Review of global polarization and spin alignment measurements in ALICE and STAR

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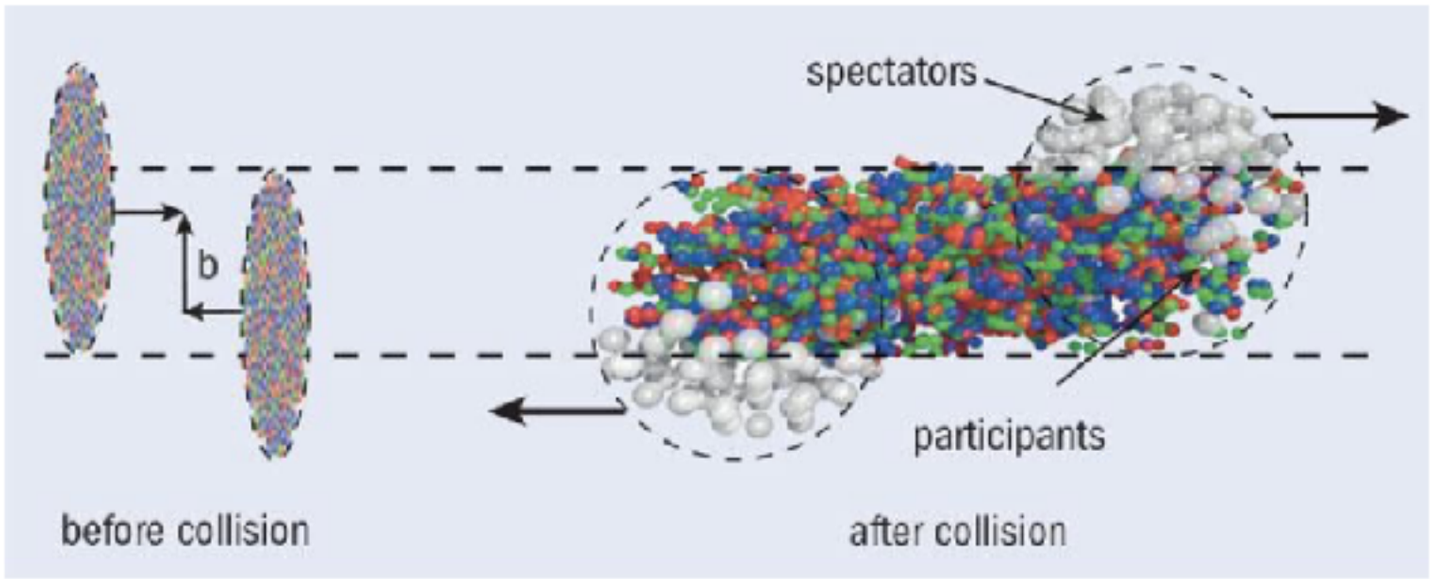
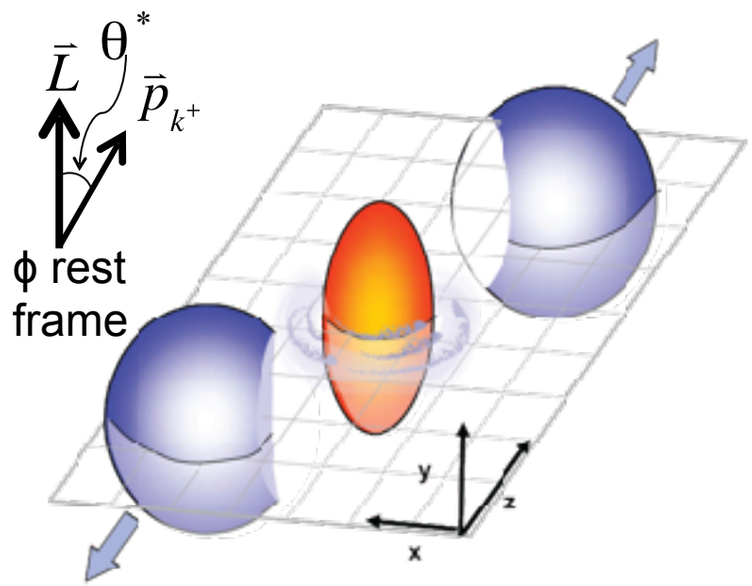
Introduction

- Initial angular momentum $\boldsymbol{L}$ ~ 10^3 ħ in non-central heavy-ion collisions.
- Baryon stopping may transfer this angular momentum, in part, to the fireball.
- Due to vorticity and spin-orbit coupling, ϕ-meson spin may align with L.





Spin alignment

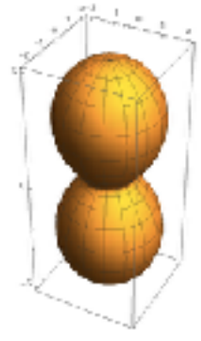
- Spin alignment can be determined from the angular distribution of the decay products*:

$$\frac{dN}{d(\cos\theta^*)} = N_0 \times \left[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta^*\right]$$

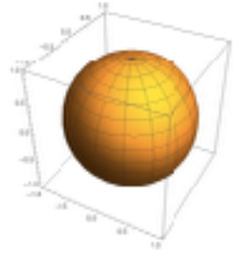
where N_0 is the normalization and θ* is the angle between the polarization direction ***L*** and the momentum direction of a daughter particle in the rest frame of the parent vector meson.

- A deviation of ρ_{00} from 1/3 signals net spin alignment.

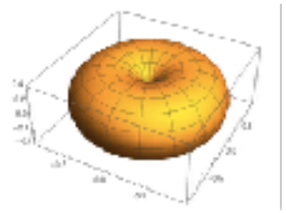
ρ_{00}>1/3:

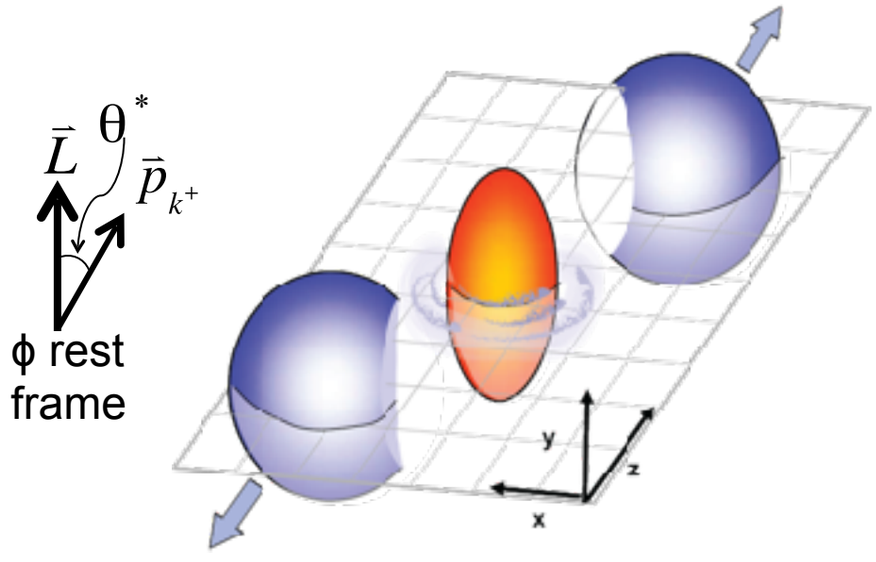


ρ_{00}=1/3:



ρ_{00}<1/3:





*Phys. B 15, 397 (1970)

Hadronization scenarios

- Recombination of polarized quarks and anti-quarks in QGP likely dominates in the low p_T and central rapidity region.

$$\rho_{00} = \frac{1 - P_1 P_2}{3 + P_1 P_2}$$

- Fragmentation of polarized quarks q -> V + X, likely happens in the intermediate p_T and forward rapidity region.

$$\rho_{00} = \frac{1 + \beta P_1 P_2}{3 - \beta P_1 P_2}$$

$P_{1,2} = -\frac{\pi}{4} \frac{\mu p}{E(E + m_{1,2})}$ is the global quark polarization

Phys. Lett. B629, 20 (2005)

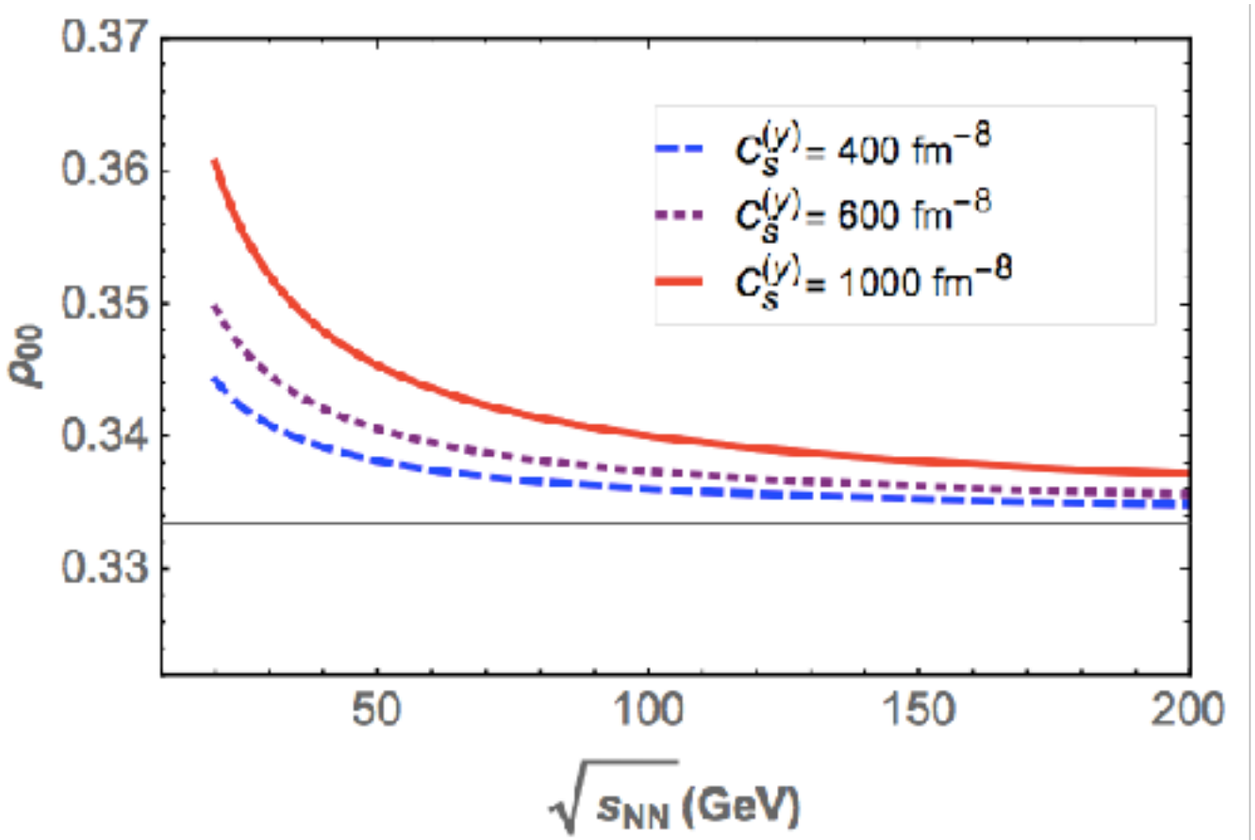
Hadronization scenarios

- Contribution from magnetic field:

$$\rho_{00}(B) = \frac{1}{3} - \frac{1}{9}\beta^2 \frac{Q_1 Q_2}{m_1 m_2} B^2$$

Phys.Rev.C 97 (2018) 3, 034917

- Contribution from vector meson filed:



Phys.Rev.D 101 (2020) 9, 096005

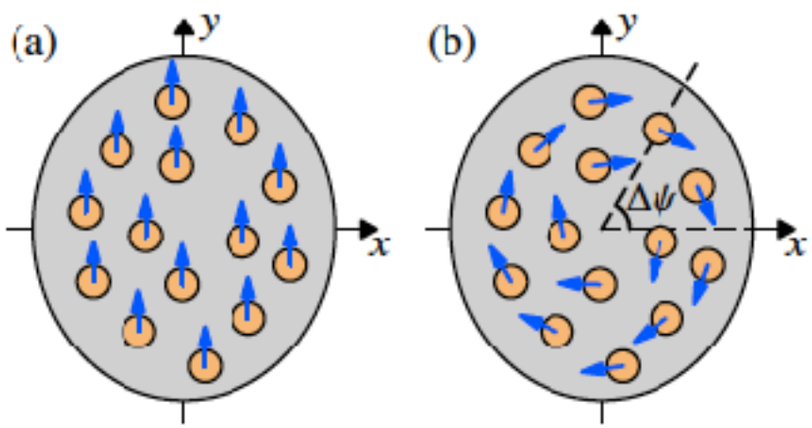
Measurements in different frames

- Measurements in production plane are related to reaction plane through v_2:

$$\rho_{00}(PP) - \frac{1}{3} = [\rho_{00}(EP) - \frac{1}{3}]\frac{1+3v_2}{4}$$

Phys.Rev.Lett. 125 (2020) 1, 012301

- The local polarization of quarks and anti-quarks can cause ρ_{00} of vector mesons to deviate from 1/3.



arXiv:2010.01474v1

Practical considerations for measurement

- Event plane resolution correction:

$$\rho_{00}^{rec} - \frac{1}{3} = \frac{4}{1+3R}(\rho_{00}^{obs} - \frac{1}{3})$$

- Acceptance correction:

$$\left[\frac{dN}{d\cos\theta^*}\right]_{|\eta|<1} \propto (1+\frac{B'F}{2})+(A'+F)\cos^2\theta^* + (A'F - \frac{B'F}{2})\cos^4\theta^*$$

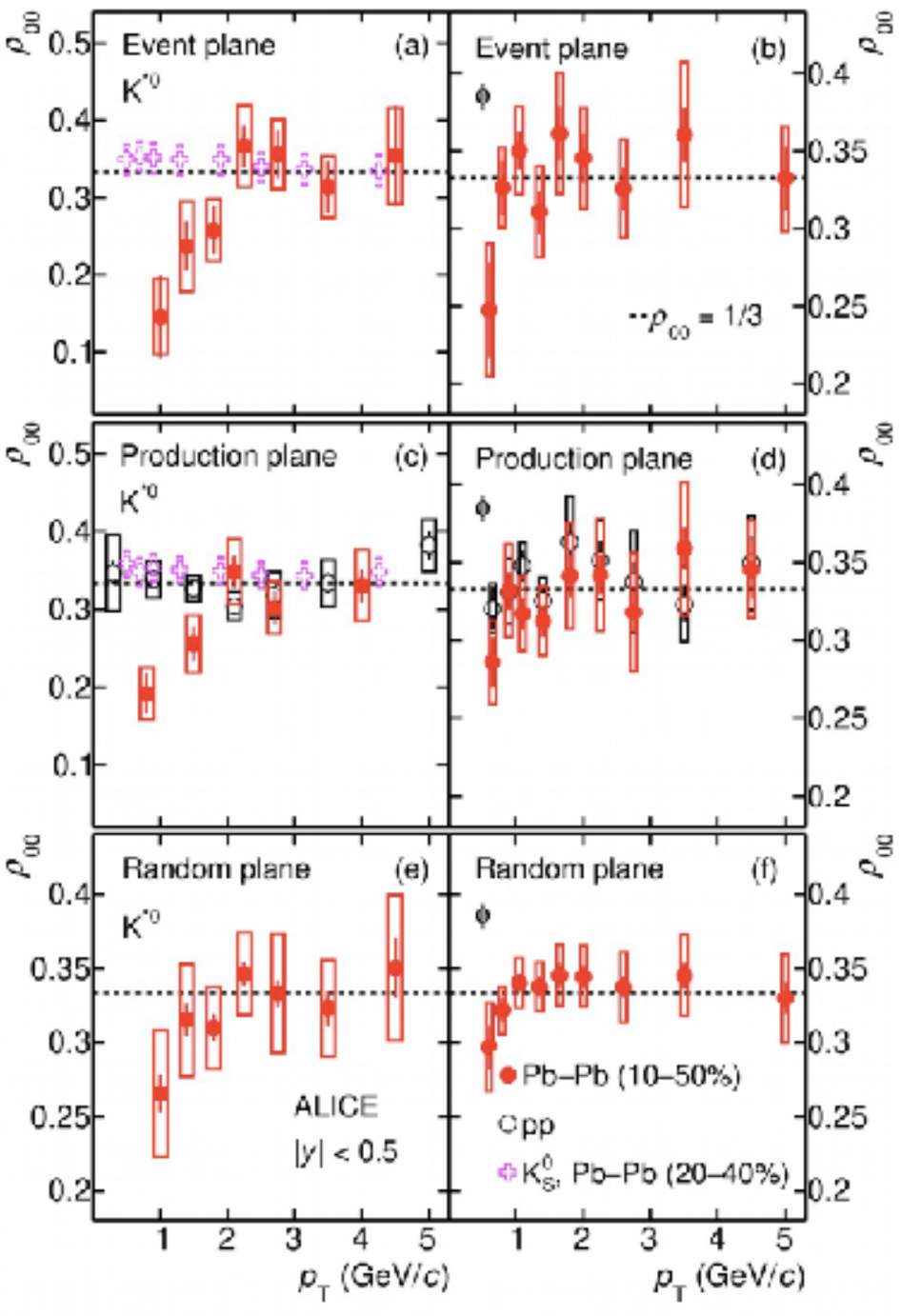
where

$$A' = \frac{A(1+3R)}{4+A(1-R)}, \quad B' = \frac{A(1-R)}{4+A(1-R)}$$

here $A = (3\rho_{00}^{real} - 1)/(1-\rho_{00}^{real})$, R is the resolution.
F describes the effect of acceptance.

Phys.Rev.C 98 (2018) 4, 044907

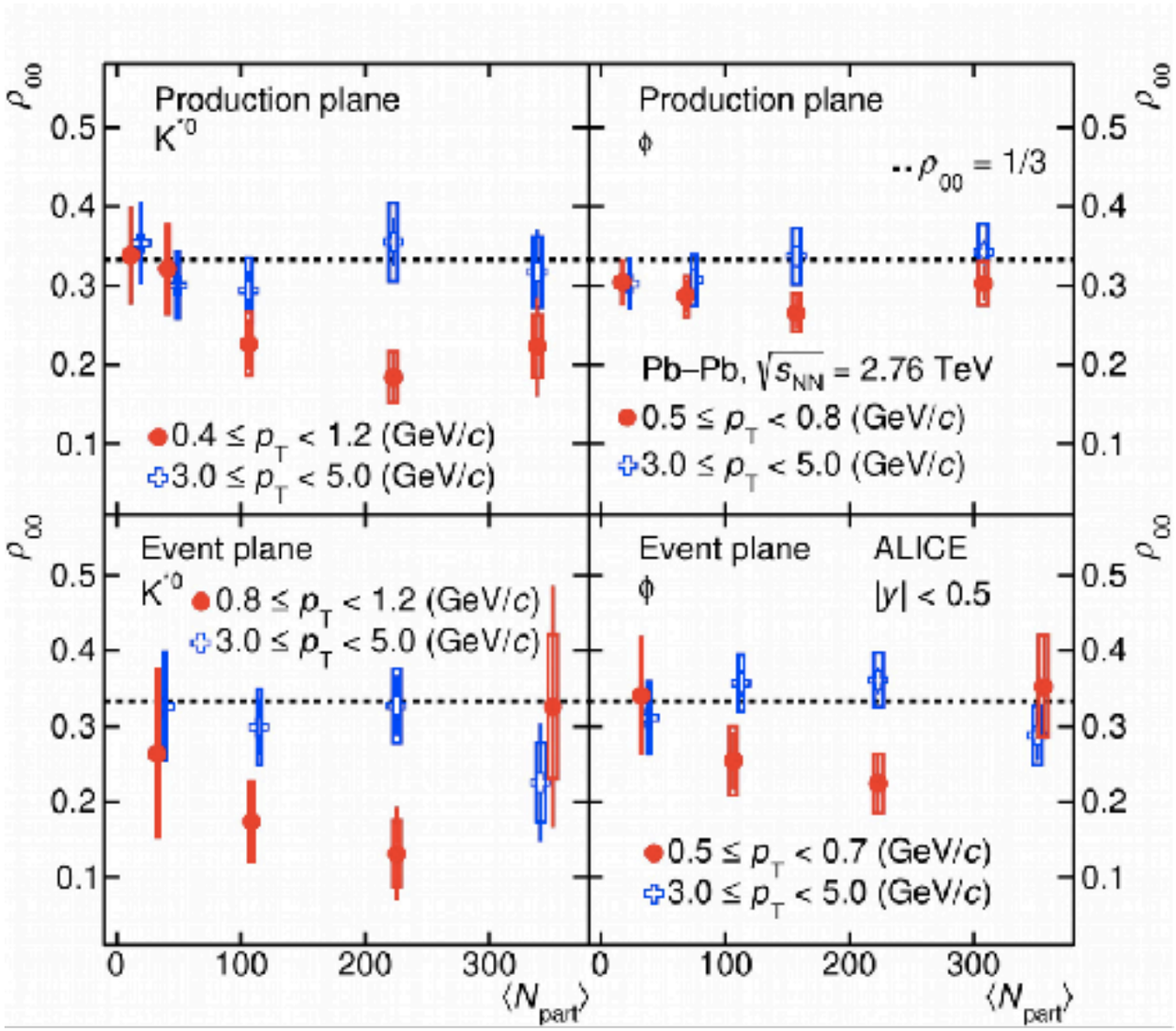
ALICE measurement: p_T dependence



- p-p collisions:
  - ρ_{00} consistent with 1/3 for both K^{*0} and ϕ mesons.
- Pb-Pb collisions:
  - ρ_{00} consistent with 1/3 for K^{*0} and ϕ mesons at high p_T
  - $\rho_{00} < 1/3$ at low p_T

Sourav Kundu, QM2019 presentation
Phys.Rev.Lett. 125 (2020) 1, 012301

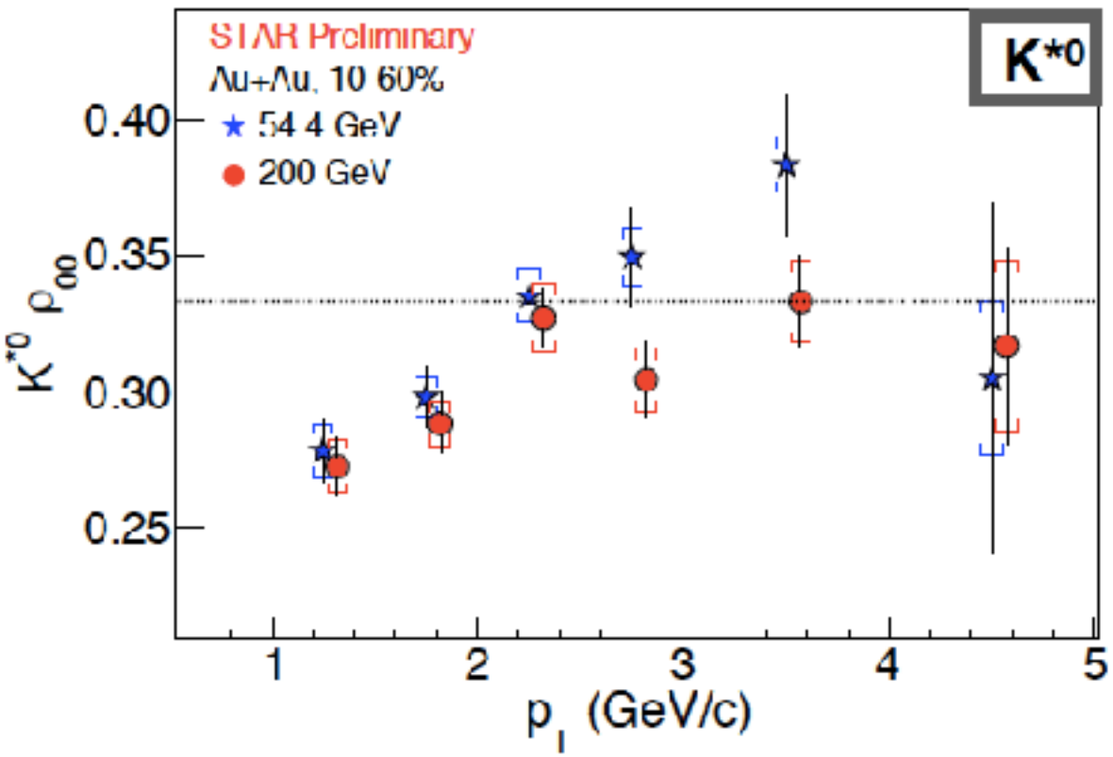
ALICE measurement: centrality dependence

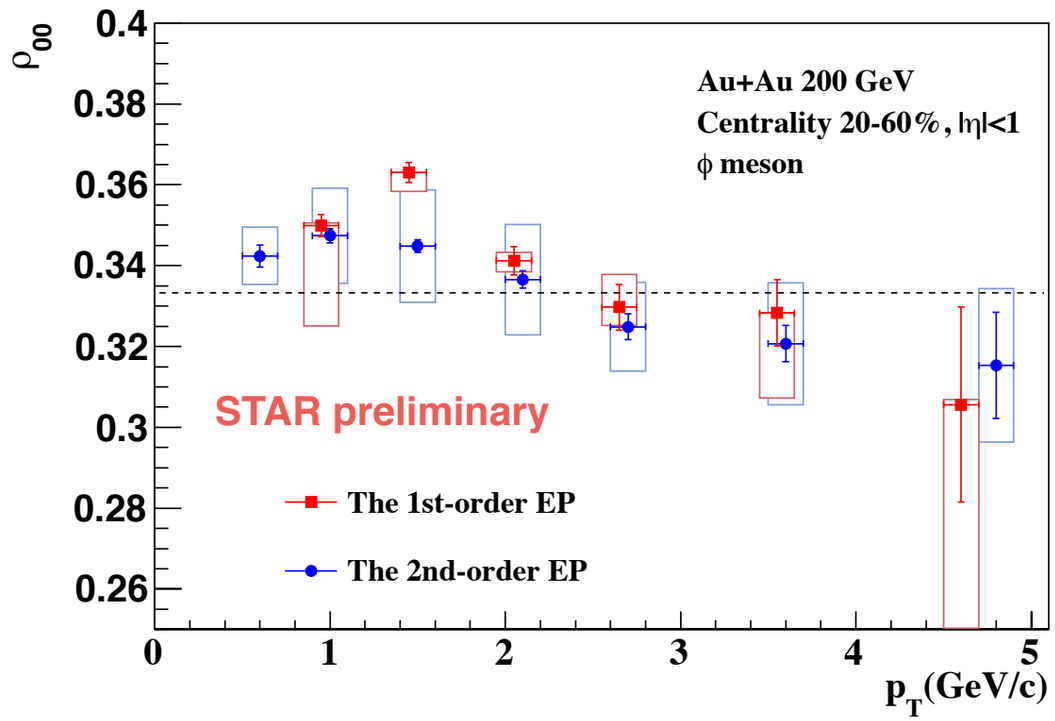


- Low p_T:
  - Centrality dependence
- High p_T:
  - No significant centrality dependence

Sourav Kundu, QM2019 presentation
Phys.Rev.Lett. 125 (2020) 1, 012301

STAR measurement: p_T dependence

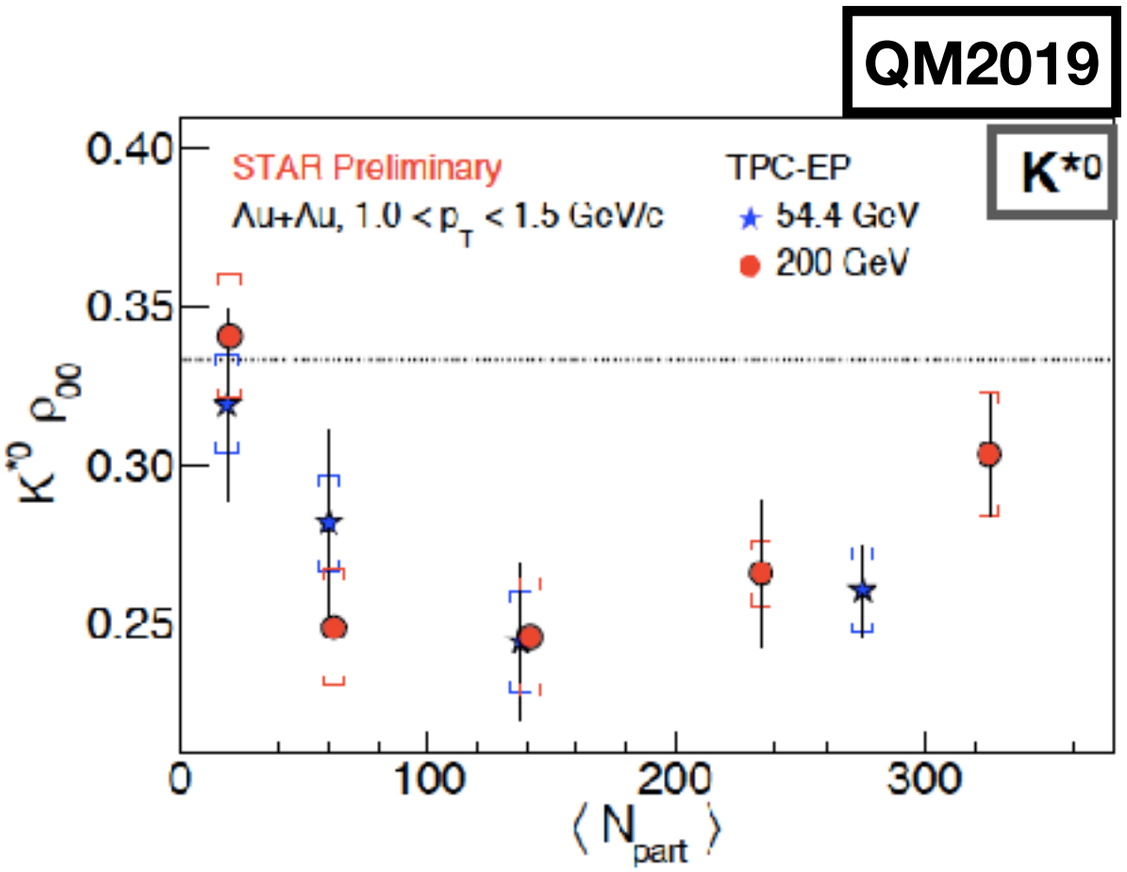


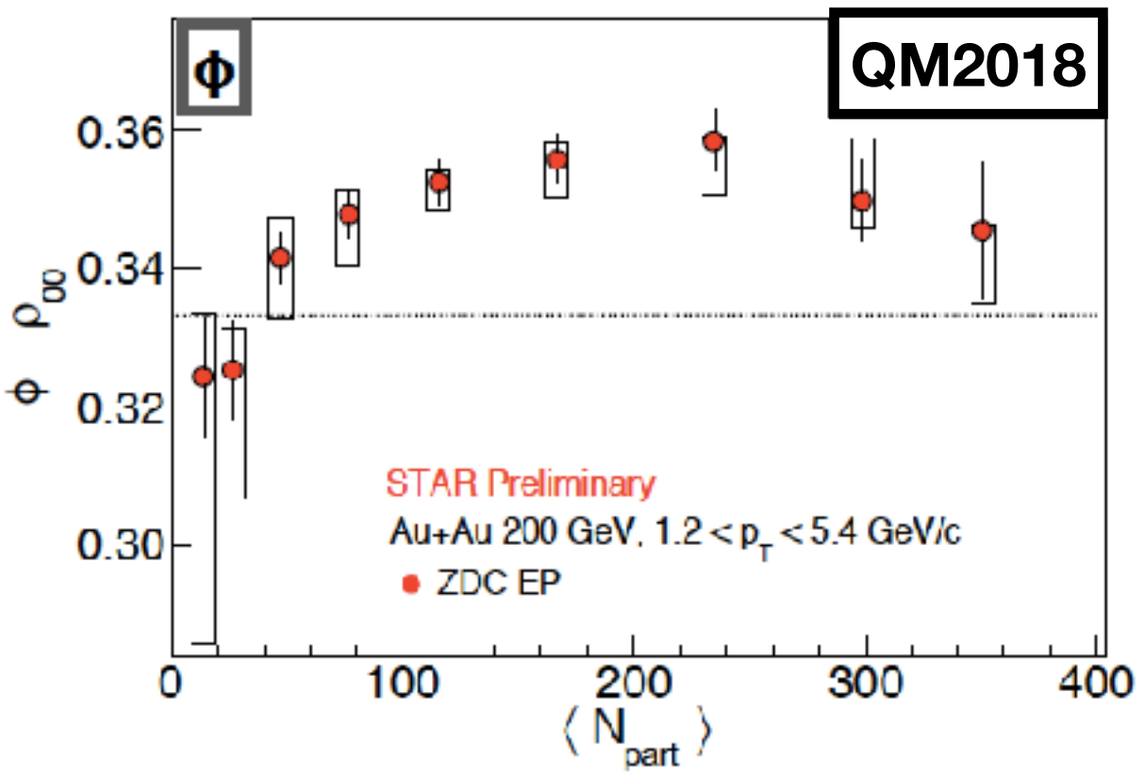


- Trend for K^{*0} ρ_{00} is qualitatively consistent with the naive expectation from recombination/ fragmentation of polarized quarks but the magnitude is much larger
- ϕ ρ_{00} does not fit into naive recombination/fragmentation picture
- But it can be explained by the existence of coherent ϕ meson field

Subhash Singha , QM2019 presentation
Chensheng Zhou, QM2018 presentation

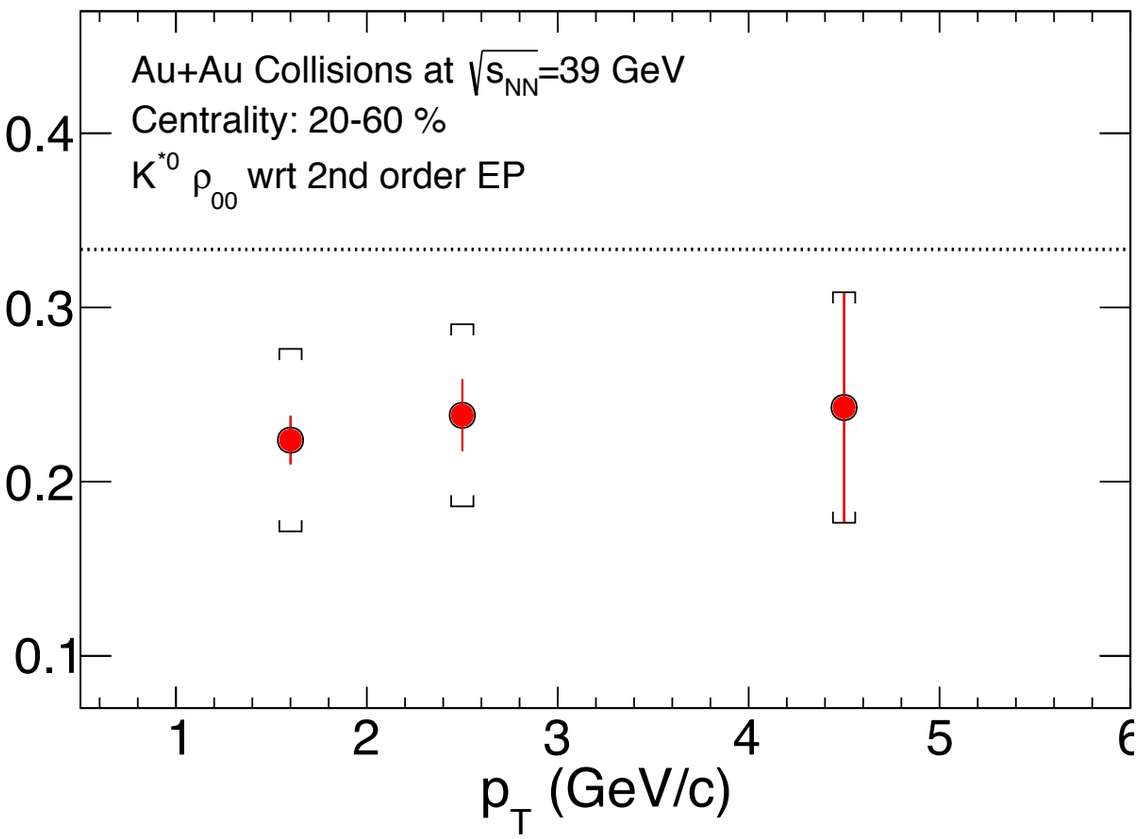
STAR measurement: centrality dependence

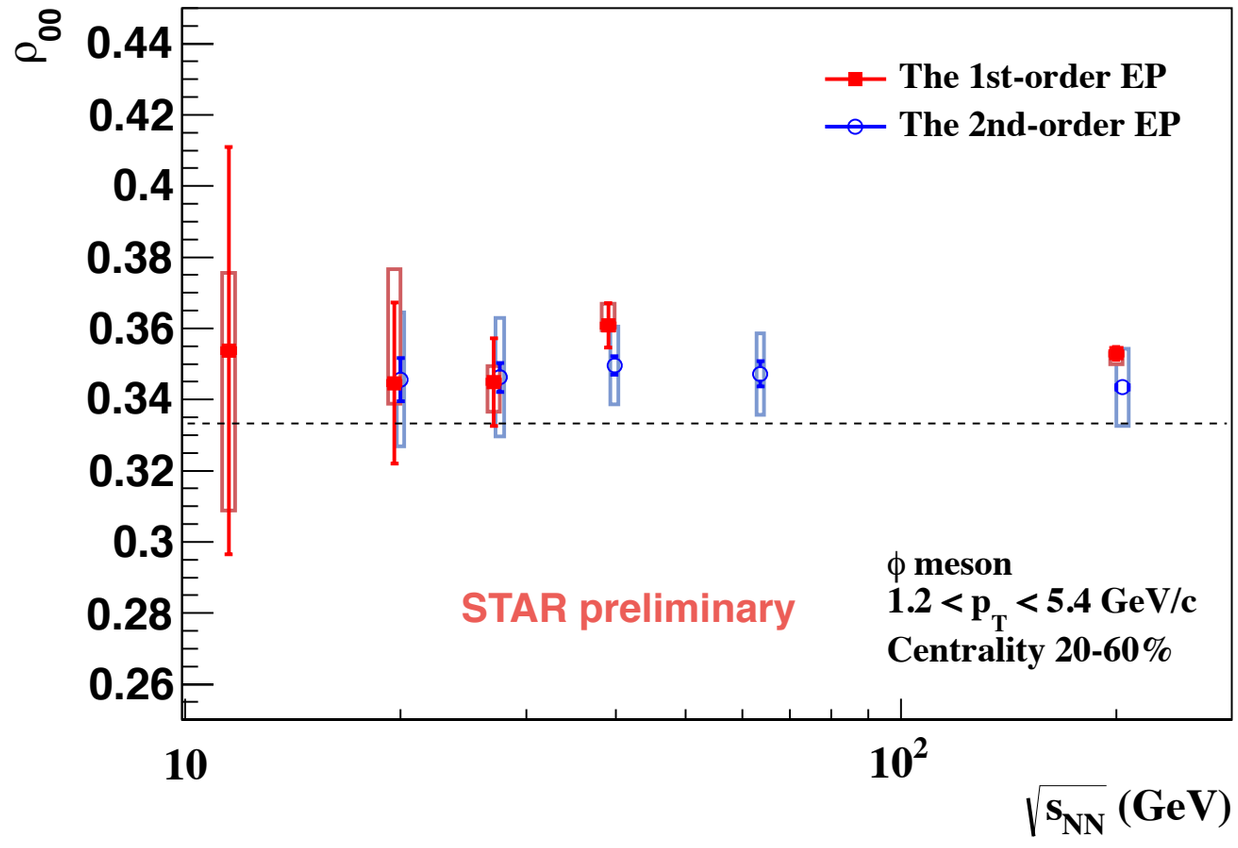




- For mid-central collisions: K^{*0} $\rho_{00} < 1/3$, ϕ $\rho_{00} > 1/3$

STAR measurement: energy dependence





- The results are integrated over $1.2 < p_T < 5.4$ GeV/c and centrality 20-60%.
- ALICE result for K^{*0}: 0.24 +/- 0.05 (10-50%, $0.8 < p_T < 5.0$ GeV/c)
- Expected ρ_{00} from Λ polarization in quark recombination model*: ~1/3

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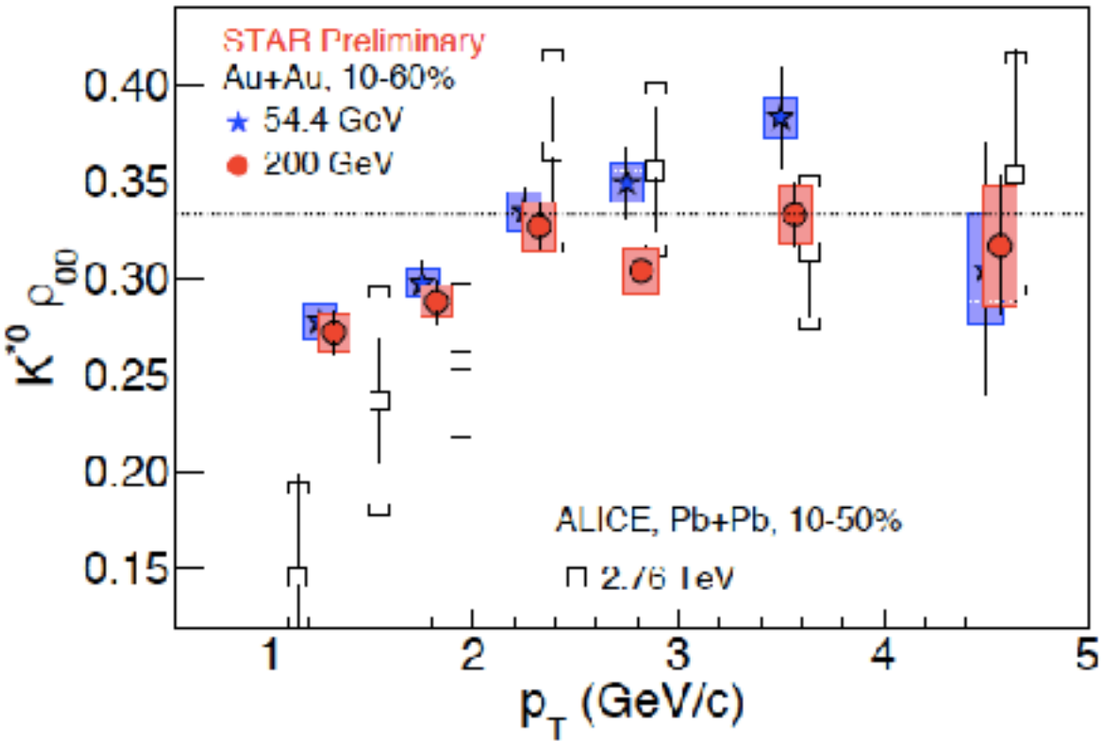
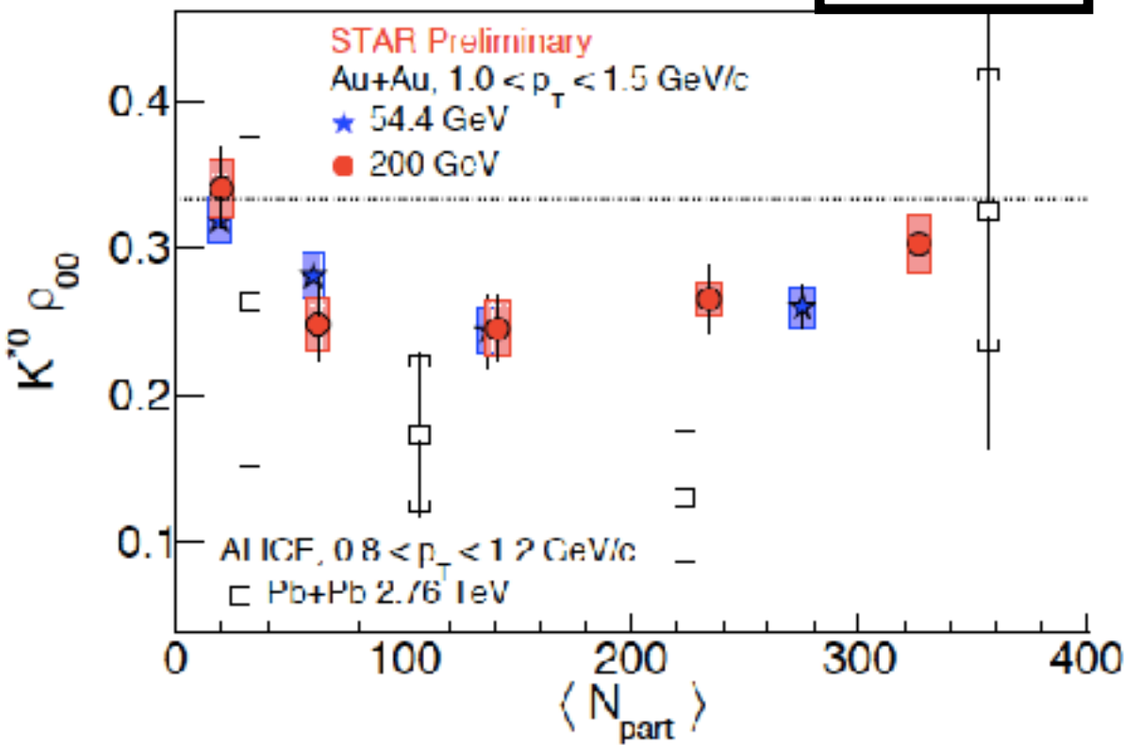
ALICE vs. STAR

QM2019





- p_T and centrality dependence of ρ_{00} at RHIC is similar to LHC energies.

- At low p_T and mid-central collisions hint that LHC measurements are lower than RHIC

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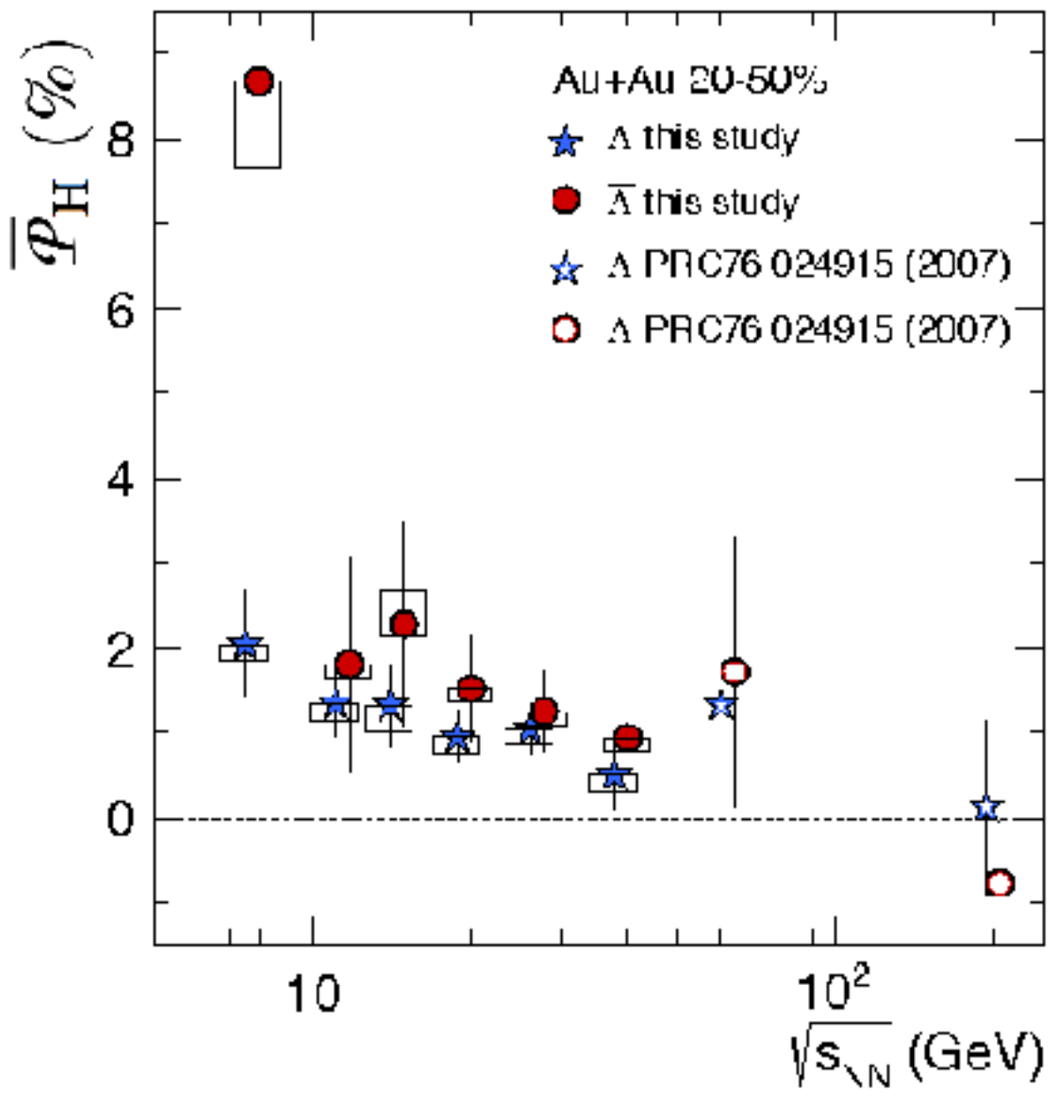
Polarization v.s spin alignment



STAR measurement

Nature 548 (2017) 62-65

- ALICE measurement in Pb-Pb 2.76 TeV: consistent with zero:
  P_Λ= 0.08 +/- 0.10 (stat.) +/-0.04 (syst.)

arXiv:1909.01281

- In quark recombination model:

$$P_\Lambda = p_s$$

$$\rho_{00} = \frac{1 - P_1 P_2}{3 + P_1 P_2}$$

Expecting a ~1/3 ρ_{00}

Summary

- K^{*0} $\rho_{00} < 1/3$ is observed for both ALICE and STAR in heavy ion collisions.
  p_T and centrality dependence of ρ_{00} is similar between RHIC and LHC for K^{*0}

- For mid-central collisions,
  $\rho_{00}(\phi) < 1/3$ (low p_T) and $\rho_{00}(\phi) \sim 1/3$ (high p_T) for ALICE
  $\rho_{00}(\phi) > 1/3$ for STAR

- Observed deviation of ρ_{00} from 1/3 is surprisingly larger than expectation based on Λ polarization.