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Global polarization measurements in Au+Au collisions

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Global polarization definition and measurement technique

Global polarization and spin alignment

Source: **Large angular orbital momentum** $\vec{L}$ of the system in non central relativistic nuclear-nuclear collisions

Effect: **transformation of the angular momentum** $\vec{L}$ **into the particles spin**

Method: $\vec{L}$ is perpendicular to the reaction plane

→ Correlations wrt the reaction plane

→ **Anisotropic flow technique**

Measurement:

global hyperons polarization / mesons spin alignment vs **centrality, transverse momentum** and **pseudo-rapidity**

Angular distribution for the global polarization

$$\frac{dN}{d\cos\theta^*} \sim 1 + \alpha_H P_H \cos\theta^*$$

$P_H\left(\vec{p}_H; \vec{L}\right)$ hyperon polarization wrt reaction plane (**global polarization**)

α_H decay parameter ($\alpha_\Lambda = 0.642$ for $\Lambda \to p\pi^-$)

θ^* angle between the system orbital momentum and the hyperon's decay product 3-momentum in the hyperons rest frame

Angular distribution for the global spin alignment

$$\frac{dN}{d\cos\theta^*} \sim 1-\rho_{00}+(3\rho_{00}-1)\cos^2\theta^*$$

ρ_{00} diagonal spin density matrix element (unpolarized case: $\rho_{00}=1/3$)

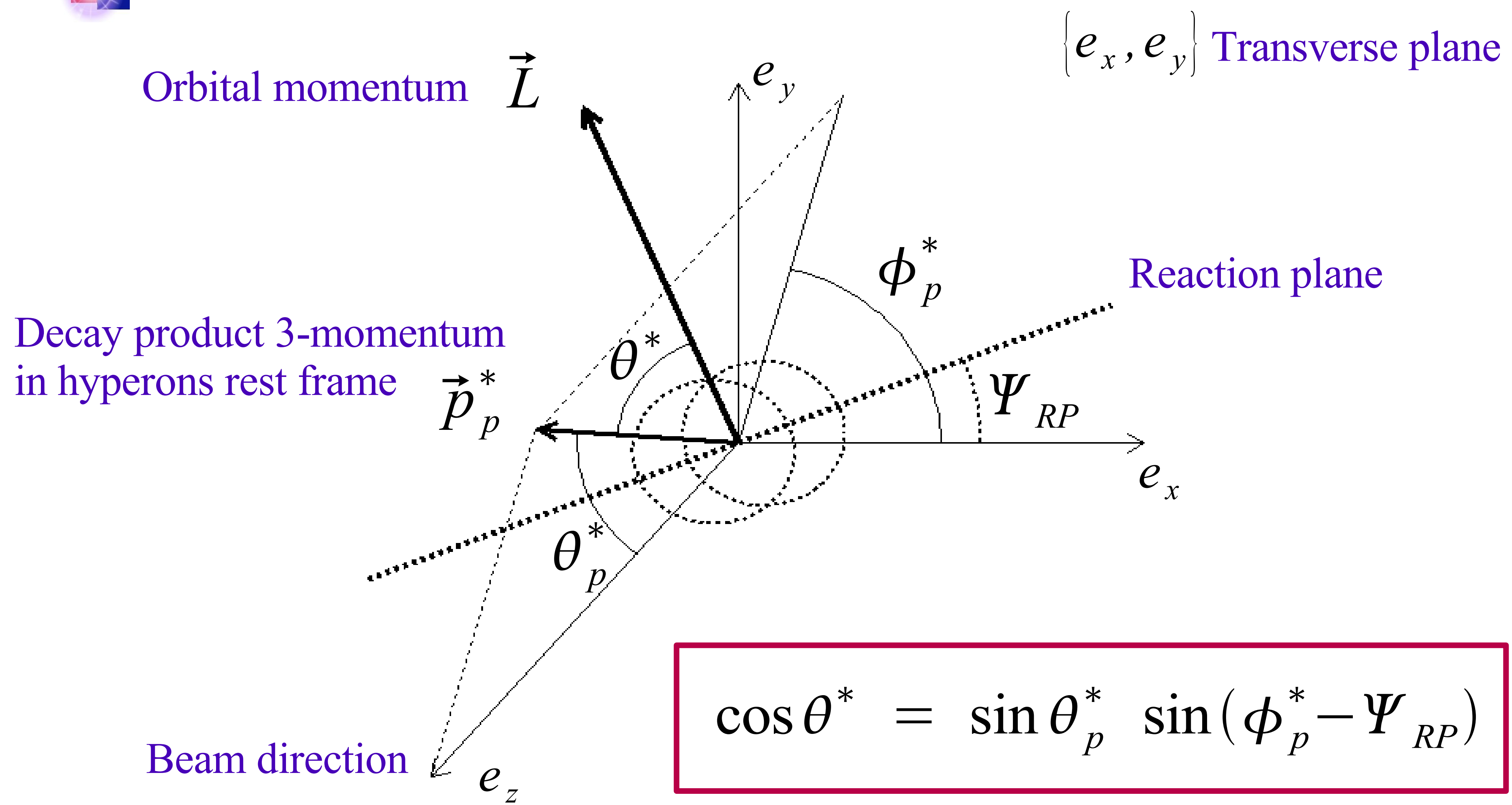
$$\rho_{00} = 1-\rho_{11}-\rho_{-1-1}$$

Note: we could not measure the sign of the vector meson polarization, thus we call it spin alignment instead of polarization

θ^* angle between the system orbital momentum and the meson's decay product 3-momentum in the mesons rest frame

For the ϕ, K^* measurements see talk by Zebo Tang, Session 8, Nov. 24

Angles definition and notations



$$\cos\theta^* = \sin\theta^*_p \sin(\phi^*_p - \Psi_{RP})$$

Observable for the global polarization: **azimuthal correlations**

$$P_H(\vec{L}, \vec{p}_H) = P_H(\phi_H - \Psi_{RP}, \eta^H, p_t^H) =$$

$$= \sum_{n=0}^{\infty} P_H^{(n)} \cos[2n(\phi_H - \Psi_{RP})]$$

$$P_H \equiv P_H^{(0)} = \frac{8}{\pi \alpha_H} \langle \sin(\phi_p^* - \Psi_{RP}) \rangle$$

$\langle ... \rangle$ **- averaging over all reaction plane orientations** and hyperon's **decay product 3-momentum directions** in the hyperon's rest frame

ϕ_p^* decay product azimuthal angle

Ψ_{RP} reaction plane angle

Similar to **directed flow** observable – **anisotropic flow technique!**

Lambda global polarization: **measurement technique**

$$P_H = \frac{8}{\pi \alpha_H} \frac{\langle \sin(\phi_p^* - \Psi_{EP}^1) \rangle}{R_{EP}^1}$$

ϕ_p^* decay product azimuthal angle

Ψ_{EP}^1 event plane angle

R_{EP}^1 event plane resolution

Reconstructing reaction plane with measured particles - **two particle correlations**

Scalar product technique

$$P_H = \frac{8}{\pi \alpha_H} \frac{\langle \sin \phi_p^* X_{EP}^1 \rangle - \langle \cos \phi_p^* Y_{EP}^1 \rangle}{R_{EP}^1}$$

$$Q_{EP}^1 = (X_{EP}^1, Y_{EP}^1)$$ **- 1st order event plane vector**

Analysis overview

Theory input:

Z.-T. Liang and X.-N. Wang Phys. Rev. Lett. 94, 102301 (2005) [**erratum**: 039901(2006)]
Z.-T. Liang and X.-N. Wang nucl-th/0411101
Sergei A. Voloshin nucl-th/0410089

Measurement technique: 2-particle correlations wrt reaction plane reconstructed with STAR **F**orward **T**ime **P**rojection **C**hamber ($2.7<|\eta|<3.9$)

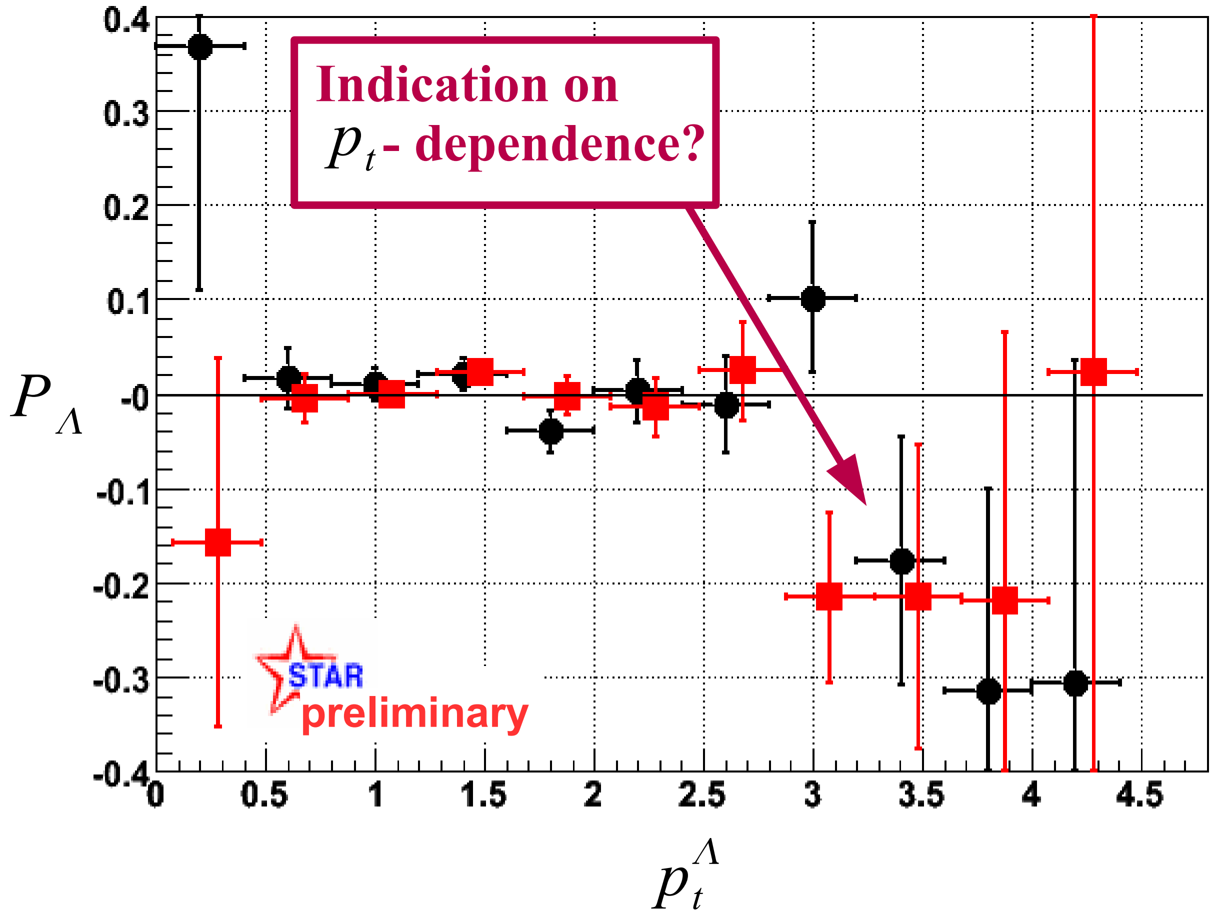
Results: Lambda global polarization in Au+Au at 62 and 200 GeV vs centrality, transverse momentum and pseudo-rapidity

Systematics study:
different collision energies
detector acceptance effects
reaction plane reconstruction

Experimental results

Lambda global polarization: **transverse momentum dependence**

RHIC Run IV data



AuAu@200GeV (20-70%)

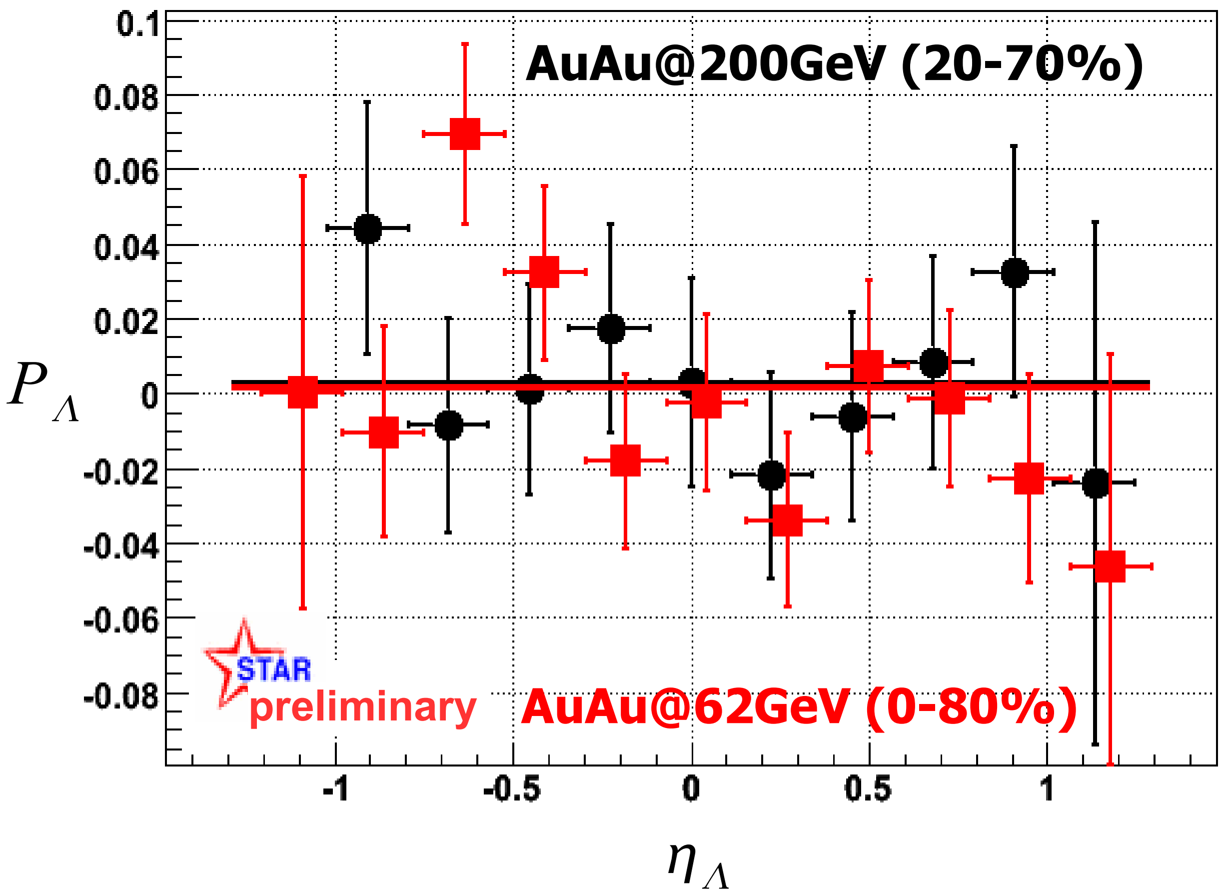
AuAu@62GeV (0-80%)

Global polarization is zero for small Lambda p_t

No theory curves on p_t dependence for the moment

Lambda global polarization: **pseudo-rapidity dependence**

RHIC Run IV data



Line fit for **AuAu@200GeV**

$$P_\Lambda = (2.6 \pm 9.5) \times 10^{-3}$$

line fit for AuAu@62GeV

$$P_\Lambda = (1.9 \pm 8.0) \times 10^{-3}$$

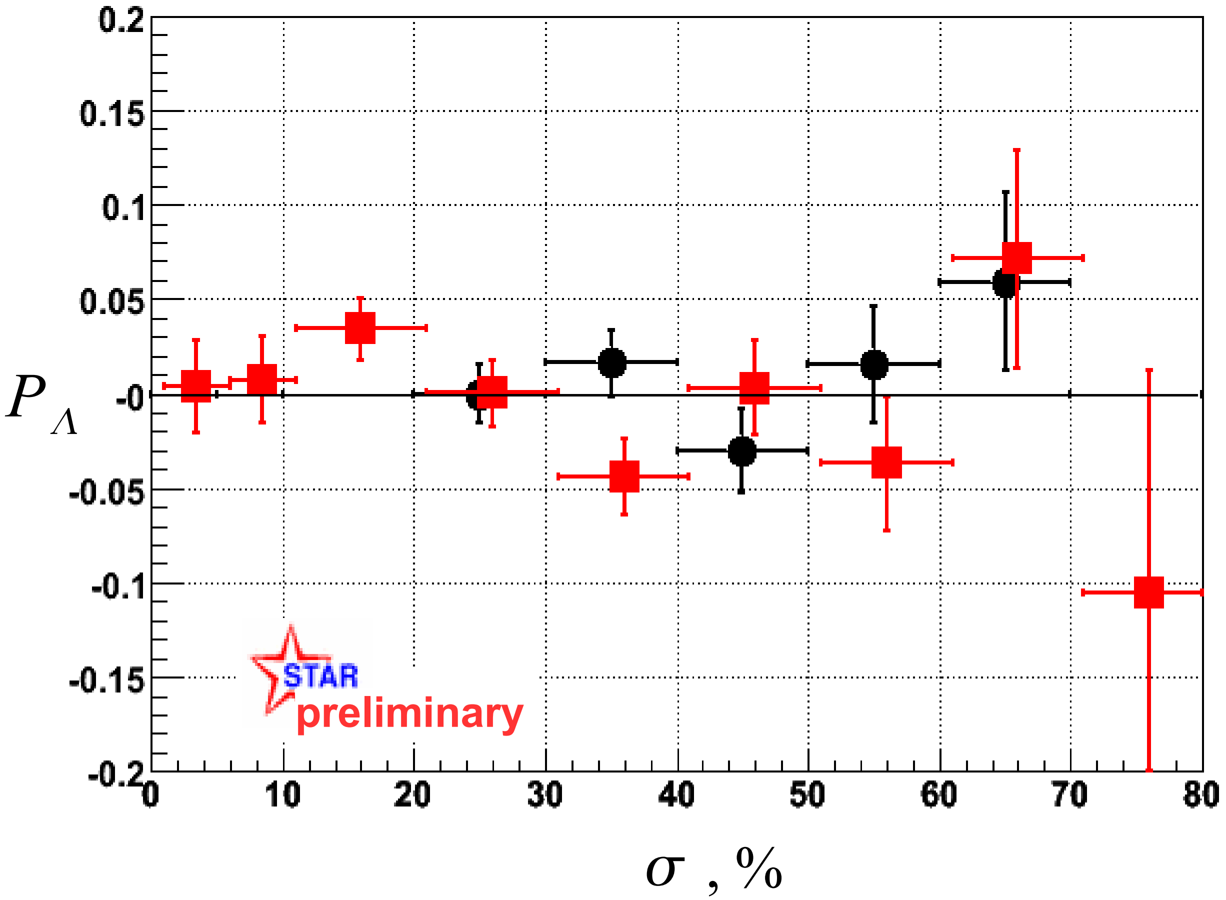
Available theory value

$$P_\Lambda = 0.3$$

Z.-T. Liang and X.-N. Wang
PRL94, 102301 (2005)
(see erratum)

Lambda global polarization: **centrality dependence**

RHIC Run IV data



AuAu@200GeV (20-70%)

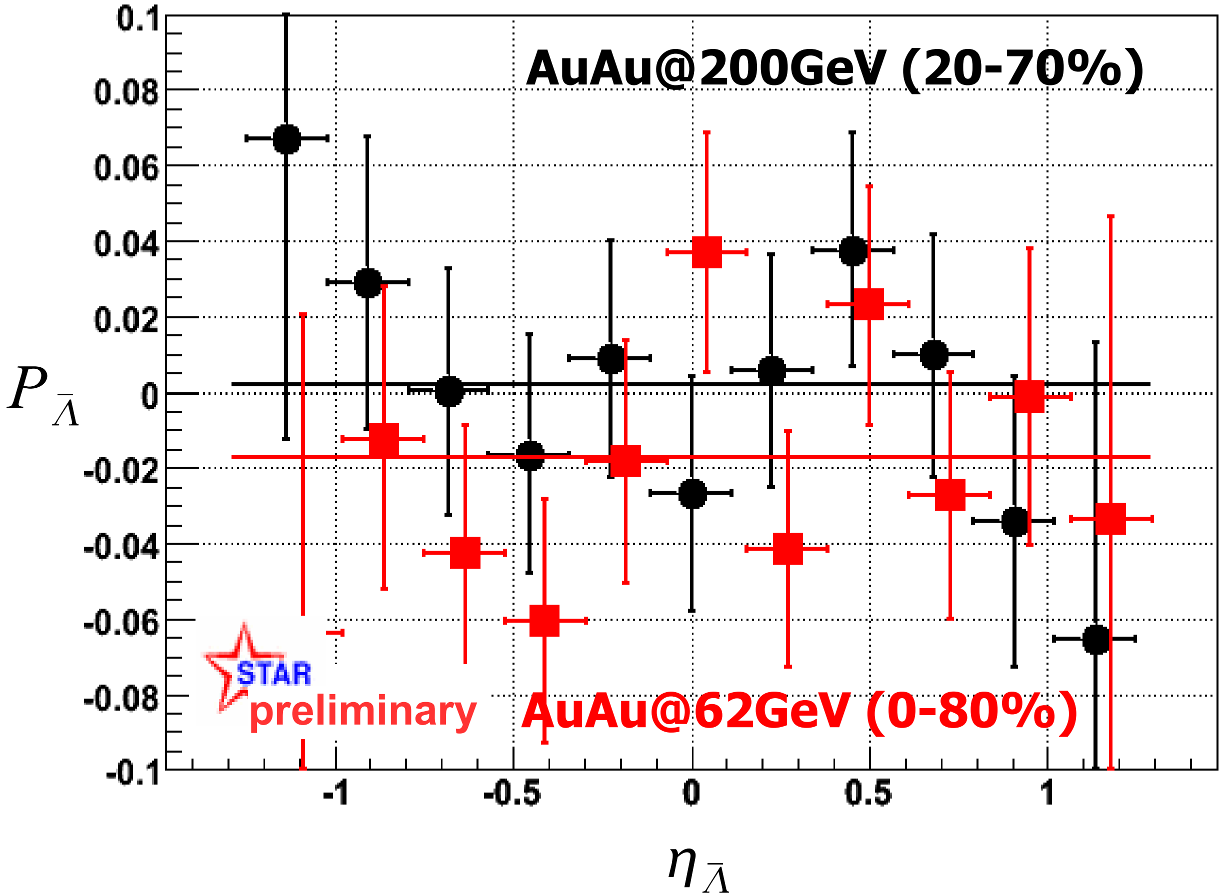
AuAu@62GeV (0-80%)

No centrality dependence observed

Could be zero signal due to **acceptance effects** or **systematics uncertainties?**

Anti-Lambda global polarization

RHIC Run IV data



Line fit for **AuAu@200GeV**

$$P_{\bar{\Lambda}} = (1.7 \pm 10.7) \times 10^{-3}$$

line fit for **AuAu@62GeV**

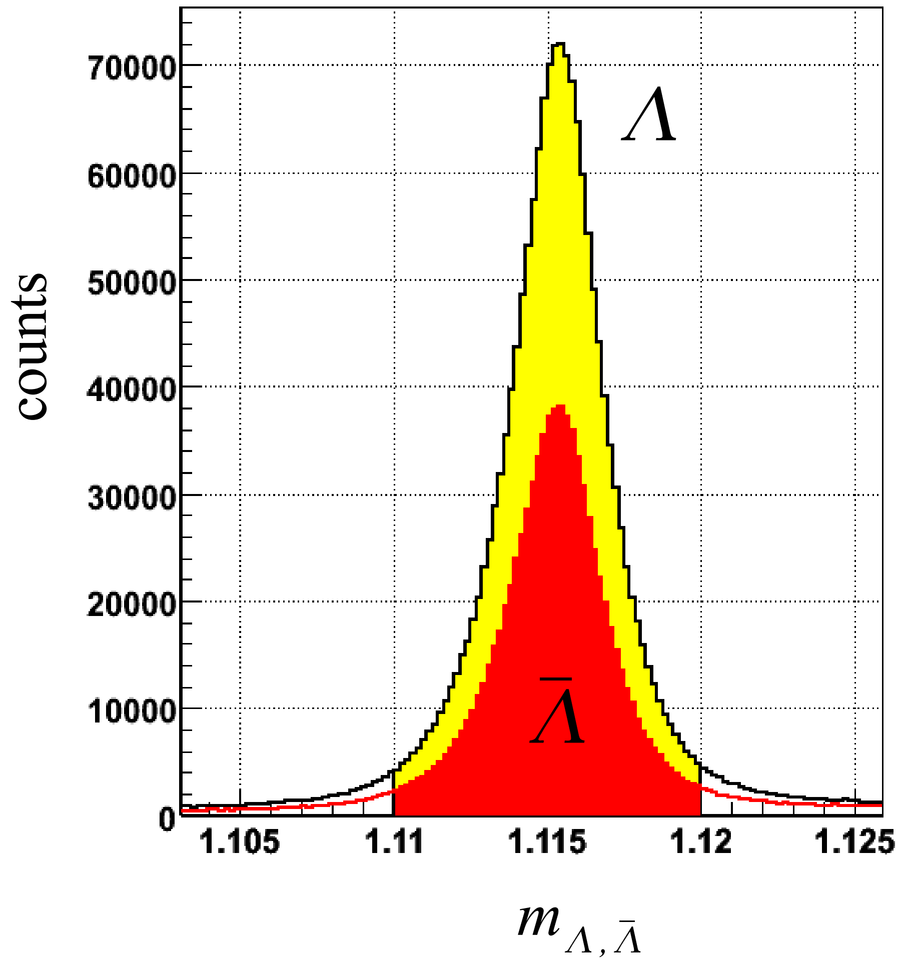
$$P_{\bar{\Lambda}} = (-17.3 \pm 11.0) \times 10^{-3}$$

Consistent with Λ results

Systematics and acceptance study

Lambda/Anti-Lambda **invariant mass distribution and background effects**

AuAu@62GeV (0-80%) reconstructed with **STAR T**ime **P**rojection **C**hamber



Yellow Lambda candidates

Red Anti-Lambda candidates

Background contribution < **8%**

Feed-down from multi-strange hyperons (Ξ , Ω) and Σ^0 is < **30%**

Hyperon **spin precession** in the detector magnetic field **is negligible**

Primordial fraction ~ **20%**

Acceptance corrections

Due to detector acceptance higher harmonics ($P_H^{(n)}, n>0$) could contribute

$$\langle \sin(\phi_p^* - \Psi_{RP}) \rangle = \frac{\alpha_H \pi}{8} \left[\frac{4}{\pi} \int \frac{d\Omega_p^*}{4\pi} \frac{d\phi_H}{2\pi} A\left(\vec{p}_H, \vec{p}^*\right) \sin\theta_p^* \right] \times$$

$$\times \left[P_H^{(0)} + \frac{P_H^{(2)}}{2} \cos[2(\phi_p^* - \phi_H)] \right]$$

$n=0$ term - multiplicative
unity for the perfect detector

$$\frac{4}{\pi} \int \frac{d\Omega_p^*}{4\pi} \frac{d\phi_H}{2\pi} A\left(\vec{p}_H, \vec{p}^*\right) \sin\theta_p^*$$

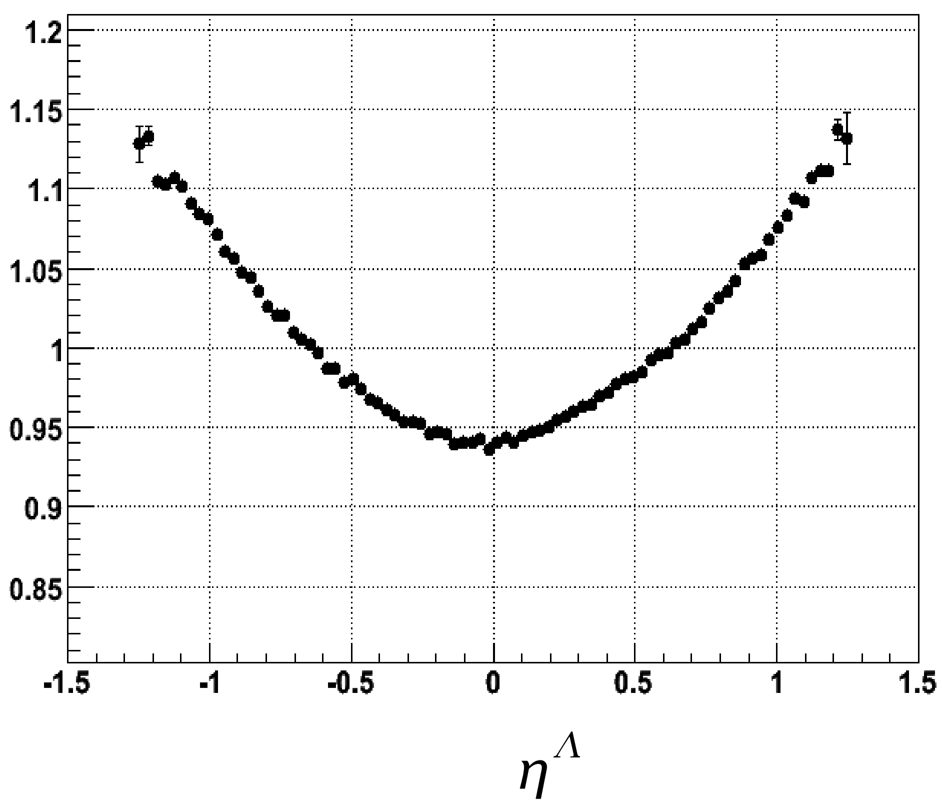
$n=2$ term - additive
zero for the perfect detector

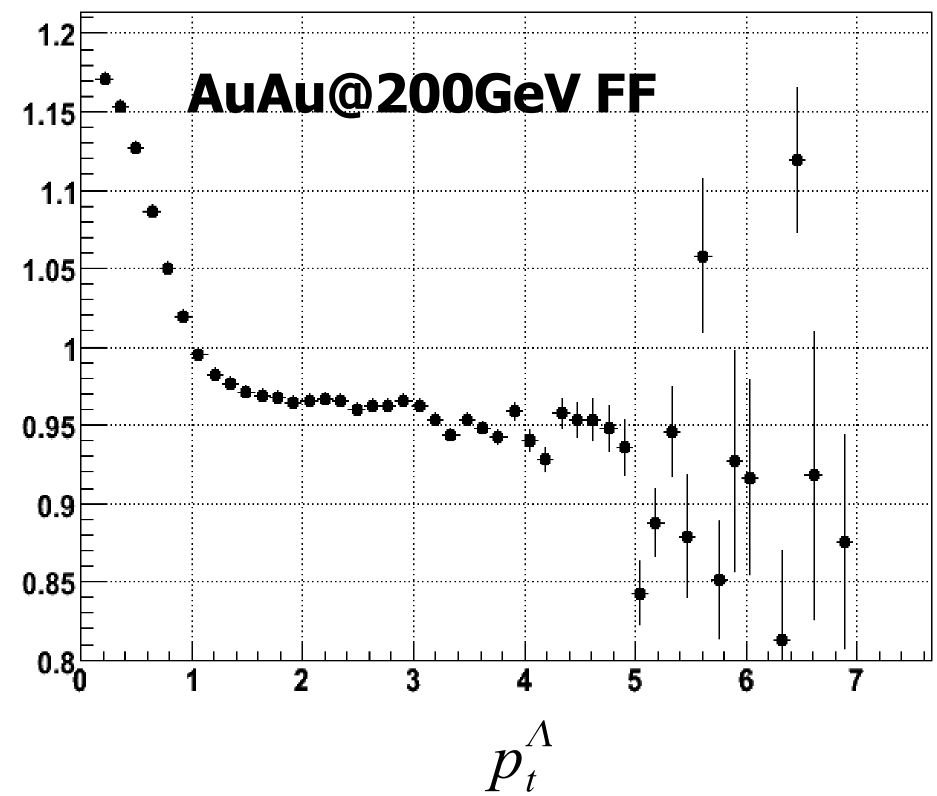
$$\frac{2}{\pi} \int \frac{d\Omega_p^*}{4\pi} \frac{d\phi_H}{2\pi} A\left(\vec{p}_H, \vec{p}^*\right) \sin\theta_p^* \cos[2(\phi_H - \phi_p^*)]$$

Detector acceptance: $n=0$

$$\frac{4}{\pi}\int \frac{d\,\Omega_p^*}{4\pi}\frac{d\,\phi_H}{2\pi}\; A\left(\vec{p}_H, \vec{p}^*\right)\; \sin\theta_p^*$$

Overall effect <20 percent

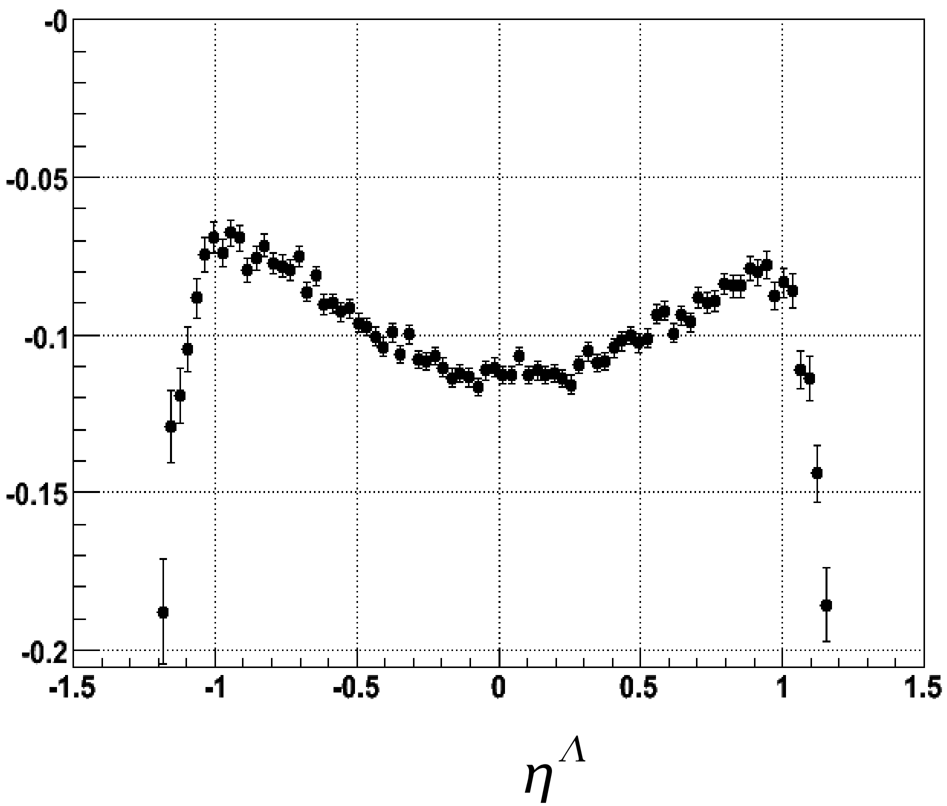


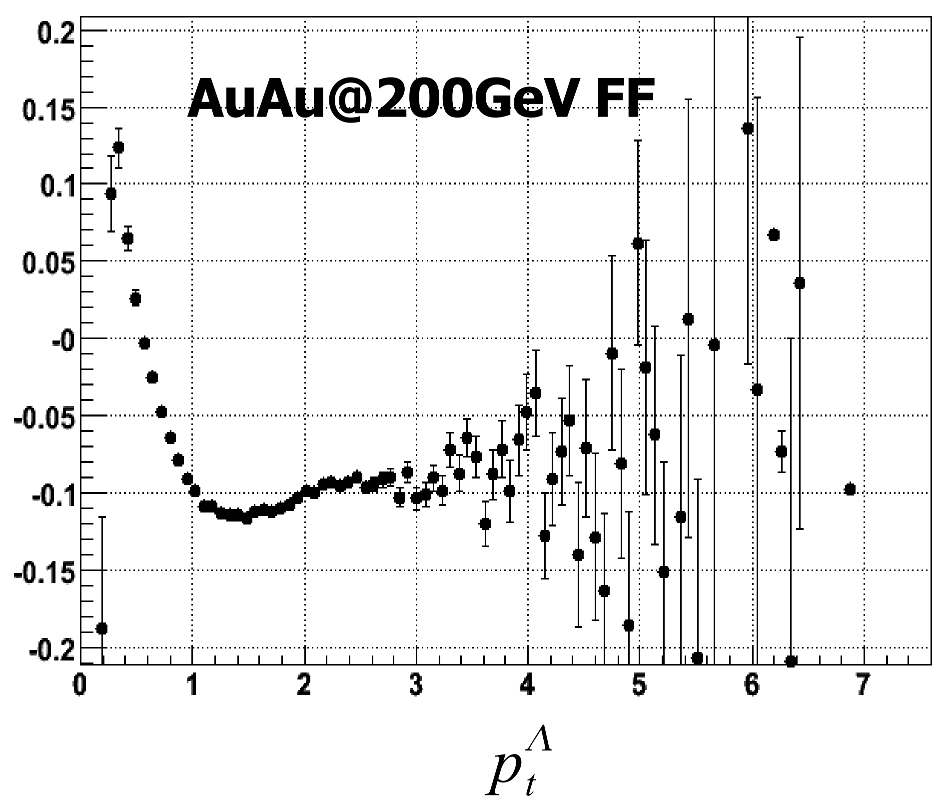


Detector acceptance: $n=2$

$$\frac{2}{\pi}\int \frac{d\,\Omega_p^*}{4\pi}\frac{d\,\phi_H}{2\pi}\;A\left(\vec{p}_H\,,\,\vec{p}^*\right)\;\sin\theta_p^*\cos[2(\phi_H-\phi_p^*)]$$

Overall effect <15 percent





Conclusion

- The $\Lambda(\bar{\Lambda})$ **global polarization has been measured in Au+Au** collisions at the center of mass **energies 62 and 200 GeV** with the **STAR detector** at RHIC

- An **upper limit for the** $\Lambda(\bar{\Lambda})$ **global polarization** is obtained:

$$\left|P_{\Lambda,\bar{\Lambda}}\right| \sim 10^{-2}$$

This **value is far below** the one **discussed in the recent theoretical papers**

$$P_{\Lambda}^{theor} = 0.3$$

- Detector acceptance and background effects has been estimated and they could not explain the observed zero global polarization

- The **reason for this** significant **discrepancy is not clear** now and there are still extensive **theoretical discussion** on this subject. As it was found later by the original authors the **predicted value of** $P_{\Lambda}^{theor} = 0.3$ **could be incorrect** due to inapplicability of the approximations used and the correct estimation for RHIC energies requires **more realistic theoretical calculations** (see **Phys. Rev. Lett. 96, 039901 (2005)** for details).

Thank you!