Sources of multiparticle correlations

a miroscopic perspective

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Introduction

- Small system collectivity: The most surprising LHC outcome!
- Challenges all around the board:
  - How far down in system size can the "SM of Heavy Ions" remain?
  - Can the standard tools for min bias pp remain standard?
- *Physics differences between similar signatures across systems?*
- *What is the role of the initial state geometry?*
- This talk: a microscopic, plasma free approach.
  1. MPIs from pp to AA: The Angantyr model.
  2. String shoving: The "ridge" in pp.
  3. The role of the initial state.
  4. Final state rescatterings and correlations in AA.

MPIs in pp

- Several partons taken from the PDF.
- Hard subcollisions with $2 \to 2$ ME:

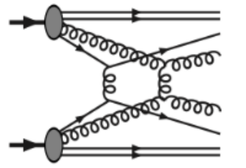


Figure T. Sjöstrand

$$\frac{d\sigma_{2\to2}}{dp_\perp^2} \propto \frac{\alpha_s^2(p_\perp^2)}{p_\perp^4} \to \frac{\alpha_s^2(p_\perp^2 + p_{\perp0}^2)}{(p_\perp^2 + p_{\perp0}^2)^2}.$$

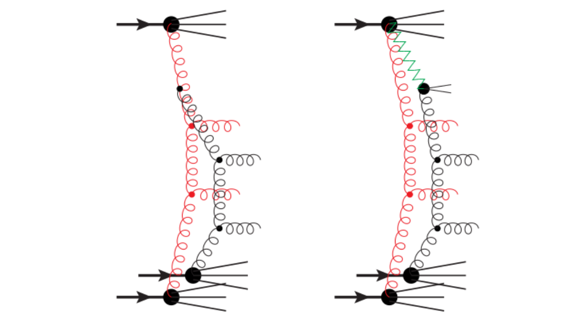
- Momentum conservation and PDF scaling.
- Ordered emissions: $p_{\perp1} > p_{\perp2} > p_{\perp4} > ...$ from:

$$\mathcal{P}(p_\perp = p_{\perp i}) = \frac{1}{\sigma_{nd}} \frac{d\sigma_{2\to2}}{dp_\perp} \exp\left[-\int_{p_\perp}^{p_{\perp i-1}} \frac{1}{\sigma_{nd}} \frac{d\sigma}{dp'_\perp} dp'_\perp\right]$$

- Picture blurred by CR, but holds in general.

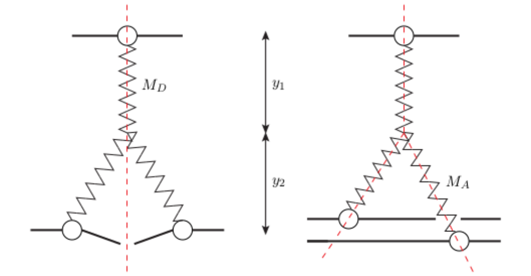
Angantyr – the Pythia heavy ion model (CB, G. Gustafson, L. Lönnblad: JHEP 1610 (2016) 139, += Shah: JHEP 1810 (2018) 134)

- 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.



Secondary absorptive interactions

- Similarity: triple-Pomeron diagrams.



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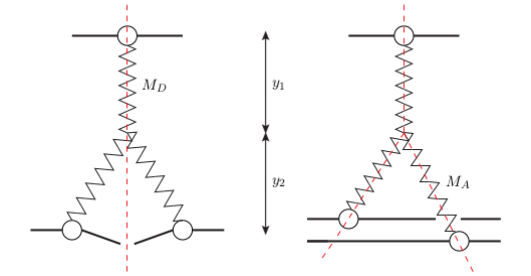


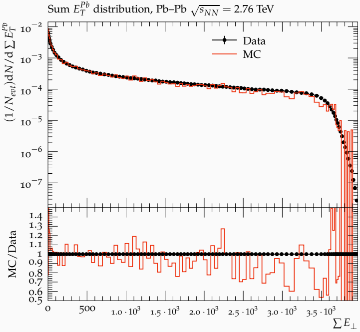
Diagram weight proportial to $(1+\Delta = \alpha_{\mathbb{P}}(0))$

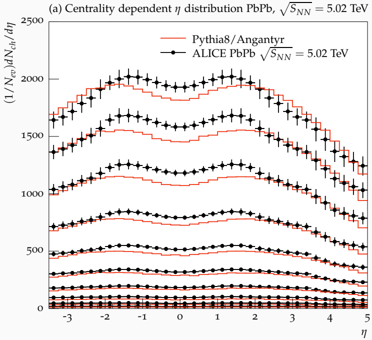
$$\frac{ds}{s^{(1-2\Delta)}} \frac{dM_D^2}{(M_D^2)^{(1+\Delta)}} \text{ diffractive excitation,}$$

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

Basic quantities in AA

- Reduces to normal Pythia in pp, in pA in AA:
    1. Good reproduction of centrality measure.
    2. Particle density at mid–rapidity.

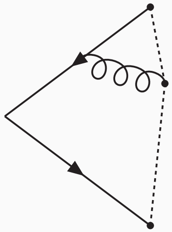




- Necessary baseline for any full model.
- FS needs hadronization mechanism.

The Lund String (80's: Andersson, Bo et al. Z.Phys. C3 (1980) 223, Z.Phys. C20 (1983) 317)

- Non-perturbative phase of final state.
- Confined colour fields ≈ *strings* with tension $\kappa \approx 1$ GeV/fm.



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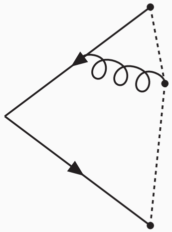

Lund symmetric fragmentation function

$$f(z) \propto z^{-1}(1-z)^a \exp\left(\frac{-bm_\perp}{z}\right).$$

a and b related to total multiplicity.

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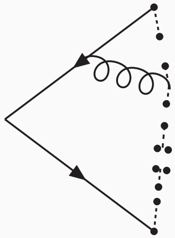

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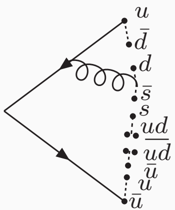

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Light flavour determination

$$\rho = \frac{\mathcal{P}_{\text{strange}}}{\mathcal{P}_{\text{u or d}}}, \xi = \frac{\mathcal{P}_{\text{diquark}}}{\mathcal{P}_{\text{quark}}}$$

Related to κ by Schwinger equation.

String shoving (CB, Gustafson, Lönnblad: 1612.05132, 1710.09725)

- Strings = interacting vortex lines.
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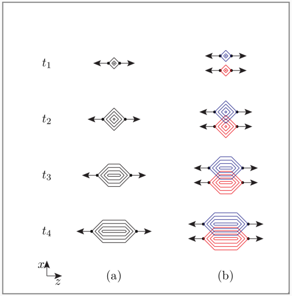

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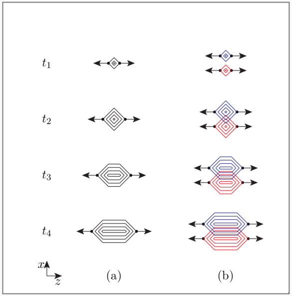


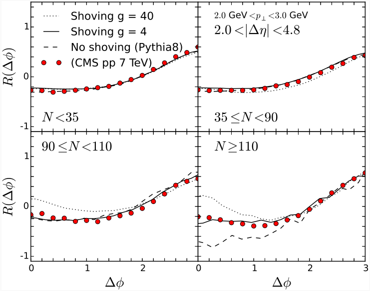
- Dominated by electric field $\to g = 1$.

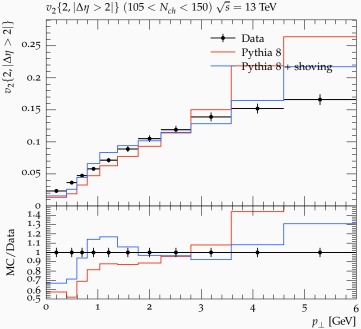
- Reality:

  Type 1 Energy to destroy vacuum.
  Type 2 Energy in current.

Some Results: shoving

- Reproduces the pp ridge with suitable choice of g parameter.
- Improved description of $v_2 2|\Delta eta| > 2.(p_\perp)$ at high multiplicity.
- Low multiplicity not reproduced well – problems for jet fragmentation?





Adding a Z-boson makes little difference (CB: PLB 795 (2019) 194-199)

- The presence of a Z should not change the physics.
- It *can* introduce kinematic biases.
- Recently measured by ATLAS (ATLAS-CONF-2017-068).

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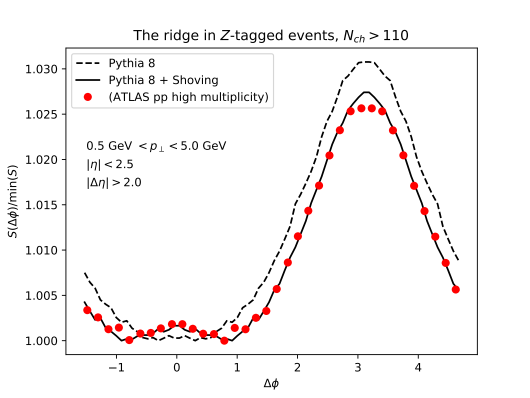
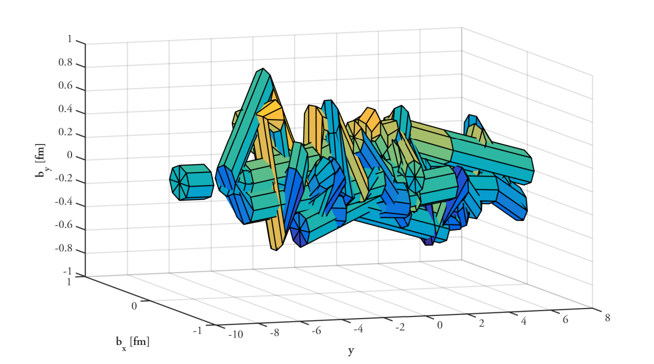


The importance of the initial state

- Space–time information is important: We rely on models! Also true for hydro.
- Here: Overlapping 2D Gaussians (p mass distribution).
- Figure string $R = 0.1$ fm, reality $R \sim 0.5$ fm.



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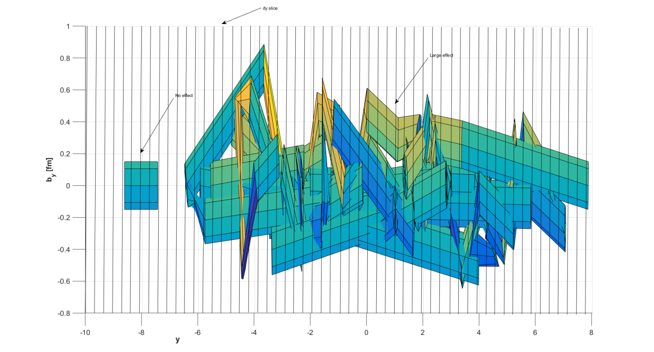

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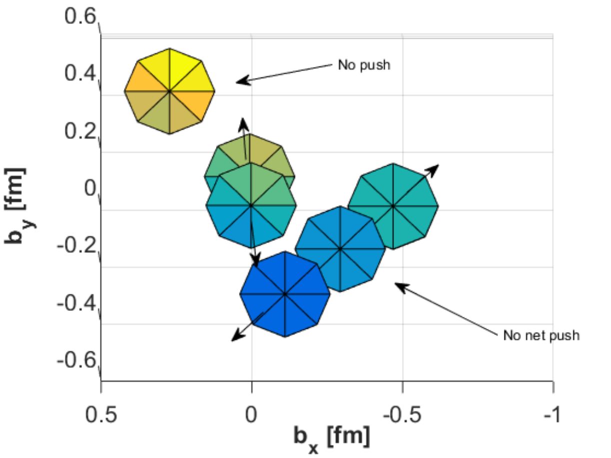

Constraining the initial state (CB and C. O. Rasmussen: 1907.12871 [hep-ph])

- *Ad hoc* models of the initial state not optimal.
- Mueller dipole BFKL as parton shower (from Pythia 8.3X).

Dipole splitting and interaction

$$\frac{\mathrm{d}\mathcal{P}}{\mathrm{d}y\ \mathrm{d}^2\vec{r}_3} = \frac{N_c\alpha_s}{2\pi^2}\frac{r_{12}^2}{r_{13}^2 r_{23}^2}\Delta(y_{\min}, y),$$

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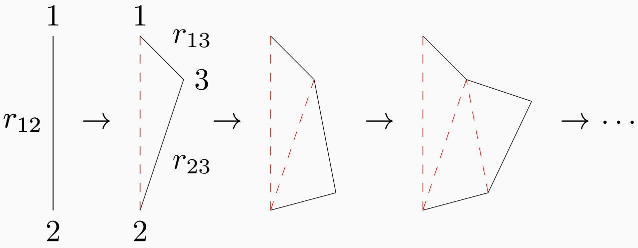

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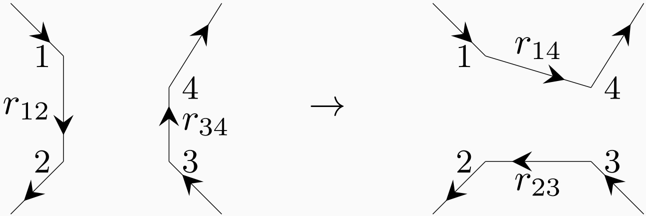
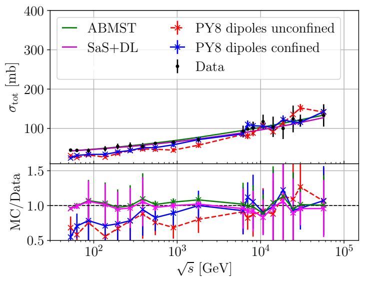
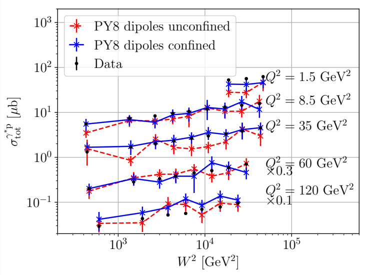


Everything fitted to cross sections

- Avoids fitting to predictions.
- Unitarized dipole-dipole amplitude plus Good-Walker.

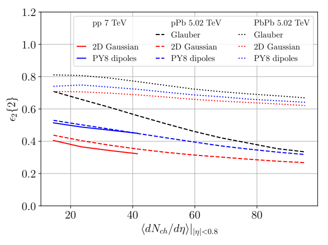
$$T(\vec{b}) = 1 - \exp\left(-\sum f_{ij}\right), \sigma_{tot} = \int d^2\vec{b}\, 2T(\vec{b})$$

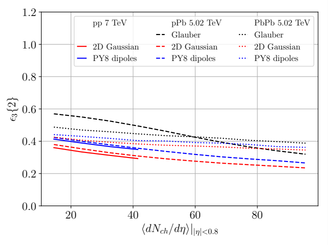




Geometry in pp, pA and AA

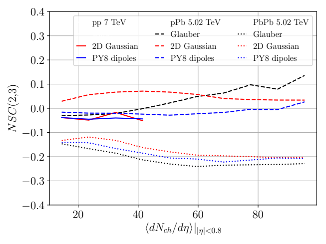
- Assuming $\epsilon_{2,3} \propto v_{2,3}$.
- Dipole model: $\epsilon_{2,3}$ equal for pp and pPb.

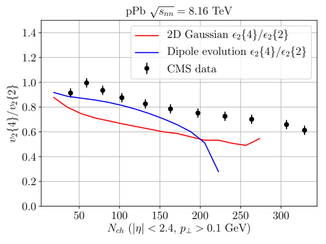




Flow fluctuations: Looking inside

- Flow fluctuations and normalized symmetric cumulants.
- Best discrimination in pPb.
- Dipole evolution → negative $NSC(2,3)$ in pPb.

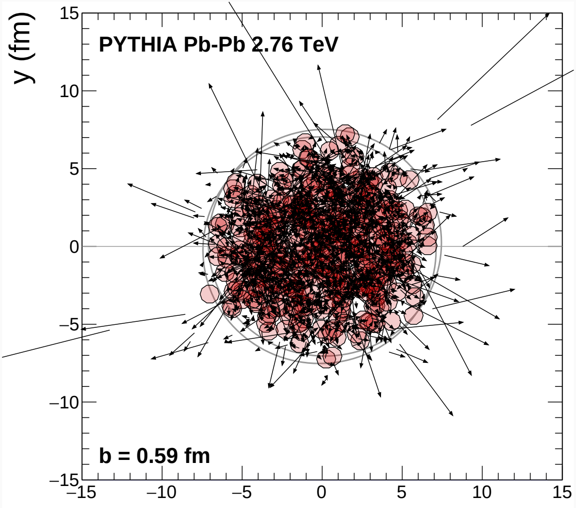




- *Important to develop realistic initial states.*
- *Point stands also for hydro.*

Final state interactions in AA (CB, D. D. Chinellato, A. Vieira, J. Takahashi: in prep.)

- Hadronic final state interactions matters in AA.
- Especially in non-fluid scenario, with short times.
- Pythia/Angantyr + URQMD.



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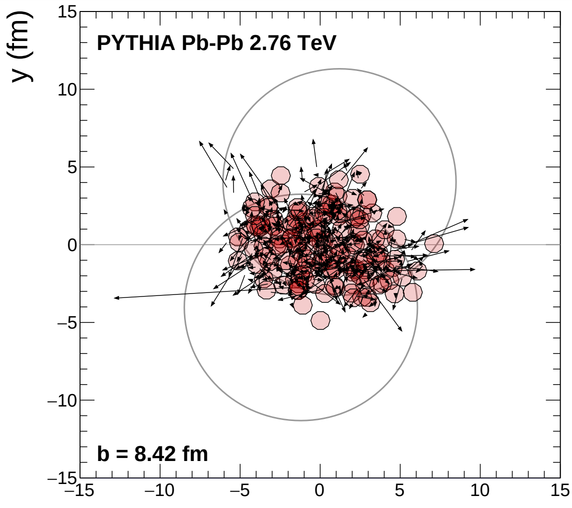

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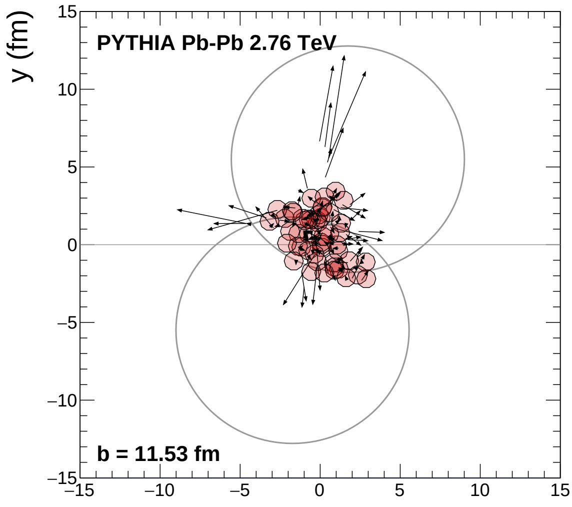
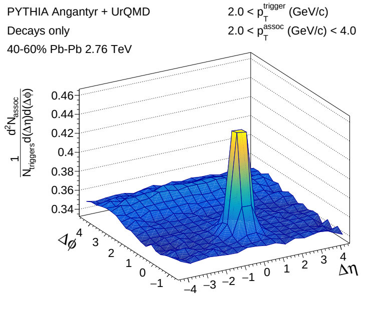
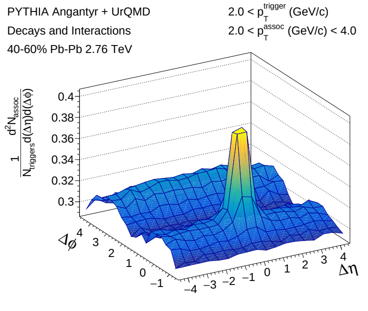


Results – flow

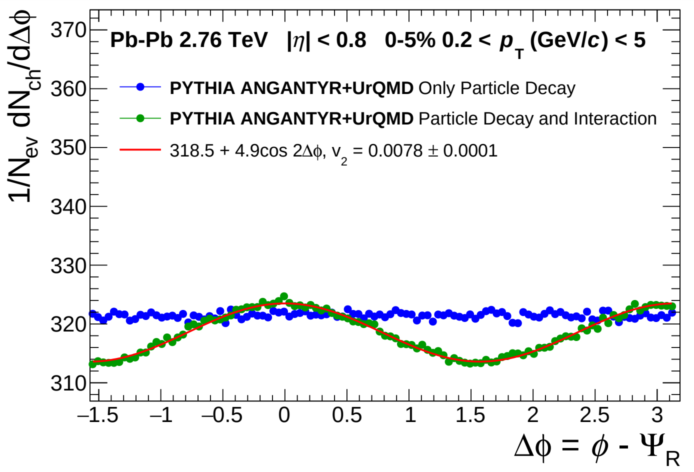
- Rescattering produces correlations long-range in η (the double ridge).
- Previously seen, but not at these energies, with general purpose MC input (Bleicher *et al.* arXiv:nucl-th/0602009).





Results – flow

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



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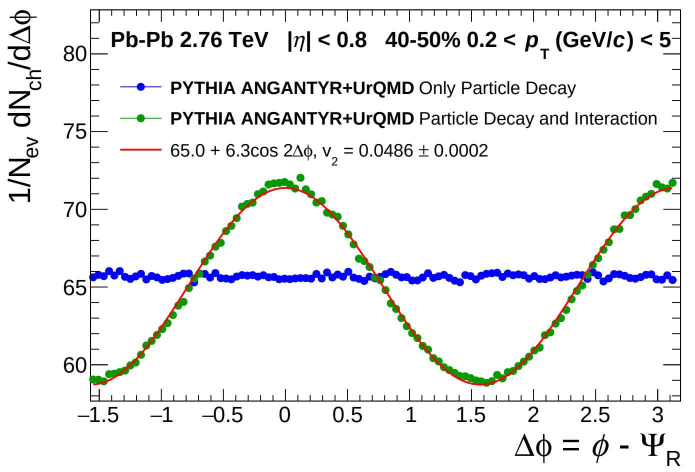

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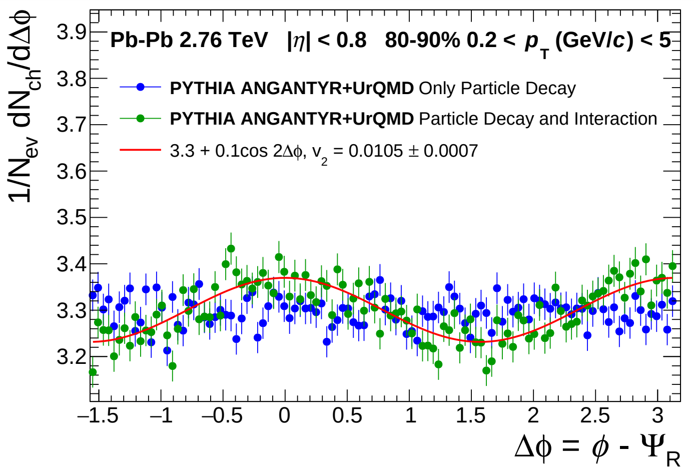
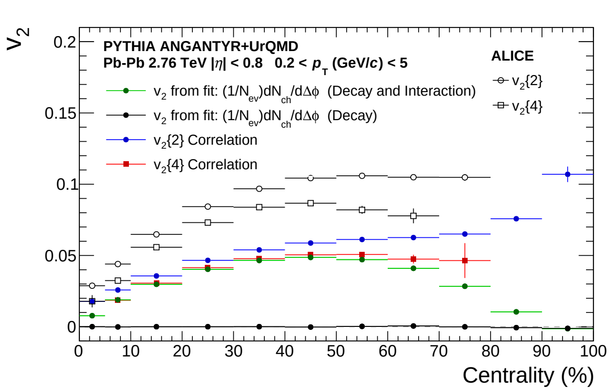


Results – elliptic flow coefficients

- 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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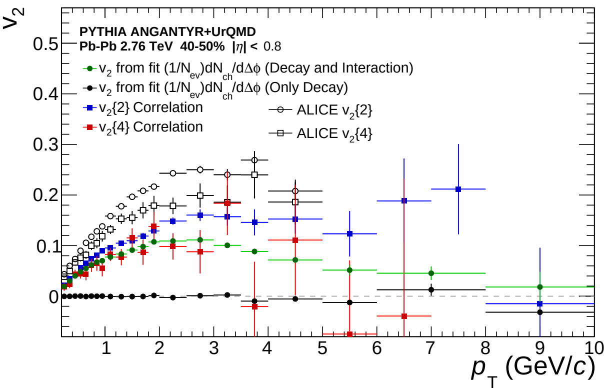

- Similar conclusion from $v_2(p_\perp)$

Summary

- Efforts to build plasma-free simulations.
- Two possible outcomes:
  1. A plasma-free background improves model comparisons.
  2. Less room for a QGP phase?
- Importance of the initial stage cannot be understated.
- ... at least if we are seeing a response to geometry.
- New developments:
  1. Remove some *ad hoc* elements.
  2. UPCs and EICs interesting new grounds!
- Final state rescatterings modifies observables.
- Any way of making a distinction between URQMD and QGP?

Have a great conference!