Underlying events: do we have the tools ?

K. Borras, H. Jung (DESY)

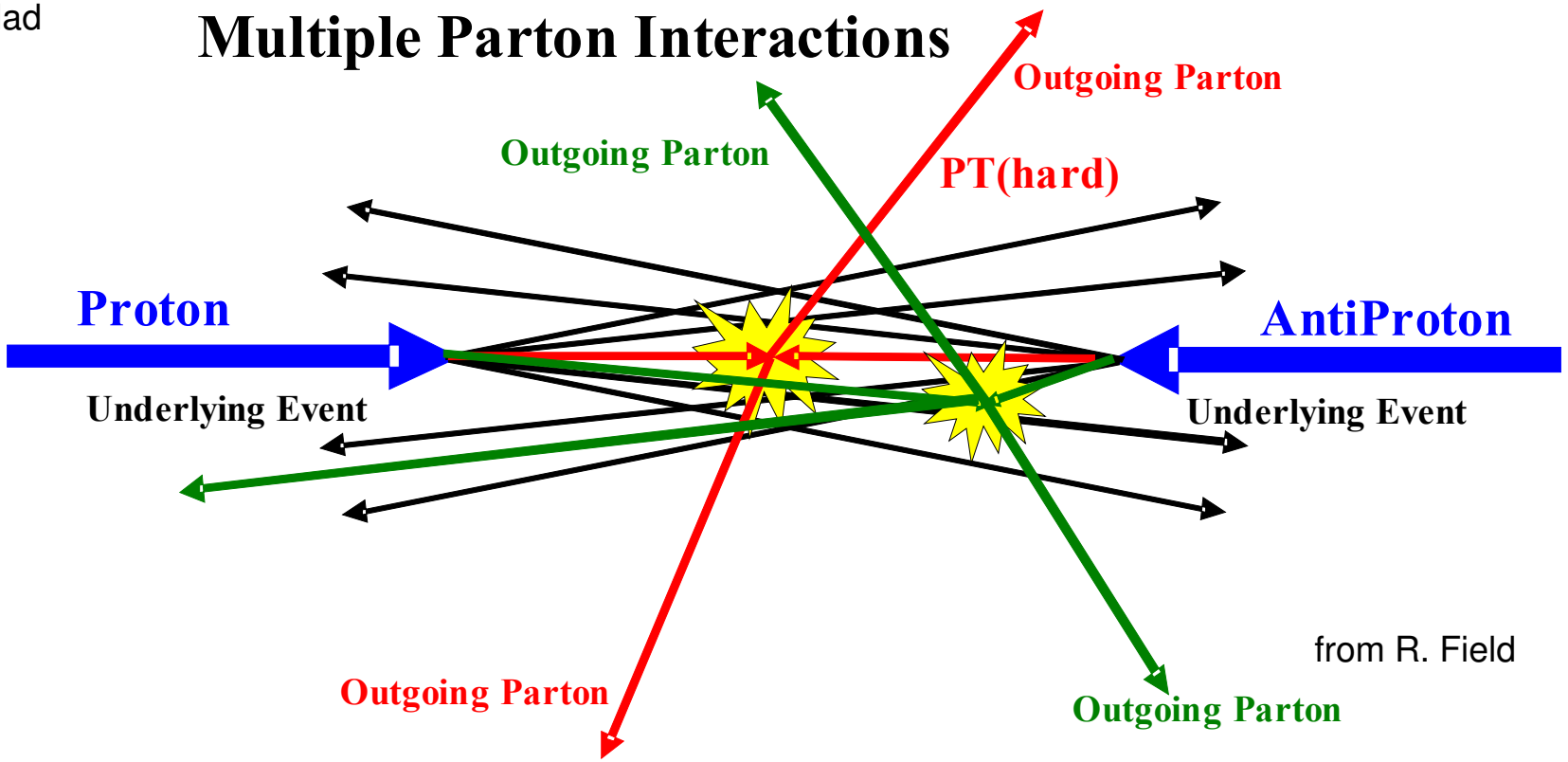
SMall x and MUltiple InteraXions Initiative

V. F. Andreev, K. Borras, A. Bunyatyan, M. Deak,
H. Jung, M. Kapichine, L. Khein, L. Lytkine, Z. Staykova

- What is the underlying event ?
- Evidence for the underlying event !
- Can we understand/describe the underlying event ?
- How to measure the underlying event and related forward physics ?

Event Topologies

from L. Loennblad



from R. Field

What is the underlying event (UE)?

➔ *Everything, except the LO process we're currently interested in*

- *parton showers*
- *additional remnant – remnant interactions (multi-parton interactions,soft/hard)*

✗ NOT pile-up events (luminosity dependent)

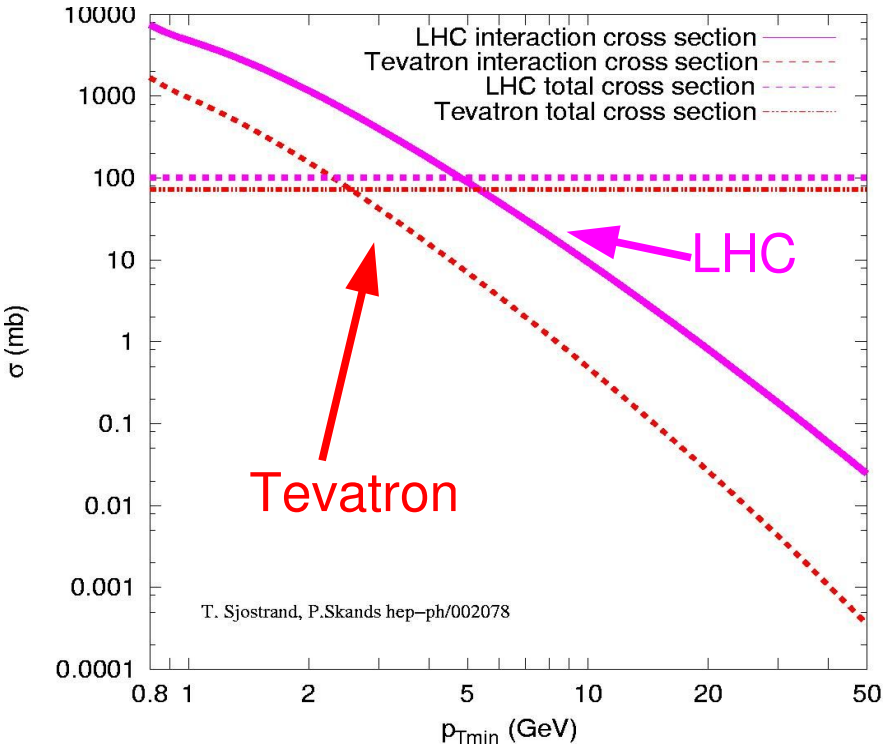
Underlying event – Multiple Interaction

- Basic partonic perturbative cross section

$$\sigma_{\mathrm{hard}}(p^2_{\perp\mathrm{min}}) = \int_{p^2_{\perp\mathrm{min}}} \frac{d\sigma_{\mathrm{hard}}(p^2_\perp)}{dp^2_\perp} dp^2_\perp$$

➔ diverges faster than $1/p^4_{\perp\mathrm{min}}$ as $p_{\perp\mathrm{min}} \to 0$ and exceeds eventually total inelastic (non-diffractive) cross section

- Interaction x-section exceeds total xsection
- happens well above λ_{QCD}
- still in perturbative region



Underlying event – Multiple Interaction

- Basic partonic perturbative cross section

$$\sigma_{\rm hard}\left(p^2_{\perp \rm min}\right) = \int_{p^2_{\perp \rm min}} \frac{d\sigma_{\rm hard}\left(p^2_\perp\right)}{dp^2_\perp} dp^2_\perp$$

➔ diverges faster than $1/p^4_{\perp \rm min}$ as $p_{\perp \rm min} \to 0$ and exceeds eventually total inelastic (non-diffractive) cross section, resulting in more than 1 interaction per event (multiple interactions, MI).

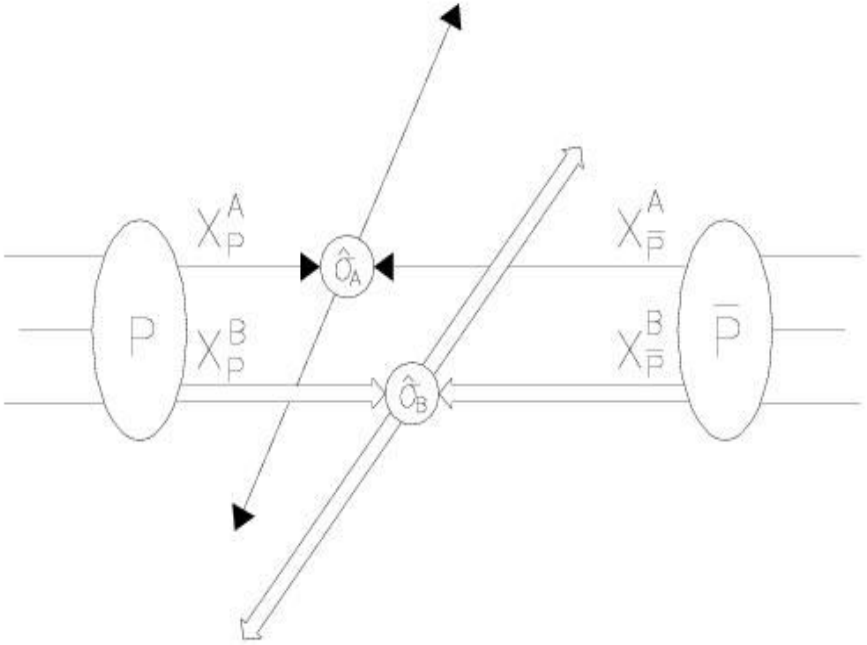
➔ Average number of interactions per event is given by:

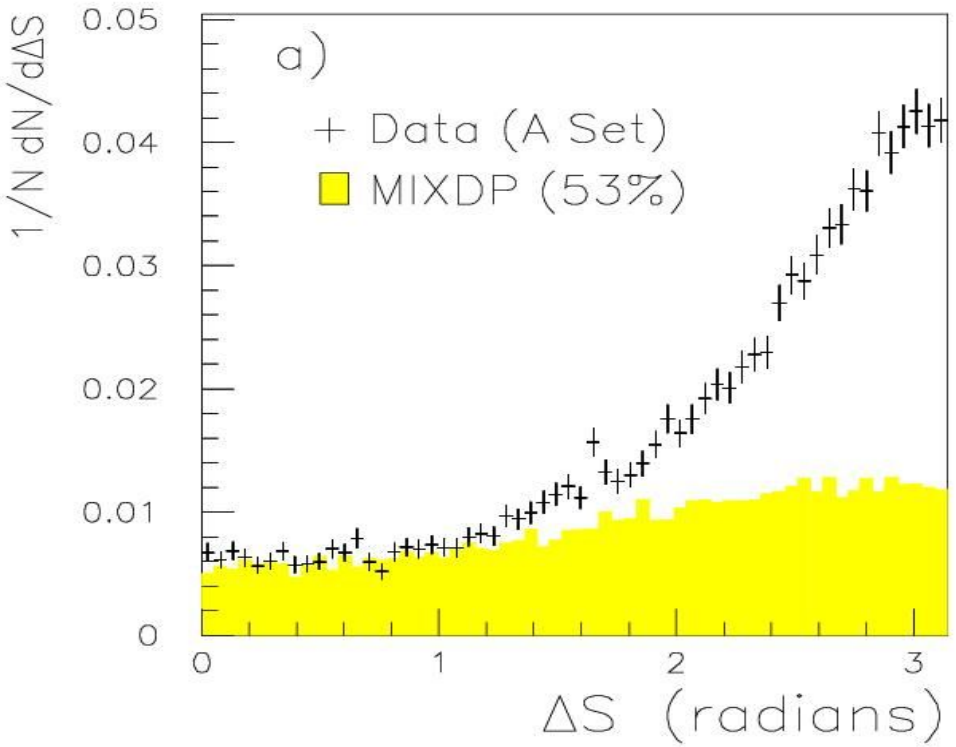
$$\langle n \rangle = \frac{\sigma_{\rm hard}\left(p_{\perp \rm min}\right)}{\sigma_{nd}}$$

- It depends on how soft interactions are treated, ***BUT*** also on the parton densities and factorization scheme, parton evolution (DGLAP/BFKL) !!!!!!!

Evidence for Multi-Parton Interactions

CDF coll. PRD 56, 3811 (1997)



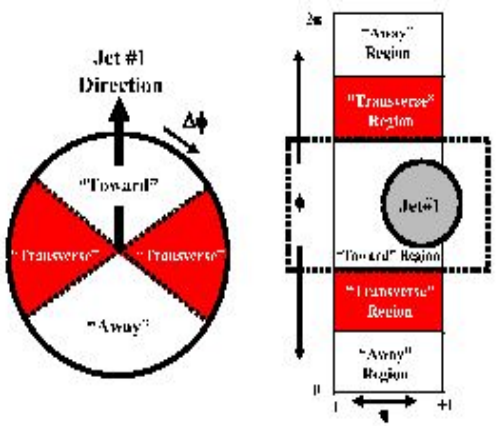


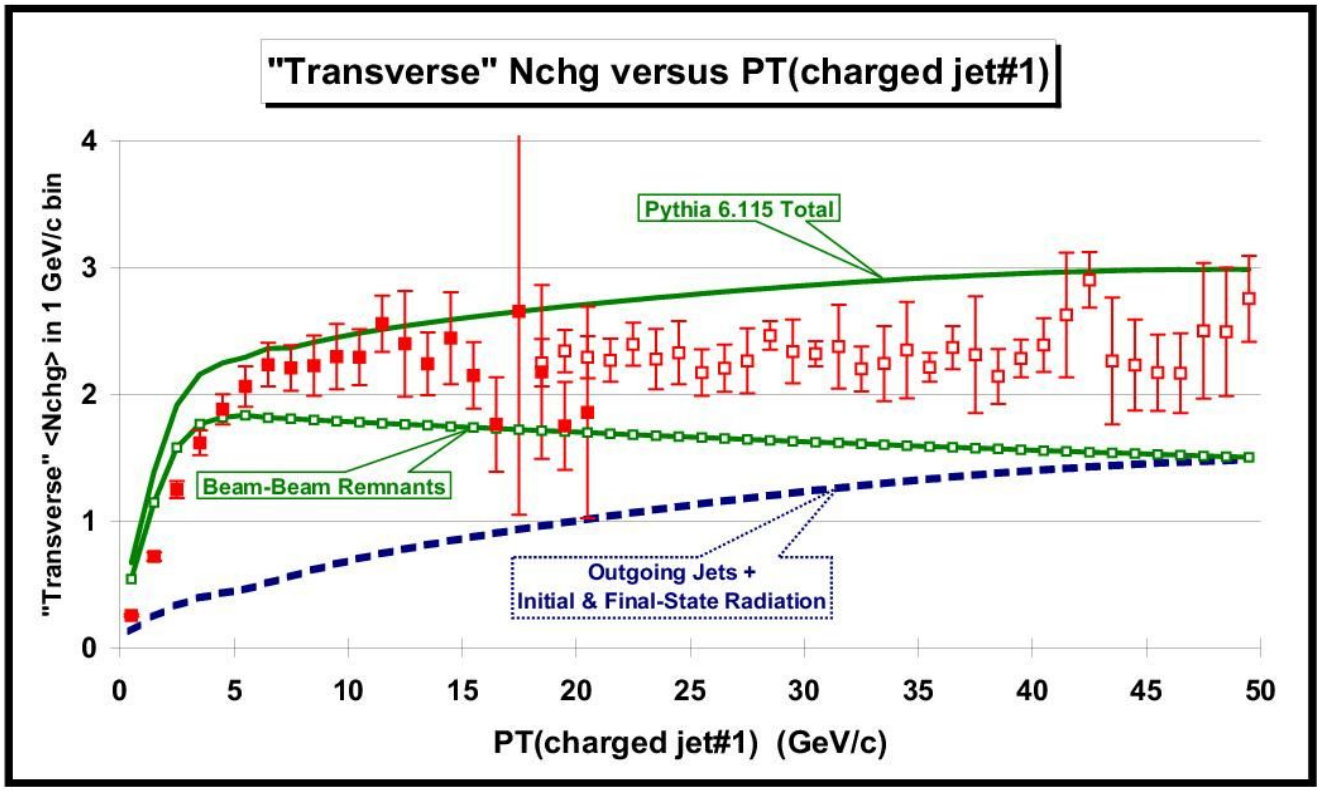
- look at $\gamma + 3$ Jets with
  $E_T^{\gamma} > 16GeV$
  $E_T^{Jets} > 5GeV$

- angular correlation of jet/photon pairs ΔS
- compare to $\gamma + 3$ Jets calculation
- **Need > 50 % double parton interaction to describe data**

Evidence for underlying events

CDF coll. PRD 65, 092002 (2002)

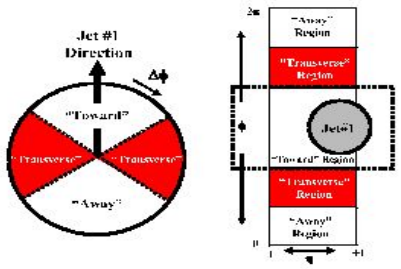




- Multiplicity distribution in region transverse to jet can only be described by adding multi-parton interactions (Remnant- Remnant Interactions)

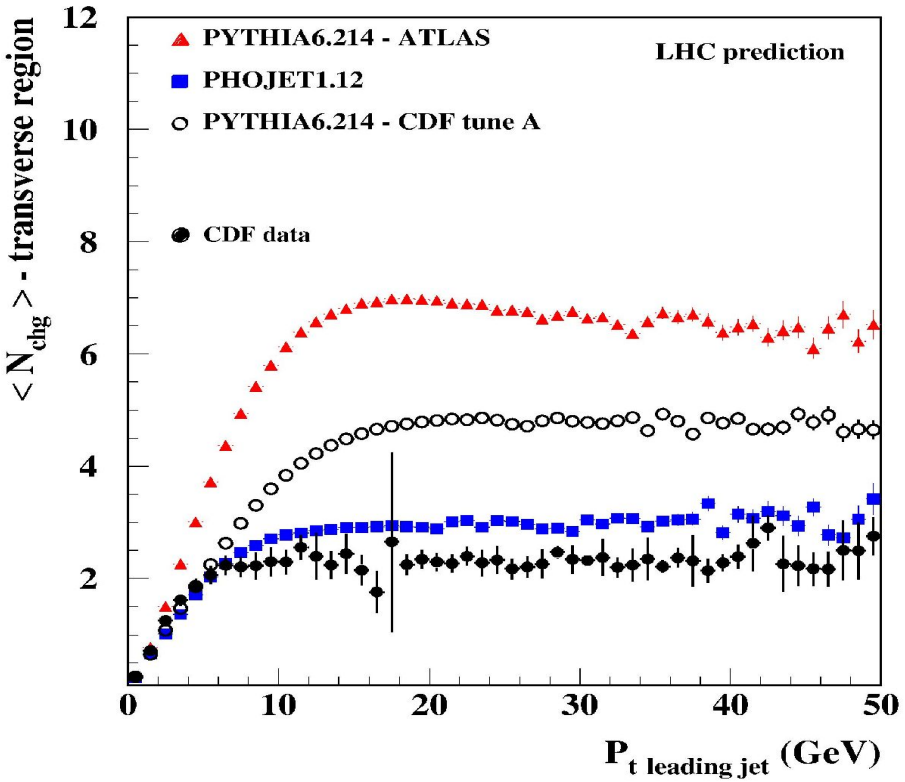
Underlying events at LHC

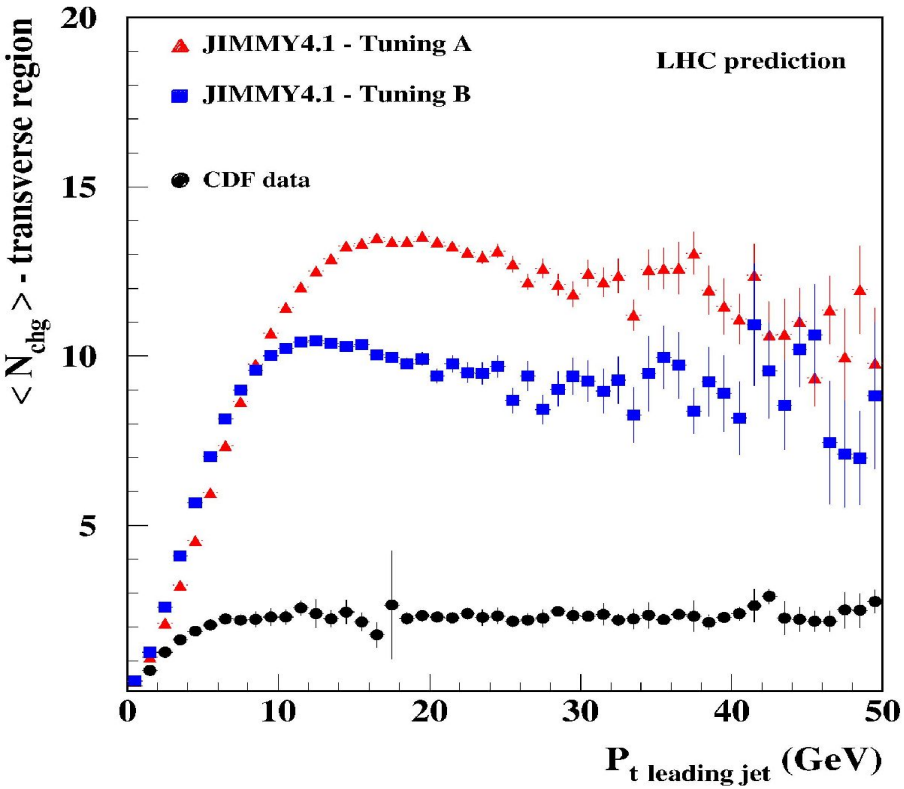
C. Buttar et al in HERA – LHC workshop proceedings hep-ph/0601012



Charged multiplicities in transverse region

- Models tuned to TeVatron data
- ➔ give **HUGE** differences at LHC ...
- ➔ **better understand multiple interactions ...**
  - ➔ photo-production of jets at HERA T. Namsoo





Tuning of MC in the first days ...

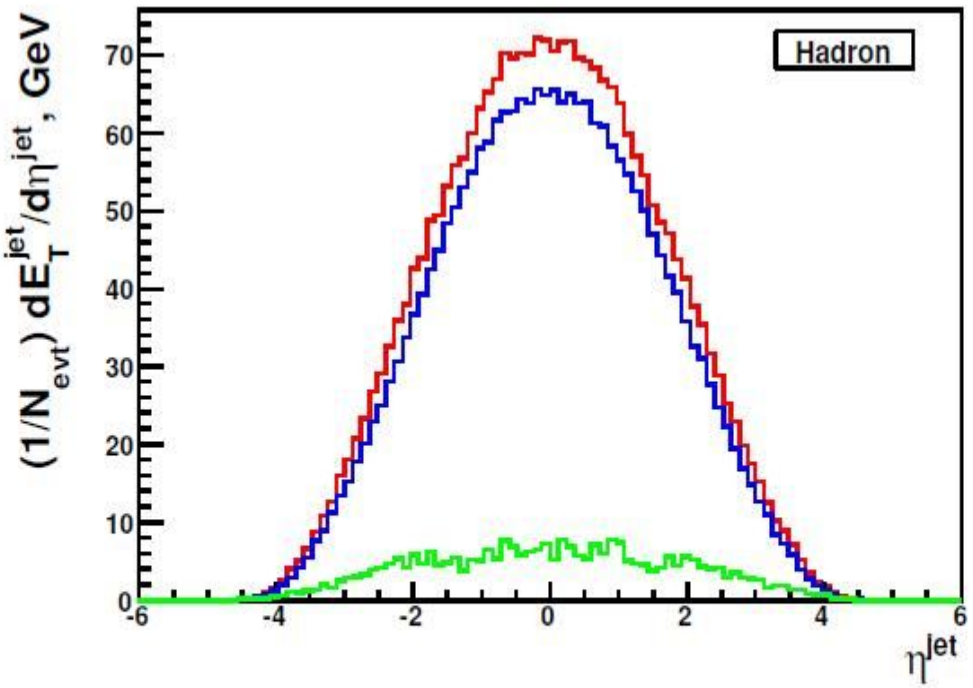
then get rid of all this dirty stuff

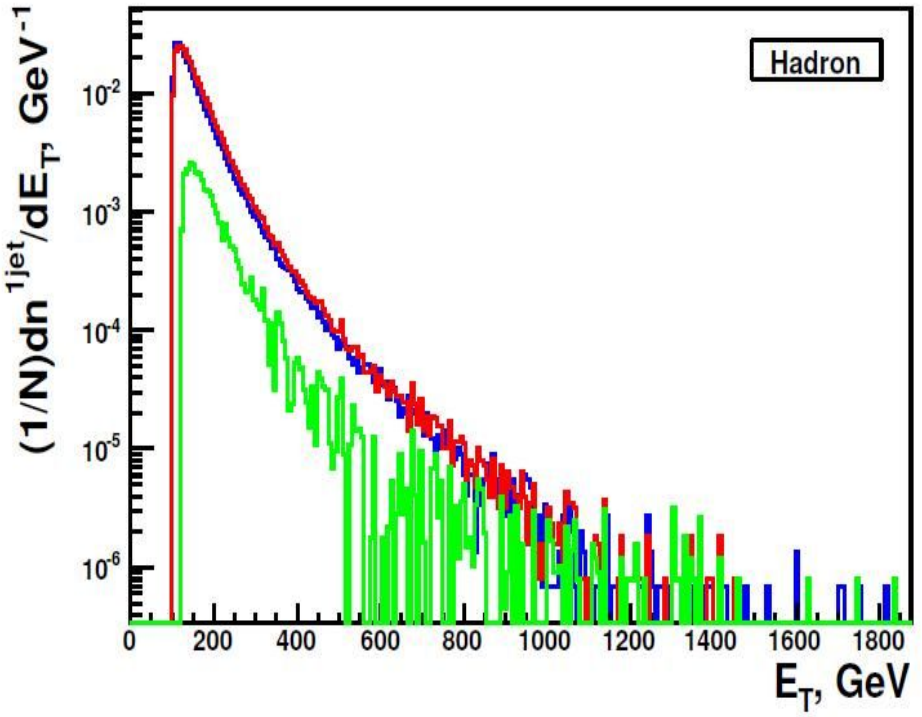
?????

Underlying event and jets

- SHERPA: $E_T > 100\,\mathrm{GeV}, |\eta| < 5$

P. Starovoitov, T. Carli
HERA-LHC WS, June 2006





Hard Scale, HS+UE, Difference

- UE contributes ~ 10 - 30 % to Jets, even at large E_t !!!!
- **need reliable model for UE**
- **Factorization ??!!??**

Multi-Parton Interactions at LHC

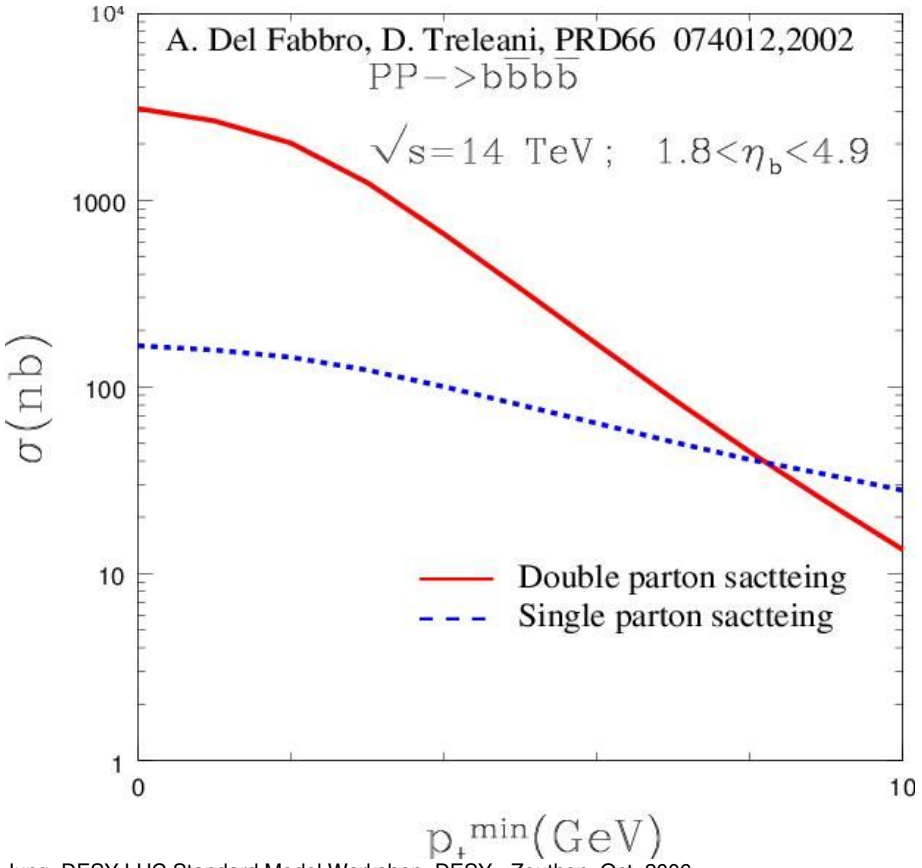
- xsection for $p + p \to b\bar{b}b\bar{b}$

  single parton exchange (SP)

  $\sigma^{SP} \sim f^2 \hat{\sigma}(2 \to 4)$

  double parton exchange (DP)

  $\sigma^{DP} \sim f^4 \hat{\sigma}^2(2 \to 2)$



- PYTHIA predictions:

  $\sigma^{DP} = 0.8 \cdots 11.1 \ \ \mu b$

➔ Depending on model for underlying event/muli-parton interactions...

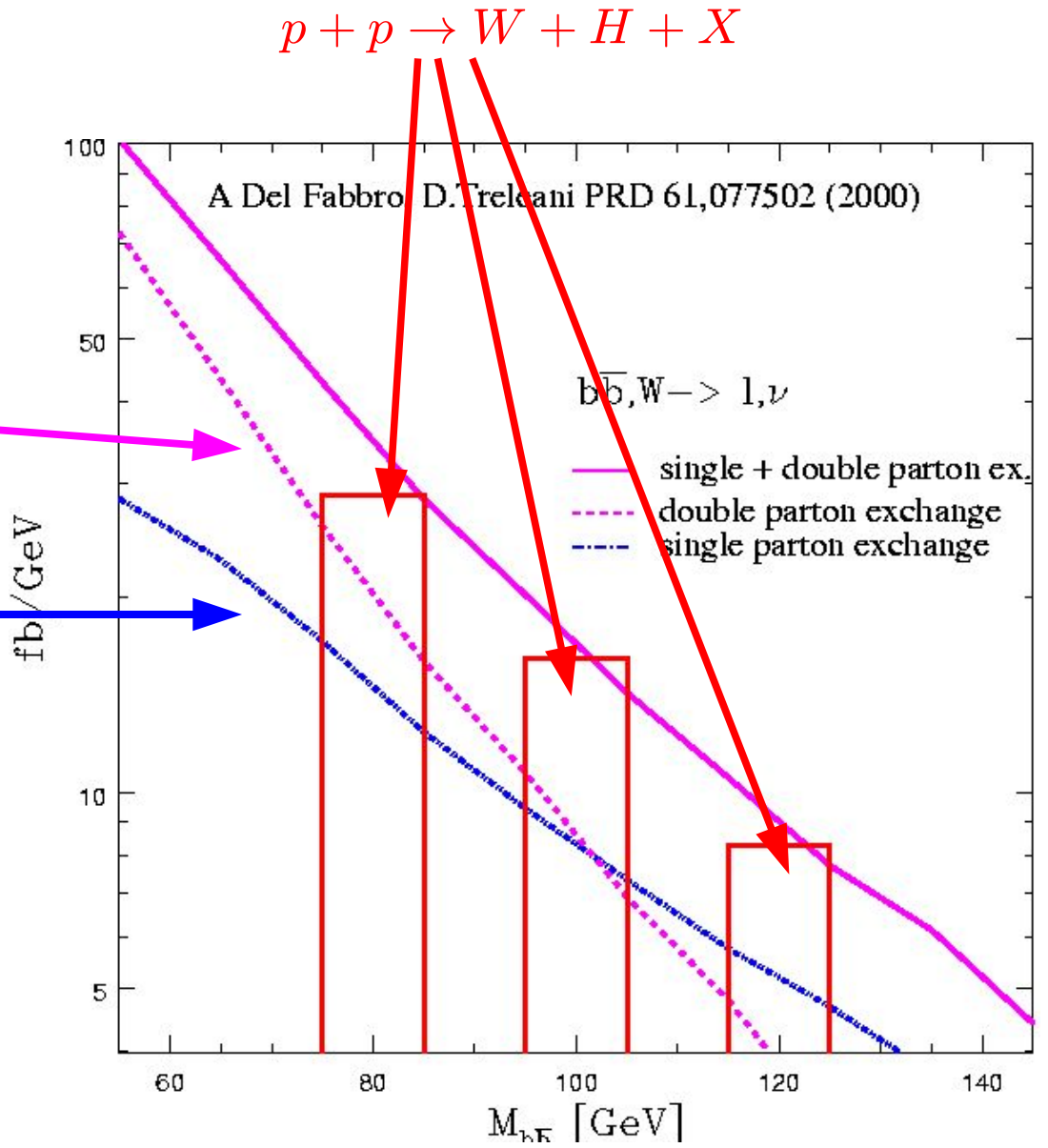
Multi-Parton Interactions at LHC

- Higgs: $p + p \to W + H + X$
  with $W \to l\nu, \quad H \to b\bar{b}$
- Double parton scattering:

➔ $p + p \to b\bar{b}X$

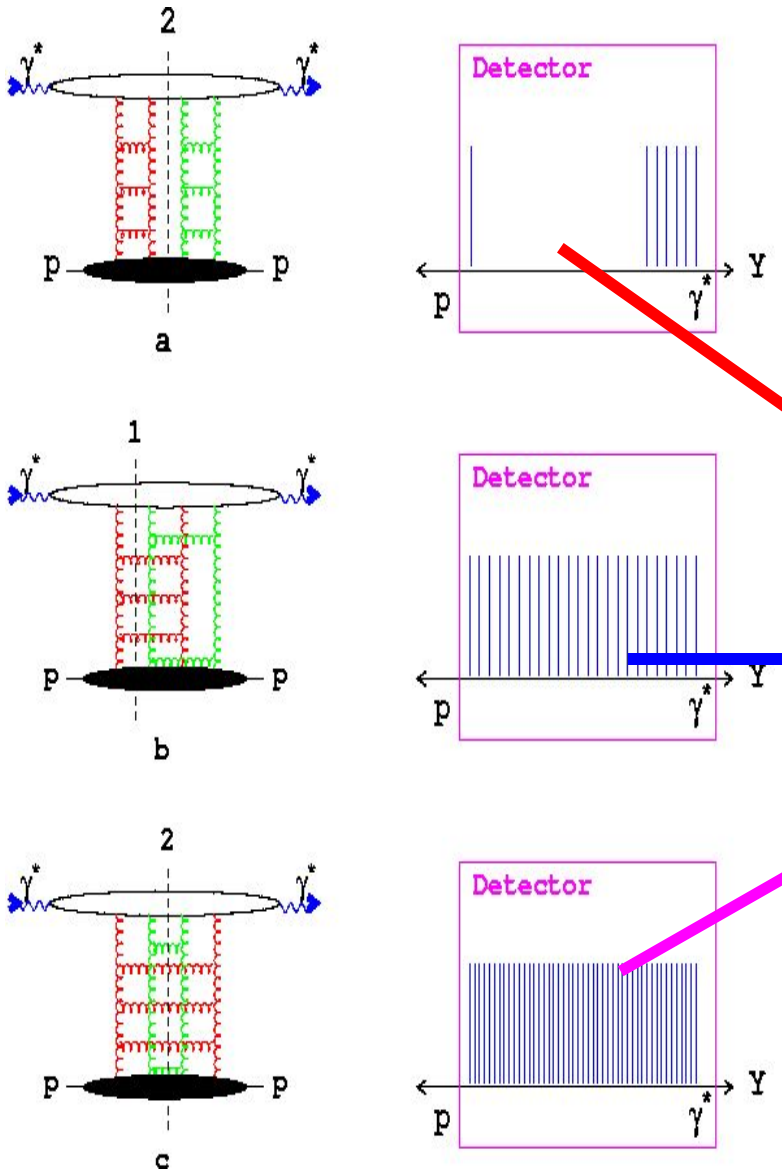
$p + p \to W + X$

- $p + p \to W + b\bar{b} + X$



Need to understand and measure multi-parton interactions !!!!!!

Towards understanding of MI



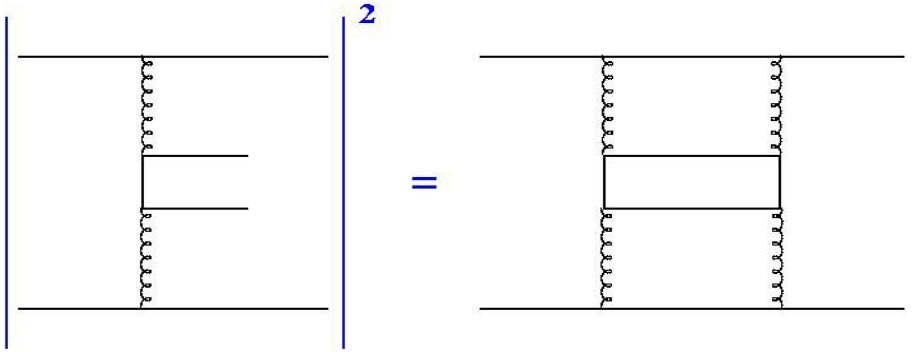
Bartels, Kowalski, Sabio-Vera in HERA – LHC workshop proceedings hep-ph/0601012/13

- Cutting rules (AGK) extended to QCD
- Relate diffraction, saturation and multiple scatterings
- All from the same amplitude, but different factors:
  - +1 Diffraction
  - - 4 Saturation
  - +2 Multiple Interactions

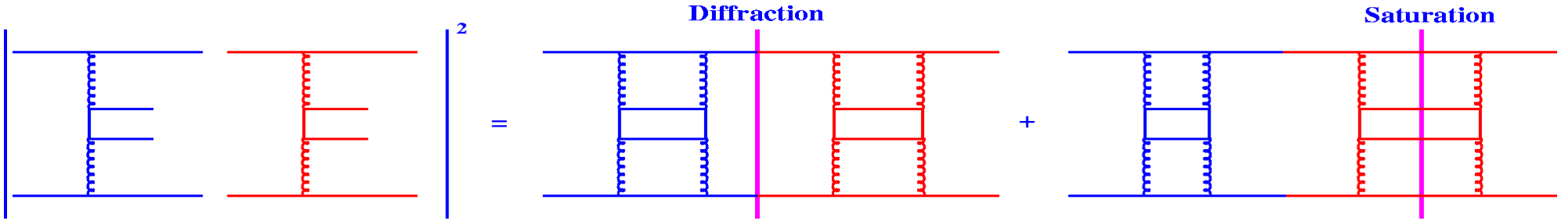
- Extended now also to pp !!!!
  - BUT further work needed ...

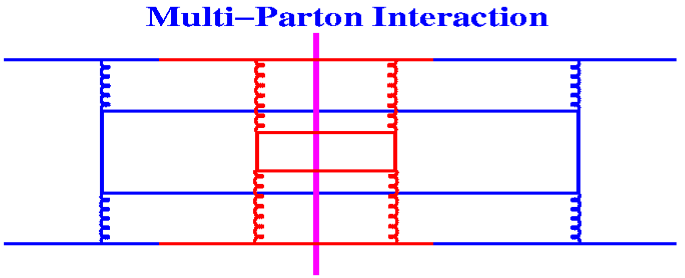
Toy Model for AGK

- where is relation of diffraction – multiple scatterings – saturation coming from ?
- single parton exchange:



- 2-parton exchange:





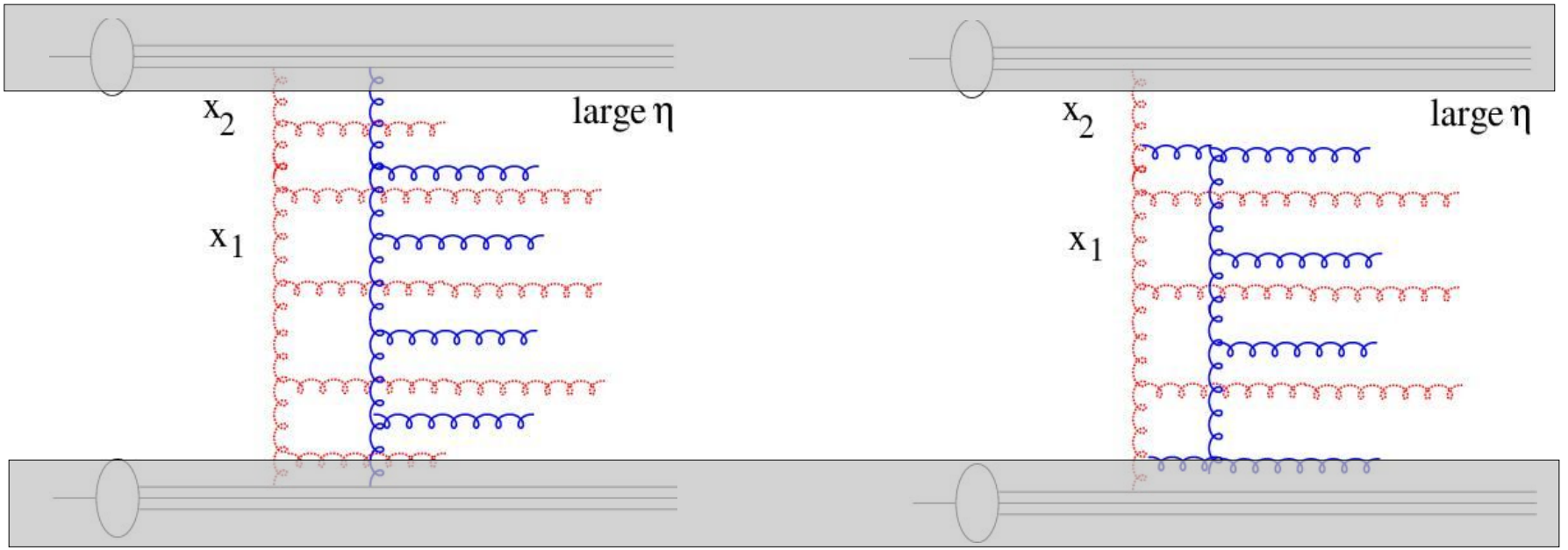
Measurements for MI studies?

- Tune MCs:
  - multiplicity measurements in central part of detector
  - Multi-jet x-section at central rapidities

Only 1st step for rough corrections

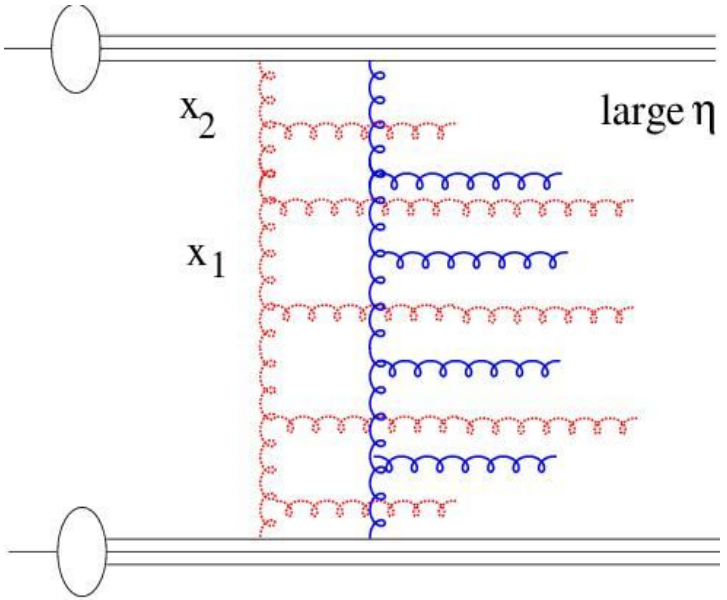
Measurements for MI studies?

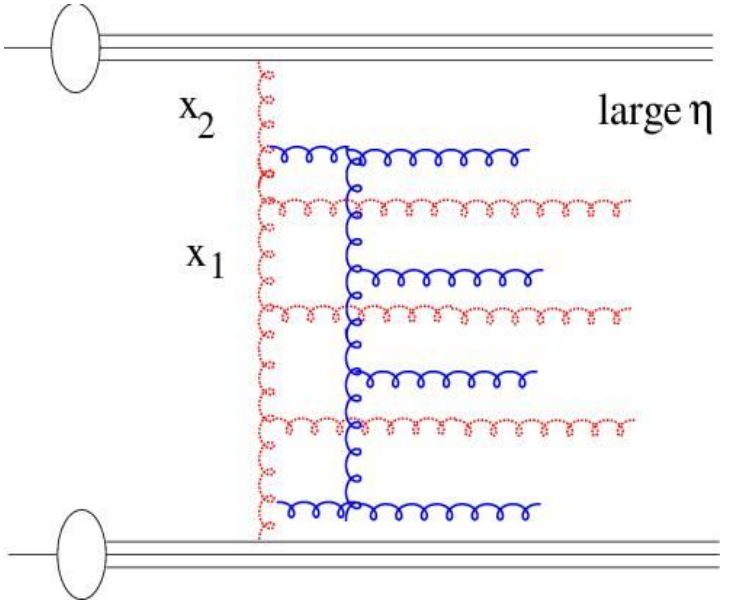
- **Understand mechanism of MI, crucial for precision meas.**
  - multi jet xsections in largest rapidity range:
    ➔ jets in forward region, i.e CASTOR at CMS $5.3 < \eta < 6.7$
  - correlations over largest rapidity range
  - what is the process of MI ?



Measurements for MI studies?

- **Understand mechanism of MI, crucial for precision meas.**
  - multi jet xsections in largest rapidity range:
    ➔ jets in forward region, i.e CASTOR at CMS $5.3 < \eta < 6.7$
  - correlations over largest rapidity range
  - what is the process of MI ?



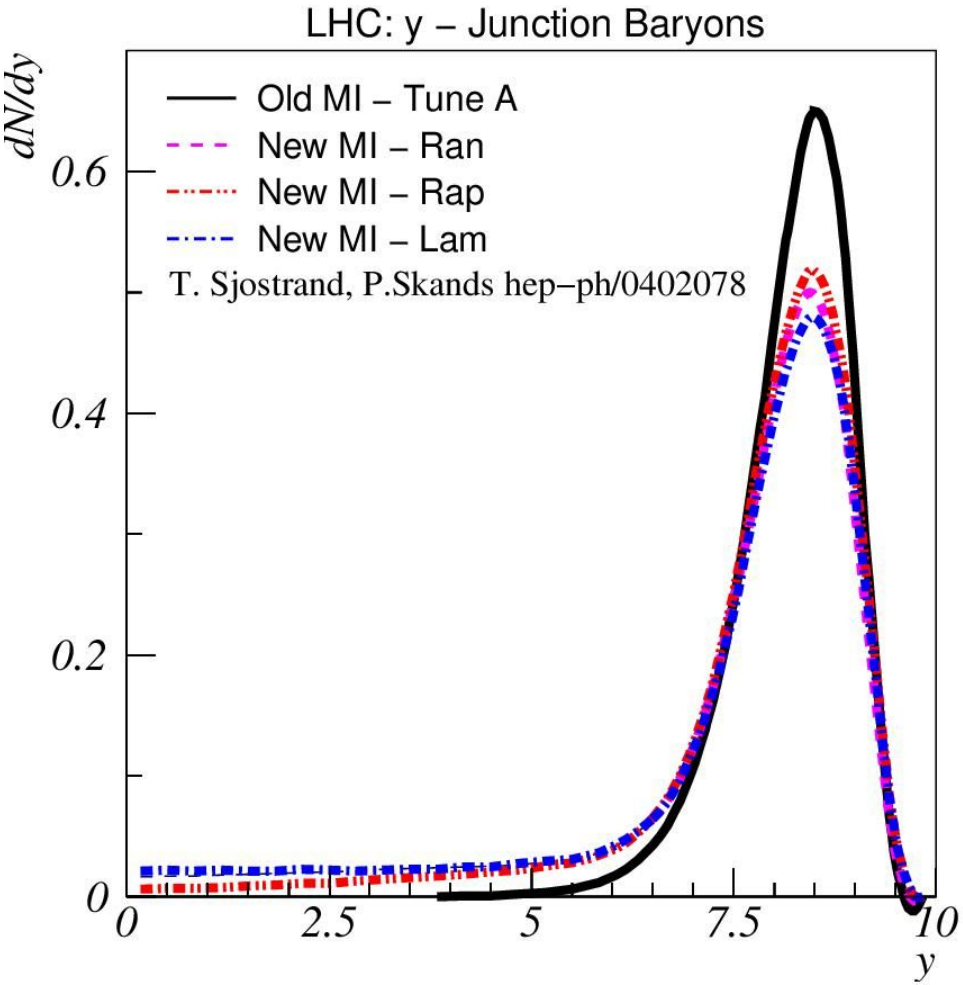


- **differences visible in p-fragmentation region, at largest rapidities** $\eta \sim 10$
- **Precison measurements possible with appropriate devices ...**

Energy flow at large rapidities

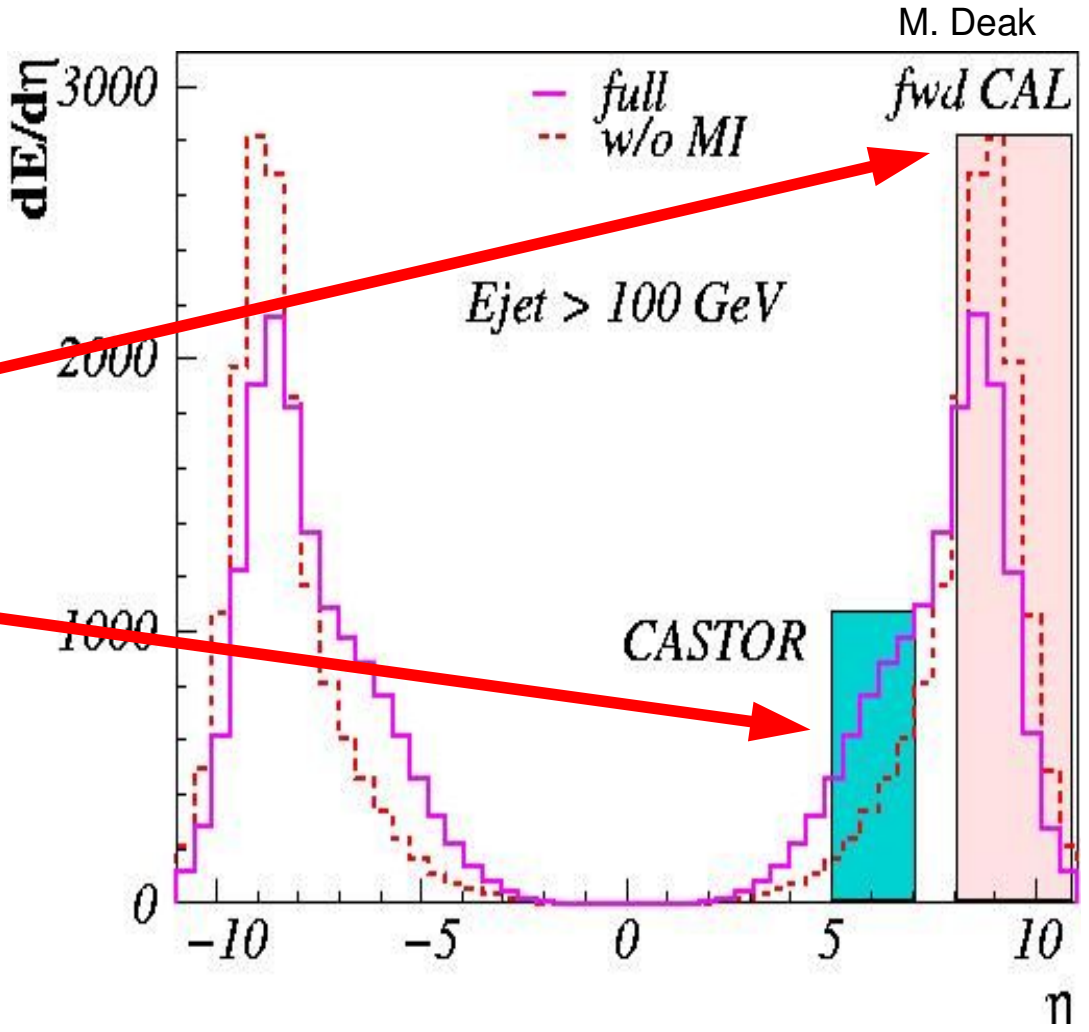
- Baryon production at large rapidities depends on the model assumptions for multi-parton interactions....
- But also extends to smaller rapidities

➔ Better understand mechanism !!!



Energyflow at forward rapidities

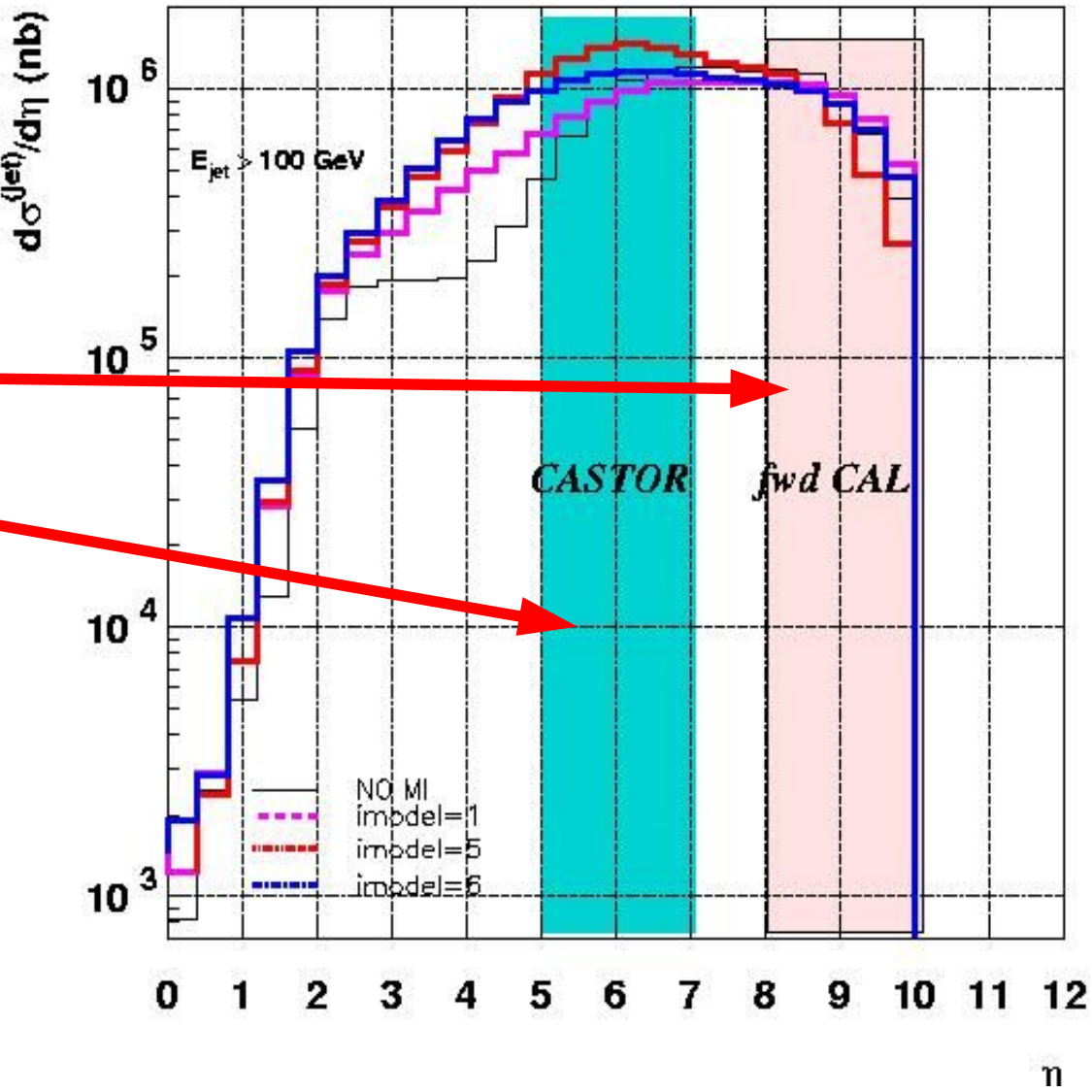
- Depending on multiple Interaction ansatz, more or less energy is taken from the beam remnants.
- Important to measure correlation and fluctuations in rapidity range $\eta \sim 9$ and $\eta \sim 6$



- Energy measurement in forward and very forward regions

Energyflow at forward rapidities

- Depending on multiple Interaction ansatz, more or less energy is observed.
- Important to measure correlation and fluctuations in rapidity range $\eta \sim 9$ and $\eta \sim 6$



- Jet xsection measurement in forward and very forward region:

➔ Huge model dependences

➔ understand dynamics of MI