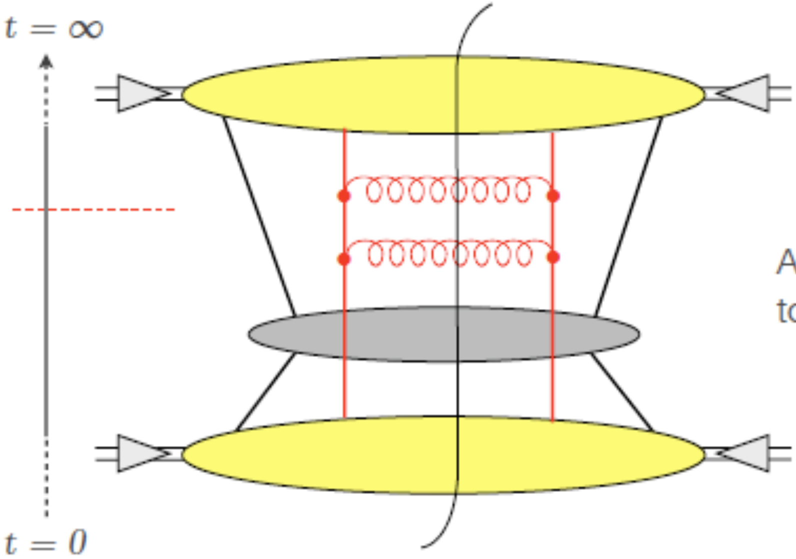
So we just need another tune to fit the data, don't we?

Multi Parton Interaction

Zoltan Nagy



We need this at least at leading color level.

$$\mathcal{H}_{\mathrm{MI}}(t) = \left(\frac{\alpha_s}{2\pi}\right)^2 \mathcal{O}(e^t)$$

Actually the real scaling is weaker due to the *power suppression*:

$$e^{t-t_0} \sim \frac{\Lambda_{\mathrm{QCD}}^2}{p_\perp^2}$$

- This is important in the very small pT regions and negligible in the large pT regions but it is hard to tell how import in the intermediate region. The cumulative effect could be sizable.
- Important to note that this is a kind of NLO contributions. Thus, compared to the standard shower this is also suppressed by an extra power of α_s.
- Requires multi parton PDF (mPDF).
- Implemented in HERWIG & PYTHIA. (No "proper" mPDF implemented.)

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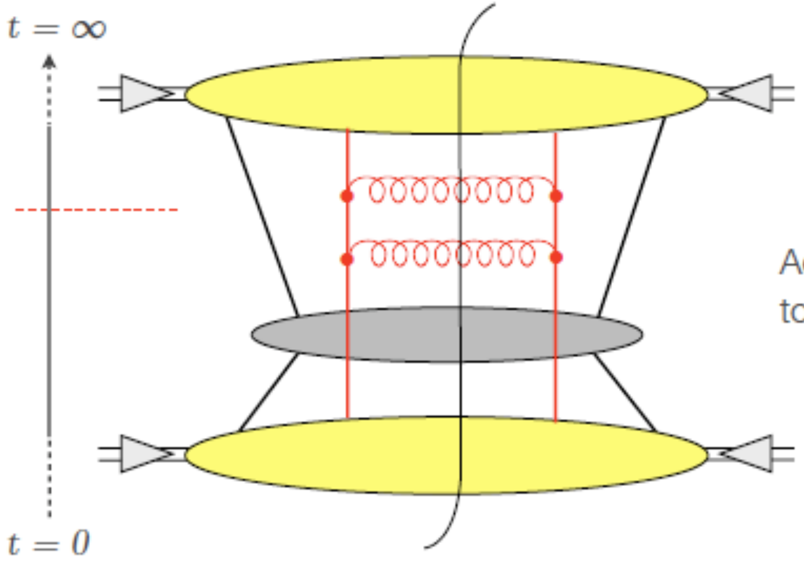

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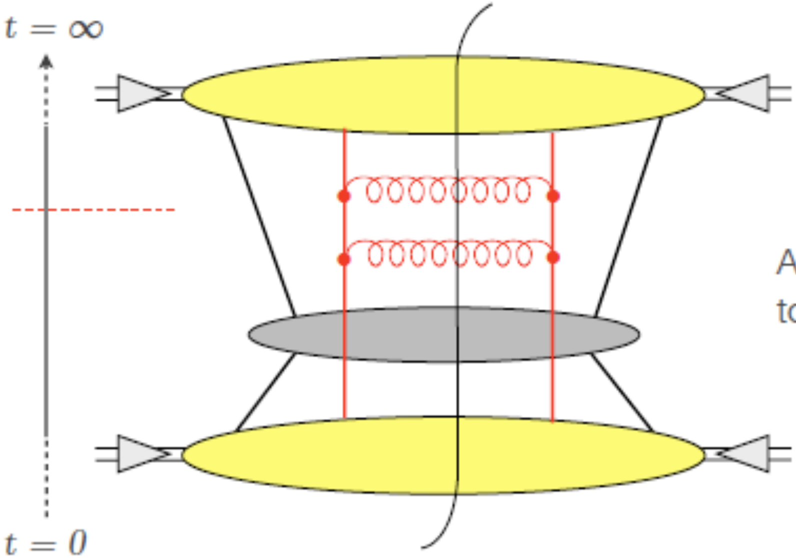

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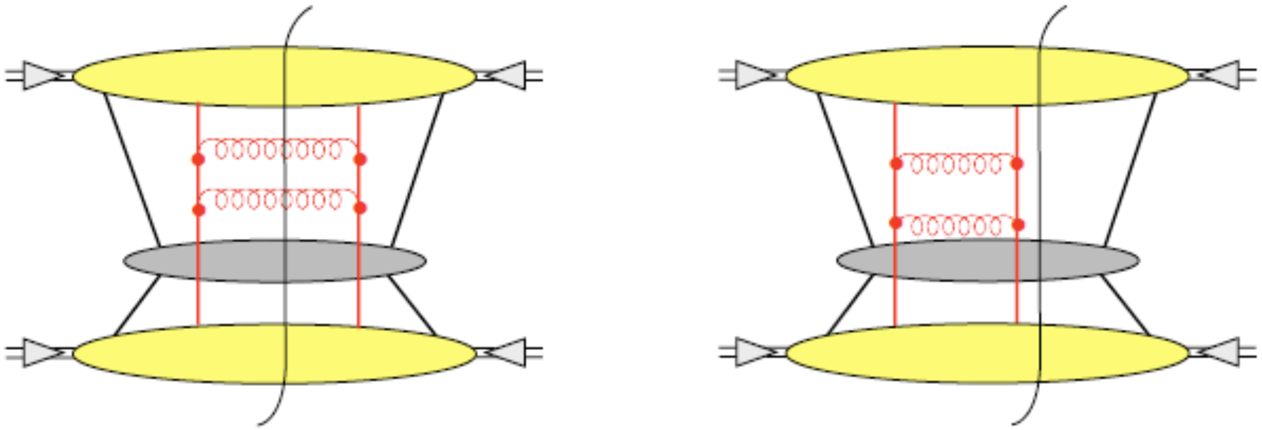
MPI: Coulomb Gluon

Zoltan Nagy

In the MPI part the "resolvable" radiation comes from extra 2 →2 scattering. This is very singular in the low pT region. This singularity must be cancelled by the corresponding virtual graps.



Real 2 →2 scattering adds two extra jets

Corresponding virtual graph.
This is a forward elastic scattering contribution. It can produce Coulomb gluon term ➡ *Color reconnection effect*

Colour reconnection effects are important when comparing MC predictions to data

$$\mathcal{U}(t,t') = \mathbb{T}\exp\left\{\int_t^{t'} d\tau\,[\mathcal{H}_I(\tau) - \mathcal{V}_I(\tau) + \sum_{\beta=\mathrm{MI,\,JI},\ldots} \{\mathcal{H}_\beta(\tau) - \mathcal{V}_\beta(\tau)\}]\right\}$$

Single radiations (IRS & FSR) — *Everything else*

So we just need another tune to fit the data, don't we?

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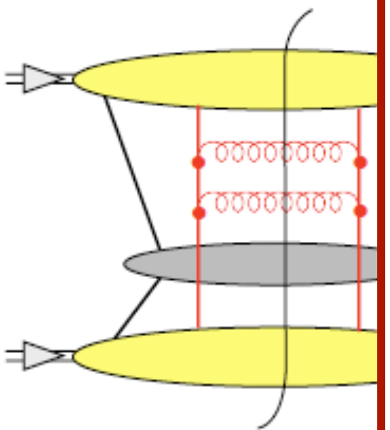

Real 2 →2 scattering adds two extra jets

- Multiple Interaction is very complicated from theory point of view.
- There are MC tool available mostly based on some tunable models (Color reconnection, simple mPDF assumption,...)
- Running of the mPDF, modeling mPDF
- Some perturbative effects are not included in our MC (Coulomb gluon,...)
- Lack of theorems (factorization,...)

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Corresponding virtual graph.

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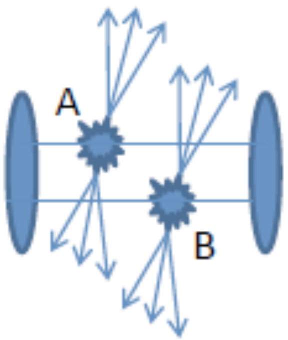
It can produce Coulomb gluon term ➡ *Color reconnection effect*

Pythia and Herwig put this graph into a simple probabilistic framework and exponentiate the extra 2→2 process.

Do we have a good understanding of MPIs and mPDFs?

Battlefield restricted to Double Parton Scattering

Jo Gaunt



Assuming only the factorisation of the hard processes A and B, the DPS cross section may be written as:

Symmetry factor — Two-parton generalised PDF (2pGPD)

$$\sigma_D^{(A,B)} = \frac{m}{2} \sum_{i,j,k,l} \int \Gamma_h^{ik}(x_1, x_2, \mathbf{b}; Q_A, Q_B)\, \Gamma_h^{jl}(x_1', x_2', \mathbf{b}; Q_A, Q_B)$$
$$\times\, \hat{\sigma}_{ij}^{A}(x_1, x_1')\, \hat{\sigma}_{kl}^{B}(x_2, x_2')\, \mathrm{d}x_1\, \mathrm{d}x_1' \mathrm{d}x_2\, \mathrm{d}x_2' \mathrm{d}^2\mathbf{b}$$

Parton level cross sections

Assumption: $$\Gamma_h^{ik}(x_1, x_2, b; Q_A, Q_B) = D_h^{ik}(x_1, x_2; Q_A, Q_B)\, F_k^{i}(b)$$

Double parton distribution functions (dPDFs) — Parton pair density in transverse space

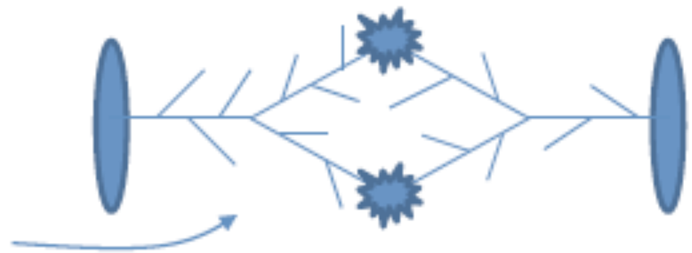
"**dPDF framework**", used in phenomenology

→ longitudinal-transverse factorization also in MCs

Do we have a good understanding of MPIs and mPDFs?

Jo Gaunt

Evolution equations for dPDFs known, would give contributions to DPS cross sections of the sort:



According to dPDF the diagram should contribute a DGLAP log but well known box diagram contributions, e.g. for $gg \rightarrow ZZ$, are finite!

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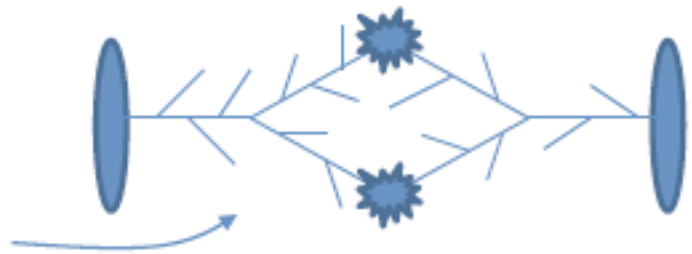


According to dPDF the diagram should contribute a DGLAP log but well known box diagram contributions, e.g. for gg→ZZ, are finite!

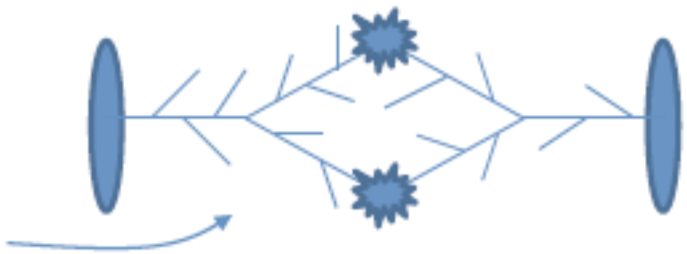
- In general, all diagrams with the "DPS-singularity" give only integrable contributions to the cross section: this is a correction to a single scattering process
- The apparent inconsistency due to the transverse-longitudinal factorization assumption: the dPDF framework breaks down!

Do we have a good understanding of MPIs and mPDFs?

Evolution equations for dPDFs known

Jo Gaunt

Under dPDF framework, there is a part of the DPS cross section that comes from multiplying two accumulated sPDF feed contributions together. Pictorially this piece looks like this:



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DGLAP log but the well know
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- In general, all diagrams wit ... s
  to the cross section: this is a
- The apparent inconsistency
  assumption: the dPDF frame

- Impact on phenomenology – definition of DPS cross section?
- DPS at high p_T will be measured: another test of MPI models in MCs
- mPDFs and mPDFs running in MC?
- Interference effects in flavour, spin and colour?

What is the impact of soft QCD corrections on jet physics?

Mrinal Dasgupta

Jet physics at hadron colliders

to jets

Mrinal Dasgupta

Traditional approach restricted to MC event generators. BUT

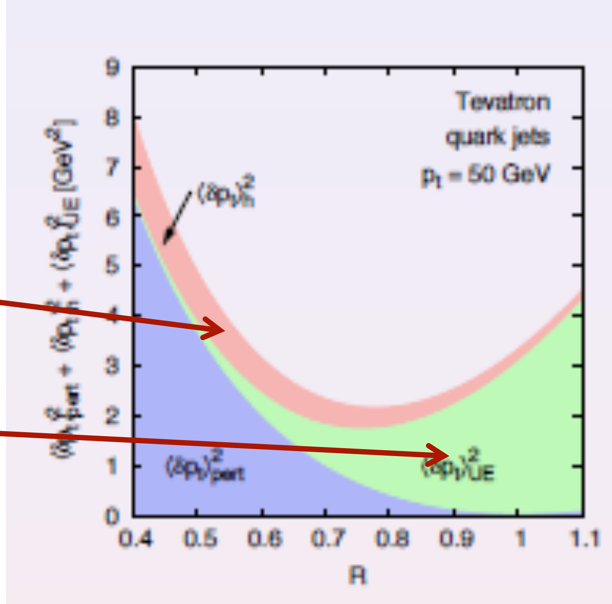
- MC (many tunable parameters) does not reflect understanding of physics of hadronisation. Analytical models can.
- MC studies do not provide any detailed parametric understanding of NP effects. How much p_t from UE vs hadronisation? As a function of jet flavour, p_t, size?

What is the impact of soft QCD corrections on jet physics?

Mrinal Dasgupta

Hadronization
<δp_t>$_h$~ -1/R

Underlying Event
<δp_t>$_{UE}$~ R^2

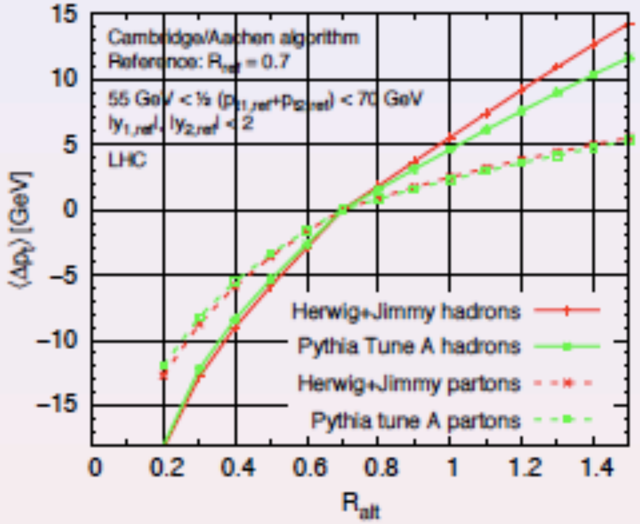


$$\langle \delta p_t^2 \rangle = \langle \delta p_t \rangle^2_{\rm h} + \langle \delta p_t \rangle^2_{\rm UE} + \langle \delta p_t \rangle^2_{\rm PT}$$

- Optimal R has been shown to be theoretically very valuable. Can the idea be exploited in practice given experimental limitations?
- Currently we have ATLAS with anti-k_t algorithm and $R = 0.4$ and $R = 0.6$. CMS have $R = 0.5$ and $R = 0.7$. At least one value in common would have been useful? Do these values cover sufficient range given that optimal R in some cases has $R > 1$.

Mrinal Dasgupta

Already seen some applications to data. One further idea could be to directly extract the scale of UE from data. Study e.g δp_t by using a reference and alternative jet



An example of measurement particularly sensitive to UE modelling?
But beware, difficult measurement! (track jets?)

$$\langle \delta p_t \rangle = \langle \delta p_t \rangle_{\mathrm{NLO}} - 2\langle C_i \rangle \left(\frac{1}{R_{\mathrm{alt}}} - \frac{1}{R_{\mathrm{ref}}} \right) \mathcal{A}(\mu_I)$$

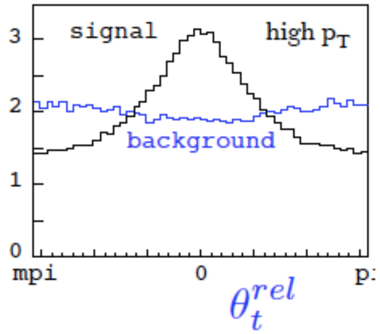
$$+ \left(R_{\mathrm{alt}} J_1(R_{\mathrm{alt}}) - R_{\mathrm{ref}} J_1(R_{\mathrm{ref}}) \right) \Lambda_{\mathrm{UE}}$$

What would be the impact of soft QCD effects on (feasibility of some) LHC searches?

Jet-pull method: identification of hard subprocess from studying colour flow

Simone Marzani

Expect:



$pp \to ZH \to Zb\bar{b}$

$pp \to Zb\bar{b}$

Gallicchio and Schwartz arXiv:1001.5027

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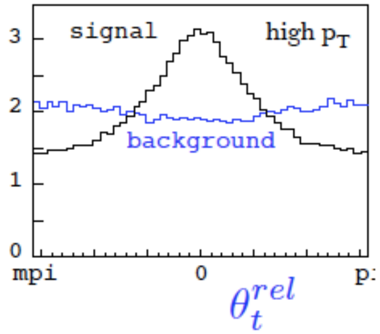

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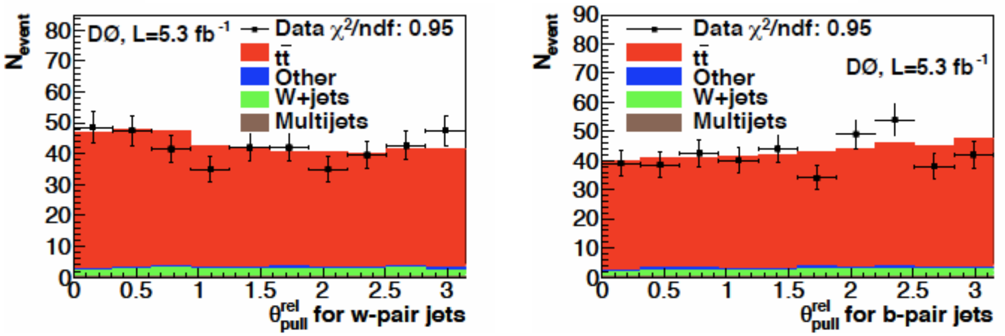
But get:

$p\bar{p} \to t\bar{t} \to WbW\bar{b} \to l\nu j\bar{j}\bar{b}b$



D0 collaboration arXiv:1101.0648

- Tough measurement: UE contamination
- Are things going to be worse at the LHC with pile-up?

The DIPSY alternative

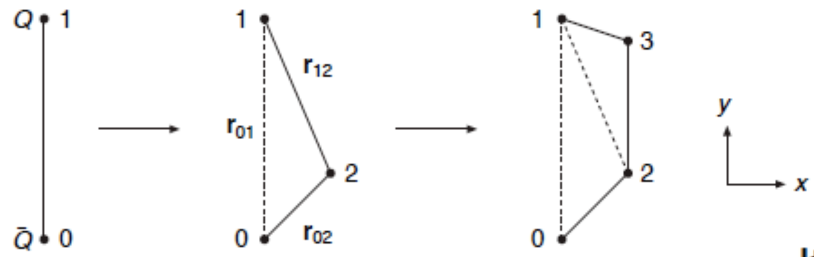
DIPSY = Dipole Event Generator

Gösta Gustafson

Small x evolution

Mueller Dipole Model:

Formulation of LL BFKL in transverse coordinate space



Emission probability: $\frac{d\mathcal{P}}{dy} = \frac{\bar{\alpha}}{2\pi} d^2\mathbf{r}_2 \frac{r_{01}^2}{r_{02}^2 r_{12}^2}$

It includes:

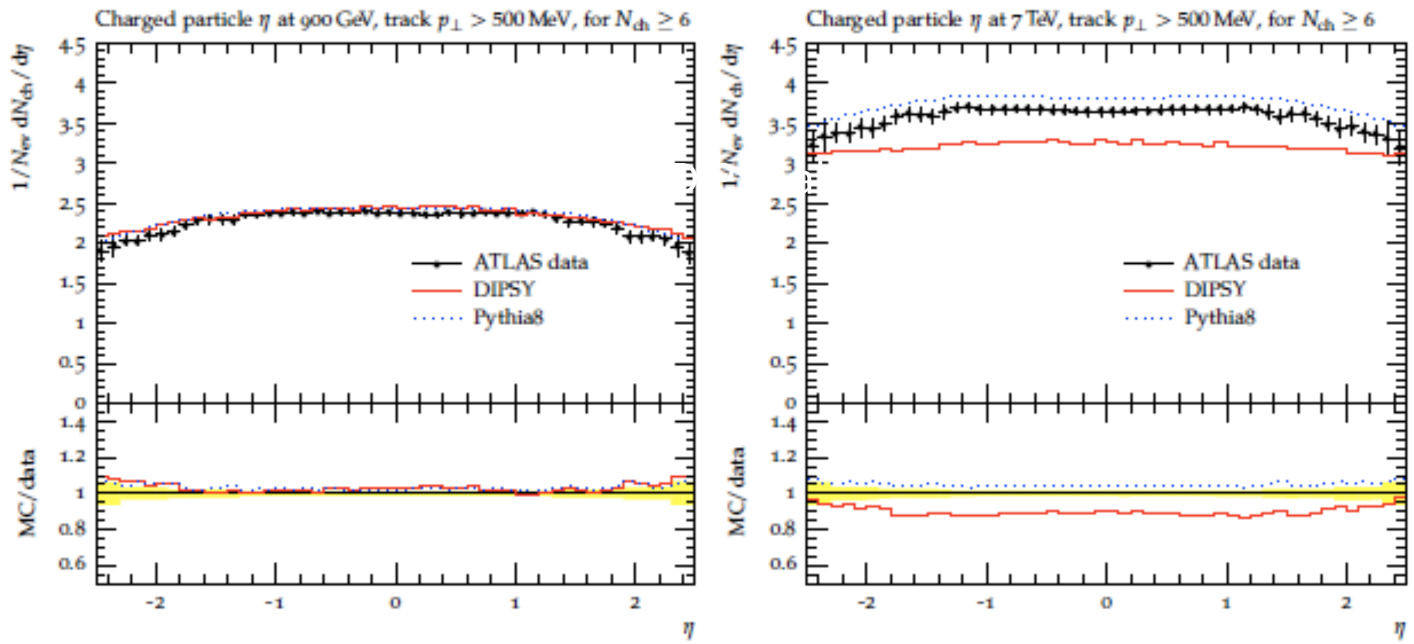
- important non-leading effects in BFKL
- saturation within the evolution
- confinement
- fluctuations and correlations
- MC implementation
- also nucleus collisions

The DIPSY alternative

Gösta Gustafson

Comparisons to ATLAS data

η distrib. of charged particles at 0.9 and 7 TeV



[arXiv:1103.4321]

Fair description of exclusive final states: MB and UE

Gösta Gustafson

C Questions and problems to be studied further

- Fluctuations
  Understand the relation between Good–Walker and Regge
  Asymmetries like triangular flow, v_3, in pp, pA, AA, DIS
- Correlations
  e.g dependence of σ_{eff} on Q^2, s, and η
- Final states in diffraction
  Min. bias and underlying events (ISR: stringlike)
- Effects of colour
  Soft colour reconnection: needed in PYTHIA, gap events?
  Pomeron mixing
- Can diffraction be well defined?
  Is it possible (in theory) to separate diffraction from inelastic events with gap?

Gösta Gustafson

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- Fluctuations
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$$\sigma_{eff}^{-1} = \int d^2b\, F(b,..)F(b,..)$$

from DIPSY

Effective cross section: $\sigma^D_{(A,B)} \equiv \frac{1}{(1+\delta_{AB})}\frac{\sigma^S_A\sigma^S_B}{\sigma_{\rm eff}}$

$\sigma_{\rm eff}$ depends strongly on Q^2 for fixed $\sqrt{s}$

Q_1^2	Q_2^2 [GeV^2]	x_1	x_2	$\sigma_{\rm eff}$ [mb]	$\int F$
1.5 TeV, midrapidity					
10	10	0.001	0.001	35.3	1.09
10^3	10^3	0.01	0.01	23.1	1.06
15 TeV, midrapidity					
10	10	0.0001	0.0001	40.4	1.11
10^3	10^3	0.001	0.001	26.3	1.07
10^5	10^5	0.01	0.01	19.6	1.03

Stronger correlations for larger Q^2

Summary of the soft QCD working group

Within this working group:

- Proposed: new measurements
- Emphasized: need to compare data with ***various available*** MC models* / identify measurements which cannot be well described by all MCs/tunes
- Highlighted: many theoretical issues / open questions in the description of soft QCD
- The real big question:

> Are we happy with the current status? Is tuning the end of the story?

Certainly not satisfactory from the theory point of view…

*i.e. Sherpa

Summary of the soft QCD working group cntd.

Open call to both theory and experiment:

Is there a need for more measurements? Can we come up with measurements sensitive to particular aspects of soft QCD (hadronization, MPI, non-perturbative)?

Proposals need to be made now!

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Many thanks to all the speakers and contributors!