Faculty of Physics
WARSAW UNIVERSITY OF TECHNOLOGY

Highlights from the heavy-ion program of the STAR and BRAHMS experiments at RHIC

Daniel Kikoła for the STAR collaboration

European Nuclear Physics Conference 2022

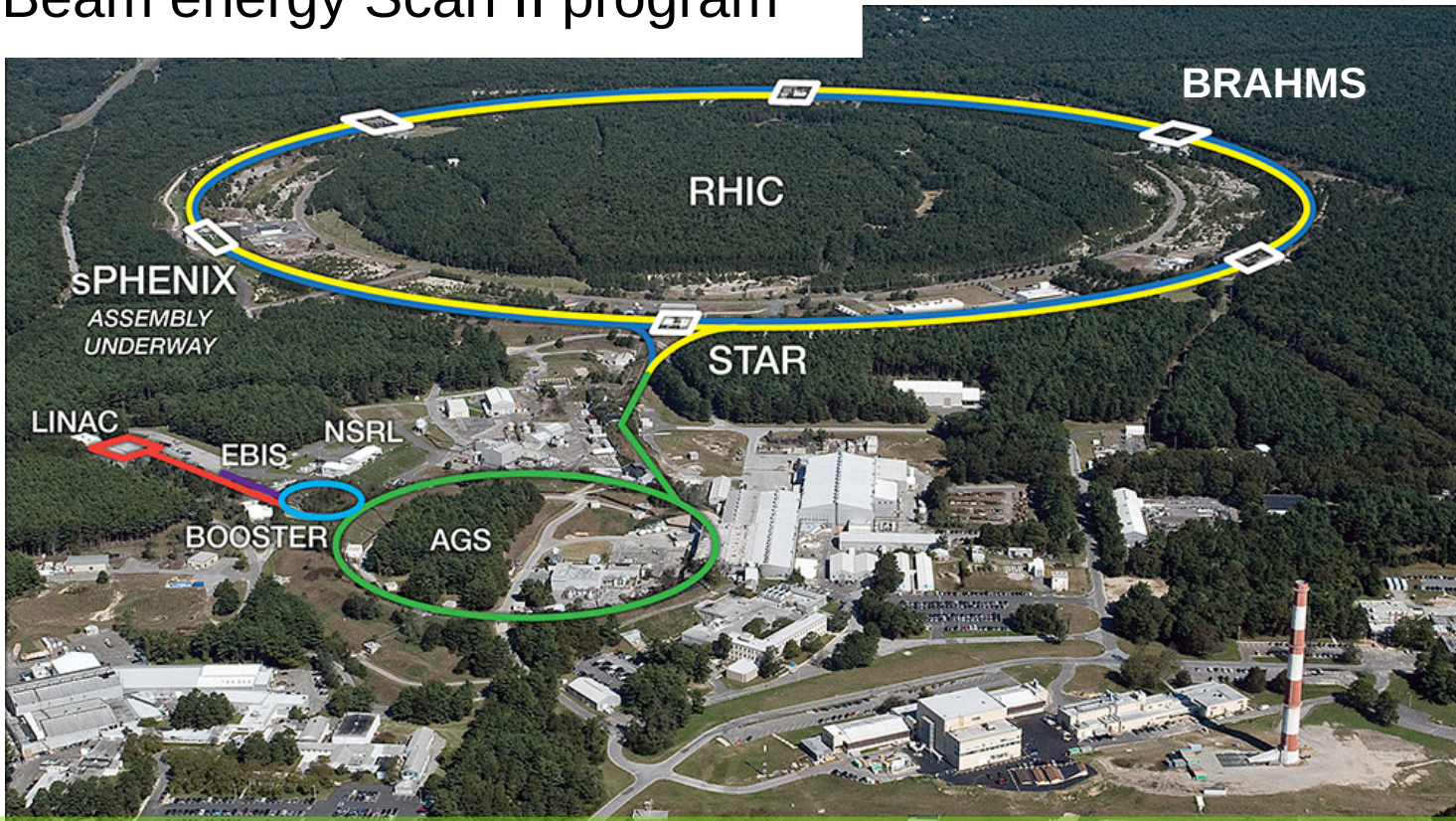
STAR

- Heavy-flavor production in HIC
- Search for Chiral Magnetic Effect in isobar collisions
- Recent results from Beam energy Scan II program

BRAHMS

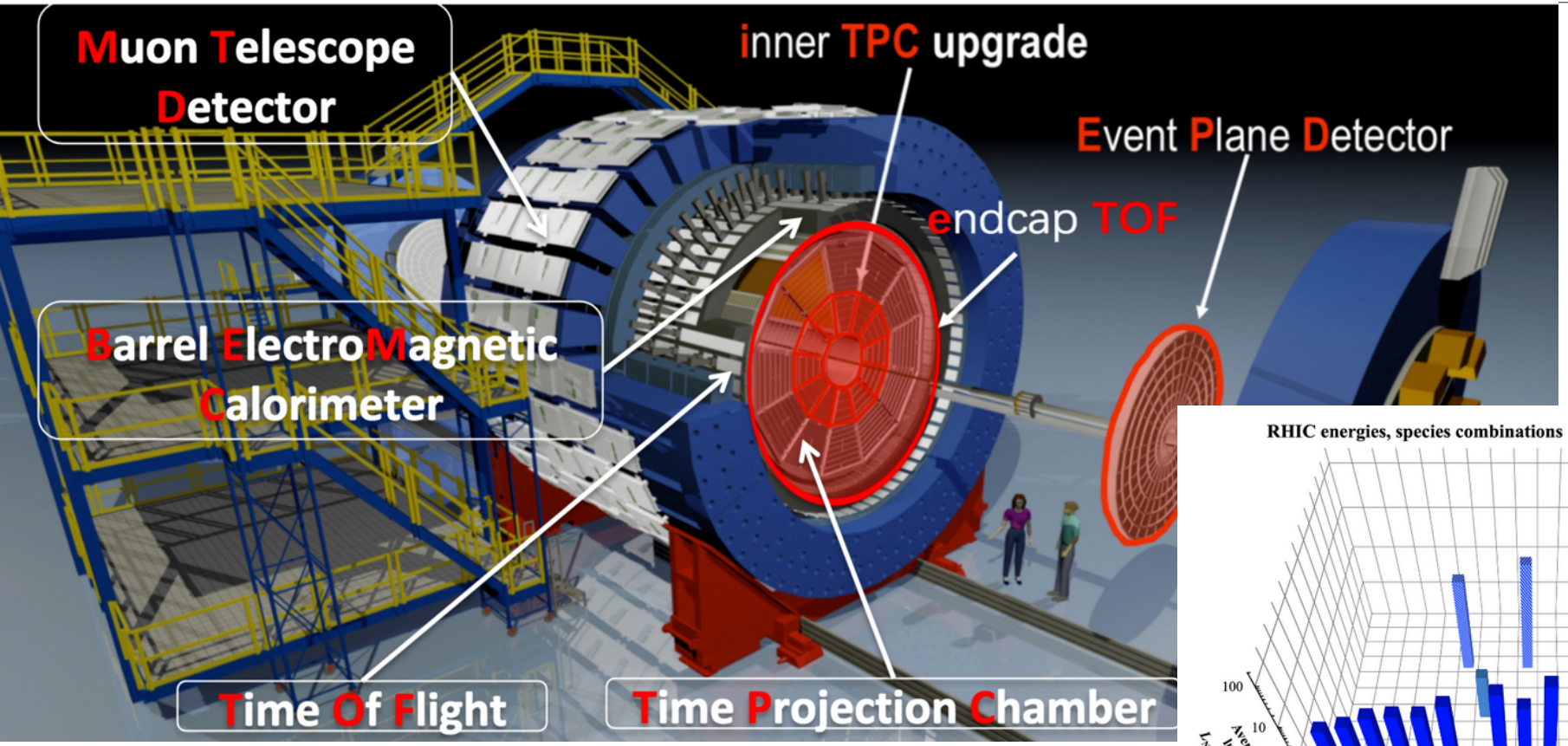
- Study of the baryon stopping in p+p and Au+Au collisions

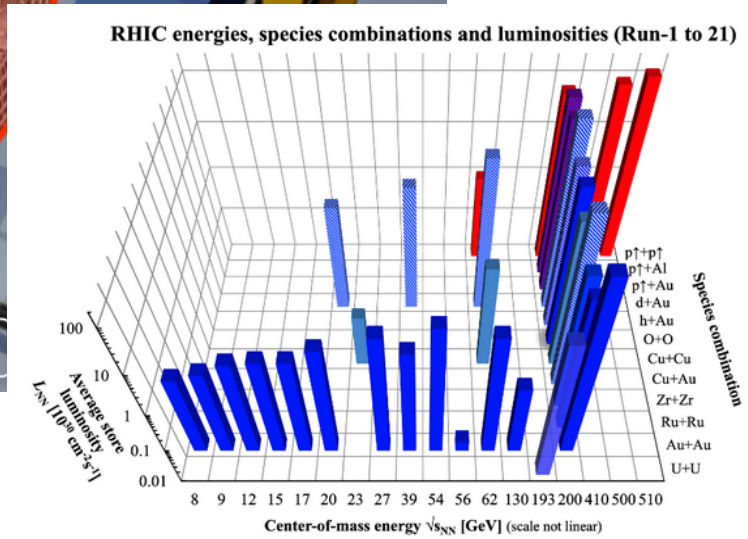
BRAHMS results courtesy of Flemming Videbaek



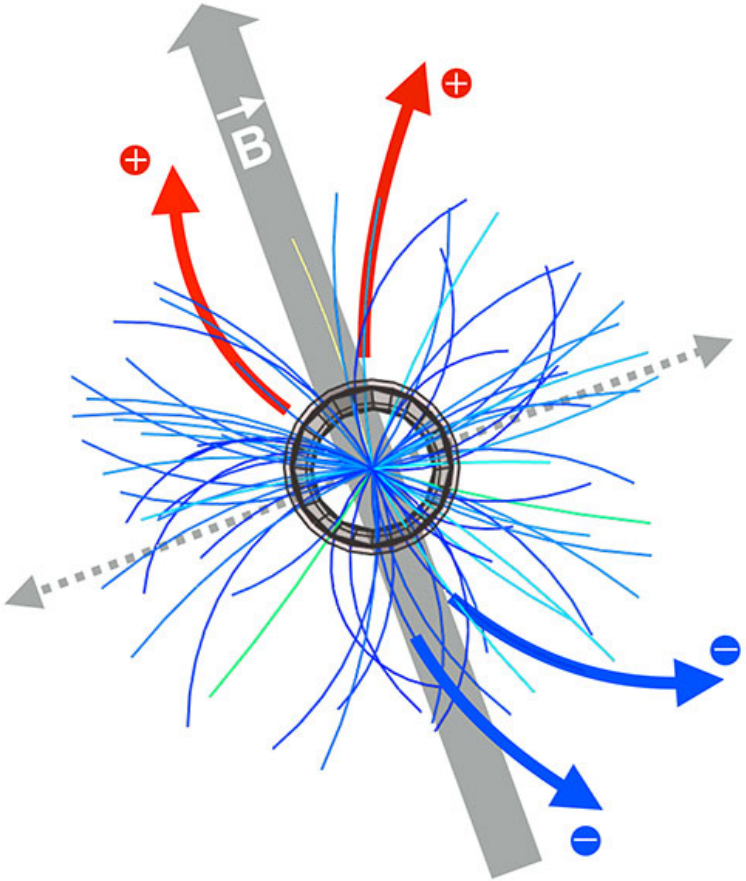
https://www.bnl.gov/newsroom/news.php?a=119262

The STAR detector





Search for Chiral Magnetic Effect in isobar collisions

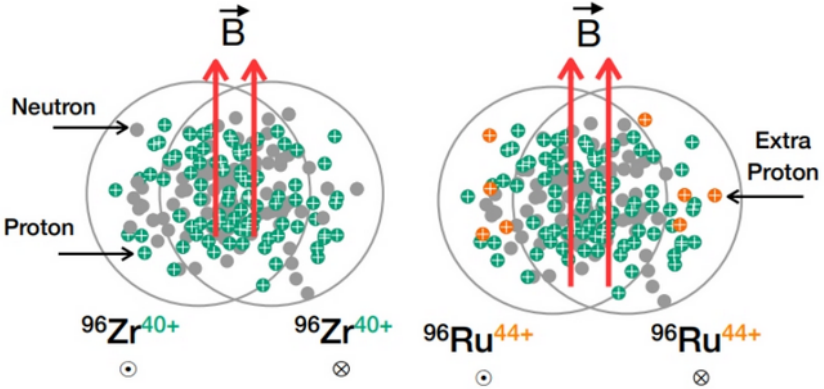


https://www.bnl.gov/newsroom/news.php?a=119062

The **Chiral Magnetic Effect (CME)** is predicted to occur as a consequence of a local violation of P and CP symmetries of the strong interaction in a strong electromagnetic field generated in relativistic heavy-ion collisions.

Experimental manifestation of the CME involves a separation of positively and negatively charged hadrons along the direction of the magnetic field.

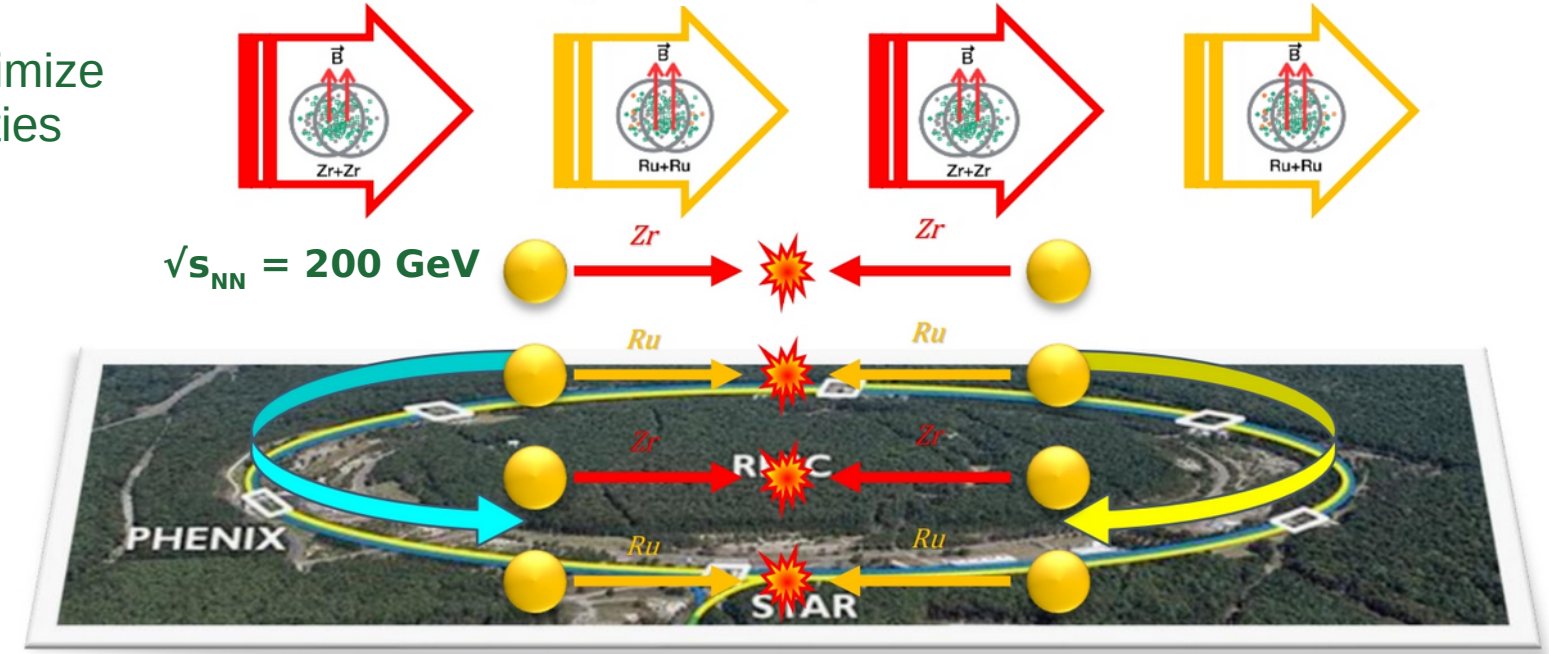
Search for Chiral Magnetic Effect in isobar collisions



B-field² in Ru+Ru ~15% larger than in Zr+Zr

Dedicated run to minimize systematic uncertainties

- Fill-by-fill switching
- Level luminosity



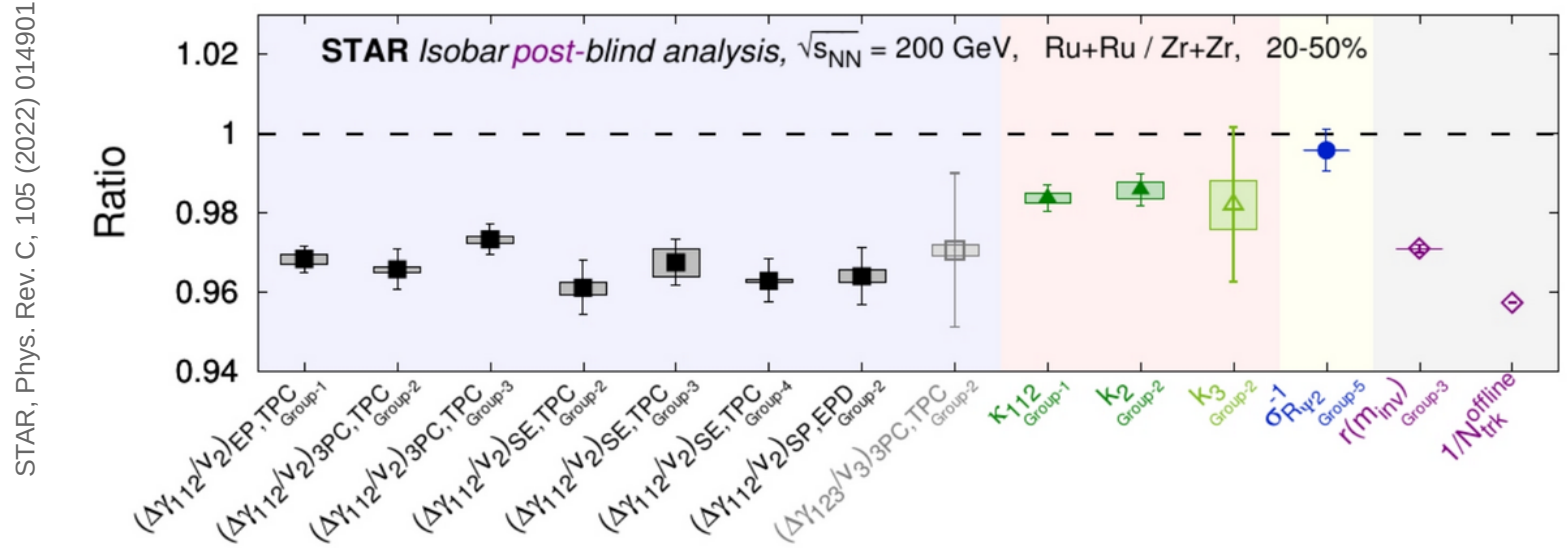
Search for Chiral Magnetic Effect in isobar collisions

CME sensitive observable

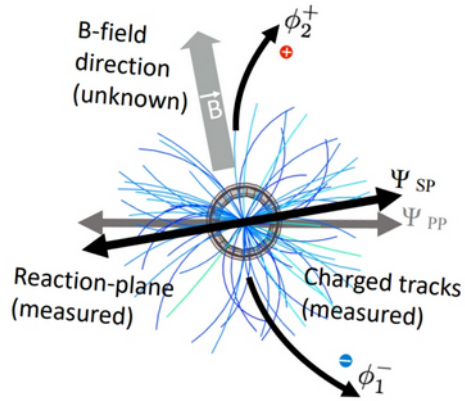
$$\Delta\gamma \equiv C_3/v_2^* \qquad C_{3,\mathrm{os}} = \langle\cos(\phi_\alpha^\pm + \phi_\beta^\mp - 2\phi_c)\rangle,$$

$$C_3 = C_{3,\mathrm{os}} - C_{3,\mathrm{ss}} \qquad C_{3,\mathrm{ss}} = \langle\cos(\phi_\alpha^\pm + \phi_\beta^\pm - 2\phi_c)\rangle,$$

Pre-defined criteria: $(\Delta\gamma/v_2)_{\mathrm{Ru+Ru}} > (\Delta\gamma/v_2)_{\mathrm{Zr+Zr}}$



STAR, Phys. Rev. C, 105 (2022) 014901



No CME signature satisfying the predefined criteria observed in blind analysis of isobar collisions

Deviation of CME baseline from unity → multiplicity difference & non-flow correlations

CME: study of non-flow background

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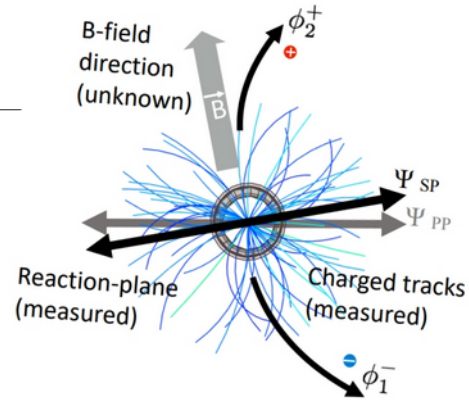
$$\Delta\gamma = \Delta\gamma^{CME} + k\frac{v_2}{N} + \Delta\gamma^{non-flow}$$

Measurement | Signal | Bkg 1 | Bkg 2



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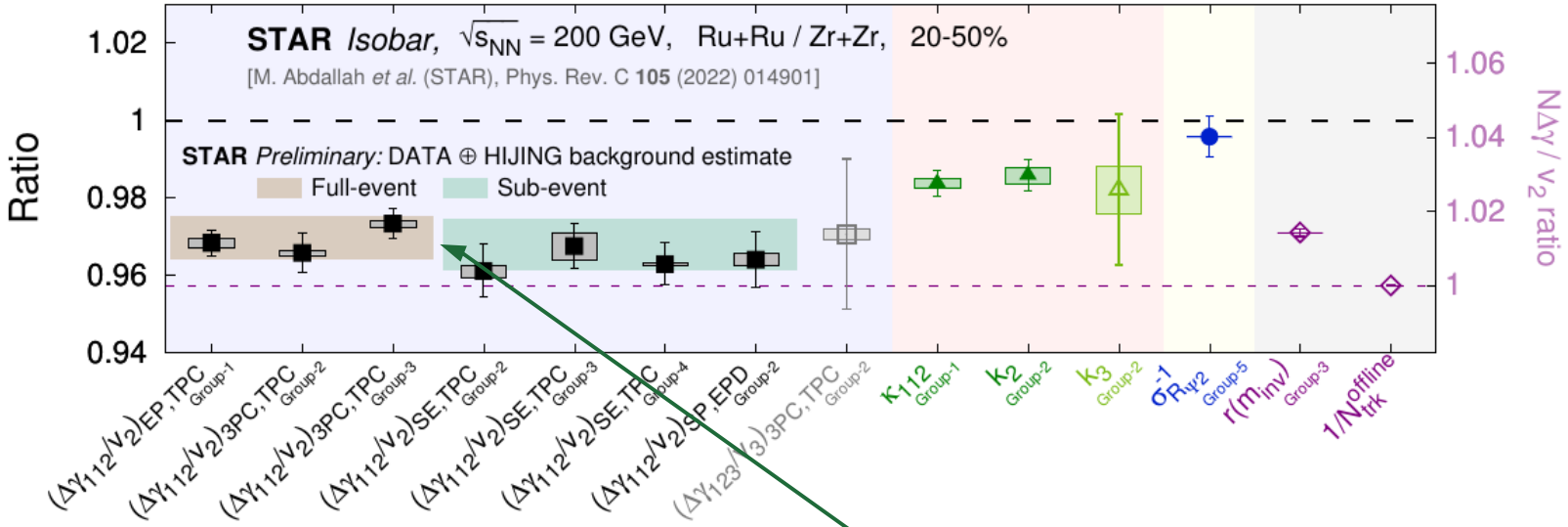
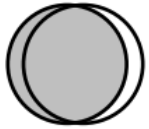


STAR, Phys. Rev. C, 105 (2022) 014901

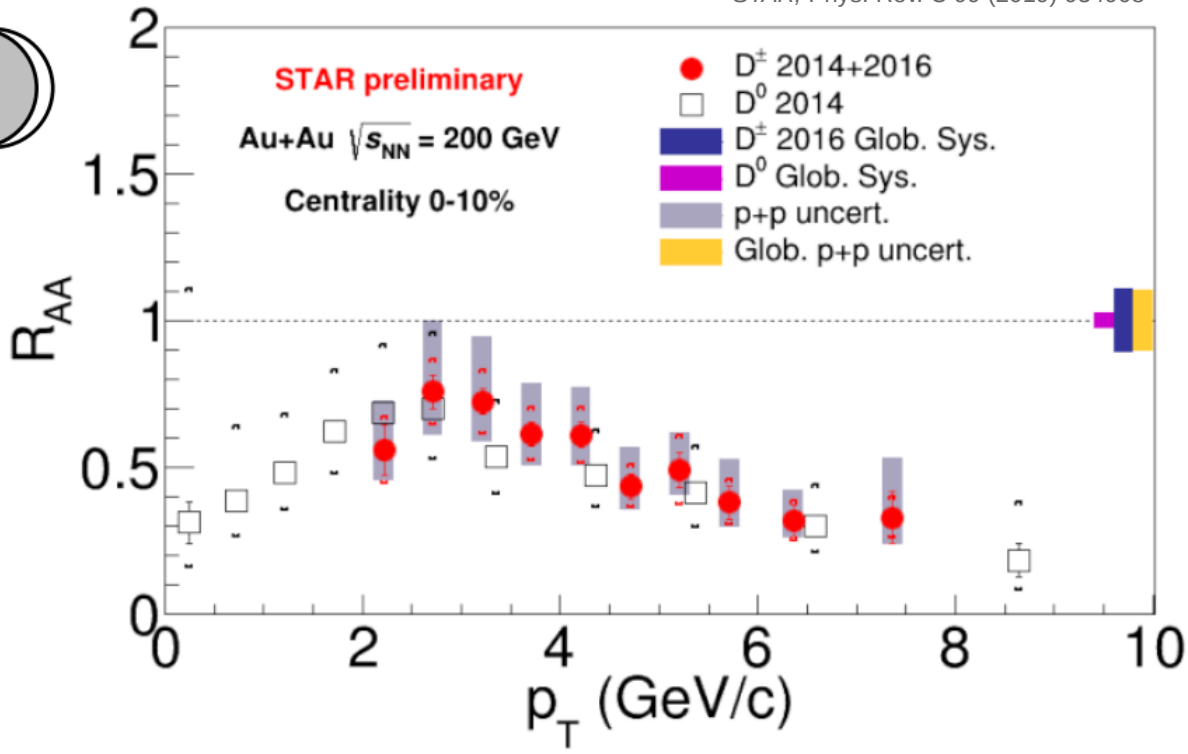
Isobar results consistent with the estimate of non-flow background within uncertainties

Energy loss of charm quarks in heavy-ion collisions

$$R_{AA} = \frac{1}{N_{coll}} \frac{d^2N_{AA}/(dp_T dy)}{d^2N_{pp}/(dp_T dy)}$$



STAR, Phys. Rev. C 99 (2019) 034908

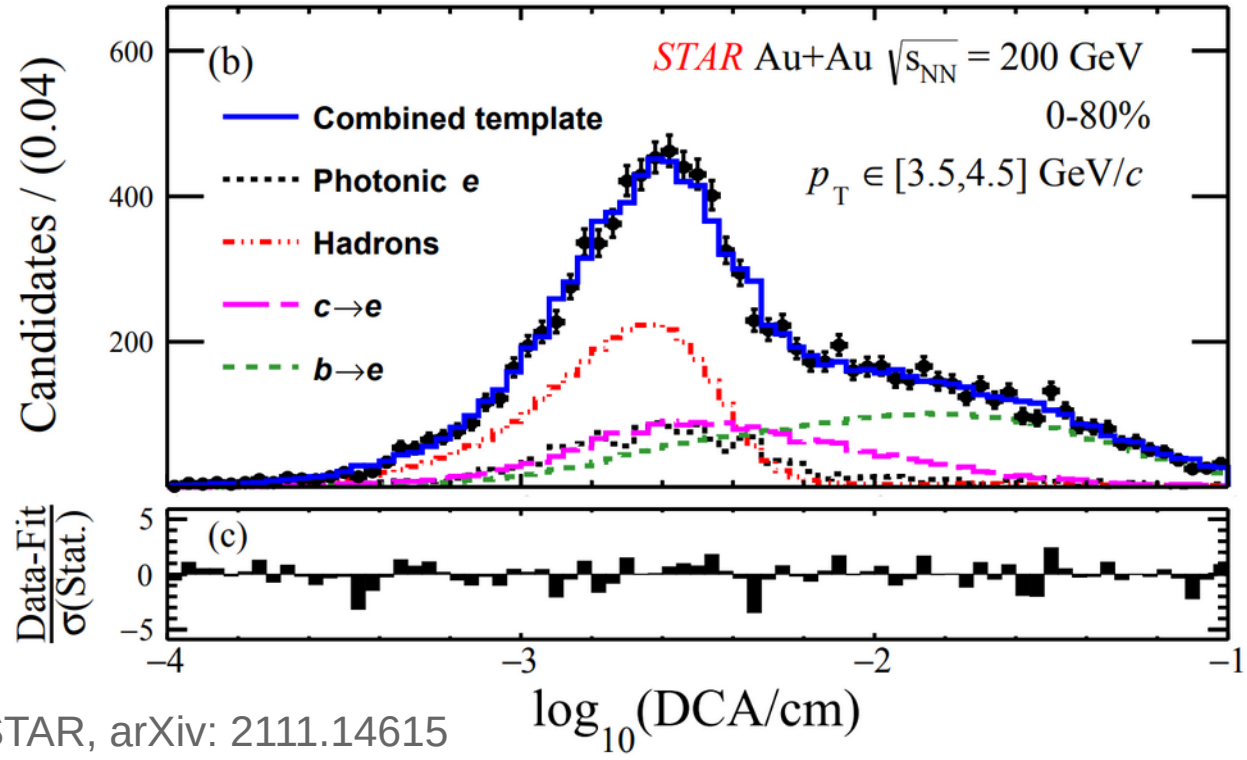


Strong suppression of D^0 and $D^{+/-}$ at high p_T
→ strong interaction of charm quarks with the medium

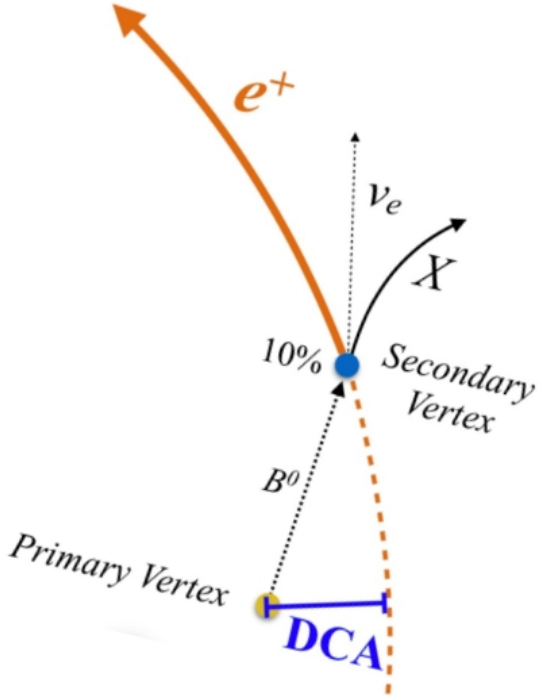
Also:
Enhanced Λ_c/D^0 and D_s/D^0 ratios in Au+Au compared PYTHIA pp results

Energy loss of bottom quarks in heavy-ion collisions

Heavy-flavor hadron decayed electrons: c → e and b → e separation thanks to Heavy Flavor Tracker.



STAR, arXiv: 2111.14615



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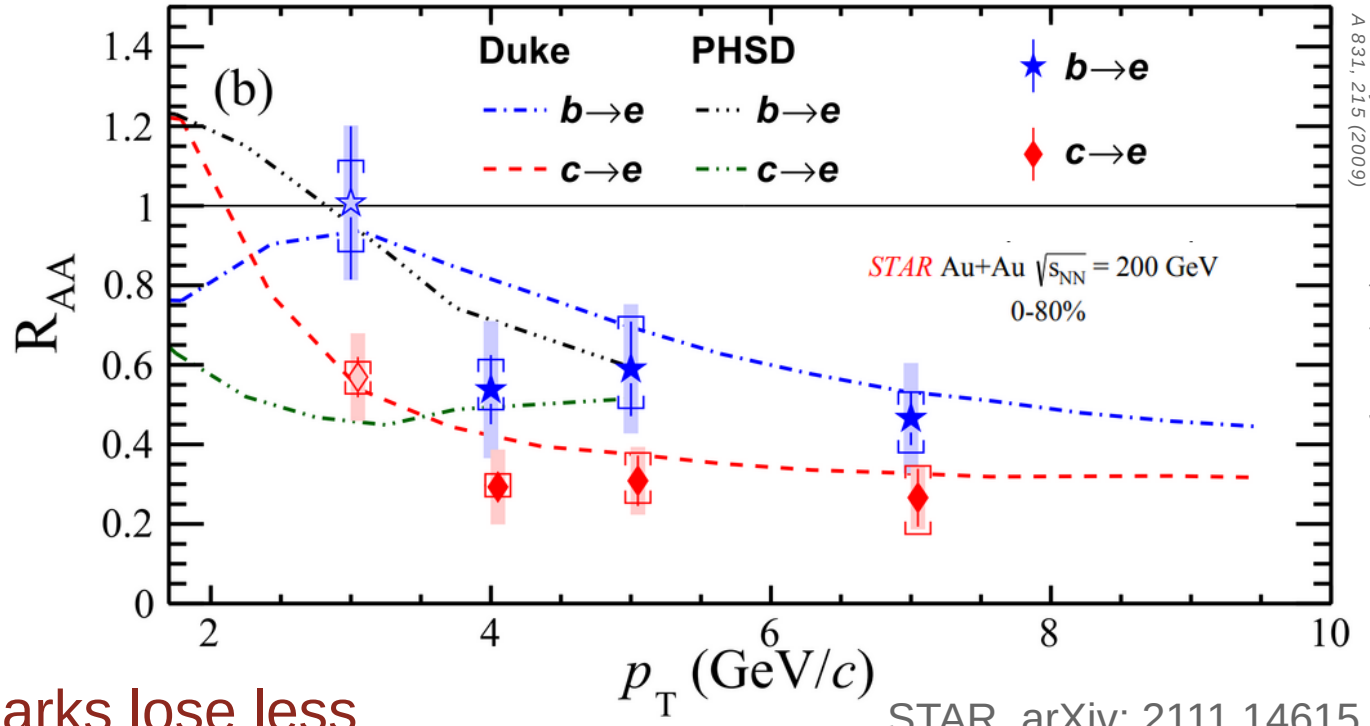

Duke, Phys. Rev. C 92, 024907 (2015)
PHSD, Phys. Rev. C 78, 034919 (2008). Nucl. Phys. A 831, 215 (2009)

Clear indication that b quarks lose less energy than c quarks.

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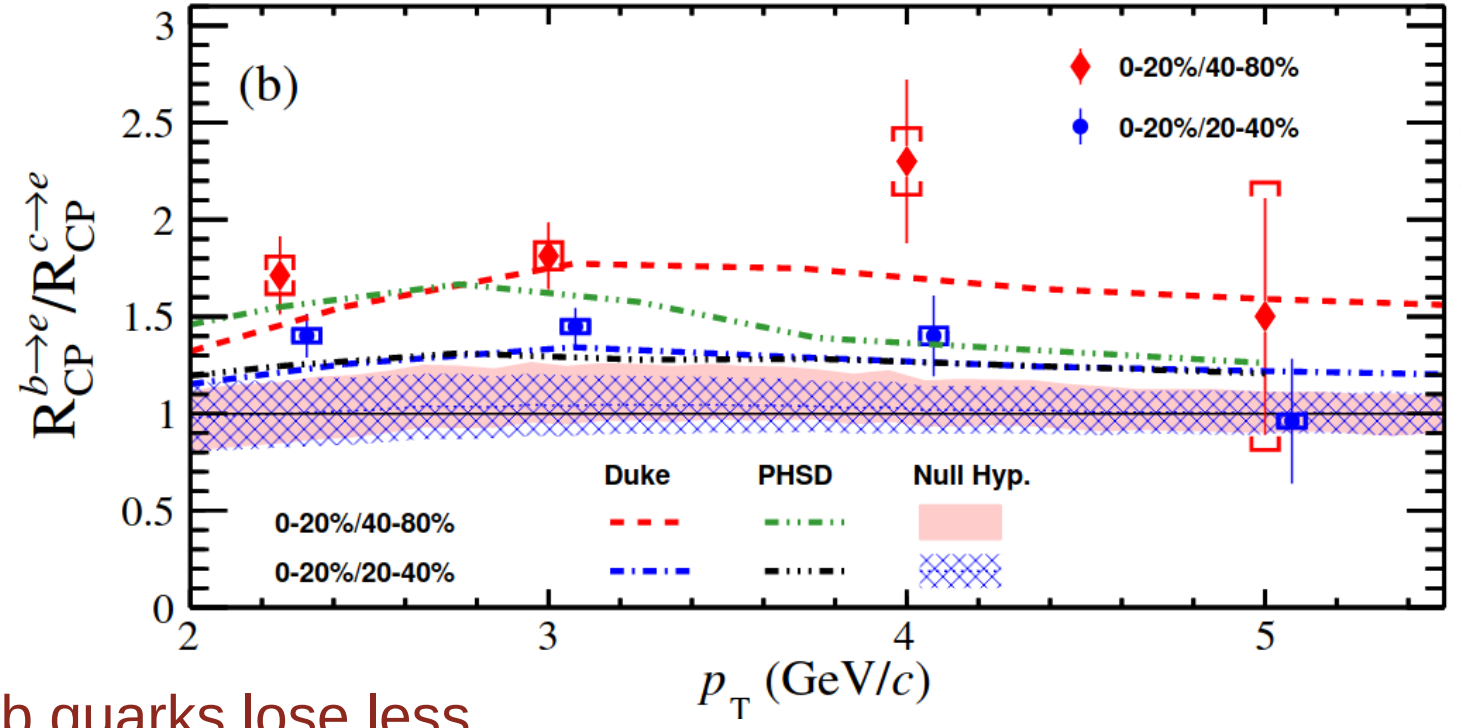

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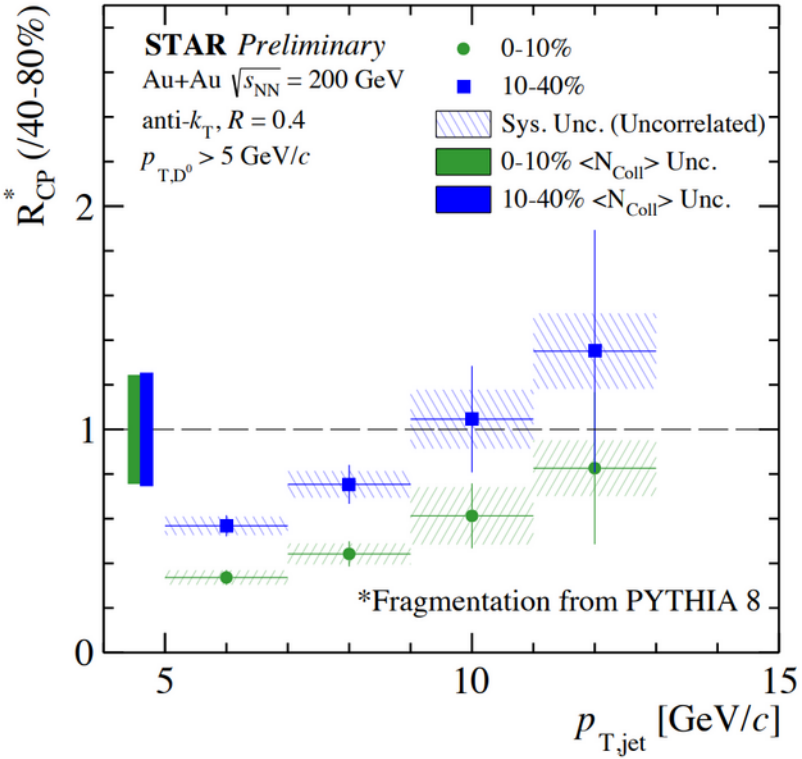
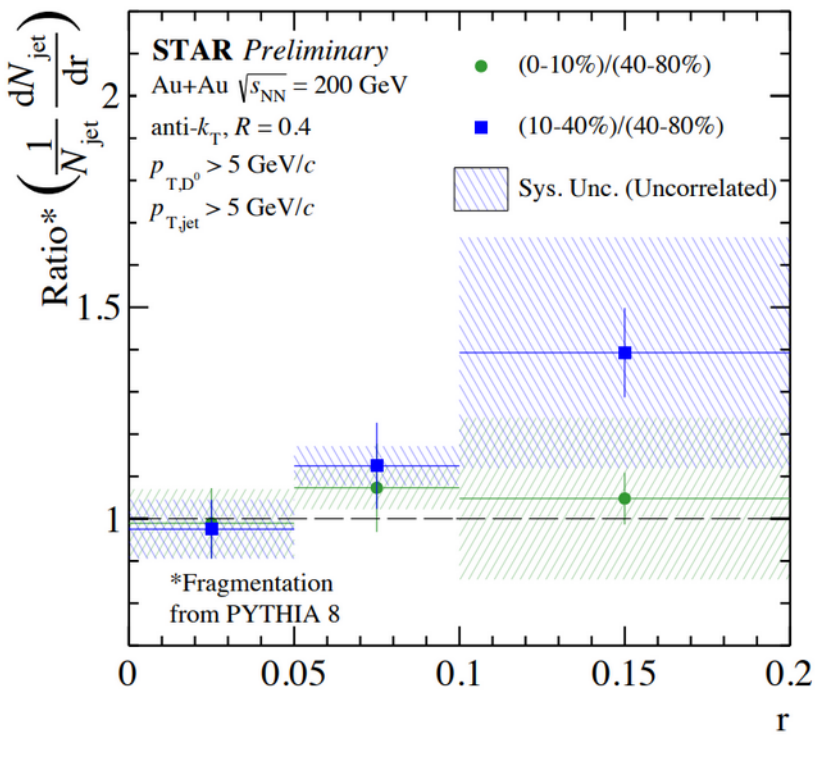
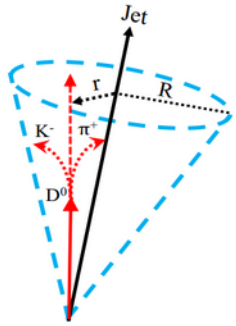
D^0-meson tagged jets

D^0-jet radial profile → charm quark diffusion in the QGP



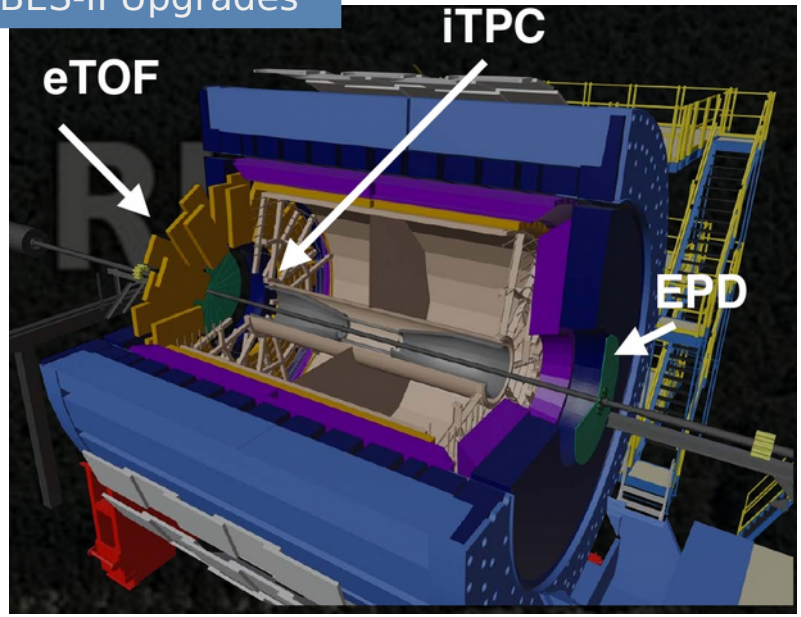




R_{CP}: strong suppression at low jet p_T, hint of increasing trend.
Ratio of radial distributions consistent with unity.

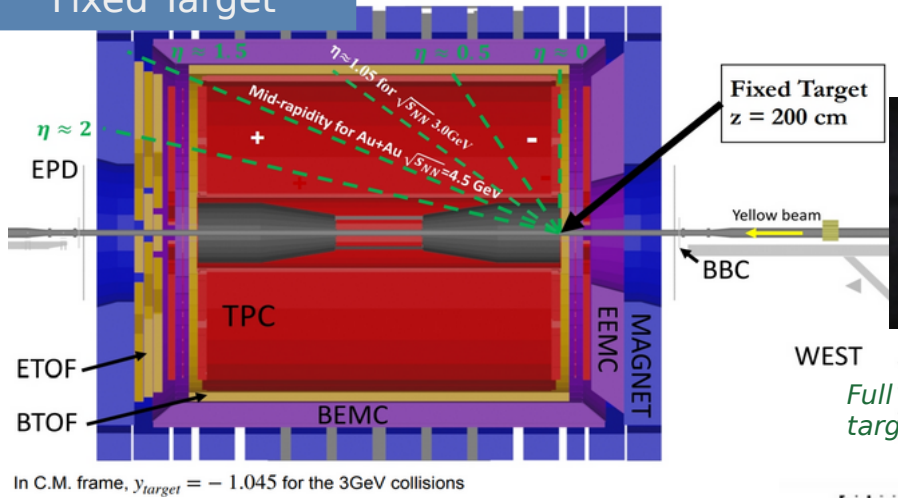
BES-II program

BES-II Upgrades

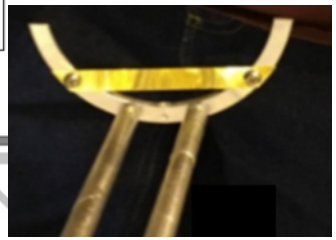


- **iTPC (2019+)**
  - Extended η acceptance and improved tracking and dE/dx resolution
- **eTOF (2019+)**
  - Extended PID coverage
- **EPD (2018+)**
  - Independent EP reconstruction

Fixed Target



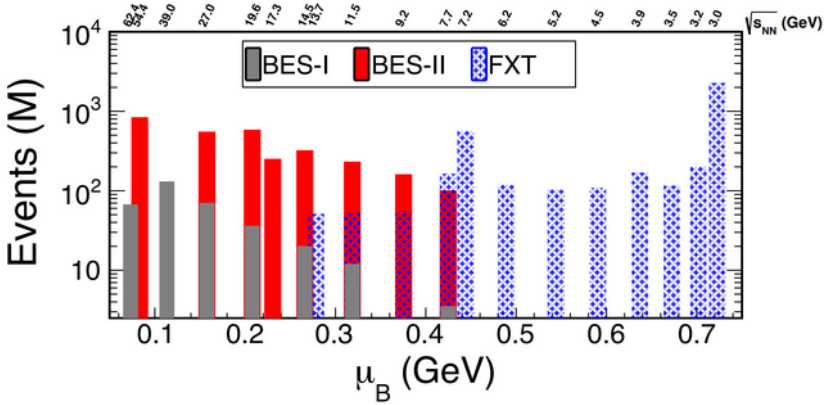
In C.M. frame, $y_{target} = -1.045$ for the 3GeV collisions

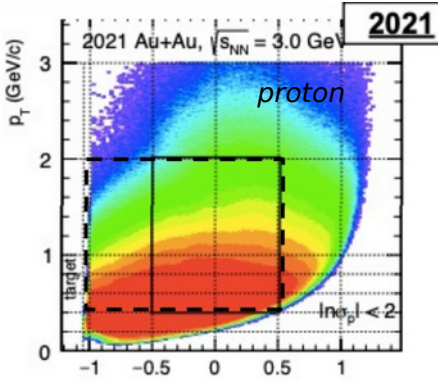


WEST

Full coverage from y=0 to target in 3 GeV Au+Au

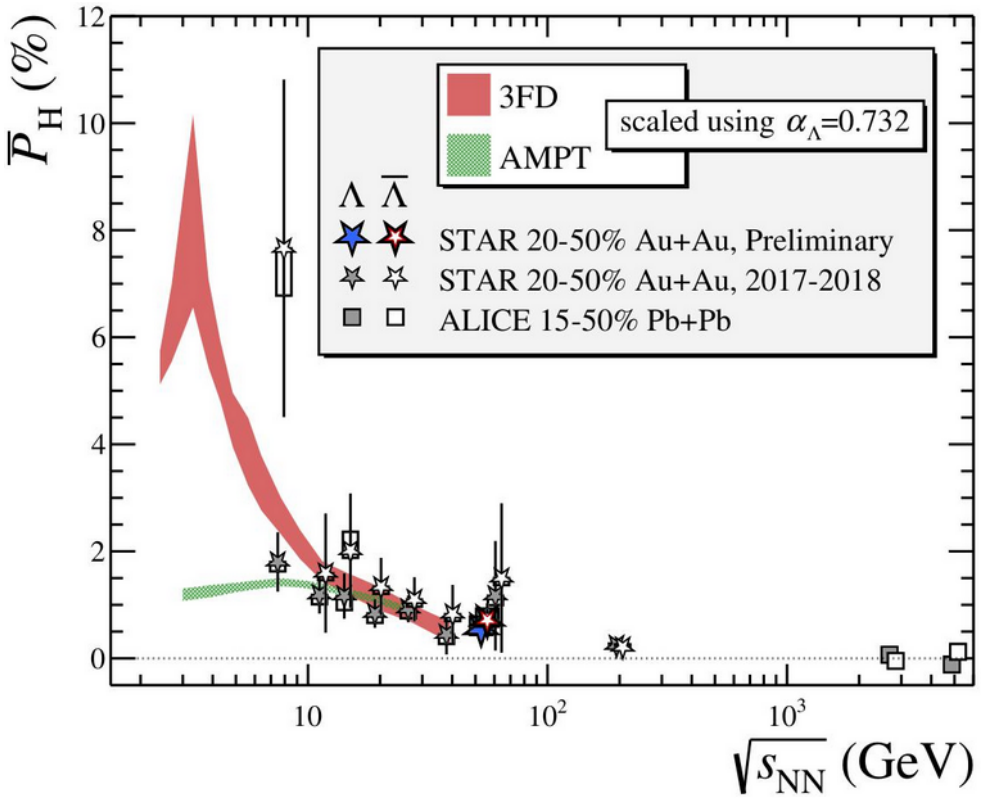
Beam Energy Scan II completed

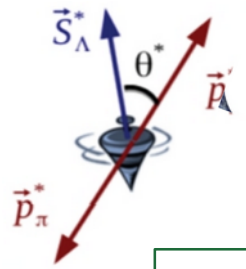


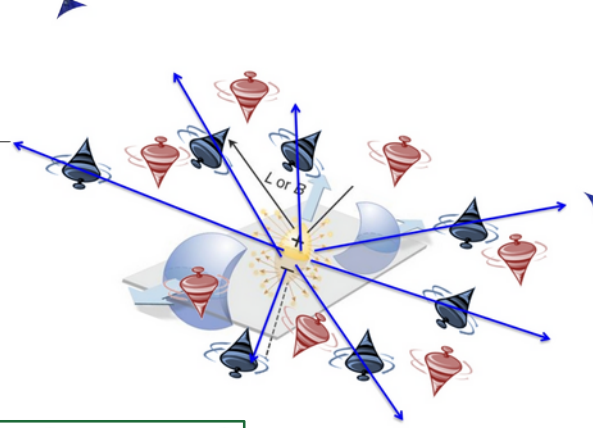


Global hyperon polarization

Vorticity of the medium and magnetic field







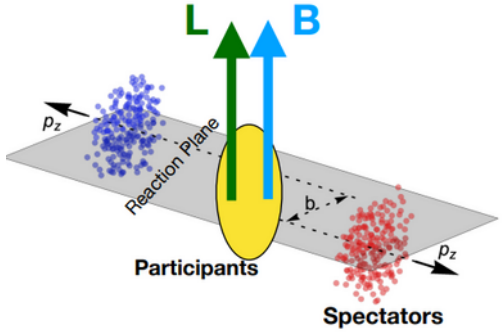
$$P_H = \frac{8}{\pi\alpha_H}\frac{\langle \sin(\Psi_1 - \phi^*_d)\rangle}{\mathrm{Res}(\Psi_1)}$$

Fluid vorticity → Λ, anti-Λ in same direction

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

Magnetic field → Λ, anti-Λ in opposite direction

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



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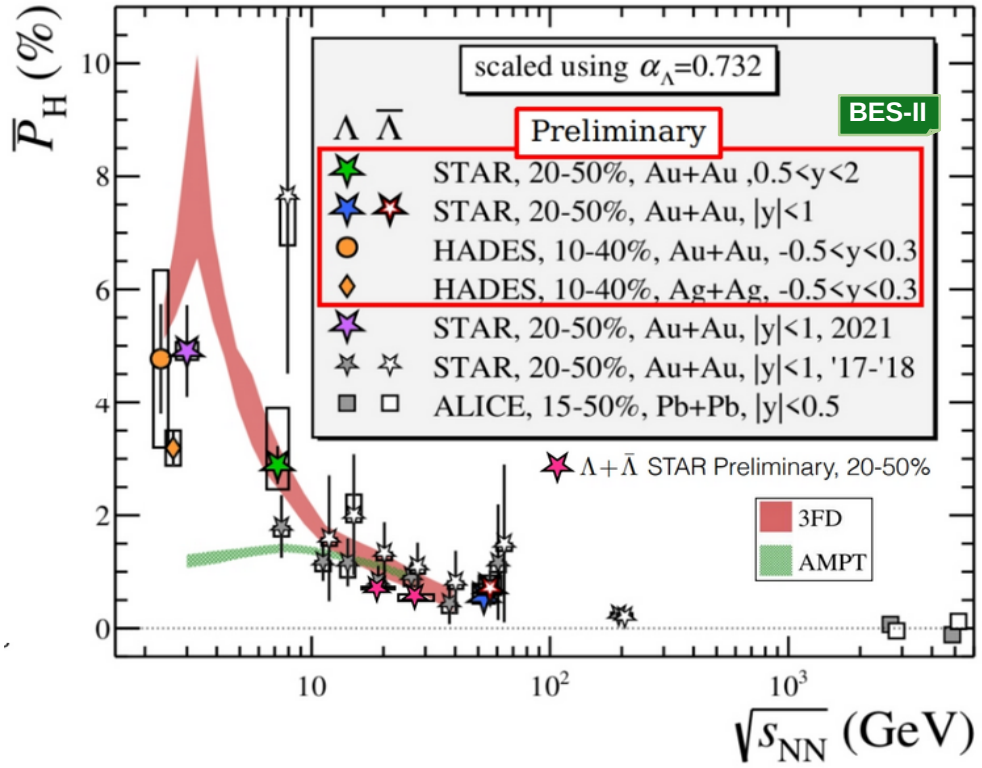

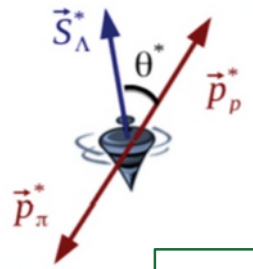

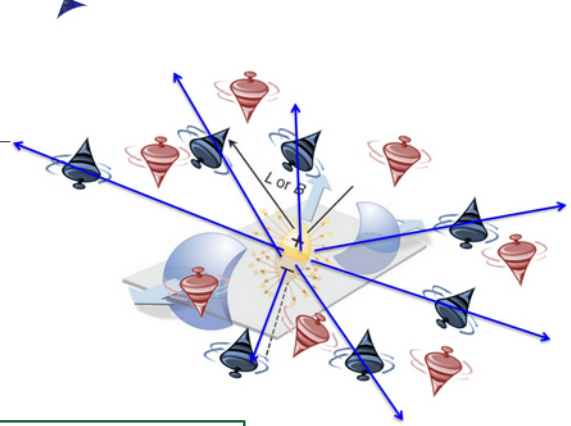

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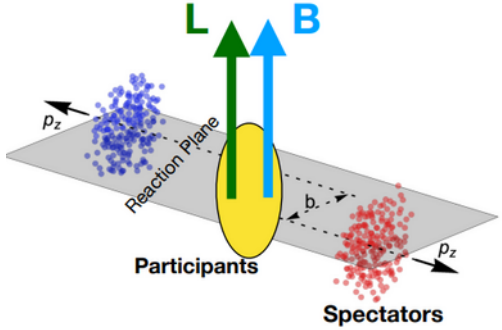
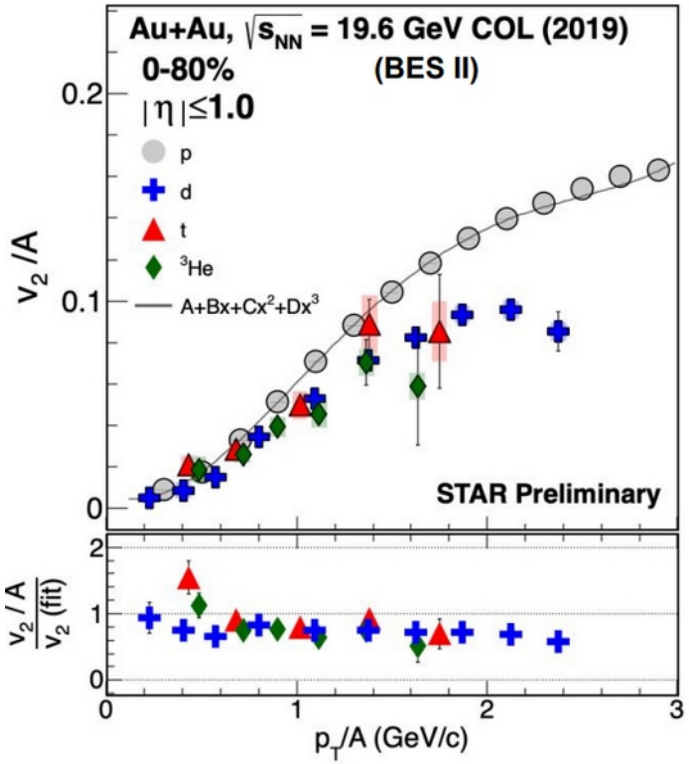


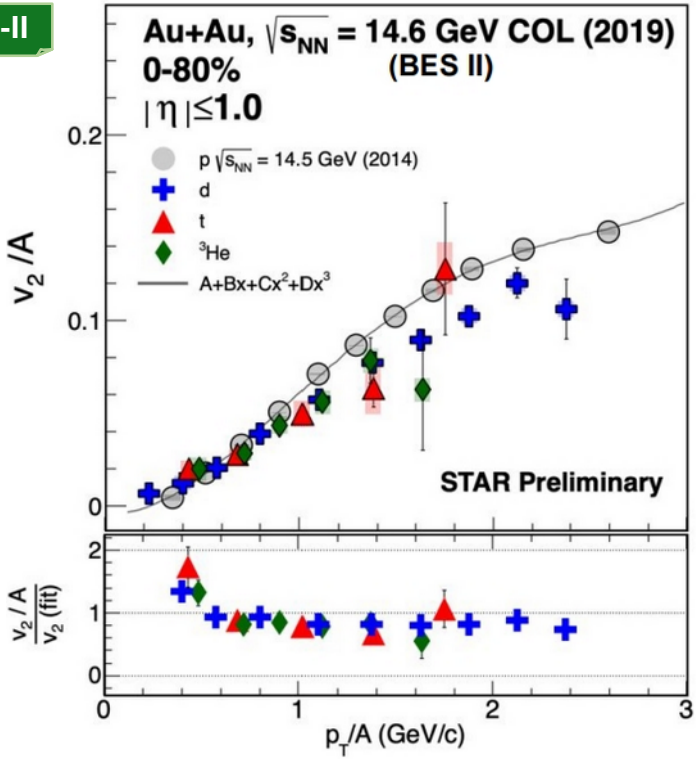
BES-II results extend the reach to $\sqrt{s_{NN}}$ = 3 GeV, P_H increases with decreasing energy

Results from STAR BES-II: $\sqrt{s_{NN}}$ = 3, 7.2, 19.6, 27, 54.4 GeV

BES-II: Elliptic flow of light nuclei



BES-II



Test of thermal production vs final-state coalescence of nucleons

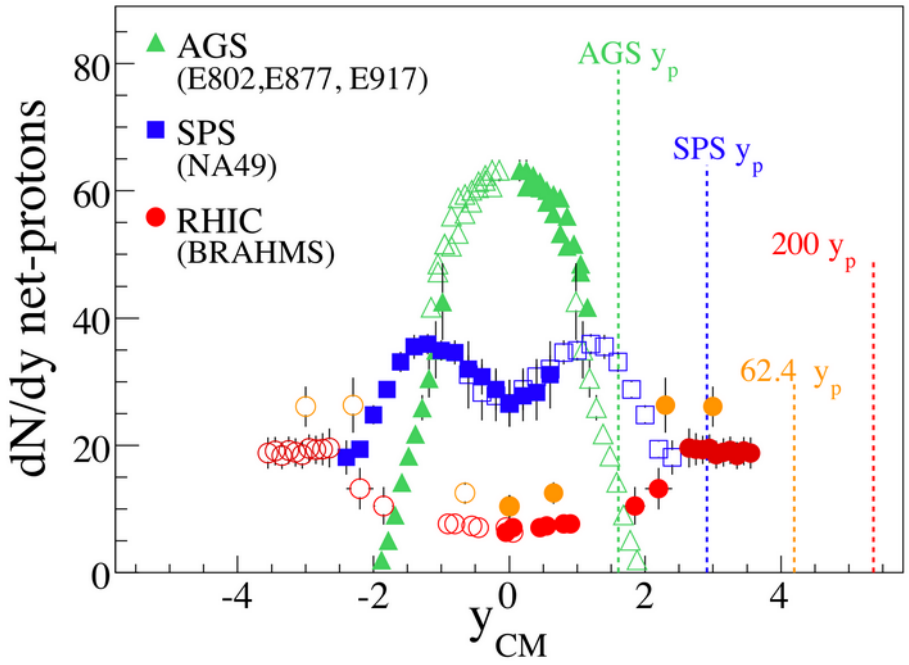
Results consistent with the mass number scaling within 20-30%

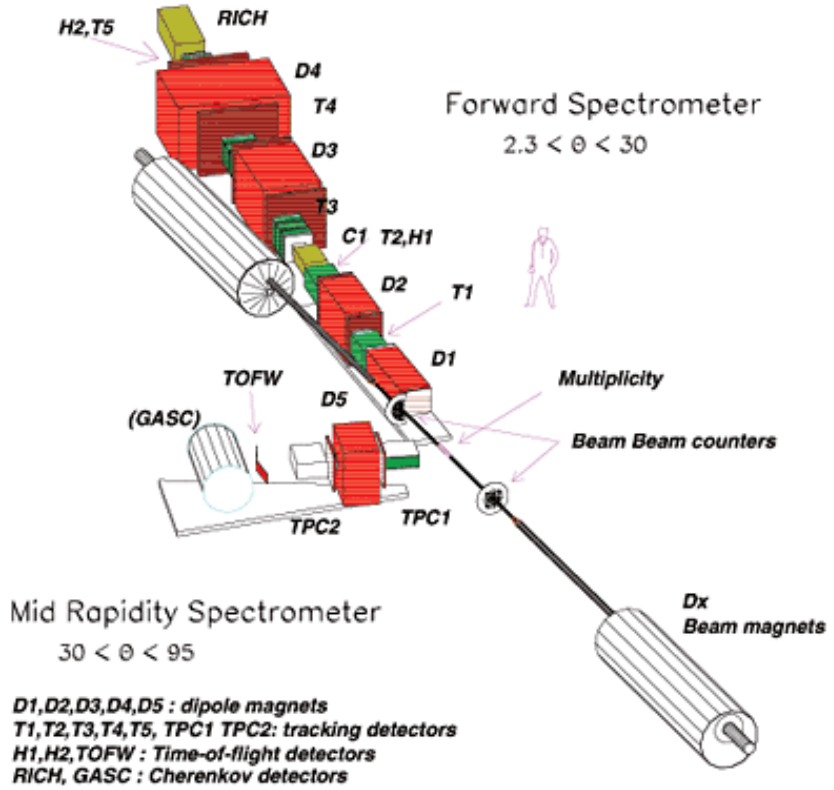
Other BES-II results with improved precision: particle spectra, elliptic flow of strange hadrons, K^{*0} production, (anti-)light hypernuclei … and more to come soon

The BRAHMS experiment

Designed to measure charged hadrons over a wide range of rapidity and transverse momentum

Major motivation: characterizing the baryon stopping in p+p and Au+Au





BRAHMS results courtesy of Flemming Videbaek

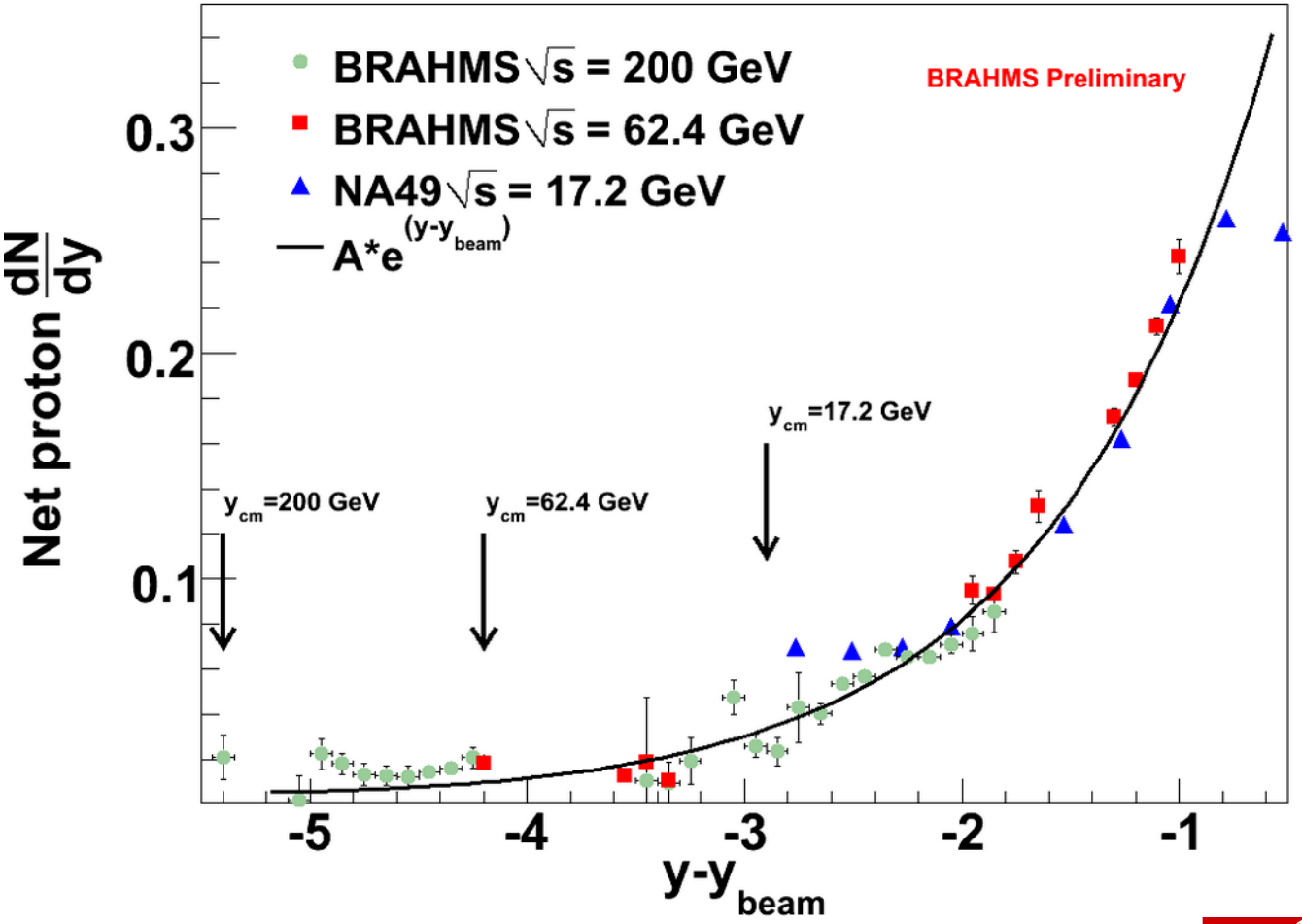
Phys. Rev. Lett. 93, 102301 (2004) & QM09

Baryon stopping in p+p and Au+Au at RHIC

p+p collision at lower energies exhibits a feature: dN/dx~const

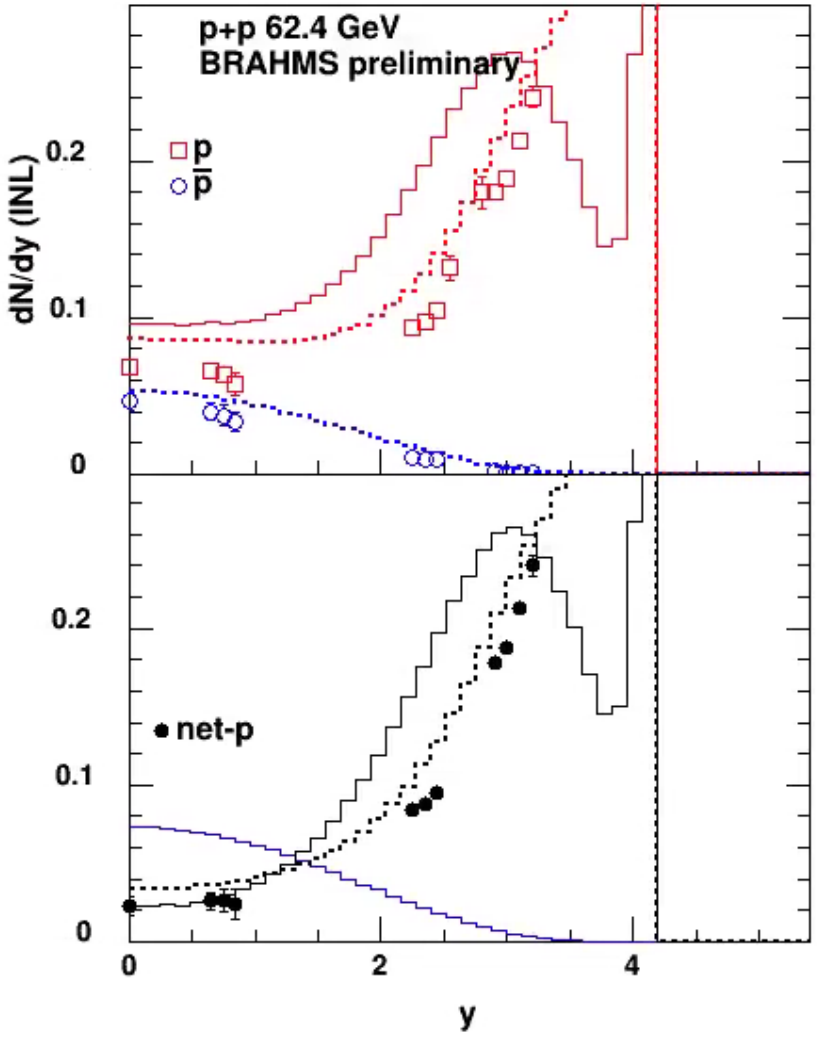
This implies that for constant <m_T> vs. rapidity → dN/dy~ exp(-y)

Data confirm this behavior up to 200 GeV



Baryon stopping at RHIC: data vs models

- p+p proton data compared to PYTHIA8 (full drawn curve) and EPOS 1.99 (dashed curve)
- Net-protons are better described by EPOS
- Many other models predict net-p distributions like PYTHIA, not in agreement with data



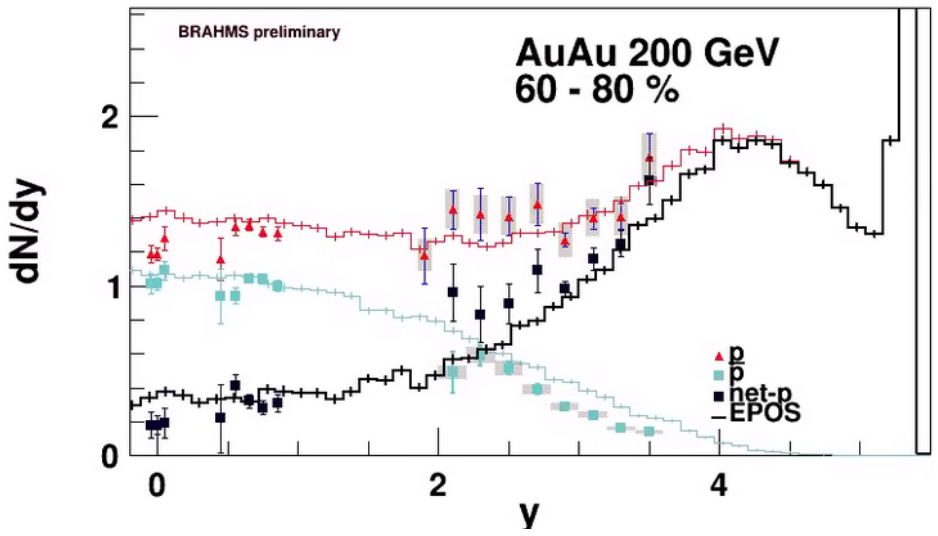
Evaluation of baryon stopping

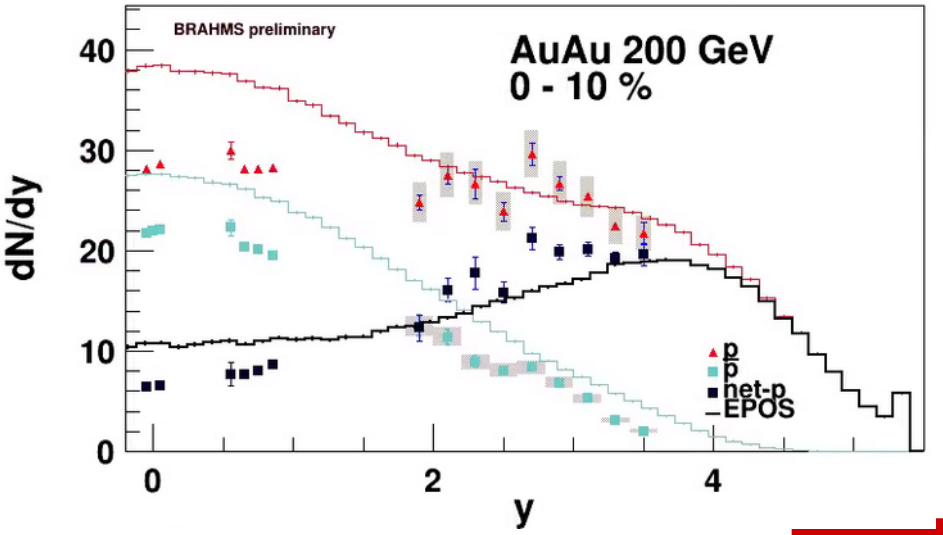
The rapidity loss can be evaluated by varying extrapolation to beam rapidity and calculate the y_b-<y>

$$\langle \delta_y \rangle = y_b - \frac{\int y dN/dy}{\int dN/dy}$$

Clear dependence on shape and thus rapidity loss with centrality.

Predictions by EPOS qualitatively describe the data





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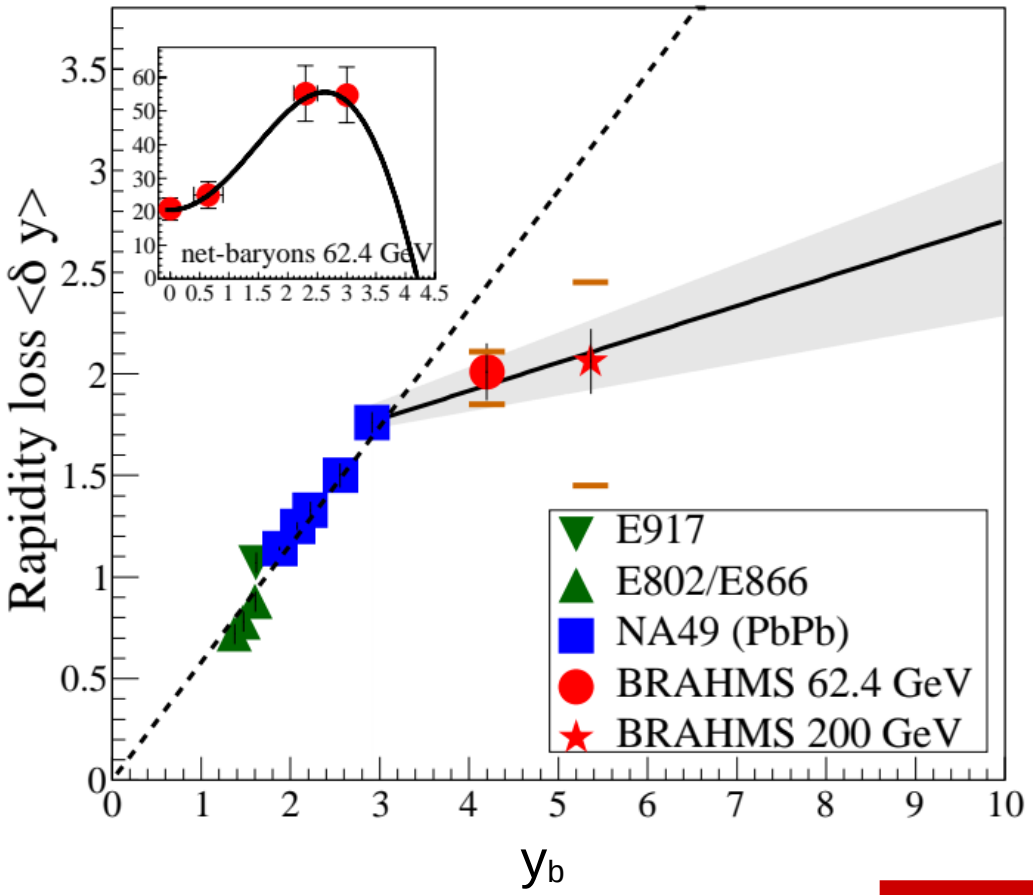
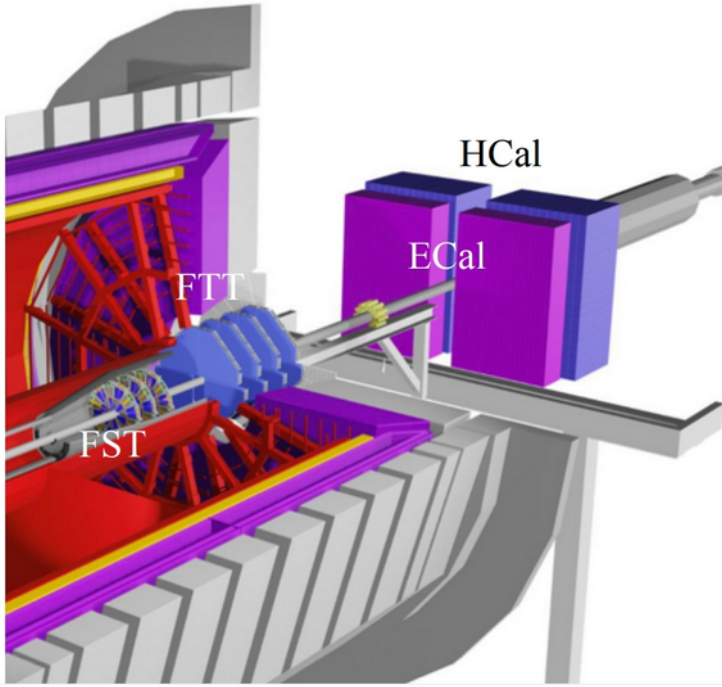


Rapidity loss estimated to be in the range 2.0-2.4 at 200 GeV

Summary and outlook

- **RHIC is a versatile machine and facilitates broad physics program**
  - Study of properties of the hot and cold nuclear matter
  - Mapping the QCD phase diagram in BES/BES-II
  - Study of origin of the nucleon spin in collisions of polarized protons
- **Recently completed forward upgrades**
  - Forward Tracking System and Forward Colorimeter System

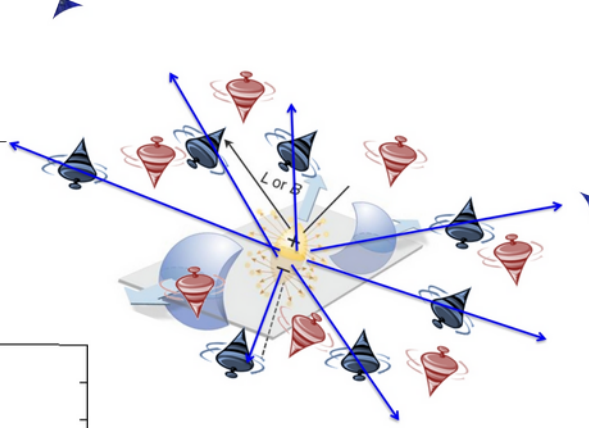


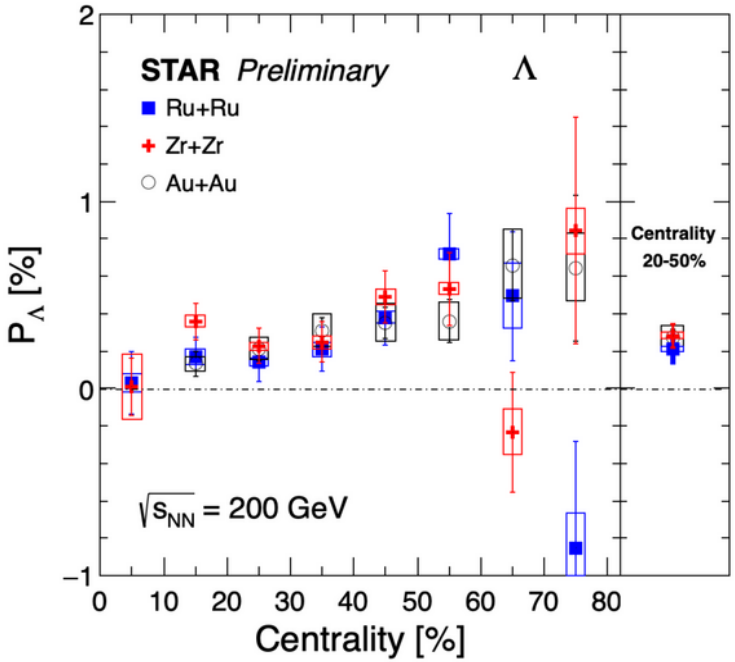
- **Rich heavy-ion physics program at RHIC** and many interesting results to come
  - BES-II data
  - More cold and hot QCD studies with high-statistics 200 GeV p+p, p+Au and Au+Au data to be collected in 2023-2025

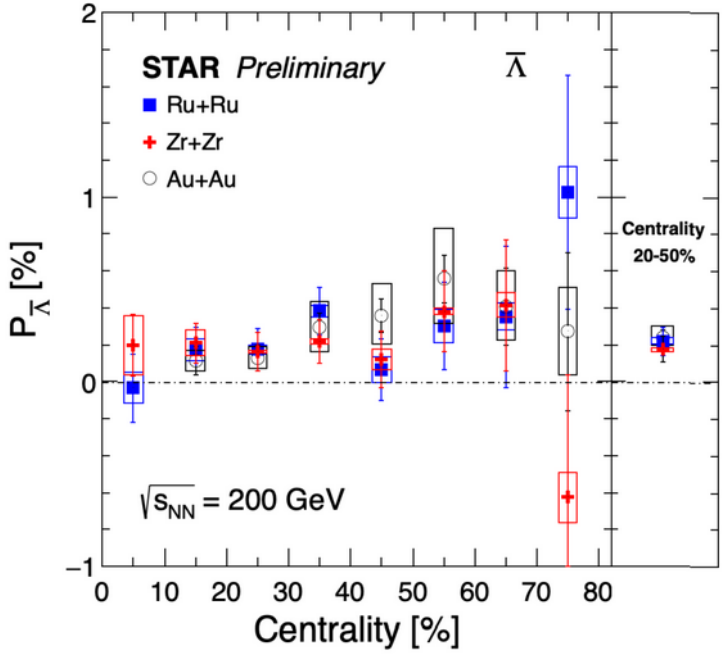
Backup

Global hyperon polarization P_H

Au+Au, Ru+Ru vs Zr+Zr at 200 GeV → system size and magnetic field driven effects







$$P_H = \frac{8}{\pi \alpha_H} \frac{\langle \sin(\Psi_1 - \phi_d^*) \rangle}{\mathrm{Res}(\Psi_1)}$$

Increasing P_H with centrality, no collision system dependence

No B-field driven splitting between P_Λ and $P_{\text{anti-}\Lambda}$ observed