Multiple Interactions in PYTHIA with Rescattering

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2. **MI in PYTHIA**
3. **Rescattering**
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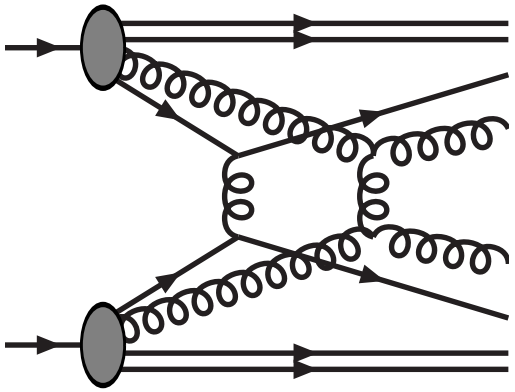
Multiple Interactions (MI)

Introduction

- Hadrons are composite objects
  - Possibility of several parton pairs interacting
- Can lead to non-trivial changes to colour topology in events, even if interactions are soft
- Essential for understanding minimum-bias physics and the underlying event

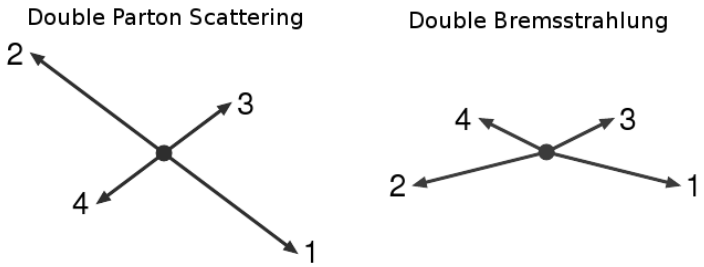


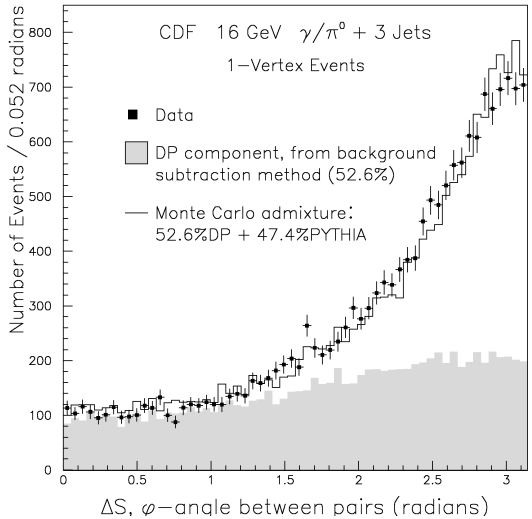
Multiple Interactions and the Structure of Beam Remnants, T. Sjöstrand, P. Skands, JHEP **0403** (2004) 053

Multiple Interactions (MI)

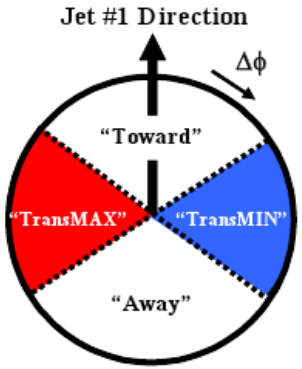
Some experimental evidence

- UA5 charged multiplicity data not explained by simple LEP based hadronisation models
  - Greatly improved agreement when MI is introduced
- Direct observation from 3-jet + prompt photon production at CDF

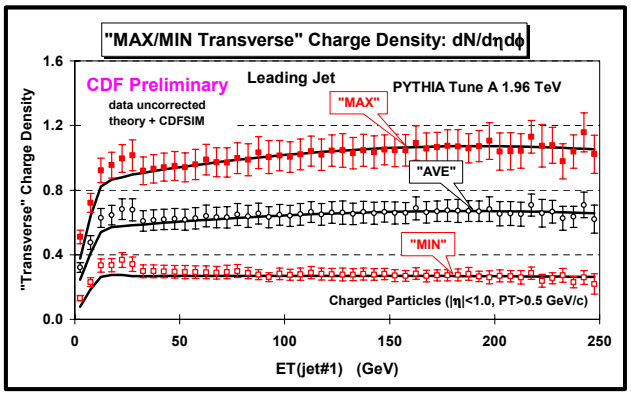




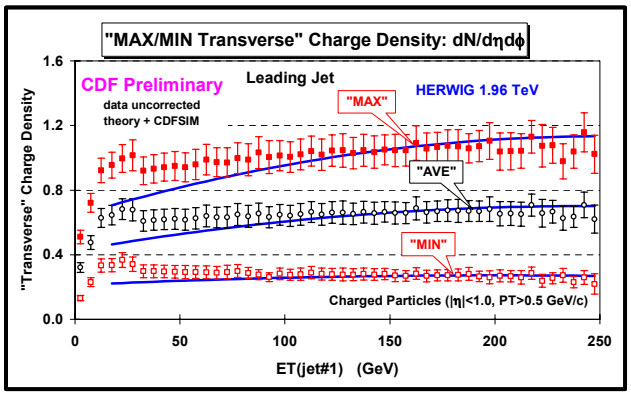
- Underlying event studies by R. Field



PYTHIA Tune A



HERWIG

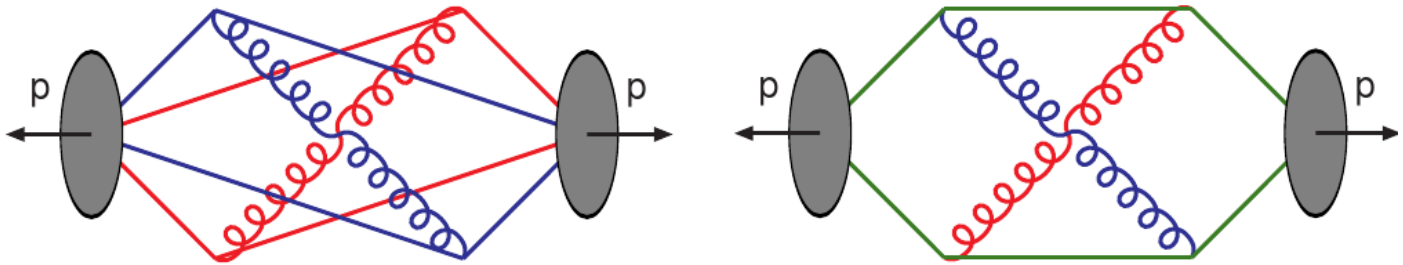


MI in PYTHIA

- Original model, T. Sjöstrand and M. van Zijl, 1987
  - Peturbative QCD and $p_\perp$ ordering
  - $2 \to 2$ cross section divergent, but colour screening effects

$$\frac{\mathrm{d}p_\perp^2}{p_\perp^4} \to \frac{\mathrm{d}p_\perp^2}{(p_{\perp 0}^2 + p_\perp^2)^2}$$

  - Variable impact parameter with a double gaussian matter distribution
  - Simple PDF rescaling to conserve energy/momentum
  - Colour reconnection



  - No parton showers for subsequent interactions
- Next generation model, T. Sjöstrand and P. Skands, 2004
  - Improved PDF rescaling (flavour modification)
  - Common interleaved $p_\perp$ scale for ISR, FSR and MI
  - Radiation from all interactions

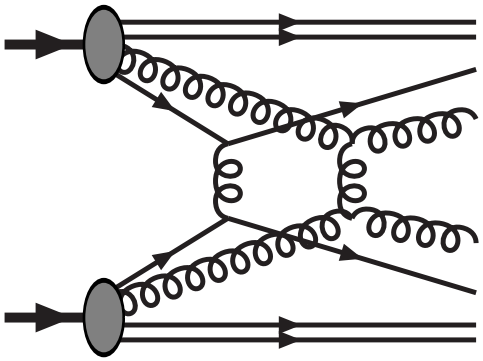
Rescattering

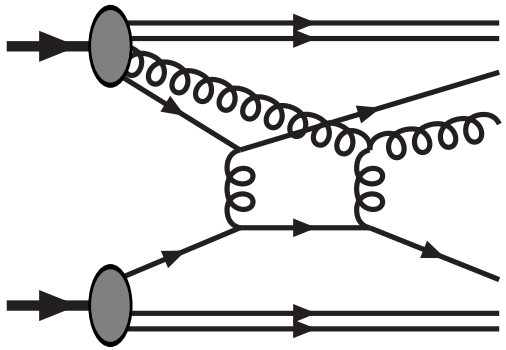
Concept

- Interaction cross-section

$$\frac{\mathrm{d}\sigma_{\mathrm{int}}}{\mathrm{d}p_\perp^2} = \sum \int \mathrm{d}x_1 \int \mathrm{d}x_2 \int f_1(x_1, Q^2)\, f_2(x_2, Q^2)\, \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}p_\perp^2}$$

- Consider a $4 \to 4$ and a $3 \to 3$ process





- Roughly speaking

$$\frac{\mathrm{d}\sigma_{\mathrm{int}}}{\mathrm{d}p_\perp^2} \sim N_1 N_2\, \hat{\sigma}$$

$$\sigma_{4\to4} \sim (N_1 N_2\, \hat{\sigma})(N_1' N_2'\, \hat{\sigma}) \qquad \sigma_{3\to3} \sim (N_1 N_2\, \hat{\sigma})(N_1'\, \hat{\sigma})$$

$$\frac{\sigma_{3\to3}}{\sigma_{4\to4}} \sim \frac{1}{N_2'} \to \text{small}$$

Rescattering

Concept

- Typical case of small angle scatterings between partons from 2 incoming hadrons, such that they are still associated with their original hadrons

$$f(x, Q^2)\,\mathrm{d}x \rightarrow f(x, Q^2)_{rescaled}\,\mathrm{d}x + \sum_n \delta(x - x_n) = f_u(x, Q^2) + f_\delta(x, Q^2)$$

  where the subscript u/δ is the unscattered/scattered component

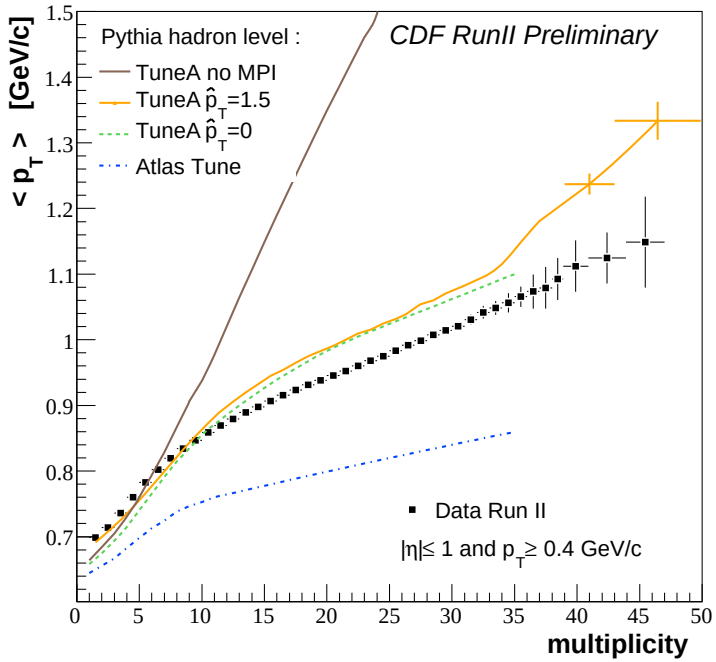
$$\int_0^1 x\, f_{rescaled}(x, Q^2) dx + \sum_n x_n = 1$$

- In general it is not possible to uniquely identify a scattered parton with one hadron. Use approximate prescription, e.g. rapidity based
- Possibility of u-δ, δ-u and δ-δ interactions in addition to original u-u.

Rescattering

Why? Some examples

- Multijet topologies - introduces a new source of 3-jet production
- Large primordial $k_\perp$ values needed to match data - currently no satisfactory explanation
- Data suggests a rise in mean $p_\perp$ with number of charged final state particles - large amount of colour reconnection needed to match this
- Rescattering may improve the situation slightly - more $p_\perp$ generated in perturbative region

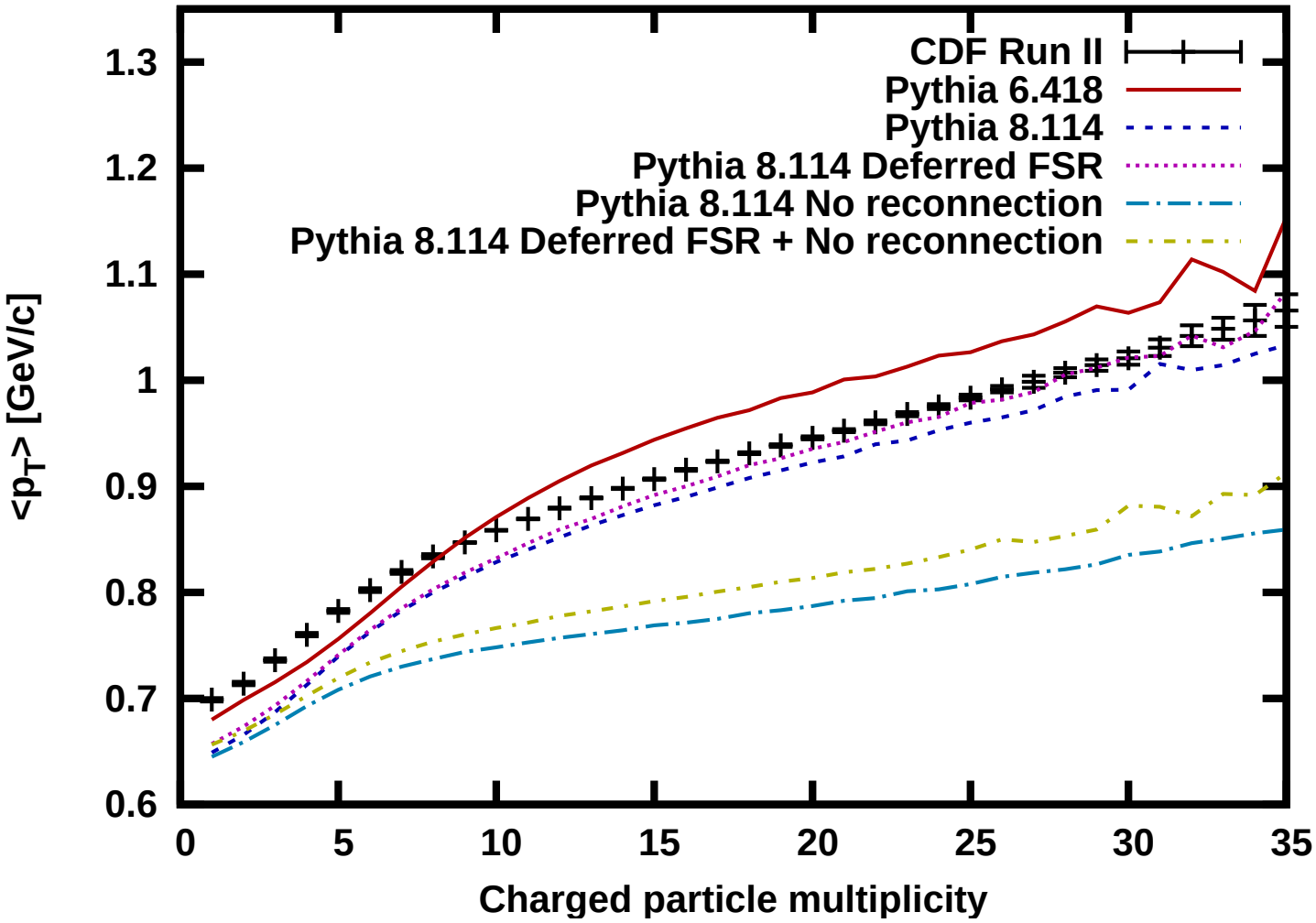


Mean $p_\perp$ as a function of multiplicity, CDF, Run II
Measurement of Inelastic $P\bar{P}$ Inclusive Cross Sections at $\sqrt{s}$=1.96 TeV, The CDF Collaboration, Preliminary

Rescattering

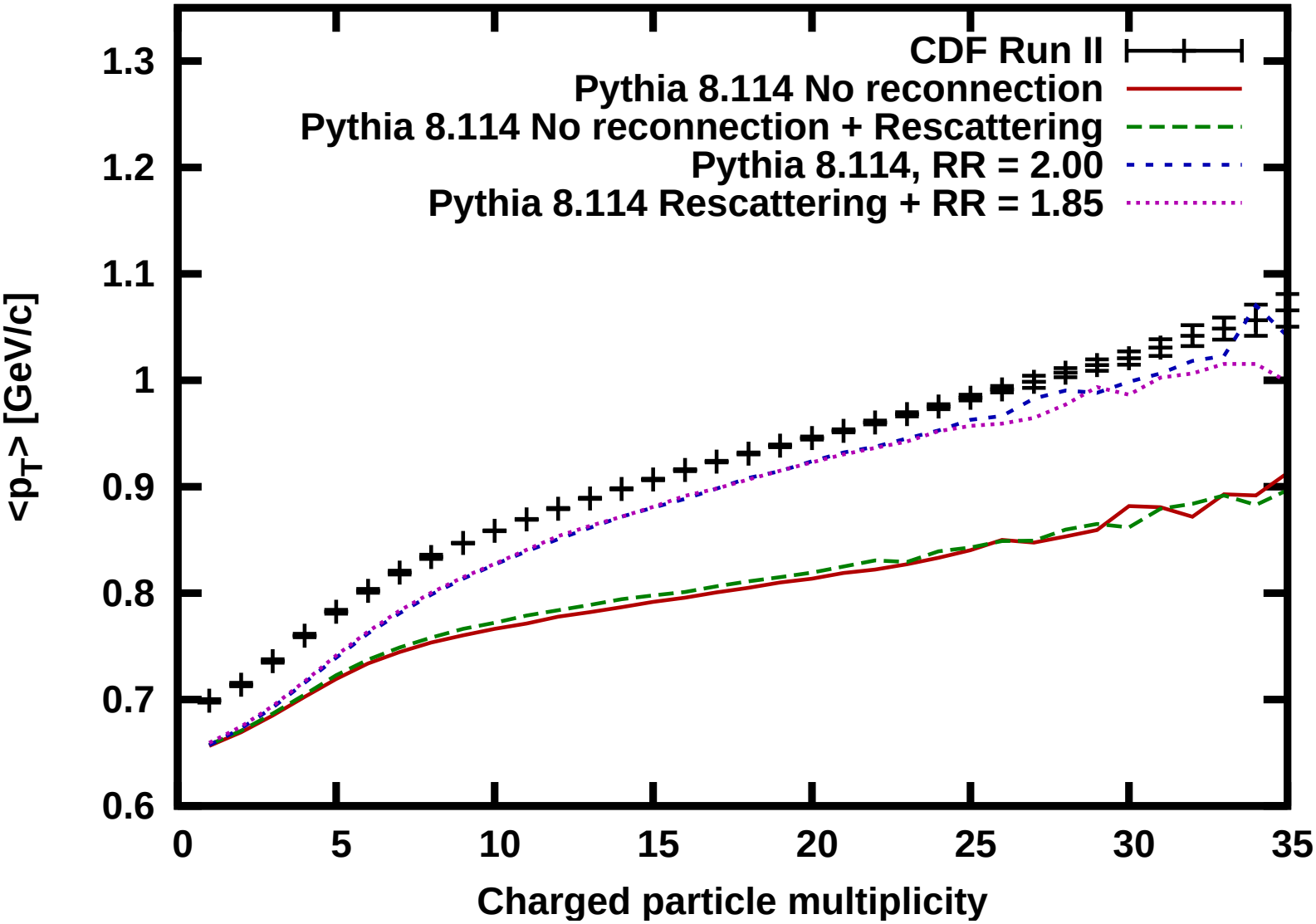
Status

- Non-trivial kinematics when combining ISR, FSR and primordial $k_\perp$
- Temporary solution of deferring FSR until after primordial $k_\perp$ is added



Rescattering

Results



Conclusions

- Framework in place to handle rescattering with ISR, primordial $k_\perp$, colour reconnection and hadronisation
- Fully interleaved FSR still to come
- Small increase in mean $p_\perp$ vs multiplicty
  - Can reduce colour reconnection by a small amount
- Other observables still to study e.g. 3-jet production rate
- Work in progress