Multiple Parton-Parton Interactions in ALICE: from pp to p-A

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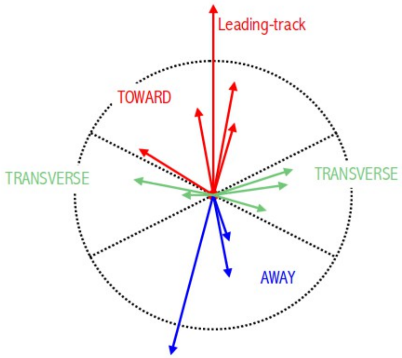
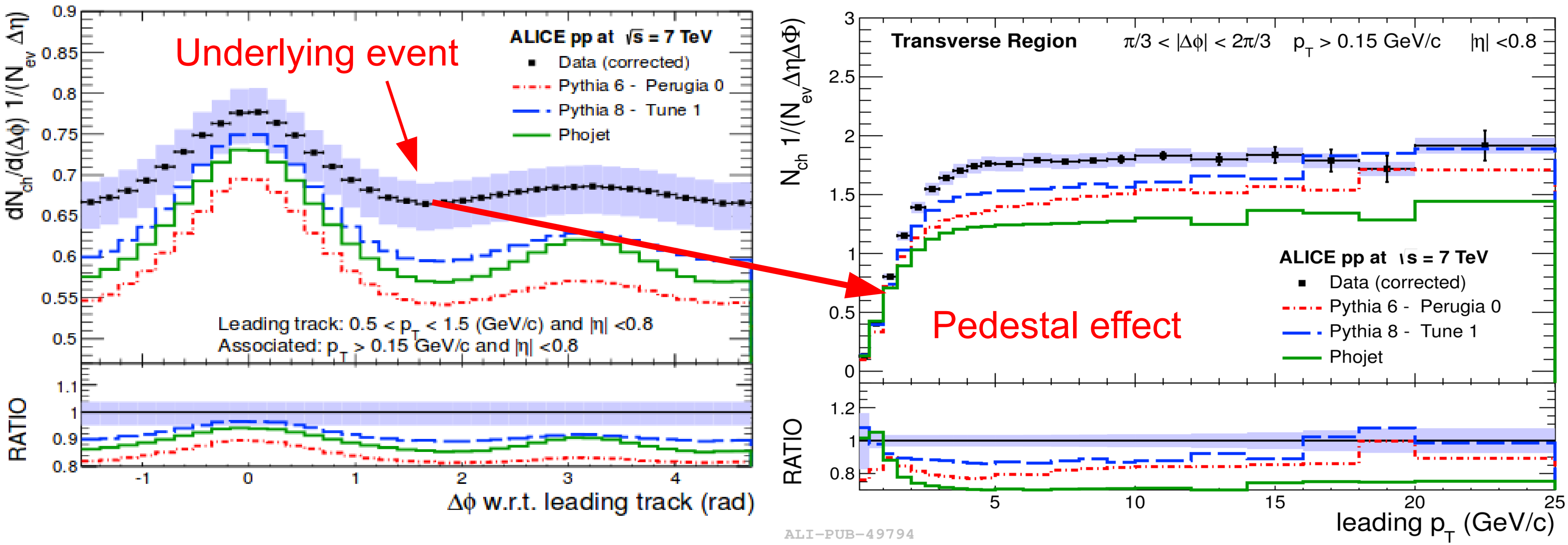
For the ALICE Collaboration

Multi Parton Interactions (MPI)

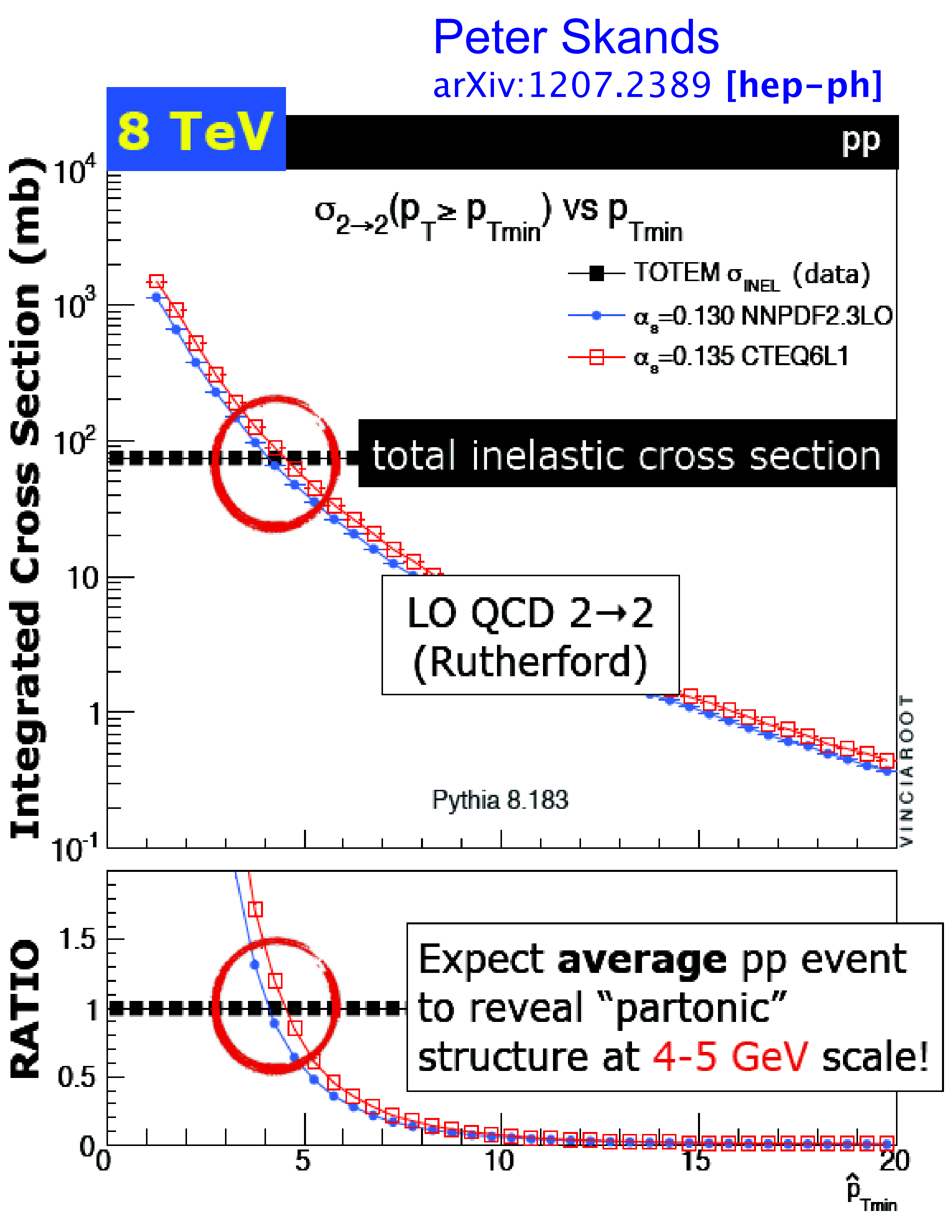
- Theoretical basis to understand — T. Sjostrand and M. van Zijl, Phys. Rev. D36 (1987) 2019.
  - Global event properties of non-diffractive, minimum-bias pp collisions
  - Jet pedestal effect (underlying event)
- Straightforward interpretation of pQCD $\sigma_{2\rightarrow 2} > \sigma_{tot}$



ALICE, Journal of High Energy Physics Volume 2012, Number 7 (2012), 116



MPI Basic Concepts



Number of 2→2 scatterings per event (naïve factorization):

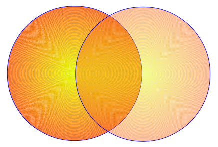
$$\langle n_{2\to2}\rangle = \frac{\sigma_{2\to2}}{\sigma_{tot}}$$

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

In reality:

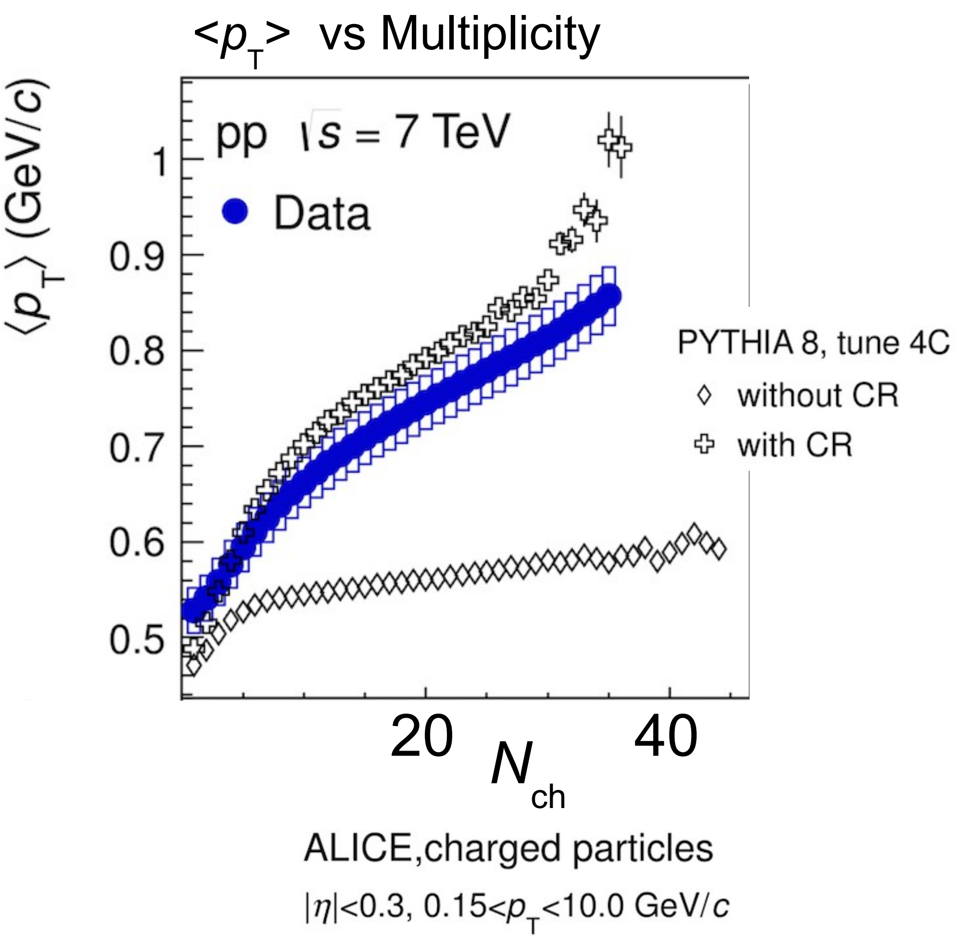
- Color screening regularizes increase of cross-section at low p_T
  => pedestal effect
- Impact parameter dependence
  => pedestal effect
- Cut-off at high *n* because of energy conservation
  => high multiplicity event structure
- Coherence (color reconnections)
  => $\langle p_T\rangle(M)$

$$d\sigma_{2\to2} = d\boldsymbol{b}^2\ T_p(b_{pp}; ..)$$



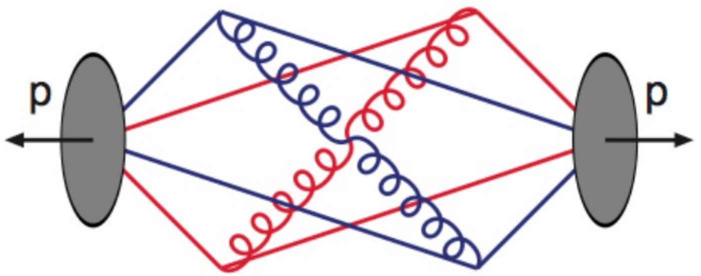
Coherent MPI Effects

ALICE Phys.Lett. B727 (2013) 371-380

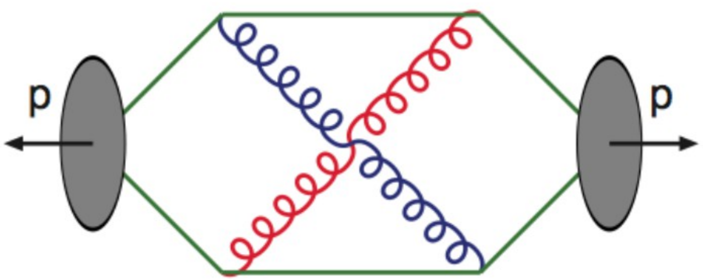


Rise of $<p_T>$ cannot be reproduced by incoherent superposition of MPI

Color Reconnections (CR)



long strings to remnants
$\Rightarrow$ comparable n_{ch}/interaction
$\Rightarrow \langle p_\perp \rangle (n_{\mathrm{ch}}) \sim$ flat.



shorter extra strings
for each consecutive interaction
$\Rightarrow \langle p_\perp \rangle (n_{\mathrm{ch}})$ rising.

T. Sjostrand

MPI in different collision systems

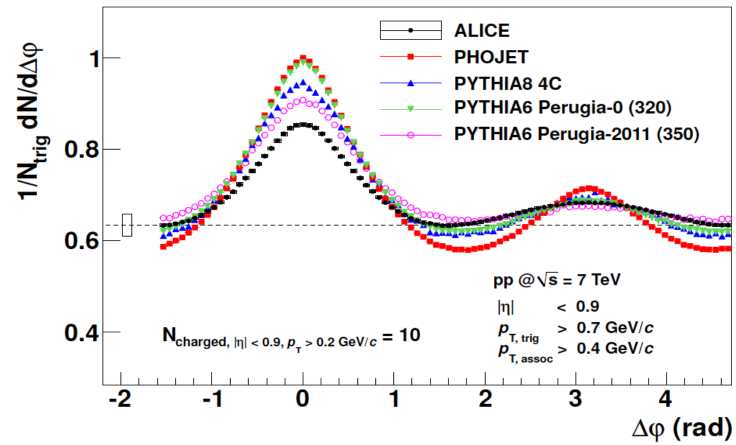
- Commonality High-Multiplicity-pp and central p-A, A-A
  - Large number of (initial) parton-parton scattering and overlapping strings
- High multiplicity pp
  - small p-p impact parameter, (Poissonian) upwards fluctuations
  - possible competition with increase of $<Q^2>$ and fragmentation
- A-A: nMPI dominated by centrality (large N_{coll})
- p-A in between
  - p-A centrality dominates, however, N_{coll} small and p-N geometry important
- High multiplicity pp as reference for p-A ?

Structure of High Multiplicity Events

- Color screening regularizes increase of cross-section at low p_T
  => pedestal effect
- Impact parameter dependence
  => pedestal effect
- Cut-off at high *n* because of energy conservation
  => high multiplicity event structure
- Coherence (color reconnections)
  => $\langle p_T \rangle(M)$

Can we experimentally corroborate the MPI model for high multiplicity pp ?

- superposition of 2→2 scatterings
- increase of nMPI vs $\langle Q^2 \rangle$ and fragmentation

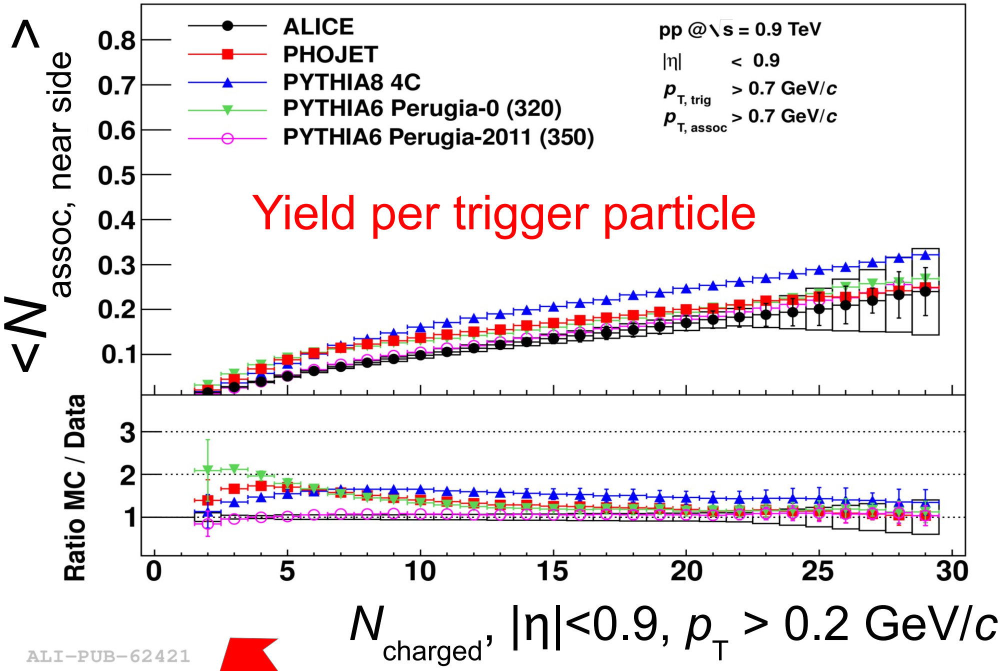


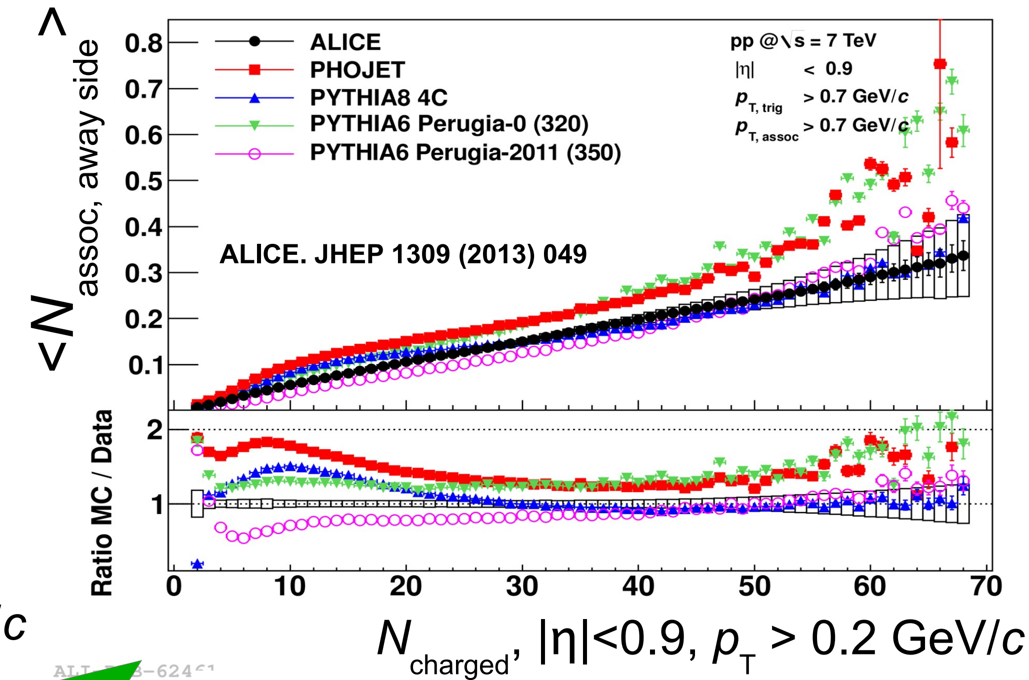
Study angular correlations as a function of multiplicity:

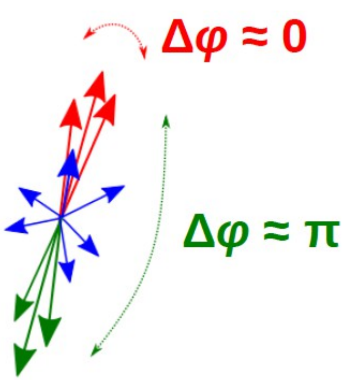
- per mini-jet: triggered azimuthal correlations
- as global event property: transverse sphericity

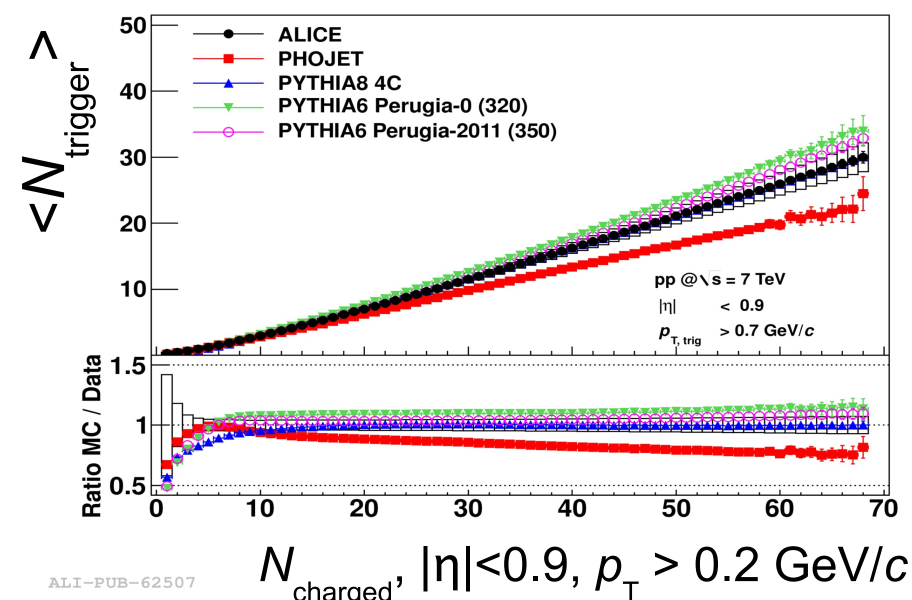
Multiplicity dependence of di-hadron azimuthal correlations

Subtract underlying event and determine correlated yield per trigger particle









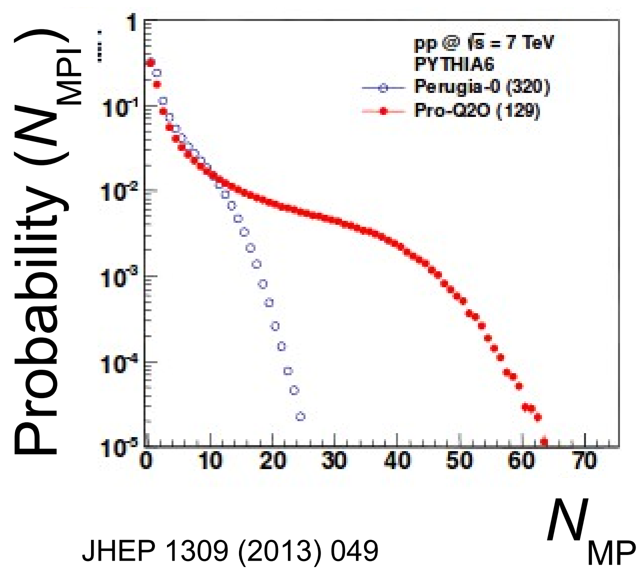
Fragmentation bias results in non-linear increase of number of particles with p_T > 0.7 GeV.

Multiplicity dependence of di-hadron correlations

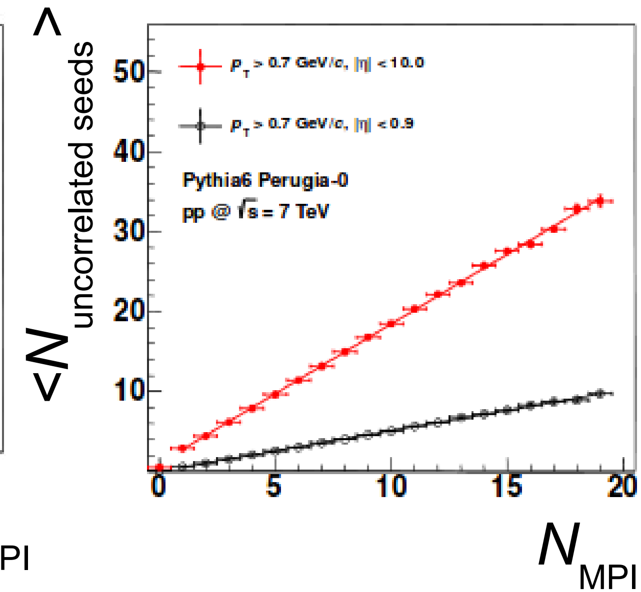
Undo multiplicative effect of fragmentation:

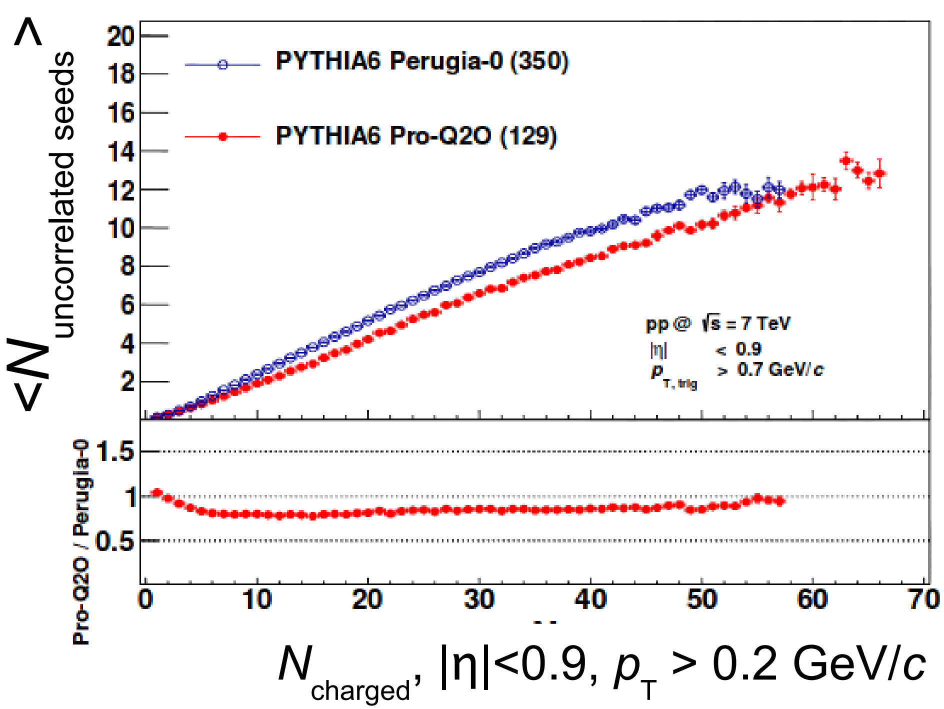
$$N_{\mathrm{uncorrelated\,seeds}} = \frac{N_{\mathrm{trig}}}{1 + N_{\mathrm{assoc}}}$$

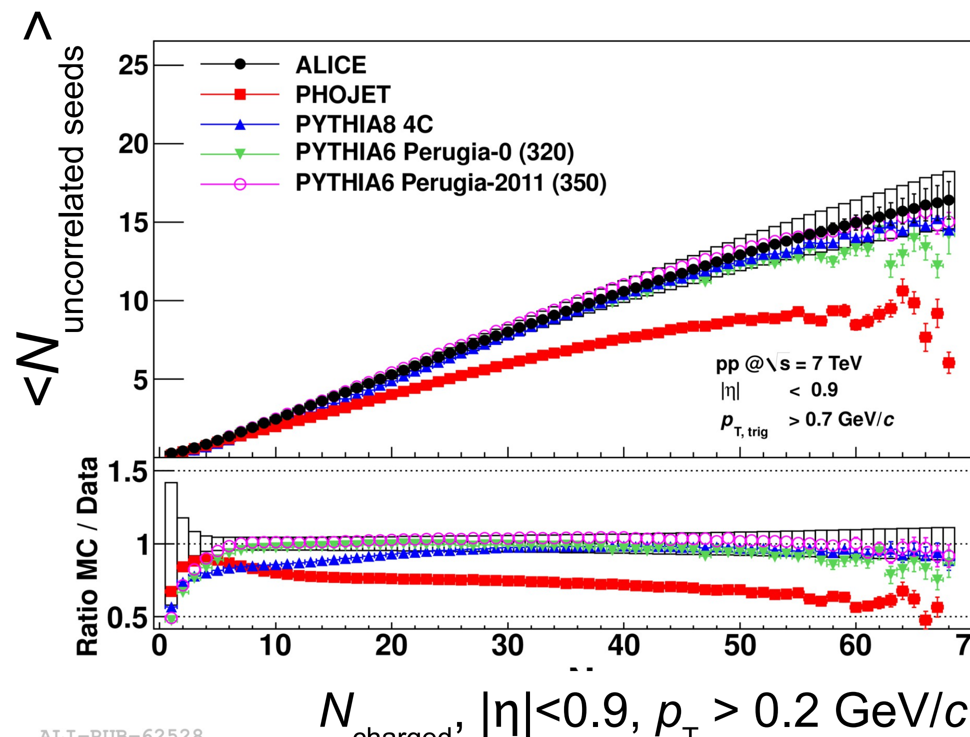
Evidence for limit on number of parton-parton interactions



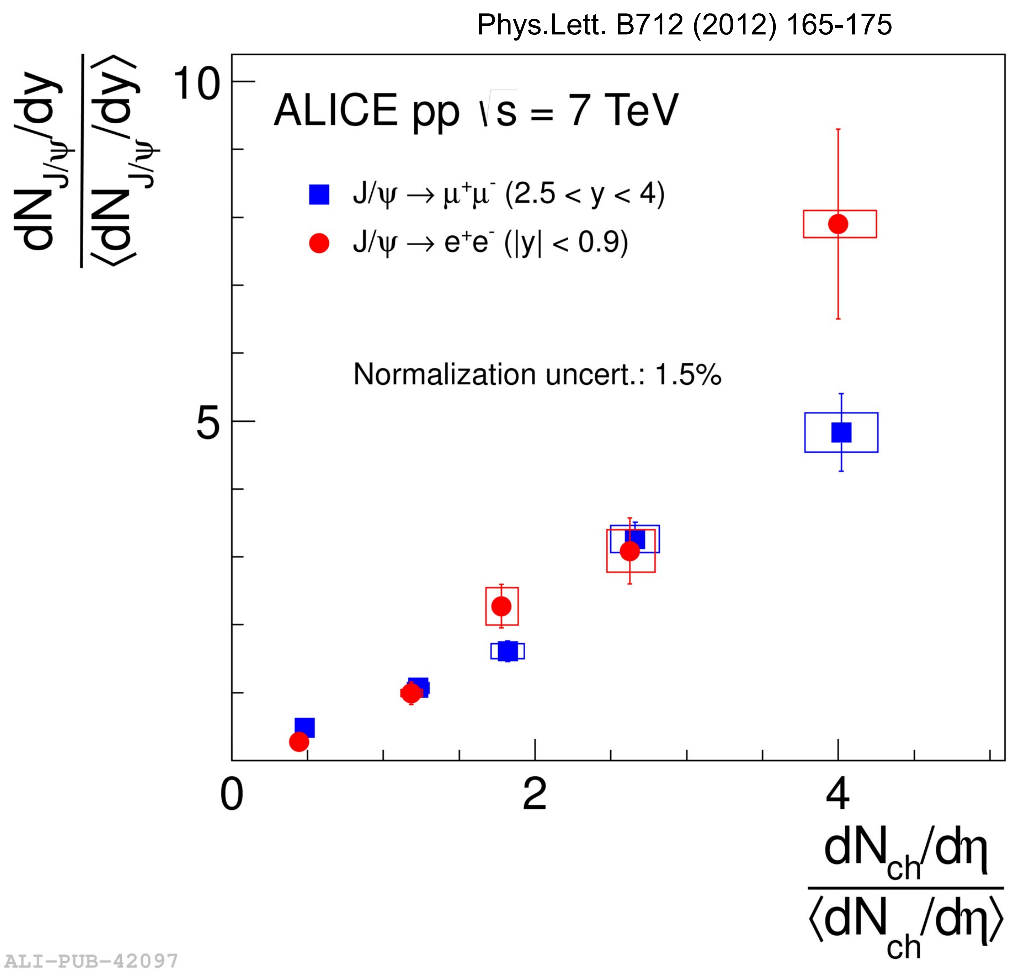
JHEP 1309 (2013) 049

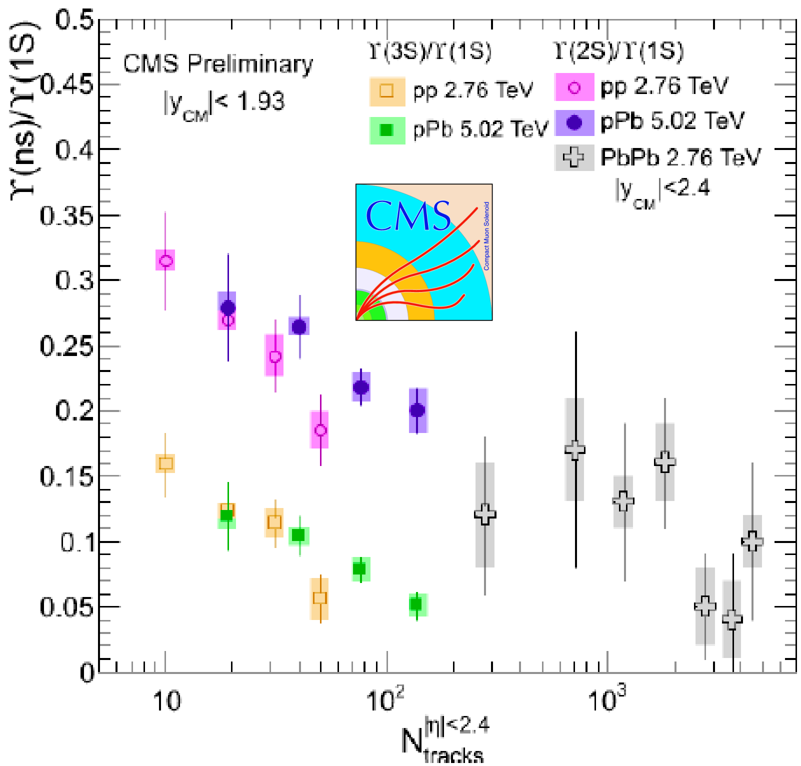






Heavy Flavor: J/ψ



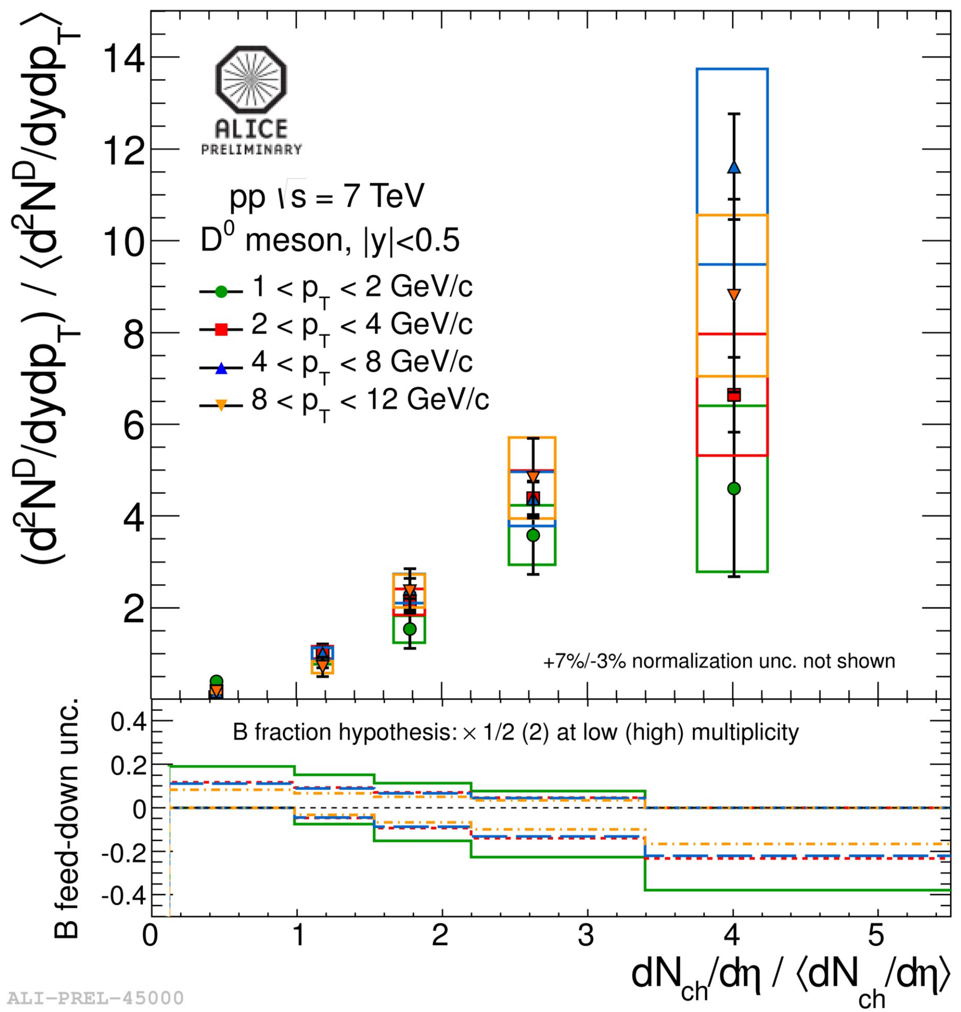


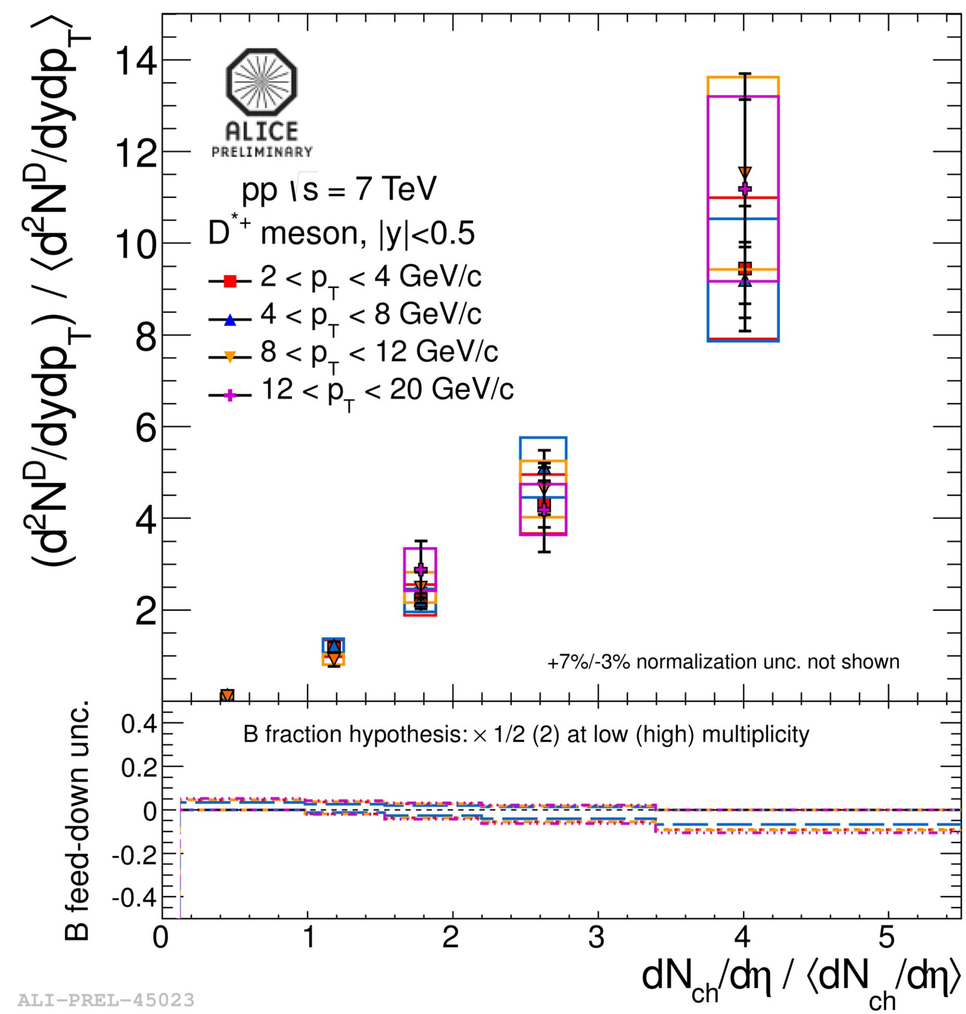
Surprisingly slope can be different !

Approximate linear increase of J/ψ yield with multiplicity.

nMPI ~ N_{ch} => yield for any 2→2 process approx. ~ N_{ch}

Heavy Flavor: Open Charm





Approximate linear increase of D-meson yield with multiplicity.

Eur. Phys. J. C (2012) 72:2124

Transverse Sphericity

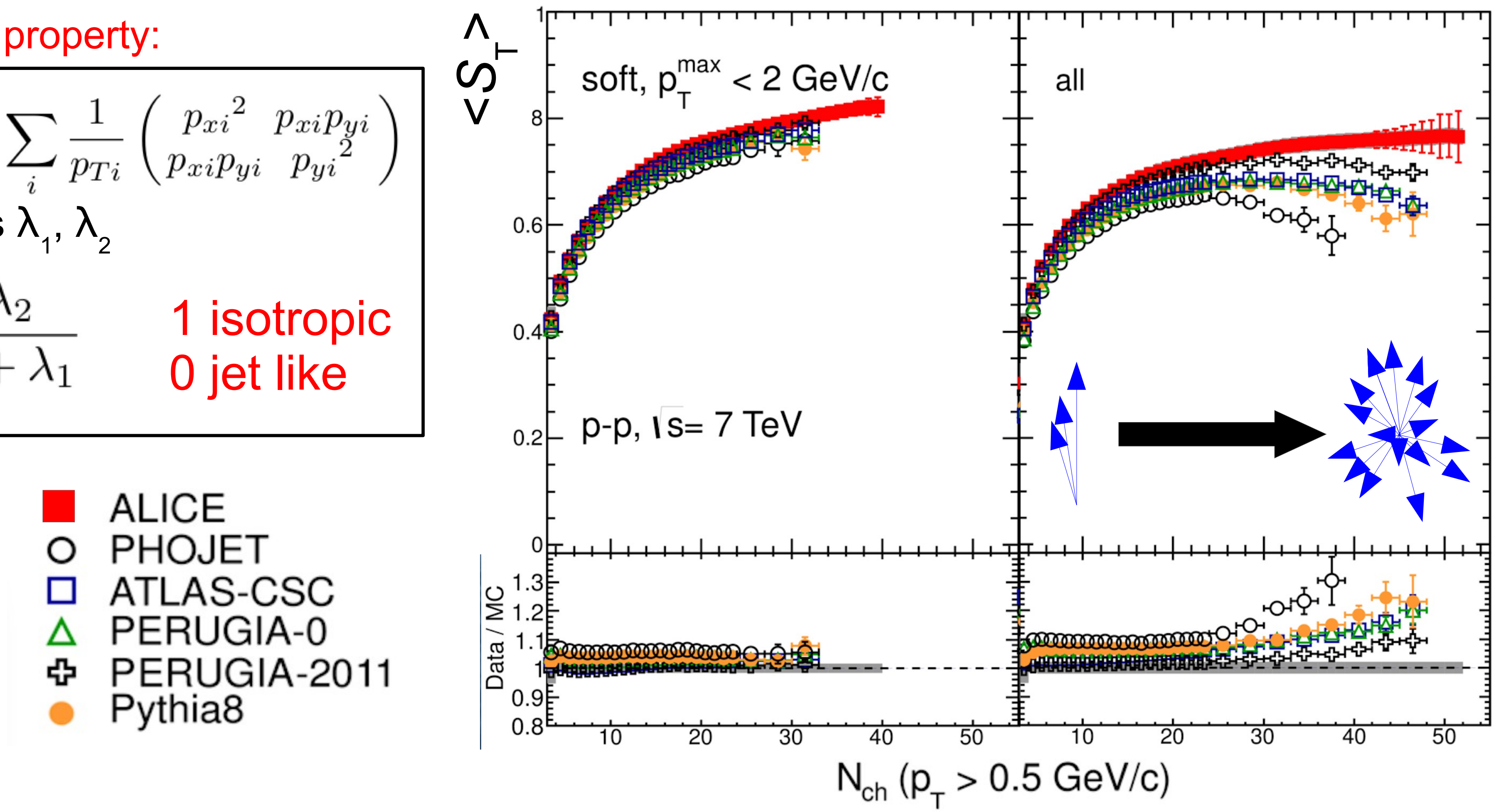
Global event property:

$$\mathbf{S^{L}_{xy}} = \frac{1}{\sum_i p_{Ti}} \sum_i \frac{1}{p_{Ti}} \begin{pmatrix} p_{xi}^2 & p_{xi}p_{yi} \\ p_{xi}p_{yi} & p_{yi}^2 \end{pmatrix}$$

Eigenvectors λ_1, λ_2

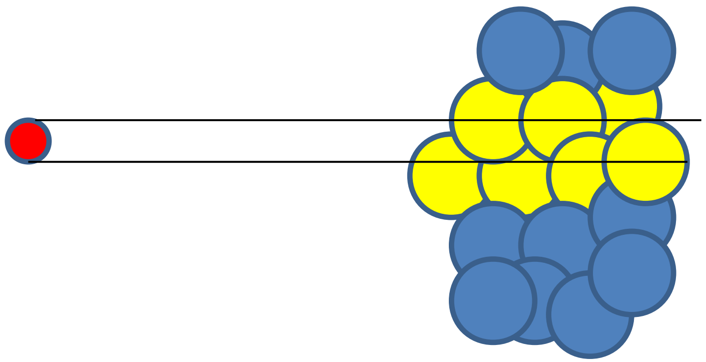
$$S_T \equiv \frac{2\lambda_2}{\lambda_2 + \lambda_1}$$

1 isotropic
0 jet like



- Increase of multiplicity due to MPI increases sphericity.
- Turning point in MC towards more "jettiness" at high multiplicity not seen in data (only leveling off)
- Limit on sphericity not yet reached in soft collisions.

MPI in p-A: Why is this interesting ?



- Large number of MPIs easily accessible
- Overlap in reaction zone of similar size as in pp
- Incoherent or coherent superposition ?
- Incoherent superposition as reference
  - But how to obtain this reference for a given centrality estimator ?
  - Where does it work where does it fail ?

Scaling

- Factorization

$$\langle n \rangle_{2\to 2}(\mathrm{pA}) = N_{\mathrm{coll}}^{\mathrm{Glauber}} \langle n \rangle_{2\to 2}(\mathrm{pp})$$

- Important: this implies that yield of hard processes scales like

$$N_{\mathrm{coll}}^{\mathrm{Glauber}} \langle n \rangle_{2\to 2}(\mathrm{pN}) / \langle n \rangle_{2\to 2}(\mathrm{pp})$$

$\langle n \rangle_{2\to 2}(\mathrm{pN}) / \langle n \rangle_{2\to 2}(\mathrm{pp}) = 1$ for minimum bias,
but can be ≠ 1 for event centrality classification based on multiplicity.

p-Pb is in between pp and Pb-Pb.
Like in pp, multiplicity can bias the number of hard scatterings per binary collisions

Biases from Multiplicity Fluctuations ?

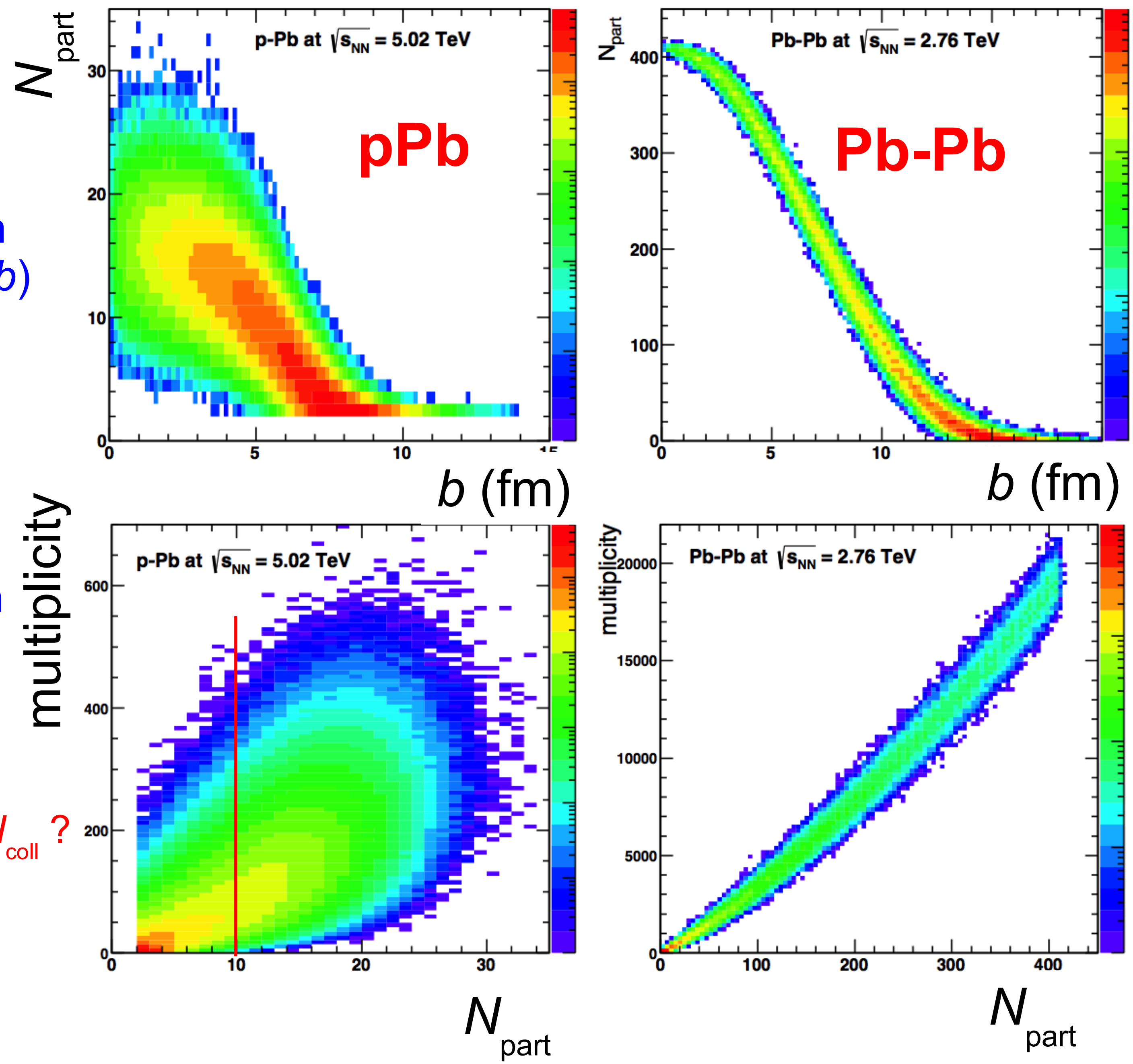
Compared to Pb-Pb

- Looser correlation between N_{part} and impact parameter (b)

- Looser correlation between N_{part} and Multiplicity

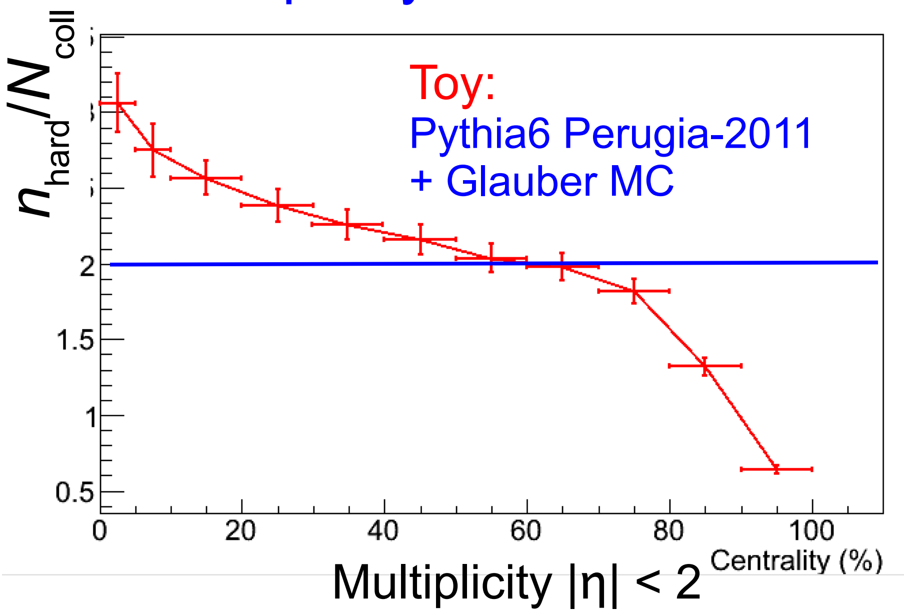
What distinguishes cent1 from cent2 for the same N_{coll} ?

Is it relevant for other physics observables ?

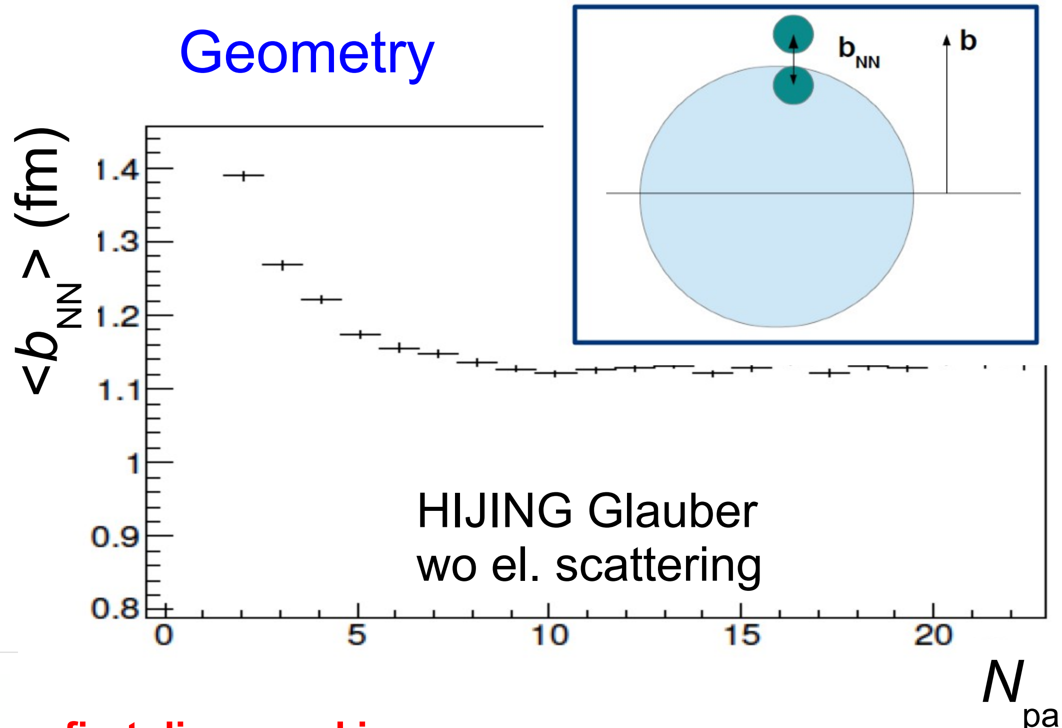


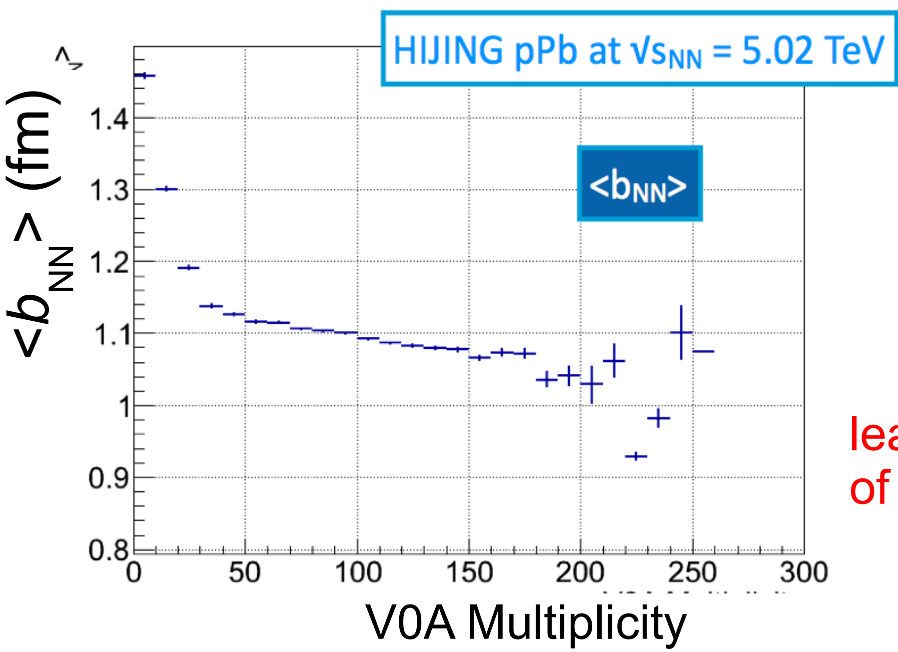
Biases

Multiplicity



Geometry





first discussed in:
Jiangyong Jia, Phys.Lett. B681 (2009) 320–325, arXiv:0907.4175 [nucl-th].

$$\langle n_{\mathrm{hard}}\rangle (b_{\mathrm{NN}}) = \sigma_{\mathrm{hard}}\, T_{\mathrm{N}}(b_{\mathrm{NN}})$$

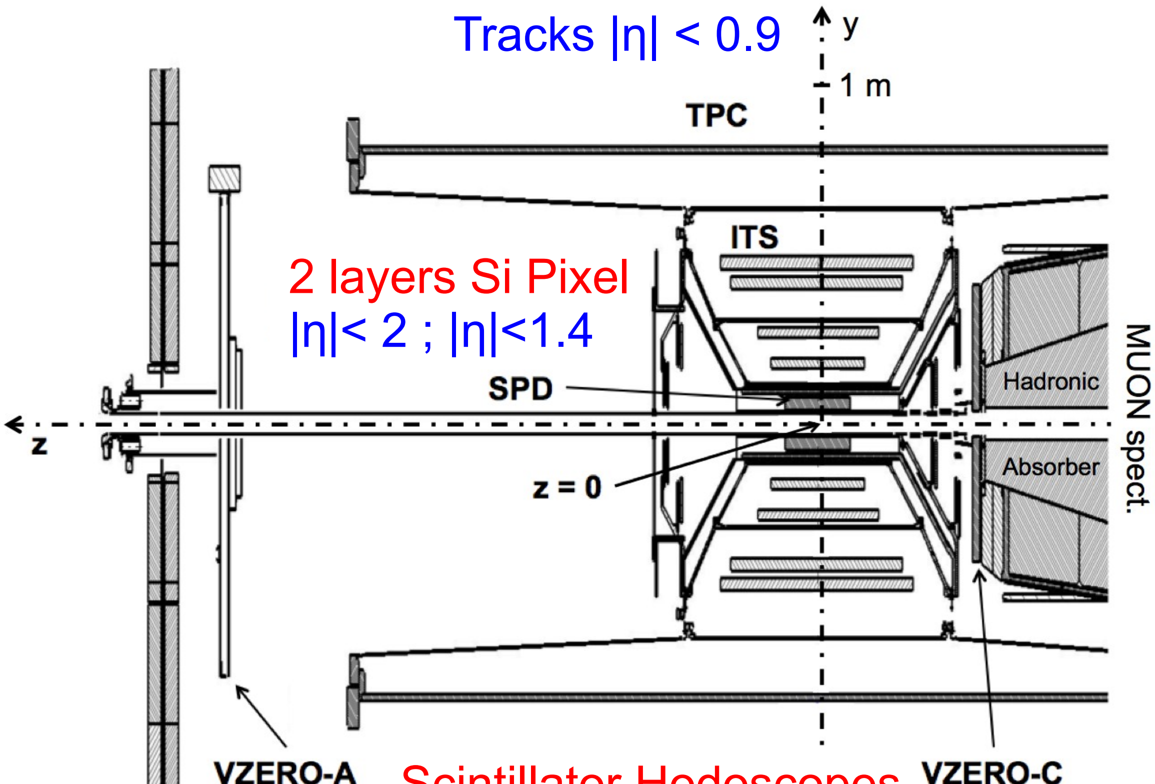
leads to long-range correlations of multiplicity fluctuations

Detectors for Centrality Estimation

p → ← Pb

TPC+ITS
Tracks |η| < 0.9

2 layers Si Pixel
|η|< 2 ; |η|<1.4



Scintillator Hodoscopes

z = 340 cm
2.8 < η < 5.1

z = -90 cm
-3.7 < η < -1.7

Quartz-Fiber “Spaghetti”
Zero Degree Calorimeters

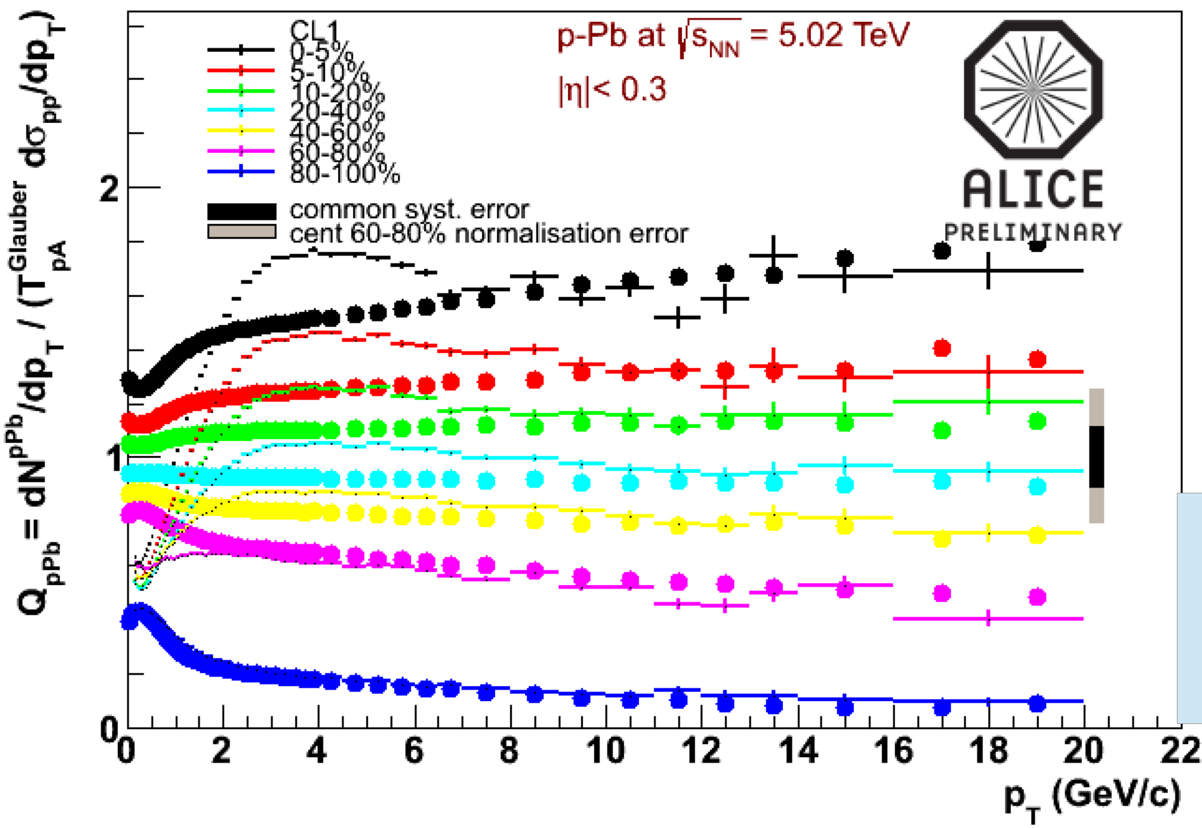
z = ·± 112.5 m

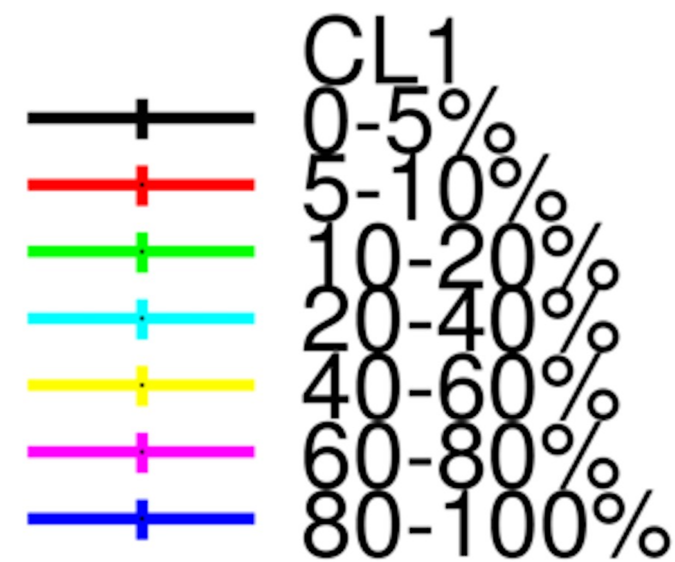
Centrality Estimators discussed here:

CL1: Clusters in 2nd Pixel Layer
V0A: VZERO-A Multiplicity
V0M: V0A+VZER0-C Multiplicity
ZNA: ZNA Energy

Biased Nuclear Modification Factor

Symbols ● MC: Glauber + Pythia

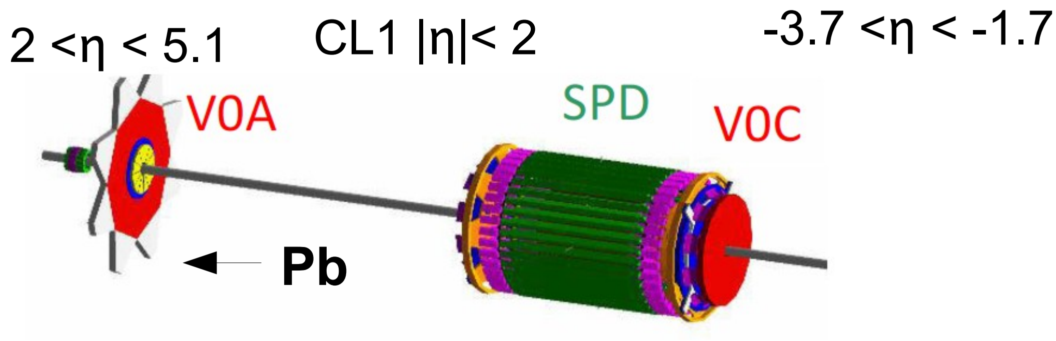


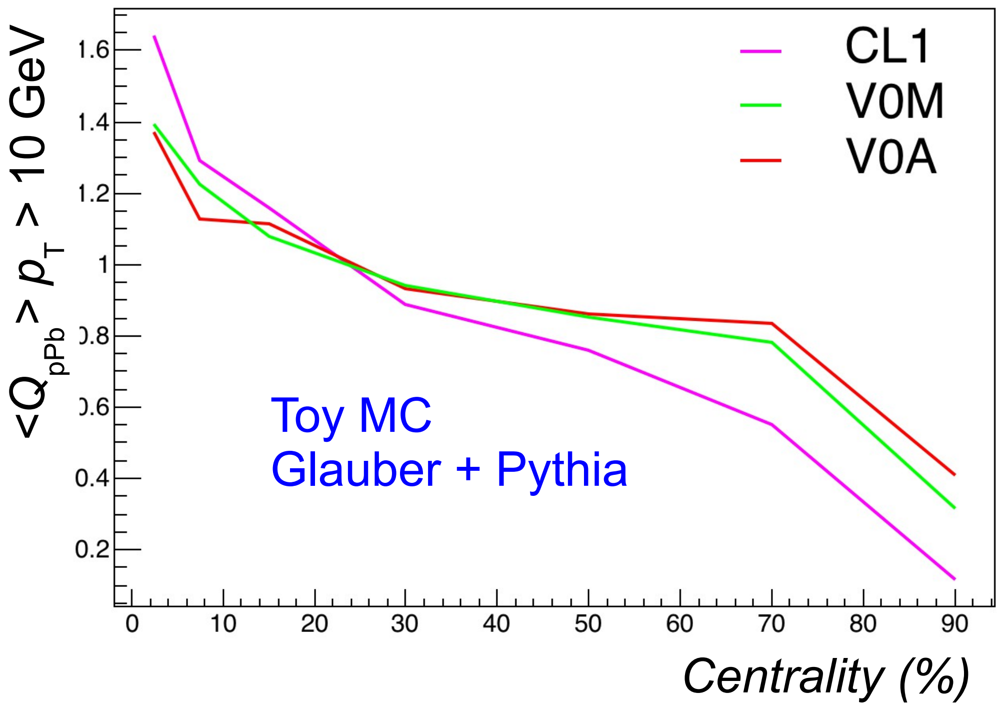


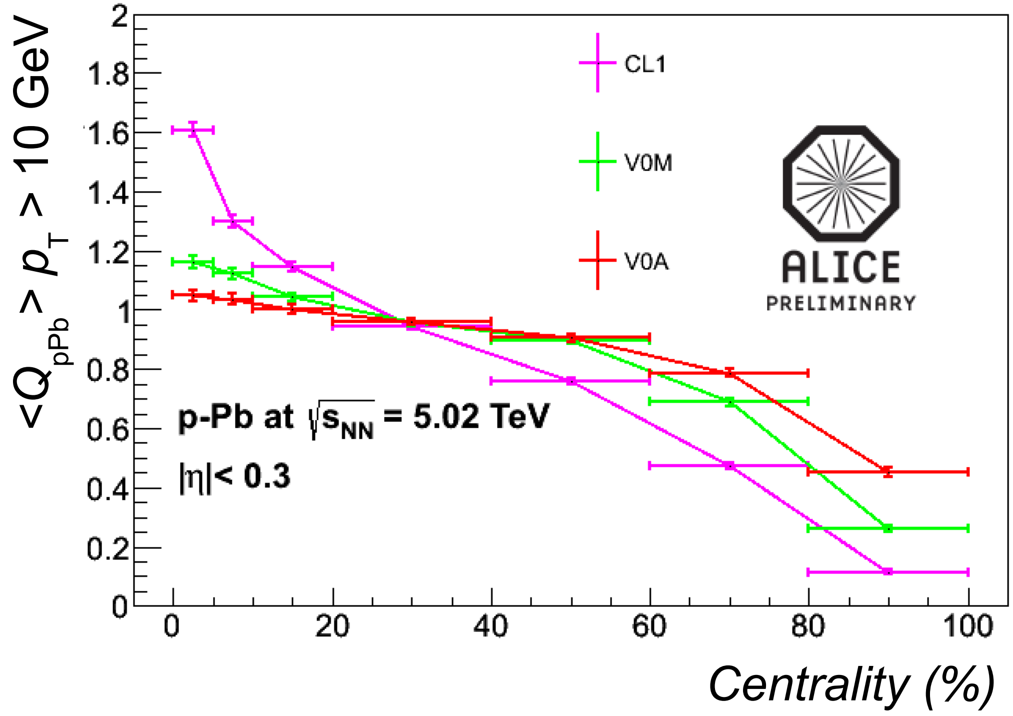
$$Q_{pA}(p_T; cent) = \frac{dN^{pA}/dp_T}{N_{coll}^{Glauber}\, dN^{pp}/dp_T} \neq 1$$

- Bias at high p_T described by incoherent superposition of pp collisions.
- For most peripheral p-Pb, good agreement also at low- and intermediate p_T.
- Strong deviations for all other centrality bins !

Centrality Estimator Dependence





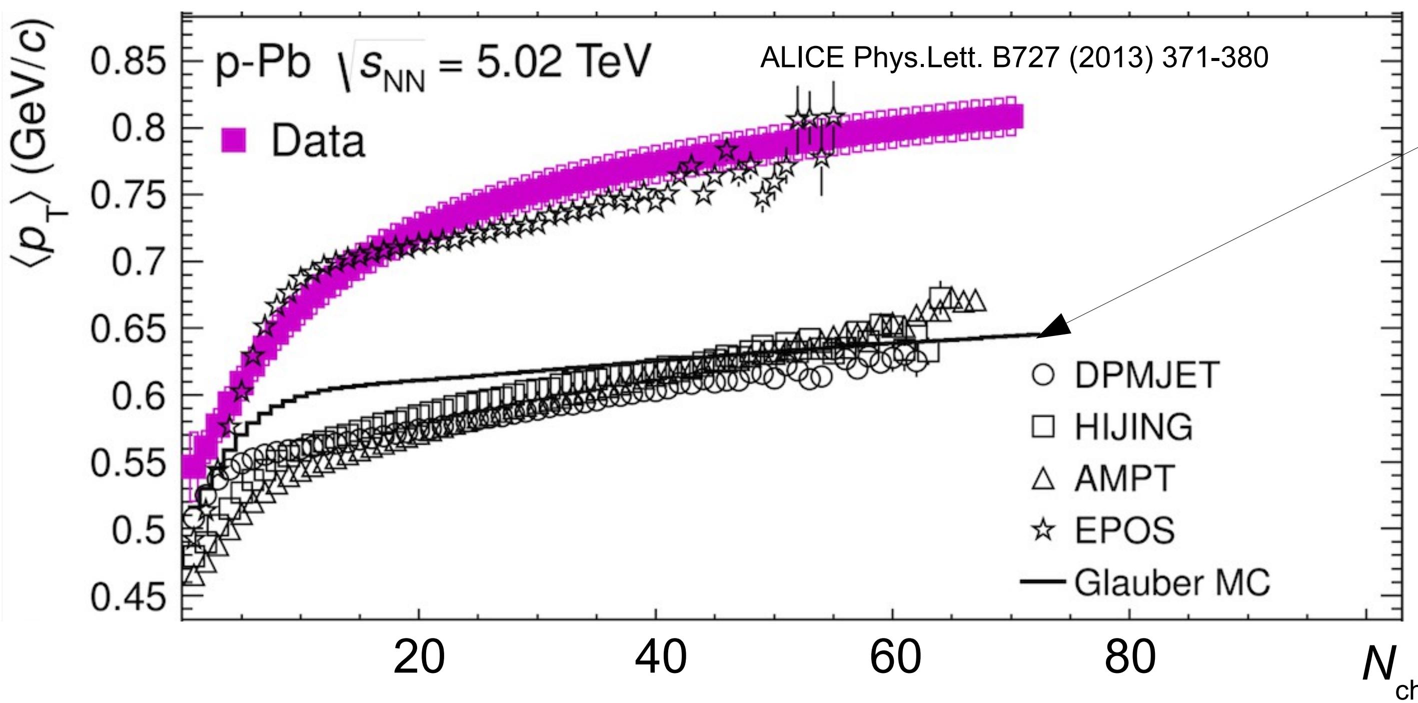


Strong long range correlations.
Bias at high centrality decreases slowly.

Reduced bias with V0A due to particles from target fragmentation.

$<p_T>$ in p-A

- What can be expected for p-A
  - More overlapping strings = stronger CR effects ?
  - Can we construct a pp reference
    - Standard Glauber approach: $<p_T>$ = const = $<p_T>$ (pp min. bias)
    - Include measured $<p_T>(N_{ch})$ dependence assuming N_{ch} (pPb) = $N_{part}/2 * <N_{ch}>$ in Glauber fit.

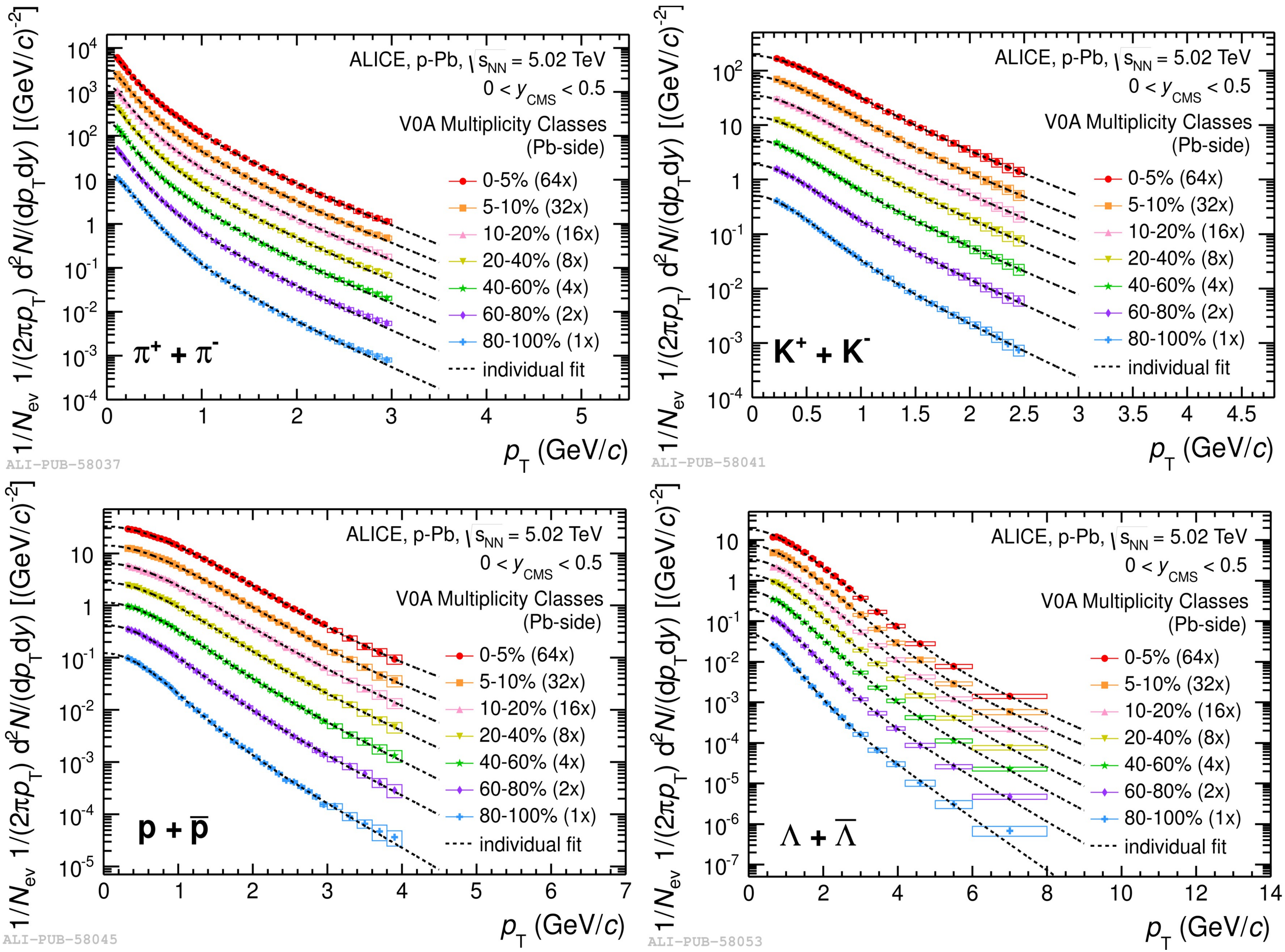


Incoherent reference

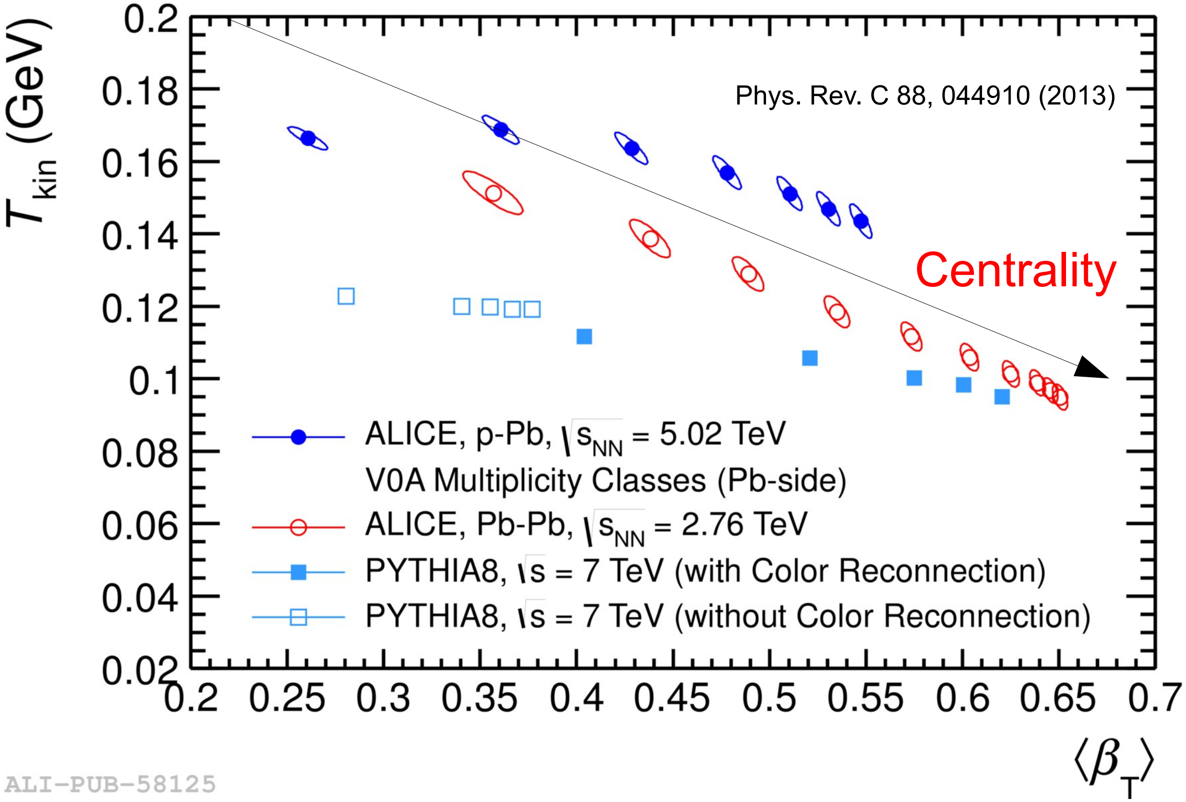
- Coherent / collective effects needed to describe data (EPOS)

- Would CR also reproduce the data ??

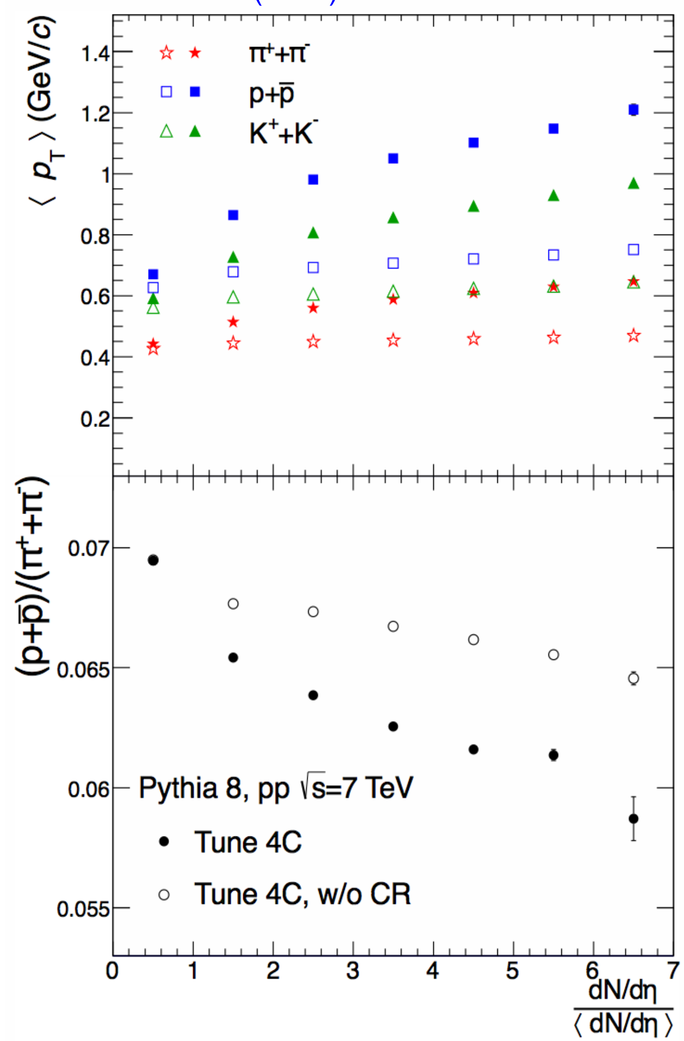
Identified Particle Spectra



Common Fit to π, K, p, Λ



A. Ortiz et al., Phys. Rev. Lett. 111, 042001 (2013)

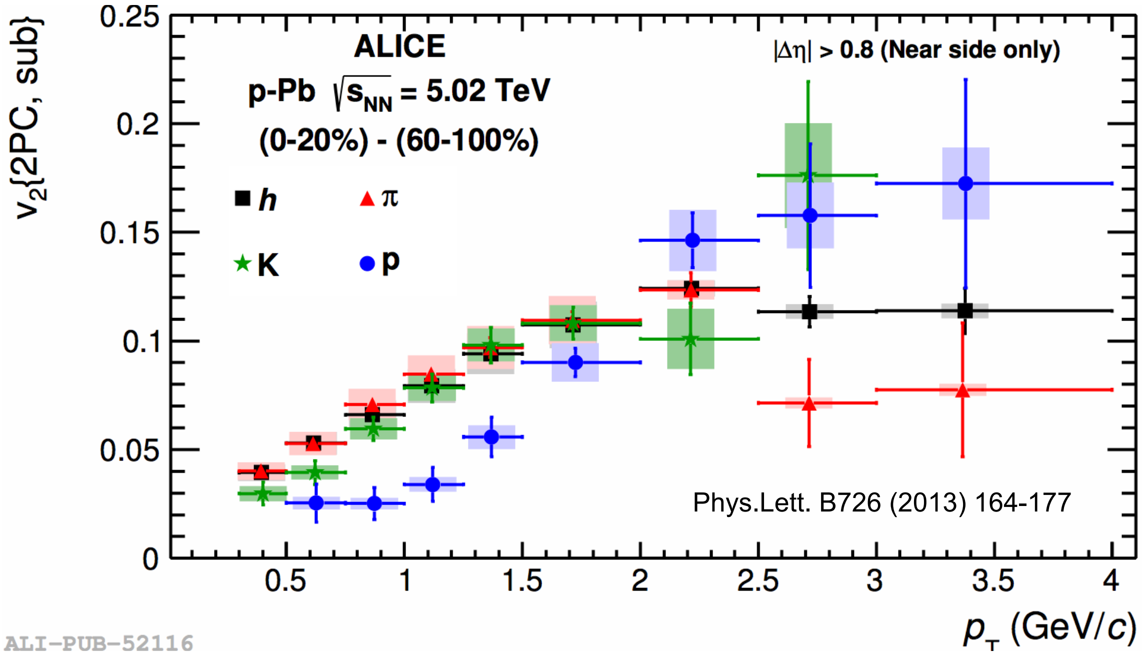


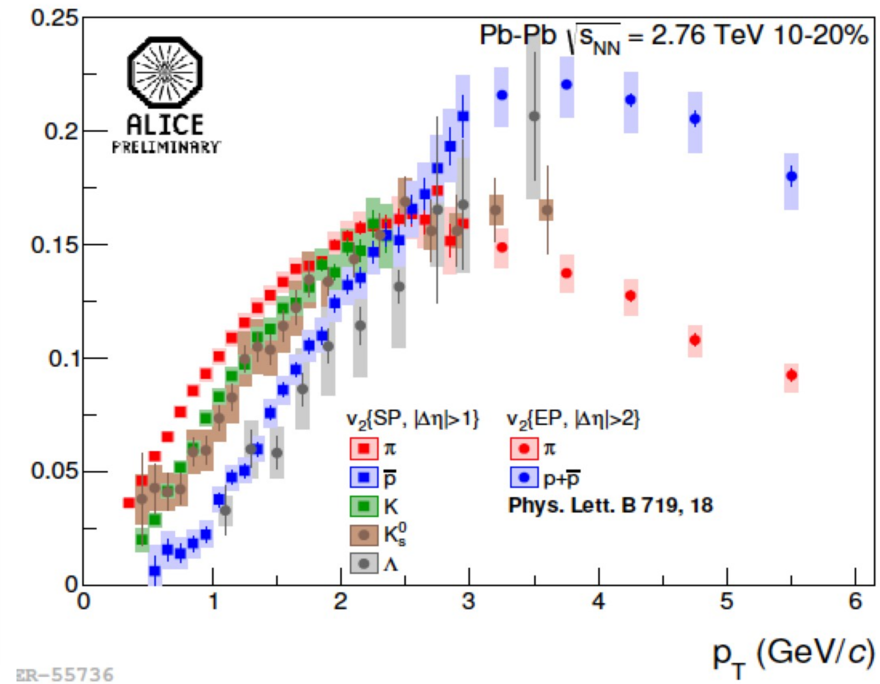
Similar trends for Pb-Pb and p-Pb
In Pythia8 pp trend reproduced with CR switched on

v_2 from h-(π, K, p) Correlations

p-Pb

Pb-Pb 10-20%





Mass ordering like in Pb-Pb !

MPI and CR also at the origin of flow-like pattern in p-Pb ?

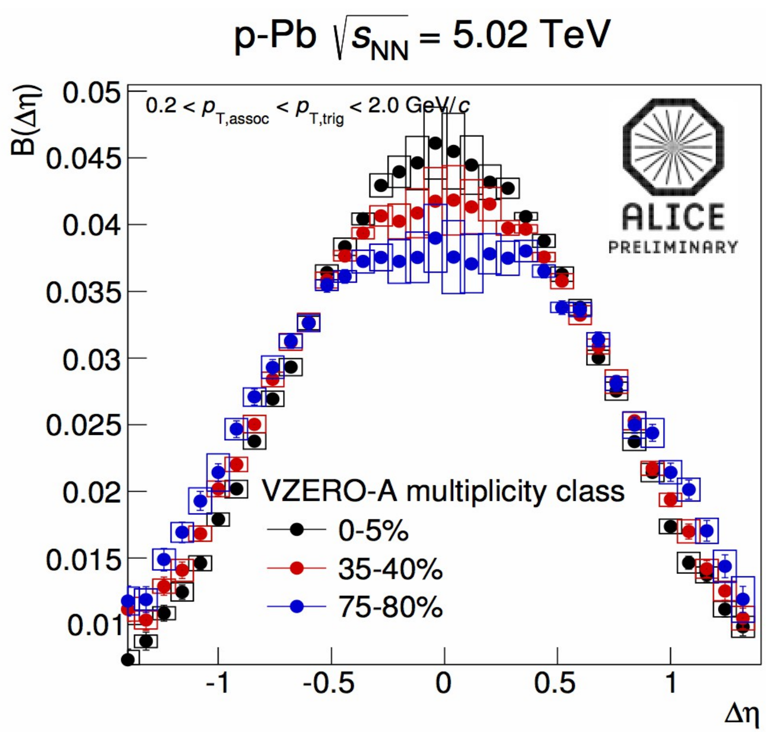
Balance Function

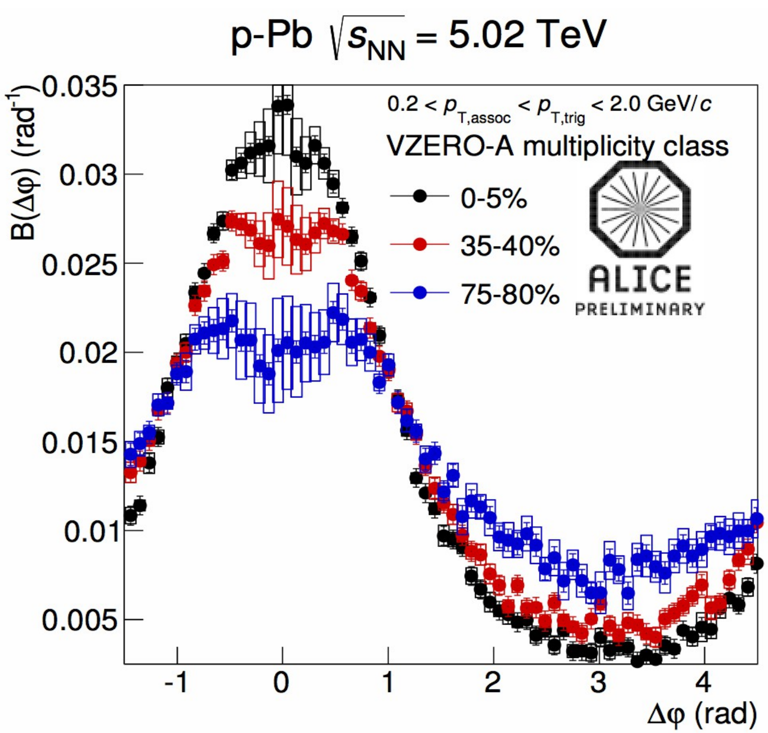
$$B(\Delta\eta, \Delta\varphi, p_{\mathrm{T,trig}}, p_{\mathrm{T,assoc}}) = \frac{1}{2}\left[C_{UL} - C_{LS}\right]$$

$$C_{UL} = C_{+-}, C_{-+}$$

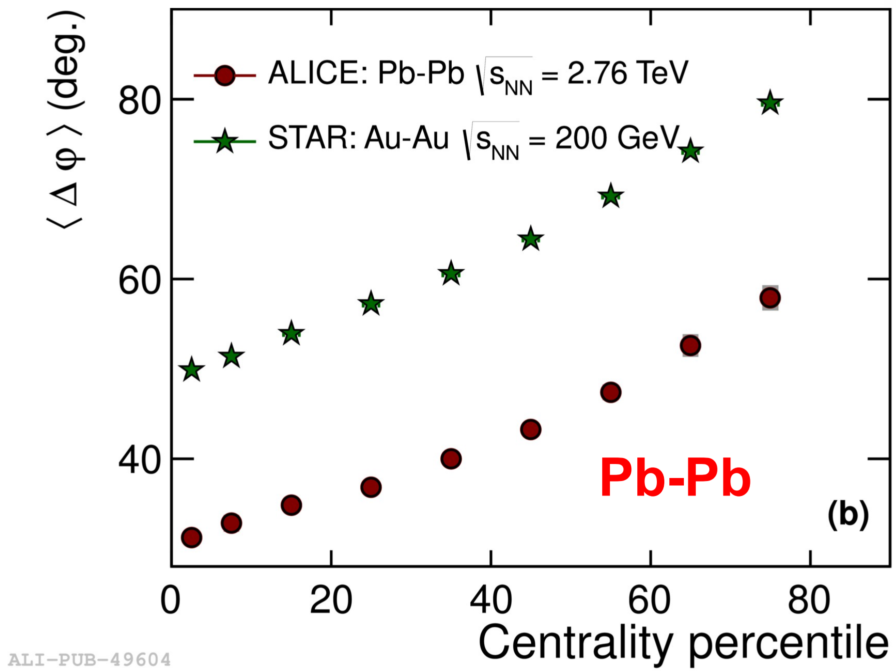
$$C_{LS} = C_{++}, C_{--}$$

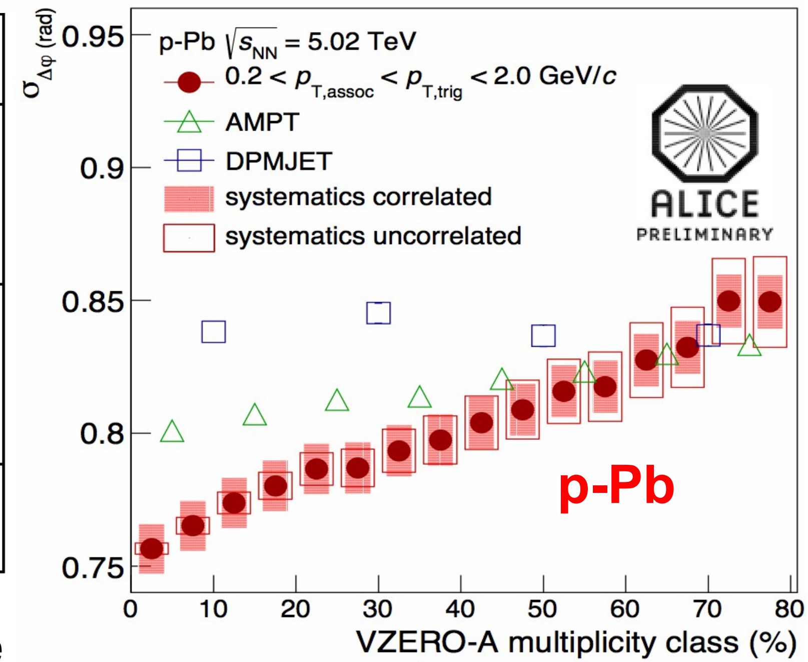
$$C_{+-} = \frac{N_{+-}}{N_{+}}$$

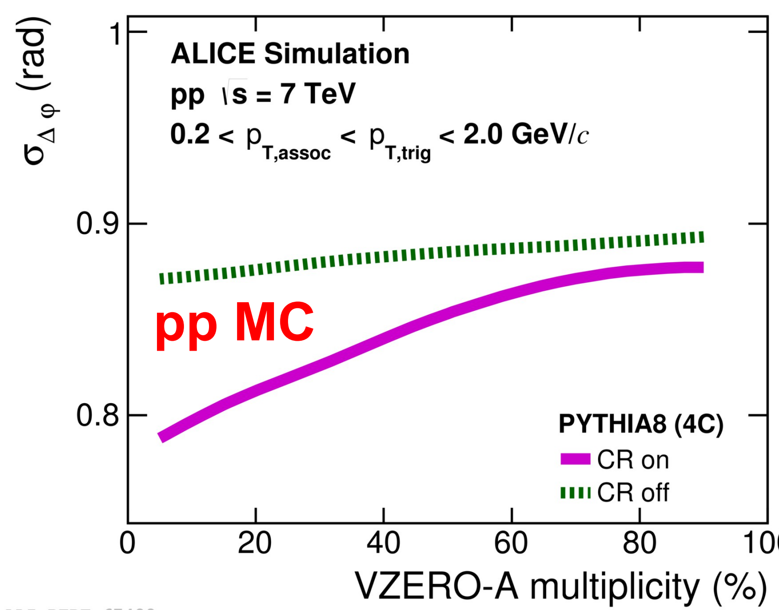




Width of the Balance Function







In expanding medium (Pb-Pb):

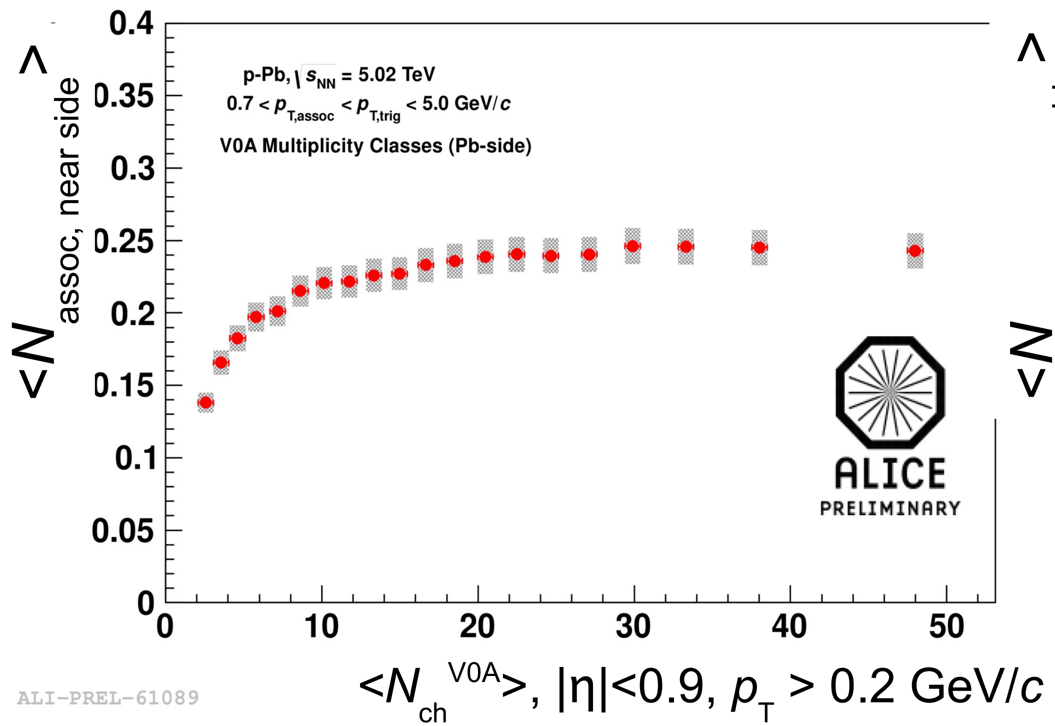
- Width depends on creation time and degree of collectivity
- Qualitatively same behavior observed in p-Pb
- AMPT describes trend seen in data (contains collective effects)
- In Pythia, pp trend can be reproduced when CR are switched on.

Bass, Danielewicz, Pras; PRL 85 (2000) 2689

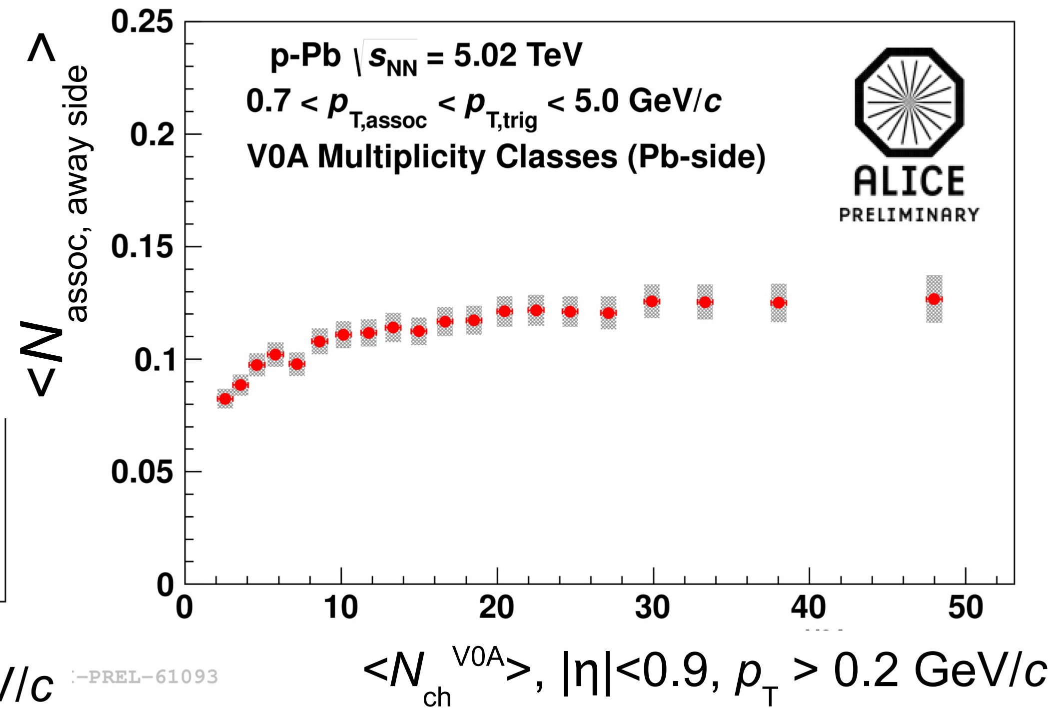
Direct evidence for low-p_T MPI

Di-Hadron Azimuthal Correlations

Near-side

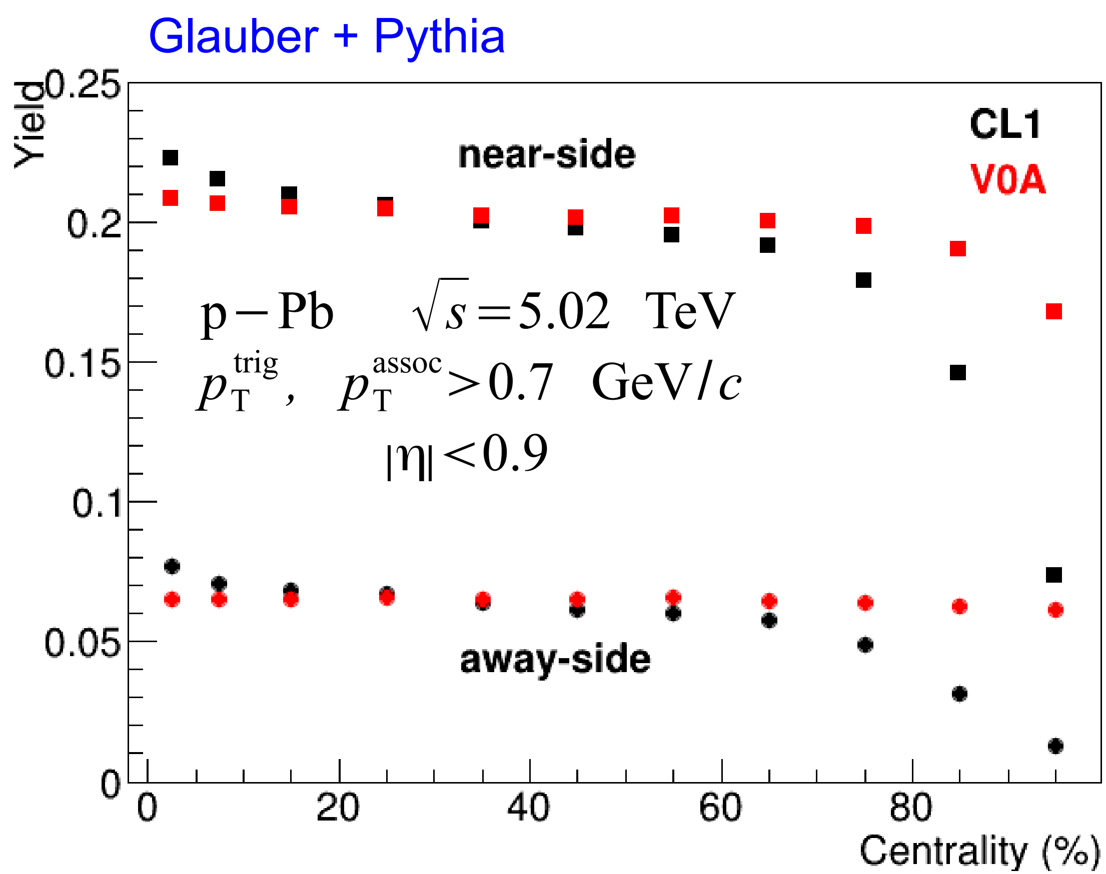


Away-side



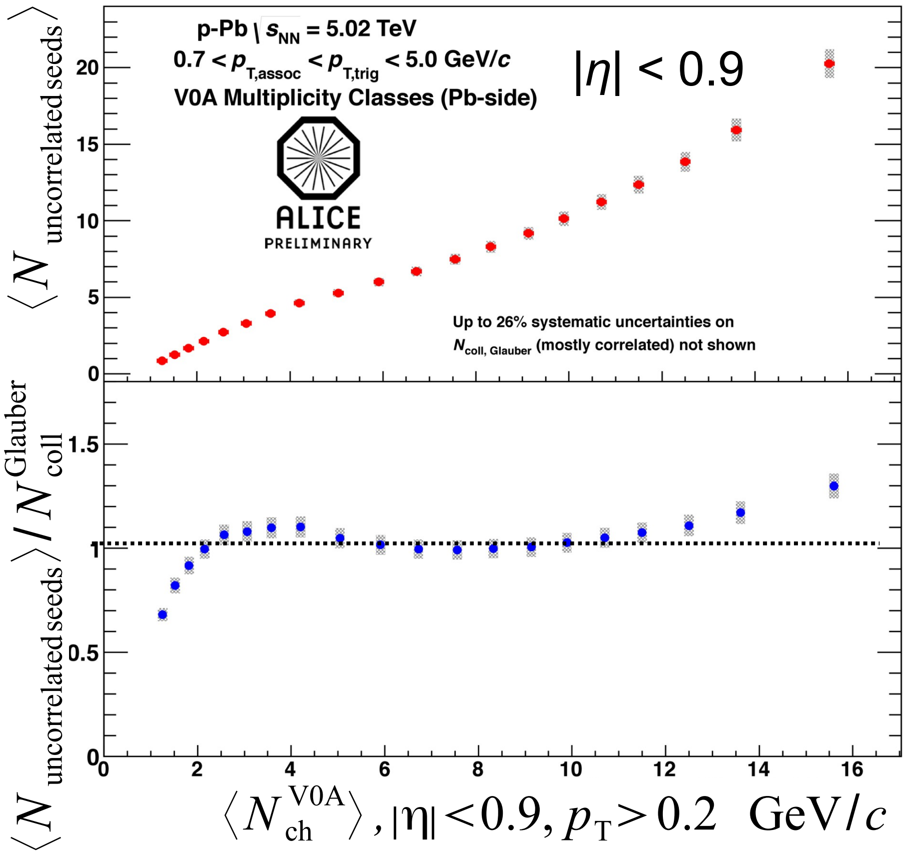
- Fragmentation biased only in peripheral collisions
- No modifications at high multiplicity.
- Absence of coherence effects for large nMPI might strong constraint for models implementing such effects.

Comparison to incoherent pp superposition



Good qualitative agreement with data !

N_{coll} scaling ?



- Approximate scaling within (10%) from $N_{\text{coll, Glauber}}$ = 3-13
- Important deviations for low and high N_{coll} => less / more semi-hard scatterings per p-N collision ?

Conclusions

- Rich phenomenology of MPI in pp used to constrain models
  - Observables first introduced by ALICE
    - Transverse sphericity as a function of multiplicity
    - Di-hadron correlation as a function of multiplicity
    - Number of uncorrelated seeds
- Interest in MPI in p-A
  - Large range of MPI overlapping in small reaction region
  - linearity with N_{coll} studied with di-hadron correlations

Conclusions

- Signs of Collectivity in p-Pb
  - $<p_T>$
  - Blast wave fit parameter: T_{kin} -$<\beta_T>$
  - Width of Balance function
  - Double ridge structure in di-hadron correlations
  - Mass ordering in v_2 of π, K, p
- Intriguing: Several trends as function of multiplicity seen in p-Pb (Pb-Pb) reproduced by PYTHIA with Color Reconnection
- However, jet-like angular correlations at low p_T do not show any sign of coherent fragmentation effects.