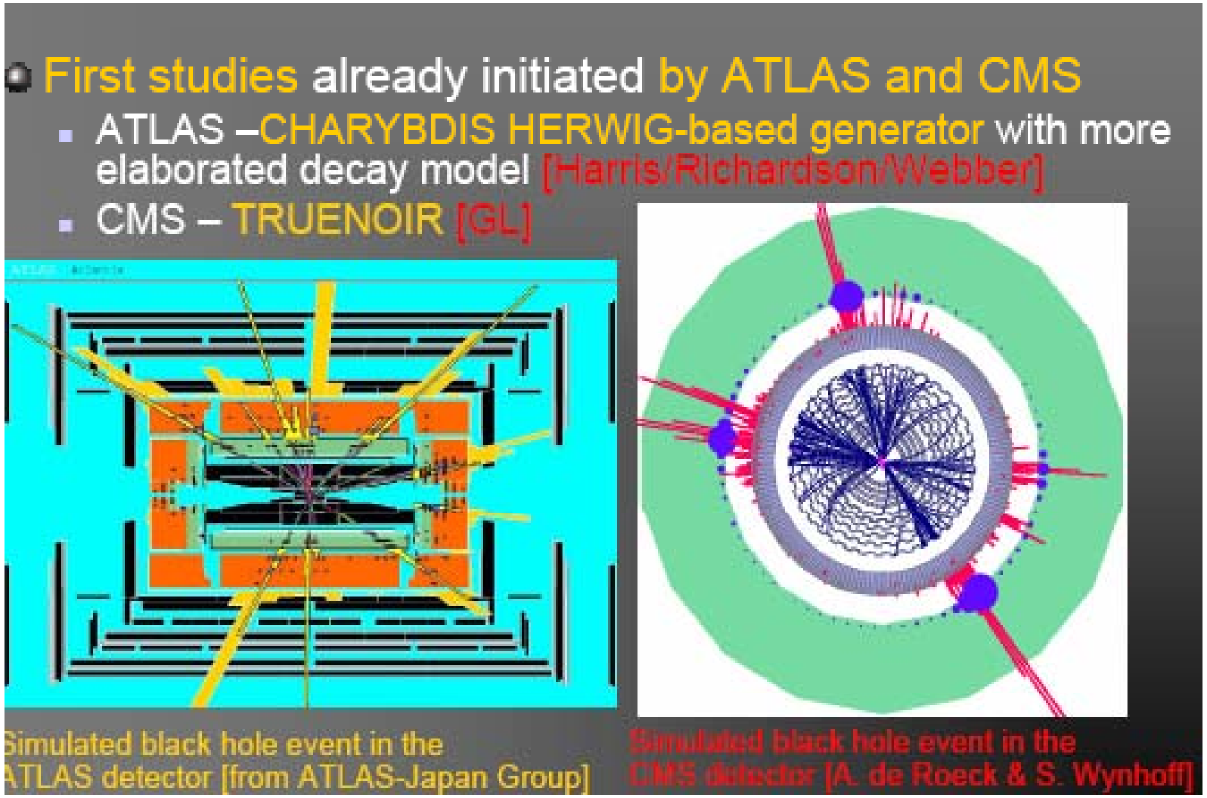
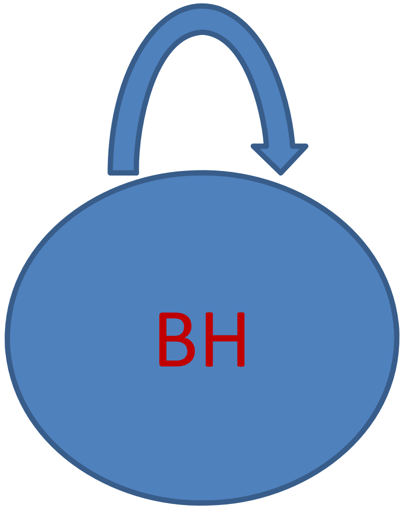
HCP and BH


First studies already initiated by ATLAS and CMS
ATLAS –CHARYBDIS HERWIG-based generator with more elaborated decay model [Harris/Richardson/Webber]
CMS – TRUENOIR [GL]
Simulated black hole event in the ATLAS detector [from ATLAS-Japan Group]
Simulated black hole event in the CMS detector [A. de Roeck & S. Wynhoff]

Černé díry v LHC ?

- Co je černá díra ?
- Může být malá ?
- Je stabilní ?
- Může vzniknout na urychlovači ?
- Závisí na počtu dimenzí ?
- Jak často ji uvidíme ?
- A jak ji uvidíme ?

Černé díry ?



$$F \approx G \frac{m_1 m_2}{r^2} \qquad E \approx m_1 c^2 \;(+\gamma)$$

$$E < F \Rightarrow m_1 c^2 < G \frac{m_1 m_2}{r^2}$$

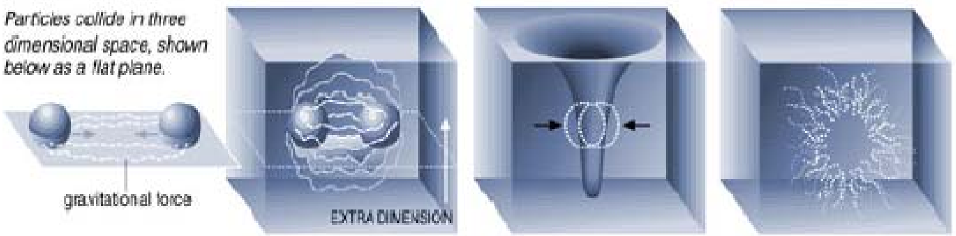
$$r < \sqrt{G \frac{m_2}{c^2}} \quad M_{BH}$$

$$R_{CH} \approx \sqrt{M_{BH}}$$

BH at Accelerators: Basic Idea

Black Holes on Demand NYT, 9/11/01 The New York Times

Scientists are exploring the possibility of producing miniature black holes on demand by smashing particles together. Their plans hinge on the theory that the universe contains more than the three dimensions of everyday life. Here's the idea:



As the particles approach in a particle accelerator, their gravitational attraction increases steadily.

When the particles are extremely close, they may enter space with more dimensions, shown above as a cube.

The extra dimensions would allow gravity to increase more rapidly so a black hole can form.

Such a black hole would immediately evaporate, sending out a unique pattern of radiation.

???

Black Holes in General Relativity

- Black holes (BH) are direct prediction of Einstein's General Relativity (GR)
- It's somewhat ironical that Einstein himself never believed in BH!
- Karl Schwarzschild showed (1916) that the space-time metric for a massive body has a singularity at $r = R_S \equiv 2MG_N/c^2$
  - r and t essentially swap places for $r < R_S$
  - Hence, if the mass M is enclosed within its *Schwarzschild radius* R_S, a "black hole" is formed
- The term "black hole" was coined much later by John Wheeler ~1967

- Naïvely, a black hole would only grow once it's formed
- In 1975 Steven Hawking showed that this is not true [Commun. Math. Phys. 43, 199 (1975)], as the black hole can evaporate by emitting virtual pairs at the event horizon, with one particle of the pair escaping the BH
- These particles have a black-body spectrum at the *Hawking temperature*: $\boxed{T_H = \hbar c / 4\pi k R_S}$
- In natural units ($\hbar = c = k = 1$), one has: $R_S T_H = (4\pi)^{-1}$
- If T_H is high enough, massive particles can be also produced in the process of evaporation

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \kappa^2 T_{\mu\nu}$$

valid in any dimension

KK in 1930   gravitation + electrmagnetism (n=1)

In 1990   n>1

$$V(r) = G_D \frac{m_1 m_2}{r^{n+1}} .$$

Planck scale, $M_P \simeq 10^{19}$ GeV.

$$G_D = 1/M_*^{n+2}$$

$$_4\, \mathscr{R}^n \simeq G_D .$$

$$M_P^2 \simeq \mathscr{R}^n M_*^{2+n} .$$

$$M_{EW} = e^{-kL} M_*$$

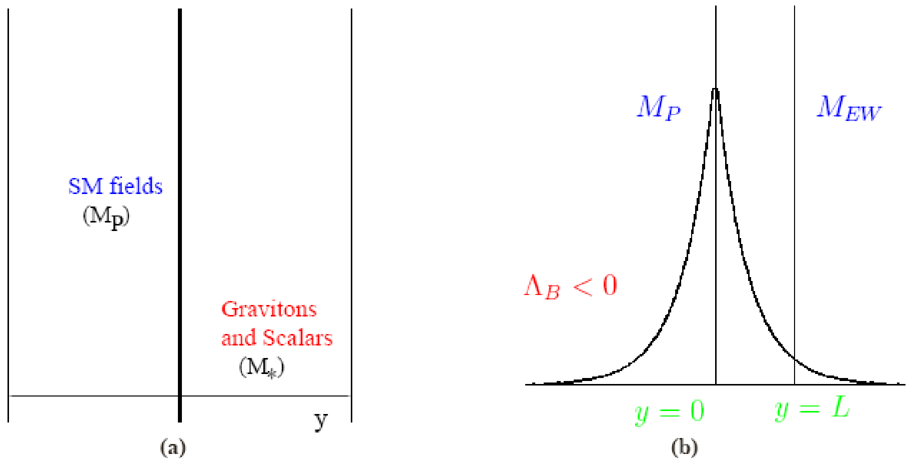


Fig. 1 (a) A 3-brane embedded in a $(4+n)$-dimensional flat spacetime. (b) Two 3-branes embedded in a 5-dimensional Anti de Sitter spacetime.

Table 1 Current limits on the fundamental energy scale

Type of Experiment/Analysis	$M_* \geq$	$M_* \geq$
Collider limits on the production of real or virtual KK gravitons [11]-[13]	1.45 TeV ($n = 2$)	0.6 TeV ($n = 6$)
Torsion-balance Experiments[14, 15]	3.2 TeV ($n = 2$)	($\mathscr{R} \leq 50\,\mu$m)
Overclosure of the Universe[16]	8 TeV ($n = 2$)	
Supernovae cooling rate [17]-[20]	30 TeV ($n = 2$)	2.5 TeV ($n = 3$)
Non-thermal production of KK modes [21]	35 TeV ($n = 2$)	3 TeV ($n = 6$)
Diffuse gamma-ray background [16, 22, 23]	110 TeV ($n = 2$)	5 TeV ($n = 3$)
Thermal production of KK modes [23]	167 TeV ($n = 2$)	1.5 TeV ($n = 5$)
Neutron star core halo [24]	500 TeV ($n = 2$)	30 TeV ($n = 3$)
Neutron star surface temperature [24]	700 TeV ($n = 2$)	0.2 TeV ($n = 6$)
BH absence in neutrino cosmic rays [25]		1-1.4 TeV ($n \geq 5$)

Vznik BH

Schwarschild-Tangherlini line element of black hole with radius r

$$ds^2 = -\left[1 - \left(\frac{r_H}{r}\right)^{n+1}\right] dt^2 + \left[1 - \left(\frac{r_H}{r}\right)^{n+1}\right]^{-1} dr^2 + r^2 d\Omega^2_{2+n}, \qquad (8$$

where $d\Omega^2_{2+n}$ is the line-element of a $(2+n)$-dimensional unit sphere

$$d\Omega^2_{2+n} = d\theta^2_{n+1} + \sin^2\theta_{n+1}\left(d\theta^2_n + \sin^2\theta_n\left(\ldots + \sin^2\theta_2\left(d\theta^2_1 + \sin^2\theta_1\, d\varphi^2\right)\ldots\right)\right)$$

In D=4+n

$$R_H = \frac{1}{M_c}\left(M_{BH}\right)^{\frac{1}{n+1}}\left(\frac{8\,\Gamma\left(\frac{(n+1)}{2}\right)}{(n+1)\sqrt{\pi}^{(n+1)}}\right)^{\frac{1}{(n+1)}}$$

$$R_H = \frac{1}{M_c}(M_{BH})^{\frac{1}{n+1}} \left(\frac{8\,\Gamma\left(\frac{(n+1)}{2}\right)}{(n+1)\sqrt{\pi}^{(n+1)}} \right)^{\frac{1}{(n+1)}}$$

$$\frac{1}{5}\sqrt{\pi}\, 8^{1/4}\, 5^{3/4}$$

$$\sqrt{\pi}\left(\frac{8\,\Gamma\left(\frac{4}{2}+\frac{1}{2}\right)}{4+2}\right)^{\frac{1}{4+1}}$$

$$\pi^{3/5}$$

$$\sqrt{\pi}\left(\frac{8\,\Gamma\left(\frac{2}{2}+\frac{1}{2}\right)}{2+2}\right)^{\frac{1}{2+1}}$$

$$\pi^{2/3}$$

$$\sqrt{\pi}\left(\frac{8\,\Gamma\left(\frac{1}{2}+\frac{1}{2}\right)}{1+2}\right)^{\frac{1}{1+1}}$$

$$\frac{1}{3}\sqrt{\pi}\,\sqrt{8}\,\sqrt{3}$$

$$\sqrt{\pi}\left(\frac{8\,\Gamma\left(\frac{1}{2}\right)}{2}\right)^{\frac{1}{1}}$$

$$4\,\pi$$

$$\sqrt{\pi}\left(\frac{8\,\Gamma\left(\frac{8}{2}+\frac{1}{2}\right)}{8+2}\right)^{\frac{1}{8+1}}$$

$$\frac{1}{80}\,\pi^{5/9}\, 4^{1/9}\, 5^{8/9}\, 105^{1/9}\, 16^{8/9}$$

Creation of BH at the LHC

Compton wavelength lC = 4p /E of the colliding particle
of energy *E/2 must lie within the corresponding Schwarzschild radius rH(E).*

high-energy scattering process with *E >M∗ and*
impact parameter *b between the colliding particles, the following two cases should*
be expected: **(i) if *b > rH(E), elastic and inelastic processes will take place, dominated***
by the exchange of gravitons, while **(ii) if *b < rH(E), a black hole will be***
formed

xmin = E/M∗,

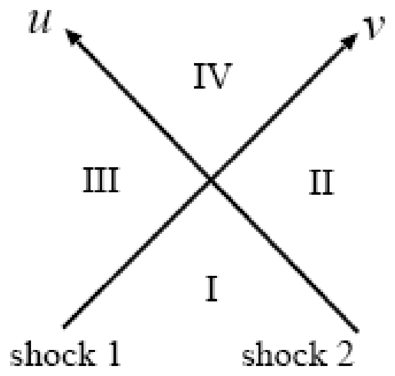
$$\frac{4\pi}{E} < \frac{1}{M_*}\left(\frac{E}{M_*}\right)^{\frac{1}{n+1}}\left(\frac{8\Gamma\left(\frac{n+3}{2}\right)}{(n+2)\sqrt{\pi}^{(n+1)}}\right)^{1/(n+1)}$$

Table 2 The values of the ratio $x_{min} = E/M_*$, necessary for the creation of a black hole, as a function of n.

$n=2$	$n=3$	$n=4$	$n=5$	$n=6$	$n=7$
$x_{min}=8.0$	$x_{min}=9.5$	$x_{min}=10.4$	$x_{min}=10.9$	$x_{min}=11.1$	$x_{min}=11.2$

Clasic BH (Penrose)

Fig. 2 Two Aichelburg-Sexl shock waves propagating at opposite directions. The two shock waves collide at $u = v = 0$ and, if a closed trapped surface or an apparent horizon is formed, a black hole has been created.



$\gamma = 1/\sqrt{1-\beta^2}$. In the limit $\gamma \to \infty$,

$$ds^2 = -du\,dv + dx^2 + dy^2 + 4\mu \ln(x^2 + y^2)\,\delta(u)\,du^2\,, \qquad (12)$$

with $u = t - z$ and $v = t + z$, and μ the particle's energy.

The creation therefore of a black hole is nothing but a Boundary Value problem. In $D = 4$ dimensions and for a head-on collision ($b = 0$), this problem can be solved analytically. This task was performed by Penrose, more than 30 years ago, who found that an apparent horizon is indeed formed with an area equal to $32\pi\mu^2$. This can put a lower bound on the area of the event horizon and thus on the black hole mass as follows:

$$A_H \equiv 4\pi r_H^2 \geq 32\pi\mu^2 \Rightarrow M_{BH} \equiv \frac{r_H}{2} \geq \frac{1}{\sqrt{2}}(2\mu) \qquad (13)$$

70 % energy => BH

In the brane-world scenario, the colliding particles need to enter the higher-dimensional regime in order to create a black hole. In that case, every closed trapped surface will be a $(D-2)$ surface instead of a 2-dimensional. Nevertheless, the same procedure for investigating the creation of a black hole can be followed in this case, too. For a head-on collision, the corresponding boundary value problem can be again solved analytically leading to [35]

$$M_{BH} \geq [0.71\,(\text{for}\, D=4) - 0.58\,(\text{for}\, D=11)]\,(2\mu)$$

$$D=4: \qquad b \leq b_{max} \simeq 0.8\, r_H\,,$$

$$D=4+n: \quad b \leq b_{max} \simeq 3\; 2^{-(n+2)/(n+1)}\, r_H$$

$$\boxed{\sigma_{\text{production}} \simeq \pi b^2}$$

$$\sigma_{\text{production}} \propto \pi r_H^2 \sim \frac{1}{M_*^2}\left(\frac{E}{M_*}\right)^{2/(n+1)} .$$

Table 3 Black-Hole production cross-section as a function of the dimensionality of spacetime [37]

D	4	5	6	7	8	9	10	11
$\sigma_{\text{production}}/(\pi r_H^2)$	0.71	1.54	2.15	2.52	2.77	2.95	3.09	3.20

$$\sigma_{\text{production}}^{pp\to BH} = \sum_{ij} \int_{\tau_m}^{1} d\tau \int_{\tau}^{1} \frac{dx}{x} f_i(x) f_j\left(\frac{\tau}{x}\right) \sigma_{\text{production}}^{ij\to BH} \quad \tau = \sqrt{x_i x_j},$$

Numerical calculations, that take into account the compositeness of the accelerated particles and the behaviour of PDF's, have derived some indicative values for $\sigma_{\text{production}}$ [39, 40]. For example, if we assume that $M_* = 1$ TeV and $D = 10$, then the production cross-section for a black hole with $M_{BH} = 5$ TeV turns out to be $\sigma_{\text{production}} \sim 10^5$ fb, while for a black hole with $M_{BH} = 10$ TeV it is found that $\sigma_{\text{production}} \sim 10$ fb. For beyond the SM processes, the aforementioned values are quite significant – in the first case, the value of $\sigma_{\text{production}}$ amounts to one black hole created per second! Whether LHC will indeed prove to be a black-hole factory, it remains to be seen.

The emission of Hawking radiation [43] is sourced by the non-vanishing temperature of the black hole. This is defined in terms of the black hole's surface gravity k as follows

$$T_H = \frac{k}{2\pi} = \frac{1}{4\pi}\frac{1}{\sqrt{|g_{tt}\,g_{rr}|}}\left(\frac{d|g_{tt}|}{dr}\right)_{r=r_H} = \frac{(n+1)}{4\pi\, r_H}\,. \tag{18}$$

Table 4 Horizon radius and temperature of the Schwarzschild-Tangherlini black hole as a function of the number of extra dimensions, for $M_* = 1$ TeV and $M_{BH} = 5$ TeV

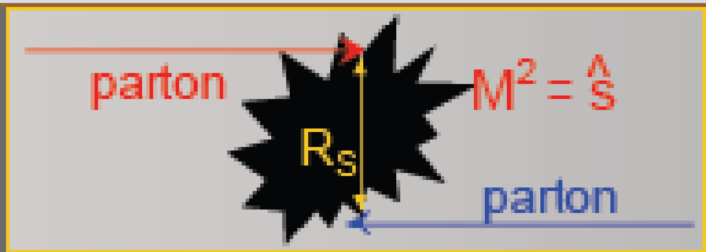
n	1	2	3	4	5	6	7
r_H (10^{-4} fm)	4.06	2.63	2.22	2.07	2.00	1.99	1.99
T_H (GeV)	77	179	282	379	470	553	629

$$\tau_{(n+4)} \sim \frac{1}{M_*}\left(\frac{M_{BH}}{M_*}\right)^{\frac{(n+3)}{(n+1)}} > \tau_{(4)}\,. \tag{19}$$

For the same values of M_* and M_{BH}, the typical lifetime of the black hole comes out to be $\tau = (1.7 - 0.5) \times 10^{-26}$ sec for $n = 1 - 7$. In other words, the produced black hole will evaporate instantly after its creation, and it will do so right in front of our detectors.

- Based on the work done with Savas Dimopoulos a few years ago [PRL 87, 161602 (2001)]
- Related study by Giddings, Thomas [PRD 65, 056010 (2002)]
- Extends previous theoretical studies by Argyres, Dimopoulos, March-Russell [PLB 441, 96 (1998)], Banks, Fischler [JHEP 9906, 014 (1999)], Emparan, Horowitz, Myers [PRL 85, 499 (2000)] to collider phenomenology
- Big surprise: BH production is not an exotic remote possibility, but the dominant effect!
- Main idea: when the c.o.m. energy reaches the fundamental Planck scale, a BH is formed; cross section is given by the black disk approximation:

$$\sigma \sim \pi R_S^{\,2} \sim 1\ \mathrm{TeV}^{-2} \sim 10^{-38}\ \mathrm{m}^2 \sim 100\ \mathrm{pb}$$



- This is an enormous cross section! For a 400 TeV machine, $R_S \sim 1$ fm, so nothing, including diffraction, will be seen except for the BH production!

Rozpad BH

That is why we need to study in the greatest possible detail the spectrum of the Hawking radiation emitted by the black hole as this will probably be the main observable effect associated with this gravitational object. Although a purely geometrical property, the temperature of a black hole leads to the emission of thermal radiation similar to that of a black body. The Hawking radiation [43] is therefore a classical phenomenon but with a quantum origin, since classically nothing is allowed to escape from within the black-hole horizon. The emission of radiation from a black hole, 4-dimensional and high-dimensional alike, can be realized through the creation of a virtual pair of particles just outside the horizon; when the antiparticle happens to fall inside the black hole, the particle can now propagate away from the black hole whose mass has decreased due to the negative amount of energy it received. The radiation spectrum is therefore a nearly black-body spectrum with energy emission rate given by an expression of the form [43]

$$\frac{dE(\omega)}{dt} = \frac{|\mathscr{A}(\omega)|^2\,\omega}{\exp(\omega/T_H) \mp 1}\,\frac{d\omega}{(2\pi)}\,. \tag{20}$$

The quantity $|\mathscr{A}(\omega)|^2$ appearing in the numerator is the Absorption Probability (or, *greybody factor*). Its presence is due to the fact that a particle, propagating in the $(4+n)$-dimensional black-hole background, needs to escape the strong gravitational field, that the black hole creates, to reach the asymptotic observer. In order to see this, we may write the equation of motion of an arbitrary field in the aforementioned background in the form of a Schrödinger-like equation

$$-\frac{d^2\Psi}{dr_*^2} + V(r_*, n, l, \omega, s, \ldots)\Psi = \omega^2 \Psi \,, \qquad dr_* = \left[1 - \left(\tfrac{r_H}{r}\right)^{(n+1)}\right]^{-1} dr$$

$$R^{up}_{\omega lm}(r) \sim \begin{cases} e^{i\omega r_*} + A^{up}\, e^{-i\omega r_*} \,, & r \to r_H \\ B^{up}\, e^{i\omega r_*} \,, & r \to \infty \end{cases}$$

$$\frac{d^2}{dt\, d\omega}\begin{pmatrix} N \\ E \\ J \end{pmatrix} = \frac{1}{2\pi} \sum_{l,m,j\ldots} \frac{|\mathscr{A}(\omega)|^2}{\exp(\tilde{\omega}/T_H) \mp 1} \begin{pmatrix} 1 \\ \omega \\ m \end{pmatrix}$$

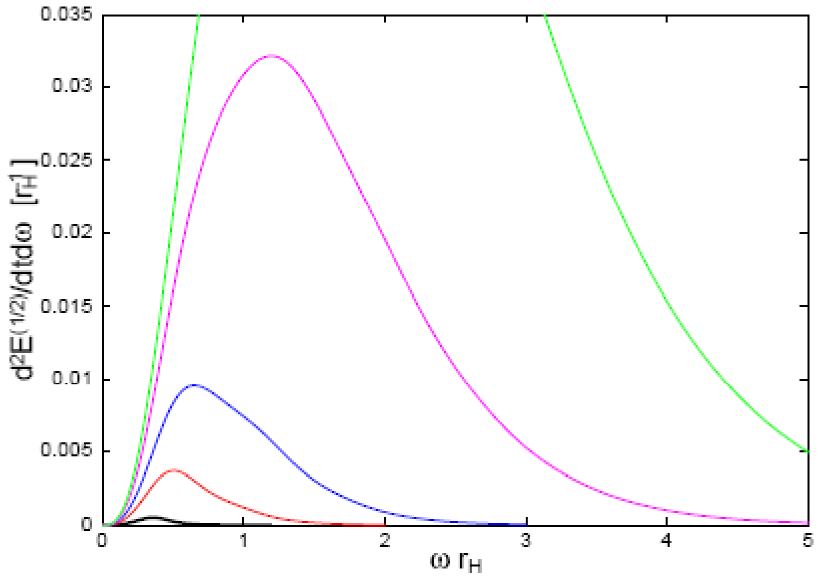


Fig. 5 Hawking radiation energy emission rates for brane-localised fermions, for $n = 0, 1, 2, 4$ and 6 (from bottom to top).

Table 5 Total emissivities for brane-localised scalars, fermions and gauge bosons [59] and bulk gravitons [60]

n	0	1	2	3	4	5	6	7
Scalars	1.0	8.94	36.0	99.8	222	429	749	1220
Fermions	1.0	14.2	59.5	162	352	664	1140	1830
G. Bosons	1.0	27.1	144	441	1020	2000	3530	5740
Gravitons	1.0	103	1036	5121	2×10^4	7×10^4	2.5×10^5	8×10^5

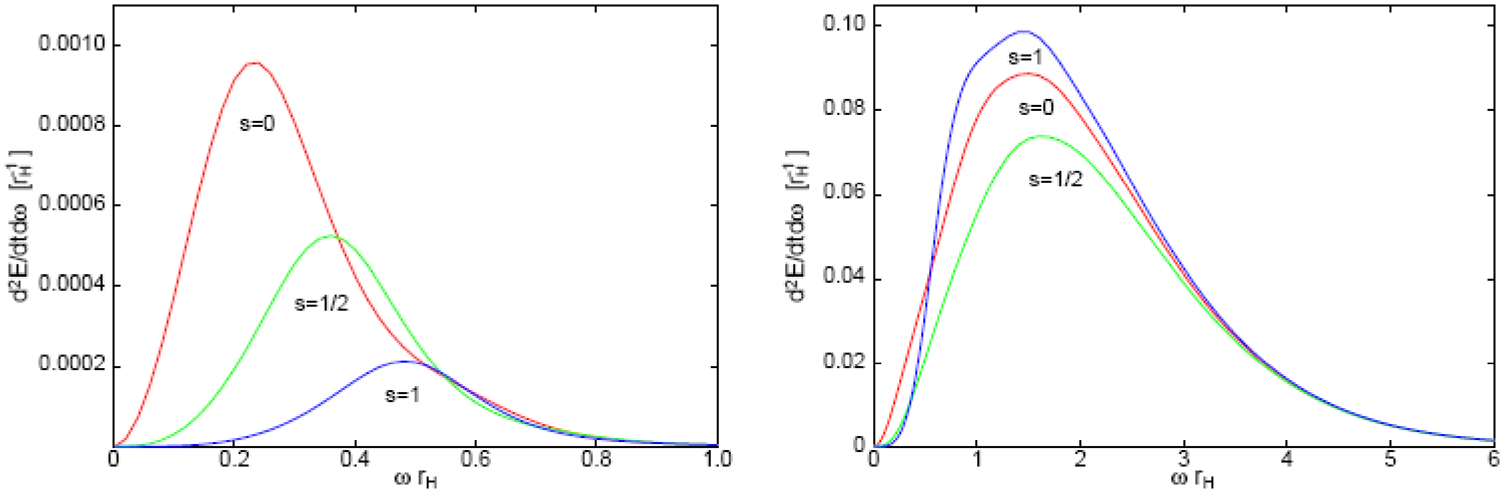


Fig. 6 Relative emissivities for brane-localised fields for $n = 0$ (left plot) and $n = 6$ (right plot).

$$ds^2 = \left(1 - \frac{\mu}{\Sigma\, r^{n-1}}\right) dt^2 + \frac{2a\mu \sin^2\theta}{\Sigma\, r^{n-1}}\, dt\, d\varphi - \frac{\Sigma}{\Delta} dr^2$$
$$- \quad \Sigma\, d\theta^2 - \left(r^2 + a^2 + \frac{a^2 \mu \sin^2\theta}{\Sigma\, r^{n-1}}\right) \sin^2\theta\, d\varphi^2 - r^2 \cos^2\theta\, d\Omega_n^2$$

where

$$\Delta = r^2 + a^2 - \frac{\mu}{r^{n-1}}, \qquad \Sigma = r^2 + a^2 \cos^2\theta\,.$$

$$M_{BH} = \frac{(n+2)A_{2+n}}{16\pi G}\,\mu \qquad \text{and} \qquad J = \frac{2}{n+2}\, a M_{BH}\,;$$

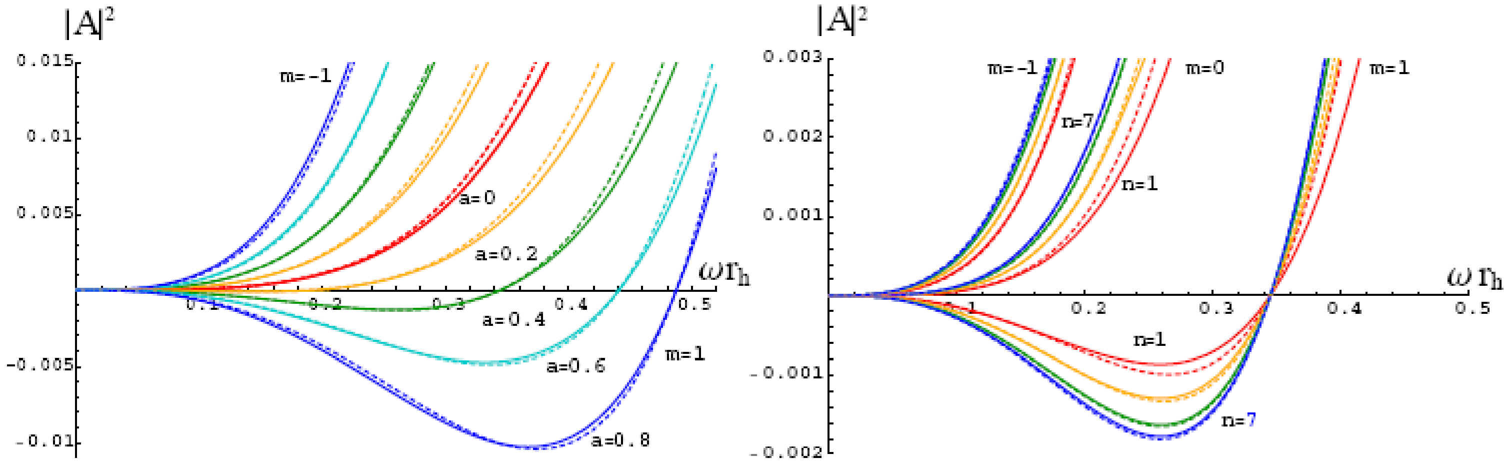


Fig. 7 Absorption probabilities for brane-localised scalar fields as a function of the angular-momentum parameter a (left plot) and number of extra dimensions n (right plot).

$$\lambda_{sj} = -s(s+1) + \sum_{k} f_k^{jms} (a\omega)^k ,$$

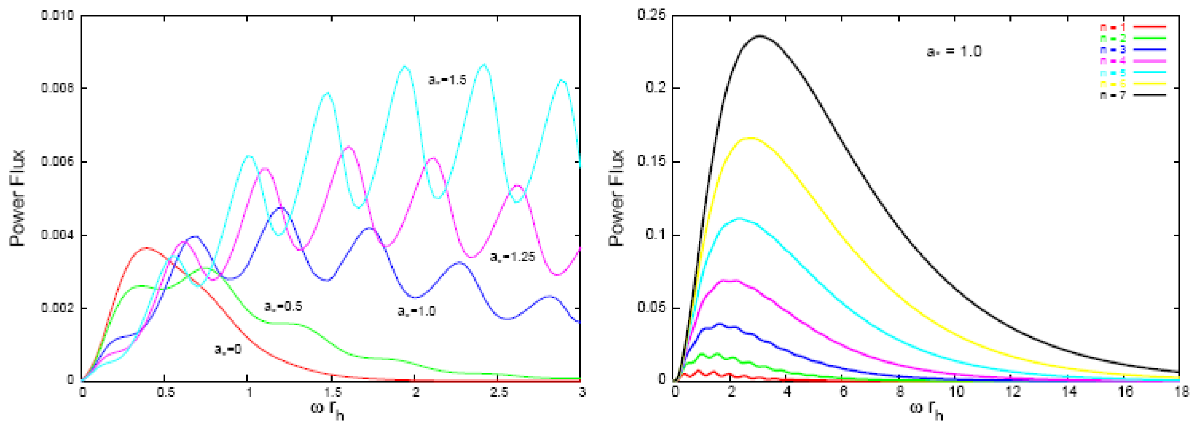


Fig. 8 Energy emission rates for brane-localised scalar fields in terms of the angular parameter (left plot) and gauge bosons in terms of the number of extra dimensions (right plot).

Table 6 Enhancement factors for the energy emission rates in terms of the angular momentum parameter and number of extra dimensions

	$(n=4)$	$a_*=0$	$a_*=1.0$	$(a_*=1)$	$n=1$	$n=7$
Scalars		1	≥ 3		1	≥ 100
Fermions		1	6		1	99
G. Bosons		1	≥ 5		1	≥ 50

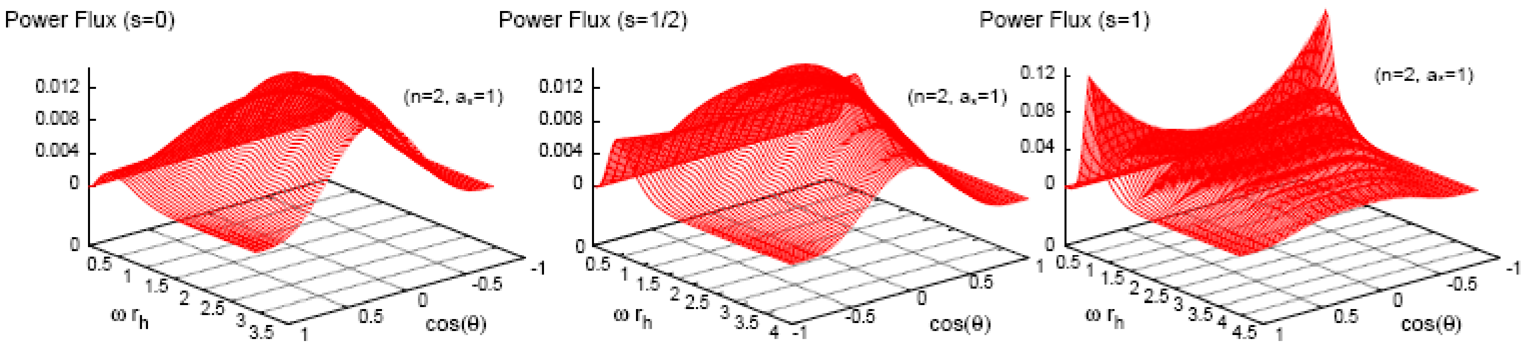


Fig. 9 Angular distribution of the energy emission spectra for scalars (left plot), fermions (central plot) and gauge bosons (right plot) for a 6-dimensional black hole with $a_* = 1$.

??? !!!

$$\frac{d^3E}{d(\cos\theta)dt\,d\omega} = \frac{1}{4\pi}\sum_{j=1}^{\infty}\sum_{m=-j}^{j}\frac{\omega\,|\mathscr{A}(\omega)|^2}{\exp(\tilde{\omega}/T_H)-1}\left[\left(S^m_{|s|j}\right)^2+\left(S^m_{-|s|j}\right)^2\right]$$

$$\frac{1}{\sqrt{-G}}\,\partial_M\left[\sqrt{-G}\,G^{MN}\,\partial_N\Phi\right]=0$$

$$\Phi(t,r,\theta_i,\varphi)=e^{-i\omega t}\,R_{\omega l}(r)\,\tilde{Y}(\Omega)$$

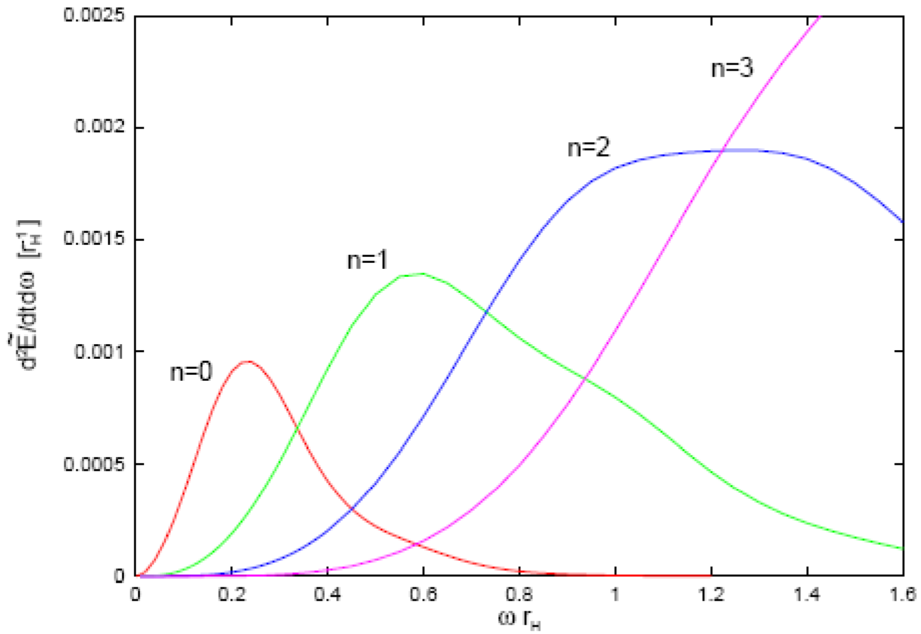


Fig. 10 Energy emission rates for bulk scalar fields, as a function of the number of additional spacelike dimensions, for the Schwarzschild phase.

Table 7 Bulk-to-Brane Relative Emissivities Ratio for scalar fields in terms of n

	$n=0$	$n=1$	$n=2$	$n=3$	$n=4$	$n=5$	$n=6$	$n=7$
Bulk/Brane	1.0	0.40	0.24	0.22	0.24	0.33	0.52	0.93

Table 8 Relative emissivities for brane-localised Standard Model fields and bulk gravitons

n	0	1	2	3	4	5	6	7
Scalars	1	1	1	1	1	1	1	1
Fermions	0.55	0.87	0.91	0.89	0.87	0.85	0.84	0.82
G. Bosons	0.23	0.69	0.91	1.0	1.04	1.06	1.06	1.07
Gravitons	0.053	0.61	1.5	2.7	4.8	8.8	17.7	34.7

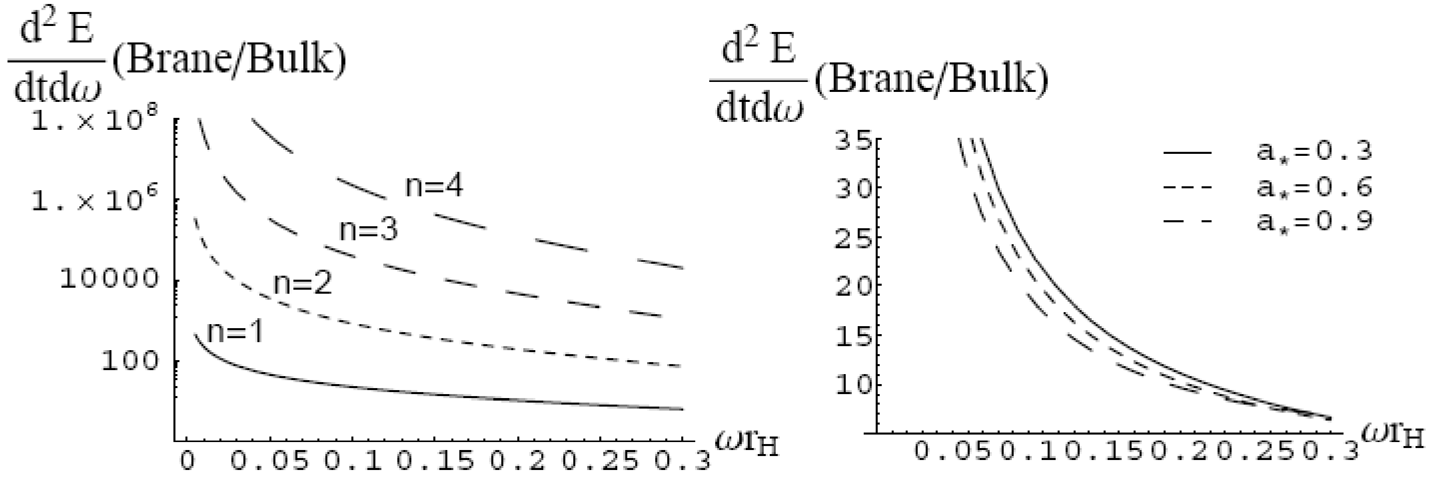


Fig. 11 Brane-to-Bulk ratio of the differential energy emission rates for scalar fields during the spin-down phase in terms of n (left plot) and a (right plot).

$$\log(T_H) = -\frac{1}{n+1}\log(M_{BH}) + const.$$

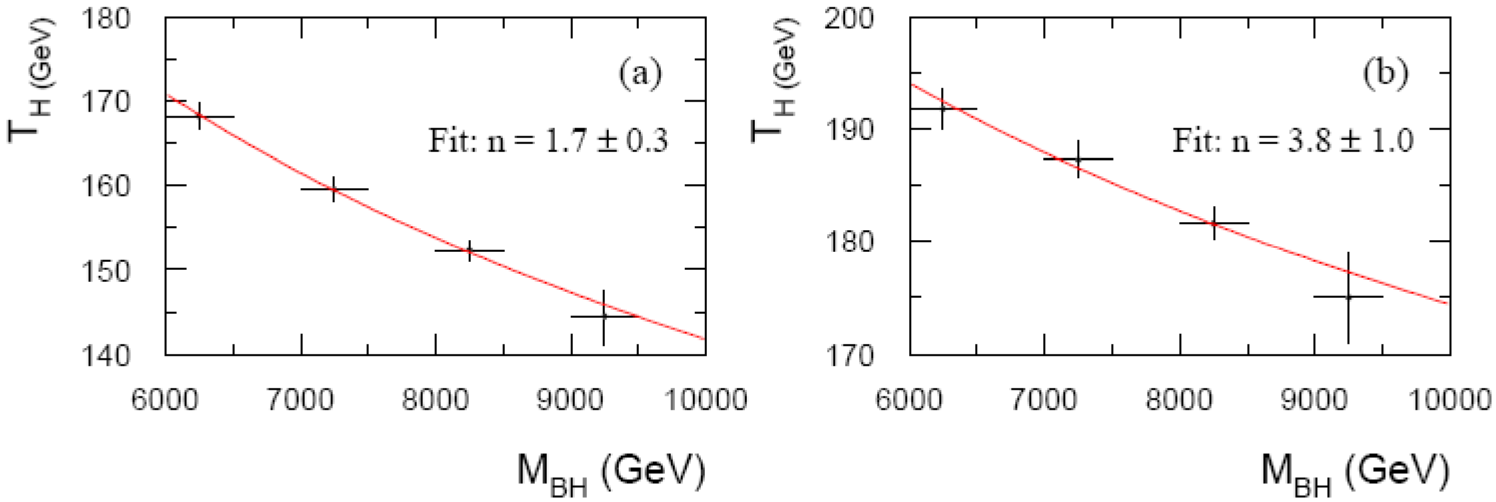


Fig. 12 Plots relating the black-hole mass and temperature measurements, and the derived value of n, for constant (left plot) and variable (right plot) temperature [78].

$$\langle N \rangle = \langle \frac{M_{BH}}{E} \rangle \simeq \frac{M_{BH}}{2T_H}$$

Fig. 13 Multiplicity of particles emitted by a black hole as the number of the additional spacelike dimensions n increases from 2 (top curve) to 6 (bottom curve) [78].

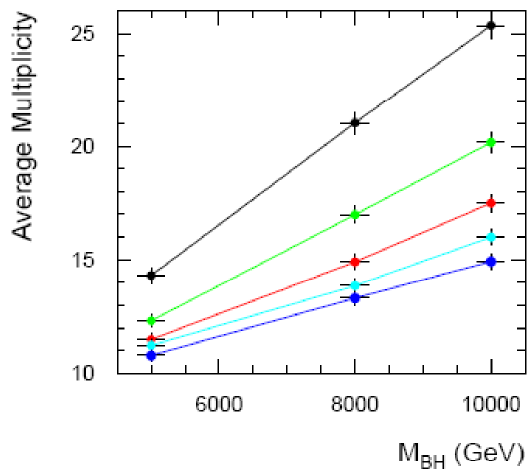


Table 9 Predictions for the relative emissivities of SM fields [78] derived by CHARYBDIS

Type	Quarks	Gluons	Charged leptons	Neutrinos	Photons	Z^0	$W^{\pm}$	Higgs
(%)	63.9	11.7	9.4	5.1	1.5	2.6	4.7	1.1

At the moment, there are several Black Hole Event Generators that have been constructed: CHARYBDIS [79], Catfish [80] and TRUENOIR [81]. For example, the CHARYBDIS generator uses the HERWIG program [82] to handle all the QCD interactions, hadronization and secondary decays. It also makes specific predictions for the relative emissivities of the different species of SM particles expected to be detected. These are shown in Table 9 [78] from where we easily deduce that the dominant type of elementary particles emitted by the black hole should be the quarks.

BH v n=1 RS

Randall-Sundrum Gravitons and Black Holes at the LHC

K.M. Black
Laboratory for Particle Physics and Cosmology, Harvard University, 18 Hammond Street, Cambridge, MA USA

$$ds^2 = e^{-2k|z|}[dt^2 - dx^2] - dz^2$$

$$M_{Pl}^2 = \frac{M_5^3}{k}(1 - e^{-2\pi kr})$$

$$R_s = \frac{1}{\sqrt{\pi}M_{Pl}}\left[\frac{M_{BH}}{M_{Pl}}\left(\frac{8\Gamma(\frac{n+3}{2})}{n+2}\right)^{\frac{1}{n+1}}\right] \qquad \sigma_{BH} \approx \pi R_s^2$$

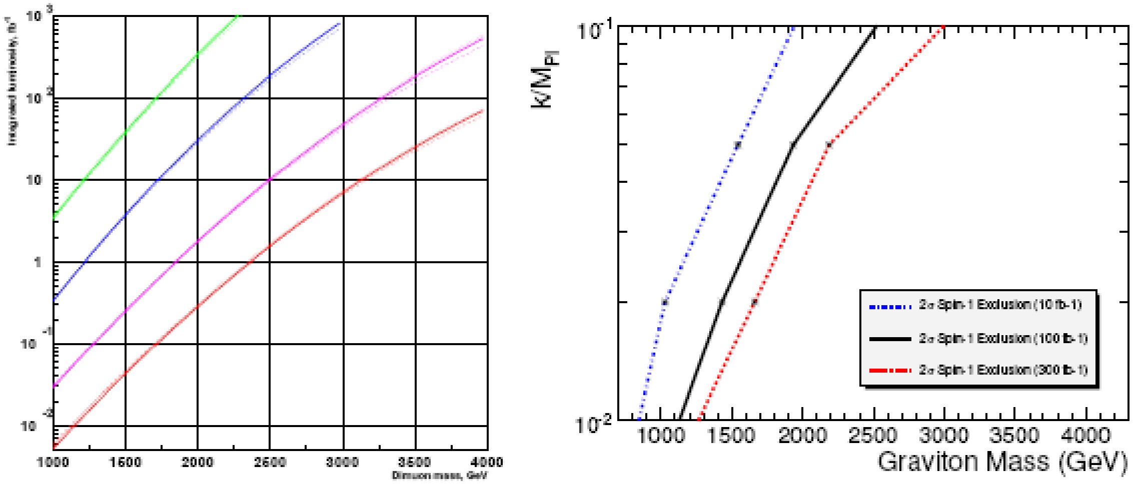
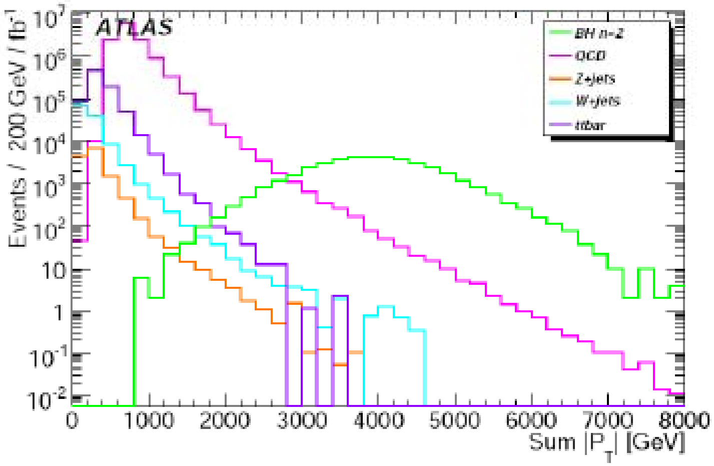


Figure 1: Discovery potential at CMS in the dimuon channel for Randall-Sundrum gravitons(left) and spin determination potential (right) .

Black Hole Searches at ATLAS



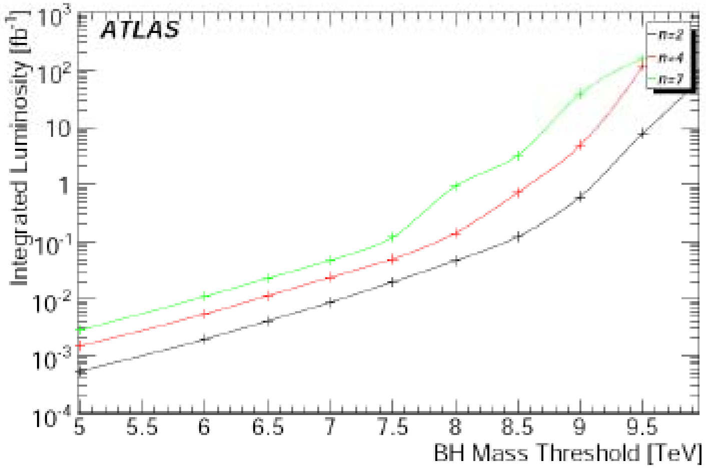
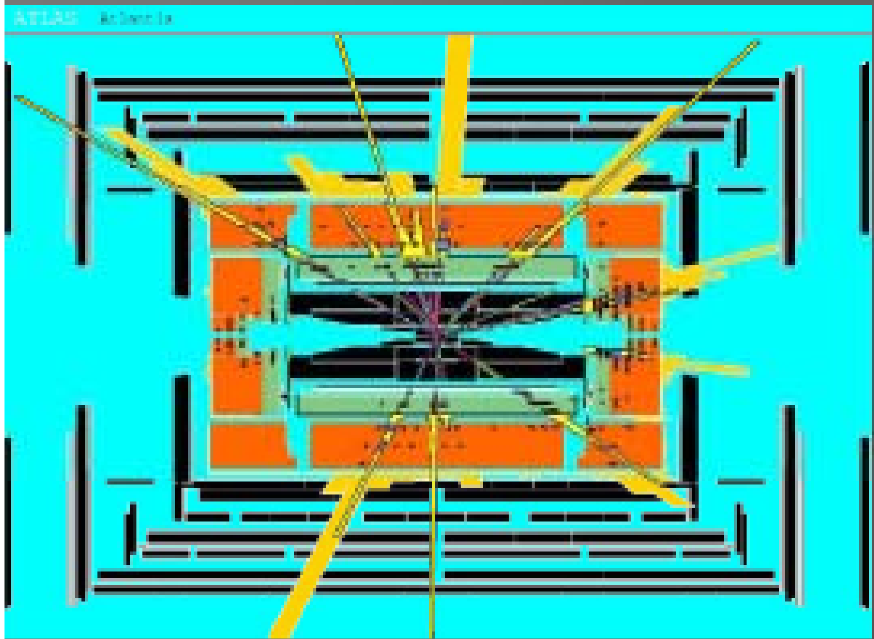


Figure 2: Scalar sum of p_T of all objects in the event (left) and black hole discovery potential as a function of black hole mass threshold (right).

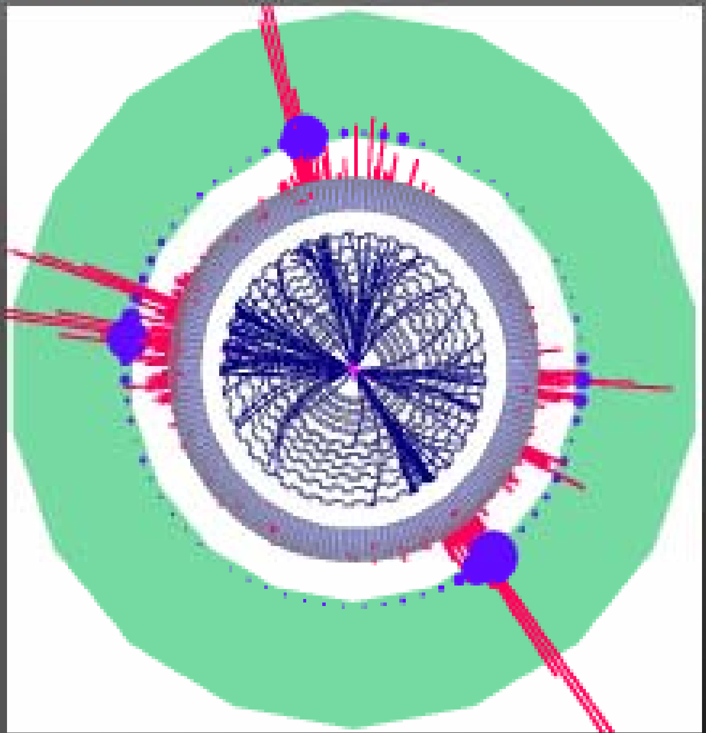
The discovery of extra spatial dimensions, strong gravity ,and black holes at the LHC would be truly fascinating and spectacular. Many detailed studies to estimate the CMS and ATLAS potential to such possibilities have been undertaken. The amount of integrated luminosity for discovery varies as a function of the model parameters but could be as small as a few inverse picobarns. Both collaborations eagerly await the startup of the LHC later this year to probe the possibility of strong gravity at the TeV scale.

We conclude that the exterior gravitational field of a Black hole is not native of an AdS_5 bulk and that the black holes produced by proton-proton collision at the LHC may be unstable. Nonetheless, it is possible that in a higher dimensional bulk $D > 5$, the behavior of the black holes is stable. This follows from the well known example given by the 6-dimensional flat bulk $M_6(4, 2)$, whose metric is also invariant under $SO(4, 2)$, so that it has the same group of isometries of the AdS_5. Consequently, all arguments of the ADS/CFT correspondence which depend only on the Lie group properties, can be extended without loss of generality to that flat bulk. By the same argument used in the ADS/CFT correspondence, the quantum unitarity of the Yang-Mills fields is maintained in the six-dimensional flat bulk.

- First studies already initiated by ATLAS and CMS
  - ATLAS –CHARYBDIS HERWIG-based generator with more elaborated decay model [Harris/Richardson/Webber]
  - CMS – TRUENOIR [GL]



Simulated black hole event in the ATLAS detector [from ATLAS-Japan Group]



Simulated black hole event in the CMS detector [A. de Roeck & S. Wynhoff]

BH a Unparticle

The inspiration for unparticles physics, as outlined in the pioneering papers by Georgi [2], is derived from the Banks-Zaks (BZ) high energy field theory with non-trivial IR fixed point, whose interactions are mediated by exchange particles of mass $M_{\mathcal{U}}$ [16]. Such a field is assumed to interact with the Standard Model (SM) fields according to the scale-suppressed non-renormalizable Lagrangian density

$$\mathcal{L} = \frac{\kappa}{\Lambda^{k_{\mathcal{U}}}} \mathcal{O}_{SM} \mathcal{O}_{\mathcal{U}} \quad , \quad \kappa = C_{\mathcal{U}} \left(\frac{\Lambda_{\mathcal{U}}}{M_{BZ}} \right)^k$$

with $k_{\mathcal{U}} = d_{SM} + d_{\mathcal{U}} - 4.$

for an unparticle of four-momentum P, the spectral density function can be shown to have the form

$$|\langle 0 | \mathcal{O}_{\mathcal{U}}(0) | P \rangle|^2 \rho(P^2) = A_{d\mathcal{U}} \theta(P^0) \theta(P^2) (P^2)^{d_{\mathcal{U}}-2} \tag{4}$$

with

$$A_{d\mathcal{U}} = \frac{16\pi^{5/2}}{(2\pi)^{2n}} \frac{\Gamma(n+1/2)}{\Gamma(n-1)\Gamma(2n)} \quad . \tag{5}$$

In the non-relativistic limit, the appropriate interactions may be computed by the usual Fourier transform method. For tensor couplings, the result is a modified potential of the form [12, 14]

$$V(r) = V_N(r)\left[1 + \frac{2}{\pi^{2d_{\mathcal{U}}-1}}\,\frac{\Gamma(d_{\mathcal{U}}+\frac{1}{2})\Gamma(d_{\mathcal{U}}-\frac{1}{2})}{\Gamma(2d_{\mathcal{U}})}\left(\frac{R_*}{r}\right)^{2d_{\mathcal{U}}-2}\right] = V_N(r)\left[1 + \Gamma_{d_{\mathcal{U}}}\left(\frac{R_*}{r}\right)^{2d_{\mathcal{U}}-2}\right], \tag{8}$$

where $V_N(r)$ is the usual Newtonian potential. The effective length-scale R_* is defined as

$$R_* = \Lambda_{\mathcal{U}}^{-1}\left(\frac{M_{Pl}}{\Lambda_{\mathcal{U}}}\right)^{\frac{1}{d_{\mathcal{U}}-1}}\left(\frac{\Lambda_{\mathcal{U}}}{M_{\mathcal{U}}}\right)^{\frac{d_{BZ}}{d_{\mathcal{U}}-1}} \quad . \tag{9}$$

If $d_{\mathcal{U}} < 1$ solutions are allowed, then the unparticle potential can be repulsive, since $\Gamma(x) < 1$ for $x < 0$ (and hence for $d_{\mathcal{U}} < 1/2$). In general, most unparticle treatments in the literature do not address the latter case. The tensor rank of the operator $\mathcal{O}_{\mathcal{U}}$ will determine the dimensionality $d_{\mathcal{U}}$.

$$T_H = \frac{1}{4\pi r_H} = \frac{\Lambda_{\mathcal{U}}}{4\pi}\left(\frac{2M_{BH}\Gamma_{d_{\mathcal{U}}}}{M_{\mathcal{U}}^2\Lambda_{\mathcal{U}}^{-1}}\right)^{-\frac{1}{2d_{\mathcal{U}}-1}}$$

23, it is presupposed that one may re-define the gravitational *potential* of a single mass m, according to the standard definition. The modified gravitational potentials for both tensor and vector couplings can be written in the general form

$$\Phi_{\mathcal{U}}(r) = \Phi_N(r)\left[1 + \Gamma_{d_{\mathcal{U}}}\left(\frac{R_*}{r}\right)^{2d_{\mathcal{U}}-2}\right] , \qquad (13)$$

"($2d_{\mathcal{U}} - 2$)-dimensional" Schwarzschild solution. Thus, the metric can now be written in the form

$$ds^2 = \left[1 - \frac{2GM}{r}\left(1 + \Gamma_{d_{\mathcal{U}}}\left(\frac{R_*}{r}\right)^{2d_{\mathcal{U}}-2}\right)\right] dt^2 + \frac{dr^2}{1 - \frac{2GM}{r}\left(1 + \Gamma_{d_{\mathcal{U}}}\left(\frac{R_*}{r}\right)^{2d_{\mathcal{U}}-2}\right)} + r^2 d\Omega^2 \quad .(15)$$

$$r_H \approx \left(\frac{2M_{BH}\Gamma_{d_{\mathcal{U}}}}{M_{\mathcal{U}}^2\Lambda_{\mathcal{U}}^{-1}}\right)^{\frac{1}{2d_{\mathcal{U}}-1}} \Lambda_{\mathcal{U}}^{-1}$$

$M_{\mathrm{BH}} = M_{\mathcal{U}}^2\Lambda_{\mathcal{U}}^{-1}$. For $\Lambda_{\mathcal{U}} \sim 1$ TeV, $M_{\mathcal{U}} \sim 10$ TeV, and $M_{BH} \sim 10$ TeV, one finds $r_H \sim 10^{-5}$ fm for all values of $d_{\mathcal{U}} \geq 4$, which corresponds to a geometric cross section $\sigma_{BH} \sim 10$ pb. This places the likelihood of unparticle-driven black hole formation at the LHC in a favorable light.

Černá díra a Top kvark

Top quark

Process	t-ch	s-ch	tW-ch	$t\bar{t}$
Cross section	245 pb	10 pb	60 pb	833 pb
Statistical uncertainty ($\frac{\Delta\sigma}{\sigma}$)	2.7%	17.6%	9.2%	0.4% (lepton+jets)

Table 1: The cross sections and the predicted statistical uncertainties on the cross sections of different top quark production processes by the CMS detector at the LHC for 10 fb^{-1} of integrated luminosity

Planck mass definitions:

- $\left(2^{(n-2)}\pi^{(n-1)}\right)^{\frac{1}{n+2}} M_p$
- M_p
- $\left(2^{(n-3)}\pi^{(n-1)}\right)^{\frac{1}{n+2}} M_p$

where n is the number of the extra dimensions.

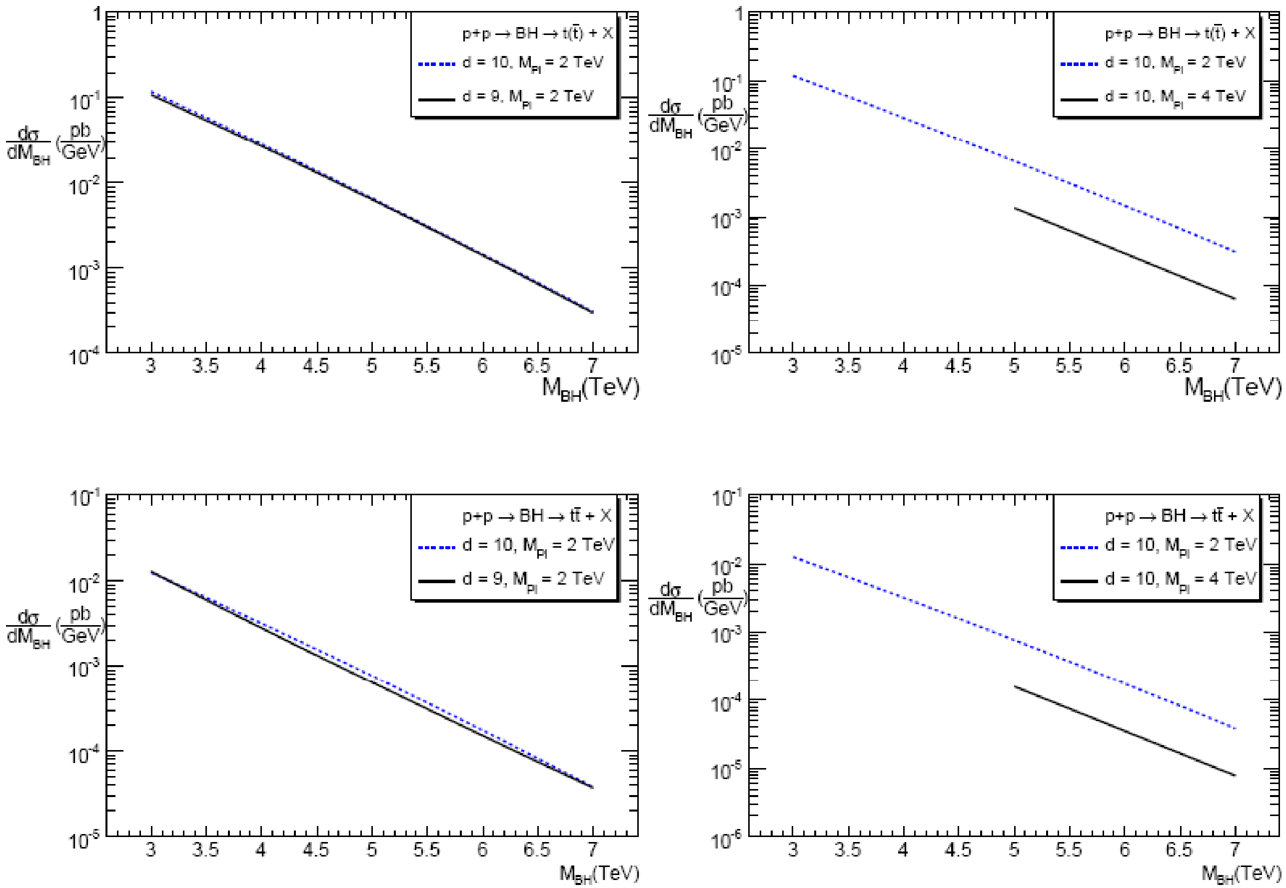


Figure 1: $\frac{d\sigma}{dM_{BH}} \times BR$ versus the black hole mass for single top (top row) and $t\bar{t}$ (bottom row) at the LHC.

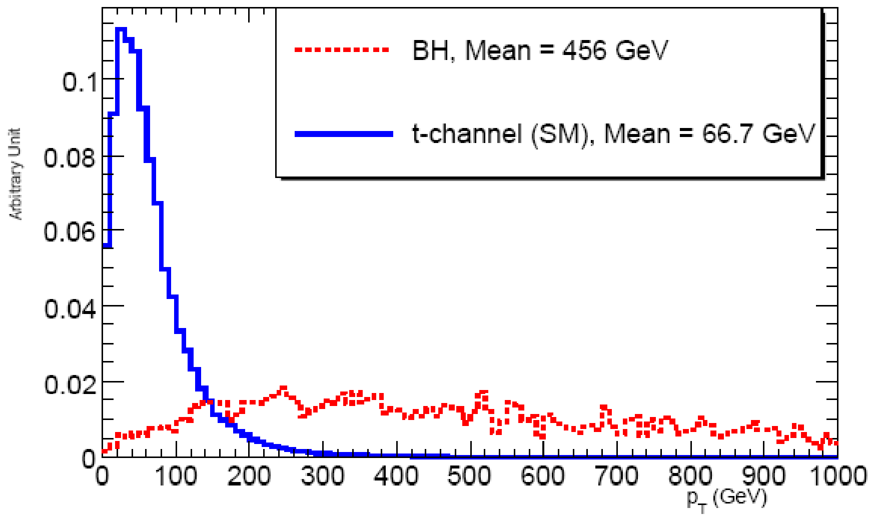


Figure 2: The transverse momentum distribution (P_T) of the top quarks from SM single top quark (t-channel) and single top quarks from the decay of a black hole are compared.

The top quark production from the decay of a black hole was considered for different values of the free parameters. It was shown that if the black holes are produced at the LHC, an unnegligible excess in the number of the produced top quarks can be seen. If the fundamental Planck mass is very high, the cross section for top quark production decreases significantly, but the produced top quarks are much harder than those from the Standard Model, so studying the high transverse momentum top quarks can indicate the presence of the signal.

Top quark energy $Q = \sqrt{p^2 + M_t^2}$ can be written [14] as

$$\frac{dN}{dt} = \frac{c_s \sigma_s}{8\pi^2} \frac{dp\, p^2}{(e^{Q/T_{BH}} + 1)},$$

The temperature of the black hole is given in [3], namely

$$T_{BH} = \frac{d+1}{4\pi R_S} = \frac{d+1}{4\sqrt{\pi}} M_P [\frac{M_P}{M_{BH}} \frac{d+2}{8\Gamma(\frac{d+3}{2})}]^{\frac{1}{1+d}},$$

$$\sigma_s = \Gamma_s 4\pi (\frac{d+3}{2})^{2/(d+1)} \frac{d+3}{d+1} R_S^2, \quad (3)$$

where we take $\Gamma_s = \frac{2}{3}$ for spin half particles. The total number of top quarks emitted from the black holes is thus given by:

$$N_{\text{top quark}} = \int_0^{t_f} dt \int_0^{M_{BH}} dp \frac{c_s \sigma_s}{8\pi^2} \frac{p^2}{(e^{\sqrt{p^2+M_t^2}/T_{BH}} + 1)}, \quad (4)$$

Time for complete evaporation

$$\boxed{t_f = \frac{C}{M_P} (\frac{M_{BH}}{M_P})^{\frac{d+3}{d+1}}.}$$

$$\sigma_{BH}^{AB\to BH+X}(M_{BH}) = \sum_{ab} \int_{\tau}^{1} dx_a \int_{\tau/x_a}^{1} dx_b f_{a/A}(x_a,\mu^2)$$
$$\times f_{b/B}(x_b,\mu^2)\hat{\sigma}^{ab\to BH}(\hat{s})\ \delta(x_a x_b - M_{BH}^2/s).$$

$$\hat{\sigma}^{ab\to BH}(\hat{s}) = \frac{1}{M_P^2}[\frac{M_{BH}}{M_P}(\frac{8\Gamma(\frac{d+3}{2})}{d+2})]^{2/(d+1)} \qquad \sigma_{\text{top quark}} = N_{\text{top quark}}\sigma_{BH}.$$

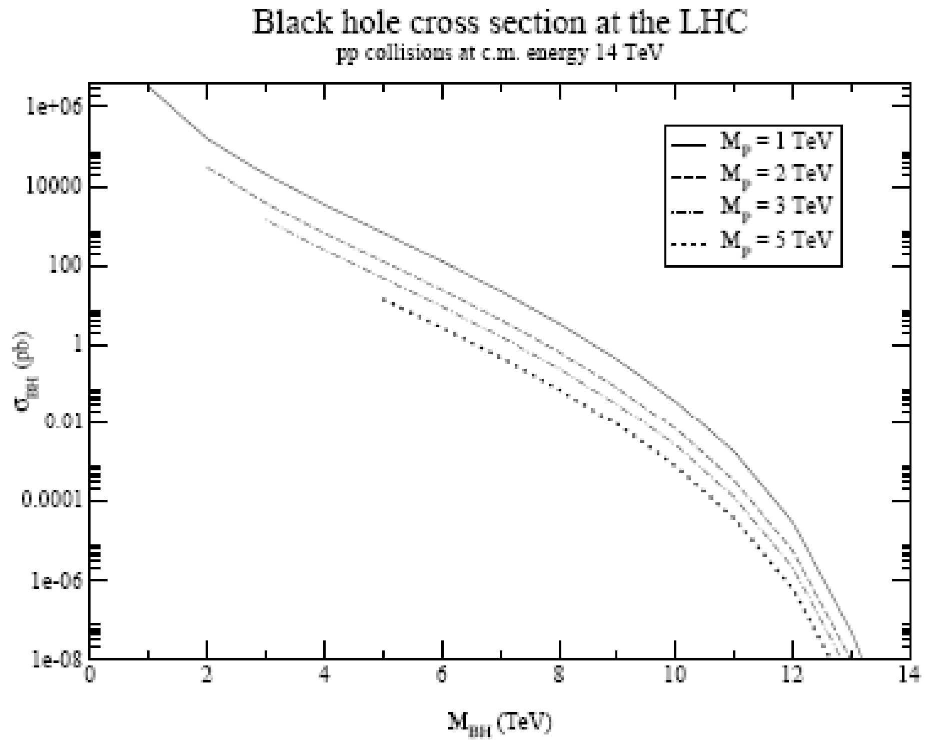


FIG. 1: Total cross sections for black hole production at the LHC.

At the next-to-next-to-leading order (NNLO) one needs to compute the following partonic subprocesses. On the leading-order (LO) level we have

$$q + \bar{q} \to t\bar{t}, \qquad g + g \to t\bar{t}. \tag{9}$$

In NLO we have in addition to the one-loop virtual corrections to the above reaction the following two-to-three body processes

$$q + \bar{q} \to t\bar{t} + g, \qquad g + q(\bar{q}) \to t\bar{t} + q(\bar{q}), \qquad g + g \to t\bar{t} + g. \tag{10}$$

At NNLO level we receive the two-loop virtual corrections to the LO processes in eq. (9) and one-loop virtual corrections to NLO reactions in eq. (10). To these contribution one has to add the results obtained from the following two-to-four body reactions

$$\begin{aligned}
&g + g \to t\bar{t} + g + g, && g + g \to t\bar{t} + q + \bar{q},\\
&g + q(\bar{q}) \to t\bar{t} + q(\bar{q}) + g, &&\\
&q + \bar{q} \to t\bar{t} + g + g, && q + \bar{q} \to t\bar{t} + q + \bar{q},\\
&q + q \to t\bar{t} + q + q, && \bar{q} + \bar{q} \to t\bar{t} + \bar{q} + \bar{q},\\
&q_1 + q_2 \to t\bar{t} + q_1 + q_2, && q_1 + \bar{q}_2 \to t\bar{t} + q_1 + \bar{q}_2.
\end{aligned} \tag{11}$$

After the phase space integrals has been done the partonic cross section $\hat{\sigma}$ is rendered finite by coupling constant renormalization, operator renormalization and the removal of collinear divergences. The renormalization scale μ_R is set equal to the mass factorization scale μ_F.

The cross section for top quark production in proton-proton collisions at the LHC is given by

$$\sigma = \sum_{a,b=q,\bar{q},g} \int dx_1 \int dx_2 \, f_a(x_1, \mu_F^2) f_b(x_2, \mu_F^2) \; \hat{\sigma}_{ab} \qquad (12)$$

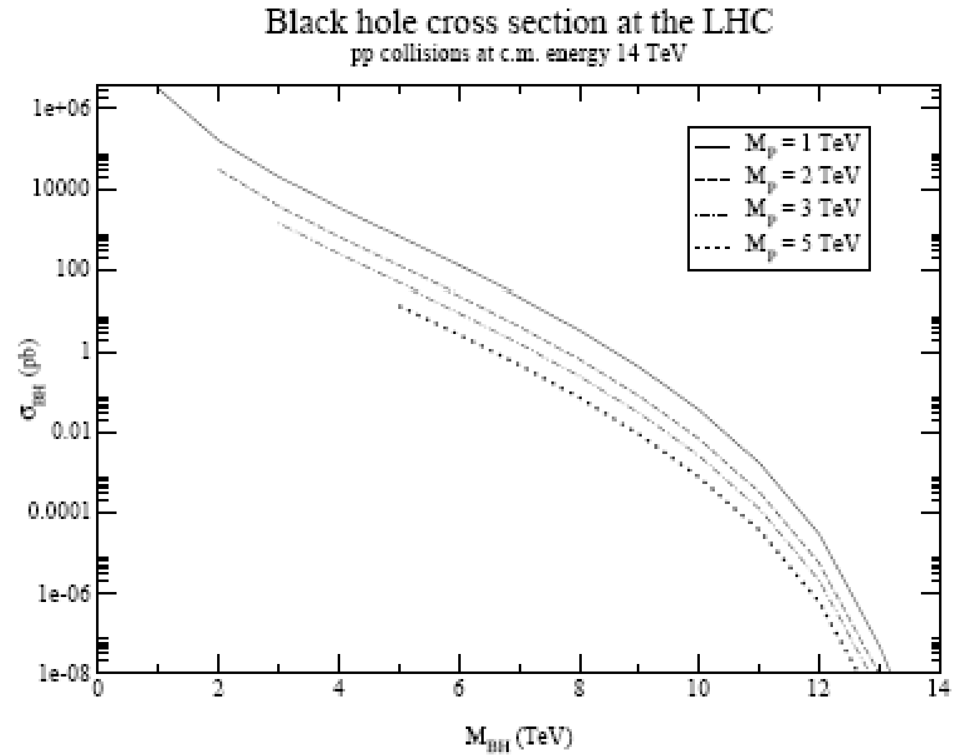


FIG. 1: Total cross sections for black hole production at the LHC.

These black hole production cross sections will be multiplied with the number of top quarks produced from a single black hole to obtain the top quark production cross section from a black hole at the LHC.

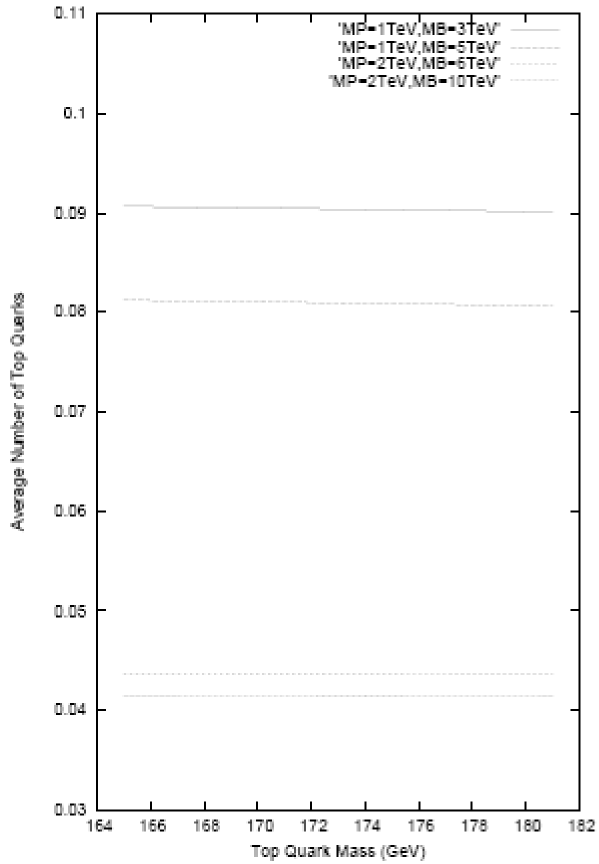


FIG. 2: Average Number of top quark production from a single black hole at LHC. The upper two lines are for black hole masses equal to 3 and 5 TeV respectively with the Planck mass equal to 1 TeV in each case. The lower two lines are for black hole masses equal to 6 and 10 TeV respectively with the Planck mass equal to 2 TeV in each case.

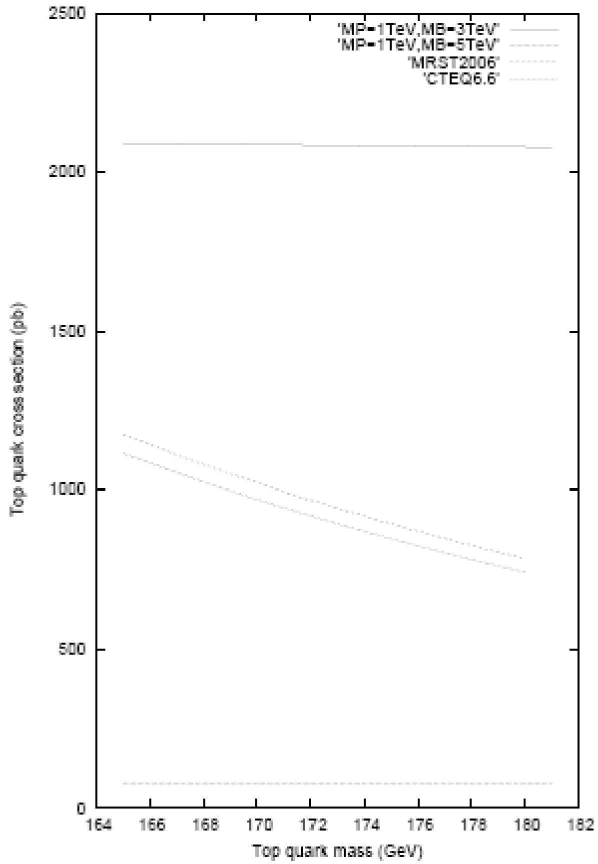


FIG. 3: Total cross section for top quark production at LHC from black holes and from direct pQCD processes at NNLO. The two middle curves are NNLO results and the upper and lower curves are from black holes of masses 3 TeV and 5 TeV respectively with the Planck mass equals 1 TeV in each case.

In summary, we have computed top quark production cross section from black holes in proton-proton collisions at the LHC at $\sqrt{s} = 14$ TeV via Hawking radiation within the model of TeV scale gravity and have compared it with the pQCD cross sections at NNLO. As the temperature of the black hole is ~ 1 TeV there is a huge amount of top quark production from black holes at the LHC if the Planck mass is ~ 1 TeV and the black hole mass is ~ 3 TeV. We also find that, unlike standard model predictions, the top quark production from black hole is not sensitive to the increase in top quark mass. Hence we suggest that the measurement of an increase in cross section for heavy particle (top quark or Higgs [23] or SUSY [22]) production at the LHC can be a useful signature for black hole production.

Závěry ?

Diskuse?

Náměty ?

??? BH at LHC ???

Literatura

The Formation of Black Holes in General Relativity

Demetrios Christodoulou

May 18, 2008

Black Holes in Higher Dimensions

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arXiv:0801.3471v2 [hep-th] 14 Feb 2008

Abstract

We review black hole solutions of higher-dimensional vacuum gravity, and of higher-dimensional supergravity theories. The discussion of vacuum gravity is pedagogical, with detailed reviews of Myers-Perry solutions, black rings, and solution-generating techniques. We discuss black hole solutions of maximal supergravity theories, including black holes in anti-de Sitter space. General results and open problems are discussed throughout.

Black Holes in Higher-Dimensional Gravity*

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Abstract

These lectures review some of the recent progress in uncovering the phase structure of black hole solutions in higher-dimensional vacuum Einstein gravity. The two classes on which we focus are Kaluza-Klein black holes, *i.e.* static solutions with an event horizon in asymptotically flat spaces with compact directions, and stationary solutions with an event horizon in asymptotically flat space. Highlights include the recently constructed multi-black hole configurations on the cylinder and thin rotating black rings in dimensions higher than five. The phase diagram that is emerging for each of the two classes will be discussed, including an intriguing connection that relates the phase structure of Kaluza-Klein black holes with that of asymptotically flat rotating black holes.

Black Holes at the LHC

Panagiota Kanti

Abstract In these two lectures, we will address the topic of the creation of small black holes during particle collisions in a ground-based accelerator, such as LHC, in the context of a higher-dimensional theory. We will cover the main assumptions, criteria and estimates for their creation, and we will discuss their properties after their formation. The most important observable effect associated with their creation is likely to be the emission of Hawking radiation during their evaporation process. After presenting the mathematical formalism for its study, we will review the current results for the emission of particles both on the brane and in the bulk. We will finish with a discussion of the methodology that will be used to study these spectra, and the observable signatures that will help us identify the black-hole events.

1 Introduction

These two lectures aim at offering an introduction to the idea that miniature black holes may be created during high-energy particle collisions at ground-based colliders. This scenario can only be realised in the context of higher-dimensional theories, i.e. theories that postulate the existence of additional spacelike dimensions in nature. An introduction to the two most important versions of these theories, namely the scenario with Large Extra Dimensions and the one with Warped Extra Dimensions will be our starting point.

We will then proceed to introduce the idea of the possible creation of black holes

Randall-Sundrum Gravitons and Black Holes at the LHC

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Models predicting the existence of extra spatial dimensions offer compelling and novel solutions to outstanding problems of the Standard Model. In such models, our universe exists on a 4 dimensional brane embedded in a larger dimensional space time. By allowing gravity to propagate in the bulk the gravitational coupling could be comparable with the other gauge interactions thus removing the hierarchy problem. The phenomenology of these models could have dramatic observable effects at the LHC including the production and decay of gravitons and mini black holes. In this note we summarize feasibility studies for the discovery of strong gravitational interactions at the LHC.

1 Theoretical Motivation

In the last decade, a number of new approaches to solving the hierarchy problem have been developed. One of the most novel approaches involves the addition of extra spatial dimensions. The perceived of weakness gravity is postulated to arise from the fact that the gravity is allowed to propagate into the extra dimensions while the rest of the Standard Model particles are confined to the standard three spatial dimensions.

Randall and Sundrum[1,2] were amongst the first to develop such models. In the original model there are two 3-dimensional branes embedded in a universe with one extra spatial dimension. The two branes are separated by a distance in the extra dimension which gravity, but not the rest of the Standard Model particles, can propagate in.

The model has a space time metric given by:

$$ds^2 = e^{-2k|z|}[dt^2 - dx^2] - dz^2 \quad (1)$$

On the Stability of Black Holes at the LHC

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August 19, 2008

We conclude that the exterior gravitational field of a Black hole is not native of an AdS_5 bulk and that the black holes produced by proton-proton collision at the LHC may be unstable. Nonetheless, it is possible that in a higher dimensional bulk $D > 5$, the behavior of the black holes is stable. This follows from the well known example given by the 6-dimensional flat bulk $M_6(4, 2)$, whose metric is also invariant under $SO(4, 2)$, so that it has the same group of isometries of the AdS_5. Consequently, all arguments of the ADS/CFT correspondence which depend only on the Lie group properties, can be extended without loss of generality to that flat bulk. By the same argument used in the ADS/CFT correspondence, the quantum unitarity of the Yang-Mills fields is maintained in the six-dimensional flat bulk.

Top Production from Black Holes at the LHC

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Top Quark Production from Black Holes at the CERN LHC

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(Dated: January 30, 2009)

Abstract

LHC is expected to be a top quark factory. If the fundamental Planck scale is near a TeV, then we also expect the top quarks to be produced from black holes via Hawking radiation. In this paper we calculate the cross sections for top quark production from black holes at the LHC and compare it with the direct top quark cross section via parton fusion processes at next-to-next-to-leading order (NNLO). We find that the top quark production from black holes can be larger or smaller than the pQCD predictions at NNLO depending upon the Planck mass and black hole mass. Hence the observation of very high rates for massive particle production (top quarks, higgs or supersymmetry) at the LHC may be an useful signature for black hole production.

PACS numbers: PACS: 04.70.Bw; 04.70.Dy; 12.38.Bx; 13.85.Ni; 14.65.Ha

Top Production from Black Holes at the LHC

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Abstract

In theories with large extra dimension and with low quantum gravity scale near a TeV, it is expected that TeV-scale black holes to be produced in proton-proton collisions at the LHC with the center of mass energy of 14 TeV. Since the black holes temperature can be around 1 TeV, top quark production is expected from them via Hawking radiation. Within the Standard Model of particle physics top quarks are produced via strong interaction in $t\bar{t}$ pairs or via electroweak interaction singly. Therefore, black holes can be the new source of top quark production. In this article we present the total cross sections and transverse momentum distributions of top quark production from black holes at the LHC. We find that the top quarks from black holes tend to reside at very high transverse momentum region so it can be a very useful signature for the black holes at the LHC.

Unparticle-Enhanced Black Holes at the LHC

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Abstract

Based on the idea that tensor unparticles can enhance the gravitational interactions between standard model particles, potential black hole formation in high energy collisions is examined. Modifications to the horizon radius r_H are derived, and the corresponding geometric cross-sections of such objects are calculated. It is shown that r_H increases dramatically to the electroweak scale for masses $M_{BH} \sim 1 - 10$ TeV, yielding a geometric cross-section on the order of $\lesssim$50 pb. This suggests that unparticle physics provides a mechanism for black hole formation in future accelerators, without the requirement of extra spatial dimensions.

SYMMETRIES OF HIGHER DIMENSIONAL BLACK HOLES

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Abstract. We prove that if a stationary, real analytic, asymptotically flat vacuum black hole spacetime of dimension $n \geq 4$ contains a non-degenerate horizon with compact cross sections that are transverse to the stationarity generating Killing vector field then, for each connected component of the black hole's horizon, there is a Killing field which is tangent to the generators of the horizon. For the case of rotating black holes, the stationarity generating Killing field is not tangent to the horizon generators and therefore the isometry group of the spacetime is at least two dimensional. Our proof relies on significant extensions of our earlier work on the symmetries of spacetimes containing a compact Cauchy horizon, allowing now for non closed generators of the horizon.

The high-energy collision of two black holes

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We study the head-on collision of two highly boosted equal mass, nonrotating black holes. We determine the waveforms, radiated energies, and mode excitation in the center of mass frame for a variety of boosts. For the first time we are able to compare analytic calculations, black hole perturbation theory, and strong field, nonlinear numerical calculations for this problem. Extrapolation of our results, which include velocities of up to $0.94c$, indicate that in the ultra-relativistic regime about $14 \pm 3\%$ of the energy is converted into gravitational waves. This gives rise to a luminosity of order $10^{-2}c^5/G$, the largest known so far in a black hole merger.

PACS numbers: 04.25.D-, 04.25.dc, 04.25.dg, 04.50.-h, 04.50.Gh, 04.60.Cf, 04.70.-s

MIFP-08-12

New Charged Black Holes in Five Dimensions

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[2] *DAMTP, Centre for Mathematical Sciences, Cambridge University, Wilberforce Road, Cambridge CB3 OWA, UK*

ABSTRACT

We obtain new stationary charged solutions of five-dimensional minimal supergravity. We first obtain purely dipole charged solutions, by extending a technique that we developed for five-dimensional Ricci-flat metrics in a previous paper, which could be viewed as being analogous to a four-dimensional construction by Demianski and Plebanski. The further introduction of electric charge is achieved by means of a solution-generating technique, which exploits the global $SL(2,\mathbb{R})$ symmetry of five-dimensional minimal supergravity reduced on a timelike direction to four dimensions. We present this procedure in detail, since it provides a particularly simple general way of adding charge to any stationary solution of five-dimensional minimal supergravity. The new charged solutions we obtain limit in special cases to black rings carrying electric and magnetic dipole charge, or to charged Myers-Perry rotating black holes. We analyse the general solutions in detail, showing that they can describe asymptotically locally flat black holes whose horizon is a lens space $L(n;m) = S^3/\Gamma(n;m)$. At infinity they approach Minkowski$_5/\Gamma(m;n)$.

Studenti na FJFI:

Dr

Z.Hubáček…….QCD

P. Vokáč…top in mj

V. Hynek……..diff

Dip

M.Vlasák….H/BH

K. Augsten….top 2l

Bak

P. Železný….CP

P. Božek…top spin

Particle Physics 2008

Some news from conferences and experiments:

ICHEP, PIC

V. Šimák, FJFI ČVUT Praha

LHC Machine Startup

ATLAS Detector Status & Physics Startup Plans

CMS Detector Status & Physics Startup Plans

Perturbative QCD Theory

QCD Experiment I

QCD Experiment II

Electroweak Physics (Includes W Mass & Width, WW, WZ, ZZ

Top Physics (Includes Single Top & Top Mass)

Theoretical Modeling of SM Processes in Hadronic Collisions

Higgs Searches

SUSY and SUSY - Higgs Theory

Beyond SM Searches

Alternative EWSB and BSM Theory

Experimental Overview of Neutrino Properties

Theoretical Overview of Neutrino Properties

CKM Angles

CKM sides

Rare Decays & New Physics

Properties of Heavy B hadrons

Study of $\Upsilon(1S)\pi\pi$ and $\Upsilon(2S)\pi\pi$ production between $\sqrt{s}\sim 10.83$ GeV and 11.02 GeV

Exotic c-cbar Resonances and Upsilon Spectroscopy

Light Hadron Spectroscopy & Charmonium

Heavy Flavor Theory

Decays of Open Charm

Lattice QCD

Review of Heavy Ion Experiment

Theoretical Review of Heavy Ion Physics

Recent Progress in Formal Theory

Early Universe ($t < 1 \mu$s)

Late Universe ($t > 1 \mu$s)

Search for Dark Matter

Status of ILC Accelerator and Detectors

Latest Developments in Technologies for Detectors

ICFA Summary

Report from C11

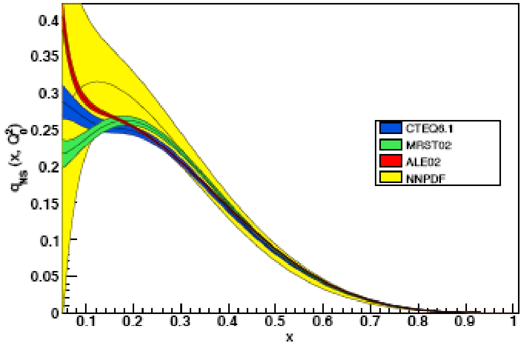
Combined analysis of Electric Dipole Moments and Lepton Flavor Violating Rare Decays

Review of Results from Pierre Auger Observatory, High-energy Gamma-ray Astronomy and Neutrino Astronomy

Observation of the bottomonium ground state, eta-b, at BaBar

Concluding Inspirational Talk

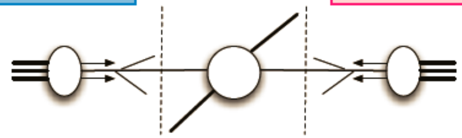
Perturbative QCD
— theory —



$$\frac{d\sigma_{\mathrm{pp}\to\mathrm{hadrons}}}{dX} = \sum_{a,b}\int dx_1 dx_2 f_a(x_1,\mu_F) f_b(x_2,\mu_F) \times \frac{d\hat{\sigma}_{\mathrm{ab}\to\mathrm{partons}}(\alpha_s(\mu_R),\mu_R,\mu_F)}{dX} + \mathcal{O}\left(\frac{\Lambda^n_{\mathrm{QCD}}}{Q^n}\right)$$

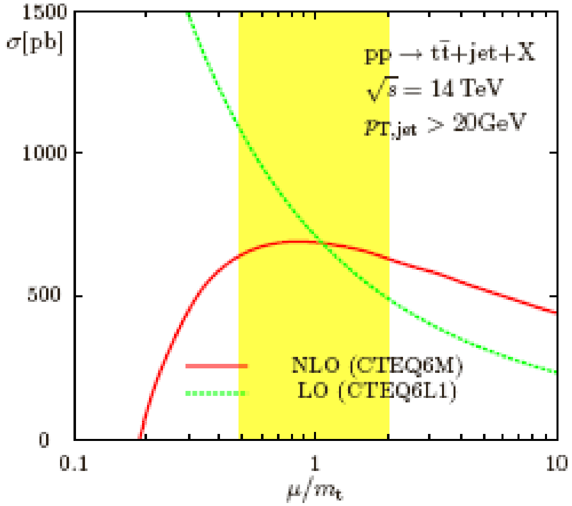
Extracted from data, but evolution is perturbative

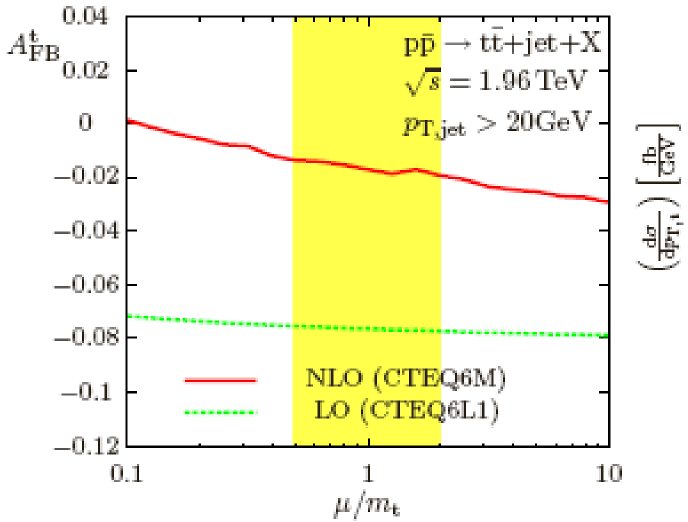
Expansion in the coupling constant (LO, NLO, NNLO…)



NB: factorization used in many contexts without proof

breakdown of factorization claimed in dijets at N³LO

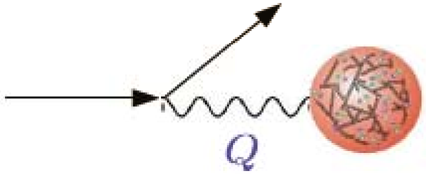




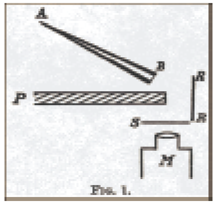
$$\alpha_s(M_Z^2) = 0.1240 \pm 0.0008\,(\mathrm{stat}) \pm 0.0010\,(\mathrm{exp}) \pm 0.0011\,(\mathrm{had}) \pm 0.0029\,(\mathrm{theo})$$

QCD Experiment I
Structure Functions

A short experimental history



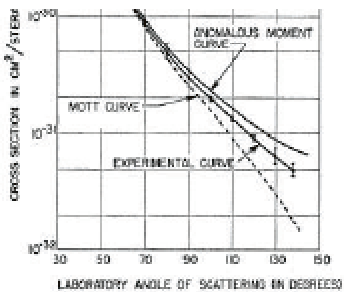
~100 years ago
α-Au
Geiger, Marsden. (1909)
Rutherford(1911)
E_α=5.5 MeV

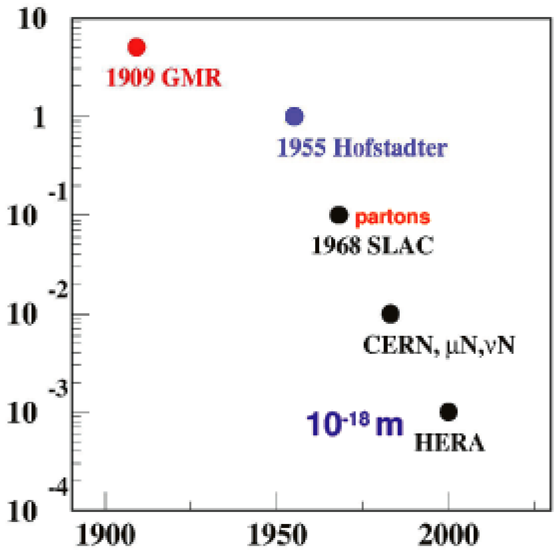


$$\delta\ [\mathrm{fm}] \simeq \frac{200\ \mathrm{MeV}}{Q}$$

53 years ago: ep
Hofstadter (1955)
$E_e \leq$250 MeV

indicate a true radius of 9.5×10^{-14} cm.

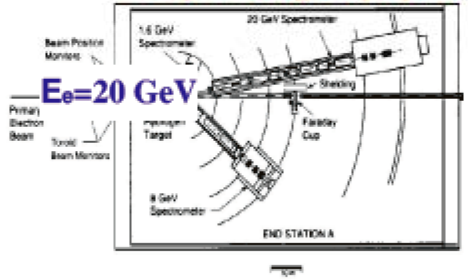


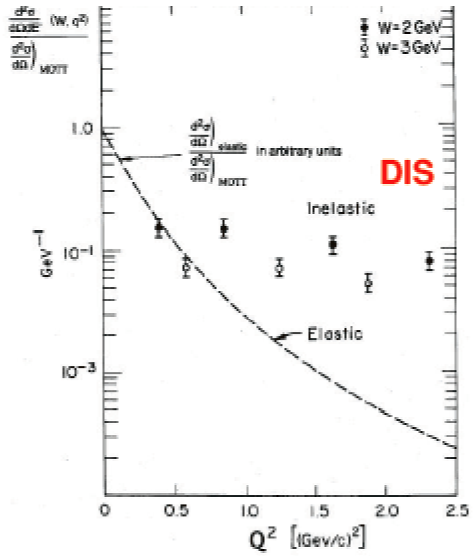


[polarised collisions since mid 70's]

40 years ago ep: partons

E_e=20 GeV





$$e^{\pm}p \ : \tilde{\sigma}^{\pm}_{NC} = \frac{d^2\sigma^{e^{\pm}p}_{NC}}{dx dQ^2} \frac{xQ^4}{2\pi\alpha^2 Y_+} = \tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+} x\tilde{F}_3, \quad Y_{\pm} = 1 \pm (1-y)^2$$

Leading Order picture of the proton

F_2 $$\left[F_2, F_2^{\gamma Z}, F_2^Z\right] = x\sum_q \left[e_q^2, 2e_q v_q, v_q^2 + a_q^2\right](q+\bar{q})$$ **quarks**

F_3 $$\left[xF_3^{\gamma Z}, xF_3^Z\right] = 2x\sum_q \left[e_q a_q, v_q a_q\right](q-\bar{q})$$ **(valence) quarks**

F_L $$F_L = 0(\sim x\alpha_s g \text{ at NLO})$$ **gluons**

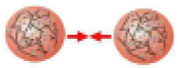
$$\sigma_{DIS} \simeq F_2 \equiv \mathcal{C}_{\text{lepton}-\text{parton}} \otimes f(x, Q^2)$$

q,g

perturbative QCD — non-perturbative

Theory developed to NNLO
[W.van Neerven (†), J.Vermaseren, et al]

factorisation



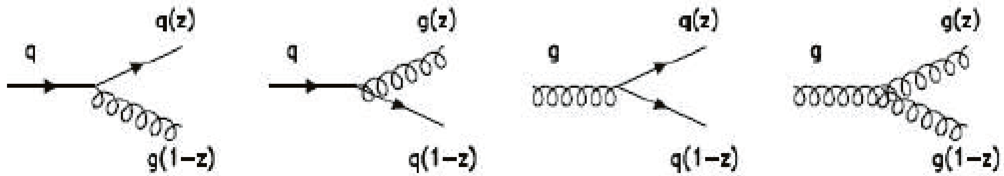
$$\sigma_{pp \to FS} \equiv \mathcal{C}_{\text{parton}-\text{parton}} \otimes f(x, Q^2) \otimes f(x, Q^2)$$

||

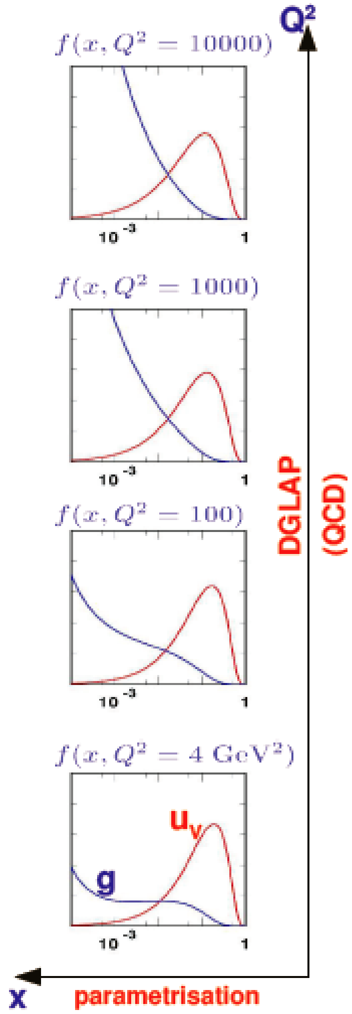
E² CM parton-parton

$f(x, Q^2)$ **Evolution** in Q² calculable in QCD **(DGLAP):**

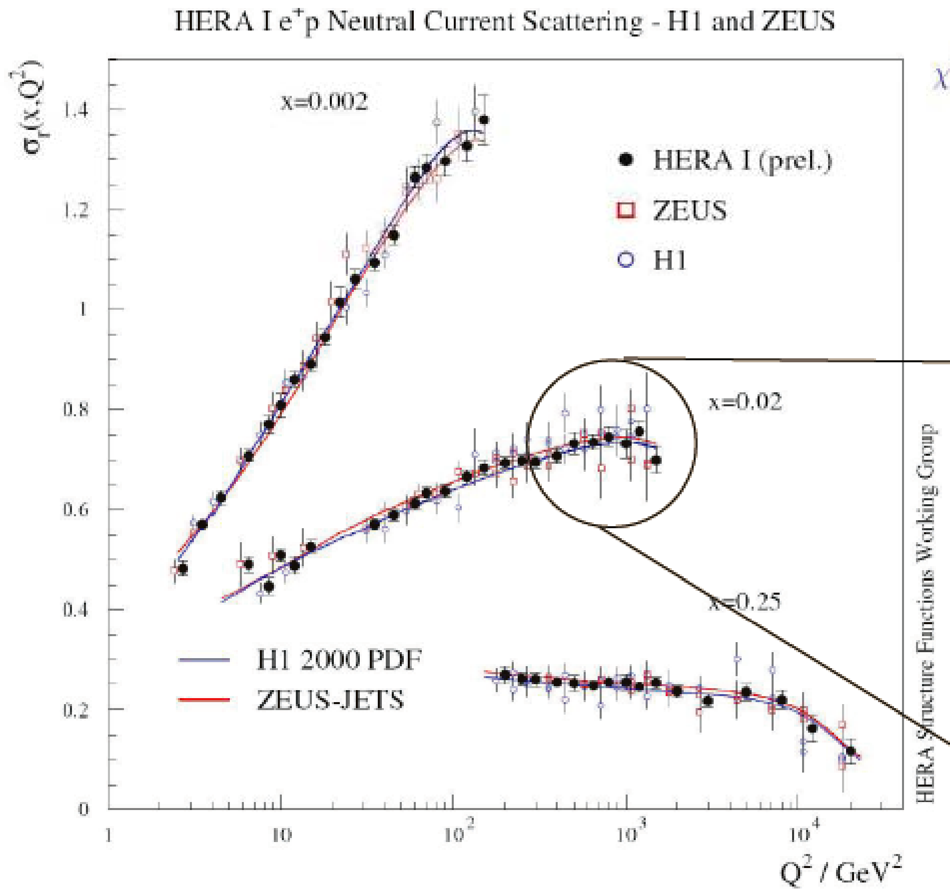
$$\frac{\partial}{\partial Q^2} f_i(x, Q^2) = \sum P^{i,j} \otimes f_j(x, Q^2)$$



$P_{qq}(z)$ $P_{gq}(z)$ $P_{qg}(z)$ $P_{gg}(z)$

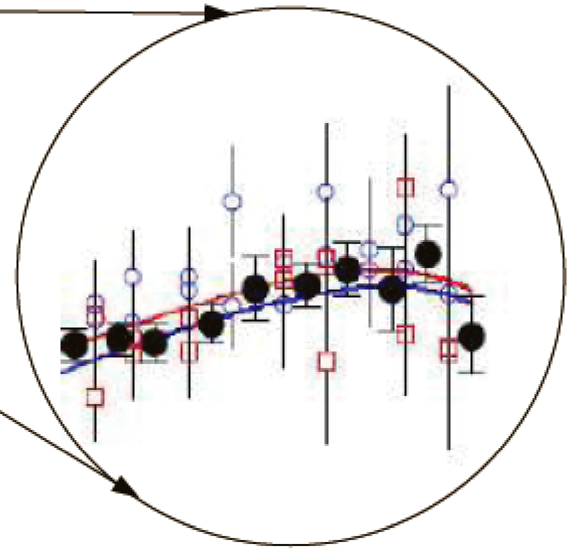


Coherent treatment of experimental effects in the average procedure (Lagrange multipliers method)



$$\chi^2(\{F_2^{true}\},\{\alpha\}) = \sum_i \frac{\left[F_2^{i,true} - \left(F_2^i + \sum_j \frac{\partial F_2^i}{\partial \alpha_j}\alpha_j\right)\right]^2}{\sigma_{F_2}^2} + \sum_j \frac{\alpha_j^2}{\sigma_{\alpha_j}^2}.$$

1153 individual NC/CC (HERA I data) averaged to 554 points

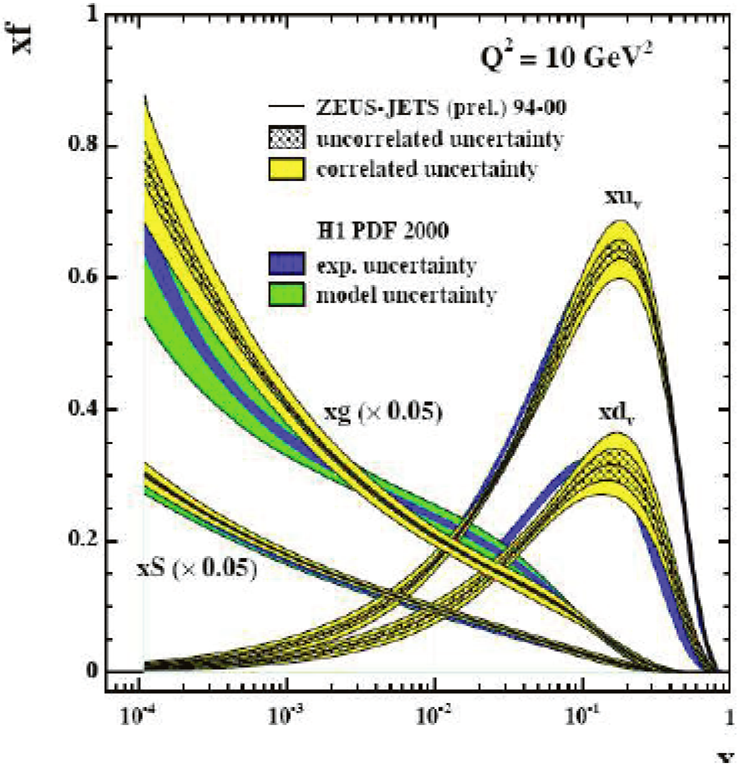


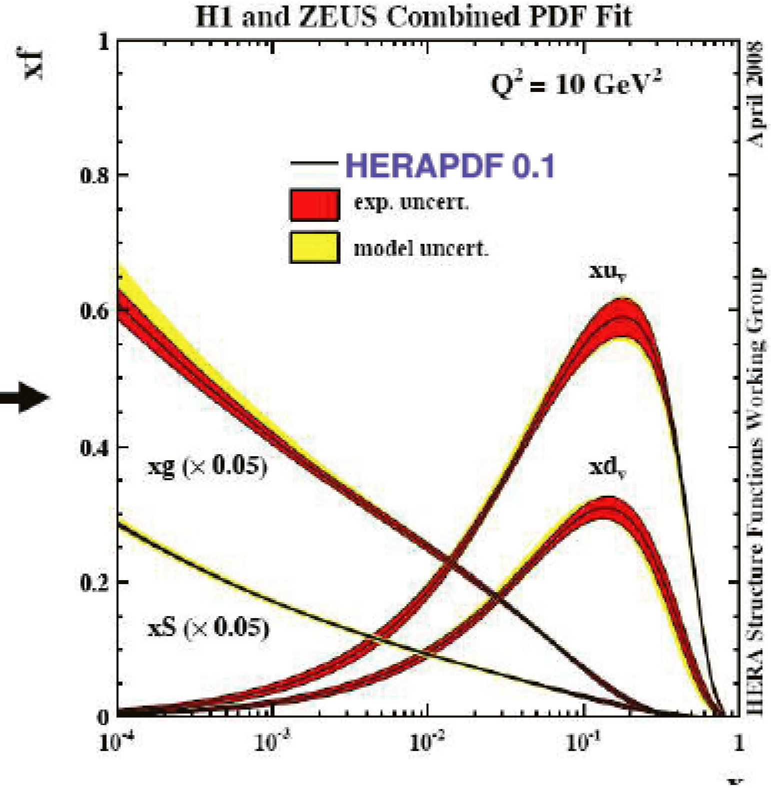
Improvements beyond the naively-expected sqrt(2): "cross calibration"

Partons parametrized at Q_0^2 = 4 GeV²

Experimental+Model uncertainties taken into account

Errors of the fit estimated using $\Delta\chi^2$=1





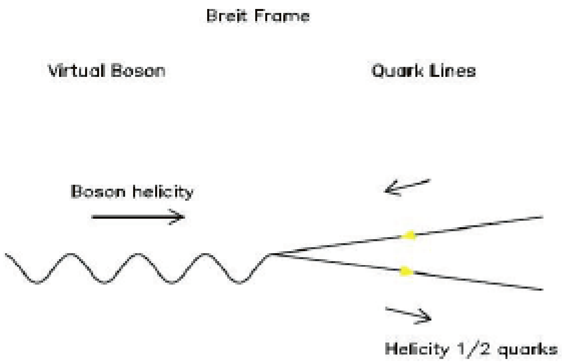
Longitudinal Structure Function F_L

$$\sigma_r = F_2(x, Q^2) - \frac{y^2}{Y_+} \cdot F_L(x, Q^2)$$

$$R = \sigma_L/\sigma_T = (F_2 - 2xF_1)/2xF_1 = F_L/2xF_1$$

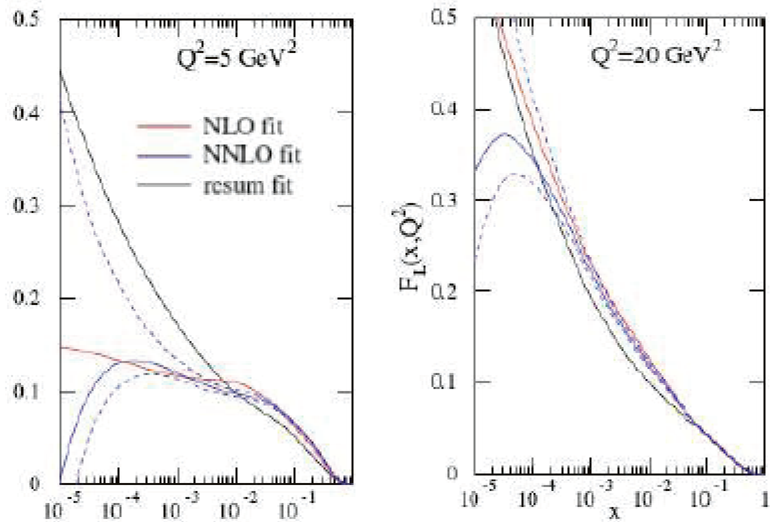
=0 for spin ½ partons in QPM
(Callan-Gross)

Fundamental form factor of the proton
Proportional to the gluon, important for PDF's
Discriminate between theoretical approaches



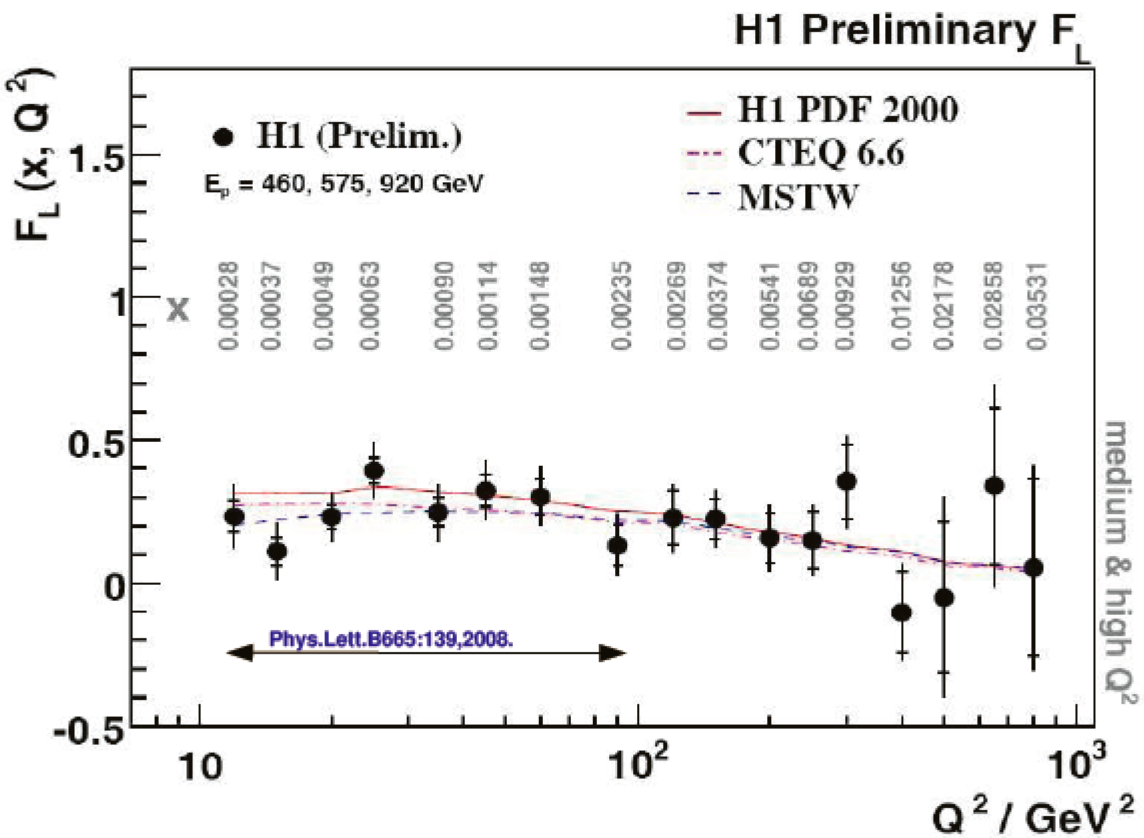
$$F_L(x, Q^2) \sim \alpha_s x g(x, Q^2)$$

Altarelli, Martinelli, 1978



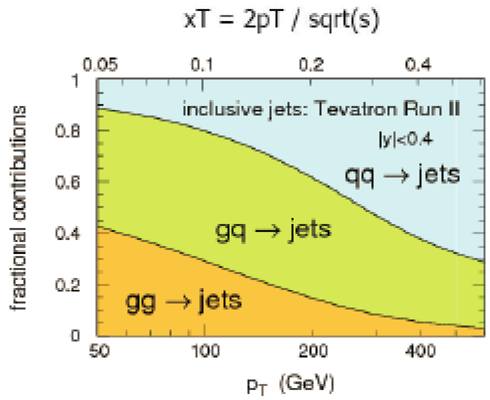
R.Thorne, DIS08

F_L averaged in each Q^2 bin

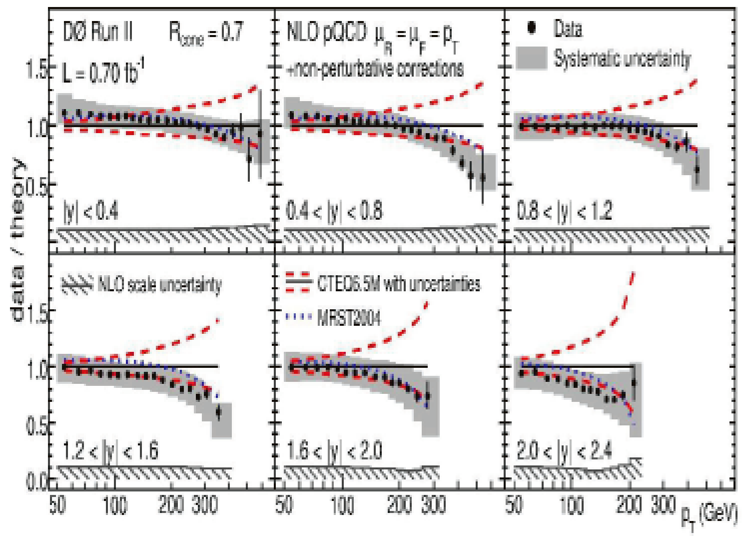


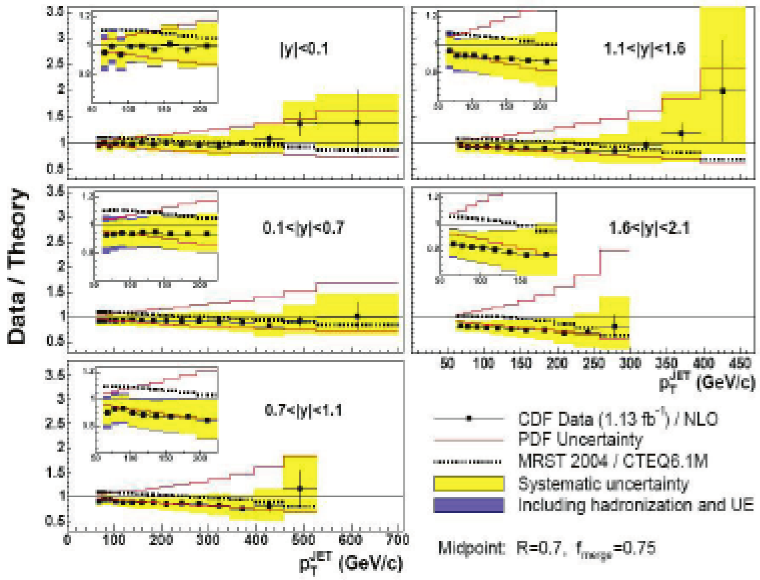
Work ongoing to extend to lower Q^2/x: test QCD, resummation, gluon

Jets production at Tevatron

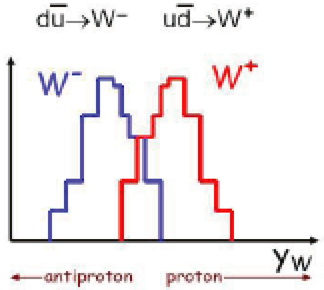


Impressive achievement in energy scale control (1%)
Sensitive to gluon at high x
Precision with present global fits
Included in MSTW





W asymmetry at Tevatron

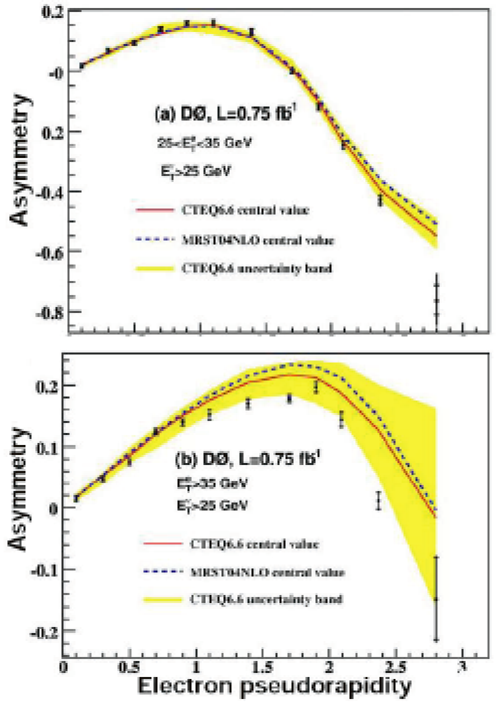


$$A_W(y) = \frac{\sigma^{W^+} - \sigma^{W^-}}{\sigma^{W^+} + \sigma^{W^-}} \sim \frac{d}{u}$$

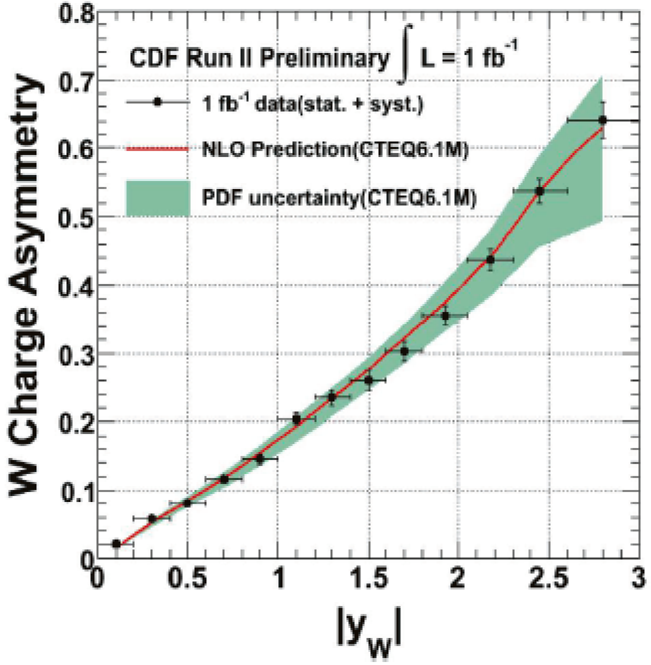
$$Q^2 = M_W^2 \quad x = \frac{M_W}{\sqrt{s}} e^{y_W}$$

$$0.002 < x < 0.8(1)$$

Use charged leptons (2 E_T bins)



W full reconstruction

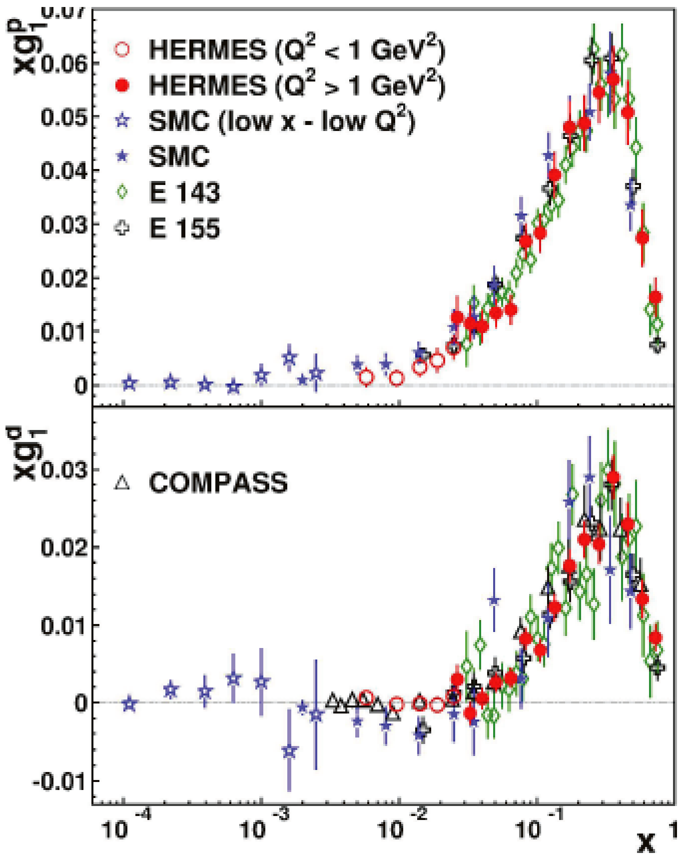


Expect to improve PDFs improvements at high x

The proton spin

Polarised lepton beam, polarised (H,D,...) targets

$$\sigma_{LL} \equiv \frac{1}{2}(\sigma^{\overleftarrow{\rightarrow}} - \sigma^{\overrightarrow{\rightarrow}})/2 \simeq g_1^{p,n}(x,Q^2) = \frac{1}{2}\sum_q e_q^2 \left[\Delta q^{p,n}(x,Q^2) + \Delta\bar{q}^{p,n}(x,Q^2)\right]$$



$$\Delta\Sigma = \int \Delta q \simeq 0.33$$

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_z^q + \Delta G + L_z^G$$

Level arm in Q^2 not large:

gluon contribution not constrained

=> semi-inclusive data

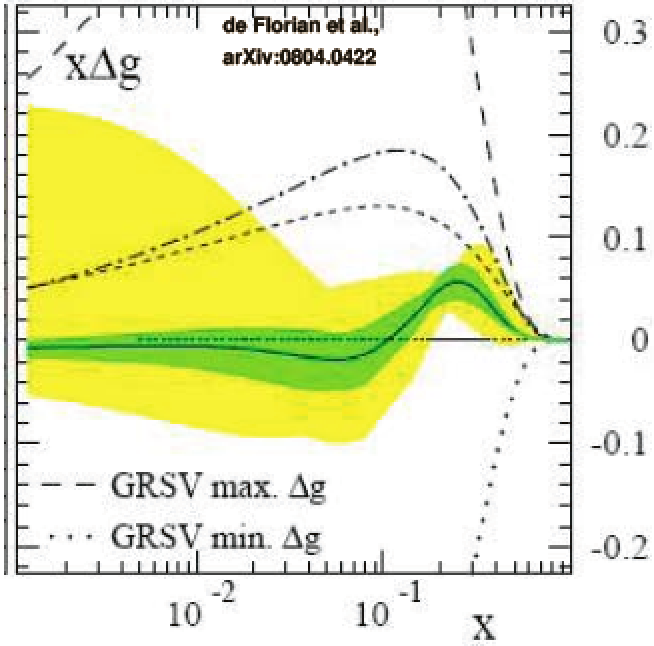
Use final states and angular distributions to further pin down the spin

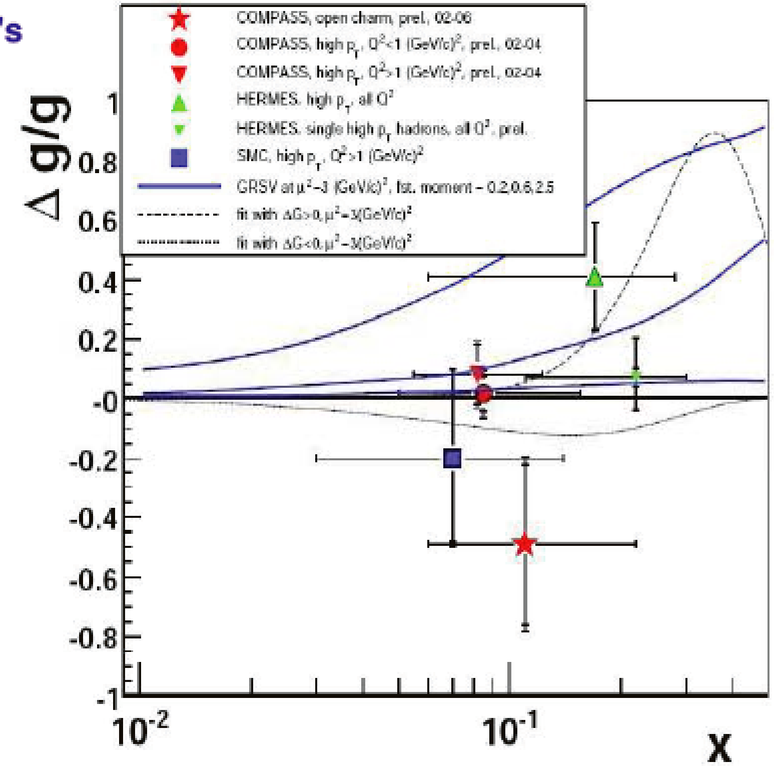
Gluon contribution to the spin

Understanding the gluon is crucial for the proton structure

Extracted via semi-inclusive processes: meson production in polarised DIS and pp (RHIC)

Global pol-analysis: extract polarised PDF's

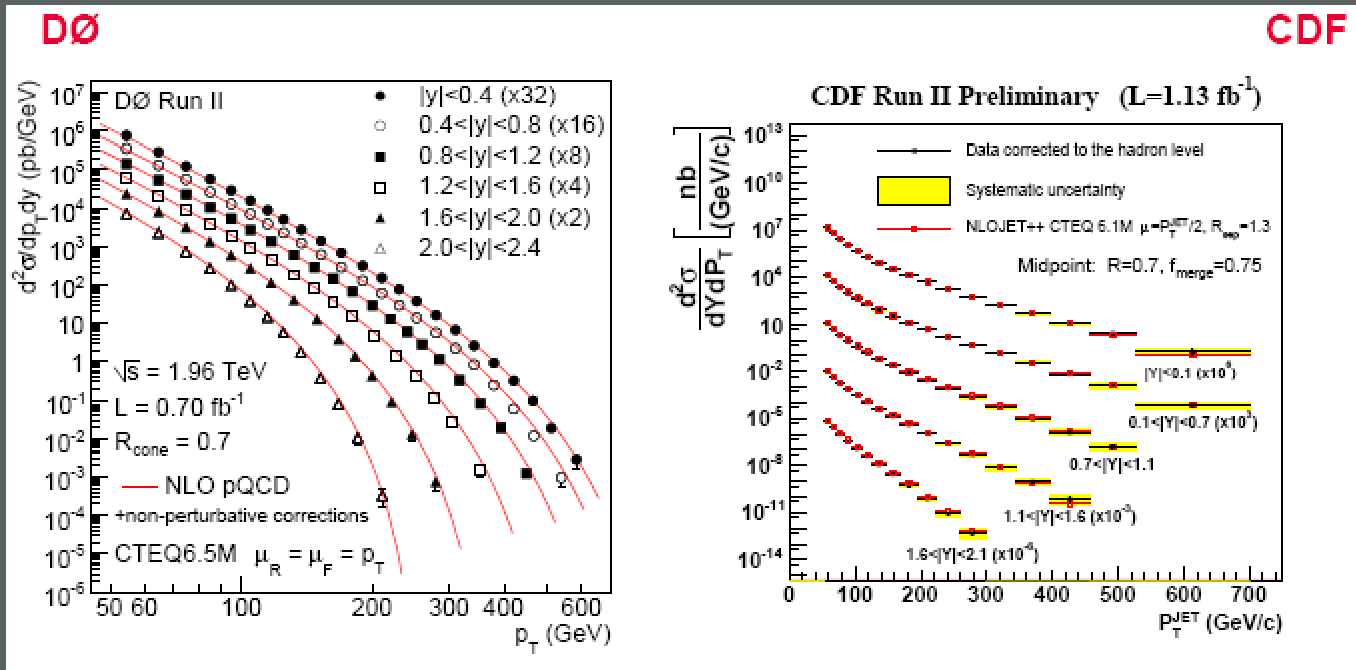




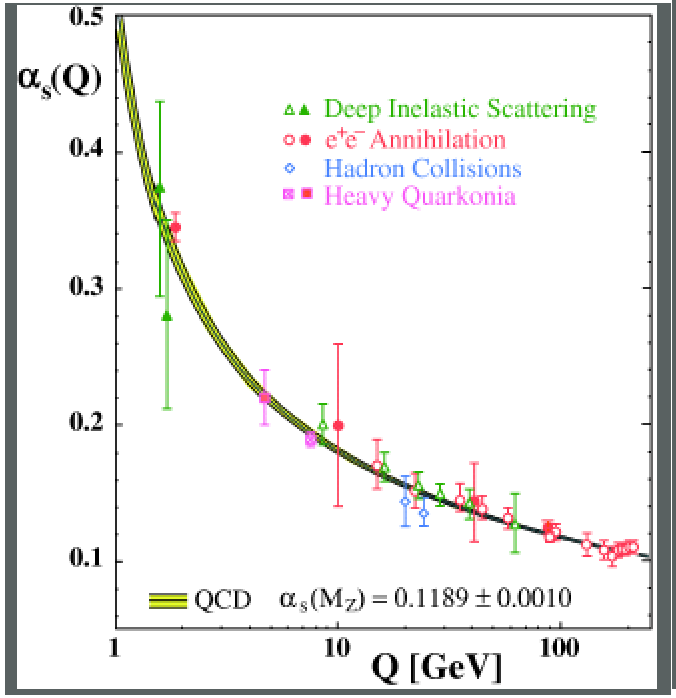
Extreme options now excluded
Extend x-range in pp at RHIC

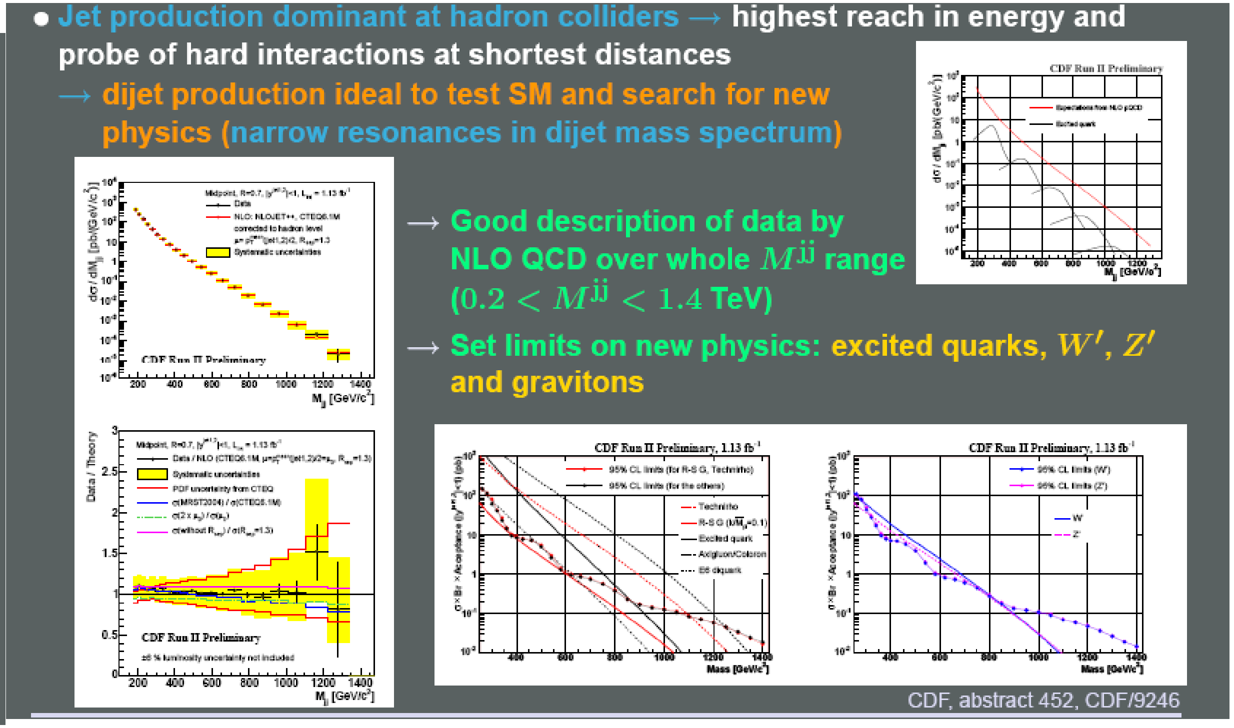
Precision tests of QCD with jets and vector bosons at HERA and TevaTron

- Inclusive-jet cross sections in $p\bar{p}$ collisions: high precision measurements at high $E_T^{\rm jet}$, where new physics might show up (and sensitive to g PDF at high x)

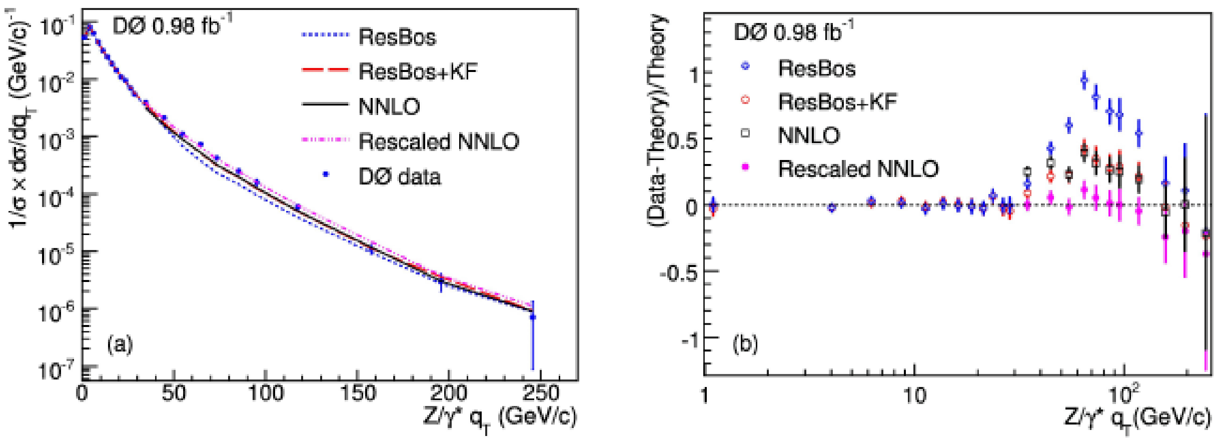


⟶ **Good description of data by NLO QCD calculations**



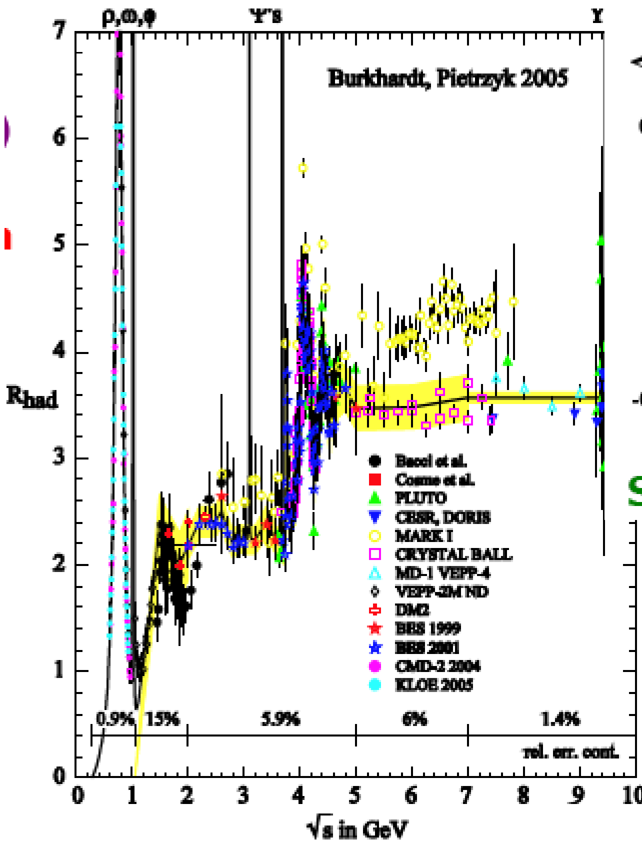


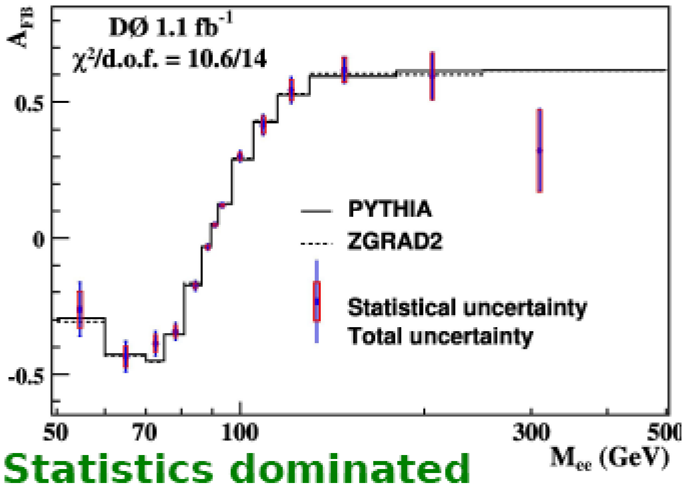
NNLO calculation describes the shape, but not the normalization (rescale cross section by 25%)



PRL 100, 102002 (2008)

Electroweak Physics

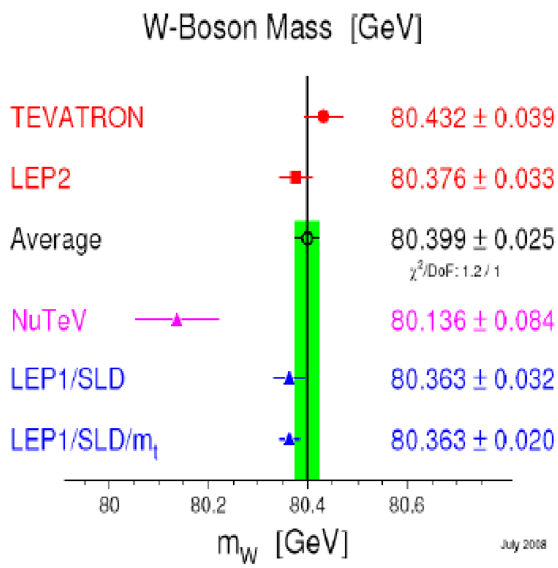


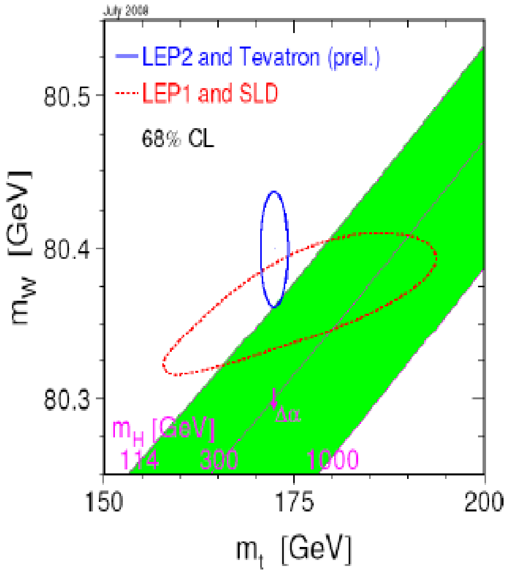


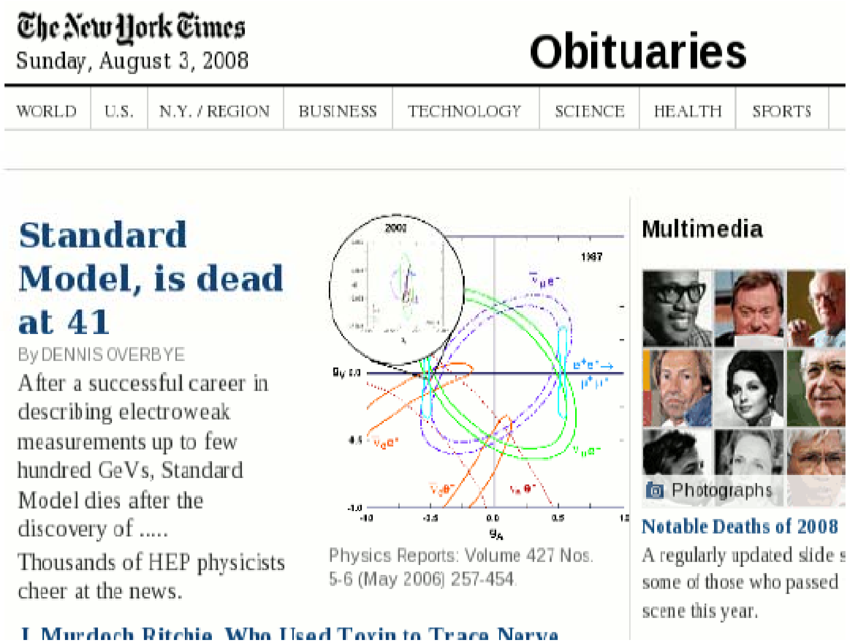
Tevatron Experiments	
Channel	Events/1fb^{-1}
$W \to l\nu$	5M
$Z \to ll$	500k
$W\gamma \to l\nu\gamma$	32000
$Z\gamma \to ll\gamma$	8000
$WW \to l\nu l\nu$	600
$WZ \to l\nu ll$	50
$ZZ \to ll\nu\nu$	40
$ZZ \to llll$	6

Statistics dominated

- small changes in Tevatron combination of M_W/Γ_W (few MeV)






The New York Times
Sunday, August 3, 2008

Obituaries

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS

Standard Model, is dead at 41

By DENNIS OVERBYE

After a successful career in describing electroweak measurements up to few hundred GeVs, Standard Model dies after the discovery of .....

Thousands of HEP physicists cheer at the news.

Physics Reports: Volume 427 Nos. 5-6 (May 2006) 257-454

Multimedia

Photographs

Notable Deaths of 2008

A regularly updated slide s... some of those who passed ... scene this year.

J. Murdoch Ritchie, Who Used Toxin to Trace Nerve

Electroweak Fits – Limits on M_H

M_t = ([redacted]) GeV

$\alpha_s(M_Z^2)=0.1185\pm0.0026$

$\Delta\alpha^{(5)}_{had}=0.02758\pm0.00035$

$M_H=84^{+34}_{-26}$

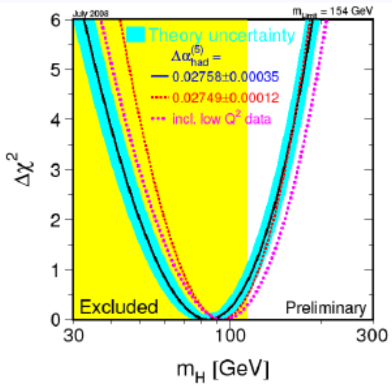
$\chi^2=17.3/13$, prob=18%

$M_H<154$ GeV @ 95% CL

with theory driven value of

$\Delta\alpha^{(5)}_{had}=0.02749\pm0.00012$

$M_H=93^{+31}_{-24}$



See next talk for updated value of ΔM_t

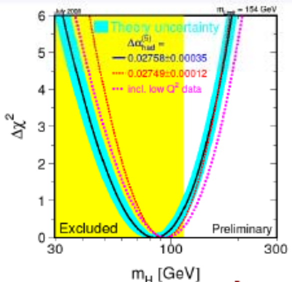
Impact of uncertainties on M_H:	
ΔM_t =±[redacted] GeV	ΔM_H = +9/-8 GeV
ΔM_W =±25 MeV	ΔM_H = -13/+17 GeV
$\Delta\alpha^{(5)}_{had}$= ±0.00035	ΔM_H = -15/+17 GeV

Just kidding.....

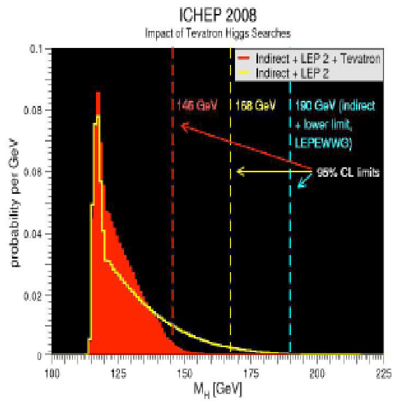
While waiting for the new energy regime of LHC

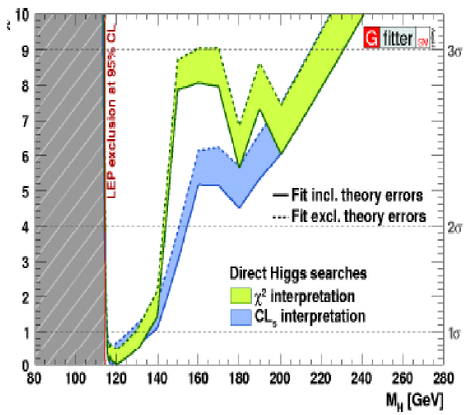
Tevatron continues to produce new results:

- expect improvements on M_W which will further constrain the expected value of M_H
- large dataset and new techniques allow measurements which can be helpful to constrain PDFs and event generators needed for LHC



Measurements of R in e^+e^- collisions at low energy could become the next bottleneck in the indirect determination of M_H

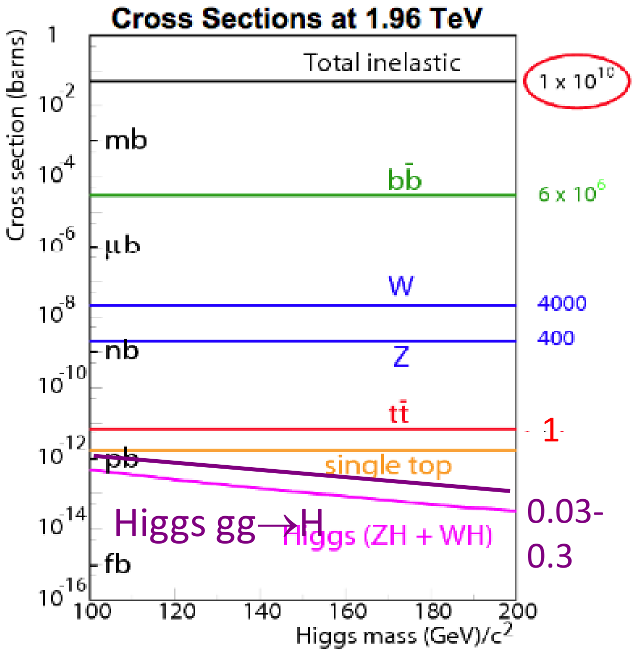


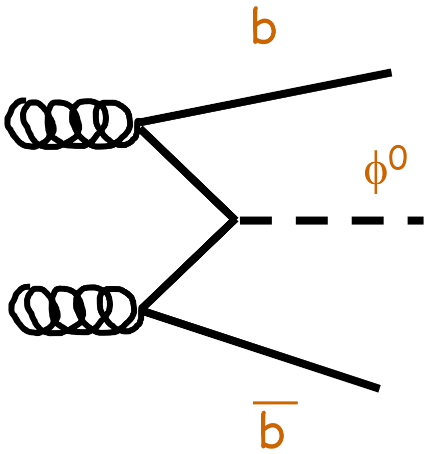


Electroweak fits prefer light Higgs....

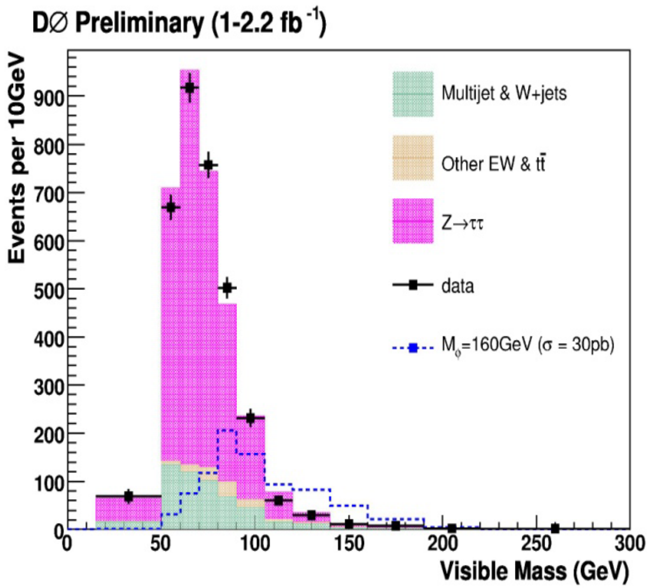
Extensions to more complicated models (2HDM, SUSY), including other observables in progress (Gfitter)

Searches for the Higgs Boson



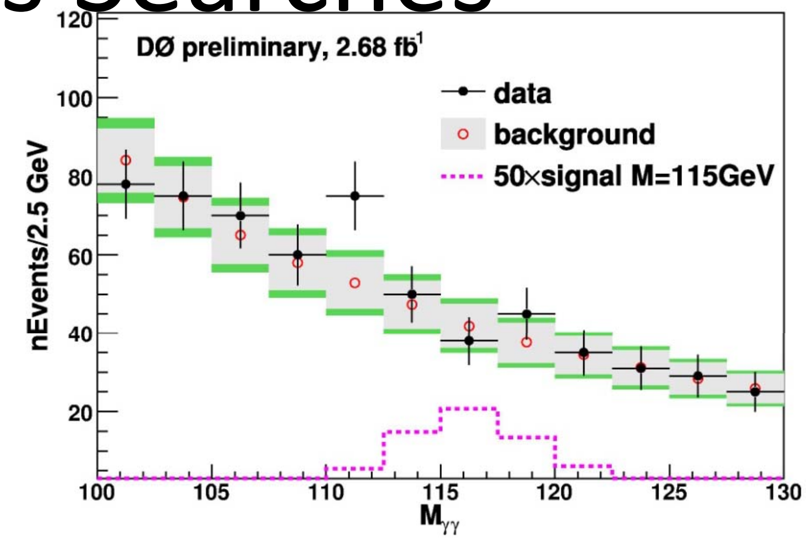


BSM Higgs

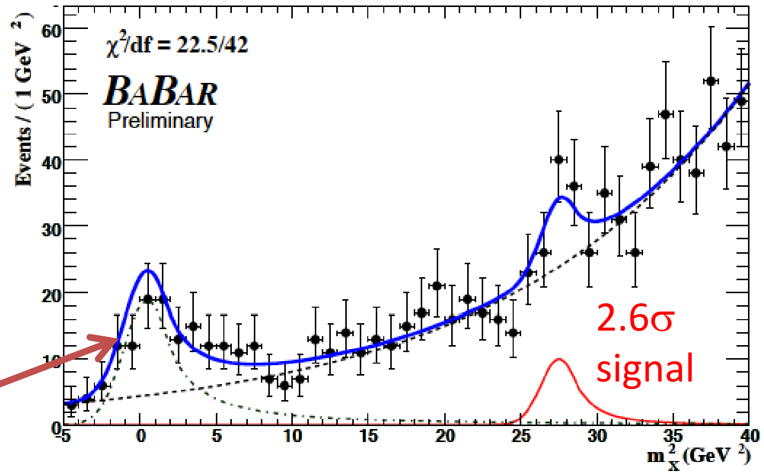


Other BSM Higgs Searches

- DØ: H→$\gamma\gamma$ benchmarked as SM search
  - Fermiophobic Higgs
  - At lower mass large BR(H→$\gamma\gamma$) ~10%
  - Key issue: understanding QCD background: uses excellent calorimeter



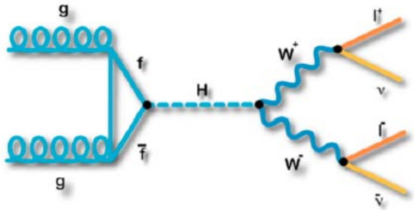
- Other BSM Higgs Searches
  - WH→WWW (also SM), charged Higgs, decays to and from top…
- Babar: $A^0 \rightarrow \chi\chi$, invisible light Higgs decay
  - Photon+Missing energy in Y(3S) decays
  - Key issue: e+e-→$\gamma\gamma$ background
  - For m_A<7.8GeV



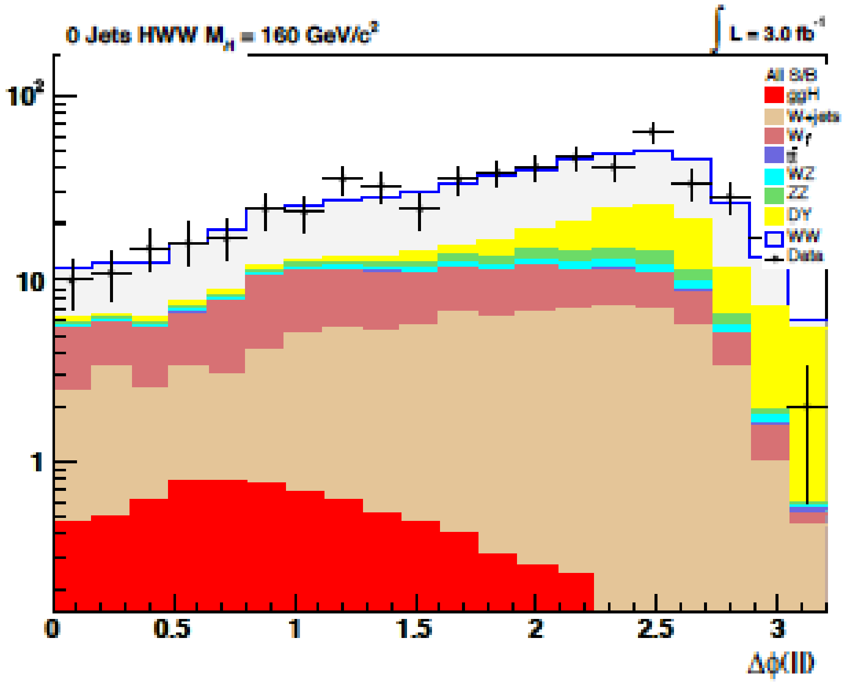
BR(Y(3S)→$\gamma A^0 \rightarrow \chi\chi$) < 0.7-31x10^{-6}

Models: up to x10^{-4}

SM Higgs: H→WW

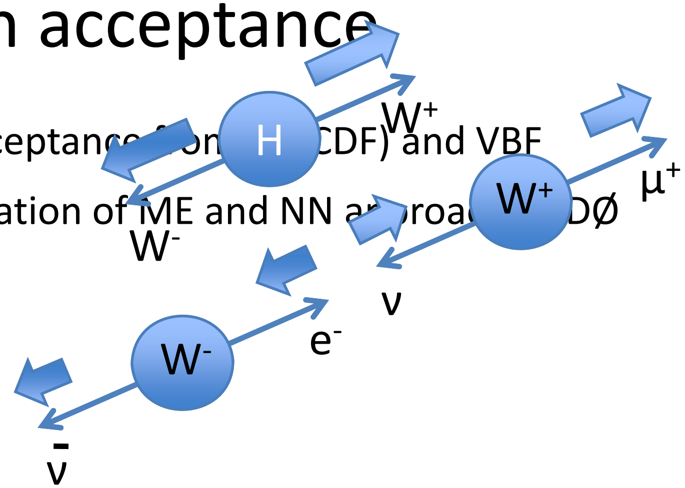


- H→WW→lνlν - signature: Two high p_T leptons and MET
  – Primary backgrounds: WW and top in di-lepton decay channel
  – Key issue: Maximizing lepton acceptance



on of acceptance from ... CDF) and VBF

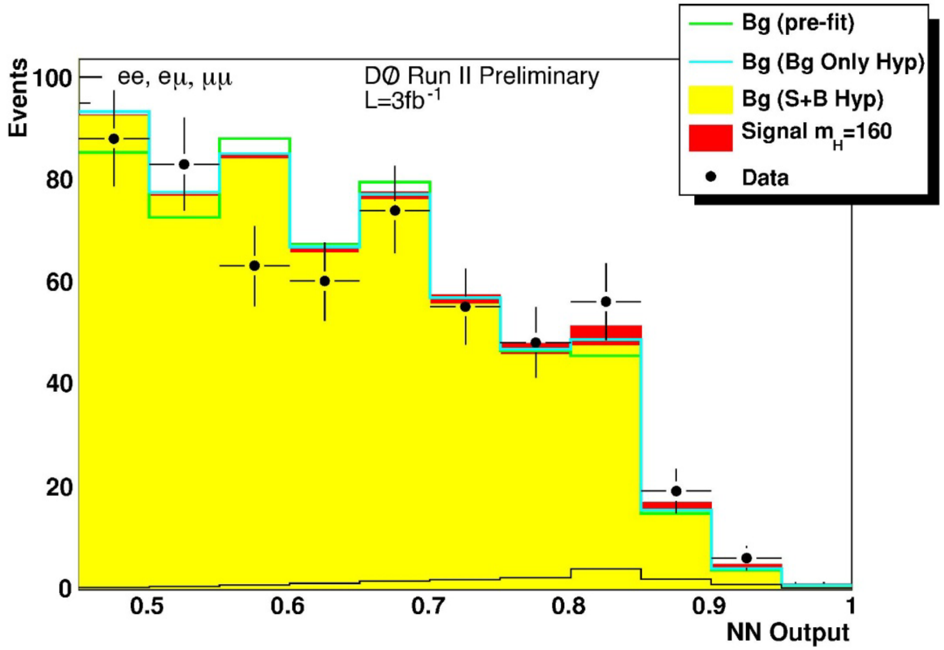
Combination of ME and NN approach DØ

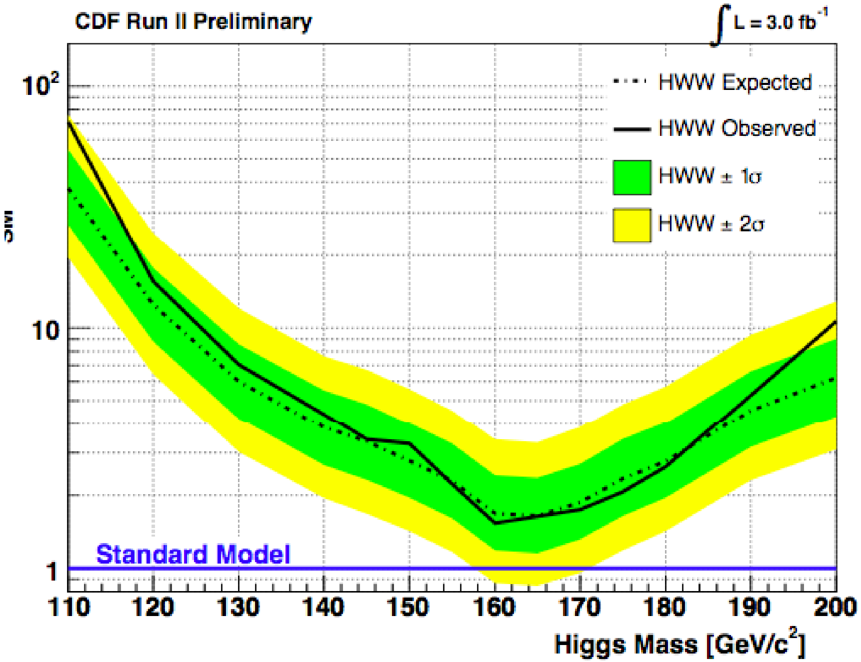


Spin correlation: Charged leptons go in the same direction

SM Higgs: H→WW

- Most sensitive Higgs search channel at the





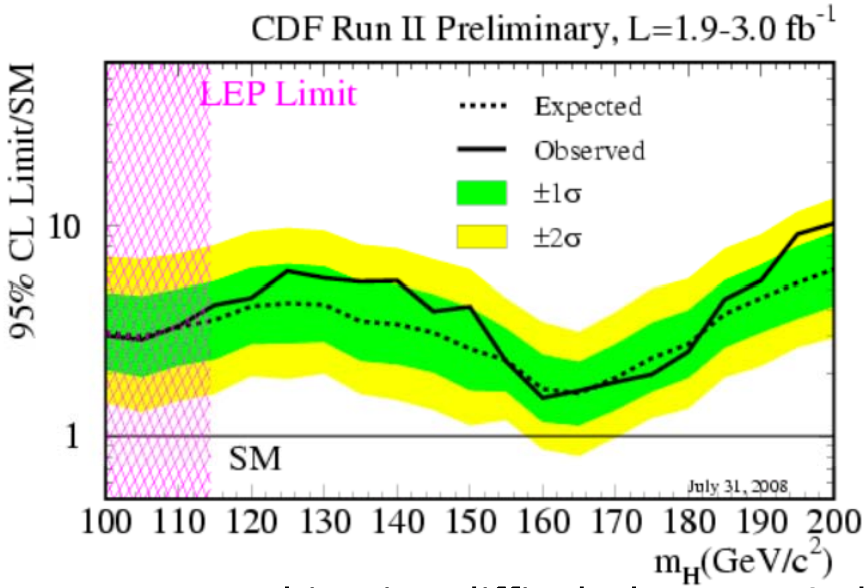
Results at mH = 165GeV : 95%CL Limits/SM

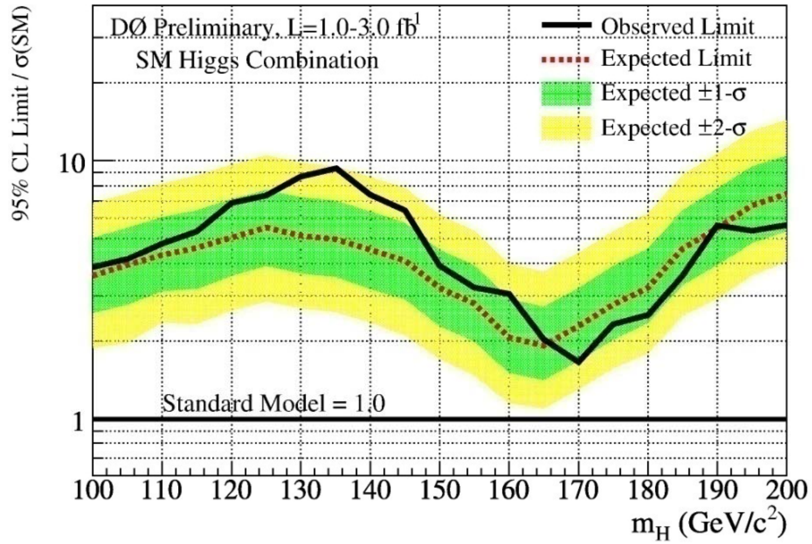
Both experiments
Approaching
SM sensitivity!

Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF ME+NN	3.0	17.2	1.6	1.6
DØ NN	3.0	15.6	1.9	2.0

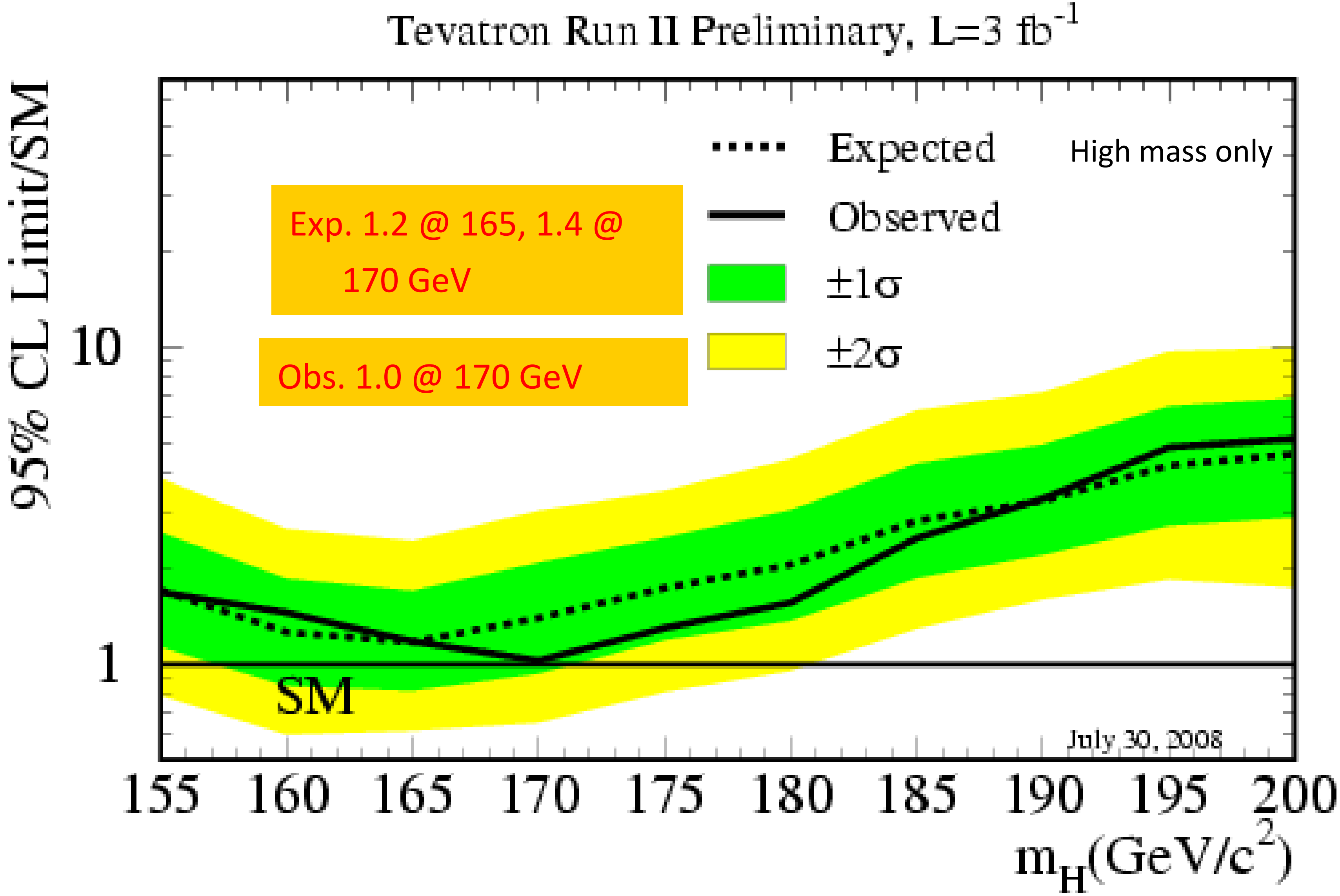
SM Higgs Combined Limits

- Limits calculating and combination
  - Using Bayesian and CLs methodologies.
  - Incorporate systematic uncertainties using pseudo-experiments (shape and rate included) (correlations taken into account between experiments)
  - Backgrounds can be constrained in the fit





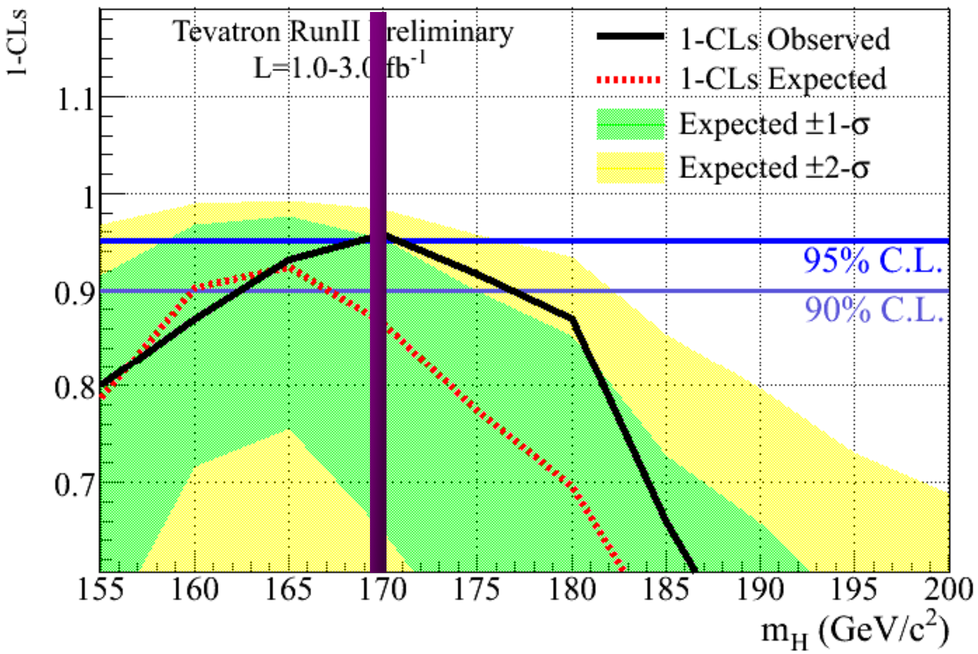
- Low mass combination difficult due to ~70 channels
  - Expected sensitivity of CDF/DØ combined: <3.0xSM @ 115GeV



SM Higgs Excluded: m_H = 170 GeV

SM Higgs Combination

- Result verified using two independent methods(Bayesian/CLs)



95%CL Limits/SM

M Higgs(GeV)	160	165	**170**	175
Method 1: Exp	1.3	1.2	1.4	1.7
Method 1: Obs	1.4	1.2	**1.0**	1.3
Method 2: Exp	1.2	1.1	1.3	1.7
Method 2: Obs	1.3	1.1	**0.95**	1.2

SM Higgs Excluded: m_H = 170 GeV

- We exclude at 95% C.L. the production of a SM Higgs boson of 170 GeV

Generation of Mass in the Standard Model :

Spontaneous Symmetry Breakdown

Particle Masses arise through the Higgs mechanism: Spontaneous breakdown of gauge symmetry

$$SU(3)_c \times SU(2)_L \times U(1)_Y \to SU(3)_C \times U(1)_{\mathrm{em}}$$

A scalar field, charged under the gauge group, acquires v.e.v.

$$V(H) = m_H^2 H^\dagger H + \frac{\lambda}{2}\left(H^\dagger H\right)^2$$

Therefore,

$$\langle H^\dagger H \rangle = -\frac{m_H^2}{\lambda}$$

the v.e.v. of the Higgs field is fixed by the value of the negative mass parameter.

Problem: The mass parameter is unstable under quantum corrections.

Minimal Supersymmetric Standard Model

SM particle	SUSY partner	G_{SM}
(S = 1/2)	(S = 0)	
$Q = (t, b)_L$	$(\tilde{t}, \tilde{b})_L$	(3,2,1/6)
$L = (\nu, l)_L$	$(\tilde{\nu}, \tilde{l})_L$	(1,2,-1/2)
$U = (t^C)_L$	$\tilde{t}_R^*$	($\bar{3}$,1,-2/3)
$D = (b^C)_L$	$\tilde{b}_R^*$	($\bar{3}$,1,1/3)
$E = (l^C)_L$	$\tilde{l}_R^*$	(1,1,1)
(S = 1)	(S = 1/2)	
B_μ	$\tilde{B}$	(1,1,0)
W_μ	$\tilde{W}$	(1,3,0)
g_μ	$\tilde{g}$	(8,1,0)

Essential Ingredient: Superpotential: gauge invariant, analytical function of chiral fields (renormalizability: polynomial of degree three, no hermitian conjugates)

$$P(A) = \frac{m_{ij}}{2} A_i A_j + \frac{\lambda_{ijk}}{6} A_i A_j A_k$$

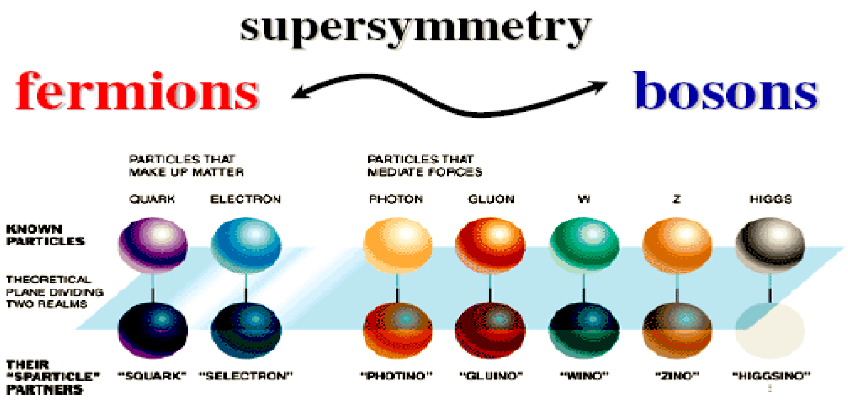
Yukawa interactions derived from it

$$\frac{1}{2}\frac{\partial^2 P(A)}{\partial A_i \partial A_j}\psi_i \psi_j + h.c.$$

$$\to \lambda_{ijk}\, \psi_i\, \psi_j\, A_k$$

Why Supersymmetry ?

- Helps to stabilize the weak scale—Planck scale hierarchy
- Supersymmetry algebra contains the generator of space-time translations. Necessary ingredient of theory of quantum gravity.
- Minimal supersymmetric extension of the SM : Leads to Unification of gauge couplings
- Starting from positive masses at high energies, electroweak symmetry breaking is induced radiatively
- If discrete symmetry, $P = (-1)^{3B+L+2S}$ is imposed, lightest SUSY particle neutral and stable: Excellent candidate for cold Dark Matter.



Photino, Zino and Neutral Higgsino: Neutralinos

Charged Wino, charged Higgsino: Charginos

No new dimensionless couplings. Couplings of supersymmetric particles equal to couplings of Standard Model ones.
Two Higgs doublets necessary. Ratio of vacuum expectation values denoted by $\tan\beta$

Unification of Couplings

- The value of gauge couplings evolve with scale according to the corresponding RG equations:

$$\frac{1}{\alpha_i(Q)} = \frac{b_i}{2\pi}\ln\left(\frac{Q}{M_Z}\right) + \frac{1}{\alpha_i(M_Z)}$$

- Unification of gauge couplings would occur if there is a given scale which couplings converge.

$$\frac{1}{\alpha_3(M_Z)} = \frac{b_3-b_2}{b_1-b_2}\frac{1}{\alpha_1(M_Z)} + \frac{b_3-b_1}{b_2-b_1}\frac{1}{\alpha_2(M_Z)}$$

- This leads to a relation between $\alpha_3(M_Z)$ and $\sin^2\theta_W(M_Z) = \alpha_1^{SM} / \left(\alpha_1^{SM} + \alpha_2^{SM}\right)$.

Results

$b_1 = -6 - 3N_H/5, \quad b_2 = -N_H, \quad b_3 = 3$

$1/\alpha_1(M_Z) \simeq 60 \quad 1/\alpha_2(M_Z) \simeq 30$

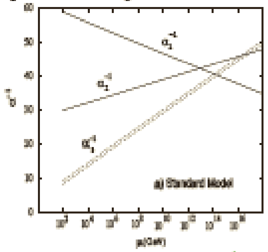
In the above, N_H is the number of pair of Higgs doublets. With these results we can compute the strong gauge coupling at M_Z

$$\frac{1}{\alpha_3(M_Z)} = \frac{15-7N_H}{25+3N_H}30$$

The result depends strongly on the number of Higgs doublets. For N_H equal to zero, we get $\alpha_3(M_Z) = 1/18 \simeq 0.05$. For $N_H = 1$, instead, we get $\alpha_3(M_Z) \simeq 0.120$!! Excellent prediction !
For $N_H = 2$ we get, again, a very bad result $\alpha_3(M_Z) \simeq 1$.
Finally, for $N_H = 1$,
$M_G = M_Z \exp(30 \times 2\pi \times (5/28)) \simeq 10^{16}\text{GeV}$
Grand Unification scale is very close to the Planck scale, suggesting a unified description of particle interactions.

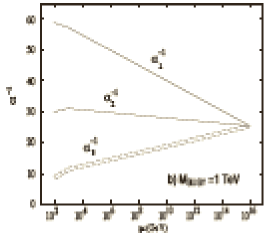
SM:

Couplings tend to converge at high energies, but unification is quantitatively ruled out.



MSSM:

Unification at $\alpha_{GUT} \simeq 0.04$ and $M_{GUT} \simeq 10^{16}$ GeV.



Bardeen, Carena, Pokorski

Experimentally, $\alpha_3(M_Z) \simeq 0.118 \pm 0.004$
in the MSSM: $\alpha_3(M_Z) = 0.127 - 4(\sin^2\theta_W - 0.2315) \pm 0.008$

Remarkable agreement between Theory and Experimen

Threshold Corrections

- The unification prediction depends strongly on the supersymmetry particle mass spectrum,

$$\alpha_3(M_Z) \simeq 0.127 - \alpha_3^2(M_Z)\ln\left(\frac{T_{SUSY}}{M_Z}\right)$$

- The threshold scale does not correspond to any particular particle scale but it may be approximated by

$$T_{SUSY} \simeq |\mu|\left(\frac{M_2}{M_3}\right)^{3/2}$$

where Mi are the SU(2) and SU(3) gaugino masses.

- Naive unification may be obtained for threshold scales of the order of 1 TeV, which are easier to obtain for a smaller ratio of the wino and gluino masses than what the simplest models predict.
- In these models the predicted value of the strong gauge coupling would be somewhat larger than the experimental value, and this variation must be compensated by thresholds at the GUT scale.

The Soft SUSY-breaking Lagrangian for the MSSM

$$\mathcal{L}_{soft} = -\frac{1}{2}(M_3\tilde{g}\tilde{g} + M_2\tilde{W}\tilde{W} + M_1\tilde{B}\tilde{B})$$
$$-m_Q^2\tilde{Q}^\dagger\tilde{Q} - m_U^2\tilde{U}^\dagger\tilde{U} - m_D^2\tilde{D}^\dagger\tilde{D} - m_L^2\tilde{L}^\dagger\tilde{L} - m_E^2\tilde{E}^\dagger\tilde{E}$$
$$-m_{H_1}^2 H_1^* H_1 - m_{H_2}^2 H_2^* H_2 - (\mu B H_1 H_2 + cc.)$$
$$-(A_u h_u \tilde{U}\tilde{Q}H_2 + A_d h_d \tilde{D}\tilde{Q}H_1 + A_l h_l \tilde{E}\tilde{L}H_1) + c.c.$$

Trilinear terms are proportional to the Yukawa couplings

→ induce L-R mixing on the squark sector once the Higgs acquire v.e.v.
mixing proportional to fermion masses: relevant for 3rd generation

B → soft SUSY breaking paramete determined from condition of proper EWSB

Cosmology data ↔ Dark Matter ↔ New physics at the EW scale

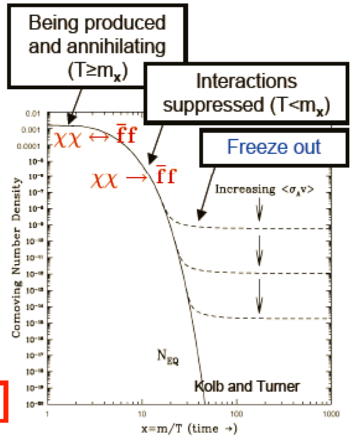
Evolution of the Dark Matter Density

- Heavy particle initially in thermal equilibrium
- Annihilation stops when number density drops

$$H > \Gamma_A \approx n_\chi < \sigma_A v >$$

- i.e., annihilation too slow to keep up with Hubble expansion ("freeze out")
- Leaves a relic abundance:

$$\Omega_{DM} h^2 \approx \ <\sigma_A v>^{-1}$$



If m_χ and σ_A determined by electroweak physics,

$\sigma_A \approx k\alpha_W^2 / m_\chi^2 \approx$ a few pb then Ω_{DM} h^2~0.1 for m_χ~0.1-1 TeV

Remarkable agreement with WMAP-SDSS → $\boxed{\Omega_{CDM} h^2 = 0.114 \pm 0.007}$

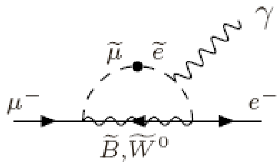
JSY Breaking and Flavour Changing Neutral Currents

Two particularly constraining examples of flavor changing neutral currents induced by off-diagonal soft supersymmetry breaking parameters

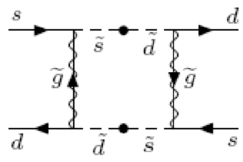
Contribution to the mixing in the Kaon sector, as well as to the rate of decay of a muon into an electron and a photon.

While the second is in good agreement with the SM predictions, the first one has never been observed.

Rate of these processes suppressed as a power of supersymmetric particle masses and they become negligible if relevant masses are heavier than 10 TeV



$\mu^- \to e^-\gamma$



$K^0 \leftrightarrow \overline{K^0}$

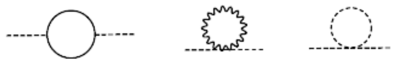
The Gravitino

- When standard symmetries are broken spontaneously, a massless Goldstone boson appears for every broken generator.
- If the symmetry is local, these bosons are absorbed into the longitudinal components of the gauge bosons, which become massive.
- The same is true in supersymmetry. But now, a massless fermion appears, called the Goldstino.
- In the case of local supersymmetry, this Goldstino is absorbed into the Gravitino, which acquires mass $m_{\tilde{G}} = F/M_{Pl}$, with F the order parameter of SUSY breaking.
- The coupling of the Goldstino (gravitino) to matter is proportional to $1/F = 1/(m_{\tilde{G}} M_{Pl})$, and couples particles with their superpartners.

If the messenger scale is significanly lower than the Planck scale, the gravitino is the LSP !

$$m_{\tilde{G}} = F/M_{Pl} \ll \quad m_{\rm soft} \sim \frac{\alpha_a}{4\pi}\frac{\langle F\rangle}{M_{\rm mess}}$$

But if Higgs elementary scalar quantum corrections drive m_h up



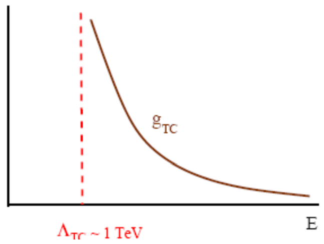
$$\delta m_h^2 \sim \frac{c^2}{16\pi^2}\Lambda^2$$

- We need $\Rightarrow m_h \lesssim 1$ TeV
- But if $\Lambda \to M_P \sim 10^{19}\ GeV$, unnatural

$\Rightarrow$ Gauge Hierarchy Problem

Analogy with QCD:

- New Strong Interaction: Technicolor
- Strong at $M_W \ll M_P$
- Breaks Electroweak symmetry: $\langle \bar{F} F \rangle \neq 0$



Need a mechanism to keep v and M_P separate.

New physics at $\Lambda \sim 1$ TeV is:

Weakly Coupled	Strongly Coupled
SM with a light Higgs	Technicolor, Walking Technicolor
SUSY (MSSM, NMSSM, Folded, ...)	Topcolor, Top See Saw
Little Higgs, Twin Higgs	Composite Higgs
LED, UED	Randall-Sundrum

TC Problem I: Fermion Masses

- Need Extended Technicolor (ETC):
  $G_{\rm ETC} \supset G_{\rm TC}$ with $\Lambda_{\rm ETC} \gg \Lambda_{\rm TC}$

$$m_f \simeq \frac{g^2_{\rm ETC}}{\Lambda^2_{\rm ETC}} \langle \bar{F} F \rangle$$

- Needs Walking (Walking TC):
  For heavier fermions (e.g. m_c, m_τ) needs to enhance $\langle \bar{F} F \rangle$
- But m_t requires $\Lambda_{\rm ETC}$ too low
  $\Rightarrow$ Topcolor, Top See Saw (Hill, Dobrescu)

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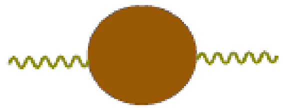
AdS/CFT Correspondence (Maldacena):

- Originally:
  AdS$_5 \times S^5$ String Theory $\leftrightarrow \mathcal{N} = 4$ 4D SU(N) Theory (CFT
- In general: Assume 5D theory in AdS$_5 \leftrightarrow$ 4D CFT
  (Arkani-Hamed, Porrati, Randall)
- Need

$$g^2 N \gg 1$$

  to ignore string corrections.
- $\Rightarrow$ Holographic dual is 4D strongly coupled theory

TC Problems II: Electroweak Precision Constraints



- E.g. Techni-fermions give

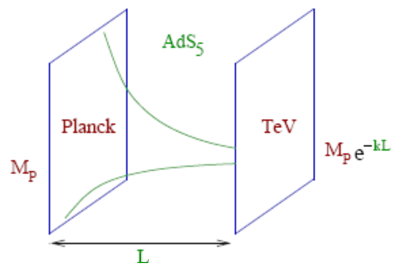
$$S \sim \frac{N}{6\pi}$$

- But

$$S^{\rm exp.} \lesssim 0.1$$

Metric in extra dimension $\Rightarrow$ small energy scale from M_P
(Randall-Sundrum)

$$ds^2 = e^{-2\kappa|y|} \eta^{\mu\nu} dx_\mu dx_\nu - dy^2$$



Corrections to m_h OK
If Higgs close to TeV brane

Need Higgs IR localization

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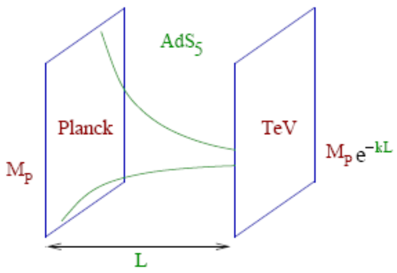

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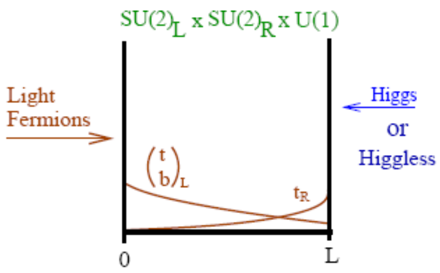


Models of EWSB *and* Flavor

- EWPC: T OK, but $S \simeq N/\pi$ at tree-level

$$M_{KK} \gtrsim (2-3)\ \mathrm{TeV}$$

- $Z \to \bar{b}b$ require discrete symmetry ($L \leftrightarrow R$) (Agashe, Contino, Da Rold, Pomarol)
- Potentially important bounds and/or effects from flavor violation

Higgsless RS Bulk Models (Csaki, Grojean, Murayama, Pilo, Terning)

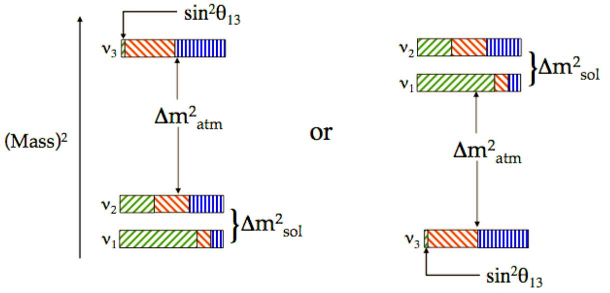
- Boundary Condition breaking

$$SU(2)_L \times SU(2)_R \times U(1)_X \to U(1)_{EM}$$

- IR localized mass terms $\Rightarrow$ fermion masses
- Kaluza-Klein modes of gauge fields unitarize amplitudes. $\Rightarrow$ KK modes "light": $M_{KK} \lesssim 1$ TeV
- Phenomenology in the Gauge boson sector:
    - $V_L V_L$ scattering
    - Sum Rules
- Corresponds to Walking Technicolor Models

1/3

Experimental Neutrino Physics



Atmos Oscillations — unknown — Solar Oscillations

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = U \begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix} \qquad U = \begin{pmatrix}1 & 0 & 0\\ 0 & c_{23} & s_{23}\\ 0 & -s_{23} & c_{23}\end{pmatrix}\begin{pmatrix}c_{13} & 0 & \boxed{s_{13}e^{i\delta}}\\ 0 & 1 & 0\\ -s_{13}e^{i\delta} & 0 & c_{13}\end{pmatrix}\begin{pmatrix}c_{12} & s_{12} & 0\\ -s_{12} & c_{12} & 0\\ 0 & 0 & 1\end{pmatrix}$$

$$c_{23} = \cos\theta_{23}$$

A. Bross (FNAL)

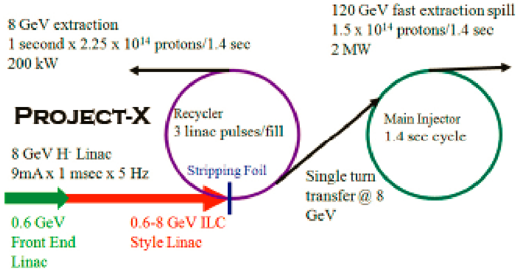
Future Facilities – What's δ ?

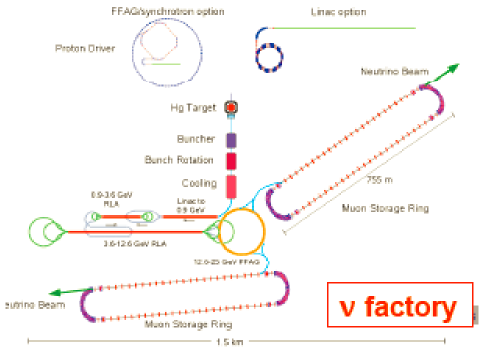
(ISS, EUROSOL, FNAL Steering Group)

Super-beams in US/Japan (2-4 MW)

Examples:

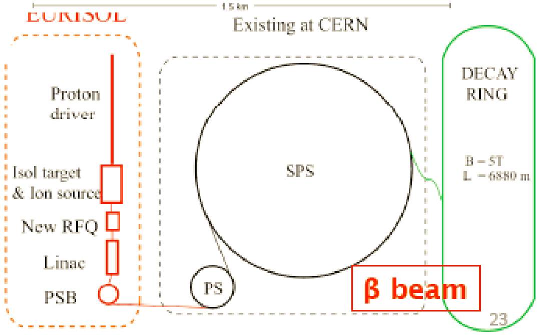
Project-X -> DUSEL / JPARC –> Hyper-K





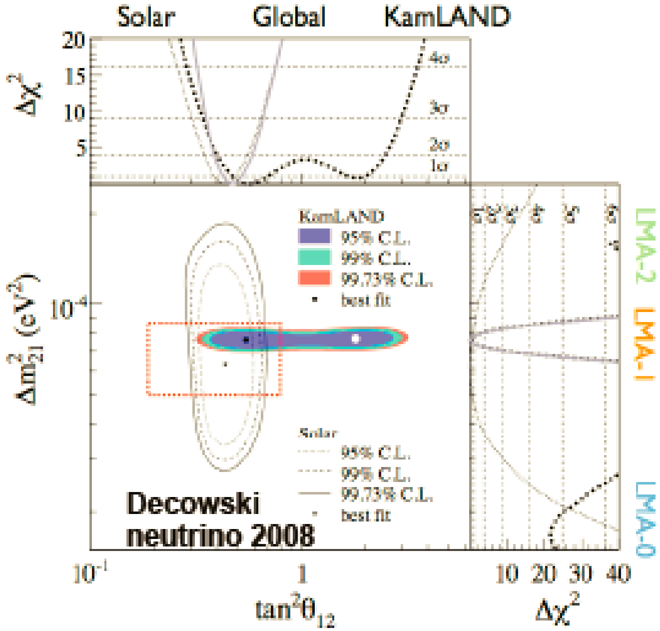
Worldwide R&D program on large WC and Lar detectors.

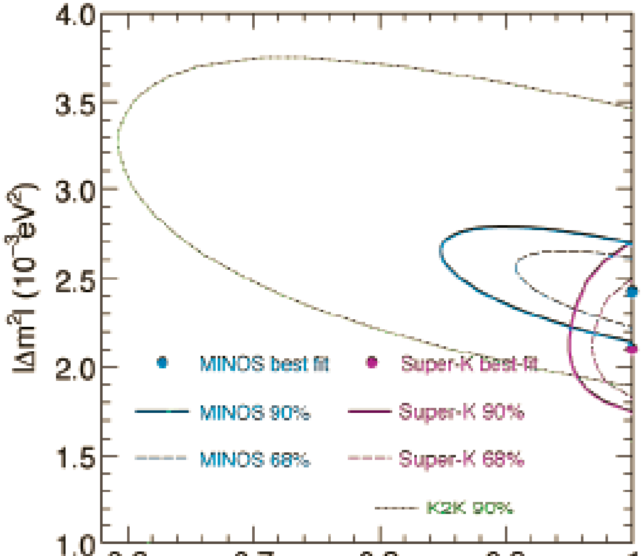
If possible make neutrinos part of the larger vision and program.



- What is the absolute mass?
- What is the pattern of neutrino masses?
- Are neutrinos their own anti-particles?
- Is there CP violation in the neutrino sector? Is it big enough to drive lepto-genesis and is it related to the quark sector?
- What is the value of the final unmeasured mixing angle, and is the atmospheric angle maximal?

Putting it all together…



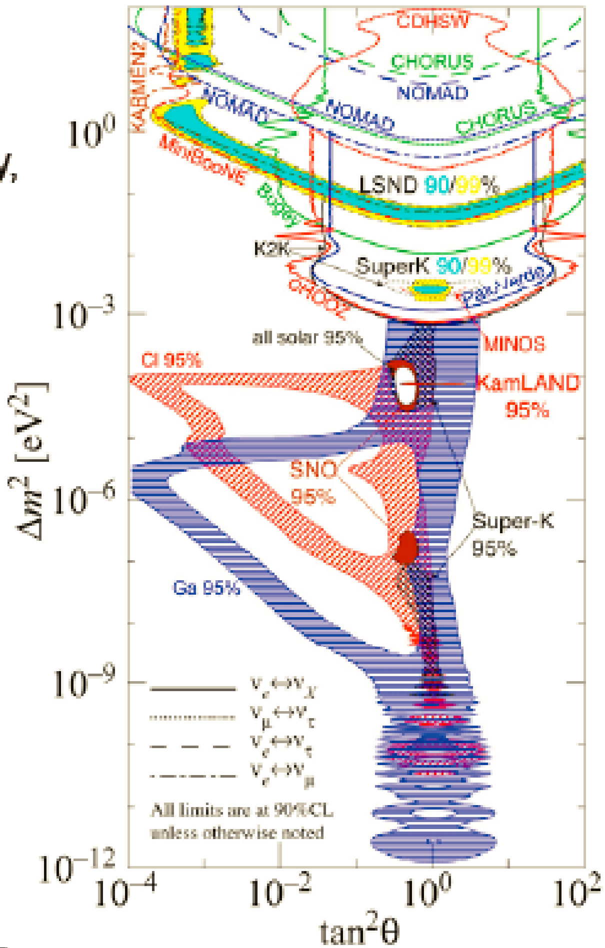


We now have a consistent set of experiments. Currently, the precision is at the 2-10% level.

The next experiments will hopefully get us close to the 1% precision level.

We also hope to add info on directly measured absolute mass to this picture along with the unknown mixing angles.

All of these techniques must work **together**.



http://hitoshi.berkeley.edu/neutrino

Part B

Unparticle and ν's

Basic idea of "unparticle" physics (H. Georgi 07; Banks & Zaks 82):

SM particles

messenger M_U

scale-invariant sector

Effective operator

$$\frac{\mathcal{O}_{\rm SM}\mathcal{O}_{\rm SI}}{M_{\mathcal{U}}^k}$$

$$\frac{C_{\mathcal{U}}\Lambda_{\mathcal{U}}^{(d_{\rm SI}-d_{\mathcal{U}})}}{M_{\mathcal{U}}^k}\mathcal{O}_{\rm SM}\mathcal{O}_{\mathcal{U}}$$

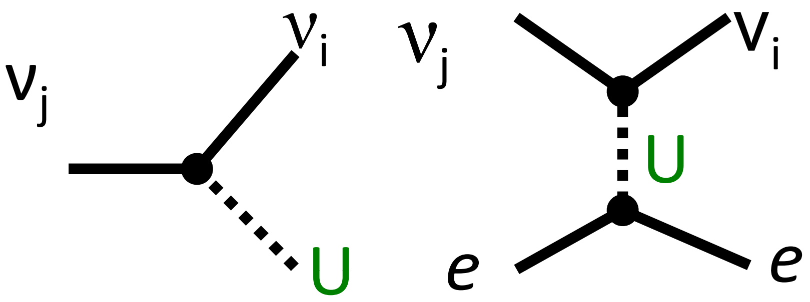
Dim. of O_{SI}

Dim. of O_U

High-energy scale | Intermediate scale | Dim.-transmutation Λ_U

$$\frac{\lambda}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}}}\mathcal{O}_{\rm SM}\mathcal{O}_{\mathcal{U}}$$

First application to ν's (S. Zhou 07):



Neutrino decay | ν-e scattering

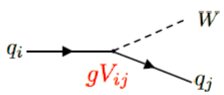
$$\frac{\lambda_\nu^{ij}}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}-1}}\overline{\nu_i}\nu_j\mathcal{U}$$

$$+$$

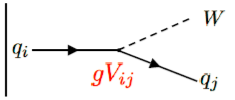
$$\frac{\lambda_e^{ij}}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}-1}}\overline{e_i}e_j\mathcal{U}$$

Li et al 07; Majumdar 07; Anchordoqui, Goldberg 07; Montanino et al 07; Balantekin, Ozansoy 07; Gonzalez-Garcia et al 08…

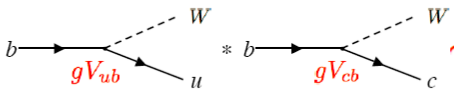
Cabibbo-Kobayashi-Maskawa Matrix



$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{td} \end{pmatrix}$$



$\Big|\ \ \Big|^2 \sim |V_{ij}|^2$ Measure magnitudes from rates: Francesca Di Lodovico's talk next



$\sim e^{-i\mathrm{Arg}(V_{ub})}$

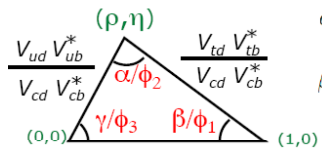
Measure phases through interference: CP violation (this talk). Need at least two amplitudes, e.g. 2 decay amplitudes ("direct CPV"), or decay and mixing

Unitarity Triangle

Unitary mixing matrix: 4 parameters (*c.f.* MNSP matrix in neutrinos)
For quarks, conventional Wolferstein parameterization:
$A,\ \rho,\ \eta \sim \mathcal{O}(1),\ \ \lambda \equiv \sin\theta_c \approx 0.22$

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$: unitarity relation for B_d decays



$\alpha \equiv \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right]$: interfere b→u & mixing

$\beta \equiv \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right]$: interfere b→c & mixing

$\gamma \equiv \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$: interfere b→u & b→c

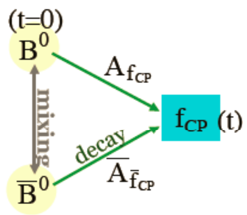
Common Definitions

***CP* violation in interference between decays with and without mixing**

$$\lambda_{f_{CP}} = \eta_{CP}\,\frac{q}{p}\cdot\frac{\bar{A}_{\bar{f}_{CP}}}{A_{f_{CP}}}$$ ← amplitude ratio

CP eigenvalue ; $\approx e^{-2i\phi_{CP}}$ ← *CP* phase

$\eta_{CP} = \pm 1;\quad \phi_{CP} = \alpha,\beta,\gamma$

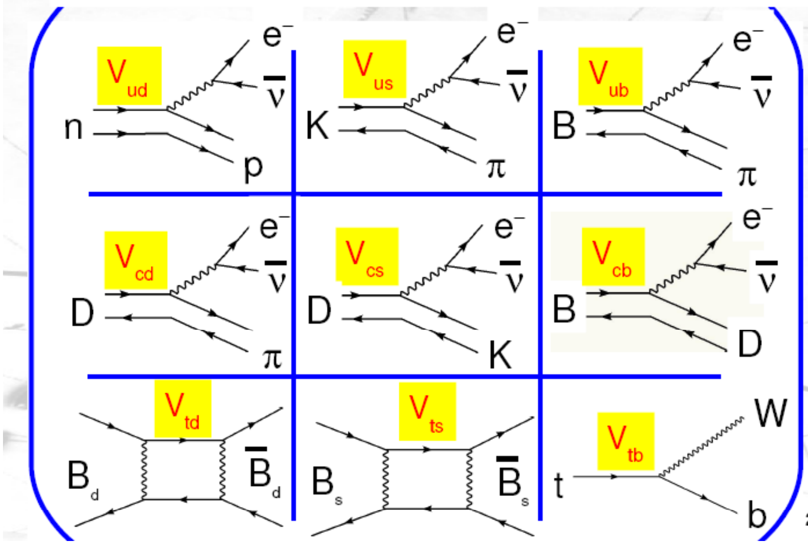


Time-dependent *CP* Observable:

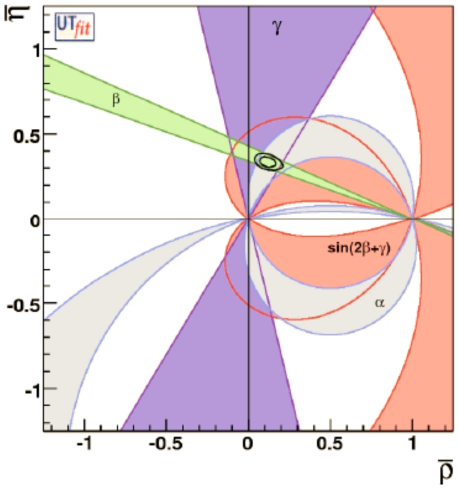
$$A_{f_{CP}}(t) = \frac{\Gamma(\bar{B}^0_{phys}(t) \to f_{CP}) - \Gamma(B^0_{phys}(t) \to f_{CP})}{\Gamma(\bar{B}^0_{phys}(t) \to f_{CP}) + \Gamma(B^0_{phys}(t) \to f_{CP})}$$
$$= C_{f_{CP}} \cdot \cos(\Delta m_{B_d} t) + S_{f_{CP}} \cdot \sin(\Delta m_{B_d} t)$$

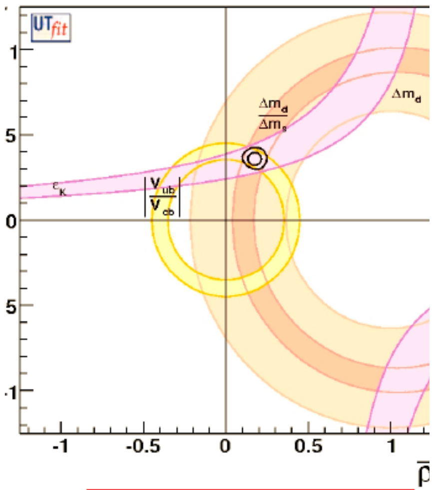
$$\boxed{C_{f_{CP}} = \frac{1-|\lambda_{f_{CP}}|^2}{1+|\lambda_{f_{CP}}|^2} \qquad S_{f_{CP}} = \frac{-2\,\mathrm{Im}\lambda_{f_{CP}}}{1+|\lambda_{f_{CP}}|^2}}$$

- Fundamental parameters of the Standard Model
- They cannot be predicted but can be measured



UT Constraints: Angles vs Sides

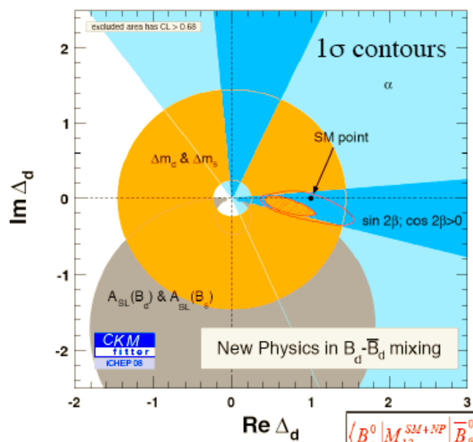


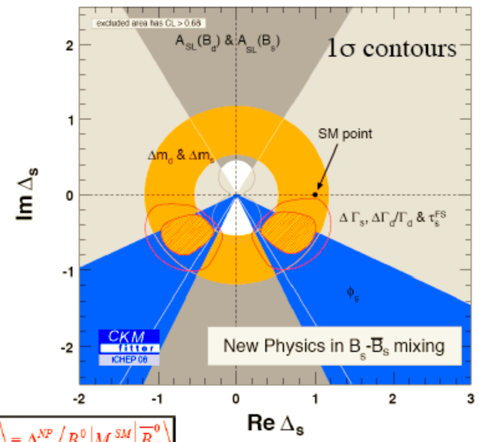


Angle-only measurements (UTFit):
$\rho = 0.120 \pm 0.034$
$\eta = 0.335 \pm 0.020$

Other constraints (UTFit):
$\rho = 0.175 \pm 0.027$
$\eta = 0.360 \pm 0.023$

New Physics Constraints in Loops



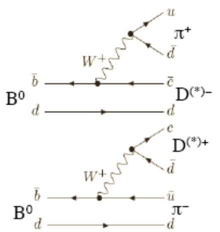


$$\langle B_q^0 | M_{12}^{SM+NP} | \bar{B}_q^0 \rangle = \Delta_q^{NP} \langle B_q^0 | M_{12}^{SM} | \bar{B}_q^0 \rangle$$

Agreement with SM at 1-2σ level
Largest deviations in β_s and $B \to \tau\nu$

S. Bahinipati
X. Prudent

$\sin(2\beta+\gamma)$ from $B^0 \to D^{(*)}\pi, D^{(*)}\rho$

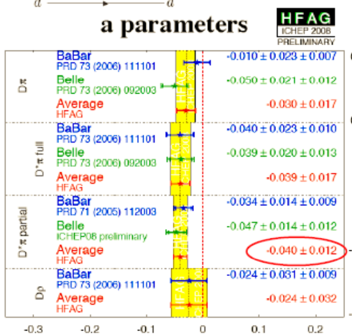


Interference between CKM-favored $b \to c$ and CKM-suppressed $b \to u$ transition: sensitive to γ. Mixing adds phase 2β. CP asymmetries proportional to

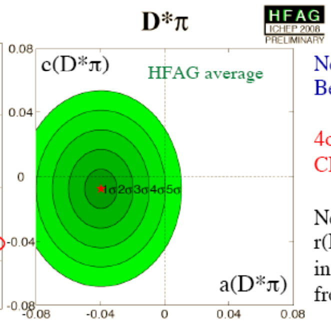
$$r(D^{(*)}\pi) = \left| \frac{A(B^0 \to D^{(*)+}\pi^-)}{A(B^0 \to D^{(*)-}\pi^+)} \right| << 1$$

Measure
$$a \equiv 2r \sin(2\beta+\gamma) \cos\delta \quad \text{strong phase}$$
$$c \equiv 2r \cos(2\beta+\gamma) \sin\delta$$

a parameters



D*π



New results from Belle @ ICHEP08

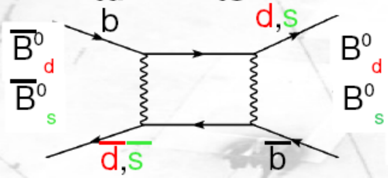
4σ significance for CP violation in D*π

New constraints on r(D(*)π) & r(D(*)ρ) in $B^0 \to D_s^{(*)}\pi,\rho$ ≈2% from BaBar

Summary

- High-precision measurements from the B-factories and Tevatron
  - Overall, excellent agreement between sides and angles of the Unitarity Triangle
    - But a few tantalizing hints
  - Nontrivial constraints on the flavor of new physics
- Still statistics limited
  - σ(β) ~ 2°; theory errors below 1°
  - σ(α) ~ 10°; limited by measurements of penguin pollution
  - σ(γ) ~ 15°; limited by statistics and modeling of D^0 Dalitz structure (CLEO-c to offer improvements)
  - First measurements of CPV in B_s decays hint at SM deviation

$|V_{td}|/|V_{ts}|$ from B_d and B_s mixing

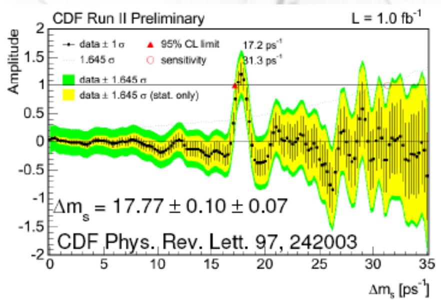


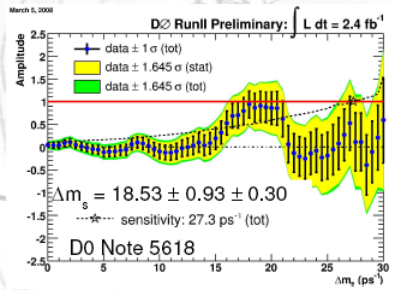
$\bar{B}^0_d$ B^0_d Slow oscillation

$\bar{B}^0_s$ B^0_s Fast oscillation

$$\boxed{\frac{\Delta m_s^2}{\Delta m_d^2} = \frac{m_{Bs} f_{Bs}^2 B_{Bs} |V_{ts}|^2}{m_{Bd} f_{Bd}^2 B_{Bd} |V_{td}|^2}}$$

Theoretical uncertainties reduced in the ratio





$|V_{td}|/|V_{ts}|$ = 0.207 ± 0.001_{exp} ± 0.006_{theo} for $(f_{Bs}\sqrt{B_{Bs}})/(f_{Bd}\sqrt{B_{Bd}}) = 1.21 \pm 0.04$

arXiv:0807.4605 [hep-ph]

Impressive amount of work done!

$\delta V_{ud}/V_{ud}$ 0.03%	$\delta V_{us}/V_{us}$ 0.4%	$\delta V_{ub}/V_{ub}$ ~8%*
$\delta V_{cd}/V_{cd}$ 5%	$\delta V_{cs}/V_{cs}$ 11%	$\delta V_{cb}/V_{cb}$ ~2%*
$\delta(V_{td}/V_{ts})/(V_{td}/V_{ts})$ ~3%		$\delta V_{tb}/V_{tb}$ ~15%

* from inclusive measurements, but better agreement with exclusive required.

Conclusion

- **Results start to probe NP but limited by statistics:**

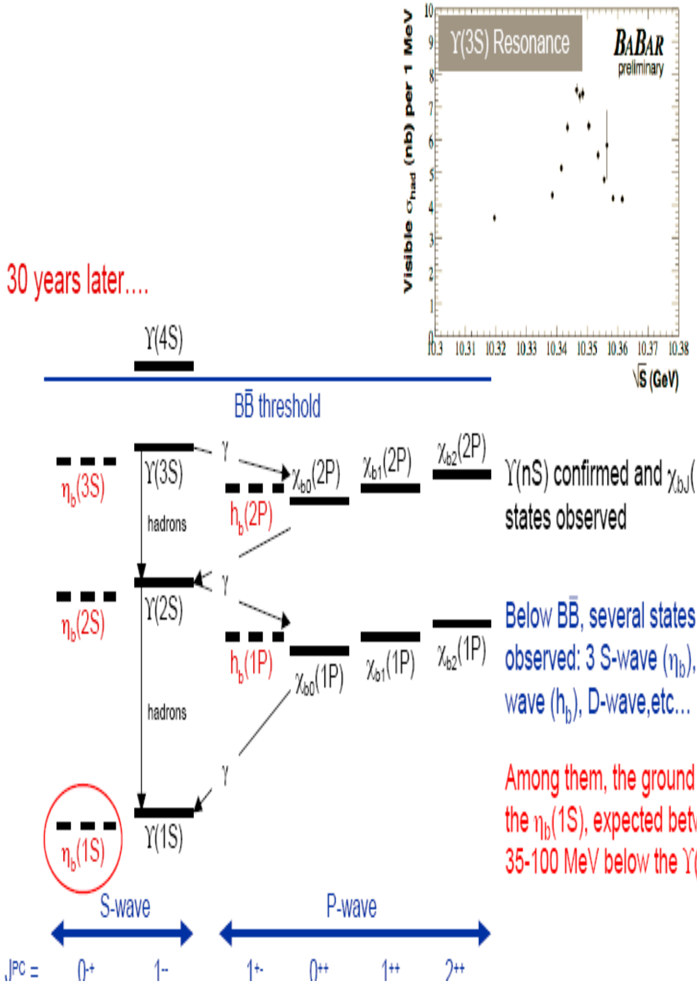
  $B \rightarrow \tau\nu$, A_{FB}, isospin asymmetry

- **$\mathcal{B}$ ($B \rightarrow Xs\gamma$) strong constraint to NP**
- **ΔS puzzle may no longer an issue.**
- **Need an order magnitude more luminosity**

SuperB: clean environment ; LHCb

Bottomonium spectrum ... until a few days ago

30 years later....



Υ(nS) confirmed and $\chi_{bJ}(1,2P)$ states observed

Below $B\bar{B}$, several states not yet observed: 3 S-wave (η_b), 2 P-wave (h_b), D-wave,etc...

Among them, the ground state, the $\eta_b(1S)$, expected between 35-100 MeV below the $\Upsilon(1S)$

η_b mass:

$$9388.9^{+3.1}_{-2.3}(\mathrm{stat}) \pm 2.7(\mathrm{syst})\ \mathrm{MeV}/c^2$$

$\Upsilon(1S)$ - η_b hyperfine splitting:

$$71.4^{+2.3}_{-3.1}(\mathrm{stat}) \pm 2.7(\mathrm{syst})\ \mathrm{MeV}/c^2$$

$\Upsilon(3S) \to \gamma\eta_b$ branching fraction:

$$[4.8 \pm 0.5(\mathrm{stat}) \pm 1.2(\mathrm{syst})] \times 10^{-4}$$

Rare Decays and New Physics

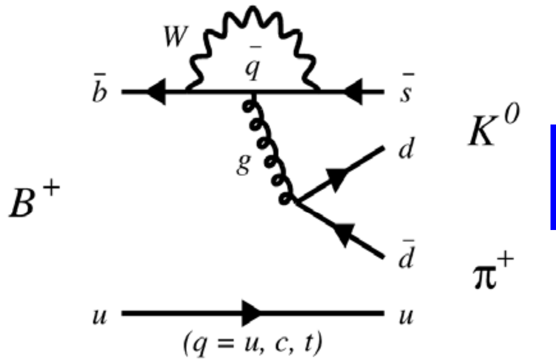
- **K, τ, Υ(nS)**
- **B→$\tau\nu$**
- **ΔS and ΔA**
- **b→sγ, B→K*ll**
- **B→K*$\nu\nu$, $B_{d,S}$→ l^+l^-**

Model independent checks for NP

M. Gronau, PLB 627, 82 (2005); D. Atwood & A. Soni, Phys. Rev. D 58, 036005(1998).

$$\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = \mathcal{A}_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + \mathcal{A}_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

$B^+ \to K^0\pi^+$



P

P dominants. $\Rightarrow$ **$A_{cp}(K^0\pi^+) \sim 0$**

World Average

$A_{cp}(K^0\pi^+) = 0.009 \pm 0.025$

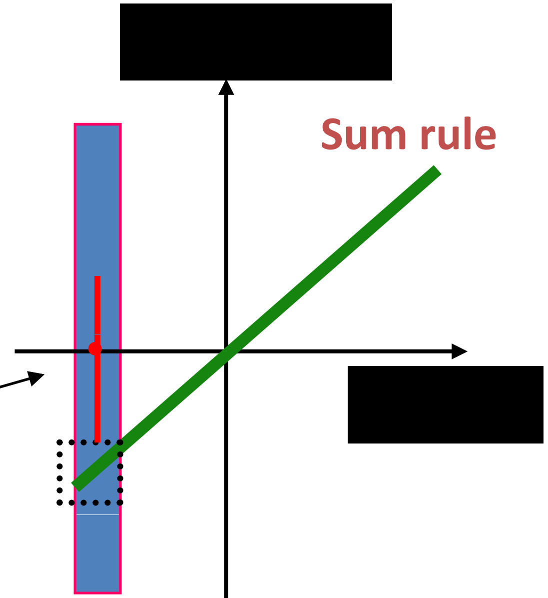
$B^0 \to K^0\pi^0$ **New**

$A = -0.13 \pm 0.13 \pm 0.03$

BELLE

$A = +0.14 \pm 0.13 \pm 0.06$

HFAG AVG: -0.01 ± 0.10



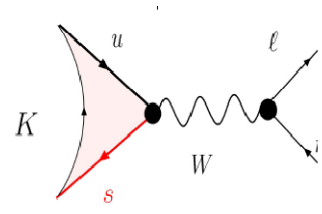
Sum rule predicts $A_{cp}(K^0\pi^0)$
$= -0.151 \pm 0.043$

Important topic for
Super B factory

Lepton Flavor Violation in Kaons

- $R_K = \Gamma(K\to e\nu)/\Gamma(K\to\mu\nu) = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2-m_e^2}{m_K^2-m_\mu^2}\right)^2\left(1+\mathcal{O}(e^2p^n)\right)$

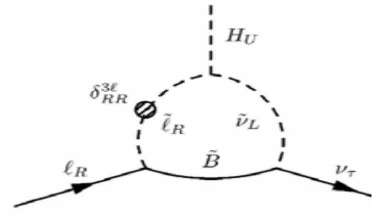
  $= (2.477 \pm 0.001) \times 10^{-5}$ in SM

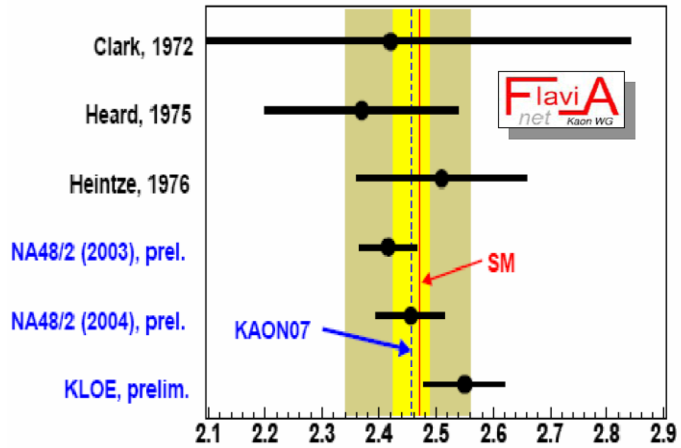


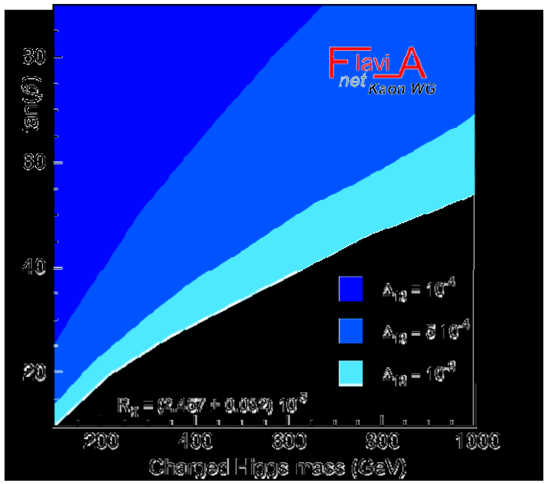
$K_{\ell 2}$: $K \to \ell\, \nu$

Leading effect f_K cancels but need radiative corrections.

- **SUSY LFV:** $R_K^{LFV} \simeq R_K^{SM}\left[1+\left(\frac{m_K^4}{M_H^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right)|\Delta_R^{31}|^2\tan^6\beta\right]$







How to improve:

KLOE: 20% more data

δ_{rel} <1.3%

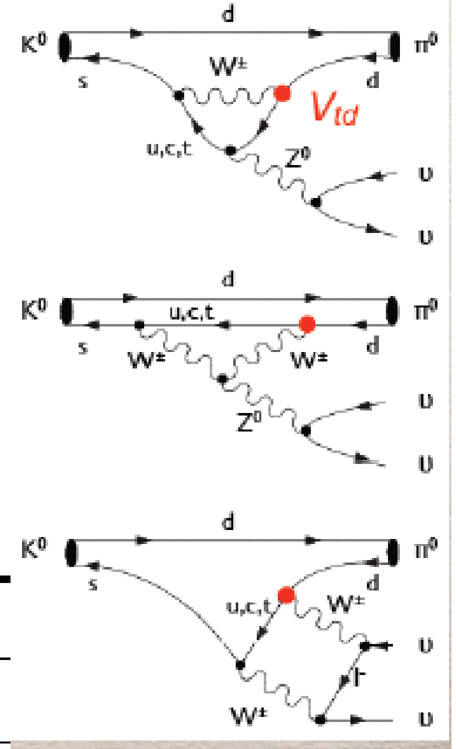
NA62: ~120 000 more evts

δ_{rel} ~ 0.3%

AVG: $\Gamma(K_{e2})/\Gamma(K_{\mu 2}) = (2.457 \pm 0.032) \times 10^{-5}$ **δ_{rel} = 1.3%**

Clean Decays Sensitive to NP

	Short-distance [%] (sensitivity to e.w scale)	Irreducible th. error on the BR
$K_L \to \pi^0 \nu \bar{\nu}$	>99%	$< 2\%$
$K^+ \to \pi^+ \nu \bar{\nu}$	91%	$< 5\%$
$K_L \to \pi^0 e^+ e^-$	38%	$< 10\%$
$K_L \to \pi^0 \mu^+ \mu^-$	28%	$< 10\%$



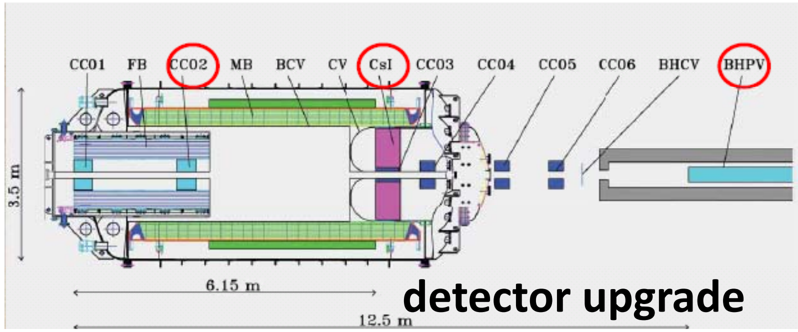
Golden Modes	Standard Model	Experiment		CKM
$K^- \to \pi^+ \nu \bar{\nu}$	$8.22^{+0.84}_{-0.84} \times 10^{-11}$	$14.7^{+13.0}_{-8.9} \times 10^{-11}$	E787 E949	$V_{ts}^* V_{td}$
$K_L \to \pi^0 \nu \bar{\nu}$	$2.76^{+0.40}_{-0.40} \times 10^{-11}$	$< 6.7 \times 10^{-8}$	$\boxed{\text{E391a}}$	$\mathrm{Im}\, V_{ts}^* V_{td} \sim \eta$
$K_L \to \pi^0 e^+ e^-$	$3.5^{+1.0}_{-0.9} \times 10^{-11}$	$< 2.8 \times 10^{-10}$	KTeV	$\mathrm{Im}\, V_{ts}^* V_{td} \sim \eta$
$K_L \to \pi^0 \mu^+ \mu^-$	$1.4^{+0.3}_{-0.3} \times 10^{-11}$	$< 3.8 \times 10^{-10}$	KTeV	$\mathrm{Im}\, V_{ts}^* V_{td} \sim \eta$

From Mescia's slides at FPCP08

Future Search for Rare Kaon Decay

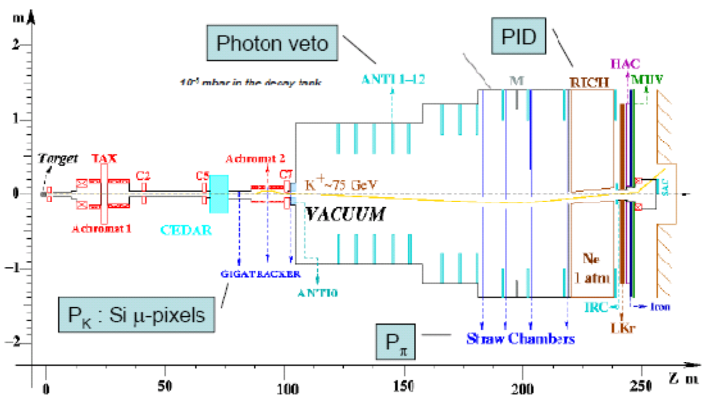
- E14 at J-PARC
  - 2008: Detector upgrade
  - 2009: Beam line construction
  - 2011: Physics run

S/B ~1.5, aim at 100 events



- P326/NA62 at CERN
  - 2008: Detector R&D,
    full approval (hope!)
  - 2009: Construction
  - 2012: Physics run

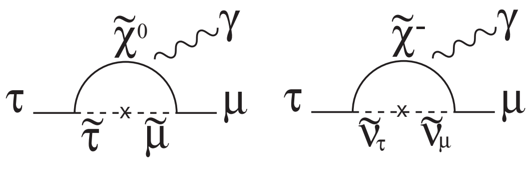
S/B ~10, 80 events in 2 years



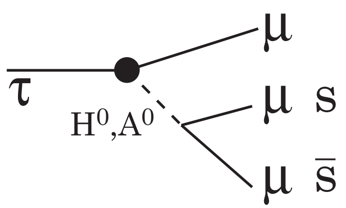
Lepton Flavor Violation in τ Decay

- Forbidden in SM but various new physics models predict $\mathcal{B}$ as high as 10^{-8}

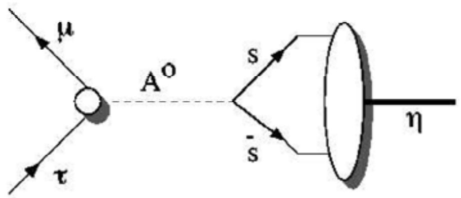
SUSY

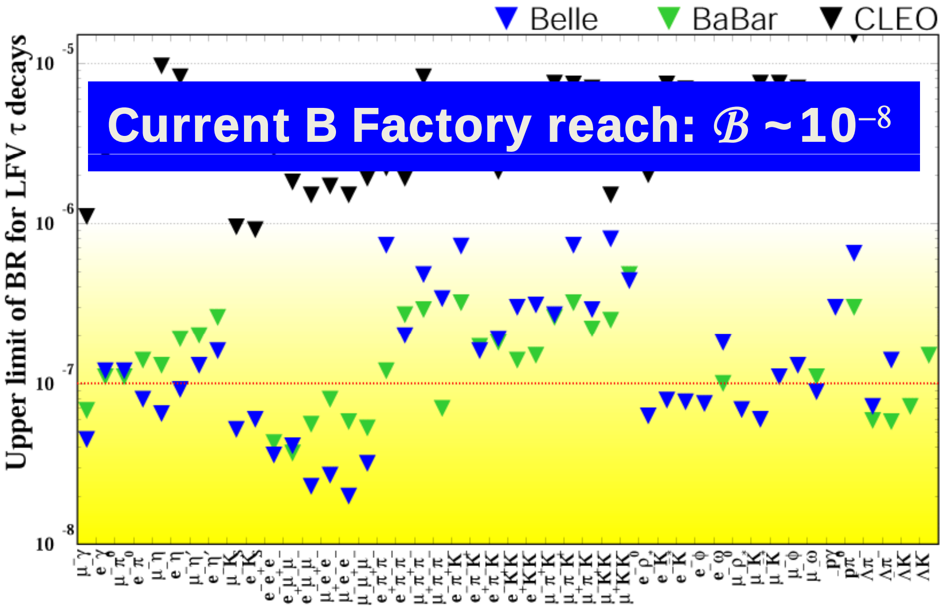


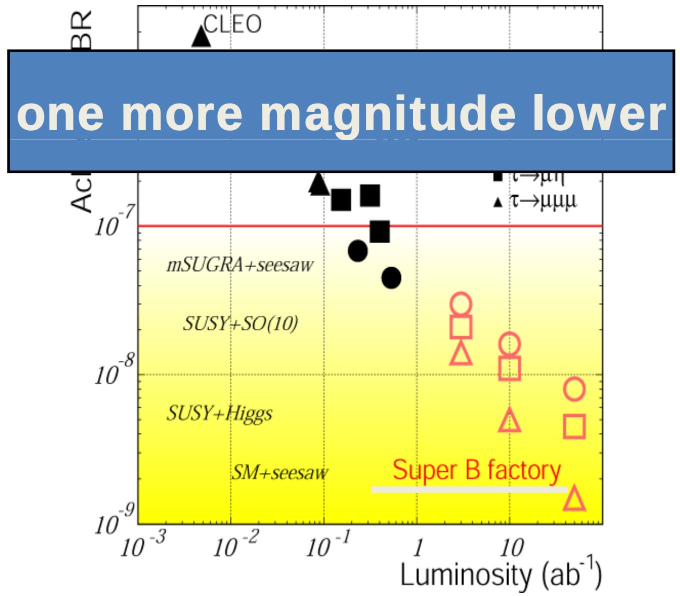
SUSY Higgs



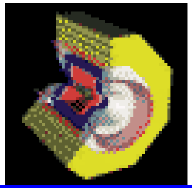
MSSM







Search for $\Upsilon(1S)^0 \to \gamma\, a_1$



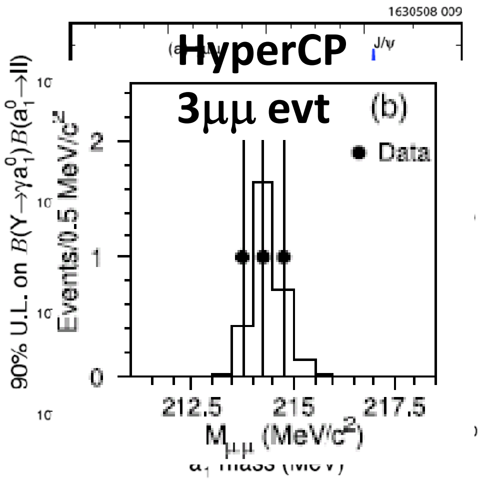
CLEO, arXiv: 0807.1427

- Light CP-odd pseudoscalar Higgs, a_1^0
- In NMSSM,an a_1^0 less than an bb

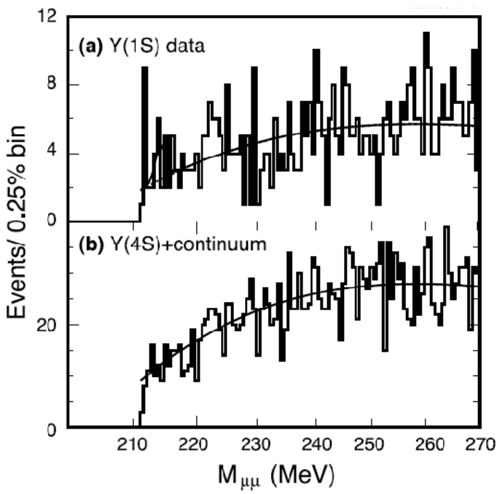
Dermisek et. al, PRD 76 051105 (2007).

- Search for $a_1^0 \to \mu\mu,\ \tau\tau$ (dominant above 2Mτ)
- Signals peak in the Eγ (γττ) Eμμ (γμμ) dist.

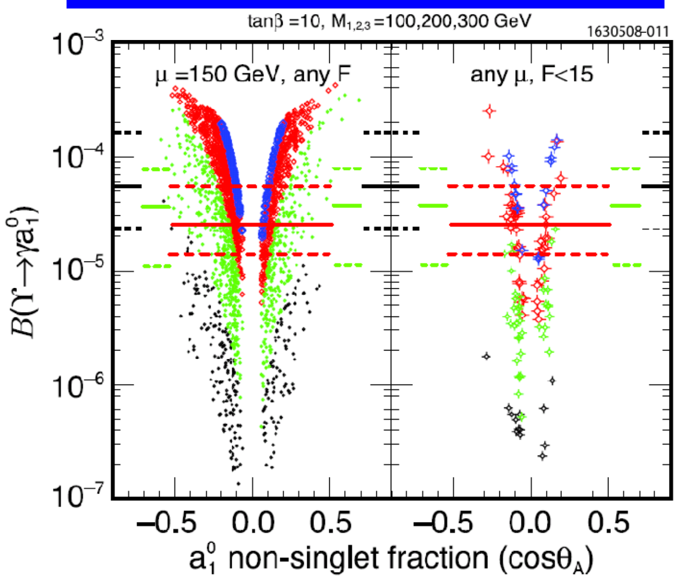
UL as $M(a_1^0)$



$\mathcal{B}(\Upsilon(1S) \to \gamma a_1^0 < 2.3\times10^{-6}$



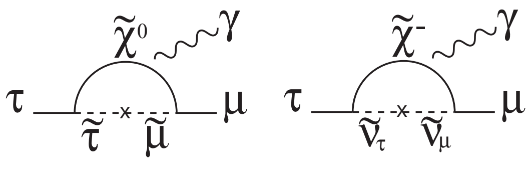
Constraints on NMSSM



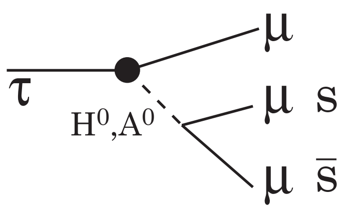
Lepton Flavor Violation in τ Decay

- Forbidden in SM but various new physics models predict $\mathcal{B}$ as high as 10^{-8}

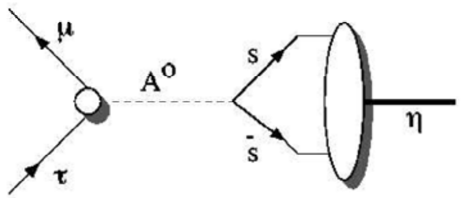
SUSY

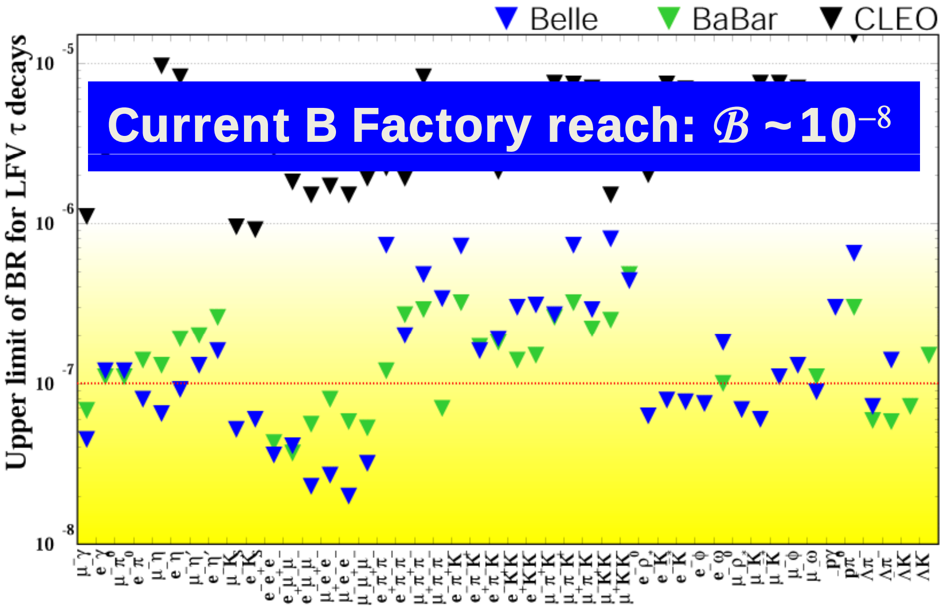


SUSY Higgs

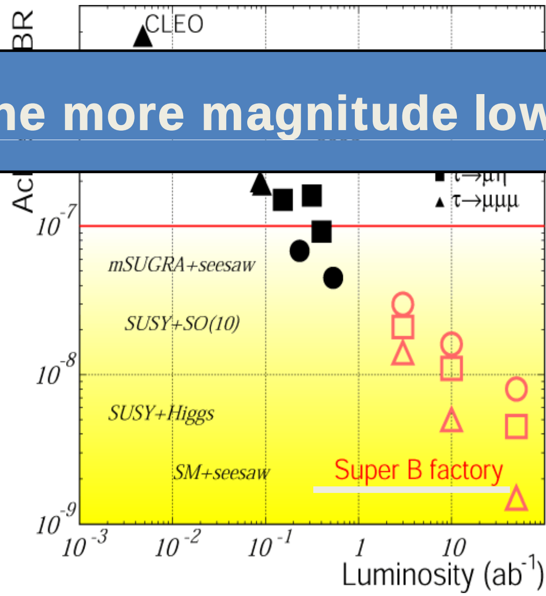


MSSM





Current B Factory reach: $\mathcal{B} \sim 10^{-8}$

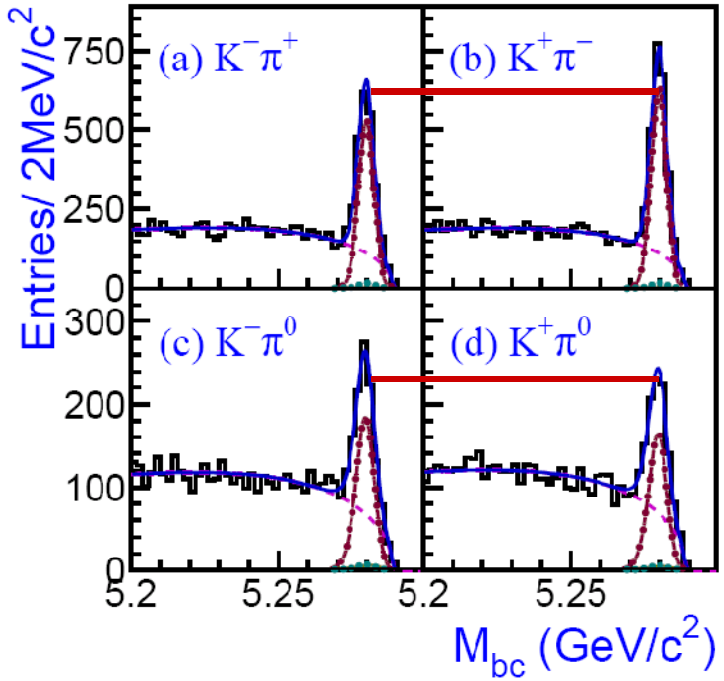


one more magnitude lower

Direct CP Violation in B→Kπ Decays

$$\mathcal{A}_{CP}(B \to f) = \frac{|\overline{A}|^2 - |A|^2}{|\overline{A}|^2 + |A|^2} \propto \sum_{i,j} A_i A_j \sin(\delta_i - \delta_j) \sin(\phi_i - \phi_j)$$

Belle Results: Nature 452, 332 (2008)



New Update

$A_{cp}(K^+\pi^-) = \begin{cases} -0.107 \pm 0.016 \,{}^{+0.006}_{-0.004} & \textbf{BaBar} \\ -0.094 \pm 0.018 \pm 0.008 & \textbf{Belle} \\ -0.086 \pm 0.023 \pm 0.009 & \textbf{CDF} \end{cases}$

$-0.04 \pm 0.16 \pm 0.02$ **CLEO**

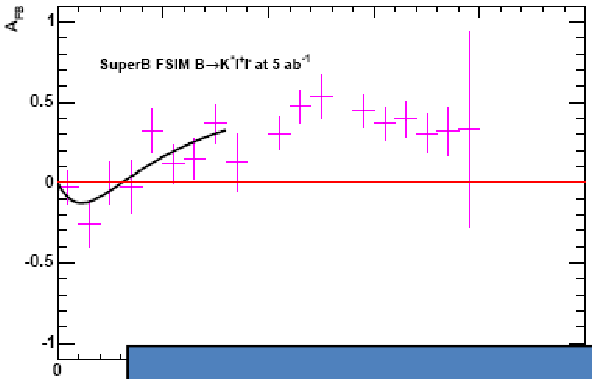
$\Rightarrow -0.098 \,{}^{+0.012}_{-0.011}$ @ 8.1σ **AVG**

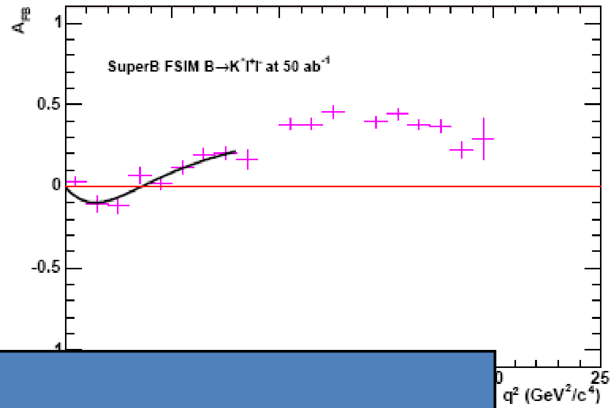
$A_{cp}(K^+\pi^0) = \begin{cases} +0.030 \pm 0.039 \pm 0.010 & \textbf{BaBar} \\ +0.07 \pm 0.03 \pm 0.01 & \textbf{Belle} \\ -0.29 \pm 0.23 \pm 0.02 & \textbf{CLEO} \end{cases}$

$\Rightarrow +0.050 \pm 0.025$ **@2.0σ** **AVG**

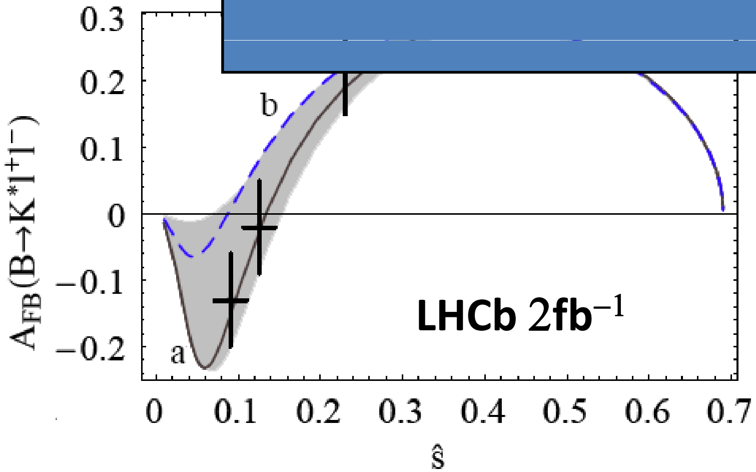
$\Delta A_{K\pi} = A_{cp}(K^+\pi^-) - A_{cp}(K^+\pi^0)$
$= -0.147 \pm 0.028$ **@ 5.3σ**

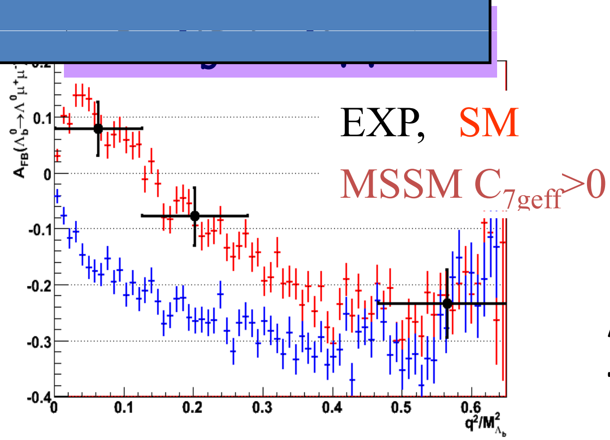
Future Prospects for $A_{FB}\,(q^2)$





CDF and D0, please contribute!



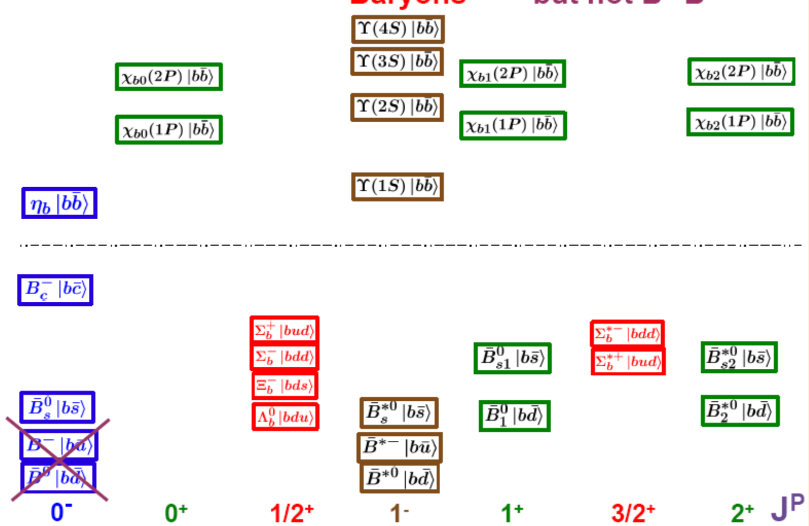


ATLAS 30 fb^{-1}

Heavy B Hadrons

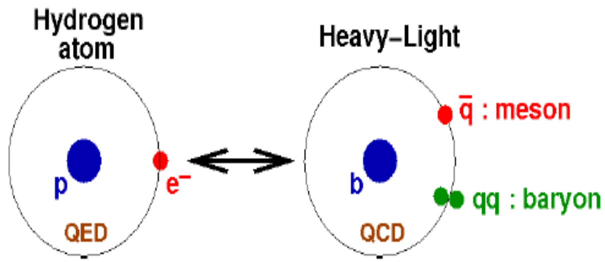
- Mesons
- Baryons

Heavy = all but not B^0-B^+



Why study B hadrons?

From hydrogen atom to B hadron spectroscopy



- Heavy quark hadrons are the hydrogen atom of QCD
  => study of B hadron states = study of (non-perturbative) QCD
- Measurements of B hadron masses provide sensitive tests of potential models, HQET and all aspects of QCD including lattice gauge calculations

Σ_b Baryon

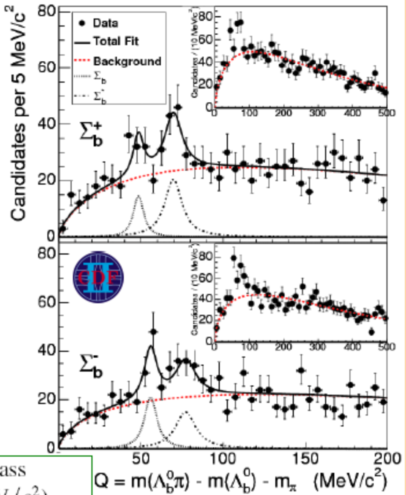
Motivation:

Until 2006 $\Lambda_b^0 = |b\,d\,u\rangle$ was only established *B* baryon
=> Search for

$$\Sigma_b^{(*)+} = |b\,u\,u\rangle \quad \Xi_b^- = |b\,d\,s\rangle$$
$$\Sigma_b^{(*)-} = |b\,d\,d\rangle \quad \Xi_b^0 = |b\,u\,s\rangle$$

Use large sample of Λ_b: ~3000

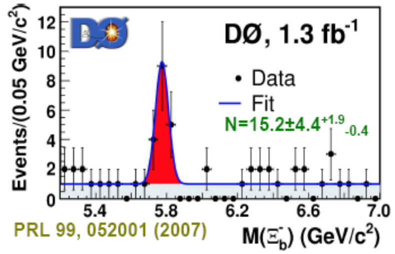
Observe peaks with >5σ w.r.t. no signal



PRL 99, 202001 (2007)

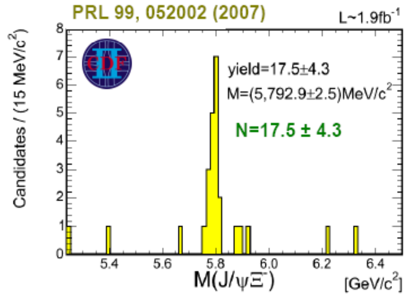
State	Yield	Q or $\Delta_{\Sigma_b^*}$ (MeV/c^2)	Mass (MeV/c^2)
Σ_b^+	32^{+13+5}_{-12-3}	$Q_{\Sigma_b^+} = 48.5^{+2.0+0.2}_{-2.2-0.3}$	$5807.8^{+2.0}_{-2.2} \pm 1.7$
Σ_b^-	59^{+15+9}_{-14-4}	$Q_{\Sigma_b^-} = 55.9 \pm 1.0 \pm 0.2$	$5815.2 \pm 1.0 \pm 1.7$
Σ_b^{*+}	77^{+17+10}_{-16-6}	$\Delta_{\Sigma_b^*} = 21.2^{+2.0+0.4}_{-1.9-0.3}$	$5829.0^{+1.6+1.7}_{-1.8-1.8}$
Σ_b^{*-}	69^{+18+16}_{-17-5}		$5836.4 \pm 2.0^{+1.8}_{-1.7}$

Ξ_b Baryon



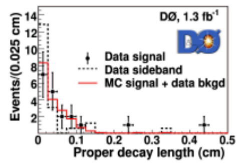
PRL 99, 052001 (2007)

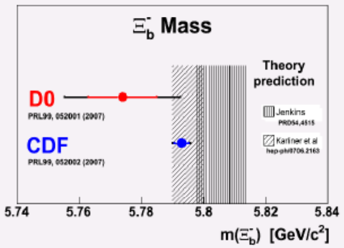
PRL 99, 052002 (2007)



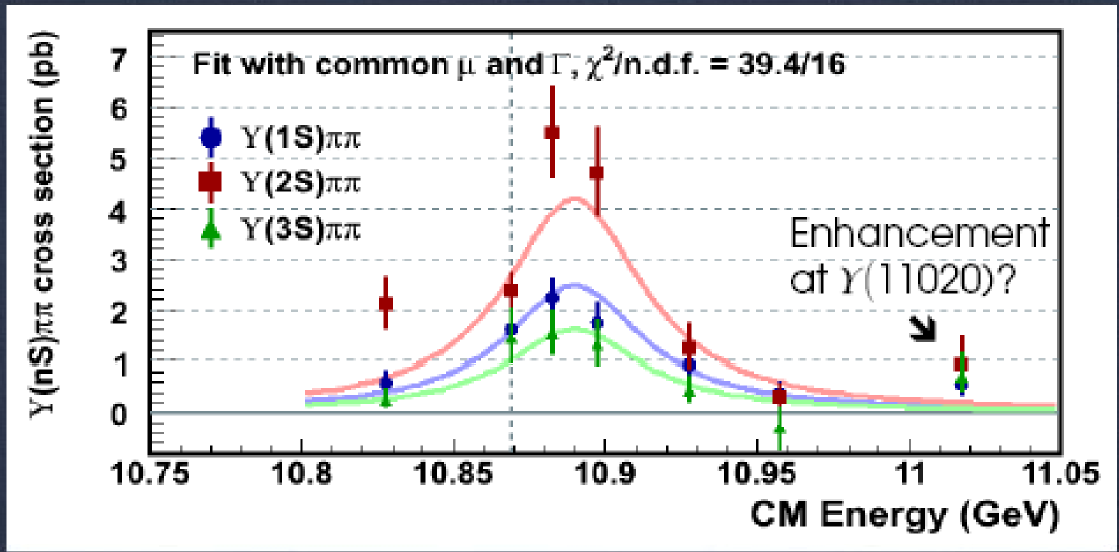
Both experiments see significant Ξ_b signals (D0: 5.5σ, CDF: 7.7σ)

- CDF: $M(\Xi_b)$ = (5792.9 ± 2.5 ± 1.7) MeV/c²
- D0: $M(\Xi_b)$ = (5774 ± 11 ± 15) MeV/c²
- World avg: $M(\Xi_b)$ = 5792.4 ± 3.0 MeV/c²
- D0: Lifetime consistent with expectations





- A χ^2 fit to the measured cross sections:
  (7 energies x 3 states = 21 points)



A common Breit-Wigner (floated mean & width) with floated 3 normalizations (for 1S, 2S, and 3S).

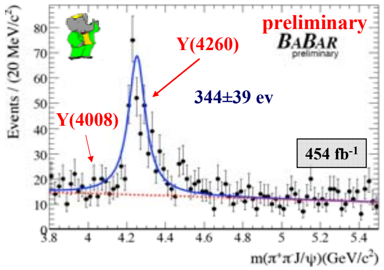
The mean value is ~20 MeV higher than the Υ(10860), and the width is around half (110 MeV → 55 MeV)!

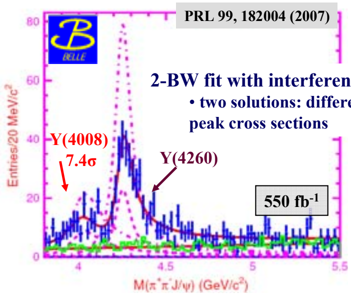
	$\Upsilon(1S)\pi\pi$	$\Upsilon(2S)\pi\pi$	$\Upsilon(3S)\pi\pi$
Peak	$2.46\,^{+0.27}_{-0.25} \pm 0.18$ pb	$4.18\,^{+0.49}_{-0.46} \pm 0.55$ pb	$1.61\,^{+0.31}_{-0.28} \pm 0.21$ pb
Mean		$10889.6 \pm 1.8 \pm 1.5$ MeV	
Width		$54.7\,^{+8.5}_{-7.2} \pm 2.5$ MeV	

(Peak cross section for Υ(5S) is around 300 pb)

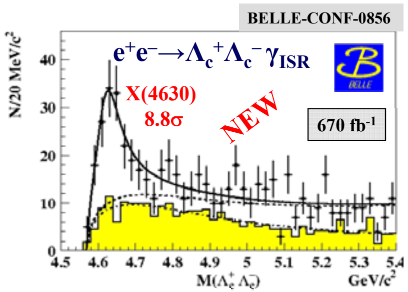
Exotic $e^+e^- \to 1^{--}$ final states *et al* Summary

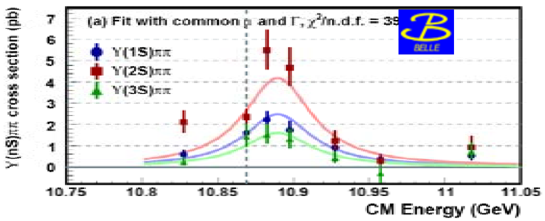
No Y(4008) in $J/\psi\pi^+\pi^-$ mass spectrum





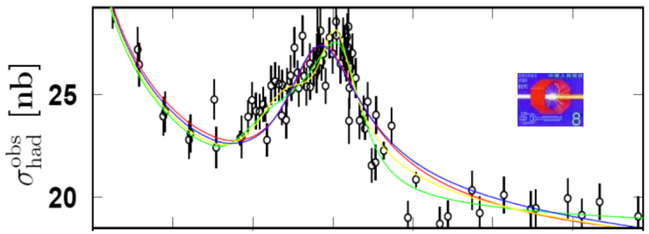
New enhancement at threshold in $\Lambda_c^+\Lambda_c^-$ mass spectrum





First observation of Υ_b candidate

Anomalous line-shape of $\sigma(e^+e^- \to \text{hadrons})$ around 3.77 GeV



X(3940) ≠ Y(3940) ≠ Z(3940)

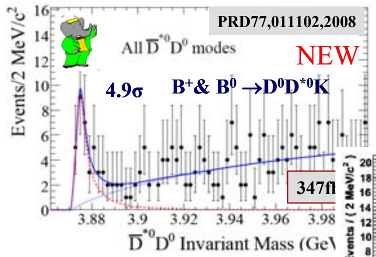
Exotic X(3872) Summary

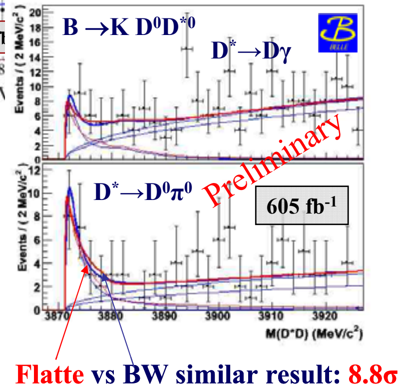
Mass splitting between X (3872) from charged and neutral B mesons decays consistent with zero!

Mass difference between two possible states $\Delta m < 3.2 \mathrm{MeV}/c^2$ at 90% CL

Mass $X(3872) \to J/\psi\pi\pi \neq X(3875) \to D^0 D^{*0}$

Mass $X(3872) \to J/\psi\pi\pi = X(3875) \to D^0 D^{*0}$





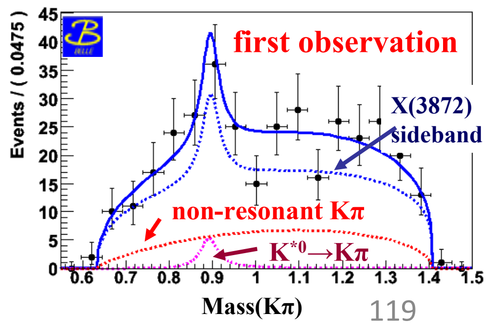
2σ difference

<u>disfavor diquark-antidiquark models</u>

Relatively large $Br(X \to \psi(2S)\gamma)$ is inconsistent with purely $D^0 D^{*0}$ molecular interpretation for X(3872)

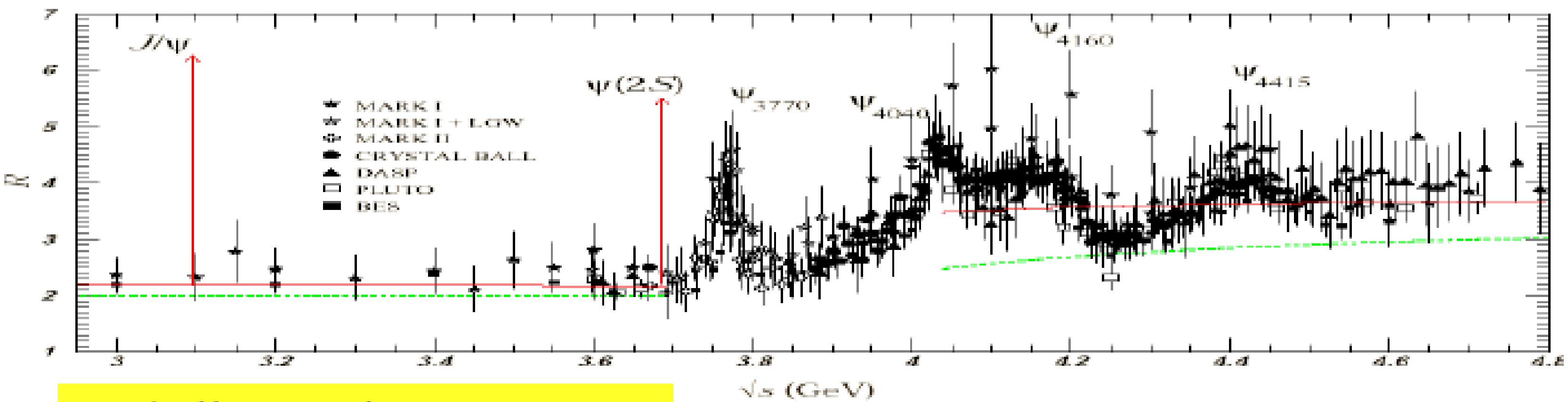
<u>favors $c\bar{c}$ - $D^0 D^{*0}$ mixing models</u>

in $B^0 \to X(3872) K^+\pi^-$ non resonant $K^+\pi^-$ dominates



Physics Topics at BESIII

- Light hadron spectroscopy.
- Charmonium: J/ψ, $\psi(2S)$, $\eta_C(1S)$, $\chi_{C\{0,1,2\}}$, $\eta_C(2S)$, $h_C(^1P_1)$, $\psi(1D)$, etc.
- New Charmonium states above open charm threshold.
- Exotics : hybrids, glueballs, and other exotics in J/ψ and $\psi(2S)$ radiative decays.
- Baryons and excited baryons in J/ψ and $\psi(2S)$ hadronic decays.
- Mesons and mixing of quark and gluon in J/ψ and $\psi(2S)$ decays.
- Electromagnetic form factors and QCD cross section (R values).
- tau mass and tau physics near the threshold.
- Search for new physics.



10 billion J/Ψ per year.

Very rich and interesting energy region.

8/4/2008

Main messages of my talk

1. Light flavor physics is now well under control, finally!
2. We are beginning to control charm quark.
3. Promising methods for b-quark are tested in quenched QCD.
4. Continuum limit and nonperturbative renormalization is essential for high precision.
5. Exact chiral symmetry is quite useful in some cases.
6. Coordinated work to combine advanced techniques will lead to few% accuracy within few years, including cross-checks with different actions.
7. Advanced methods in lattice QCD is now applied to new physics.

Recent Progress in Lattice QCD

Main messages of my talk

1. Light flavor physics is now well under control, finally!
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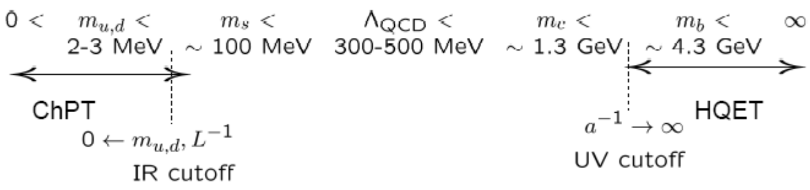
5. Exact chiral symmetry is quite useful in some cases.
6. Coordinated work to combine advanced techniques will lead to few% accuracy within few years, including cross-checks with different actions.
7. Advanced methods in lattice QCD is now applied to new physics.

QCD including b quark has a large hierarchy in energy scale



We need a good lattice data with controlled systematic errors.

1. Lighter and larger: light flavor physics, hadronic decays
2. Finer: heavy flavor physics

In addition, we need renormalization factor for matrix elements.

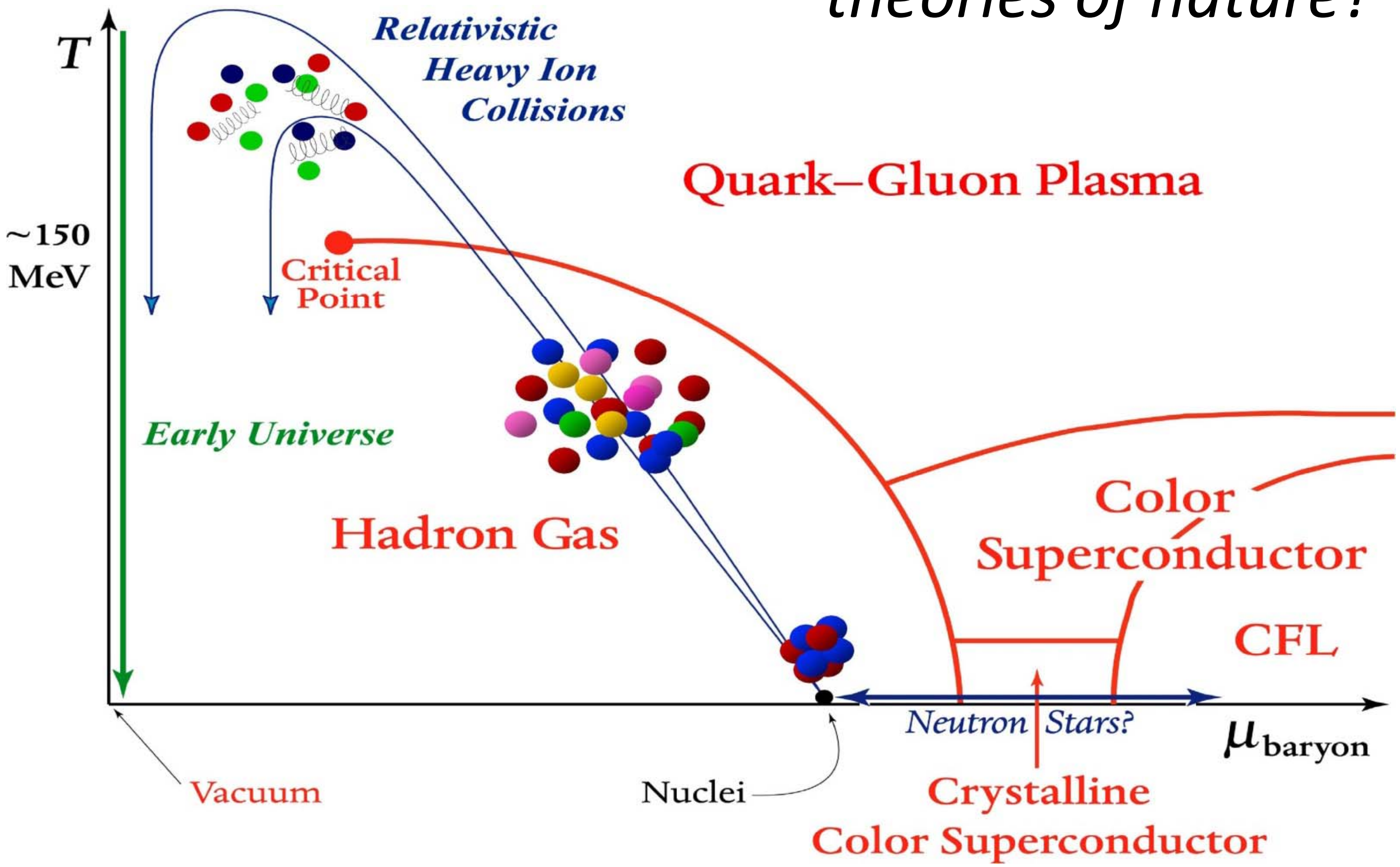
$$\langle \mathcal{O}(\mu) \rangle = \lim_{a \to 0} Z_{\mathcal{O}}(a\mu, g_0^2(a)) \langle \mathcal{O}(a) \rangle$$

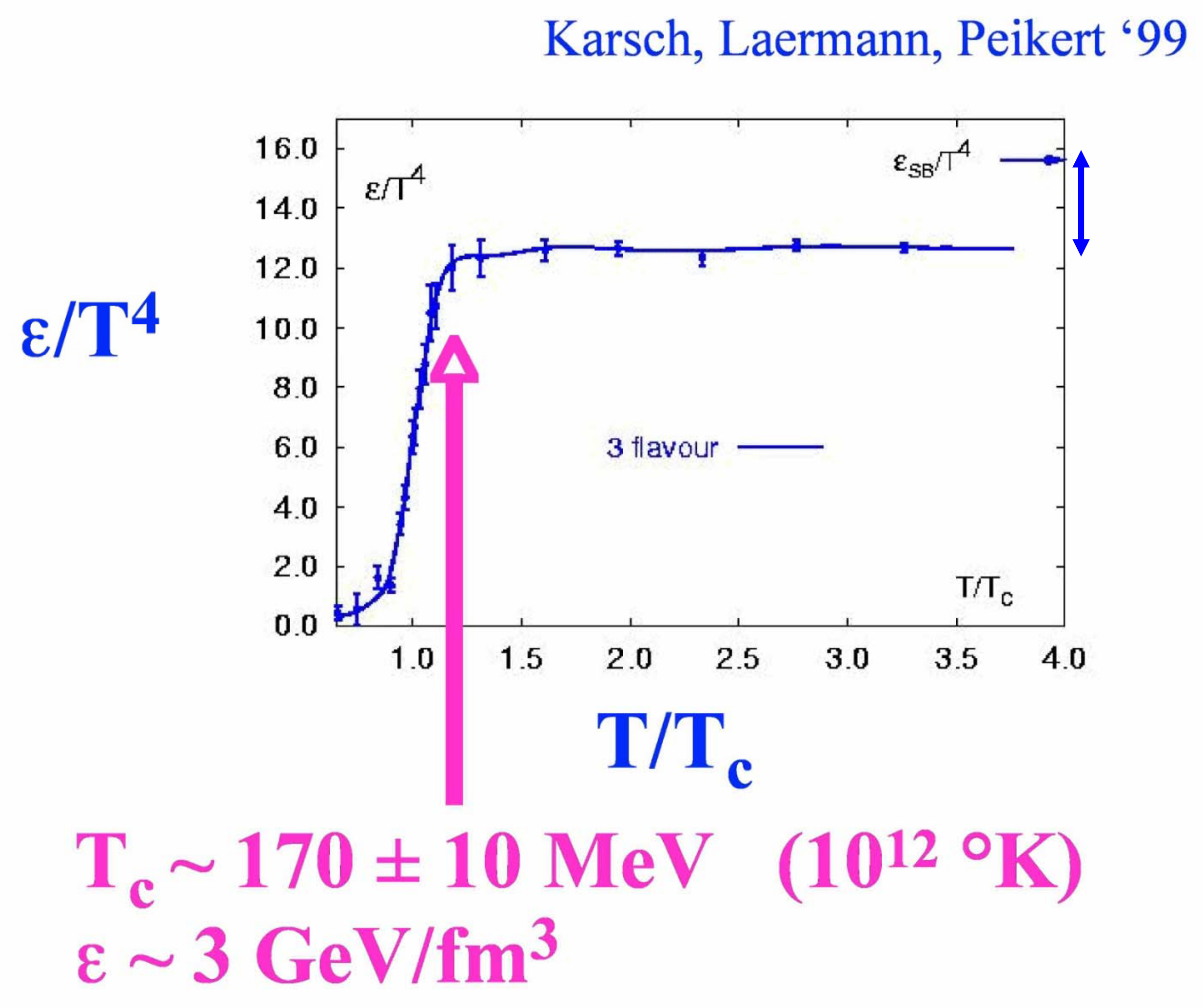
Conclusion

1. Light flavor physics is now well under control, finally!
2. We are beginning to control charm quark.
3. Promising methods for b-quark are tested in quenched QCD.
4. Continuum limit and nonperturbative renormalization is essential for high precision.
5. Exact chiral symmetry is quite useful in some cases.
6. Coordinated work to combine advanced techniques will lead to few% accuracy within few years, including cross-checks with different actions.
7. Advanced methods in lattice QCD is now applied to new physics.

Why study QCD matter?

Q: what are the fundamental thermal properties of gauge theories of nature?





transition

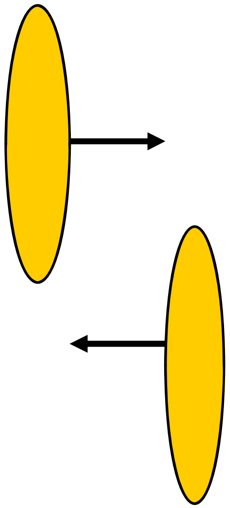
$$\varepsilon = g\frac{\pi^2}{30}T^4$$

Low T:
 non-perturbative
Very high T:
 perturbative
Transition:
 surely non-pQCD!

Creating and probing hot QCD matter

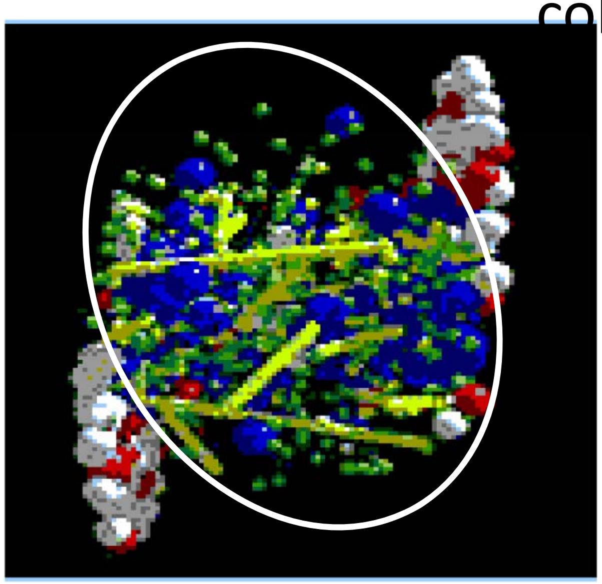
Au or Pb

√s > 20 GeV/A



Initial state radiation:

γ, $\gamma^* \rightarrow e^+e^-$, $\mu^+\mu^-$



Internal probes:

radiation,

collective motion

Final state:

π, K, p, n, ϕ, Λ, Δ, Ξ, Ω, d…

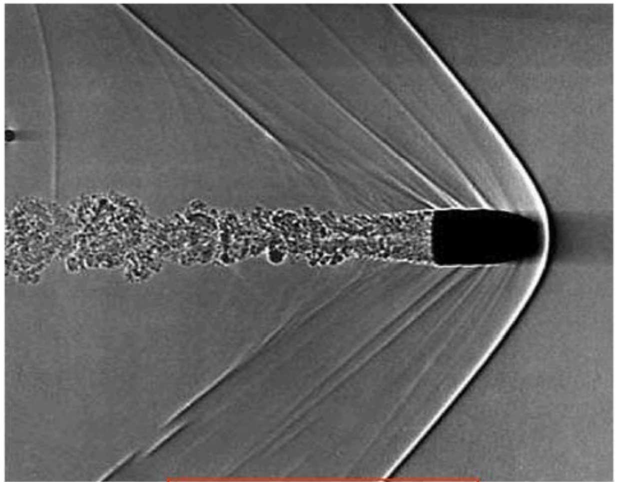
Collectivity: particle correlations reflect initial shape, pressure gradients. p_T<2 GeV/c

"external" probes produced early in collision itself:

hard scattered g, q ($\rightarrow$ jets) in initial NN

heavy quarks and quarkonia; scale = mass of c, b

lost energy excites a sound (density) wave?

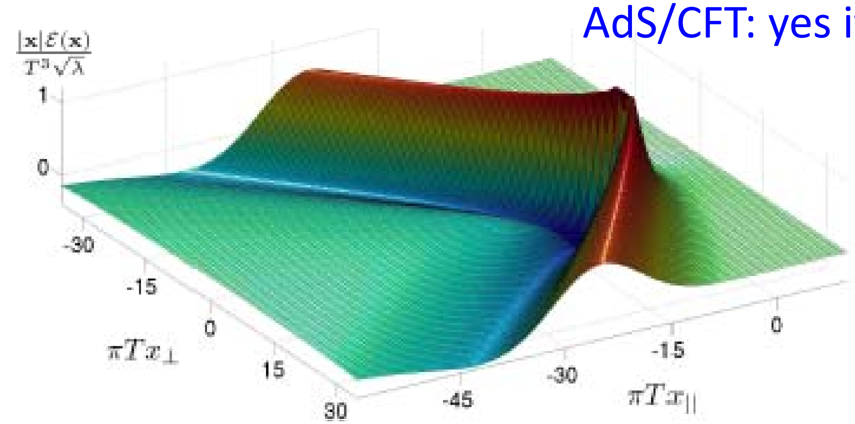


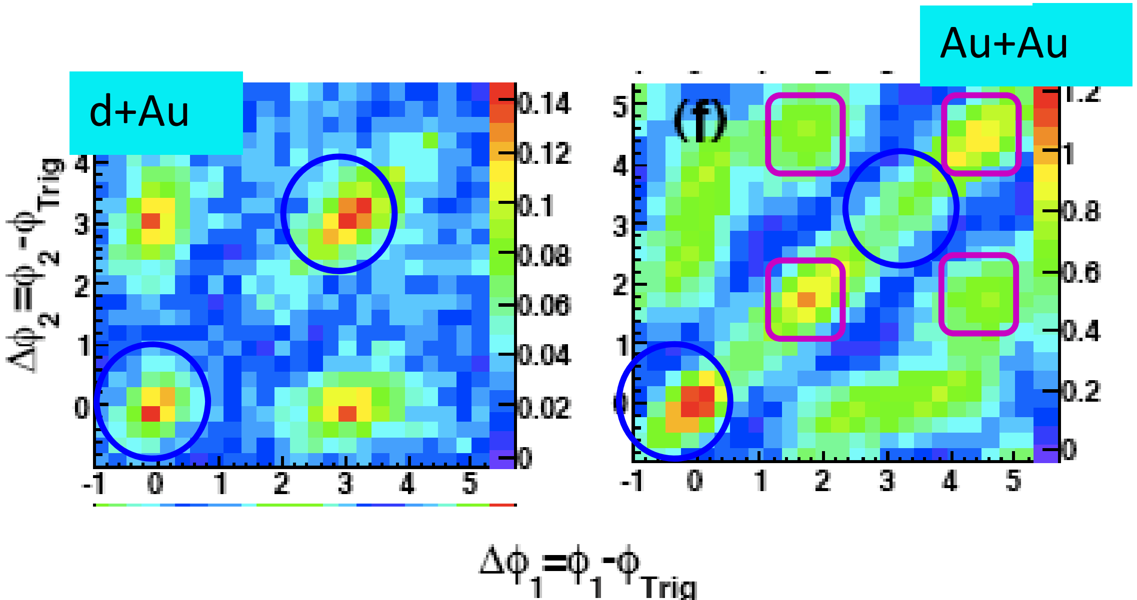
$$\cos\left(\theta_M\right) = c_s$$

Peak: $\phi = \pi$ -(1.2-1.38)
→ speed of sound
c_s~0.2-0.4
(c_s^2=0.33 in QGP,
~0.19 in hadron gas)

Chesler & Yaffe, 0706.0368(hep-th)

AdS/CFT: yes it does!



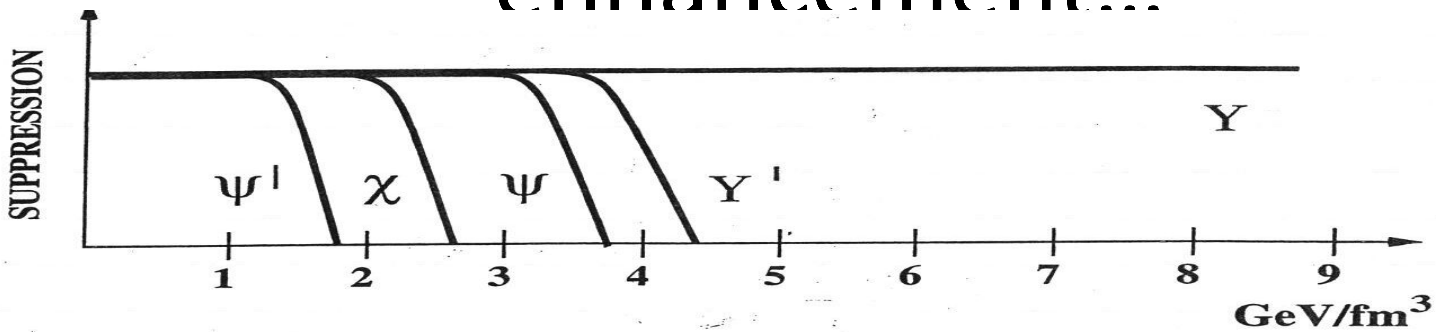


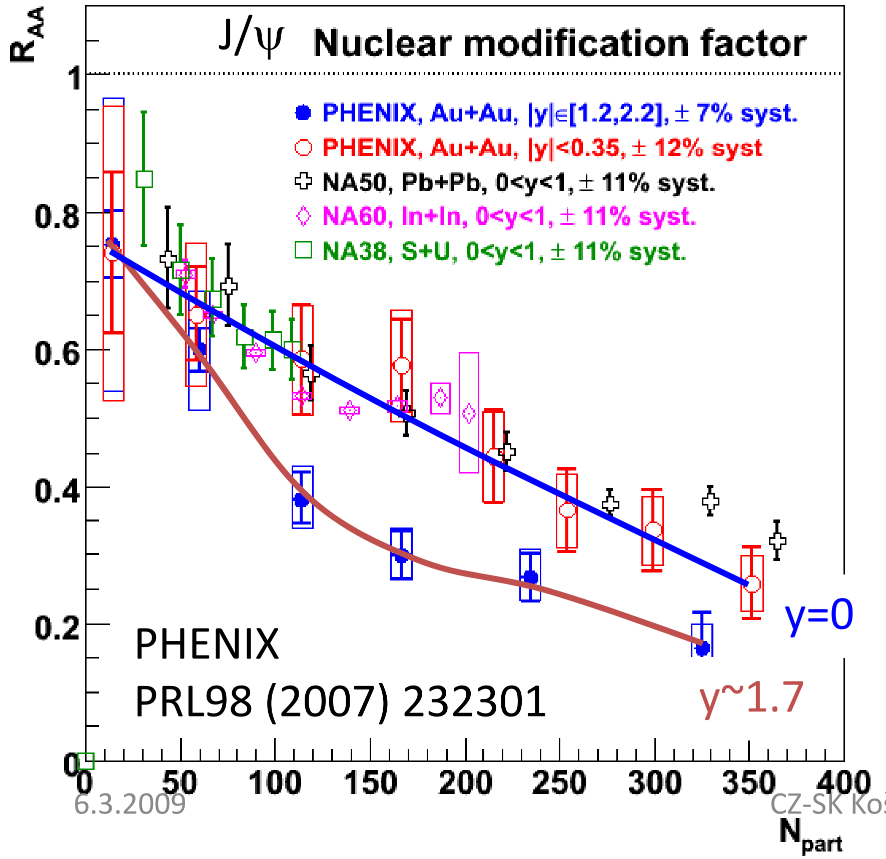
3 particle correlation

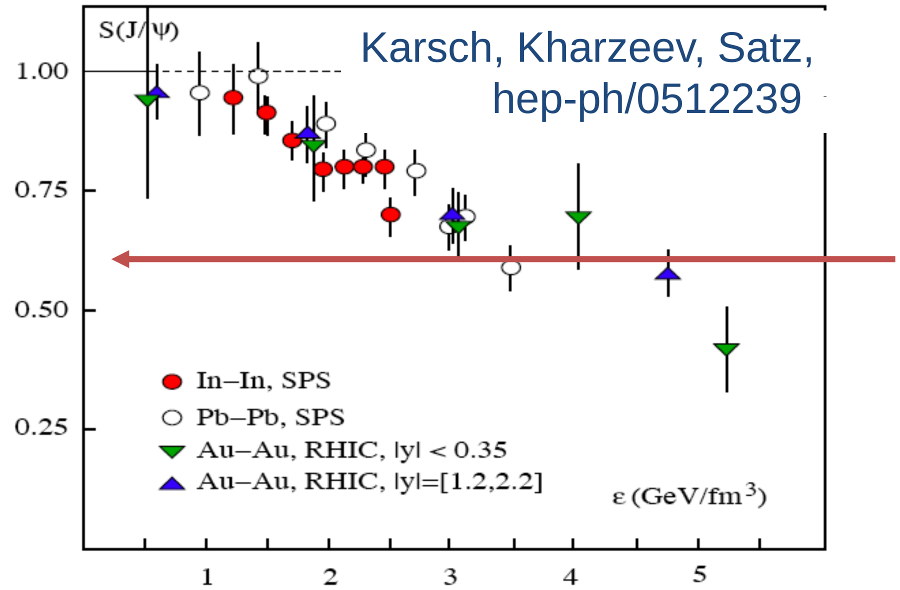
STAR, 0805.0622

J/ψ: shadowing, suppression, enhancement…

M. Brooks





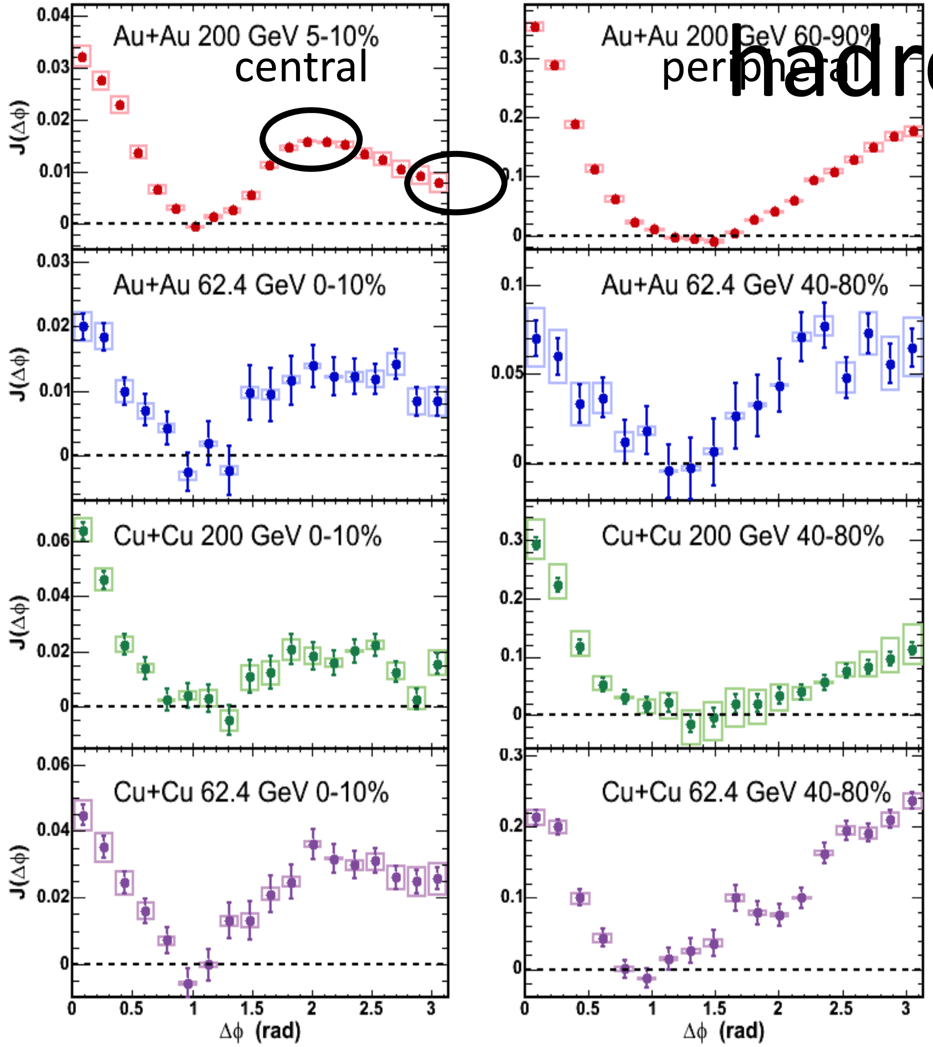


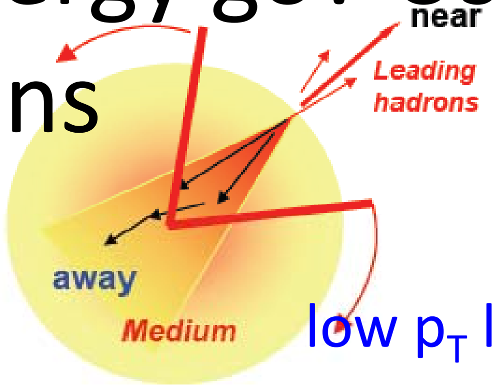
40% of J/ψ from χ and ψ' decays

these suppressed but direct J/ψ not?

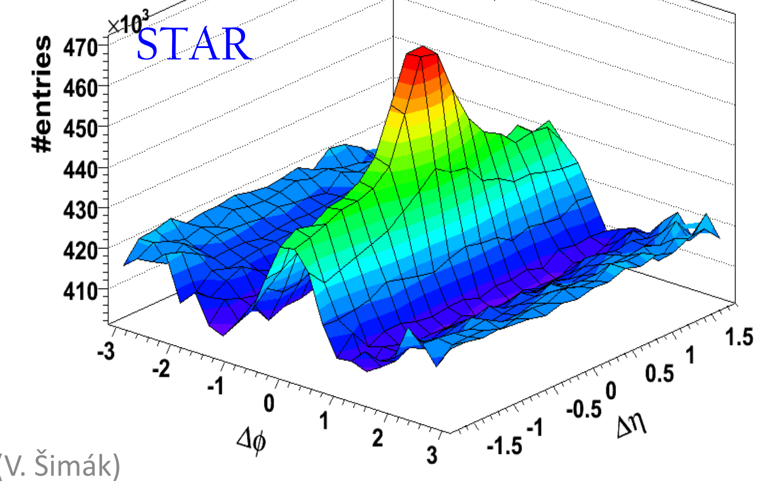
Where does lost energy go? Use di-hadrons

R. Lacey





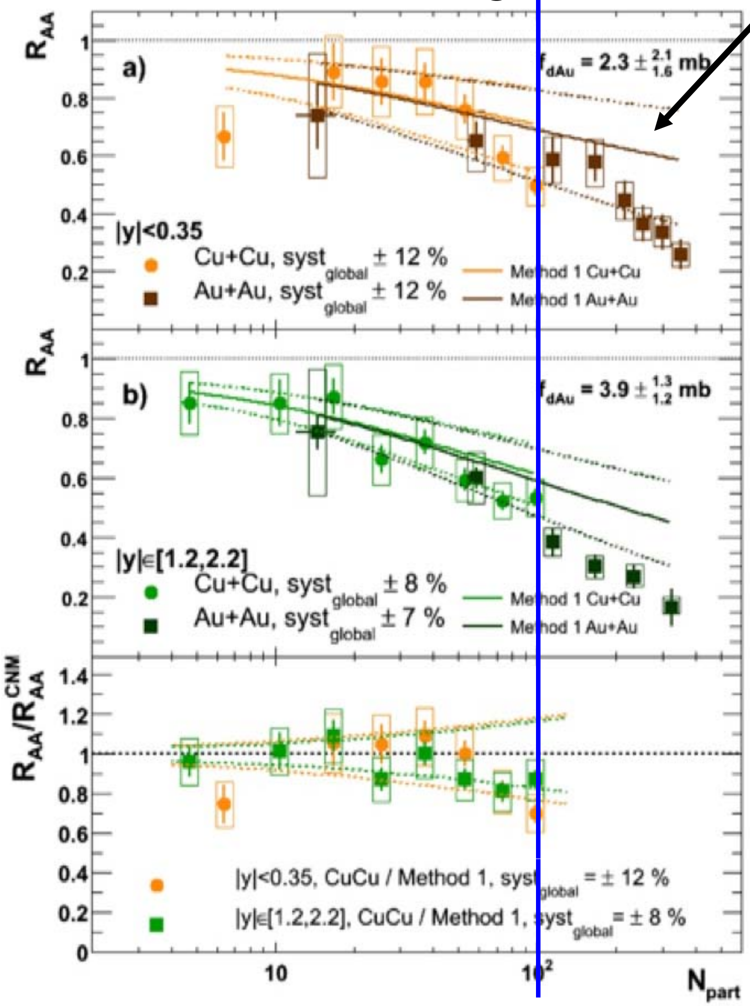
low p_T looks very modified medium response?



$1 < p_{T,a} < 2.5 < p_{T,t} < 4$ GeV/c

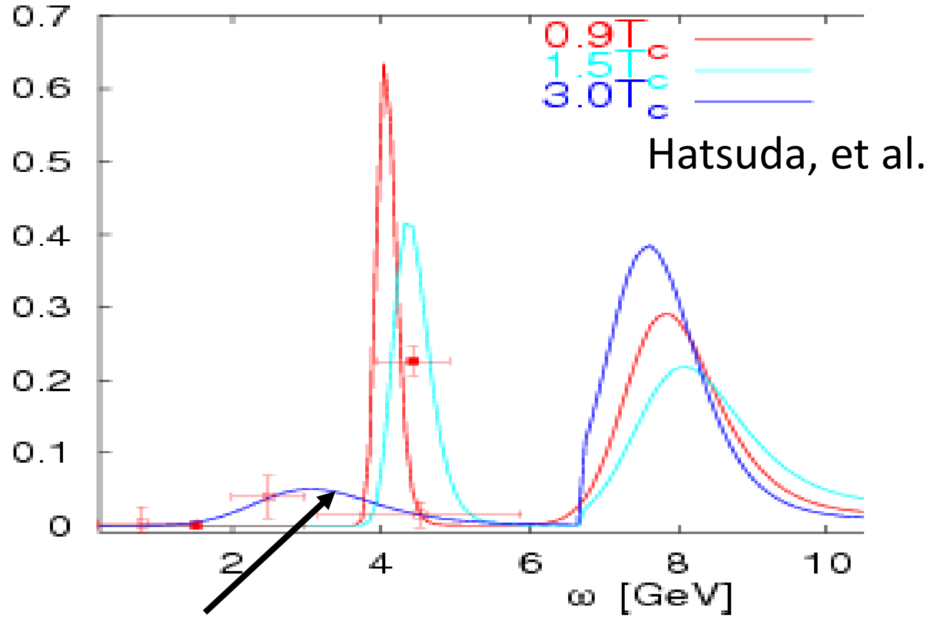
Current status

Shadowing from d+Au



All normal to ε ~ 1.5-2.5 GeV/fm^3

Lattice spectral function



$c\bar{c}$ correlations at $T > T_c$

resonant states? Interactions?

Color screening but not fully…

Some J/ψ could emerge intact

J/ψ could form in final state if c and cbar find each other…

Conclusions

- We know:
  Energy & k_T transfer to medium is large. Mechanism?
  Gluon dN/dy ~ 1400. Matter is opaque
  Coupling is not small α_s ~ 0.27. Liquid behavior
  $\eta/S = (1 – 3)/ 4\pi$ Close to conjectured quantum bound
  Deposited energy may shock the medium. Mach cones?
  c_s ~ (0.2 – 0.4) c Stay tuned…
  Color screening incomplete. }
- We don't know:
  - Are b quarks stopped as c quarks are?
  - How is the jet fragmentation function modified?
  - Are the funny structures really medium response?
  - Is QCD liquid same as other strongly coupled matter?

2/3

Formal theory at ICHEP08:

I. Advances in perturbation theory for gauge theory and gravity: Britto, Marquard, Maldacena, Bern, Ward, Rahman

II. Nonperturbative methods (new applications of gauge/string duality): Myers, Starinets, Kachru

III. Vacuum energy: Milton, Mannheim, Nevzorov

IV. String theory models of particle physics and cosmology: Gmeiner, Camara, Krefl, Ratz, Seiberg, Weigand, Quevedo, Haack, McAllister

(I will cite parallel speakers, see their talks for primary references!)

Spinor-helicity:

(Kosower 1990)

$$A(1^-,2^-,3^-,4^+,\ldots,n^+)$$

$$\begin{aligned}
&\frac{1}{[n\,1][1\,2][2\,3][3\,4]\prod_{k=3}^{n}\langle k\,k+1\rangle}\\
&\times\Bigg(\frac{\langle 1\,2\rangle\langle 3\,4\rangle[1\,n]\left\langle 1|P_{1,3}|4\right]^2}{P_{5,1}^2}+\frac{\langle 3\,2\rangle\langle 1\,n\rangle[3\,4]\left\langle 3|P_{1,3}|n\right]^2}{P_{3,n-1}^2}+\frac{\langle 2\,1\rangle\langle 3\,1\rangle\langle 3\,n\rangle[3\,2][3\,4][1\,n]\left\langle 3|P_{1,3}|n\right]}{P_{3,n-1}^2}\\
&+\frac{\langle 2\,3\rangle\langle 1\,3\rangle\langle 1\,4\rangle[1\,2][3\,4][1\,n]\left\langle 1|P_{1,3}|4\right]}{P_{5,1}^2}-\langle 3\,1\rangle^2P_{4,n}^2[3\,4][1\,n]-\frac{\langle 1\,2\rangle\langle 3\,2\rangle\langle 3\,1\rangle\left\langle 3|P_{1,3}|n\right][3\,4]}{P_{3,n-1}^2}\\
&-[2\,3][2\,1][3\,4][1\,n]\times\sum_{i=5}^{n-1}\Bigg[\frac{\langle 2\,1\rangle^2\langle 1\,3\rangle\langle 3|P_{3,i-1}k_i|3\rangle}{P_{3,i-1}^2P_{3,i}^2}+\frac{\langle 2\,3\rangle^2\langle 3\,1\rangle\langle 1|P_{i+1,1}k_i|1\rangle}{P_{i+1,1}^2P_{i,1}^2}\\
&-\frac{\langle 2\,3\rangle\langle 2\,1\rangle\langle 1\,3\rangle\langle 1|P_{i+1,2}k_i|3\rangle}{P_{3,i}^2P_{i,1}^2}-\frac{\langle 2\,3\rangle\langle 2\,1\rangle^2\langle 1|P_{i+1,2}k_i|3\rangle\left\langle 3|P_{i,2}|2\right]}{P_{3,i-1}^2P_{3,i}^2P_{i,1}^2}\\
&-\frac{\langle 2\,3\rangle^2\langle 2\,1\rangle\langle 1|P_{i+1,1}k_i|3\rangle\left\langle 1|P_{i+1,2}|2\right]}{P_{3,i}^2P_{i+1,1}^2P_{i,1}^2}\Bigg]\Bigg)
\end{aligned}$$

Twistor geometry:

(Cachazo, Svrček, Witten 2004)

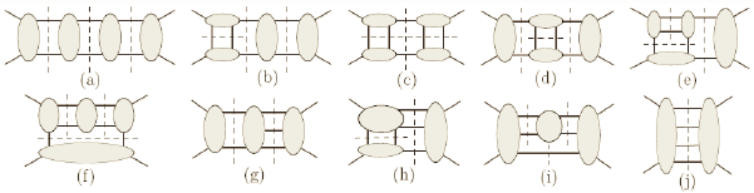
$$\begin{aligned}
&\frac{1}{\prod_{k=3}^{n}\langle k\,k+1\rangle}\\
&\times\Bigg[\sum_{i=4}^{n-1}\frac{\langle i\,i+1\rangle}{\left\langle i|P_{2,i}|2\right]\left\langle i+1|P_{i+1,2}|2\right]\left\langle 2|P_{2,i}|2\right]}\left(\frac{\langle 3\,2\rangle^3\left\langle 1|P_{2,i}|2\right]^3}{P_{2,i}^2}+\frac{\langle 1\,2\rangle^3\left\langle 3|P_{i+1,2}|2\right]^3}{P_{i+1,2}^2}\right)\\
&-\langle 1\,3\rangle^2\left(\frac{\langle 1\,3\rangle+2\langle 1\,2\rangle+2\langle 2\,3\rangle}{[3\,2][1\,2]}+\frac{\langle 1\,2\rangle\langle n\,3\rangle}{[1\,2]\langle n\,1\rangle}+\frac{\langle 3\,2\rangle\langle 1\,4\rangle}{[3\,2]\langle 3\,4\rangle}\right)\Bigg]
\end{aligned}$$

Construction from residues:

(RB, Feng, Roiban, Spradlin, Volovich 2005)

$$\frac{1}{\prod_{k=3}^{n}\langle k\,k+1\rangle}\sum_{i=4}^{n-1}\frac{\langle 1|P_{2,i}P_{i+1,2}|3\rangle^3}{P_{2,i}^2P_{i+1,2}^2}\frac{\langle i+1\,i\rangle}{[2|P_{2,i}|i+1\rangle\langle i|P_{i+1,2}|2]}$$

Bern and collaborators find that N = 8 supergravity amplitudes are finite through 3 loops.

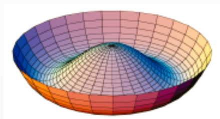


Is this due to supersymmetry, or something else? Some SUGRA experts expected divergences at 3 loops, but other arguments predict that the first divergences won't appear until 5, 6, 7, 8 or even 9 loops! (Problem: no good superspace).

If the theory is finite order by order, what does this mean? Perturbation theory still breaks down at high energy.

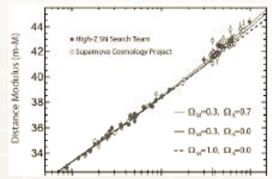
III. Vacuum energy

The vacuum is full of stuff (Higgs fields, color fluctu-ations, zero-point energies), and gravity is a universal force.



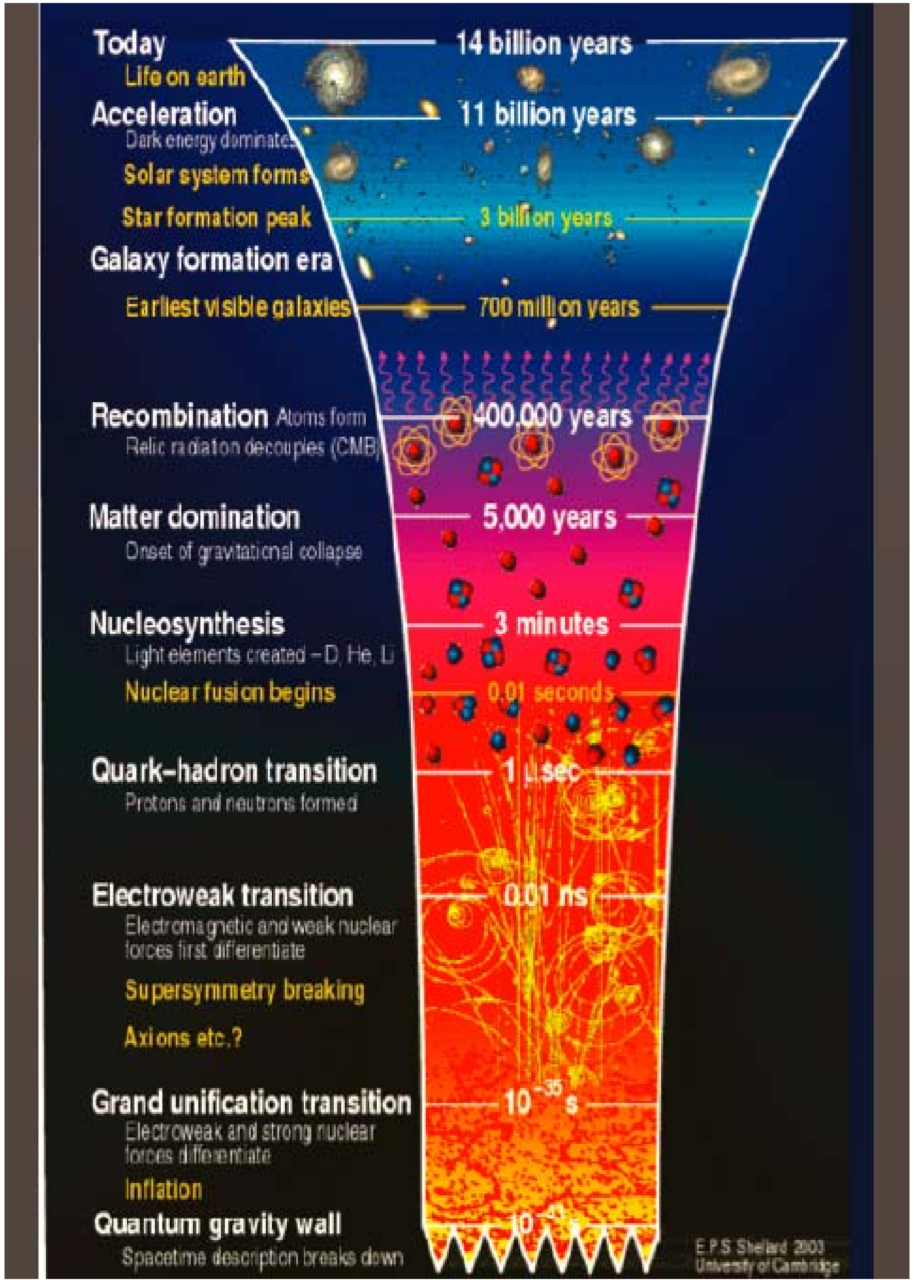
• So why is the vacuum energy density not huge?

This question has been around since Pauli, but since the discovery of the cosmic acceleration we have two new puzzles:

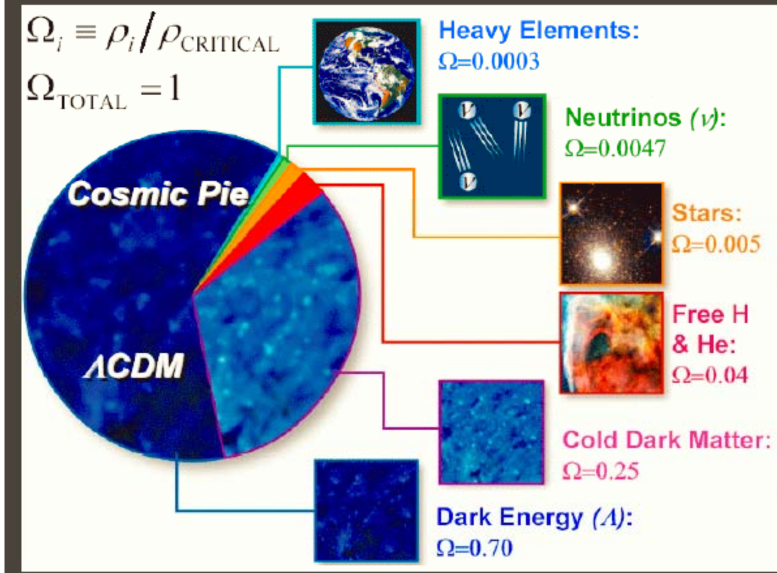


• Why is the vacuum energy not exactly zero?

• Why is it's magnitude so similar to the matter density in the universe today (cosmic coincidence)?



Components of the Universe



25%
Dark Matter:
Dominant in Galaxies & Clusters

70%
Dark Energy:
Dominates the Universe, causing Expansion to speed up

4% baryons

What is causing cosmic acceleration?

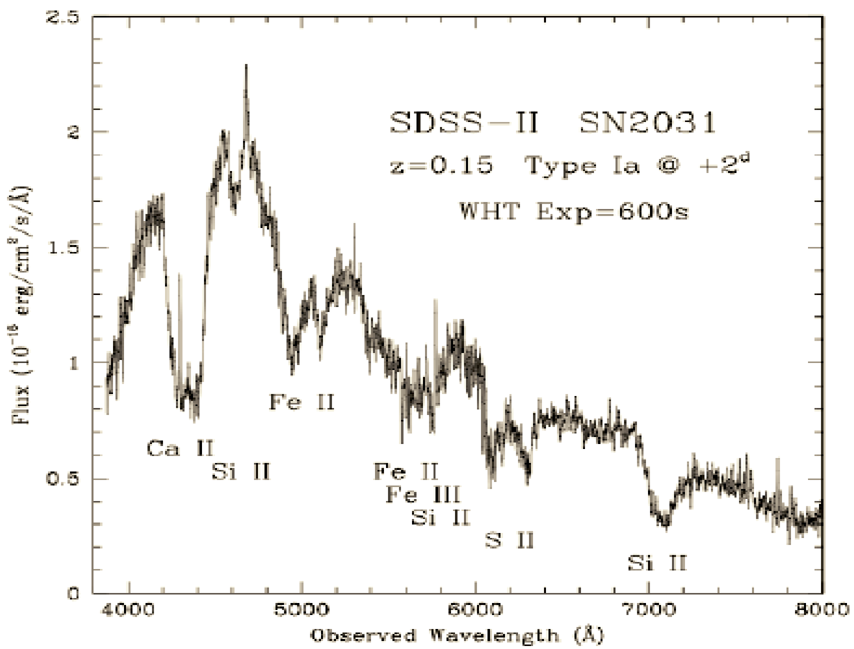
Dark Energy: $G_{\mu\nu} = 8\pi G[T_{\mu\nu}(\text{matter}) + T_{\mu\nu}(\text{dark energy})]$

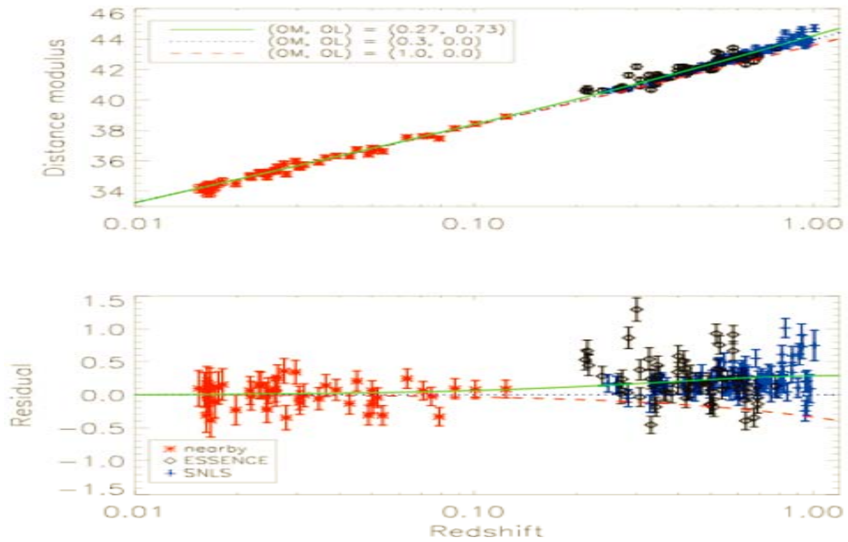
DE equation of state : $w = T_i^i / T_0^0 < -1/3$

Gravity: $G_{\mu\nu} + f(g_{\mu\nu}) = 8\pi G T_{\mu\nu}(\text{matter})$

Key Experimental Questions:

1. Is DE observationally distinguishable from a cosmological constant, for which $w = -1$?
2. Can we distinguish between gravity and dark energy?
   Combine distance with structure-growth probes
3. Does dark energy evolve: $w=w(z)$?





Conclusions

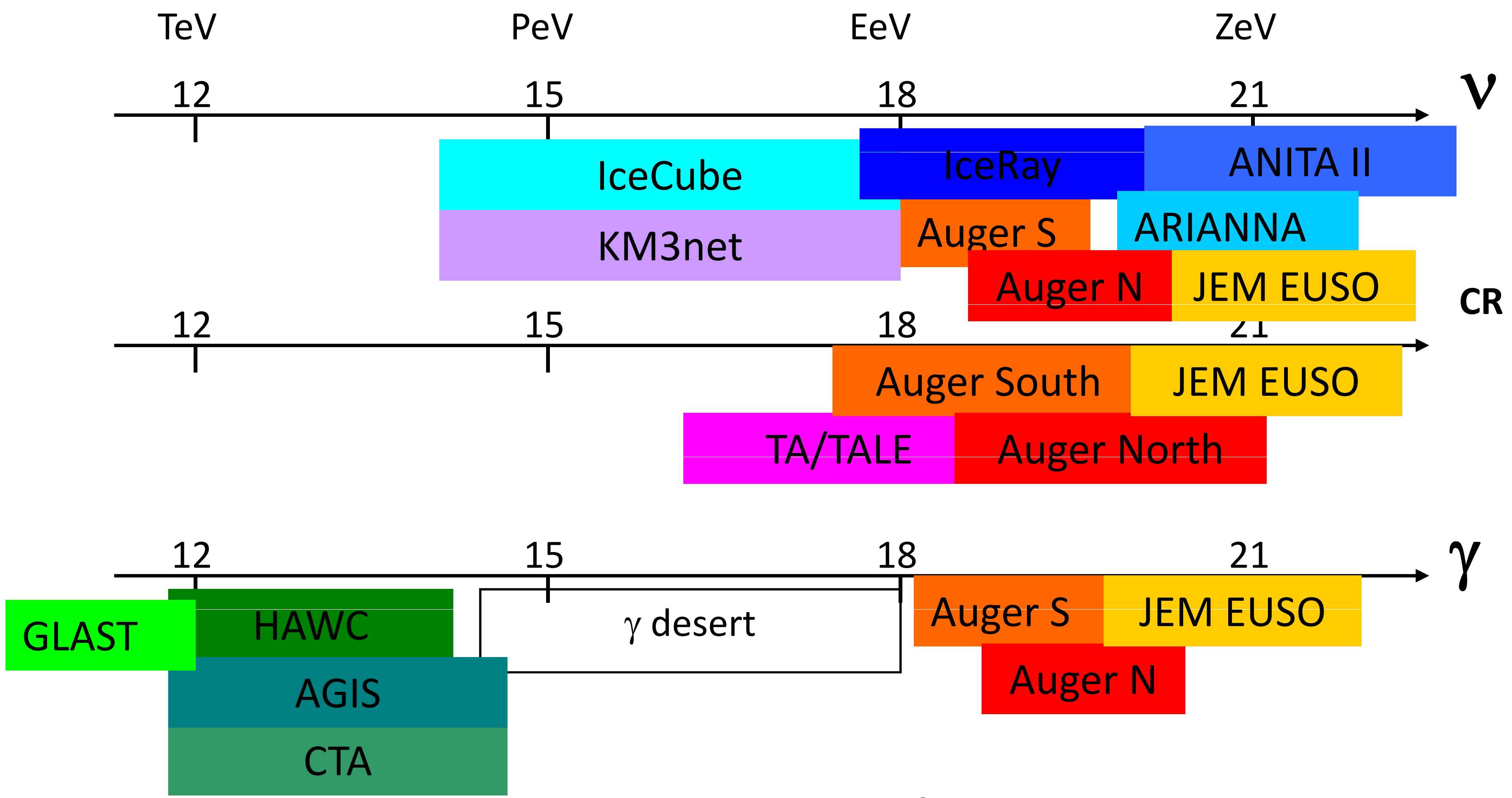
• Excellent prospects for increasing the precision on cosmological parameters from a sequence of increasingly complex and ambitious ground- and space-based (Planck, JDEM) experiments over the next 5-15 years

• Exploiting complementarity of multiple probes will be key: we don't know what the ultimate systematic error floors for each method will be. Combine geometric with structure-growth probes to help distinguish modified gravity from dark energy.

• What parameter precision is needed to stimulate theoretical progress and understanding?

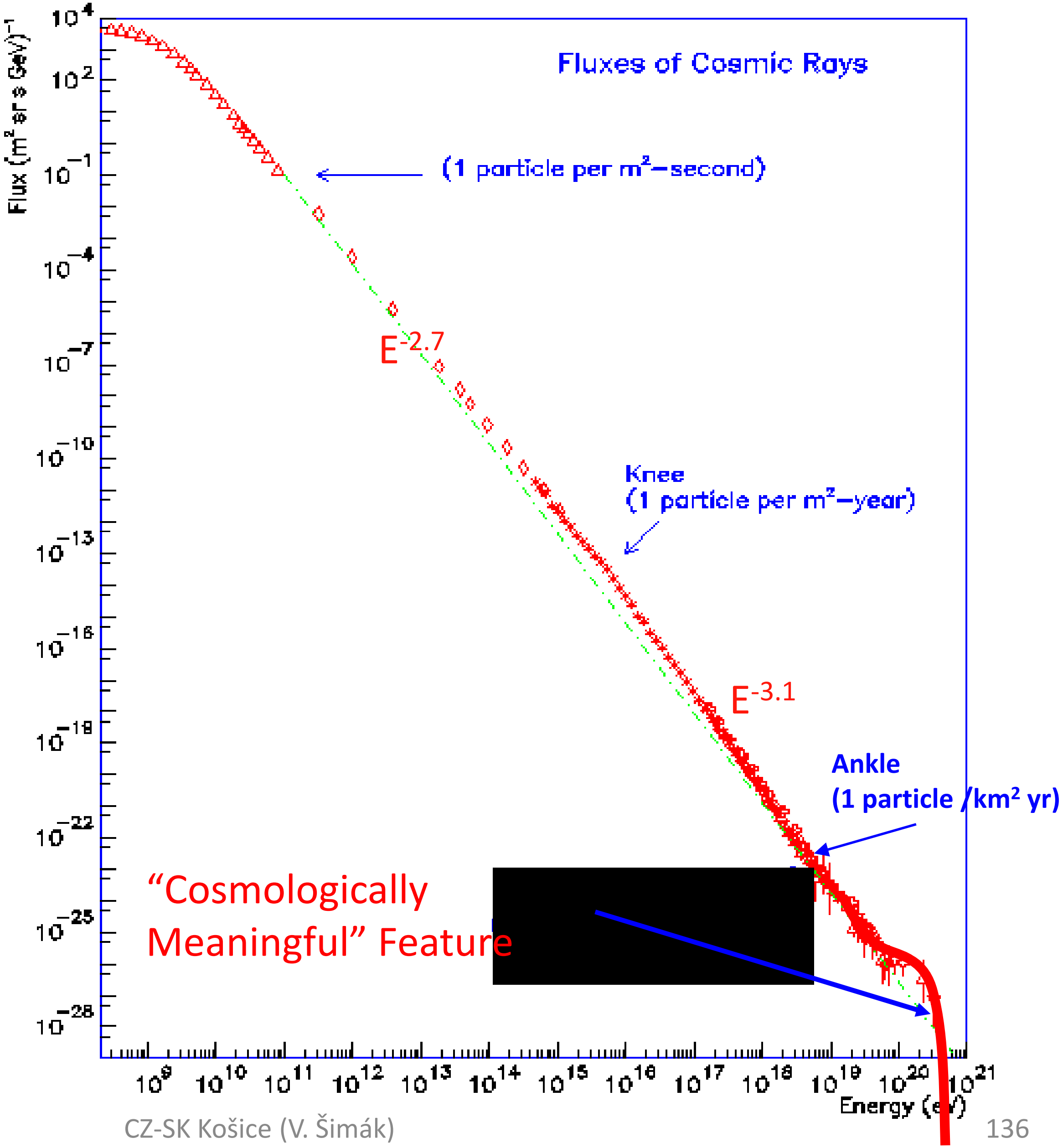
Particle Astrophysics @ UHEs

The Energy Frontier



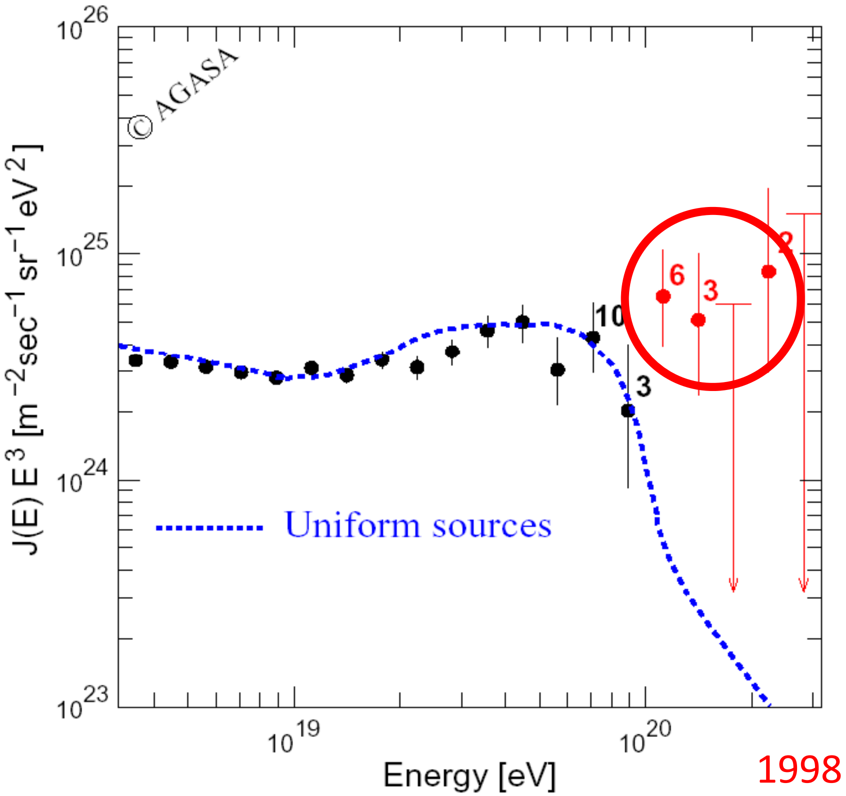
Leading & FUTURE Projects

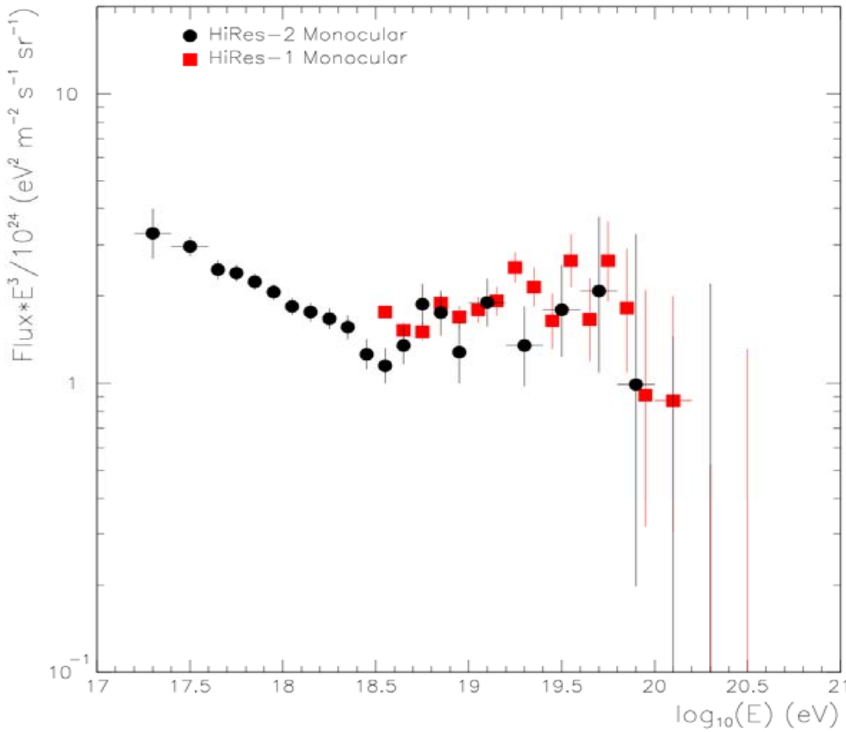
GZK Feature


Fluxes of Cosmic Rays
Flux (m² sr s GeV)⁻¹
(1 particle per m²–second)
E-2.7
Knee
(1 particle per m²–year)
E-3.1
Ankle
(1 particle /km² yr)
“Cosmologically
Meaningful” Feature
[redacted]
Energy (eV)

AGASA (1984-2003)
100 km^2 area,
111 scintillators, 1km spacing

High Resolution Fly's Eye (1997-2006) 2 fluorescence telescopes





No GZK cutoff

Consistent w/ GZK cutoff

New detector ideas/concepts

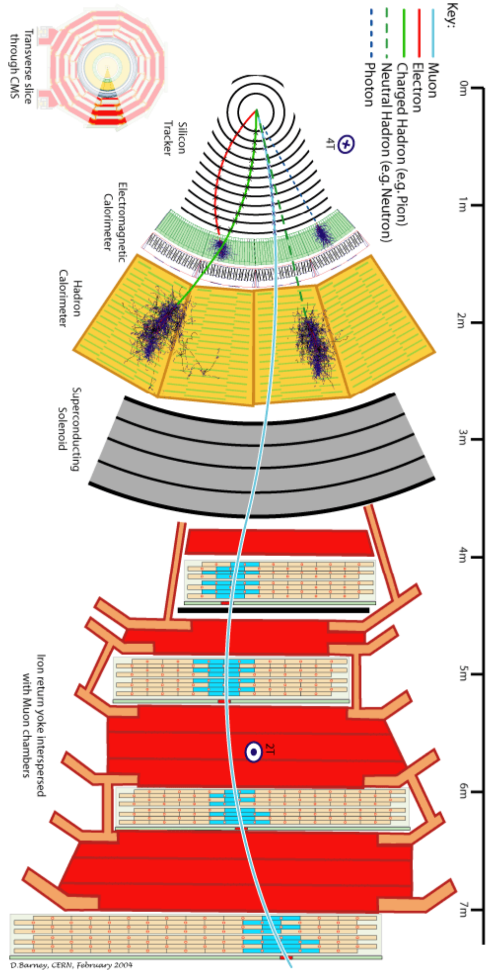
- The major R&D drivers are Linear Collider detectors and upgrade of LHC detectors – but there are many other detector systems (neutrino – lower rate ad energy, flavour studies – high intensity and lower energy, heavy ion physics – high occupancy, astroparticle systems – low rate and low noise, etc) being planned, investigated or implemented.
- Silicon systems
    - Vertex systems and Large silicon strip systems
- Gas detector systems
    - Micropatterns systems in particular

    - Particle flow measurements (fine granularity)
    - Dual mode measurements (scint and cherenkov)
    - Photo-readout (SiPM)

    - Submicron electronics and improved power distribution systems – (the latter possibly ou weakest point)

    - Trigger and Data Acquisition – not to mention computing and software – crucial but I hav not included here

> 100 Million Electronics Channels, 40 MHz ---> hundreds of Hz



ILC Global Parameters

Global accelerator parameters for 500GeV cms (RDR Table 2.1-1)			
Parameter	**Value**	**Units**	
Center of mass energy	500	GeV	
Peak luminosity	2.00E+34	cm-2s-1	
Availability	75	%	
Repetition rate	5	Hz	
Duty cycle	0.5	%	
Main linacs			
Average accelerating gradient in cavities	31.5	MV/m	
Length of each main linac	11	km	
beam pulse length	1	ms	$I_{ave} = eN / t_b$
average beam current in pulse	9	mA	
Damping Rings			
Beam energy	5	GeV	
Circumference	6.70	km	
Length of Beam Delivery Section (2 beams)	4.5	km	
Total site length	31	km	
Total site power consumption	230	MW	
Total installed power	300	MW	

Responding to LHC

- Systematic studies needed
  - When are we likely to know what from LHC?
    - Possible LHC discovery scenarios
  - For each scenario
    - What physics modes to study at ILC
    - What kind of machine to build
    - What kind of detector to build
    - Priorities and timescale
  - Cost and political realities to be included
- Rethinking of the machine parameter will be needed.
  - Energy (250 GeV, 360 GeV, 500 GeV, 800 GeV…)
  - Luminosity
  - Upgrade path
- Accelerator and physics/detector community should have close and intensive discussions
  - Cost and politics
  - GDE + the RD structure (we need name)

C11 Activities

- Oversight and sponsorship of two international conferences: ICHEP and Lepton Photon in alternate years
- Other Activities:
  - Other IUPAP-C11 sponsored conferences
  - Young Scientist Prize
  - WG on Assessment of Individual Achievements in Large Collaborations.

ICHEP-08	Philadelphia
LP-09	Hamburg
ICHEP-10	Paris
LP-11	Mumbai
ICHEP-12	Melbourne

Recommendations:

1. Define clear criteria to be eligible author of a publication.
2. Establish a publication web page with supporting notes and details of individual contributions.
3. List most relevant publications in the CV (with major personal contributions)
4. Specialist notes, published by few authors (methods, procedures)
5. Public track record in large collaborations (authorship of internal notes, leadership and convener positions)
6. Two-Tier authorlist (list a few main authors first).
7. More awards on the national, institute and collaboration level.