Supported in part by

Global polarization of hyperons at BES-II energies by the STAR experiment

Outline:

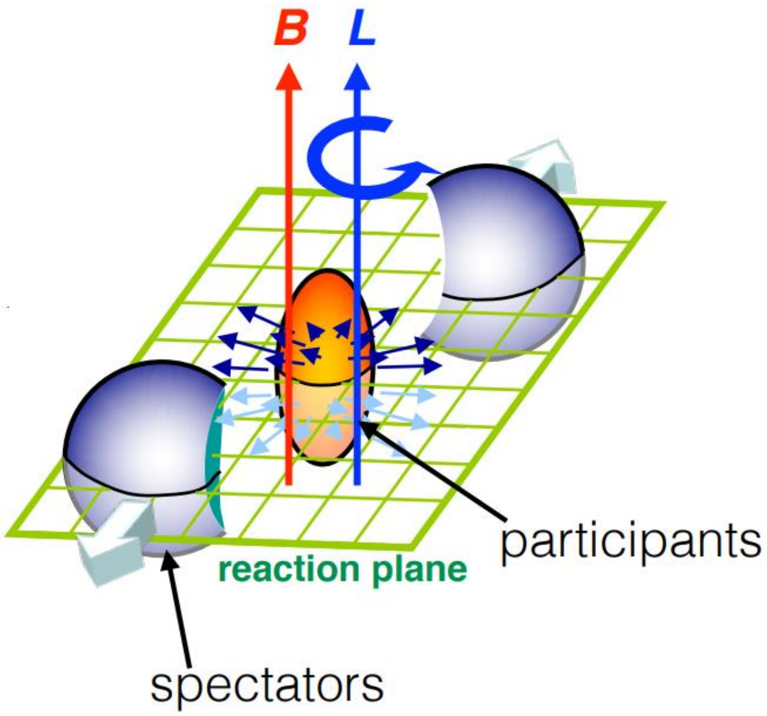
- Introduction
- Global hyperon polarization
- Motivation
- The STAR experiment
- Hyperon polarization measurements
- Results
- Conclusions

Egor Alpatov (for the STAR Collaboration)

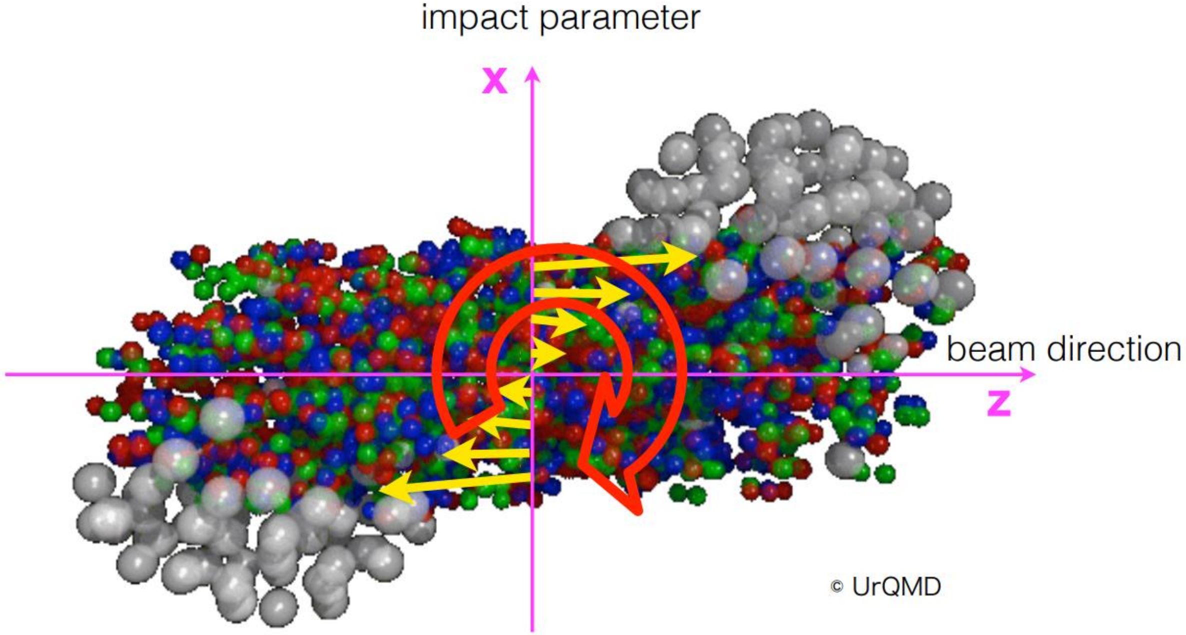
National Research Nuclear University MEPhI

Introduction

- The Quark-Gluon Plasma (QGP) formed in non-central nucleus-nucleus collisions may exhibit vorticity as a result of the large angular momentum carried by the initial collision system
- Spin-orbit coupling aligns spin directions of produced particles along the direction of <u>vorticity</u>
  - Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)
  - S. A. Voloshin, arXiv:nucl-th/0410089
- Another possible source of particle polarization is <u>magnetic field</u>, created in non-central collisions in the initial stage
  - D. Kharzeev, L. McLerran, and H. Warringa, Nucl.Phys.A803, 227 (2008)
  - McLerran and Skokov, Nucl. Phys. A929, 184 (2014)



Vorticity



- In non-central Heavy-Ion Collisions the initial collective longitudinal flow velocity depends on the velocity gradient:

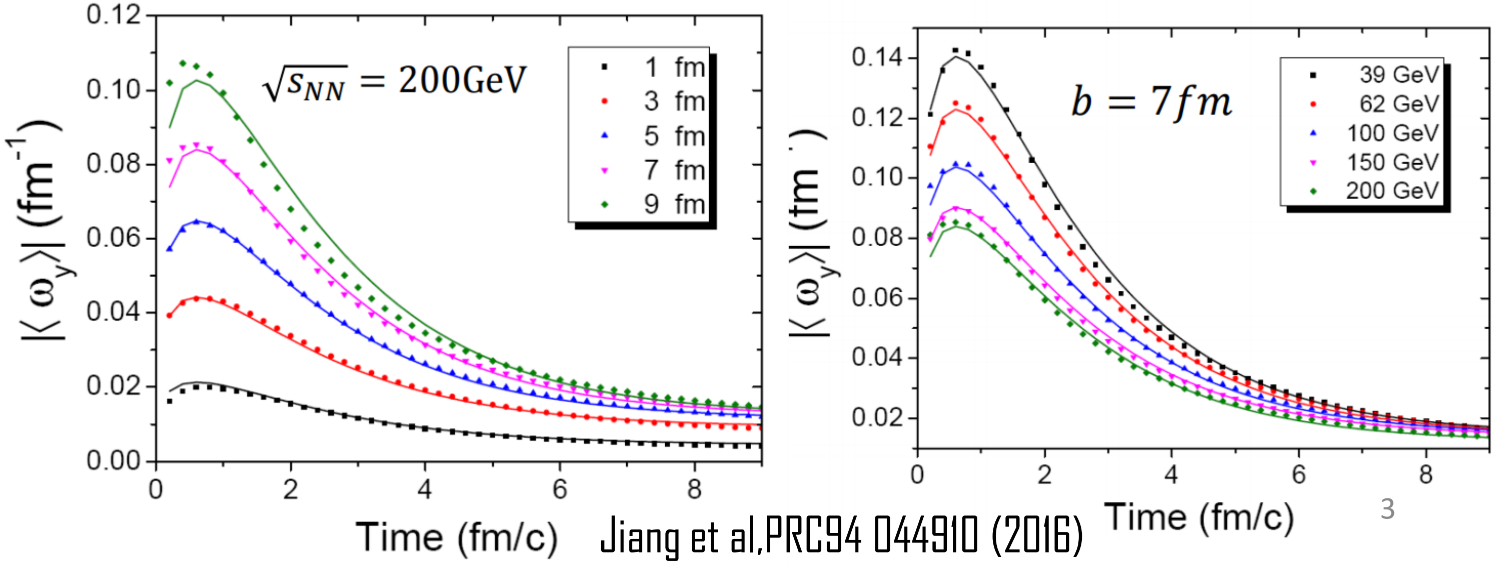
$$\omega_y = \frac{1}{2}(\nabla \times v)_y \approx -\frac{1}{2}\frac{dv_z}{dx}$$

- For small polarization:

Becattini, Karpenko, Lisa, Upsal, Voloshin PRC95.054902 (2017)

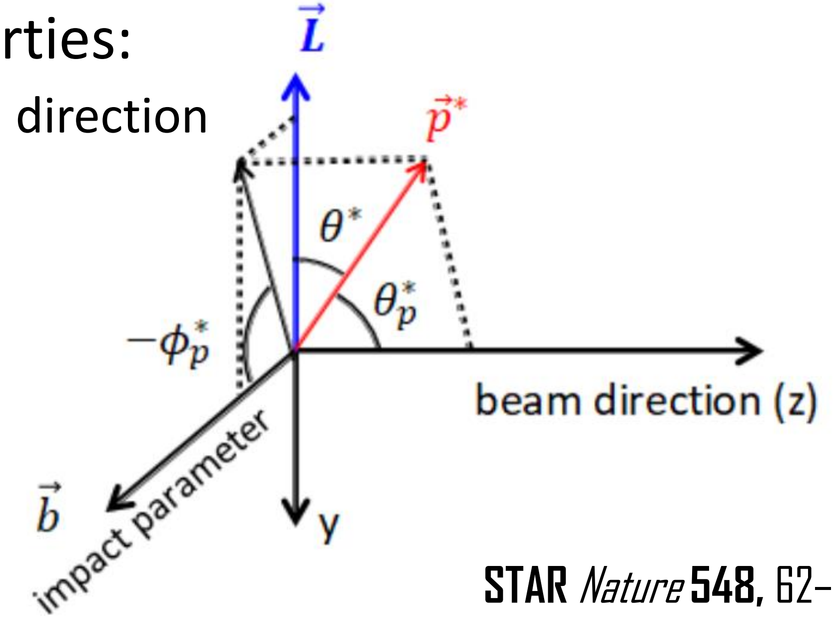
$$P_\Lambda \simeq \frac{1}{2}\frac{\omega}{T} + \frac{\mu_\Lambda B}{T}$$

$$P_{\bar{\Lambda}} \simeq \frac{1}{2}\frac{\omega}{T} - \frac{\mu_\Lambda B}{T}$$



Jiang et al,PRC94 044910 (2016)

How to measure global polarization?



STAR *Nature* **548,** 62–65 (2017)

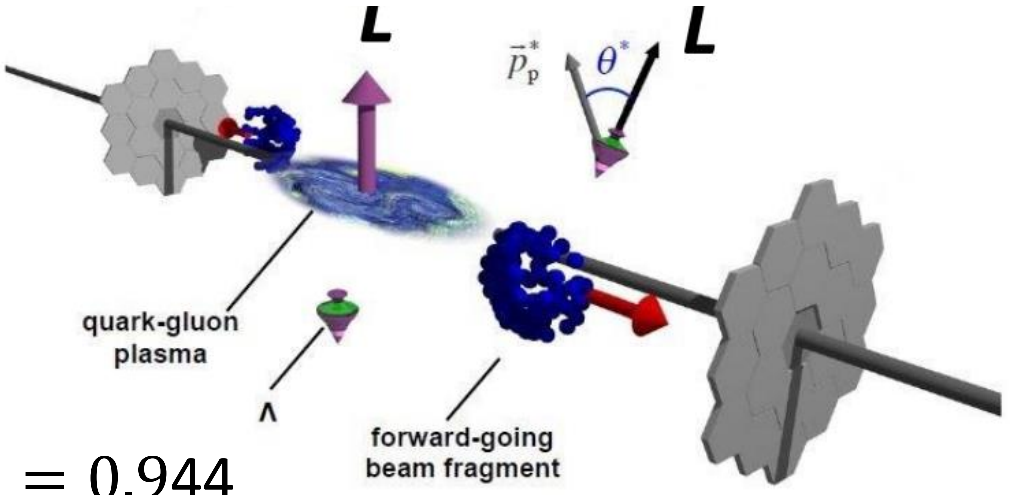
- Hyperons are “self-analyzing” due to weak decay properties:
  - Daughter baryons are preferentially emitted along parent spin direction
- Daughter baryons of hyperons with polarization ($\vec{P}$) follows the distribution:

$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}\left(1 + \alpha_H|\vec{P}| \cdot \widehat{p_b^*}\right) = \frac{1}{4\pi}(1 + \alpha_H P \cos\theta^*)$$

  - α_H - decay parameter, unique for each hyperon species
  - $\widehat{p_b^*}$ is the daughter baryon momentum in the parent frame
- Projection to the transverse plane can be measured:

$$P_H = \frac{8}{\pi\alpha_H}\frac{\langle sin(\psi_1 - \varphi_p^*)\rangle}{Res(\psi_1)}$$

  - ψ_1 is first-order event plane angle (proxy for reaction plane)
  - ψ_1 and its resolution $Res(\psi_1)$ can be calculated with spectator’s signal.

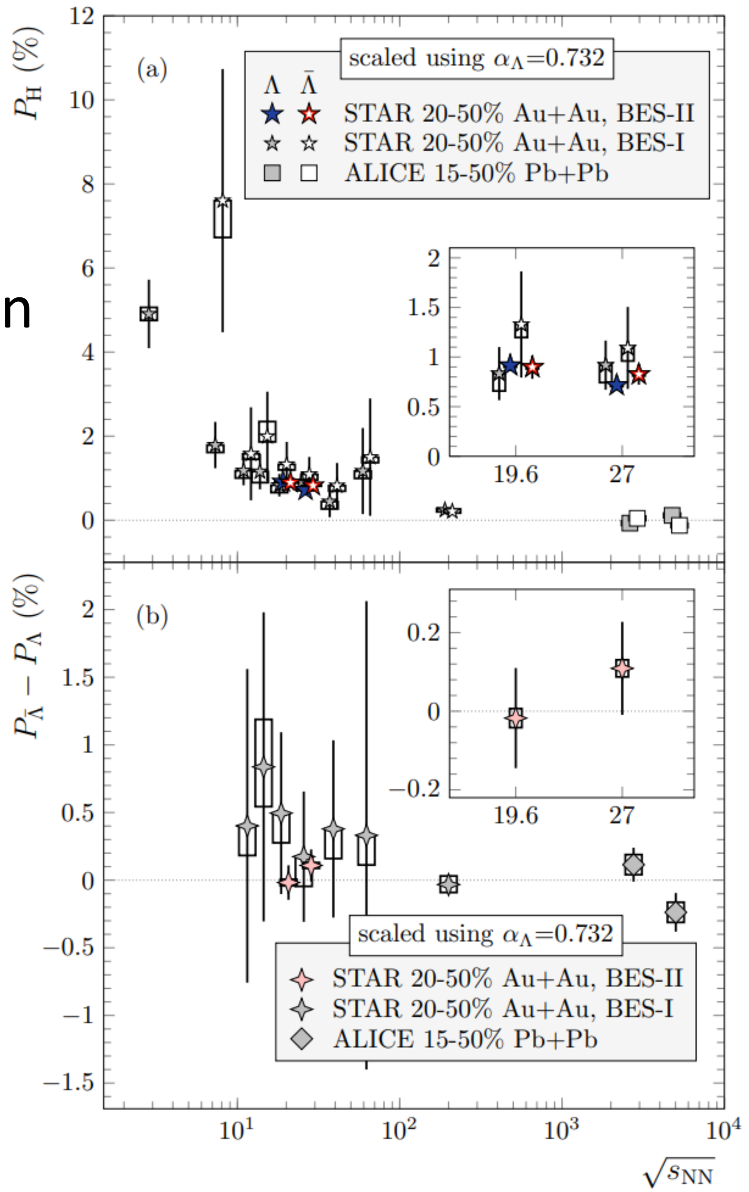


- Ξ global polarization could also be measured via its daughter Λ polarization with transfer factor $C_{\Xi\Lambda} = 0.944$

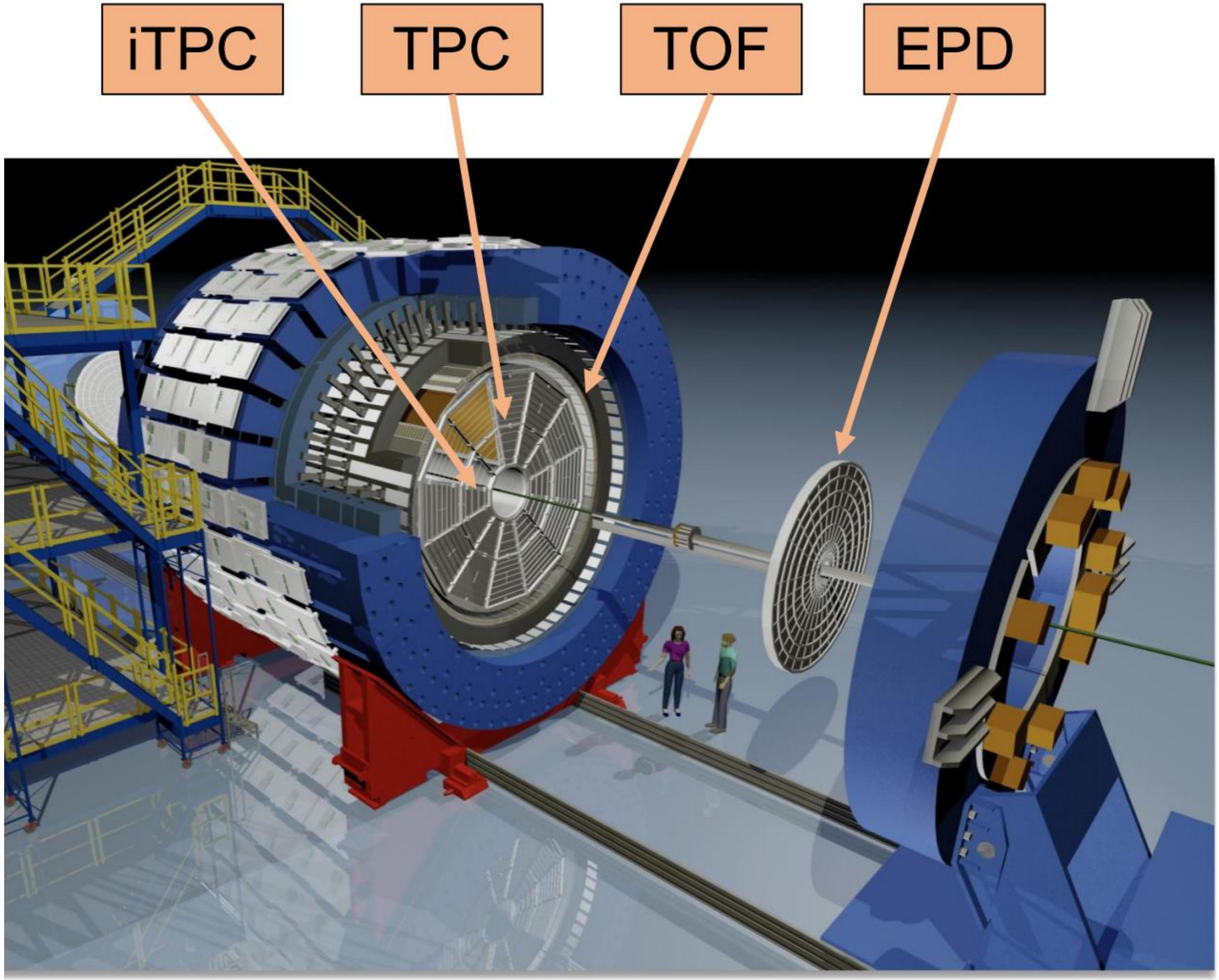
Motivation

- Global polarization of Λ hyperons was measured for $\sqrt{s_{NN}}$ = 3-200 GeV at STAR
- P_H decreases with increasing collision energy
- Recent BES-II Λ global polarization studies shows no significant difference between Λ and $\bar{\Lambda}$ global polarization
- Theoretical calculations can quantitively explain the energy dependence of the Λ polarization, but many of them fail to explain differential measurements like azimuthal dependence of local polarization
- Nowadays there is a growing interest to measure the global polarization of other hyperons such as Ξ.
- Ξ and Ω hyperons global polarization was measured in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
- Ξ polarization may provide new input for global polarization and vorticity studies

PRC 108, 014910 (2023)



The STAR experiment



Detectors with their η acceptance:

Hyperon reconstruction:

- **T**ime **P**rojection **C**hamber
  $|\eta| \in [-1, 1]$
- **iTPC** increases TPC acceptance to [-1.5, 1.5]
- **T**ime-**O**f-**F**light
  $|\eta| \in [-0.9, 0.9]$

Event plane angle measurement:

- **B**eam-**B**eam **C**ounter
  $|\eta| \in [3.3, 5.0]$
- **E**vent-**P**lane **D**etector
  $|\eta| \in [2.1, 5.1]$
- Larger EPD acceptance and granularity improves event-plane resolution ~1.5 times compared to BBC in BES-I

Experimental technique

- **Event plane** Ψ_1 is determined by detectors at forward rapidity where directed flow is large

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

, where w_i is detector's tile ADC

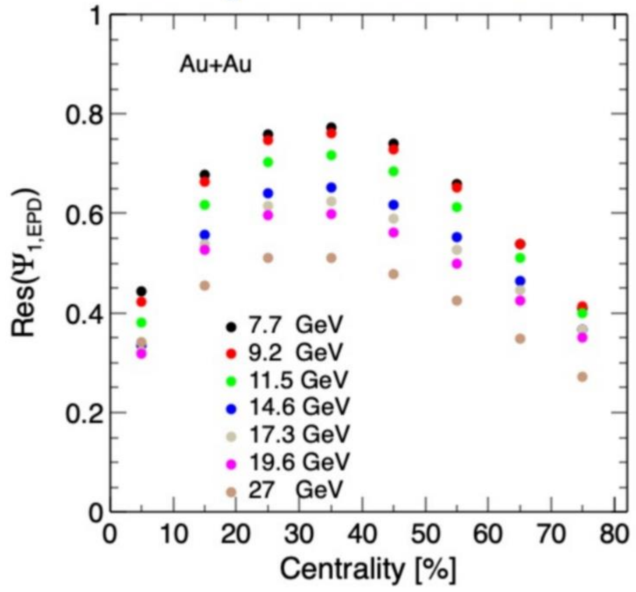
A. M. Poskanzer, S. A. Voloshin, PRC58.1671(1998)

- $Res\left(\Psi_{1,\text{ Full }\eta}\right) = \sqrt{2 < \cos(\Psi_{1,Forward\ \eta} - \Psi_{1,Backward\ \eta}) >}$

Zyzak, Maksym, Kisel, Ivan, Kulakov, Igor, & Vassiliev, Iourii (2013). The KFParticle package for the fast particle reconstruction in ALICE and CBM

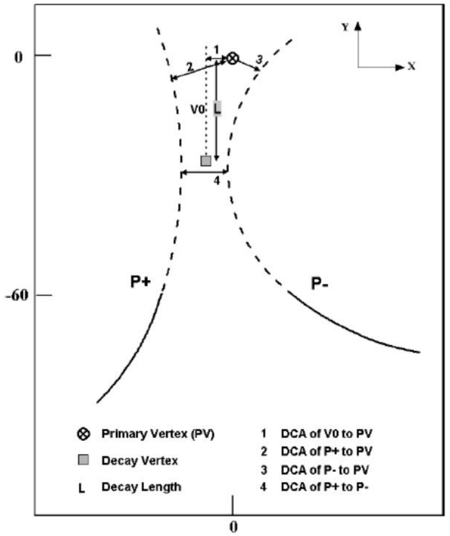
- EPD was used to determine event-plane angle

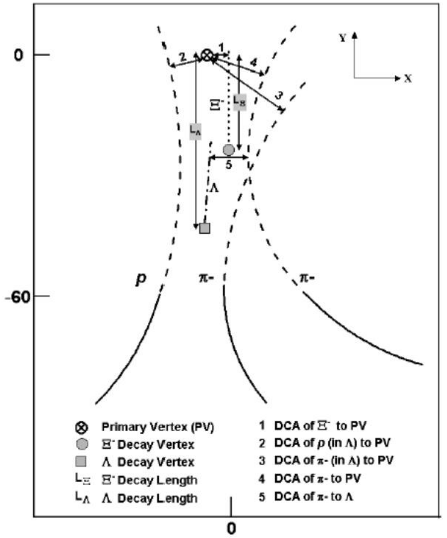
Event plane resolution



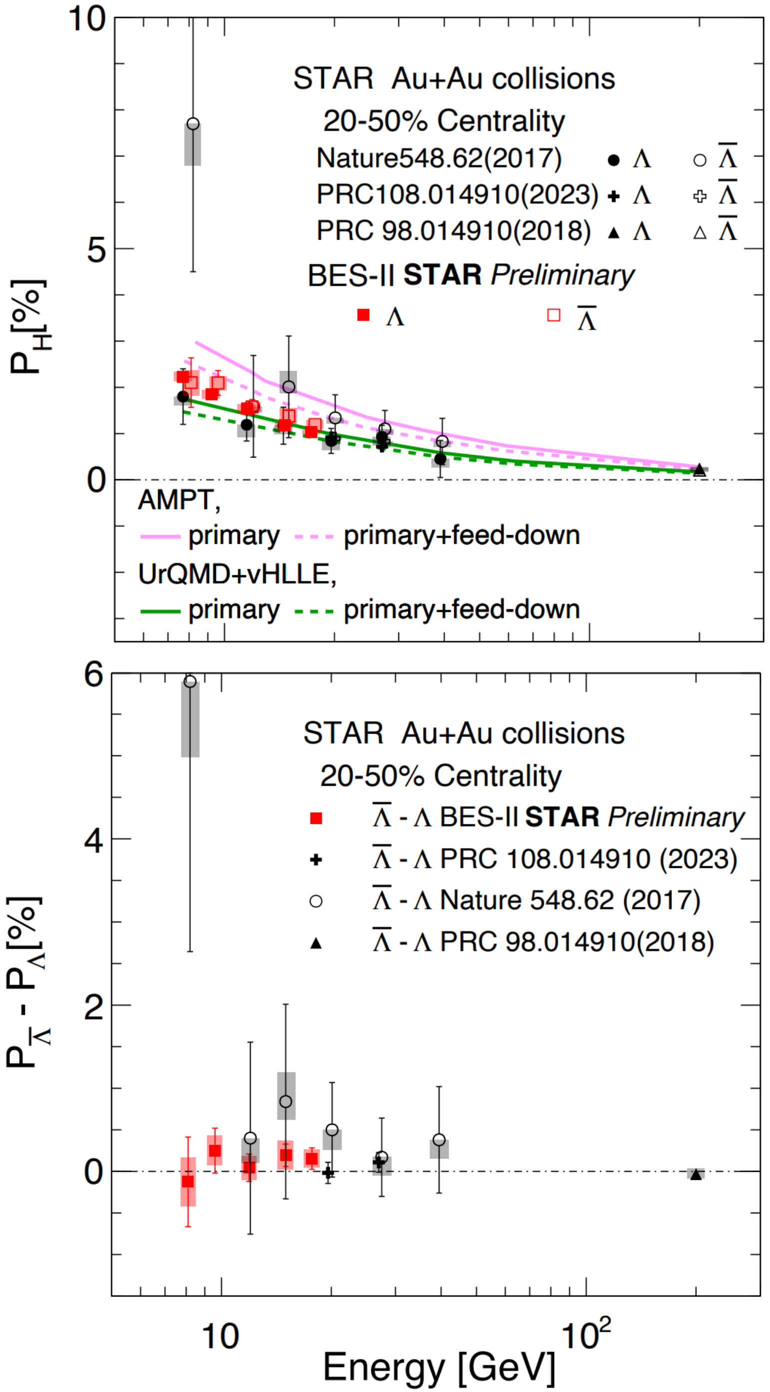
Hyperon reconstruction performed via decay topology with KFParticle tecnique

- Λ daughters identified via TPC and TOF
- Ξ were reconstructed via $\Xi \rightarrow \Lambda + \pi$





$$P_H = \frac{8}{\pi\alpha_H}\frac{\langle sin(\psi_1 - \varphi_p^*)\rangle}{Res(\psi_1)}$$

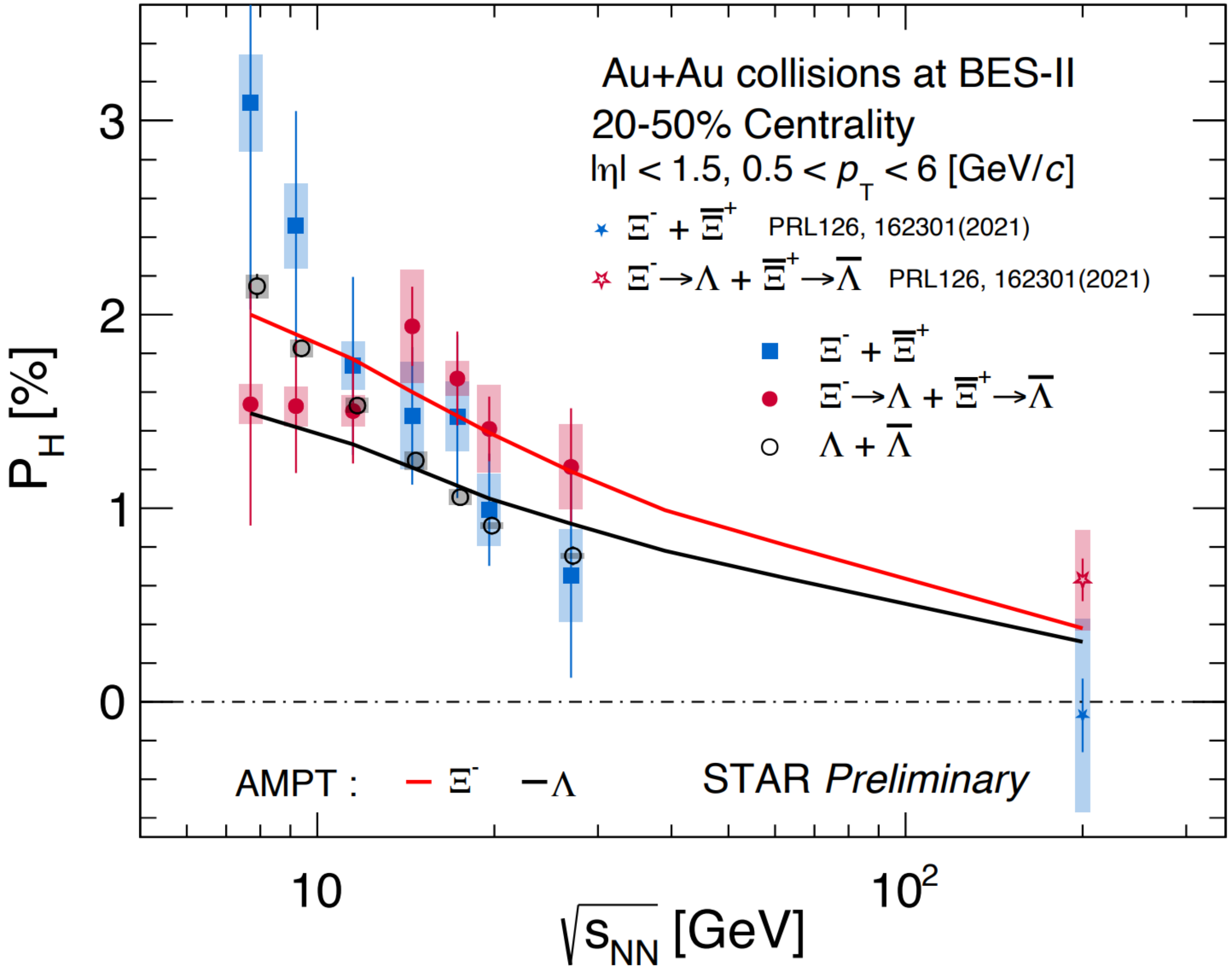


BES-II results: Λ global polarization

- New STAR Preliminary results at $\sqrt{s_{NN}}$=7.7-17.3 GeV
- Significant improvement in precision, consistent dependence with BES-I
- No obvious splitting between Λ and $\overline{\Lambda}$ global polarization with high precision
- Upper limit on late stage magnetic field ignoring feed-down effect:
  - $|B| \approx \frac{T_S|P_{\overline{\Lambda}} - P_\Lambda|}{2|\mu_\Lambda|}$
  - $B \lesssim 10^{13}$T (95% confidence level)

STAR: PRC 108.014910(2023)

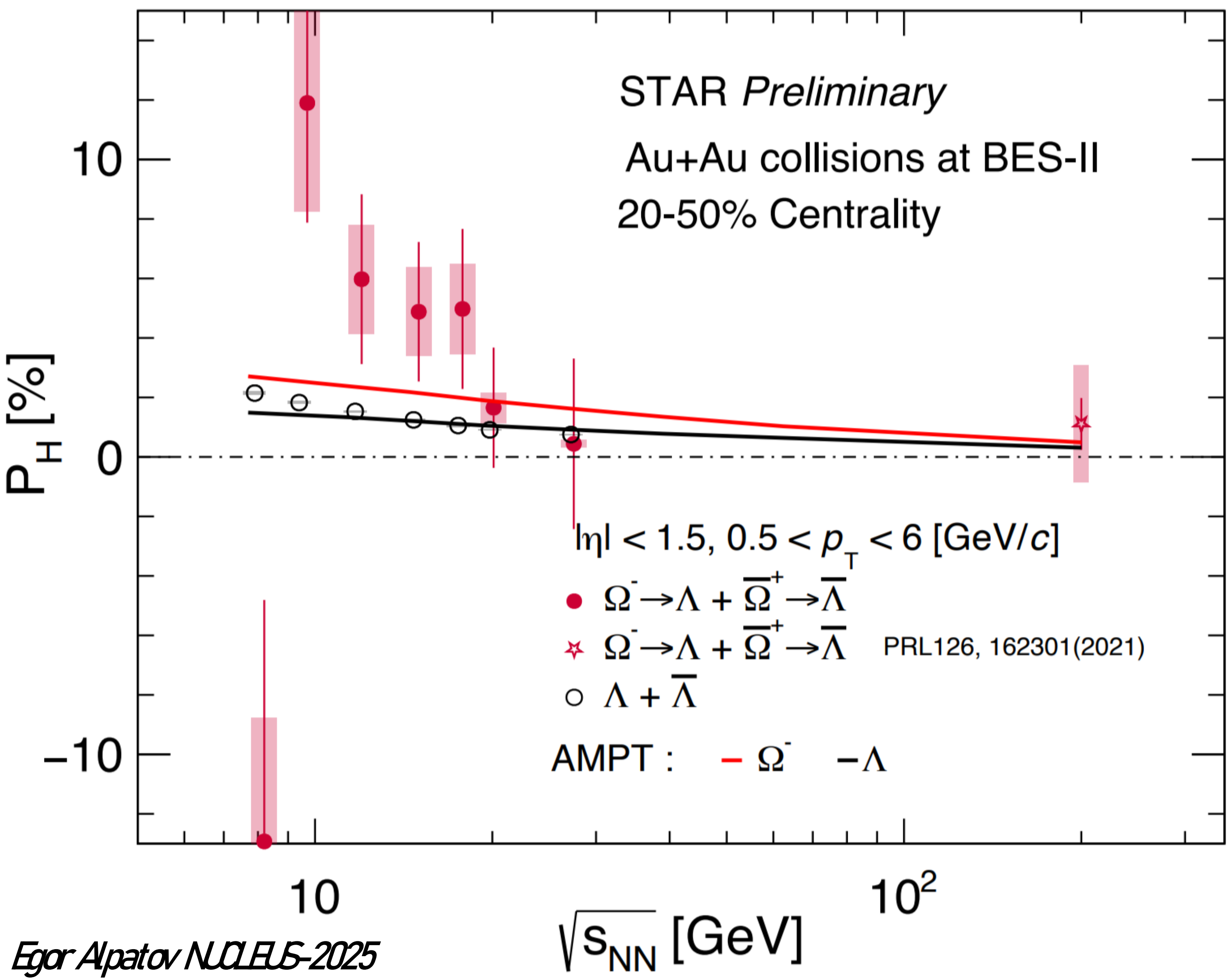
BES-II results: Ξ global polarization



- Significant non-zero signal of Ξ global polarization observed
- Decreasing with increase in collision energy
- Consistent between direct (via φ^*_Λ) and indirect ($P_\Lambda = C_{\Xi\Lambda} P_\Xi$) measurements
- No significant difference between Λ and Ξ global polarization
  - While $P_\Xi \sim P_\Lambda$ is expected from pure spin transfer from vorticity, there is possible difference due to different freeze-out properties

Z.-T. Liang and X.-N. Wang, PRL 94, 102301 (2005)
Hui Li et al., PLB 827, 136971(2022)

BES-II results: Ω global polarization



- Ω global polarization seems to decrease with increase in collision energy
- A hint of larger Ω global polarization than Λ at lower energies
  - Theory expects larger global polarization of Ω
  - $P_\Omega \sim \frac{5}{3} P_\Lambda$

Conclusions

- No splitting observed between Λ and $\bar{\Lambda}$ global polarization in Au+Au collisions at 7.7 - 27 GeV Au+Au collisions
- First measurements of $\Xi^- + \bar{\Xi}^+$ and $\Omega^- + \bar{\Omega}^+$ global polarization at 7.7-27 GeV Au+Au collisions
- Global polarization decrease with increase in collision energy
- Hint of larger $\Omega^- + \bar{\Omega}^+$ global polarization

Thank you for your attention!