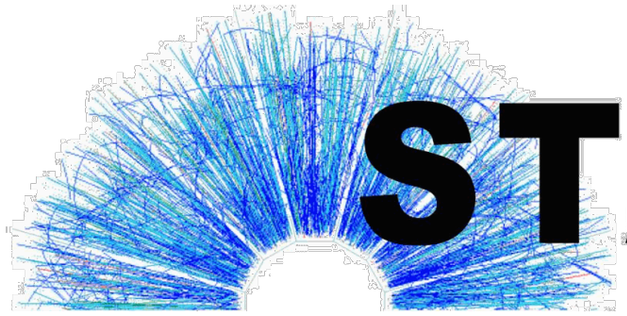
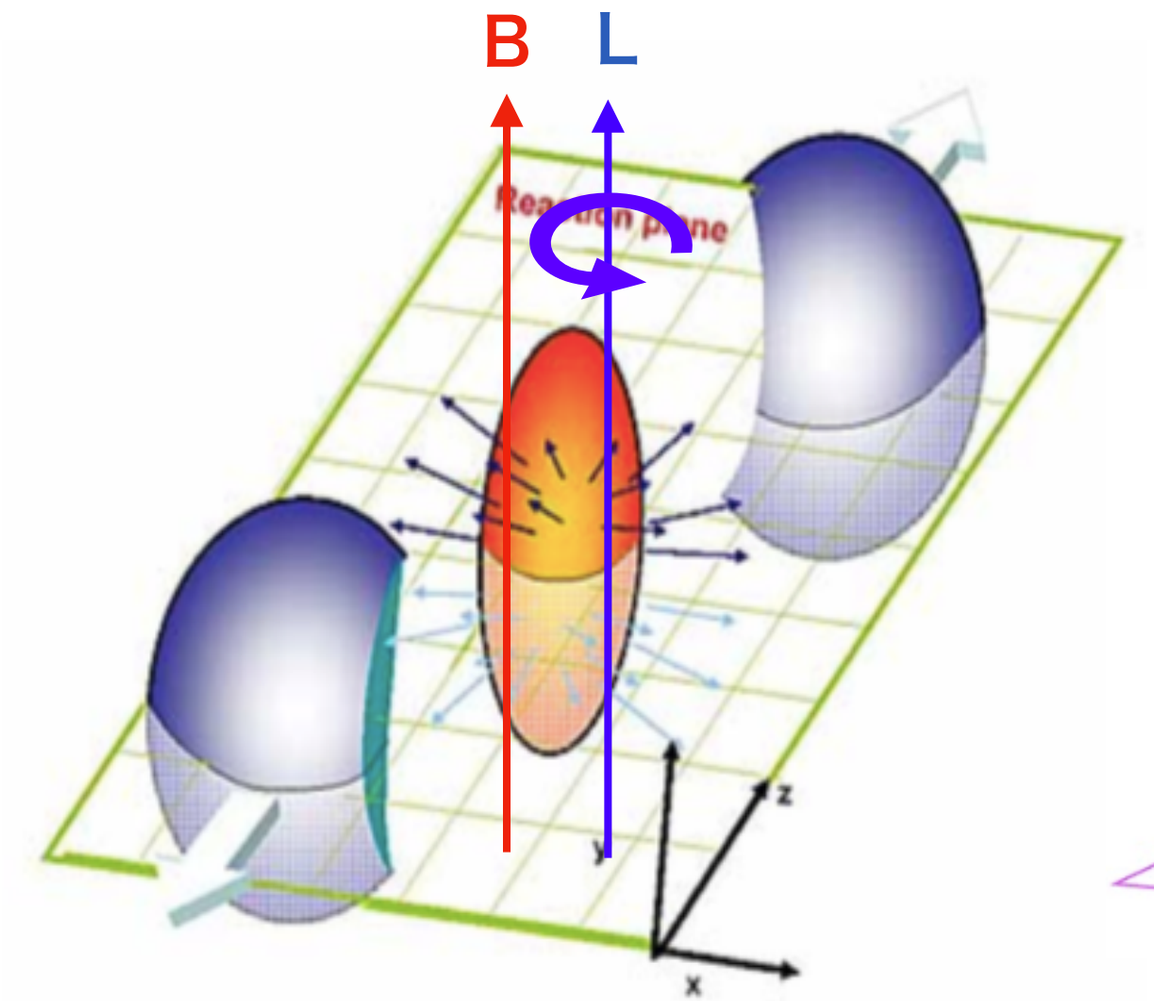


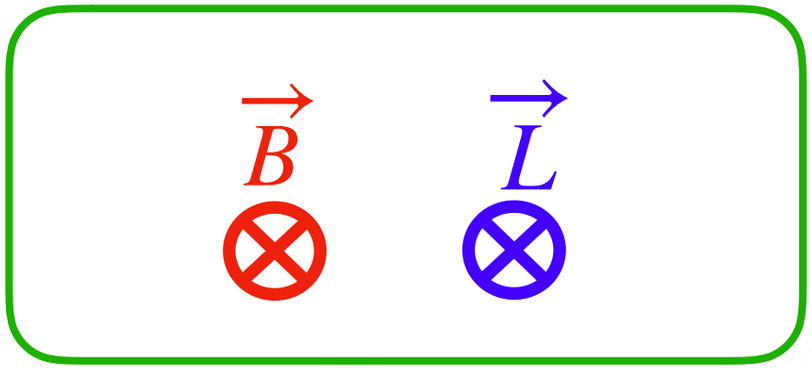
Measurements of the Lambda polarization in Au+Au collisions at $\sqrt{s_{NN}} = 54.4\mathrm{GeV}$

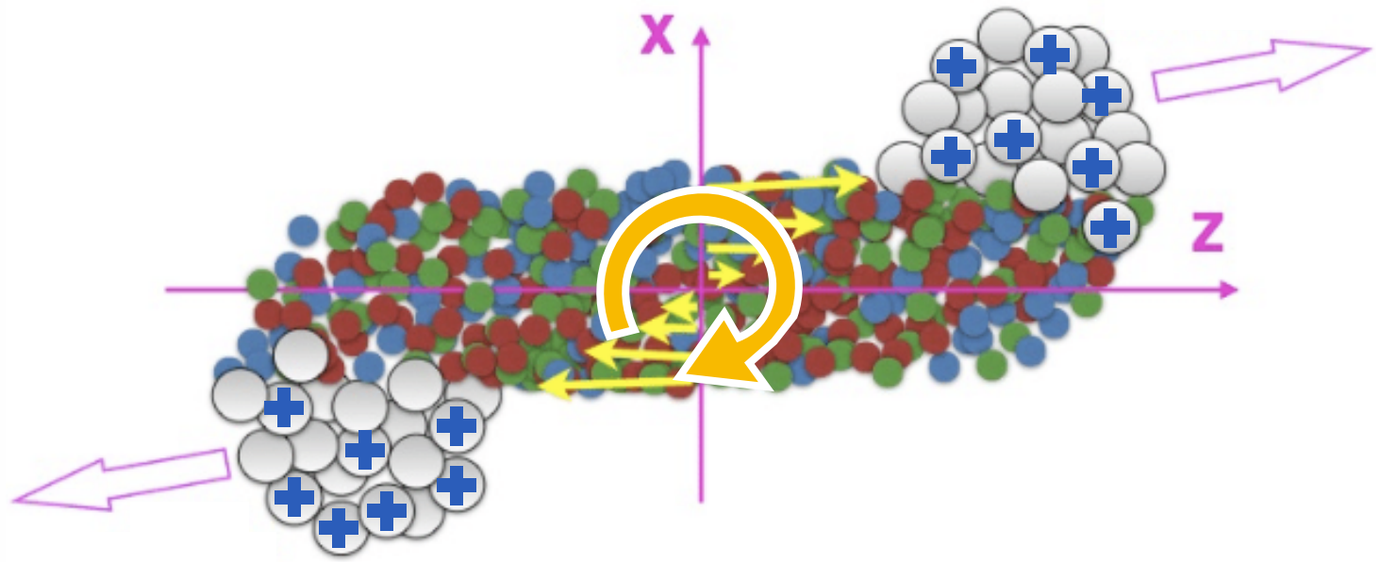
Kosuke Okubo, for the STAR collaboration
University of Tsukuba

Workshop on the QCD Phase Structure
at High Baryon Density region
CCNU,2019/11/14

Introduction

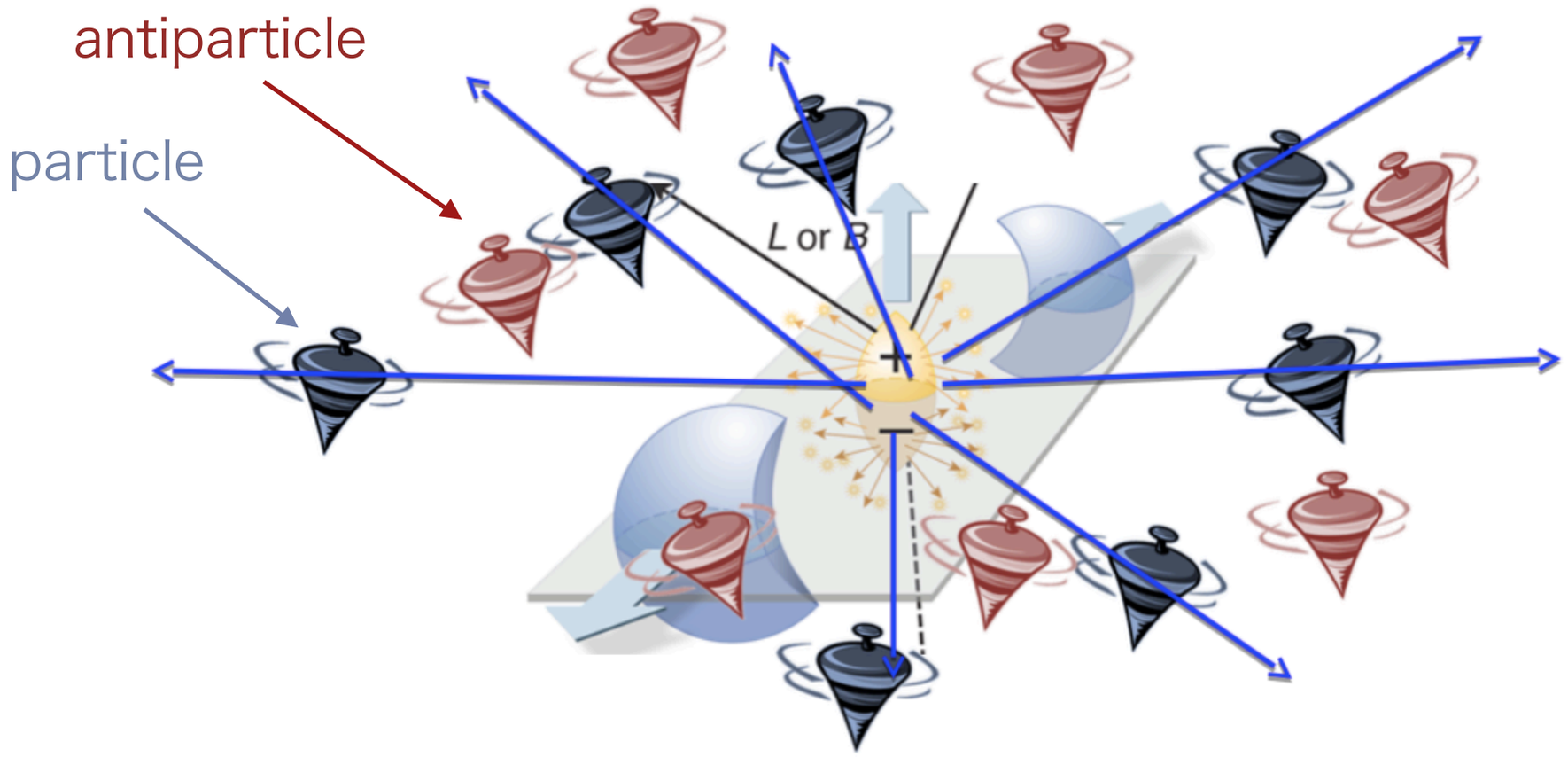






- In non-central collision...
  - The created matter should exhibit rotation motion.
    -Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)
  - The strong magnetic field would appear in the initial state.
    -D. Kharzeev, L. McLerran, and H. Warringa, Nucl.Phys.A803, 227 (2008)
    -McLerran and Skokov, Nucl. Phys. A929, 184 (2014)

Global polarization



◆Large angular momentum transfers to the spin degrees of freedom :

- Particle and anti-particle's spin are aligned with angular momentum, $\vec{L}$.

◆Spin alignment by magnetic field :

- Particle's spin are aligned with magnetic field, $\vec{B}$.
- Antiparticle's spin is oppositely aligned.

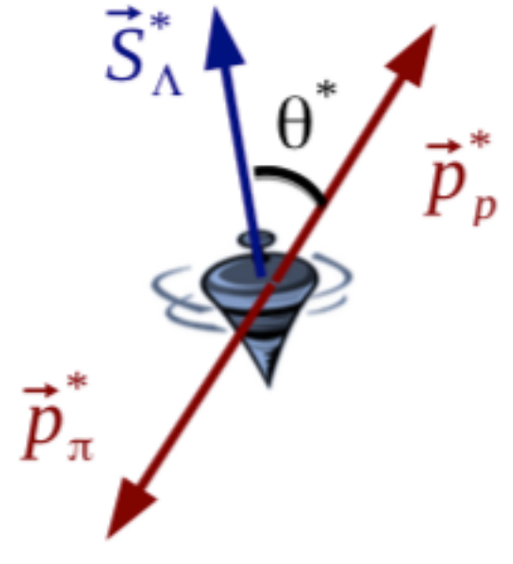
✔**Both may contribute**

How to measure the global polarization?

✦Parity-violating decay of hyperon

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

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



✦Projection onto the transverse plane

- The global polarization can be measured via the distribution of the azimuthal angle of the hyperon decay baryon(in the hyperon rest frame).

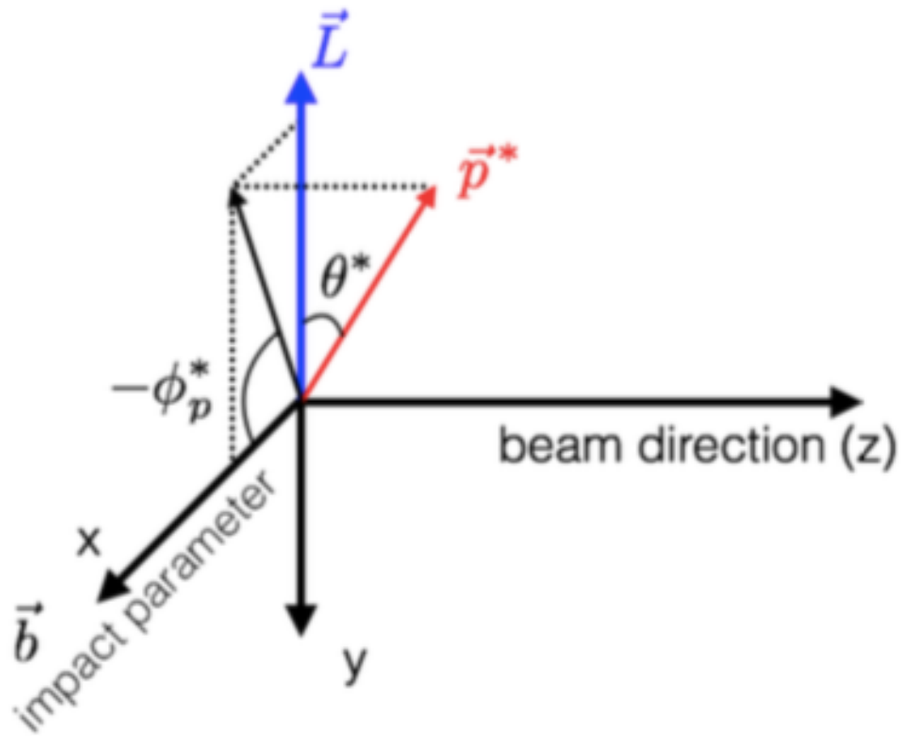
-STAR, PRC76, 024915(2007)

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

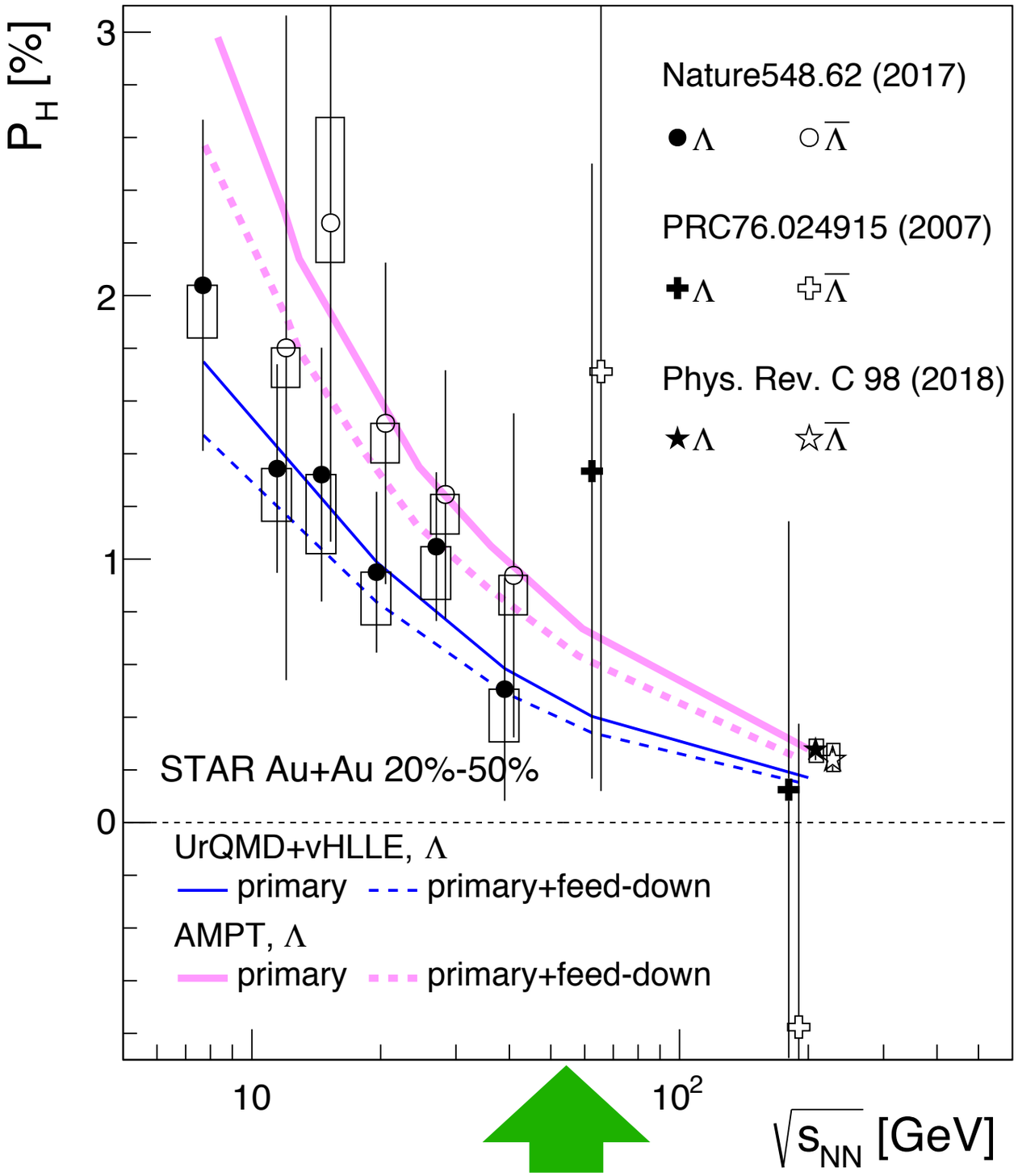
α_H : decay parameter

Ψ_1 : 1st-order event plane

ϕ_p^* : ϕ of the azimuthal angle of the daughter baryon (in the hyperon's rest frame)



Motivation

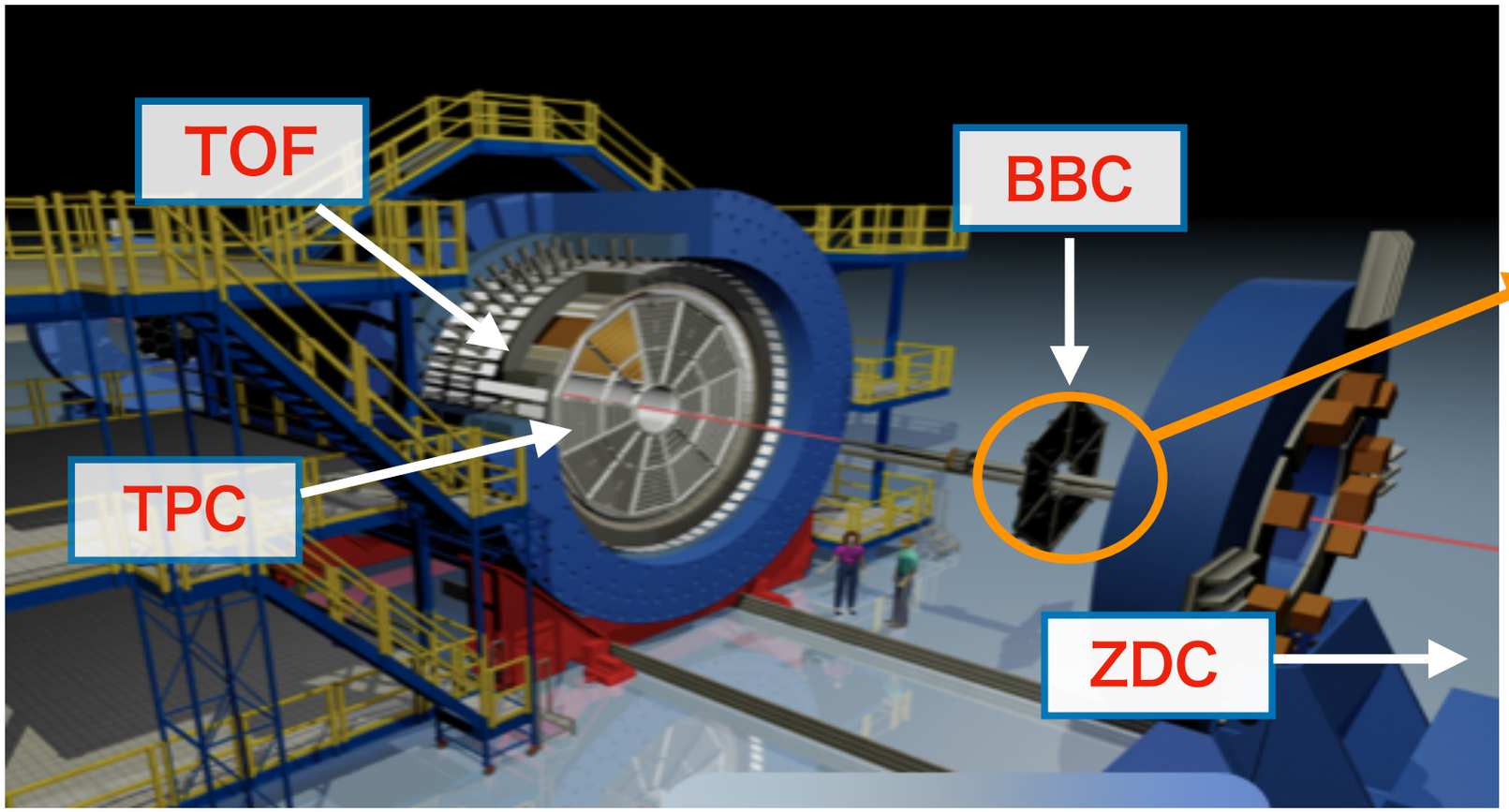


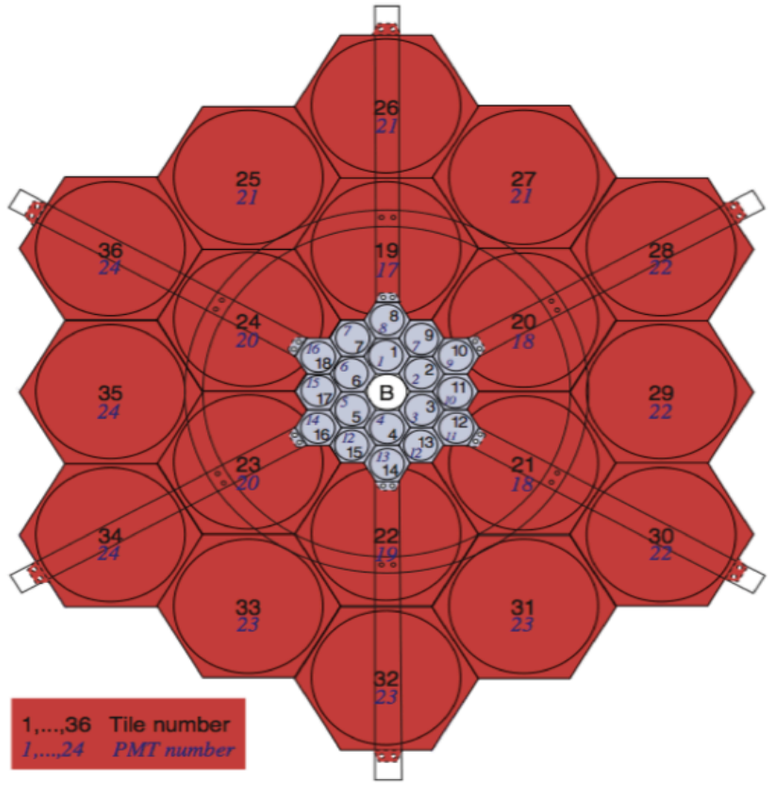
- Previous study
  - ✓Positive increases at low collision energy.
  - ✓No significant difference between Λ and anti-Λ
  - ✓At lower energy, uncertainties are large...

We measured global polarization with 54.4GeV which has large statistics

★**The gap between 39 GeV and 200 GeV data can be filled with new 54.4 GeV large statistics data set.**

STAR detector





- Time Projection Chamber (TPC)
  - Main tracking detector and Particle identification, $|\eta|<1.0$, full azimuth
- Time-Of-Flight (TOF)
  - Particle identification, $|\eta|<0.9$, full azimuth

✓ Beam-Beam Counters (BBC)
- Event plane reconstruction , $3.3<|\eta|<5.0$ ($|y_{beam}| \sim 4.0$)

✓ Zero Degree Calorimeters (ZDC)
- Event plane reconstruction using spectator neutrons, $|\eta|>6.3$

Lambda reconstruction

- Charged particle can be identified via specific ionization energy loss in the TPC and mass estimated from the TOF

✦Proton

✓ $|n\sigma| < 3$

✓ $0.5 < m^2 < 1.5$ $(GeV/c^2)^2$

✦Pion

✓ $|n\sigma| < 3$

✓ $-0.029+0.017p < m^2 < 0.04$ $(GeV/c^2)^2$

✦Topological cut

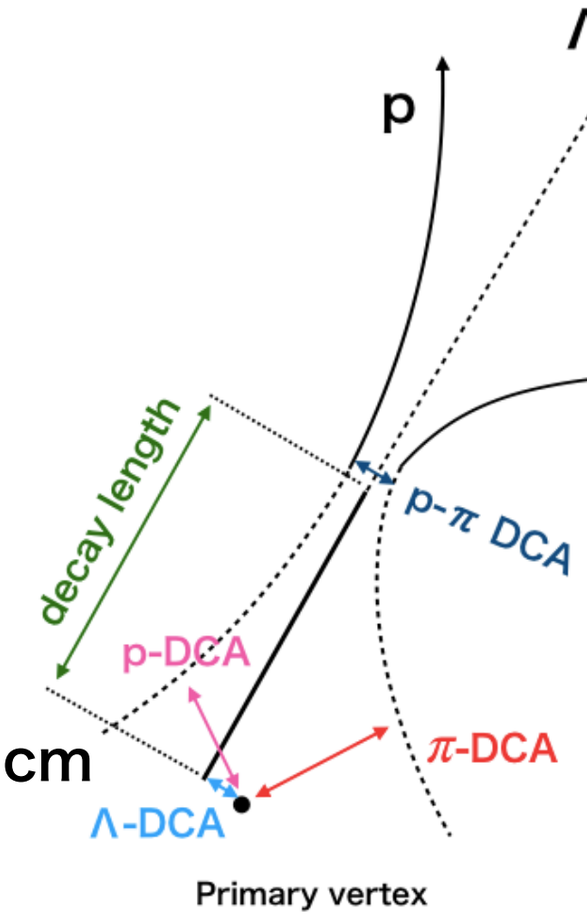
✓ p-DCA > 0.2 cm

✓ π-DCA > 1.2 cm

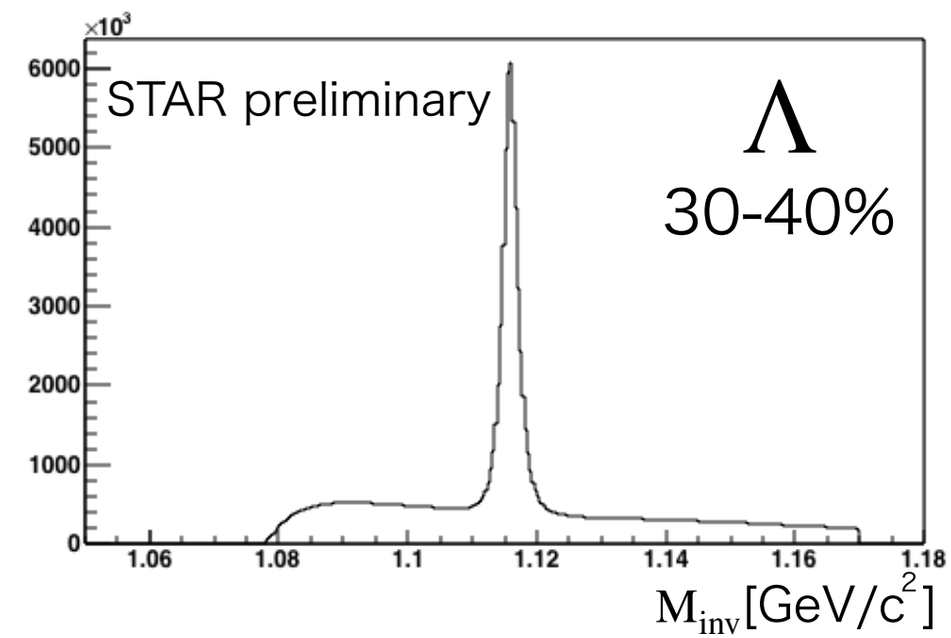
✓ p-π DCA < 1.0 cm

✓ Λ-DCA < 0.9 cm

✓ Decay length > 3.5 cm



$$\frac{\text{Signal}}{\text{Signal + Background}} \sim \begin{cases} 86\%(\text{for } \Lambda) \\ 80\%(\text{for } \overline{\Lambda}) \end{cases}$$



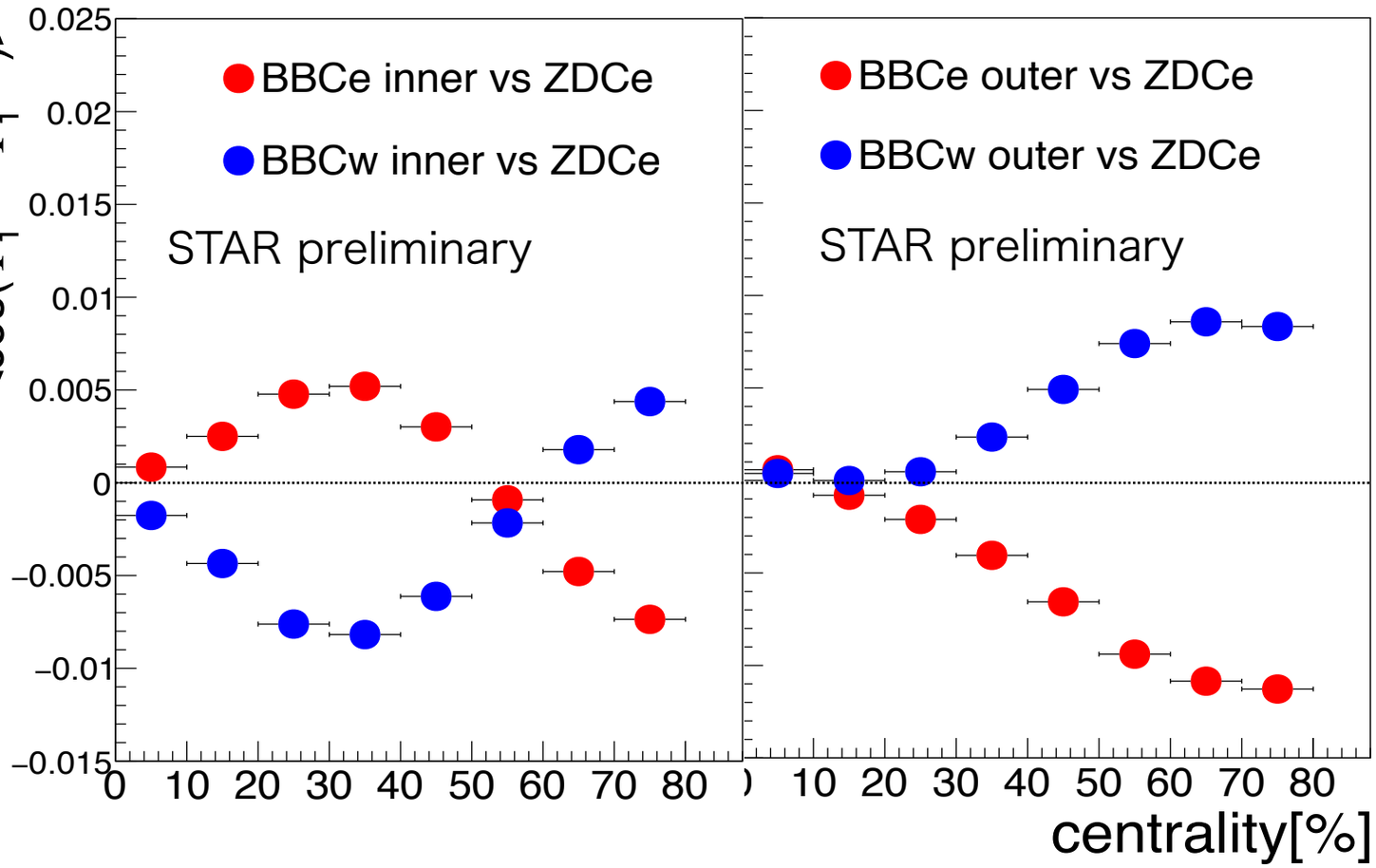
✳These value of topological cut is 30-40%

Event plane correlation

✦EP Correlation

Inner ring : 1-6 for the tile number (3.9 < |η| < 5.0)

Outer ring : 7-18 for the tile number (3.3 < |η| < 5.0)



- **BBC inner ring**
  - In central region

$$\langle \cos(\Psi_1^{\text{BBCeast inner}} - \Psi_1^{\text{ZDCeast}}) \rangle > 0$$

  - In peripheral region

$$\langle \cos(\Psi_1^{\text{BBCeast inner}} - \Psi_1^{\text{ZDCeast}}) \rangle < 0$$

- **BBC outer ring**

$$\langle \cos(\Psi_1^{\text{BBCeast outer}} - \Psi_1^{\text{ZDCeast}}) \rangle < 0$$

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

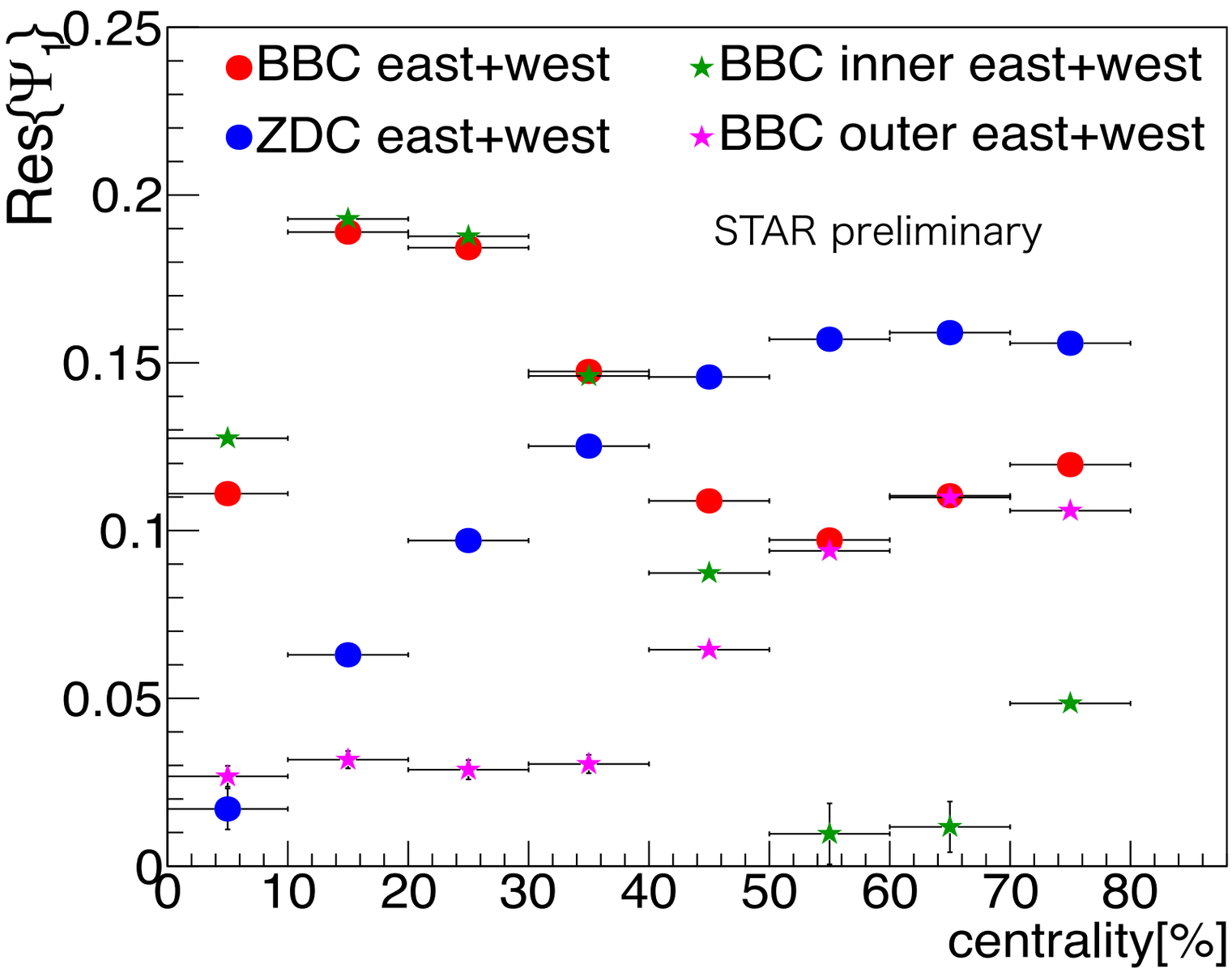
$$w_i^{BBC} = \langle \cos(\Psi_1^{BBC} - \Psi_1^{ZDCE}) \rangle \times \text{BBCADC}$$

✓The contribution of spectator only in the central collision of BBC inner ring (3.3 < |η| < 5.0) is observed.

- Beam rapidity ～ 4.0

Event plane resolution

✦EP resolution



✓Resolution was calculated by 2-subevent method

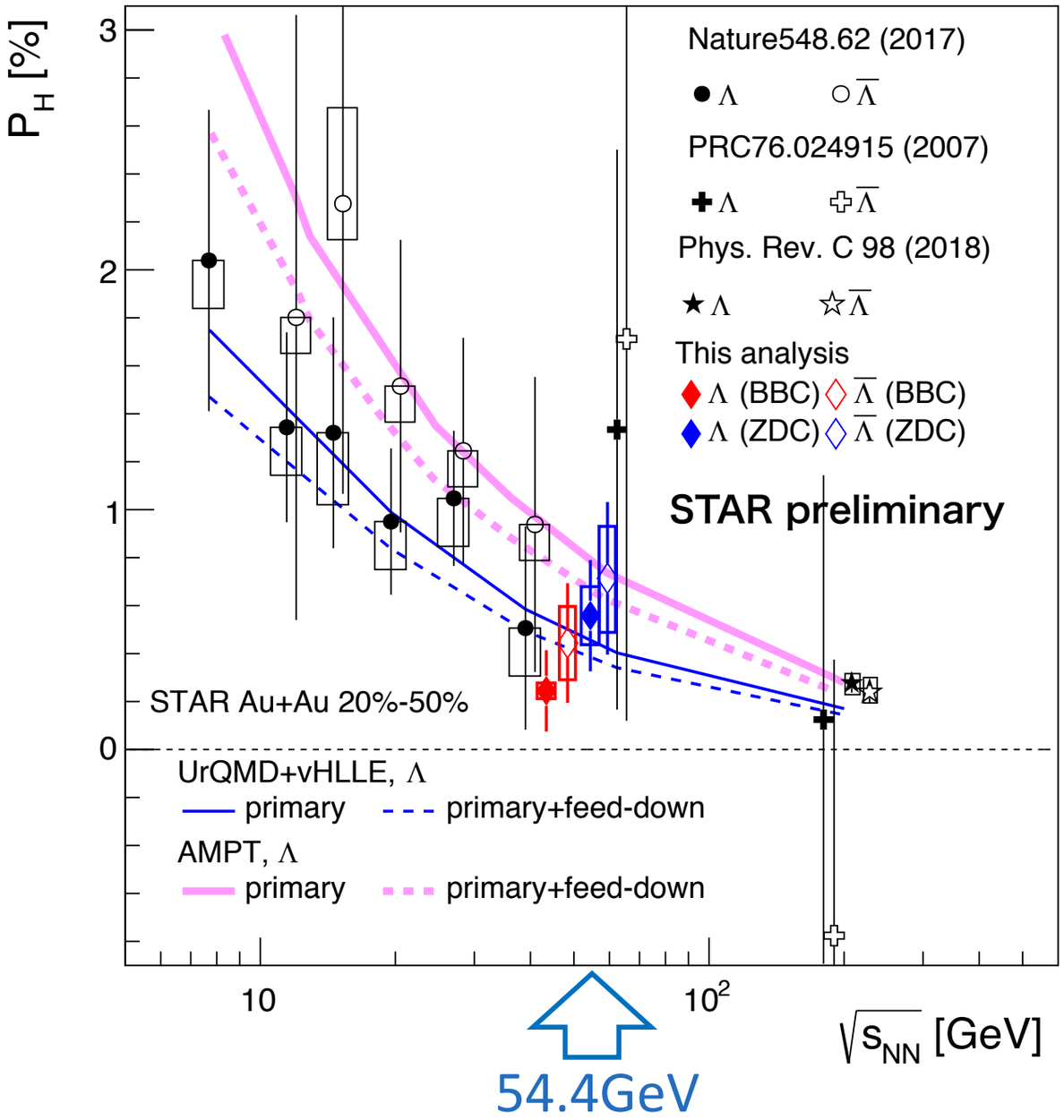
$$Res_A = Res_B = \sqrt{\langle \cos(\Psi_A - \Psi_B) \rangle}$$

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.

Collision energy dependence of P_H

✦We observed positive $\Lambda(\overline{\Lambda})$ global polarization!



$$P_H^{BBC}(\Lambda)[\%] = 0.245 \pm 0.170(\text{stat}) \pm^{0.033}_{0.033} (\text{sys})$$

$$P_H^{BBC}(\overline{\Lambda})[\%] = 0.444 \pm 0.250(\text{stat}) \pm^{0.152}_{0.153} (\text{sys})$$

$$P_H^{ZDC}(\Lambda)[\%] = 0.558 \pm 0.232(\text{stat}) \pm^{0.121}_{0.121} (\text{sys})$$

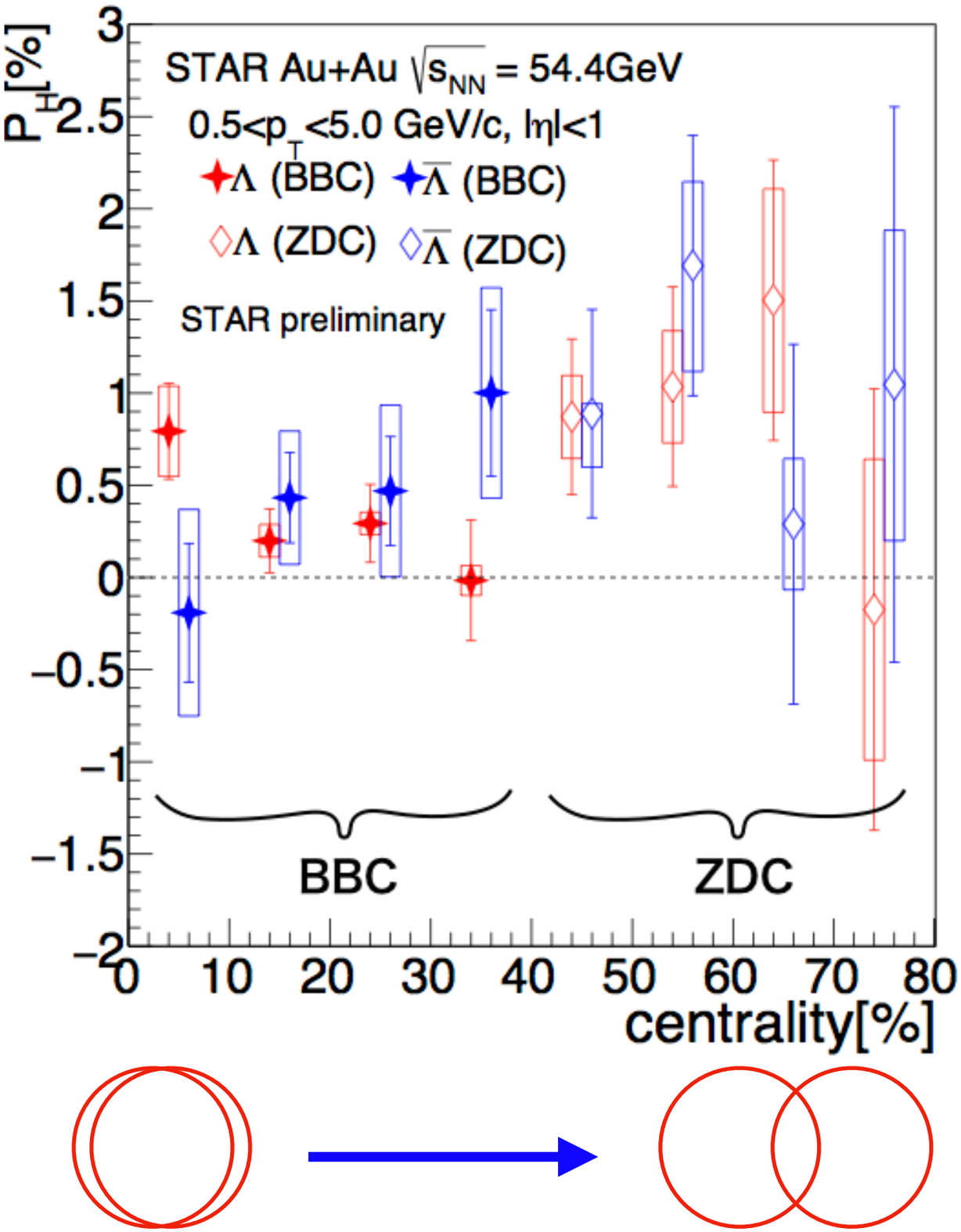
$$P_H^{ZDC}(\overline{\Lambda})[\%] = 0.714 \pm 0.318(\text{stat}) \pm^{0.217}_{0.225} (\text{sys})$$

- The result follows global trend of the energy dependence and agree with UrQMD model and AMPT model calculation within uncertainties.
- There is no significant difference between Λ and $\overline{\Lambda}$.
- The results obtained from ZDC is slightly higher than those from BBC.

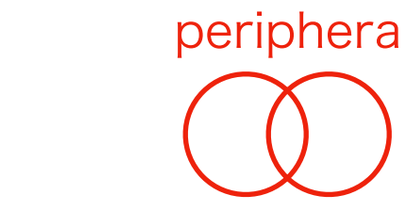
UrQMD : I.Karpenko and F.Becattini,EPJC(2017)77:213

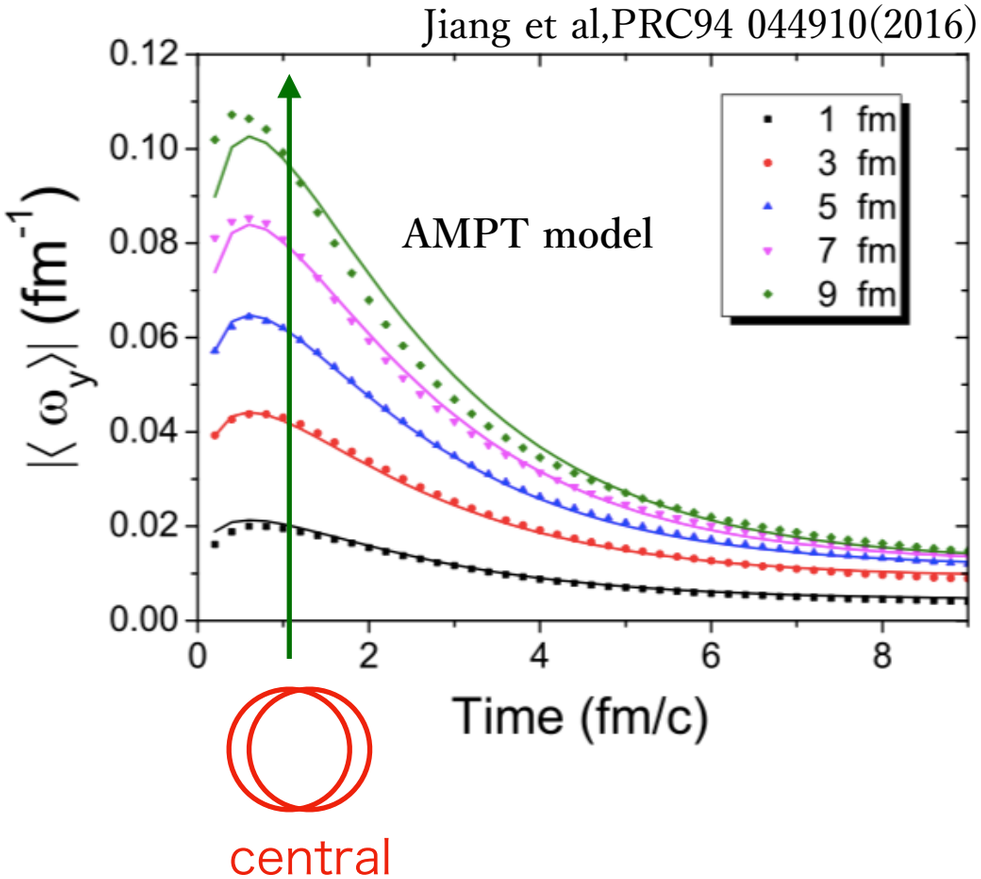
AMPT : H.Li et al.,Phys.Rev.C96,054908(2017)

Centrality dependence of P_H

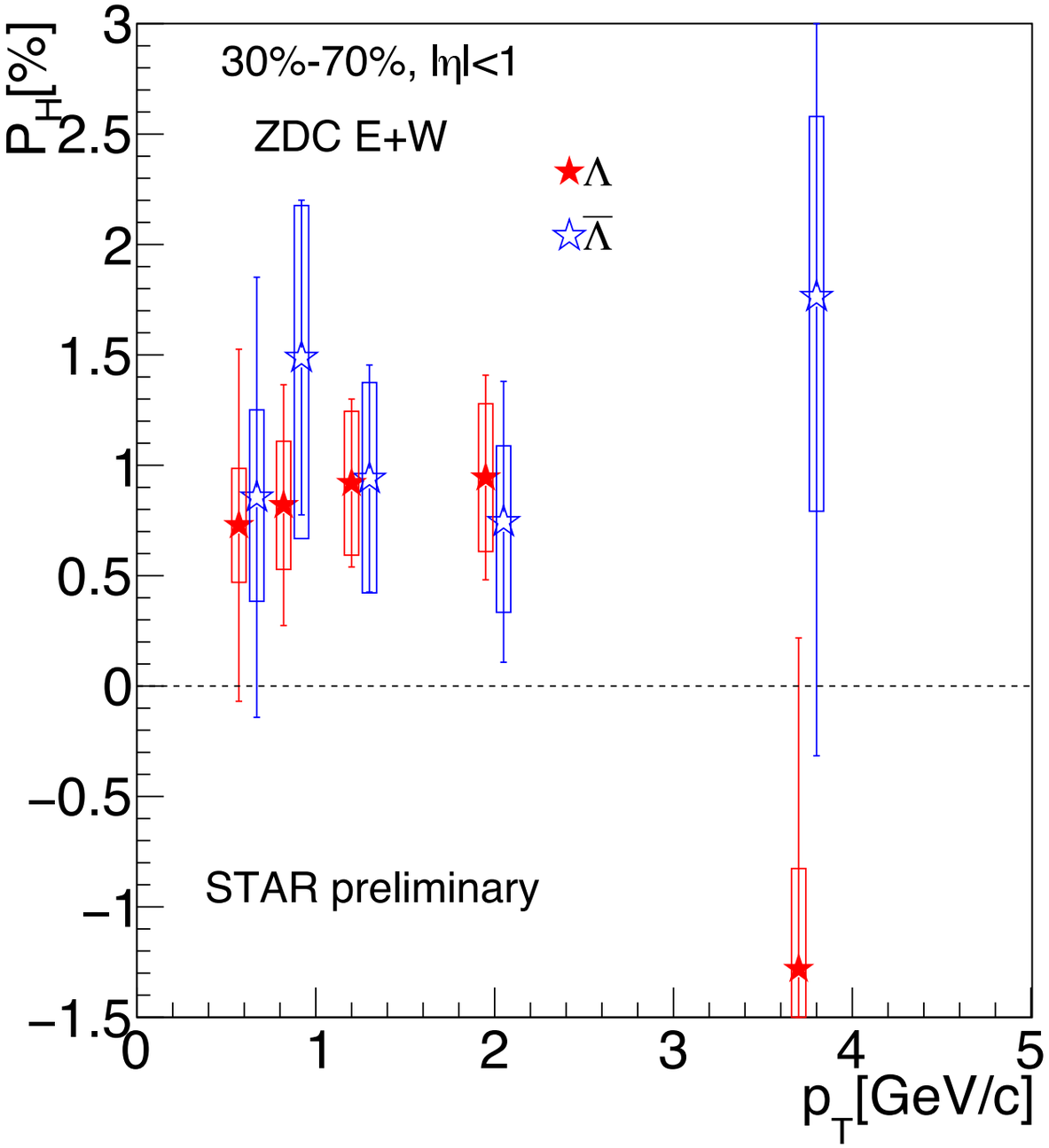


- We used BBC and ZDC based on event plane resolution.
- Polarization may increase in more peripheral collision.





p_T dependence of P_H



- One might expected...

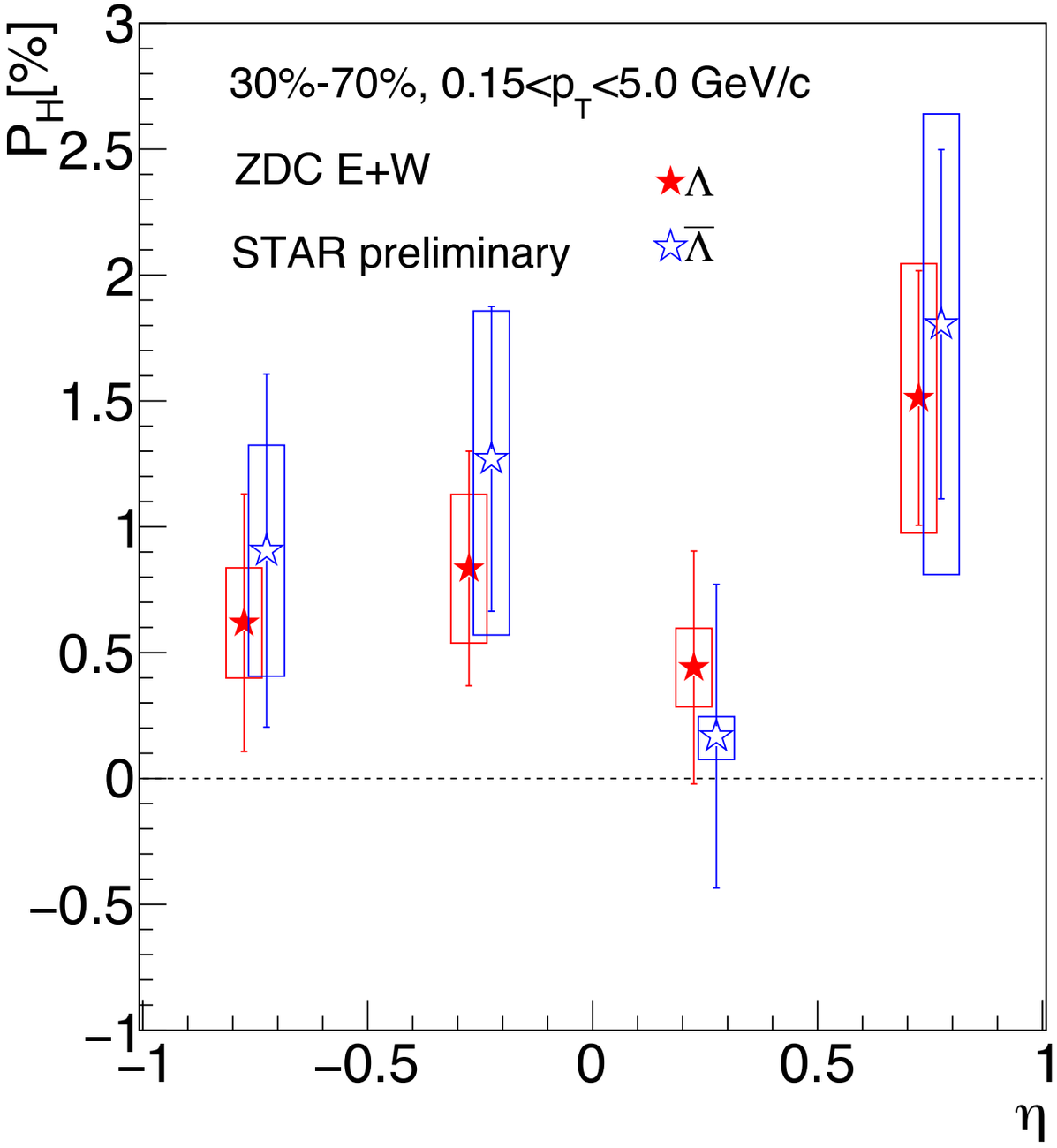
  - decrease at low p_T due to smearing effect caused by scattering at the later stage of the collisions.

  - decrease at high p_T due to jet fragmentation.

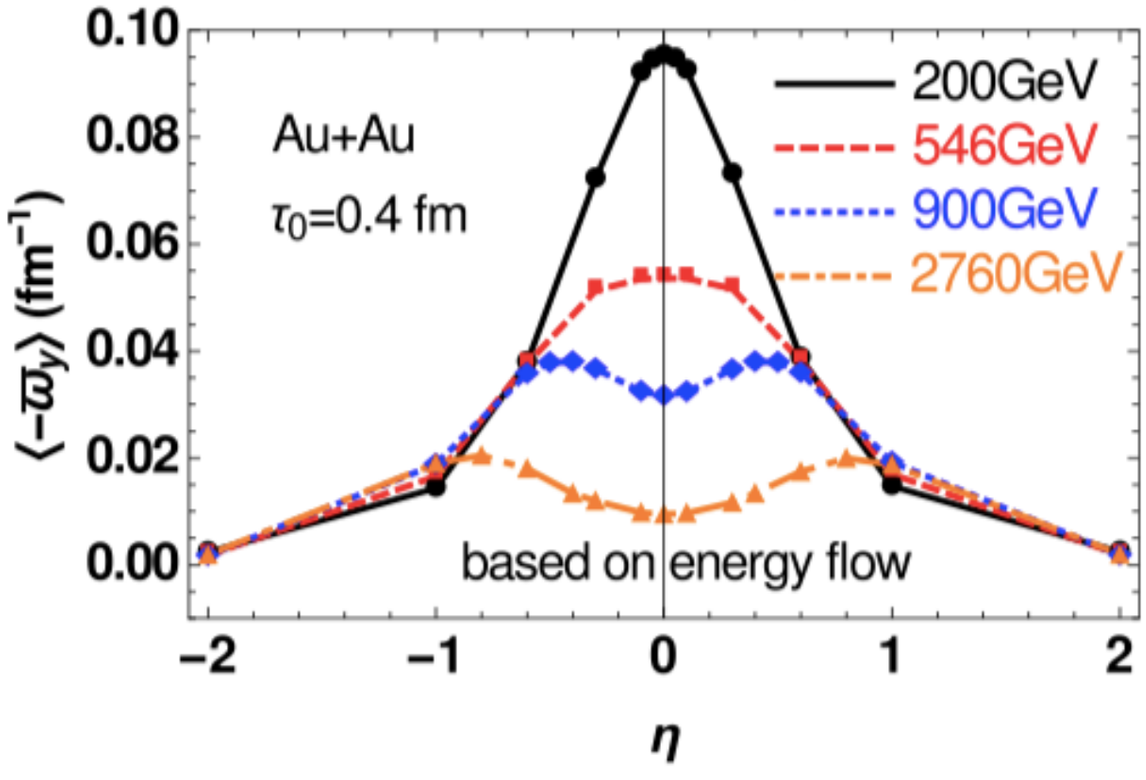
J.Adam, et al,PRC98 14910(2018)

- **No significant p_T dependence.**

η dependence of P_H



W.-T.Deng and X.-G Huang:C93,064907



- The vorticity is expected decrease at large rapidity.

  ➡P_H is also expected depending on rapidity.

- **The result does not show significant η dependence.**

Summary

✦**We presented first measurement of Λ global polarization in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV.**

- Positive polarization is observed.

- The result agree with model calculations and follows global trend of the energy dependence.

- No significant difference between Λ and $\overline{\Lambda}$.

- There are no observable η and p_T dependence.

Back up

Data set

Data set

- Au+Au $\sqrt{s_{NN}}$ = 54.4 GeV
- Run 17 minimum bias
- Trigger ID : 580021
- Events ~ 570M(after event cut)

Event select

- $|V_z| < 40\ cm$
- $|V_r| < 2\ cm$
- $|V_z - V_z^{vpd}| < 3\ cm$

Track cut

- $|\eta| < 1$
- $0.15 < p_T < 5$ GeV/c
- **nHitsFit > 15**
- **nHitsFit/nHitsPoss > 0.52**

Systematic uncertainty

✦Estimate systematic uncertainty

- Methods of the signal extraction : ~12%
- Background P_H assumption in the invariant mass method : ~20%
- Uncertainty from the decay parameter : ~2.0% for Λ, ~9.6% for anti-Λ

✔Also, the following studies were done to check if there is no experimental effect

- Different time period during the data taking
- Cumulant effect

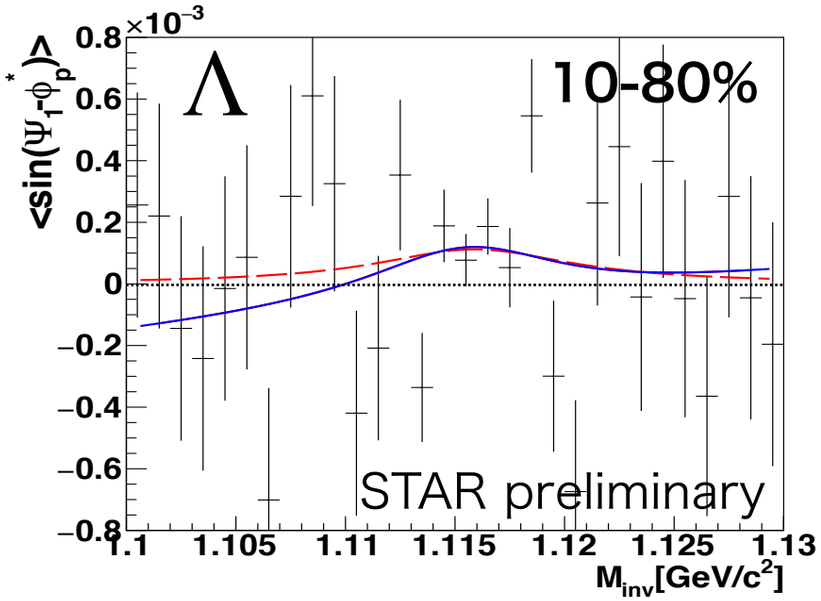
Extract the signal

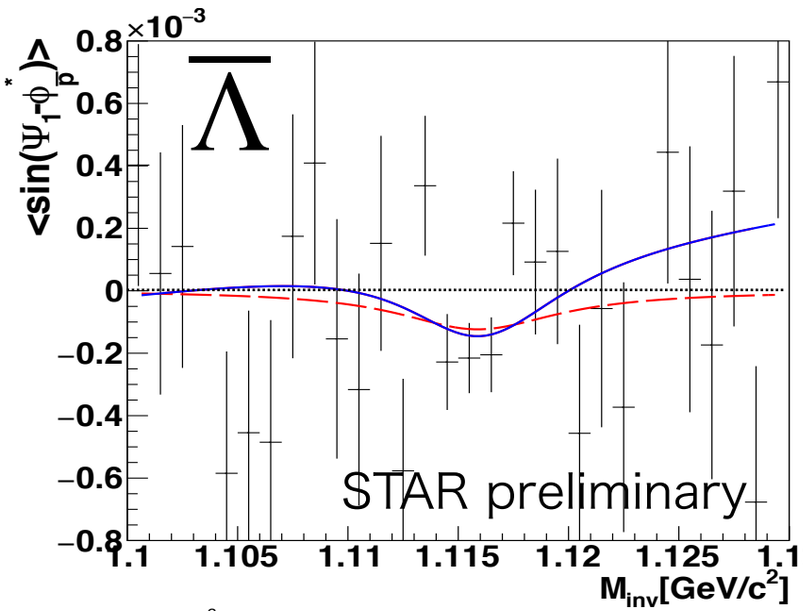
✦Invariant mass method

- The data was fitted with the following equation

$$\langle \sin(\Delta\phi)\rangle^{\mathrm{obs}} = (1 - f^{\mathrm{Bg}}(M_{inv}))\langle \sin(\Delta\phi)\rangle^{\mathrm{Sg}} + f^{\mathrm{Bg}}(M_{inv})\langle \sin(\Delta\phi)\rangle^{\mathrm{Bg}}$$

$$\begin{cases} \Delta\phi = \Psi_1 - \phi_p^* \\ f^{Bg}(M_{inv}) = f(M_{inv}^{Bg})/f(M_{inv}^{obs}) \end{cases}$$





$\langle \sin(\Delta\phi)\rangle^{Bg}$=0

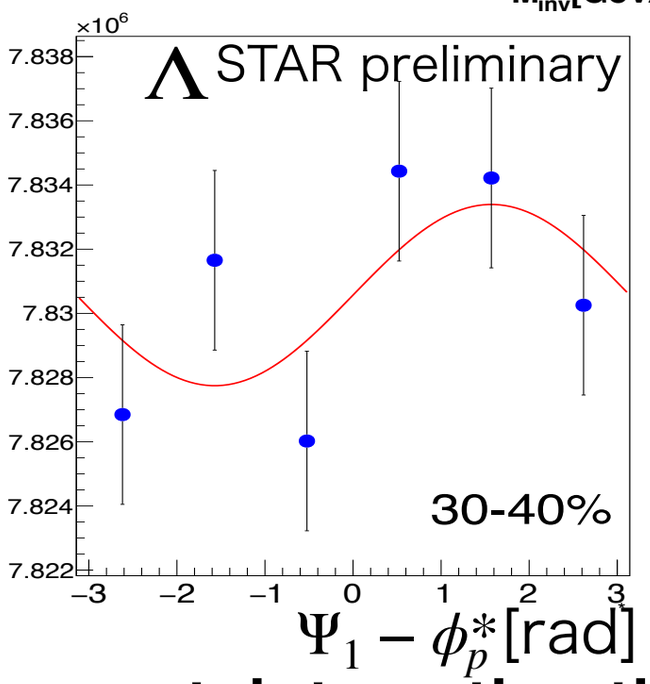
$\langle \sin(\Delta\phi)\rangle^{Bg} = \alpha M_{inv} + \beta$

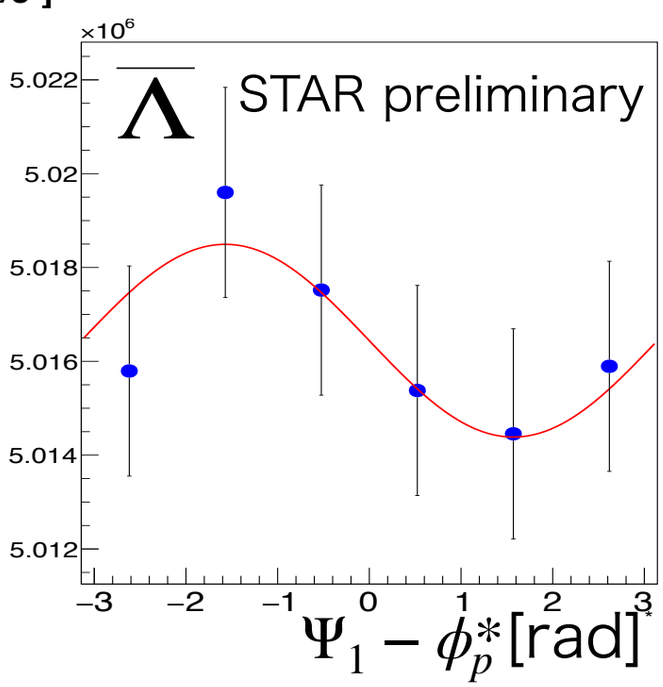
✦Event Plane method

- Fitting with a sine function

$$p_0(1 + 2p_1 \sin(\Psi_1 - \phi_p^*))$$

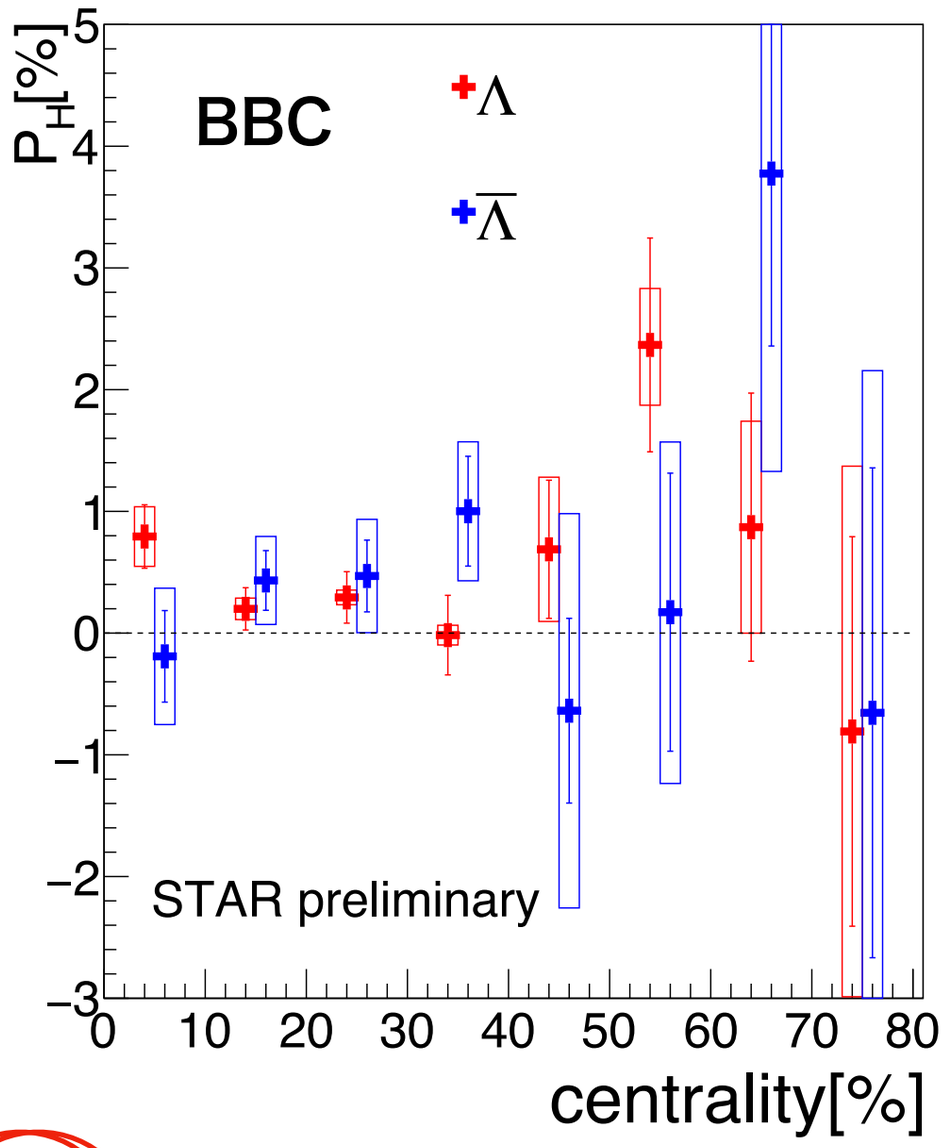
✓ The difference between two Methods was considered in the systematic uncertainty

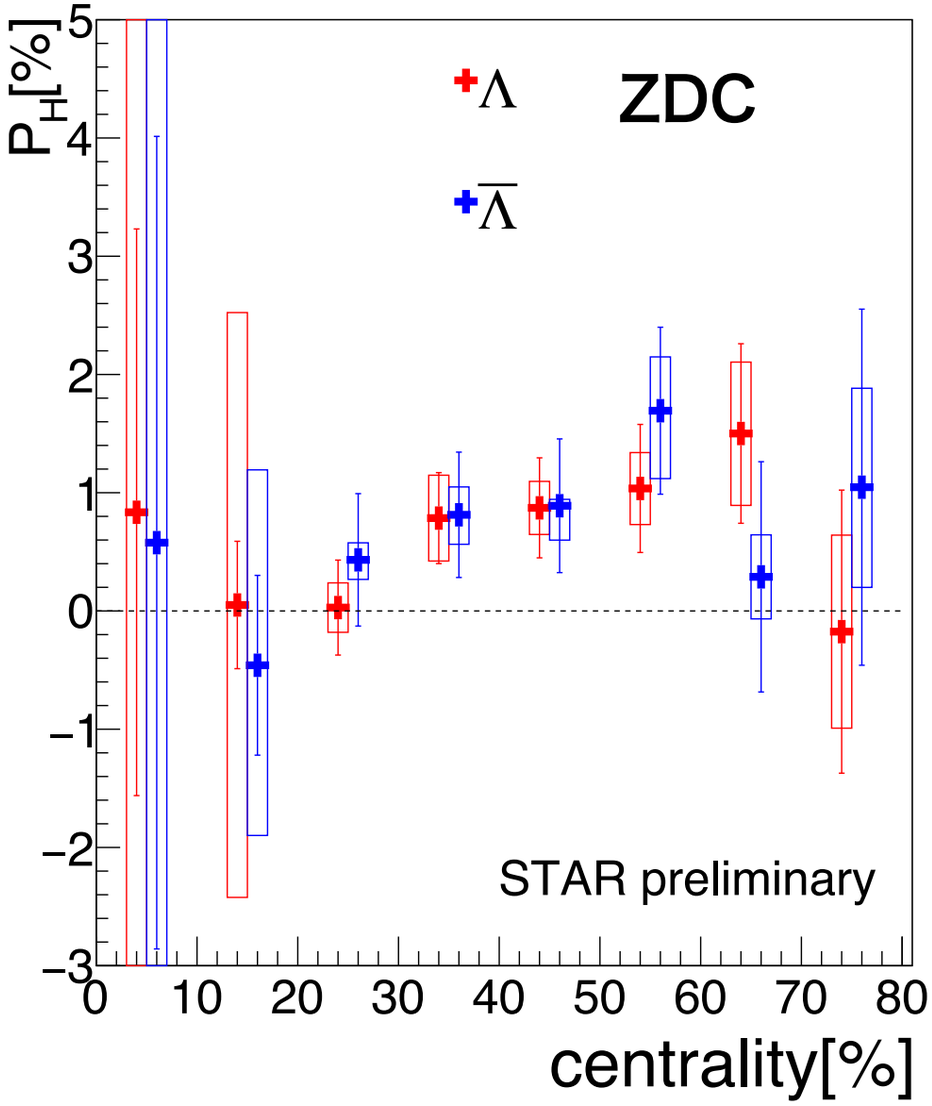


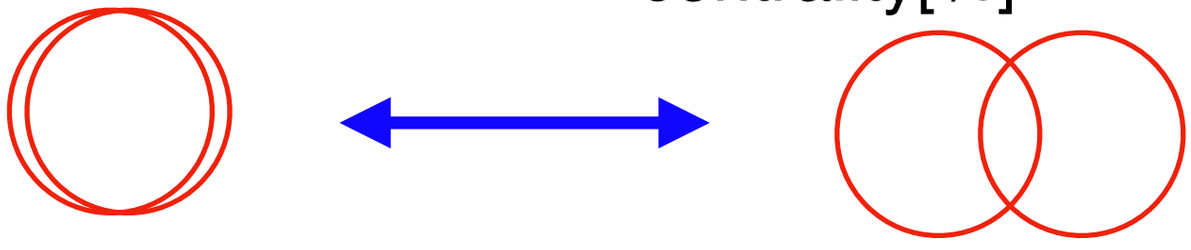


★Tow methods was considered in uncertainty estimation.

Centrality dependence of P_H

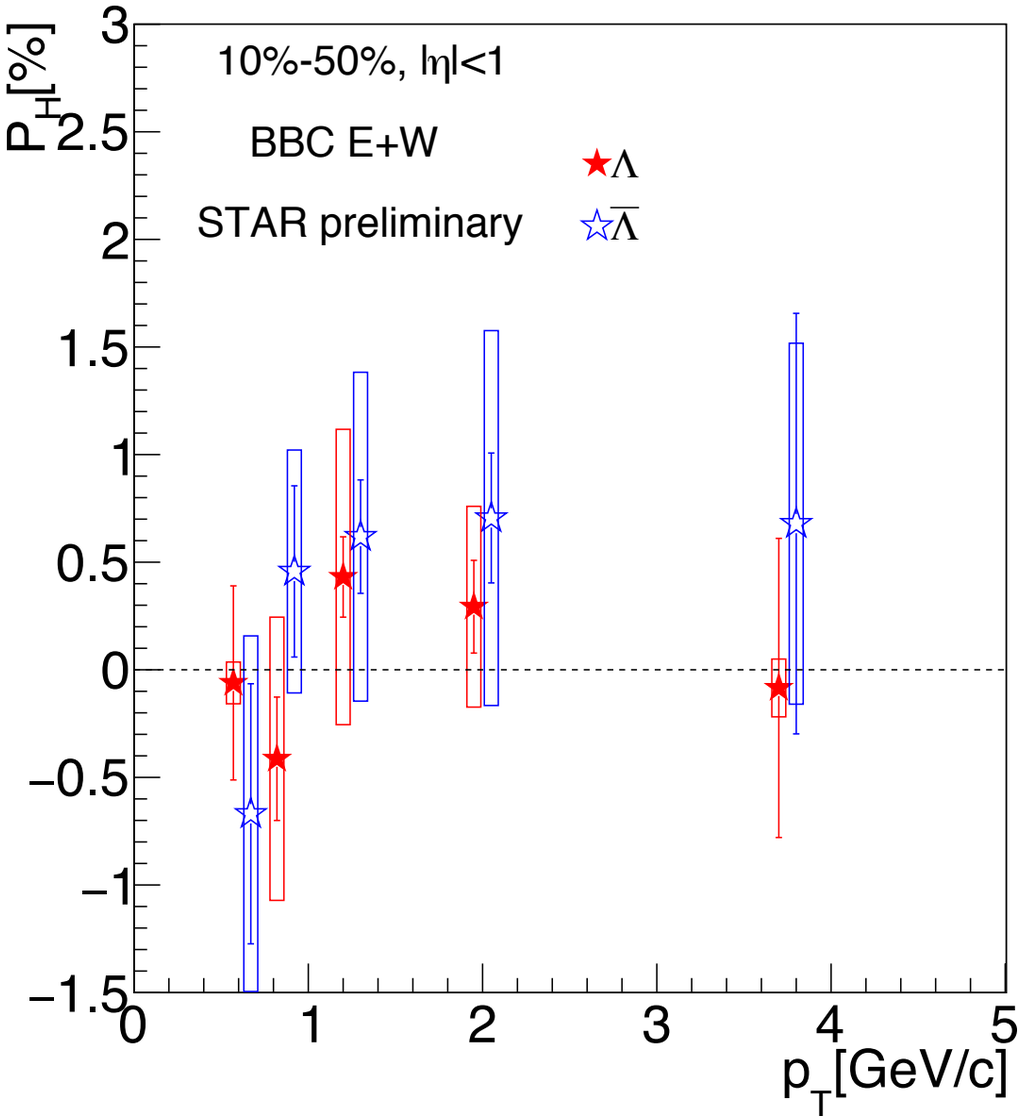


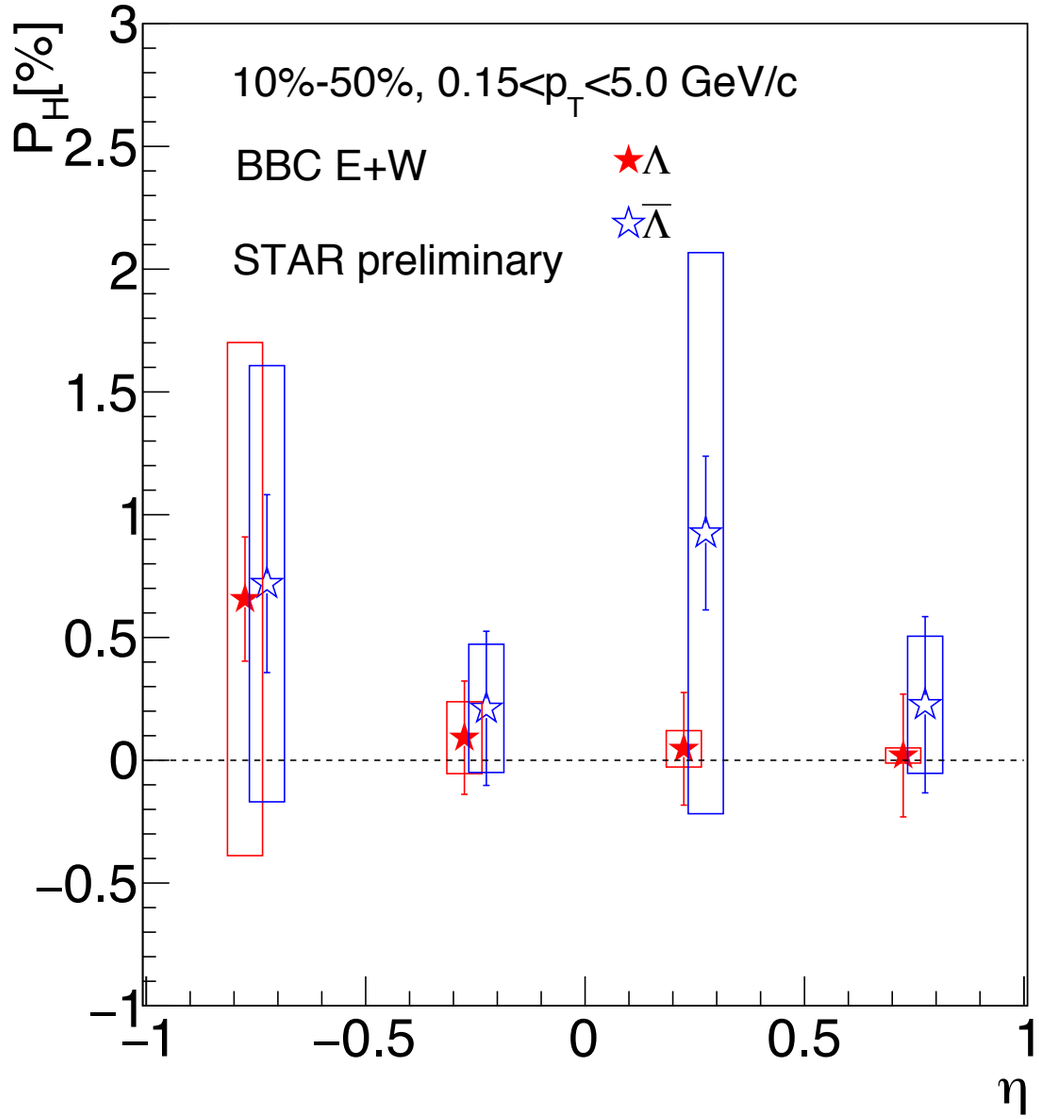




- Polarization might increase from central to peripheral collision.

p_T and η dependence of P_H using BBC

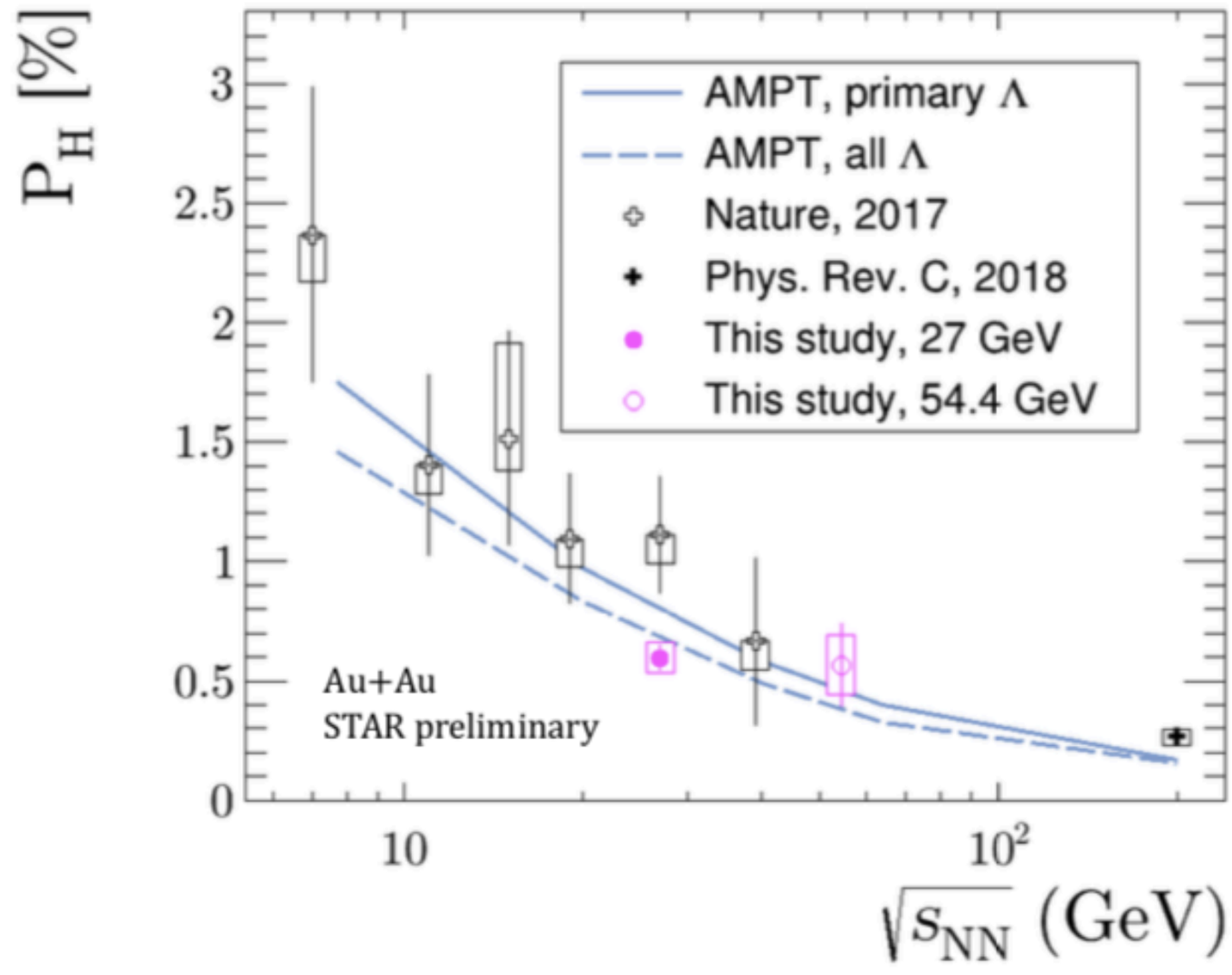




- We observed no dependence on p_T and η.

$\sqrt{s_{NN}}$ dependence of P_H

- AMPT shows decrease in P_H with increasing $\sqrt{s_{NN}}$ (1)
- Previous studies across broad range of $\sqrt{s_{NN}}$ suggest this trend (2)
- These studies agree with this trend
- Recent high-statistics run at 19 GeV, 14.5, and 3 GeV will be useful



[1] Y. Jiang, et. al., Phys. Rev., vol. C94, no. 4, p. 044910, 2016

[2] STAR, Nature 548 (2017) 62548

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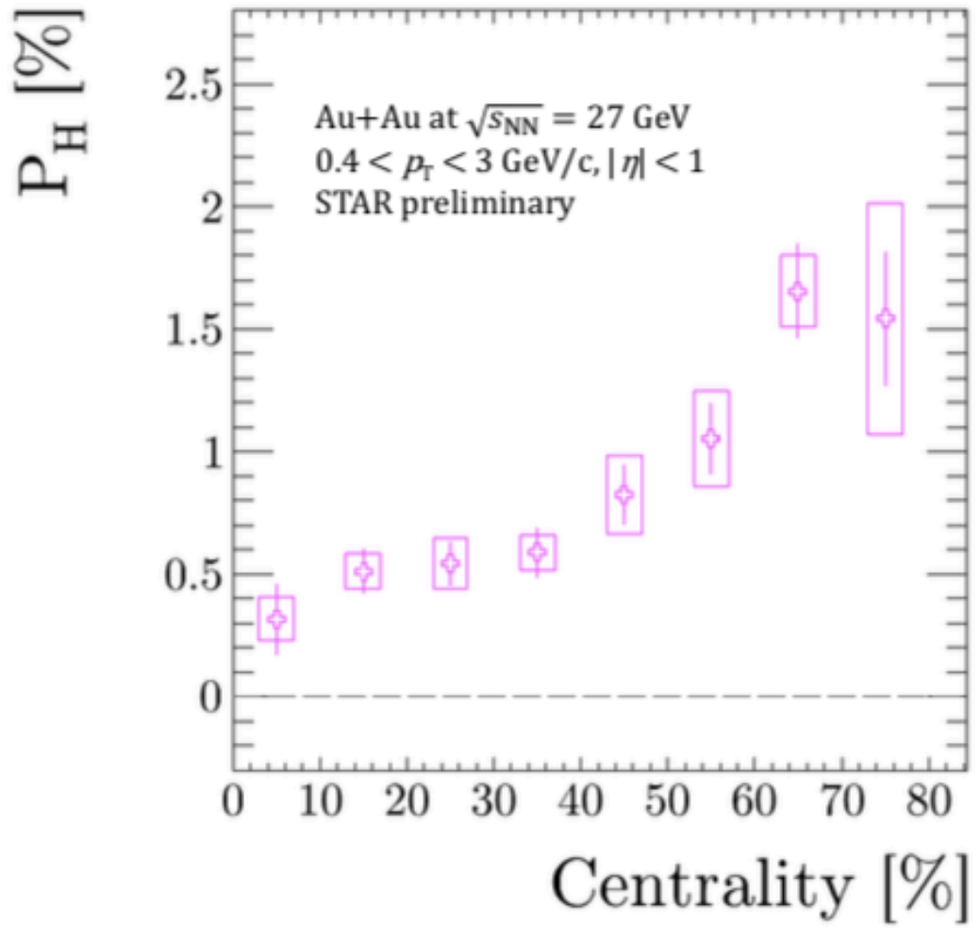
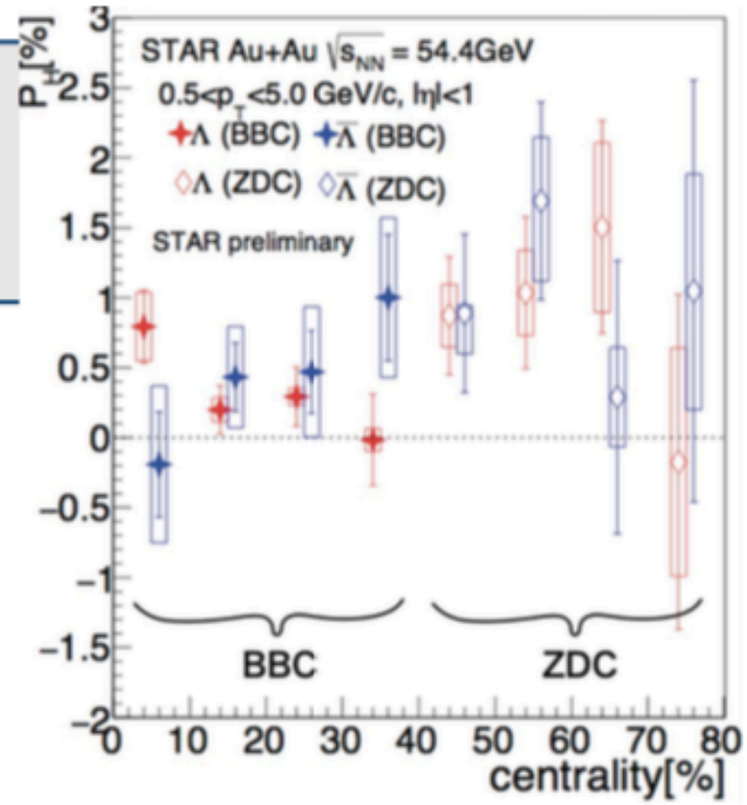
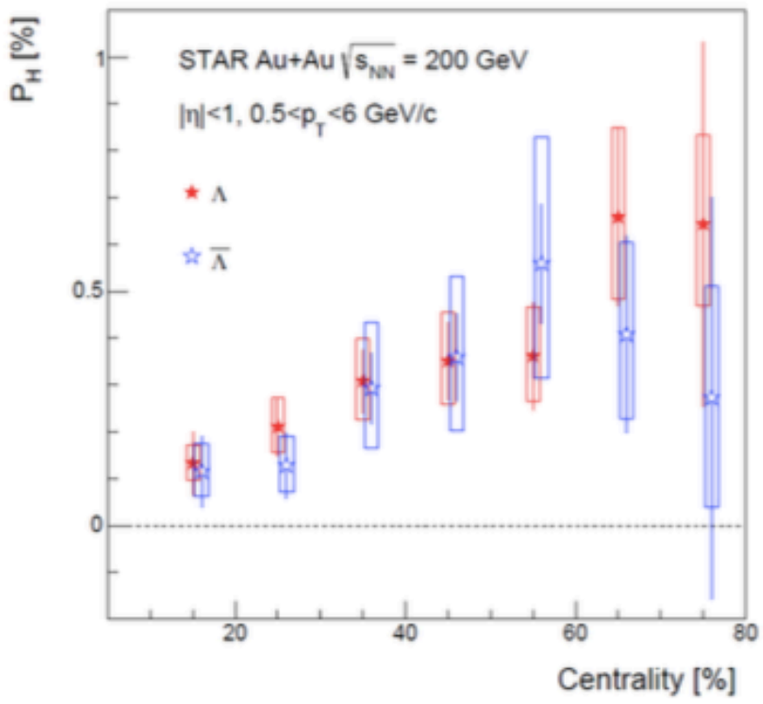
Centrality dependence of P_H

- We observe P_H increasing with centrality
  - 54 GeV study uses BBC and ZDC based on $R_{\mathrm{EP}}^{(1)}(centrality)$
- This trend previously suggested by study at 200 GeV (1)







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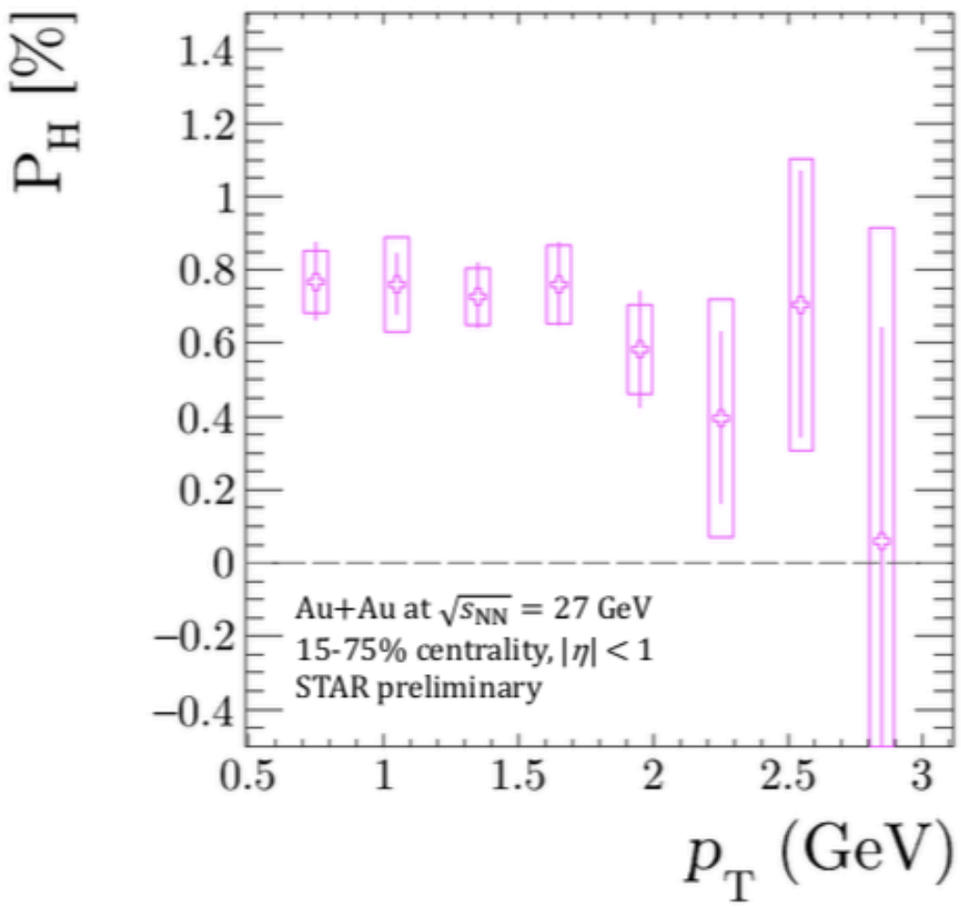
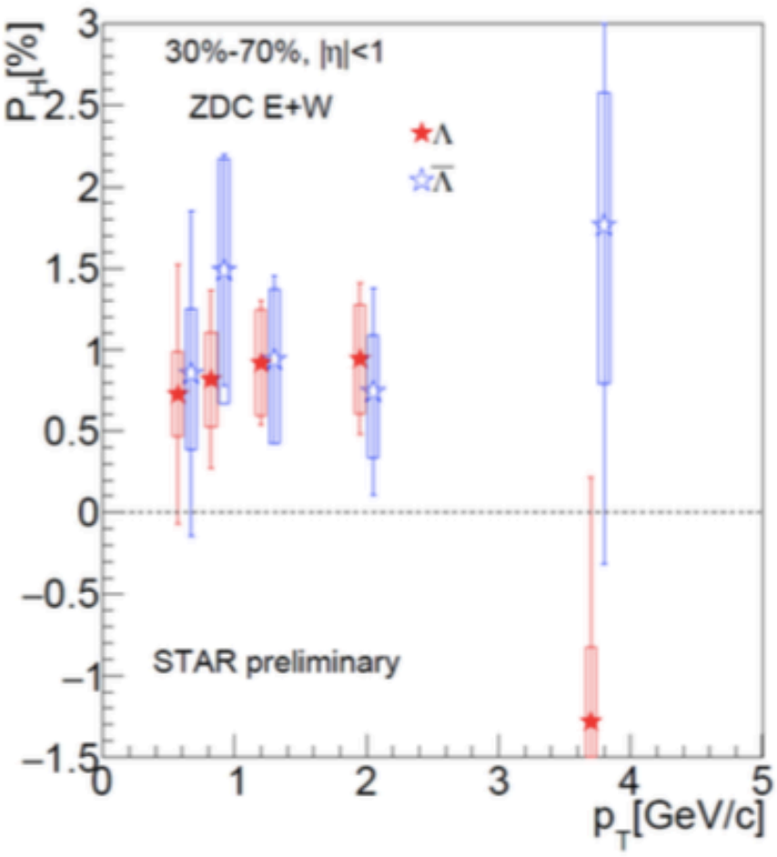
p_T dependence of P_H

- We see no dependence on p_T at 27 or 54.4 GeV
  - Enough statistics to say P_H flat in range $0.5 < p_T < 1.75$ GeV
- If P_H drops at low p_T due to scattering or high p_T due to jet fragmentation, it must be outside this p_T range





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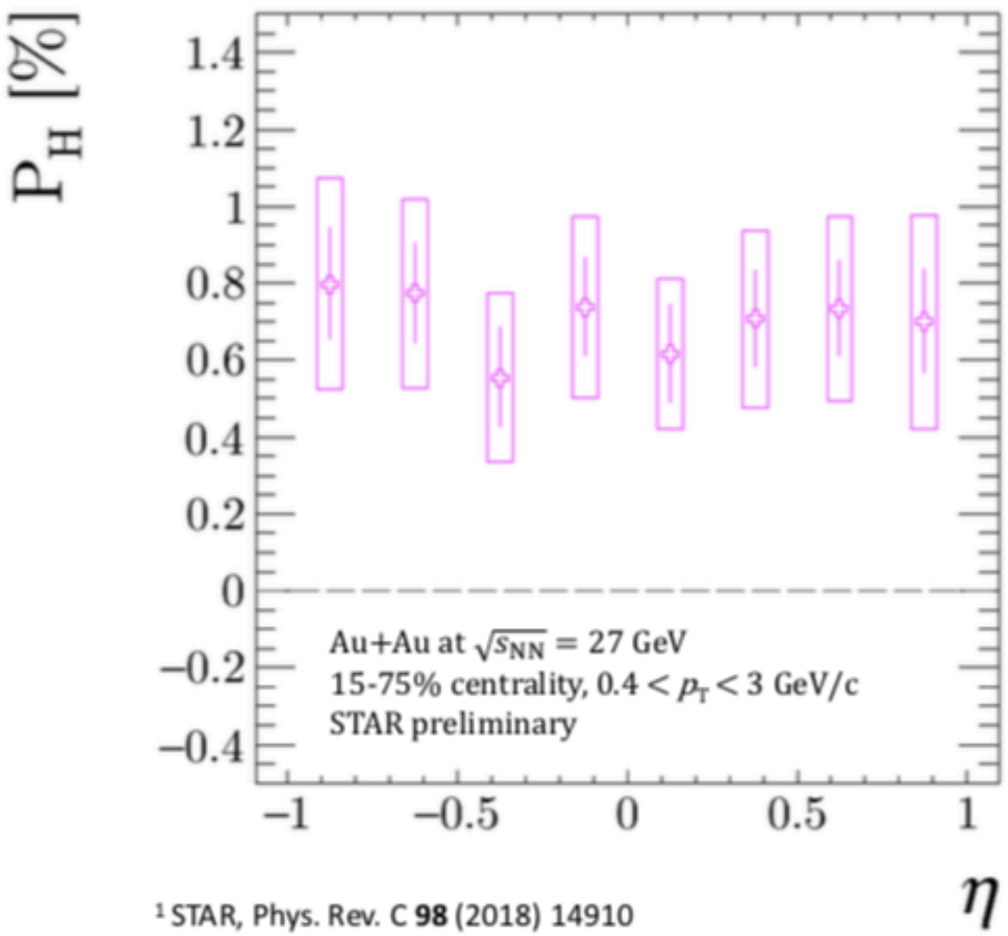
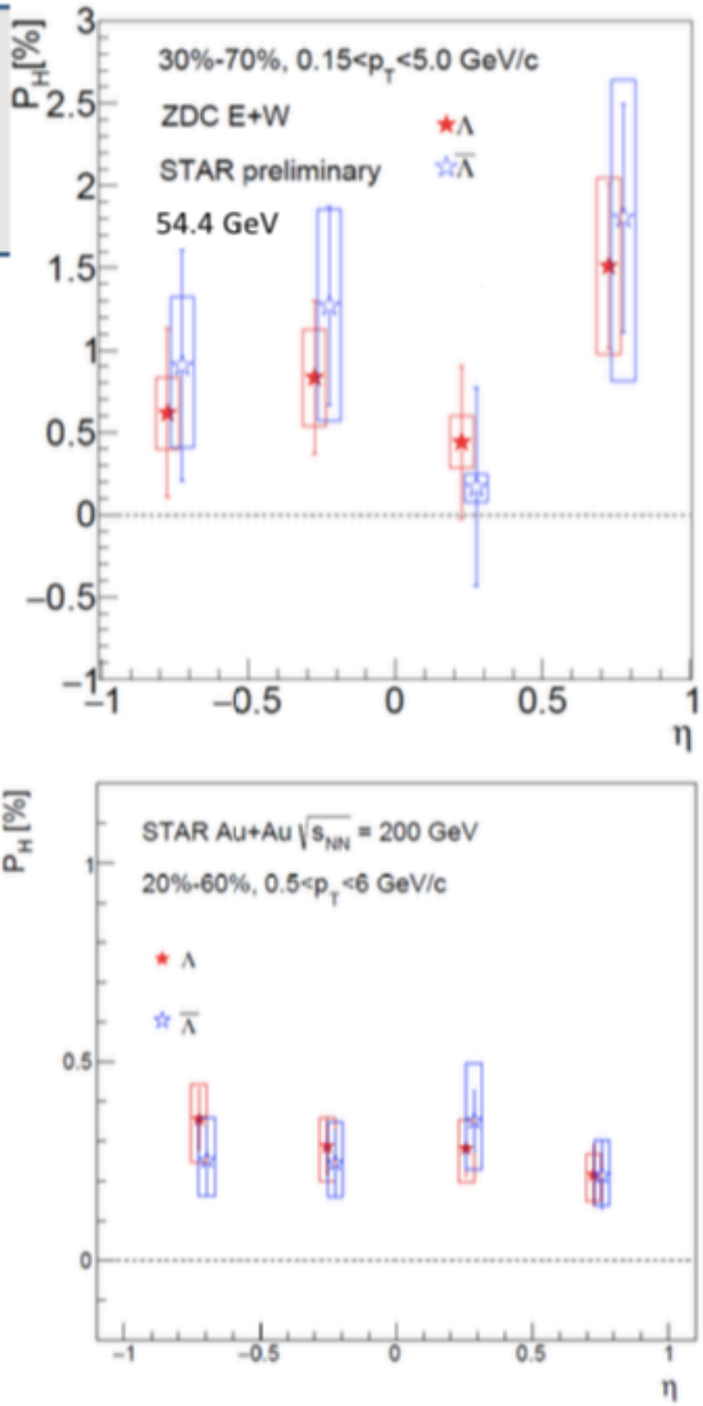
η dependence of P_H

- We see no dependence on η with our statistics and acceptance
  - Consistent with study at 200 GeV [1]





[1] STAR, Phys. Rev. C **98** (2018) 14910

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