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Differential measurement of global polarization of Λ hyperons at RHIC-STAR experiment

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University of Tsukuba

JPS meeting

8th, Sep, 2022

Introduction

✦In non-central collisions…

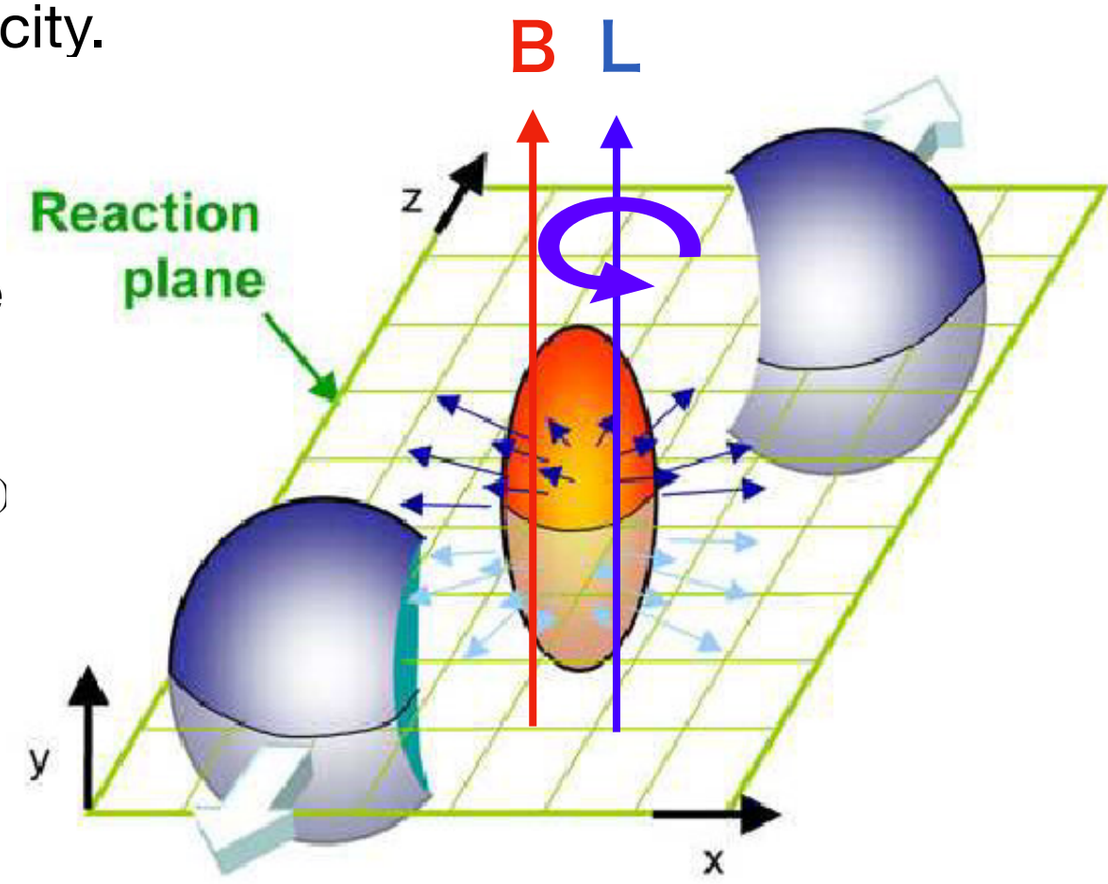
- The created matter should exhibit strong vorticity.

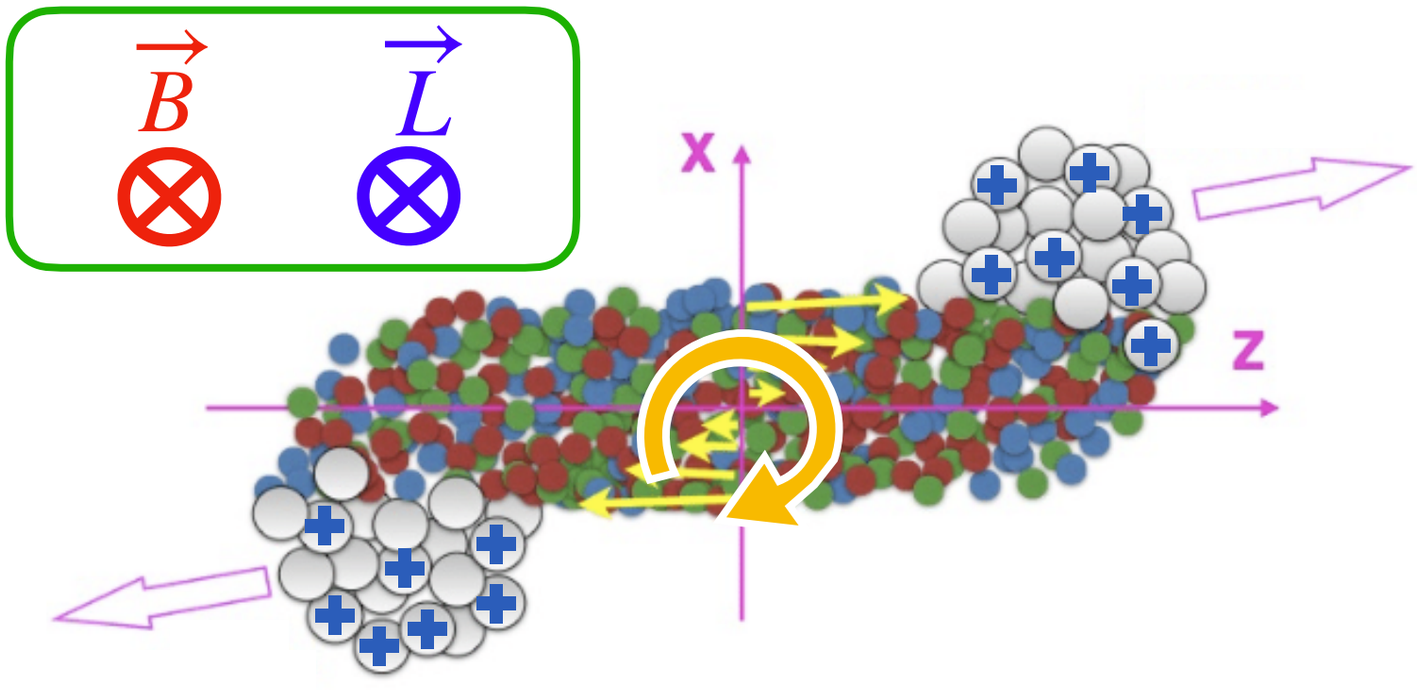
  -Z.-T.Liang and X.-N. Wang, PRL94, 102301

- The strong magnetic field would appear in the initial state.

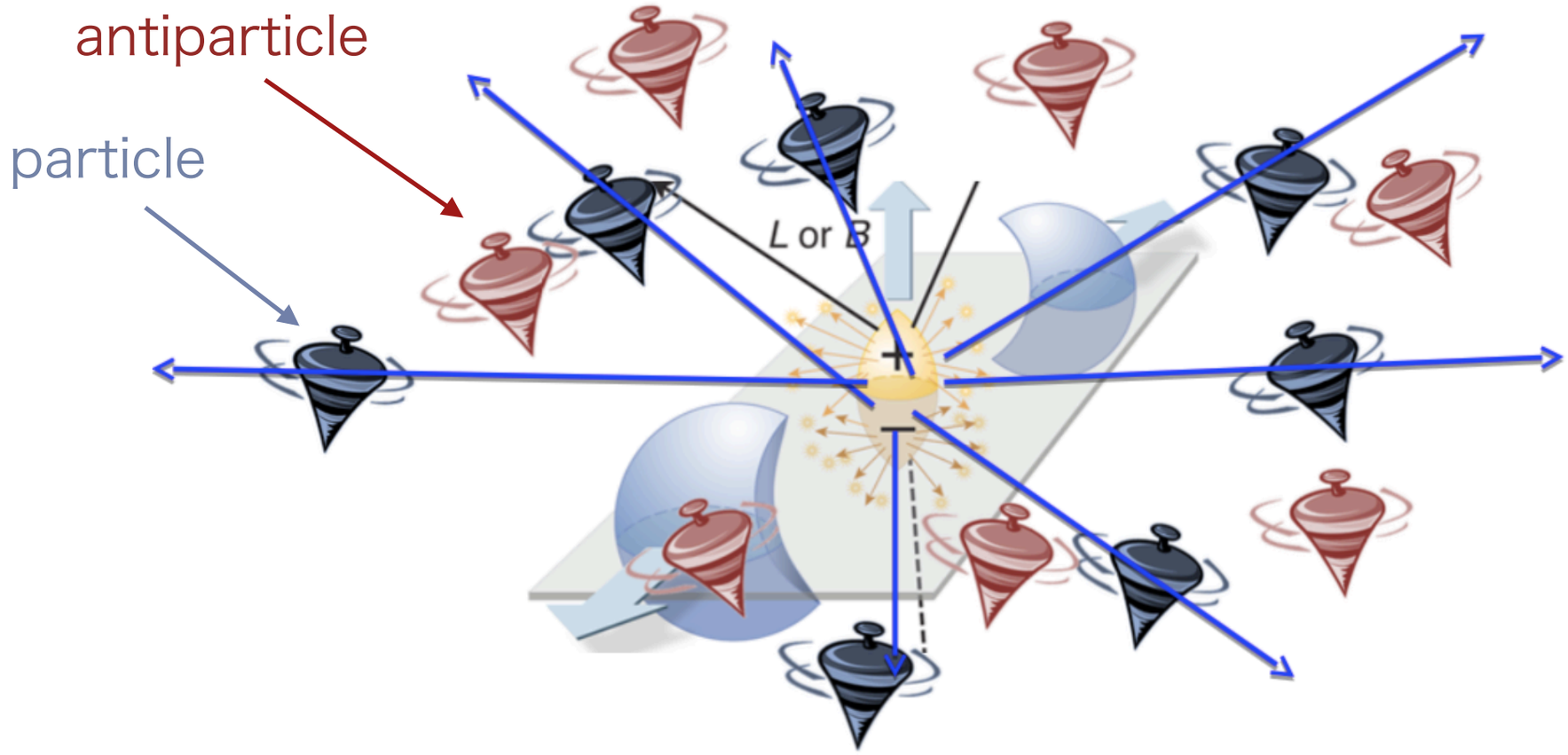
  -D. Kharzeev, L. McLerran, and H. Warring, Nucl.Phys.A803, 227 (2008)

  -McLerran and Skokov, Nucl. Phys. A929, 184 (2014)





Global polarization



- Large orbital angular momentum transfers to the spin degrees of freedom:

  - Quarks and anti-quarks' spins are aligned with the angular momentum.

- Spin alignment by magnetic field:

  - Quarks and anti-quarks get aligned in the opposite direction due to the opposite signs of their magnetic moments.

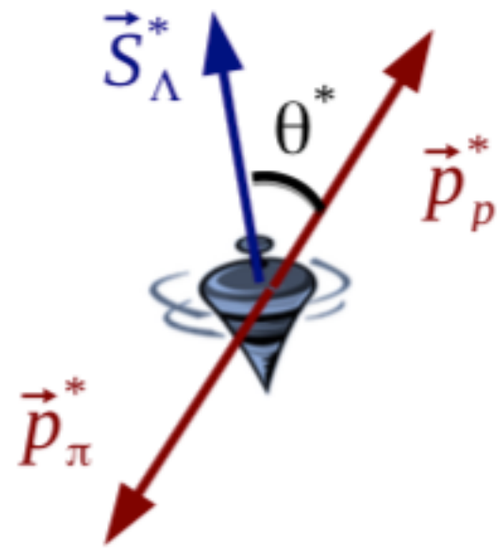
How to measure the global polarization?

✦Parity-violating decay of hyperon

- Daughter proton preferentially decays along the Λ's spin (opposite for anti-Λ).

$$\Lambda \rightarrow p + \pi^- \quad \text{(BR:63.9\%, } c\tau\text{~7.9cm)}$$

- Polarization can be measured via the distribution of the azimuthal angle of the daughter proton (in the hyperon rest frame).



✦Projection onto the transverse plane

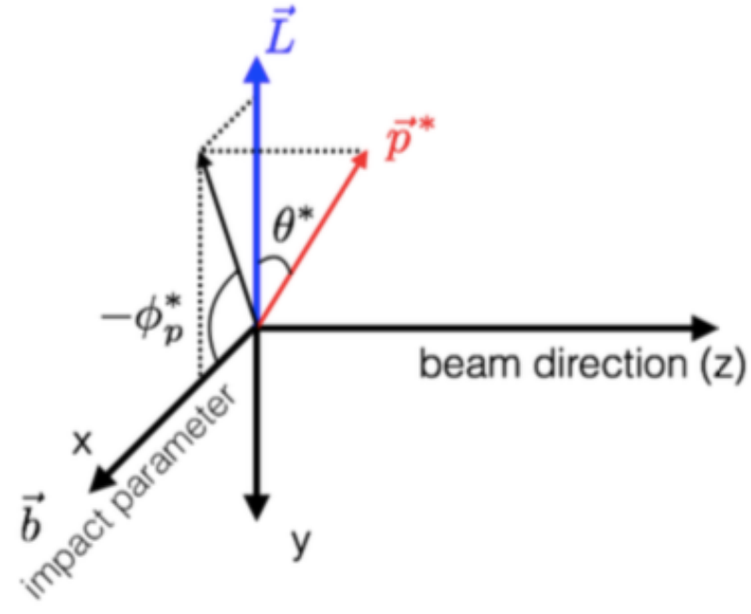
$$P_H = \frac{8}{\pi \alpha_H} \frac{\langle \sin(\Psi_1 - \phi_p^*) \rangle}{Res(\Psi_1)}$$

- STAR, PRC76, 024915(2007)

α_H : decay parameter ($\alpha_\Lambda = 0.732 \pm 0.014$)

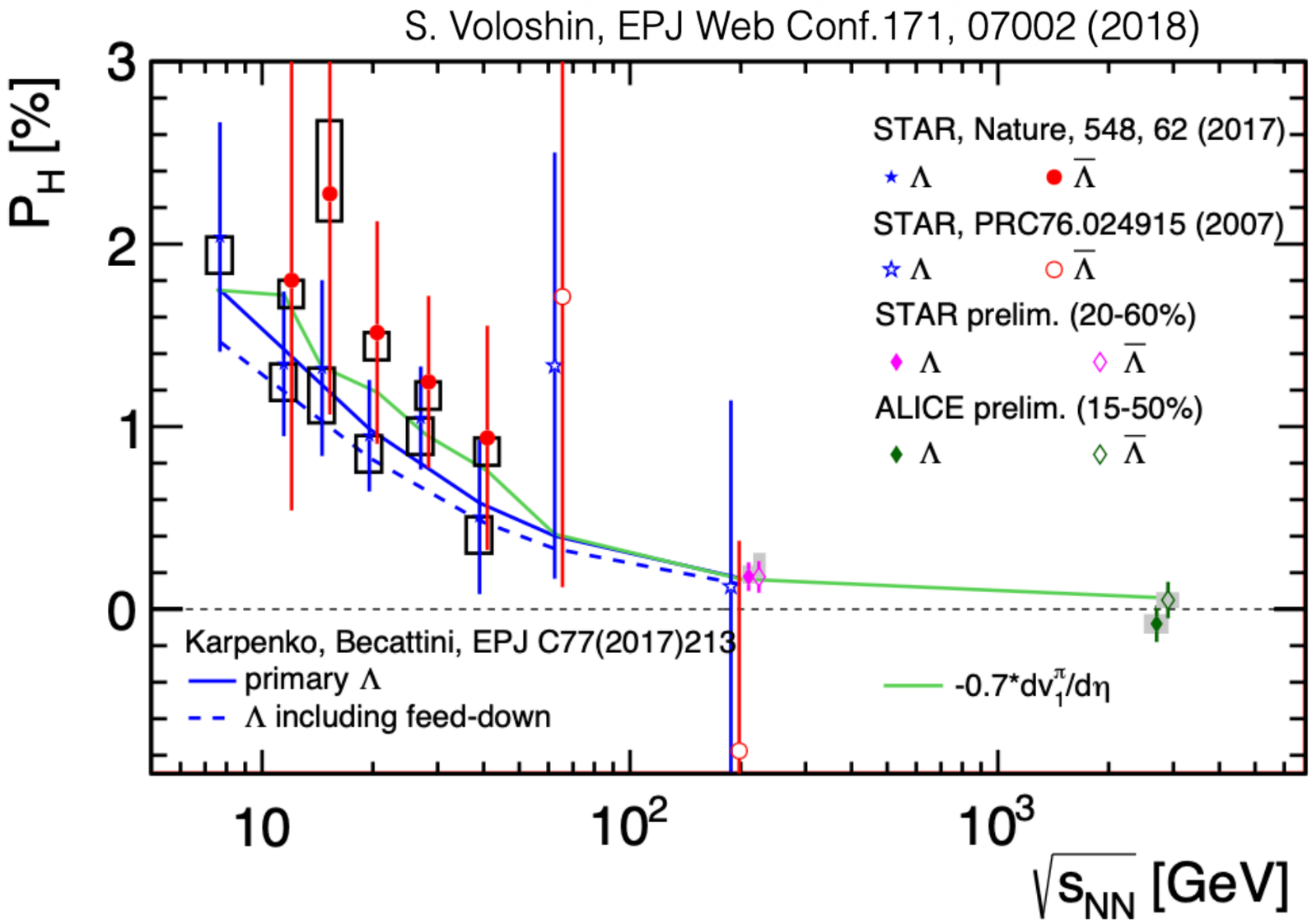
Ψ_1 : 1st-order event plane

ϕ_p^* : azimuthal angle of the daughter proton in the Λ's rest frame



P.A. Zyla et al. (PDG),
Prog. Theor. Exp. Phys.2020, 083C01 (2020).

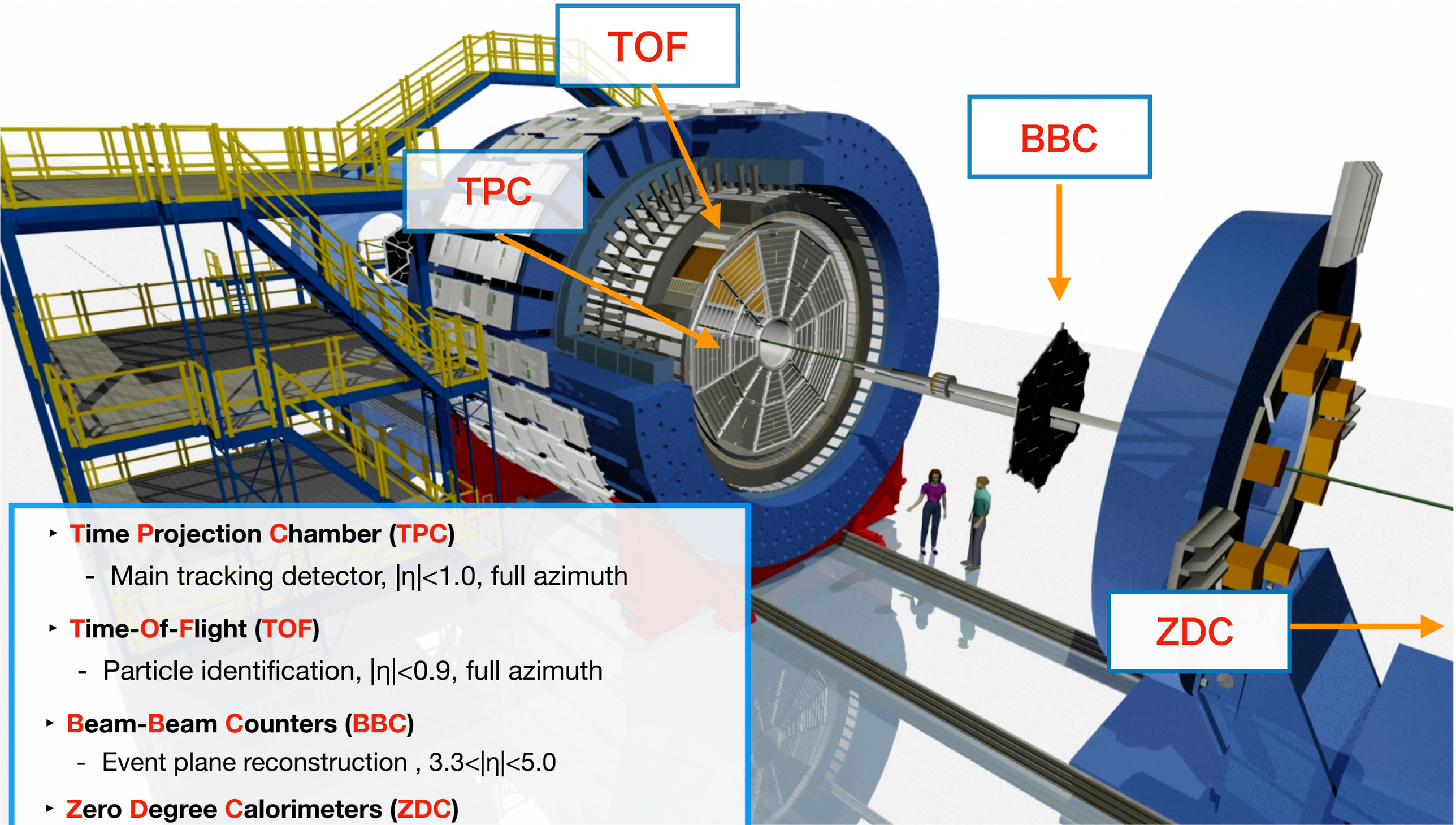
Motivation



✓**The slope of the directed flow at mid-rapidity is likely correlated with the vorticity.**

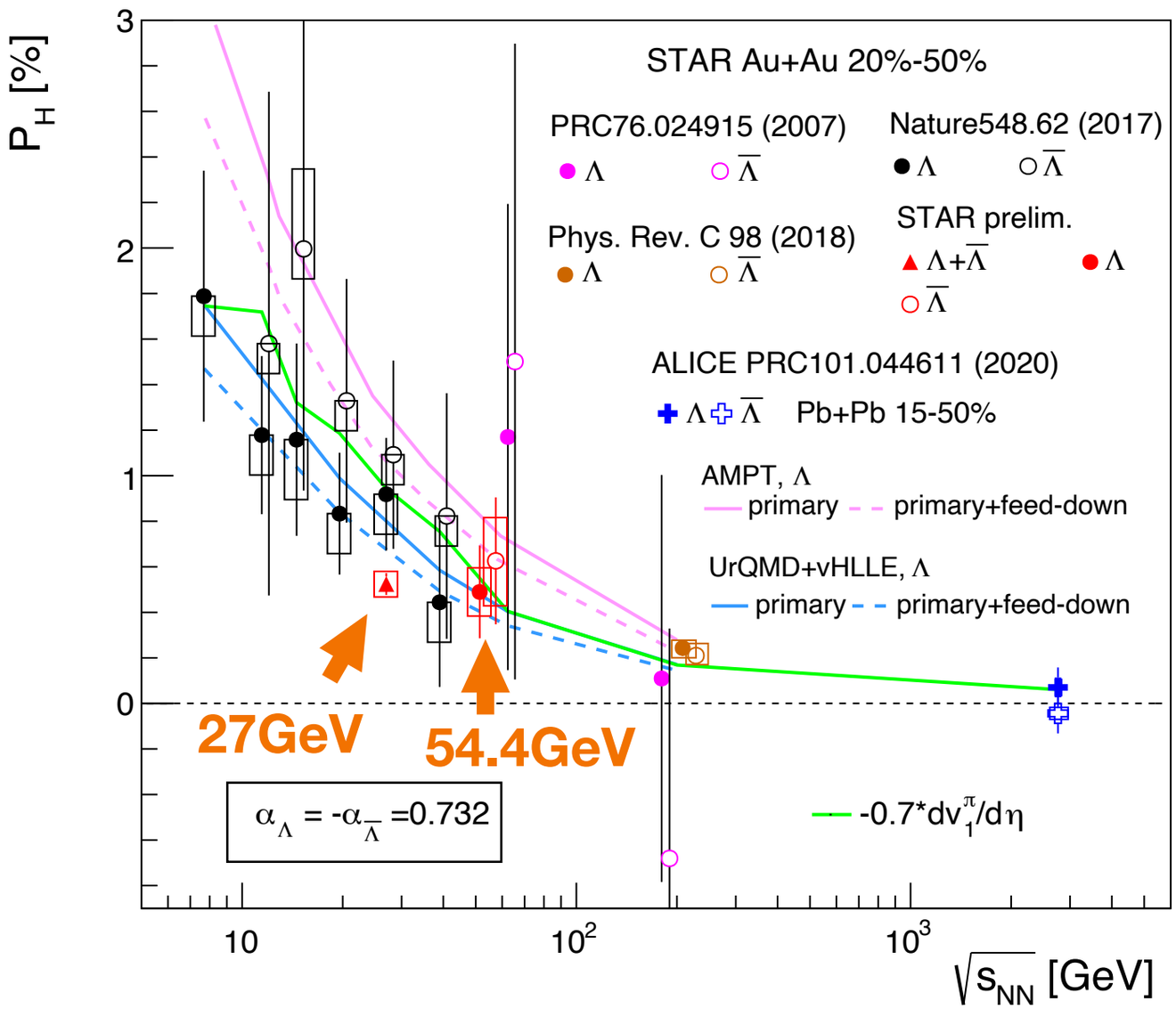
- Global polarization and the negative slope of directed flow of pions have a similar collision energy dependence.

The STAR detector



- **Time Projection Chamber (TPC)**
  - Main tracking detector, |η|<1.0, full azimuth
- **Time-Of-Flight (TOF)**
  - Particle identification, |η|<0.9, full azimuth
- **Beam-Beam Counters (BBC)**
  - Event plane reconstruction , 3.3<|η|<5.0
- **Zero Degree Calorimeters (ZDC)**
  - Event plane reconstruction using spectator neutrons, |η|>6.3

Collision energy dependence of P_H



✓Global polarization of Λ in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 27, 54.4 GeV.

✓The increasing trend with the decreasing of collisions energy.

- **This result also has similar behavior with the slope of the directed flow of pion.**

First order flow vector q_1

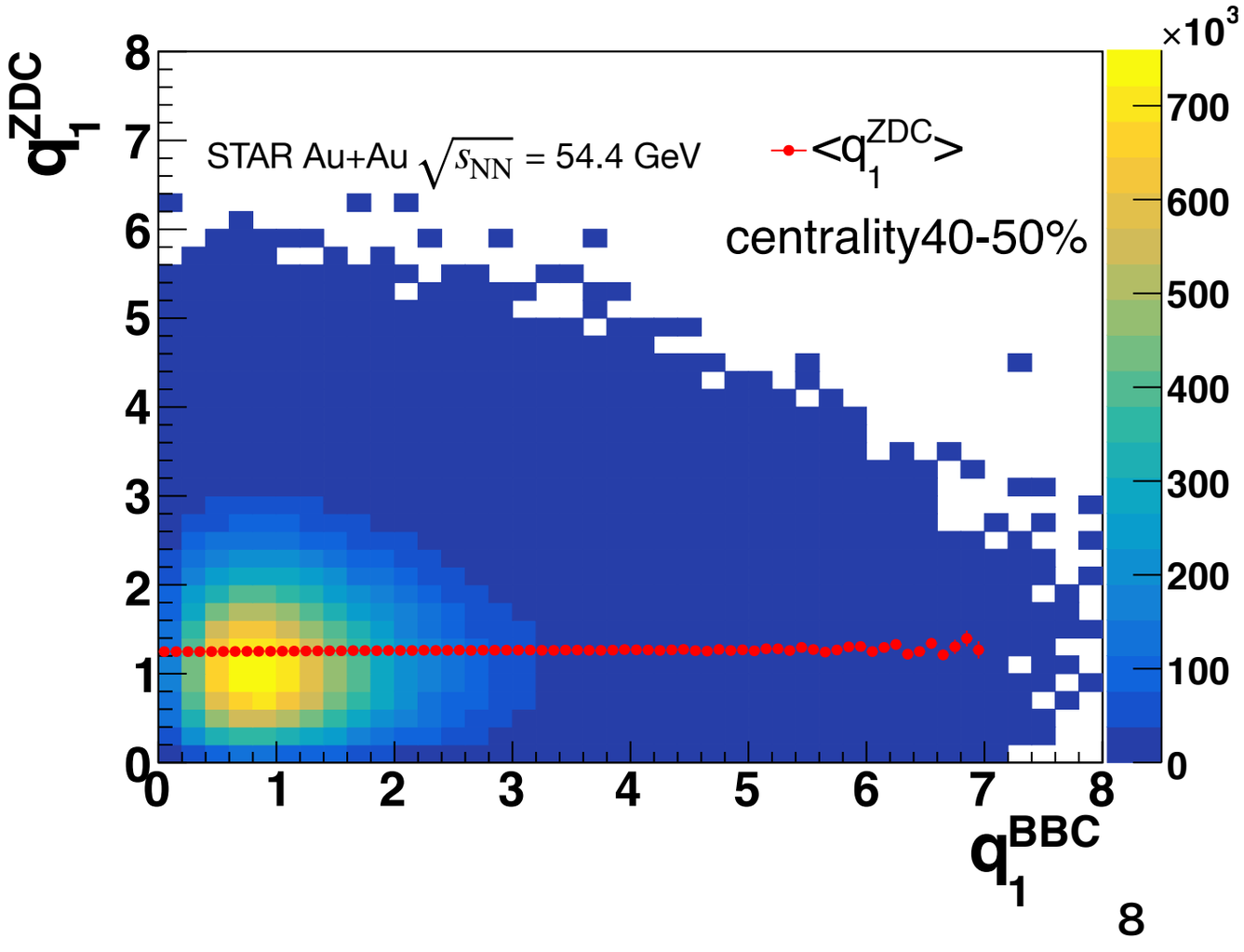
- First order flow vector q_1 quantifies the magnitude of directed flow :

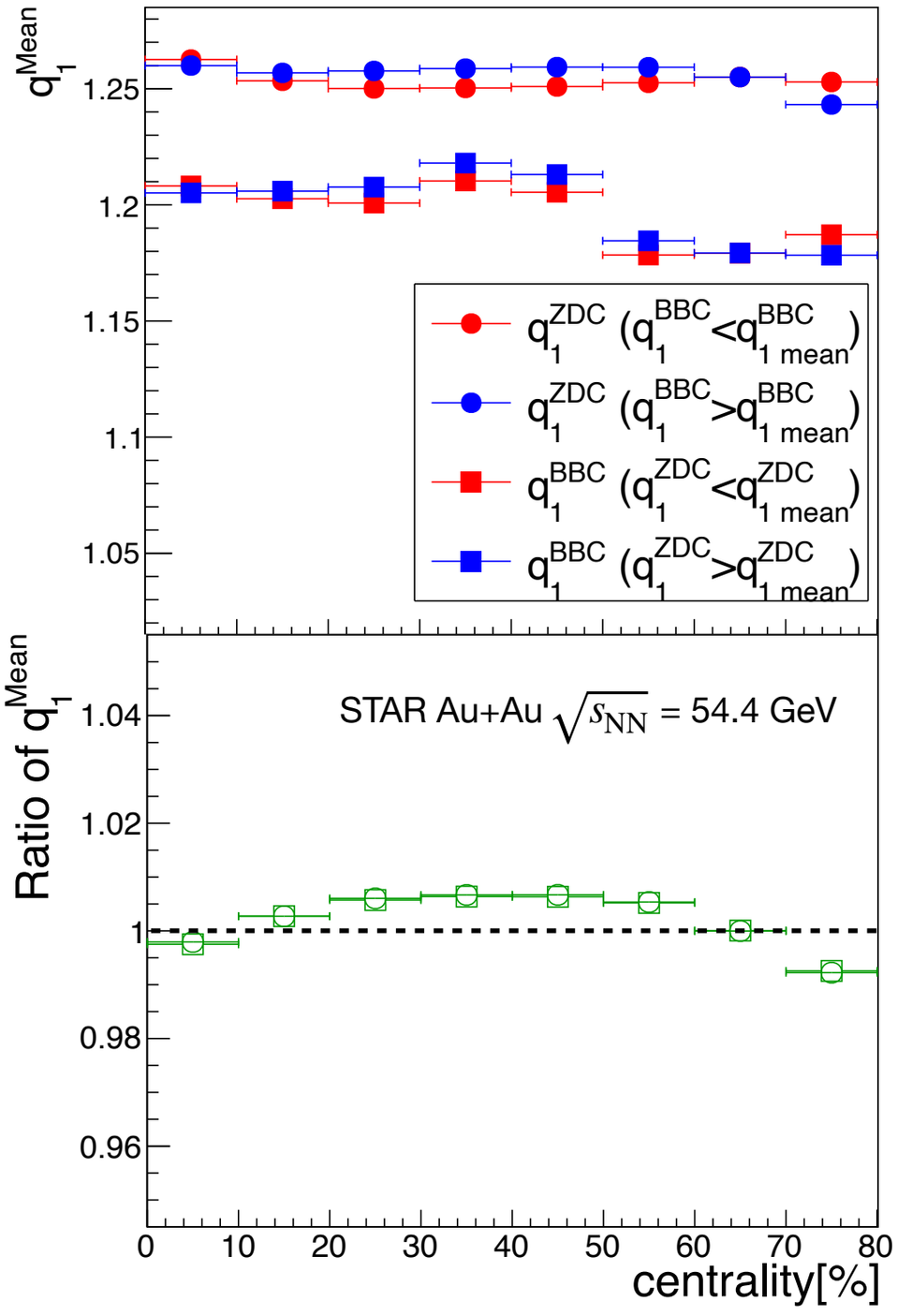
$$q_1 = \sqrt{Q_{x,1}^2 + Q_{y,1}^2}$$

$$Q_{x,1} = \Sigma_i w_i \cos(\phi_i)/\sqrt{\Sigma_i w_i}$$

$$Q_{y,1} = \Sigma_i w_i \sin(\phi_i)/\sqrt{\Sigma_i w_i}$$

- There is positive correlation between q_1^{ZDC} and q_1^{BBC}.





Event plane reconstruction

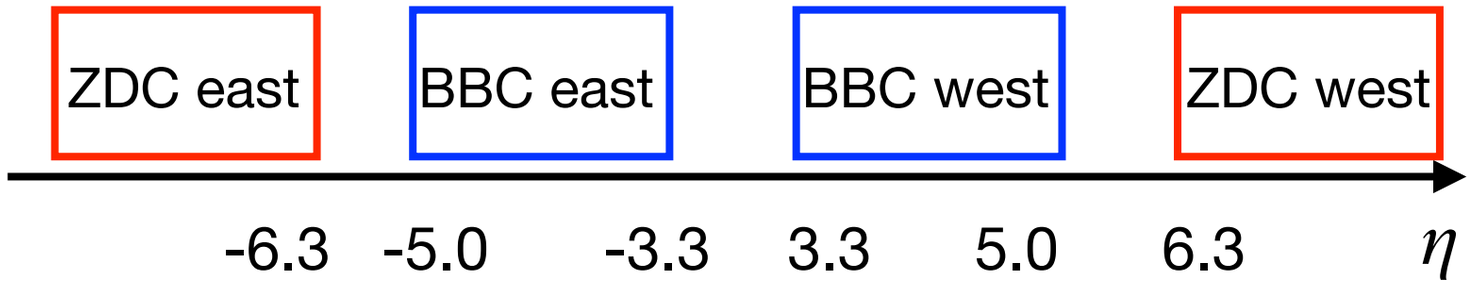
- The first-order event plane was reconstructed as:

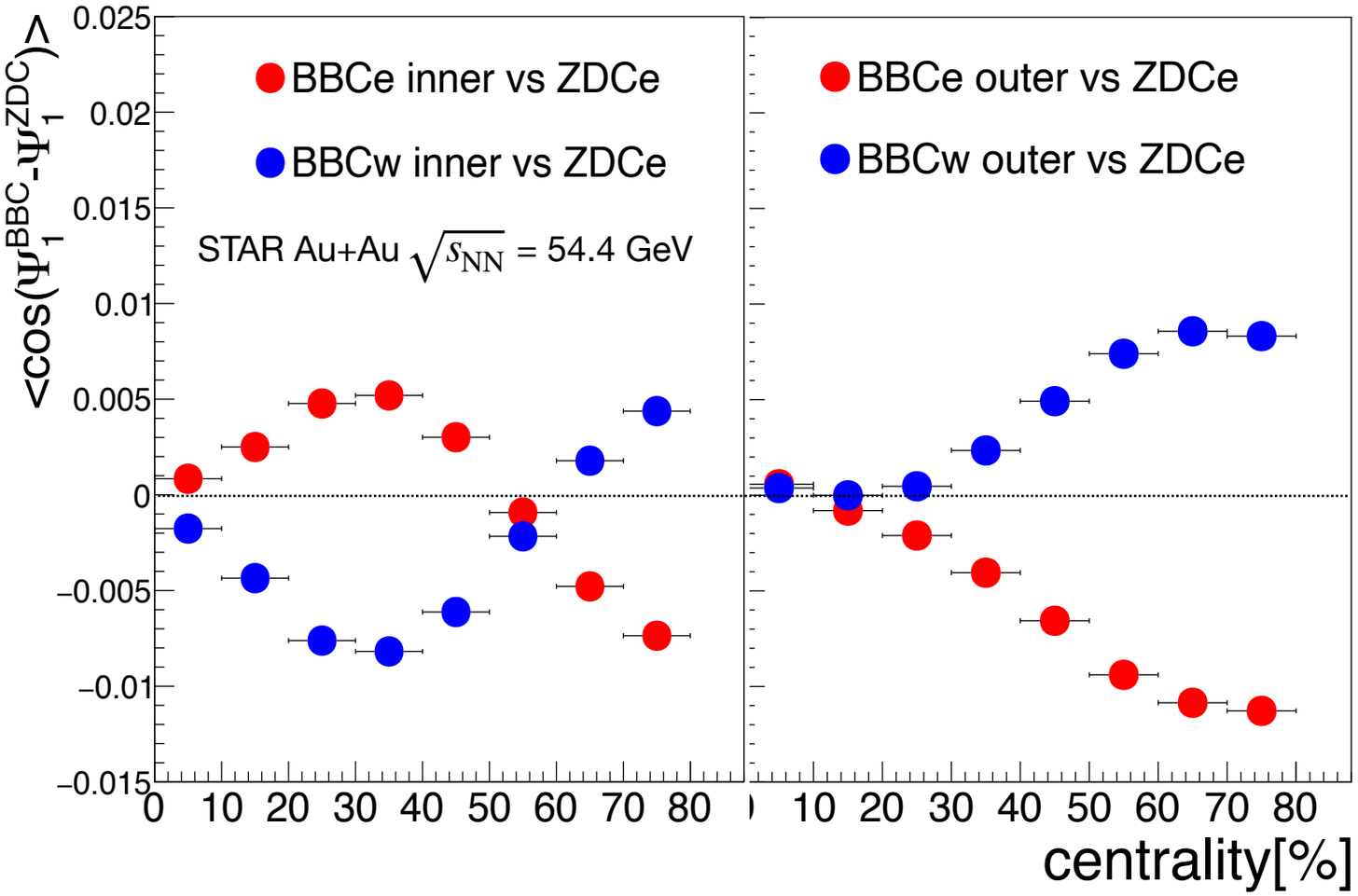
$$\Psi_1 = \tan^{-1}\left(\frac{\sum_i w_i \sin(\phi_i)}{\sum_i w_i \cos(\phi_i)}\right)$$

$$w_i^{BBC} = \langle \cos(\Psi_1^{\mathrm{BBC}} - \Psi_1^{\mathrm{ZDCe}}) \rangle \times \mathrm{BBCADC}$$

BBC inner tiles : $3.9 < |\eta| < 5.0$

BBC outer tiles : $3.3 < |\eta| < 3.9$





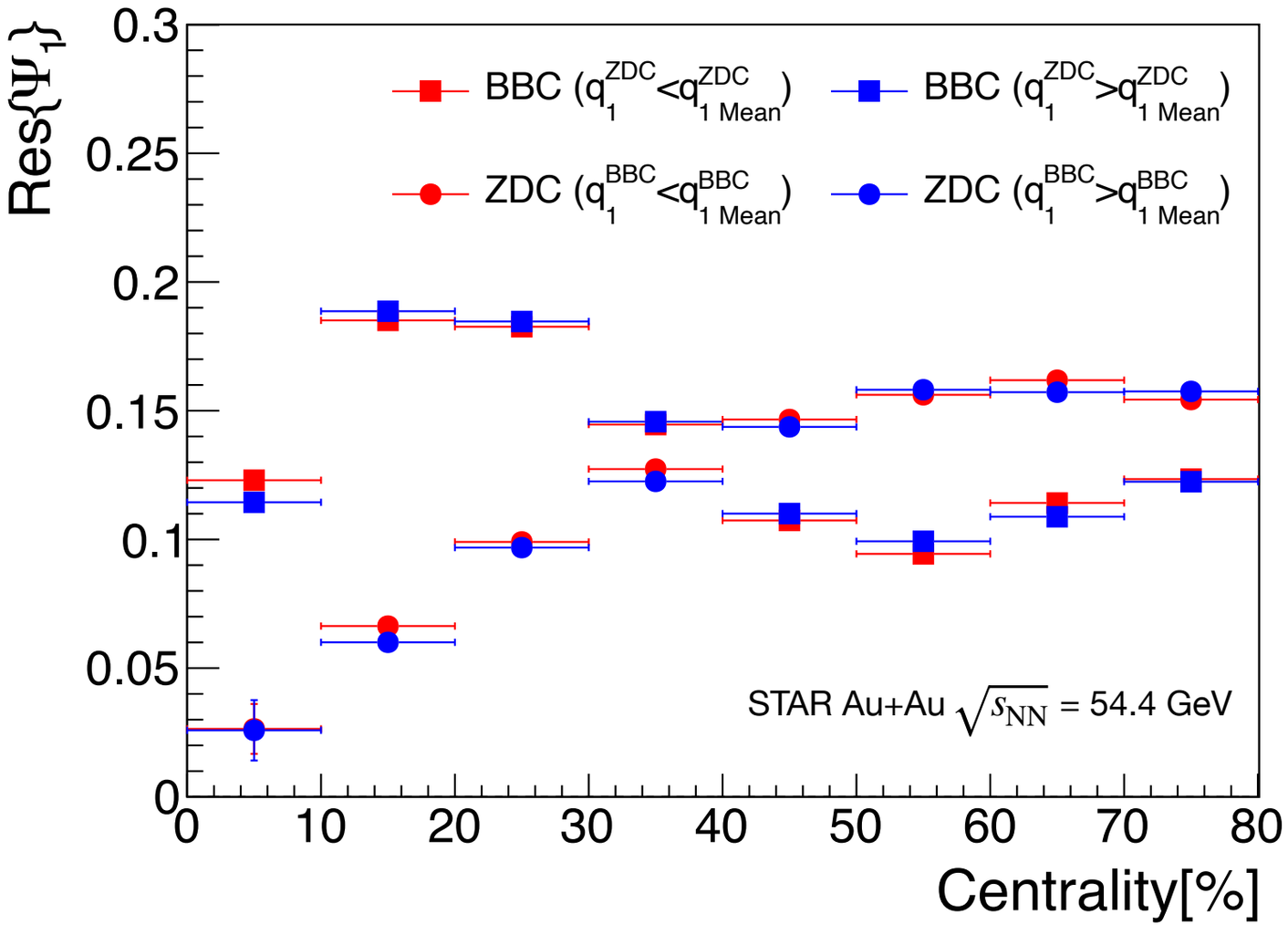
- **The contribution of spectators is observed only for central collisions of BBC inner tiles ($3.9 < |\eta| < 5.0$).**
  - Beam rapidity ~ 4.0

Event plane resolution

- The event plane resolution was calculated by 2-subevent method:

$$Res_A = Res_B = \sqrt{\langle \cos(\Psi_A - \Psi_B) \rangle}$$

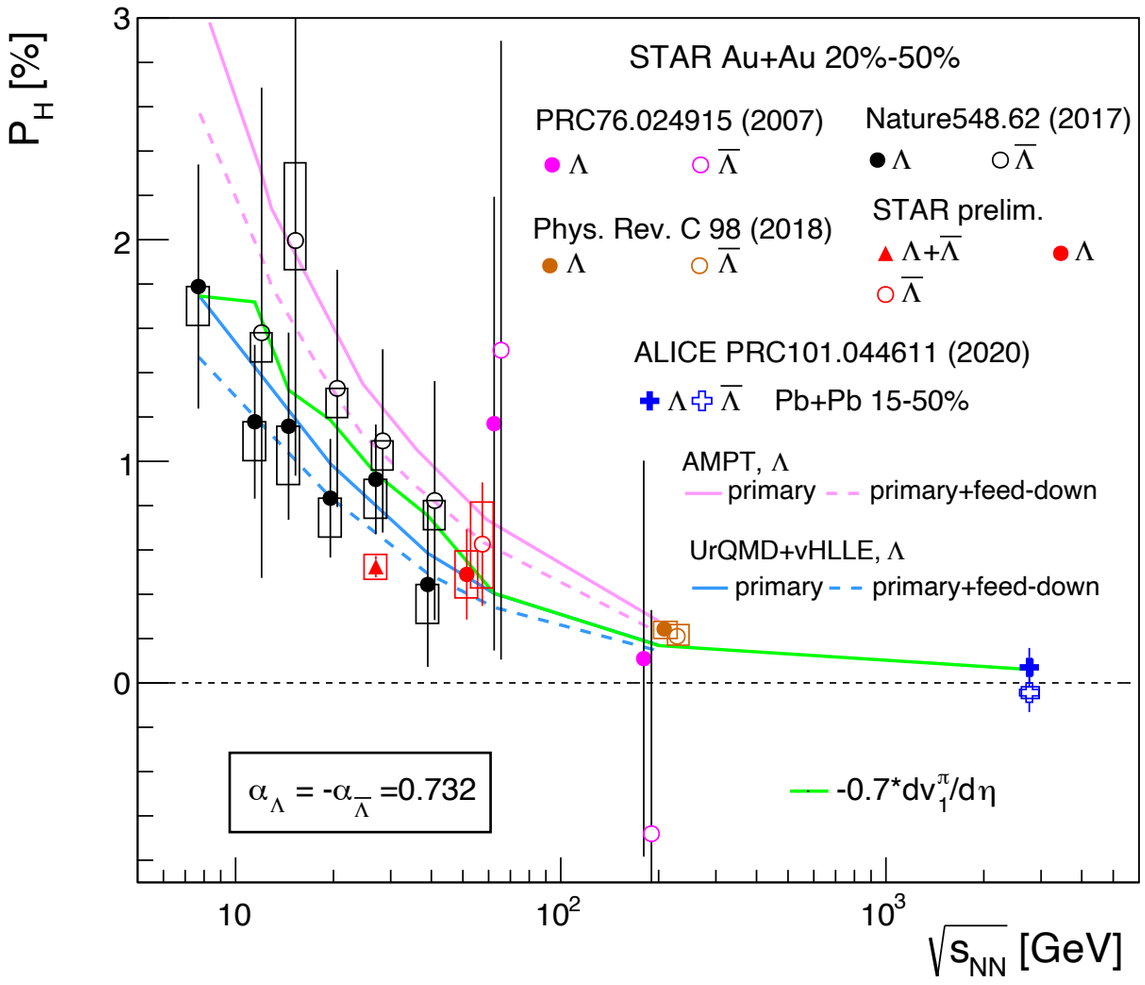
A. M. Poskanzer and S. A. Voloshin,Phys. Rev. C 58, 1671 (1998).

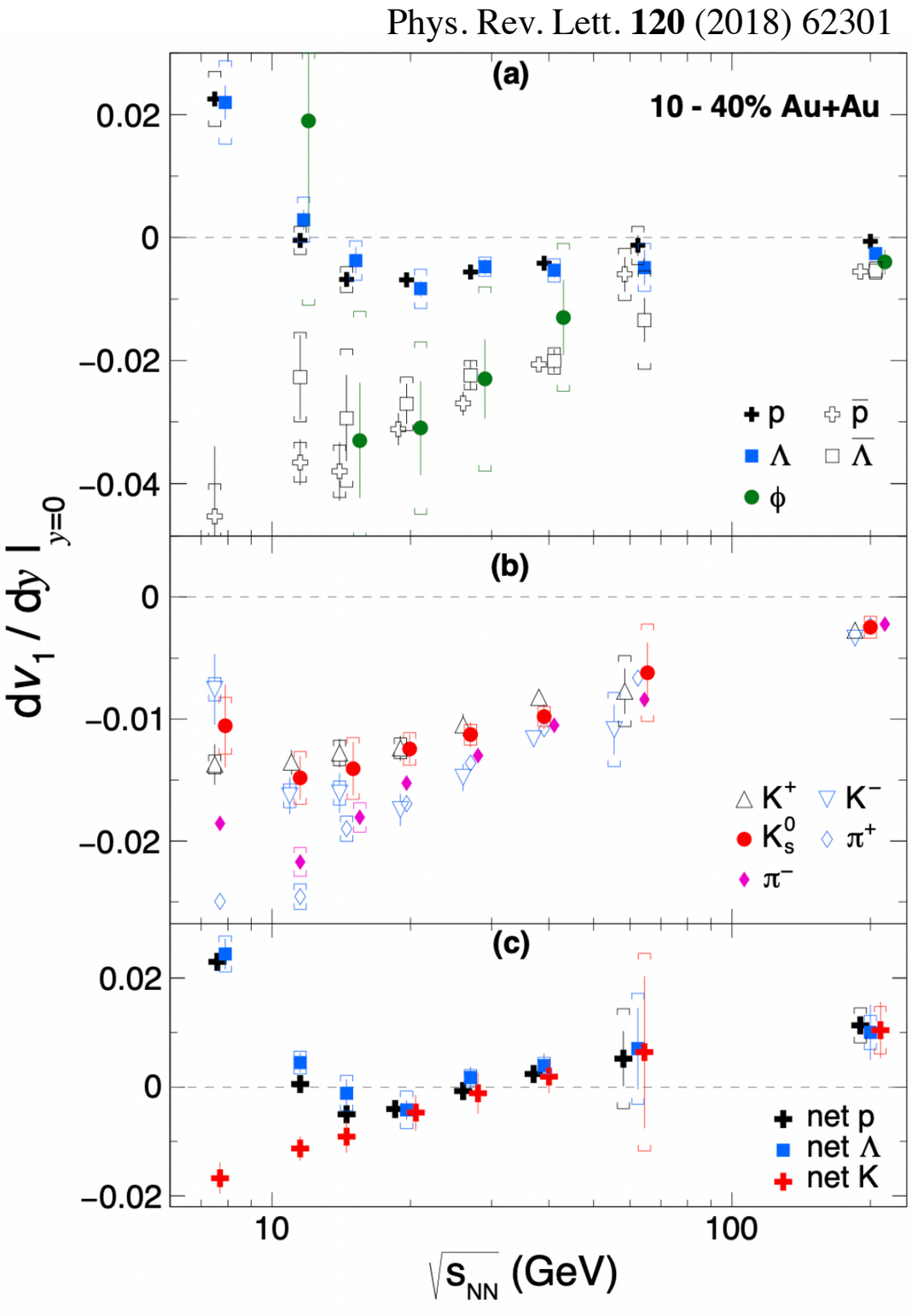


✓In peripheral collisions, the event plane resolution of ZDC is better than that of BBC.

✓The event plane resolution depends little on q_1.

Global polarization and directed flow





- ✓The negative slope of directed flow of pions has similar trend with global polarization of Λ hyperons.
- ✓The behavior of the slope of directed flow depends on particle species.

Summary

Summary

✓First order flow vector q_1 was measured in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 54.4 GeV.

✓Event plane resolution was estimated with q_1 selection.

Outlook

✓Measure the q_1 dependence of global polarization of Λ at $\sqrt{s_{\mathrm{NN}}}$ = 54.4 GeV.

✓We have completed the data taking of BES II + FXT.

- Large statistics at low energies.
- Good event plane resolution.

Collider mode data at BES II

Beam Energy (GeV/nucleon)	$\sqrt{s_{\mathrm{NN}}}$ (GeV)	μ_{B} (MeV)	Number Events Requested (Recorded)	Date Collected
13.5	27	156	(560 M)	Run-18
9.8	19.6	206	400 M (582 M)	Run-19
7.3	14.6	262	300 M (324 M)	Run-19
5.75	11.5	316	230 M (235 M)	Run-20
4.59	9.2	373	160 M (162 M)	Run-20+20b
3.85	7.7	420	100 M (100 M)	Run-21

Fixed-target mode data at BES II

Beam Energy (GeV/nucleon)	$\sqrt{s_{\mathrm{NN}}}$ (GeV)	μ_{B} (MeV)	Run Time	Number Events Requested (Recorded)	Date Collected
31.2	7.7 (FXT)	420	0.5+1.1 days	100 M (50 M+112 M)	Run-19+20
19.5	6.2 (FXT)	487	1.4 days	100 M (118 M)	Run-20
13.5	5.2 (FXT)	541	1.0 day	100 M (103 M)	Run-20
9.8	4.5 (FXT)	589	0.9 days	100 M (108 M)	Run-20
7.3	3.9 (FXT)	633	1.1 days	100 M (117 M)	Run-20
5.75	3.5 (FXT)	666	0.9 days	100 M (116 M)	Run-20
4.59	3.2 (FXT)	699	2.0 days	100 M (200 M)	Run-19
3.85	3.0 (FXT)	721	4.6 days	100 M (259 M)	Run-18

Back up

First order flow vector q_1