Polarization study at STAR and toward CBM

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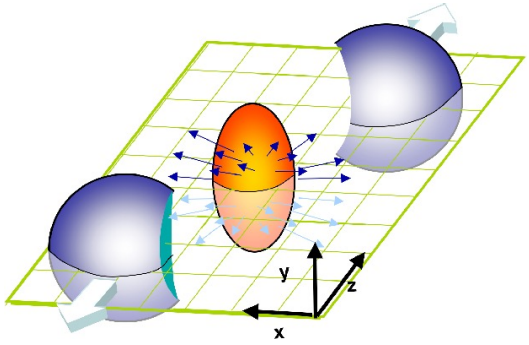
Physics motivation

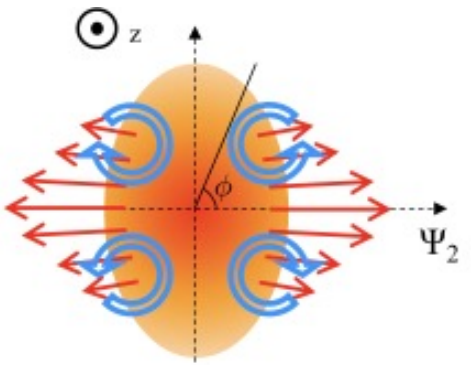
- Local polarization
  - Elliptic flow indicates a significantly stronger expansion in the reaction plane direction compared to the out-of-plane direction.
  - This may lead to a quadrupole structure in the z component of vorticity, leading to particle polarization.
  - This polarization can be measured through the distribution of the azimuthal angle of the daughter baryons in the hyperon rest frame.



L. Adamczyk et al. , Phys. Rev. C 93 14907 (2016).

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} \propto 1 + \alpha_H P_H \cos\theta^*$$

α_H: hyperon decay parameter ($\alpha_\Lambda = -\alpha_{\bar{\Lambda}} = 0.732 \pm 0.014$)
θ^* : the polar angle of the daughter baryon in hyperon rest frame
P_H : hyperon polarization



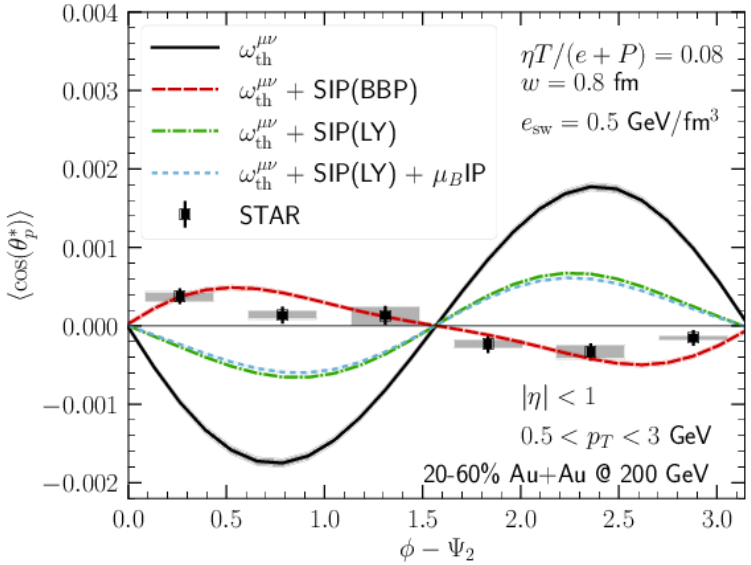
M. I. Abdulhamid et al., Phys. Rev. Lett. 131, 202301 (2023).

Physics motivation

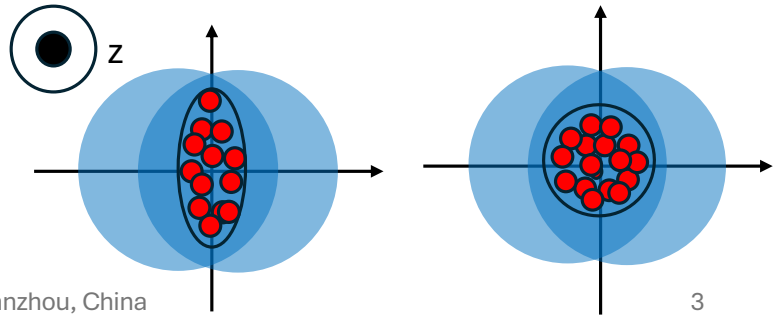
- Spin Puzzle
  - Some theoretical calculations show results that differ from measurements.
  - To solve the spin puzzle, it is necessary to isolate the cause of the local polarization, e.g. initial geometry.

- Event Shape Engineering (ESE)
  - The method to select initial geometry within a certain centrality.

→ Elliptic flow and local polarization are measured with ESE to reveal the relation among the initial geometry, elliptic flow, and the local polarization.

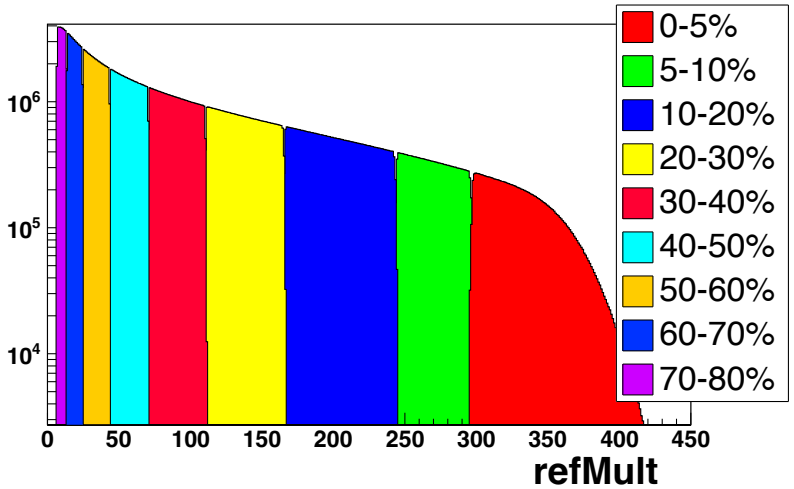


Alzhrani et al., PRC106, 014905 (2022)



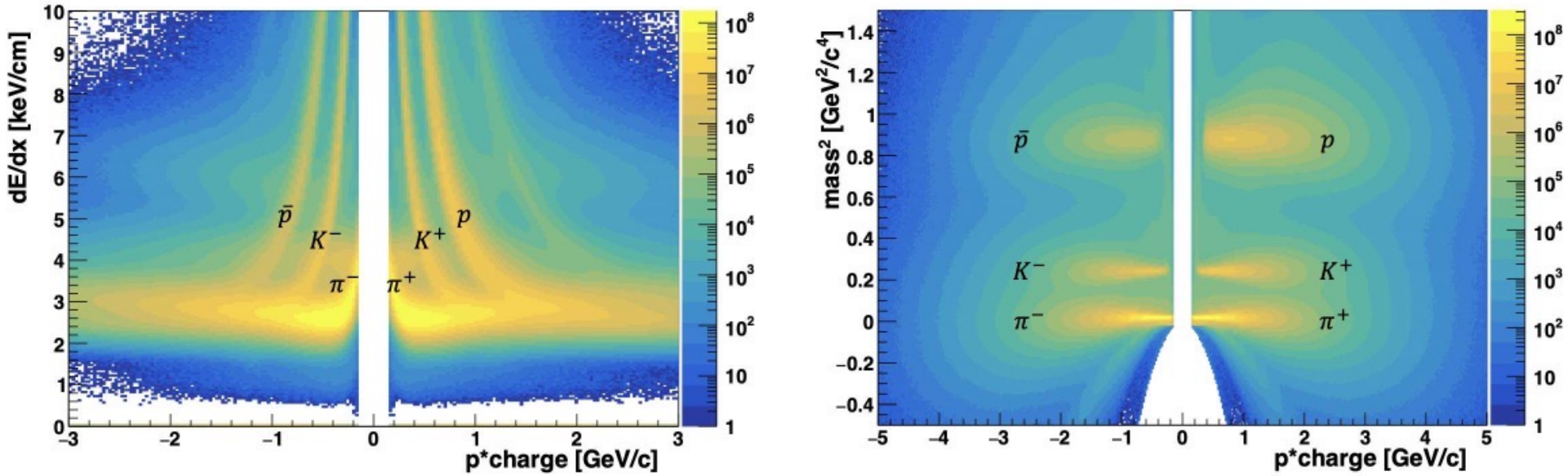
Dataset and Cuts

- Dataset : Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 19.6$ GeV (2019, minimum bias)
- Event cut : $|V_z| < 70$ cm, $V_r < 2$ cm
- Number of events : 300M
- Track cut : $0.15 < p_{\mathrm{T}} < 10.0$ GeV/c, $|\eta| < 1.5$, nHitsFit > 15
- Centrality definition : StRefMultCorr class



Charged particle identification by TPC and TOF

	Proton	Pion
TPC	$\lvert n\sigma_p\rvert < 2, \lvert n\sigma_K\rvert > 2, \lvert n\sigma_\pi\rvert > 2$	$\lvert n\sigma_\pi\rvert < 2, \lvert n\sigma_p\rvert > 2, \lvert n\sigma_K\rvert > 2$
	$p_T > 0.4$ [GeV/c]	
if TOF avairable	$0.5 < m^2 < 1.5$ [GeV^2/c^4]	$-0.01 < m^2 < 0.5$ [GeV^2/c^4]



Event plane reconstruction

Calibration: Re-centering and Flattening

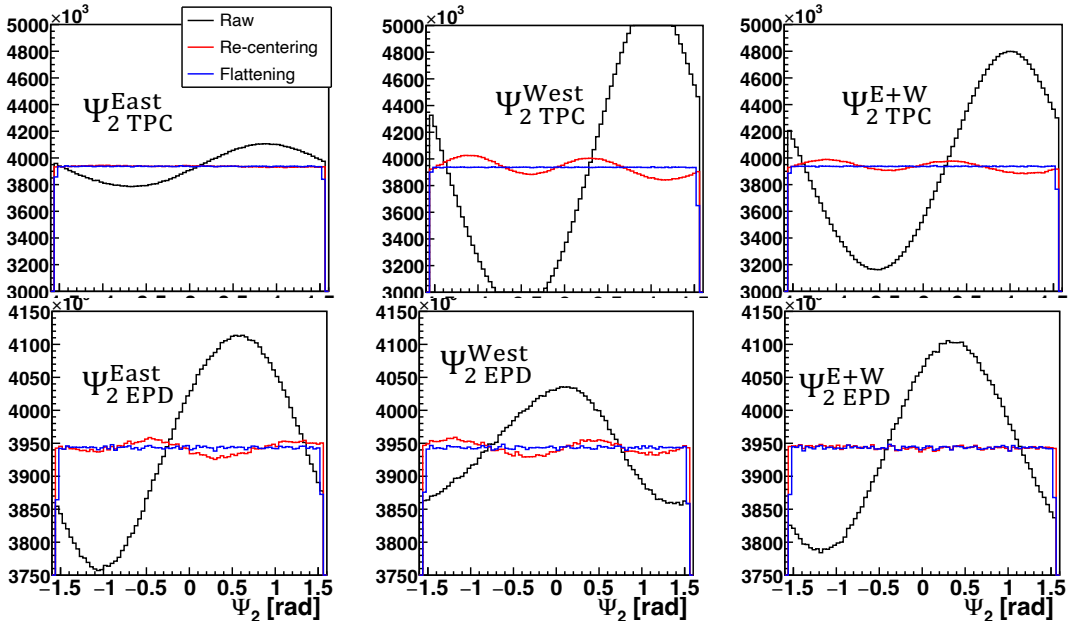
- Q-vector

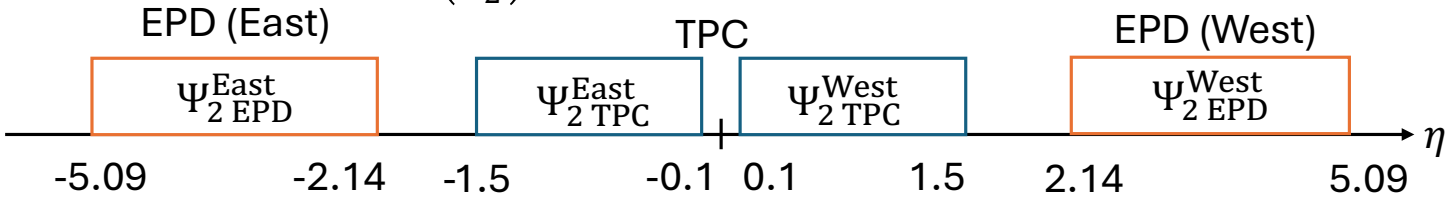
$$Q_2^x = \sum_i \omega_i \cos(2\phi_i),\ Q_2^y = \sum_i \omega_i \sin(2\phi_i)$$

ϕ_i : the azimuthal angle of particle
ω_i : weight for Q-vector
TPC : p_T , EPD : nMip (if nMip>3,used 3)

- Event Plane angle

$$\Psi_2 = \frac{1}{2}\arctan\left(\frac{Q_2^y}{Q_2^x}\right)$$





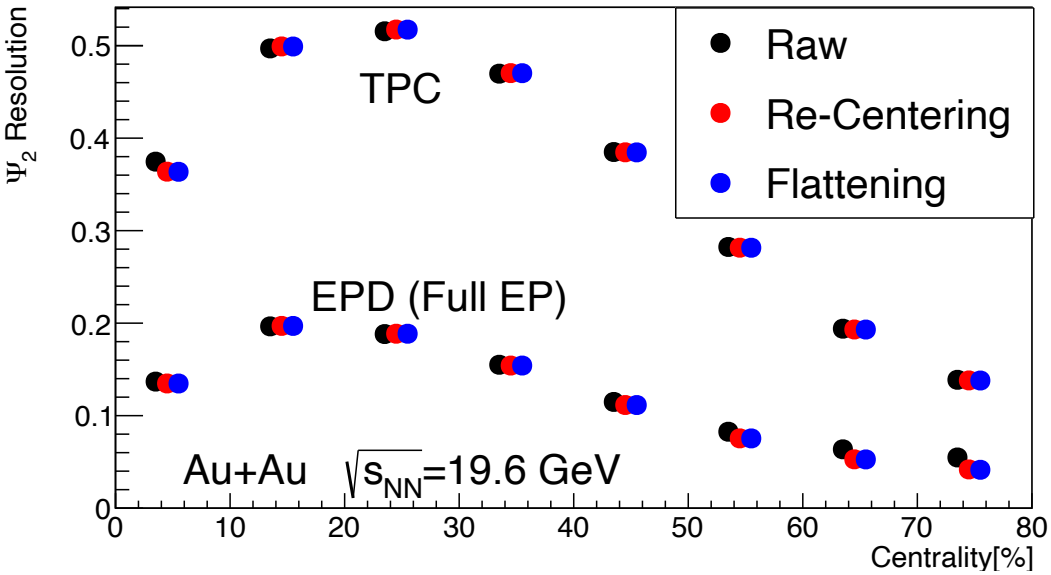
Event plane resolution

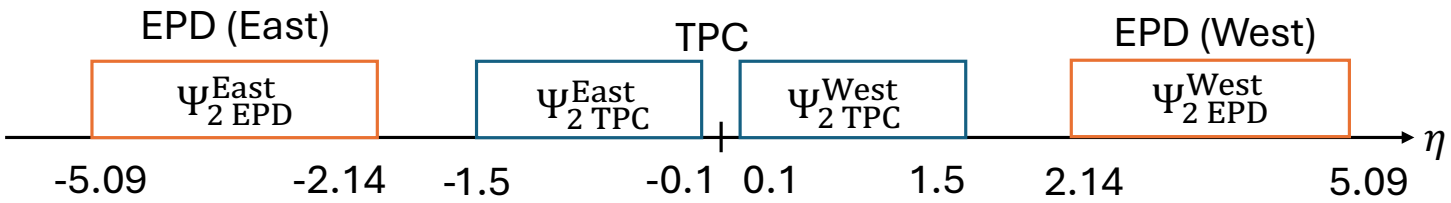
- 2-sub event plane resolution
  - TPC

$$Res\{\Psi_2^{\mathrm{TPC}}\} = \sqrt{\langle \cos\left[2\left(\Psi_{2\ \mathrm{TPC}}^{\mathrm{East}} - \Psi_{2\ \mathrm{TPC}}^{\mathrm{West}}\right)\right]\rangle}$$

  - EPD : full event plane (East + West)

$$Res\{\Psi_{2\ \mathrm{EPD}}^{\mathrm{E+W}}\} = \sqrt{2\langle \cos\left[2\left(\Psi_{2\ \mathrm{EPD}}^{\mathrm{East}} - \Psi_{2\ \mathrm{EPD}}^{\mathrm{West}}\right)\right]\rangle}$$





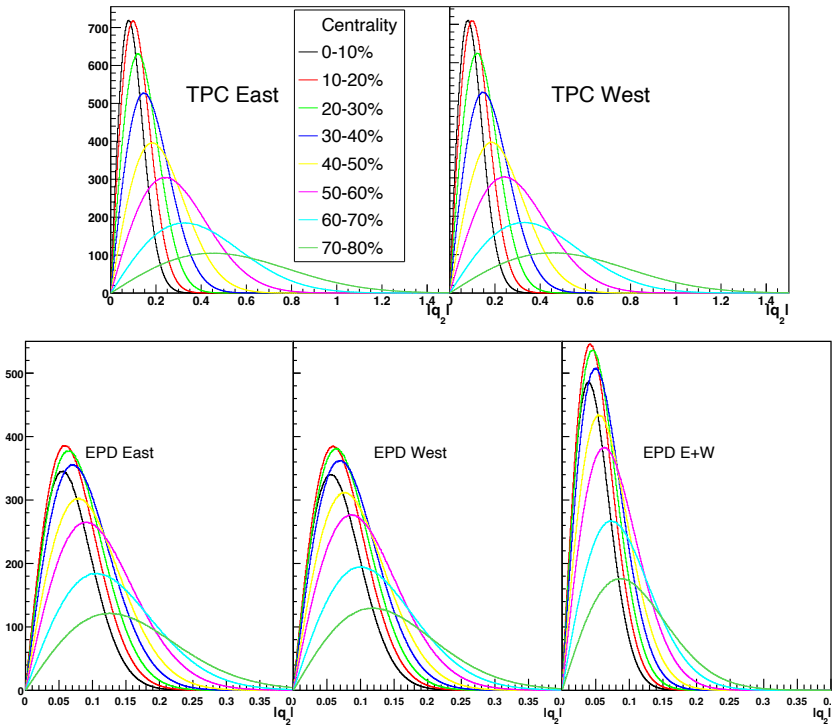
Event Shape Engineering

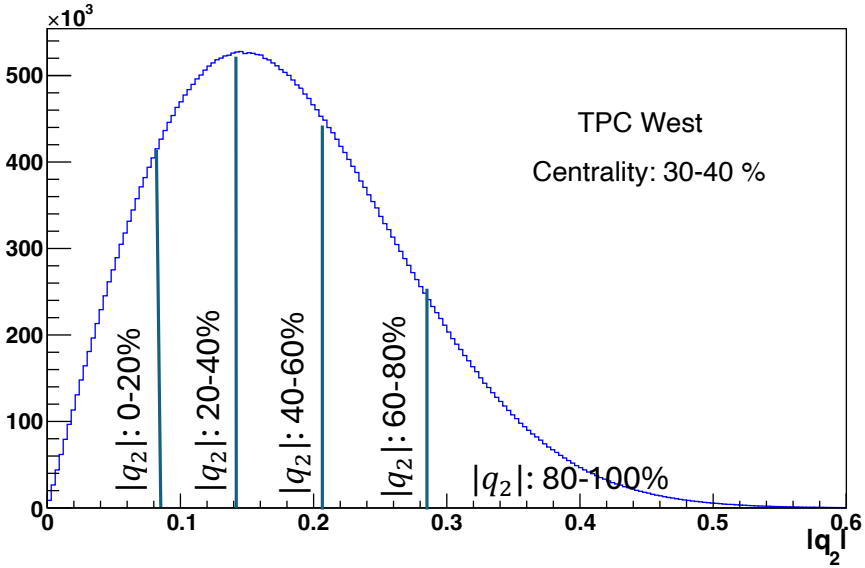
Based on the magnitude of the so-called reduced flow vector, $\boldsymbol{q}_2$, events were divided into five segments.

$$|\boldsymbol{q}_2| = \frac{|\boldsymbol{Q}_2|}{\sqrt{\sum \boldsymbol{\omega_i}}}$$

ω_i : weight for Q-vector

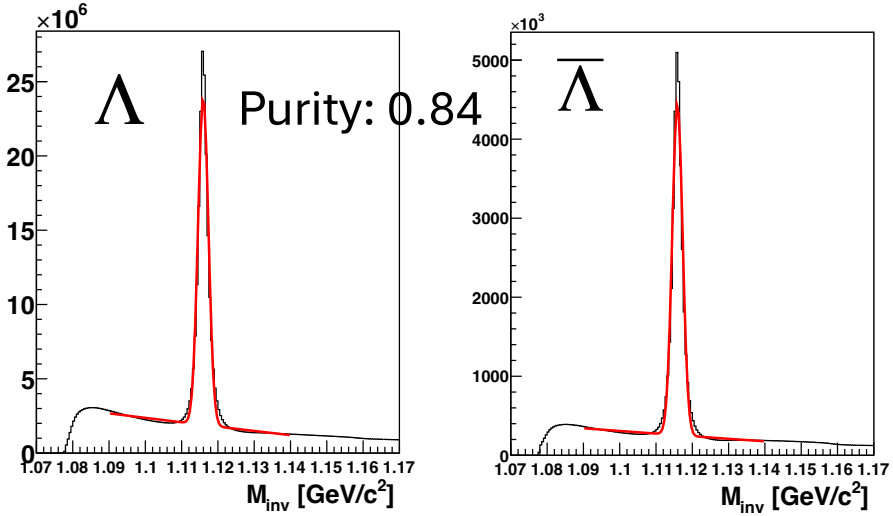
TPC : p_T , EPD : nMip (if nMip>3,used 3)





Lambda reconstruction

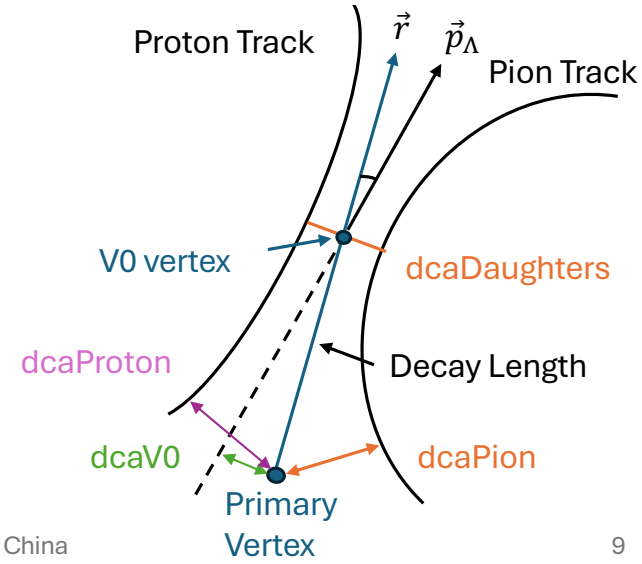
Used topological cuts and kinematic cuts



Centrality	dcaProton	dcaPion	dcaV0	DecayLength	dcaDaughters
0-10%	> 0.5	> 1.6	< 0.9	> 5.0	< 1.0
10-20%	> 0.3	> 1.6	< 0.9	> 5.0	< 1.0
20-30%	> 0.3	> 1.3	< 1.0	> 4.0	< 1.0
30-40%	> 0.3	> 1.2	< 1.0	> 3.0	< 1.0
40-50%	> 0.2	> 1.0	< 1.0	> 3.0	< 1.0
50-60%	> 0.1	> 0.9	< 1.0	> 3.0	< 1.0
60-70%	> 0.1	> 0.8	< 1.0	> 3.0	< 1.0
70-80%	> 0.1	> 0.7	< 1.0	> 3.0	< 1.0
All	$\vec{r} \cdot \vec{p}_\Lambda > 0$	$(\vec{p}_\Lambda)_T > 0.5$	$\lvert\eta\rvert < 1.5$		

[cm]

*Same cuts as previous publication were used



Measurements of v_2 and $P_{z,2}$

・Elliptic flow was measured by v_2, the second Fourier coefficient of the azimuthal particle distribution relative to the event plane.

・Local polarization was measured by $\mathrm{P}_{z,2}$

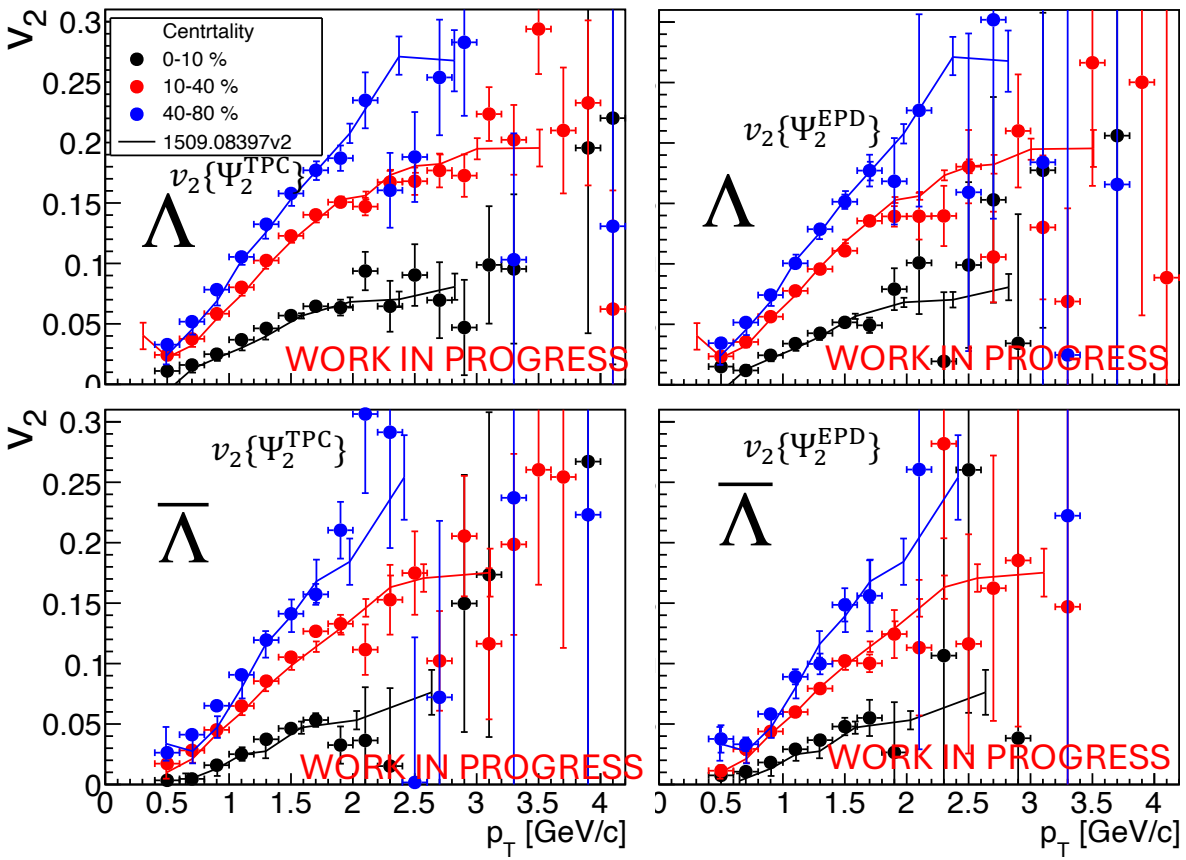
$$v_2 = \frac{\langle \cos[2(\phi - \Psi_2)] \rangle}{Res\{\Psi_2\}}$$

$$\mathrm{P}_{z,2} = \frac{3}{\alpha_\Lambda} \frac{1}{A_z} \frac{\langle \cos\theta_p^* \sin\big(2(\phi_\Lambda - \Psi_2)\big) \rangle}{Res\{\Psi_2\}}$$

α_Λ: lambda decay parameter ($\alpha_\Lambda = -\alpha_{\bar{\Lambda}} = 0.732 \pm 0.014$)
θ_p^* : the polar angle of the daughter proton in Λ rest frame
A_z (≈ 1): the acceptance correction factor
ϕ_Λ: the azimuthal angle of Λ particle

p_T dependence of v_2 without ESE

- Consistent with previous results
- η-gap
  - 0.2 (these results)
  - 0.1 (previous results)



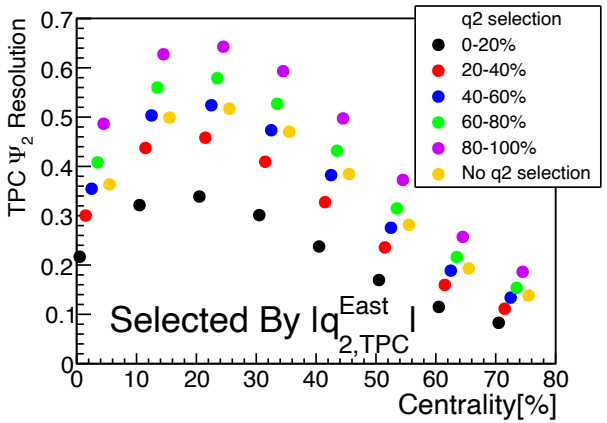
Event plane resolution with ESE

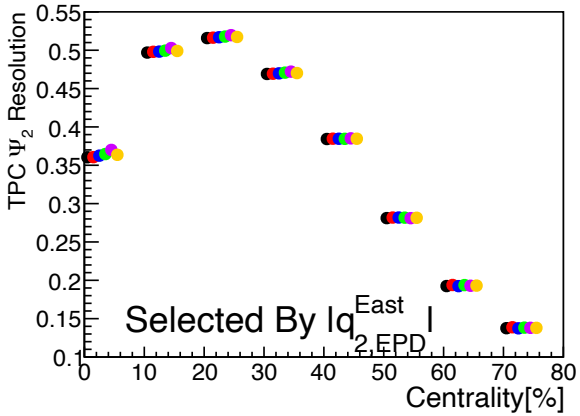
- 2-sub event plane resolution
  - TPC

$$Res\{\Psi_2^{\mathrm{TPC}}\} = \sqrt{\langle \cos\left[2\left(\Psi_{2\ \mathrm{TPC}}^{\mathrm{East}} - \Psi_{2\ \mathrm{TPC}}^{\mathrm{West}}\right)\right]\rangle}$$

  - EPD : full event plane (East + West)

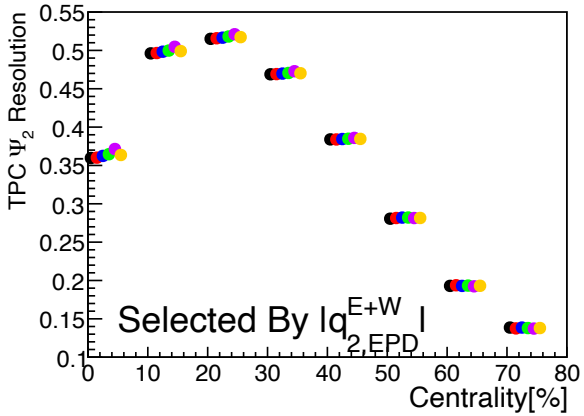
$$Res\{\Psi_{2\ \mathrm{EPD}}^{\mathrm{E+W}}\} = \sqrt{2\langle \cos\left[2\left(\Psi_{2\ \mathrm{EPD}}^{\mathrm{East}} - \Psi_{2\ \mathrm{EPD}}^{\mathrm{West}}\right)\right]\rangle}$$

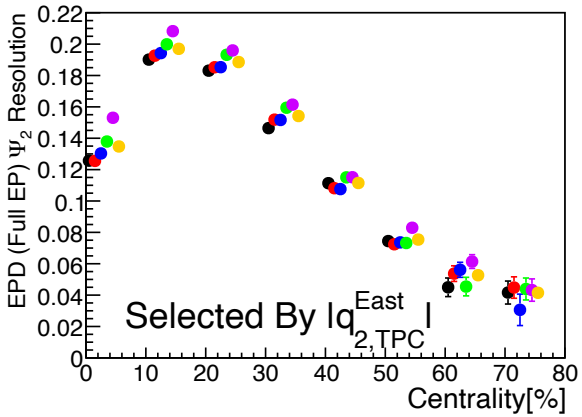




- All event selections show clear $|q_2|$ dependence.
- Self-correlation have a large effect in the upper left.

- We should use 3-sub resolution instead to remove self-correlation.





Toward CBM

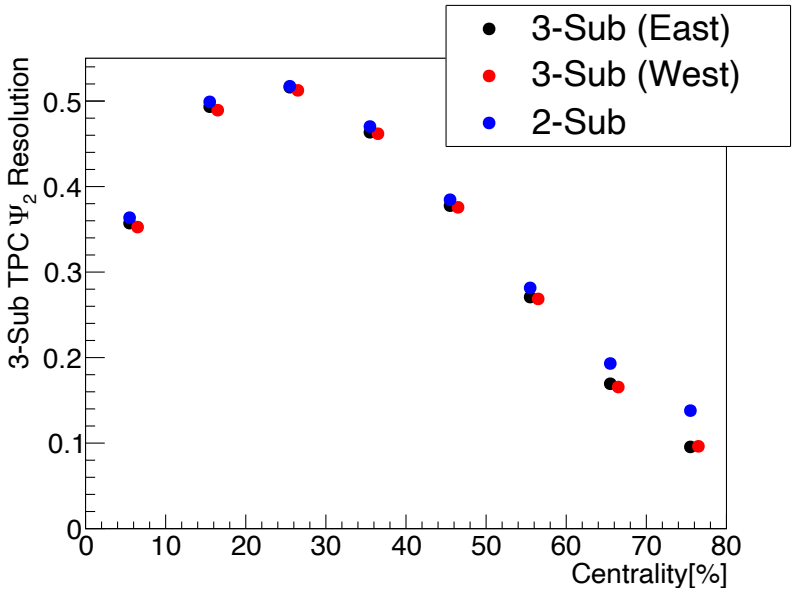
- Spin hall effect
- Global polarization
- CBM-TOF data analysis

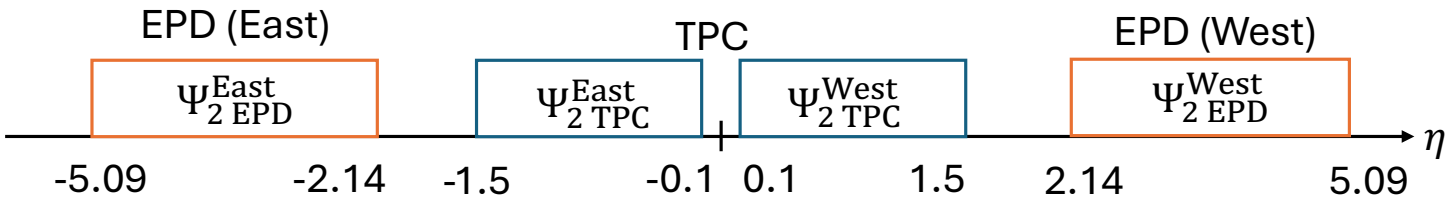
Back Up

3-sub TPC resolution

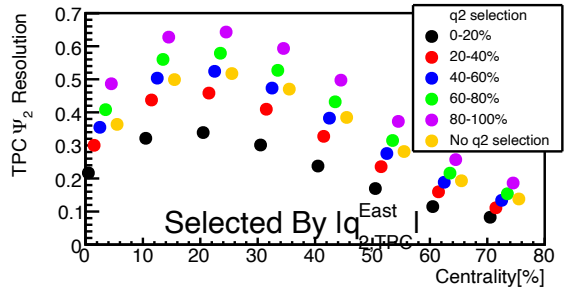
$$Res\{\Psi_{2\,\mathrm{TPC}}^{\mathrm{East}}\} = \sqrt{\frac{\langle\cos[2(\Psi_{2\,\mathrm{EPD}}^{\mathrm{East}} - \Psi_{2\,\mathrm{TPC}}^{\mathrm{East}})]\rangle\langle\cos[2(\Psi_{2\,\mathrm{EPD}}^{\mathrm{West}} - \Psi_{2\,\mathrm{TPC}}^{\mathrm{East}})]\rangle}{\langle\cos[2(\Psi_{2\,\mathrm{EPD}}^{\mathrm{East}} - \Psi_{2\,\mathrm{EPD}}^{\mathrm{West}})]\rangle}}$$

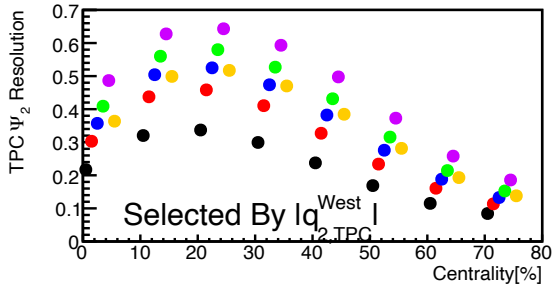
$$Res\{\Psi_{2\,\mathrm{TPC}}^{\mathrm{West}}\} = \sqrt{\frac{\langle\cos[2(\Psi_{2\,\mathrm{EPD}}^{\mathrm{East}} - \Psi_{2\,\mathrm{TPC}}^{\mathrm{West}})]\rangle\langle\cos[2(\Psi_{2\,\mathrm{EPD}}^{\mathrm{West}} - \Psi_{2\,\mathrm{TPC}}^{\mathrm{West}})]\rangle}{\langle\cos[2(\Psi_{2\,\mathrm{EPD}}^{\mathrm{East}} - \Psi_{2\,\mathrm{EPD}}^{\mathrm{West}})]\rangle}}$$

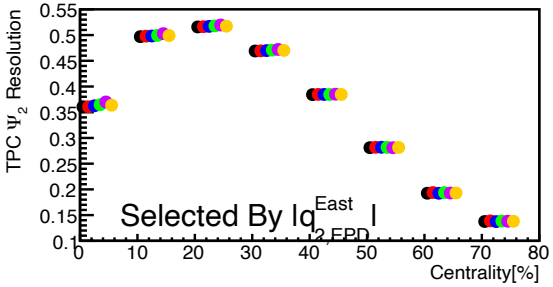


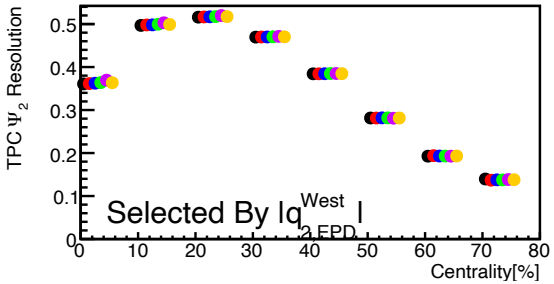


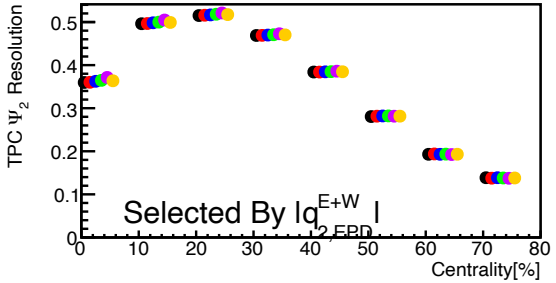
Event plane resolution with ESE (all)

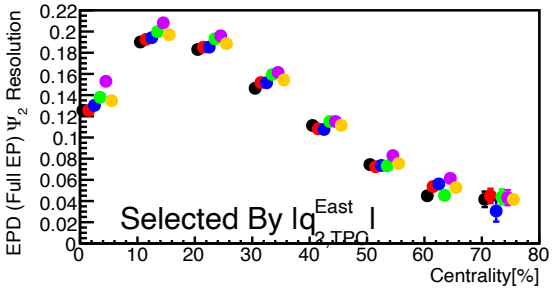


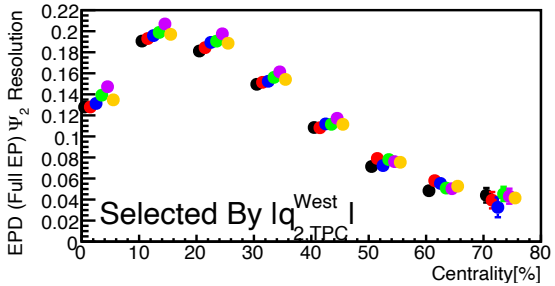












Removed Pileup Events