# $\Lambda$ polarization along the beam direction in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

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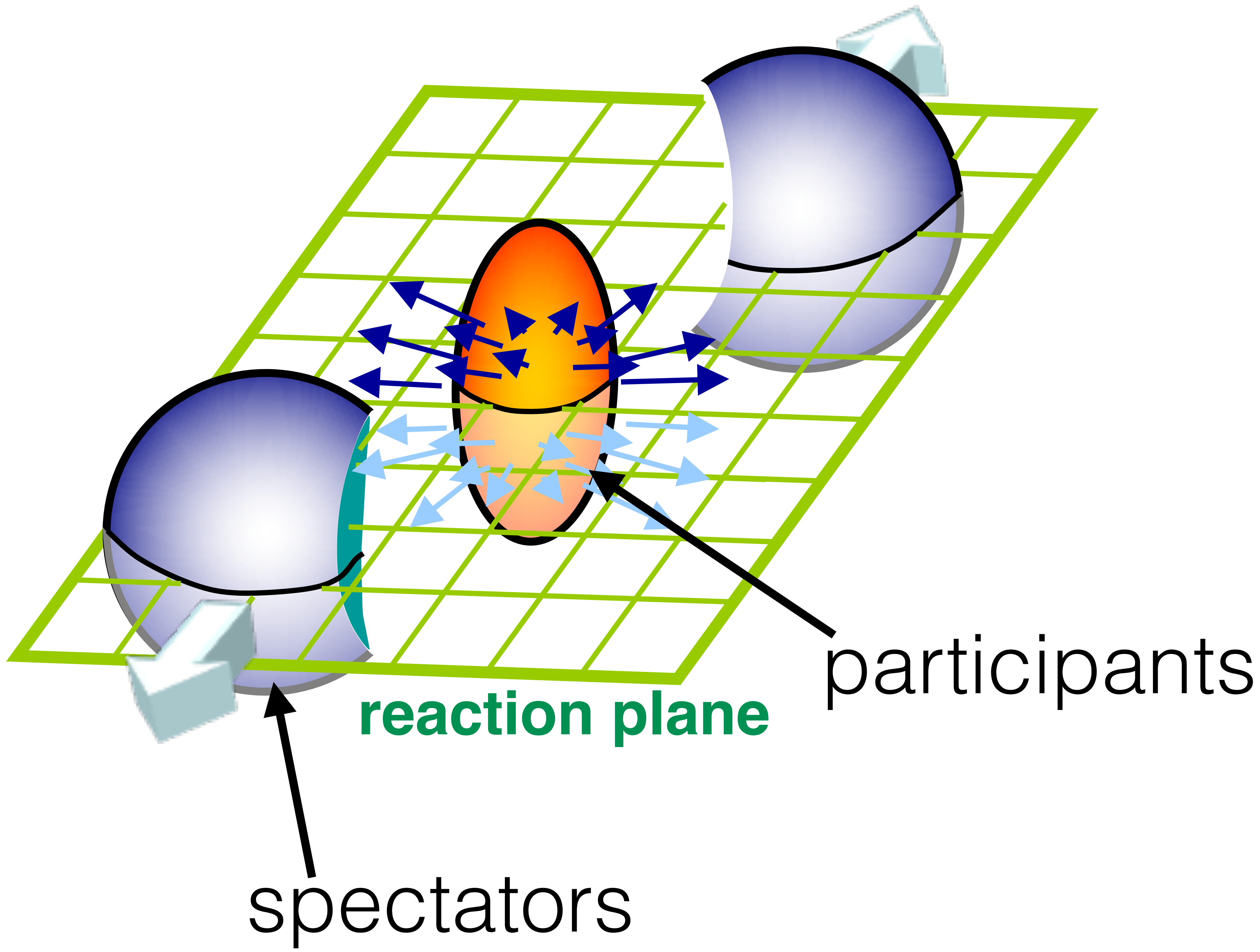
**for the STAR Collaboration**

WAYNE STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

*The 5th Workshop on Chirality, Vorticity, and Magnetic Field in Heavy Ion Collisions*
*@Tsinghua University, Beijing*

# Important features in non-central heavy-ion collisions



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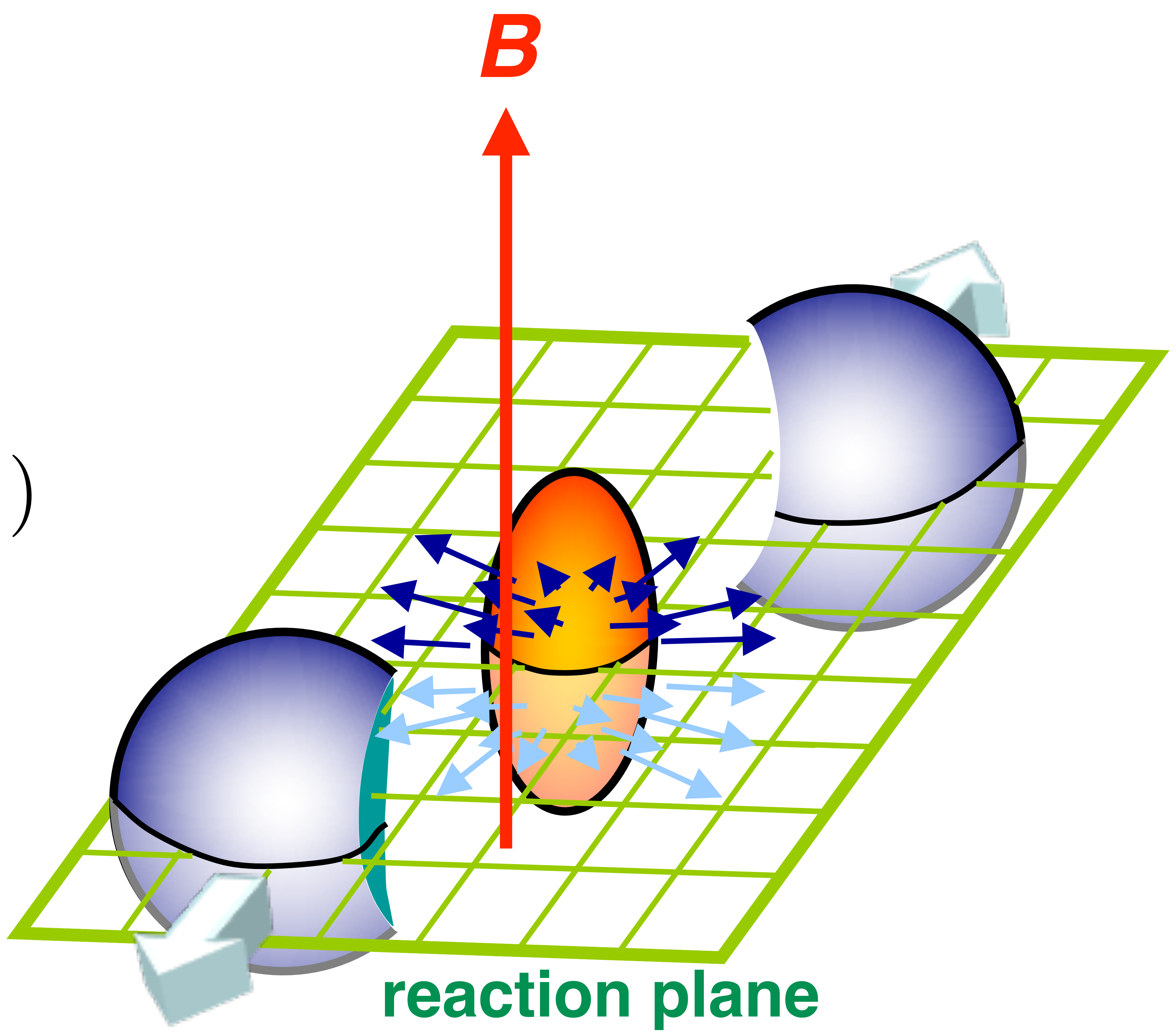
Strong magnetic field

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

$$(eB \sim \mathrm{MeV}^2\ (\tau = 0.2\ \mathrm{fm}))$$

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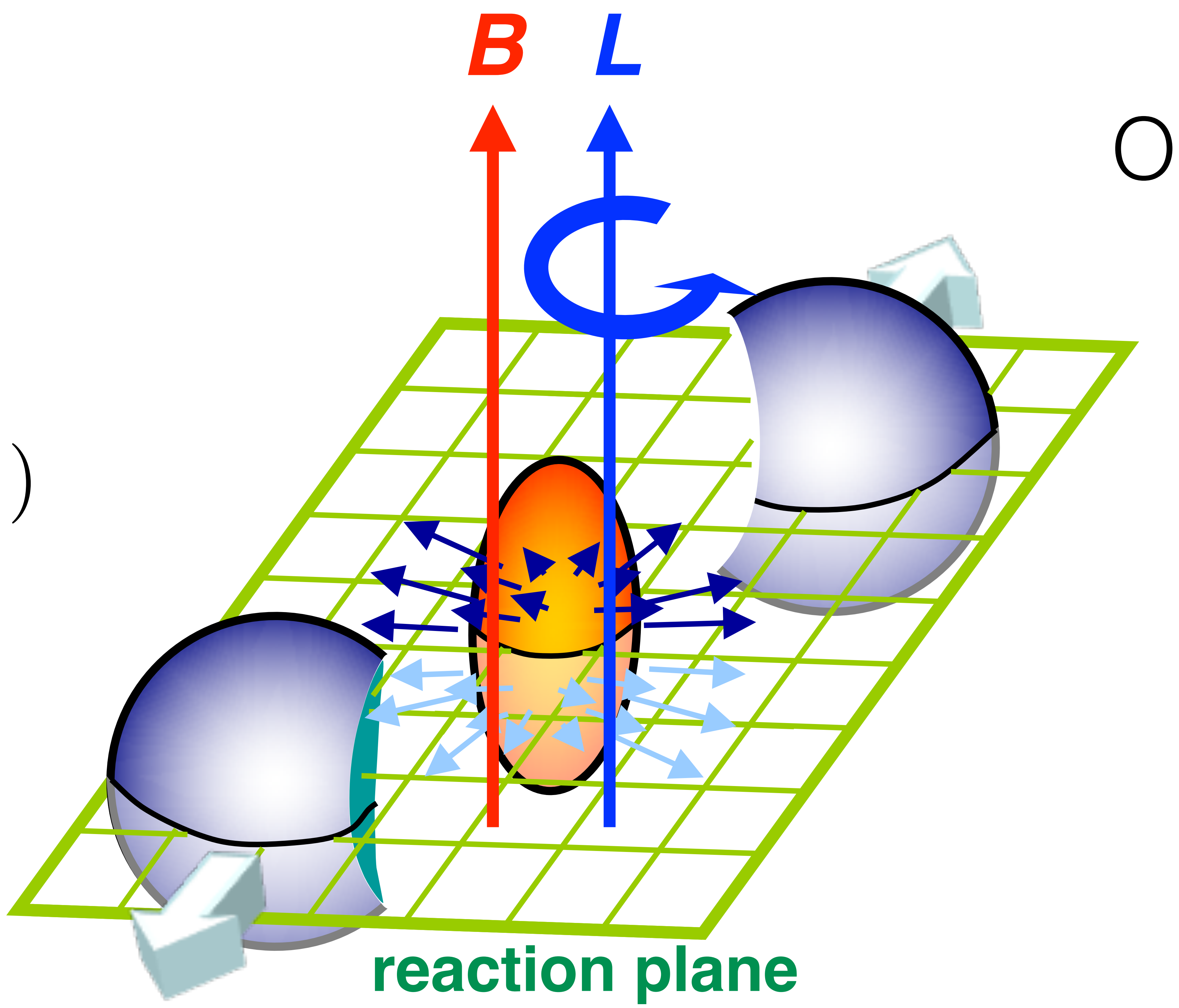


Orbital angular momentum

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

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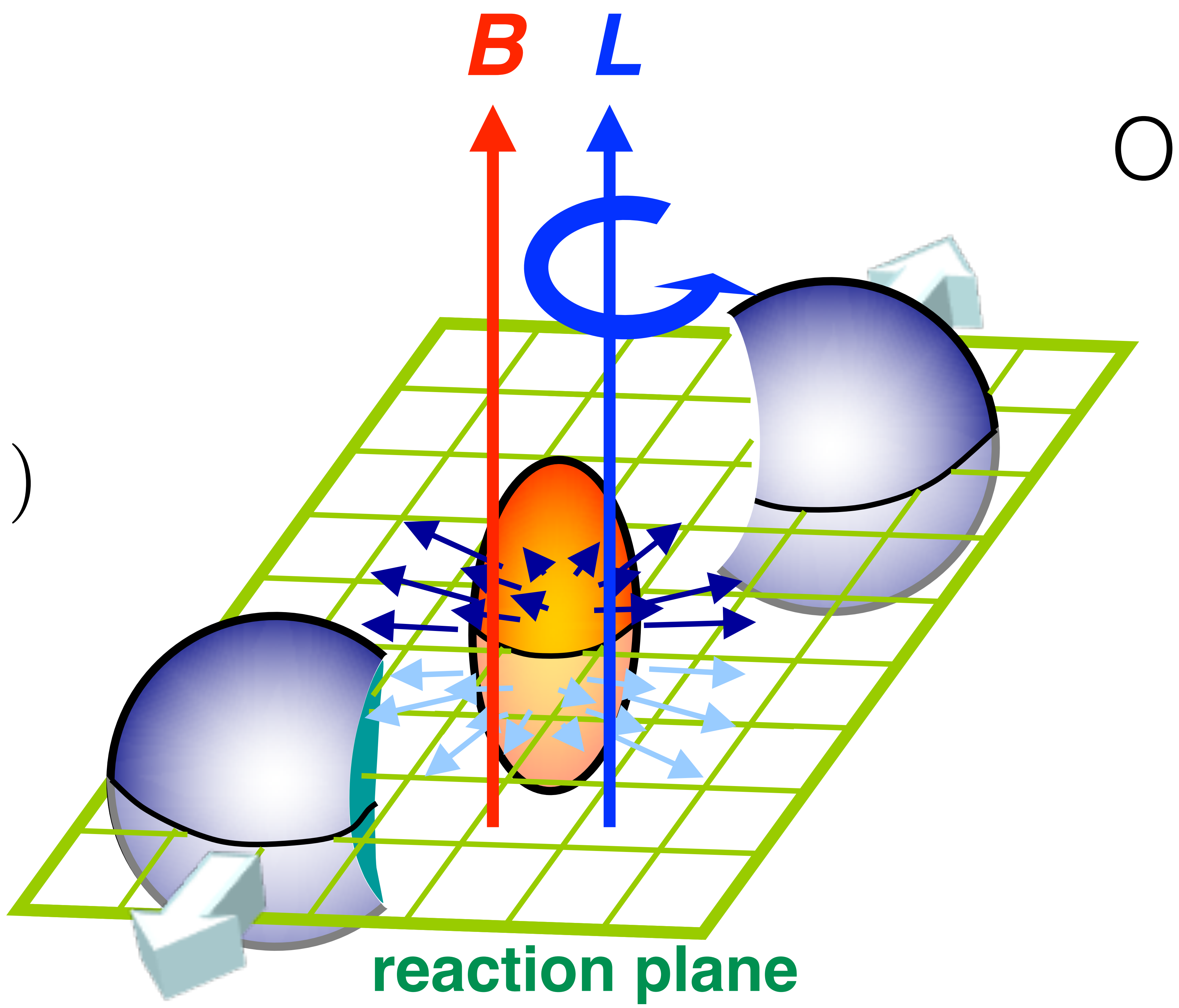


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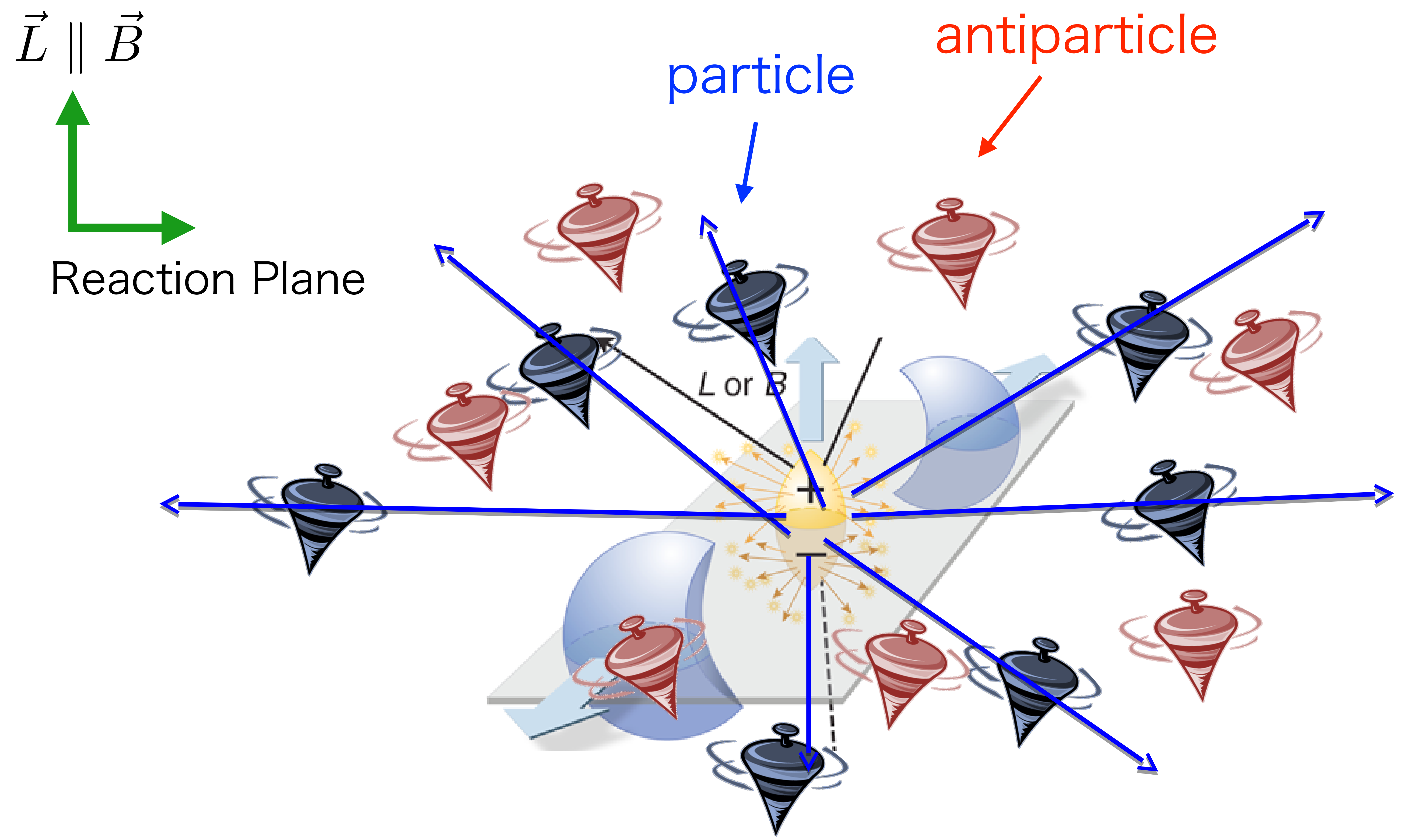
→Chiral magnetic effect
Chiral magnetic wave
particle polarization

→Chiral vortical effect
particle polarization

# Global polarization

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




- Non-zero angular momentum transfers to the spin degrees of freedom (polarization)
  - Particles' and anti-particles' spins are aligned with angular momentum, ***L***
- Magnetic field align particle's spin
  - Particles' and antiparticles' spins are aligned oppositely along ***B*** due to the opposite sign of magnetic moment

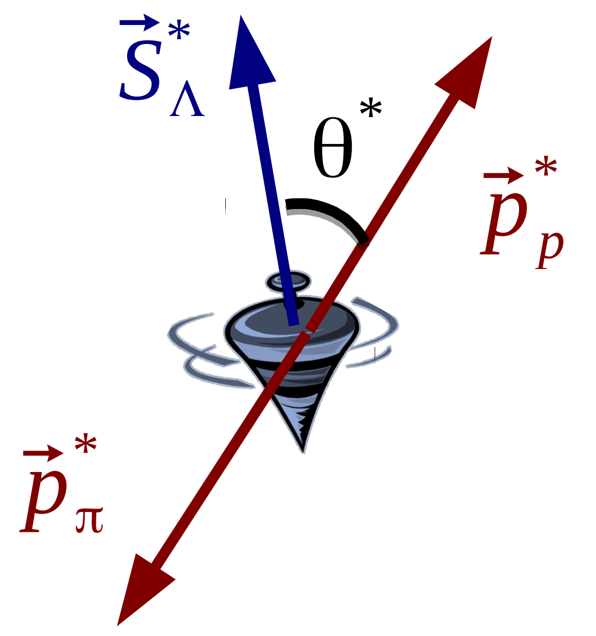
# How to measure the global polarization?

## Parity-violating decay of hyperons

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

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

$P_H$: Λ polarization
$p_p^*$: proton momentum in the Λ rest frame
$\alpha_H$: Λ decay parameter
($\alpha_{\Lambda} = -\alpha_{\bar{\Lambda}} = 0.642 \pm 0.013$)



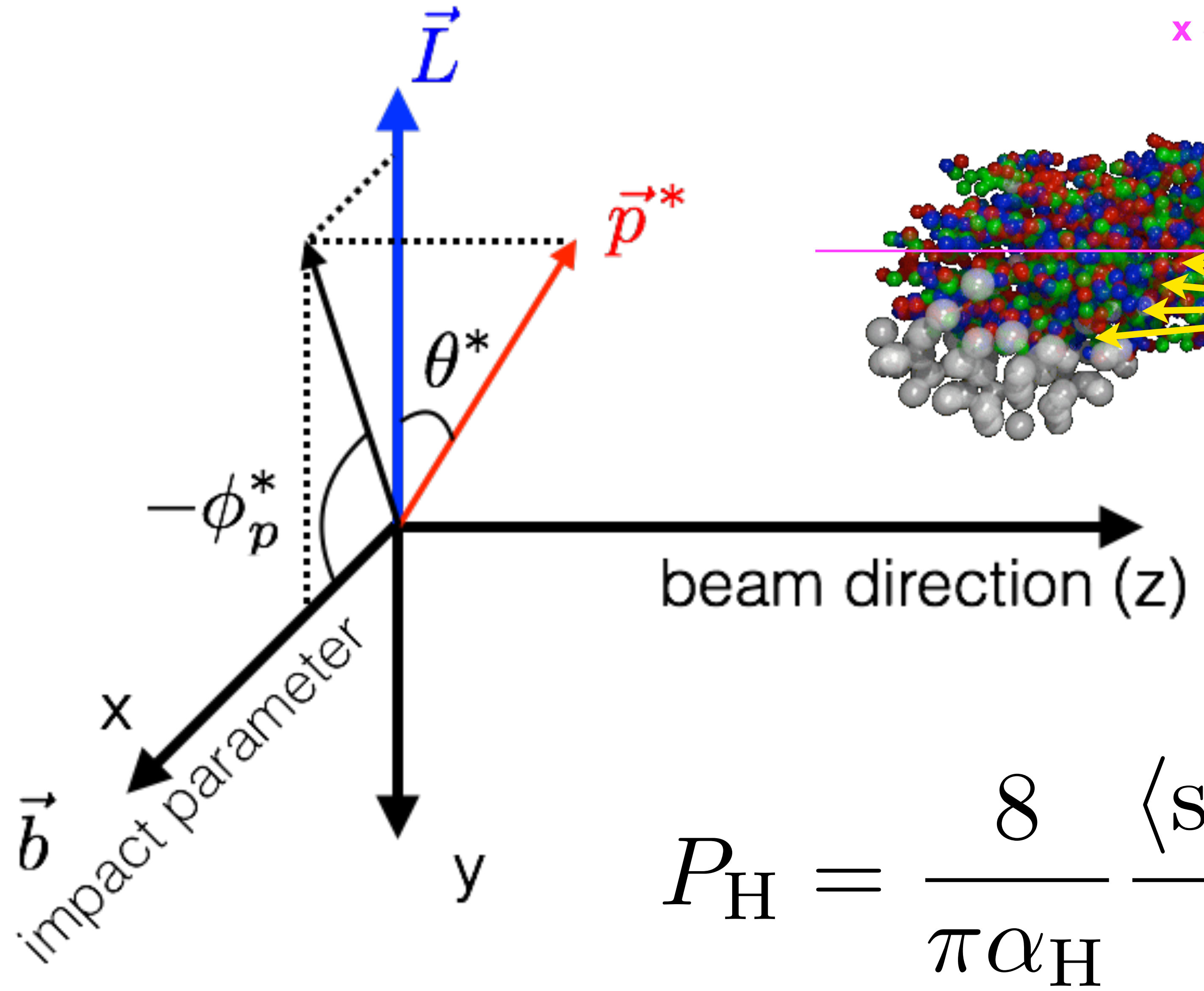

$$\Lambda \rightarrow p + \pi^-$$

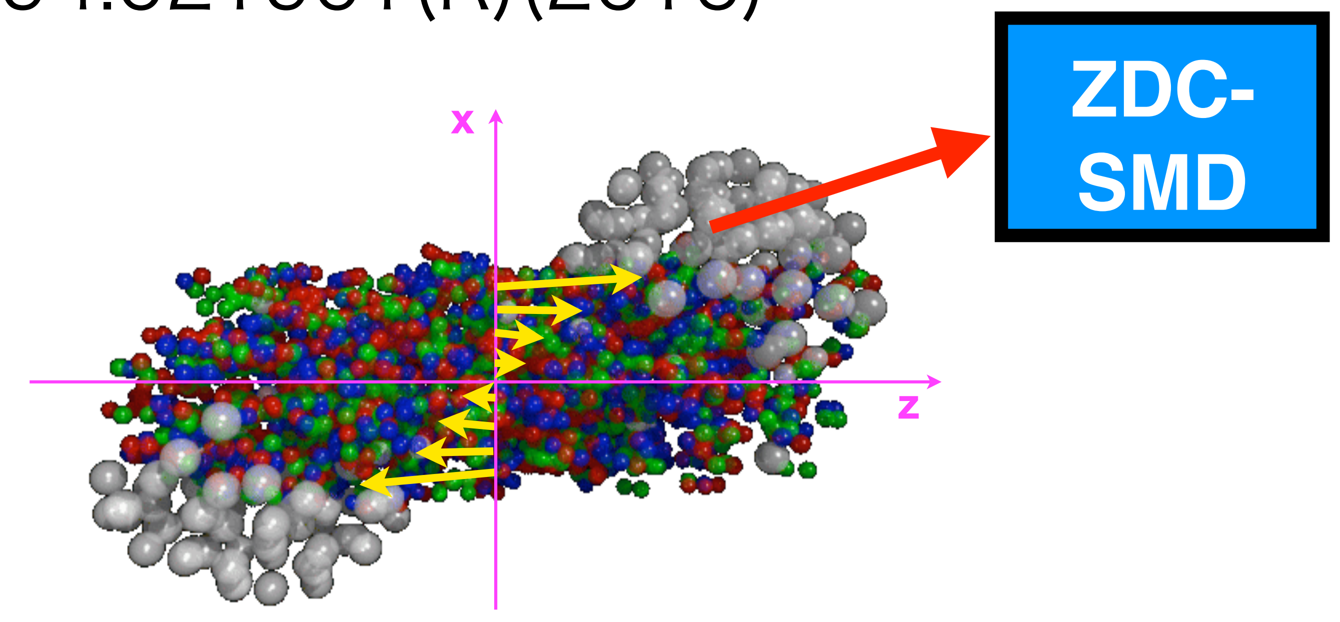
(BR: 63.9%, c$\tau$ ~7.9 cm)

C. Patrignani et al. (PDG), Chin. Phys. C 40, 100001 (2016)

## 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)



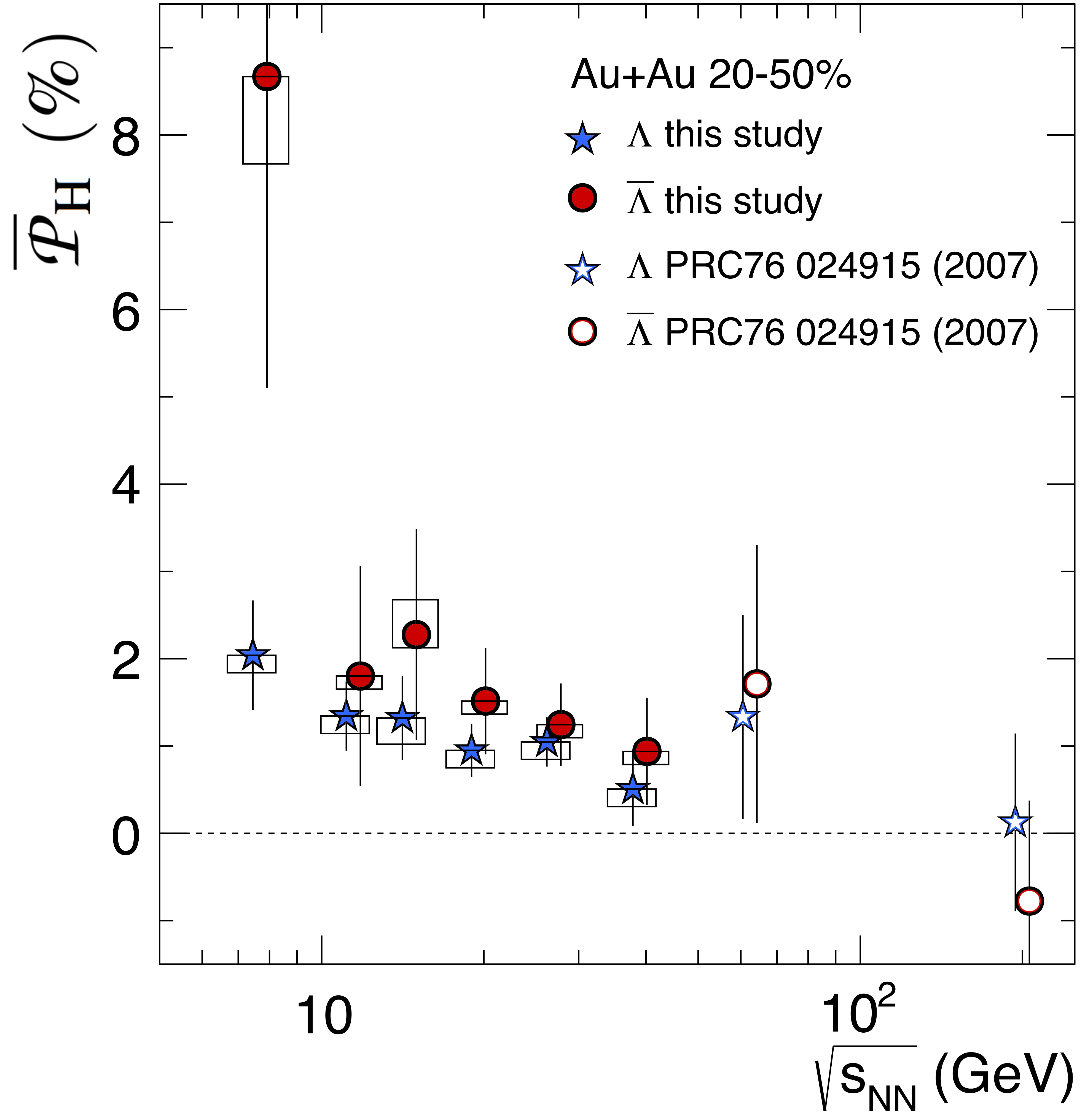

$$P_{\rm H} = \frac{8}{\pi\alpha_{\rm H}} \frac{\langle \sin(\Psi_1 - \phi_p^*) \rangle}{{\rm Res}(\Psi_1)}$$

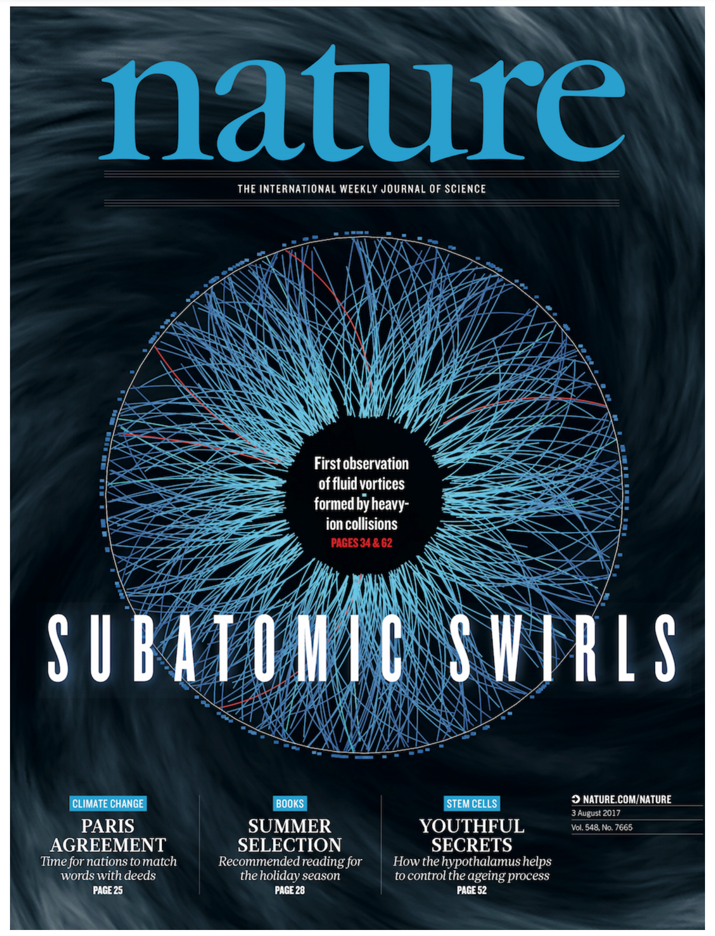
$\Psi_1$: azimuthal angle of b
$\phi_p^*$: $\phi$ of daughter proton in Λ rest frame

STAR, PRC76, 024915 (2007)

# First observation of fluid vortices in HIC

STAR, Nature 548, 62 (2017)





#38

**The Fastest Fluid**

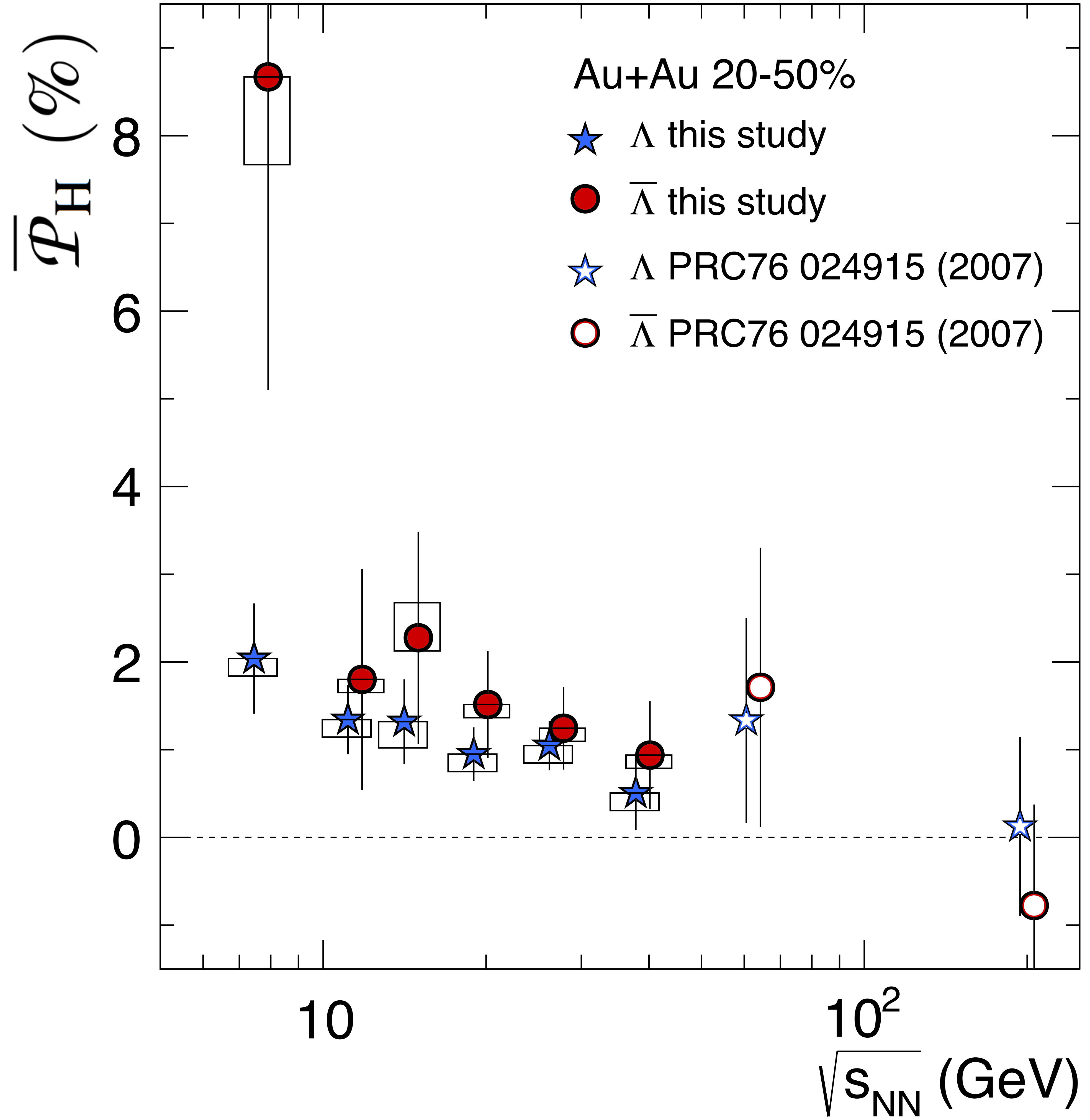
by Sylvia Morrow

Superhot material spins at an incredible rate.

Positive polarization signal at lower energies!

- polarization looks to increase in lower energies
- anti-Λ looks larger than Λ, possible effect of B-field?

# First observation of fluid vortices in HIC





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

$\mu_\Lambda$: Λ magnetic moment
T: temperature at thermal equilibrium

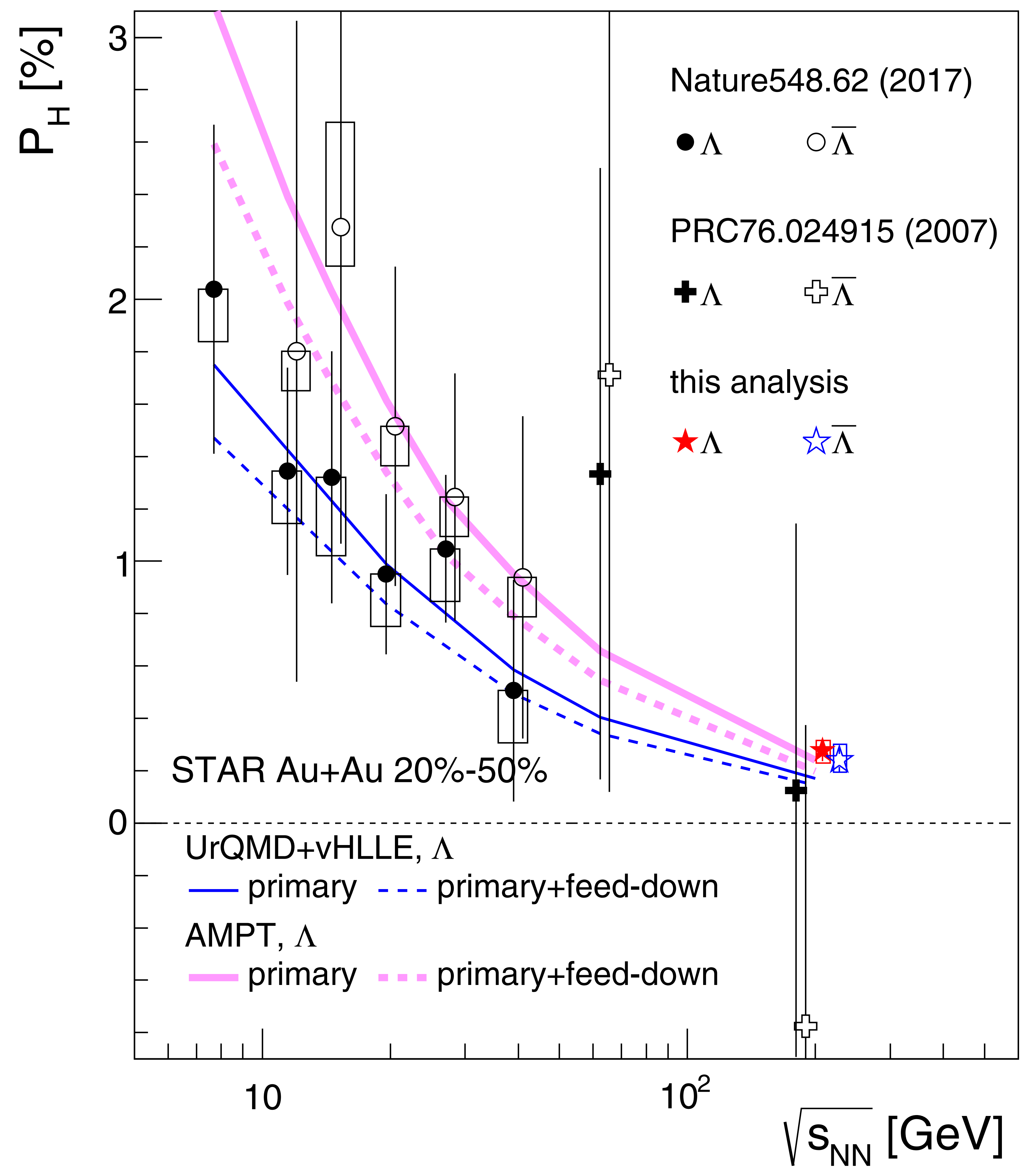
$$P_\Lambda \simeq \frac{1}{2}\frac{\omega}{T} + \frac{\mu_\Lambda B}{T}$$
$$P_{\bar{\Lambda}} \simeq \frac{1}{2}\frac{\omega}{T} - \frac{\mu_\Lambda B}{T}$$

$$\omega = (P_\Lambda + P_{\bar{\Lambda}})k_B T/\hbar$$
$$\sim 0.02\text{-}0.09\ \mathrm{fm}^{-1}$$
$$\sim 0.6\text{-}2.7 \times 10^{22}\mathrm{s}^{-1}$$
(T=160 MeV)

The most vortical fluid ever observed!

# Positive signal at $\sqrt{s_{NN}}$ = 200 GeV

STAR, PRC98, 014910 (2018)




UrQMD+vHLLE: I. Karpenko and F. Becattini, EPJC(2017)77:213
AMPT: H. Li et al., Phys. Rev. C 96, 054908 (2017)

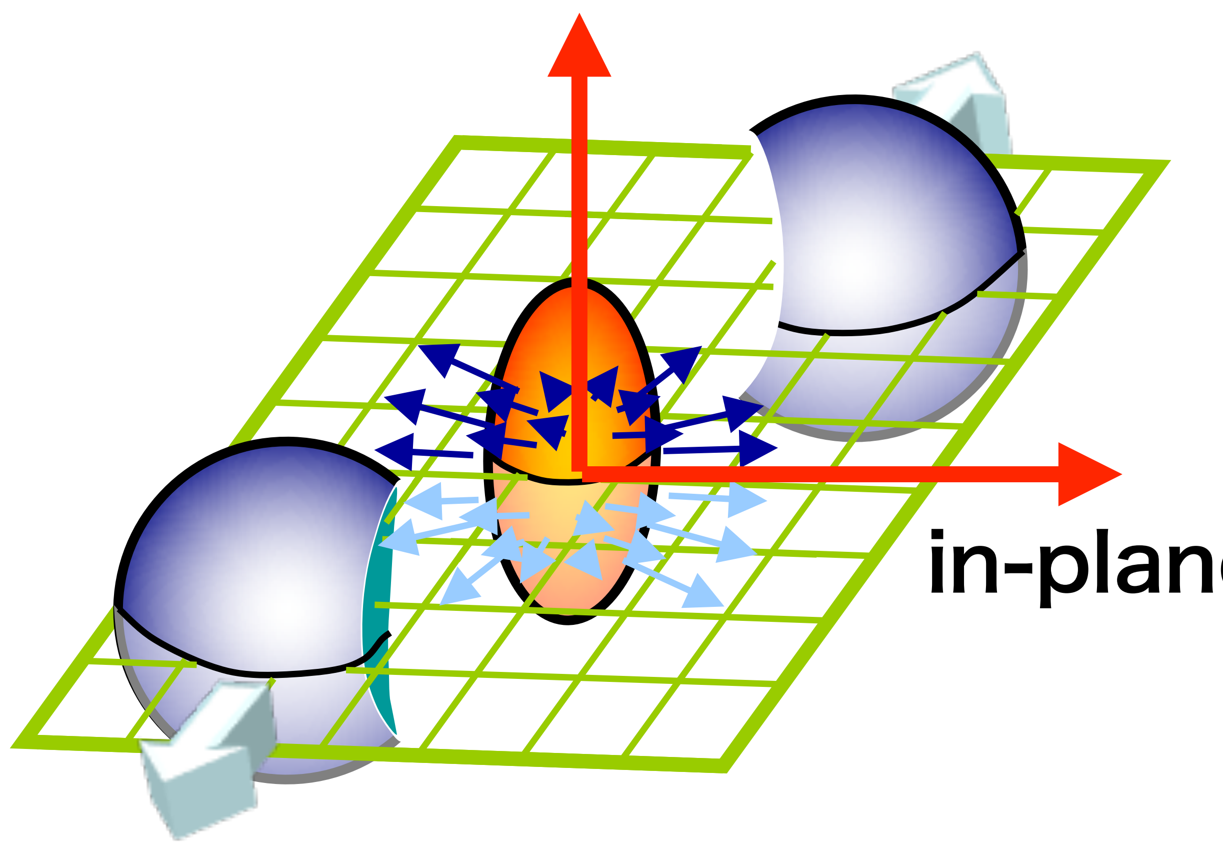
Average $P_H$ for 20-50%:

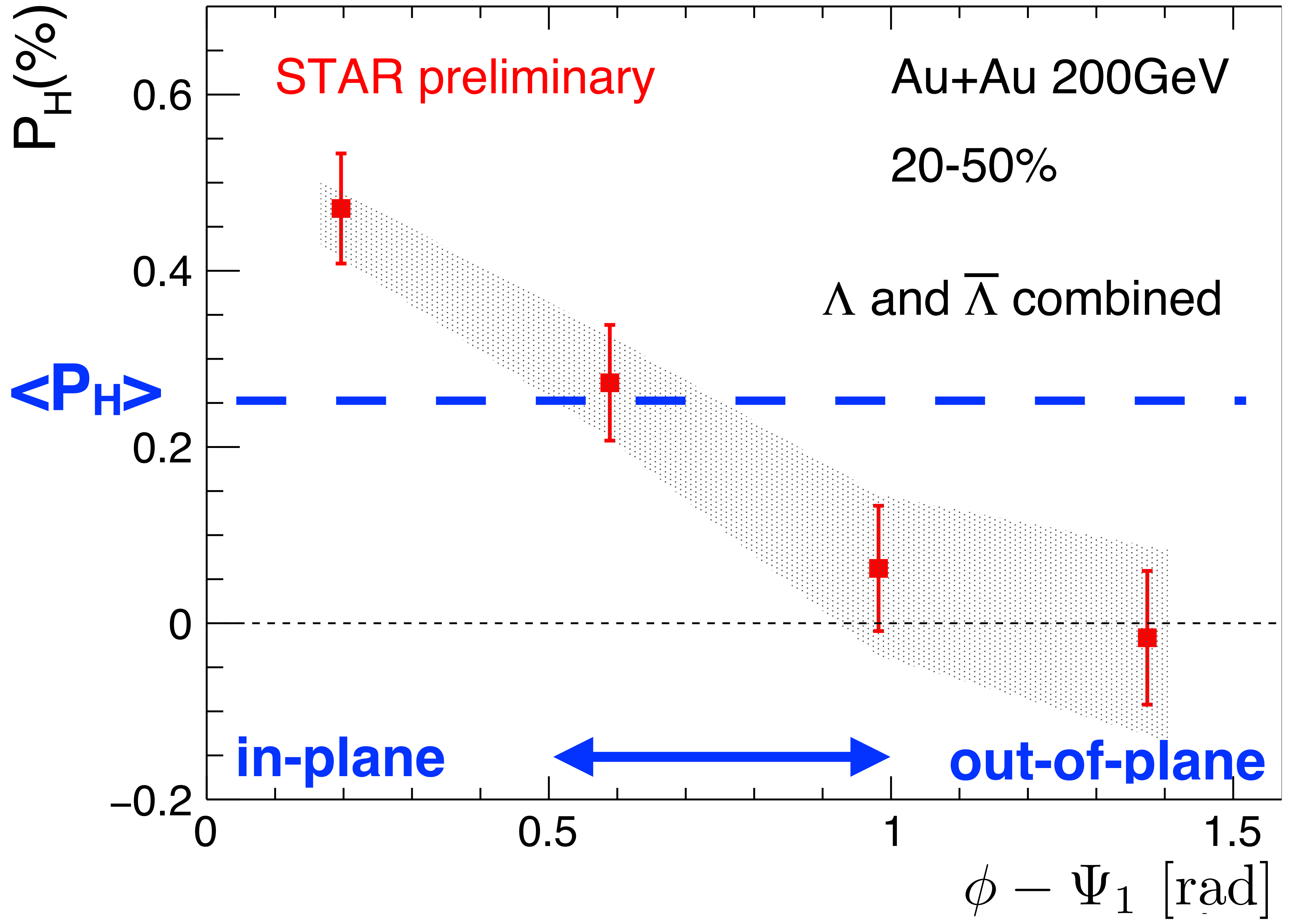
$$P_H(\Lambda)\ [\%] = 0.277 \pm 0.040(\text{stat}) \pm^{0.039}_{0.049}\ (\text{sys})$$
$$P_H(\bar{\Lambda})\ [\%] = 0.240 \pm 0.045(\text{stat}) \pm^{0.061}_{0.045}\ (\text{sys})$$

- Having new results for 200 GeV, $P_H$ decreases in higher energy
  - partly due to stronger shear flow structure in lower $\sqrt{s_{NN}}$ because of baryon transparency
- Both hydrodynamic and AMPT models describe the data
  - 15%-20% smearing effect in the data due to feed-down

F. Becattini, I. Karpenko, M. Lisa, I. Upsal, and S. Voloshin, PRC95.054902 (2017)

# Azimuthal angle dependence of $P_H$




✦ Larger polarization in in-plane than in out-of-plane

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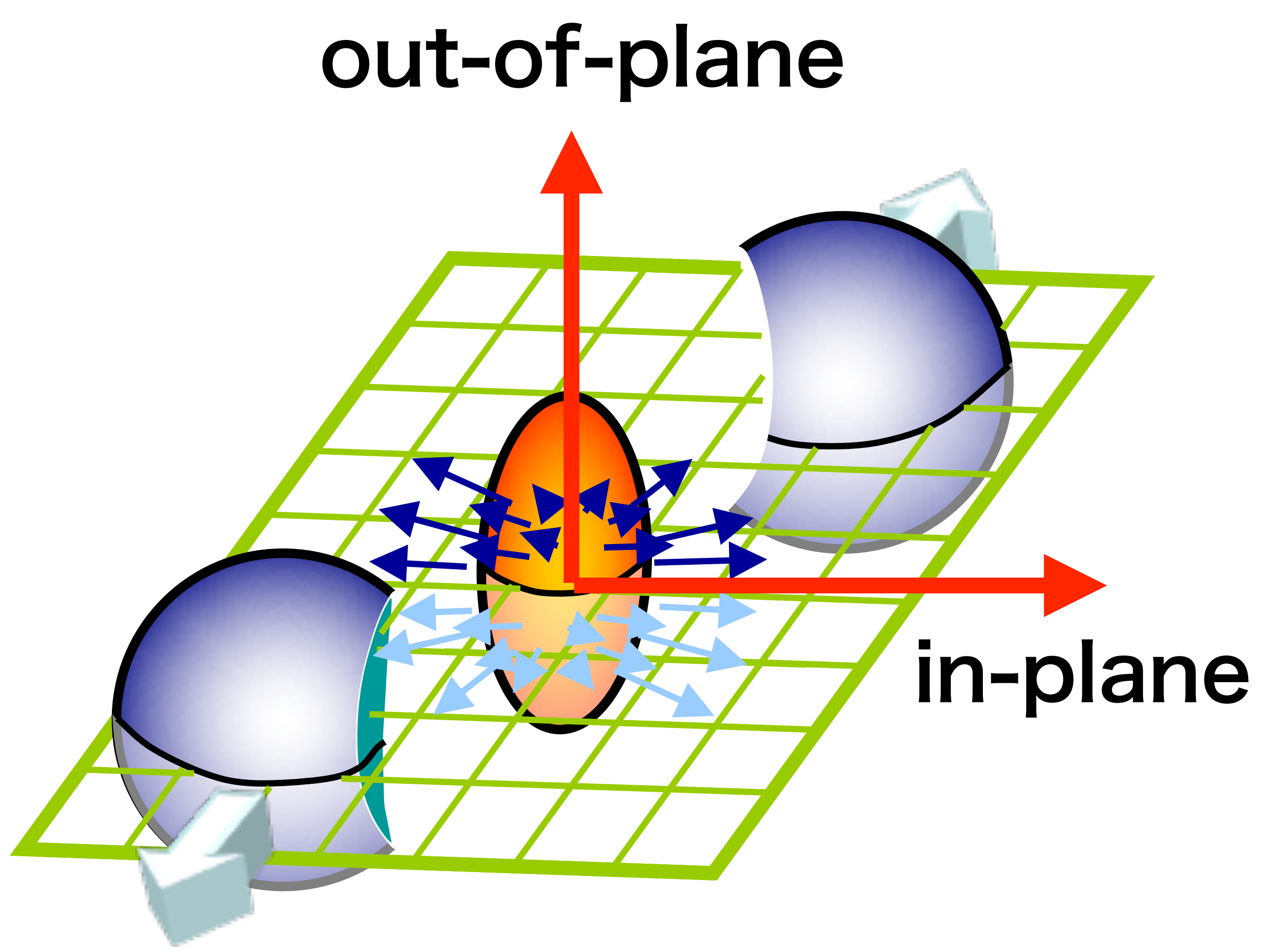
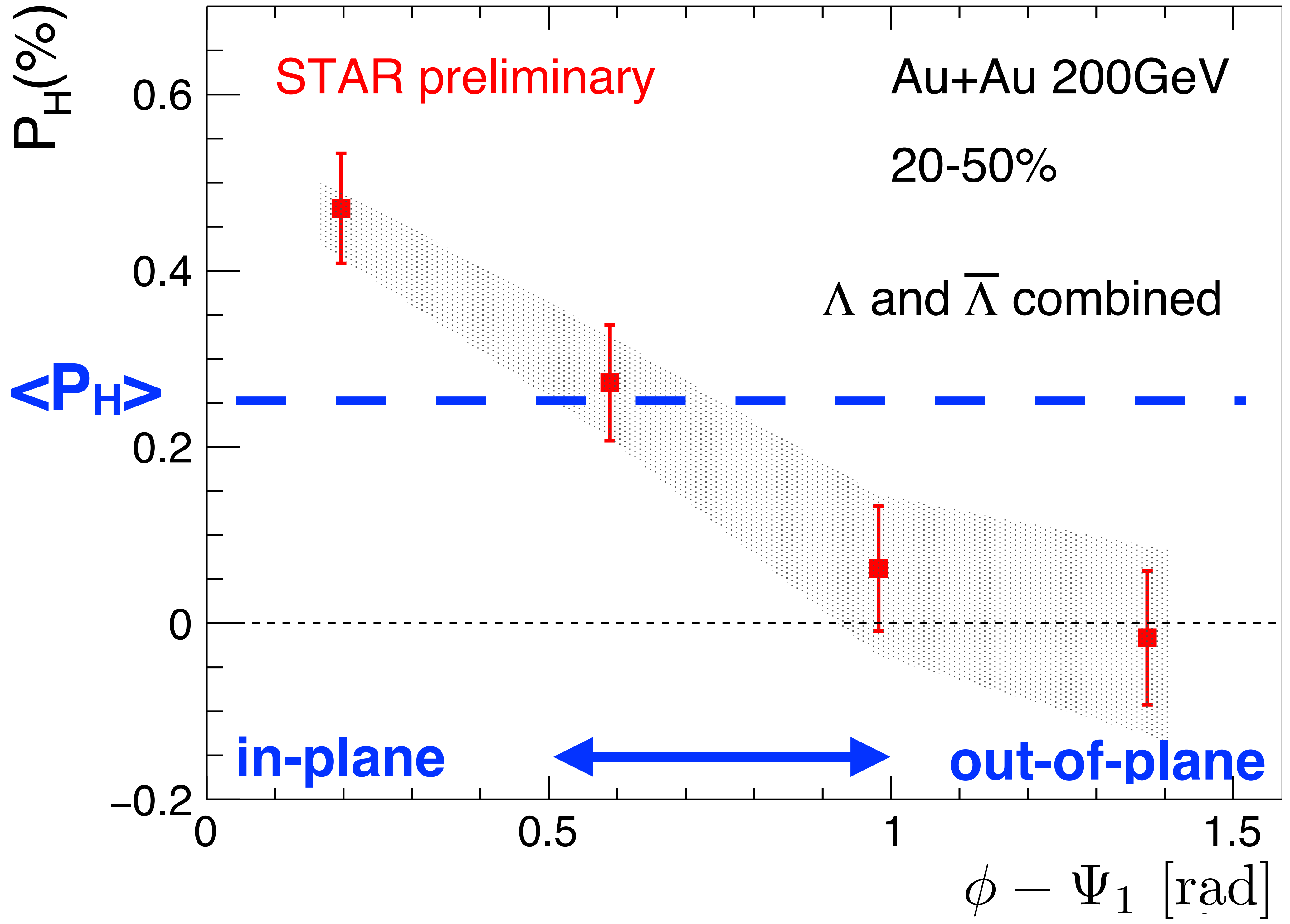
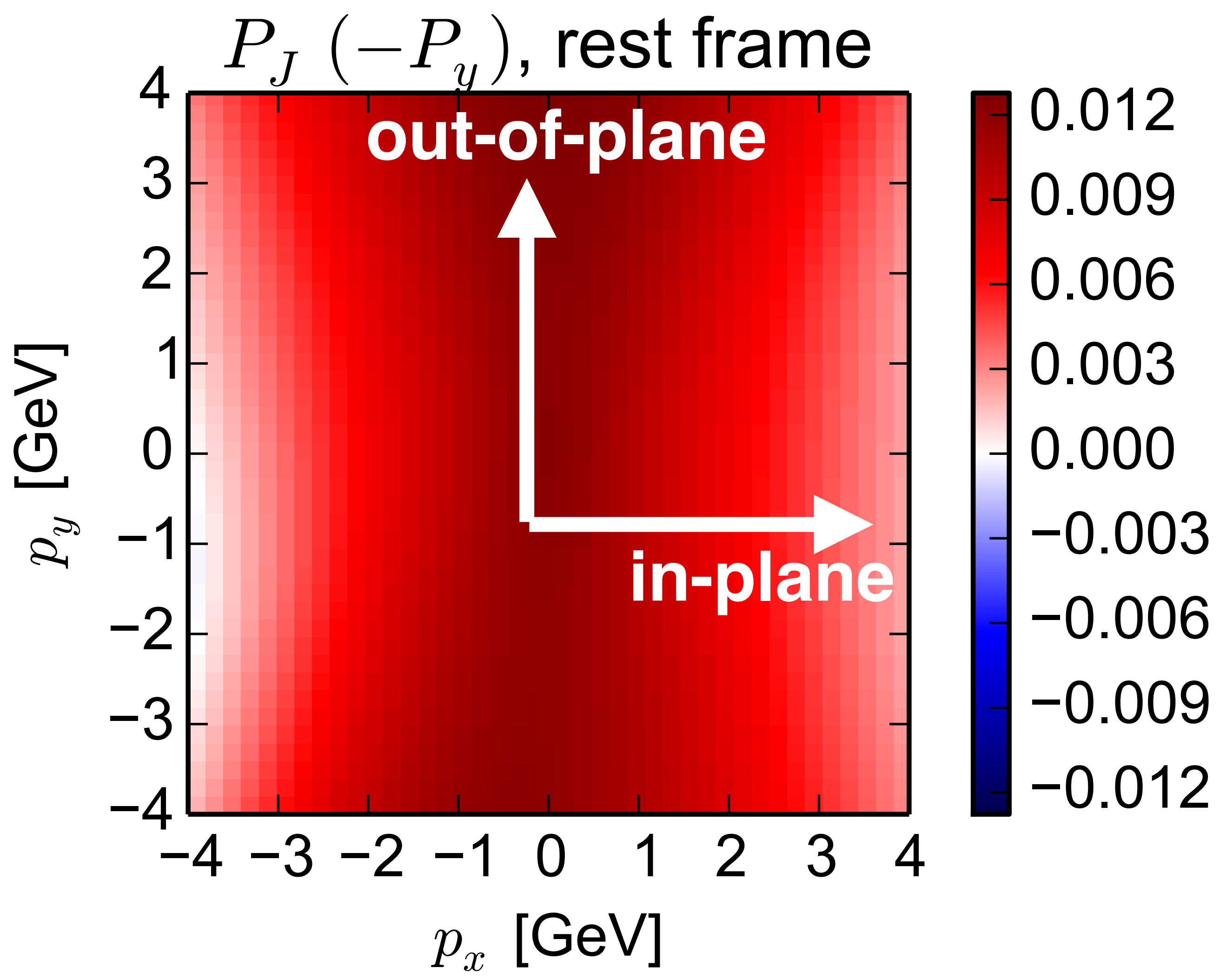


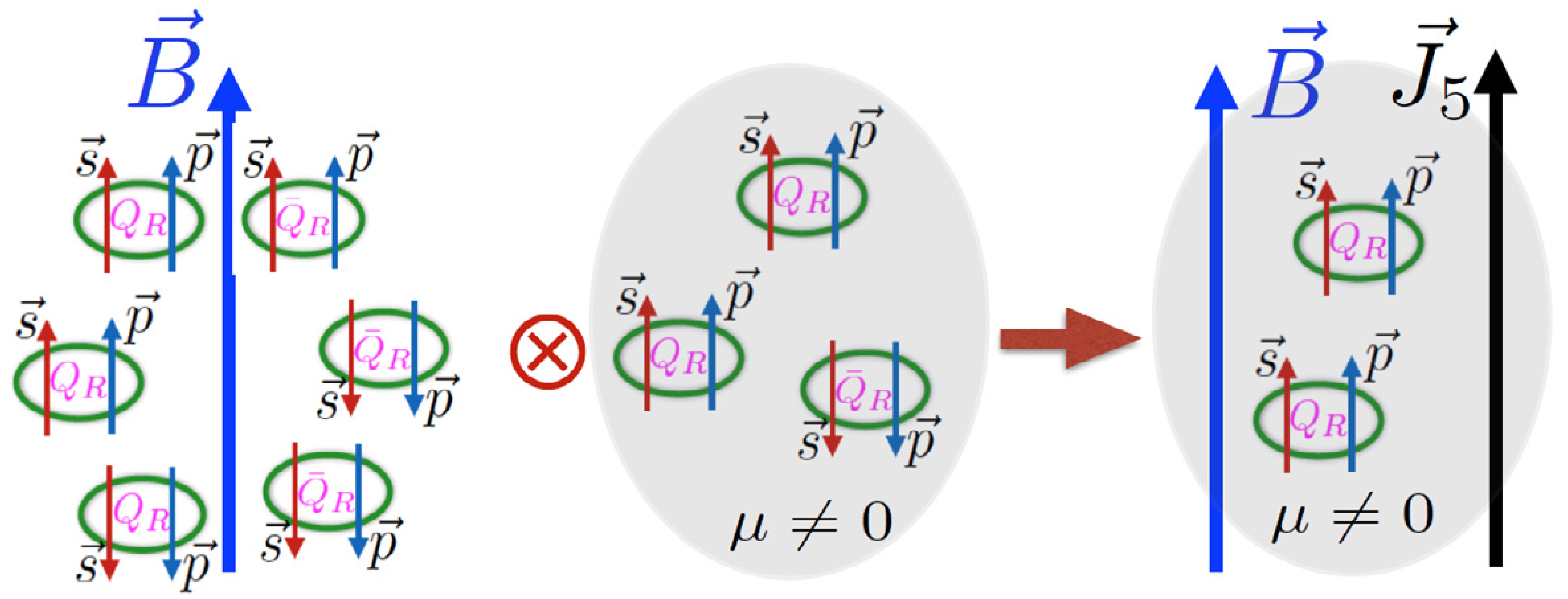

I. Karpenko and F. Becattini, EPJC(2017)77:213

✦ Larger polarization in in-plane than in out-of-plane

✦ Opposite to the hydrodynamic expectation (larger in out-of-plane)

# Λ polarization vs. charge asymmetry

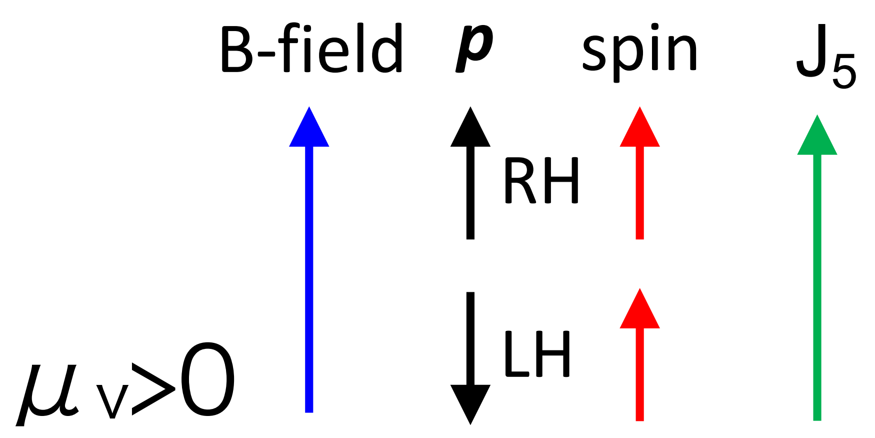
*Chiral Separation Effect*



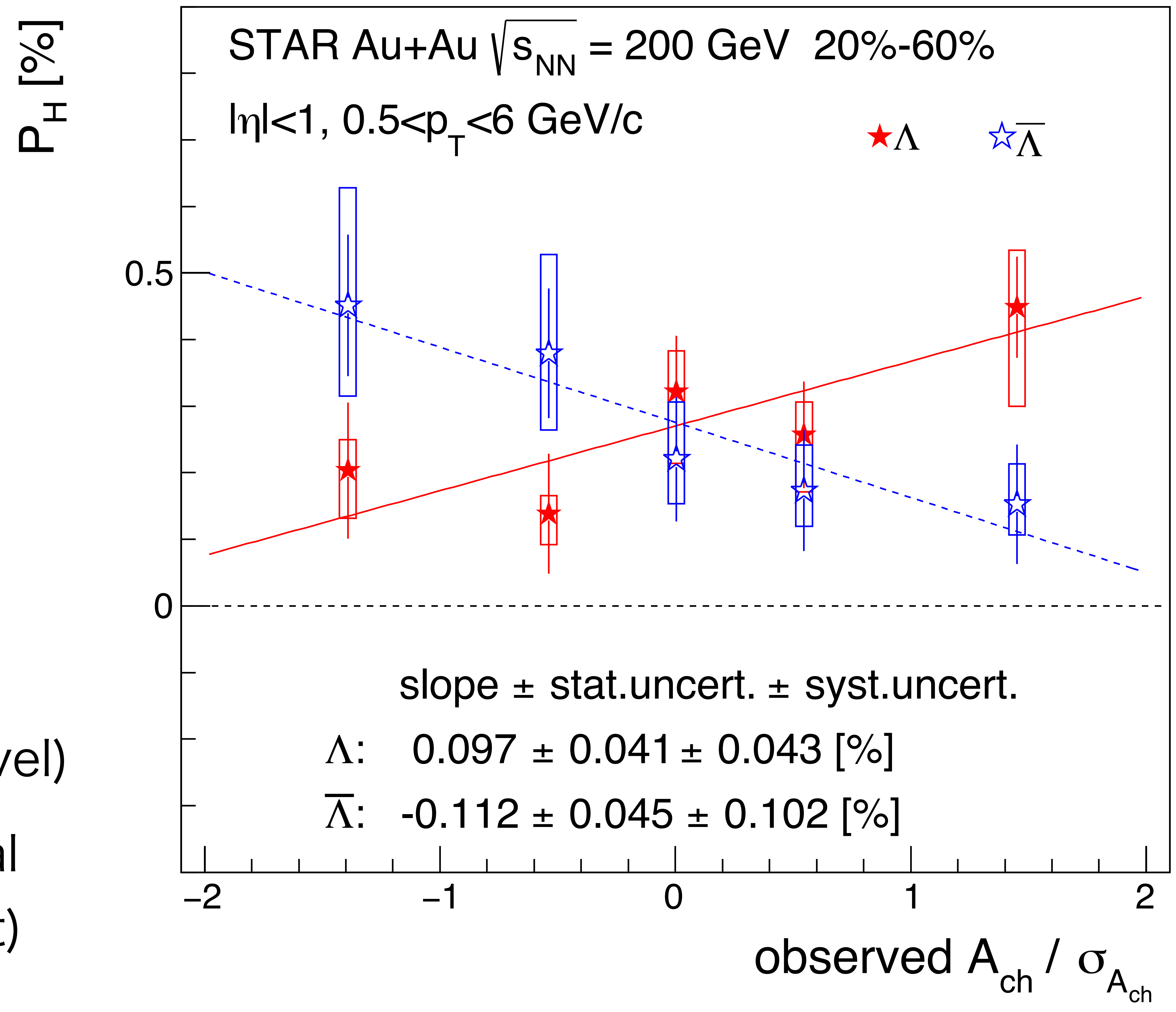

$$\mathbf{J}_5 \propto \mu_{\mathrm{v}} \mathbf{B}$$

B-field + massless quarks + non-zero $\mu_V$ → axial current $J_5$

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




STAR, PRC98, 014910 (2018)

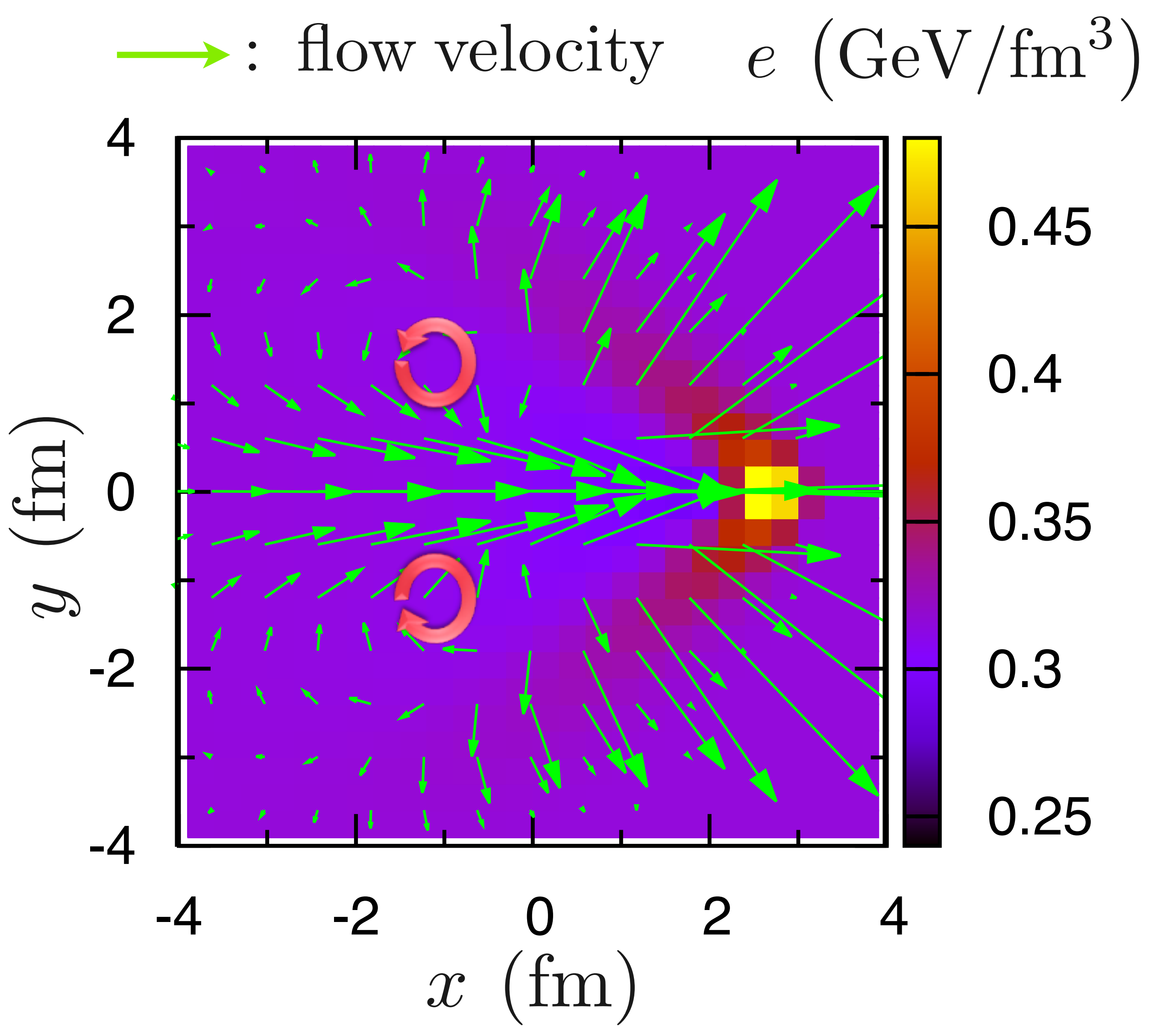



- Slopes of Λ and anti-Λ seem to be different (~2σ level)
- Possible contribution to the polarization from the axial current $J_5$ induced by B-field (Chiral Separation Effect)
  S. Shlichting and S. Voloshin

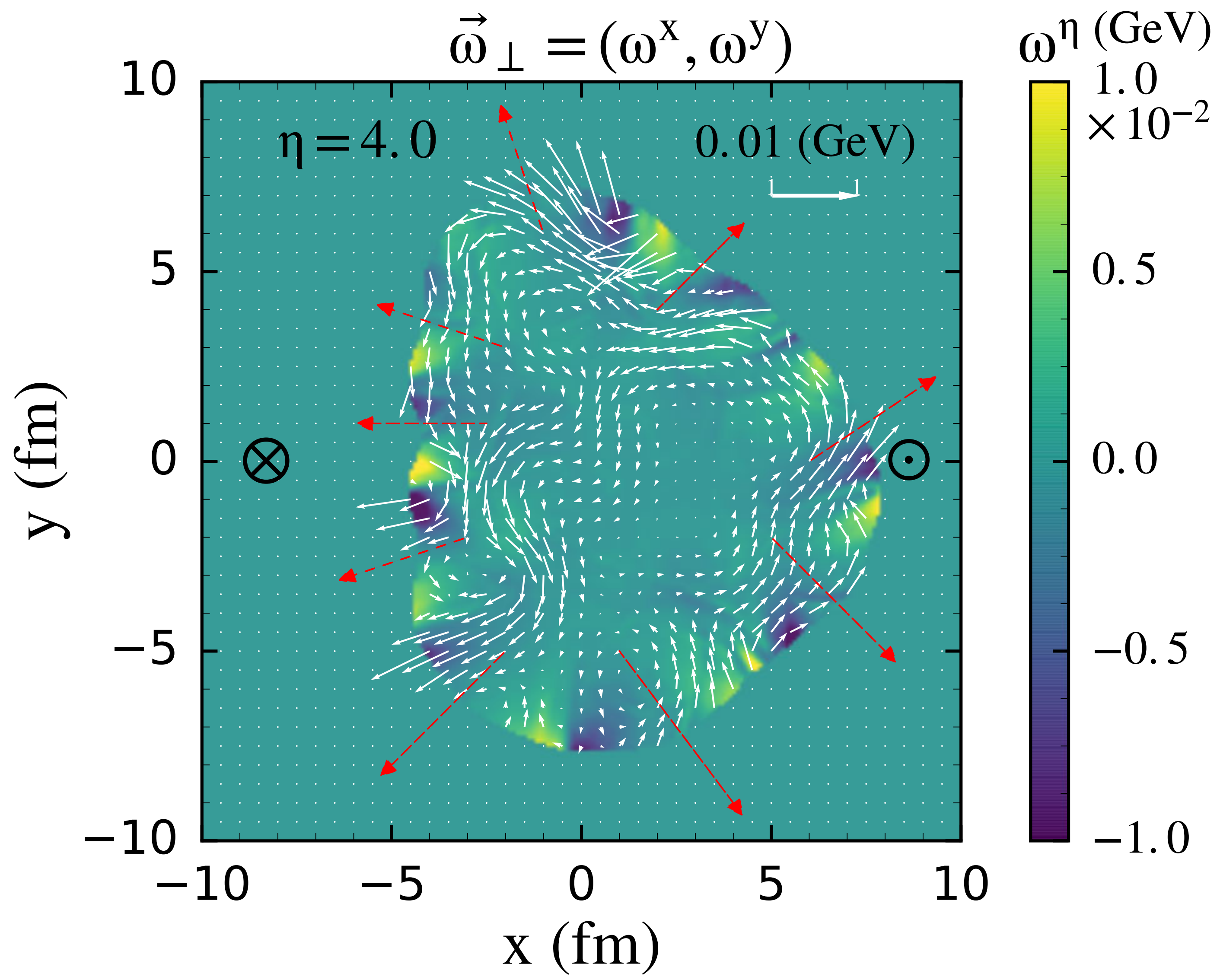
# Local vorticity

vortex induced by jet

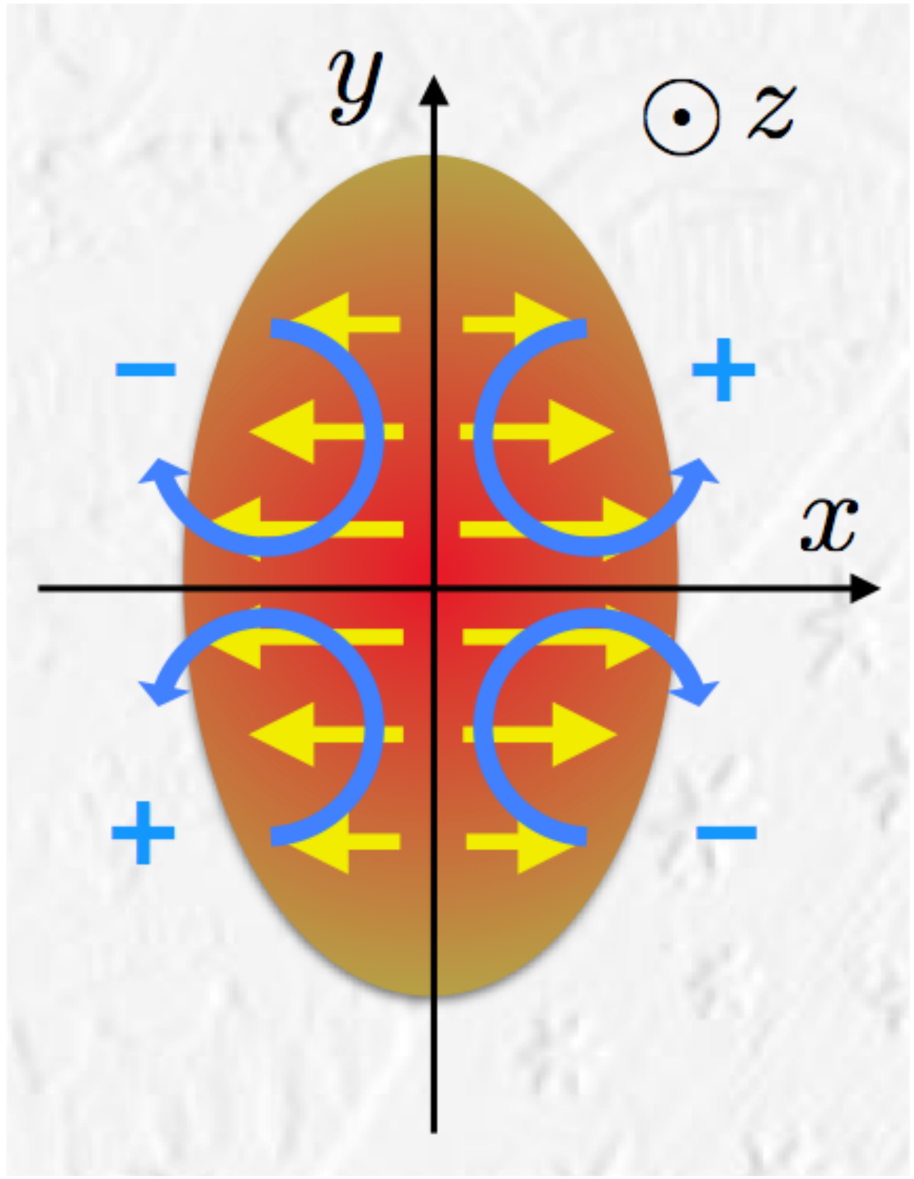
local vorticity induced by collective flow




Y. Tachibana and T. Hirano,
NPA904-905 (2013) 1023




L.-G. Pang, H. Peterson, Q. Wang, and X.-N. Wang
PRL117, 192301 (2016)




F. Becattini and I. Karpenko, PRL120.012302 (2018)
S. Voloshin, EPJ Web Conf.171, 07002 (2018)

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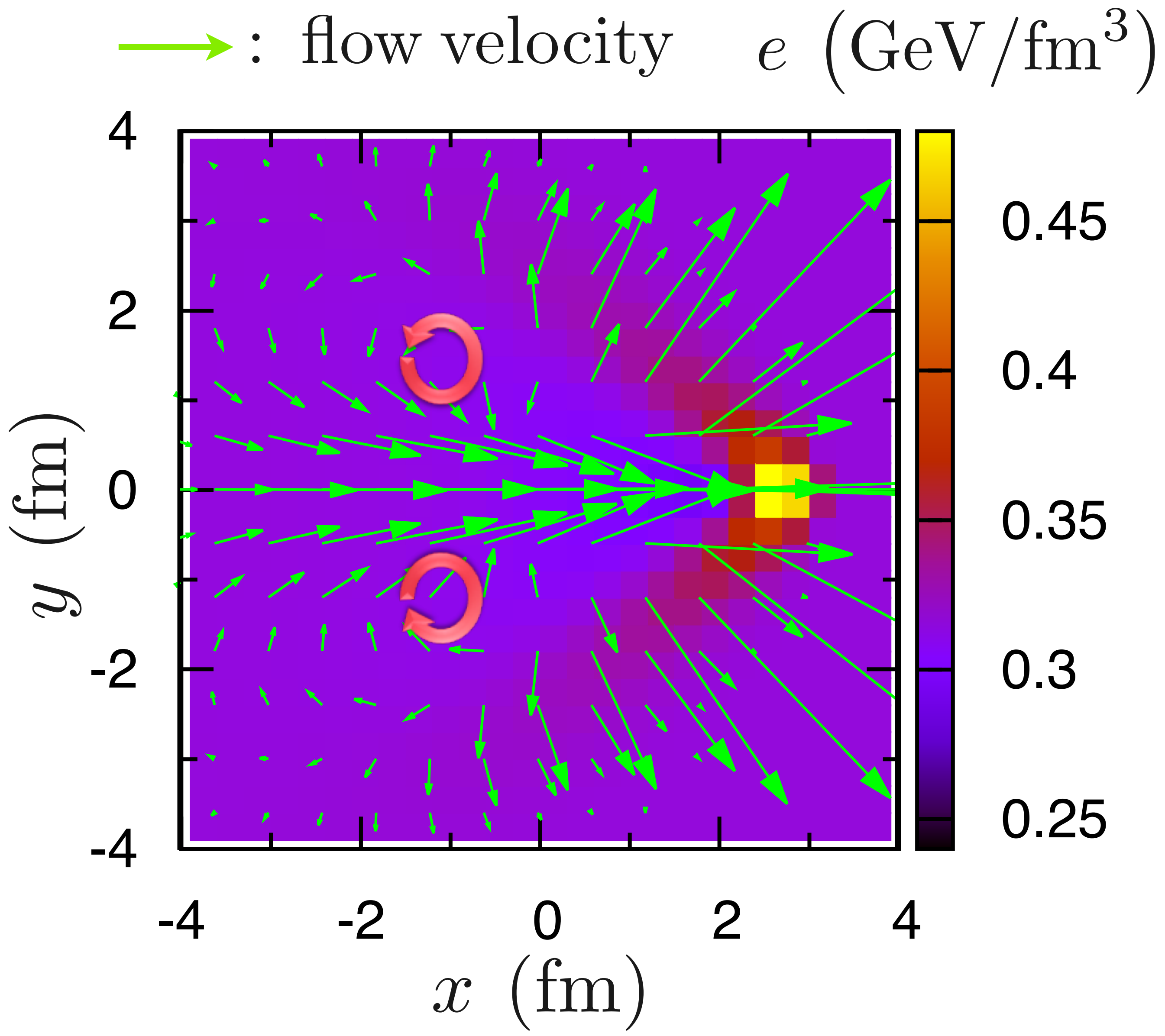


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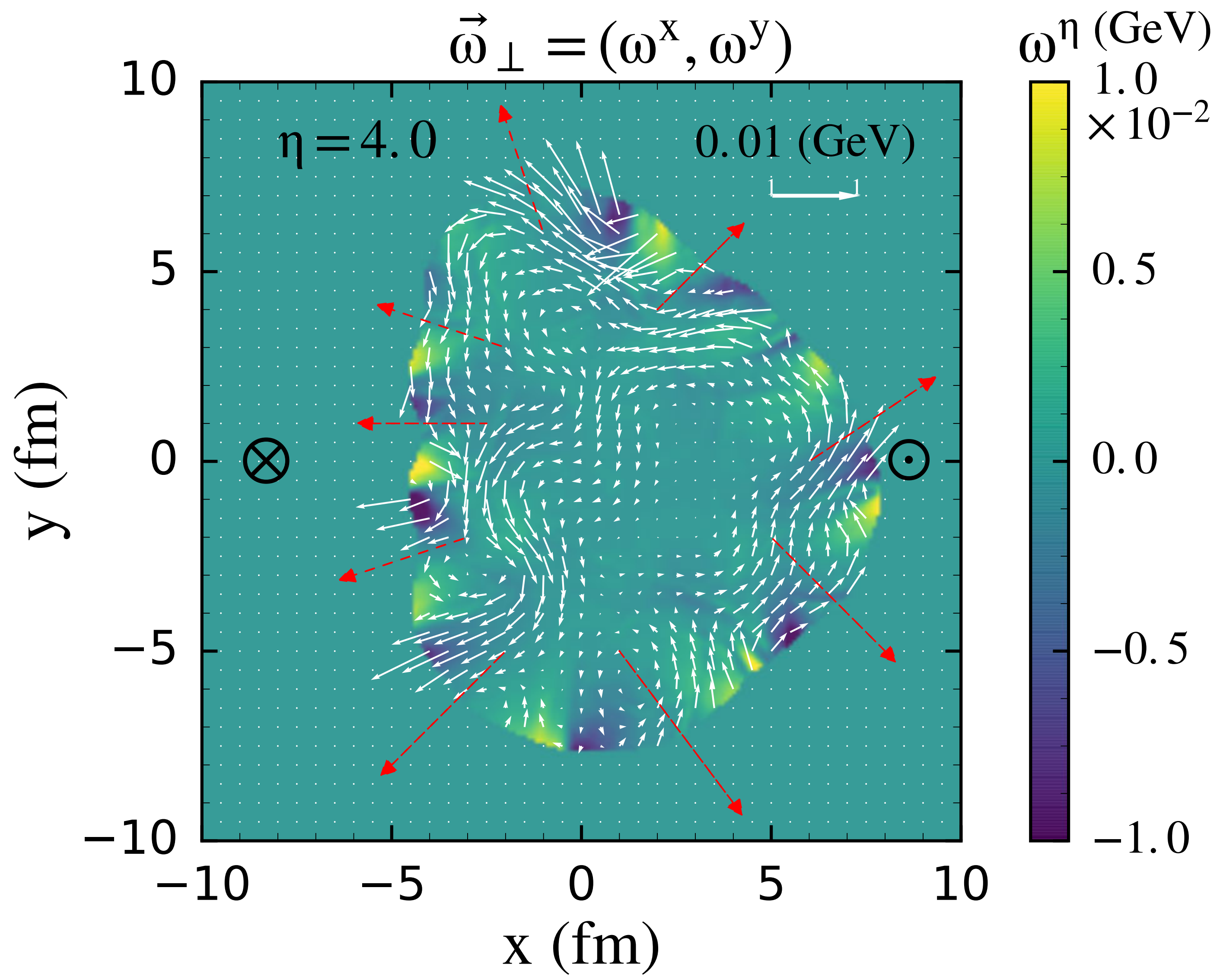


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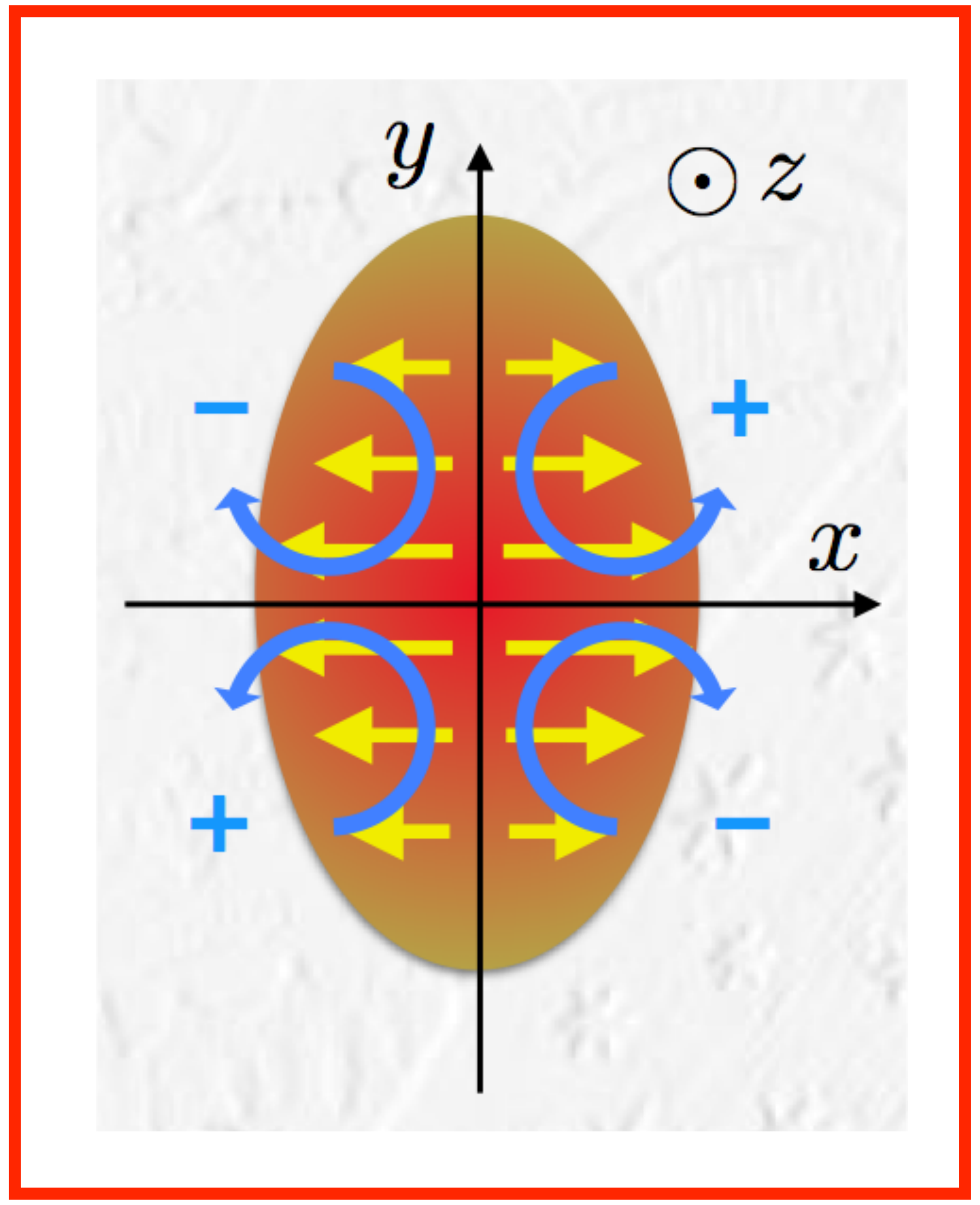


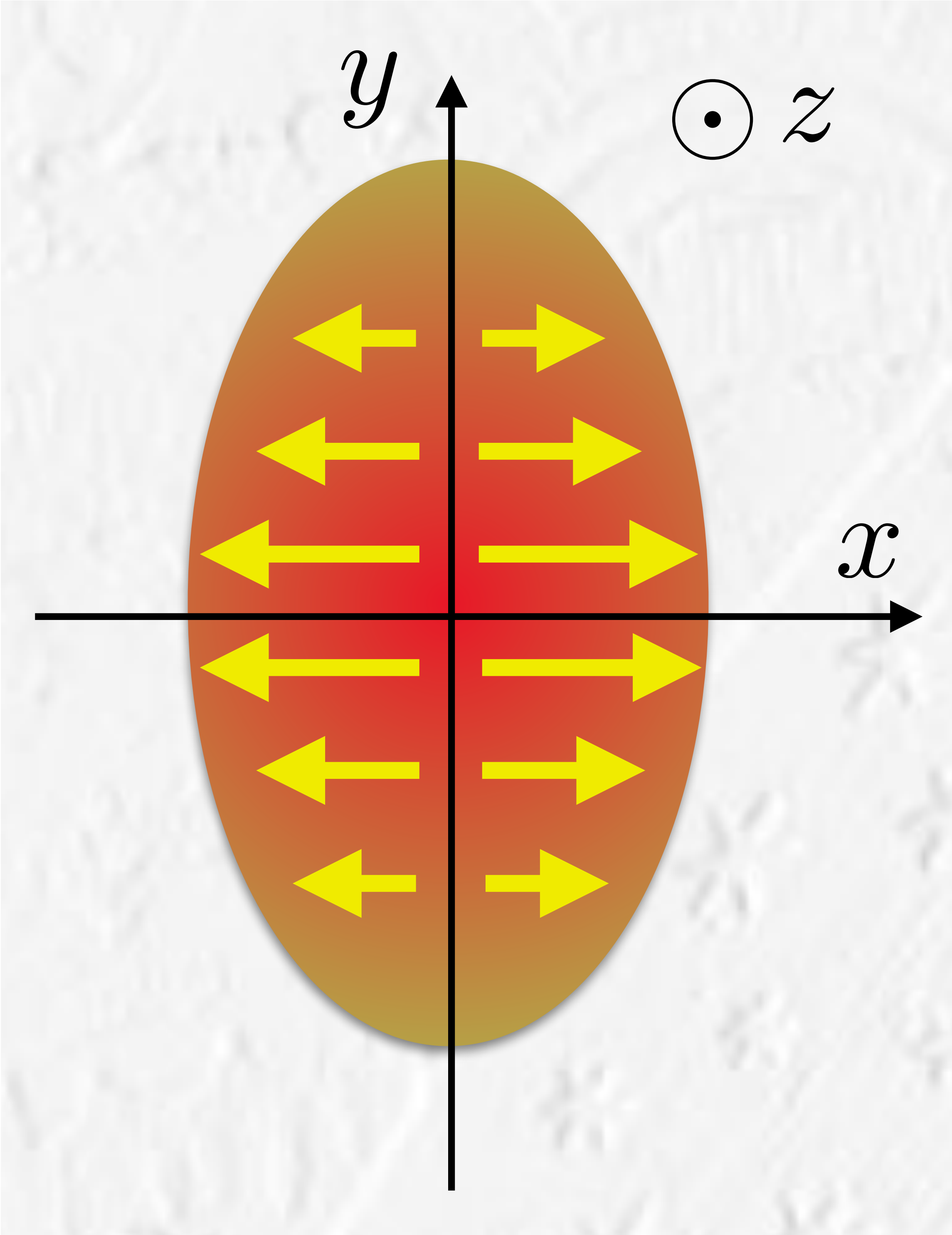

F. Becattini and I. Karpenko, PRL120.012302 (2018)
S. Voloshin, EPJ Web Conf.171, 07002 (2018)

Vorticity (polarization) along the beam direction due to the elliptic flow

# Polarization along the beam direction

S. Voloshin, SQM2017

F. Becattini and I. Karpenko, PRL120.012302 (2018)




Stronger flow in in-plane than in out-of-plane
could make local polarization along beam axis!

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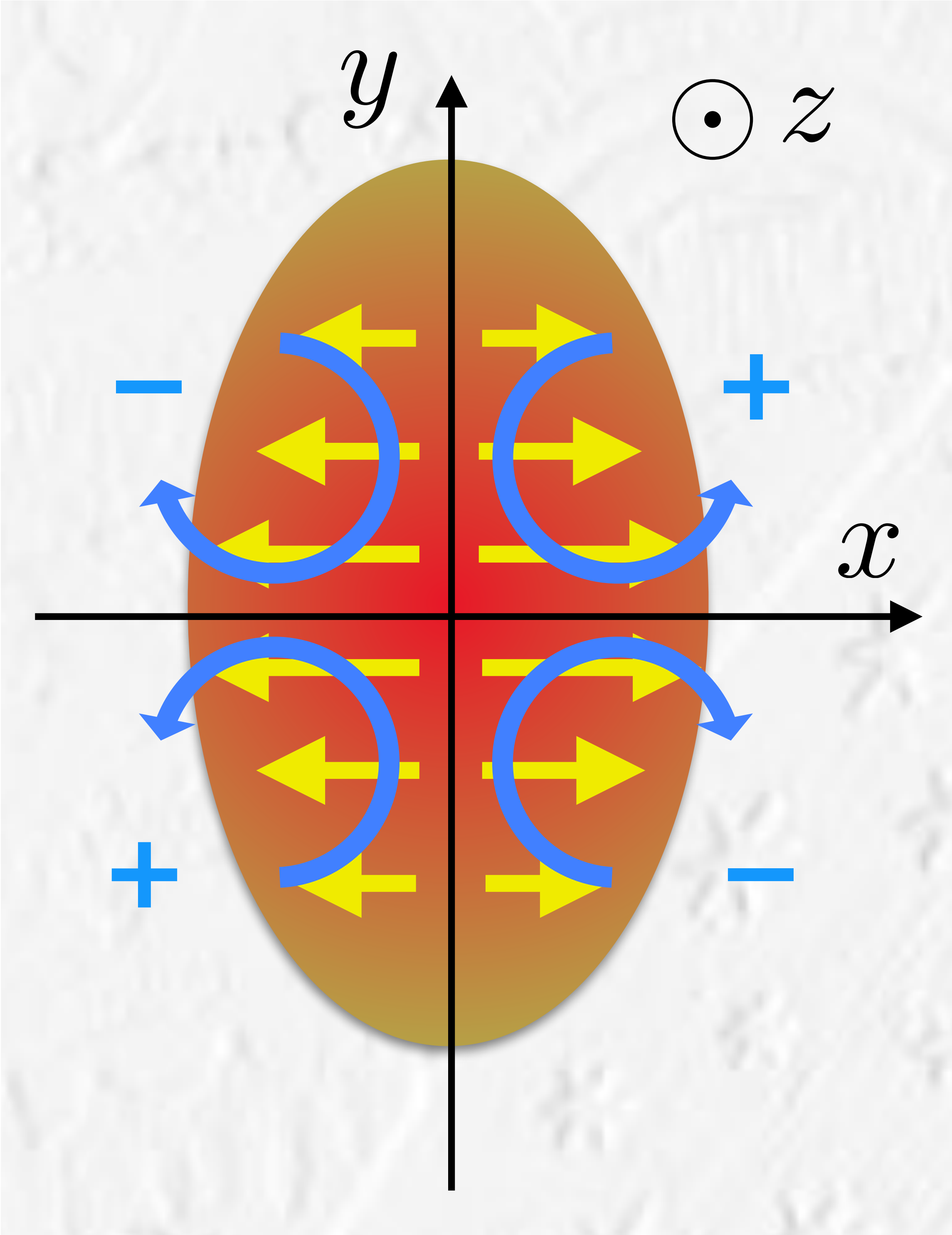


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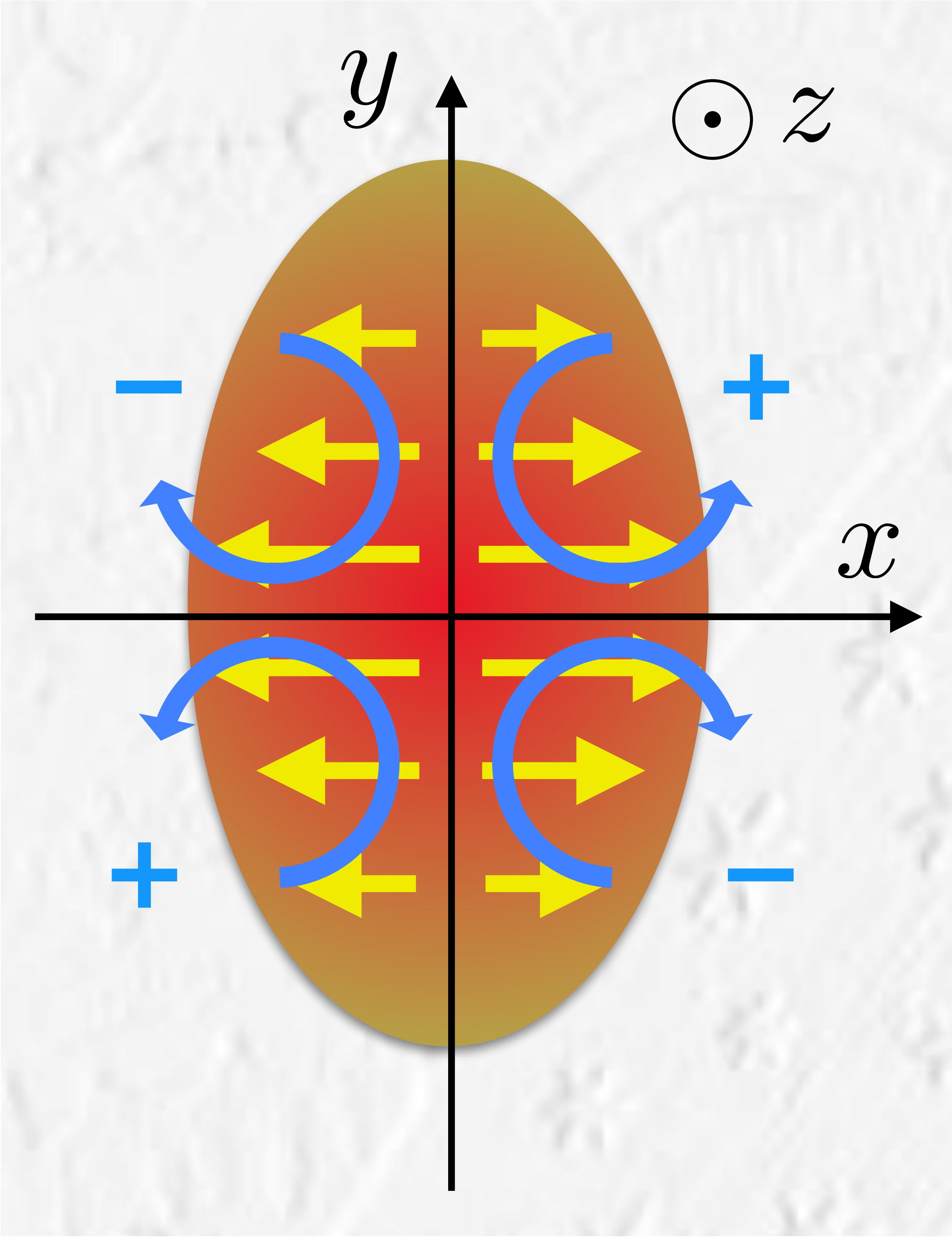
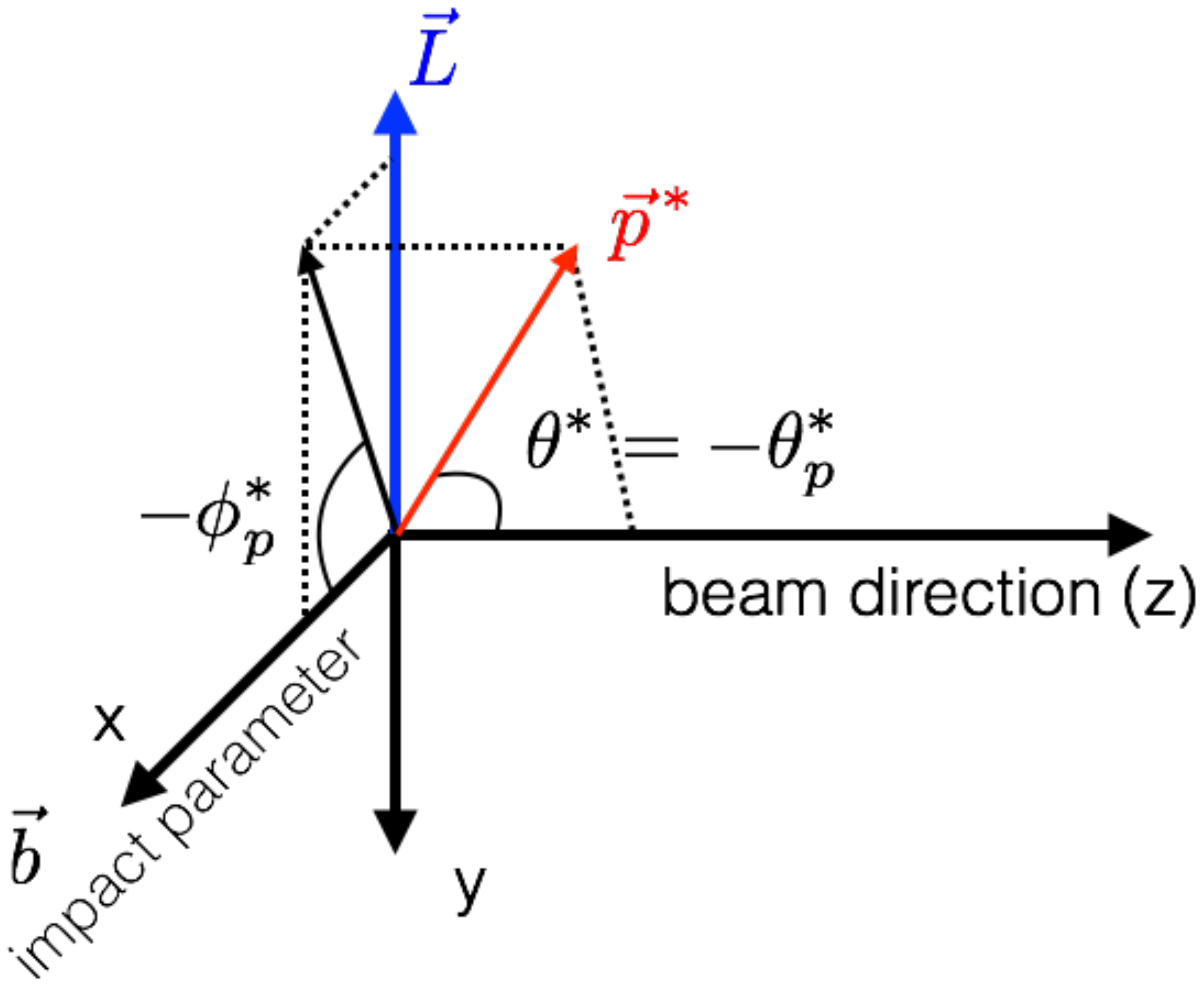



$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}(1 + \alpha_H \mathbf{P_H} \cdot \mathbf{p}_p^*)$$

$$\langle \cos\theta_p^* \rangle = \int \frac{dN}{d\Omega^*} \cos\theta_p^* d\Omega^*$$

$$= \alpha_H P_z \langle (\cos\theta_p^*)^2 \rangle$$

$$\therefore \; P_z = \frac{\langle \cos\theta_p^* \rangle}{\alpha_H \langle (\cos\theta_p^*)^2 \rangle}$$

$$= \frac{3\langle \cos\theta_p^* \rangle}{\alpha_H} \quad \text{(if perfect detector)}$$

$\alpha_H$: hyperon decay parameter

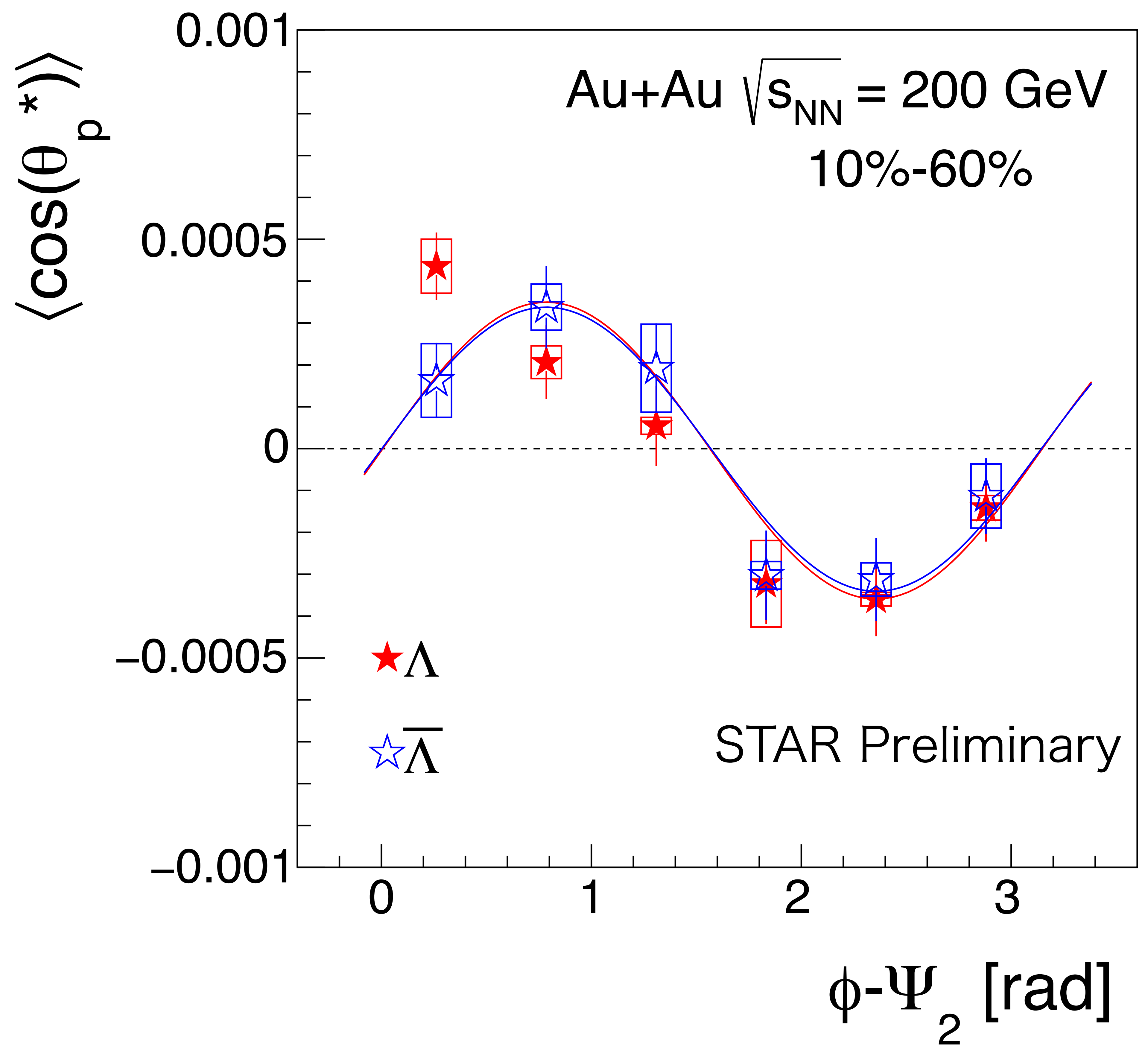
$\theta_p^*$: $\theta$ of daughter proton in $\Lambda$ rest frame

Stronger flow in in-plane than in out-of-plane could make local polarization along beam axis!

Longitudinal component, $P_z$, can be expressed with $\langle\cos\theta_p^*\rangle$.

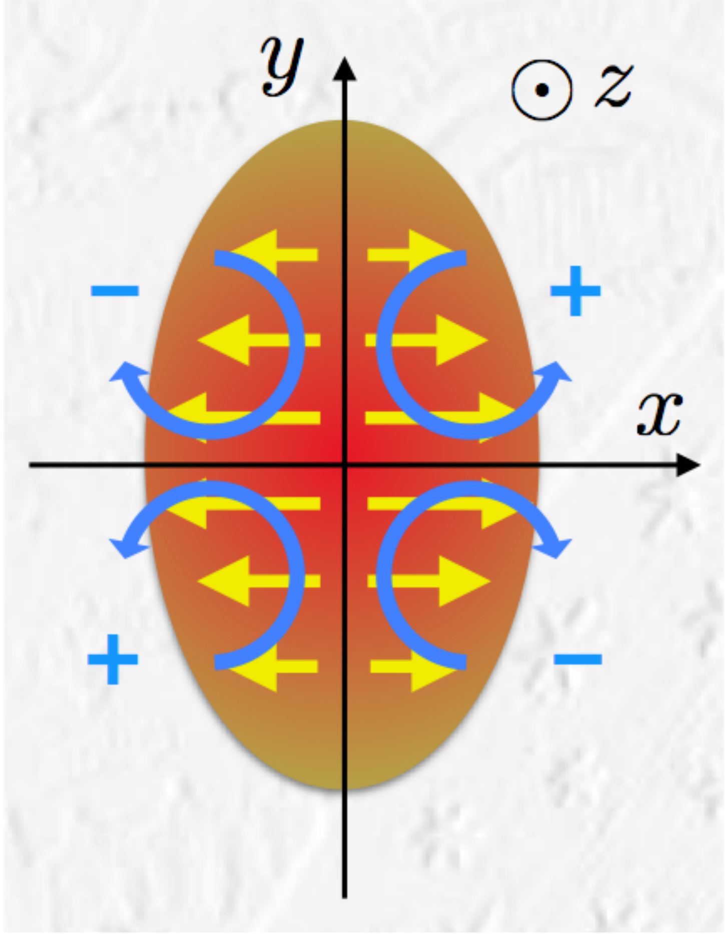
$\langle(\cos\theta_p^*)^2\rangle$ accounts for an acceptance effect

# Polarization along the beam direction



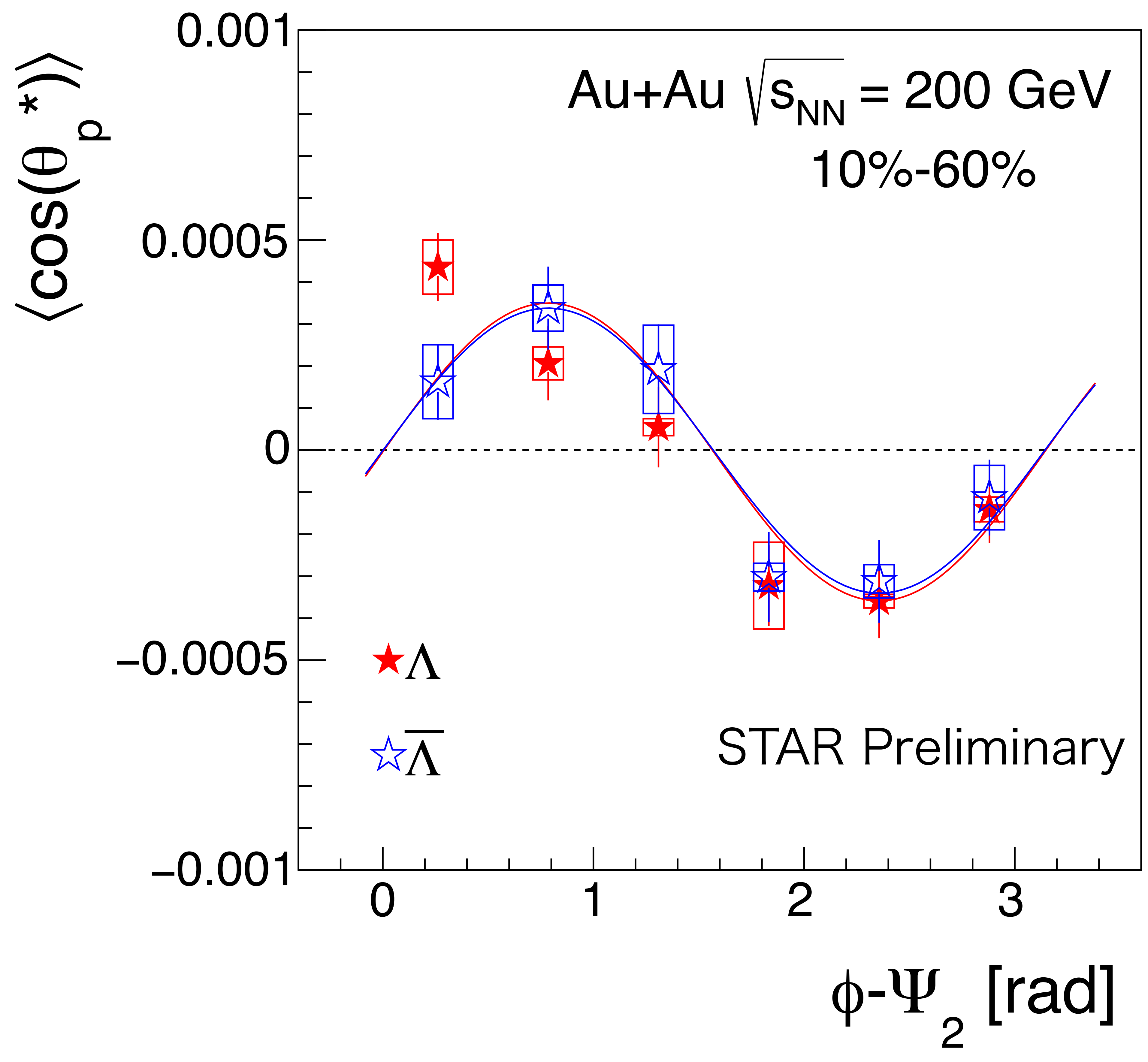

- Effect of $\Psi_2$ resolution is not corrected here

S. Voloshin, SQM2017




- Sine structure as expected from the elliptic flow!

# Polarization along the beam direction

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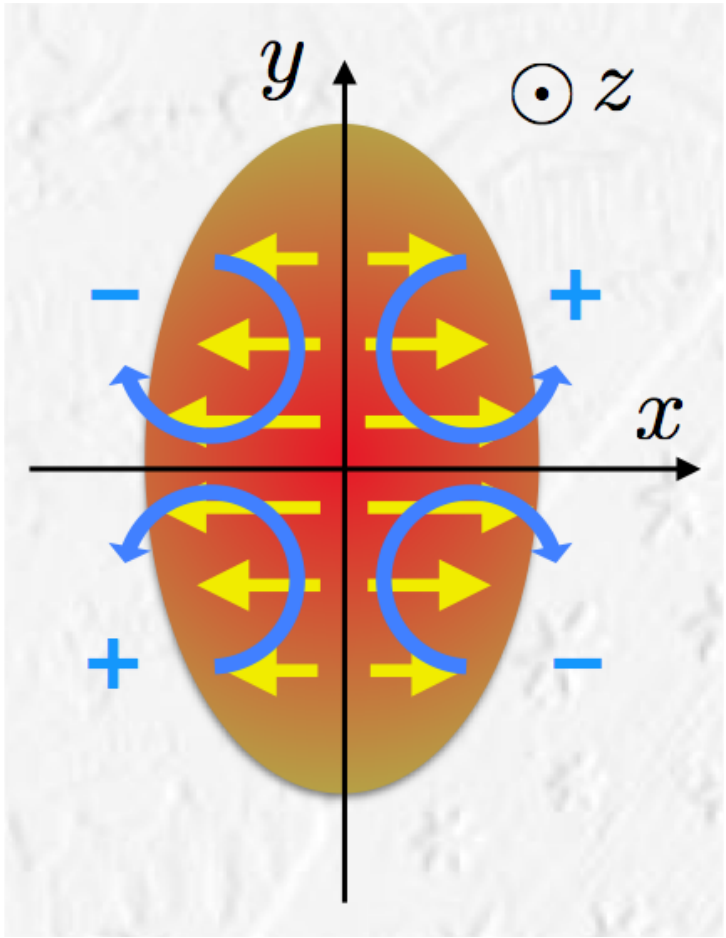
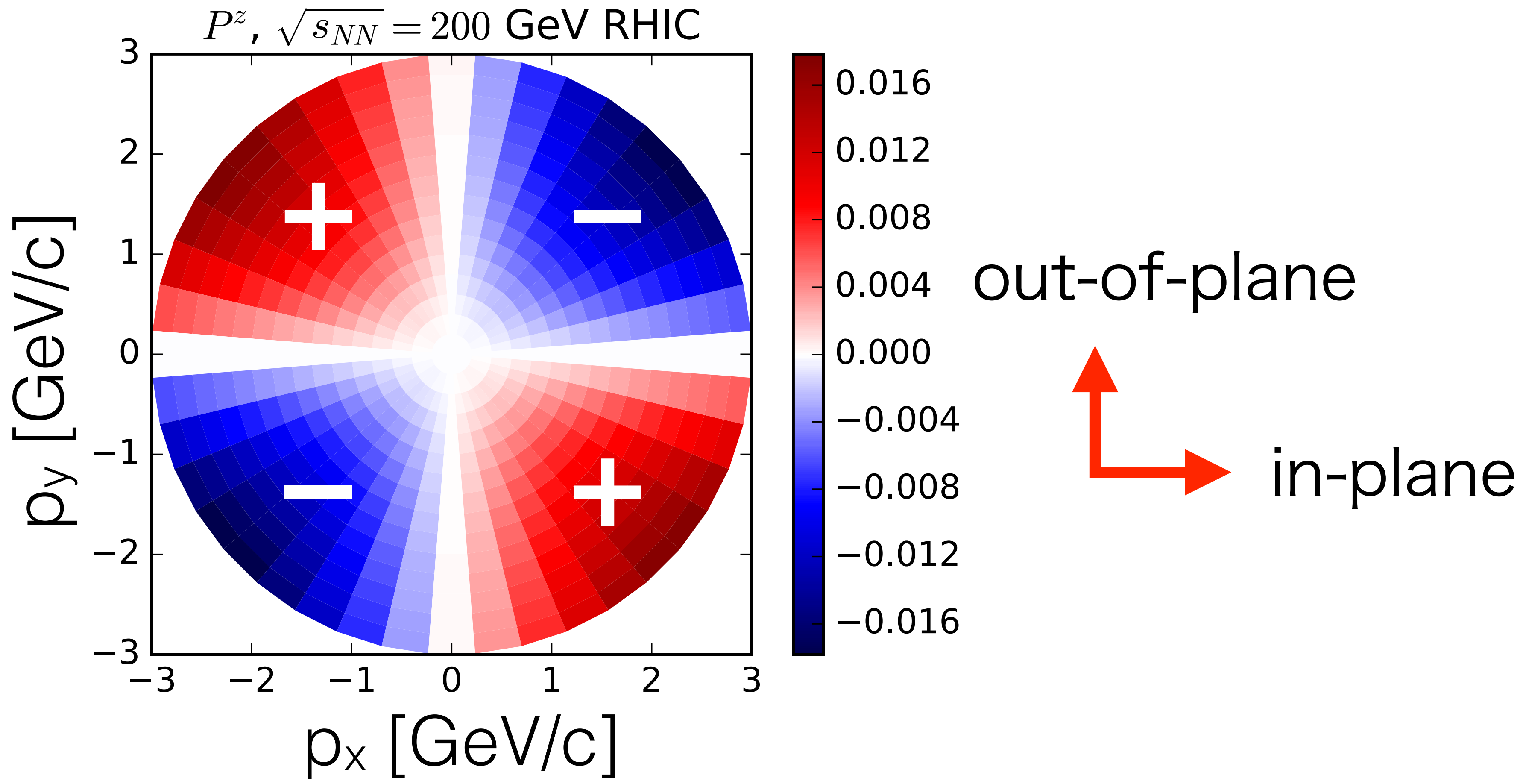
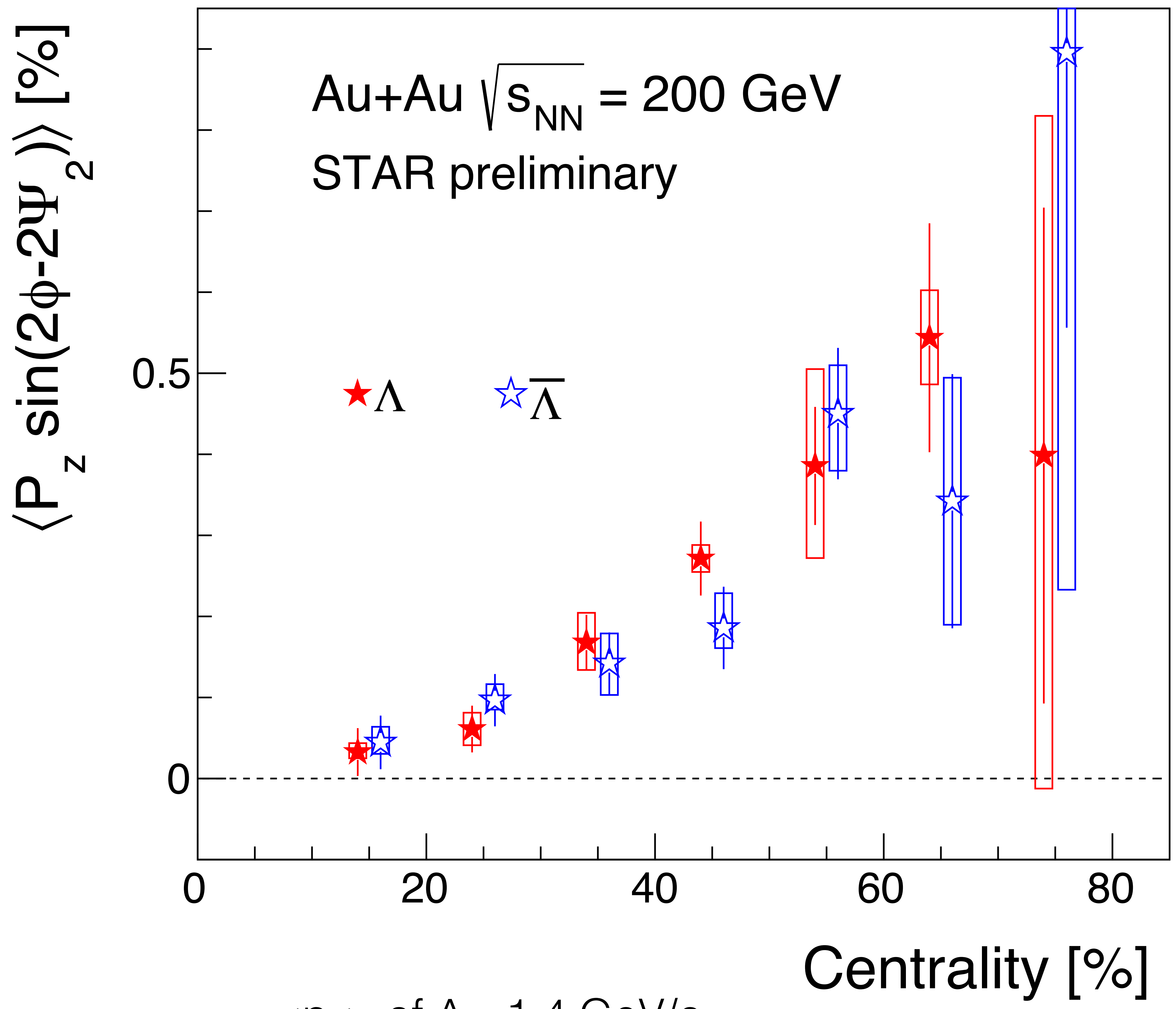



Hydro calculation of $P_z$
F. Becattini and I. Karpenko, PRL.120.012302 (2018)




- Sine structure as expected from the elliptic flow!
- Opposite sign to the hydrodynamic model and transport model (AMPT)
  - Hydro model: F. Becattini and I. Karpenko, PRL.120.012302 (2018)
  - AMPT model: X. Xia, H. Li, Z. Tang, Q. Wang, arXiv:1803.0086

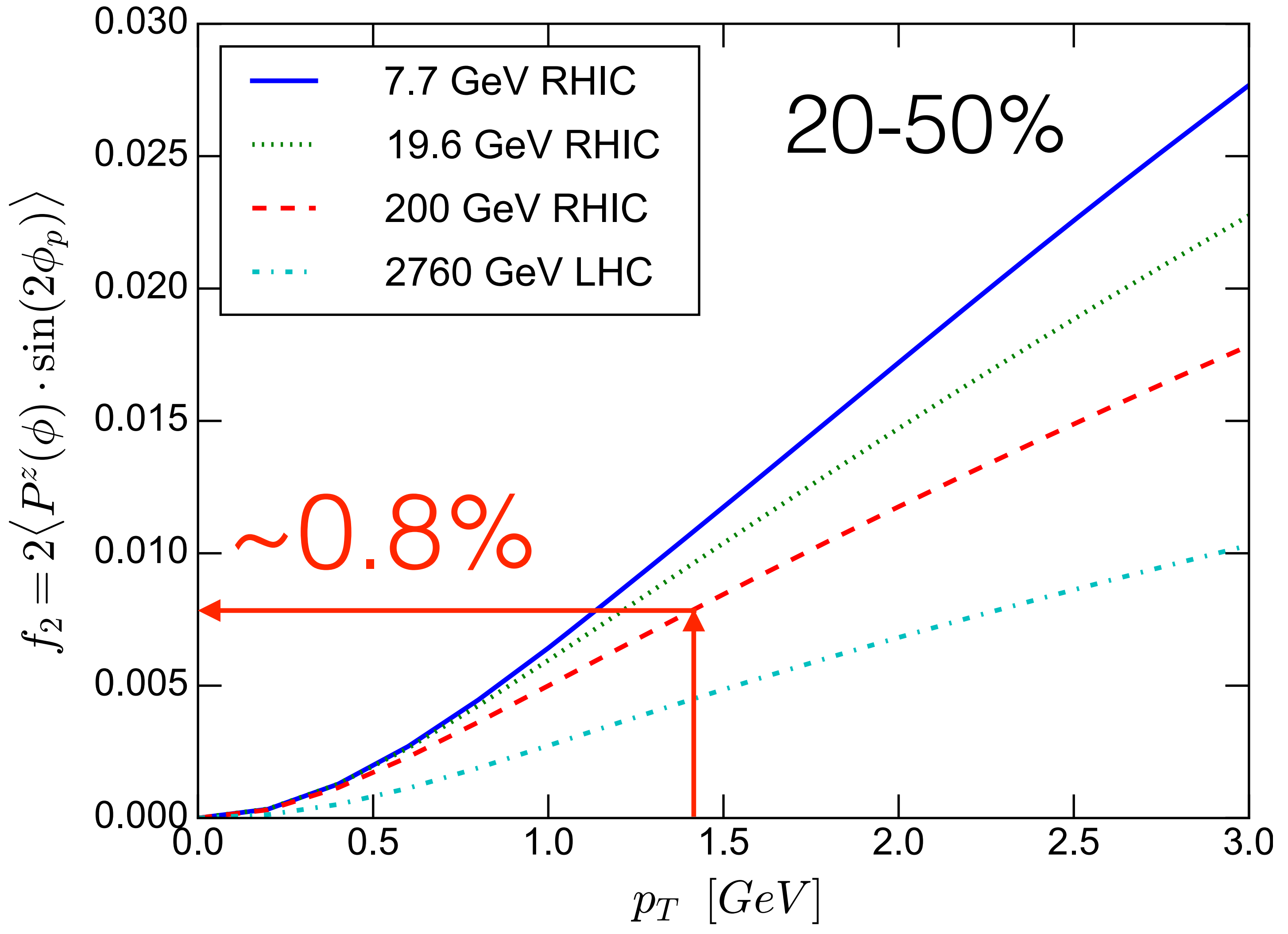
# Centrality dependence of $P_z$ modulation




<$p_T$> of Λ ~1.4 GeV/c
(0.5<$p_T$<6 GeV/c)

- Strong centrality dependence as in $v_2$
- Similar magnitude to the global polarization
- ~5 times smaller magnitude than the hydro and AMPT with the opposite sign!

F. Becattini and I. Karpenko, PRL.120.012302 (2018)



# Sign problem in $P_z$

Opposite sign to hydrodynamic model and AMPT model

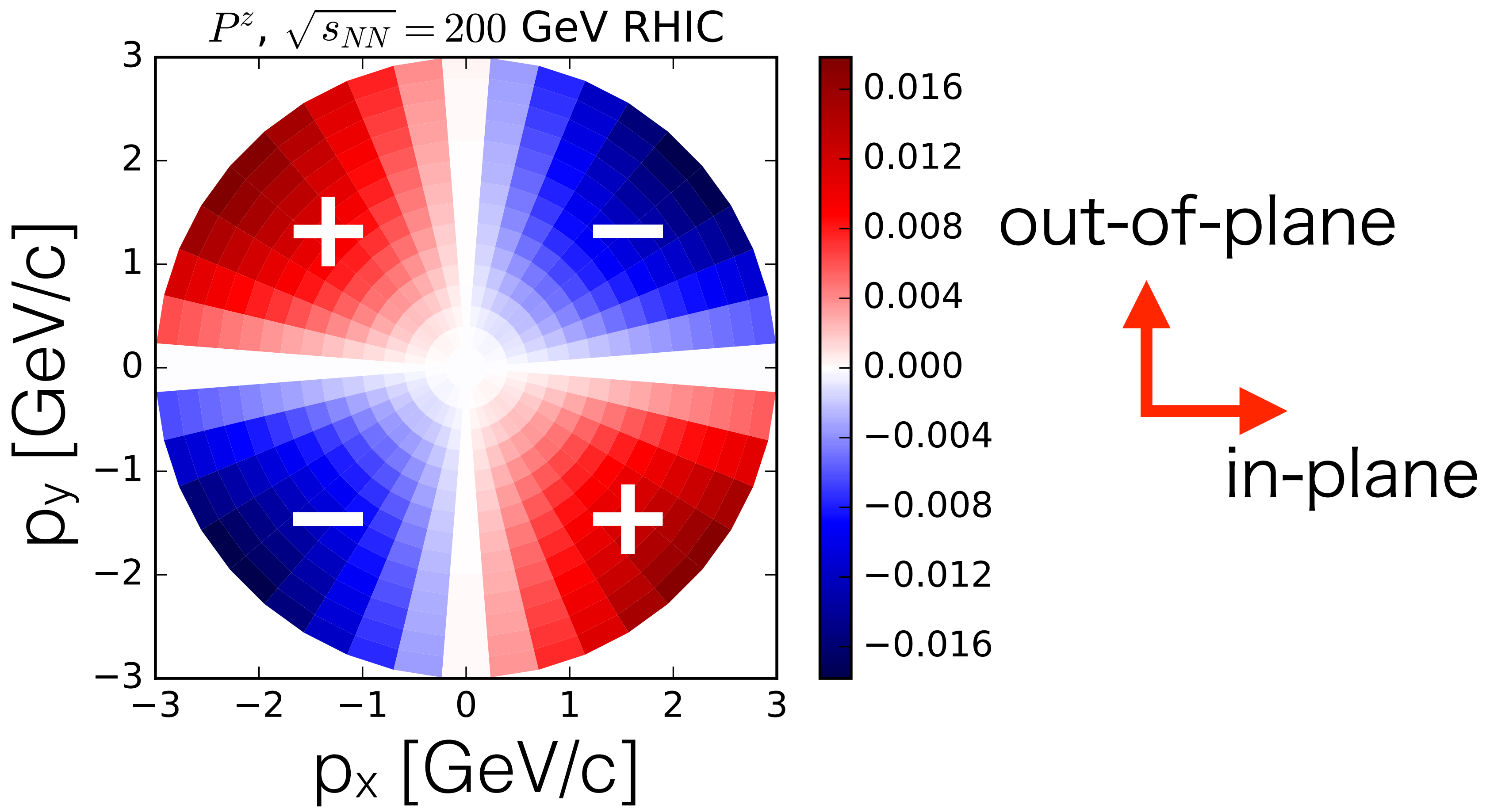
- F. Becattini and I. Karpenko, PRL.120.012302 (2018)
  3D viscous hydrodynamic model with UrQMD initial condition assuming a local thermal equilibrium
- AMPT: X. Xia, H. Li, Z. Tang, Q. Wang, PRC98.024905 (2018)

Same sign as chiral kinetic approach

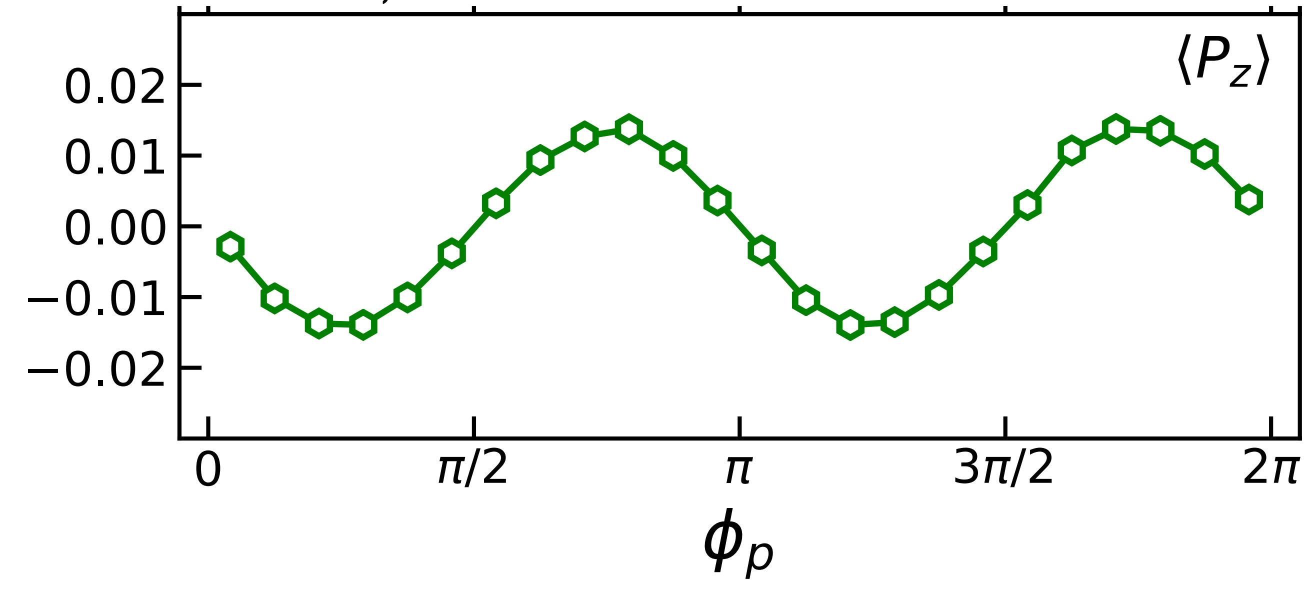
- Y. Sun and C.-M. Ko, PRC99, 011903(R) (2019)
- Assuming non-equilibrium of spin degree of freedom
- Smaller quark scattering cross section changes the sign

*Suggest incomplete thermal equilibrium of spin degree of freedom as it may develop later in time unlike the global polarization?*

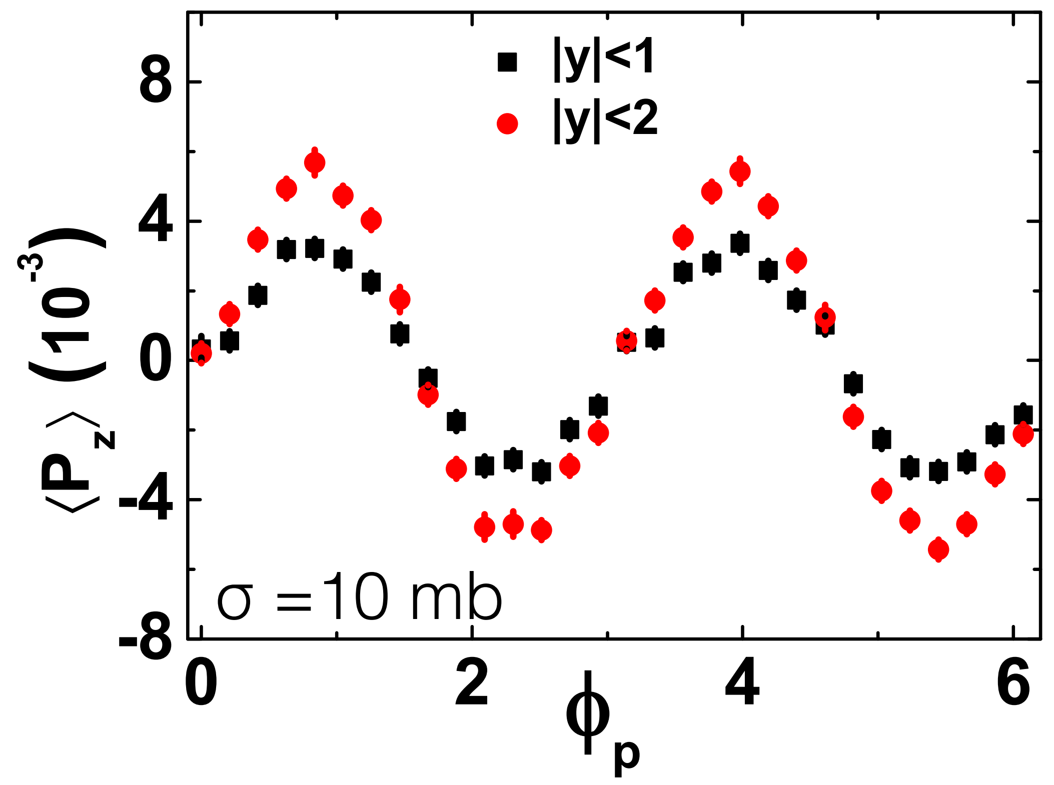
Hydrodynamic model




AMPT, Au+Au 200 GeV 20-50%




chiral kinetic approach



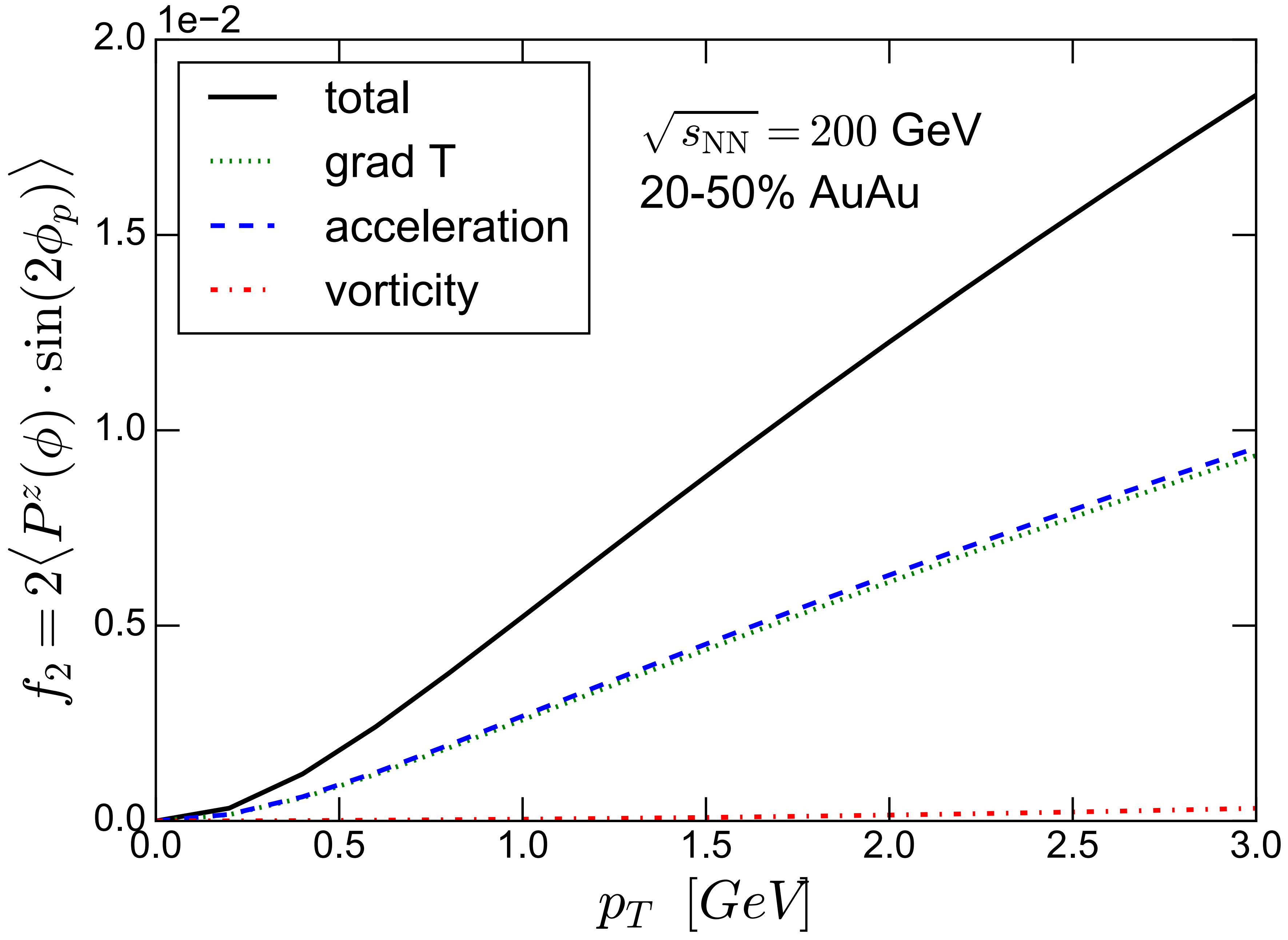
# Contributions to $P_z$ in hydro

I. Karpenko, QM2018

$$S^\mu \propto \varepsilon^{\mu\rho\sigma\tau}\varpi_{\rho\sigma}p_\tau = \varepsilon^{\mu\rho\sigma\tau}(\partial_\rho\beta_\sigma)p_\tau = \underbrace{\varepsilon^{\mu\rho\sigma\tau}p_\tau\partial_\rho\left(\frac{1}{T}\right)u_\sigma}_{\mathrm{grad}T} + \underbrace{\frac{1}{T}2\left[\omega^\mu(u\cdot p) - u^\mu(\omega\cdot p)\right]}_{\text{“NR vorticity”}} + \underbrace{\varepsilon^{\mu\rho\sigma\tau}p_\tau A_\sigma u_\rho}_{\text{acceleration}}$$

**temperature gradient** **kinematic vorticity** **relativistic term**

**Longitudinal quadrupole $f_2$:**

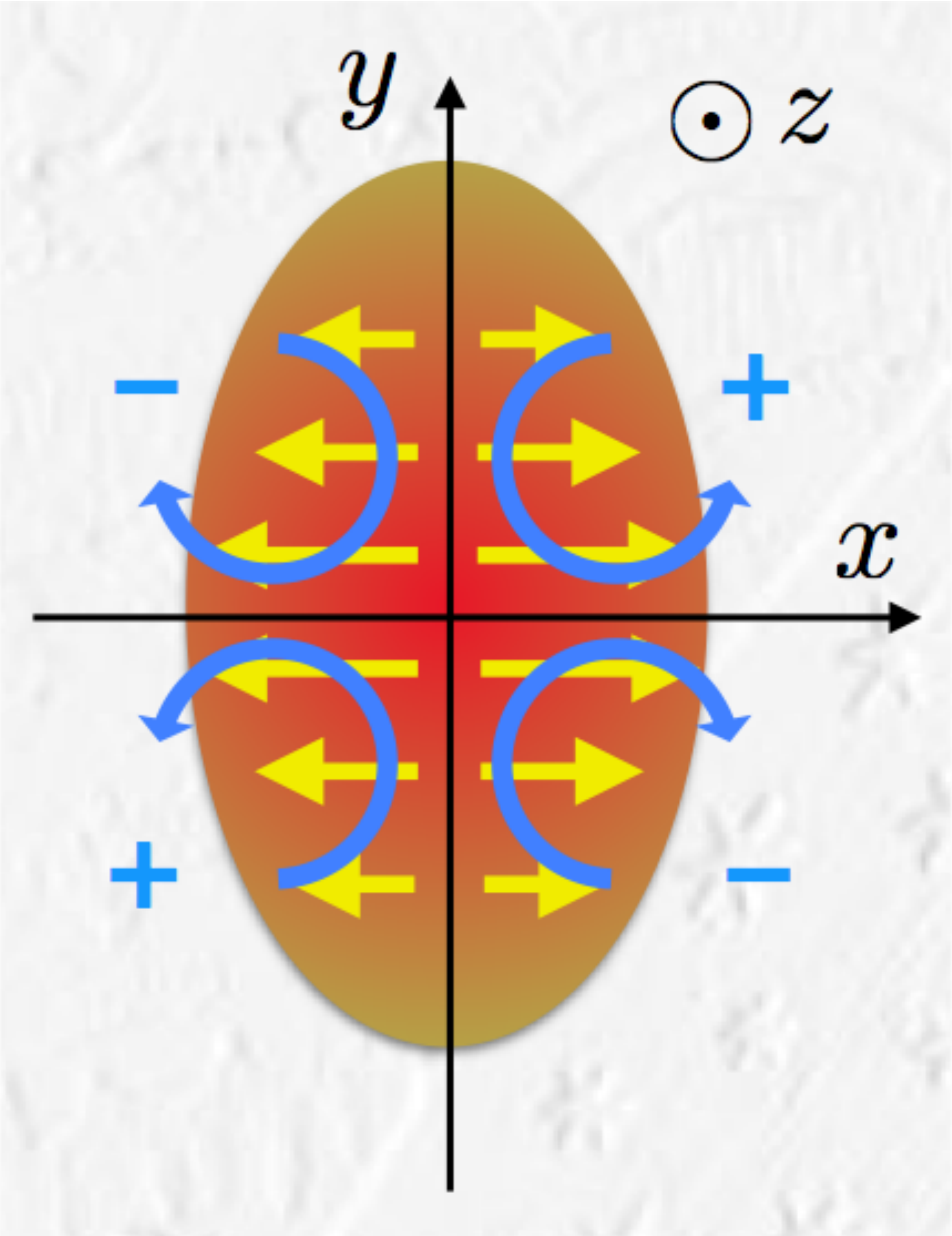


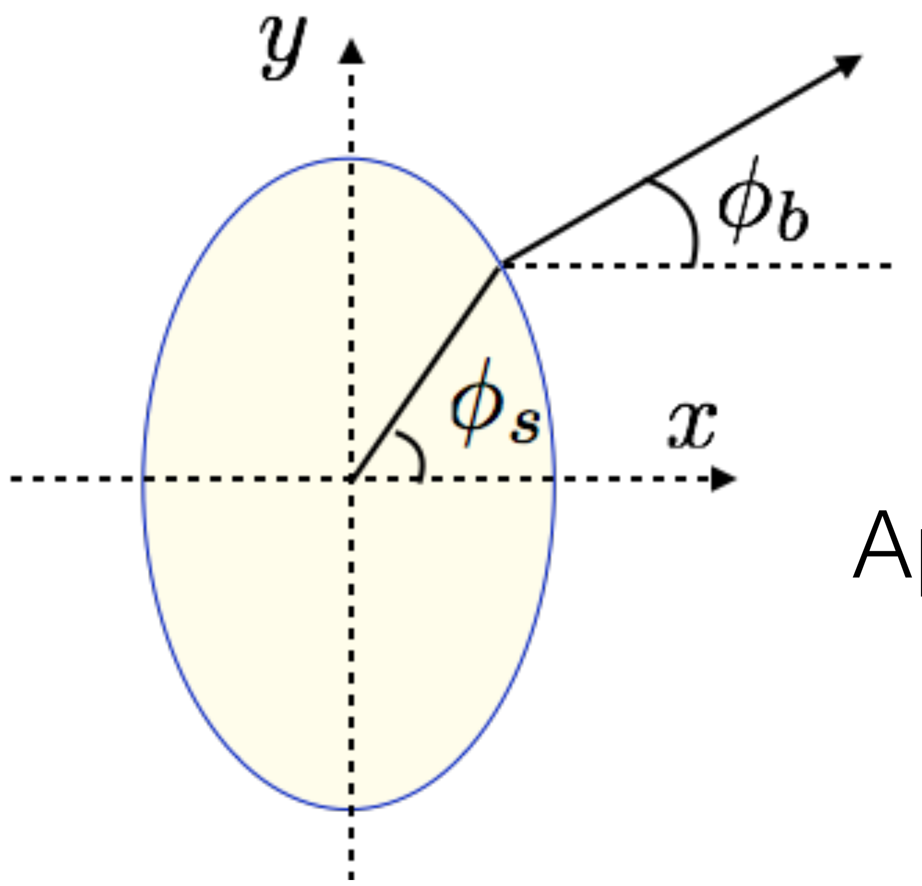

$P_z$ dominated by temperature gradient and relativistic term, but not by kinematic vorticity based on the hydro model.

Can we get such a small kinetic vorticity in the blast-wave model?

# Kinematic vorticity in the blast-wave model

S. Voloshin, SQM2017
EPJ Web Conf.171, 07002 (2018)




$$r_{max} = R[1 - a\cos(2\phi_s)],$$

$$\rho_t = \rho_{t,max}[r/r_{max}(\phi_s)][1 + b\cos(2\phi_s)] \approx \rho_{t,max}(r/R)[1 + (a+b)\cos(2\phi_s)].$$

Approximation of the kinetic vorticity in the blast-wave model:

$$\omega_z = 1/2(\nabla \times \mathbf{v})_z \approx (\rho_{t,nmax}/R)\sin(n\phi_s)[b_n - a_n].$$

$a_n$: spatial anisotropy  R: reference source radius
$b_n$: flow anisotropy  $\rho_t$: transverse flow velocity

Quadrupole or sine structure of $\omega_z$ is expected with the factor $[b_n-a_n]$.
The sign could be negative depending on the relation of flow and spatial anisotropy.

# Blast-wave model parameterization

- Hydro-inspired model parameterized with freeze-out condition assuming the longitudinal boost invariance
  - Freeze-out temperature $T_f$
  - Radial flow rapidity $\rho_0$ and its modulation $\rho_2$
  - Source size $R_x$ and $R_y$

$$\rho(r, \phi_s) = \tilde{r}[\rho_0 + \rho_2 \cos(2\phi_b)]$$

$$\tilde{r}(r, \phi_s) = \sqrt{(r\cos\phi_s)^2/R_x^2 + (r\sin\phi_s)^2/R_y^2}$$

F. Retiere and M. Lisa, PRC70.044907 (2004)

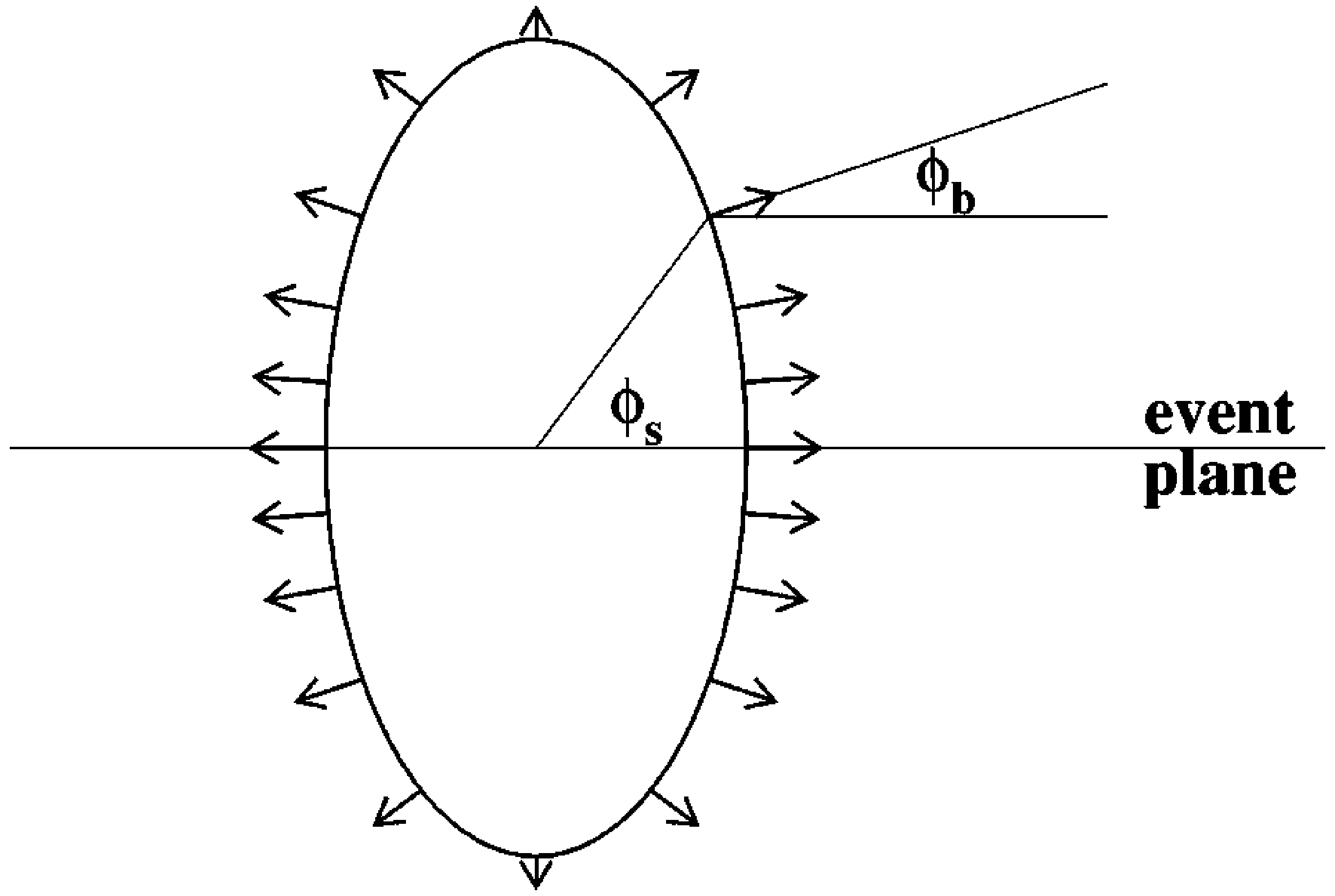



FIG. 2. Schematic illustration of an elliptical subshell of the source. Here, the source is extended out of the reaction plane ($R_y > R_x$). Arrows represent the direction and magnitude of the flow boost. In this example, $\rho_2 > 0$ [see Eq. (4)].

$\phi_s$: azimuthal angle of the source element

$\phi_b$: boost angle perpendicular to the elliptical subshell

- Calculate vorticity at the freeze-out using the parameters extracted from spectra, $v_2$, and HBT fit
  -

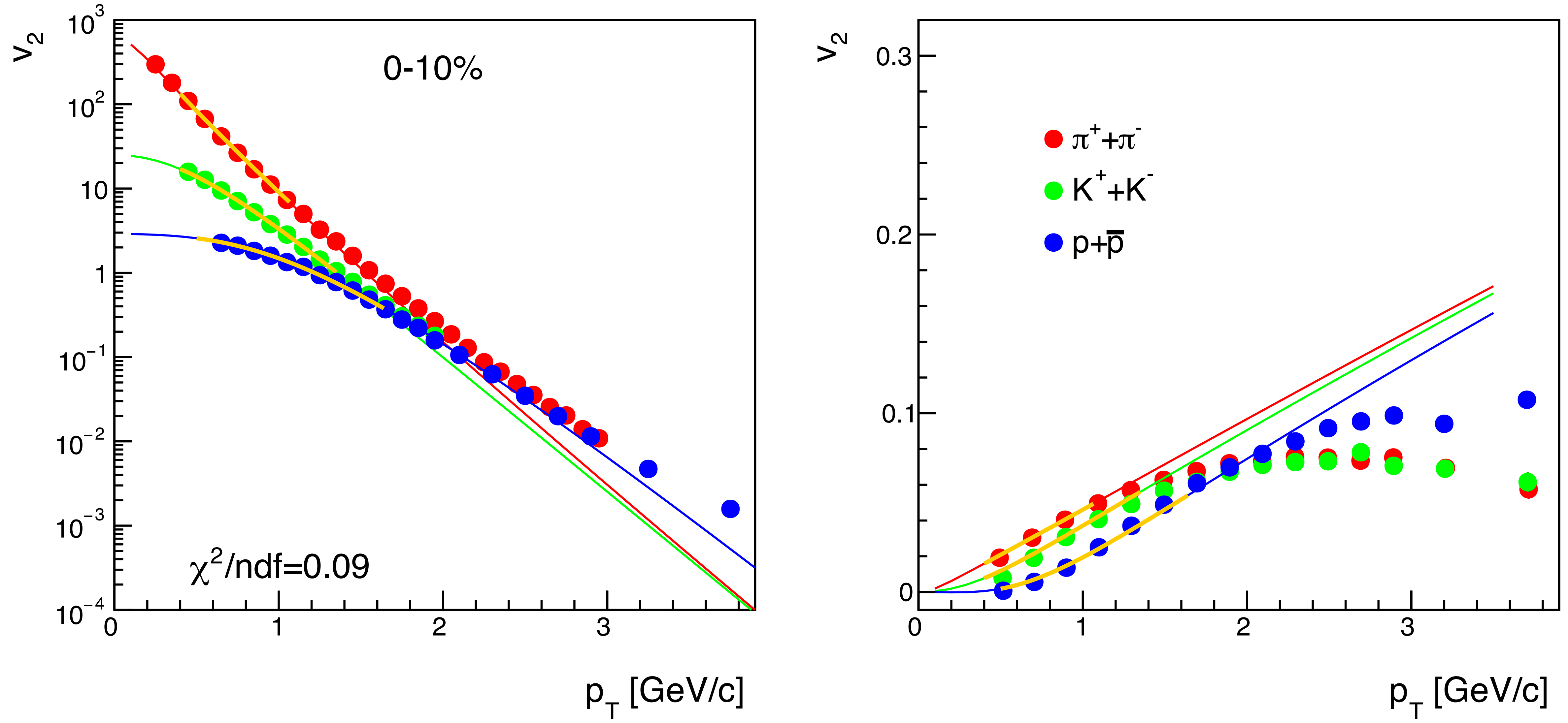
$$\langle \omega_z \sin(2\phi) \rangle = \frac{\int d\phi_s \int r dr\, I_2(\alpha_t) K_1(\beta_t) \omega_z \sin(2\phi_b)}{\int d\phi_s \int r dr\, I_0(\alpha_t) K_1(\beta_t)}$$

$$\omega_z = \frac{1}{2}\left(\frac{\partial u_y}{\partial x} - \frac{\partial u_x}{\partial y}\right),$$

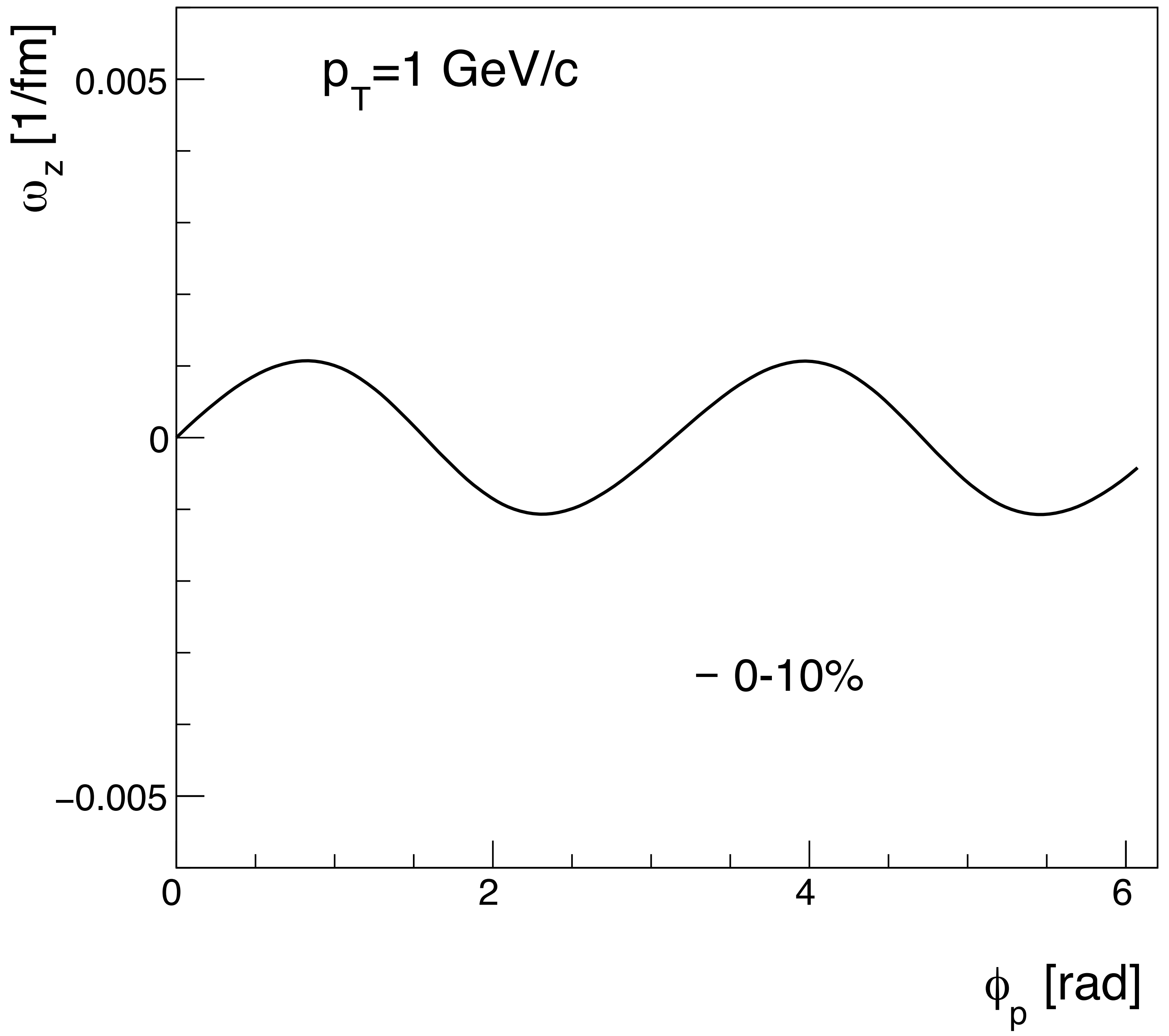
u: local flow velocity, $I_n$, $K_n$: modified Bessel functions

# $\omega_z$ and $P_z$ from the BW model

e.g. Blast-wave fit to spectra and $v_2$

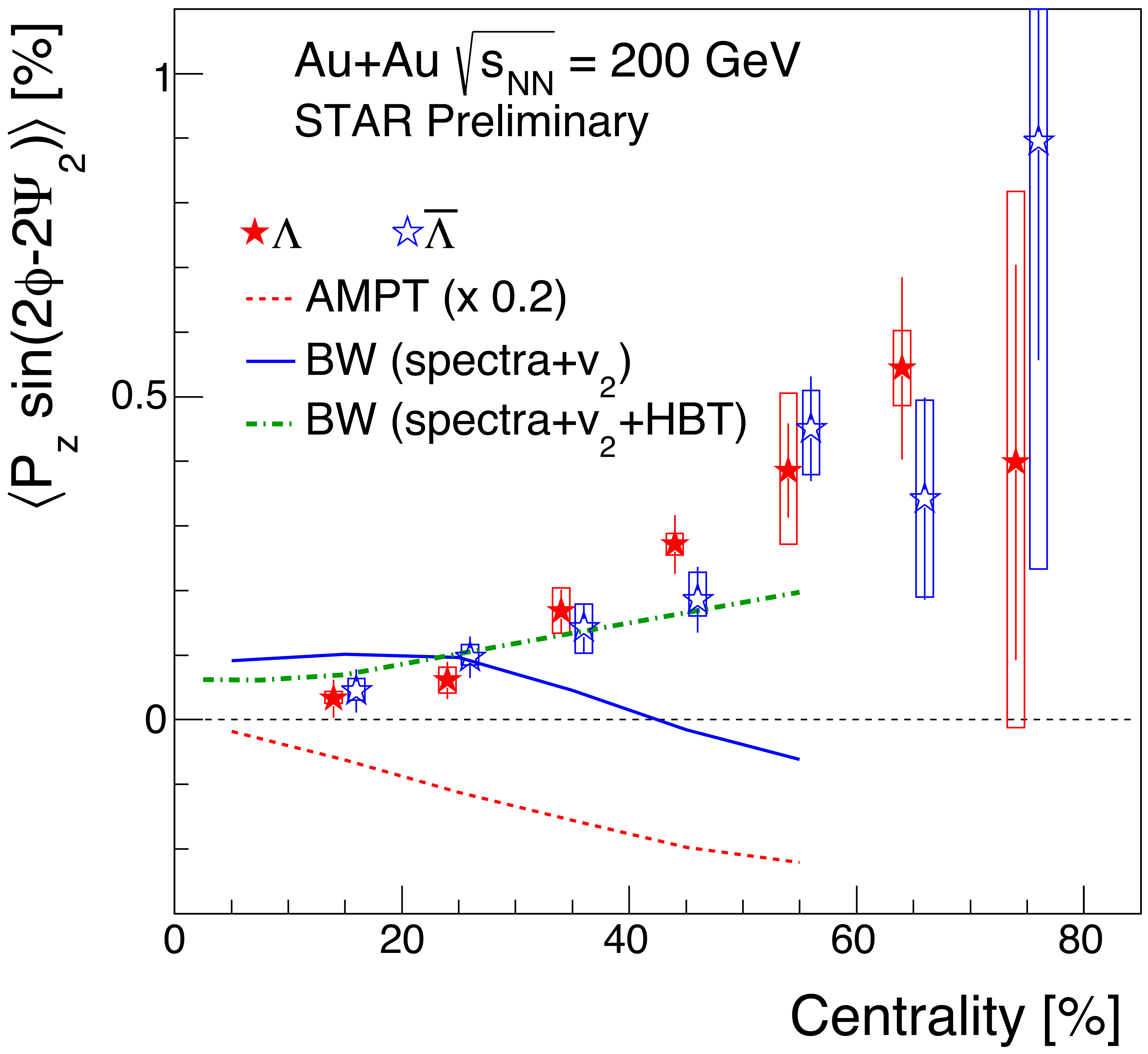



Data:
PHENIX, PRC69.034909 (2004)
PHENIX, PRC93.051902(R) (2016)




Calculated vorticity $\omega_z$ shows the sine modulation. Assuming a local thermal equilibrium, z-component of polarization is estimated as follows: $P_z \approx \omega_z/(2T)$

# $P_z$ modulation from the BW model




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

- AMPT model
  - opposite sign and 5 times larger in magnitude

    X. Xia, H. Li, Z. Tang, Q. Wang, PRC98.024905 (2018)

- Blast-wave model
  - simple estimate for kinematic vorticity
  - similar magnitude to the data
  - inclusion of HBT in the fit affects the sign in peripheral collisions

  T. Niida, S. Voloshin, A. Dobrin, and R. Bertens, in preparation

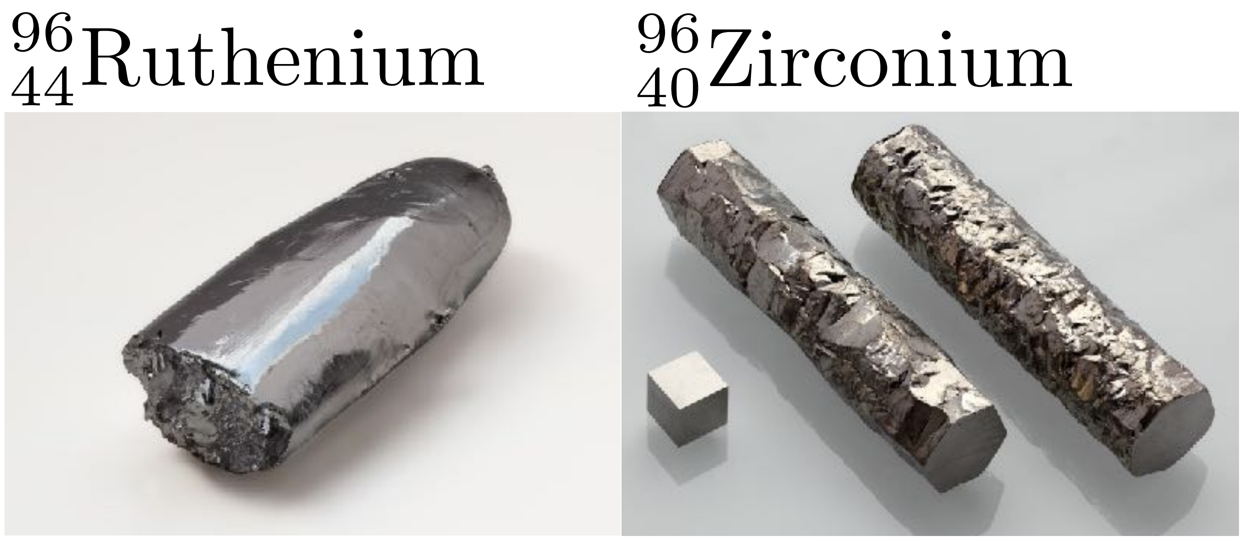
# Summary

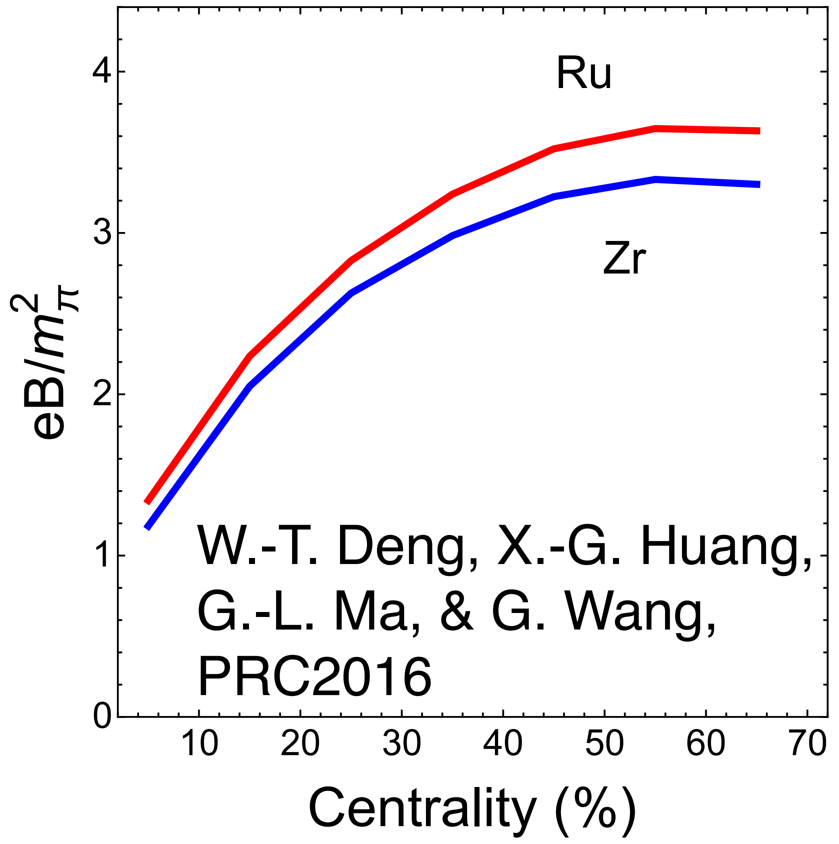
- Observation of Λ global polarization at $\sqrt{s_{NN}}$ = 7.7-200 GeV
  - Polarization decreases at higher energies
    → **Quantitatively consistent with hydrodynamic and AMPT models**
  - Larger signal in in-plane than in out-of-plane
    → **Disagree with hydrodynamic and AMPT model**
  - Charge-asymmetry dependence with different slopes between Λ and anti-Λ (~2σ level)
    → **A possible relation to the axial current induced by B-field?**

- First study of Λ polarization along the beam direction at $\sqrt{s_{NN}}$ = 200 GeV
  - Quadrupole structure of the polarization relative to the 2$^{nd}$-order event plane
    → **Qualitatively consistent with a picture of the elliptic flow but agree/disagree among the data and theoretical calculations in the sign**
  - Strong centrality dependence as in the elliptic flow
  - Sign problem among different models and data, but the blast-wave model predicts the same sign and similar magnitude to the data

# Outlook

- Isobar collision data (Ru+Ru, Zr+Zr) already taken in 2018!
  - Same mass number but different number of protons
    →10% difference in the magnetic field
    →More $P_H$ splitting between Λ and anti-Λ in Ru?

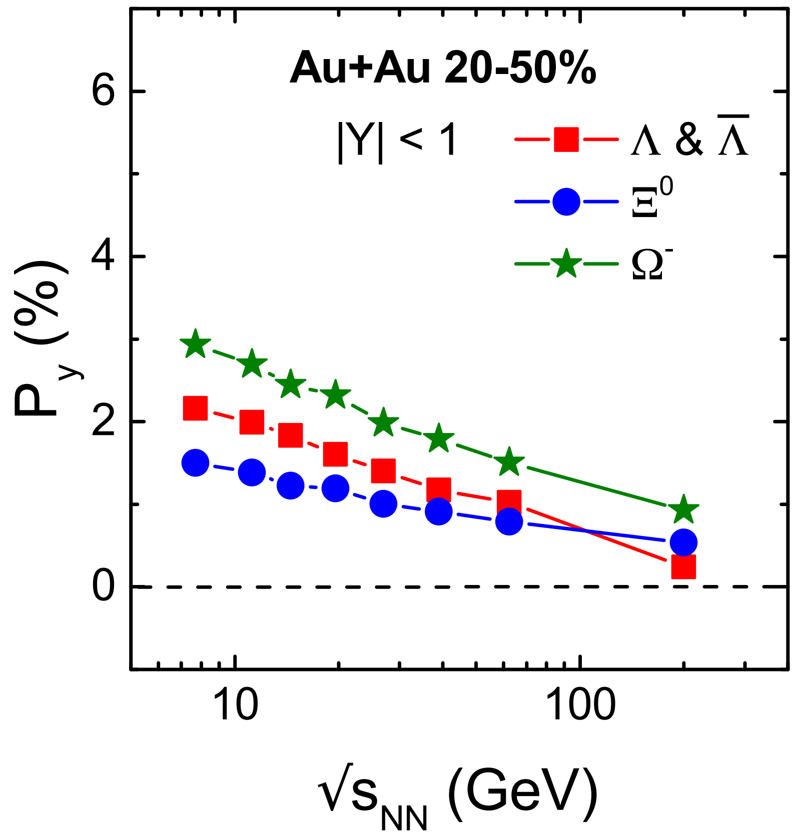



- New 27 GeV data taken in 2018! (x10 events with ~1.5 better EP resolution)
  - Possible probe of the magnetic field from Λ vs anti-Λ global polarization

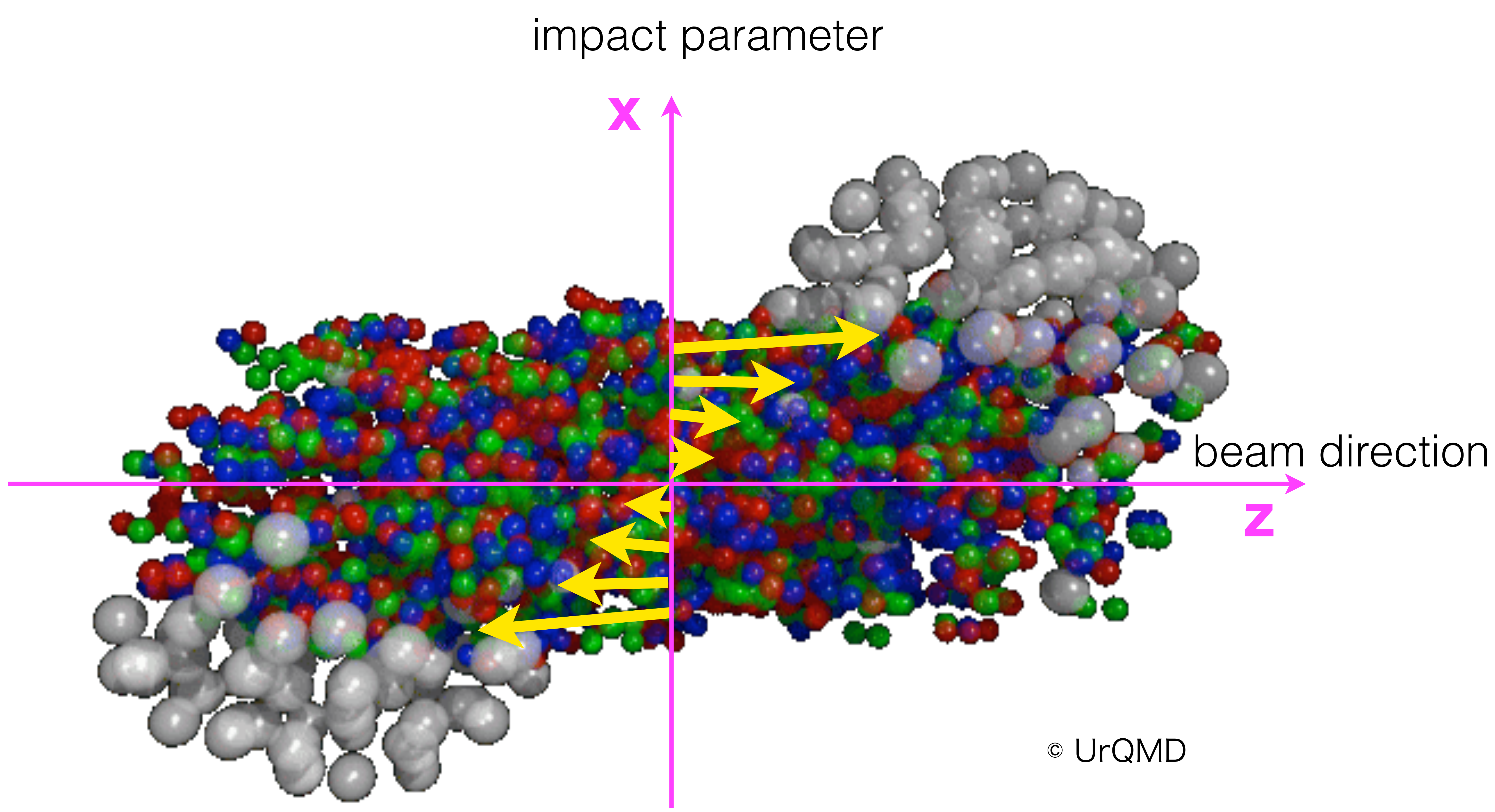
D.-X. Wei *et al.*, arXiv:1810.00151

- Beam Energy Scan II (2019+) with STAR detector upgrade
  - x10 events for $\sqrt{s_{NN}}$ = 7.7-19.6 GeV (collider mode) + $\sqrt{s_{NN}}$ = 3-7.7 GeV (Fixed target)
  - How about at forward/backward rapidity? How about for multi-strangeness?



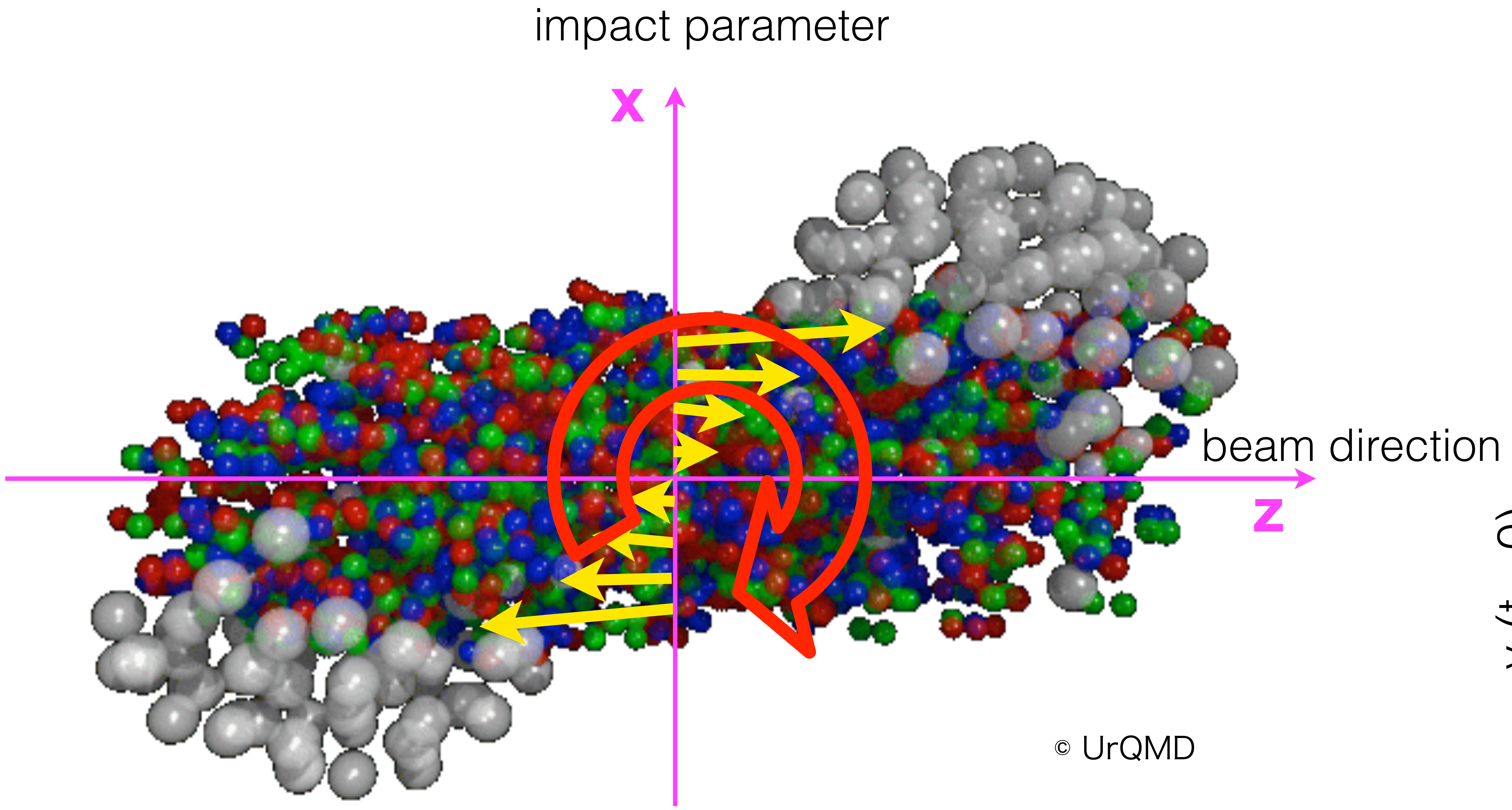
# Back up

# Vorticity in HIC

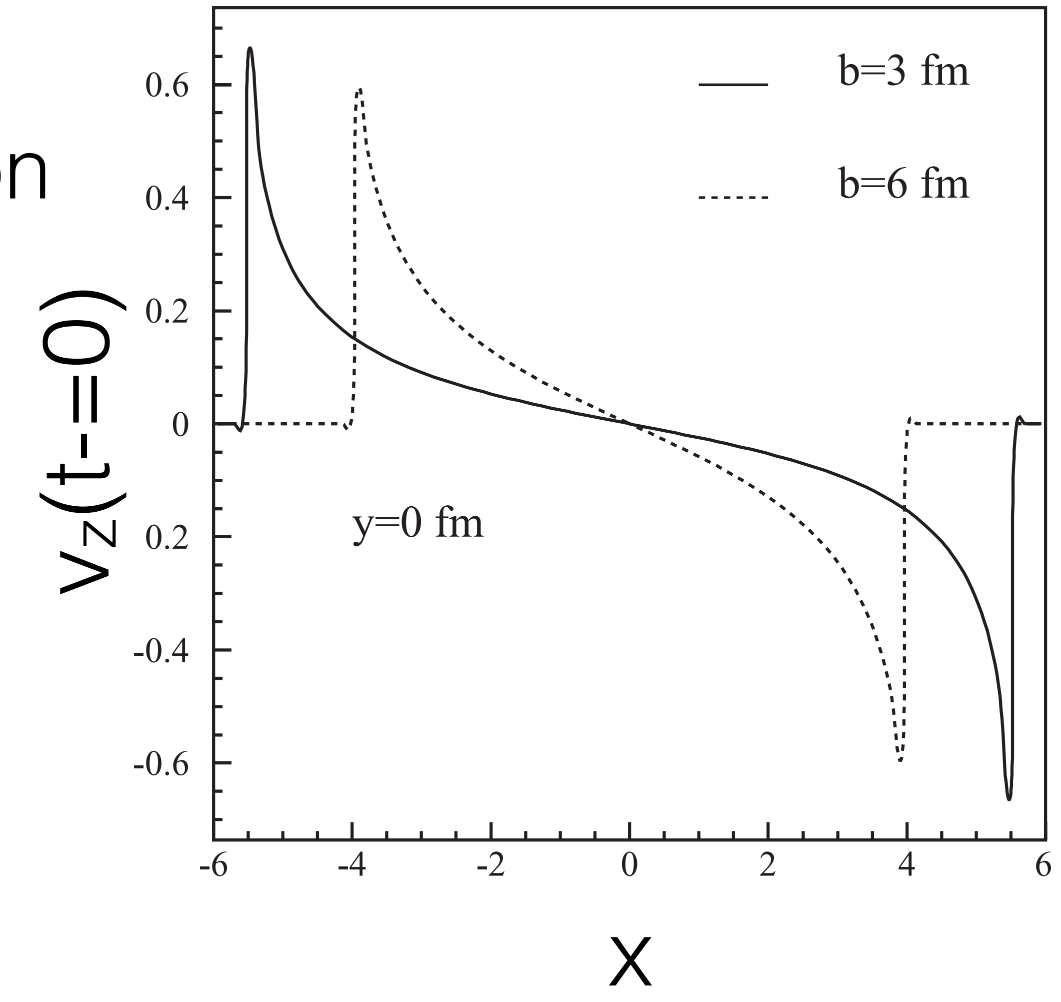



In non-central collisions,
the initial collective longitudinal flow velocity depends on x.

# Vorticity in HIC



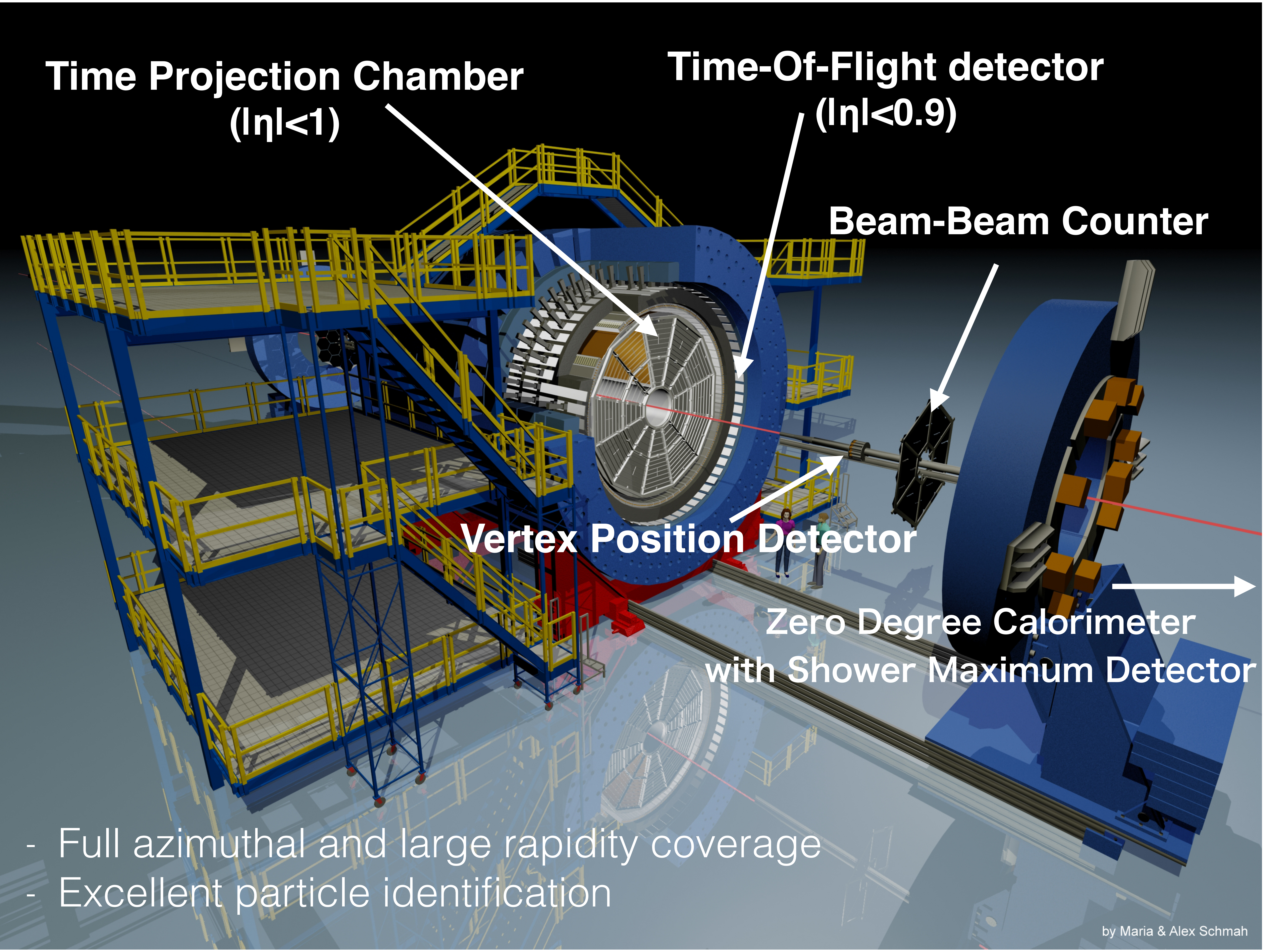

Becattini et al.,
PRC77, 024906 (2008)



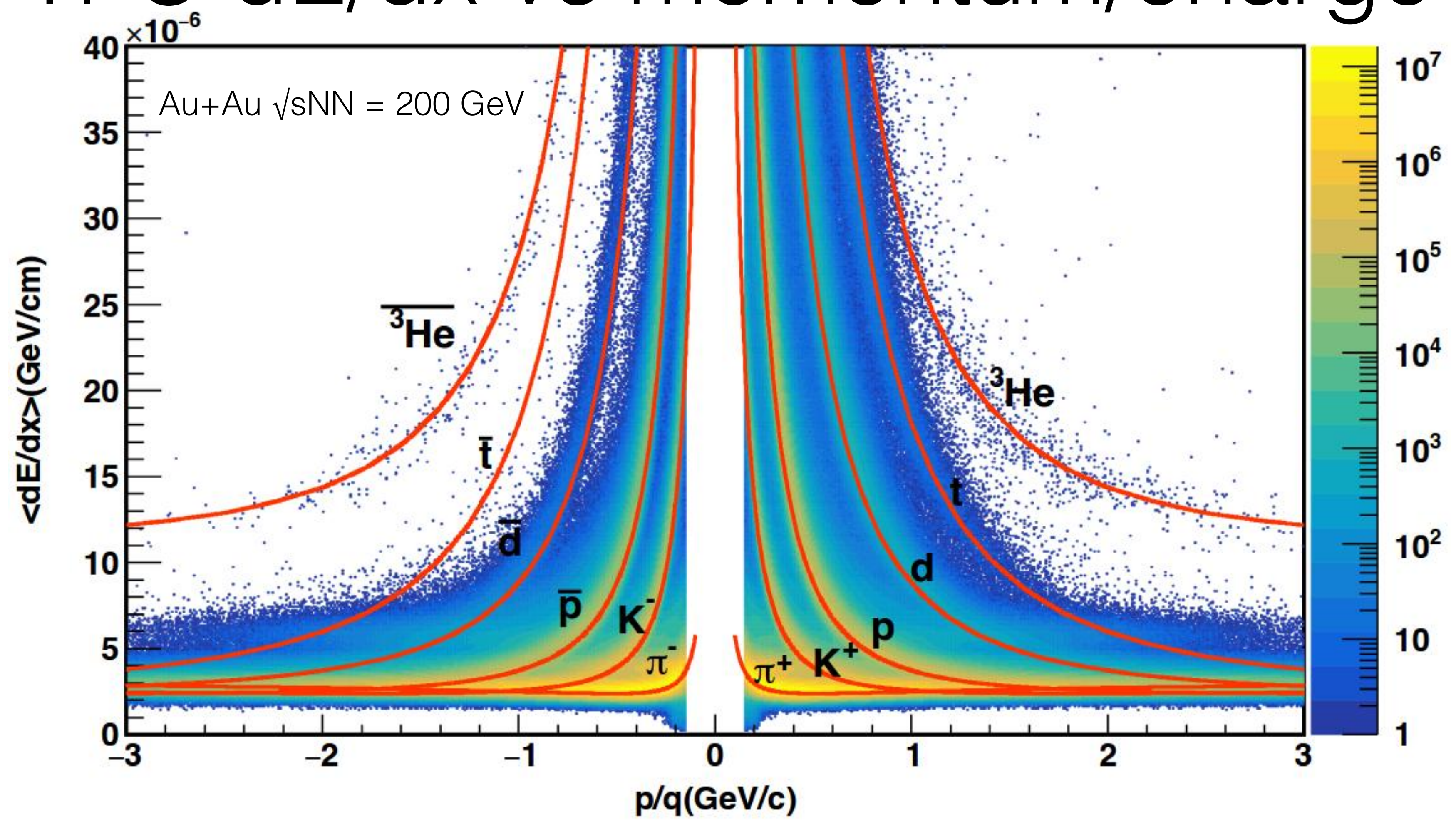

In non-central collisions,
the initial collective longitudinal flow velocity depends on x.

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

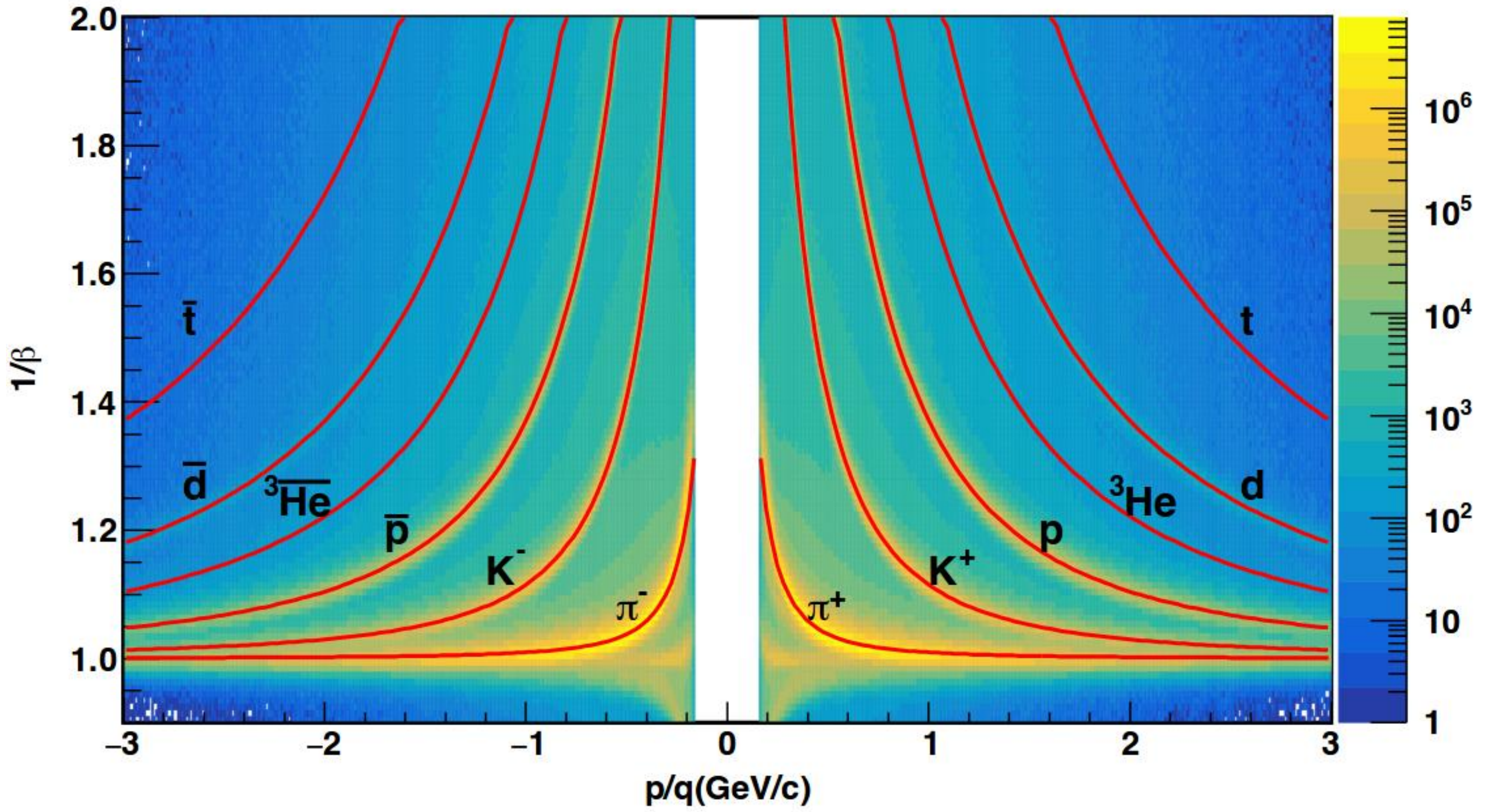
# STAR Detectors



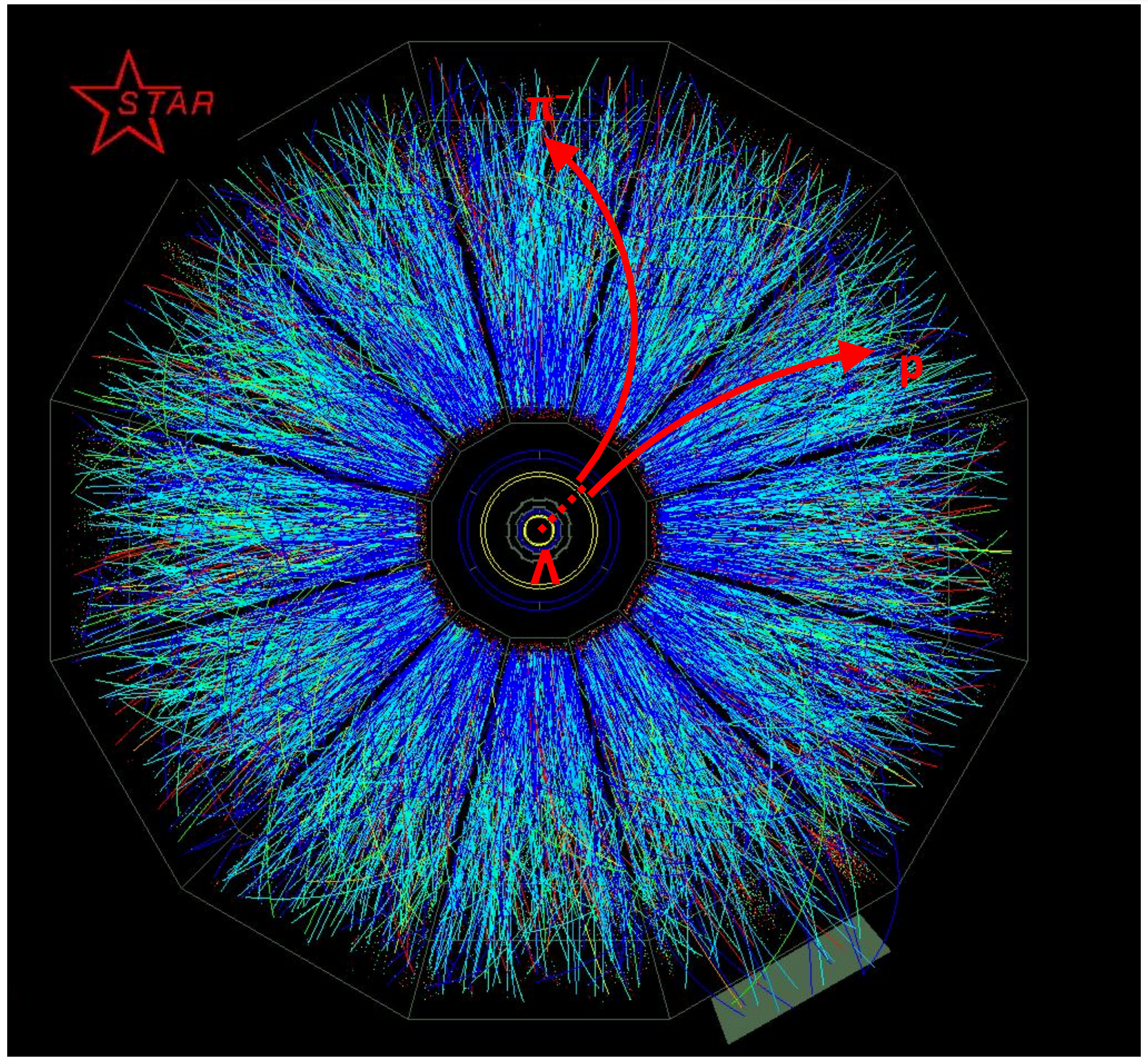

TPC dE/dx vs momentum/charge

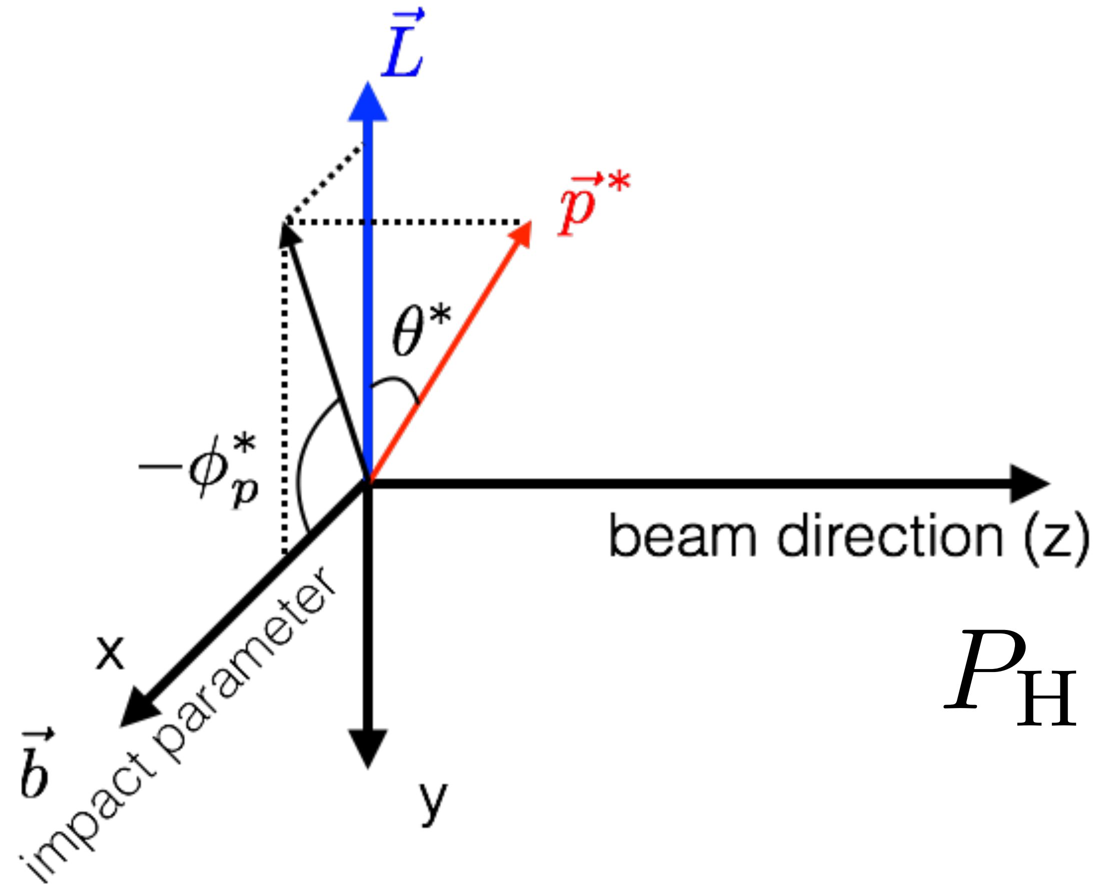



TOF 1/β vs momentum/charge



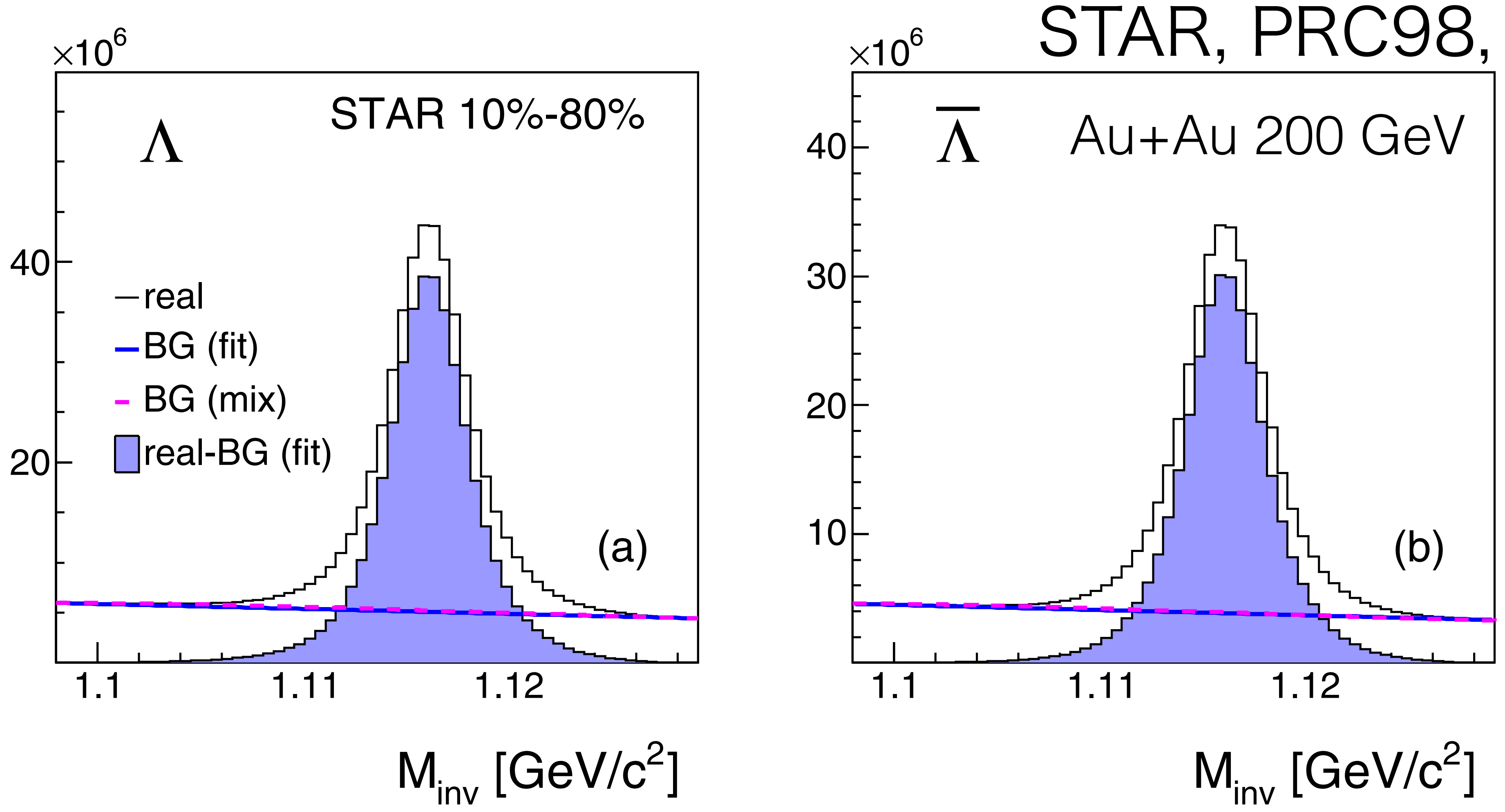
# Signal extraction with Λ hyperons

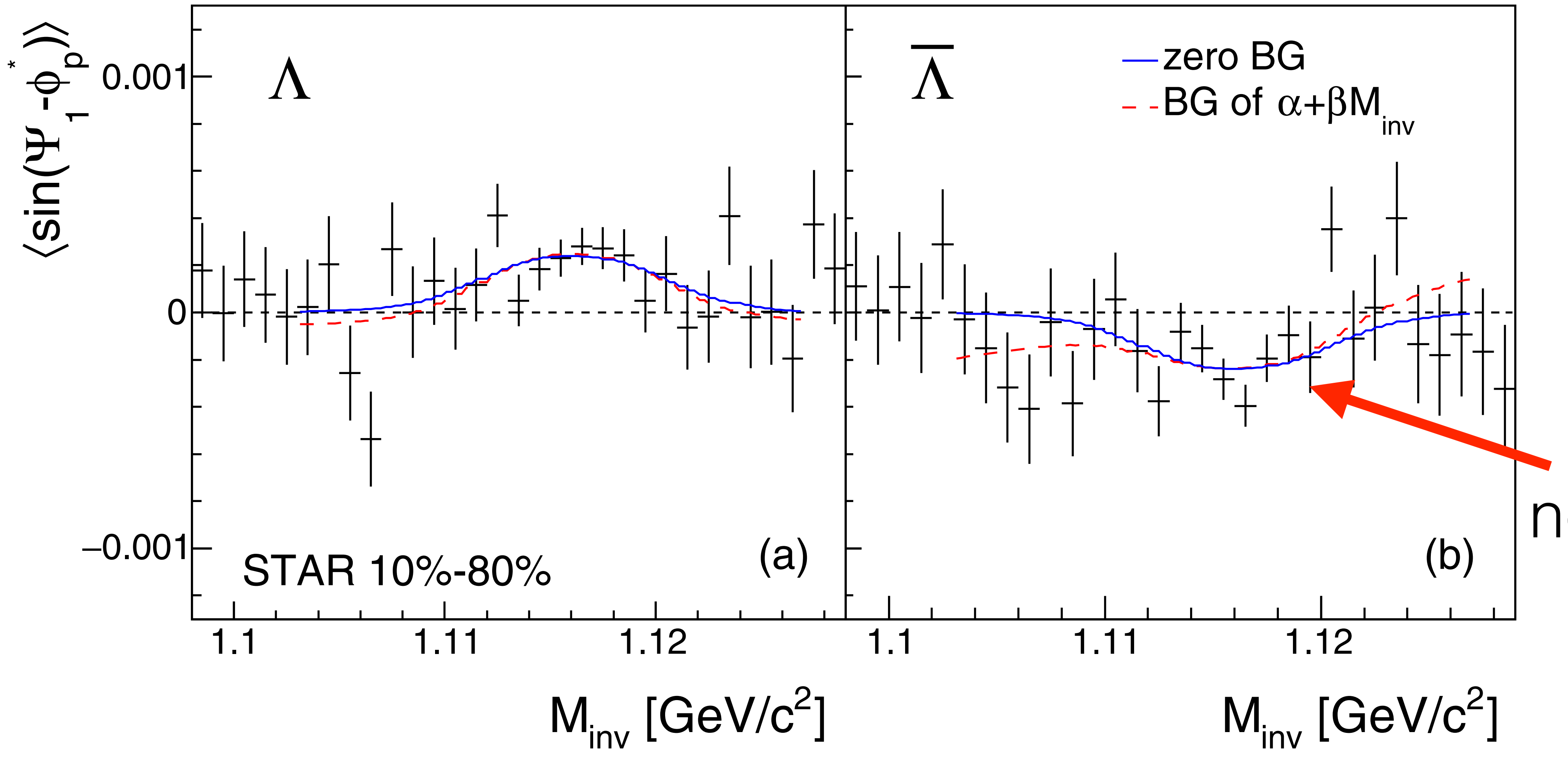



$$P_{\rm H} = \frac{8}{\pi\alpha_{\rm H}}\frac{\langle\sin(\Psi_1-\phi_p^*)\rangle}{{\rm Res}(\Psi_1)}$$

STAR, PRC98, 014910 (2018)




negative for anti-Λ

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

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

# Feed-down effect

- Only ~25% of measured Λ and anti-Λ are primary, while ~60% 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

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

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

$C_{\Lambda R}$ : 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
$\mu_R$ : magnetic moment of particle R

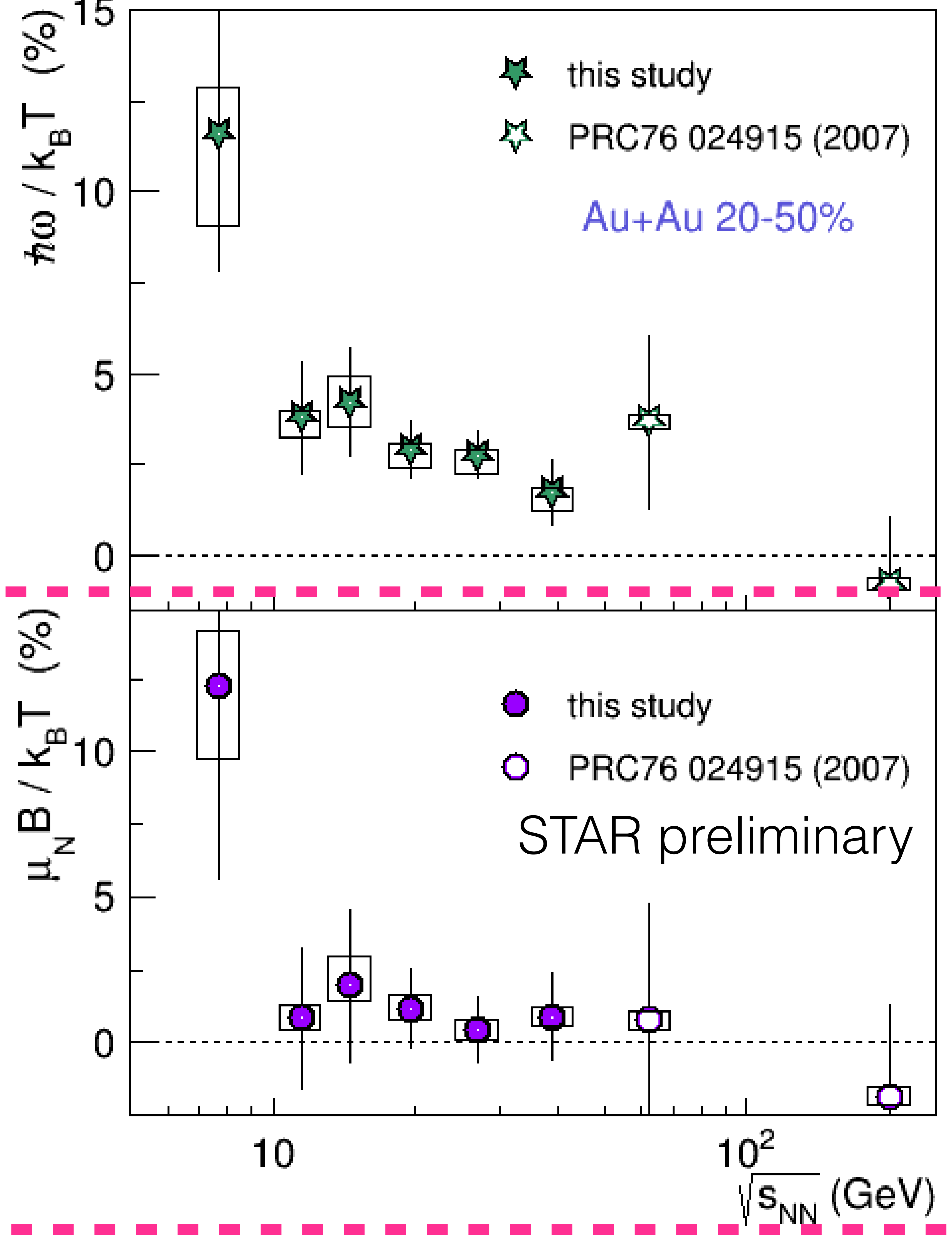
$$\begin{pmatrix} \varpi_c \\ B_c/T \end{pmatrix} = \begin{bmatrix} \frac{2}{3}\sum_R \left(f_{\Lambda R}C_{\Lambda R} - \frac{1}{3}f_{\Sigma^0 R}C_{\Sigma^0 R}\right) S_R(S_R+1) & \frac{2}{3}\sum_R \left(f_{\Lambda R}C_{\Lambda R} - \frac{1}{3}f_{\Sigma^0 R}C_{\Sigma^0 R}\right) (S_R+1)\mu_R \\ \frac{2}{3}\sum_{\overline{R}}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

| 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 |
| $\Sigma^0 \to \Lambda + \gamma$ | $-1/3$ |

15%-20% dilution of primary Λ polarization (model-dependent)

# Possible probe of magnetic field

QM17, I. Upsal (STAR)




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

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

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

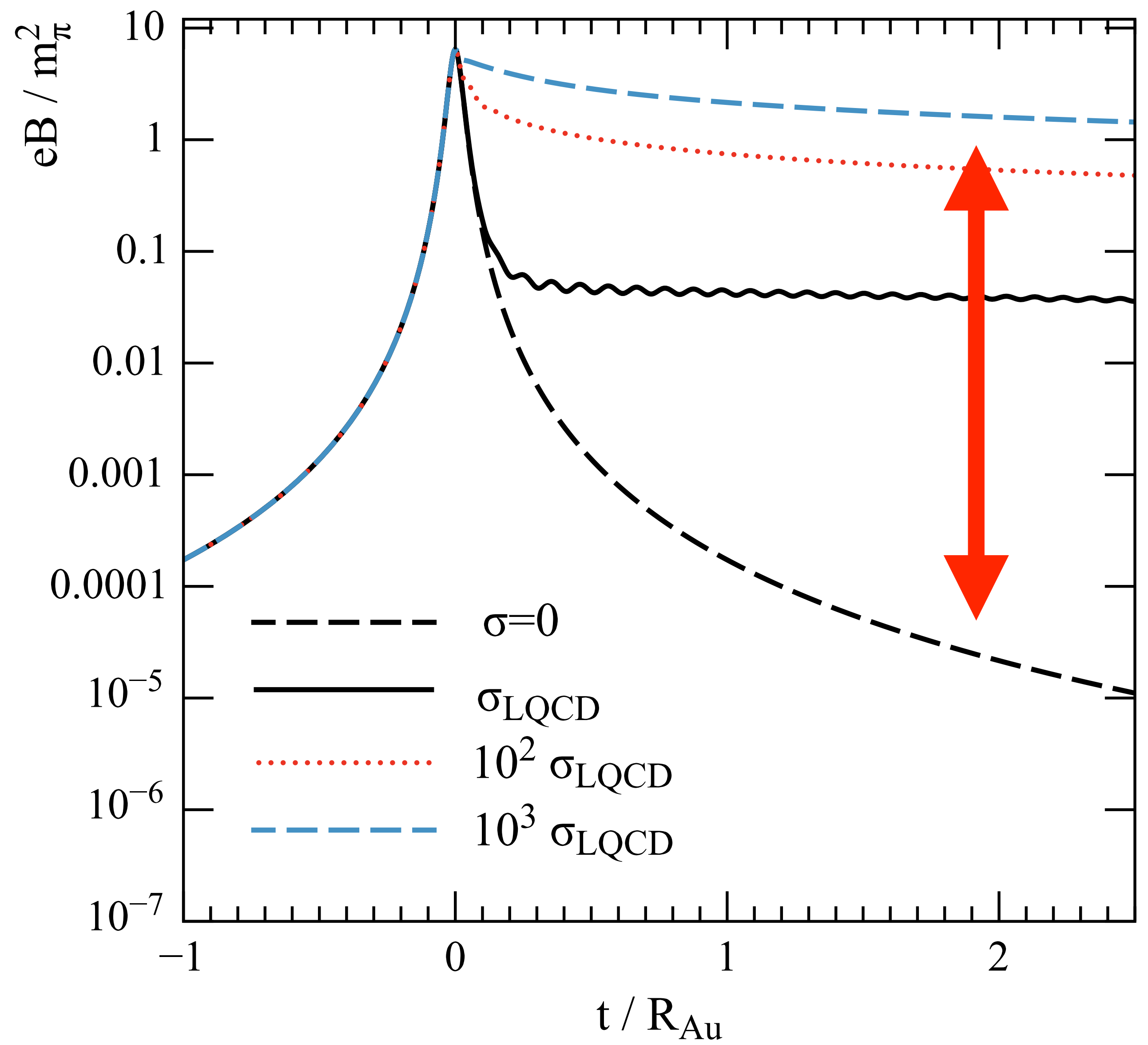
$\mu_\Lambda$: Λ magnetic moment

$$B = (P_\Lambda - P_{\bar{\Lambda}})k_B T/\mu_N$$

$$\sim 5.0 \times 10^{13}\ [\text{Tesla}]$$

nuclear magneton $\mu_N = -0.613\mu_\Lambda$

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




conductivity increases lifetime (not magnitude)

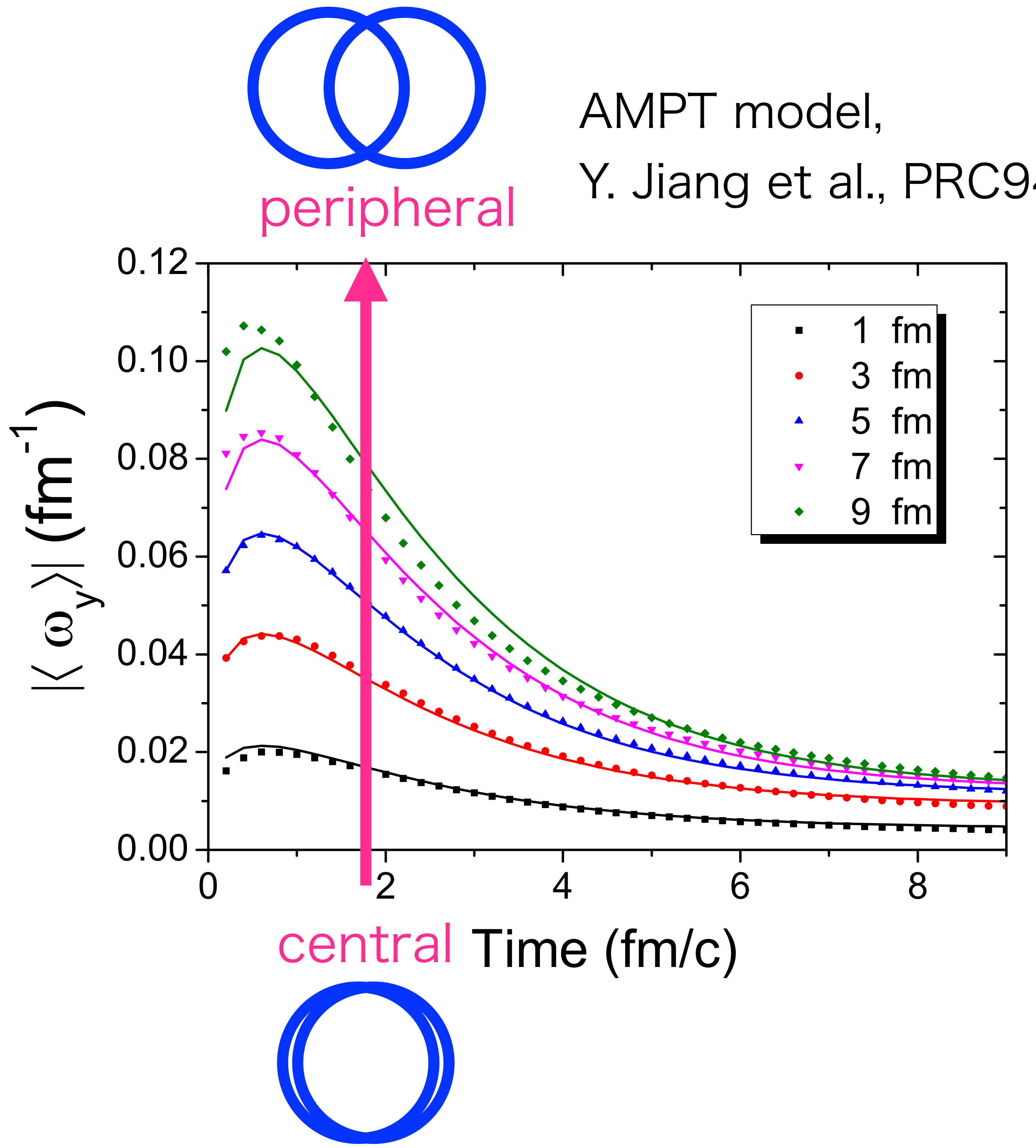
$$B \sim 10^{13}\ \text{T}$$

$$(eB \sim \text{MeV}^2\ (\tau = 0.2\ \text{fm}))$$

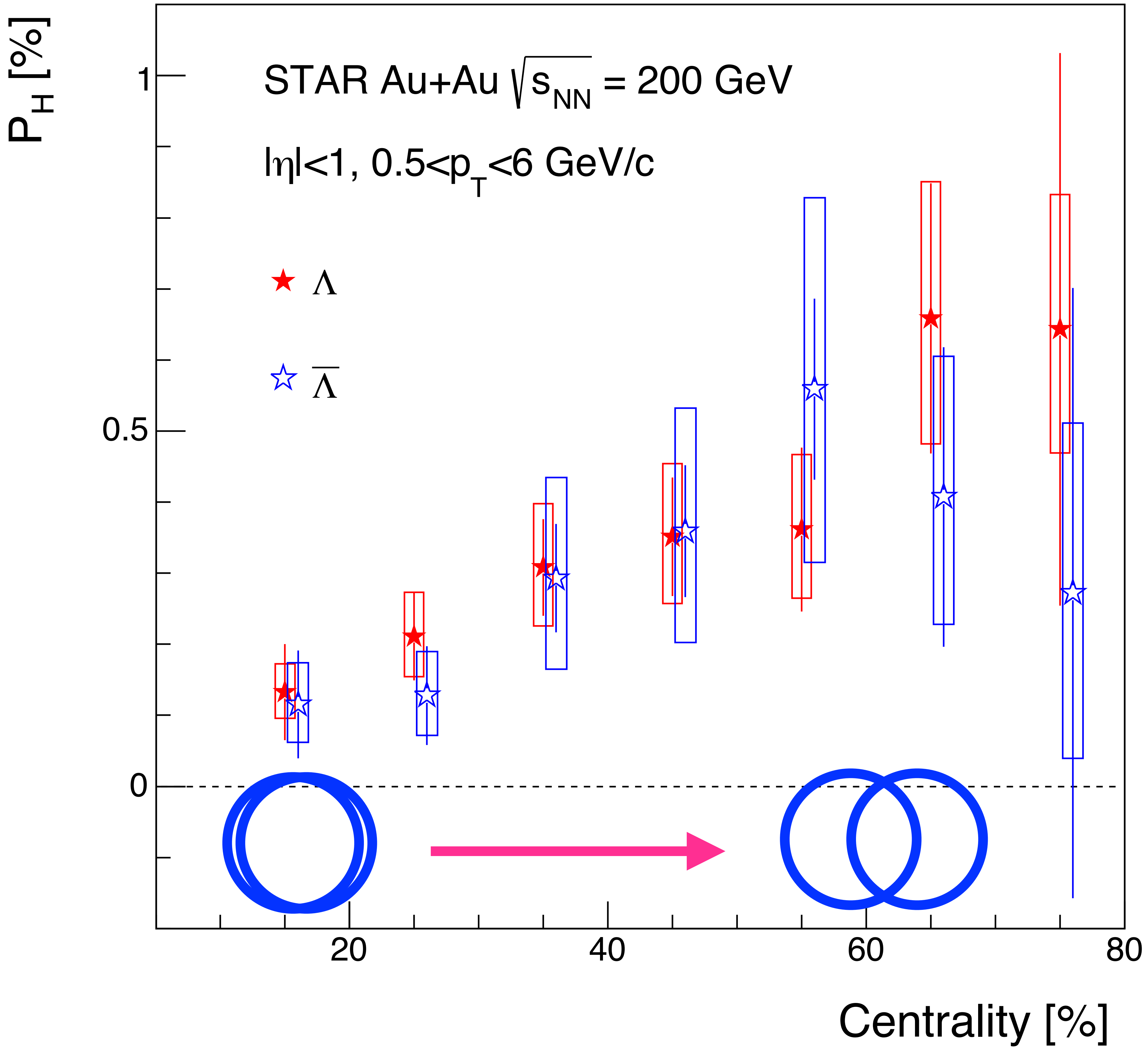
Extracted B-field is close to our expectation.
Need more data with better precision
→BES-II and Isobaric collisions

# Centrality dependence of $P_H$

AMPT model,
Y. Jiang et al., PRC94, 044910 (2016)

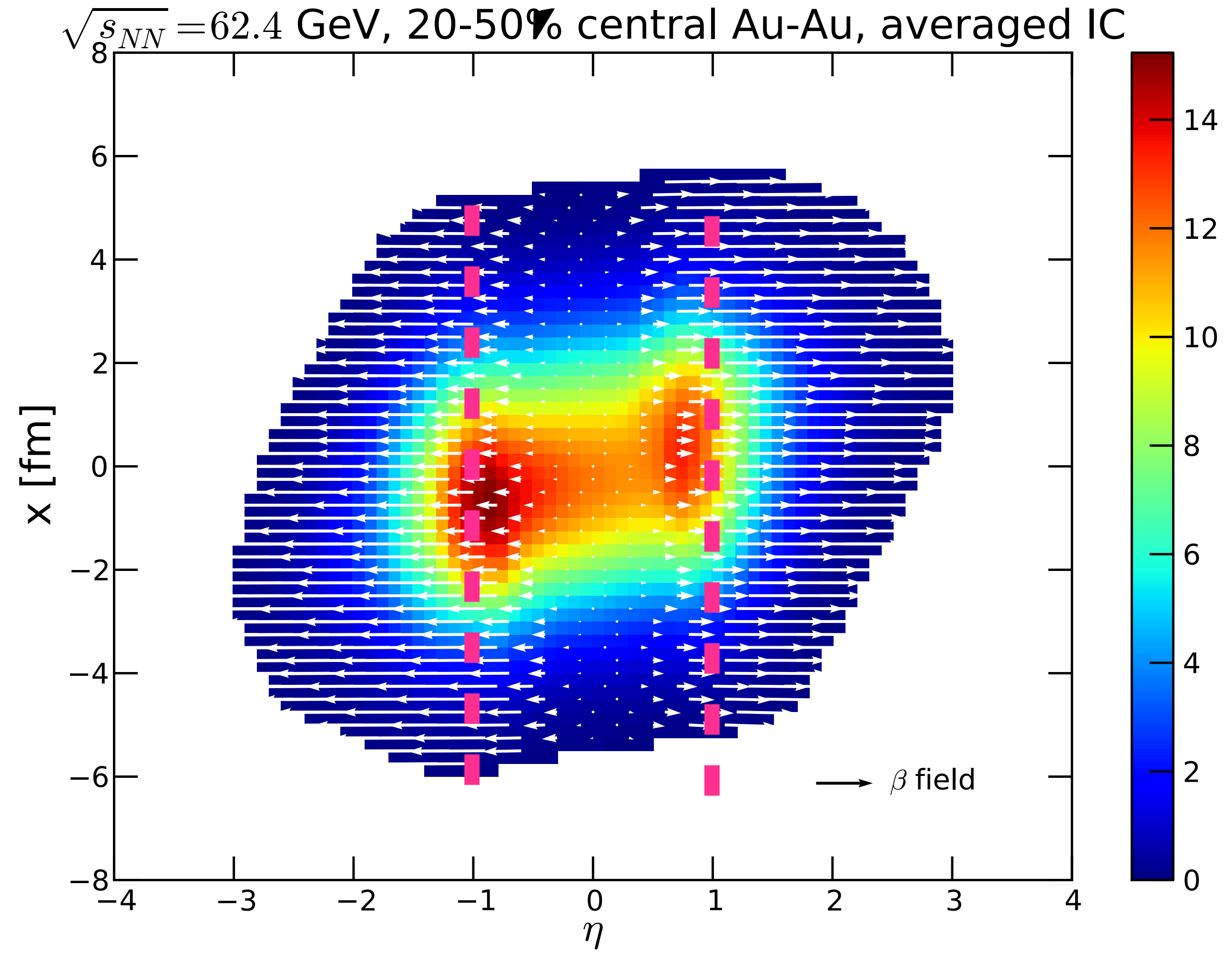


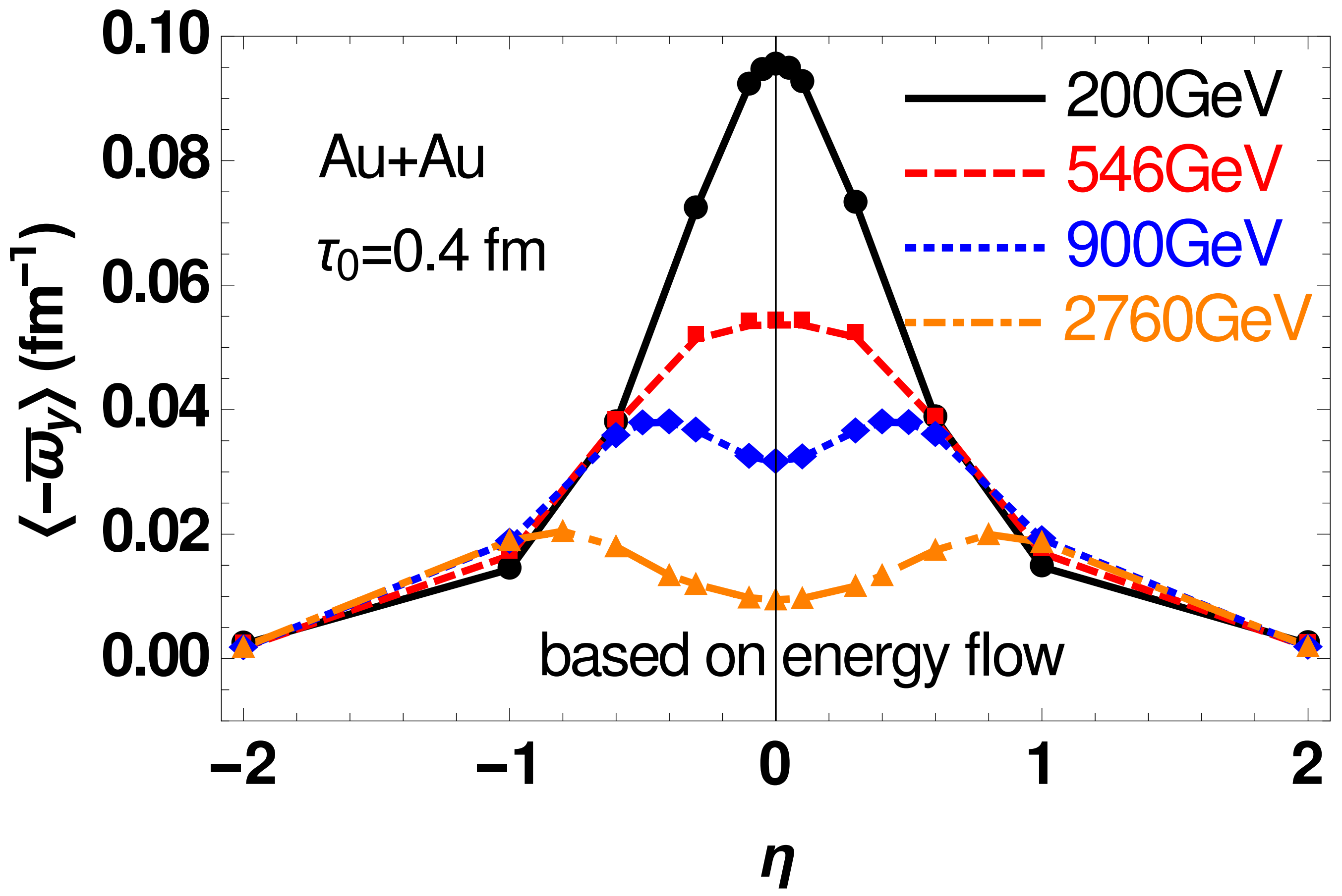

STAR, PRC98, 014910 (2018)



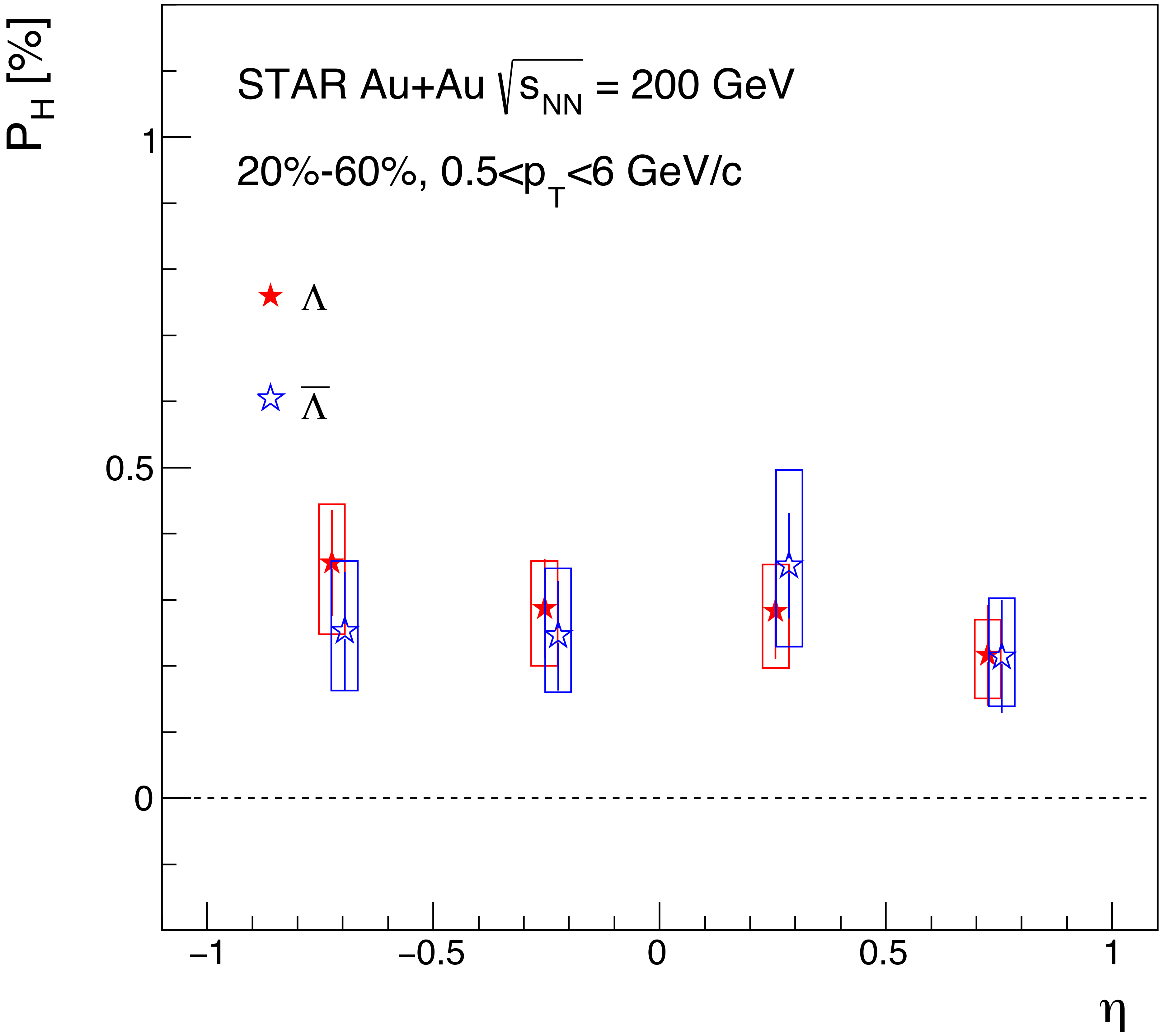

In most central collision → no initial angular momentum
As expected, the polarization decreases in more central collisions

# η dependence of $P_H$




STAR, PRC98, 014910 (2018)



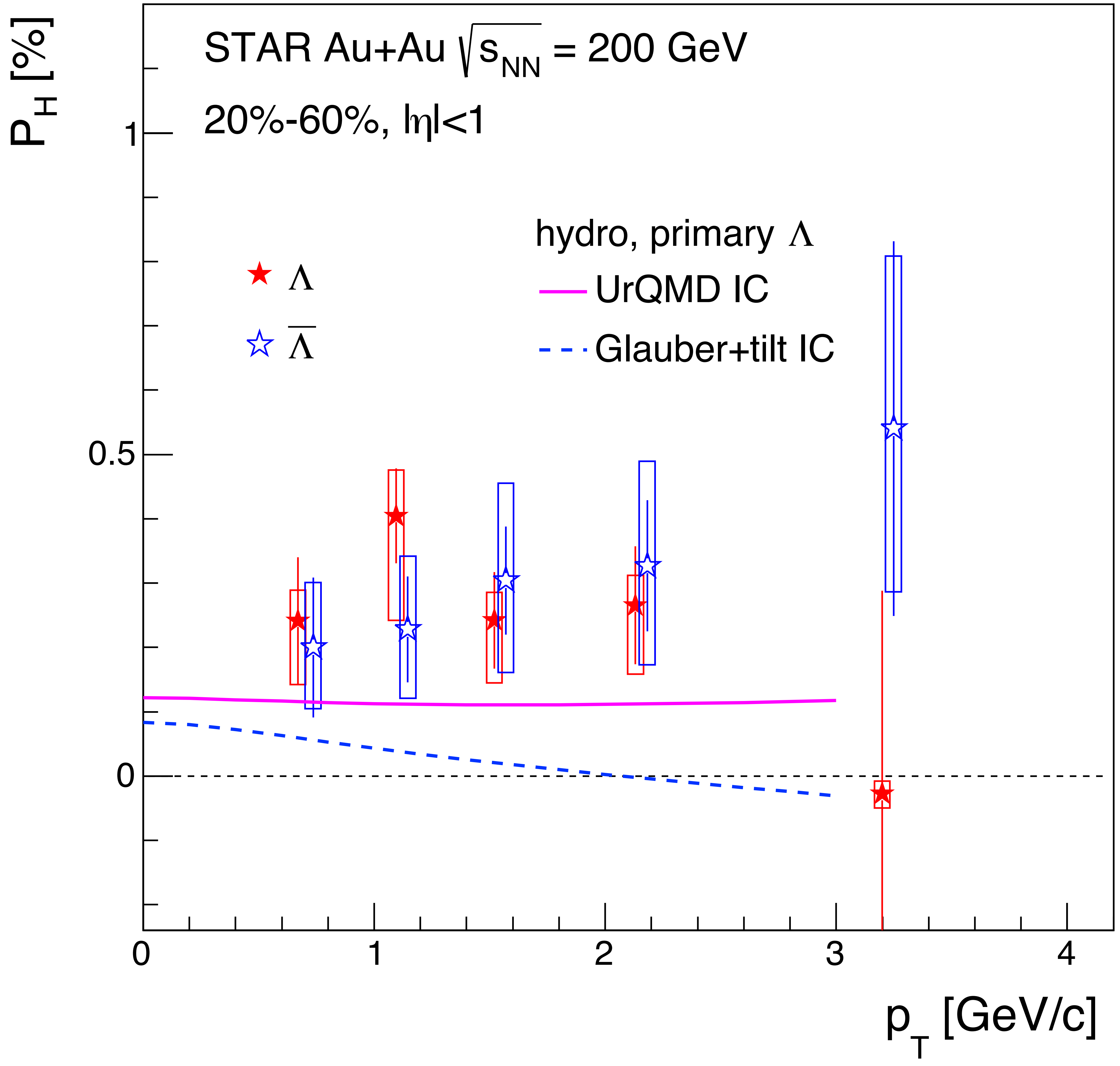

- Shear flow structure/initial flow velocity would be stronger in forward/backward region
- Expect rapidity dependence of the polarization

I. Karpenko and F. Becattini, EPJC(2017)77:213
W.-T. Deng and X.-G. Huang, arXiv:1609.01801

- The data do not show significant $\eta$ dependence
  - Maybe due to baryon transparency at higher energy
  - Also due to event-by-event C.M. fluctuations

# $p_T$ dependence of $P_H$

STAR, PRC98, 014910 (2018)




- No significant $p_T$ dependence, as expected from the initial angular momentum of the system
- Hydrodynamic model underestimates the data. Initial conditions affect the magnitude and dependence on $p_T$

3D viscous hydrodynamic model with two initial conditions (ICs)
- UrQMD IC
- Glauber with source tilt IC

F. Becattini and I. Karpenko, PRL120.012302, 2018

# Systematic uncertainties

Case of 200 GeV as an example

- Event plane determination: ~22%
- Methods to extract the polarization signal: ~21%
- Possible contribution from the background: ~13%
- Topological cuts: <3%
- Uncertainties of the decay parameter: ~2% for Λ, ~9.6% for anti-Λ
- Extraction of Λ yield (BG estimate): <1%

Also, the following studies were done to check if there is no experimental effect:

- Two different polarities of the magnetic field for TPC
- Acceptance effect
- Different time period during the data taking
- Efficiency effect