Overview of MC Models

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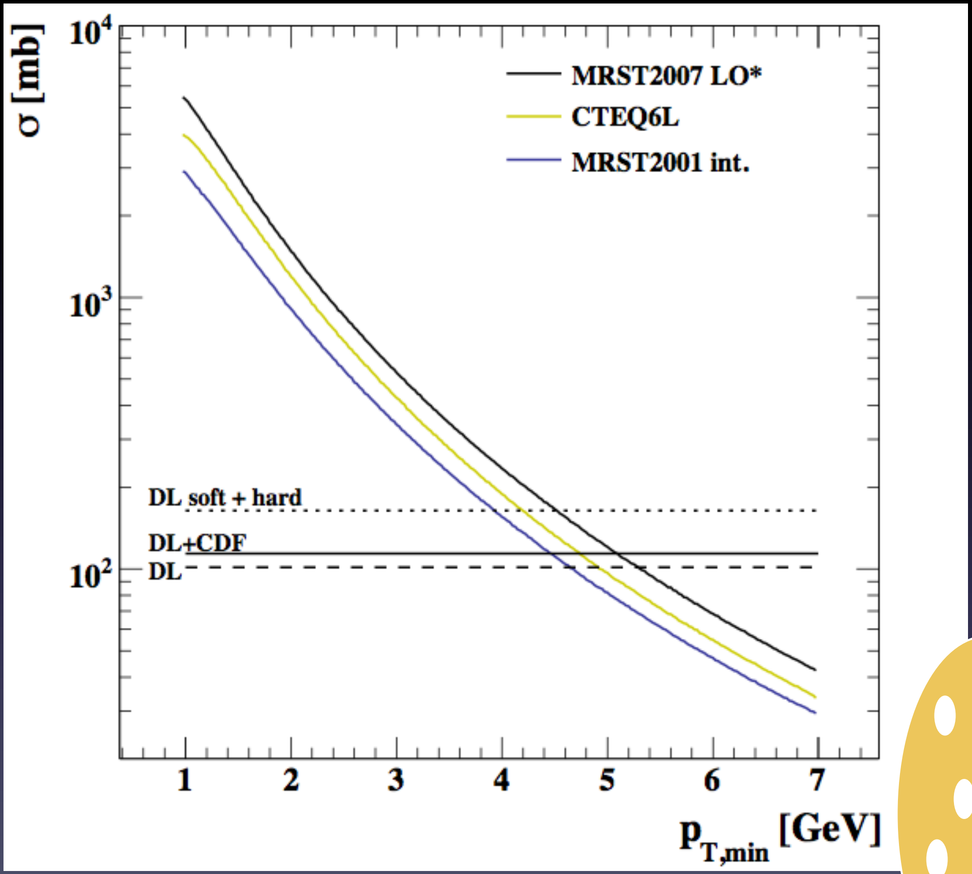
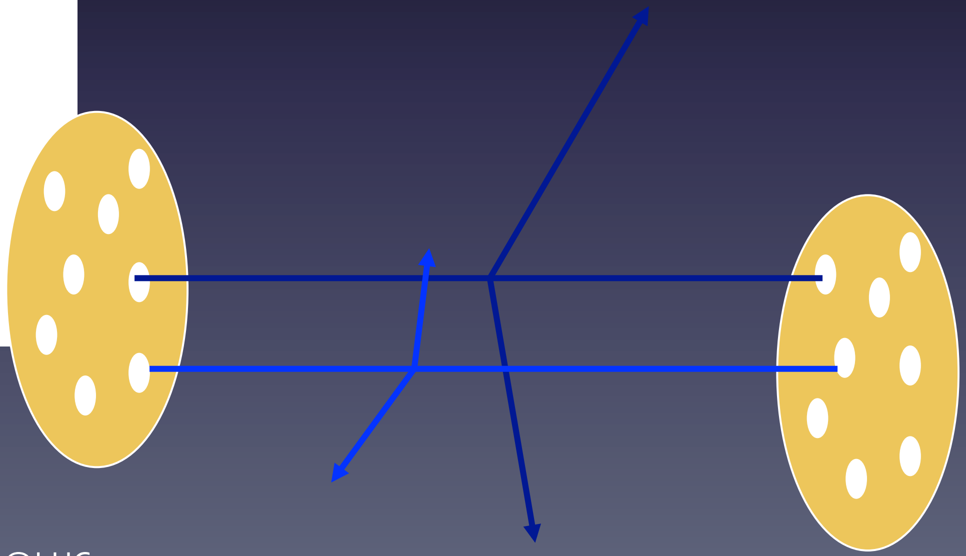
Overview of MC Models of MPI





Overview of MC Models of MPI

- Herwig++
- Pythia 8
- Sherpa → Korinna Zapp
- DIPSY → Leif Lönnblad
- EPOS → MPI@LHC 2012

MPI Model Basics (Herwig & Pythia)

- Matter distributions
- Model of low-p_t scattering
- Colour connections

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 later)

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

- ⇒ scatters Poissonian at fixed impact parameter

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

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

Aside 1: Inclusive Cross Sections

- Defining cross section inclusively: $$\sigma_{incl\,\mathrm{i}} \equiv \frac{N_{\mathrm{i}}}{\mathcal{L}}$$
- Reproduces partonic cross section: $$\sigma_{incl\,\mathrm{i}} = \sum_n n\,\sigma_{n\mathrm{i}} = \sigma_{\mathrm{i}}$$

- see MHS & A. Siodmok: arXiv:1308.6749

Aside 1: Inclusive Cross Sections

- Analogous double-inclusive cross section is:

$$\sigma_{incl\mathrm{ii}} = \sum_n \tfrac{1}{2} n(n-1)\sigma_{n\mathrm{i}}$$

$$\sigma_{incl\mathrm{ij}} = \sum_{n,m} n\, m\, \sigma_{n\mathrm{i},m\mathrm{j}}$$

$$\sigma_{incl\mathrm{ii}} = \frac{1}{2}\sigma_{\mathrm{i}}^2 \int \mathrm{d}^2 b\, A(b)^2$$

$$\sigma_{incl\mathrm{ij}} = \sigma_{\mathrm{i}}\, \sigma_{\mathrm{j}} \int \mathrm{d}^2 b\, A(b)^2$$

$$\sigma_{\mathit{eff}} = \frac{\sigma_{incl\mathrm{i}}^2}{2\sigma_{incl\mathrm{ii}}} = \frac{\sigma_{incl\mathrm{i}}\, \sigma_{incl\mathrm{j}}}{\sigma_{incl\mathrm{ij}}} = \frac{1}{\int \mathrm{d}^2 b\, A(b)^2}$$

Aside 1: Inclusive Cross Sections

- Other cross section definitions do not give process-independent A(b)!

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 ⇒ size and σ_{inc}

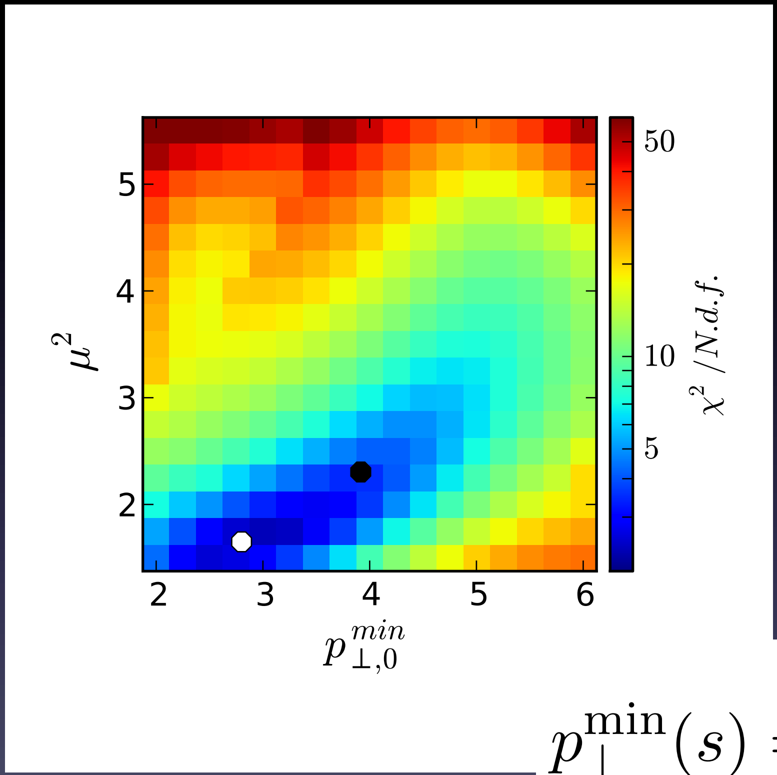
Bähr, Butterworth & MHS, JHEP 0901:067, 2009

- too restrictive ⇒

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

- ⇒ two free parameters

The Herwig++ Model



$$p_\perp^{\min}(s) = p_{\perp,0}^{\min}\left(\frac{\sqrt{s}}{E_0}\right)^b$$

- see A. Siodmok's talk →

The Pythia Model

- Double Gaussian matter distribution
- Replace σ_{tot} by σ_{NSD}
- Consider x-dependent matter distribution

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

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

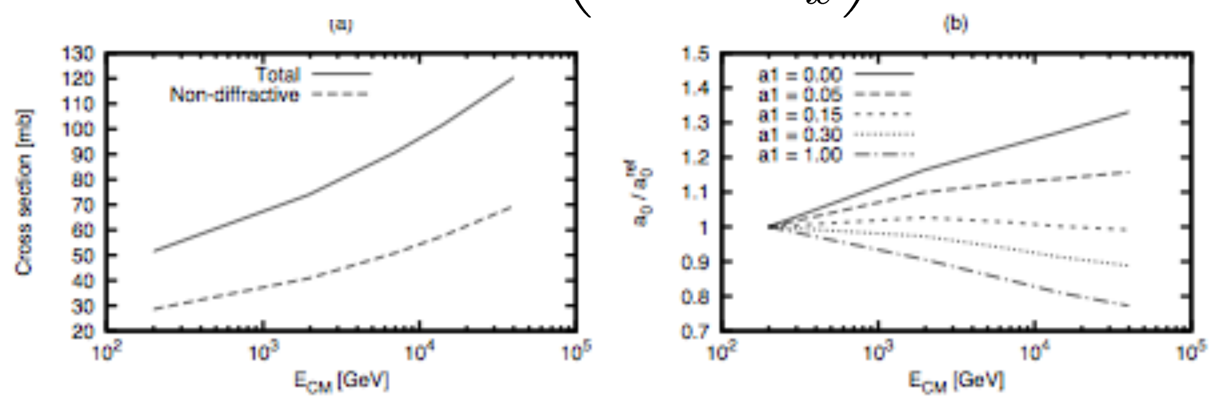


Figure 1: (a) The rise of the total and non-diffractive pp cross section with energy, and (b) the ratio $a_0(E_{CM})/a_0(200\,\mathrm{GeV})$, over the same energy range, for a set of different a_1 values

x-dependent matter distributions

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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

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- Model of low-p_t scattering
- Colour connections

Low p_t scattering - Pythia

- Use perturbative cross sections right down to p_t=0, with regulator p_{t0}

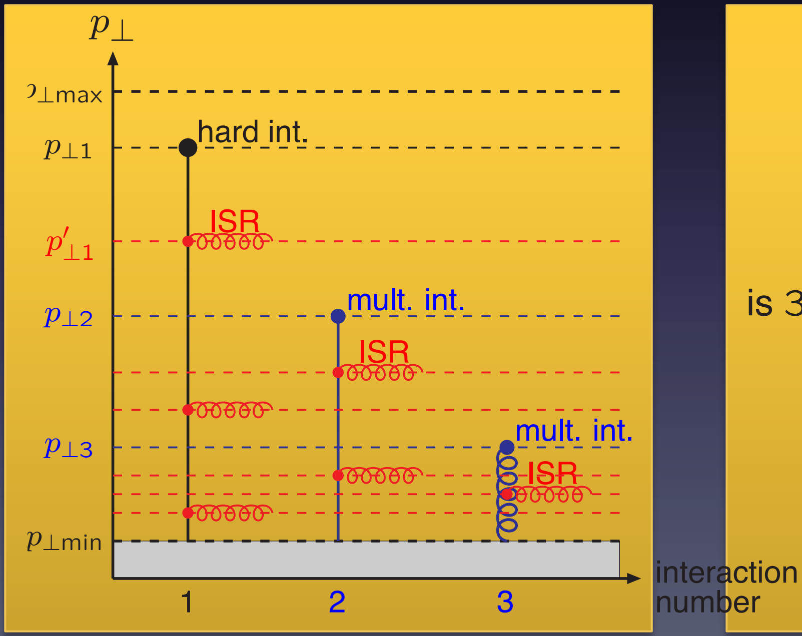
Pythia implementation

(4) Evolution interleaved with ISR

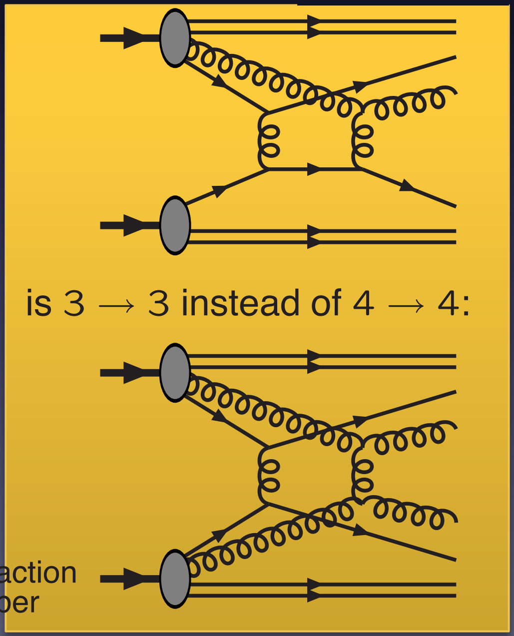
- Transverse-momentum-ordered showers

$$\frac{d\mathcal{P}}{dp_\perp} = \left(\frac{d\mathcal{P}_{MI}}{dp_\perp} + \sum \frac{d\mathcal{P}_{ISR}}{dp_\perp}\right) \exp\left(-\int_{p_\perp}^{p_{\perp i-1}} \left(\frac{d\mathcal{P}_{MI}}{dp'_\perp} + \sum \frac{d\mathcal{P}_{ISR}}{dp'_\perp}\right) dp'_\perp\right)$$

with ISR sum over all previous MI



(5) Rescattering

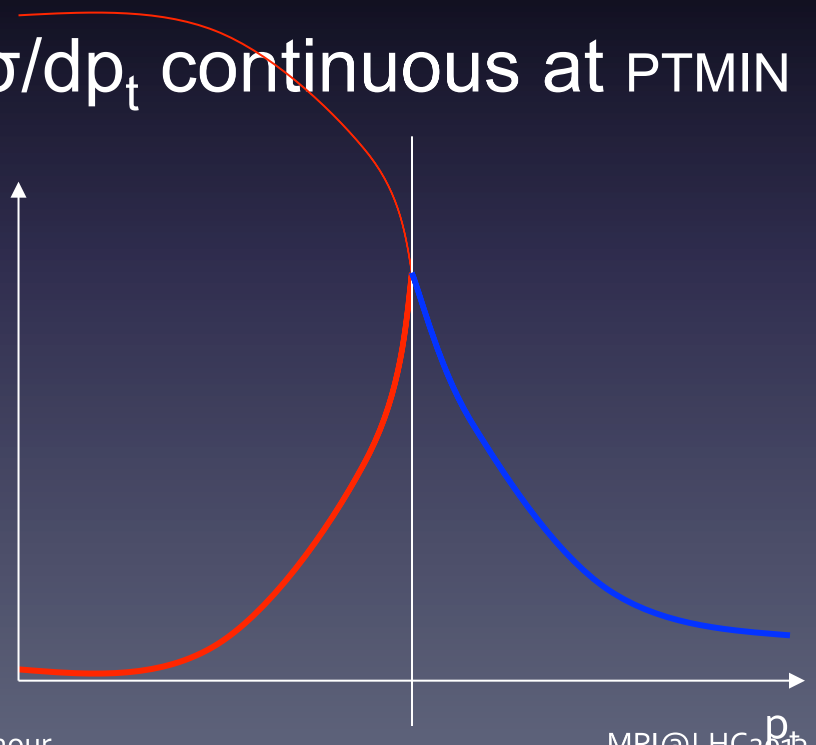


Low p_t scattering - Herwig

- View $p_{t,min}$ as a transition scale between hard and soft scatters…

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?

MPI Model Basics (Herwig & Pythia)

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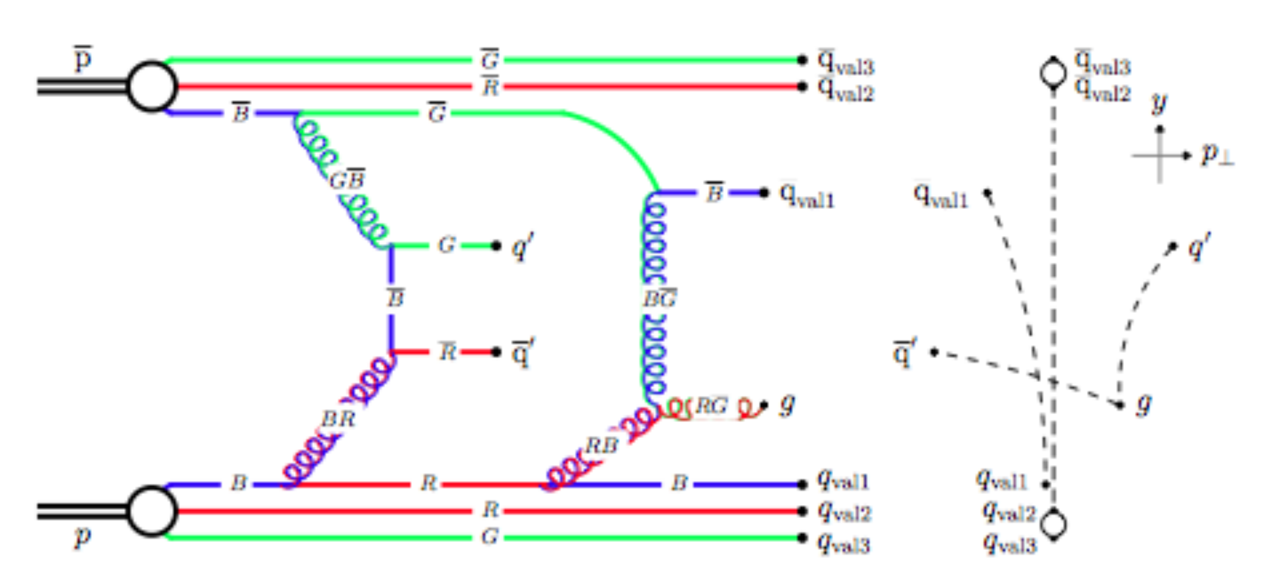
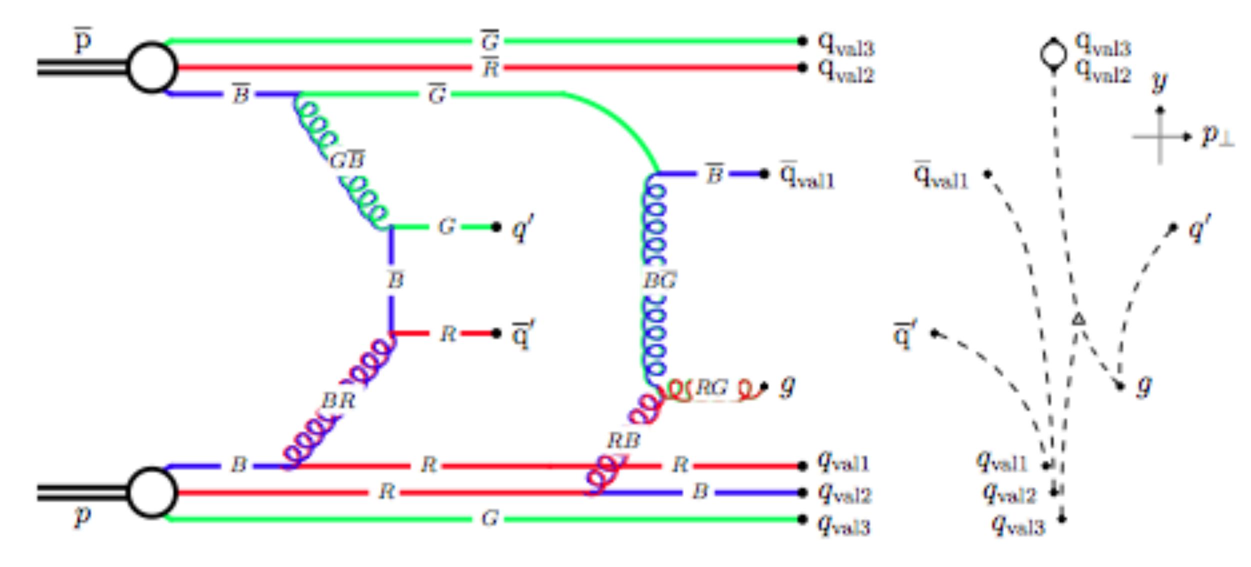
Colour correlations

Can have a big influence on final states



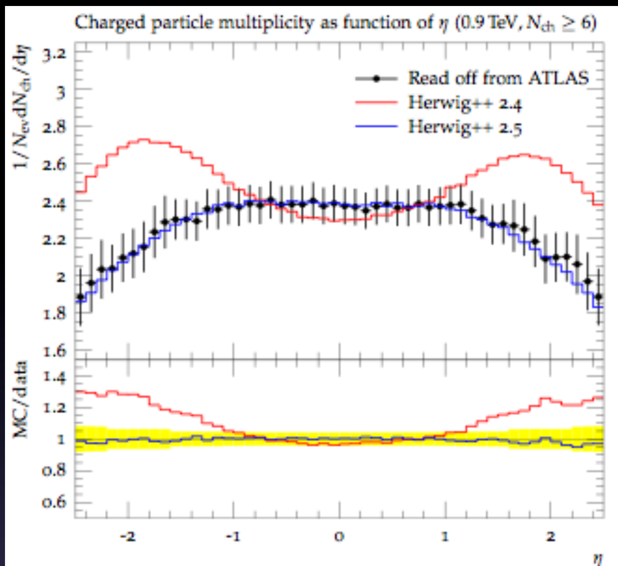


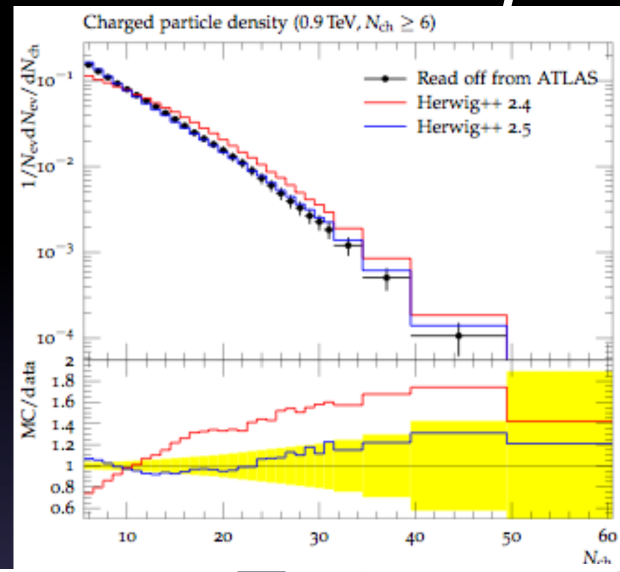
→ see later

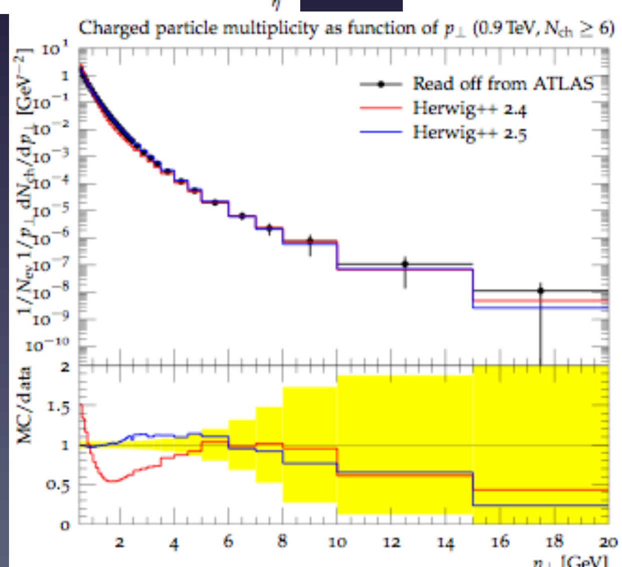
Herwig - colour reconnection model

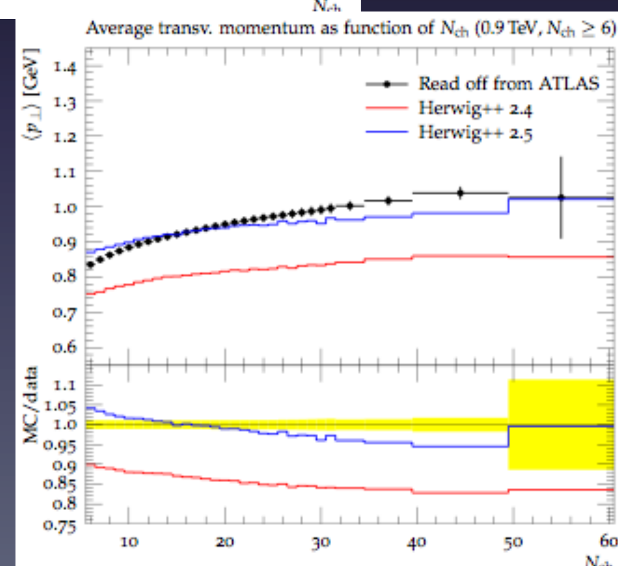
- Röhr, Siodmok and Gieseke implemented new model based on momentum structure
- Refit LEP-I and LEP-II data
- Conclusion: hadronization parameters correlated with reconnection probability, but good fit can be obtained for any value of p_{reco}

Colour reconnection model/MPI tuning





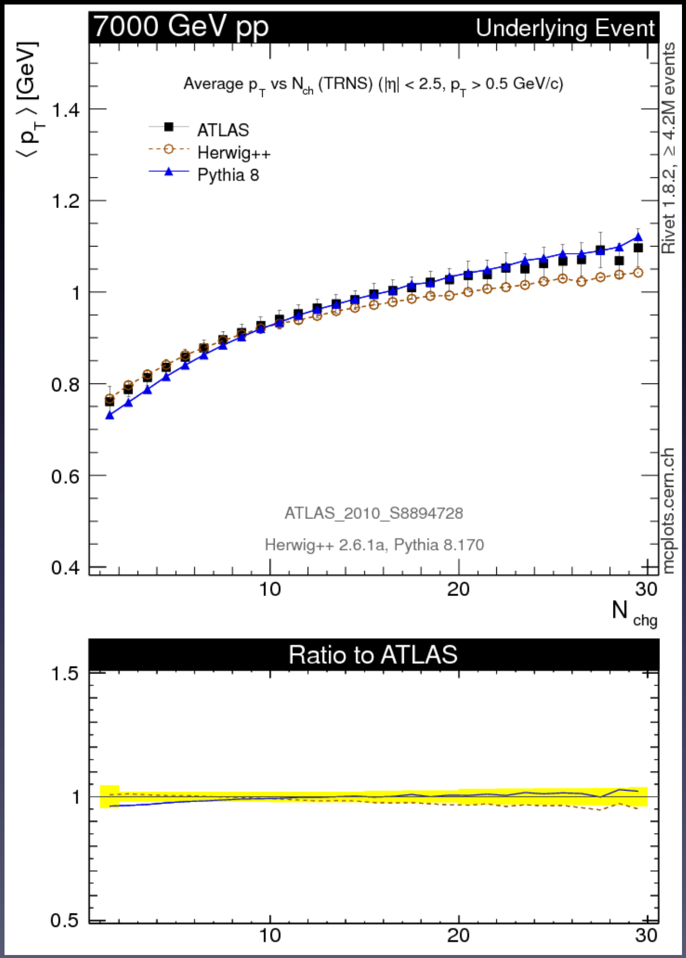


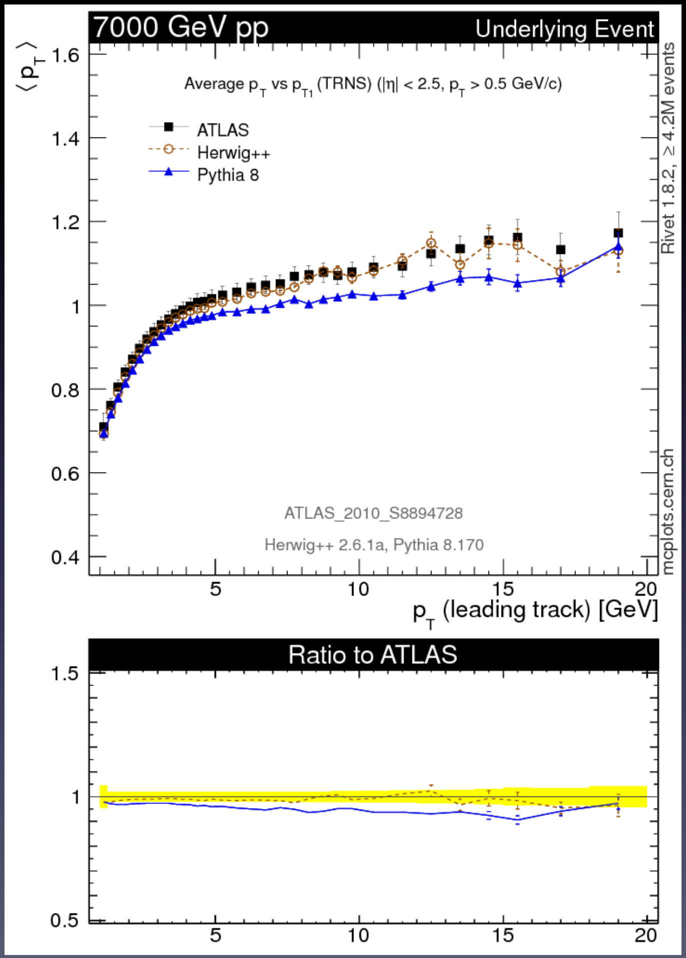


Description of Data…

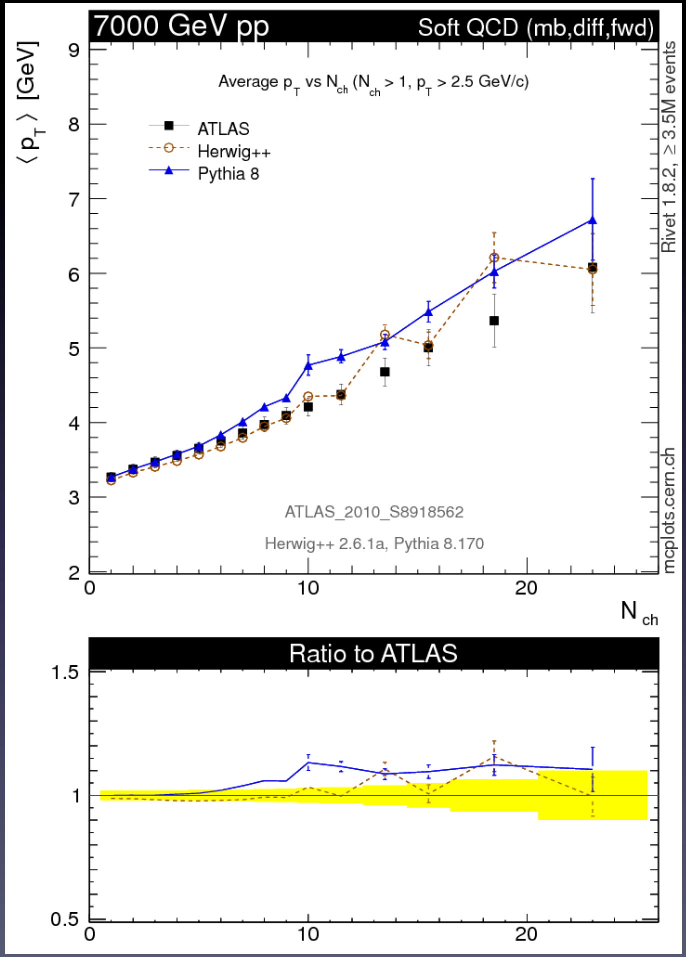
- Not a review, but some snapshots…

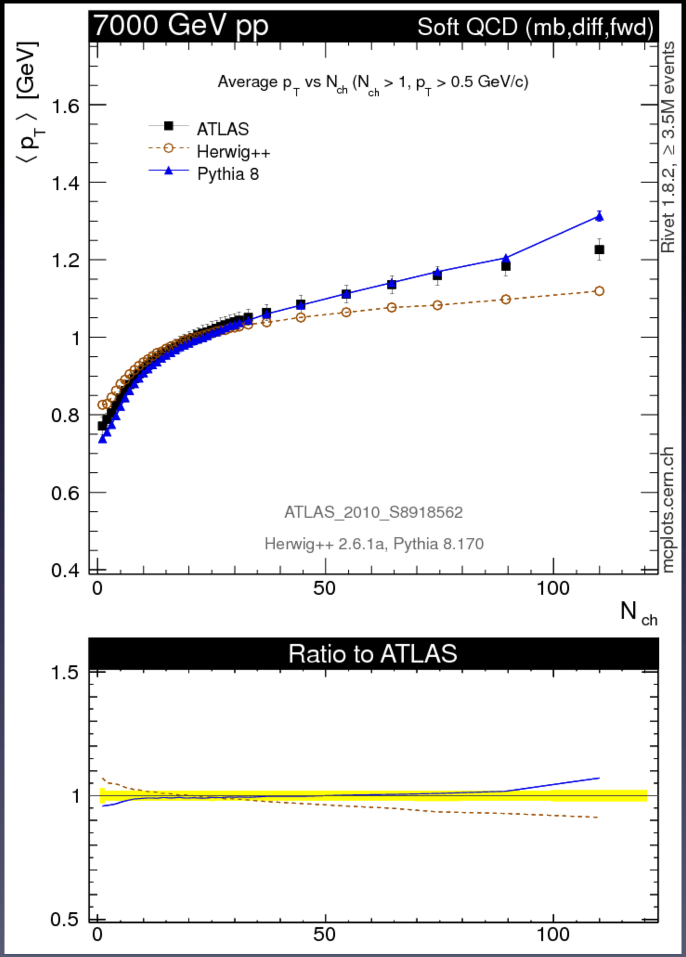
Underlying Event (Trans region)





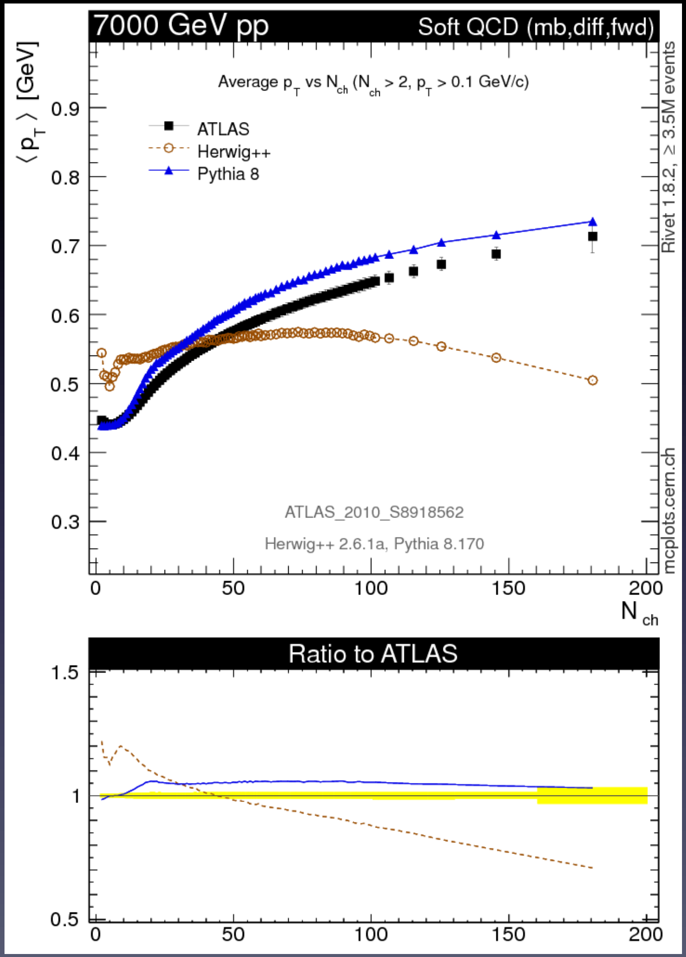
Minimum bias events

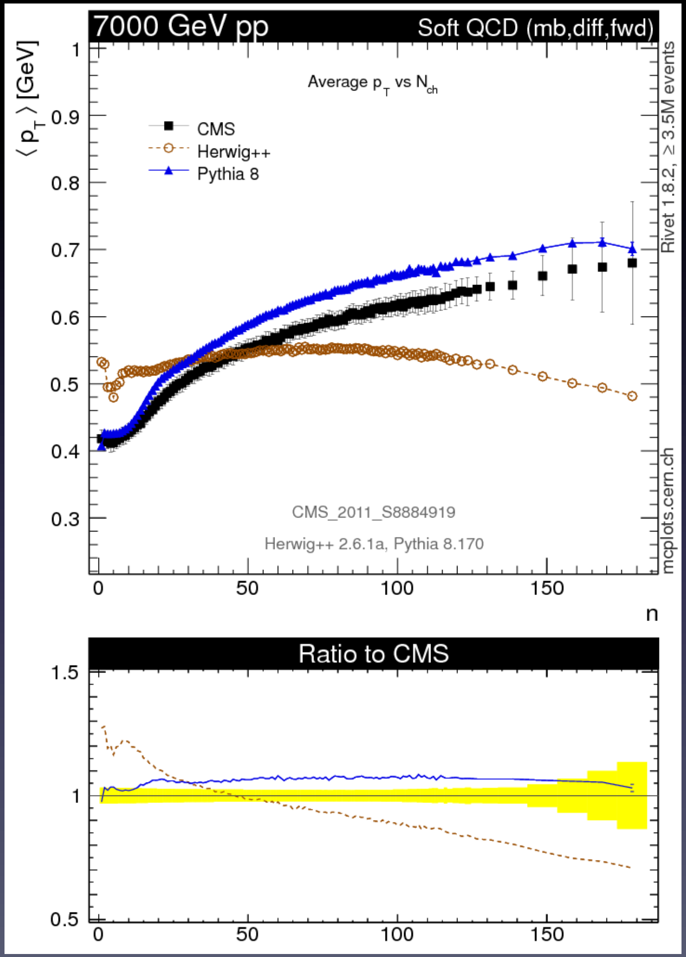




Herwig too flat for soft hadrons

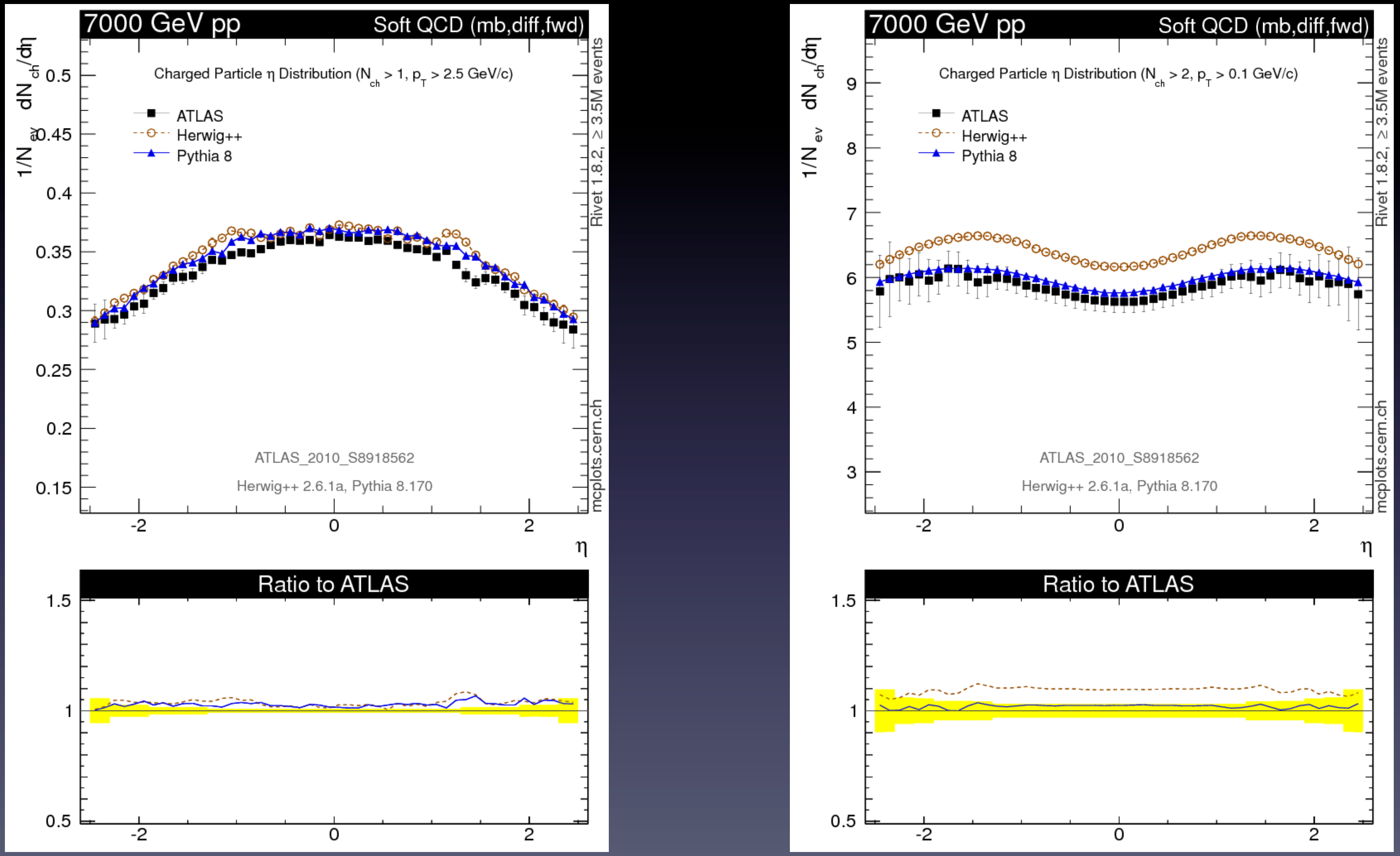
Minimum bias events





increasingly so for very soft hadrons

Minimum bias events

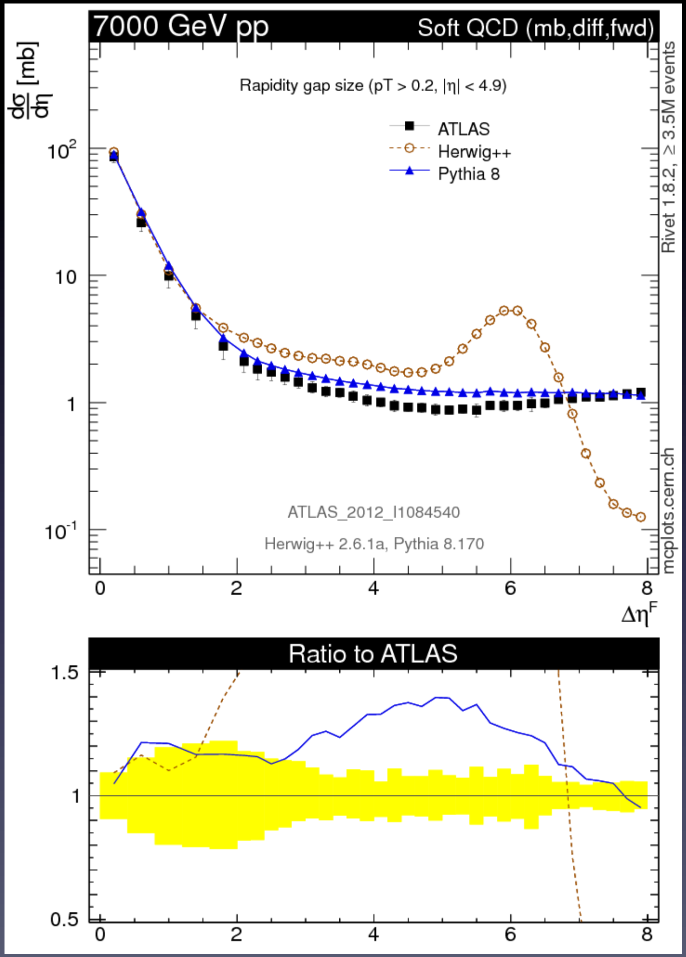


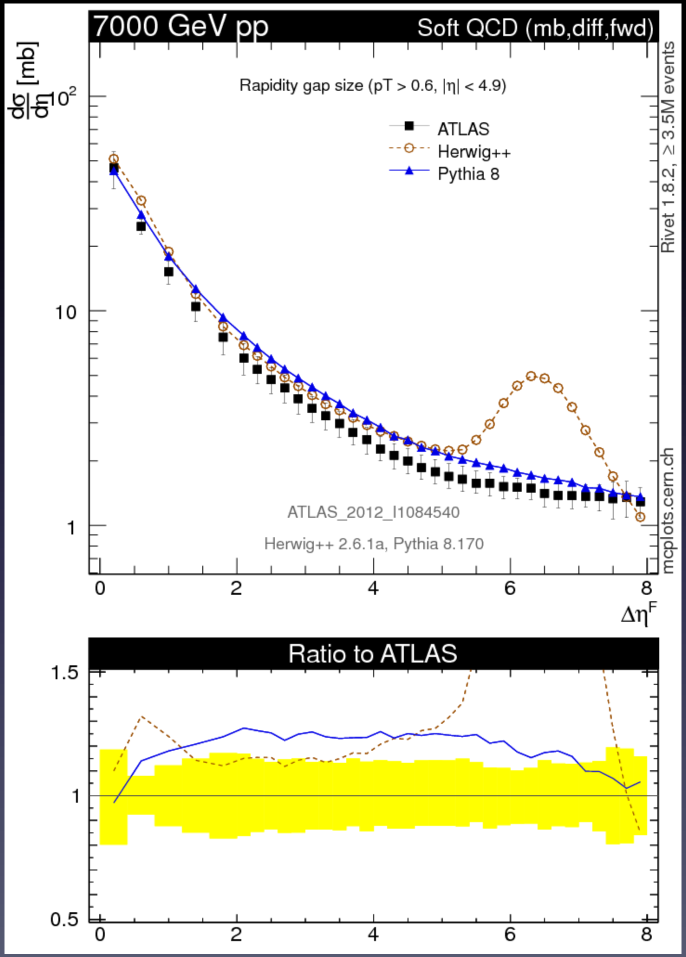
and too many soft hadrons

Herwig's dirty laundry…

- Forward gaps:
  1. Takes eikonal model seriously ⇒ should produce all inelastic events, including diffractive
     - but no diffractive model! → in progress
  2. Despite this, produces too many rapidity gaps

Forward rapidity gaps distn.





Forward rapidity gaps distn.

- “Bump” events are only those with no hard scatters
  - related to colour structure of soft scatters?
  - colour connection between soft and hard scatters?

Herwig 2.7.0

- released 25 Oct 2013
- an interface to the Universal FeynRules Output (UFO) format allowing the simulation of a wide range of new-physics models;
- developments of the Matchbox framework for next-to-leading order (NLO) simulations;
- better treatment of QCD radiation in heavy particle decays in new-physics models;
- a new tune of underlying event and colour connection parameters that allows a good simultaneous description of both Tevatron and LHC underlying event data and the effective cross-section parameter for double-parton scattering.

Summary

- (Herwig and Pythia) MPI models well developed and describe underlying event data well
  – also $\sigma_{eff} \rightarrow$ A. Siodmok
- Herwig some problems for min bias
  – increasingly so for very soft events, and very gappy events
- Data increasingly sensitive probe of colour structures and connections

Aside 2: *A(b)* definitions

- Recall

$$\sigma_{ij} = \int \sigma_i \, \sigma_j \, A(b)^2 \, \mathrm{d}^2 b$$

- = convolution over two *x*s and two *b*s in each hadron

$$\int A(b)^2 \, \mathrm{d}^2 b = \int \mathrm{d}^2 b_1 G(b_1) \, \mathrm{d}^2 b_2 G(b_2) \, \mathrm{d}^2 b_3 G(b_3) \, \mathrm{d}^2 b_4 G(b_4) \, \mathrm{d}^2 b \, \delta(b - b_1 + b_2) \delta(b - b_3 + b_4)$$

- identical to convolution over two *b*s in the same hadron

$$\begin{aligned} \int A(b)^2 \, \mathrm{d}^2 b &= \int \mathrm{d}^2 b_1 G(b_1) \, \mathrm{d}^2 b_3 G(b_3) \, \delta(B - b_1 + b_3) \, \mathrm{d}^2 b_2 G(b_2) \, \mathrm{d}^2 b_4 G(b_4) \, \delta(B - b_2 + b_4) \, \mathrm{d}^2 B \\ &= \int A(B)^2 \, \mathrm{d}^2 B \end{aligned}$$

Aside 2: *A(b)* definitions

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- *A(B)* is a single-hadron property

$$n(x_1, x_3, b_1, b_3) = f(x_1)G(b_1)\, f(x_3)G(b_3)$$

- natural framework to include correlations

$$n(x_1, x_3, b_1, b_3) = f(x_1)\, f(x_3)\, G(b_1, b_3)$$

- but extension to triple- scattering (and higher) ?