Unterstützt von / Supported by

Alexander von Humboldt
Stiftung / Foundation

Initial State Fluctuations at RHIC and LHC: Hadronic or Partonic Origin?

Quark Matter 2011, Annecy, France

05/26/2011

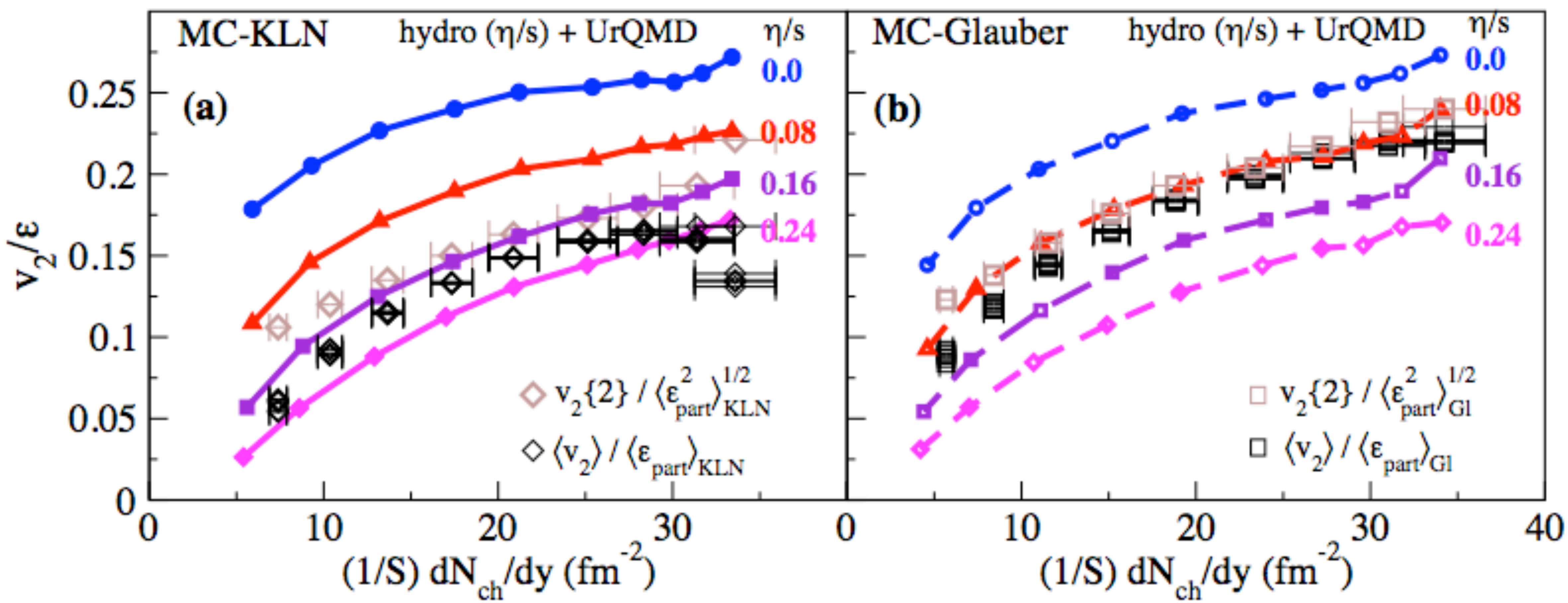
Hannah Petersen

Phys.Rev. C82 (2010) 041901
J. Phys. G 38 (2011) 045102
arXiv: 1105.0340
arXiv: 1105.1766

Thanks to: Guang-You Qin, Steffen A. Bass, Berndt Mueller, Vivek Batthacharya, Christopher Coleman-Smith (poster today on board #7)

Motivation

Elliptic flow from viscous hydrodynamics+hadron transport



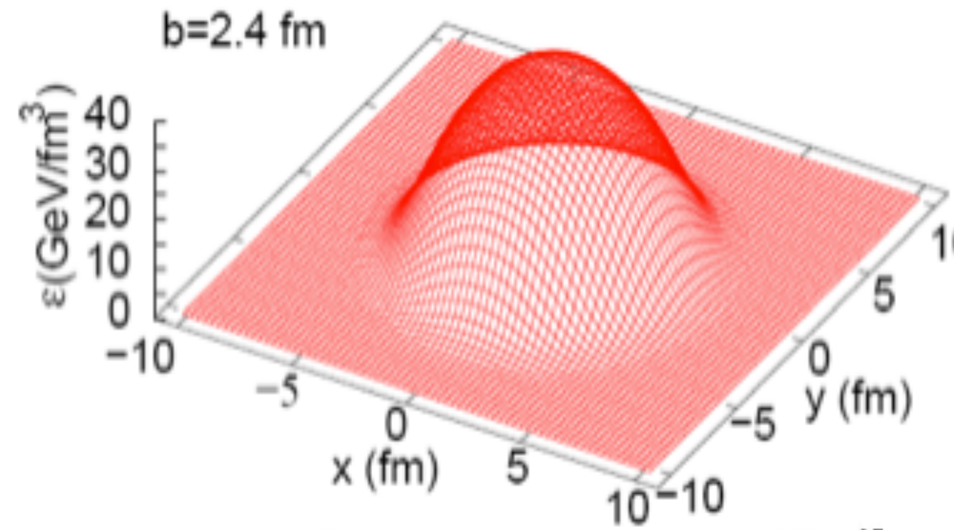
H.Song et al, PRL 106, 192301 (2011)

- Different initial conditions ~ factor of 2 difference in η/s
→ Major **uncertainty** to constrain transport coefficients in the quark gluon plasma

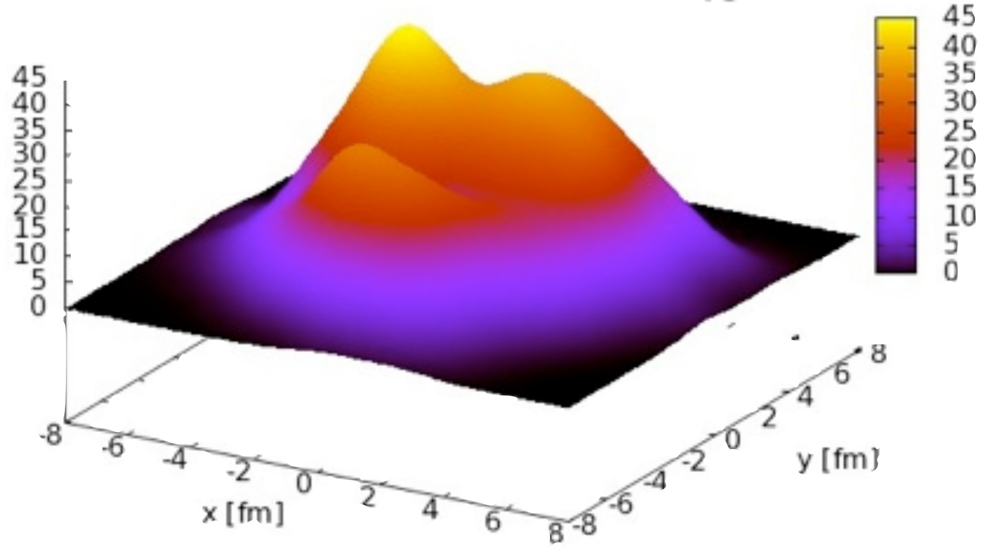
Sources of Fluctuations

- Density profiles are not smooth, but there are **local peaks** in transverse and longitudinal direction
- **Impact parameter** fluctuations within one specific centrality class, multiplicity fluctuations and differences in initial geometry
- Event plane **rotation** with respect to reaction plane in the laboratory

→ All these effects are **averaged out** if assuming a smooth symmetric initial density profile



C. Nonaka and S.A. Bass, PRC 75, 014902, 2007



J.Steinheimer et al., PRC 77,034901,2008

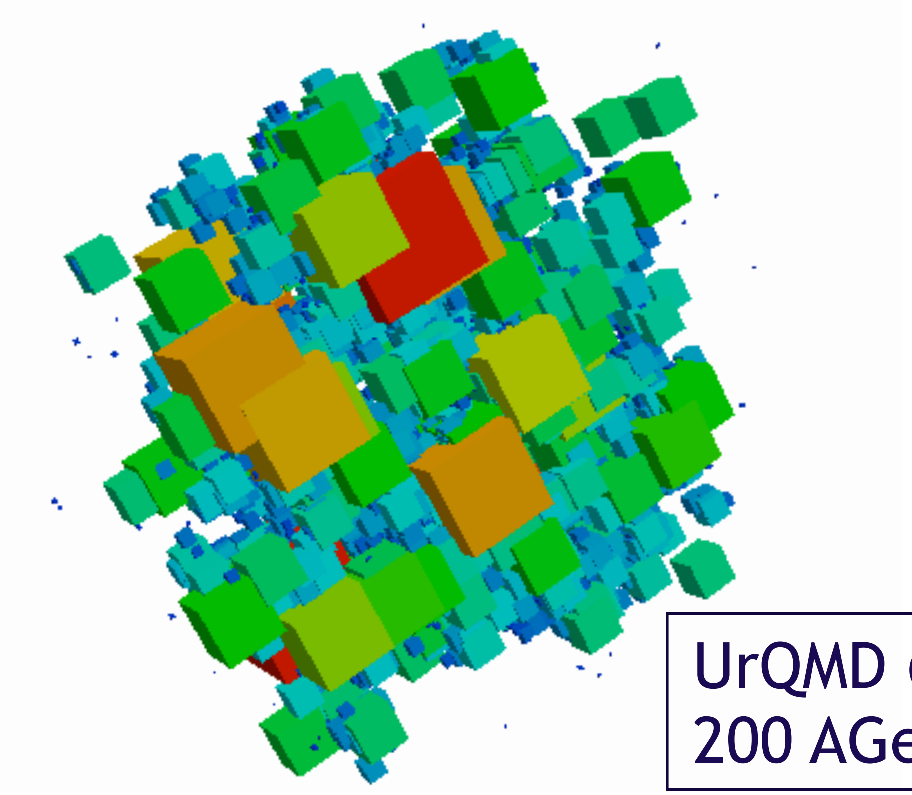
Included in dynamical models of the initial state (e.g. a parton cascade, NEXUS/EPOS, UrQMD) or in Glauber or CGC Monte Carlo approaches

Initial Conditions from Dynamical Approaches

- The **initial $T^{\mu\nu}$** for hydrodynamics has to be given via:

$$\epsilon(x,y,z),\ p(x,y,z)\ \text{and}\ n(x,y,z)$$

- **Energy deposition** model needs to describe final dE_T/dy in p-p and A-A correctly
- Granularity is influenced by
  - Shape of the incoming nuclei
  - Distribution of binary collisions
  - Interaction mechanism
  - Degree of thermalization

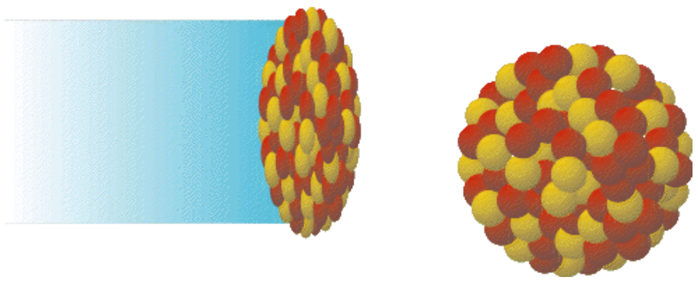

UrQMD @ 200 AGeV

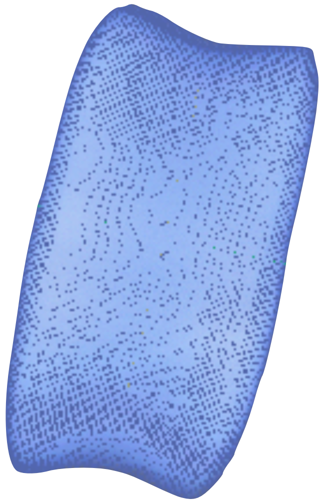
- Differences in **shape** and **fluctuations** need to be quantified
  – First attempt: use **higher** Fourier coefficients

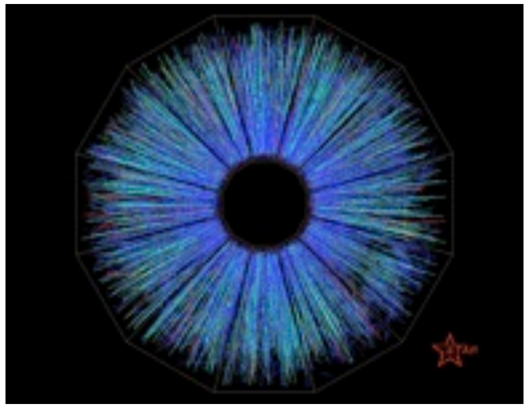
Hybrid Approach

- Use advantages of **transport** and **hydrodynamics** and create combined model
- Modular Setup: Fix the hydro evolution and freeze-out

  → learn something about the influence of different **initial conditions**







1) Non-equilibrium initial conditions via UrQMD

2) Hydrodynamic evolution

3) Freeze-out via hadronic cascade (UrQMD)

H.P. et al., PRC 78:044901, 2008

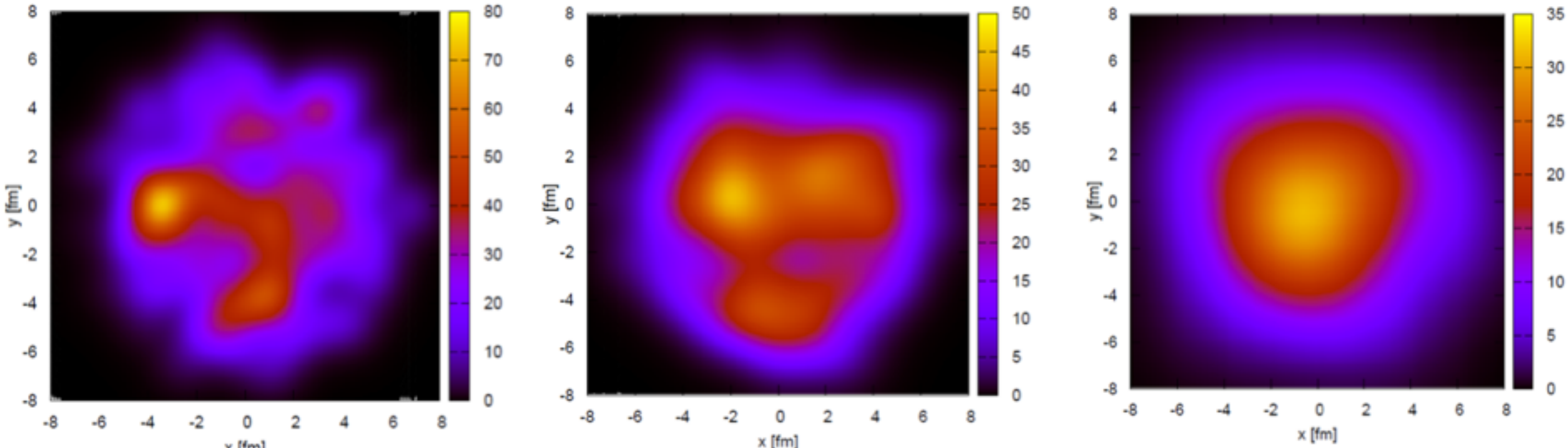
UrQMD-3.3p1 is available at http://urqmd.org

Initial State at RHIC

- Energy-, momentum- and baryon number densities are mapped onto the hydro grid using for each particle

$$\epsilon(x,y,z) = \left(\frac{1}{2\pi}\right)^{\frac{3}{2}} \frac{\gamma_z}{\sigma^3} E_p \exp - \frac{(x-x_p)^2 + (y-y_p)^2 + (\gamma_z(z-z_p))^2}{2\sigma^2}$$

- Main parameters are σ and t_{start}



σ = 0.8 fm

σ = 1.0 fm

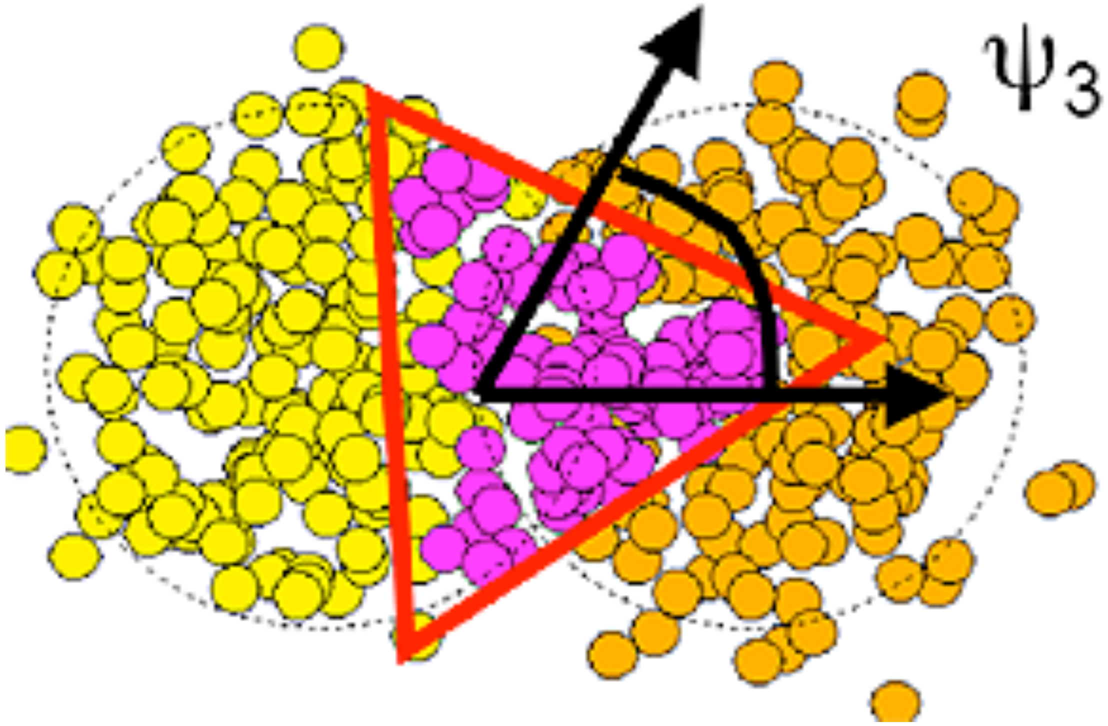
σ = 2.0 fm

H.P. et al, PRC 83, 014916, 2011 and JPG 38, 045102, 2011

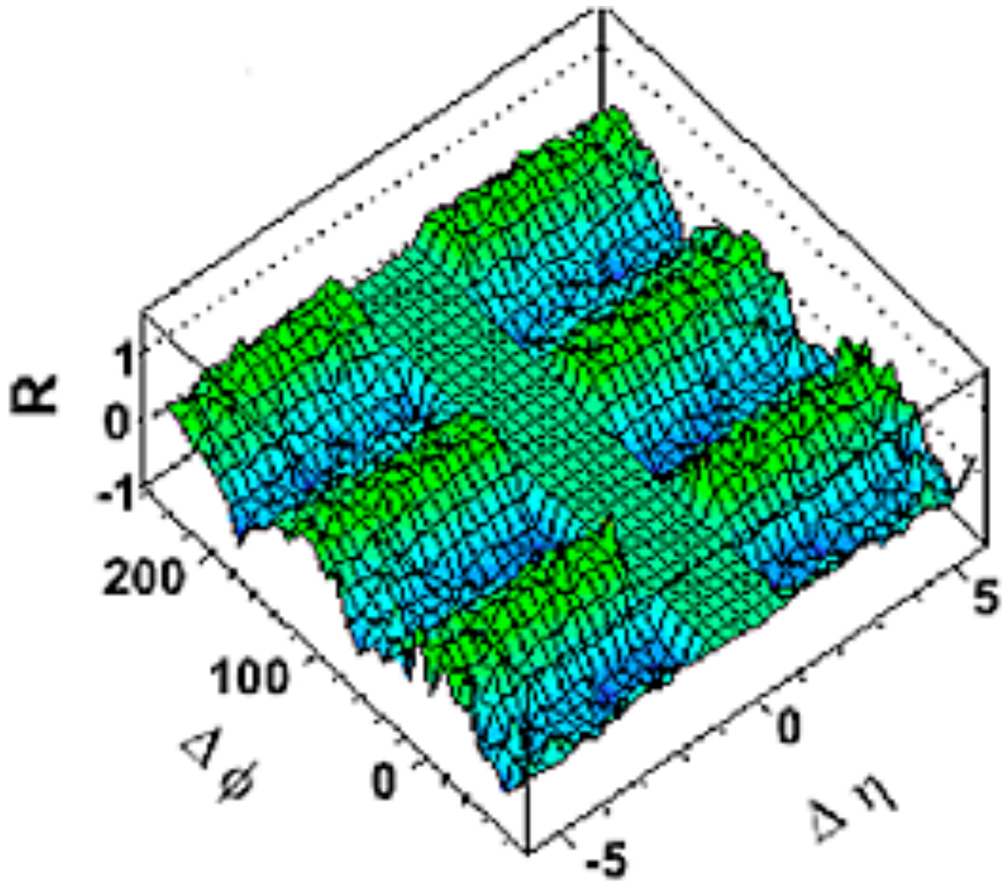
- To fit yields and elliptic flow: $\sigma \sim 1$ fm and $t_{start} \sim 0.5$ fm

Triangular Flow

Initial State Fluctuations



Third Harmonic Coefficient

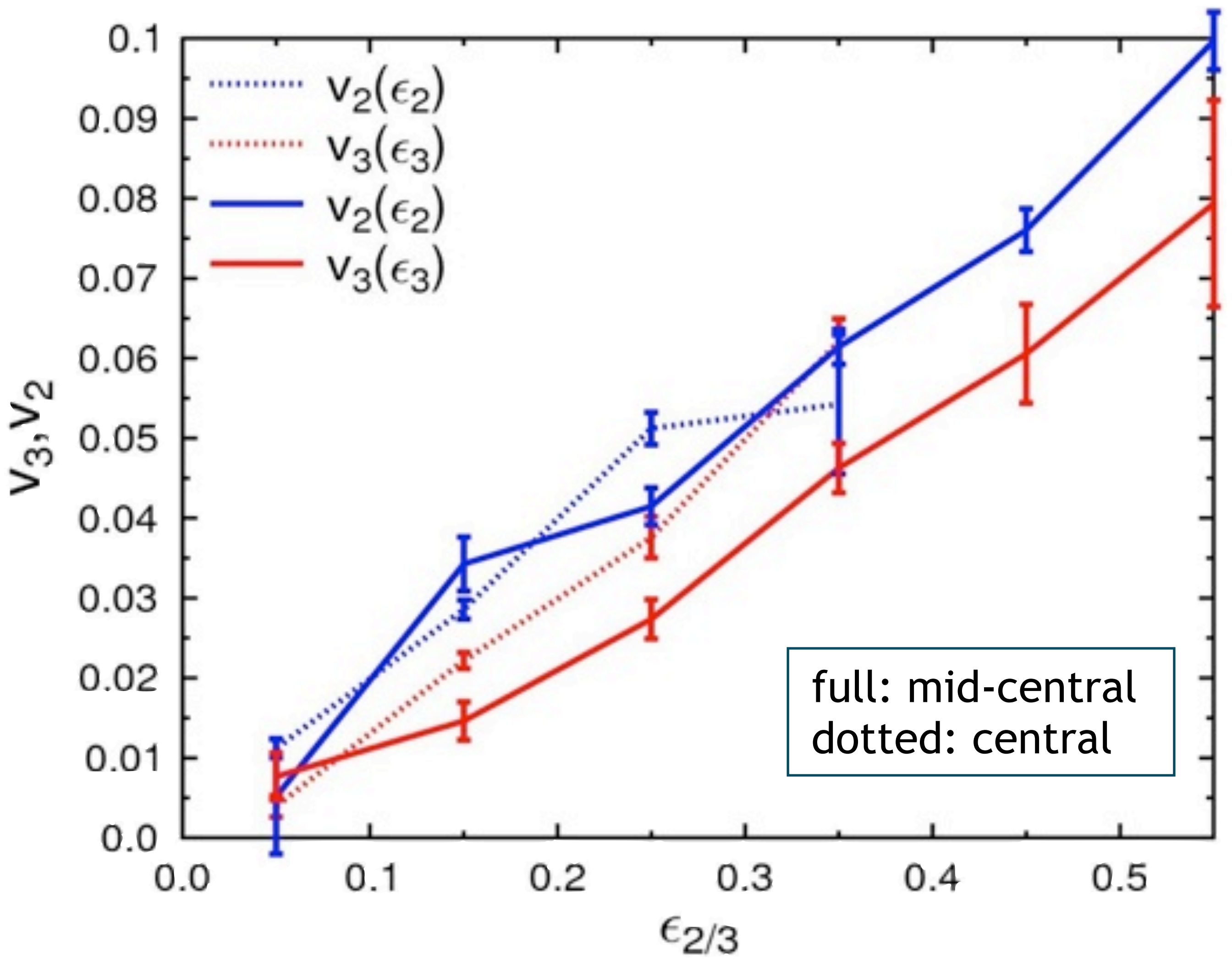


INT Workshop Seattle, 2010, B. Alver

- Collective hydrodynamic behaviour
- Responsible for most of the structures in two-particle angular correlation data?
- Without fluctuations the odd coefficients are zero

Earlier studies: NEXspheRIO, PRL 103,242301, 2009; P. Sorensen, JPG, 37, 094011,2010

From Initial to Final State



- v_n and ε_n and initial and final event plane angles are correlated on an **event-by-event** basis
- Confirms collective behaviour

Initial State Coordinate Space Asymmetry

$$\Phi_n = \frac{1}{n}\arctan\frac{\langle r^n \sin(n\phi)\rangle}{\langle r^n \cos(n\phi)\rangle}$$

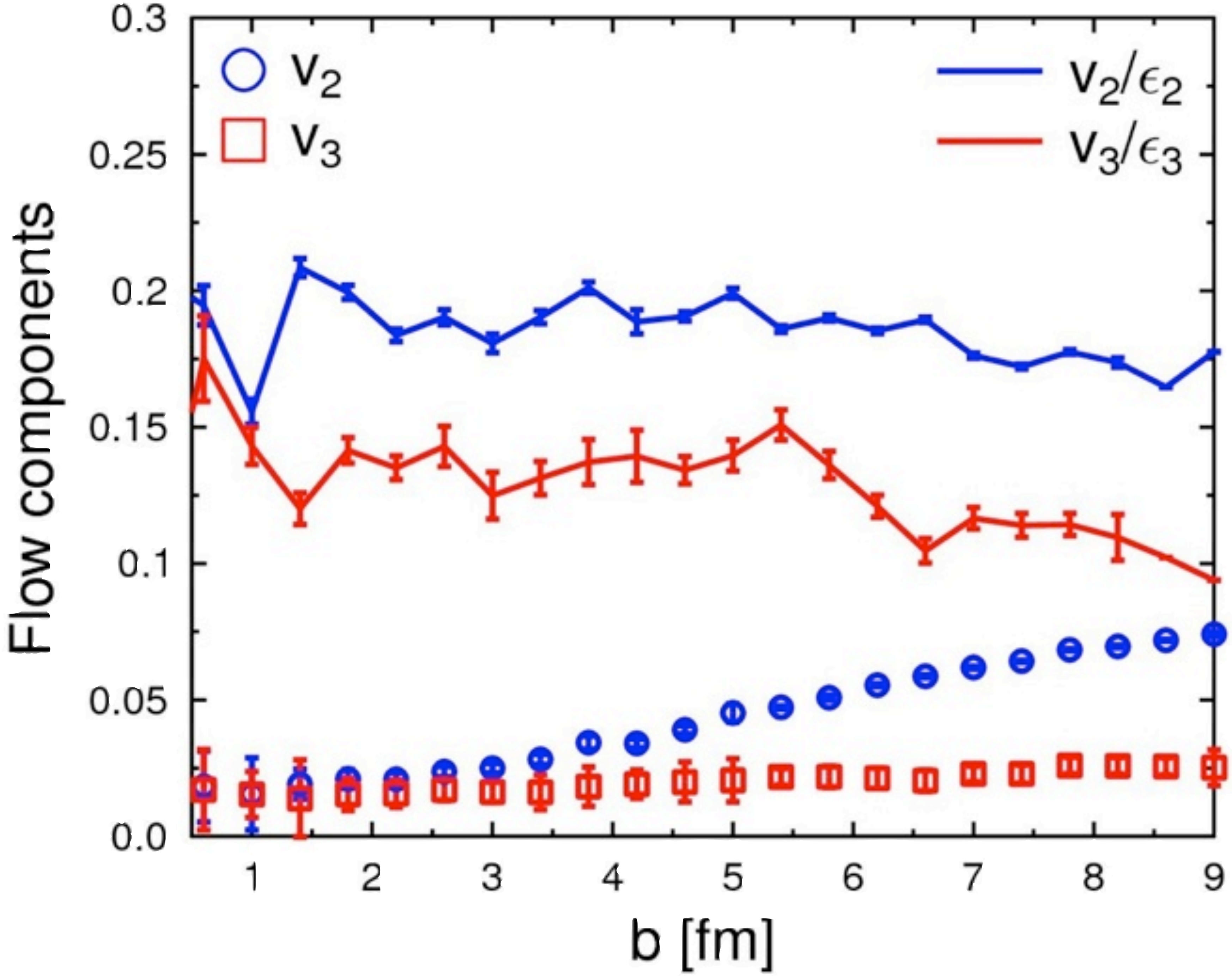
$$\epsilon_n = \frac{\sqrt{\langle r^n \cos(n\phi)\rangle^2 + \langle r^n \sin(n\phi)\rangle^2}}{\langle r^n \rangle}$$

Final State Momentum Space Asymmetry

$$\Psi_n = \frac{1}{n}\arctan\frac{\langle p_T \sin(n\phi_p)\rangle}{\langle p_T \cos(n\phi_p)\rangle}$$

$$v_n = \langle \cos(n(\phi_p - \Psi_n))\rangle$$

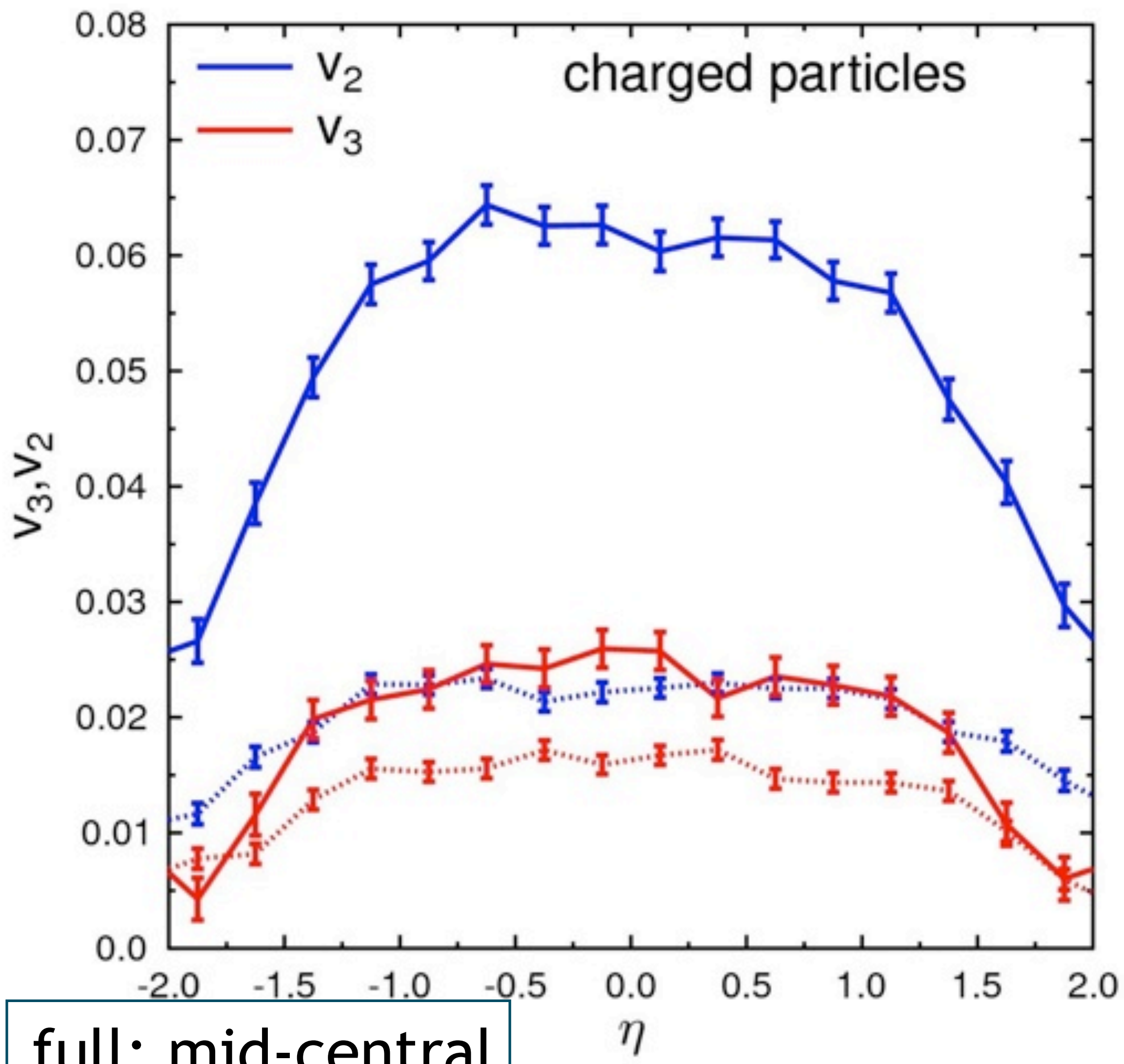
Centrality Dependence



- Hydrodynamic response **stronger** for elliptic flow
- Triangular flow exhibits only **weak** centrality dependence

Longitudinal Structure

Is this really a longitudinal long-range correlation?

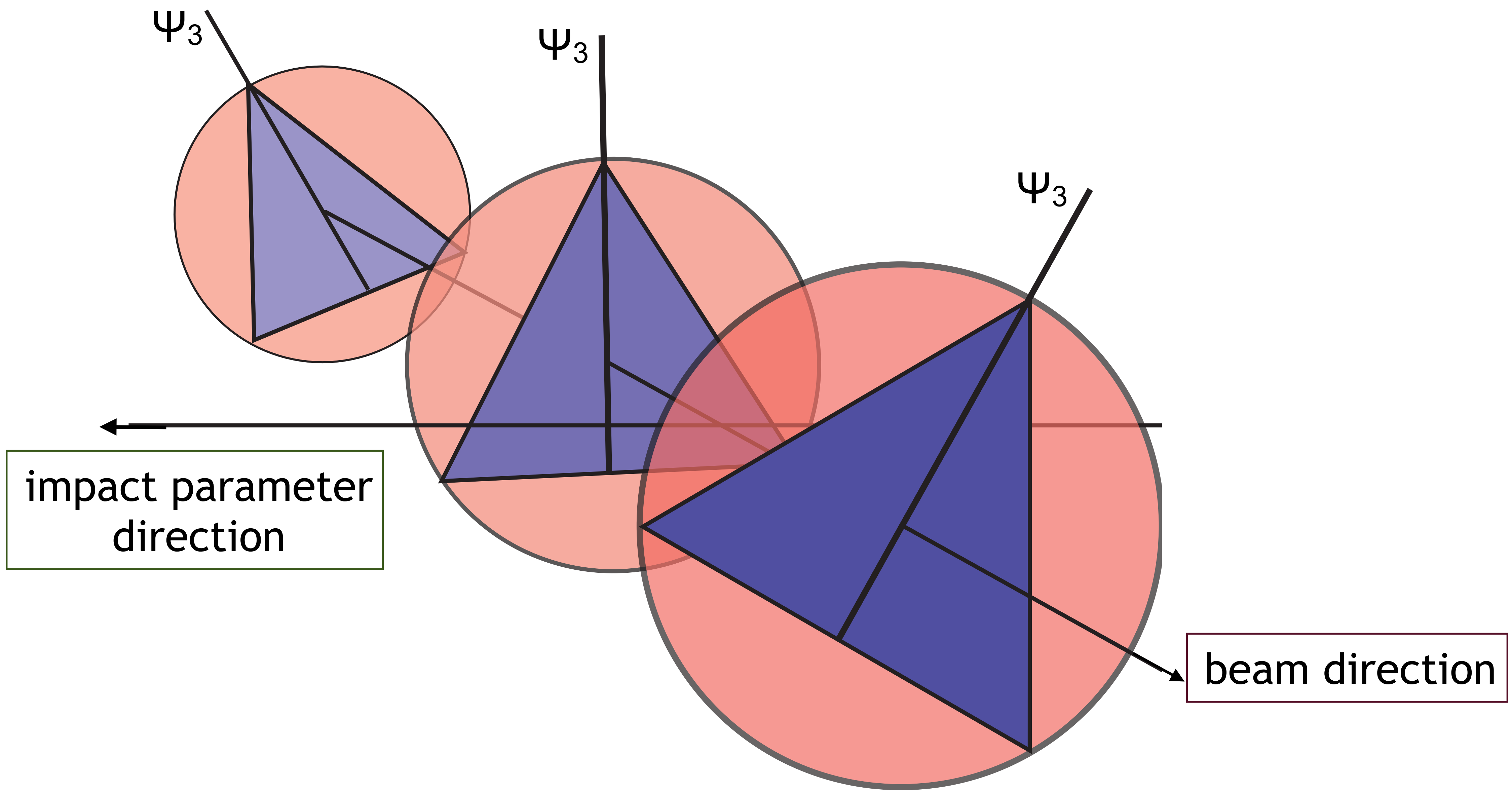


full: mid-central
dotted: central

- Idea: look at event plane angles in different rapidity **slices**
- Verify correspondence of initial to final state correlation in each bin
- Potential to distinguish **physics mechanisms** without calculating numerically expensive $\Delta\eta$-$\Delta\phi$ correlations
- New **observable** that could be measured

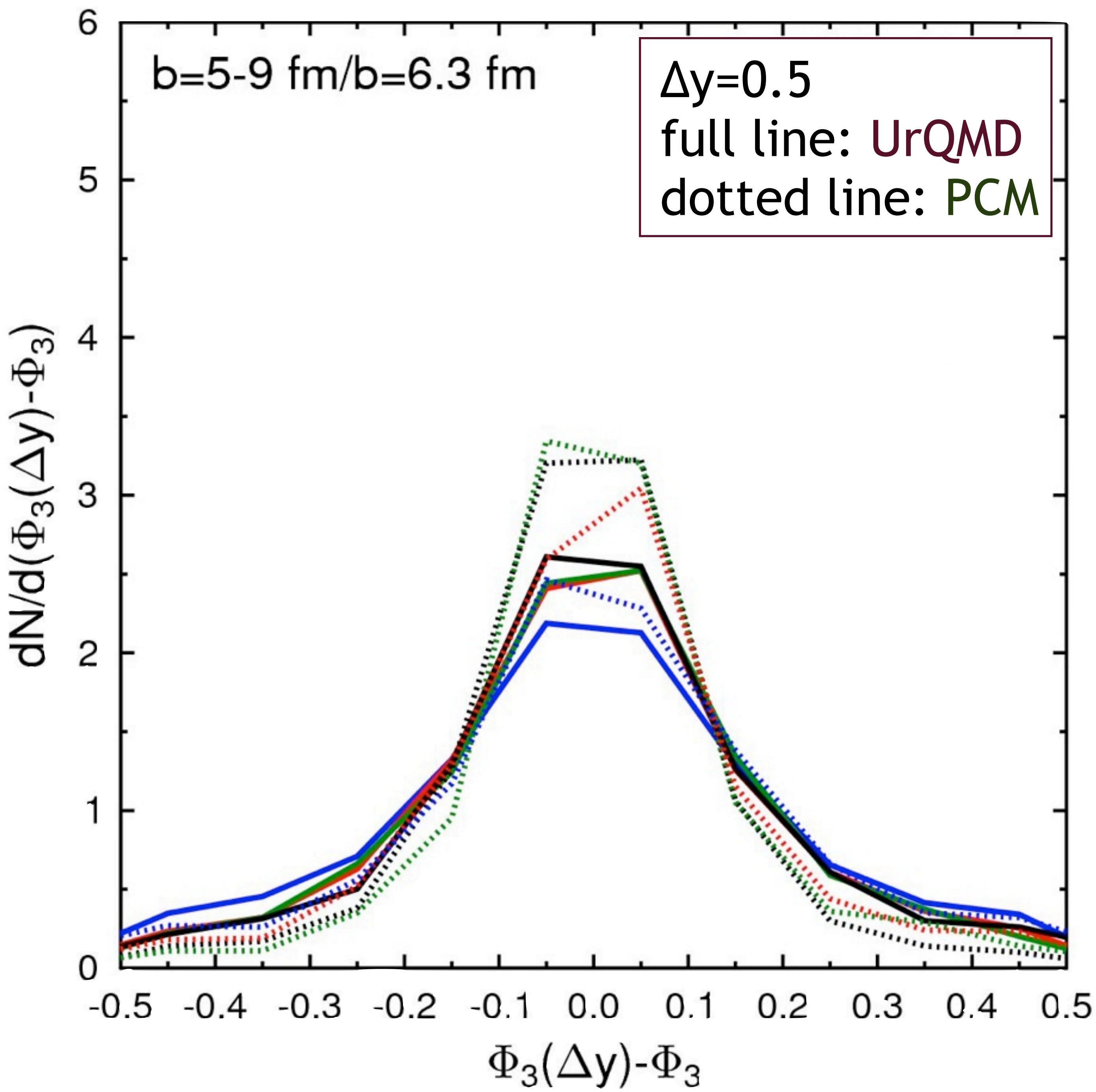
H.P. et al, arxiv:1105.0340, in collaboration with C. Greiner

Longitudinal Correlation



- Idea: look at event plane angles in different rapidity **slices**
- Important verification of the **event plane method** which relies on a single plane for the whole event

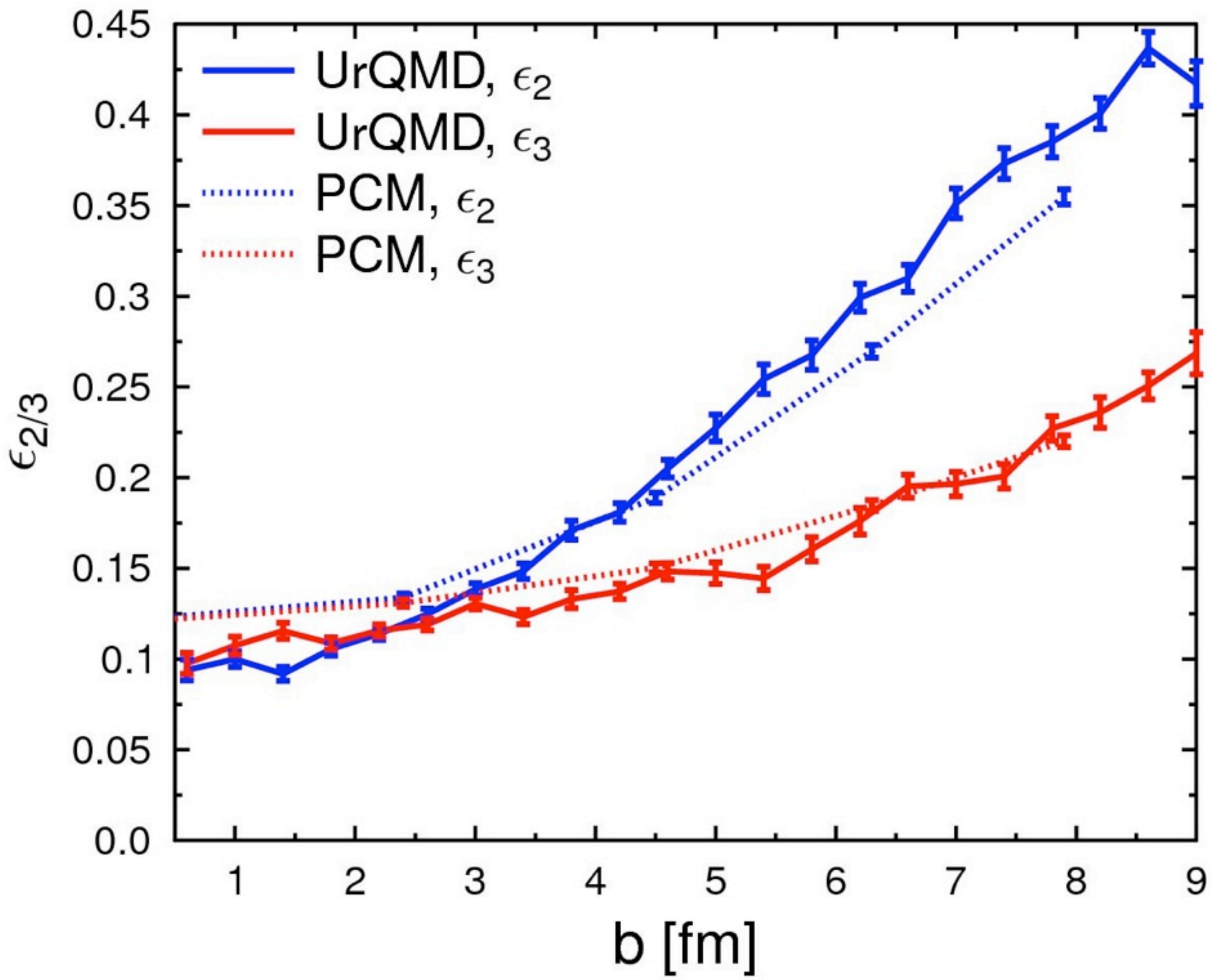
Longitudinal Correlation

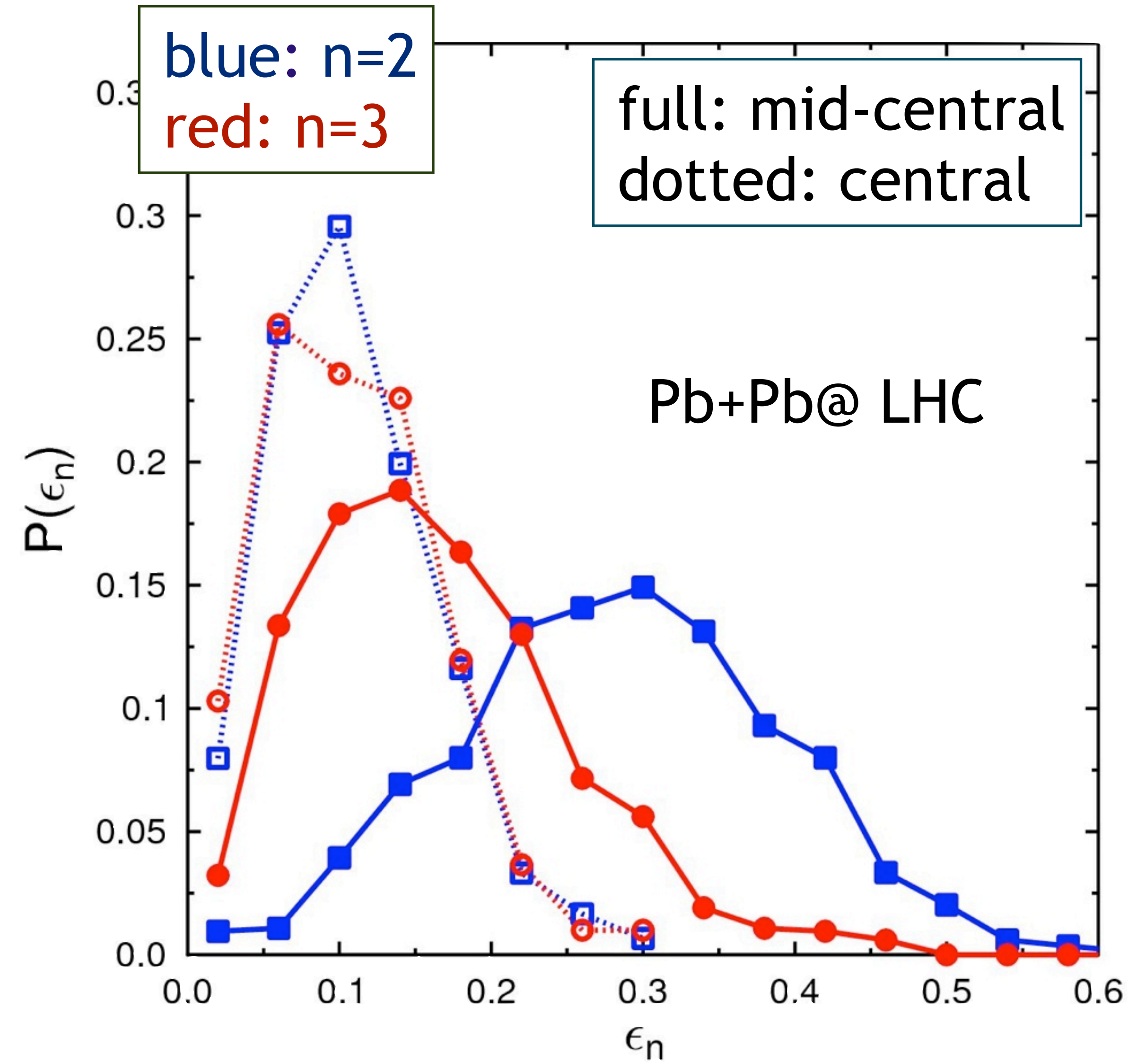


- **String** fragmentation and final state **radiation** produce long-range correlations
- Gets **smeared** out, but is still there in the final state
- Hadron and Parton cascade rely on mechanism based on **interactions**
- **CGC flux tubes** are an initial state feature in the incoming nuclei
- How can we distinguish these two scenarios?

H.P. et al, arXiv: 1105.0340

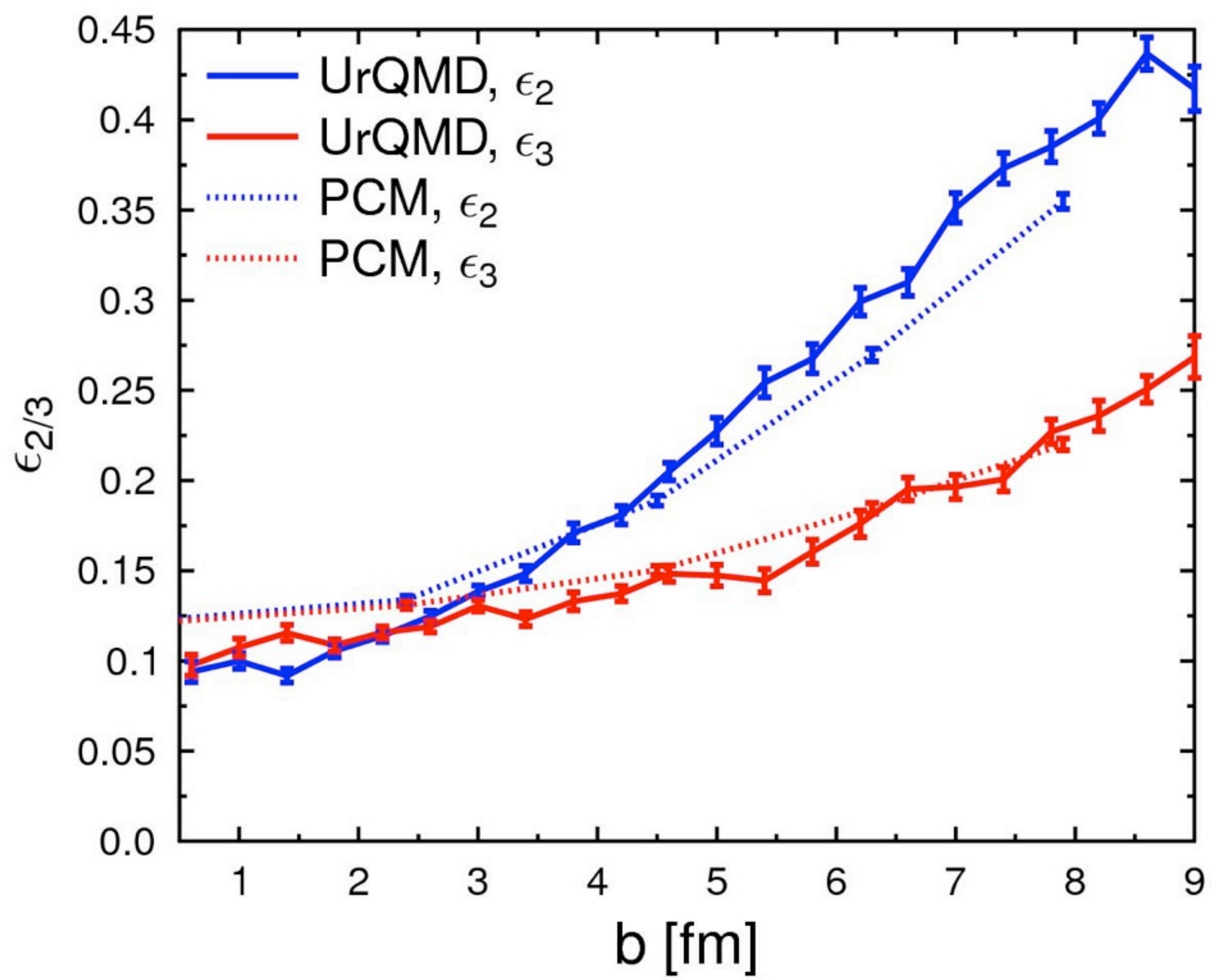
Eccentricity Distributions

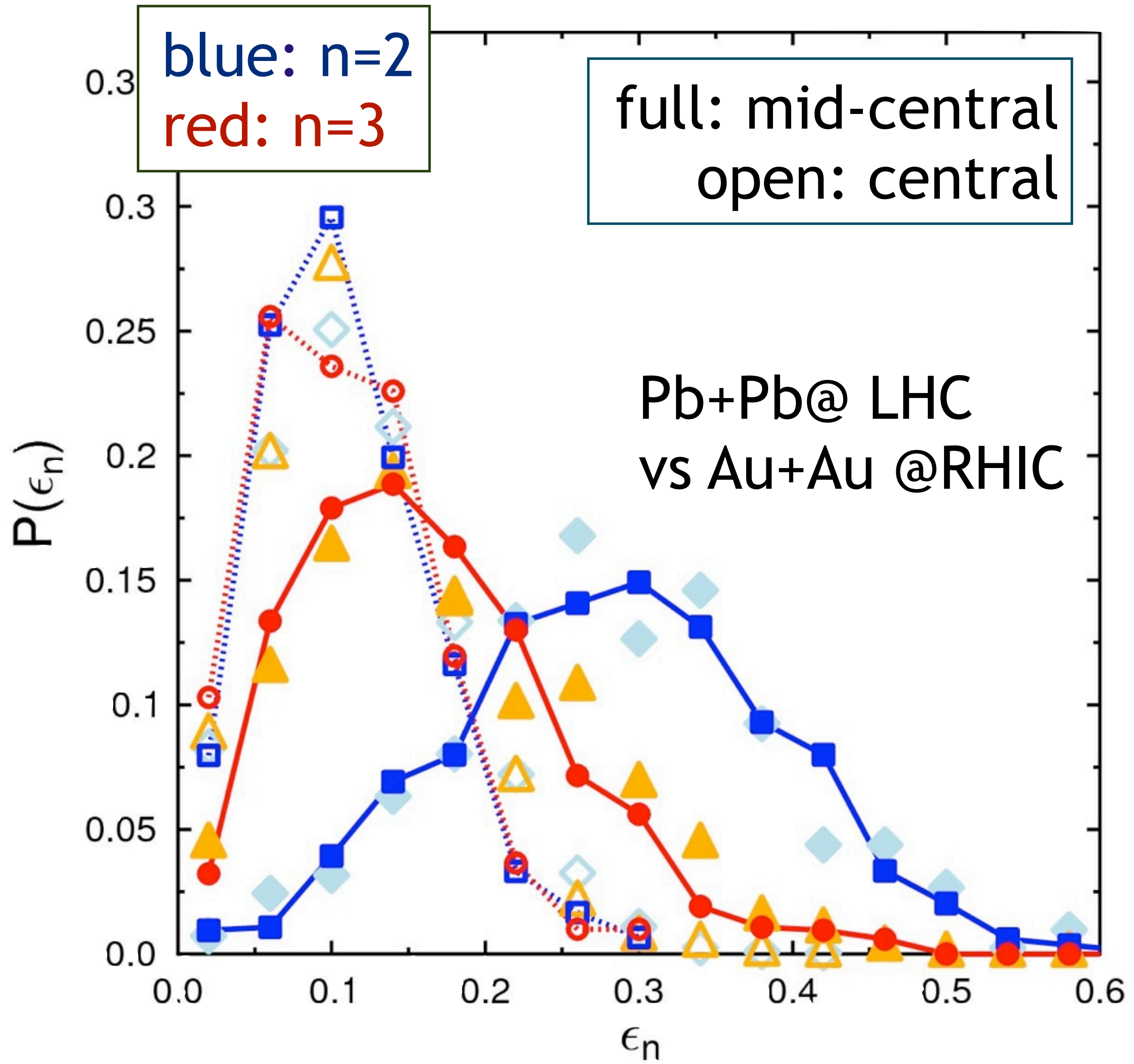




- Average eccentricity and triangularity have **similar** centrality dependence in parton and hadron cascade
- **Probability distribution** contains information about fluctuations

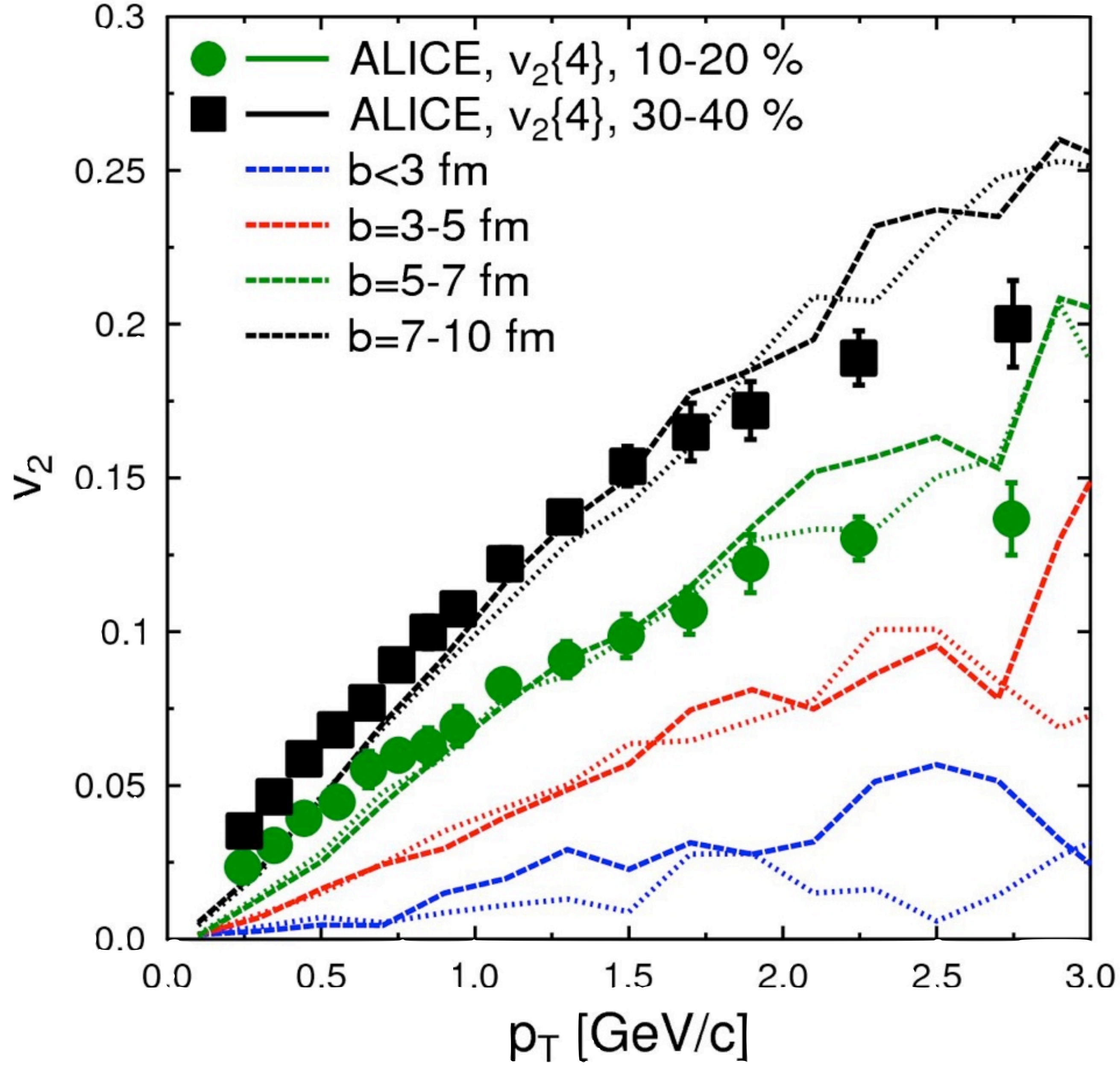
Eccentricity Distributions





- In UrQMD the whole probability distribution is almost **identical** at RHIC and LHC
- Geometry of overlap region does not change
- Higher multiplicity has no visible effect on fluctuations

Comparison to LHC data

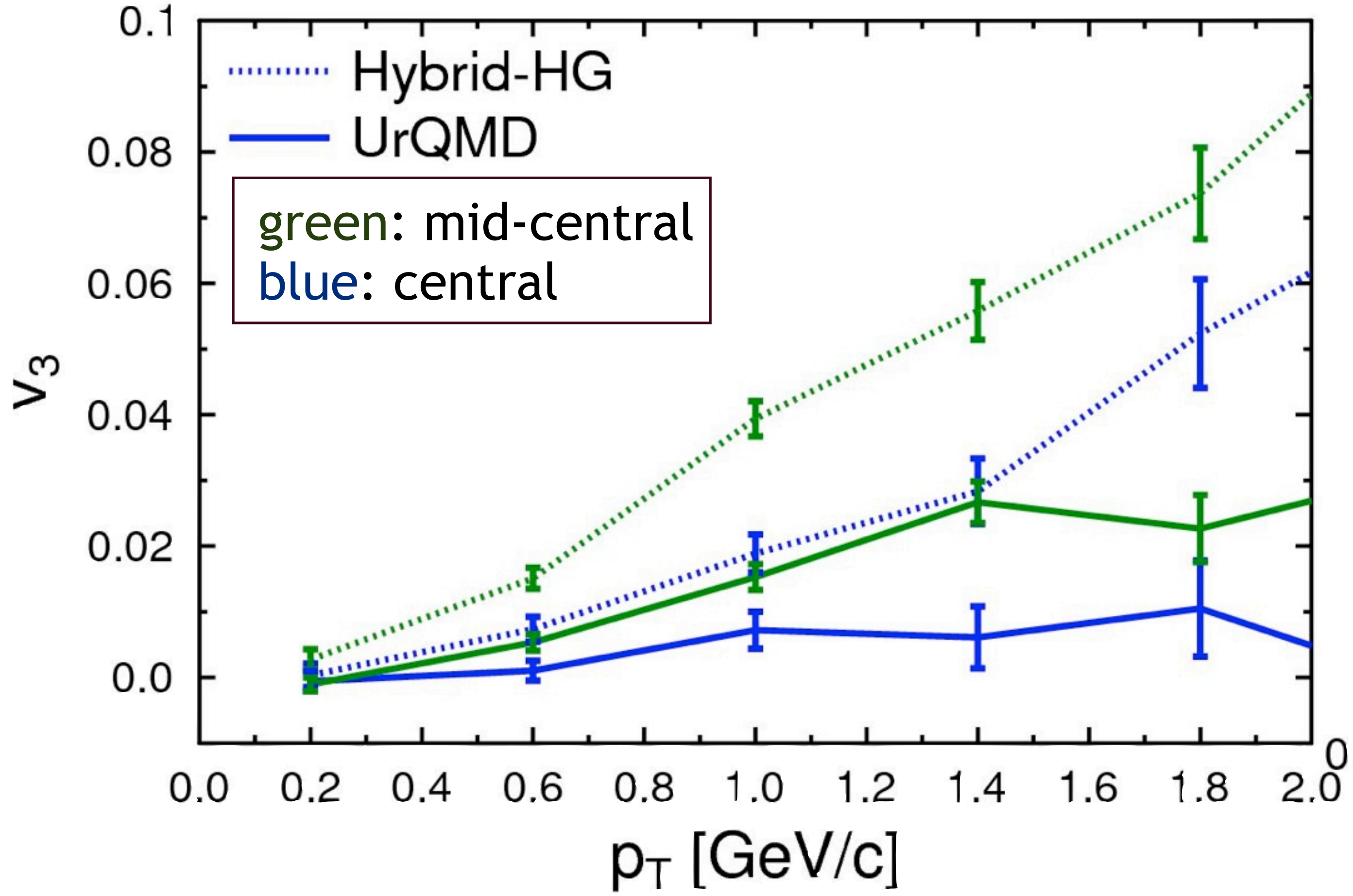


dashed line: DE-EoS
dotted line: HG-EoS

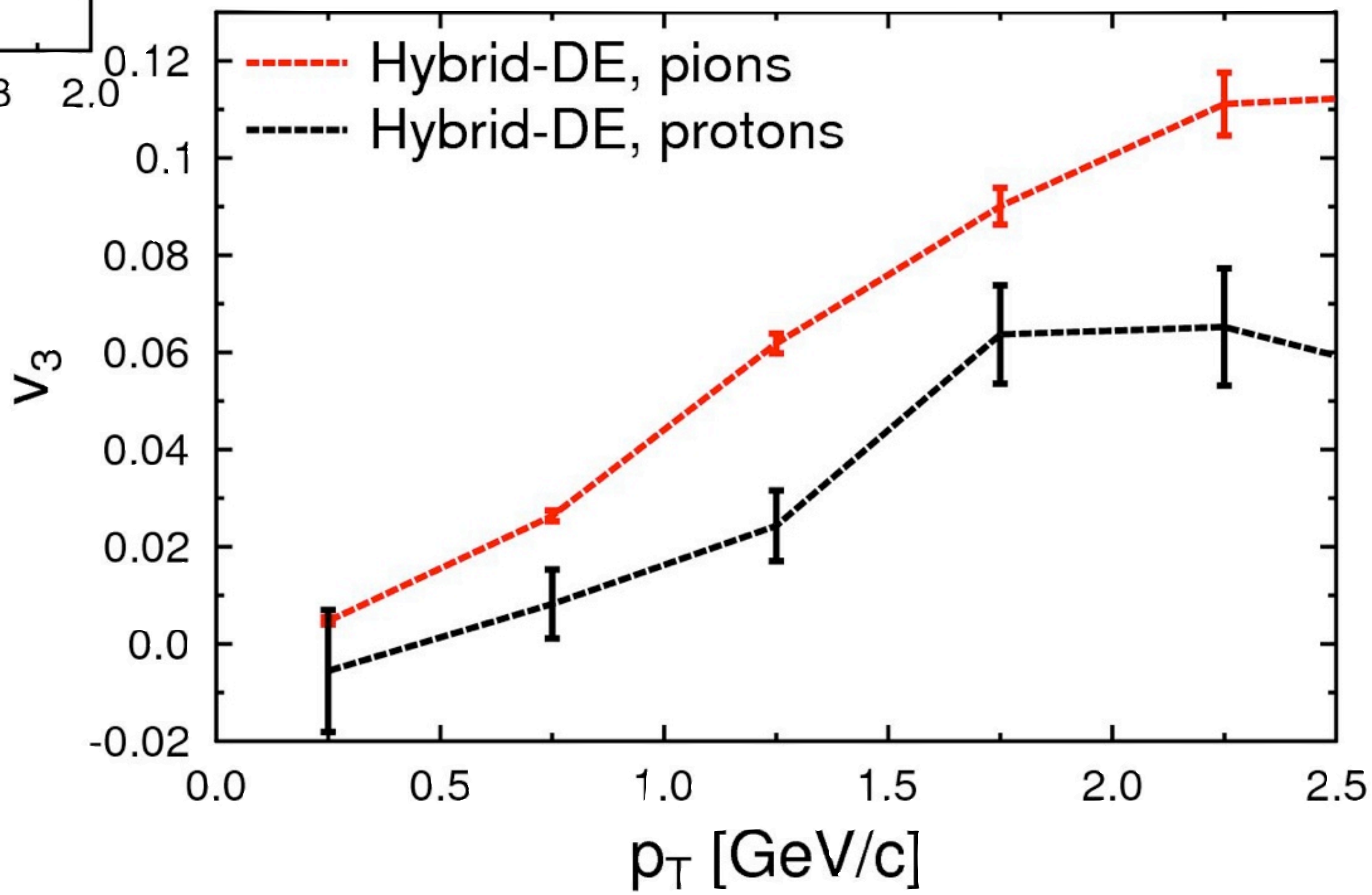
- Exact **same parameter** set as applied at RHIC
- Hybrid approach is in good **agreement** at low p_T
- Different **EoS** give similar results

H.P., arXiv: 1105.1766

Triangular Flow at LHC



- Triangular flow is almost **zero** in UrQMD
  → Very sensitive to viscosity
- Similar **magnitude** in hybrid compared to RHIC



- Minimum bias result for **identified** particles
- Mass splitting

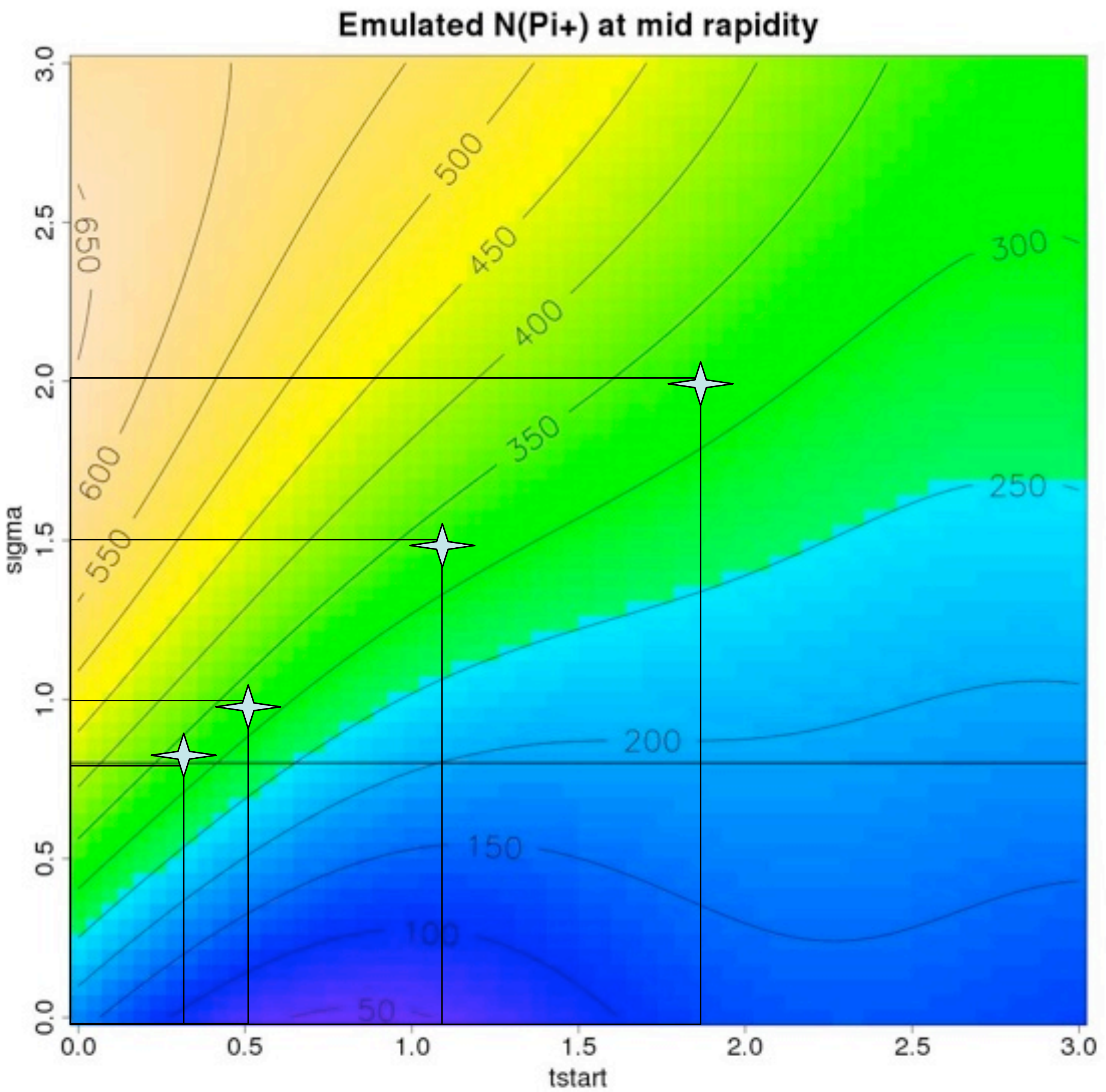
H.P., arXiv: 1105.1766

Conclusions

- Dynamic transport approaches provide **fluctuating initial conditions**
- Parameters for initial conditions can be **constrained** by looking at bulk observables as yields, spectra and elliptic flow
- **Triangular flow** only occurs if event-by-event fluctuations are included
- Triangular flow might be a good measure for initial state **granularity** (in addition to other correlation/fluctuation observables)
- **Longitudinal correlation** of event plane angles can also be generated by radiation processes in parton cascade
- LHC results from **event-by-event** hydro are similar to RHIC
- **Systematic** comparison of different initial state models is needed to draw quantitative conclusions

Backup

Parameter Sensitivity Tests

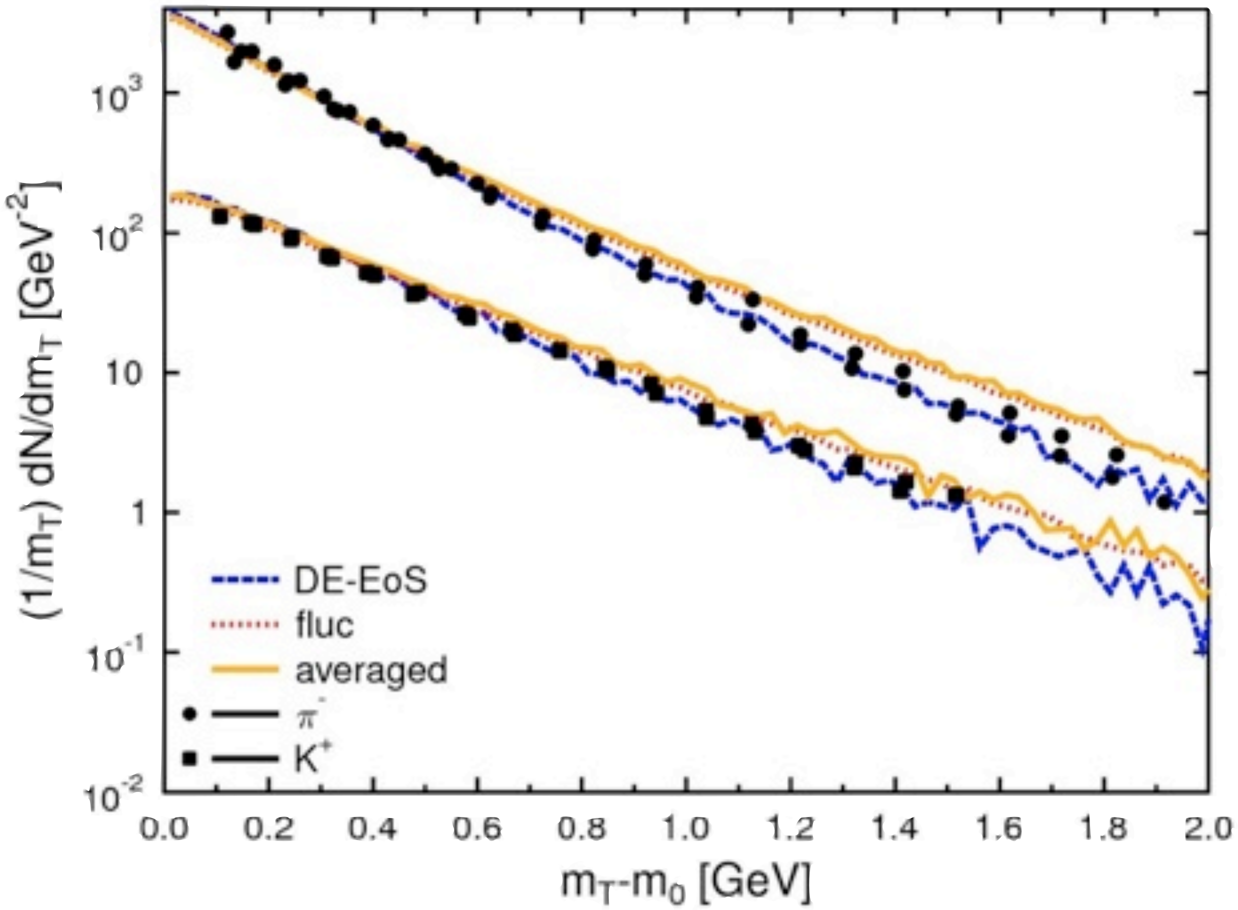


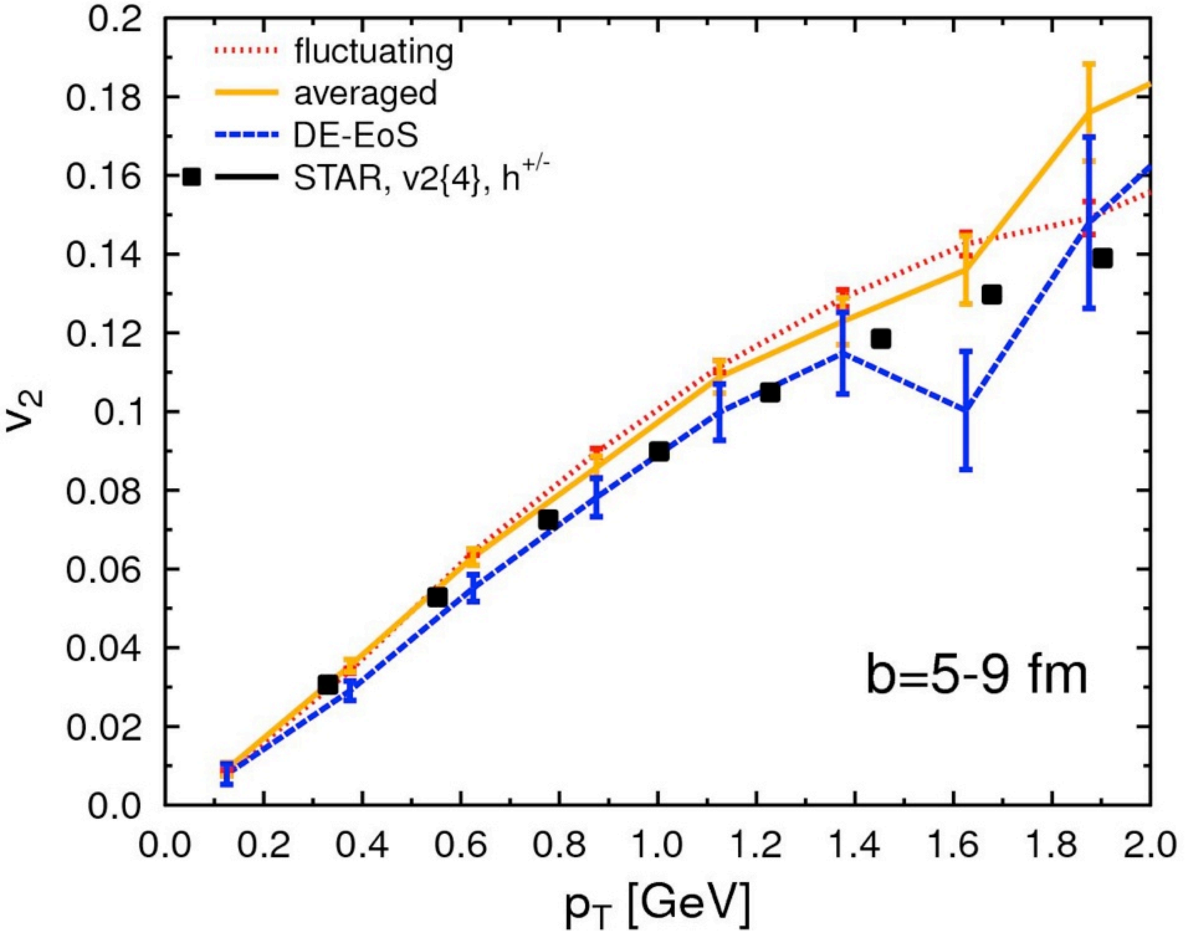
- Sophisticated statistical analysis
- **Emulator** predicts results of calculations for parameter sets by means of advanced statistics
- Number of pions in the t_{start}- σ plane

→ Determine reasonable **combinations** of parameters

Thanks to Chris Coleman-Smith, MADAI collaboration

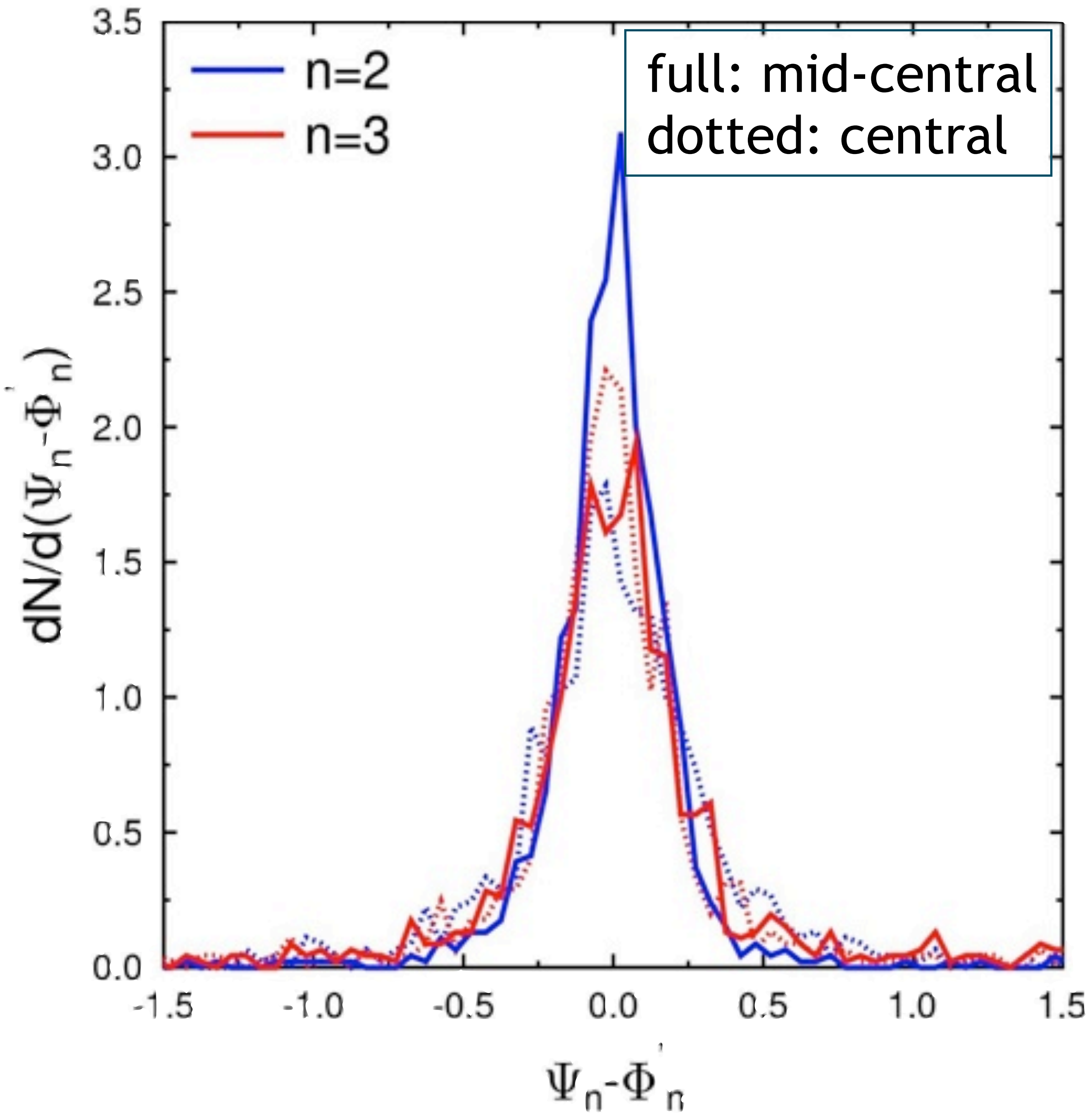
Averaged IC & Lattice EoS





- **Averaged** conditions give very similar results for spectra and elliptic flow see also H.P., M. Bleicher, PRC 81, 044906, 2010
- Realistic **equation of state:**
  - m_T spectra better reproduced
  - similar elliptic flow results
- **Freeze-out** procedure has to be improved (work in progress)

From Initial to Final State

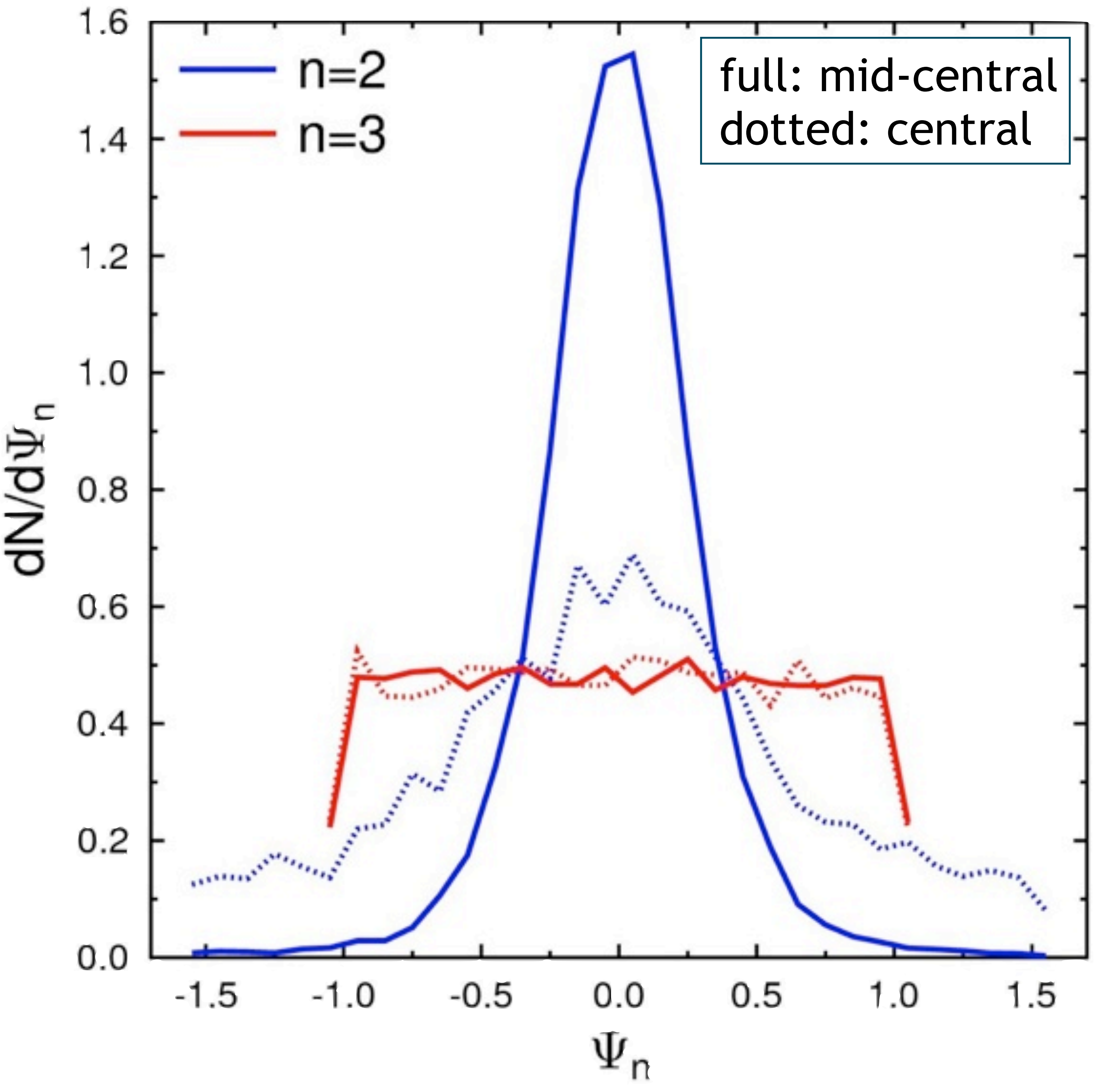


- Φ_n is calculated in **initial** coordinate space
- Ψ_n from **final** momentum space distribution
- There is a strong **correlation** between the two angles
- For elliptic flow stronger in more peripheral events

$$\Phi_n = \frac{1}{n}\arctan\frac{\langle r^n \sin(n\phi)\rangle}{\langle r^n \cos(n\phi)\rangle} \longrightarrow \Psi_n = \frac{1}{n}\arctan\frac{\langle p_T \sin(n\phi_p)\rangle}{\langle p_T \cos(n\phi_p)\rangle}$$

H.P. et al., PRC 82, 041901, 2010, arXiv:1008.0625

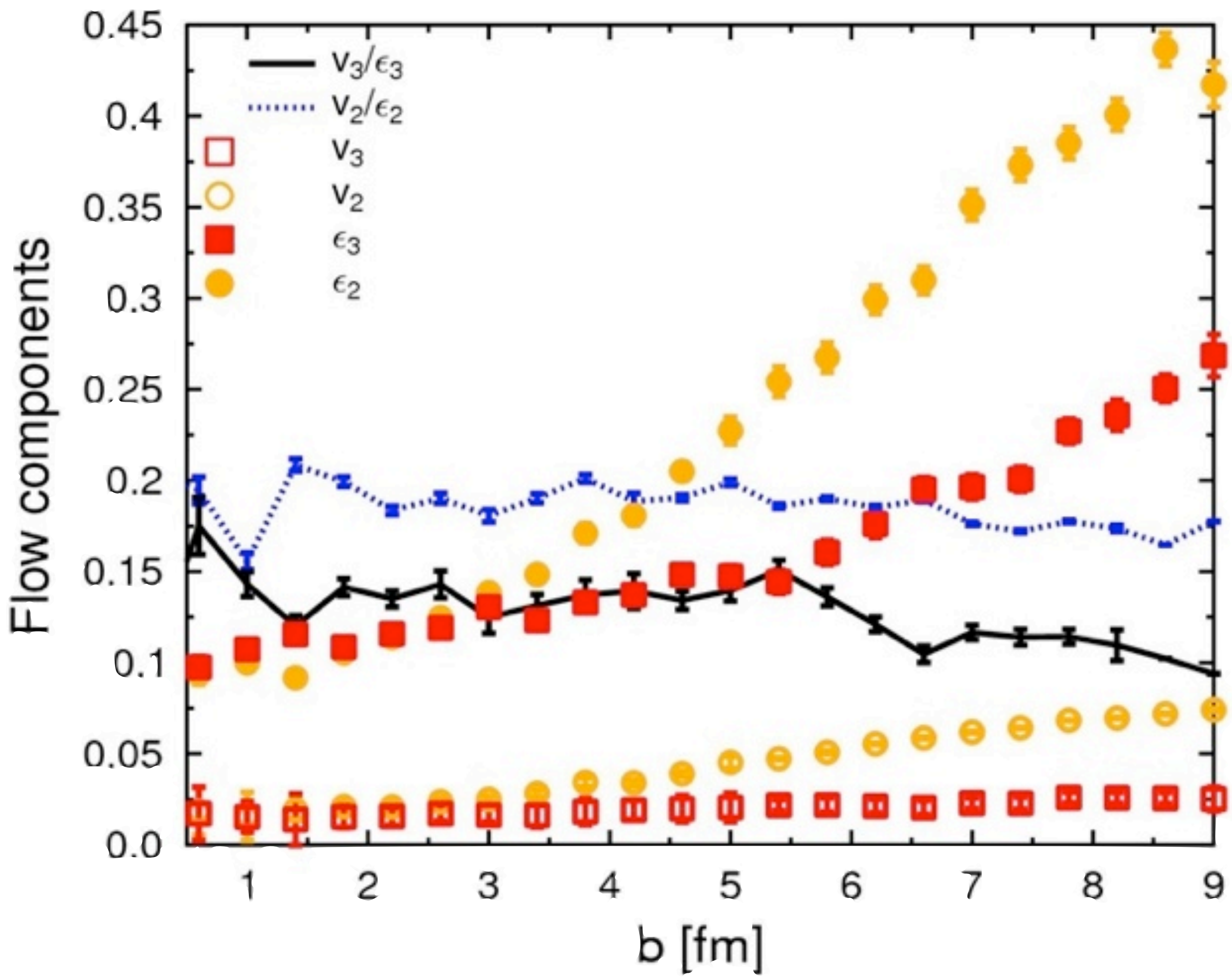
Event Plane Angles



- Ψ_2 is **correlated** to reaction plane
- Ψ_3 distribution is **flat**
- **Only** fluctuations, no geometry in contrast to elliptic flow where both are mixed

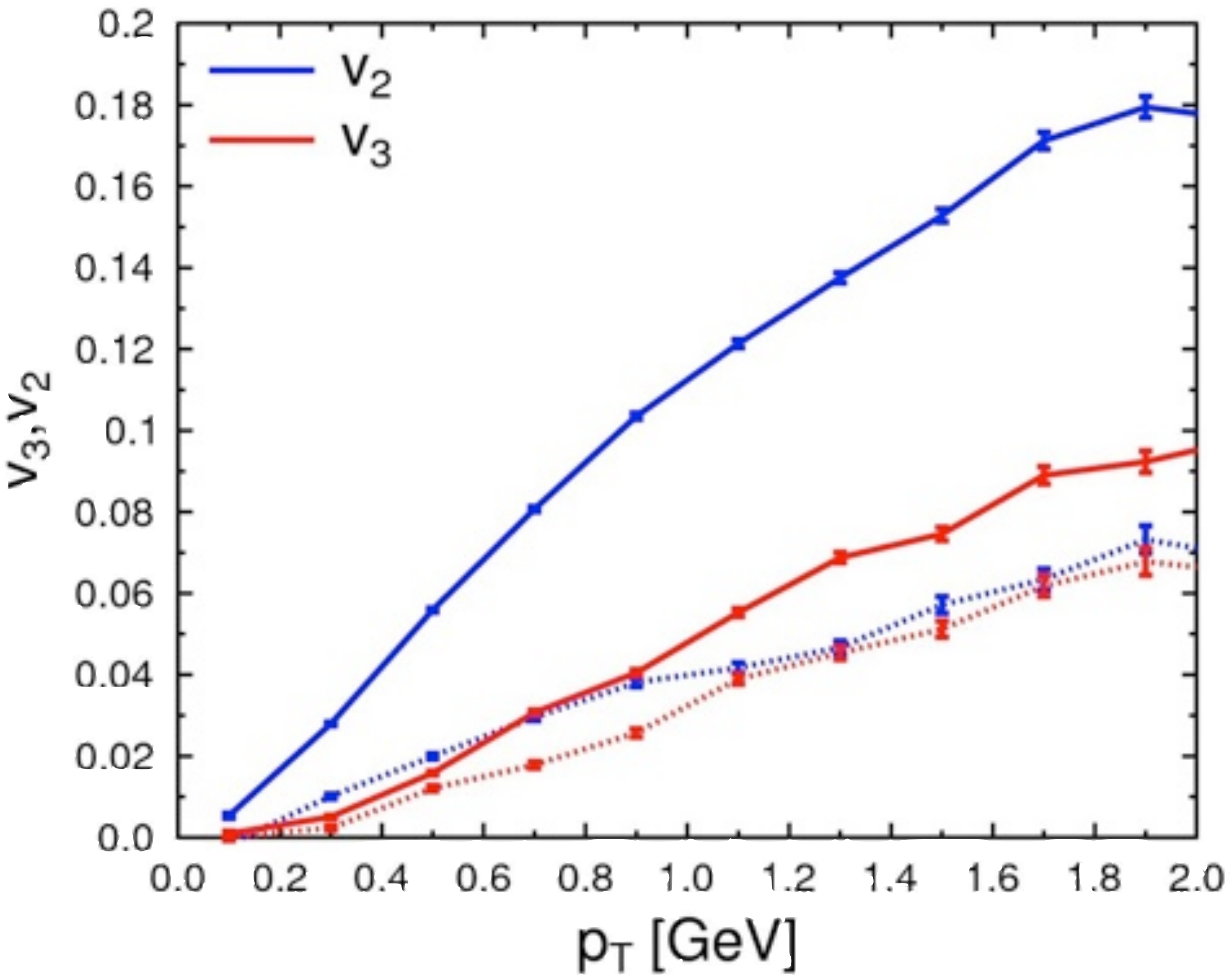
- Triangular flow can be used for measuring granularity

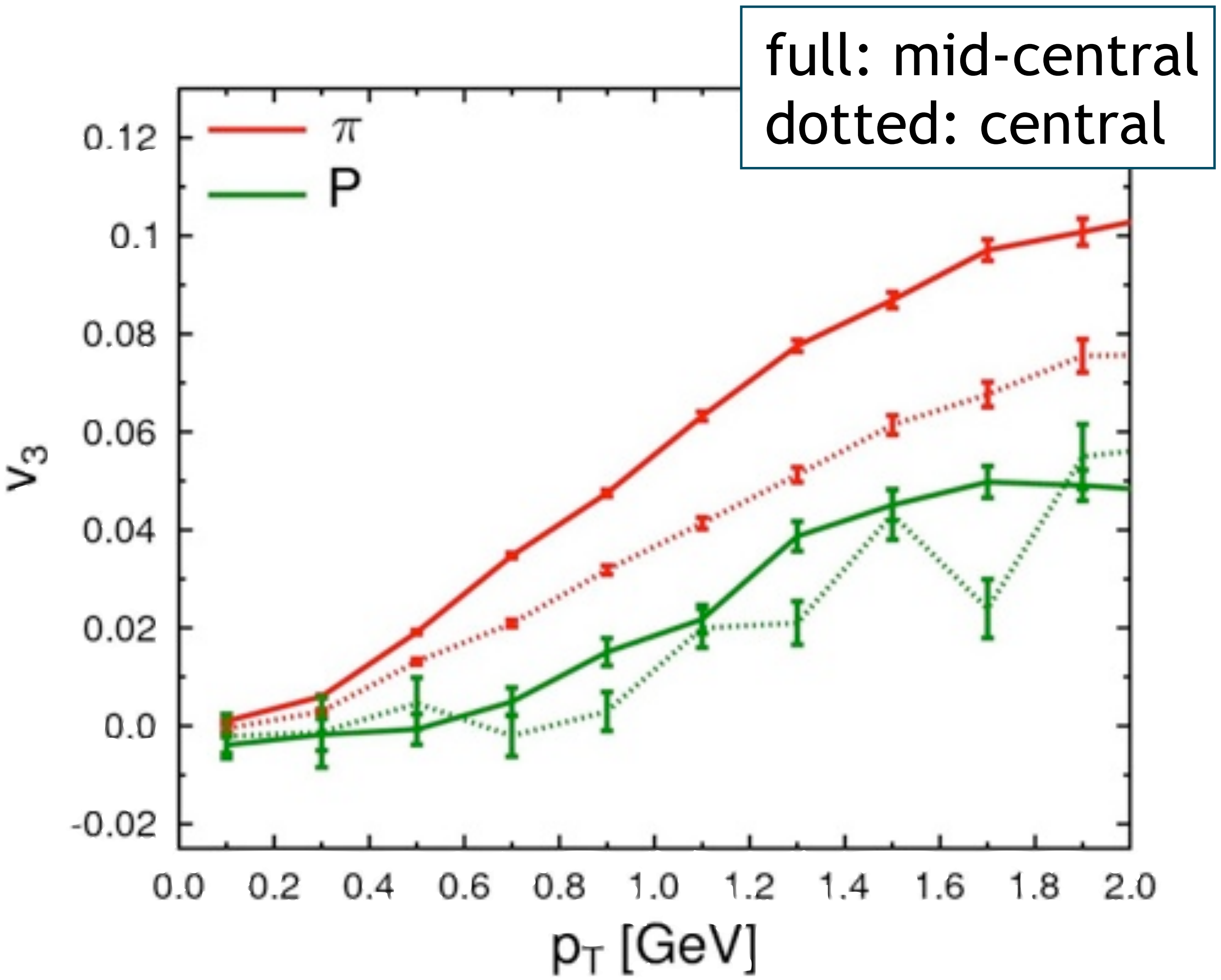
Centrality Dependence



- Hydrodynamic response **stronger** for elliptic flow
- Triangular flow exhibits only **weak** centrality dependence

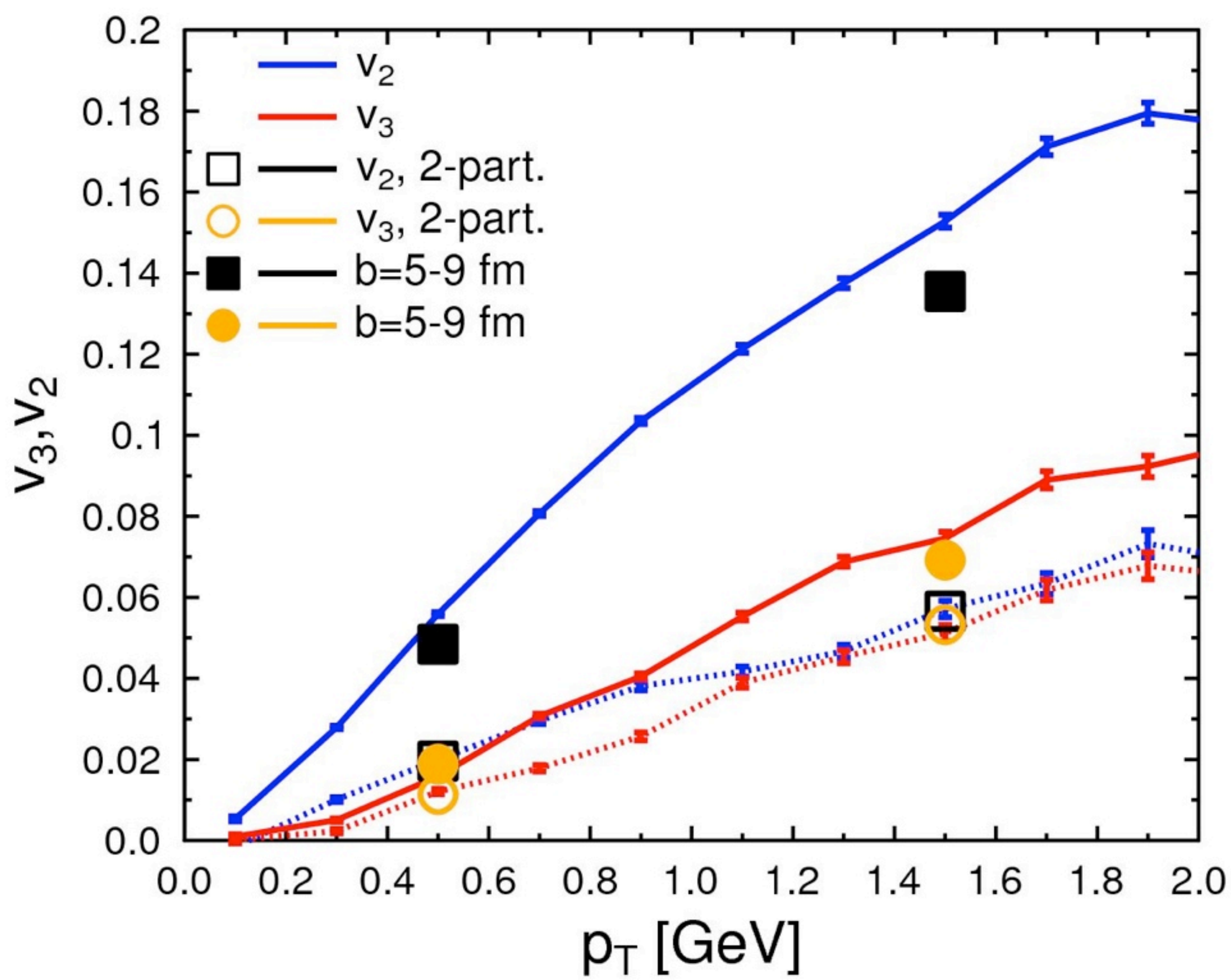
Transverse Momentum Dependence

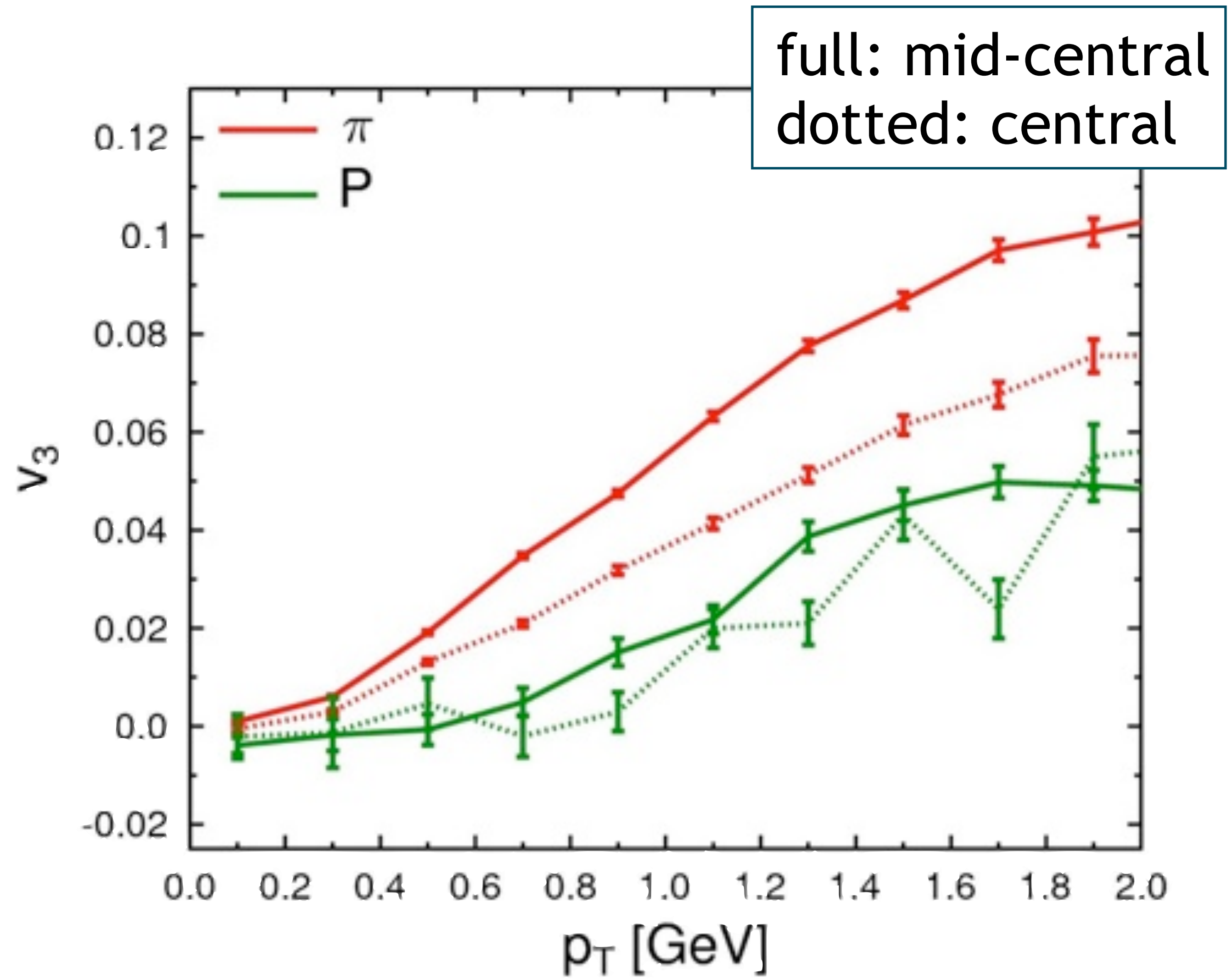




- Central Collisions: $v_2 \approx v_3$
- Mid-central collisions: $v_2 \approx 2 \cdot v_3$
- Mass splitting for identified particles

Two-Particle Correlation

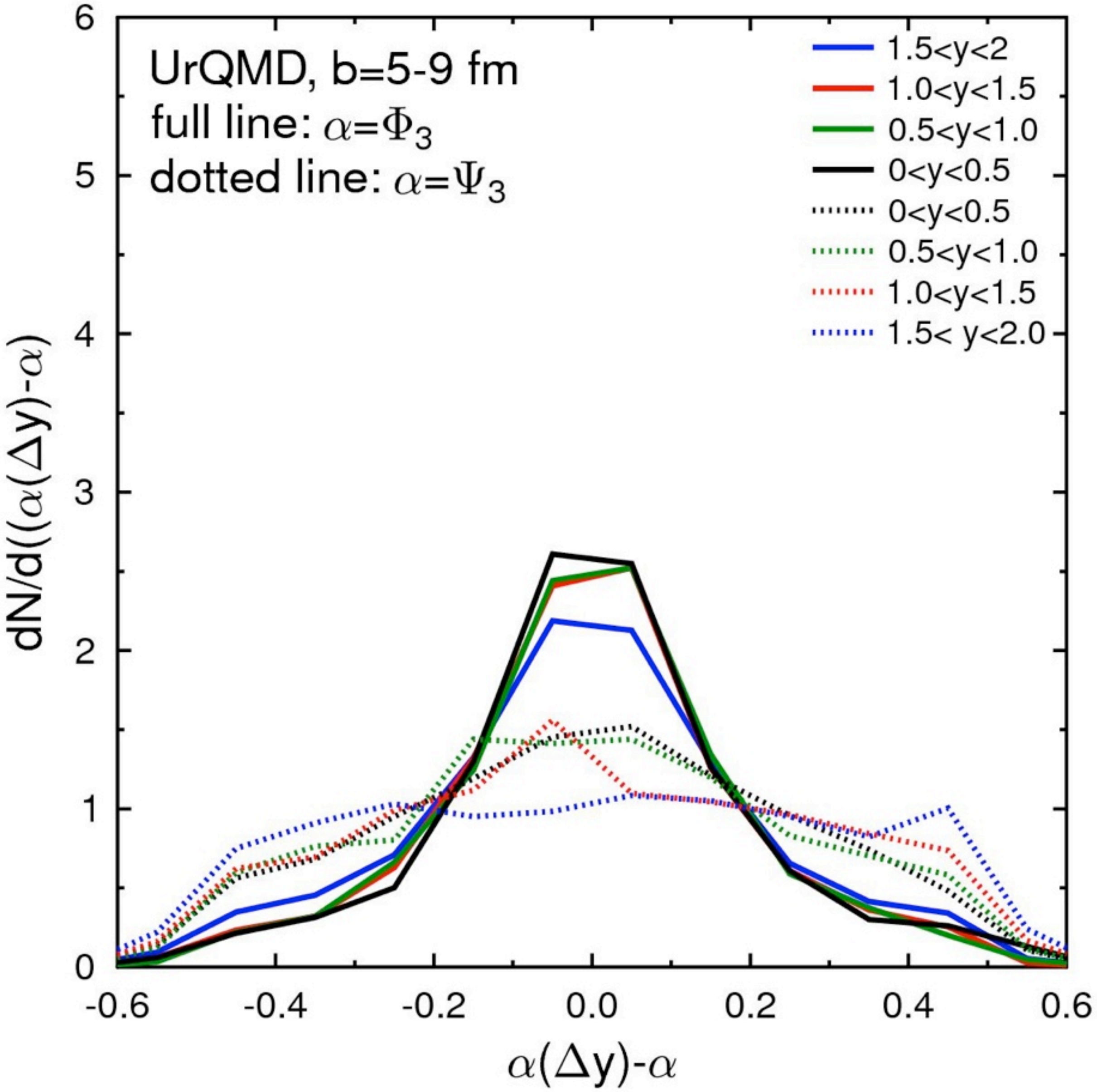




- v_2/v_3 values are very similar, when they are extracted from two-particle correlations
- Identified particles might be helpful to disentangle different contributions to $\Delta\phi$-correlations

Longitudinal Correlation

- Calculate overall event plane angle and angle in each bin
- Look at the distribution of the **differences** of these angles

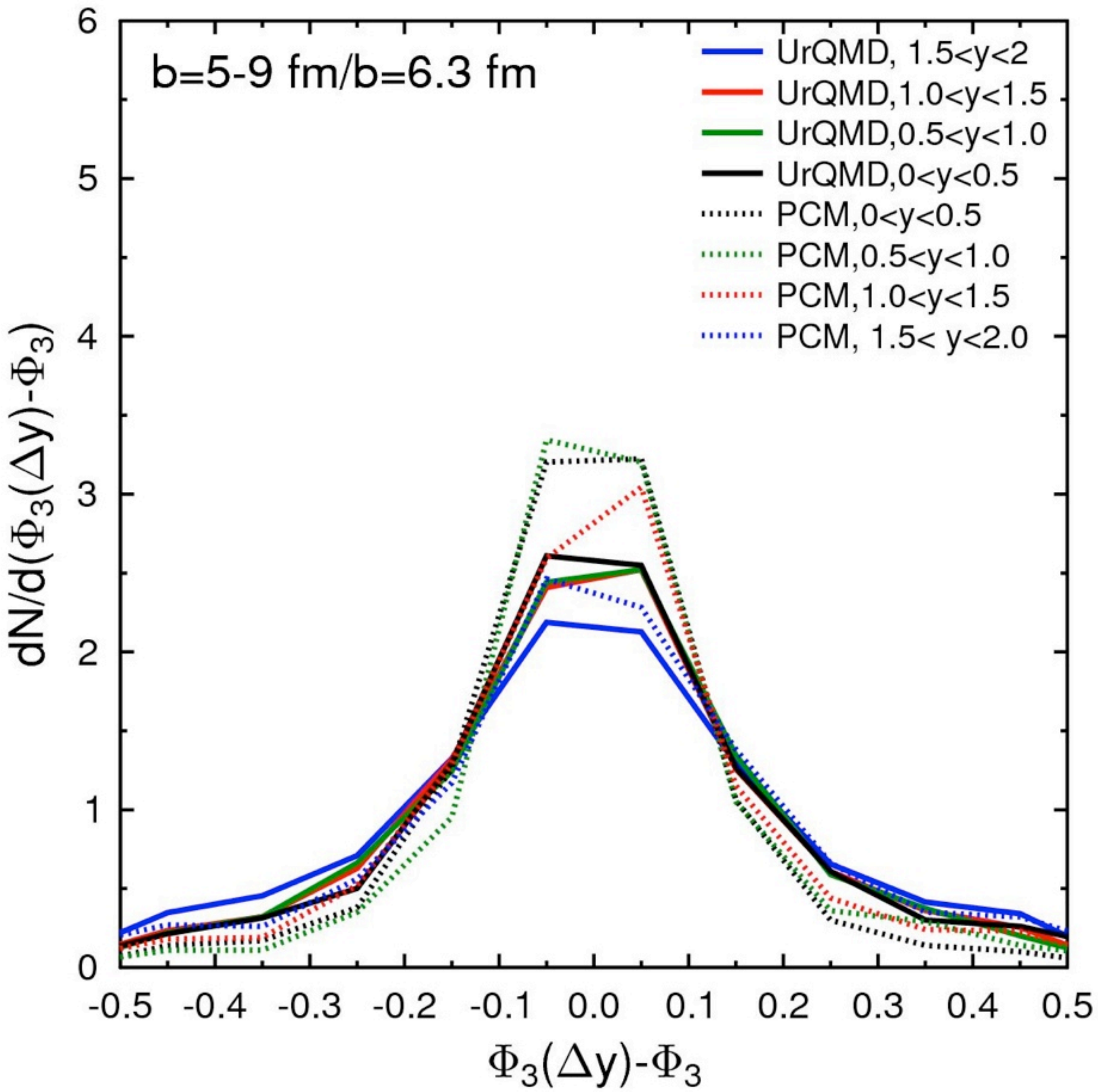


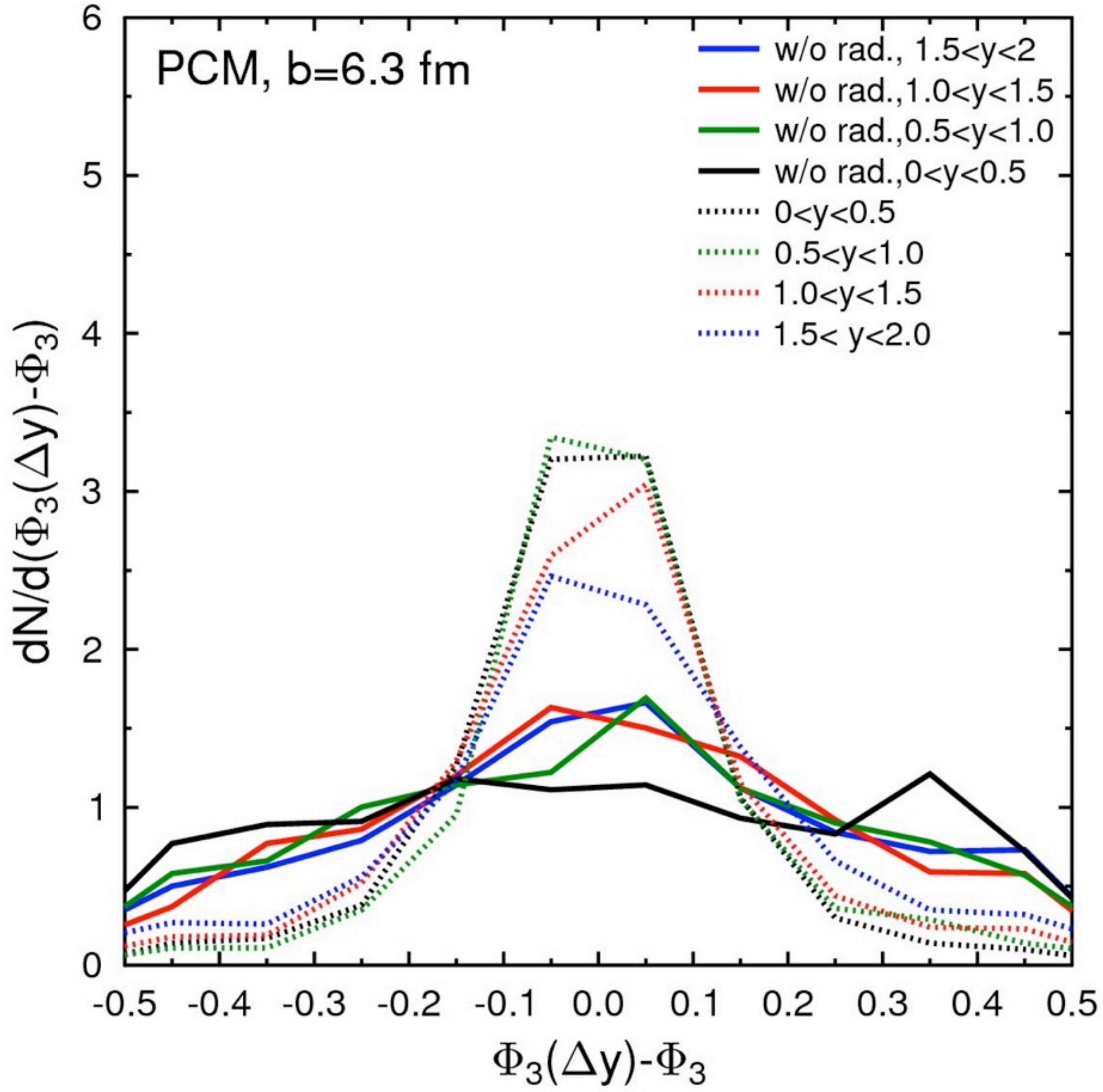
H.P. et al, arXiv: 1105.0340

→ There is a **correlation** in the initial state generated by **string** fragmentation
→ Stronger at midrapidity
→ Gets **smeared** out during hydro evolution

Compare to **parton cascade** initial conditions to explore a different initial scenario

PCM Initial State

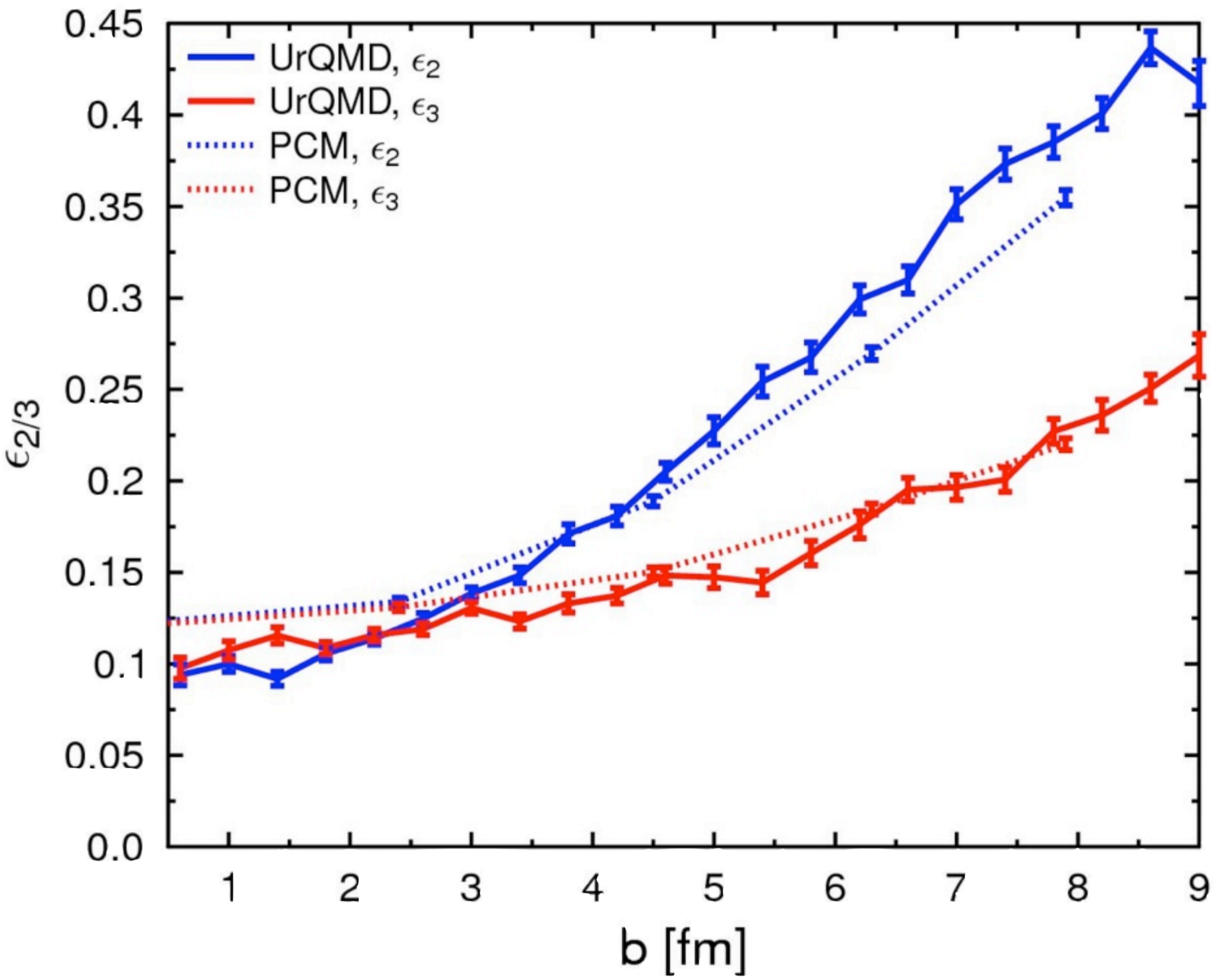


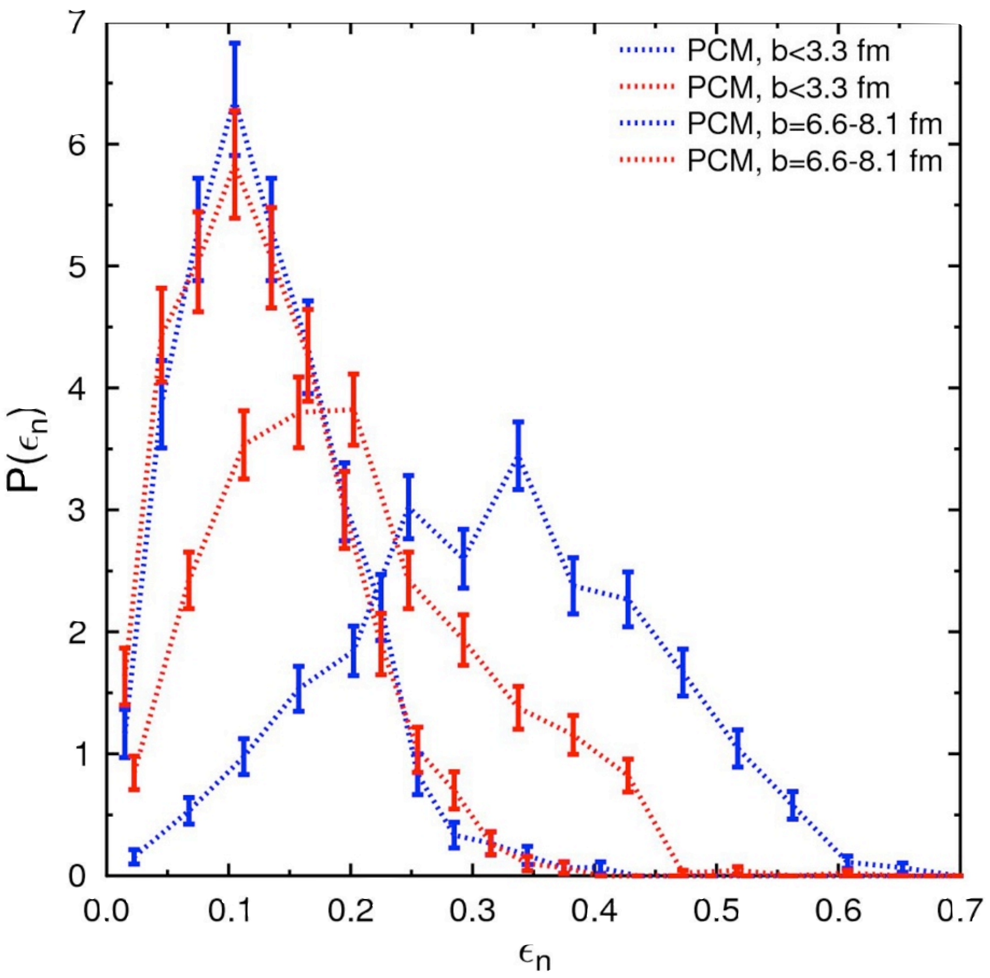


- **Time-like branchings** following binary scattering also introduce long-range longitudinal correlation
- Not **unique** to flux tube/string picture

H.P. et al, arXiv: 1105.0340

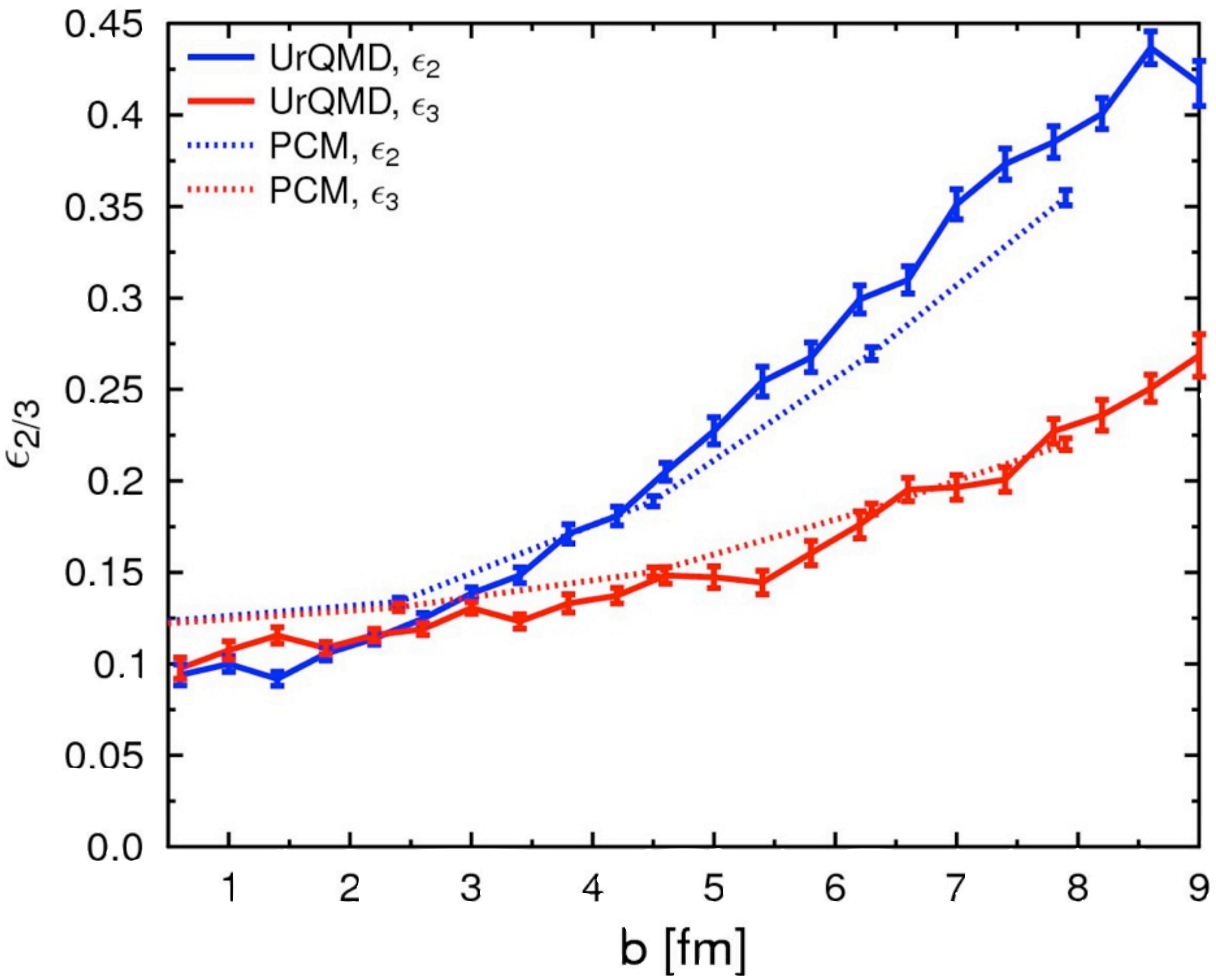
Eccentricity Distributions

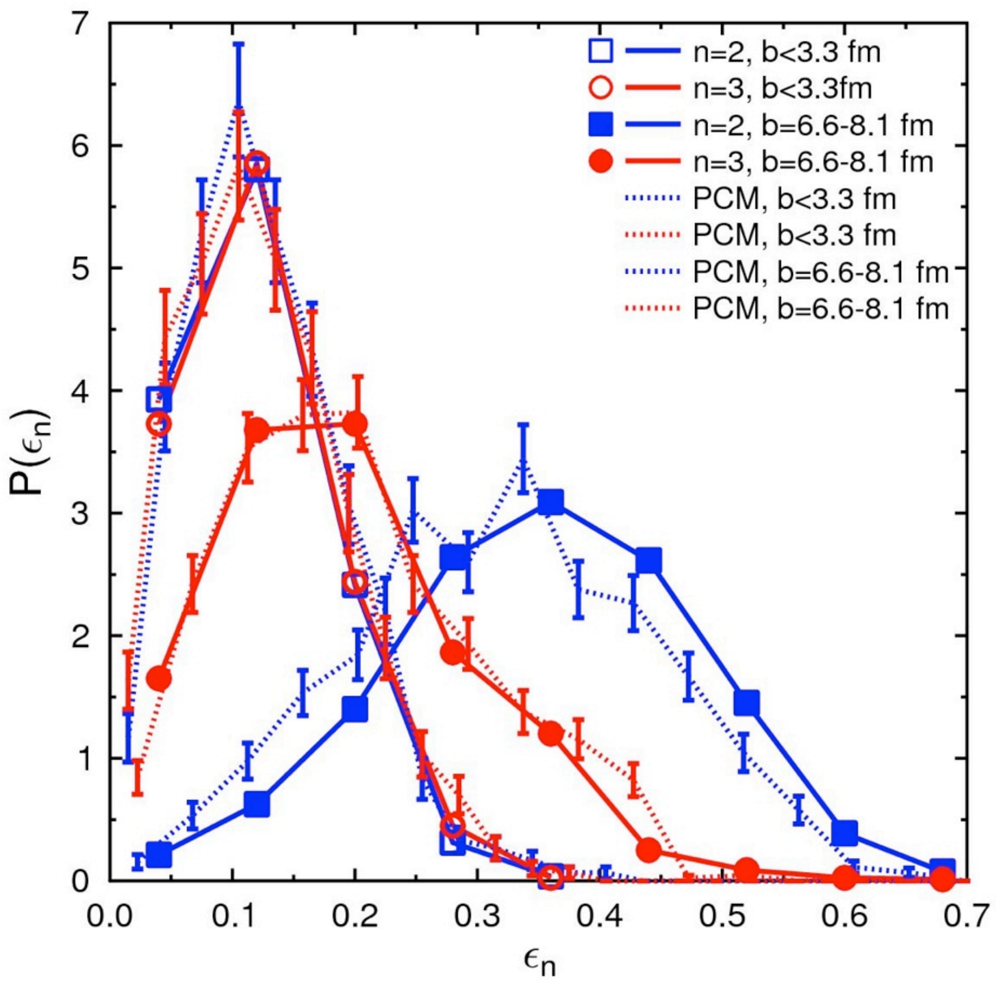




- Initial eccentricity and triangularity are **very similar** in hadron and parton cascade
- The **mean** value of the eccentricity is a bit larger in UrQMD for non-central collisions, but the **fluctuations** are similar in both approaches

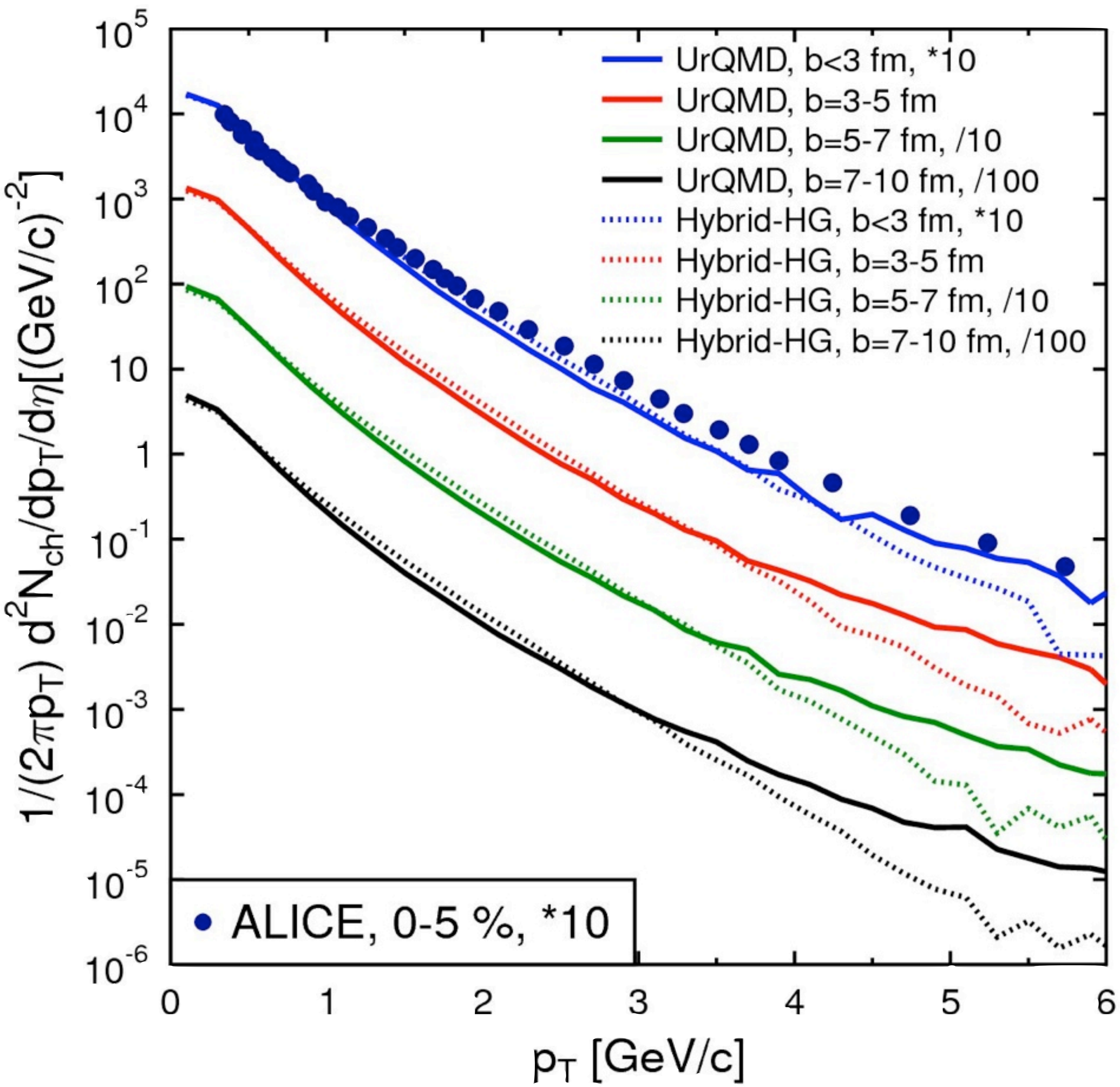
Eccentricity Distributions





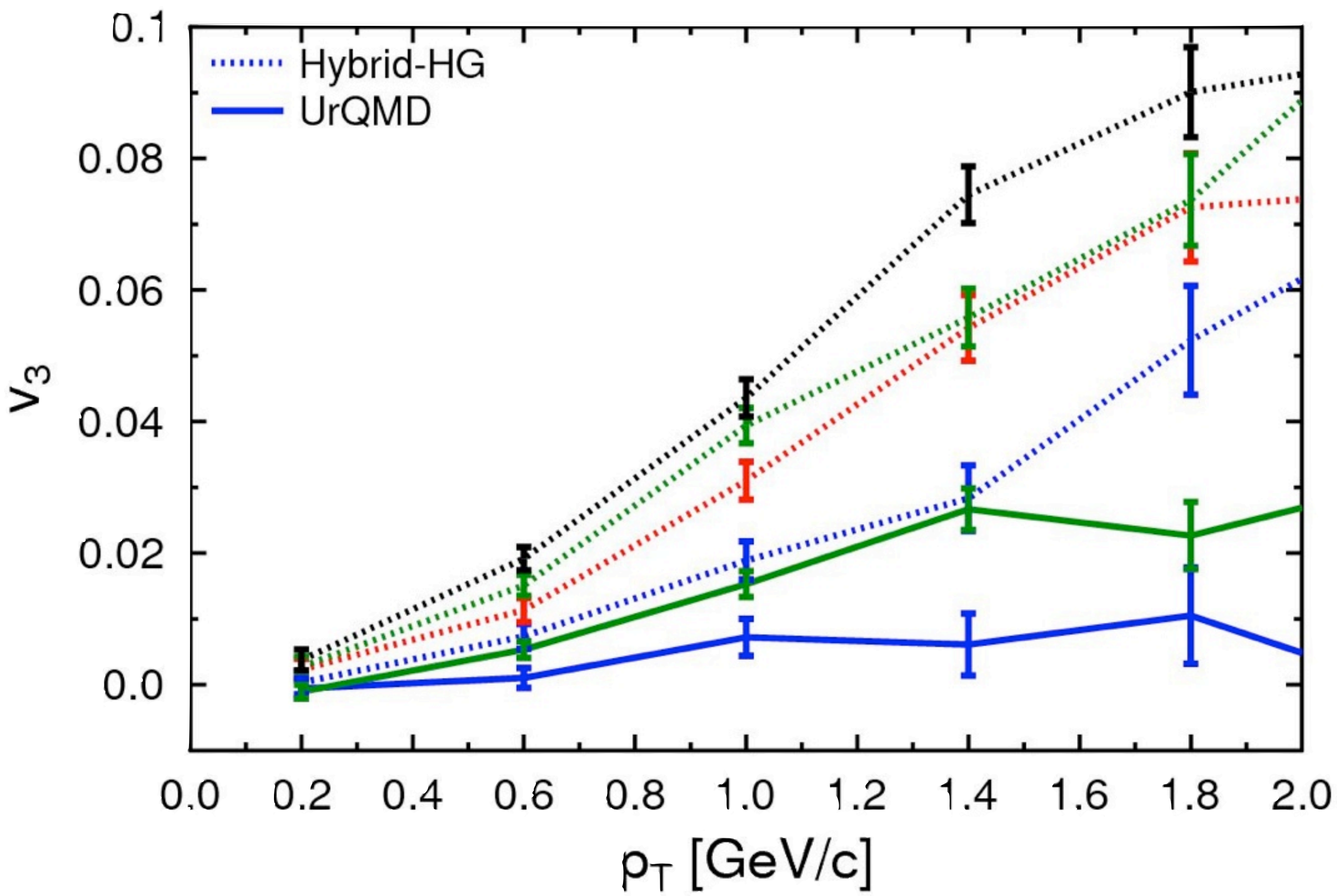
- Initial eccentricity and triangularity are **very similar** in hadron and parton cascade
- The **mean** value of the eccentricity is a bit larger in UrQMD for non-central collisions, but the **fluctuations** are similar in both approaches

Spectra at LHC

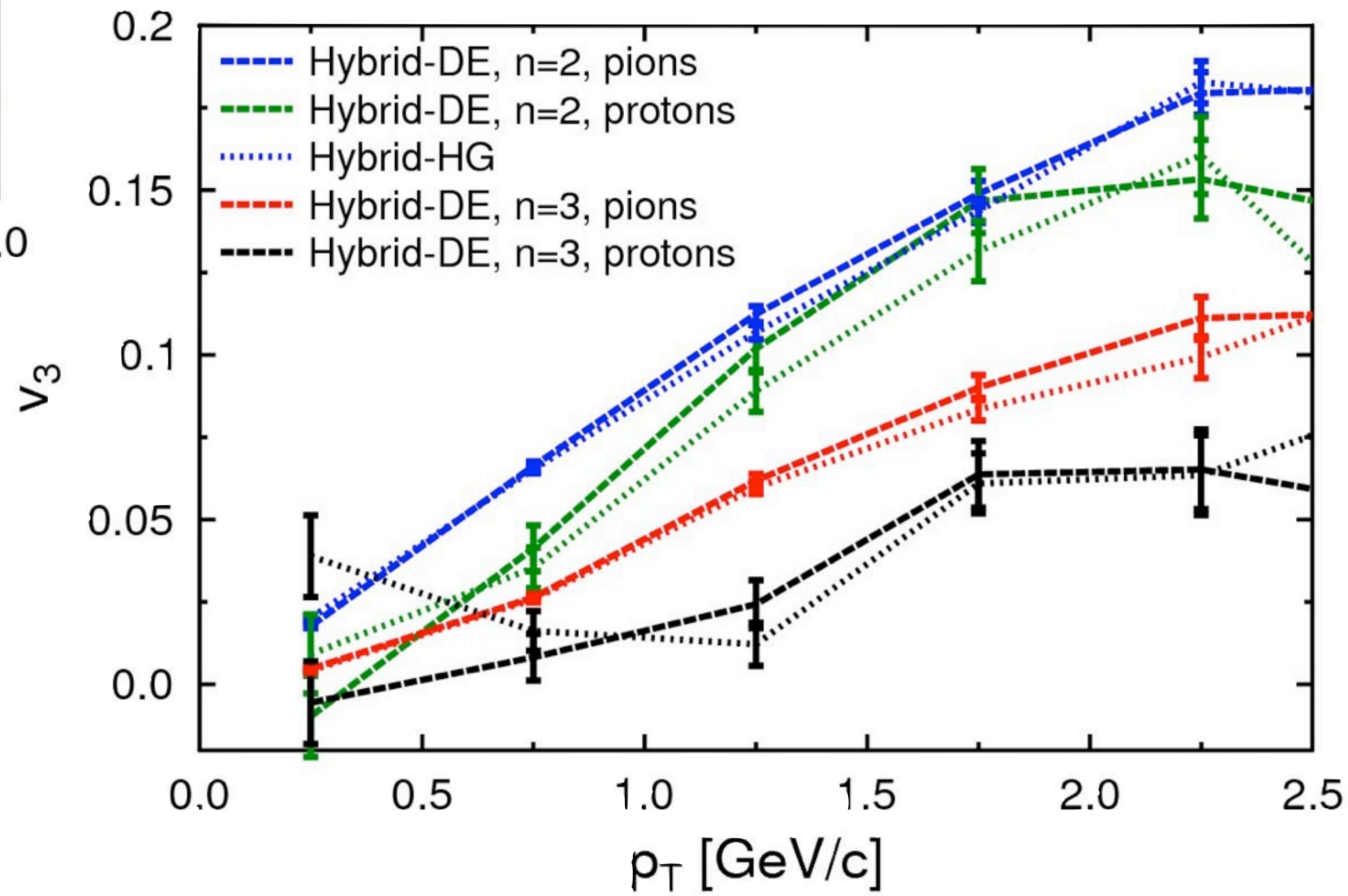


- Hybrid works well for pt<3 GeV

Triangular Flow at LHC



- Minimum bias result for **identified** particles



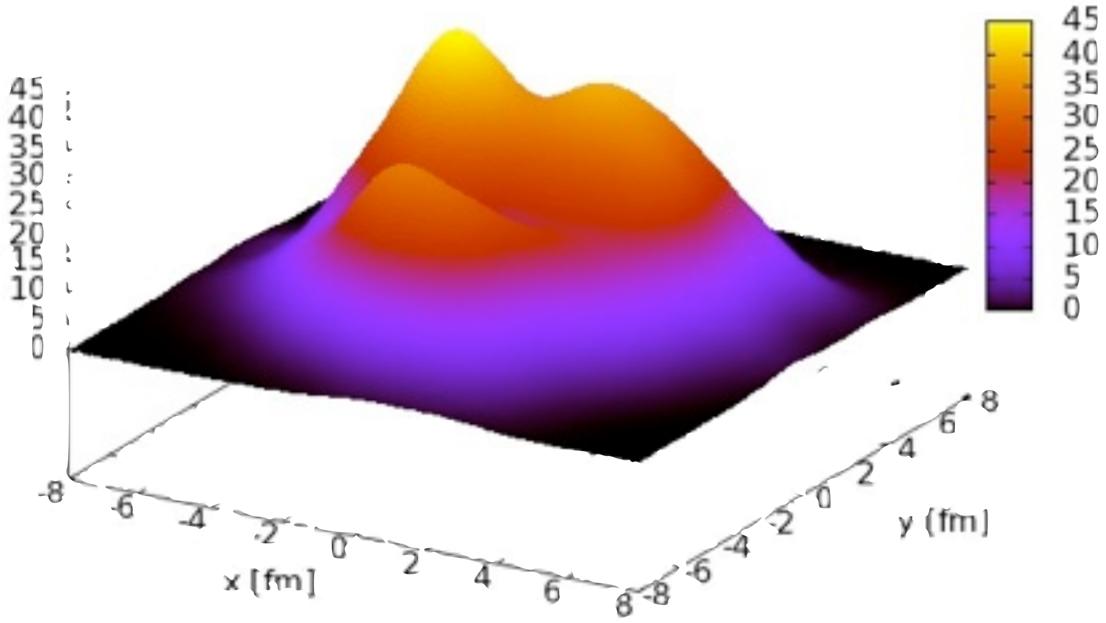
- Triangular flow is almost **zero** in UrQMD
  → Very sensitive to viscosity
- Similar **magnitude** in hybrid compared to RHIC

less crowded figs

H.P., arXiv: 1105.1766

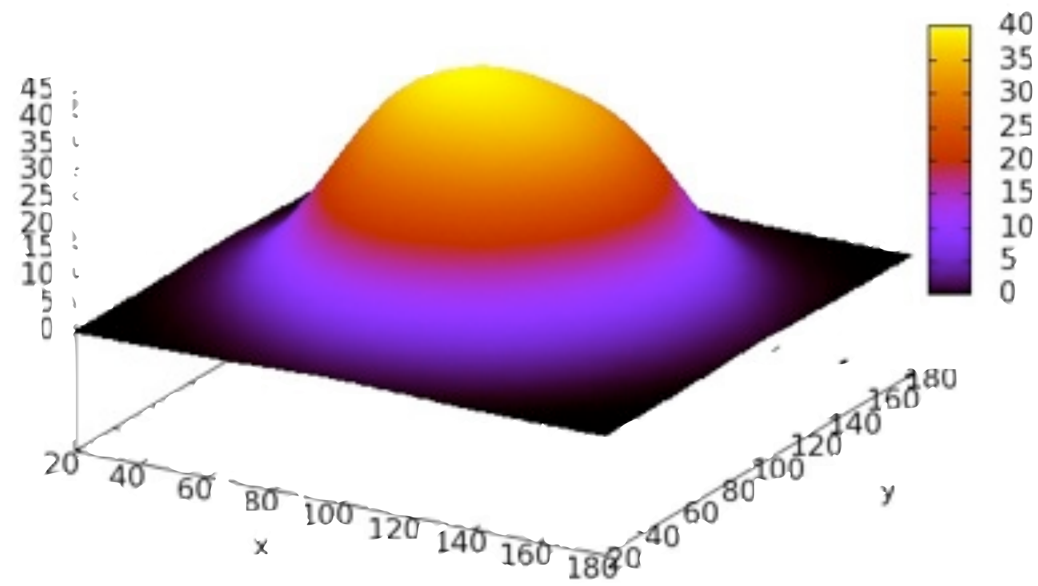
Outlook - ‘Measuring’ Granularity ?

Fluctuating (default)



Triangular flow ≈ 2 %

Averaged (over 100 events)



Triangular flow ≈ 0

- Different **granularities** by averaging over 1,2, 5, 10, ... 100 events that can be quantified
- Yields, spectra and elliptic flow are **identical**
- **Triangular flow** ranges from zero (smooth) to a few percent

Outlook

	Dynamic Approach	Parametrization
Hadron - based	Hadron Cascade (UrQMD)	Monte Carlo Glauber
Parton- based	Parton Cascade (PCM)	CGC, KLN MC

- Characterize differences by looking at **shapes** and harmonic coefficients and their **fluctuations**
- Use the same dynamical model to explore effect on bulk observables and anisotropic flow
- Energy and system size dependence will be studied