Working group C summary

Hadronic final states theory

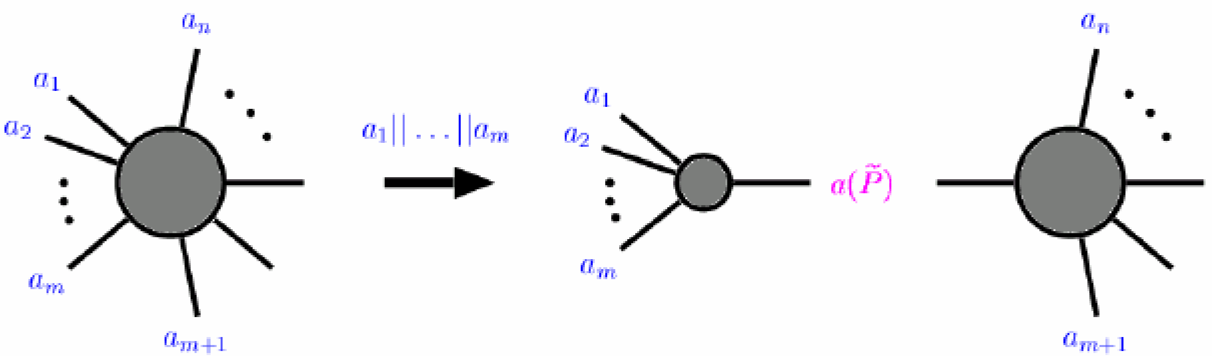
Mrinal Dasgupta

Collinear factorisation in QCD

G.Rodrigo

Understanding multiple collinear limit of QCD important : fixed order calculations, resummations, PDF evolution etc.

Factorisation in colour space : splitting matrix



$$|\mathcal{M}^{(0)}_{a_1,\dots,a_m,a_{m+1},\dots}(p_1,\dots,p_m,p_{m+1},\dots)\rangle \simeq \boldsymbol{Sp}^{(0)}_{a_1\dots a_m}(p_1,\dots,p_m)\ |\mathcal{M}^{(0)}_{a,a_{m+1},\dots}(\widetilde{P},p_{m+1},\dots)\rangle$$

Derivation of one to three splitting functions :

$$\langle \hat{P}^{(0)}_{a_1\cdots a_m} \rangle = \left(\frac{s_{1\ldots m}}{2\,\mu^{2\epsilon}} \right)^{m-1} \overline{|\boldsymbol{Sp}^{(0)}_{a_1\ldots a_m}|^2}$$

$$\langle \hat{P}^{(1)}_{a_1\cdots a_m} \rangle = \left(\frac{s_{1\ldots m}}{2\,\mu^{2\epsilon}} \right)^{m-1} \overline{\left[(\boldsymbol{Sp}^{(0)})^\dagger\, \boldsymbol{Sp}^{(1)} + (\boldsymbol{Sp}^{(1)})^\dagger\, \boldsymbol{Sp}^{(0)} \right]}$$

One-loop splitting matrix

$$\boldsymbol{Sp}^{(1)} = \boldsymbol{Sp}^{(1)\,\mathrm{div.}} + \boldsymbol{Sp}^{(1)\,\mathrm{fin.}}$$

where (unrenormalized)

$$\boldsymbol{Sp}^{(1)\,\mathrm{div.}}(p_1,\ldots,p_m) = \frac{S_\epsilon}{2} \left\{ \frac{1}{\epsilon^2} \sum_{i,j=1(i\neq j)}^{m} \boldsymbol{T}_i \cdot \boldsymbol{T}_j \left(\frac{-s_{ij} - i0}{\mu^2} \right)^{-\epsilon} \right.$$

$$+ \left(\frac{-s_{1\ldots m} - i0}{\mu^2} \right)^{-\epsilon} \left[\frac{1}{\epsilon^2} \sum_{i,j=1}^{m} \boldsymbol{T}_i \cdot \boldsymbol{T}_j \, \left(2 - (z_i)^{-\epsilon} - (z_j)^{-\epsilon} \right) \right.$$

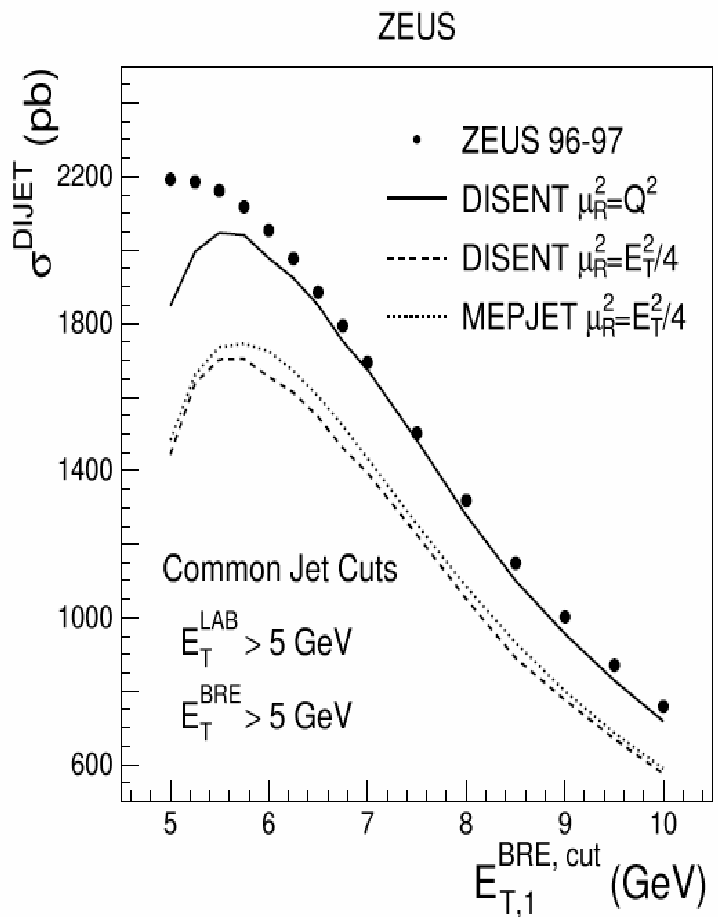
$$\left. \left. -\frac{1}{\epsilon} \left(\sum_{i=1}^{m} (\gamma_i - \epsilon \tilde{\gamma}_i^{\mathrm{R.S.}}) - (\gamma_a - \epsilon \tilde{\gamma}_a^{\mathrm{R.S.}}) - \frac{m-1}{2} (\beta_0 - \epsilon \tilde{\beta}_0^{\mathrm{R.S.}}) \right) \right] \right\}$$

$$\times \boldsymbol{Sp}^{(0)}(p_1,\ldots,p_m)$$

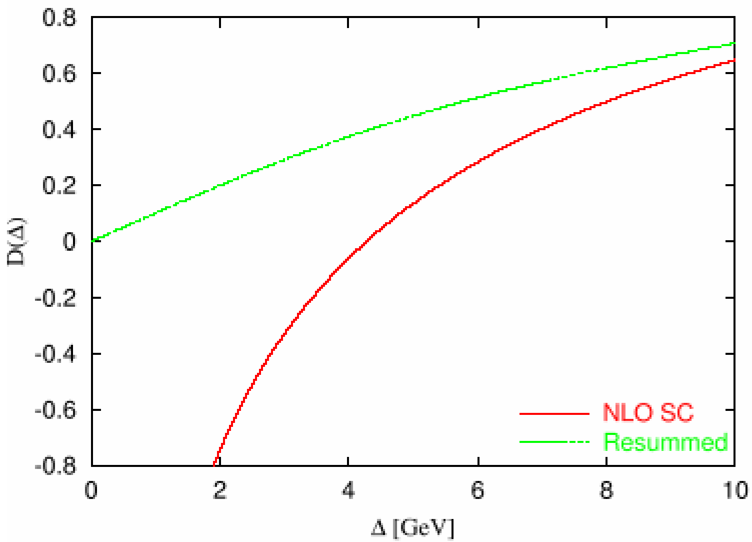
Dijet rates with symmetric Et cuts

A.Banfi

Resummation is potentially very instructive : multiparton and involving jet definition



$$W(\Delta) = \int_{-\infty}^{\infty} dk_x\, U(k_x)\, \Theta(\Delta - |k_x|) = \frac{2}{\pi} \int_0^{\infty} \frac{db}{b} \sin(b\Delta)\, \Sigma(b)$$



$$\Sigma(b) = e^{L\underbrace{g_1(\alpha_s L)}_{\mathrm{LL}} + \underbrace{g_2(\alpha_s L)}_{\mathrm{NLL}}} = \underbrace{\frac{f_{p/P}(Q/b)}{f_{p/P}(Q)} \cdot e^{-R(b)}}_{\mathrm{global}} \cdot \underbrace{S(b)}_{\mathrm{non-global}} \qquad L = \ln b$$

Work in progress involves matching to fixed NLO and understanding resummation effects with different algorithms (NLL terms).

Sudakov logs and power corrections

Lorenzo Magnea

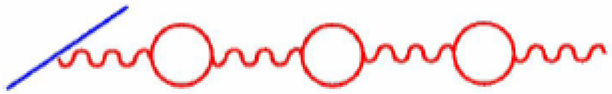
Power corrections to event shape distributions :

$$S_{\rm NP}(\nu/Q,\mu) = \int_0^{\mu^2} \frac{dq^2}{q^2} A\left(\alpha_s(q^2)\right) \int_{q^2/Q^2}^{q/Q} \frac{du}{u} \left({\rm e}^{-u\nu} - 1\right)$$
$$= \sum_{n=1}^{\infty} \frac{1}{n!} \left(\frac{\nu}{Q}\right)^n \lambda_n(\mu^2) \; ,$$

Dokshitzer-Webber approach is to shift the perturbative distribution by an amount proportional to 1/Q. Approximation works over large range but for very small values would break down. Need shape function ansatz (Korchemsky and Sterman)

It is possible to combine renormalon methods and Sudakov resummation to construct models of power corrections. One method is dressed gluon exponentiation (Gardi).

- Step 1: compute characteristic function $\mathcal{F}(k^2)$ of the dispersive method in the Sudakov limit (resum "bubble graphs").



- Step 2: use dressed gluon distribution as kernel of exponentiation.

$$\ln\left(\frac{d\tilde{\sigma}}{d\nu}\Big|_{DGE}\right) = \int_0^\infty d\tau\, \frac{d\sigma}{d\tau}\Big|_{SDG}\left(1 - e^{-\nu\tau}\right) \ .$$

- Step 3: Borel representation of the exponent suggests pattern of power corrections.

Exponentiated renormalons

Results are summarized by the exponentiated Borel function.

$$S\left(\nu, Q^2\right) = \frac{C_F}{2\beta_0} \int_0^\infty du \, \left(Q^2/\Lambda^2\right)^{-u} \, B_c(\nu, u) \, .$$

- For the C-parameter

$$\begin{aligned} B_c(\nu, u) \; &= \; 2\, \mathrm{e}^{5u/3} \, \frac{\sin \pi u}{\pi u} \, \left[\Gamma(-2u) \left(\nu^{2u} - 1\right) 2^{1-2u} \frac{\sqrt{\pi}\,\Gamma(u)}{\Gamma(\frac{1}{2} + u)} \right. \\ &- \; \left. \Gamma(-u) \left(\nu^u - 1\right) \left(\frac{2}{u} + \frac{1}{1-u} + \frac{1}{2-u} \right) \right] \, . \end{aligned}$$

- Renormalons from wide angle soft radiation $u = m/2$, $m\,\mathrm{odd}$, corresponding to leading power corrections $(\nu/Q)^m$. NOTE: Even powers absent in the large n_f inclusive approximation.

- Definition: $\tau_a = \frac{1}{Q} \sum_i (p_\perp)_i \mathrm{e}^{-|\eta_i|(1-a)}$.

  Also: $\tau_a = \frac{1}{Q} \sum_i \omega_i (\sin\theta_i)^a (1 - |\cos\theta_i|)^{1-a}$,
- Some properties
  - $\tau_0 = t$; $\tau_1 = B$.
  - $a \leq 2$ for IR safety.
  - $a \leq 1$ for feasibility of resummation.

- In the shape function language

$$\ln\left[S_{\mathrm{NP}}^{(a)}(\nu/Q,\mu)\right] = \frac{1}{1-a} \ln\left[S_{\mathrm{NP}}^{(0)}(\nu/Q,\mu)\right] ,$$

in principle, a testable prediction.

Computer automated resummations

Gavin Salam

Hybrid analytical & numerical

- Derive, analytically, a resummed result, for a *general observable*, in terms of clearly identifiable properties of that observable.
- Derive associated *applicability conditions* to ensure that result is applied only to observables for which it is valid.
- Use computer subroutine for observable & high-precision *numerics* to
  - test applicability conditions
  - determine observable-specific ‘properties’ needed for the explicit resummed answer.

Computer Automated Expert Semi-Analytical Resummation (CAESAR)

- Observable must have standard functional form for soft & collinear gluon emission

$$V(\{p\}, k) = d_\ell \left(\frac{k_t}{Q}\right)^{a_\ell} e^{-b_\ell \eta} g_\ell(\phi) \,.$$

Born momenta — soft collinear emission

- *Determine coefficients* a_ℓ, b_ℓ, d_ℓ and $g_\ell(\phi)$ for emissions close to each hard Born parton (leg) ℓ.

- Require *continuous globalness*, *i.e.* uniform dependence on k_t independently of emission direction ($a_1 = a_2 = \cdots = a$)

$$\left[\lim_{\epsilon\to 0}, \lim_{\epsilon'\to 0}\right] \frac{1}{\epsilon} V(\{p\}, \epsilon k_1, \epsilon' \epsilon k_2, \ldots) = 0$$

Recursive IRC safety

With all the information in place :

$$\ln \Sigma(v) = -\sum_{\ell=1}^{n} C_\ell \left[r_\ell(v) + r'_\ell(v) \left(\ln \bar{d}_\ell - b_\ell \ln \frac{2E_\ell}{Q} \right) + B_\ell T\left(\frac{\ln 1/v}{a+b_\ell} \right) \right] + \sum_{\ell=1}^{n_i} \ln \frac{f_\ell(x_\ell, v^{\frac{2}{a+b_\ell}} \mu_f^2)}{f_\ell(x_\ell, \mu_f^2)} + \ln S\left(T\left(\frac{\ln 1/v}{a} \right) \right) + \ln \mathcal{F}(C_1 r'_1, \ldots, C_n r'_n) \,,$$

C_ℓ = colour factor (C_F or C_A), $f_\ell(x_\ell, \mu_f^2)$ = parton distributions

$$r_\ell(L) = \int_{v^{\frac{2}{a}} Q^2}^{v^{\frac{2}{a+b_\ell}} Q^2} \frac{dk_t^2}{k_t^2} \frac{\alpha_s(k_t)}{\pi} \ln \left(\frac{k_t}{v^{1/a} Q} \right)^{a/b_\ell} + \int_{v^{\frac{2}{a+b_\ell}} Q^2}^{Q^2} \frac{dk_t^2}{k_t^2} \frac{\alpha_s(k_t)}{\pi} \ln \frac{Q}{k_t} \,,$$

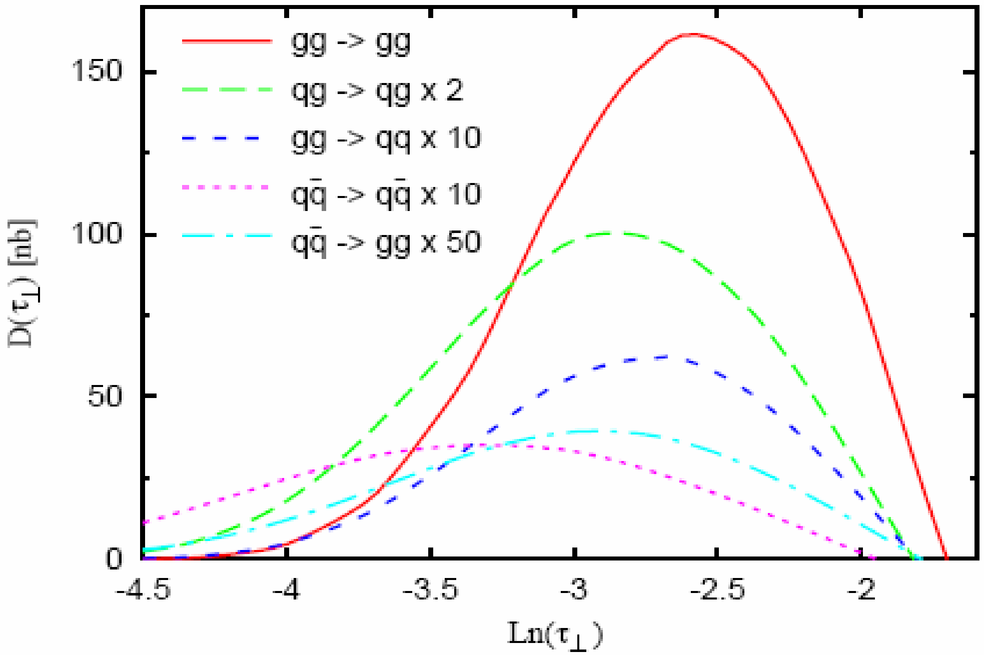
$S(T(\frac{1}{a} \ln 1/v))$ = large-angle logarithms (process dependence)

Example : Transverse thrust at the Tevatron

run II regime $\sqrt{s} = 1.96$ TeV

- cut on rapidity $|\eta| < 1$

cut on jet transverse energy $E_T > 50$GeV



PRELIMINARY!

Monte Carlo models at the LHC

Frank Krauss

The need for event generators

Physics demands:

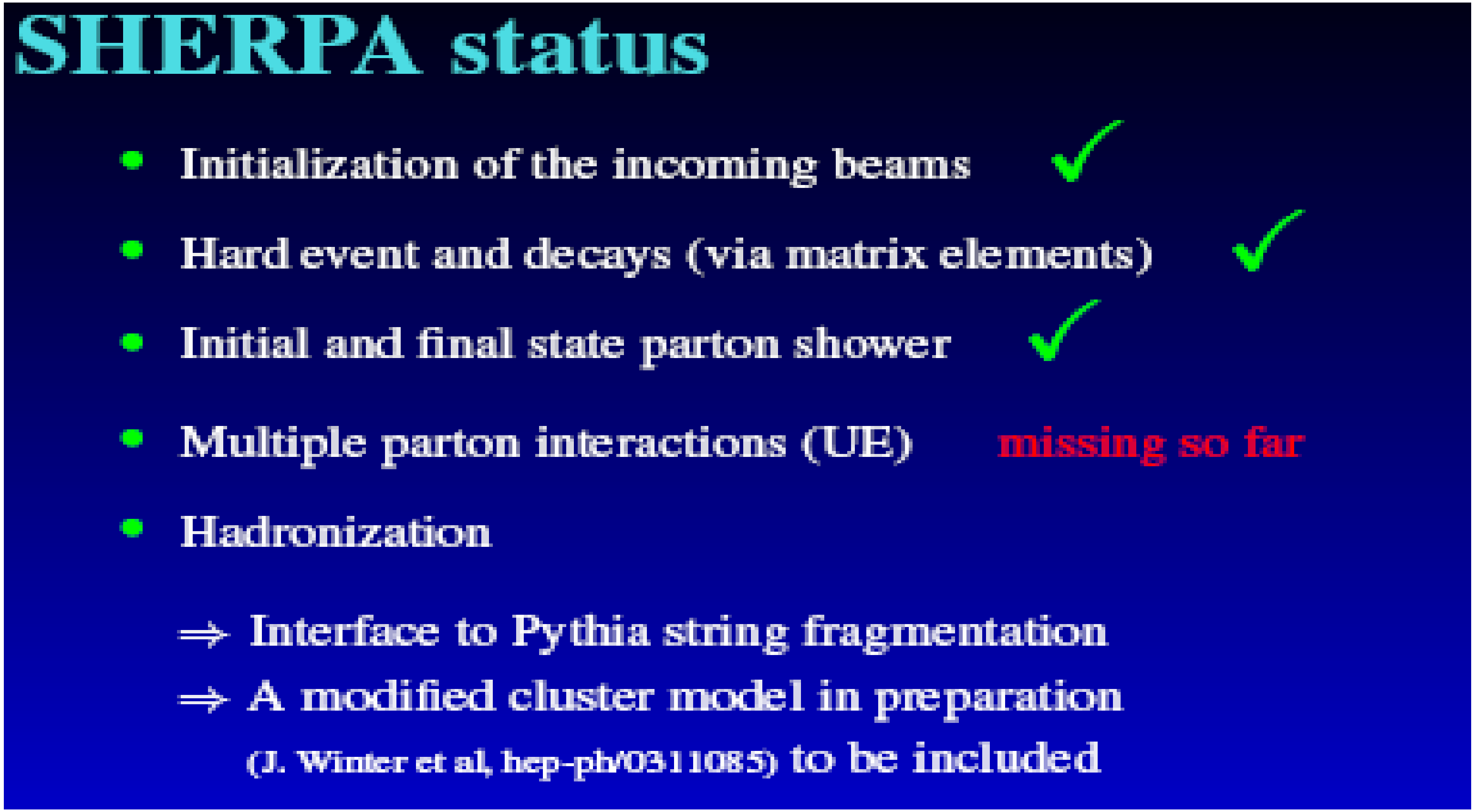
1. Signals for new physics: (n)MSSM, extra dimensions . . .
2. Good treatment of backgrounds: SM physics
3. Different ME's, PDF's etc.
4. Model the underlying event
5. Different fragmentation schemes
6. Hadron decays a la PDG

The need for event generators

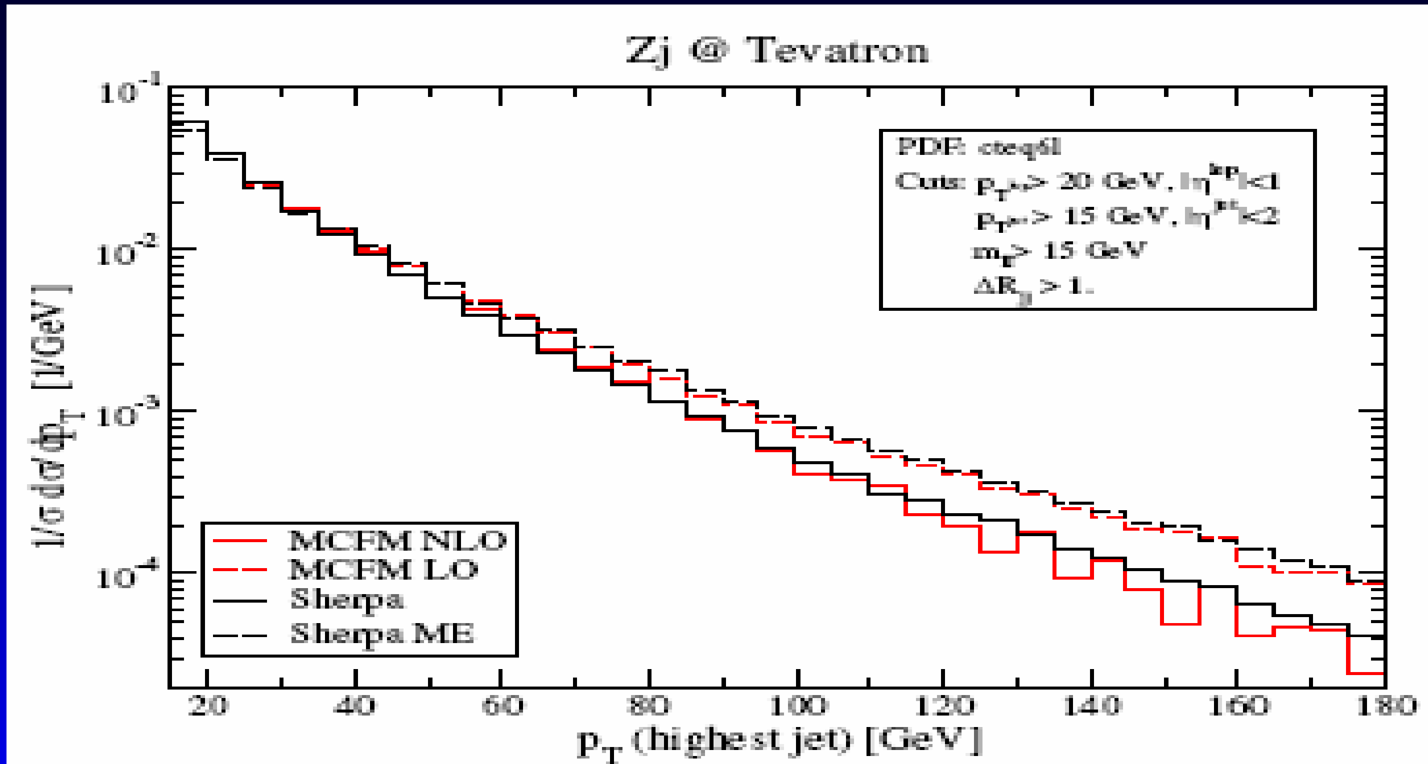
Computing demands:

1. Transparency - maintenance becomes an issue!
2. Modularity for checks & simple replacements
3. Extensibility for new models etc.
4. Fast - for quick checks
5. Object–oriented language (the new paradigm)

New event generators : SHERPA



Results: CKKW vs. NLO (I)

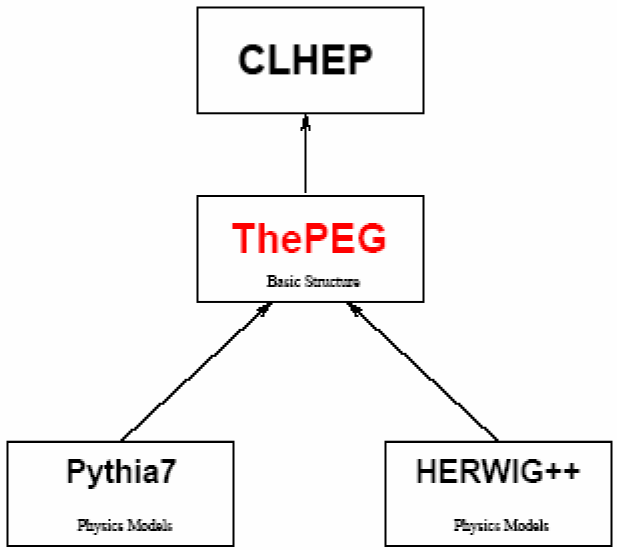


THEPEG, Pythia7 and ARIADNE

- Leif Lonnblad

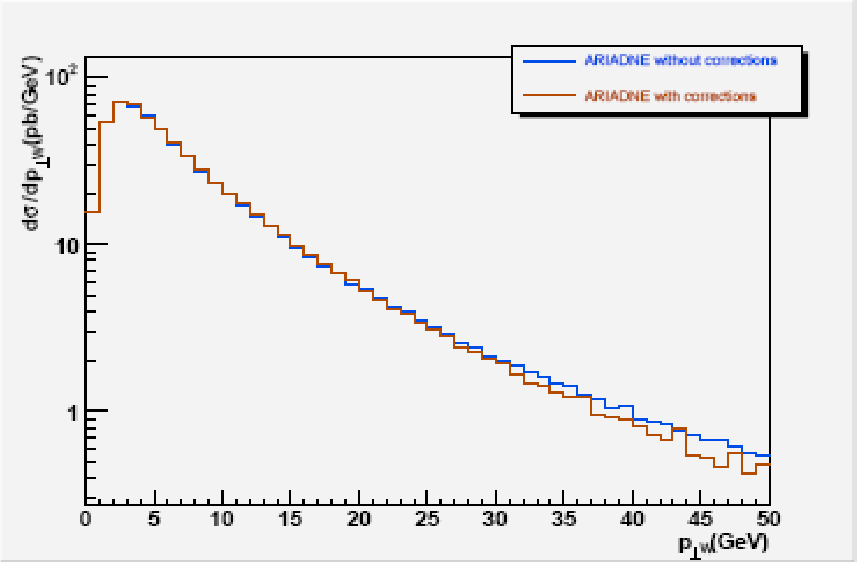
THEPEG is a general and modular C++ framework for implementing event generator models.

Both PYTHIA7 and HERWIG++ are built on THEPEG.

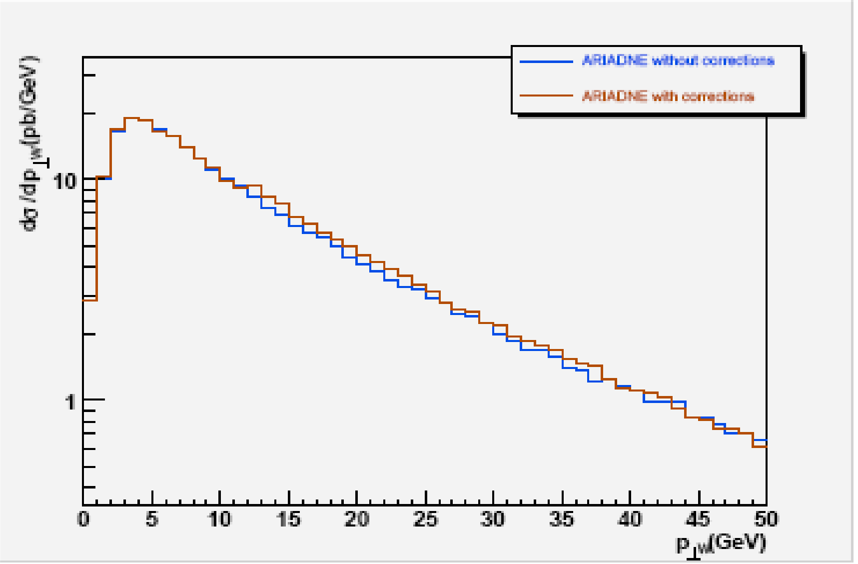


ME +PS matching in Ariadne

W production at the Tevatron :



$q\bar{q}' \to W g$



$qg \to W q'$

- Basic infrastructure: Smart pointers, extended type information, object persistency, Exceptions, Dynamic loading, ...
- Kinematics: Extra utilities on top of CLHEP vectors, 5-vectors, flat n-body decay, ...should be moved to CLHEP.
- Repository: Manipulation of interfaced objects. Setting of parameters and switches and connecting objects together.
- Handler classes: to inherit from to implement a specific physics model.
- Event record: Used to communicate between handler classes.
- Particle data: particle properties, decay tables, decayers etc...

The new event generator HERWIG++

- Stefan Gieseke

New parton shower , different evolution variable

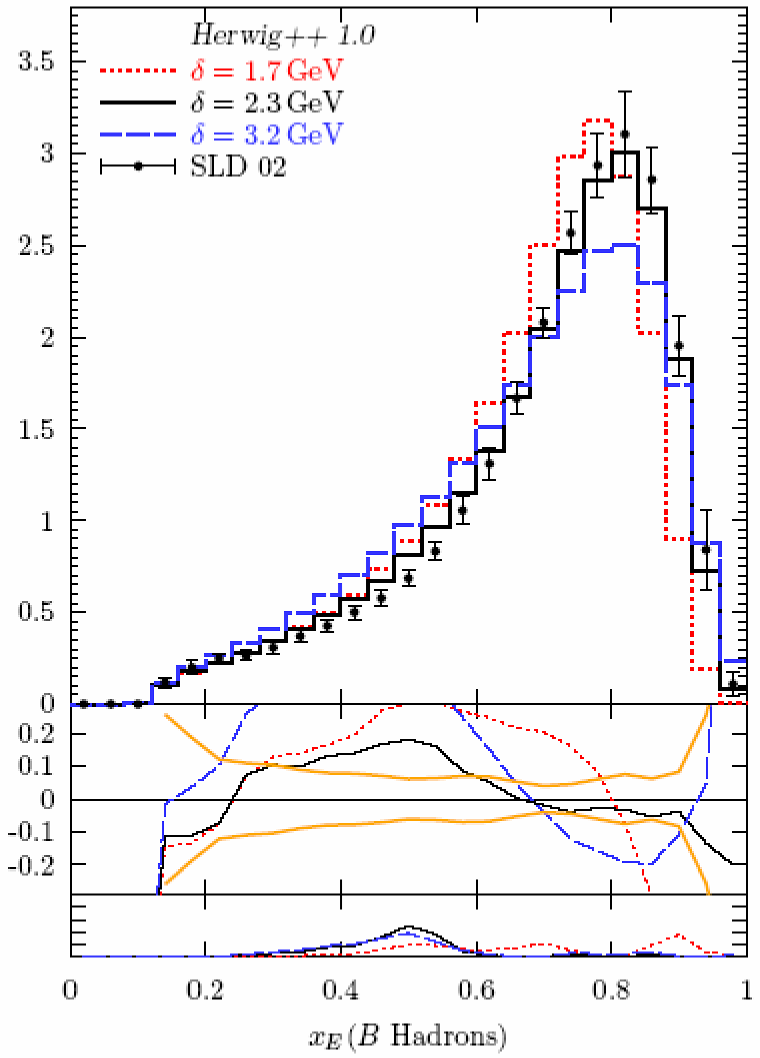
Collinear limit for radiation off heavy quark,

$$P_{gq}(z, \boldsymbol{q}^2, m^2) = C_F \left[\frac{1+z^2}{1-z} - \frac{2z(1-z)m^2}{\boldsymbol{q}^2 + (1-z)^2 m^2} \right]$$

$$= \frac{C_F}{1-z} \left[1 + z^2 - \frac{2m^2}{z\tilde{q}^2} \right]$$

Better coverage of soft gluon phase space

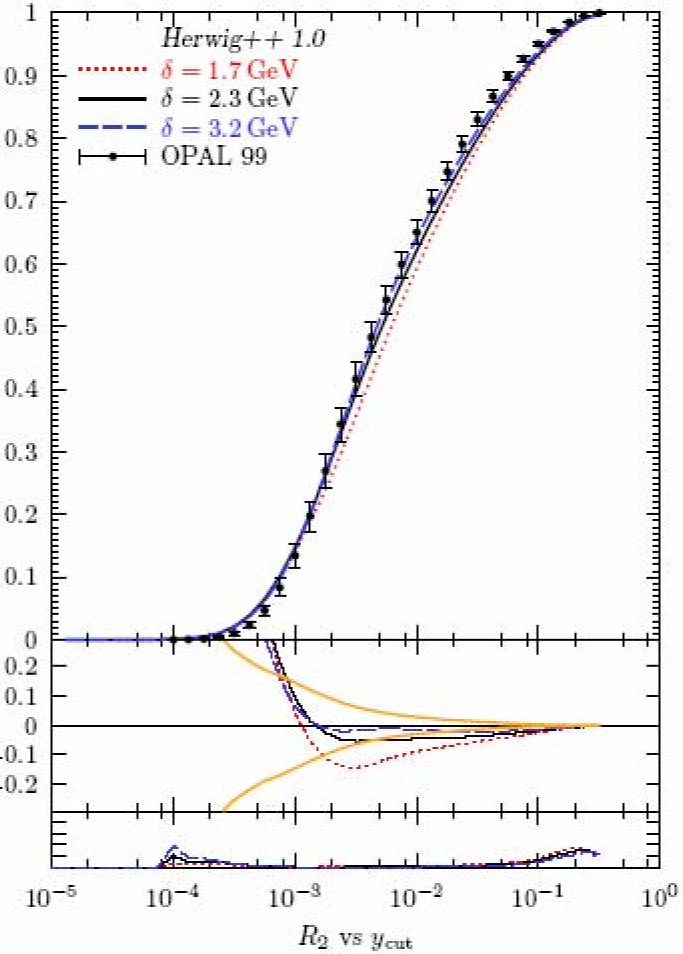
B fragmentation function

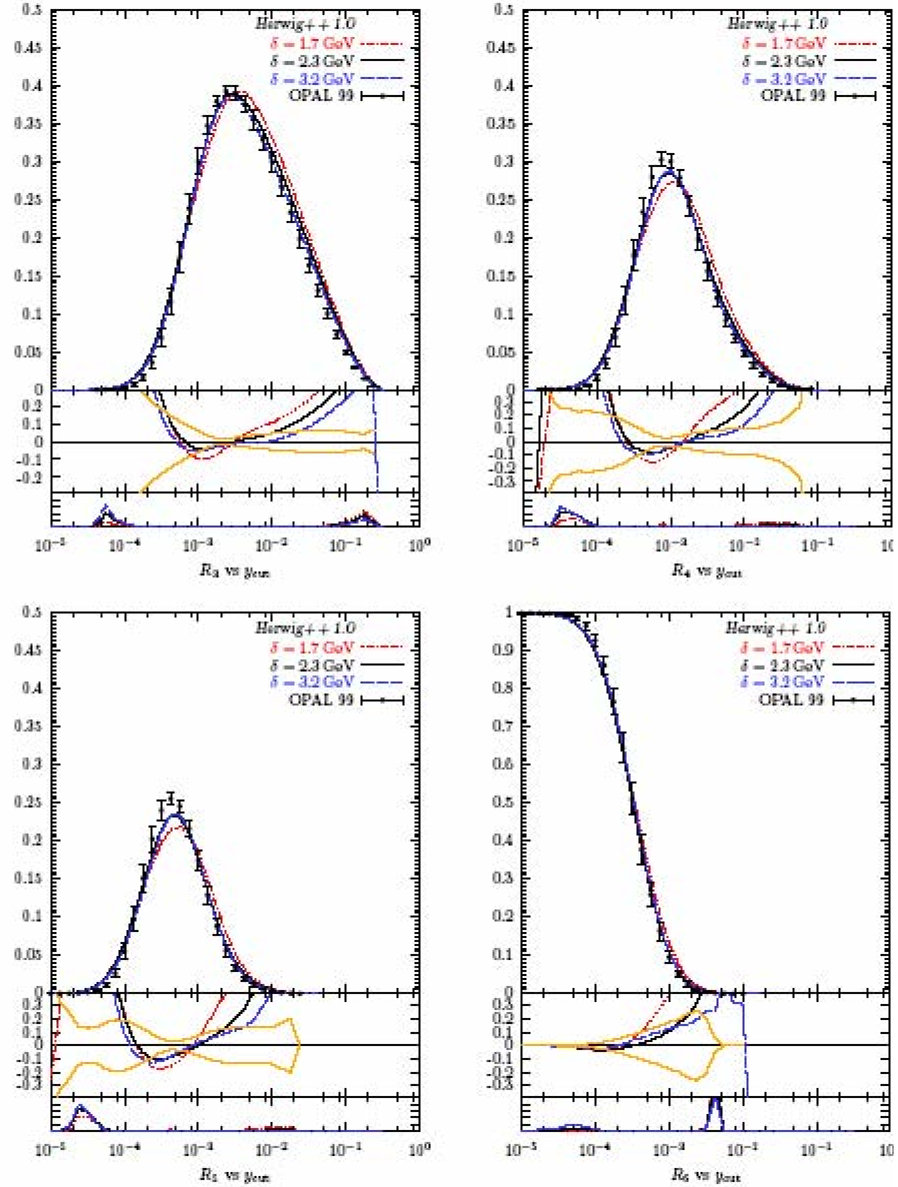


Only parton shower parameters varied!

$$R_n = \sigma(n\text{–jets})/\sigma(\text{jets}) \qquad (n = 2..5)$$

$$R_6 = \sigma(> 5\text{–jets})/\sigma(\text{jets})$$





Photon production at hadron colliders

NLO codes

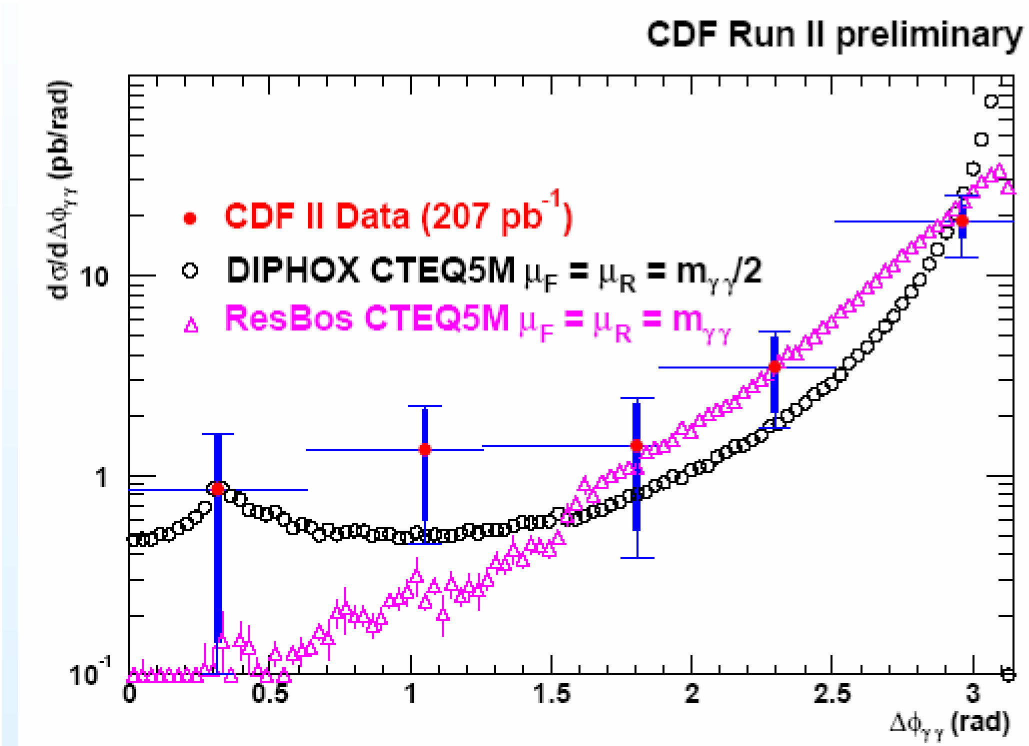
	type of code	Direct	Fragmentation
INCNLO (*)	I/FO	NLO	NLO
Vogelsang, Gordon (*)	I/FO	NLO	NLO
Owens et al. (*)	G/FO	NLO	LO
Frixione, Vogelsang	G/FO	NLO	LO
JETPHOX (*)	G/FO	NLO	NLO

I : Inclusive
G : Generator
FO : Fixed Order

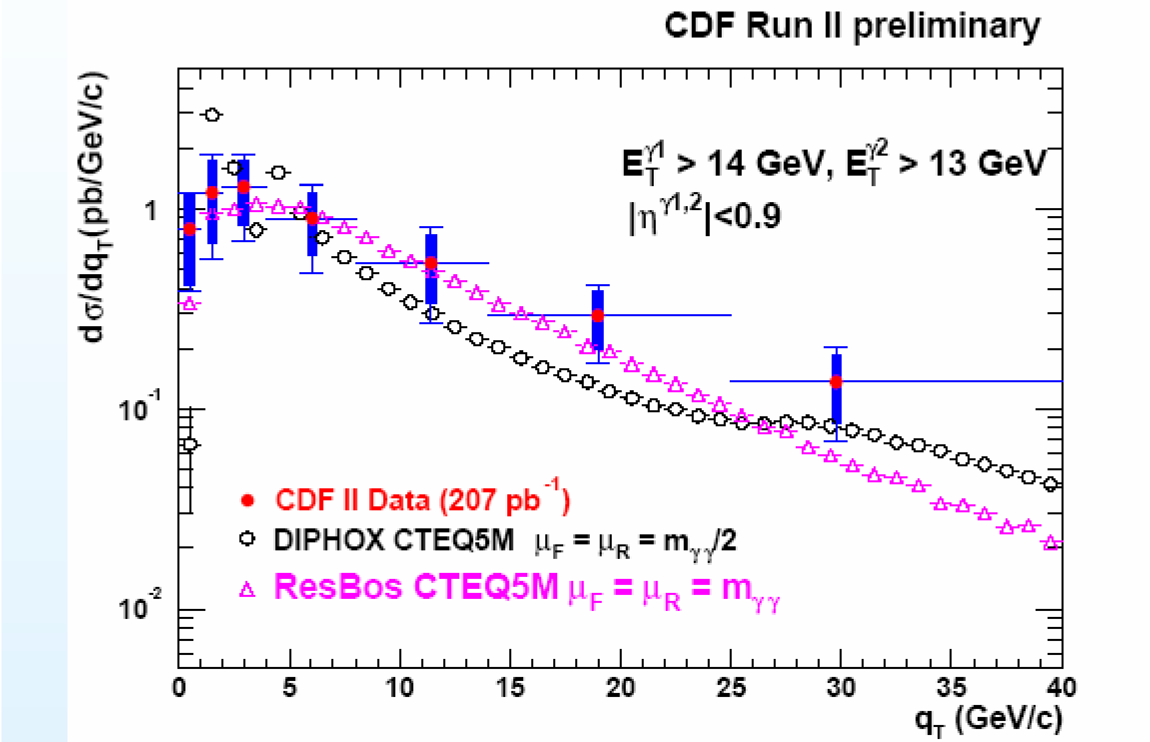
(*) http://wwwlapp.in2p3.fr/lapth/PHOX_FAMILY/main.html

Threshold resummation: (*) Catani et al.
(*) Kidonakis, Owens

- Azimuthal angle distribution



- Gamma pair Qt distribution



- Needs for new data on inclusive photon production (RHIC, RUNII)
- Two photon production at Tevatron is understood, waiting for LHC