Event geometrical anisotropy and fluctuation viewed by HBT interferometry

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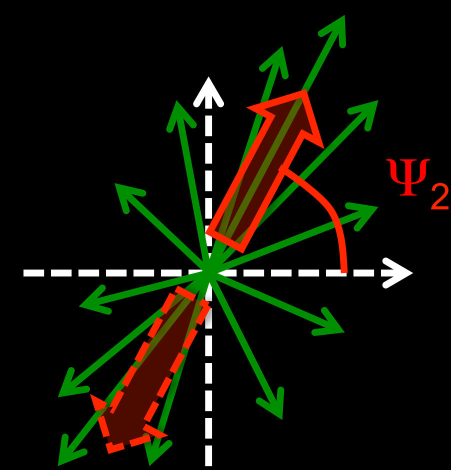
- Event twist selection with HBT with AMPT model

Event shape engineering with HBT at the PHENIX experiment

Event shape engineering

- Event shape engineering (ESE)
  - J. Schukraft et al., arXiv:1208.4563
  - Selecting e-b-e v_2 by the magnitude of flow vector

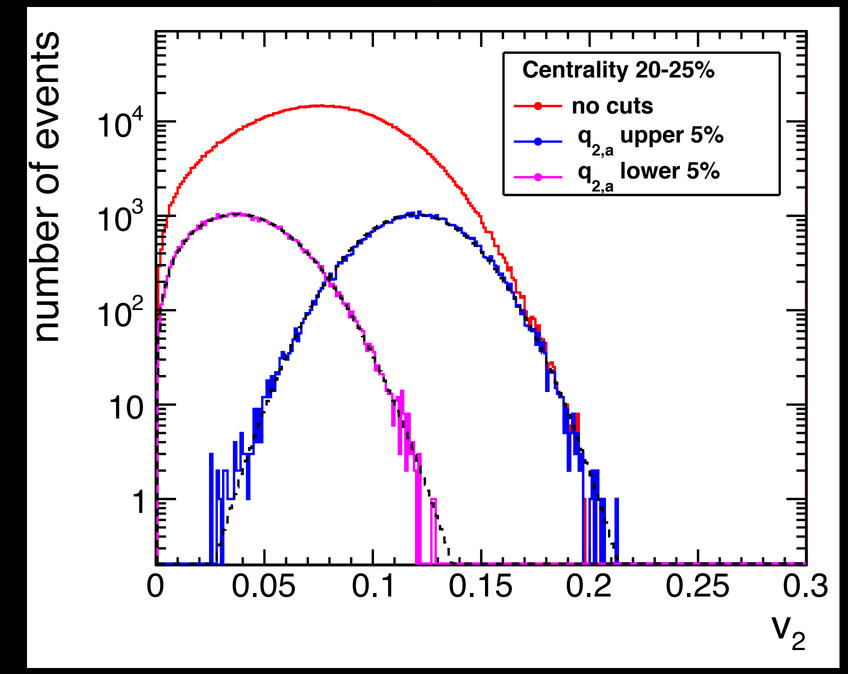
$$Q_{2,x} = \Sigma w_i \cos(2\phi)$$
$$Q_{2,y} = \Sigma w_i \sin(2\phi)$$
$$Q_2 = \sqrt{Q_{2,x}^2 + Q_{2,y}^2} / \sqrt{\Sigma w_i}$$
$$\Psi_2 = \tan^{-1}\left(\frac{Q_{2,y}}{Q_{2,x}}\right)$$



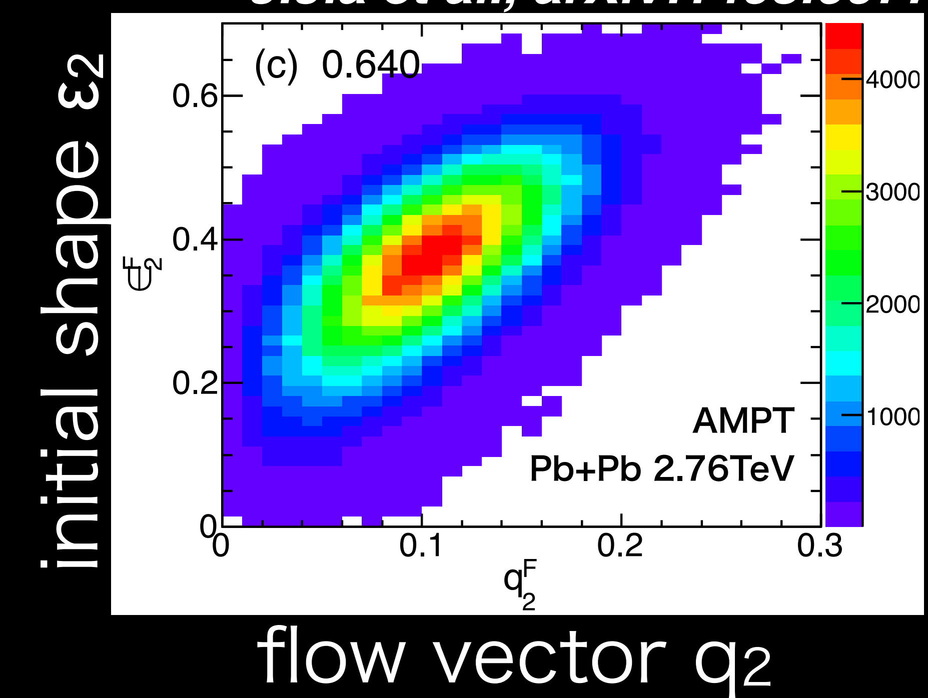
  - **Possibly control the initial geometry**

- More accurate connection between initial and final source eccentricity ?
  - Azimuthal HBT w.r.t Ψ_2

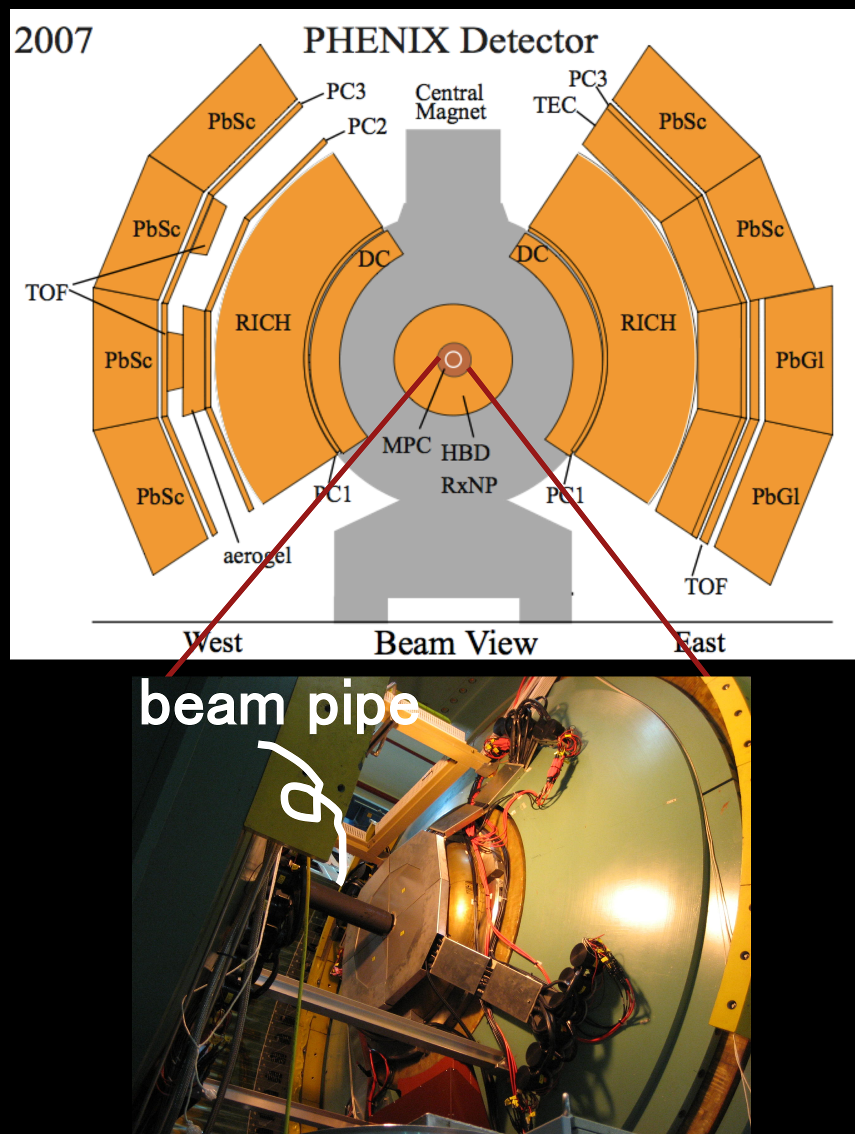
J.Schukraft et al., arXiv:1208.4563



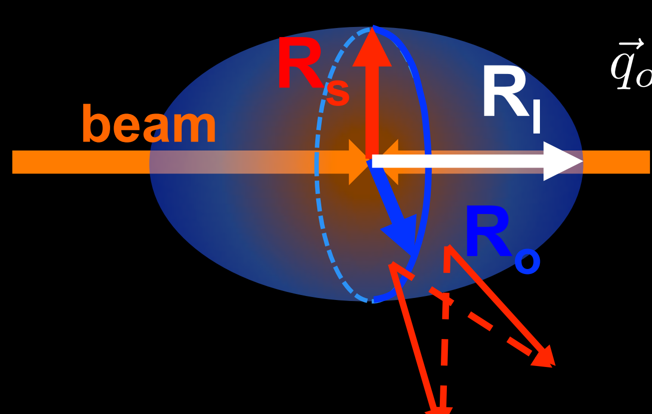
J.Jia et al., arXiv:1403.6077



Measurement at PHENIX



- Event plane & flow vector determination
  - Reaction Plane Detectors (RxNP) ($1<|\eta|<2.8$)
  - Res(Ψ_2)~75%
- Charged pion Identification
  - Electromagnetic calorimeter (EMCal) ($|\eta|<0.35$)
  - using time-of-flight at EMCal
- HBT measurement
  - $\pi\pi$-correlation
  - Core-halo picture with out-side-long frame



$$\vec{k}_T = (\vec{p}_{T1} + \vec{p}_{T2})/2$$

$$\vec{q}_o \parallel \vec{k}_T, \vec{q}_s \perp \vec{k}_T$$

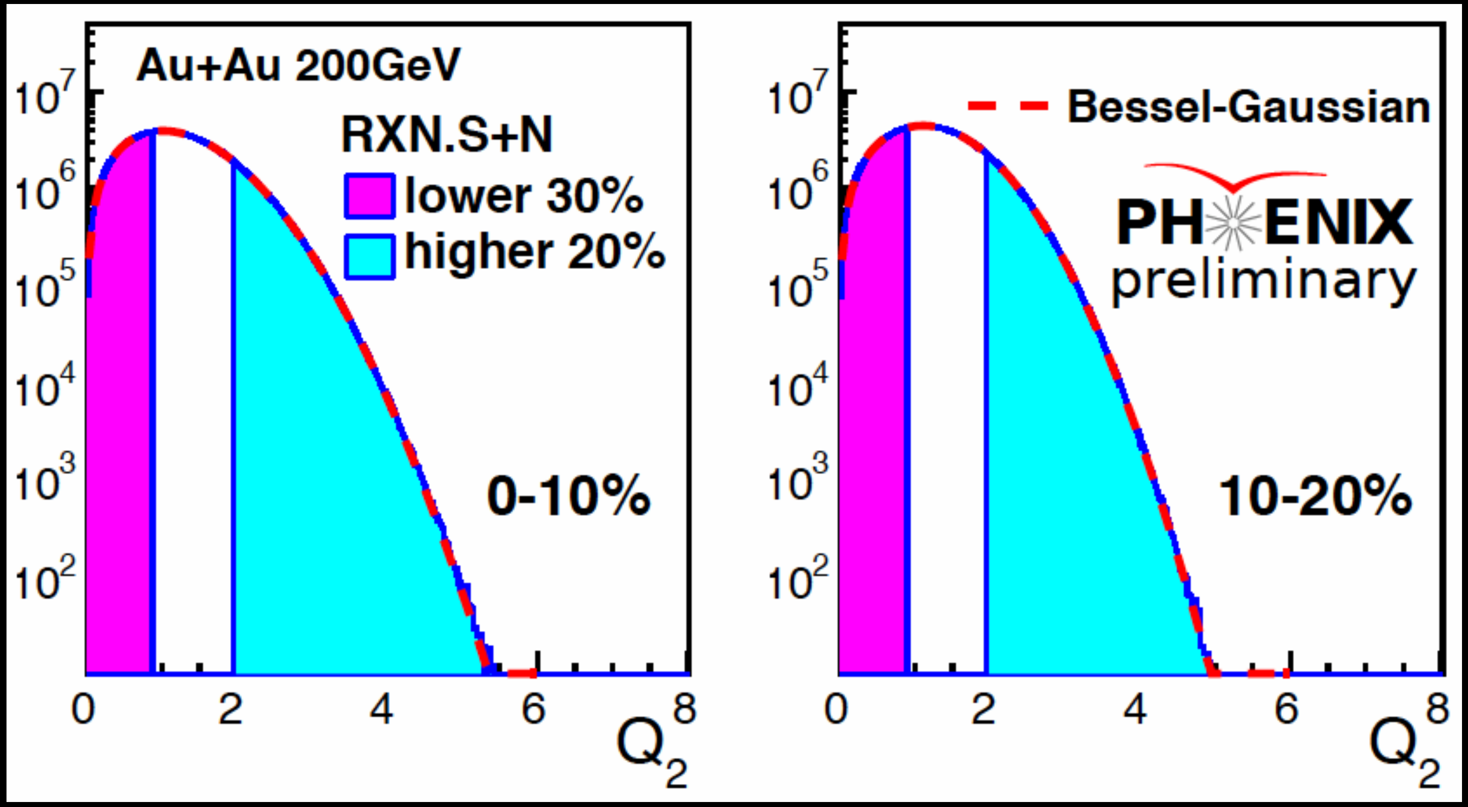
$$\begin{aligned} C_2 &= C_2^{core} + C_2^{halo} \\ &= [\lambda(1+G)F_{coul}] + [1-\lambda] \\ G &= \exp(-R_s^2 q_s^2 - R_o^2 q_o^2 - R_l^2 q_l^2 - 2R_{os}^2 q_s q_o) \end{aligned}$$

How to apply the ESE

1. Q_2 distribution measured by RxNP
2. Fitted with the Bessel-Gaussian function

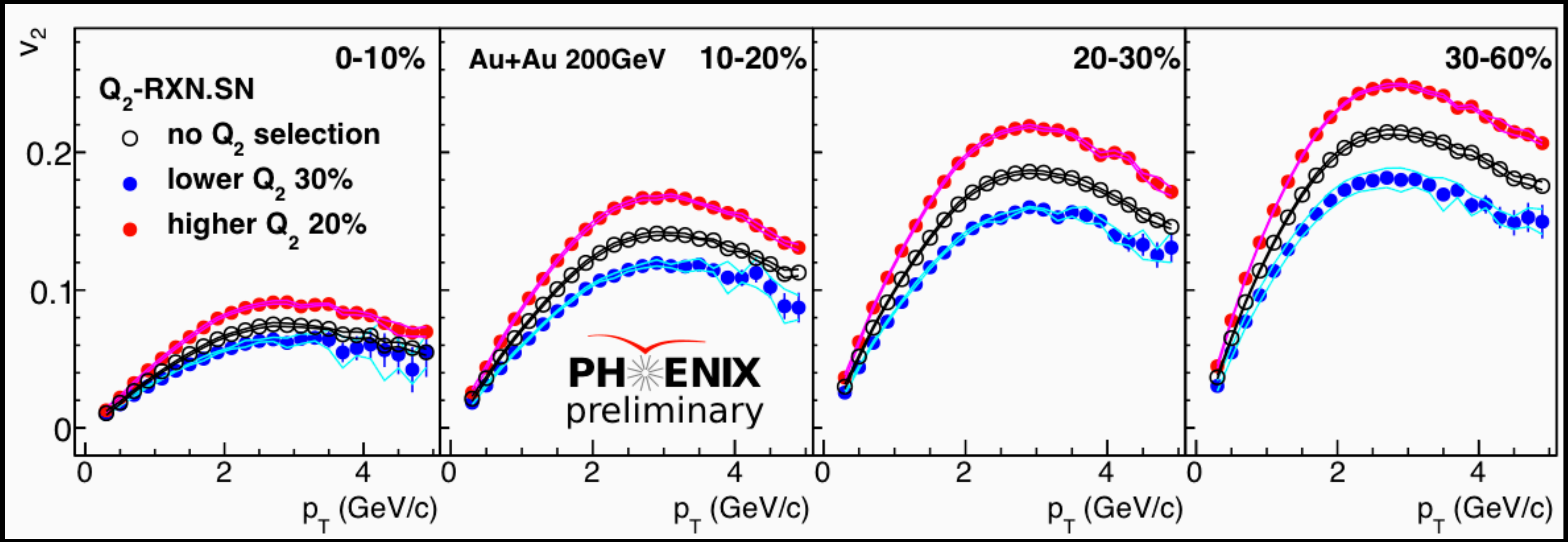
$$f_{BesselGaus} = \frac{x}{\sigma} I_0(\frac{x_0 x}{\sigma^2}) \exp(-\frac{(x_0^2 + x^2)}{2\sigma^2})$$

3. Select higher or lower Q_2 events



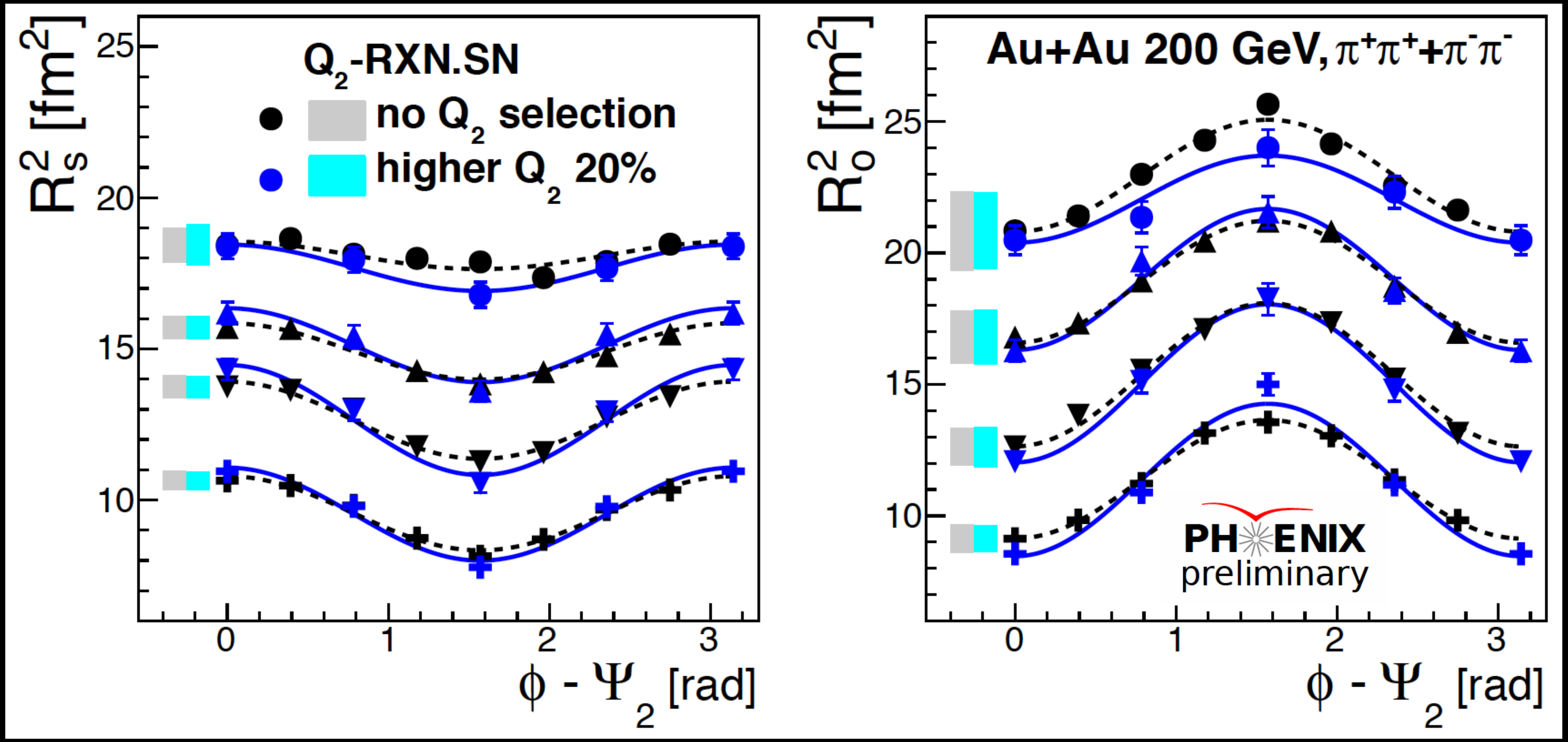
Resolutions of event planes were estimated by 3-sub method using RxNP($1<|\eta|<2.8$) and BBC($3<|\eta|<3.9$) applying Q_2 selection.

Charged hadron v_2 with ESE



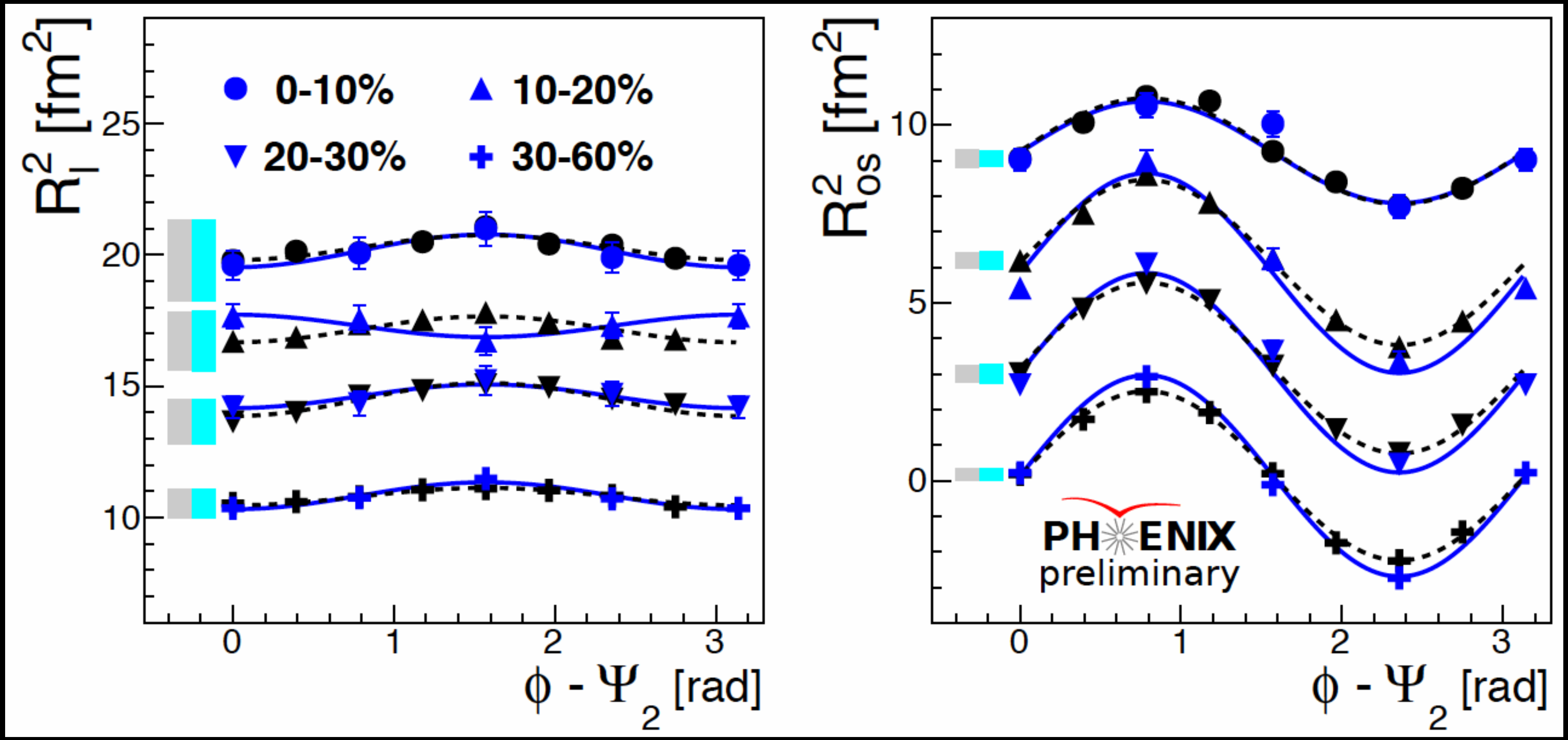
- Test of the event shape engineering for v_2 in Au+Au 200GeV collisions
  - v_2 measured at mid-rapidity ($|\eta|<0.35$)
  - Q_2 and EP determined at $1<|\eta|<2.8$
- Confirmed that higher(lower) Q_2 selects larger(smaller) v_2

HBT radii w.r.t Ψ_2 with ESE



- Applying the ESE to azimuthal HBT
  - charged $\pi\pi$-correlation measured at mid-rapidity ($|\eta|<0.35$)
  - Q_2 and EP determined at $1<|\eta|<2.8$
- Oscillations of R_s and R_o become larger when selecting higher Q_2

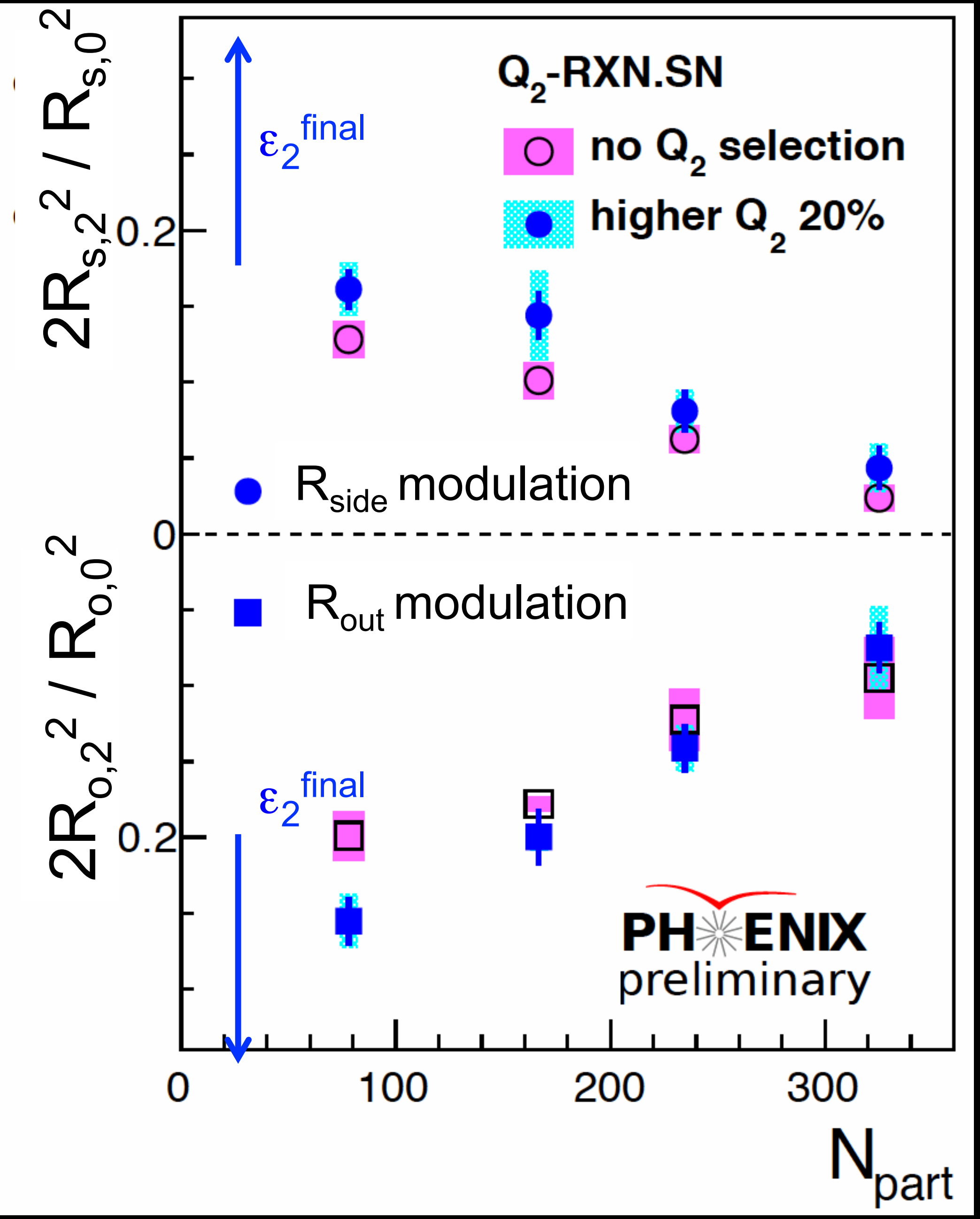
HBT radii w.r.t Ψ_2 with ESE (R_l and R_{os})



- Oscillation of R_l doesn't change, while R_{os} increases when selecting higher Q_2 events as well as R_s and R_o

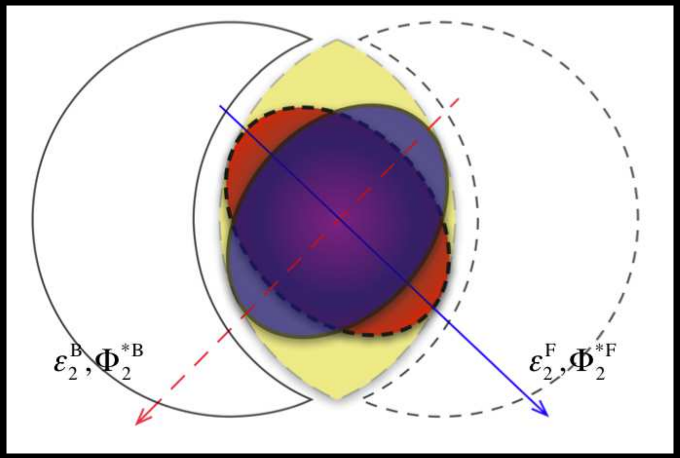
Freeze-out eccentricity vs N_{part} with ESE

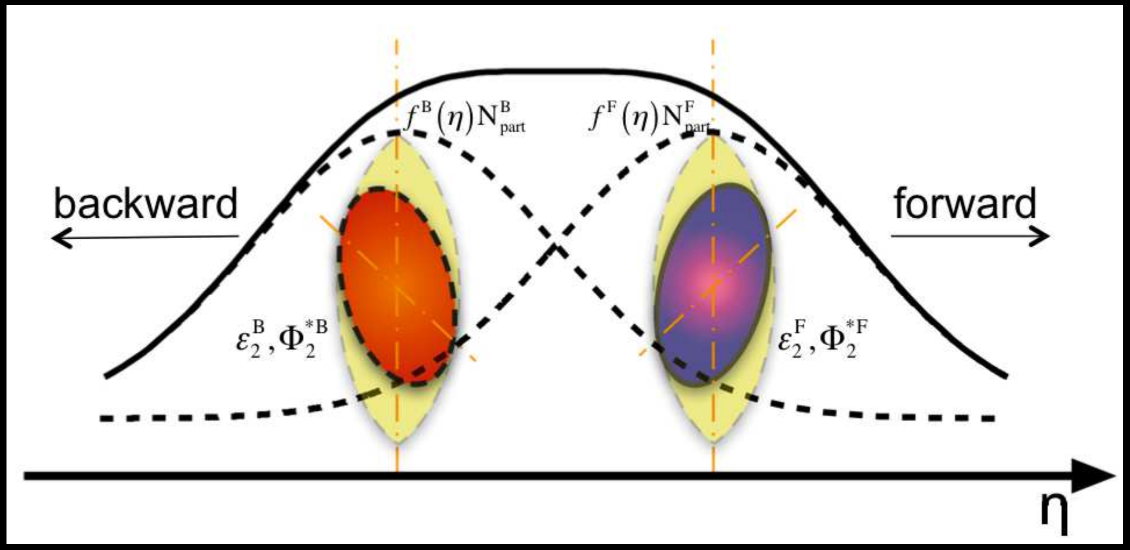
- $\varepsilon_{final} \sim 2R_{s,2}^2/R_{s,0}^2$
  - F. Retiere and M. A. Lisa, PRC70.044907
  - at the limit of $k_T=0$
- Higher Q_2 selection increases the measured ε_{final}
  - Selected more elliptical source at freeze-out?
  - might be originated from ε_{init} with larger $Q_2(v_2)$
  - Or just v_2 effect?



Event twist selection with HBT with AMPT model

Twisted source?



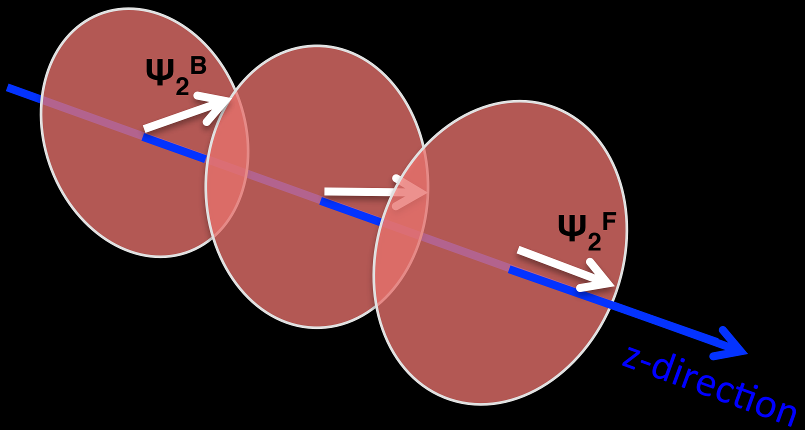


$$N^B_{part} \neq N^F_{part}$$

$$\varepsilon^B_n \neq \varepsilon^F_n$$

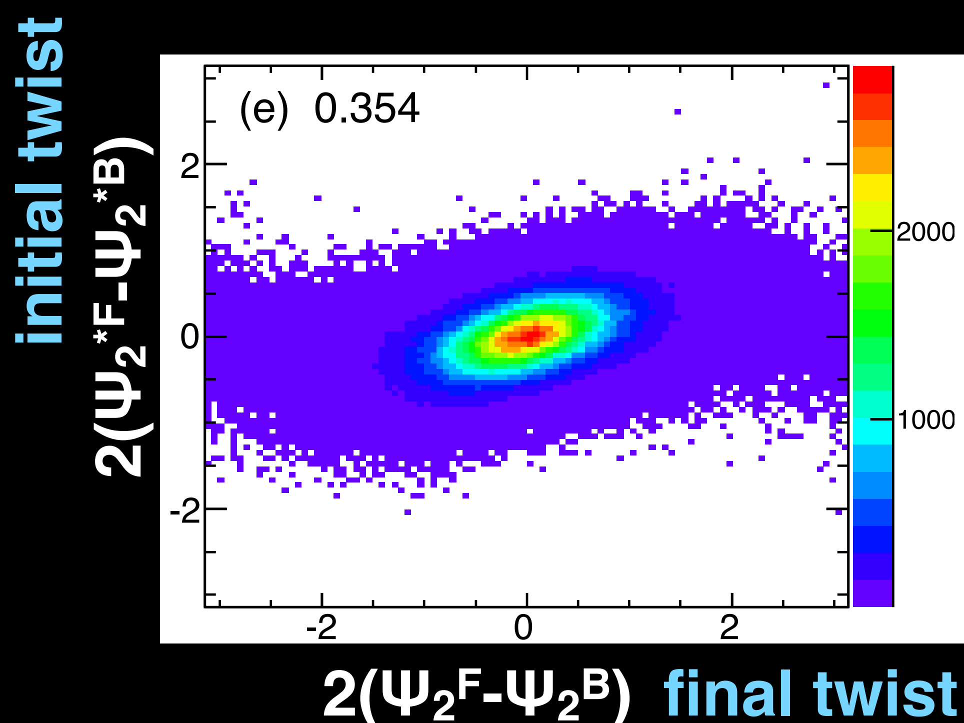
$$\Psi^B_{part,n} \neq \Psi^F_{part,n}$$

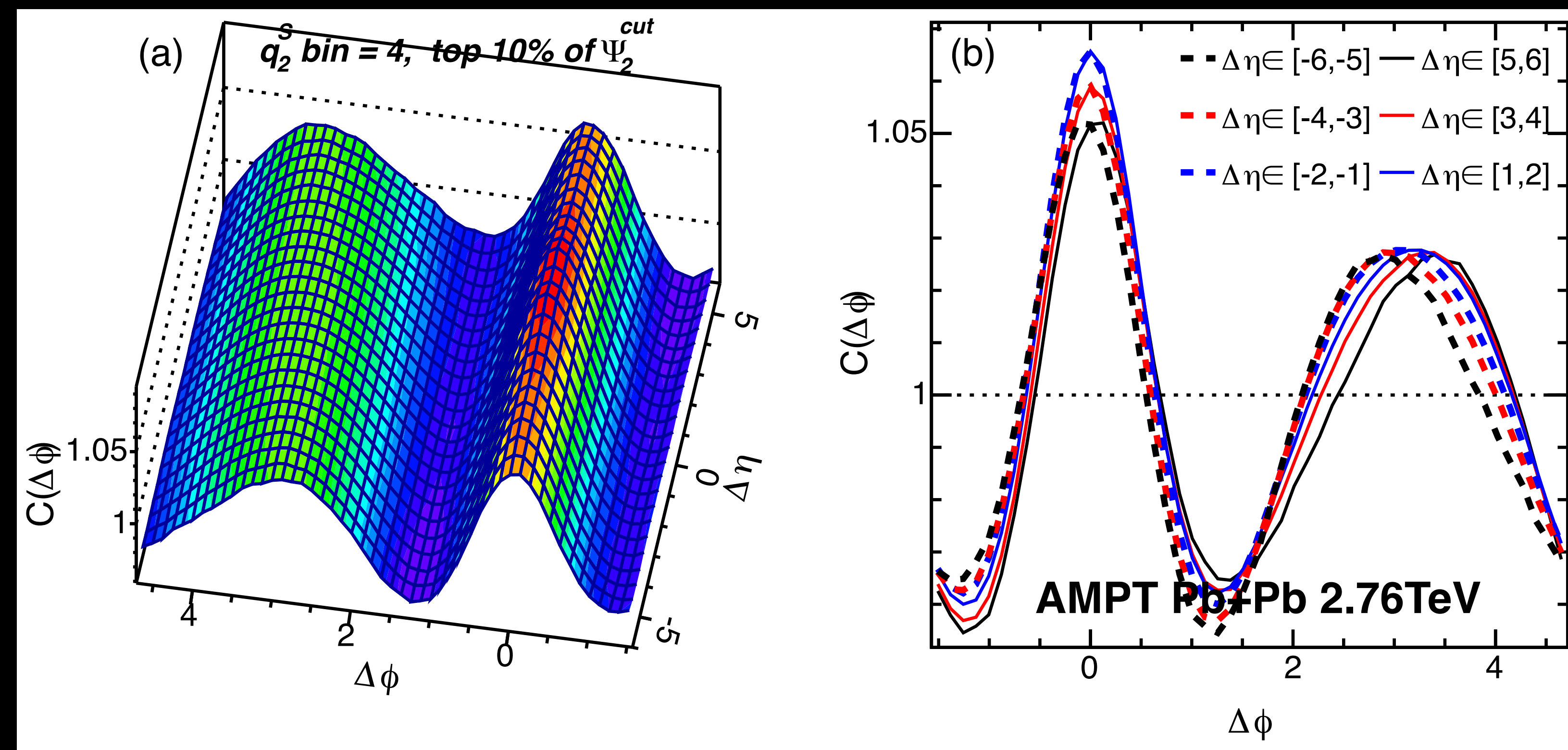
- Twisted fireball due the density fluctuation of wounded nucleons going to forward and backward directions
  - P. Bozek et al., PRC83.034911
- Also known as “event plane decorrelation"
  - K. Xiao et al., PRC87.011901
  - decorrelation increases with increasing η-gap
- v_n may be underestimated, which might lead to overestimating η/s



Event twist selection

J.Jia et al., arXiv:1403.6077



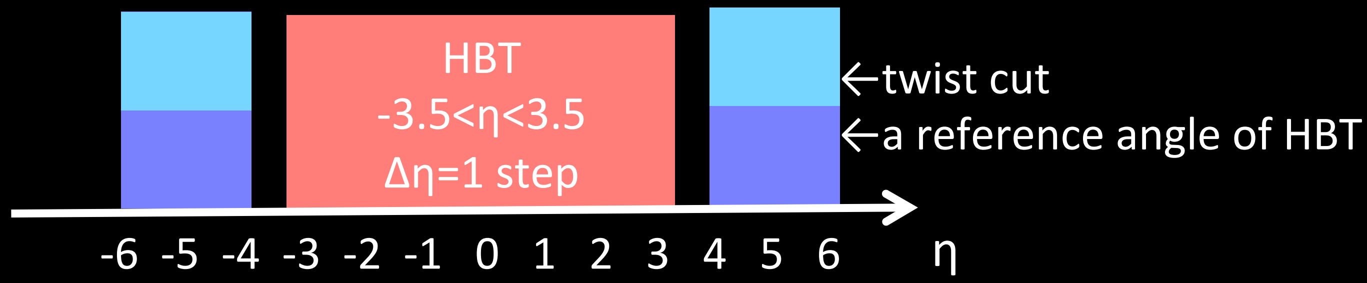


$$C(\Delta\phi, \Delta\eta) \propto 1 + 2\Sigma v_n^a v_n^b \cos(n\Delta\phi - n\Delta\phi_n^{rot})$$

- Twist effect on anisotropic flow&2PC studied with AMPT
  - Requiring finite difference b/w forward and backward EPs (Ψ_2^B-Ψ_2^F)
- Twist effect appears as a phase shift in Δφ-Δη correlation
  - initial twist survives as a final state flow in momentum space
- How about in spatial coordinate space?

HBT study in AMPT

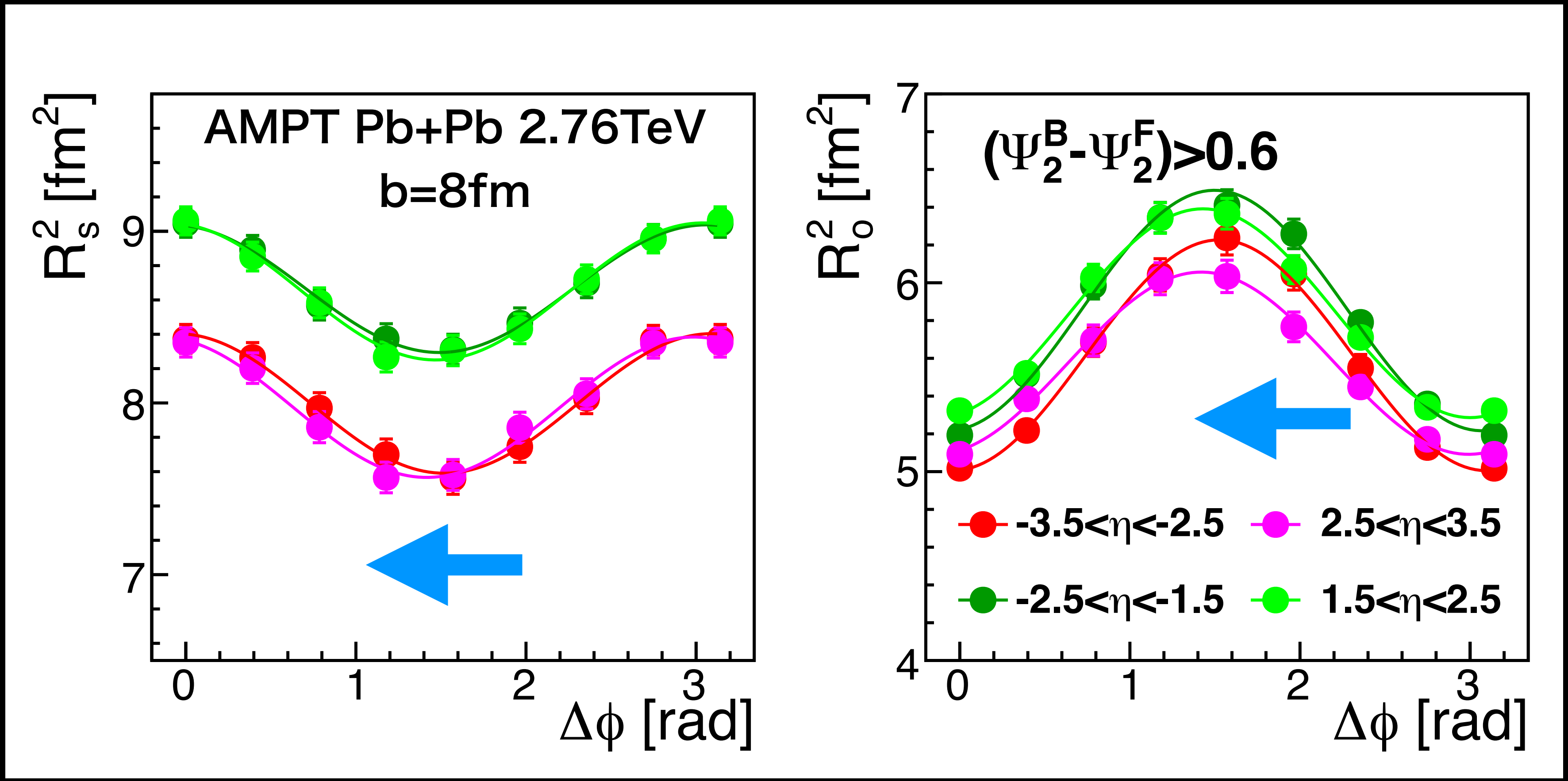
- AMPT model
  - ver.2.25 (string melting)
  - Pb+Pb 2.76 TeV collisions, b=8fm
  - initial fluctuation based on Glauber model and final state interaction via transport model
- EP determination at $4<|\eta|<6$

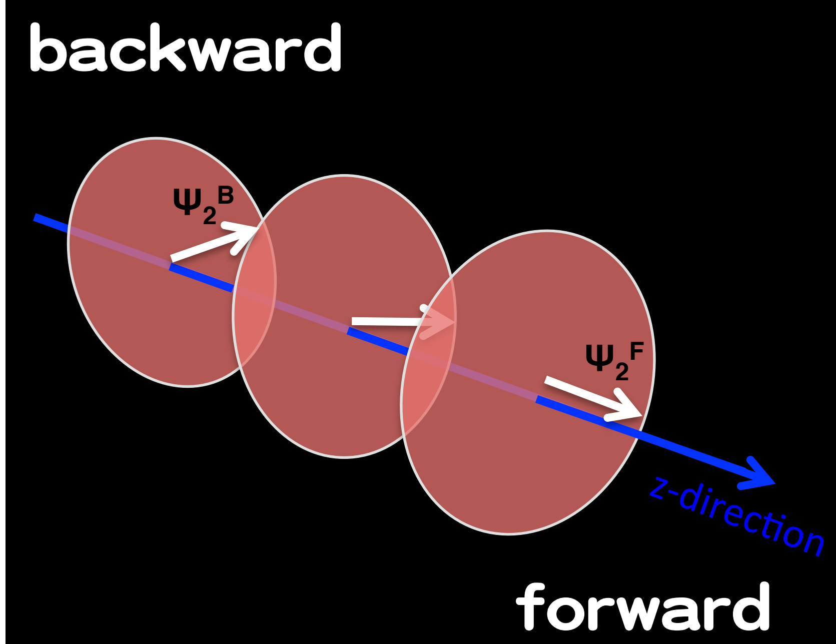


- HBT analysis
  - Add HBT correlation (1+cos(ΔrΔq)) between two pion pairs
  - Allowing to take $\pi+\pi-$ pairs to increase statistics
    - confirmed a good agreement between $\pi^+\pi^+$ and $\pi^-\pi^-$
  - No EP resolution correction
  - Bowler-Sinyukov C_2

$$C_2 = 1 + \exp(-R_s^2 q_s^2 - R_o^2 q_o^2 - R_l^2 q_l^2 - 2R_{os}^2 q_o q_s - 2R_{ol}^2 q_o q_l - 2R_{sl}^2 q_s q_l)$$

HBT radii w.r.t backward Ψ_2



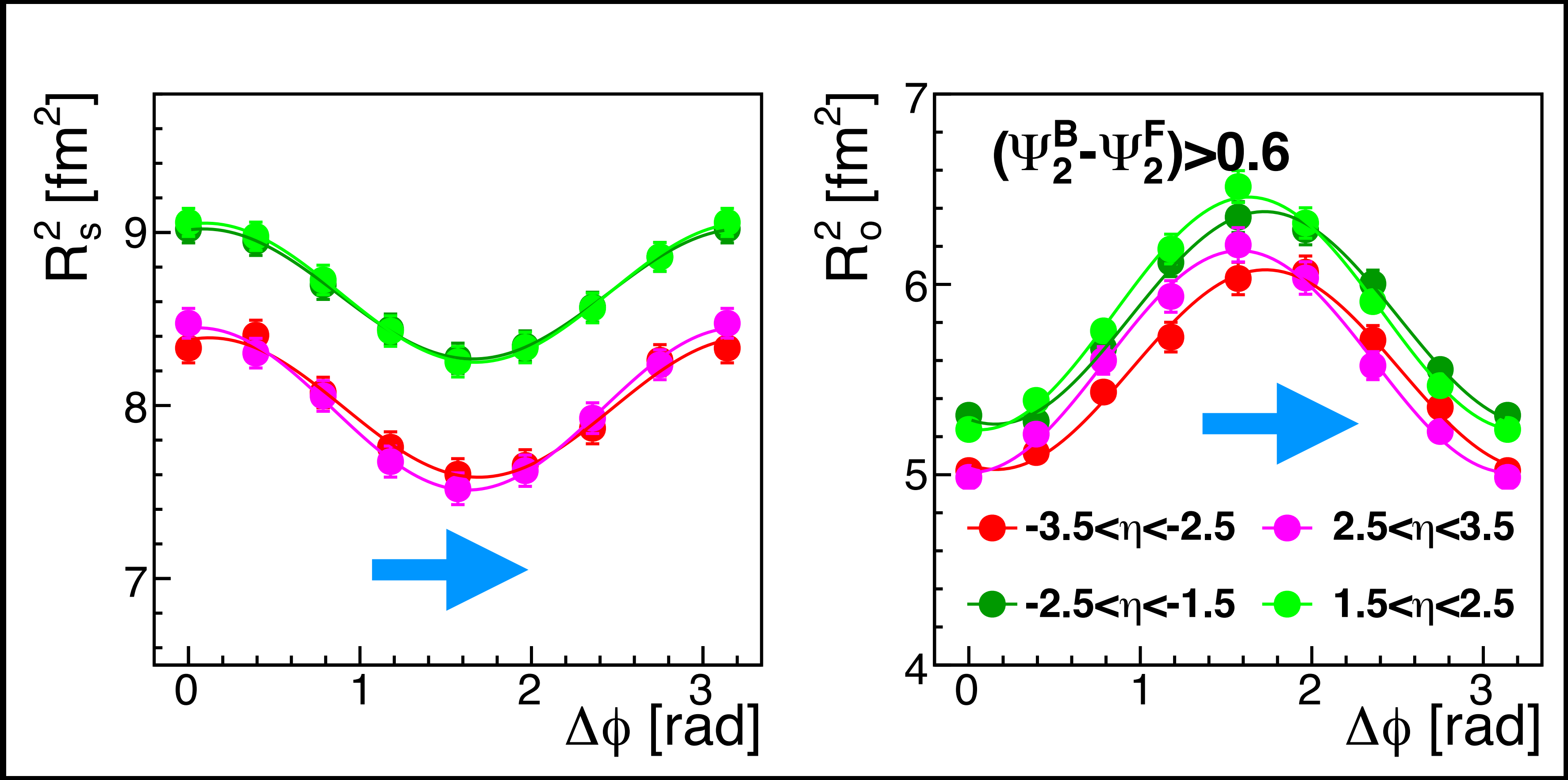


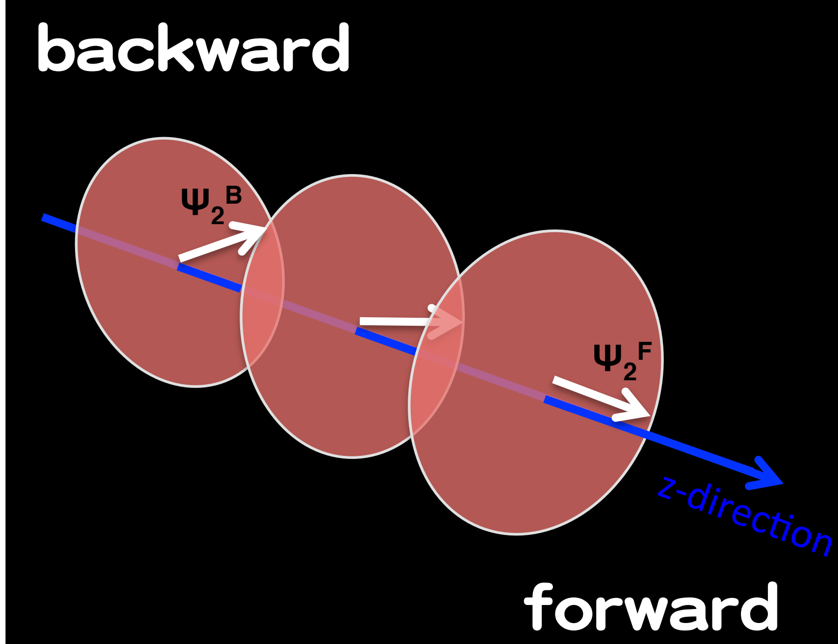
- Selected events with $(\Psi_2{}^B-\Psi_2{}^F)>0.6$
- Phase shift can be seen, and data are fitted with cosine(sine) function including a phase shift parameter α

$$R_\mu^2 = R_{\mu,0}^2 + 2R_{\mu,2}^2\cos(2\Delta\phi+\alpha)$$

$$R_\mu^2 = 2R_{\mu,2}^2\sin(2\Delta\phi+\alpha)$$

HBT radii w.r.t forward Ψ_2

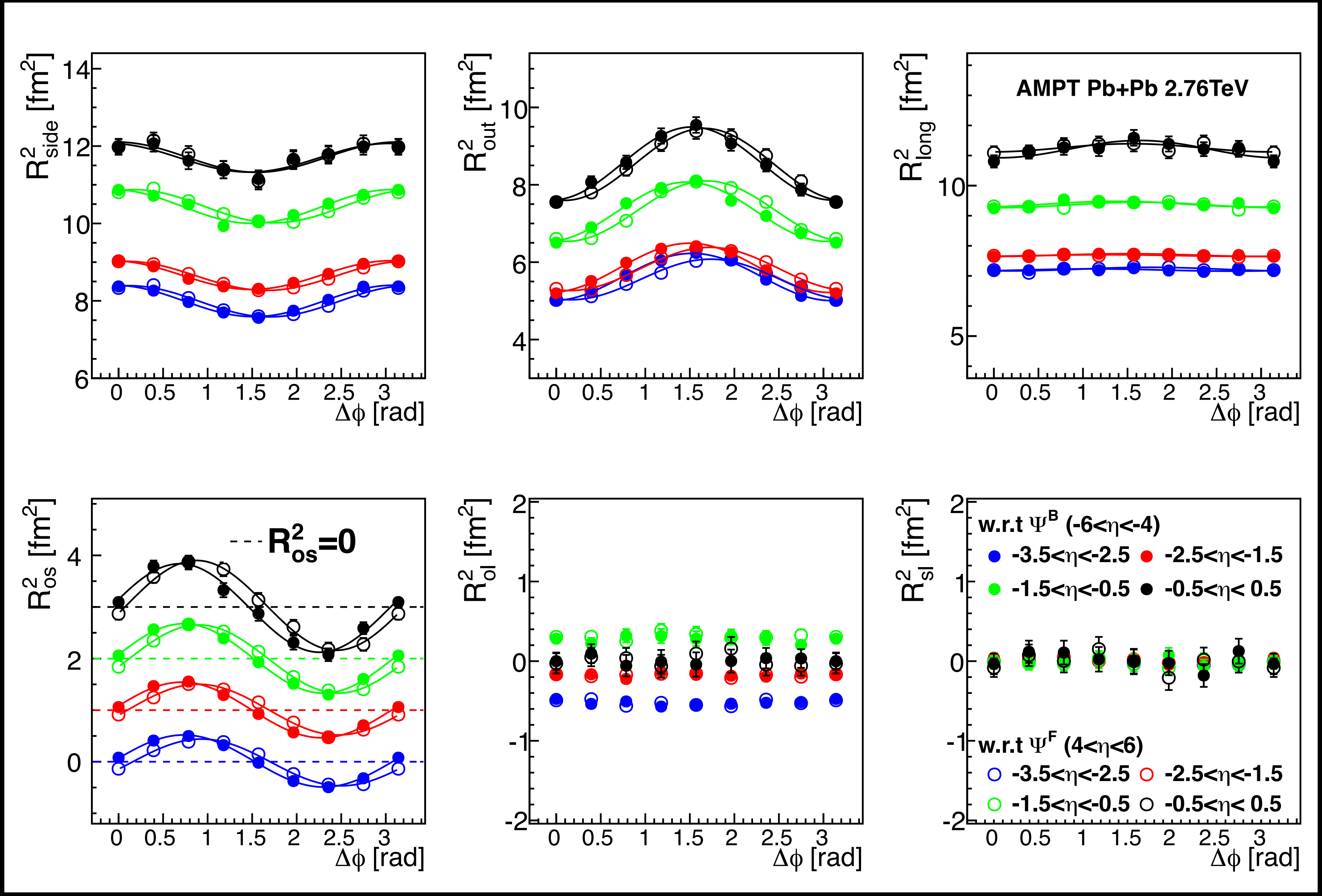




- Selected events with $(\Psi_2^B-\Psi_2^F)>0.6$
- Phase shift can be seen, and data are fitted with cosine(sine) function including a phase shift parameter α

$$R_\mu^2 = R_{\mu,0}^2 + 2R_{\mu,2}^2\cos(2\Delta\phi+\alpha)$$
$$R_\mu^2 = 2R_{\mu,2}^2\sin(2\Delta\phi+\alpha)$$

HBT radii w.r.t $\Psi_2^{B(F)}$ (η<0)

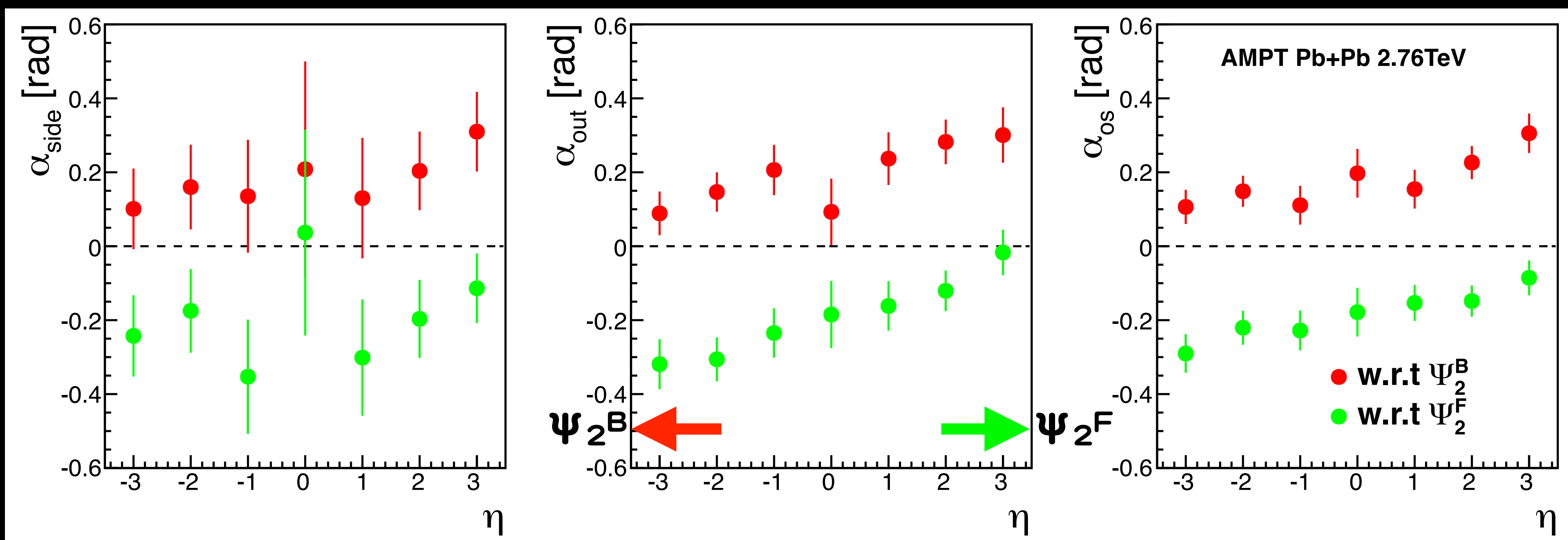


$$R_\mu^2 = R_{\mu,0}^2 + 2R_{\mu,2}^2\cos(2\Delta\phi+\alpha)$$
$$R_\mu^2 = 2R_{\mu,2}^2\sin(2\Delta\phi+\alpha)$$

- Selected events with $(\Psi_2^B - \Psi_2^F) > 0.6$
- Phase difference between Ψ_2^B and Ψ_2^F can be seen in R_s, R_o, and R_{os}

η-dependence of phase shift

$$R^2_\mu = R^2_{\mu,0} + 2R^2_{\mu,2}\cos(2\Delta\phi + \alpha)$$
$$R^2_\mu = 2R^2_{\mu,2}\sin(2\Delta\phi + \alpha)$$



- Phase shifts become larger with going far from η of a reference EP (-6<η<-4 or 4<η<6)
- Source at freeze-out might be also twisted as well as EP angles
  - It may include the effect from twisted flow
- This twist effect could be measured experimentally

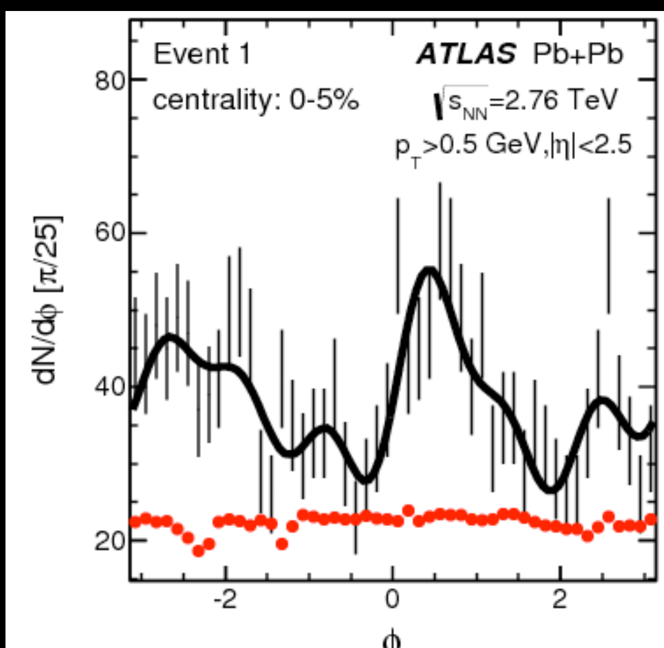
Summary

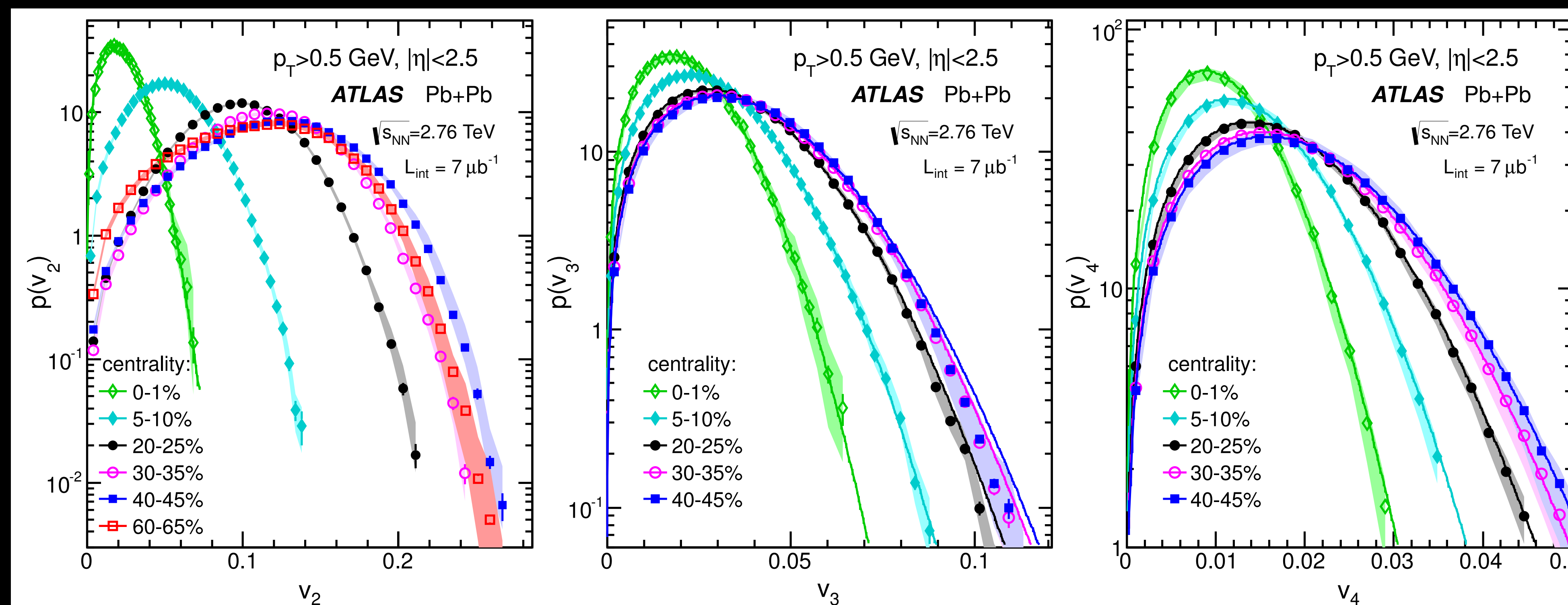
- Event shape engineering at PHENIX
  - Azimuthal HBT measurement with the event shape engineering have been performed in Au+Au 200GeV collisions
  - Higher Q_2 selection enhances the measured ε_{final} as well as v_2
  - More accurate relation between initial and final eccentricity

- Event twist selection with AMPT model
  - A possible twisted source have been studied via HBT measurement with AMPT Pb+Pb 2.76TeV collisions
  - Phase shifts of HBT oscillations are seen as a function of η, possibly indicating the twisted source at final state
  - This effect might be measured in RHIC and the LHC, especially in ATLAS or CMS

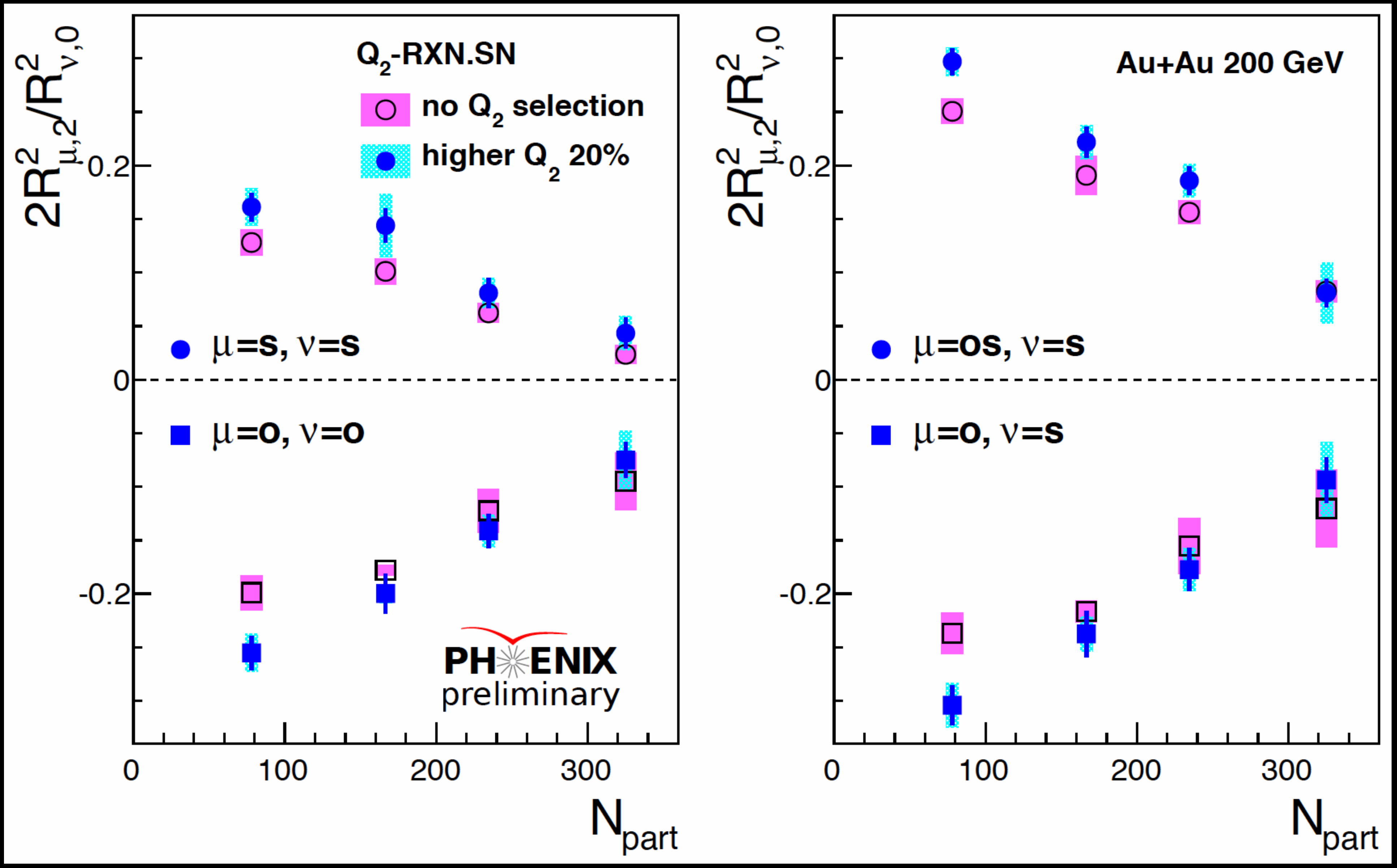
Back up

Event-by-event v_n at ATLAS

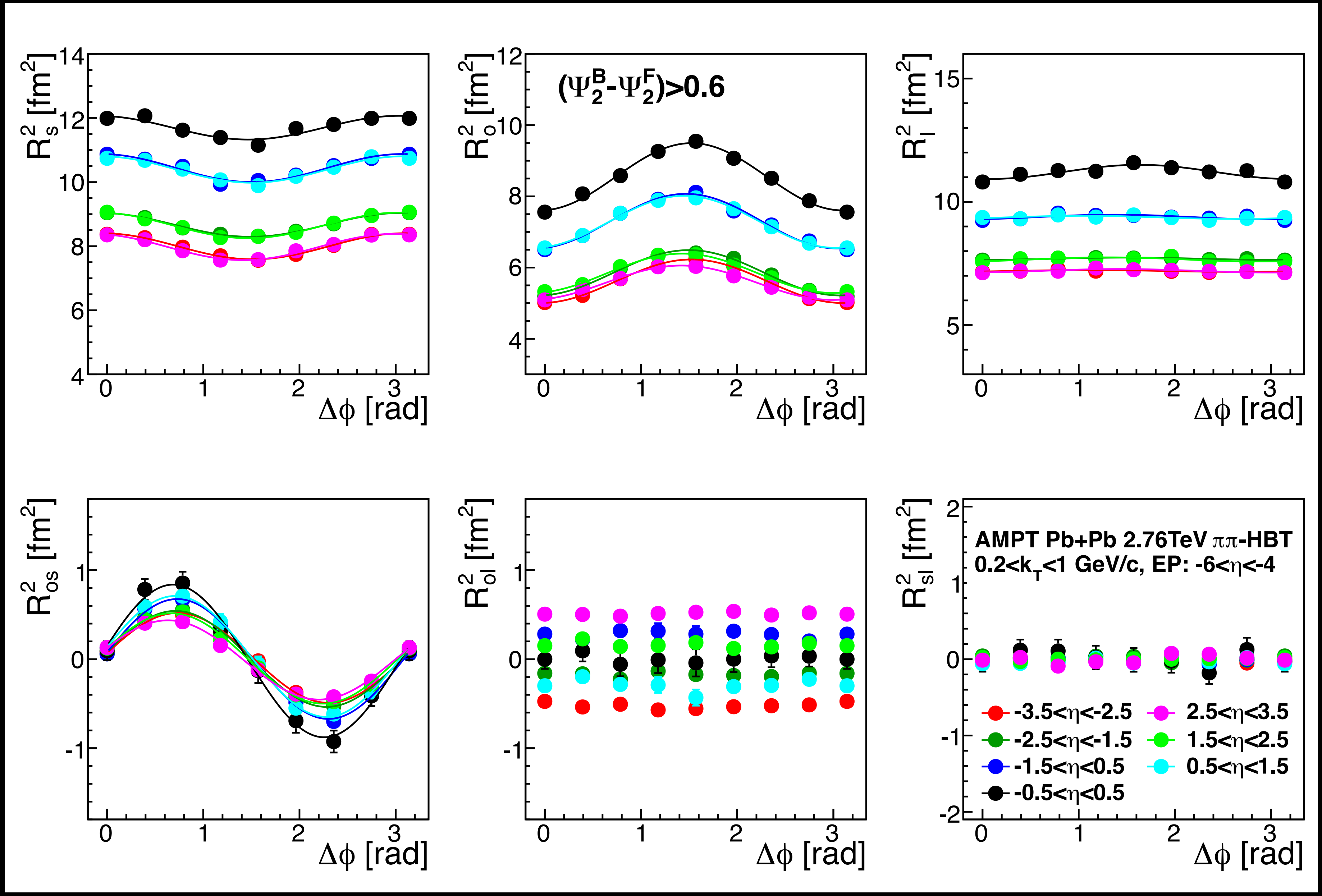




Oscillation amplitudes as a function of N_{part} with ESE

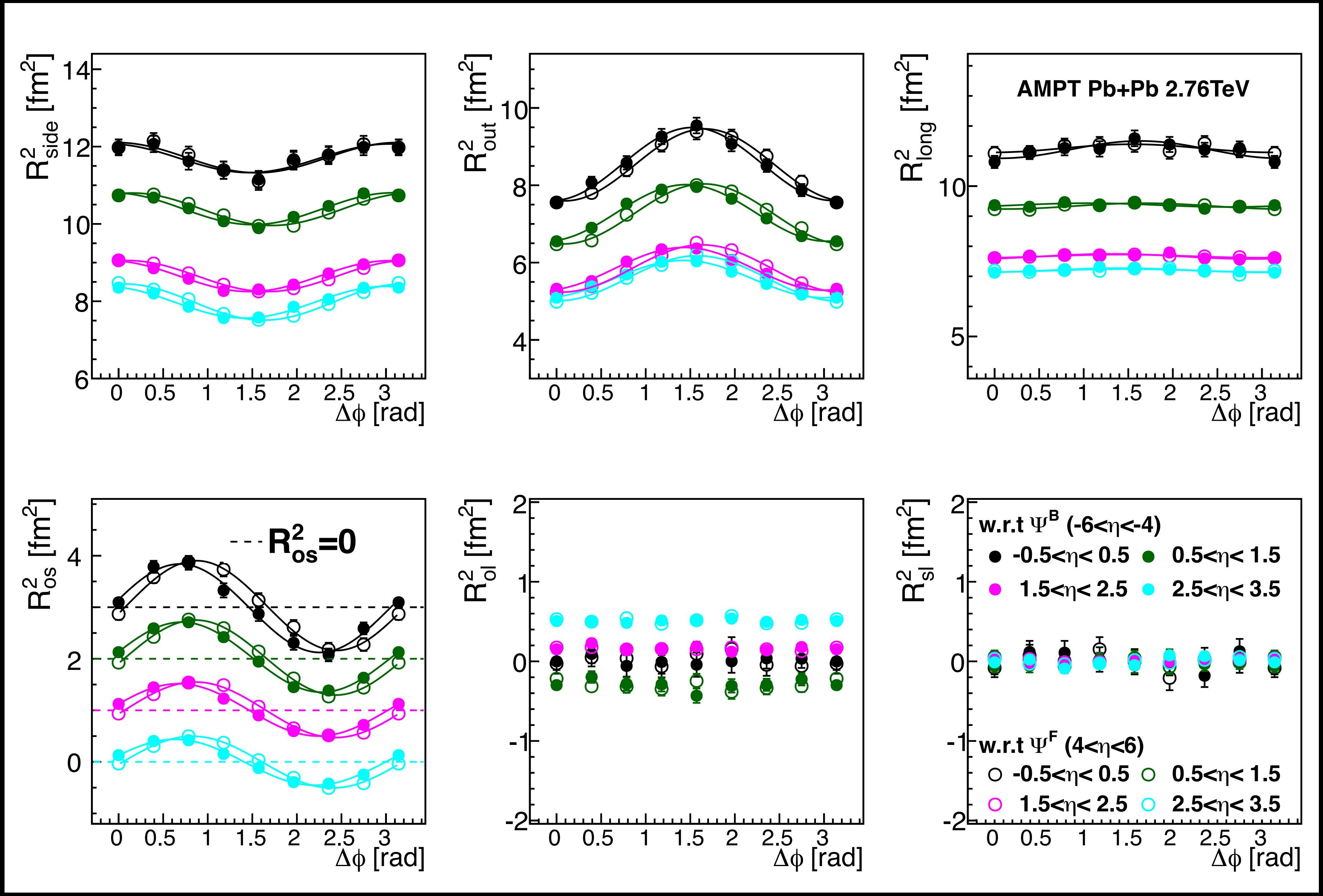


HBT radii w.r.t Ψ_2^B



- Selected events with $(\Psi_2^B-\Psi_2^F)>0.6$
- Phase shift can be seen, and become larger with going far from η of EP for a reference angle ($-6<\eta<-4$)

HBT radii w.r.t $\Psi_2^{B(F)}$ (η>0)



- Selected events with (Ψ_2^B-Ψ_2^F)>0.6
- Phase difference between Ψ_2^B and Ψ_2^F can be seen in R_s, R_o, and R_{os}