Global polarization of hyperons from STAR experiment

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Important features in non-central heavy-ion collisions

Strong magnetic field

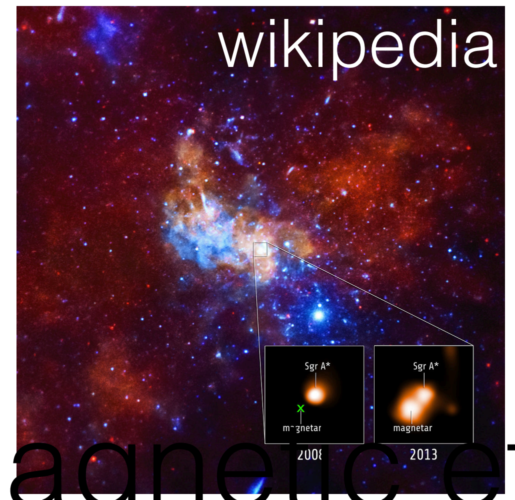
$$B \sim 10^{13}\ \mathrm{T}$$

$$(eB \sim m_\pi^2\ (\tau \sim 0.2\ \mathrm{fm}))$$

D. Kharzeev, L. McLerran, and H. Warringa, Nucl.Phys.A803, 227 (2008)
McLerran and Skokov, Nucl. Phys. A929, 184 (2014)

typical magnet

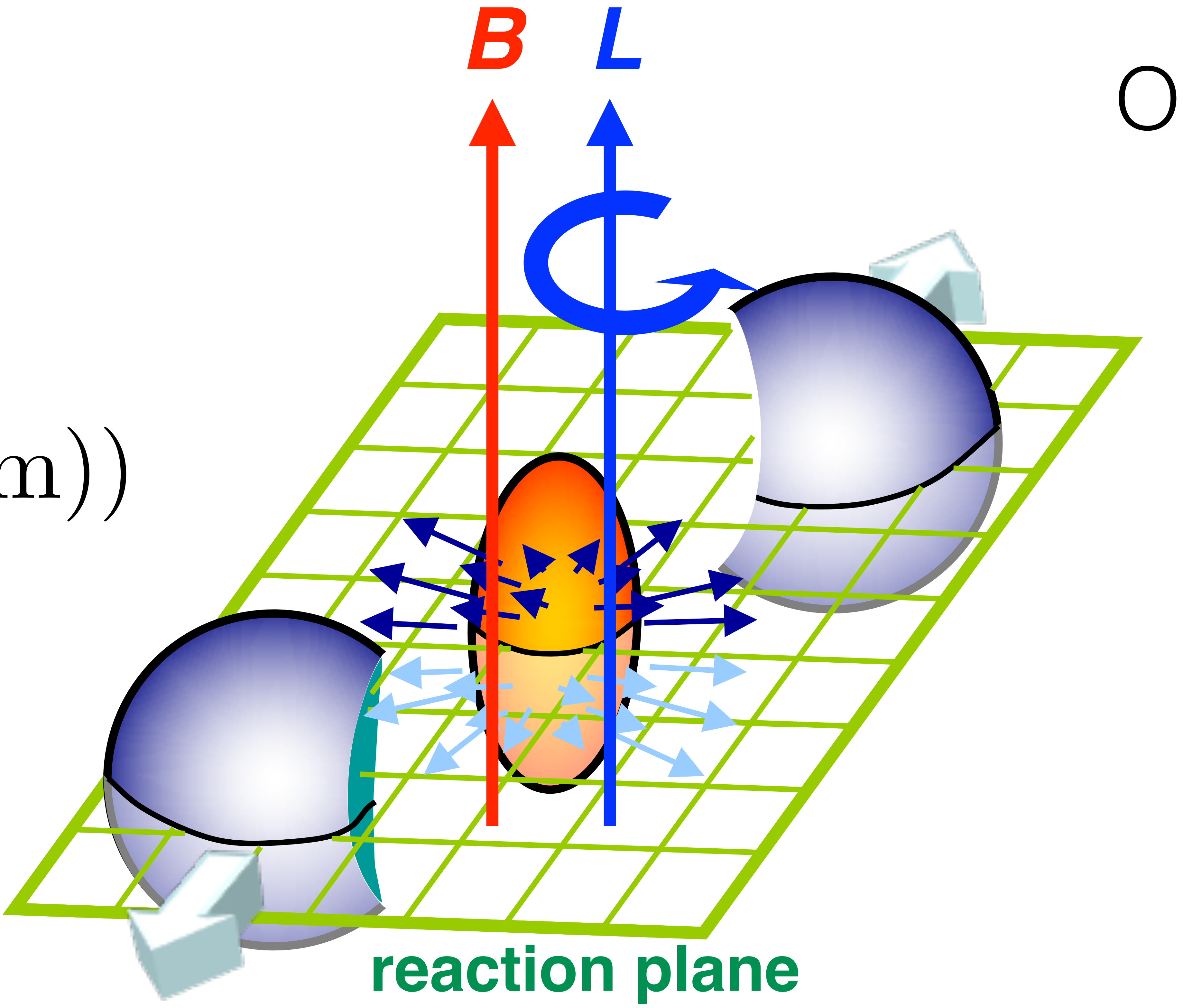
$B \sim 0.1 - 0.5\ \mathrm{T}$



magnetar

$B \sim 10^{11}\ \mathrm{T}$

→Chiral magnetic effect/wave
→**Particle polarization**



Orbital angular momentum

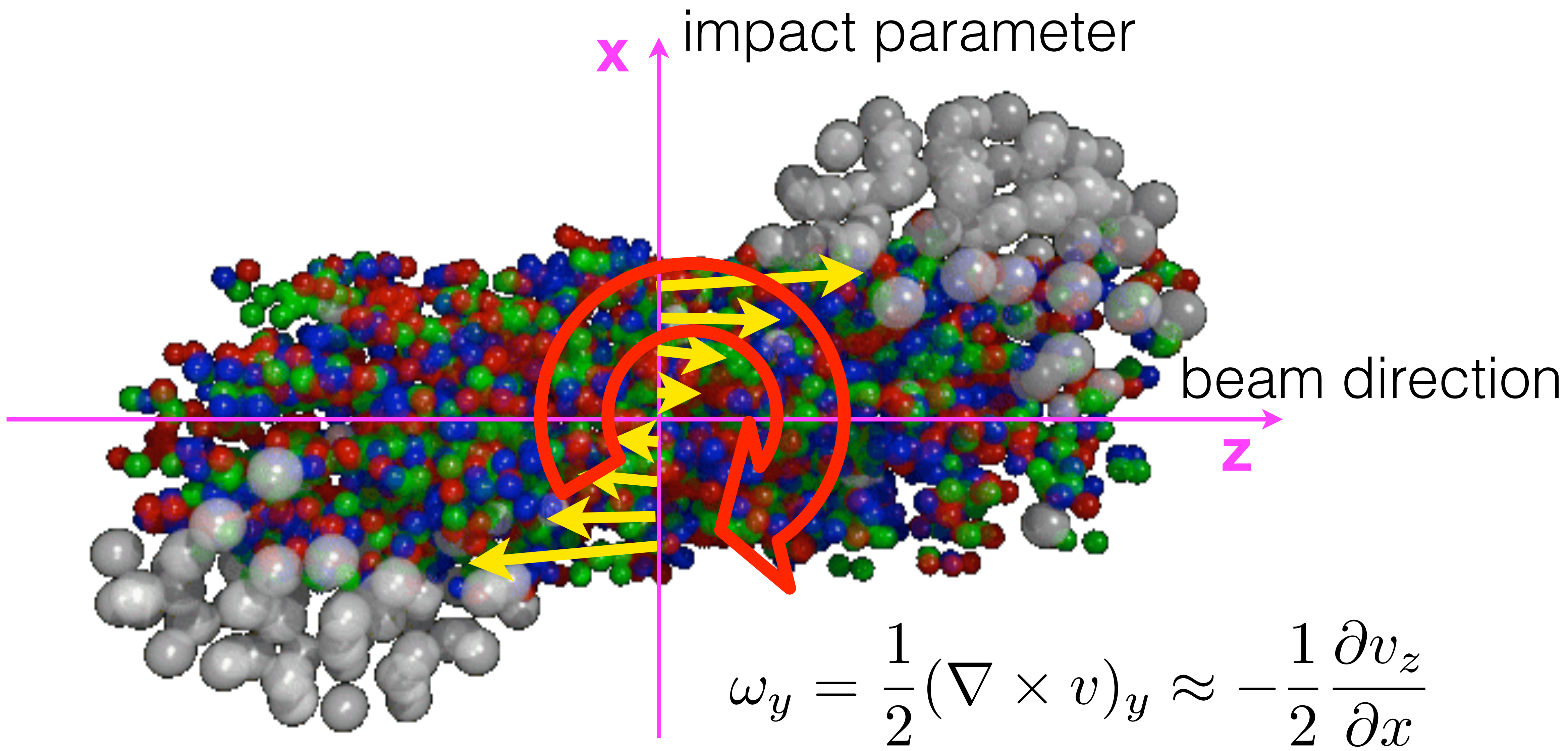
$$\mathbf{L} = \mathbf{r} \times \mathbf{p}$$

$$\sim bA\sqrt{s_{NN}} \sim 10^6 \hbar$$

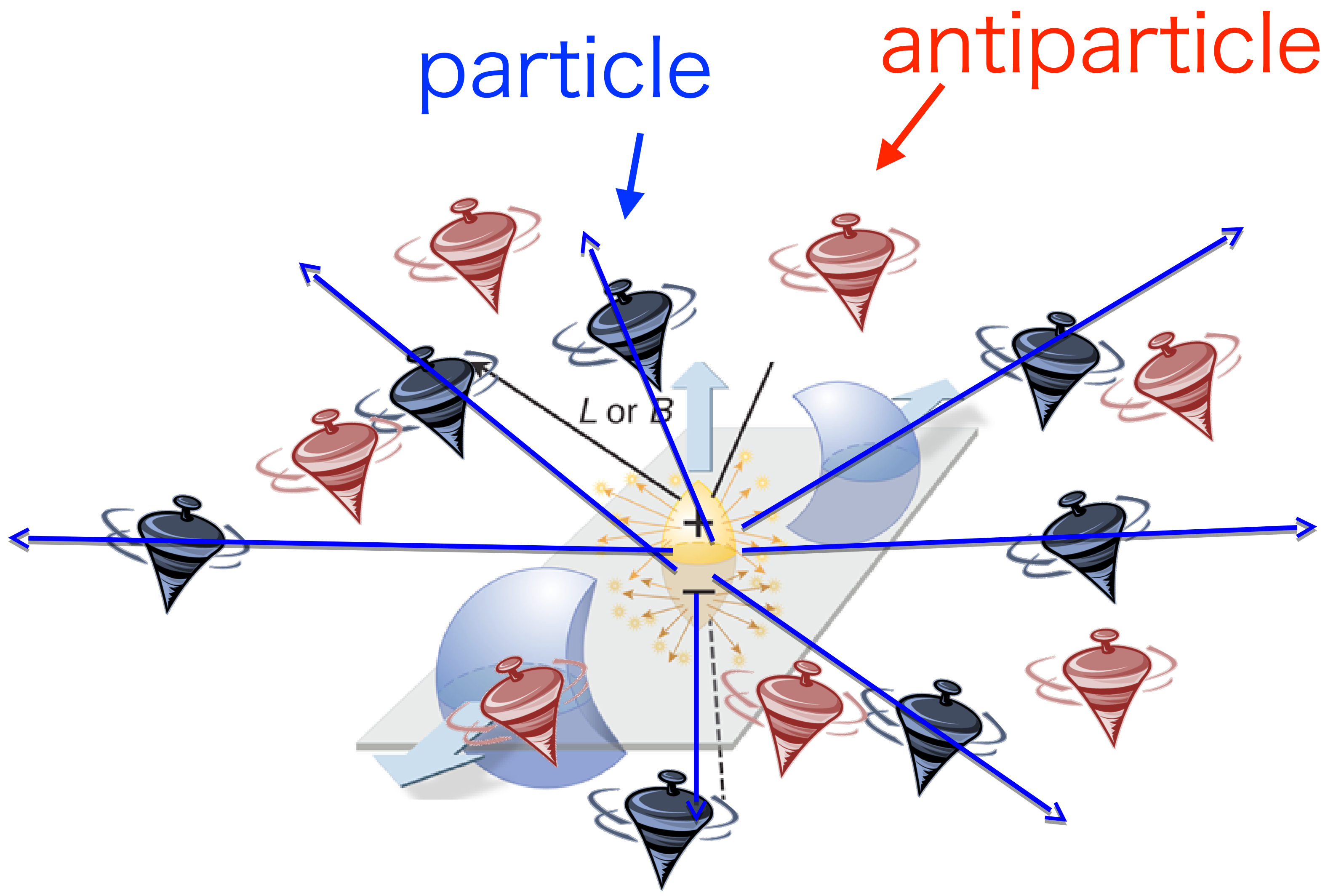
Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)

→Chiral vortical effect
→**Particle polarization**

Global polarization



$$\omega_y = \frac{1}{2}(\nabla \times v)_y \approx -\frac{1}{2}\frac{\partial v_z}{\partial x}$$



Z.-T. Liang and X.-N. Wang, PRL94, 102301 (2005)
S. Voloshin, nucl-th/0410089 (2004)

- Orbital angular momentum is transferred to particle spin
  - Particles' and anti-particles' spins are aligned along angular momentum, ***L***
- Magnetic field align particle's spin
  - Particles' and antiparticles' spins are aligned in opposite direction along ***B*** due to the opposite sign of magnetic moment

Produced particles will be "globally" polarized along ***L*** and ***B***.
B might be studied by particle-antiparticle difference.

How to measure the polarization?

Parity-violating weak decay of hyperons ("self-analyzing")

Daughter baryon is preferentially emitted in the direction of hyperon's spin (opposite for anti-particle)

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

$\mathrm{P_H}$: hyperon polarization

θ^*: polar angle of daughter relative to the polarization direction in hyperon rest frame

α_H: hyperon decay parameter

Note: α_H for Λ recently updated (BESIII and CLAS)

α_Λ=0.732±0.014, $\alpha_{\bar{\Lambda}}$=-0.758±0.012

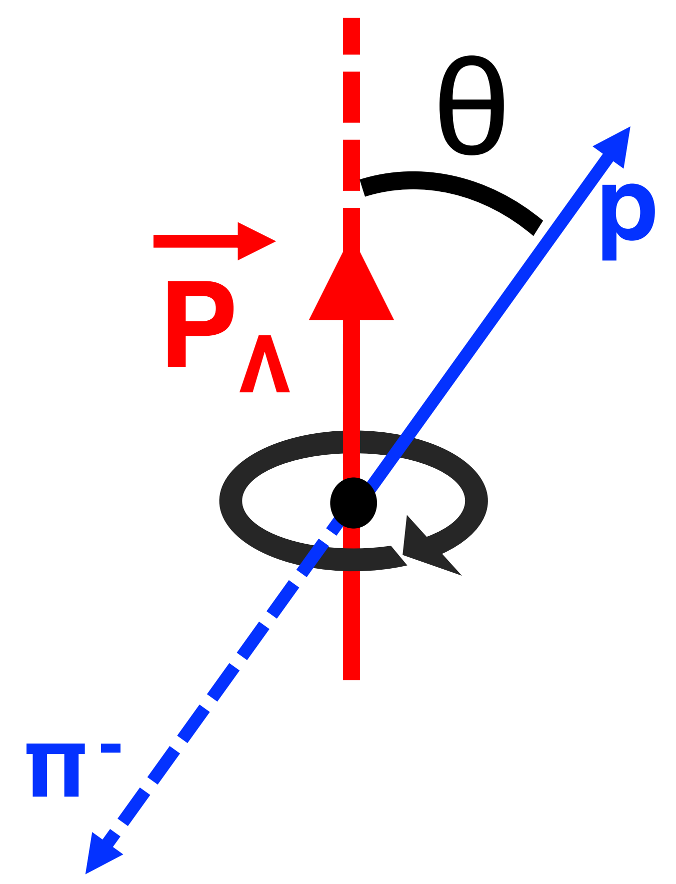
P.A. Zyla et al. (PDG), Prog.Theor.Exp.Phys.2020.083C01

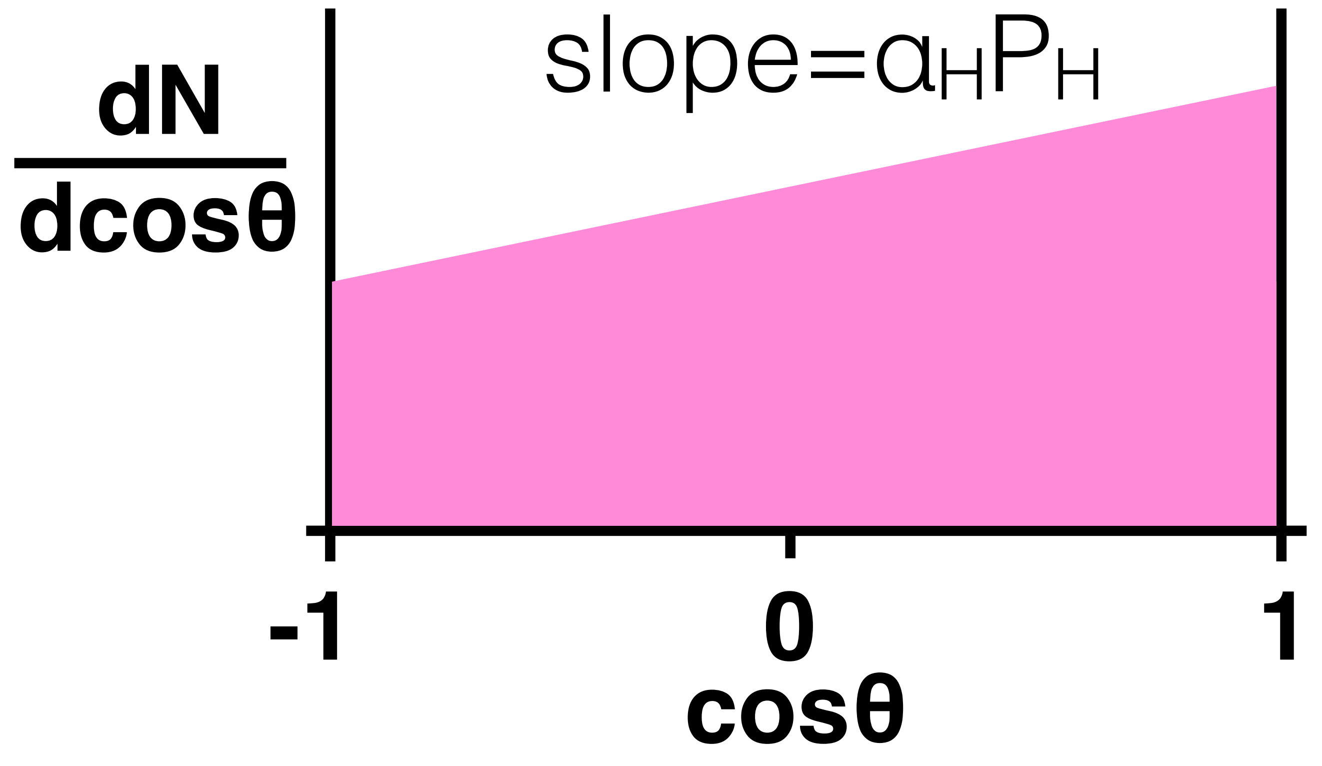
* Published results are based on $\alpha_\Lambda=-\alpha_{\bar{\Lambda}}$=0.64±0.013

New results use new α where existing results are scaled by $\alpha_{old}/\alpha_{new}$

$$\Lambda \to p + \pi^-$$

(BR: 63.9%, cτ~7.9 cm)

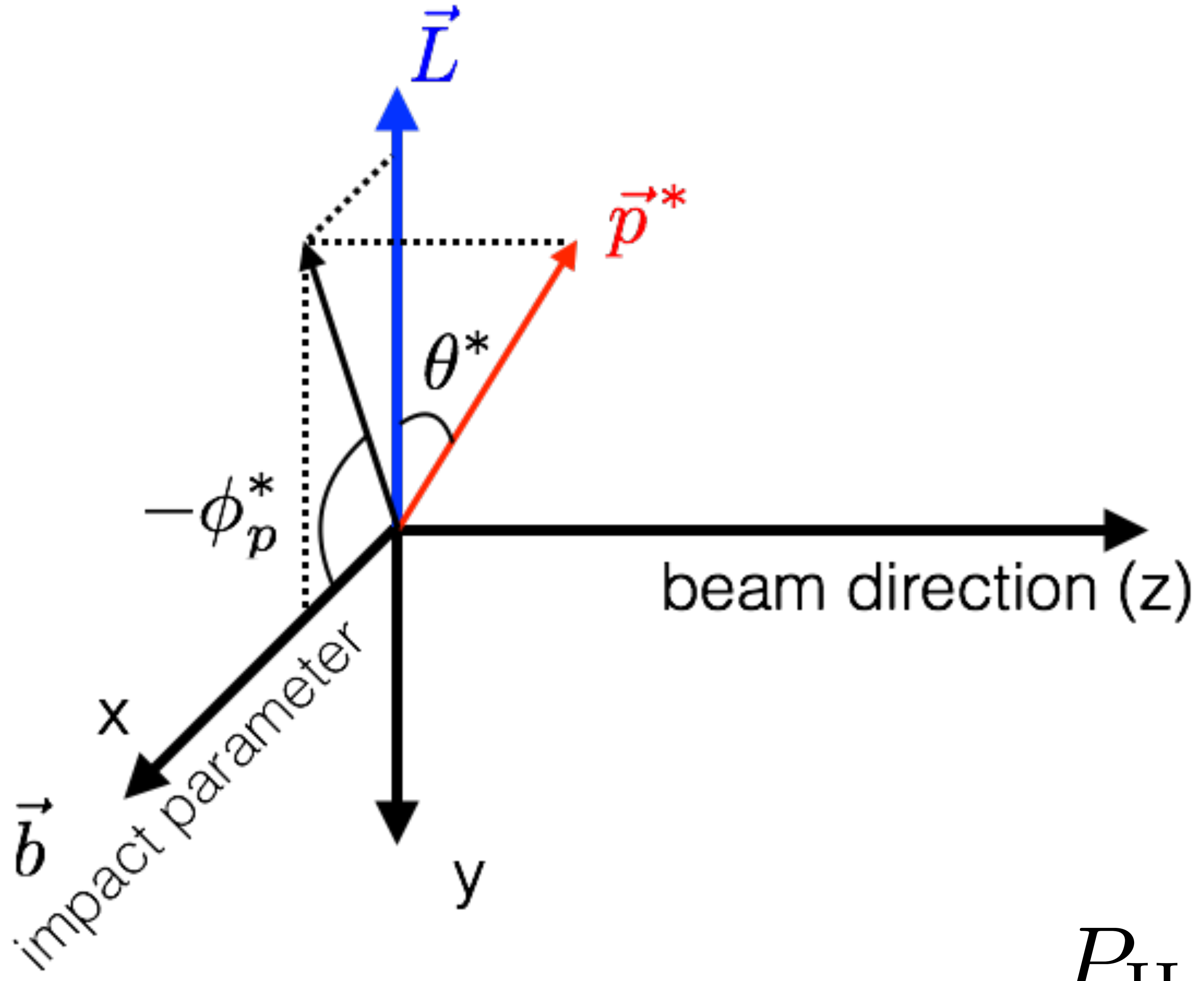


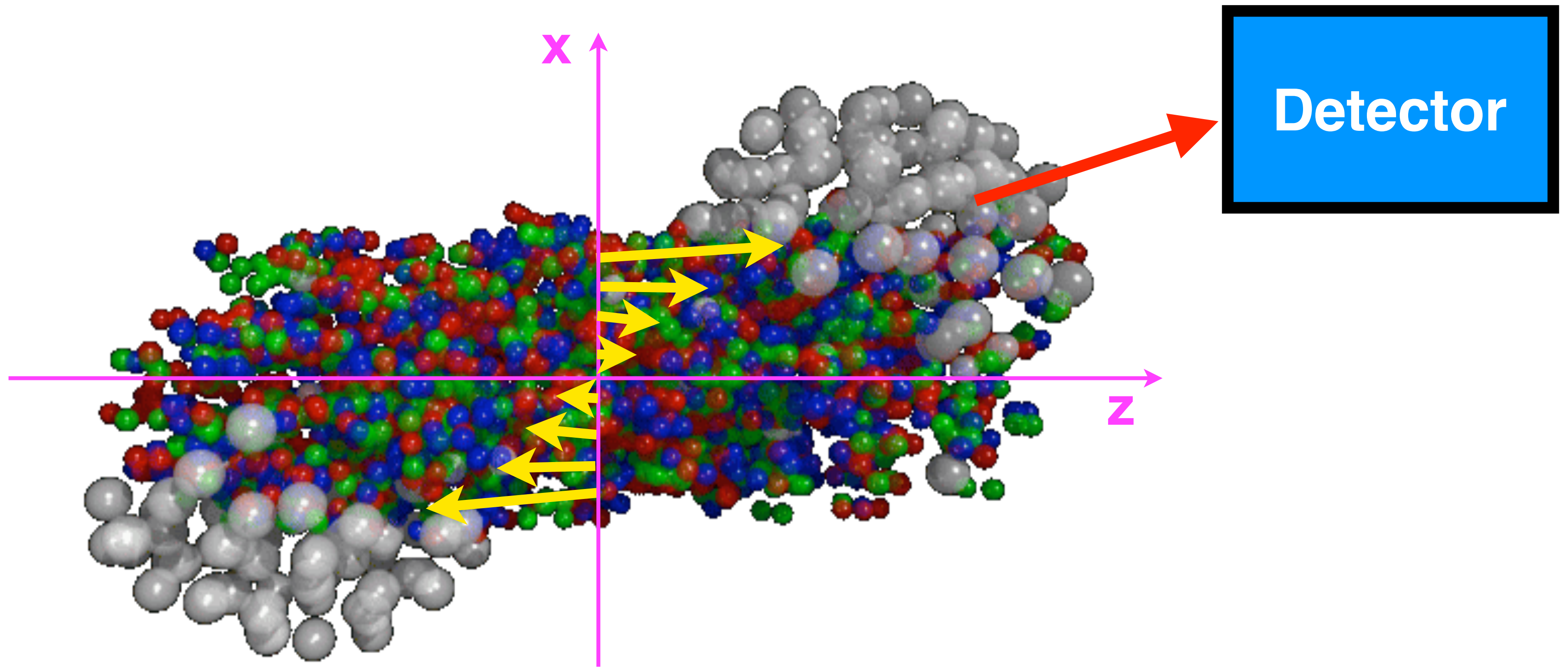


How to measure the "global" polarization?

"global" polarization : spin alignment along the initial angular momentum

Projection onto the transverse plane





Angular momentum direction can be determined by spectator deflection (spectators deflect outwards)

S. Voloshin and TN, PRC94.021901(R)(2016)

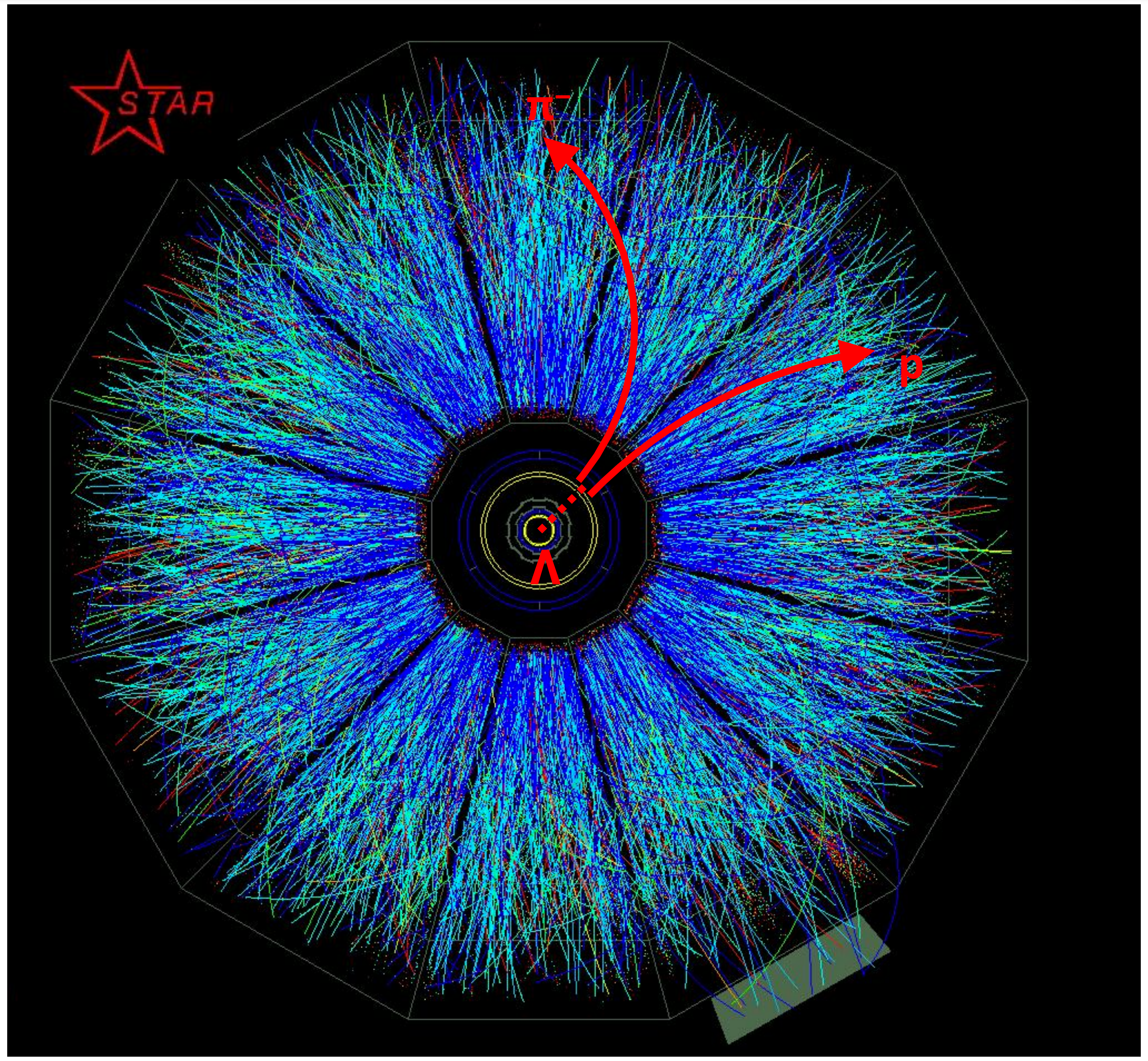
$$P_{\rm H} = \frac{8}{\pi \alpha_{\rm H}} \frac{\langle \sin(\Psi_1 - \phi_p^*) \rangle}{{\rm Res}(\Psi_1)}$$

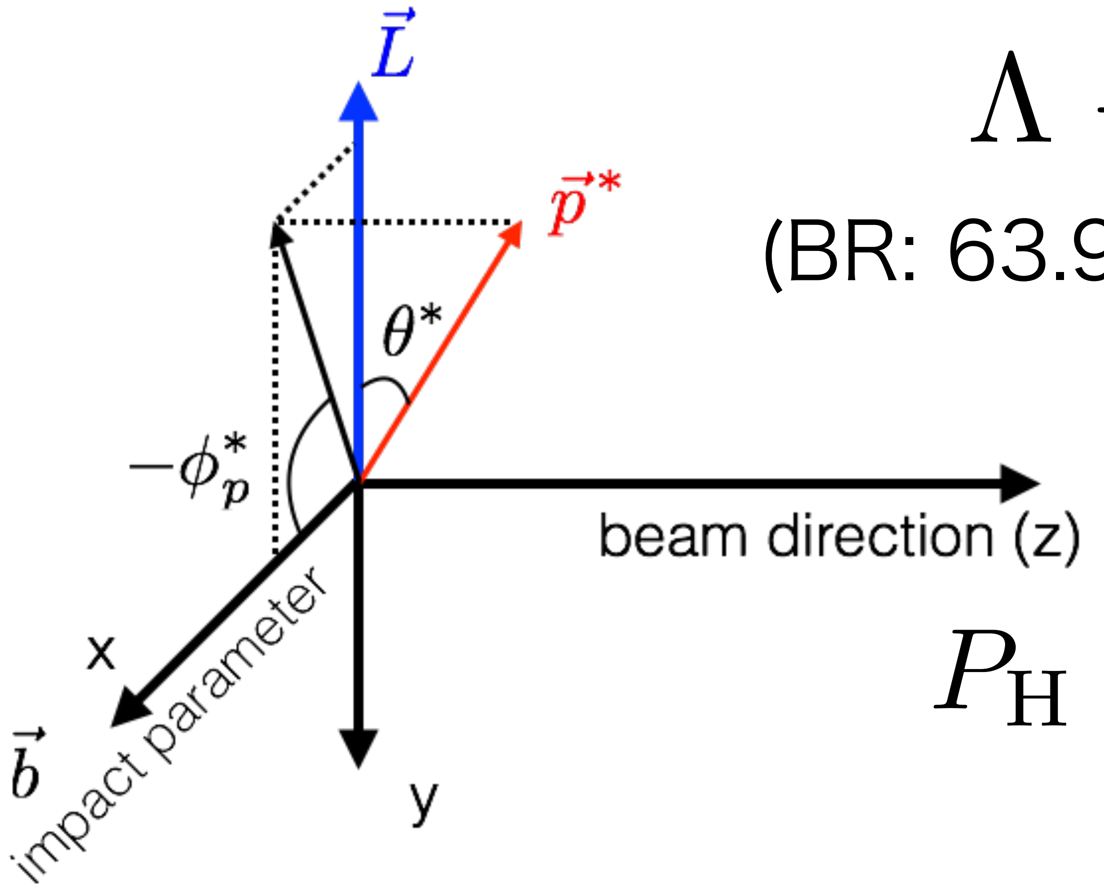
Ψ_1: azimuthal angle of b

ϕ_p^*: angle of daughter proton in Λ rest frame

STAR, PRC76, 024915 (2007)

Signal extraction with Λ hyperons





$$\Lambda \to p + \pi^-$$

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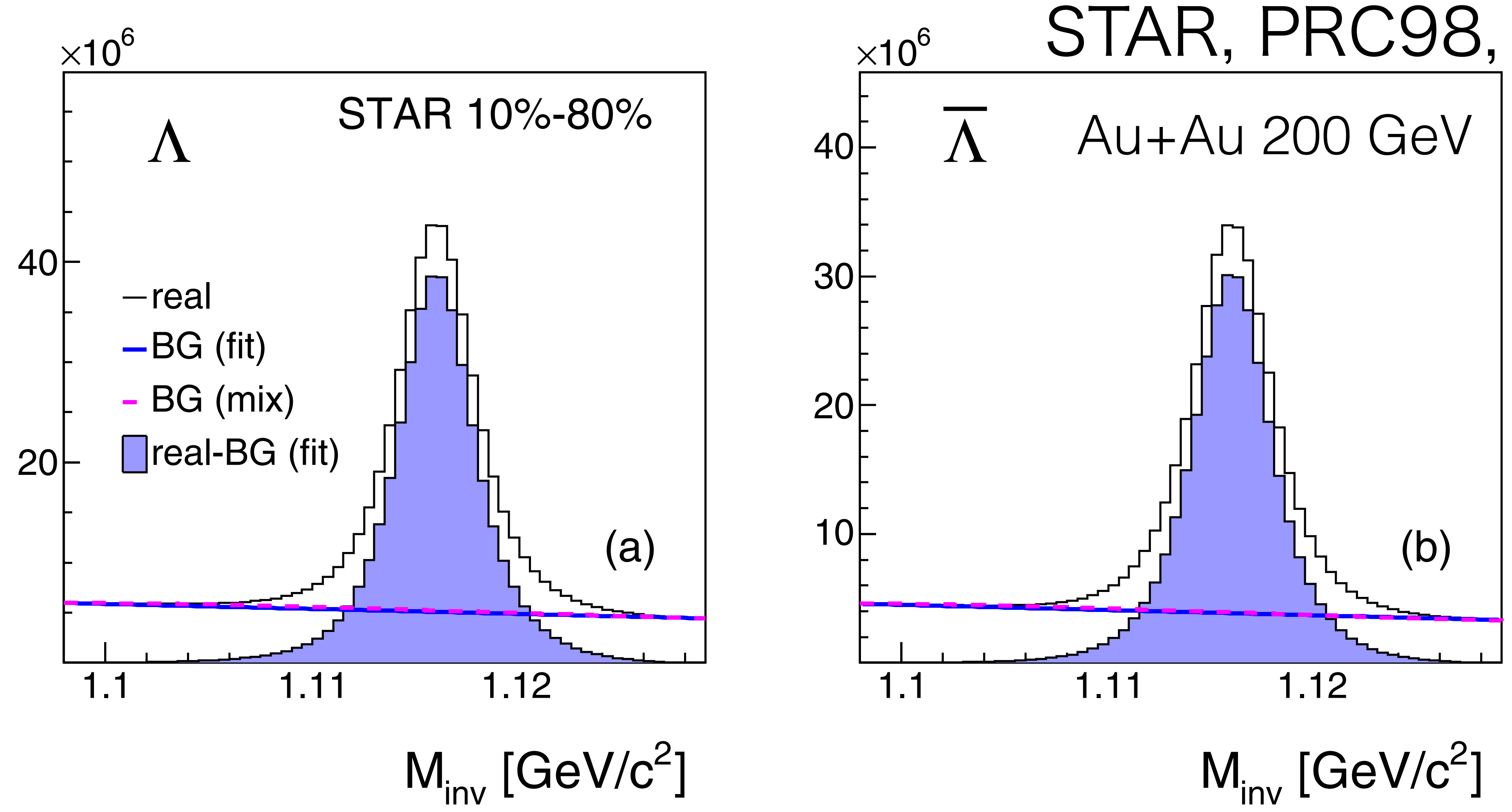
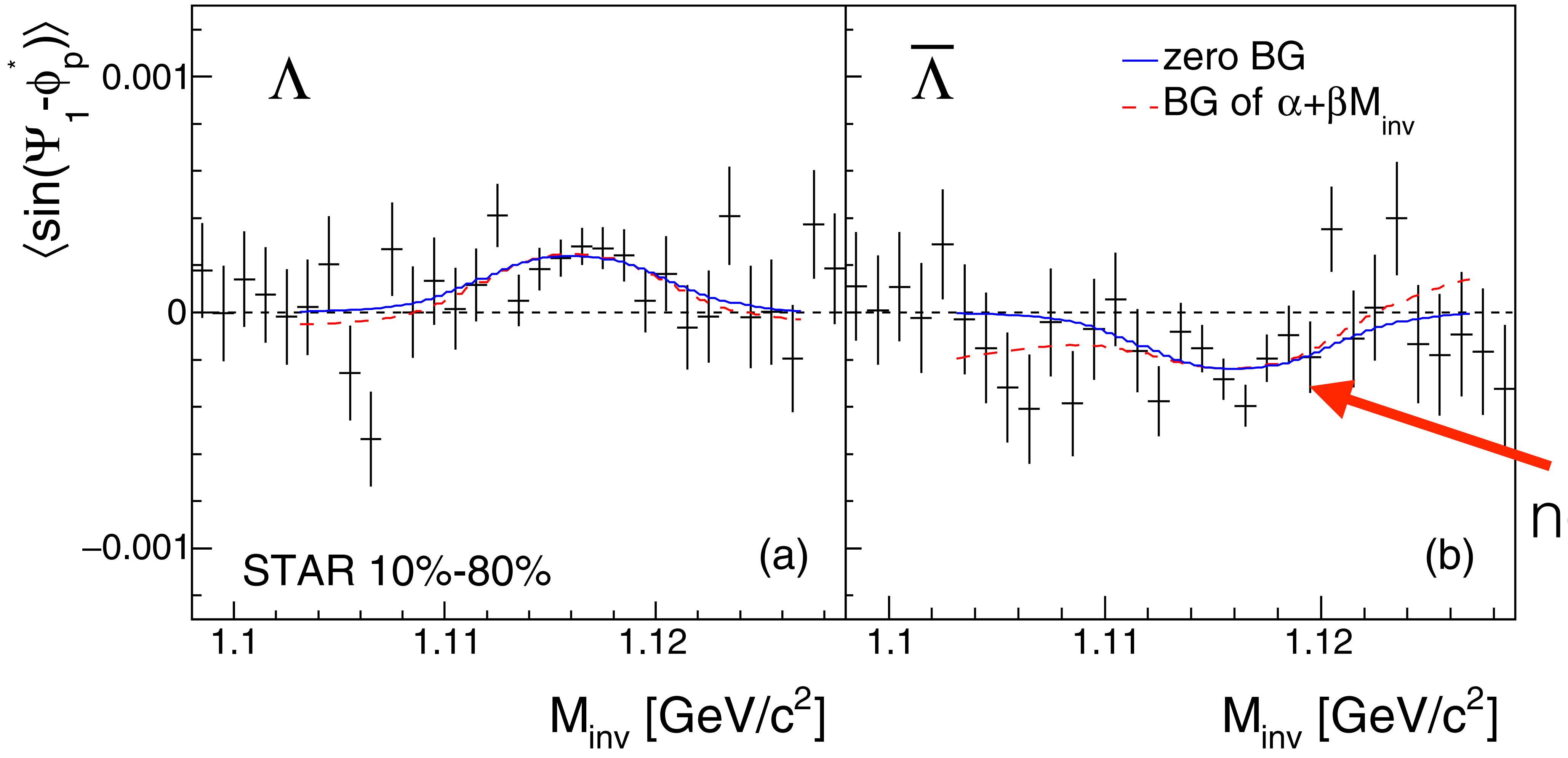
$$P_{\mathrm{H}} = \frac{8}{\pi \alpha_{\mathrm{H}}} \frac{\langle \sin(\Psi_1 - \phi_p^*) \rangle}{\mathrm{Res}(\Psi_1)}$$

STAR, PRC98, 014910 (2018)





negative for anti-Λ

$$\alpha_H = -\alpha_{\bar{H}}$$

$$\langle \sin(\Psi_1 - \phi_p^*) \rangle^{\mathrm{obs}} = (1 - f^{\mathrm{Bg}}(M_{\mathrm{inv}})) \langle \sin(\Psi_1 - \phi_p^*) \rangle^{\mathrm{Sg}} + f^{\mathrm{Bg}}(M_{\mathrm{inv}}) \langle \sin(\Psi_1 - \phi_p^*) \rangle^{\mathrm{Bg}},$$

Feed-down effect

- ~60% of measured Λ are feed-down from $\Sigma^* \to \Lambda\pi$, $\Sigma^0 \to \Lambda\gamma$, $\Xi \to \Lambda\pi$
- Polarization of parent particle R is transferred to its daughter Λ
  (Polarization transfer could be negative!)

$C_{\Lambda R}$: coefficient of spin transfer from parent R to Λ
S_R : parent particle's spin
$f_{\Lambda R}$: fraction of Λ originating from parent R
μ_R : magnetic moment of particle R

$$\mathbf{S}^*_\Lambda = C\mathbf{S}^*_R \qquad \langle S_y \rangle \propto \frac{S(S+1)}{3}(\omega + \frac{\mu}{S}B)$$

$$\begin{pmatrix} \varpi_c \\ \\ B_c/T \end{pmatrix} = \begin{bmatrix} \frac{2}{3}\sum_R \left(f_{\Lambda R}C_{\Lambda R} - \frac{1}{3}f_{\Sigma^0 R}C_{\Sigma^0 R}\right) S_R(S_R+1) & \frac{2}{3}\sum_R \left(f_{\Lambda R}C_{\Lambda R} - \frac{1}{3}f_{\Sigma^0 R}C_{\Sigma^0 R}\right) (S_R+1)\mu_R \\ \frac{2}{3}\sum_{\overline{R}} \left(f_{\overline{\Lambda R}}C_{\overline{\Lambda R}} - \frac{1}{3}f_{\overline{\Sigma^0}\overline{R}}C_{\overline{\Sigma^0}\overline{R}}\right) S_{\overline{R}}(S_{\overline{R}}+1) & \frac{2}{3}\sum_{\overline{R}} \left(f_{\overline{\Lambda R}}C_{\overline{\Lambda R}} - \frac{1}{3}f_{\overline{\Sigma^0}\overline{R}}C_{\overline{\Sigma^0}\overline{R}}\right) (S_{\overline{R}}+1)\mu_{\overline{R}} \end{bmatrix}^{-1} \begin{pmatrix} P_\Lambda^{\rm meas} \\ \\ P_{\overline{\Lambda}}^{\rm meas} \end{pmatrix}$$

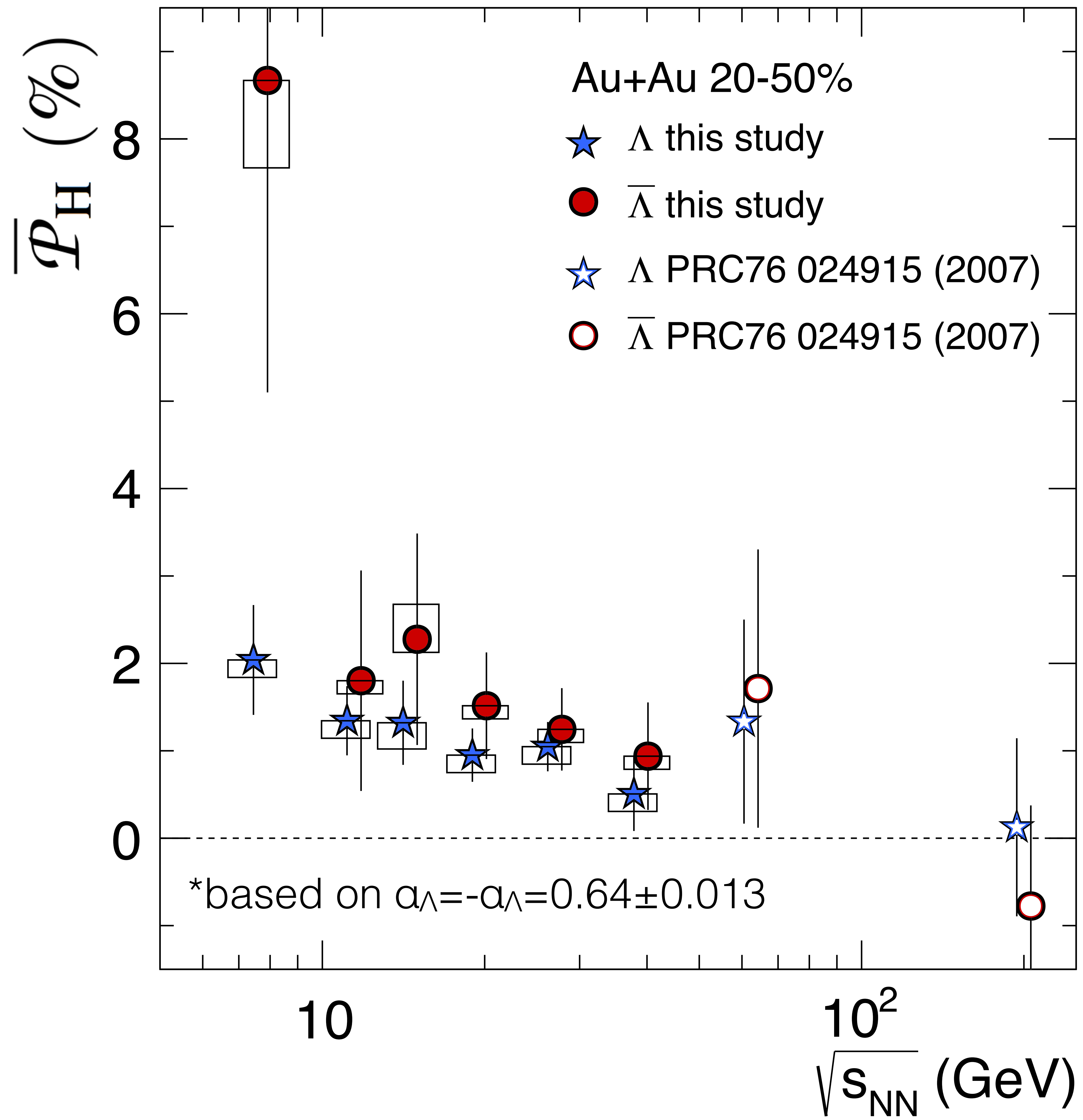
Becattini, Karpenko, Lisa, Upsal, and Voloshin, PRC95.054902 (2017)

Decay	C
Parity conserving: $1/2^+ \to 1/2^+\ 0^-$	−1/3
Parity conserving: $1/2^- \to 1/2^+\ 0^-$	1
Parity conserving: $3/2^+ \to 1/2^+\ 0^-$	1/3
Parity-conserving: $3/2^- \to 1/2^+\ 0^-$	−1/5
$\Xi^0 \to \Lambda + \pi^0$	+0.900
$\Xi^- \to \Lambda + \pi^-$	+0.927
$\Sigma^0 \to \Lambda + \gamma$	−1/3

Primary Λ polarization will be diluted by 15%-20% (model-dependent)
This also suggests that **the polarization of daughter particles can be used to measure the polarization of its parent!** e.g. Ξ, Ω

First observation in BES-I

STAR, Nature 548, 62 (2017)



Positive polarization signal at lower energies!

- P_H looks to increase in lower energies

Becattini, Karpenko, Lisa, Upsal, and Voloshin, PRC95.054902 (2017)

$$P_{\Lambda} \simeq \frac{1}{2}\frac{\omega}{T} + \frac{\mu_{\Lambda}B}{T}$$

$$P_{\bar{\Lambda}} \simeq \frac{1}{2}\frac{\omega}{T} - \frac{\mu_{\Lambda}B}{T}$$

$$\omega = (P_{\Lambda} + P_{\bar{\Lambda}})k_B T/\hbar$$

$$\sim 0.02\text{-}0.09\ \mathrm{fm}^{-1}$$

$$\sim 0.6\text{-}2.7 \times 10^{22}\mathrm{s}^{-1}$$

μ_{Λ}: Λ magnetic moment
T: temperature at thermal equilibrium (T=160 MeV)

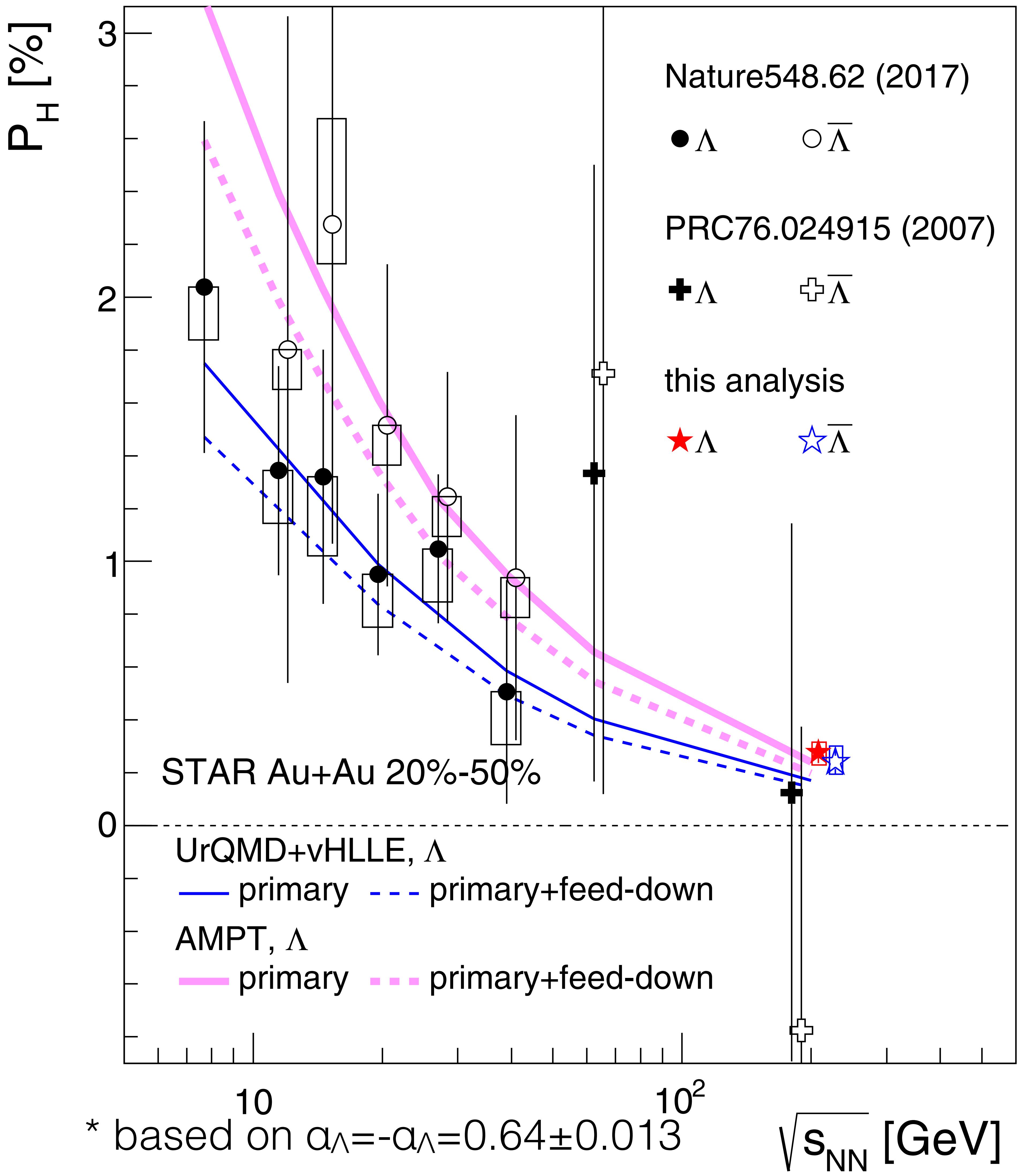
- The most vortical fluid!

Hint of the difference between Λ and anti-Λ P_H

- Effect of the initial magnetic field? (discussed later)

Precise measurements at $\sqrt{s_{NN}}$ = 200 GeV

STAR, PRC98, 014910 (2018)



* based on α_Λ=-$\alpha_{\bar{\Lambda}}$=0.64±0.013

Confirmed energy dependence with new results at 200 GeV

- >5σ significance utilizing 1.5B events
- partly due to stronger shear flow structure at lower $\sqrt{s_{NN}}$ because of baryon stopping

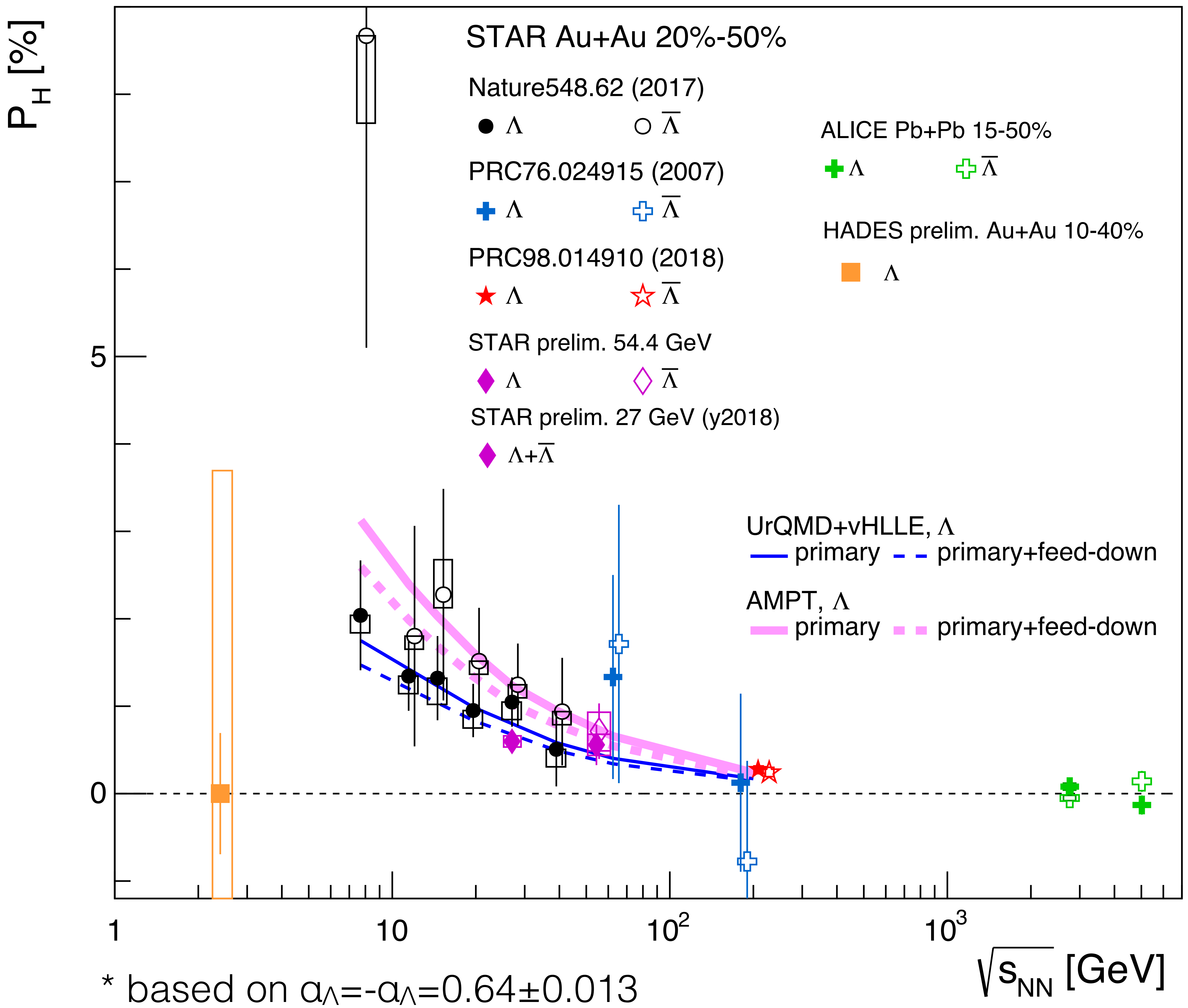
$$P_H(\Lambda)\ [\%] = 0.277 \pm 0.040(\text{stat})\ \pm^{0.039}_{0.049}\ (\text{sys})$$
$$P_H(\bar{\Lambda})\ [\%] = 0.240 \pm 0.045(\text{stat})\ \pm^{0.061}_{0.045}\ (\text{sys})$$

Theoretical models can describe the data well

I. Karpenko and F. Becattini, EPJC(2017)77:213, UrQMD+vHLLE
H. Li et al., PRC96, 054908 (2017), AMPT
Y. Sun and C.-M. Ko, PRC96, 024906 (2017), CKE
Y. Xie et al., PRC95, 031901(R) (2017), PICR
D.-X. Wei et al., PRC99, 014905 (2019), AMPT

Collection of recent results

ALICE, PRC101.044611 (2020)
F. Kornas (HADES), SQM2019
J. Adams, K. Okubo (STAR), QM2019

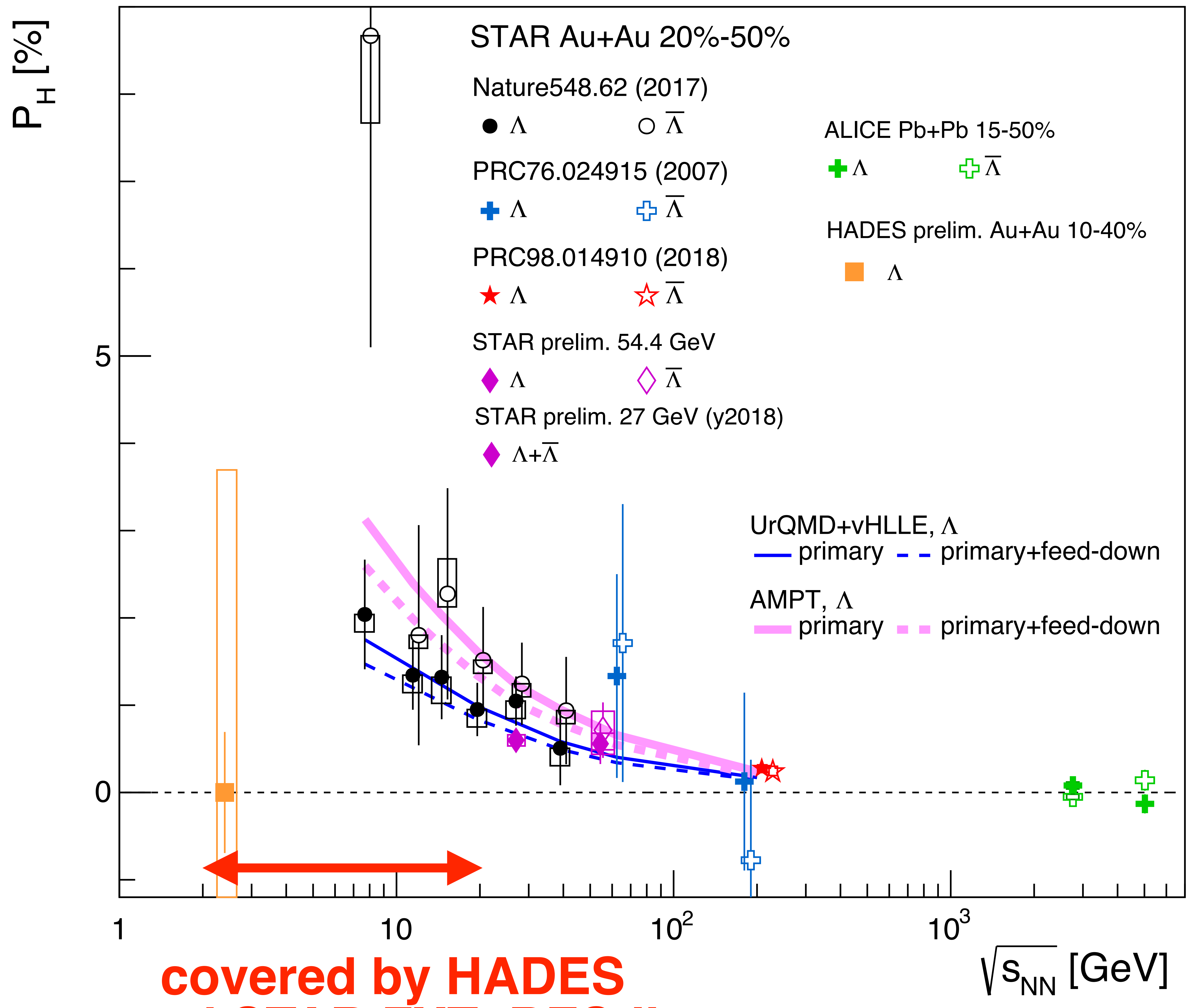


* based on $\alpha_\Lambda = -\alpha_{\bar{\Lambda}} = 0.64 \pm 0.013$

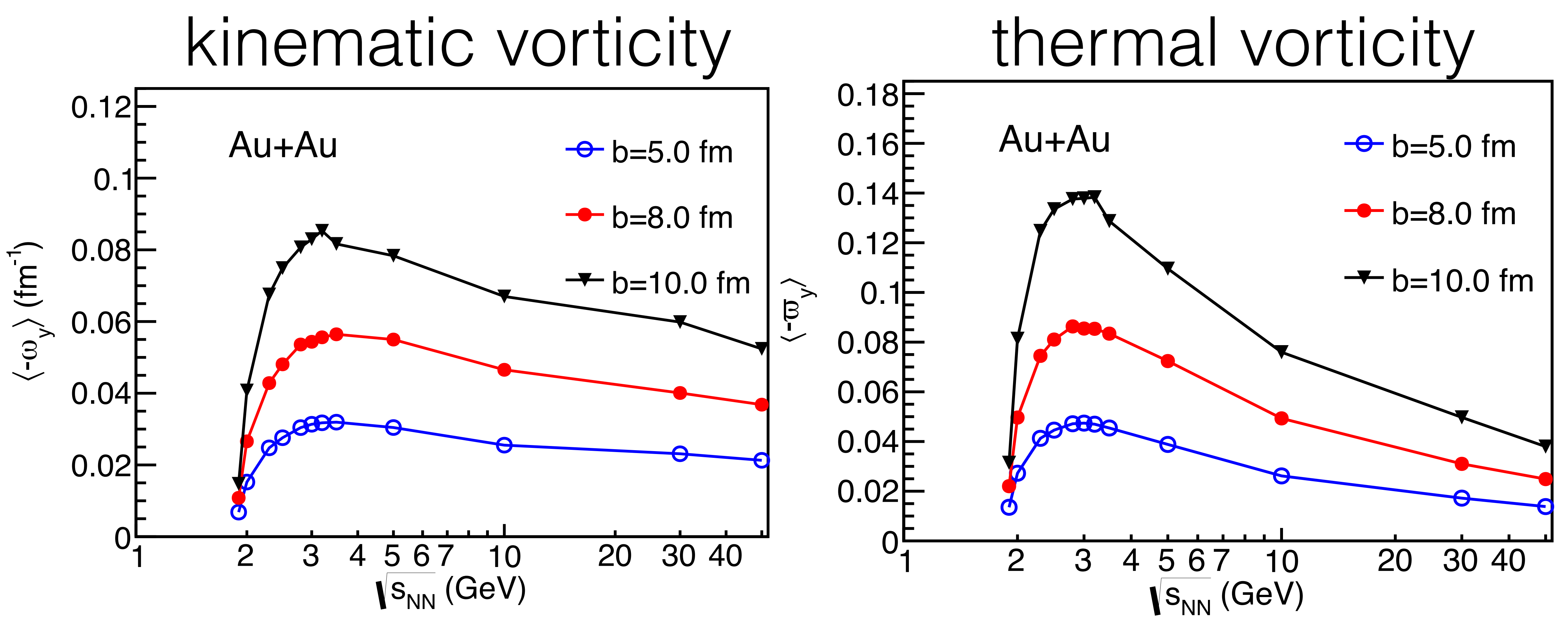
- STAR preliminary at 27 and 54.4 GeV
- ALICE at 2.76 and 5.02 TeV
  - Expected signal is of the order of current statistical uncertainty
- HADES at 2.4 GeV
  - Large uncertainty but still preliminary
  - Hopefully reduce systematic uncertainty

Collection of recent results

ALICE, PRC101.044611 (2020)
F. Kornas (HADES), SQM2019
J. Adams, K. Okubo (STAR), QM2019



covered by HADES and STAR FXT+BES-II



Energy dependence of kinematic and thermal vorticity with UrQMD
X.-G. Deng et al., PRC101.064908 (2020)

HADES: 2-3 GeV
STAR FXT: 3-7.7 GeV
STAR BES-II: 7.7-19 GeV

A possible probe of B-field

Becattini, Karpenko, Lisa, Upsal, and Voloshin, PRC95.054902 (2017)

$$P_\Lambda \simeq \frac{1}{2}\frac{\omega}{T} + \frac{\mu_\Lambda B}{T}$$

$$P_{\bar{\Lambda}} \simeq \frac{1}{2}\frac{\omega}{T} - \frac{\mu_\Lambda B}{T}$$

μ_Λ: Λ magnetic moment

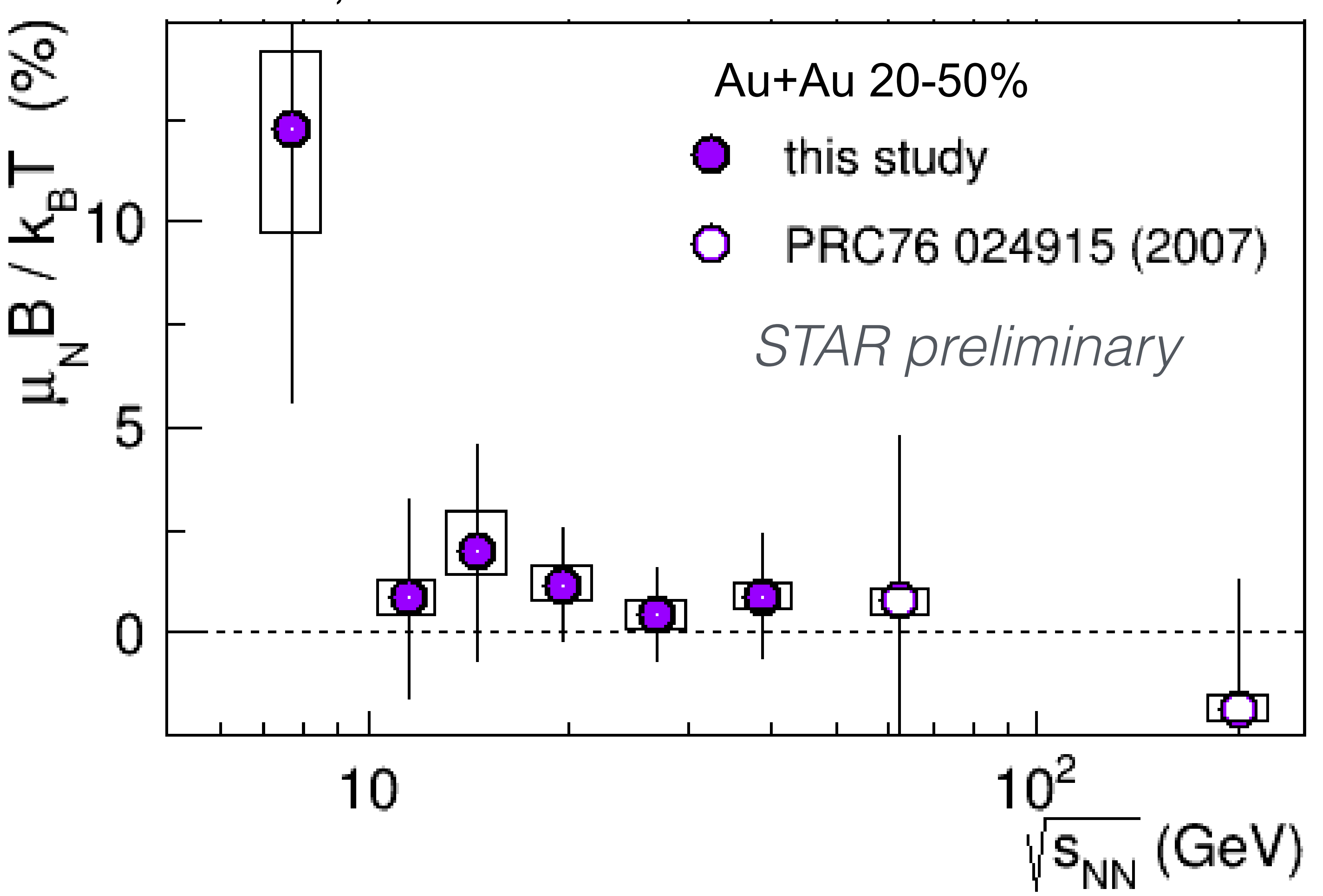
$$B = (P_\Lambda - P_{\bar{\Lambda}})T/(2\mu_\Lambda)$$

$$\sim 2 \times 10^{11}\ [\mathrm{T}]$$

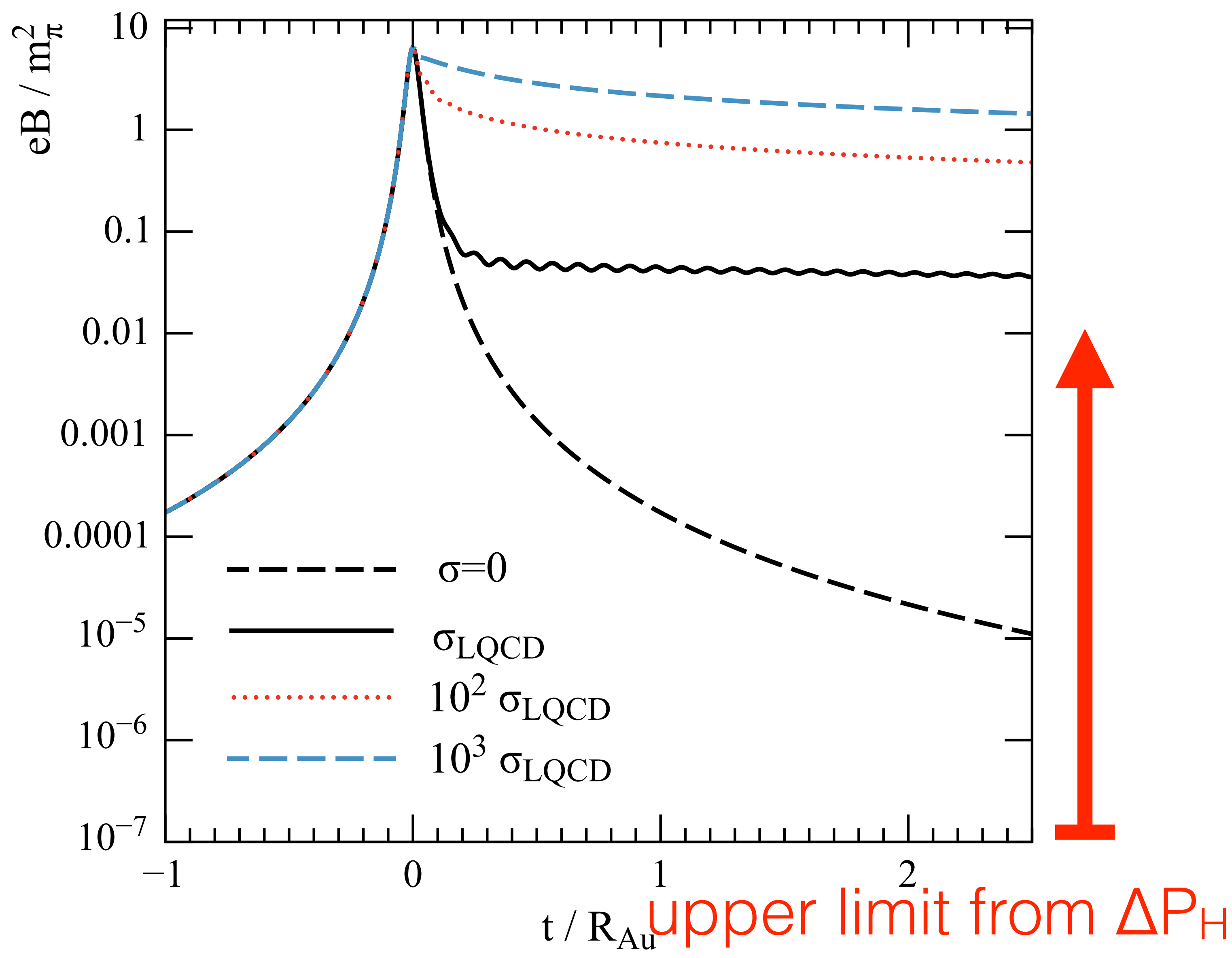
$$eB \sim 10^{-2} \mathrm{m}_\pi^2$$

$\Delta P_\Lambda \sim 0.5\%$, T=160MeV

STAR, QM17



McLerran and Skokov, Nucl. Phys. A929, 184 (2014)

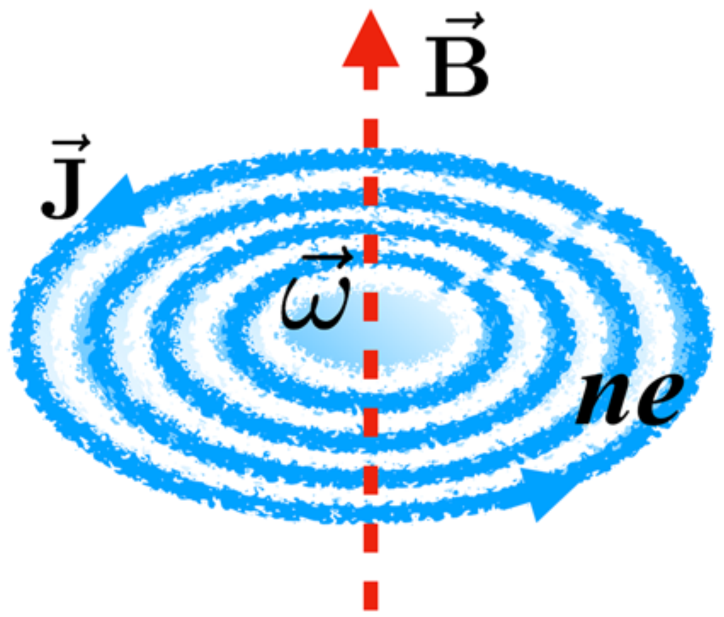


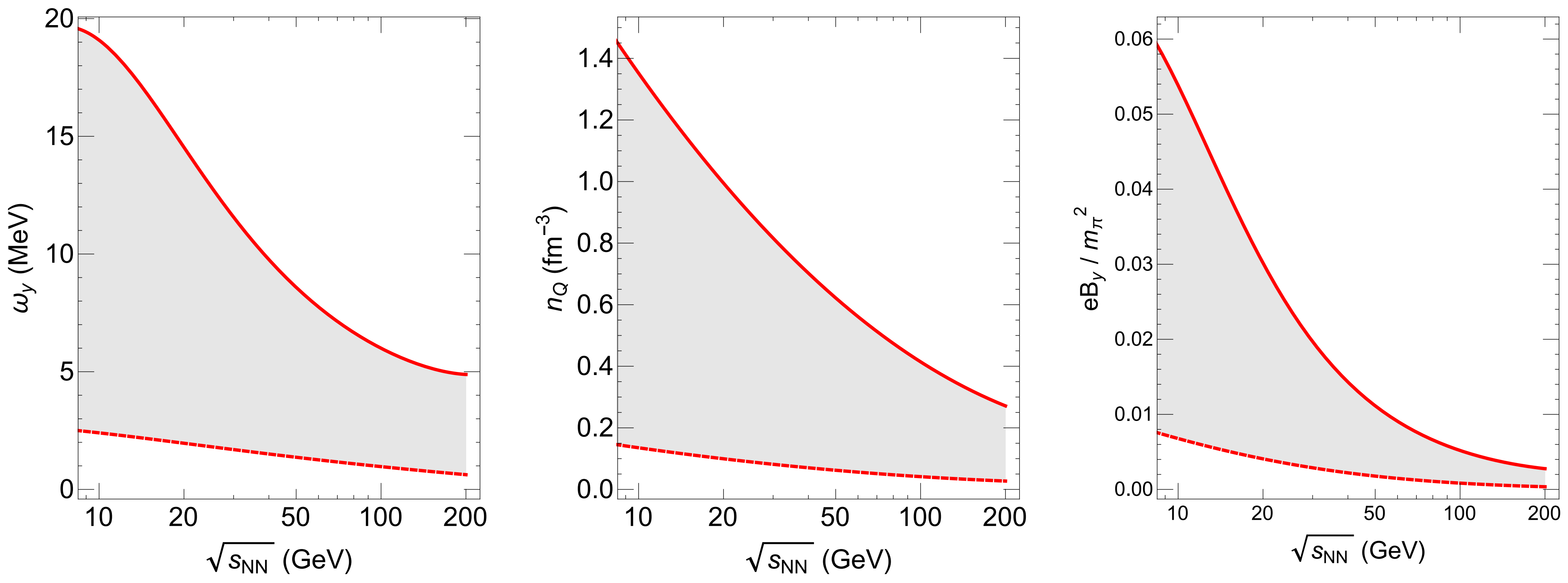
Conductivity increases lifetime.

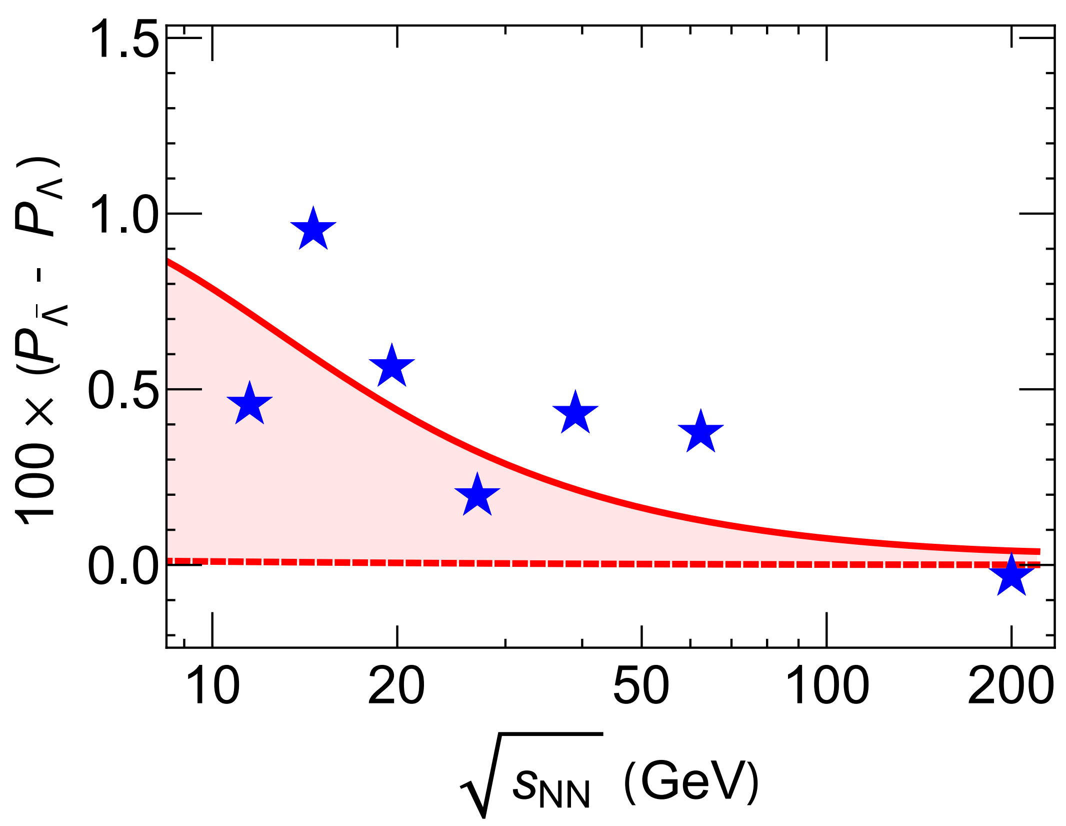
- Based on thermal model, B-field at kinetic freeze-out could be probed by Λ-antiΛ splitting
  - Current results are consistent with zero (except 7.7 GeV)
- But the splitting could be also due to other effects…

Need caution for the interpretation

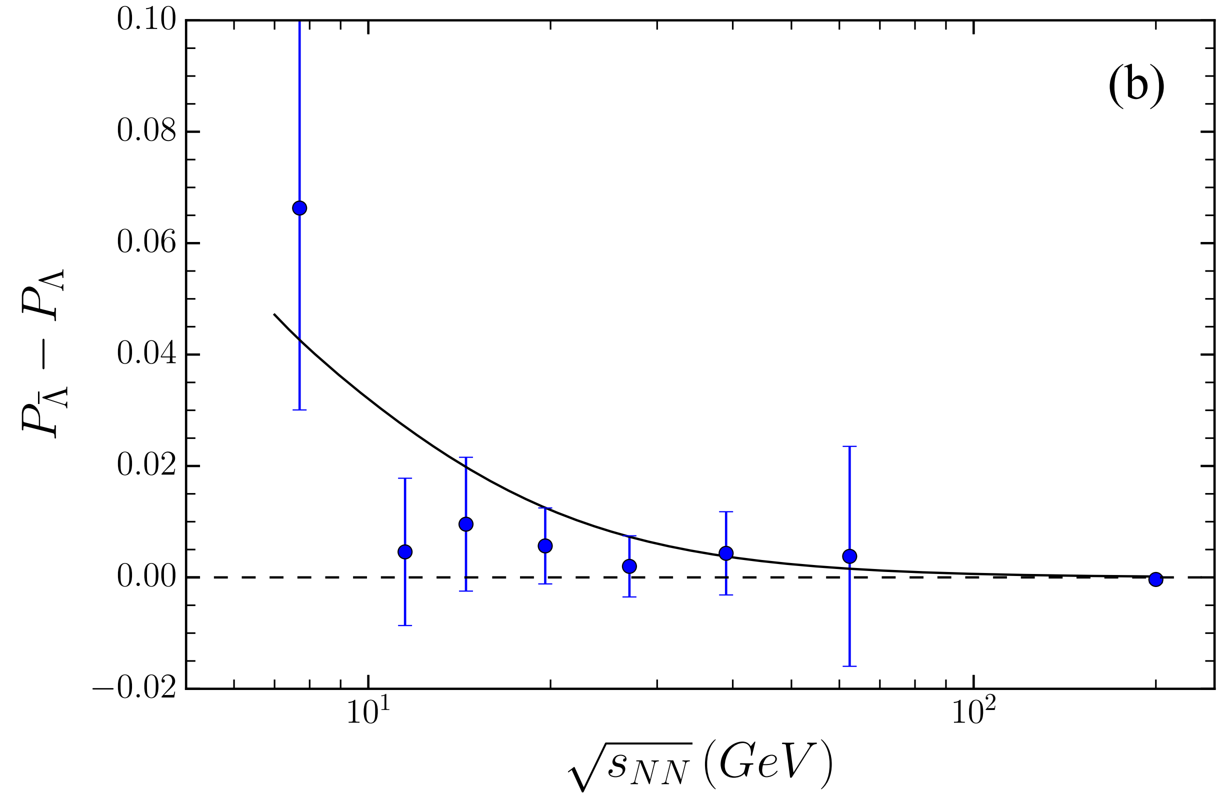
- Initial magnetic field
- Effect of chemical potential (expected to be small)
  R. Fang et al.,, PRC94, 024904 (2016)
- Rotating charged fluid produces B-field with longer lifetime
  X. Guo, J. Liao, and E. Wang, PRC99.021901(R) (2019)
- Spin interaction with the meson field generated by the baryon current
  L. Csernai, J. Kapusta, and T. Welle, PRC99.021901(R) (2019)
- Different space time distributions and freeze-out of Λ and antiΛ
  O. Vitiuk, L.Bravina, E. Zabrodin, PLB803(2020)135298







X. Guo, J. Liao, and E. Wang, PRC99.021901(R) (2019)



L. Csernai et al., PRC99.021901(R) (2019)

Differential measurements: centrality

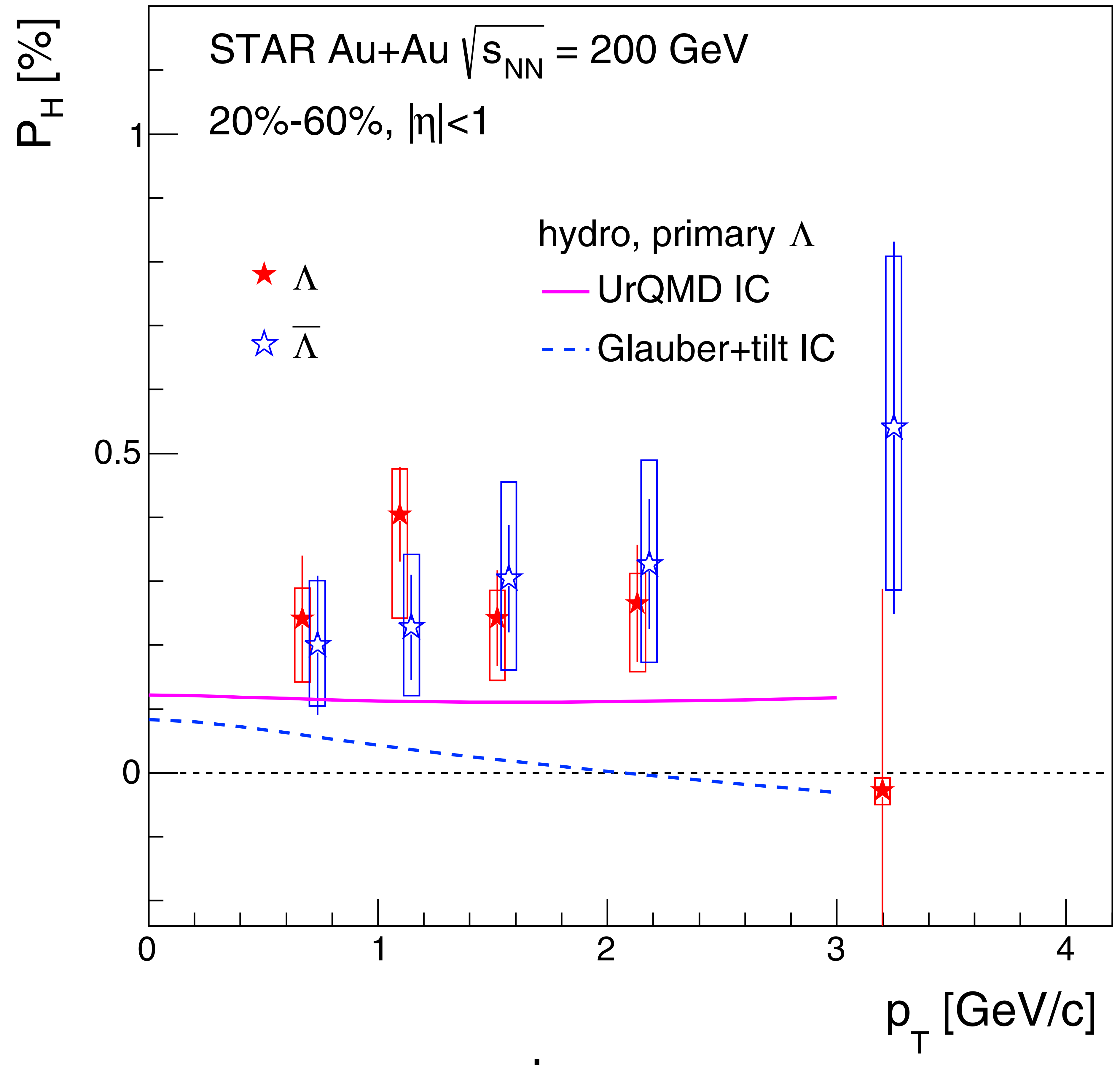
In most central collision → no initial angular momentum

The polarization decreases in more central collisions.

Similar trend was confirmed at lower energies.

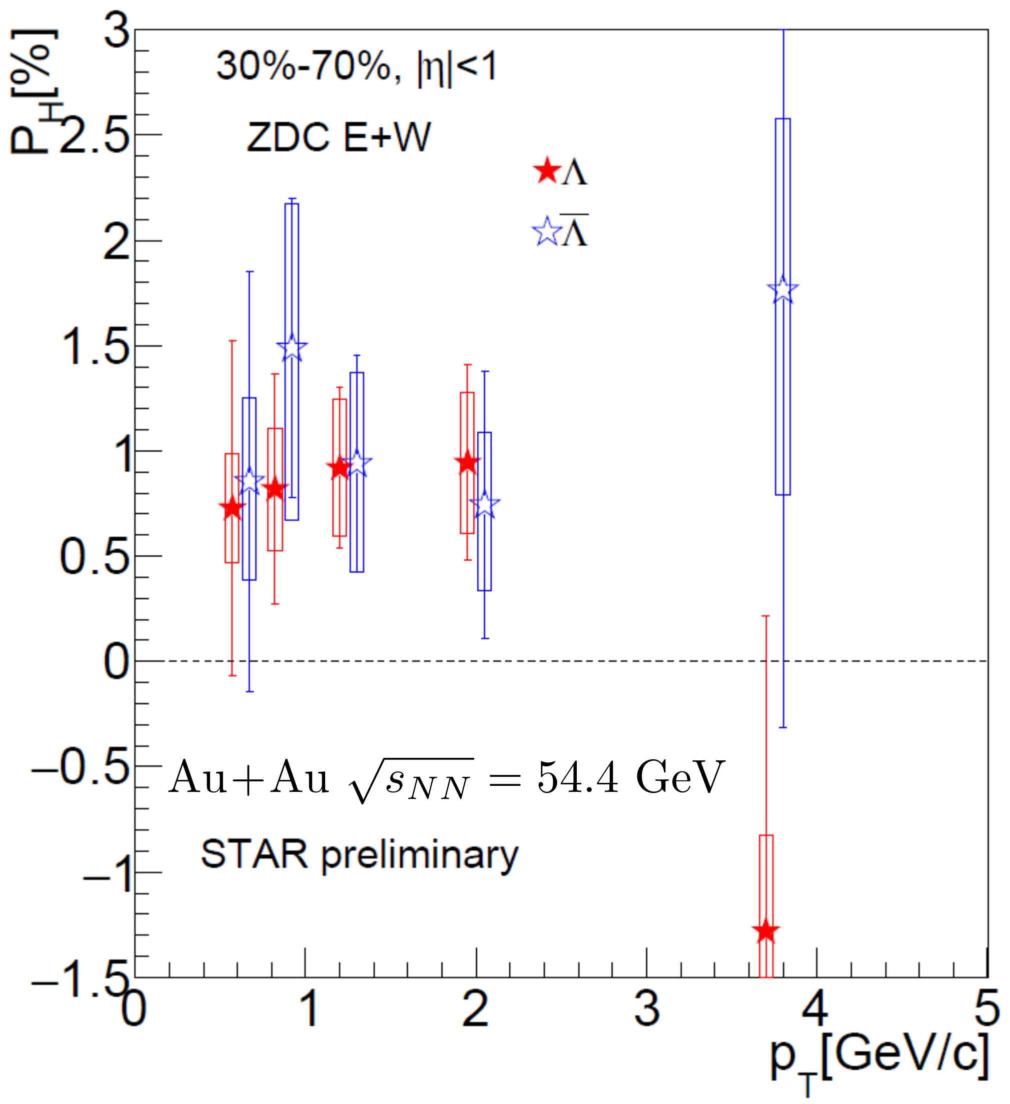
Differential measurements: p_T

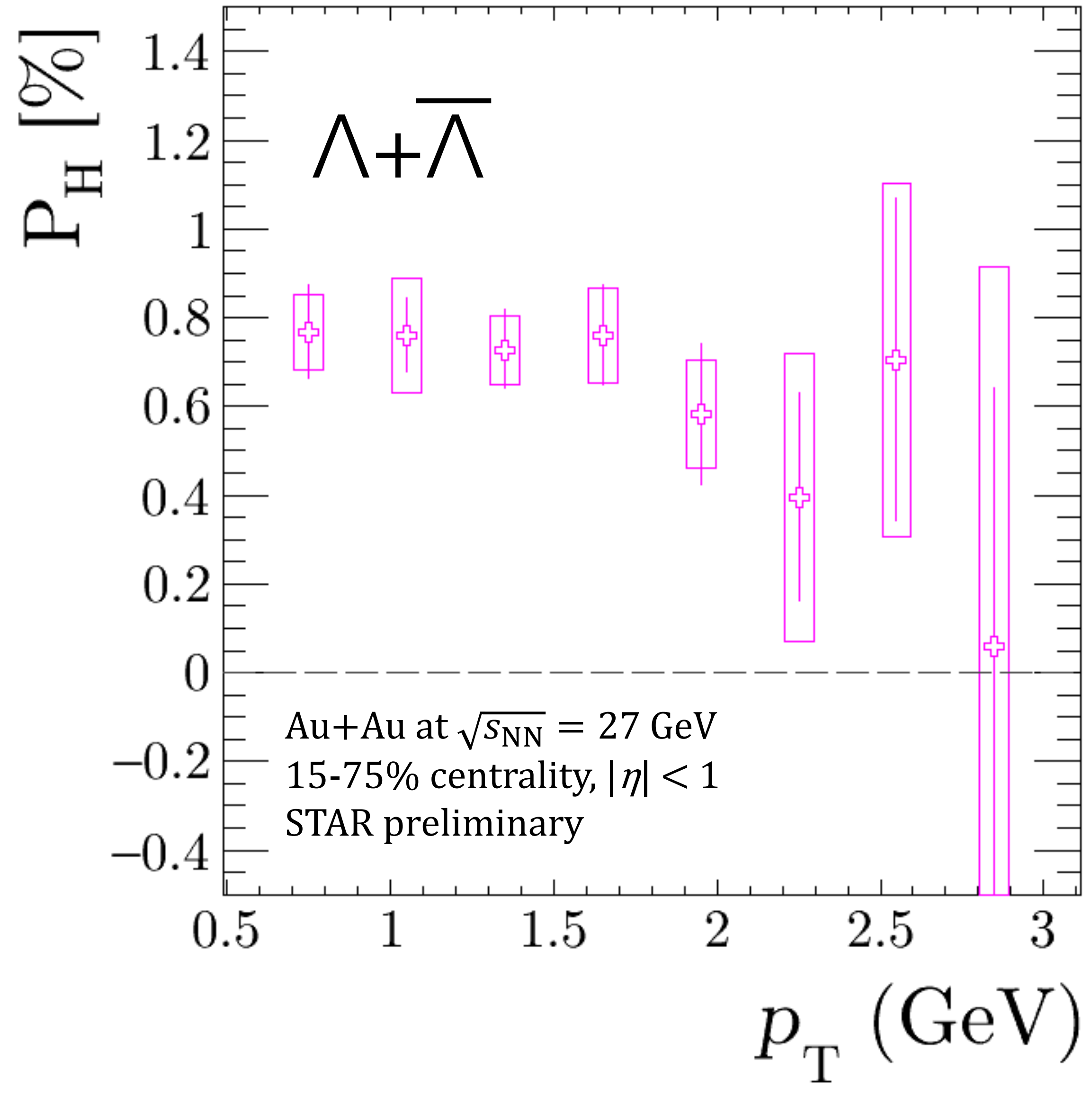
STAR, PRC98, 014910 (2018)



- Naive expectation of smaller P_H due to scattering at low p_T, fragmentation at high p_T
- No clear p_T dependence with current precision

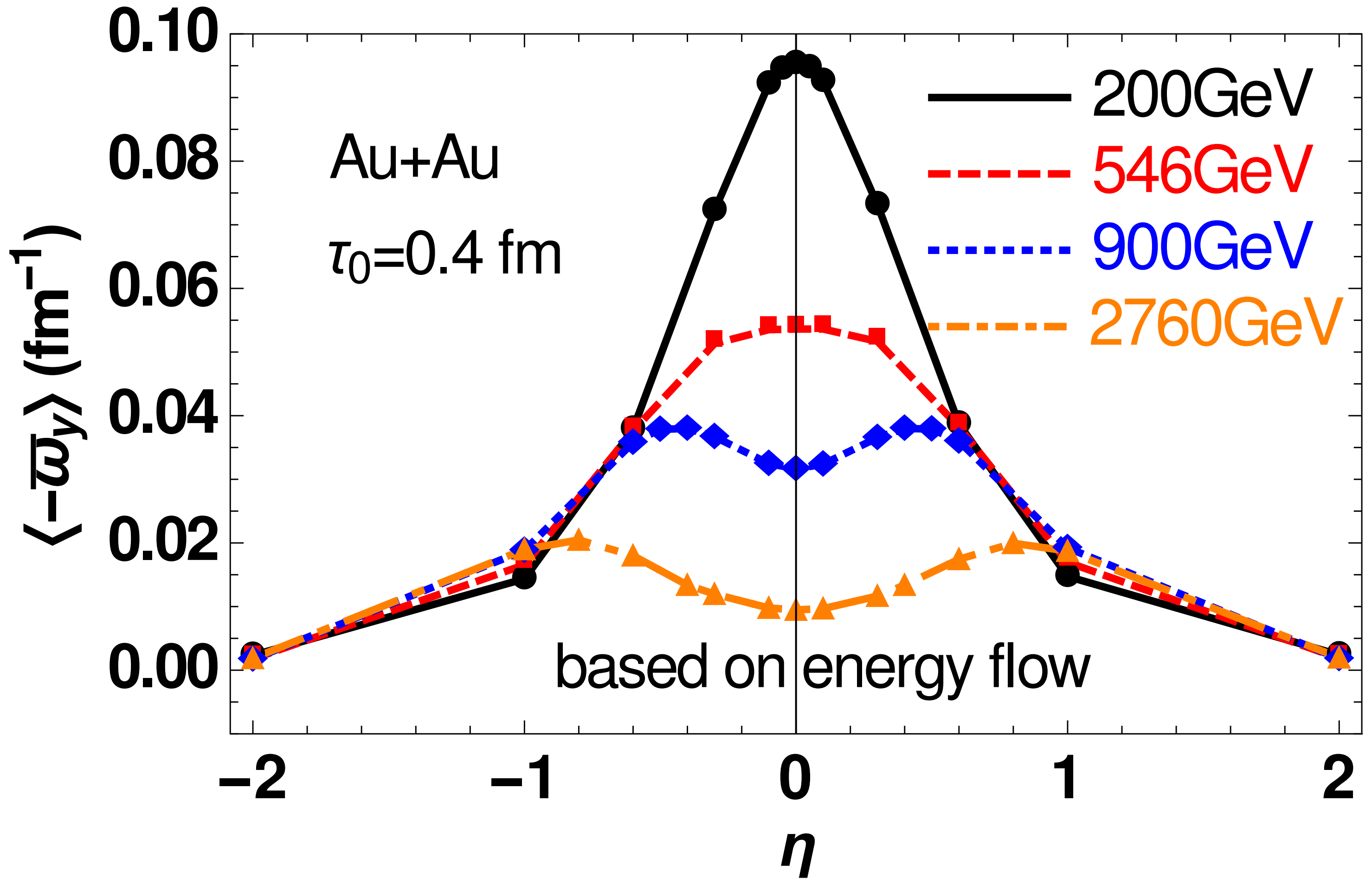
STAR, QM19





Differential measurements: rapidity

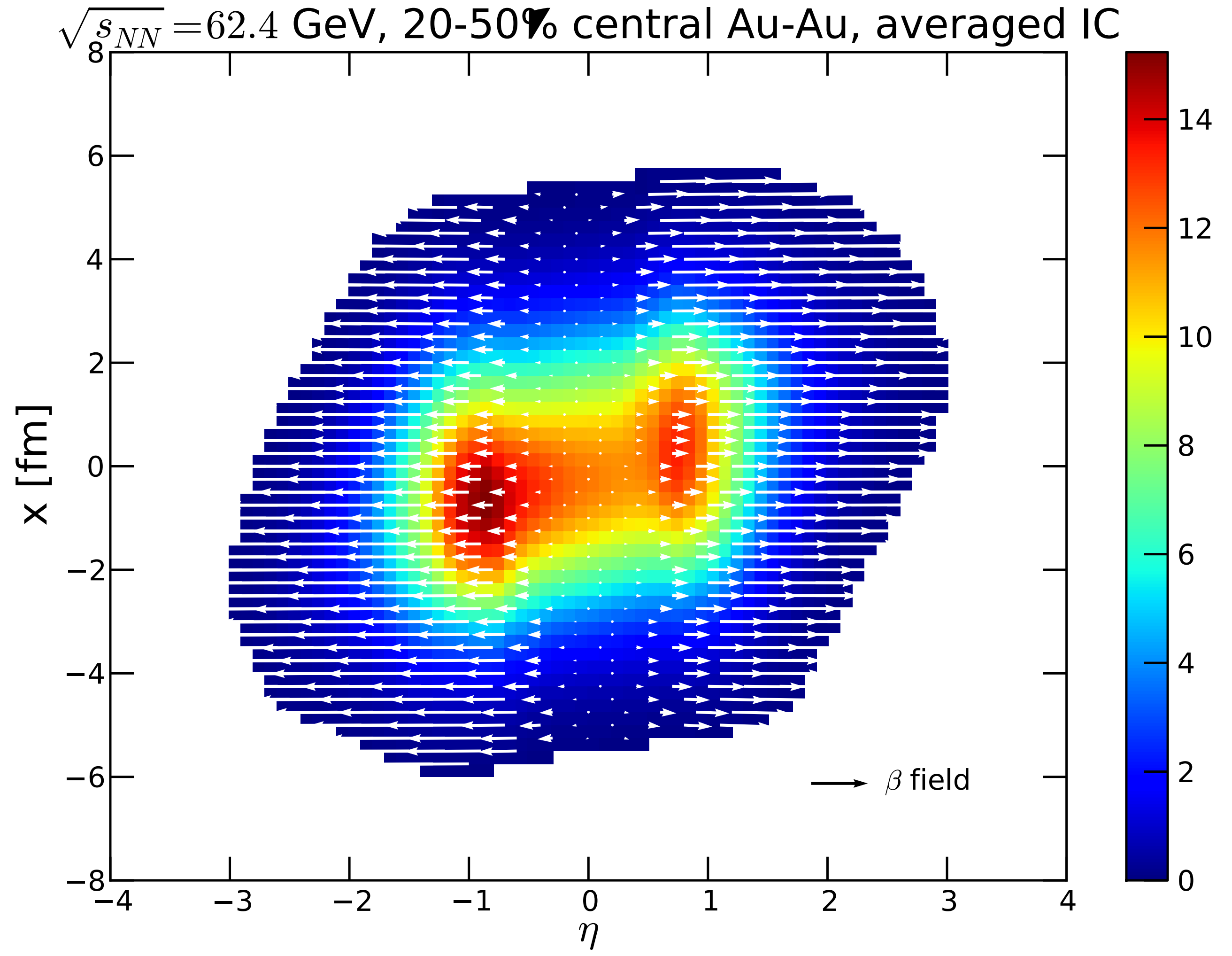
W.T.Feng and X.G.Huang, PRC93.064907 (2016)



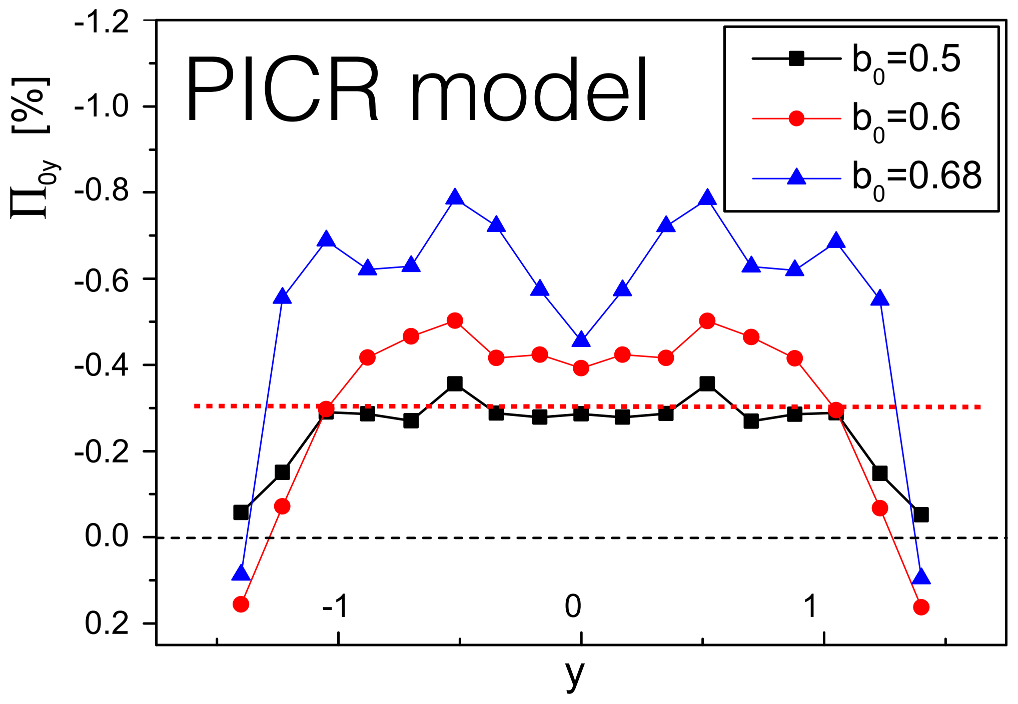
Energy dependence of vorticity vs. rapidity

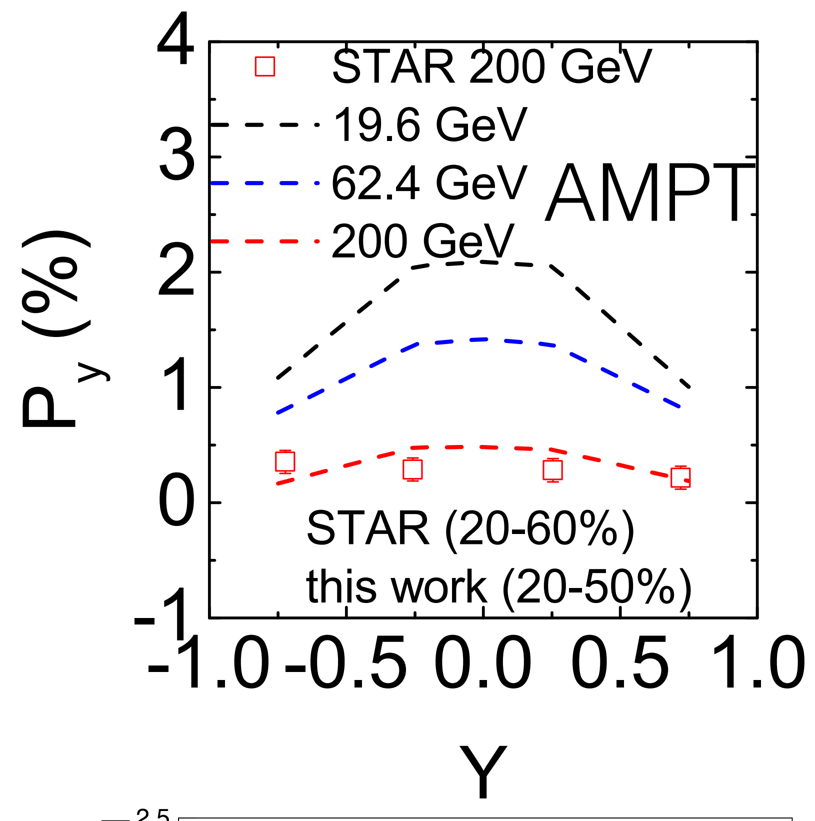
- Baryon stopping and velocity profile in the initial state at given acceptance

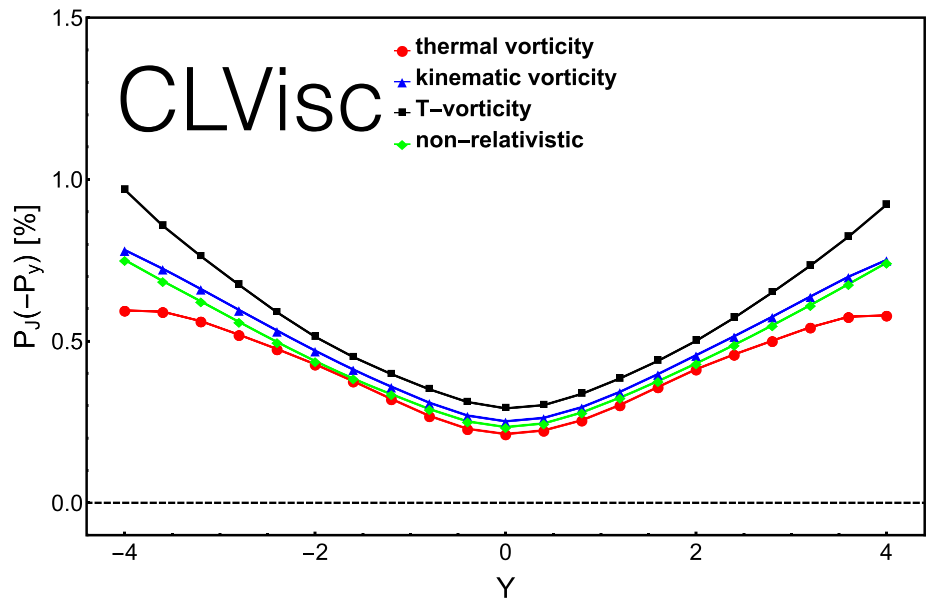
But the predicted polarization trend **differs among models**

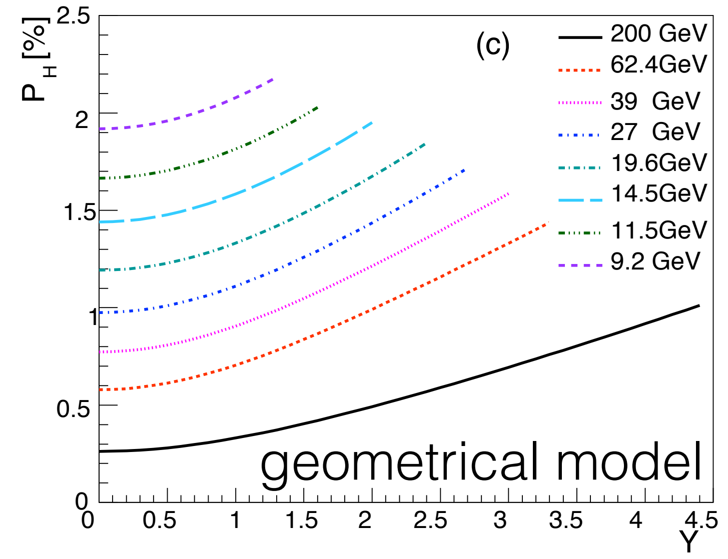


I.Karpenko and F.Becattini, EPJ(2017)77.213





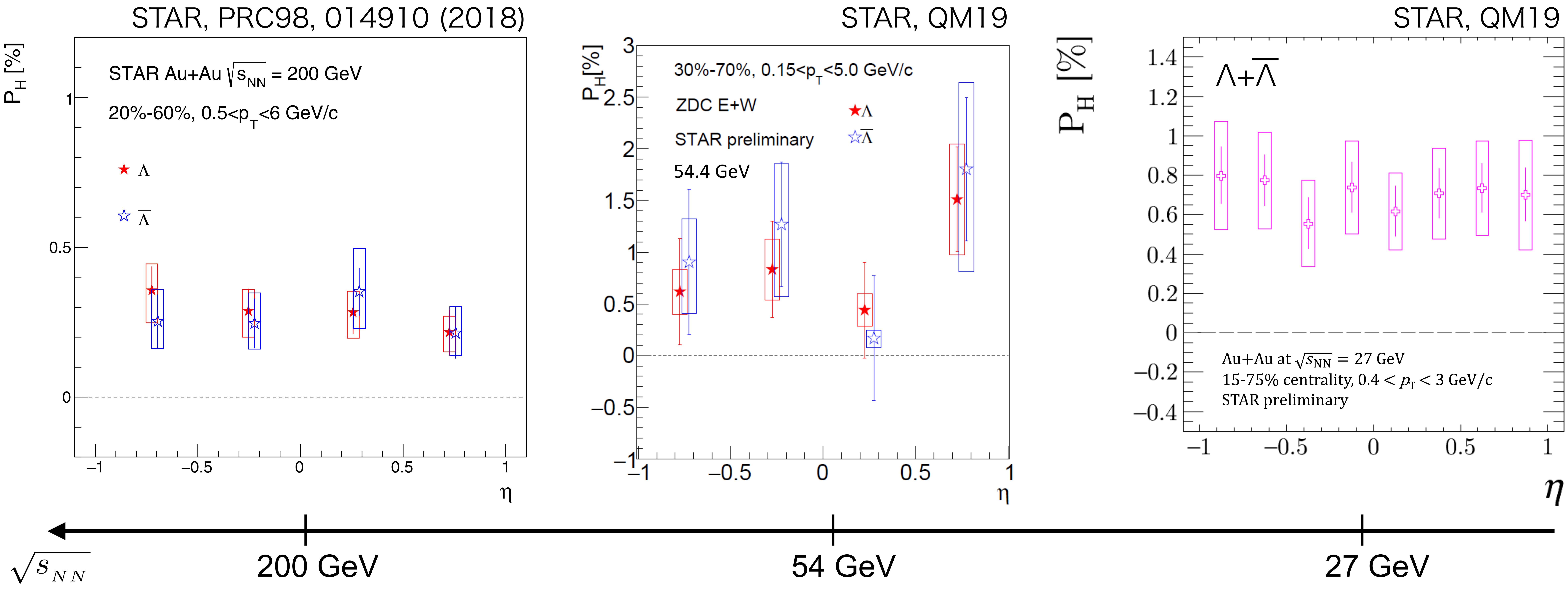




Y.Xie, D.Wang, and L.P.Csernai, RPJ(2020)80:39
H.Z.Wu et al, PRResearch1.033058(2019)

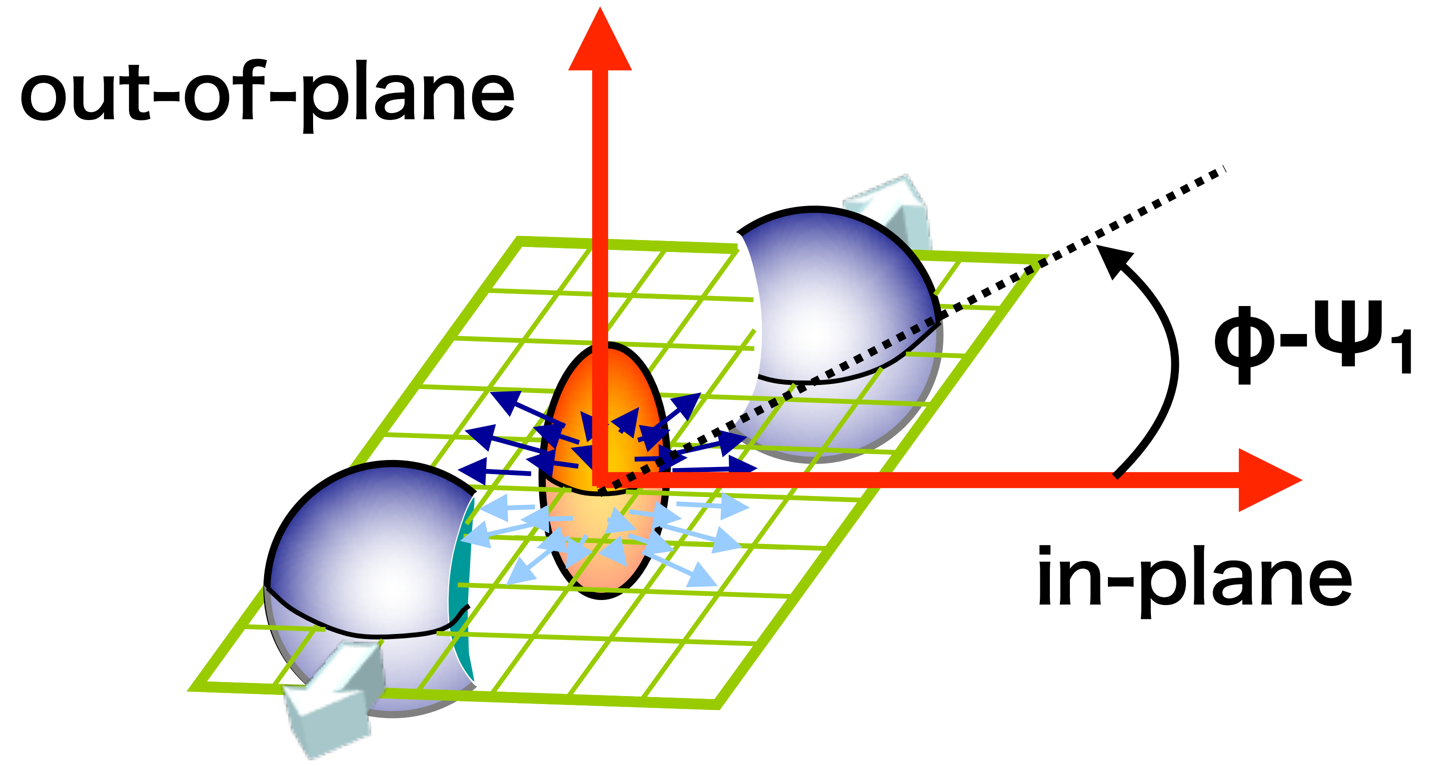
D.X.Wei, W.T.Deng and X.G.Huang, PRC99.014905 (2019)
Z.T.Liang et al., arXiv:1912.10223

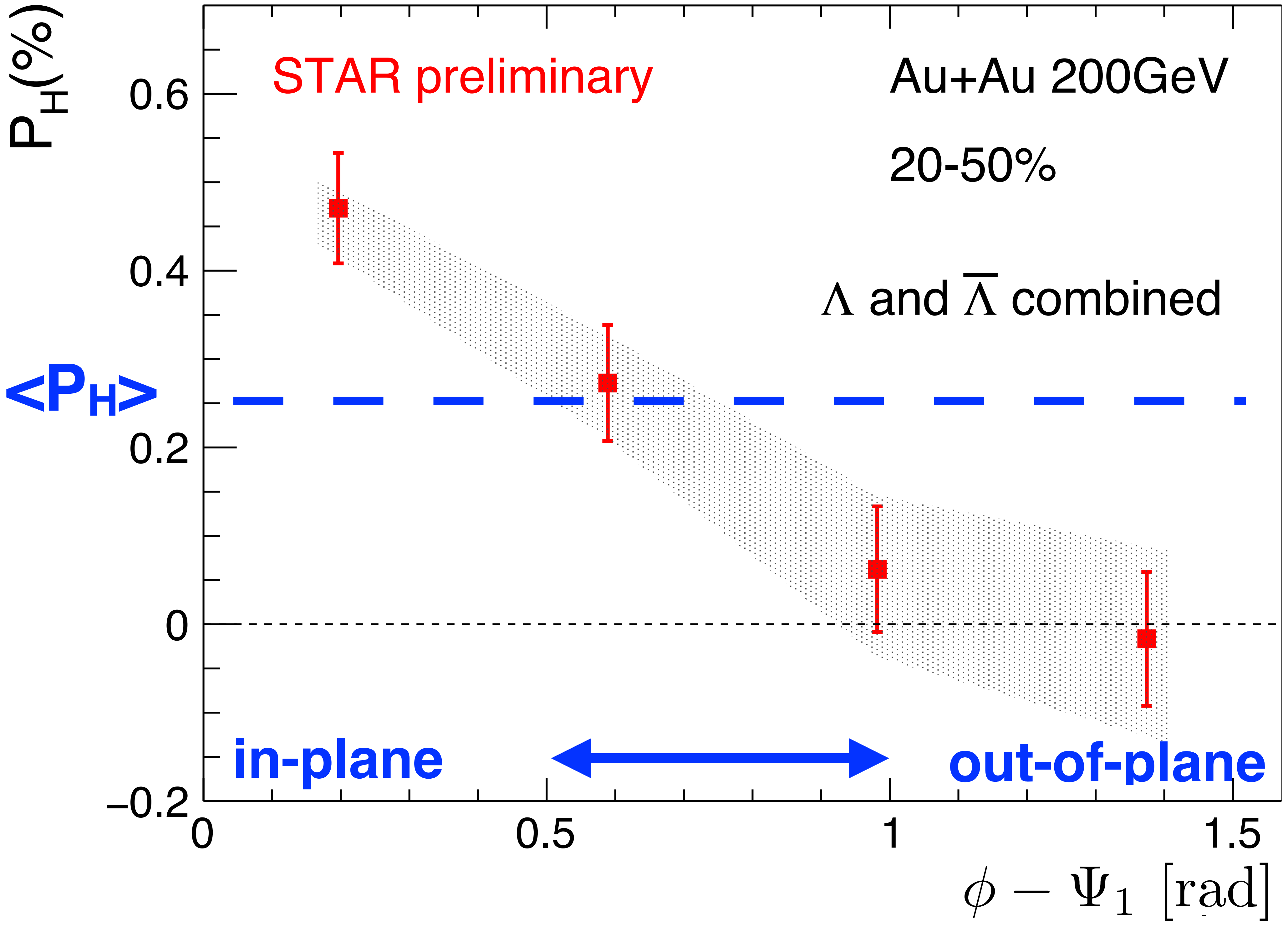
Differential measurements: rapidity



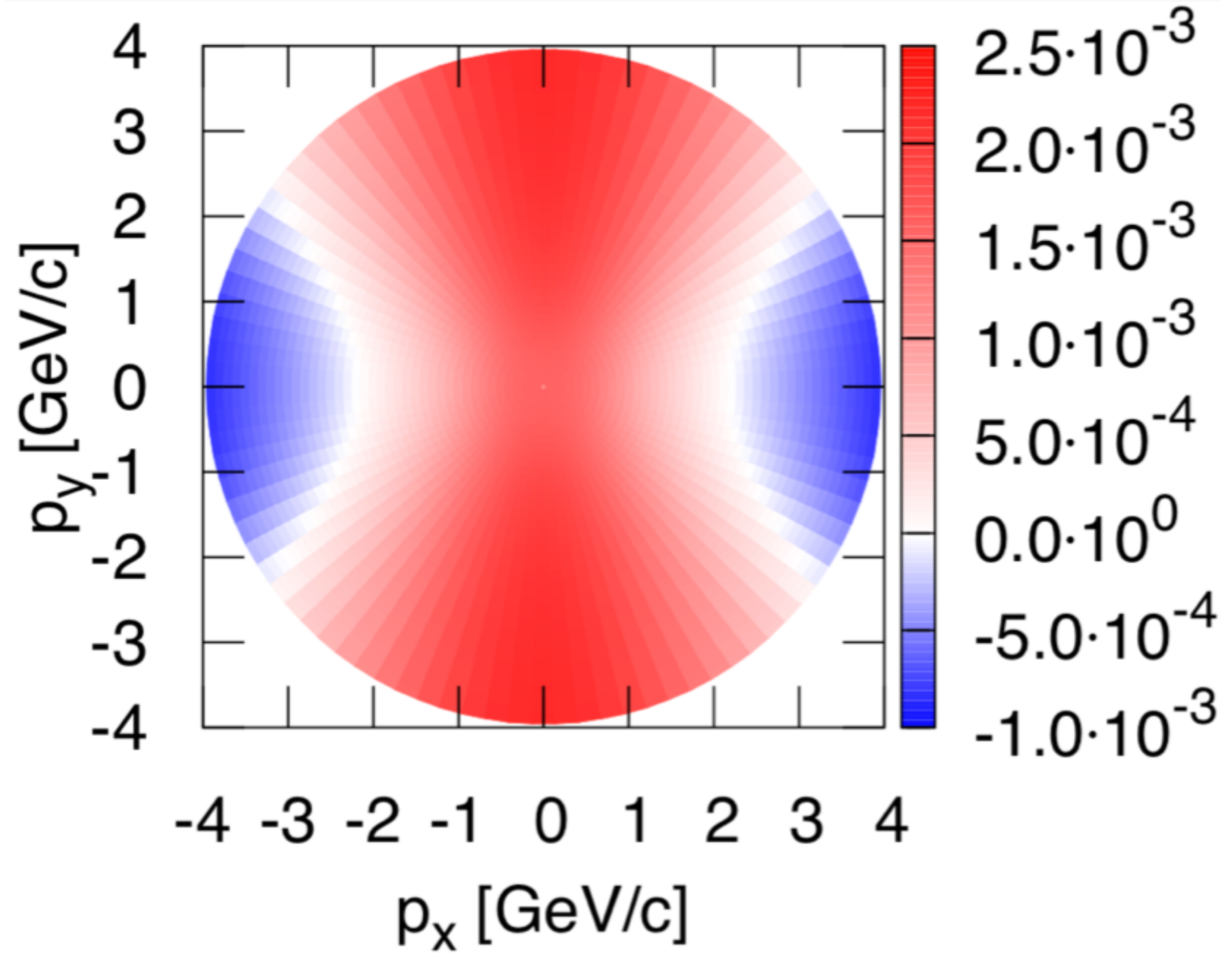
No strong rapidity dependence within |η|<1.
This can be explored further with iTPC(|η|<1.5) and Forward upgrade (2023-).

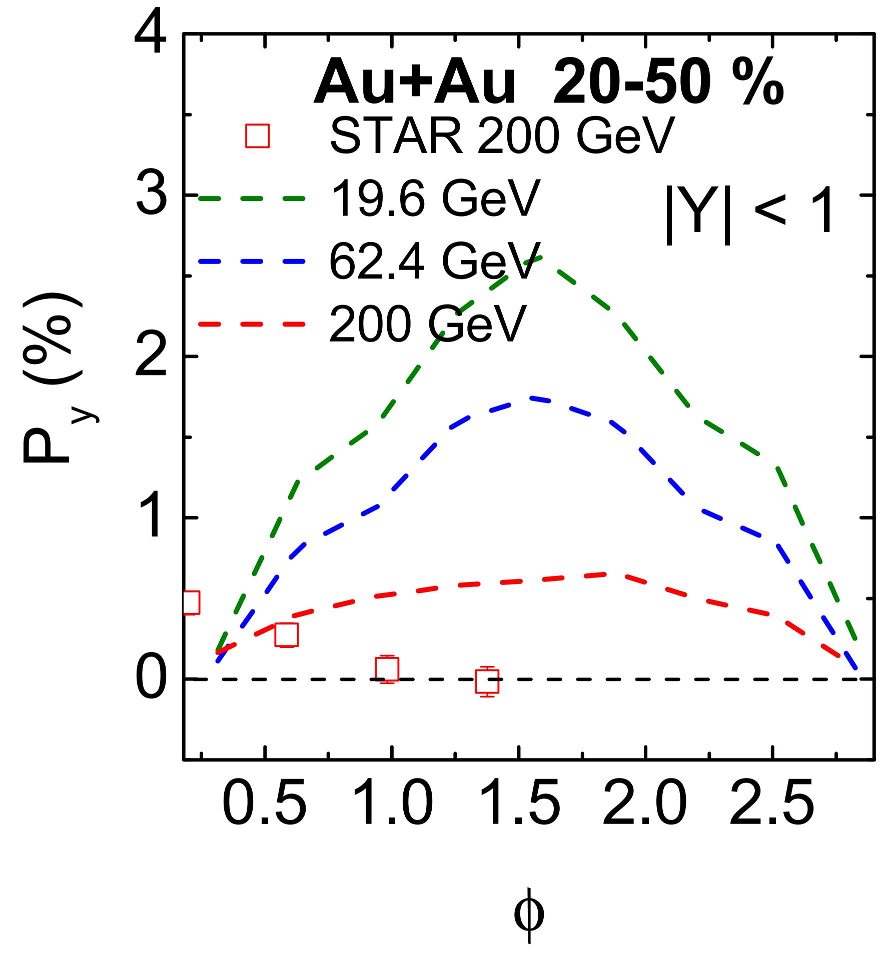
Differential measurements: azimuthal angle





F. Becattini and M. Lisa, arXiv:2003.03640





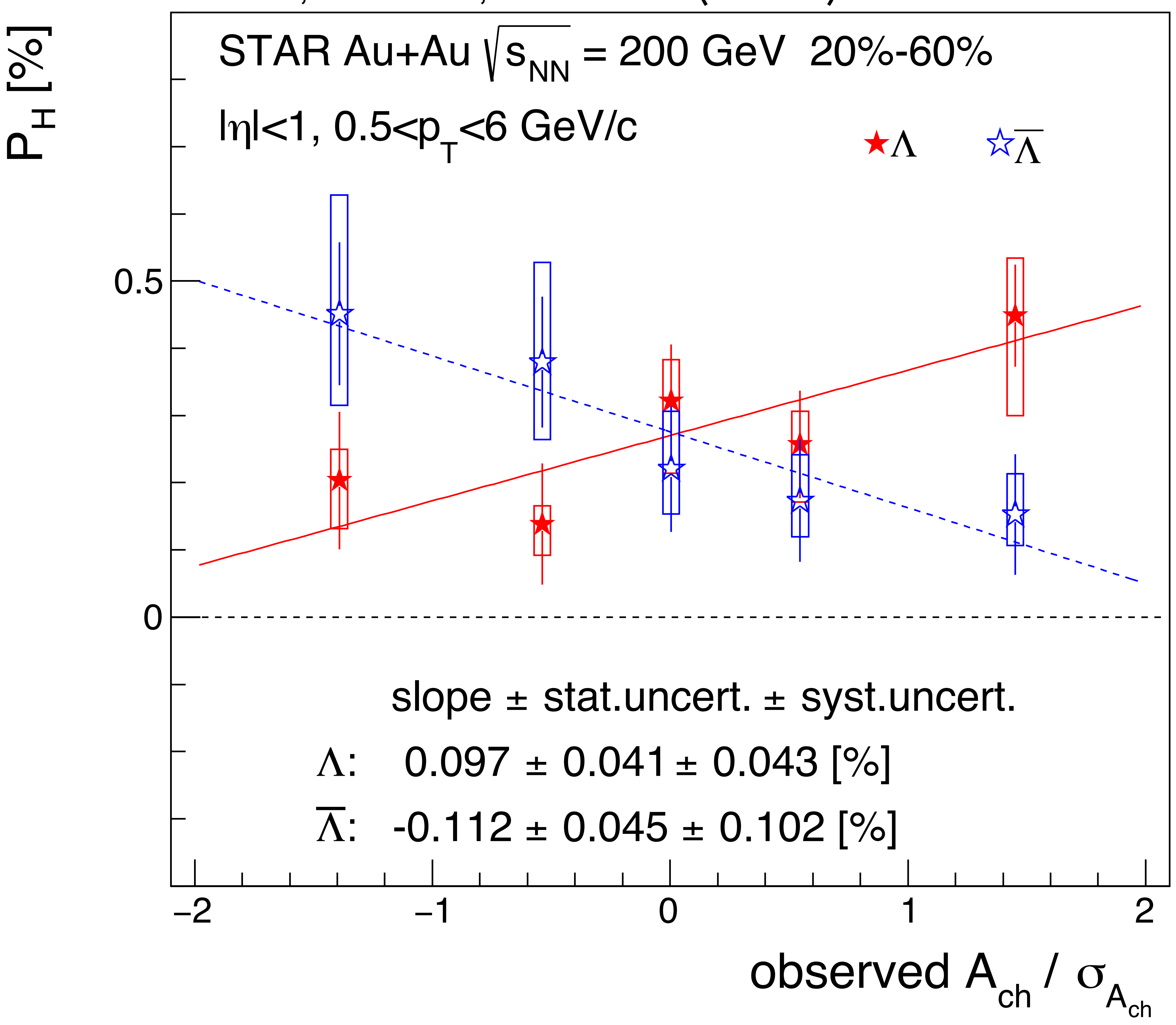
I. Karpenko and F. Becattini, EPJC(2017)77.213
D. Wei, W. Deng, and X. Huang, PRC99.014905 (2019)

"T-vorticity" may explain the data?
H. Wu et al., PR.Research1.033058 (2019)

- The data shows larger polarization for in-plane, while many models predict the opposite, i.e. larger for out-of-plane.
- **Not fully understood yet**

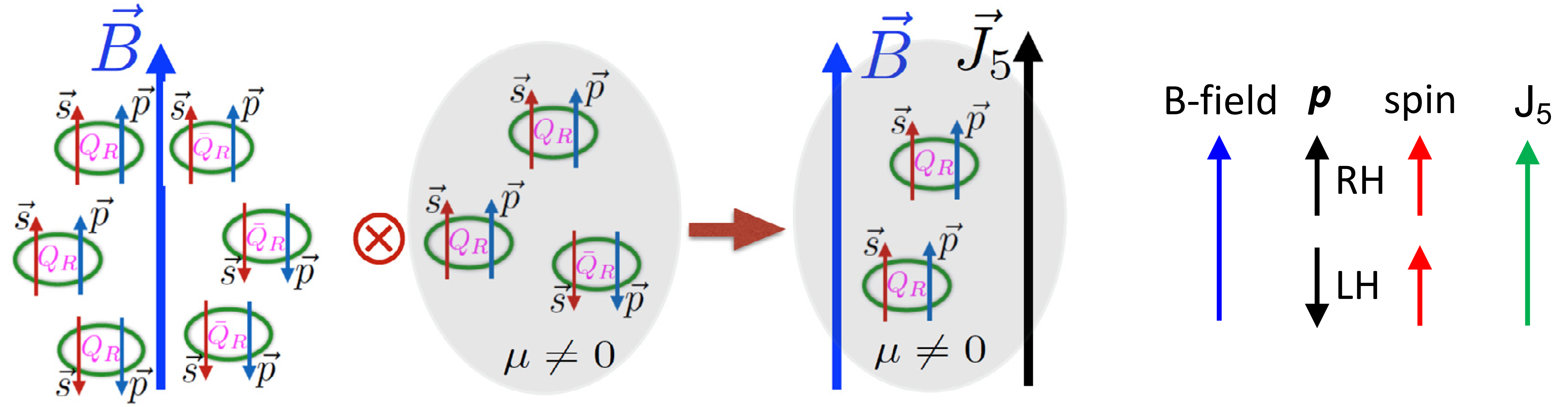
Differential measurements: charge asymmetry

STAR, PRC98, 014910 (2018)



$$\mu_v/T \propto \frac{\langle N_+ - N_- \rangle}{\langle N_+ + N_- \rangle} = A_{ch}$$

Chiral Separation Effect $\mathbf{J}_5 \propto e\mu_v \mathbf{B}$



B-field + massless quarks + non-zero μ_v → axial current J_5

- A_{ch} dependence observed
  - Slopes of Λ and anti-Λ seem to be opposite (~2σ level)
- Possible contribution from axial charge or
- Quark vector chemical potential may explain the data

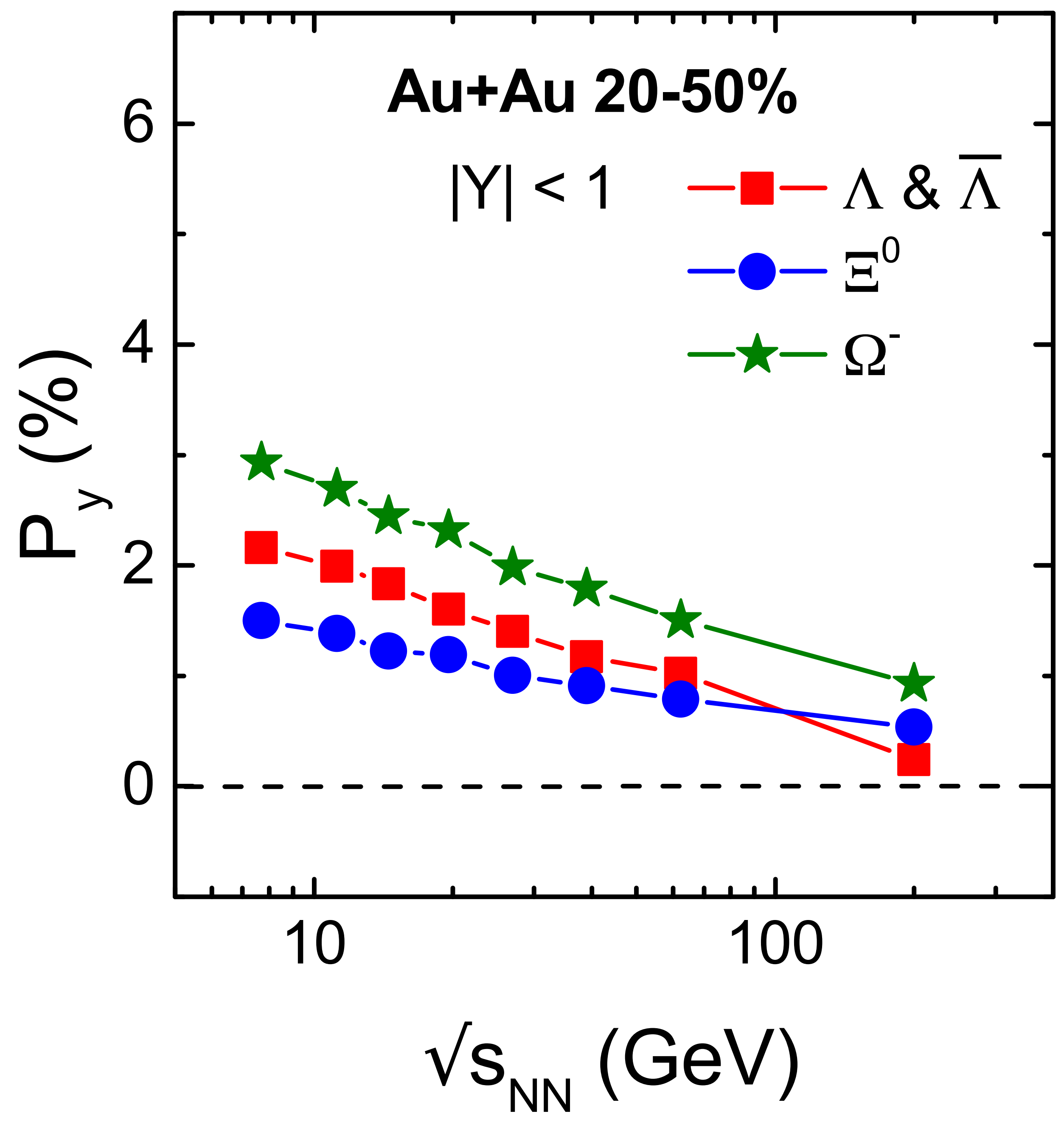
Sun and Ko, INT20-1-c

Other particles to measure polarization?

P. A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)

	Mass (GeV/c^2)	cτ (cm)	decay mode	decay parameter	magnetic moment (μ_N)	spin
Λ (uds)	1.115683	7.89	Λ->πp (63.9%)	0.732±0.014	−0.613	1/2
Ξ^- (dss)	1.32171	4.91	Ξ^-->Λπ^- (99.887%)	−0.401±0.010	−0.6507	1/2
Ω^- (sss)	1.67245	2.46	Ω^-->ΛK^- (67.8%)	0.0157±0.002	-2.02	3/2

W.-T. Deng and X.-G. Huang, PRC93.064907 (2016)



Natural candidates would be Ξ and Ω hyperons.

- Different spin and magnetic moments
- Less feed-down in Ξ and Ω compared to Λ
- Could be different freeze-out
- Different valence s-quarks

Based on thermal model:

$P(s=1/2) \sim \omega/(2T)$, $P(s=3/2) \sim 4\,\omega/(5T)$

F.Becattini et al., PRC95.054902 (2017)

Ξ and Ω polarization measurements

$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}\left(1 + \alpha_H \mathbf{P}_H^* \cdot \hat{\boldsymbol{p}}_B^*\right)$$

Getting difficult due to smaller decay parameter for Ξ and Ω…

$$\alpha_\Lambda = 0.732,\ \alpha_{\Xi^-} = -0.401,\ \alpha_{\Omega^-} = 0.0157$$

spin 1/2

Polarization of daughter Λ in a weak decay of Ξ:
(based on Lee-Yang formula)

T.D. Lee and C.N. Yang, Phys. Rev.108.1645 (1957)

$$\mathbf{P}_\Lambda^* = \frac{(\alpha_\Xi + \mathbf{P}_\Xi^* \cdot \hat{\boldsymbol{p}}_\Lambda^*)\hat{\boldsymbol{p}}_\Lambda^* + \beta_\Xi \mathbf{P}_\Xi^* \times \hat{\boldsymbol{p}}_\Lambda^* + \gamma_\Xi \hat{\boldsymbol{p}}_\Lambda^* \times (\mathbf{P}_\Xi^* \times \hat{\boldsymbol{p}}_\Lambda^*)}{1 + \alpha_\Xi \mathbf{P}_\Xi^* \cdot \hat{\boldsymbol{p}}_\Lambda^*}$$

$$\mathbf{P}_\Lambda^* = C_{\Xi^-\Lambda}\mathbf{P}_\Xi^* = \tfrac{1}{3}\left(1 + 2\gamma_\Xi\right)\mathbf{P}_\Xi^*.$$

$$C_{\Xi^-\Lambda} = +0.927,\ \alpha^2 + \beta^2 + \gamma^2 = 1$$

spin 3/2

Similarly, daughter Λ polarization from Ω:

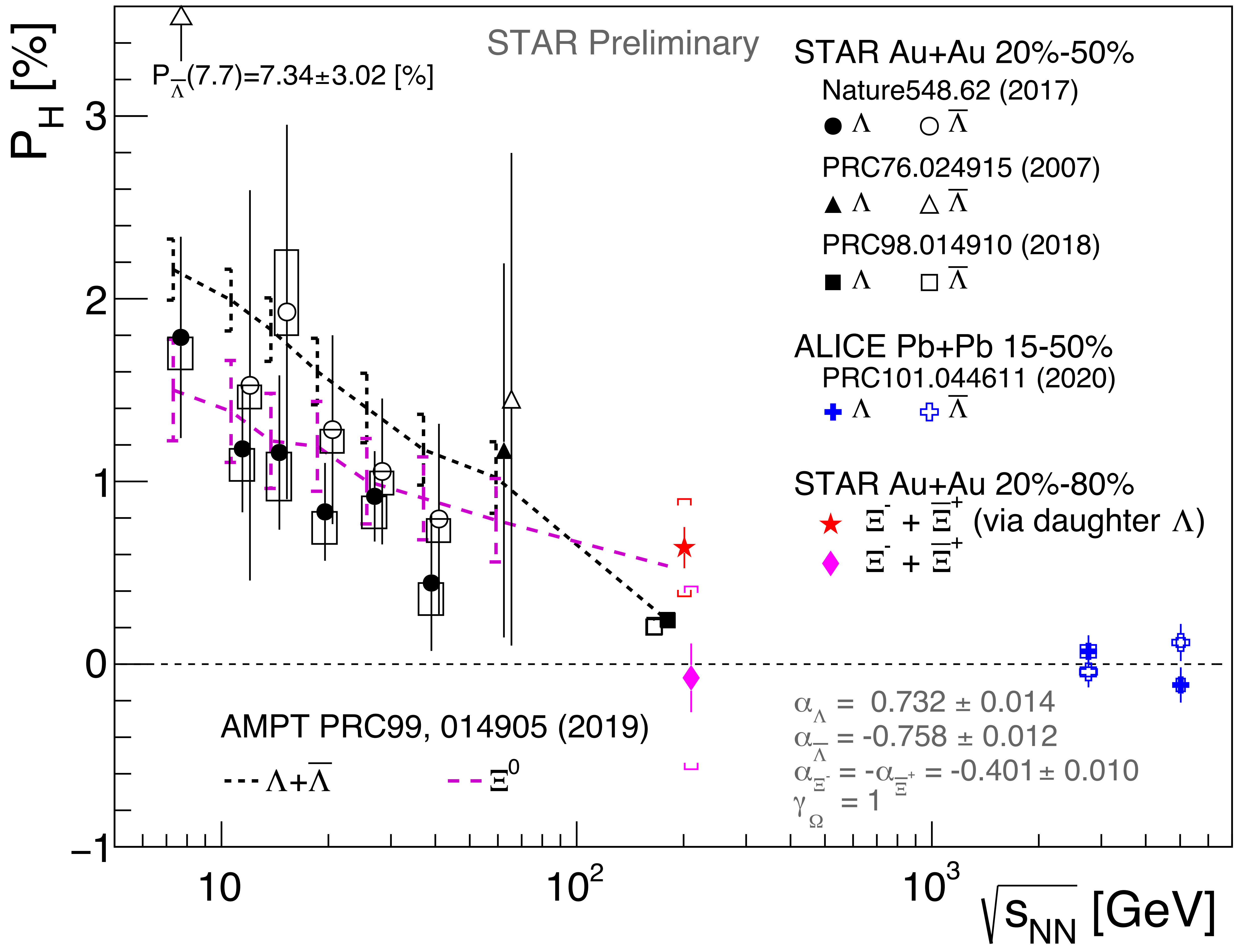
$$\mathbf{P}_\Lambda^* = C_{\Omega^-\Lambda}\mathbf{P}_\Omega^* = \tfrac{1}{5}\left(1 + 4\gamma_\Omega\right)\mathbf{P}_\Omega^*.$$

Here **γ_Ω is unknown**.
Time-reversal violation parameter β would be small, then the polarization transfer $C_{\Omega\Lambda}$ leads to:

$$C_{\Omega\Lambda} \approx +1 \text{ or } -0.6$$

Parent particle polarization can be studied by measuring daughter particle polarization!

Ξ global polarizations at $\sqrt{s_{NN}}$ = 200 GeV



* published results are rescaled by $\alpha_{old}/\alpha_{new}$~0.87

Ξ P_H by analyzing daughter Λ distributions

- less sensitive due to smaller α_Ξ=-0.4 than α_Λ=0.732

Ξ P_H via daughter Λ P_H (by granddaughter proton) with the polarization transfer $C_{\Xi\Lambda}$=+0.927

- positive polarization with 2.2σ level
- slightly larger than inclusive Λ P_H
- close to AMPT prediction

W.-T. Deng and X.-G. Huang, PRC93.064907 (2016)

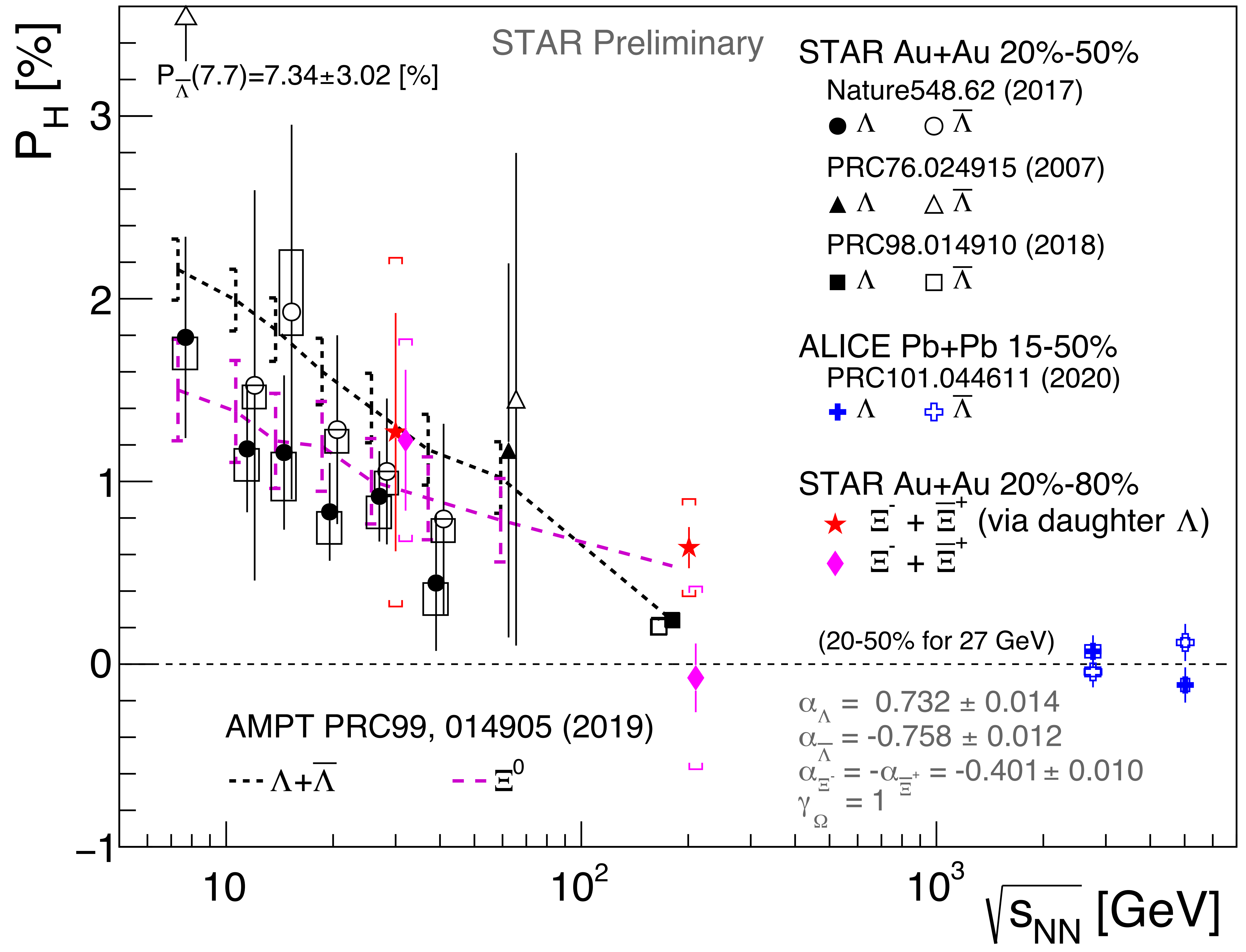
Naive expectations in Ξ vs. Λ P_H

- Lighter particles could be more polarized (**Ξ<Λ**)
- Earlier freeze-out (of multi-strangeness) leads to larger P_H (**Ξ>Λ**)

O.Vitiuk, L.V.Bravina, and E.E.Zabrodin, PLB803(2020)135298

- Feed-down: ~15-20% reduction for primary Λ P_H

Ξ global polarizations at $\sqrt{s_{NN}}$ = 200 GeV and 27 GeV



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W.-T. Deng and X.-G. Huang, PRC93.064907 (2016)

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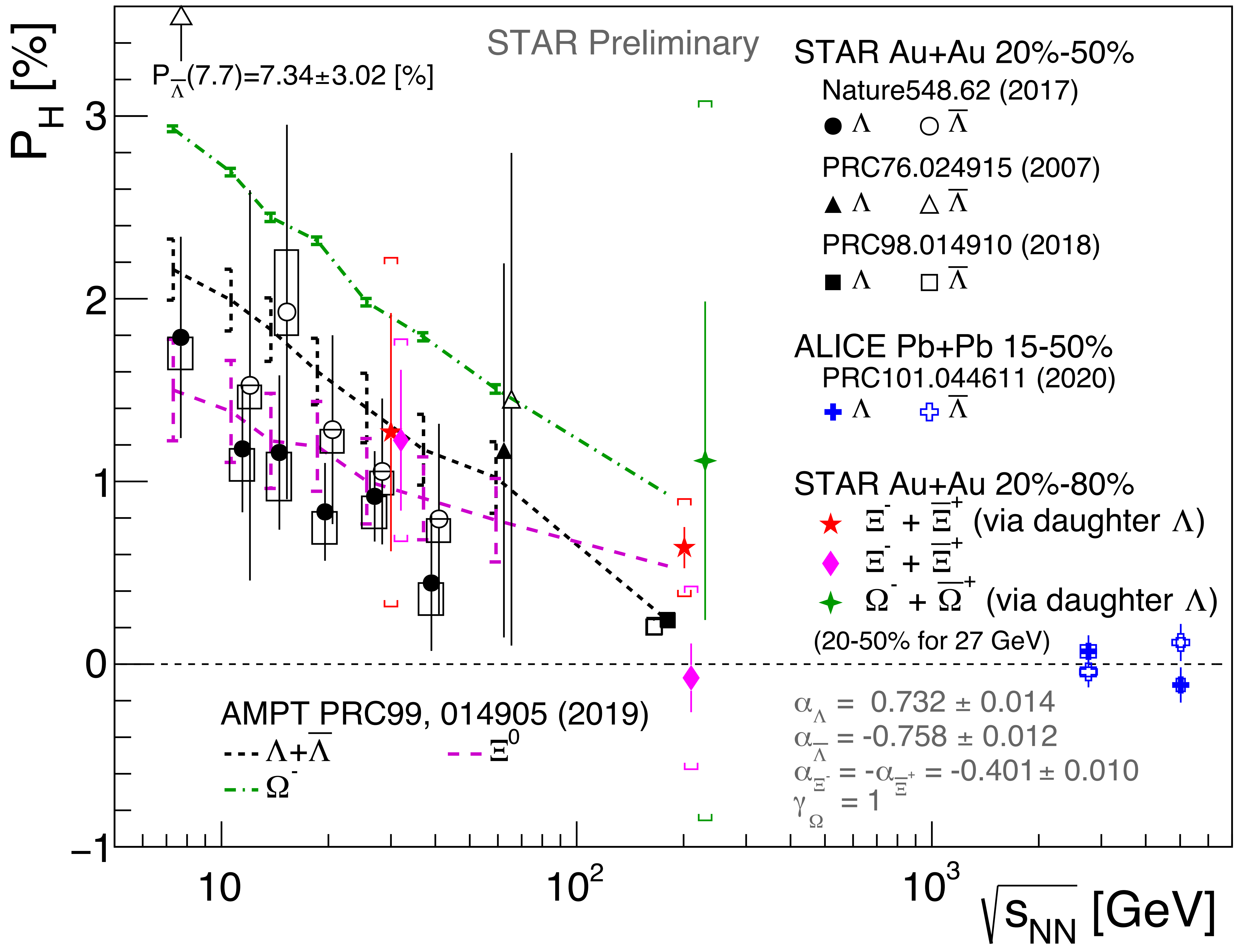
Ω global polarizations at $\sqrt{s_{NN}}$ = 200 GeV



* published results are rescaled by $\alpha_{old}/\alpha_{new}$~0.87

Ω P_H via daughter Λ P_H assuming the polarization transfer $C_{\Omega\Lambda}$=+1

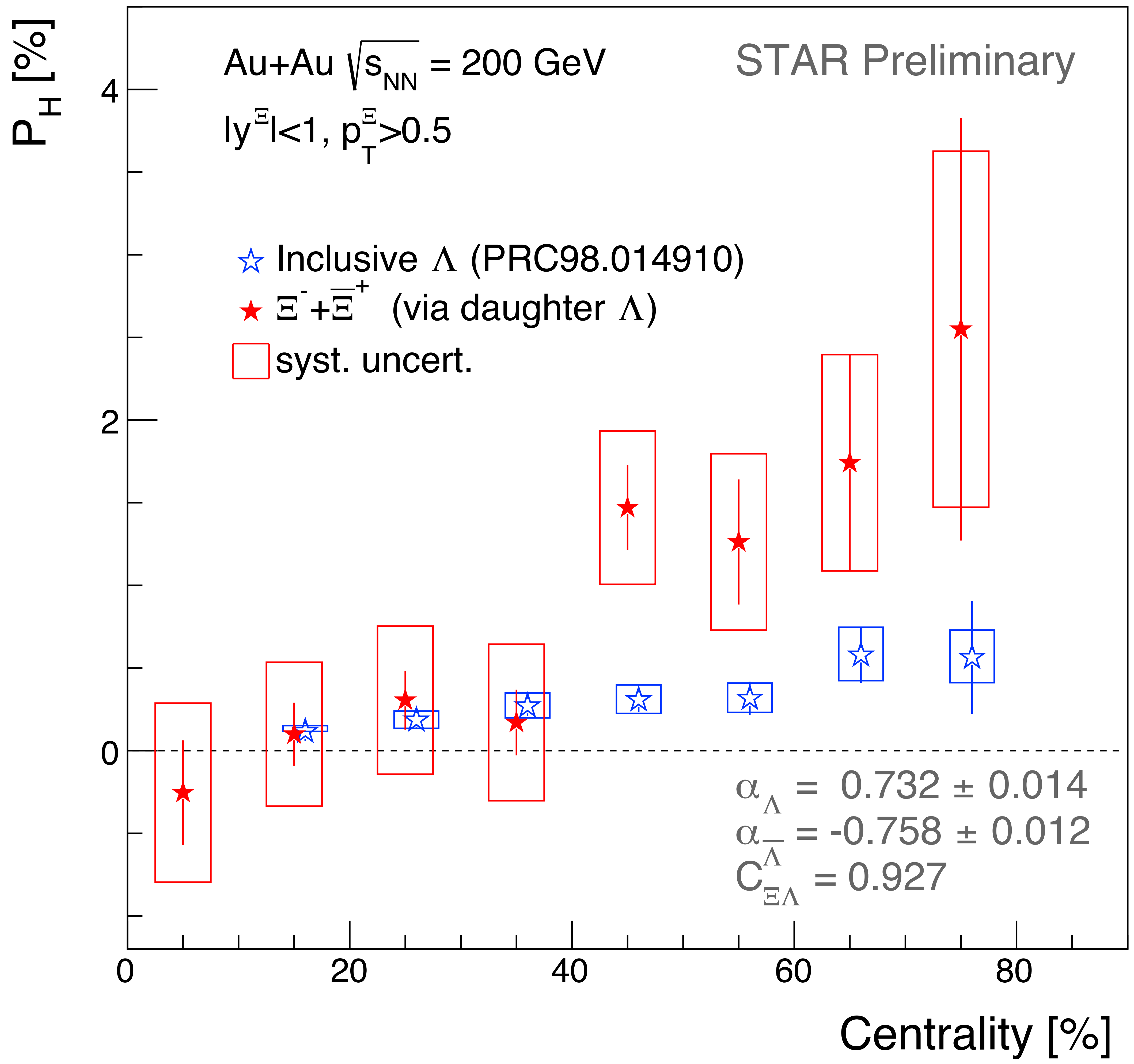
- Large uncertainty, to be improved in future analysis

- Based on the vorticity picture, the data seems to favor $C_{\Omega\Lambda}$=+1 (γ_Ω=+1) rather than $C_{\Omega\Lambda}$=-0.6 (γ_Ω=-1)

  ** In other words, γ_Ω can be measured in HIC assuming the global polarization*

- Also close to AMPT expectation

Centrality dependence of Ξ P_H



* published results are rescaled by $\alpha_{old}/\alpha_{new}$~0.87

Ξ P_H via daughter Λ P_H seems to increase in peripheral events, as seen in Λ P_H at 200 GeV

- No significant difference between Ξ and Ξbar, therefore results are combined
- Qualitatively consistent with the centrality dependence of vorticity predicted in models

Y.Jiang, Z.W.Lin, and J.Liao, PRC94.044910 (2016)

Global spin alignment of vector mesons

Angular distribution of the decay products can be written with spin density matrix ρ_{nn}.

$$\frac{dN}{d\cos\theta^*} \propto \rho_{0,0}|Y_{1,0}|^2 + \rho_{1,1}|Y_{1,-1}|^2 + \rho_{-1,-1}|Y_{1,1}|^2 \propto \rho_{0,0}\cos^2\theta^* + \frac{1}{2}(\rho_{1,1}+\rho_{-1,-1})\sin^2\theta^*$$

$$\propto (1-\rho_{0,0}) + (3\rho_{0,0}-1)\cos^2\theta^*$$

$$\rho_{00} = \frac{1}{3} - \frac{8}{3}\langle\cos[2(\phi_p^* - \Psi_{RP})]\rangle$$

Species	K^{*0}	φ
Quark content	$d\bar{s}$	$s\bar{s}$
Mass (MeV/c^2)	896	1020
Lifetime (fm/c)	4	45
Spin (J^P)	1^-	1^-
Decays	Kπ	KK
Branching ratio	**~100%**	66%

Deviation from 1/3 in ρ_{00} indicates spin alignment.

* sign of the polarization cannot be determined. Therefore it's called "spin alignment measurement" rather than "polarization measurement"

Z.-T. Liang and X.-N. Wang, PRL94.102301(2005)
Y. Yang et al., PRC97.034917(2018)

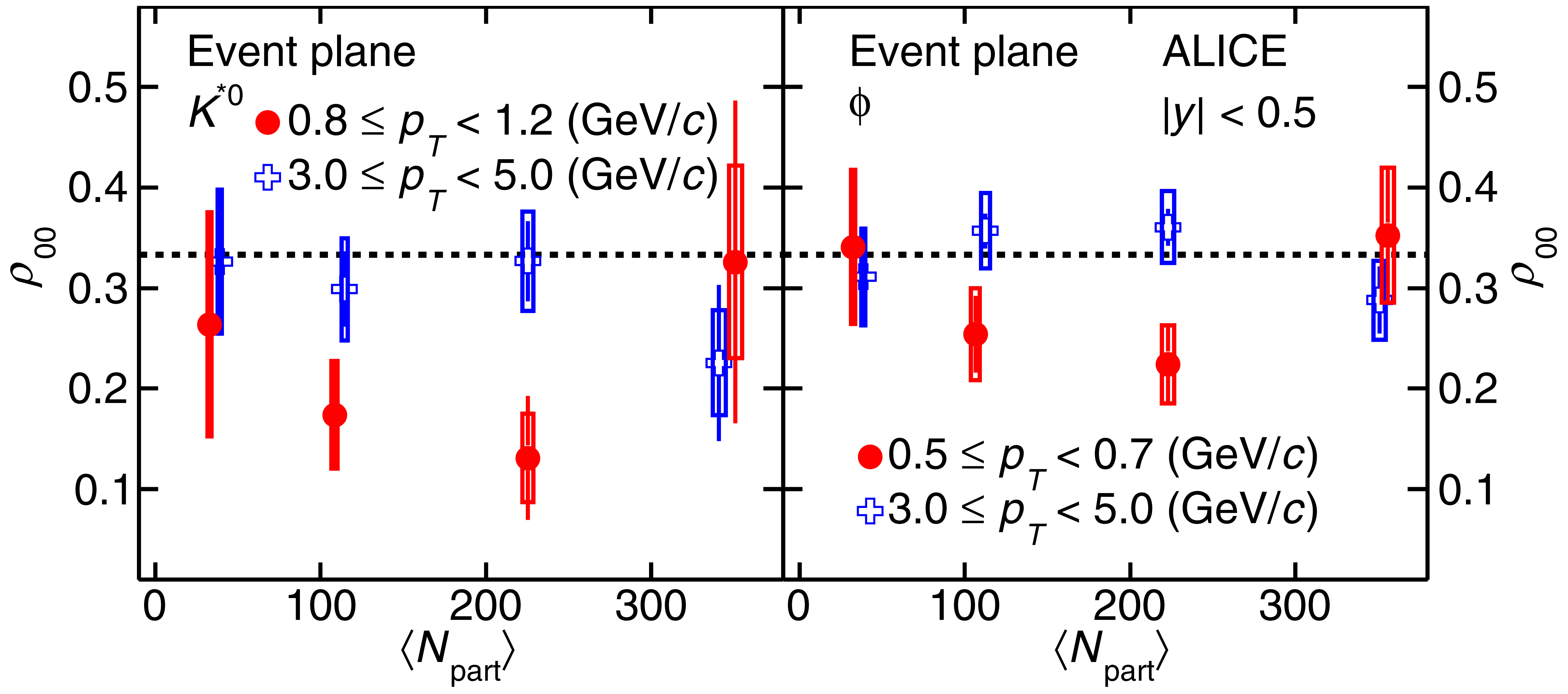
Theoretical expectation for ρ_{00}

Vorticity	
recombination	$\rho_{00} < 1/3$
fragmentation	$\rho_{00} > 1/3$
Magnetic field	$\rho_{00} > 1/3$ (for neutral vector mesons)

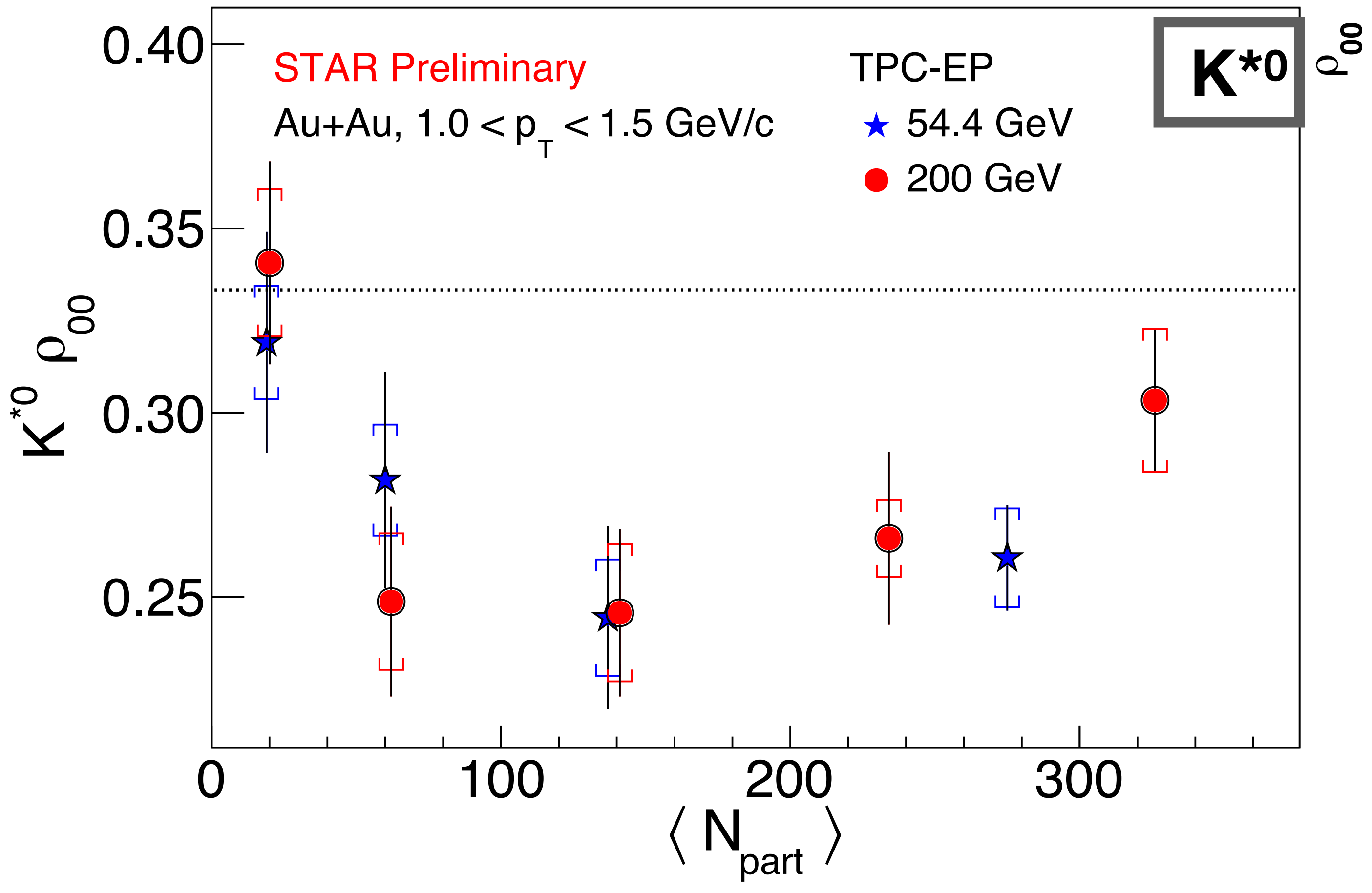
ρ_{00} depends on hadronization process

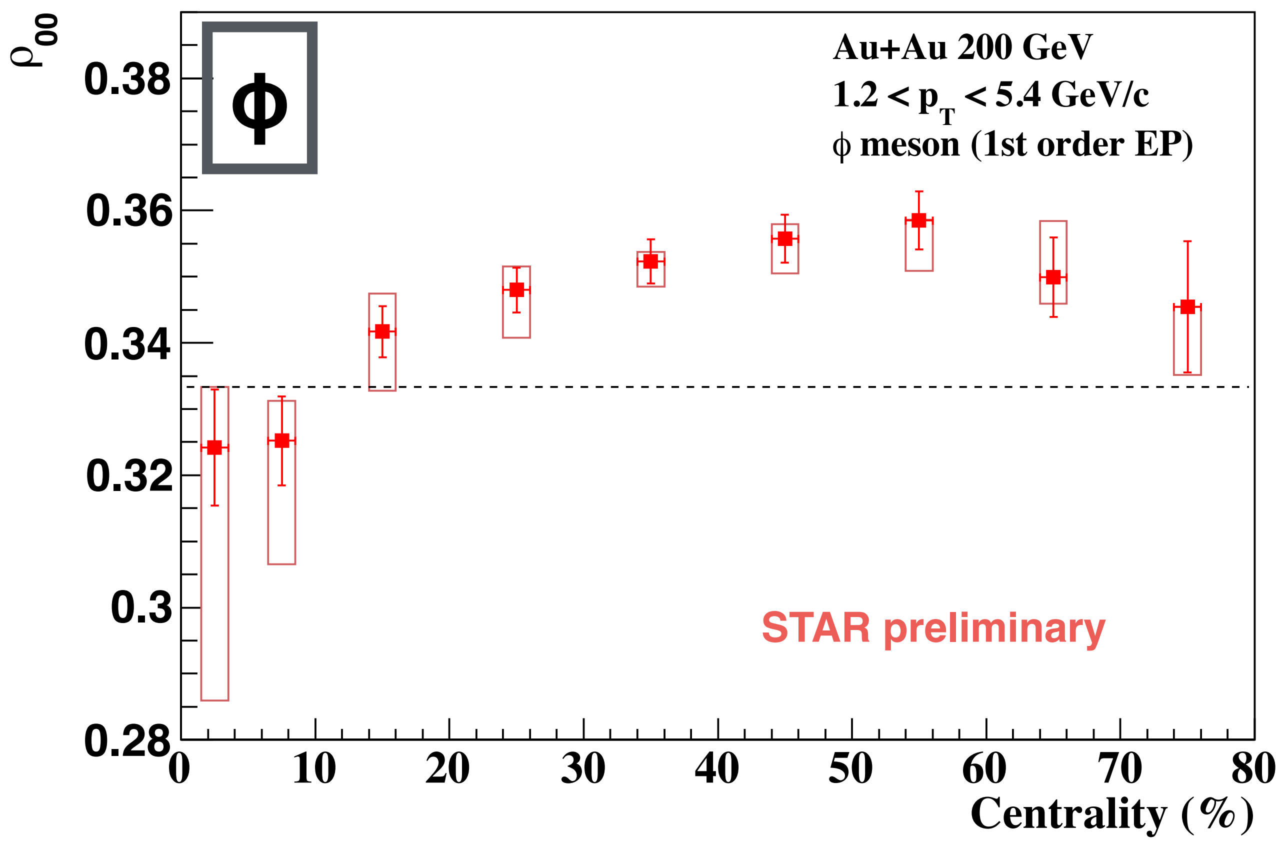
Results from LHC and RHIC

ALICE, PRL125.012301 (2020)



STAR, QM18, QM19





- Large deviation from 1/3, which cannot be explained by the vorticity picture

$$\rho_{00} = 1/[3 + (\omega/T)^2].$$

- The deviation in opposite way between:
  - K* and ϕ at RHIC
  - LHC and RHIC for ϕ

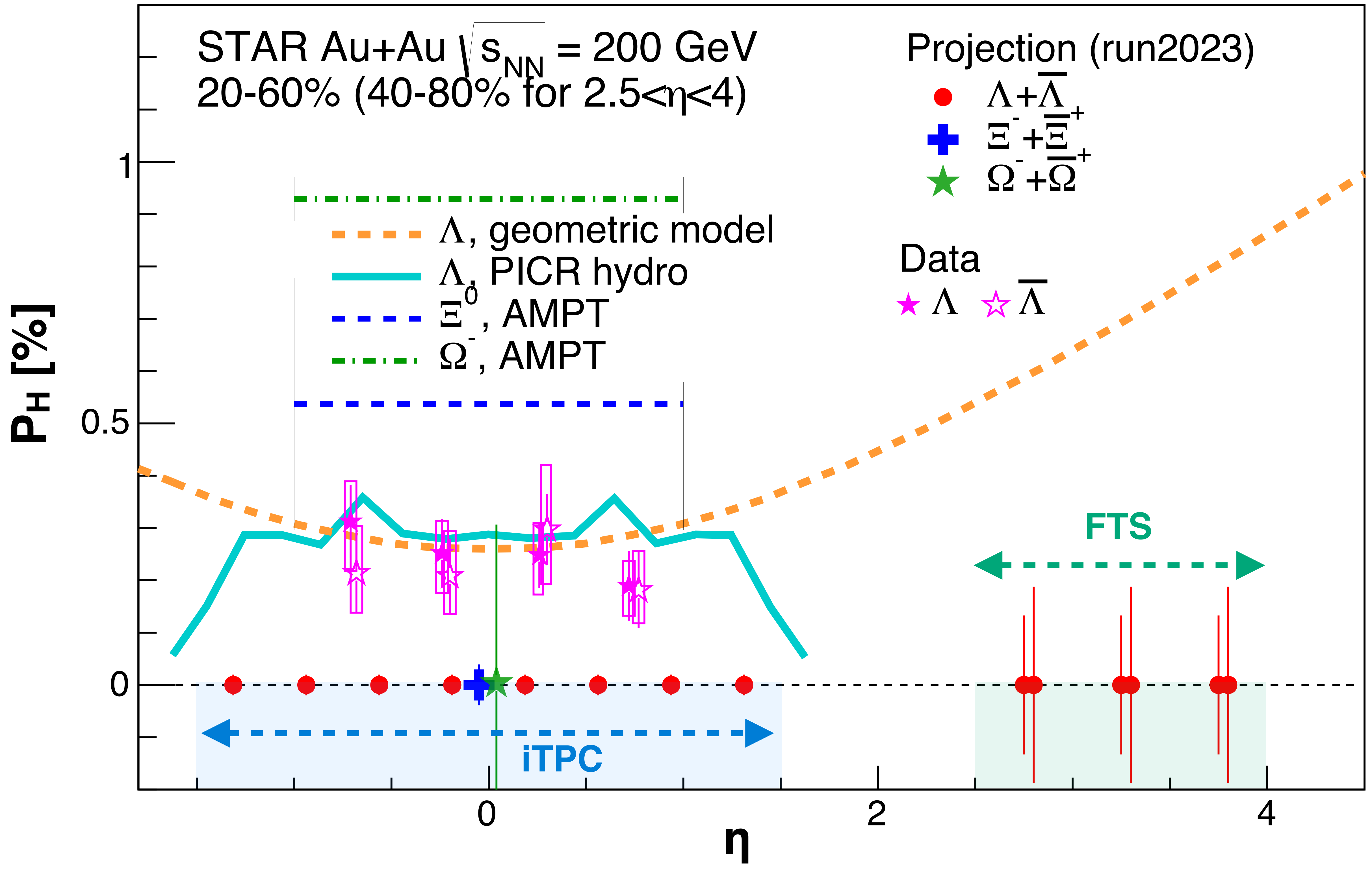
Mean field of ϕ meson may play a role?
Does it change from RHIC to LHC only for ϕ?

X. Sheng, L. Oliva, and Q. Wang, PRD101.096005(2020)
X. Sheng, Q.Wang, and X. Wang, PRD102.056013 (2020)

Outlook

- More precise measurements will be done in the following years
  - High statistics data of BES-II 7.7-19.6 GeV and FXT 3-7.7 GeV
  - Isobaric collision data (Ru+Ru, Zr+Zr), ~10% difference in B-field
  - Forward detectors in Run-2023 Au+Au 200 GeV

BUR2020, STAR Note SN0755



Summary

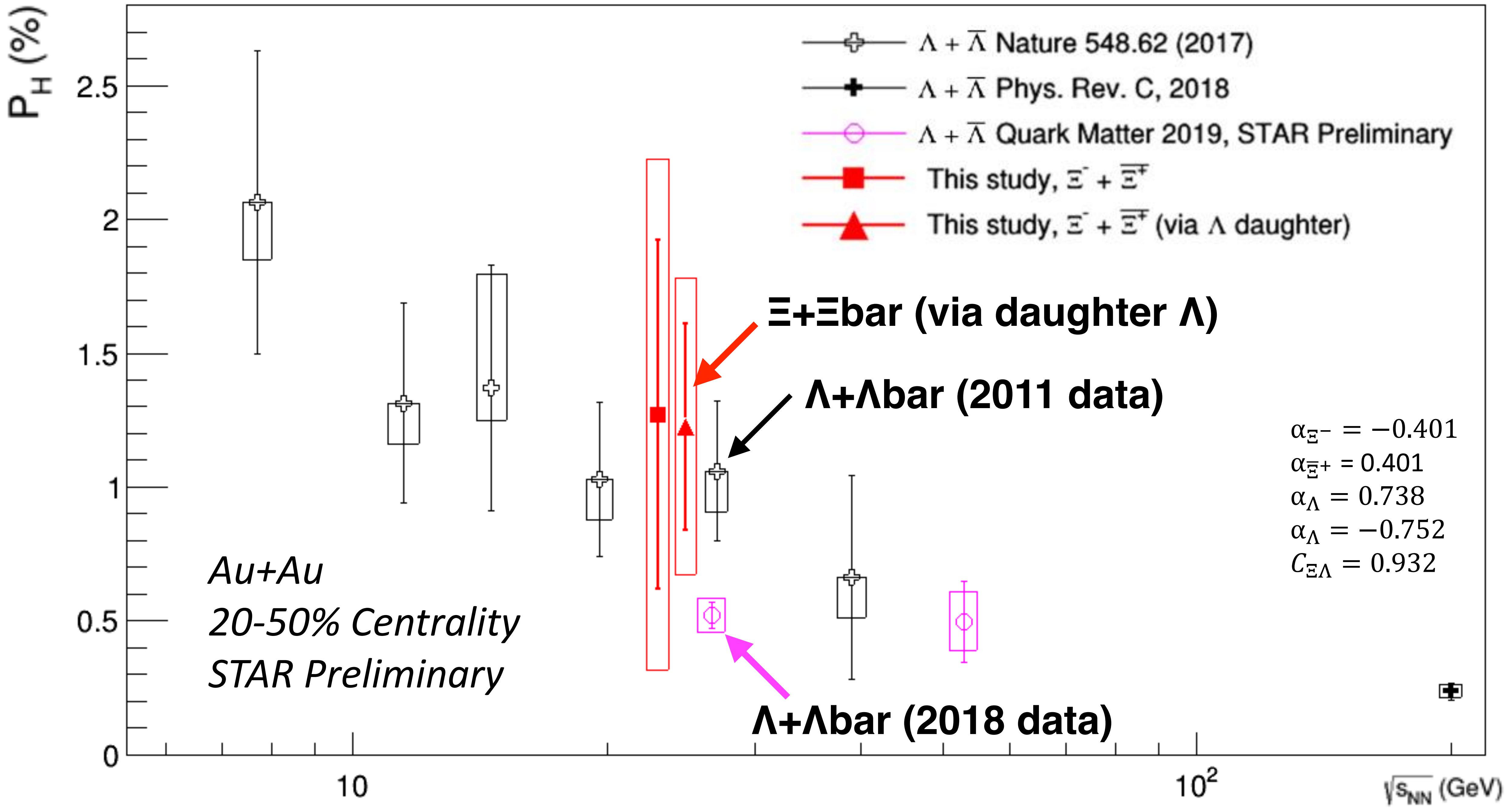
- Global polarization of Λ has been observed at $\sqrt{s_{NN}}$ = 7.7-200 GeV
  - Most vortical fluid (ω~10^{21} s^{-1}) created in heavy-ion collisions
  - Energy dependence, increasing in lower $\sqrt{s_{NN}}$, is captured well by theoretical models
  - Azimuthal angle dependence is not fully understood yet
- First measurements of Ξ and Ω global polarizations at $\sqrt{s_{NN}}$ = 27 and 200 GeV
  - Positive signal of Ξ polarization, comparable to or slightly larger than Λ, has been observed
  - Qualitatively consistent with AMPT predictions
  - Current result of Ω polarization has large uncertainty, which can be improved in future analysis
- Global spin alignment shows larger deviation from 1/3
  - ϕ meson field may explain this large deviation?
  - Different trends between RHIC and LHC; ϕ meson needs to be understood

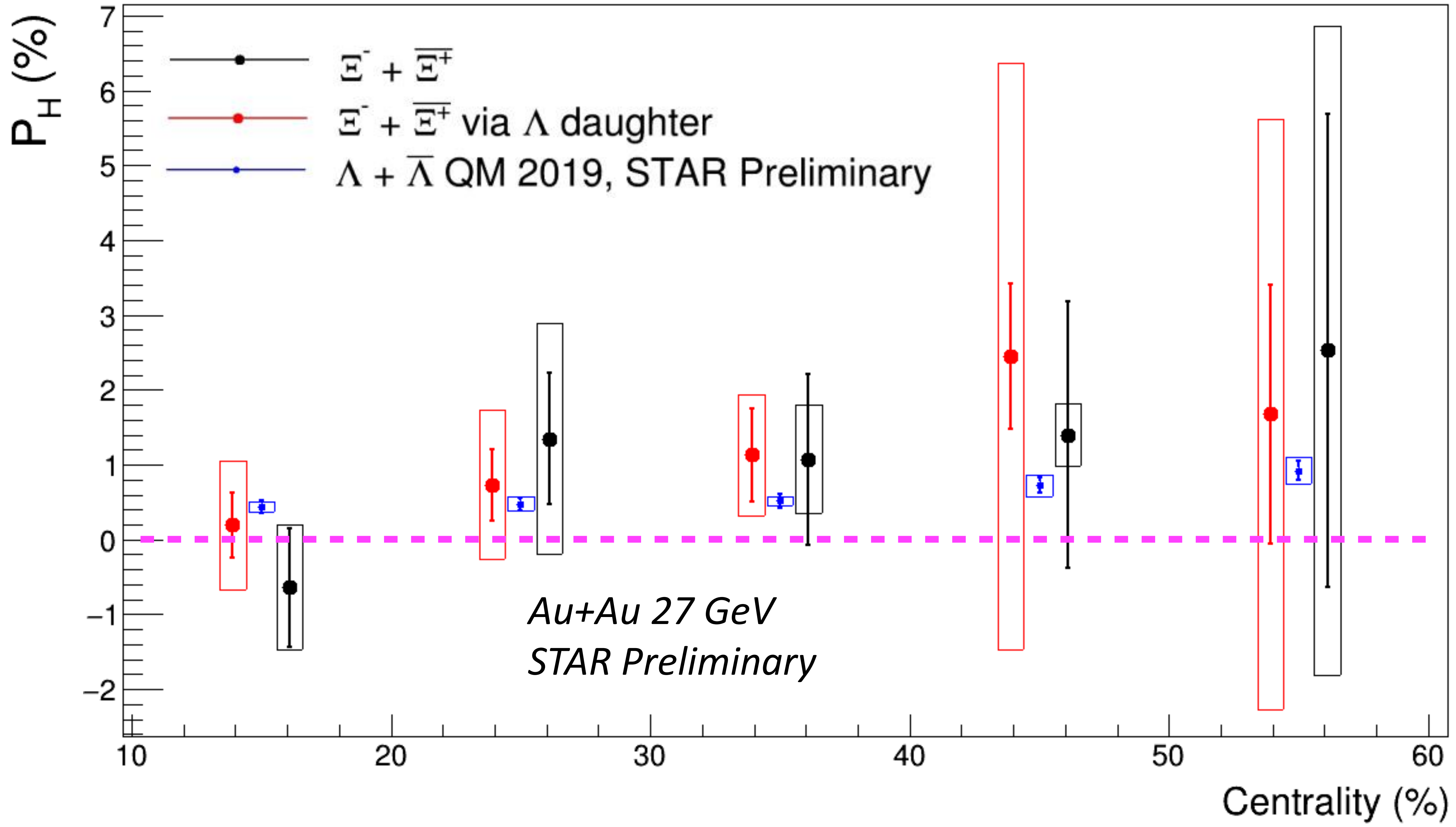
There are still many open questions and more precise results are needed.

Back up

Ξ global polarization at $\sqrt{s_{NN}}$ = 27 GeV

STAR, ICPPA2020





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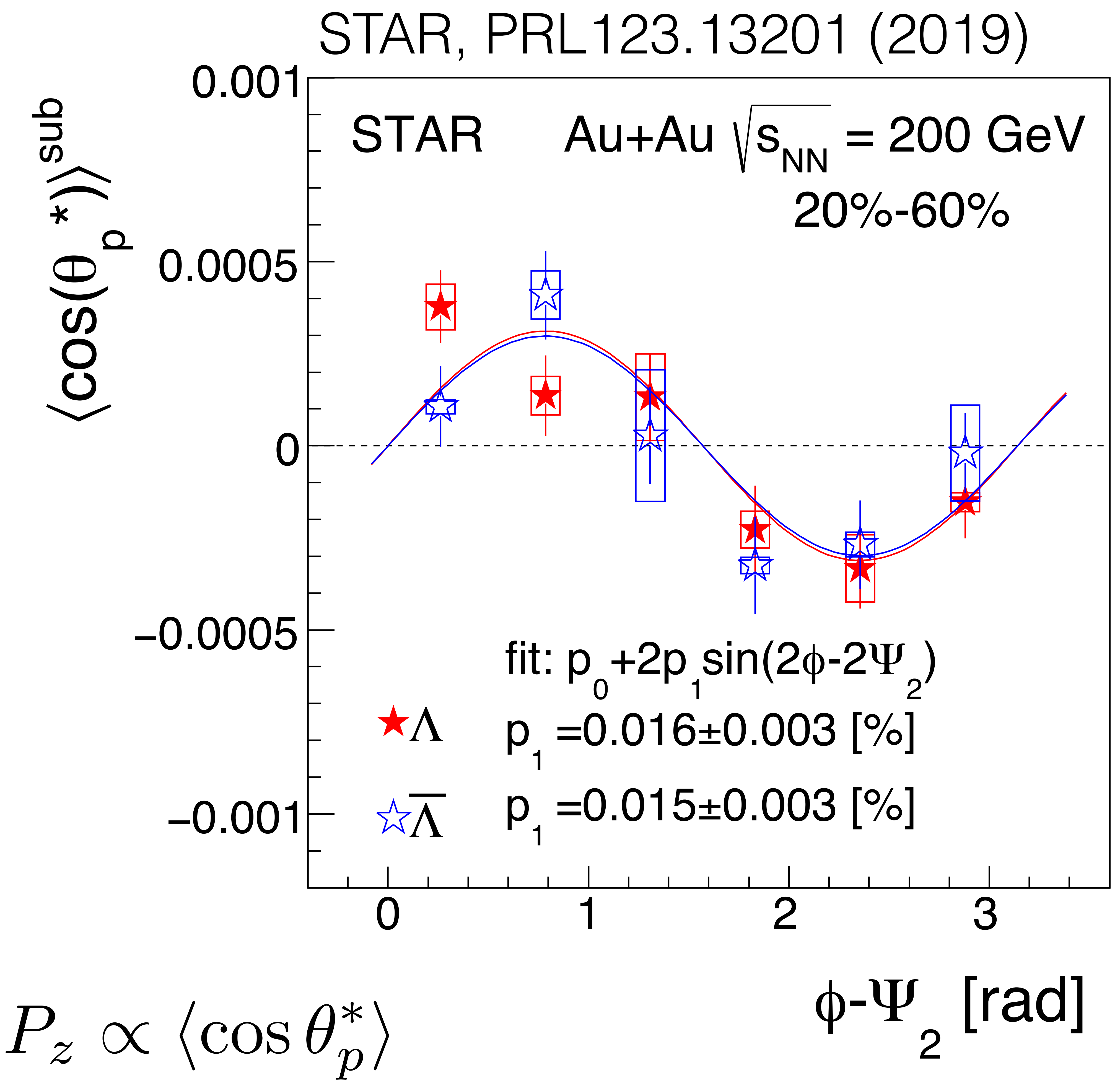
- Ξ polarization signal can be also seen at 27 GeV, comparable to or slightly larger than inclusive Λ.
- No clear centrality dependence with current precision.

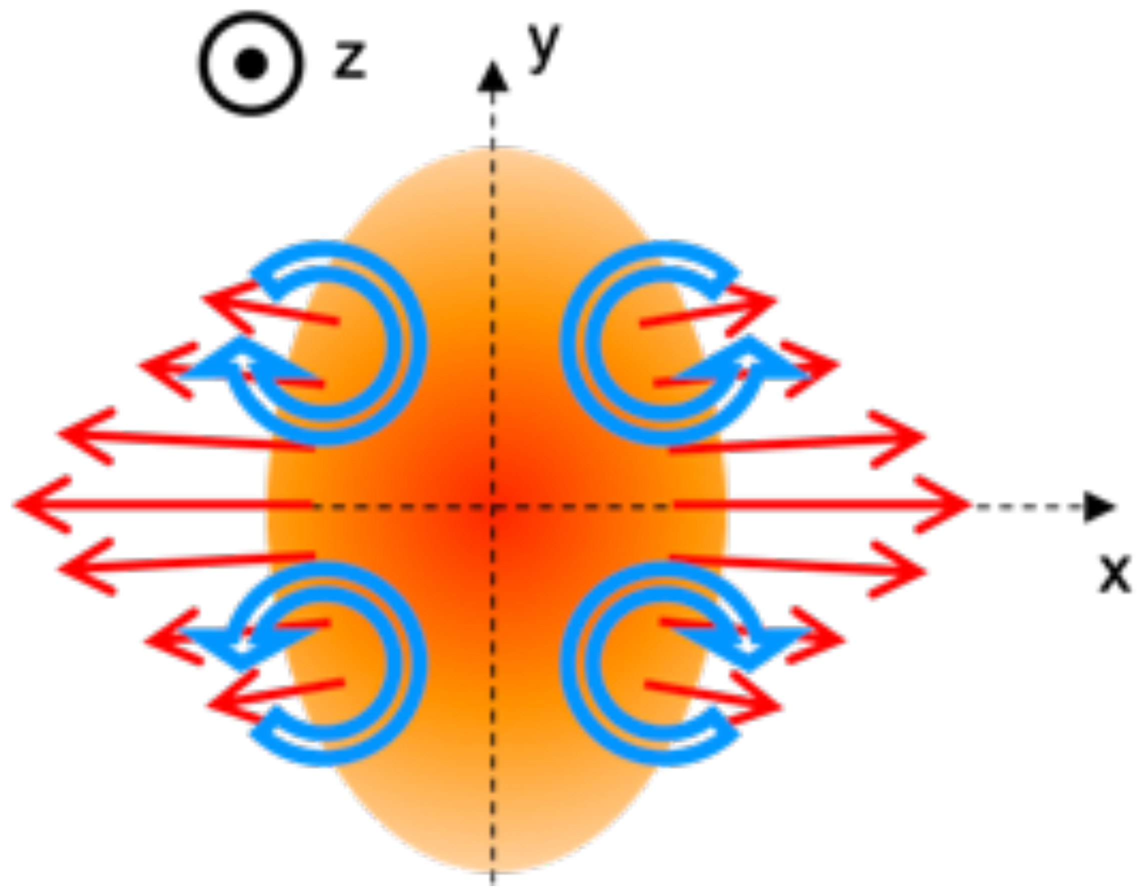
Polarization along the beam direction



$$P_z \propto \langle \cos\theta_p^* \rangle$$

- Sine structure as expected from the elliptic flow
- Some models cannot describe the sign but some can do. Note that they reasonably describe "global" P_H.

- F. Becattini and I. Karpenko, PRL.120.012302 (2018)
- X. Xia et al., PRC98.024905 (2018)
- Y. Sun and C.-M. Ko, PRC99, 011903(R) (2019)
- Y. Xie, D. Wang, and L. P. Csernai, Eur. Phys. J. C (2020) 80:39
- W. Florkowski et al., Phys. Rev. C 100, 054907 (2019)
- H.-Z. Wu et al., Phys. Rev. Research 1, 033058 (2019)



Disagreement in P_z sign

Opposite sign

- UrQMD IC + hydrodynamic model
  F. Becattini and I. Karpenko, PRL.120.012302 (2018)
- AMPT
  X. Xia, H. Li, Z. Tang, Q. Wang, PRC98.024905 (2018)

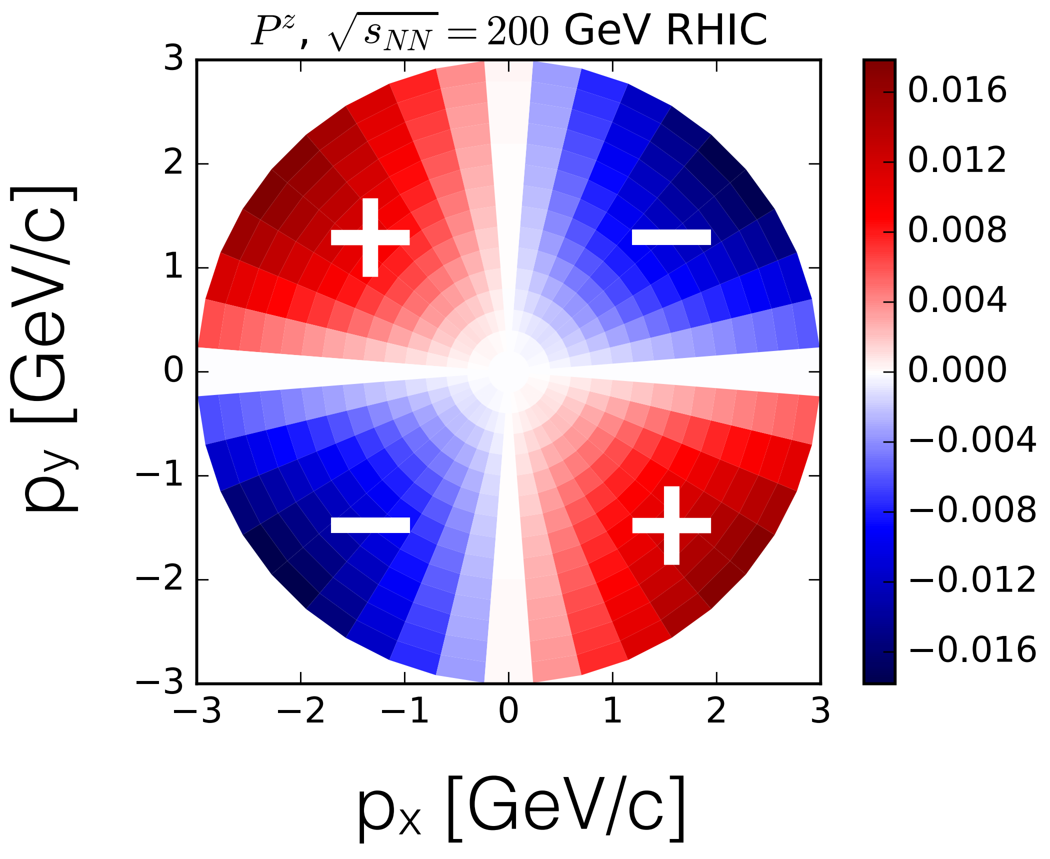
Same sign

- Chiral kinetic approach
  Y. Sun and C.-M. Ko, PRC99, 011903(R) (2019)
- High resolution (3+1)D PICR hydrodynamic model
  Y. Xie, D. Wang, and L. P. Csernai, EPJC80.39 (2020)
- Blast-wave model
  S. Voloshin, EPJ Web Conf.171, 07002 (2018), STAR, PRL123.13201

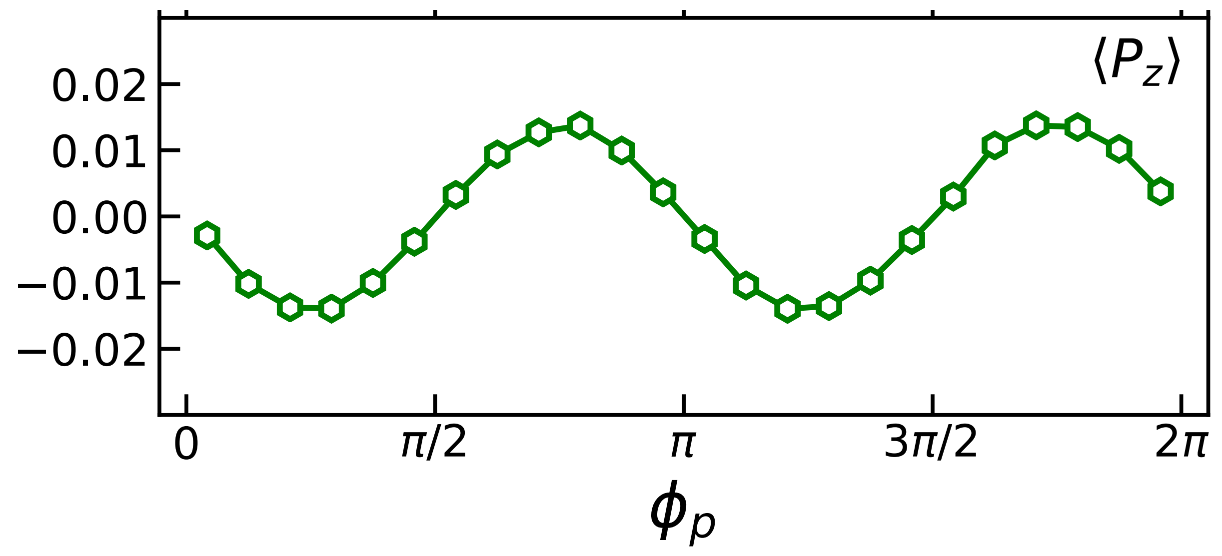
Partly (one of component showing the same sign)

- Glauber/AMPT IC + (3+1)D viscous hydrodynamics
  H.-Z. Wu et al., Phys. Rev. Research 1, 033058 (2019)
- Thermal model
  W. Florkowski et al., Phys. Rev. C 100, 054907 (2019)

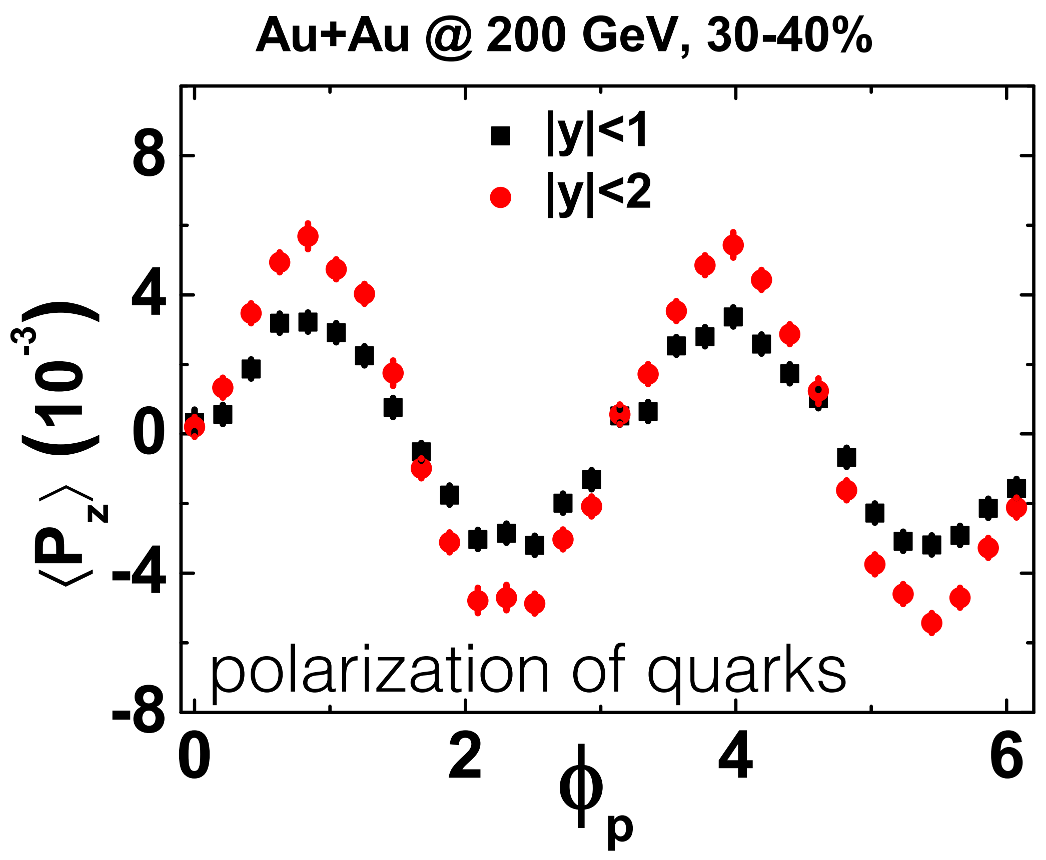
Hydrodynamic model



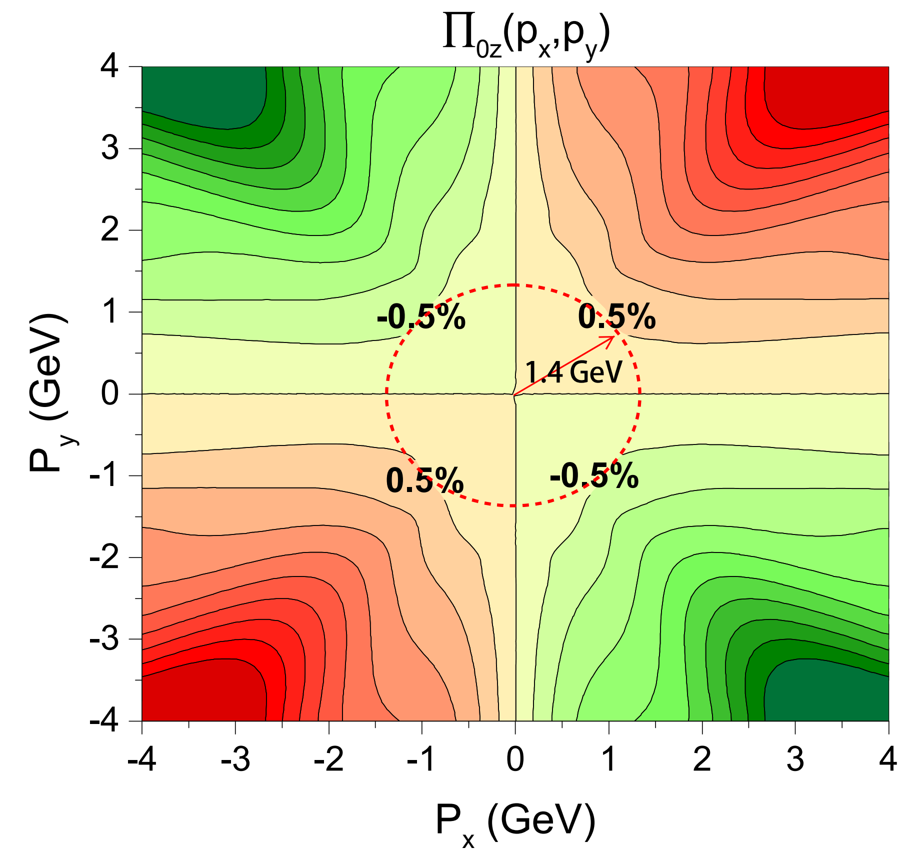
AMPT, Au+Au 200 GeV 20-50%



Chiral kinetic approach



PICR model

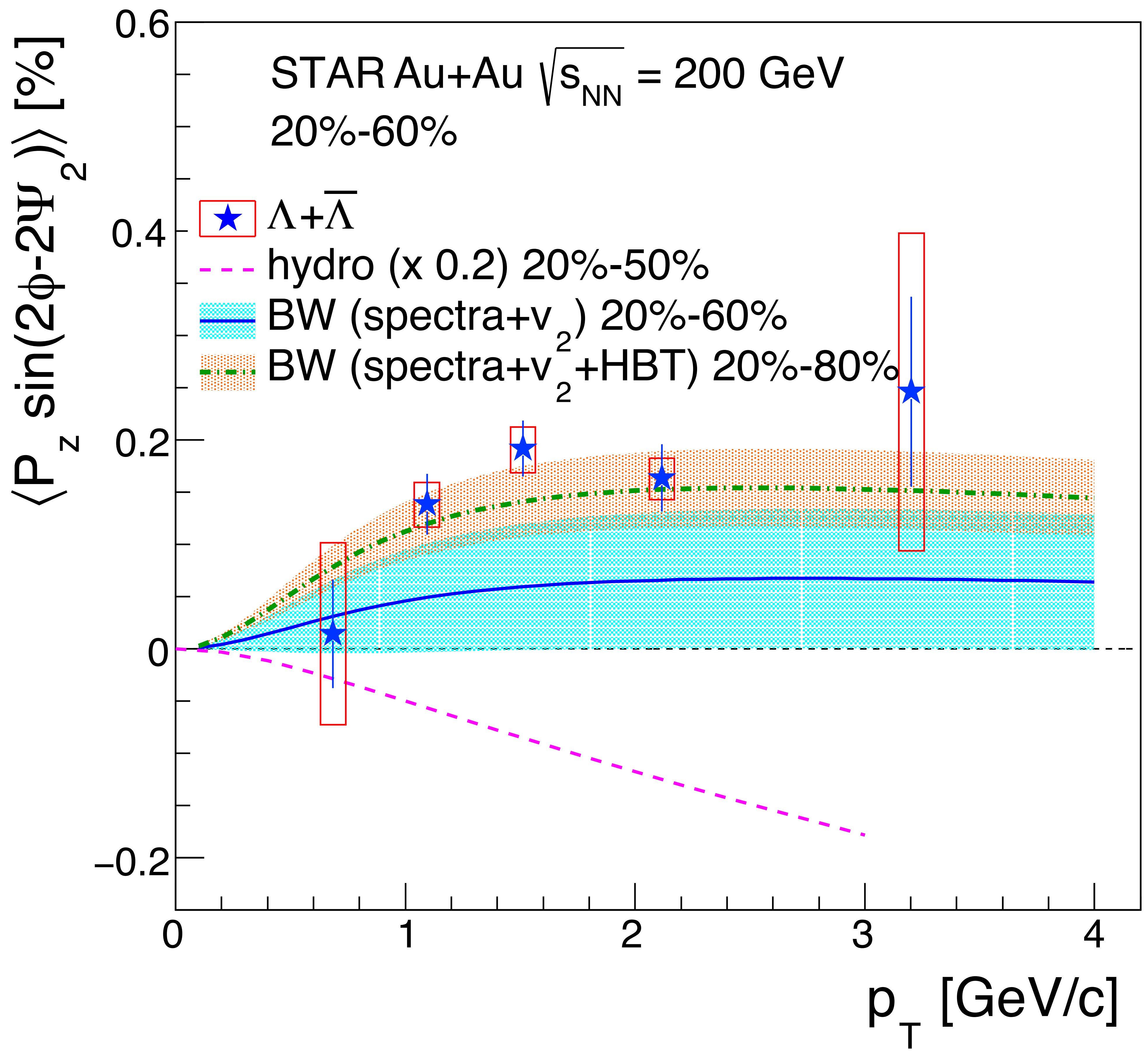


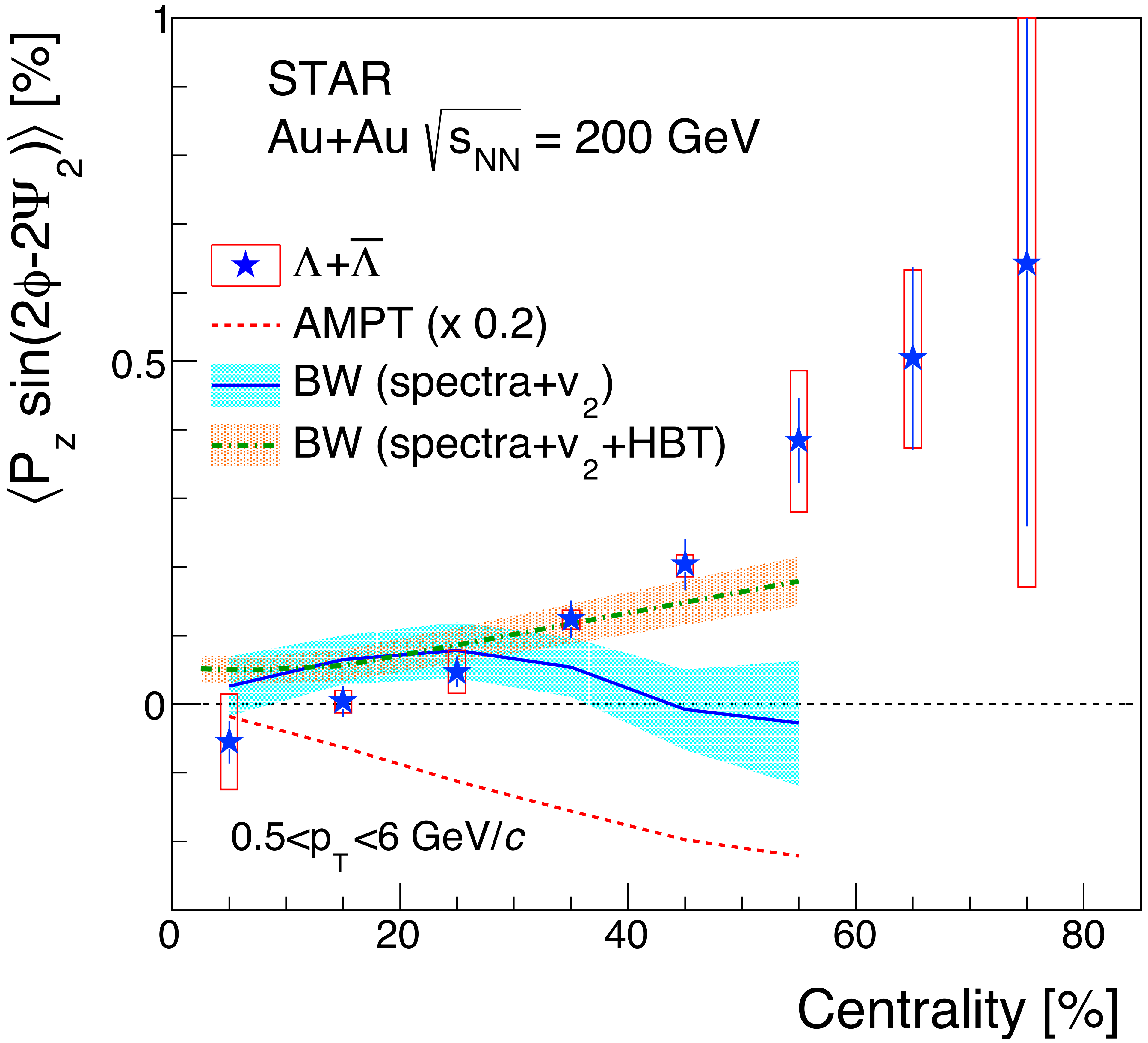
Incomplete thermal equilibrium of spin degree of freedom?

p_T and centrality dependence of P_z modulation

STAR, PRL123.13201 (2019)

BW parameters obtained with HBT: STAR, PRC71.044906 (2005)





- No strong p_T dependence but a hint of drop-off at p_T<1 GeV/c
- Strong centrality dependence as in v_2
- Blast-Wave model as a simple estimate for kinematic vorticity can describe the data