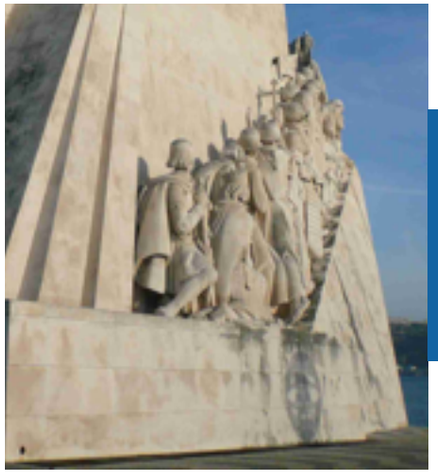
Multi-Parton and Multi-Nucleon Correlations: Experiment

Andreas Morsch
CERN



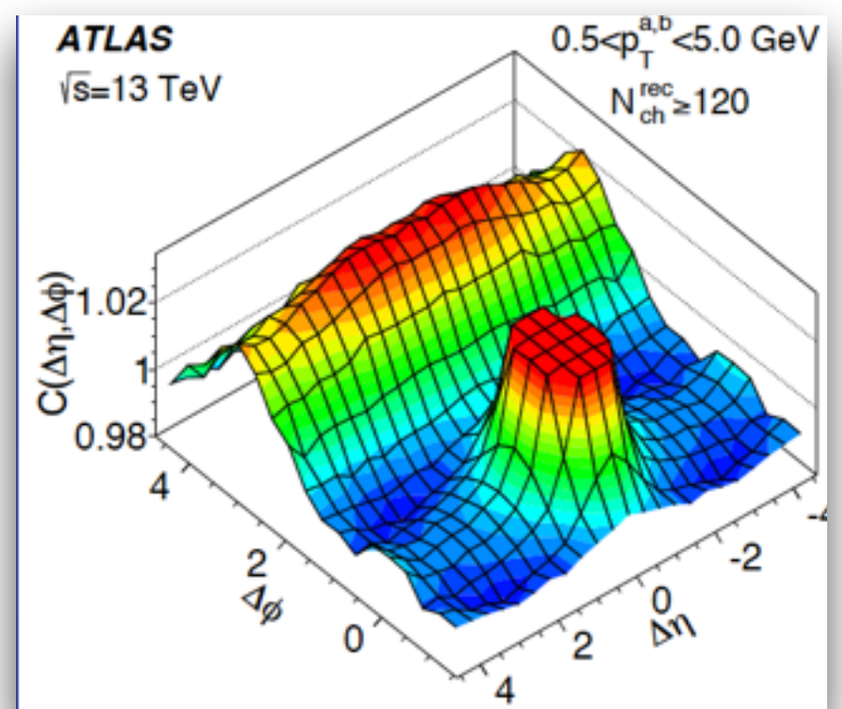
3rd International Conference on the Initial Stages in High-Energy Nuclear Collisions (InitialStages2016)

Lisbon, 27 May 2016

Multi-Parton/Multi-Nucleon Correlations ?

- pp, pA, AA: collisions of beams of confined partons
  - most of the experimental results are related to Multi-Parton or Multi-Nucleon interaction and their correlations …

Challenging subject for a 20 min talk …



… and the most spectecular results have been already discussed

Focus of this Talk

- Measurements interpreted in the framework of MPI that provide information about
  - **correlation between hard and soft** particle production
  - the **initial state** of small systems (pp, p(d)A)
  - **final state correlations** that might help to understand the origin of collectivity in small systems
- Emphasis is on **experimental challenges** rather than an exhaustive catalogue of experimental results

Importance of MPI in pp (at LHC)

- Straightforward interpretation of pQCD $\sigma_{2\to2} > \sigma_{tot}$

Number of 2→2 scatterings per event, naïve factorization:

$$\langle n_{2\to2} \rangle = \frac{\sigma_{2\to2}}{\sigma_{tot}}$$

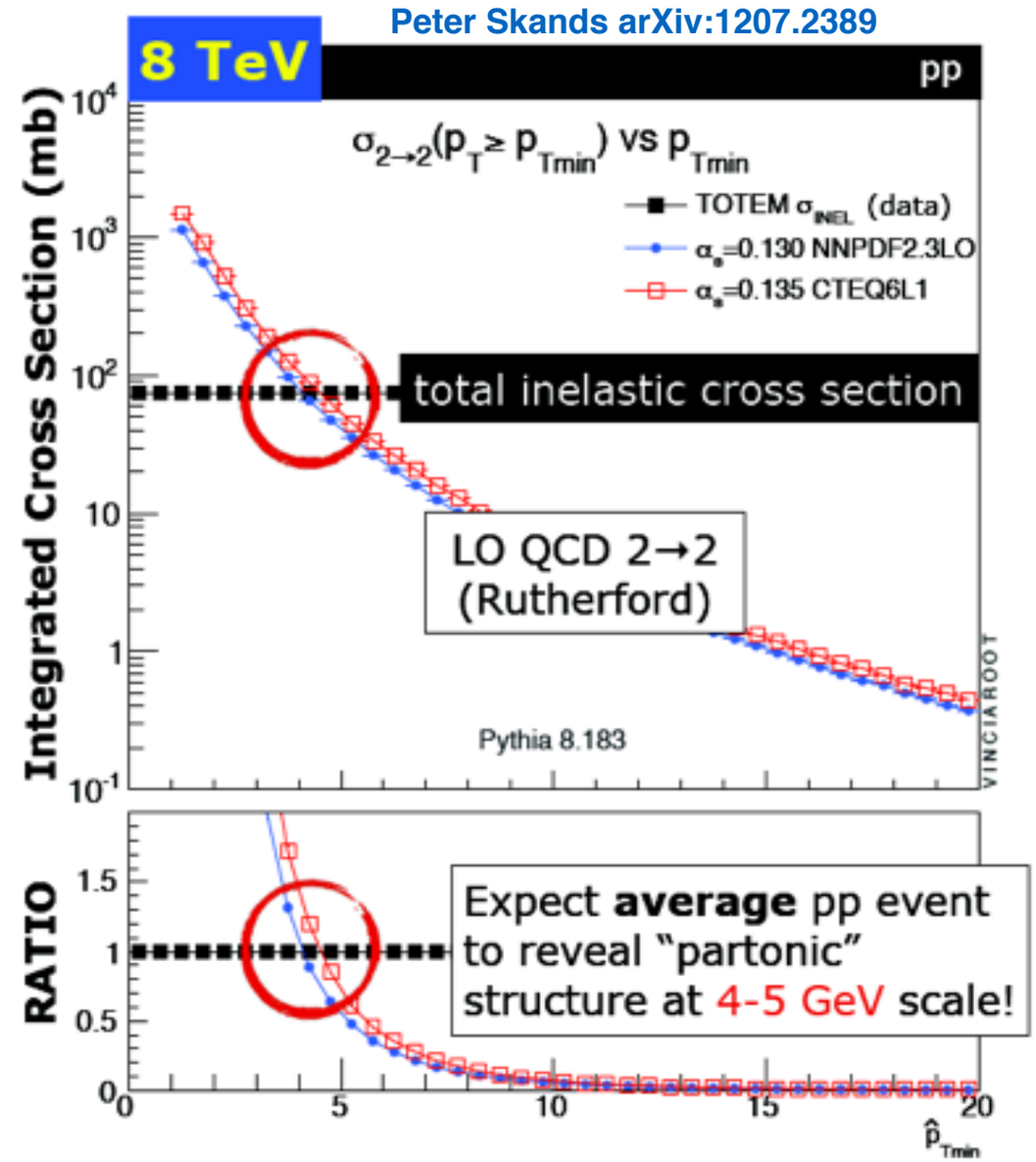
$$P_n = \frac{\langle n_{2\to2} \rangle^n}{n!} e^{-\langle n_{2\to2} \rangle}$$

$p_T \gg \Lambda_{QCD}$ for pQCD to be applicable

factorisation breaks for $n_{2\to2}$ large in area $\frac{1}{p_T^2}$

Challenge models based on MPI in this region!

Peter Skands arXiv:1207.2389

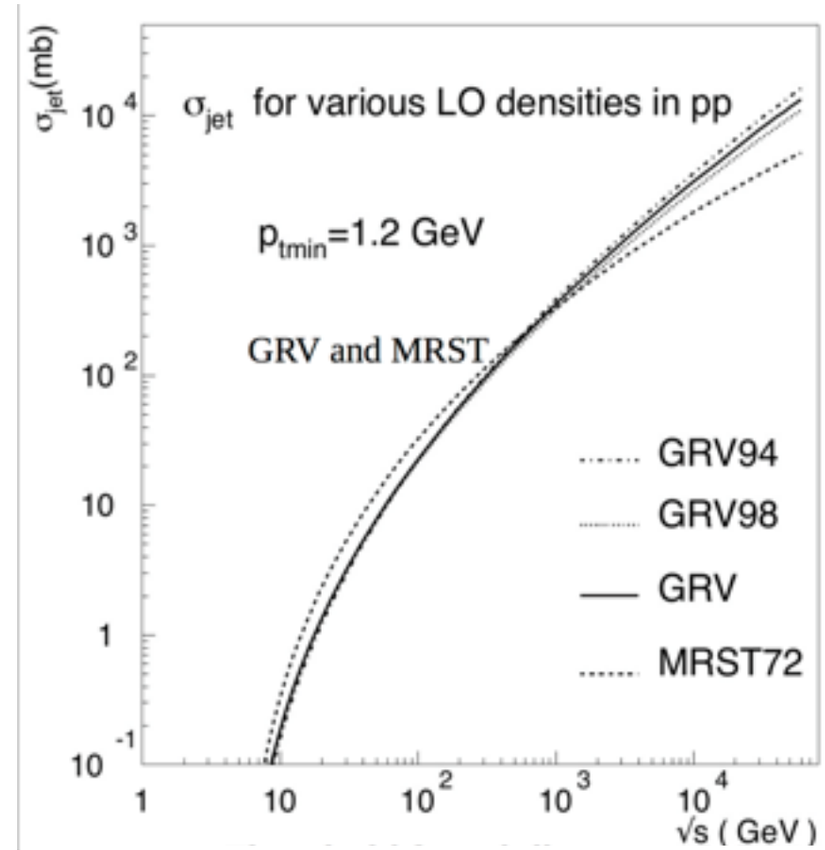


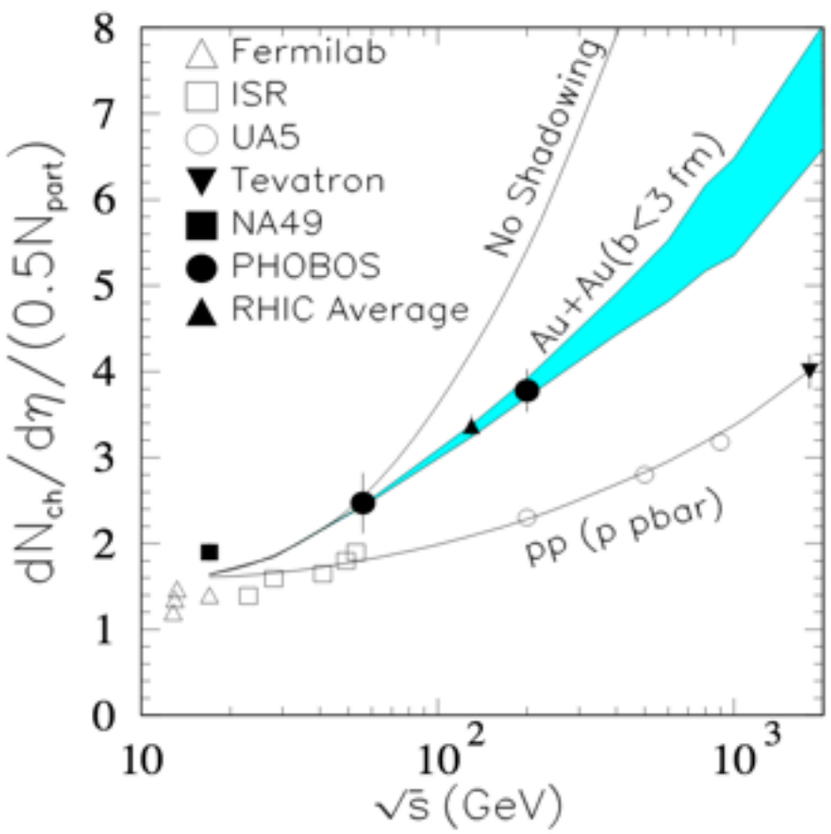
At LHC multiple hard scatterings at perturbative scales

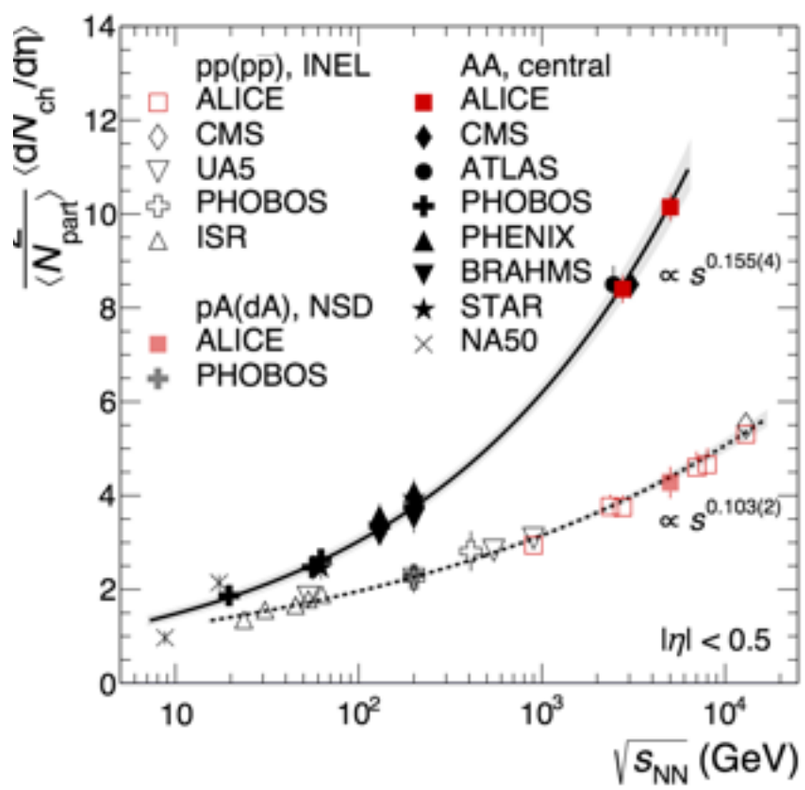
What do we know about the contribution to "bulk (low-p_T) particle" production ?
(event activity = proxy for MPI)

MPI and Charged Particle Multiplicity

- Particle yield from MPI ∝ $\sigma_{hard}/\sigma_{soft}$ steeply rising with $\sqrt{s}$
  - additional factors ∝ $A^{1/3}$ (pA), ∝ $A^{4/3}$ (AA)
- Dominance of particle production at LHC ?
  - $dN_{ch}/d\eta$ does not follow this trend
  - hard cross-section must be damped at low p_T
  - additional soft processes are important





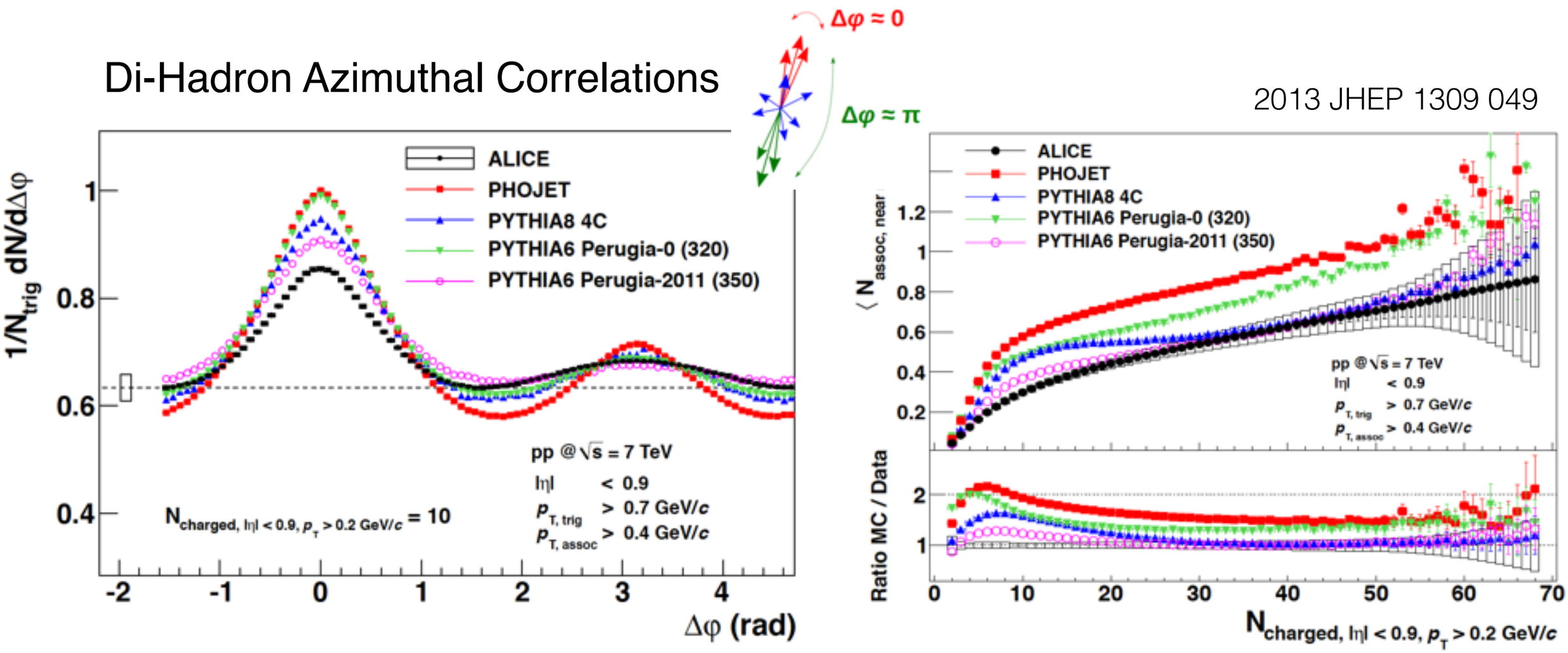


What about jet like correlations ?

Topological Identification of MPI

Di-Hadron Azimuthal Correlations

2013 JHEP 1309 049



- "mini-jets" contribution to low-p_T "bulk" particle production

- Multiplicity dependence sensitive to relative contribution of hard-soft processes
- should be the Achilles heel of MPI based models

Quite well described by some of the MC tunes.

Two additional MPI model ingredients

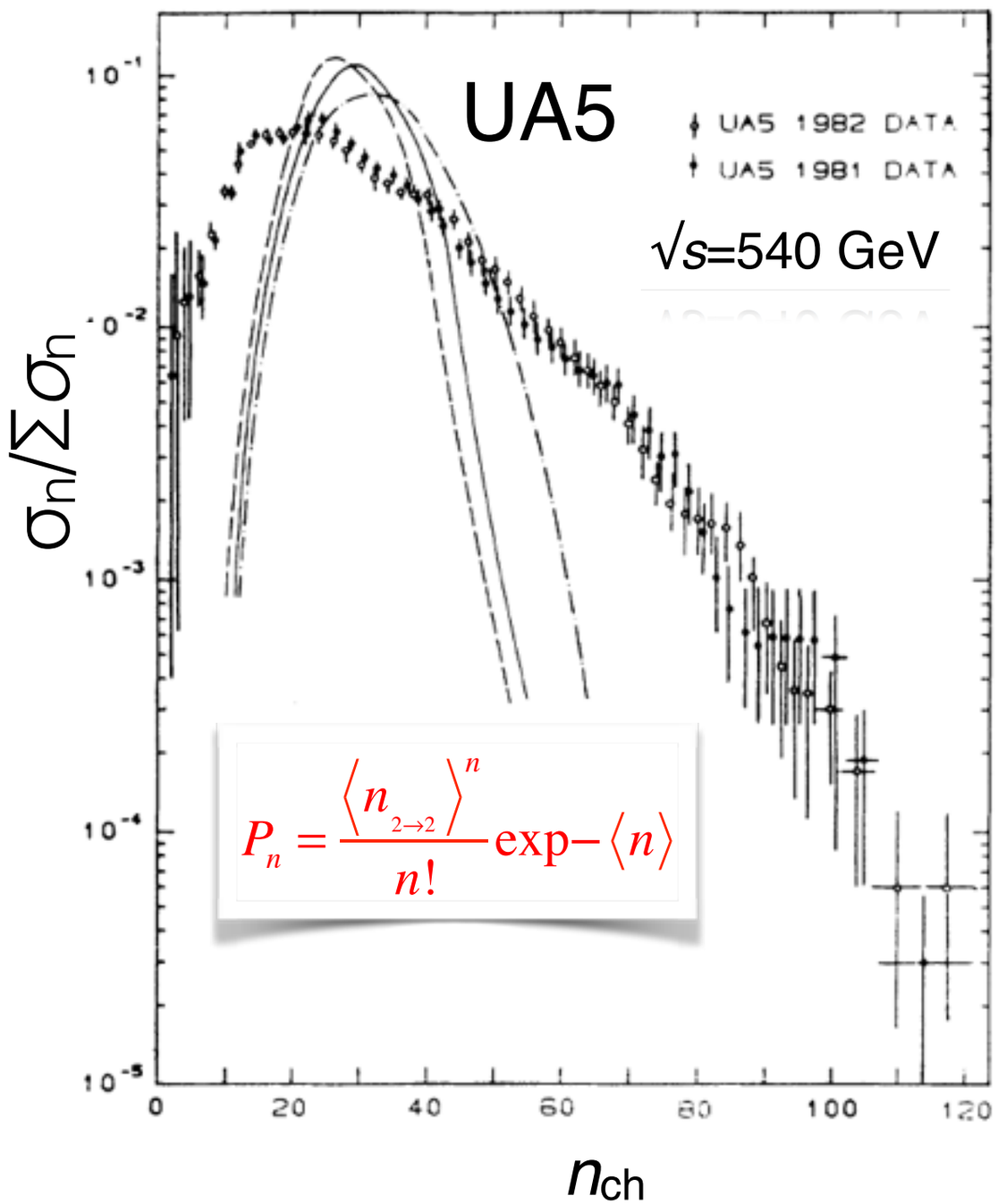
$$\langle n_{2\to 2}\rangle = \frac{\sigma_{2\to 2}}{\sigma_{\text{tot}}}$$

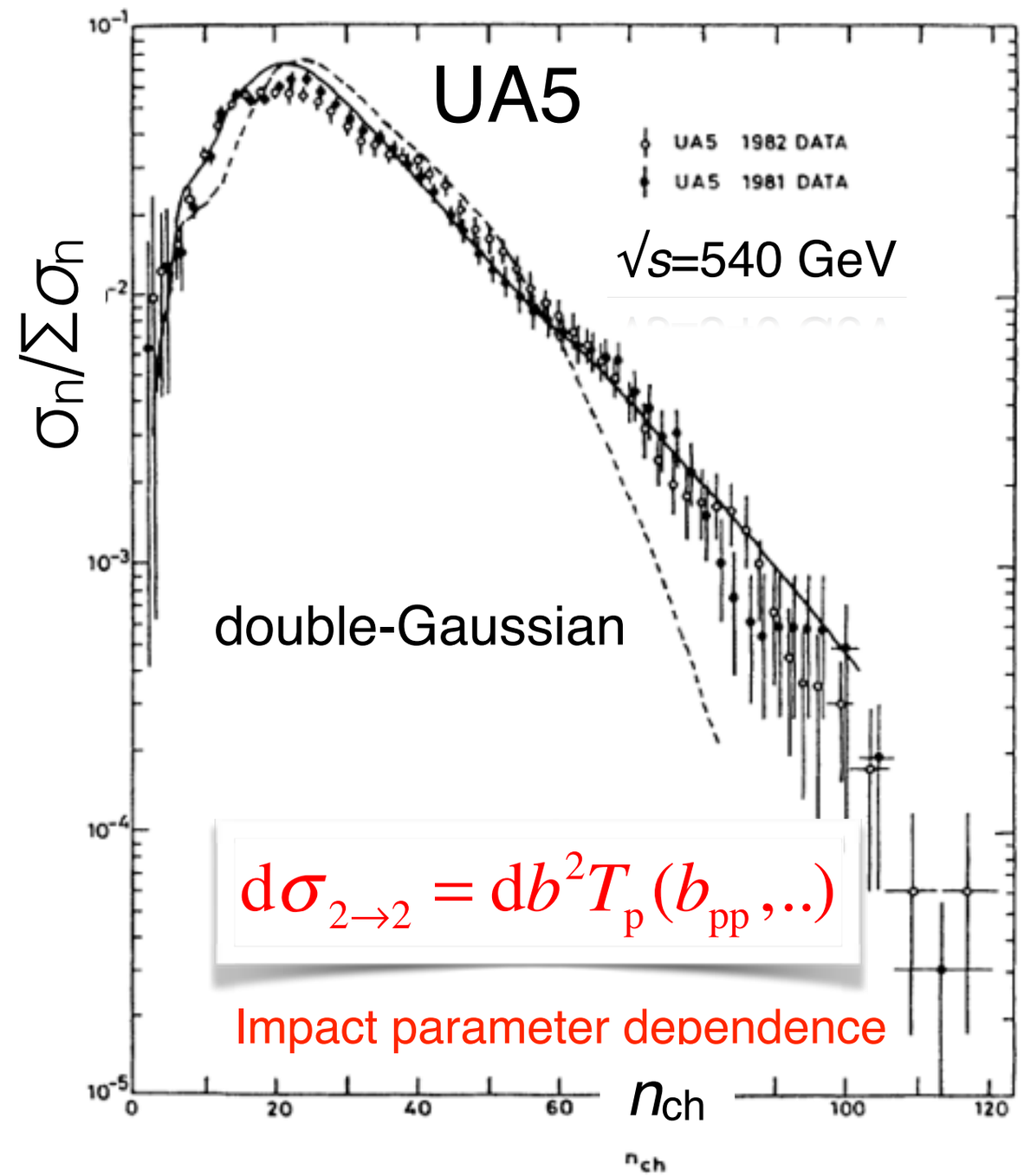
$$P_n = \frac{\langle n_{2\to 2}\rangle^n}{n!} e^{-\langle n_{2\to 2}\rangle}$$

Factorisation with Poisson Fluctuations not enough

- Impact parameter dependence (needs proton density function)
- Coherence effects between MPIs
  - Color Reconnections (Pythia, Herwig, …)
  - Collective Hadronization (EPOS)
  - Rope Hadronisation (DIPSY)

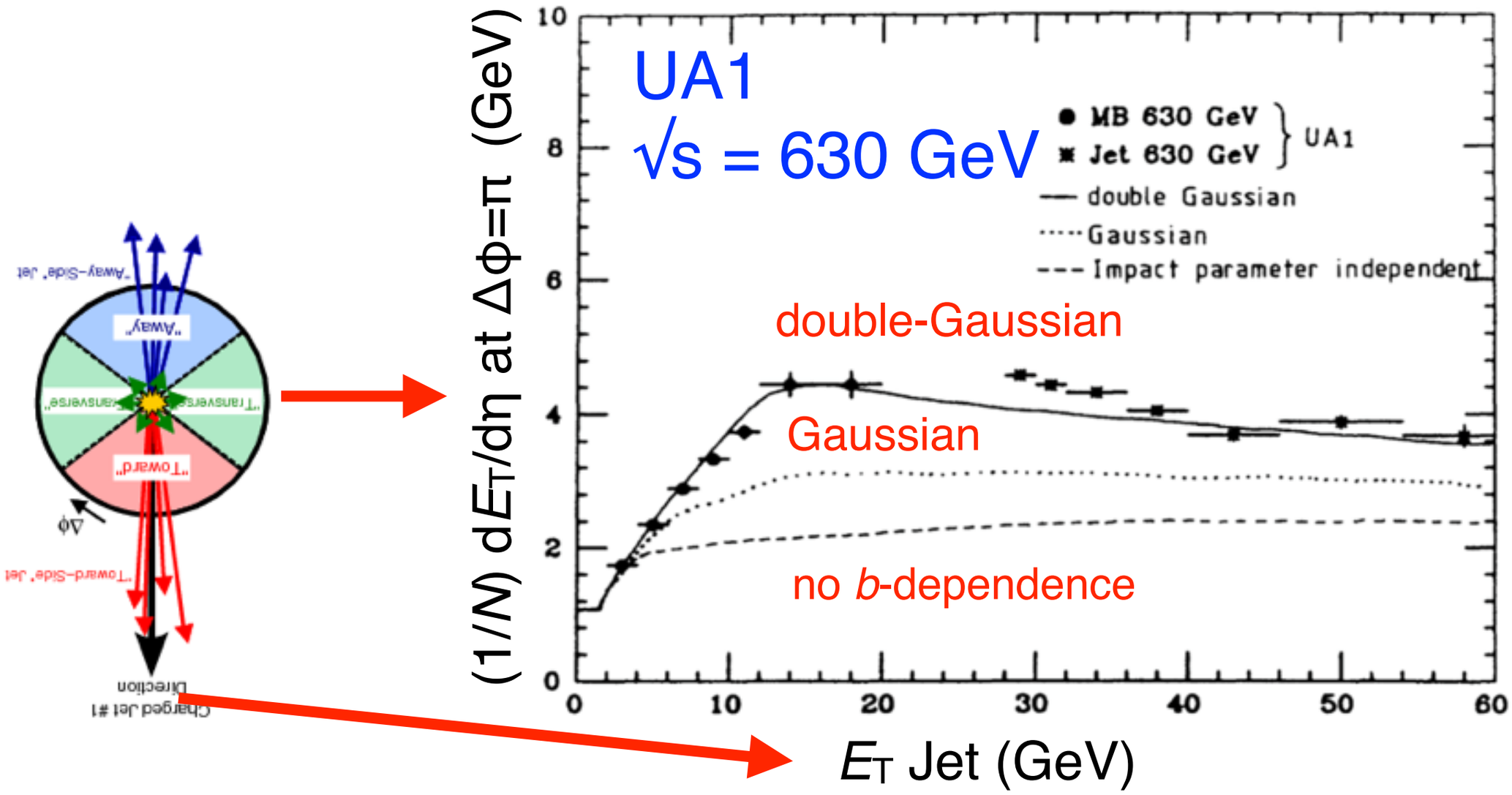
Sensitivity to Impact Parameter Dependence:
Charged Particle Multiplicity Distributions





Shape of multiplicity distribution sensitive to impact parameter dependence

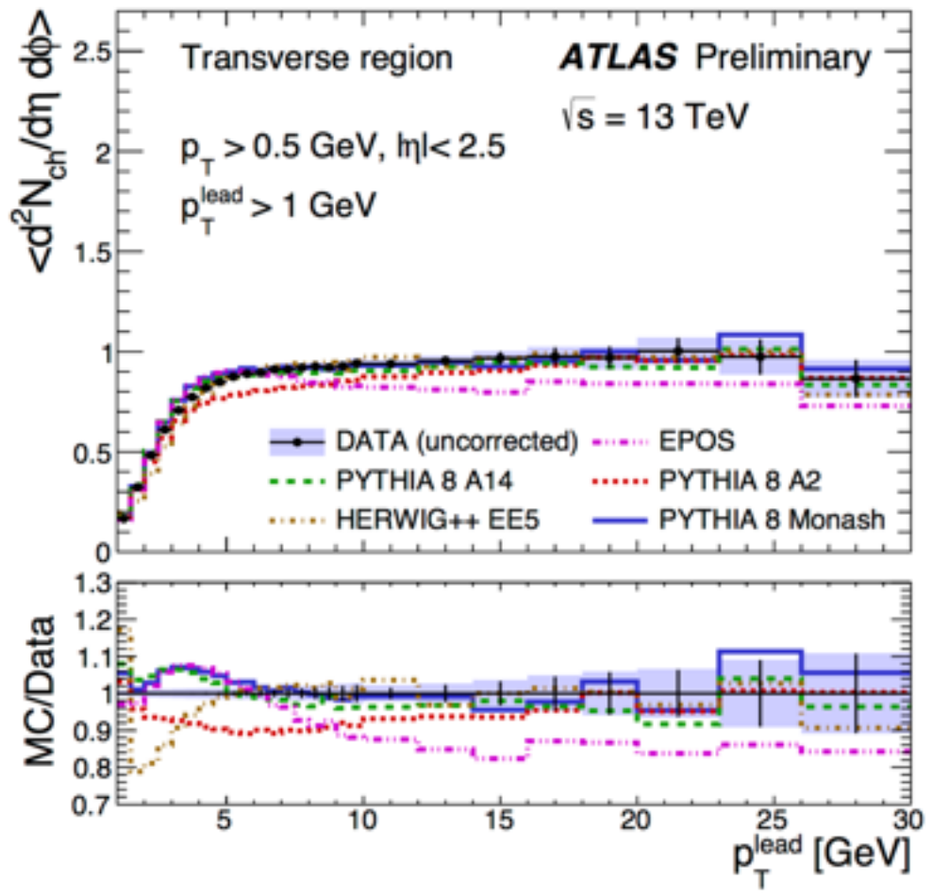
Jet Pedestal (Underlying Event)

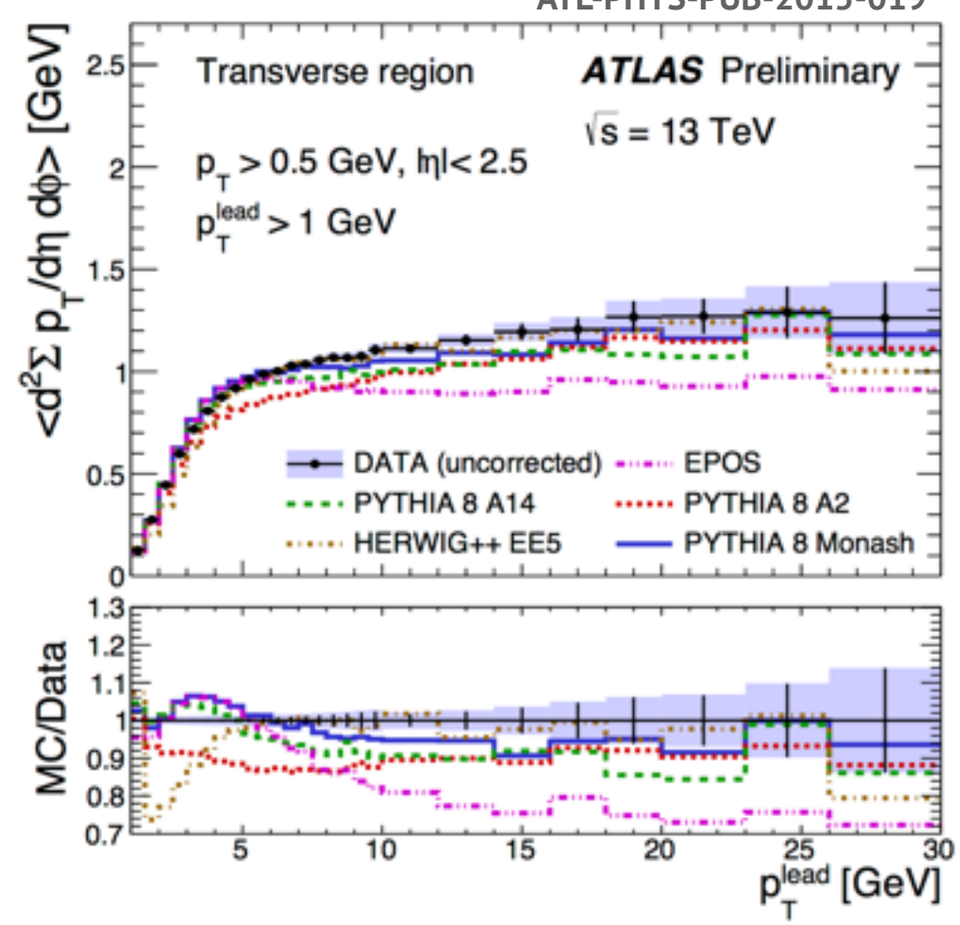


Hallmark of MPI based models:
High p_T objects bias towards smaller b where probability for additional interactions is larger increased UE activity.

UE in pp @ √s =13 TeV

ATL-PHYS-PUB-2015-019





- Clear discriminating power between different models (tunes)

- However, to which extent can we constrain individual mode components:
  - exact impact parameter dependence of hard/soft scattering ?
  - modelling of soft processes ?
  - confidence intervals for the parameters ?

$$\rho(r,x) \propto \frac{1}{a^3(x)} \exp\left(-\frac{r^2}{a^2(x)}\right)$$

- In principle proton density function could be *x*-dependent
  - Which measurement would be sensitive to this ?

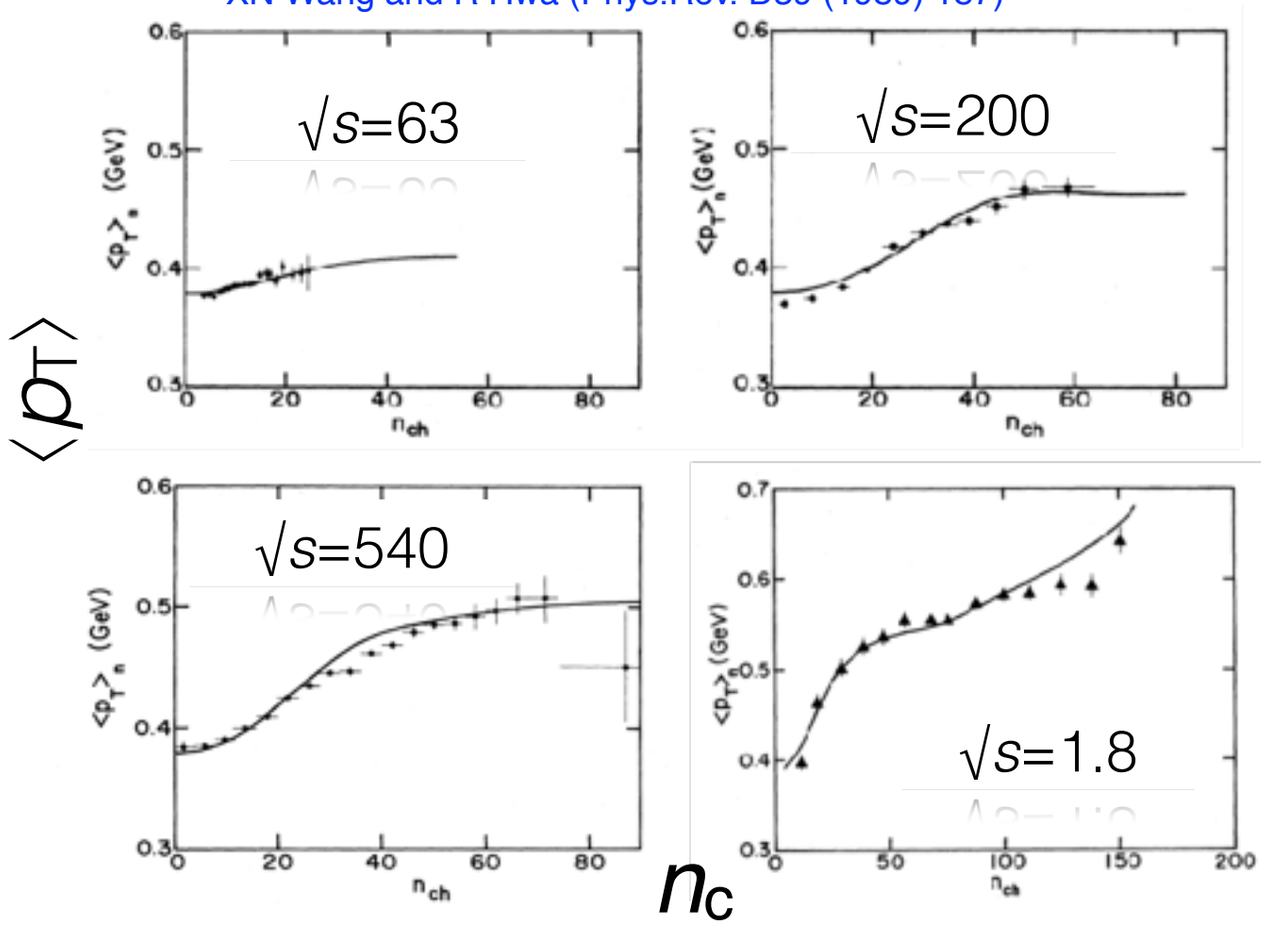
$$a(x) = a_0\left(1 + a_1 \ln\frac{1}{x}\right)$$

Probing Coherence Effects

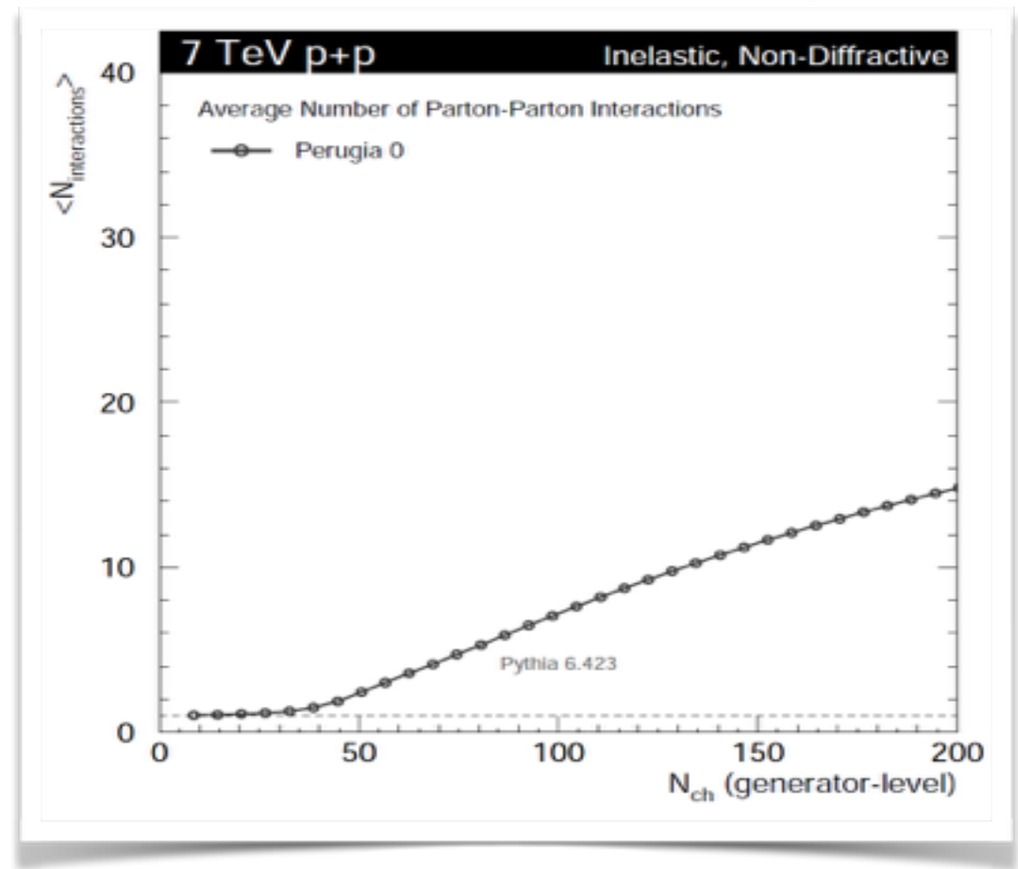
- N_{ch} dependent measurements inform
  - to which extend high-multiplicity events can be understood as incoherent superposition of elementary collisions
  - as such sensitive to coherence effects

Probing Coherence Effects

XN Wang and R Hwa (Phys.Rev. D39 (1989) 187)



P. Skands



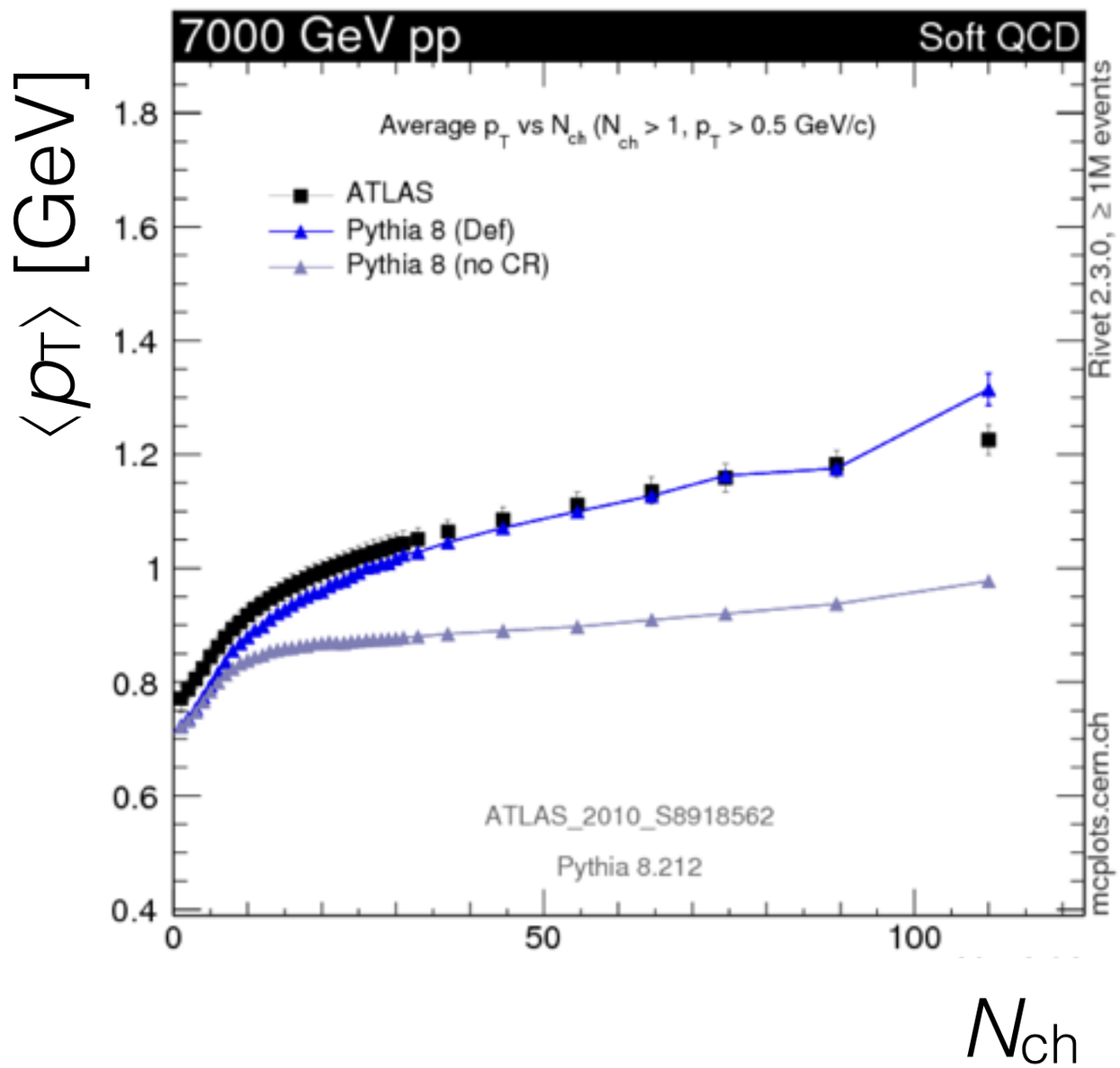
Two component model

➠Ledge Effect: rise – plateau – rise

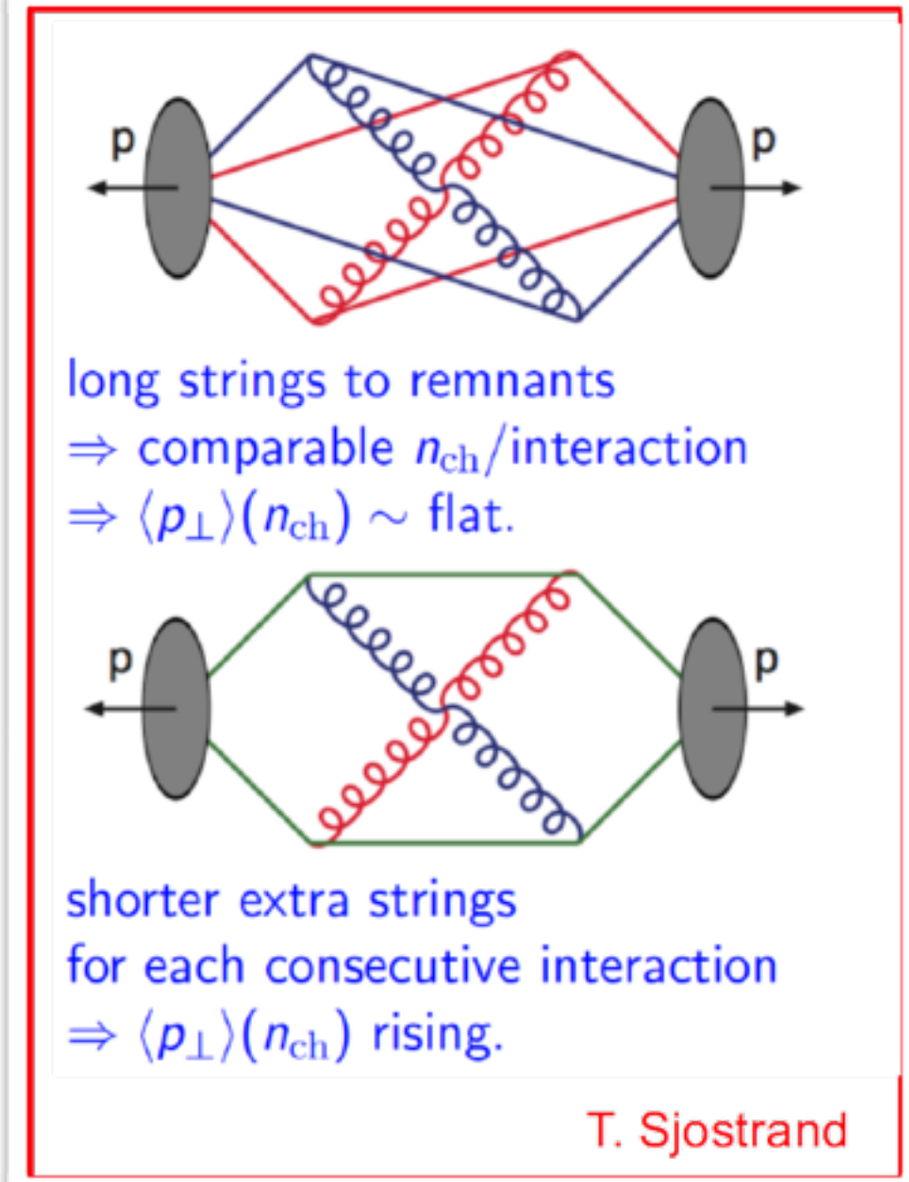
1st rise: increased dominance of hard over soft interactions

2nd rise: jet bias (jets contribute to soft particle production ~ ln E_{jet})

Pythia: Color Reconnections

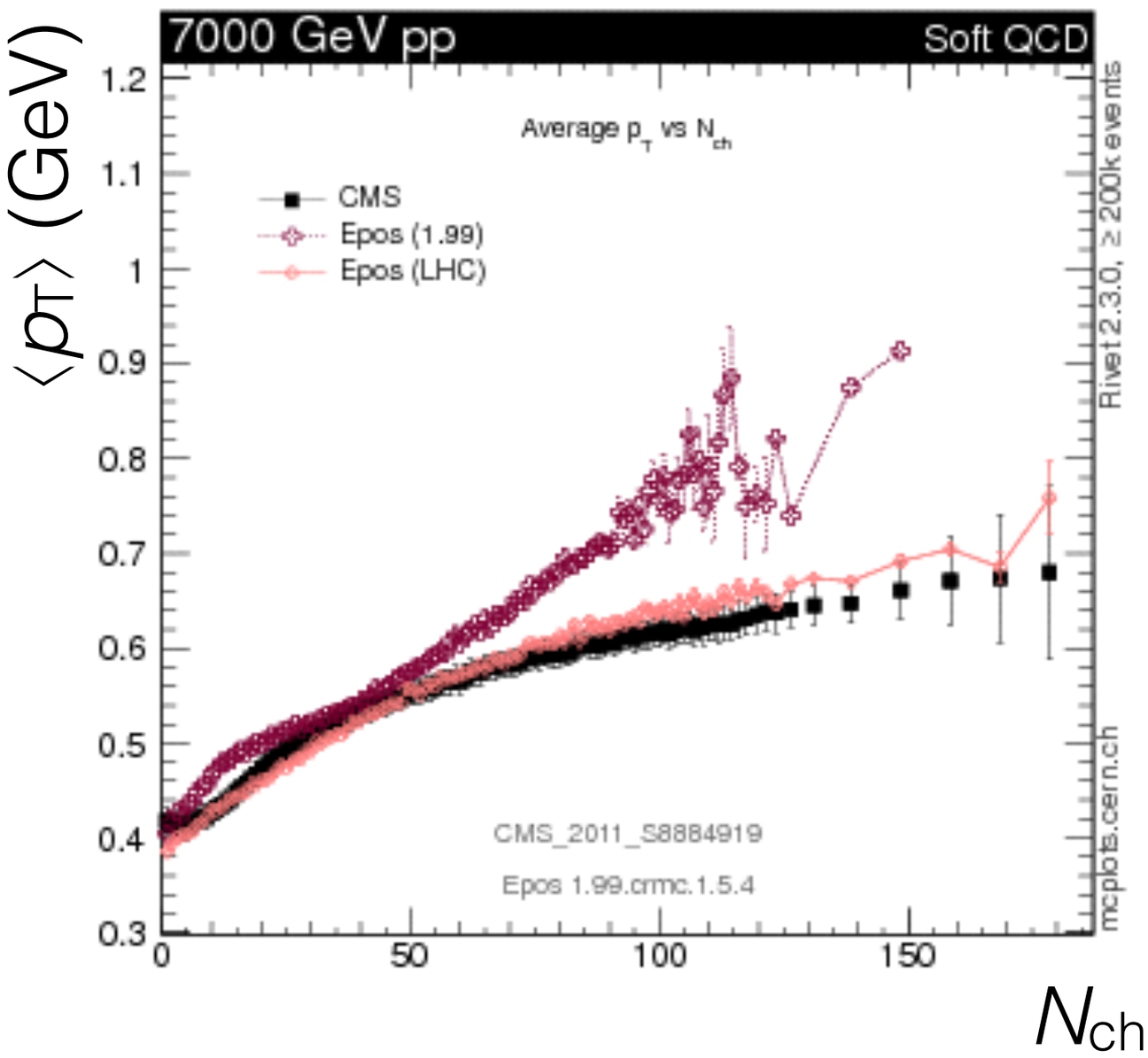


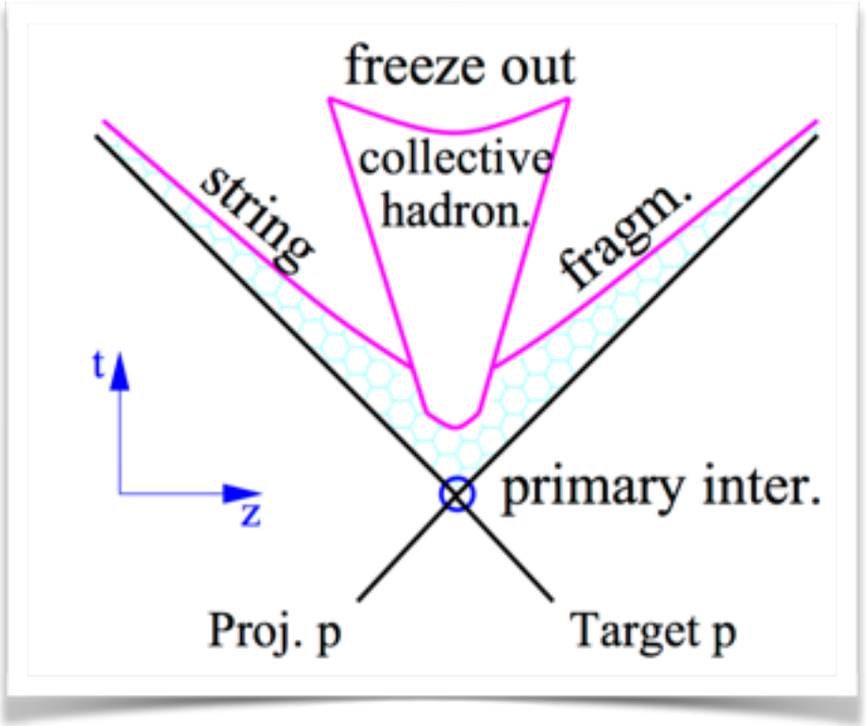
Color Reconnections (CR)

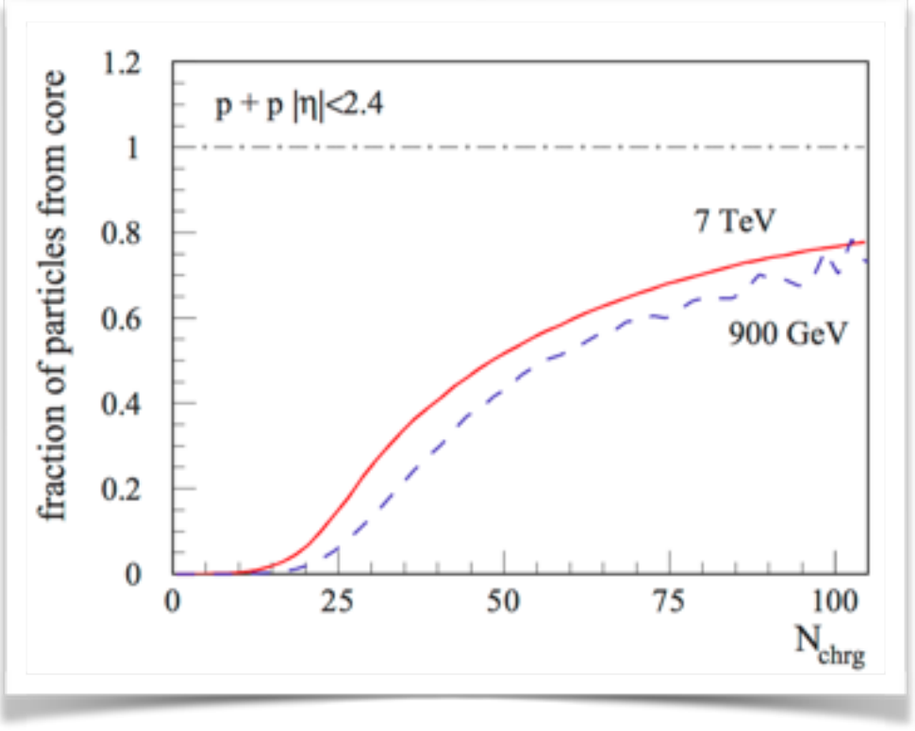


Pythia:
Interplay between hard and soft not enough to describe rise

EPOS: Collective Hadronization

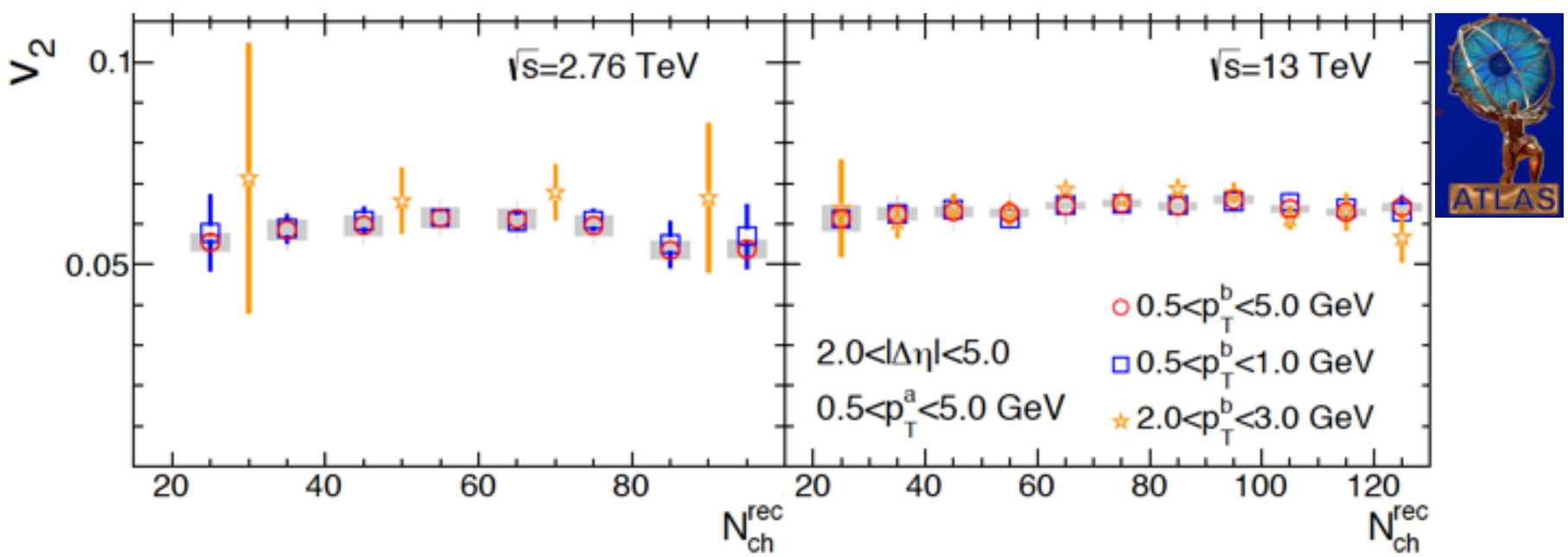






What's Next ?

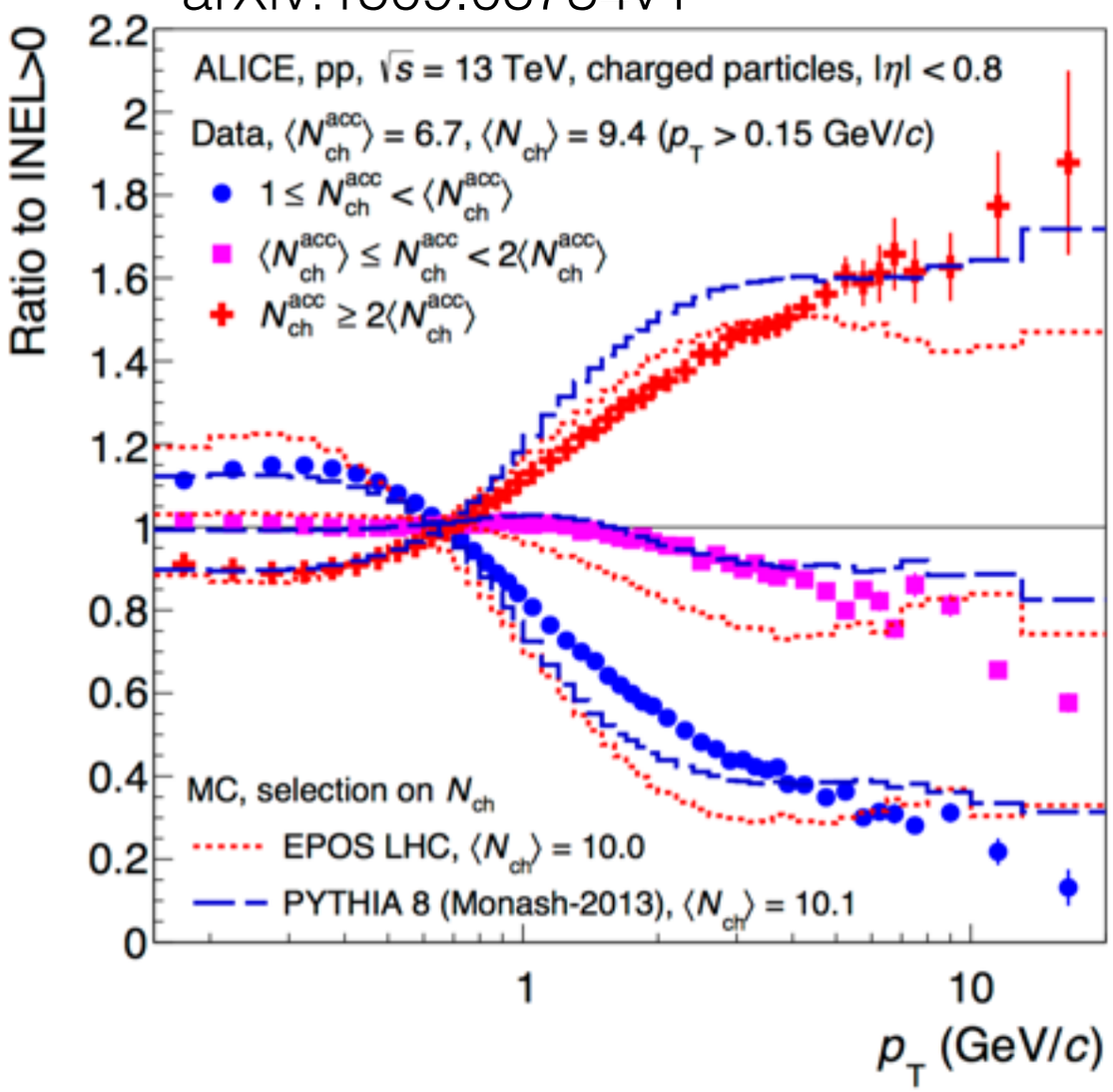
- Quite unsatisfactory that we cannot get separate effects related to
  - interplay of hard and soft particle production processes
  - jet biases
  - collective / coherence effects
- New observables ?
- Absence of multiplicity dependence of v_2 (ATLAS) should be contrasted with multiplicity dependence of other observables



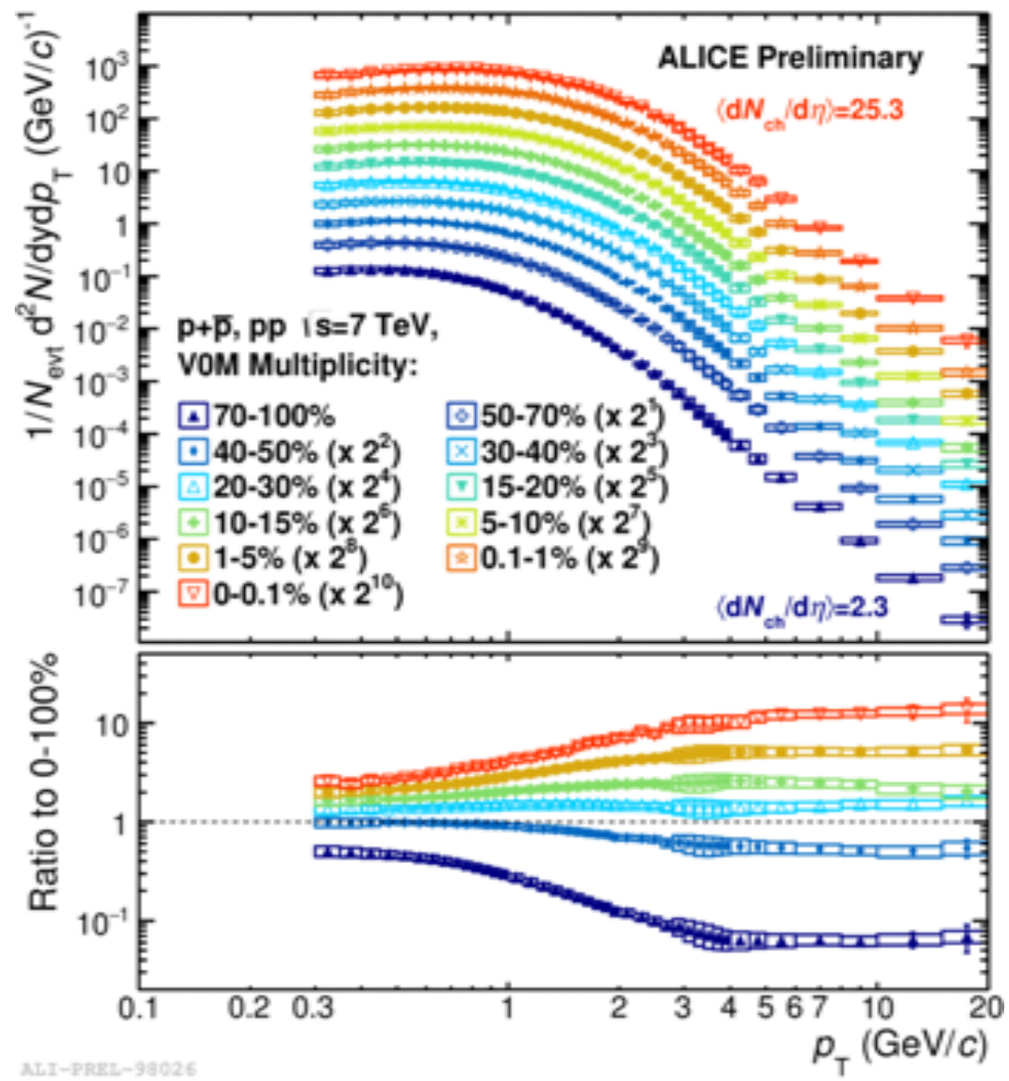
Ledge Effect Re-visited

Multiplicity measured in: $|\eta|<0.9$

arXiv:1509.08734v1



$2.8 < \eta < 4.1 \cup -3.7 < \eta < -1.7$



- Spectra measured at mid-rapidity,
- hardness multiplicity dependent

- Scaling at high p_T, reminiscent of R_{pA}
- Informs about N_{MPI}
- "Some kind of centrality measure"

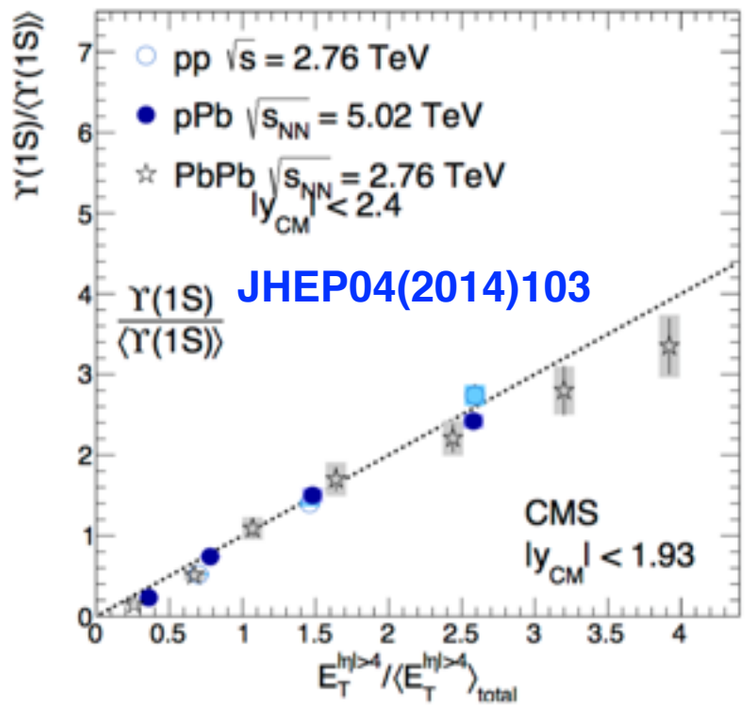
Rapidity Separated Measurements

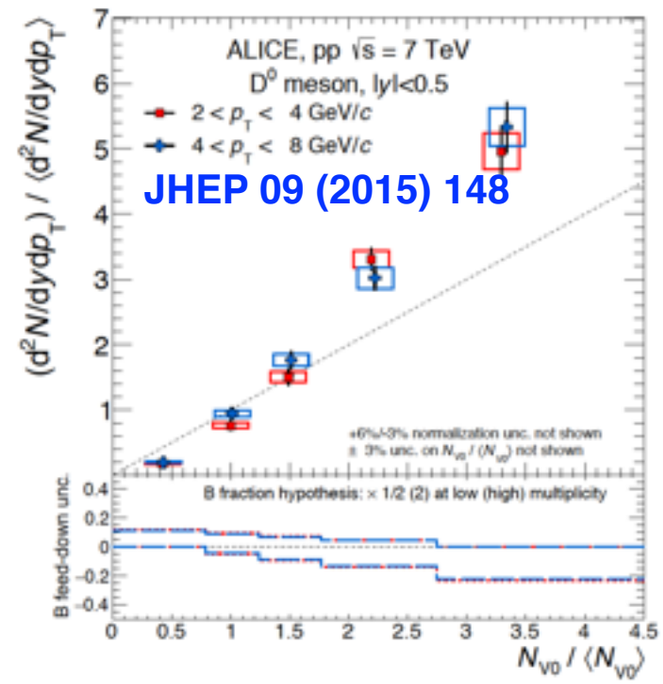
Υ(1S)

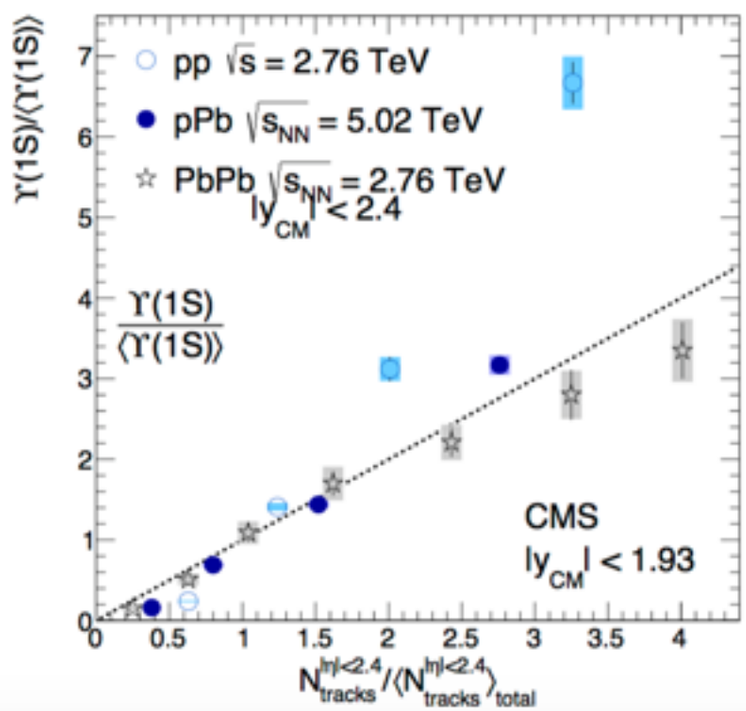
D

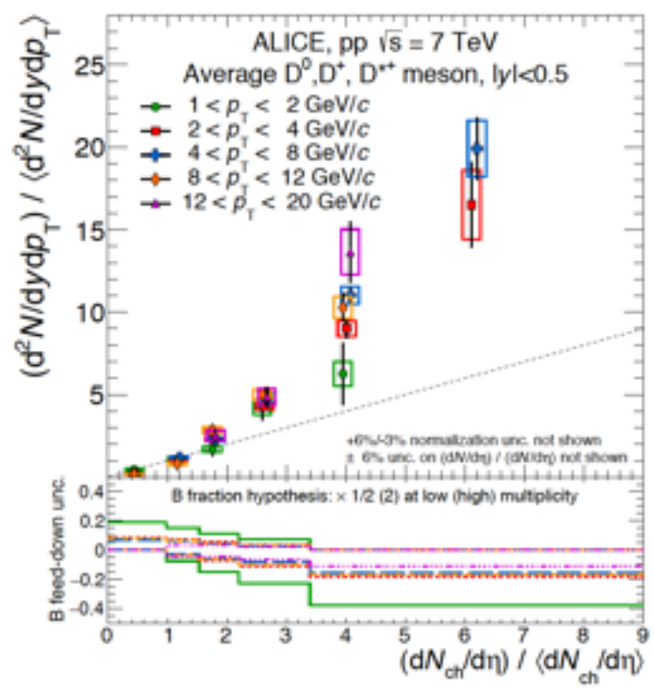
forward
event activity

central
event activity







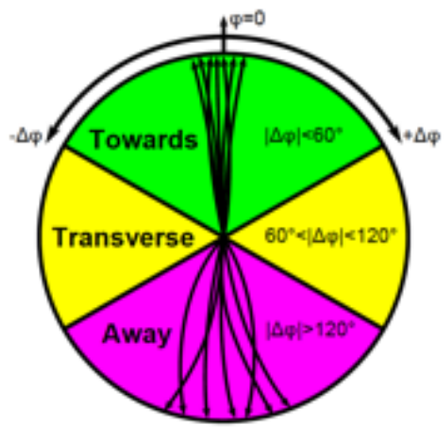


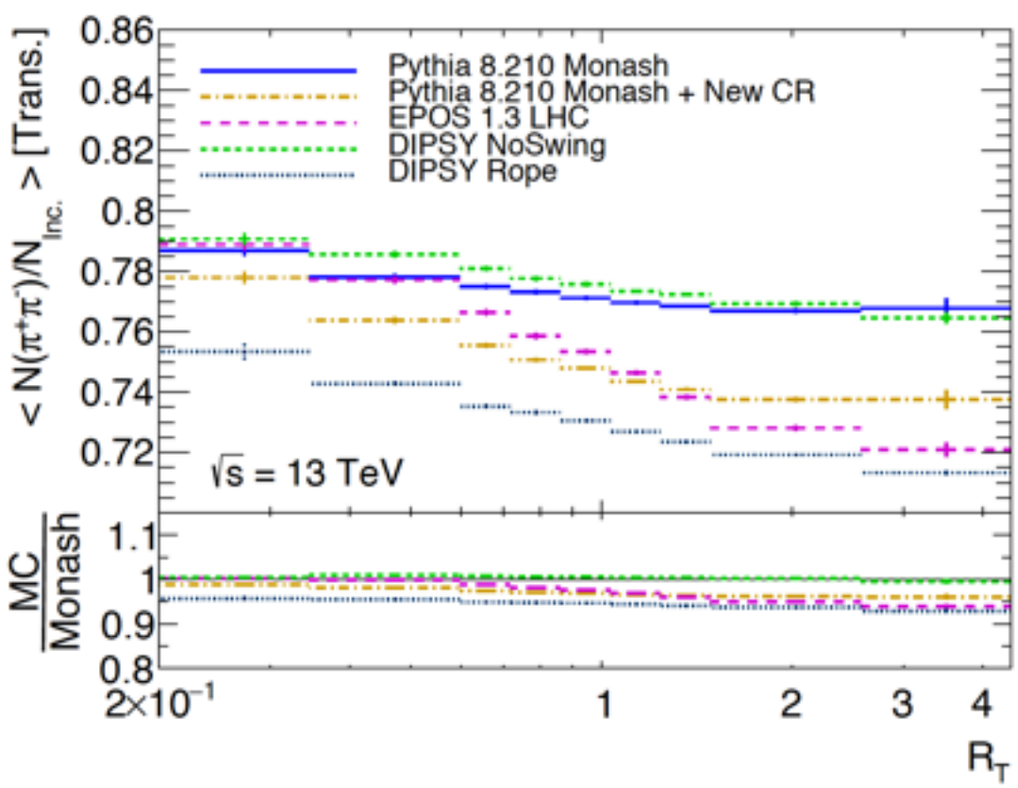
New Ideas

Measurements as a function of the UE activity for fixed jet p_T range

P. Skands, arXiv:1603.0529

$$R_T = \frac{N_{\text{inc}}}{\langle N_{\text{inc}} \rangle} \longrightarrow$$



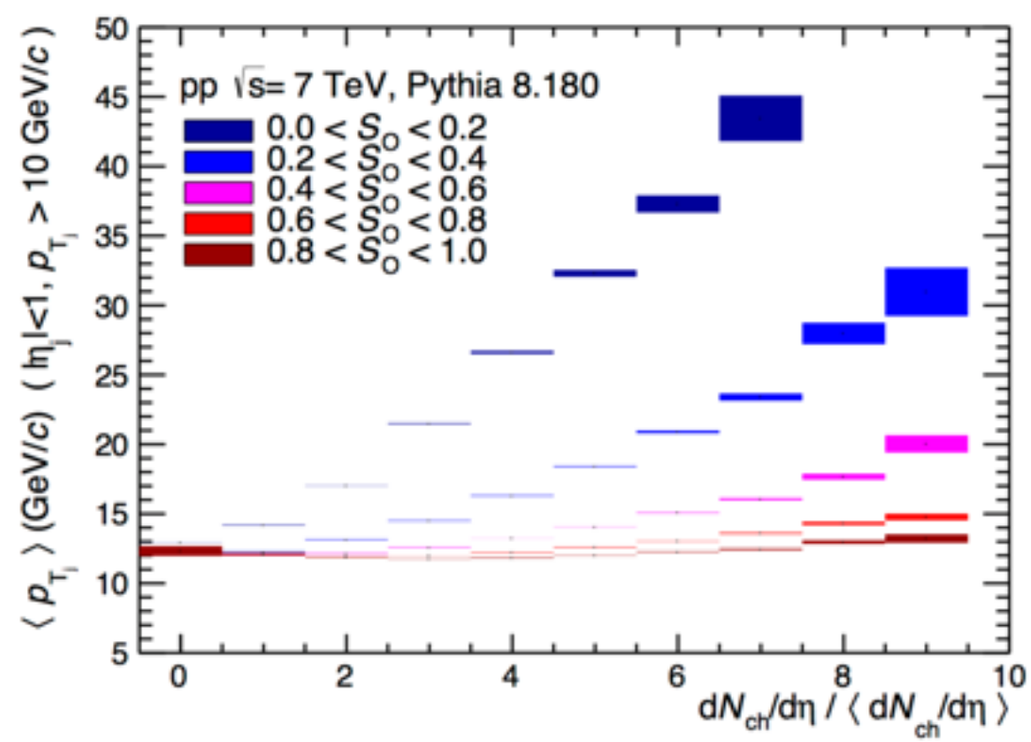


Measurements as a function of event shape (transverse spherocity)

E Cautl, A Ortiz, G Paic, Nucl. Phys. A941, 78-86 (2015)
Poster, G Paic

$$S_0 = \frac{\pi^2}{4}\left(\frac{\sum_i |\vec{p}_{\mathrm{T}i} \times \hat{\mathbf{n}}|}{\sum_i p_{\mathrm{T}i}}\right)^2$$

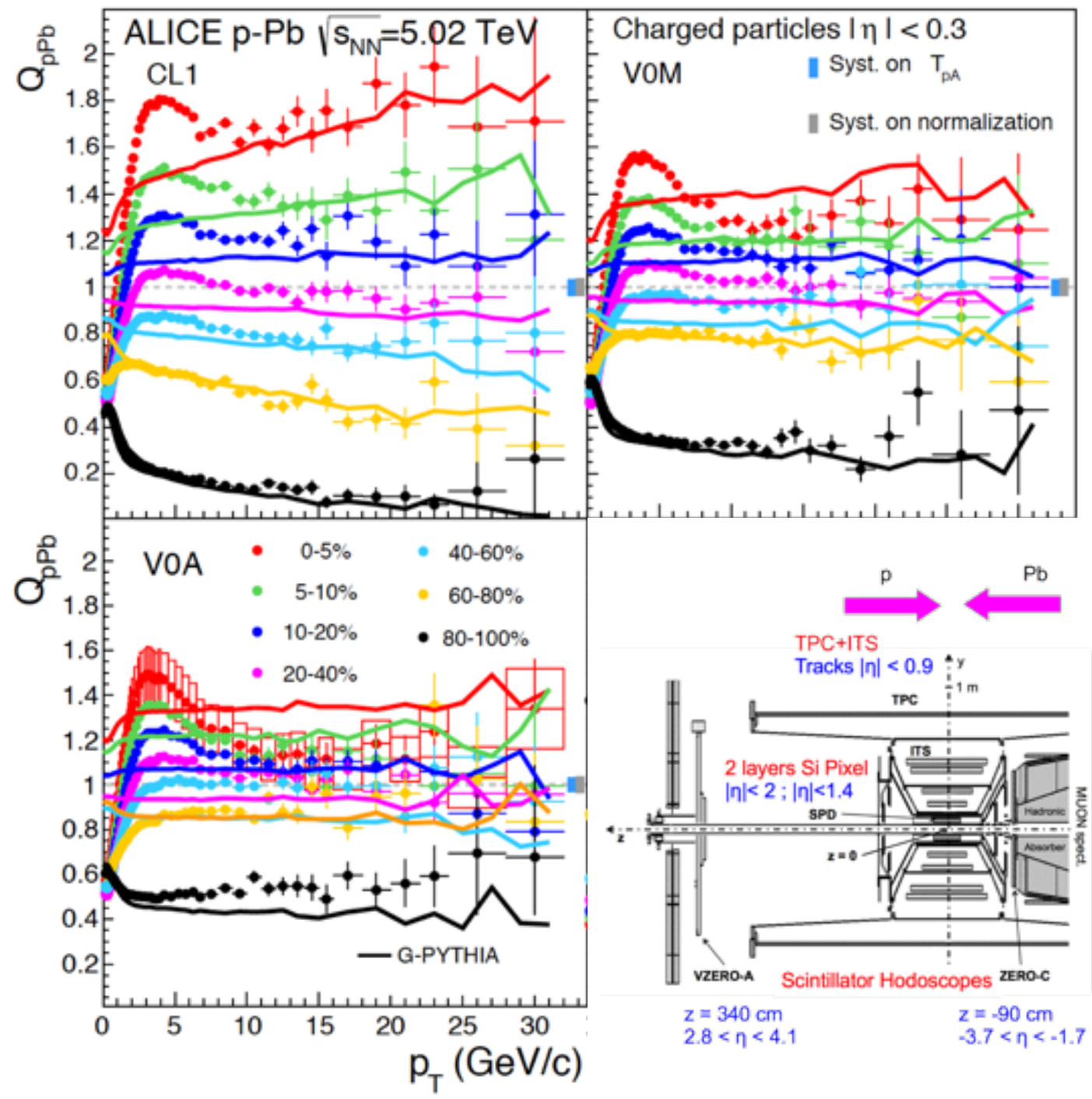
$$S_0 = \begin{cases} 0 & \text{“pencil-like” limit (hard events)} \\ 1 & \text{“isotropic” limit (soft events)} \end{cases}$$



pA: Bias on hard processes from soft-hard correlations

Phys. Rev. C 91, 064905 (2015)

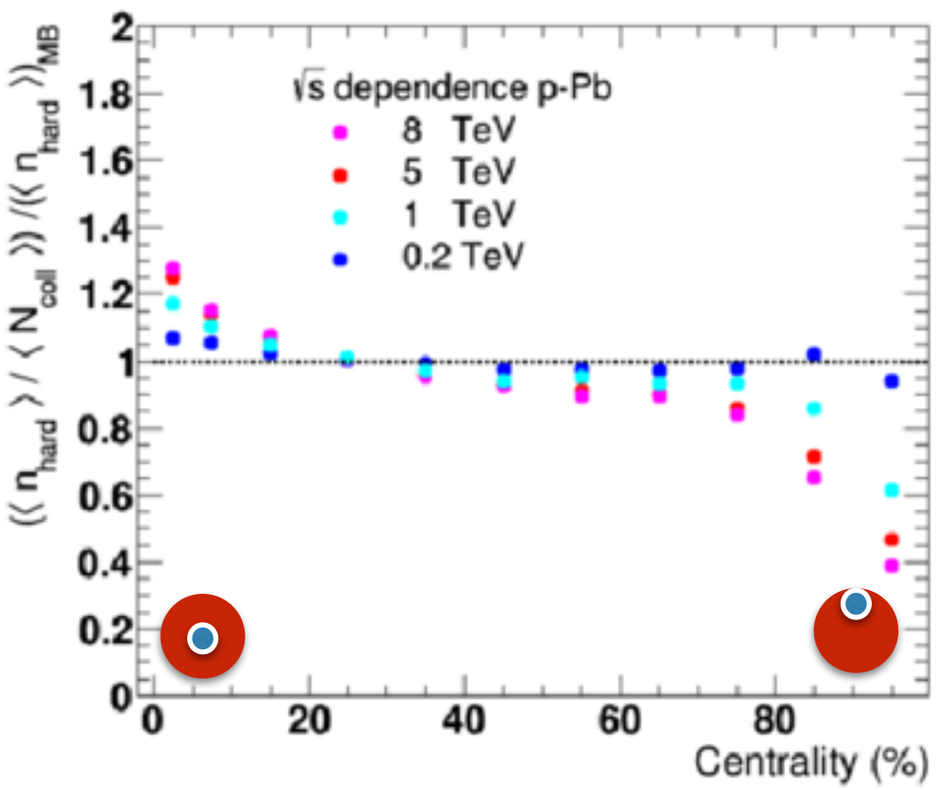
- Study of soft-hard correlations and MPI in pp has lead to a better understanding of centrality determination (N_{coll}) in pA
- Deviation from N_{coll} scaling if bias on hard processes in binary N-N collisions is not taken into account.



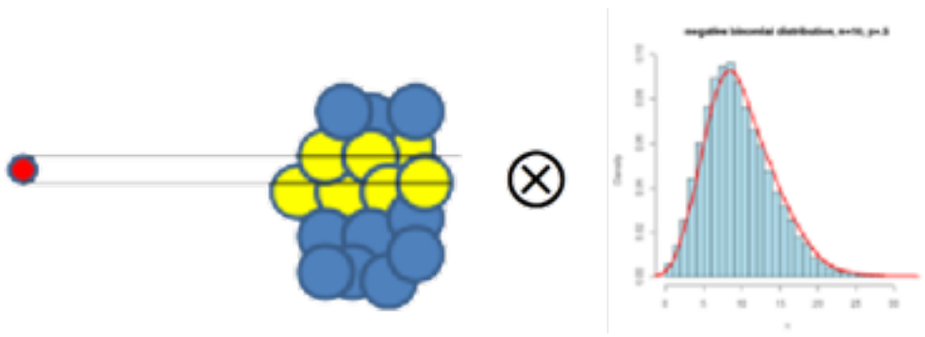
pA: Bias on hard processes from soft-hard correlations

MC

Phys. Rev. C 91, 064905 (2015)



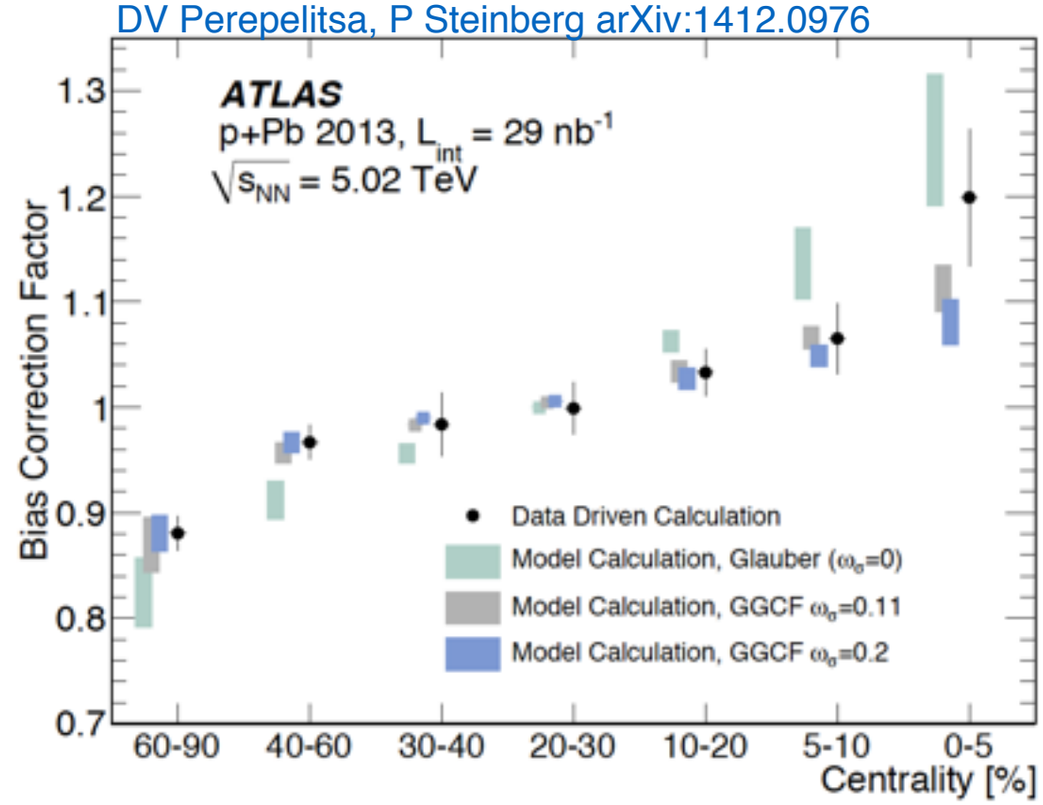
Slicing of Multiplicity in 2.8 < η< 5.1



Glauber ⊗ Pythia

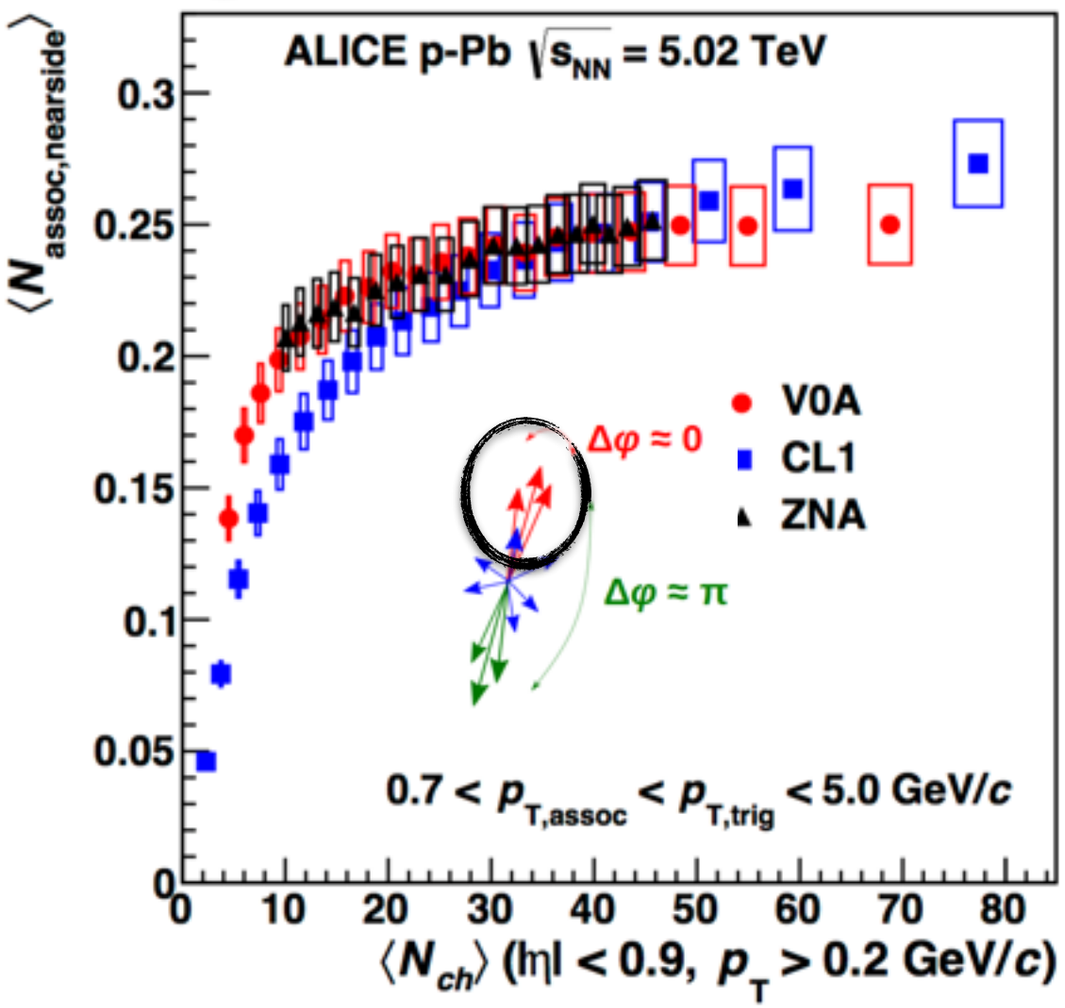
Data driven

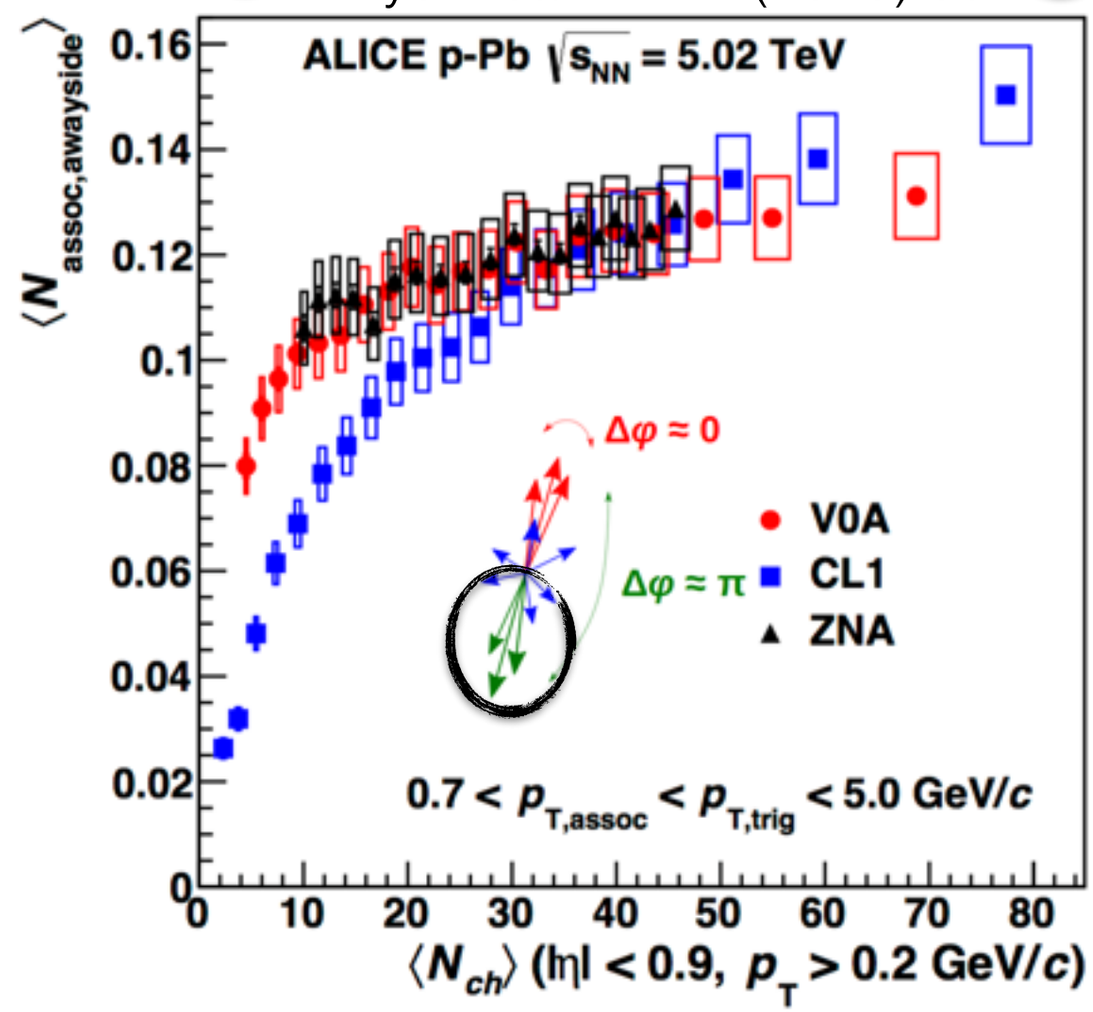
ATLAS, Phys. Rev. C 92, 044915 (2015)
DV Perepelitsa, P Steinberg arXiv:1412.0976



Low-p_T jet-like correlations in p-Pb

Phys. Lett. B 741 (2015) 38





- Corrected for contribution from v_2
- Do collective effects modify di-hadron correlations ?
- With forward event activity estimators di-hadron correlations level out at high multiplici
  - Despite strong collective effects
  - Can this discriminate models ?

Correlations between MPIs in the Initial State

- Complete incoherent superposition of MPI relies also on naive pdf factorisation beyond standard QCD factorisation:

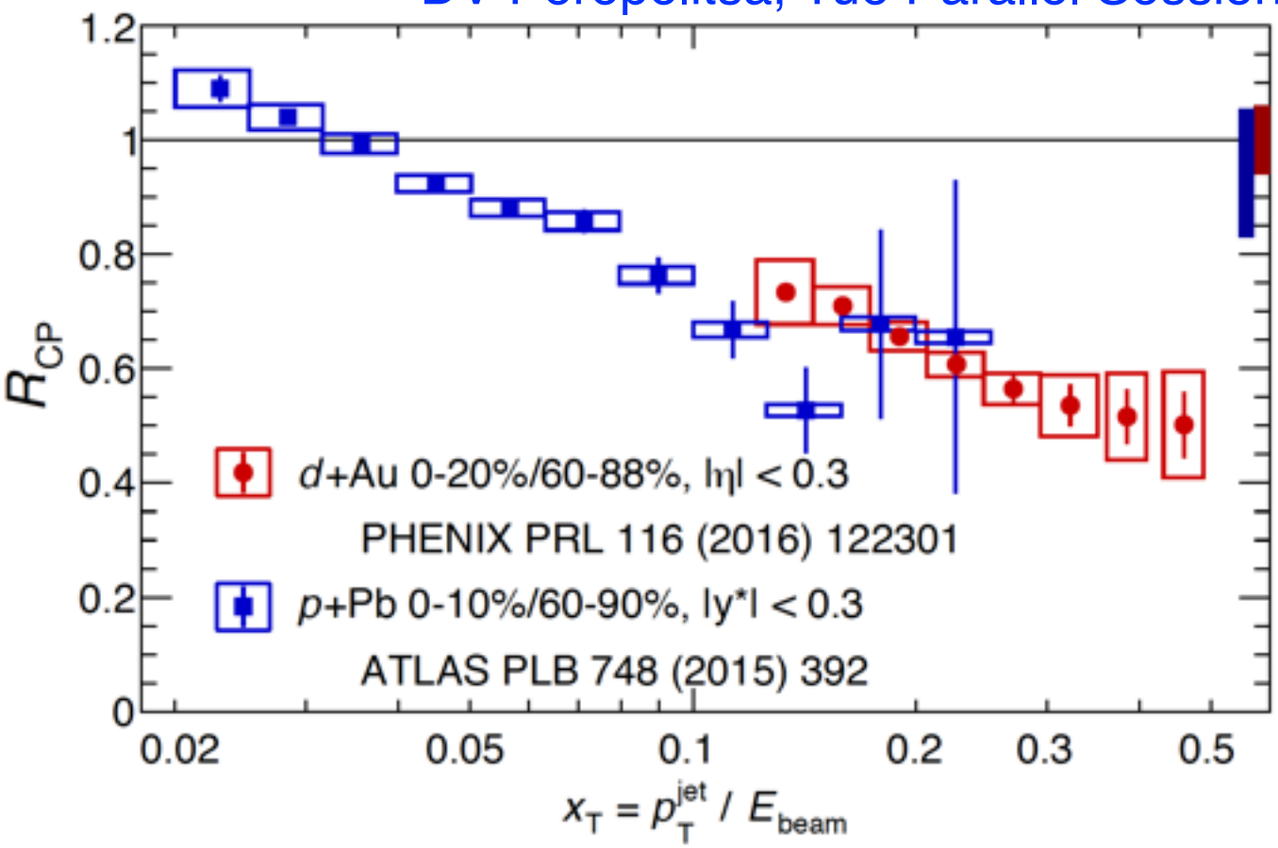
$$\frac{\mathrm{d}\sigma^{AA\to X}}{\mathrm{d}p_T} \propto \sum_n^{N_{\mathrm{MPI}}} f_i\left(x_i^n, Q_n^{\,2}\right) \circ f_j\left(x_j^n, Q_n^{\,2}\right) \circ \sigma^{ii\to k}\left(x_i^n, x_j^n, p_T / z, Q_n^{\,2}\right) \circ D_{k\to X}(z, Q_n^{\,2})$$

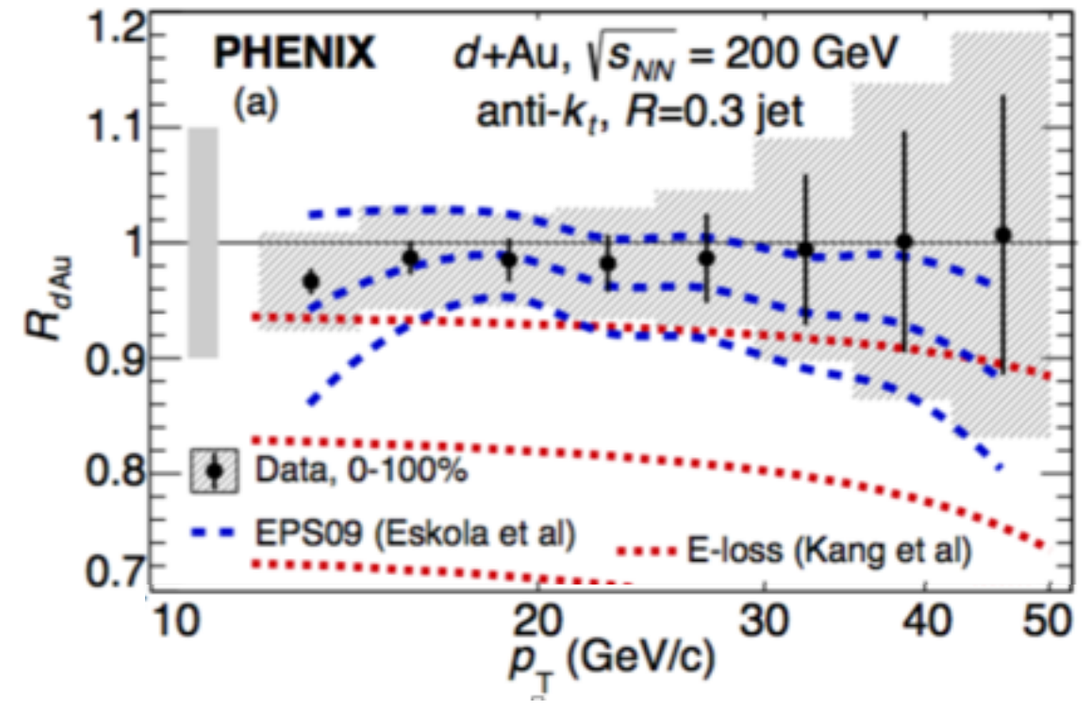
- Draw partons many times from the same *pdf*
- Must be trivially broken at some level due to energy conservation
  - Taken into account by MC
- Non-trivial correlations between partons
  - in particular between *x* of the hardest scattering parton and the proton size

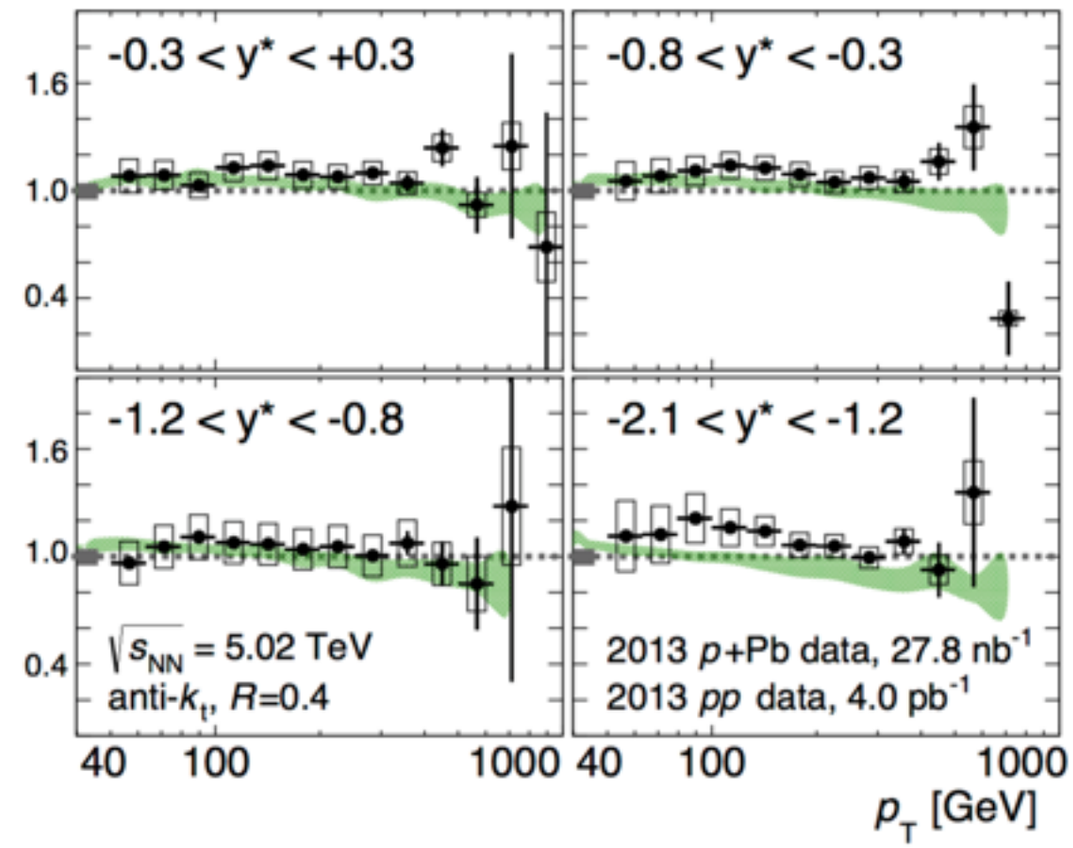
DV Perepelitsa, Tue Parallel Session
N Armesto et al., arXiv:1502.02986

x_{proj} Dependence of Jet Production

DV Perepelitsa, Tue Parallel Session





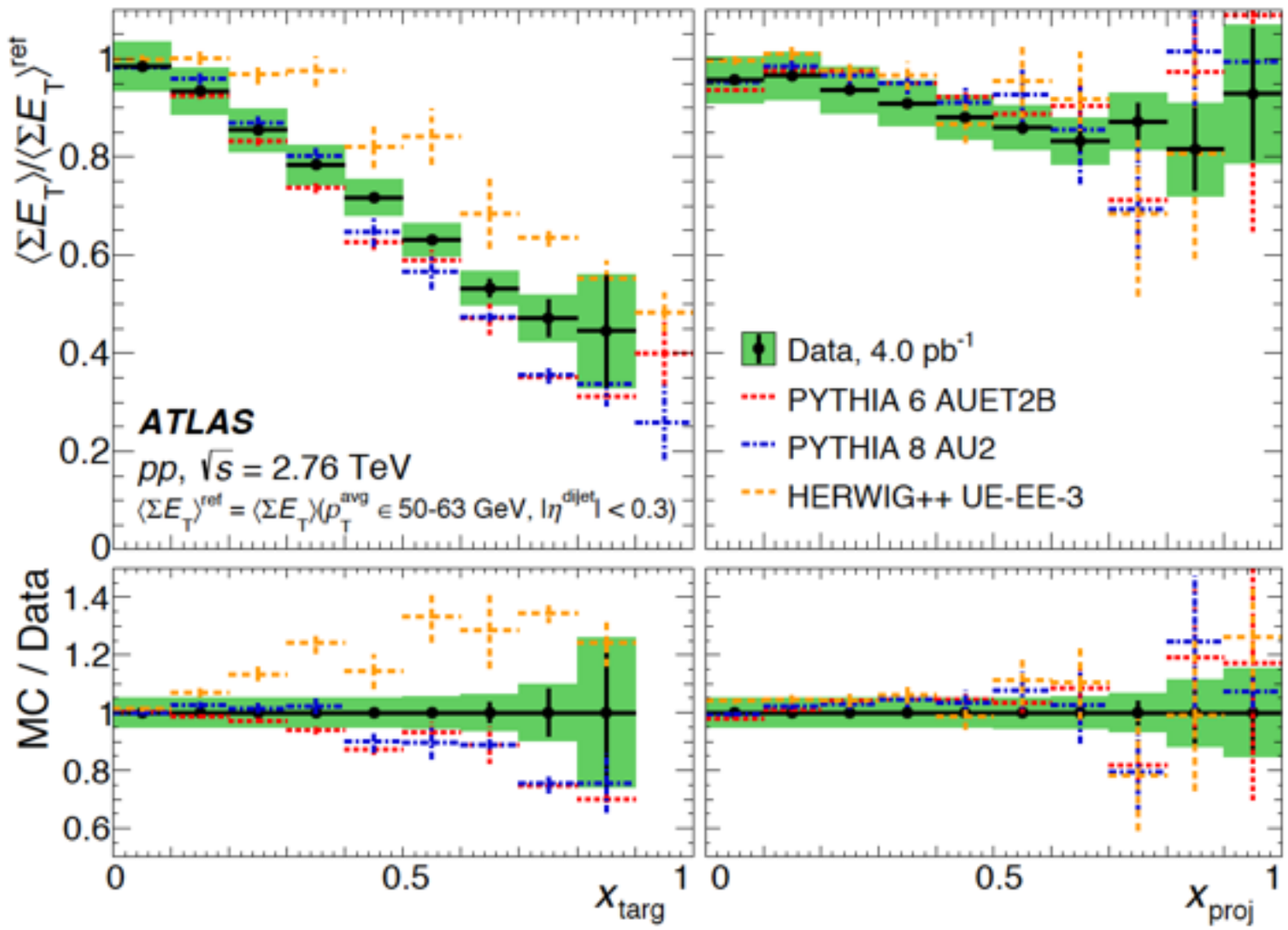


- Common "initial state" proton-x effect at RHIC and the LHC?
- Minimum Bias Unmodified
  - Centrality Bias ?

Can effect be understood as superposition of N-N collisions ?

Physics Letters B 756 (2016) 10-28

Control measurement:
Forward summed E_T vs projectile (target) x

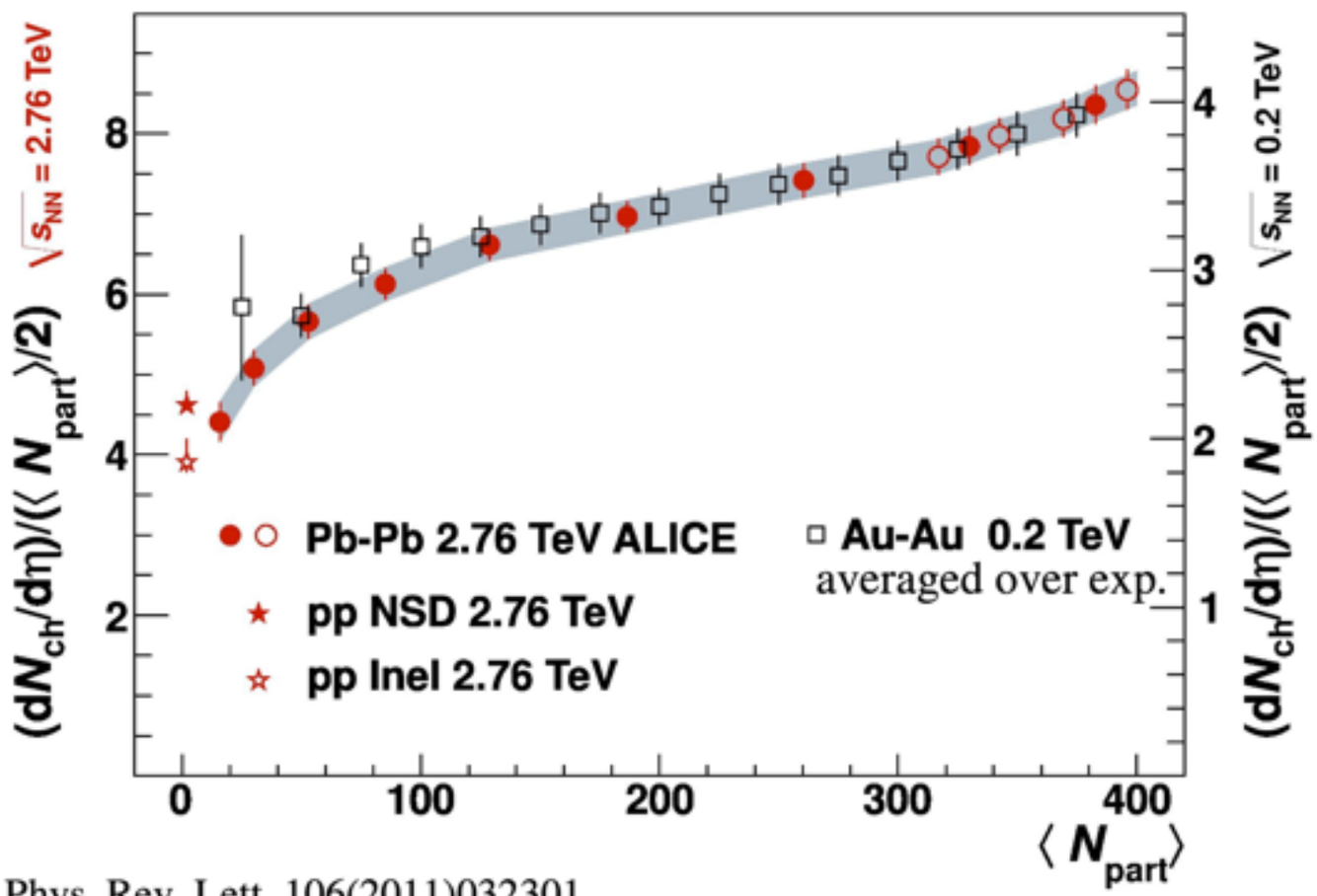


- Contrary to pPb, weak dependence on x_{proj}
- Effect in pPb not explained by N-N superposition.
- This is qualitatively expected if kinematic constraints on the proton pdf are responsible for the effect (more scatterings in pPb)

N_{ch} Centrality Dependence in AA

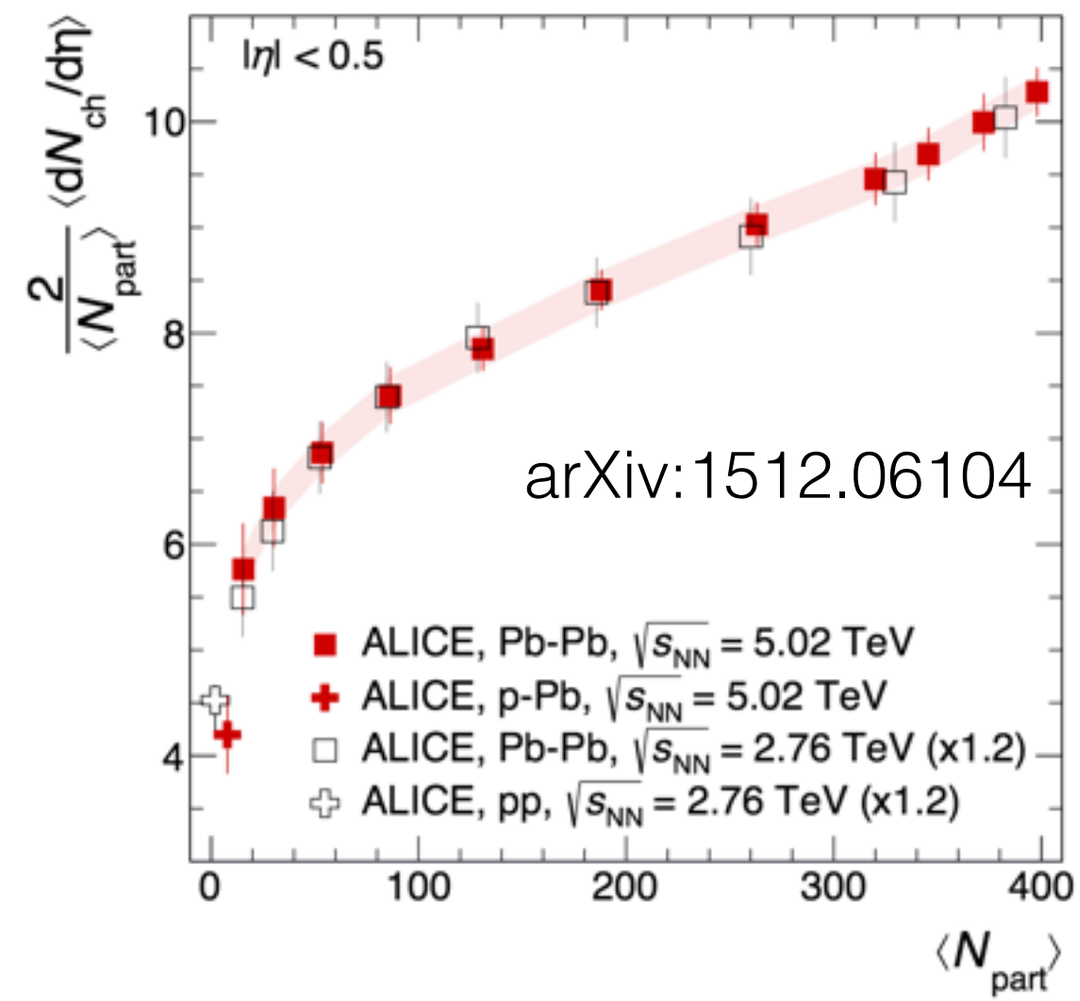
- S-shape reflects hard+soft scaling ($f\ N_{part} + (1-f)\ N_{coll}$)
- But shape almost energy independent.
  - Strong $\sqrt{s}$ dependence of the hard component expected

0.2 and 2.76 TeV



Phys. Rev. Lett. 106(2011)032301

2.76 and 5.02 TeV



Charged particle density depends only on geometry.

Questions (instead of summary)

- How to move from MC tuning to extraction of physical parameters for the transverse structure of hadrons (including errors) ?
- Can one constrain generalised *pdf* (g(x,b)) and multi-parton *pdf s*
- How does re-scattering modify (de-correlate) low-p_T jet-like correlations ?
- Can “elementary” string interactions explain collective bahavior in small systems ?