26th International Symposium on Spin Physics

A Century of Spin

100 YEARS SPIN 2025

STAR

Measurements of Hyperons Spin Correlation in Au+Au collisions from STAR

Xingrui Gou (for the STAR Collaboration)

Shandong University

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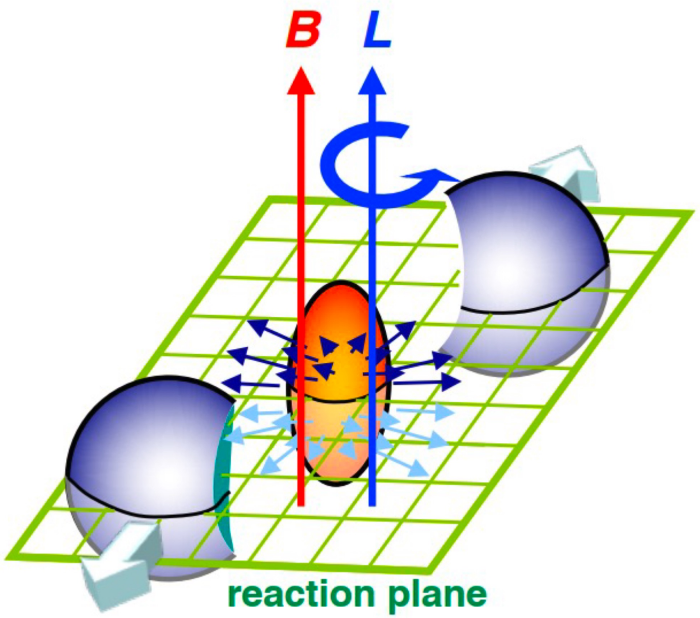
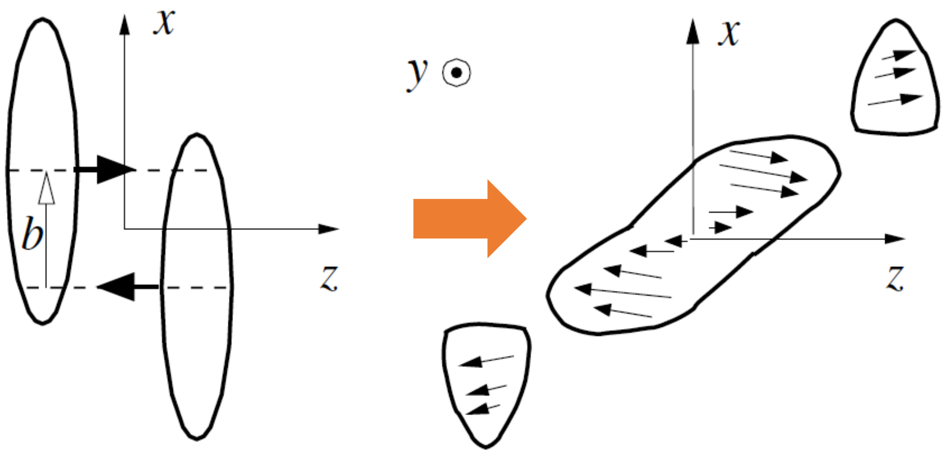
U.S. DEPARTMENT OF ENERGY | Office of Science

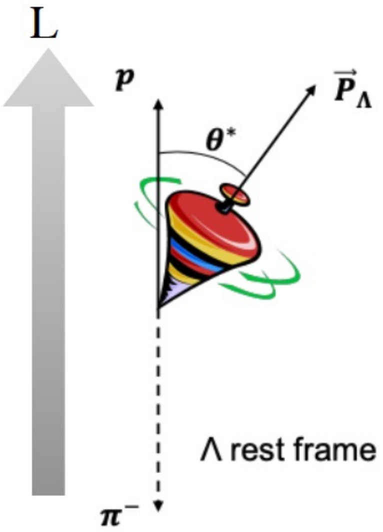
山东大学 SHANDONG UNIVERSITY

NSFC

Motivation







Orbital angular momentum

Local fluid vorticity $\omega = \frac{1}{2}\nabla\times v$

The most vortical fluid $\sim\ 10^{20} - 10^{21} s^{-1}$
(Au+Au@RHIC at ***b***=10 fm)

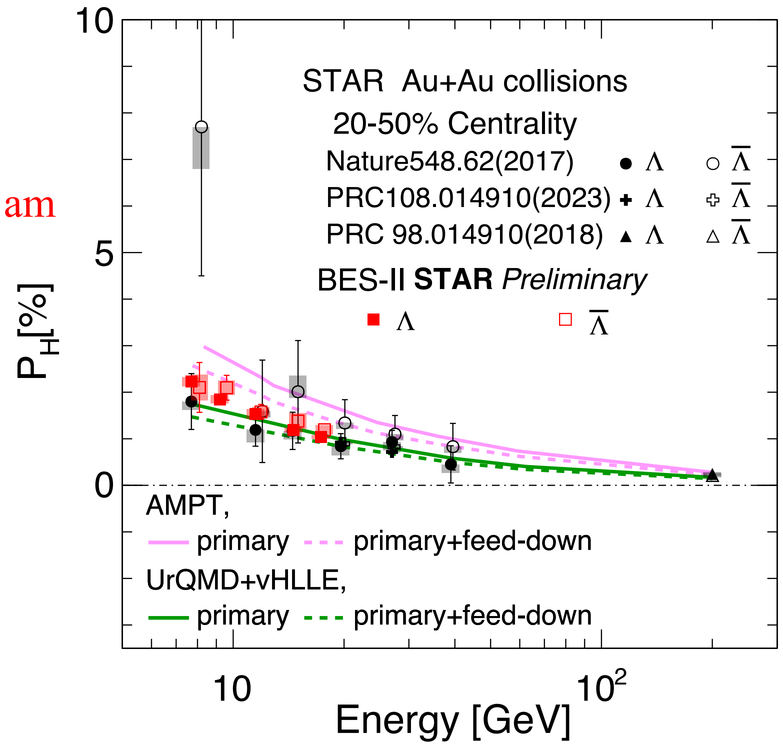
- Global orbital angular momentum leads to global polarization along ***L*** though spin-orbit coupling

Z.-T. Liang and X.-N. Wang, PRL 94, 102301 (2005)

Motivation

Tong Fu
9/23,11:00 am

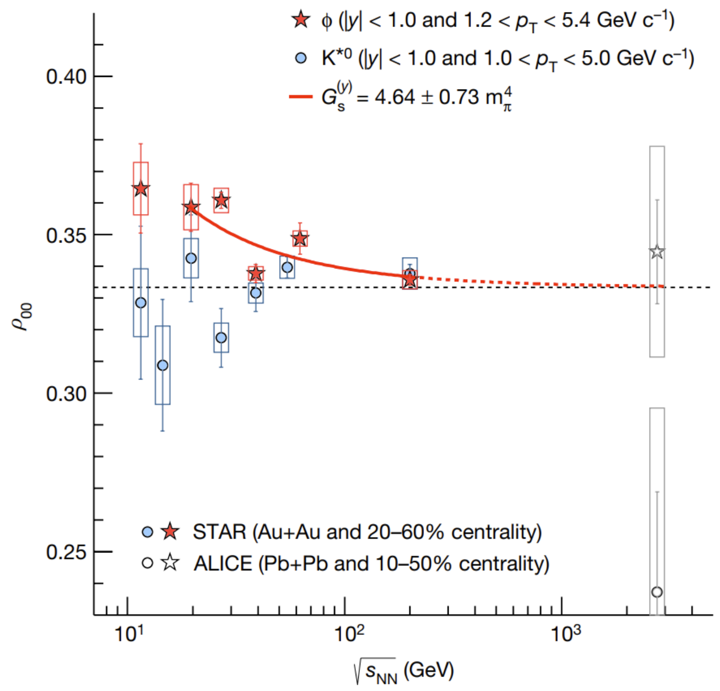
Global polarization



$$P_q = P_{\bar{q}} \sim 10^{-2}$$

Spin alignment

STAR, Nature 614 (2023) 7947



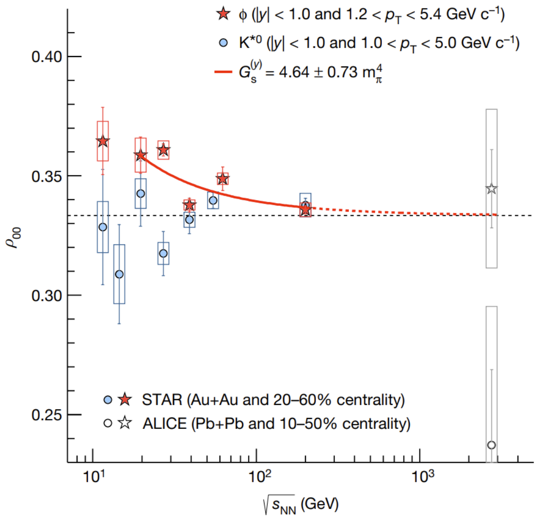
$$\rho_{00} - \frac{1}{3} \sim 10^{-2} \gg P_q^2(10^{-4}) \qquad \langle P_q P_{\bar{q}} \rangle \neq \langle P_q \rangle \langle P_{\bar{q}} \rangle$$

- Significant global polarization and spin alignment observed by STAR experiment
- Spin correlation between P_q and $P_{\bar{q}}$? Lv J P, et. al, Phys. Rev. D 109, 114003 (2024)

Motivation

Spin alignment

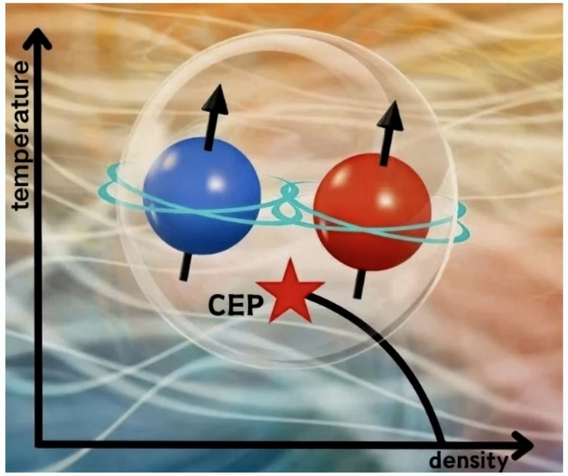
STAR, Nature 614 (2023) 7947

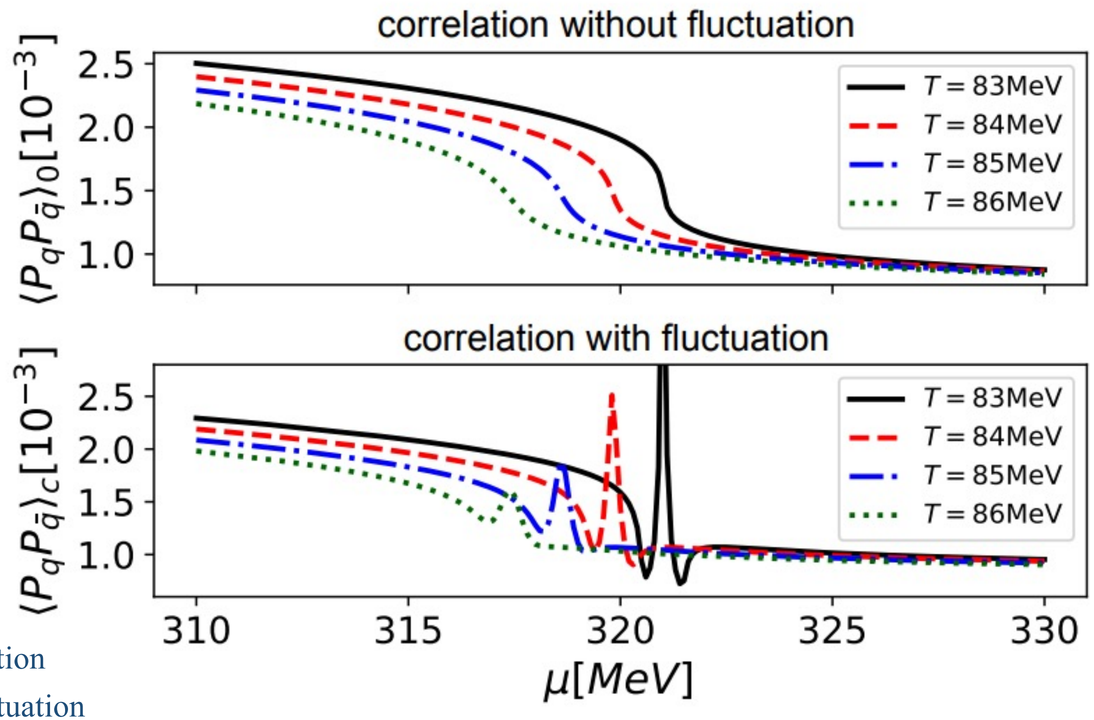


$$\rho_{00} - \frac{1}{3} \sim 10^{-2} \gg P_q^2(10^{-4})$$

$$\langle P_q P_{\bar{q}} \rangle \neq \langle P_q \rangle \langle P_{\bar{q}} \rangle$$

Hao-Lei Chen, et. al, PRL 135. 032302 (2025)





μ is quark chemical potential, $\mu = \mu_B/3$

$\langle P_q P_q \rangle_c$: spin correlation with critical fluctuation

$\langle P_q P_q \rangle_0$: spin correlation without critical fluctuation

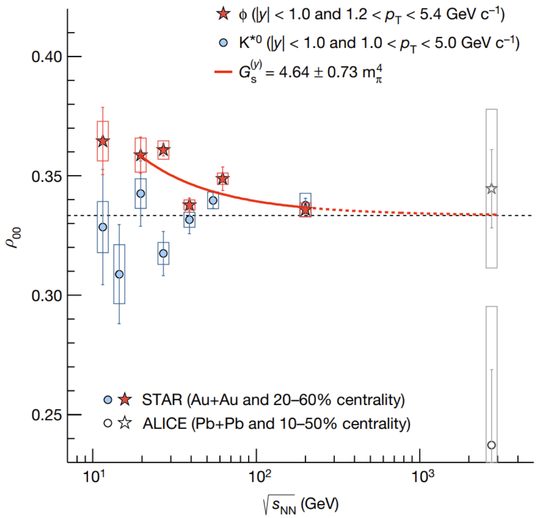
and correlations. We propose the quark-antiquark correlation, which relates to the vector meson spin alignment and the $\Lambda - \bar{\Lambda}$ correlation, can be used as a novel probe of the critical end point (CEP) in the QCD phase diagram. Using the Nambu-Jona-Lanisio model, we qualitatively study

The hyperon spin correlation is sensitive to the CEP in the QCD phase diagram

Motivation

- Spin alignment

STAR, Nature 614 (2023) 7947



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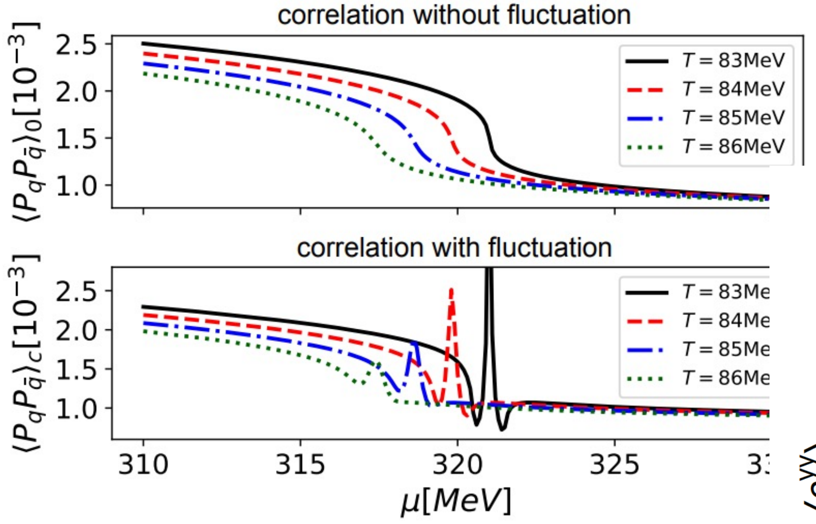
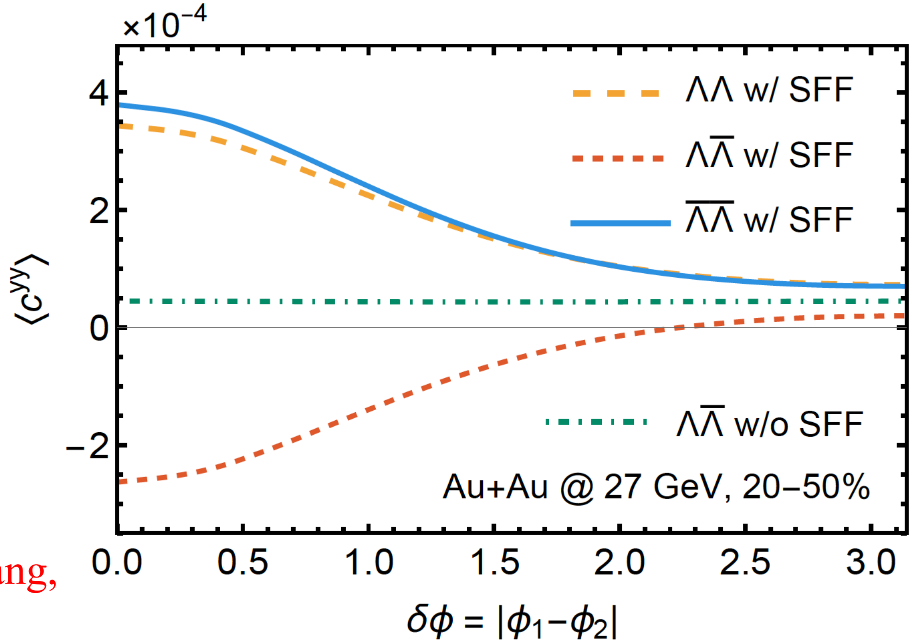


SFF : local strong force field

Xin-Li Sheng 9/23,16:15 pm

Xin-Li Sheng, et. al, arXiv: 2508.03496



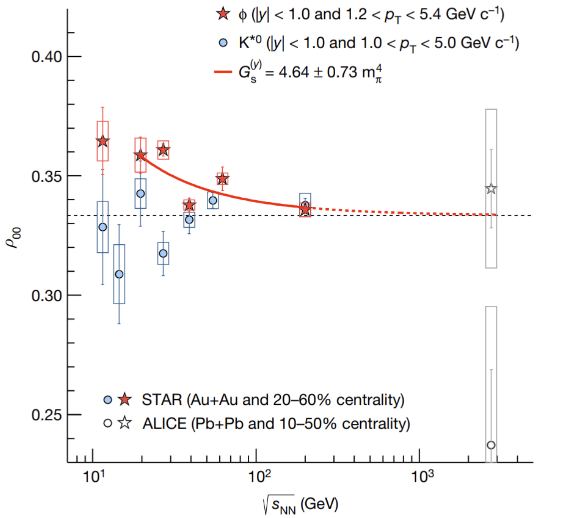
More talks:
Qun Wang, Ji-Peng Lv, Shi Pu, Xu-Guang Huang, Zi-Han Yu, etc

- The hyperon spin correlation is sensitive to the CEP in the QCD phase diagram
- Different spin correlation behaviors of $\Lambda\Lambda$ and $\Lambda\bar{\Lambda}$ pairs are predicted by the theoretical model

Motivation

Spin alignment

STAR, Nature 614 (2023) 7947



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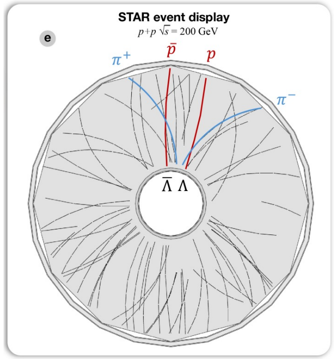
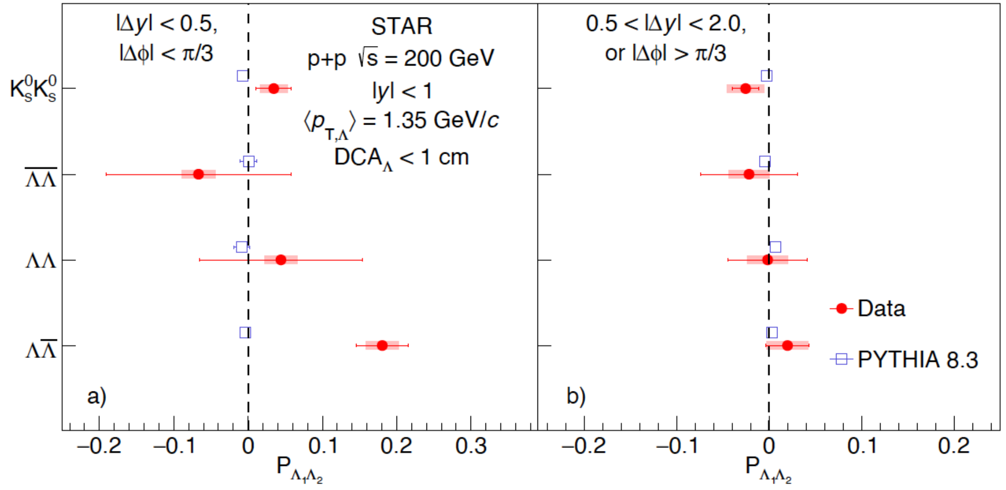


Spin correlations in pp measurement

STAR, arXiv: 2506.05499



- Spin correlation $C^S_{\Lambda_1\Lambda_2}(P_{\Lambda_1\Lambda_2})$ can be determined as follow,

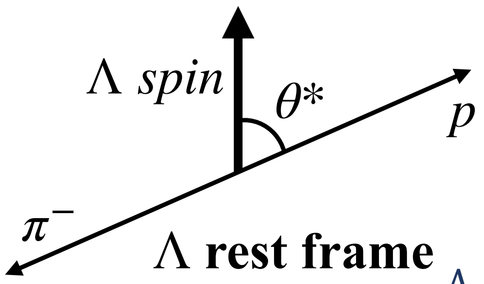
$$\frac{1}{N}\frac{dN}{d\cos\theta^*_{1,2}} = \frac{1}{2}[1 + \alpha_1\alpha_2 C^S_{\Lambda_1\Lambda_2}\cos\theta^*_{1,2}]$$

$\theta^*_{1,2}$ is the angle between the momentum of the protons, each boosted to the rest frame of their parent particle

- A nonzero spin correlation is observed in $\Lambda\bar{\Lambda}$ pairs
- ***How about heavy ion collisions?***

Spin Correlation Measurement

- "Self-analyzing", parity-violating weak decay channel of hyperons
  - Daughter baryon is preferentially emitted in the direction of the hyperon spin



$\Lambda \rightarrow p + \pi^-$

(BR:63.9%,cτ~7.9cm)

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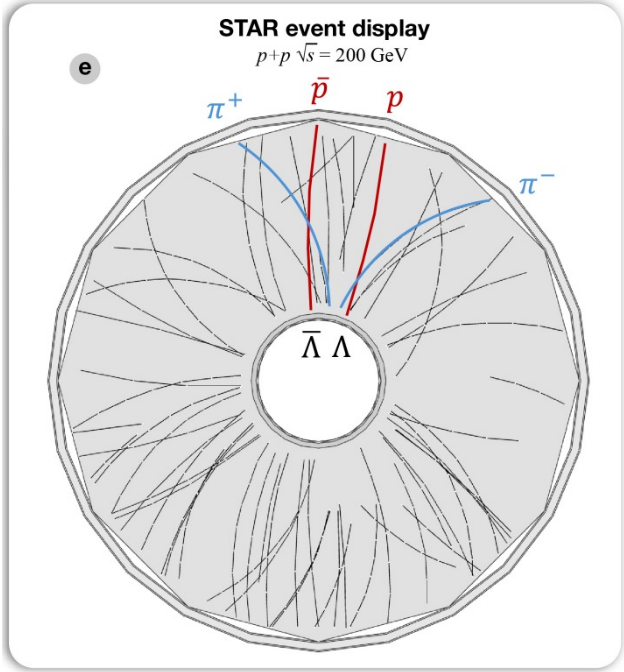
STAR, arXiv: 2506.05499

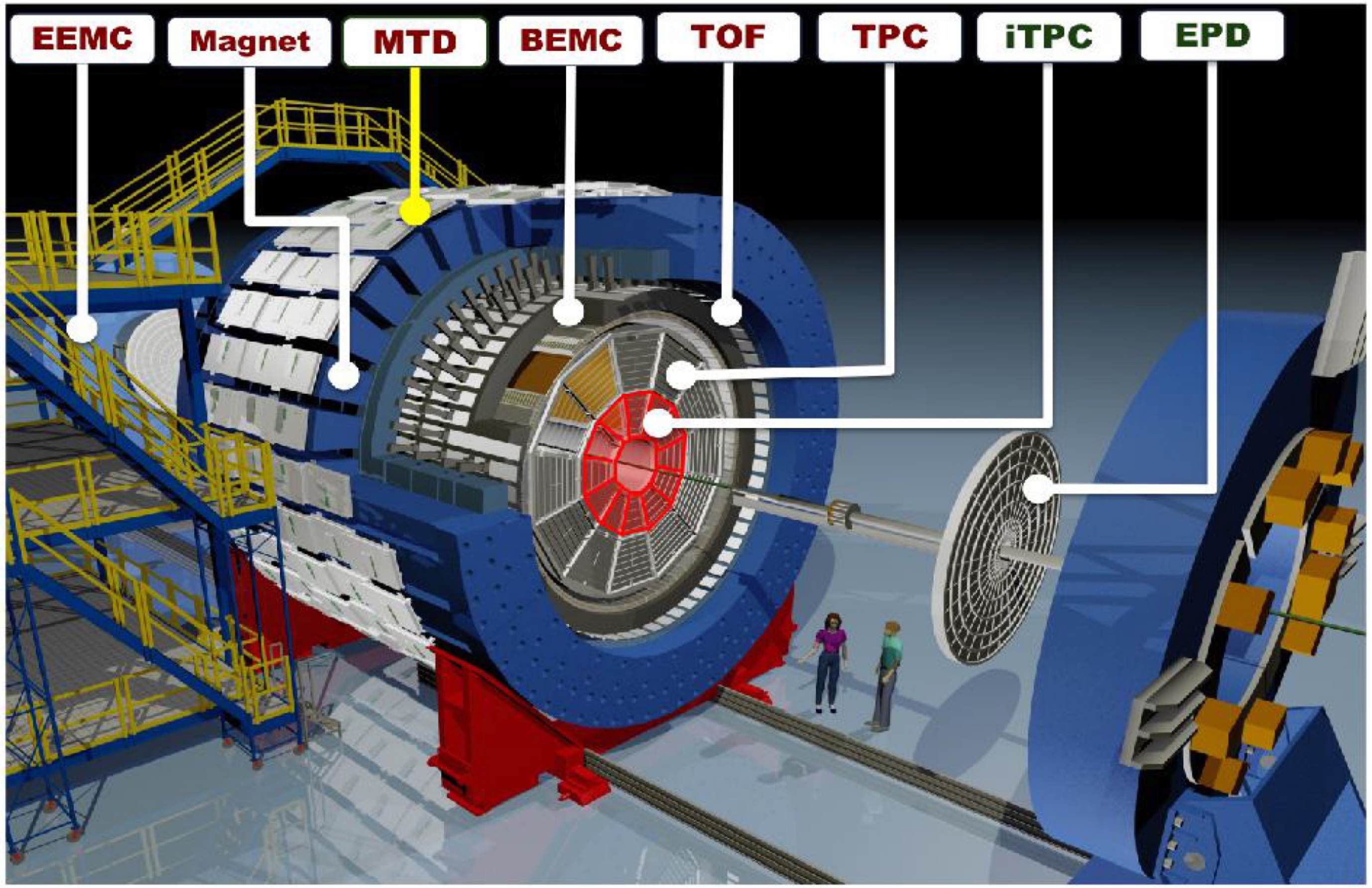
$\theta^*_{1,2}$: the angle between the momentum of the protons, each boosted to the rest frame of their parent particle

α_H : hyperon decay parameter

$C^S_{\Lambda_1\Lambda_2}$: spin correlation of $\Lambda_1\Lambda_2$ pair



STAR Detector

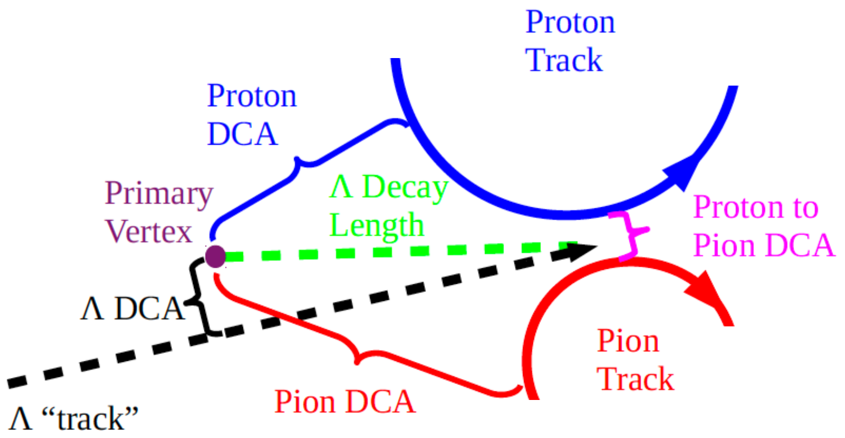


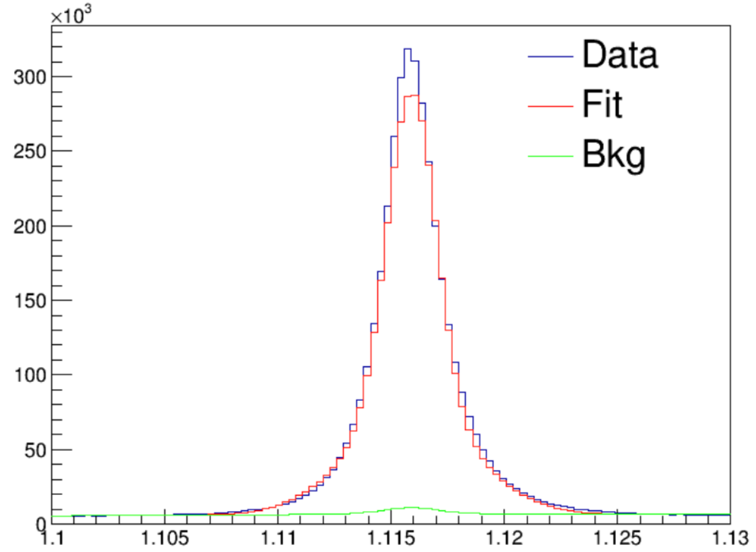
- **Time Projection Chamber**
  - Upgrade with inner TPC
  - Better track quality
  - Larger acceptance
  - $|\eta| < 1.0 \rightarrow |\eta| < 1.5$

- **Time Of Flight**
  - PID via particle velocity
  - $|\eta| < 0.9$

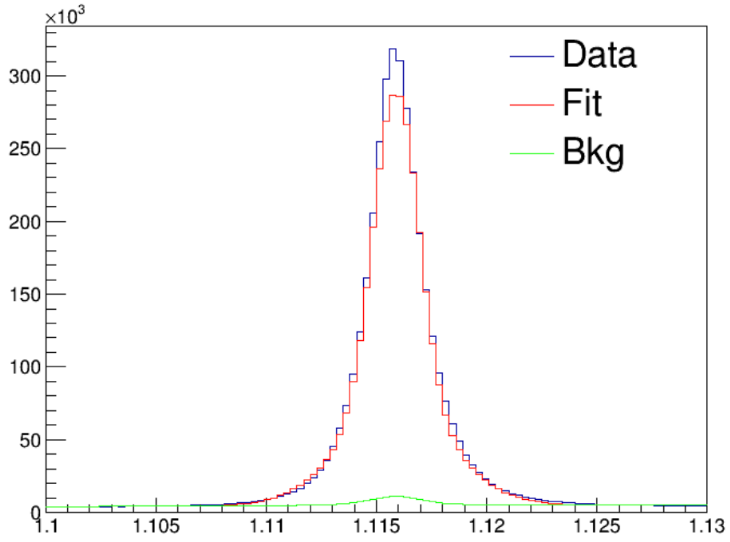
Λ Hyperon Reconstruction

- Particle identification by TPC and TOF
- Hyperons reconstructed using KF Particle package
  - $\Lambda \rightarrow p + \pi^-$
  - $\bar{\Lambda} \rightarrow \bar{p} + \pi^+$





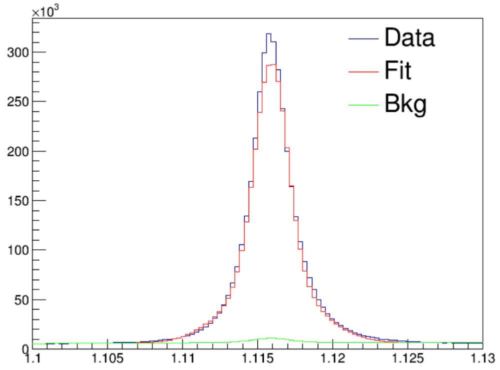
Λ_1 Mass



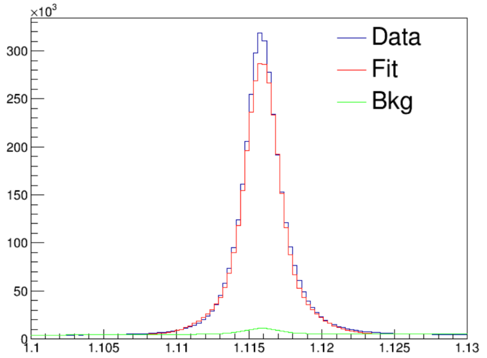
Λ_2 Mass

$\Lambda_1\Lambda_2$ Pair Signal Extraction

- Fit the $\Lambda_1\Lambda_2$ pair invariant mass distribution in $\cos\theta^*_{1,2}$ bin
  - Signal (2D Gaussian) + background (2nd order polynomial)

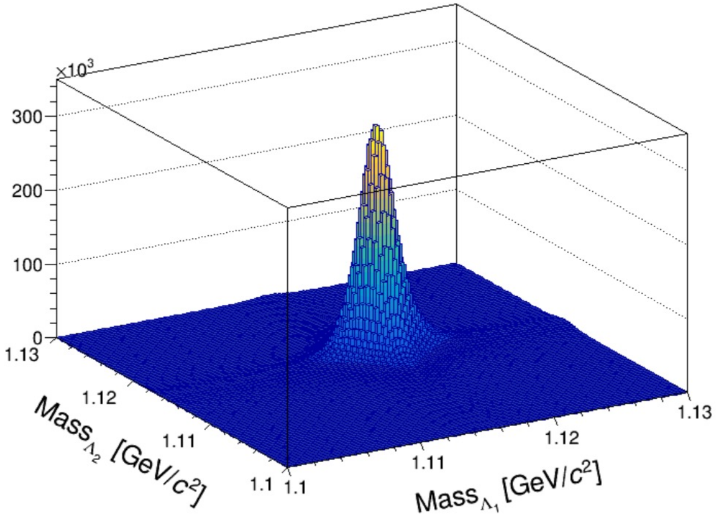


Λ_1 Mass



Λ_2 Mass

- The combinatorial under peak
  - Peak: Λ_1 signal + Λ_2 signal
  - Ridges: Λ_1 signal + Λ_2 background, Λ_2 signal + Λ_1 background
  - Continuum: Λ_1 background + Λ_2 background



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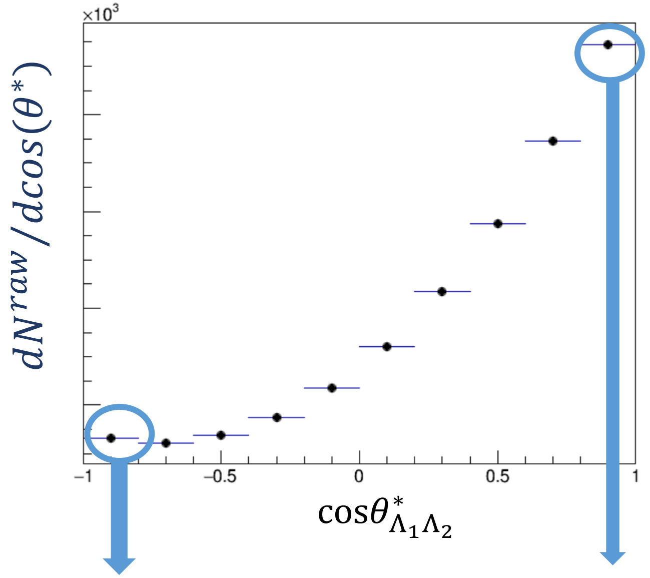

- The combinatorial under peak
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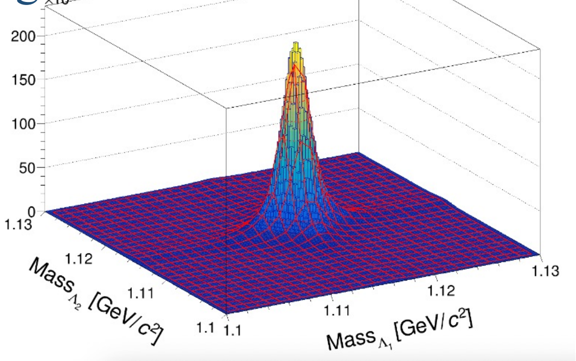
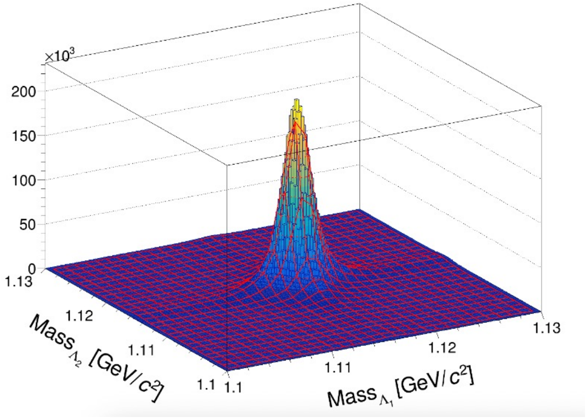
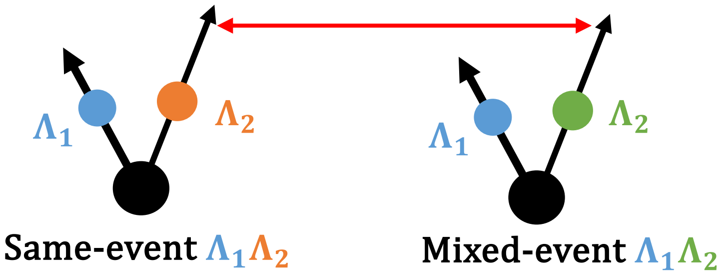




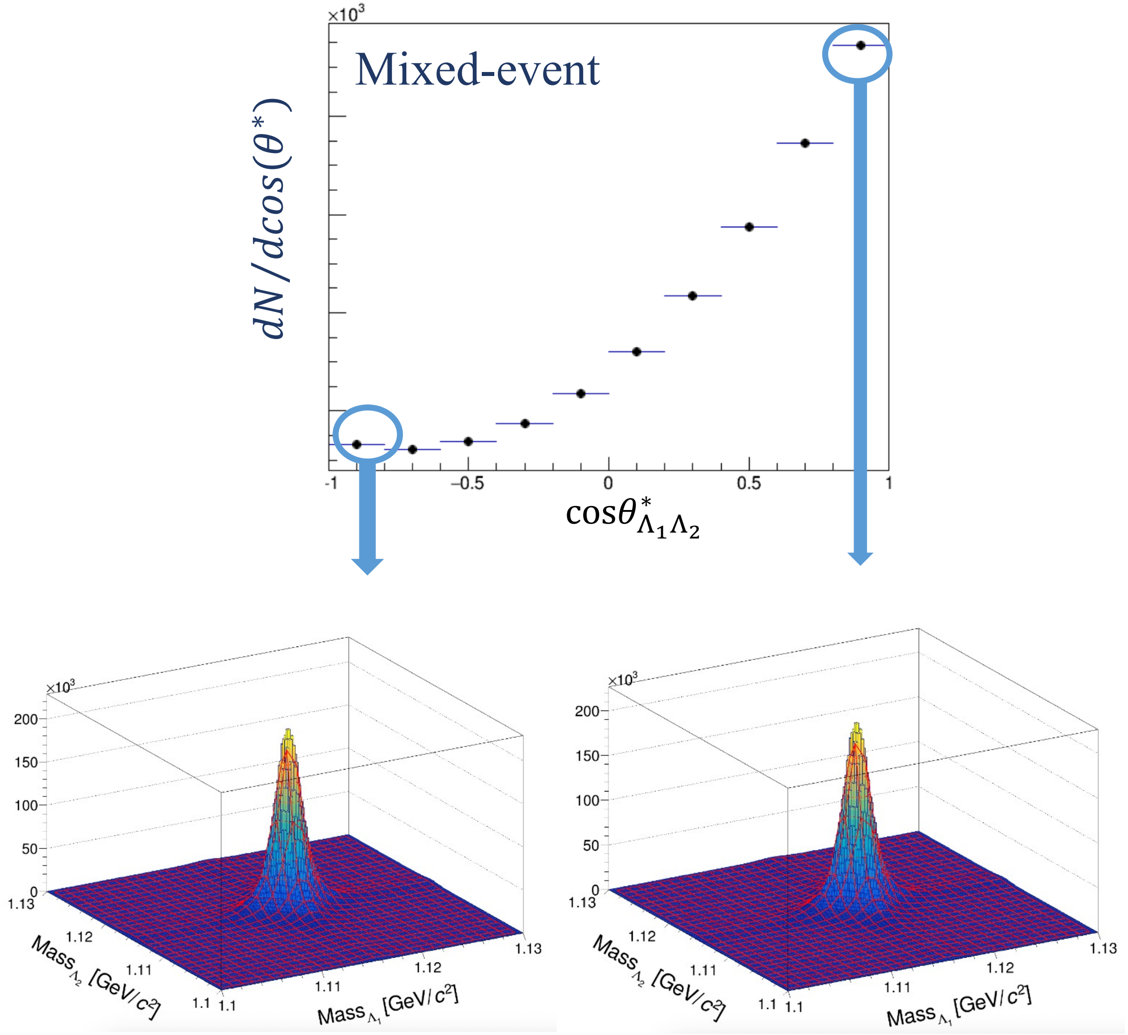
- Signal = Total counts – Fit background counts

Detector Acceptance Effect

- Measured $dN/dcos(\theta^{*})$ distributions affect by the detector acceptance
- Mixed-event hyperon pairs use to correct the effect
  - High statistics, data driven
- Mixed-event definition, eg, $\Delta\ V_z = |V_{z,\Lambda_2} - V_{z,\Lambda_2}|$
  - $\Delta\ V_z < 5$ cm, same centrality
  - $\Delta\ P_T < 0.1, \Delta\ \eta < 0.1, \Delta\ \phi < 0.1$

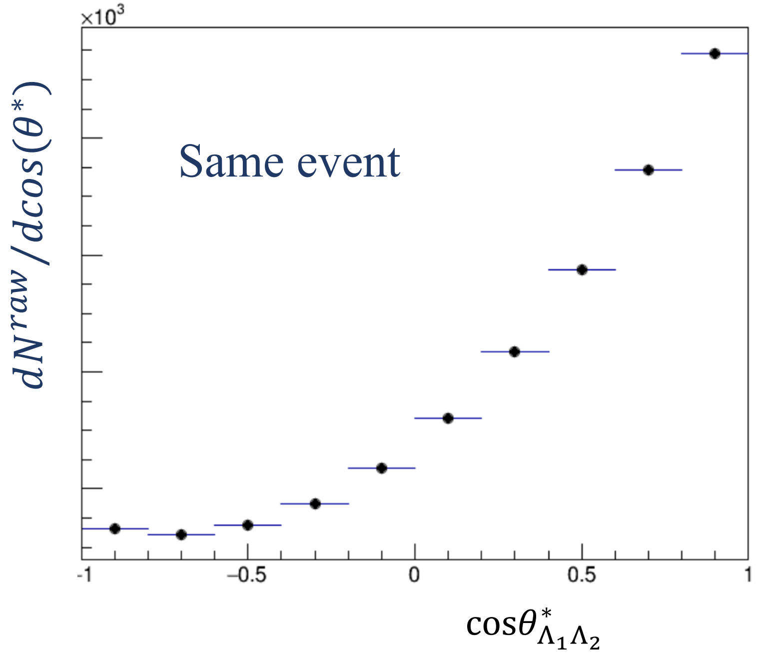


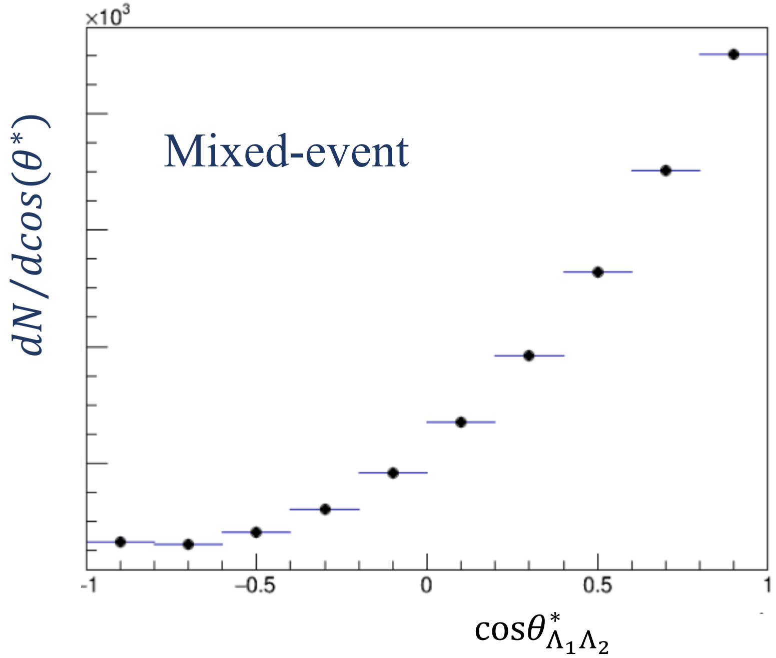
Mixed single Λ_2 from different event



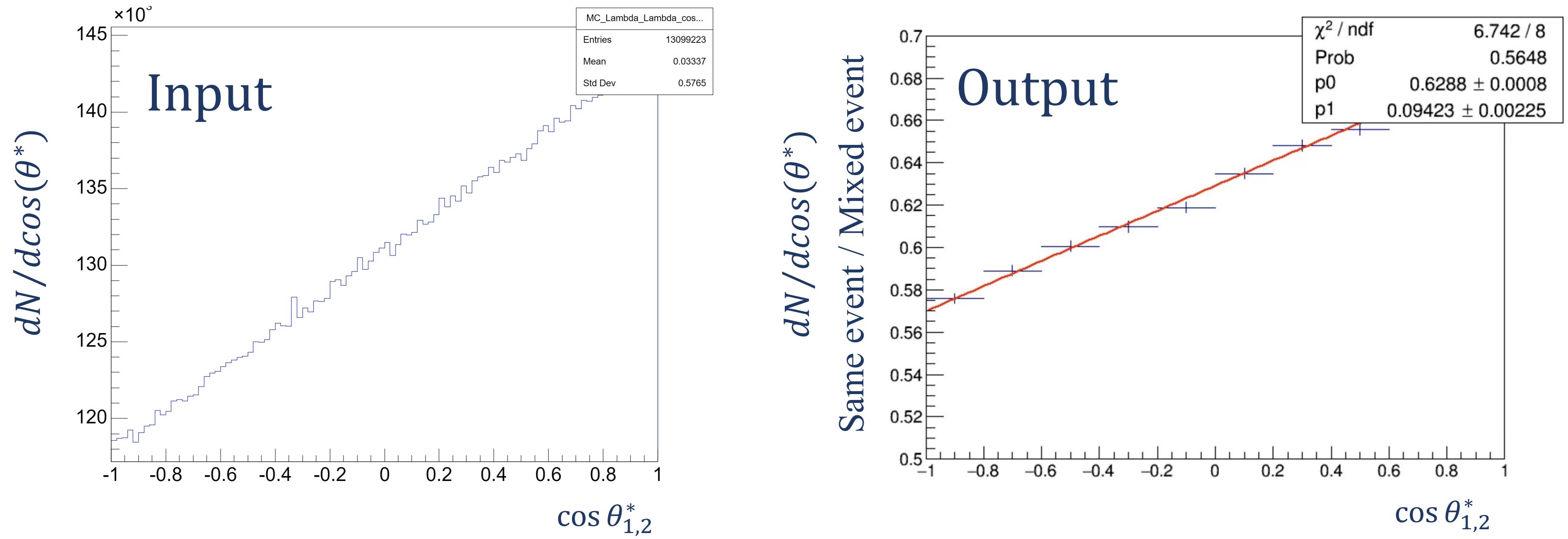
Spin Correlation Extraction

- Mixed-event hyperon pairs use to correct the acceptance effect : **Same event** / **Mixed event**
- Correlation signal is extracted by fitting $dN/dcos(\theta^*)$ distribution after Mixed-event correction





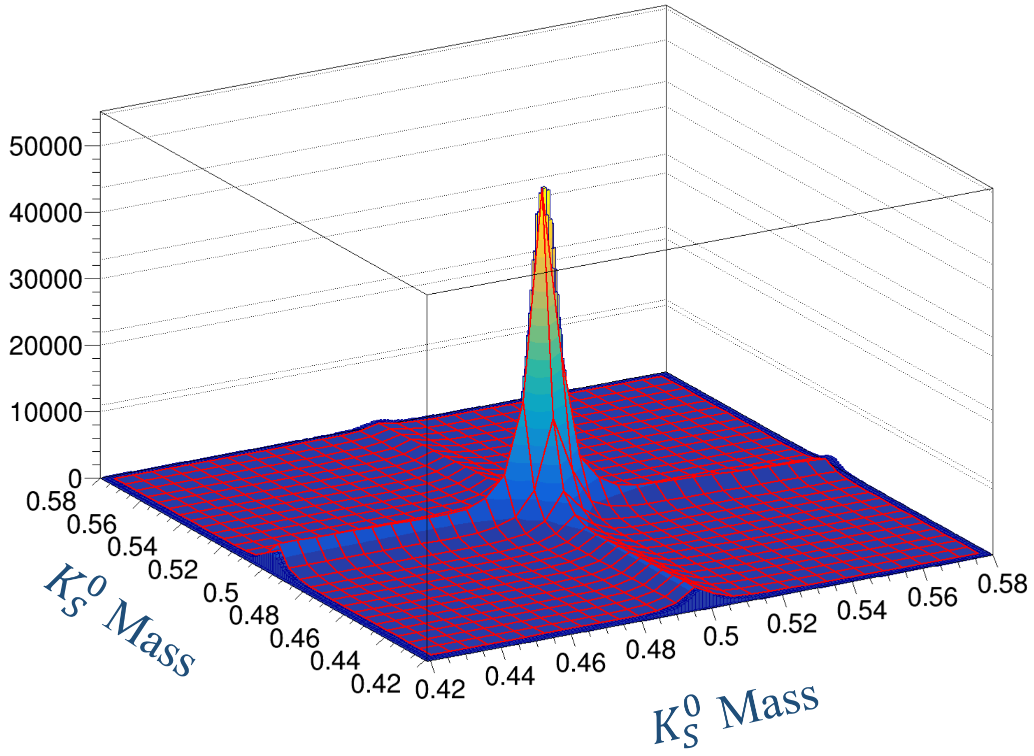
Mixed-event method -- Closure test with simulation



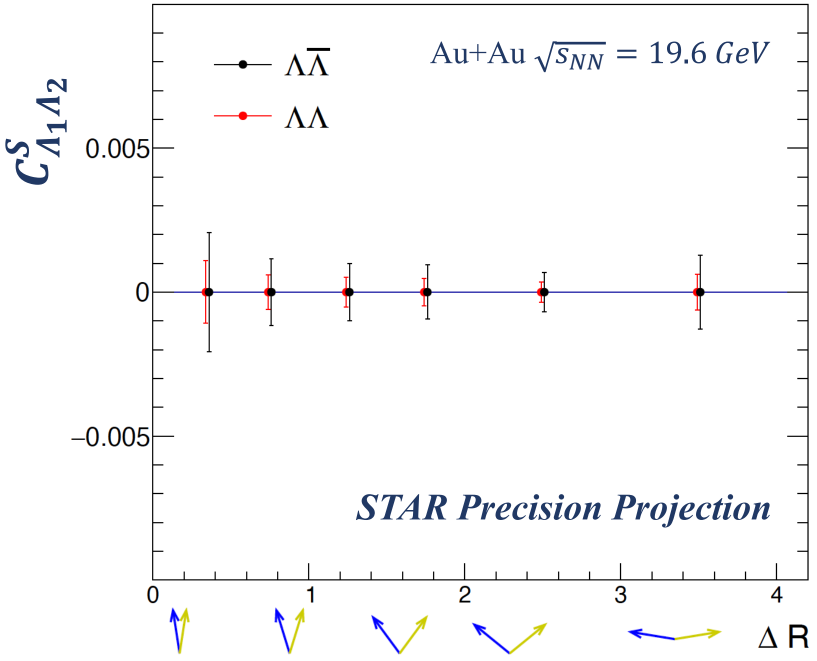
- Pure simulation with embedding data in Au+Au collisions at 14.6 GeV
- Input spin correlation = 0.1000
- Fit function: $dN/dcos(\theta^*) = p_0[1 + p_1 cos(\theta^*)]$ p_0 is normalization, $p_1 = \alpha_1\alpha_2 C^S_{\Lambda_1\Lambda_2}$
- Spin correlation: $C^S_{\Lambda_1\Lambda_2} = \frac{p_1}{\alpha_1\alpha_2} = 0.0942 \pm 0.0023$
- Input and Output are consistent within ~2.5 σ

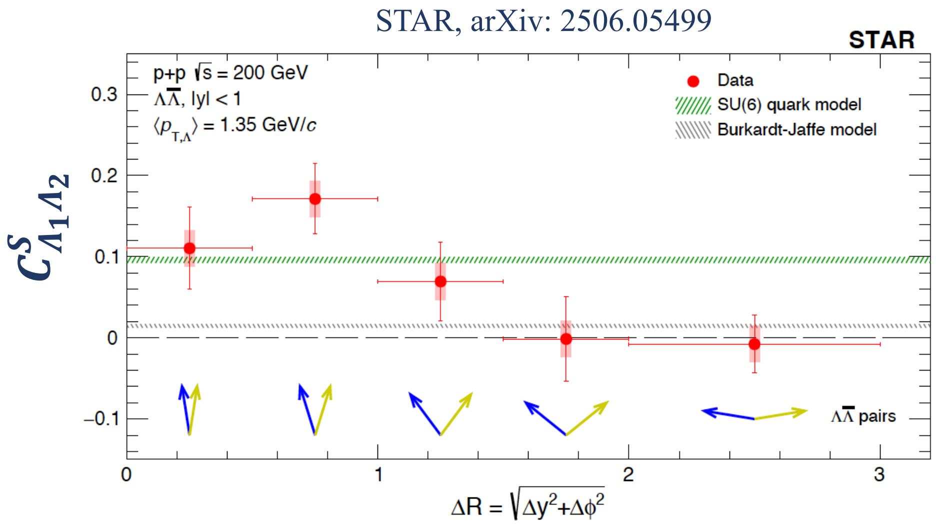
$K_S^0 K_S^0$ spin correlation

- The K_S^0 reconstructed by π^-, π^+ decay channel using TPC and TOF
- Spin correlation signal is extracted by fitting $dN/dcos(\theta^*)$ distribution after Mixed-event correction
- Spin correlation of $K_S^0 K_S^0$ pair is consistent with zero within uncertainty.



$\Lambda\Lambda$ and $\Lambda\bar{\Lambda}$ Spin Correlation Statistical Projection





- Spin correlation as a function of distance between Λ_1 and Λ_2 $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$
- Measurement precision in Au+Au collisions is better than in pp collisions, detailed analysis is on going

Summary

- The hyperon spin correlation provide more information to the QGP properties
- The measurement of hyperon spin correlation in heavy ion collision
  - Hyperon reconstruction using TPC and TOF detector
  - Detector acceptance corrected using mixed-event method
  - Spin correlation to be extracted after correction
  - Analysis method was validated by the closure test and $K_s^0 K_s^0$ spin correlation
  - Further checks on-going
- Stay tuned for the results
  - Au+Au collisions at BES-II energies, isobar collisions at 200 GeV, and more

Back Up

Background subtraction

- Fit the invariant mass distribution in each $\cos\theta^*_{12}$ bin to subtract the background counts.

Fit function(a): $\Lambda_1 : 2D\ Gaussian(signal) + (Aq^{\frac{1}{2}} + Bq^{\frac{3}{2}})(background)$

× $\Lambda_2 : 2D\ Gaussian(signal) + (Aq^{\frac{1}{2}} + Bq^{\frac{3}{2}})(background)$

$q = M_{inv} - m_\pi - m_p$

Fit function (2): $\Lambda_1 : 2D\ Gaussian(signal) + (Pol2)(background)$

× $\Lambda_2 : 2D\ Gaussian(signal) + (Pol2)(background)$

- Signal = Totalcounts – [background fit Function]