STAR

Tomonaga Center for the History of the Universe

Measurement of Λ polarization in Au+Au $\sqrt{s_{NN}} = 7.2$ GeV Fixed-target collisions at STAR

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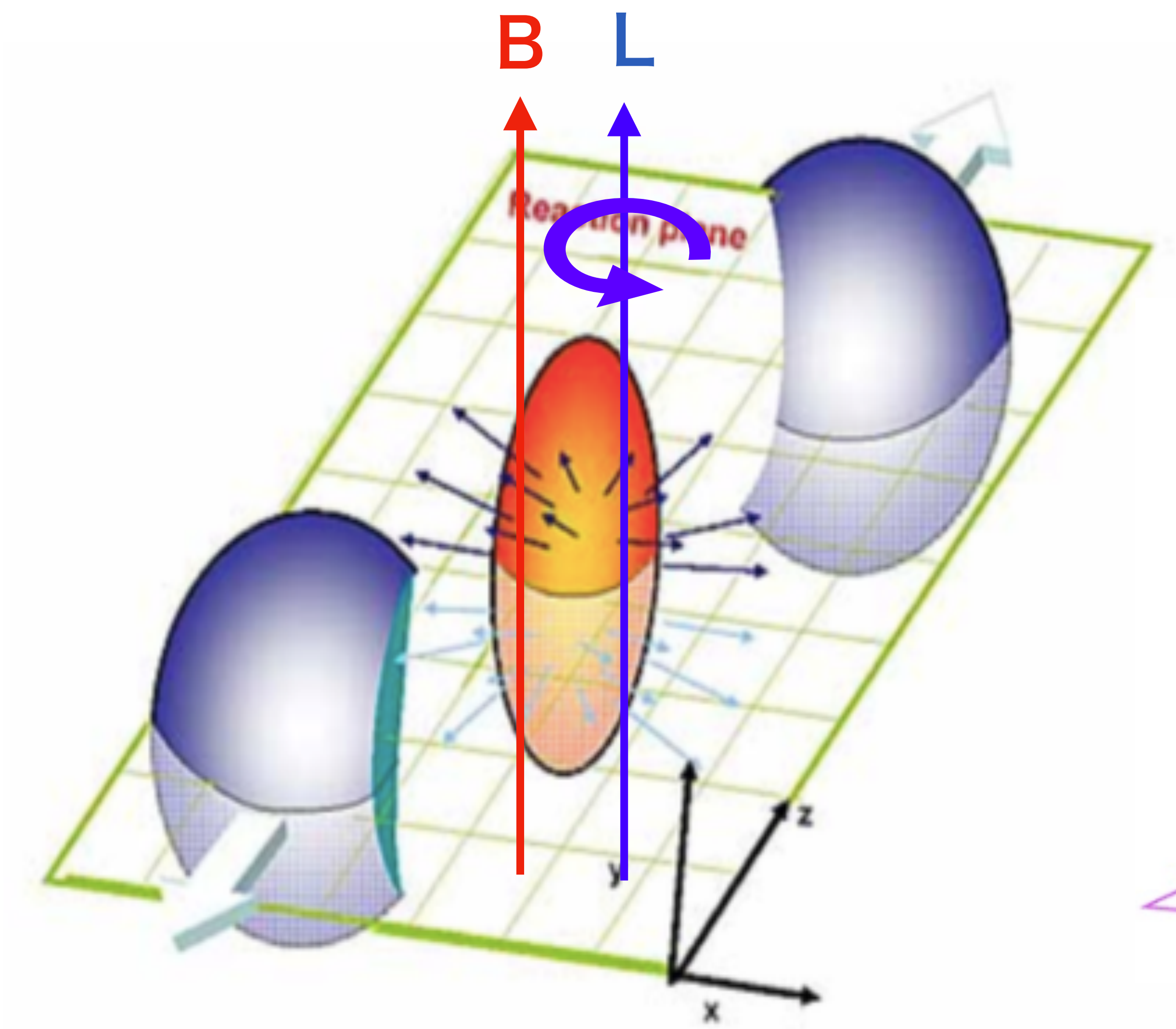
University of Tsukuba

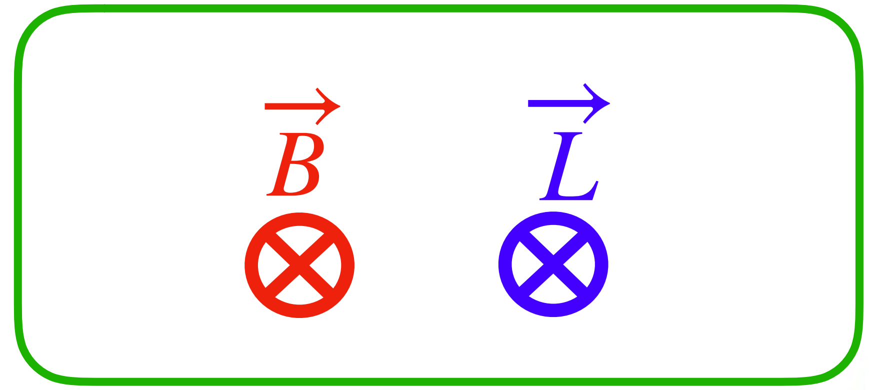
JPS meeting

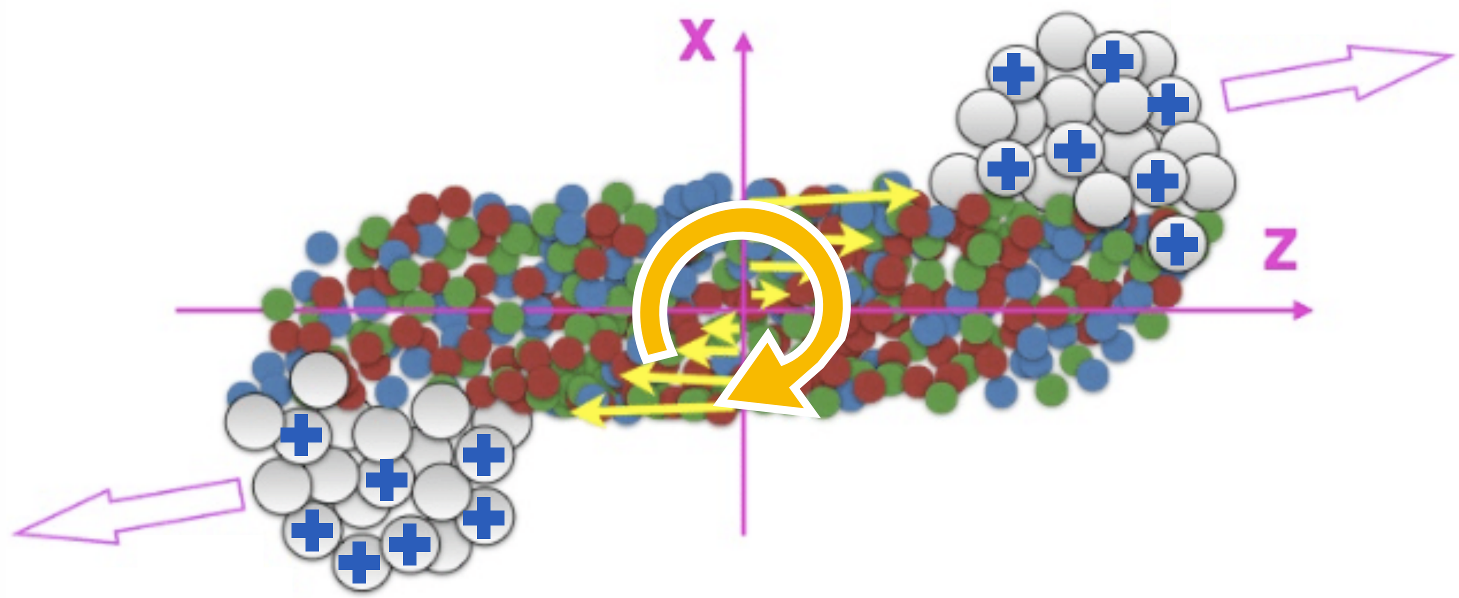
Sep. 17th, 2020

筑波大学
University of Tsukuba

Introduction

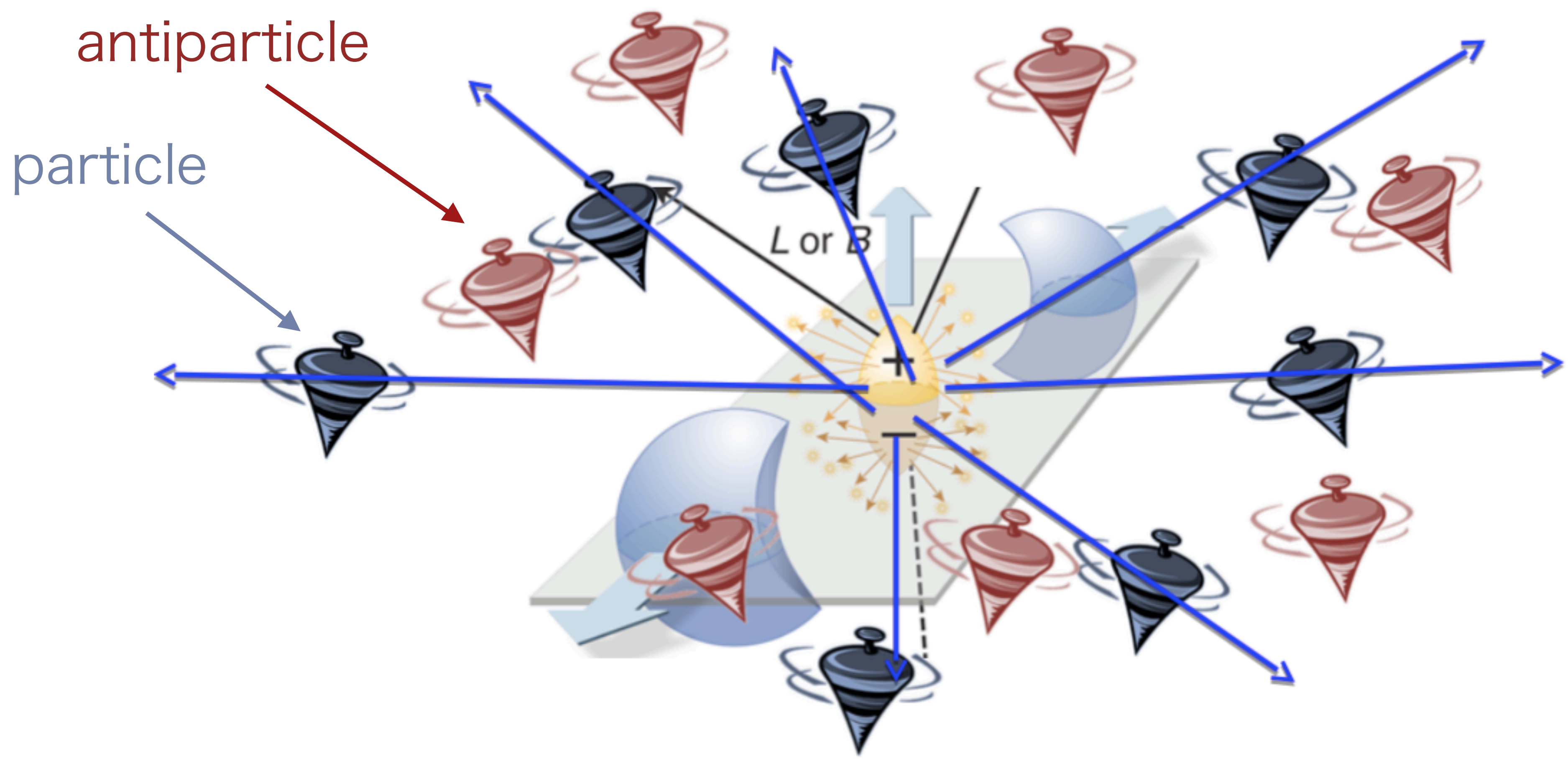






- In non-central collision…
  - The created matter should exhibit rotation motion.
    -Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)
  - The strong magnetic field would appear in the initial state.
    -D. Kharzeev, L. McLerran, and H. Warringa, Nucl.Phys.A803, 227 (2008)
    -McLerran and Skokov,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

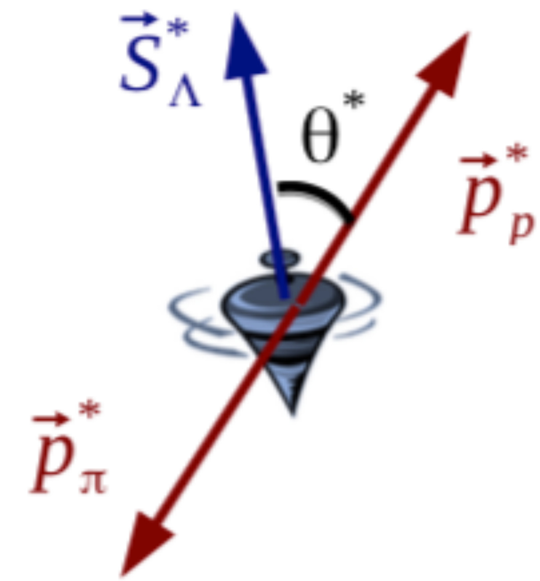
◆Spin alignment by magnetic field :

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

✔**Both are considered to contribute to the global polarization**

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).

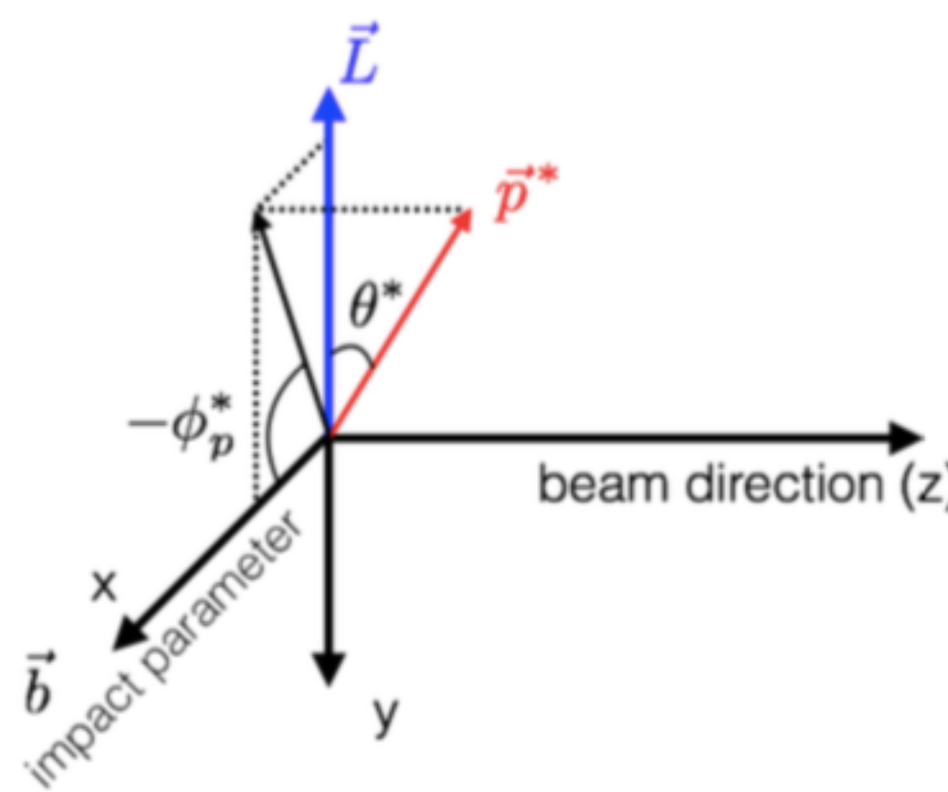
  -STAR, PRC76, 024915(2007)

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

α_H : decay parameter

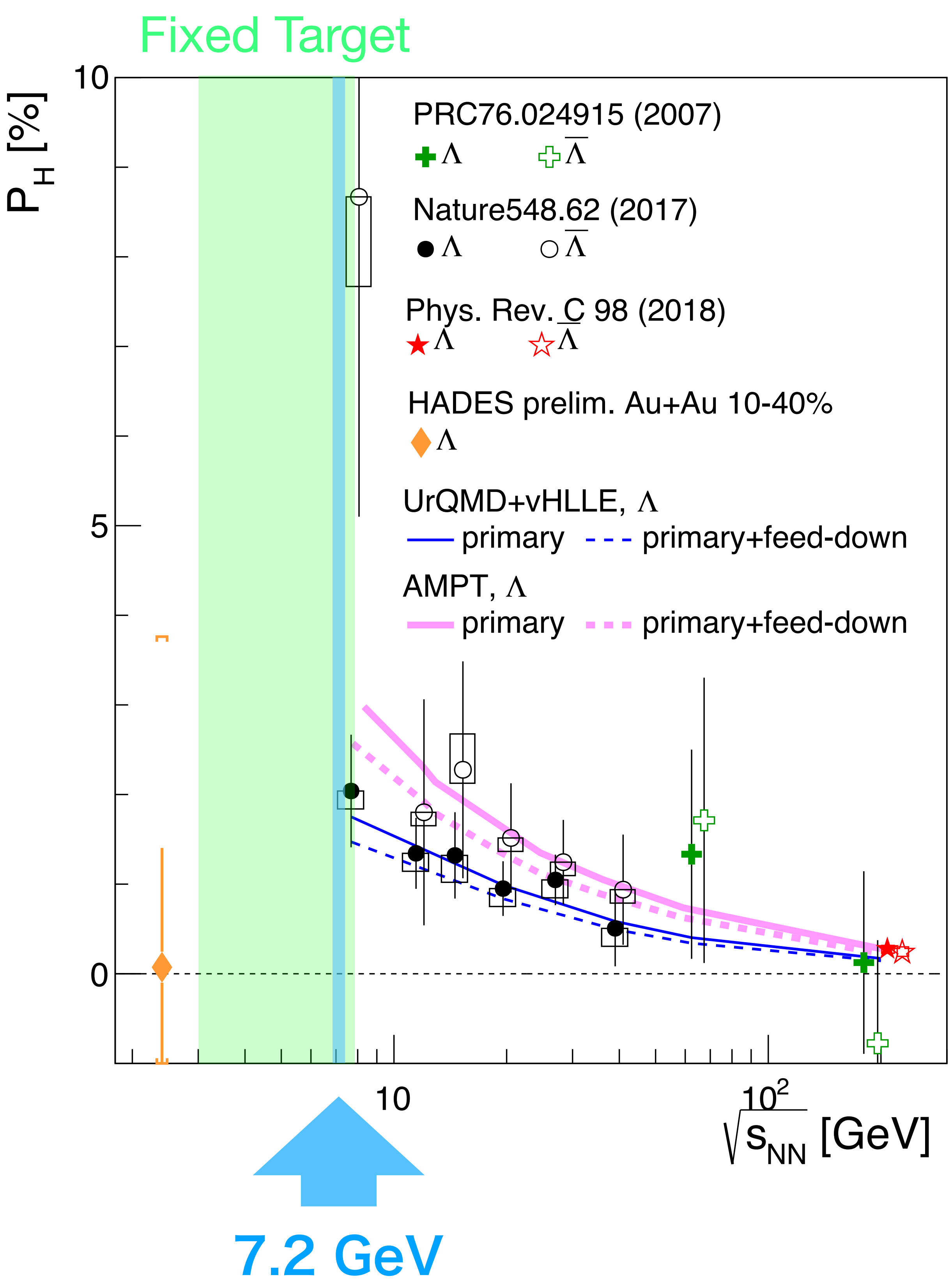
Ψ_1 : 1st-order event plane

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



Motivation

- **So far, Λ global polarization have been measured from $\sqrt{s_{NN}}$ = 7.7 to 200 GeV at STAR experiment.**



✓Polarization increases at low collision energy.

✓No significant difference between Λ and anti-Λ.

✓At lower energy, uncertainties are large.

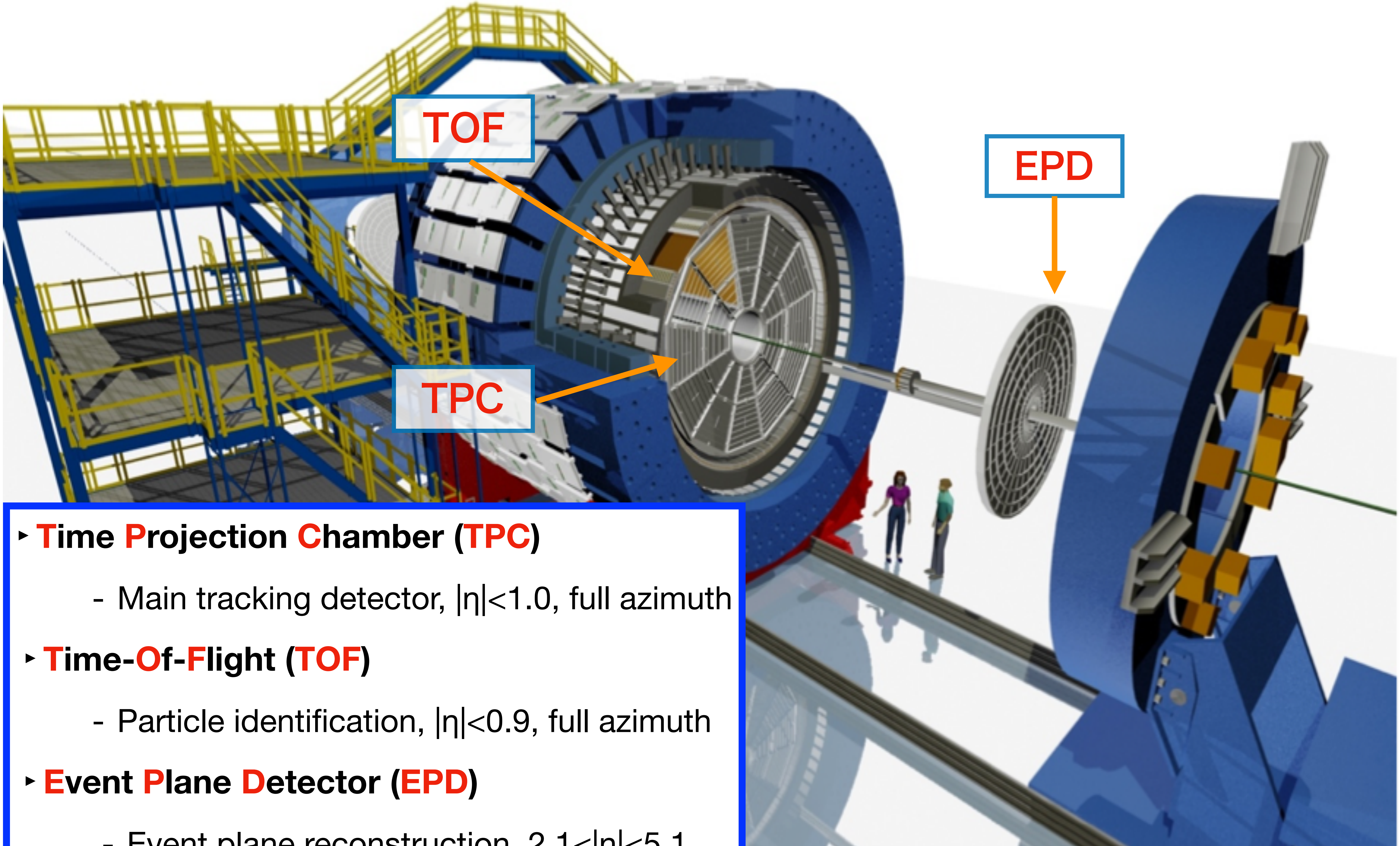
✓Lambda polarization is zero consistent at $\sqrt{s_{NN}}$ = 2.4 GeV ?

★**New analysis of global polarization in $\sqrt{s_{NN}}$ = 7.2 GeV with Fixed Target experiment.**

✓139 M events in 7.2 GeV > 4 M events in 7.7 GeV(BES I).

✓The difference between Λ and anti-Λ might be measured.

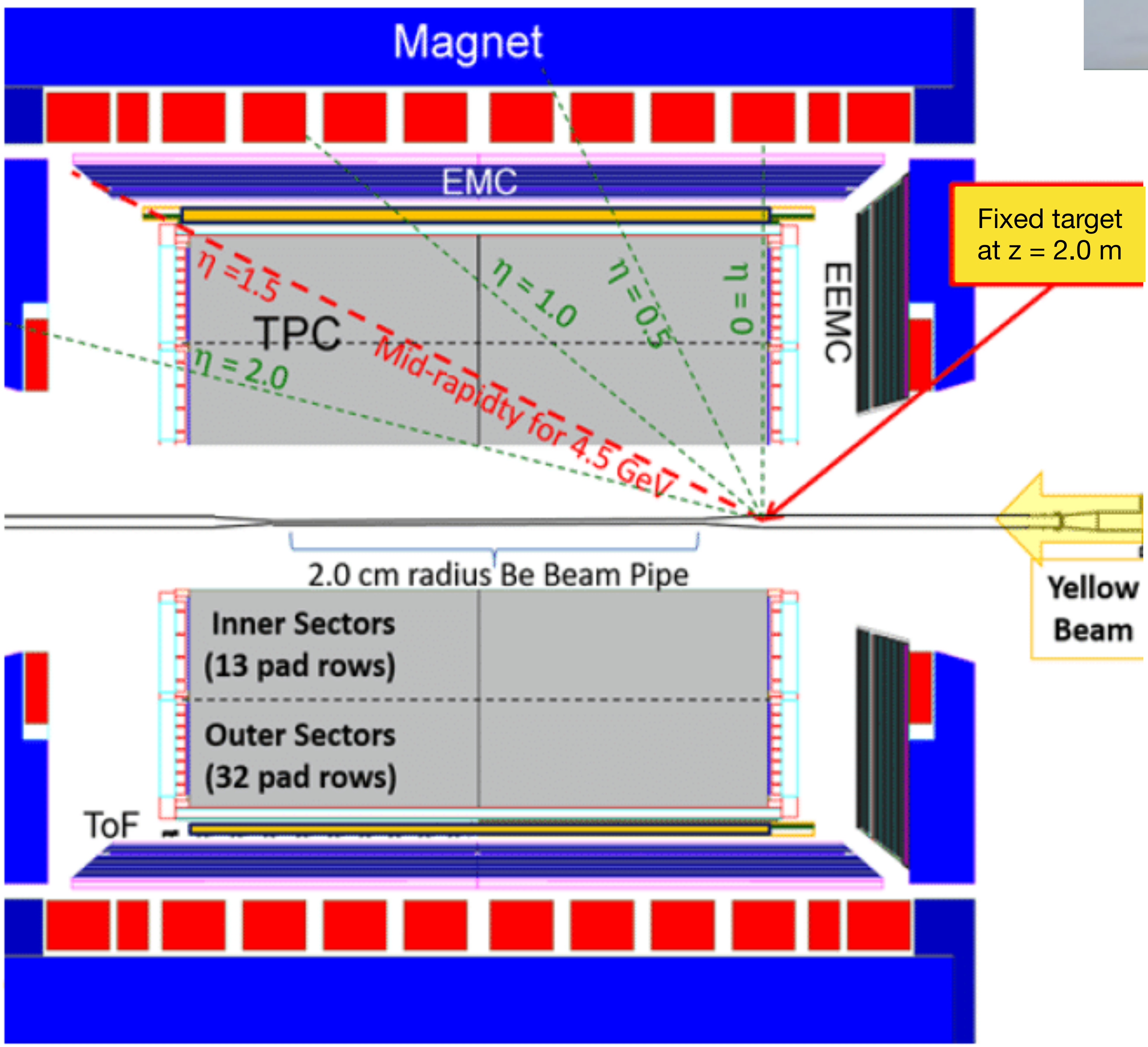
The STAR detector

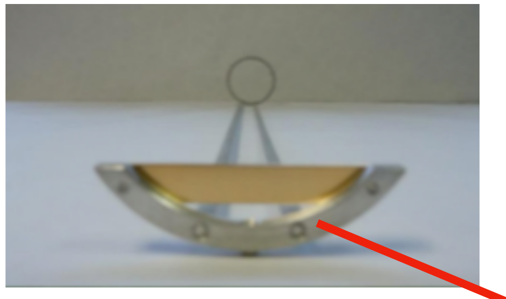


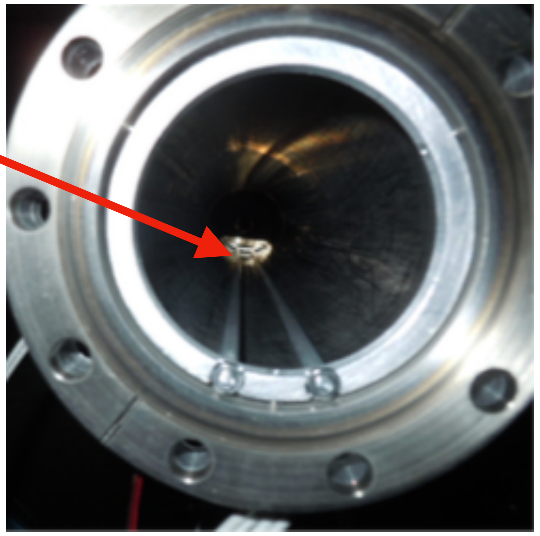
- **Time Projection Chamber (TPC)**
  - Main tracking detector, |η|<1.0, full azimuth
- **Time-Of-Flight (TOF)**
  - Particle identification, |η|<0.9, full azimuth
- **Event Plane Detector (EPD)**
  - Event plane reconstruction, 2.1<|η|<5.1

STAR Fixed-target program(FXT)

Mid-rapidity for 7.2 GeV ~ 2.02







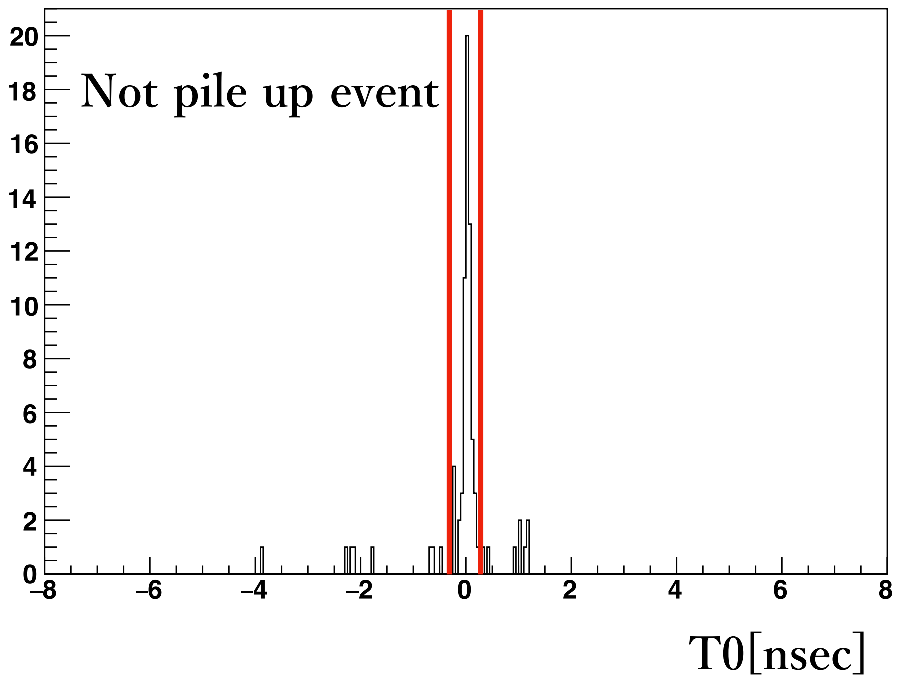
✓The gold target was installed inside the vacuum pipe at z = 200 cm.

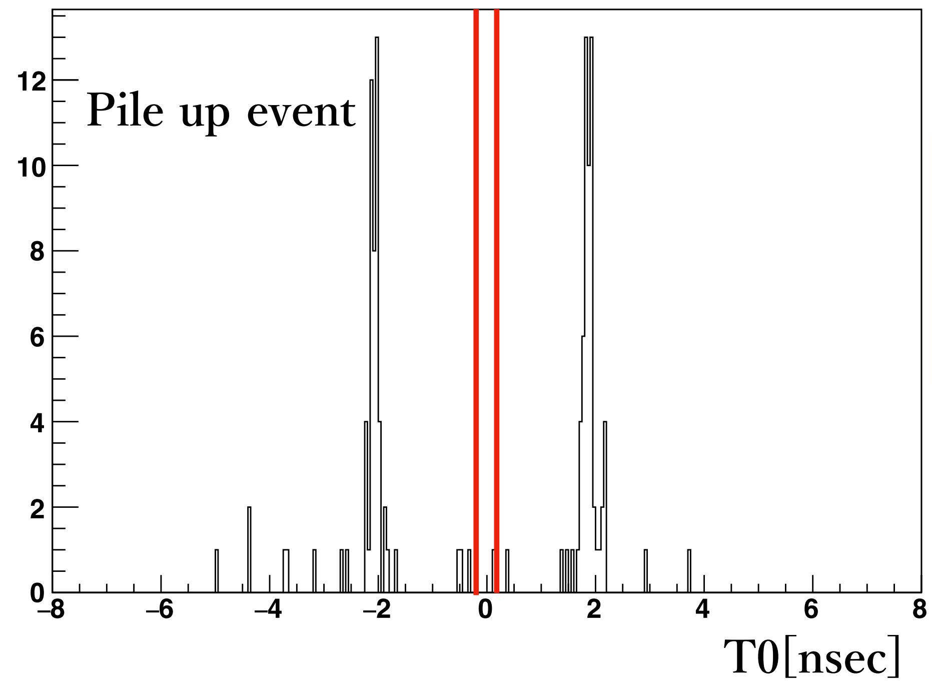
✓Target is 0.25mm thick and ~ 1% interaction probability.

✓139 M events for Au+Au FXT at $\sqrt{s_{NN}}$ = 7.2 GeV.

Pile up rejection

✓ Pile up events are removed using TOF start timing (T0).





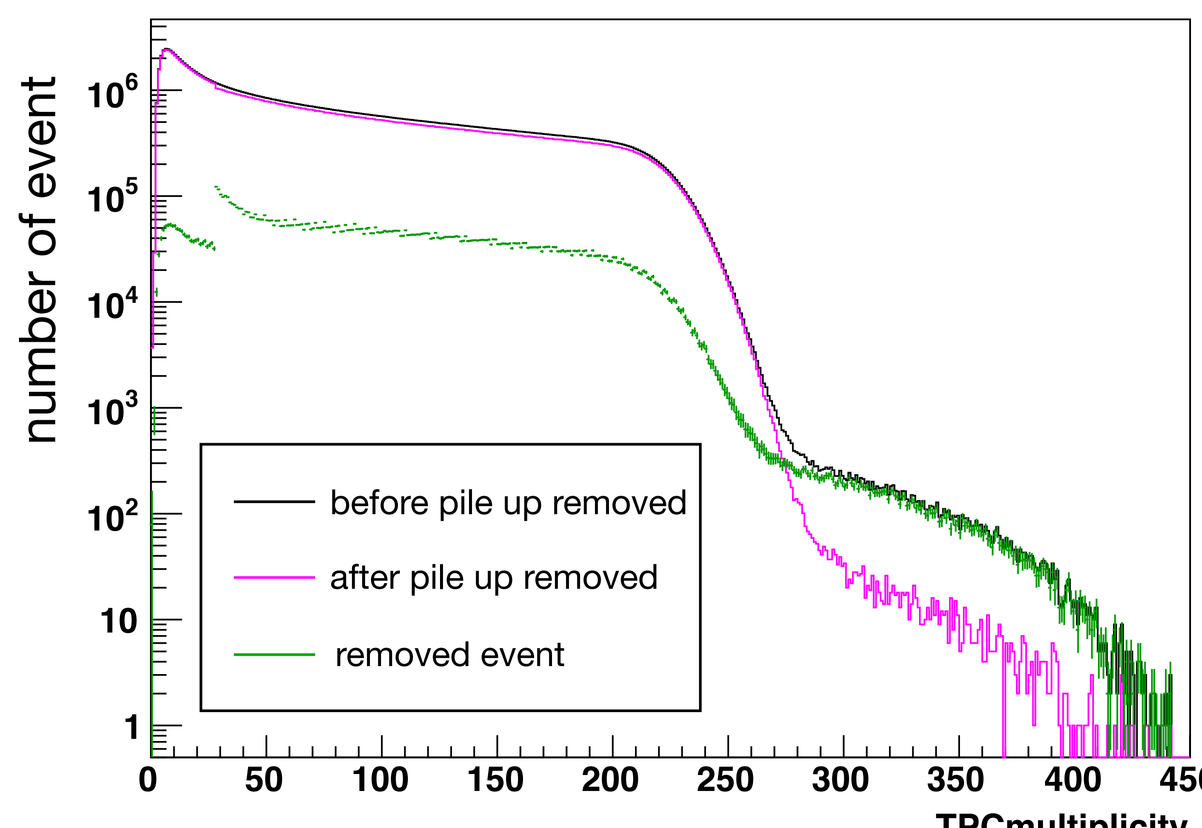
T0 = the average of Time of Flight

- Time of Flight of each particle

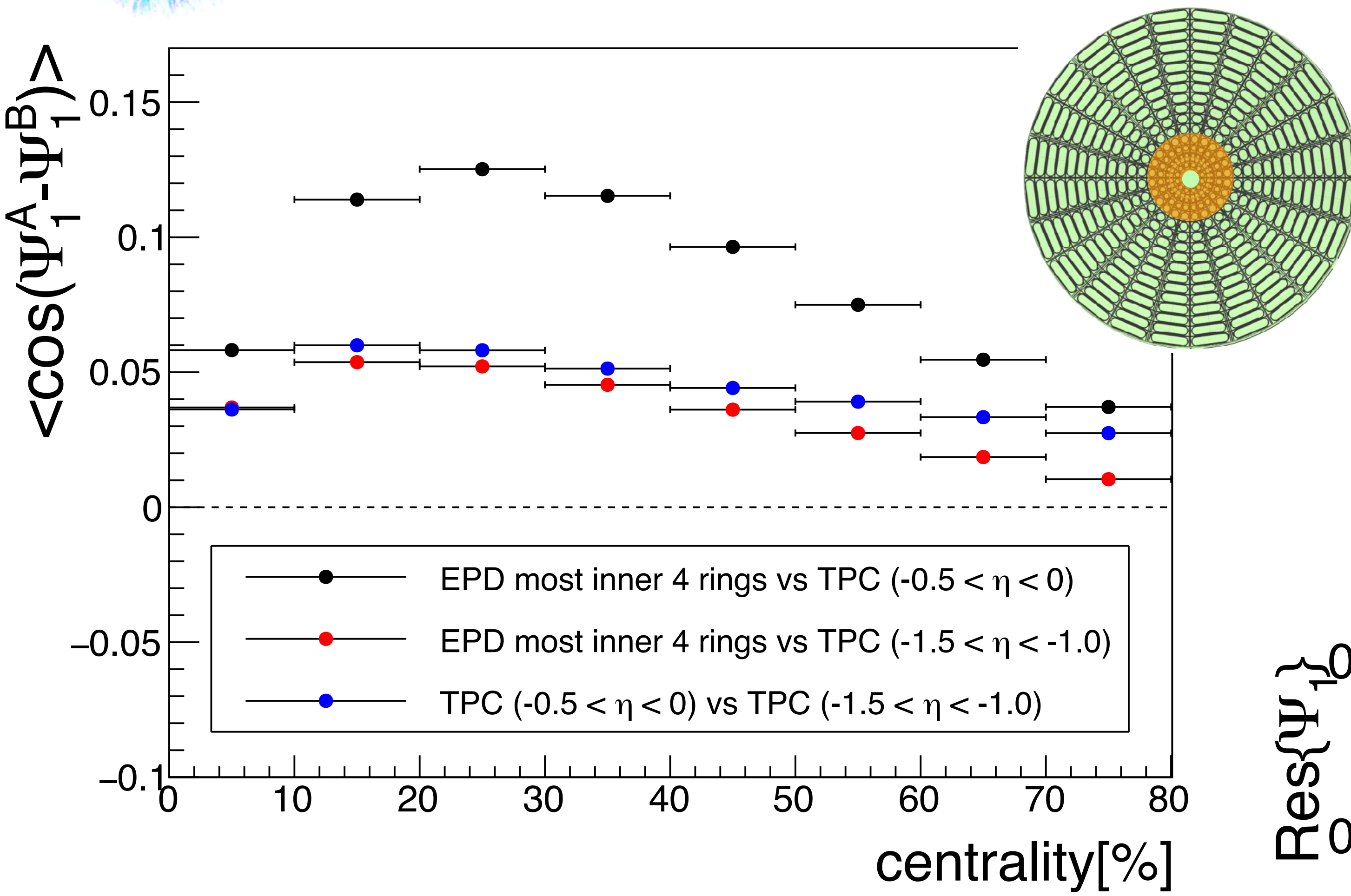
Step1: Count number of pion and proton with T0 from -0.3 to 0.3 [nsec].

Step2: The event where the number of pion and proton is far from average are removed as pile up events in each multiplicity bin.

➡ **About 90% pile up events would be removed.**



Event plane correlation and resolution



✓First-oder event plane was reconstructed by following formula.

$$\Psi_1 = \tan^{-1}\left(\frac{\Sigma \mathrm{w_i} \sin(\phi_\mathrm{i})}{\Sigma \mathrm{w_i} \cos(\phi_\mathrm{i})}\right)$$

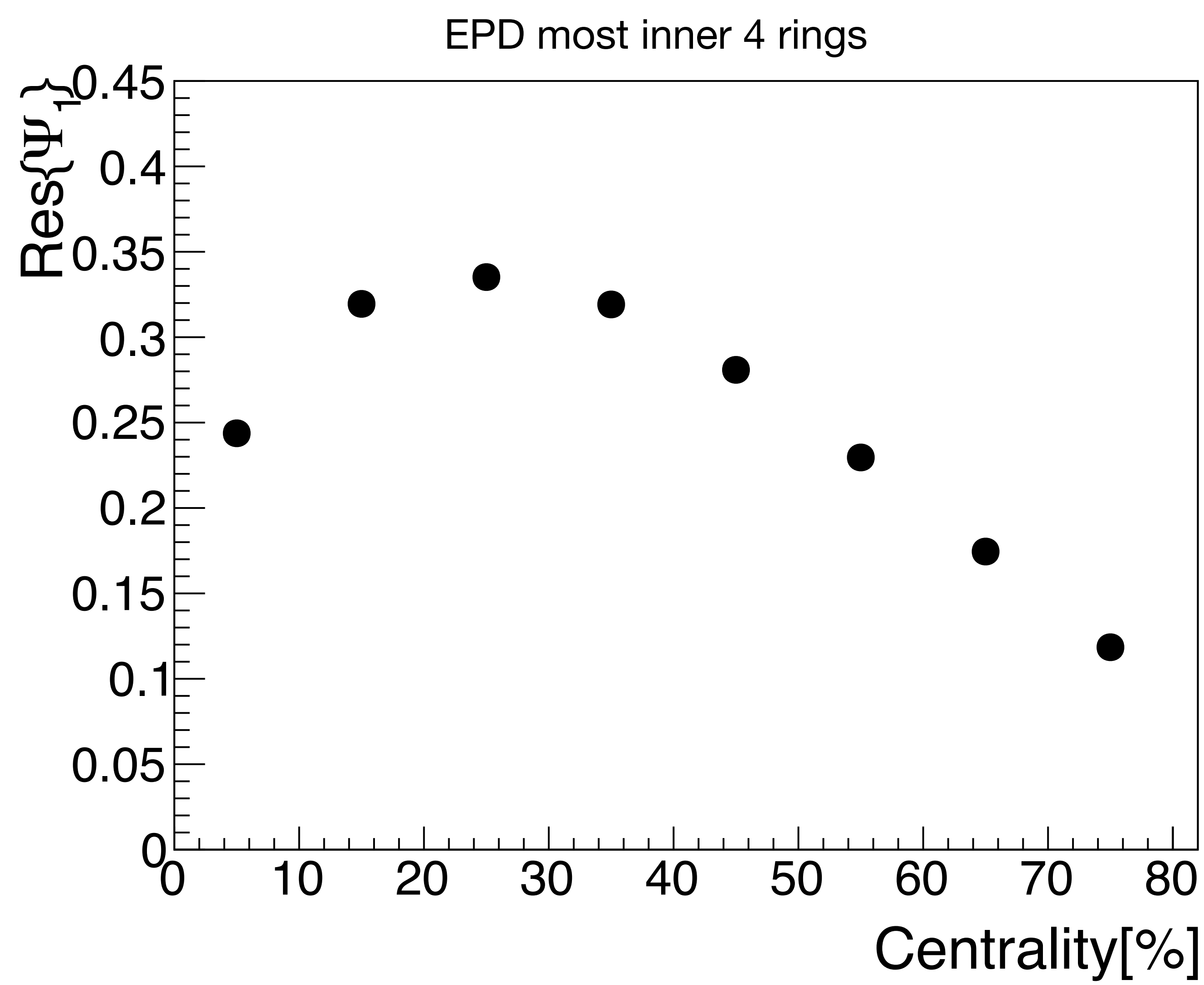
✓Event plane resolution was calculated by 3-subevent method.

$$\langle \cos([\Psi_1^A - \Psi_1^B]) \rangle = \langle \cos([\Psi_1^A - \Psi_1^{\mathrm{true}}] \rangle \langle \cos([\Psi_1^{\mathrm{true}} - \Psi_1^B] \rangle$$

$$= \sigma_n^A \sigma_n^B$$

$$Res(\Psi_1^A) = \sqrt{\frac{\langle \cos([\Psi_1^A - \Psi_1^B]) \rangle \langle \cos([\Psi_1^A - \Psi_1^C]) \rangle}{\langle \cos([\Psi_1^B - \Psi_1^C]) \rangle}}$$

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



Λ reconstruction

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

✦Proton

✓ $|n\sigma| < 3$

✓ $0.5 < m^2 < 1.5\ (\mathrm{GeV}/c^2)^2$

✦Pion

✓ $|n\sigma| < 3$

✓ $0.5 < m^2 < 1.5\ (\mathrm{GeV}/c^2)^2$

✦Topological cut

✓ p-DCA > 0.4 cm

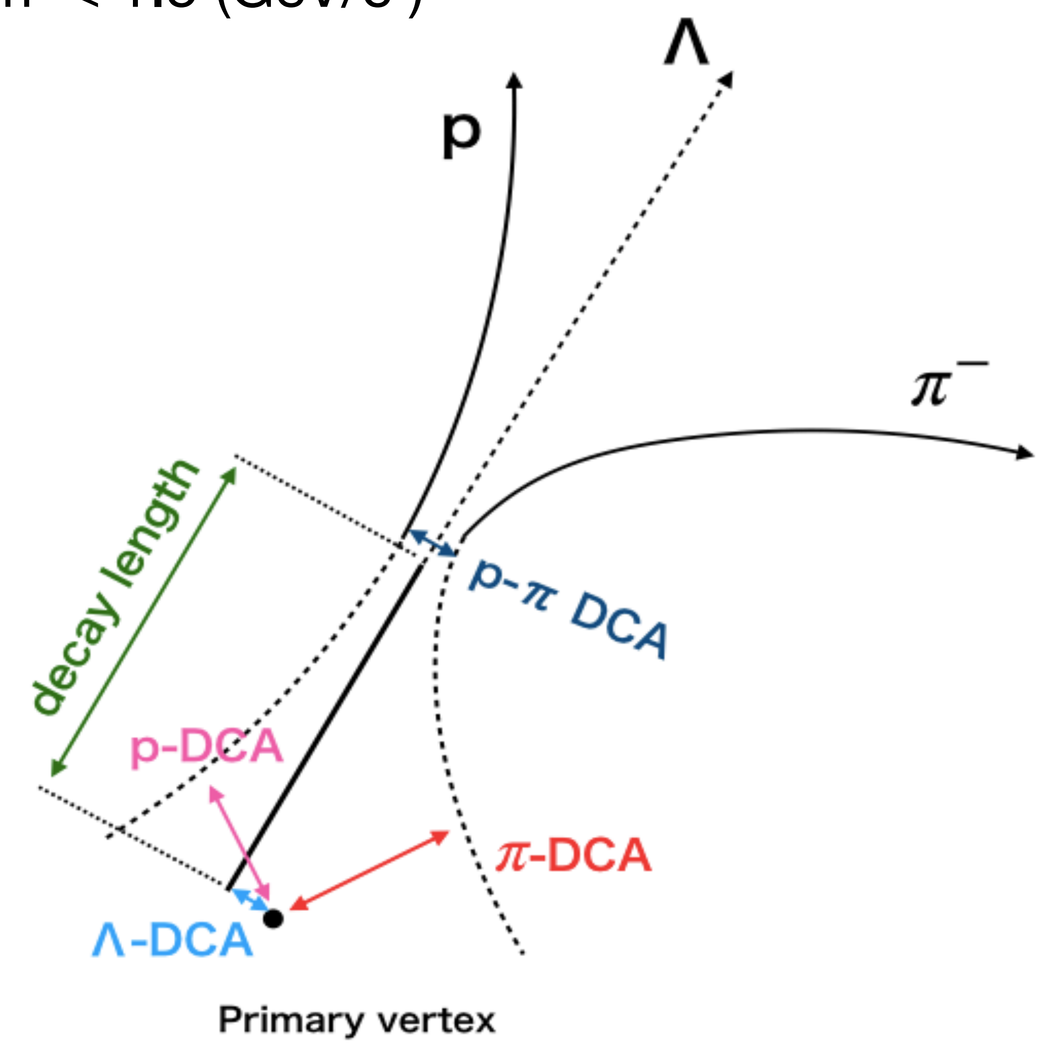
✓ Λ-DCA < 0.7 cm

✓ π-DCA > 1.6 cm

✓ Decaylength > 5.0 cm

✓ p-π DCA < 1.1 cm

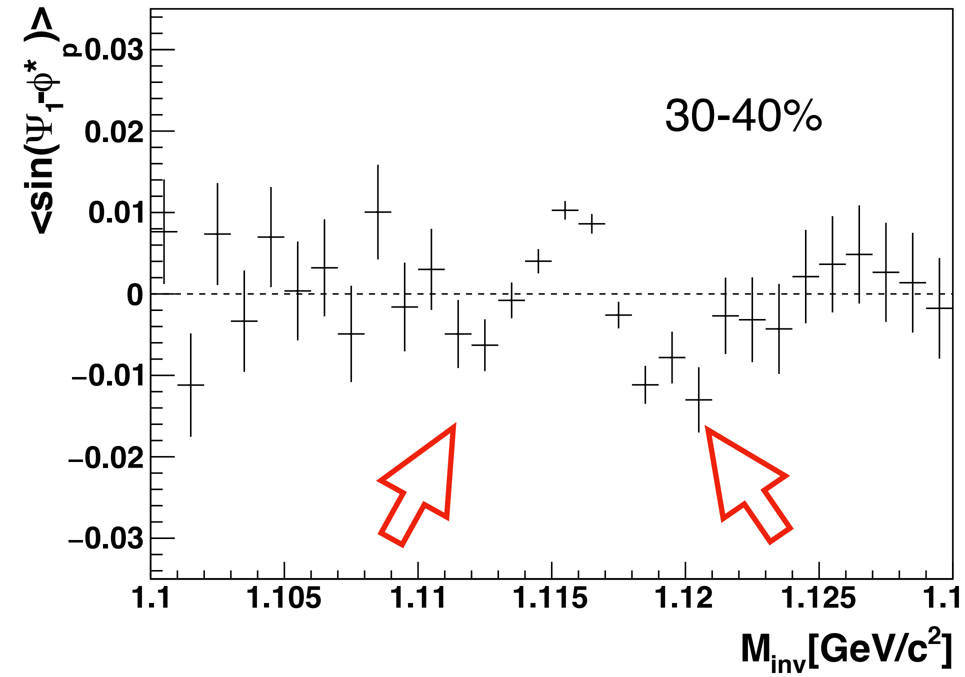
These value of topological cut are slightly changed depends on centrality.

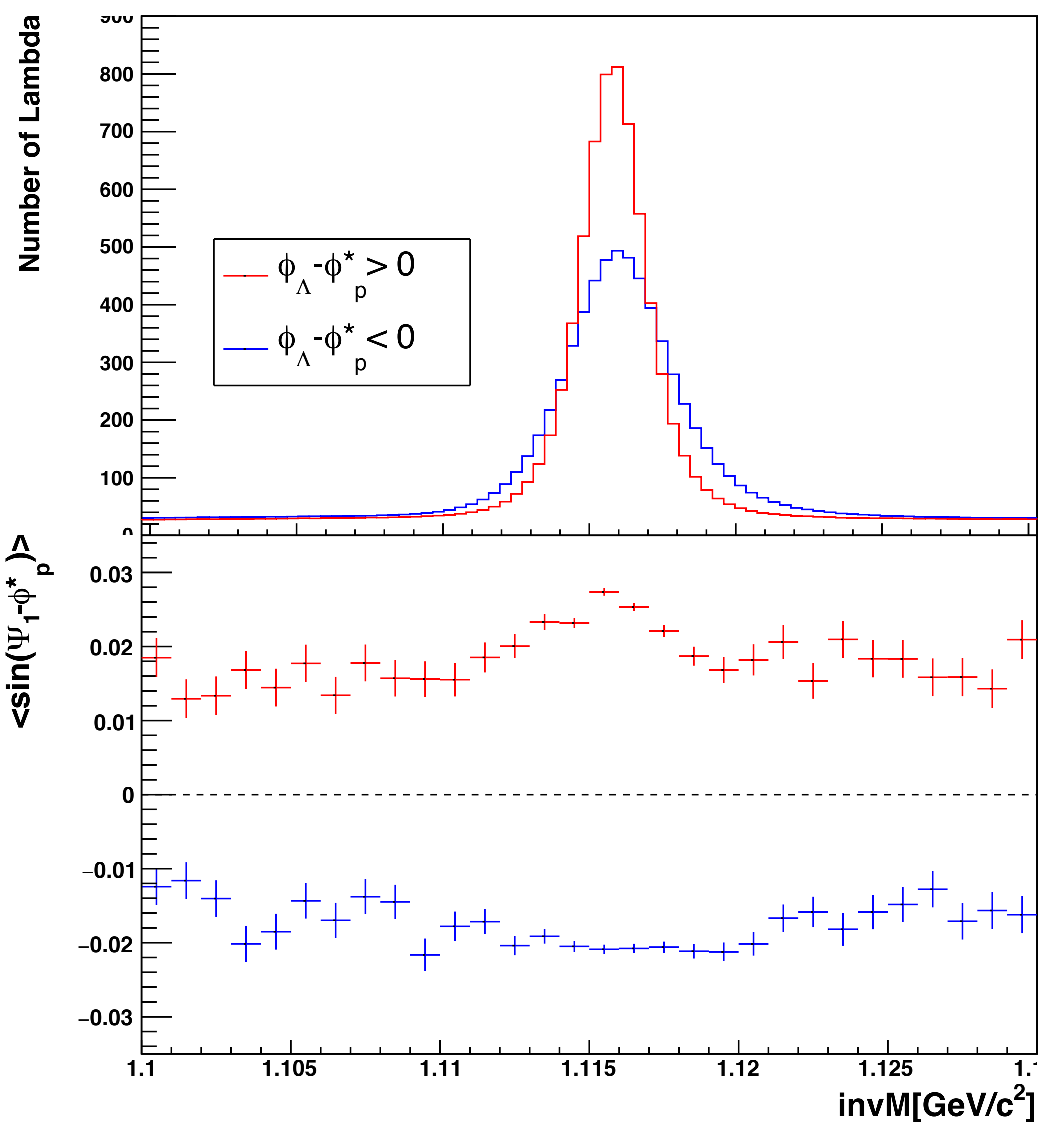


Current status of polarization measurement in $\sqrt{s_{NN}}$ = 7.2 GeV

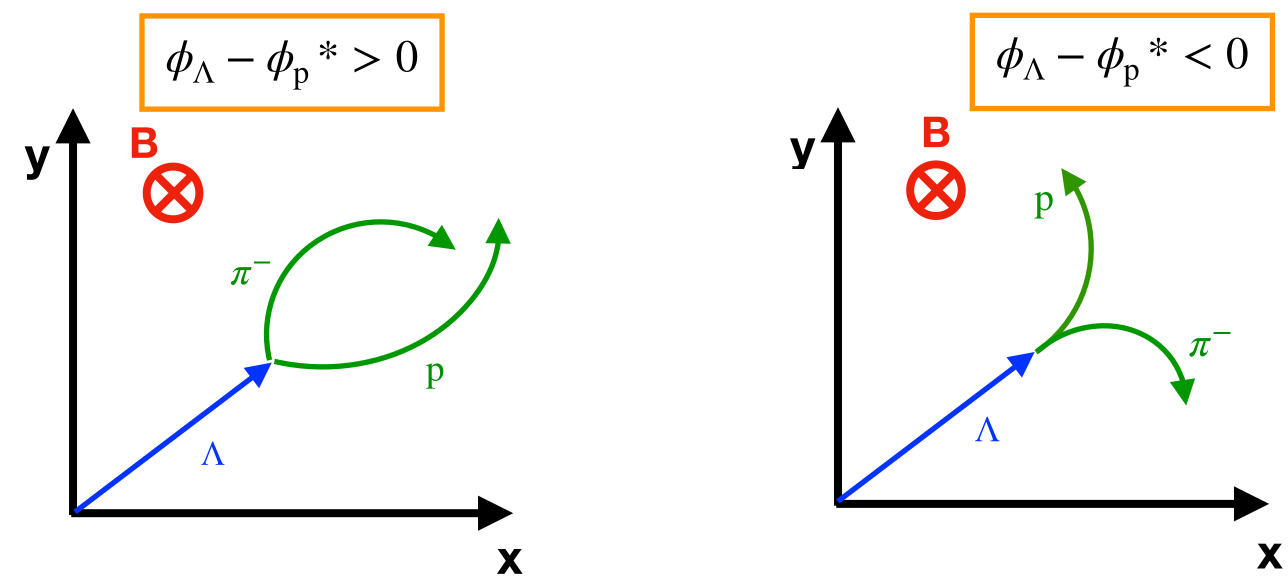
Not corrected for resolution and detector effects

✓Observed polarization is more sharply peaked near Λ mass and it dips on the sides mass peak.





The width of the invariant mass depends on the daughter's azimuthal emission angle relative to the Λ.



Two tracks are crossing

Two tracks fly away (worse mass resolution)

Summary and Outlook

Summary

- **We reported the current status of measurement of Λ global polarization in Au+Au at $\sqrt{s_{NN}}$ = 7.2 GeV Fixed-target collisions.**
  - Observed polarization rises around Λ mass and it dips in low/high sides of the mass peak.
  - We need to understand why this structure occurs.

Outlook

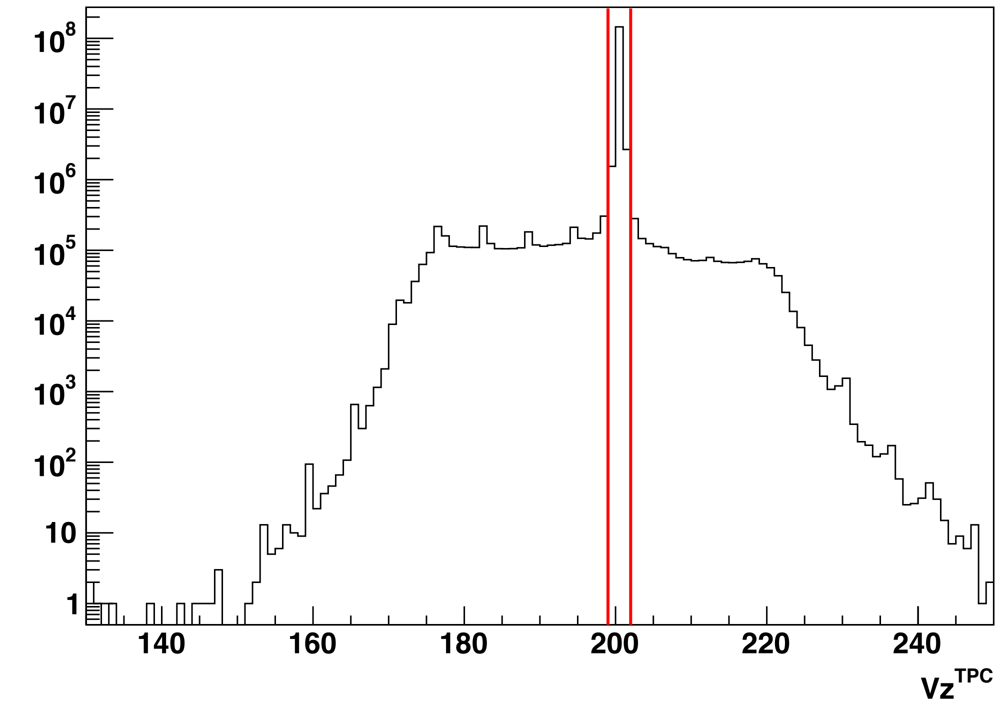
- **We will perform differential measurements on Λ global polarization in Au+Au at $\sqrt{s_{NN}}$ = 7.2 GeV Fixed-target collisions.**
- **Beam Energy Scan II is ongoing now at STAR experiment.**
  - High statistics data are being taken in low energy.
  - iTPC and eTOF are installed.

Back up

Data selection

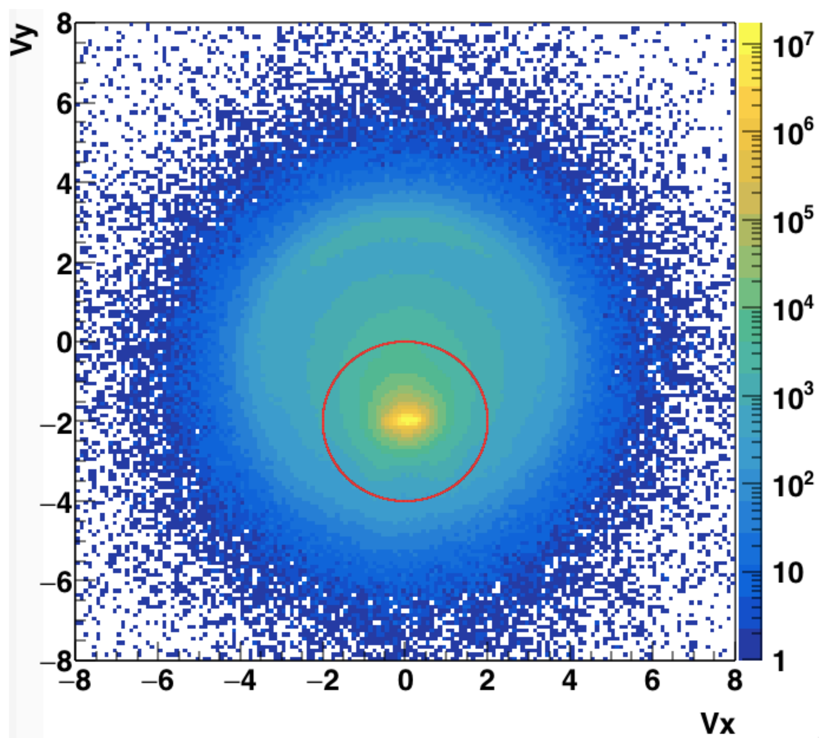
Data set

- Au+Au $\sqrt{s_{NN}}$ = 7.2 GeV with Fixed Target
- Run18 minimum bias
- # of events ~ 139M (after event selection)



Event selection

- Vertex Z = 199 to 202cm
- Vertex R = 0 to 2cm
- Pile up events are removed.



Track selection

- nHitsFit > 10
- nHitsFit/nHitsPoss > 0.52

TOF start timing calculation

- We calculated TOF start timing using pion and proton.

✓ Pion and proton are identified via specific ionization energy loss in TPC.

- Pion : |nSigmaPion|<2
- Pion : |nSigmaPion|<2

✓ T0 = TOF① - TOF②

T0 : TOF start timing

TOF① = btofPidTraits -> btof()

TOF② = L/v

L : flight distance of particle

L=tofPathLength(&origin, &btofHitPos, ptrk->helix(picoEvent->bField()).curvature)*0.01

v : velocity of particle

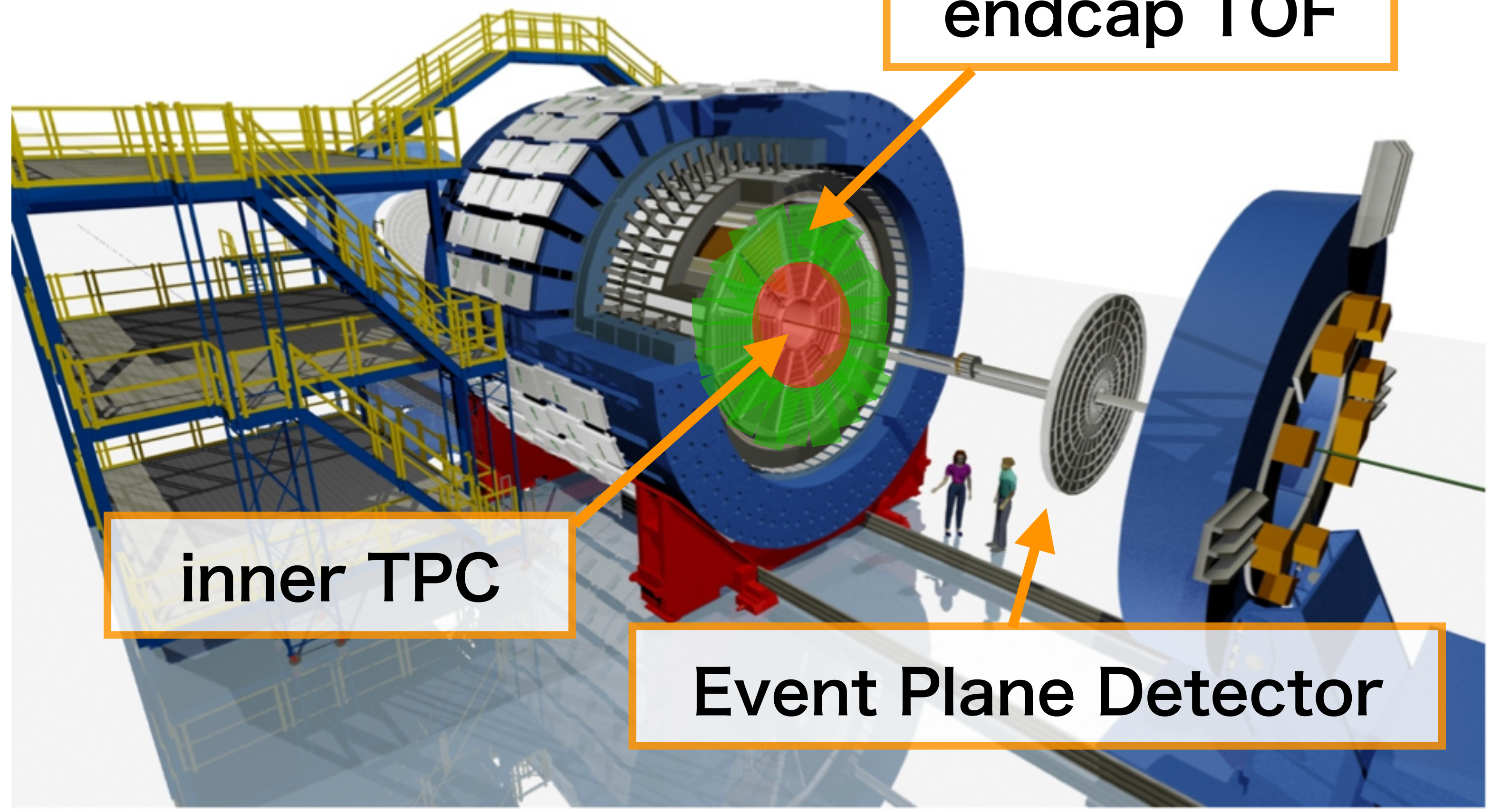
$$v = c * \sqrt{\frac{\alpha^2}{1+\alpha^2}}$$

$\alpha = p/m$ (p : momentum, m : mass of pion or proton)

Beam Energy Scan II

✦High statistics data are being taken in low energy region.

(10 times more events than BES I)



✦New detectors are installed.

- **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, $-1.6 < \eta < -1.1$