Global spin polarization and alignment in heavy-ion collisions

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Outline

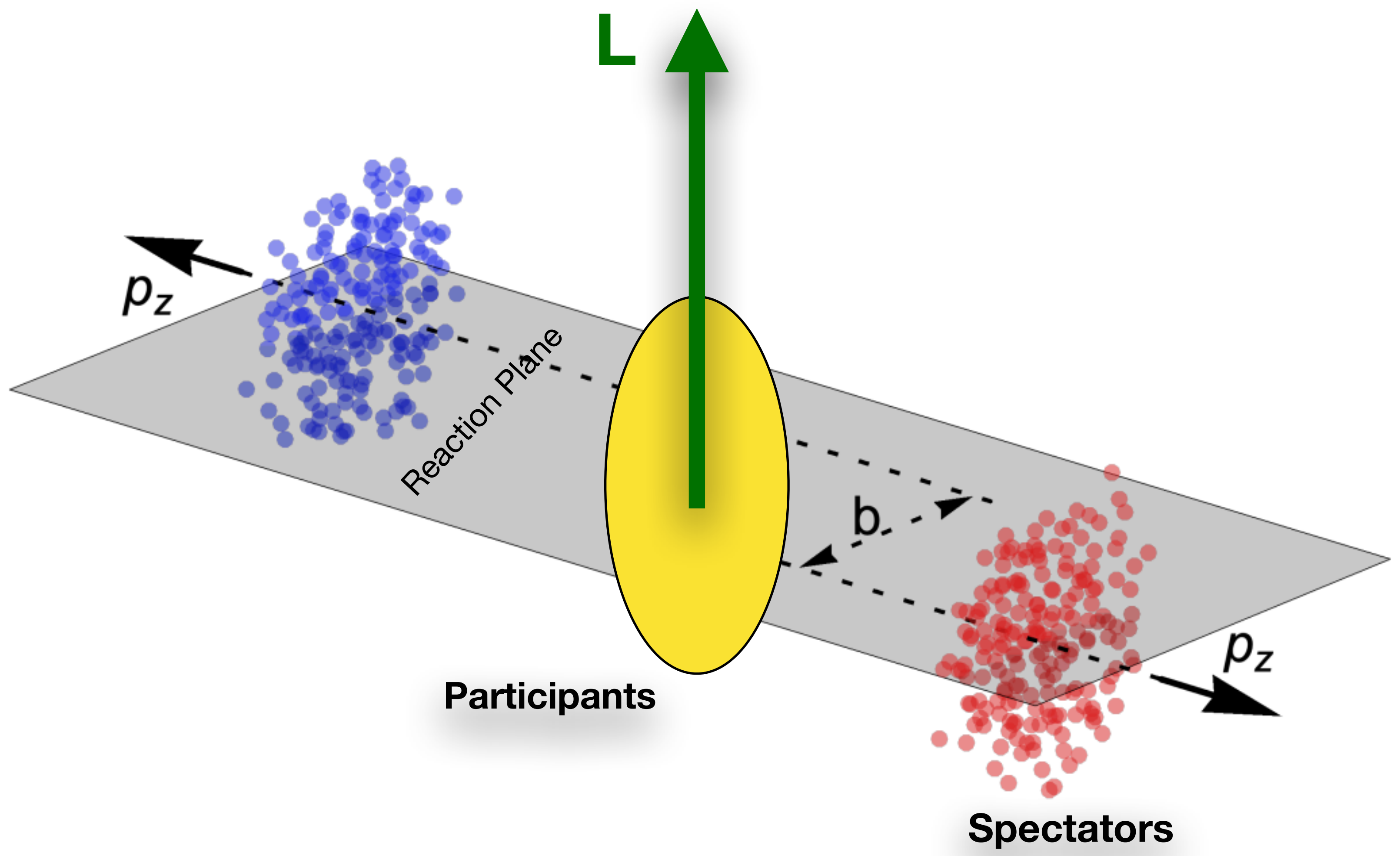
- Brief motivation
- Experimental results:

1. Global spin polarization of hyperons: **(Λ, Ξ, Ω)**
2. Local spin polarization of hyperons: **(Λ)**
3. Spin alignment of vector mesons: **ϕ, K* ($K^{*0,+/-}$), J/Ψ**

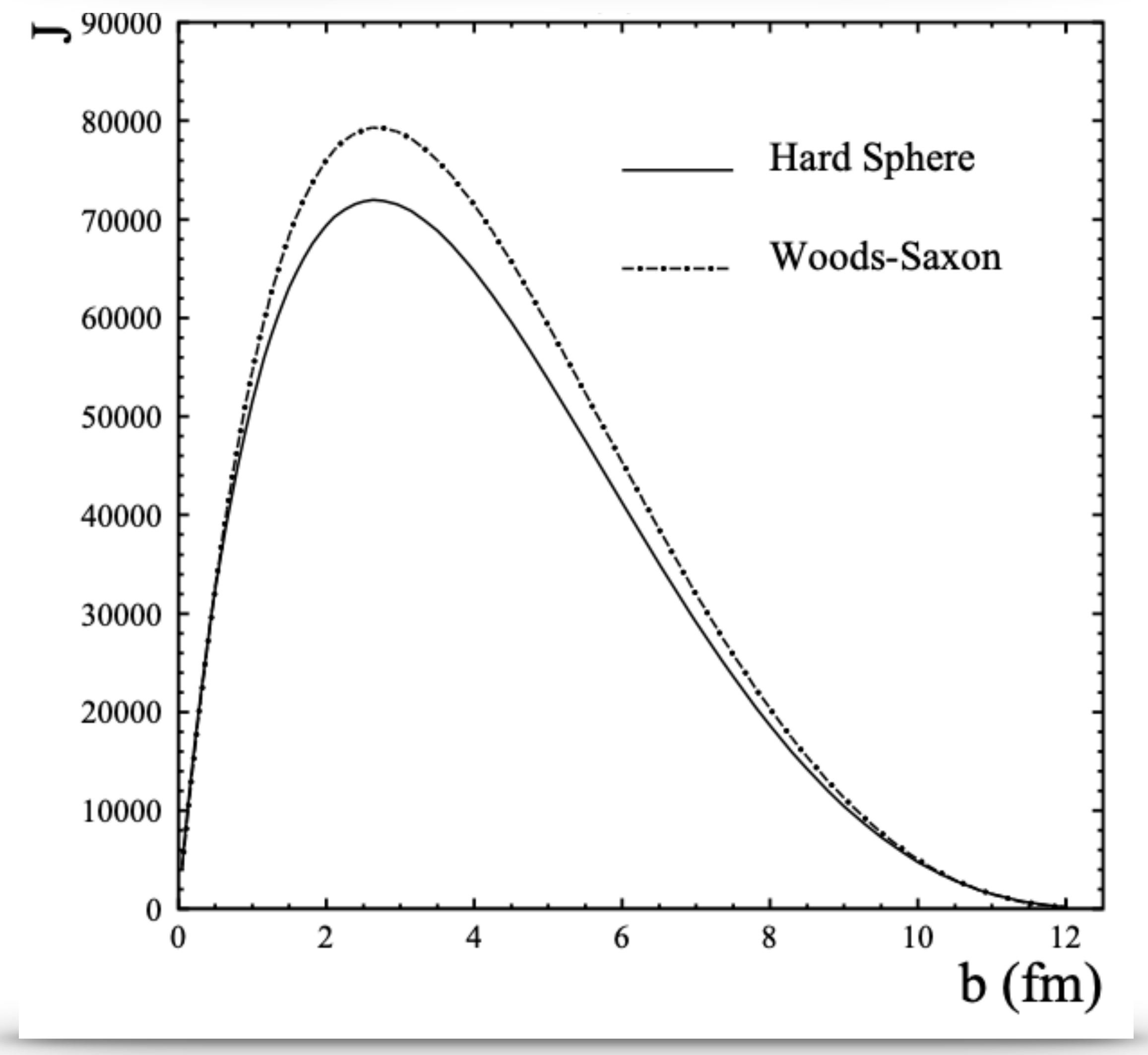
- Summary

For Theoretical overview:
Xu Guang, 12/06
Matteo Buzzeloi, 16/06

Motivation



Angular momentum



Becattini et. al., Phys Rev C 77, 024906 (2008)

In non-central heavy-ion collisions

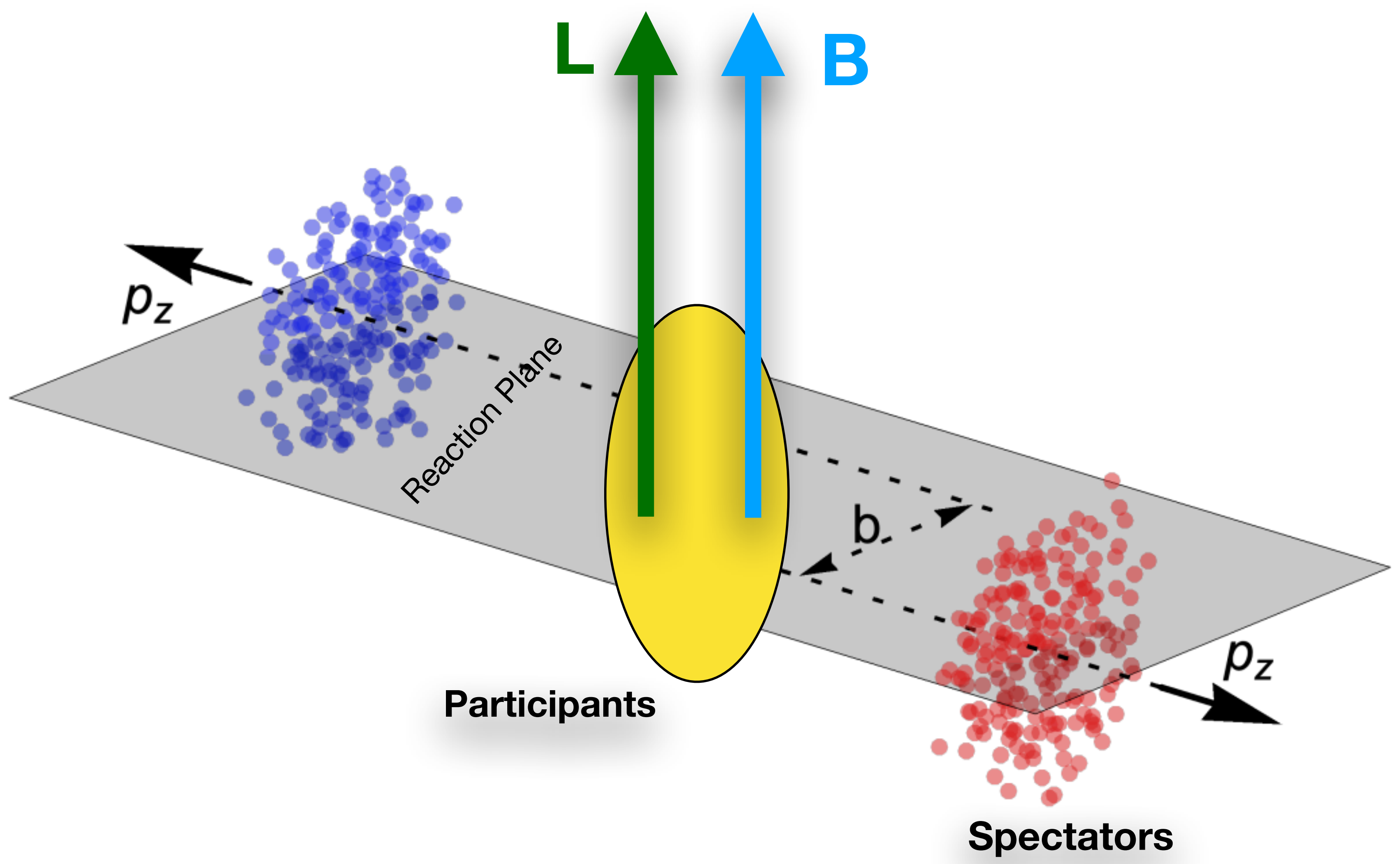
- A **large orbital angular momentum** (OAM) imparted into the system

$$L = r \times p \sim bA\sqrt{s_{\rm NN}} \sim 10^4\ \hbar$$

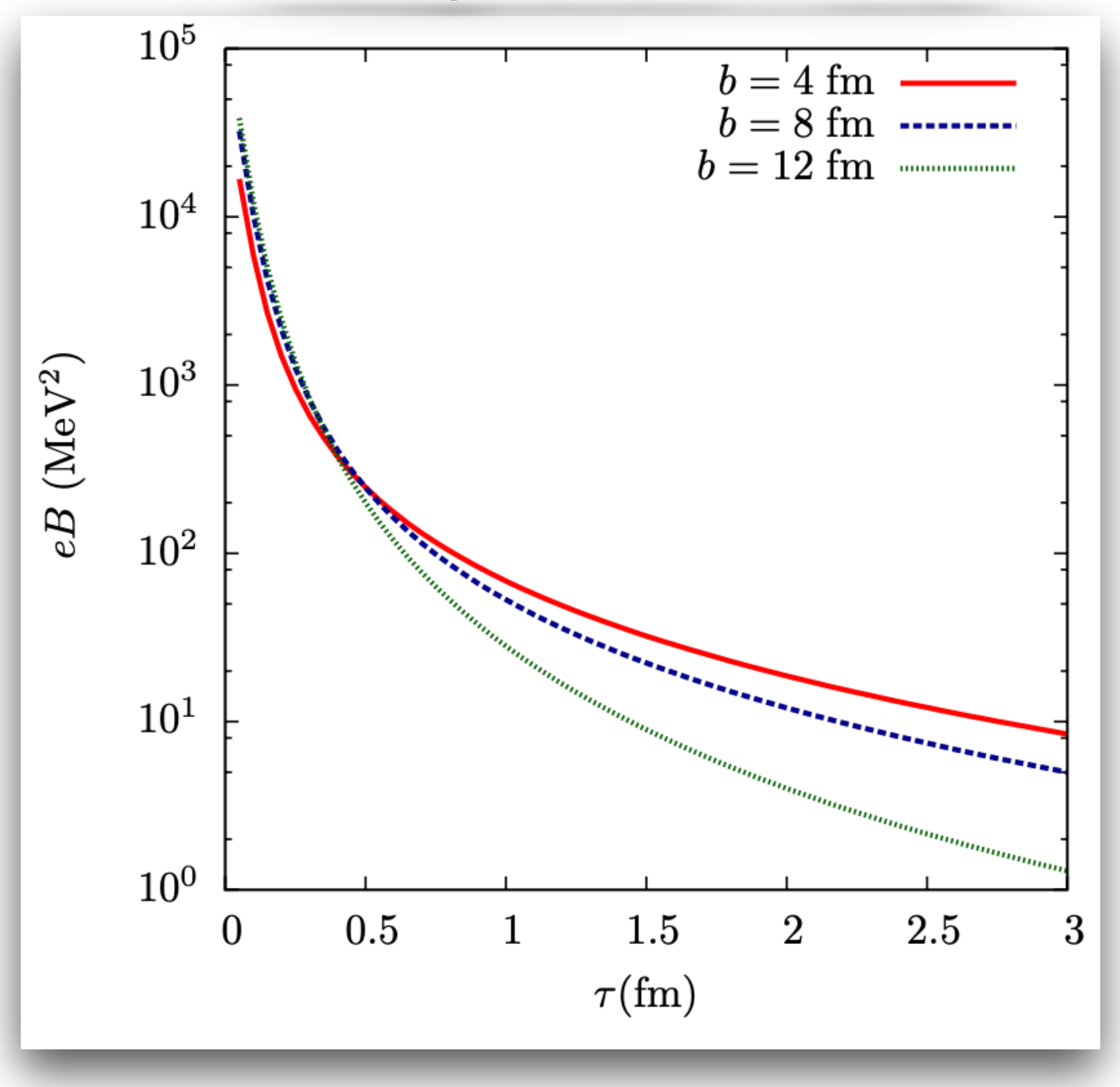
- Part of OAM transferred to QGP can polarize quarks and anti-quarks due to “spin-orbit” interaction.

Liang et. al., Phys Rev Lett B 94, 102301 (2005)

Motivation



Magnetic Field



Kharzeev, Nucl Phys A803, 227 (2008)

In non-central heavy-ion collisions

- **Initial strong magnetic field** (**B**) is expected

  $$eB \sim m_\pi^2 \sim 10^{18} \text{ Gauss}$$

- Such strong **B** field can also polarize quarks. Can induce different spin polarization for quarks and anti-quarks with different magnetic moments

<u>Through polarization measurement</u>

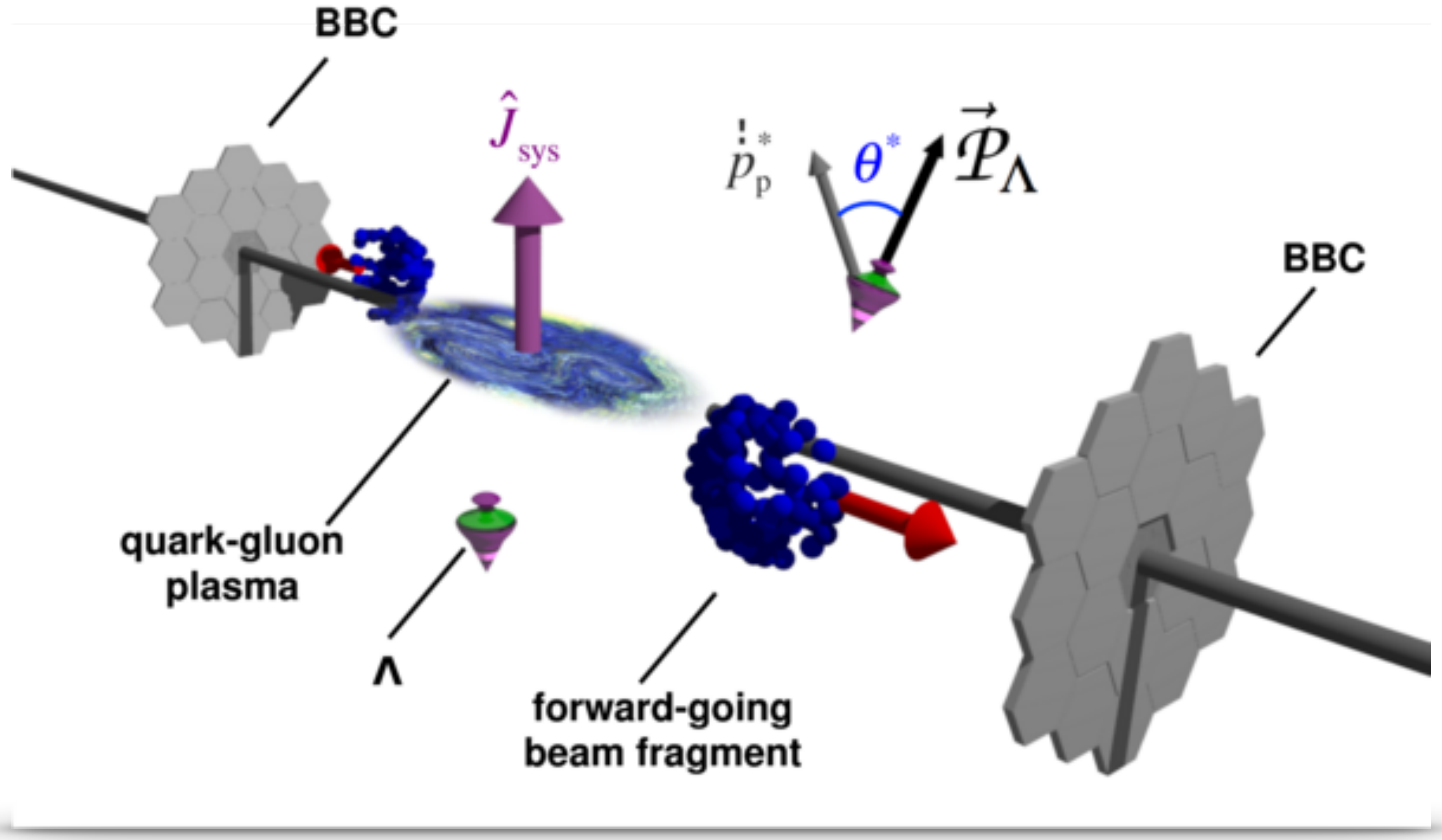
- Search for signatures of L and B
- Understand the properties of QGP medium under extreme conditions (L and B)
- Provide the unique opportunity to probe the spin degrees of freedom of the QGP

Measurement global spin polarization

Global polarization is measured from the angular distributions using parity violating weak decay of hyperons (“self-analyzing”):

- $$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}(1 + \alpha_H \mathbf{P}_\mathbf{H}^* \cdot \mathbf{p}_\mathbf{d}^*)$$

$\mathbf{P}_\mathbf{H}$: Hyperon polarization
α_H : Hyperon decay parameter
$\mathbf{p}_\mathbf{d}$: Daughter momentum direction
$*$: Measurements in parent’s rest frame



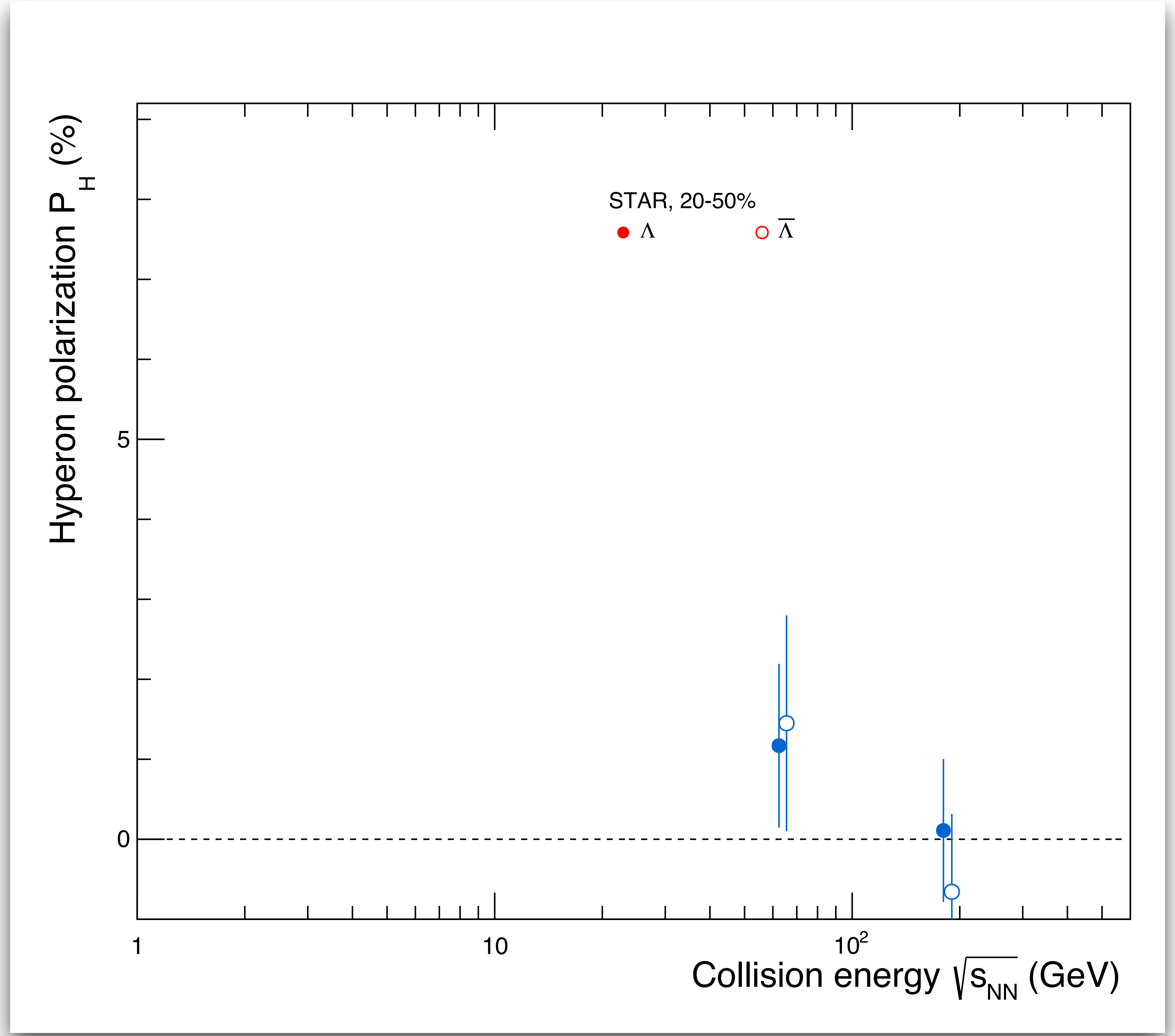
Component perpendicular to reaction plane:

- $$P_H = \frac{8}{\pi\alpha_H}\frac{\langle \sin(\Psi_1 - \phi_d^*)\rangle}{\mathrm{Res}(\Psi_1)}$$

ϕ_d : Daughter azimuthal angle
Ψ_1: 1st order event plane

Schiling et. al., Nucl Phys B 15, 397 (1970)
(STAR Collaboration) Phys Rev C 76, 024915 (2007)

Beam energy dependence of global P_Λ

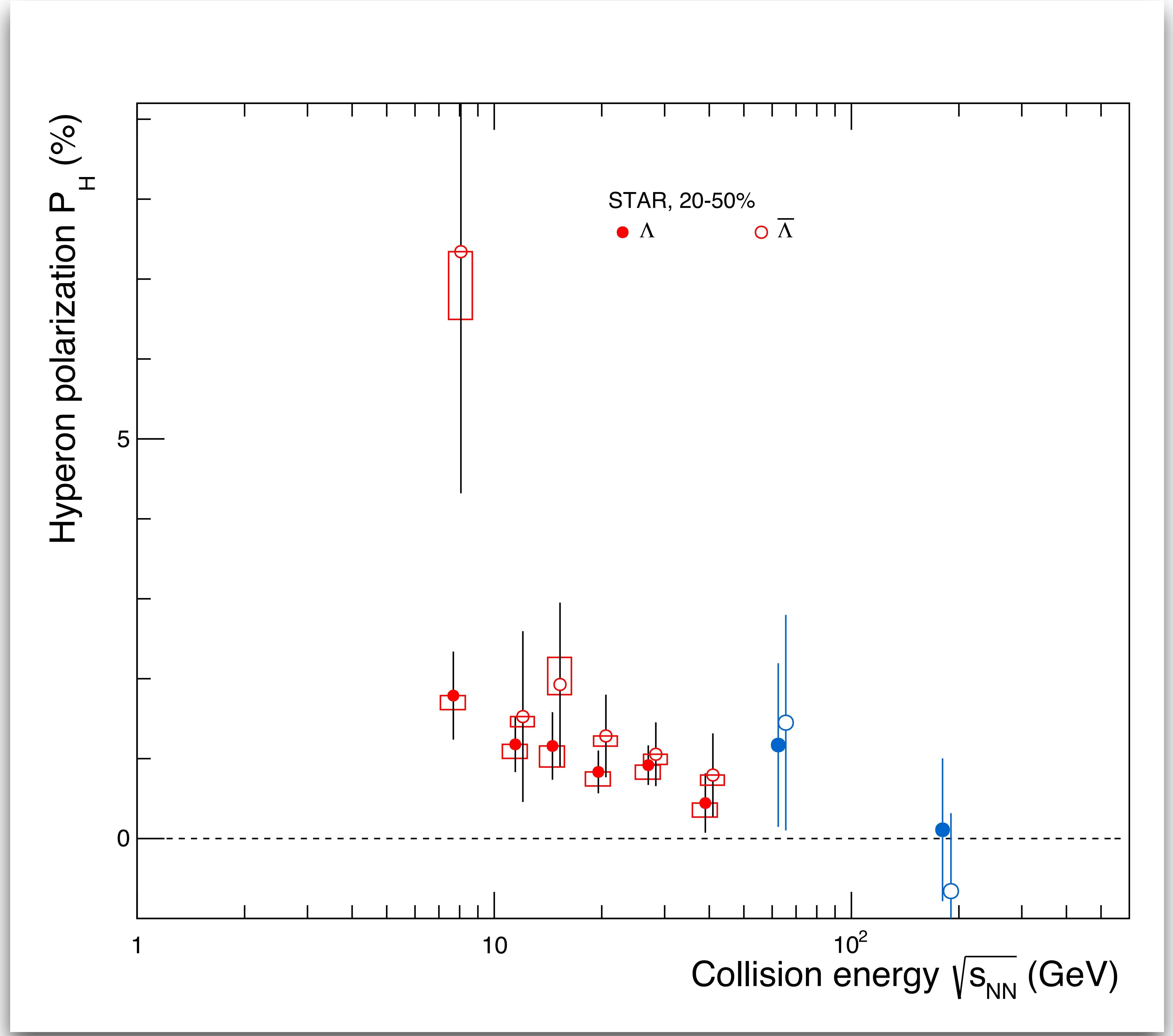


- Sets an upper limit on hyperon polarization

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

STAR: Phys Rev C 76, 024915 (2007)

Beam energy dependence of global P_Λ



- First observation of global spin polarization of hyperons in HIC
- Thermal vorticity $\omega = k_B T(P_\Lambda + P_{\bar{\Lambda}})/\hbar$

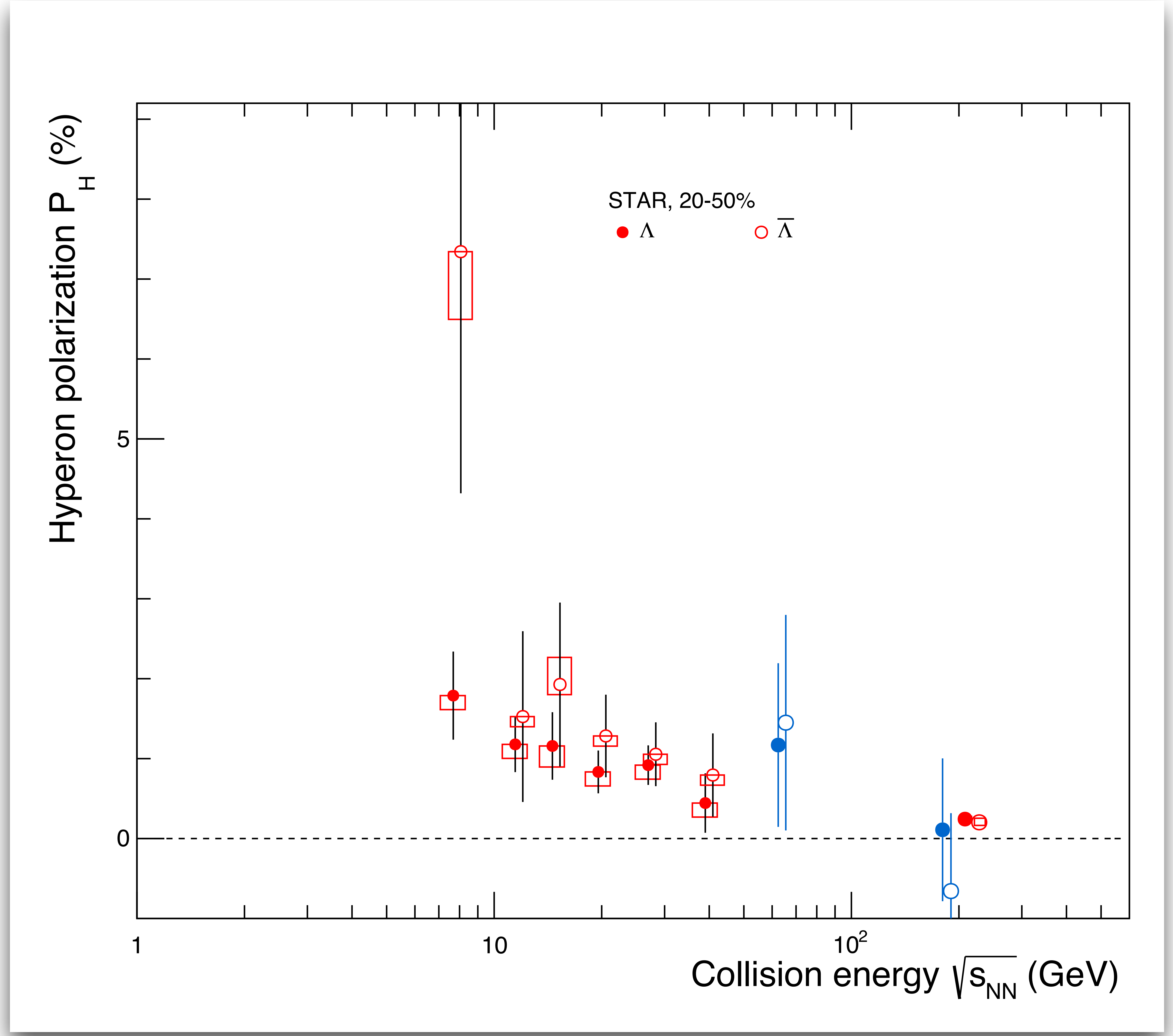
$$\omega \sim (9 \pm 1) \times 10^{21}\ s^{-1}$$

Most vortical fluid created at RHIC

Becattini, et. al.,
Phys Rev C 95, 054902 (2017)

STAR:
Phys Rev C 76, 024915 (2007)
Nature 548, 62 (2017)

Beam energy dependence of global P_Λ



- Precise hyperon polarization from high statistics Au+Au collisions at 200 GeV

$P_{\Lambda,\bar{\Lambda}} \sim 0.1 - 0.5\,\%$ ($\sim 5\sigma$ significance)

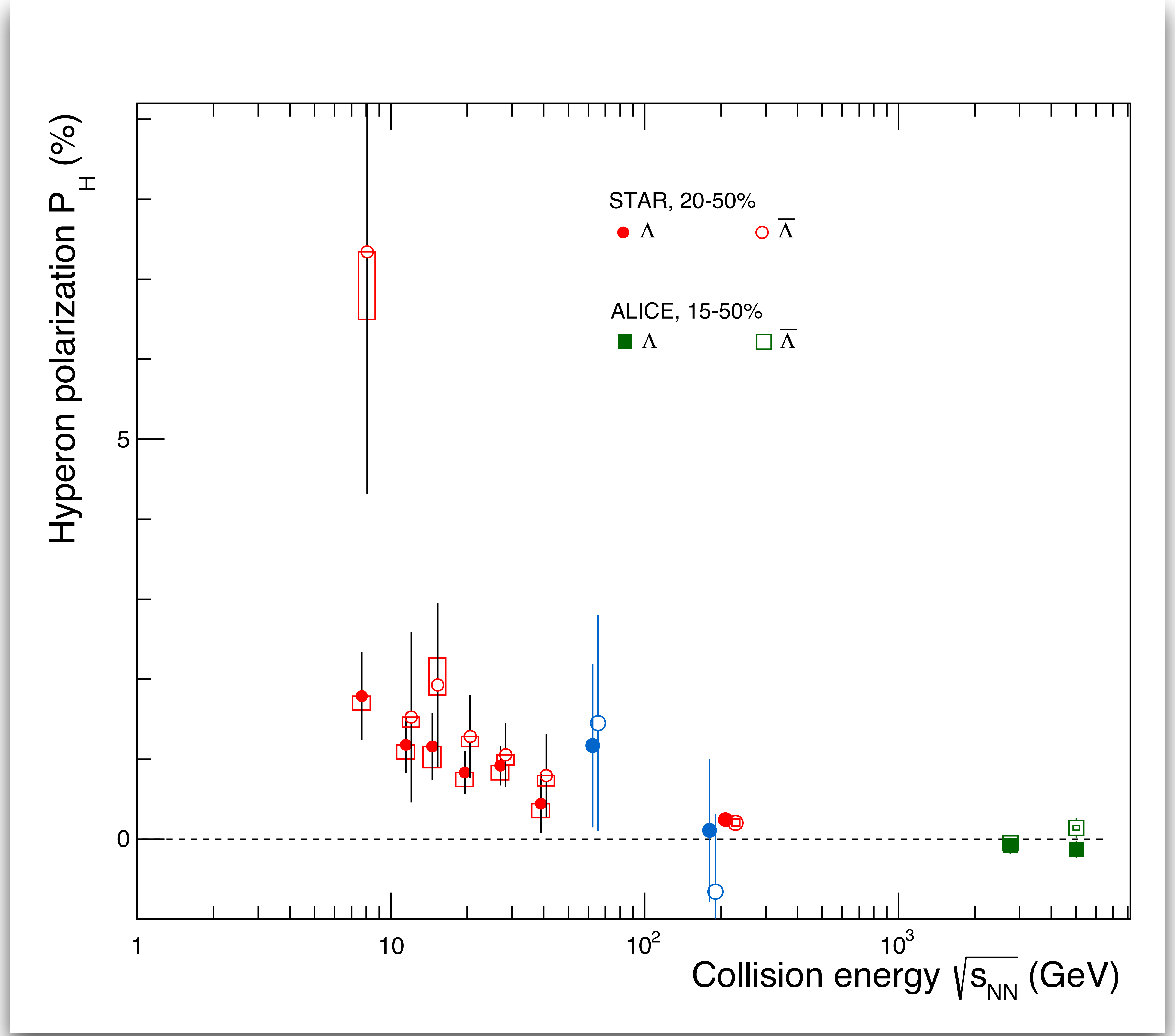
STAR:

Phys Rev C 76, 024915 (2007)

Nature 548, 62 (2017)

Phys Rev C 98, 014910 (2018)

Beam energy dependence of global P_Λ



- First hyperon polarization from Pb+Pb collisions at 2.76 and 5.02 TeV

$P_{\Lambda,\bar{\Lambda}} \sim 0$ at LHC

STAR:

Phys Rev C 76, 024915 (2007)

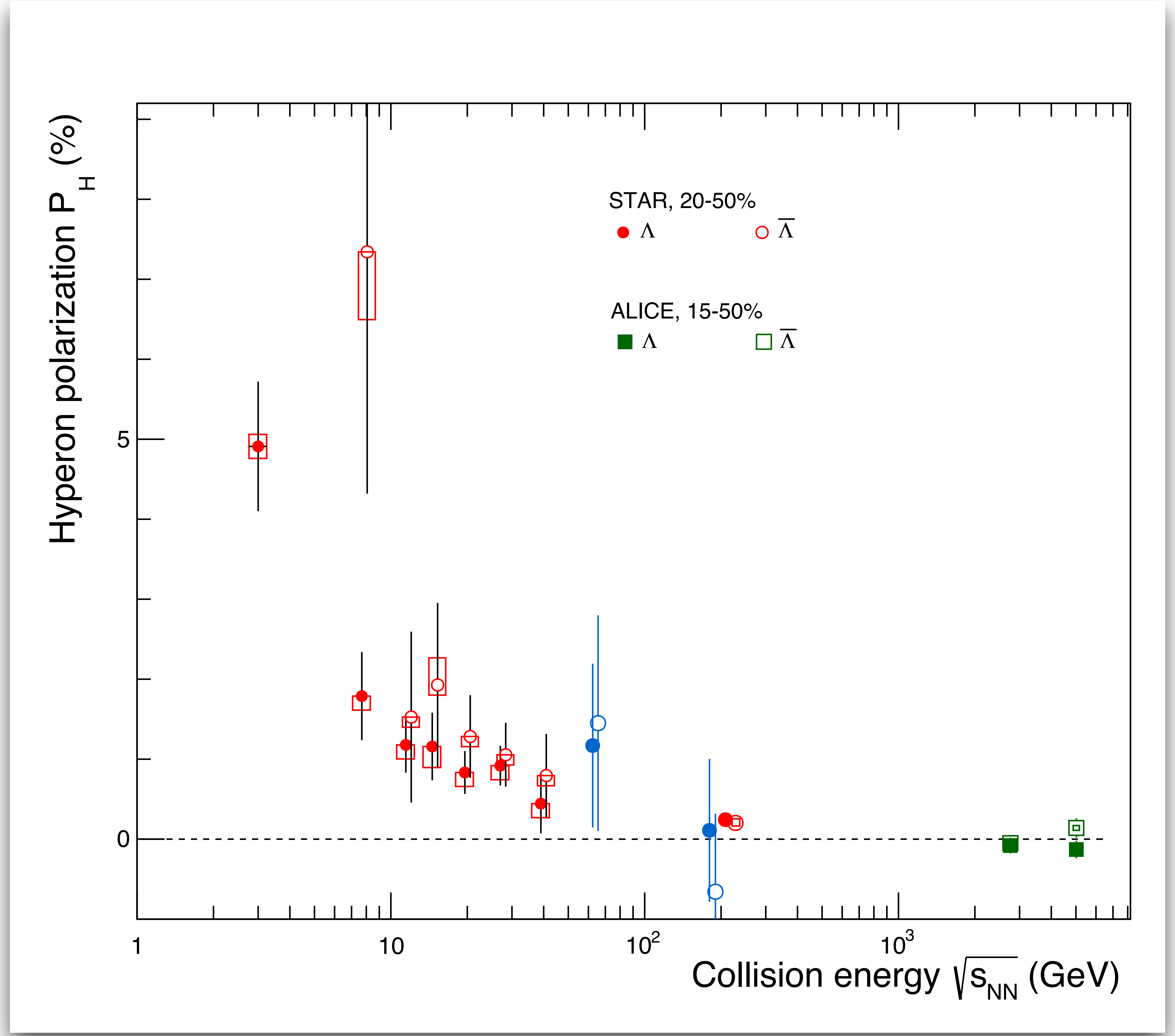
Nature 548, 62 (2017)

Phys Rev C 98, 014910 (2018)

ALICE:

Phys Rev C 101, 044611 (2020)

Beam energy dependence of global P$_\Lambda$



- Hyperon polarization from Fixed target Au+Au collisions at 3.0 GeV

$$P_{\Lambda,\bar{\Lambda}} = 4.91 \pm 0.81 \pm 0.15 \; (\sim 5\sigma \text{ significance})$$

STAR:

Phys Rev C 76, 024915 (2007)

Nature 548, 62 (2017)

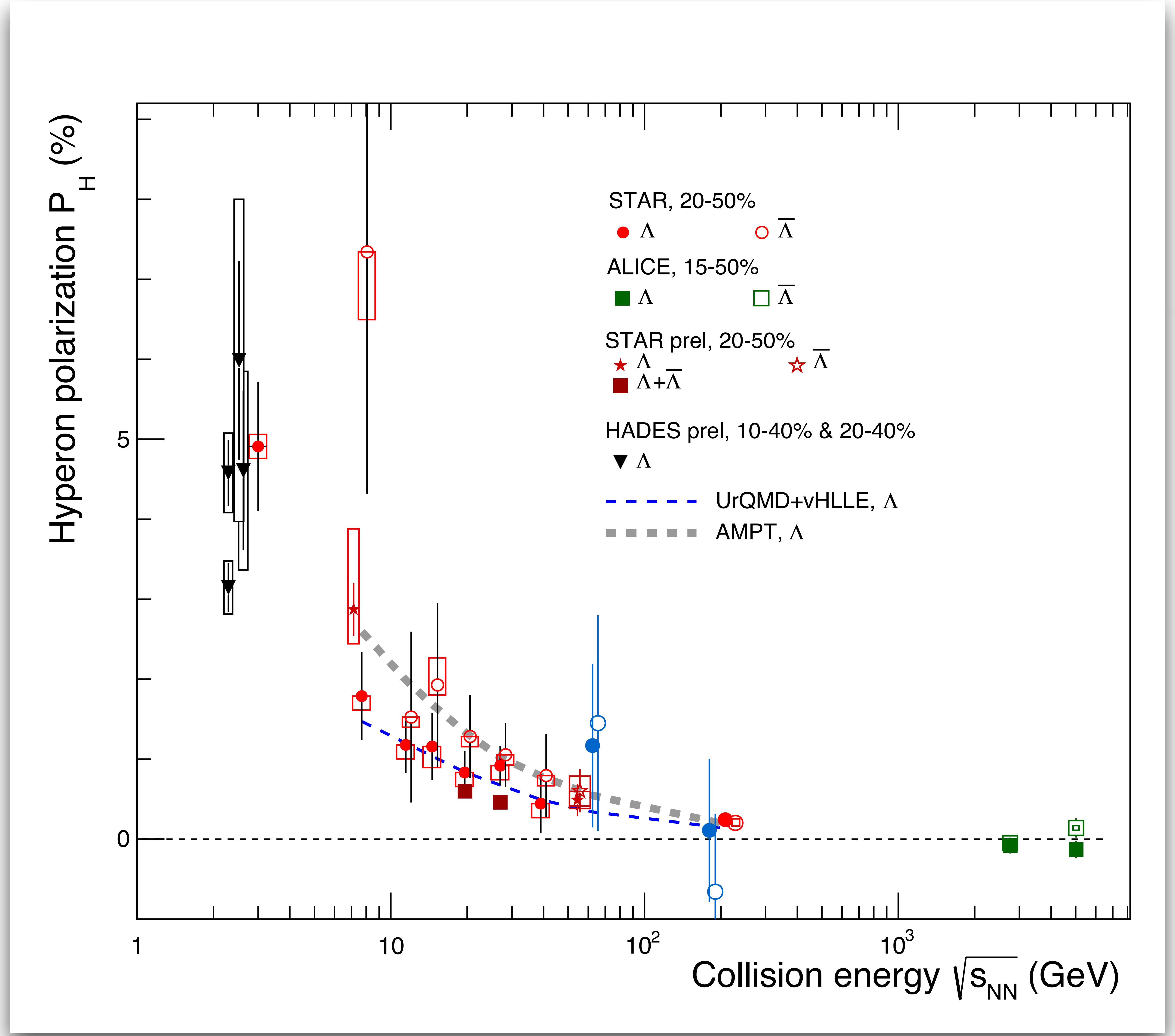
Phys Rev C 101, 044611 (2020)

Phys Rev C 104, 061901 (2021)

ALICE:

Phys Rev C 101, 044611 (2020)

Beam energy dependence of global P_Λ



- P_Λ follows increasing trend from 5.02 TeV down to 2.4 GeV
- Models can capture the energy dependence trend

STAR:

Phys Rev C 76, 024915 (2007)

Nature 548, 62 (2017)

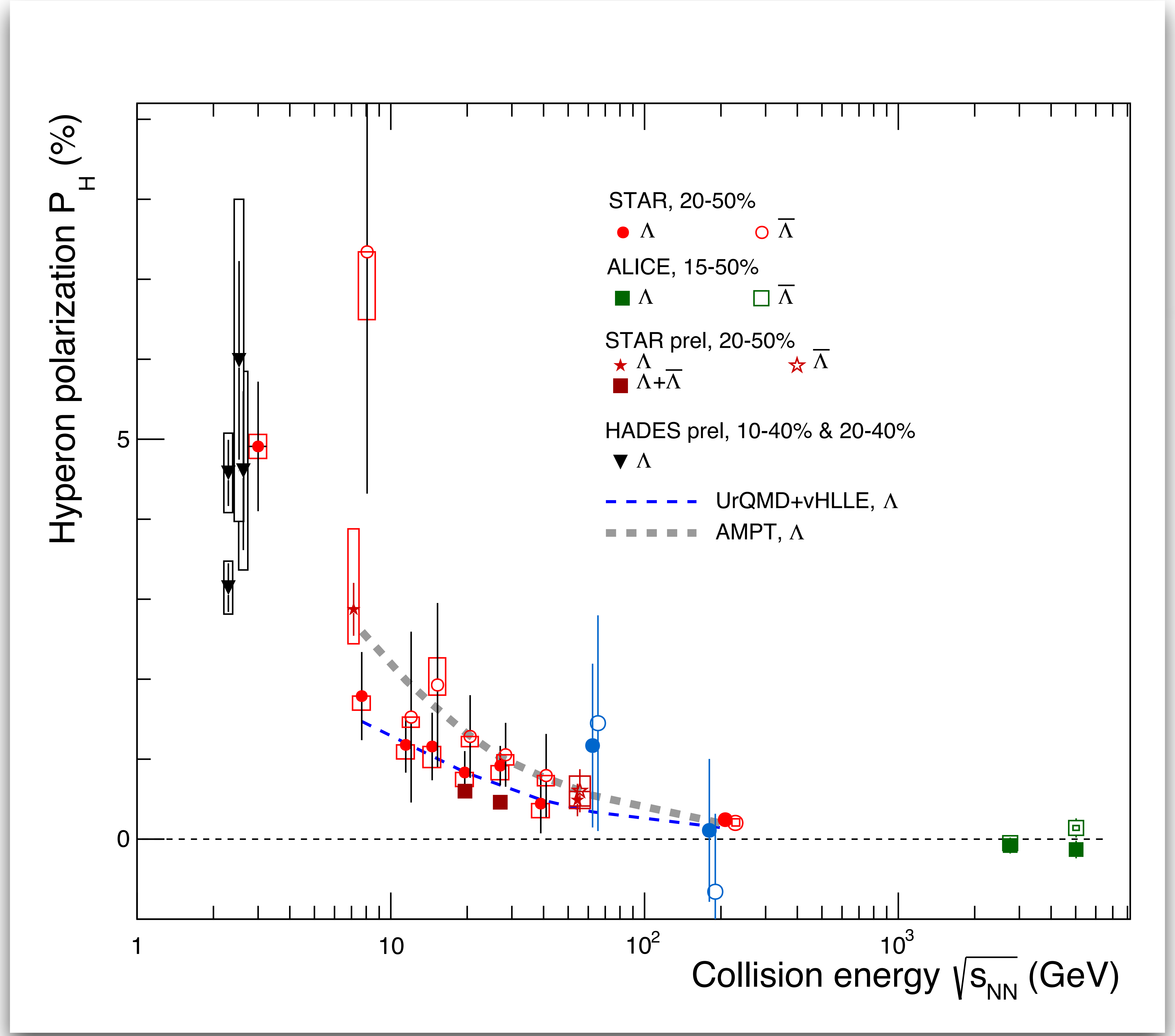
Phys Rev C 101, 044611 (2020)

Phys Rev C 104, 061901 (2021)

ALICE:

Phys Rev C 101, 044611 (2020)

Beam energy dependence of global P_Λ



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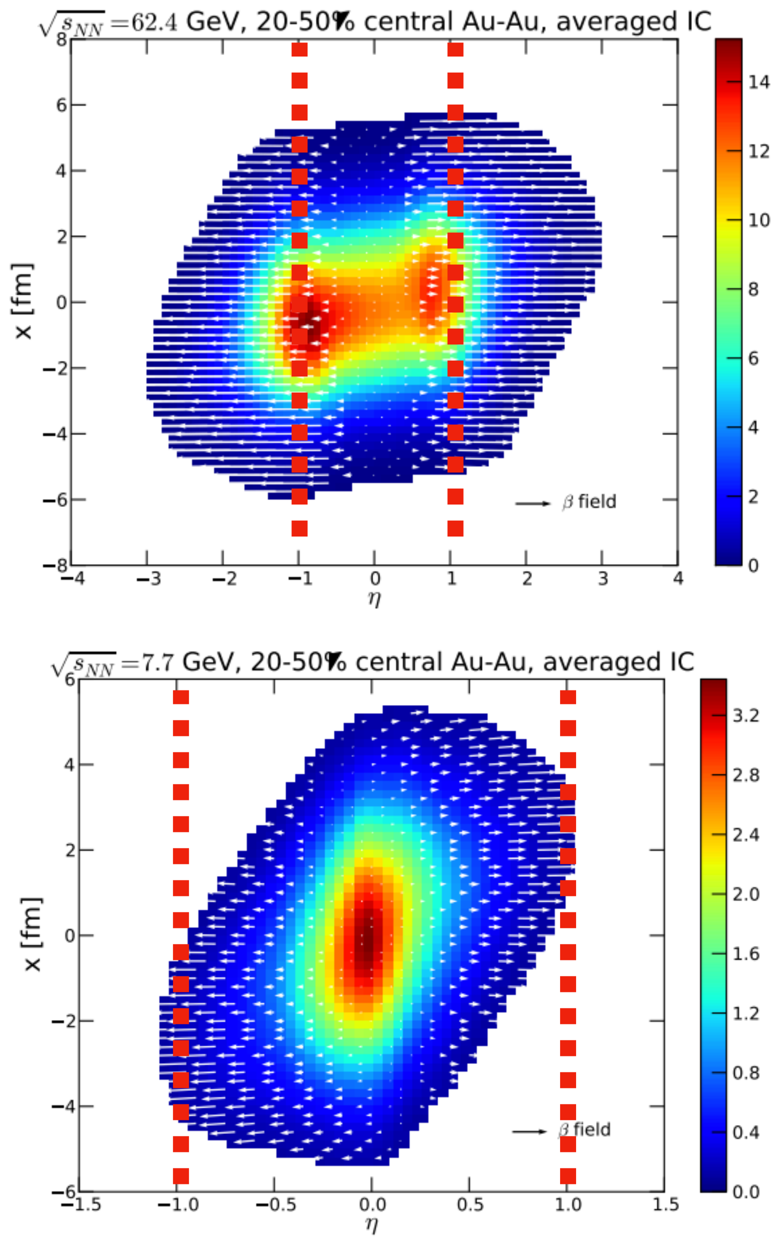
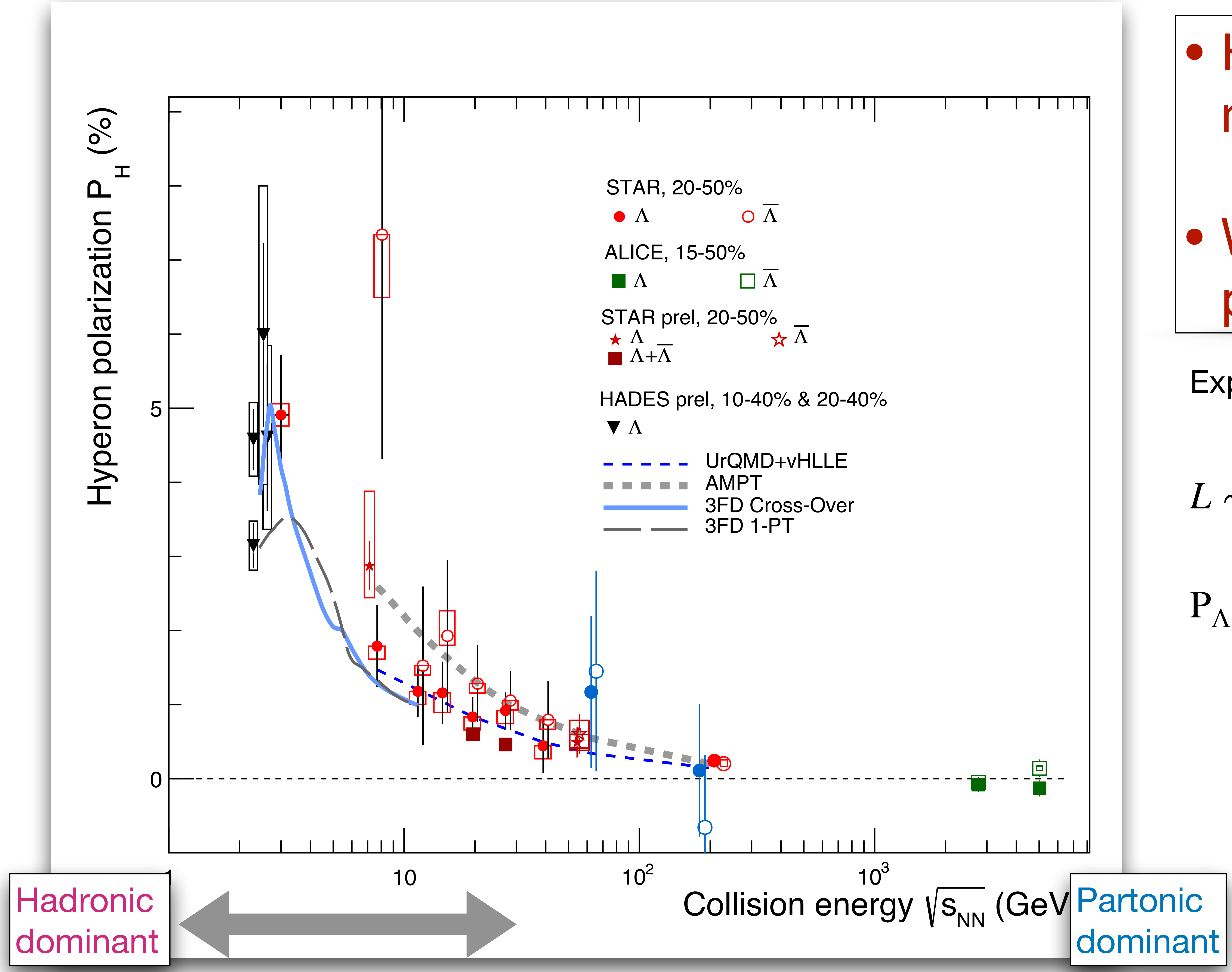


- Can be understood as shear flow and baryon stopping
- Rapidity acceptance (migration of polarization to forward rapidity)
- Lifetime of system
- …

Karpenko et. al., Eur Phys J C 77, 213 (2017)
Ivanov et. al., Phys Rev C 102, 024916 (2020)

Beam energy dependence of global P_Λ



RHIC BES-II

FAIR, NICA, HIAF

- Hadronic dominant matter retains more vorticity (?)
- Where do we observe the vanishing polarization?

Expectation:

$$L \sim \frac{1}{2} A b \sqrt{s} \sqrt{1-(2M/\sqrt{s})^2}$$

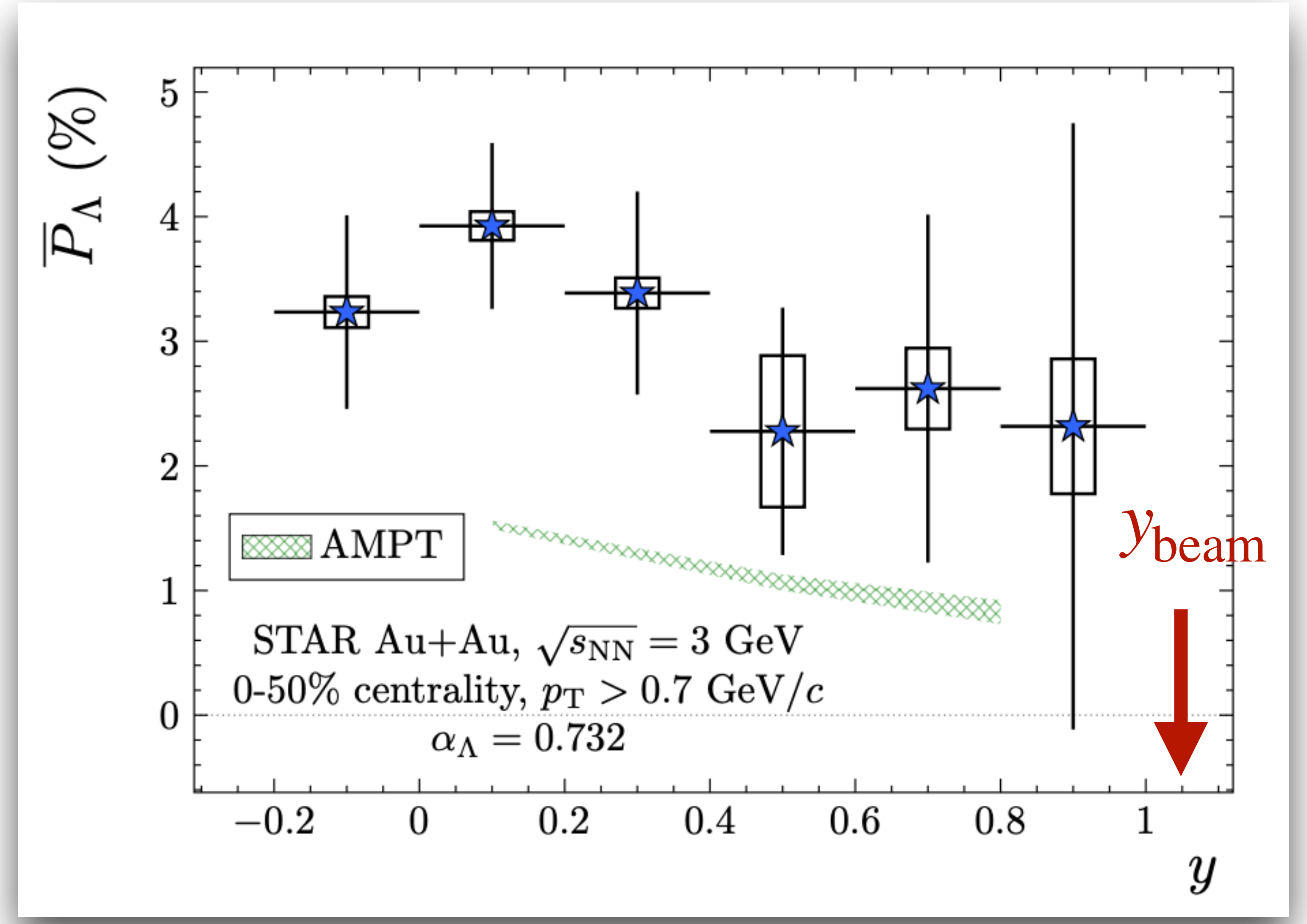
$$P_\Lambda \sim 0 \text{ at } \sqrt{s_{NN}} \sim 2m_N$$

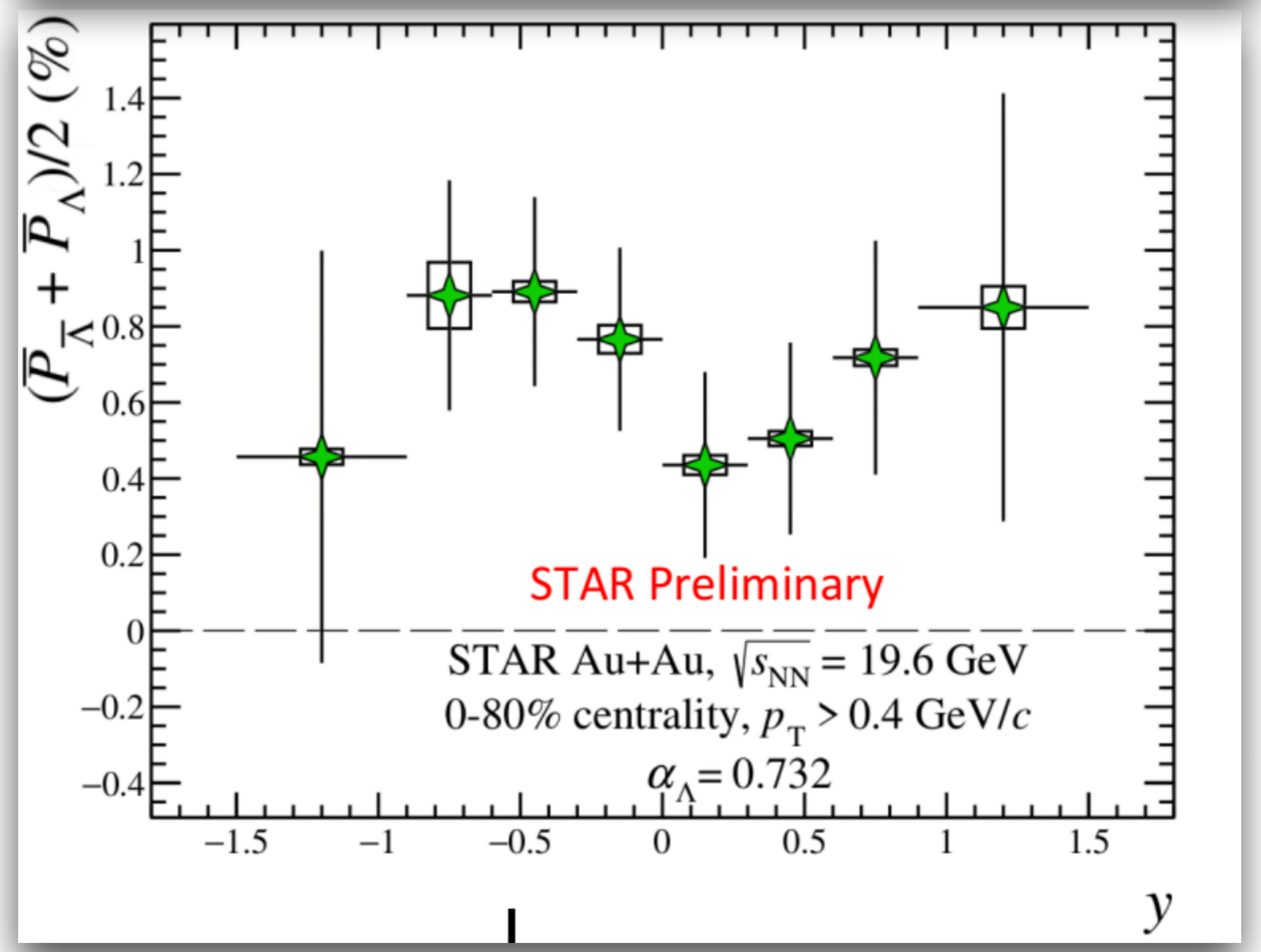
Talk-(Bulk,15/06) Jinfeng Liao

<u>Theory calculations for P_Λ at low energies</u>

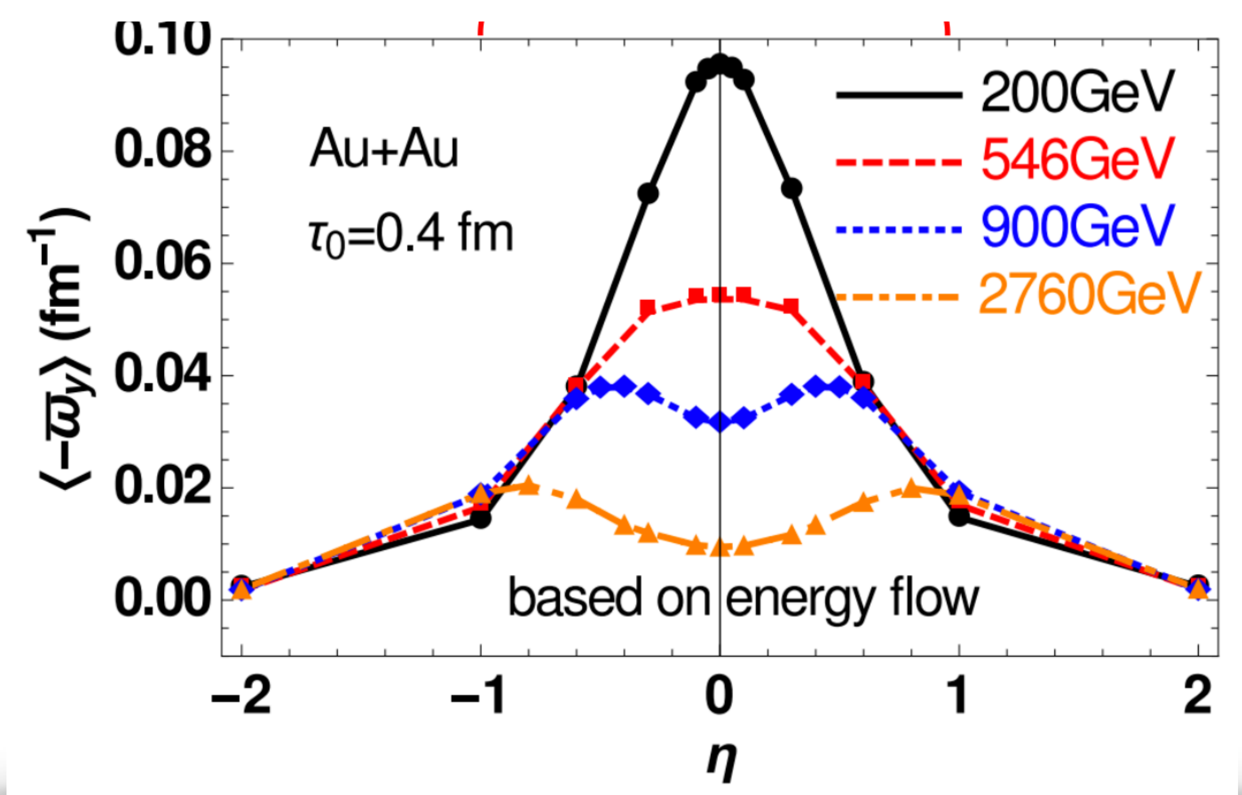
Deng et. al, Phys Rev C 101, 064908 (2020)
Deng et., al., arXiv: 2109.09956
Ivanov, Phys Rev C 103, L031903 (2021)
Guo et al, Phys Rev C 104, L041902 (2021)
…..

Differential measurements of P_Λ: rapidity dependence

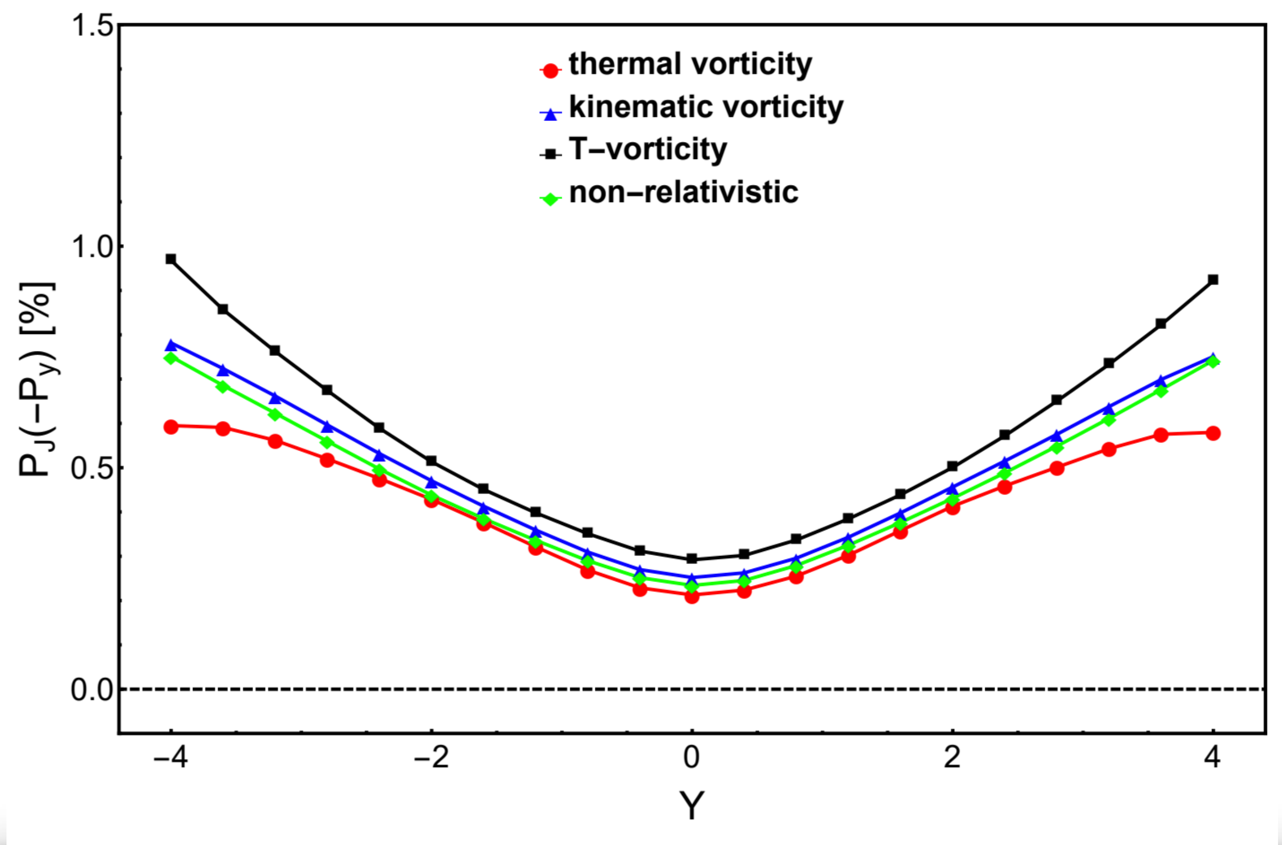




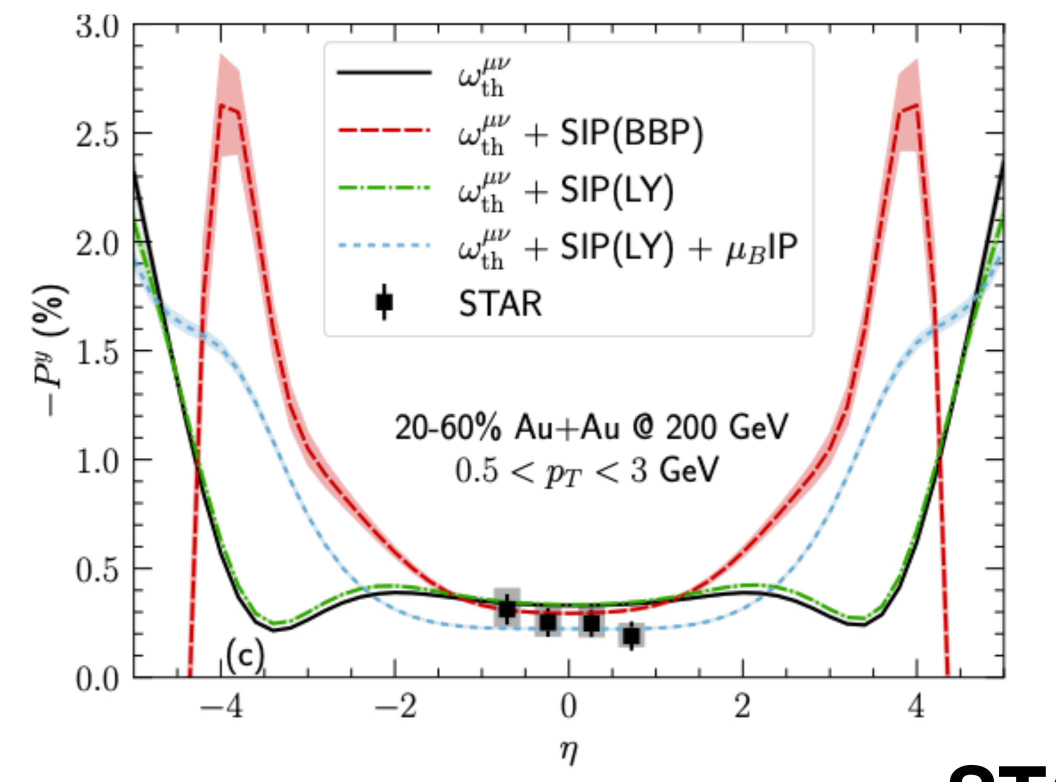
Deng and Huang, Phys Rev C 93, 064907



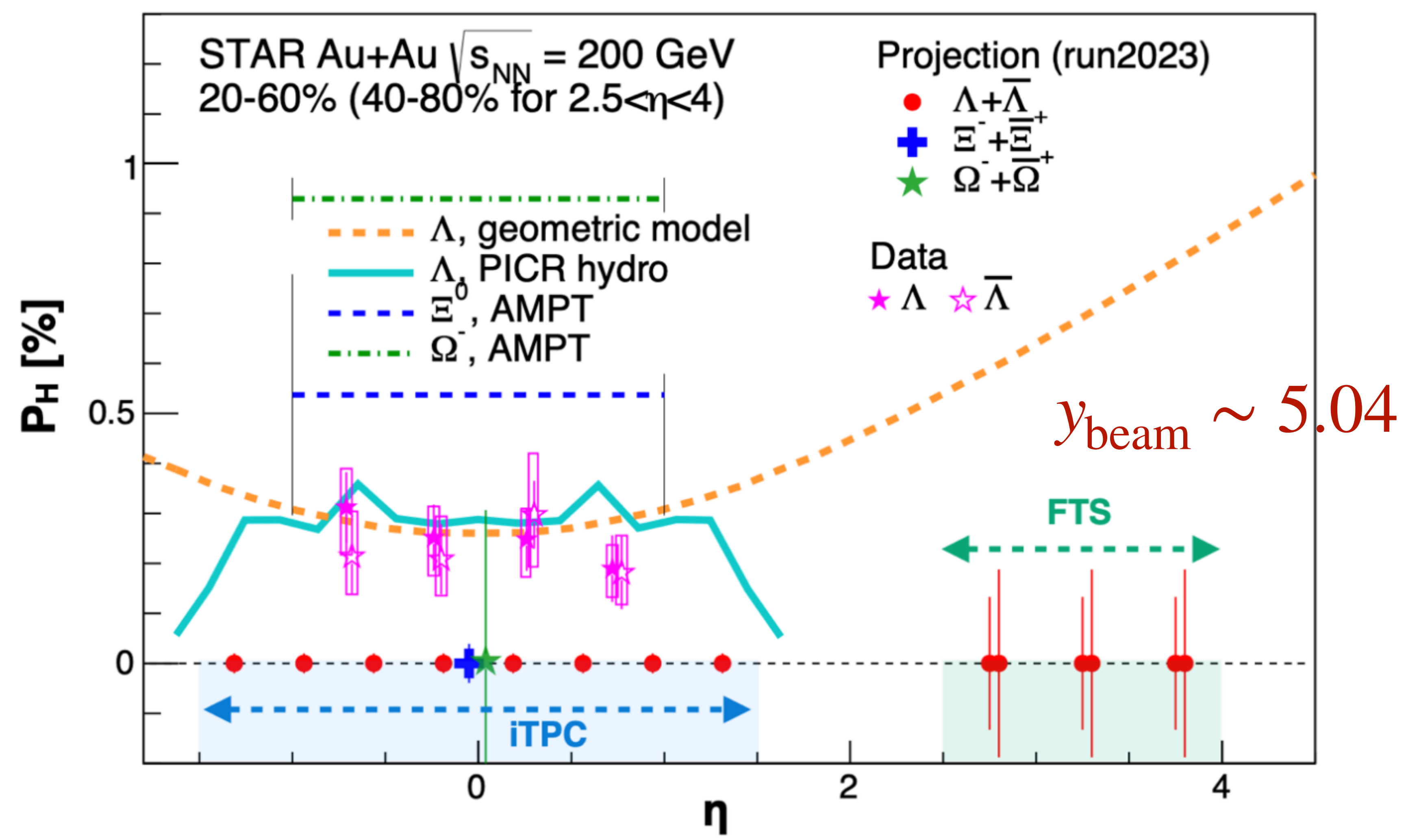
Wu et al, Phys Rev Research 1, 033058



Alzhrani et. al., arXiv: 2203.15718



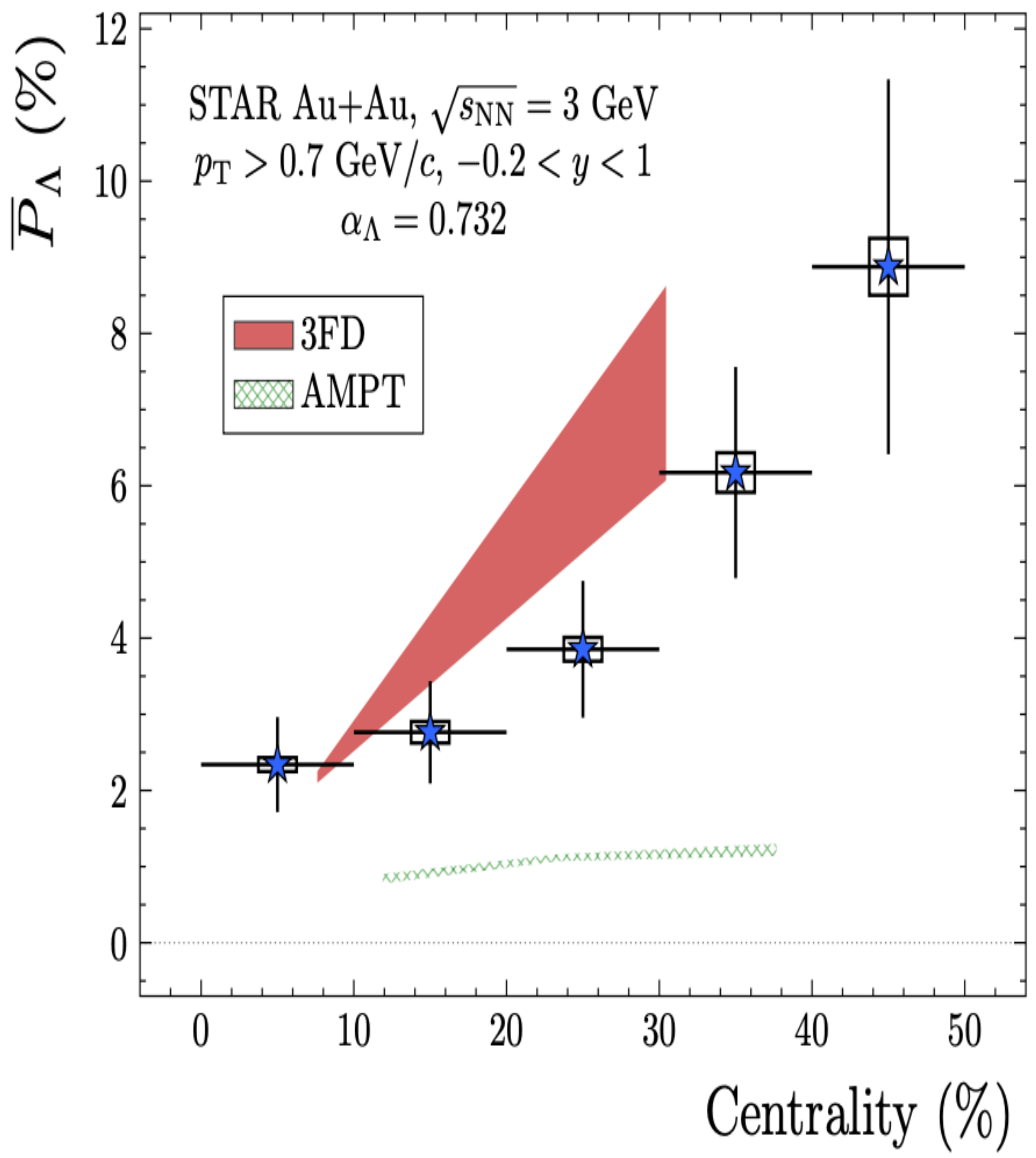
STAR BUR



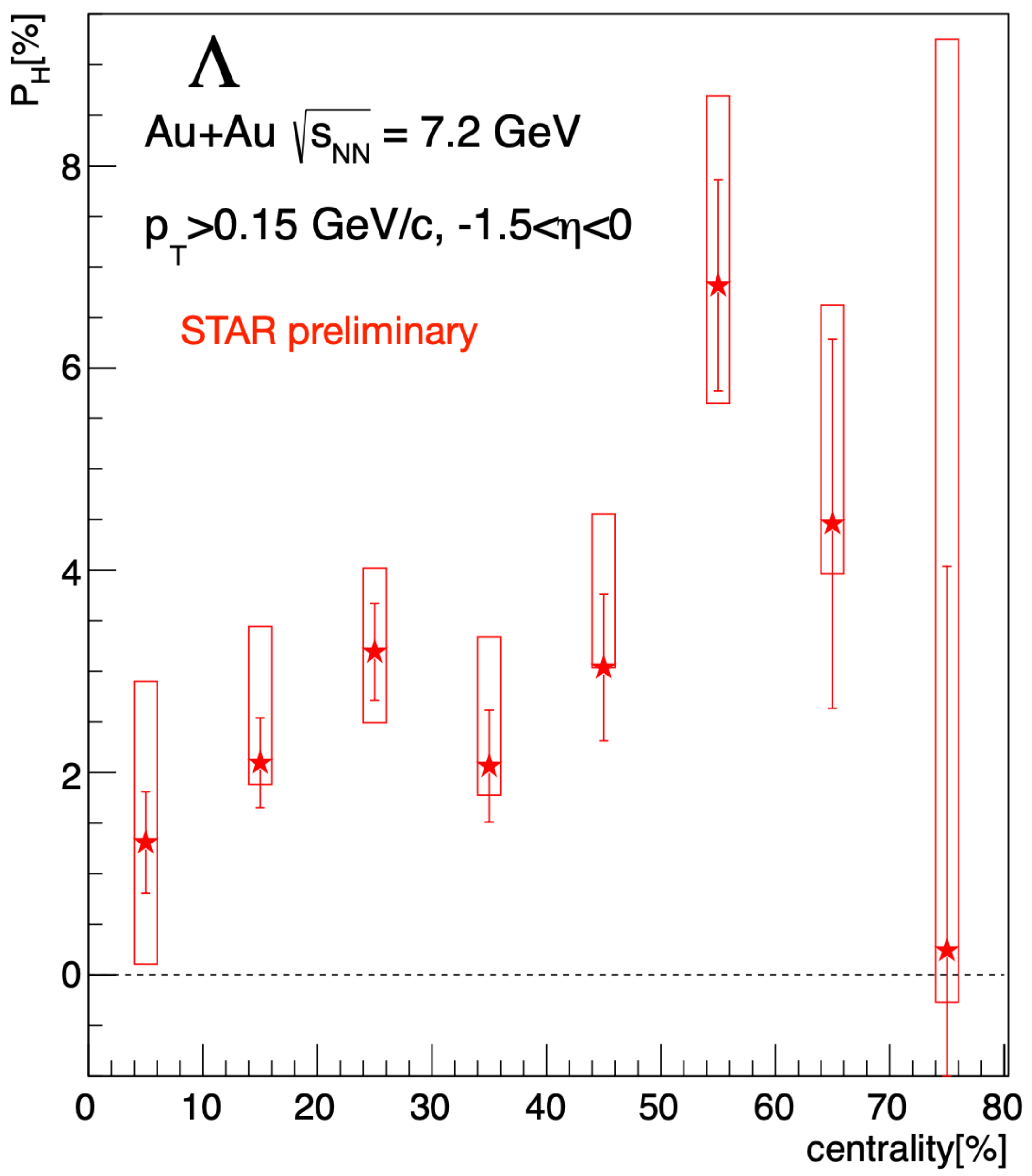
- No significant rapidity dependence observed
- Rapidity dependence of P_Λ is different among various models
- High precision rapidity dependence P_Λ is needed to constrain models

Differential measurements of P_Λ: centrality dependence

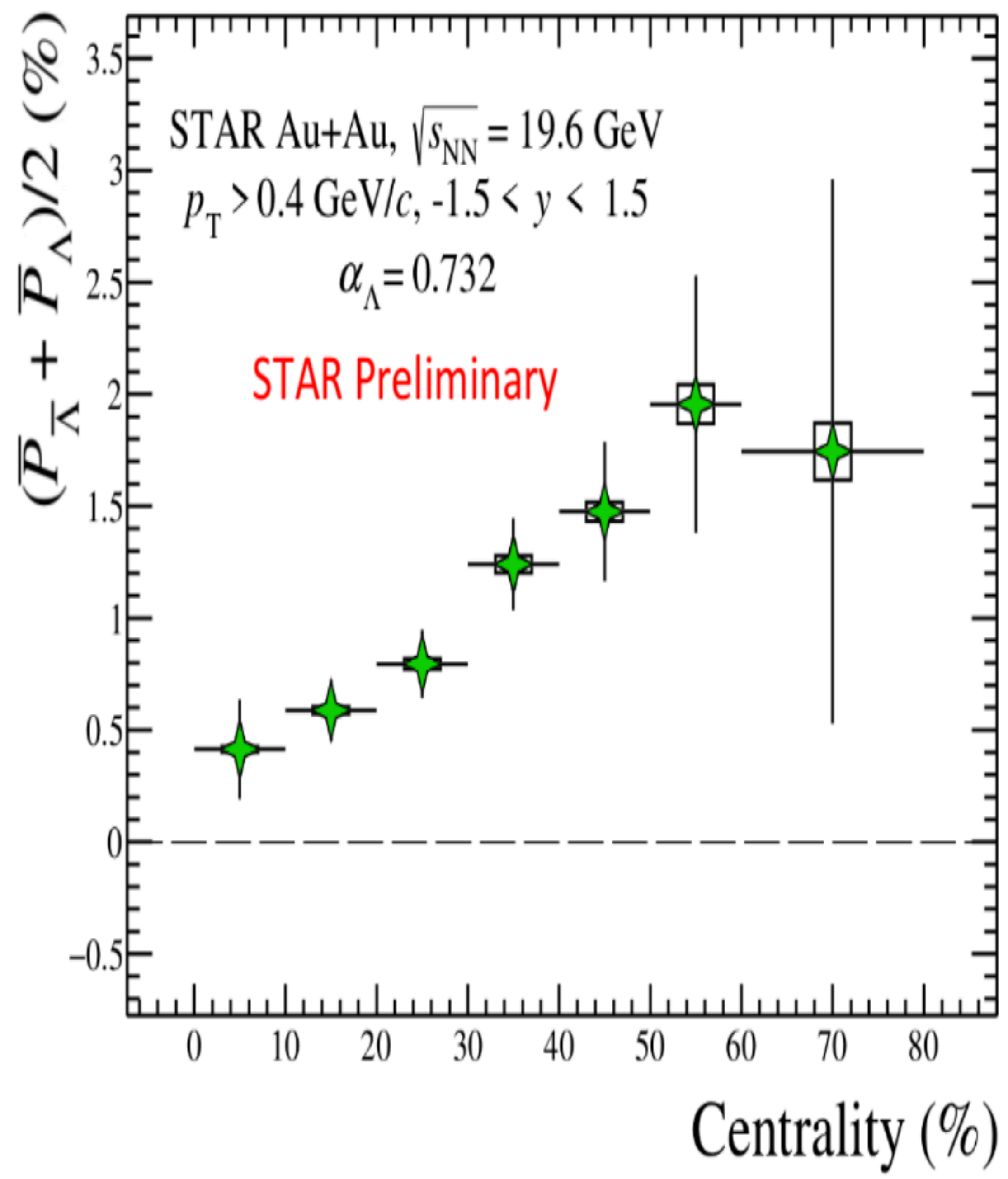
Au+Au $\sqrt{s_{NN}}$ = 3 GeV



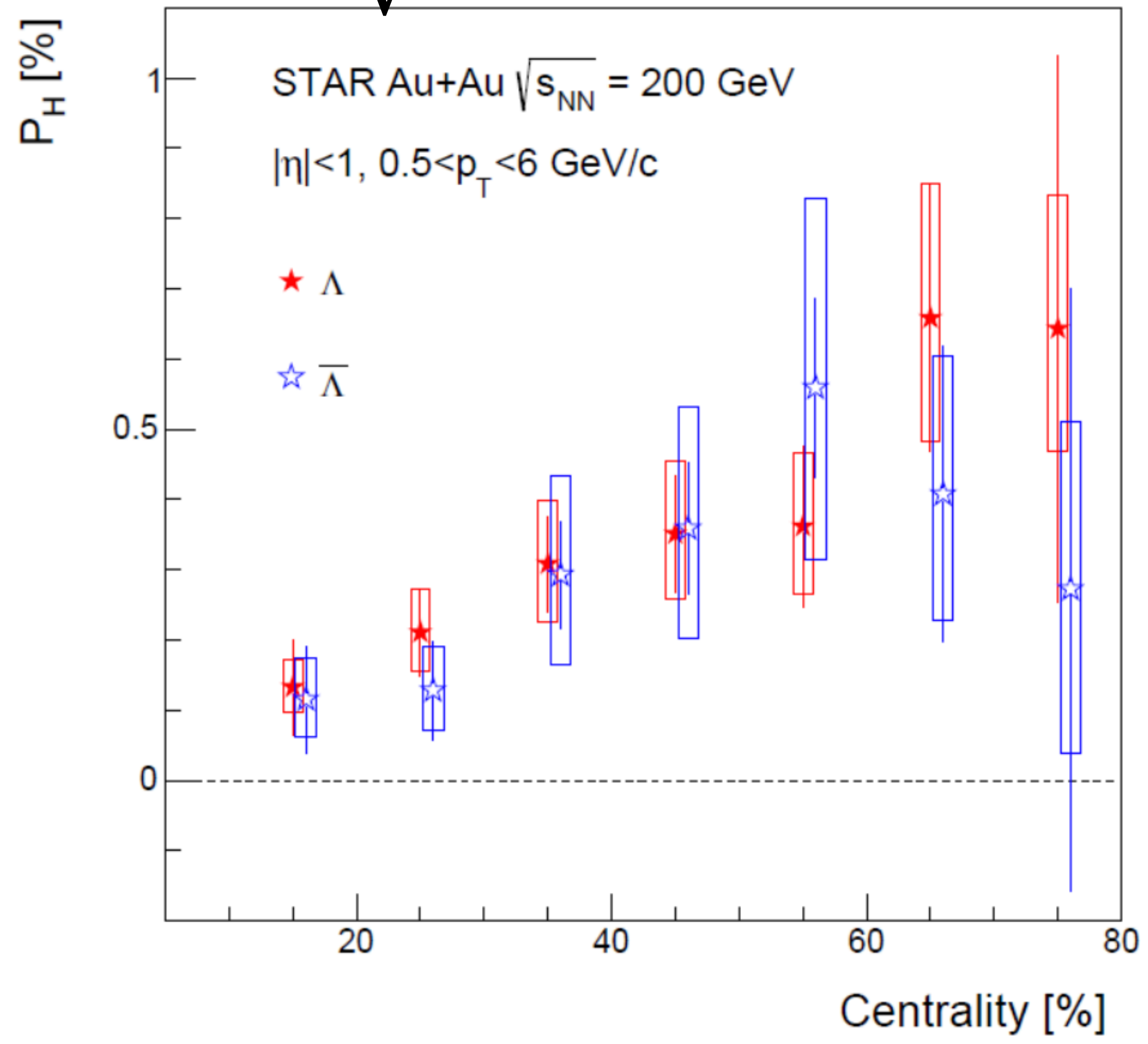
$\sqrt{s_{NN}}$ = 7.2 GeV

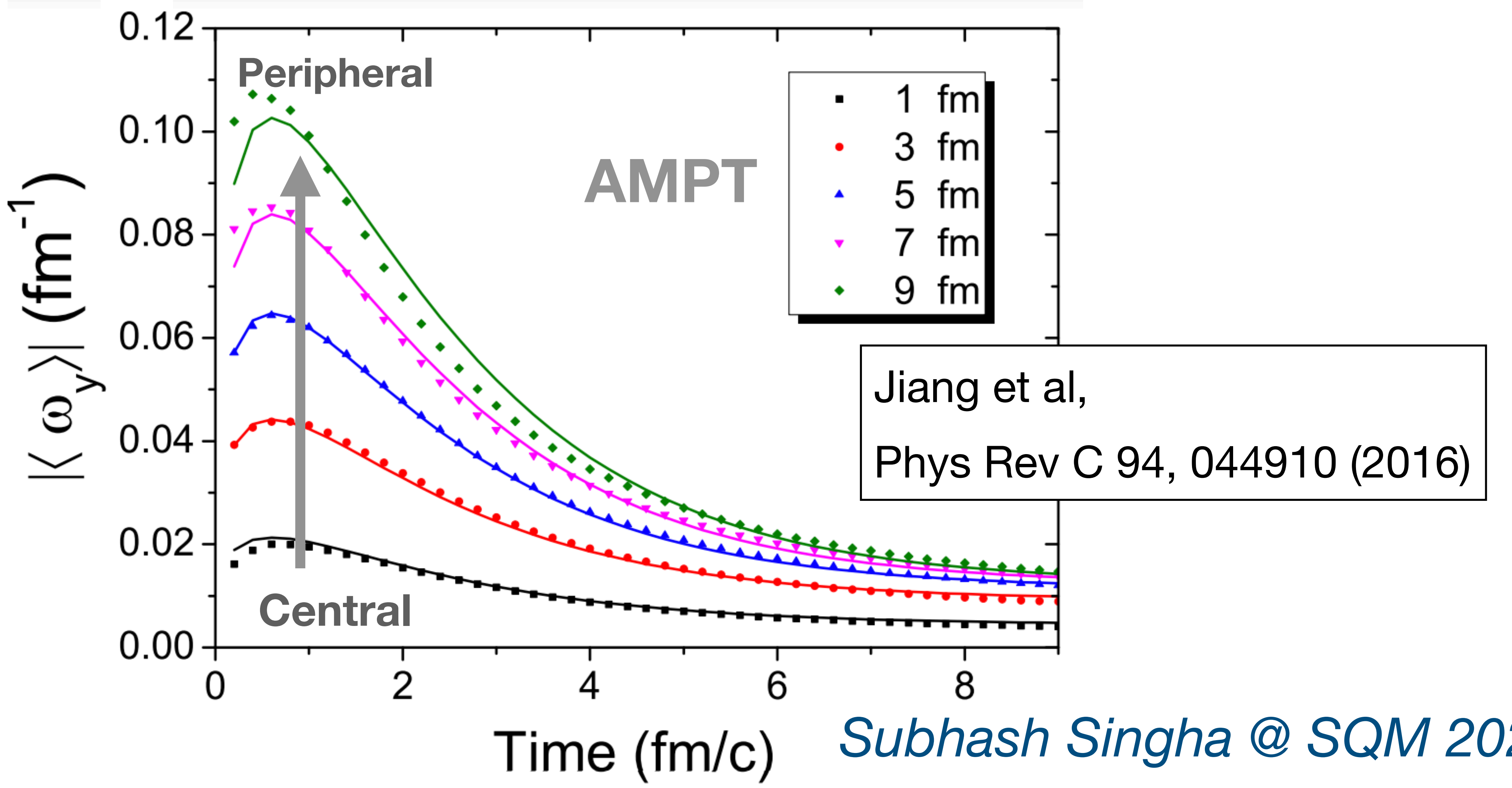


$\sqrt{s_{NN}}$ = 19.6 GeV



$\sqrt{s_{NN}}$ = 200 GeV



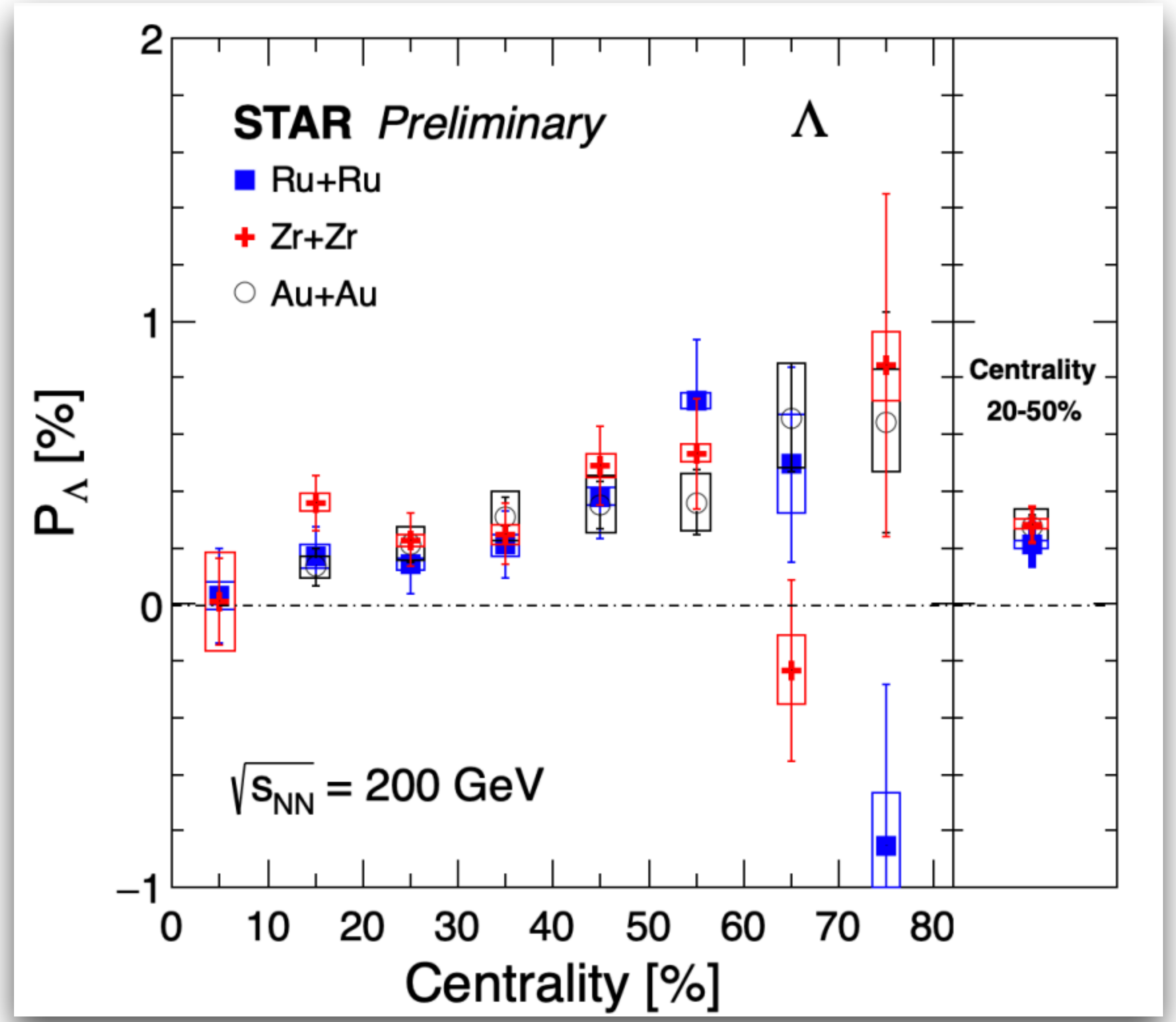


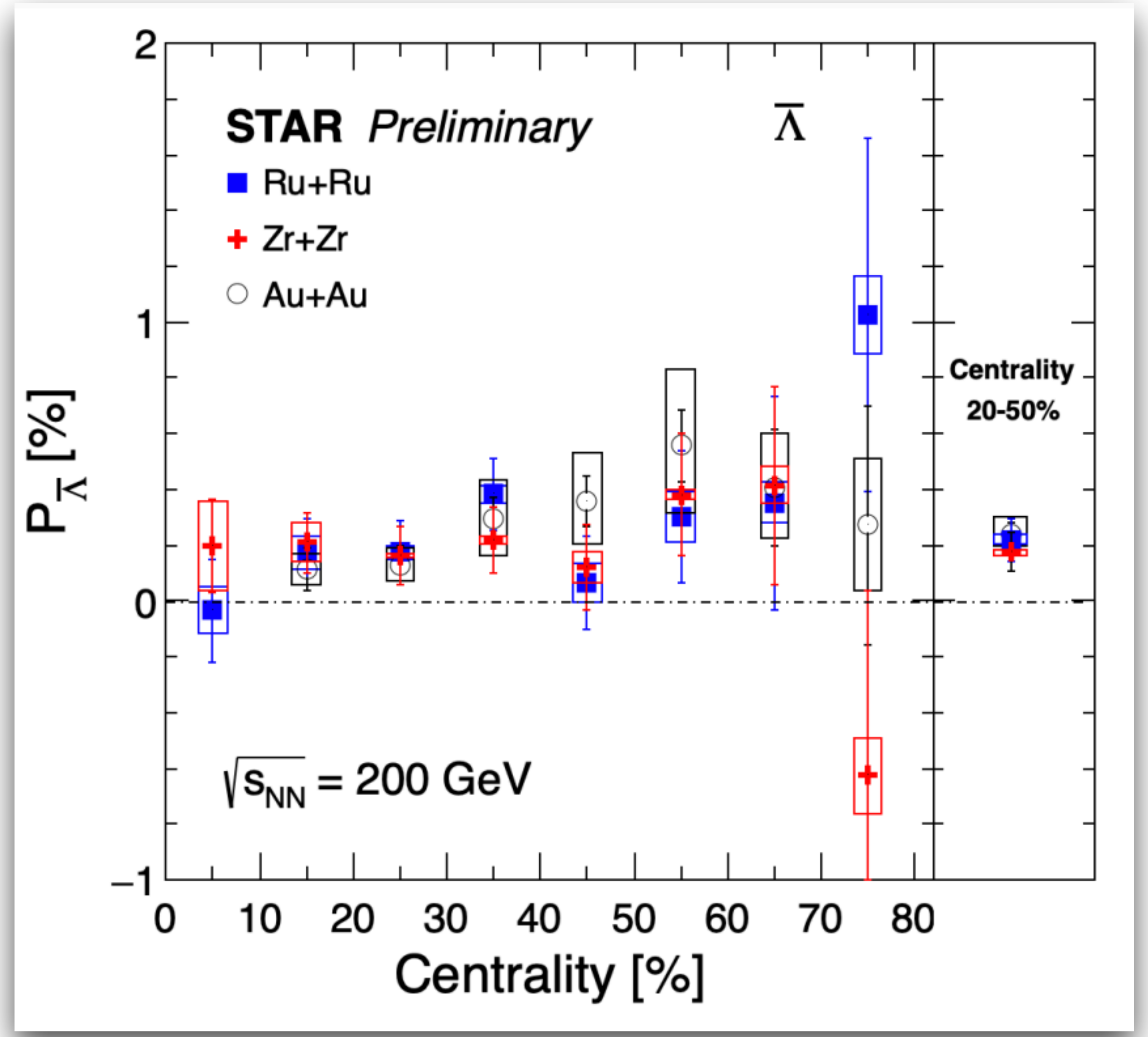
- P_Λ increases from central to peripheral collisions
- Similar pattern followed from 200 GeV down to 3 GeV

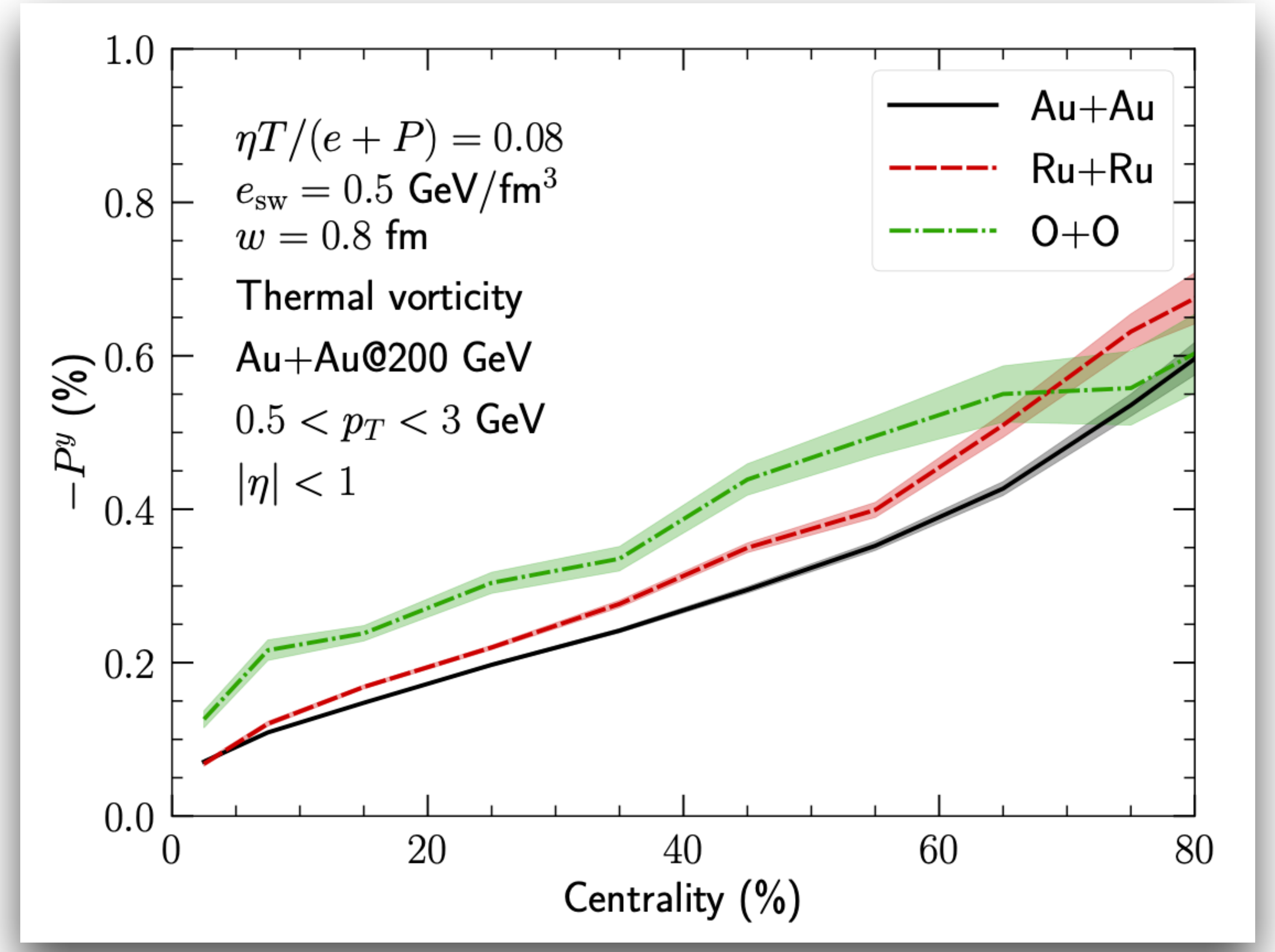
- Trend consistent with expectation from vorticity

Collision system size dependence of P_Λ

Talk-(Bulk,14/06)
Xingrui Gou (STAR)







Model expectation:

$$P_\Lambda^{O+O} > P_\Lambda^{Ru+Ru} > P_\Lambda^{Au+Au}$$

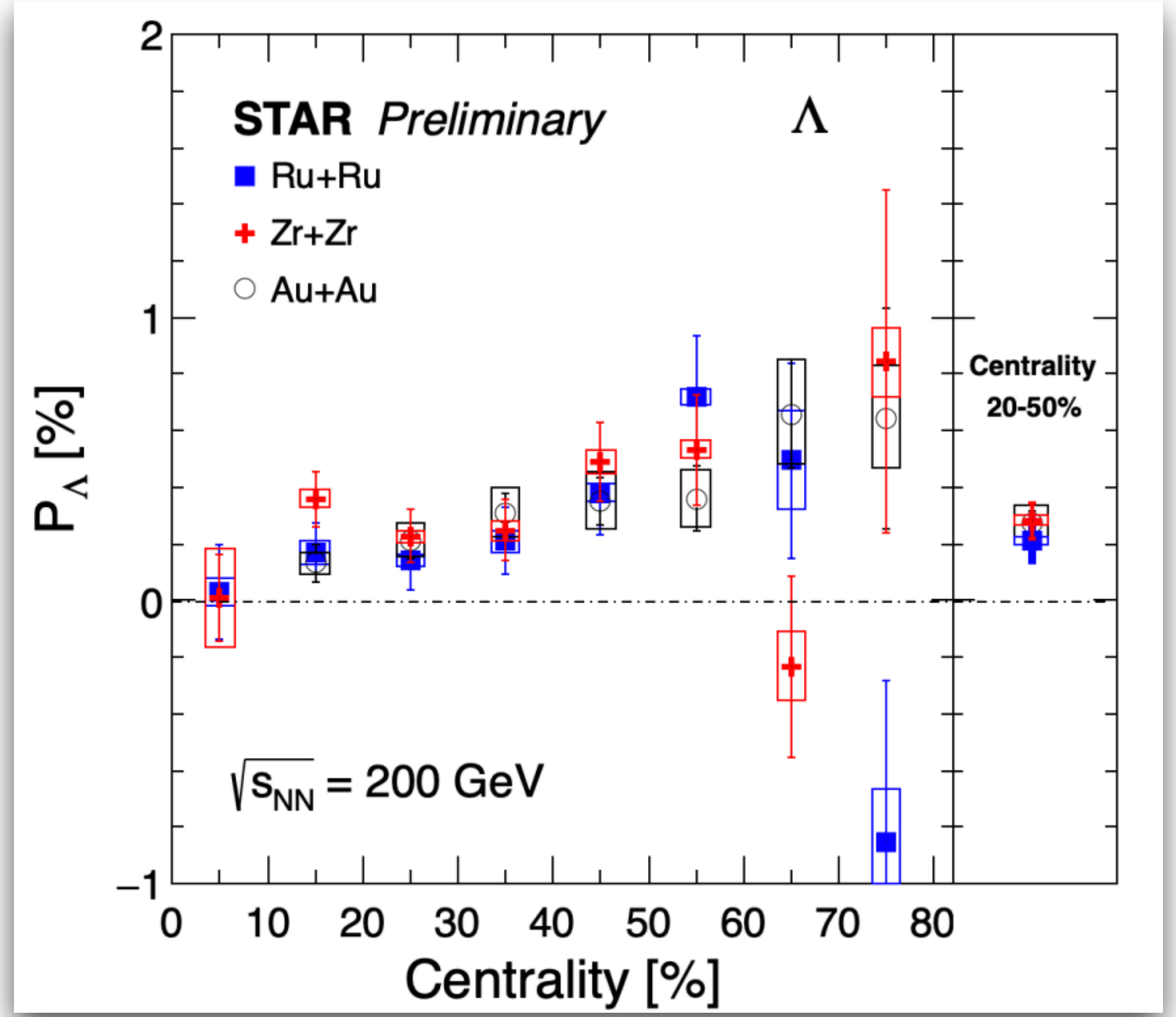
Alzhrani et. al., arXiv: 2203.15718

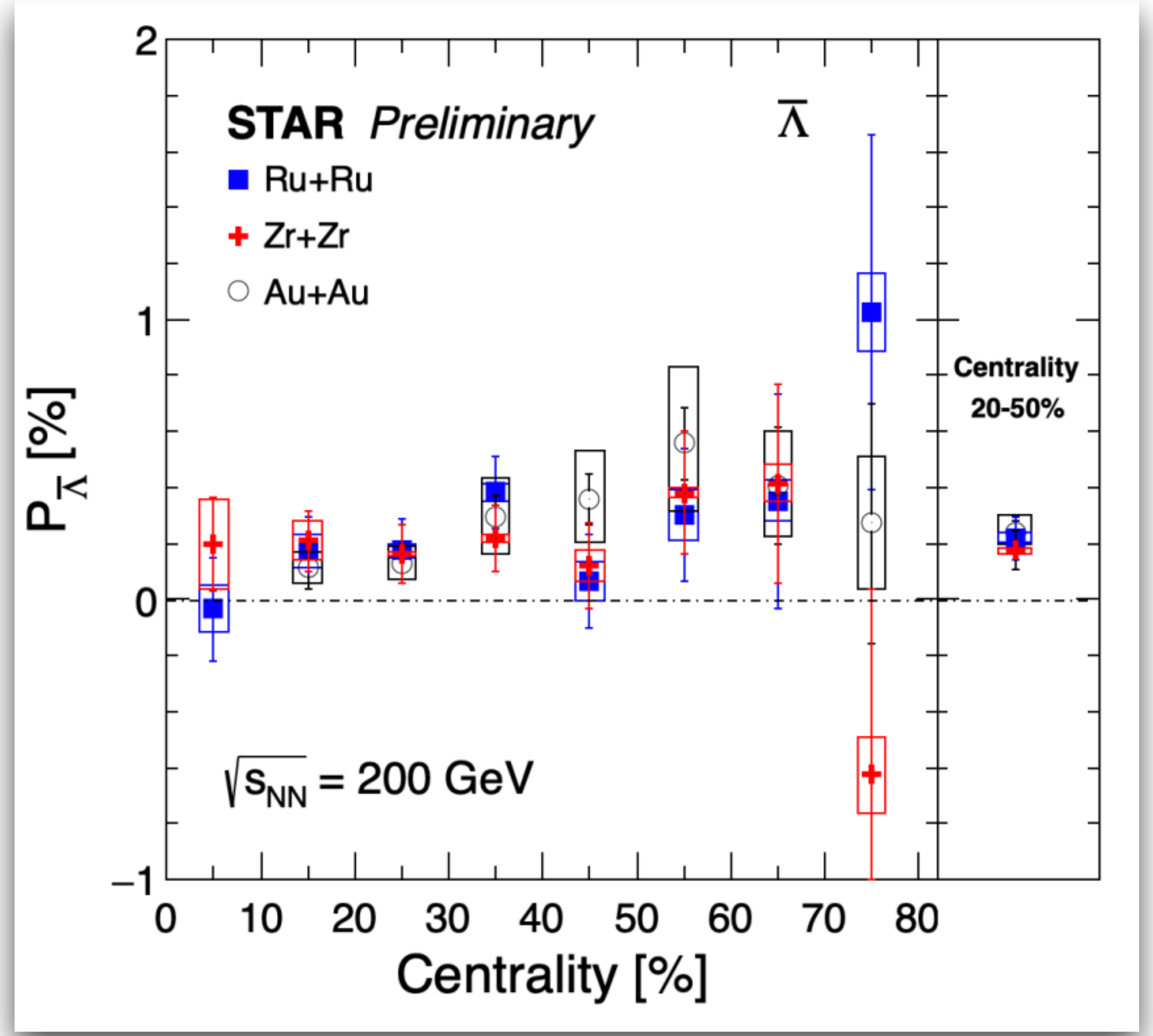
Shi et. al., Phys Lett B 788, 409413 (2019)

- Zr+Zr ~ Ru+Ru ~ Au+Au
- No obvious system size dependence observed
- O+O data ?

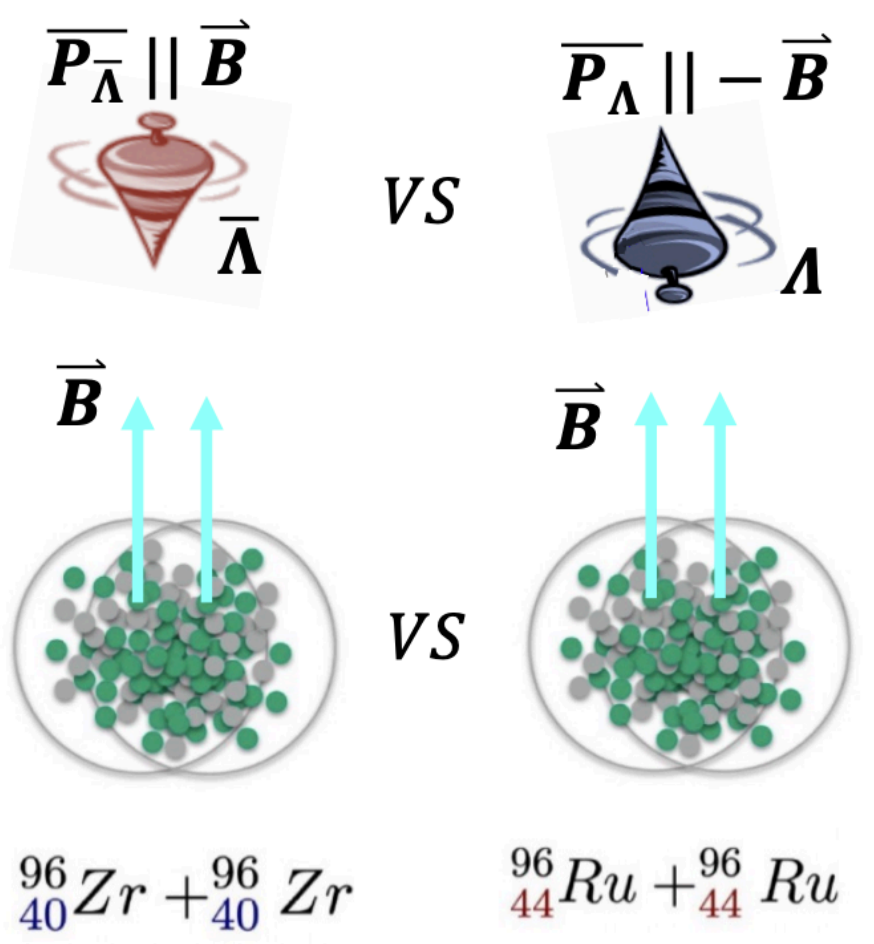
Possible constraint on B field by P$_\Lambda$

Talk-(Bulk,14/06) Xingrui Gou (STAR)





Zr+Zr vs. Ru+Ru



~10-15% difference in **B** field

Naive expectation:

$$P^{Ru+Ru}_{\Lambda-\bar{\Lambda}} > P^{Zr+Zr}_{\Lambda-\bar{\Lambda}}$$

- Ru+Ru ~ Zr+Zr
- No difference between Λ, $\bar{\Lambda}$ is observed in isobar data
- High precision RHIC BES-II and LHC data?

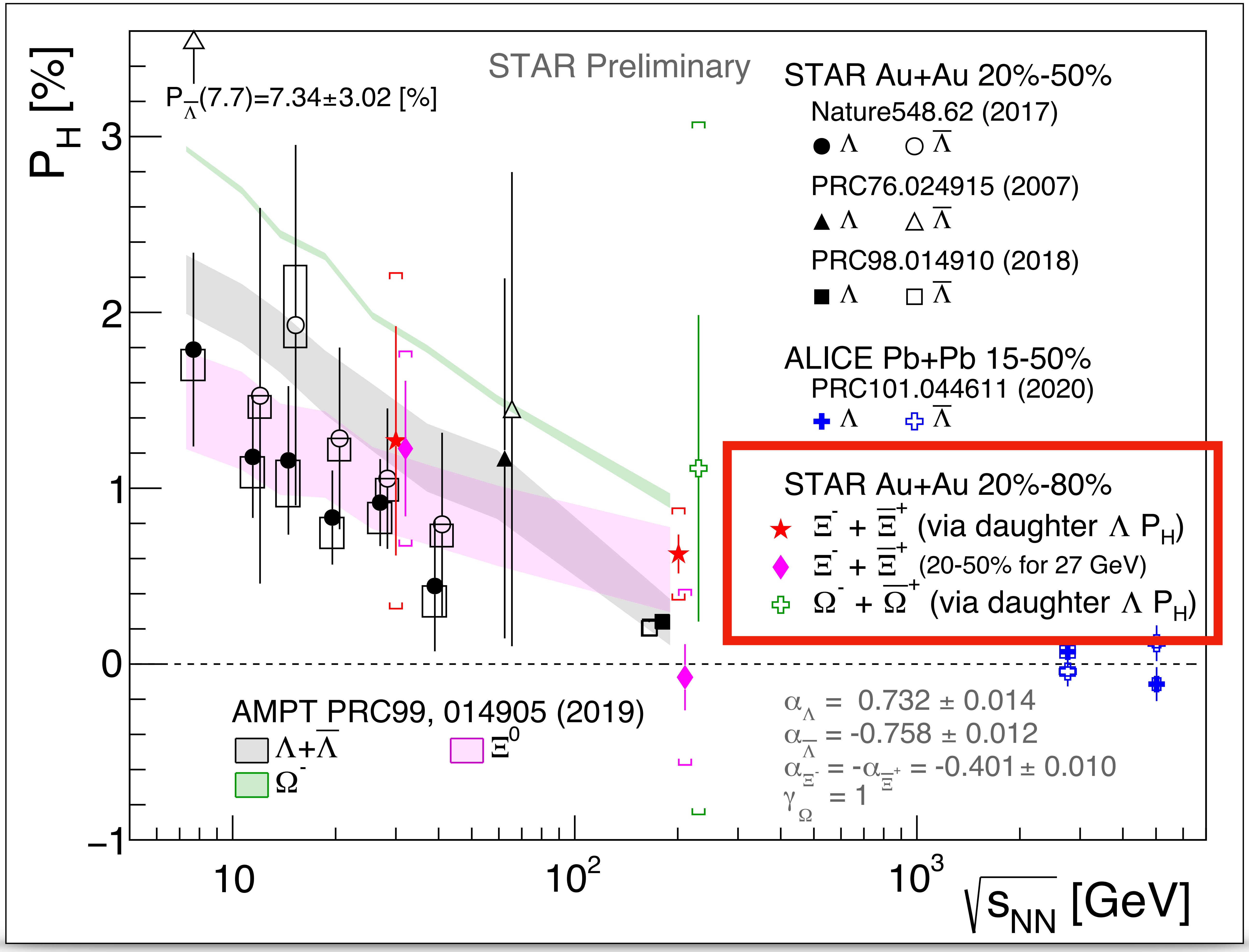
- Magnetic field

$$B \approx \frac{T}{2\mu_\Lambda}(P_\Lambda - P_{\bar{\Lambda}})$$

Subhash Singha @ SQM 2022

Global spin polarization of Ξ, Ω

STAR: Phys Rev Lett 126, 162301 (2021)



Ξ, Ω can be measured via daughter particle polarization

- $P_\Lambda = 0.24 \pm 0.03(\text{stat.}) \pm 0.03(\text{syst.})\,\%$
- $P_\Xi = 0.47 \pm 0.10(\text{stat.}) \pm 0.23(\text{syst.})\,\%$
- $P_\Omega = 1.11 \pm 0.87(\text{stat.}) \pm 1.97(\text{syst.})\,\%$

- First non-zero polarization for Ξ, Ω
- $P_{\Xi,\Omega}$ follows global trend of P_Λ
- Global nature of polarization in HIC

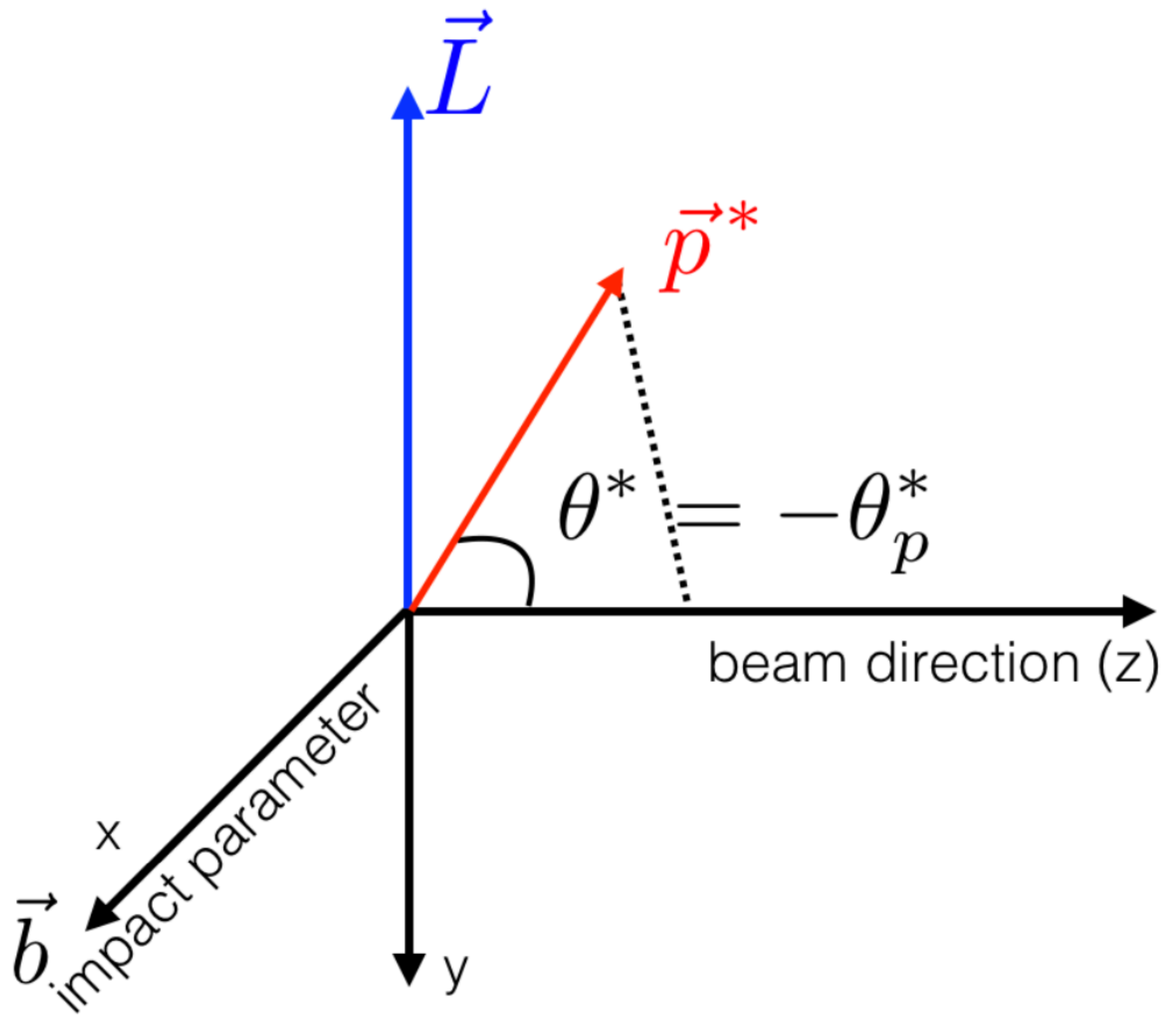
	Mass (GeV/c²)	Spin	μ_N
Λ (uds)	1.115683	1/2	0.613
Ξ (dss)	1.32171	1/2	-0.6501
Ω (sss)	1.67245	3/2	-2.02

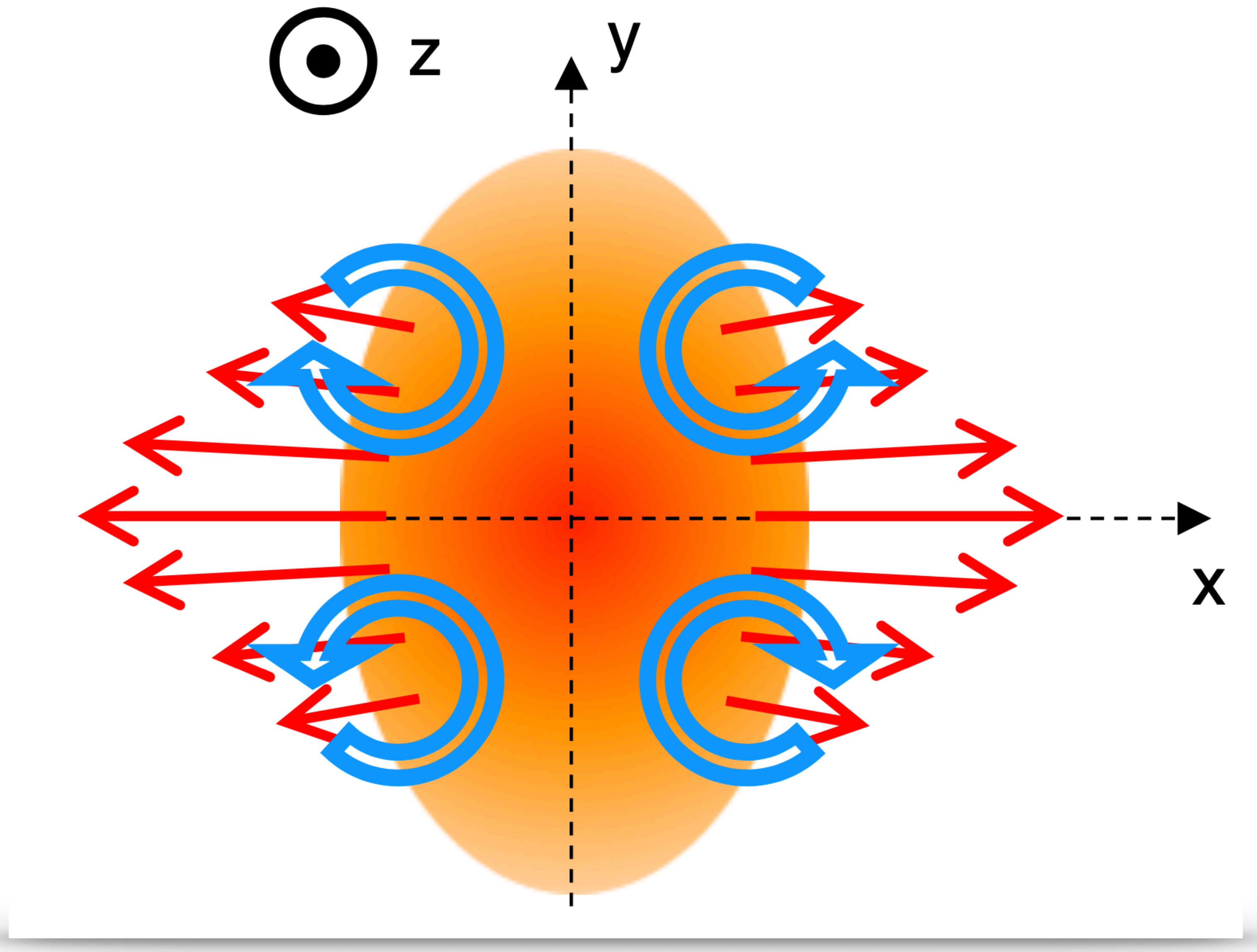
Precise measurement can help testing species dependent splitting

Local spin polarization of hyperons

- How polarization distributed in azimuthal angle of particle momentum?
- Results on longitudinal polarization (P_z)

Local spin polarization of hyperons





Longitudinal polarization

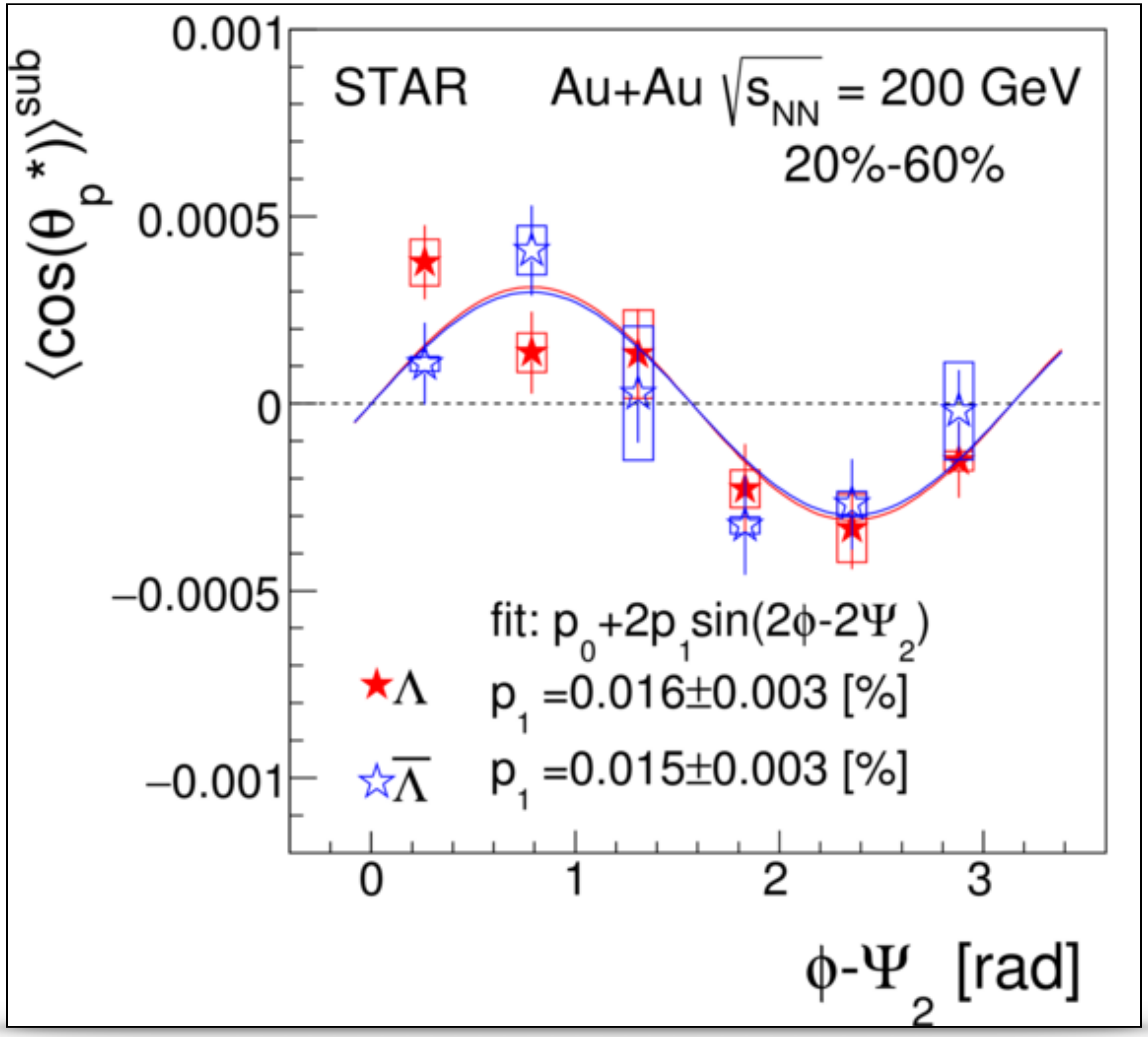
- Elliptic flow is expected to generate a longitudinal component of polarization (P_z)
- $P_z = \frac{3}{\alpha_H}\langle \cos \theta_{\mathrm{p}}^* \rangle$
- Local polarization is expected to be sensitive to space and time variation of vorticity and convolute with flow driven space-momentum correlation

Becattini, Karpenko, Phys Rev Lett 120, 012302 (2018)

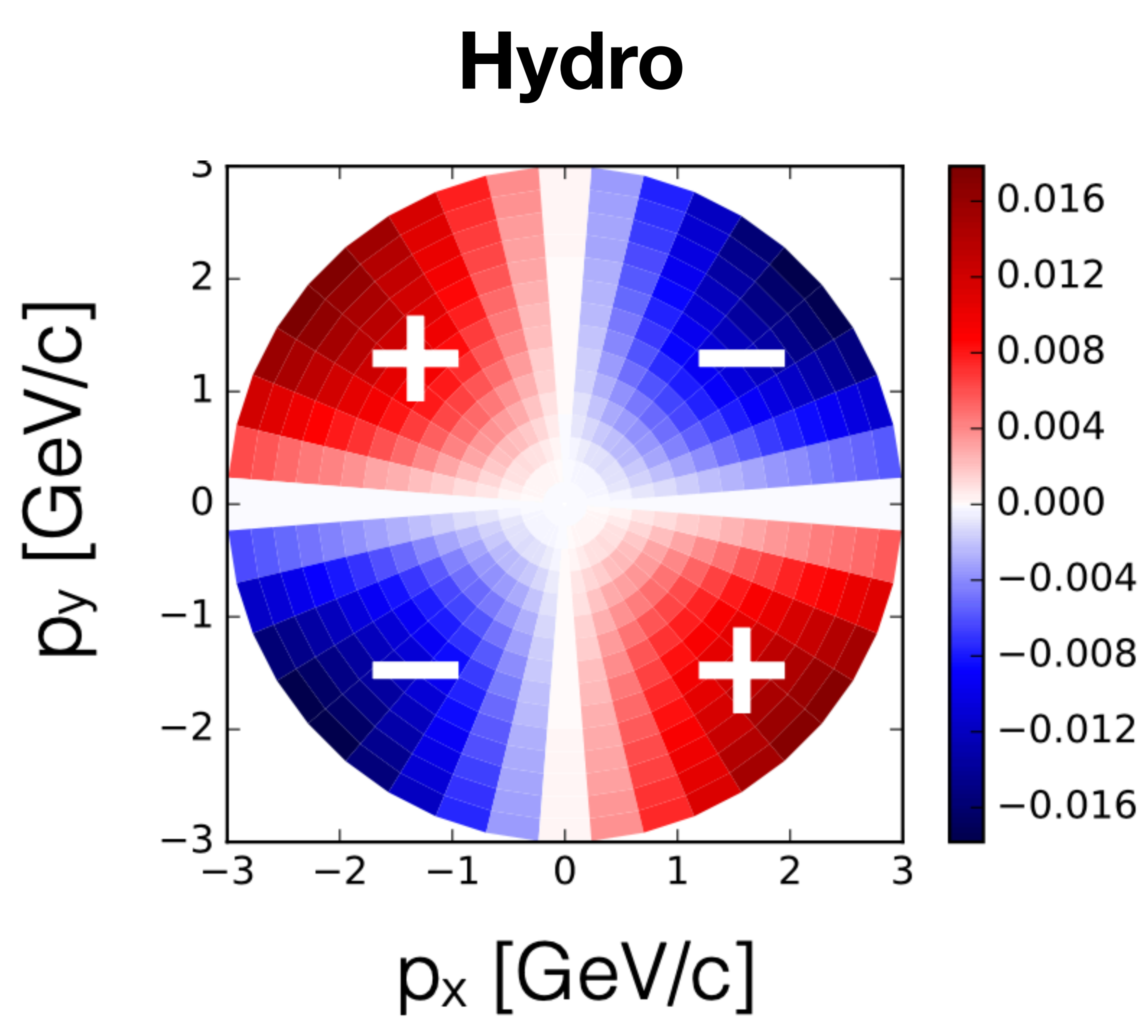
STAR: Phys Rev Lett 123, 132301 (2019)

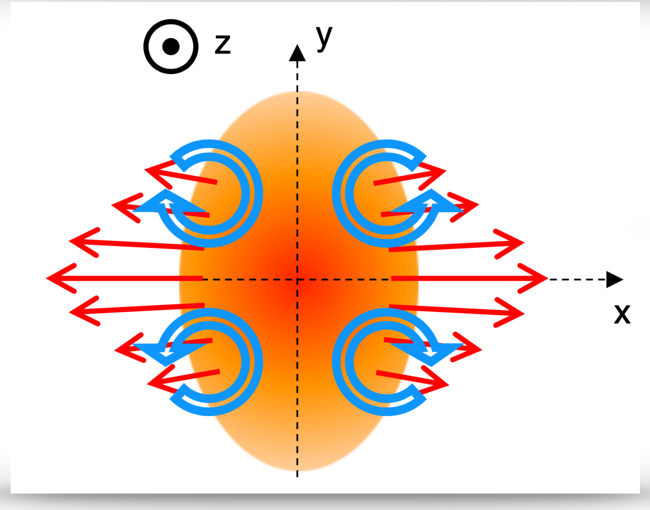
Local spin polarization of hyperons

STAR: Phys Rev Lett 123, 132301 (2019)



- First observation of longitudinal polarization P_z wrt Ψ_2
- *"Sign puzzle"* in P_z: Many models fail to capture trend with proper sign



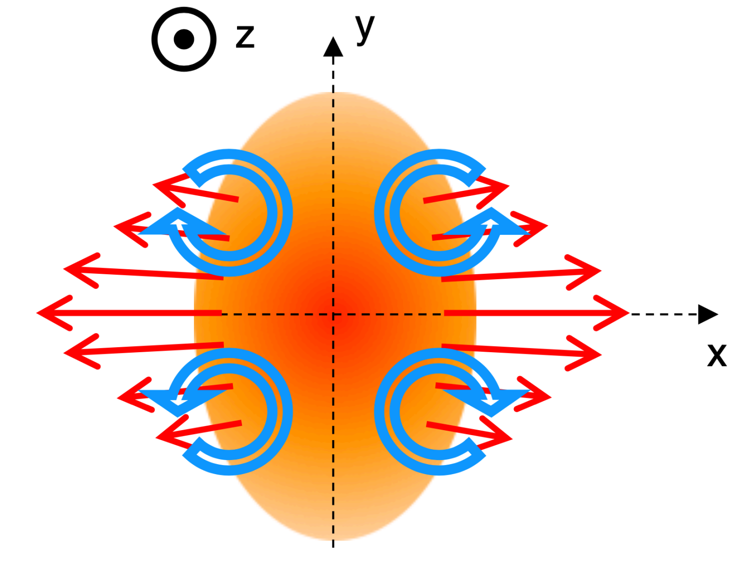


Same pattern observed at LHC

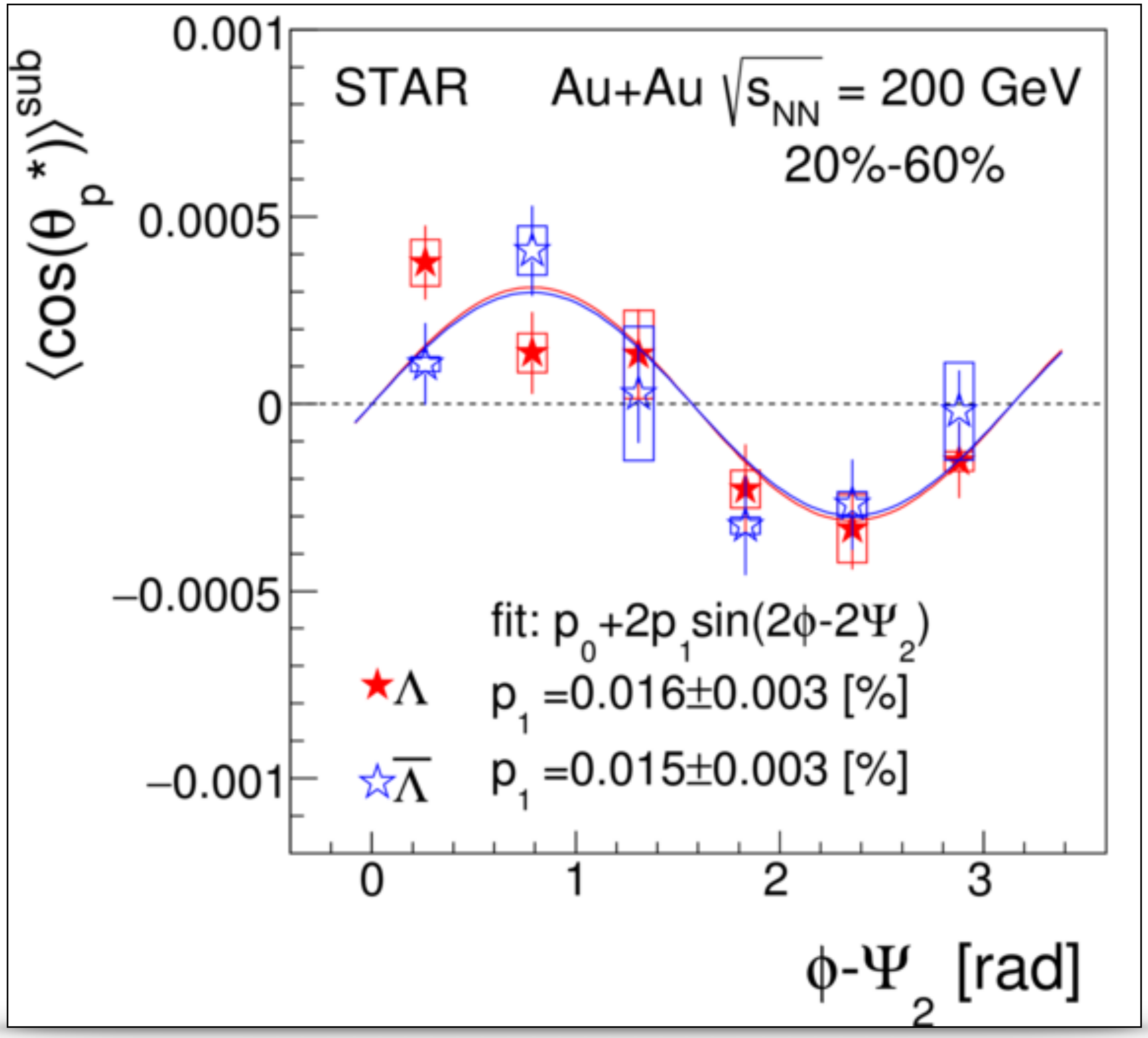
ALICE, Phys Rev Lett 128, 172005 (2022)

Theory developments addressing spin puzzle:
Liu et al, JHEP 07, 188 (2021)
Fu et., al, Phys Rev Lett 127, 142301 (2021)
Becattini et al, Phys Rev Lett 127, 272302 (2021)
Becattini et al, Phys Lett B820, 136519 (2021)
Alzhrani et. al., arXiv: 2203.15718

Local spin polarization of hyperons



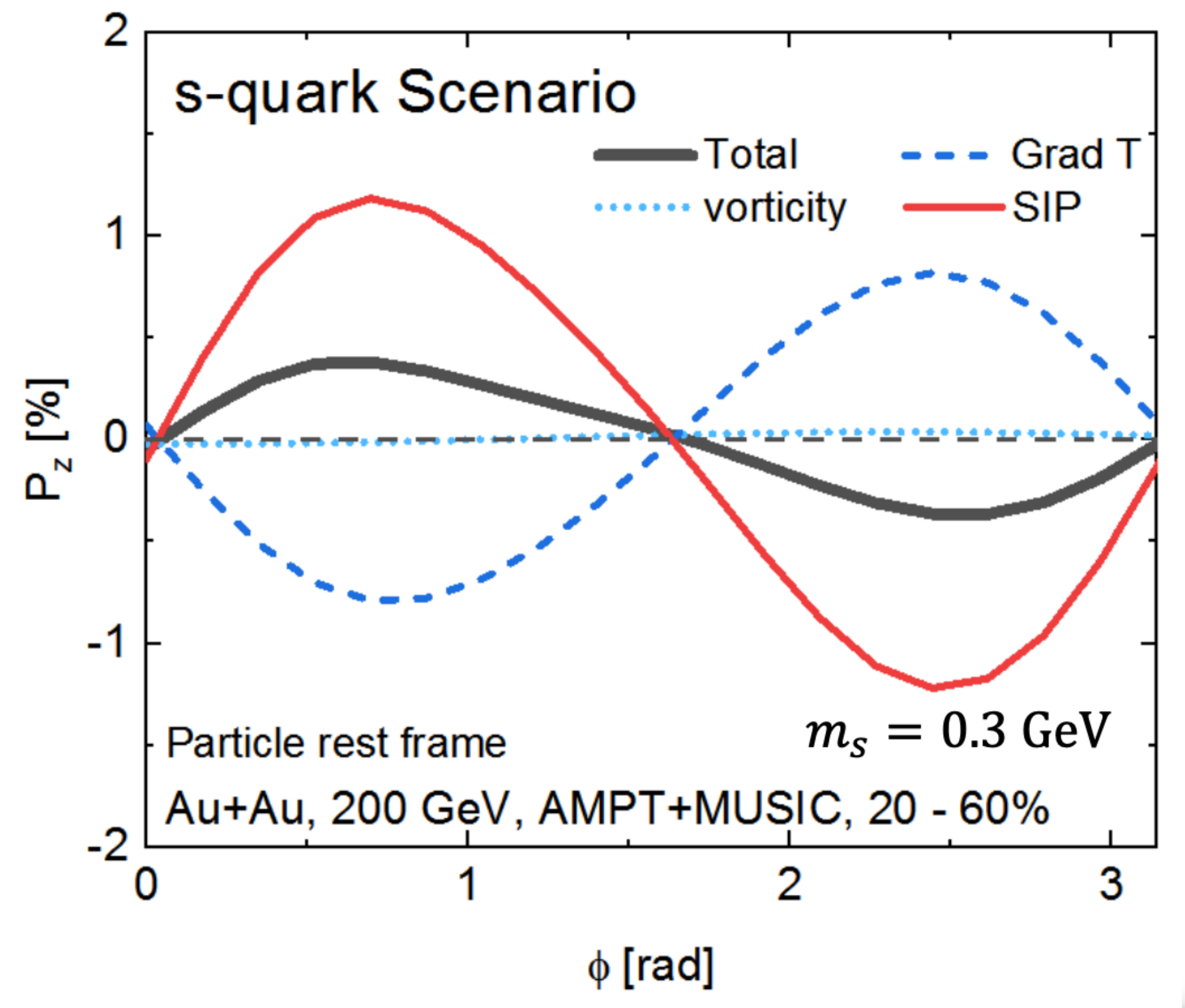
STAR: Phys Rev Lett 123, 132301 (2019)



One of the new developments:

Shear Induced Polarization (SIP)

Total = vorticity $\bigoplus$ ∇T $\bigoplus$ Shear

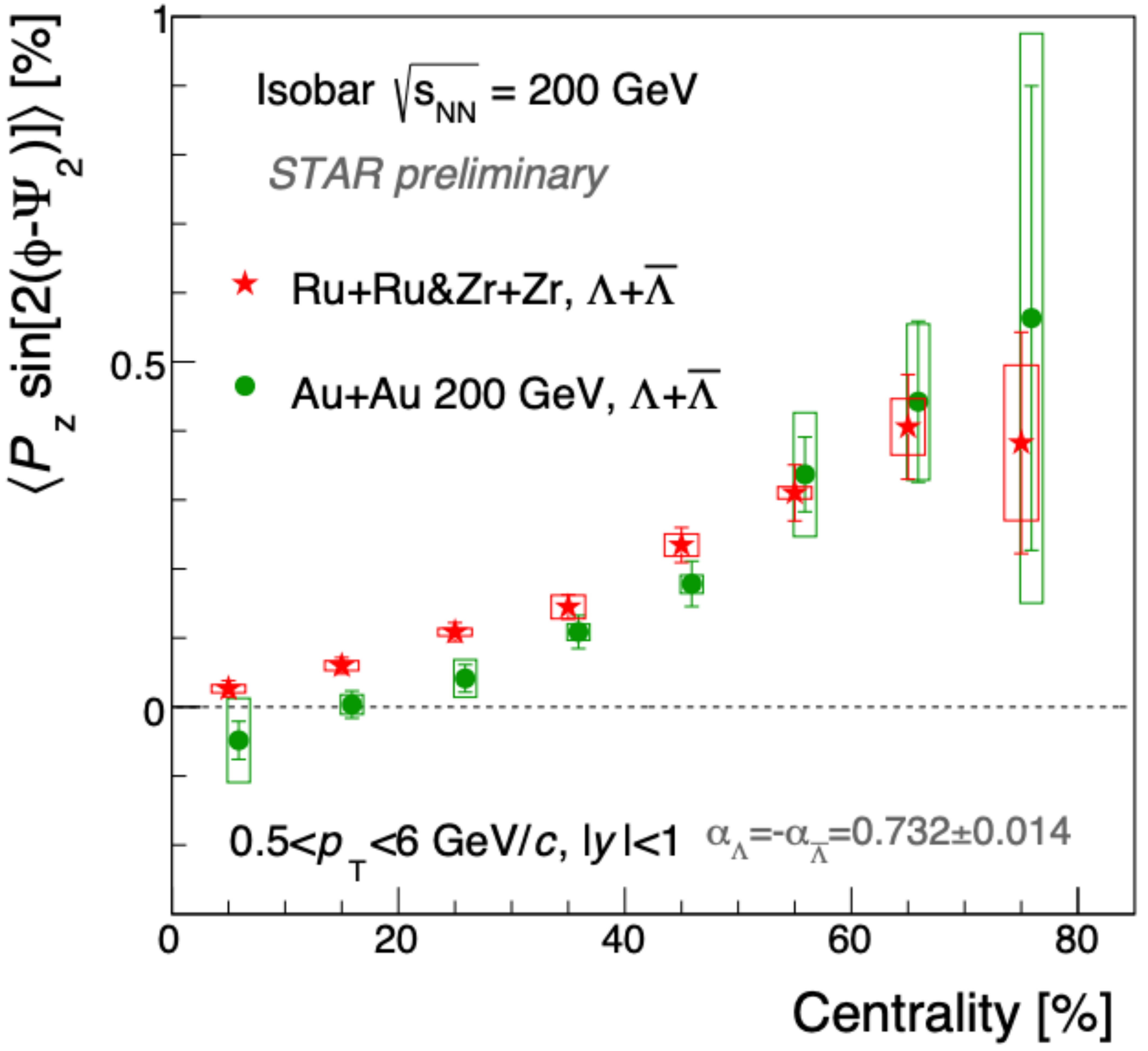


Fu et., al, Phys Rev Lett 127, 142301 (2021)

System size and energy dependence of P_z

Talk-(Bulk,14/06)
Xingrui Gou (STAR)

$P_{z,n} = \langle P_z \sin[n(\phi - \Psi_n)] \rangle$

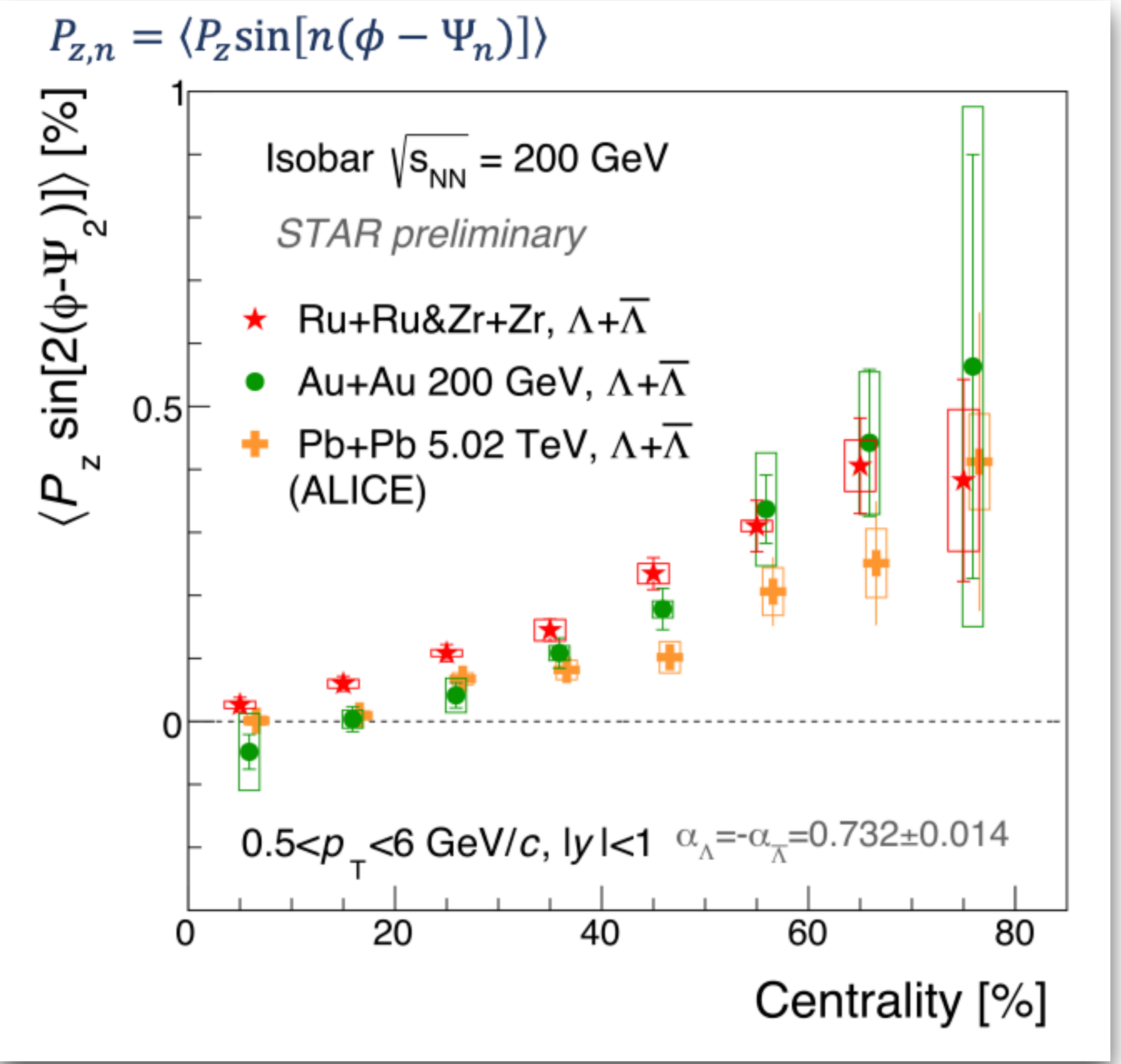


- At mid-central collisions Zr+Zr,Ru+Ru > Au+Au
- Hints of system size dependence

STAR: Phys Rev Lett 123, 132301 (2019)

System size and energy dependence of P_z

Talk-(Bulk,14/06)
Xingrui Gou (STAR)

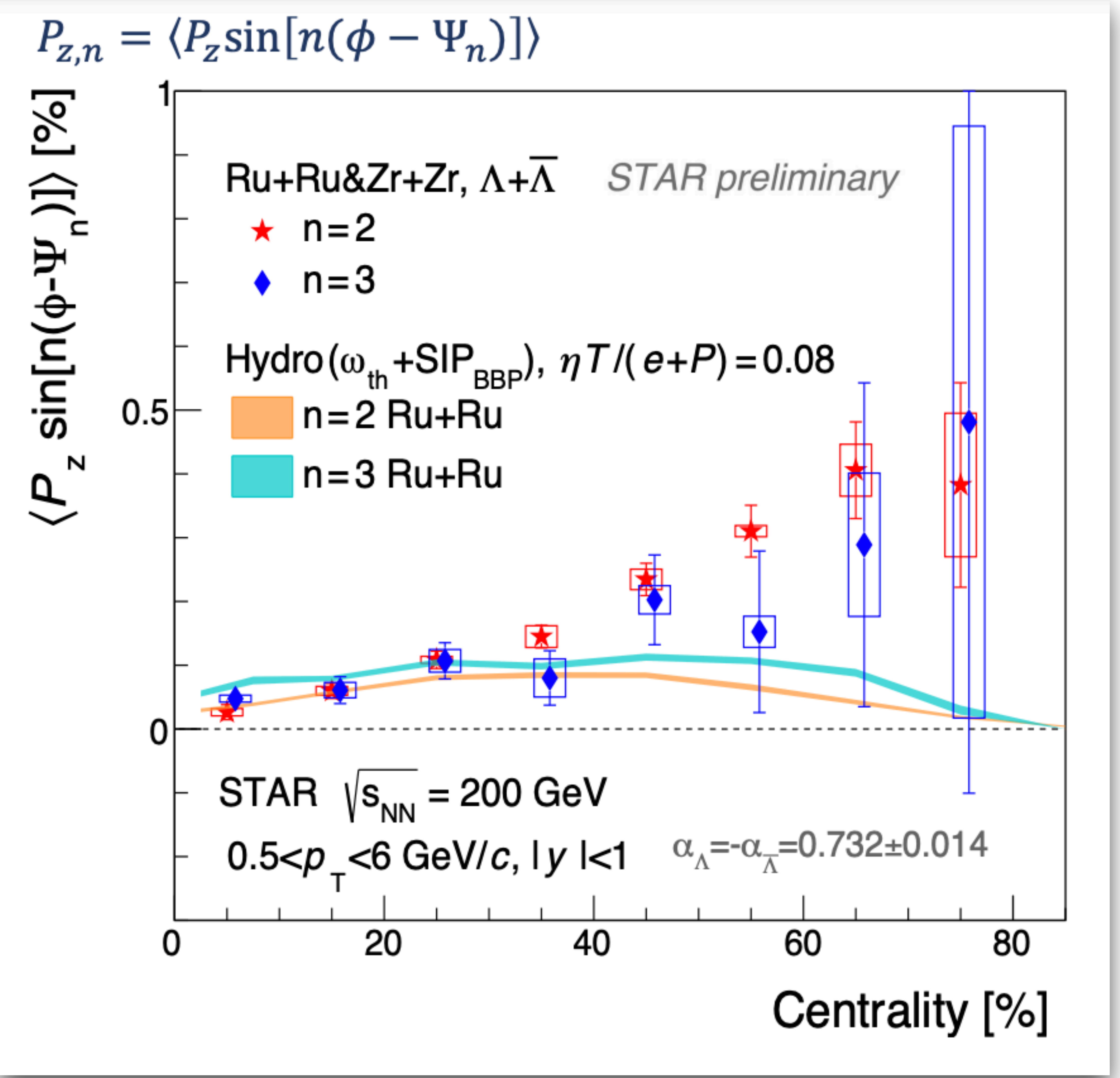


- At mid-central collisions Zr+Zr,Ru+Ru > Au+Au ~ Pb+Pb
- Hints of system size dependence, No obvious energy dependence
- O+O, Xe+Xe data?

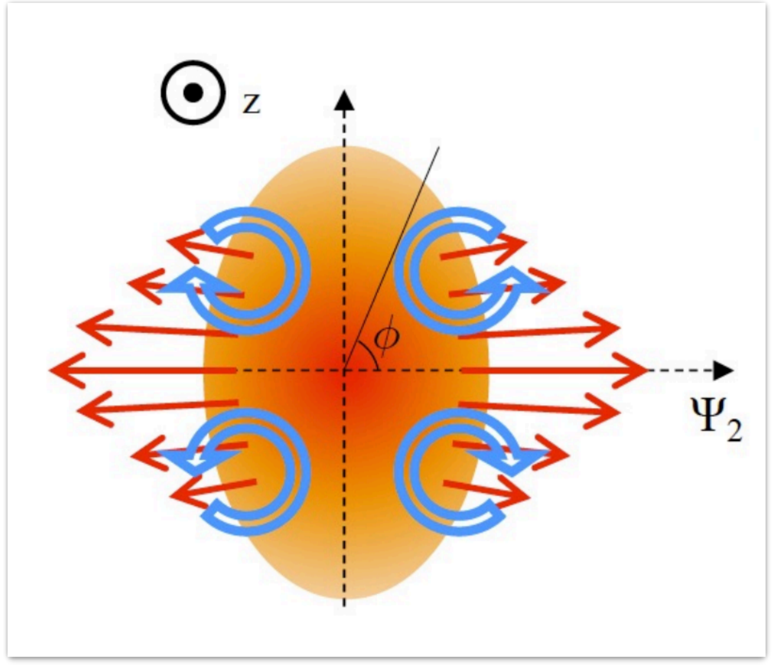
STAR: Phys Rev Lett 123, 132301 (2019)
ALICE, Phys Rev Lett 128, 172005 (2022)

Event plane harmonic dependence of P_z

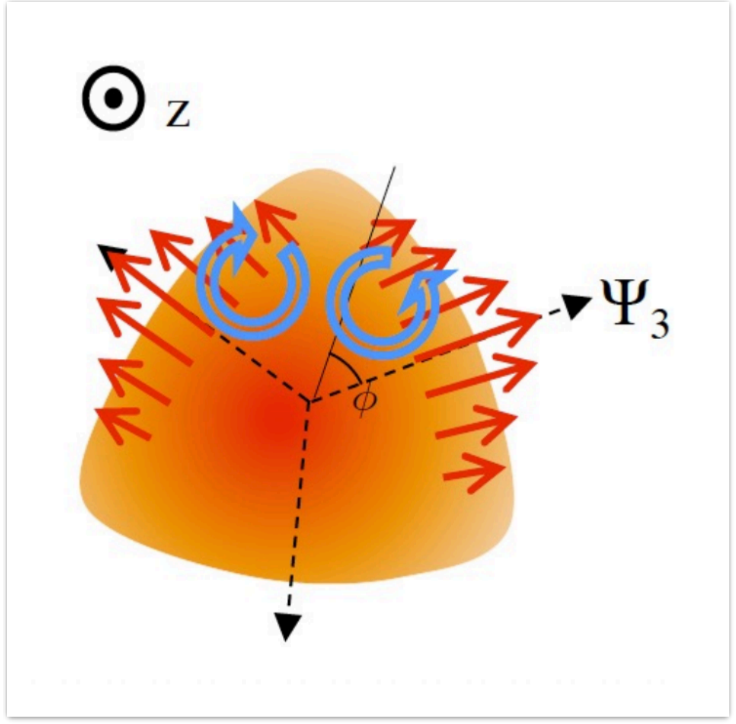
Talk-(Bulk,14/06)
Xingrui Gou (STAR)



Alzhrani et. al., arXiv: 2203.15718



Vs.



- Significant local polarization wrt 3rd order event plane
  $P_z(\Psi_3) \sim P_z(\Psi_2)$
- Results can provide information on complex vortical structures; constrain on initial conditions, transport parameters …

Baryonic Spin Hall effect (SHE)

Condensed matter

$$s \propto \pm p \times E$$

Heavy Ion Collisions

$$s \propto \pm p \times \nabla \mu_B$$

Predicted Spin Hall type effect driven by gradient of baryonic density ($\nabla \mu_B$)

Can be accessed by splitting in local polarization of Λ and $\overline{\Lambda}$: $P_z^{\Lambda} - P_z^{\overline{\Lambda}}$

Fu et., al., arXiv: 2201.12970

Polarization ~ vorticity $\bigoplus$ ∇T $\bigoplus$ Shear $\bigoplus$ $\nabla \mu_B$

Baryonic Spin Hall effect (SHE)

Poster-(Bulk,14/06)
Qiang Hu (STAR)

Condensed matter

$$\mathrm{s} \propto \pm \mathrm{p} \times \mathrm{E}$$

Heavy Ion Collisions

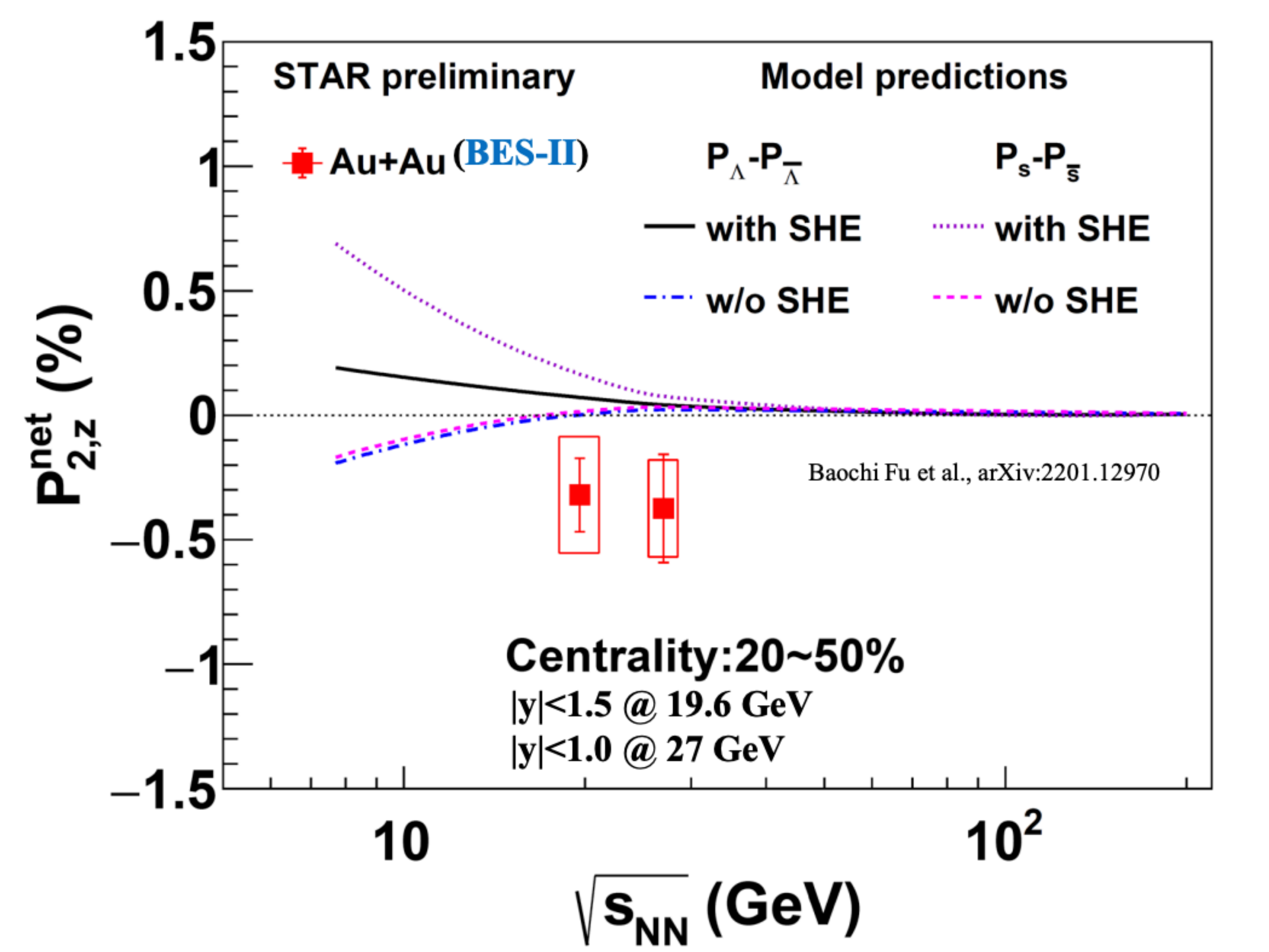
$$\mathrm{s} \propto \pm \mathrm{p} \times \nabla \mu_{\mathrm{B}}$$

Predicted Spin Hall type effect driven by gradient of baryonic density ($\nabla \mu_B$)

Can be accessed by splitting in local polarization of Λ and $\overline{\Lambda}$: $\mathrm{P}_{\mathrm{z}}^{\Lambda} - \mathrm{P}_{\mathrm{z}}^{\overline{\Lambda}}$

Fu et., al., arXiv: 2201.12970

Polarization ~ vorticity $\oplus$ ∇T $\oplus$ Shear $\oplus$ $\nabla \mu_B$



- $\mathrm{P}_{\mathrm{z}}^{\Lambda} - \mathrm{P}_{\mathrm{z}}^{\overline{\Lambda}}$ ~< 0 : No indication of baryonic SHE yet
- Measurement at lower energies?

Global spin alignment of vector mesons

- Complementary to hyperon spin polarization
- Can offer information on spin dynamics of QCD medium
- Can access "spin-orbit" type interaction ($S \cdot (E_v \times p)$)

Baryons	Vs.	Mesons
Fermions		Bosons
Λ (uds), spin = 1/2		ϕ ($s\bar{s}$), spin = 1
Ξ (dss), spin = 1/2		K*($d\bar{s}$), spin = 1
Ω (sss), spin = 3/2		J/Ψ($c\bar{c}$), spin = 1

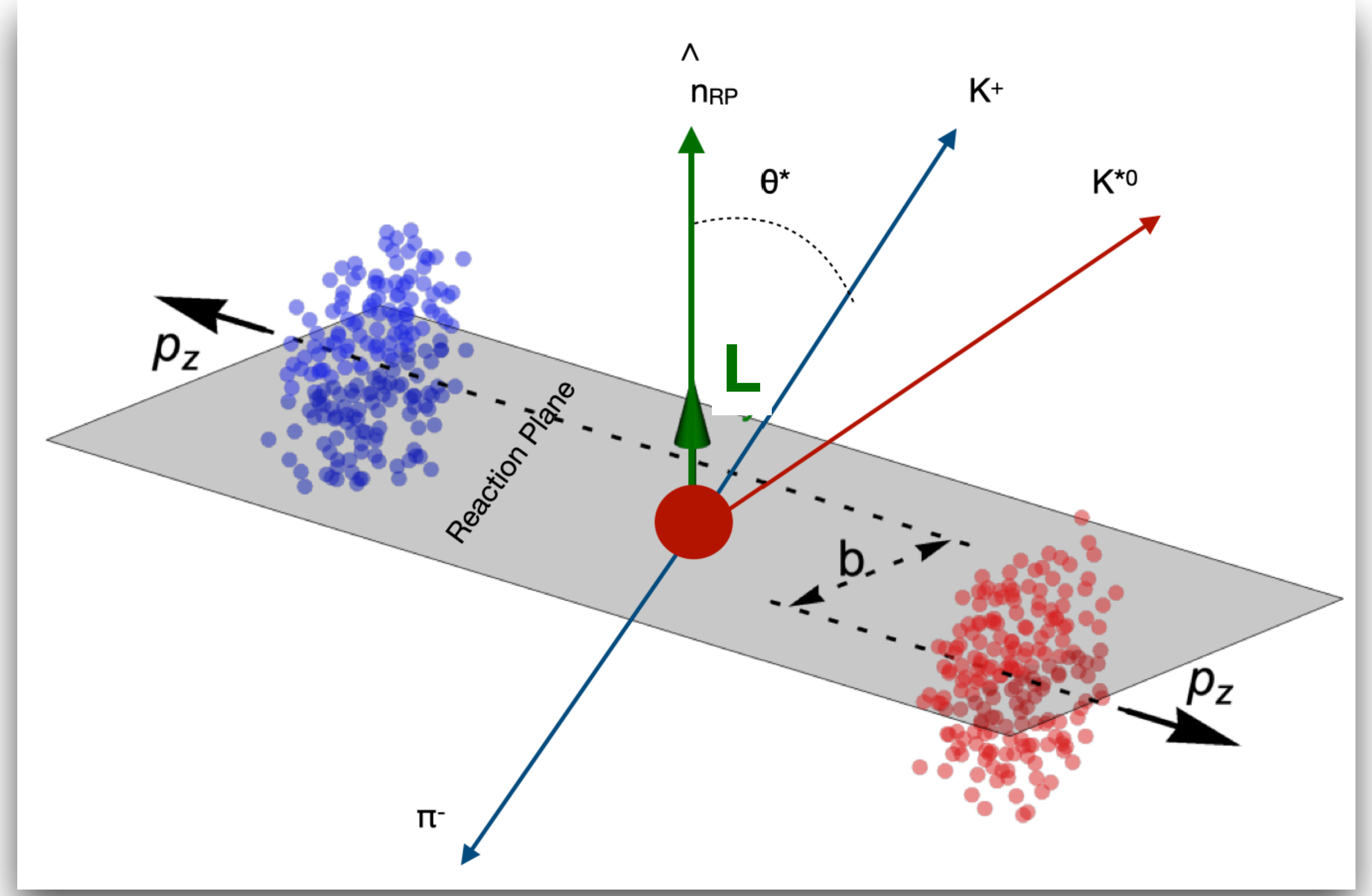
Vector meson spin alignment (ρ_{00})

Spin alignment (ρ_{00}):
Measured from the angular distribution (θ^*) of the daughter particle in parent's rest frame

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

ρ_{00} : *00*th component of spin density matrix

θ^* : Angle between momentum of daughter and polarization axis in parent's rest frame



- Deviation of ρ_{00} from (1/3) indicates spin alignment

Schiling et. al., Nucl Phys B 15, 397 (1970)
STAR: Phys Rev C 77, 61902 (2008)

Expectation of ρ_{00} from theory

Physics Mechanisms	(ρ_{00})
c_Λ: Quark coalescence vorticity & magnetic field[1]	< 1/3 (Negative ~ 10^{-5})
c_ε: Vorticity tensor[1]	< 1/3 (Negative ~ 10^{-4})
c_E: Electric field[2]	> 1/3 (Positive ~ 10^{-5})
Fragmentation[3]	> or, < 1/3 (~ 10^{-5})
Local spin alignment and helicity[4]	< 1/3
Turbulent color field[5]	< 1/3
c_ϕ: Vector meson strong force field[6]	> 1/3

$$\rho_{00}(\omega) \sim \frac{1}{3} - \frac{1}{9}(\beta\omega)^2$$

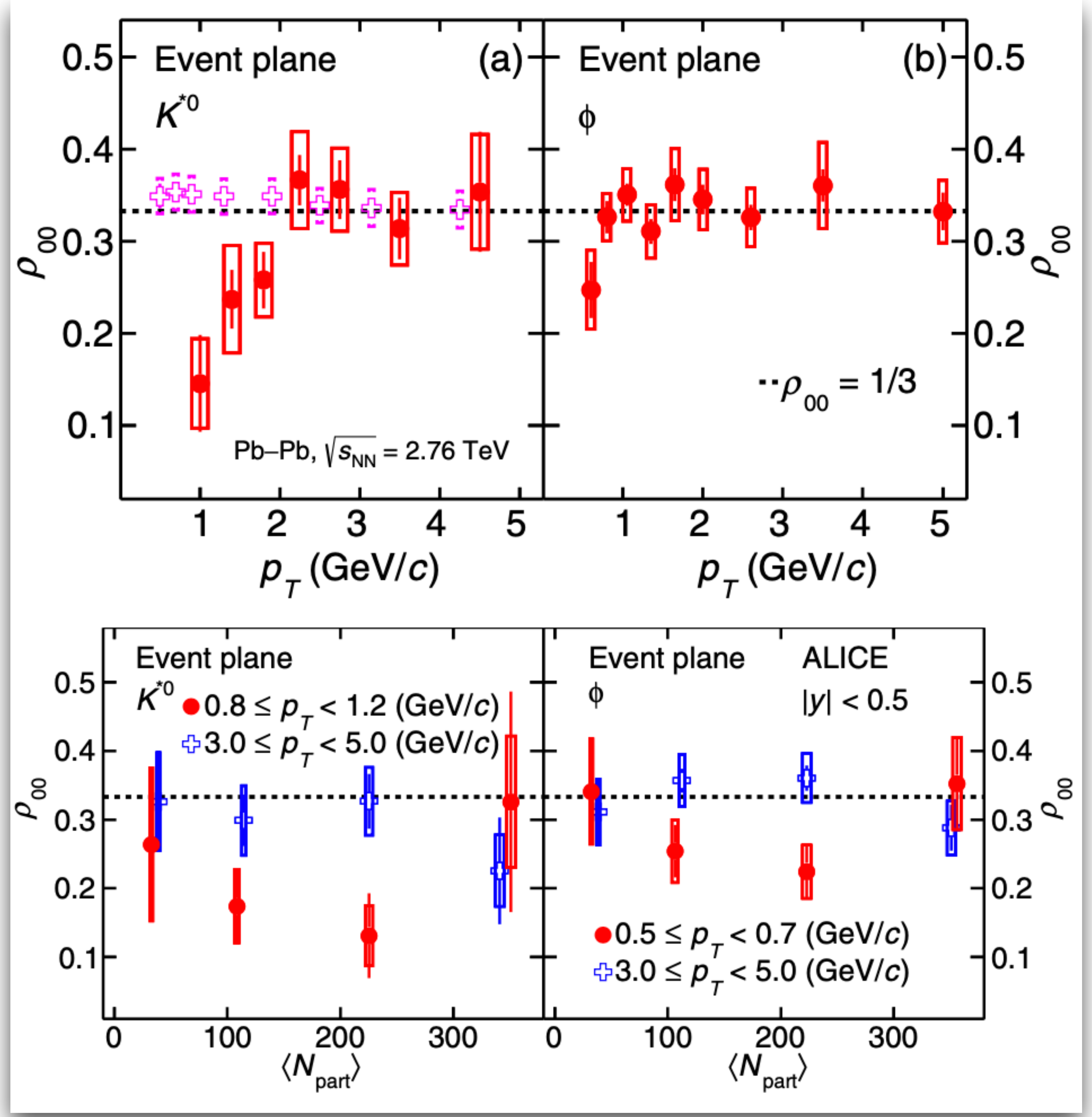
$$\rho_{00}(\mathrm{coal}) \sim \frac{1 - \mathrm{P_q P_q}}{3 + \mathrm{P_q P_q}}$$

$$\rho_{00}(B) \approx \frac{1}{3} - \frac{4}{9}\beta^2 \mu_{q_1}\mu_{q_2} B^2$$

$$\rho_{00}(\mathrm{frag}) \sim \frac{1 + \beta \mathrm{P_q P_q}}{3 - \beta \mathrm{P_q P_q}}$$

[1]. Liang et., al., Phys Lett B 629, (2005);
Yang et., al., Phys Rev C 97, 034917 (2018);
Xia et., al., Phys Lett B 817, 136325 (2021);
Beccattini et., al., Phys Rev C 88, 034905 (2013)
[2]. Sheng et., al., Phys Rev D 101, 096005 (2020);
Yang et., al., Phys Rev C 97, 034917 (2018)
[3]. Liang et., al., Phys Lett B 629, (2005)
[4]. Xia et., al., Phys Lett B 817, 136325 (2021);
Guo, Phys Rev D 104, 076016 (2021)
[5]. Muller et., al., Phys Rev D 105, L011901 (2022)
[6]. Sheng et., al., Phys Rev D 101, 096005 (2020);
Sheng et., al., Phys Rev D 102, 056013 (2020)

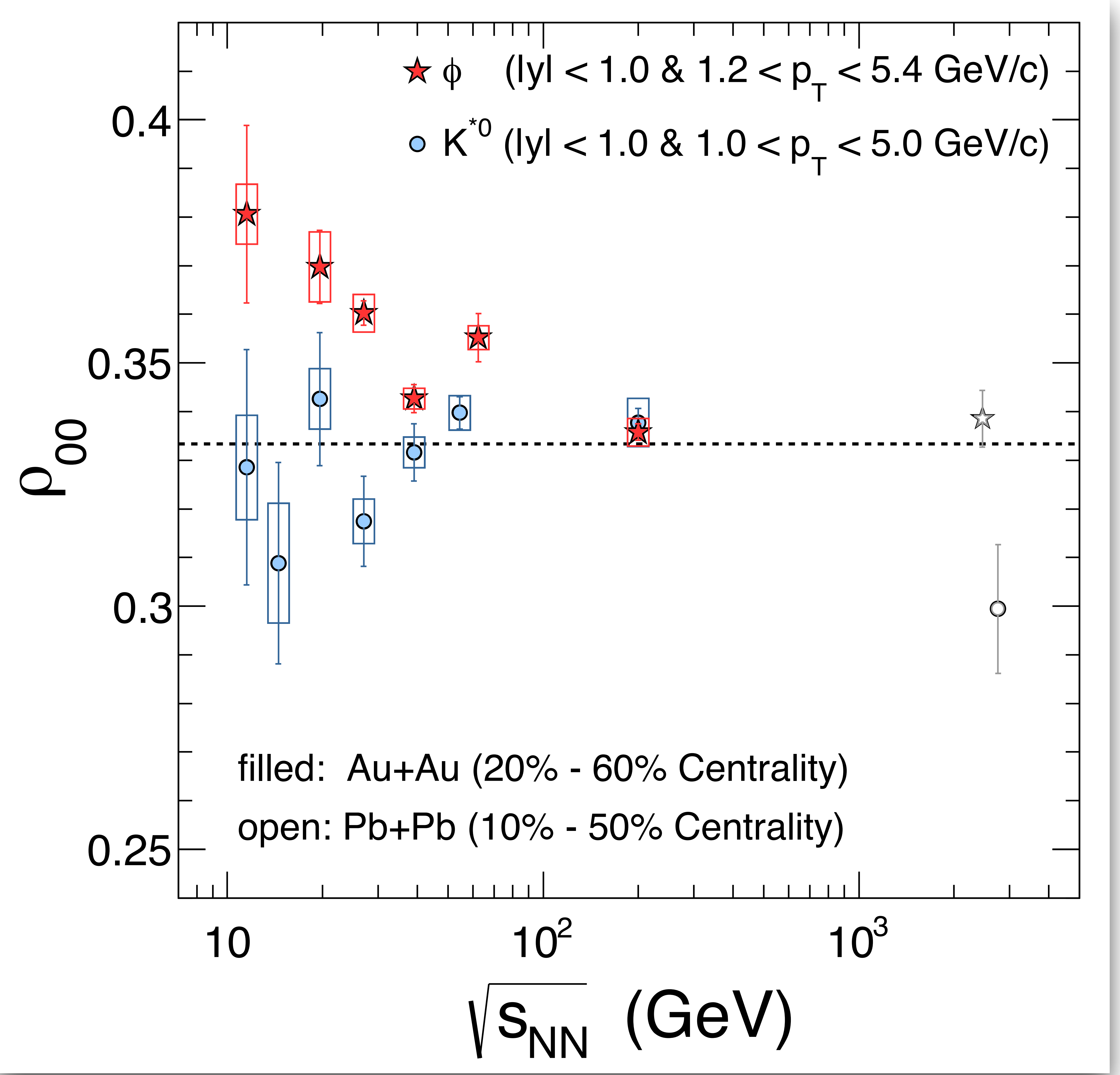
ρ_{00} (p_T, centrality) of ϕ and K^{*0} at LHC



- For $\sqrt{s_{NN}}$ = 2.76 TeV (at 10-50% and low p_T)
  - K^{*0} $\rho_{00} < 1/3$ with 2.6σ
  - ϕ ρ_{00} ~< 1/3 with 1.9σ
  - Centrality dependence at low p_T
- Observed deviation order of magnitude larger than naive expectation: $\rho_{00} \propto \omega^2$ from P_Λ

ALICE: Phys. Rev Lett 125, 012301 (2020)

ρ_{00} ($\sqrt{s_{NN}}$): ϕ and K*0 from RHIC BES-I



For 20-60%:

- For $\sqrt{s_{NN}}$ <= 62.4 GeV:
  - ϕ ρ_{00} = 0.3451 ± 0.0017 (stat.) ± 0.0018 (sys.)

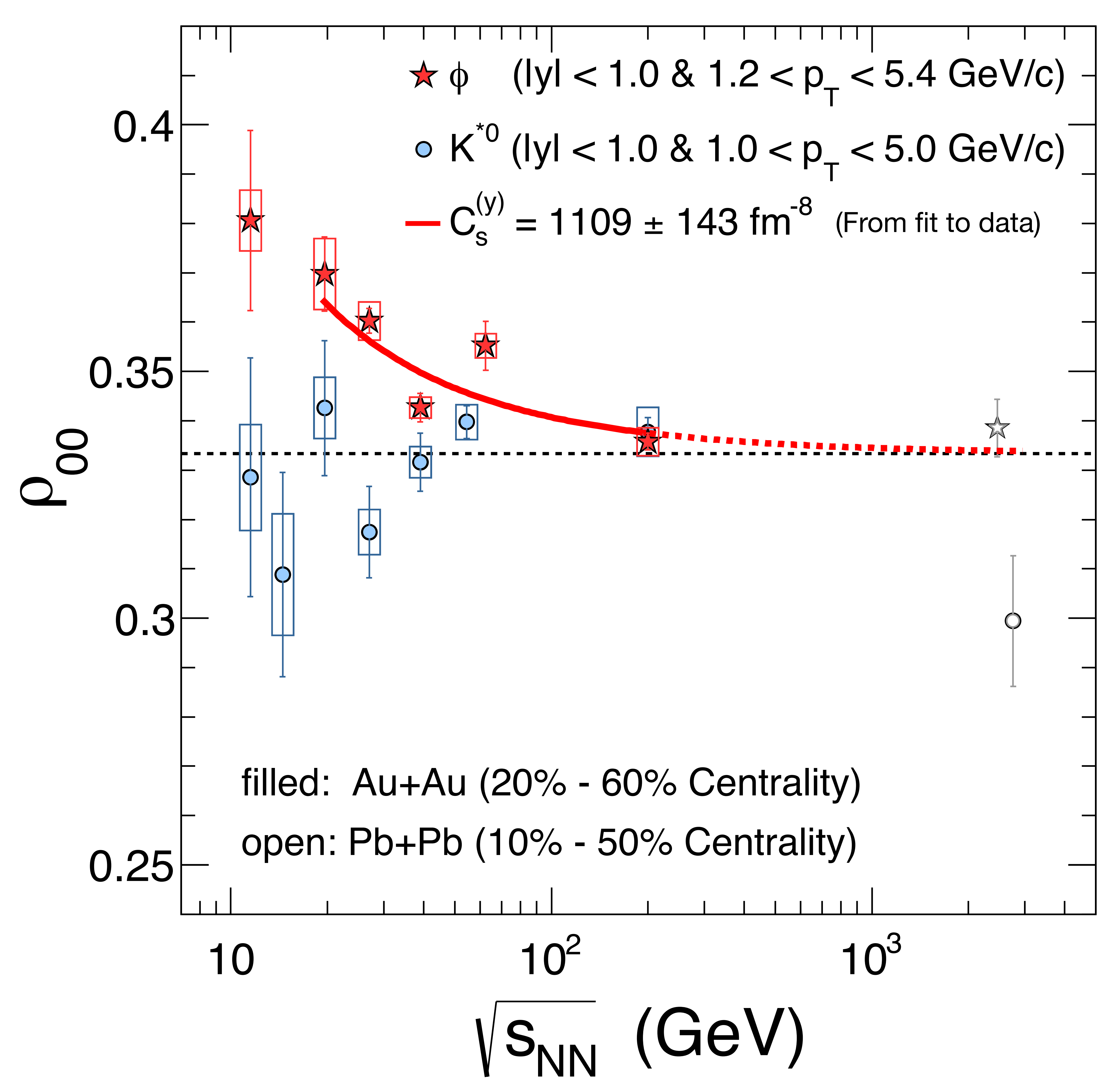
    ρ_{00} > 1/3 with 8.4σ

- For $\sqrt{s_{NN}}$ <= 54.4 GeV:
  - K^{*0} ρ_{00} = 0.3356 ± 0.0034 (stat.) ± 0.0043 (sys.)

    ρ_{00} ~ 1/3

ALICE: Phys Rev Lett 125, 012301 (2020)
STAR: arXiv: 2204.02302

ρ_{00} ($\sqrt{s_{NN}}$): ϕ and K*0 from RHIC BES-I



- Polarization by a strong force field of vector meson → Can accommodate large deviation for ϕ ρ_{00} at mid-central collisions

$$\rho_{00}(\phi) \approx \frac{1}{3} + c_\Lambda + c_\epsilon + c_E + c_\phi;$$

$$c_\phi \equiv \frac{g_\phi^4}{27 m_s^4 m_\phi^4 T_{eff}^2} \langle \boldsymbol{p}^2 \rangle_\phi \langle \tilde{E}_{\phi,z}^2 + \tilde{E}_{\phi,x}^2 \rangle;$$

$$C_s(y) \equiv g_\phi^4 \langle \tilde{E}_{\phi,z}^2 + \tilde{E}_{\phi,x}^2 \rangle$$

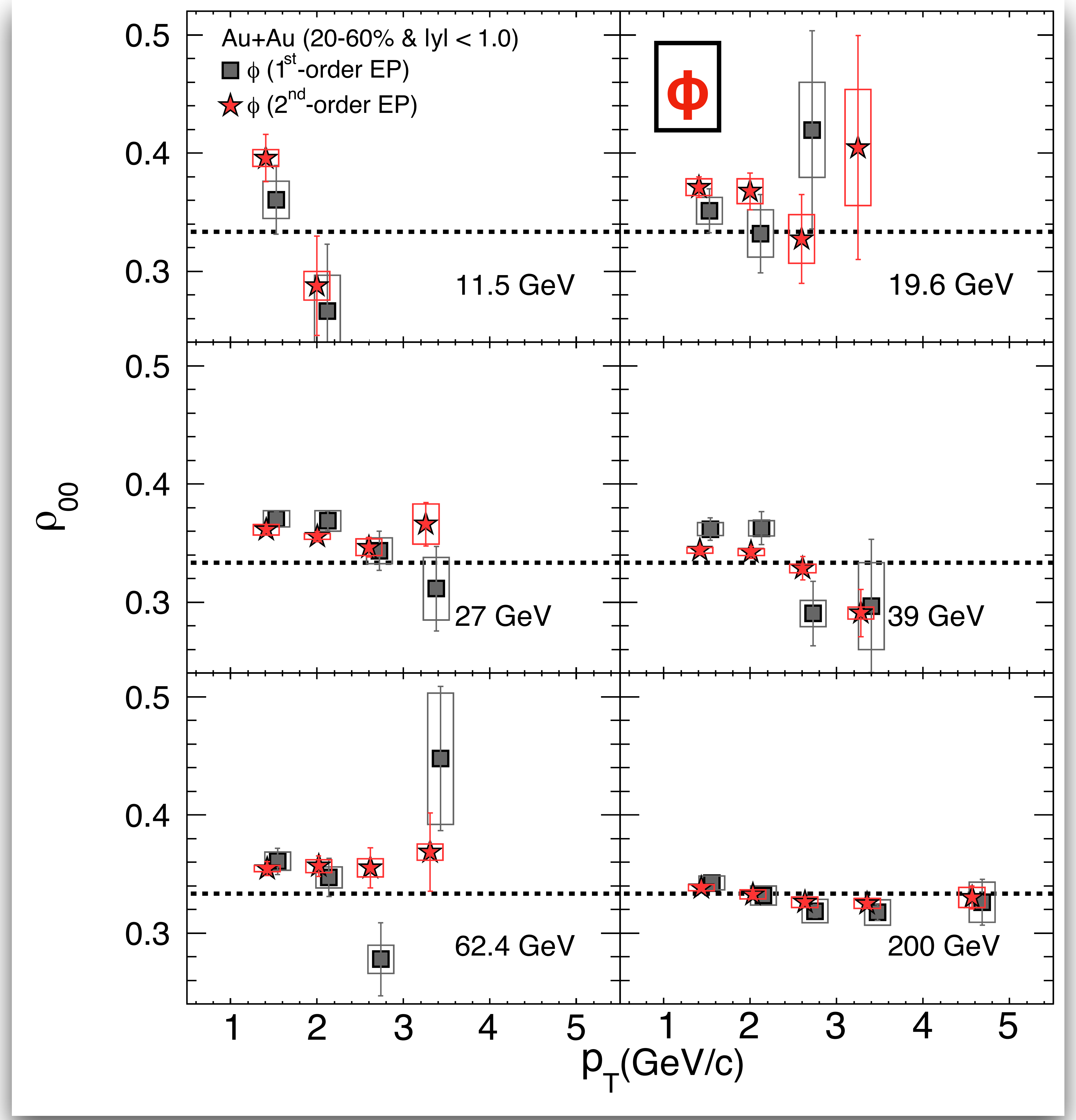
Vector meson field strength ~ $2.5\ m_\pi^2$

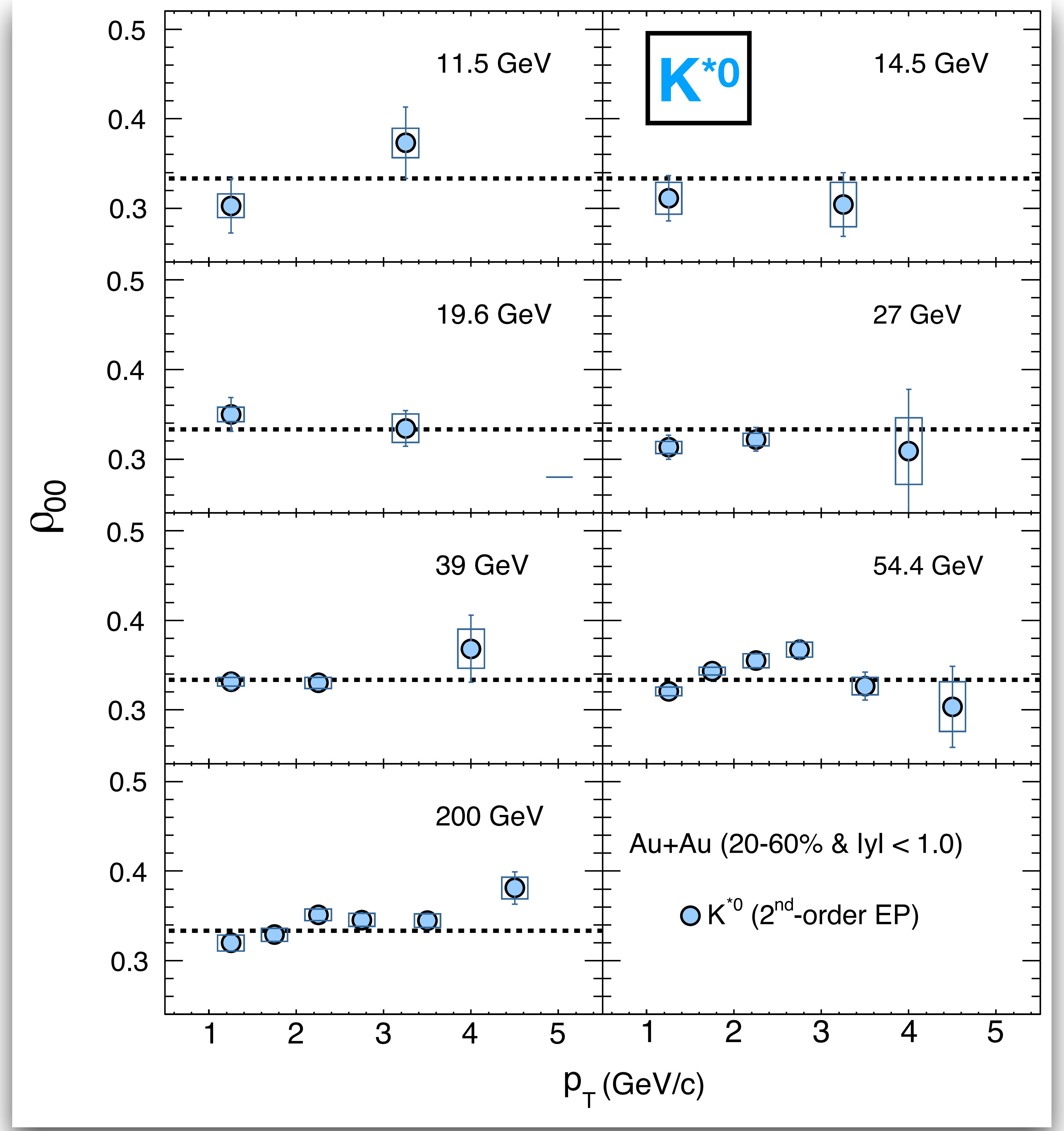
ALICE: Phys. Rev. Lett. 125, 012301 (2020)
STAR: arXiv: 2204.02302

Sheng el. al., Phys Rev D 101, 096005 (2020)
Sheng el. al., Phys Rev D 102, 056013 (2020)

ρ_{00} (p_T): ϕ and K^{*0} from RHIC BES-I

STAR: arXiv: 2204.02302

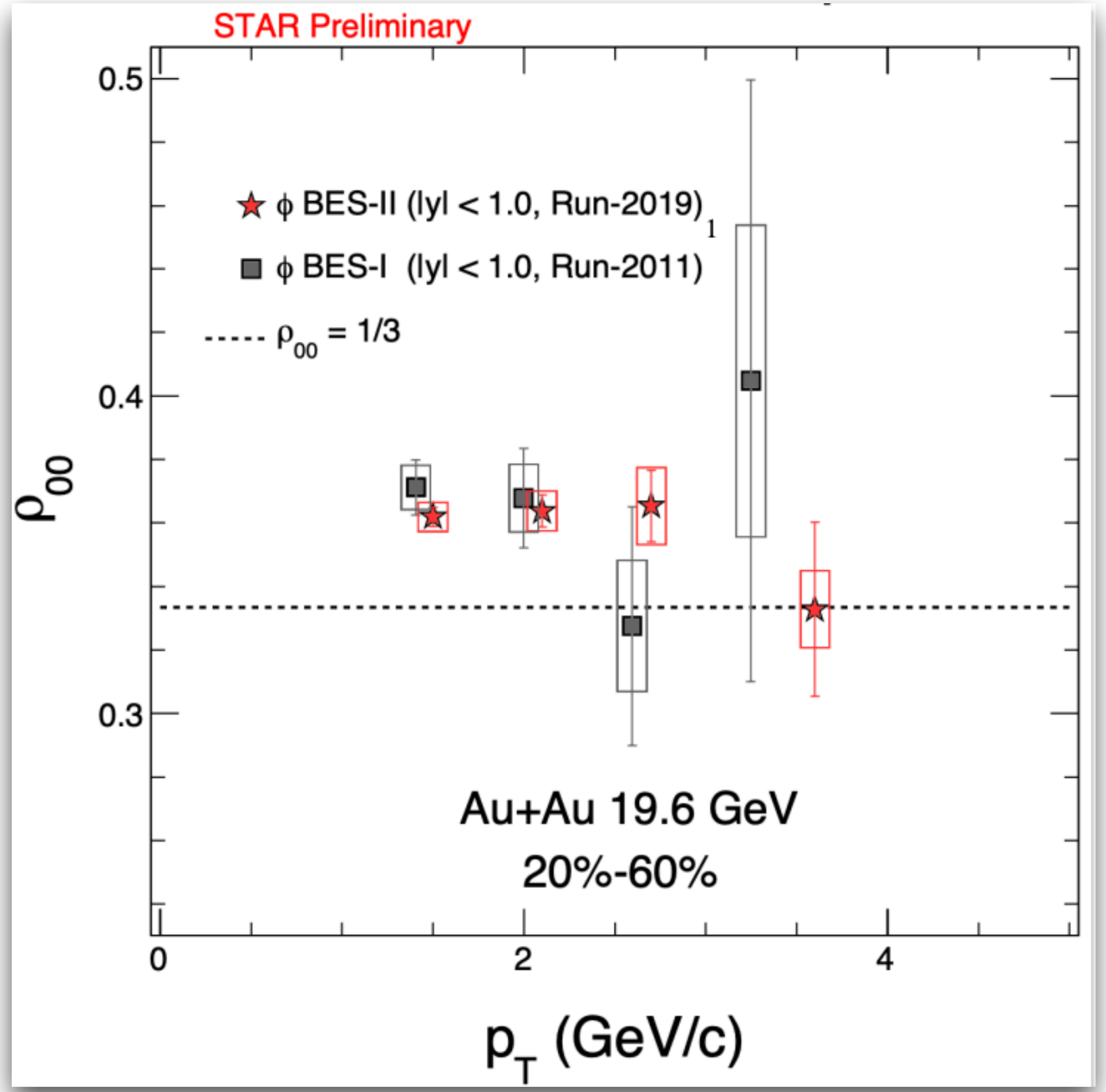




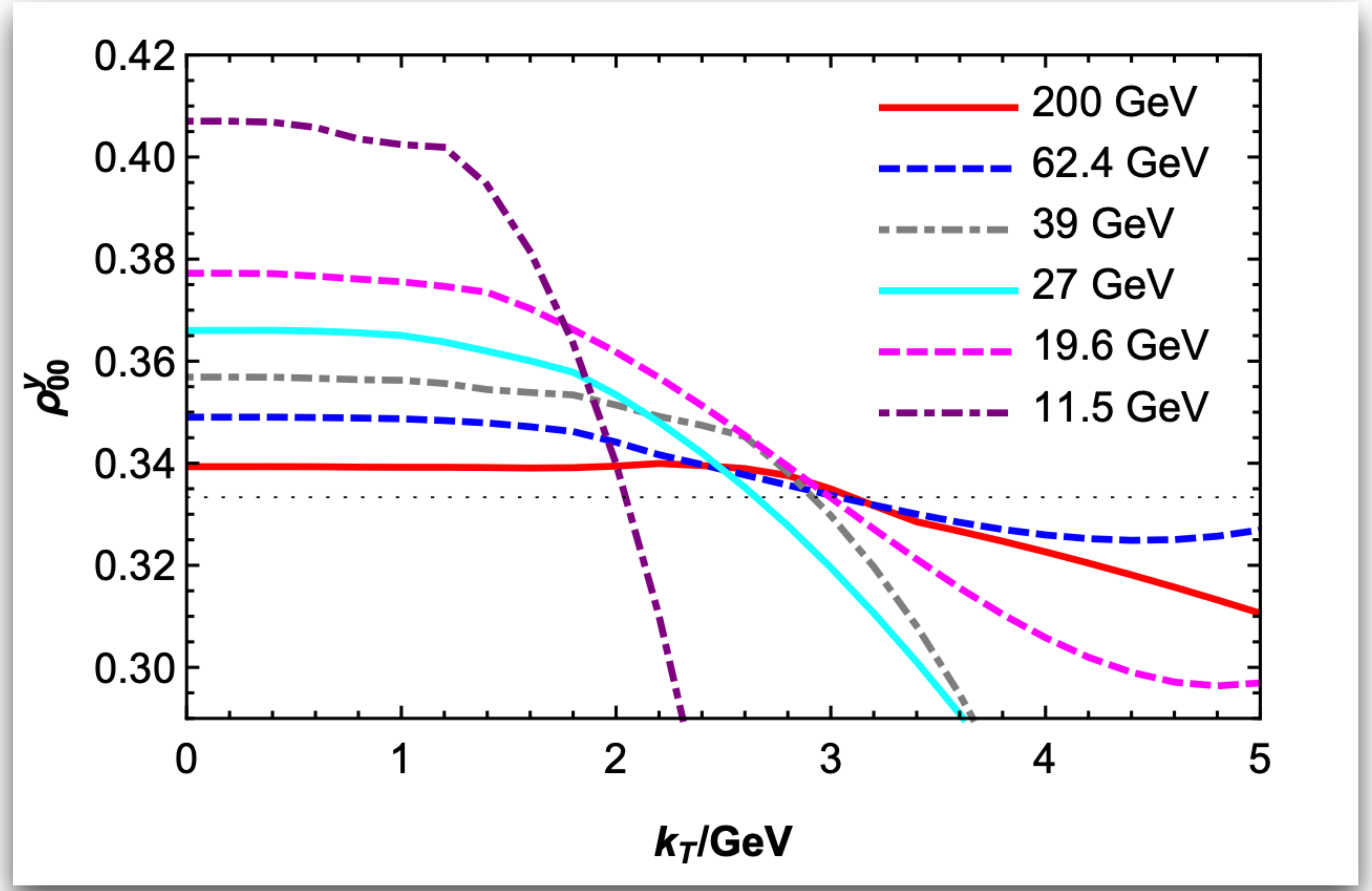
- For 20-60%: non-trivial p_T dependence

ρ_{00} (p_T): ϕ meson from RHIC BES-II

Talk-(Bulk,14/06)
Gavin Wilks (STAR)



Expectation from model with vector meson force field



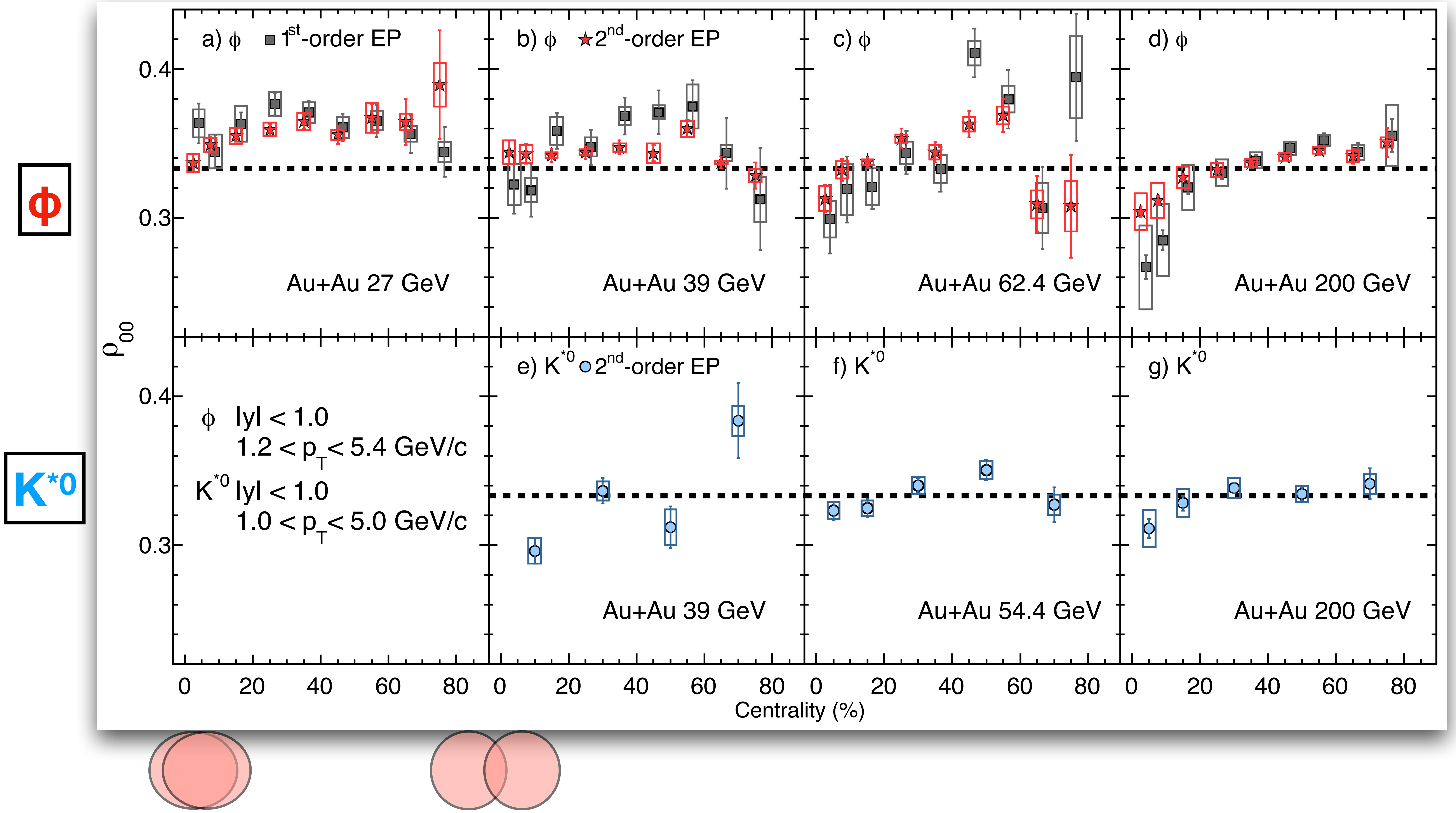
Sheng el. al., arXiv: 2205.15689
Sheng el. al., Phys Rev D 101, 096005 (2020)
Sheng el. al., Phys Rev D 102, 056013 (2020)

- BES-I: ϕ ρ_{00} = 0.3622 ± 0.0026 (stat.) ± 0.0049 (sys.)
- BES-II: ϕ ρ_{00} = 0.370 ± 0.008 (stat.) ± 0.007 (sys.)

  ~ 5.3 σ

ρ_{00} (centrality): φ and K^{*0} from RHIC BES-I

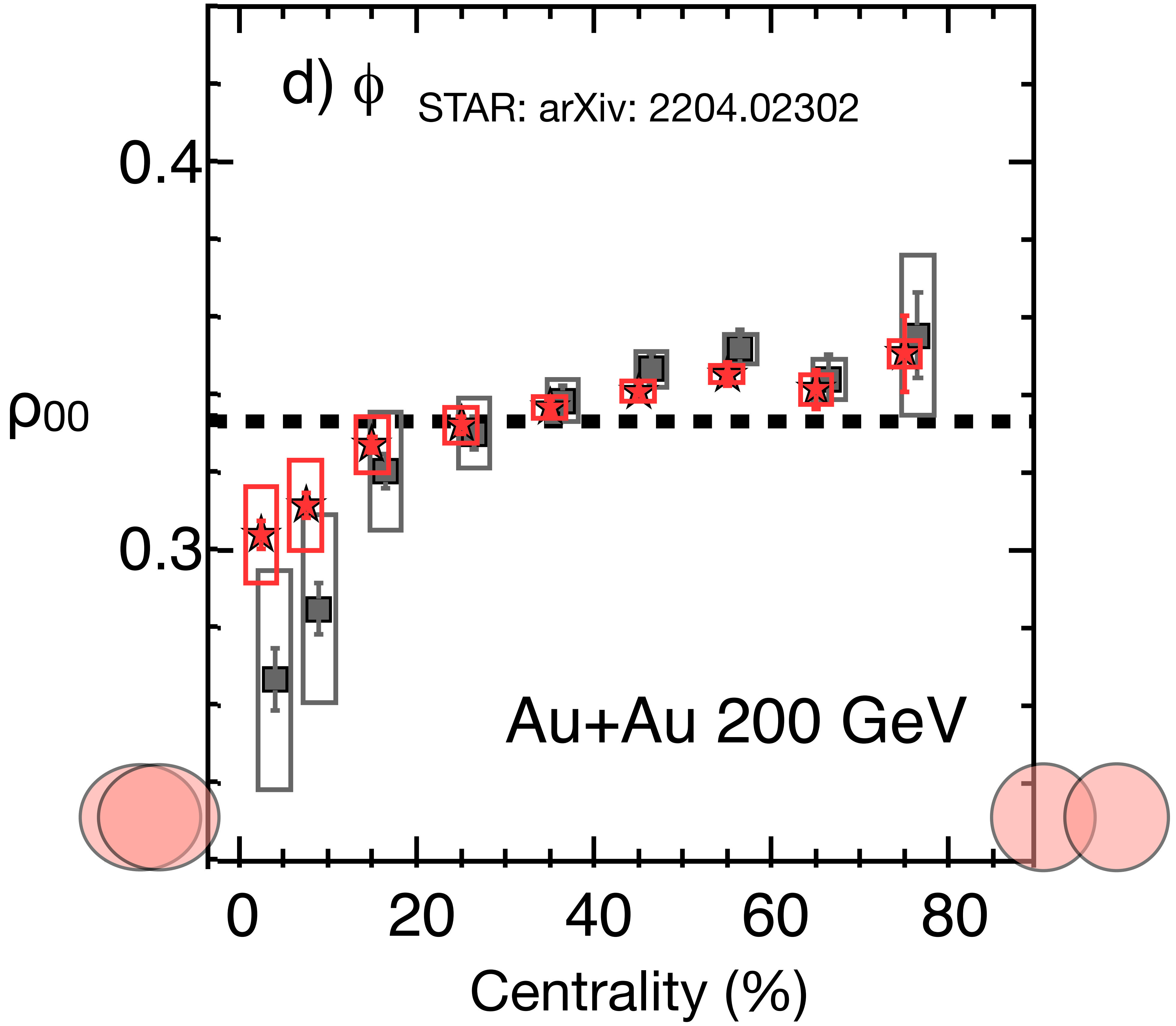
STAR: arXiv: 2204.02302



- **For central at 200 GeV:**
  - φ, K^{*0} $\rho_{00} < 1/3$
    Local spin alignment[1]
    or, helicity contribution[2]
- **For mid-central and peripheral:**
  - φ, K^{*0} ρ_{00} >~ 1/3

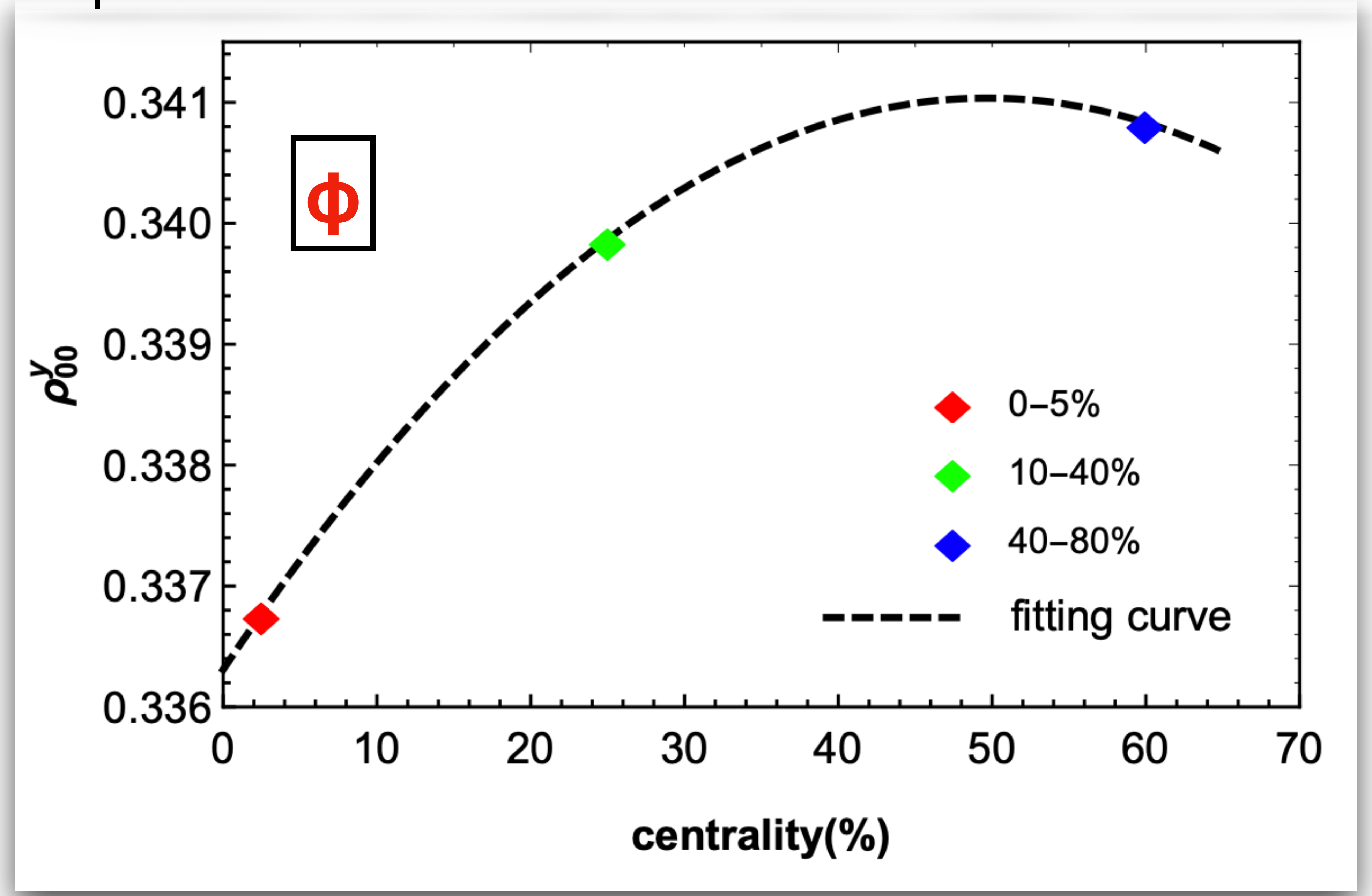
[1]. Xia et al, Phys Lett B 817, 136325 (2021)
[2]. Gao, Phys Rev D 104, 076016 (2021)

ρ_{00} (centrality): φ from RHIC BES-I



Is the contribution from local spin alignment dominant in central collisions and at higher energies?

Expectation from model with vector meson force field



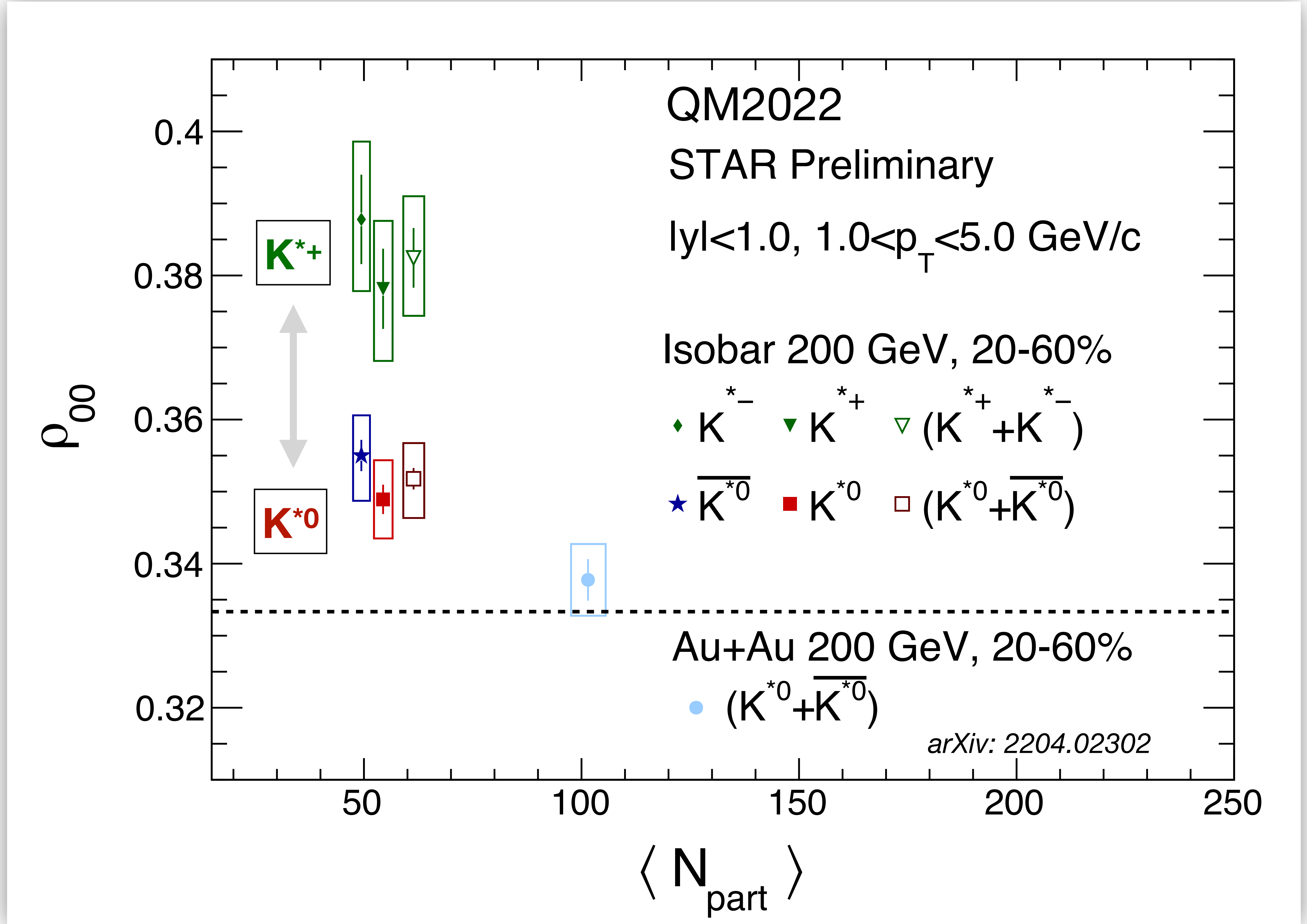
Can accommodate positive deviation in mid-central and peripheral collisions

Sheng el. al., arXiv: 2205.15689
Sheng el. al., Phys Rev D 101, 096005 (2020)
Sheng el. al., Phys Rev D 102, 056013 (2020)

- Need measurements of local spin alignment at RHIC and LHC

Xia et., al., Phys Lett B 817, 136325 (2021)

Charged K* ρ_{00} at RHIC Isobar collisions



$$\rho_{00}(B) \approx \frac{1}{3} - \frac{4}{9}\beta^2 \mu_{q_1}\mu_{q_2} B^2$$

Yang, et. al.,
Phys Rev C 97, 034917 (2018)

- K^{*0} vs. $K^{*+/-}$
  - Ordering opposite to the naive expectation from **B** field
  - What is the origin of different ρ_{00} ?

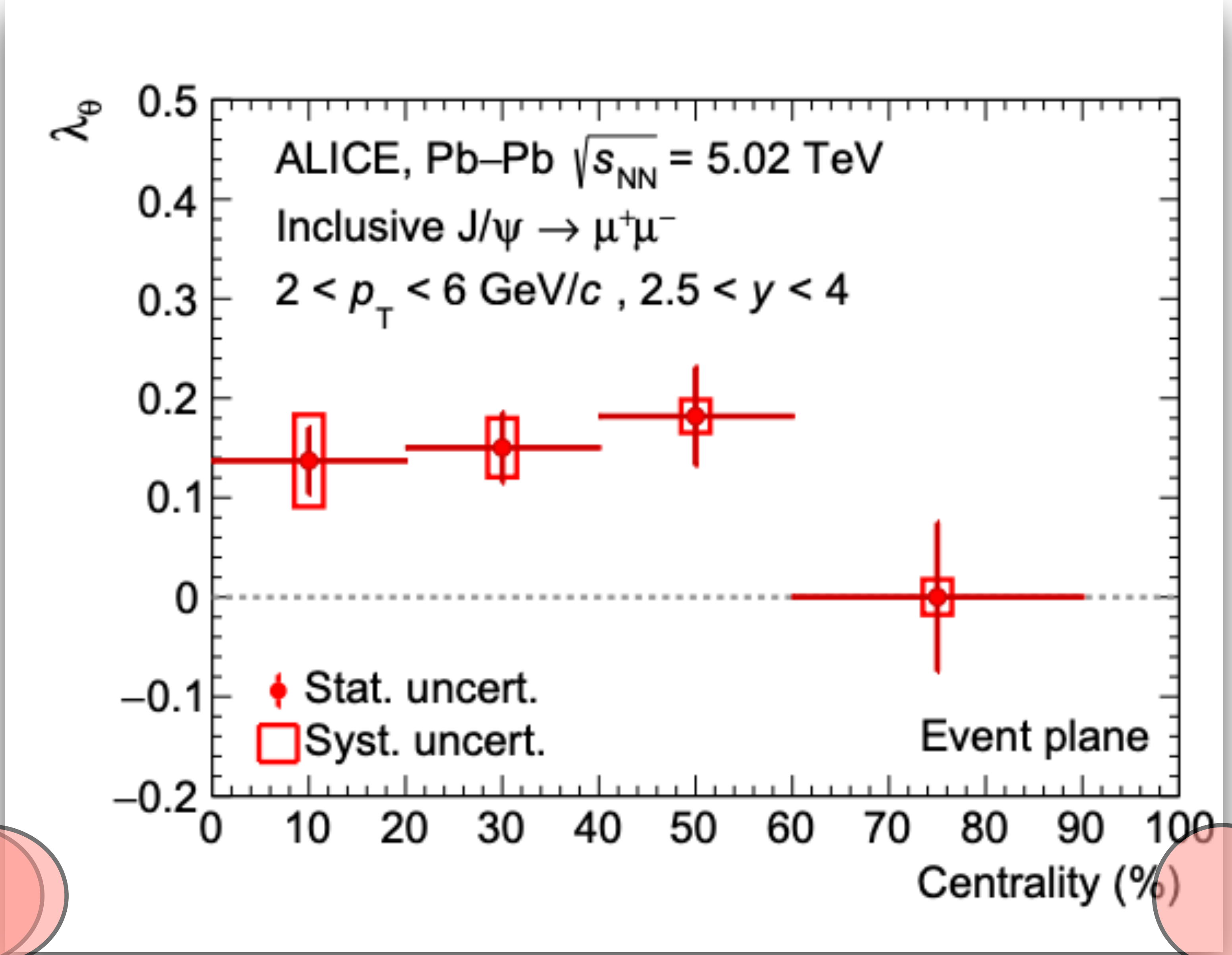
Particle Species	Magnetic moment
$K^{*0}(d\bar{s})$	$\mu_d \approx -0.97,\ \mu_{\bar{s}} \approx 0.61\mu_N$
$K^{*+}(u\bar{s})$	$\mu_u \approx 1.85,\ \mu_{\bar{s}} \approx 0.61\mu_N$

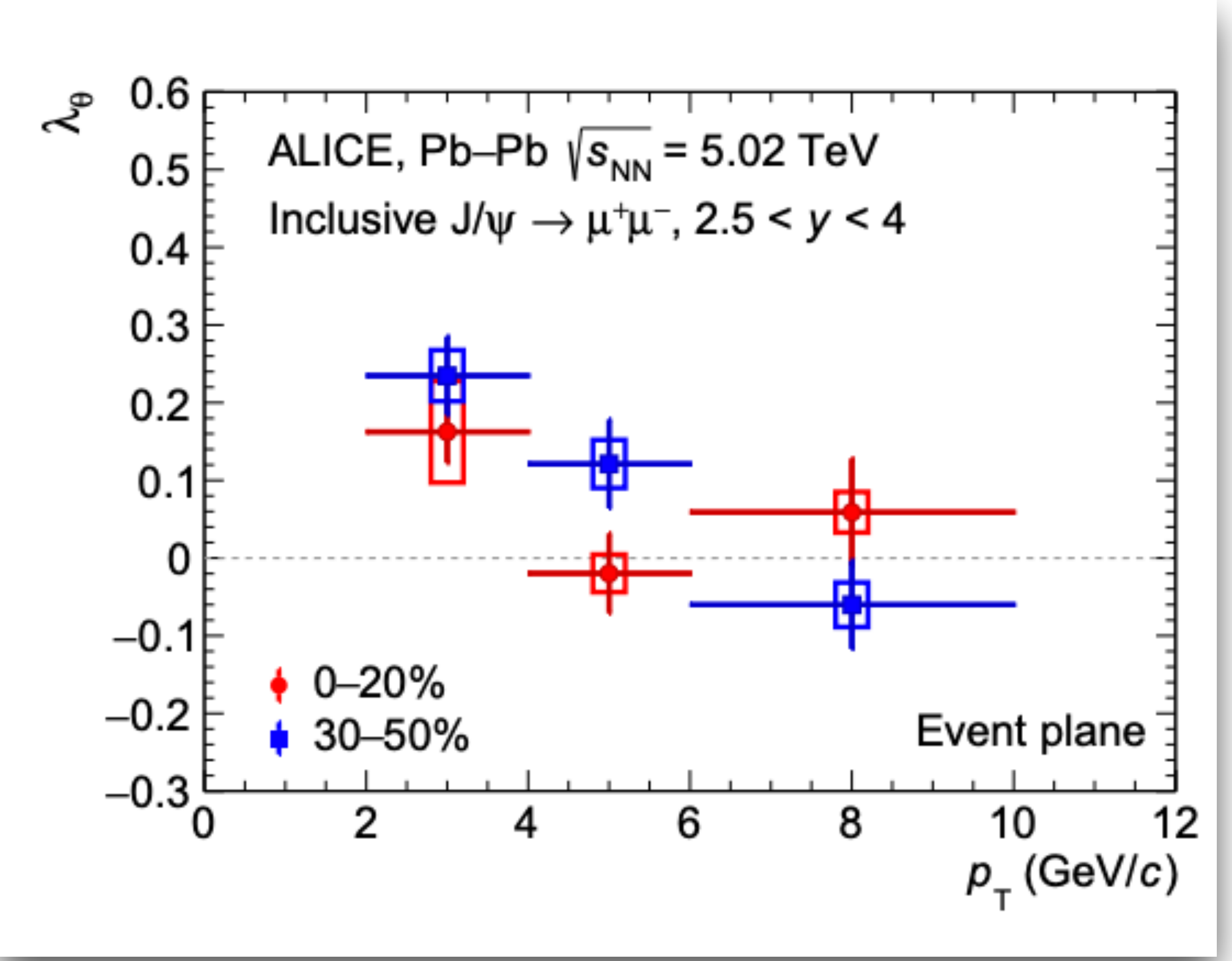
- Need inputs from theory

ρ_{00} (centrality, p_T): J/Ψ at LHC

ALICE: arxiv 2204.10171

Talk-(HF,14/06)
Xiaozhi Bai (ALICE)





First observation of global spin alignment of J/Ψ at LHC

- $J/\psi : \lambda_\theta \sim 0.2, \rho_{00} \sim 0.37\ (> \frac{1}{3})$ $\qquad \lambda_\theta \propto \frac{3\rho_{00} - 1}{1 - \rho_{00}}$
- $K^{*0}\ \rho_{00} \sim -0.2,\ \ \phi\ \rho_{00} \sim -0.1\ \ (< \frac{1}{3})$

Note: Kinematic ranges of above measurements are different

- What is the origin of different sign of ρ_{00} ?

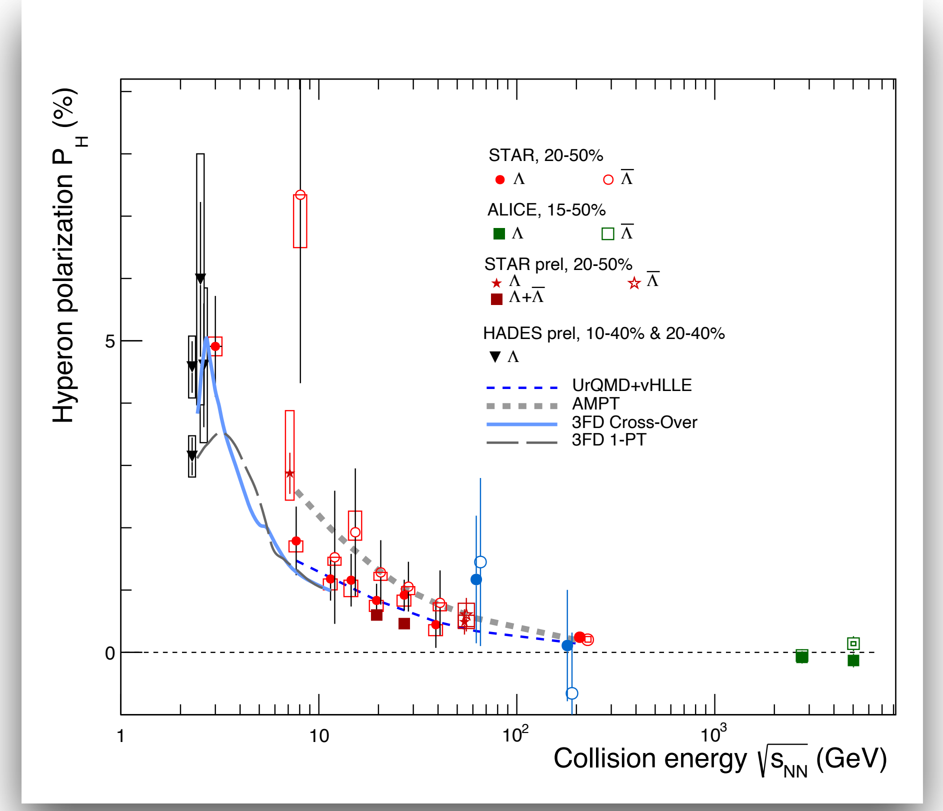
- J/Ψ ρ_{00} from mid-rapidity?
- Need inputs from theory

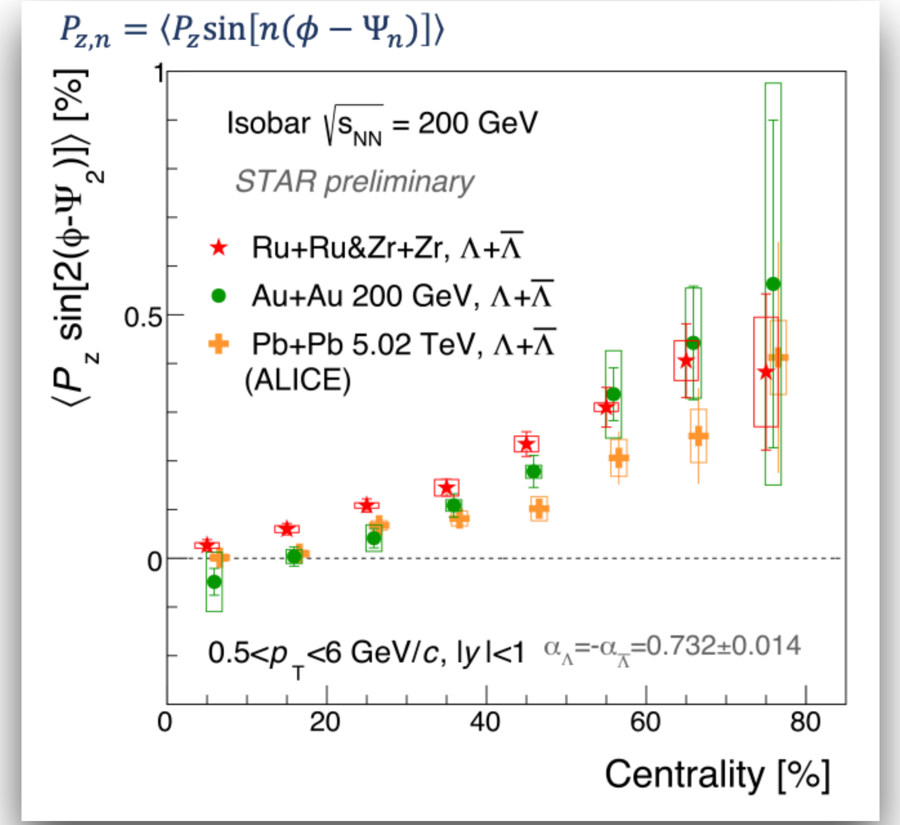
Summary

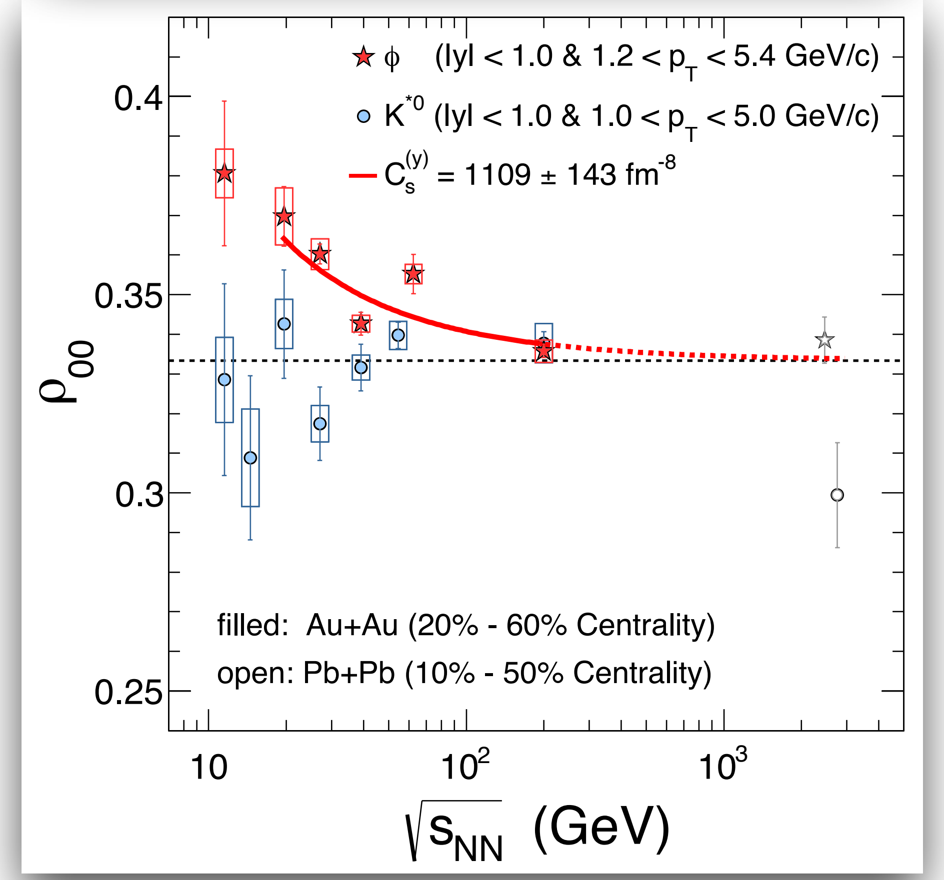
- **<u>Global spin polarization:</u>**
- Global nature of hyperon spin polarization is established
- High energy: More precise and differential measurement (p_T, rapidity, centrality) will help constrain models
- Low energy: Where do we observe vanishing polarization?

- **<u>Local spin polarization:</u>**
- Interesting and precise measurements from RHIC to LHC
- Provide information on vortical structure; constraint on initial conditions, transport parameters; drive development of new phenomena (SIP, SHE), spin hydrodynamics, spin kinetic theories …

- **<u>Vector meson spin alignment:</u>**
- Surprising (and puzzling!) signal of spin alignment from RHIC and LHC
- Need more inputs from theory for better understanding of the data



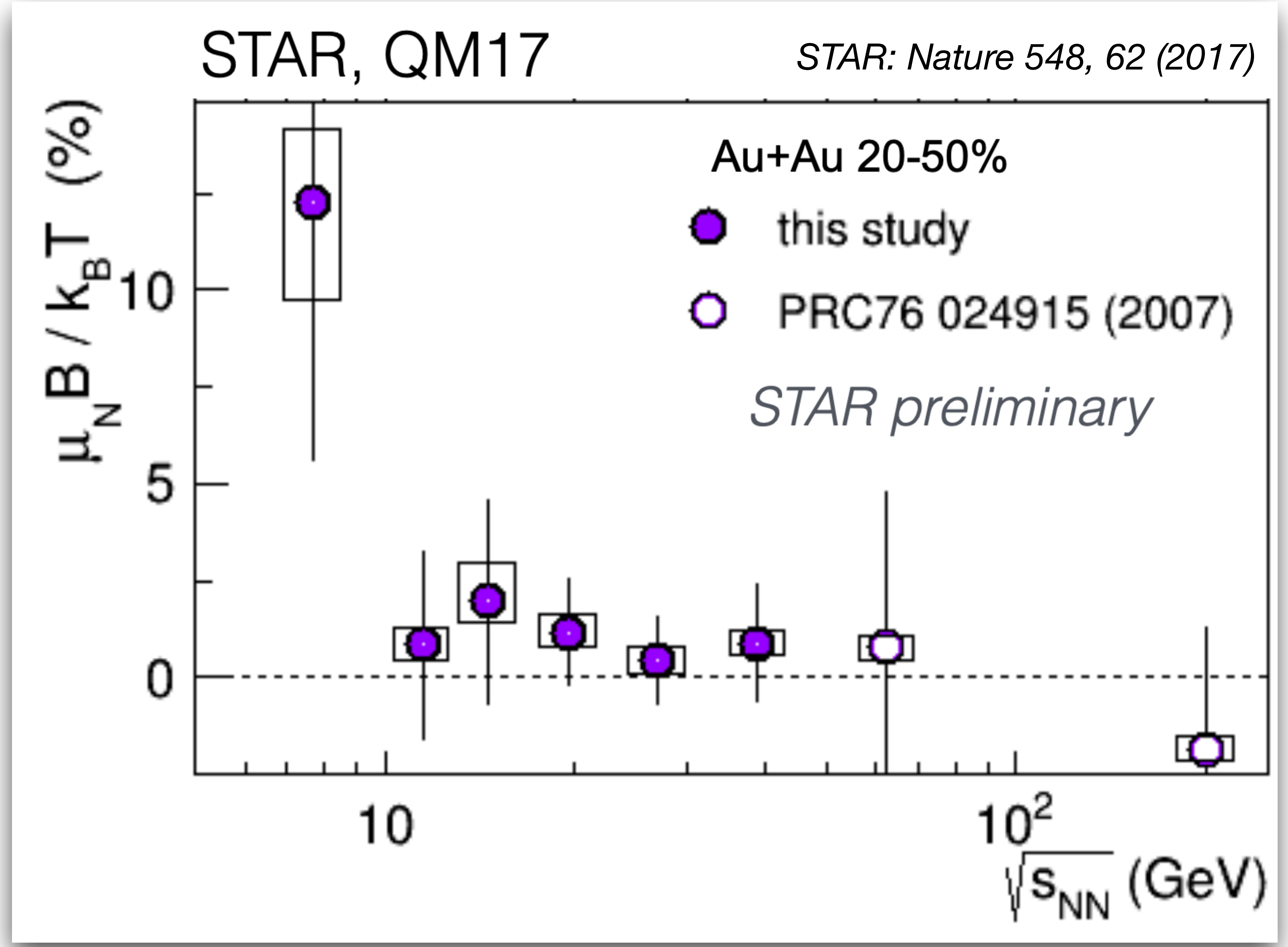




Subhash Singha @ SQM 2022

Thank you for your attention

Possible constraint on B field by P_Λ



Hints of difference between Λ and anti-Λ
(Effect from initial B field ?)**

- Upcoming BES-II data will provide better precision

- Magnetic field

$$B = \frac{T}{2\mu_\Lambda}(P_\Lambda - P_{\bar{\Lambda}})$$

$$B \sim 10^{-2}\, m_\pi^2$$

$\Delta P_\Lambda = 0.5\%$

T=160 MeV

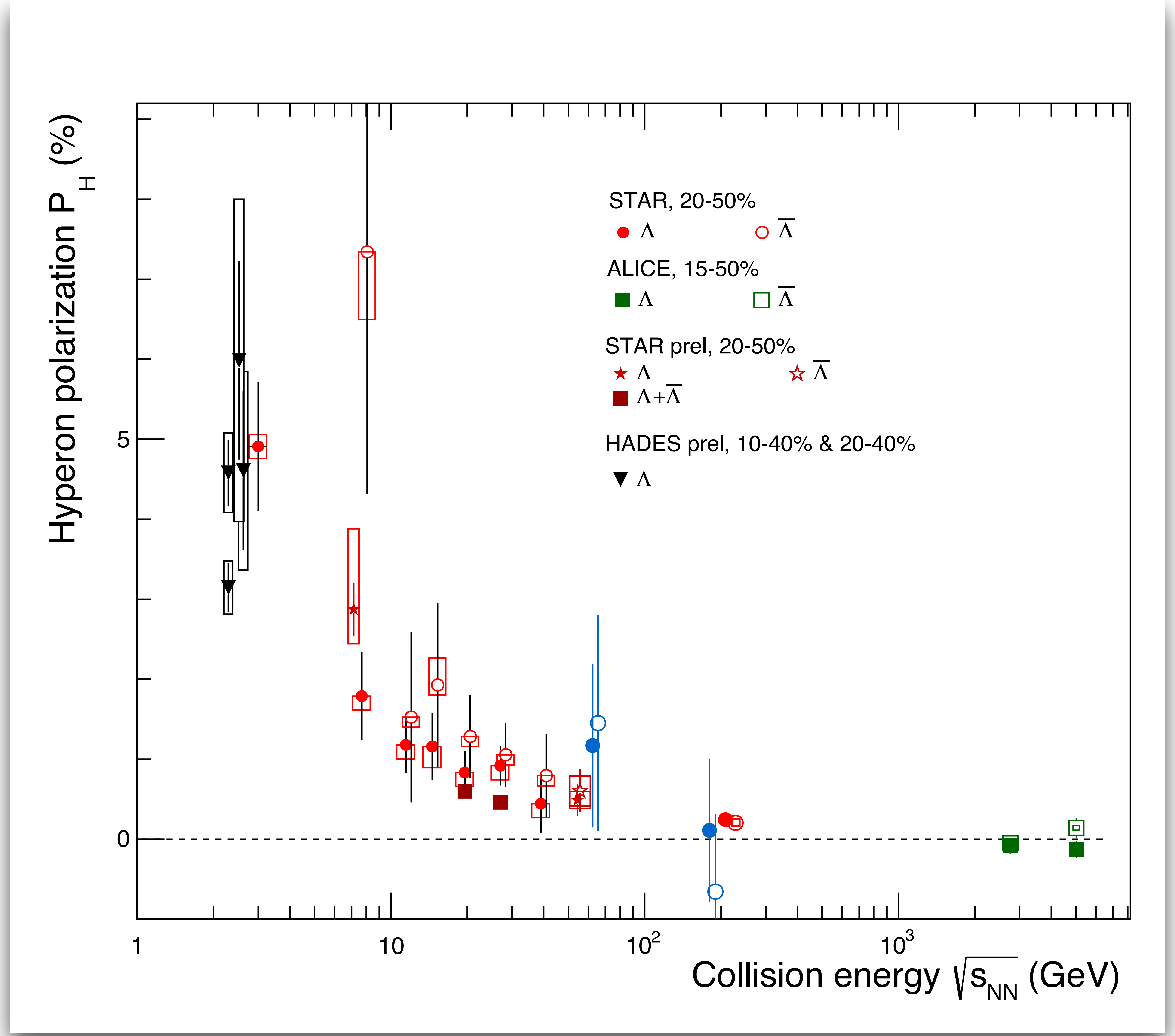
Becattini, et. al., Phys Rev C 95, 054902 (2017)

** Difference between Λ and anti-Λ can also be caused by

- Different freeze out for particles and anti-particles
- Different response to mesonic field generated by baryonic current
- .....

Vituik, et. al., Phys Lett B 803, 135298 (2020)
Csernai et al, Phys Rev C 99, 021901 (2019)

Beam energy dependence of global P_Λ



STAR

Au+Au Collider $\sqrt{s_{NN}}$ = 7.7-200 GeV

Au+Au Fixed Target $\sqrt{s_{NN}}$ = 3.0 GeV

STAR Preliminary

Au+Au Collider $\sqrt{s_{NN}}$ = 19.6, 27, 54.4 GeV

Au+Au Fixed Target $\sqrt{s_{NN}}$ = 7.2 GeV

ALICE

Pb+Pb $\sqrt{s_{NN}}$ = 2.76, 5.02 TeV

HADES Preliminary, QM 2022

Au+Au $\sqrt{s_{NN}}$ = 2.4 GeV

Ag+Ag $\sqrt{s_{NN}}$ = 2.55 GeV

STAR:

Phys Rev C 76, 024915 (2007)

Nature 548, 62 (2017)

Phys Rev C 101, 044611 (2020)

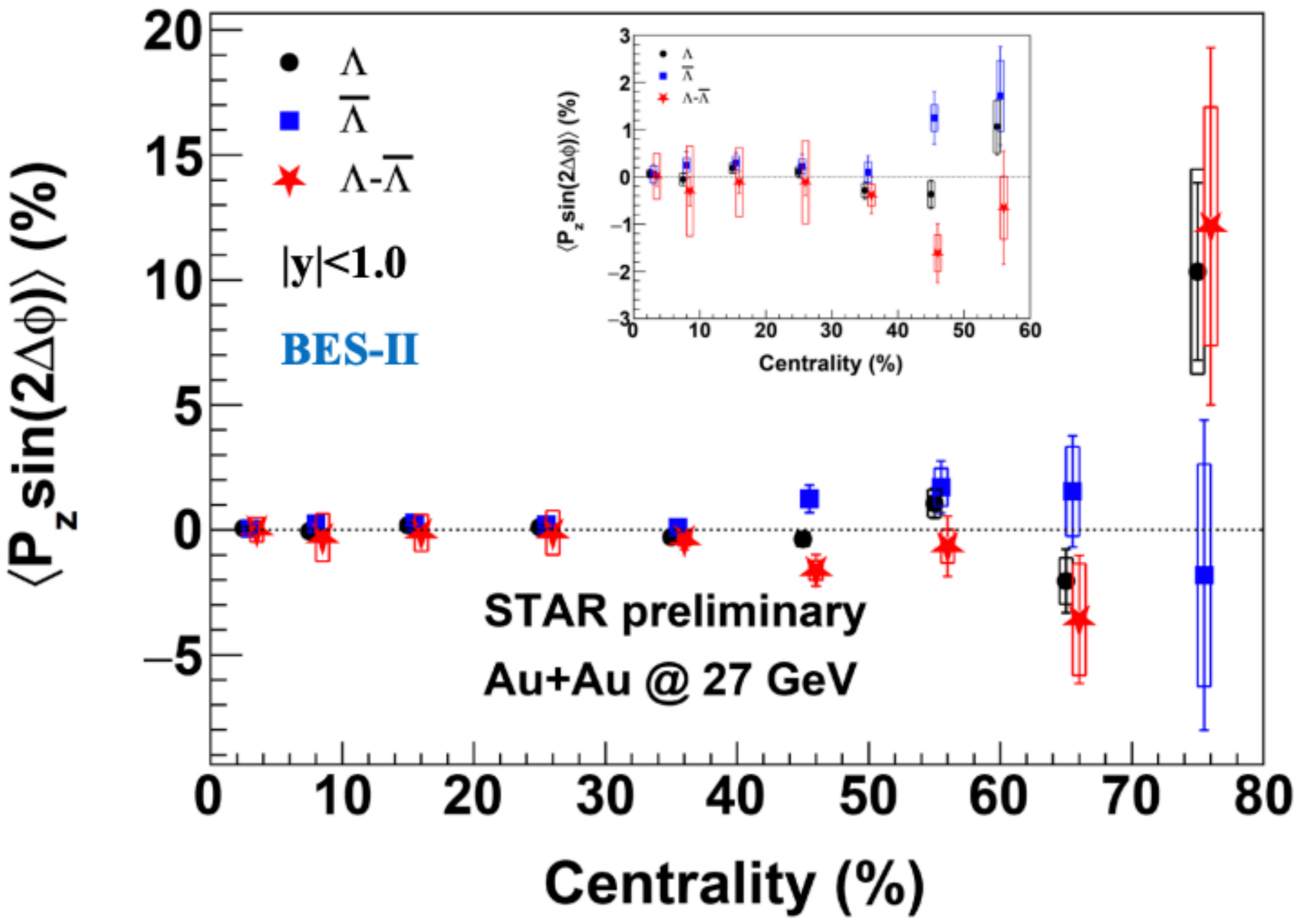
Phys Rev C 104, 061901 (2021)

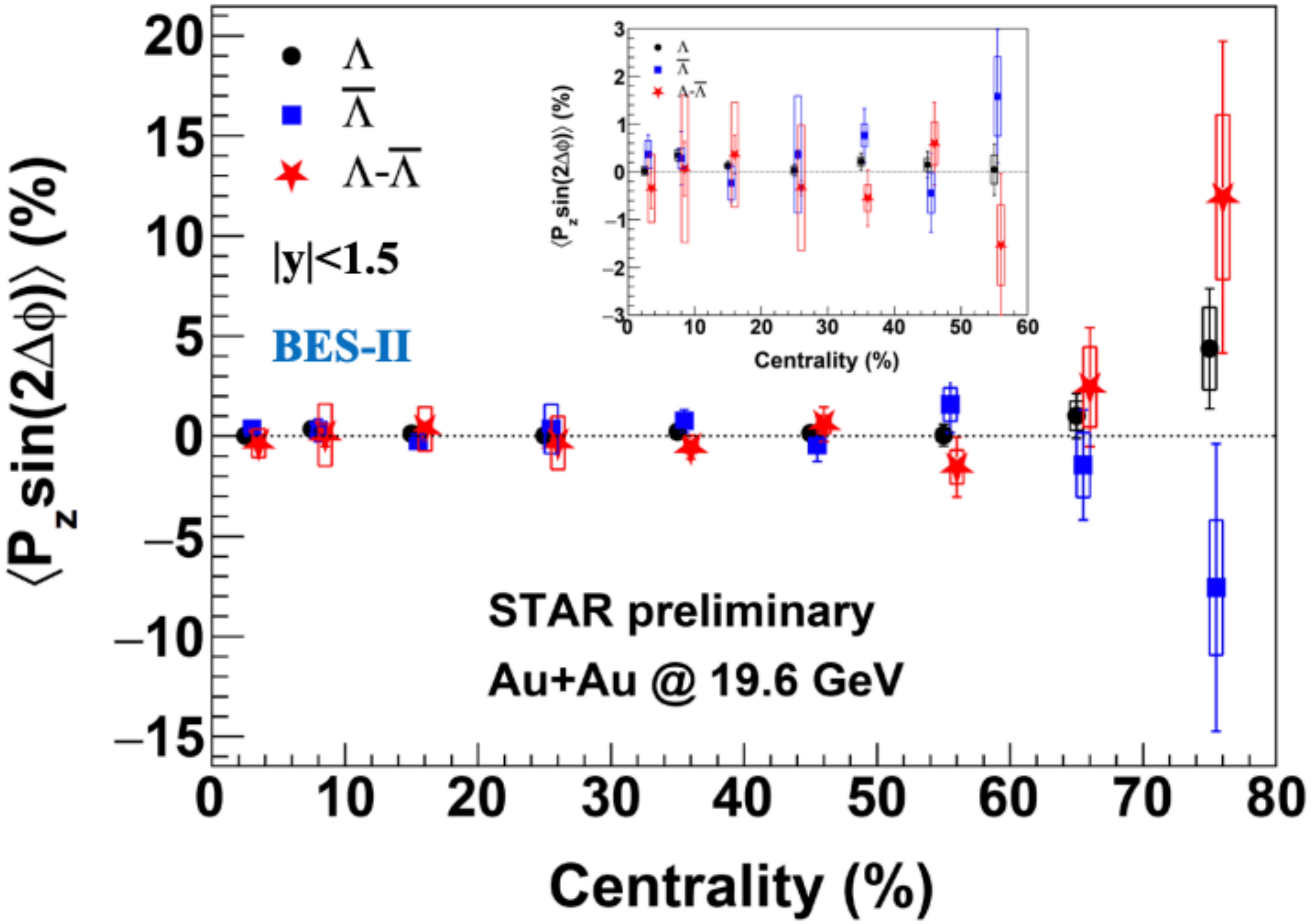
ALICE:

Phys Rev C 101, 044611 (2020)

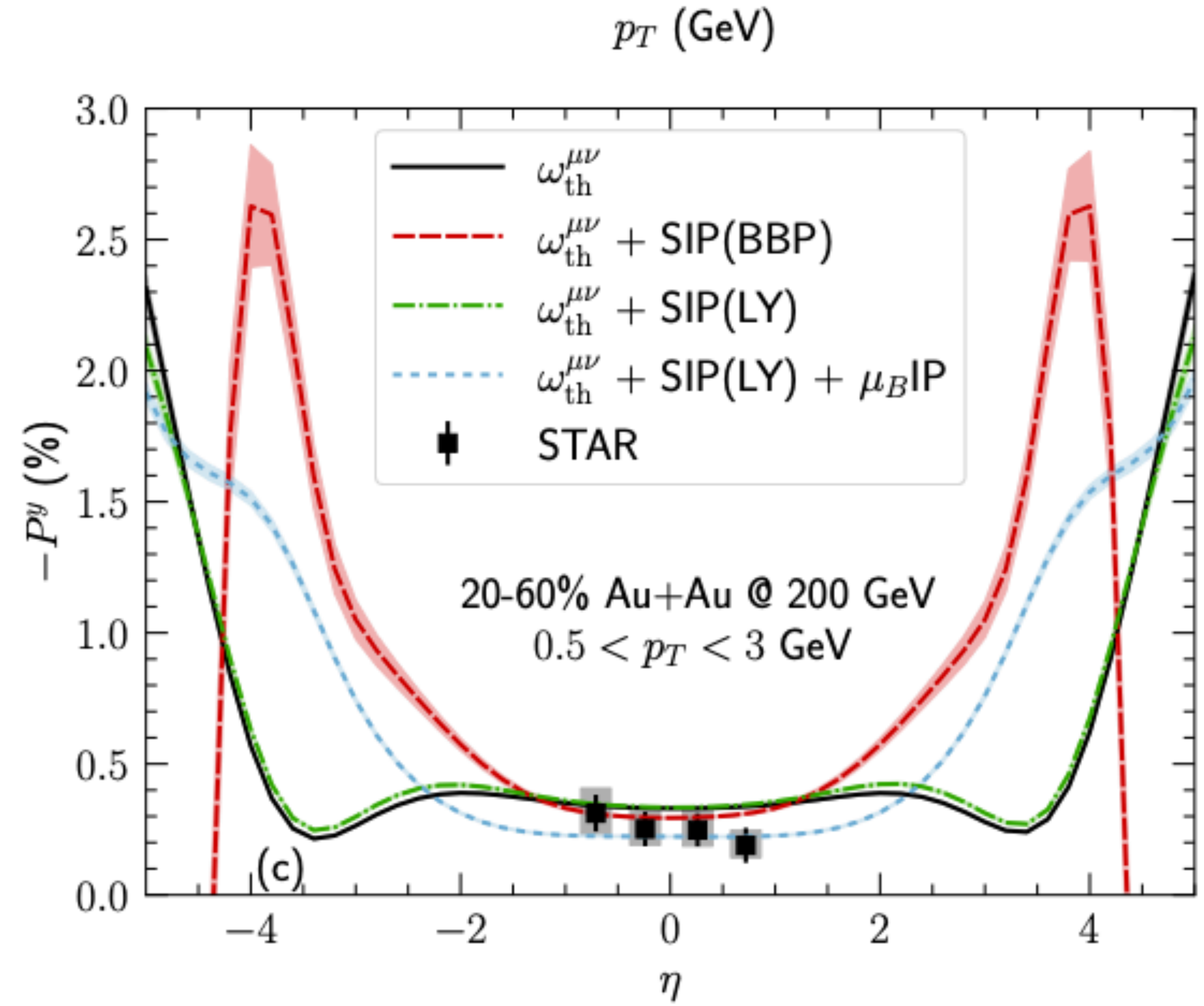
Energy dependence of P_z

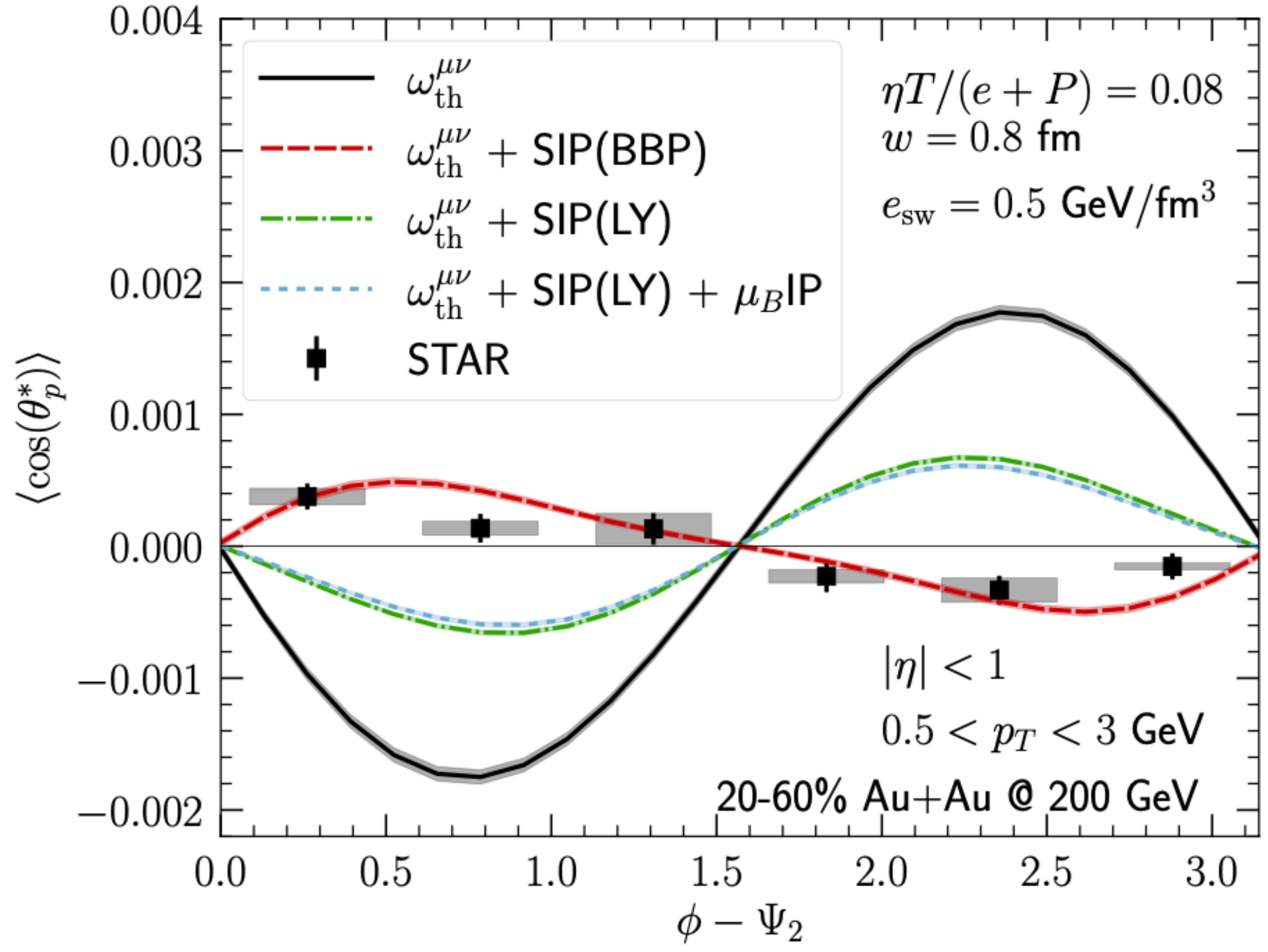
Poster-(Bulk,14/06)
Qiang Hu (STAR)





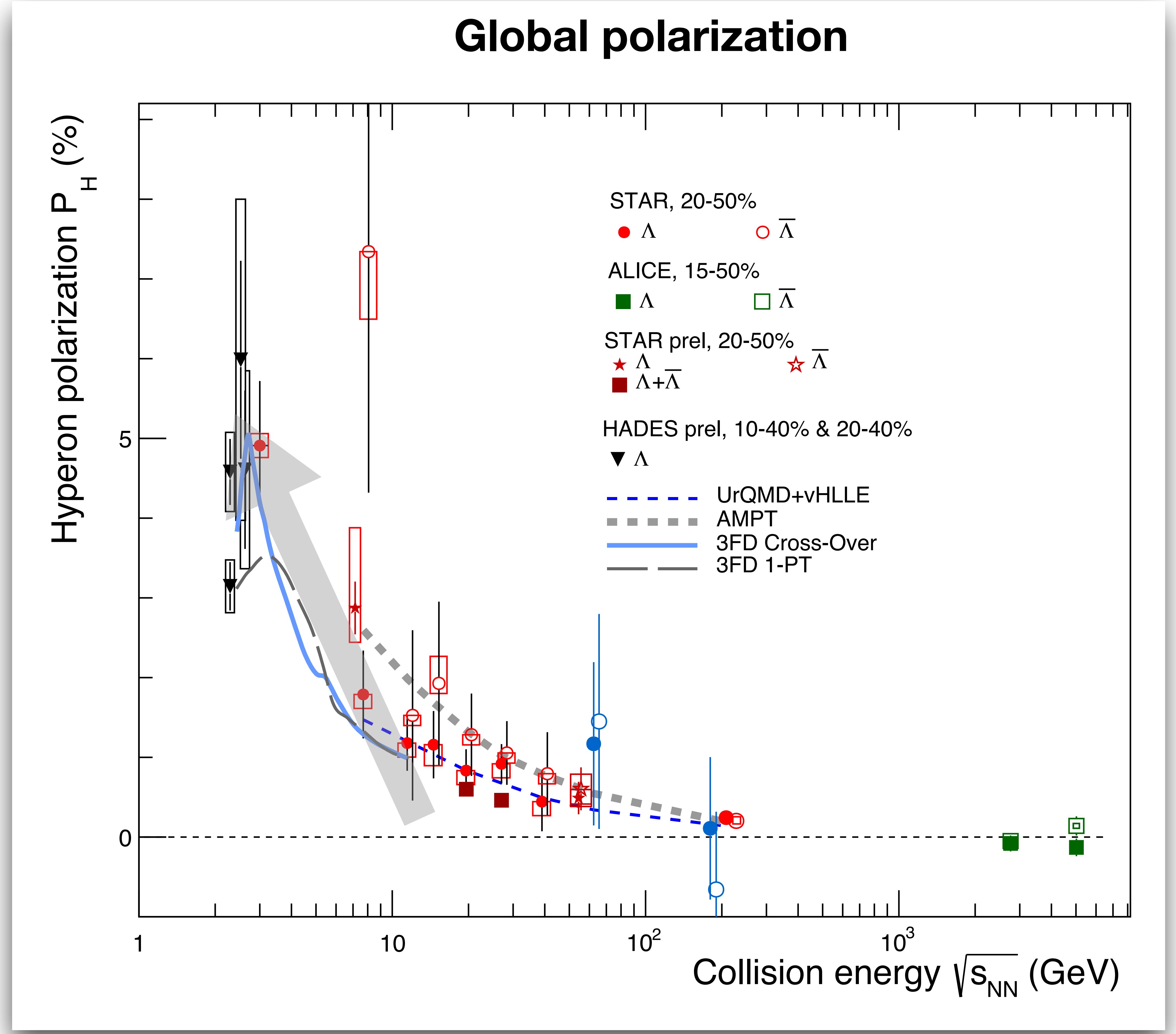
Local spin polarization

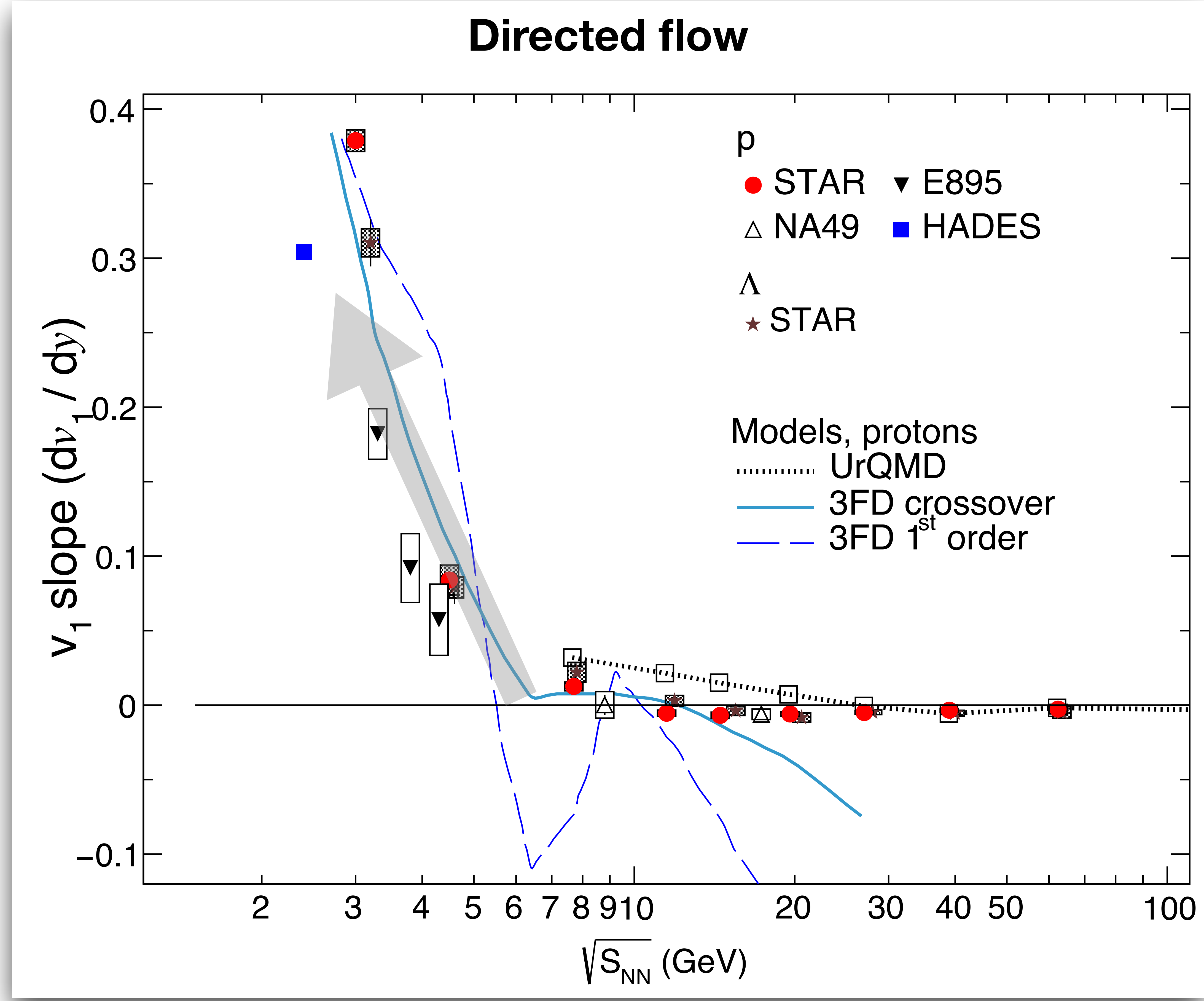




Alzhrani et. al., arXiv: 2203.15718

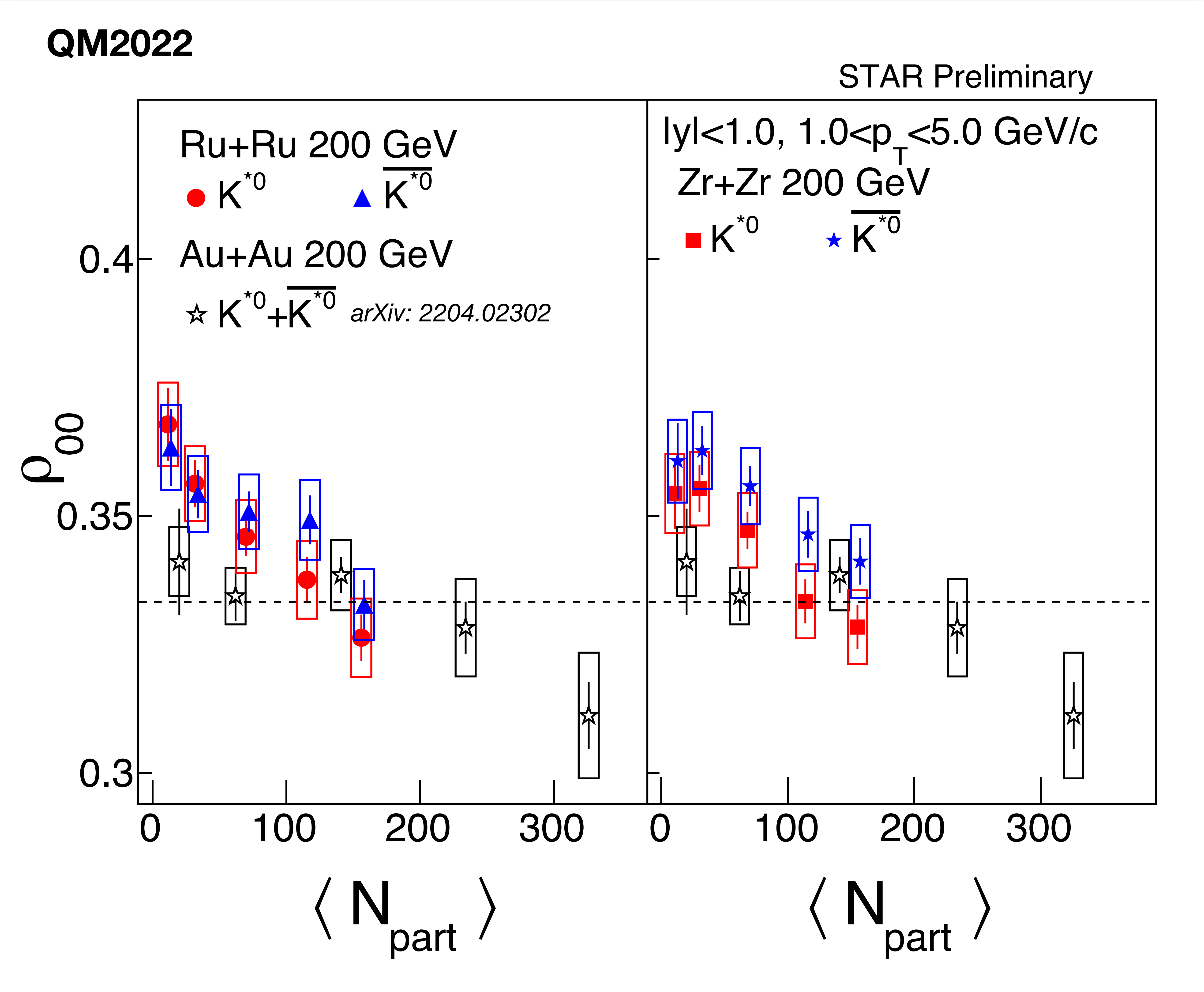
Beam energy dependence of global P_Λ





- Similar rising pattern in polarization and directed flow at low energy
- Some models can capture such rising trend in both P_H and v_1

ρ_{00} (Centrality): K^{*0} and anti-K^{*0} from isobar



- Species dependence:
  - K^{*0} ρ_{00} ~ anti-K^{*0} ρ_{00}
- System size dependence:
  - ρ_{00} Au+Au ~ Zr+Zr ~ Ru+Ru

ρ_{00} ($\sqrt{s_{NN}}$): ϕ and K^{*0} for central collisions from BES-I

STAR, arXiv: 2204.02302