Summary (theory) WG D: "Heavy Flavour Physics"

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(with Karin Daum & Leonid Gladilin)

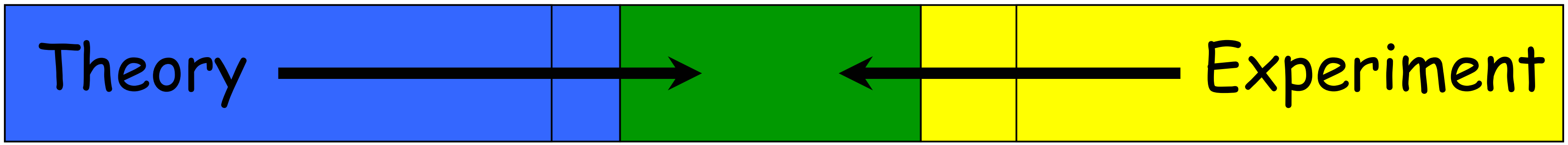
10 theory talks on

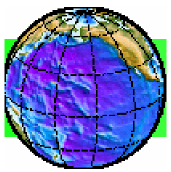
- NLO corrections
- Charm and Bottom
- Resummations
- Factorization
  - Collinear factorization
  - $K_\perp$ factorization
- Electroweak implications
- NRQCD
- ...

27 experimental talks on

- ....

Leonid Gladilin will summarize!



Real  data/theory comparisons

A hurdle for theory (HQ or not) to compare with data:
Low particle number final states in perturbation theory

Different aspects of this perturbative shortcoming are cured by:

- Interfacing with MC showers: MC@NLO

Stefano Frixione

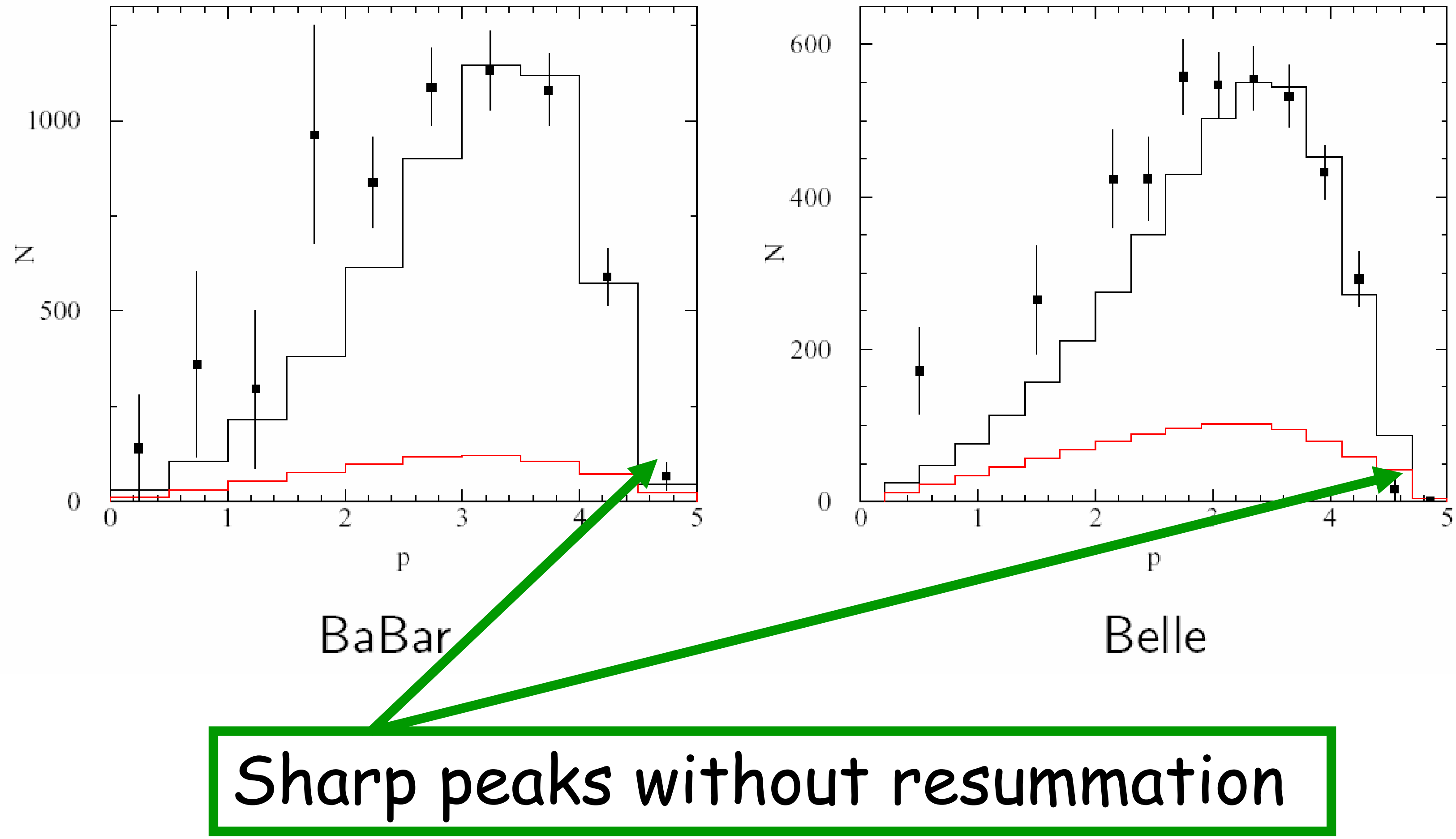
- Sudakov resummation near kinematic endpoints.

Thomas Mehen

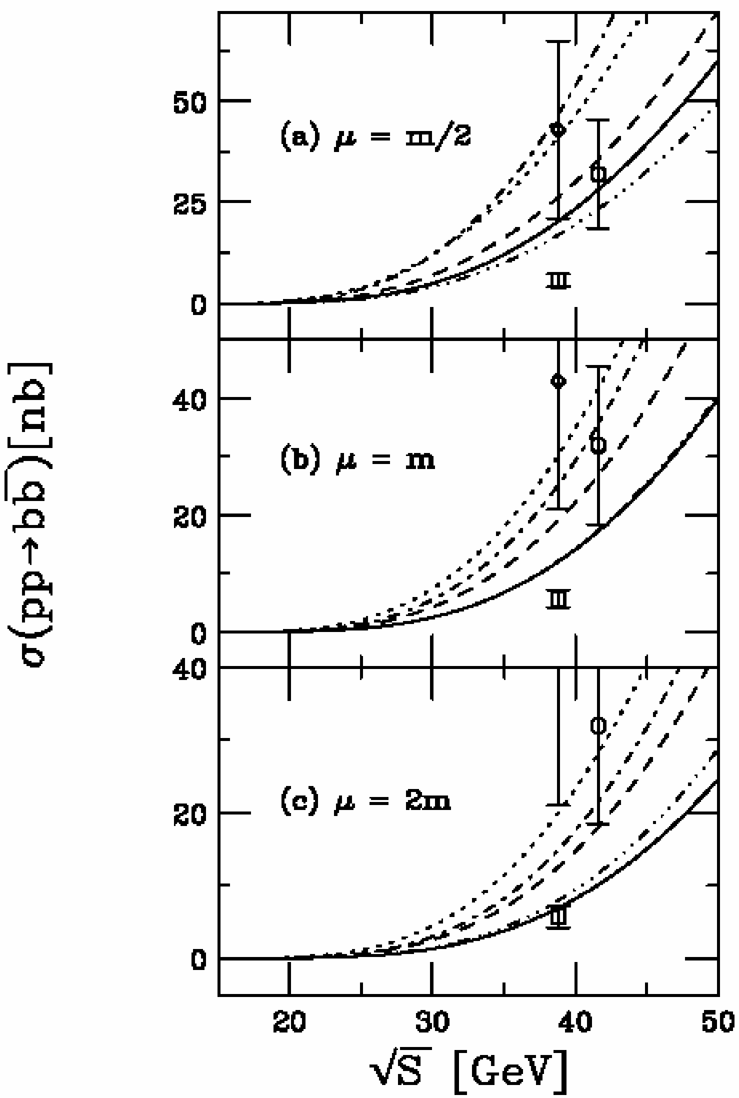
Sudakov effects in J/Ψ cross section

- Comparison with Data (Different Normalization)

Thomas Mehen

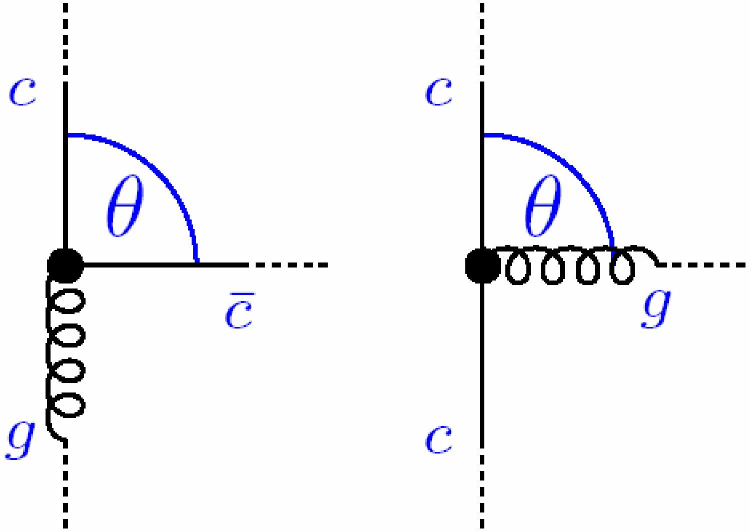


At HERA-B, soft gluons are enhanced in the form of threshold resummations (Nikolaos Kidonakis).



“Canonical” pQCD predictions for HQ (bottom) production based on:

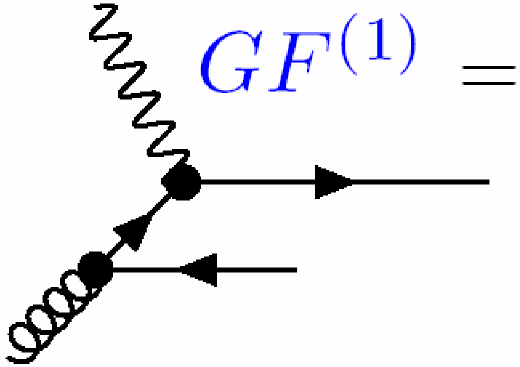
Collinear Factorization, collinear resummation and refinements



collinear $\ln Q^2/m^2$

from small θ

Ingo Schienbein



$$GF^{(1)} = \underbrace{\frac{\alpha_s}{2\pi} g \otimes \left[P_{qg}^{(0)} \ln \frac{Q^2}{m^2}\right.}_{\equiv c(x,Q^2)} \left. + C_2^{g,\overline{\mathrm{MS}}} \right] + \mathcal{O}\left(\frac{m^2}{Q^2}\right)$$

$$\boxed{\frac{dc(x,Q^2)}{d\ln Q^2} = \sum_i P_{ci} \otimes f_i}$$

DGLAP resums collinear logs

We have heard about the usual suspects:

FOPT, FFNS, FONLL, ACOT, ACOT(X), “massless”, “matched”, LO, NLO, N^kLO, R&T, LL, NLL, NNLL, NNNLL, NNLO-NNLL, VFNS, GMVFNS, ZMVFNS, …

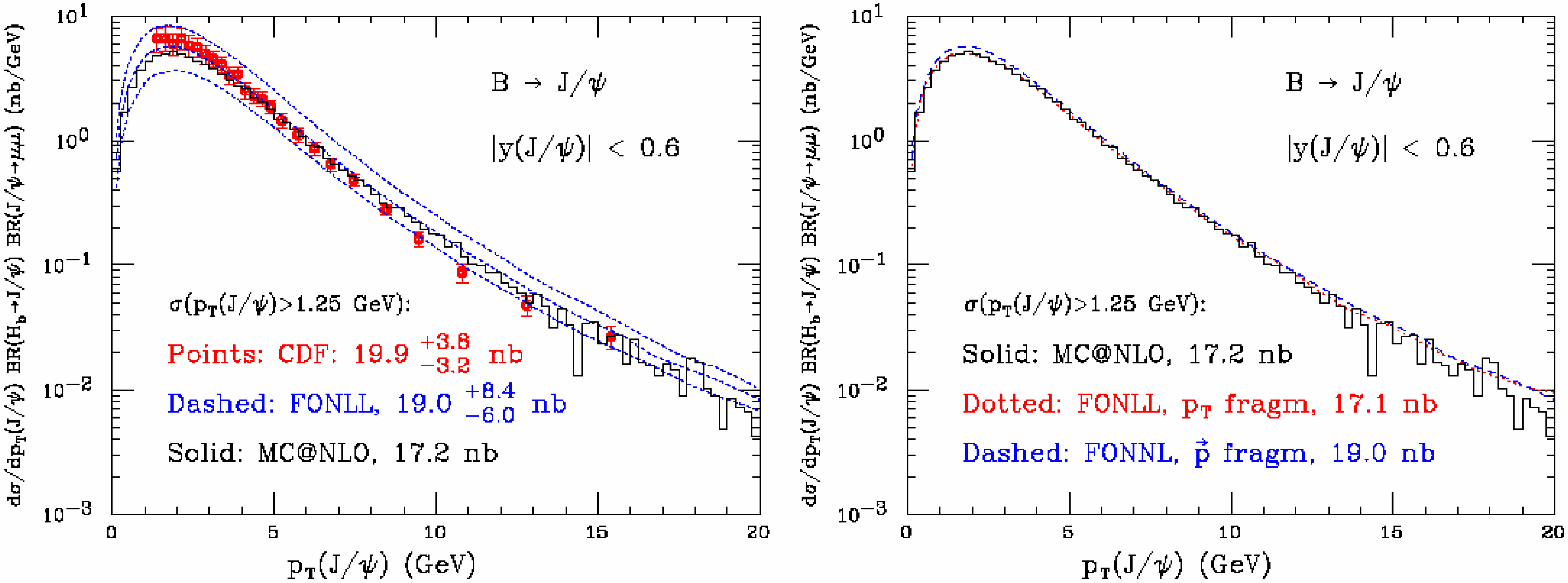
Ingo Schienbein

Catalogue of questions to ask for classification (and clarification):

- Which $O(\alpha_s^{\,l=1,2,\ldots})$?
- Resummation of $[\alpha_s^{\,n} \ln^n(\mu/m)]$?
- Inclusion of $O(m^2)$? (and, perhaps, how?)
- Soft Gluon / Sudakov resummation ? (and do they come with a new non-perturbative component?)
- How have the ab initio non-perturbative dof-s been treated? (Mostly, PDFs and FF)
- And, if in doubt: Has all of this been applied consistently and to what accuracy?

Along these lines, good news:

Run II data



Best ever agreement with data

Stefano Frixione

Developments in compariosons of pQCD to bottom production data:

Stefano Frixione, ...

- Better knowlegde of theory parameters Λ_{QCD}, PDFs, FF. Such parameters came (and come) with an error.
- Data for unbiased observables minimize the unreliable impact of deconvolutions and extrapol[redacted]
- We have become / been made aware that most of the discrepancies (if/where existant) were no worse than 2 σ effects.

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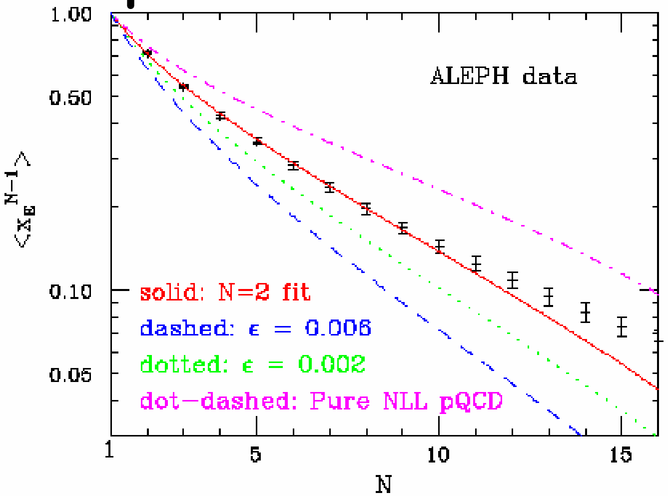
Heavy Quark Fragmentation

Simple, one-parmetric functional forms (e.g. Peterson form) may misguide the comparison of data and theory.
This can be avoided by flexible functional forms or a systematic investigation of the relevant Mellin moments $D_N = \int dz\, z^{N-1} D(z)$.
Extracting up to date HQ FFs is more than a sideproduct.

Stefano Frixione



- The p_T spectrum is power-like

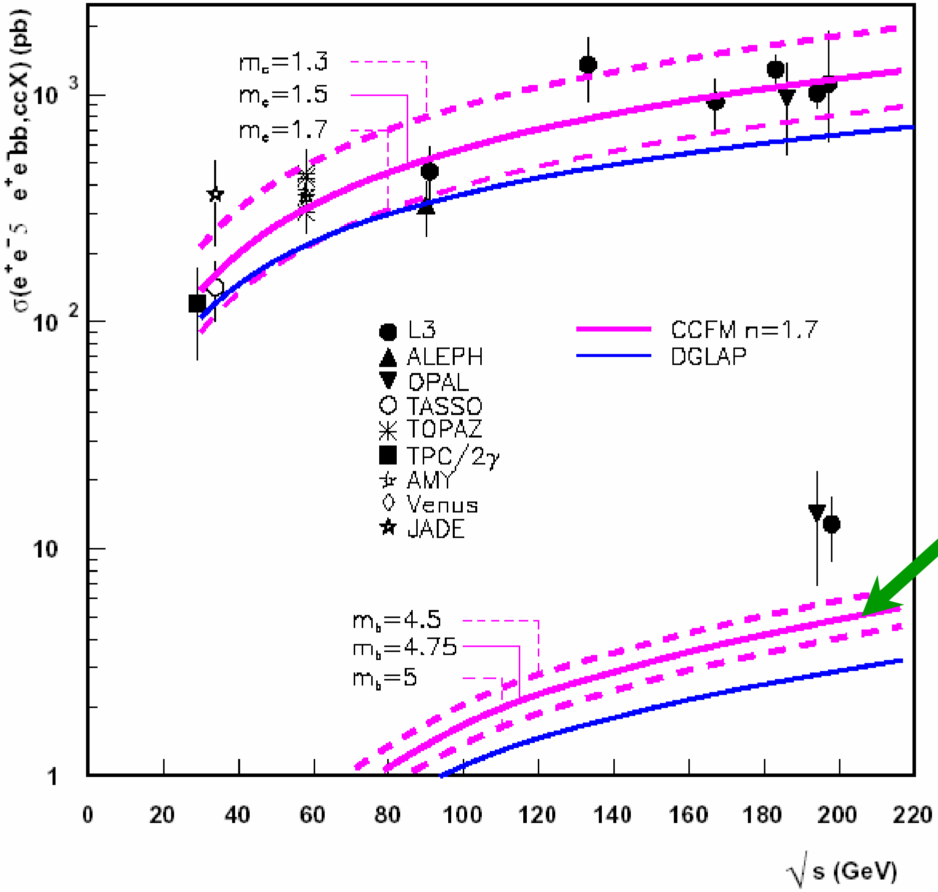
$$\frac{d\sigma_b}{d\hat{p}_T} \simeq \frac{C}{\hat{p}_T^N} \Longrightarrow \frac{d\sigma_B}{dp_T} = \frac{C}{p_T^N} D_N^{b\to B}$$

$$D_N^{b\to B} = \int dz z^{N-1} D^{b\to B}(z;\epsilon)$$

This approximates $d\sigma_B$ fairly well

Those were the good news. Now …

… but wait:
Maybe, you consider the failures better news?
Then here is good (old) news for you:



CASCADE result from Hannes Jung:

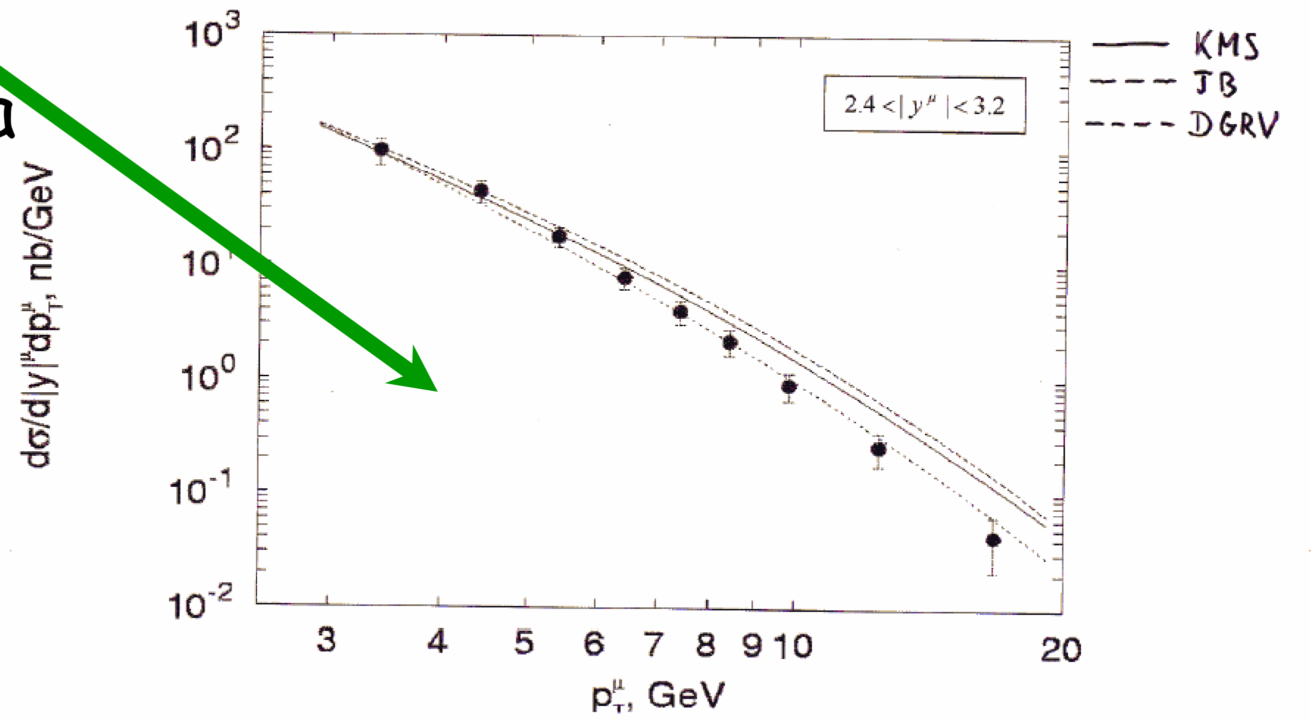
What is going on in $\gamma\gamma$:

•Uncalculated higher order terms ? (Jiri Chyla)

And is there generally room for other dynamics?

•$K_\perp$ factorization ? (Hannes Jung, Anatoly Kotikov, Sergey Baranov,)

For D0 data

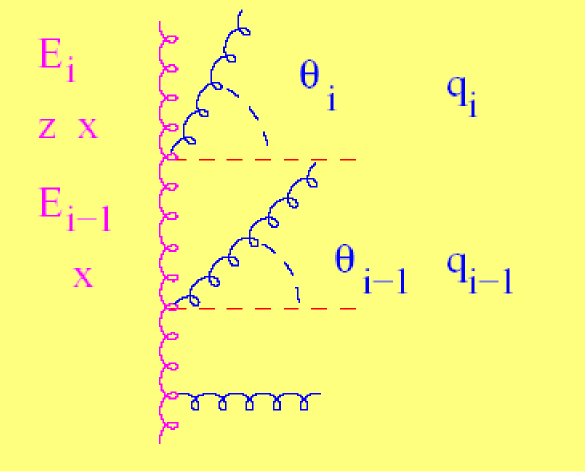


An introduction to $k_\perp$-factorization

Sergey Baranov

1. Gluon off-shellness

QED	QCD
Weizsäcker–Williams (collinear approximation)	Conventional Parton Model gluon density
$F_\gamma(y) = \frac{\alpha}{2\pi y}\left[1+(1-y)^2\right]\ln\frac{s}{4m^2}$	$G(x,\mu^2)$
Equivalent Photon Approx.	Noncollinear = Unintegrated gluon density $\mathcal{F}(x,k_\perp^2,\mu^2)$
$F_\gamma(y,Q^2) = \frac{\alpha}{2\pi y}\frac{1}{Q^2}\left[1+(1-y)^2\right]$	$\int \mathcal{F}(x,k_\perp^2,\mu^2)\,dk_\perp^2 = G(x,\mu^2)$
$Q^2 \simeq k_\perp^2/(1-y)$	



Angularly ordered CASCADE

Hannes Jung

NLO corrections are needed in k_t-factorization approach

Anatloy Kotikov (on F_L^c)

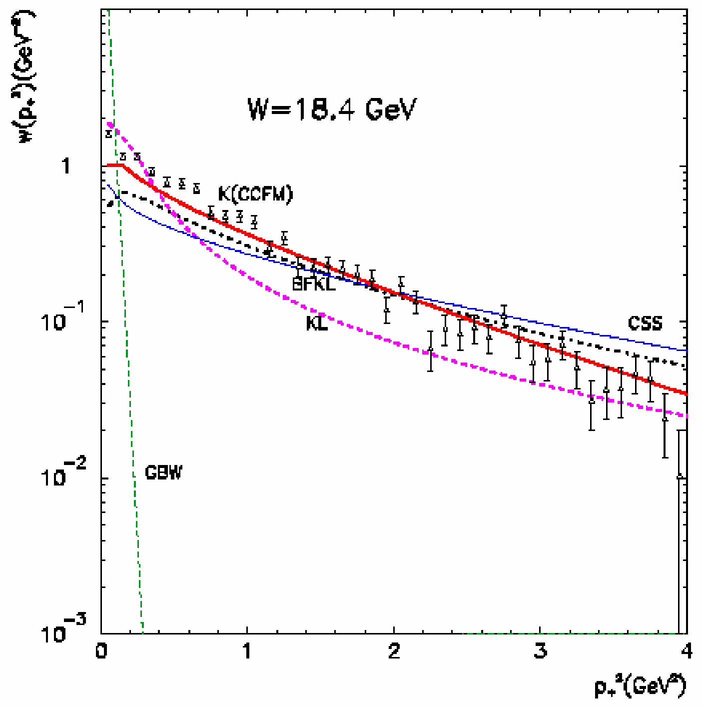
and a global picture – to decide on the significance of terms beyond collinearly factorized pQCD.

Collins & Ellis (1991)

	$\sigma_2[\mu b]$	$\sigma_3[\mu b]$	$\sigma_r[\mu b]$
x^{-1}	12	23	33
$x^{-1.5}$	29	44	51

Correlations: A complementary window to look into HQ production dynamics

Results based on $k_\perp$ factorization.
Again … yes, it does work!
Is it the dynamics or the unintegrated input gluon function?
Comparison with FMRN?

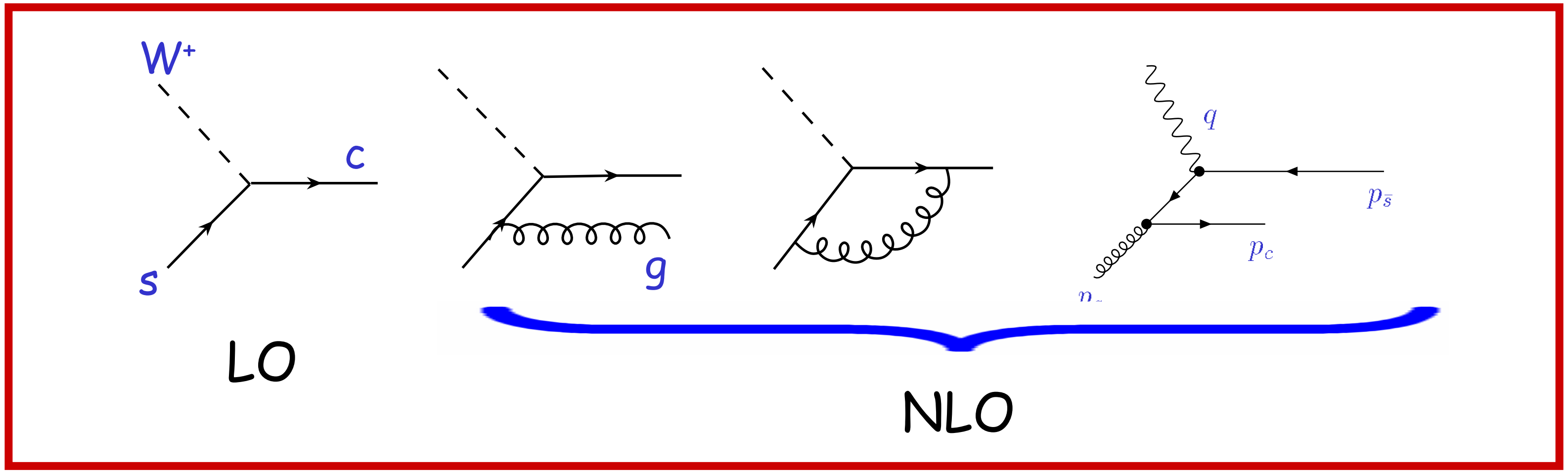


(h)

Figure 6: p_+^2 *distribution of* $c - \bar{c}$.
FOCUS collaboration data

Antoni Szczurek
Sergey Bararnov

Charged Current neutrinoproduction of charm:



SK, Wu-Ki Tung

Implications for precision physics:

$$R^- \simeq \frac{1}{2} - \sin^2\Theta_W - \left(\frac{1}{2} - \frac{7}{6}\sin^2\Theta_W\right)\frac{[S^-]}{[Q^-]} \qquad [S^-] \equiv \int_0^1 dx\; x\,(s-\bar{s})\,(x)$$

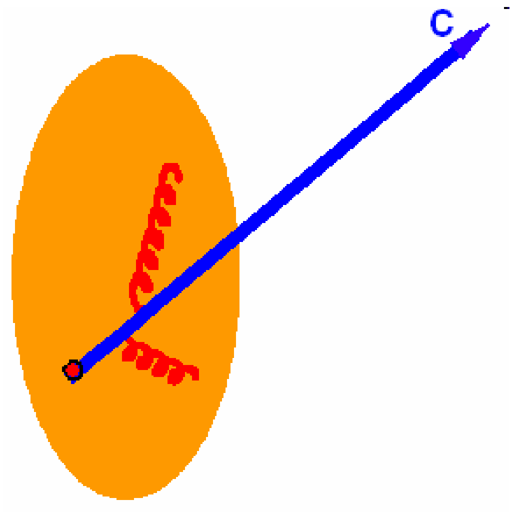
Potential to reduce the "NuTeV anomaly" (3 σ deviation from the SM) substantially.

Another perspective on HQ dynamics:

Heavy Quark Energy Loss in Media

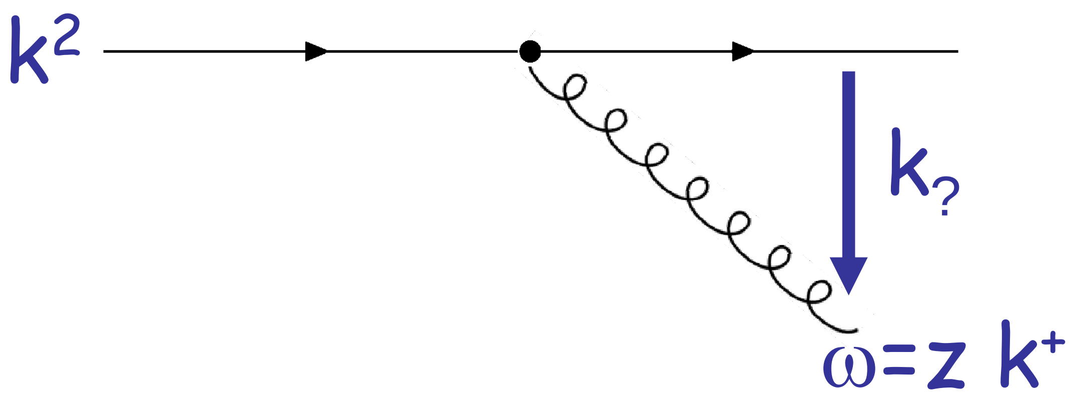
Matthias Grosse Perdekamp (exp.)
on HQ physics at RHIC

Theoretical Work by:
Shuryak
Dokshitzer & Kharzeev
Djordjevic & Gyulassy
Arnesto & Salgado & Wiedemann



The Dead Cone

Y. Dokshitzer



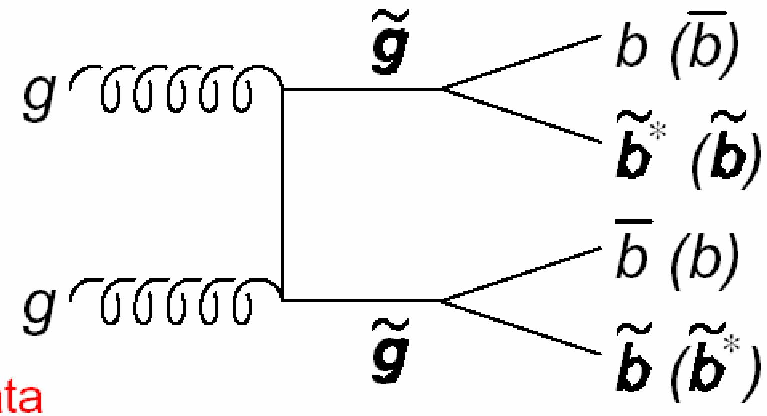
$$\frac{dk^2}{k^2-m^2} = \frac{k_\perp^2\, dk_\perp^2}{(k_\perp^2+z^2m^2)^2} \to 0 \quad \text{as} \quad k_\perp \to 0$$

$$\left.\frac{dk^2}{k^2-m^2}\right|_{m=0} = \frac{dk_\perp^2}{k_\perp^2} \to \infty \quad \text{as} \quad k_\perp \to 0$$

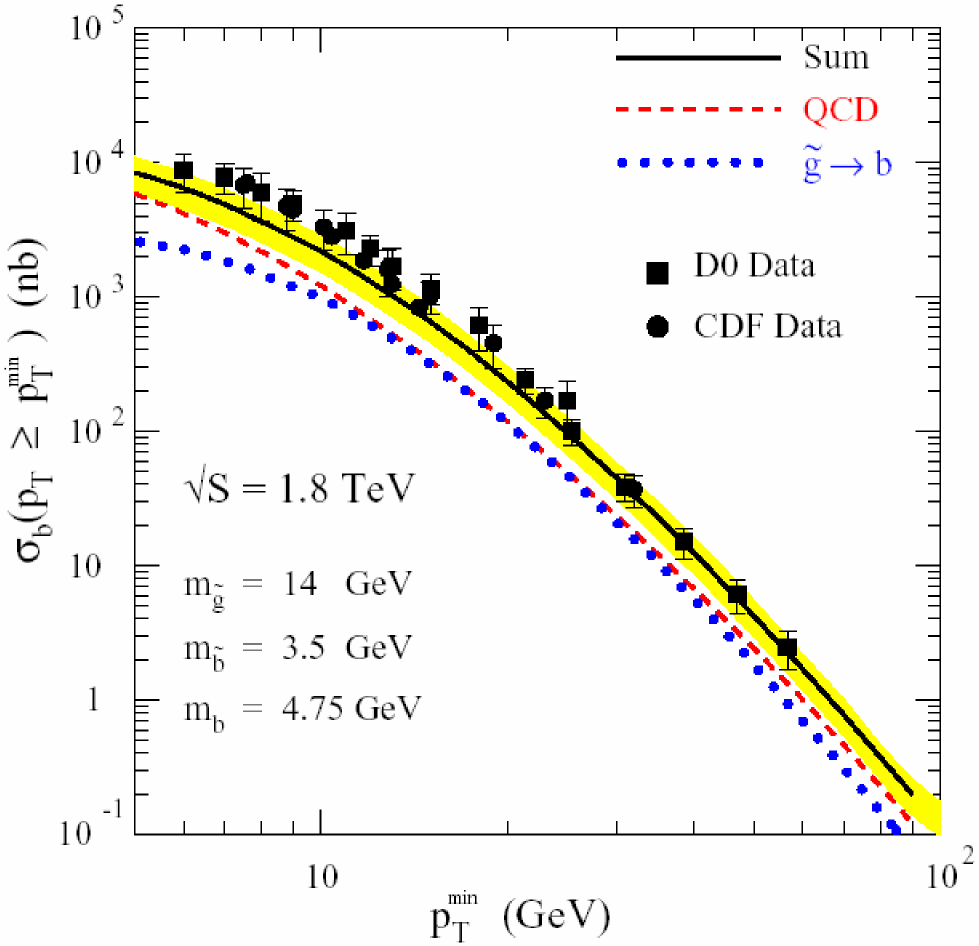
Unheard of!

Thanks (for sending their contributions):
Ed Berger and Maciej Nowak.

Ed Berger



Comparison of with Tevatron Run-I Data



Maciej Nowak (via Andrzej Czarnecki):

Maciej Nowak

Chiral Doublers

Each heavy-light hadron has

- an almost degenerate, different spin, same parity partner (heavy quark symmetry):

$$M\left(D^{*}\right)=M\left(D\right)+O\left(\frac{\Lambda_{\mathrm{QCD}}^{2}}{M_{c}}\right)$$

Isgur & Wise 1991

- a nearby, same spin, opposite parity partner (chiral symmetry):

$$M\left(\Lambda_{c}^{+}(2285)\right)+154\,\mathrm{MeV} \;=\; M\left(\Lambda_{c}(2593)\right)-154\,\mathrm{MeV}$$

Nowak, Rho, Zahed 1992,   Bardeen & Hill 1993

H1 charm Pentaquark(?) at 3099 MeV a chiral doubler of a 2700 MeV state?

Thanks:

Sergei Baranov, Ed Berger, Dusan Bruncko, Jiri Chyla, Karin Daum, Jozef Ferencei, Stefano Frixione, Leonid Gladilin, Hannes Jung, Nikolaos Kidonakis, Anatoly Kotikov, Thomas Mehen, Maciej Nowak, Ingo Schienbein, Antoni Szczurek, Wu-Ki Tung

And here I pass to Leonid Gladilin for his experimental summary …