

Azimuthally differential pion femtoscopy relative to the second harmonic in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV from ALICE



Mohammad Saleh - Wayne State University
on behalf of the ALICE Collaboration

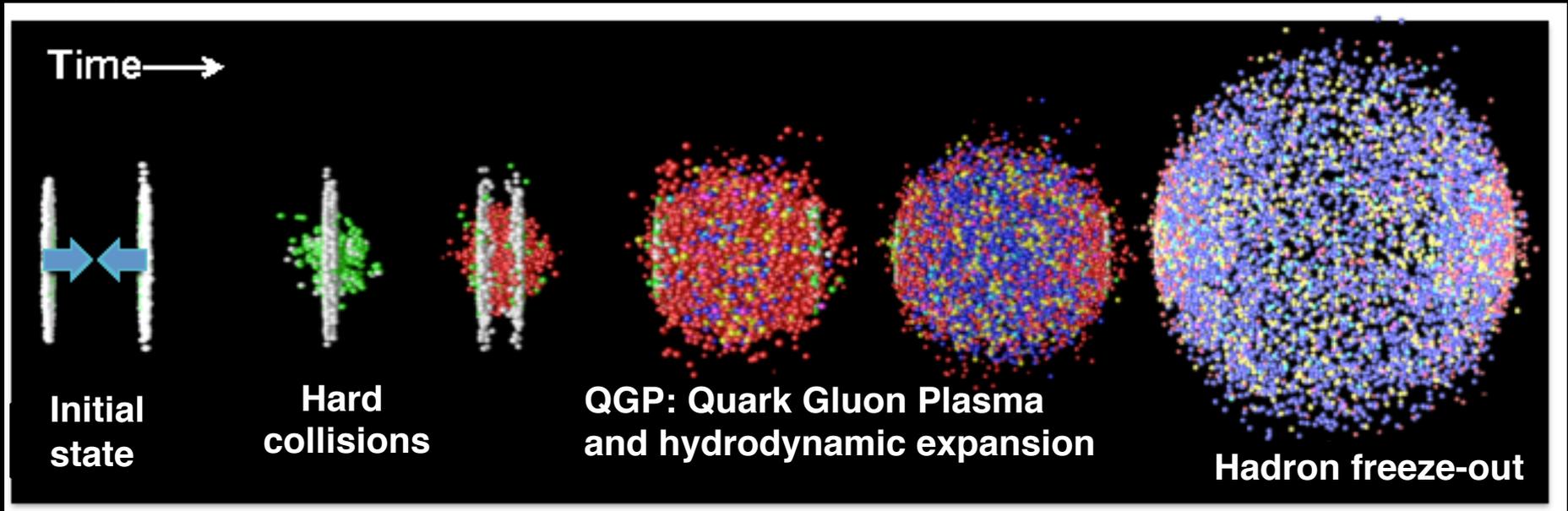
US LHC Users Association Meeting, Nov 3, 2017

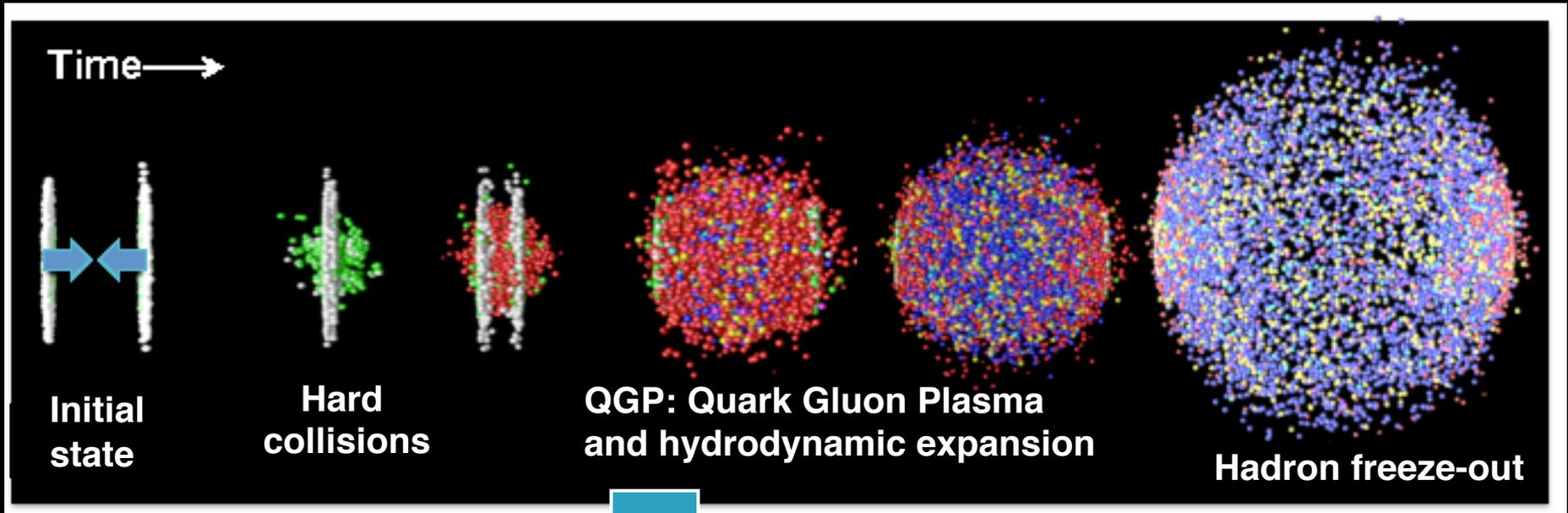
- Introduction
- ALICE at the LHC
- Azimuthal HBT:
 - second harmonic
 - third harmonic
- Summary

PRL 118, 222301 (2017)

Not included in this presentation

Introduction: Heavy Ion Collisions

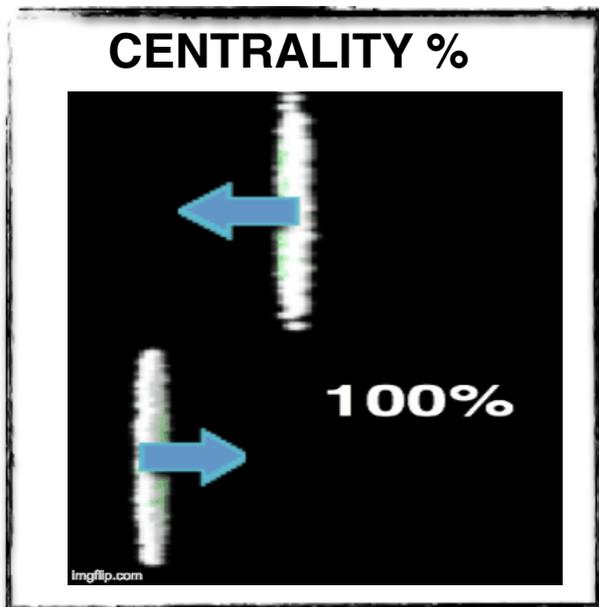
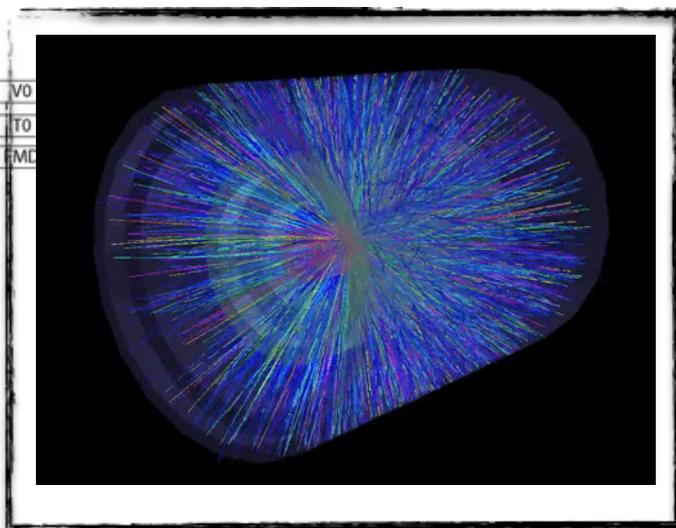
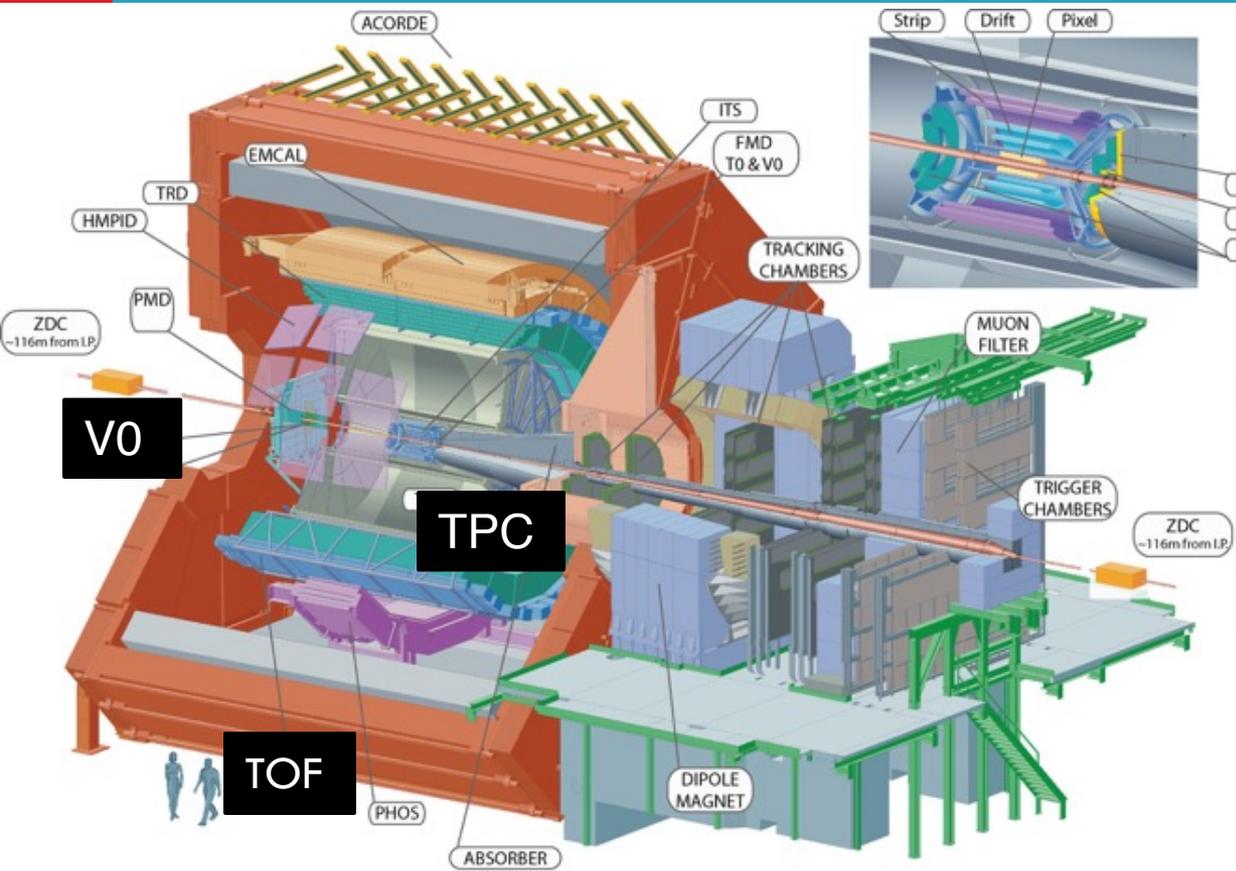




We want to study the QGP

We measure the correlations between identified particles

Experimental setup



- **Centrality**: V0 multiplicity, Centrality: 0-50%
- **Main tracking device**: Time Projection Chamber (TPC),
- **Particle identification (PID)**: TPC (dE/dx) & TOF (time of flight), pions were used in this analysis

Analysis Methods

- **HBT**: Hanbury Brown and Twiss, measured the angular diameter of Sirius
- A very powerful tool to study the source space-time extension in heavy-ion collisions

Theory

- Bowler and Sinyukov:

$$C(\vec{q}) = N[(1 - \lambda) + \lambda K(q_{inv})(1 + G(\vec{q}))]$$

$$q_{inv} = \sqrt{|\vec{q}|^2 - q_0^2} \quad q_0 = E_1 - E_2$$

$$\vec{q} = \vec{p}_1 - \vec{p}_2$$

N : normalization; K : Coulomb correction;
 λ : chaoticity

Experiment



$$C(q) = \frac{A(q)}{B(q)}$$

$A(q)$ is the measured (same-event) pair distribution in relative momentum

$B(q)$ is the measured (mixed-event) pair distribution in relative momentum

Our goal is to estimate $G(q)$, the source function

- Gaussian parametrization of the source function in the out-side-long system

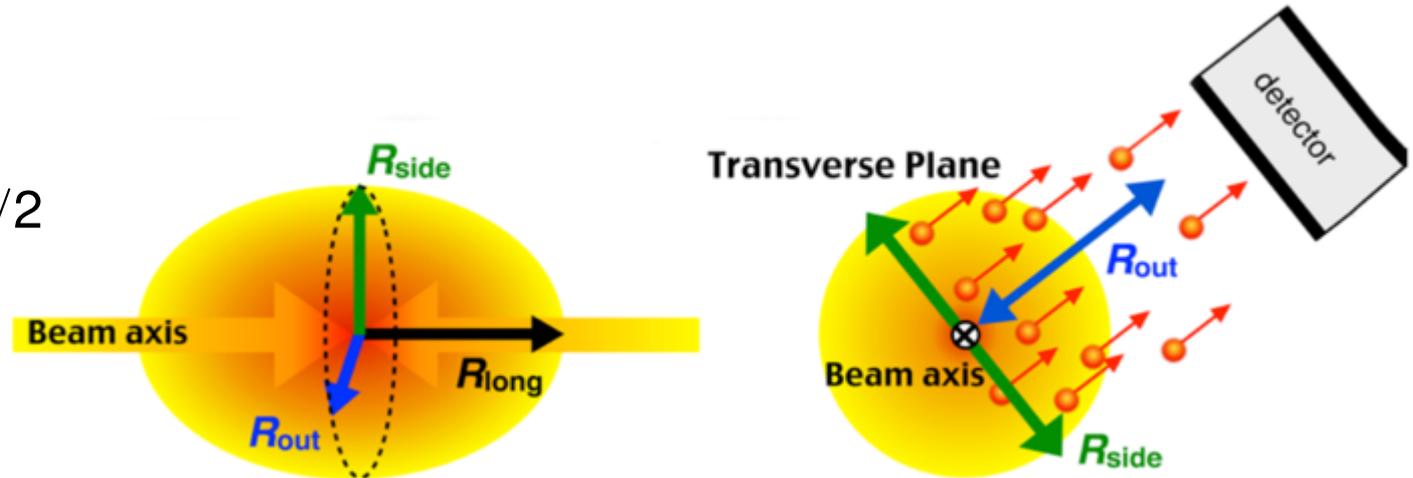
[2]

$$G(\vec{q}) = \exp(-q_{\text{out}}^2 R_{\text{out}}^2 - q_{\text{side}}^2 R_{\text{side}}^2 - q_{\text{long}}^2 R_{\text{long}}^2 - 2q_{\text{out}}q_{\text{side}}R_{\text{os}}^2)$$

$$\vec{k}_T = (\vec{p}_{T,1} + \vec{p}_{T,2})/2$$

$$\vec{q}_{\text{out}} \parallel \vec{k}_T$$

$$\vec{q}_{\text{side}} \perp \vec{k}_T$$

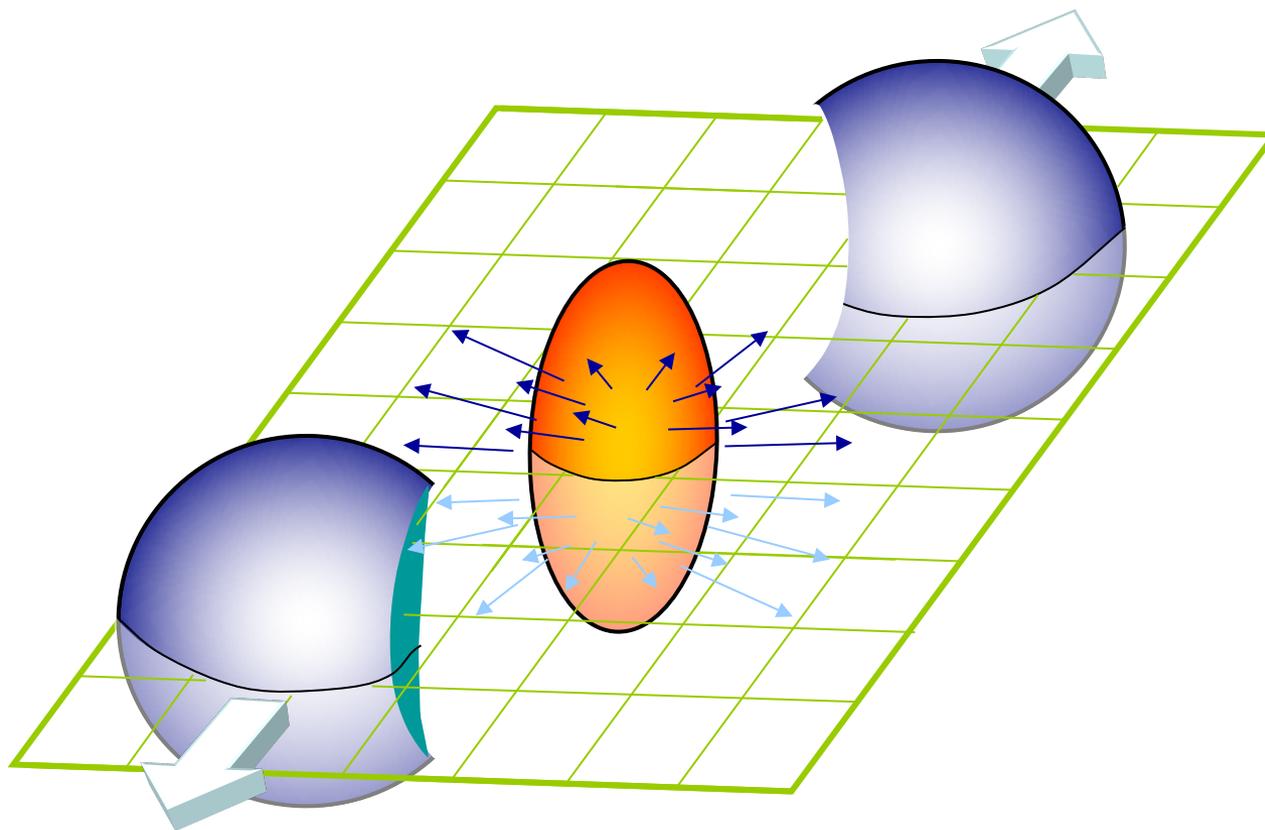


R_{out} : source size along the pair transverse momentum direction

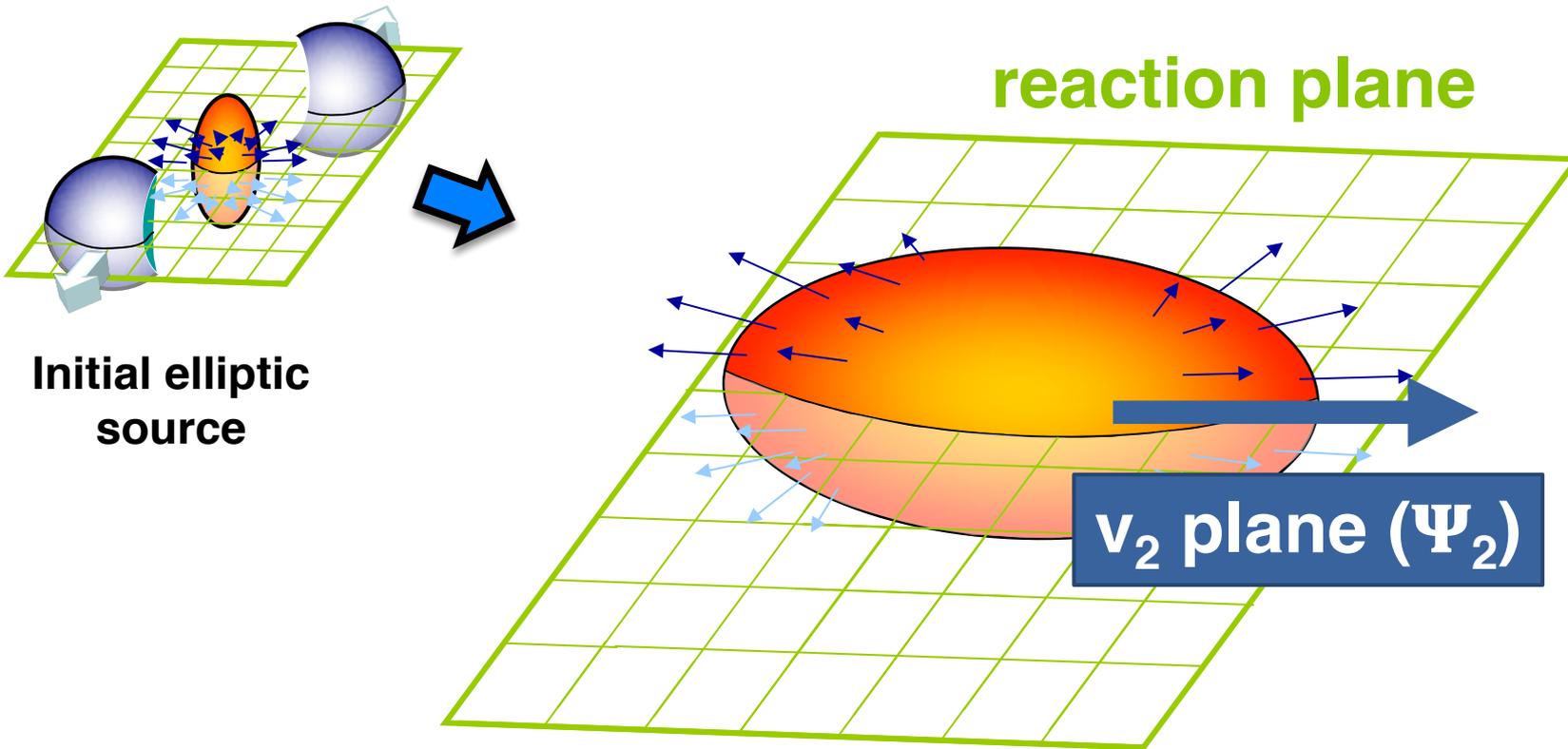
R_{side} : source size perpendicular to pair transverse momentum direction

R_{long} : longitudinal size

R_{os} : out-side cross term



Initial elliptic source

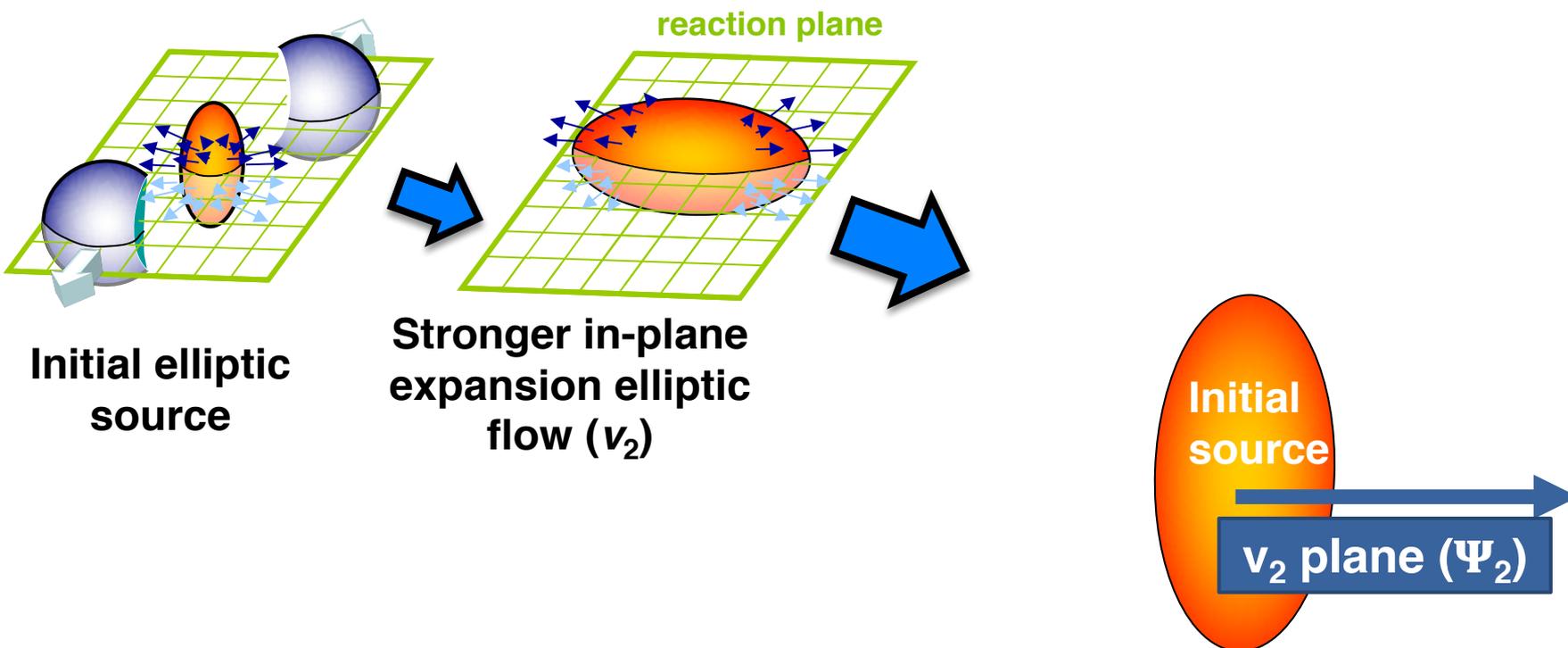


Initial elliptic source

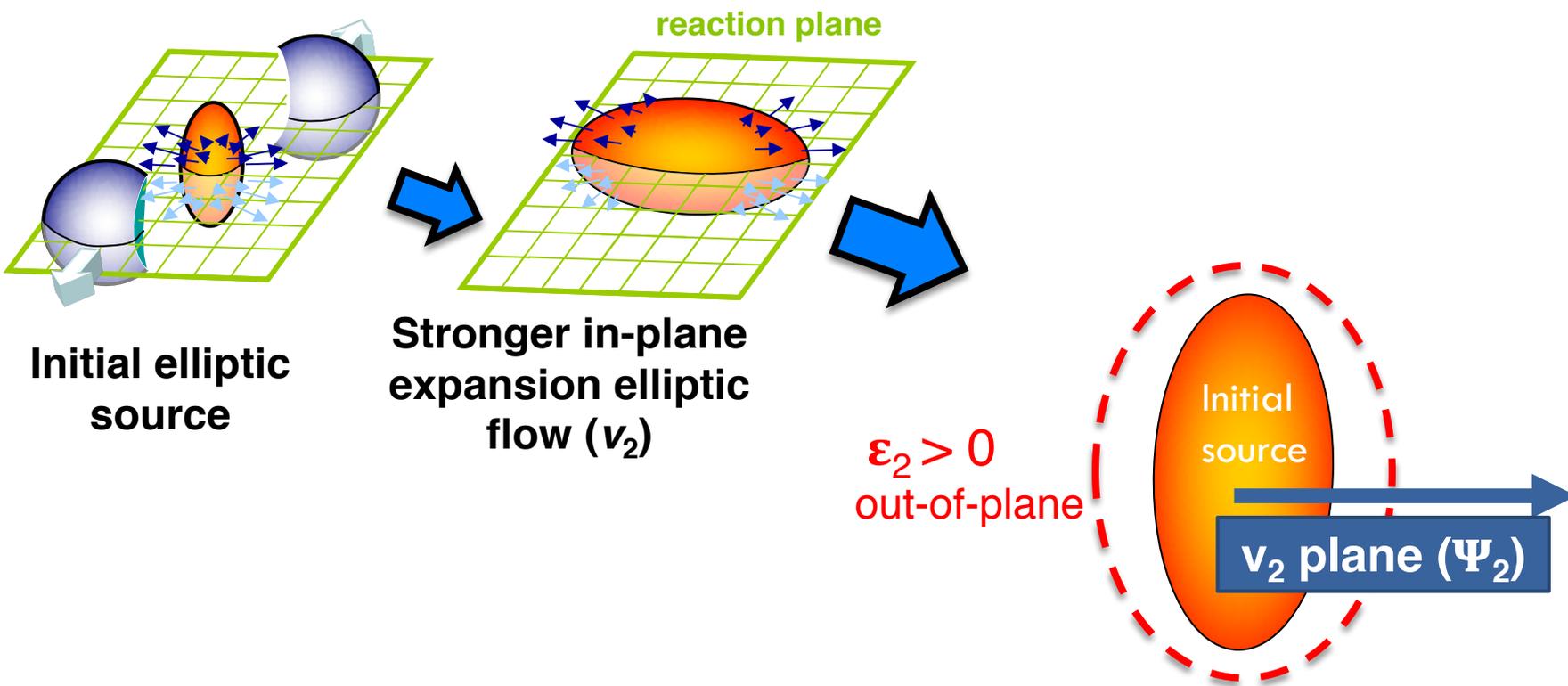
reaction plane

v₂ plane (Ψ_2)

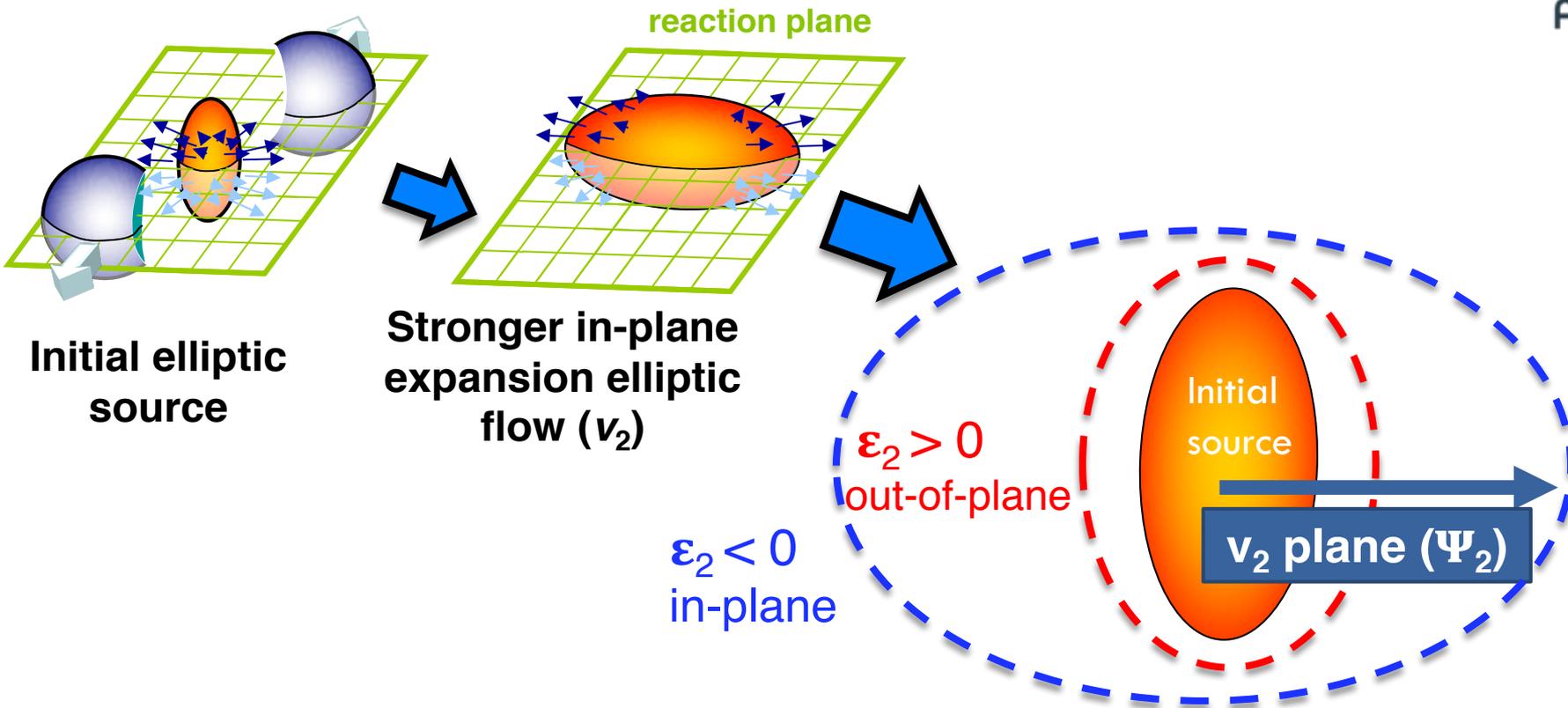
Stronger in-plane expansion



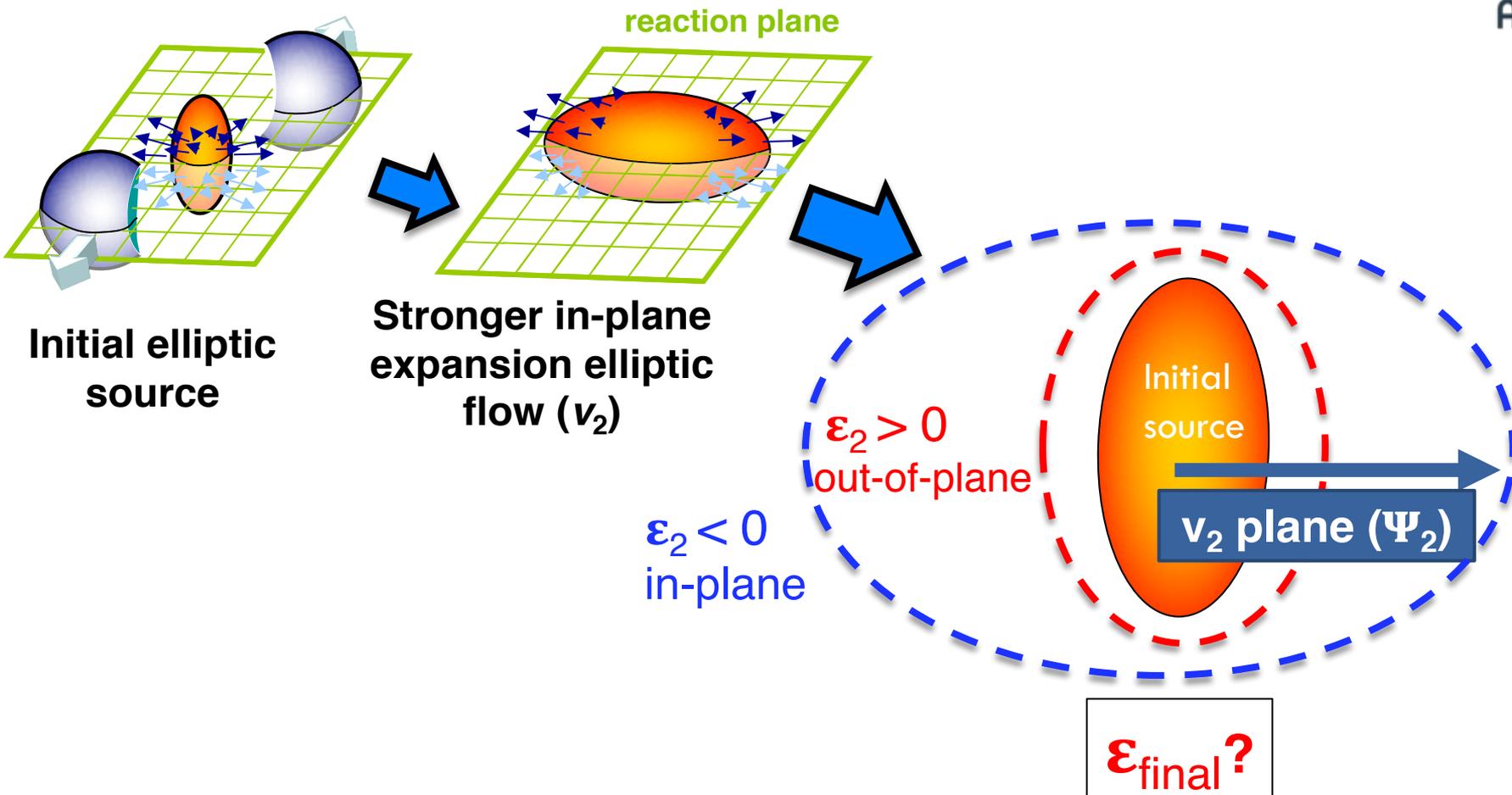
- Final eccentricity can be measured by azimuthal HBT w.r.t second harmonic event plane
 - ▣ It depends on initial eccentricity, lifetime and dynamics of the source evolution



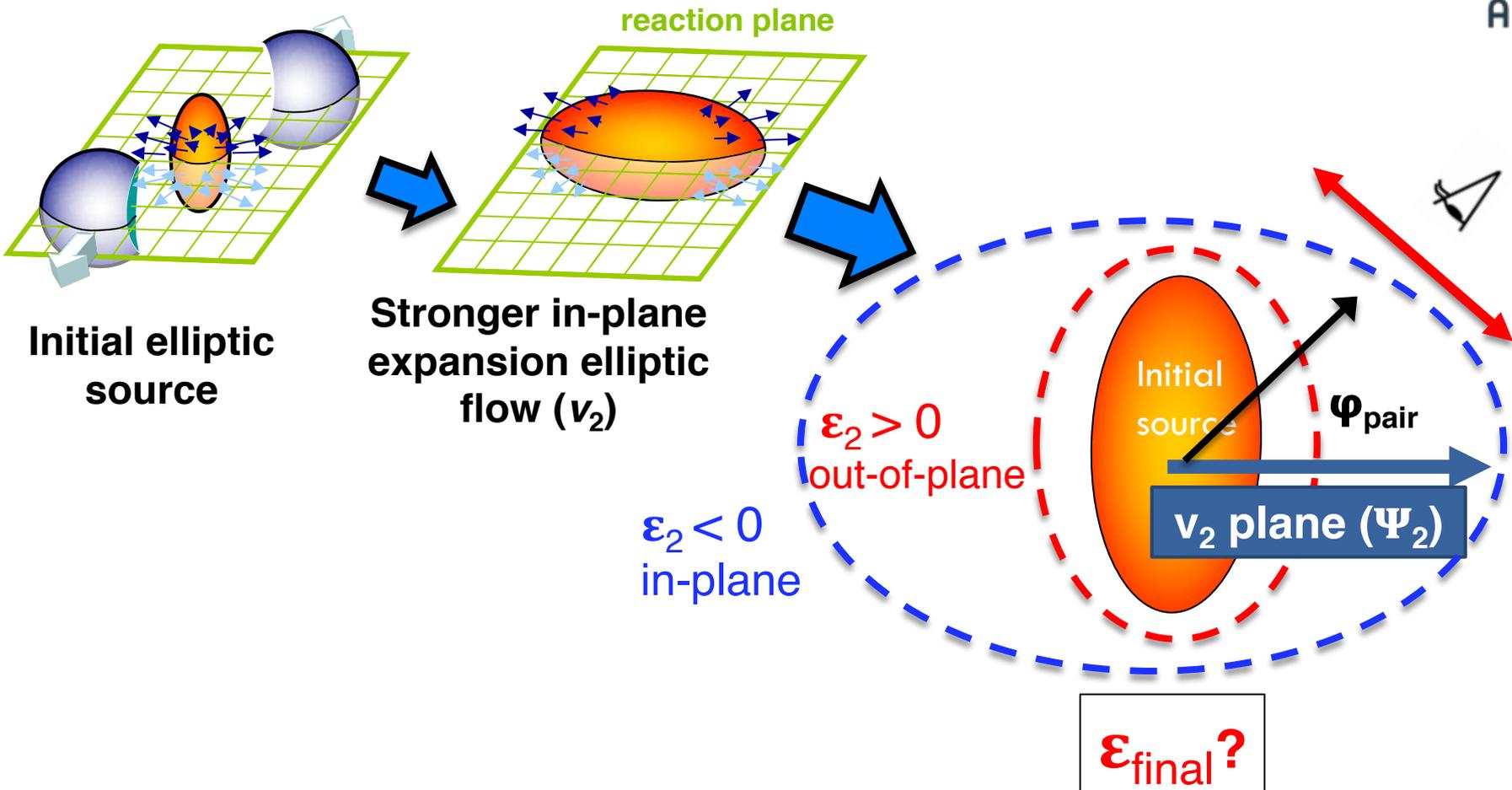
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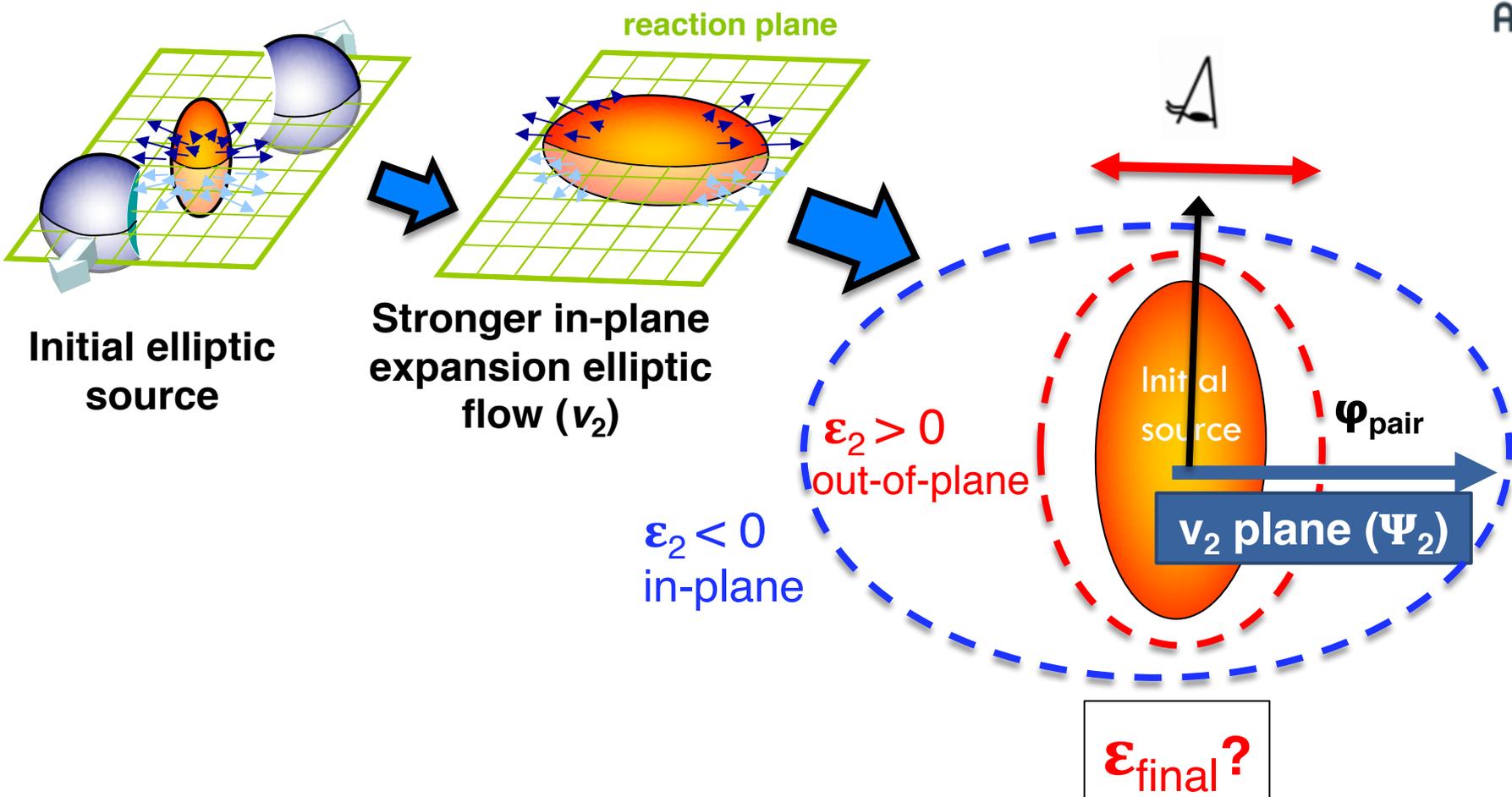
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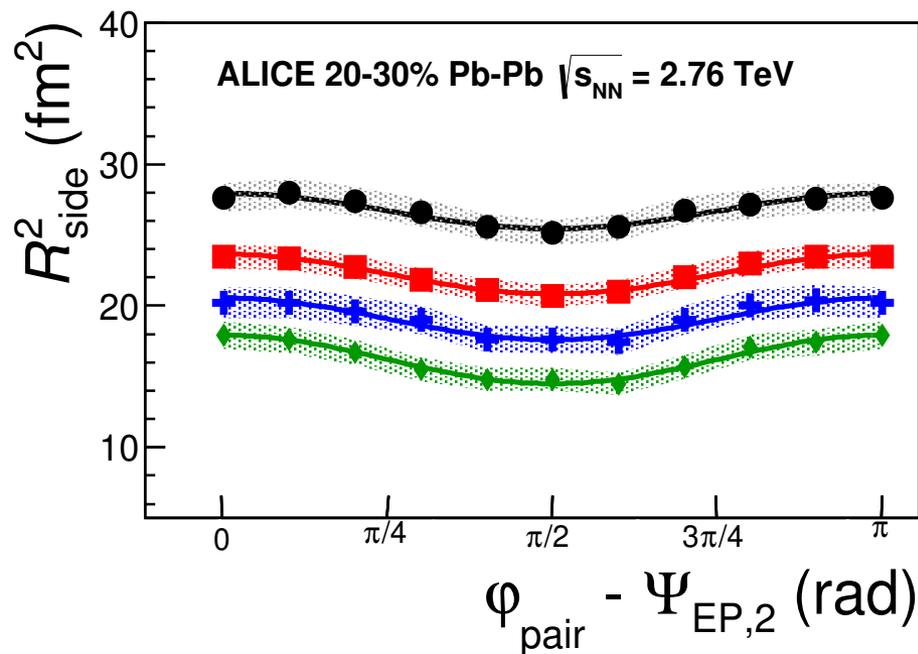
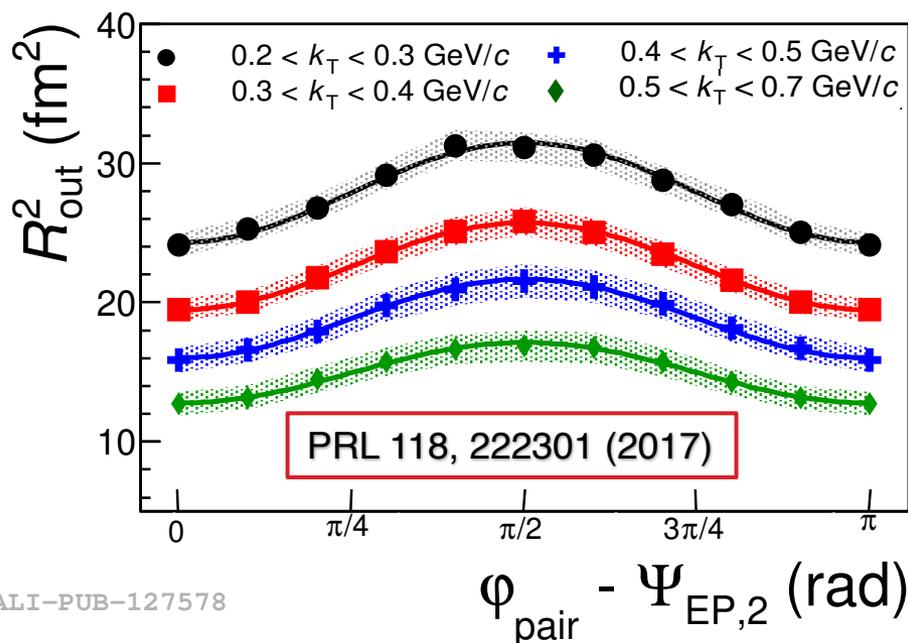


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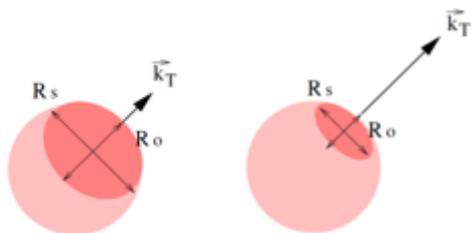
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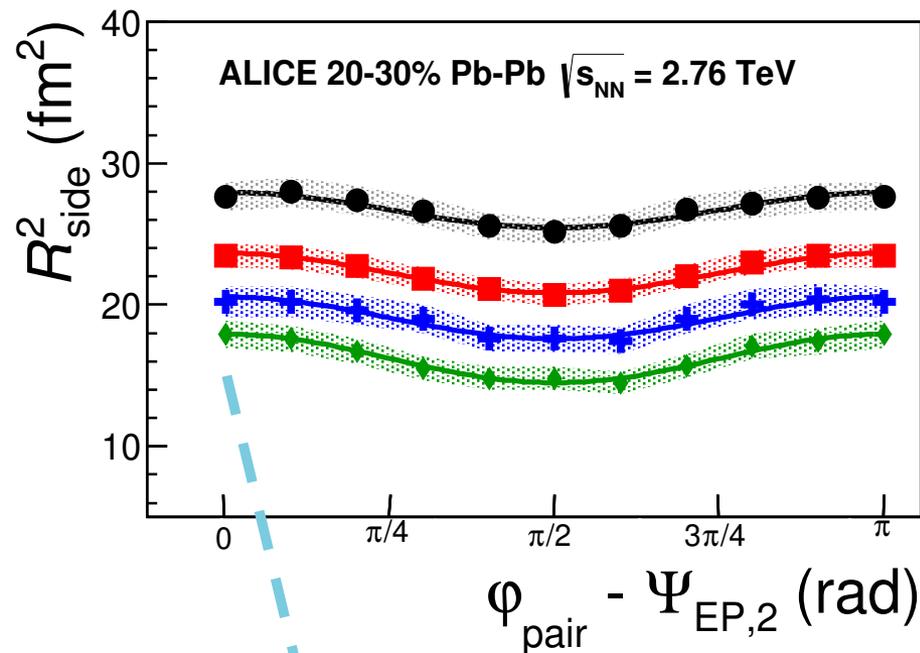
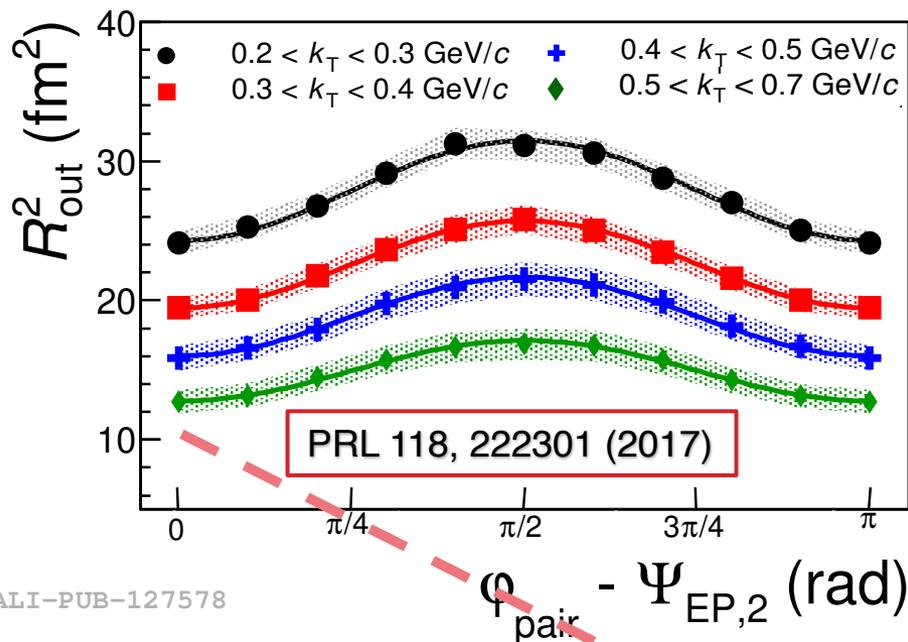
Results



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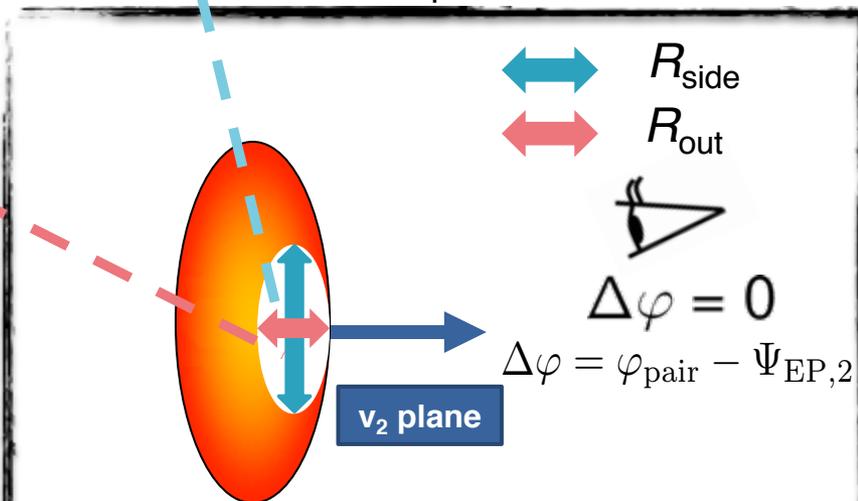
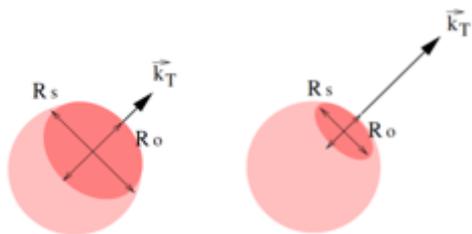
- As the value of k_T increases, the radii decrease.
- ▣ Space-momentum correlation = collective flow



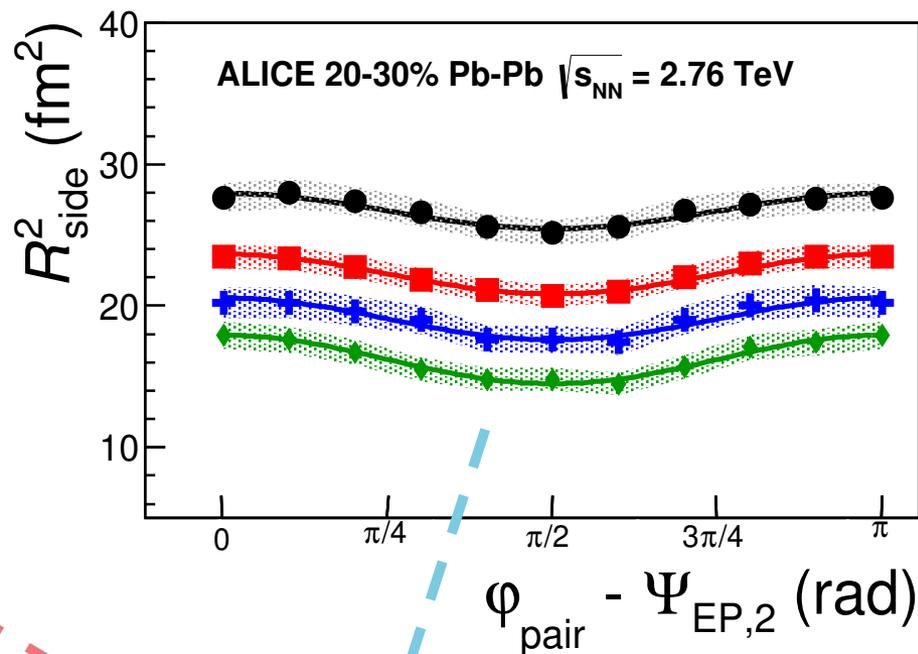
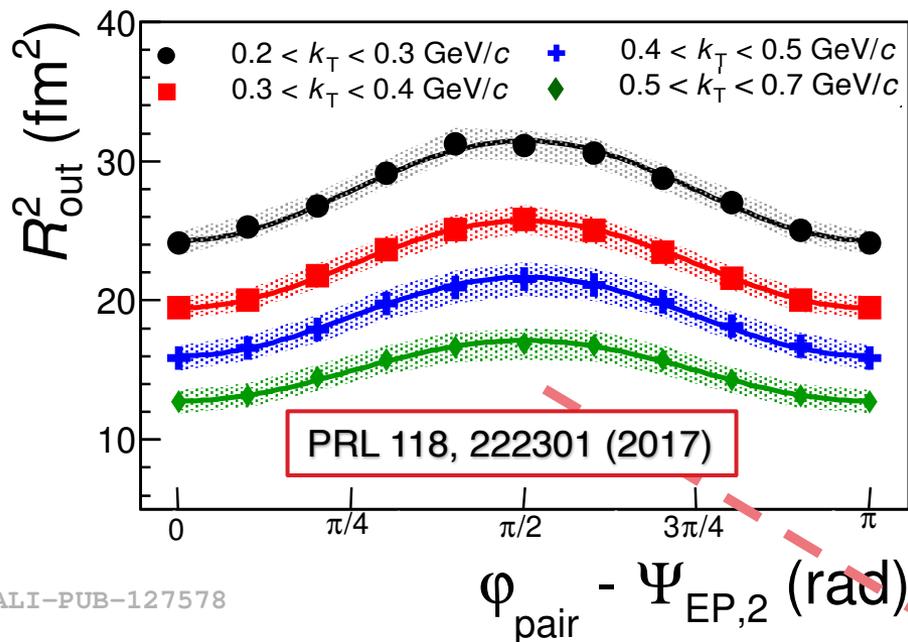


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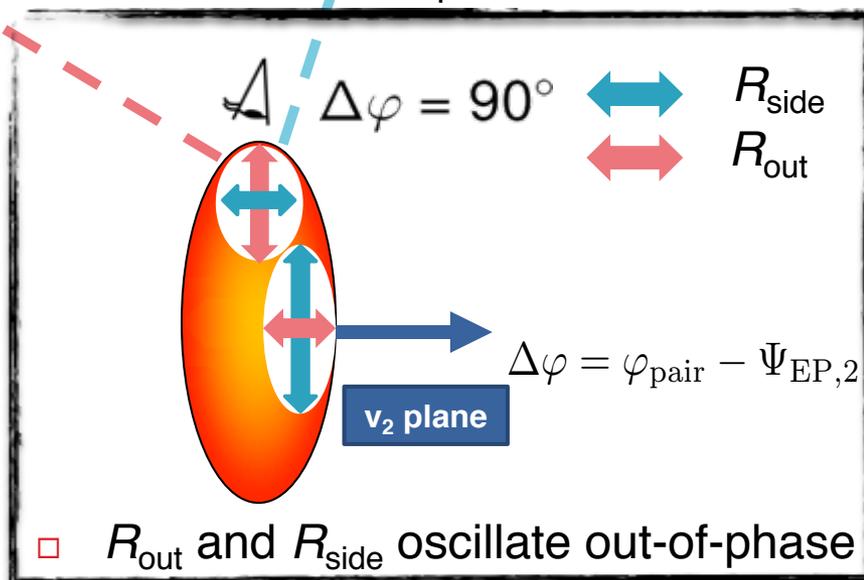
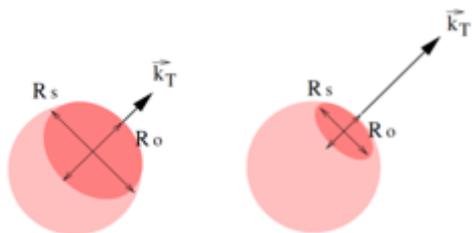
- R_{out} and R_{side} oscillate out-of-phase



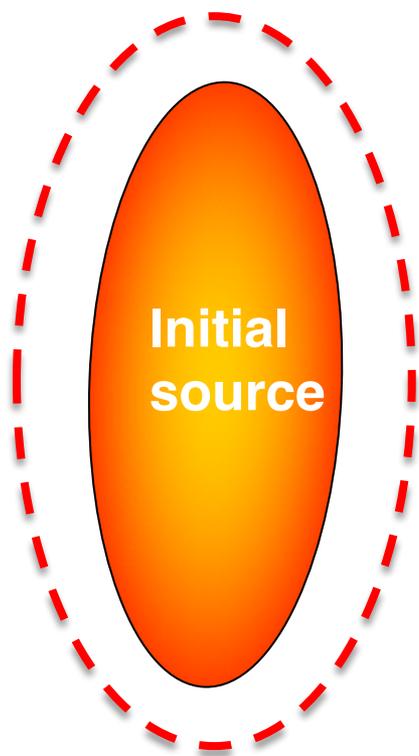
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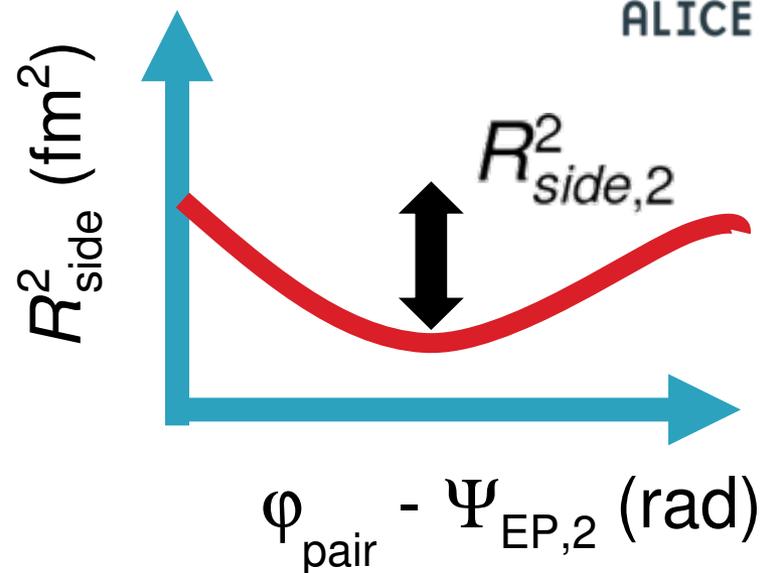
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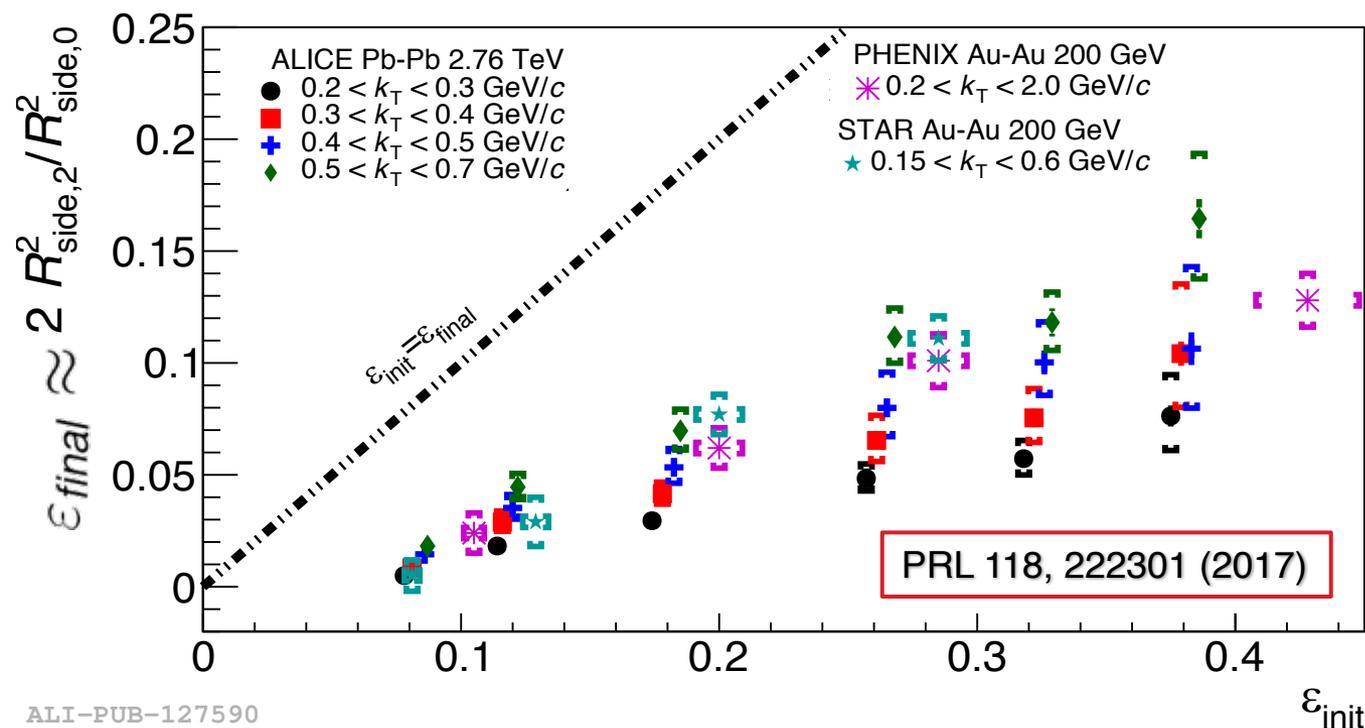


$$\epsilon_{final} \approx \frac{2R_{side,2}^2}{R_{side,0}^2}$$

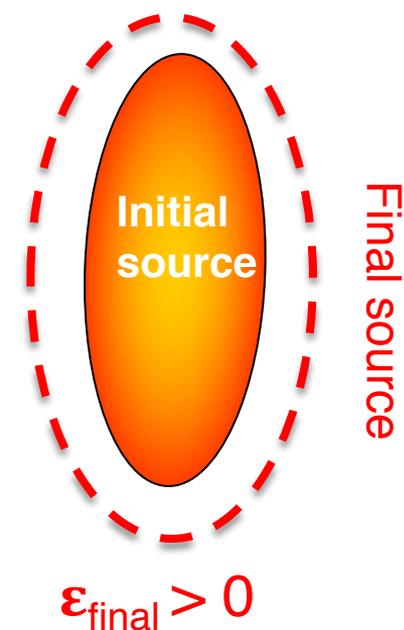


Final source



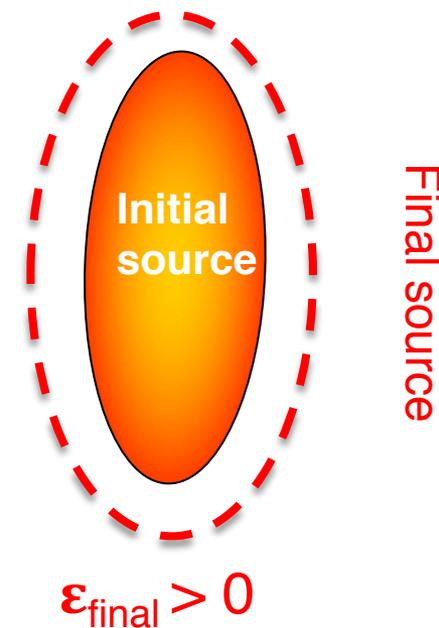
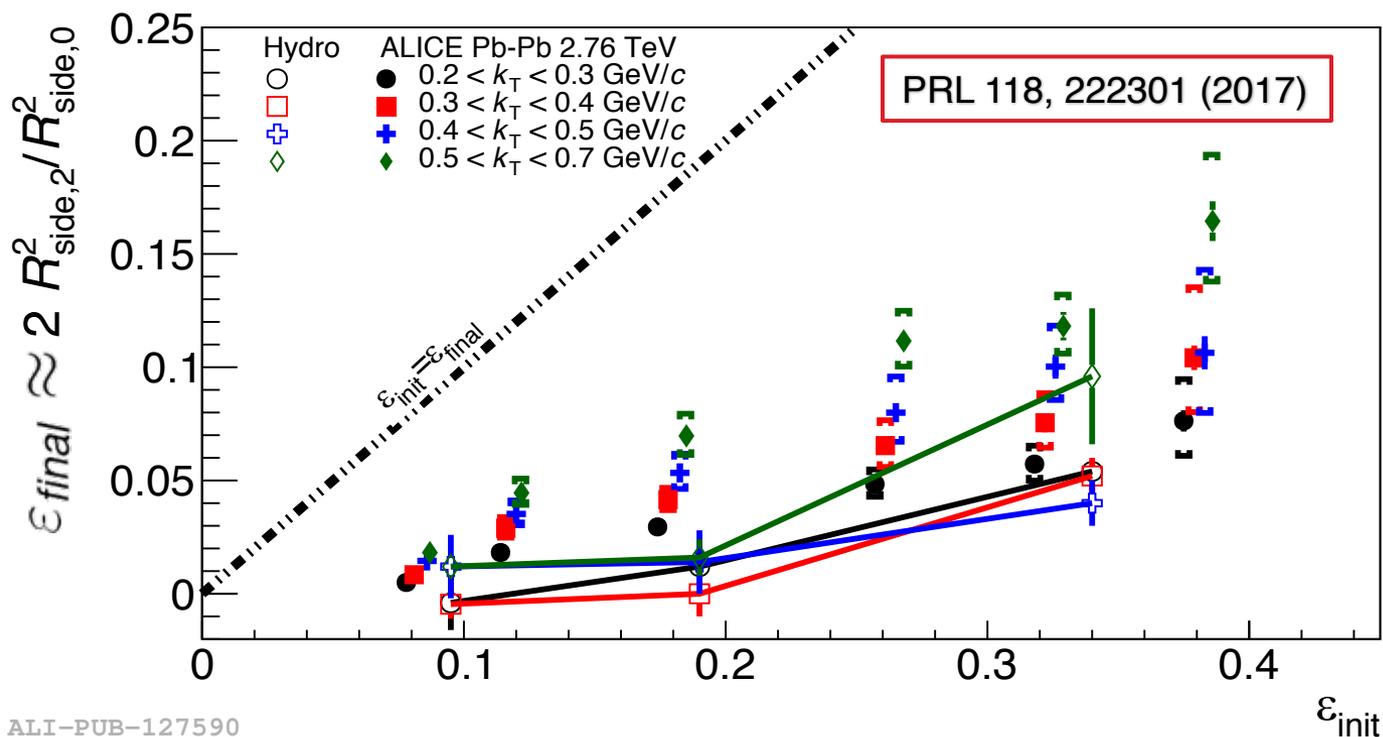


$$\varepsilon_{final} \approx \frac{2R_{side,2}^2}{R_{side,0}^2} \quad [1]$$



$$0 < \varepsilon_{final} \text{ (LHC)} < \varepsilon_{final} \text{ (RHIC)} < \varepsilon_{initial}$$

Final eccentricity is smaller than the initial eccentricity, but remains positive (still out-of-plane extended)



The lines connect the hydro points

The 3+1D hydro calculations agree qualitatively but predict a more isotropic final source

□ Azimuthal HBT w.r.t v_2 plane:

- Final eccentricity is smaller than the initial eccentricity, but remains positive (still out-of-plane), $0 < \epsilon_{\text{final}} \text{ (LHC)} < \epsilon_{\text{final}} \text{ (RHIC)} < \epsilon_{\text{initial}}$
- The 3+1D hydro calculations for final eccentricity agree qualitatively but predict a more isotropic final source

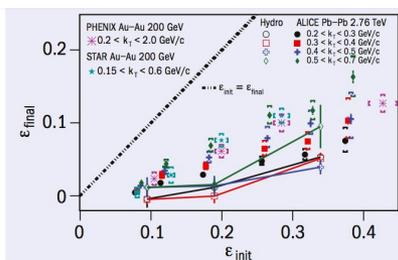
CERN Courier, April issue

ALICE measures shape of the QGP fireball at freeze-out



ALICE

Heavy-ion collisions at LHC energies create a hot and dense medium of deconfined quarks and gluons, known as the quark–gluon plasma (QGP). The QGP fireball first expands, cools and then freezes out into a collection of final-state hadrons. Correlations between the free particles carry information about the space–time extent of the emitting source, and are imprinted on the final-state spectra due to a quantum-mechanical interference effect. To measure these correlations and to determine the space–time parameters of the



Freeze-out eccentricity measured for different ranges of pair transverse momentum as a function of initial-state eccentricity obtained from Monte Carlo models for six centrality ranges, 0–5%, 5–10%, 10–20%, 20–30%, 30–40% and 40–50%.

and Twiss (HBT) interferometry, a technique first used in astronomy for determining the angular sizes of stars. Using azimuthally

PRL publication

PRL 118, 222301 (2017)

PHYSICAL REVIEW LETTERS

week ending
2 JUNE 2017

Azimuthally Differential Pion Femtoscopy in Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV

D. Adamová *et al.**

(ALICE Collaboration)

(Received 21 February 2017; published 2 June 2017)

We present the first azimuthally differential measurements of the pion source size relative to the second harmonic event plane in Pb-Pb collisions at a center-of-mass energy per nucleon-nucleon pair of $\sqrt{s_{NN}} = 2.76$ TeV. The measurements have been performed in the centrality range 0%–50% and for pion pair transverse momenta $0.2 < k_T < 0.7$ GeV/c. We find that the R_{side} and R_{out} radii, which characterize the pion source size in the directions perpendicular and parallel to the pion transverse momentum, oscillate out of phase, similar to what was observed at the Relativistic Heavy Ion Collider. The final-state source eccentricity, estimated via R_{side} oscillations, is found to be significantly smaller than the initial-state source eccentricity, but remains positive—indicating that even after a stronger expansion in the in-plane direction, the pion source at the freeze-out is still elongated in the out-of-plane direction. The 3 + 1D hydrodynamic calculations are in qualitative agreement with observed centrality and transverse momentum R_{side} oscillations, but systematically underestimate the oscillation magnitude.

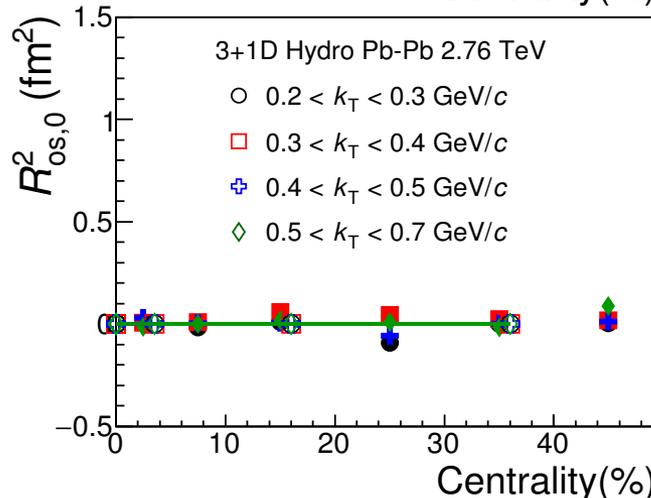
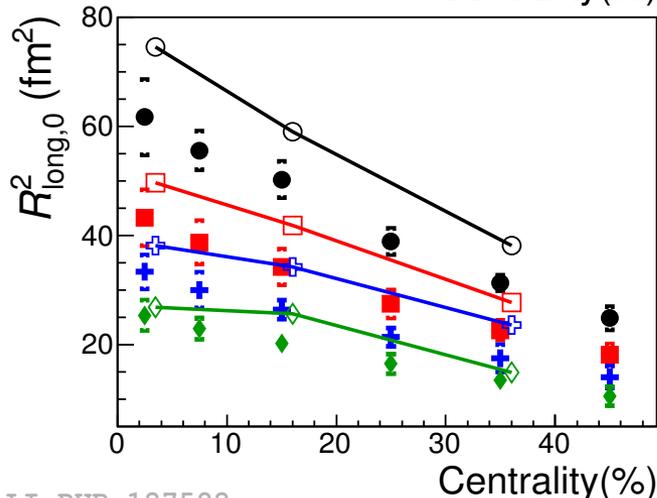
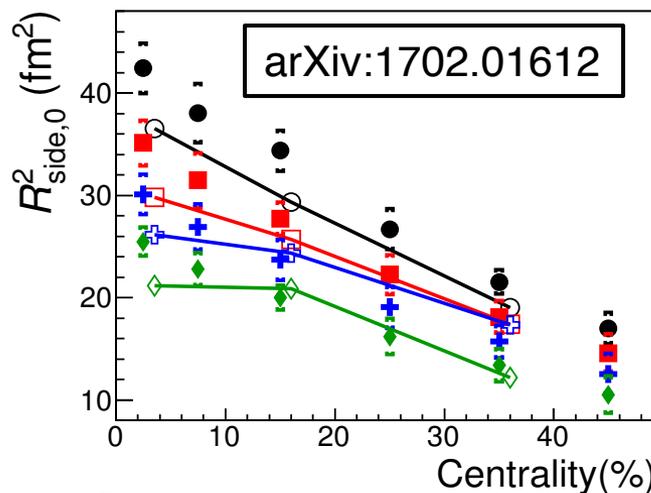
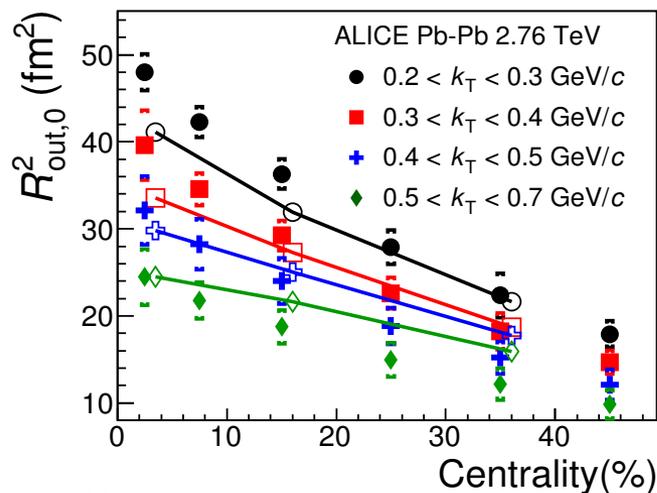
DOI: 10.1103/PhysRevLett.118.222301

Thank you

Backup slides



ALICE

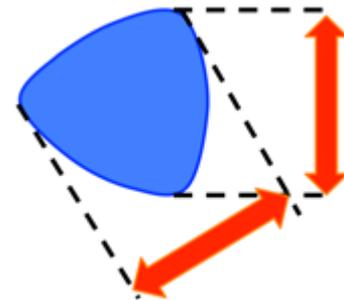
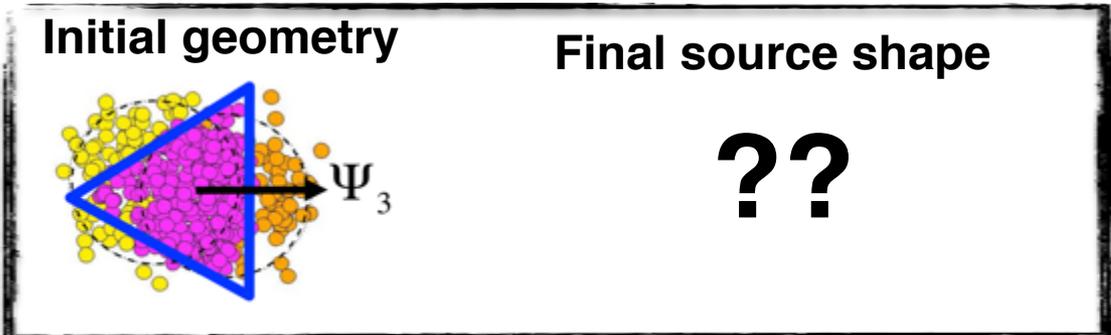


- R_{out} , R_{side} , and R_{long} have clear centrality and k_T dependence
- 3+1D Hydro agrees qualitatively with ALICE data points

ALI-PUB-127582

Average radii are larger for more central collisions which is related to the initial eccentricity

31 Motivation: Azimuthal HBT w.r.t v_3 plane



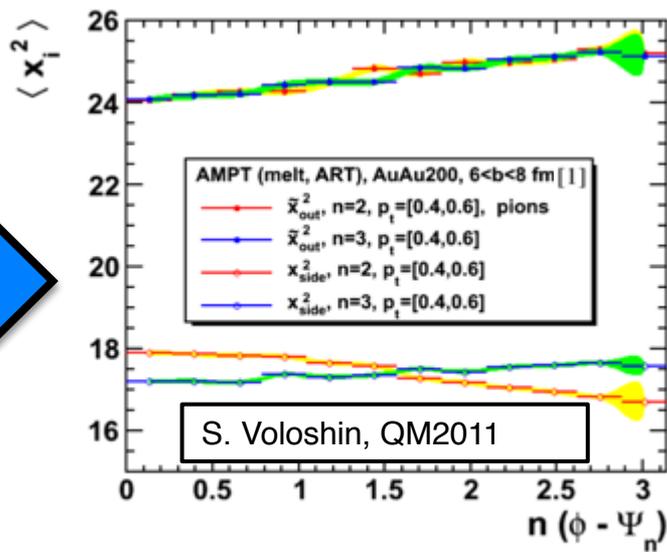
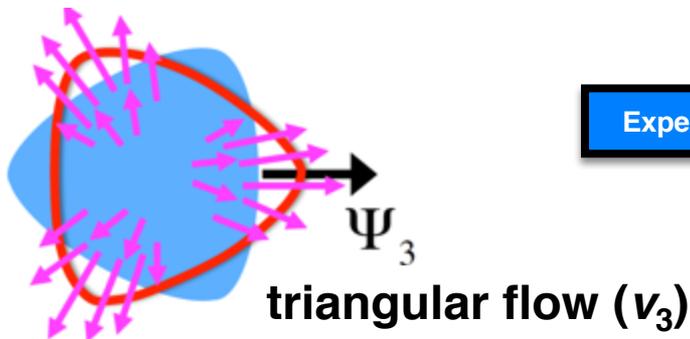
□ For non-expanding source:

$$R_{side}^2 = \langle x_{side}^2 \rangle = \langle x^2 \rangle \sin^2 \phi + \langle y^2 \rangle \cos^2 \phi - \langle xy \rangle \sin 2\phi$$



no R_{side} oscillations should be observed w.r.t Ψ_3

Triangular flow leads to Radii oscillations

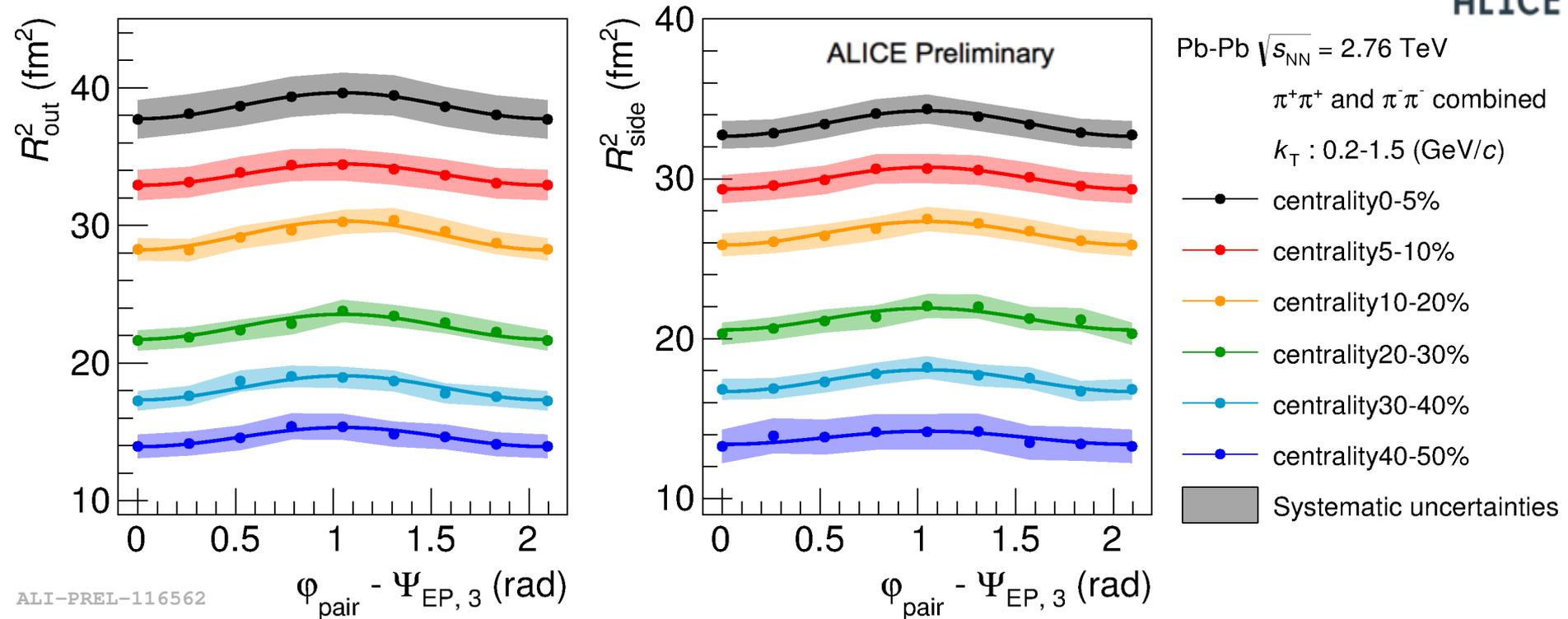


Radii oscillations will confirm the collective nature of triangular flow

[1] AMPT model: B. Zhang, C. M. Ko, B. -A. Li, Z. -w. Lin, Phys. Rev. C61, 067901 (2000)

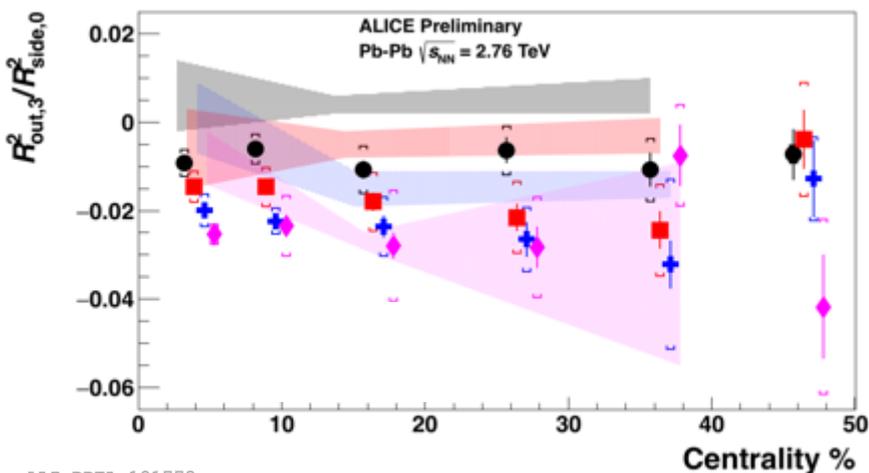


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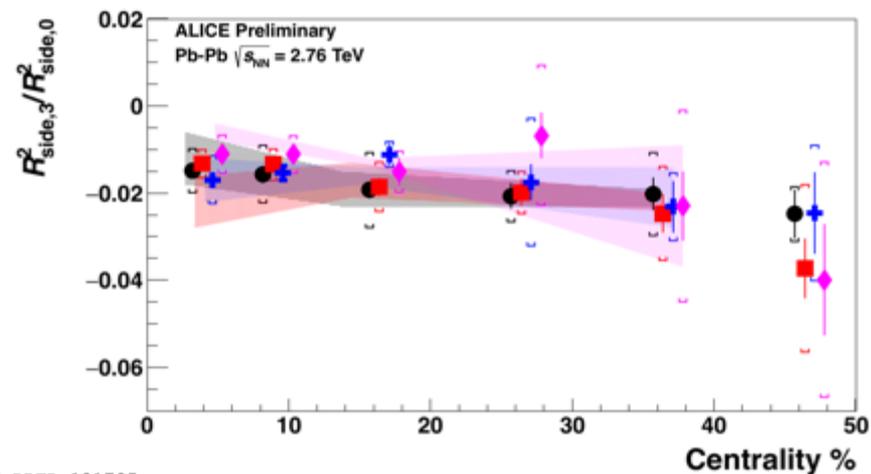


Radii oscillations were observed for all centralities

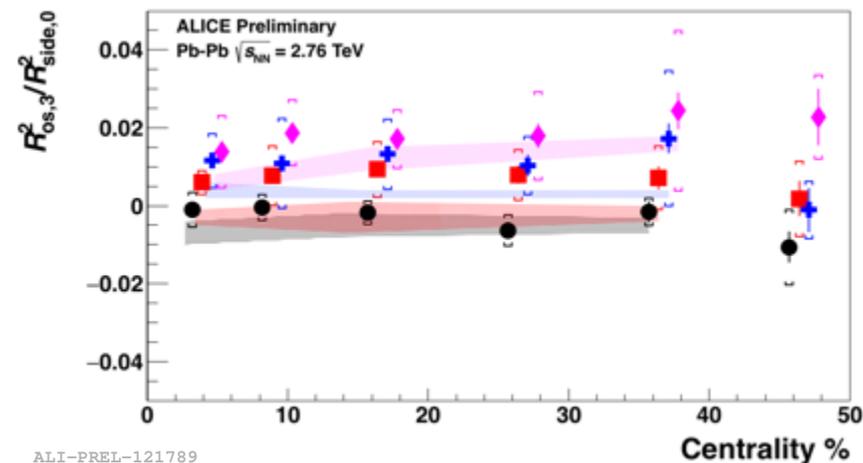
R_{out} and R_{side} oscillate in-phase



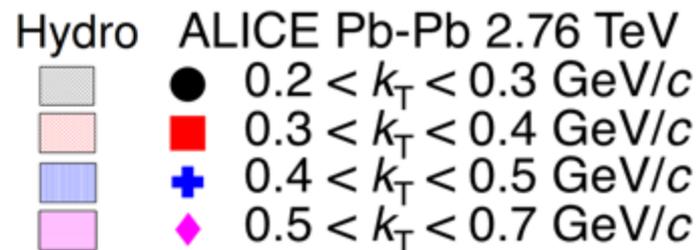
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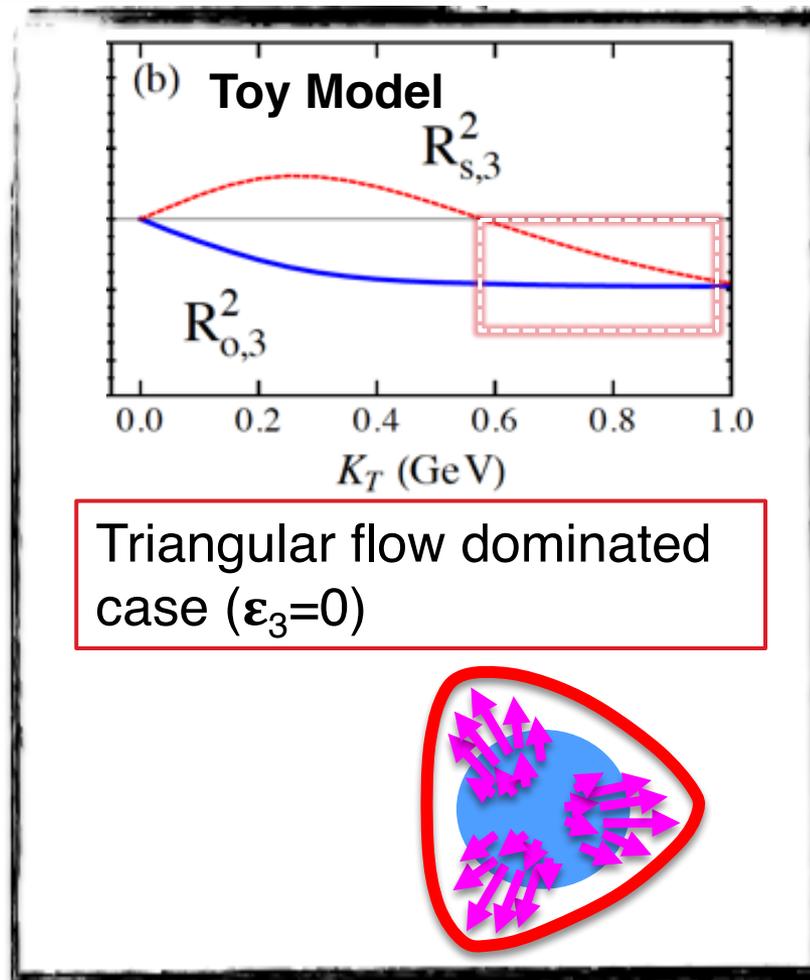
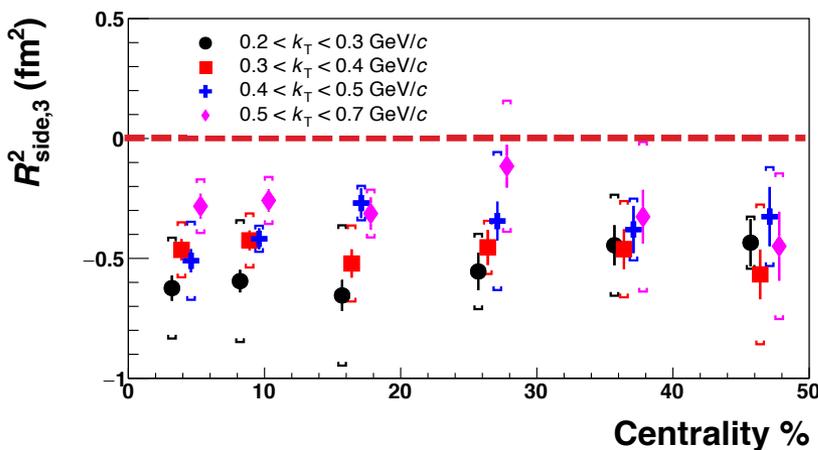
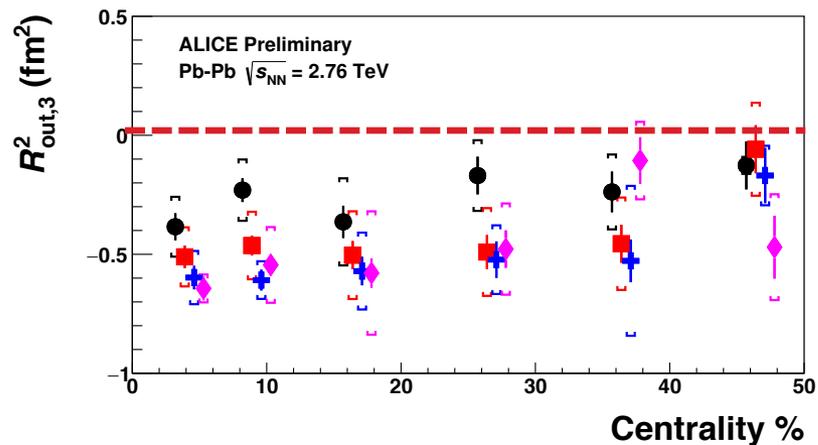
ALI-PREL-121785



ALI-PREL-121789

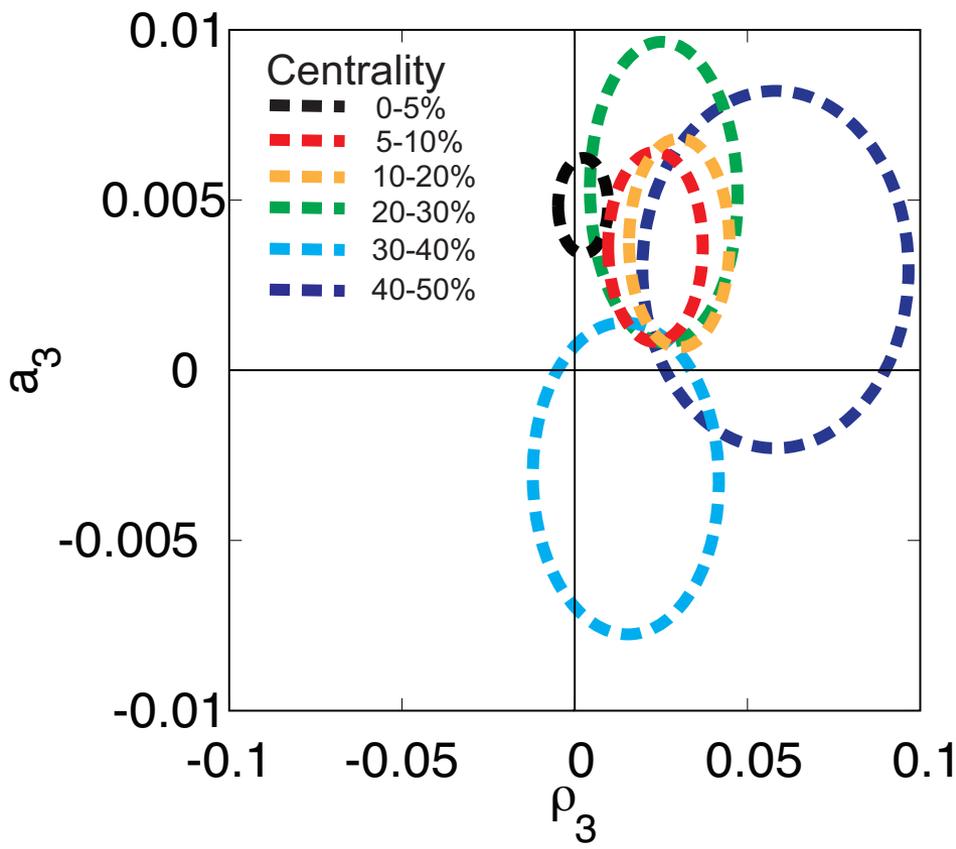
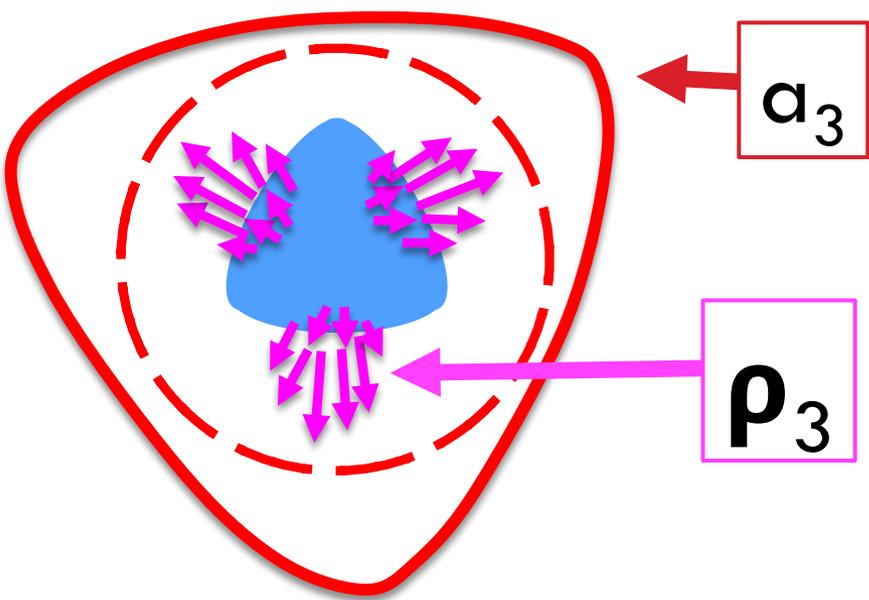


Amplitudes of the relative radii oscillations for R_{out} agree qualitatively with hydro while R_{side} and R_{os} agree quantitatively



Toy model shows in-phase oscillations of R_{out} and R_{side} for $k_T > 0.6$ GeV

Initial triangular deformation is washed-out, or even reversed.



Isotropic final source, Initial triangular shape is washed out