Studying the effect of the hadronic phase in nuclear collisions

with PYTHIA and URQMD

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Introduction

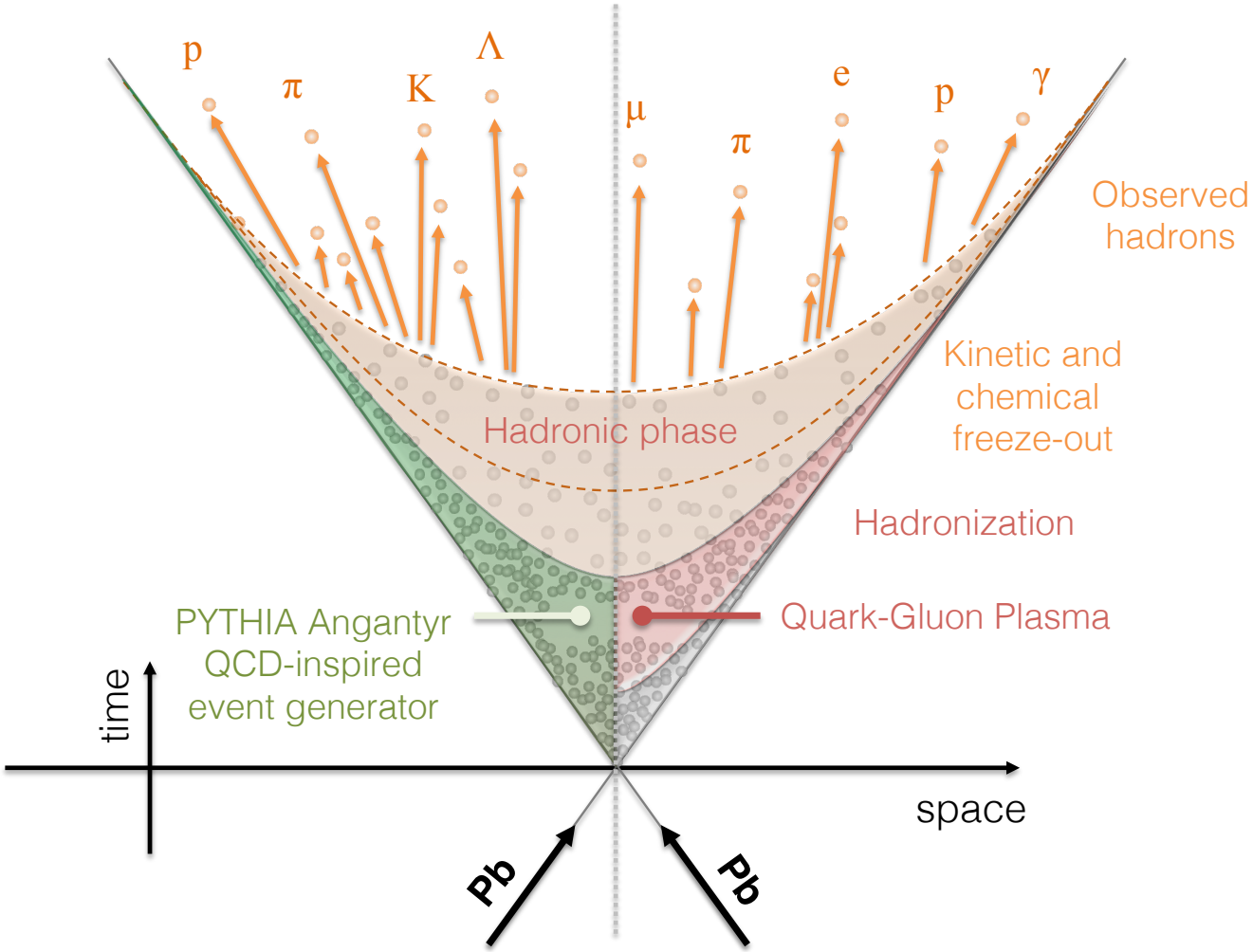
- Status: A plethora of observables, and almost as many models.
- Analytic and MC approches competitive.
  - 👍 Descriptions at percent precision.
  - 👍 Well founded in theory.
  - 👎 Often lacking a non-QGP baseline.
  - 👎 Possibility of over tuning.
- *Remove the QGP!*
  - Pythia (pQCD + strings) &
  - URQMD (hadronic final state interactions.)
- Establish a solid baseline for AA collisions.

How much room is left on top?

- This talk:
  1. The basic idea.
  2. The used models (Pythia 8/Angantyr / Hadron vertices / URQMD).
  3. Results.

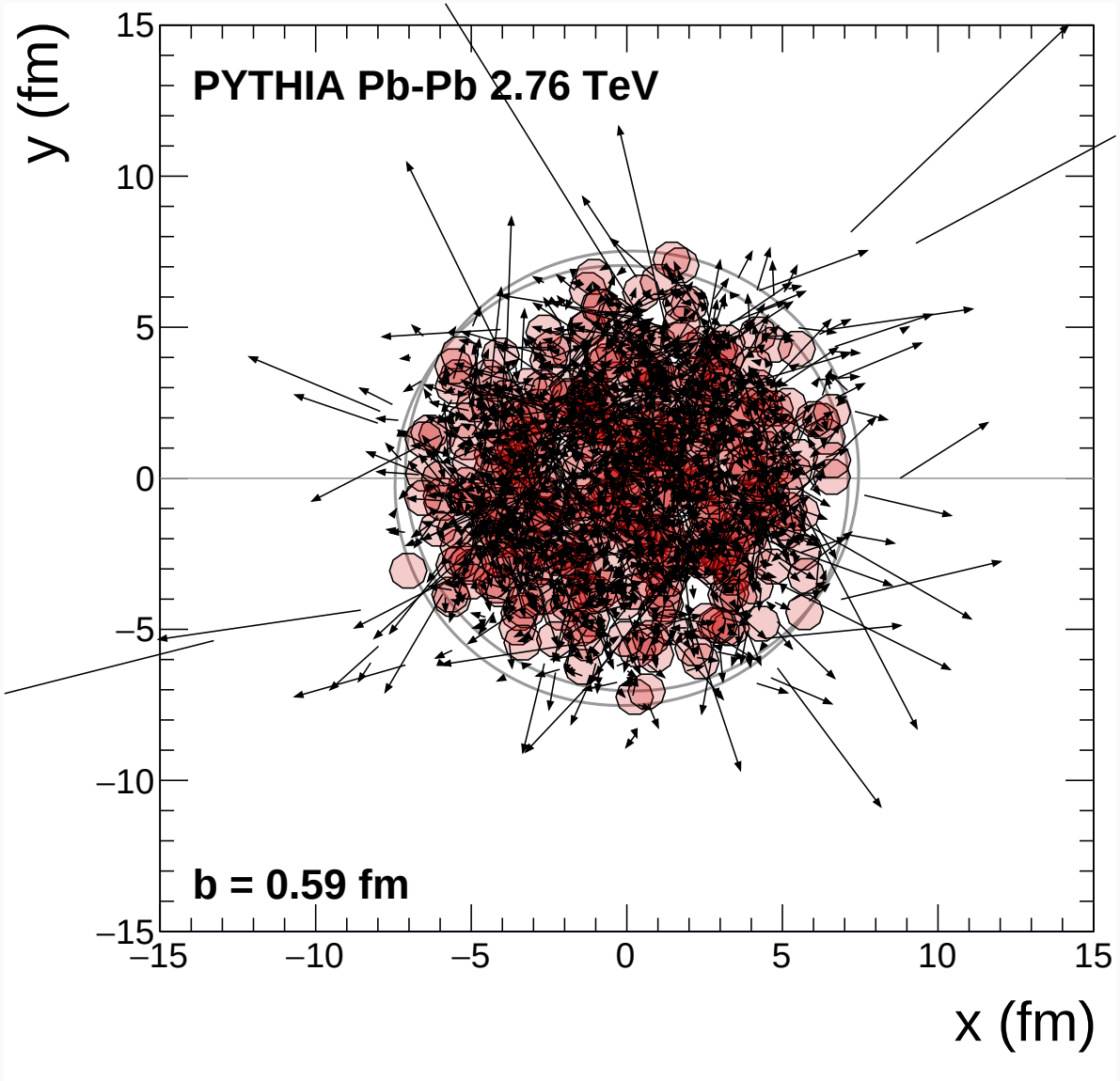
The basic idea

- Pythia8/Angantyr delivers a QGP-free final state.



Input

- Produced hadrons with positions and momenta.



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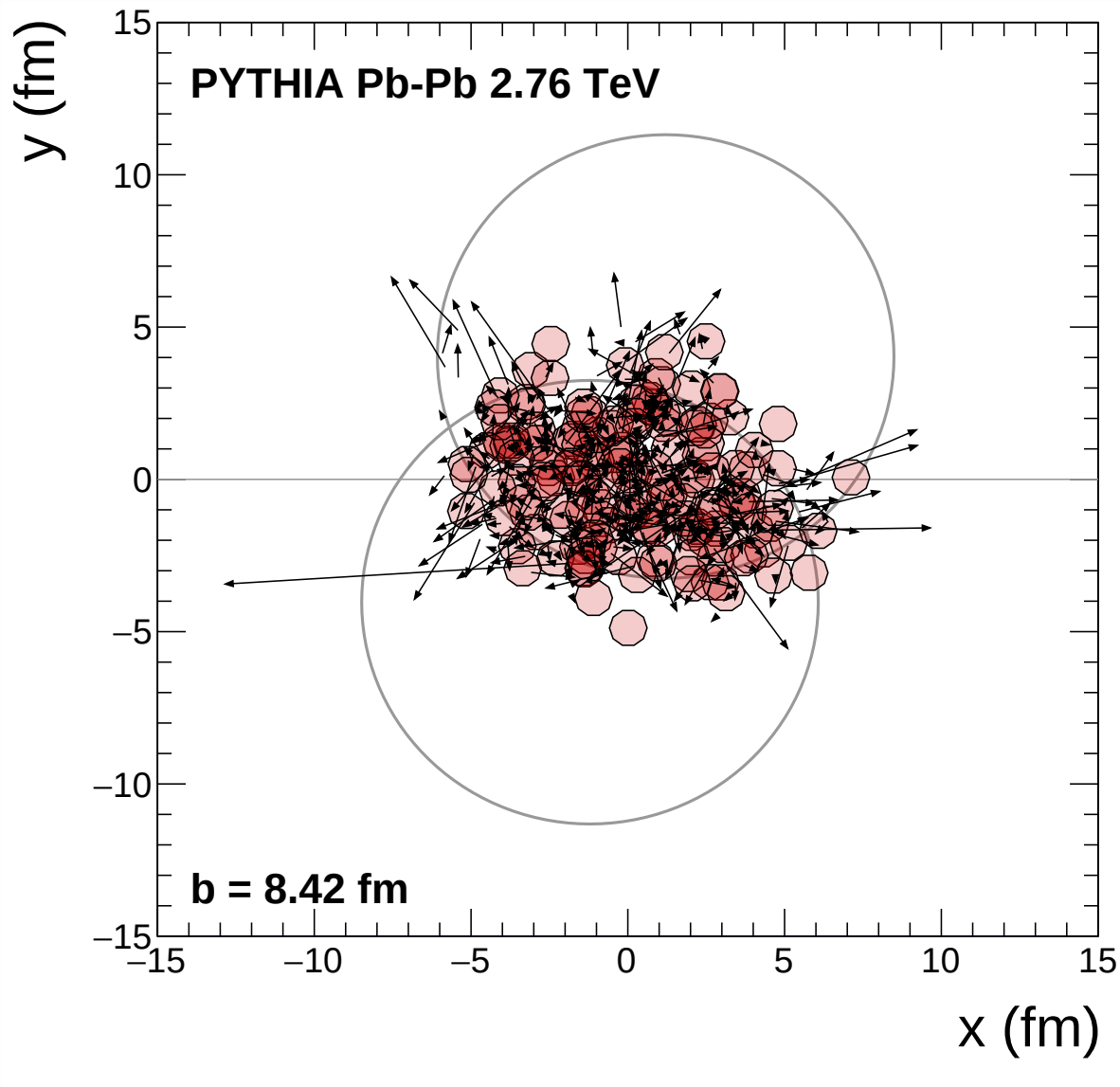

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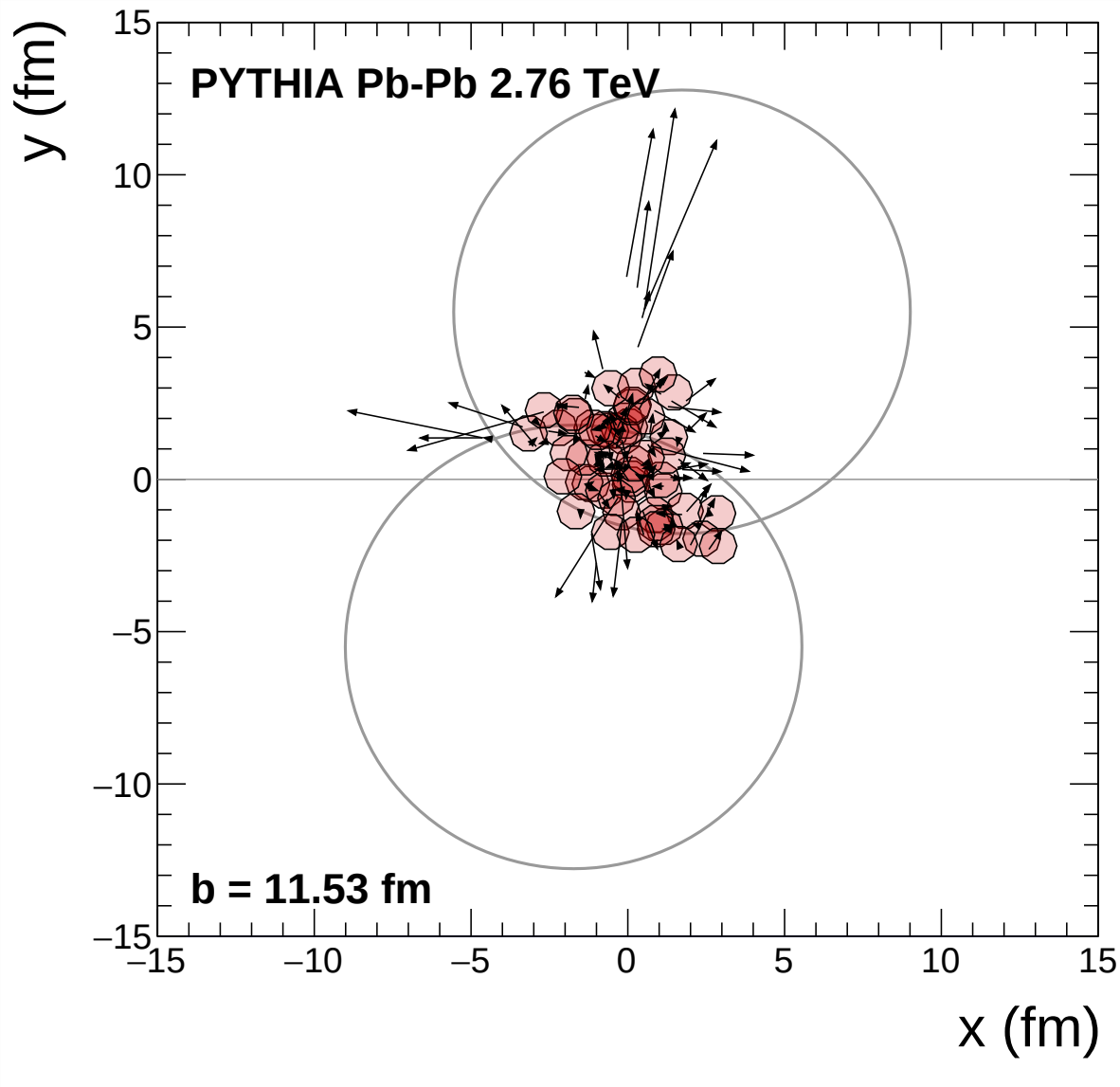
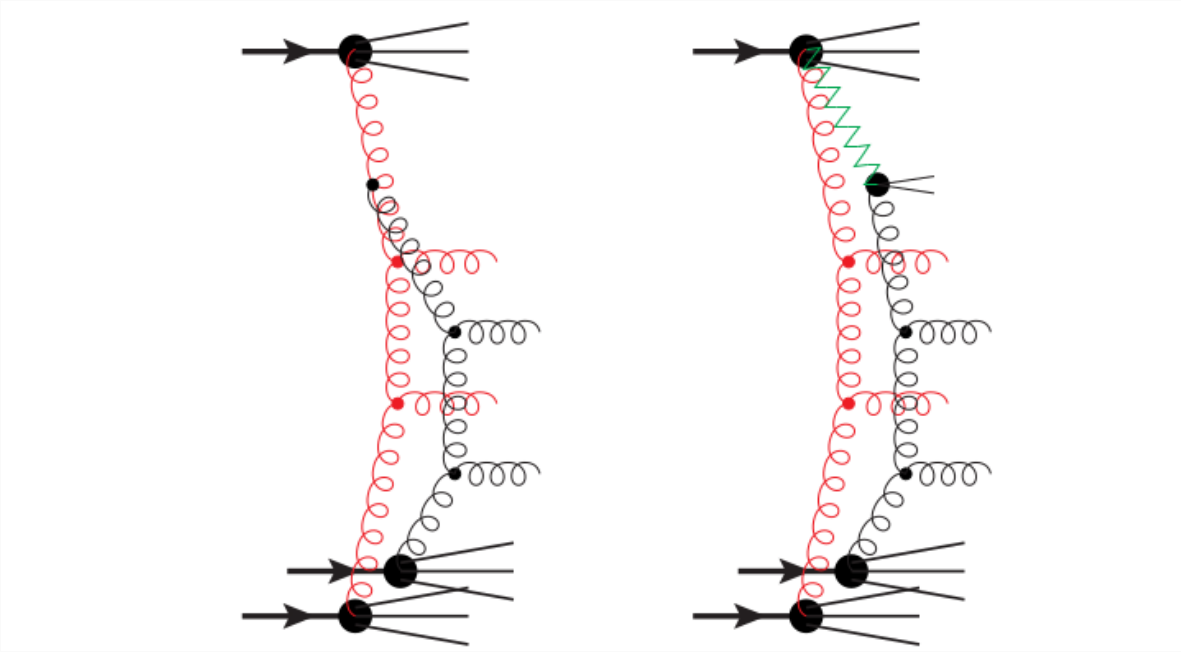


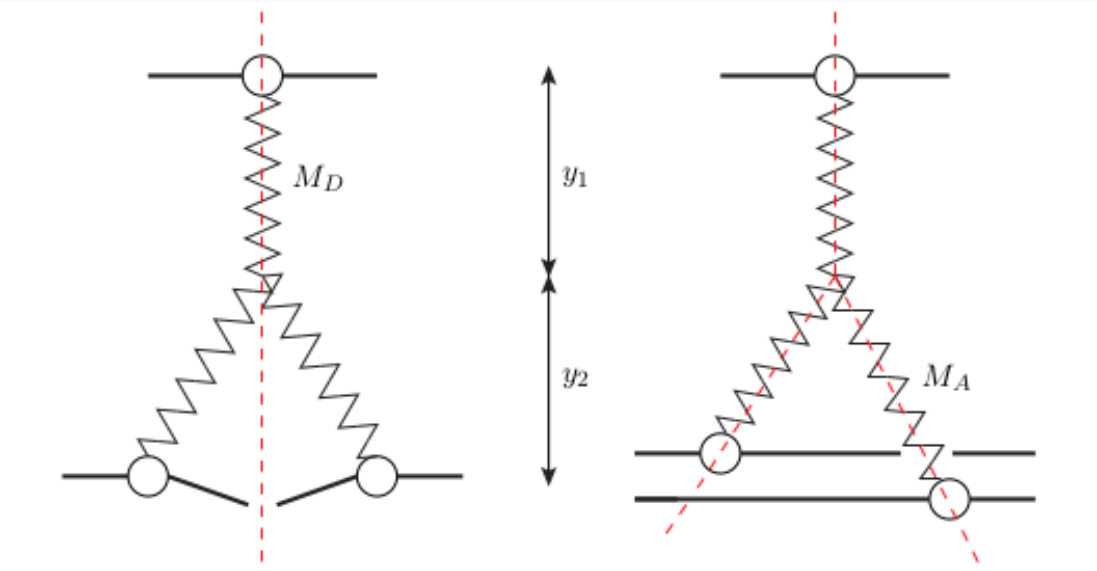
Angantyr – the Pythia heavy ion model (CB, Gustafson, Lönnblad: JHEP 1610 (2016) 139, += Shah: JHEP 1810 (2018) 134)

- Pythia MPI model extended to heavy ions since v. 8.235.
  1. Glauber geometry with Gribov colour fluctuations.
  2. Attention to diffractive excitation & forward production.
  3. Hadronize with Lund strings.
- Particle production: Similarity between:
  1. Single diffractive excitation.
  2. Secondary absorption.



Secondary absorptive interactions

- Similarity: triple-Pomeron diagrams.



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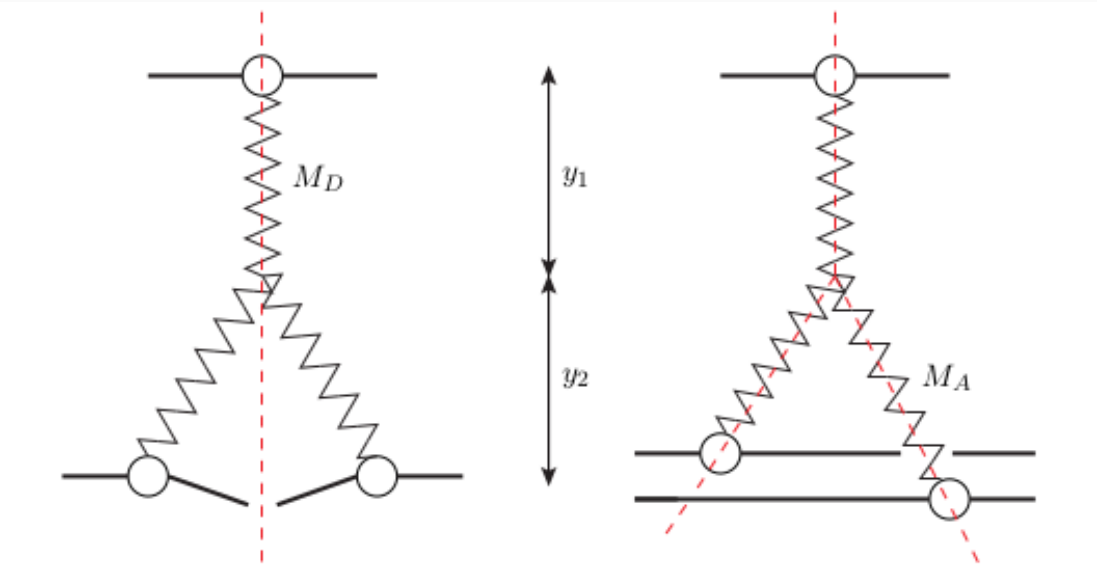


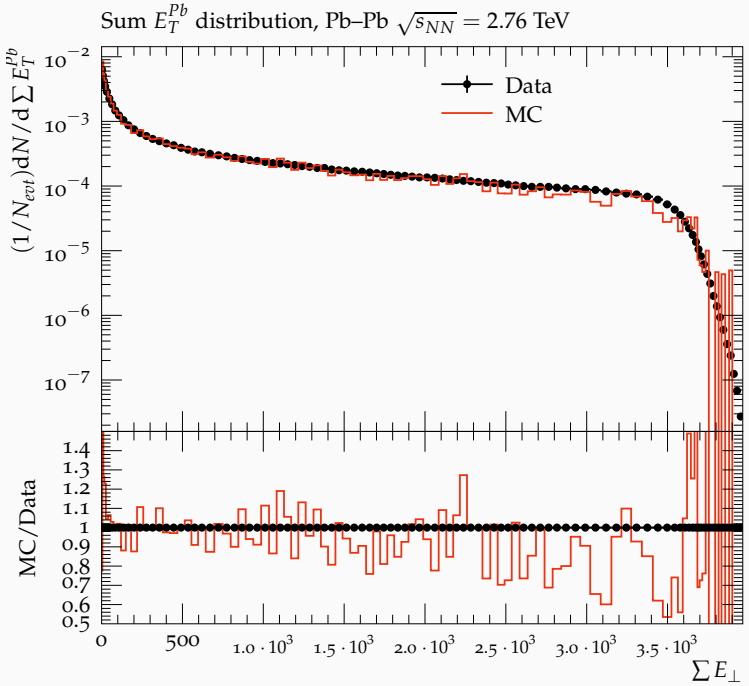
Diagram weight proportial to $(1 + \Delta = \alpha_{\mathbb{P}}(0))$

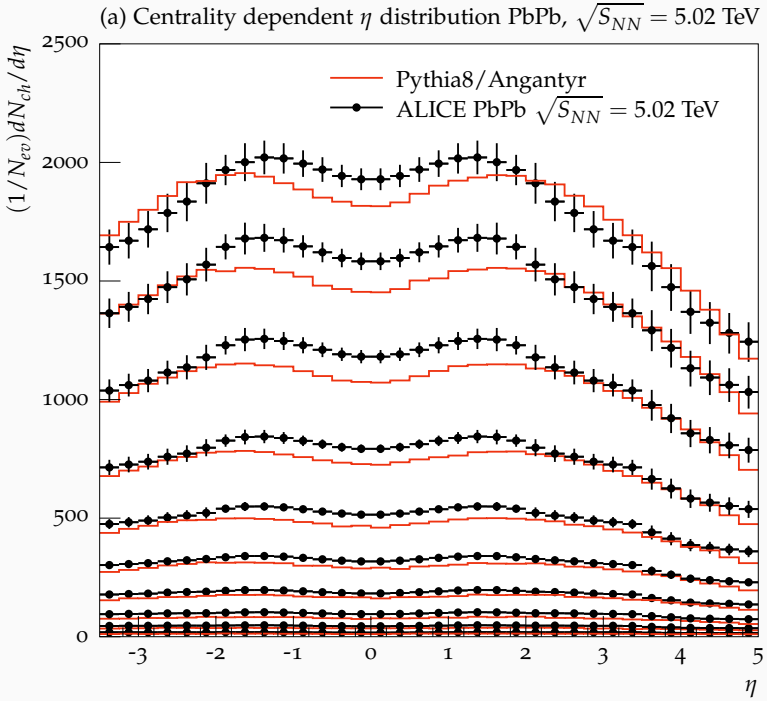
$$\frac{ds}{s^{(1-2\Delta)}} \frac{dM_D^2}{(M_D^2)^{(1+\Delta)}} \text{ diffractive excitation,}$$

$$\frac{ds}{s^{(1-\Delta)}} \frac{dM_A^2}{(M_A^2)^{(1-\Delta)}} \text{ secondary absorption.}$$

Relevant results

- Neccesary baseline for URQMD input:
  1. Good reproduction of centrality measure.
  2. Particle density at mid–rapidity.





- And hadron production vertices!

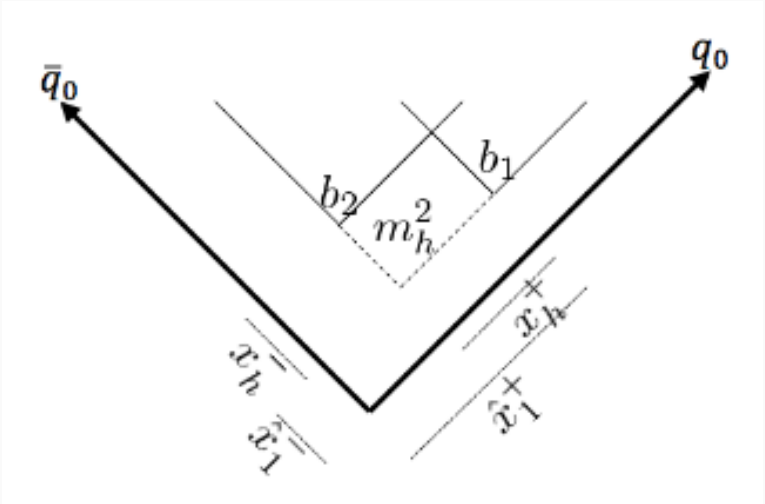
String kinematics (B. Andersson et al.: Phys. Rept.97(1983) 31)

- Lund string connects $q\bar{q}$, tension $\kappa = 1\text{GeV/fm}$.
- String obey yo–yo motion:

$$p_{q_0/\bar{q}_0} = \left(\frac{E_{cm}}{2} - \kappa t\right)(1;0,0,\pm 1).$$

- String breaks to hadrons with 4-momenta:

$$p_h = x_h^+ p^+ + x_h^- p^- \text{ with } p^\pm = p_{q_0/\bar{q}_0}(t=0)$$



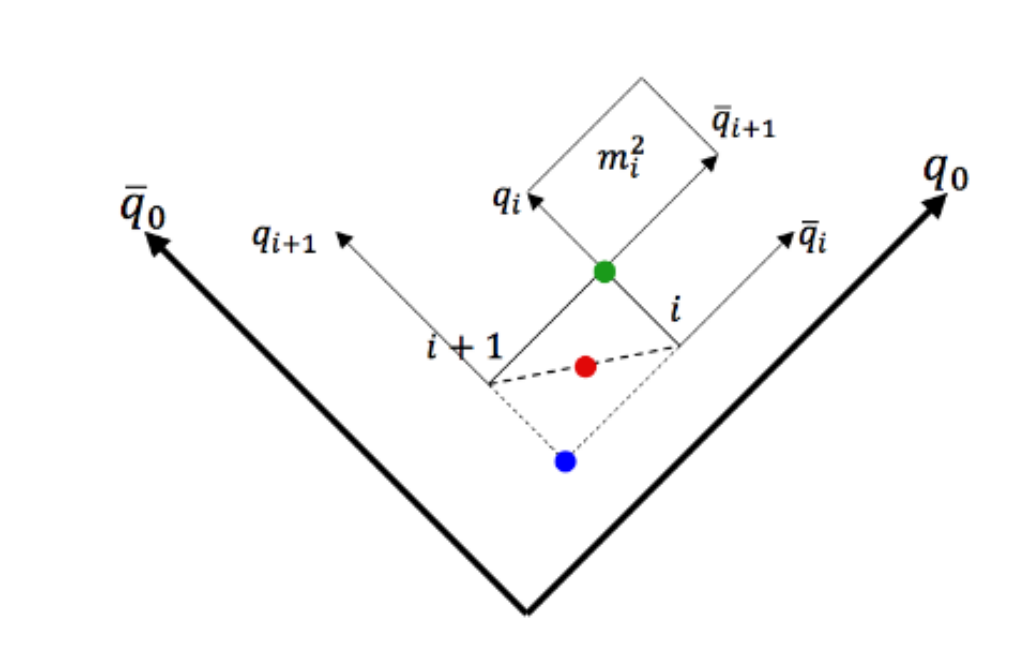
- ... which gives breakup vertices in momentum picture.

Hadron vertex positions (Ferreres-Solé & Sjöstrand: 1808.04619)

- Translate to space–time breakup vertices through string EOM.

$$v_i = \frac{\hat{x}_i^+ p^+ + \hat{x}_i^- p^-}{\kappa}$$

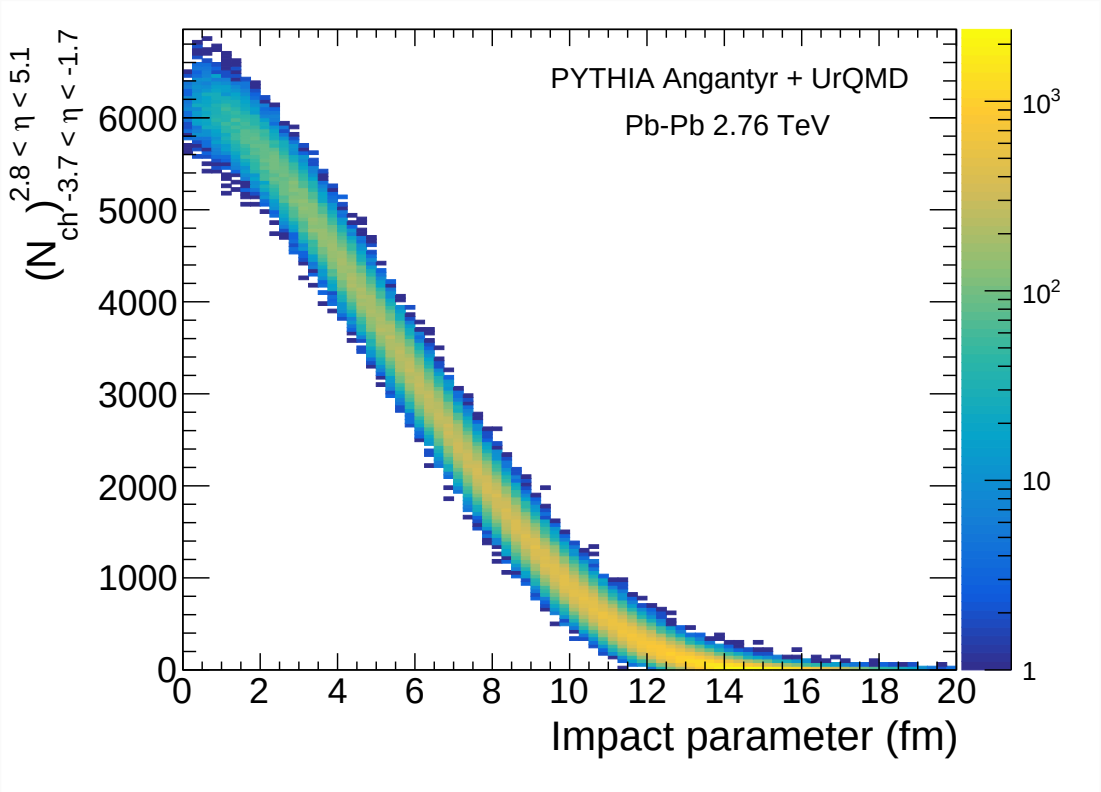
- Hadron located between vertices: $v_i^h = \frac{v_i + v_{i+1}}{2} \left(\pm \frac{p_h}{2\kappa} \right)$



- Formalism also handles complex topologies (99 % of the

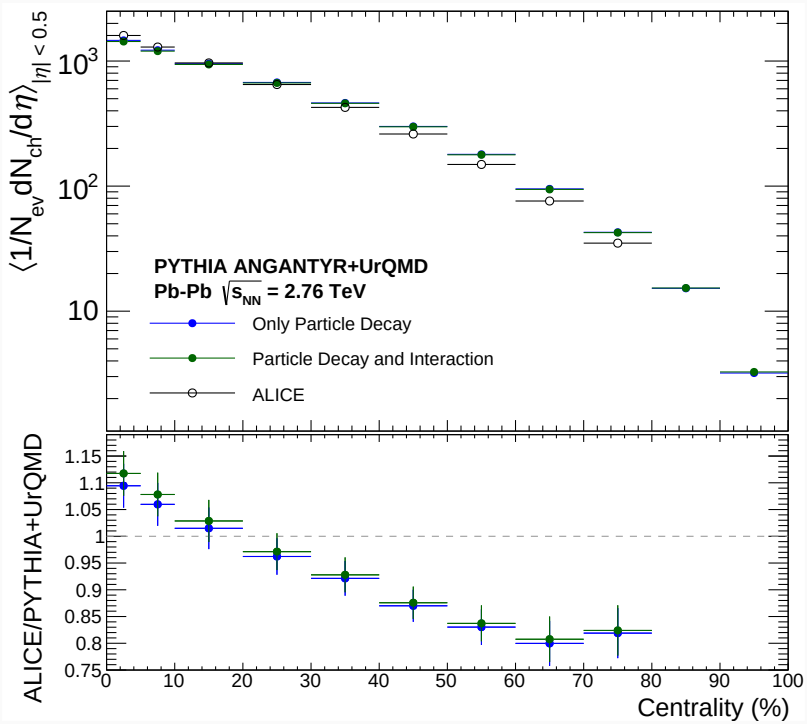
Interfacing to URQMD (S. Bass el al.: Prog. Part. Nucl. Phys 41 (1998) 225-370)

- UrQMD v3.4 handles 99.8% of all prompt hadrons
- Remaining 0.2%: heavy flavor, leptons, γ not treated by UrQMD
  - Heavy flavor ($\sim$0.2%): decayed by PYTHIA;
  - Leptons+photons ($\sim$0.01%): removed for now
- Centrality obtained via N_{ch} in the ALICE V0M acceptance

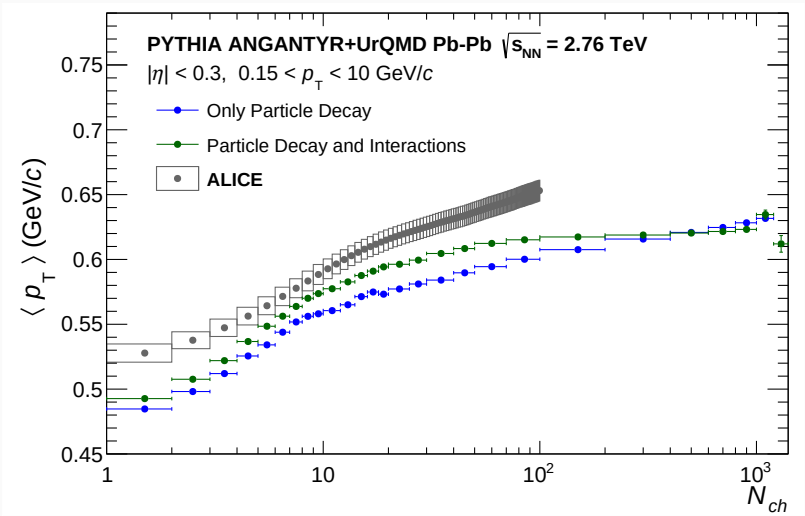


Results – Multiplicity and Average Transverse Momenta

- Basic average quantities as expected.
- Little change to multiplicity.

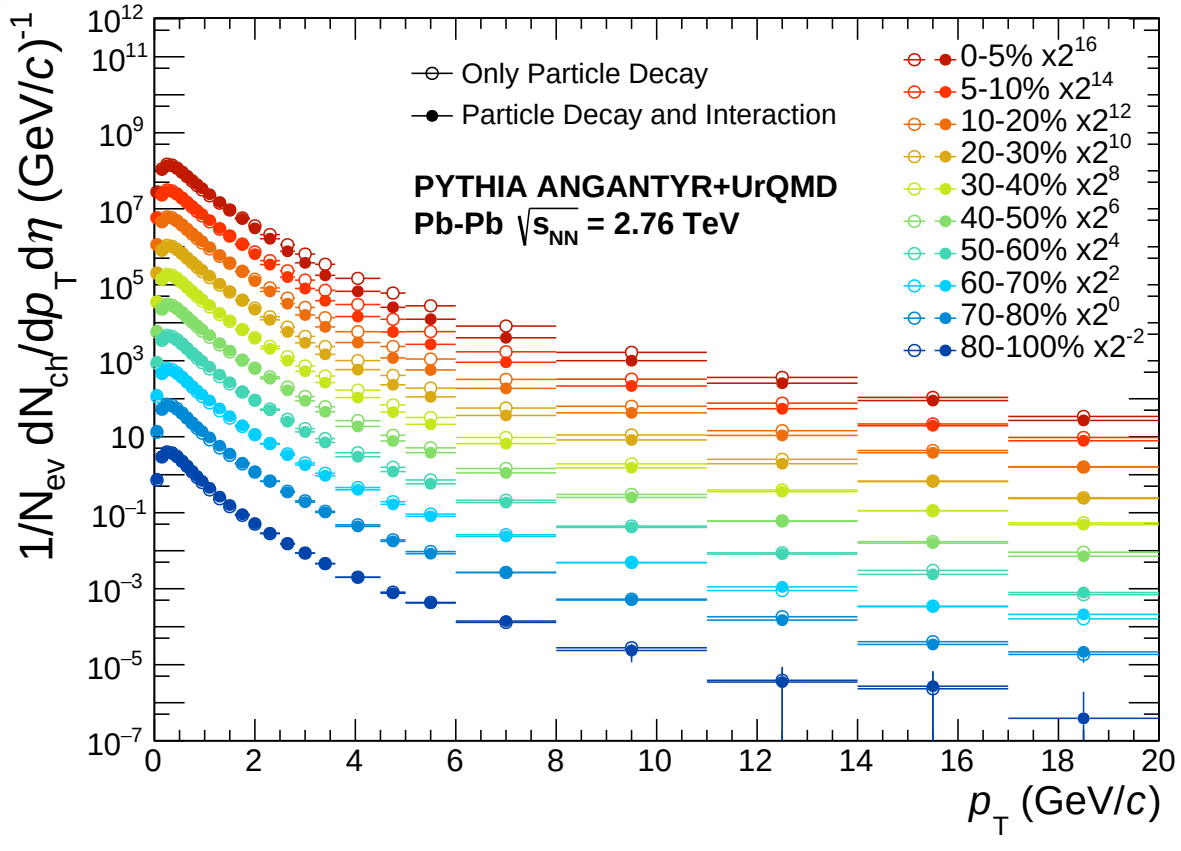


- Slight increase in $\langle p_\perp \rangle$.
- Angantyr missing cross–nucleon CR.



Results – spectra and R_{AA}

- High-$p_\perp$ particles stopped by low-$p_\perp$ ones.
- Effect increases with centrality.



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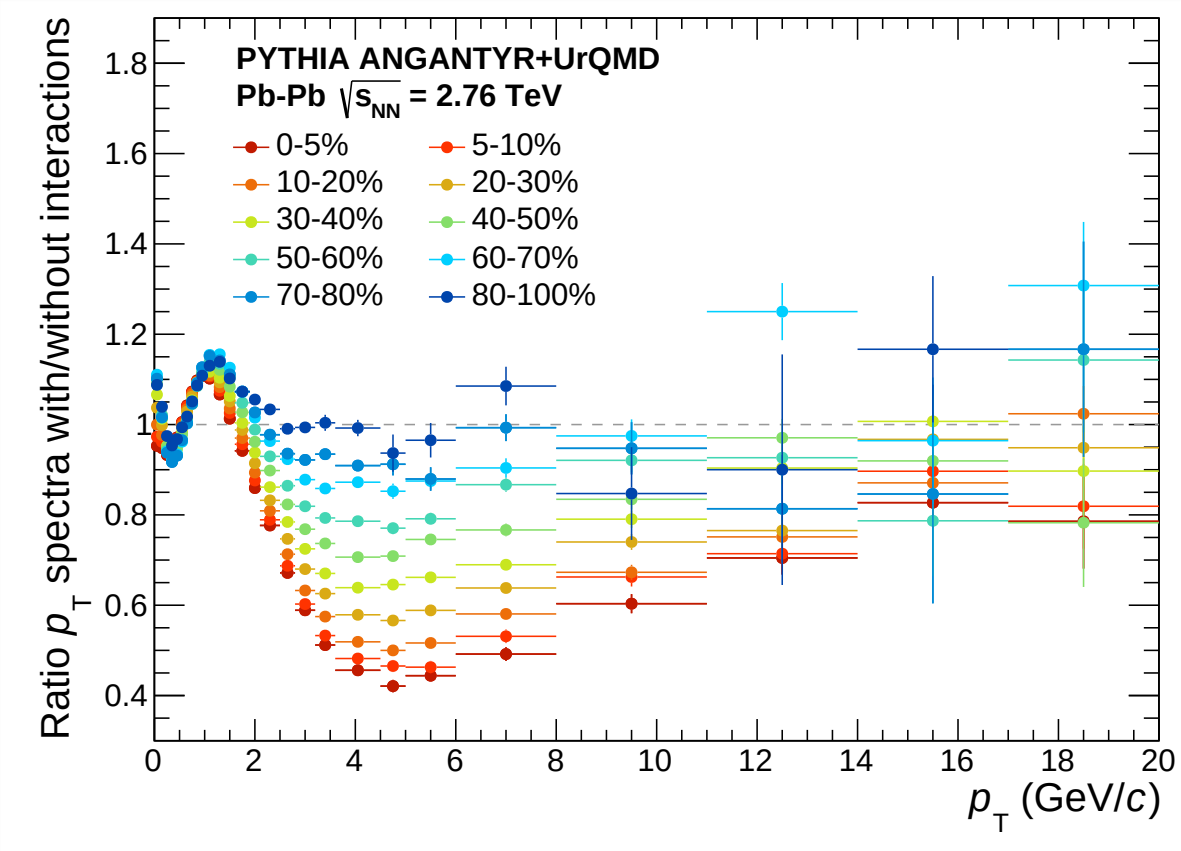

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- Low-$p_\perp$: poor description already by Pythia for $p_\perp < 1$ GeV.

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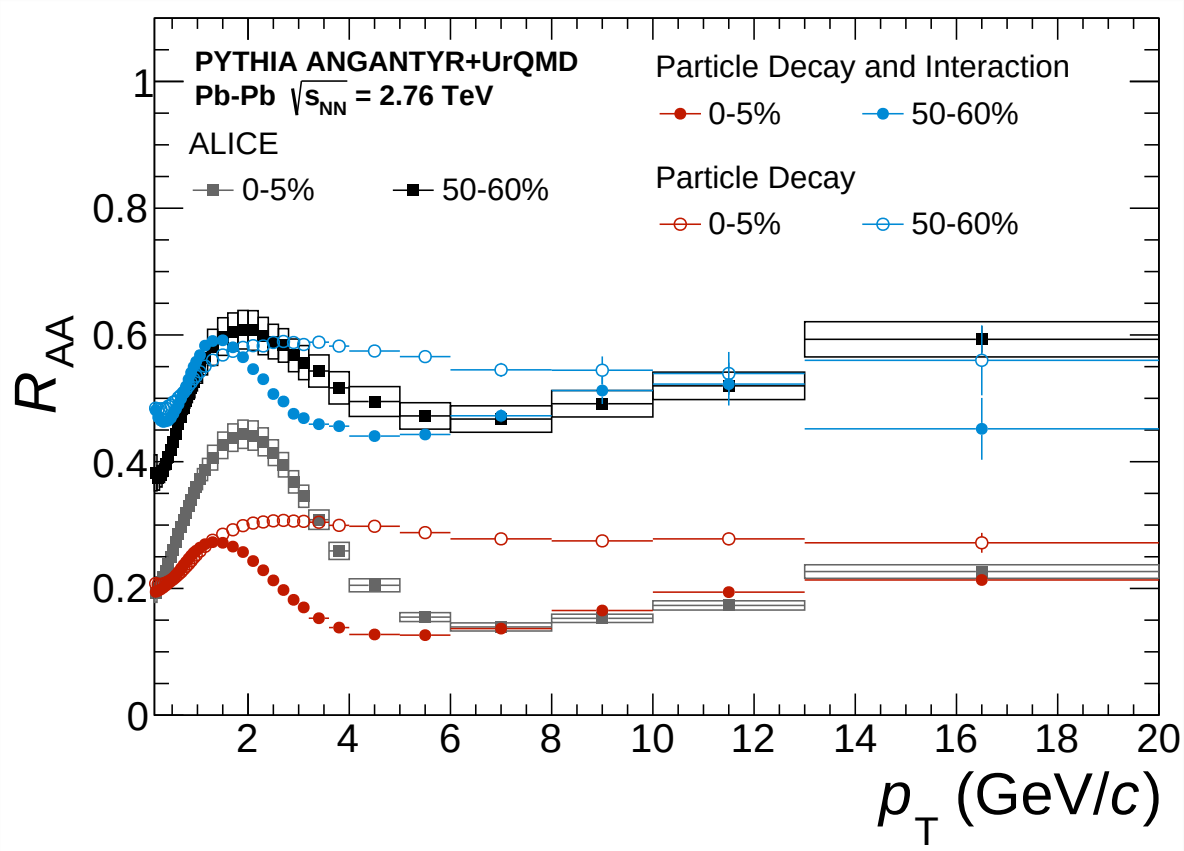

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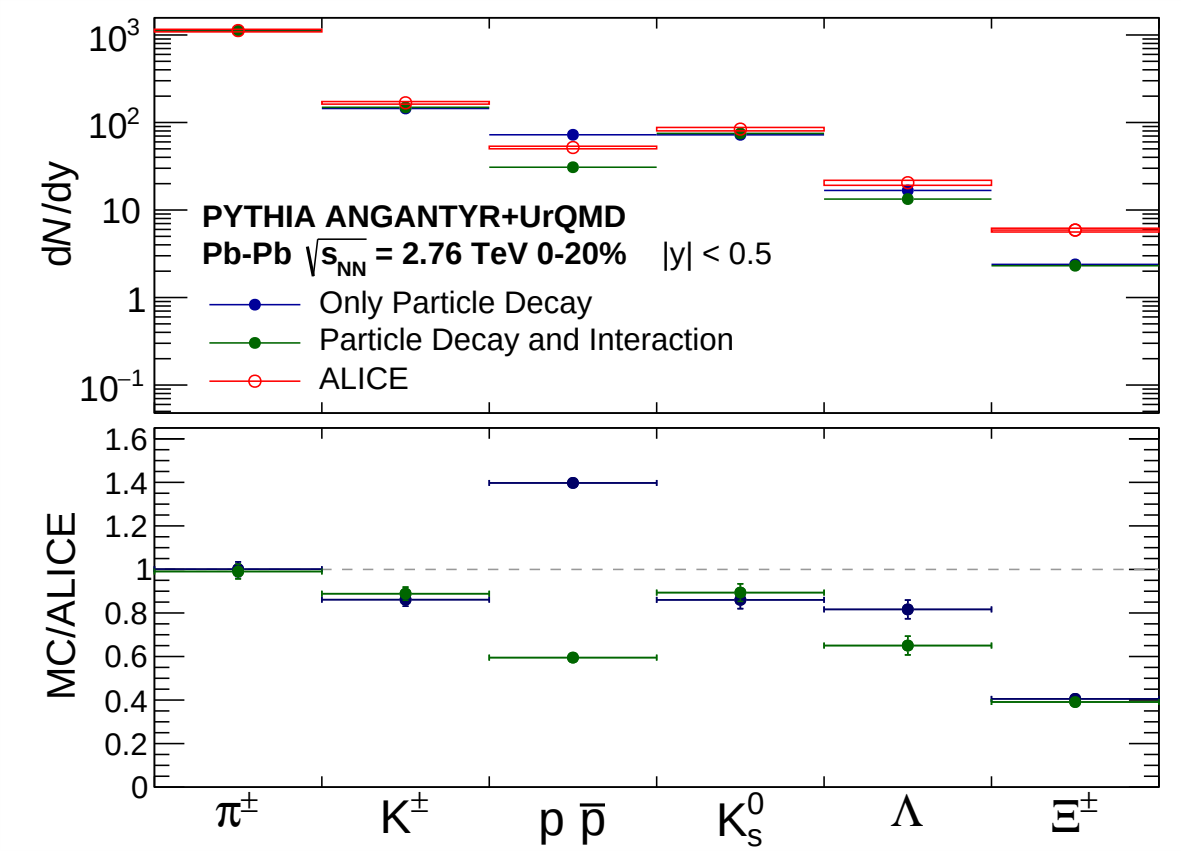
Results – yields

- Large effect from annihilations, especially protons.
- Persists even to peripheral PbPb – possibility for pp?



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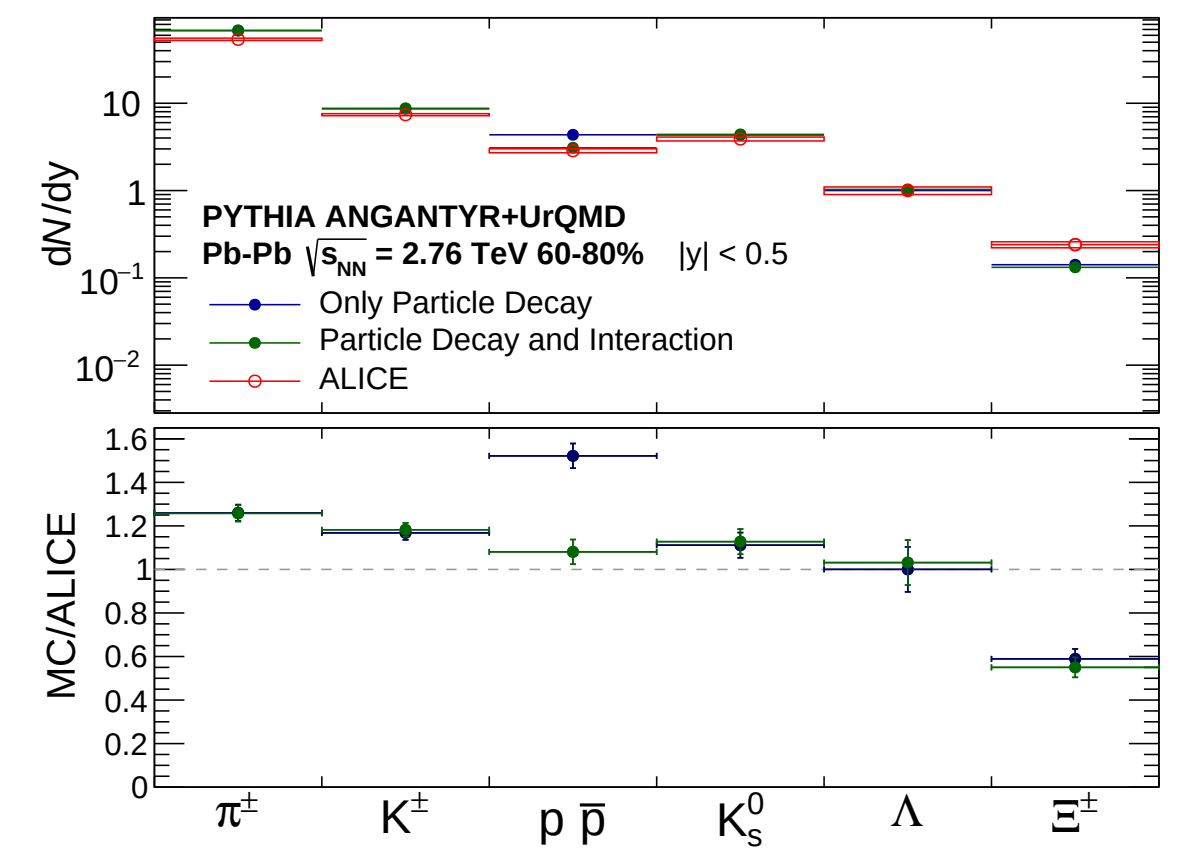
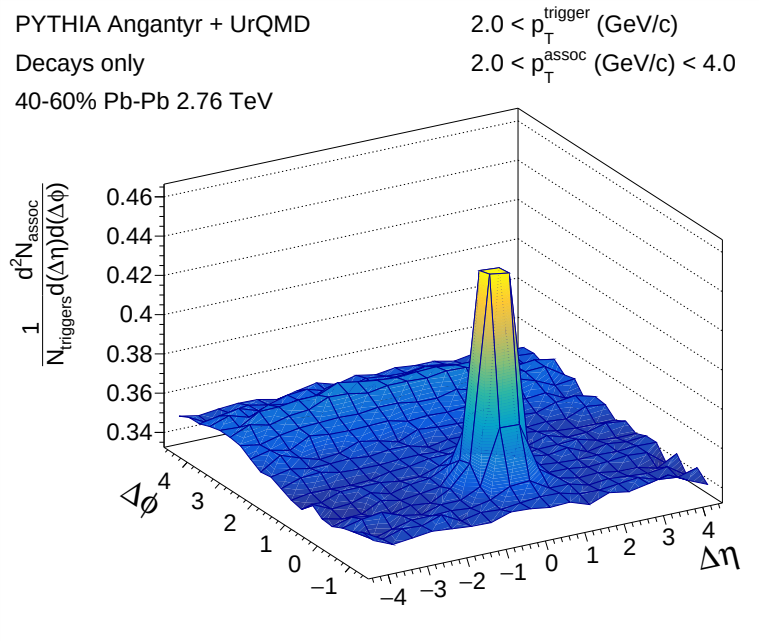
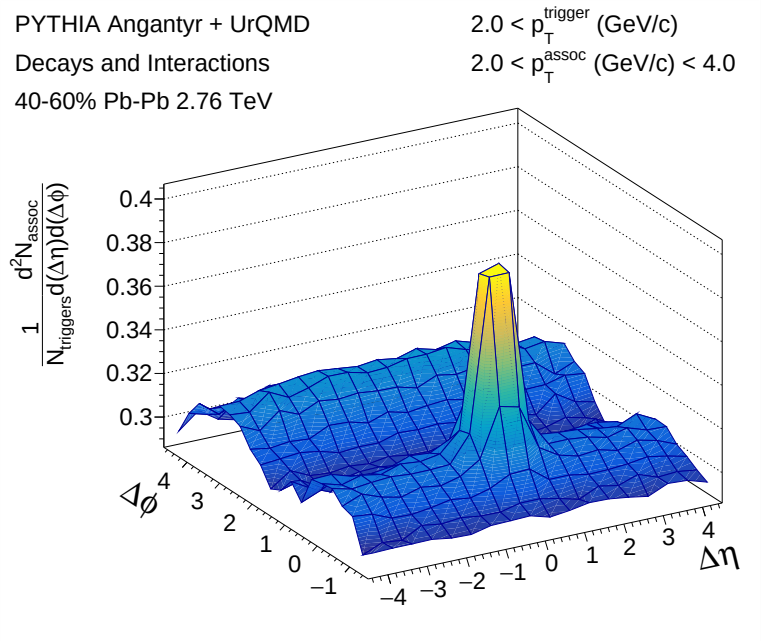


Results – flow

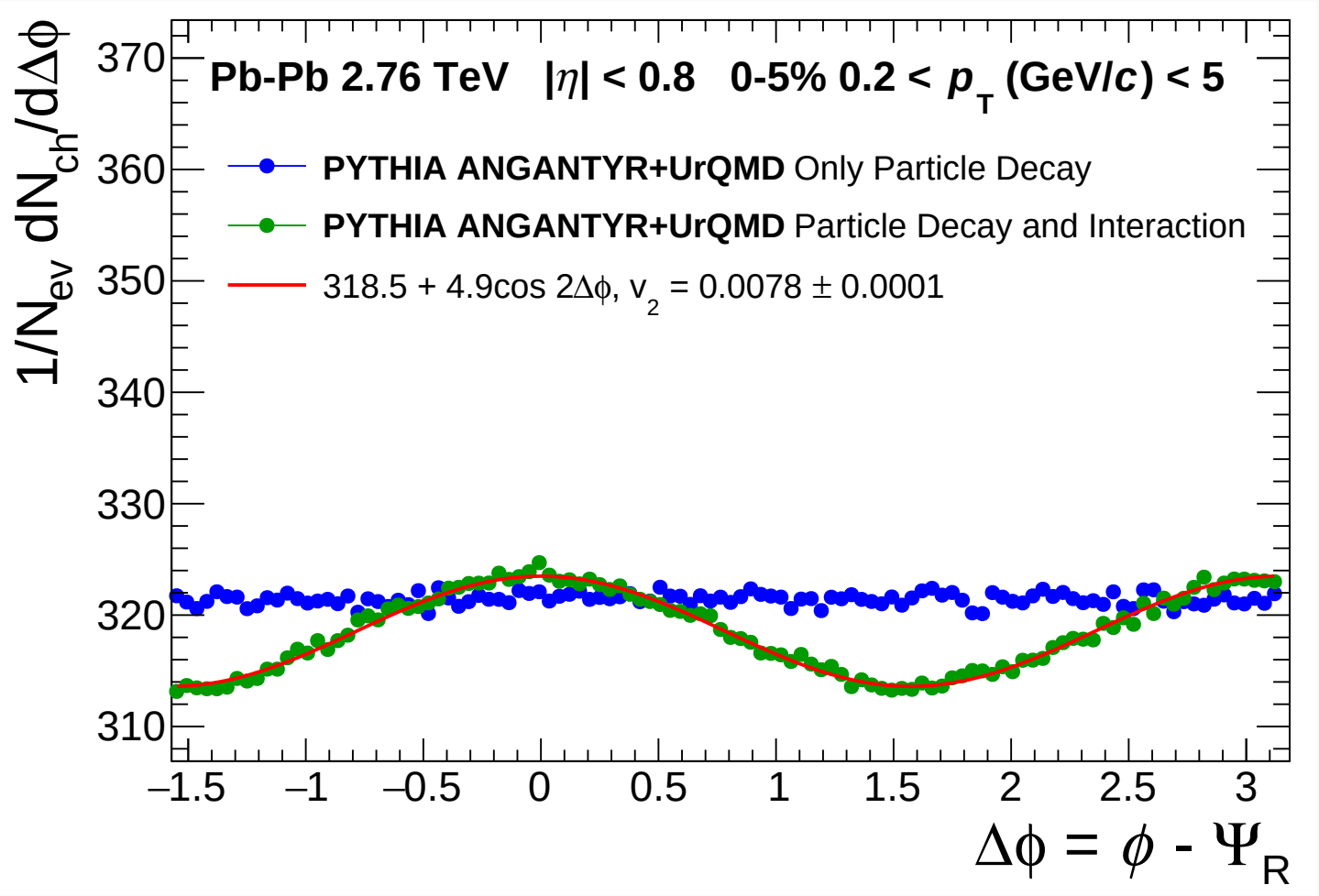
- Rescattering produces correlations long-range in η (the double ridge).
- Previously seen, but not at these energies, with general purpose MC input (Bleicher *et al.* arXiv:nucl-th/0602009).





Results – flow

- Understanding model influence: Correlations wrt. event plane calculated from Pythia Glauber.
- Automatic removal of jet peak.



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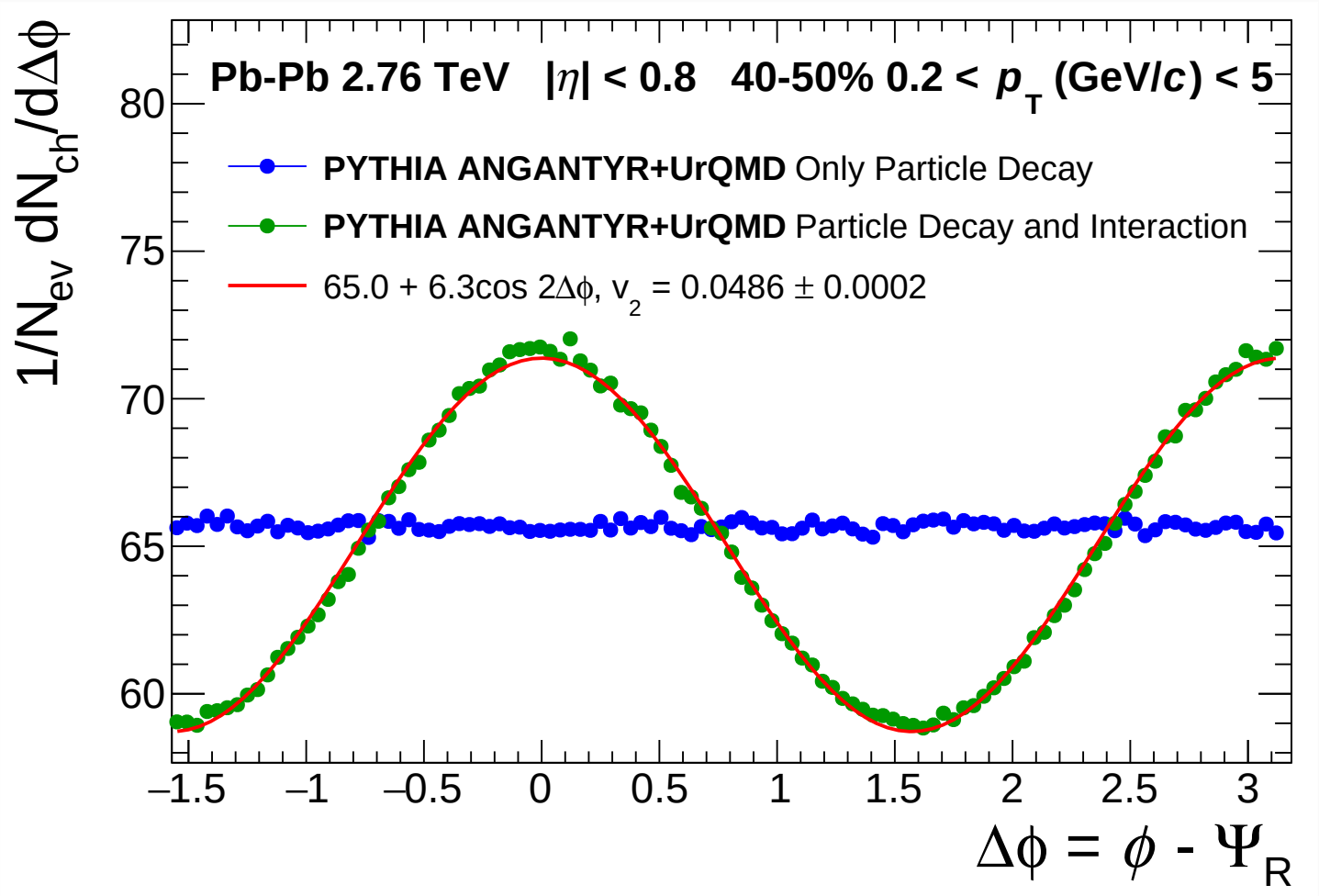

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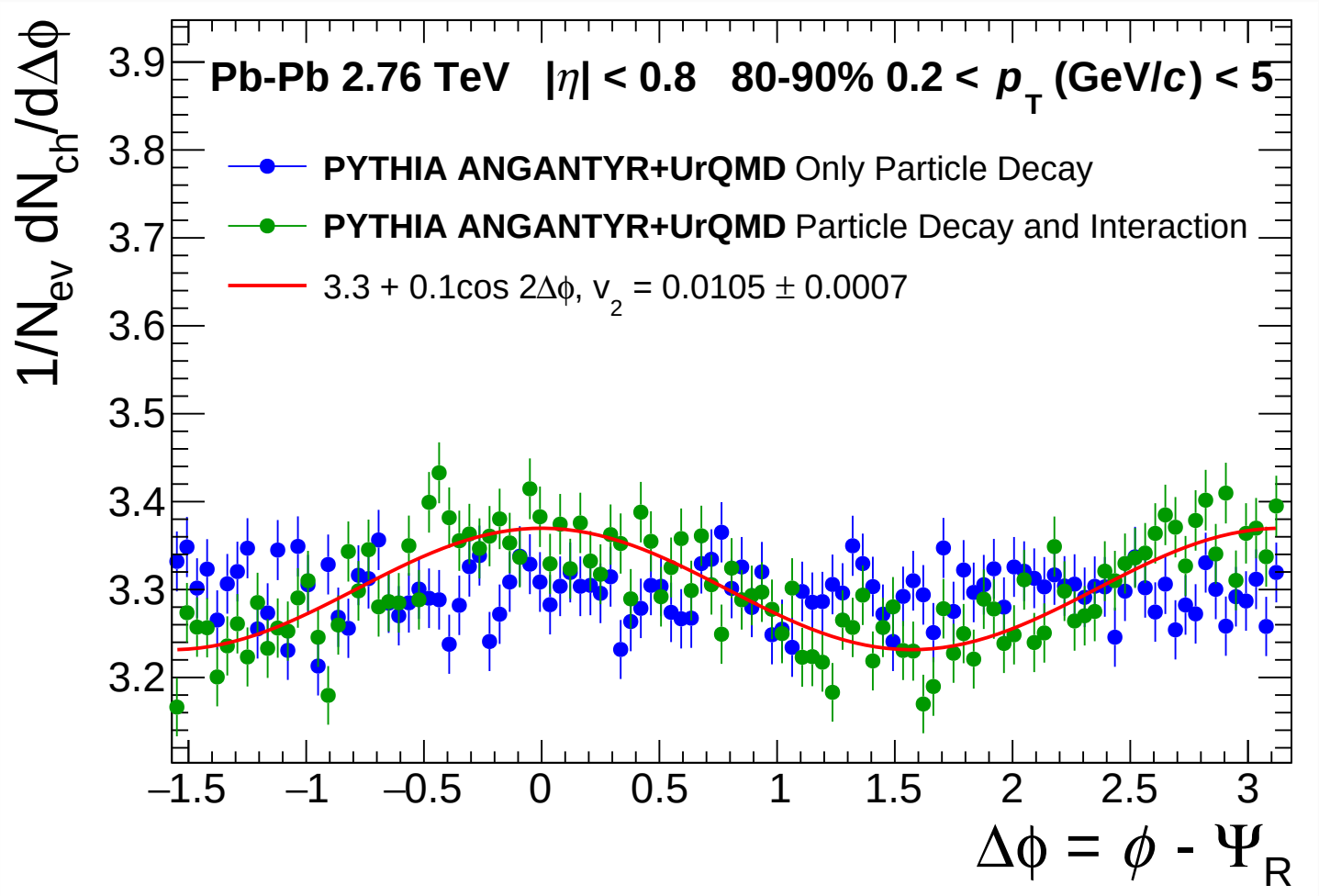
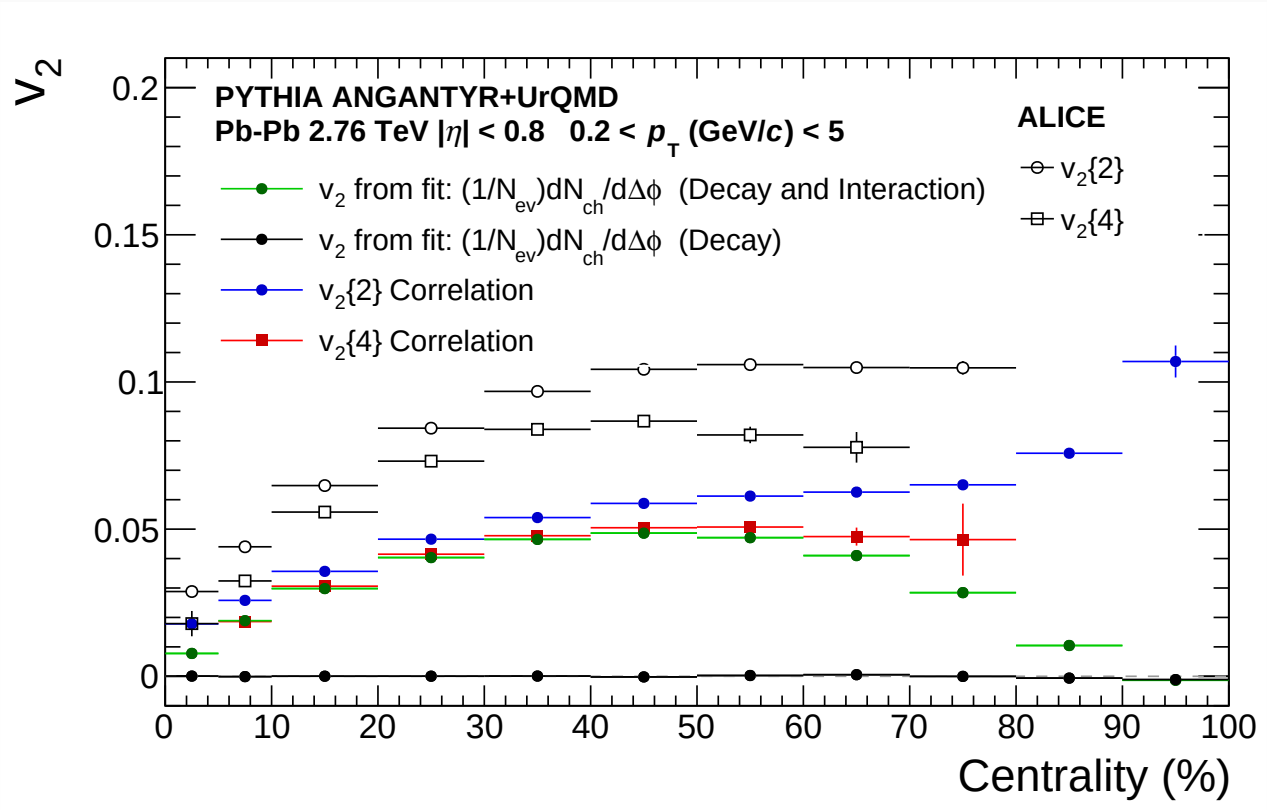


Results – elliptic flow coefficients

- v_2 vs centrality: same dynamics as in ALICE data, but 50% magnitude; v_2 via cumulants similar to v_2 with correlations wrt. event plane



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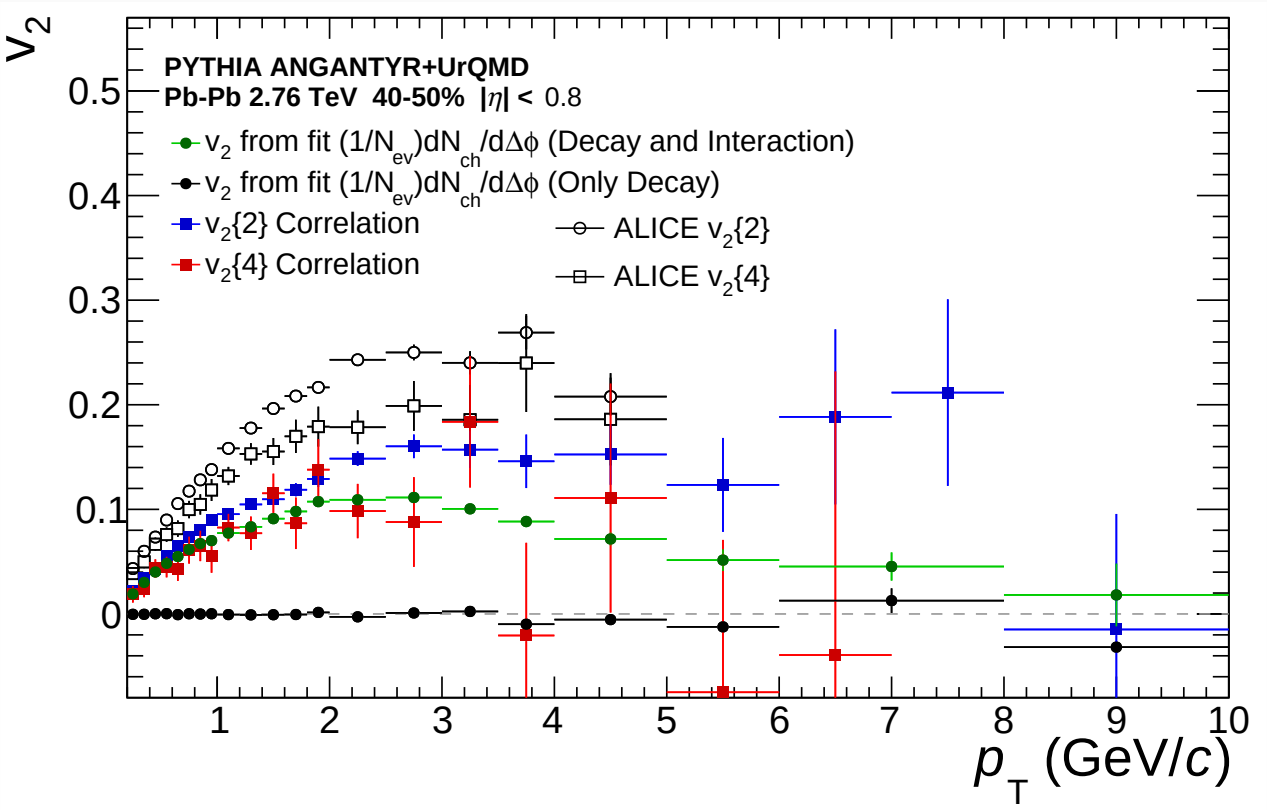


- Similar conclusion from $v_2(p_\perp)$

Conclusions

- First results from Pythia Heavy Ion collisions + URQMD hadronic final state.
- MC generated full final states $\rightarrow$ direct comparison to measured quantities.
- No QGP effects, but sizeable effects on:
  - **Spectra:** rescatterings produce R_{AA}-like peak, high-$p_\perp$ well described.
  - **Yields:** sizeable corrections to baryon yields, esp. protons.
  - **Flow:** Hadronic dynamics generates roughly half of observed v_2!

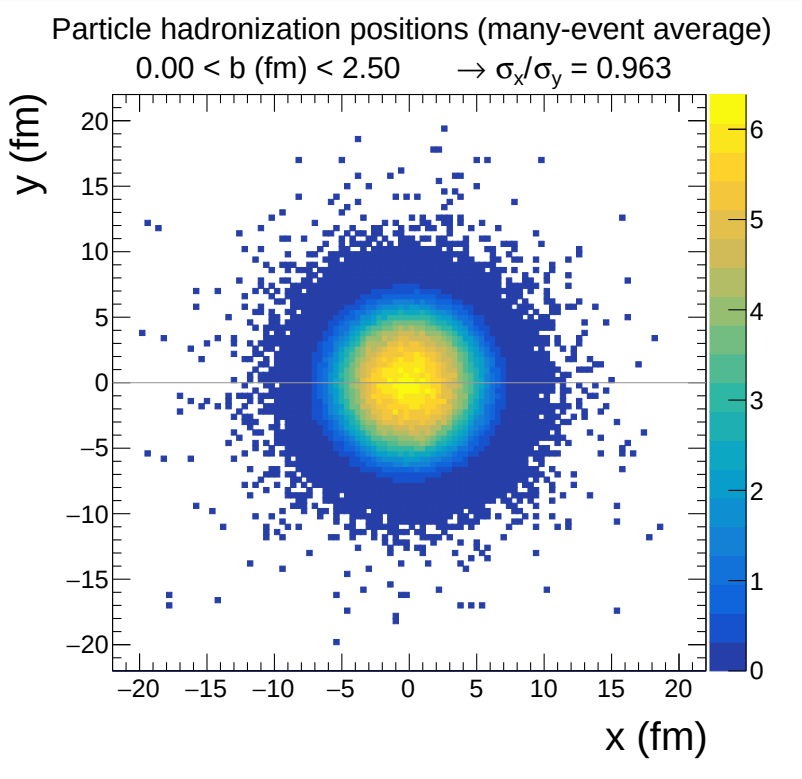
New baseline leaves significantly less room for QGP effects!

- Opens the door for models with smaller effects.
- Suggests reinterpretation of QGP properties as previously estimated at RHIC and LHC.

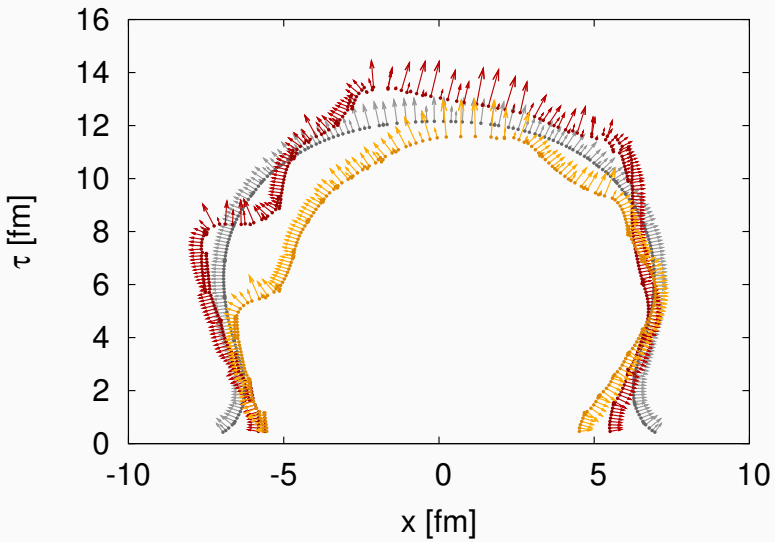
Backup

Comparing hadron densities: Hydro vs PYTHIA Angantyr

PYTHIA Angantyr



MUSIC (3+1)D Hydro



- At hadronization: similar dimensions in transverse space and similar N_{ch} in PYTHIA versus hydro models such as MUSIC (Schenke *et al.* arXiv:1009.3244)
- → Hadron densities comparable to typical UrQMD use case
  - Further checks ongoing