Polarization Measurements of Hyperons and Vector Mesons in Heavy Ion Collisions at STAR

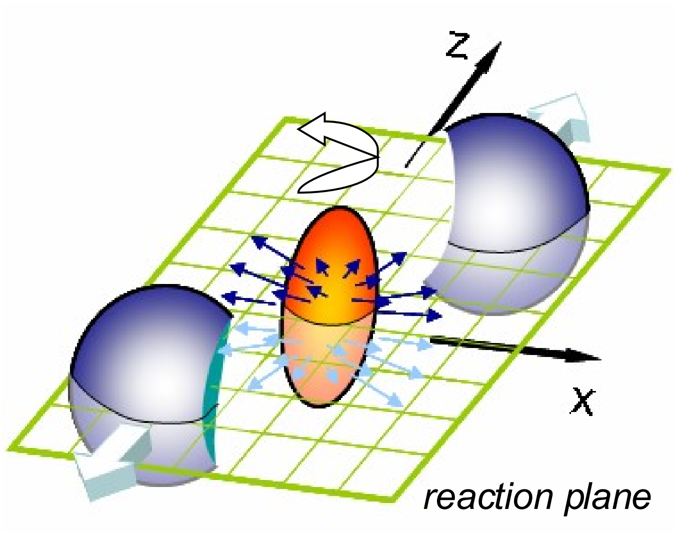
Xin Dong for the ***STAR*** Collaboration

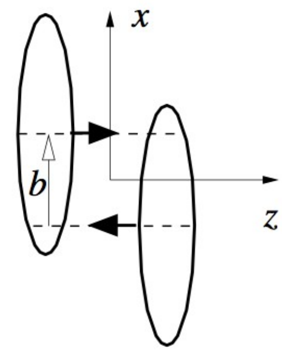
- Motivations
- Detector Setup and Analysis Technique
- Results
  - Λ *Global Polarization Measurement*
  - *Spin alignment measurement of vector mesons (K*,* ϕ *)*
    - *w.r.t. Reaction Plane – Global Polarization*
    - *w.r.t. Production Plane – Production dynamics*
- Conclusions

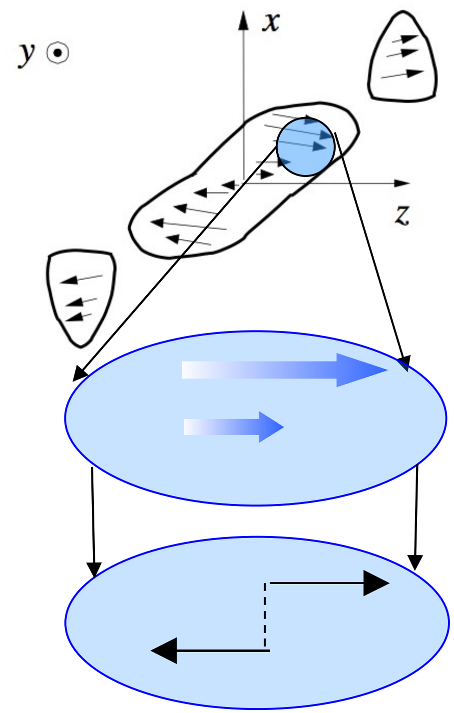
Phys. Rev. C 76 (2007) 024915; Phys. Rev. C 77 (2008) 061902(R)

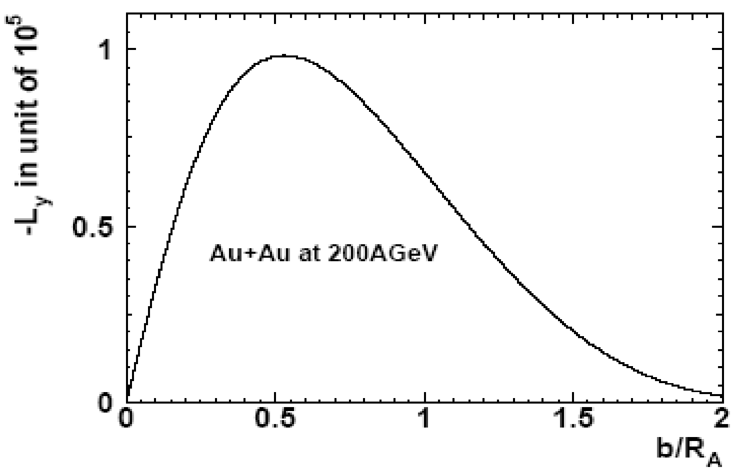
System orbital angular momentum

- Large orbital angular momentum possessed in non-central Au+Au collisions:









$$\Delta p_z = \Delta x \frac{dp_z}{dx}$$

$$L_y = -\Delta x \Delta p_z$$

$$= -\Delta x^2 \frac{dp_z}{dx}$$

Z.T. Liang and X.N. Wang, Phys. Rev. Lett. 94 (2005) 102301

Global Polarization

- Transformation of the large angular momentum $\vec{L}$ into the particle spin

→ Global Polarization

- Features of global polarization:
  - *For non-central collisions, it should have a finite value, at small p_T in central rapidity;*
  - *It should increase with the impact parameter **b**;*
  - *It should vanish in central collisions*

$\vec{L}$ is perpendicular to the reaction plane
Correlations with respect to (w.r.t.) the reaction plane
(Anisotropic flow technique)

Global vector meson spin alignment and global hyperon polarization

Spin Alignment

Spin alignment (w.r.t. the reaction plane) – *probe global polarization in HIC*

It is sensitive to different hadronization scenarios in different kinematic region

- Coalescence *(ρ_{00}<1/3)*
- Fragmentation *(ρ_{00}>1/3)*

$$\rho_{00}^{\rho(\mathrm{rec})} = \frac{1-P_q^2}{3+P_q^2},$$

$$\rho_{00}^{K^*(\mathrm{rec})} = \frac{1-P_q P_s}{3+P_q P_s}.$$

$$\rho_{00}^{\rho(\mathrm{frag})} = \frac{1+\beta P_q^2}{3-\beta P_q^2},$$

$$\rho_{00}^{K^*(\mathrm{frag})} = \frac{f_s}{n_s+f_s}\frac{1+\beta P_q^2}{3-\beta P_q^2} + \frac{n_s}{n_s+f_s}\frac{1+\beta P_s^2}{3-\beta P_s^2}$$

Z.T. Liang and X.N. Wang, Phys. Lett. B 629 (2005) 20.

Spin alignment w.r.t the production plane – *production mechanisms*

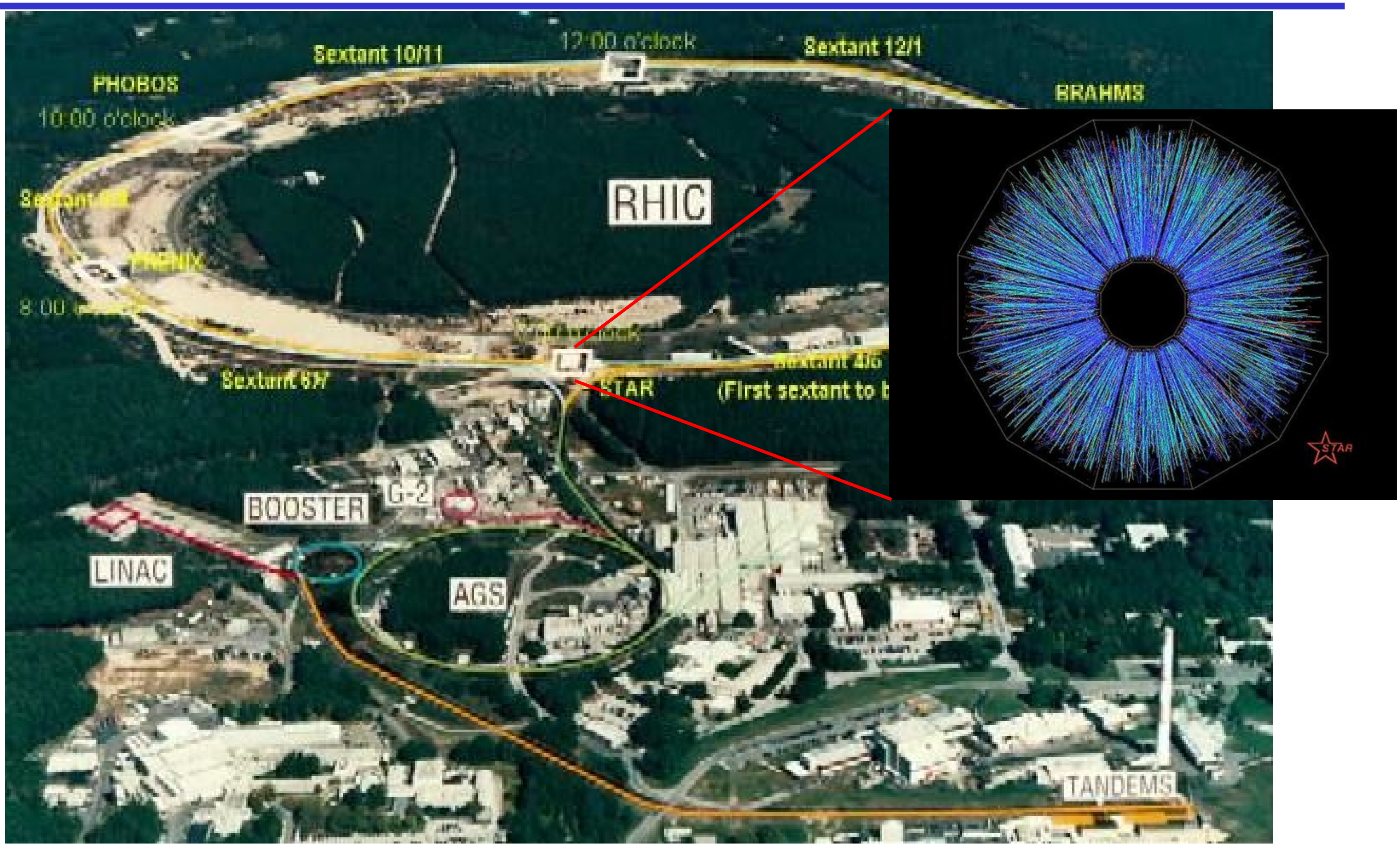
- particle formation dynamics or to intrinsic quark transverse spin distribution

B. Andersson et. al. PLB 85, 417 (1979); J. Szwed PLB 105, 403 (1981); R. Barni et. al. PLB 296, 251 (1992); J. Soffer et. al. PRL 68, 907 (1992)

- May be correlated with the global polarization convoluted with an azimuthal angular anisotropy (v_2) *S. Voloshin, nucl-th/0410089*

ρ_{00} *-- spin density matrix element (1/3 for unpolarized case)* $\rho_{00} = 1 - \rho_{11} - \rho_{-1-1}$

Relativistic Heavy Ion Collider (RHIC)



Heavy Ion Collisions: Au + Au, Cu + Cu, *d* + Au $\sqrt{s_{NN}}$ = 200 GeV

Polarized p + p Collisions: $\vec{p} + \vec{p}$, $p^{\uparrow} + p^{\uparrow}$ $\sqrt{s}$ = 200 (500) GeV

Detector, Data Sample & Reconstruction

<u>Solenoidal Tracker At RHIC (STAR)</u>

<u>Time Projection Chamber</u> ($|\eta|<1$, full azimuth)

Data Samples:

Au+Au 200 GeV minimum bias

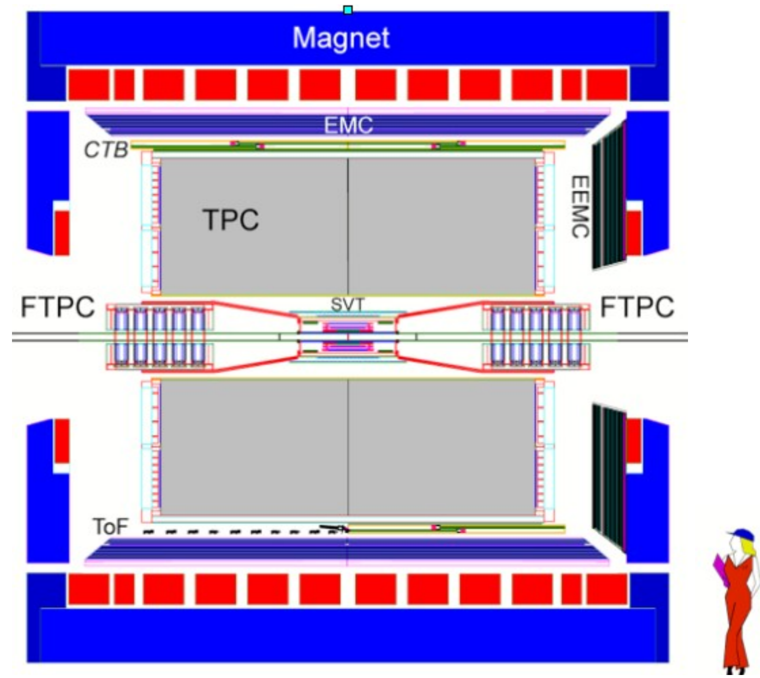
~23 M events

Au+Au 62.4 GeV minimum bias

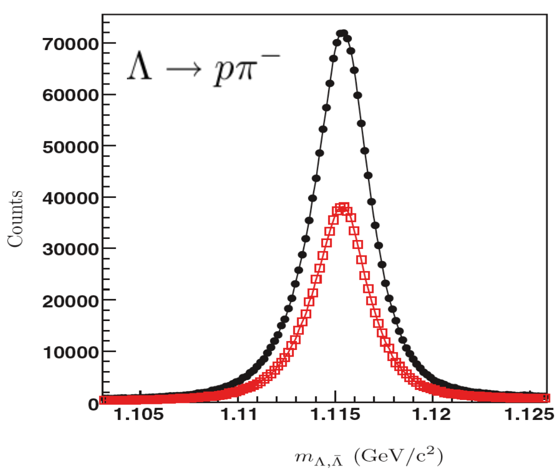
~8 M events

p+p 200 GeV Non-Singly Diffractive

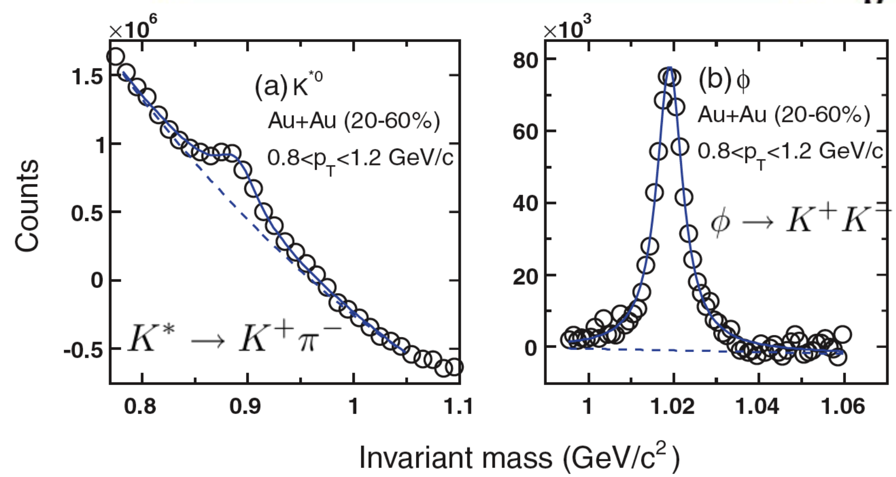
~6 M events



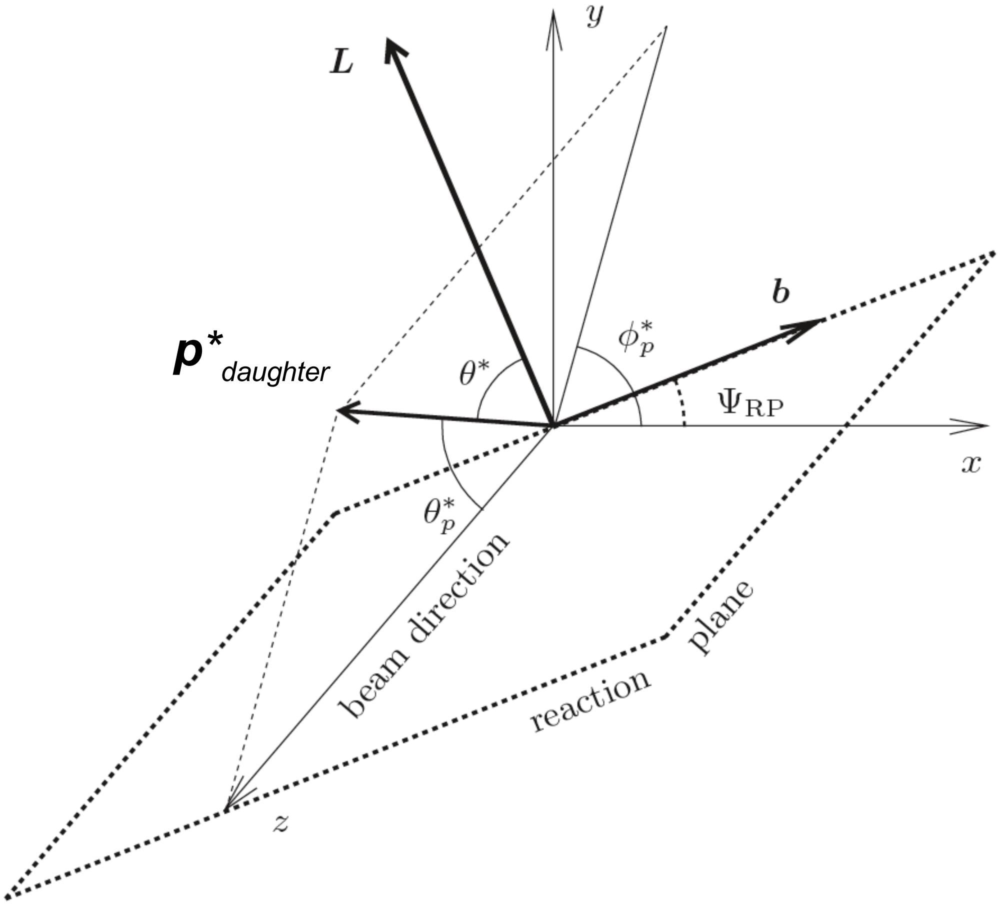
Topological reconstruction



Mixed-event method to describe the combinatorial background



Analysis Technique



θ^* Angle between the daughter momentum in the rest frame of the parent particle and the polarization direction

Measuring the decay daughter momentum distribution in the rest frame of its parent particle w.r.t. the polarization direction.

Lambda global polarization

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

decay parameter = 0.642 for Λ

$$P_H = \frac{3}{\alpha_H}\langle\cos\theta^*\rangle$$

Vector meson spin alignment

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

ρ_{00} *-- spin density matrix element*
1/3 for unpolarized case

Event Plane Reconstruction

Standard event plane reconstruction method in flow analysis in STAR.

A.M. Poskanzer and S.A. Voloshin, Phys. Rev. C 58 (1998) 1671

$$Q_n \cos(n\Psi_n) = X_n = \sum_i w_i \cos(n\phi_i)$$

$$Q_n \sin(n\Psi_n) = Y_n = \sum_i w_i \sin(n\phi_i).$$

$$\Psi_n = \left(\tan^{-1} \frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)} \right) \Big/ n$$

Λ global polarization – similar to v_1 analysis

Use tracks at the Forward TPC detectors ($2.8<|\eta|<3.8$) for the 1st order event plane reconstruction.

The direction is fixed by convention that spectator neutrons are deflected along the direction of the impact parameter.

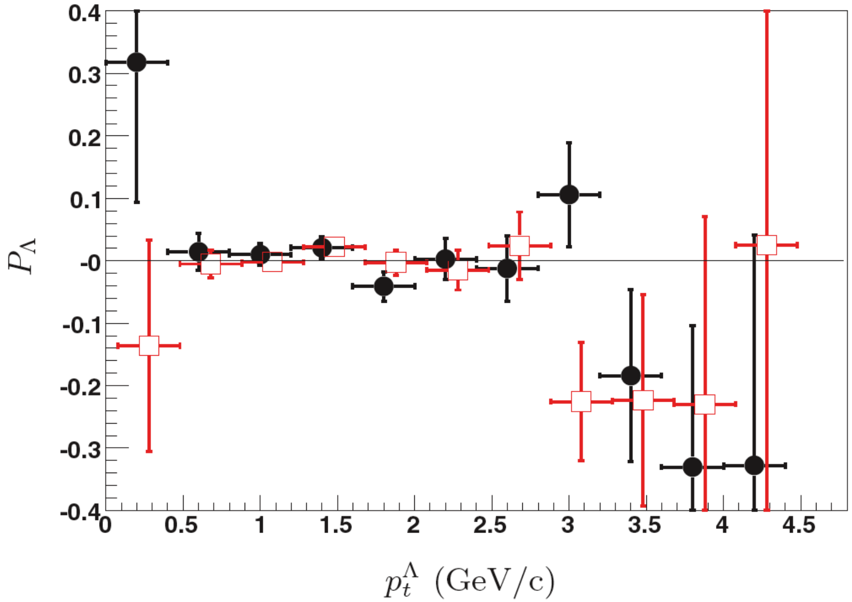
Spin alignment of vector mesons - similar to v_2 analysis

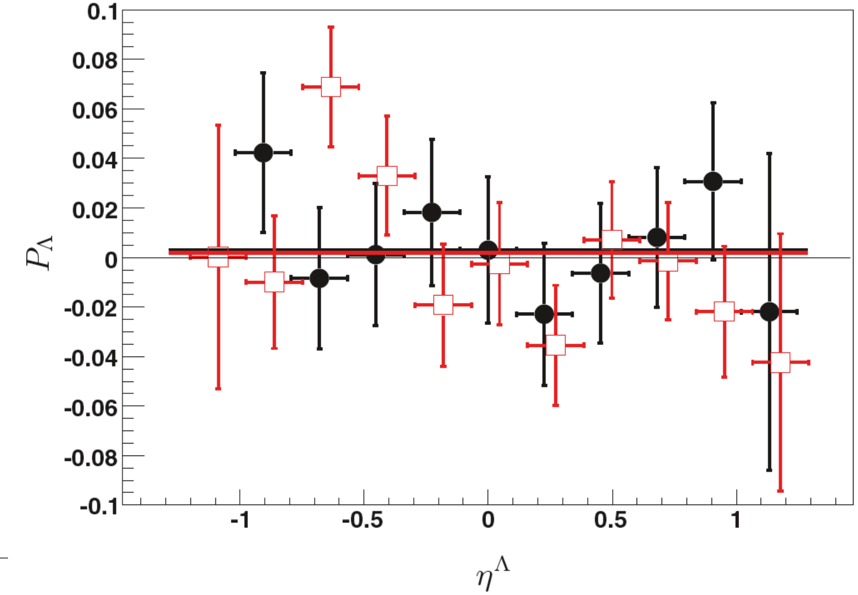
advantage: no need to know the polarization direction

use tracks in the TPC (mid-rapidity) for the 2nd order event plane reconstruction.

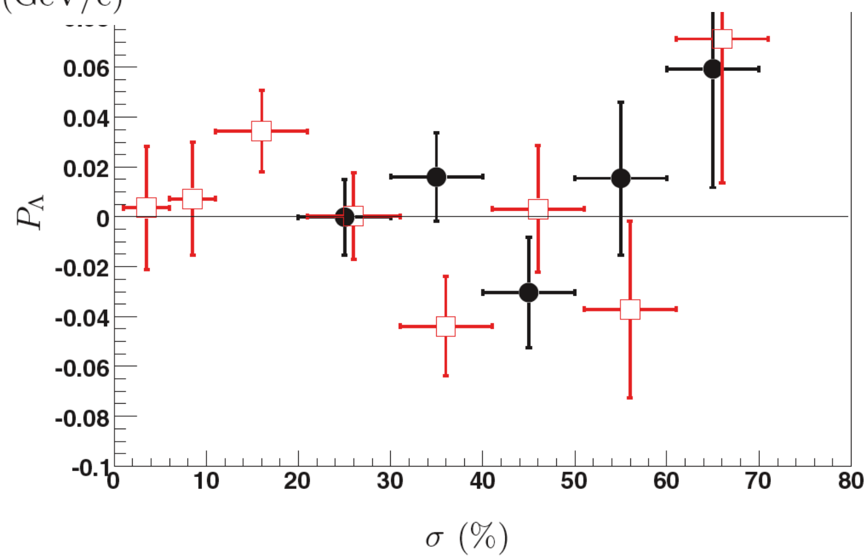
Finite event plane resolutions were corrected in the final physics results.

Lambda Global Polarization





Filled:
200 GeV, 20-70%
Open:
62.4 GeV, 0-80%



- $P_{\Lambda,\bar{\Lambda}}$ is consistent with zero with statistical error ~ 0.01
- no obvious dependence on p_T, η , centrality

Lambda Global Polarization

- $P_{\Lambda,\bar{\Lambda}}$ is consistent with zero with statistical error ~ 0.01

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

- No obvious dependence on p_T, η , centrality.

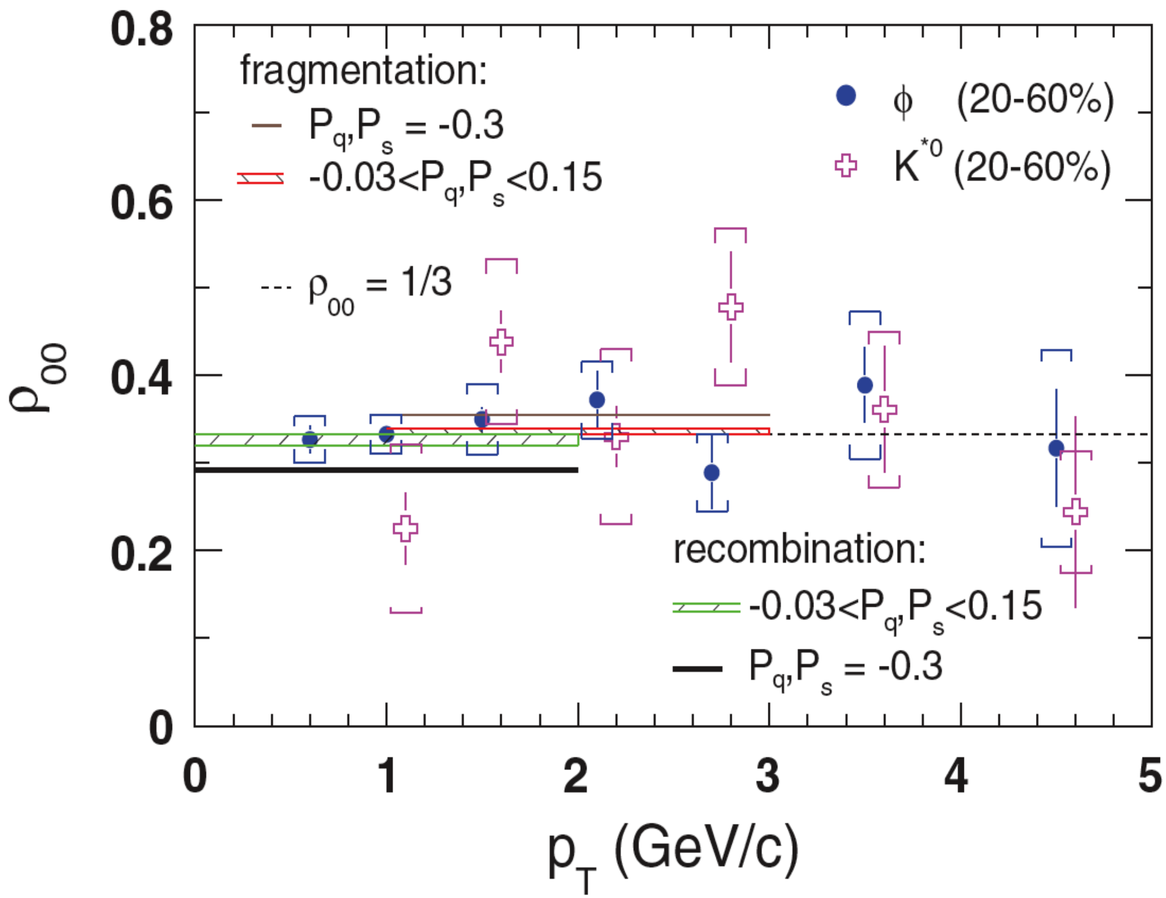
- Major Systematic Errors

Acceptance effect	~ 20%
Feed-down from Σ^0	~ 30%
Multistrange feed-down	~ 15%
Reaction Plane	~ 30%

Upper limit for the global Lambda polarization in Au+Au collisions at RHIC

$$|P_{\Lambda,\bar{\Lambda}}| \leq 0.02$$

Spin alignment w.r.t. the reaction plane

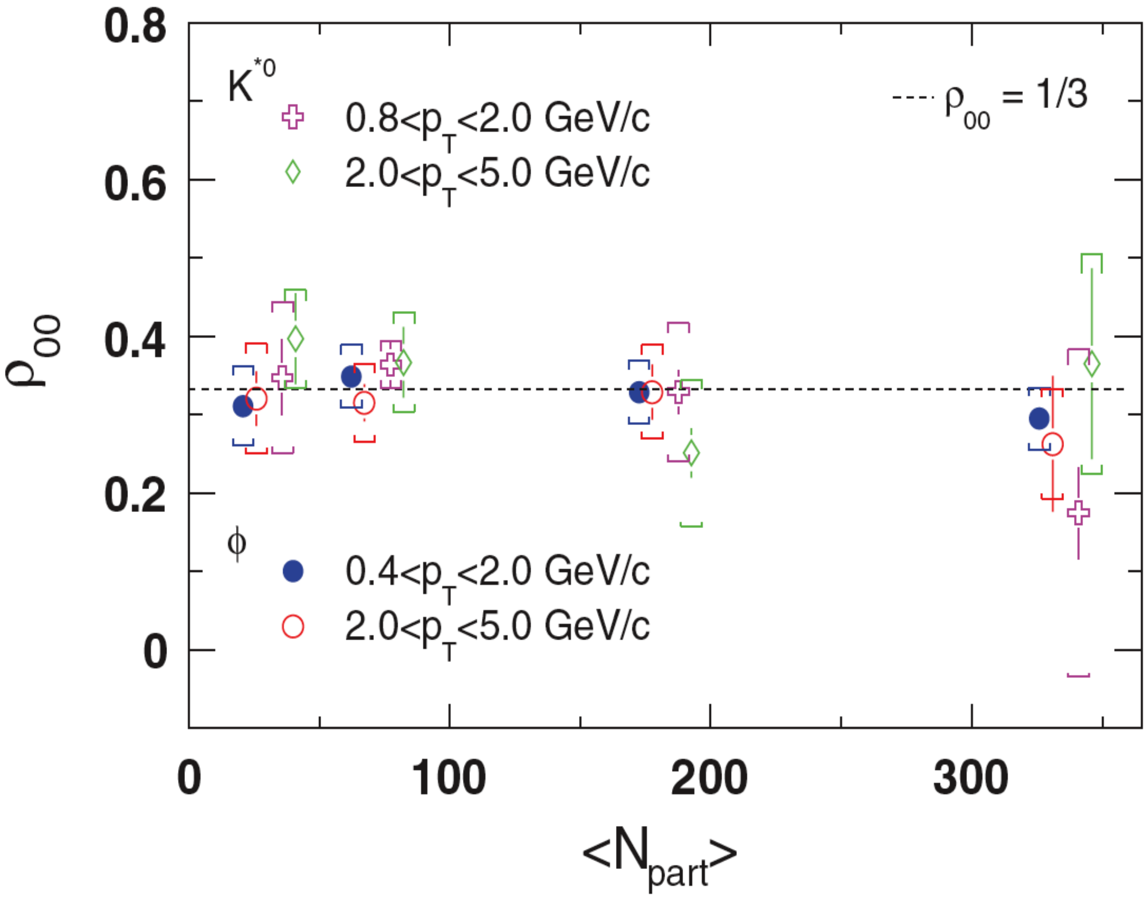


K^{*0} (0.8<p_T<5.0 GeV/c):
ρ_{00} = 0.32 ± 0.03 ± 0.09

φ (0.4<p_T<5.0 GeV/c):
ρ_{00} = 0.34 ± 0.02 ± 0.03

- ✔*Data favor no large global polarization for vector mesons in heavy ion collisions.*
- ✔*Consistent with Lambda global polarization measurements.*
- ✔*Current uncertainty cannot distinguish different hadronization mechanisms.*

Spin alignment w.r.t the reaction plane

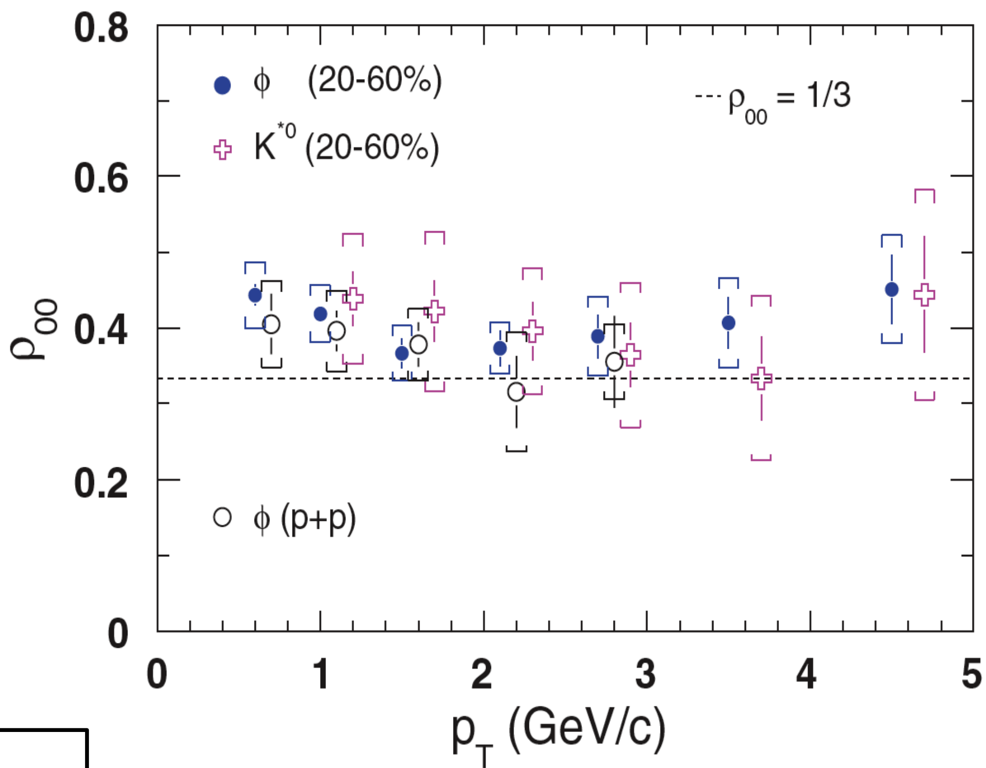


Within current sensitivity, our measurement exhibits no strong spin alignment for vector meson at all collision centralities, presumably because the spin-orbit coupling for quark polarization is not large enough to be manifested in our measurement.

Spin alignment w.r.t. the production plane

Production plane:
produced particle momentum and beam line

Similar analysis as that was done w.r.t. reaction plane



p_T<2.0 GeV/c

$\rho_{00}(K^*) = 0.43 \pm 0.04 \pm 0.09$; $\rho_{00}(\varphi) = 0.42 \pm 0.02 \pm 0.04$

p_T>2.0 GeV/c

$\rho_{00}(K^*) = 0.38 \pm 0.04 \pm 0.09$; $\rho_{00}(\varphi) = 0.38 \pm 0.03 \pm 0.05$

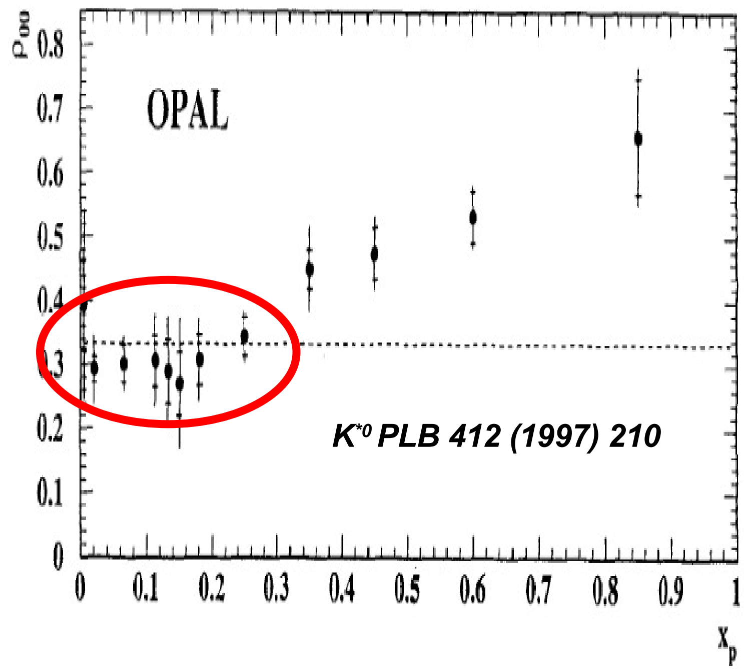
In p+p, $\rho_{00}(\varphi) = 0.39 \pm 0.03 \pm 0.06$

Comparison between different systems

DELPHI Col. PLB 406 (1997) 271

The spin density matrix elements for the ρ^0, $K^{*0}(892)$ and ϕ produced in hadronic Z^0 decays are measured in the DELPHI detector. There is no evidence for spin alignment of the $K^{*0}(892)$ and ϕ in the region $x_p \leq 0.3$ ($x_p = p/p_{beam}$), where $\rho_{00} = 0.33 \pm 0.05$ and $\rho_{00} = 0.30 \pm 0.04$, respectively. In the fragmentation region, $x_p \geq 0.4$, there is some indication

$$e^+e^- \rightarrow Z \rightarrow q\bar{q} \rightarrow K^{*0} + X$$



- At small x_p region, ρ_{00} are consistent with 1/3 from ee, pp, to AuAu collisions

Conclusions

- *Lambda global polarization w.r.t. The reaction plane is consistent with zero with statistical uncertainty ~ 0.01.* *Upper limit* $|P_{\Lambda,\bar{\Lambda}}| \leq 0.02$
- *w.r.t the reaction plane, $\rho_{00}(p_T)$ of (K^*, ϕ) are consistent within 1/3 within statistical and systematic uncertainty in the measured p_T up to 5 GeV/c and no strong dependence on collision centrality or transverse momentum was observed.*

→ *Vector mesons and hyperons in the measured kinematic region appear not to be produced with a strong global polarization despite the presence of a large orbital angular momentum for the system created in non-central Au+Au collisions.*

- *w.r.t. the production plane, $\rho_{00}(p_T)$ is less than 2 standard deviation above 1/3 and is similar to the results from p+p collisions.*

→ *Vector mesons in the measured p_T region at mid-rapidity don't seem to carry a significant polarization through production dynamics.*