Flow and initial state fluctuations

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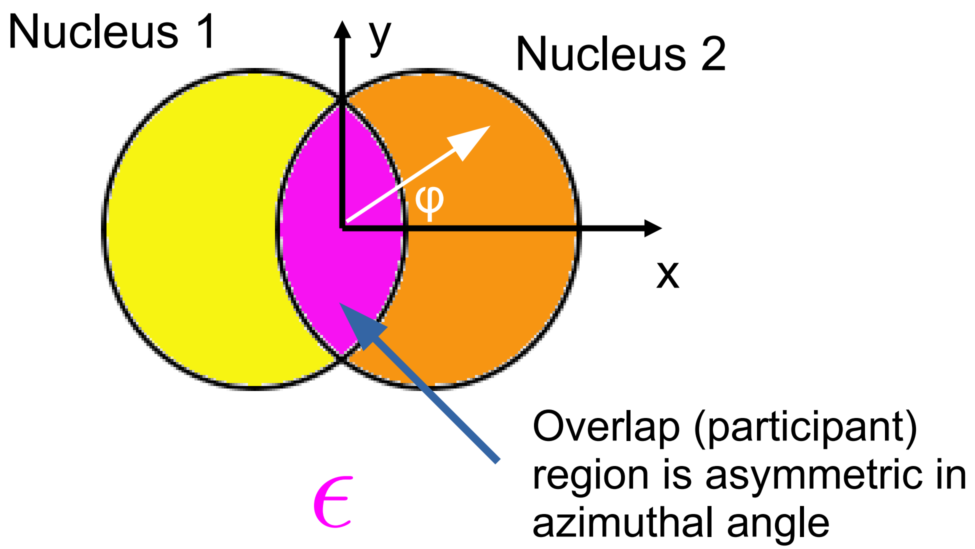
(LBNL)

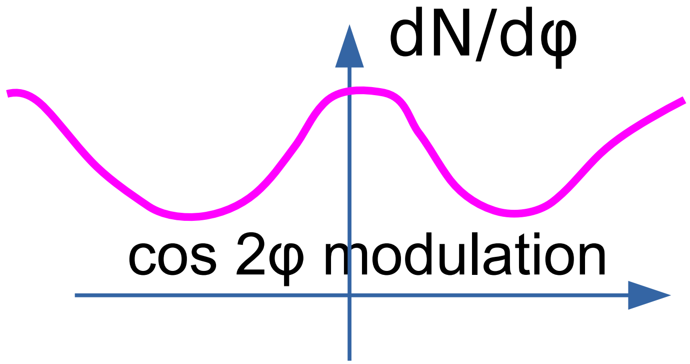
16 December 2014

"Ab initio approaches in many-body QCD confront HI experiments" workshop, Heidelberg

Initial and final state anisotropy

Ollitrault, 1992





$$\frac{dN}{d\varphi} \sim 1 + 2 v_2 \cos[2(\varphi - \psi_R)] + \ldots$$

Initial spatial anisotropy: Eccentricity

Interactions present early

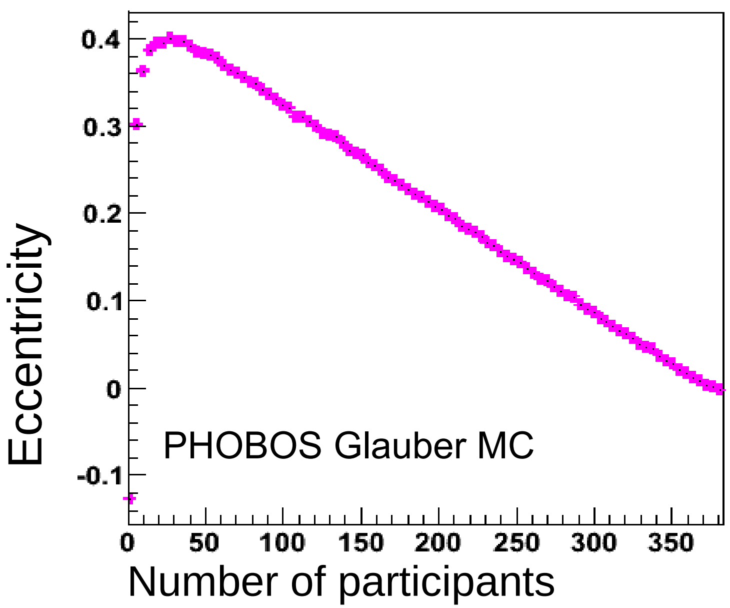
(self quenched)

Momentum space anisotropy: Elliptic flow

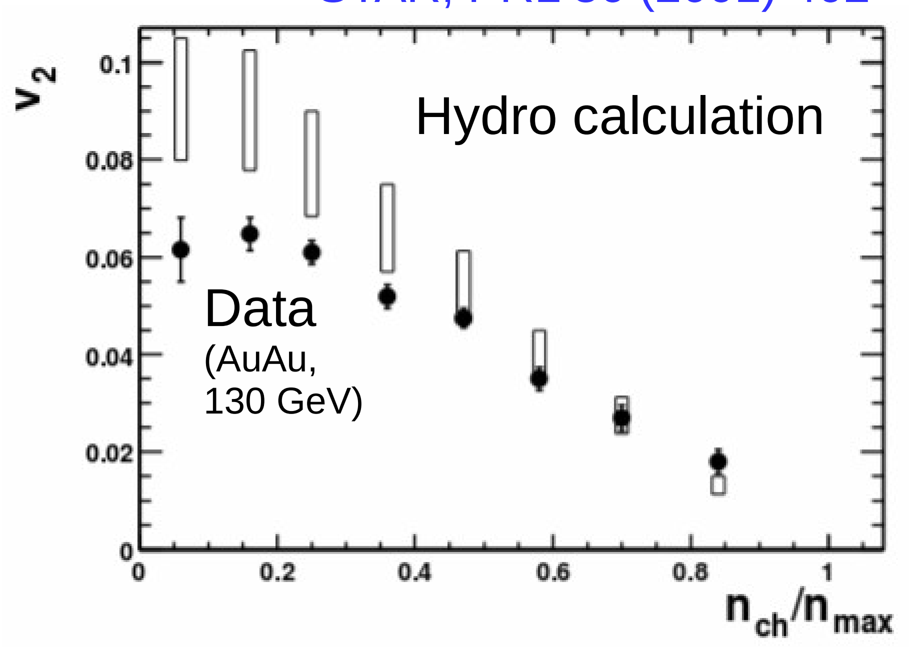
$$\epsilon_{\mathrm{std}} = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$$

$$v_2 = \langle \cos(2\varphi - 2\Psi_R) \rangle$$

Initial and final state anisotropy



STAR, PRL 86 (2001) 402



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$$\epsilon_{std} = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$$

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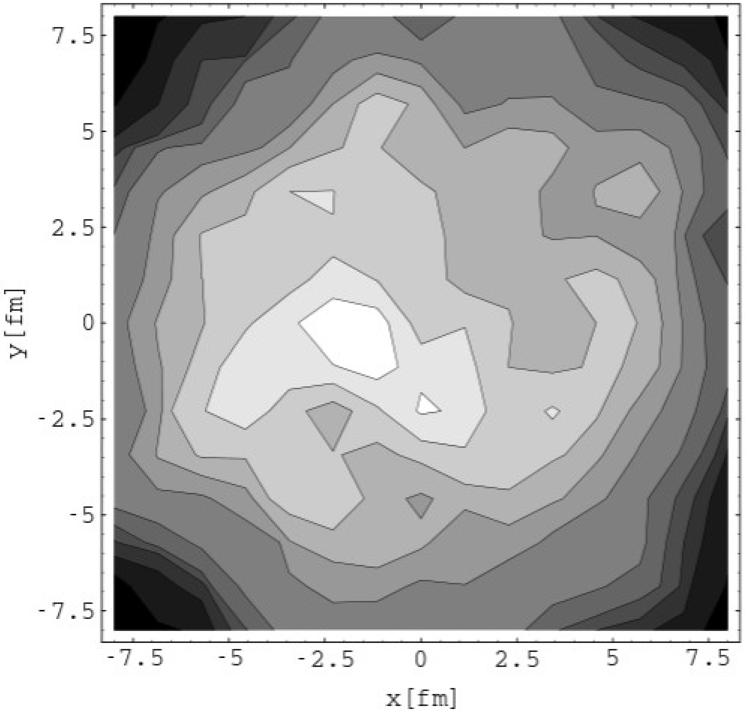
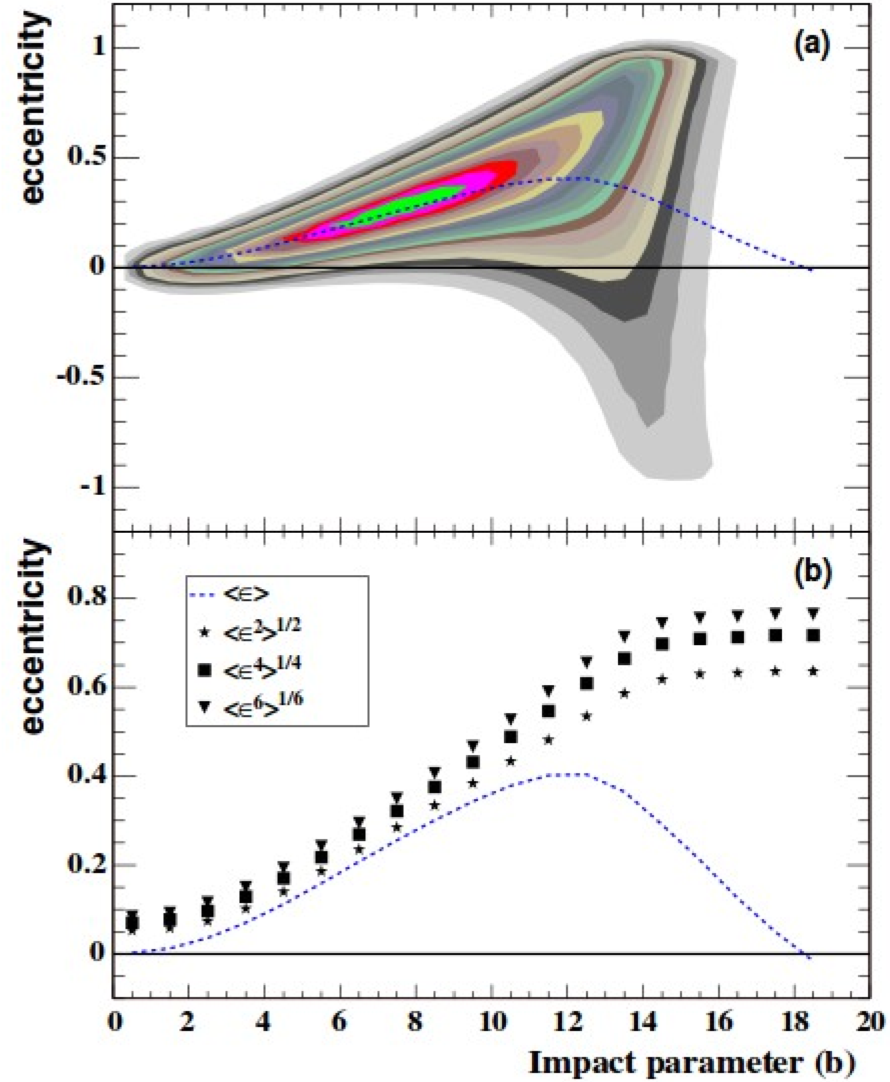
Geometry fluctuations

Hama et al., nucl-th/0102011



Hydrodynamic calculation
with fluctuating initial conditions

Miller, Snellings, nucl-ex/0312008



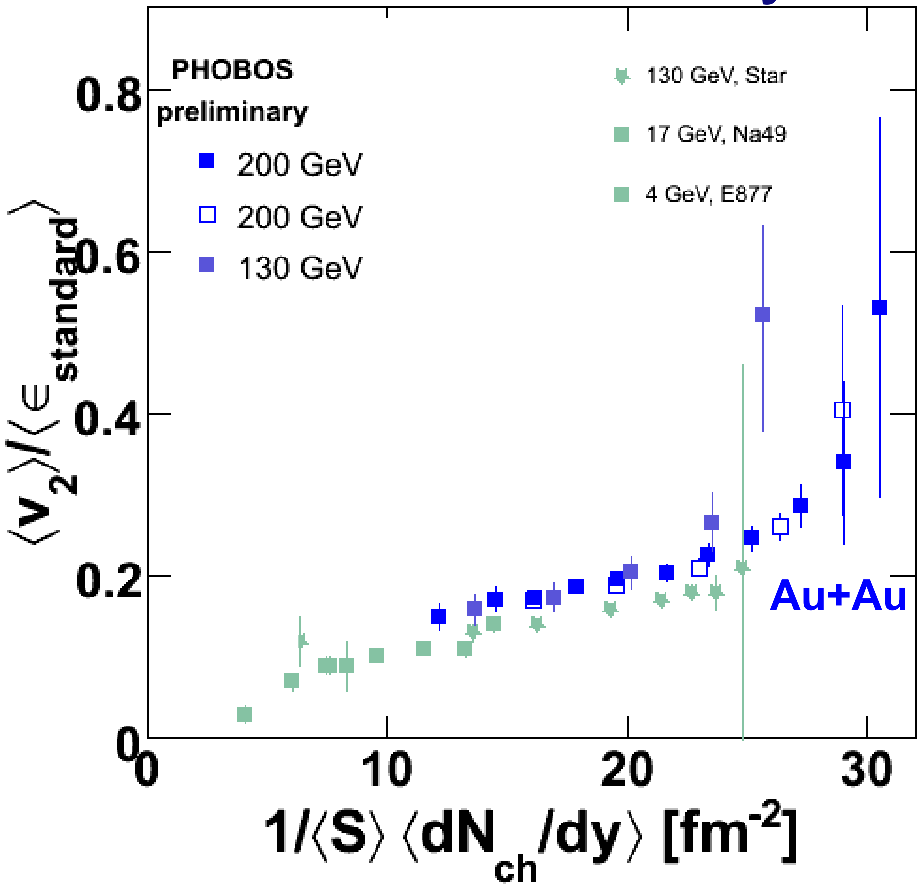
Eccentricity fluctuations
relative to reaction plane

Geometry fluctuations
understood as a perturbation
of reaction plane eccentricity

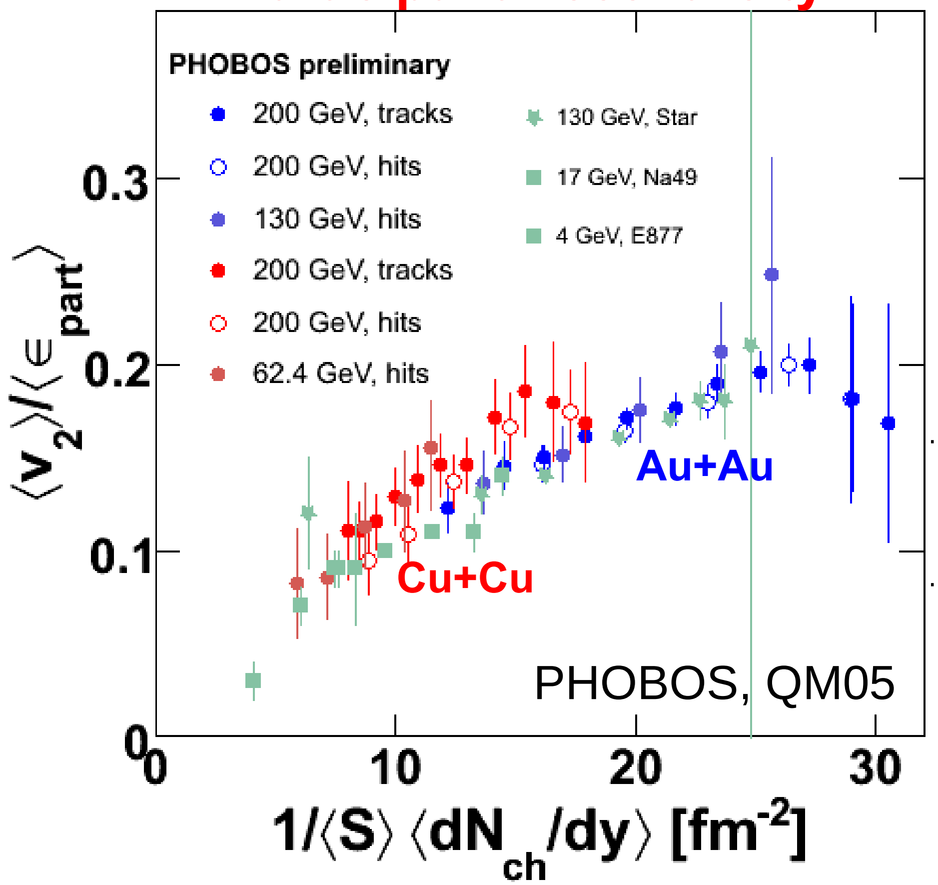
Importance of initial state fluctuations

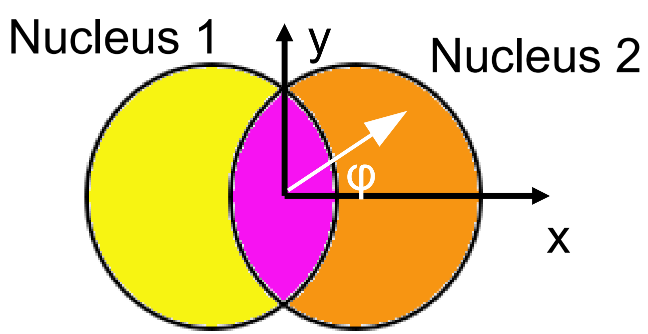
PHOBOS, PRL 98 (2007) 242302

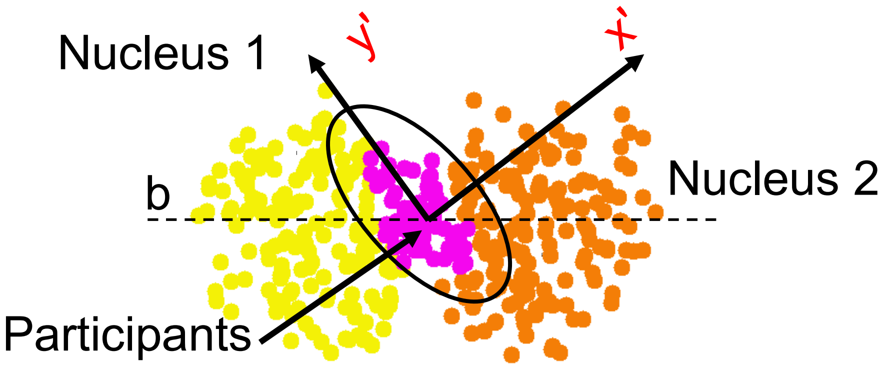
Standard Eccentricity



Participant Eccentricity



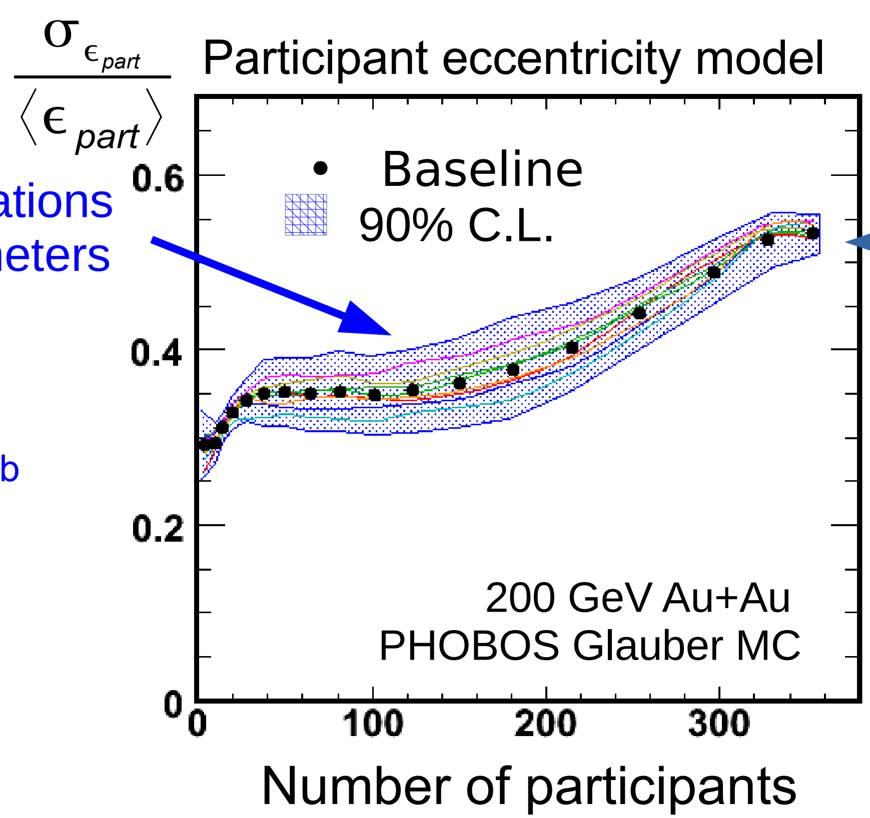




Expected relative flow fluctuations

Uncertainty from variations of Glauber MC parameters

Baseline parameters:
- Nucleon-nucleon cross section: σ_{NN}=42mb
- Skin depth: a=0.535fm
- Wood-saxon radius: R_A=6.38fm
- Inter-nucleon separation distance: d=0.4fm



Analytic (b=0fm)

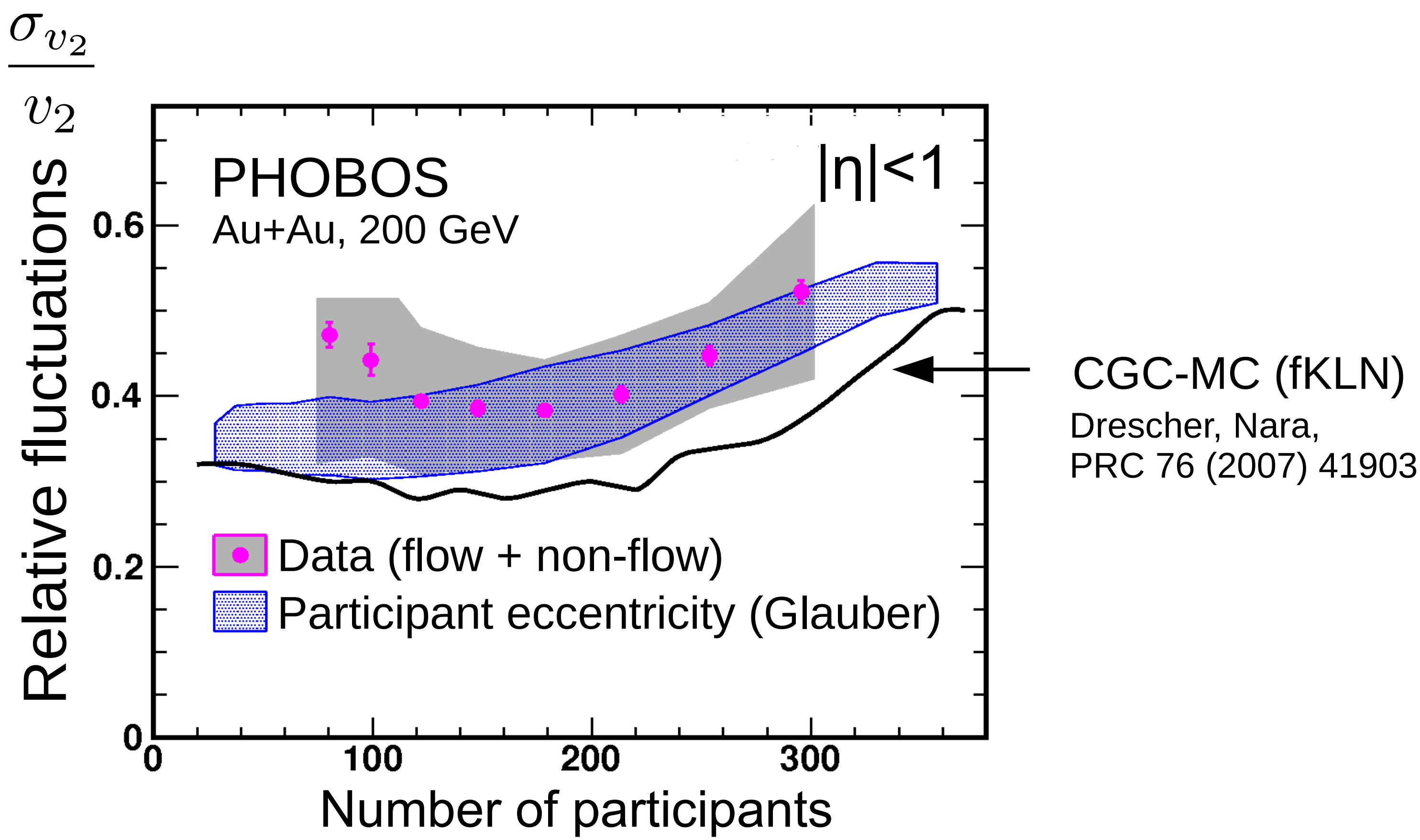
$$\sqrt{\frac{4}{\pi} - 1} \approx 0.52$$

Broniowski et al., PRC 76 054905 (2007)

If initial state fluctuations are present, expect large relative flow fluctuations: $\frac{\sigma_{v_2}}{\langle v_2 \rangle} \sim \frac{\sigma_{\epsilon_{part}}}{\langle \epsilon_{part} \rangle}$

PHOBOS, nucl-ex/0608025

Measured relative total fluctuations



Shown at QM06 as flow fluctuations, however non-flow contribution (included in sys.error from HIJING) not subtracted. Now interpreted as total v_2 fluctuations.

PHOBOS, PRL 104 (2010) 142301

Measure non-flow contribution

Data driven analysis to measure the contribution of non-flow

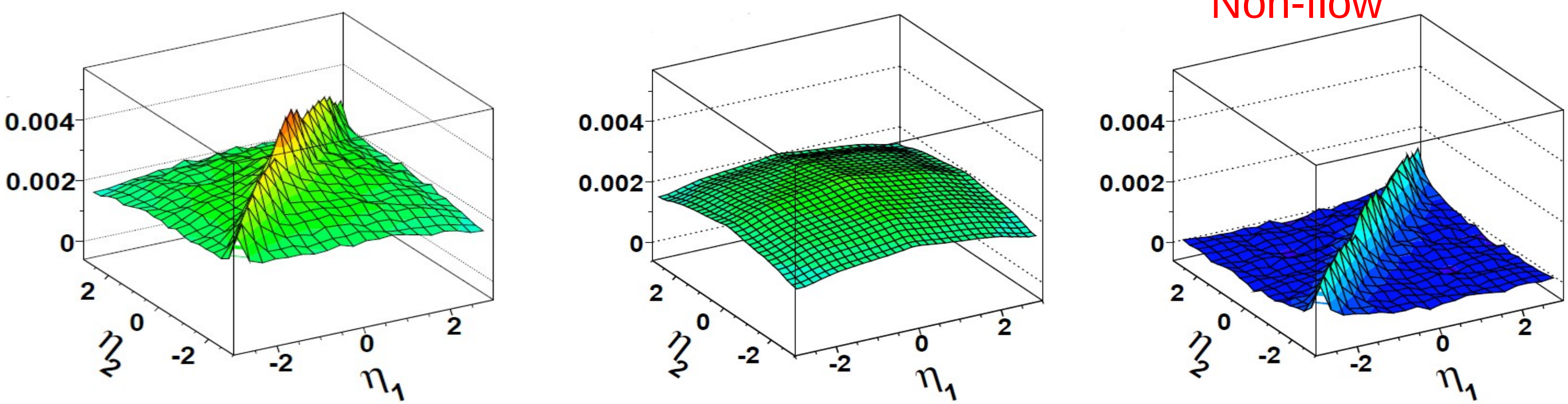
- Flow is a function of η and correlates particles at all Δη
- Non-flow (δ) is dominated by short range correlations (small Δη)
- Study correlations at different Δη

$$v_2^2(\eta_1,\eta_2) \equiv \langle \cos(2\Delta\varphi) \rangle (\eta_1,\eta_2)$$
$$= v_2(\eta_1) * v_2(\eta_2) + \delta(\eta_1,\eta_2)$$

- Assume non-flow to be zero for Δη>2
- Fit $v_2^2(\eta_1,\eta_2) = v_2^{fit}(\eta_1) * v_2^{fit}(\eta_2)$, $|\eta_2 - \eta_1| > 2$
- Subtract fit results at all (η_1,η_2)
- Integrate over particle pairs to obtain δ / v_2^2
- Numerically relate δ / v_2^2 and $\sigma_{v_2} / \langle v_2 \rangle$ to obtain $\sigma_{flow} / \langle v_2 \rangle$

$$v_2^2(\eta_1,\eta_2) \quad - \quad v_2^{fit}(\eta_1) \times v_2^{fit}(\eta_2) \quad = \quad \delta(\eta_1,\eta_2)$$

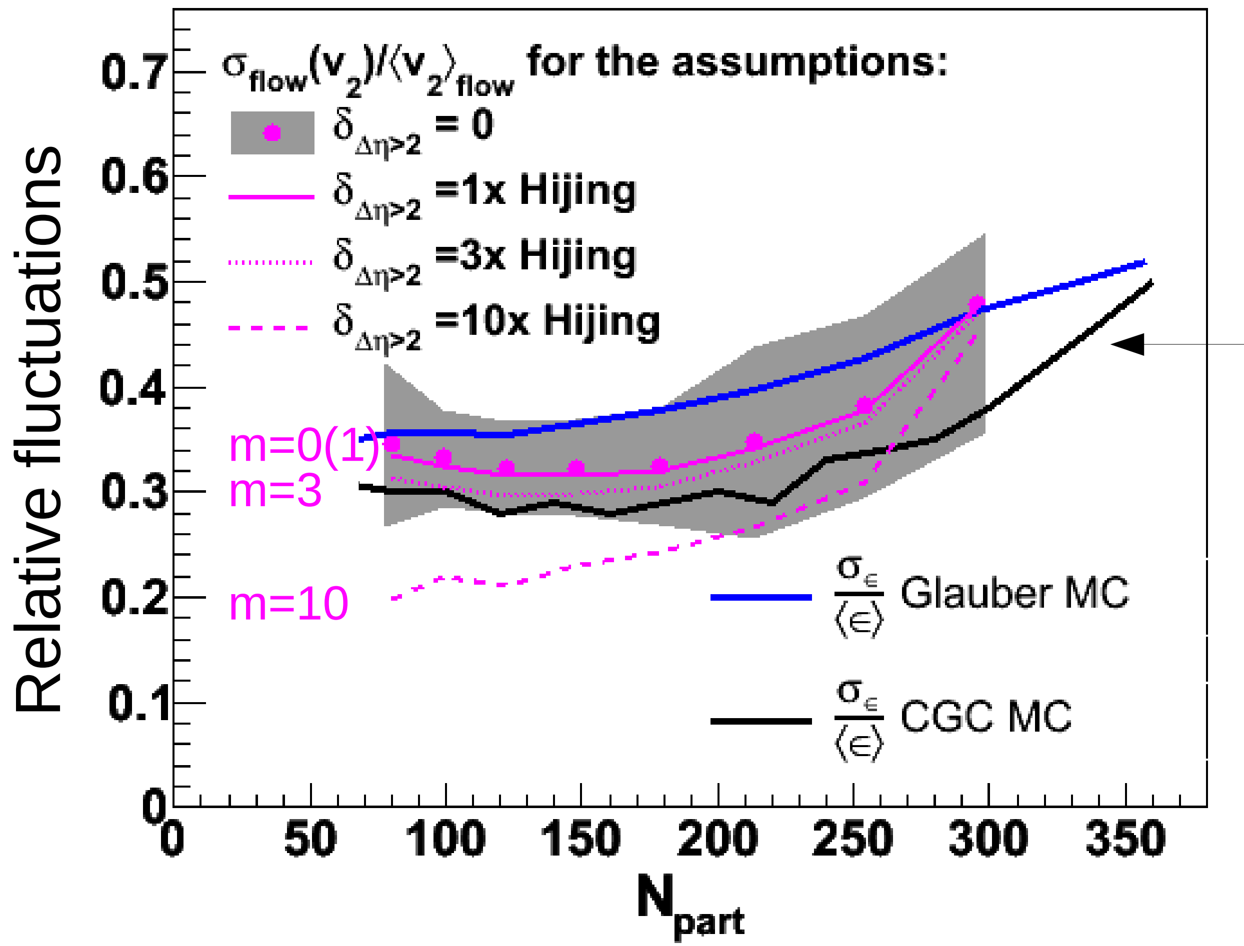
Non-flow



PHOBOS, PRC 81 034915 (2010)

Relative flow fluctuations

For m=3
80-95%
of σ_{v_2}/v_2



CGC-MC (fKLN)

Drescher, Nara,
PRC 76 (2007) 41903

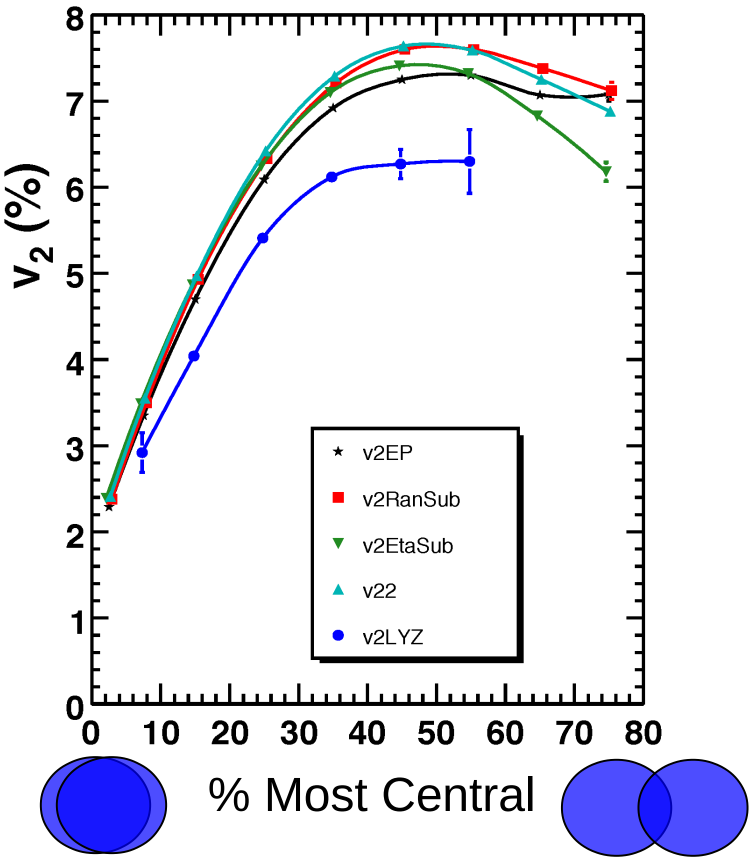
Flow fluctuations observed similar to what those predicted by simple models of initial state fluctuations.

Short-range ($\Delta\eta$<2) non-flow contribution are removed

PHOBOS, PRC 81 (2010) 034915

Correction for non-flow and fluctuations

Published STAR results



Derive analytic correction for non-flow and fluctuations in leading order of δ and $\sigma_{v_2}^2$

$$v_2\{2\}^2 = \langle v_2\rangle^2 + \sigma_{v_2}^2 + \delta$$

$$v\{4\}^2 = \langle v\rangle^2 - \sigma_{v_2}^2$$

$$v\{\text{subEP}\}^2 = \langle v\rangle^2 + (1-f(R))\,\sigma_{v_2}^2 + (1-2f(R))\,\delta$$

$$0 \le f(R) < 0.2$$

Differences between methods proportional to

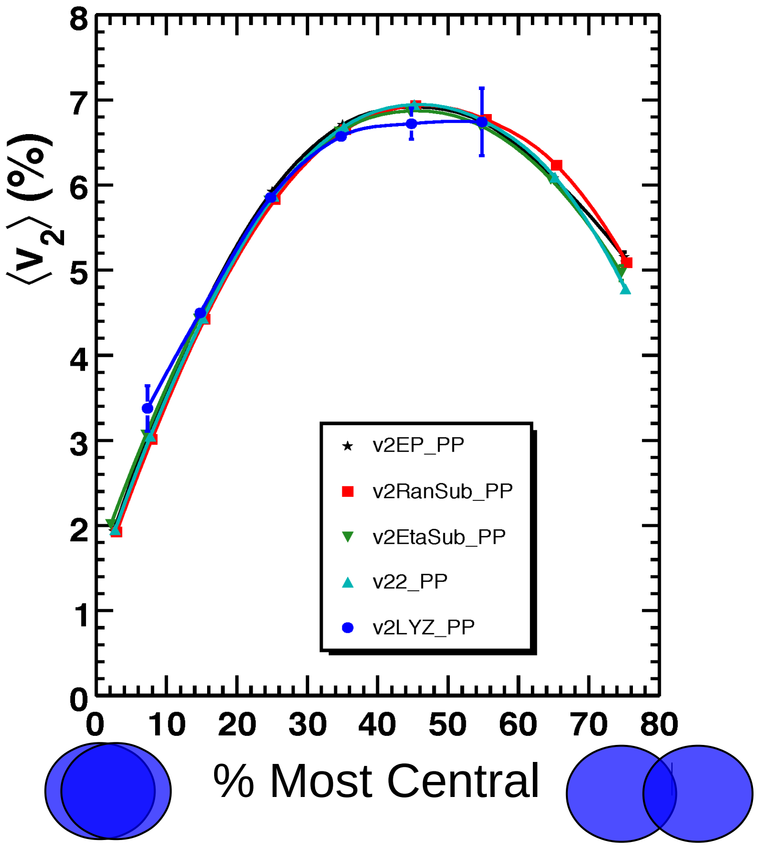
$$\sigma_{tot} = \delta + 2\,\sigma_{v_2}^2$$

Need additional assumption or information to separate between non-flow and fluctuations

Ollitrault, Poskanzer, Voloshin
PRC 80 (2009) 014904

Correction for non-flow and fluctuations

Corrected mean results



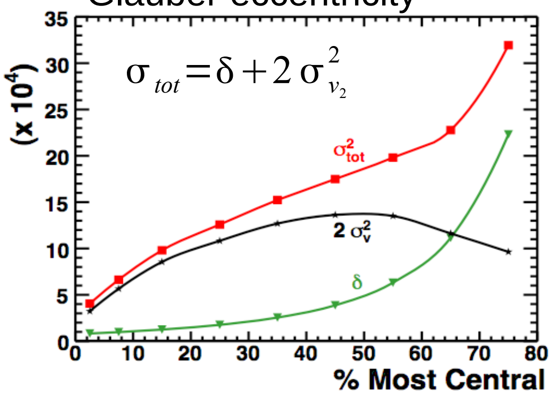
Model assuming:

$$\sigma_{v_2} = \frac{\sigma_{\epsilon_{part}}}{\langle \epsilon_{part} \rangle} \langle v_2 \rangle$$

$$\delta = \frac{2}{N_{part}} \delta_{pp}$$

with $\delta_{pp} = 0.0145$

Glauber eccentricity



Corrected mean values agree in participant frame.
Reduces errors on v_2 measurements by about 20%.

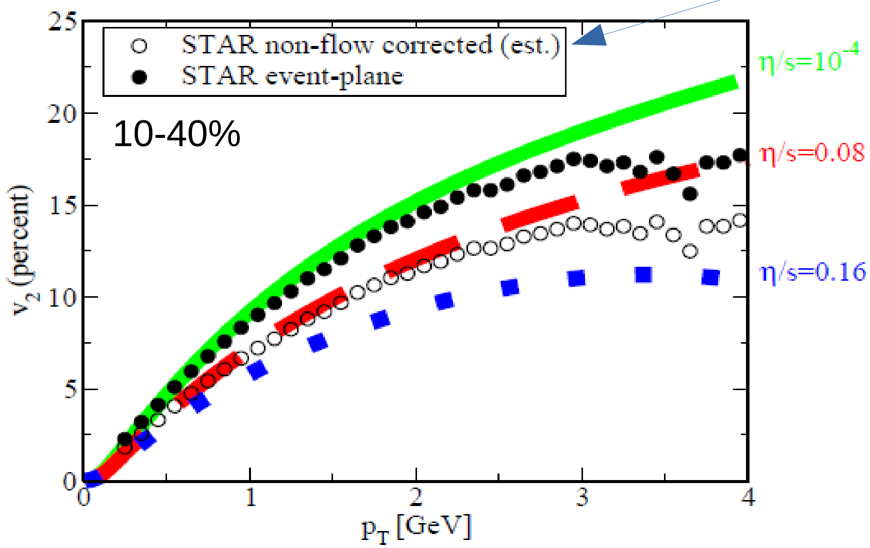
Eccentricity values are calculated for standard Glauber and a mix of 30:70 CGC (not shown)

Ollitrault, Poskanzer, Voloshin
PRC 80 (2009) 014904

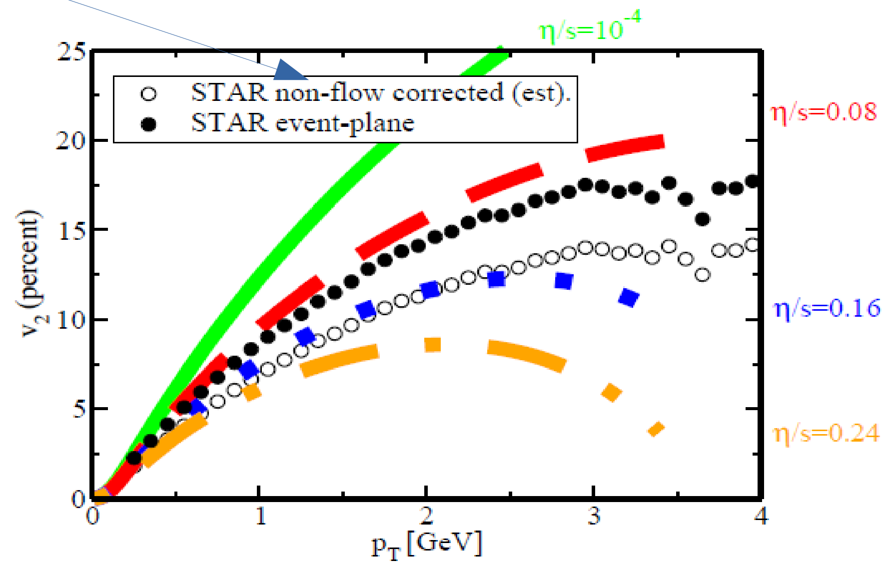
How viscous is the liquid?

20% reduced

Glauber IC



CGC IC



State-of-art results from second-order conformal hydro-dynamics (2+1D) yield a low shear viscosity to entropy ratio.

General consensus (from QM09) that: $\frac{\eta}{s} < 6 \times \frac{1}{4\pi}$

Reduced errors on v_2 data allows to study 20% effects.

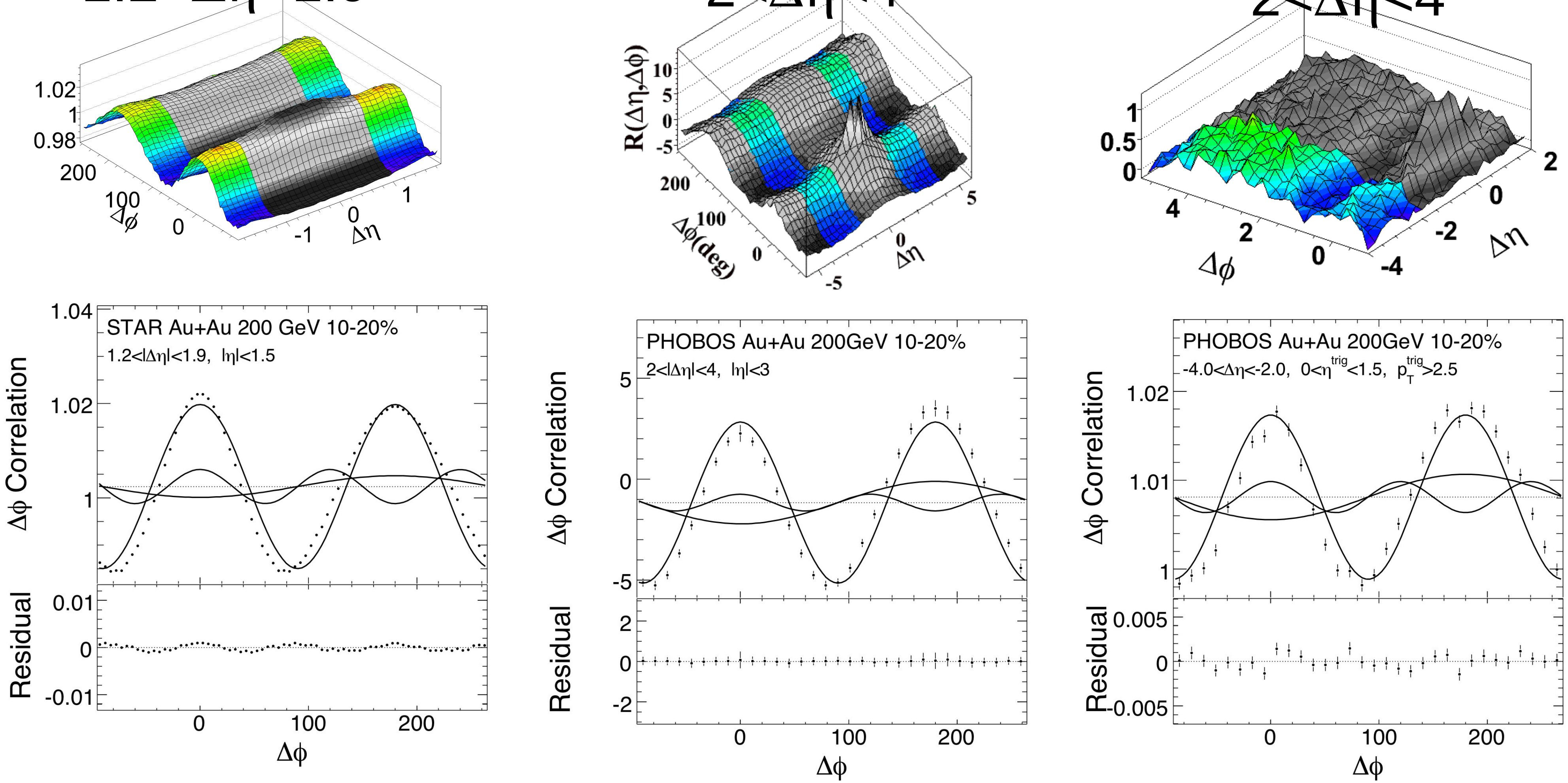
Luzum, Romatschke, PRC 78 034915 (2008); PRC 79 039903 (2009)

Correlations at large Δη

STAR inclusive
$1.2<\Delta\eta<1.9$

PHOBOS inclusive
$2<\Delta\eta<4$

PHOBOS p_T^{trig}>2GeV
(v2 subtracted)
$2<\Delta\eta<4$



Long range correlations are well described by 3 Fourier components

Alver, Roland, PRC 81 (2010) 054905

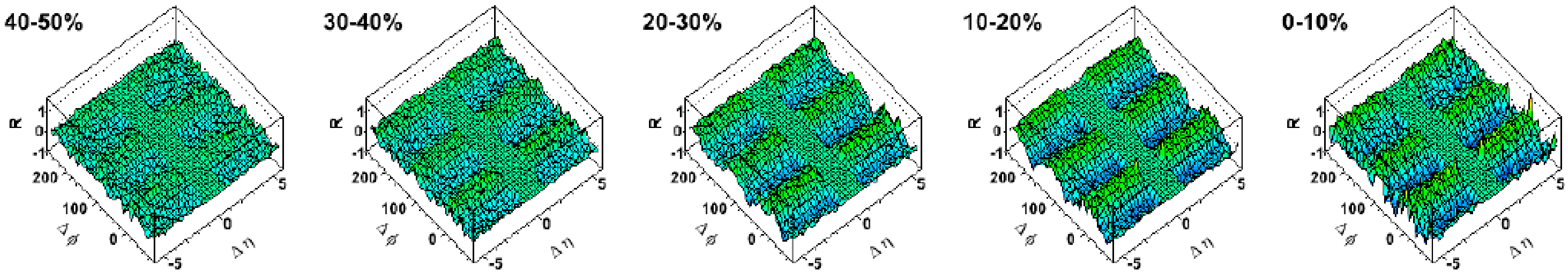
Closer look at “non-flow”

(Burak Alver, MIT meeting)

Remove first and second Fourier contribution and suppress short-range peak (|Δη|<1)

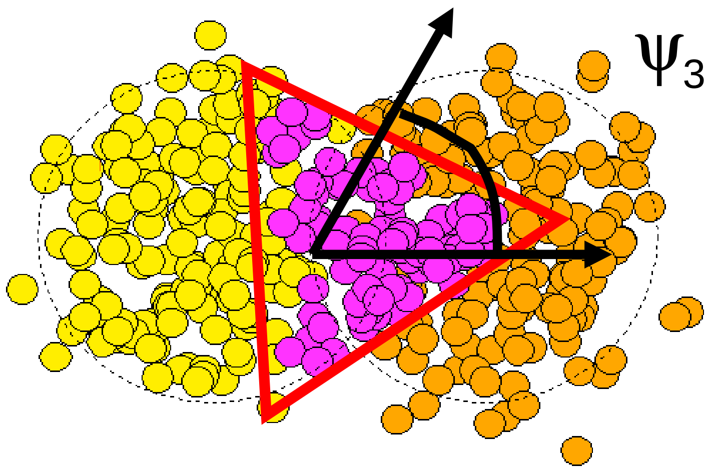
Is Third Fourier special?

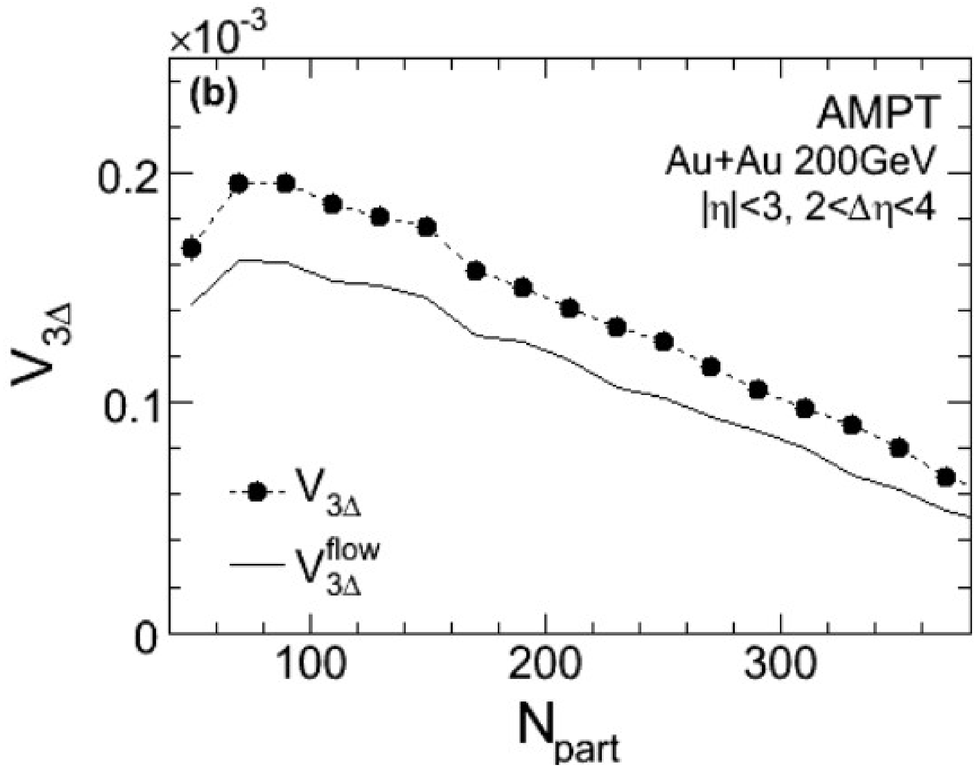
- It is a large effect
- It is there at large Δη
- Can it be linked to initial state?
- Is it a function of η (?)
- Measure centrality + p_T dependence, 3 particle correlations, non-flow, etc.



Ridge and broad away side: Even without trigger particle and at large Δη

Participant triangularity and triangular flow





Initial shape fluctuations:
Triangularity

Interactions present early

Momentum space anisotropy:
Triangular flow

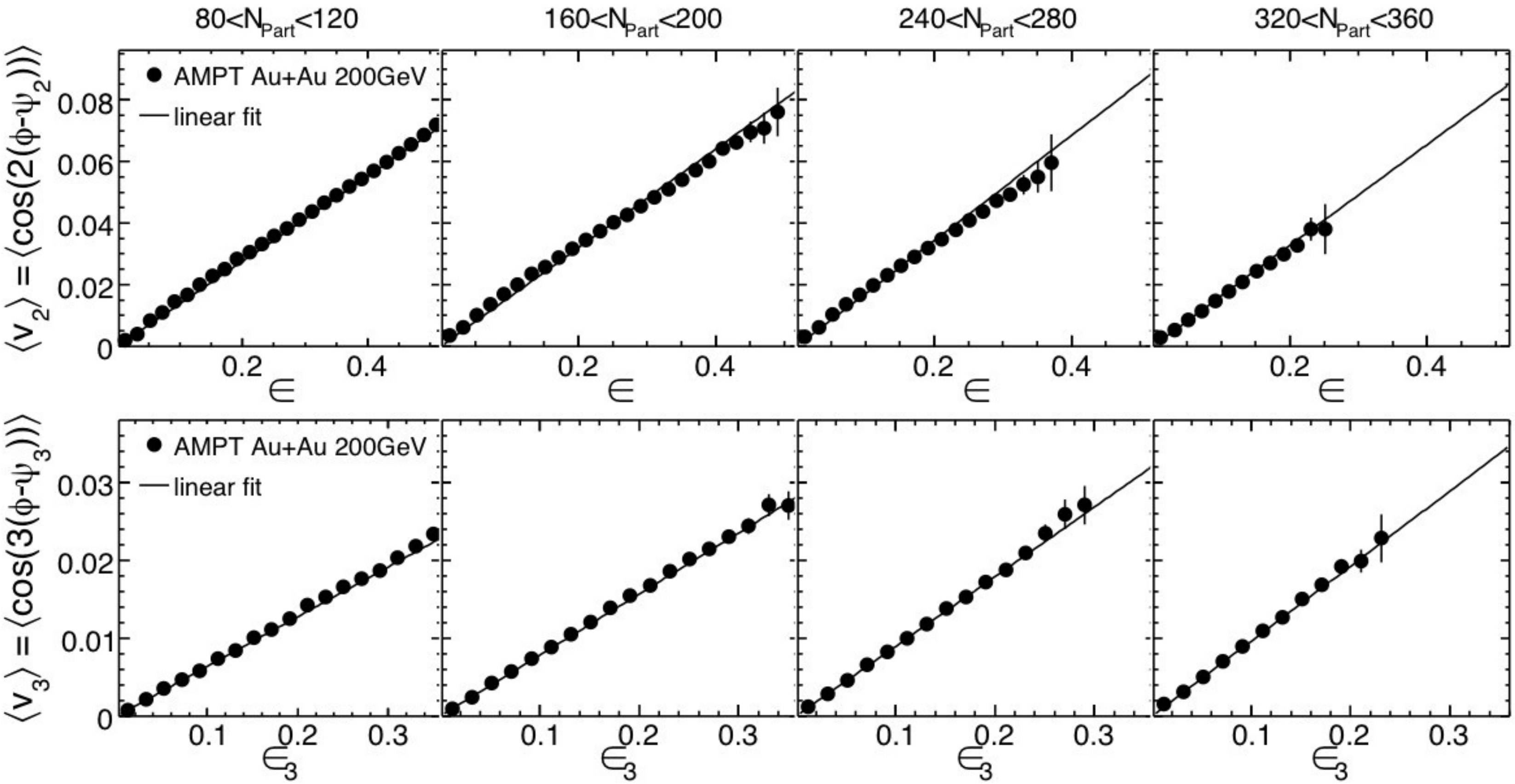
$$\varepsilon_3 = \frac{\sqrt{\left\langle\left(r^2\cos(3\phi)\right)\right\rangle^2 + \left\langle\left(r^2\sin(3\phi)\right)\right\rangle^2}}{\left\langle r^2\right\rangle}$$

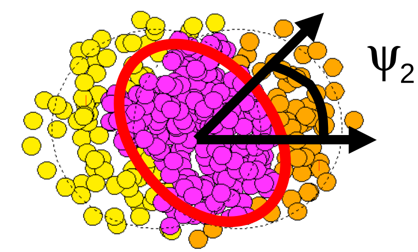
$$v_3 = \langle \cos(3\phi - 3\psi_3) \rangle$$

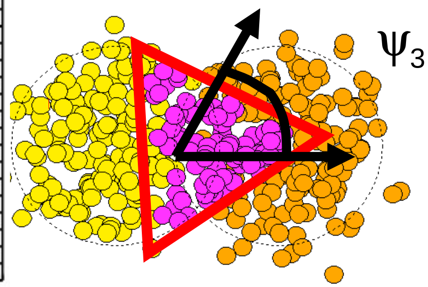
Alver, Roland, PRC 81 (2010) 054905

Triangular flow in AMPT

$$v_2 = \langle \cos(2\varphi - 2\psi_2) \rangle \sim \epsilon_2$$





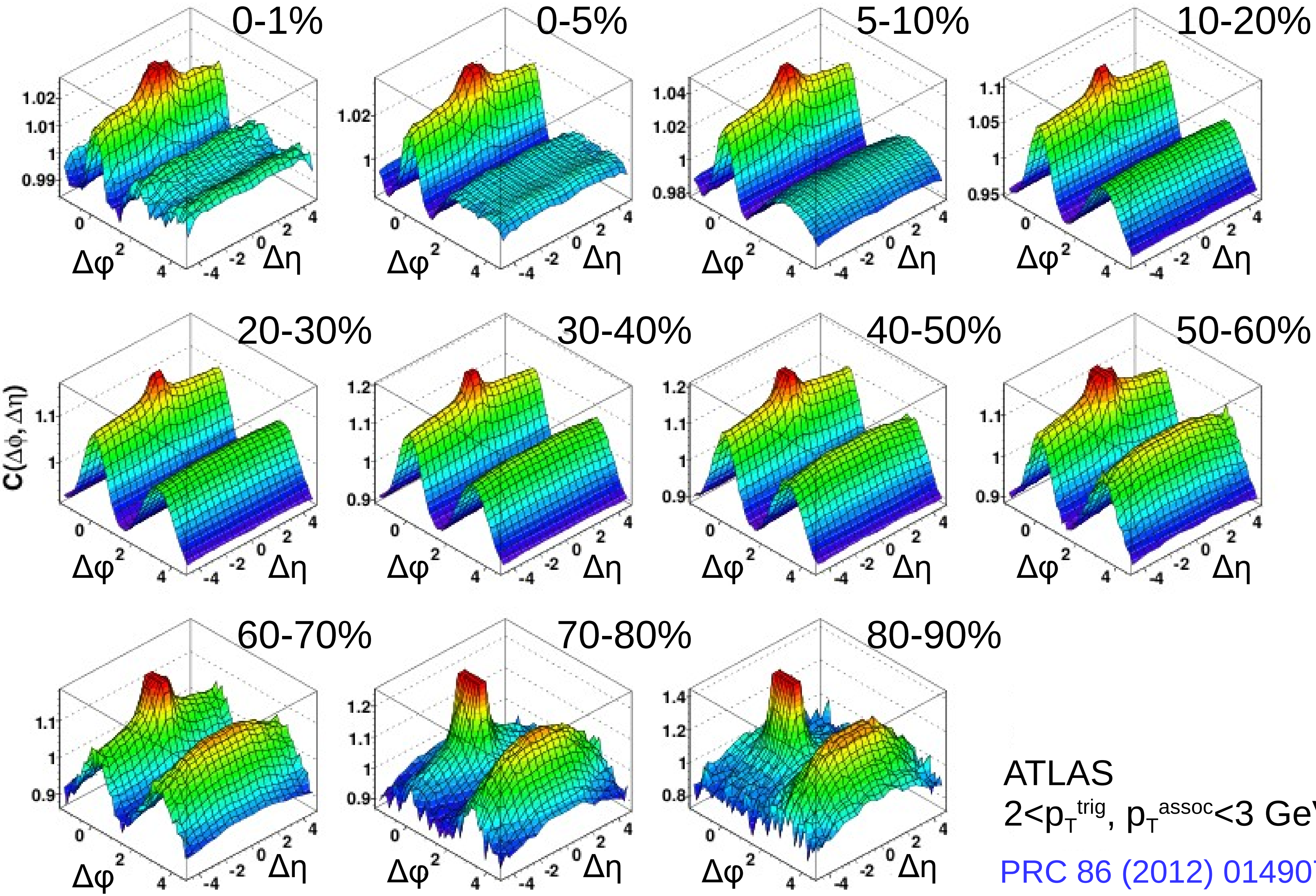


$$v_3 = \langle \cos(3\varphi - 3\psi_3) \rangle \sim \epsilon_3$$

Participant triangularity leads to triangular flow in AMPT

Alver, Roland, PRC 81 (2010) 054905

Two-particle angular correlations

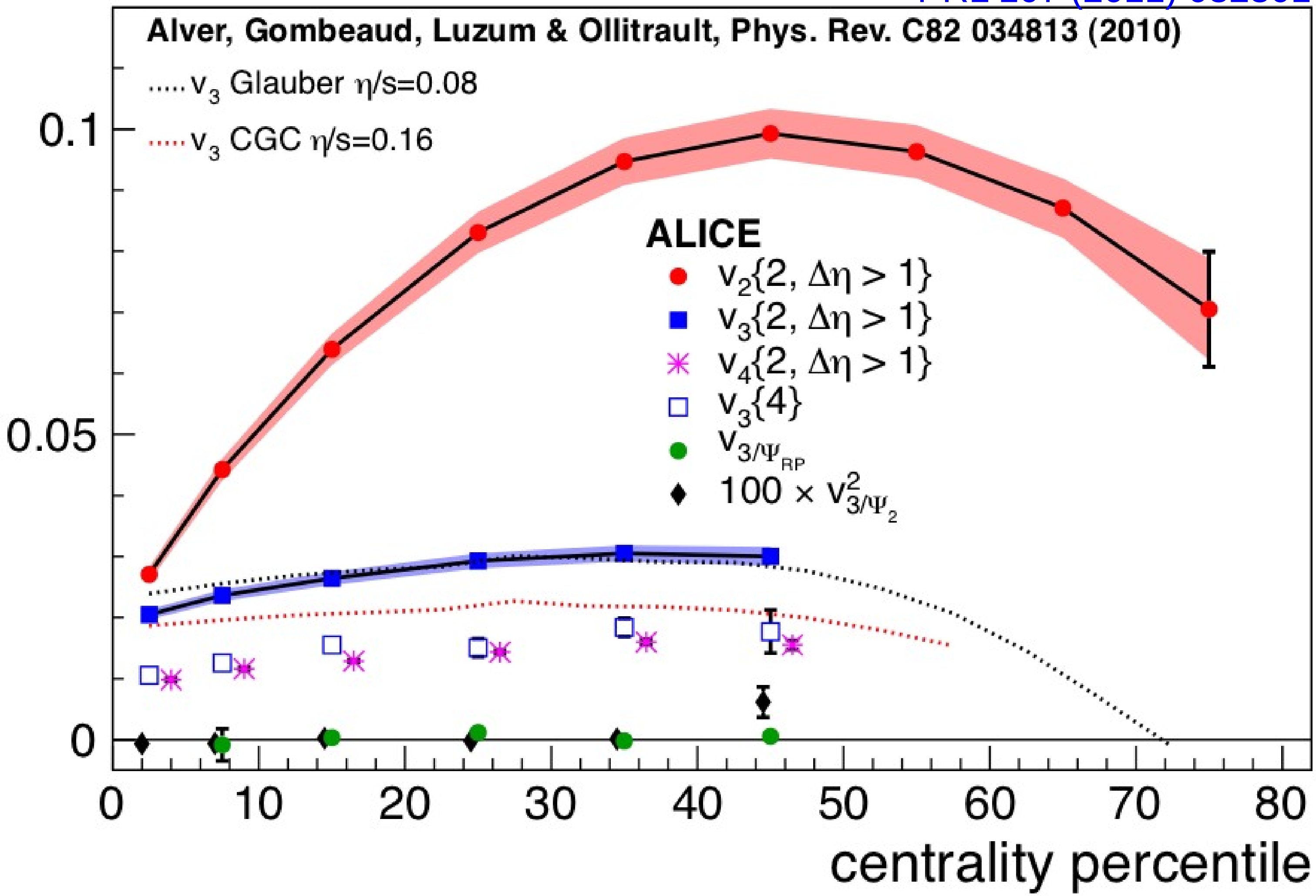


ATLAS
$2<p_T^{trig}, p_T^{assoc}<3$ GeV/c

PRC 86 (2012) 014907

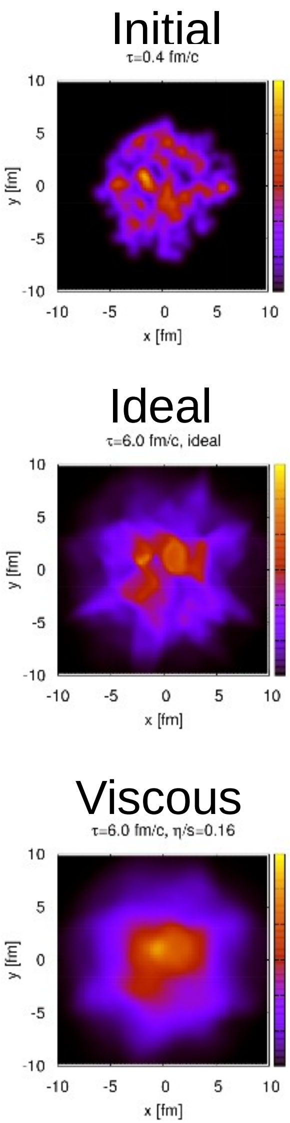
Higher harmonic flow

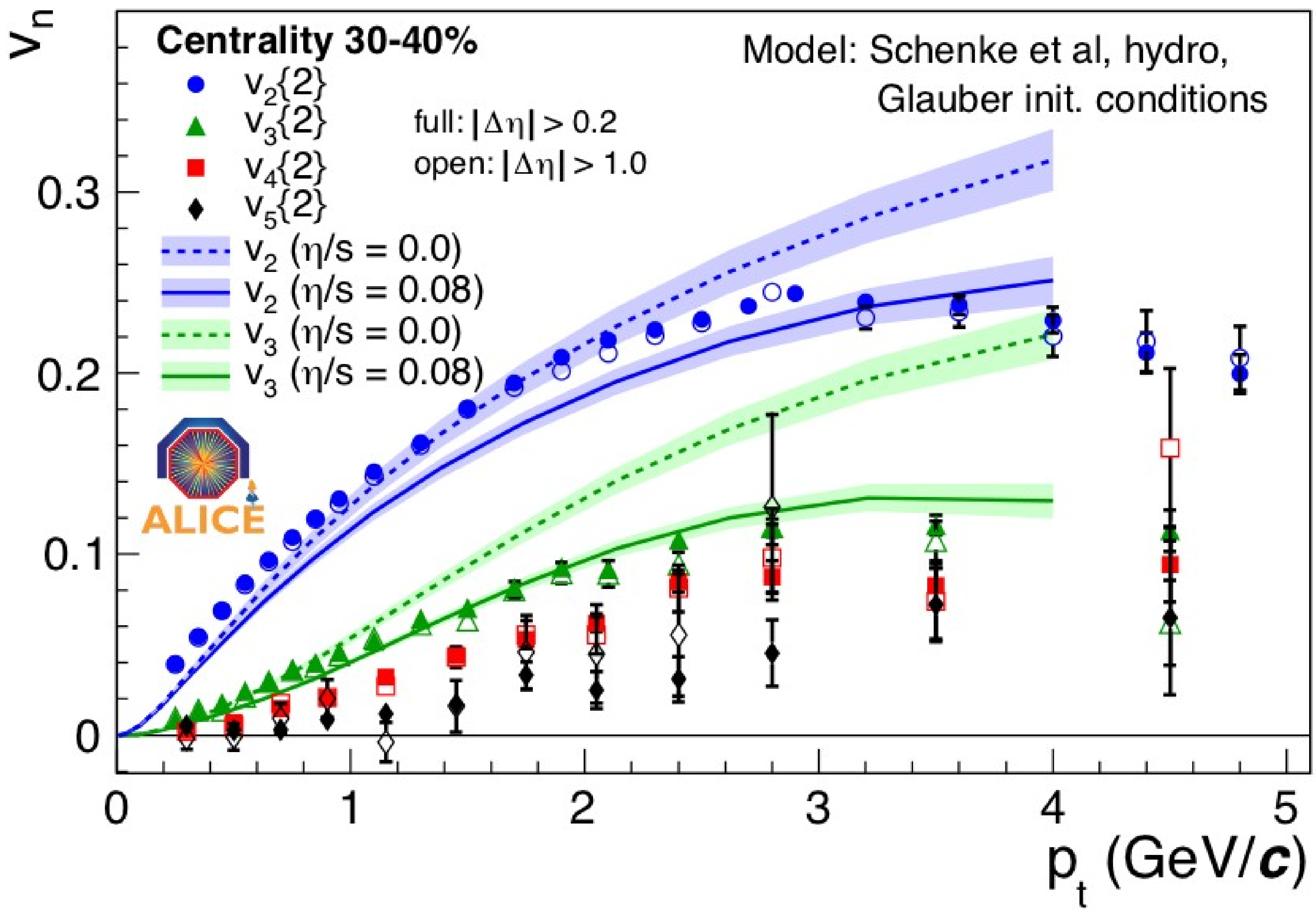
PRL 107 (2011) 032301



Significant triangular flow observed. Centrality dependence is different to that of elliptic flow. Measurements vs reaction plane yield zero as expected if it arises from fluctuations.

Fluctuations, viscosity and e-by-e hydro

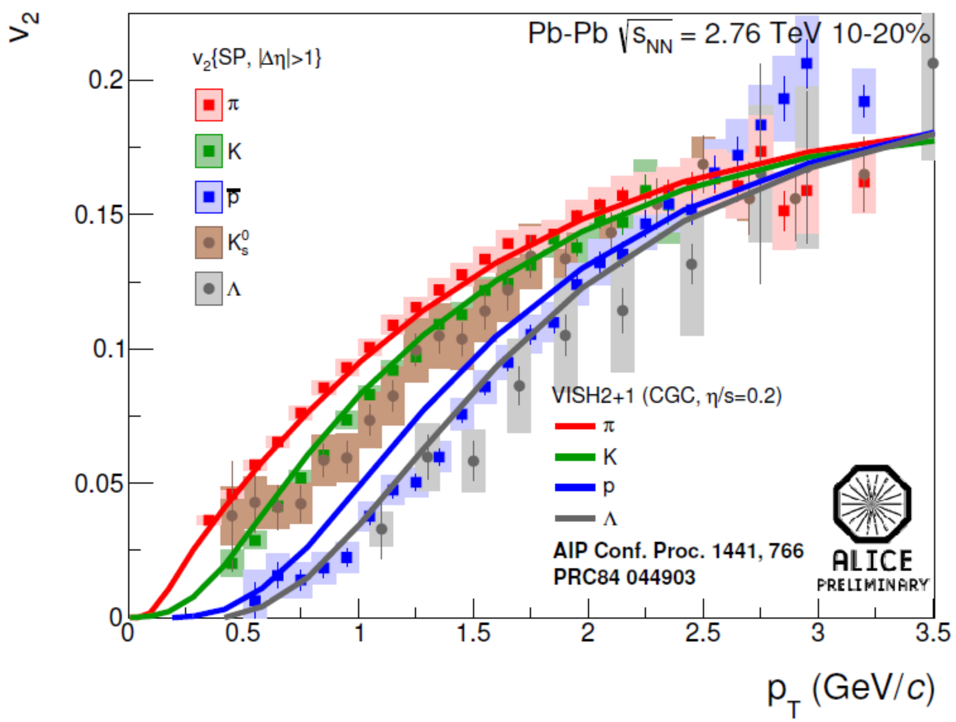




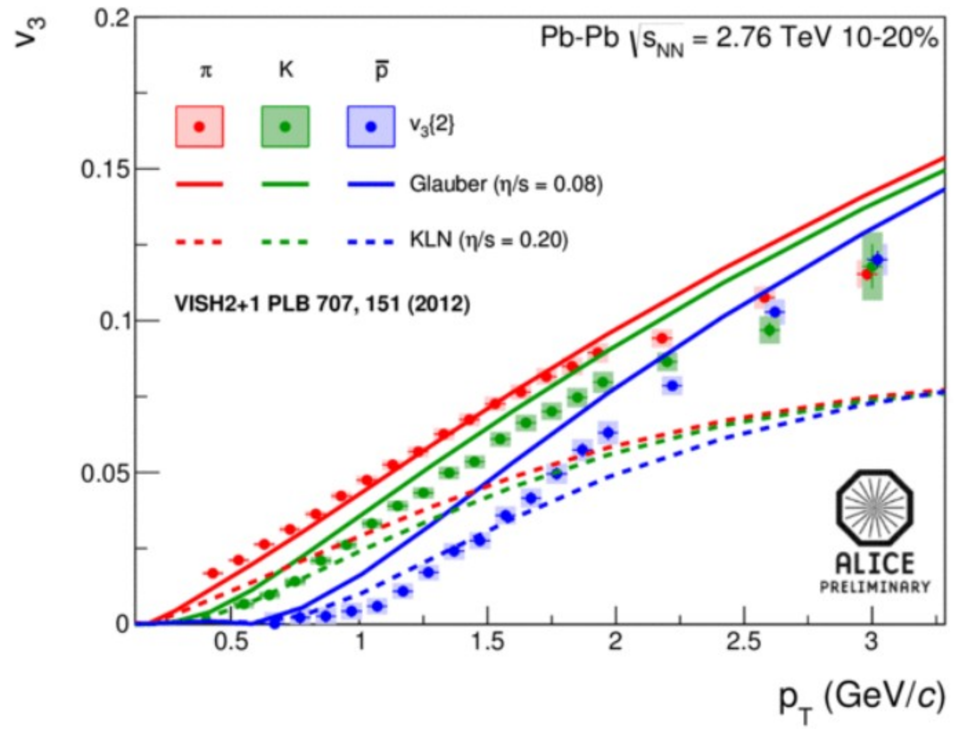
The overall dependence of v_2 and v_3 is described. However, not yet for a single η/s value. More constraints on initial conditions provided by v_3 and higher harmonics.

Mass-dependent splitting of v_2 and v_3

Elliptic flow



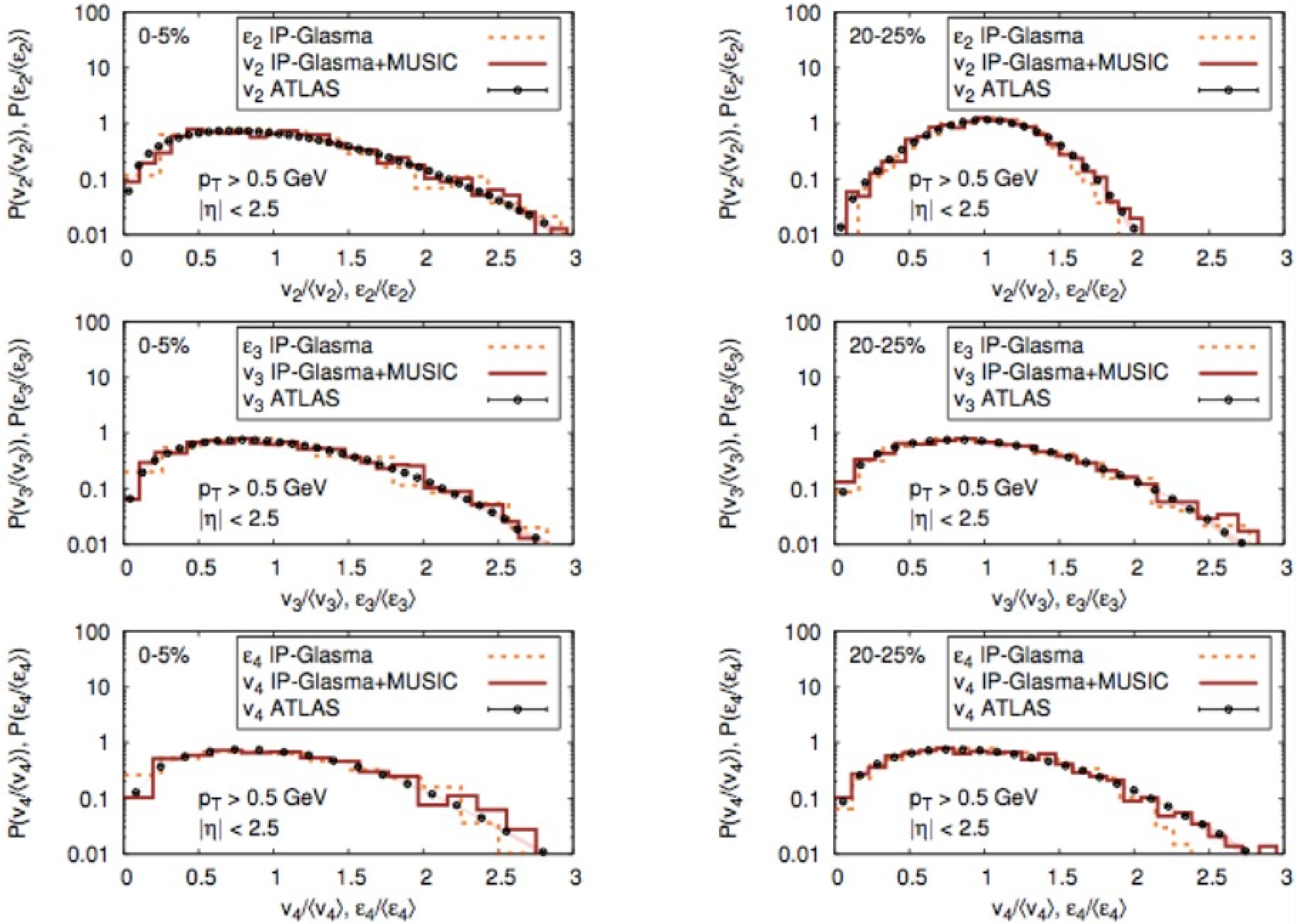
Triangular flow



- Particle mass dependent splitting from radial flow characteristic for v_2
- Can be described by hydrodynamical models (+ hadronic afterburners)

- Similar mass splitting for v_3
- Qualitatively described by hydrodynamical models (+ hadronic afterburners)
- Provides additional constraints on η/s

Event-by-event fluctuations



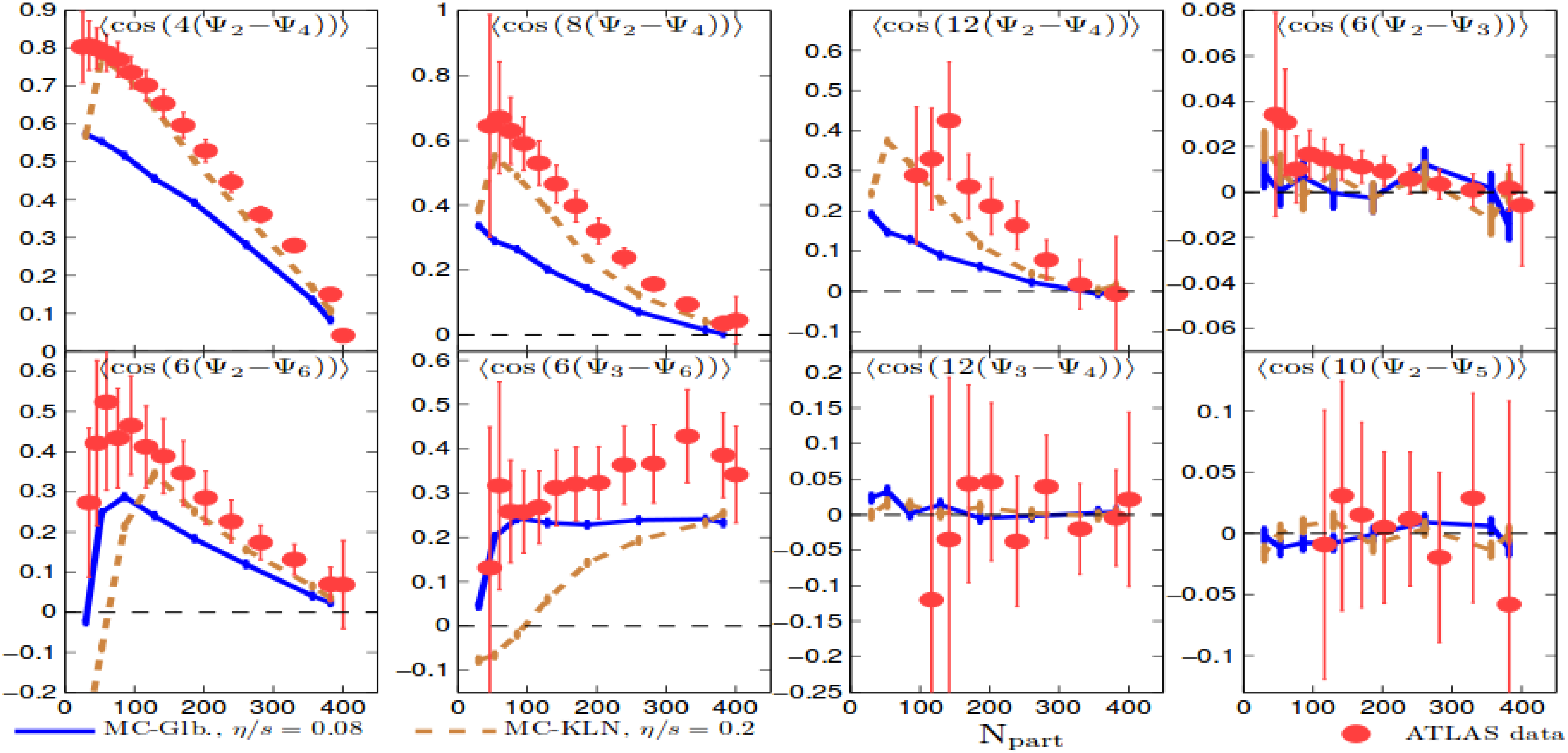
Hydro describes more than only average v_N

ATLAS, JHEP 11 (2013) 183

Schenke et al., PRL 110 (2013) 012302

Event plane angle correlations

Heinz et al., PLB 717 (2012) 261

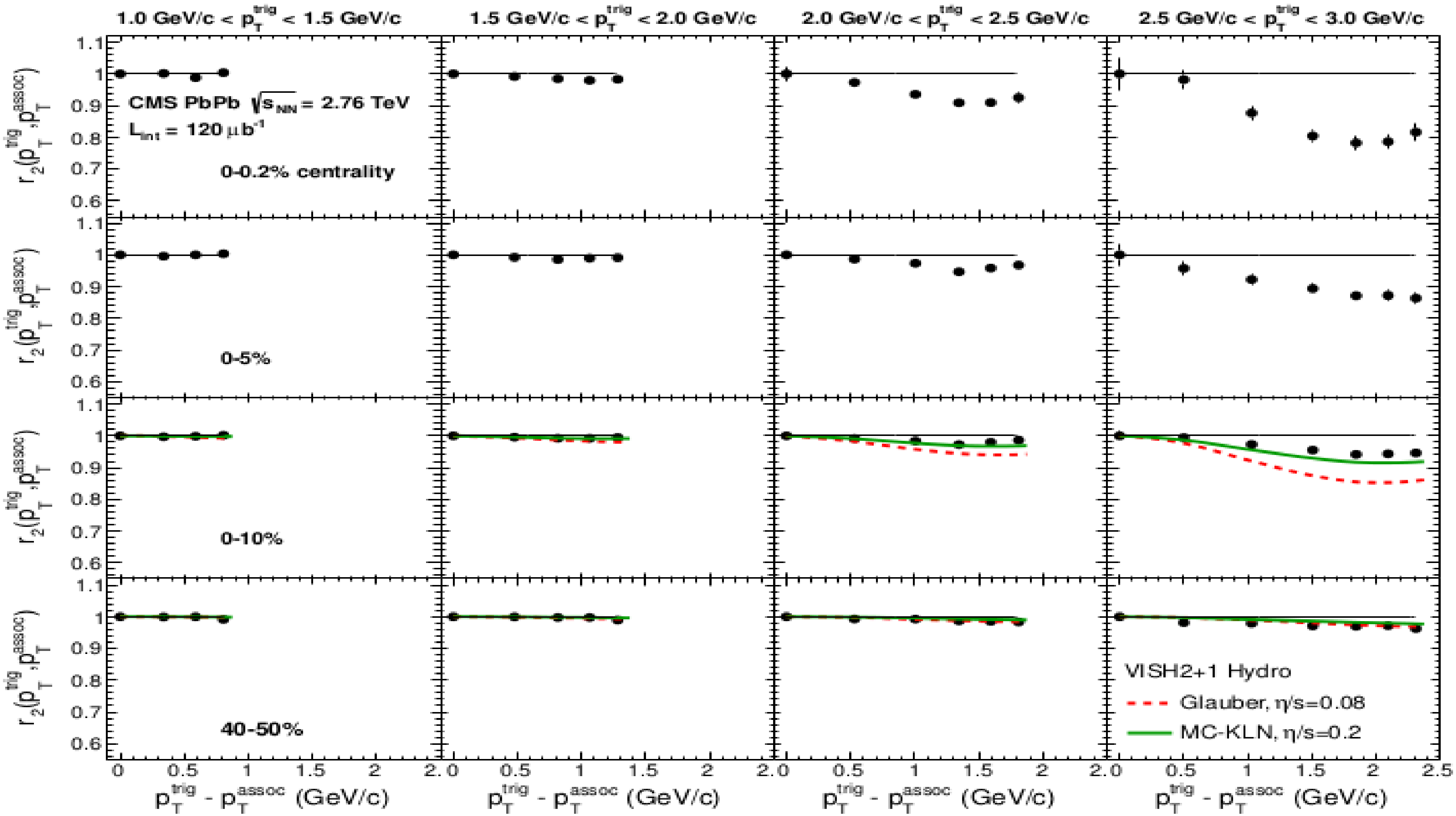


Fluctuations and hydrodynamic evolution lead to specific correlations of different order event plane angles

ATLAS, PRC 90 (2014) 024905

Factorization breakdown

JHEP 02 (2014) 088

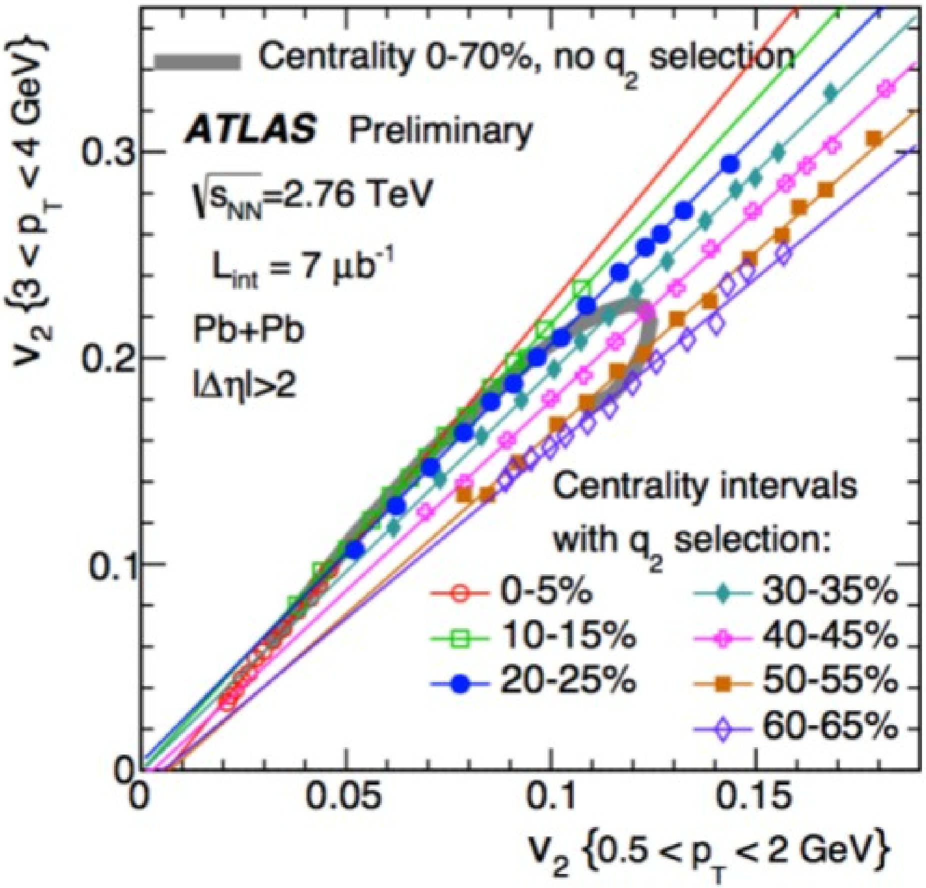


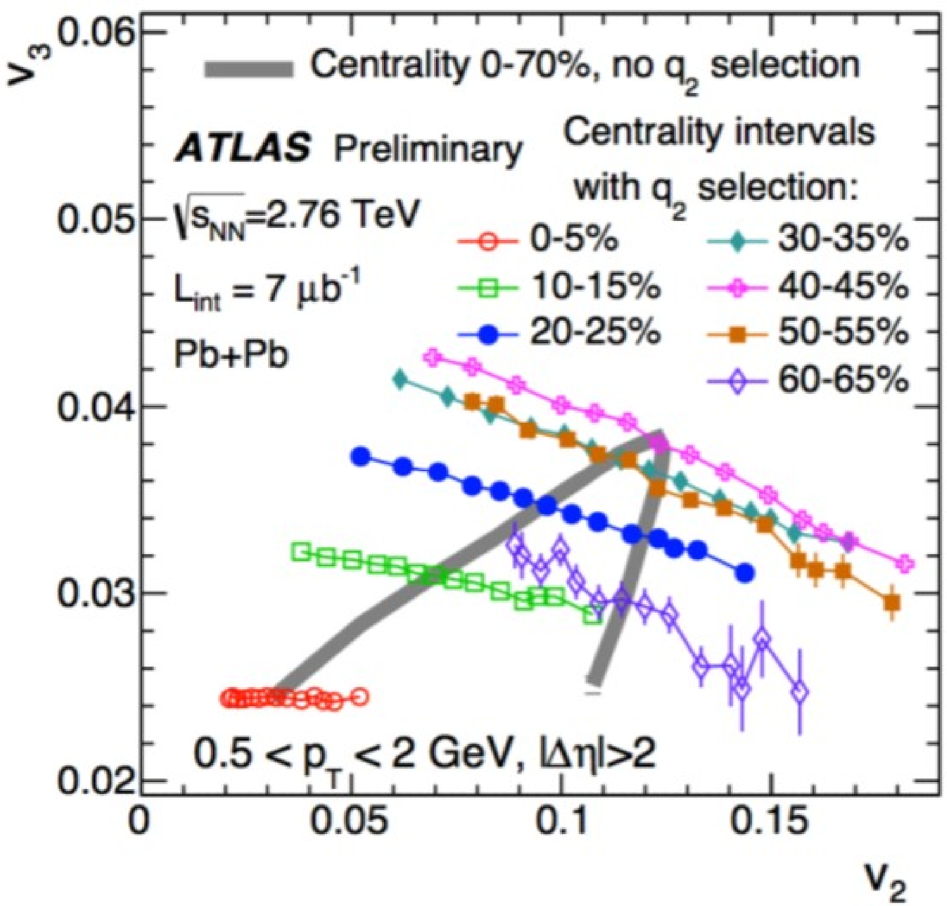
$$r_n \equiv \frac{V_{n\Delta}(p_T^a, p_T^b)}{\sqrt{V_{n\Delta}(p_T^a, p_T^a)}\sqrt{V_{n\Delta}(p_T^b, p_T^b)}}$$

$$\sim \left\langle \cos[n(\Psi_n(p_T^a) - \Psi_n(p_T^b))] \right\rangle$$

Factorization is broken by fluctuations that lead to p_T dependent event-plane angles

Event shape engineering





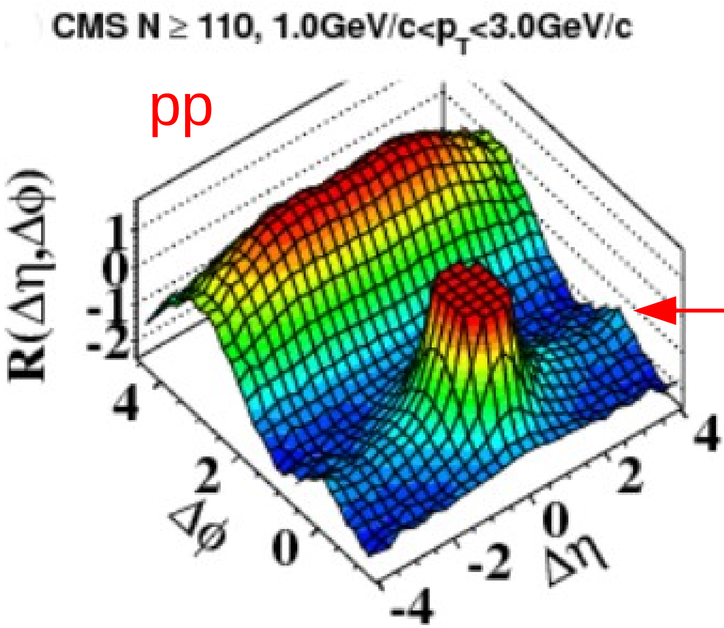
May indicate that viscous effects mostly controlled by system size rather by shape

Anti-correlation at fixed centrality: Constrain for models, in particular at 0-5% class

ATLAS-CONF-2014-022

Two-particle angular correlations at LHC

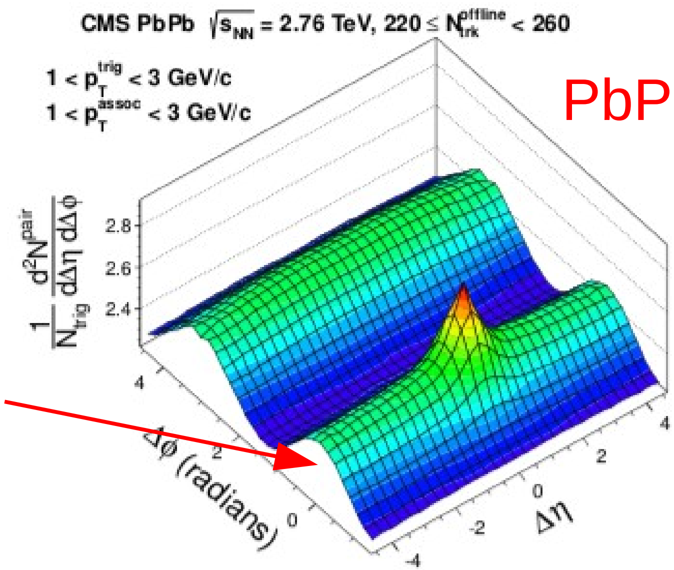
pp



CMS, JHEP 1009 (2010) 91

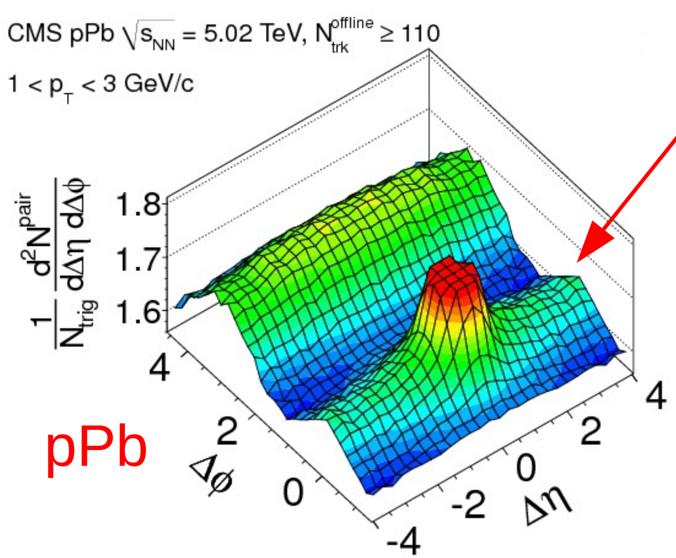
Near-side ridges apparent in high multiplicity events at LHC energies

PbPb



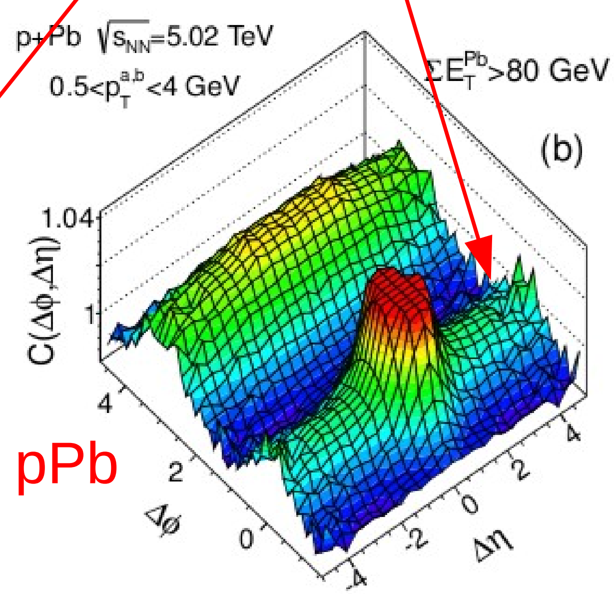
CMS, PLB 724 (2013) 213

pPb



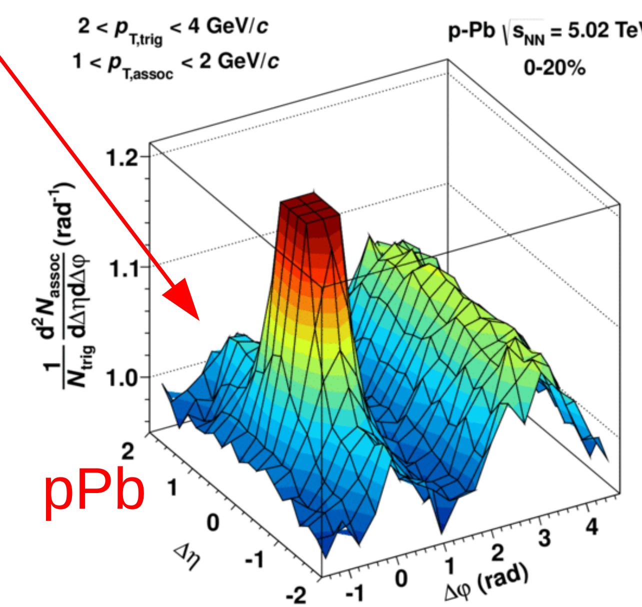
CMS, PLB 718 (2012) 795

pPb



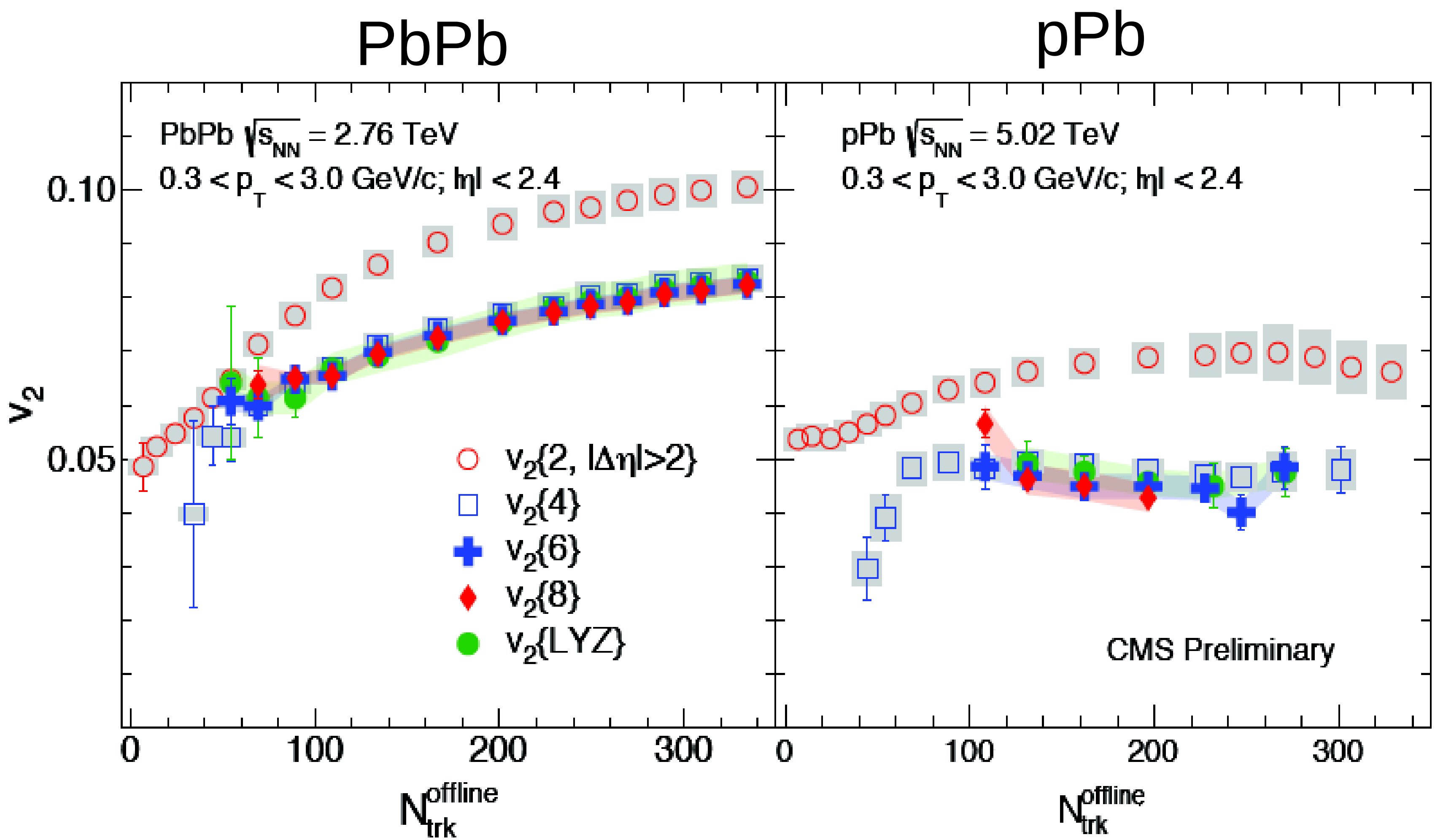
ATLAS, PRL 110 (2013) 182302

pPb



ALICE, PLB 719 (2013) 29

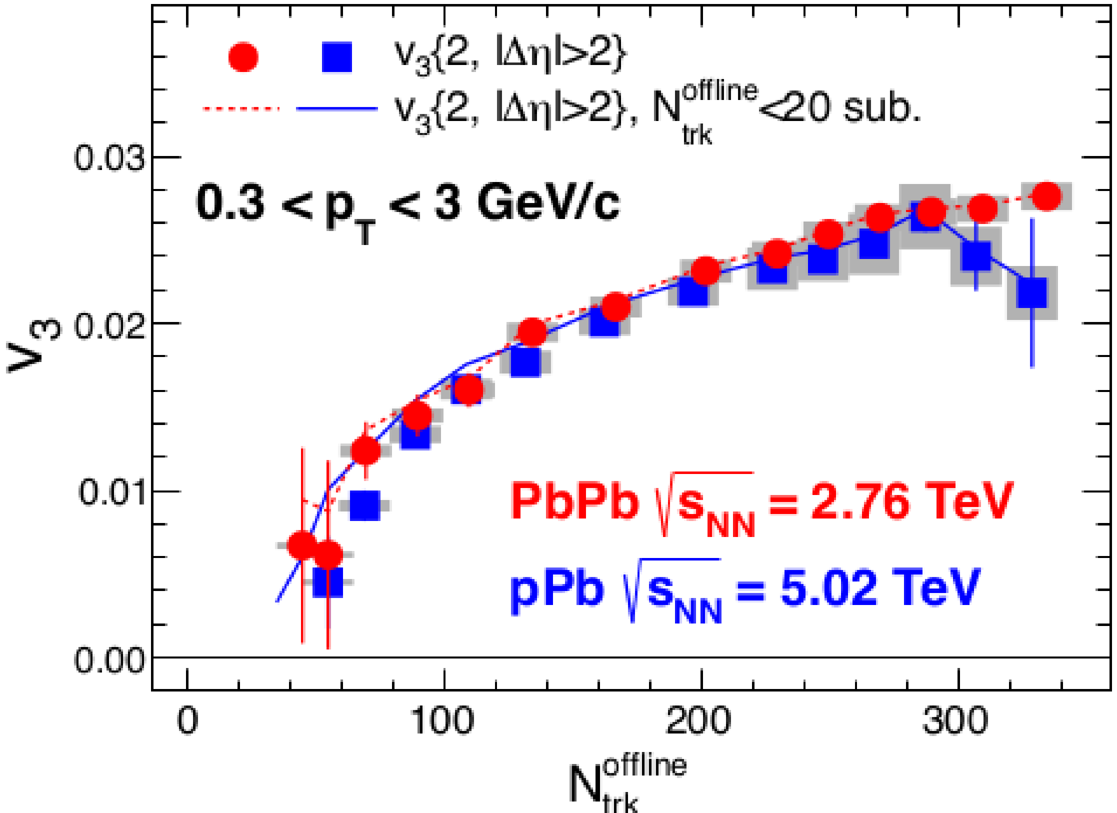
Multi-particle correlations in PbPb and pPb



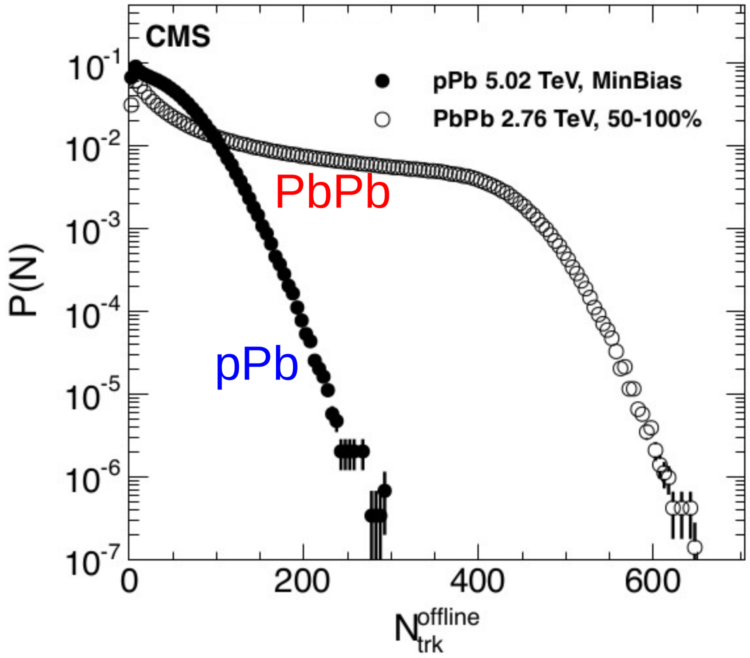
Multi-particle correlation results are the same within 10%.
Strong evidence of collective nature of correlations.

CMS-HIN-14-006

Integrated v_3 in PbPb and pPb



CMS, PLB 724 (2013) 213

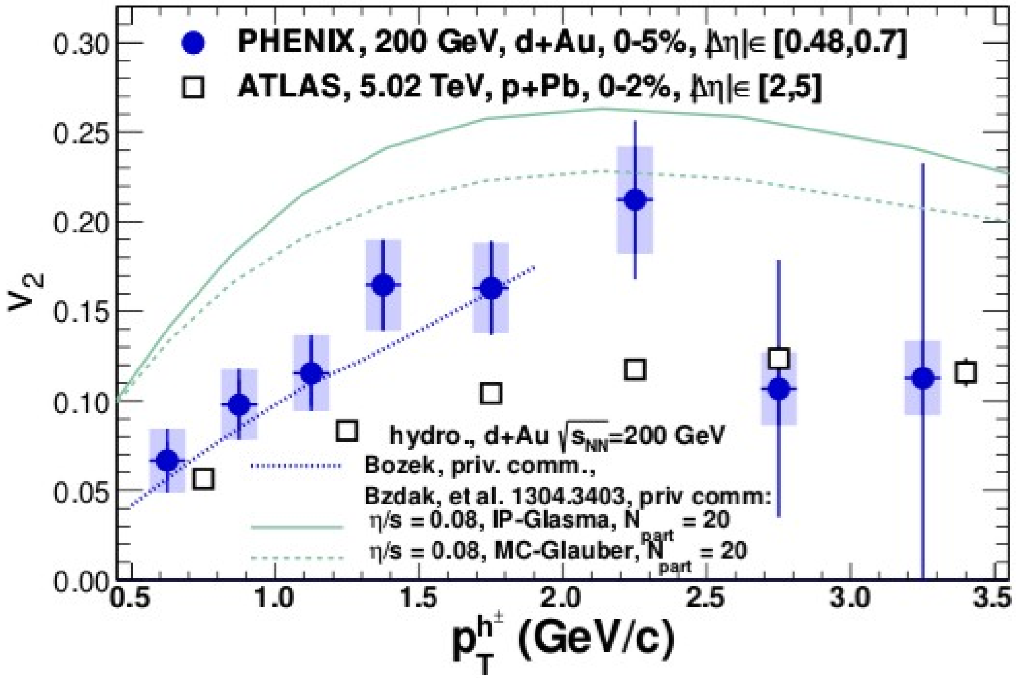


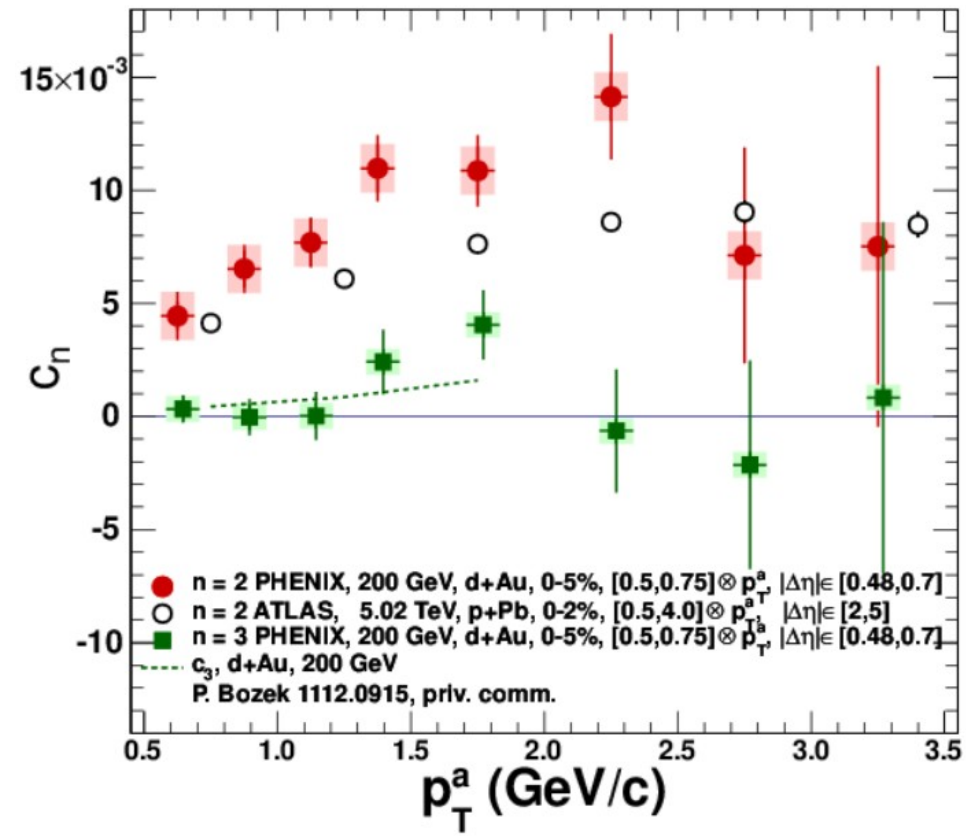
- Same v_3 in pPb as in PbPb
- Turn on at around M=50 tracks (~minbias pPb)
- Established picture in PbPb
  - Transformation of IS fluctuations into FS via interactions

- Same physics mechanism despite different underlying dynamics (+ system size)?
- Maybe we select on events in which the proton wave function fluctuated to large values (fat proton, Mueller, arXiv:1307.5911v2)

v_2 and v_3 in dAu at RHIC

PHENIX, PRL 111 (2013) 212301

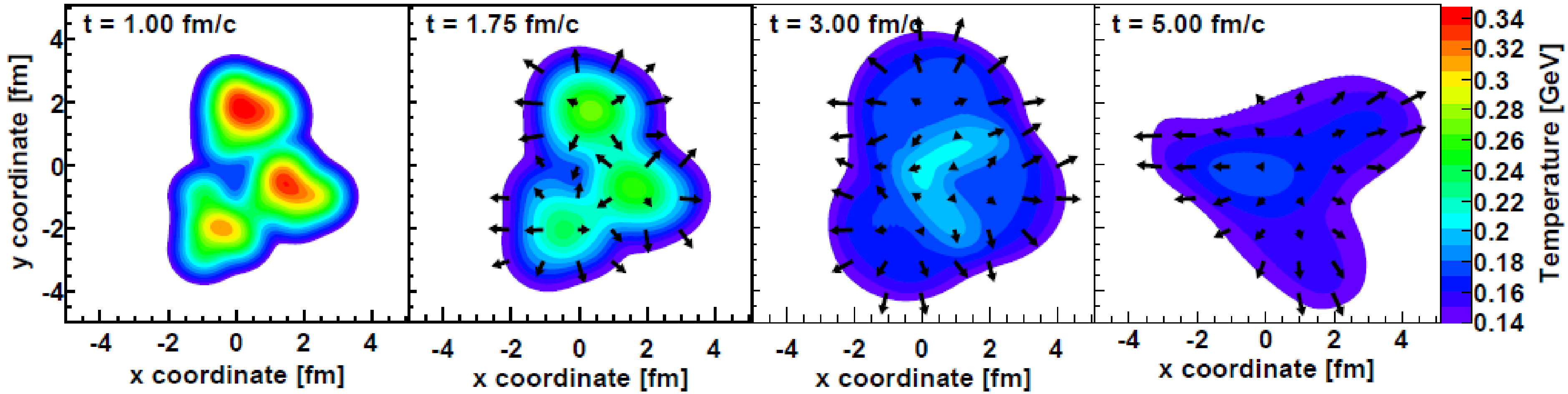


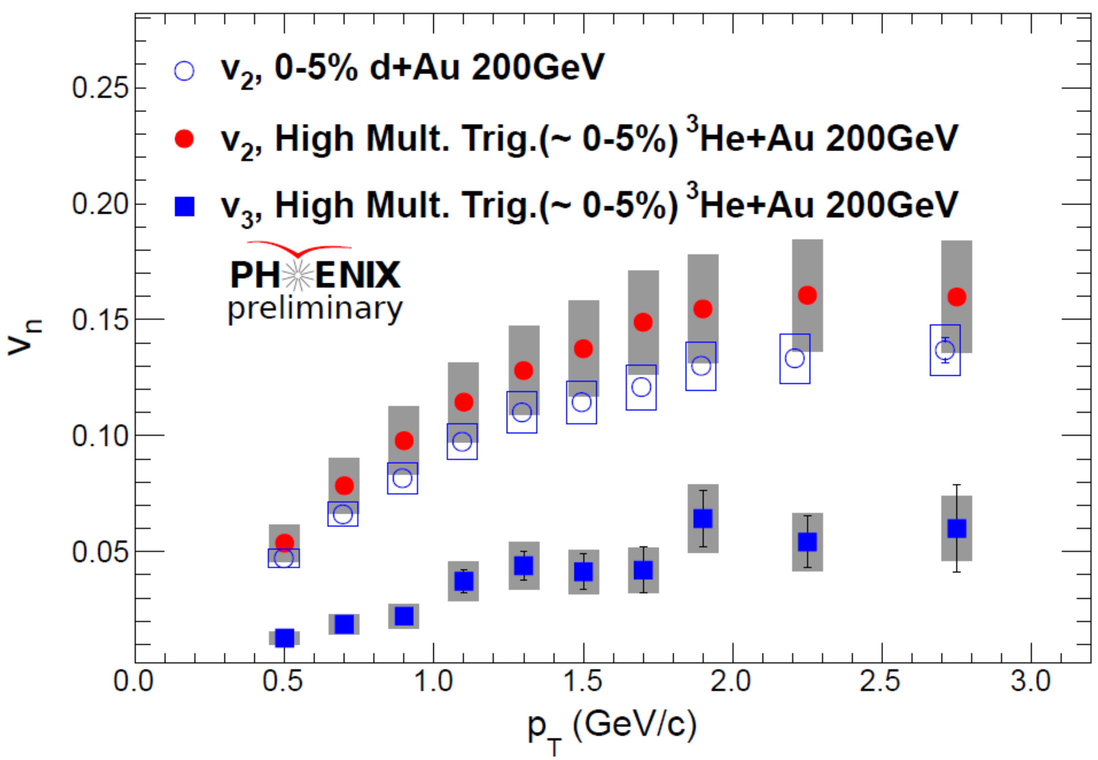


Large v_2 (about twice as much as that of pPb) and negligible v_3 found in dAu, as expect from initial state eccentricities.

Geometric engineering

Nagle et al., PRL 113 (2014) 112301





Expectation from IS:

- **^{3}He+Au (0-5%) N_{part}=25.0**
  ε_2=0.504 ε_3=0.283
- **d+Au (0-5%) N_{part}=17.8**
  ε_2=0.540 ε_3=0.190

Measurement:

- The v_2 of **^{3}He+Au** is similar to that of **d+Au**
- A clear $\boldsymbol{v_3}$ signal observed in 0-5% **^{3}He+Au** collisions

Summary / Outlook

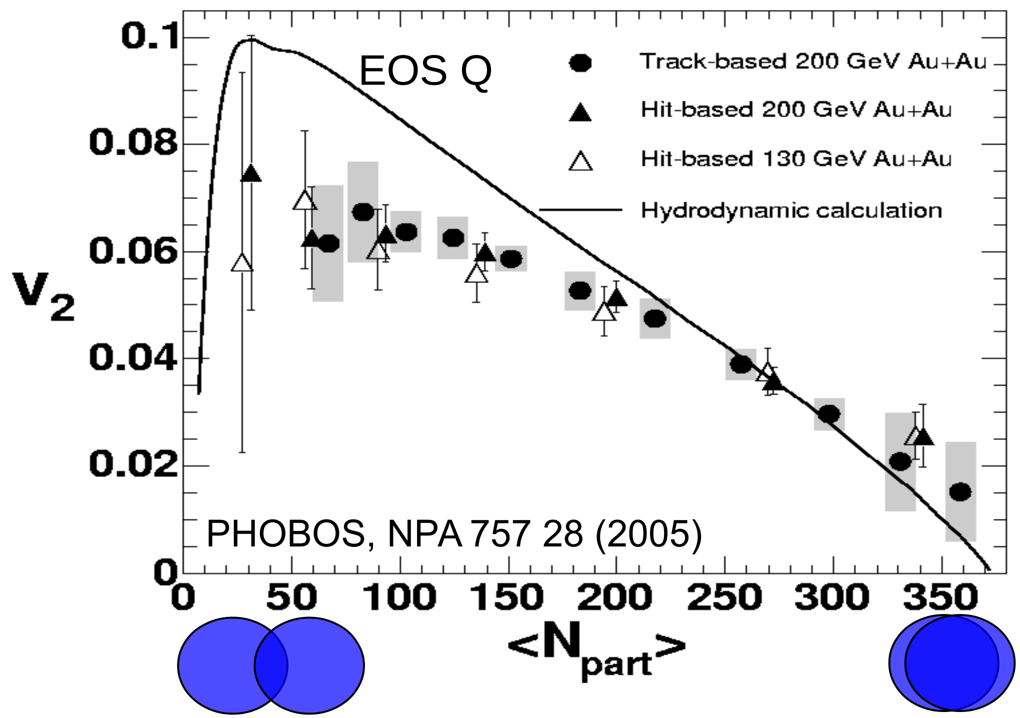
- Understanding of connection between initial and final state in AA collisions significantly advanced in past 10 years
- Hydrodynamical models passed a variety of tests
  - Still often qualitatively and not fully systematically applied
  - Many aspects also described by AMPT
- Onset of collectivity in small systems not surprising if the created system is “comparable in size” to that of a peripheral AA
  - Small systems allow one to study flow from fluctuations only
  - In pA collisions the (sub-)structure of p is probed
    - Long pAu run in 2015 at RHIC for further experimental insight
  - Models should attempt to describe p/dA and AA and systematically explore the similarity and difference between them (if any)
    - Is there (partial) thermalization?
    - Is there jet modification or suppression?
    - Is the physics origin in high mult pp the same?
    - Is there a change from IS (GLASMA) dominance to FS (HYDRO) evolution?

Extra

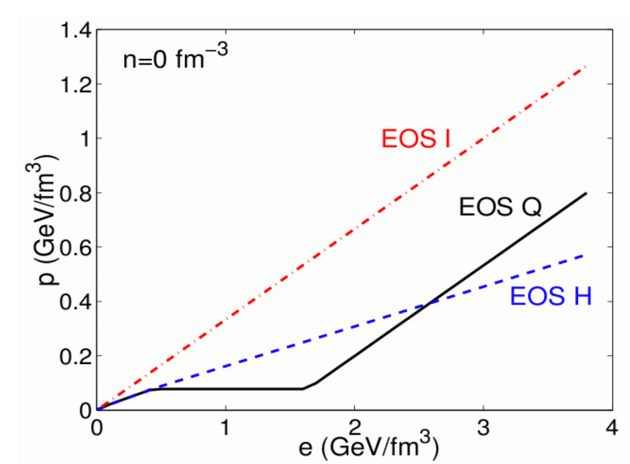
Elliptic flow and ideal hydro

Ideal relativistic hydrodynamics

$$T^{\mu\nu}=(e+p)u^{\mu}u^{\nu}-p\,g^{\mu\nu}$$
$$\delta_{\mu}T^{\mu\nu}=0$$
$$\delta_{\mu}N_{i}^{\mu}=0,\ i=B,S,\ldots$$
$$p=p(e,n)$$ Closure with EoS

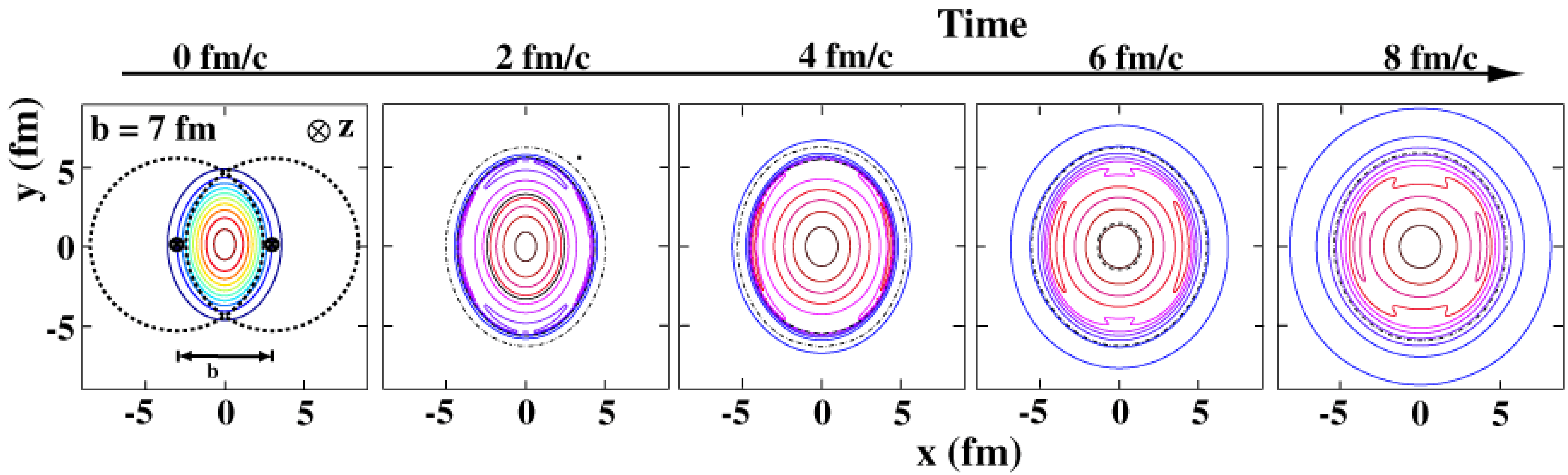


Assumption:
After a short thermalization time (≤1fm/c) a system in local equilibrium with zero mean free path and zero viscosity is created



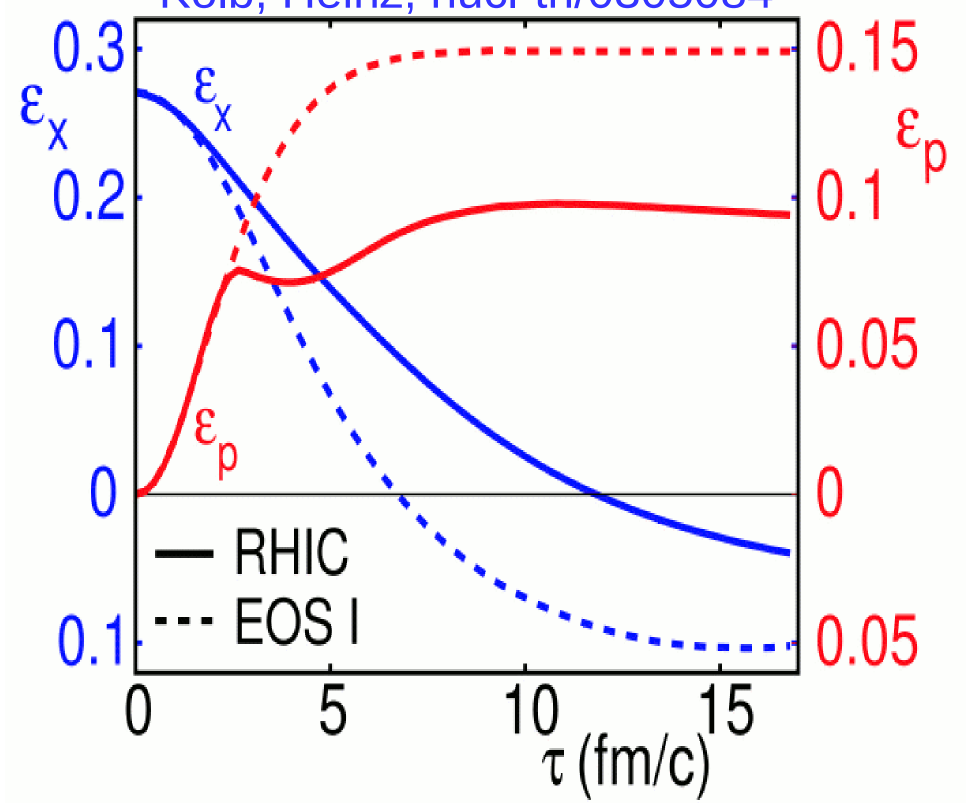
Initial conditions (IC) →
Equation of state (EOS) → **Hydro** → Observables
Freeze-out cond. (FO) →

Elliptic flow: Self quenching



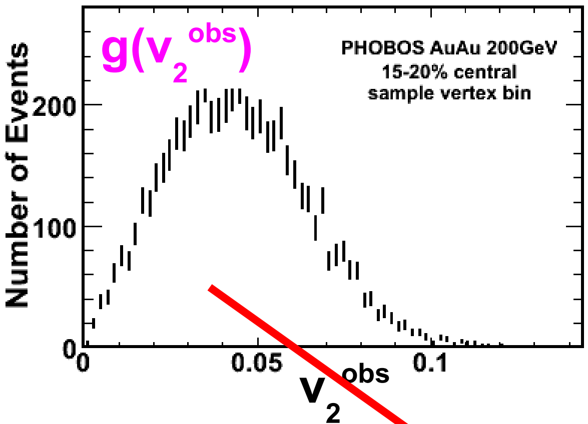
- The picture is supported by a hydrodynamical calculation using two different equations of state
- The momentum anisotropy is dominantly built up in the QGP (τ<2-3fm/c) phase and stays constant in the (first-order) phase transition, and only slightly rises in the hadronic phase

Kolb, Heinz, nucl-th/0305084

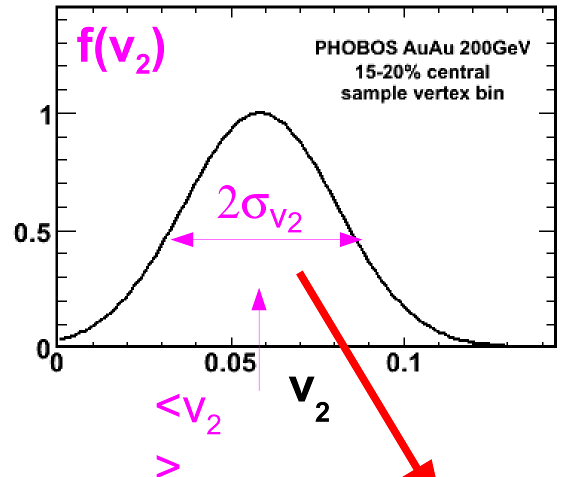


Measuring elliptic flow fluctuations

Observed v_2 distribution



Parametrized v_2 distribution



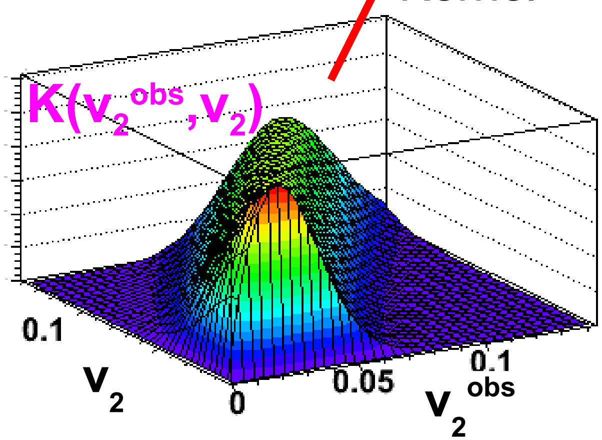
Max-Likelihood fit to determine: $\langle v_2 \rangle$ and σ_{v2}

$$g(v_2^{obs}) = \int_0^1 K(v_2^{obs}, v_2)\, f(v_2)\, dv_2$$

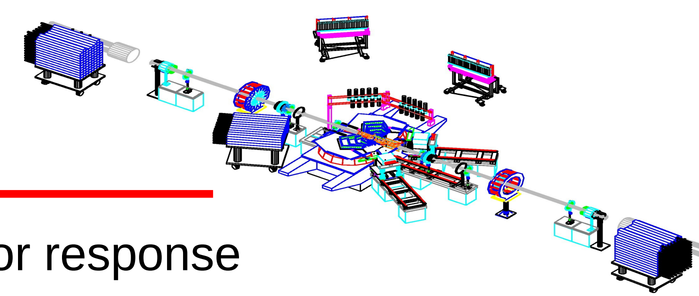
Kernel

- Detector and acceptance effects
- Finite-number fluctuations
- Multiplicity fluctuations

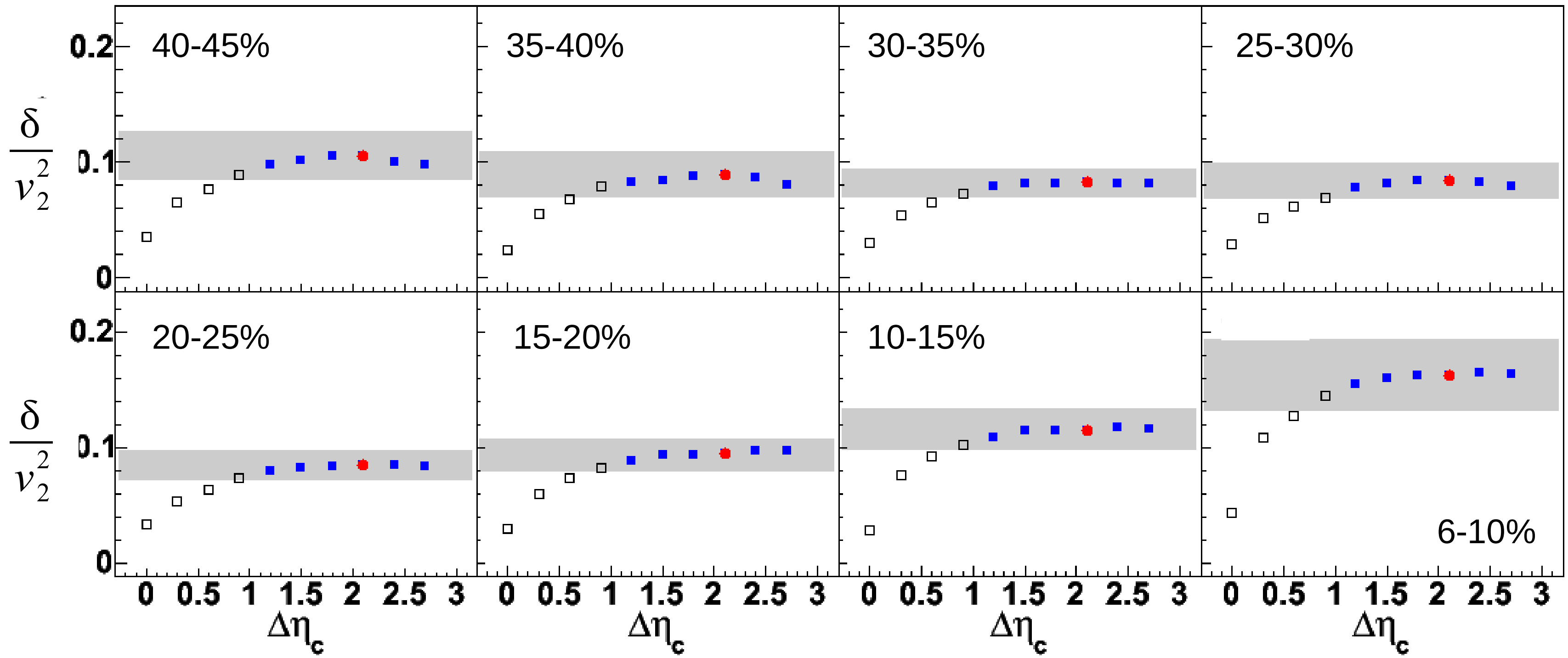
Kernel



Detector response



Variation of the fit region



Non-flow ratio as a function of Δη cut used to define the fit region.

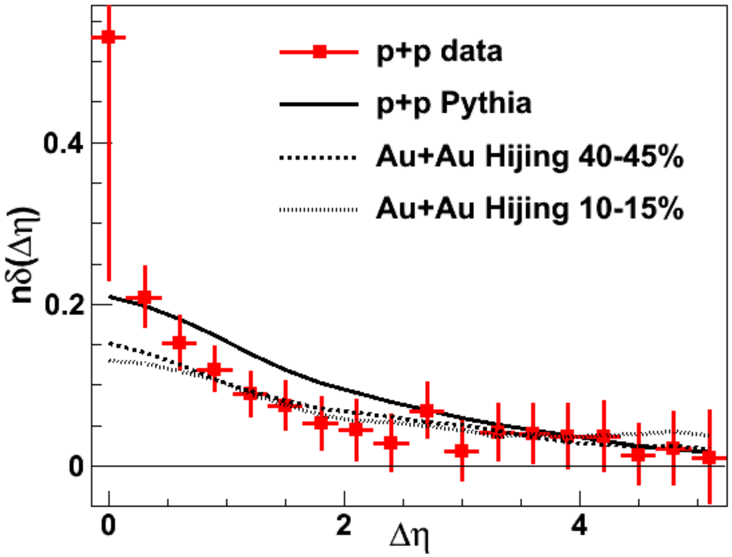
Red-point is baseline for analysis, while black points are used for systematic error

Saturation is very encouraging, however does not rule out contributions with very little Δη dependence.

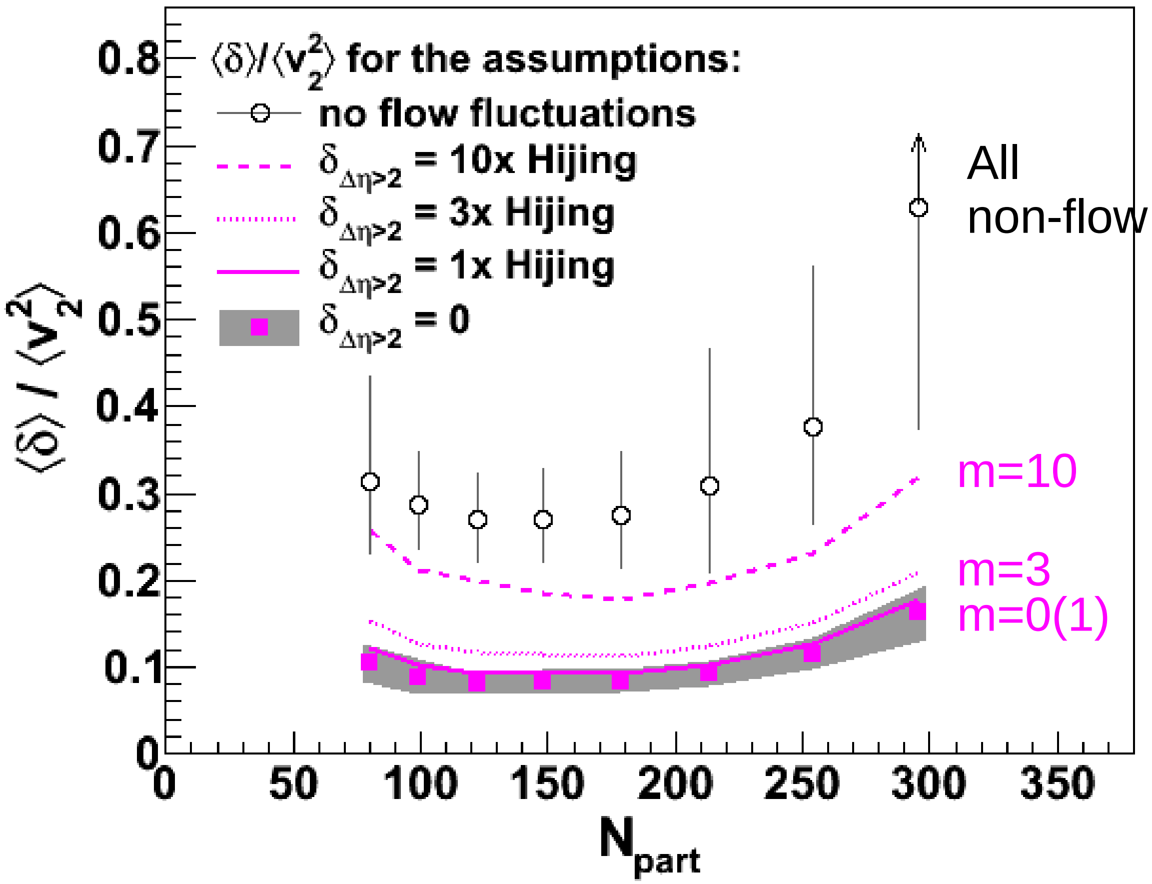
PHOBOS, PRC 81 (2010) 034915

Variation of non-flow strength in fit region

Non-flow in p+p, 200 GeV



δ / v_2^2 for assumptions in Au+Au, 200 GeV



Measure "non-flow" in p+p data, and compare to MC generators

Assume non-flow in fit region to be m times non-flow in p+p (rather than 0)

$$v_2^2(\eta_1, \eta_2) - m\,\delta_{MC}^{HIJING} = v_2^{fit}(\eta_1) * v_2^{fit}(\eta_2) \quad |\eta_2 - \eta_1| > 2$$

PHOBOS, PRC 81 (2010) 034915

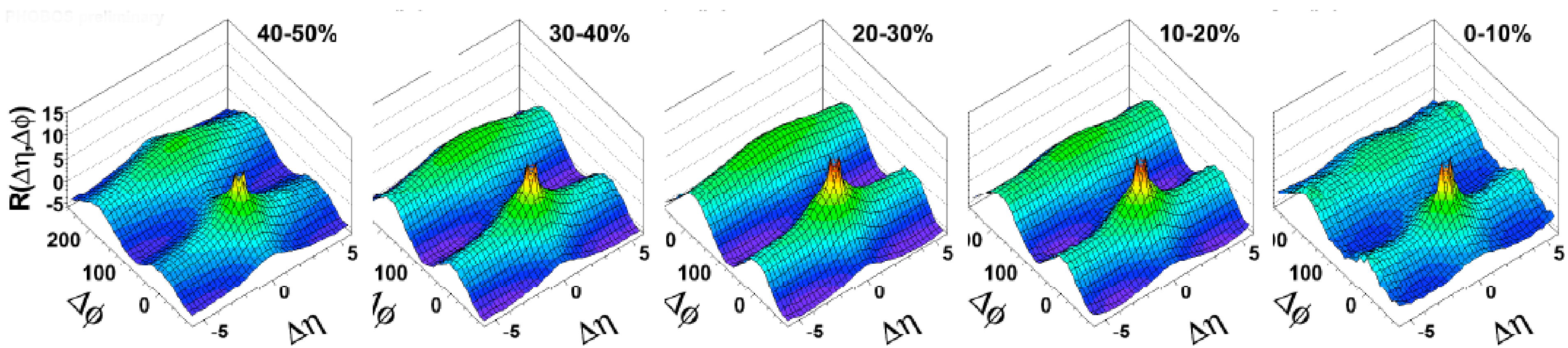
Flow vs non-flow

Standard picture:

- Flow = global ("collective")
  - Second Fourier coefficient
- Non-flow = local ("clusters")
  - All Fourier coefficients

Why is Second Fourier special?

- It is a large effect
- It is present at large Δη
- It is a function of η
- v_2/ε, $v_2(p_T)$, $v_2(RP)$, $v_2\{4\}$, fluctuations, etc., make "sense"



Measuring the v_2 coefficient

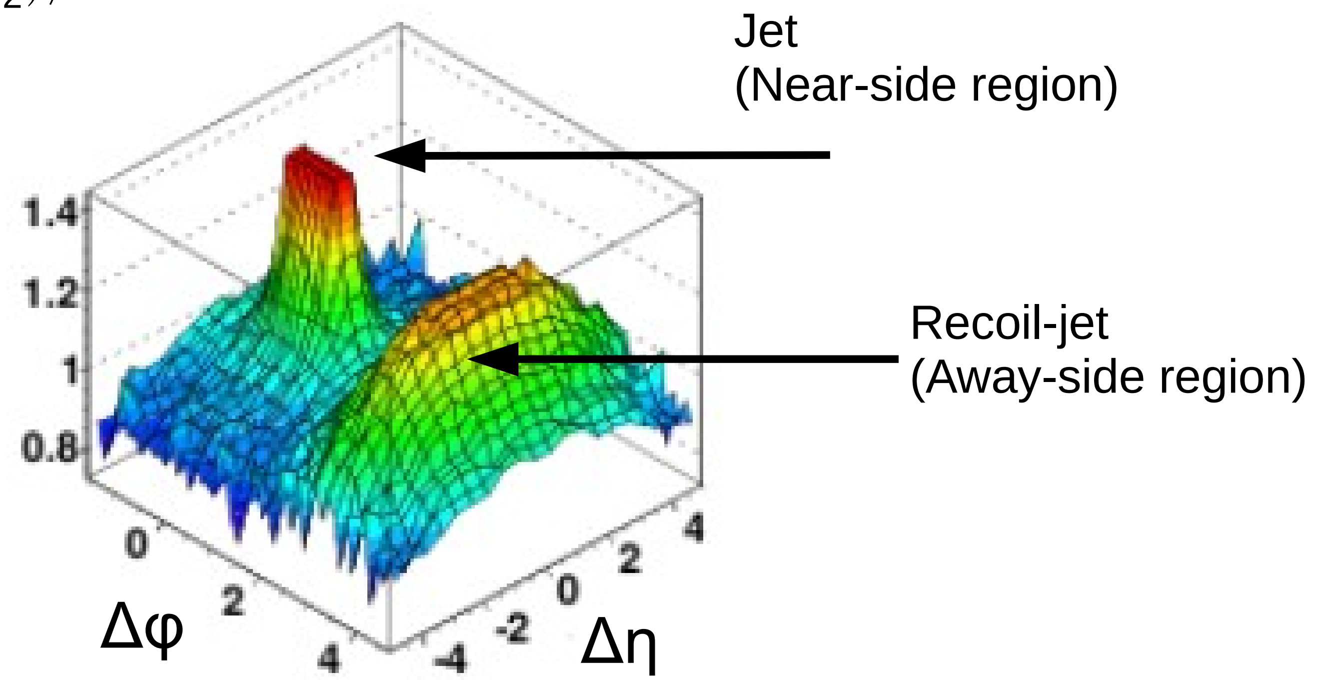
$$v_2 = \langle \cos(2\varphi - 2\Psi_R) \rangle$$

Need to deal with the reaction plane angle:
Use differences between particles in azimuth
(or attempt to reconstruct it directly)

Two-particle correlations

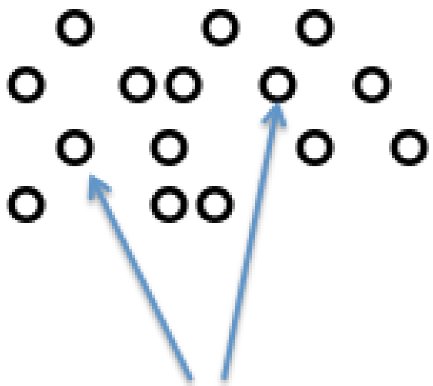
$$v_2\{2\} = \sqrt{\langle \cos(2\varphi_1 - 2\varphi_2) \rangle}$$

Can suppress "non-flow"
by employing cuts in $|\Delta\eta|$
If p_T cuts are used:
$v\{2\} = \sqrt{v(p_{T,1})\, v(p_{T,2})}$

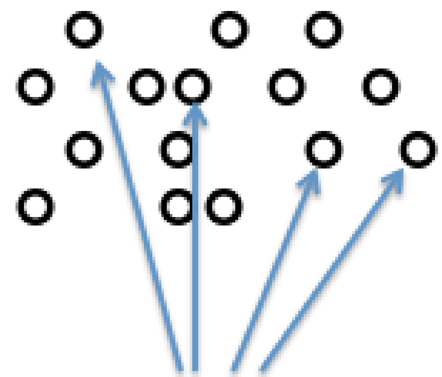


Multi-particle correlations: $v_2\{4\}$ and higher

(From S. Tuo)

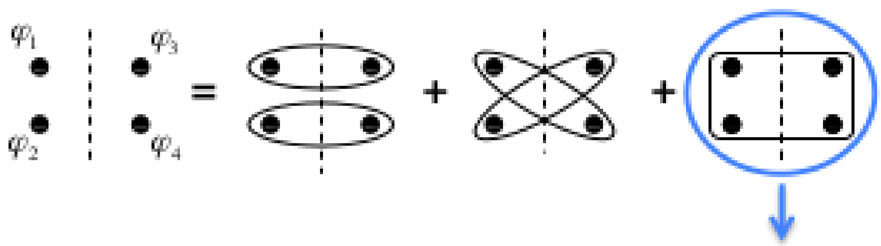


$$\left\langle e^{in(\varphi_1-\varphi_2)} \right\rangle$$



$$\left\langle e^{in(\varphi_1+\varphi_2-\varphi_3-\varphi_4)} \right\rangle$$

Four particle correlations (Q-cumulant method):



$$c_n\{4\} = \langle\langle 4\rangle\rangle - 2\cdot\langle\langle 2\rangle\rangle^2$$

$$v_2\{4\} = \sqrt[4]{-c_n\{4\}}$$

$$\left\langle e^{in(\varphi_1+\varphi_2-\varphi_3-\varphi_4)} \right\rangle - \left\langle e^{in(\varphi_1-\varphi_3)} \right\rangle \left\langle e^{in(\varphi_2-\varphi_4)} \right\rangle - \left\langle e^{in(\varphi_1-\varphi_4)} \right\rangle \left\langle e^{in(\varphi_2-\varphi_3)} \right\rangle$$

Multi-particle correlations (cumulant) studies extract the genuine multi-particle correlation

Flow methods

Two-particle cumulant

$$v\{2\} = \sqrt{\langle \cos(\phi_1 - \phi_2) \rangle}$$

Measures:

$$v\{2\}^2 = \langle v \rangle^2 + \sigma_{v_2}^2 + \delta$$

$$v \gg 1/\sqrt{M}$$

Four-particle cumulant

$$v\{4\} = \left(2\langle \cos(\phi_1 - \phi_2)\rangle^2 - \langle \cos(\phi_1 + \phi_2 - \phi_3 - \phi_4)\rangle\right)^{1/4}$$

Measures:

$$v\{4\}^2 = \langle v \rangle^2 - \sigma_{v_2}^2$$

$$v \gg 1/M^{3/4}$$

$$v\{\mathrm{subEP}\} = \frac{\langle \cos(\phi - \psi_A) \rangle}{R}$$

$$R = \sqrt{\langle \cos(\psi_A - \psi_B) \rangle}$$

Measures:

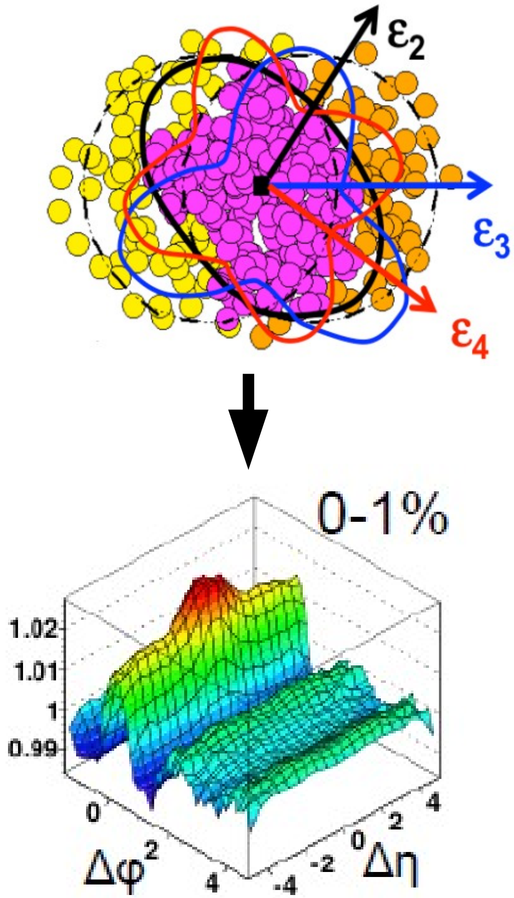
$$v\{\mathrm{subEP}\}^2 = \langle v \rangle^2 + \left(1 - f(R)\right)\sigma_{v_2}^2 + \left(1 - 2f(R)\right)\delta$$

NB: For simplicity, n (as index and in cos terms) dropped

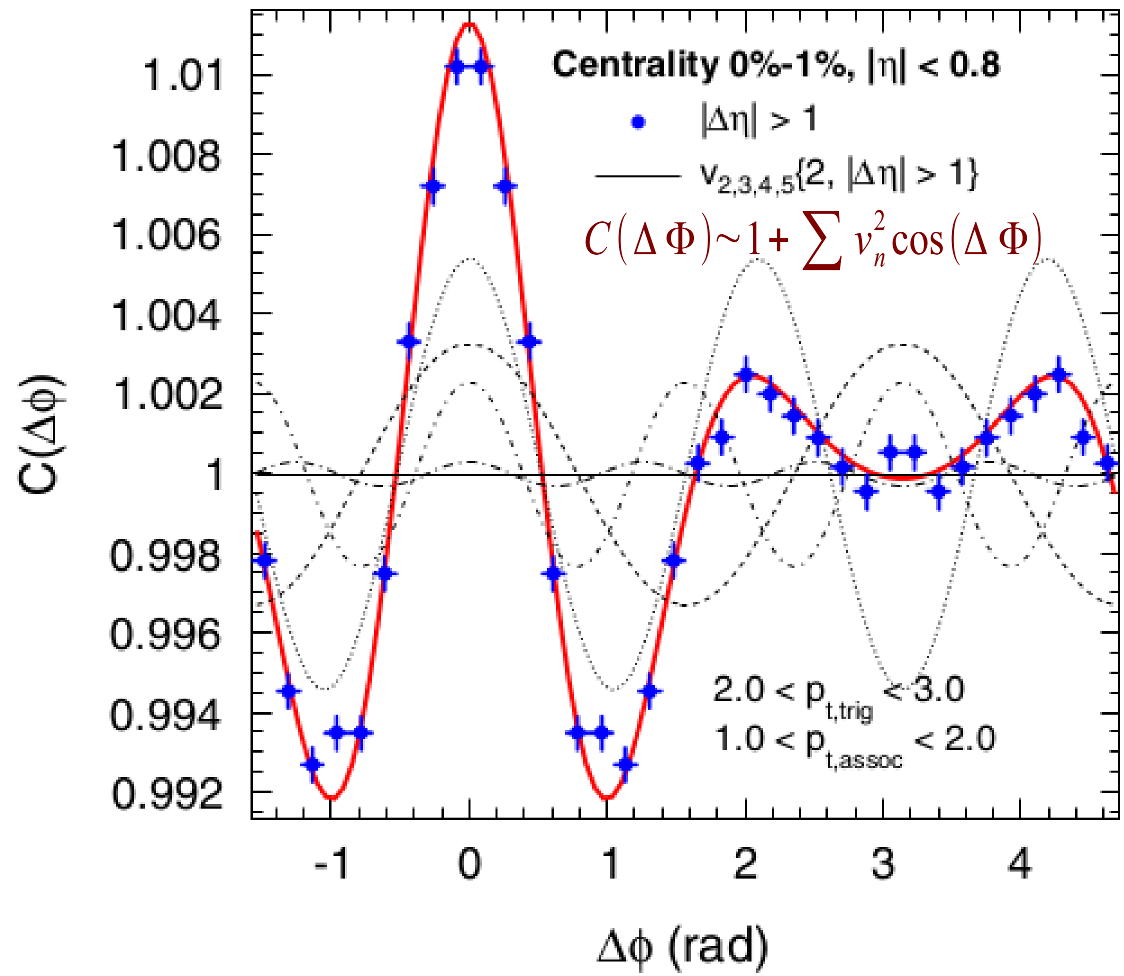
Ollitrault, Poskanzer, Voloshin
PRC 80 80 014904 (2009)

Initial state fluctuations and flow ridges

Alver+Roland, 2010



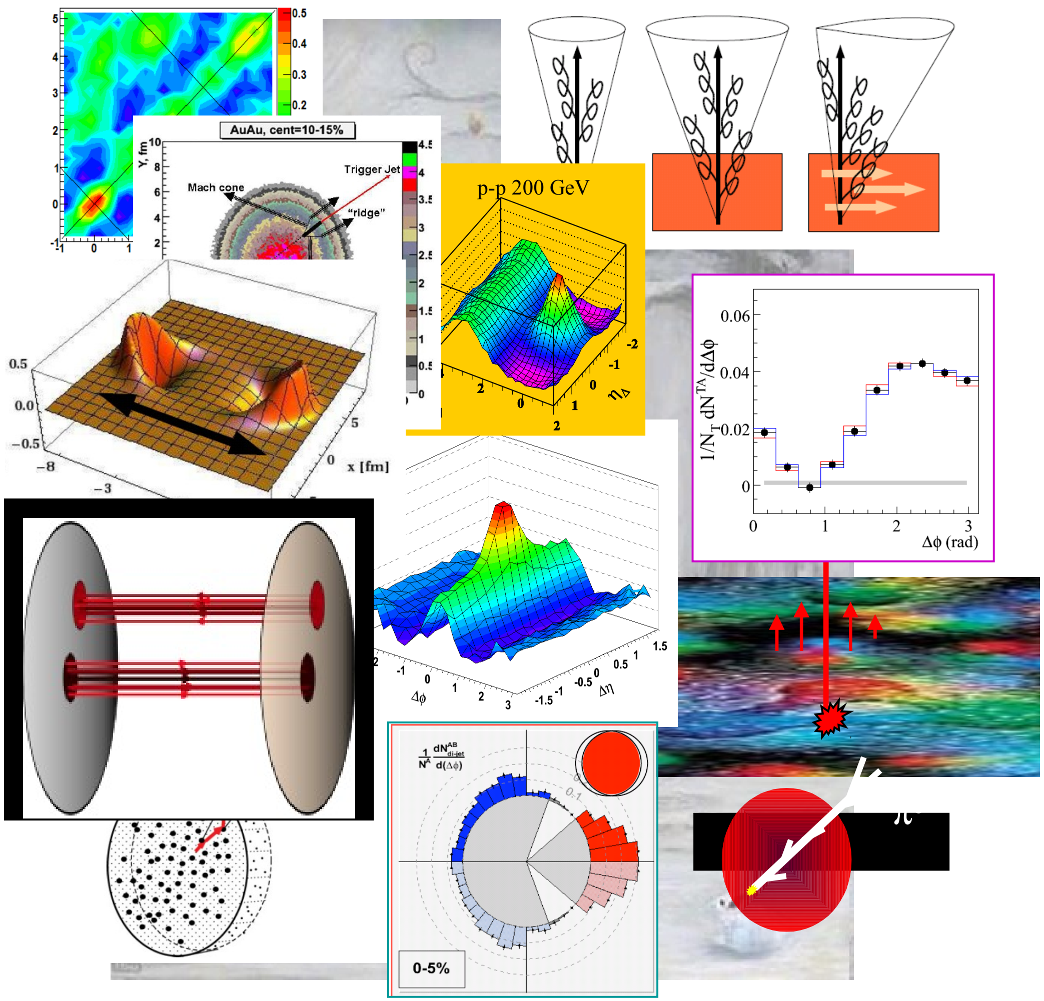
ALICE, PRL 107 (2011) 032301



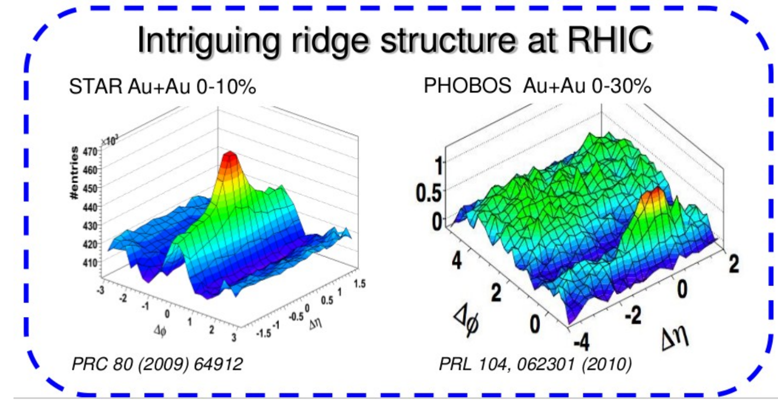
Structures seen in two particle correlations are naturally explained by measured flow harmonics assuming fluctuating initial conditions.

“Death of the Mach cone and the ridge”

Dozen's of models

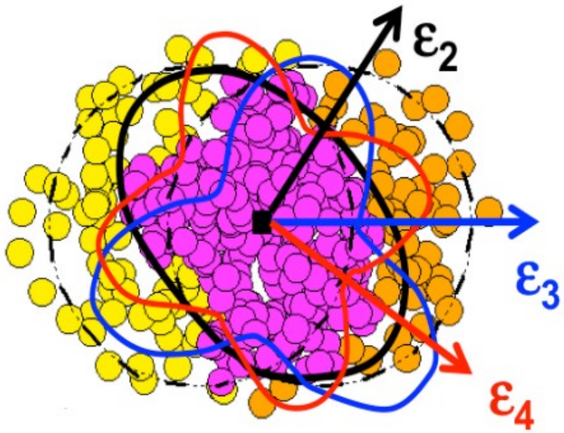


From Jamie Nagle's talk at QM'09



Structures seen in two particle correlations (reported mainly at RHIC) are naturally explained by measured anisotropic flow coefficients.

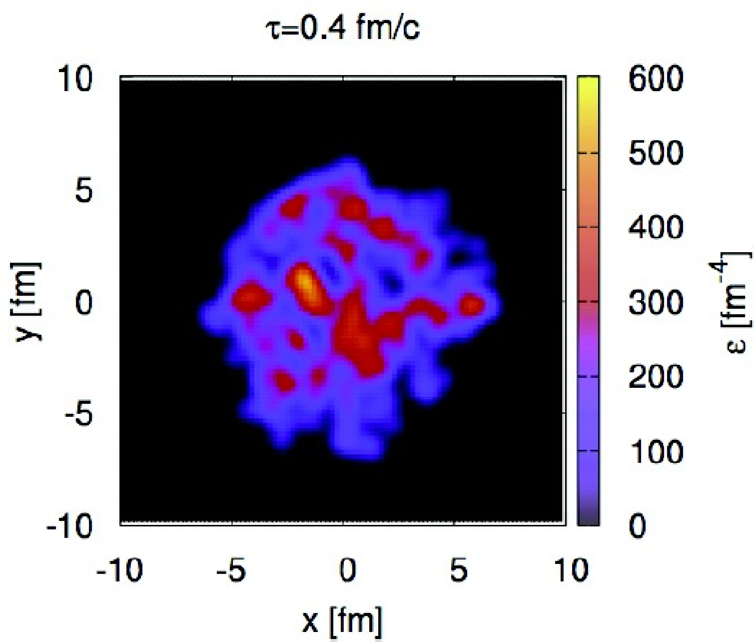
Higher harmonics and viscosity



Alver, Roland

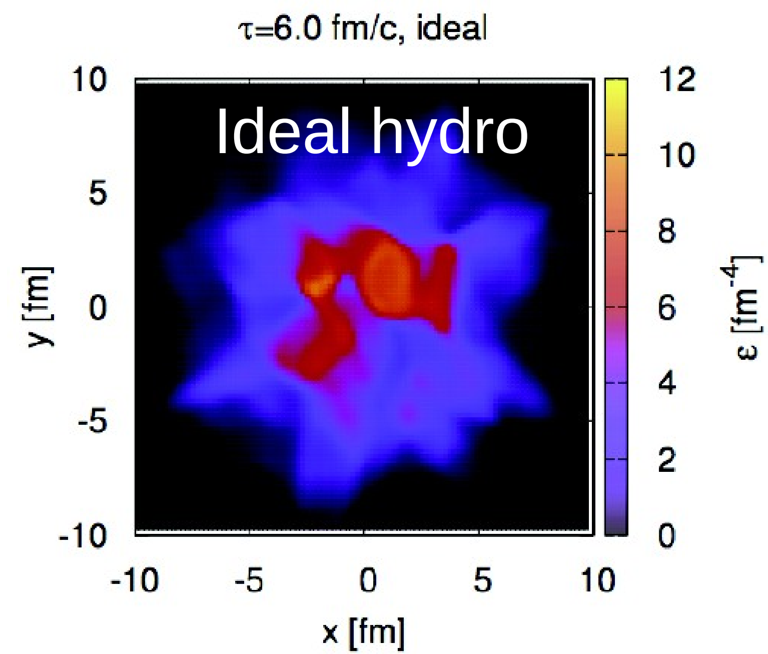
Initial spatial anisotropy not smooth, leads to higher harmonics / symmetry planes.

$$\frac{dN}{d\varphi} \sim 1 + 2v_2\cos[2(\varphi-\psi_2)] + 2v_3\cos[3(\varphi-\psi_3)] + 2v_4\cos[4(\varphi-\psi_4)] + 2v_5\cos[5(\varphi-\psi_5)] + \ldots$$



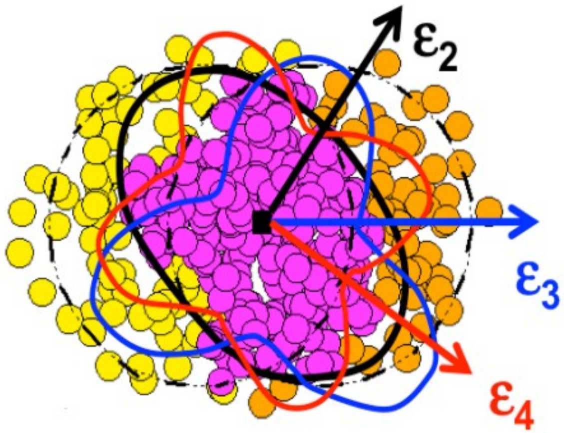
e-by-e hydro

B. Schenke et al.



Ideal hydrodynamical models preserves these “clumpy” initial conditions

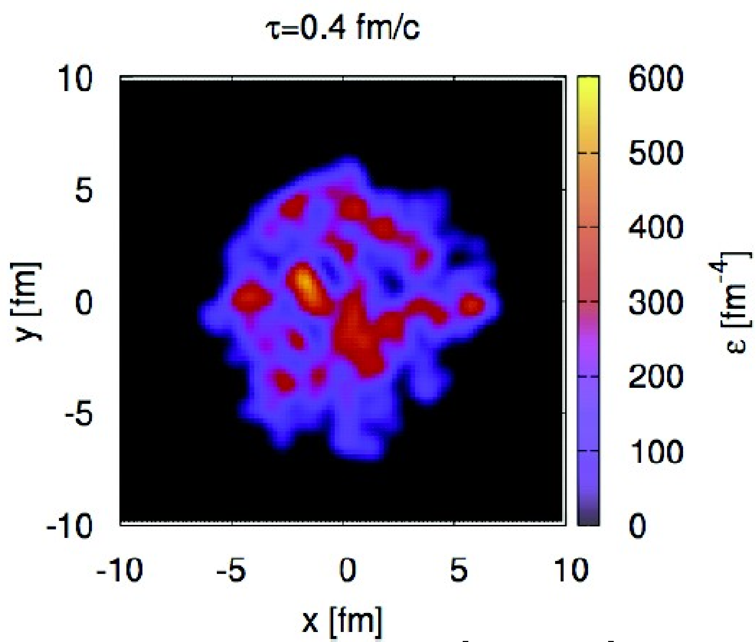
Higher harmonics and viscosity



Alver, Roland

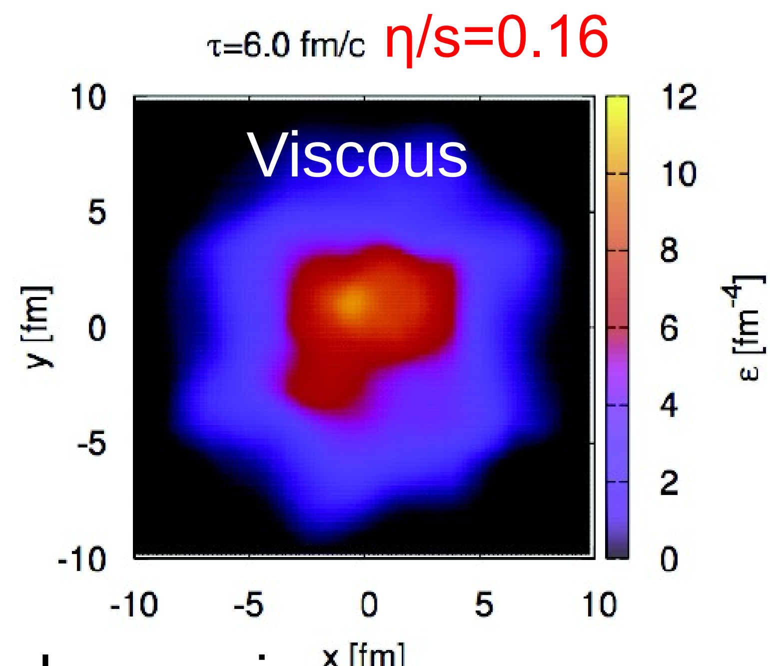
Initial spatial anisotropy not smooth, leads to higher harmonics / symmetry planes.

$$\frac{dN}{d\varphi} \sim 1 + 2v_2 \cos[2(\varphi-\psi_2)] + 2v_3 \cos[3(\varphi-\psi_3)] + 2v_4 \cos[4(\varphi-\psi_4)] + 2v_5 \cos[5(\varphi-\psi_5)] + \ldots$$



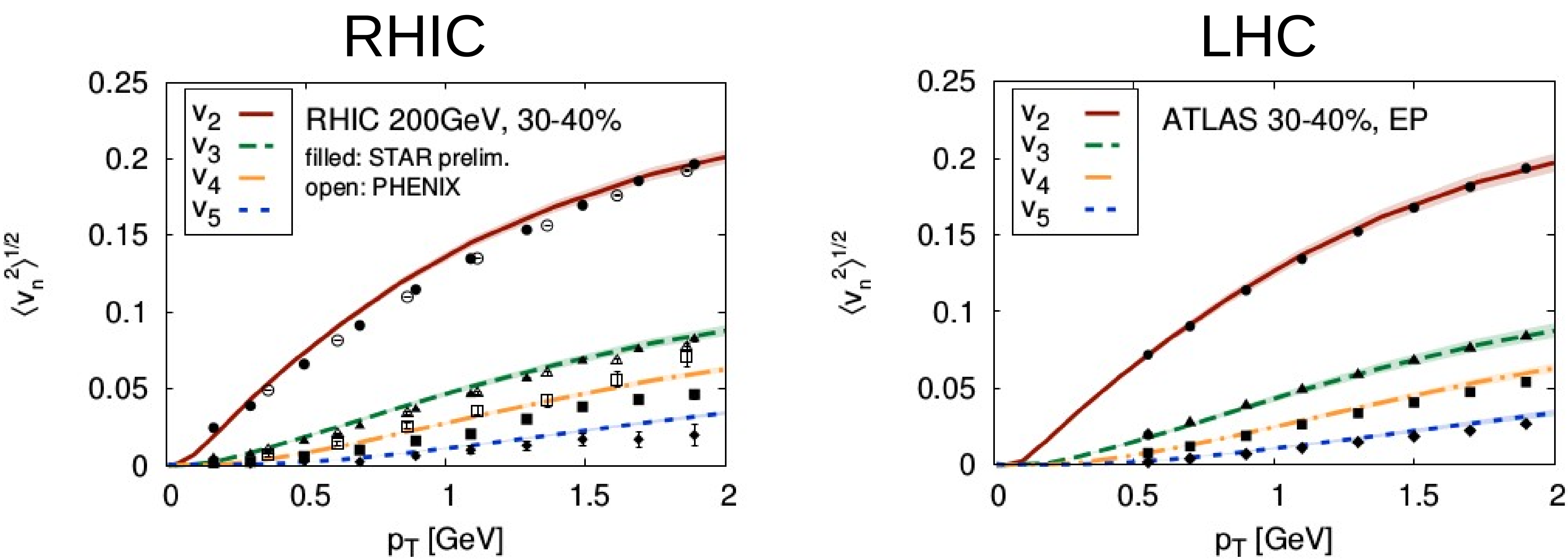
e-by-e hydro →

B. Schenke et al.



Viscosity suppresses higher harmonics,
→ v_n provide additional sensitivity to η/s

Constraints on η/s from model calculations



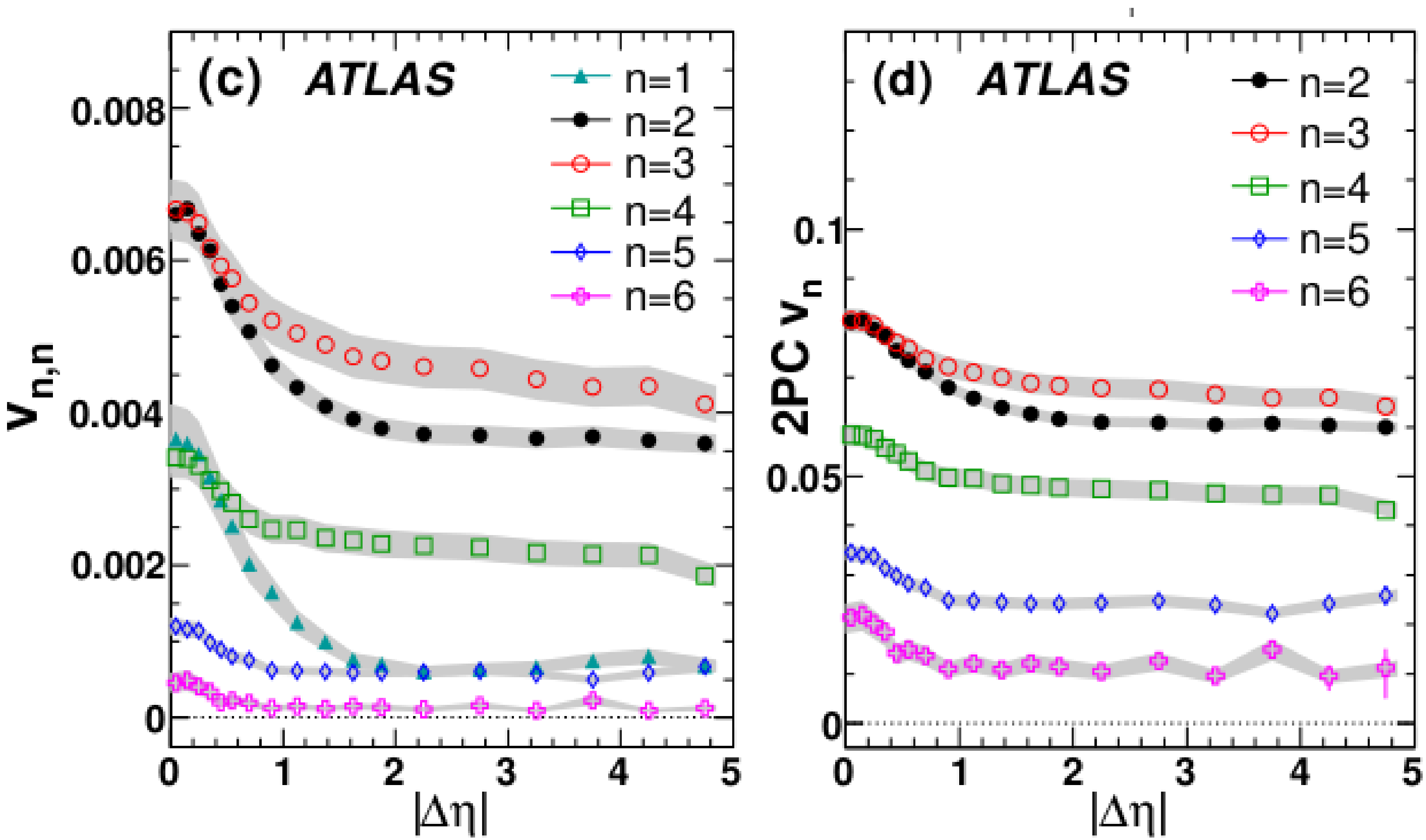
$\eta/s \approx 0.12$ at $\sqrt{s} = 0.2$ TeV

$\eta/s \approx 0.2$ at $\sqrt{s} = 2.76$ TeV

Model (IP-Glasma) consistently describes all flow harmonics for a given η/s (but uncertainty on η/s still very large)

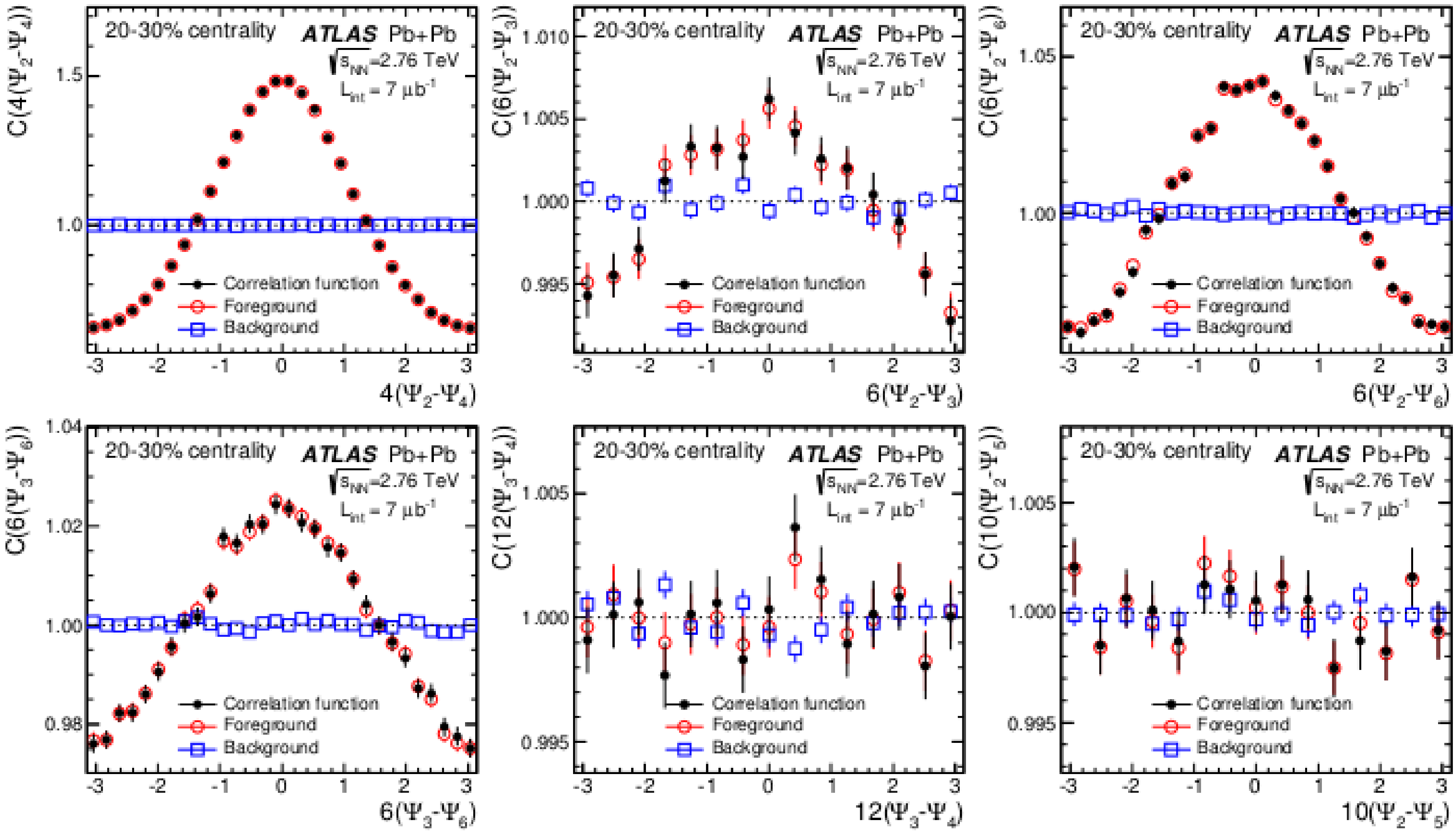
Schenke et al., PRL 110 (2013) 012302

Flow coefficients vs rapidity gap



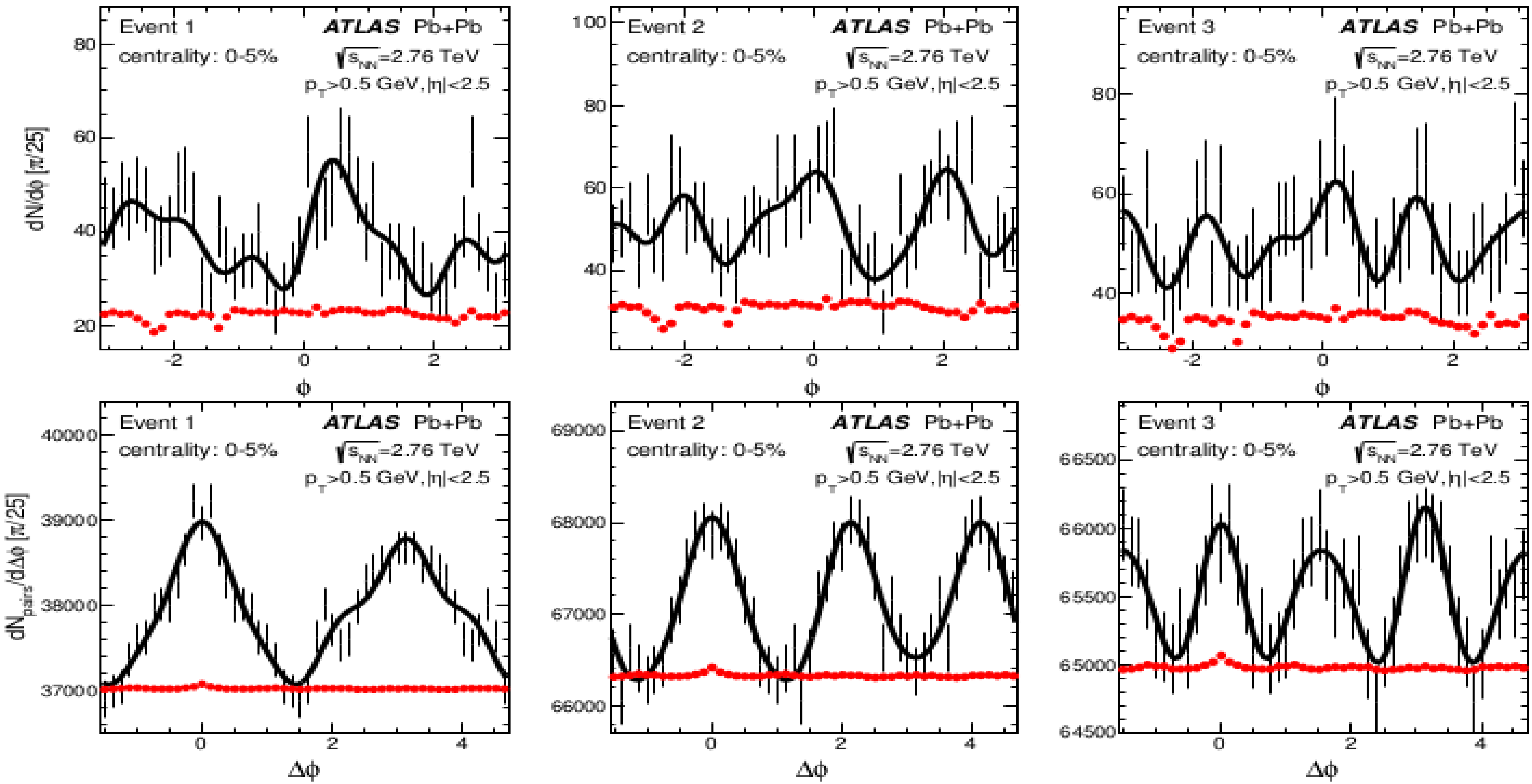
PRC 86 (2012) 014907

Event angle correlations



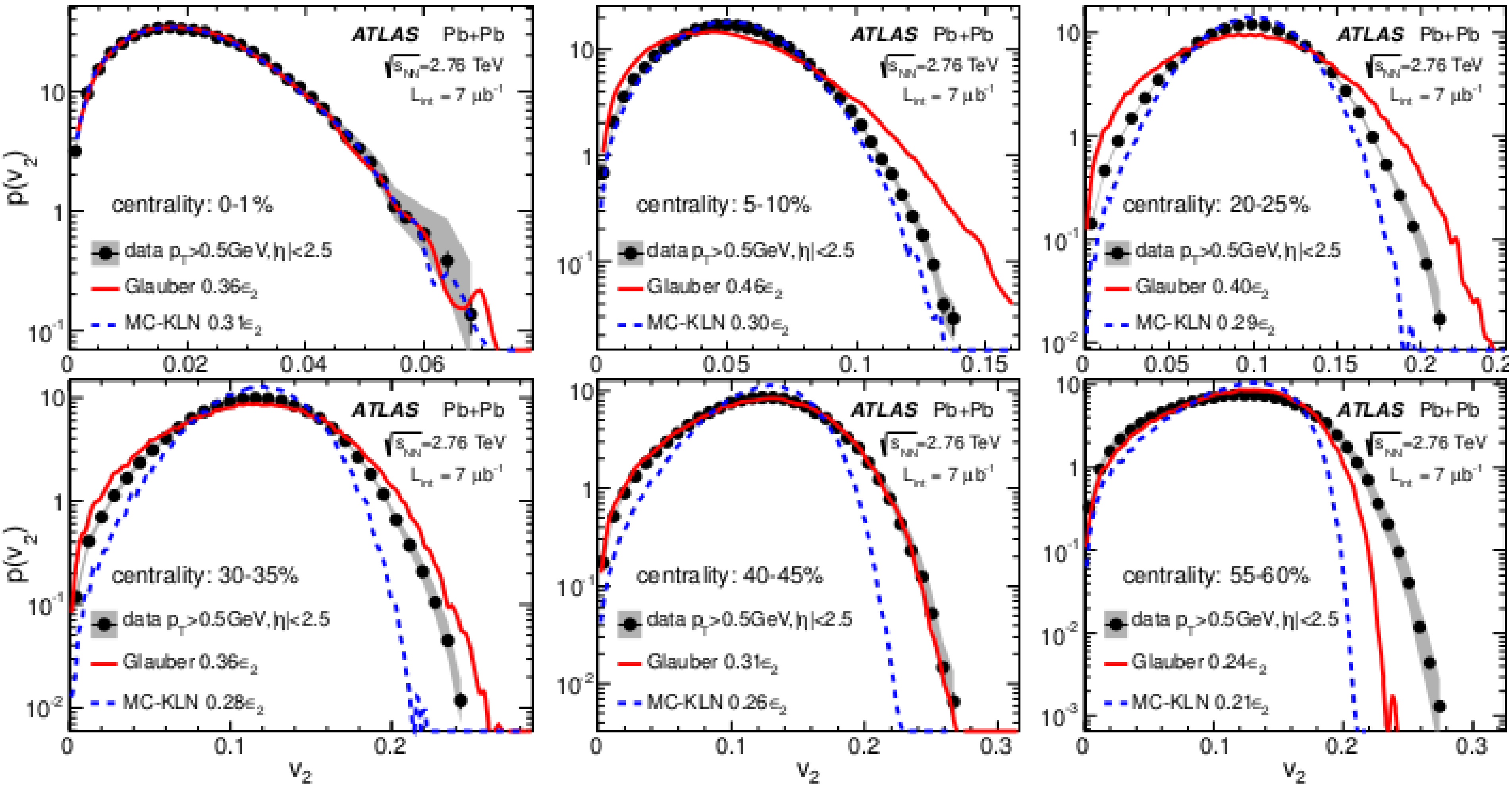
PRC 90 (2014) 024905

Event-by-event flow distributions



JHEP 11 (2013) 183

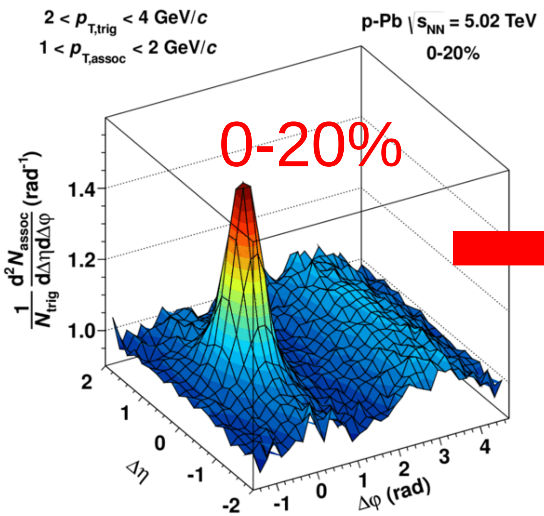
Event-by-event flow distributions

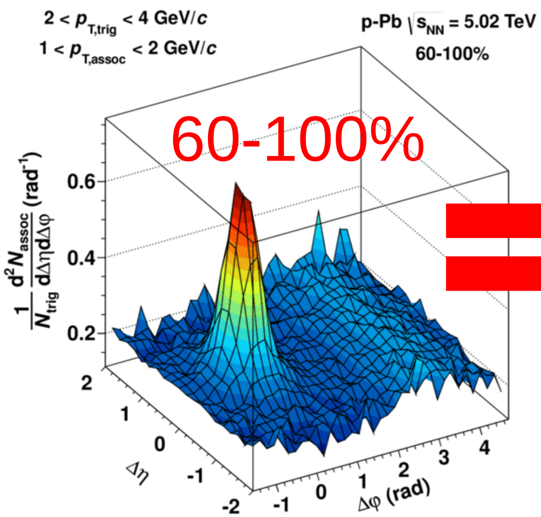


JHEP 11 (2013) 183

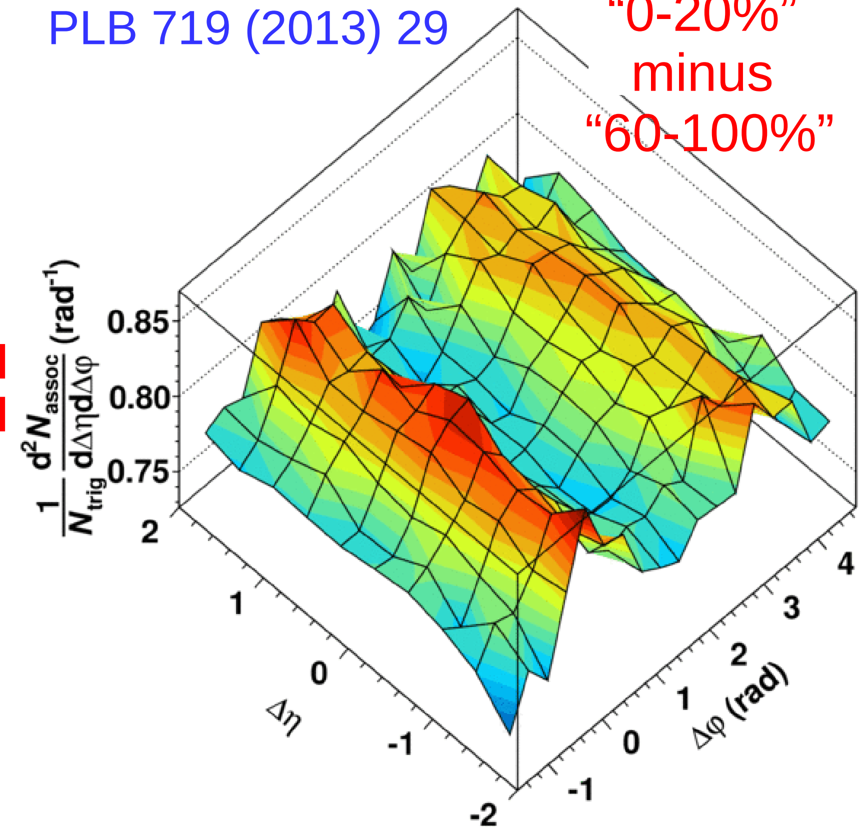
Extraction of double ridge structure

ALICE, PLB 719 (2013) 29



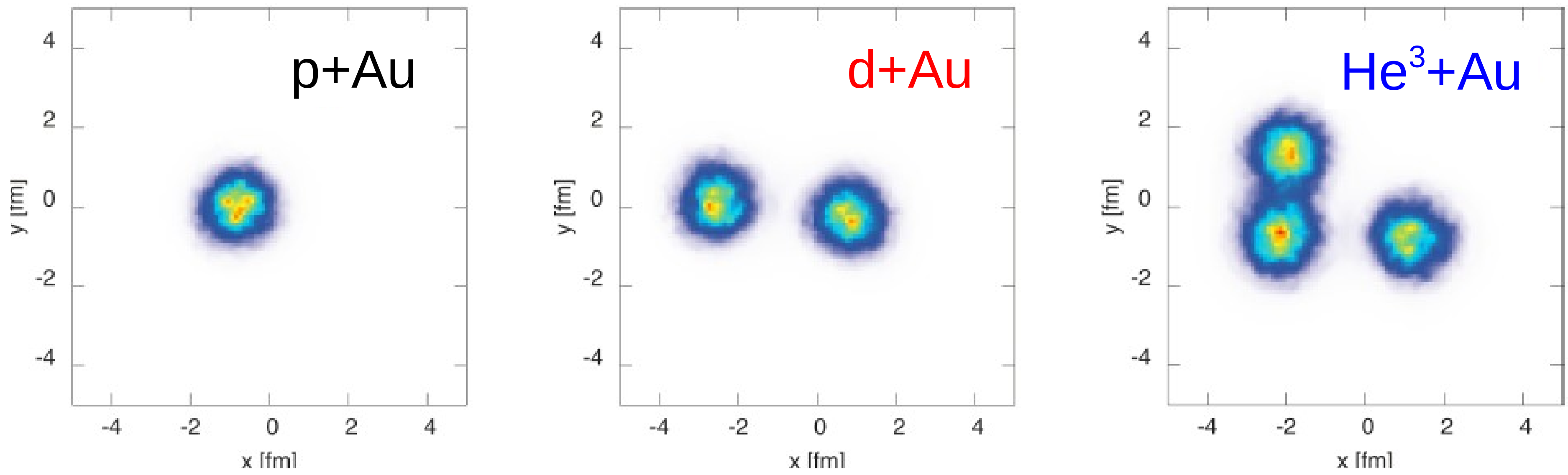


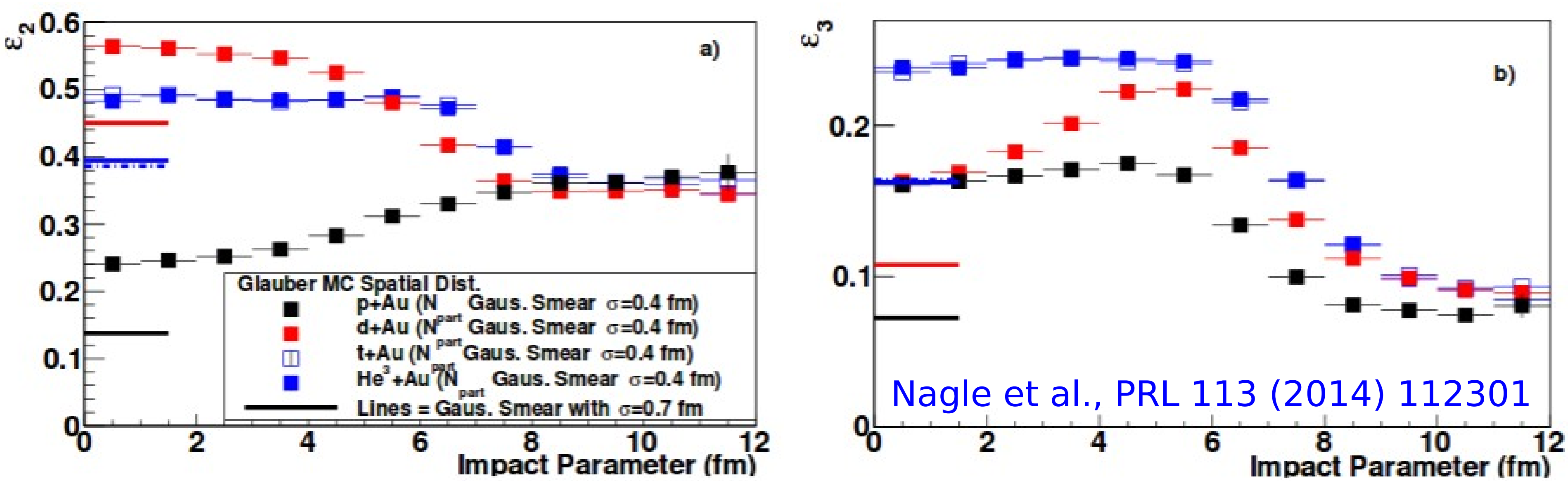
ALICE, PLB 719 (2013) 29



- Extract double ridge structure using a standard technique in AA collisions, namely by subtracting the jet-like correlations
  - Assumed that 60-100% class is free from non-jet like correlations

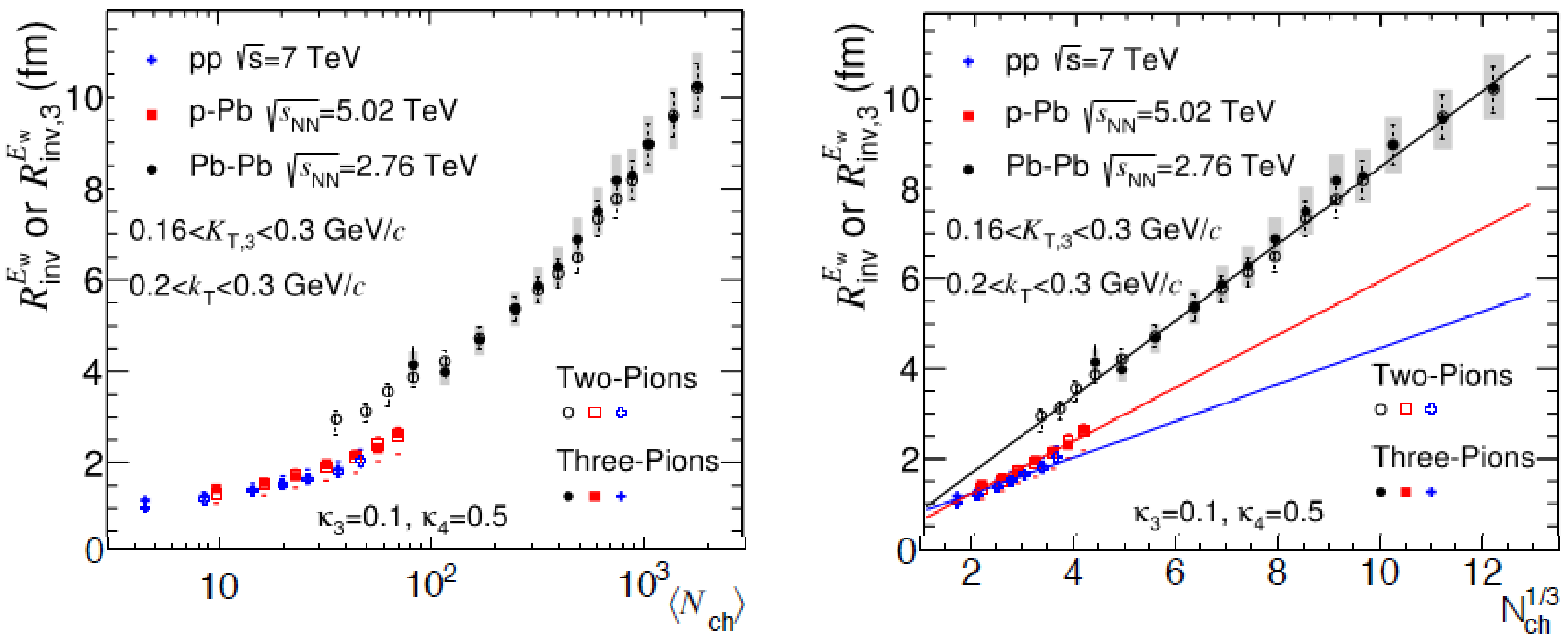
Geometry engineering





Nagle et al., PRL 113 (2014) 112301

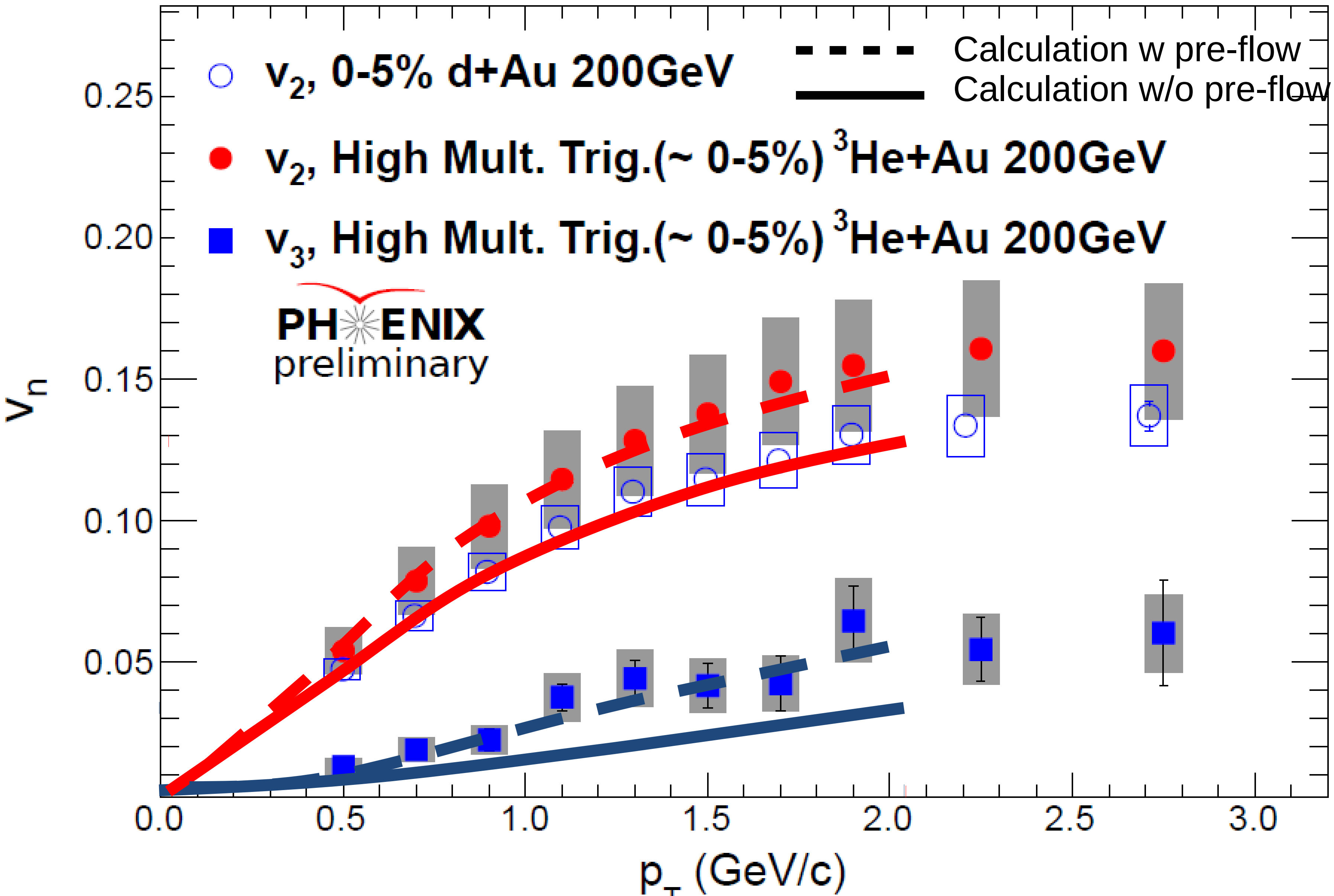
Freeze-out radii (R_{inv}) vs N_{ch}



- Exhibit different trend (with linear fit over measured region)
- Radii in pp and pPb at similar measured Nch are with 5-15% while larger difference (up to 30-50%) between pPb and PbPb
- Not much room for a hydro-dynamical expansion in pPb beyond what might already be there in pp

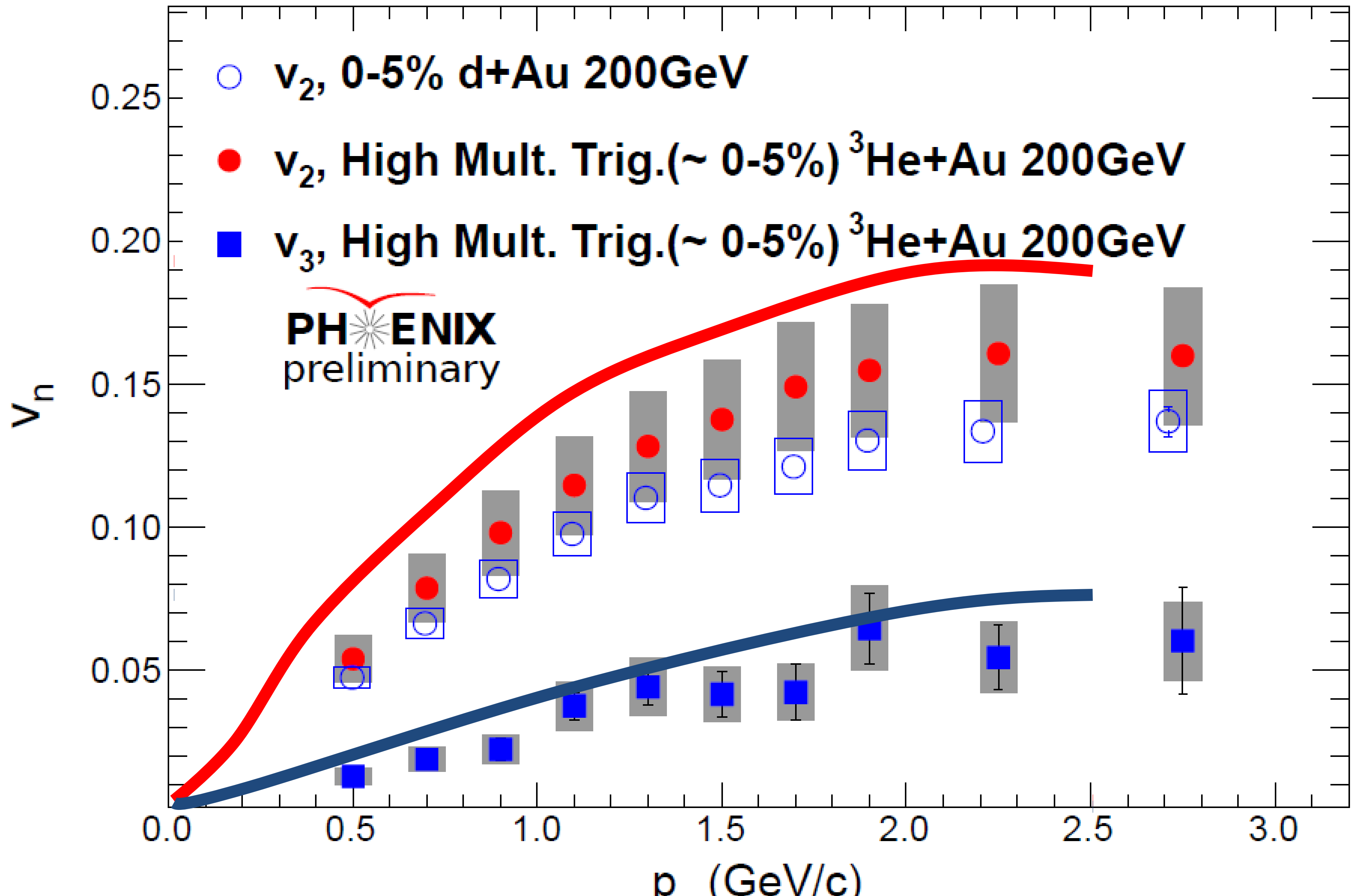
PLB 739 (2014) 139

Geometry engineering: He^3-Au data



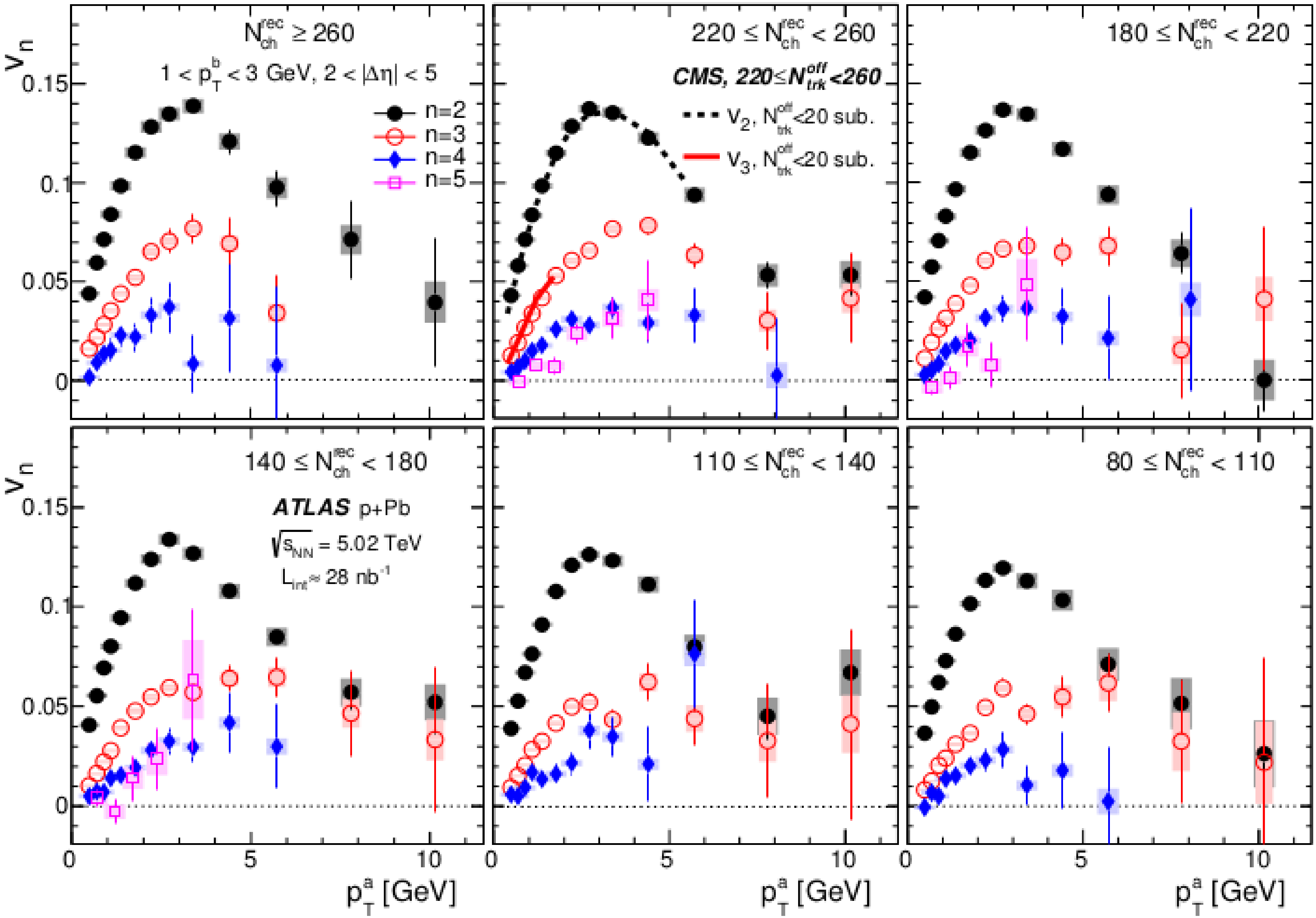
Glauber+Hydro+Hadron Cascade (with pre-flow) describe data

Geometry engineering: He^3-Au data



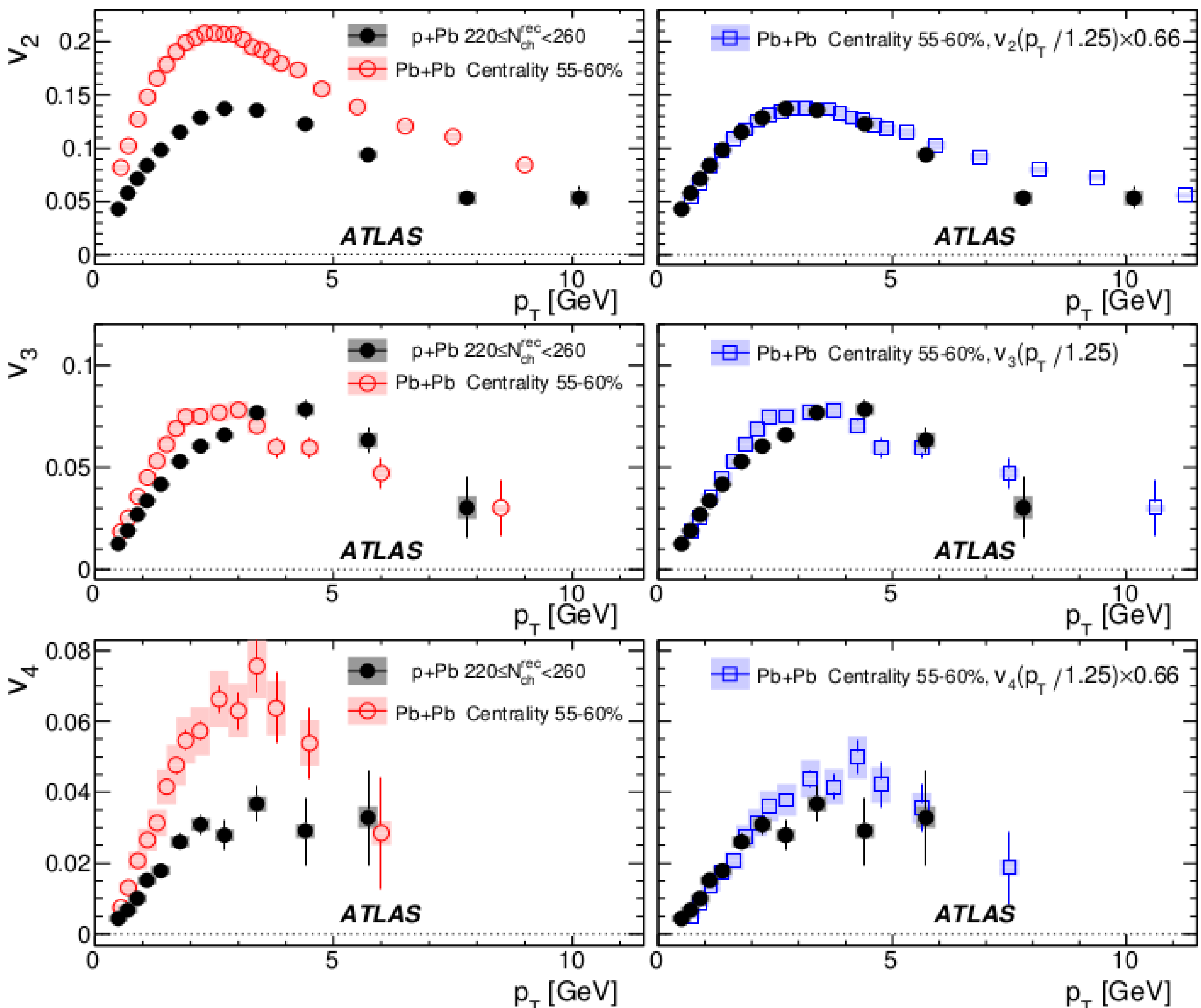
IP-GLASMA+MUSIC also reasonably well predict data

Higher harmonics in pPb



arXiv:1408.4342v1

v_n in PbPb and pPb at high p_T



arXiv:1408.4342v1

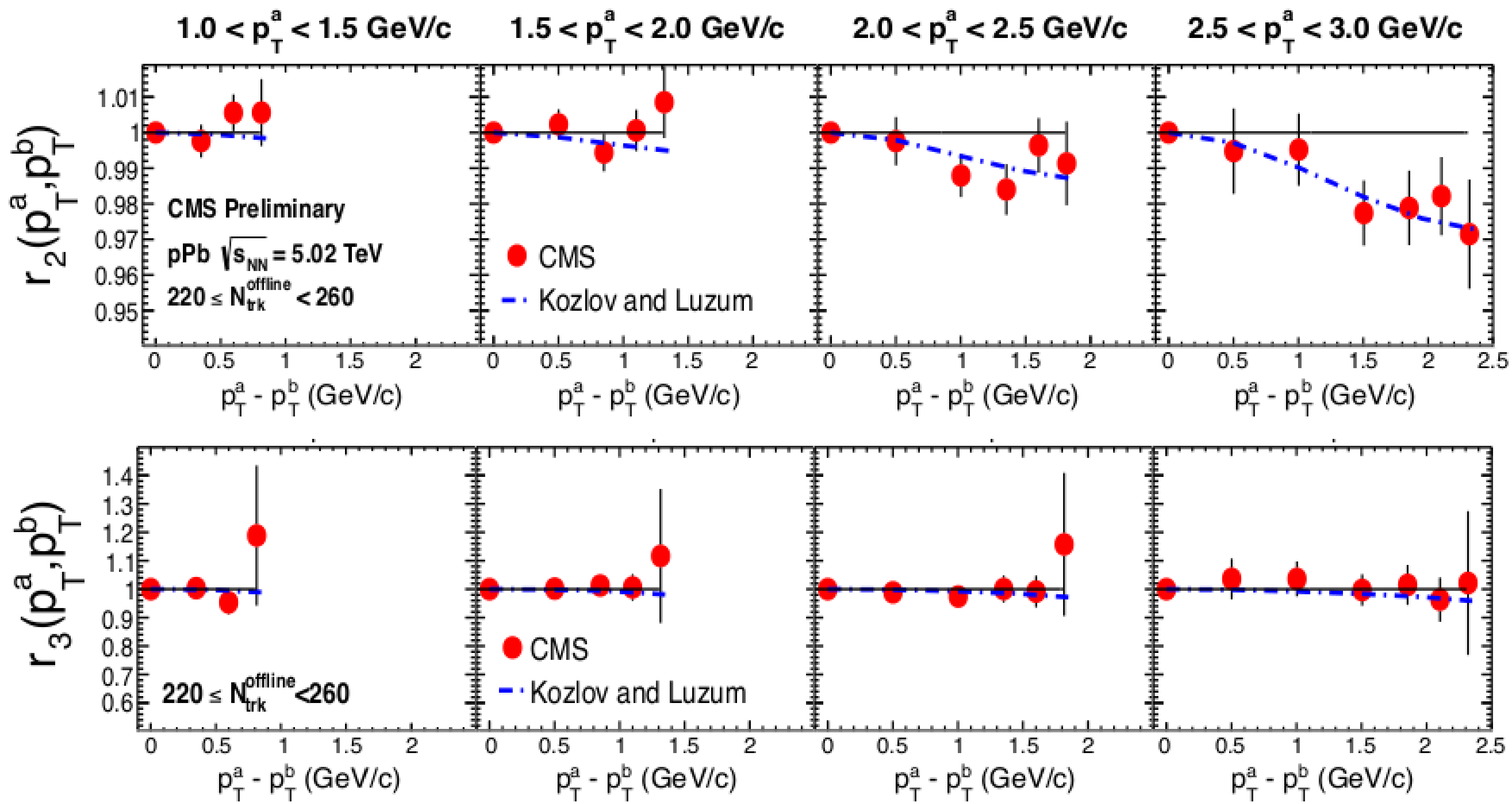
Breaking of factorization

$$r_n \equiv \frac{V_{n\Delta}(p_T^a, p_T^b)}{\sqrt{V_{n\Delta}(p_T^a, p_T^a)}\sqrt{V_{n\Delta}(p_T^b, p_T^b)}}$$

$$\sim \left\langle \cos[n(\Psi_n(p_T^a) - \Psi_n(p_T^b))] \right\rangle$$

$220<N_{trk}<260$

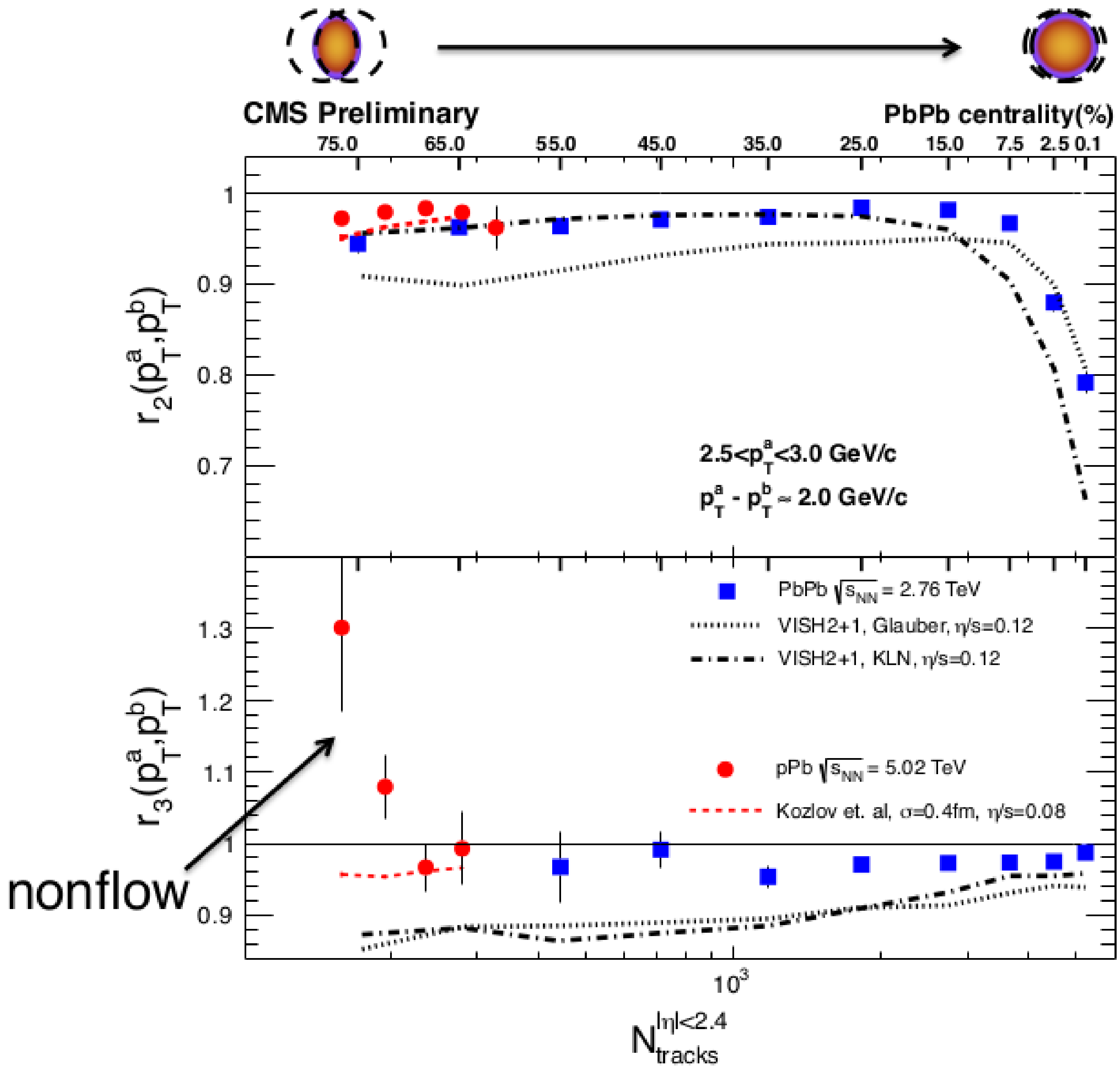
Increasing p_T^a



Only a small effect, pPb is very smooth

Breaking of factorization

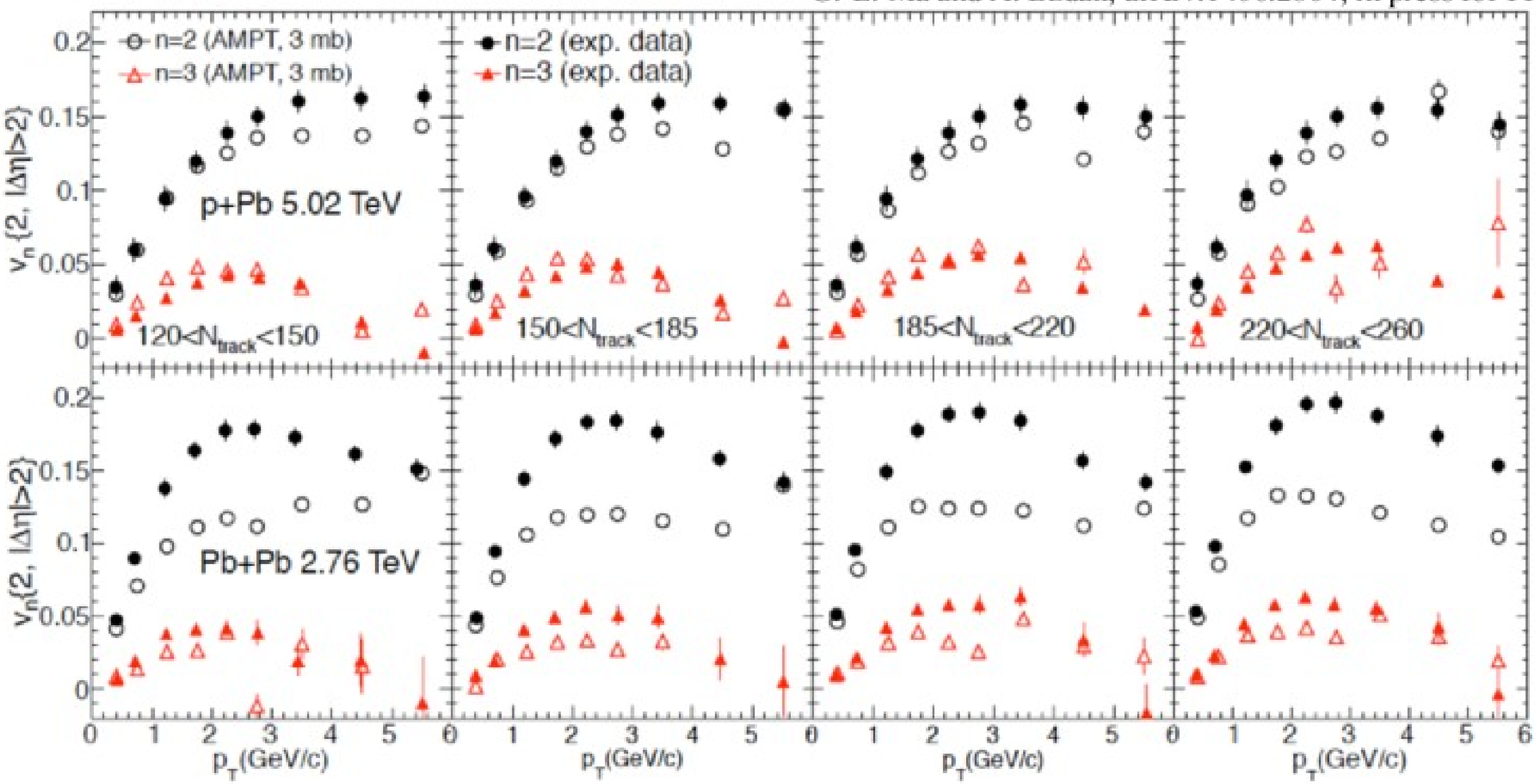
$$r_n \equiv \frac{V_{n\Delta}(p_T^a, p_T^b)}{\sqrt{V_{n\Delta}(p_T^a, p_T^a)}\sqrt{V_{n\Delta}(p_T^b, p_T^b)}}$$



Effect in pPb is comparable to that in peripheral PbPb

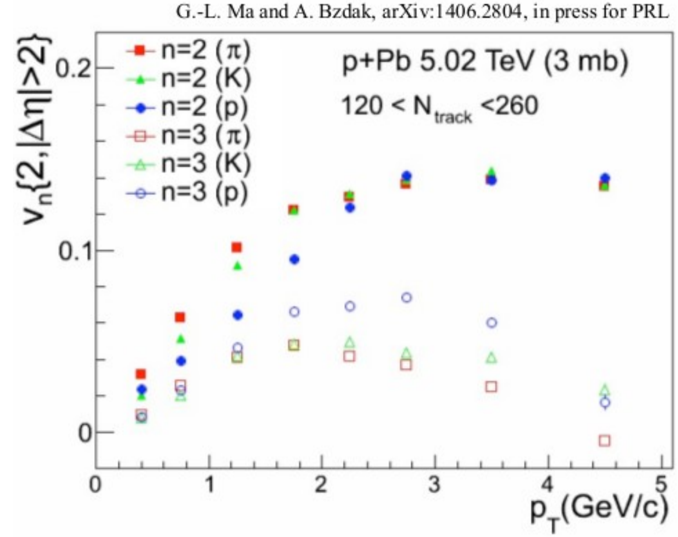
AMPT comparison with pPb and PbPb

G.-L. Ma and A. Bzdak, arXiv:1406.2804, in press for PRL

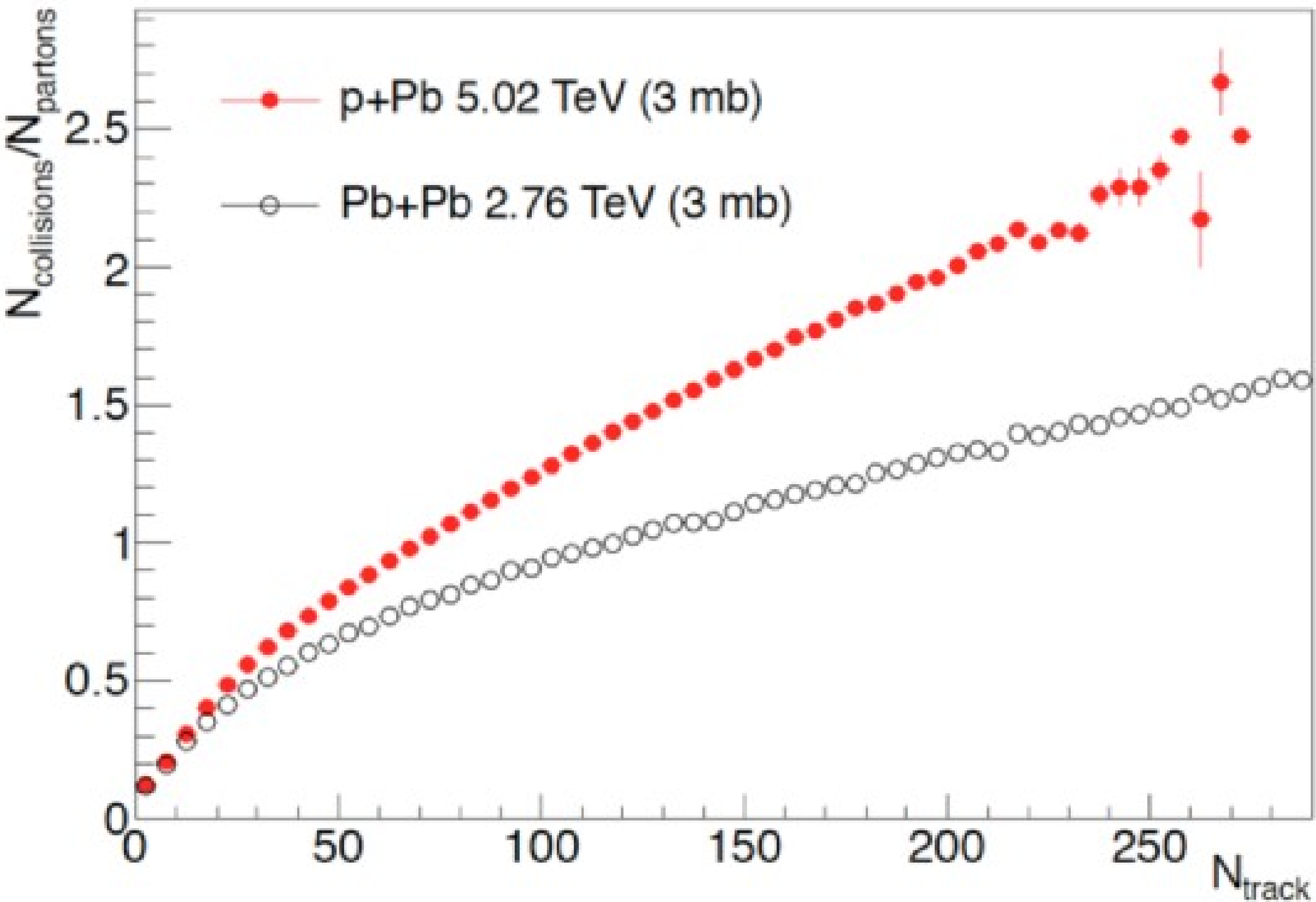


AMPT does a good job describing data except for mass dependence of v_3

G.-L. Ma and A. Bzdak, arXiv:1406.2804, in press for PRL

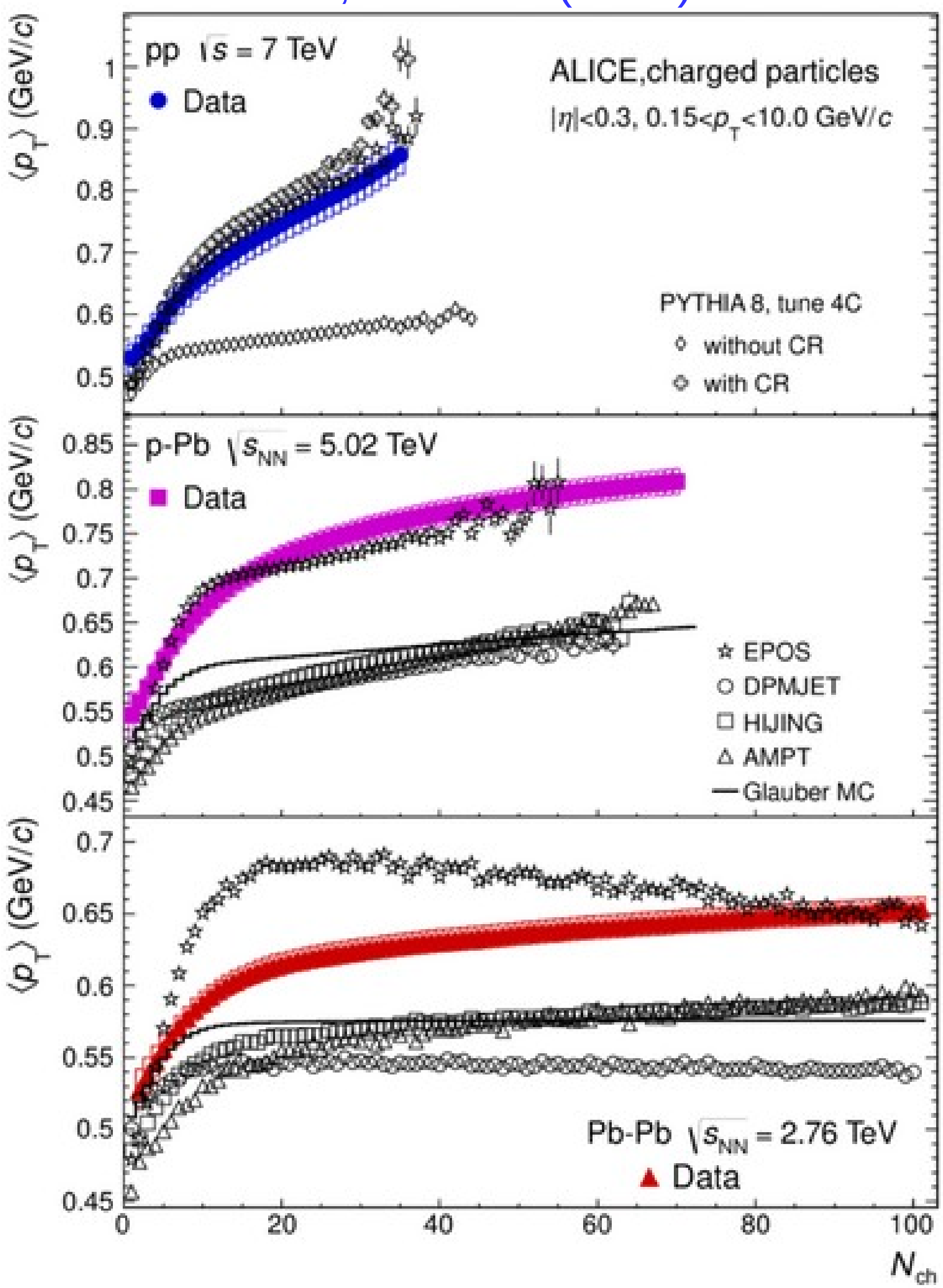


Elastic scatterings per parton in AMPT



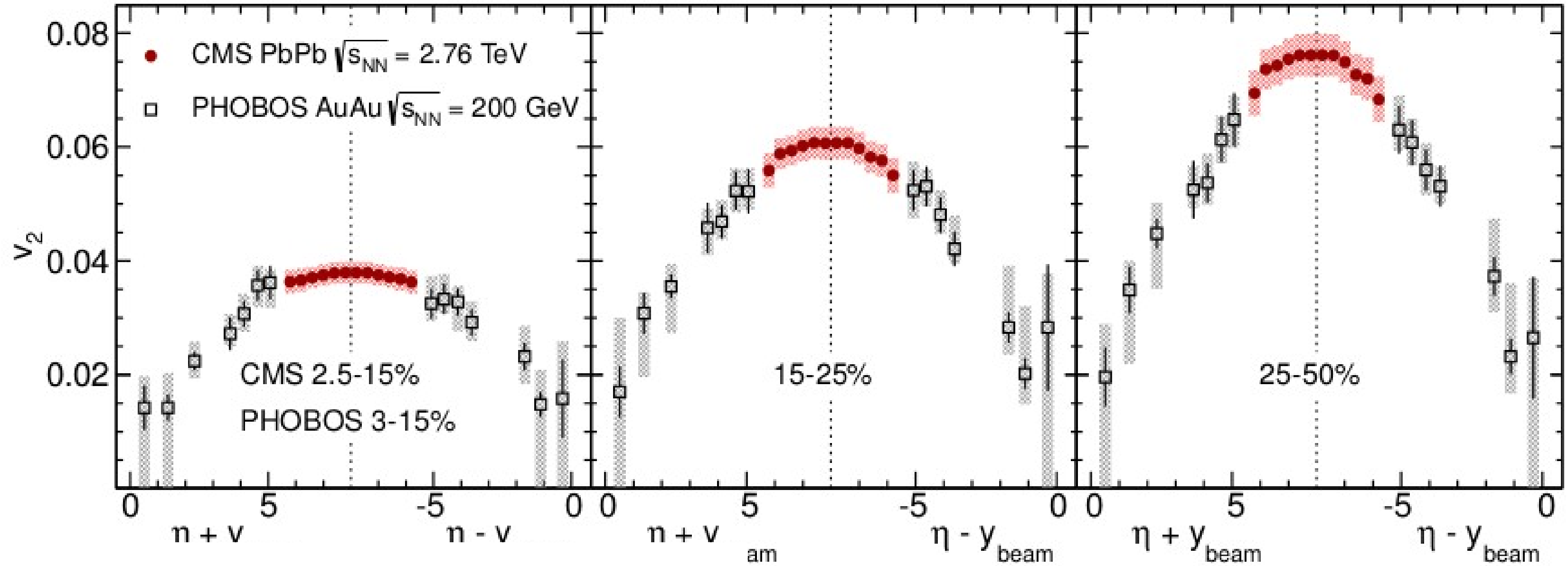
Average p_T versus N_{ch}

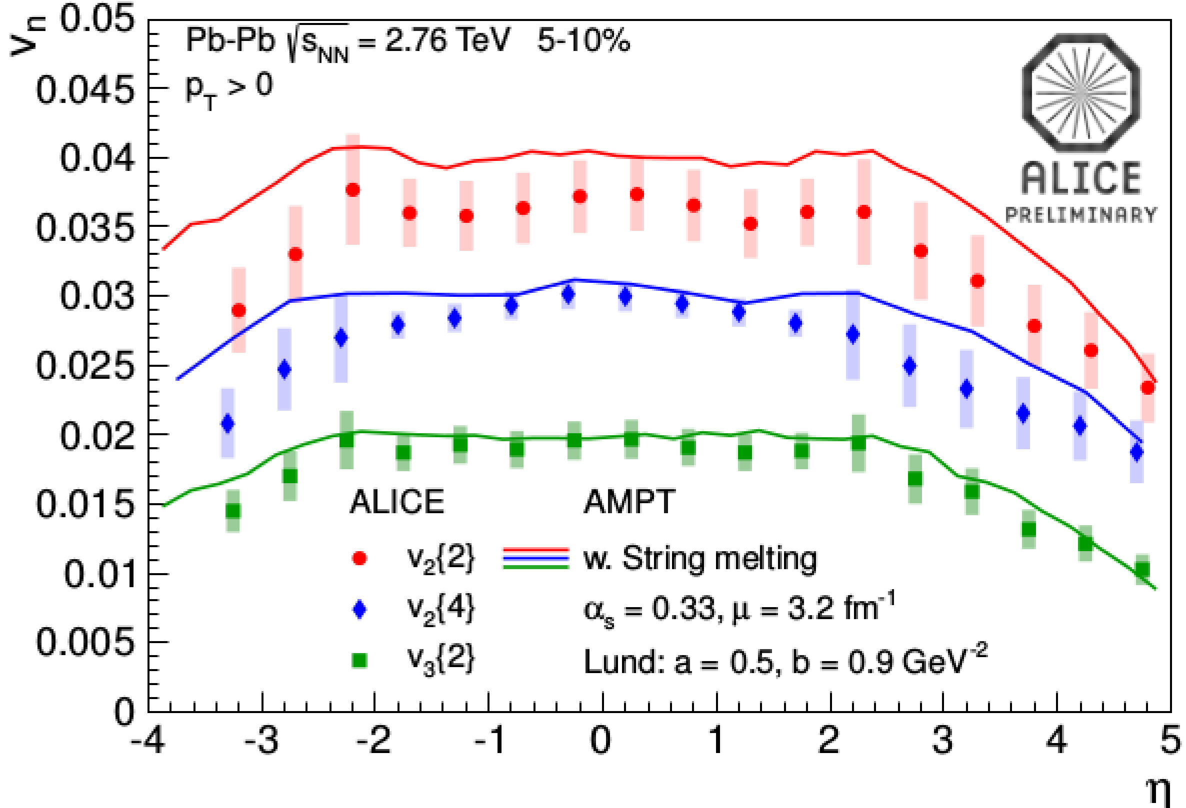
ALICE, PLB 727 (2013) 371



- pp
  - Within PYTHIA model increase in mean p_T can be modeled with Color Reconnections between strings
  - Can be interpreted as collective effect (e.g. Velasquez et al., arXiv:1303.6326v1)
- pPb
  - Increase follows pp up to N_{ch}~14 (90% of pp cross section, pp already biased)
  - Glauber MC (as other models based on incoherent superposition) fails
  - Like in pp: Do we need a (microscopic) concept of interacting strings?
  - EPOS LHC which includes a hydro evolution describes the data (also pp)
- PbPb
  - As expected, incoherent superposition can not describe data

Longitudinal direction





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