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Global polarization of Λ and Ξ hyperons in Au+Au collisions in the STAR experiment

Outline:

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- Conclusions

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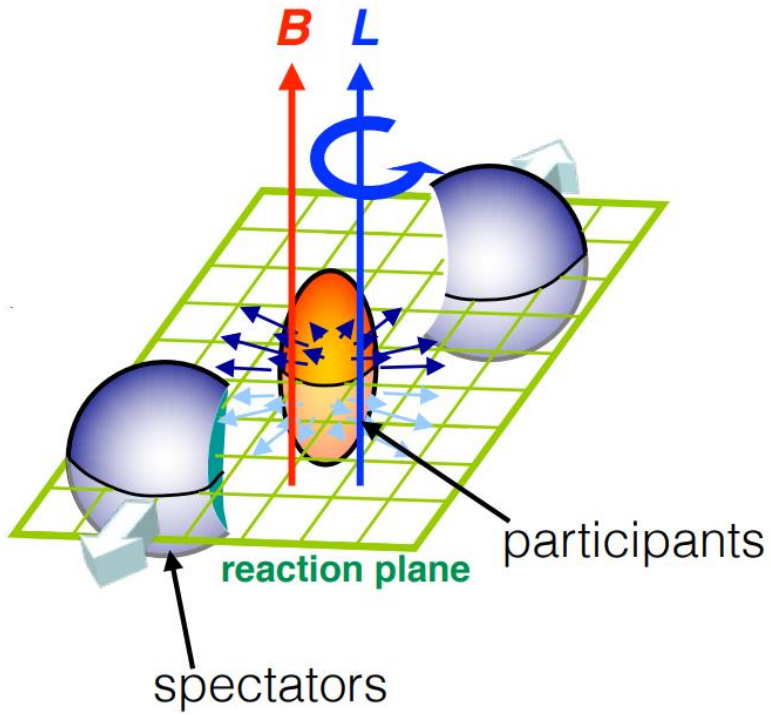
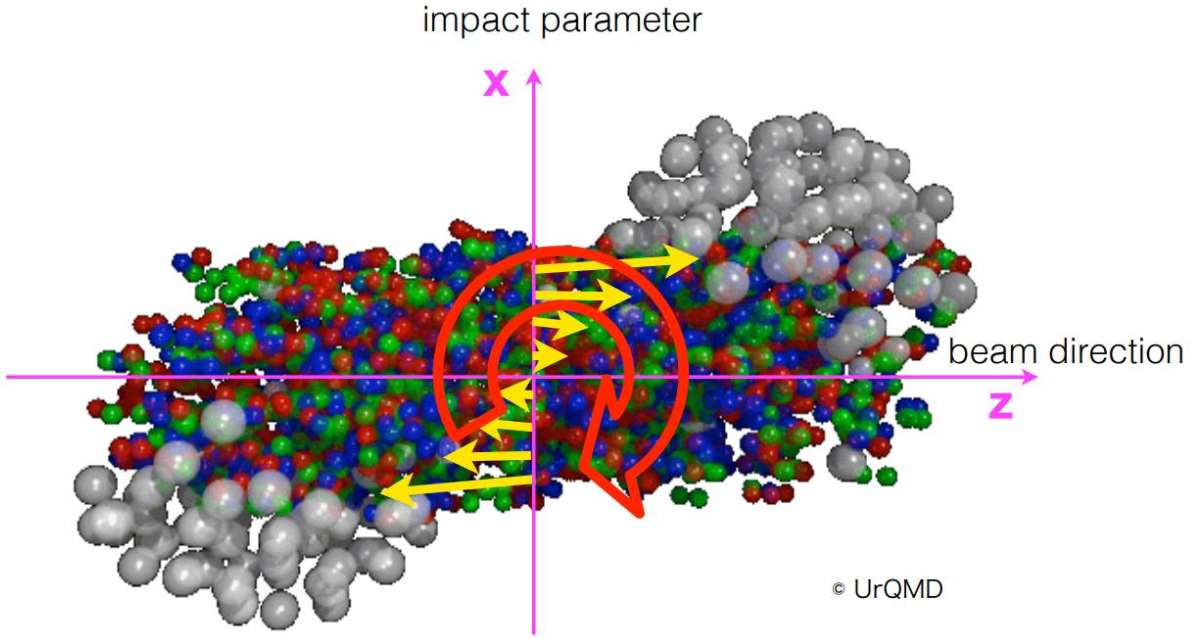
Introduction

- The Quark-Gluon Plasma (QGP) formed in non-central nucleus-nucleus collisions is associated with large angular momentum, that leads to vorticity in the medium
- Spin-orbit coupling aligns spin directions of produced particles along the direction of vorticity
  - Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)
  - S. A. Voloshin, arXiv:nucl-th/0410089
- Another possible source of particle polarization is magnetic field, 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 HIC the initial collective longitudinal flow velocity depends on the velocity gradient:

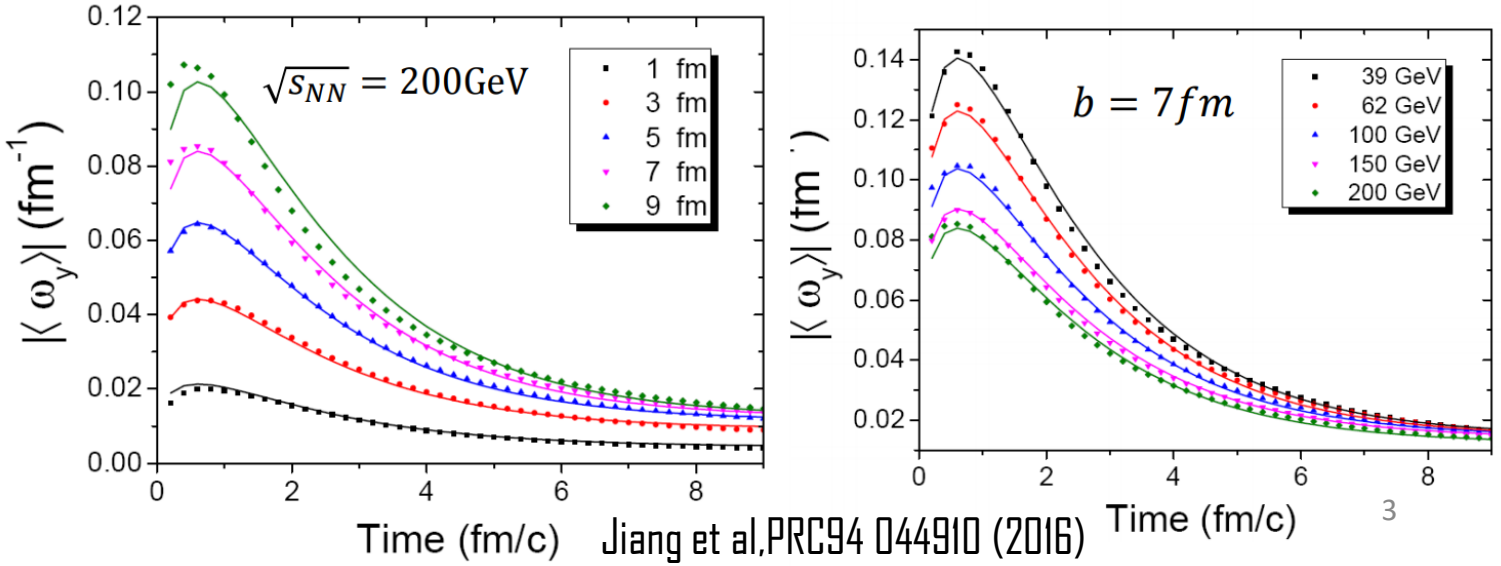
$$\omega_y = \frac{1}{2}(\nabla \times v)_y \approx -\frac{1}{2}\frac{dv_z}{dx}$$

- 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?

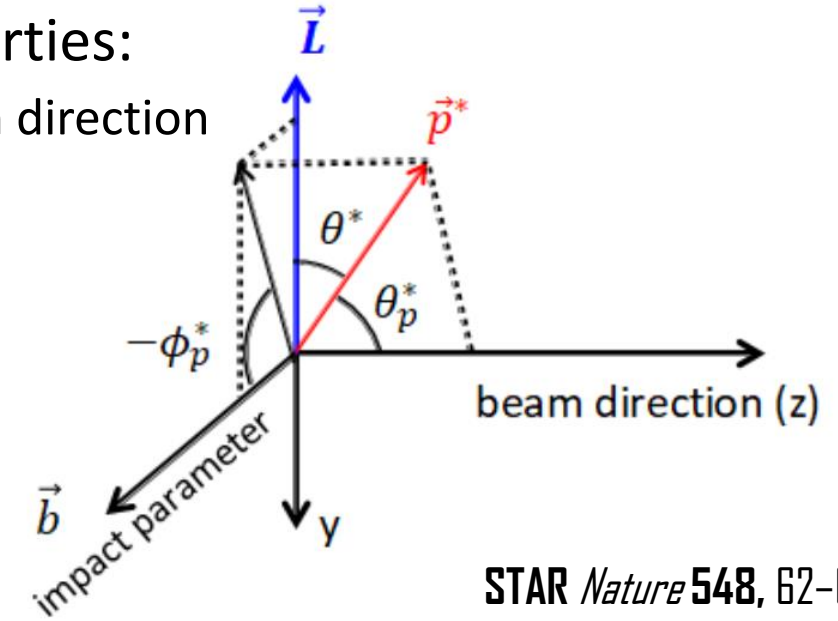
- Hyperons are “self-analyzing” due to weak decay properties:
  - Daughter baryons are preferentially emitted along parent spin direction
- Daughter baryons of hyperons with polarization ($\vec{P}$) follows the distribution:

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

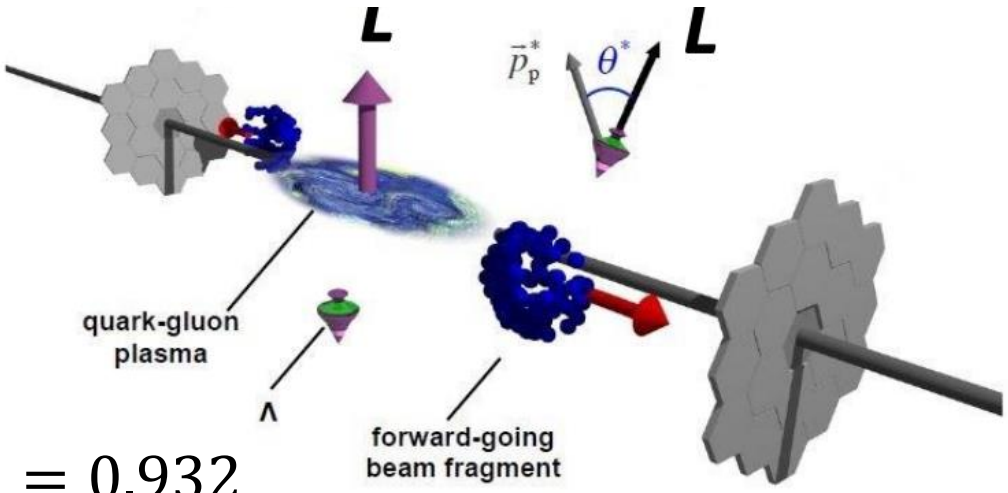
  - α_H - decay parameter, unique for each hyperon species
  - $\widehat{p_b^*}$ is the daughter baryon momentum in the parent frame
- Projection to the transverse plane can be measured:

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

  - ψ_1 is firs-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 $C_{\Xi\Lambda} = 0.932$

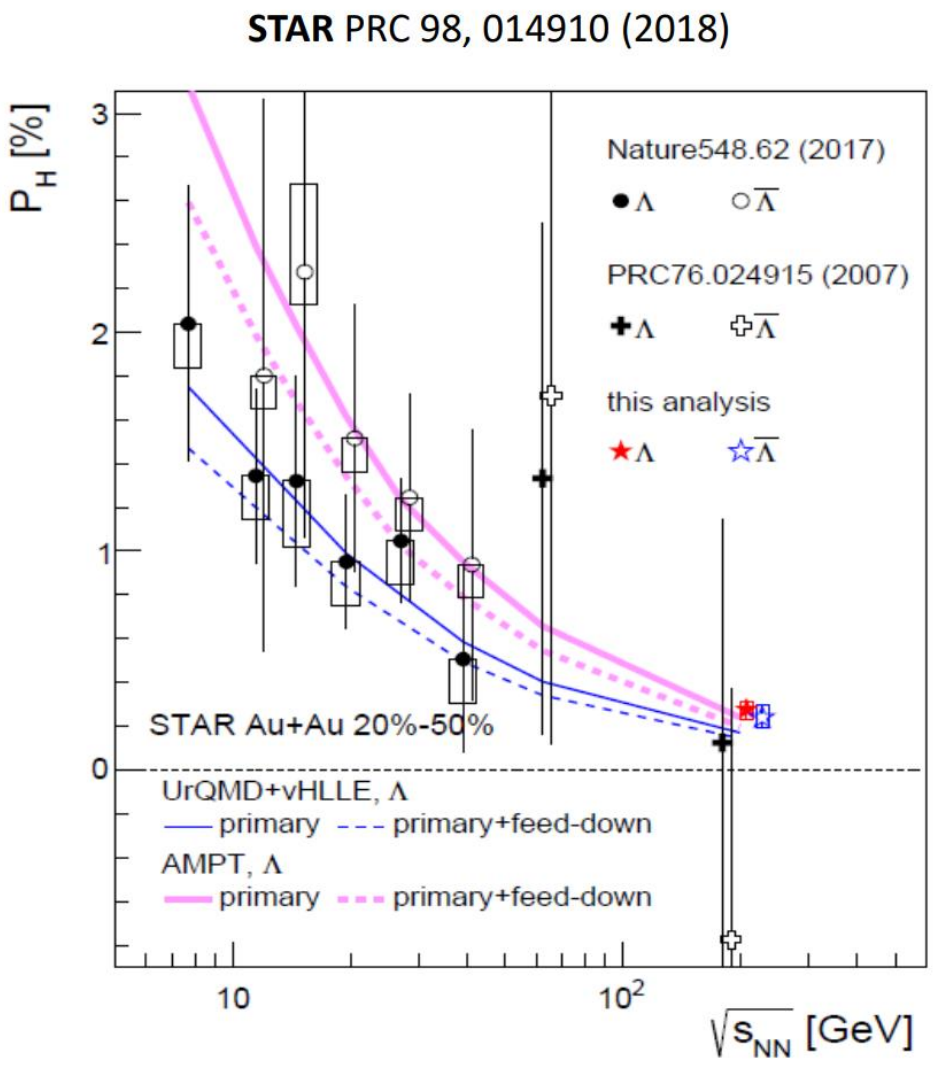


STAR *Nature* **548,** 62–65 (2017)

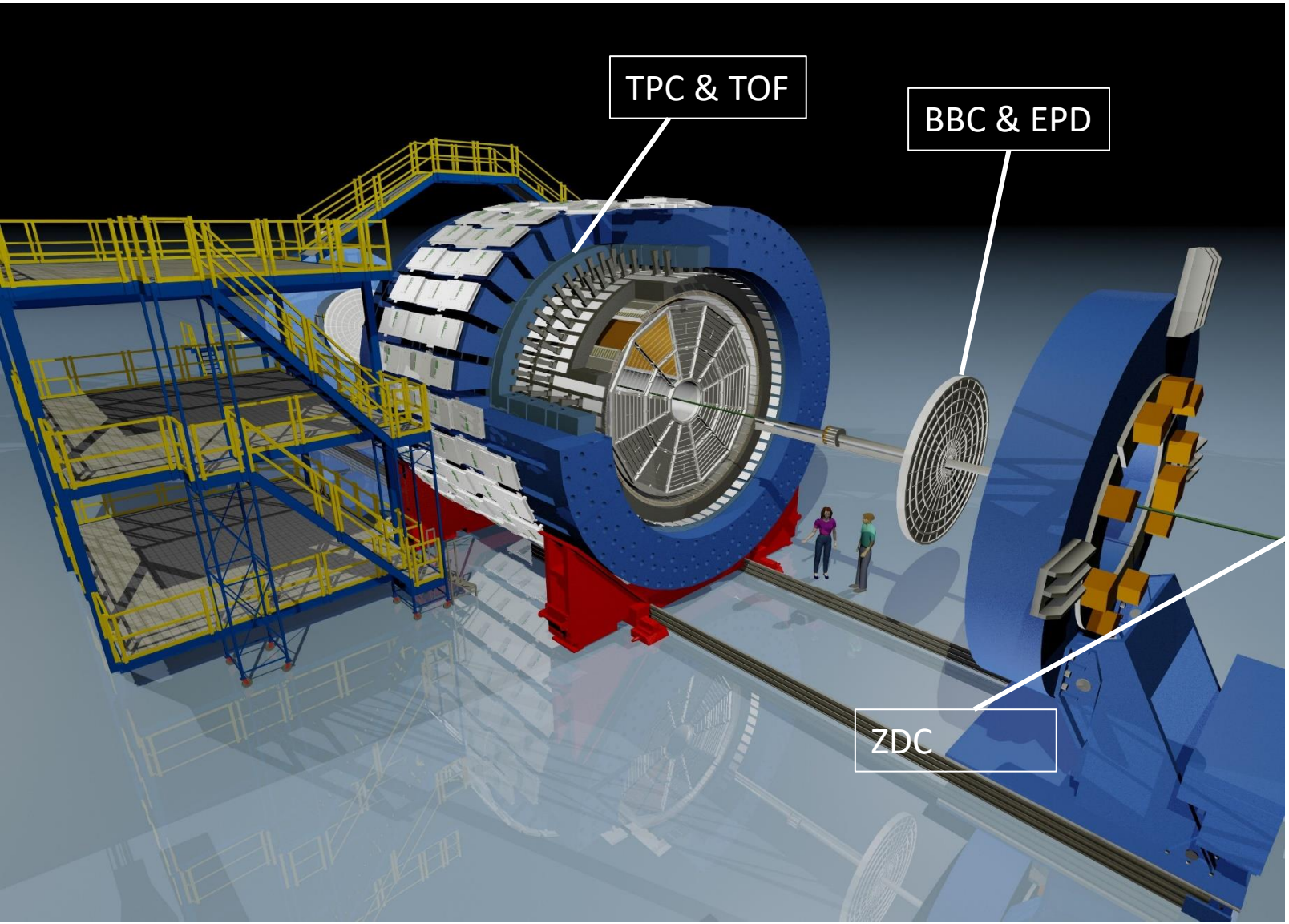


Motivation

- Global polarization of Λ hyperons was measured for $\sqrt{s_{NN}}$ = 7.7-200 GeV at STAR
- P_H decreases with increasing collision energy
- Difference between P_Λ and $P_{\bar{\Lambda}}$ maybe due to B-field effect
- Theoretical calculations can quantitatively explain the energy dependence of the Λ polarization, but many of them fail to explain differential measurements
- Nowadays there is a growing interest to measure the global polarization of other hyperons such as Ξ.
- Ξ polarization may provide new input for global polarization and vorticity studies



The STAR experiment



Detectors with their η acceptance:

Hyperon reconstruction:

- **T**ime **P**rojection **C**hamber
  $|\eta| \in [-1, 1]$
- **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
  $|\eta| \in [2.1, 5.1]$
- **Z**ero **D**egree **C**alorimeter
  $|\eta| > 6.3$

Experimental technique

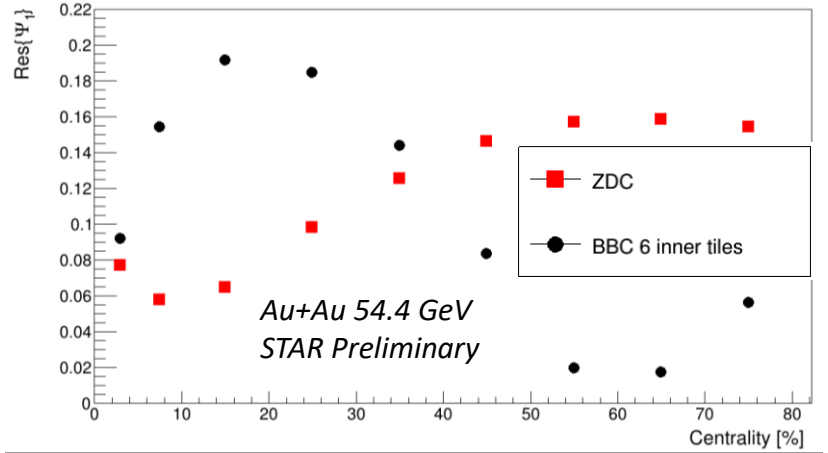
- **Event plane** Ψ_1 is determined by detectors at forward rapidity where directed flow is large

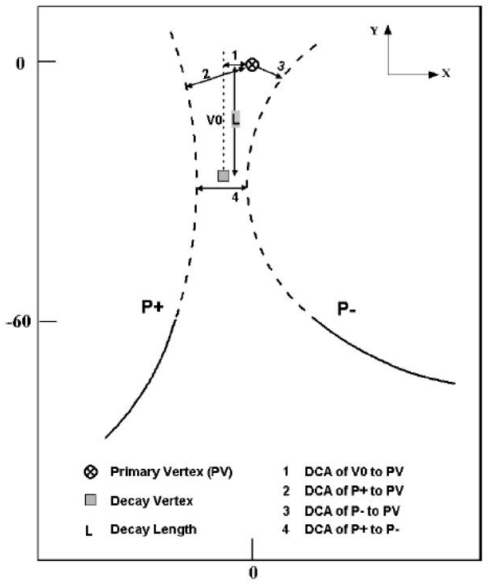
$$\Psi_1 = \tan^{-1}\left(\frac{\sum w_i \sin(\phi_i)}{\sum w_i \cos(\phi_i)}\right)$$, where w_i is detector's tile ADC

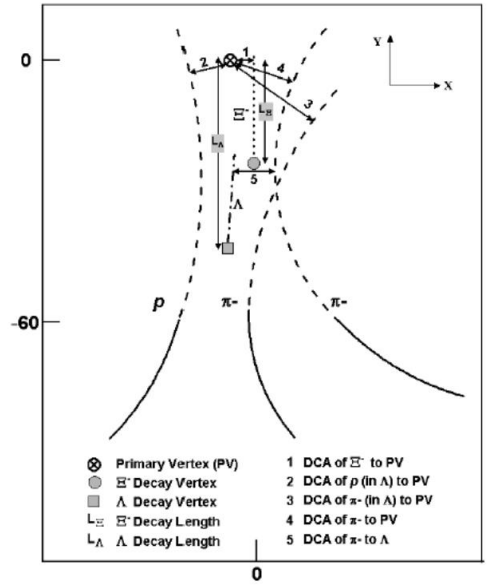
A. M. Poskanzer, S. A. Voloshin, PRC58.1671(1998)

- $Res(\Psi_{1,Forward}\,\eta) = Res(\Psi_{1,Backward}\,\eta) = \sqrt{< \cos(\Psi_{1,Forward}\,\eta - \Psi_{1,Backward}\,\eta) >}$
- BBC and ZDC for $\sqrt{s_{NN}} = 54.4$ GeV, EPD and BBC for lower energies

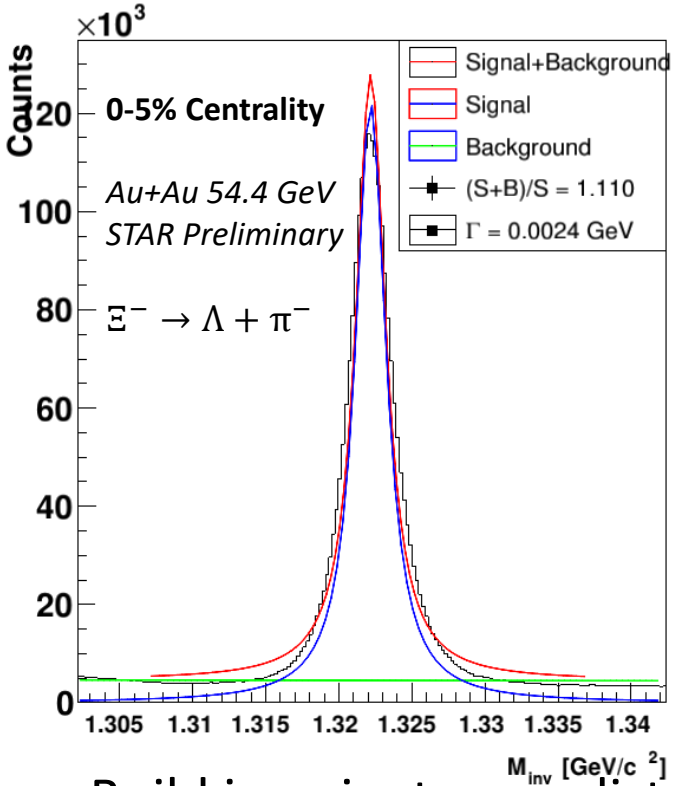
- **Hyperon reconstruction** performed via decay topology
- Λ daughters identified via TPC and TOF
- Ξ were reconstructed via $\Xi \rightarrow \Lambda + \pi$

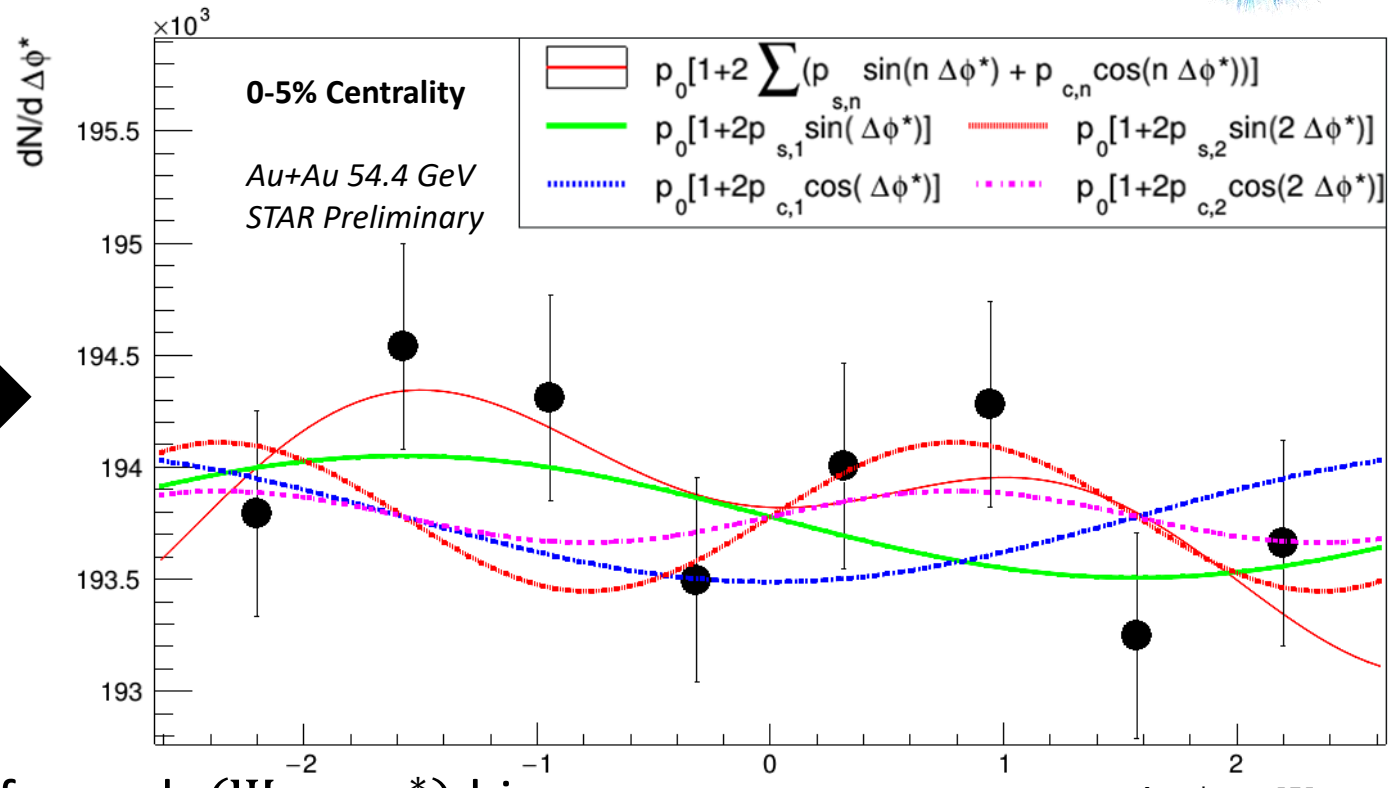






Global polarization: event-plane method



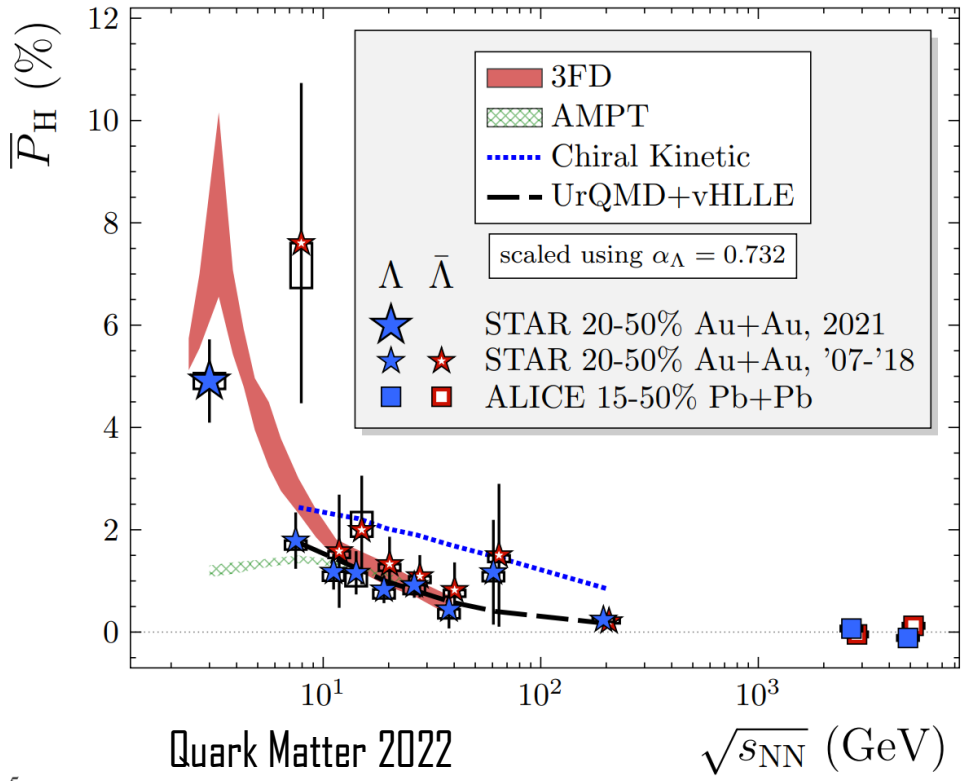


- Build invariant mass distribution for each $(\Psi_1 - \varphi^*)$ bin $\Delta\varphi^* = \Psi_1 - \varphi^*$
- Subtract background and integrate subtracted distribution
- Fit $dN/d(\Psi_1 - \varphi^*)$ with Fourier function up to 2nd order
- Coefficient for $\sin(\Delta\varphi^*)$ term is the polarization signal
- $\boldsymbol{P_H = \frac{8}{\pi\alpha_H}\frac{\langle sin(\psi_1 - \varphi_p^*)\rangle}{Res(\psi_1)}}$ - apply resolution correction and take decay parameter into account

Λ global polarization results

- **Λ** global polarization was measured in Au+Au collisions at $\sqrt{s_{NN}}$ = 3 GeV in fixed-target mode
- Constrain models at low collision energies
- High-statistics BES-II datasets at $\sqrt{s_{NN}}$ = 27 & 19.6 GeV provide opportunity to measure particle and antiparticle global polarization splitting with high precision
- Results will be released soon

PRC58.104 (2021) L061901



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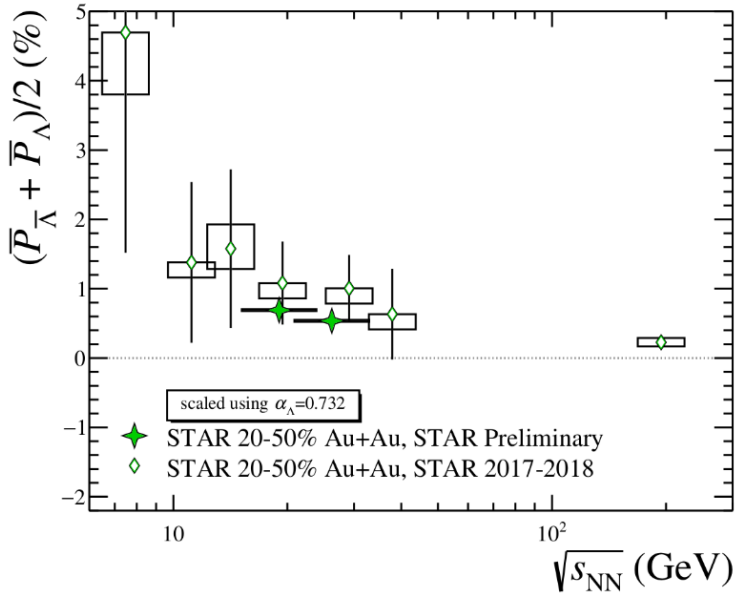
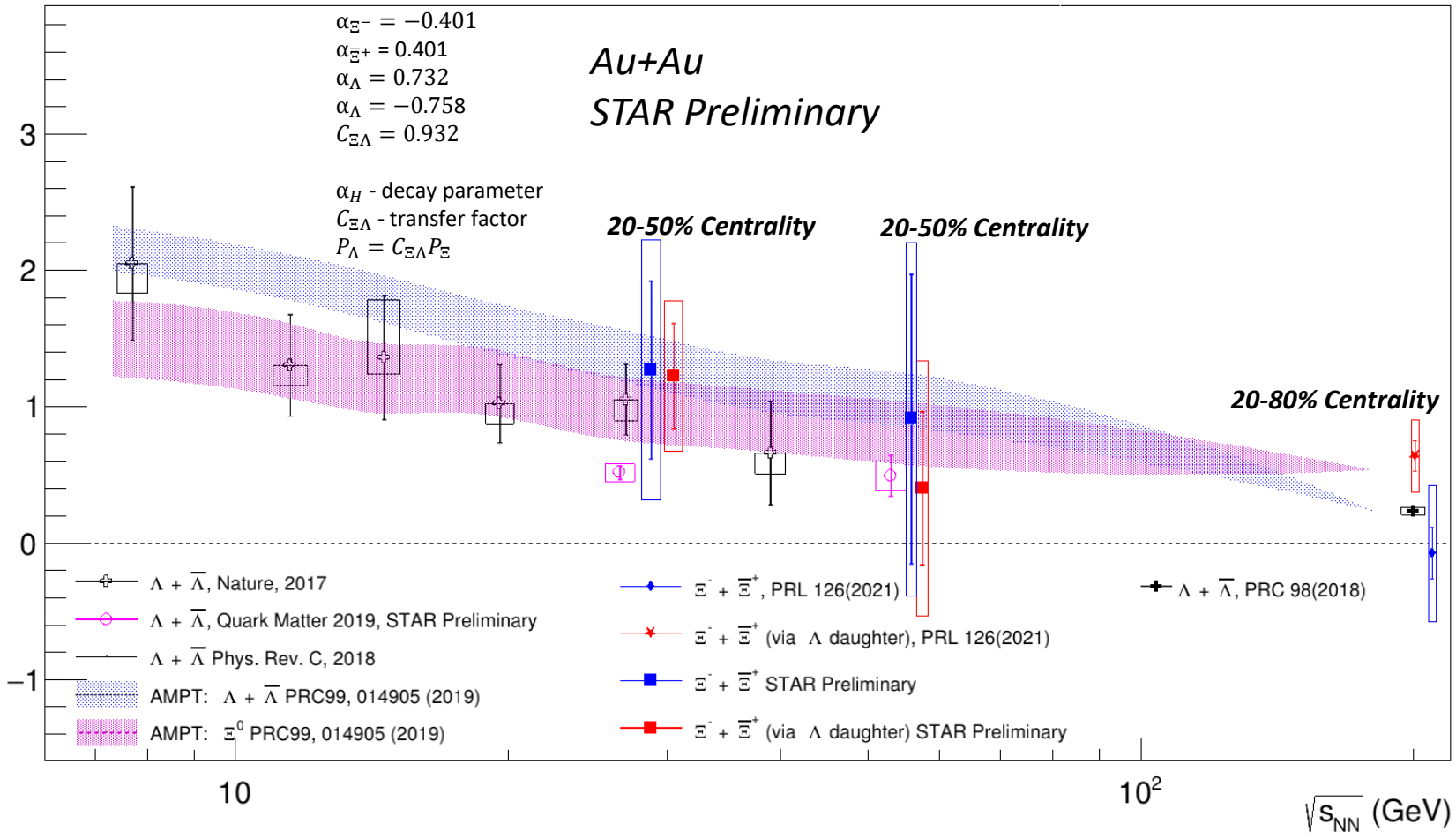


Ξ global polarization results

- Observed non-zero positive Ξ global polarization
- Experimental results for Ξ global polarization consistent with each other with given large uncertainties at different collision energies
- Both Ξ global polarization measurement methods are consistent within uncertainties
- Ξ and inclusive Λ global polarization are consistent within statistical uncertainties
- Global polarization of Ξ hyperons consistent with model predictions

Global hyperon polarization $\sqrt{s_{NN}}$ dependence



Conclusions

- We presented $\Xi + \bar{\Xi}$ and $\Lambda + \bar{\Lambda}$ global polarization measurements in Au+Au collisions at $\sqrt{s_{NN}}$ = 3 – 200 GeV, which helps to understand QCD spin dynamics and vorticity of QGP medium
  - This information can be used in theoretical development
- New high-statistics datasets provide opportunity to measure $\Lambda - \bar{\Lambda}$ global polarization splitting, expected from initial magnetic-field
- $\Xi + \bar{\Xi}$ global polarization is comparable with $\Lambda + \bar{\Lambda}$ global polarization within uncertainties, indicating a global nature of polarization

Thank you for your attention!