

Study of strange particle polarization with ALICE at the LHC

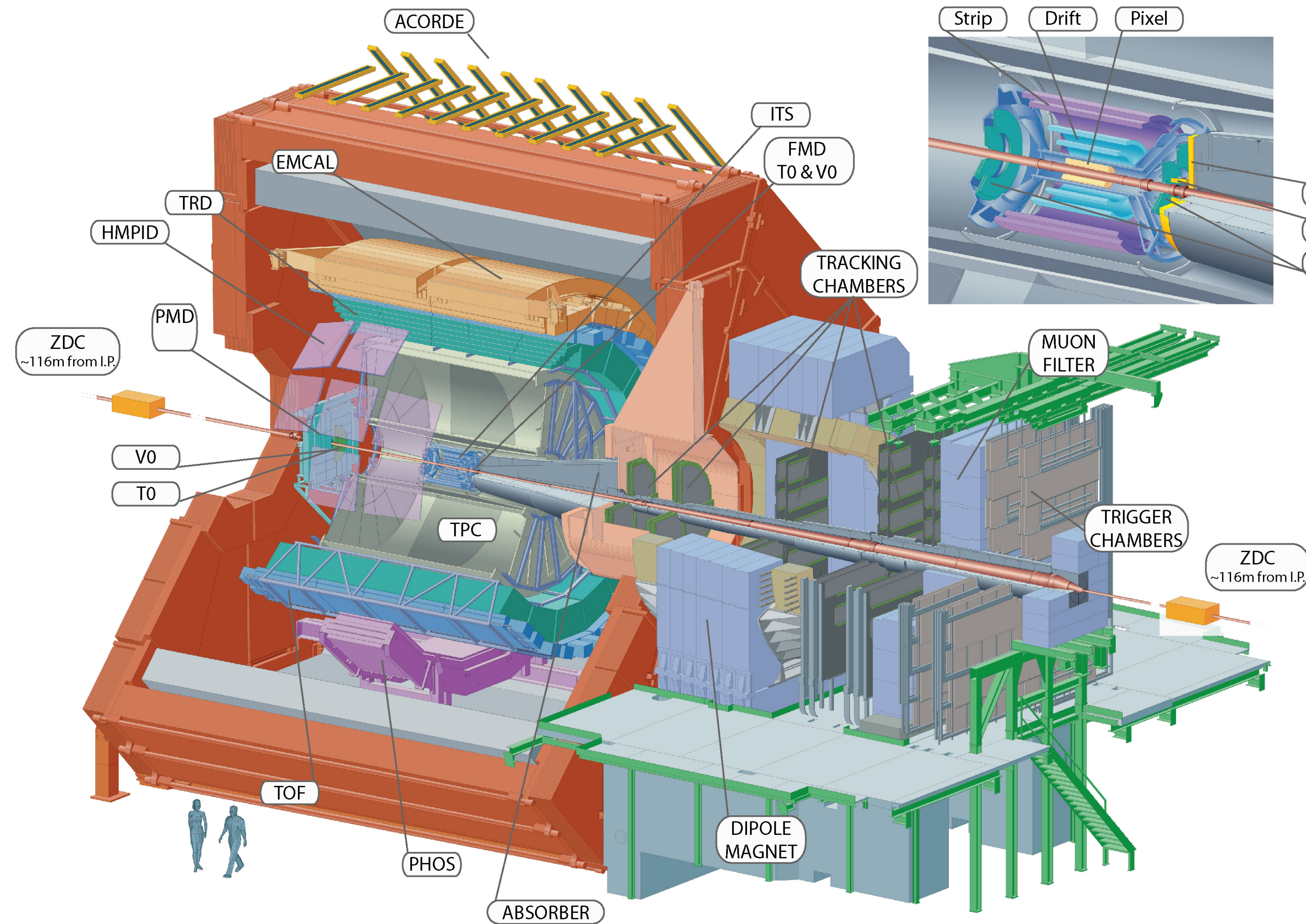


Xiaoming Zhang (张晓明)
Central China Normal University

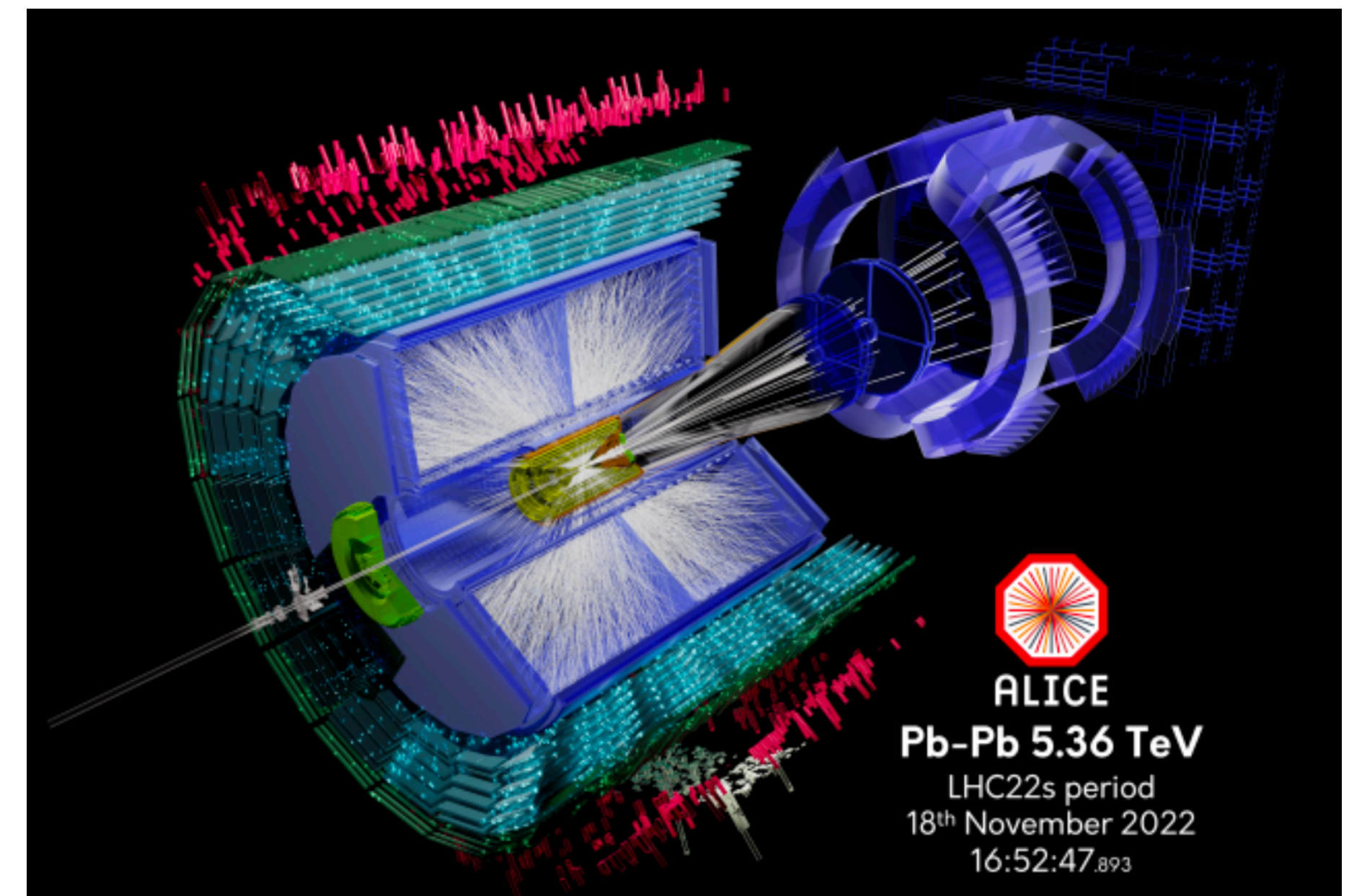
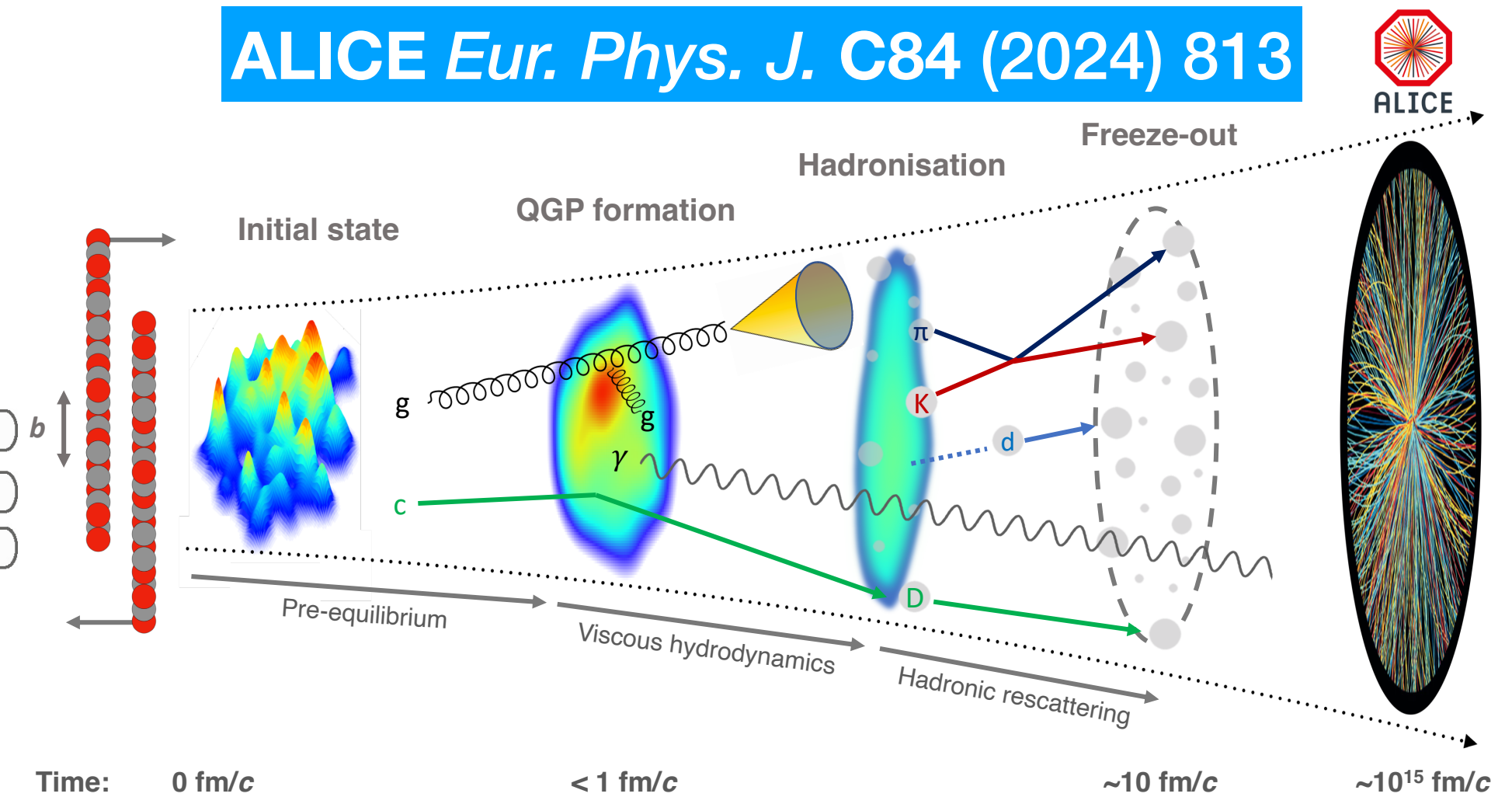


The first conference on strong-interaction spin physics
26–31 Jun 2026, Qingdao, China

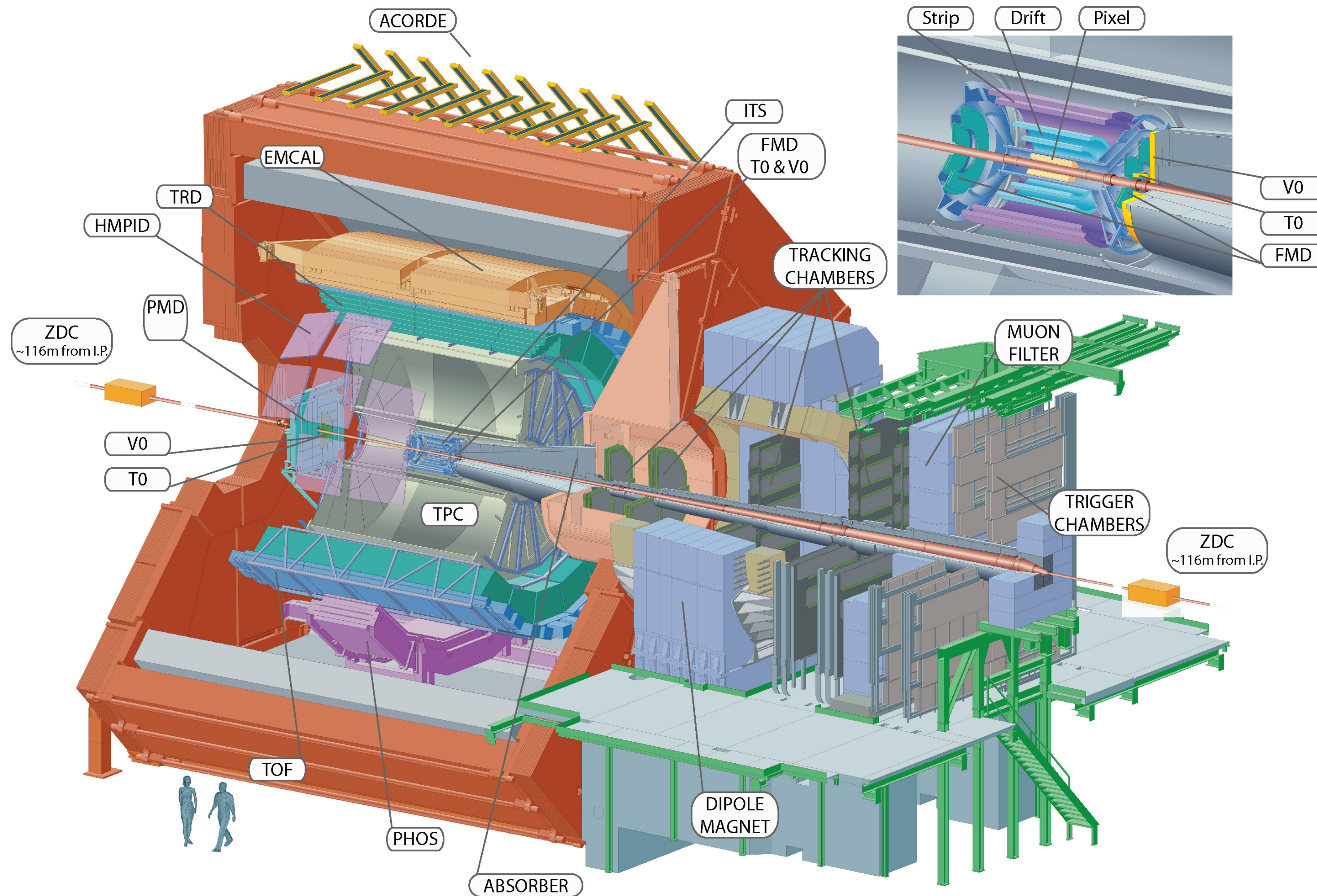
ALICE experiment at the LHC



ALICE *Eur. Phys. J. C*84 (2024) 813



A journey through QCD



CERN-EP-2022-227

27 October 2022



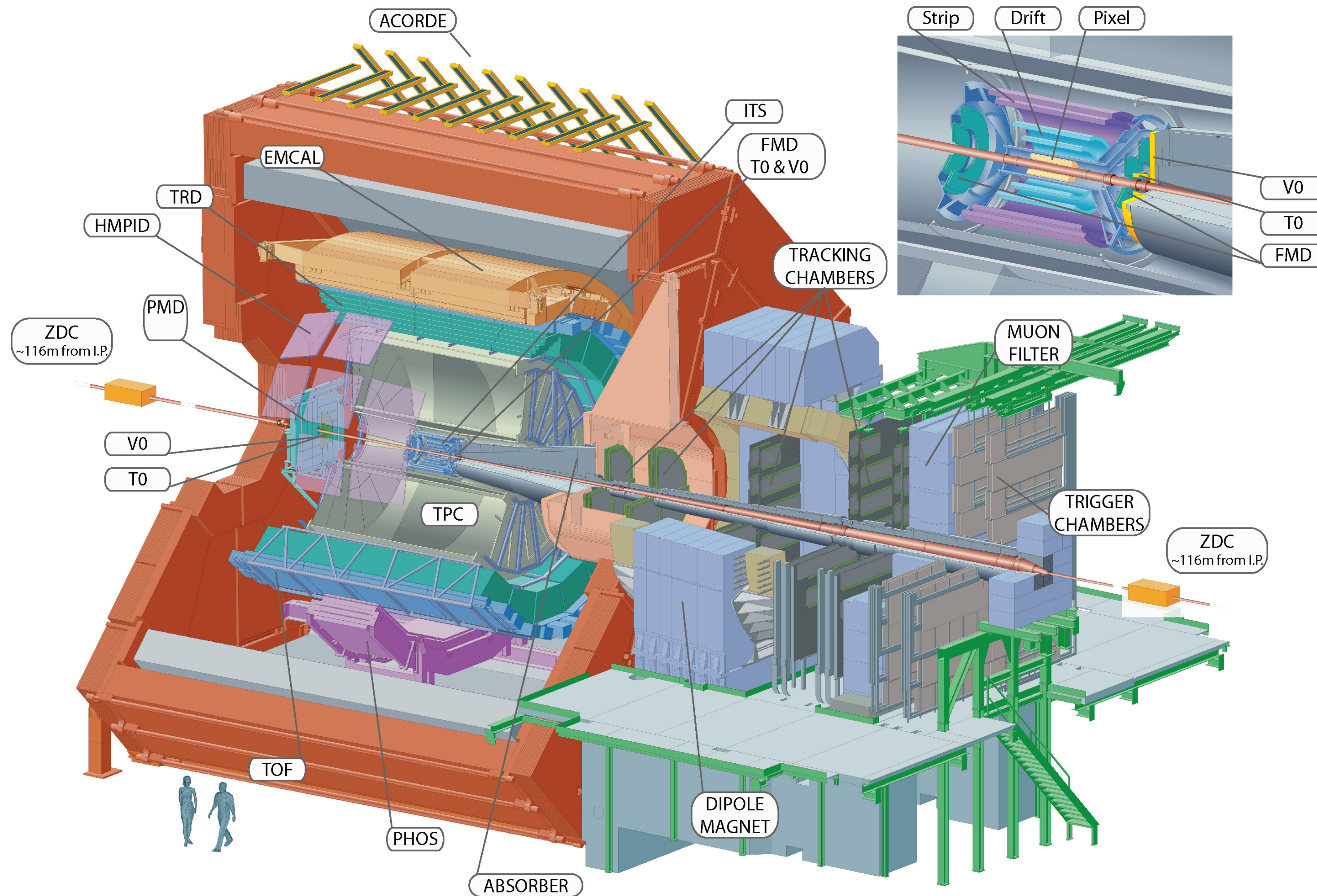
ALICE *Eur. Phys. J. C*84 (2024) 813

The ALICE experiment:
A journey through QCD

**ALICE Physics achievement
2009–2018**

- **QGP properties**
- Spin physics
- Nuclear structures
- Hadronic physics
- Fundamental symmetries
- Contribution to cosmology

A journey through QCD



CERN-EP-2022-227

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ALICE *Eur. Phys. J. C*84 (2024) 813

The ALICE experiment:
A journey through QCD

**ALICE Physics achievement
2009–2018**

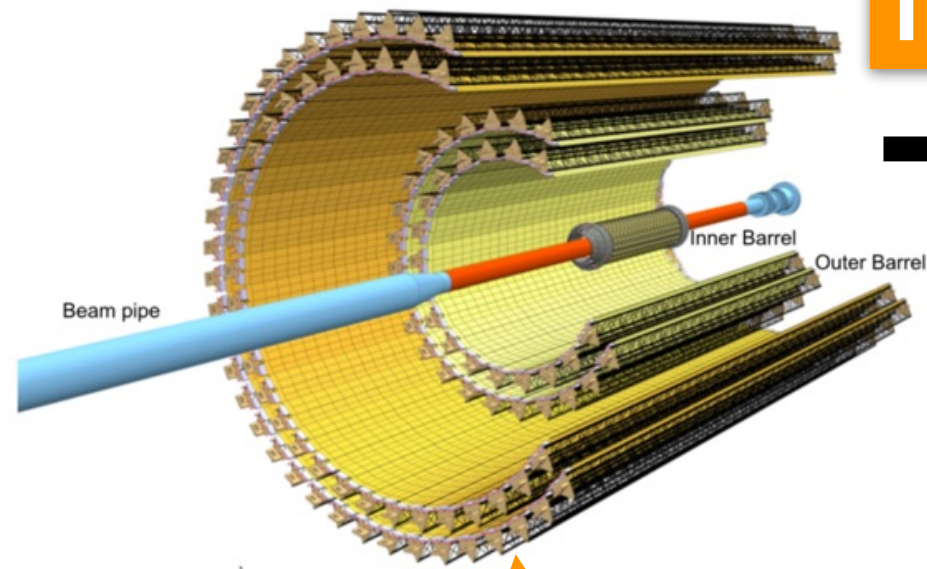
- QGP properties
- ➔ **Spin physics**
- Nuclear structures
- Hadronic physics
- Fundamental symmetries
- Contribution to cosmology

ALICE at LHC Run 3 (2022–Jul 2026)



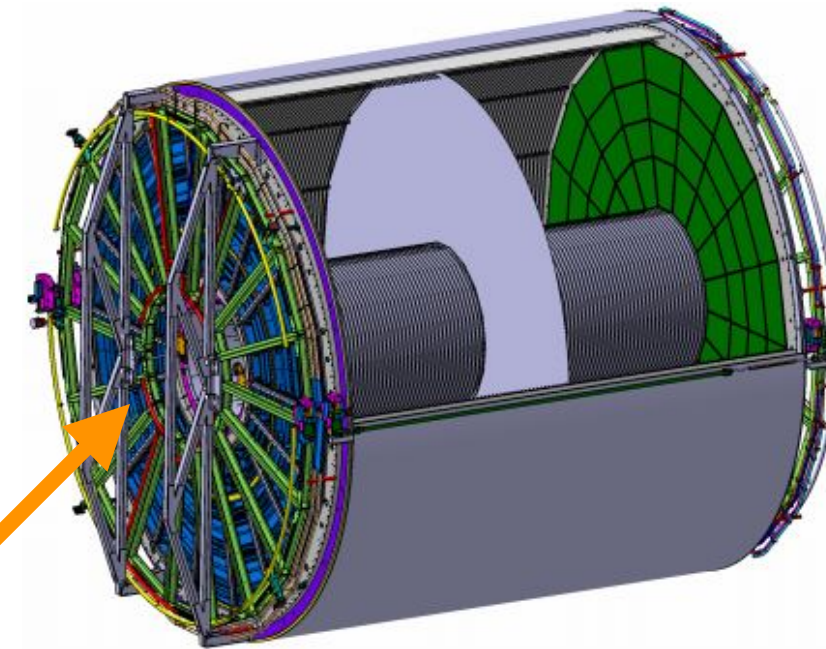
The 2nd generation inner tracking system (ITS2)

→ 7 layers MAPS detector, the innermost layer closer to interaction point



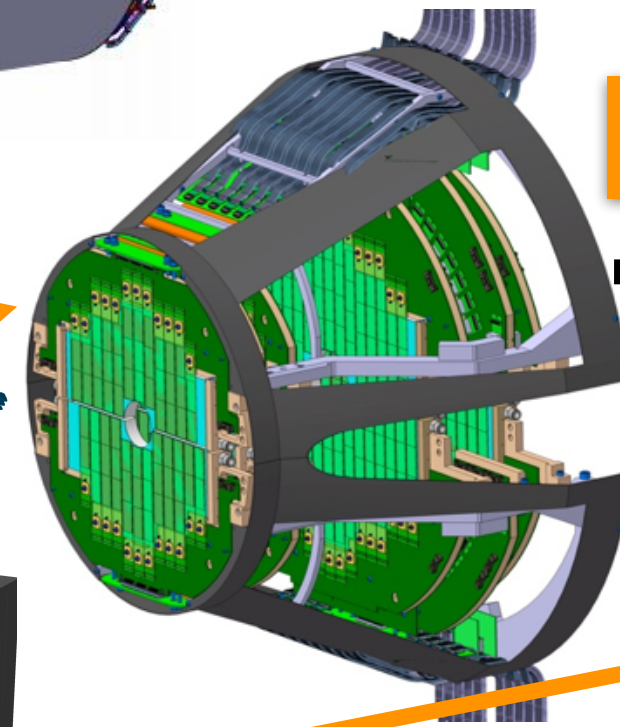
Time projection chamber (TPC)

→ New readout: MWPC → GEM



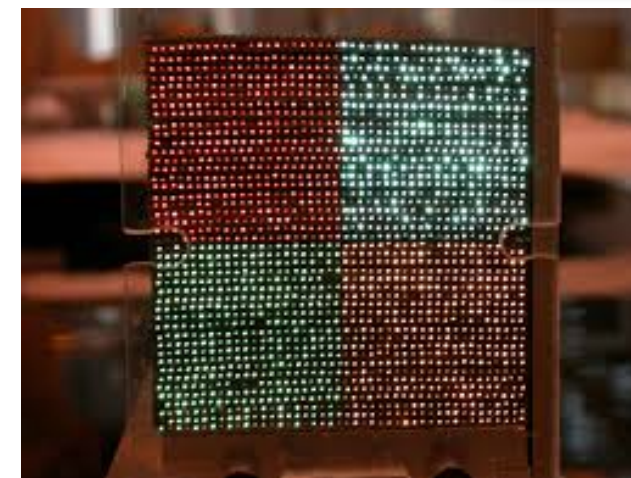
Muon forward tracker (MFT)

→ 5 planes of MAPS, vertexing for forward rapidity muons



Zero-degree calorimeter (ZDC)

→ First order event plane (EP) determination via measurement of spectator fragments

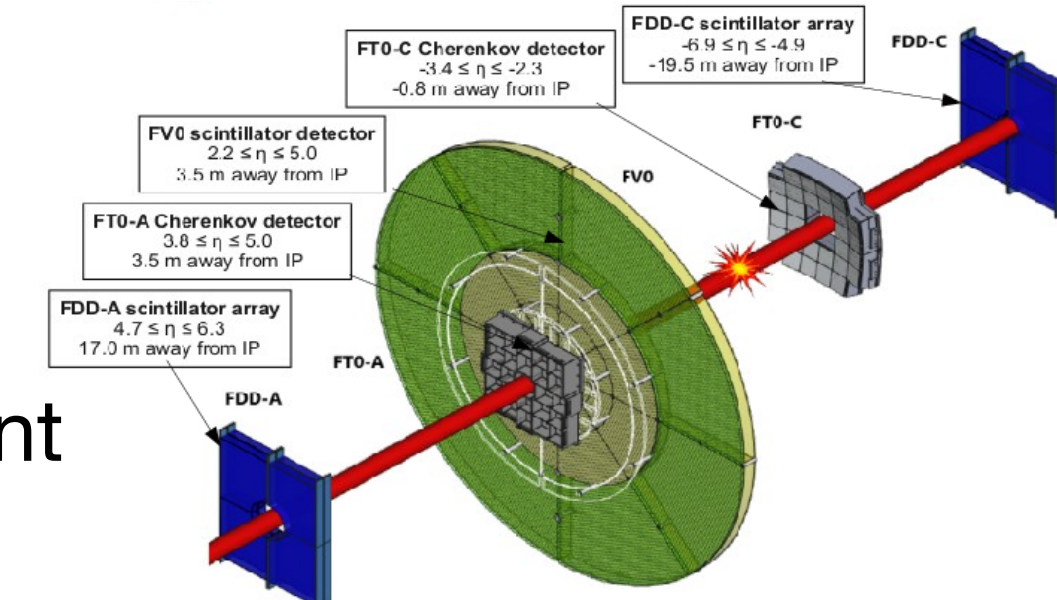


Readout of most detectors are upgraded to allow continuous readout

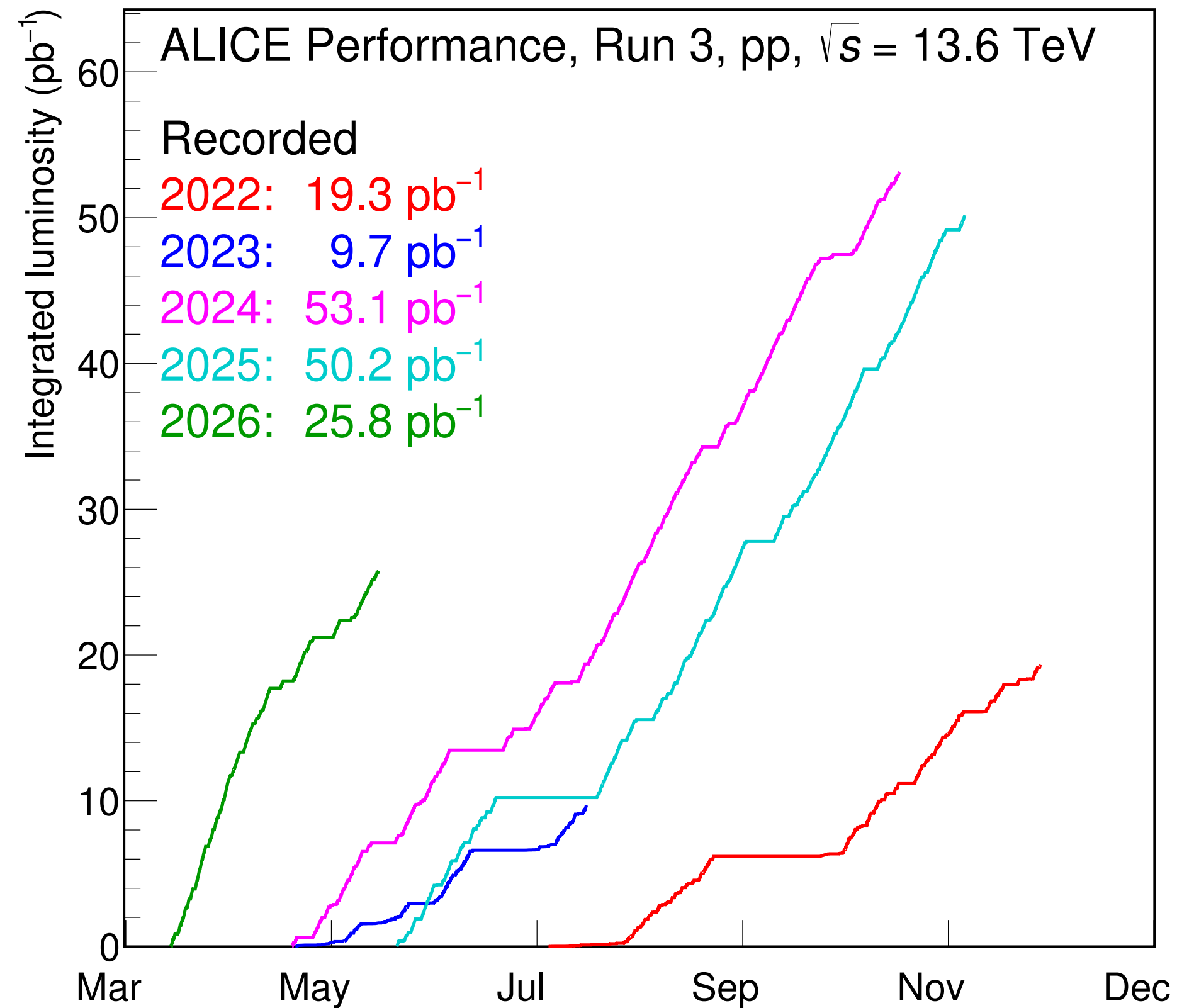
- pp data taking at 500 kHz
- Pb–Pb data taking up to 50 kHz
- Improved vertexing
- Improved tracking at low p_T

Fast integration trigger (FIT)

→ Event trigger, luminometer, EP reconstruction

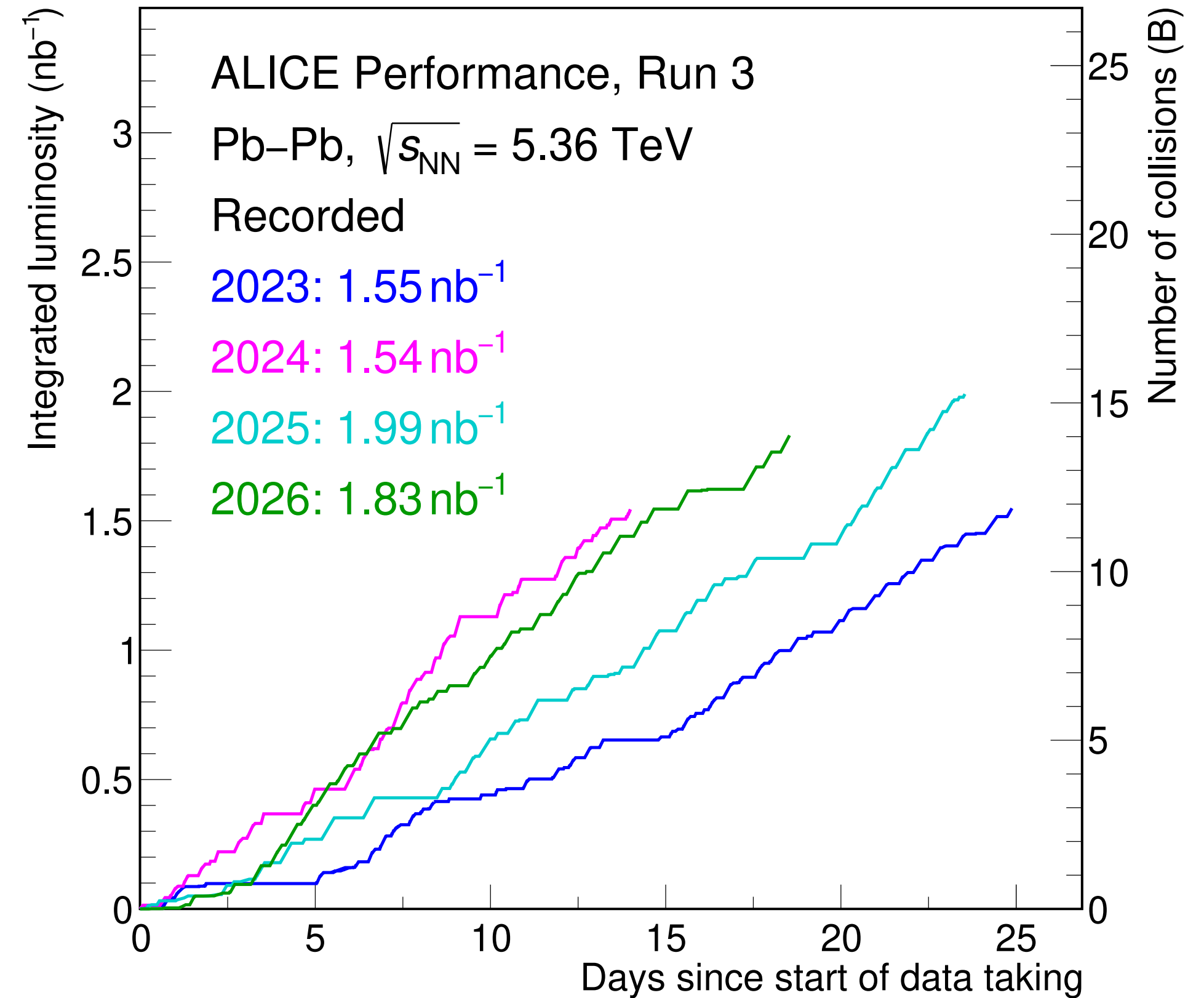


ALICE date taking in Run 3



ALI-PERF-632114

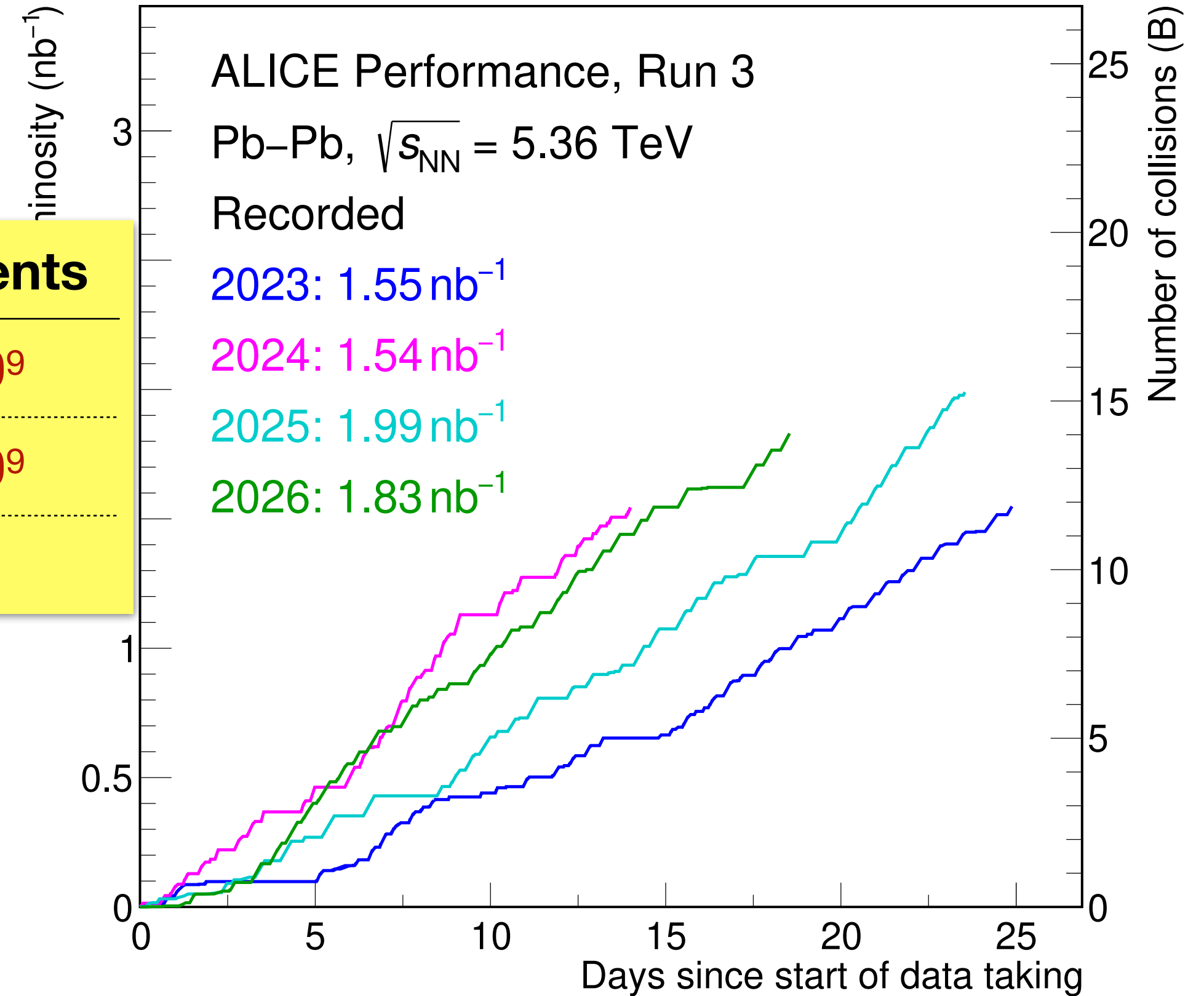
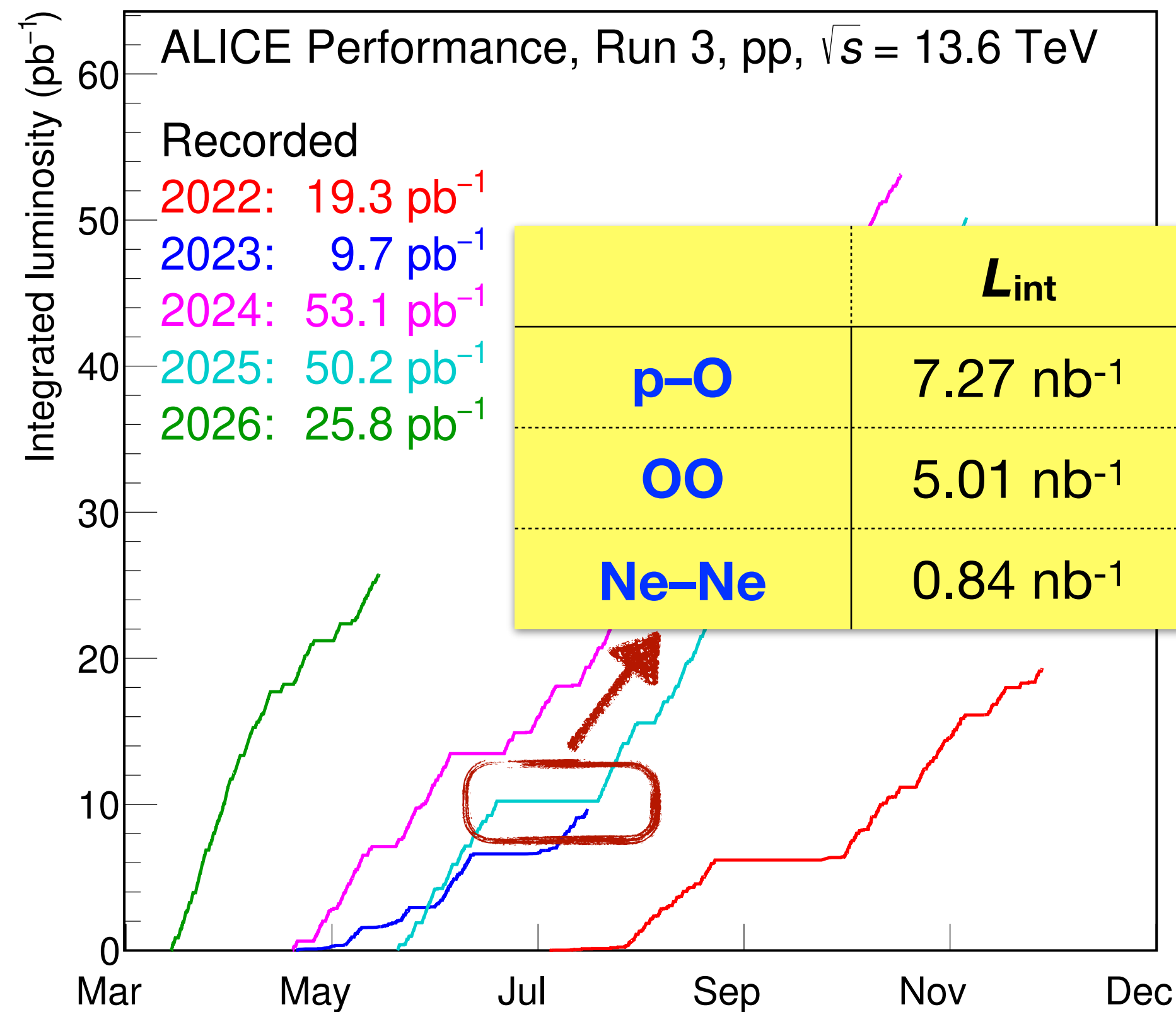
pp: 8 trillion MB events
×2000 more than Run 1+2



ALI-PERF-634120

Pb–Pb: 52 billion MB events
×160 more than Run 1+2

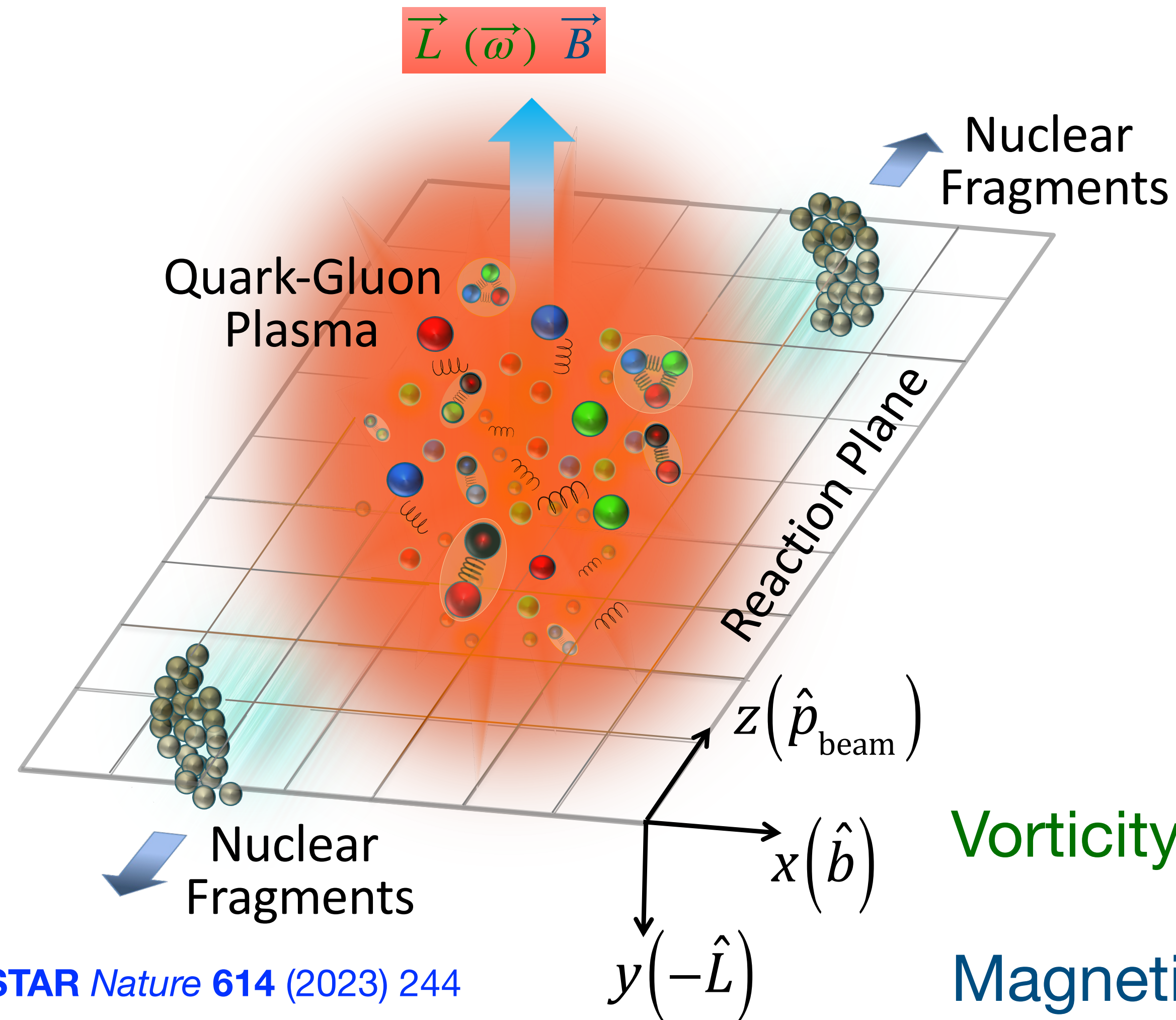
ALICE date taking in Run 3



pp: 8 trillion MB events
×2000 more than Run 1+2

Pb-Pb: 52 billion MB events
×160 more than Run 1+2

QGP in extreme fields



STAR Nature 614 (2023) 244

High temperature (T) limit

[F. Becattini et al., Phys. Rev. C95 (2017) 054902]

$$\vec{P} = \frac{\langle \vec{s} \rangle}{s} \approx \frac{s+1}{3} \frac{\vec{\omega} + \mu/s \vec{B}}{T}$$

Spin-orbit coupling [S. J. Barnett, Phys. Rev. 6 (1915) 239]

Z.-T. Liang and X.-N. Wang, Phys. Rev. Lett. 94 (2005) 102301

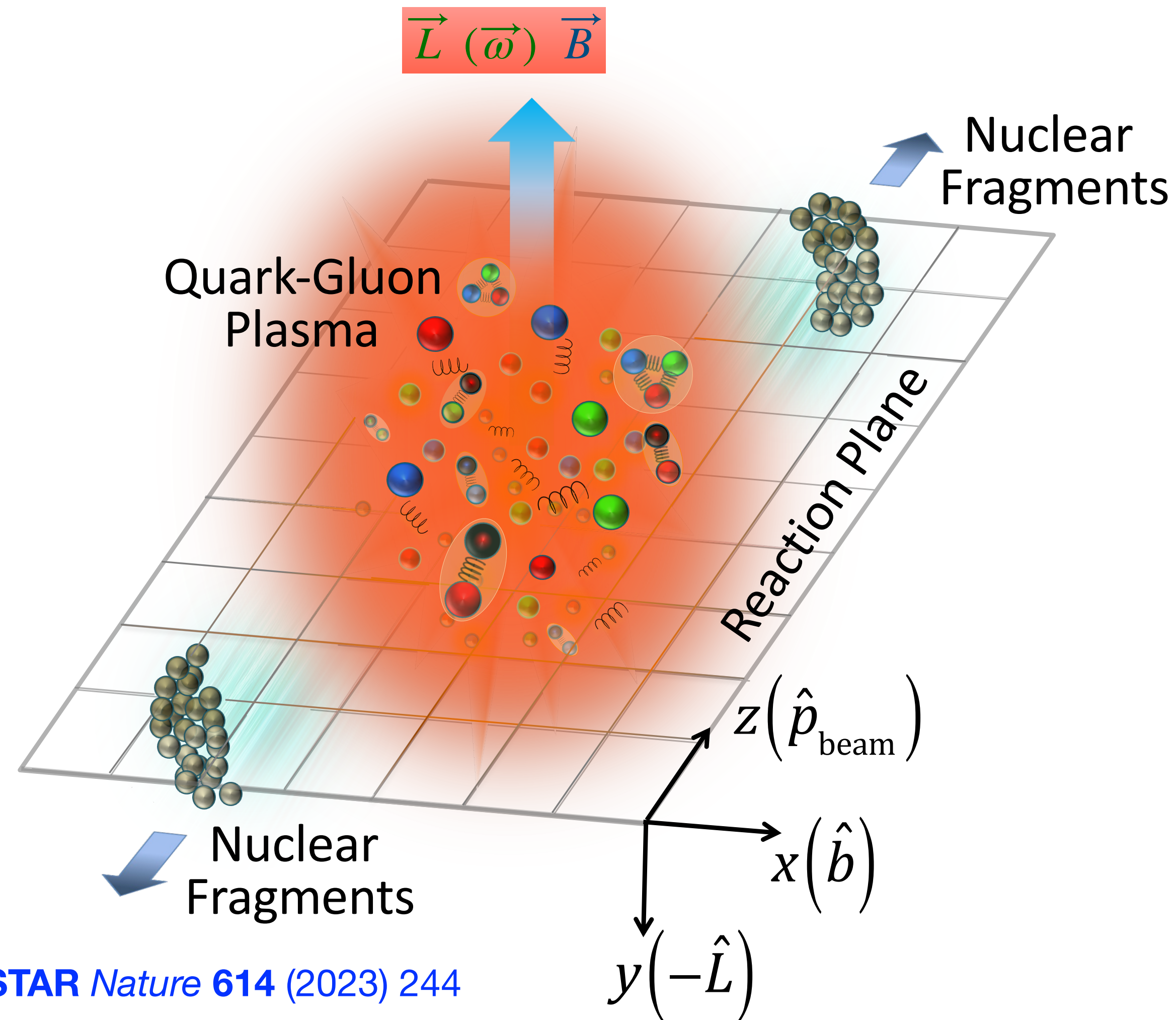
Z.-T. Liang and X.-N. Wang, Phys. Lett. B629 (2005) 20

Vorticity ($\vec{\omega}$) $\Rightarrow$ polarization independent on charges

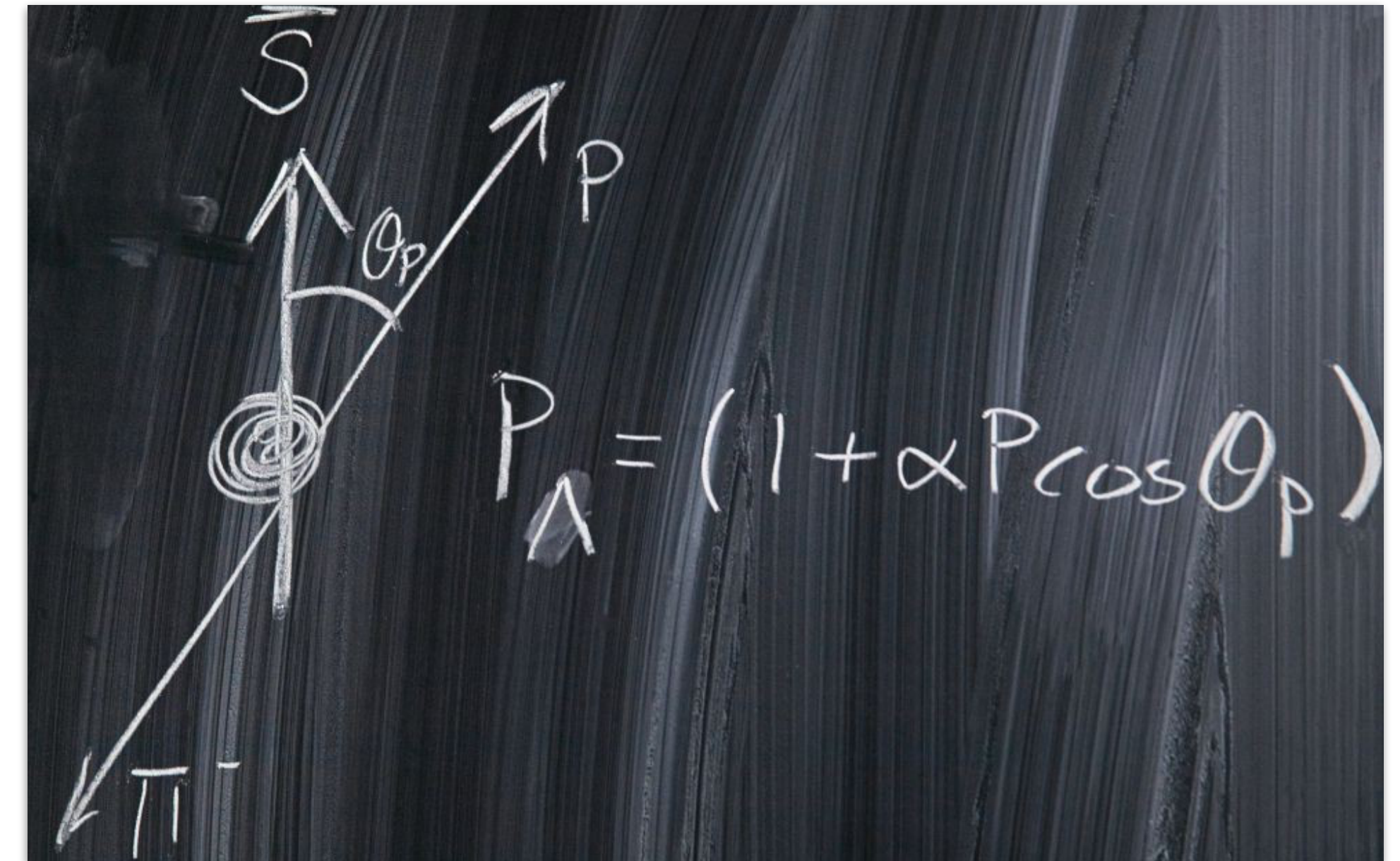
Magnetic Field ($\vec{B}$) $\Rightarrow$ charge-dependent polarization

Polarization estimation

The Feynman lectures on physics, Volume III, Chapter 17–5



STAR Nature 614 (2023) 244



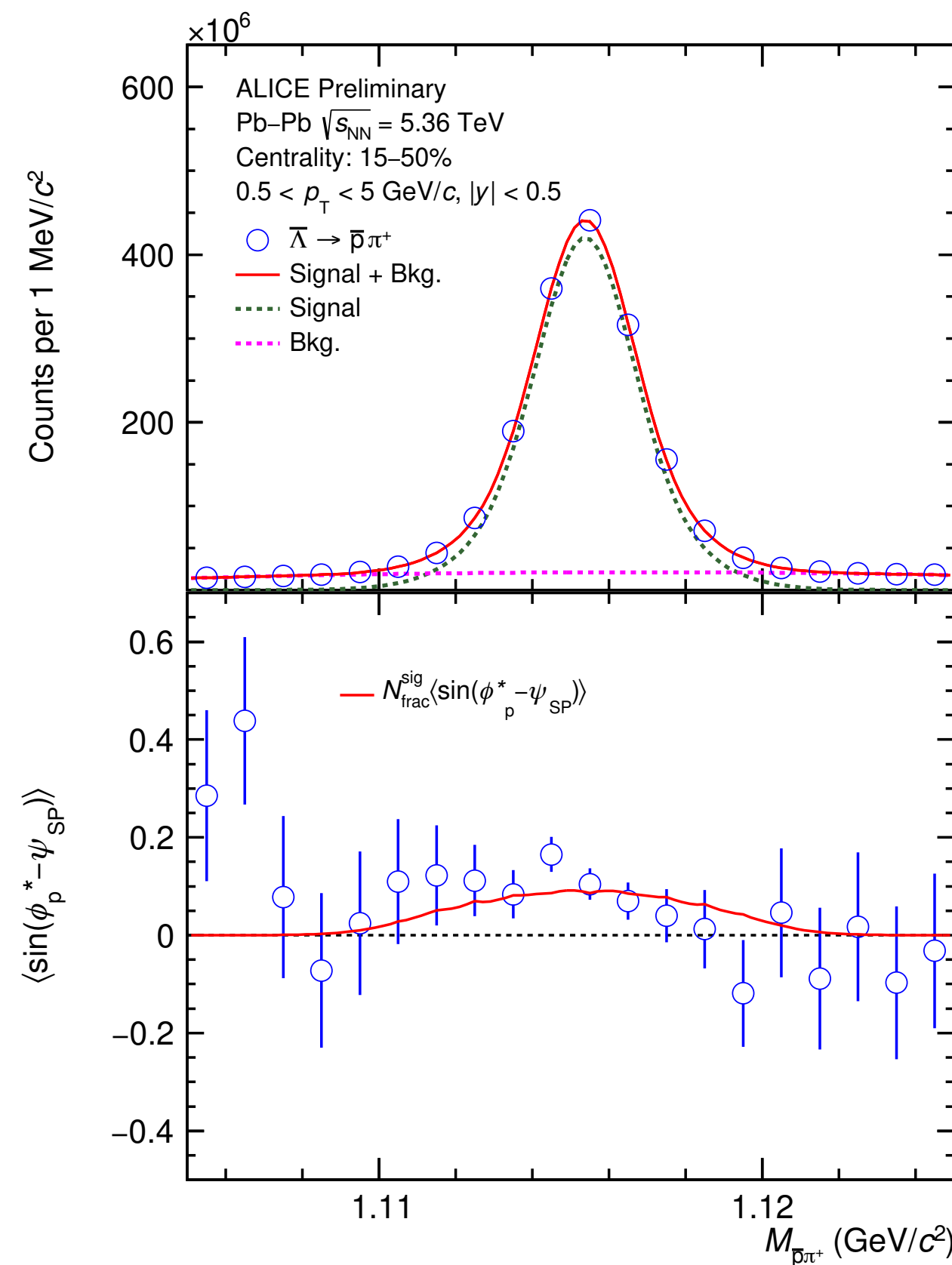
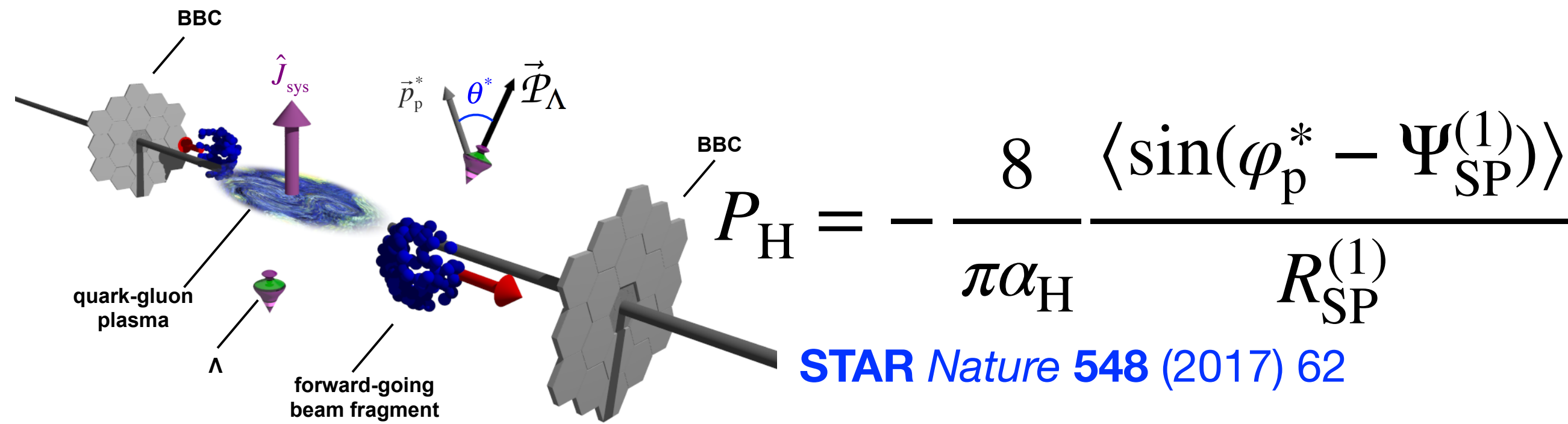
$$\frac{dw}{d\Omega^*} = \frac{1}{4\pi} (1 + \alpha_H \vec{P}_H \cdot \hat{e}_P^*)$$

$$\alpha_\Lambda = 0.732 \pm 0.014 \quad \alpha_{\bar{\Lambda}} = -0.758 \pm 0.012$$

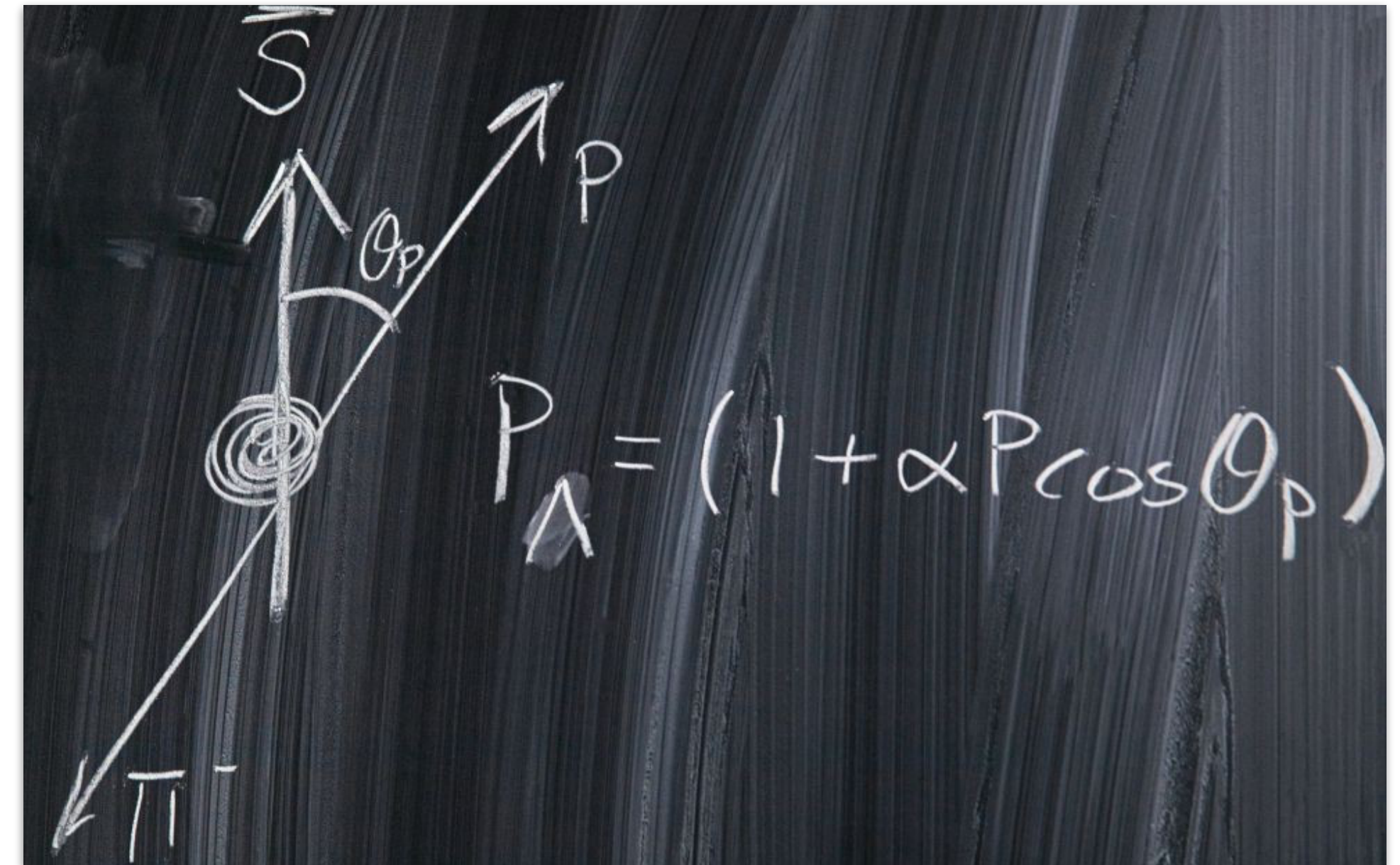
[PDG Phys. Rev. D110 (2024) 030001]

Global polarization measurements

[The Feynman lectures on physics, Volume III, Chapter 17–5](#)



- Signal is extracted from simultaneous fit to M_{inv} and polarization variable distributions
- By default, polarization contribution of bkg is taken to be zero

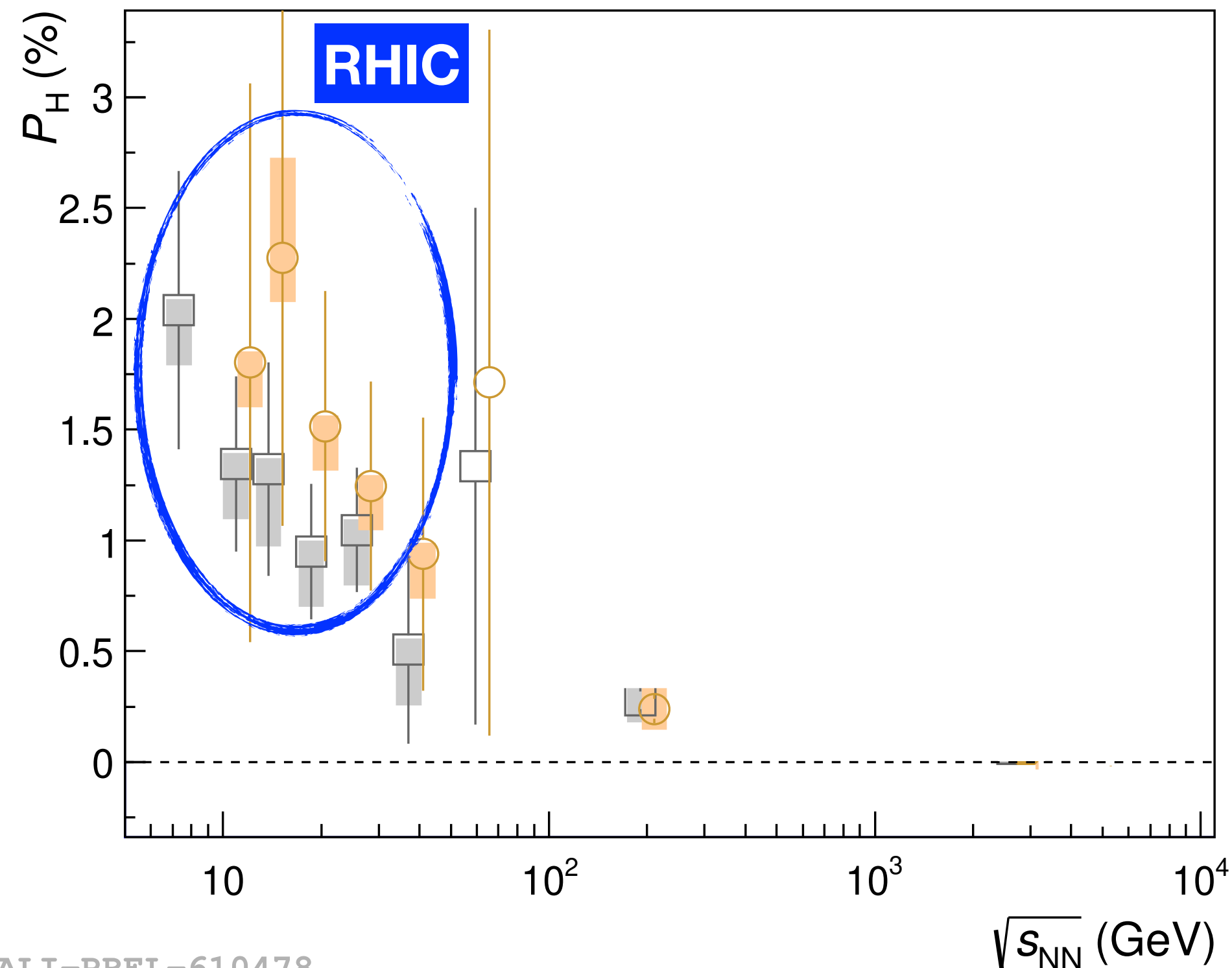
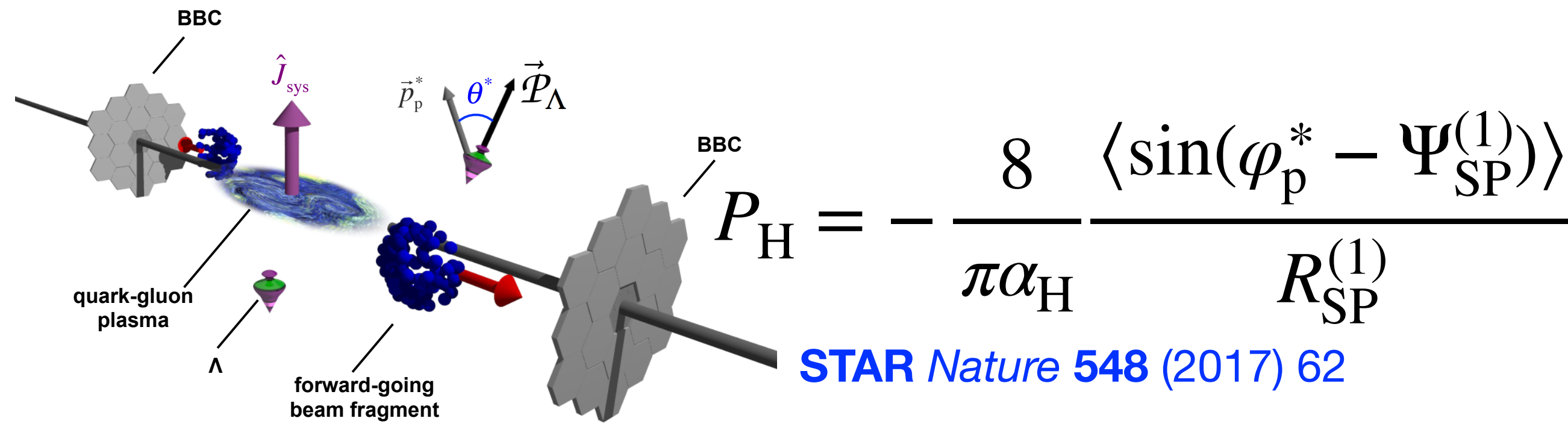


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[PDG *Phys. Rev.* **D110** (2024) 030001]

Global polarization of Λ — RHIC

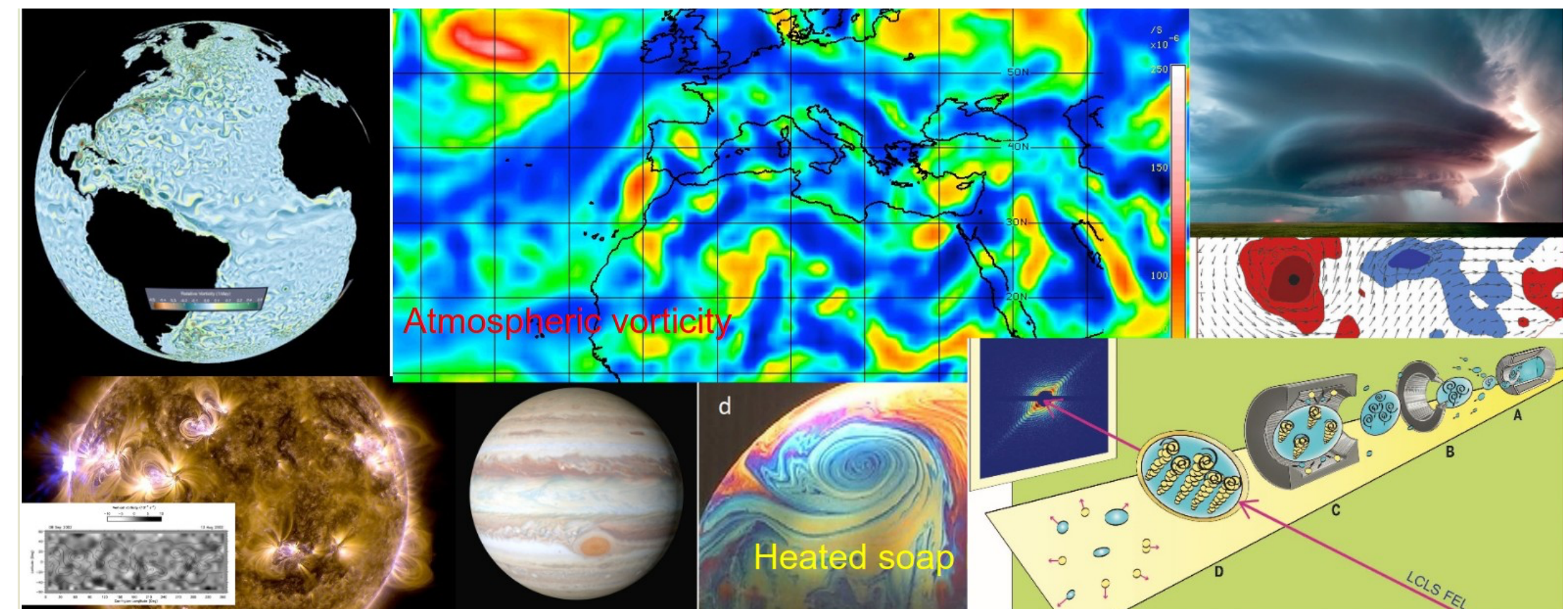


ALI-PREL-610478

Significant non-zero P_H at RHIC

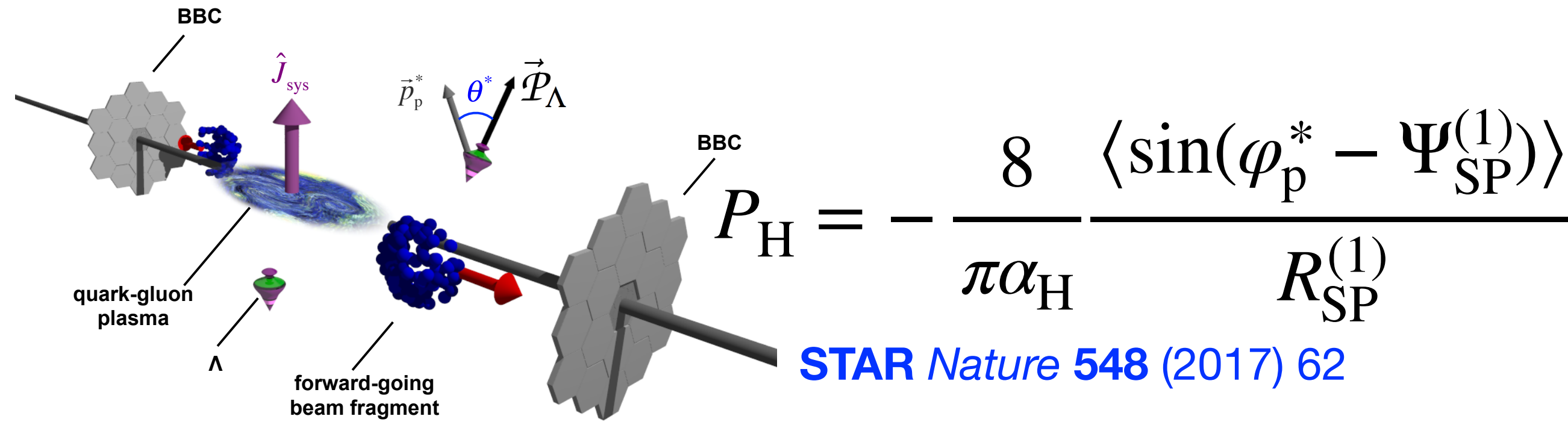
- Indicate QGP rotation $\omega \sim 10^{21} \text{ s}^{-1}$
 - ➔ Solar flow: $\omega \sim 10^{-6} \text{ s}^{-1}$
 - ➔ Jupiter's zonal winds: $\omega \sim 10^{-4} \text{ s}^{-1}$
 - ➔ Core of supercell tornado: $\omega \sim 10^{-1} \text{ s}^{-1}$
 - ➔ Superfluid He-II: $\omega \sim 10^6 \text{ s}^{-1}$

➔ Most vortical fluid in nature



Science On a Sphere: Ocean Surface Vorticity

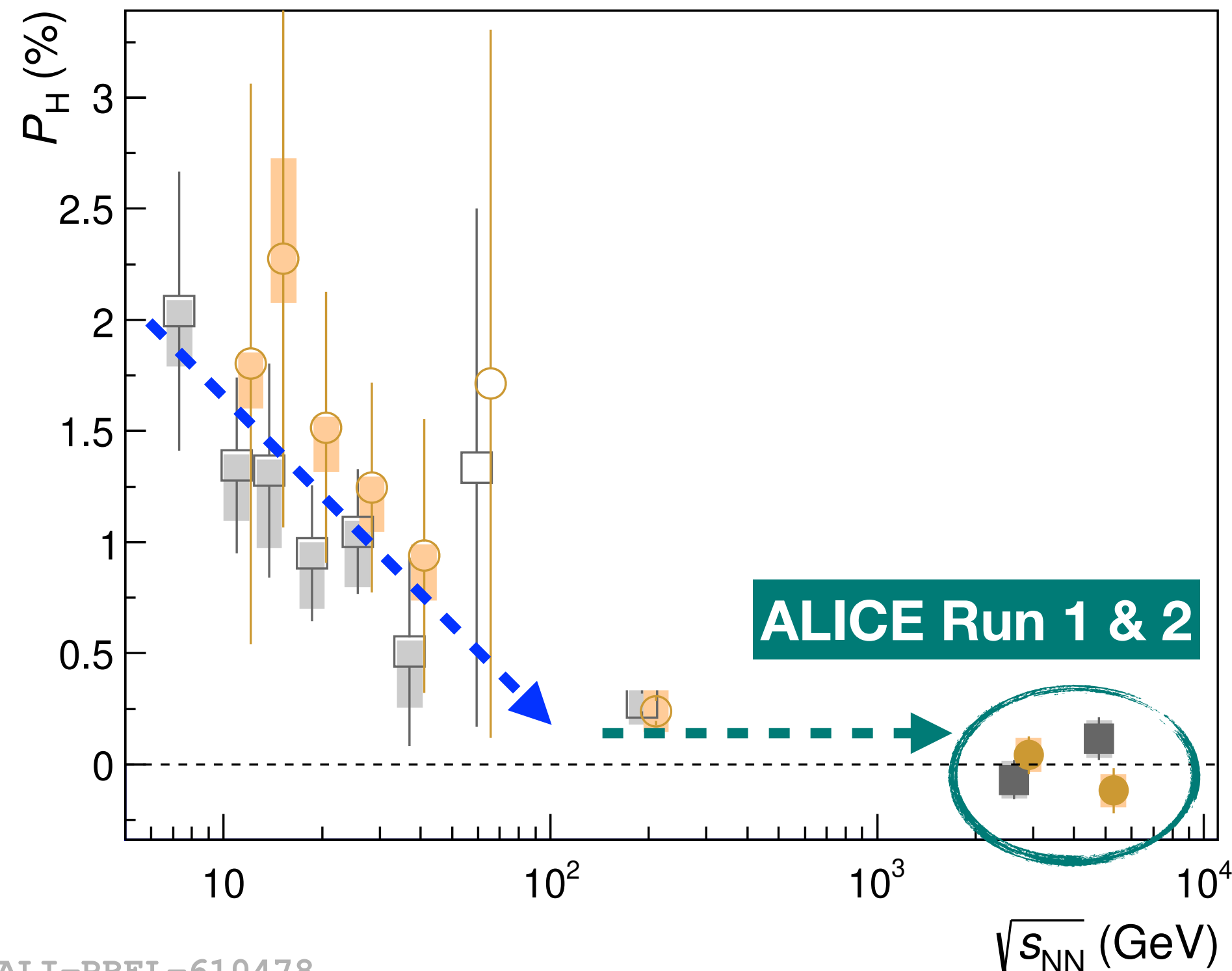
Global polarization of Λ — RHIC & LHC



ALICE Run 1 & 2

- $P_H \sim 0$ within large uncertainties
- Correlation of P_H and dv_1/dy

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



ALICE *PRC* **101**, 044611 (2020)

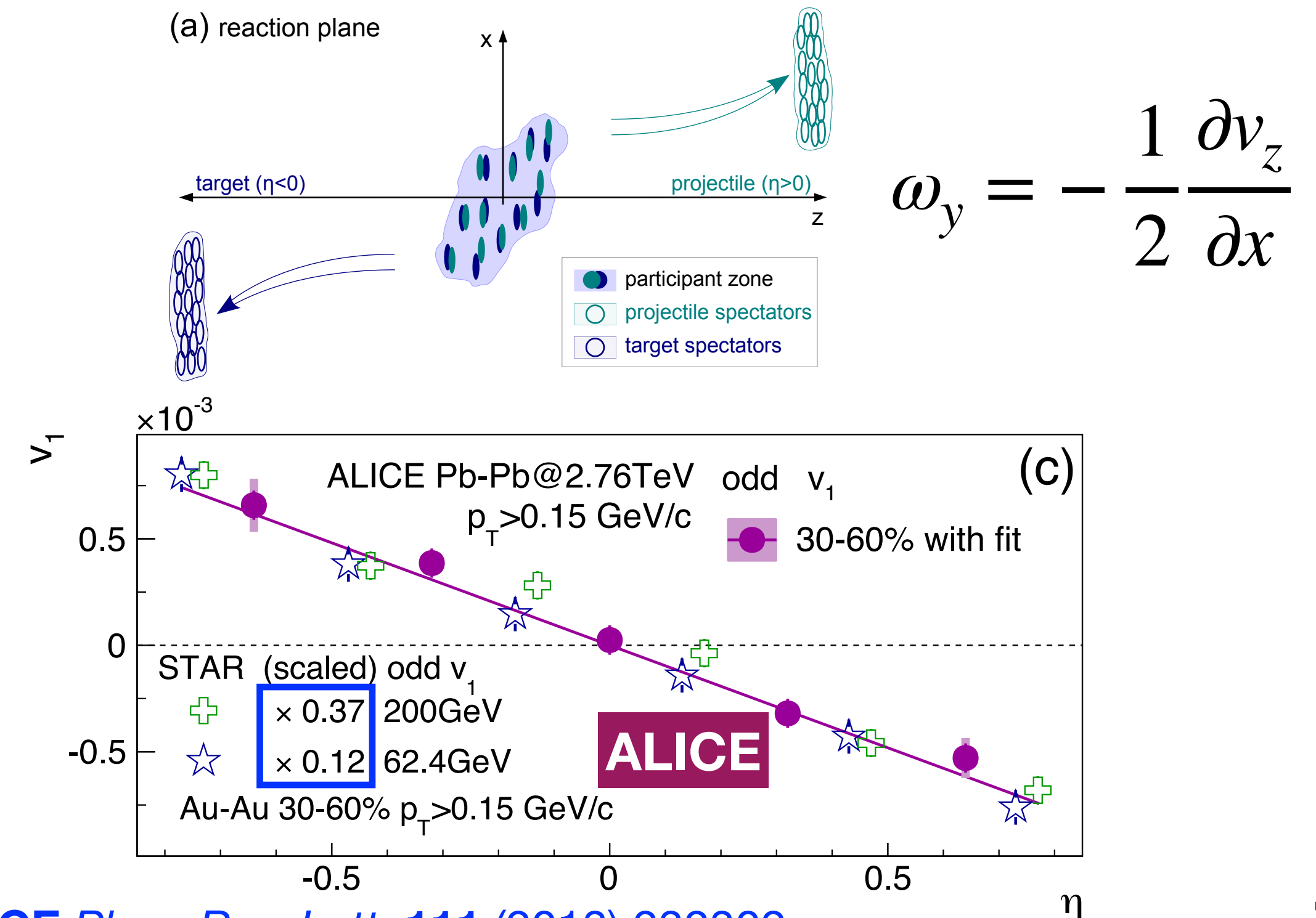
Λ $\bar{\Lambda}$

Pb-Pb 15–50%
 $0.5 < p_T < 5$ GeV/c
 $|y| < 0.5$

STAR *Nature* **548**, 62–65 (2017)

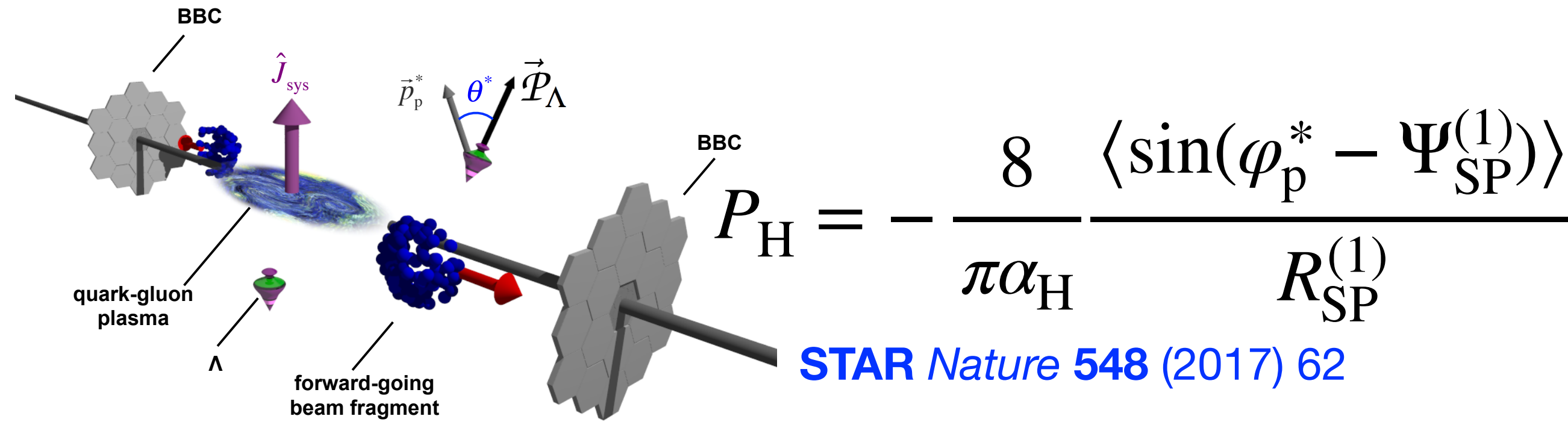
Λ $\bar{\Lambda}$

Au-Au 20–50%
 $0.5 < p_T < 6$ GeV/c
 $|\eta| < 0.8$



ALICE *Phys. Rev. Lett.* **111** (2013) 232302

Global polarization of Λ — New Run 3



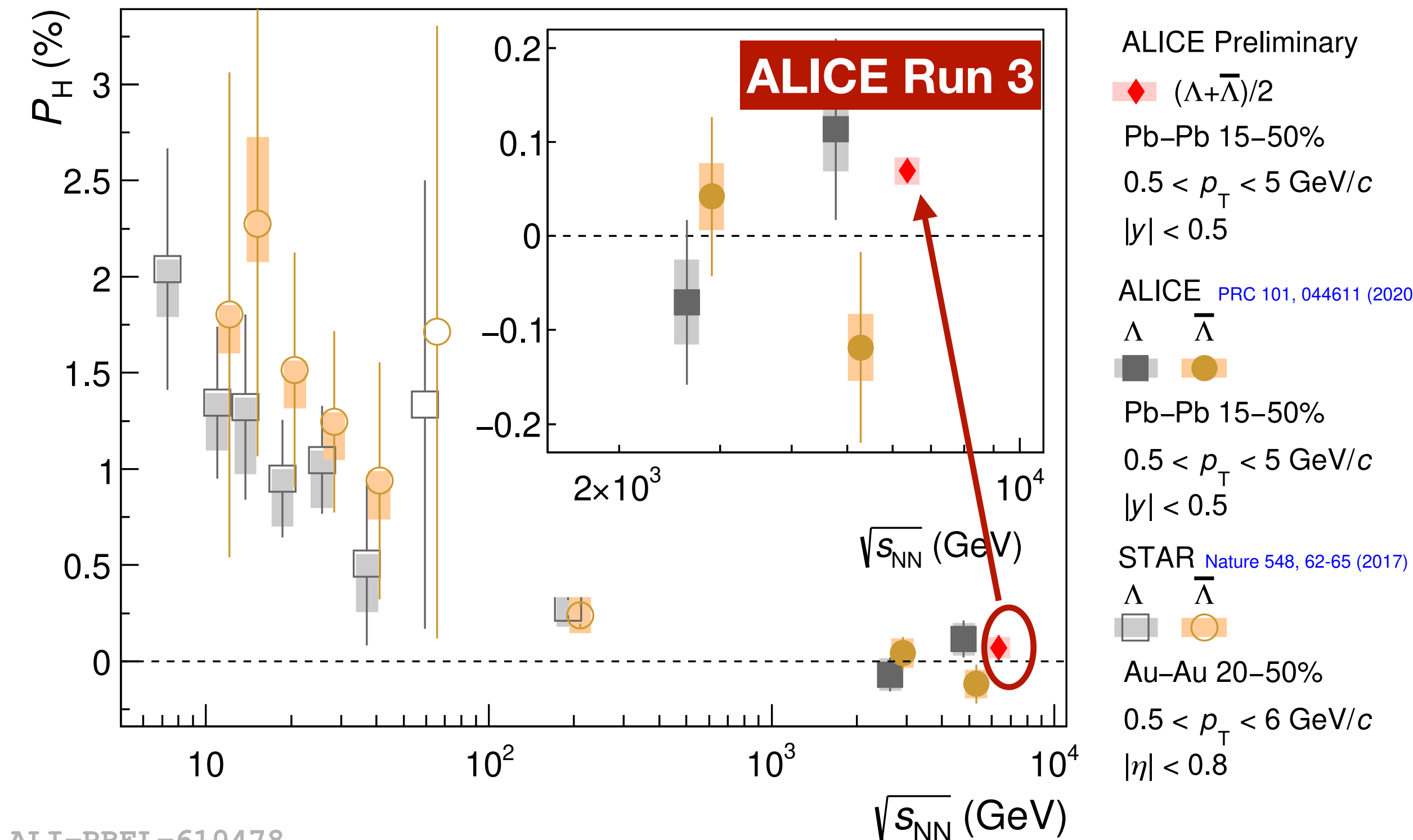
New ALICE Run 3

- First observation of polarized Λ at LHC energies with 5σ

- $\omega \sim 10^{20} \text{ s}^{-1}$ at the LHC

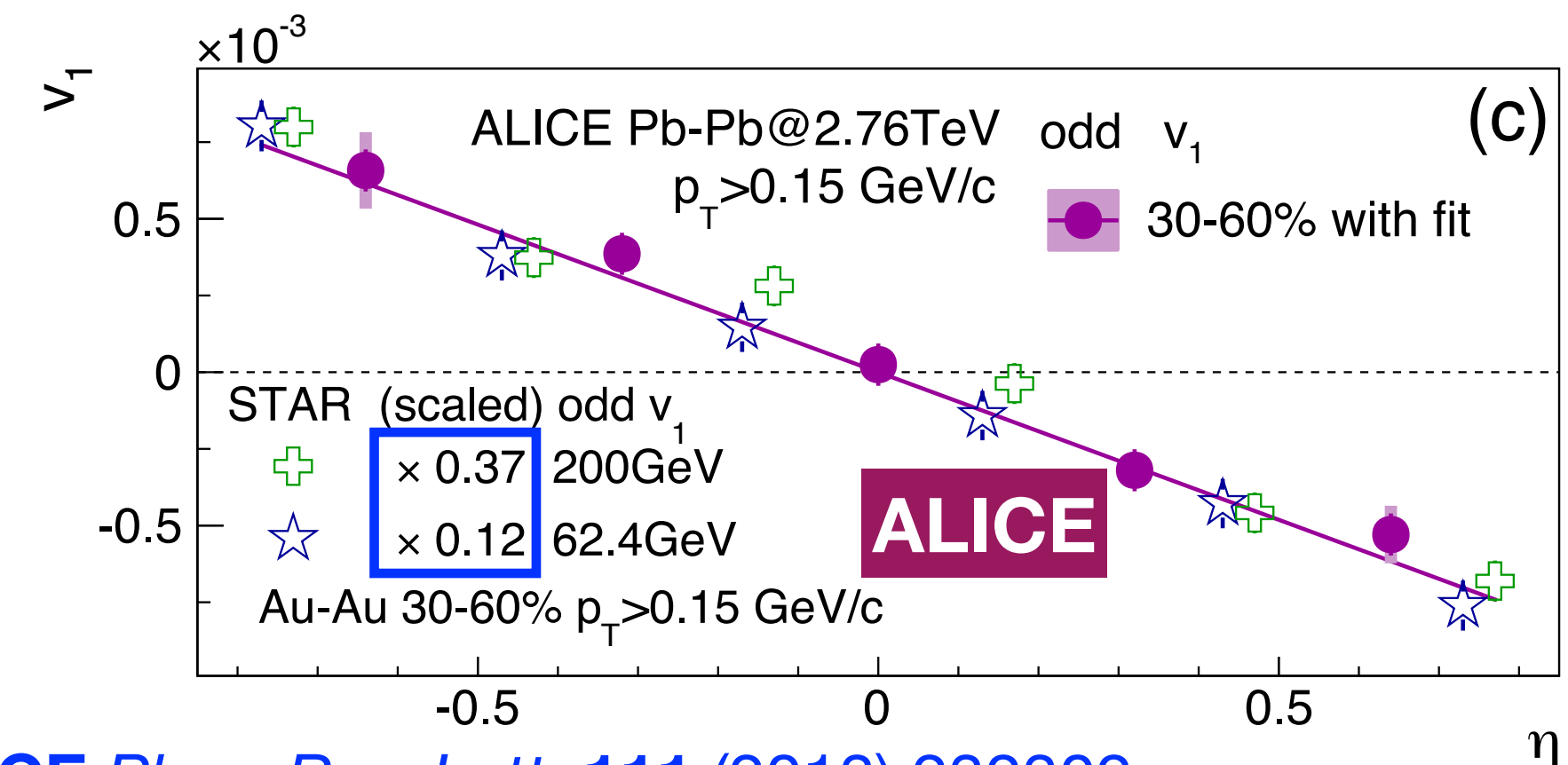
➡ $\omega \sim 10^{21} \text{ s}^{-1}$ at RHIC

➡ Consistent with the empirical prediction based on dv_1/dy



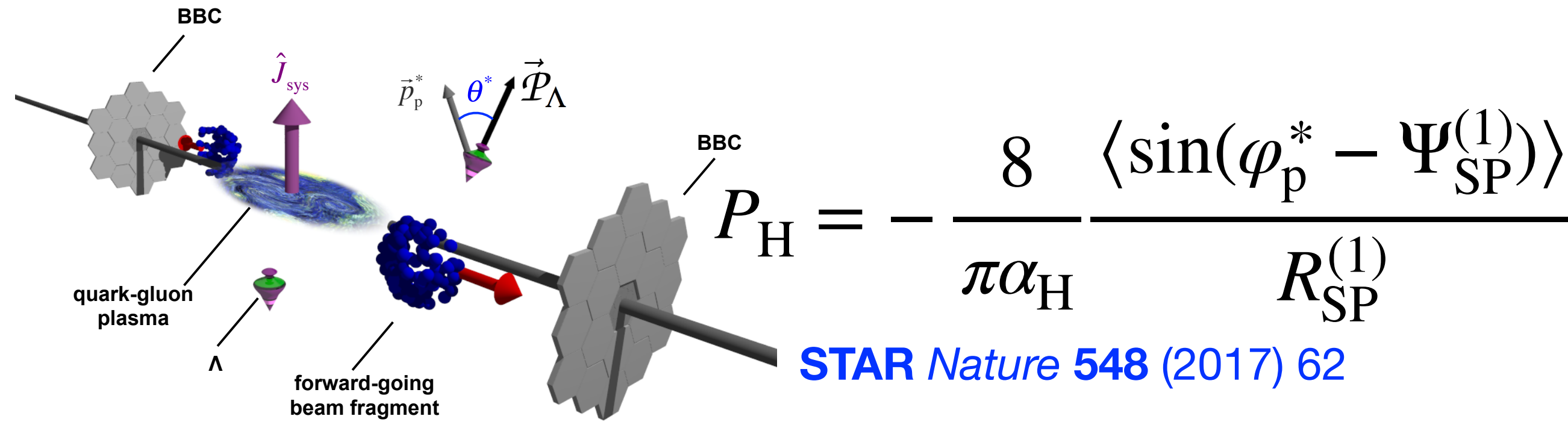
ALI-PREL-610478

ALICE *Phys. Rev. C* 101 (2020) 044611



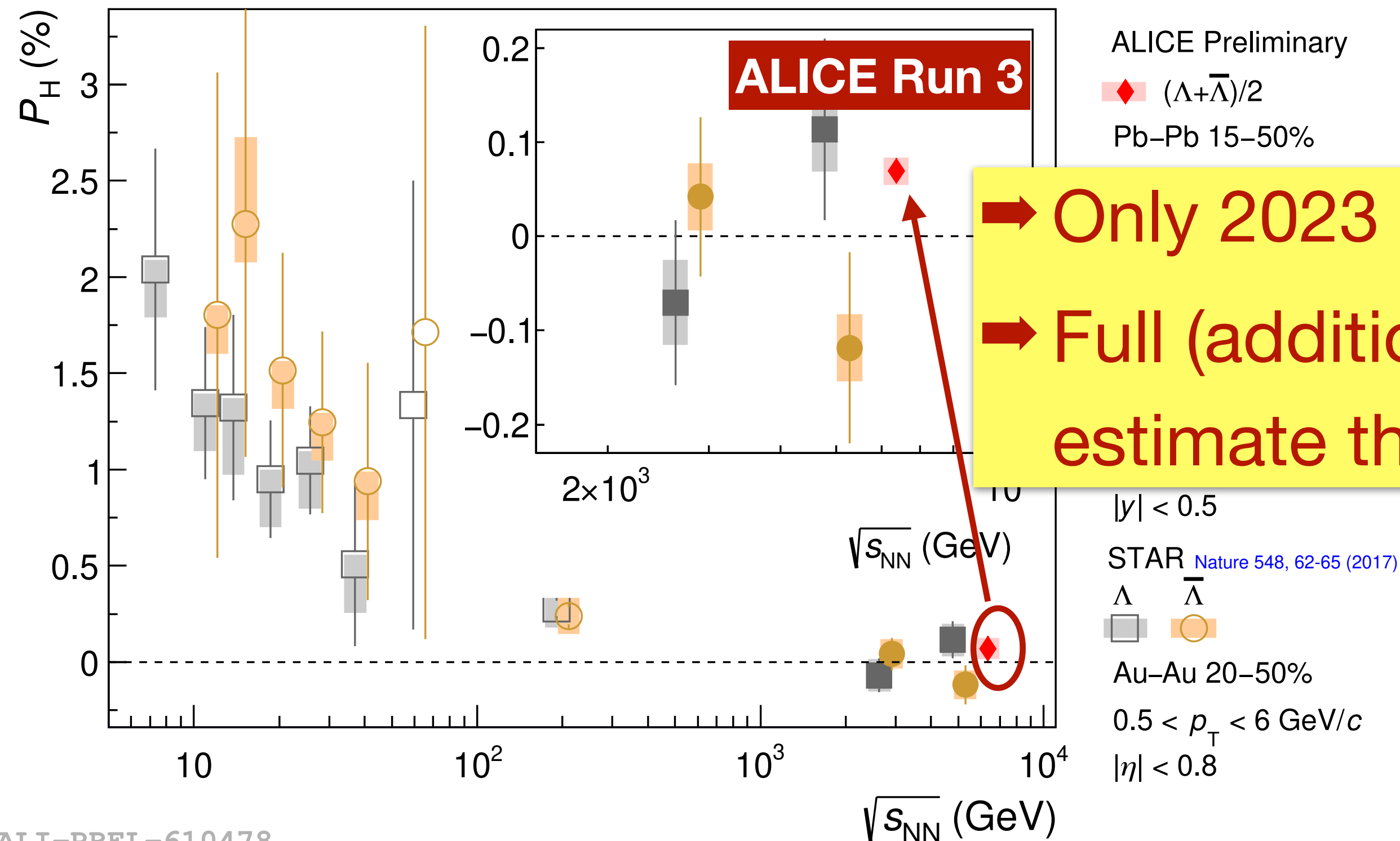
ALICE *Phys. Rev. Lett.* 111 (2013) 232302

Global polarization of Λ — New Run 3



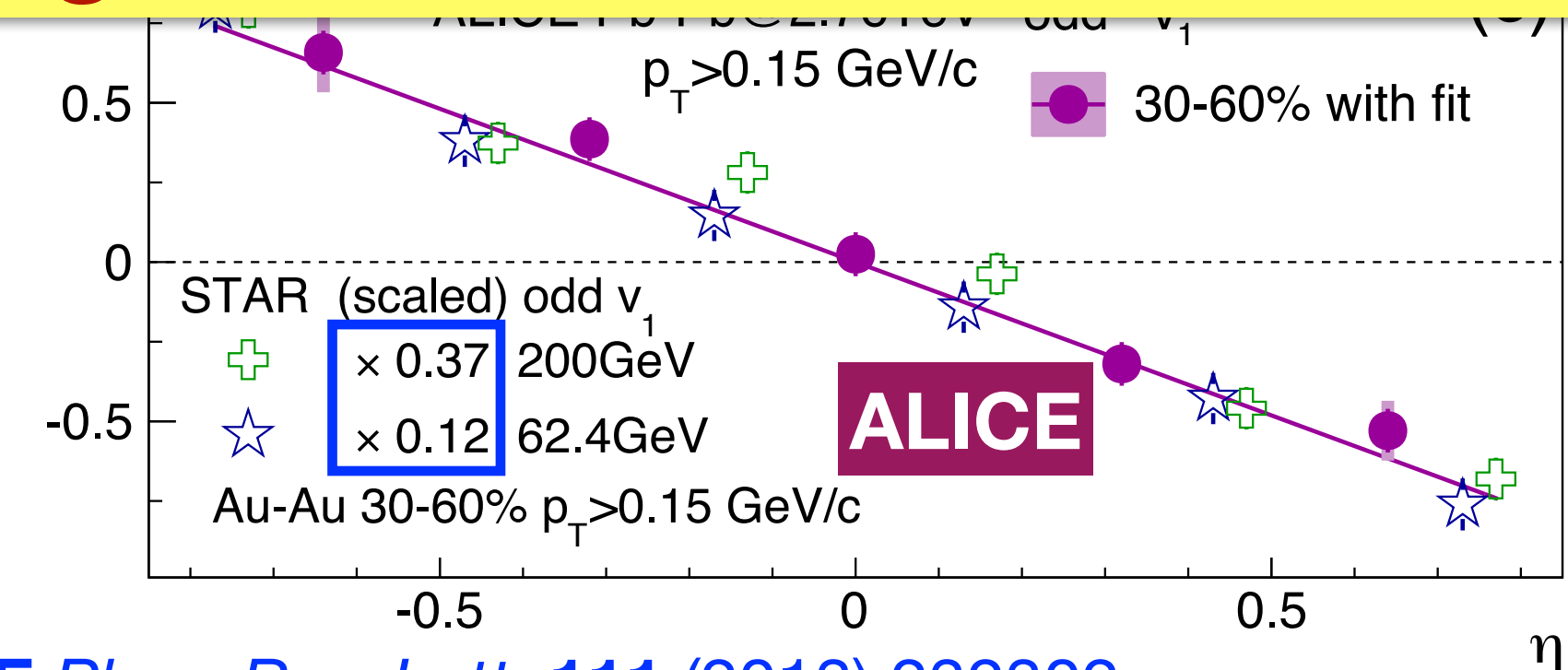
New ALICE Run 3

- First observation of polarized Λ at LHC energies with 5σ
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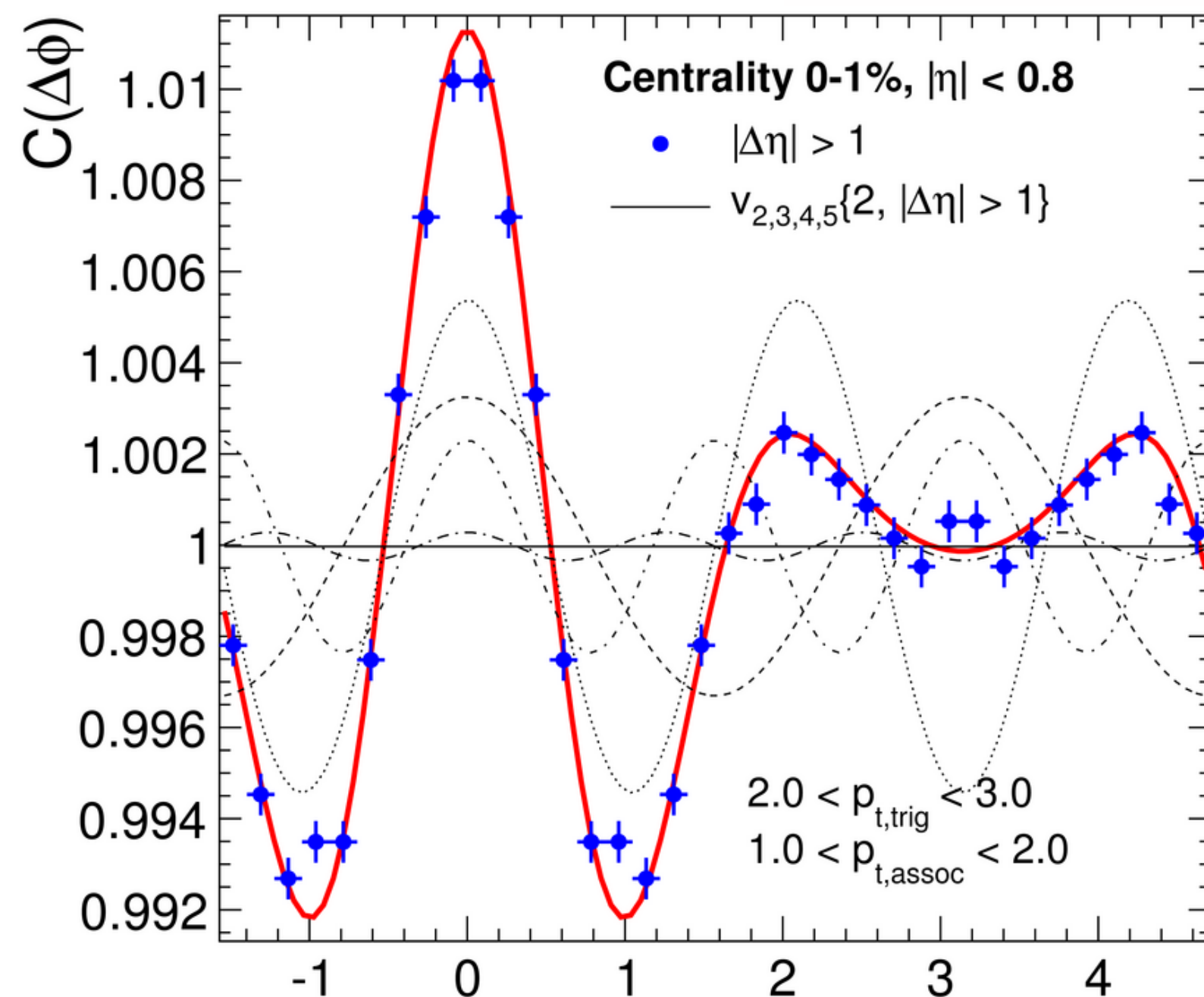
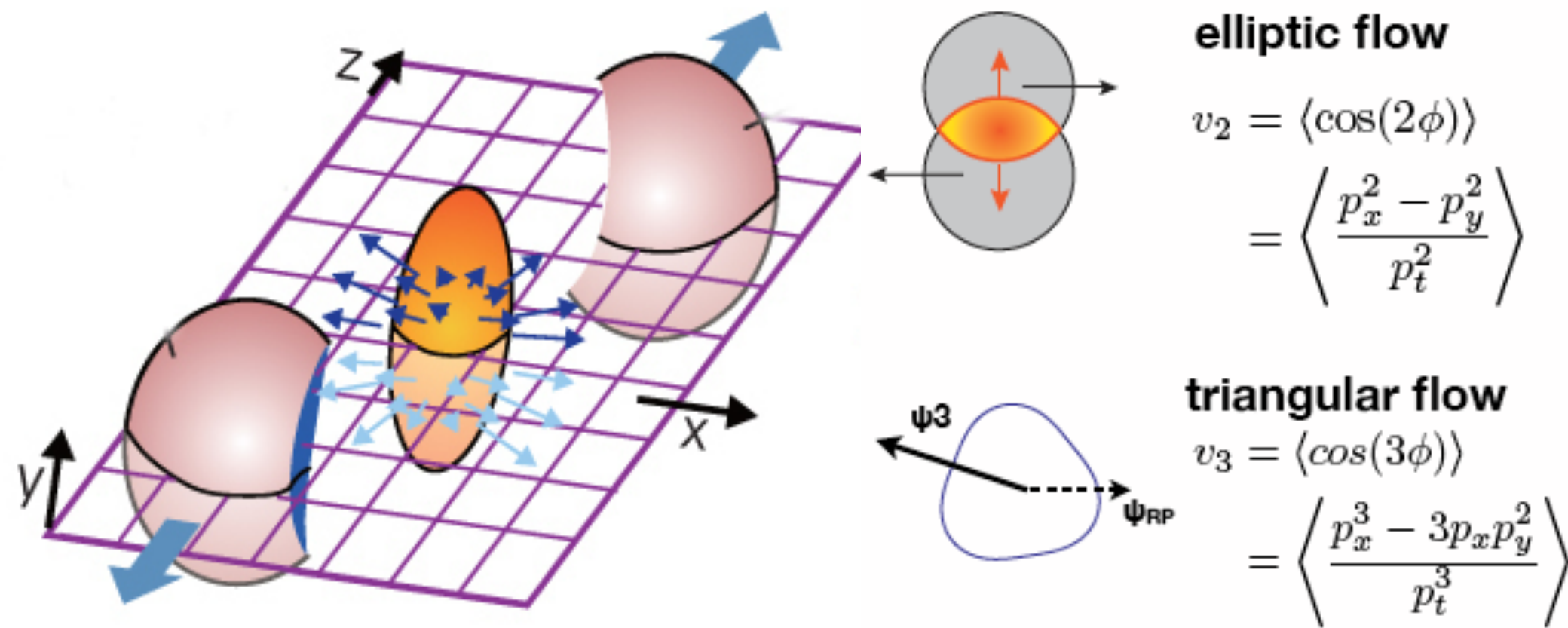


→ Only 2023 Pb-Pb sample is used ($\sim 6 \times 10^9$ collisions)

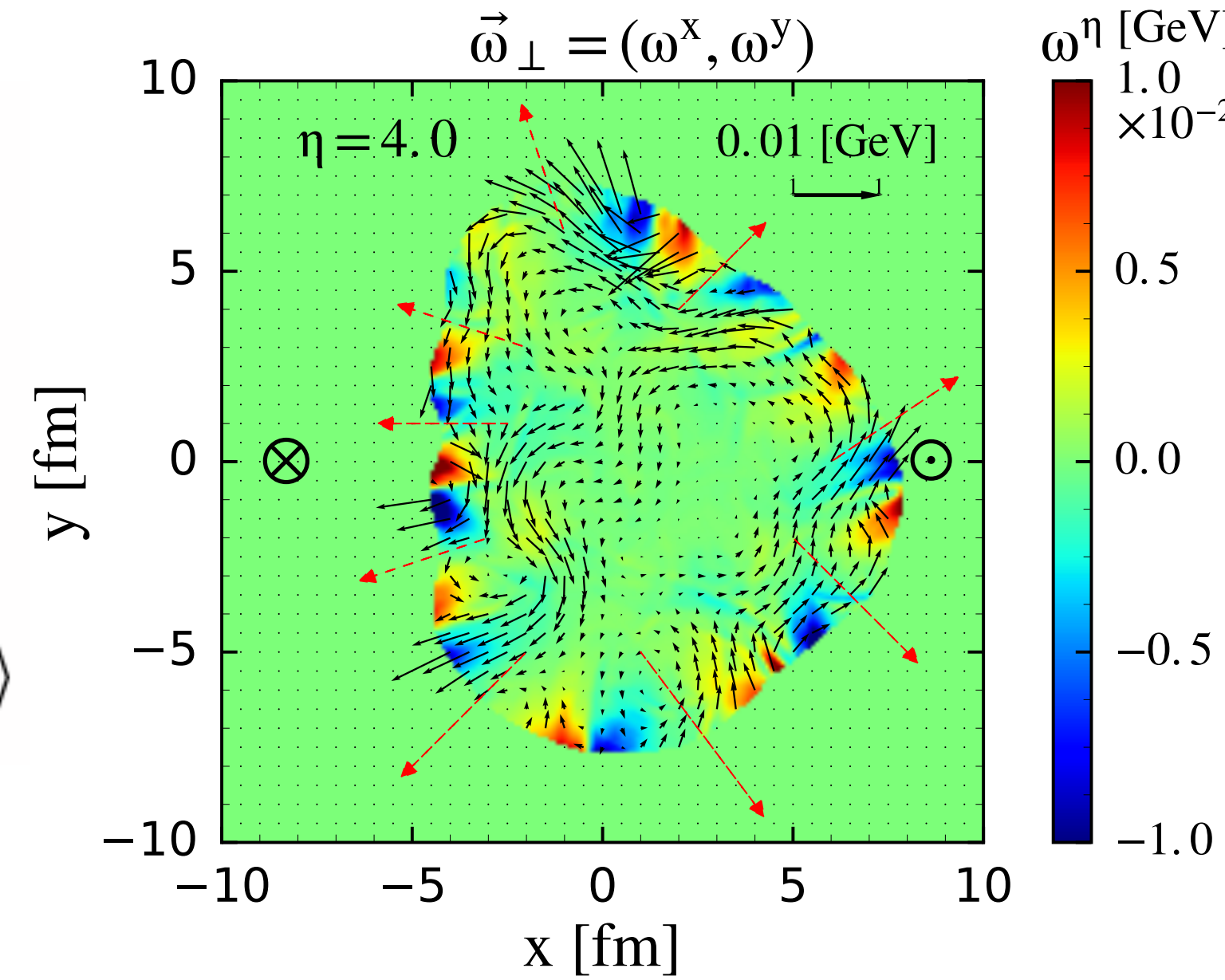
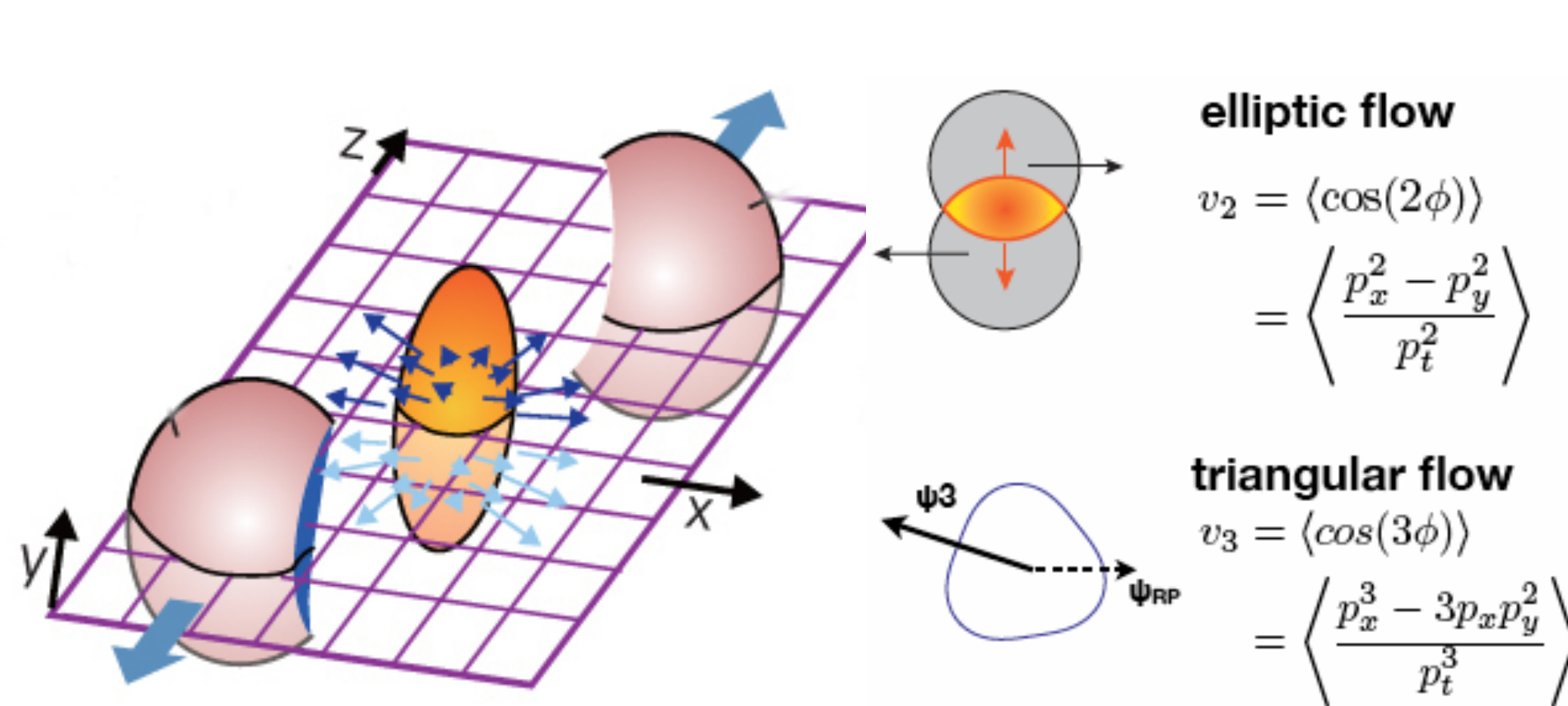
→ Full (addition 2024–2026) data will allow us to estimate the **magnetic field**



Anisotropic expansion of the QGP



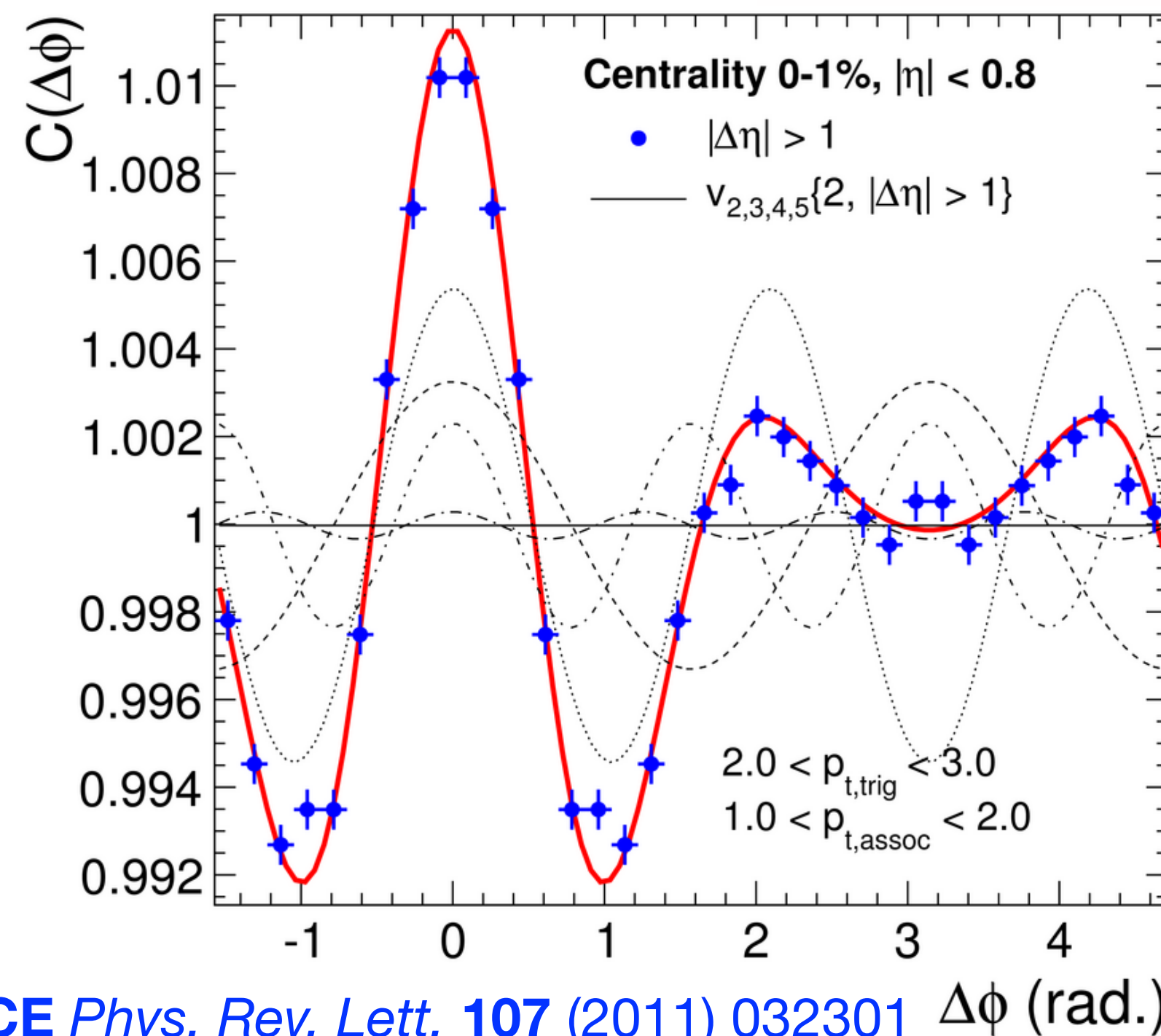
Polarization along the beam direction



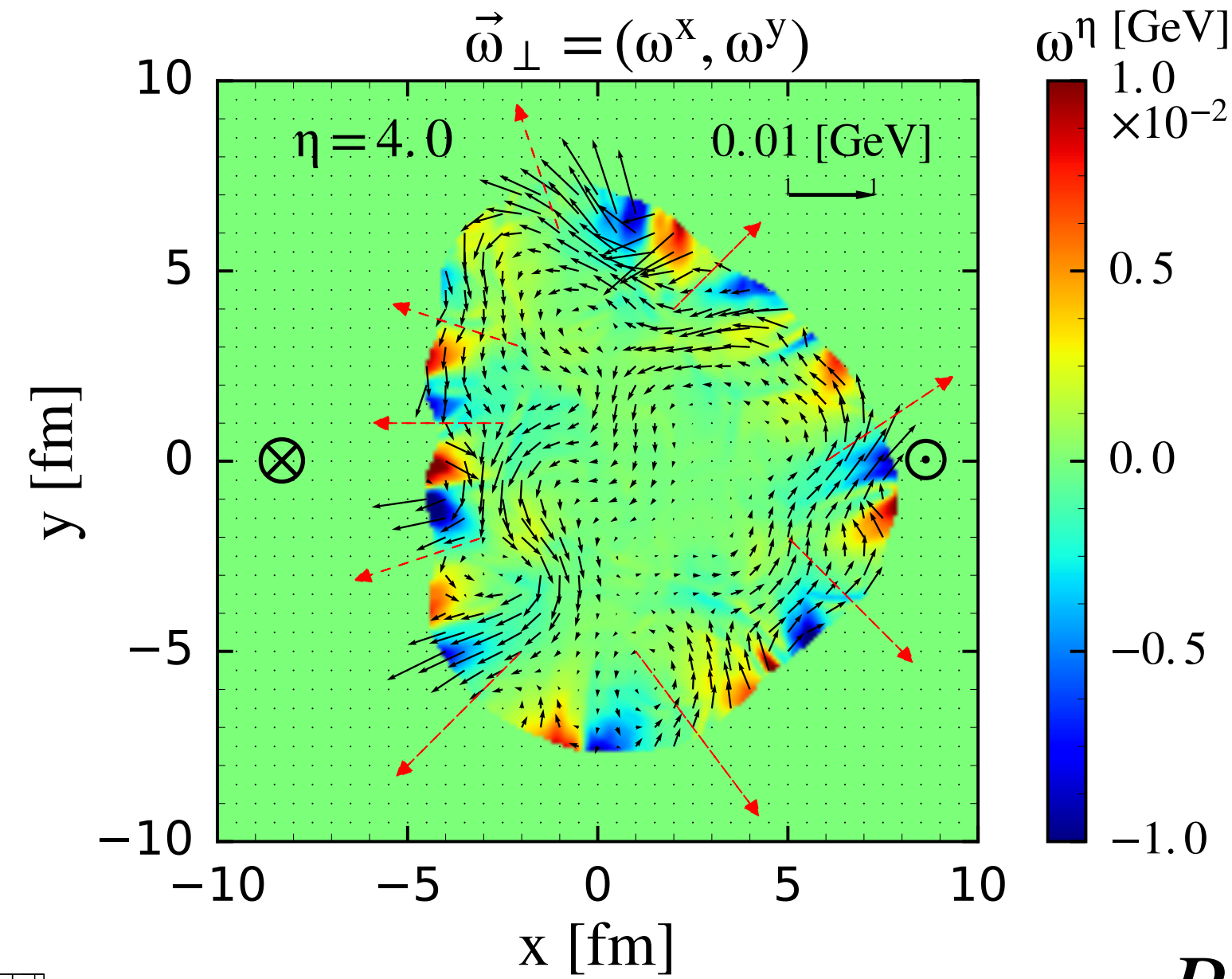
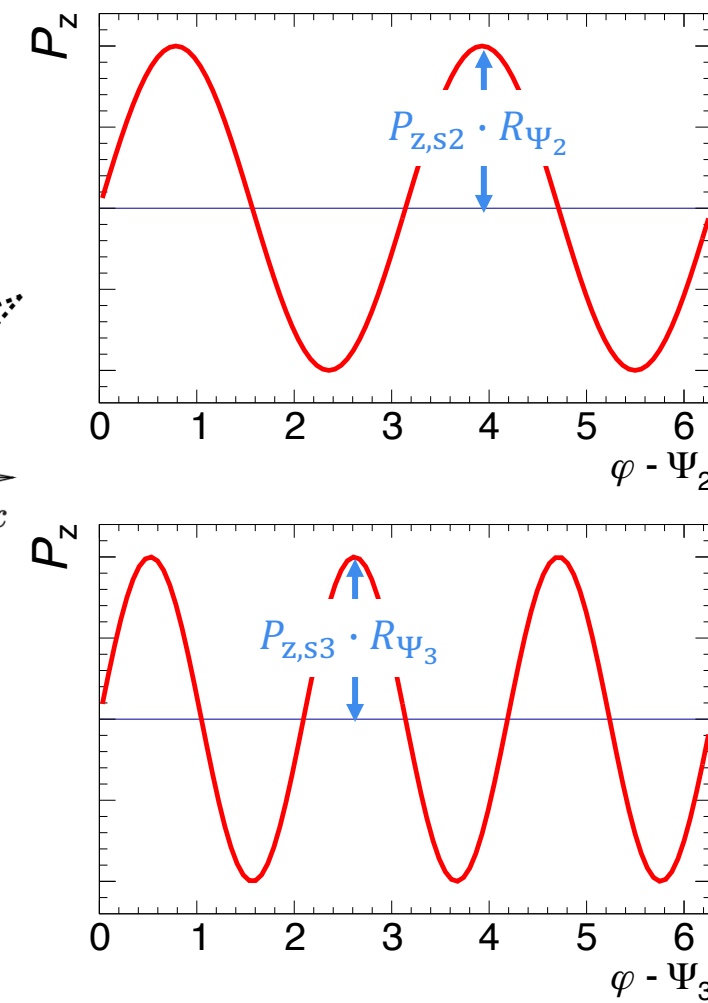
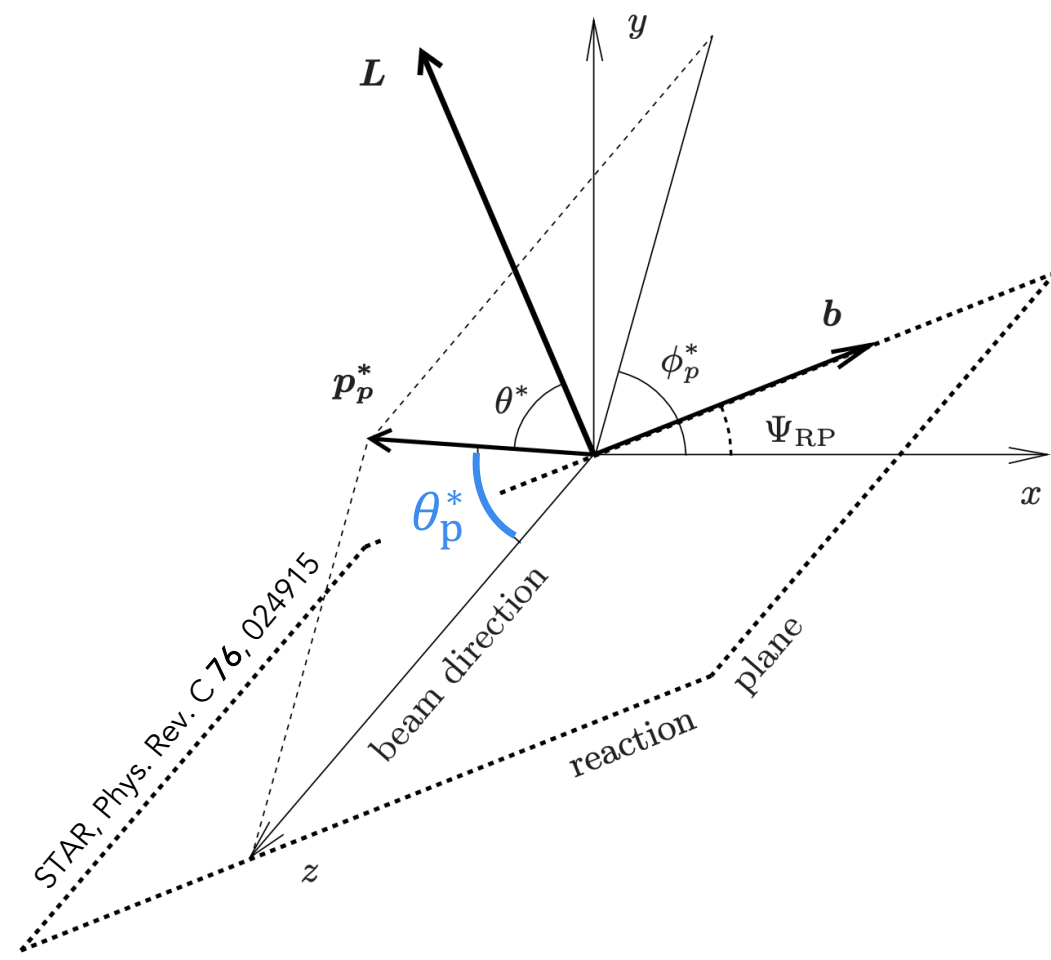
L.-G. Pang, Q. Wang, X.-N. Wang *et al.*
Phys. Rev. Lett. **117** (2016) 192301

S. A. Voloshin, T. Niida
Phys. Rev. **C94** (2016) 021901

$$P_z = \frac{\langle \cos \theta_p^* \rangle}{\alpha_H \langle \cos^2 \theta_p^* \rangle}$$



Longitudinal polarization harmonics

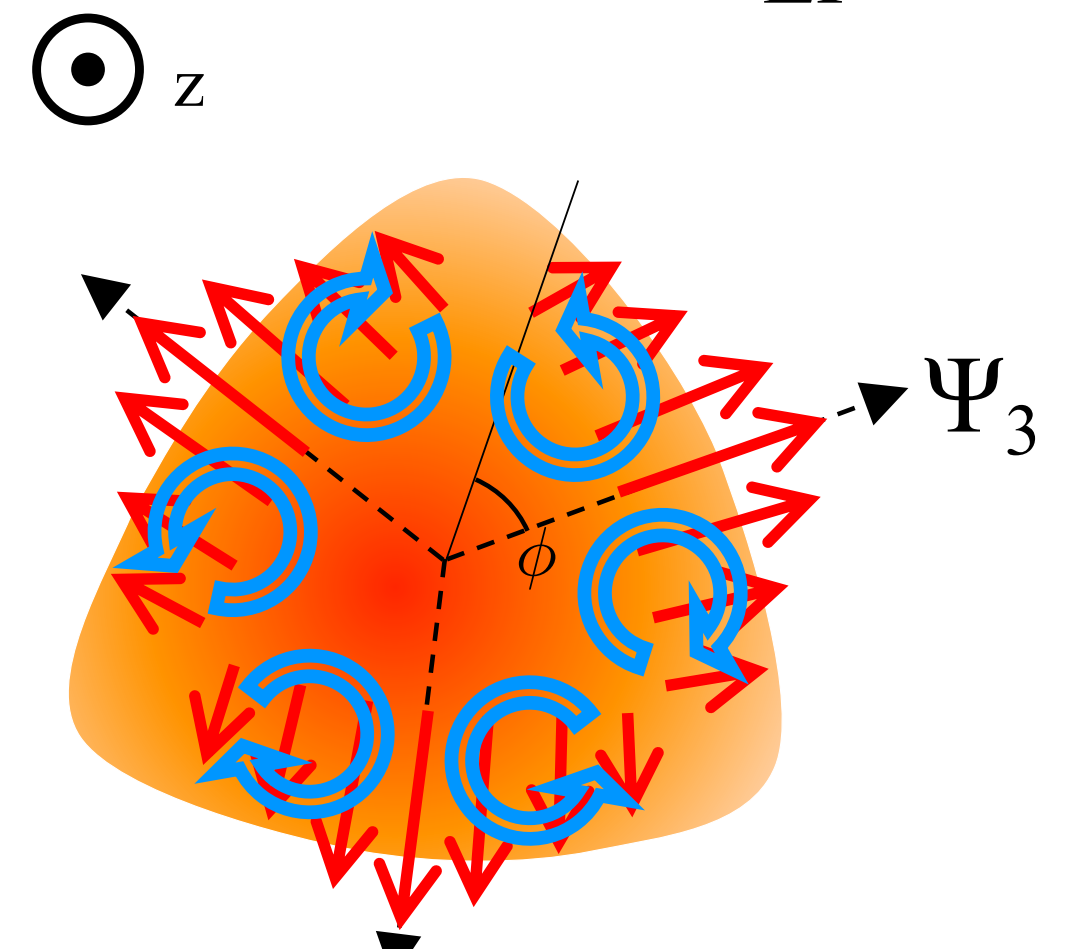
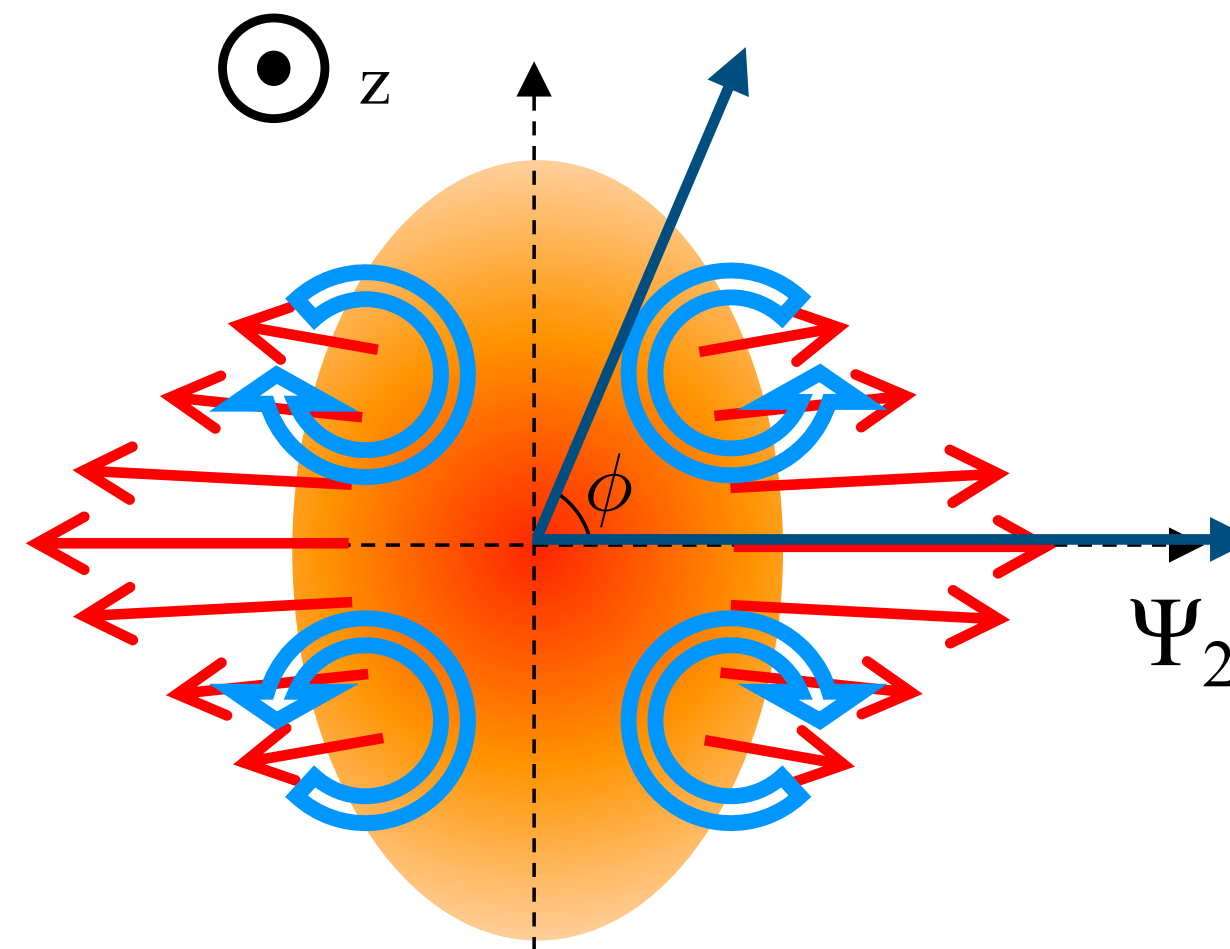
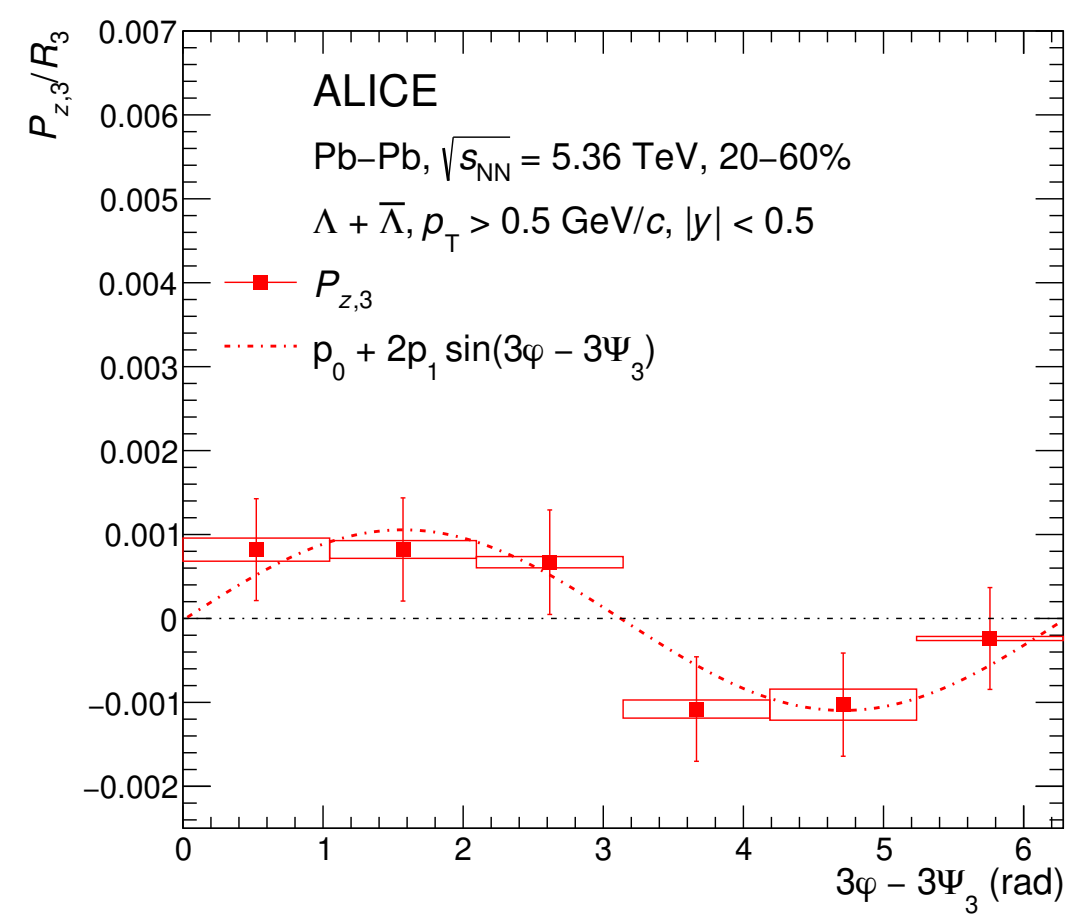
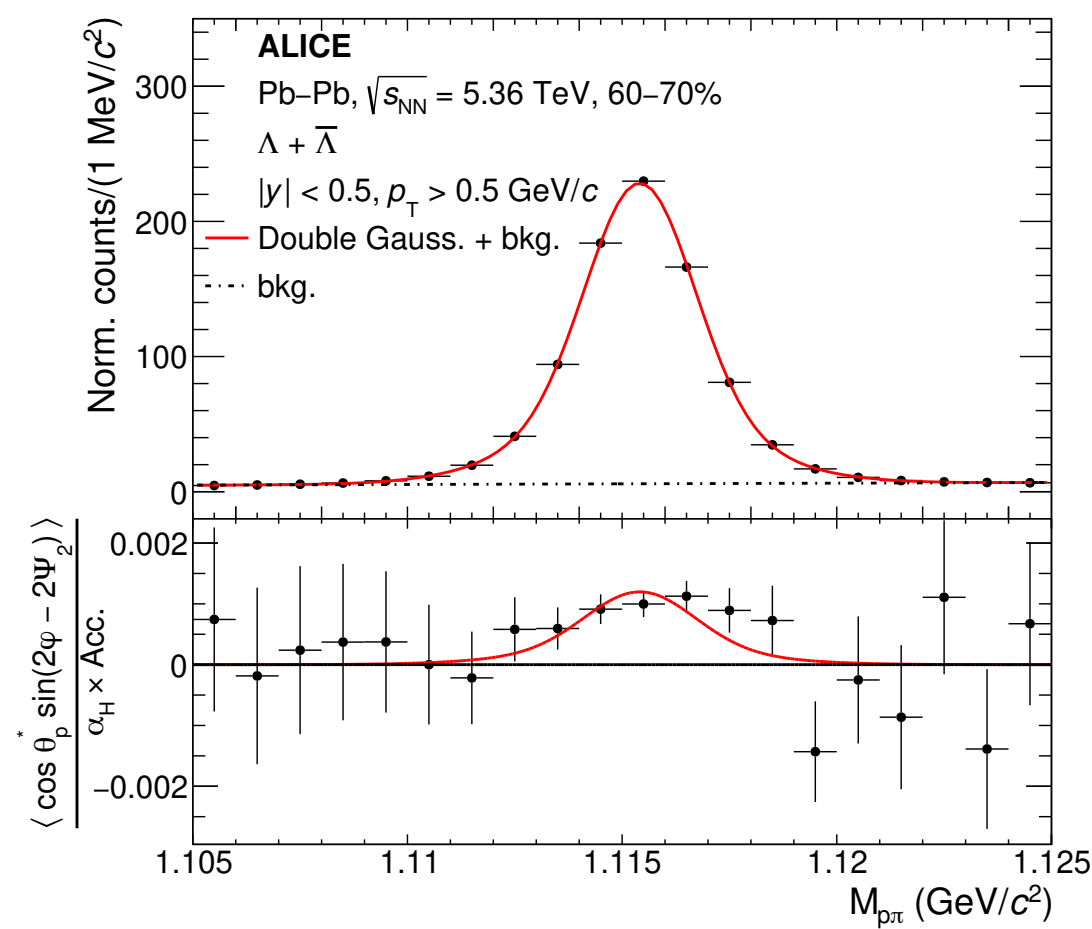


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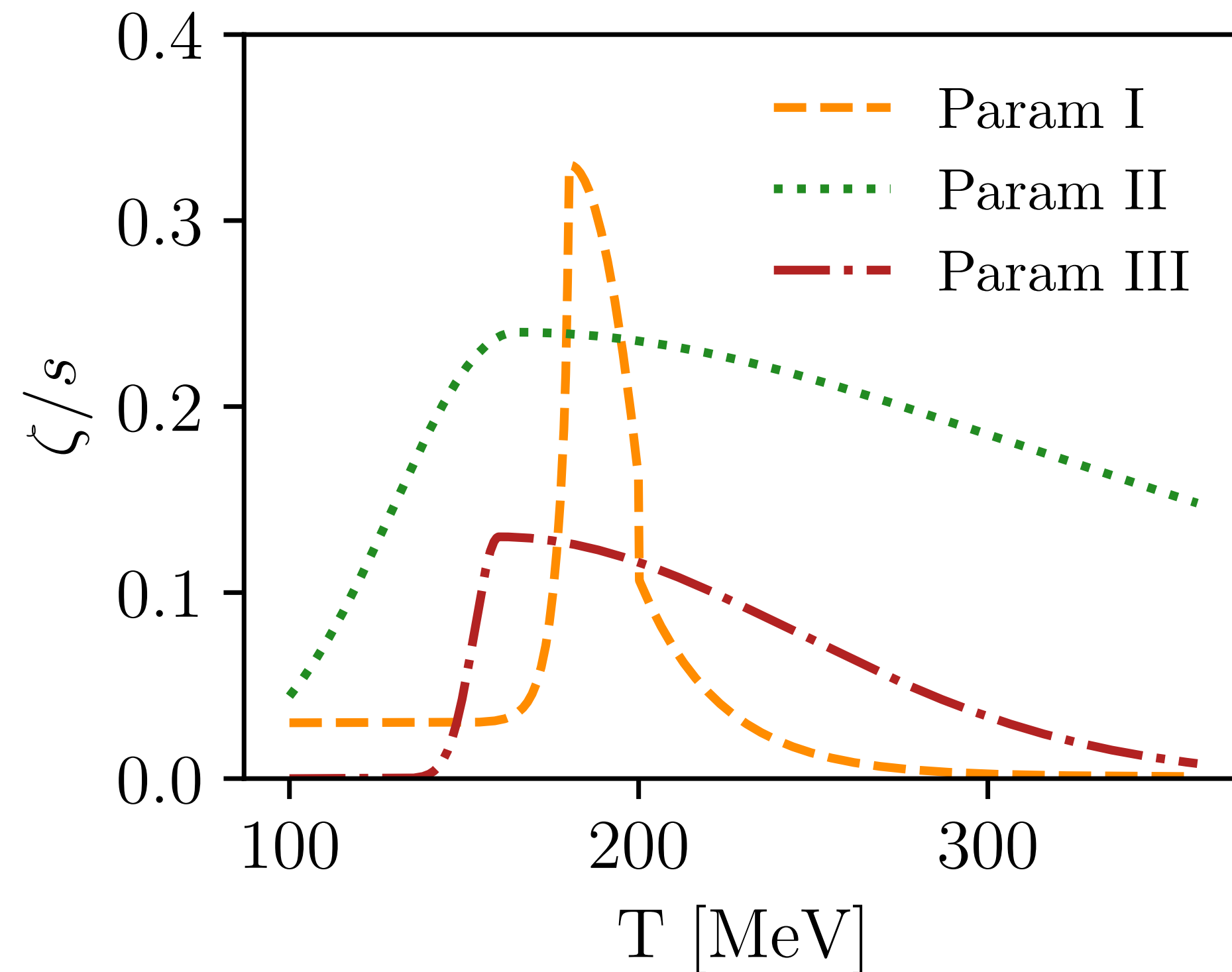
$$P_{z,sn} = \frac{\langle P_z \sin n(\varphi_H - \Psi_n) \rangle}{R_{EP}^{(n)}}$$



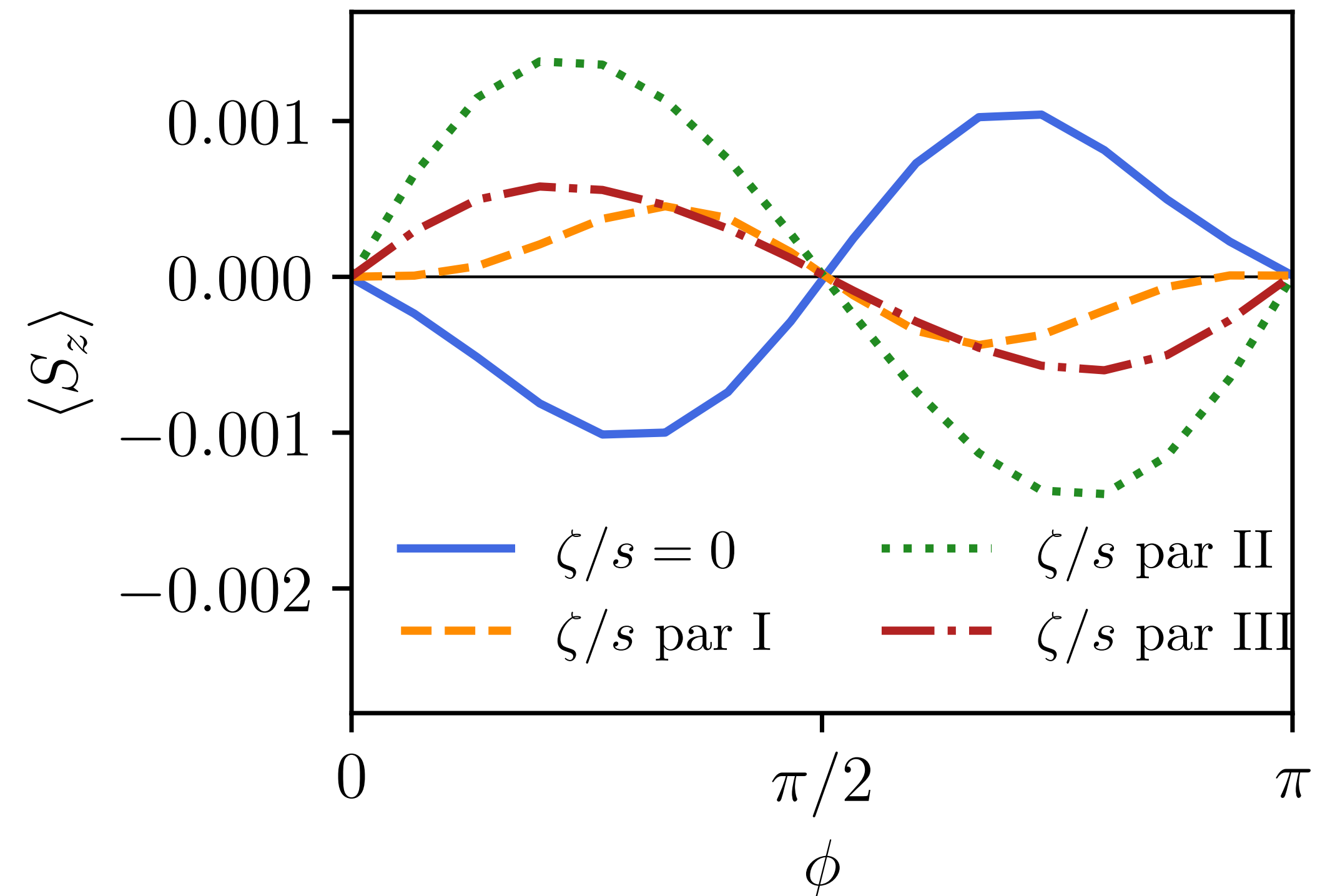
QGP property with local polarization



Bulk Viscosity Parametrizations



LHC PbPb 5020 GeV



At LHC P_z is sensitive to

- Bulk viscosity ζ/s of the QGP at LHC energies $\Rightarrow$ change the sign of P_z
- Shear-induced polarization $\Rightarrow$ competes with the thermal vorticity

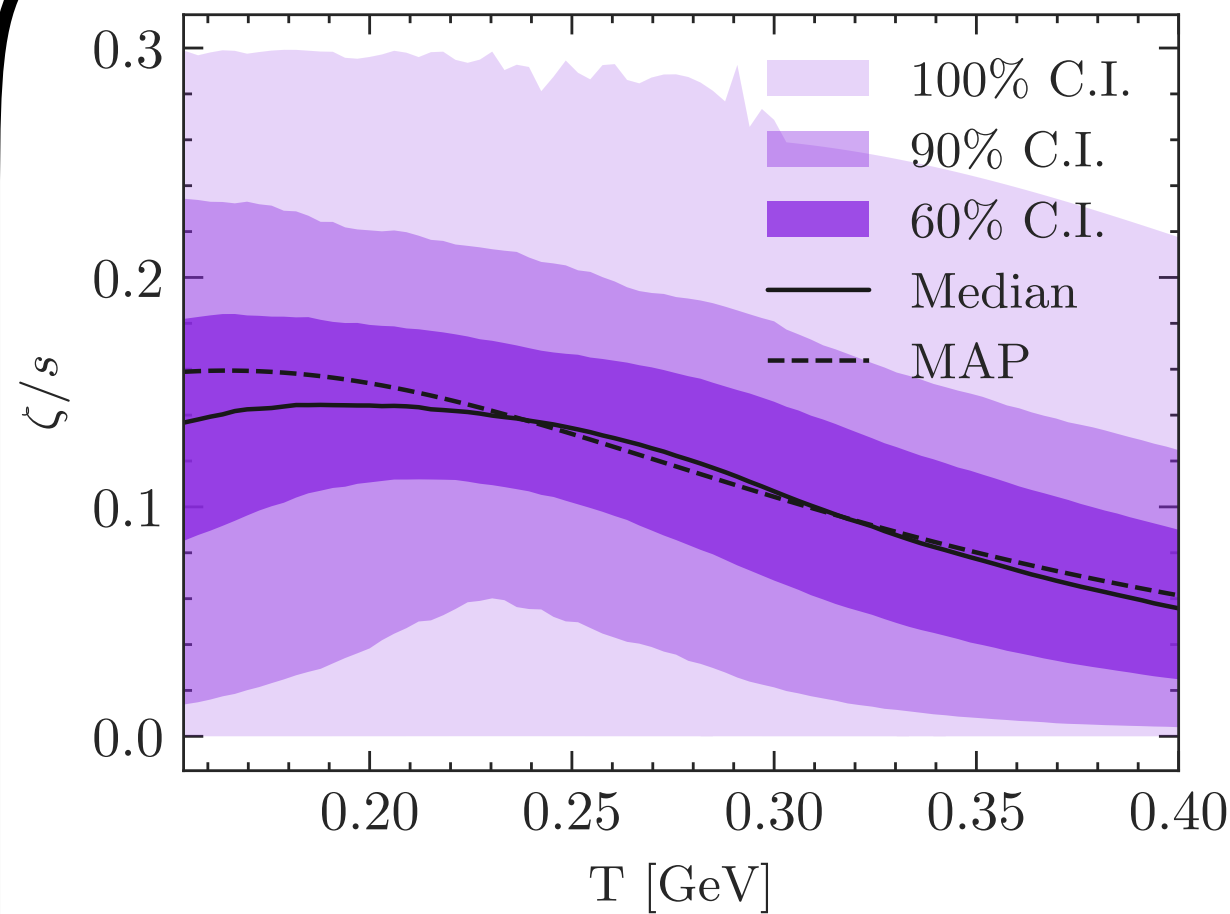
A. Palermo et al., *Eur. Phys. J.* **C84** (2024) 920

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

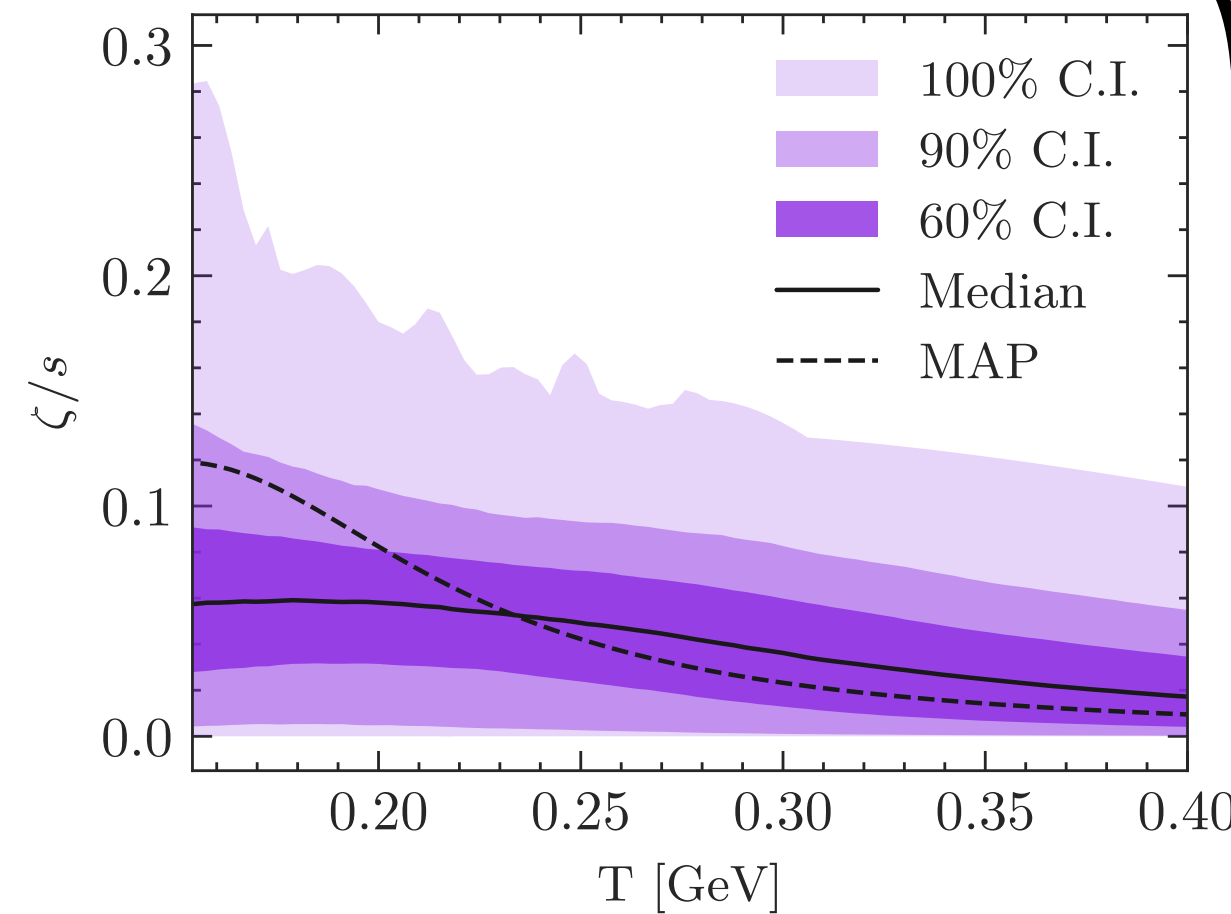
QGP property with local polarization



w/o P_z



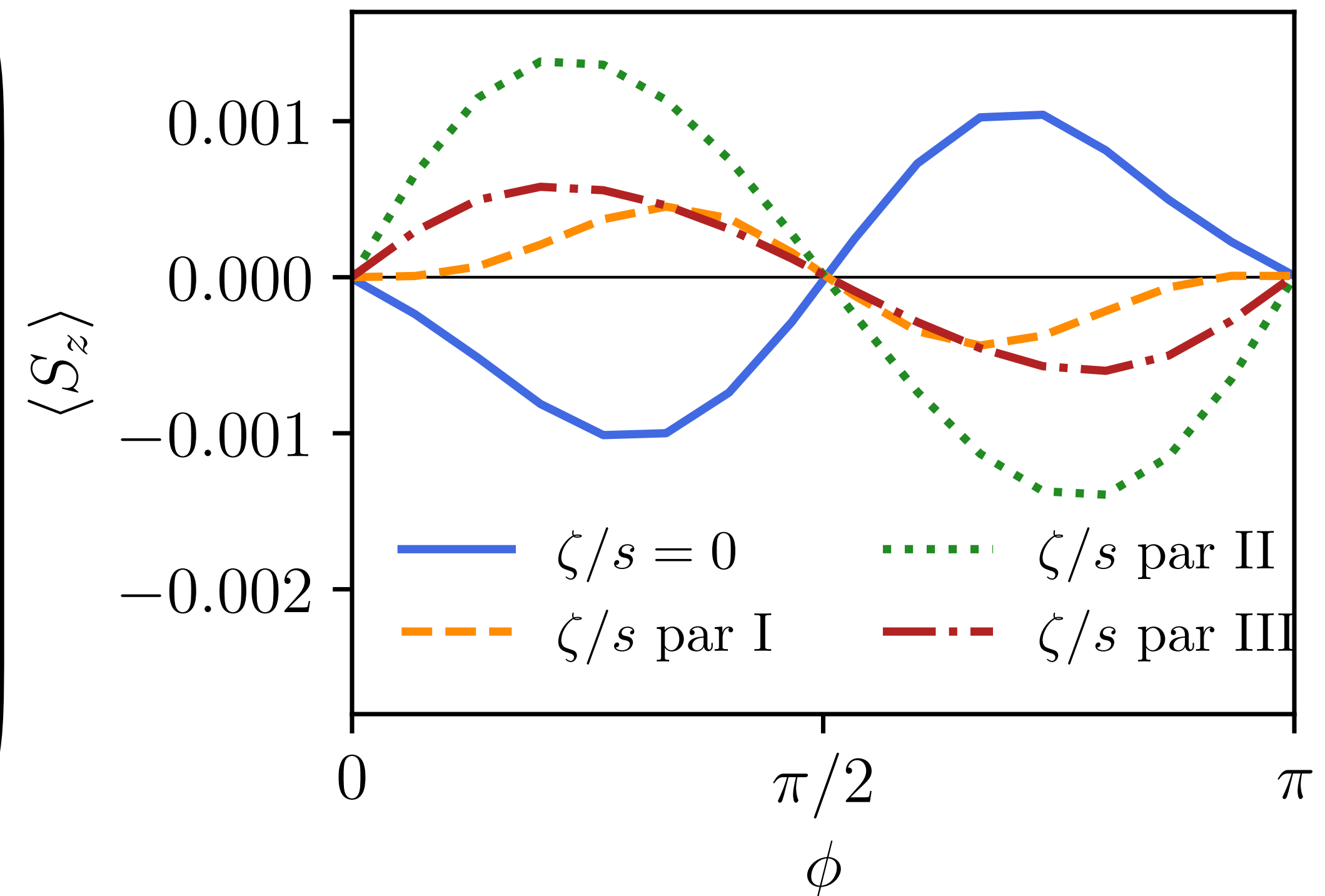
w/ P_z



S. K. Singh *et al.*, [arXiv:2605.29383](#)

P_z significantly influences the Bayesian fits of ζ/s extraction

LHC PbPb 5020 GeV



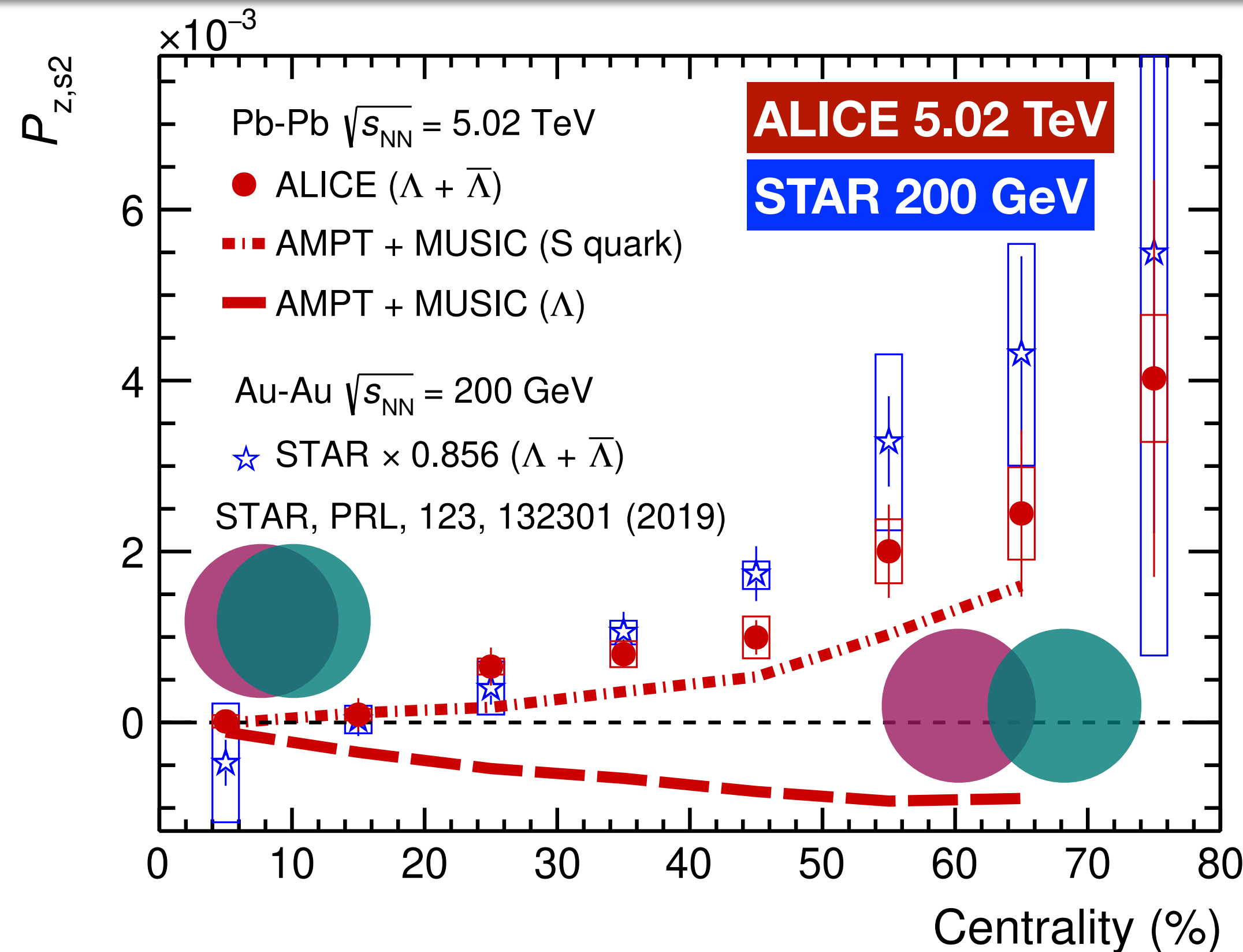
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B. Fu *et al.*, *Phys. Rev. Lett.* **127** (2021) 142301

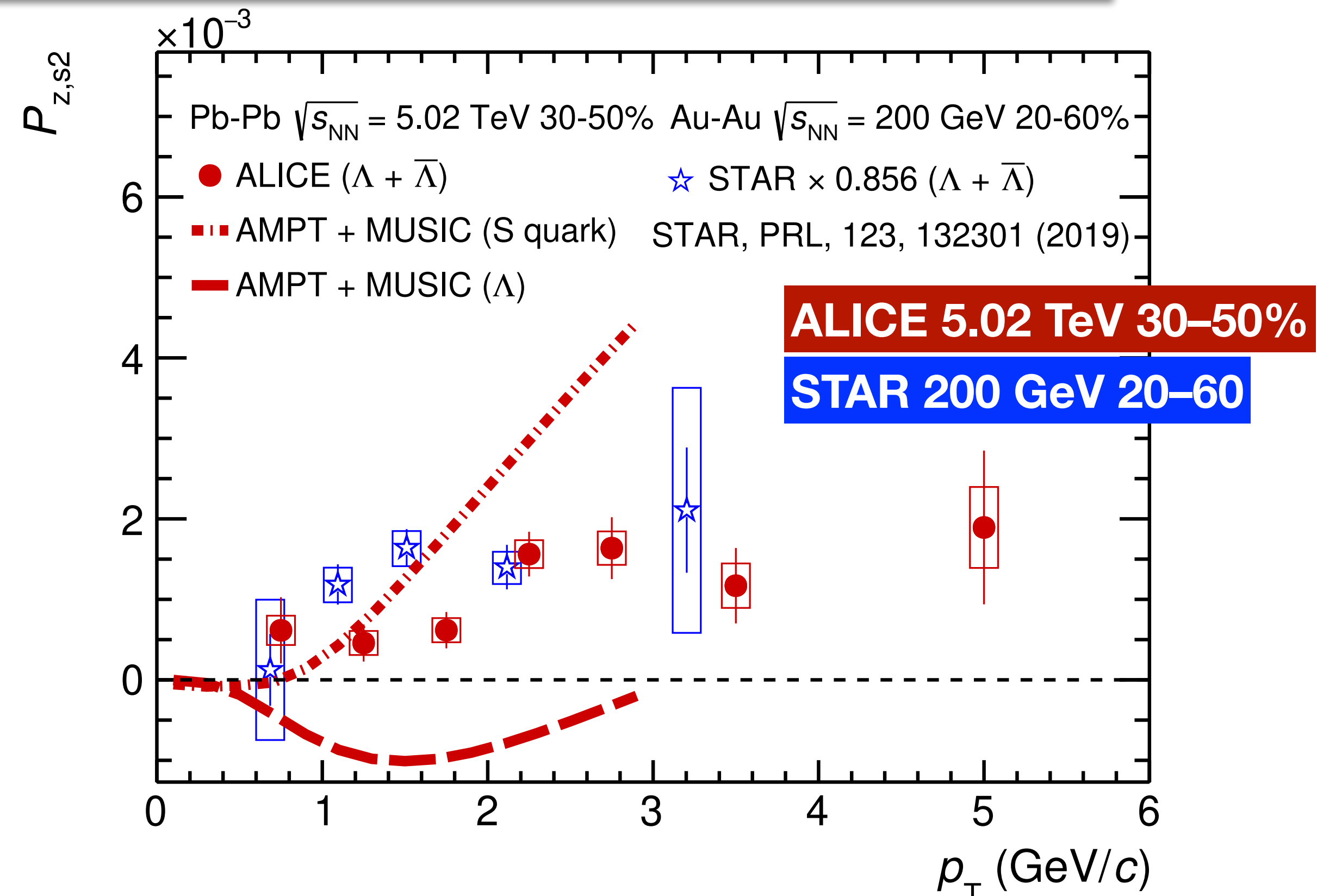
At LHC P_z is sensitive to

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- Shear-induced polarization $\Rightarrow$ competes with the thermal vorticity

Comparison with STAR and predictions



ALI-PUB-530307



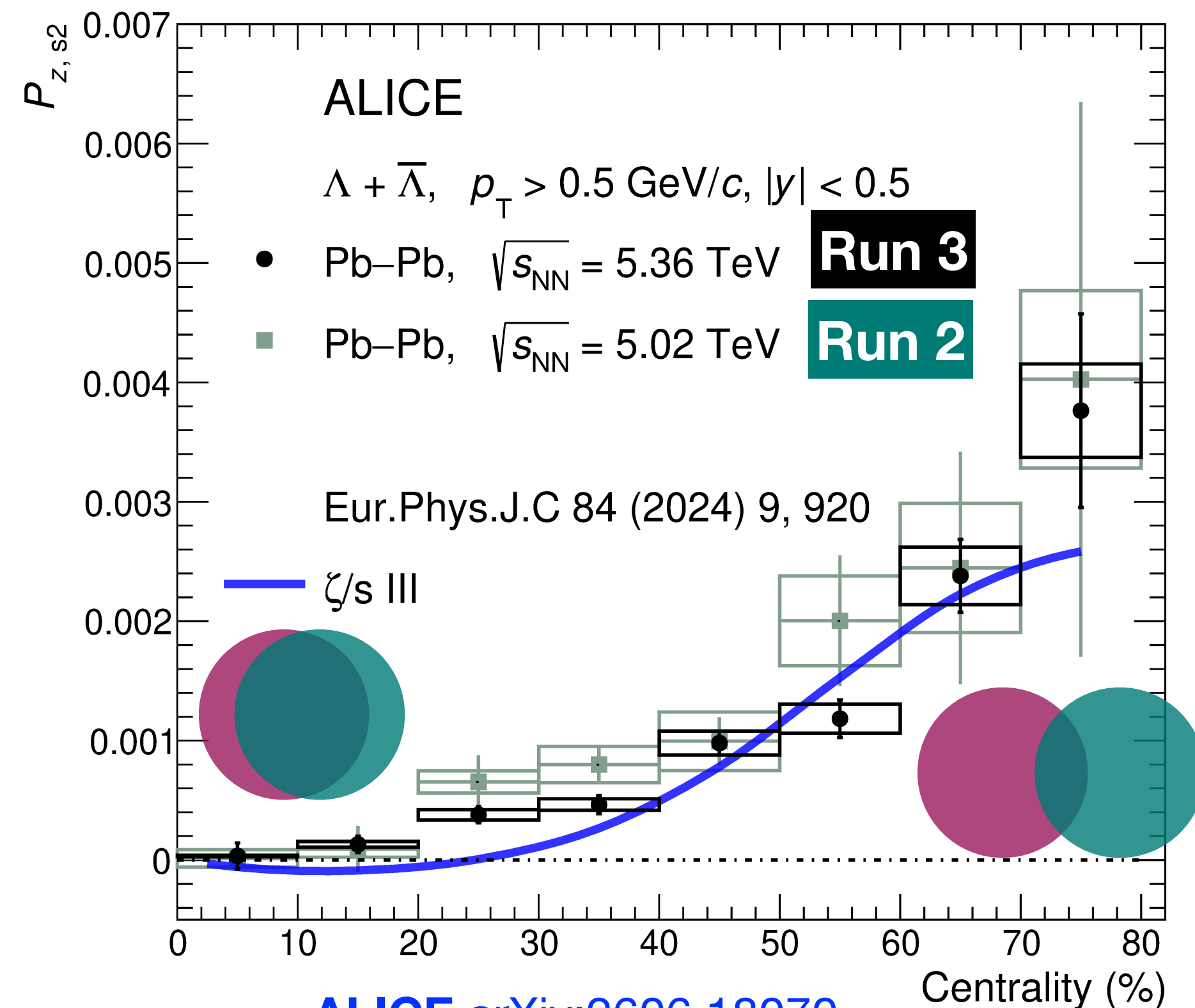
ALI-PUB-530311

ALICE *Phys. Rev. Lett.* **128** (2022) 172005

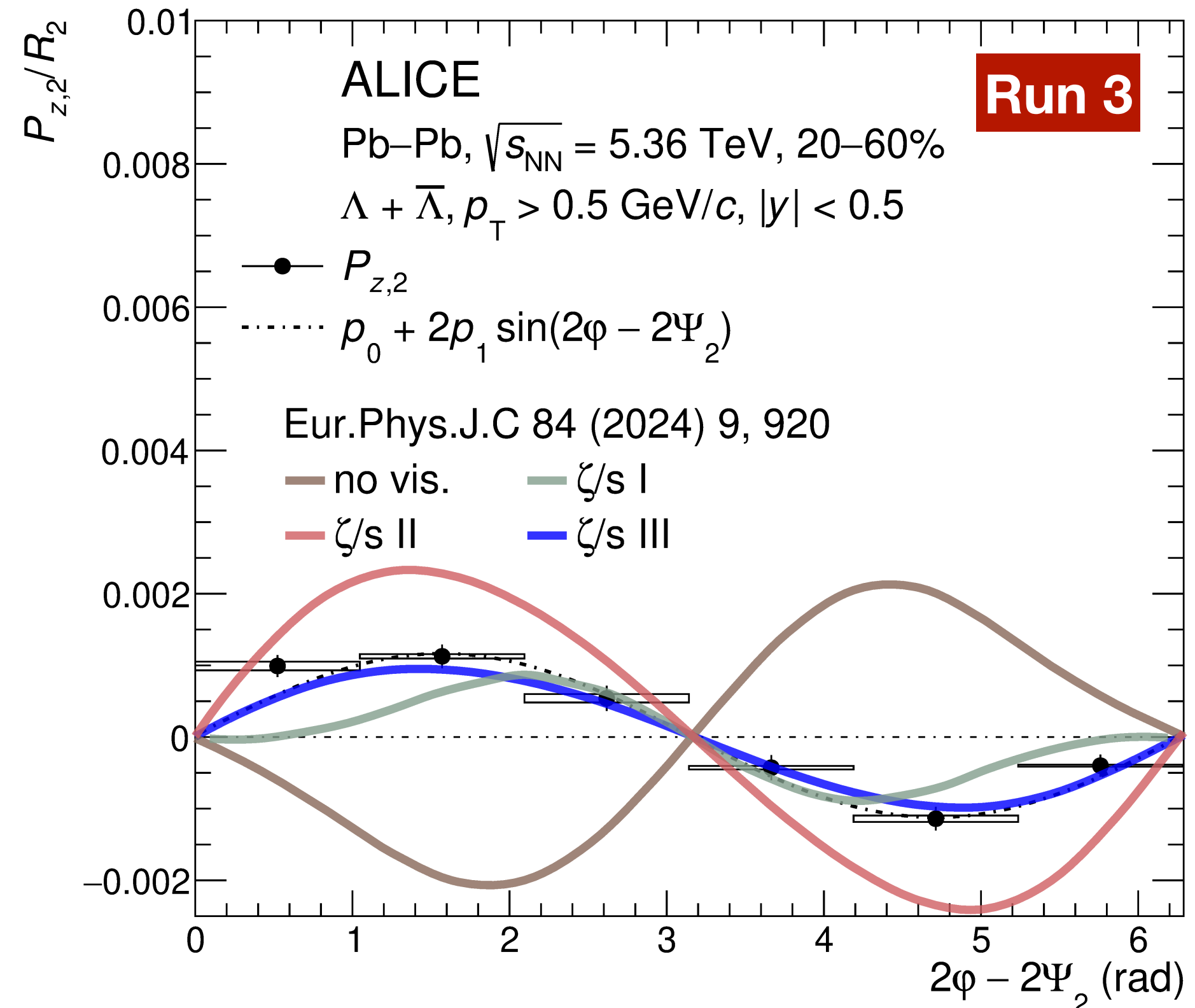
B. Fu et al., *Phys. Rev. Lett.* **127** (2021) 142301

- $P_{z,s2}$ at the LHC is similar in magnitude to top RHIC energy
- Model predicts correct sign if shear-induced polarization is included and Λ inherits s-quark polarization

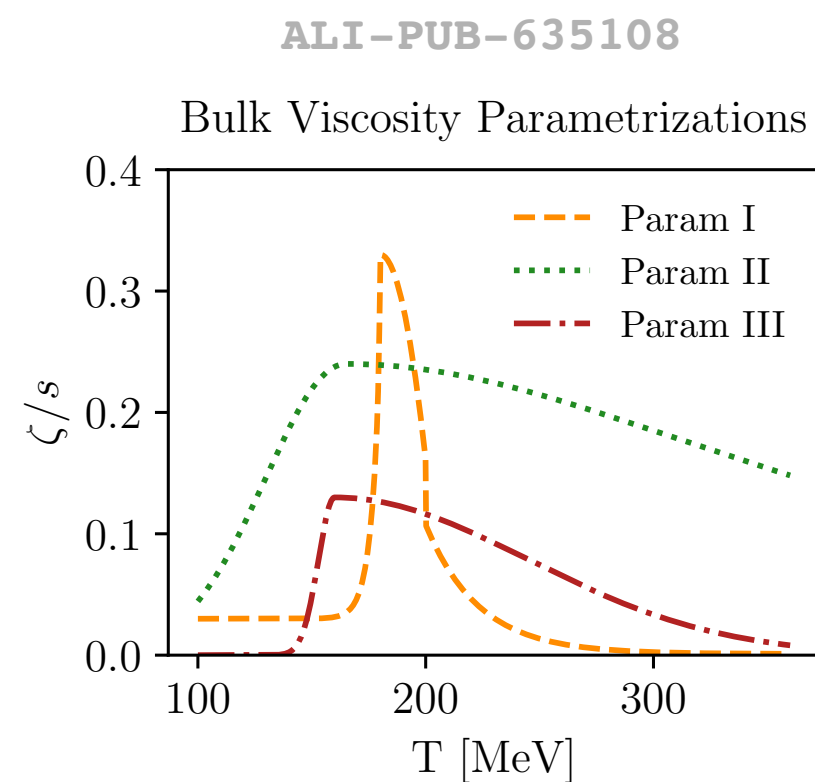
New Run 3 results compare to model



ALICE arXiv:2606.18070



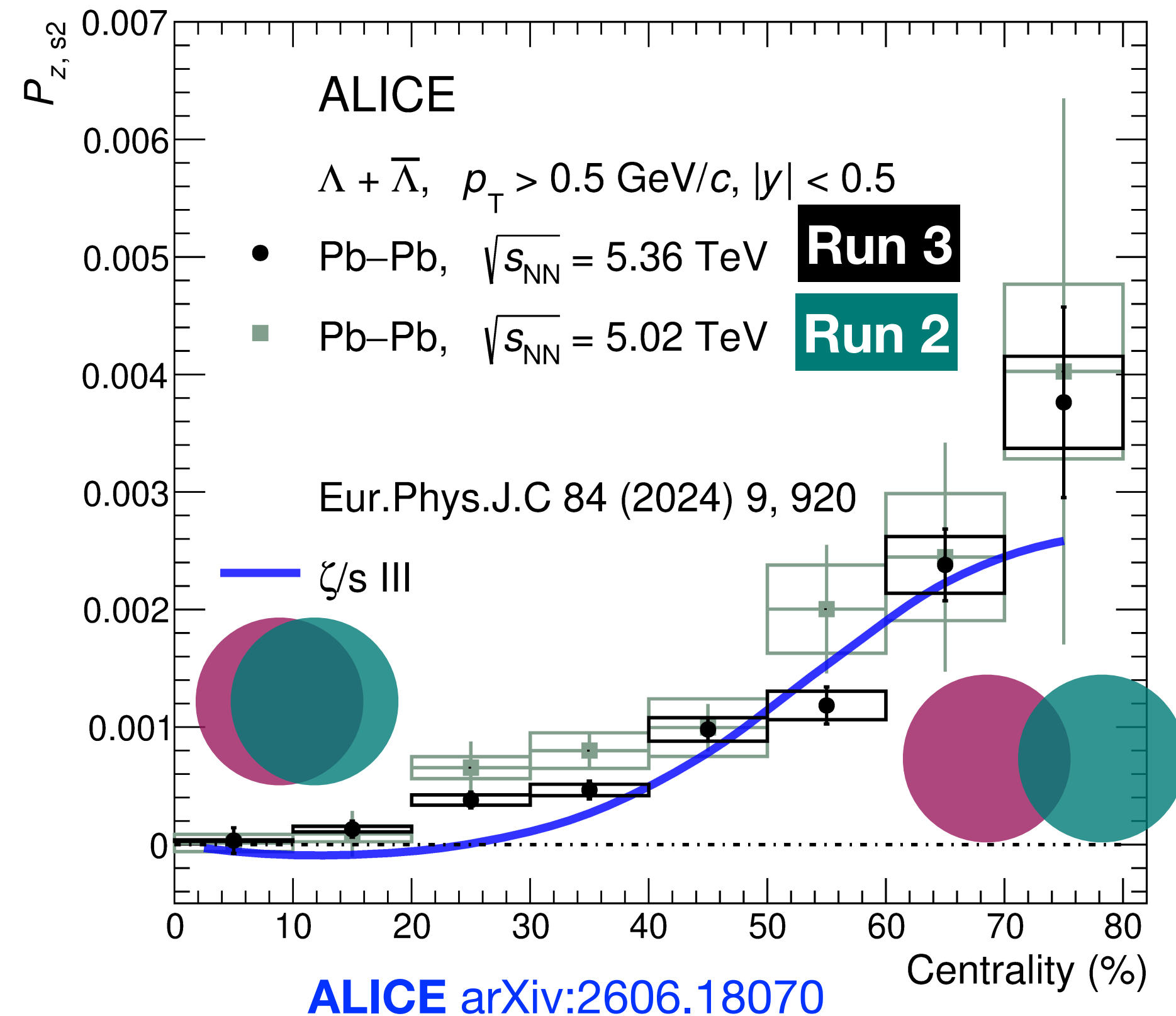
ALI-PUB-635098



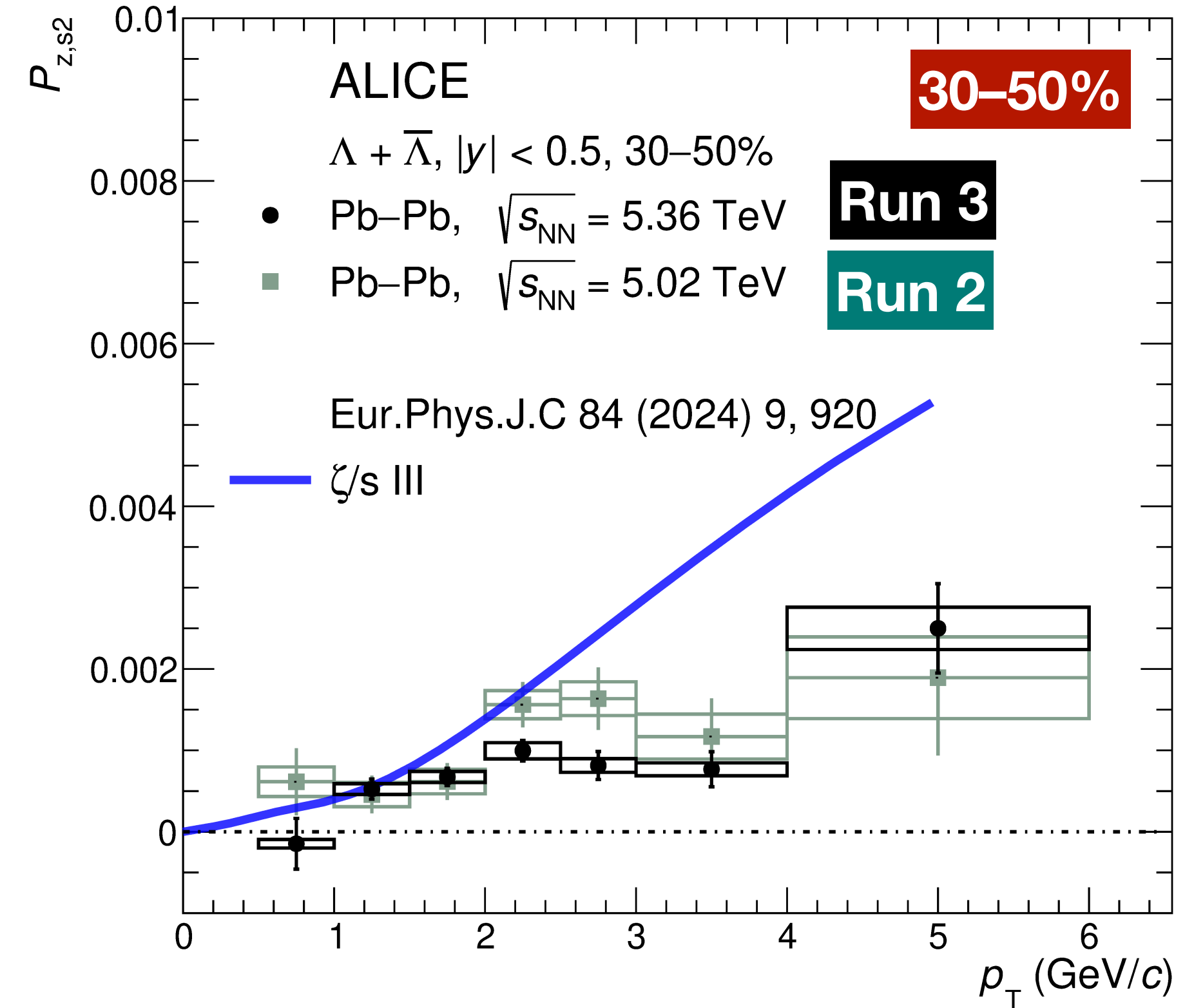
Good agreement between data and model including

- ➡ Shear-induced polarization
- ➡ Assuming a temperature dependent bulk viscosity ζ/s (**par III**)
- ➡ An isothermal hadronization hypersurface

New Run 3 results p_T -dependence



ALI-PUB-635108

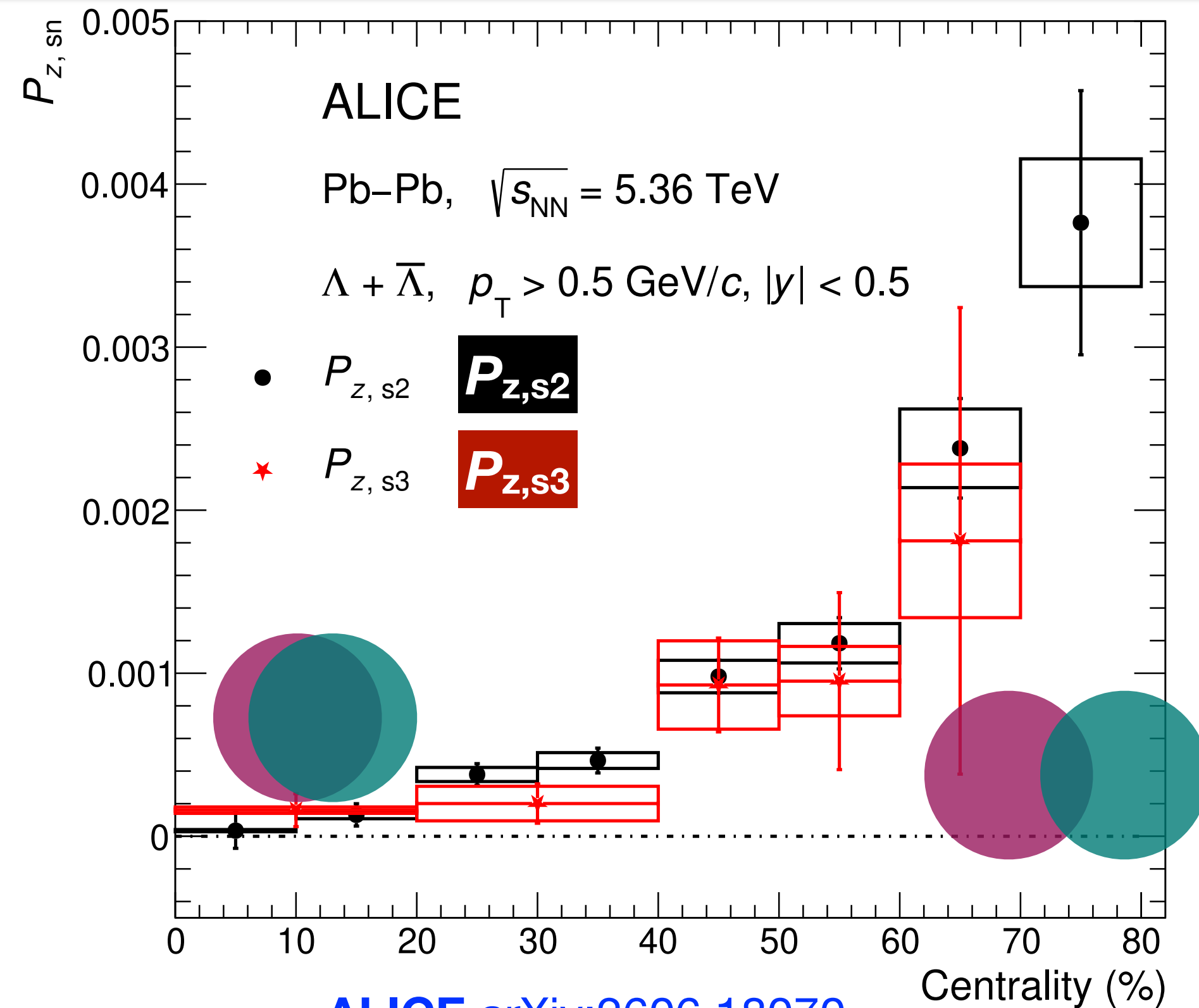


ALI-PUB-635113

The measured p_T dependence is not fully described by the model, which predicts a steeper increase with p_T , indicating the need for further model development

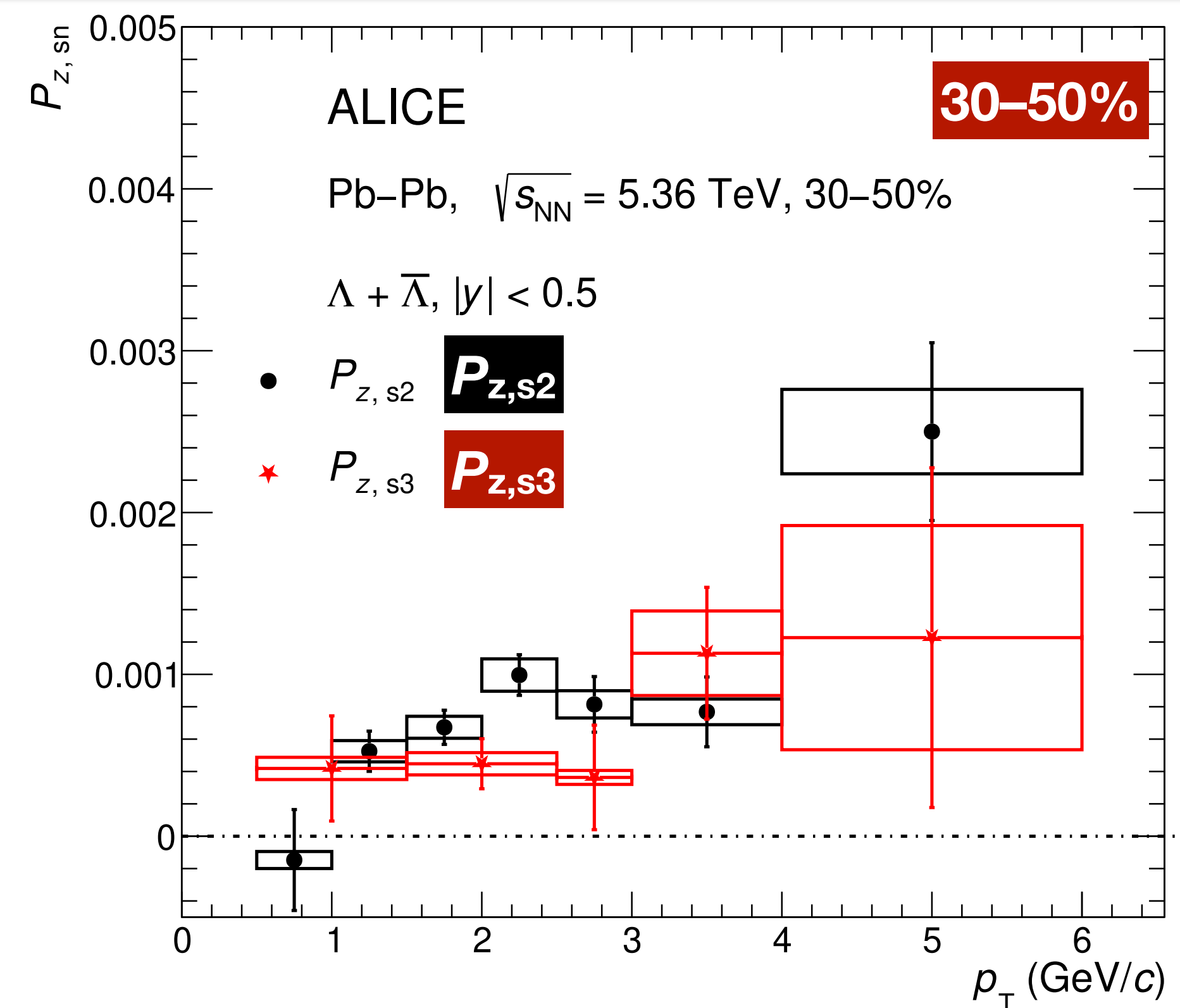
➡ Only 2023 Pb–Pb data is used, to be improved with full Pb–Pb sample

Polarization induced by triangle flow



ALICE arXiv:2606.18070

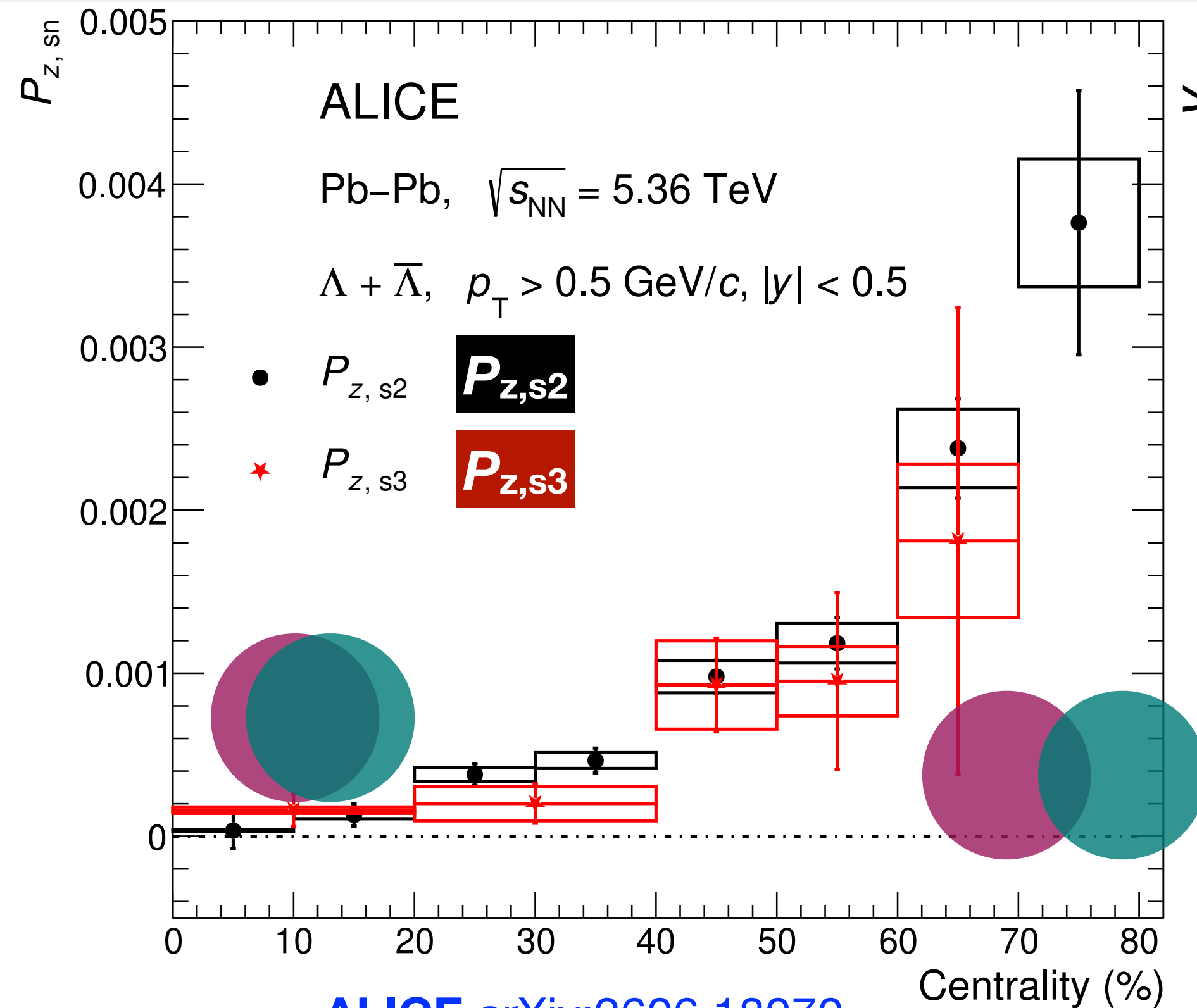
ALI-PUB-635118



ALI-PUB-635123

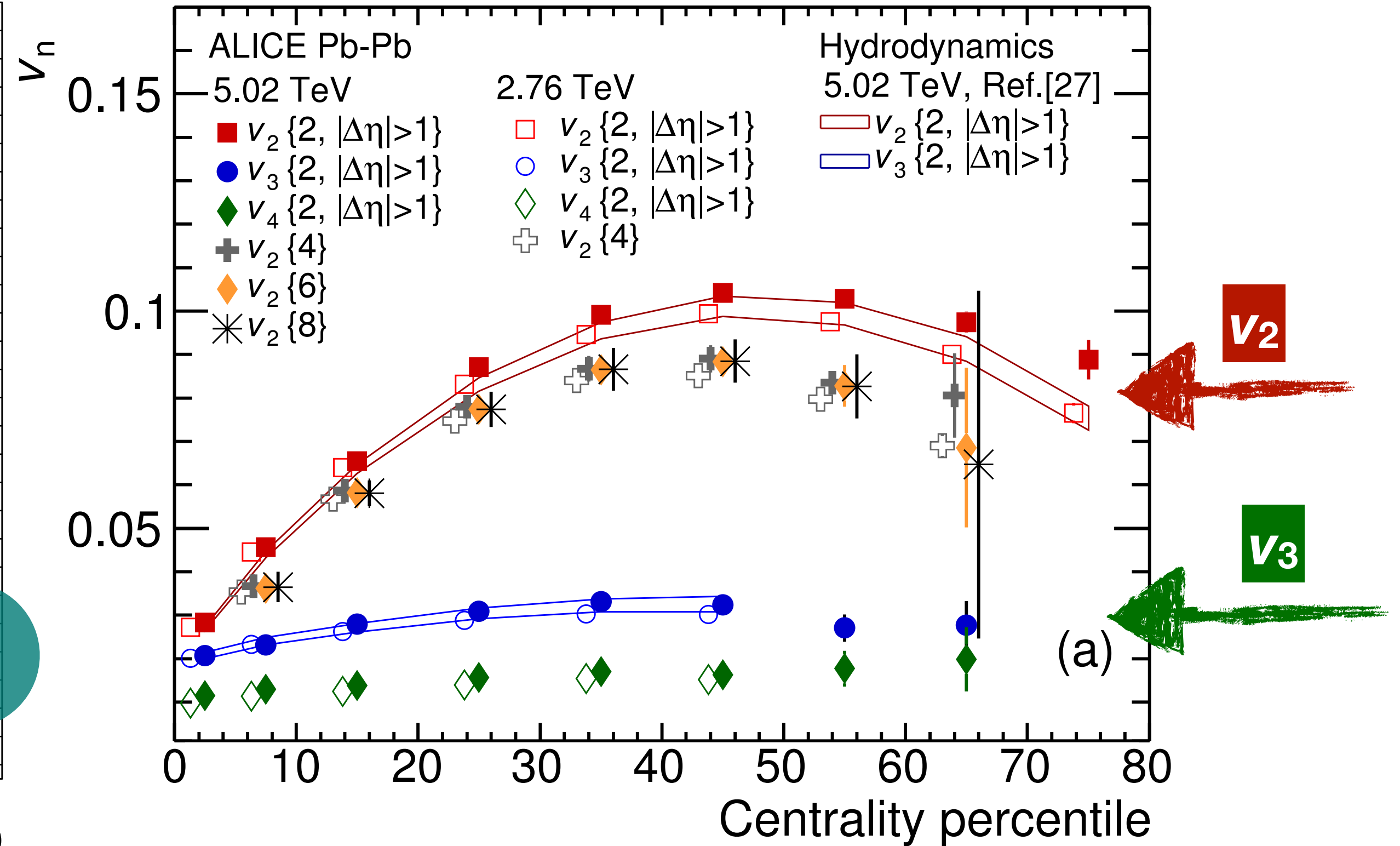
- $P_{z,s3}$ is compatible with $P_{z,s2}$, despite the v_3 is smaller v_2
- Measurements of polarization induced by higher harmonics flow will be possible with 2024, 2025 and 2026 data

Polarization induced by triangle flow



ALICE arXiv:2606.18070

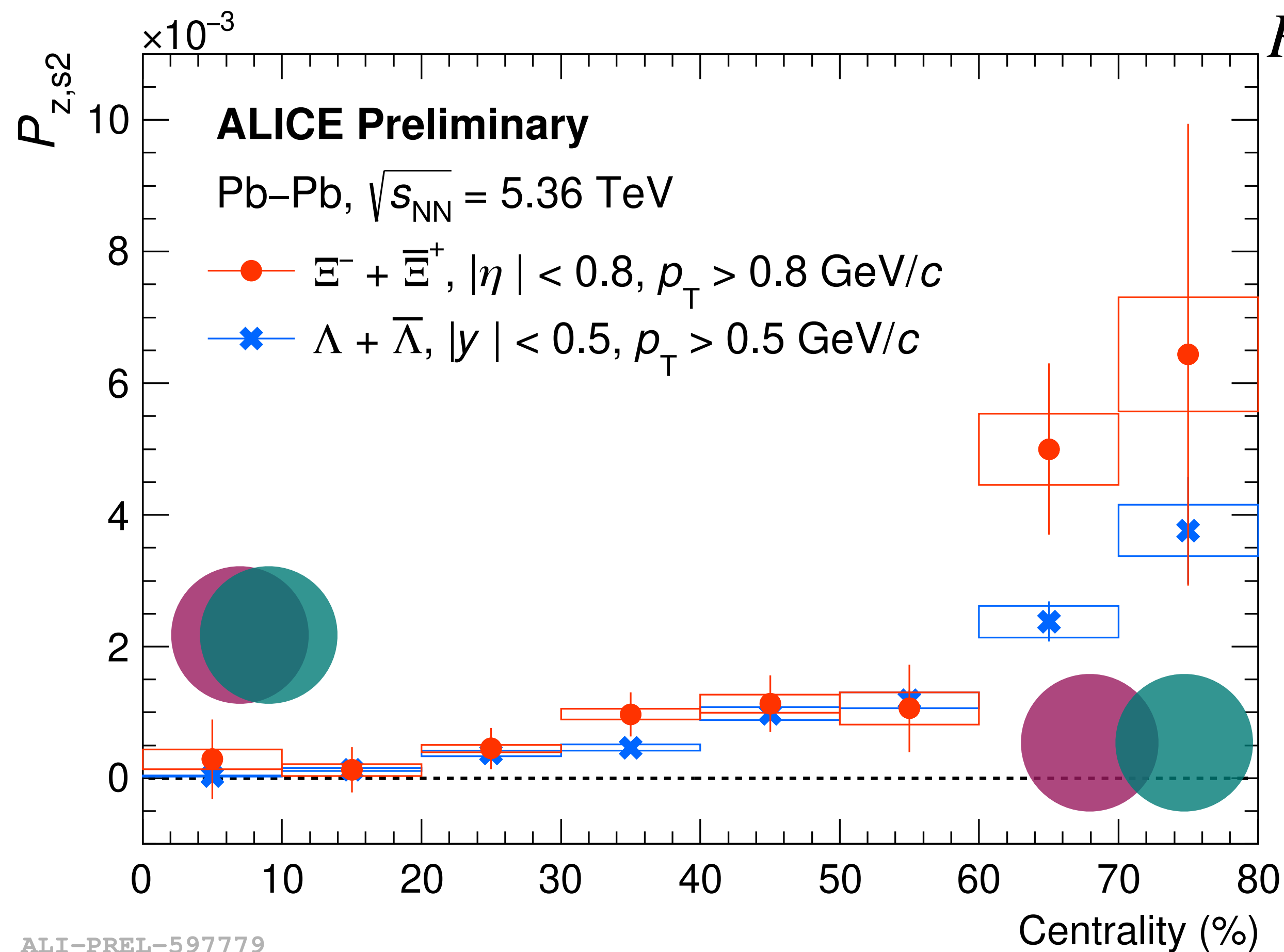
ALI-PUB-635118



ALICE Phys. Rev. Lett. **116** (2016) 132302

- $P_{z,s3}$ is compatible with $P_{z,s2}$, despite the v_3 is smaller v_2
- ➡ Similar relations is observed by STAR [STAR Phys. Rev. Lett. **131** (2023) 202301]
- ➡ Model predictions are needed to interpret these results

Longitudinal polarization of Ξ

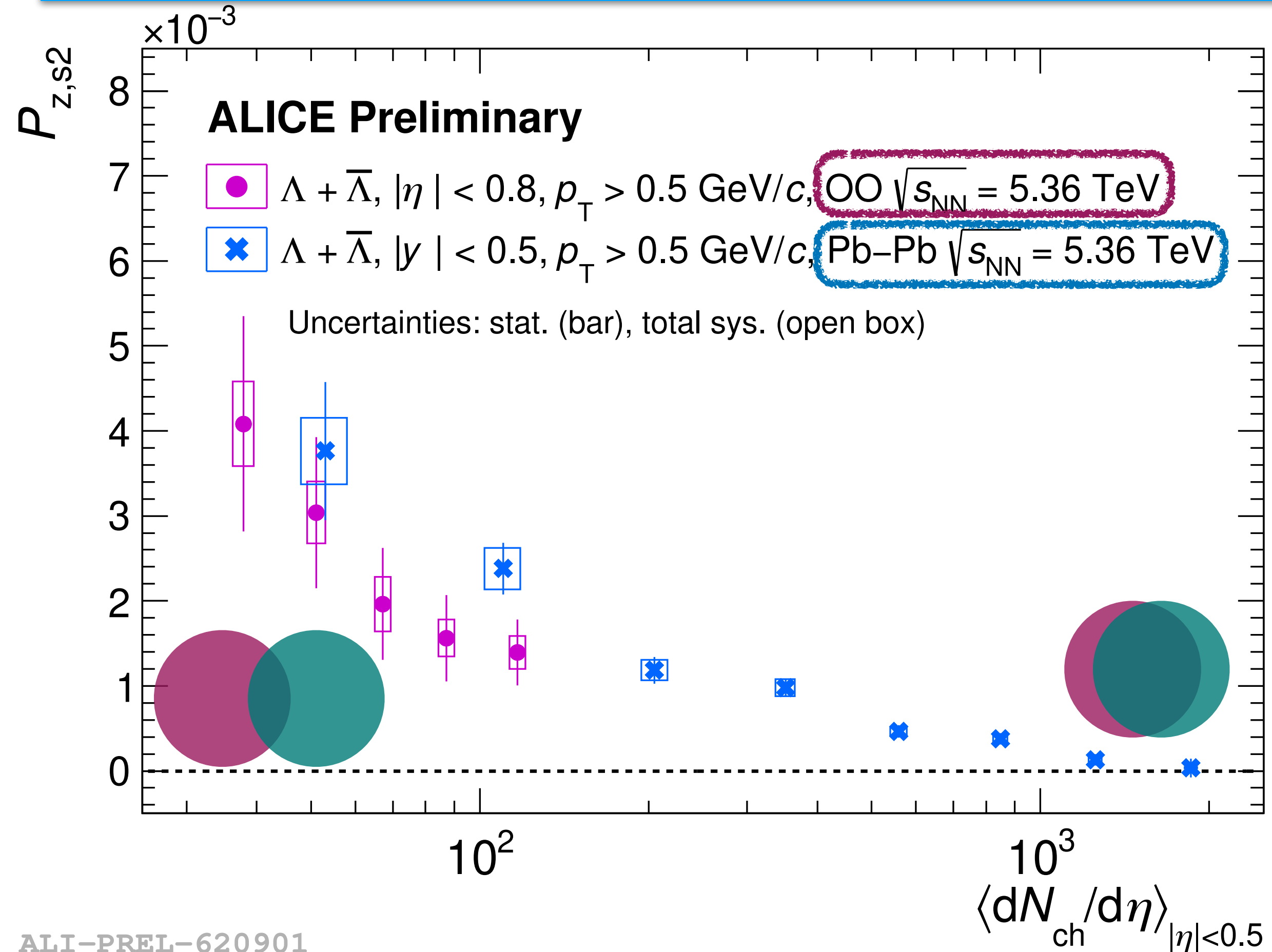


$$P_z^\Xi = \frac{\langle \cos \theta_p^* \rangle}{c_{\Xi\Lambda} \alpha_H \langle \cos^2 \theta_p^* \rangle} \quad P_{z,sn}^\Xi = \frac{\langle P_z^\Xi \sin n(\varphi_\Xi - \Psi_n) \rangle}{R_{EP}^{(n)}}$$

- The first measurement of Ξ longitudinal polarization in Pb–Pb collisions
 ➔ Only 2023 Pb–Pb data is used
- The Ξ longitudinal polarization shows a hint of increase from central to peripheral collisions
 ➔ It is compatible with Λ , confirming the spin hierarchy ($s_\Lambda = s_\Xi = 1/2$)

2024–2026 data allows us to reduce uncertainty and to test spin hierarchy by measuring Ω ($s_\Omega = 3/2$)

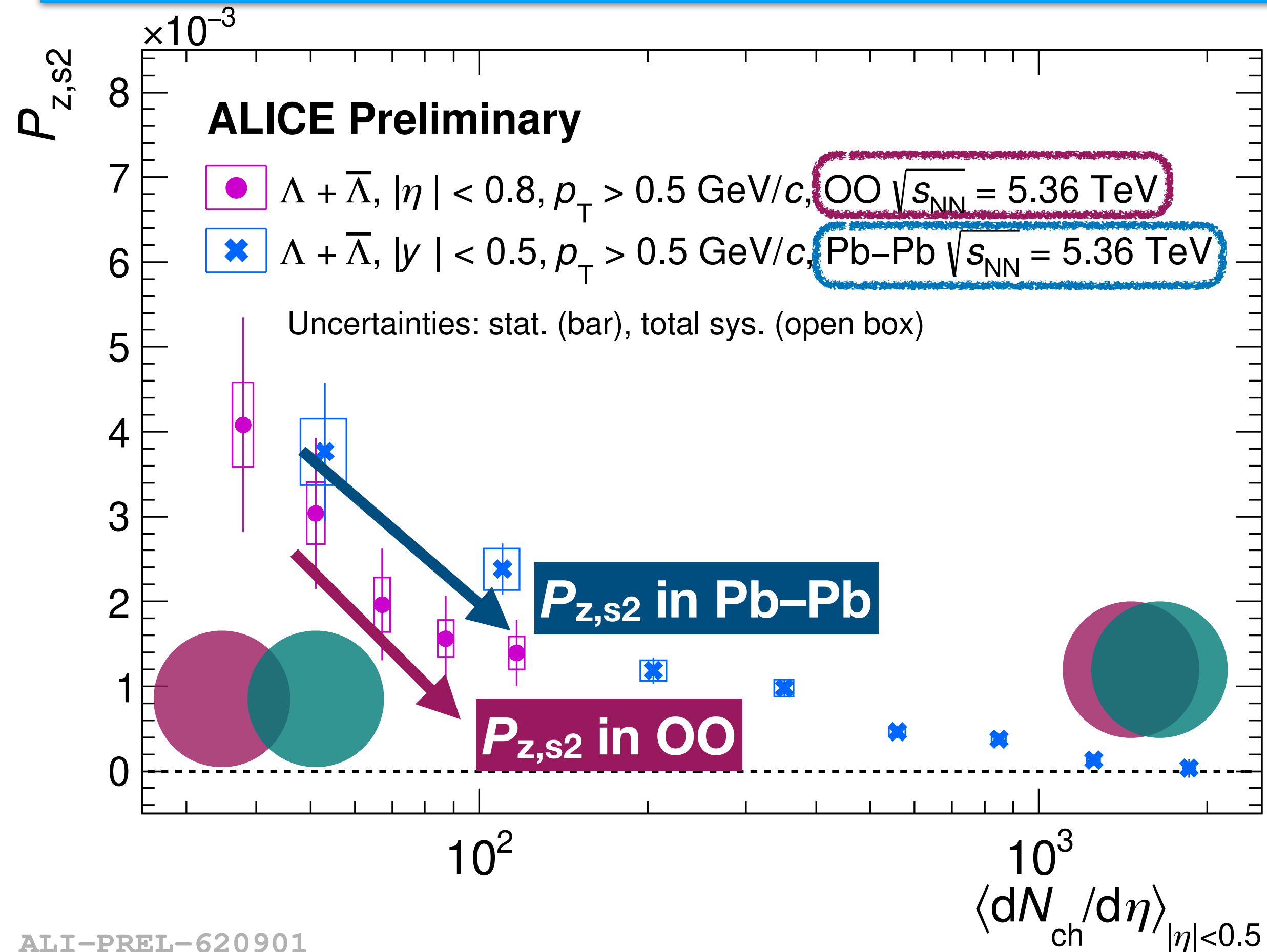
Longitudinal polarization of Λ in OO



ALI-PREL-620901

- Very first measurement of Λ longitudinal polarization in OO collisions
 ➔ $\sim 5 \times 10^9$ collisions collected in 2025
- Significantly non-zero values for 0–50% centrality class with 6σ
- $P_{z,s2}$ approximately scales with event multiplicity
 ➔ Used as a proxy for the produced system size

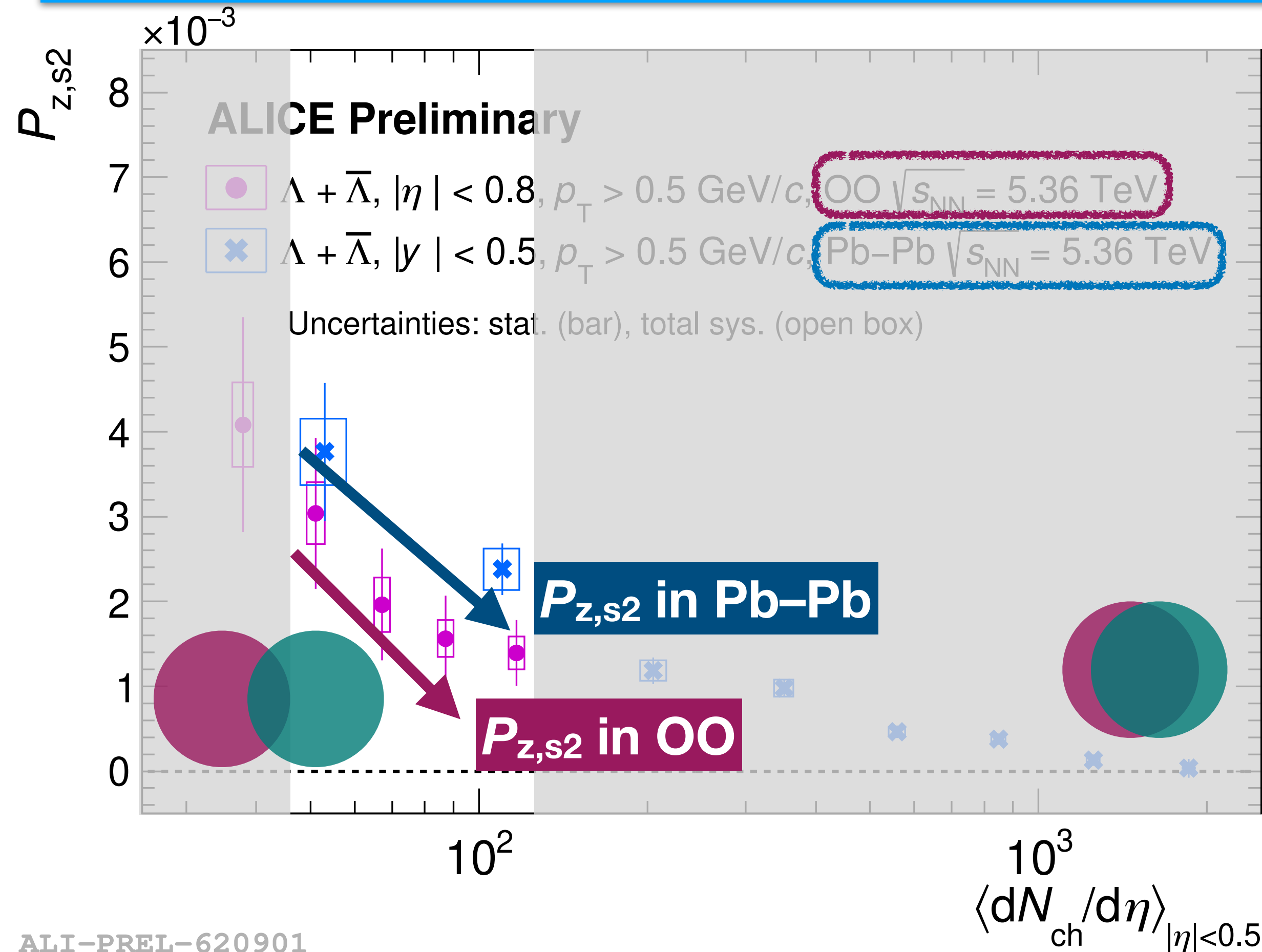
Longitudinal polarization of Λ in OO



ALI-PREL-620901

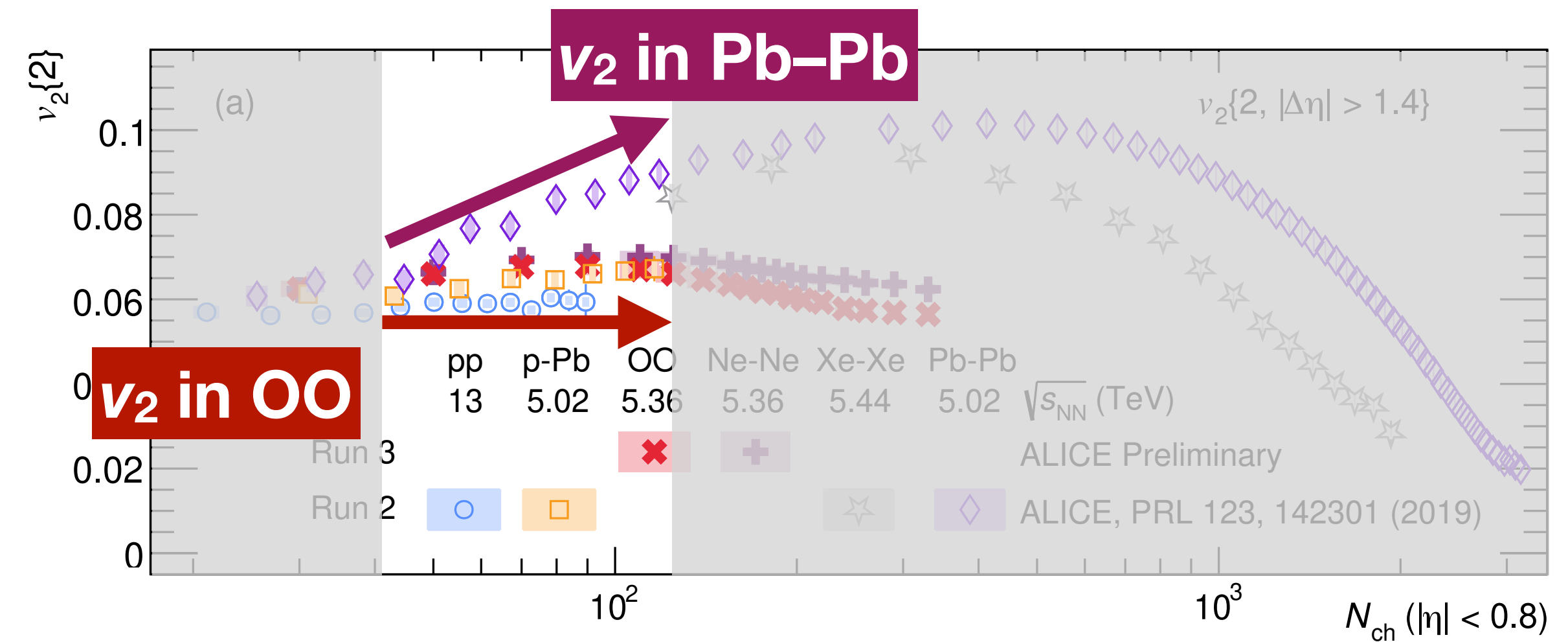
- Very first measurement of Λ longitudinal polarization in OO collisions
 $\Rightarrow \sim 5 \times 10^9$ collisions collected in 2025
- Significantly non-zero values for 0–50% centrality class with 6σ
- Compatible with the one observed in **Pb-Pb** collisions at similar multiplicity

Longitudinal polarization of Λ in OO



ALI-PREL-620901

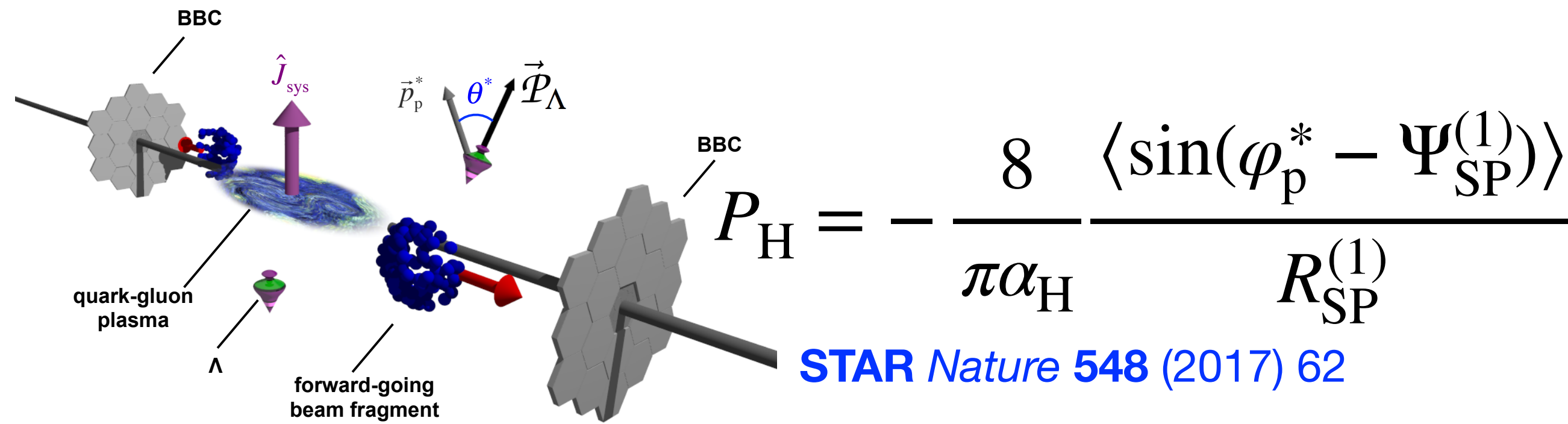
Comparison with model predictions would constrain for the first time the bulk viscosity of the medium in OO collisions



ALI-PREL-623658

- Compatible with the one observed in **Pb-Pb** collisions at similar multiplicity
- $P_{z,s2}$ does not scale with v_2 : **OO** and **Pb-Pb** collisions show different polarization at comparable v_2

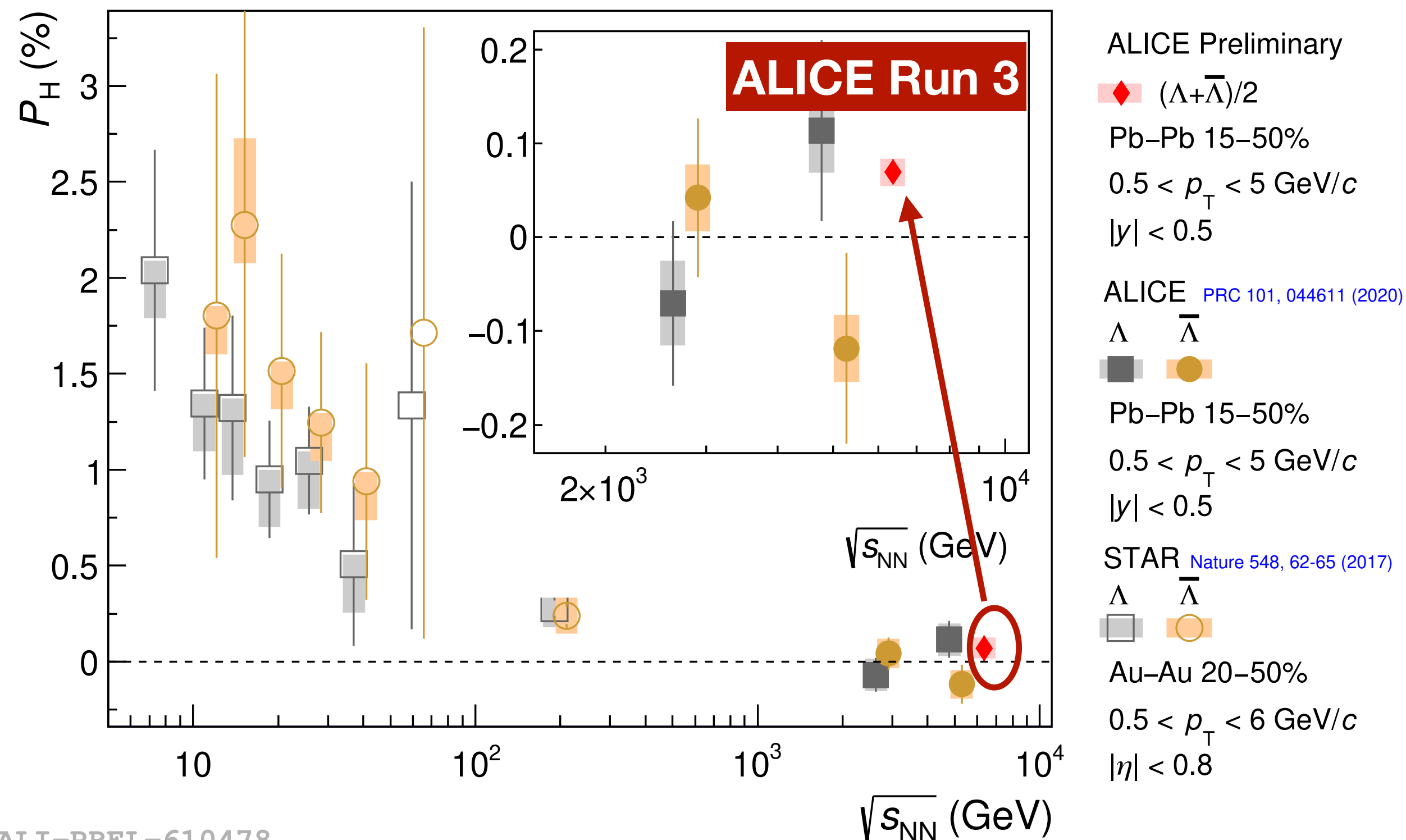
Polarization puzzle



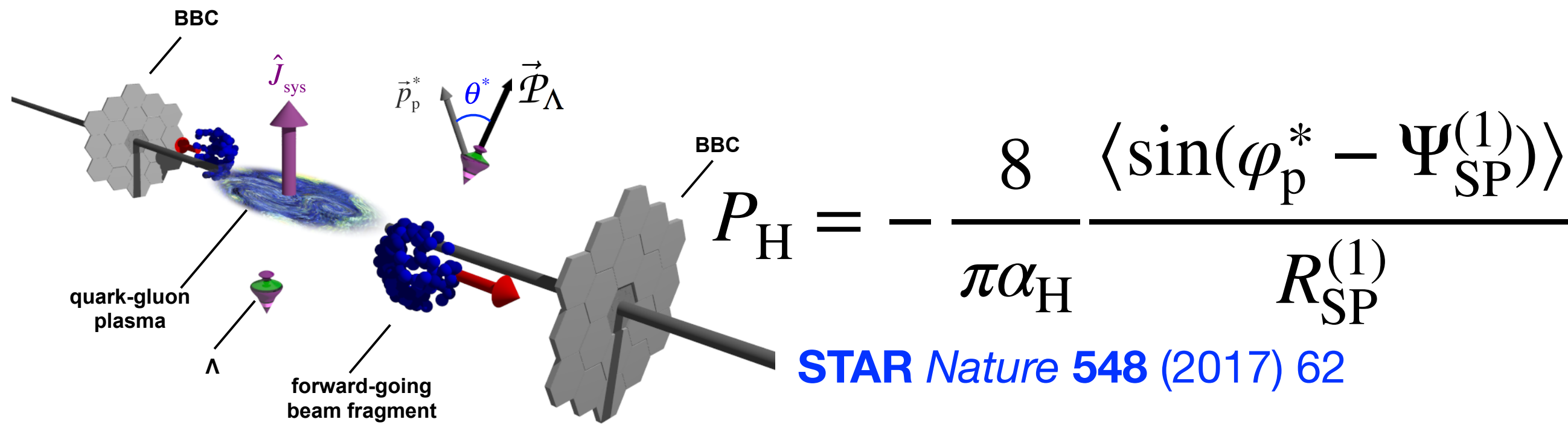
Thermal estimation

$$\rho_{00} - 1/3 \sim \mathcal{O}(P_H^2)$$

$$P_H < 0.1\% \Rightarrow \rho_{00} - 1/3 \sim 0$$



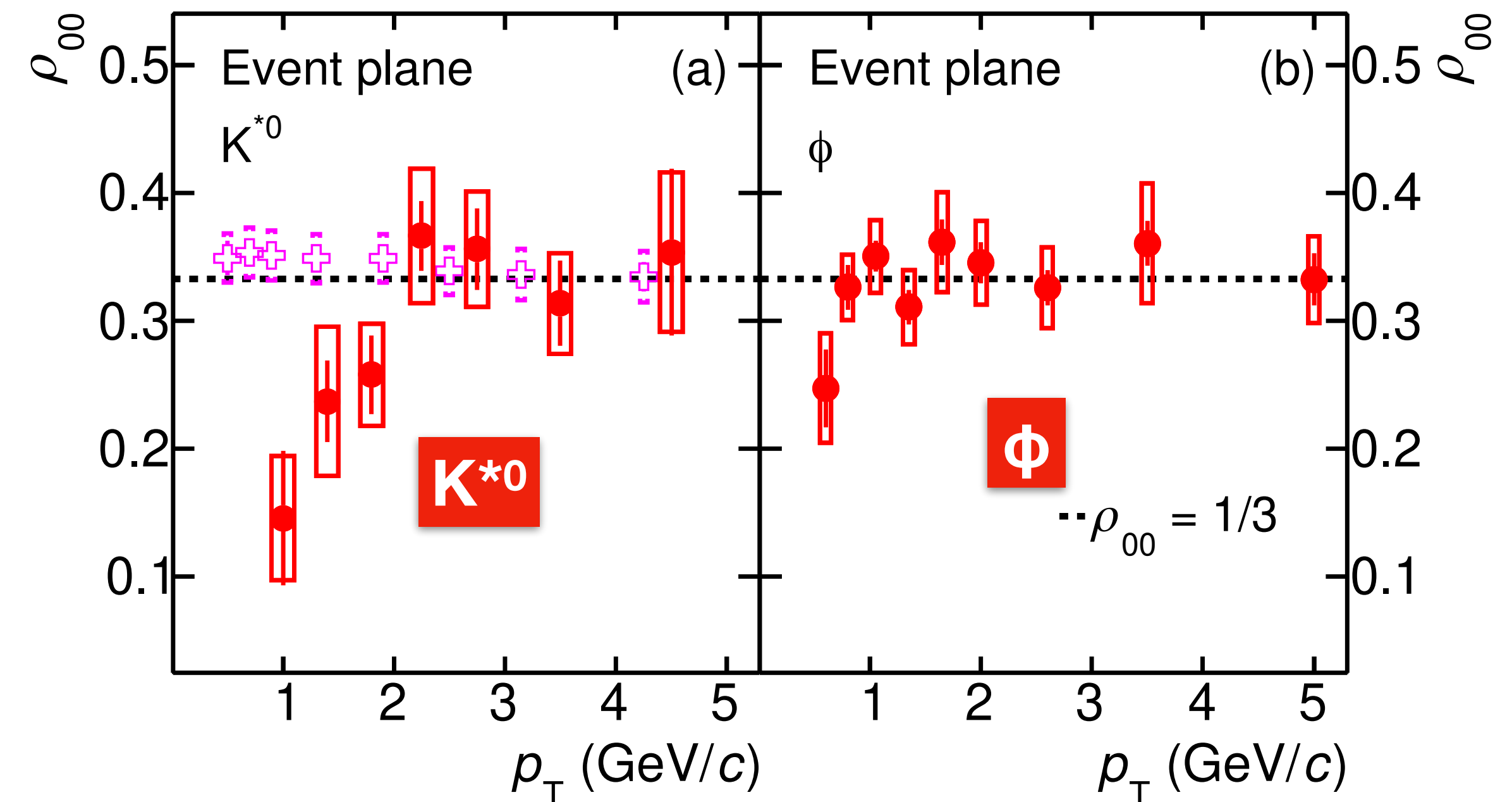
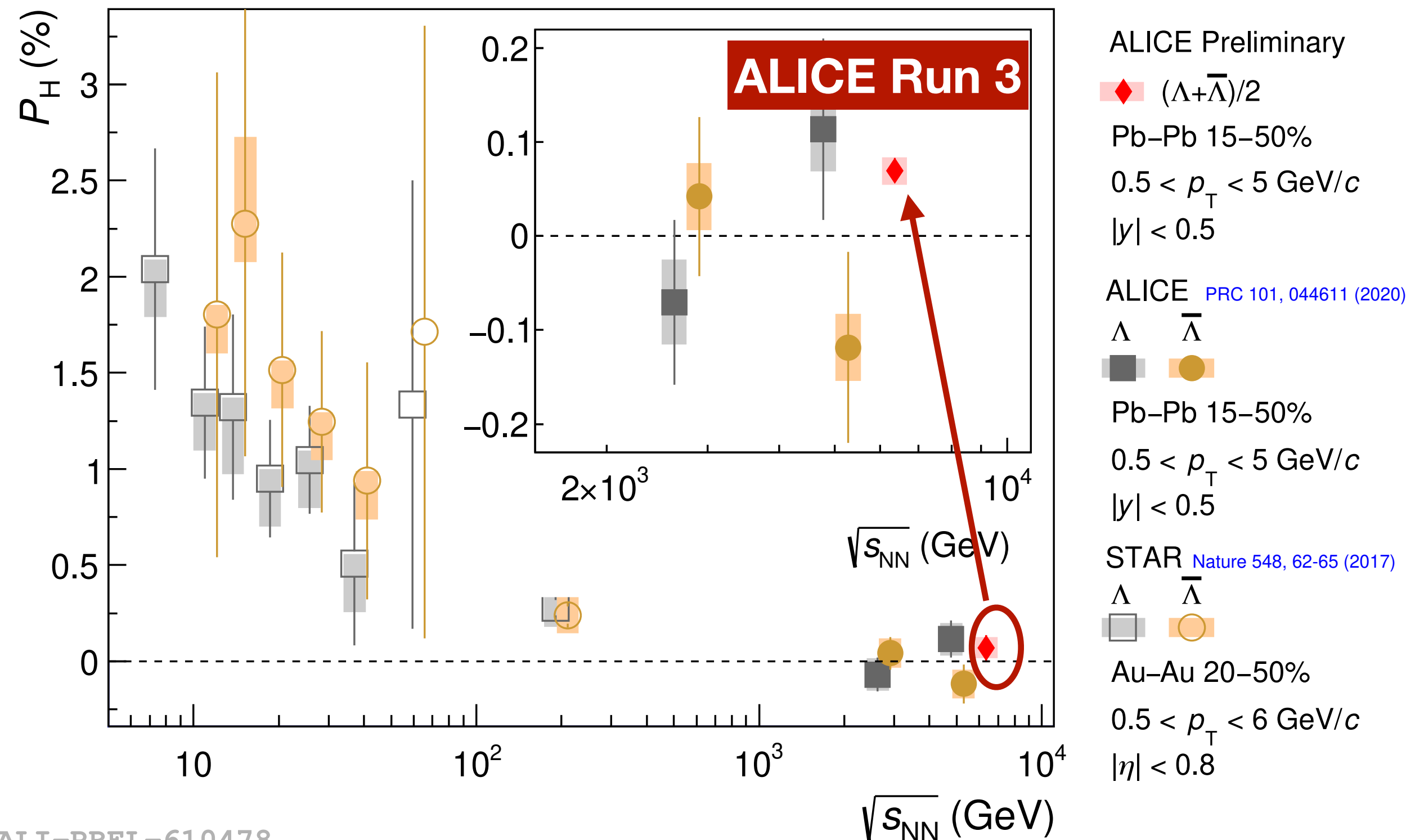
Polarization puzzle



Thermal estimation

$$\rho_{00} - 1/3 \sim \mathcal{O}(P_H^2)$$

$$P_H < 0.1\% \rightarrow \rho_{00} - 1/3 \sim 0$$



Possible mechanisms



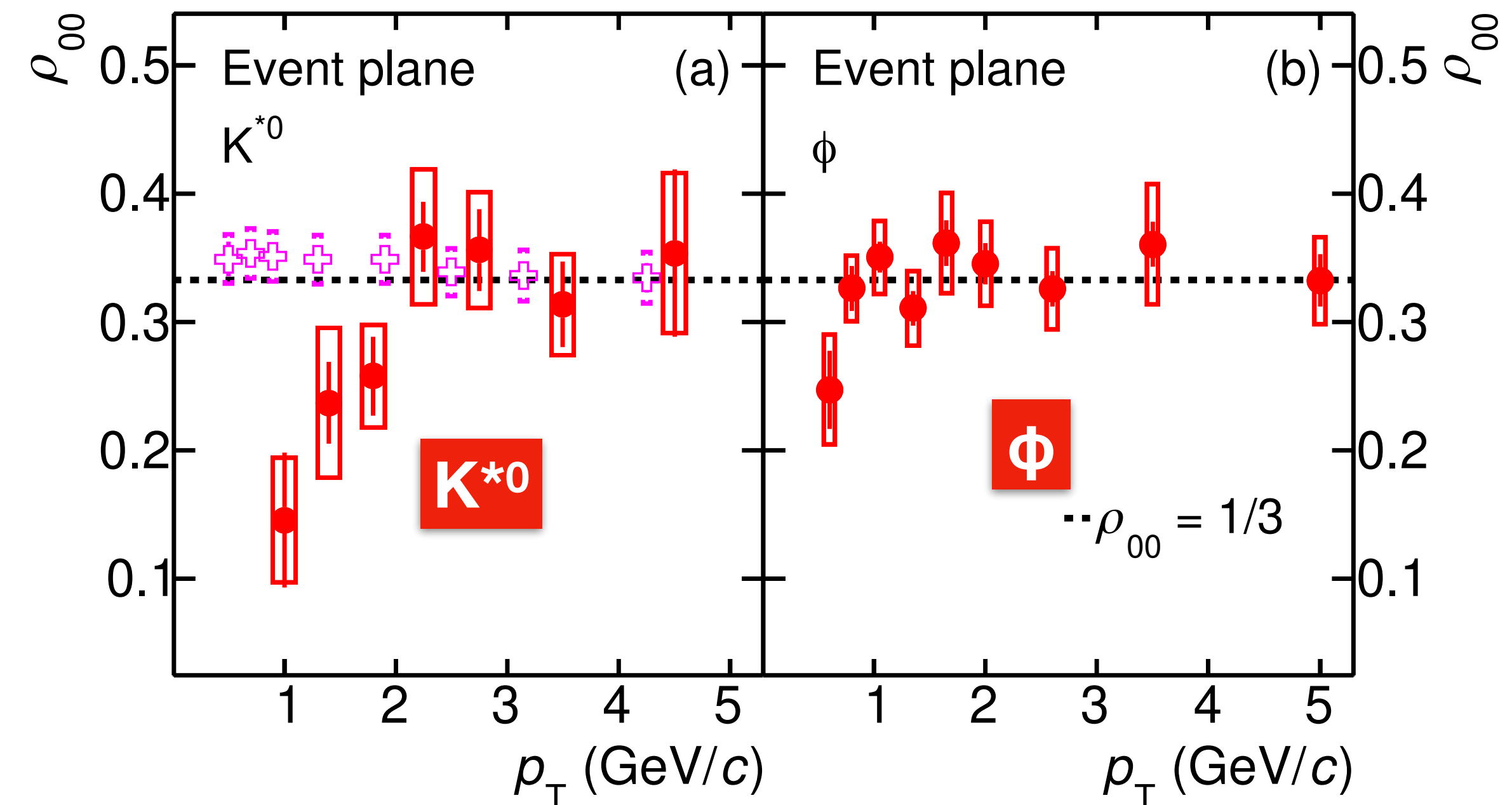
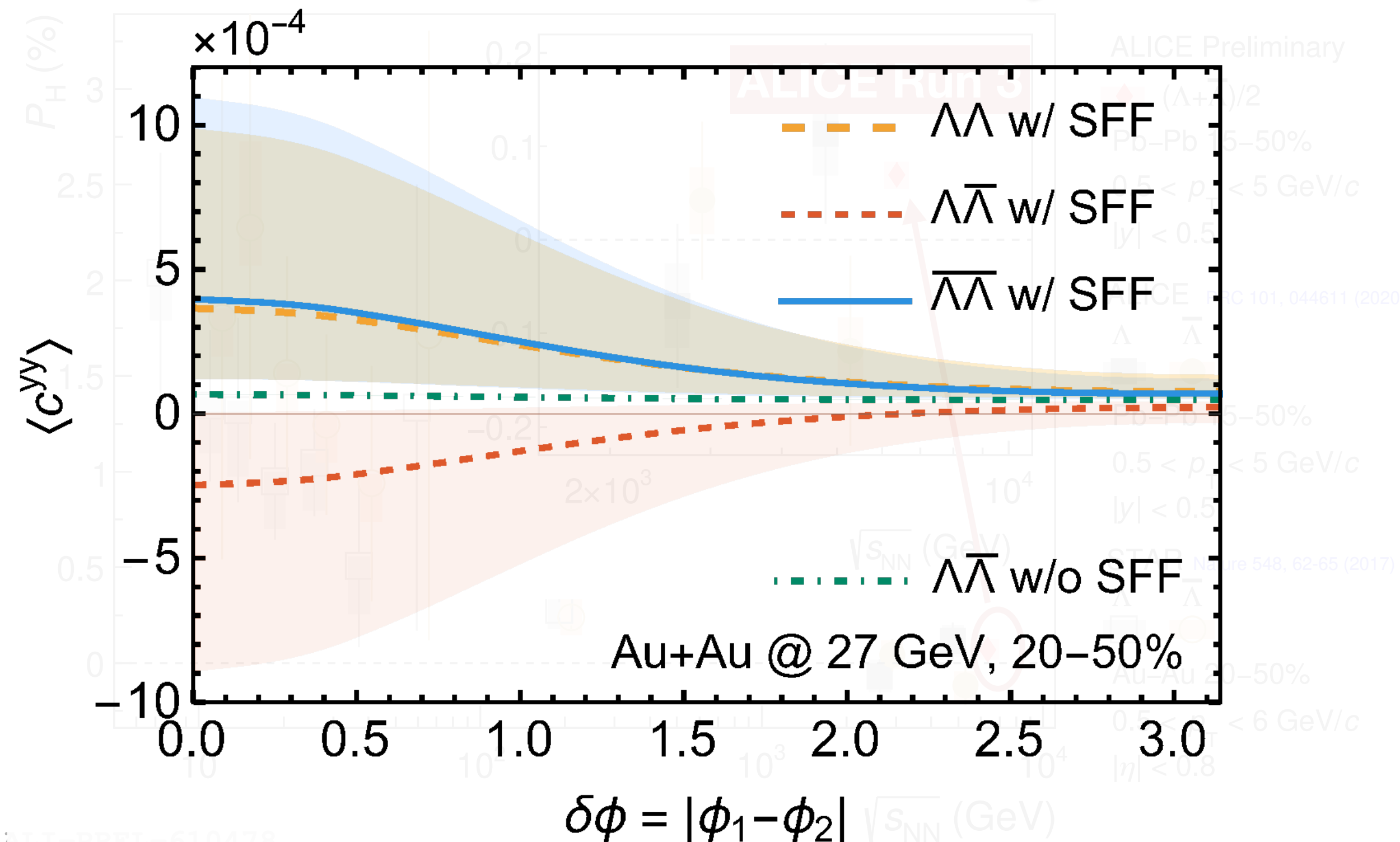
D. Hou et al., *Phys. Rev.* **D110** (2024) 056047
 A. Kumar et al., *Phys. Rev.* **D109** (2024) 054038
 Z.-T. Liang, Q. Wang, and X.-N. Wang et al., *Phys. Rev.* **D109** (2024) 114003
 A. Kumar et al., *Phys. Rev.* **D108** (2023) 016020
 B. Muller et al., *Phys. Rev.* **D105** (2022) L011901
 Q. Wang et al., *Phys. Rev.* **D105** (2022) 099903
 X.-G. Huang et al., *Phys. Lett.* **B817** (2021) 136325

Uncompleted list

Thermal estimation

$$\rho_{00} - 1/3 \sim \mathcal{O}(P_H^2)$$

$$P_H < 0.1 \% \rightarrow \rho_{00} - 1/3 \sim 0$$



ALI-PUB-520388

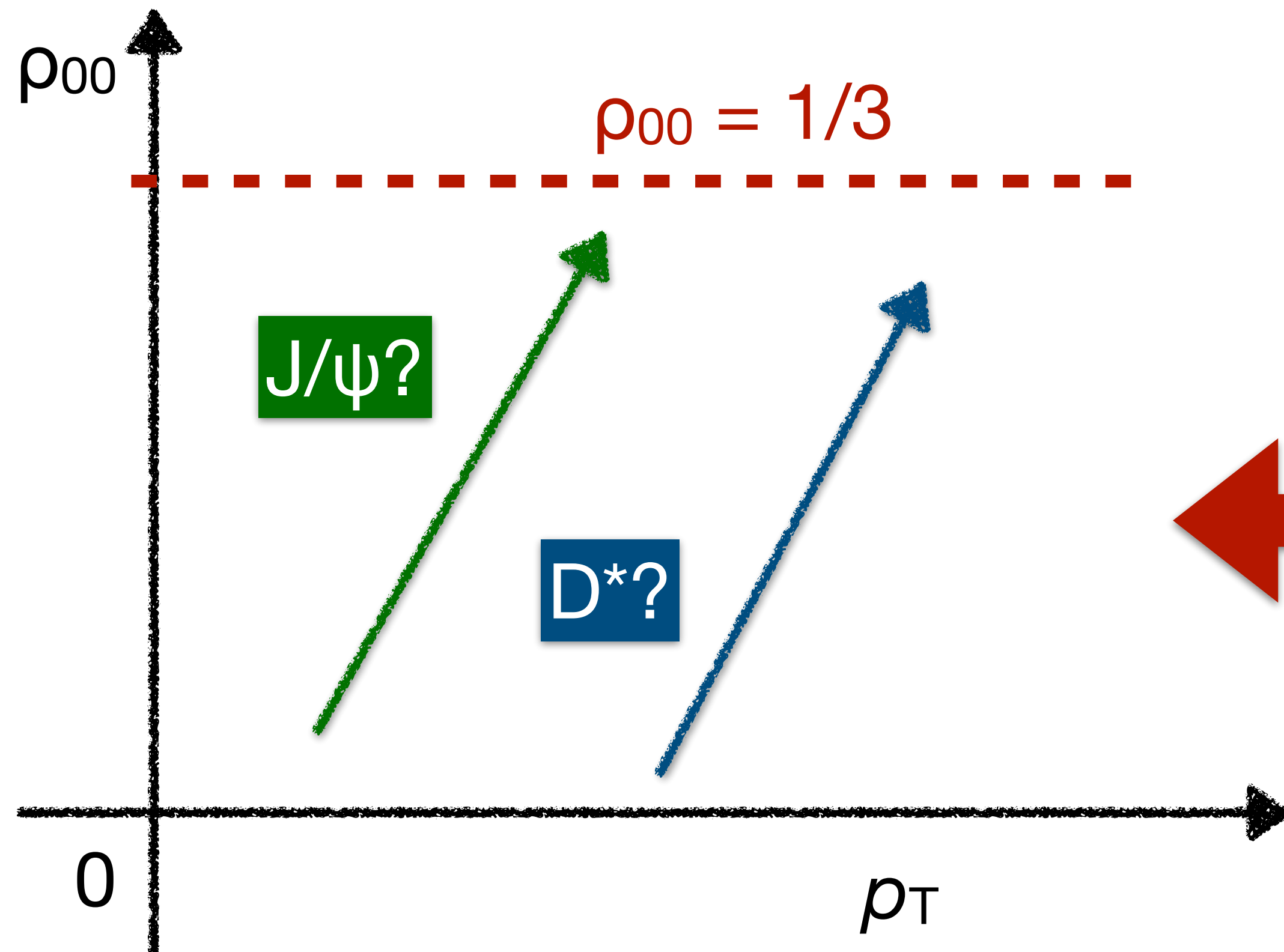
ALICE *Phys. Rev. Lett.* **125** (2020) 012301

X.-N. Wang et al., *Phys. Rev. Lett.* **136** (2026) 082301

Spin alignment of HF particles



Prediction at heavy-quark sector

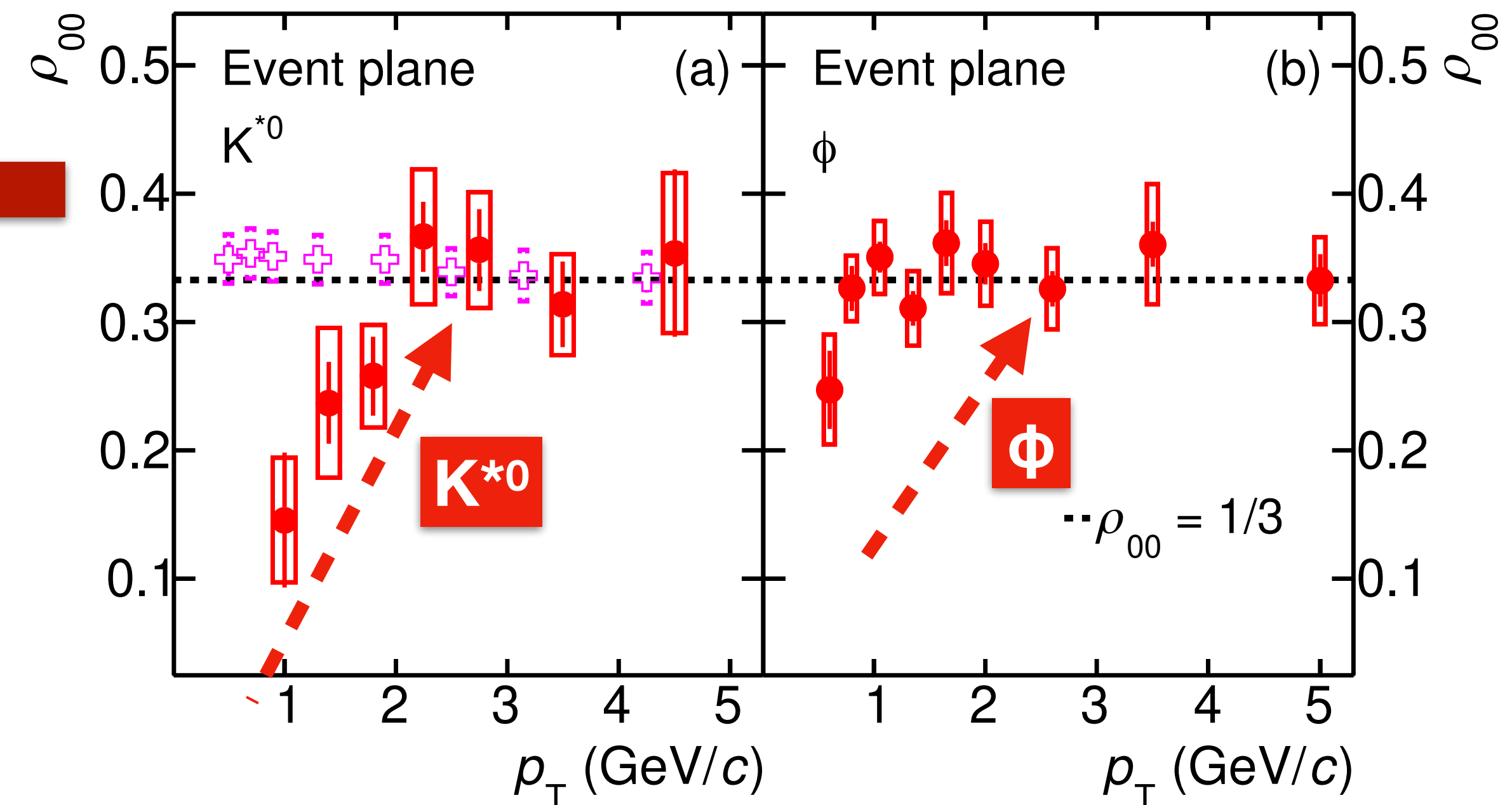


Would a similar trend show at heavy-quark sector?

Thermal estimation

$$\rho_{00} - 1/3 \sim \mathcal{O}(P_H^2)$$

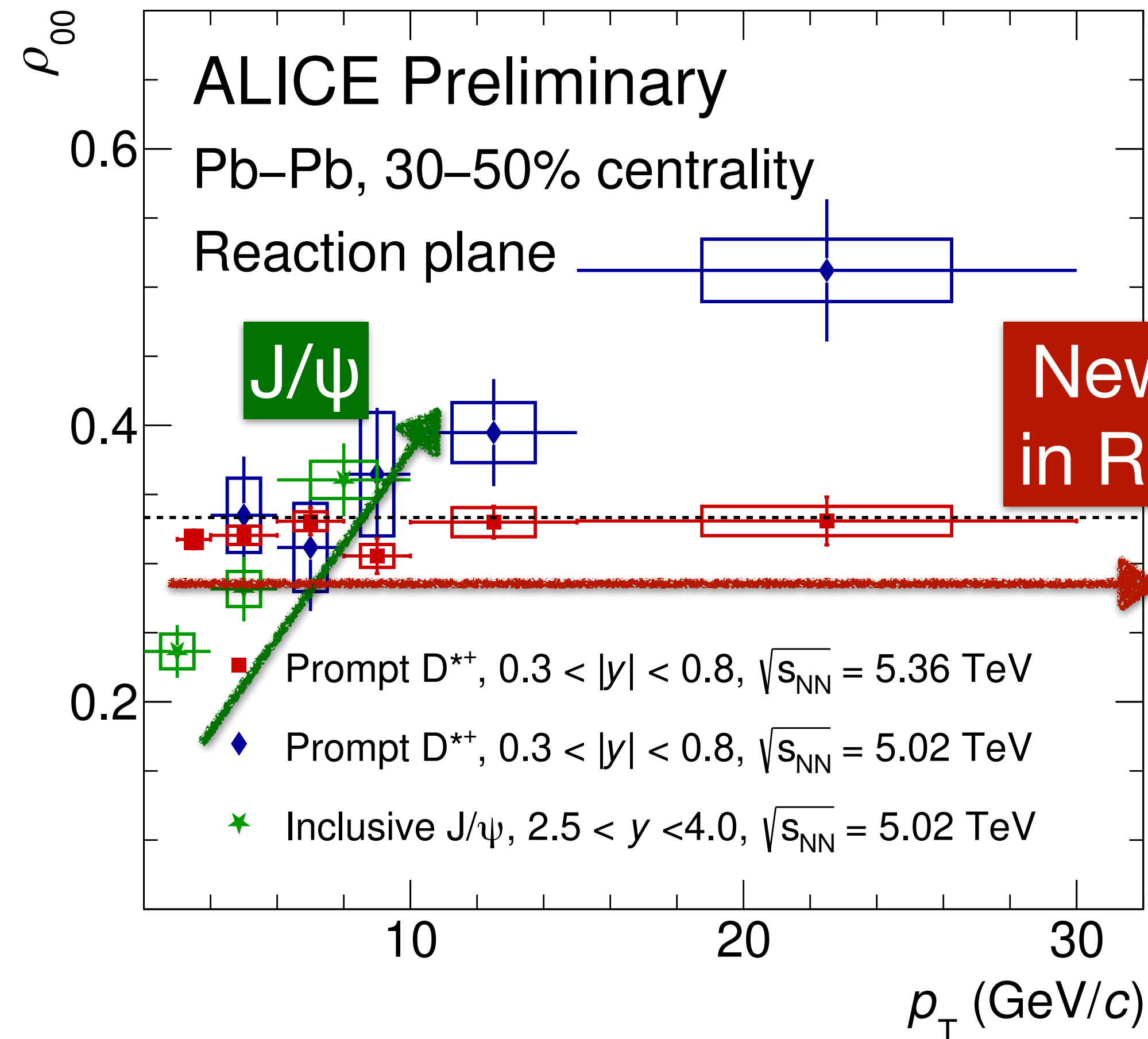
$$P_H < 0.1\% \rightarrow \rho_{00} - 1/3 \sim 0$$



ALI-PUB-520388

ALICE Phys. Rev. Lett. **125** (2020) 012301

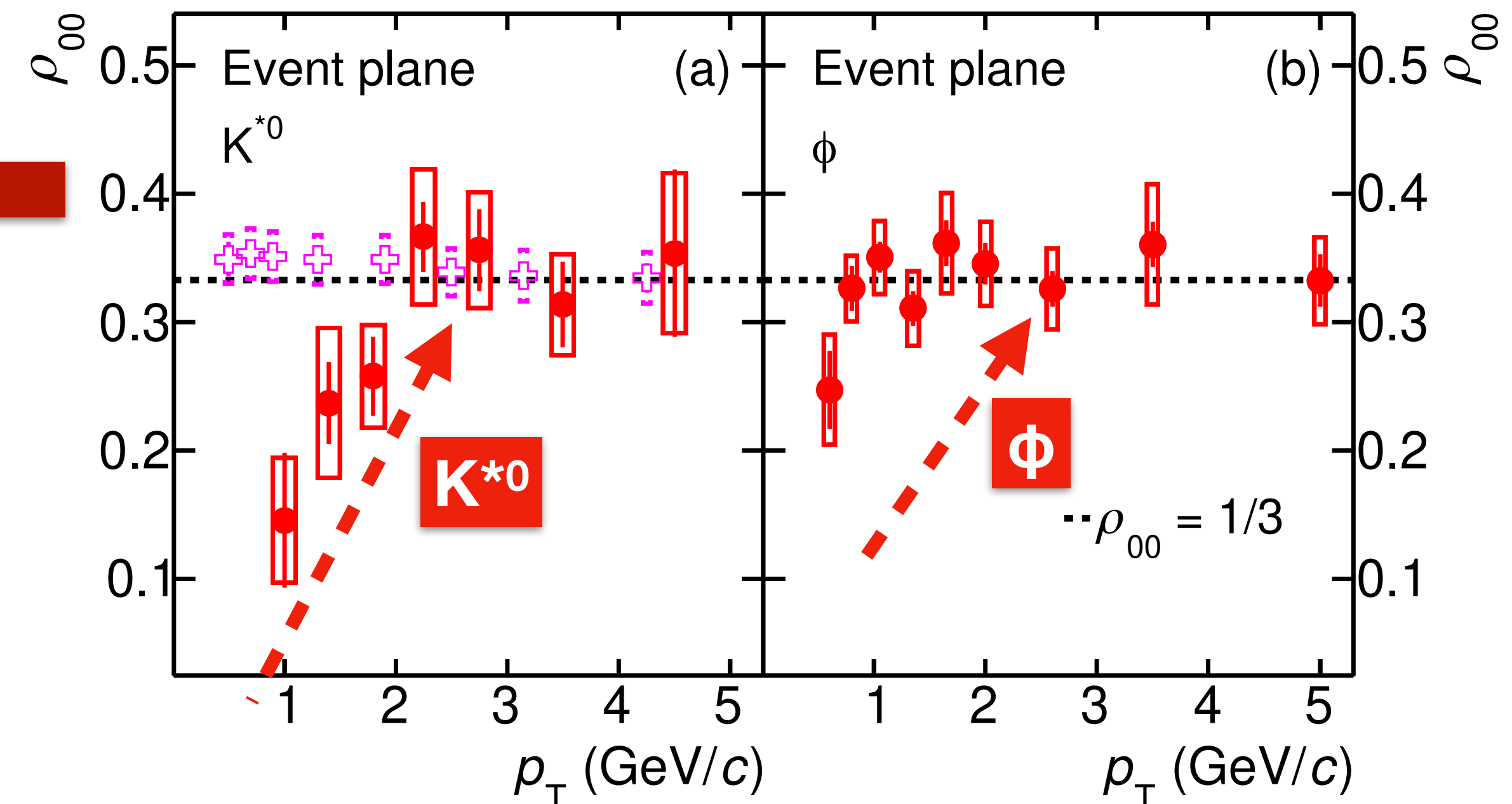
Spin alignment of HF particles



Thermal estimation

$$\rho_{00} - 1/3 \sim \mathcal{O}(P_H^2)$$

$$P_H < 0.1\% \rightarrow \rho_{00} - 1/3 \sim 0$$



ALI-PREL-633298

ALI-PUB-520388

Charm quarks exhibit different spin alignment and polarization behaviors

ALICE Phys. Rev. Lett. **125** (2020) 012301

Conclusion



With Run 3 data, ALICE has performed new and more precise measurements of hyperon polarization in Pb-Pb and OO collisions

- First observation of non-zero Λ polarization at LHC energies with 5σ
- The first measurement at the LHC of Λ longitudinal polarization induced by triangular flow is compatible with second-order one
- First measurement of Ξ longitudinal polarization in Pb-Pb, compatible with Λ and supporting the expected spin hierarchy
- First measurement of Λ longitudinal polarization in OO collisions, positive and consistent with Pb-Pb at similar multiplicities
- Vector meson spin alignment still to be understood, new efforts are ongoing

Backup



