Measurement of Λ polarization in Au+Au $\sqrt{s_{NN}} = 7.2$ GeV

Fixed-target collisions at STAR

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Introduction

- In non-central collision...
  - The created matter should exhibit rotation motion.
  - The strong magnetic field would appear in the initial state.
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 \( \Lambda \)'s spin (opposite for anti-\( \Lambda \)).

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

**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)

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

- \( \alpha_H \): decay parameter
- \( \Psi_1 \): 1st-order event plane
- \( \phi_p^* \): \( \phi \) of the azimuthal angle of the daughter baryon (in the hyperon's rest frame)

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Motivation

- So far, $\Lambda$ 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 $\Lambda$ and anti-$\Lambda$.
  ✓ 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 $\Lambda$ and anti-$\Lambda$ might be measured.
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
- **Event Plane Detector (EPD)**
  - Event plane reconstruction, $2.1<|\eta|<5.1$
The gold target was installed inside the vacuum pipe at $z = 200$ cm.

Target is 0.25mm thick and $\sim 1\%$ 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).

Step 1: Count number of pion and proton with T0 from -0.3 to 0.3 [nsec].

Step 2: 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-order event plane was reconstructed by following formula.

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

Event plane resolution was calculated by 3-sub-event method.

\[
\langle \cos([\Psi^A_1 - \Psi^B_1]) \rangle = \langle \cos([\Psi^A_1 - \Psi^{\text{true}}_1])\cos([\Psi^{\text{true}}_1 - \Psi^B_1]) \rangle
\]

\[
= \sigma_n^A \sigma_n^B
\]

\[
\text{Res}(\Psi^A_1) = \sqrt{\frac{\langle \cos([\Psi^A_1 - \Psi^B_1])\cos([\Psi^A_1 - \Psi^{\text{true}}_1]) \rangle}{\langle \cos([\Psi^B_1 - \Psi^{\text{true}}_1]) \rangle}}
\]

Λ reconstruction

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

**Proton**
- $|n\sigma| < 3$
- $0.5 < m^2 < 1.5 \text{ (GeV/c)^2}$

**Pion**
- $|n\sigma| < 3$
- $0.5 < m^2 < 1.5 \text{ (GeV/c)^2}$

**Topological cut**
- $p$-DCA $> 0.4 \text{ cm}$
- $\pi$-DCA $> 1.6 \text{ cm}$
- $p$-$\pi$ DCA $< 1.1 \text{ cm}$
- $\Lambda$-DCA $< 0.7 \text{ cm}$
- Decaylength $> 5.0 \text{ cm}$

These values of topological cut are slightly changed depending 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 $\Lambda$ 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 $\Lambda$.

Not corrected for resolution and detector effects

Two tracks are crossing (worse mass resolution)

Two tracks fly away

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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 $\sim 139$M (after event selection)

Event selection

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

Track selection

- $n_{\text{HitsFit}} > 10$
- $n_{\text{HitsFit}}/n_{\text{HitsPoss}} > 0.52$
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: $|n\text{SigmaPion}| < 2$
  - Pion: $|n\text{SigmaPion}| < 2$

- $T_0 = \text{TOF}_1 - \text{TOF}_2$
  - $T_0$: TOF start timing
  - $\text{TOF}_1 = \text{btofPidTraits} \rightarrow \text{btof}()$
  - $\text{TOF}_2 = \frac{L}{v}$
  - $L$: flight distance of particle
    - $L = \text{tofPathLength}(&\text{origin}, &\text{btofHitPos}, \text{ptrk} \rightarrow \text{helix(picoEvent} \rightarrow \text{bField()}\text{.curvature})*0.01$
  - $v$: velocity of particle
    - $v = c \sqrt{\frac{\alpha^2}{1 + \alpha^2}}$
  - $\alpha = \frac{p}{m}$ (p: momentum, m: mass of pion or proton)
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, $-1.6 < \eta < -1.1$