Global polarization of Λ hyperons in Au+Au collision at $\sqrt{s_{NN}}$ = 54.4 GeV with STAR

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JPS meeting @Yamagata
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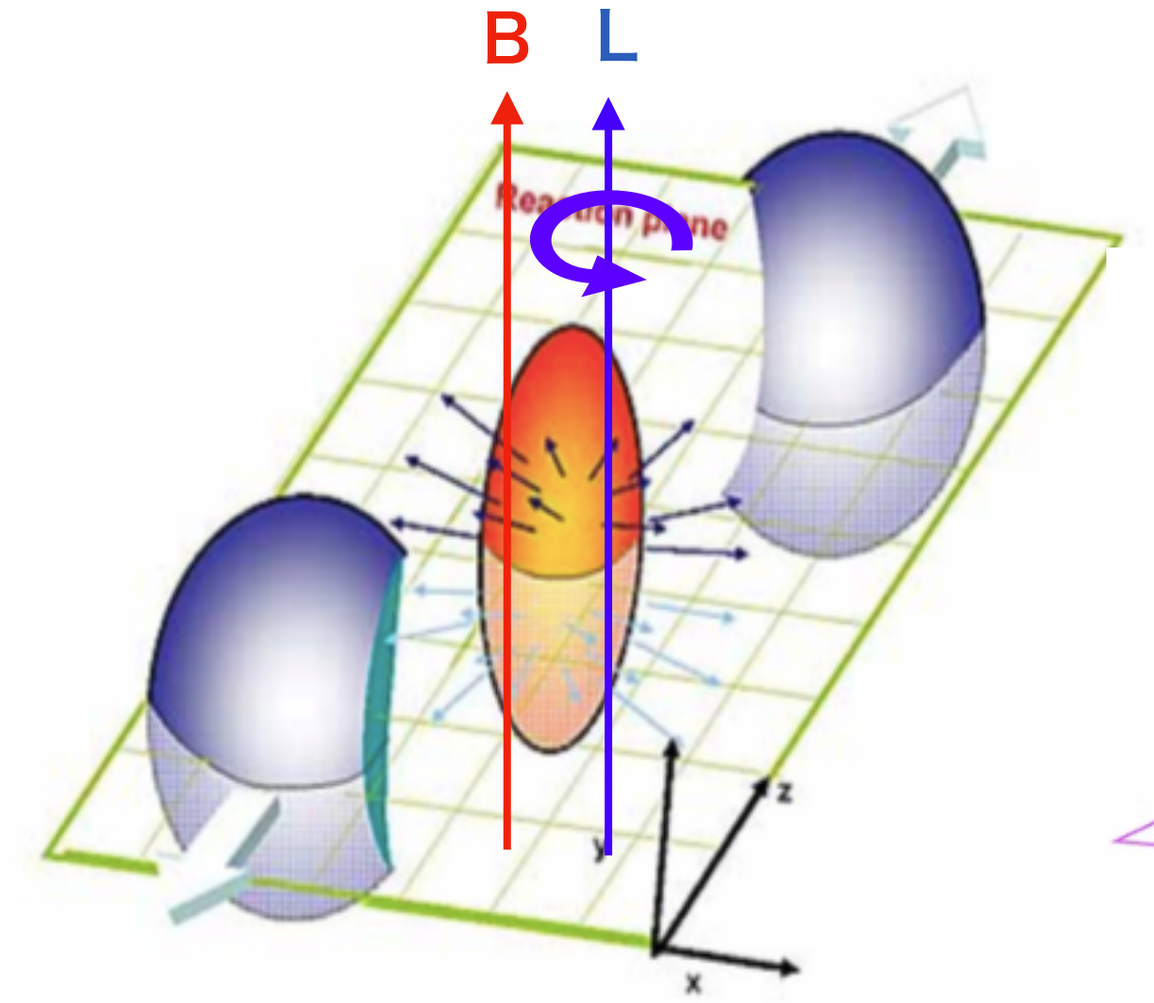
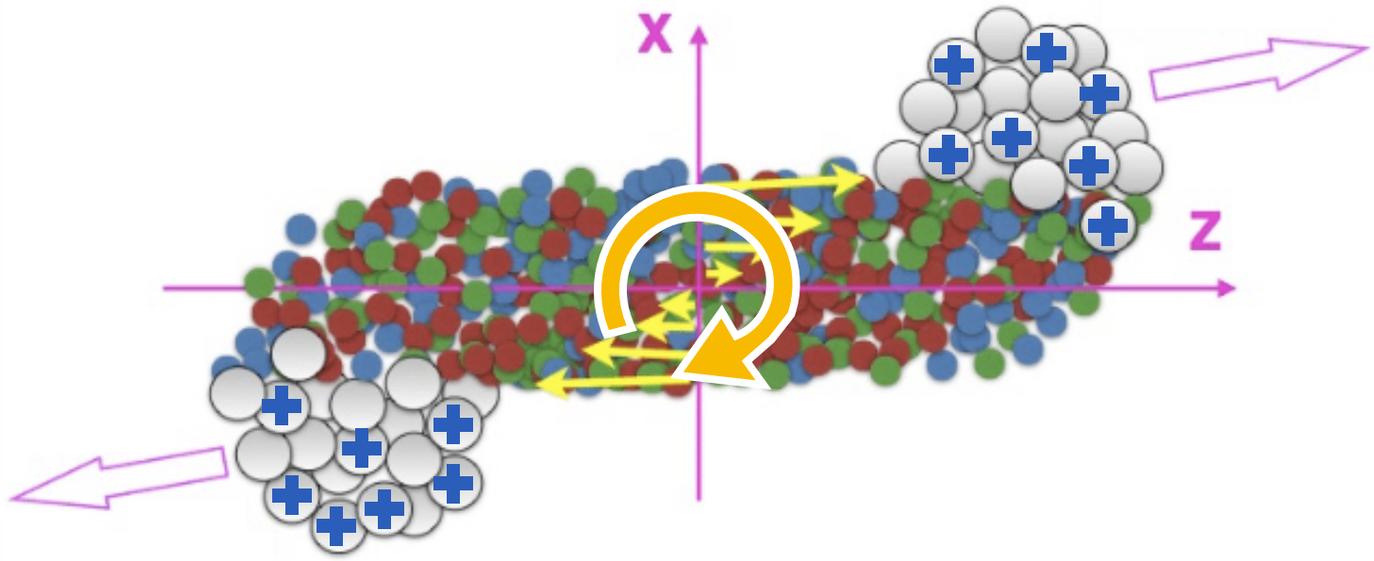
Introduction

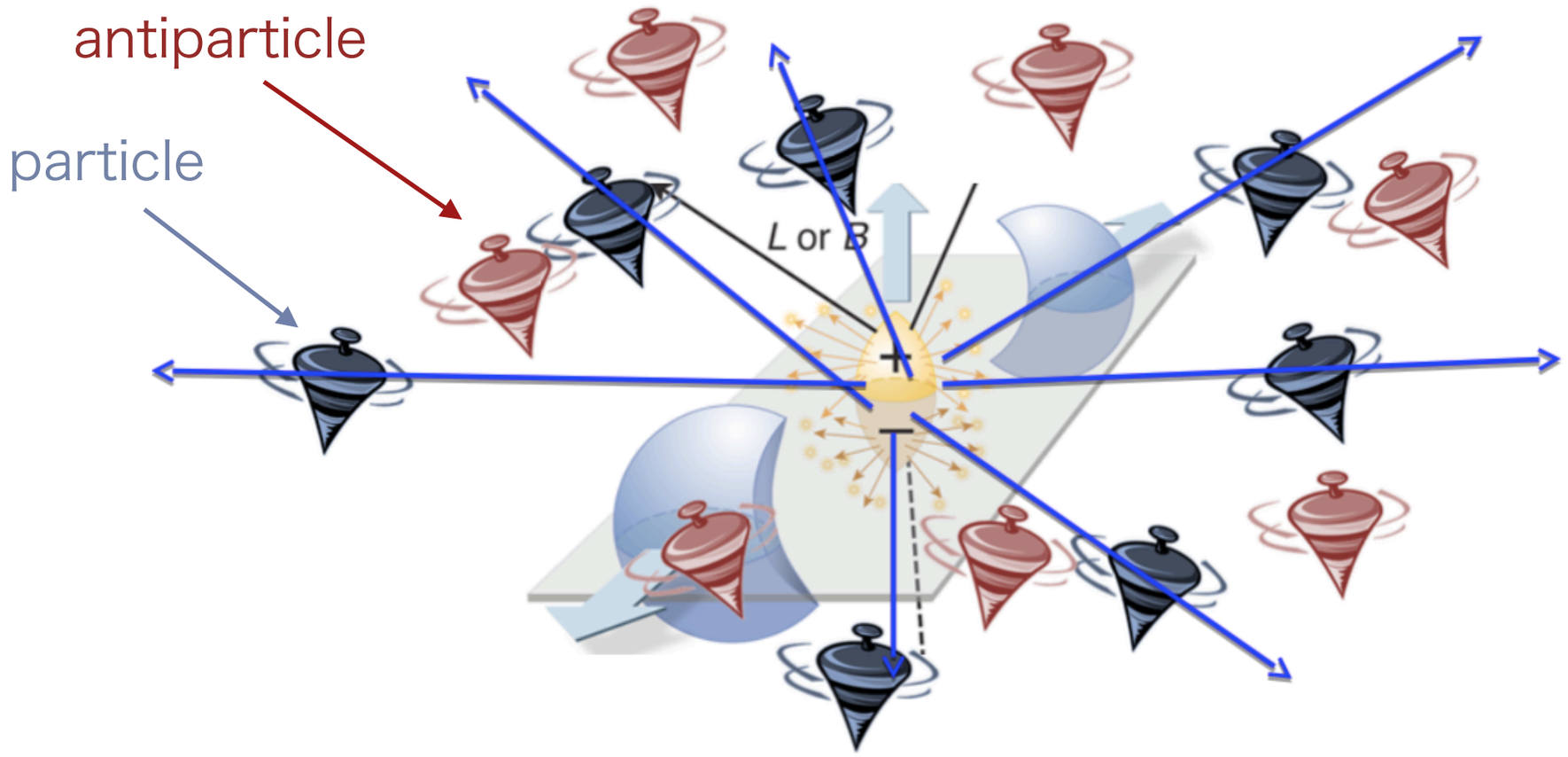


$\vec{B}$ ⊗ $\vec{L}$ ⊗



- 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.

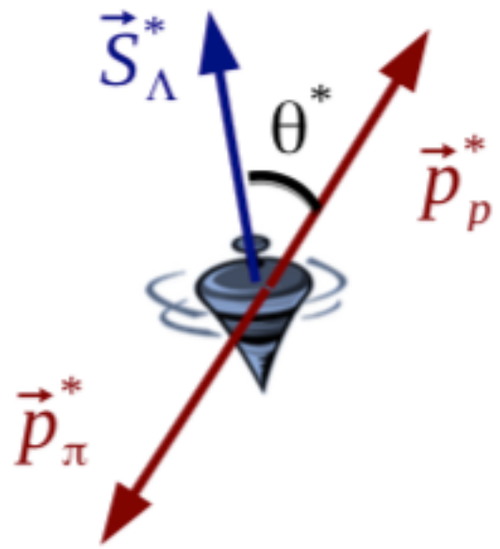
✔**Both may contribute**

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).

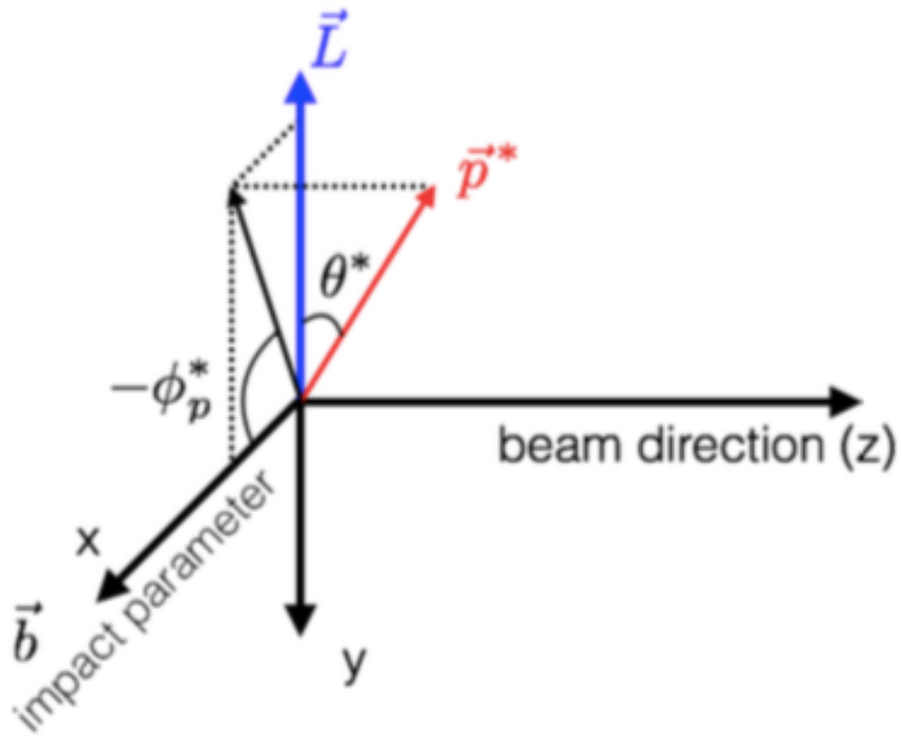
-STAR, PRC76, 024915(2007)

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

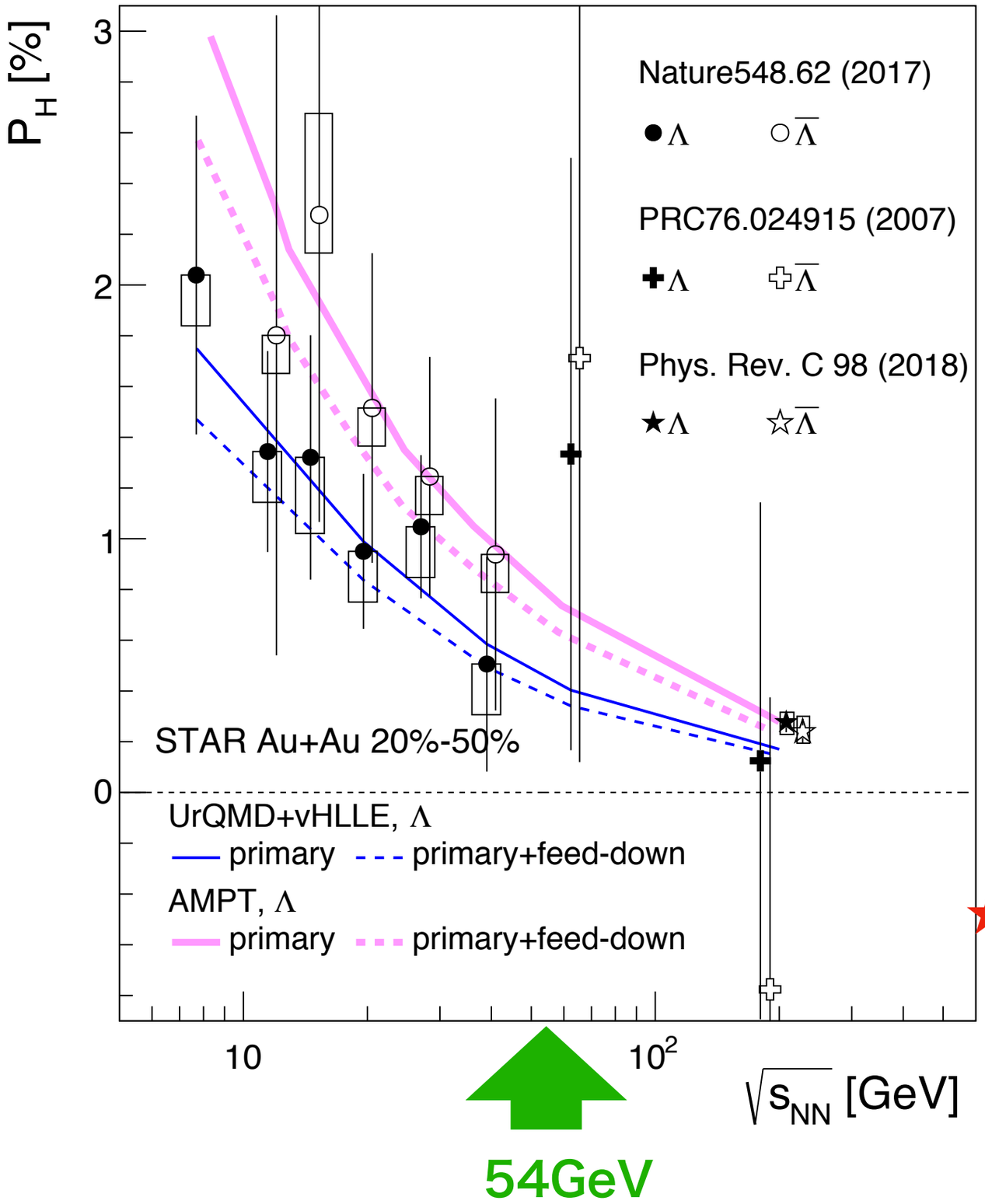
α_H : decay parameter

Ψ_1 : 1st-order event plane

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



Motivation



✓Positive signal at low collision energy.

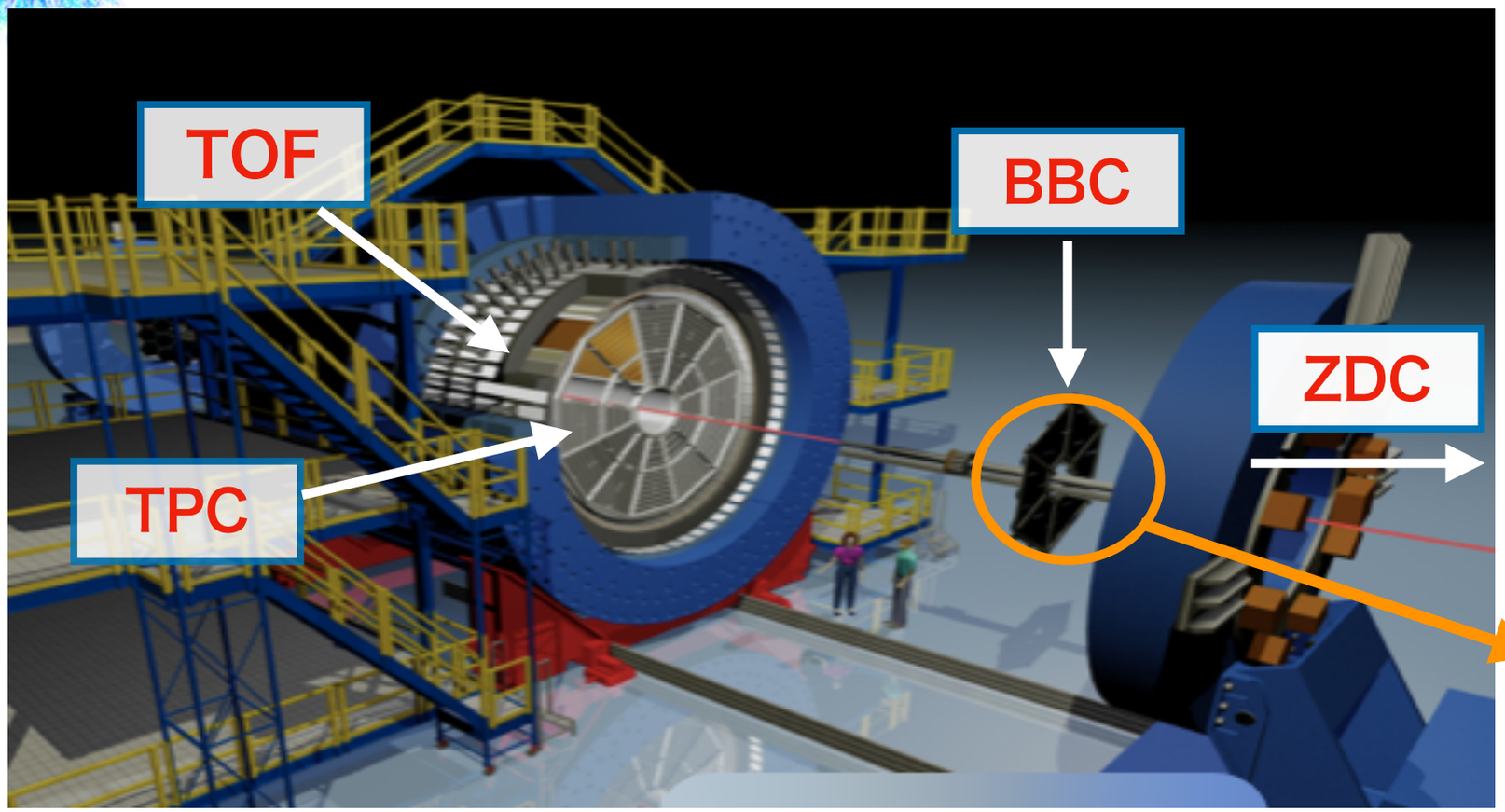
✓No significant difference between Λ and anti-Λ

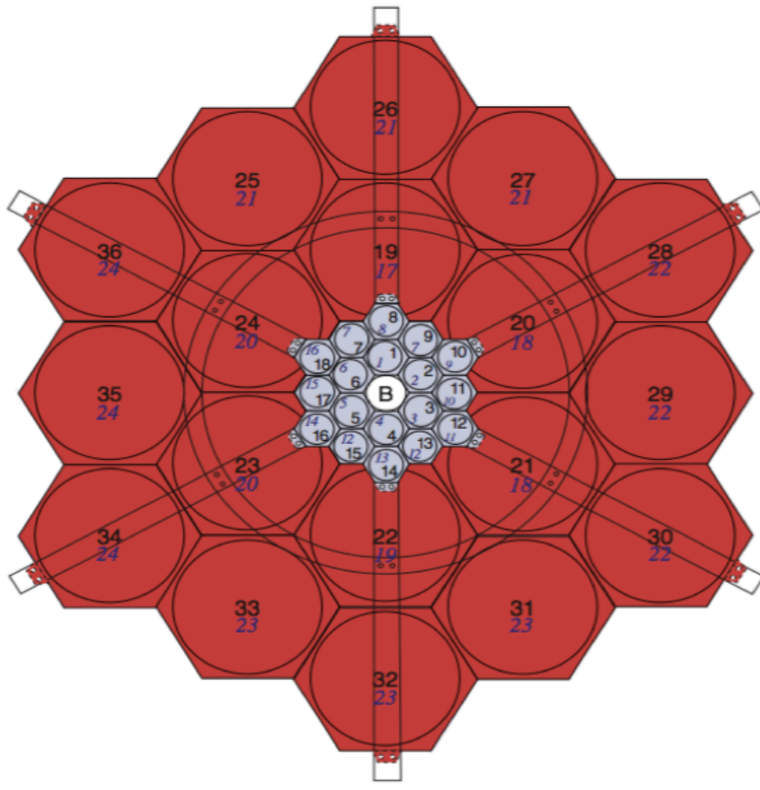
✓At lower energy, uncertainties are large...

We measured global polarization with 54GeV 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.

The STAR detector





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

✓ Beam-Beam Counters (BBC)

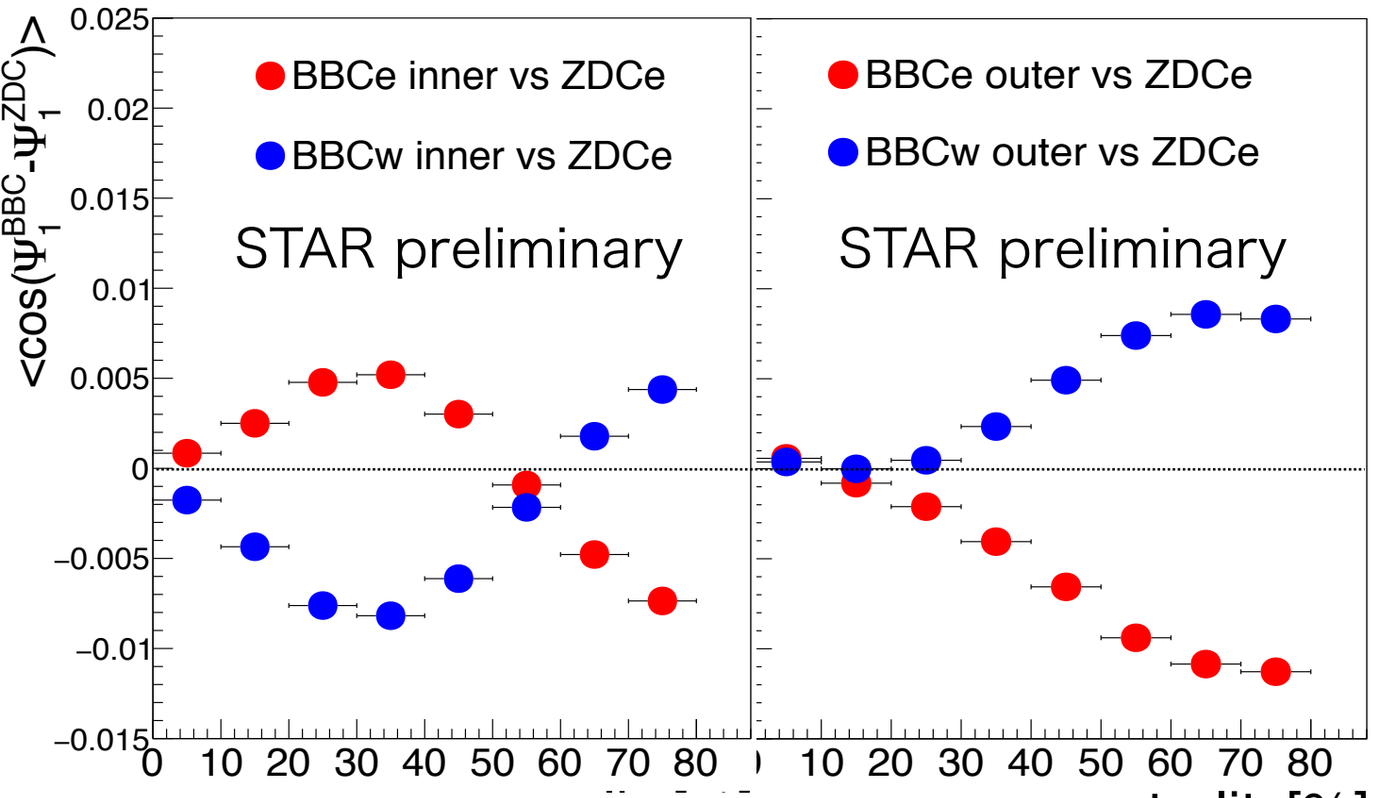
- Event plane reconstruction , $3.3<|\eta|<5.0$ ($|y_{beam}| \sim 4.0$)

✓ Zero Degree Calorimeters (ZDC)

- Event plane reconstruction using spectator neutrons, $|\eta|>6.3$

EP correlation and resolution

✦EP Correlation



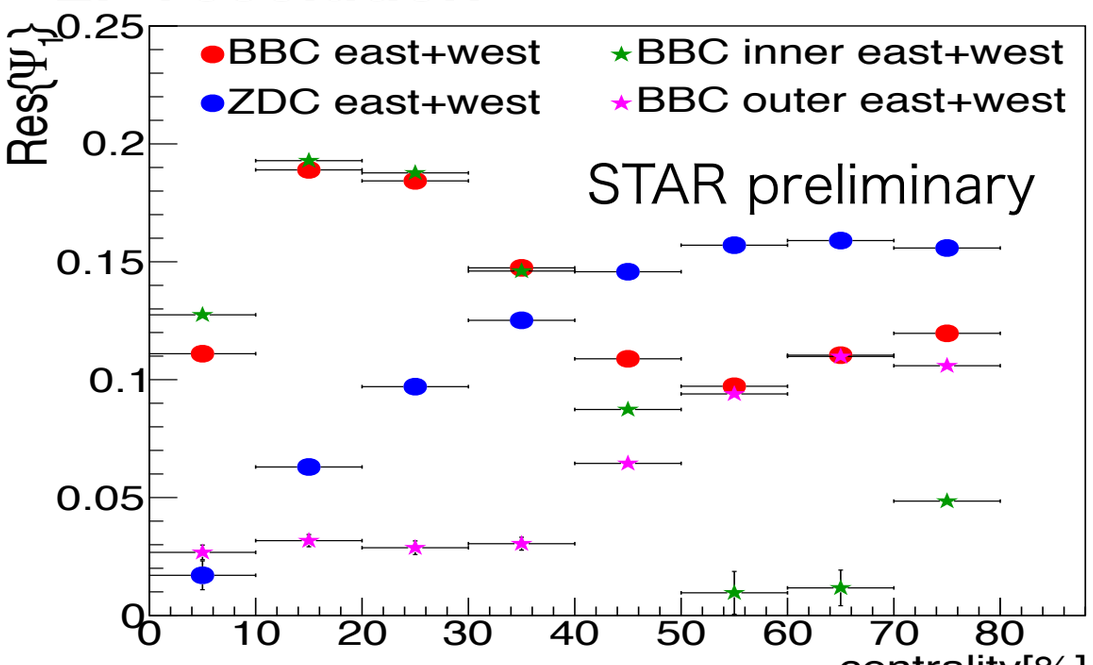
$$\Psi_1 = \tan^{-1}\left(\frac{\sum w_i \sin(\phi_i)}{\sum w_i \cos(\phi_i)}\right) \quad w_i \text{ :ADC}$$

✓The correlation sign of inner and outer is different in mid-central

➡w_i of BBC was changed

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

✦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).

Λ 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

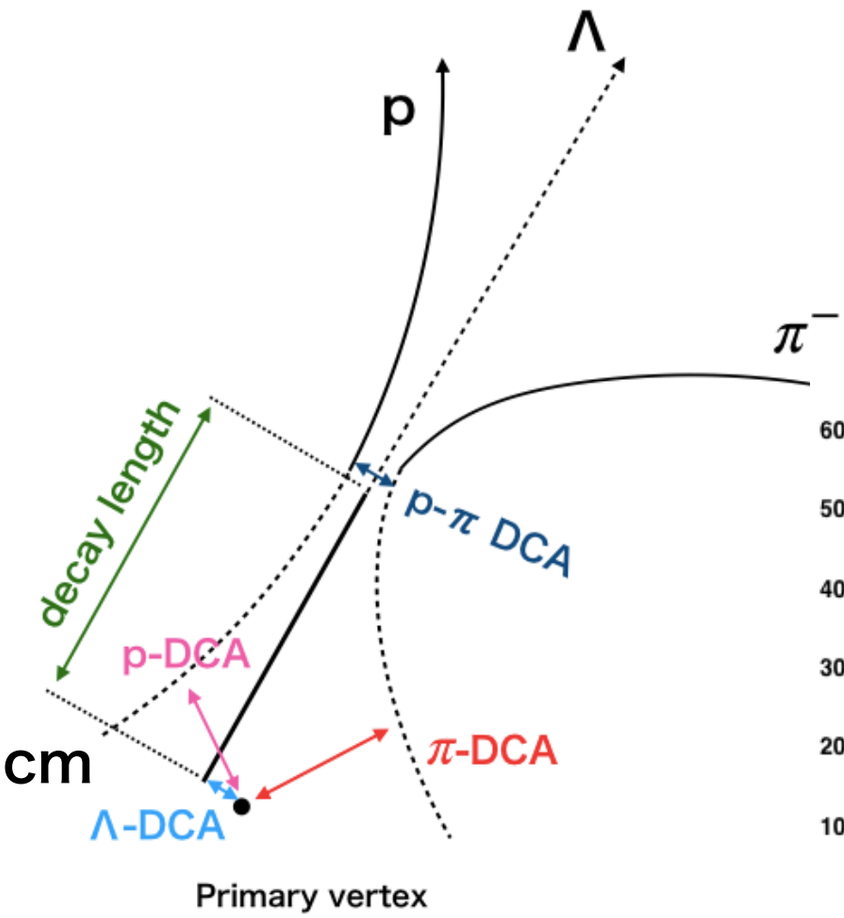
✓ p-DCA > 0.2 cm

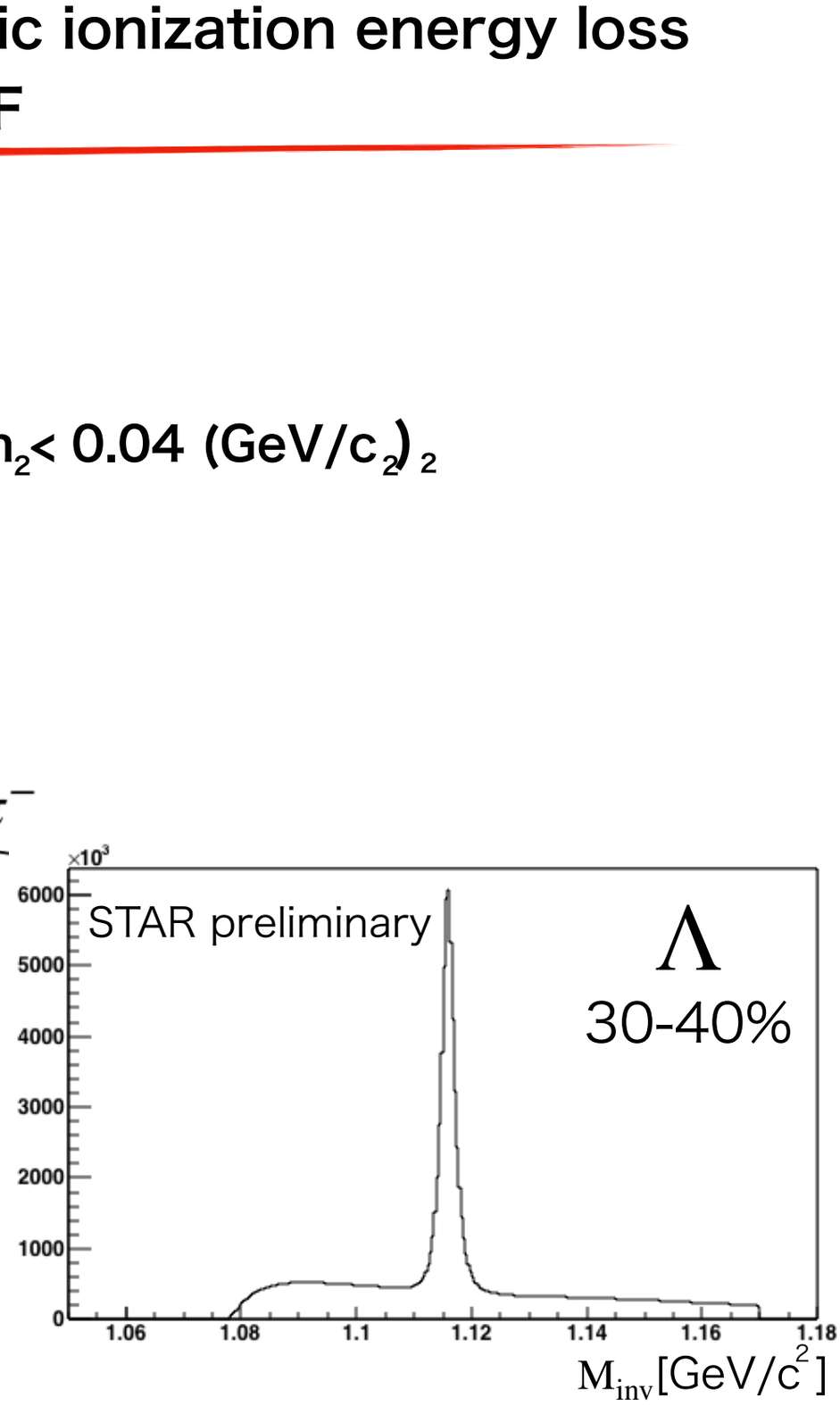
✓ π-DCA > 1.2 cm

✓ p-π DCA < 1.0 cm

✓ Λ-DCA < 0.9 cm

✓ Decay length > 3.5 cm





✳These value of topological cut is 30-40%

Extract the signal

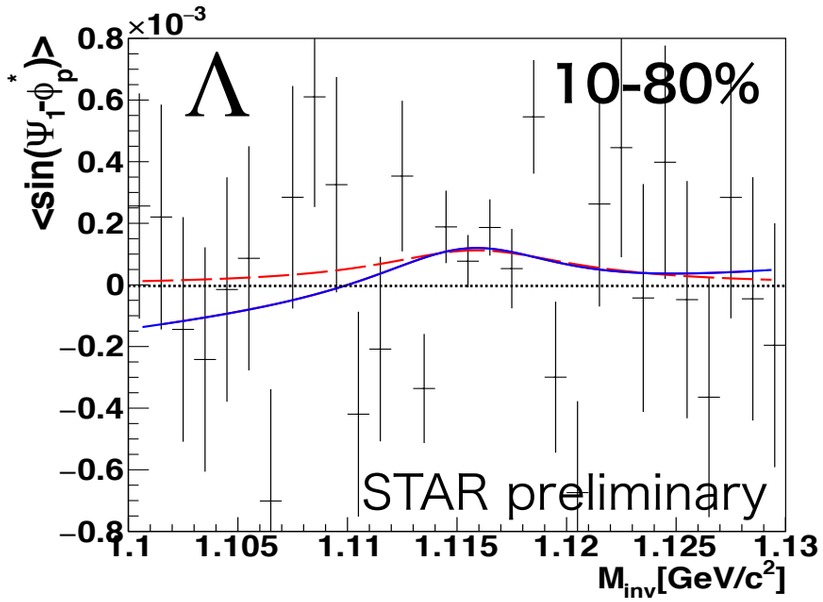
✦Invariant mass method

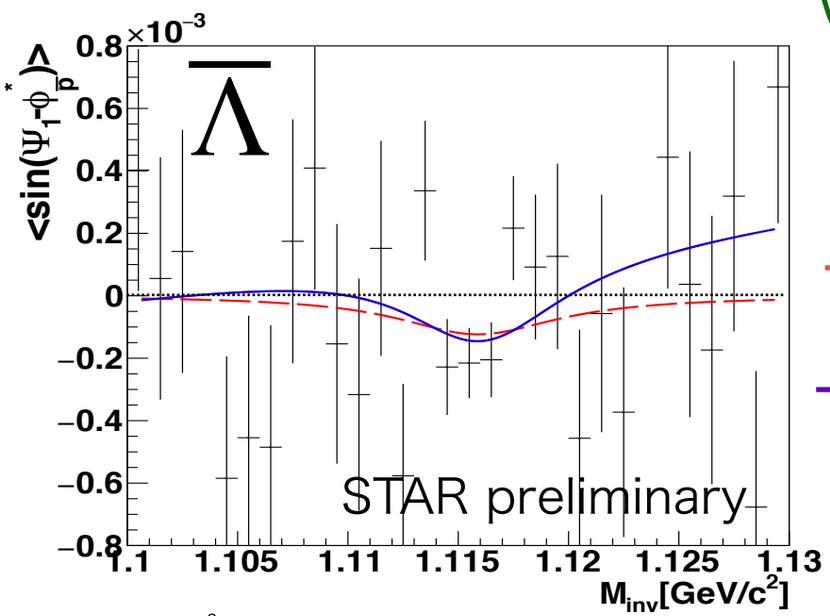
- The data was fitted with the following equation

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

$$\Delta\phi = \Psi_1 - \phi_p^*$$

$$f^{Bg}(M_{inv}) = f(M_{inv}^{Bg})/f(M_{inv}^{obs})$$





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

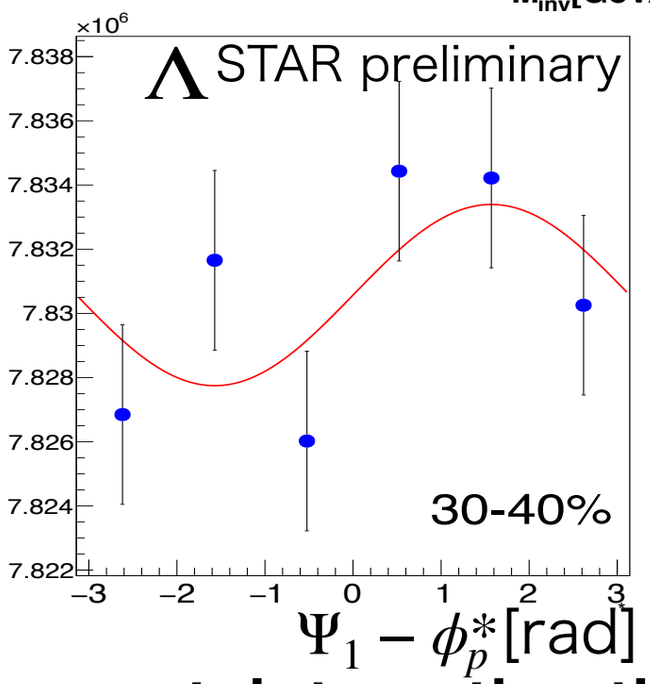
$\langle \sin(\Delta\phi) \rangle^{Bg} = \alpha M_{inv} + \beta$

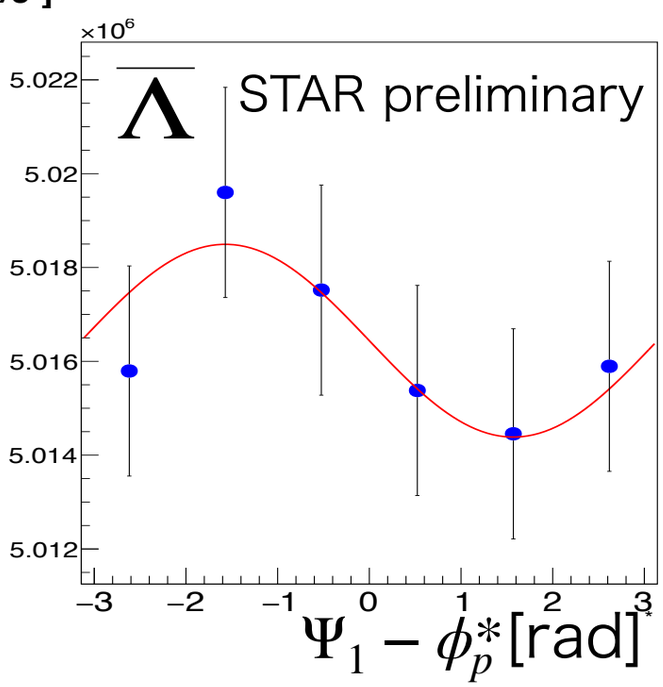
✦Event Plane method

- 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

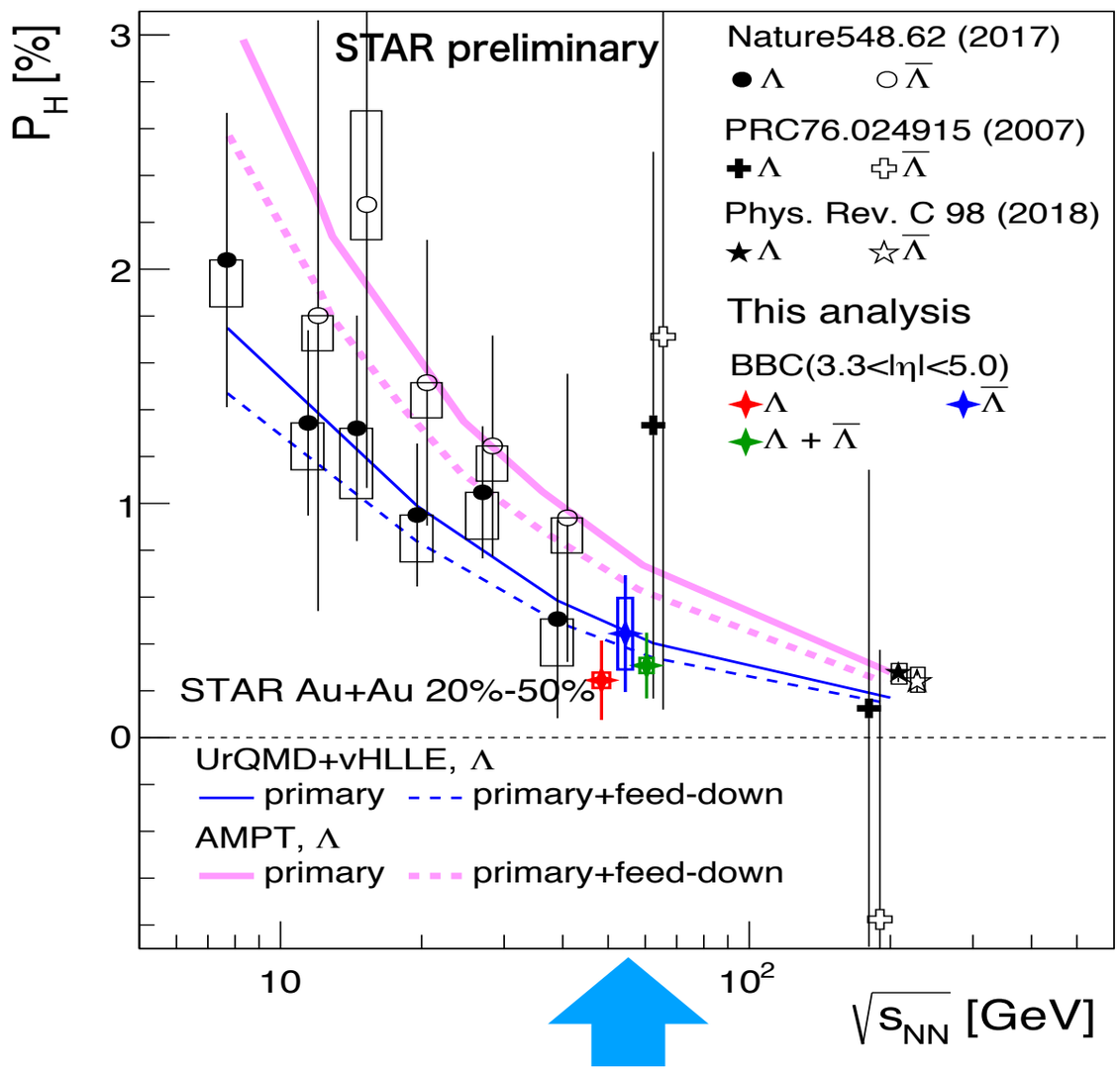




★Tow methods was considered in uncertainty estimation.

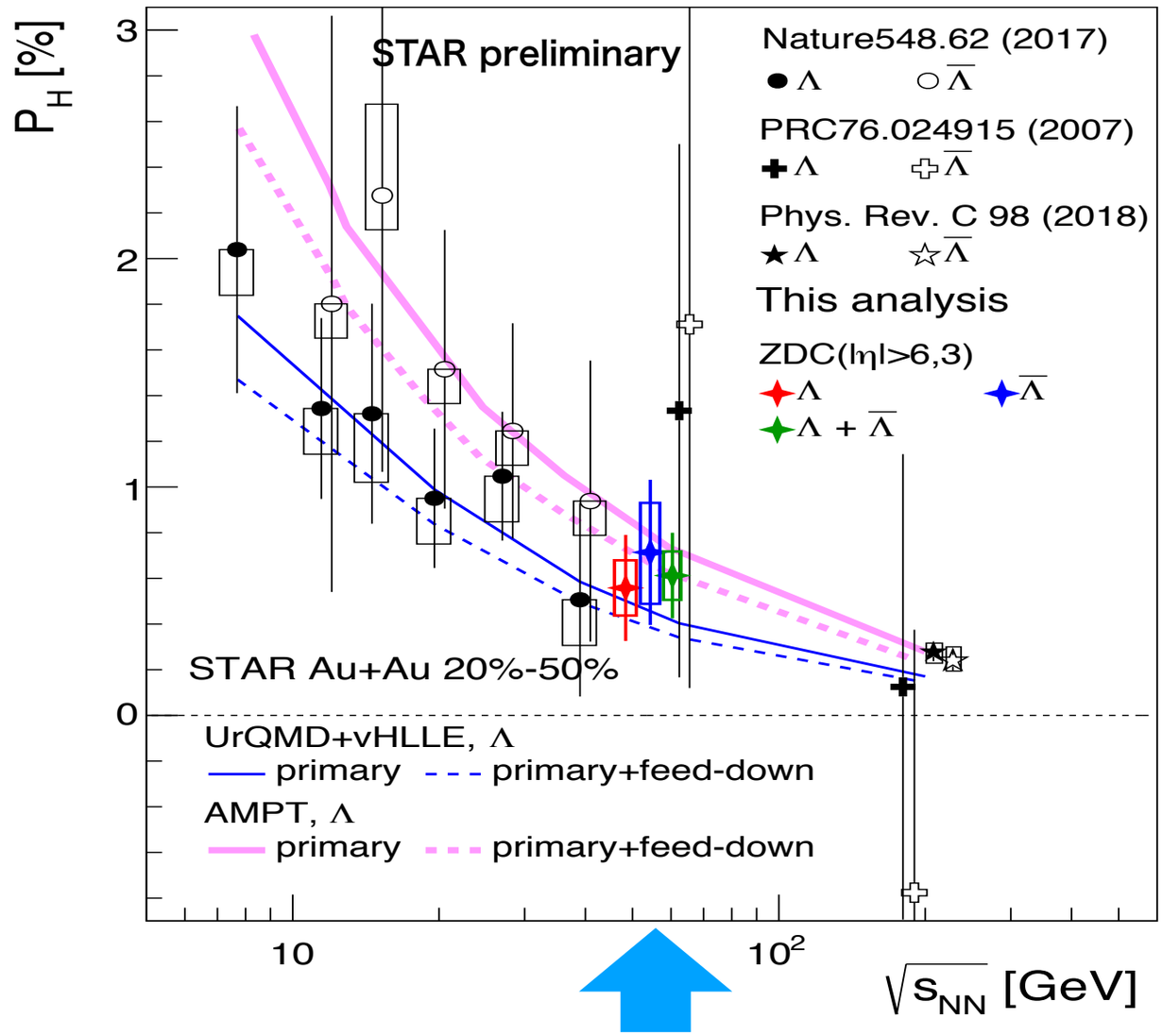
P_H collision energy dependence

BBC



54GeV

ZDC



54GeV

✓ First measurement at $\sqrt{s_{NN}}$ = 54.4 GeV

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

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

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

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

- Observed positive $\Lambda(\bar{\Lambda})$ global polarization
- ZDC is slightly higher than BBC

Summary and outlook

Summary

- **We presented first measurement of Λ global polarization in Au+Au collision at $\sqrt{s_{NN}}$ = 54 GeV**
  - Positive polarization is observed
  - The result agree with model calculations
  - No significant difference between Λ and anti-Λ

Outlook

- Calculate dependence for charged asymmetry and azimuthal angle dependence.
- Calculate Λ global polarization using TPC event plane

  -TPC : $|\eta| < 1.0$, BBC : $3.3 < |\eta| < 5.0$, ZDC : $|\eta| > 6.3$
- Further systematic checks (e.g. acceptance correction ...)
- Beam Energy Scan II
  - 7.7-19.6 GeV (10 times more events than BES I)
  - New detectors were installed

Kosuke Okubo, JPS meeting 2018/9/18

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

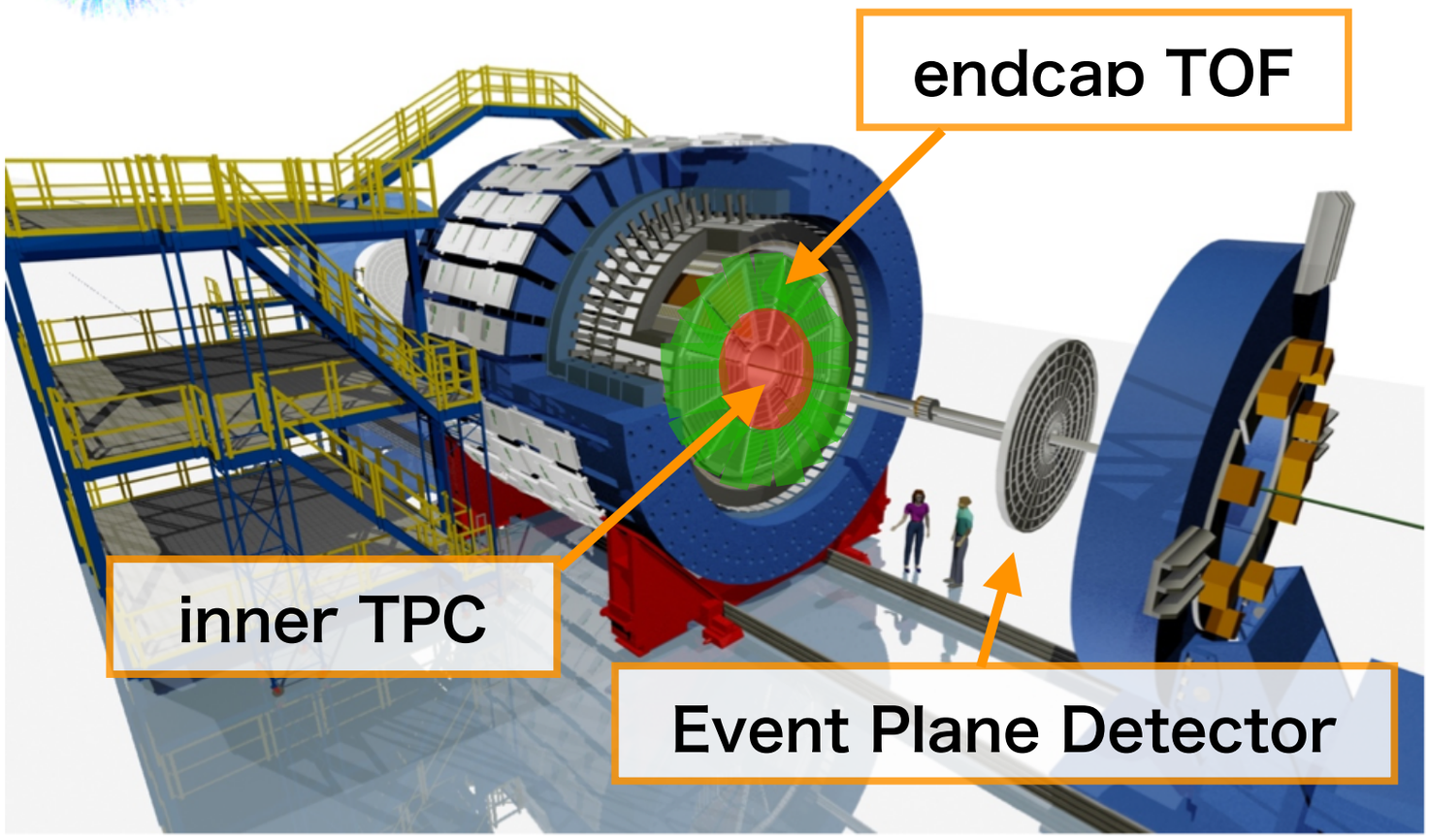
✦Estimate systematic uncertainty

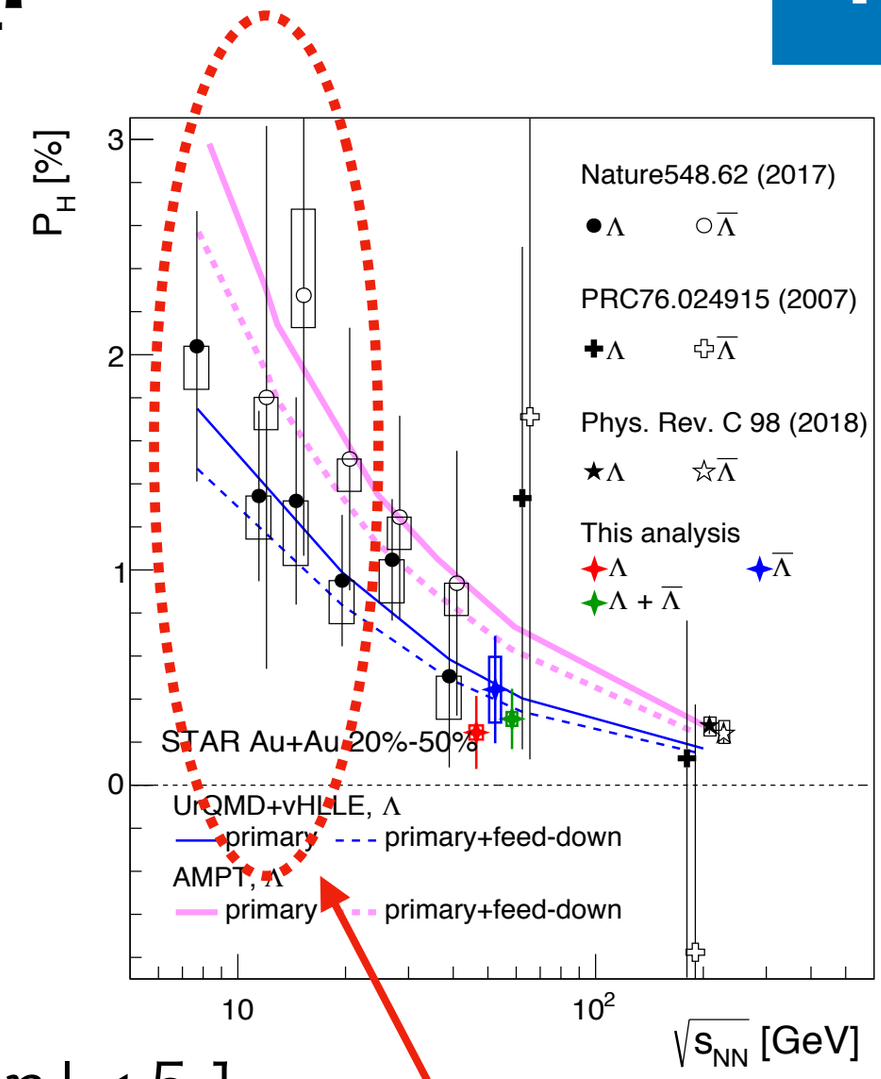
- Methods of the signal extraction : ~12%
- Background P_H assumption in the invariant mass method : ~20%
- Uncertainty from the decay parameter : ~2.0% for Λ, ~9.6% for anti-Λ

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

- Different time period during the data taking
- Cumulant effect

Beam Energy Scan II





- **Event Plane Detector(EPD)**
  - Improve event plane resolution, $2.1 < |\eta| < 5.1$
- **inner TPC(iTPC)**
  - $p_T > 60$ MeV/c
  - Extension from $|\eta| < 1$ to $|\eta| < 1.5$
- **endcap TOF(eTOF)**
  - Extends forward PID capability, $-1.6 < \eta < -1.1$

Higher statistics data are being taken!

✦7.7-19.6 GeV(10 times more events than BES Ⅰ)