Multiple Partonic Interaction

Brief introduction

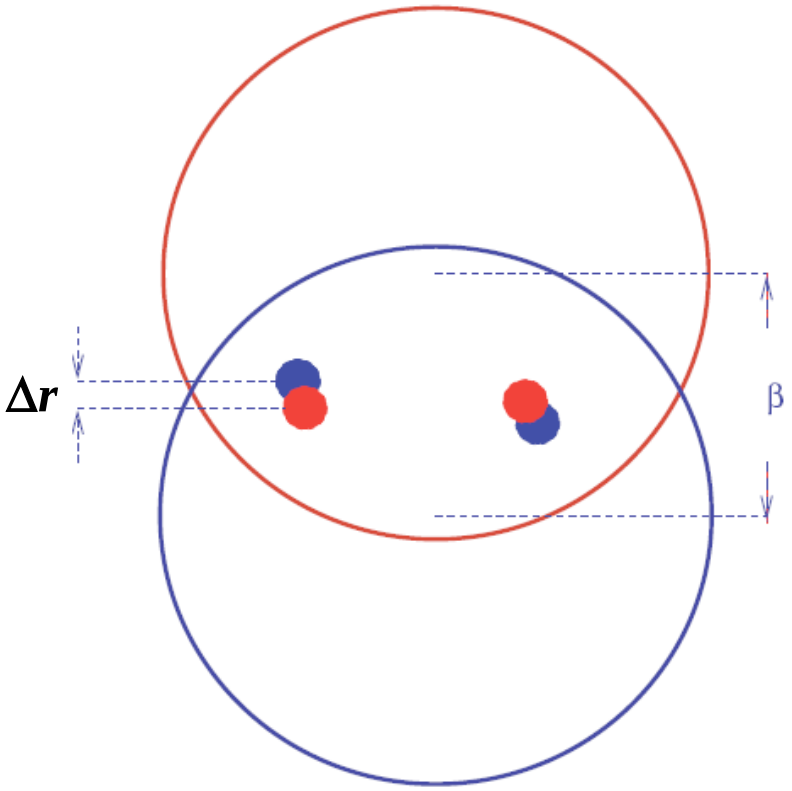
HD-Jet-Meeting
23.03.2009
Klaus Reygers

References

- **Papers:**
  - **Sjöstrand, van Zijl,**
    ***A Multiple Interaction Model for the Event Structure in Hadron Collisions*,**
    Phys. Rev. D36, 2019 (1987)
  - **Sjöstrand, Skands,**
    Multiple interactions and the structure of beam remnants,
    JHEP 03, 053 (2004)

- **Workshop:**
  MPI@LHC 2008 (first International Workshop on Multiple Partonic Interactions at the LHC):
  http://www.pg.infn.it/mpi08/index.htm

What are Multiple Partonic Interactions?



$$\Delta p_T^{\min} \cdot \Delta r \approx \hbar$$

$$\Delta r \approx \frac{\hbar c}{\Delta p_T^{\min} \cdot c} = \frac{0{,}2 \text{ GeV fm}}{\Delta p_T^{\min} \text{ (GeV)}}$$

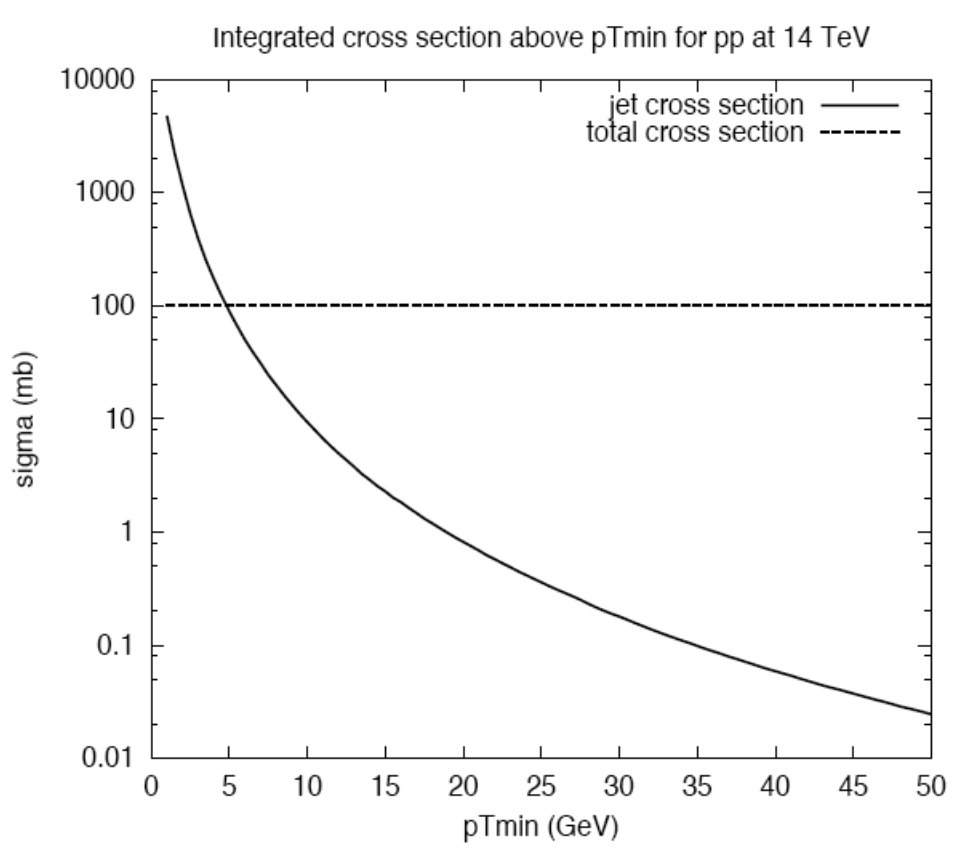
Multiple parton interaction:

- Two or more pairs of partons interacting in the same inelastic p+p collision
- Momentum transfer larger than some lower cut-off $p_T^{\min}$ which establishes the hard scale
- $p_T^{\min}$ should correspond to a transverse size much smaller than the overlap area
- Thus, the two interaction region are well separated in space and should contribute incoherently to the cross section

Multiple Partonic Interactions are Inevitable

Mini-jet cross section diverges for $p_{\perp\min} \to 0$:

$$\sigma_{\rm int}(p_{\perp\min}) = \int_{p_{\perp\min}}^{\sqrt{s}/2} \frac{{\rm d}\sigma}{{\rm d}p_\perp}\,{\rm d}p_\perp \propto \frac{1}{p^2_{\perp\min}}$$



Even for scales $p_{\perp\min} \gg \Lambda_{QCD}$ one has $\sigma_{\rm int}(p_{\perp\min}) > \sigma_{\rm tot}$

The number of hard interactions per p+p collisions is thus given by

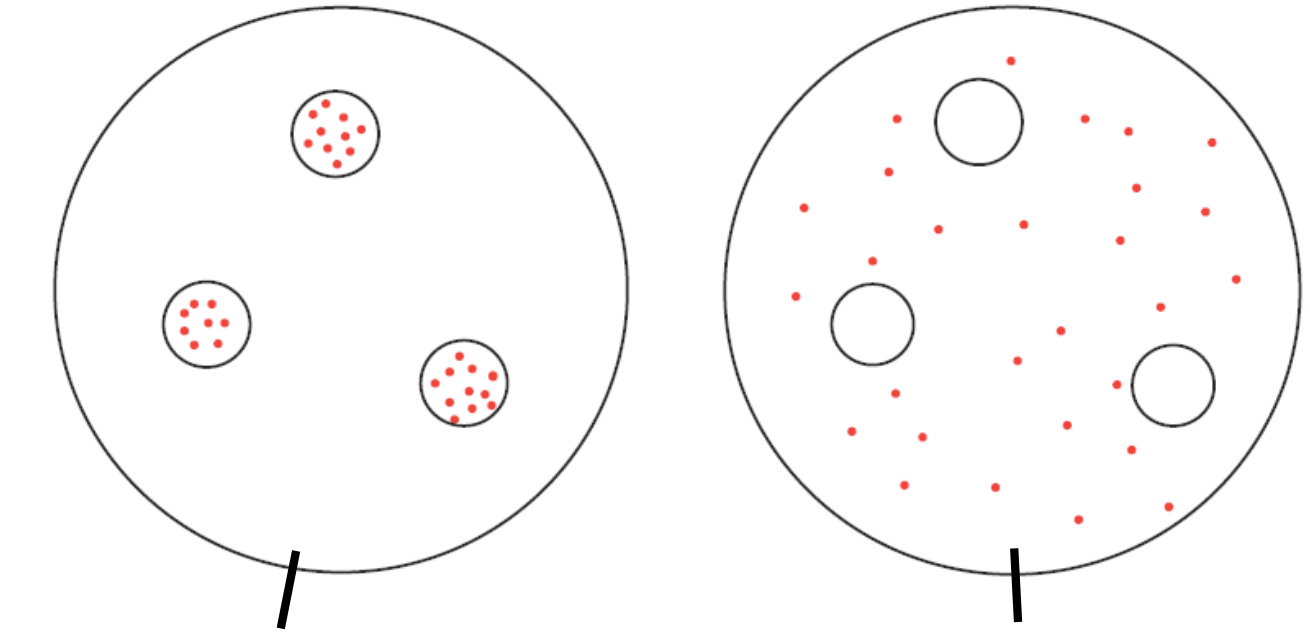
$$\langle n_{\rm hard} \rangle (p_{\perp\min}) = \frac{\sigma_{\rm int}(p_{\perp\min})}{\sigma_{\rm tot}}$$

Motivation for Studying Multiple Parton Interactions

- **Important for understanding of minimum bias p+p collisions at the Tevatron and the LHC**
  - **Tevatron: ~ 2 – 6 hard interactions per collision**
  - **LHC: ~ 4 – 10 hard interactions per collision**
- **Understanding of the "underlying event" important in specialized analyses, e.g., Higgs searches, jet production**
  - **Pedestal effect:**
    Events with high-p_T jets have more underlying activity than minimum-bias events
- **Study distribution of the partons and parton correlations in the plane transverse to the beam axis**

Transverse Profile of the Proton

Where are the sea quarks and gluons inside the proton in the plane transverse to the beam axis?



Inside the constituent quarks?

Or outside?

FELIX coll., J. Phys. G: Nucl. Part. Phys. 28 (2002) R117–R215

→ Study multiple parton interactions

Definition of σ_{eff}

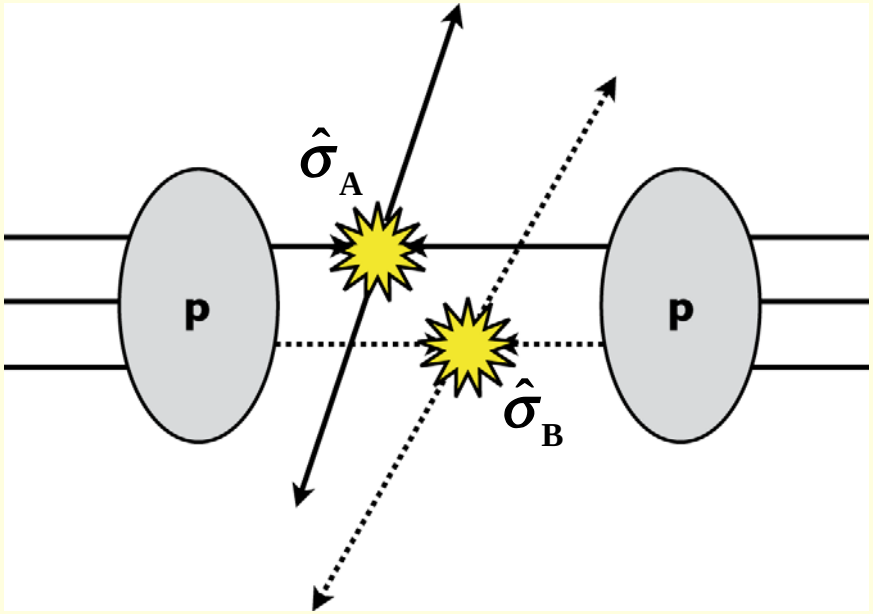
Cross section for double parton scattering (DPS) expressed via σ_{eff}:

$$\sigma_{DPS} = m \frac{\sigma_A \cdot \sigma_B}{2 \cdot \sigma_{eff}}$$

$m = 1$: A and B indistinguishable

$m = 2$: A and B distinguishable

σ_{eff} is a process-independent parameter



A and B Indistinguishable: Poisson Statistics

Let's assume p_T^{min} is sufficiently large so that $\exp(-\langle n \rangle) \approx 1$

In case of uncorrelated multi-parton distribution the number of parton interactions follows Poisson statistics

$$P_n = \frac{\langle n \rangle^n}{n!} \exp(-\langle n \rangle)$$

Hence: $P_1 = \langle n \rangle \exp(-\langle n \rangle), \quad P_2 = \frac{\langle n \rangle^2}{2} \exp(-\langle n \rangle), \quad P_2 \approx \frac{P_1^2}{2}$

The cross section for a double parton interaction would then be:

$$\sigma_2 = \sigma_{ND} \frac{1}{2} \left(\frac{\sigma_1}{\sigma_{ND}} \right)^2$$

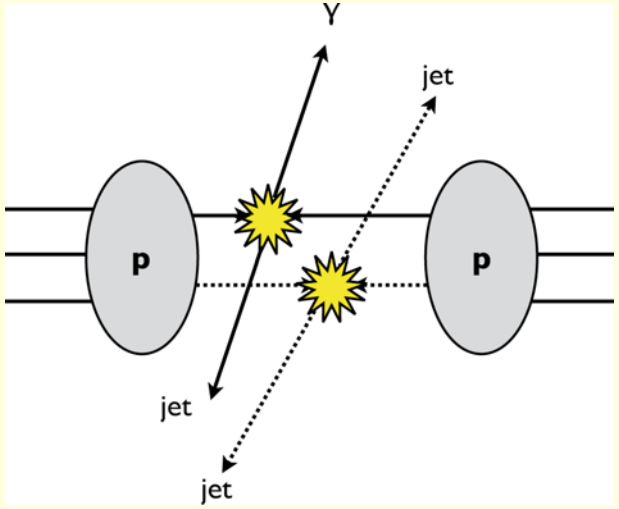
"Non-diffractive"

Measure deviations from Poissonian ansatz with σ_{eff}:

$$\sigma_2 = \sigma_{ND} \frac{1}{2} \left(\frac{\sigma_1}{\sigma_{ND}} \right)^2 \frac{\sigma_{ND}}{\sigma_{eff}} = \frac{1}{2} \frac{\sigma_1^2}{\sigma_{eff}}$$

CDF's 3 Jets + γ Result

CDF studied p+ pbar → (jet+jet) + (jet+γ) = 3 jets + γ events and found



CDF, PRD 56, 3811 (1997)

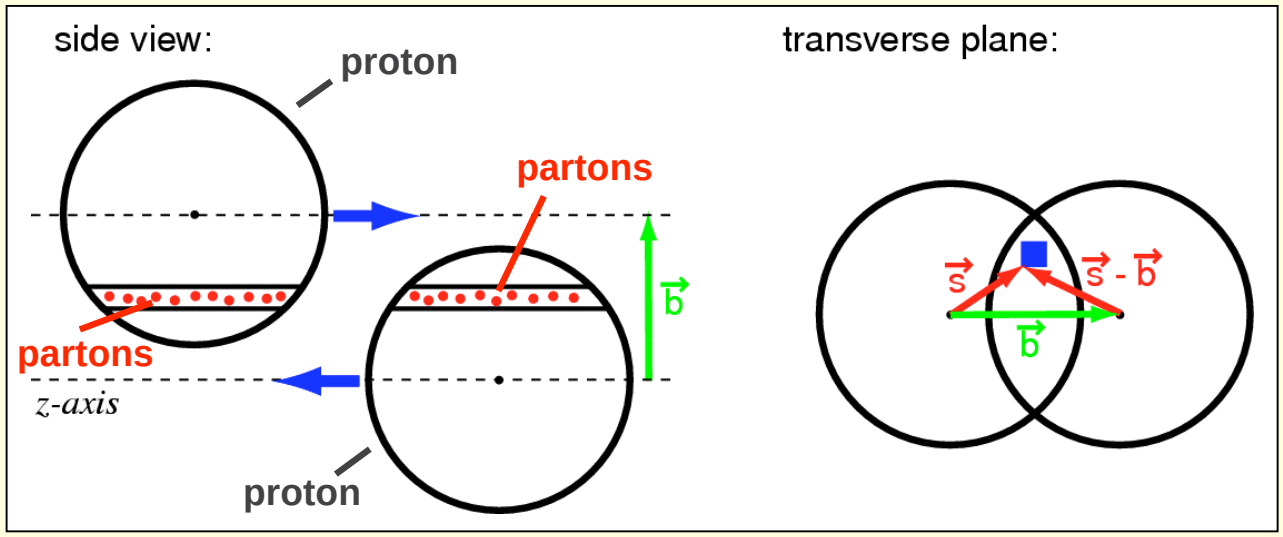
$$\sigma_{eff} = 14.5 \pm 1.7^{+1.7}_{-2.3}\ \text{mb}$$

$$(\sigma_{NSD} = 50.9\ \text{mb})$$

- **Typically the double parton cross section is a factor three to four higher than the Poissonian prediction**

- **$\sigma_{eff} < \sigma_{ND}$ arises naturally in models with variable p+p impact parameter**
  - **Presence of 1 hard collision biases sample towards small impact parameters**
  - **Hence the probability for a second scattering given the first is enhanced**

σ_{eff} and the Transverse Profile of the Proton (I)



2D profile of the proton:

$$F(\vec{s}) := \int \rho_{\text{parton}}(\vec{s}, z)\,\mathrm{d}z$$

Can also be considered as a function of x_{Bjorken}

Normalization:

$$\int F(\vec{s})\,\mathrm{d}^2 s = 1$$

Overlap function: $T(b) = \int F(\vec{s}) \cdot F(\vec{s} - \vec{b})\,\mathrm{d}^2 s$

(completely analogous to T_{AB} in heavy-ion collisions)

σ_{eff} given by the transverse profile:

$$\sigma_{\text{eff}} = \frac{1}{\int \mathrm{d}^2 b\, T^2(b)}$$

σ_{eff} and the Transverse Profile of the Proton (II)

σ_{eff} for uniform distribution of partons within the proton (hard sphere with $r \approx 0.8$ fm):

$$\sigma_{\text{eff}} = \left[\int \mathrm{d}^2 b \, T^2(b) \right]^{-1} \approx 50 \text{ mb}$$

→ 3 times larger than CDF result

Discrepancy persists (but reduced to a factor 2) if a profile based on generalized parton distributions (GDPs) from data on J/ψ photoproduction is used

→ Evidence for transverse correlations of partons in the proton

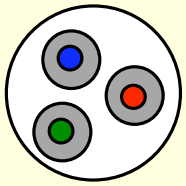
L. Frankfurt, M. Strikman, L. Treleani, C. Weiss,
Phys. Rev. Lett. 101, 202003 (2008)

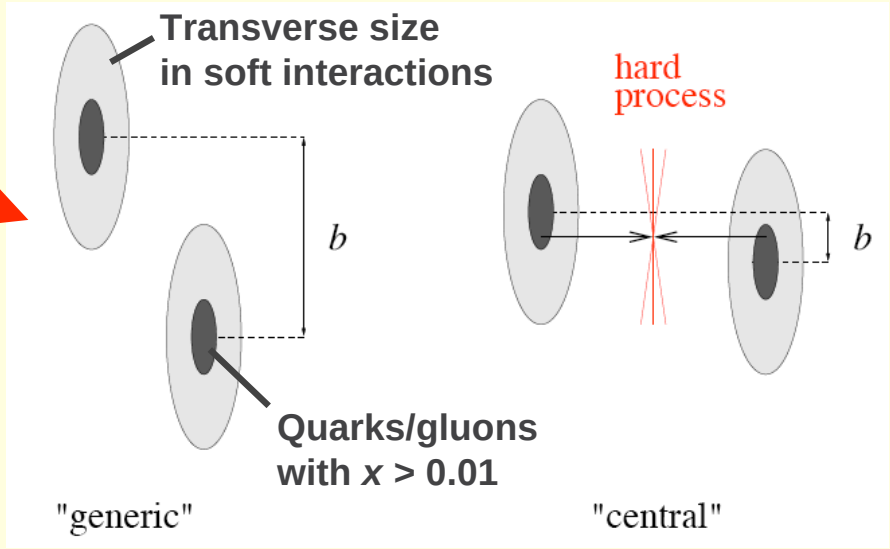
Footnote: CDF comes to the wrong conclusions due to a mistake in their paper (PRD 56, 3818 (1997), Eq. 11, factor 1/2 is wrong)

A Possible Explanation (M. Strikman et al.)

1) **Small transverse size of hard partons**

2) **Gluons concentrated in „constituent quarks“ with a radius of ≈ 1/3 r_{proton} (as expected in the instanton model of chiral symmetry breaking)**

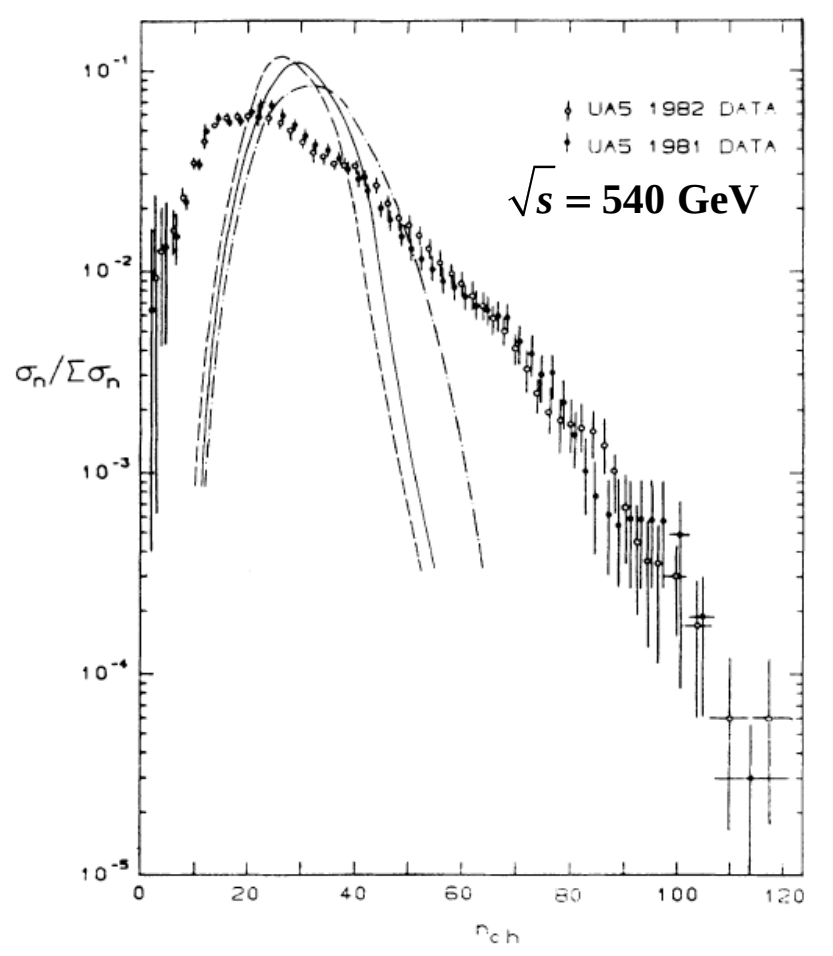


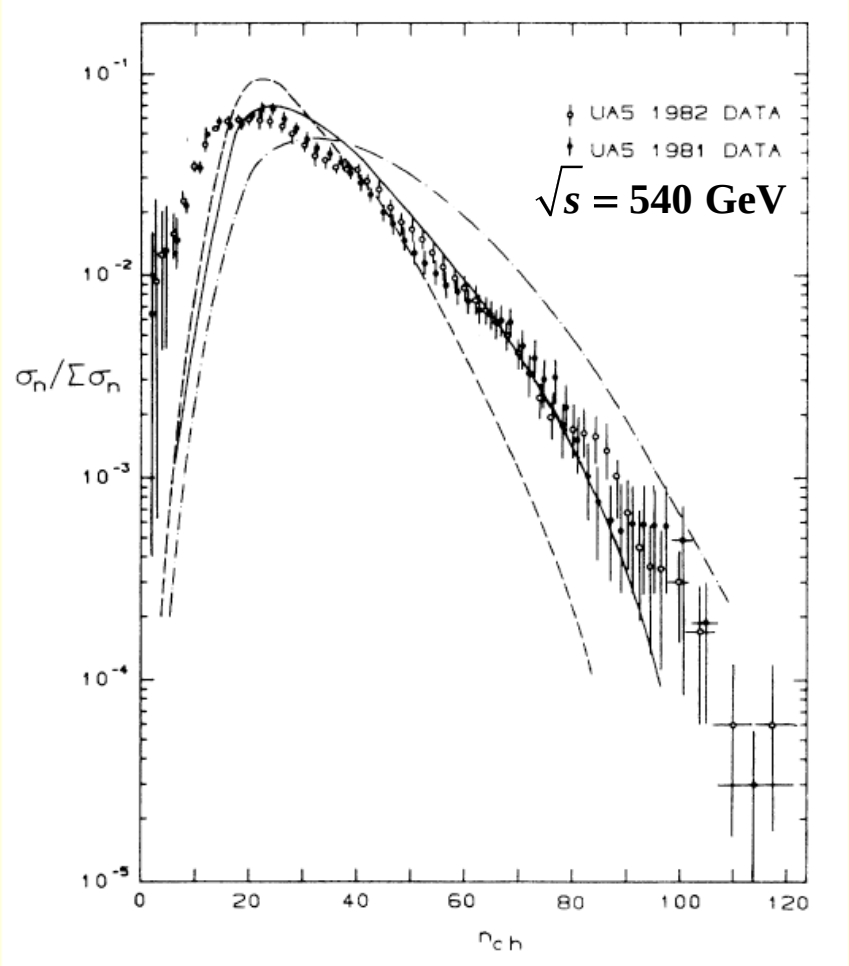


The claim is that a combination of 1) and 2) can resolve the discrepancy

L. Frankfurt, M. Strikman, C. Weiss,
Ann.Rev.Nucl.Part.Sci.55:403-465,2005

Observables Related to MPI's: Multiplicity Distributions (I)



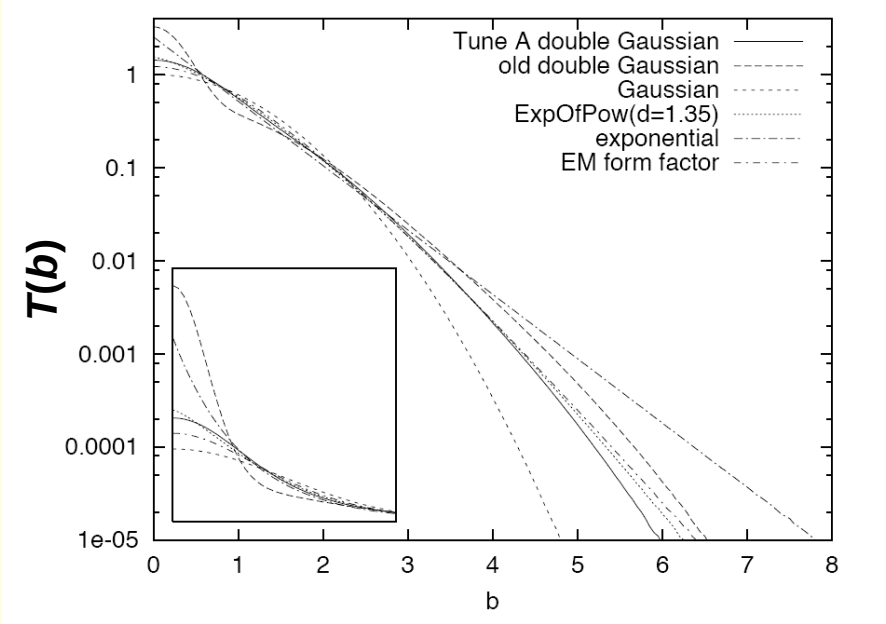


Violation of KNO scaling and deviation from negative binomial distribution described by MPI's

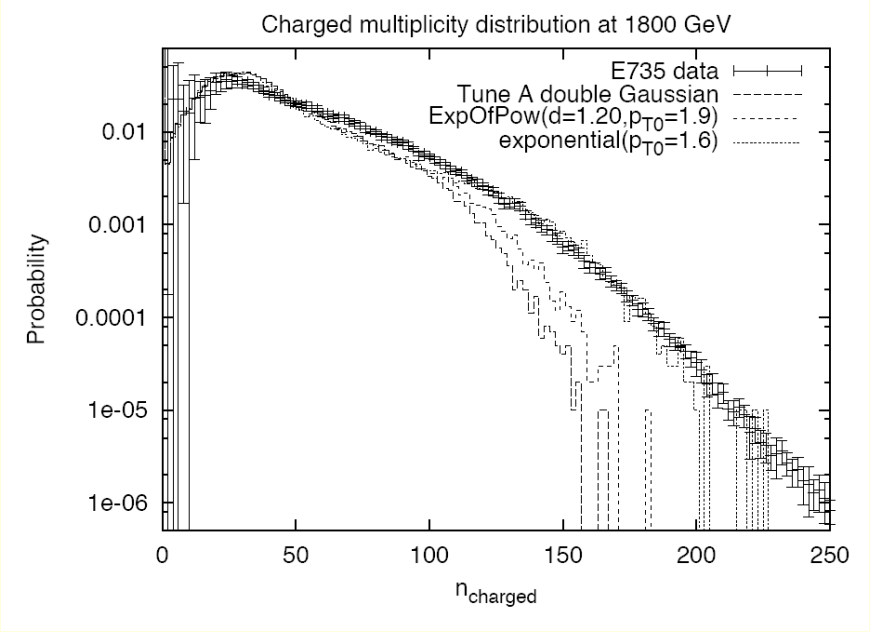
Observables Related to MPI's: Multiplicity Distributions (II)

A more sophisticated study with Pythia:

Overlap function for different parton profiles of the proton:



Corresponding multiplicity distributions in p+pbar at 1800 GeV:

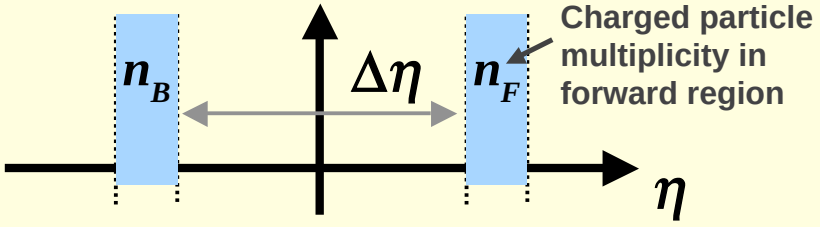


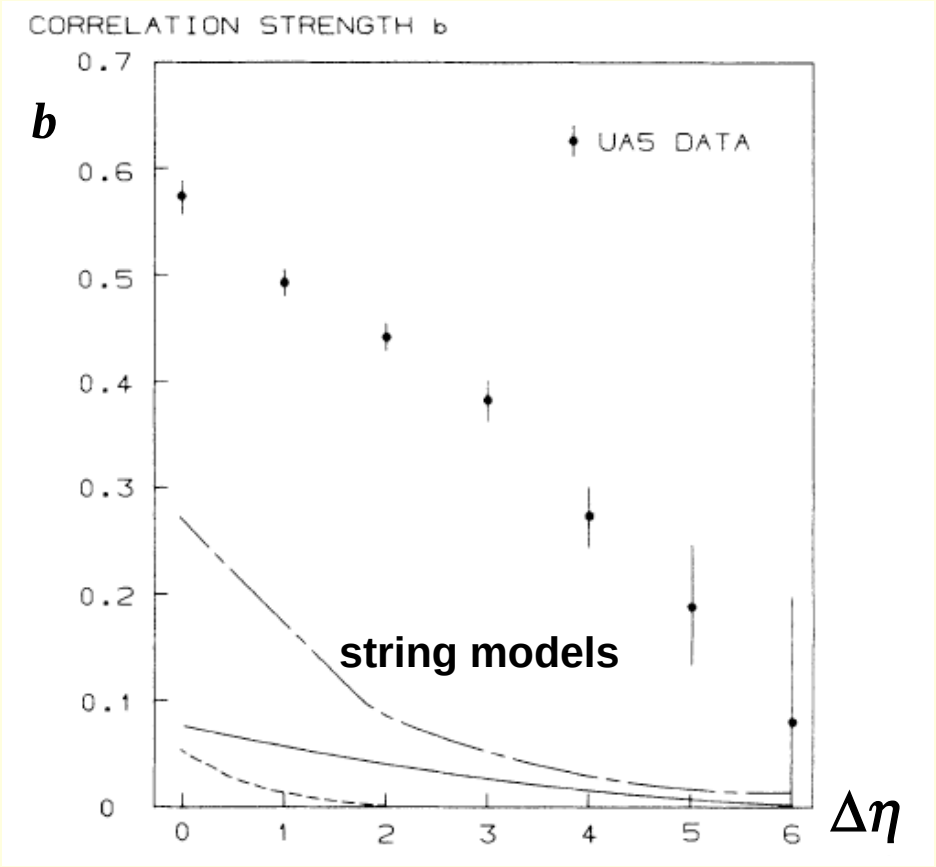
T. Sjöstrand, P. Skands, JHEP03 (2004) 053 (arXiv:hep-ph/0402082)

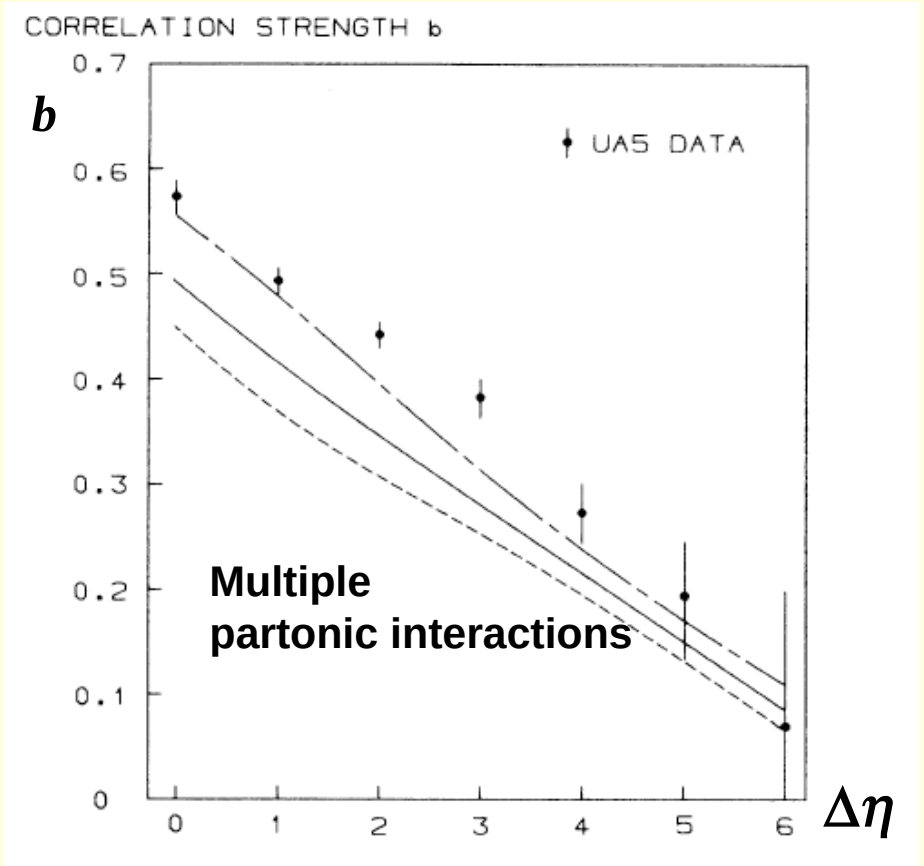
Measured multiplicity distributions constrain the partonic profile of the proton

Observables Related to MPI's: Forward-Backward Correlations

$$n_B = a + b \cdot n_F, \qquad b = \frac{\langle n_F n_B \rangle - \langle n_F \rangle \langle n_B \rangle}{\langle n_F^2 \rangle - \langle n_F \rangle^2}$$

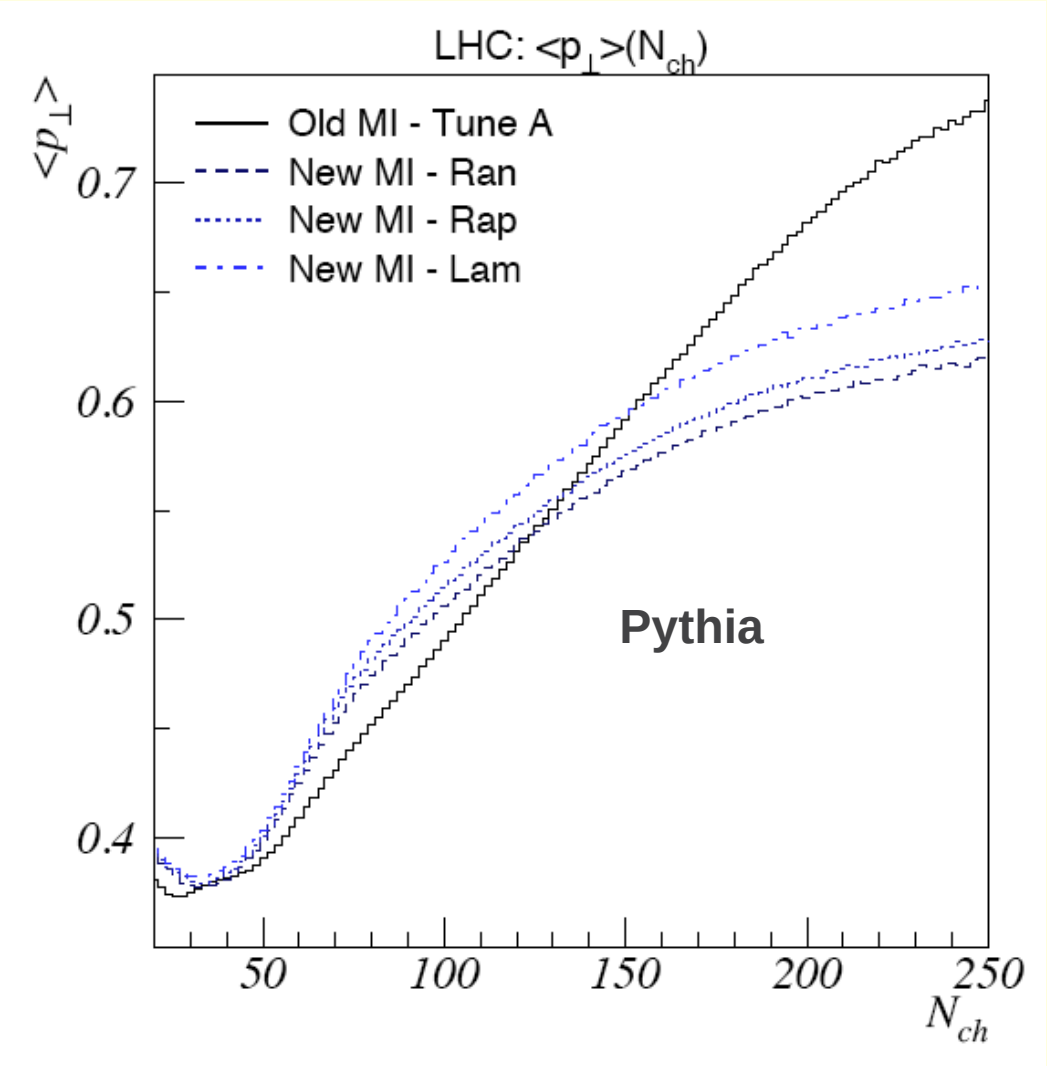






MPI's can explain observed forward-backward correlations

Observables Related to MPI: $\langle p_T \rangle$ as a Function of N_{ch}

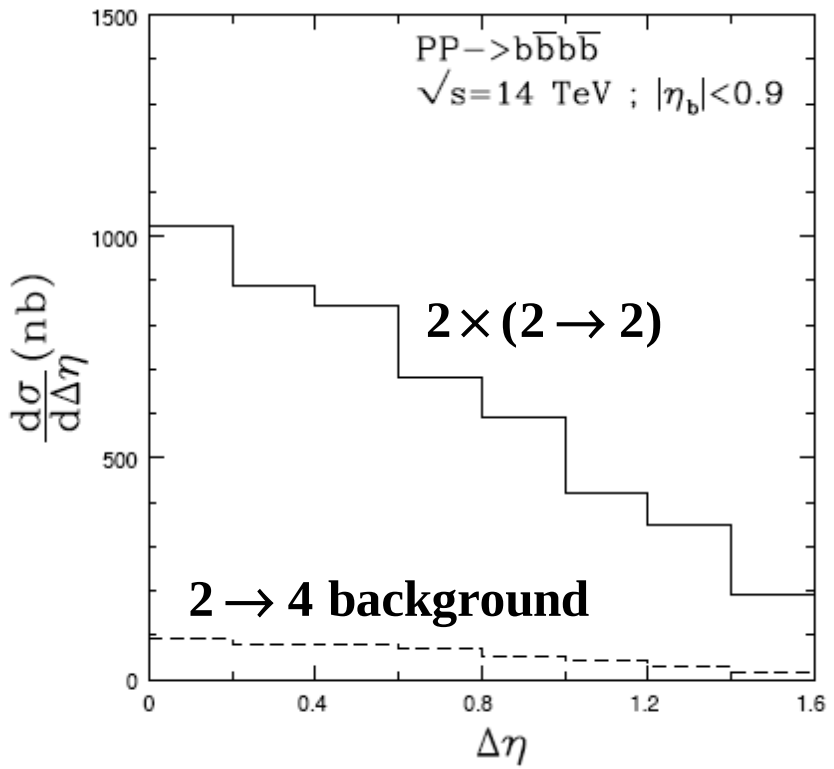


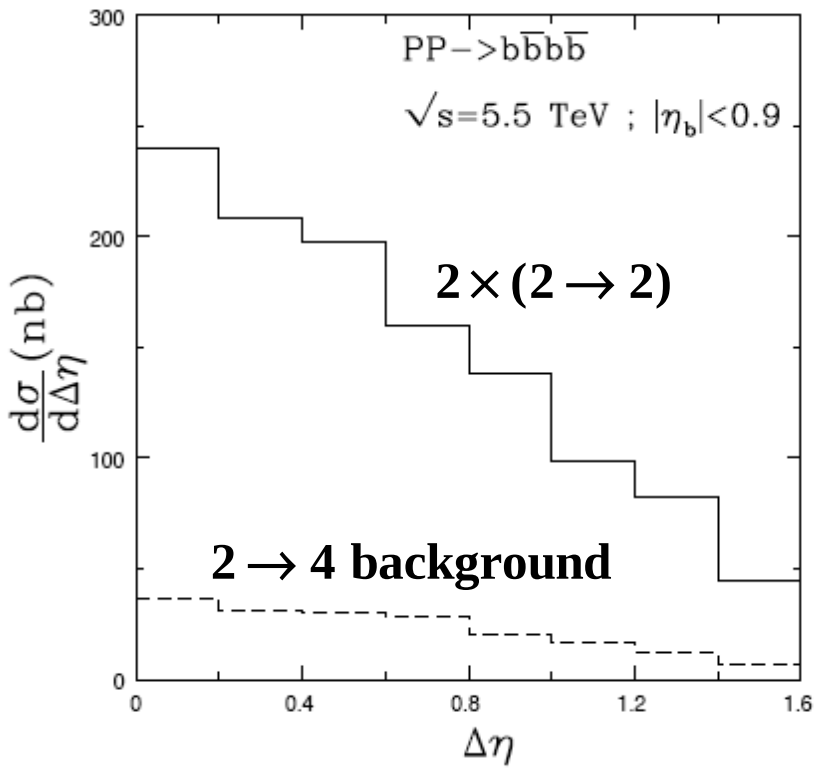
- MPI's explain rise of $\langle p_T \rangle$ with N_{ch}
  - Both $\langle p_T \rangle$ and N_{ch} increase with increasing number of hard parton-parton interactions
- Prediction for LHC depend on details of the MPI model

MPI Studies with ALICE: p+p → (b bbar) + (b bbar)

Fabbro, A D ; Treleani, D, ALICE-INT-2002-026-V3 (hep-ph/0301178)

Cross section for the production of two b bbar pairs with $\Delta\eta < 0.9$:





- **Cross section for two b bbar pairs with $\Delta\eta < 0.9$: ≈ 1 μb**
- **MPI result in strong event-by-event fluctuations in the number of produced b-quarks**

Summary

- Multiple Partonic Interactions (MPI) important for the understanding of p+p minimum bias physics at the LHC
- MPI essential for the description of the underlying event e.g. in jet measurements
- Double parton interaction cross-section expressed via process-independent parameter σ_{eff}
- σ_{eff} contains information about the spatial profile of the proton
- CDF measurement (3 Jet + γ) hints at strong parton correlations in the transverse direction