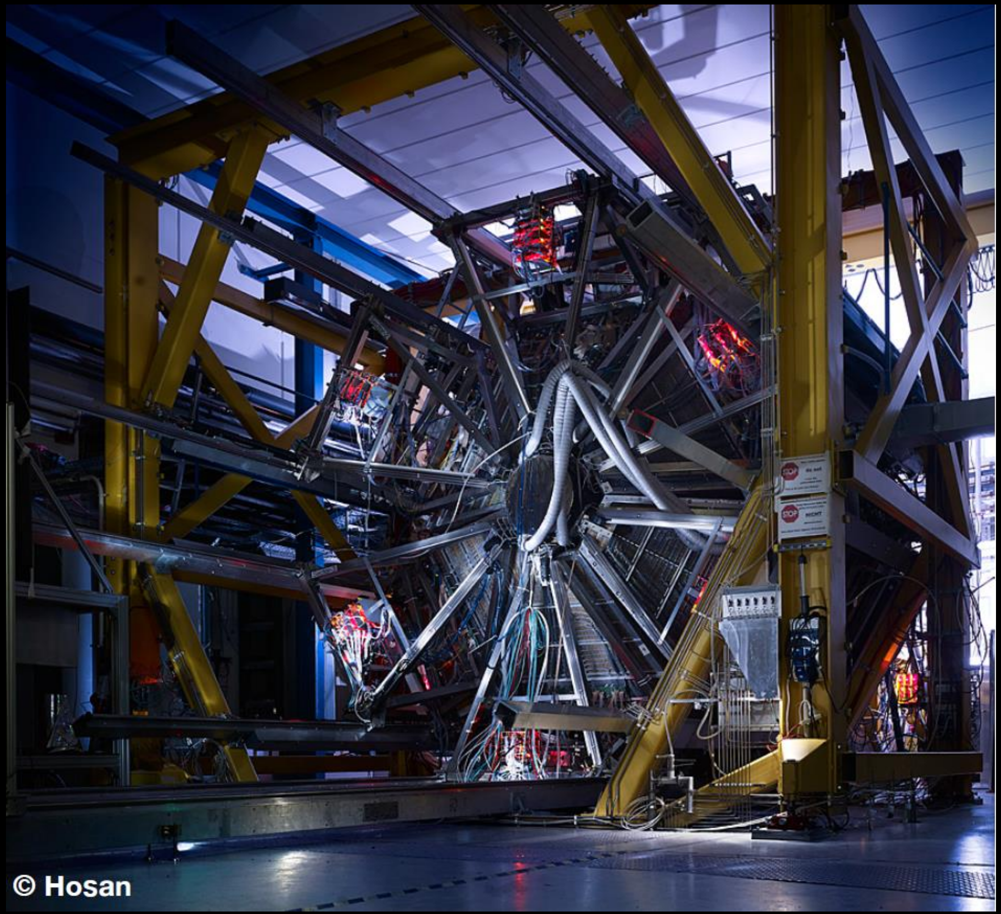
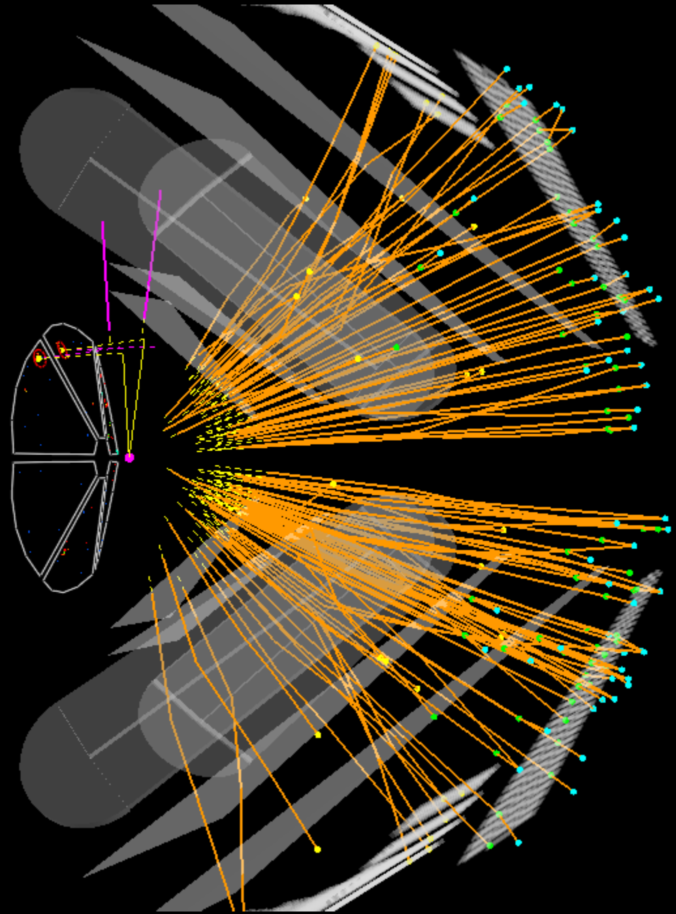
HADES results on hyperon polarization

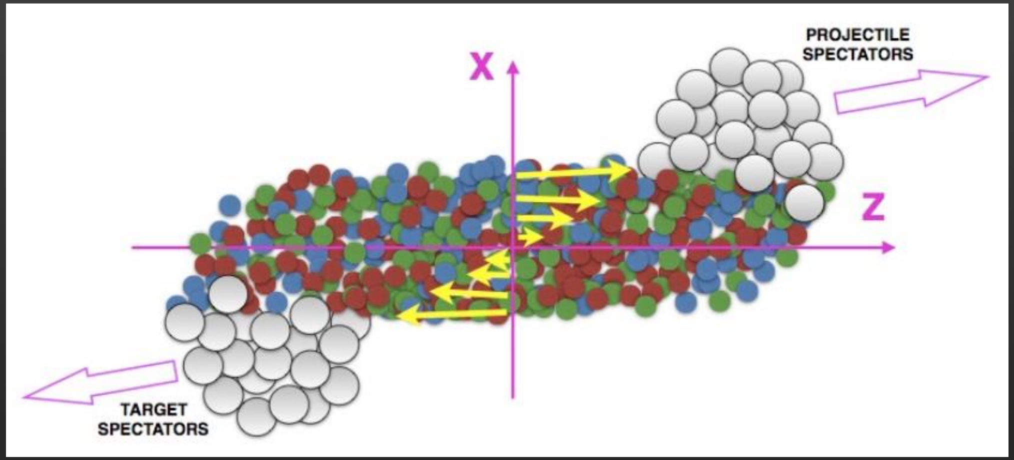




Frédéric Julian Kornas for the HADES Collaboration

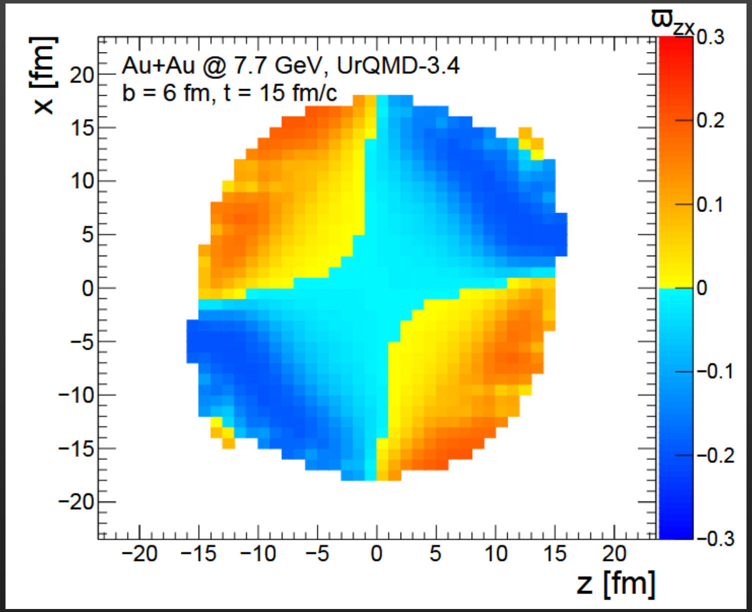
02.11.2021
6th International Conference on Chirality, Vorticity and Magnetic field in HIC

Non-central heavy-ion collisions



F. Becattini et al. Phys.Rev. C95 (2017) no.5, 054902

Thermal vorticity in xz-plane



O. Vitiuk et al., Phys.Lett.B 803 (2020) 135298

Large orbital angular momenta

$$L \sim bA\sqrt{s_{NN}} \sim 10^{4-6}\hbar$$

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

Vortical structure of the system?

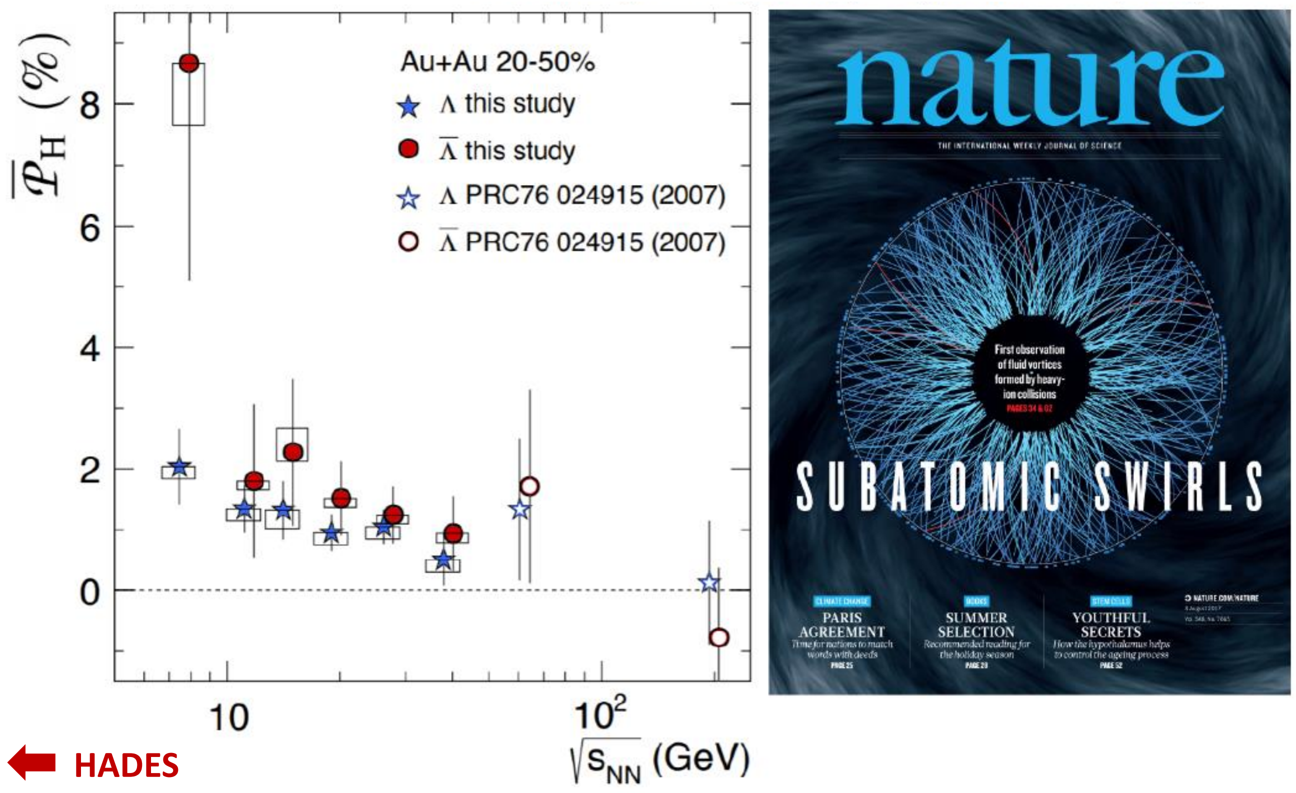
Vorticity: $\vec{\omega} = \frac{1}{2}\vec{\nabla} \times \vec{v}$

Global spin polarization of the particles? Relation to directed flow?

First measurements of the global polarization

- Increasing trend of the polarization towards lower beam energies measured by STAR collaboration
- HADES measurements of Au+Au and Ag+Ag collisions around $\sqrt{s_{NN}} \sim 2$ GeV
- What happens to the global polarization at lower collision energy?

STAR, Nature 548 (2017) 62-65.



Introduction

Observables

HADES setup

Λ reconstruction

Analysis Methods

Results

Summary

Global Polarization Measurement

- $\Lambda \rightarrow p + \pi^-$
- Proton is preferentially emitted in the direction of the Λ spin („self-analyzing“)
- $\vec{s}_\Lambda$: *Spin measurement* $\longrightarrow$ $\vec{p}_p^*$: *Momentum measurement*

$$\frac{dN}{d\Omega} = \frac{N_0}{4\pi}(1 + \alpha_\Lambda \vec{P} \cdot \vec{p}_p^*)$$

- Assuming perfect detector acceptance:

$$P_\Lambda = \frac{8}{\pi\alpha_\Lambda} \frac{\langle sin(\Psi_{EP} - \phi_p^*)\rangle}{R_{EP}}$$

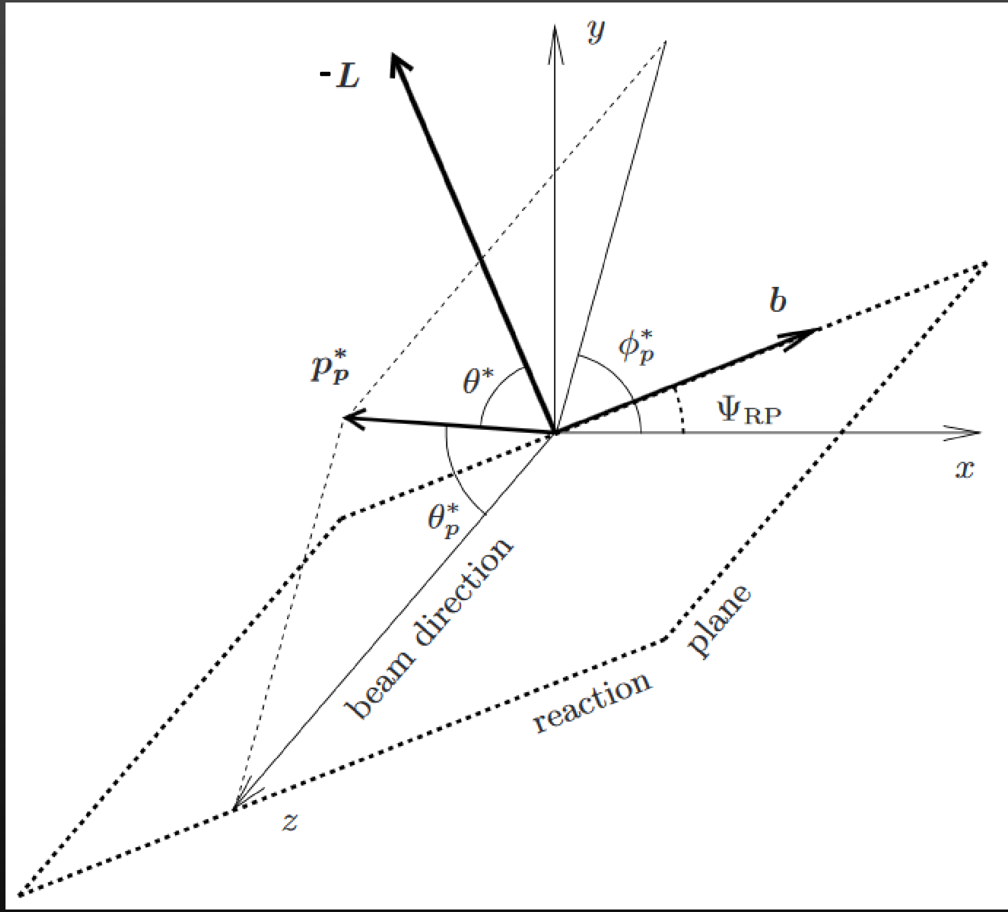
- Event plane angle Ψ_{EP} as a measure for the direction of $\vec{L}$
- Azimuthal angle of the proton in the Λ frame ϕ_p^*
- Decay parameter $\alpha_\Lambda = 0.732 \pm 0.014$

- Directed flow:

$$v_1 = \frac{\langle cos(\phi_\Lambda - \Psi_{EP})\rangle}{R_{EP}}$$

- Similar measurement technique

STAR, Phys.Rev. C76 (2007) 024915,
Erratum: Phys.Rev. C95 (2017) no.3, 039906



High Acceptance DiElectron Spectrometer

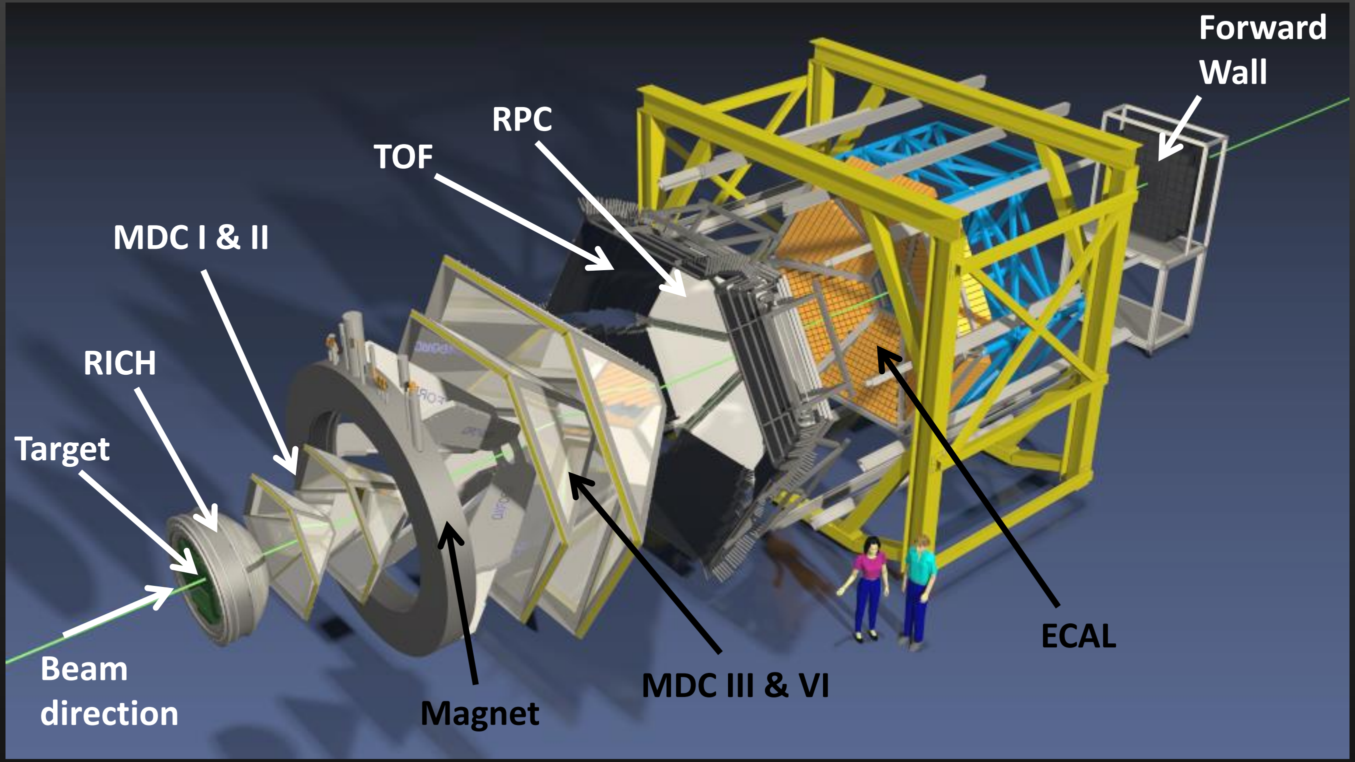
Data samples:

Au+Au 2012:

- $\sqrt{s_{NN}} = 2.4$ GeV
- $7 \cdot 10^9$ events

Ag+Ag 2019:

- $\sqrt{s_{NN}} = 2.55$ GeV
- $14 \cdot 10^9$ events



Fixed-target experiment

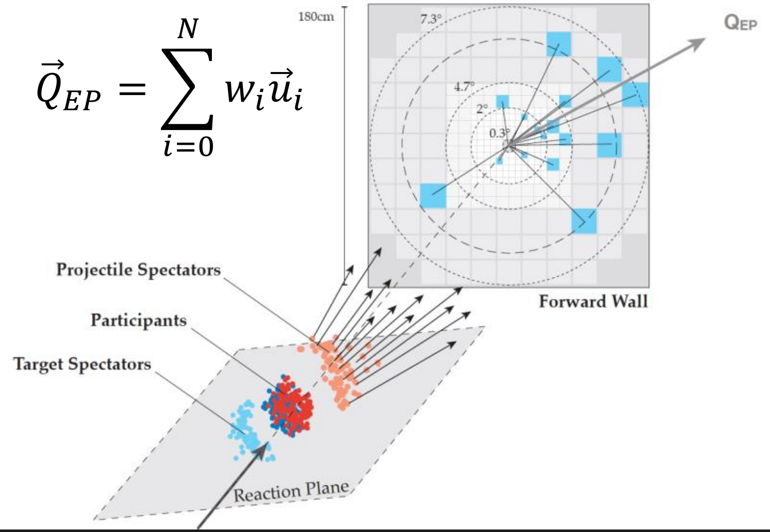
Fast detector: 10 kHz trigger rate for Au+Au, 22 kHz for Ag+Ag

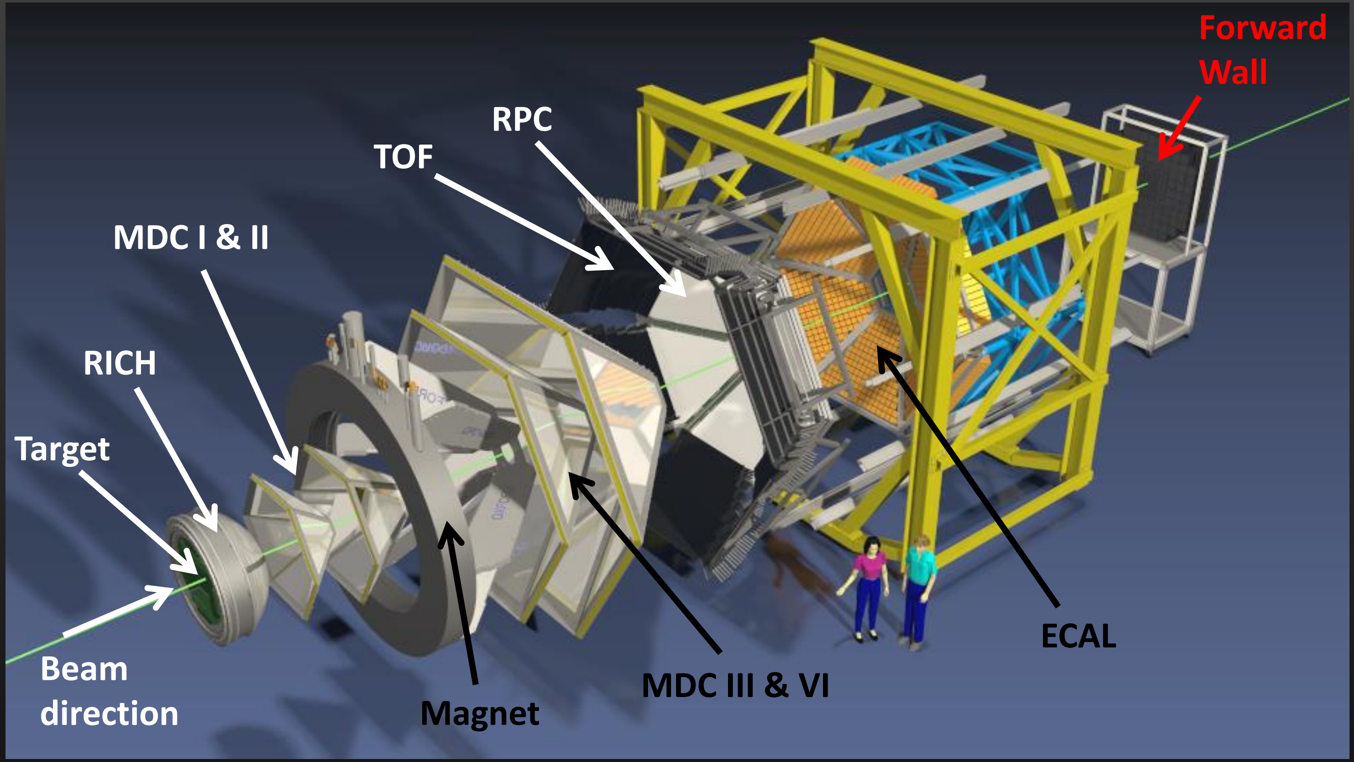
High acceptance: full azimuthal coverage, $18° - 85°$ polar angle

High Acceptance DiElectron Spectrometer

- Forward Wall: Event plane reconstruction

$$\vec{Q}_{EP} = \sum_{i=0}^{N} w_i \vec{u}_i$$





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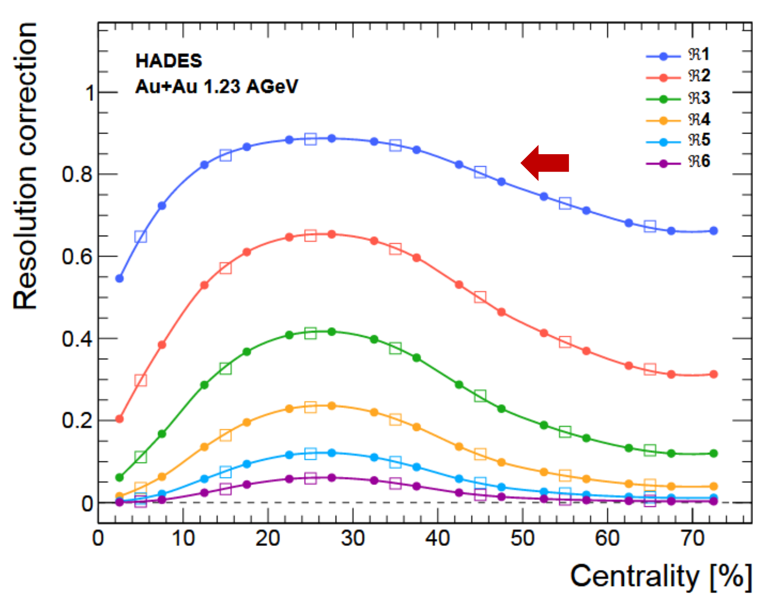
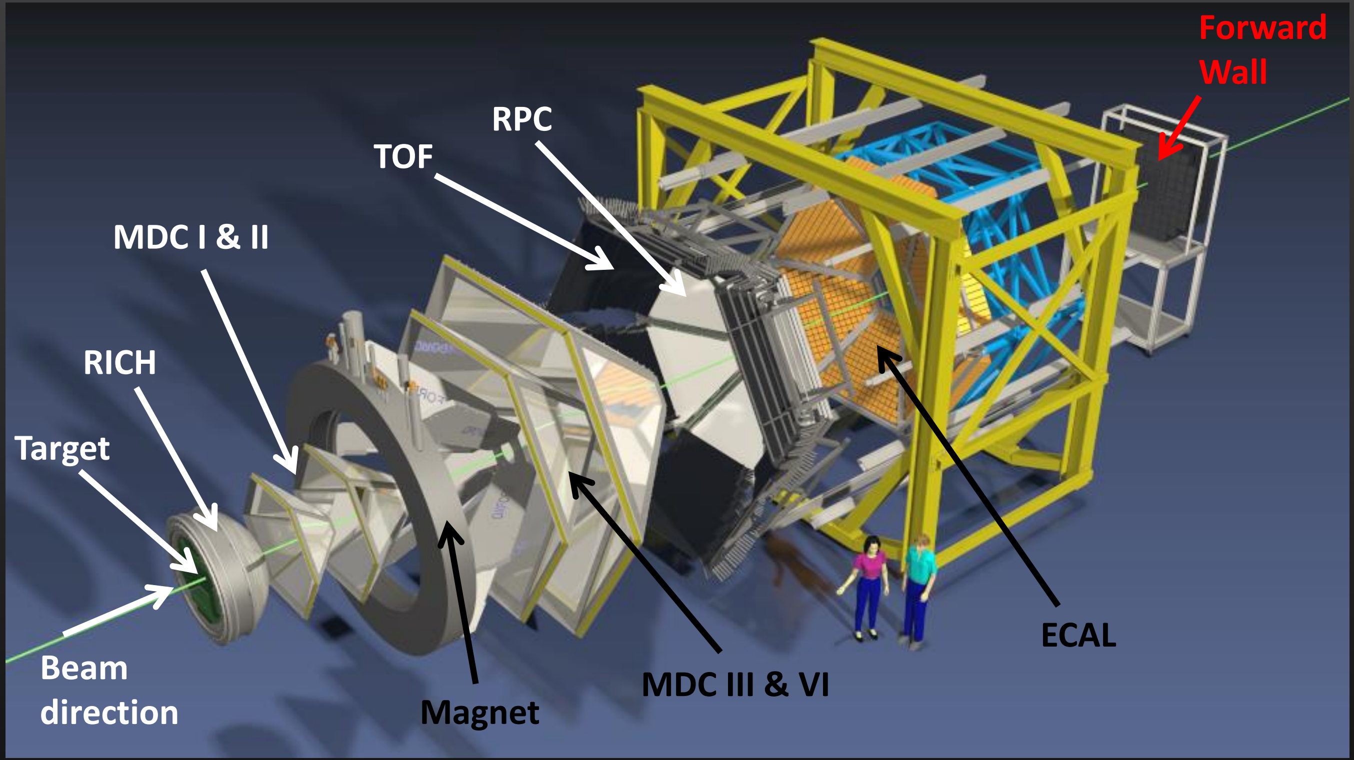
Event plane resolution ⇒ Sub-event method

J.-Y. Ollitrault, Nucl. Phys. A638 (1998) 195-206.

HADES, Phys.Rev.Lett 125 (2020) 262301.





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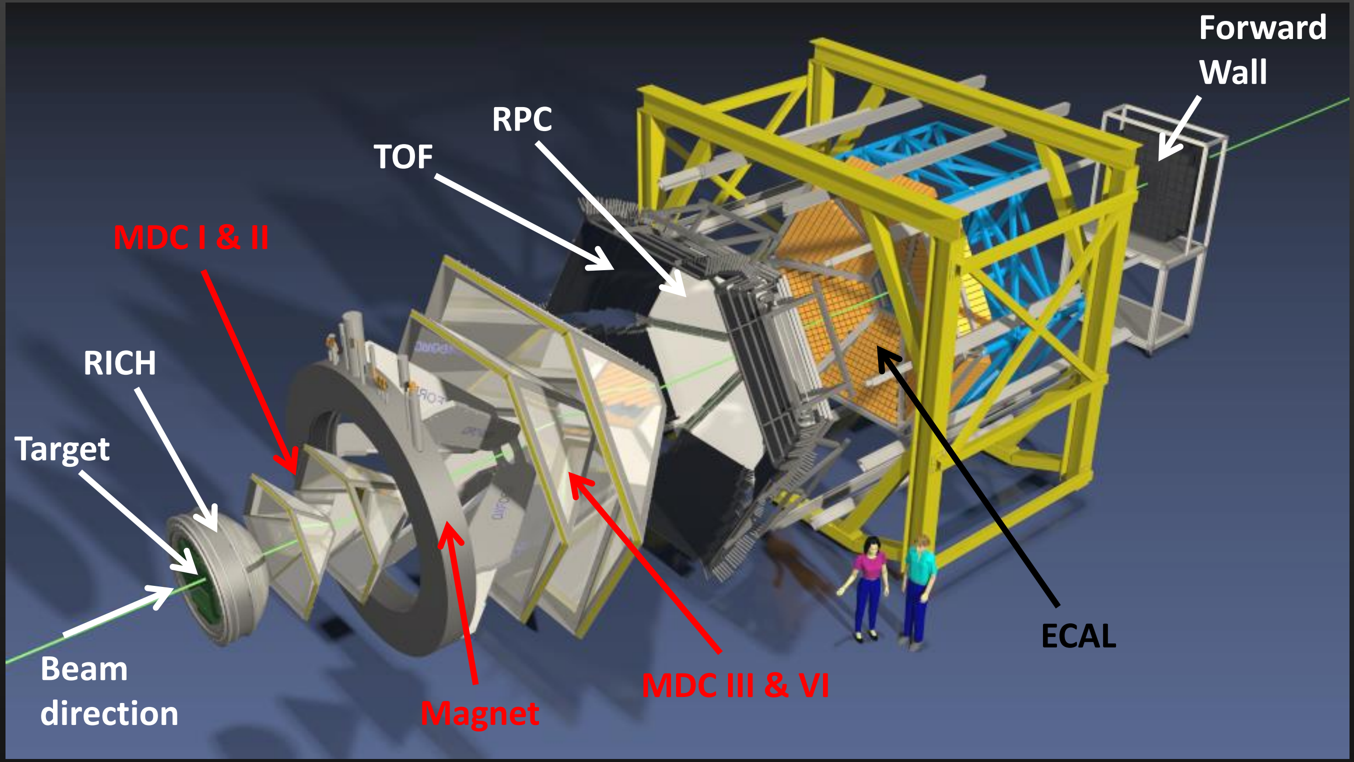
- MDCs+Magnet:
Tracking and momentum measurement



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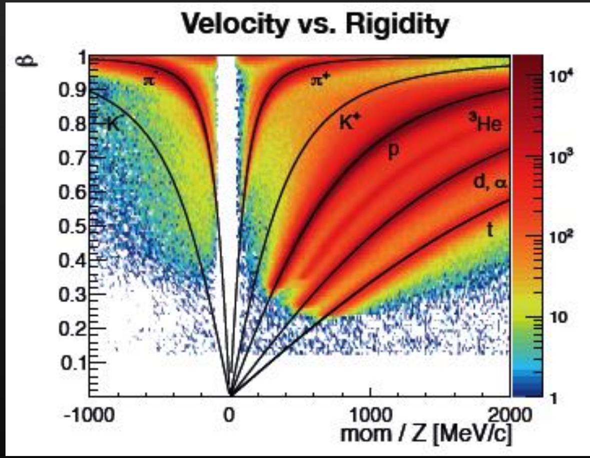
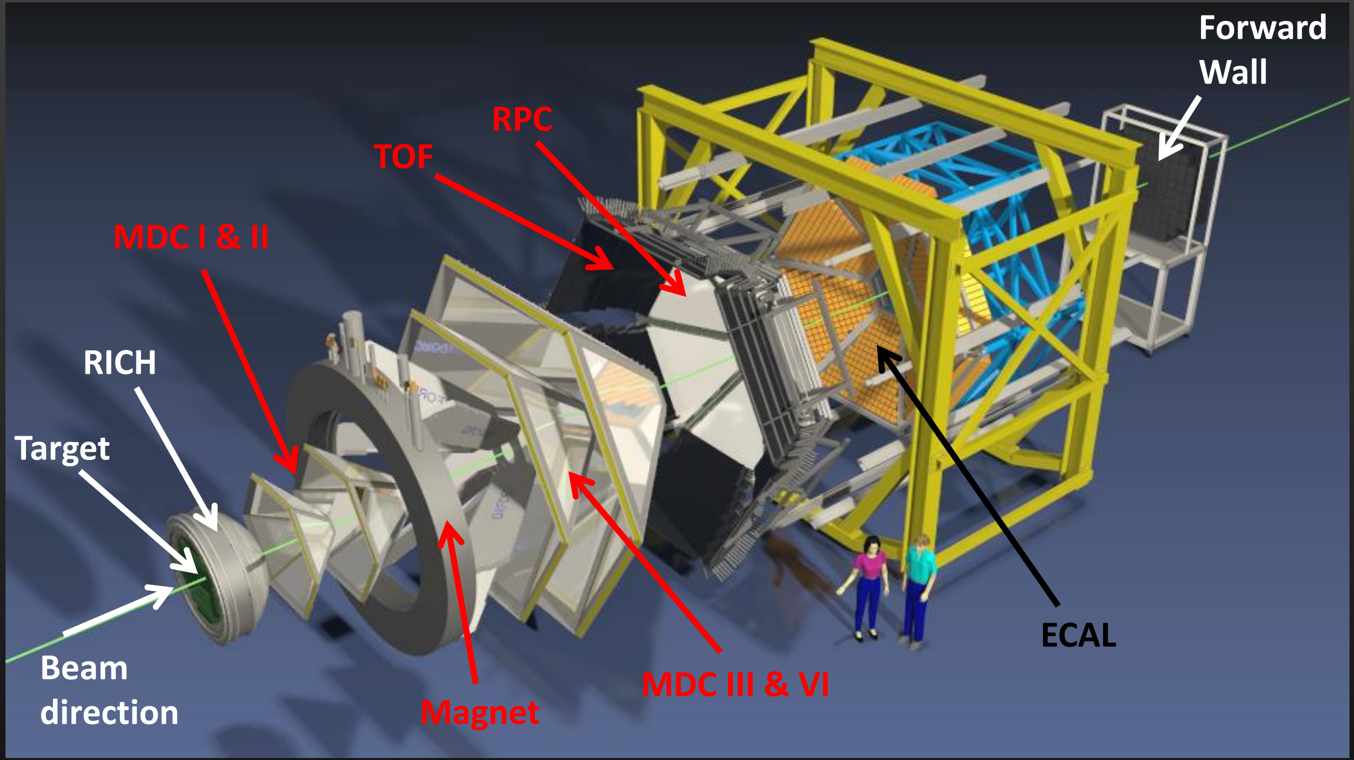
Tracking and momentum measurement

- +TOF/RPC:
Particle Identification





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J.-Y. Ollitrault, Nucl. Phys. A638 (1998) 195-206.

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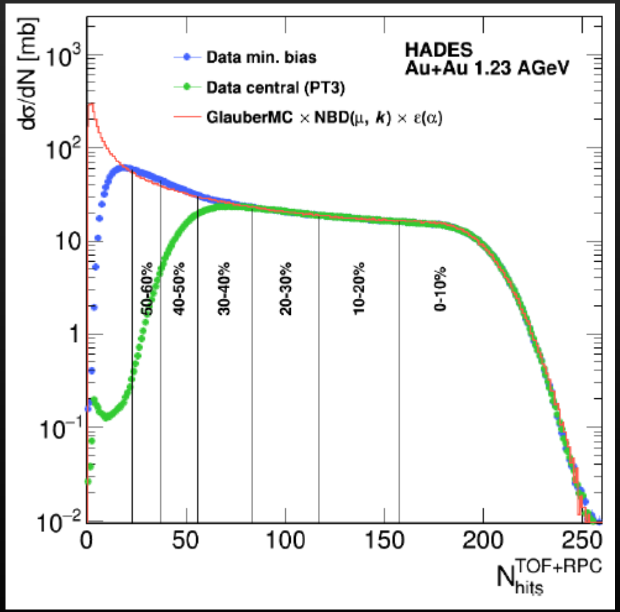
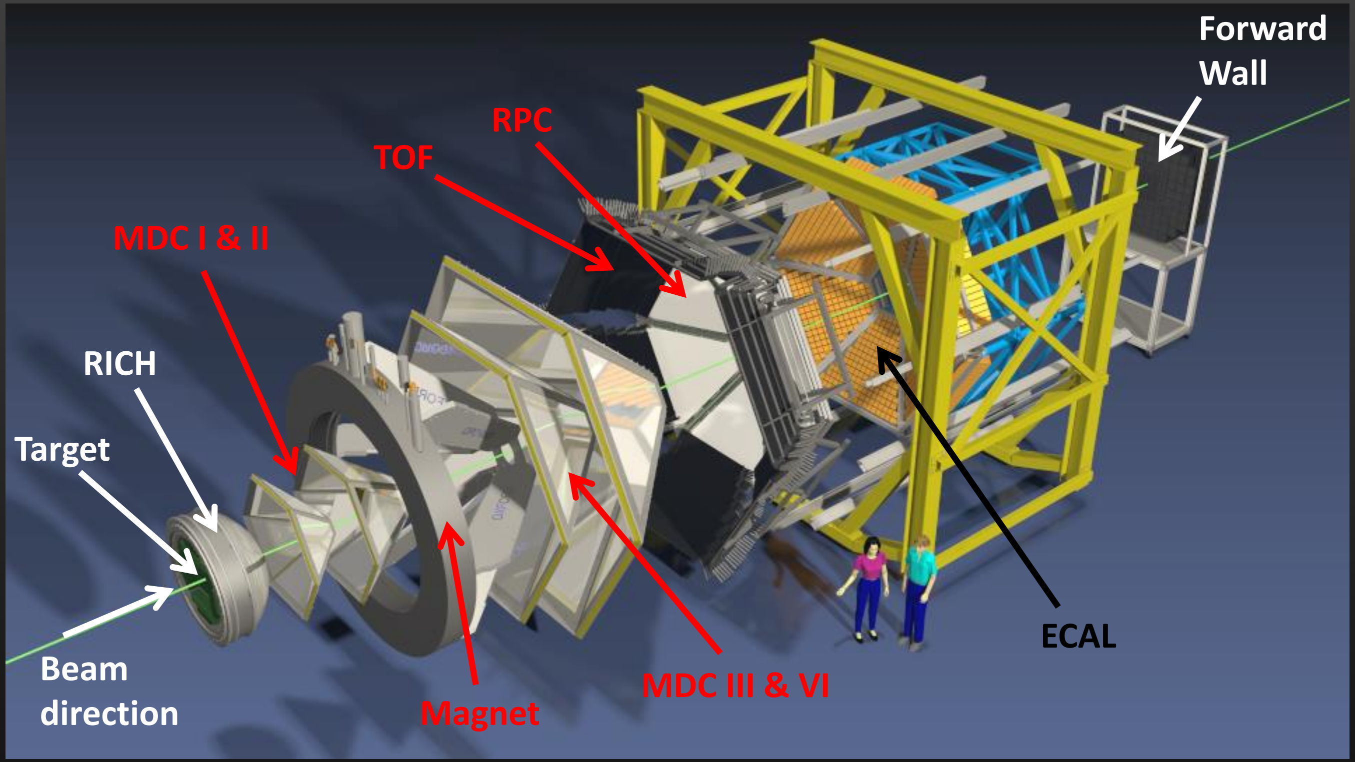
Centrality determination based on Glauber MC



Eur. Phys. J. A54 (2018) 85



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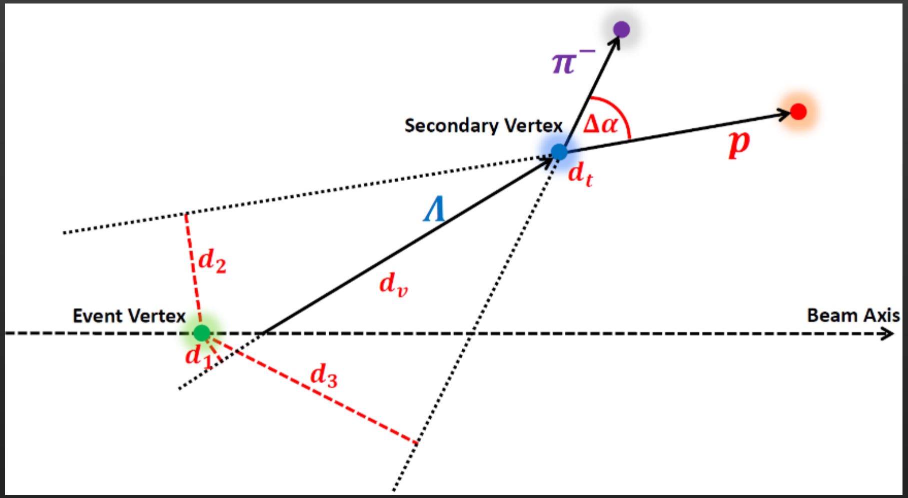
Λ Reconstruction

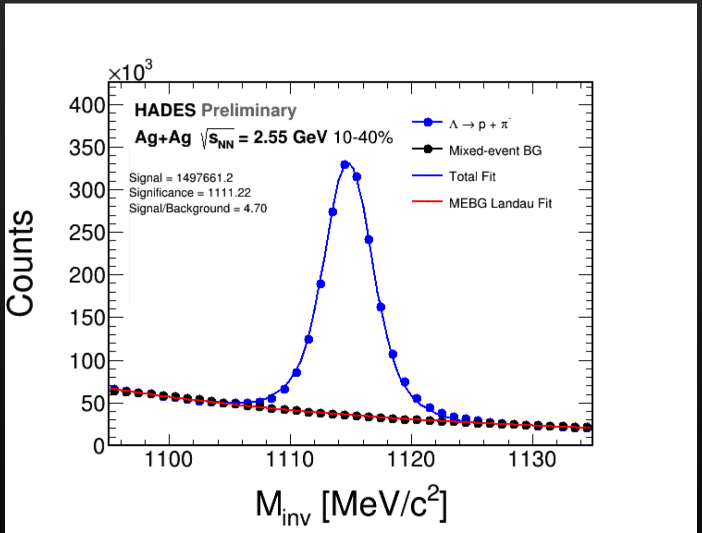
Decay Topology



- **Topology parameters:**
  - d_1: Λ has to come from the primary vertex
  - d_2, d_3: p and π^- are most likely not pointing to the collision vertex
  - d_t: common crossing point for p and π^- track
  - d_v: Λ distance before decay ($c\tau \sim 8$ cm)
  - $\Delta\alpha$: Opening angle, accounts for efficiency loss of closed pairs
- **Additionally:** m_{π^-}, m_p

- Fed into neural network to maximize significance of the signal

  $\Rightarrow$ Factor $\sim$ 3 more signal compared to hard-cut analysis!



Method to extract the Λ polarization

$$P_\Lambda = \frac{8}{\pi\alpha_\Lambda}\frac{\langle \sin(\Psi_{EP} - \phi_p^*)\rangle}{R_{EP}}$$

- Extract the correlator as a function of the invariant mass:

$$C_{tot} = \langle \sin(\Delta\phi_p^*)\rangle_{tot} \quad , \quad C_{tot} = C_{tot}(M_{inv})$$

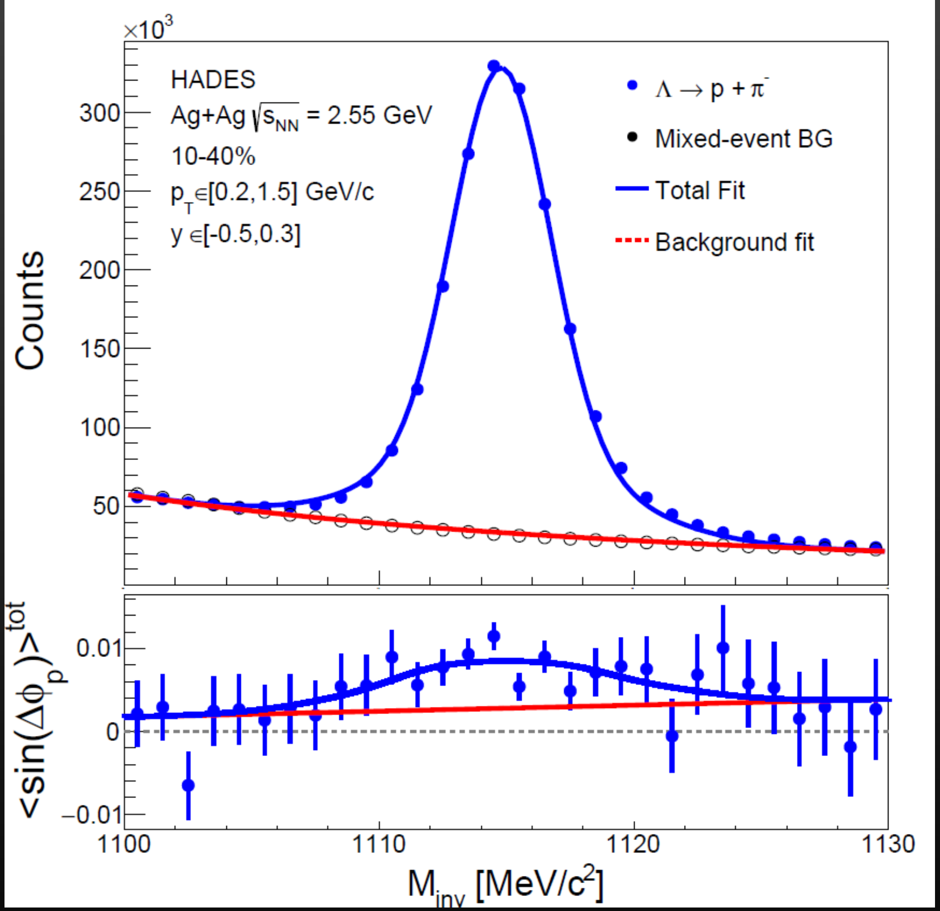
- Signal- and background fractions are known from invariant mass distribution:

$$f_{SG}(M_{inv}) = \frac{S}{S+B} \quad , \quad f_{BG}(M_{inv}) = \frac{B}{S+B}$$

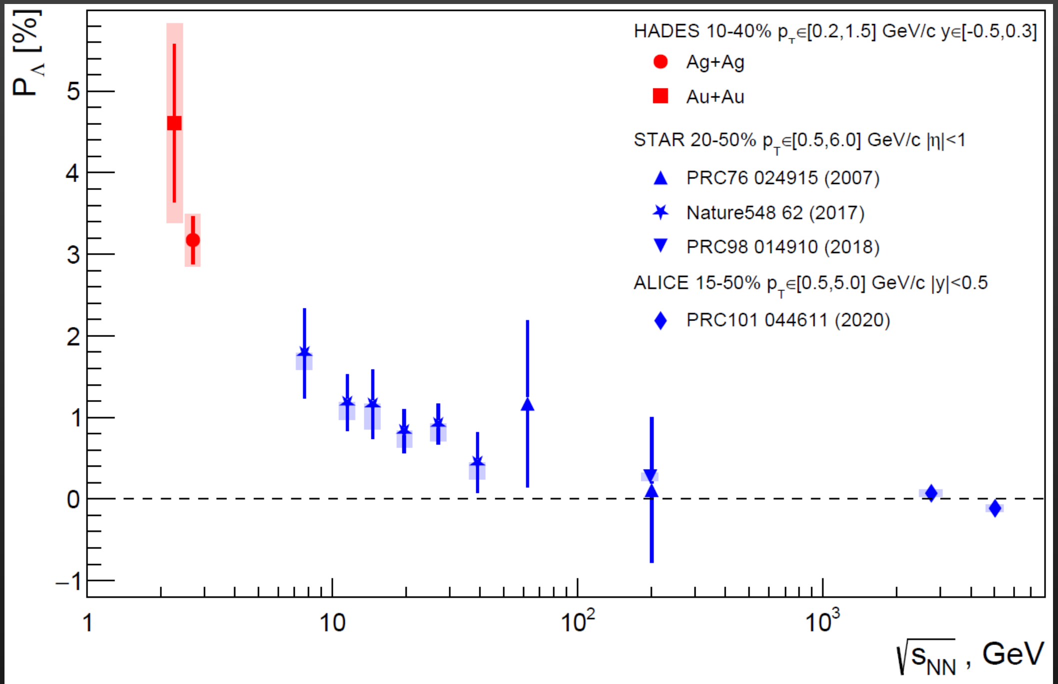
- $C_{tot}(M_{inv})$ has two contributions: C_{SG}, C_{BG}
- Assumptions:

1. Signal correlator does not depend on M_{inv}
2. Background correlator behaves smoothly and can be determined from the sidebands

$$C_{tot} = f_{SG}(M_{inv}) \cdot C_{SG} + f_{BG}(M_{inv}) \cdot C_{BG}(M_{inv})$$



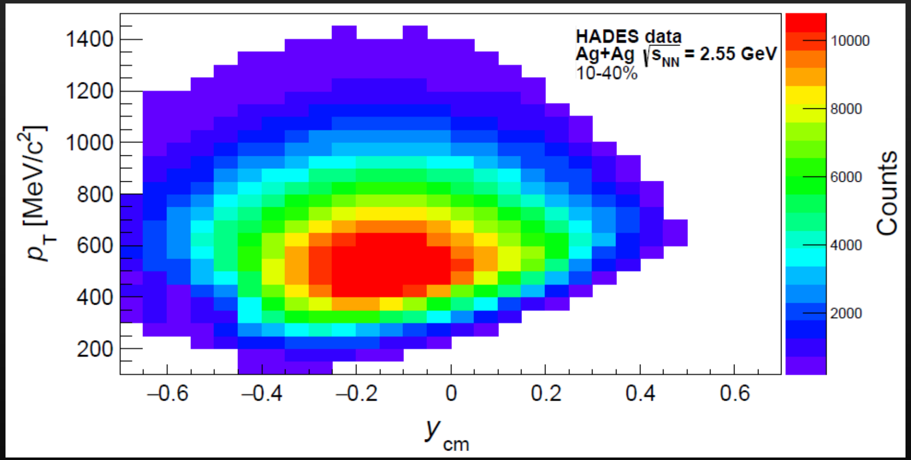
HADES Results on Global Λ Polarization



- Smaller statistics and more combinatorial background in the Au+Au collisions:

$$\left(\frac{S}{B}\right)_{Au} \approx 2.3 \text{ vs. } \left(\frac{S}{B}\right)_{Ag} \approx 4.7$$

- First estimation of the effect of the system size, Ag+Ag vs. Au+Au
- High precision measurement of the Λ polarization in Ag+Ag: allows for multi-differential measurements



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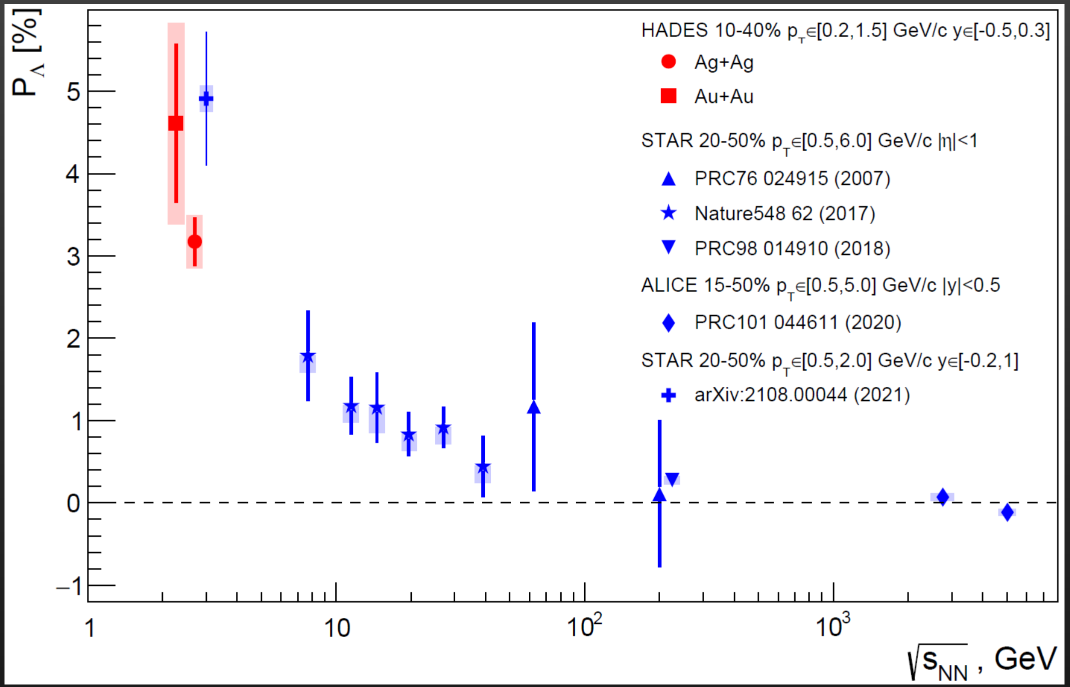

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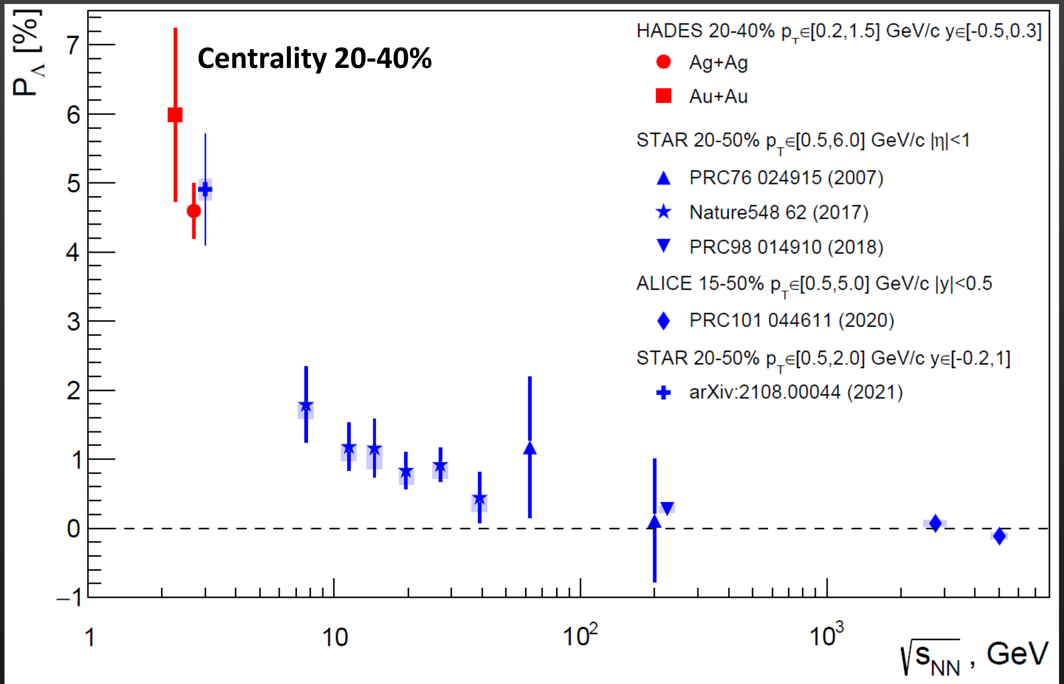
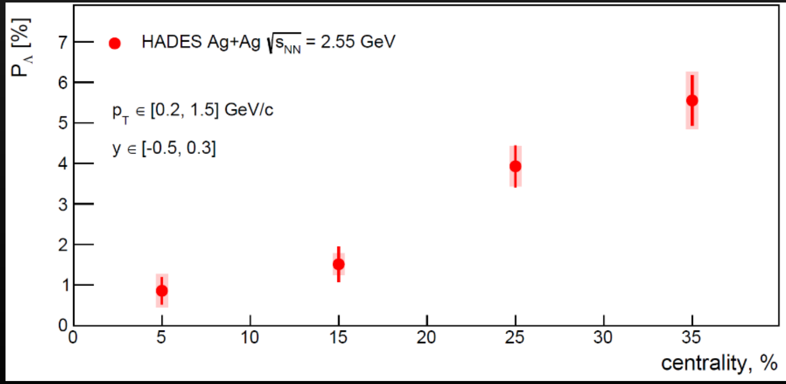
- Large global polarization of Λ hyperons measured in HIC, following the increasing trend by STAR BES I
- Similar magnitude measured by STAR FXT run at $\sqrt{s_{NN}} = 3\ GeV$ **(different centrality range!)**

HADES Results on Global Λ Polarization





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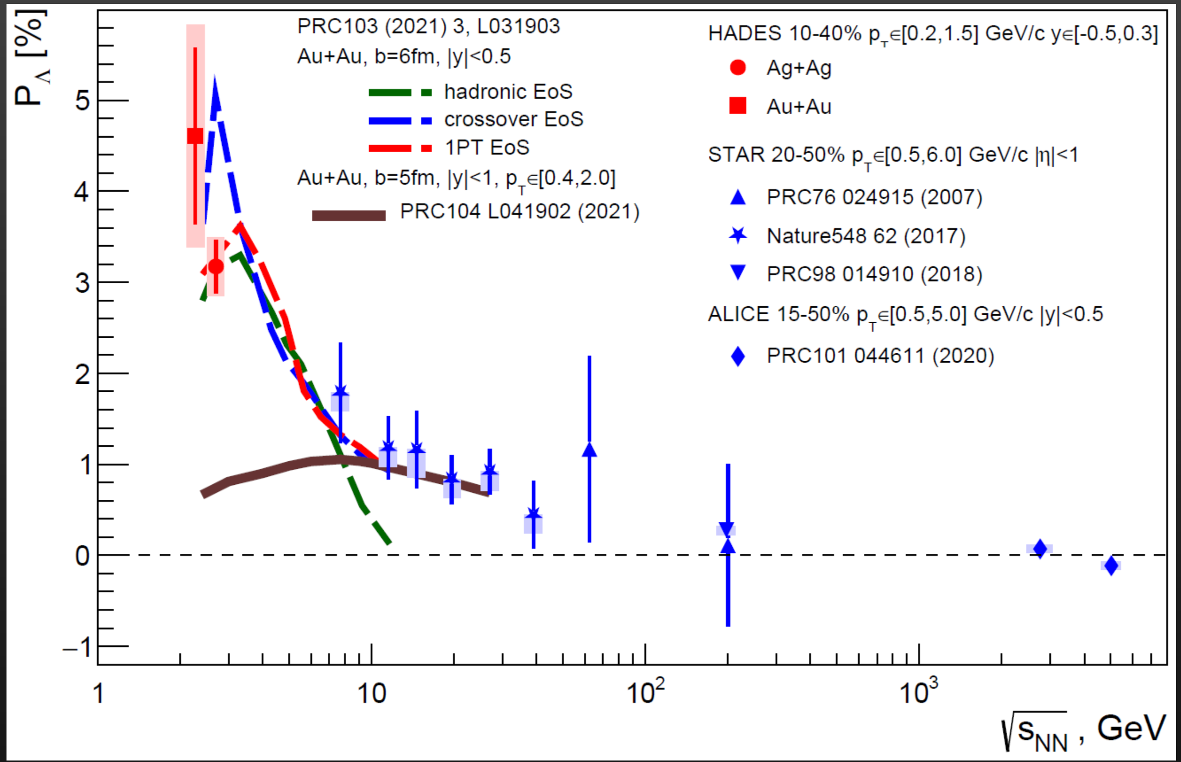
- Similar magnitude measured by STAR FXT run at $\sqrt{s_{NN}} = 3\ GeV$ **(different centrality range!)**
- **Strong increase of the polarization with centrality: Removal of 10-20% centrality bin results in a significant increase of the integrated polarization:**

$$\frac{\Delta \mathbf{P}}{\mathbf{P}} \approx +30\%$$

HADES Results on Global Λ Polarization



Comparison to theory calculations:

- 3D-fluid-dynamics:
  - Thermodynamic approach
  - Two counterstreaming baryon-rich fluids to take into account non-equilibrium effects
  - **Calculations consistent with HADES data, predict maximum of Λ polarization around $\sqrt{s_{NN}} \sim 3$ GeV**
- AMPT model calculations:
  - Based on thermal vorticity:

$$\widetilde{\omega}_{\mu\nu} = \frac{1}{2}\left(\partial_\nu \frac{u_\mu}{T} - \partial_\mu \frac{u_\nu}{T}\right)$$

  - T – proper temperature; u^μ — fluid four velocity
  - Relating it locally to the mean spin vector:

$$S^\mu = -\frac{1}{8m}\epsilon^{\mu\nu\rho\sigma} p_\nu \widetilde{\omega}_{\rho\sigma}$$

  - Implemented within AMPT model calculations
  - **Underprediction of Λ polarization at lower center-of-mass energies**

HADES Results on Global Λ Polarization

- Polarization increases towards peripheral events as expected due to the larger orbital angular momentum:

$$L \sim bA\sqrt{s_{NN}} \sim 10^{4-6}\ \hbar$$

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

- Slightly decreasing trend towards higher transverse momenta
- No significant rapidity dependence observed within HADES acceptance
- Well in agreement with theory calculation:

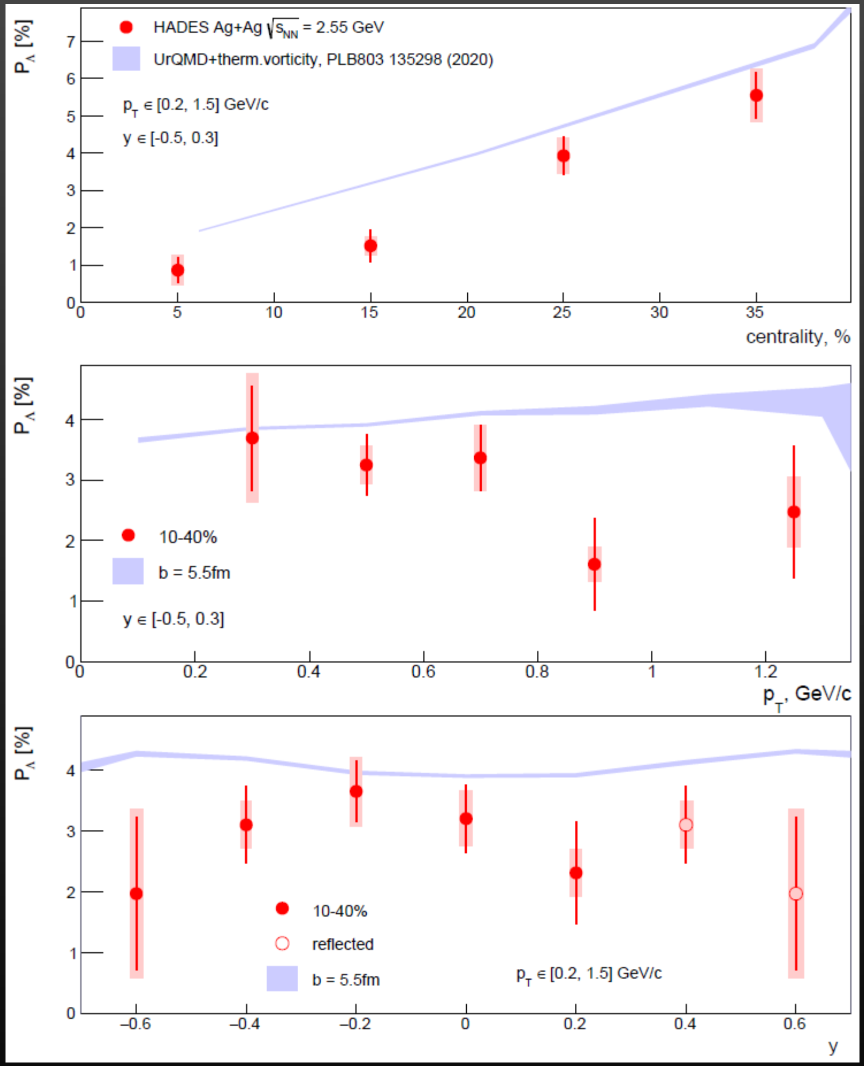
O. Vitiuk et al., Phys.Lett.B 803 (2020) 135298

  - Assuming local equilibrium, relating particle spin vector to the thermal vorticity:

$$S^{\mu} = -\frac{1}{8m}\epsilon^{\mu\nu\rho\sigma} p_{\nu}\tilde{\omega}_{\rho\sigma}$$

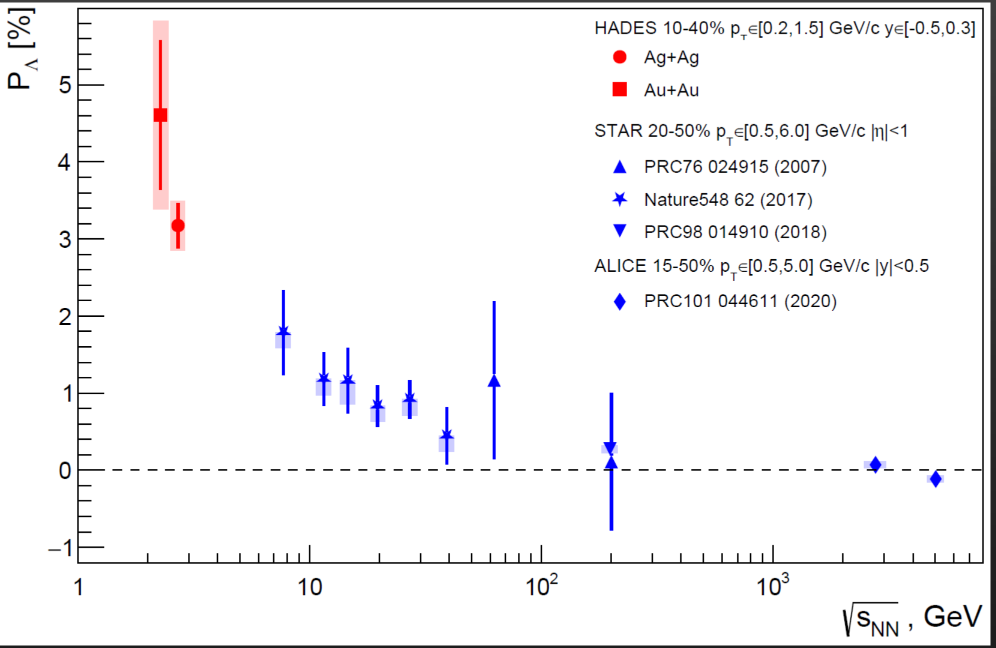
  - Implemented within UrQMD model calculations

- Theory calculation almost constant over p_t down to 100 MeV/c: Should $P_{\Lambda} \sim 0$ at $p_t \sim 0$?



Summary

- Large global polarization of Λ hyperons at the low $\sqrt{s_{NN}} \sim 2.5$ GeV
  - Multi-differential analysis of P_Λ in Ag+Ag collisions
  - Good model description of P_Λ at HADES
- First hints for system-size dependence



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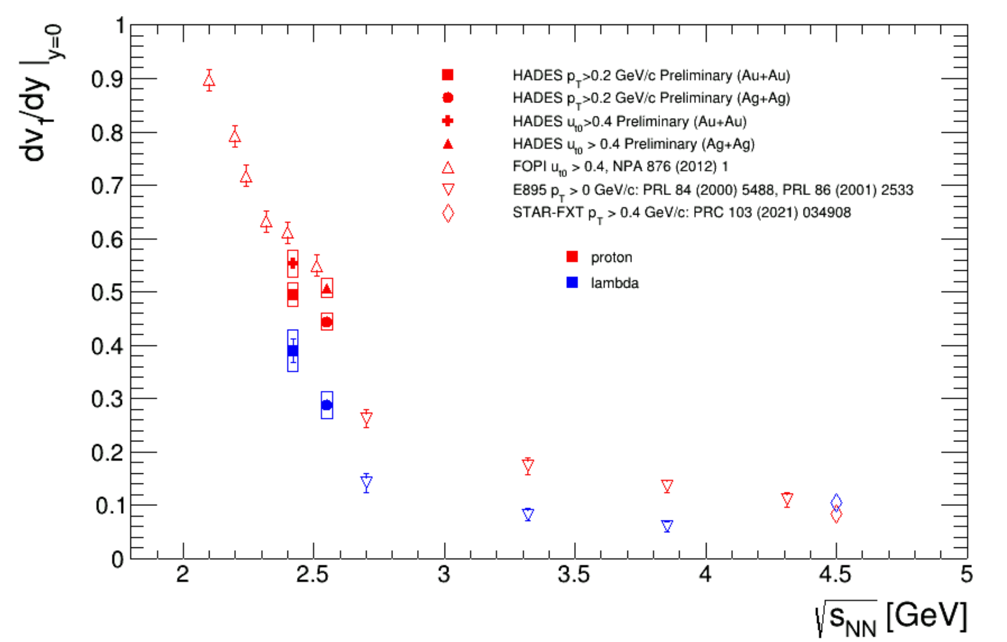
- First measurement of the directed flow of Λ hyperons at HADES
  - Significant difference in the slope of the directed flow at midrapidity between p and Λ hyperons
- Connection between P_Λ and v_1
  - Model description of both at the same time?
  - No rapidity dependence of P_Λ observed in contrast to v_1



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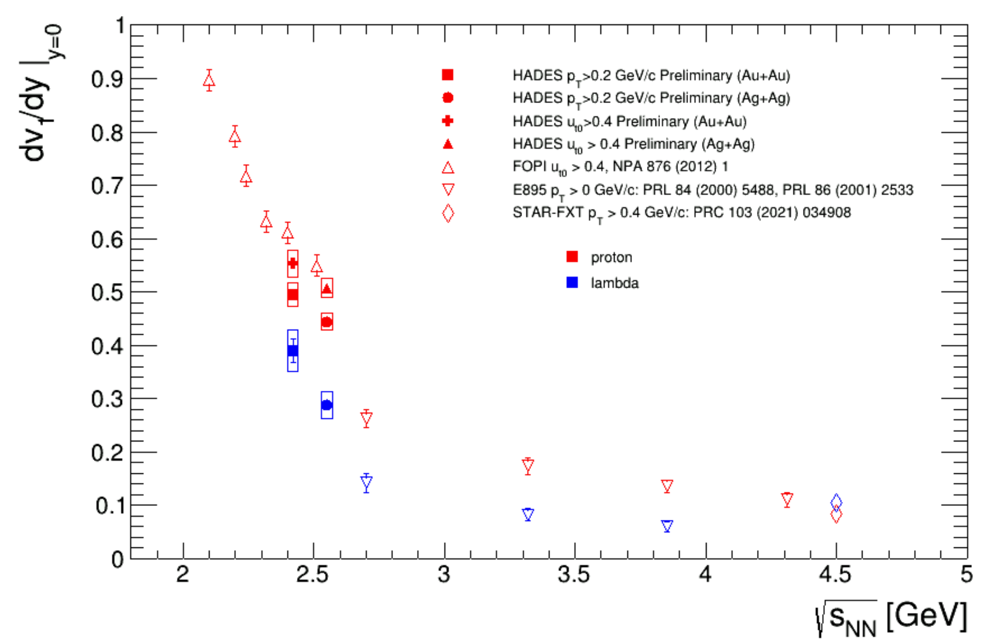

THANK YOU FOR YOUR ATTENTION!