Phenomenology and Models for Minimum Bias and the Underlying Event

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SM@LHC
11th-14th April 2011, IPPP Durham

Recent Progress in Models for Minimum Bias and the Underlying Event

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Recent Progress in Models for Soft Inclusive and the Underlying Event

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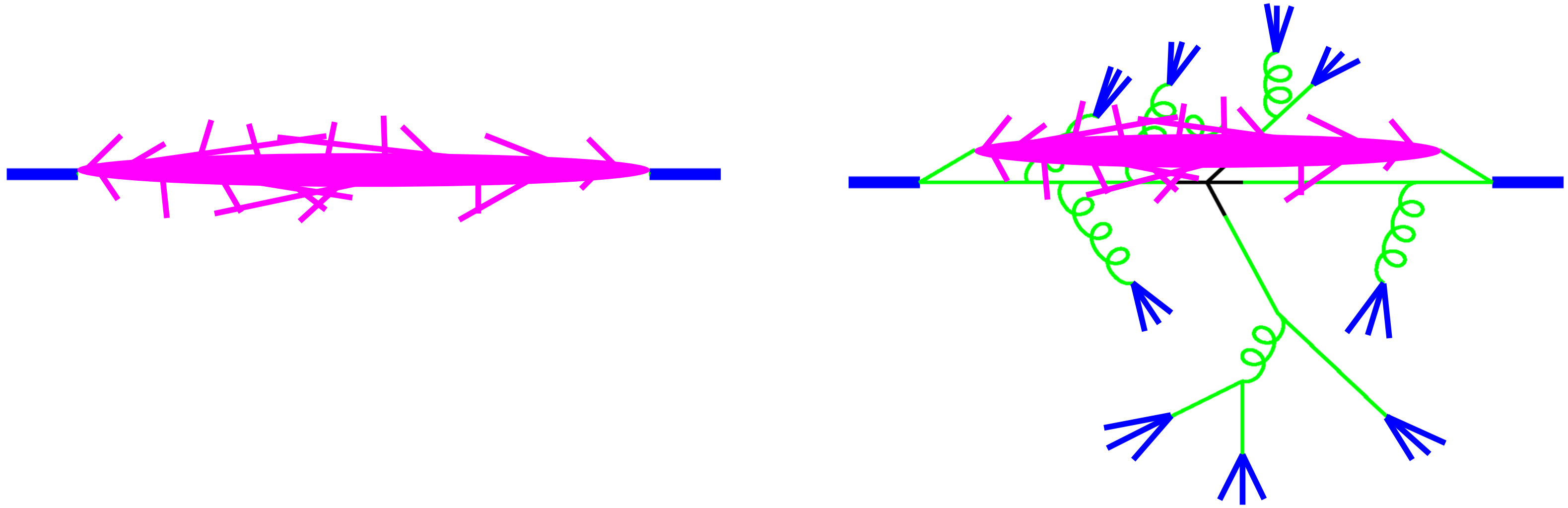
The Basics: event classes

‘Minimum bias’ collision and underlying event



Minimum bias = experimental statement

Models = zero bias? i.e. inclusive sample of all inelastic (non-diffractive?) events

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General-purpose event generators for LHC physics

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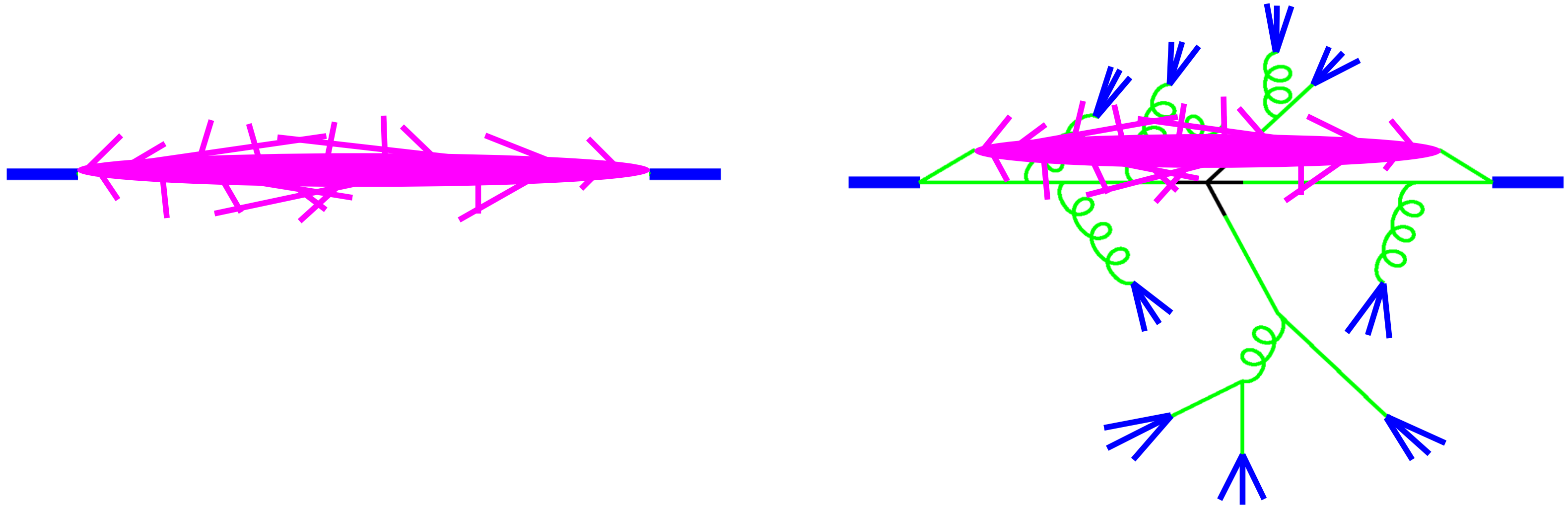
Abstract

We review the physics basis, main features and use of general-purpose Monte Carlo event generators for the simulation of proton-proton collisions at the Large Hadron Collider. Topics included are: the generation of hard-scattering matrix elements for processes of interest, at both leading and next-to-leading QCD perturbative order; their matching to approximate treatments of higher orders based on the showering approximation; the parton and dipole shower formulations; parton distribution functions for event generators; non-perturbative aspects such as soft QCD collisions, the underlying event and diffractive processes; the string and cluster models for hadron formation; the treatment of hadron and tau decays; the inclusion of QED radiation and beyond-Standard-Model processes. We describe the principal features of the ARIADNE, Herwig++, PYTHIA 8 and SHERPA generators, together with the Rivet and Professor validation and tuning tools, and discuss the physics philosophy behind the proper use of these generators and tools. This review is aimed at phenomenologists wishing to understand better how parton-level predictions are translated into hadron-level events as well as experimentalists wanting a deeper insight into the tools available for signal and background simulation at the LHC.

Physics Reports *January 13, 2011*

The Basics: event classes

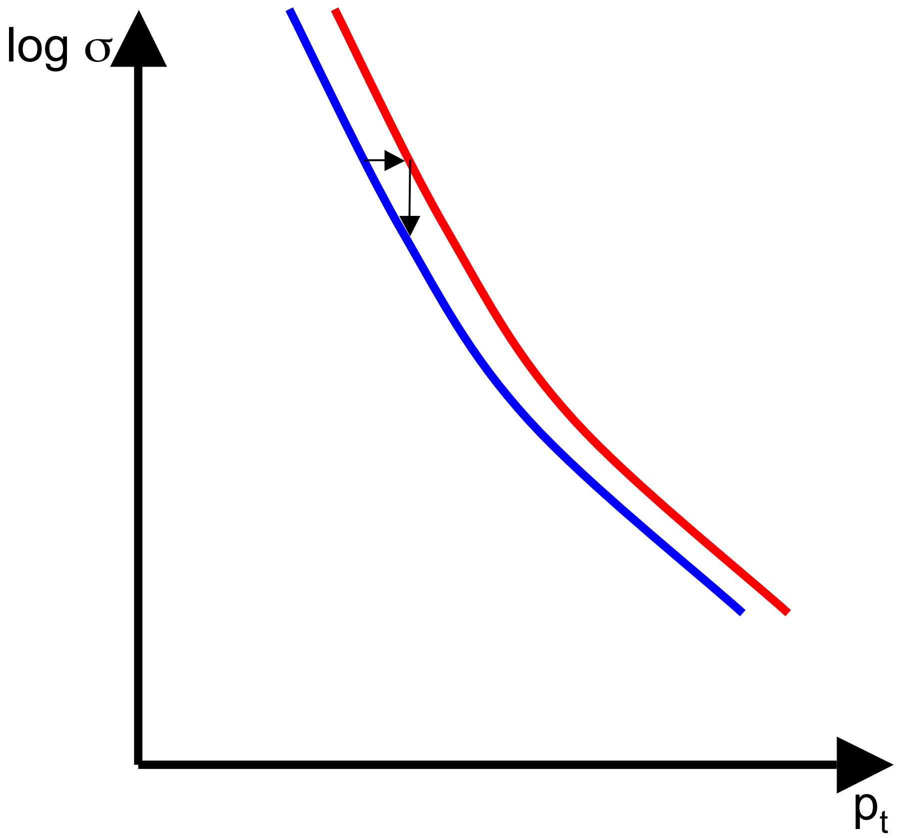
'Soft inclusive' events and the underlying event



How similar are they?

Fluctuations and correlations play crucial role

Fluctuations and correlations



Steep distribution ⇒ small sideways shift = large vertical

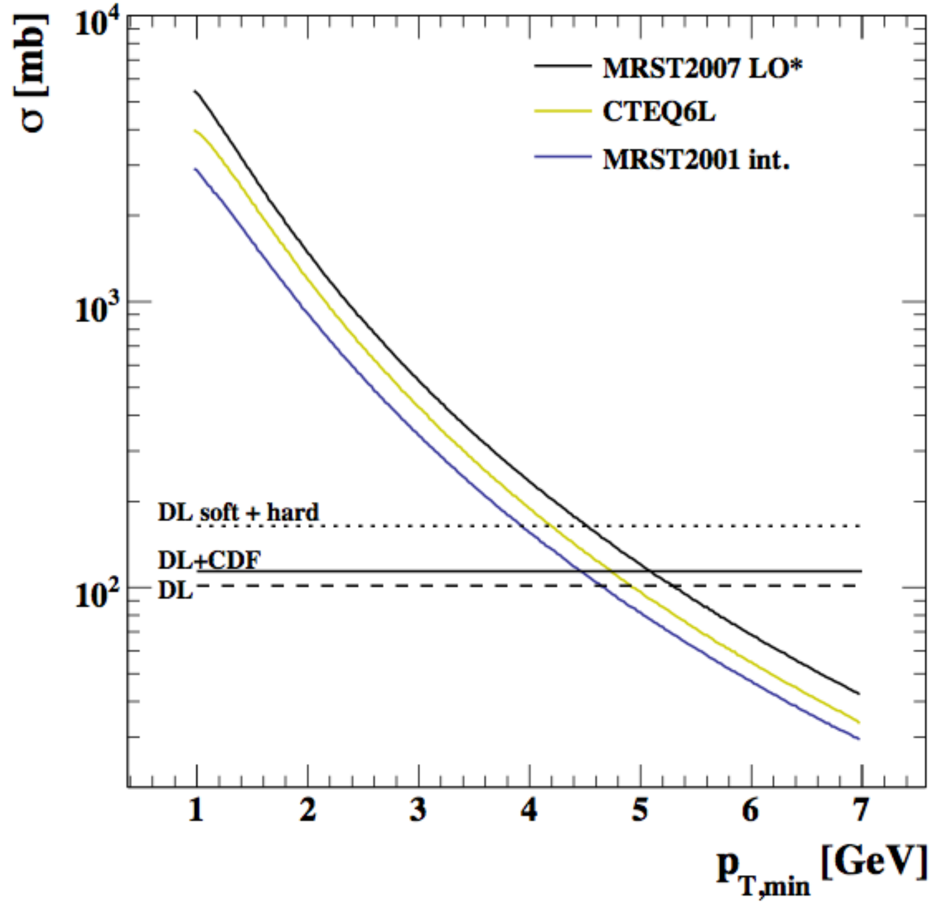
Rare fluctuations can have a huge influence

$1/p_t^n \rightarrow n$th moment

⇒ corrections depend on physics process

The Basics: Multiparton Interaction Model

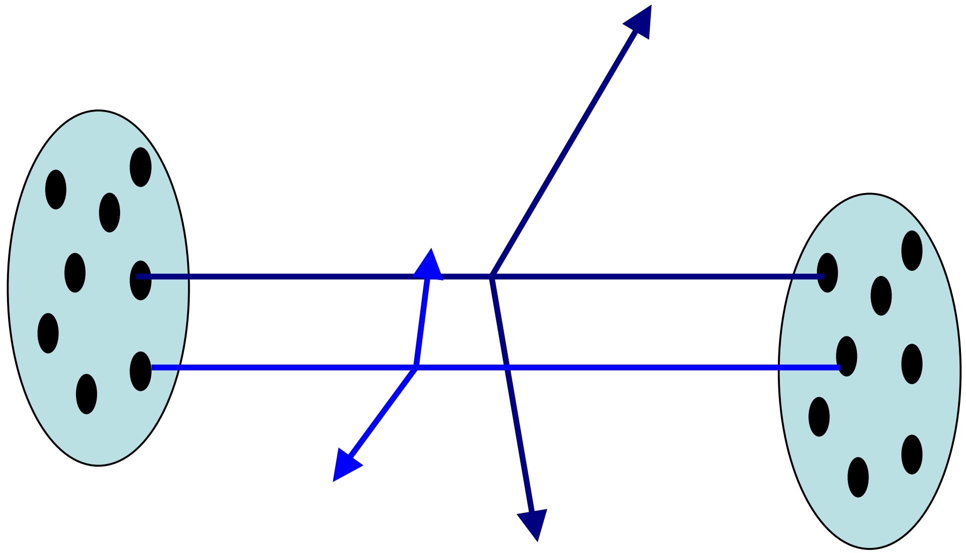
For small $p_{t\,min}$ and high energy inclusive parton—parton cross section is larger than total proton—proton cross section.



The Basics: Multiparton Interaction Model

For small $p_{t\,min}$ and high energy inclusive parton—parton cross section is larger than total proton—proton cross section.

→ More than one parton—parton scatter per proton—proton



Need a model of spatial distribution within proton

→ Perturbation theory gives you n-scatter distributions

Matter Distributions

- Usually assume *x* and *b* factorize (→ see later)

$$n_i(x,b;\mu^2,s) = f_i(x;\mu^2)\,G(b,s)$$

- and *n*-parton distributions are independent (→ see soon)

$$n_{i,j}(x_i,x_j,b_i,b_j) = n_i(x_i,b_i)\,n_j(x_j,b_j)$$

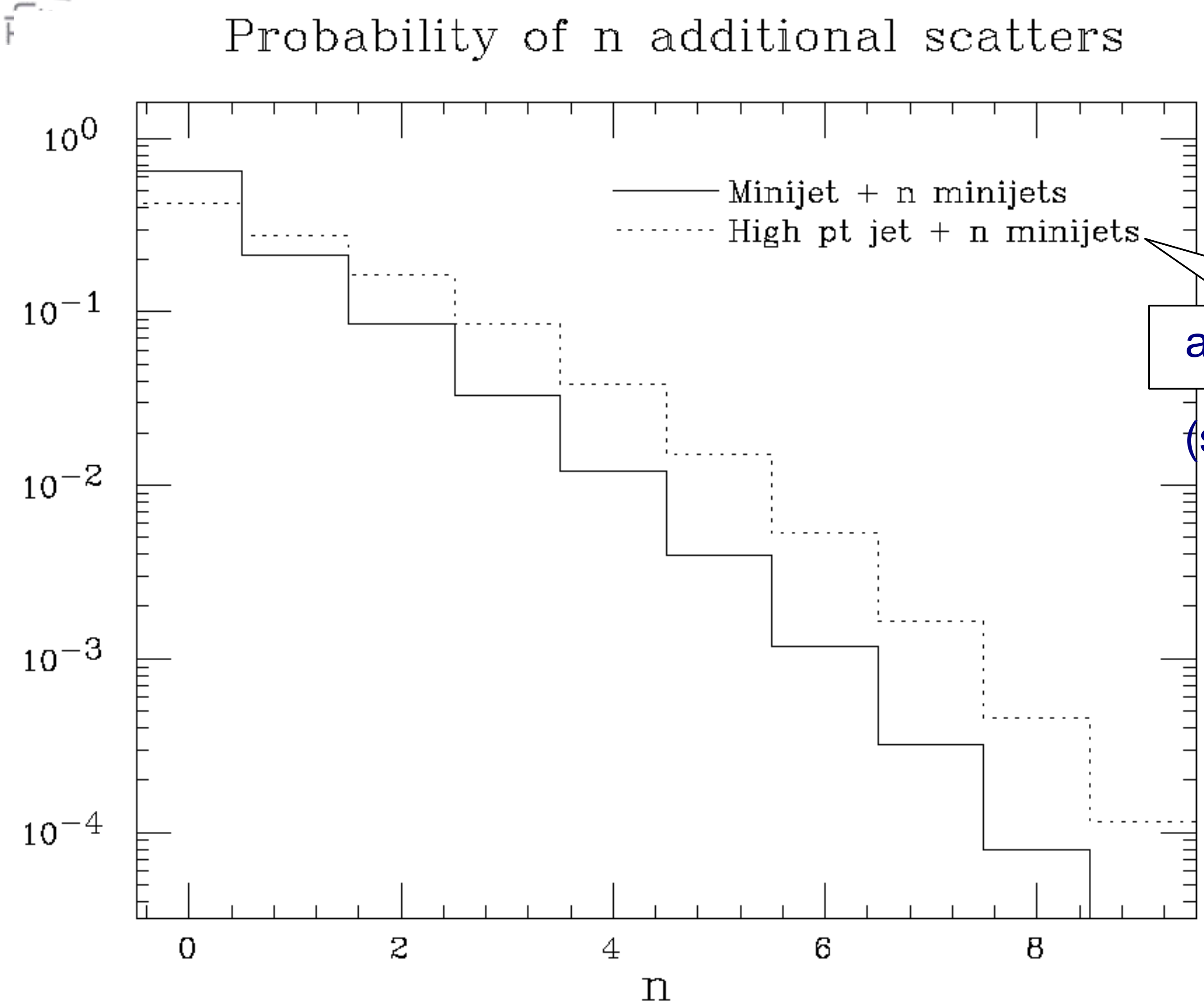
⇒ scatters Poissonian at fixed impact parameter

$$\sigma_n = \int d^2b\,\frac{(A(b)\sigma^{inc})^n}{n!}\,\mathrm{exp}(-A(b)\sigma^{inc})$$

$$A(b) = \int d^2b_1 G(b_1)\,d^2b_2 G(b_2)\,\delta(b-b_1+b_2)$$

→ Non-Poissonian Distribution

~ Geometric Distribution



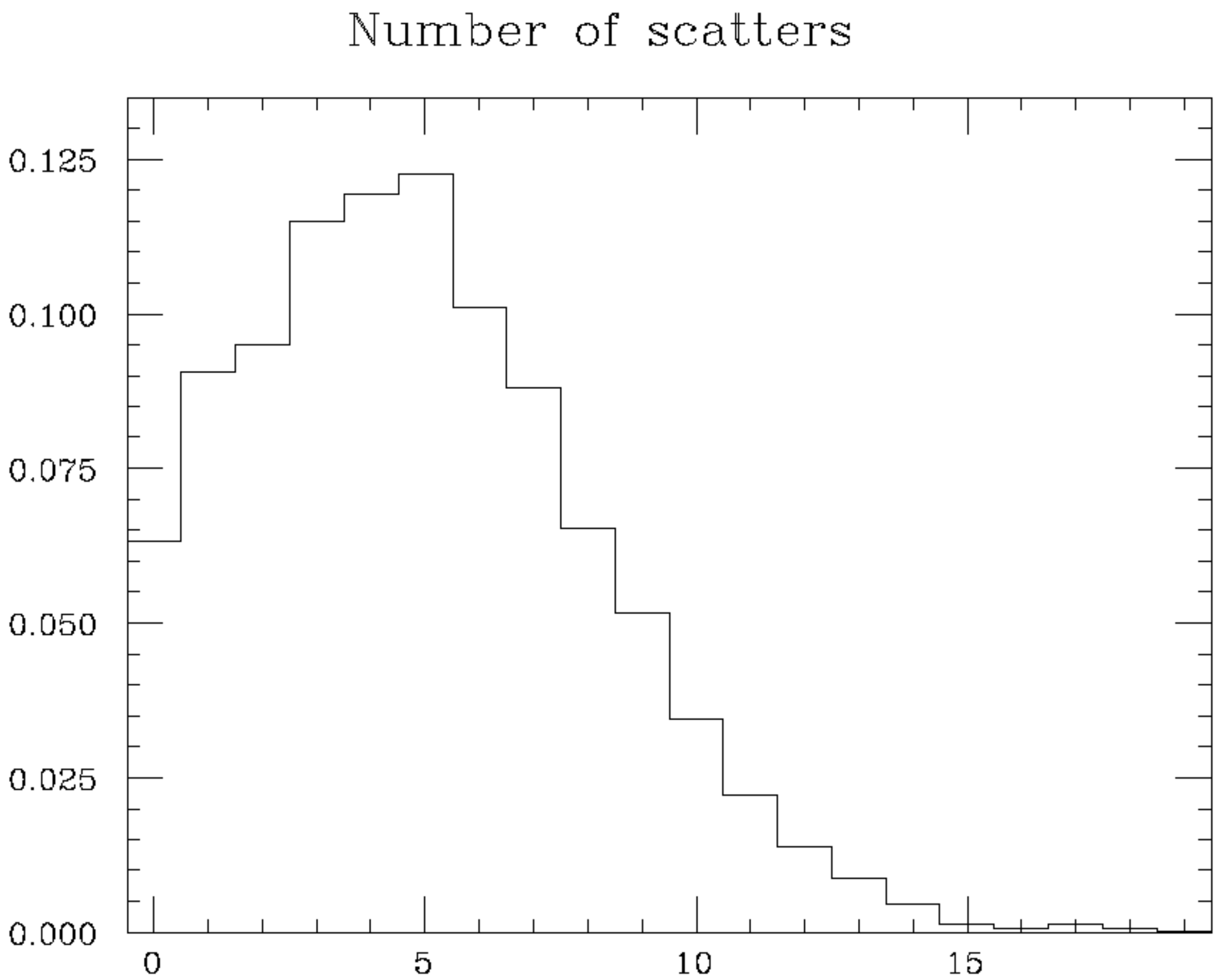
and b-space correlations

(saturates at pt~10 GeV)

Energy Conservation

Narrows distribution.

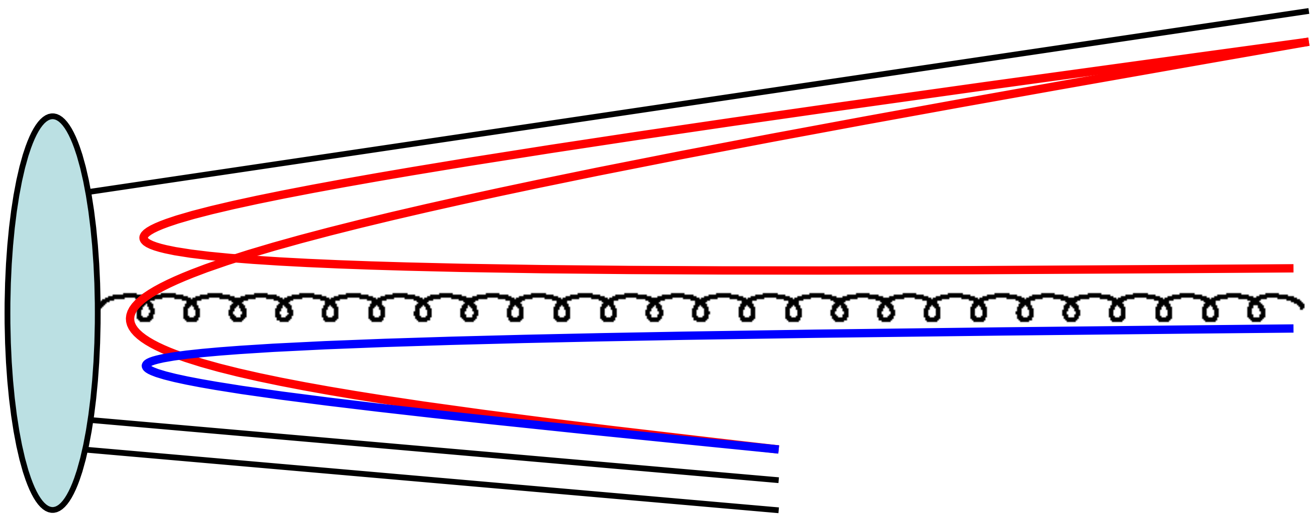
Ask for infinite number of scatters. How many do you get?



Flavour conservation

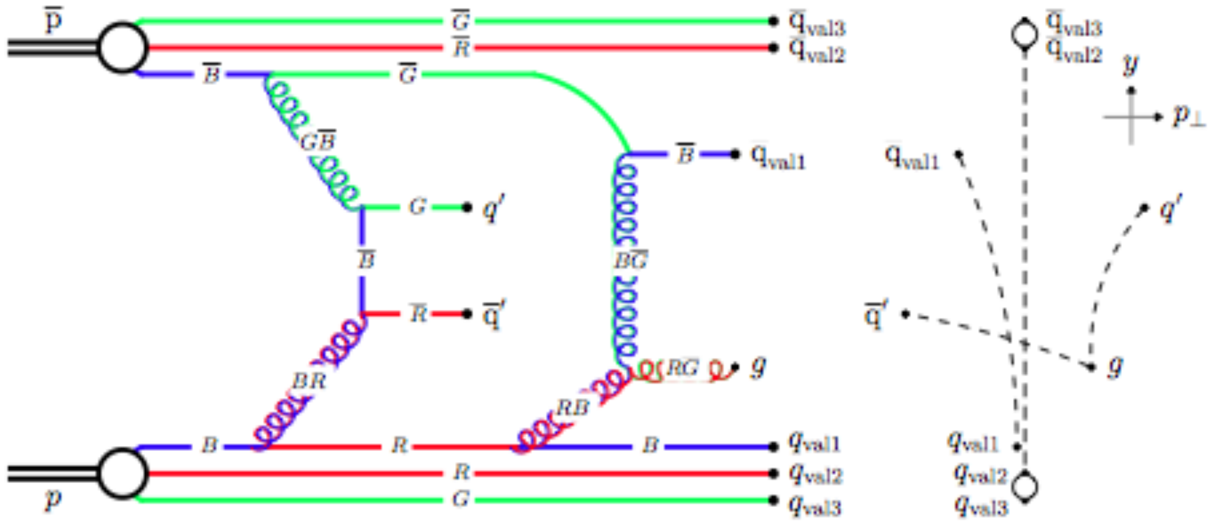
- Primary interactions “use up” valence partons
- additional scatters are sea quarks and gluons

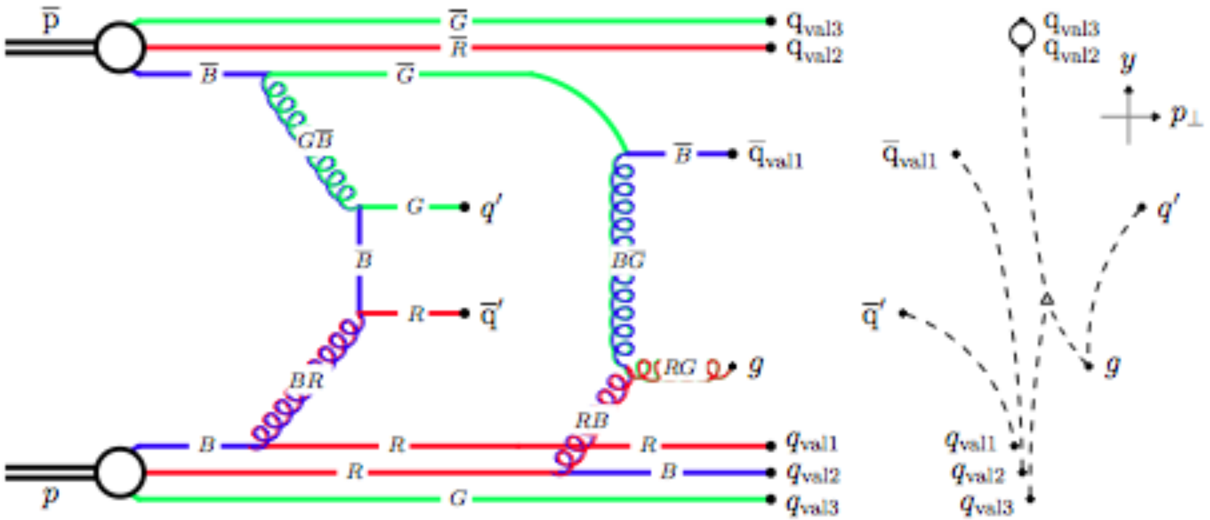
Colour correlations



Colour correlations

Can have a big influence on final states





→ see later

The Herwig++ Model (formerly known as Jimmy+Ivan)

- Take eikonal+partonic scattering seriously

$$\sigma_{tot} = 2\int d^2b\left(1-e^{-\frac{1}{2}A(b)\sigma_{inc}}\right)$$

$$B = \left[\frac{d}{dt}\left(\ln\frac{d\sigma_{el}}{dt}\right)\right]_{t=0} = \frac{1}{\sigma_{tot}}\int d^2b\, b^2\left(1-e^{-\frac{1}{2}A(b)\sigma_{inc}}\right)$$

- given form of matter distribution $\Rightarrow$ size and σ_{inc}

Bähr, Butterworth & MHS, JHEP 0901:067, 2009

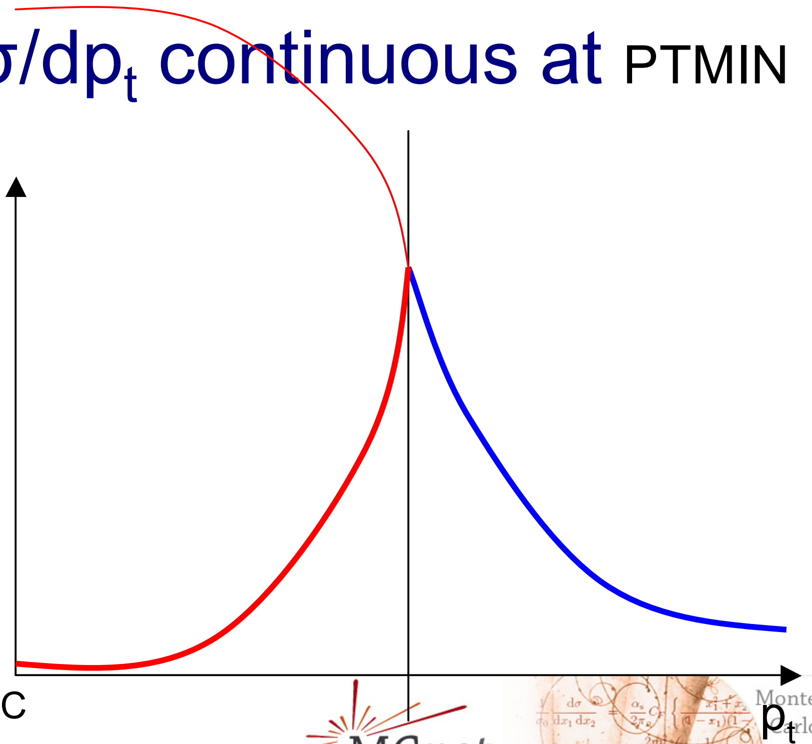
- too restrictive $\Rightarrow$

$$\sigma_{tot} = 2\int d^2b\left(1-e^{-\frac{1}{2}(A_{\rm soft}(b)\sigma_{\rm soft,inc}+A_{\rm hard}(b)\sigma_{\rm hard,inc})}\right)$$

- $\Rightarrow$ two free parameters

Final state implementation

- Pure independent perturbative scatters above PTMIN
- Gluonic scattering below PTMIN with total $\sigma_{soft,inc}$ and Gaussian distribution in p_t
- $d\sigma/dp_t$ continuous at PTMIN

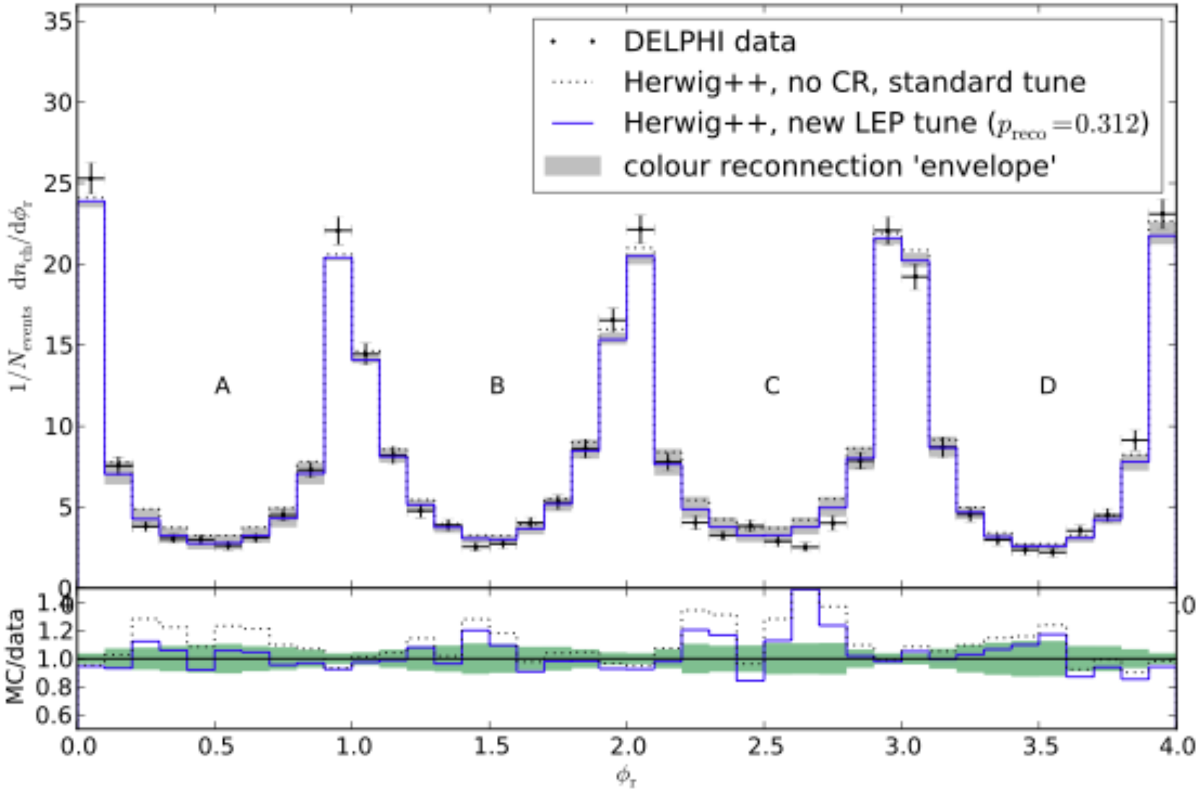


→ possibility that entire process could be described perturbatively?

Colour reconnection model

- Röhr, Siodmok and Gieseke have implemented a new model based on momentum structure
- Refit LEP-I and LEP-II data
- Conclusion: hadronization parameters correlated with reconnection probability, but good fit can be obtained for any value of p_{reco}

Retrospective: particle flow in $WW \to 4j$ at LEP



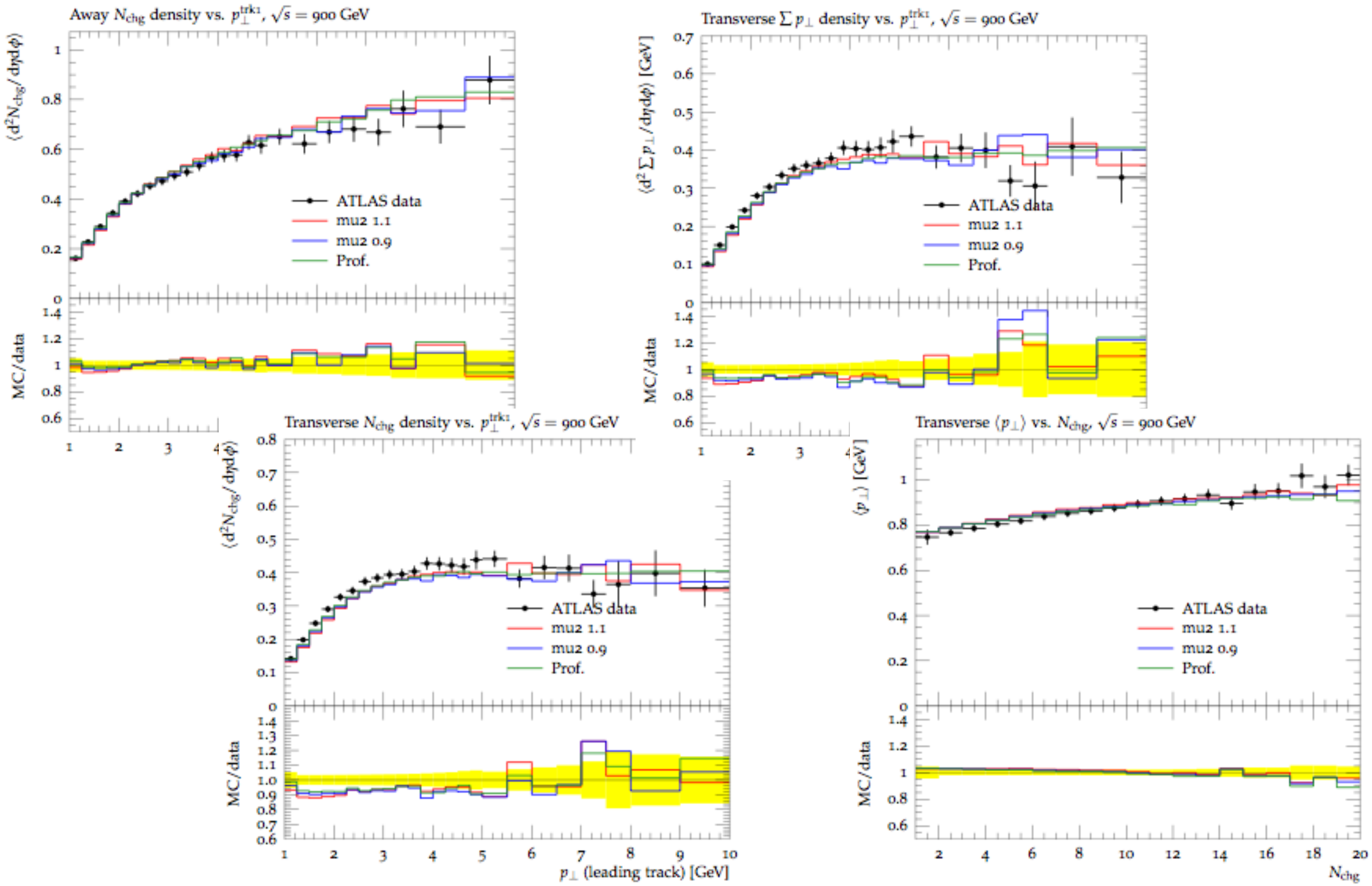
- small effects here
- marginal improvement (if at all)

data from [DELPHI Collaboration, Eur. Phys. J. C51 (2007) 249-269]

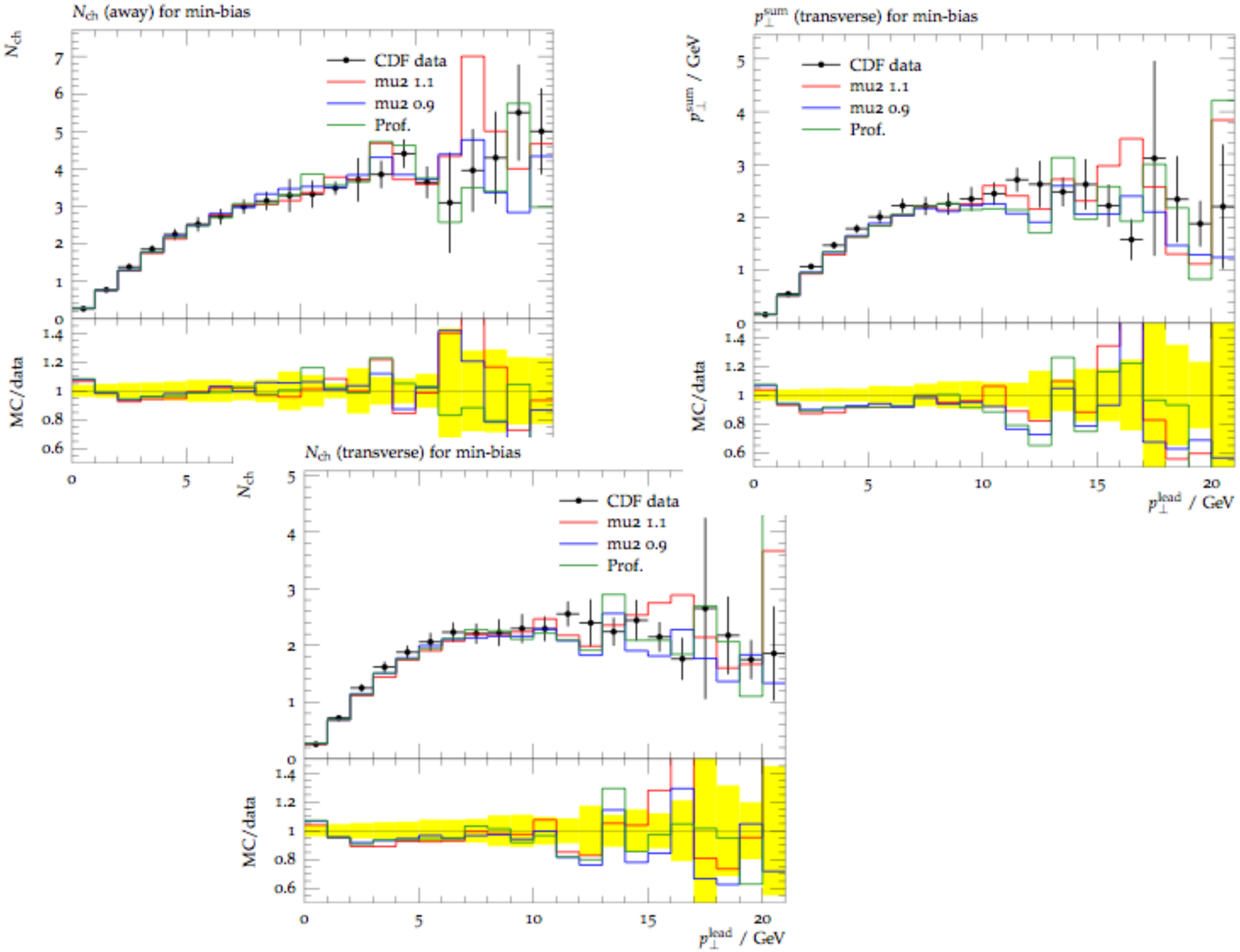
Parameter tuning

- Procedure:
  - fix parton shower and hadronization parameters to LEP data, as a function of colour reconnection p_{reco}
  - choose a total cross section and elastic slope parameter $\Rightarrow A_{soft,inc}(b)$ and $\sigma_{tot,inc}$
  - fit $A_{hard,inc}(b)$, $p_{t,min}$ ($\Rightarrow \sigma_{hard,inc}$ and $\sigma_{soft,inc}$) and p_{reco} to minimum bias and underlying event data

Underlying event at 900 GeV



Underlying event at 1800 GeV



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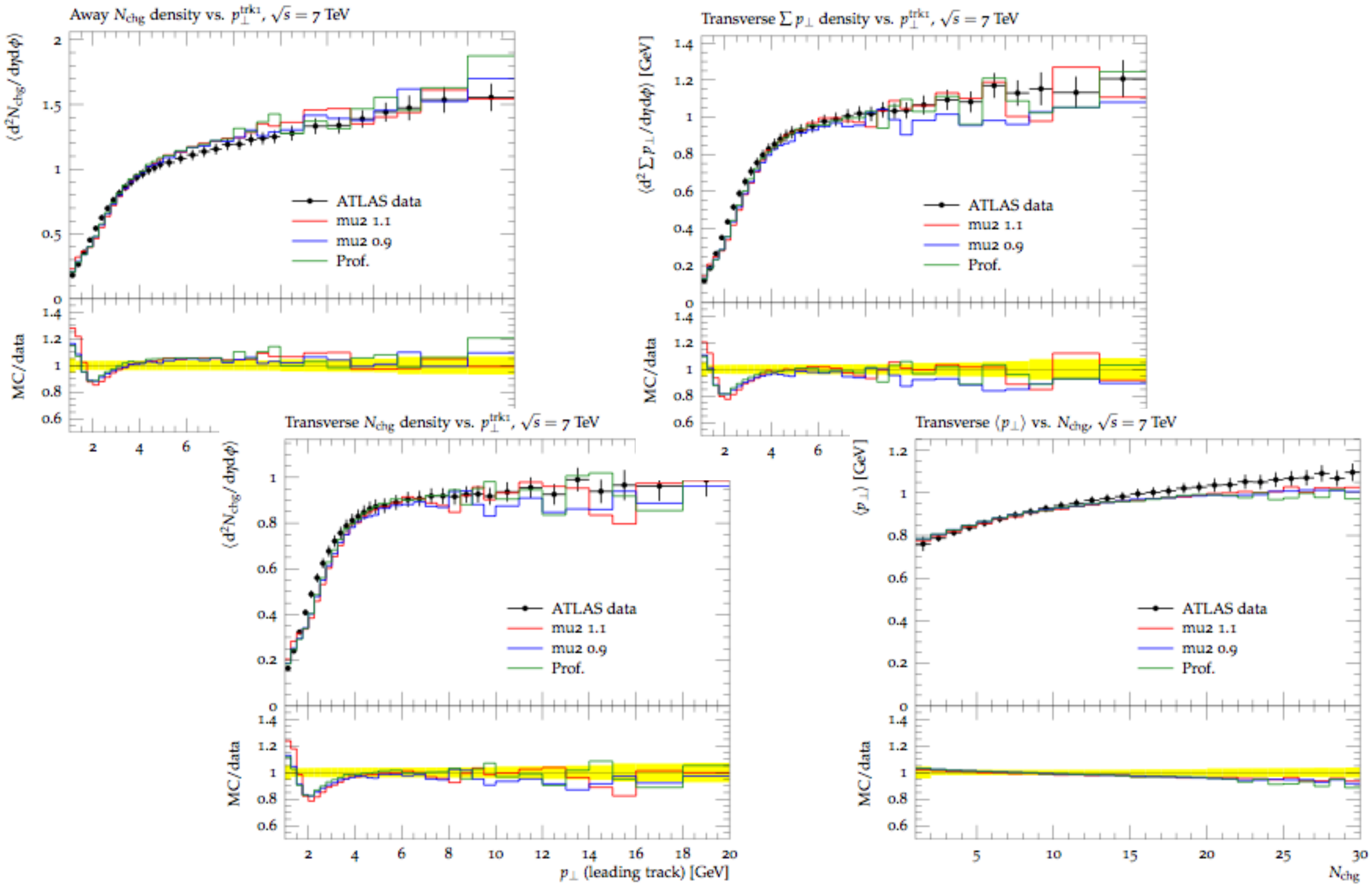
Underlying event at 7000 GeV



Tuning conclusion

- Not possible to fit with energy-independent parameters
- Possible to fit with energy-dependent $p_{t,min}$ and all else energy-independent
- e.g.

For μ^2=	1.1 GeV^2	0.9 GeV^2
and $\sqrt{s}$=	PTMIN=	PTMIN=
900	2.34	2.17
1800	3.09	2.80
2760	3.31	2.92
7000	4.02	3.36

Prediction/ Recommendation

Tuning conclusion

- Not possible to fit with energy-independent parameters
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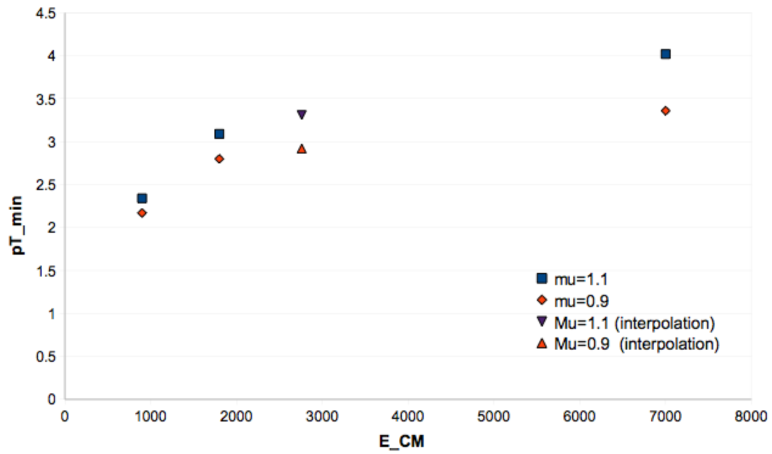
- e.g.



Tuning conclusion

- Public version: 2.5.0, released 8th Feb 2011
  - does not come with latest tuned values
    - check http://projects.hepforge.org/herwig/trac/wiki/MB_UE_tunes for updates

x-dependent matter distributions

- Most existing models use factorization of x and b
  - or (Herwig++) crude separation into hard and soft components (simple hot-spot model)
- R.Corke and T.Sjöstrand, arXiv:1101.5953 consider Gaussian matter distribution with width

$$a(x) = a_0 \left(1 + a_1 \ln \frac{1}{x}\right)$$

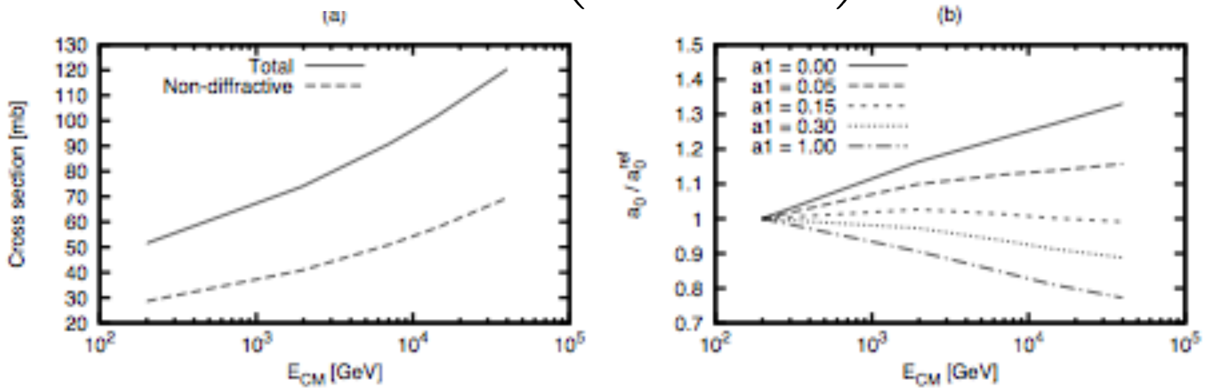


Figure 1: (a) The rise of the total and non-diffractive pp cross section with energy, and (b) the ratio $a_0(E_{CM})/a_0(200\,\mathrm{GeV})$, over the same energy range, for a set of different a_1 values

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$$a(x) = a_0 \left(1 + a_1 \ln \frac{1}{x}\right)$$

- for $a_1 \approx 0.15$, matter distribution can be E-indep

x-dependent matter distributions

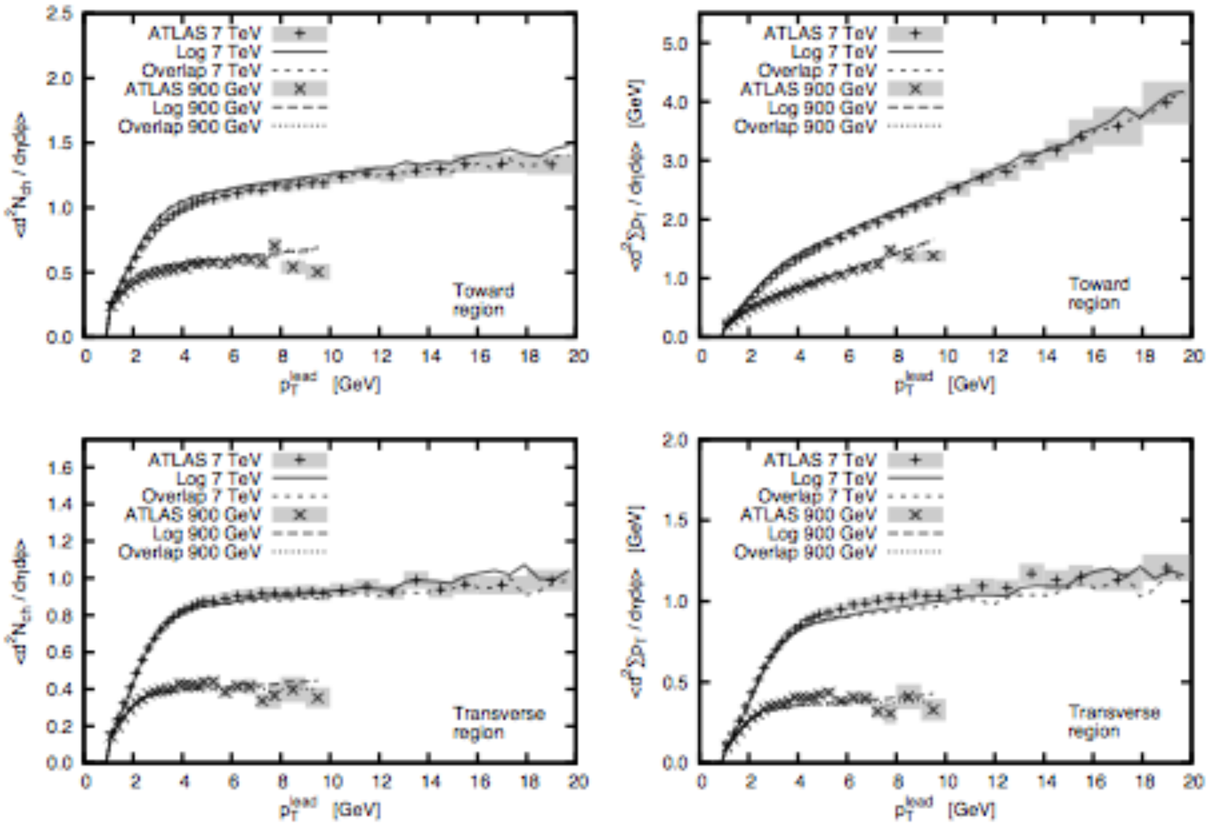

Figure 11: Tune 4C, using the log profile, and with a raised $p_{\perp 0}$ in the MPI framework, compared against an overlap profile with $p = 1.6$, also with a raised $p_{\perp 0}$, and LHC data

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x-dependent matter distributions

- (My) conclusion: for soft inclusive and jet underlying event data compatible with data but not required, but sheds interesting light on energy dependence
- Interesting correlation with hardness of hard scatter, e.g. less underlying event in 1 TeV Z' events than in Z events

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Conclusions

- Despite ~25 year history, multi-parton interaction models are still in their infancy
- LHC experiments'
  - step up in energy
  - high efficiency, purity and phase space coverage
  - emphasis on physical definition of observables

  have given us a huge amount of *useful* data
- existing models describe data well with tuning
- need more understanding of correlations/corners of phase space/relations between different model components

Conclusions

- don’t forget that jet corrections depend on correlations and high moments of distributions and are physics-process dependent

Backup slides

'Interesting features' of Herwig++ #1

- The additional scatters are not p_t ordered, so it can occasionally happen that a high p_t jet comes from a low p_t primary scattering event
  - this is a disaster if you generate weighted primary scatters or mix event samples with different p_t ranges
  - it is safe to remove such events from your sample
    - provided they are a small fraction of the eikonal cross section
    - i.e. provided it is an underlying event not part of a soft inclusive sample

‘Interesting features’ of Herwig++ #2

- Soft inclusive event generation is built on top of the underlying event machinery: a fictional (totally ineffective) hard process is needed
  - unfortunately ThePEG does not know about this and reports the cross section of the fictional process as the total cross section
    - needs to be fixed! But in the meantime, extract the correct cross section from the log file!

‘Interesting features’ of Herwig++ #3

- Double- (or more) scattering is built in - just select a list of the hard processes you want to include in each event
  - unfortunately ThePEG does not know about this and reports the cross section of the first process as the total cross section
    - needs to be fixed! But in the meantime, extract the correct cross section from the log file!