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Summary of WG2: Multi-jet Final States and Energy Flows

- Underlying events
- Underlying events in DIS
- Gap-survival and factorization breaking
- Factorization breaking in gamma-p
- Exclusive diffractive production
- Jet production
- Unintegrated PDFs
- Resummation
- ME-PS matching
- Future development of parton showers

DESY
2005.03.23
Leif Lönnblad

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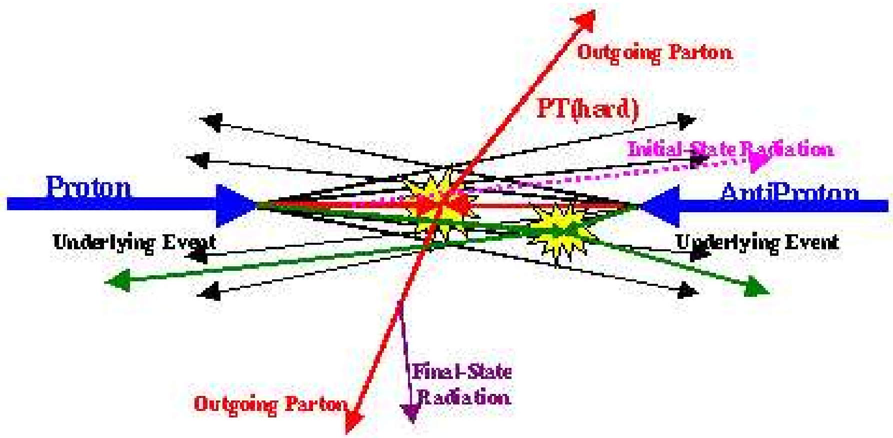
Jon Butterworth, Craig Buttar, Valery Khoze, Niels Tuning

my sincerest apologies

Underlying events

Talks by: Jon Butterworth, Mike Seymour, Elzbieta Richter-Was, Arthur Moraes, Paul Szczypka, Ben Waugh, Günter Grindhammer, Niels Tuning, Rick Field, Victor Lendermann, Stefan Hoeche, Torbjörn Sjöstrand, Aliosha Kaidalov, Konstantin Boreskov, Jochen Bartels, . . .



What is the Underlying event?

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Everything except the LO process we're currently interested in.

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- Parton Showers?
- Additional remnant–remnant interactions?
- Pile-up events?

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Everything except the LO process we're currently interested in.

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- Additional remnant–remnant interactions?
- Pile-up events?

The parton evolution typically includes physics we want to look at.
Pile-up events we can typically get rid of.

Underlying event $\equiv$
additional (partonic) remnant–remnant interactions (MI).

There are lots of models for MI.

Theoretical models: Tel Aviv, Durham, ... (Maor, Kaidalov)

Event Generator models: PYTHIA, JIMMY/HERWIG, SHERPA, ... (Sjöstrand, Butterworth/Seymour, Höche)

All of them have a similar philosophy, relating the rise of the total cross-section with the unitarization/eikonalization of basic leading order interactions, using partons or pomerons

E.g. look at the basic perturbative partonic cross section

$$\sigma_{\rm hard}(p_{\perp\rm min}^2) = \int_{p_{\perp\rm min}^2} \frac{d\sigma_{\rm hard}(p_\perp^2)}{dp_\perp^2} dp_\perp^2$$

Diverges faster than $1/p_{\perp\rm min}^4$ as $p_{\perp\rm min}^2 \to 0$ and eventually exceeds the total inelastic (non-diffractive) cross section. Clearly we have multiple partonic scattering in each event.

The average number of scatterings are given by

$$\langle n \rangle = \sigma_{\rm hard}(p_{\perp\rm min})/\sigma_{\rm nd}$$

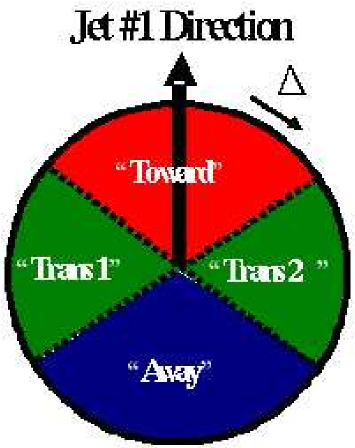
Note that it depends on how to treat the soft interactions.

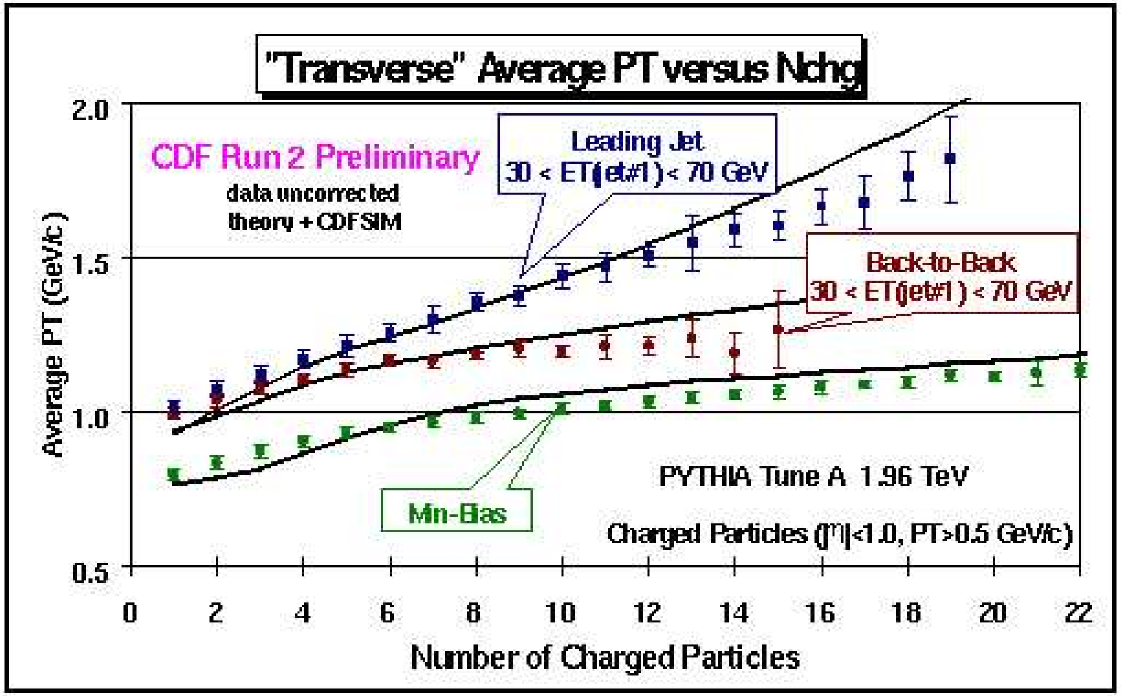
Eikonalization gives

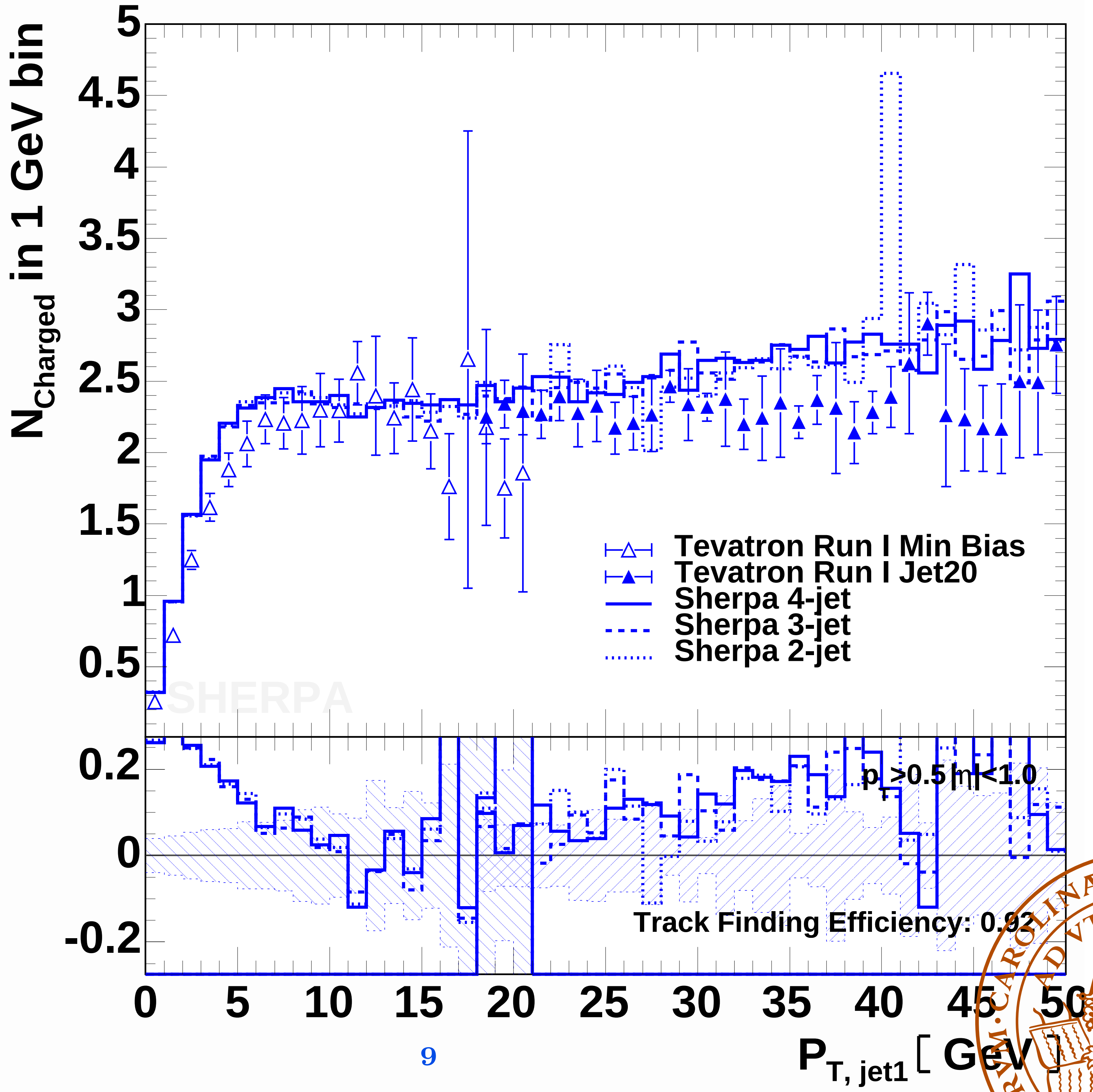
$$\frac{dP_{\text{hardest}}(b, p_\perp^2)}{d^2b\, dp_\perp^2} \propto e(b)\frac{d\sigma(p_\perp^2)}{dp_\perp^2} \exp\left\{-\int_{p_\perp^2} e(b)\frac{d\sigma(p_\perp^{\prime 2})}{dp_\perp^{\prime 2}} dp_\perp^{\prime 2}\right\}$$

Also depends on the overlap function $e(b)$. Influences the distribution in number of MI.

We need to tune these models. (Field, Moraes, Rodrigues, . . .)


Jet #1 Direction
Δ
"Toward"
"Trans 1"
"Trans 2"
"Away"


"Transverse" Average PT versus Nchg
CDF Run 2 Preliminary
data uncorrected
theory + CDFSIM
Leading Jet
30 < ET(jet#1) < 70 GeV
Back-to-Back
30 < ET(jet#1) < 70 GeV
Min-Bias
PYTHIA Tune A 1.96 TeV
Charged Particles (|η|<1.0, PT>0.5 GeV/c)
Average PT (GeV/c)
Number of Charged Particles
2.0
1.5
1.0
0.5
0
2
4
6
8
10
12
14
16
18
20
22



$N_{Charged}$ in 1 GeV bin
Tevatron Run I Min Bias
Tevatron Run I Jet20
Sherpa 4-jet
Sherpa 3-jet
Sherpa 2-jet
SHERPA
p_T>0.5 |η|<1.0
Track Finding Efficiency: 0.92
$P_{T, jet1}$ [GeV]

Why do we need to understand UE/MI at LHC? Can't we just subtract a GeV or two from each jet?

Most models agree approximately on average number of MI and average extra multiplicity. Important for LHCb

But there are fluctuations. Indications of non-Poissonian distribution of MI. Also, the UE is *jetty*.

The large energy at LHC means many MI and the probability of them not being perturbative interactions is small.

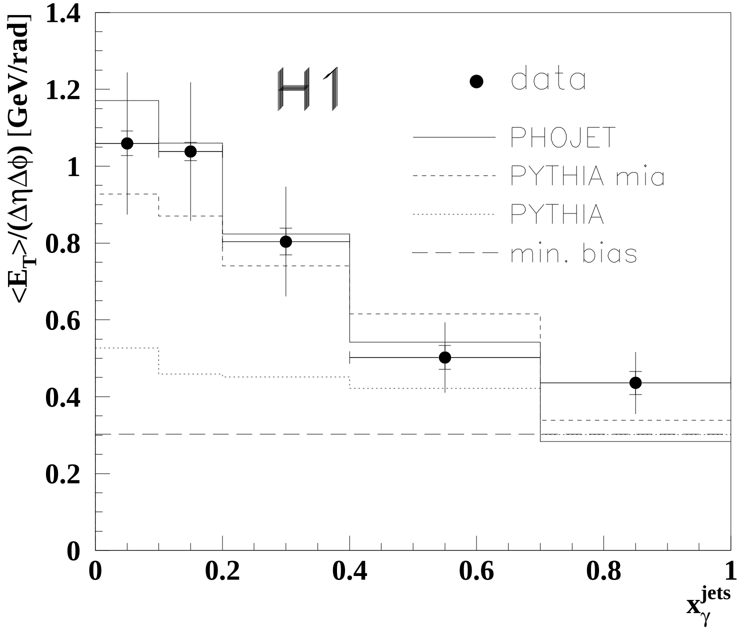
Multiple Interactions will destroy gaps

Most models agree approximately on the size of the *gap-survival probabilities* at LHC

What is the connection with HERA?

In photo-production we have effectively a hadron–hadron collision, and there may be multiple interactions.

Clear evidence for UE for resolved (low x_γ), no evidence for direct (high x_γ)



Can we learn more about MI by being able to switch it on/off and using the variable γ-p energy at HERA? Or is the extra complication from having a photon obscuring things?

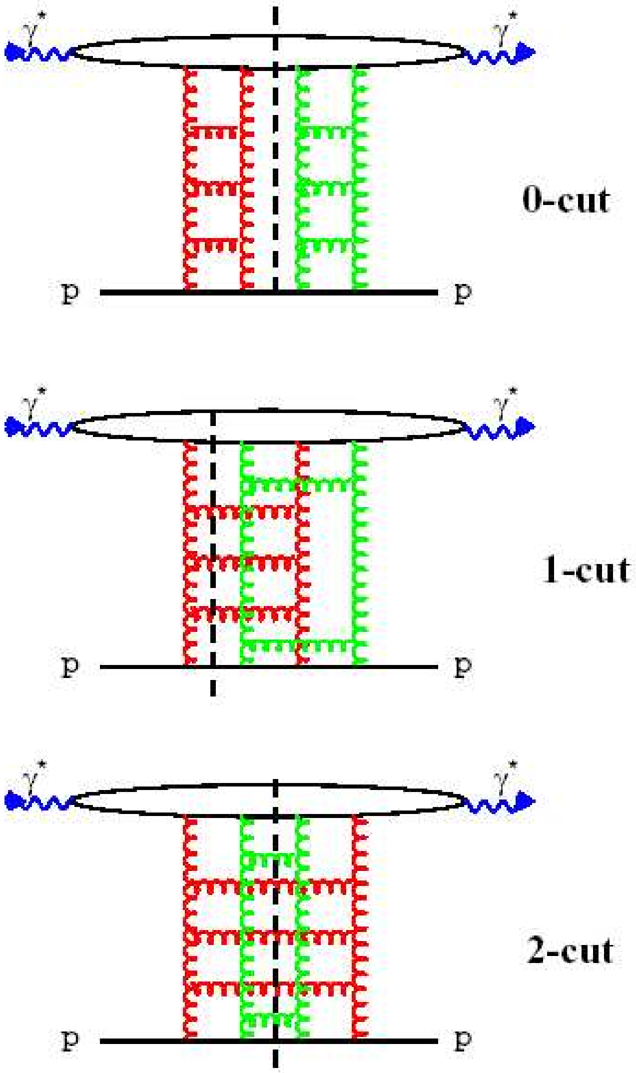
How about gap-survival probability in eg. diffractive photo-production of di-jets? Probability 1 for high x_γ, smaller for low x_γ?

Underlying events in DIS

Talks by: Agustin Sabio-Vera, Henri Kowalski, Jochen Bratels, Jacek Turnau, . . .

Multiple interactions, Diffraction and Saturation are intimately connected.

In DIS we know we have diffraction, we have seen saturation (perturbative?). Maybe there are also multiple interactions in DIS.



AGK cutting rules developed before QCD to cut pomerons. Now we cut gluon ladders.

To leading order in $1/N_c$ the result is the same: The same amplitude for all cut with factors

$+1$ Diffraction

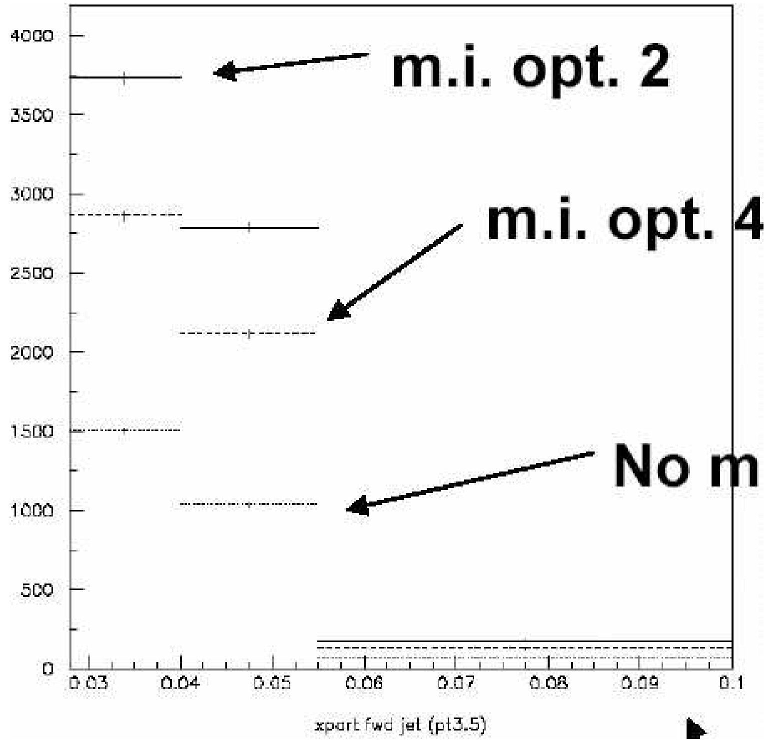
-4 Saturation

$+2$ Multiple interactions

But QCD cuts can be more complicated . . .

[Bartels, Kowalski, Sabio-Vera]

Resolved virtual photons (low x_γ) is achieved in forward jets. Underlying events will add extra radiation under the jet, boosting the jet rate.



Surely important to understand perturbative saturation. But is it useful for LHC?

[Turnau]

Jet production

Talks by: Jacek Turnau, Jeppe Andersen, Eduardo Rodrigues, Gianluca Cerminara, Hannes Jung, Bruce Mellado, Brian Cox, Giovanna Davatz, Sascha Caron, Steve Magill, Zofia Czyczula, ...

HERA has jets of $\mathcal{O}(10$ GeV$)$, Atlas/CMS will not trigger on jets below 100 GeV.

LHCb will have to understand forward jets.

Also in W/Z/H production there may be effects from *unordered evolution* (again cf. forward jets).

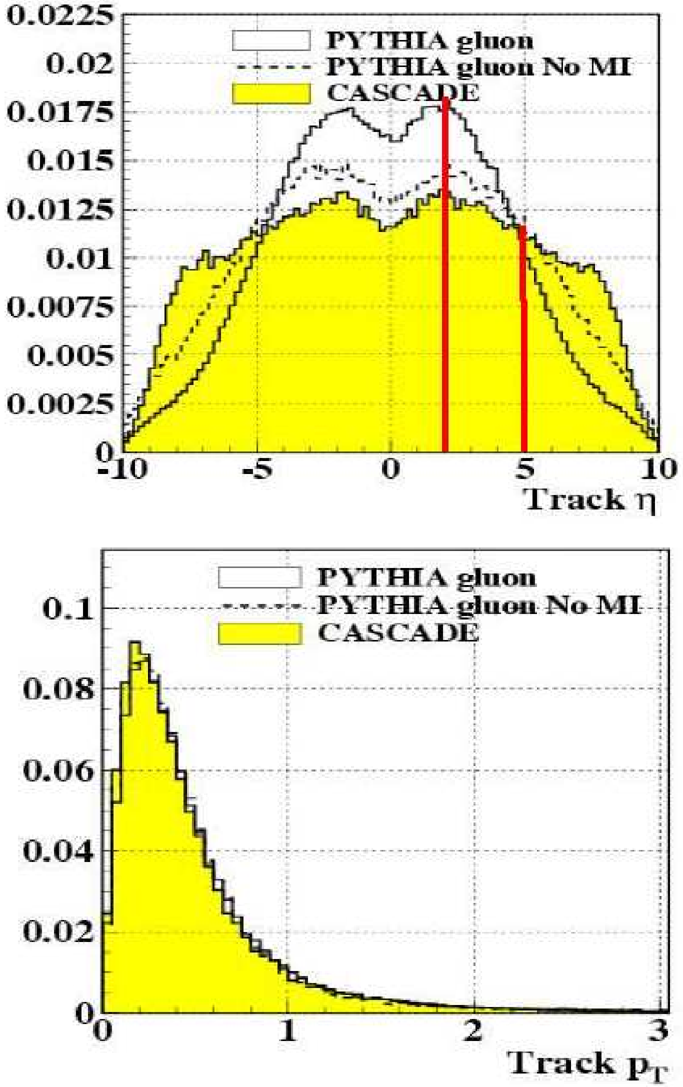
Matrix Element – Parton Shower matching $\rightarrow$ WG5

Why unordered evolution? Large scales for W/Z/H-production, but LHC energy is large giving eg. $x_W \sim 0.001 - 0.005$.

Several talks looking at comparisons between event generators.

PYTHIA, HERWIG: Standard DGLAP evolution.

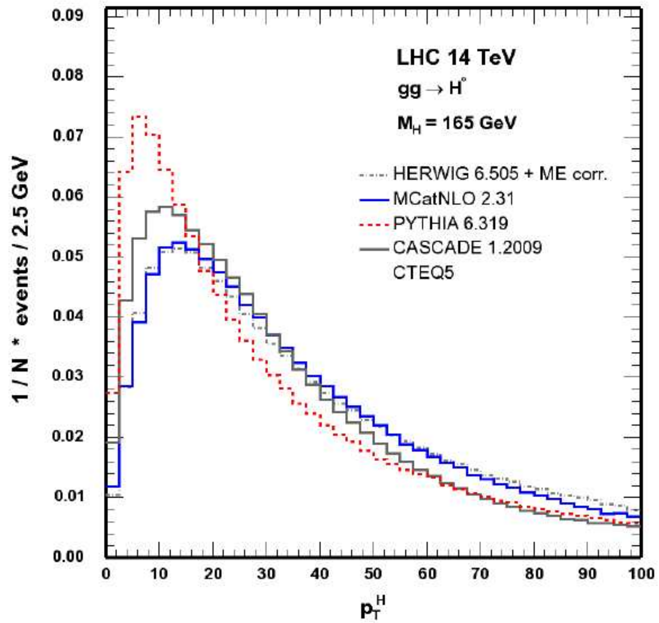
CASCADE, ARIADNE: Unordered evolution.

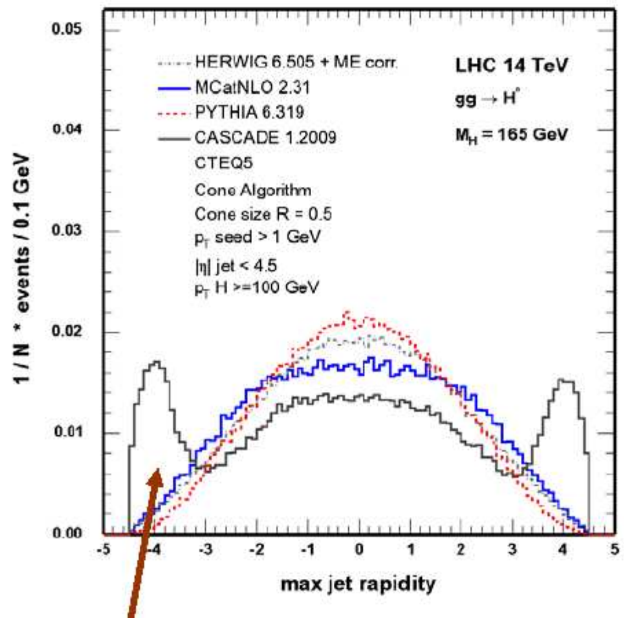


LHCb needs to understand forward (small-x) particles/jets at low scales. Similar to the DIS small-x at HERA.

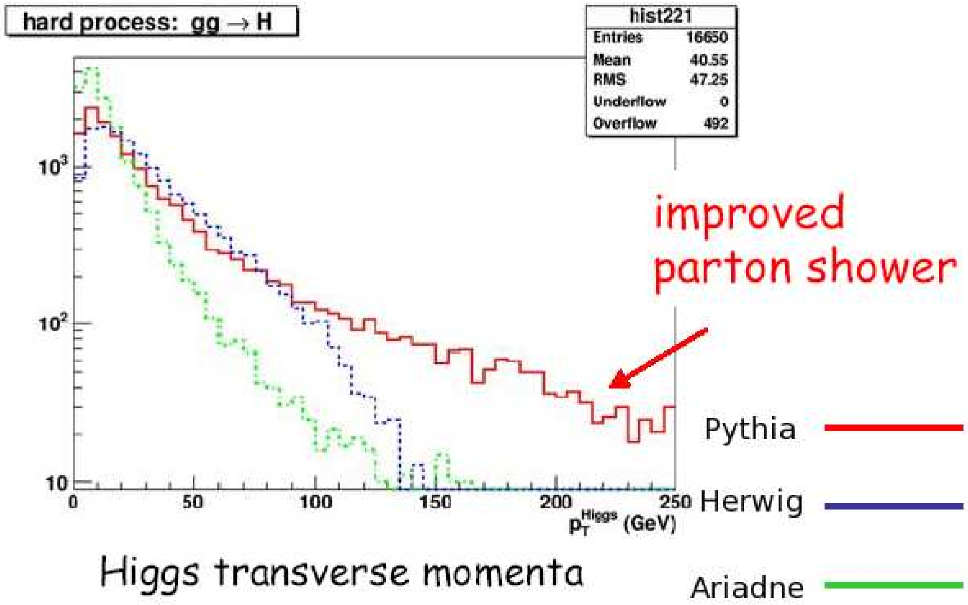
PYTHIA and CASCADE are similar for may distributions, but especially the rapidity distributions differ.

Do we understand the $p_\perp$ spectrum of eg. the Higgs at LHC? Important for the $gg \to H \to WW \to l\nu l\nu$ to understand jet veto for $\mathrm{t\bar{t}}$ suppression.

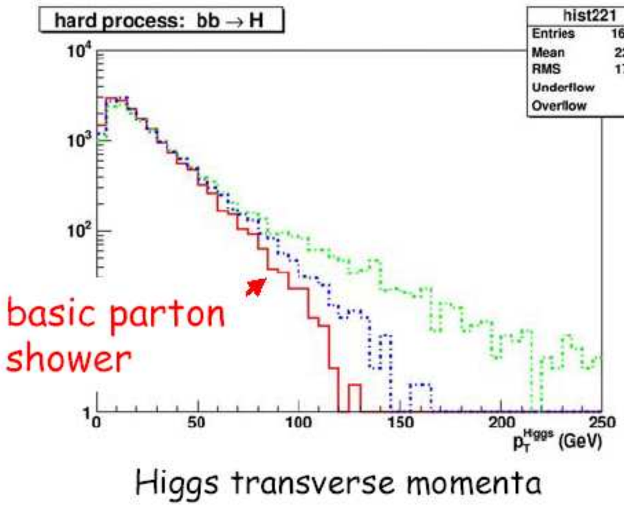


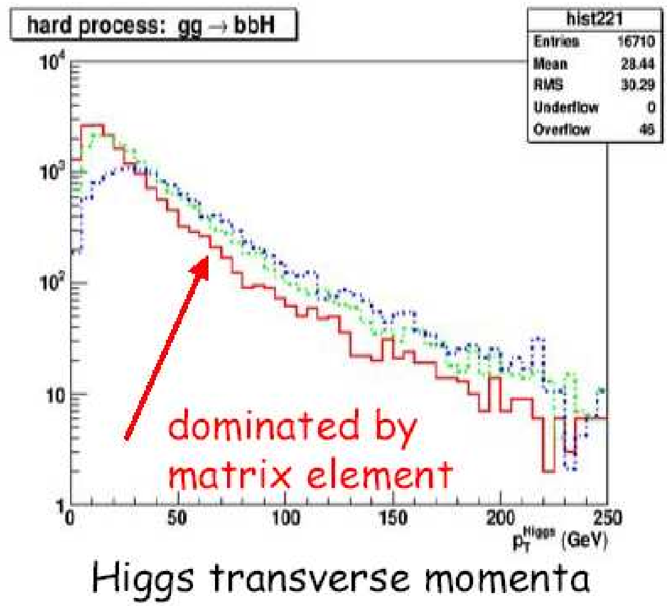


Study acceptance for $gg \to h/H/A \to \tau\tau$.

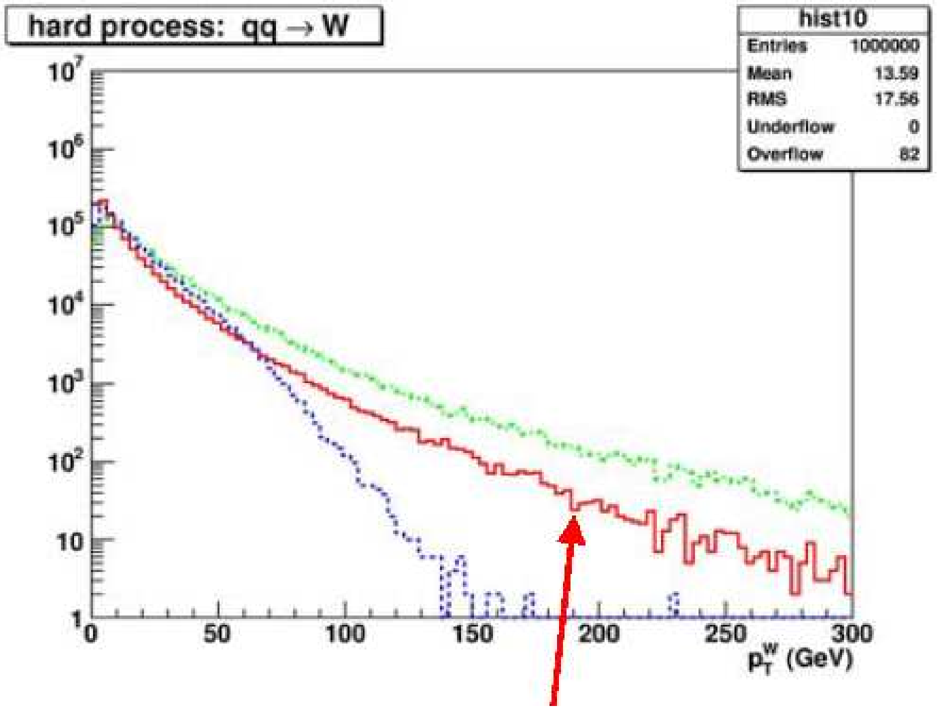


We also have $gg \to h/H/A \to \tau\tau\mathrm{b}\bar{\mathrm{b}}$. Where should we start the parton shower generators





[Czyczyla]


hard process: qq → W
hist10
Entries 1000000
Mean 13.59
RMS 17.56
Underflow 0
Overflow 82
10^7
10^6
10^5
10^4
10^3
10^2
10
1
0 50 100 150 200 250 300
p_T^W (GeV)

[Richter-Was]

Are CASCADE and/or ARIADNE up to the task of describing jets at LHC?

ARIADNE is being improved (ME/PS matching $\rightarrow$ WG5).

CASCADE is also being improved. Relies heavily on the unintegrated gluon densities. How well do we know these?

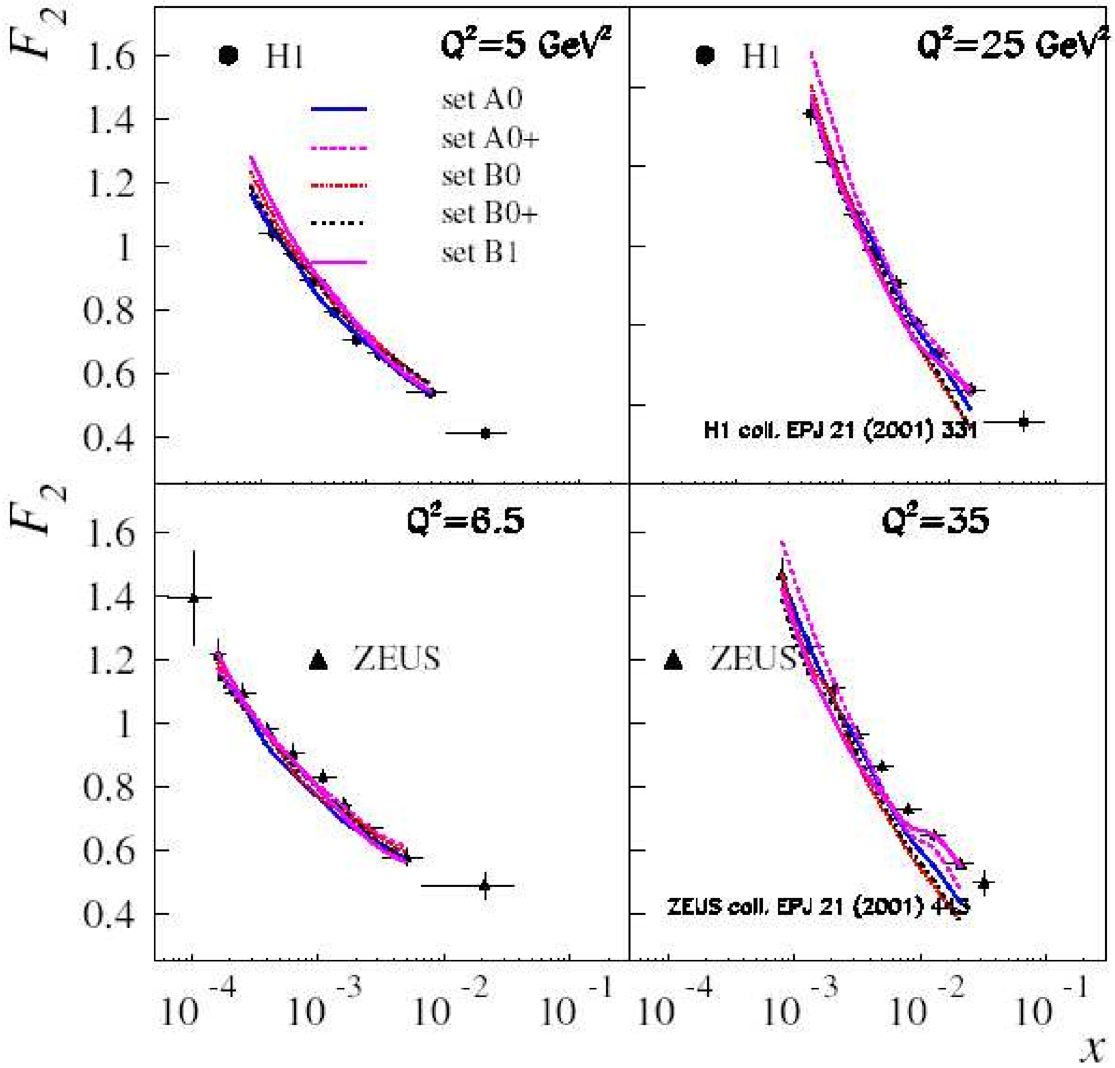
Unintegrated PDFs

Talks by: Hannes Jung, John Collins, Krisztian Peters,

The fitting of uPDFs is in its infancy as compared to the standard global DGLAP fits of the integrated PDFs.

The uPDFs used in CASCADE are tuned to F_2 in the region $x < 0.01$, $Q^2 < 100$ GeV^2.

Can it be used for eg. Higgs production at the LHC? $x < 0.01$, $Q^2 > 10\,000$ GeV^2 Through evolution sensitive to large x at small scales.


F_2
H1
Q^2=5 GeV^2
set A0
set A0+
set B0
set B0+
set B1
Q^2=25 GeV^2
H1 coll. EPJ 21 (2001) 331
Q^2=6.5
ZEUS
Q^2=35
ZEUS coll. EPJ 21 (2001) 443
x

We need to constrain the uPDFs better.

Fitting *unintegrated gluon* distributions to *integrated quark* distributions in F_2 is clearly not enough.

We need to also fit to jet rates etc. Both at HERA and at Tevatron.

Also questions about validity of $k_\perp$-factorization in hadron–hadron, especially when including saturation. (Peters)

Maybe we need Unintegrated parton *correlation* functions (Collins).

Resummation

Talks by: Mrinal Dasgupta, Gavin Salam, Gennaro Corcella, . . .

Resummed event shape observables have been very successful tool at LEP, contributing eg. to the precise α_{s} determination

At HERA new difficulties arise eg. due to limited acceptance introducing *non-global* logs.

At the LHC we need the experience from HERA, and then some...

Multijet resummation

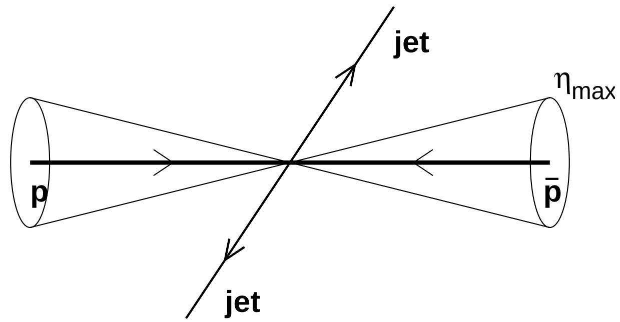
Refers to resummations involving more than 2 hard partons at Born level. E.g DIS (2+1) jet observables and hadron-hadron dijet event shapes.

Important since the corresponding NLL resummations have not been tested against data extensively unlike the 2/(1+1) jet event shapes.

Also vital to establish if the soft gluon approach to power corrections holds for multijet events.

- Hadronic dijet event shapes resummed semi-analytically by CAESAR A. Banfi, G.P. Salam and G. Zanderighi
- Dijet systems with nearly equal transverse energy jets (or e.g. those with $\Delta\phi_{jj} \approx \pi$) need analytical treatment mainly due to non-globalness. A. Banfi, M. Dasgupta, G. Corcella

Most significant potential problem is cut around beam direction.



Potential non-globalness from angular cut while CAESAR resums only global variables.

BUT over the range $L = \ln 1/v < c\eta_{\max}$ the observable is global since emissions beyond this rapidity are negligible.

c depends on the observable. $\eta_{\max} = 3.5$ for Tevatron and 5 for the LHC.

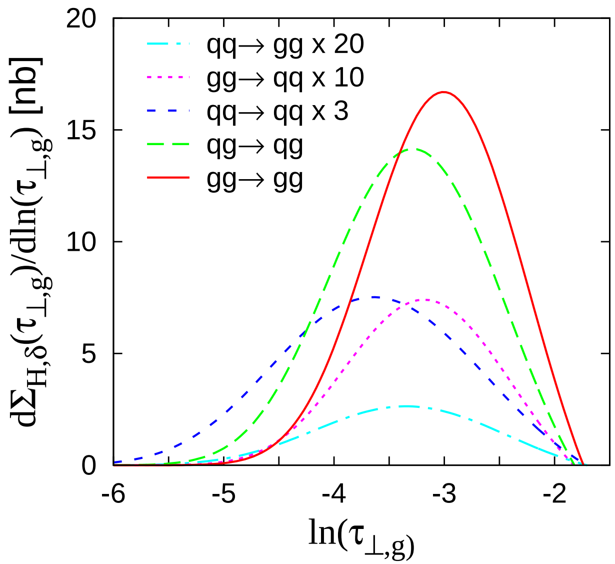
Hence one can do calculation over all η but restrict range of measurement of v.

[Dasgupta]

Global transverse thrust

$$T_{\perp,g} \equiv \max_{\vec{n_T}} \frac{\sum_i |\vec{q}_{\perp i} \cdot \vec{n_T}|}{\sum_i q_{\perp i}}$$

$$\tau_{\perp,g} = 1 - T_{\perp,g}$$



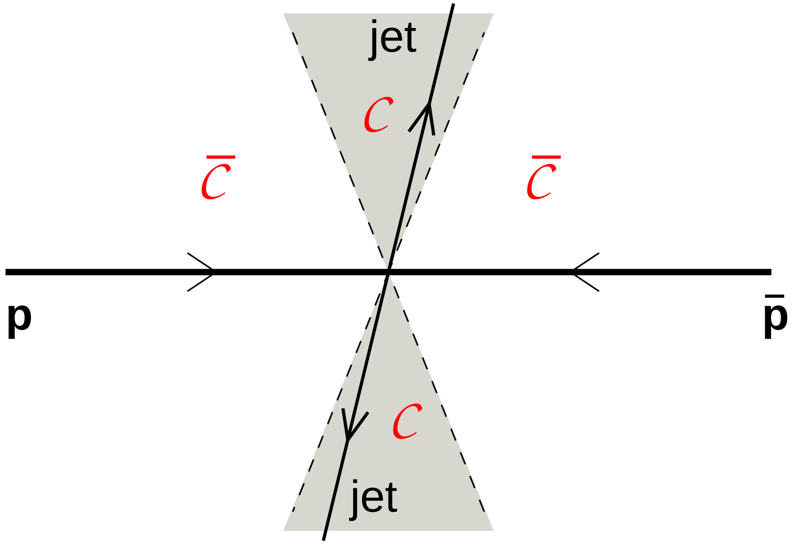
Probability that observable is less than v

$$P(v) = \exp[-(2C_B + C_J)\alpha_s L^2/2\pi],\ L = \ln 1/v$$

where C_B and C_j refer to beam and jet partons. Full answer at NLL is very complicated in terms of colour structure....

[Dasgupta]

Forward suppressed central obs.



Define observable in central region $\mathcal{C}$ (say $|\eta| \sim 1.1$) and add exponentially suppressed forward term in complementary region, to restore globalness. Example is sum of "up and down" jet masses:

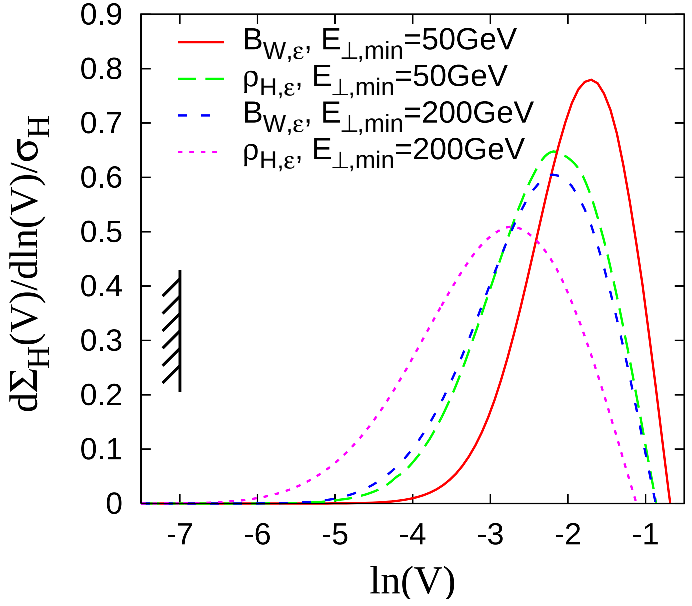
$$\rho_{X,\mathcal{C}} \equiv \frac{1}{Q_{\perp,\mathcal{C}}^2} \left(\sum_{i \in \mathcal{C}_X} q_i \right)^2, X = U, D$$

[Dasgupta]

Central heavy jet mass and wide broadening

Addition of forward suppression term (helps to extend range of study and reduce underlying event influence):

$$\frac{1}{Q_{\perp,\mathcal{C}}}\sum_{i\notin\mathcal{C}} q_{\perp i}\exp[-|\eta_i-\eta_{\mathcal{C}}|]$$



Also resummed by CAESAR are recoil observables where a $q_{t,\mathcal{C}}$ term is included to the event shape in $\mathcal{C}$ that by recoil is sensitive to emissions outside a central region and hence global.

[Dasgupta]

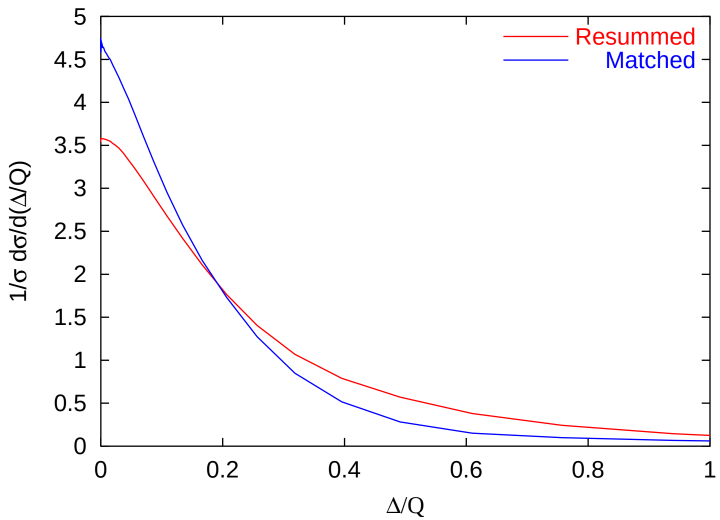
Dijet resummations are alternative to multijet event shapes, smaller hadronisation corrections. Test NLL resummations with dijet systems in ep collisions jets both in DIS (2+1)jets and photoproduction (2+2) jets.

So far results have been obtained for the jet transverse energy difference $\Delta = E_{t1} - E_{t2}$ between the highest E_T jets. This was previously in the cone algorithm. A. Banfi, M. Dasgupta

During the course of this workshop results extended to the k_t algorithm and matched to LO predictions from DISENT:

$$W(\Delta, x/\xi) = \frac{2}{\pi} \int_0^\infty \frac{db}{b} \sin(b\Delta) \exp[-\Sigma(b), R] \mathcal{S}(b) q \left(x/\xi, 1/b^2\right)$$

Σ is form factor and R the jet radius parameter. $\mathcal{S}$ accounts for non-global logs while q is the parton density. Observable is non global due to studying energy flow outside jets.



The final result is linear in Δ at very small Δ:

$$W(\Delta, x/\xi) \sim \frac{\Delta}{\sqrt{\alpha_s}} + \cdots$$

Note the absence of a Sudakov peak. Same resummation applies to $\Delta\phi_{jj}$ measurements near $\phi = \pi$ (in progress). Matching here is rough and combines channels. Same matching possible for hh event shapes. To obtain a better matching one needs flavour information in the fixed order codes.

Summary^3

We have identified a number of issues where understanding of HERA data is needed to prepare for LHC.

Work has started on many of these issues. Far from ready yet.

The HERA/LHC communities have started to talk to each other

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The HERA/LHC communities have started to talk to each other (via theory/phenomenology community)