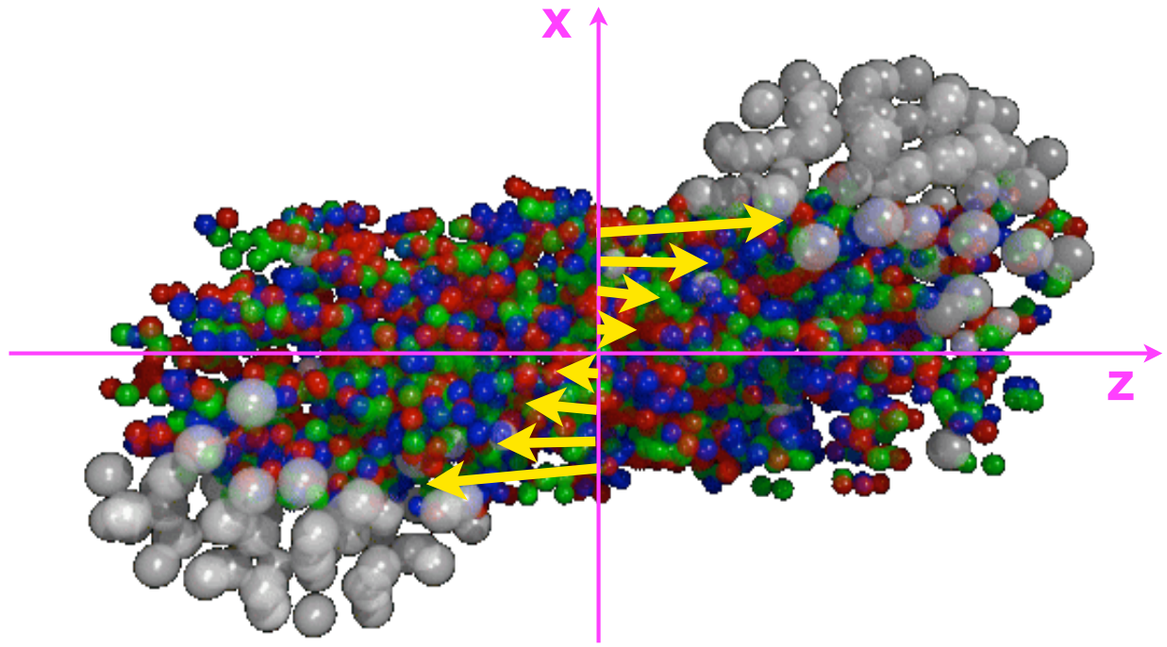
Global Polarization of Λ hyperons in Au+Au collisions at STAR

Takafumi Niida
(for the STAR Collaboration)

Wayne State University

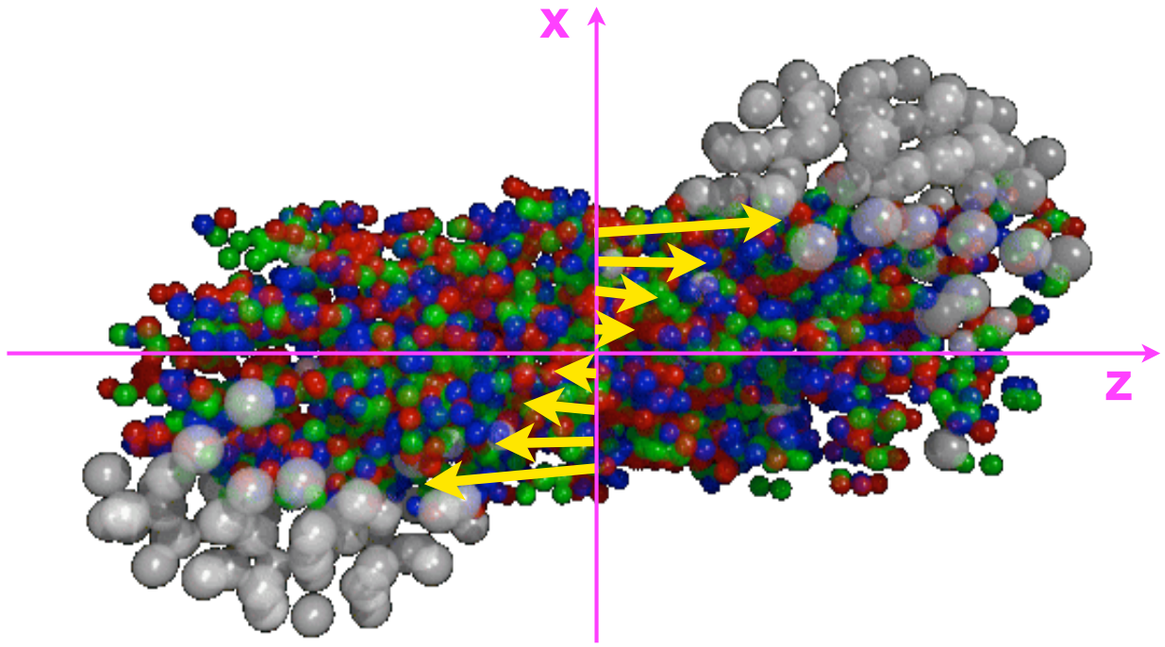
QCD Chirality Workshop 2017, UCLA

Vorticity in HIC

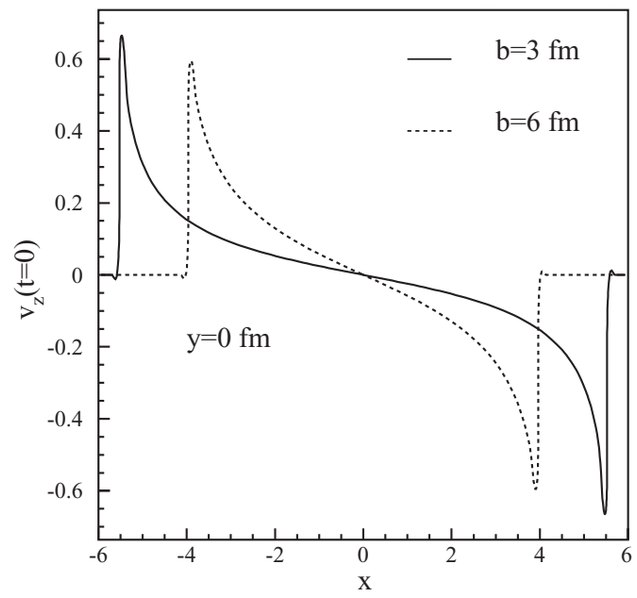


In non-central collisions, the initial longitudinal flow velocity depends on x.

Vorticity in HIC



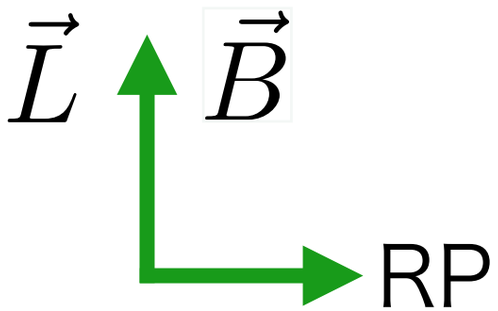
Becattini et al.,
PRC77, 024906 (2008)

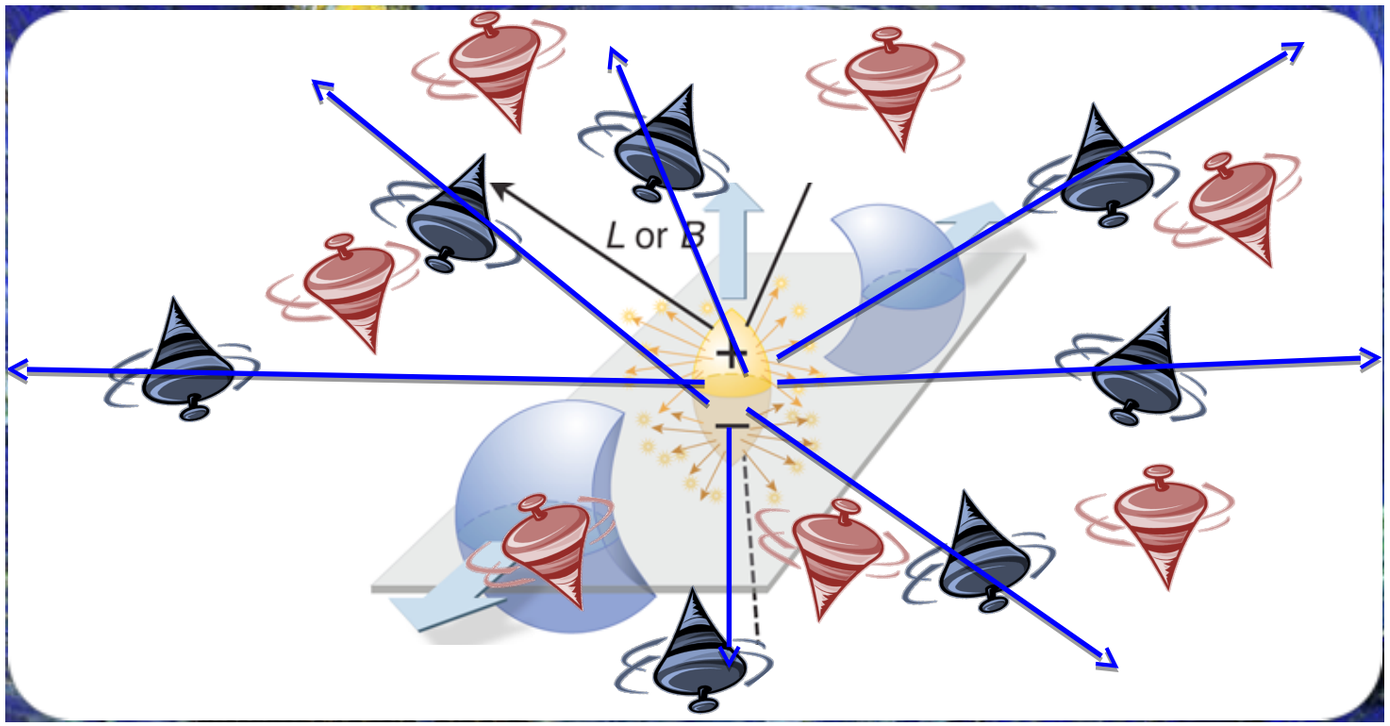


In non-central collisions, the initial longitudinal flow velocity depends on x, which makes the initial angular momentum.

Global Polarization of Λ

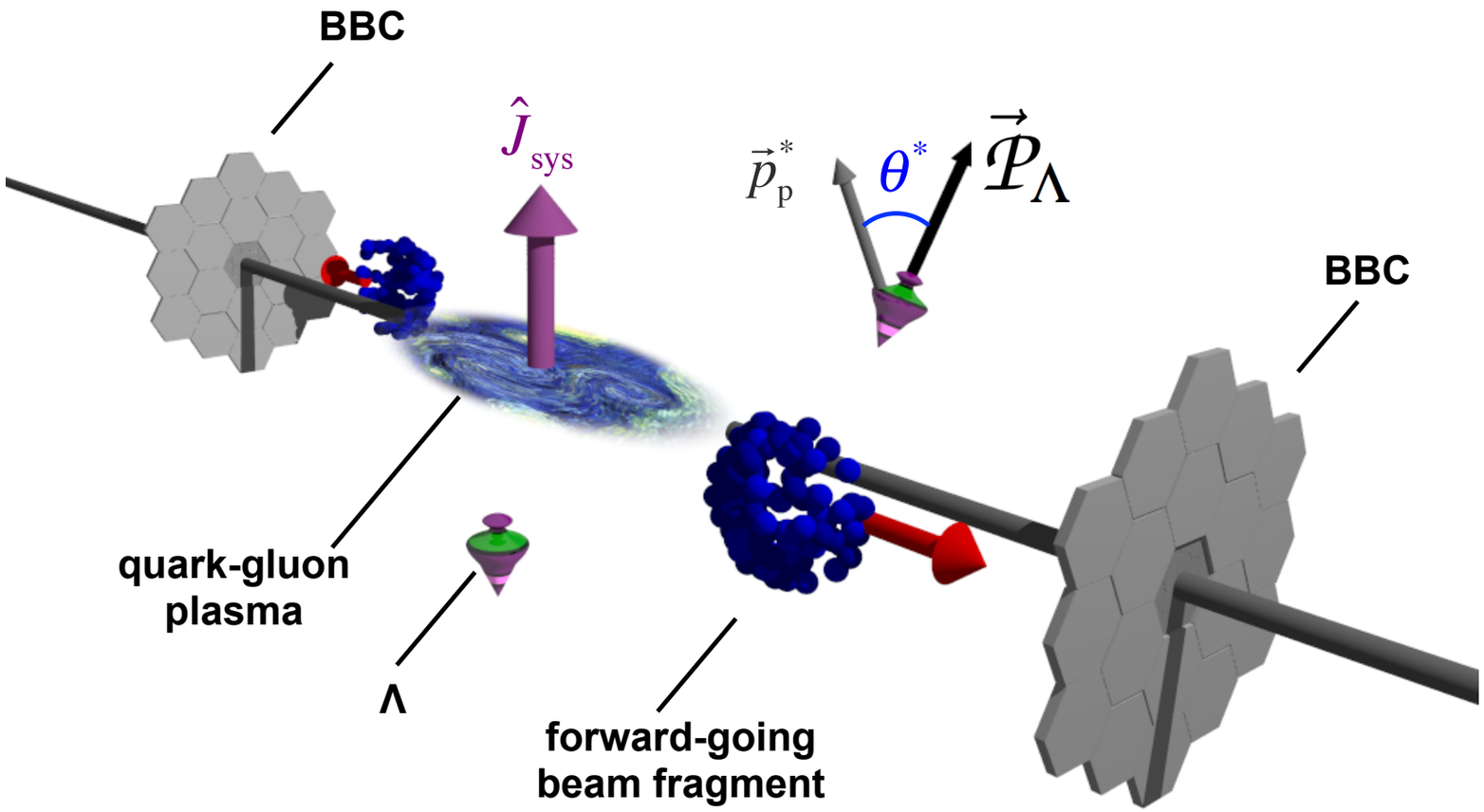
★ Non-zero angular momentum transfers to Λ polarization

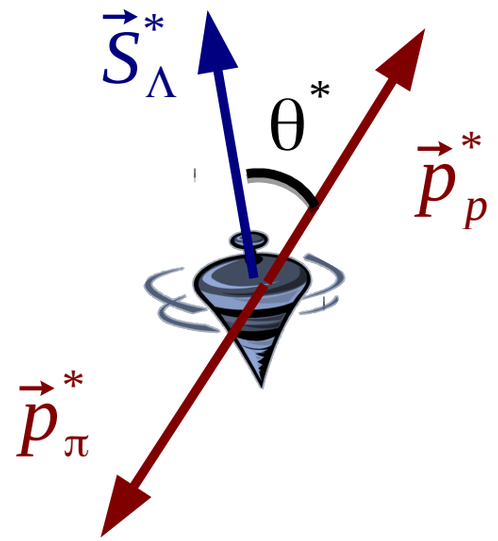




- spin-orbit coupling
  - spins of Λ and anti-Λ are aligned with angular momentum ***L***
- spin alignment by B-Field
  - Λ spin anti-aligned along ***B***
  - anti-Λ spin aligned along ***B***

How to measure it?





parity-violating decay

daughter proton preferentially decays into the direction of Λ's spin (opposite for anti-Λ)

$$P_H = \frac{8}{\pi\alpha}\frac{\langle \sin(\Psi_1 - \phi_p^*)\rangle}{\mathrm{Res}(\Psi_1)}\mathrm{sgn}_\Lambda$$

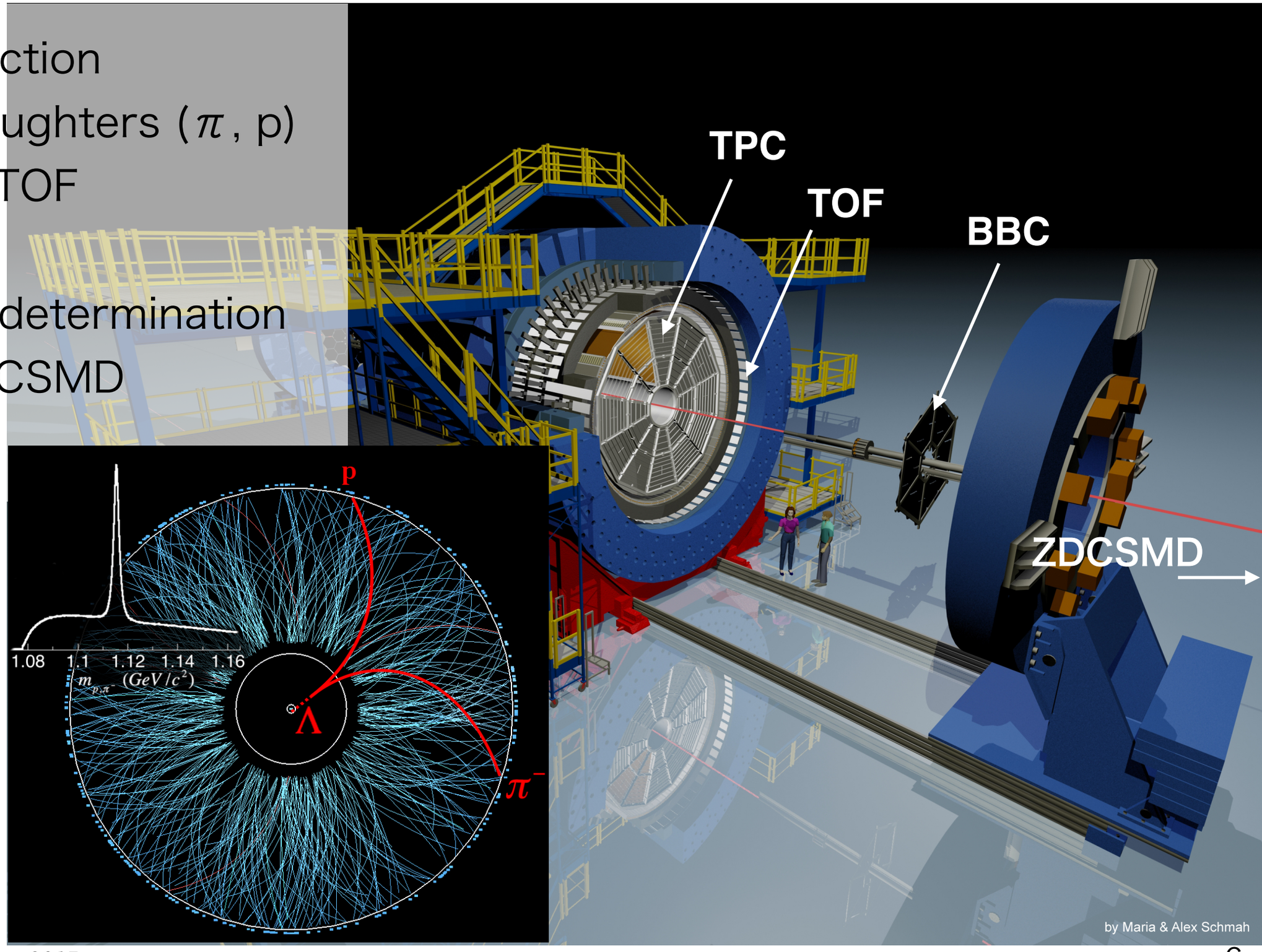
STAR, PRC76, 024915 (2007)

$\phi_{\rm p}^*$: ϕ of daughter proton in Λ rest frame
Ψ_1: 1st-order event plane
sgn_Λ: 1 for Λ, -1 for anti-Λ
α: Λ decay parameter (=0.642±0.013)

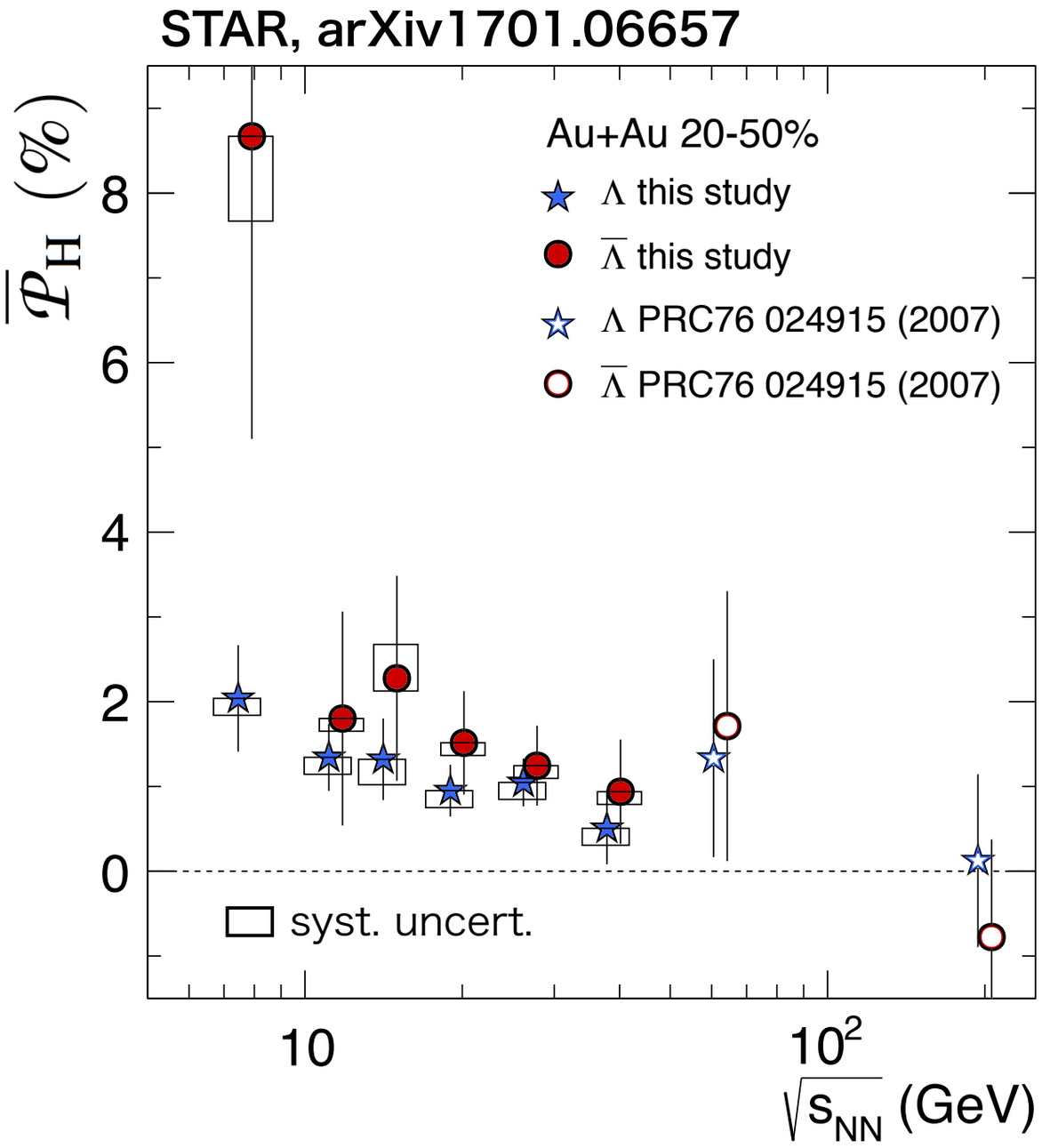
STAR detectors

Λ reconstruction
- identify daughters (π, p) with TPC+TOF

Event Plane determination
- BBC or ZDCSMD



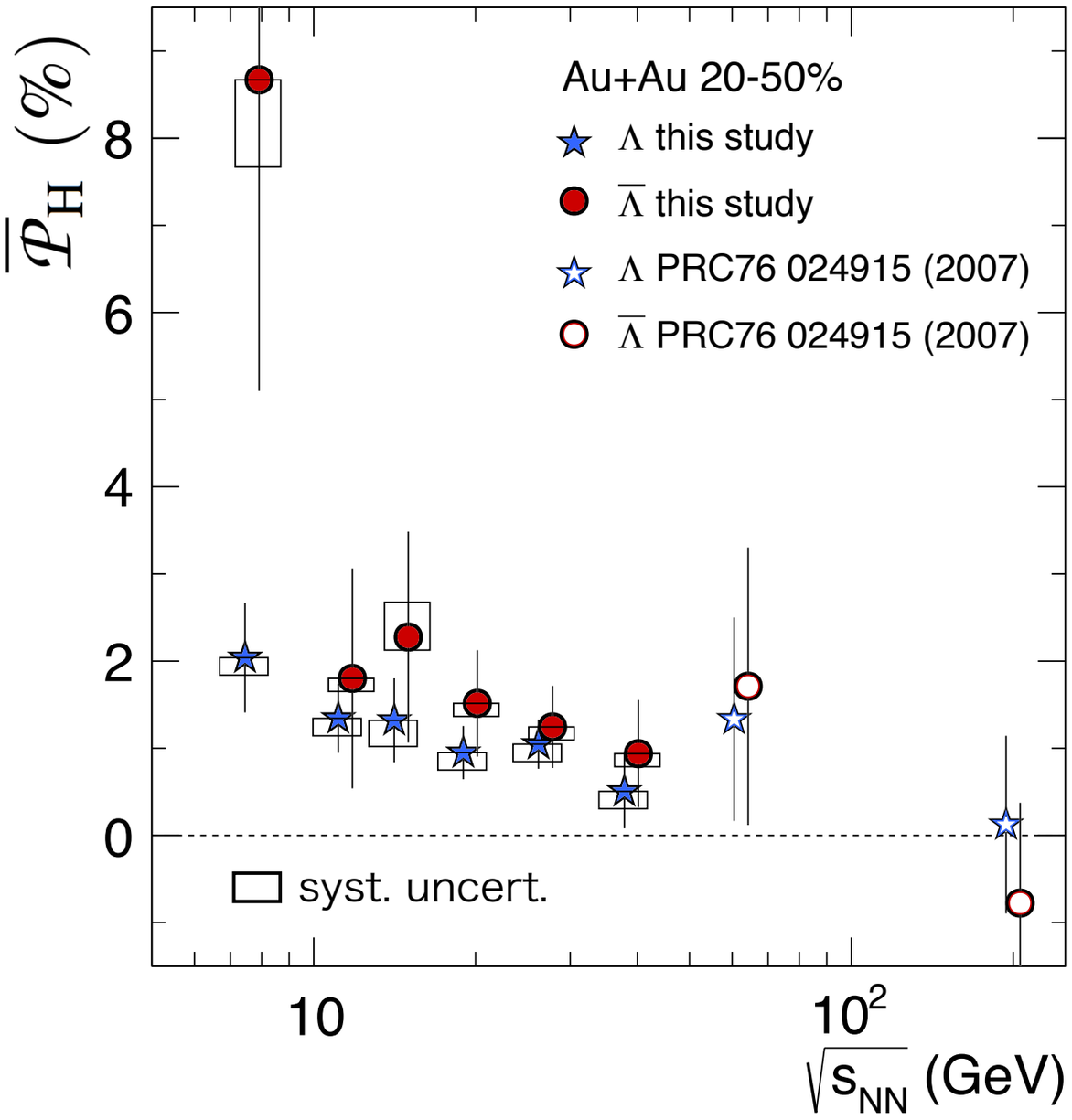
Λ global polarization vs $\sqrt{s_{NN}}$



- Positive signals in $\sqrt{s_{NN}}$=7.7-62.4 GeV
  - vorticity!

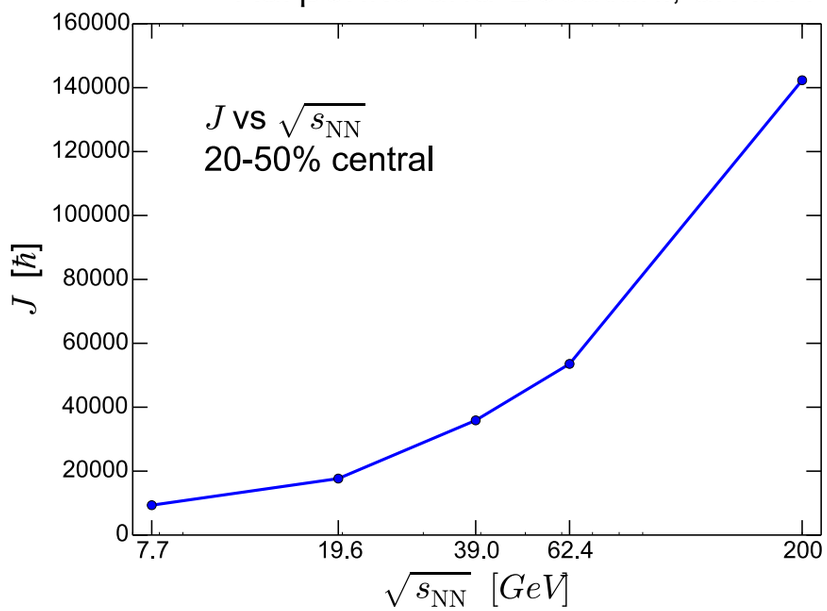
Λ global polarization vs $\sqrt{s_{NN}}$

STAR, arXiv1701.06657



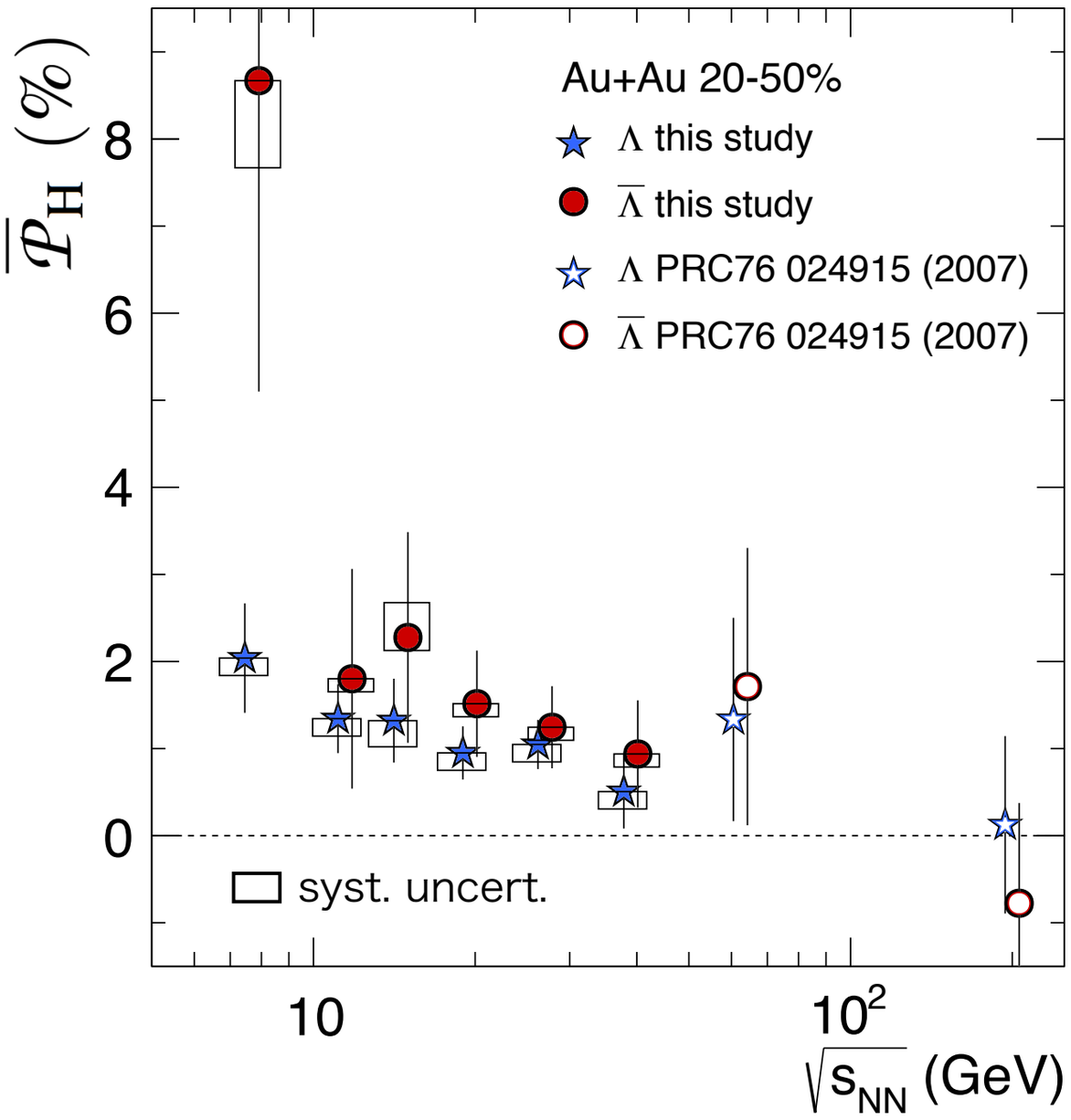
- Larger signal in lower energy
  - Initial angular momentum is largest at high energy

Karpenko and Becattini, arXiv:1610.0477



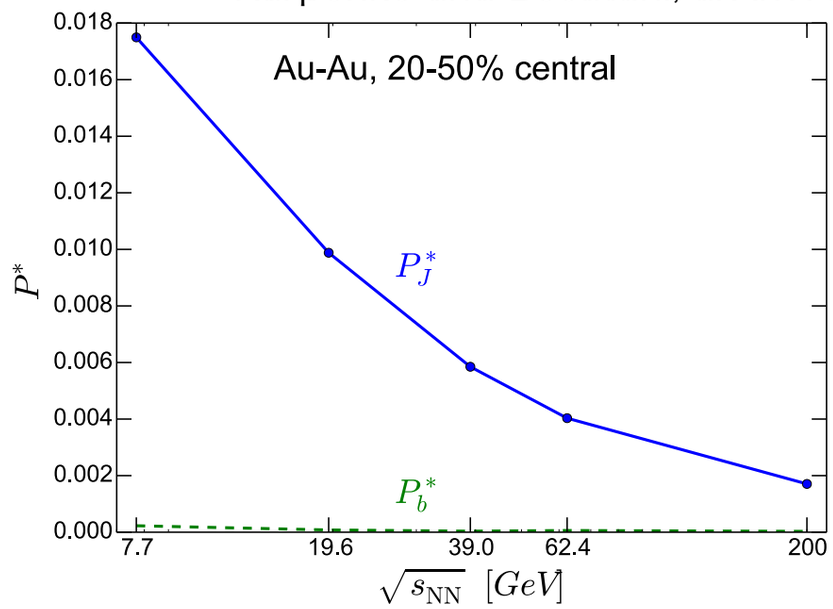
Λ global polarization vs $\sqrt{s_{NN}}$

STAR, arXiv1701.06657



- Larger signal in lower energy
  - Initial angular momentum is largest at high energy

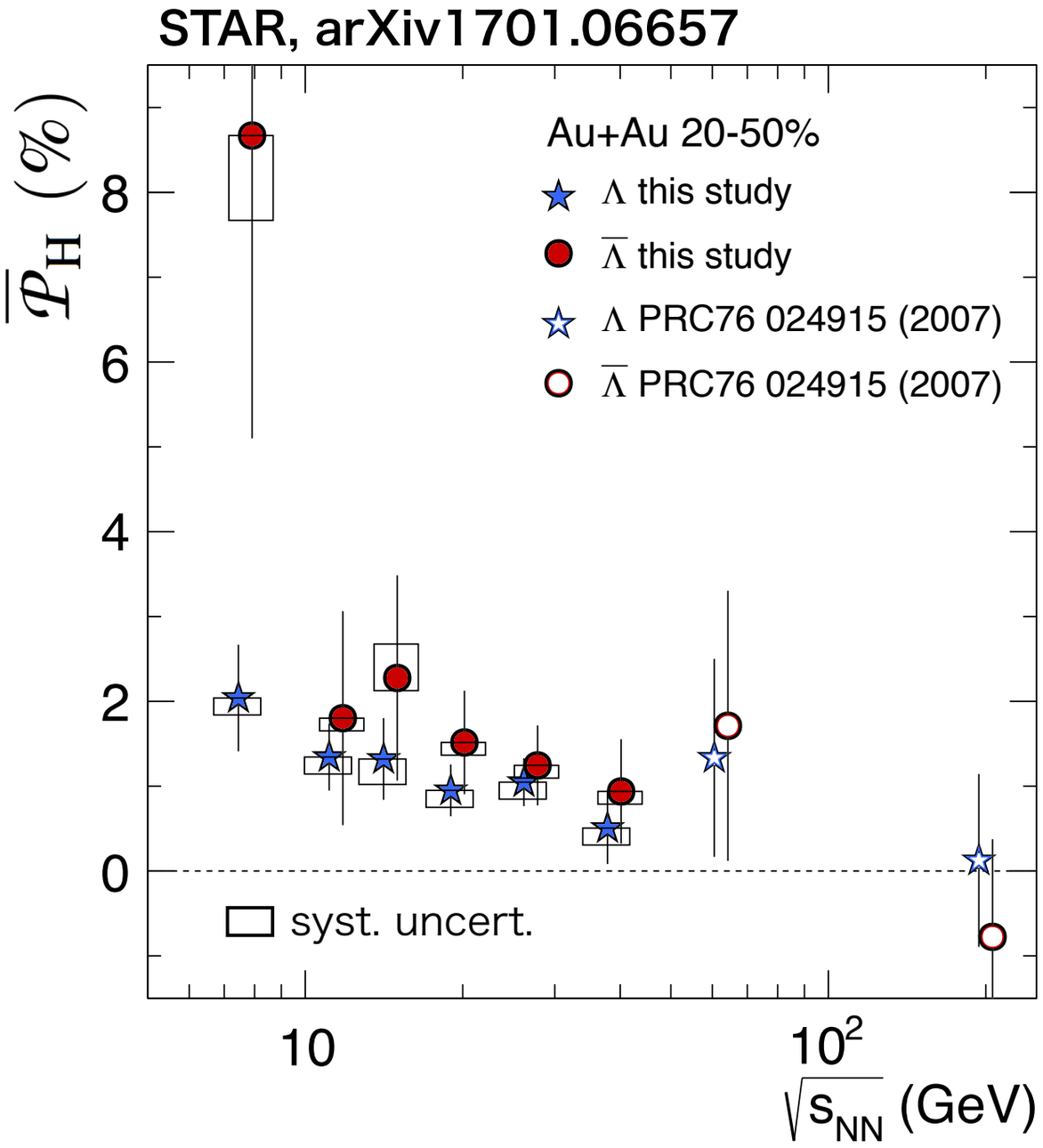
Karpenko and Becattini, arXiv:1610.0477



When increasing the collisions energy:

- Longer lifetime of system would dilute the polarization
- Smaller longitudinal flow velocity at mid-η due to baryon transparency

Λ global polarization vs $\sqrt{s_{NN}}$



- Positive signals in $\sqrt{s_{NN}}$=7.7-62.4 GeV
  - vorticity!
- systematically $P_H(\Lambda) < P_H(\text{anti-}\Lambda)$
  - implying a contribution from B-field

For small polarization,

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

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

Becattini, Karpenko, Lisa, Upsal, and Voloshin
arxiv1610.02506 (2016)

Accounting for feed-down

- ~25% of measured Λ and anti-Λ are primary, while ~60% are feed-down from $\Sigma^{*} \to \Lambda\,\pi$, $\Sigma^{0} \to \Lambda\,\gamma$, $\Xi \to \Lambda\,\pi$
- One needs to correct it before extracting physical parameters

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

Becattini, Karpenko, Lisa, Upsal, and Voloshin, arXiv:1610.02506 (2016)

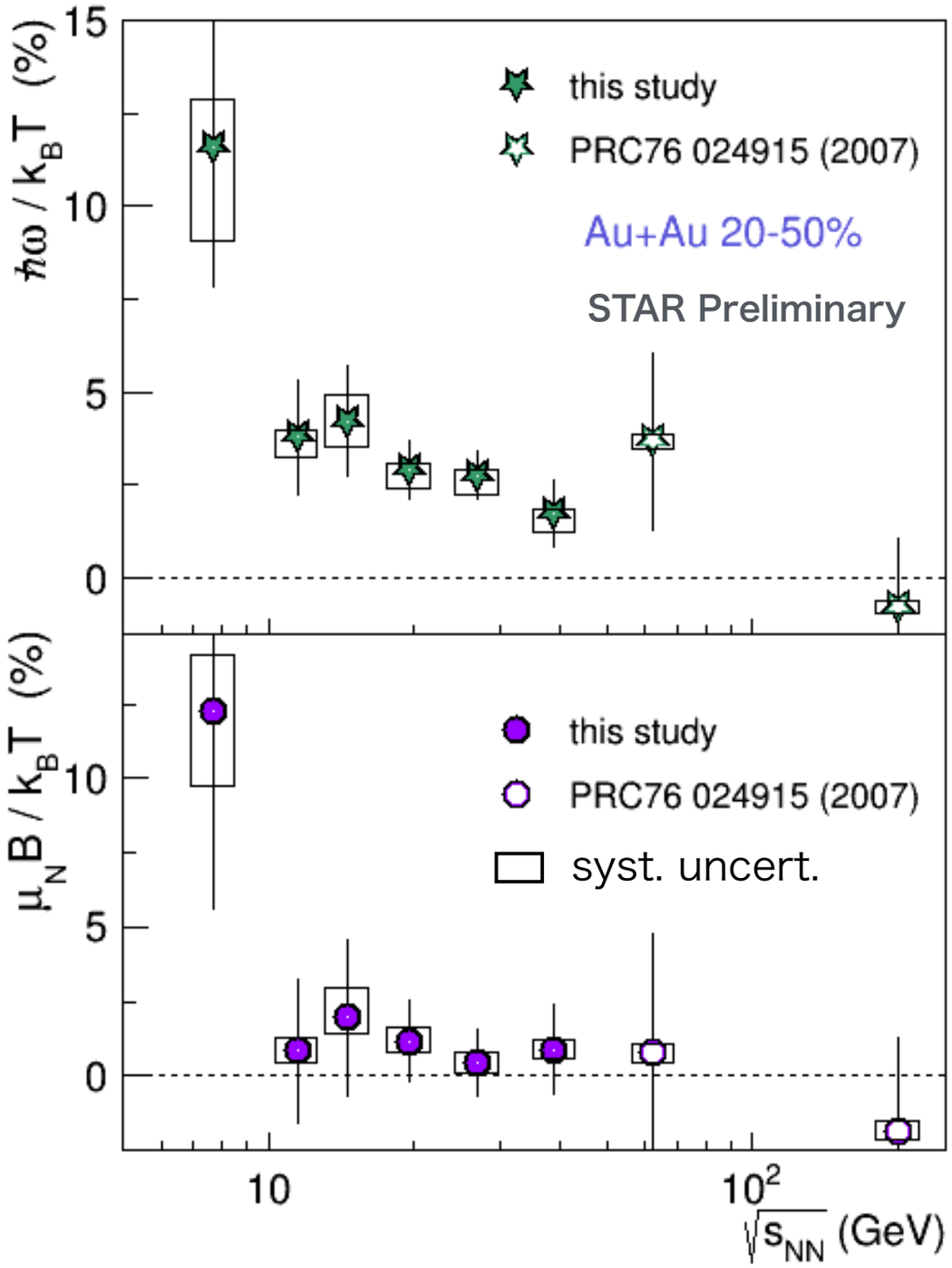
$f_{\Lambda R}$: fraction of Λ originating from parent R

$C_{\Lambda R}$: coefficient of spin transfer from parent R to Λ

S_R : parent particle's spin

μ_R : magnetic moment of particle R

Extracted vorticity and B-field



- Vorticity
  - ω/T ~ 2-10% ($\hbar = 1,\ k_B = 1$)
  - ω~0.02-0.09 fm^{-1}
    (when assuming T=160 MeV)

Jiang et al., PRC94, 044910 (2016)

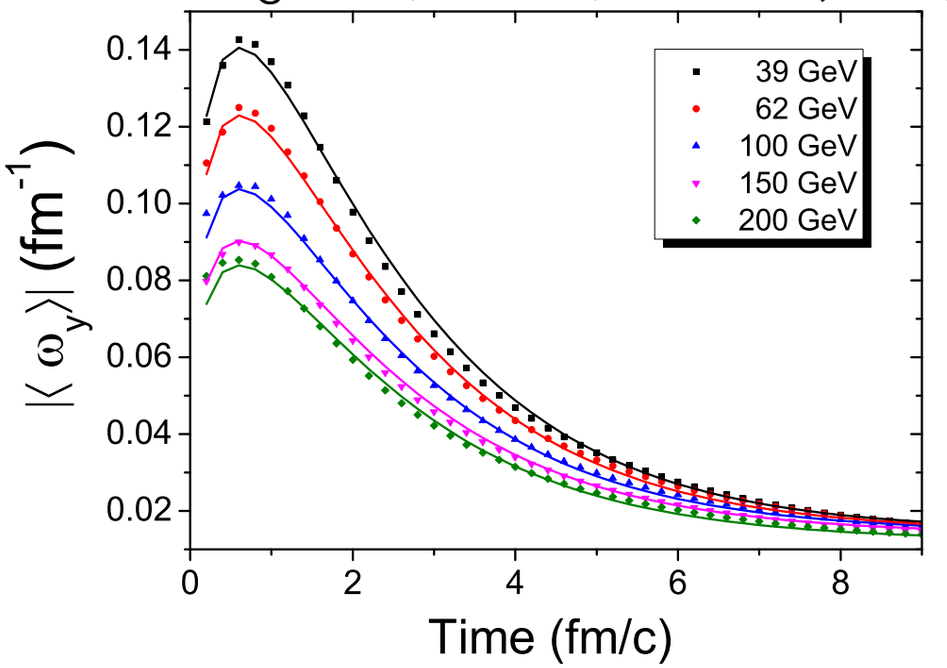
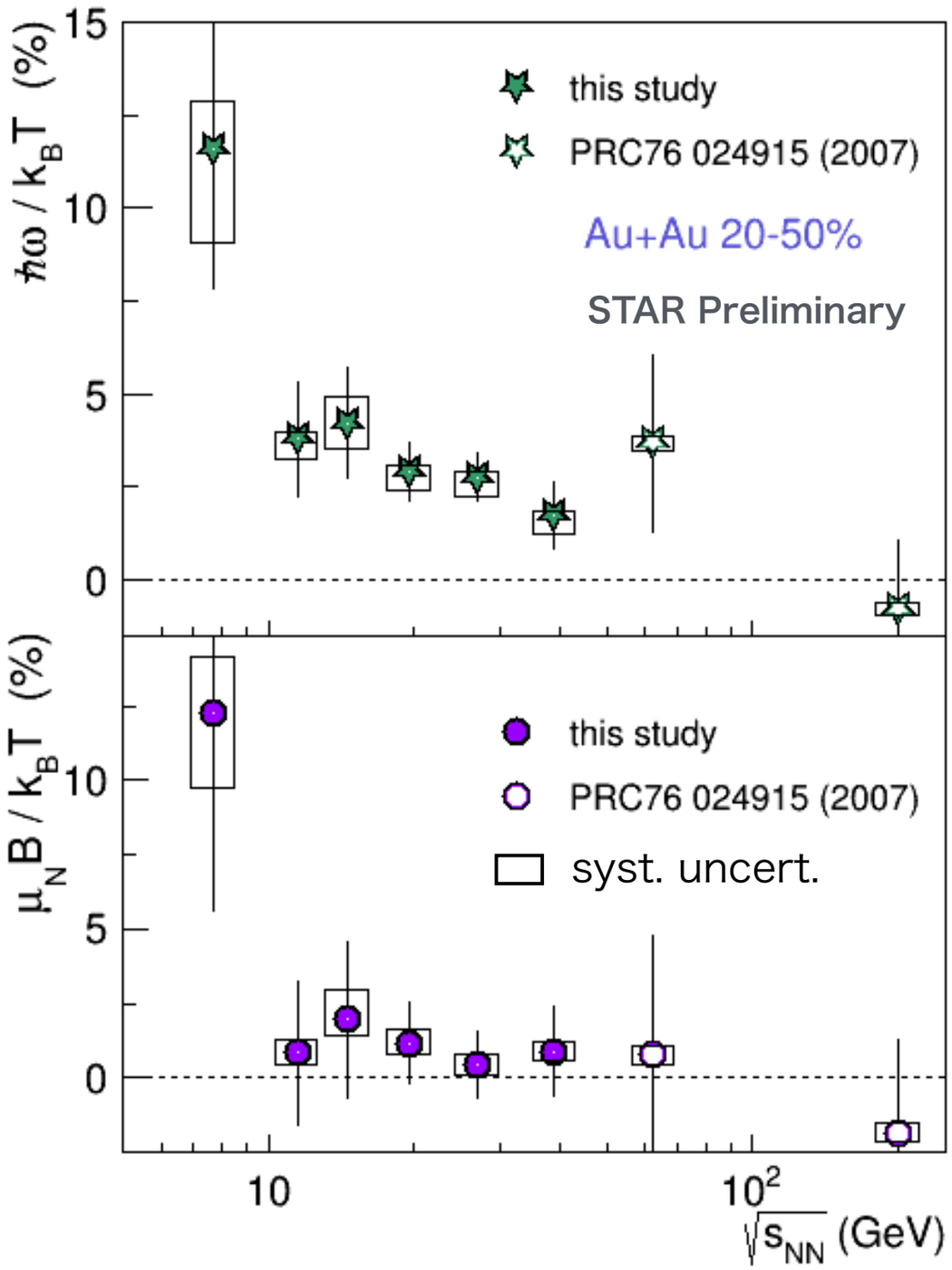


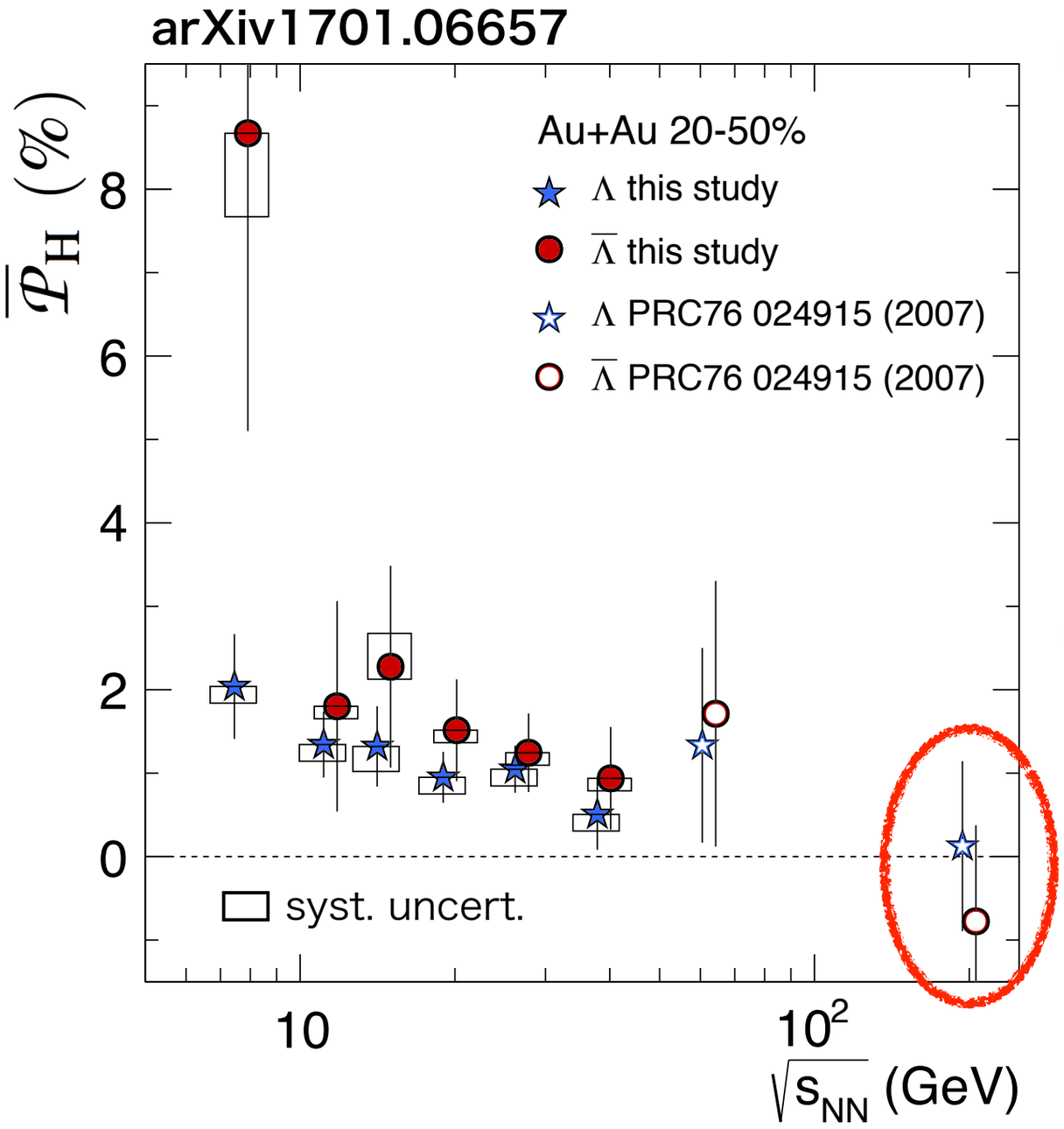
FIG. 12. Averaged vorticity $\langle \omega_y \rangle$ from the AMPT model as a function of time at varied beam energy $\sqrt{s_{NN}}$ for fixed impact parameter $b = 7$ fm. The solid curves are from a fitting formula (see text for details).

Extract vorticity and B-field



- Vorticity
  - ω/T ~ 2-10% ($\hbar = 1,\ k_B = 1$)
  - ω~0.02-0.09 fm^{-1} (when assuming T=160 MeV)
- Magnetic field
  - possible direct measure of B-field, but the data are consistent with zero
  - need more events

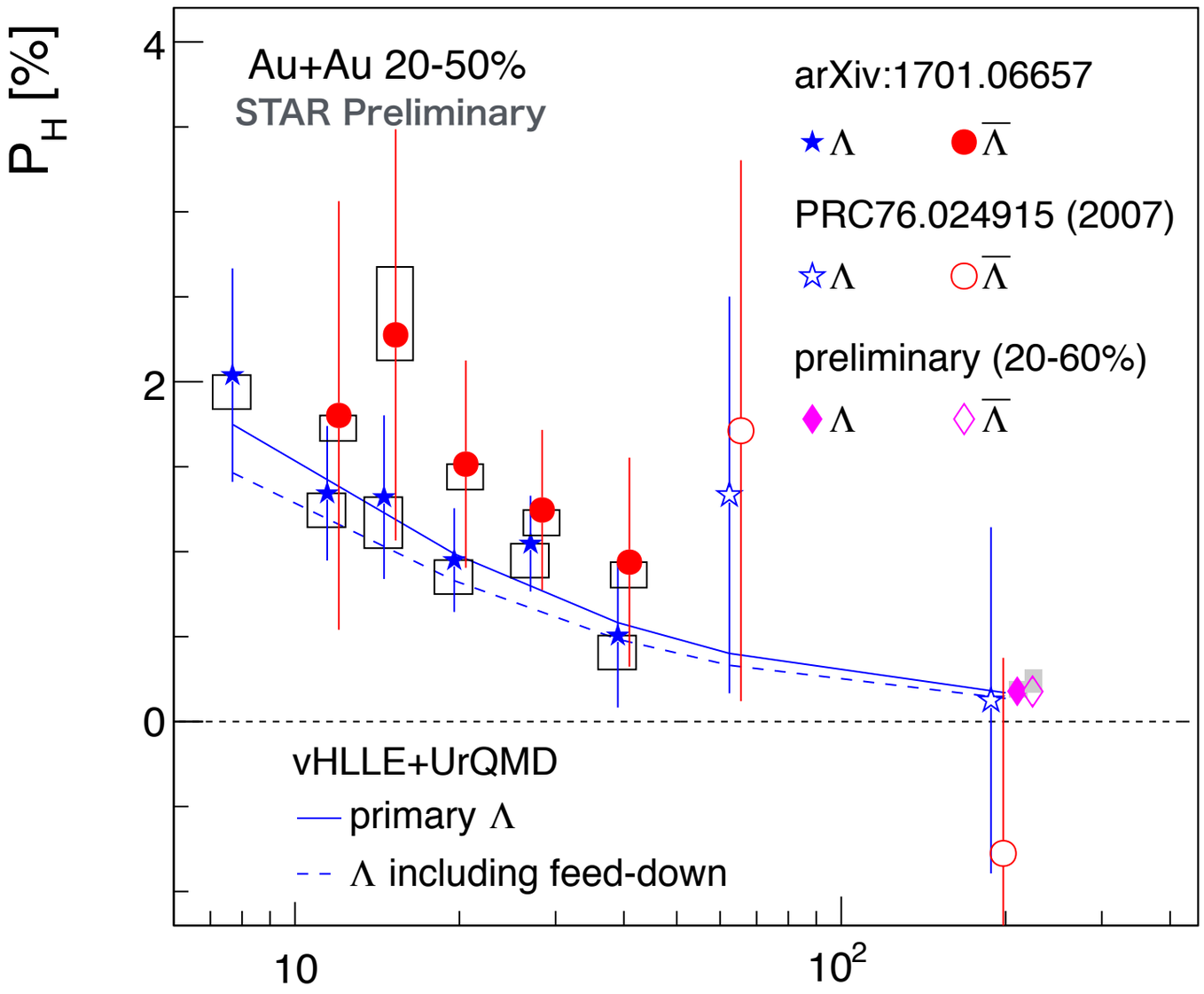
Back to Λ polarization results



- Previous results at 200 GeV (using year 2004 data) were consistent with zero
  →Can we see the signal when using recent data with more statistics?

- previous study used
  - year 2004 data ~**9M** events
- new study used
  - year 2011 data ~**350M** events

Λ global polarization vs $\sqrt{s_{NN}}$



vHLLE+UrQMD
Karpenko and Becattini, arXiv:1610.0477

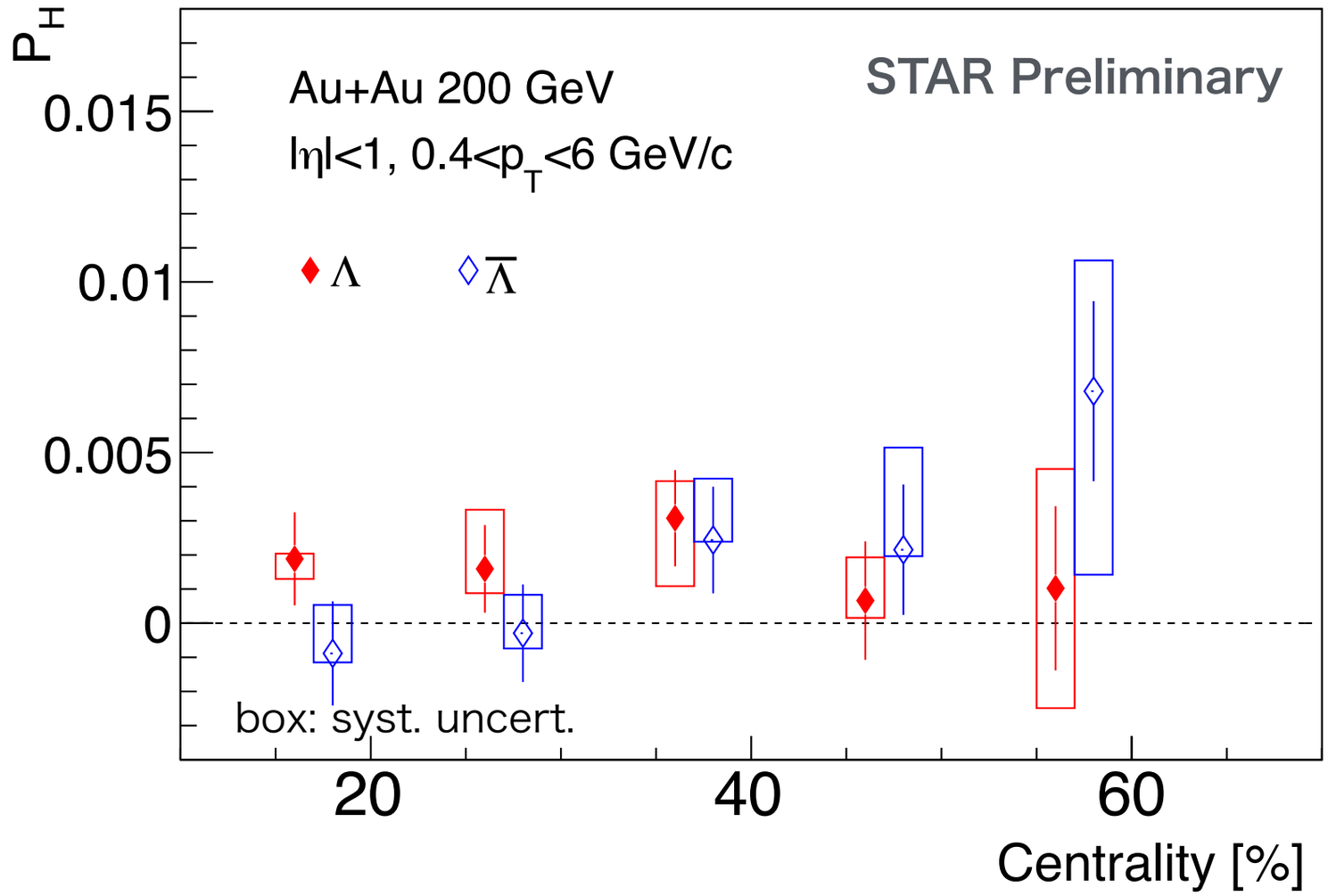
- Non zero signal of P_H at $\sqrt{s_{NN}}$ = 200 GeV

  ~0.18%±0.08

  (syst. uncert. ~0.06% for Λ)

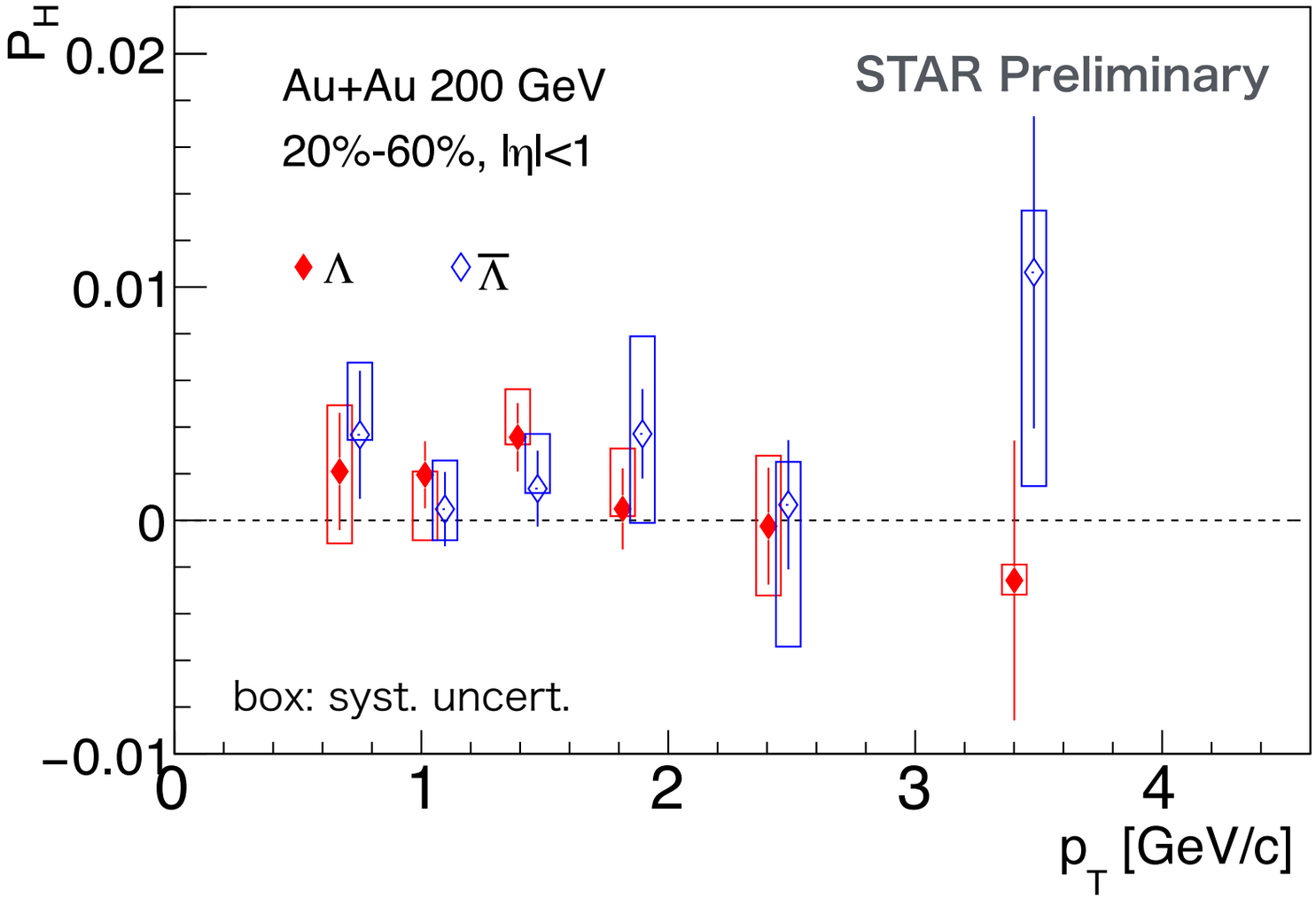
  - no significant difference between Λ and anti-Λ
  - close to viscous-hydro +UrQMD calculation

Centrality dependence of P_H



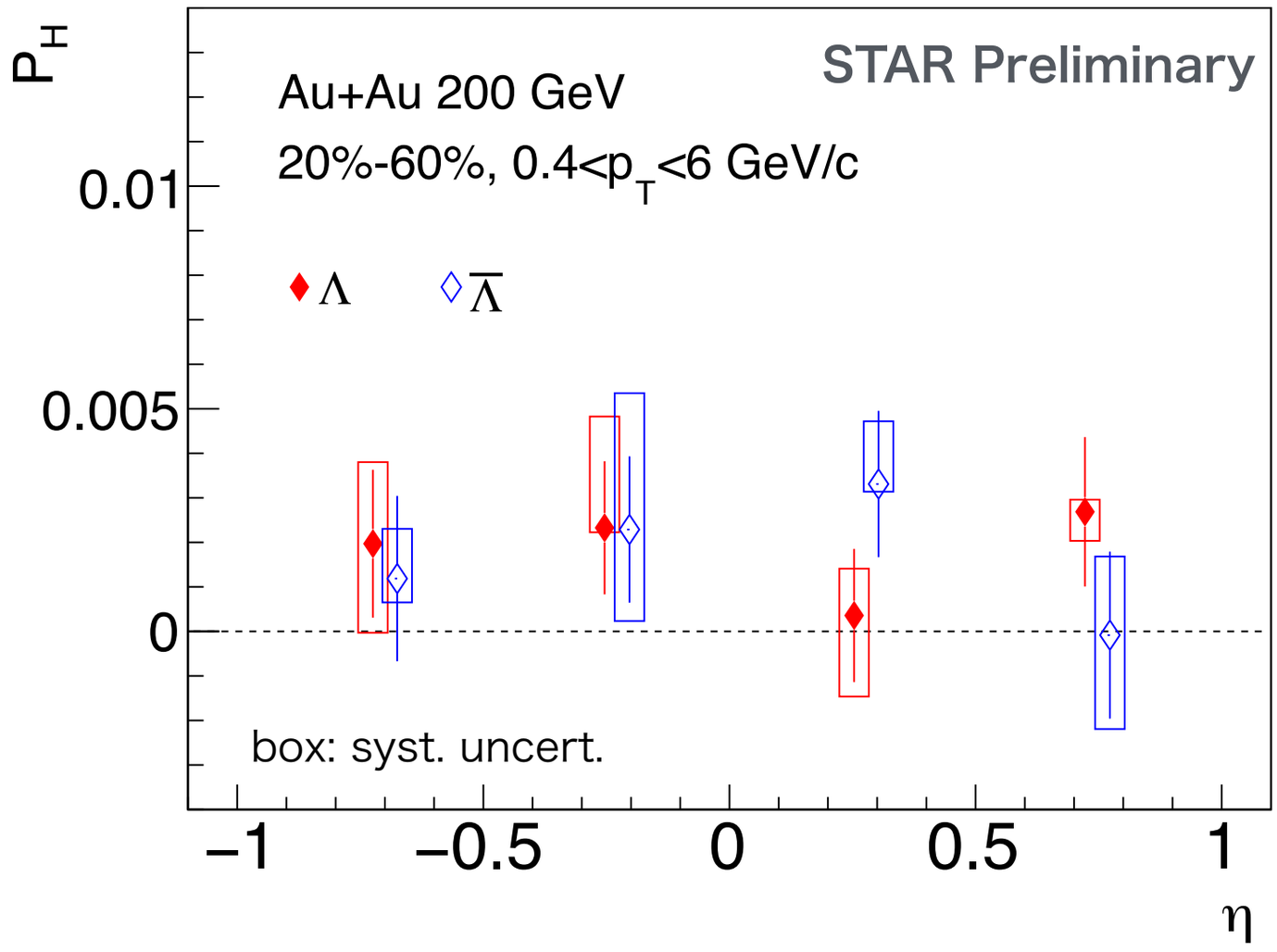
- Weak centrality dependence for Λ
- Looks to slightly increase in peripheral events for anti-Λ

pT dependence of PH



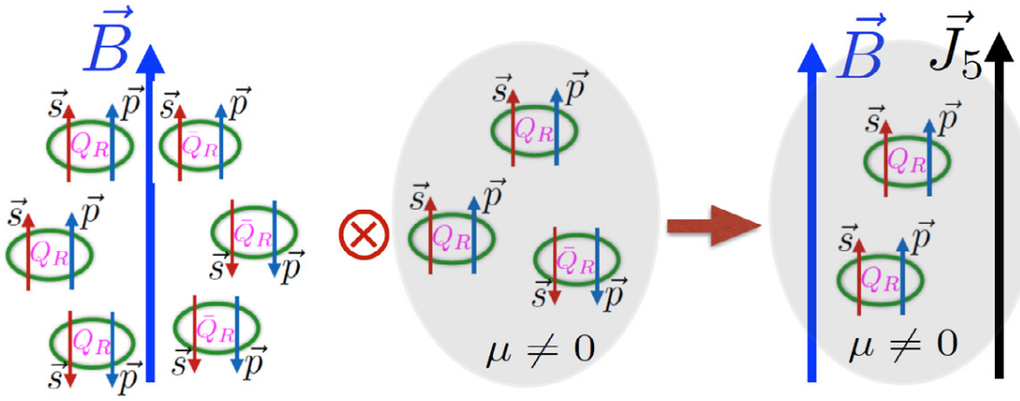
- No significant pT dependence was observed within current uncertainties

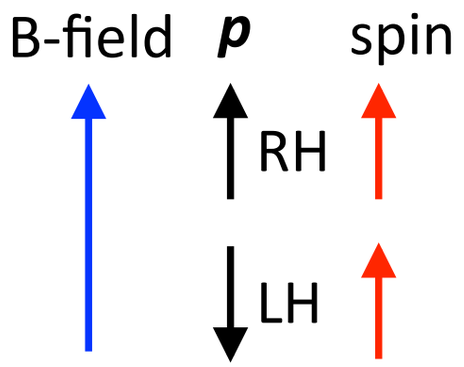
η dependence of P_H



- No significant η dependence within current uncertainties

Λ polarization vs charge asymmetry?

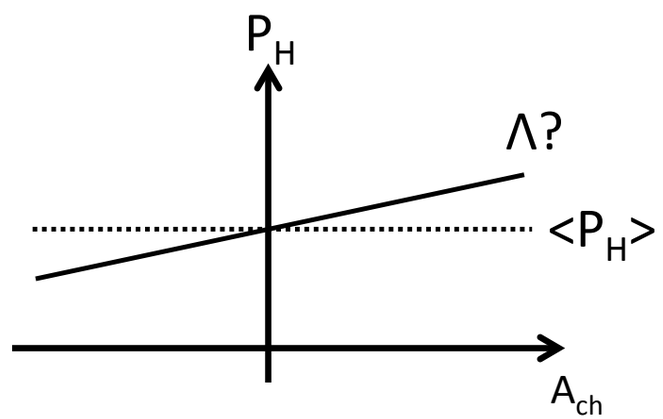




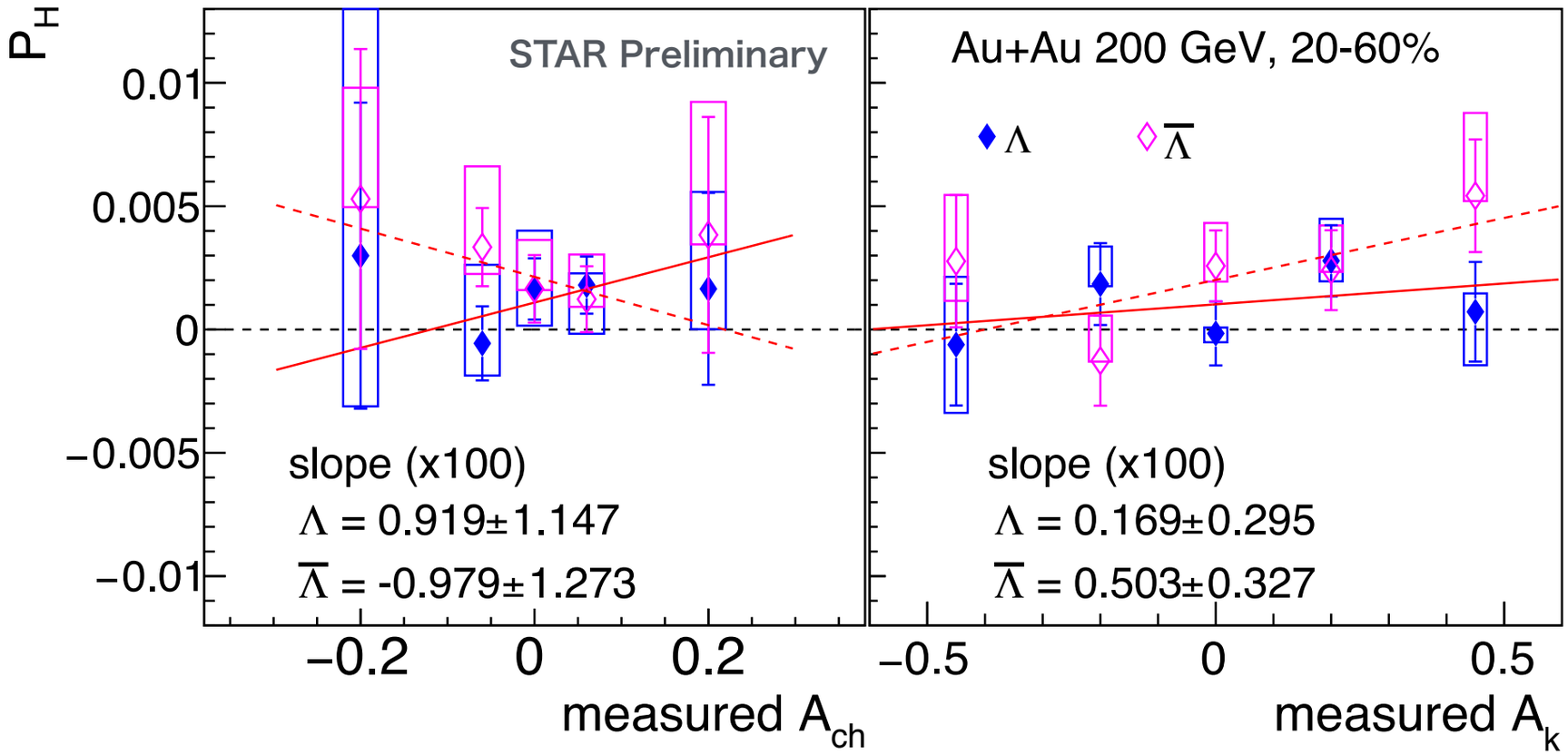
$$\mathbf{J}_5 \propto \mu_\mathrm{v}\mathbf{B}$$

- Idea (S. Shlichting and S. Voloshin, in preparation)
  - Λ polarization may be related to the axial current J_5
  - Use (kaon) charge asymmetry instead of μ_v

$$\mu_\mathrm{v}/T \propto \frac{\langle N_+ - N_- \rangle}{\langle N_+ + N_- \rangle} \quad \text{or} \quad \mu_\mathrm{v}/T \propto \frac{\langle N_{K^+} - N_{K^-} \rangle}{\langle N_{K^+} + N_{K^-} \rangle}$$



Charge asymmetry dependence of P_H



No clear trend within current uncertainties.

Need more events…

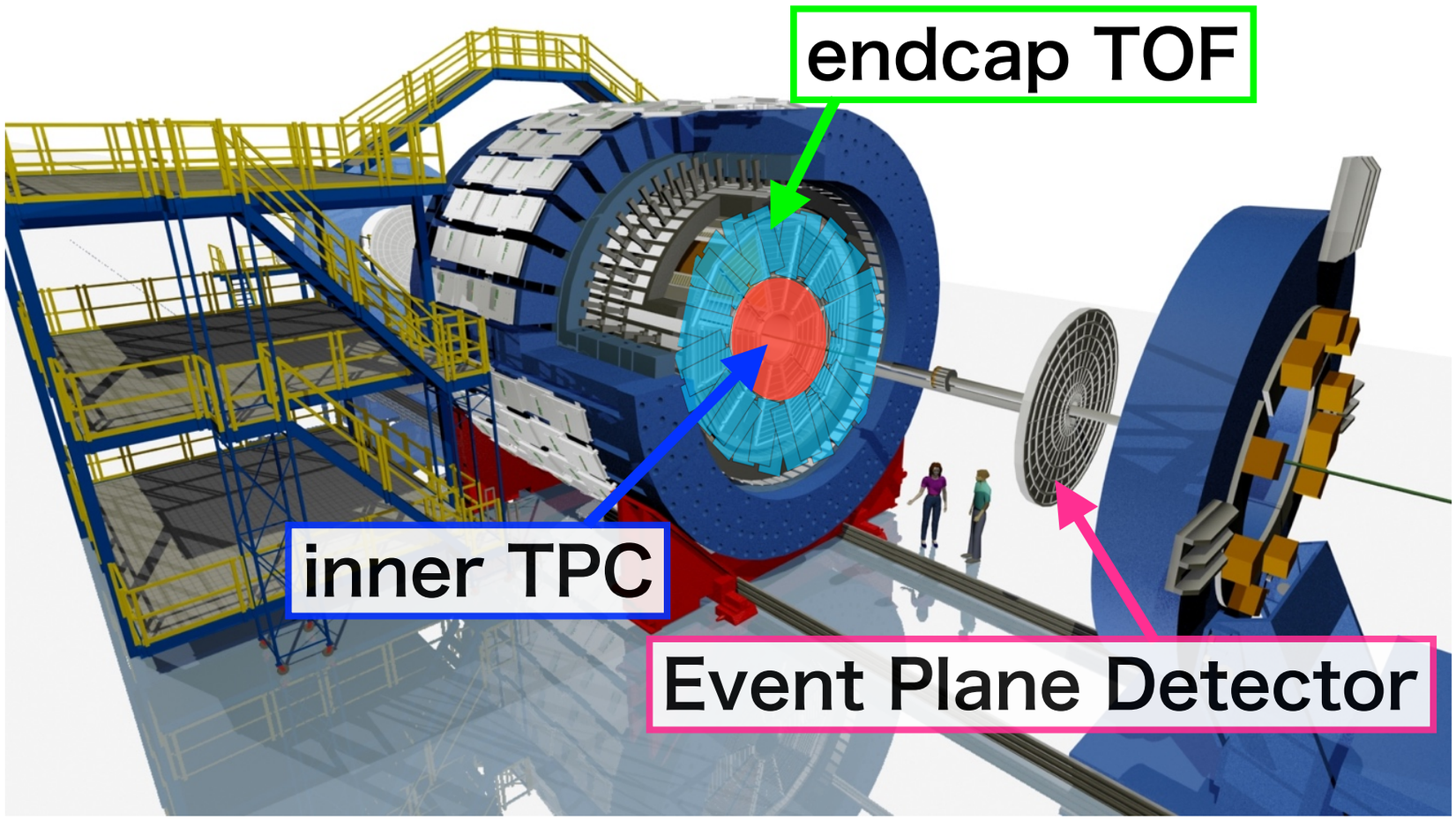
Summary

- STAR has made the first observation of Λ global polarization in Au +Au collisions at $\sqrt{s_{NN}}$=7.7-200 GeV
  - Clear signal of vorticity from the medium in non-central heavy-ion collisions
  - Current data cannot distinguish the difference between Λ and anti-Λ, but the difference may lead to a possible direct measurement of the magnetic field
  - Preliminary results for $\sqrt{s_{NN}}$ = 200 GeV also show non-zero signal of Λ polarization (P_H = 0.18% ± 0.08%)
  - First look at charge asymmetry dependence of Λ polarization

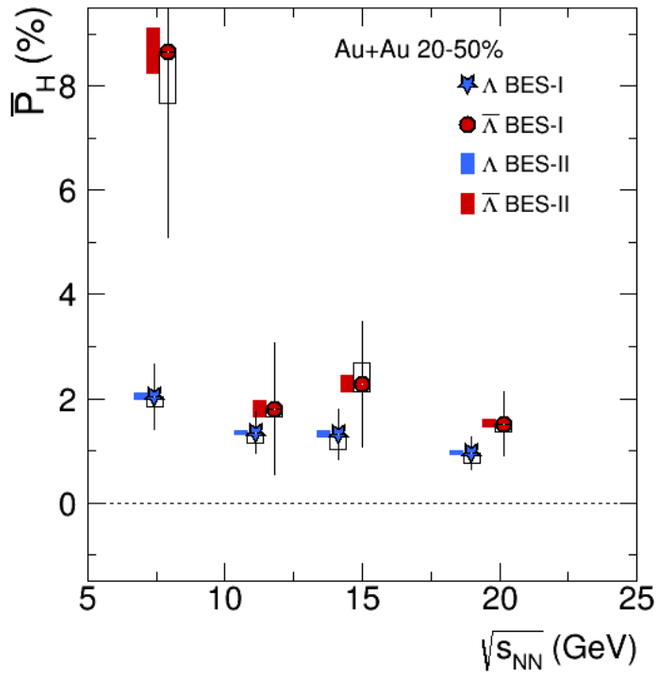
- Outlook
  - STAR upgrade for BES- II
  - Connection to other observables

→see next slides

STAR upgrade for BES-II



Expect significant improvements in BES-II



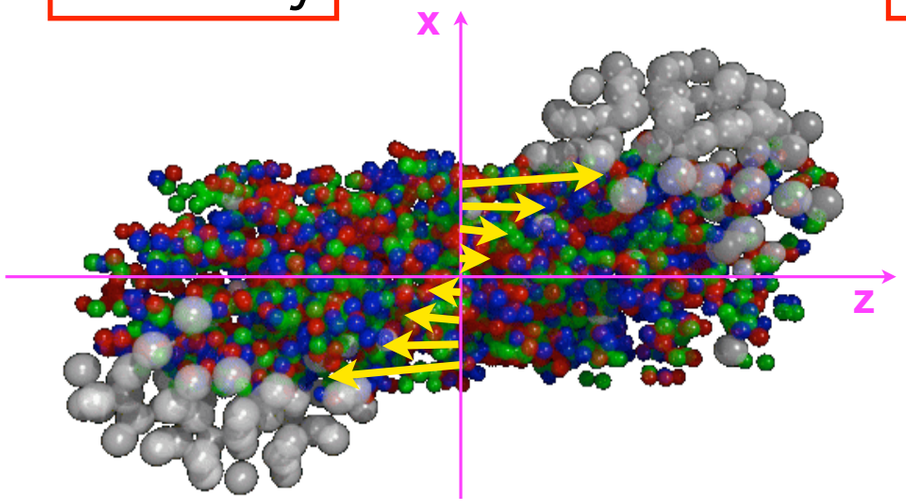
iTPC upgrade
- extend η coverage from $|\eta|<1$ to $|\eta|<1.5$
- $p_T>60$ MeV
- improve dE/dx resolution
- ready in 2019

eTOF upgrade
- $-1.6<\eta<-1.1$
- extend forward PID capability
- mid-rapidity coverage in Fixed Target Program
- ready in 2019

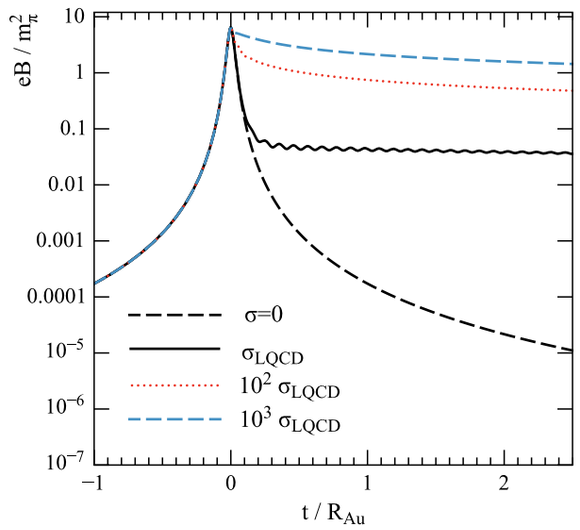
EPD upgrade
- $2.1<|\eta|<5.1$
- improve EP resolution
- independent trigger
- ready in 2018

Possible relation to other observables

Vorticity

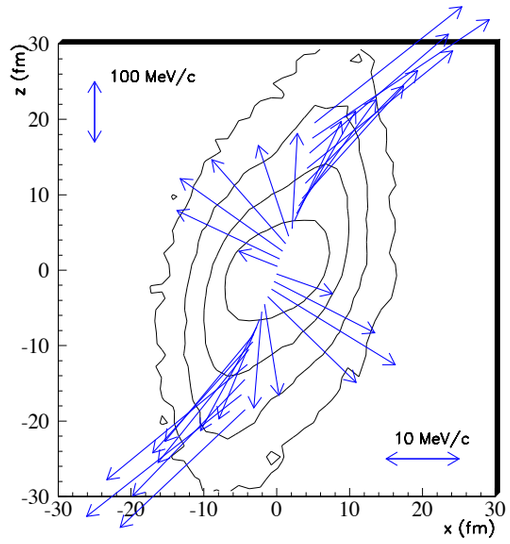


B-field, conductivity, CME…



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

Tilted source via HBT



Lisa, Heinz, and Wiedemann,
PLB489 (2000) 287
Lisa et al.(E895), PLB496 (2000) 1

Directed flow

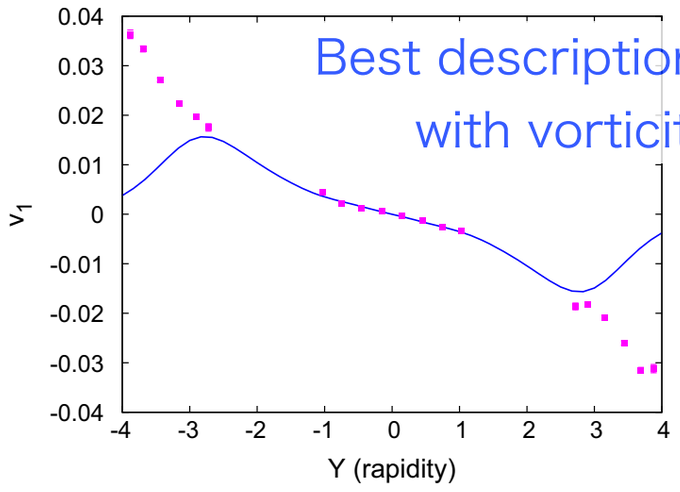


Fig. 8 Directed flow of pions at $\eta/s = 0.1$ and $\eta_m = 2.0$ compared with STAR data [22]

Becattini et al., Eur. Phys. J. C (2015) 75: 406

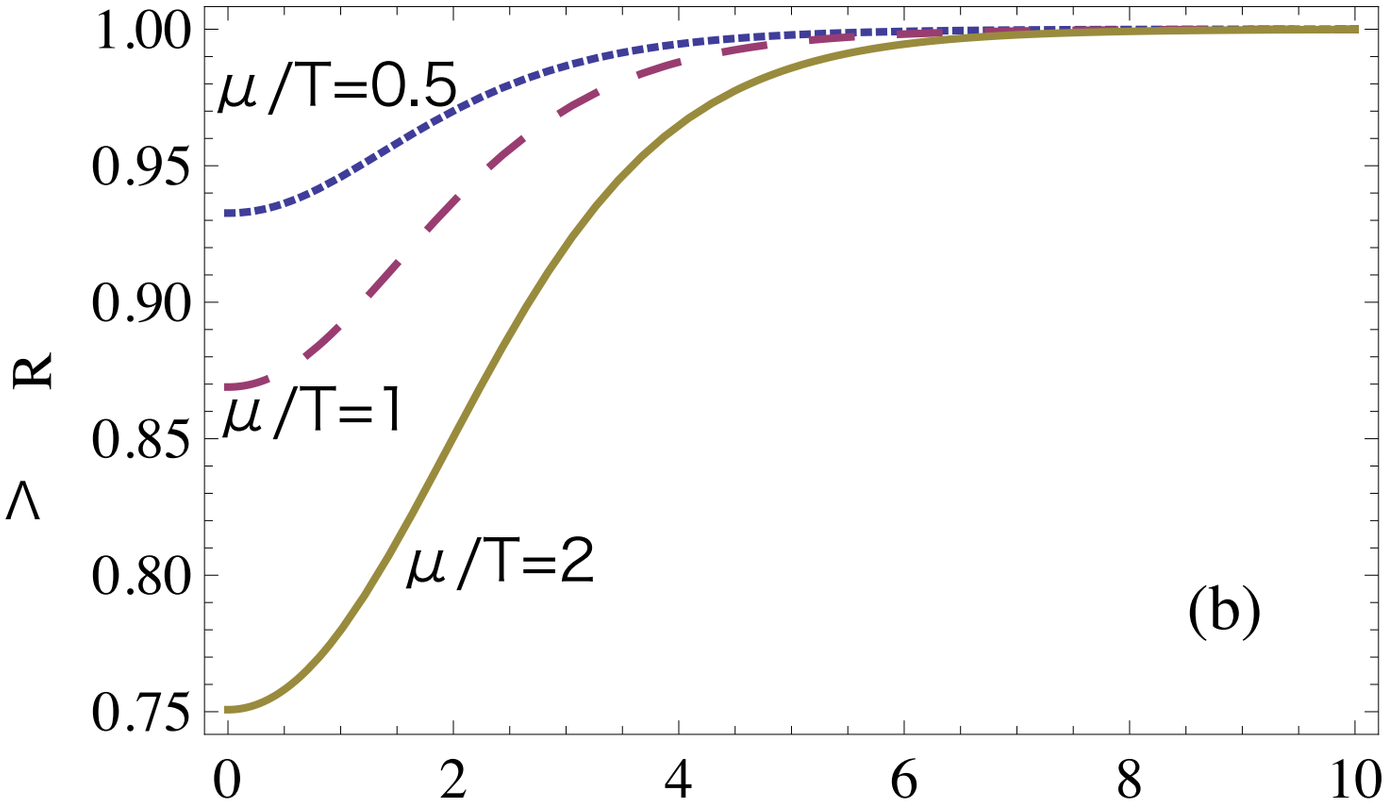
Vorticity is an important piece for further understanding the picture of HIC!

Back up

Effect of non-zero chemical potential

R. Fang, L. Pang, Q. Wang, and X. Wang, PRC94, 024904 (2016)

$R = P_{\Lambda}/P_{\text{anti-}\Lambda}$



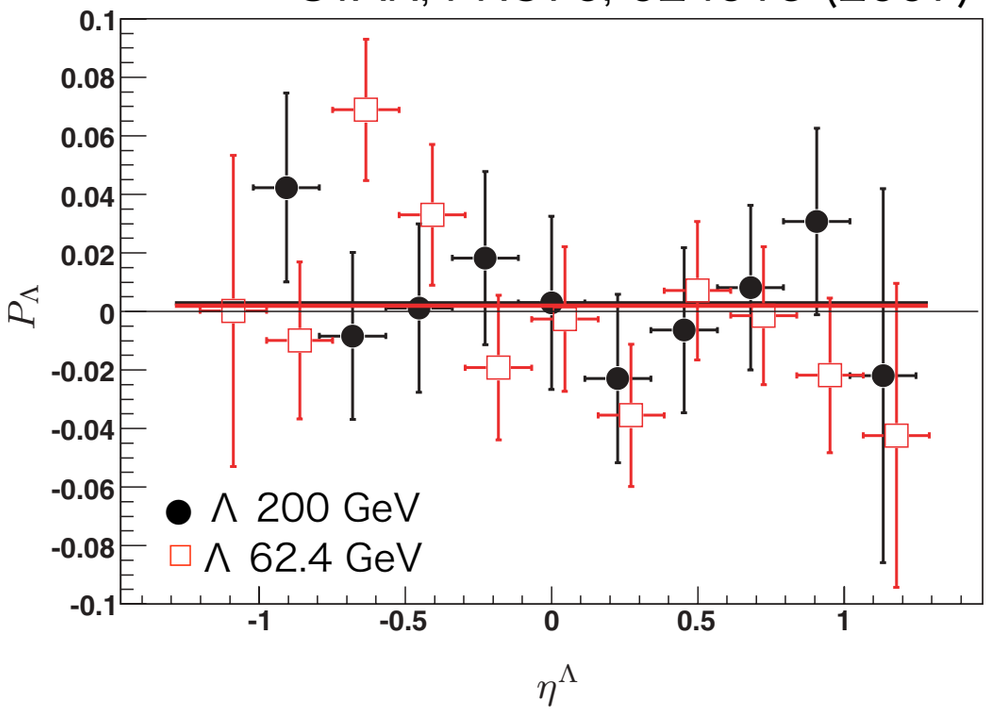
$\beta m = m/T$

~ 1.1GeV/(160-200)MeV

~ 5.5-6.8

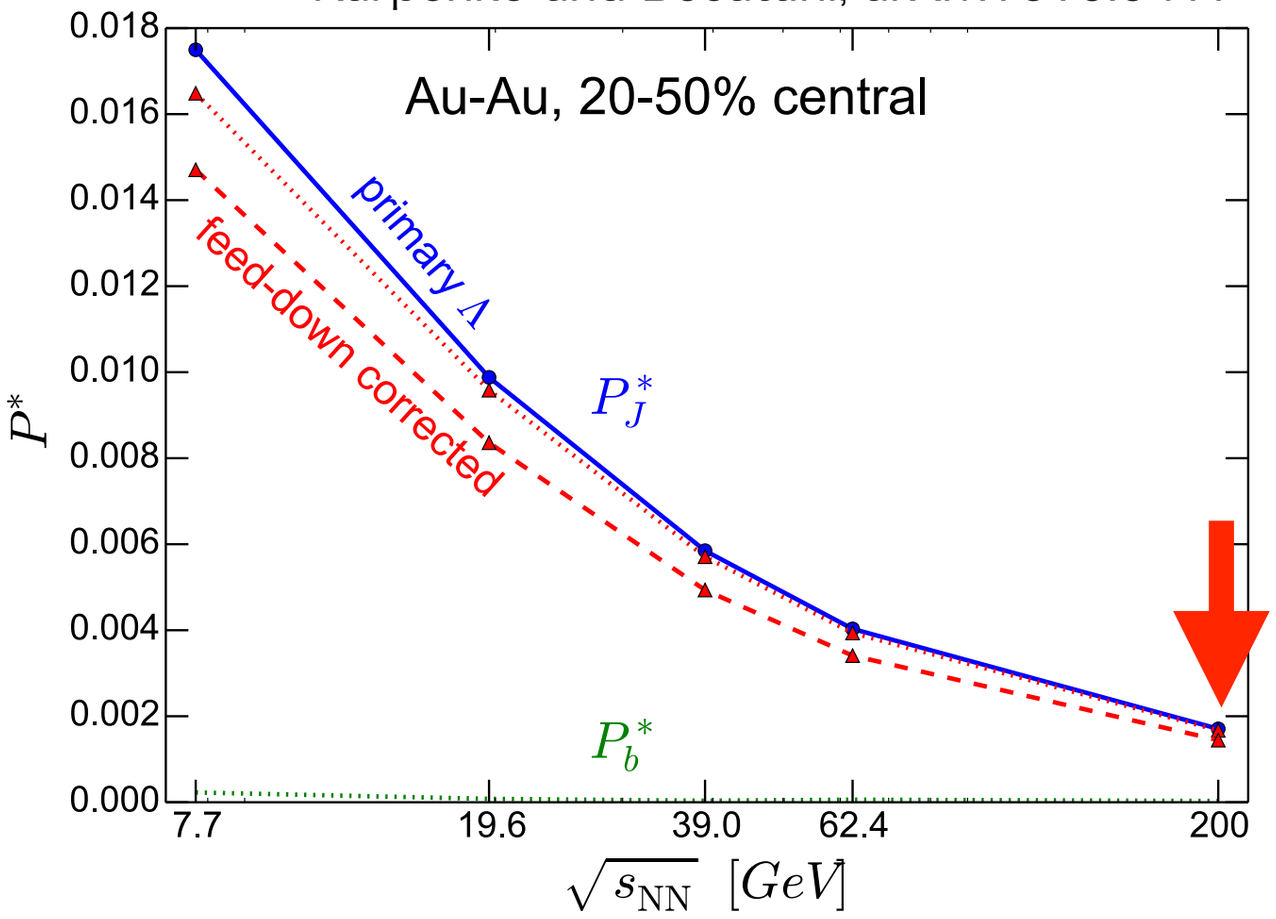
Previous results at $\sqrt{s_{NN}}$ = 200GeV

STAR, PRC76, 024915 (2007)



Previous Λ polarization result in Au+Au 200 GeV (year2004) was zero-consistent.

Karpenko and Becattini, arXiv:1610.0417



- 3+1D viscous hydro+cascade model predicts P*~**0.2%** for Au+Au 200 GeV.