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STAR Highlights: Recent results from STAR

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Shandong University

The 21st International Conference on Strangeness in Quark Matter
3-7 June 2024, Strasbourg, France

RHIC-STAR experiment

Physics to be explored in heavy-ion collisions:

- Onset of deconfinement
- Nature of QCD phase diagram
- High baryon density matter
- QGP properties …

BES-II detector Upgrades

- iTPC: Extended η acceptance and improved tracking and PID
- eTOF: Extended PID coverage
- EPD: Improved EP resolution

Fixed Target

Recent data recorded and future plan

2018 - Isobars (Ru/Zr), Au+Au 27 GeV, FXT: 3.0, 7.2

2019 - 19.6, 14.6, 200 GeV, FXT 3.2

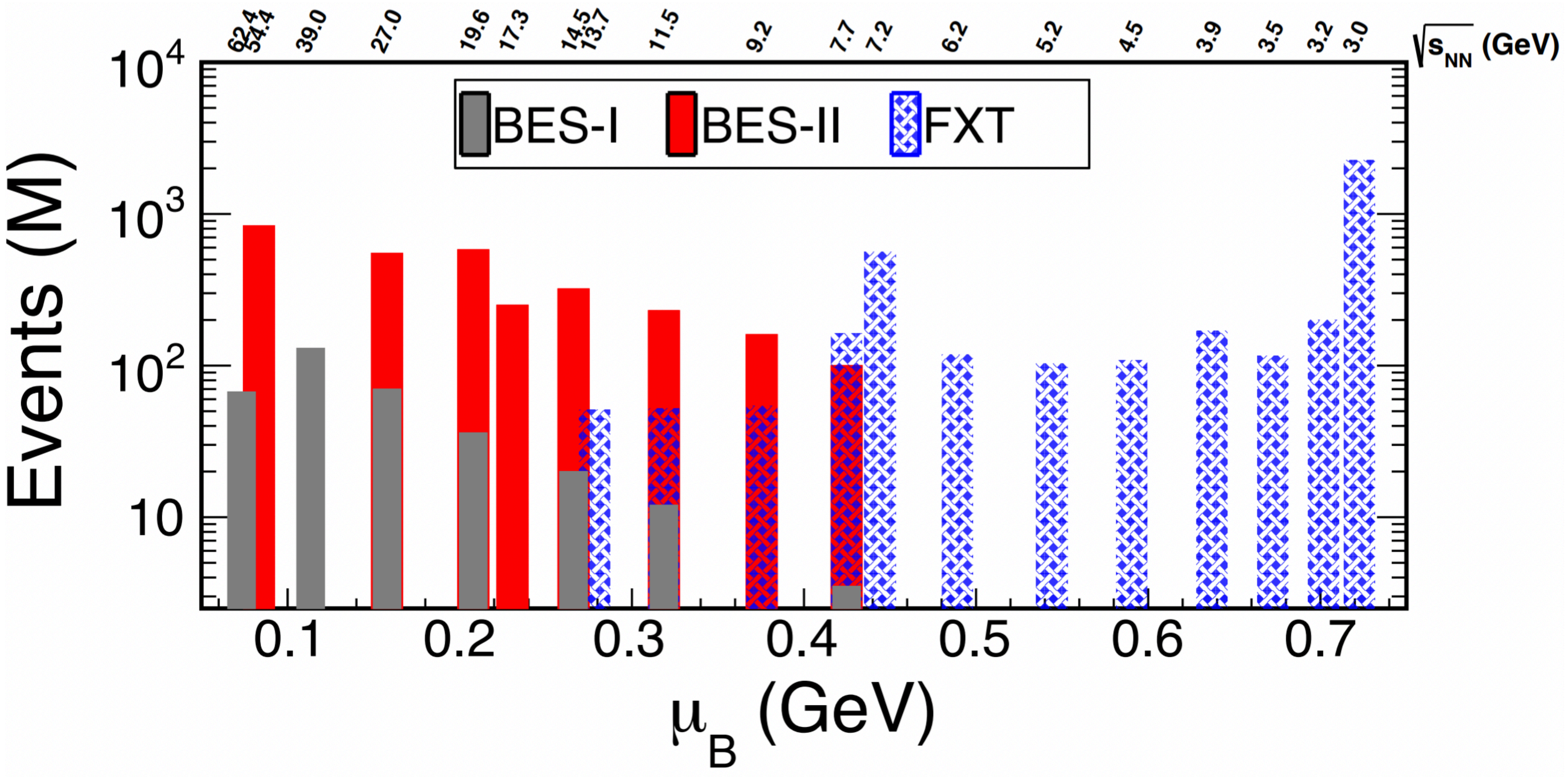
2020 - 11.5, 9.2, FXT: 3.5, 3.9, 4.5, 5.2, 6.2, 7.7

2021 - 7.7, 17.3, O+O, d+Au, FXT: 3.0, 9.2, 11.5, 13.7

2022 - p+p 510

2023 - Au+Au 200

2024/25 - Au+Au 200, p+p 200 and p+Au 200



Outline

QCD phase diagam

- CEP, Collectivity, and EoS, HBT, Strangeness, Dielectron

Particle production

- Light (hyper-)nuclei production, HBT and Baryon Junction

QGP properties

- Collectivity, Vorticity, D^0 tagged-jet, D^0-hadron HBT, CNM, Strangeness

Detector upgrades and future plan

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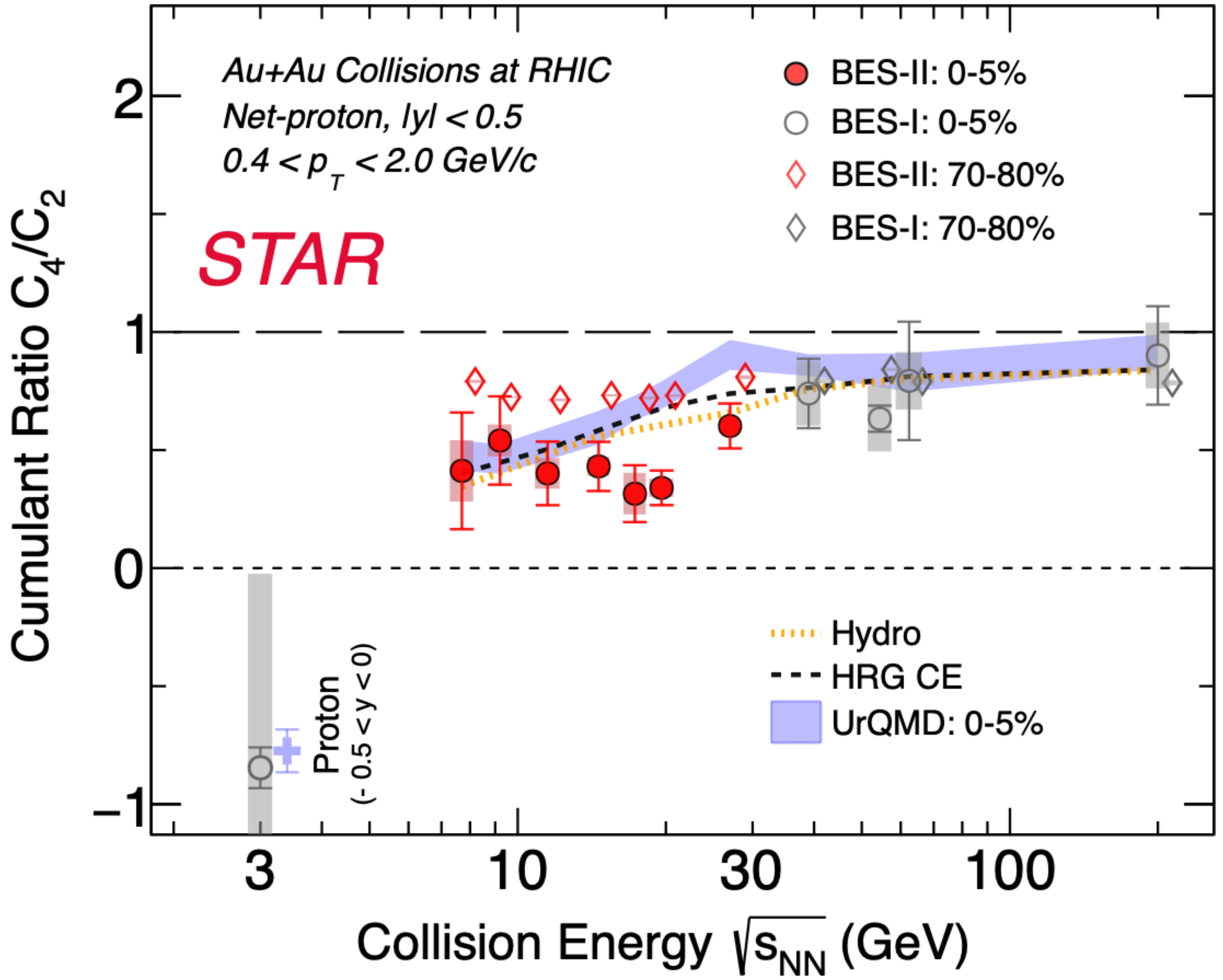
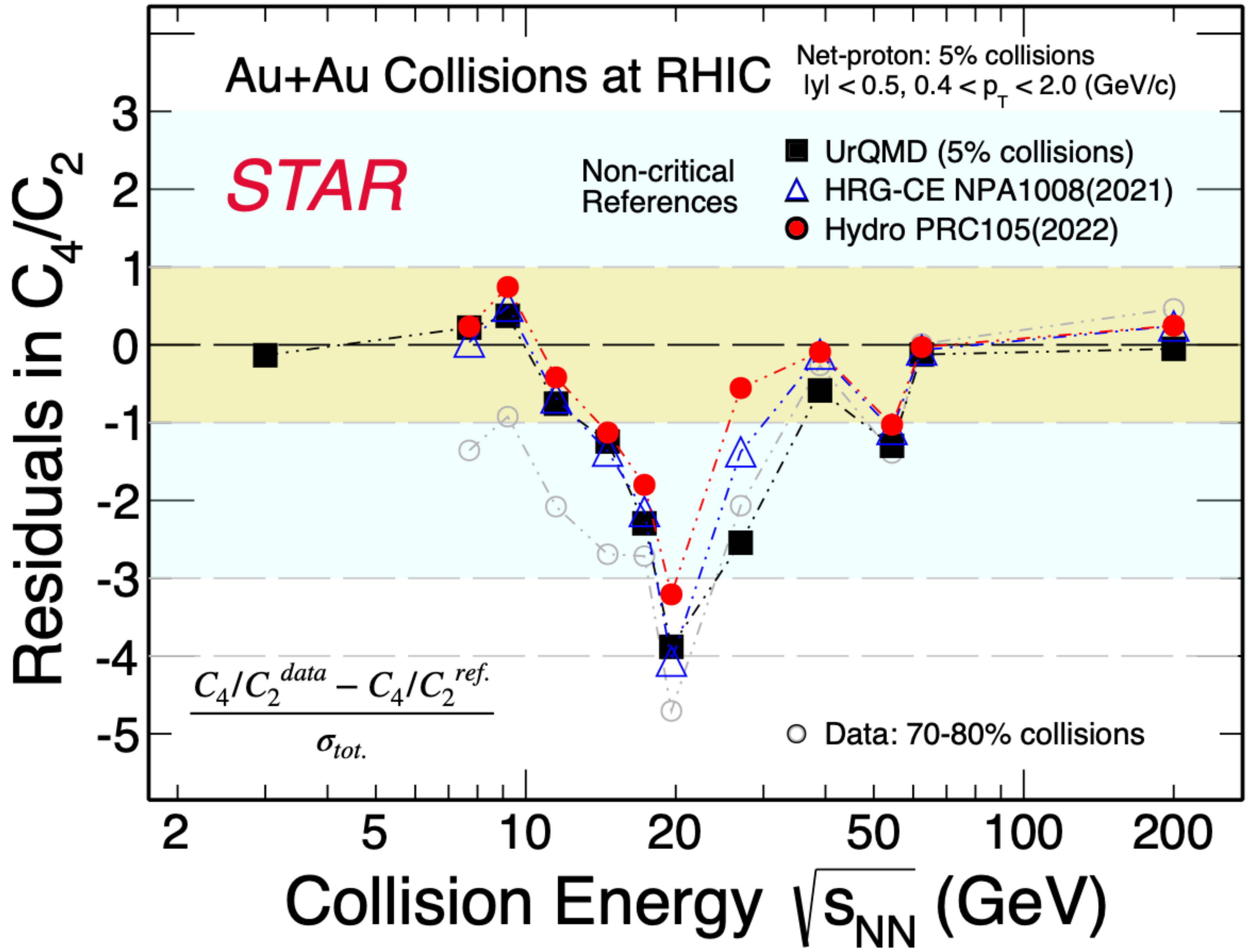
Detector upgrades and future plan

Search for CEP: Net-proton cumulants





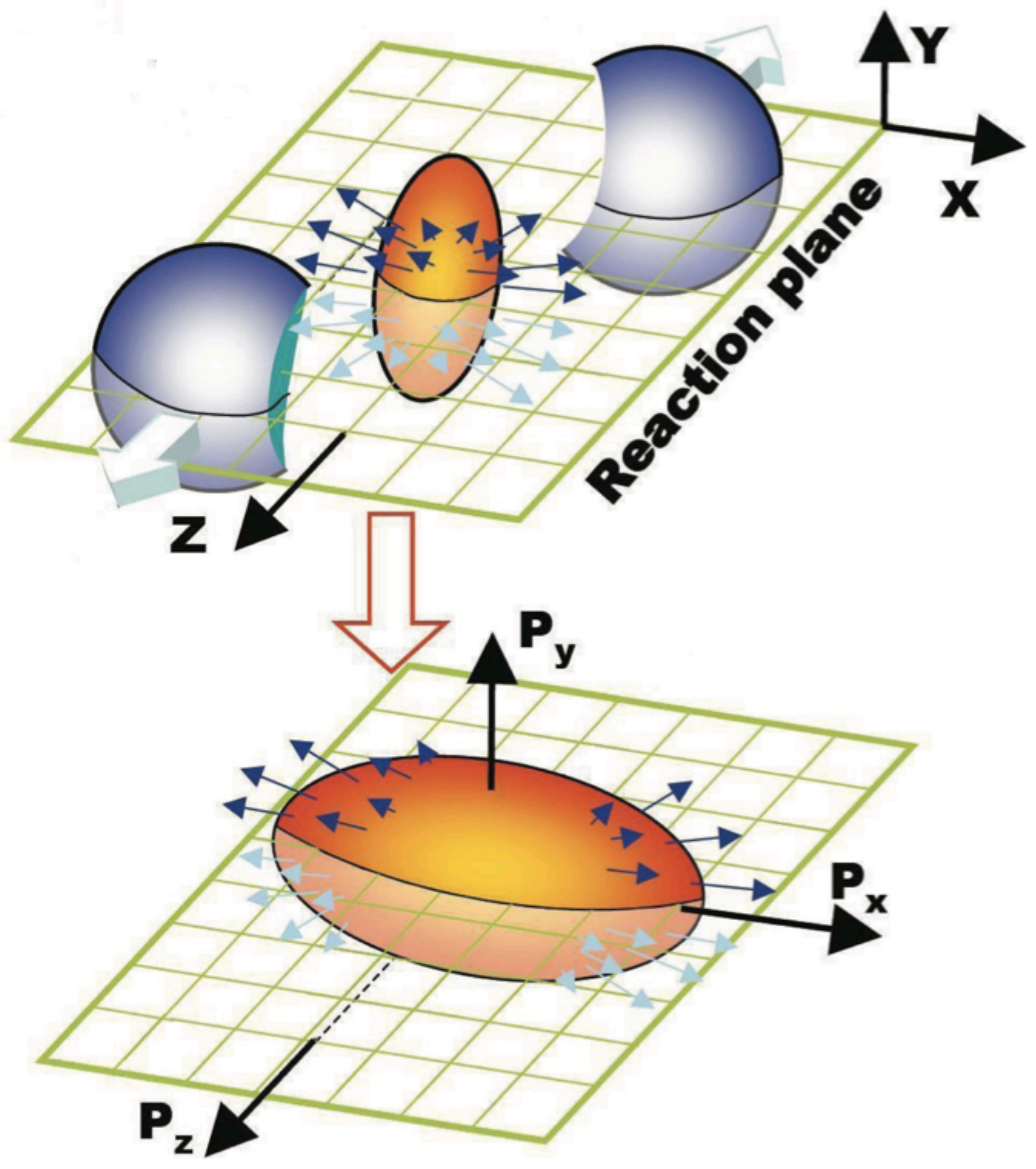
Yifei Zhang
06/06 08:30AM

- New high precision BES-II Measurement from 7.7-27 GeV
- C_4/C_2 shows minimum around ~20 GeV comparing to models without CP, 70-80% data

Light and strange hadron elliptic flow at high μ_B

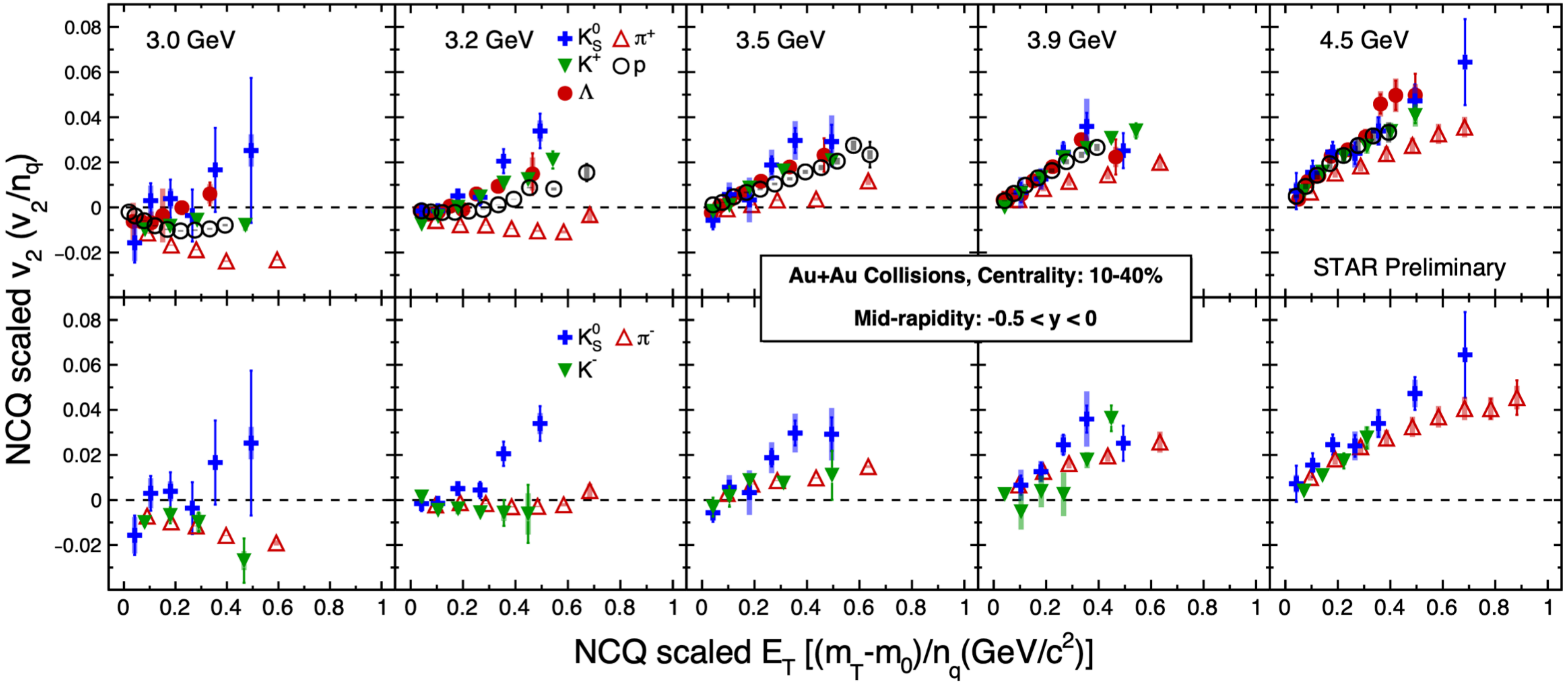
Shusu Shi
04/06 11:20 AM

- The equation of state (EoS) of the medium and degrees of freedom



Hadronic interaction
Collision energy

Partonic interaction
Collision energy



Postive charge

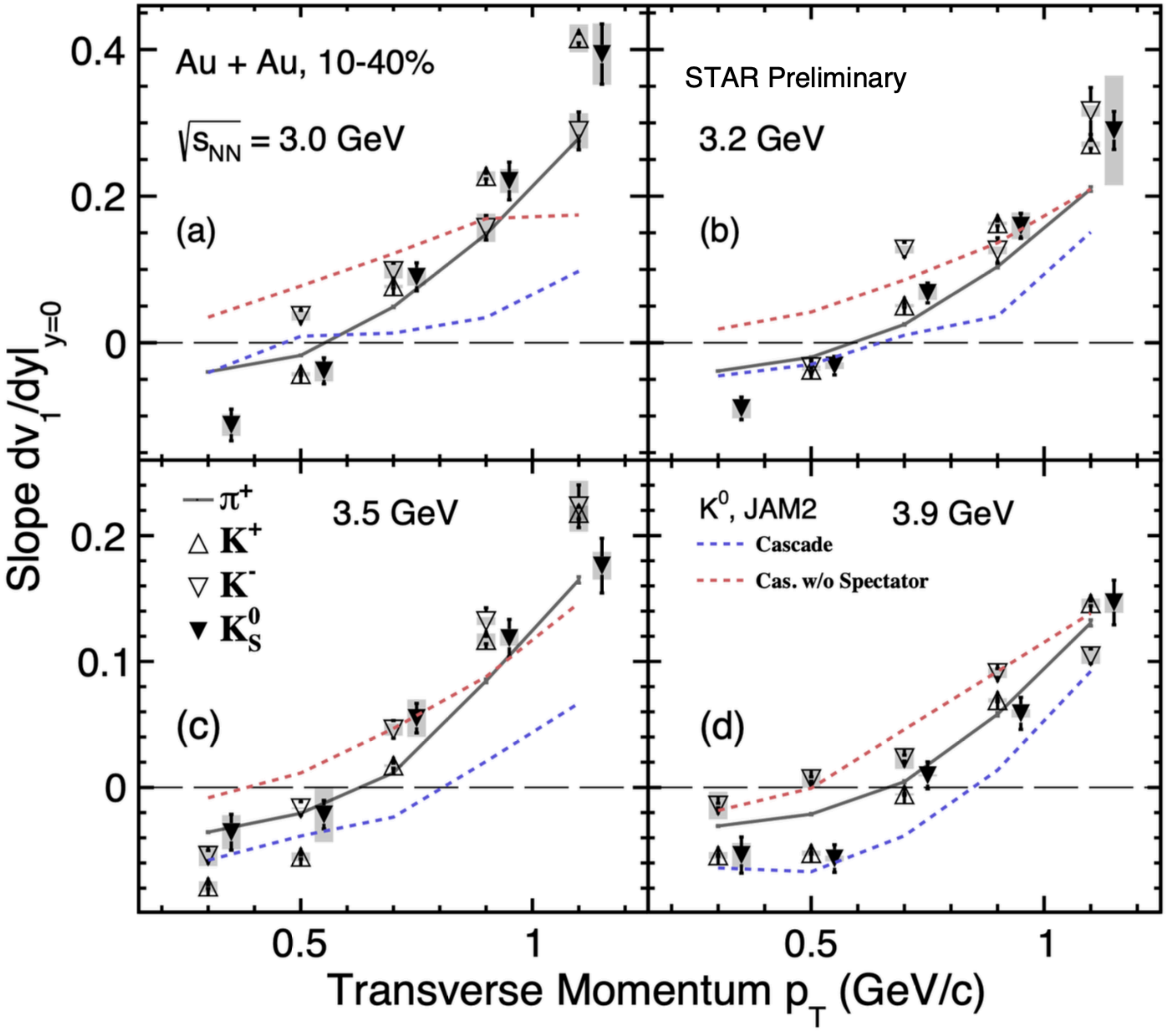
Negative charge

- v_2 NCQ scaling breaks at 3.2 GeV and gradually restores towards 4.5 GeV

p_T dependence of directed flow slope at high μ_B

Shusu Shi
04/06 11:20 AM

π^+, K^+, K^- and K_s^0

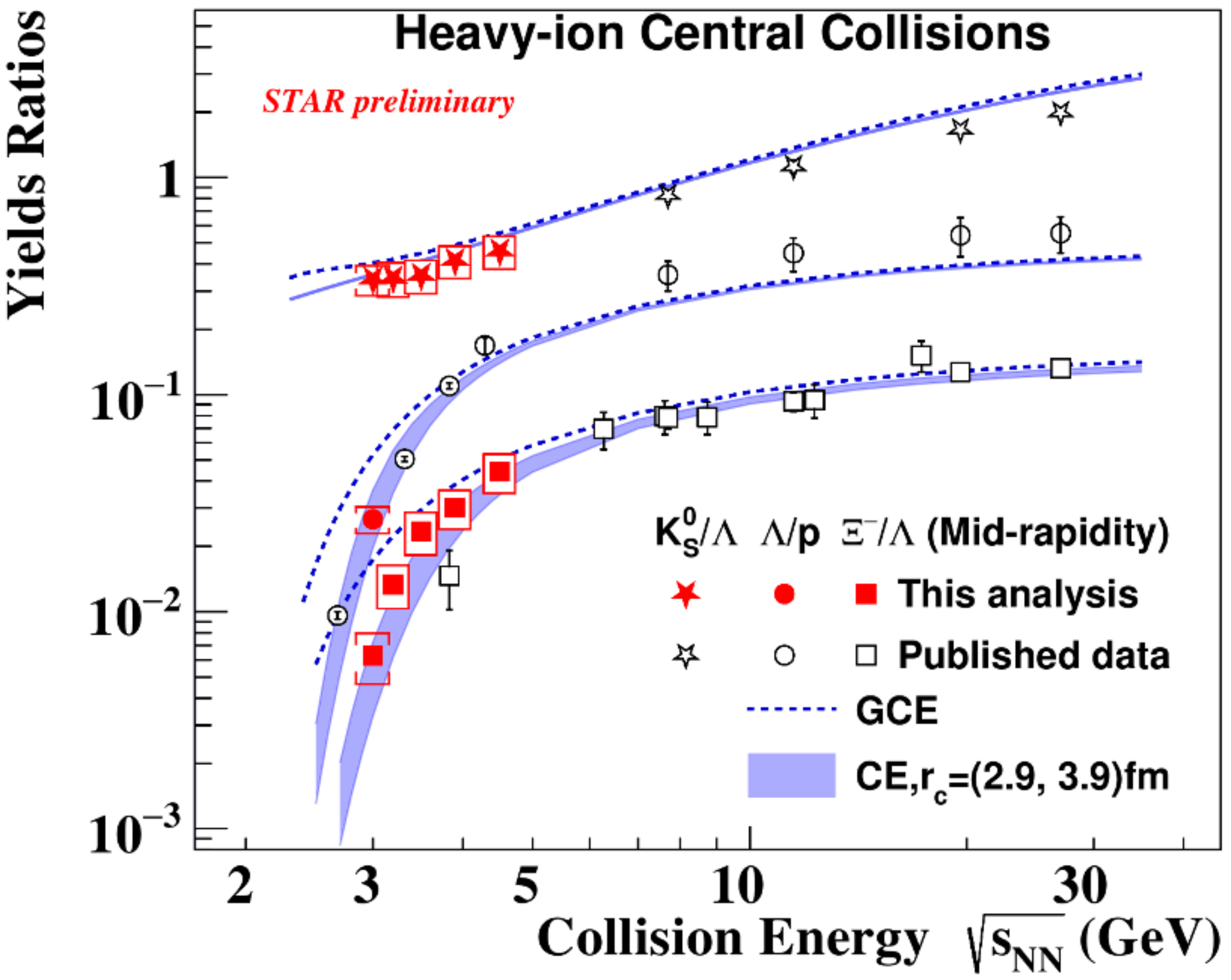


- Anti-flow of π^+ and K_S^0, $K^\pm$at low p_T

- Anti-flow could be explained by shadowing effect from spectators

Strangeness production at high-μ_B region

Hongcan Li
05/06 11:40 AM

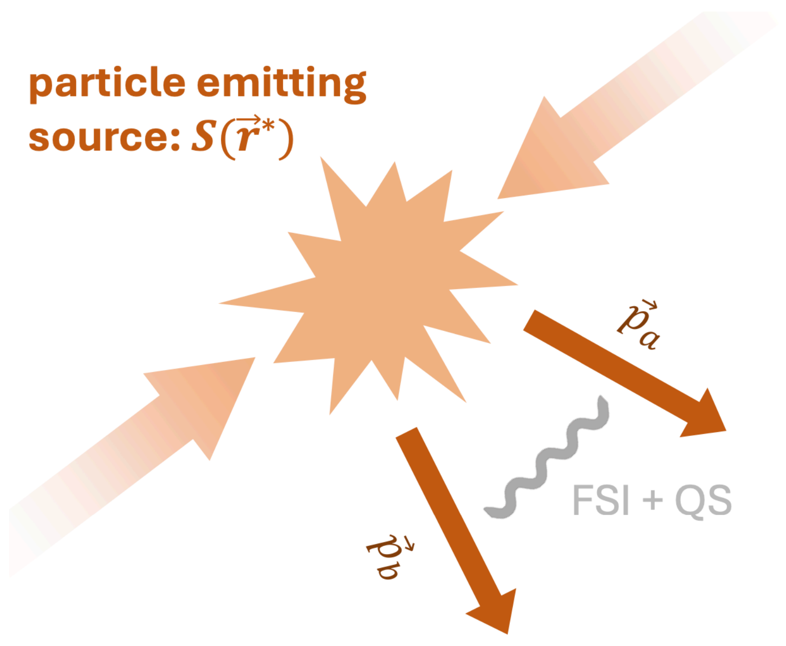


- Grand Canonical Ensemble (GCE) fails with $\sqrt{s_{NN}}$ < 4 GeV
- Canonical Ensemble (CE) with strangeness correlation length 2.9-3.9 fm, simultaneously describes data
- Change of medium properties at the high-baryon-density region

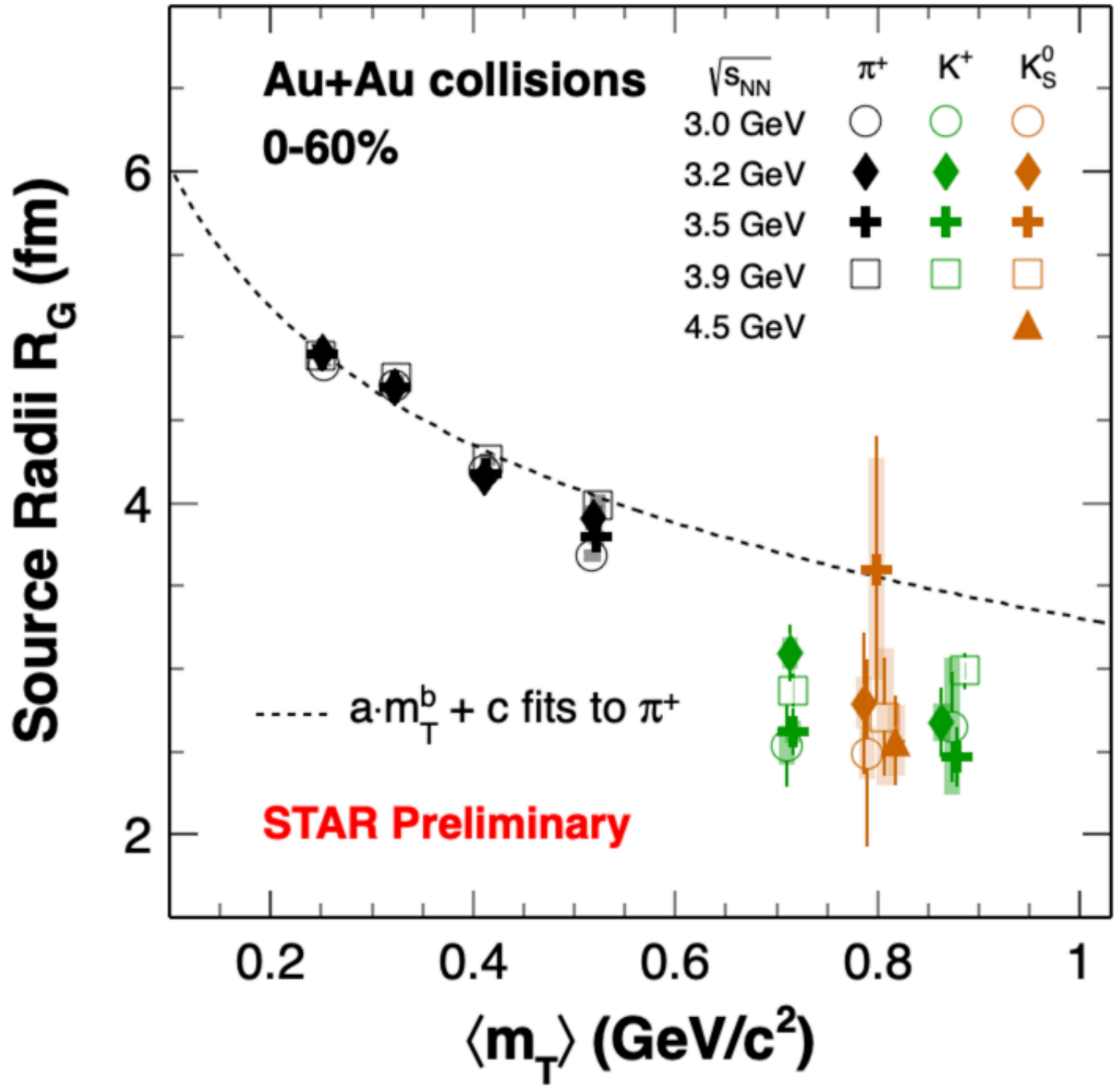
Femtoscopy of two-kaon at high μ_B region

Bijun Fan
04/06 5:30 PM

- Spatial and temporal extent of the emission source



- Fitting to CF to extract source radii and correlation strength



- Bowler-Sinyukov method to includes FSI (Coulomb effect)

Coulomb effect QS effect

$$CF(q_{inv}) = N[(1-\lambda) + \boxed{K_{coul}(q_{inv}, R_G)}\lambda\left(\boxed{e^{-[R_G^2 q_{inv}^2]}} + 1\right)]$$

R_G: source radii parameter;
λ: correlation strength;
N: normalization factor;

- Lednicky-Lyuboshitz approach to includes FSI(Strong interaction)

QS effect Strong interaction through $f_0(980)$ /$a_0(980)$ resonances

$$CF(q_{inv}) = 1 + \lambda(\boxed{e^{-[R_G^2 q_{inv}^2]}} + \boxed{\frac{1-\epsilon^2}{2}}\boxed{[\left|\frac{f(k^*)}{R_G}\right|^2 + \frac{4Re[f(k^*)]}{\sqrt{\pi}R_G}F_1(q_{inv}R_G) - \frac{2Im[f(k^*)]}{R_G}F_2(q_{inv}R_G)]})$$

abundance asymmetry ϵ

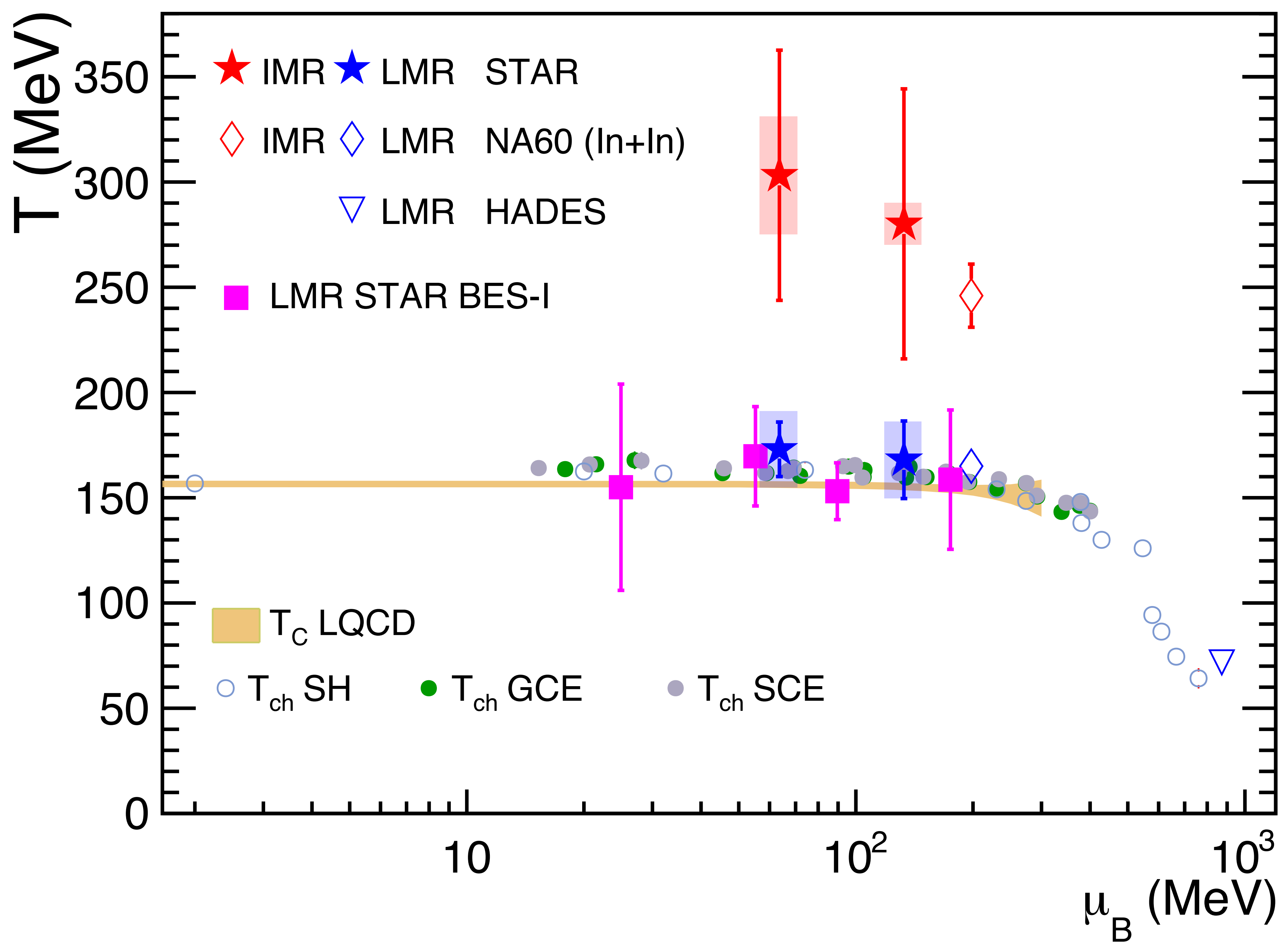
- Kaon's source radii do not follow m_T-scaling
  - Kaon source size smaller than pion at freeze-out

Thermal dielectron measurements

- Direct access to temperature of QGP phase and partonic➜hadron phase transition

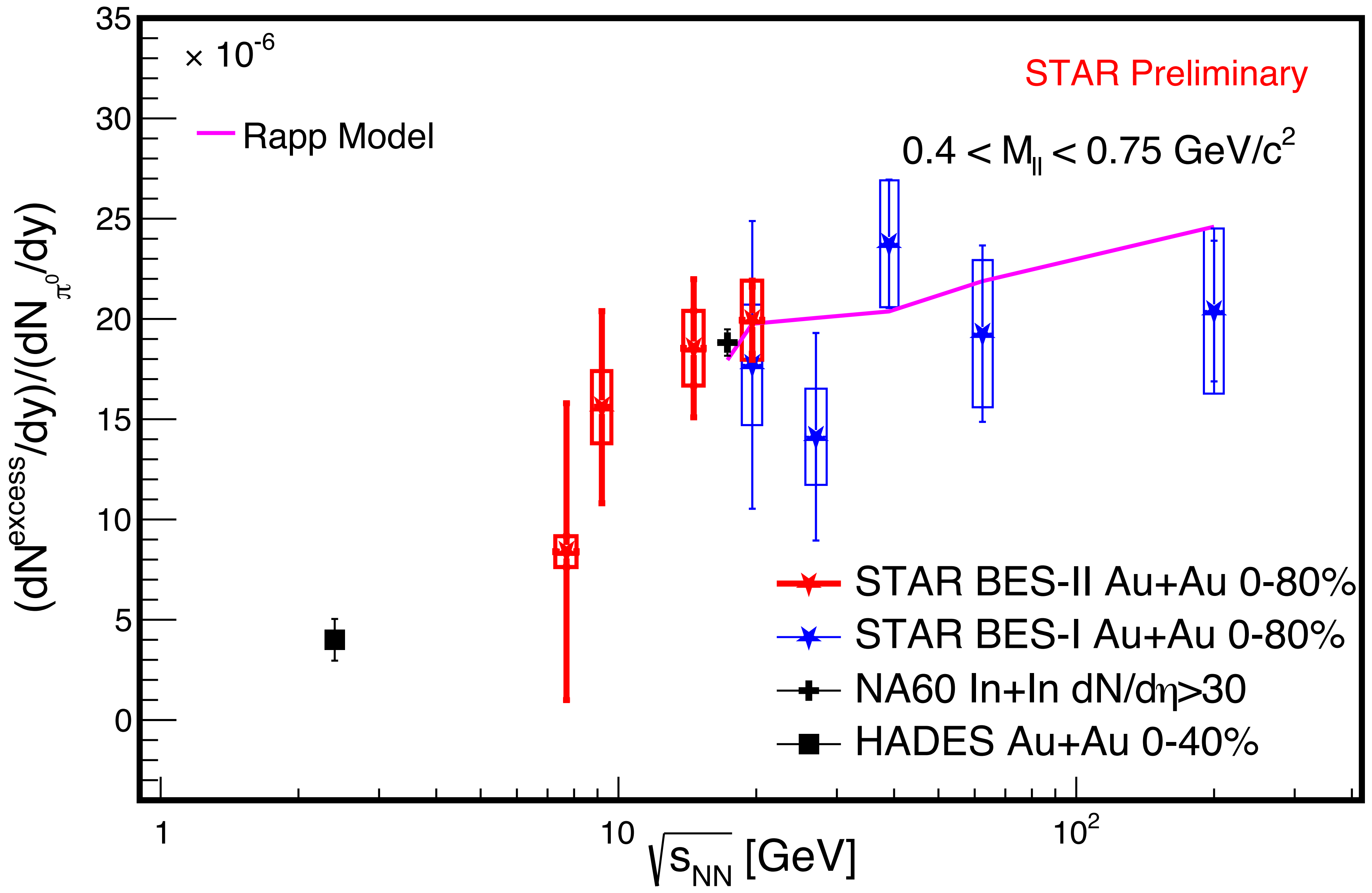
Zhen Wang
04/06 3:00 PM

STAR: arXiv: 2402.01998



- T^{LMR} is close to both T_{ch} and T_{pc}
- T^{IMR} is higher than T^{LMR} ➜ QGP phase

Normalized excess yield



- The integrated excess yield shows a hint of decreasing trend with decreasing $\sqrt{s_{NN}}$

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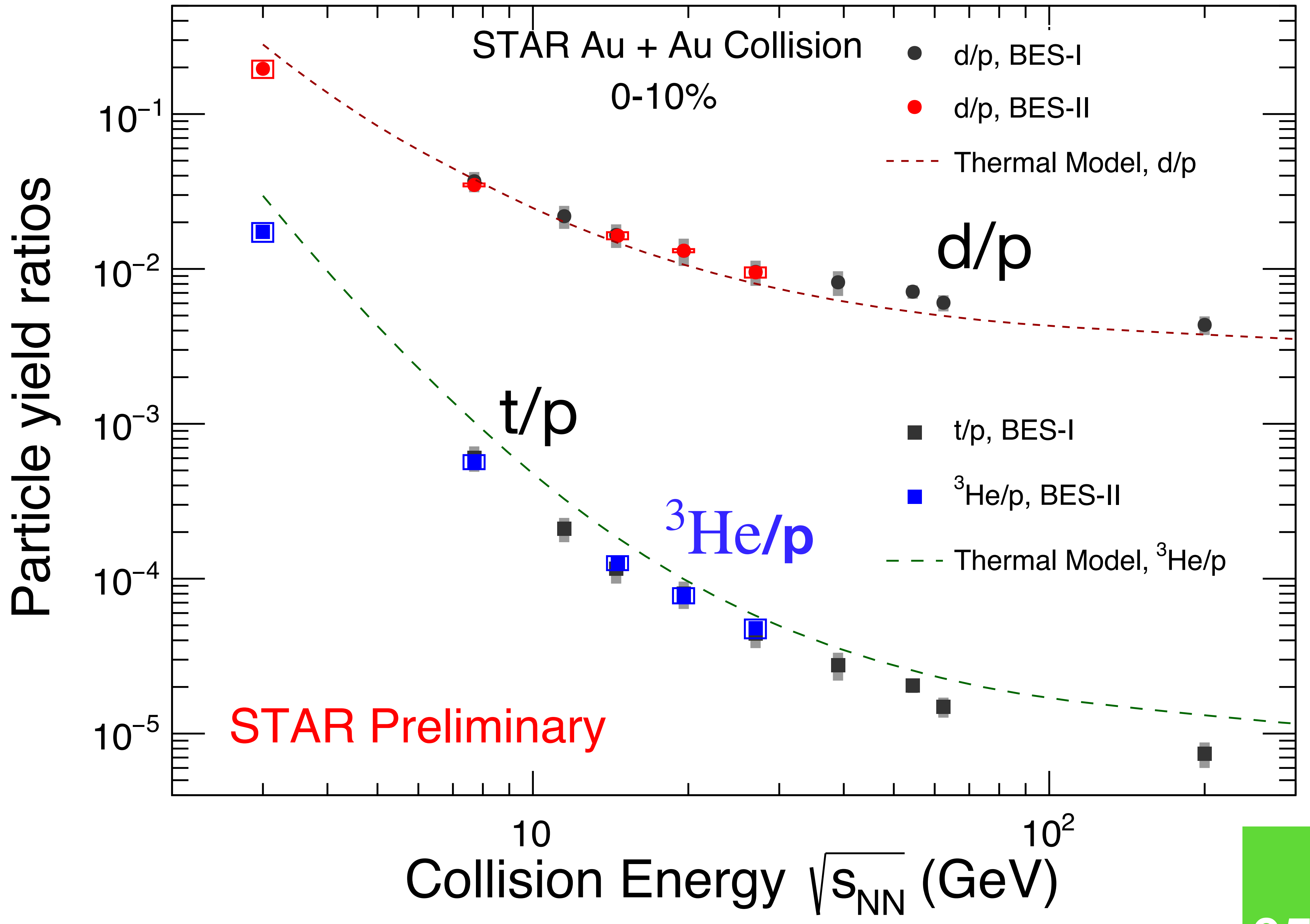
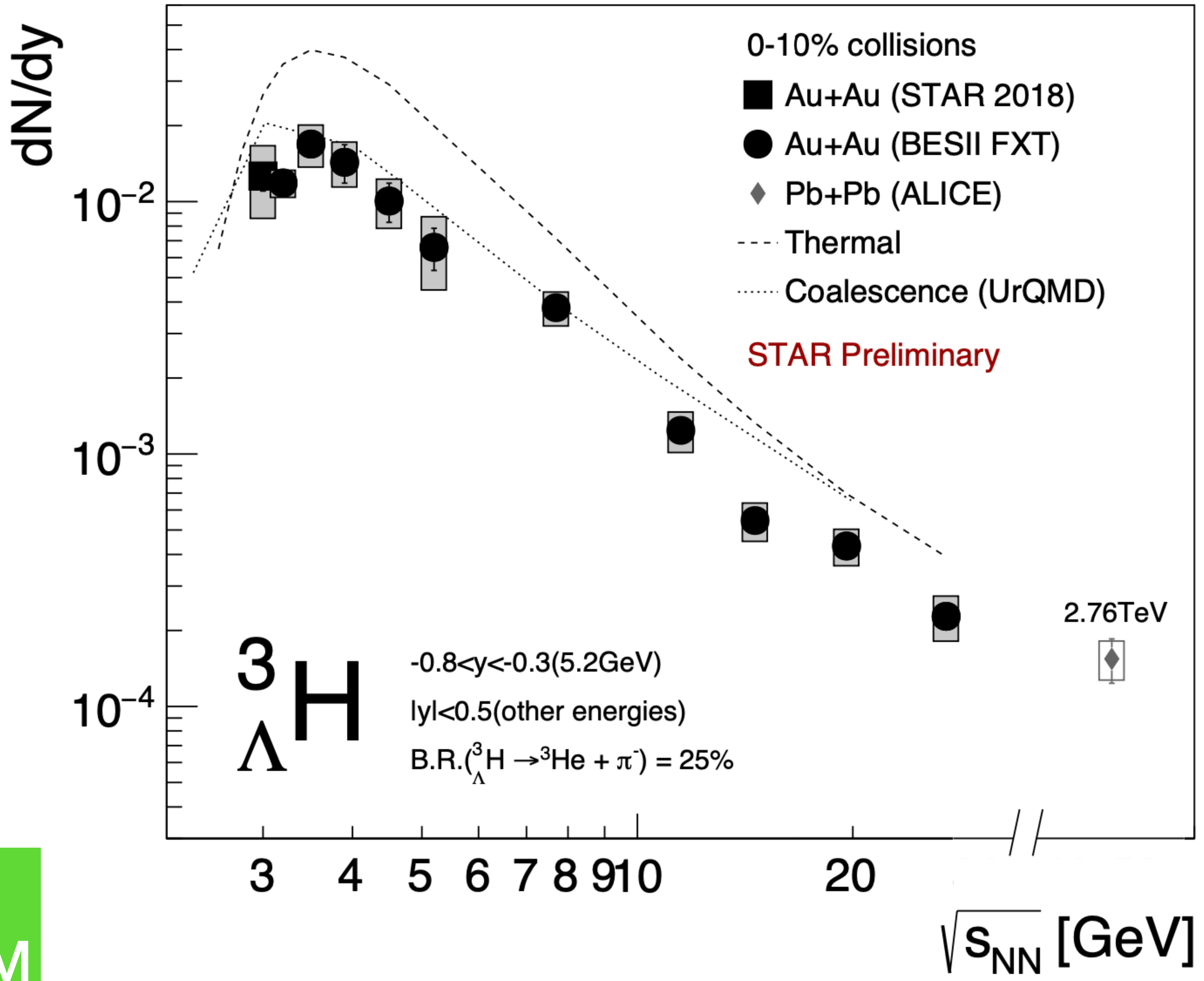
Detector upgrades and future plan

Light (hyper-)nuclei production



Yixuan Jin
05/06 12:00 PM



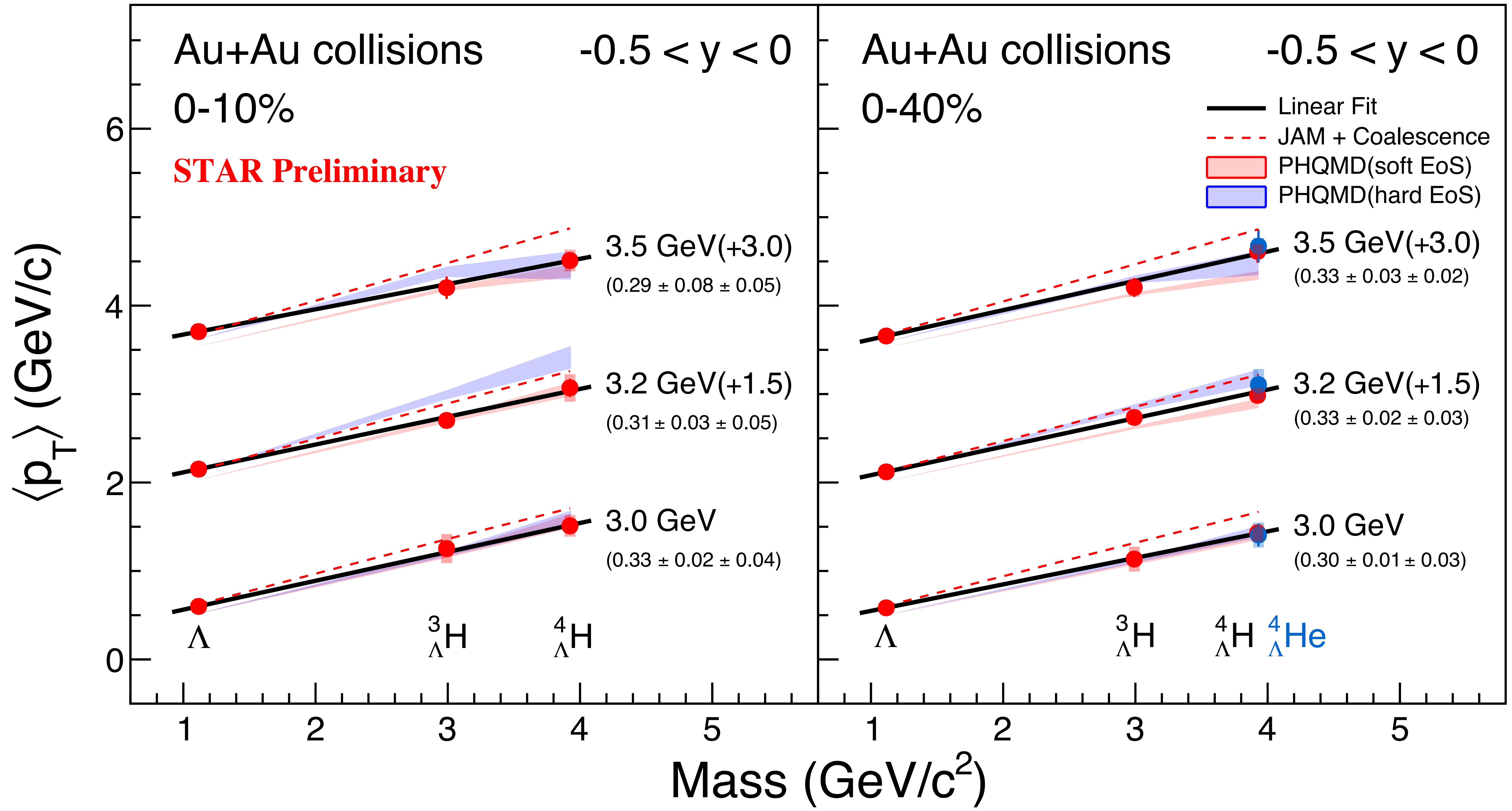
Xiujun Li
04/06 4:30 PM

- Thermal model over-predicts t/p and $^{3}\mathrm{He}/p$ and $^{3}_{\Lambda}\mathrm{H}/\Lambda$ ratios

➜$^{3}_{\Lambda}\mathrm{H}$, t, and $^{3}\mathrm{He}$ not in equilibrium at hadron chemical freeze out at RHIC

Hyper-nuclei $\langle p_T \rangle$ slope vs energy

Chenlu Hu
05/06 9:10 AM



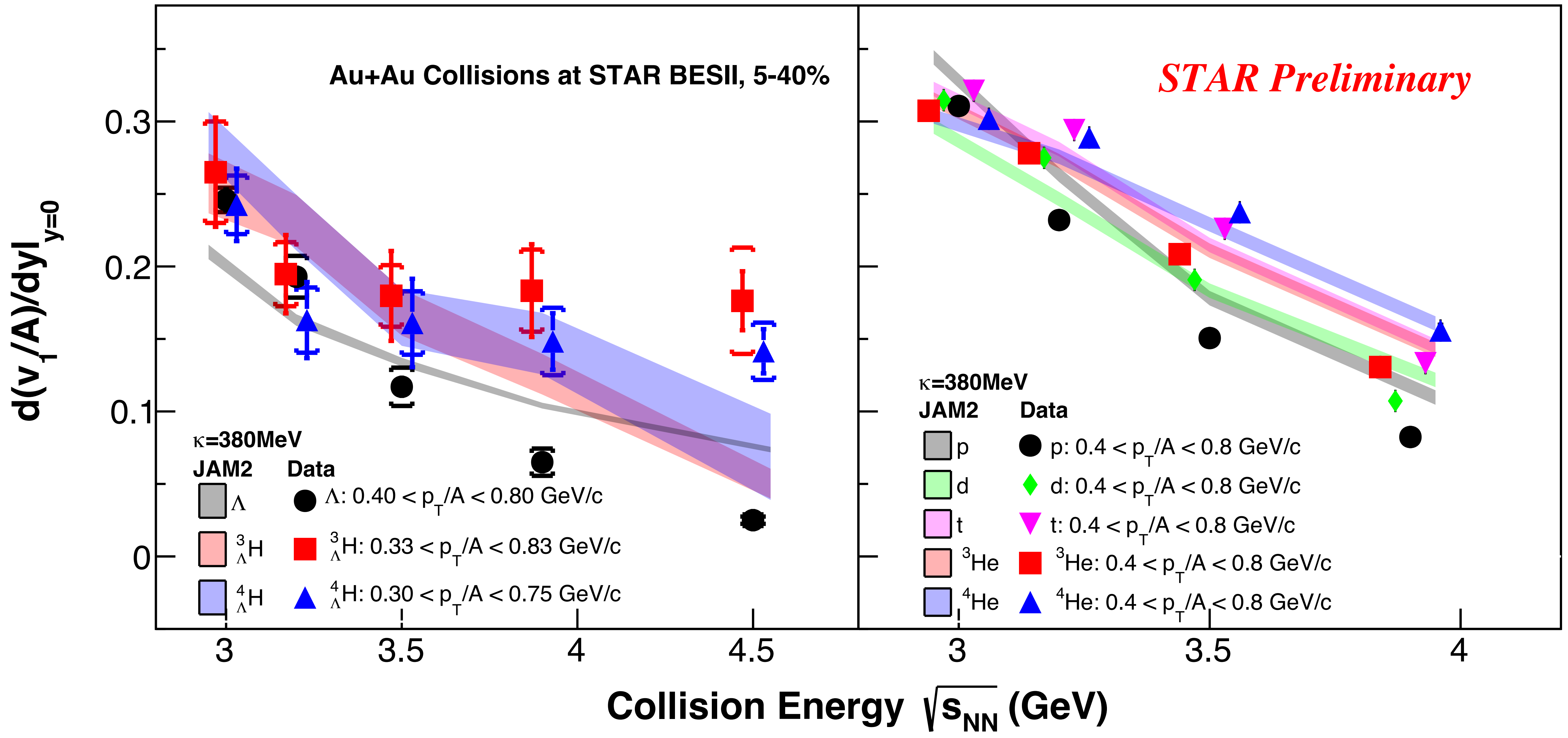
$\langle p_T \rangle$ vs mass follows a linear mass scaling for $\sqrt{s_{NN}}$ = 3.0, 3.2, 3.5 GeV

- Consistent with coalescence production of hyper-nuclei at mid-rapidity

Directed flow of light and hyper nuclei at high μ_B

Junyi Han
04/06 2:40 PM

$\Lambda, {}^{3}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{H}$ — p,d,t,^{3}He and ^{4}He



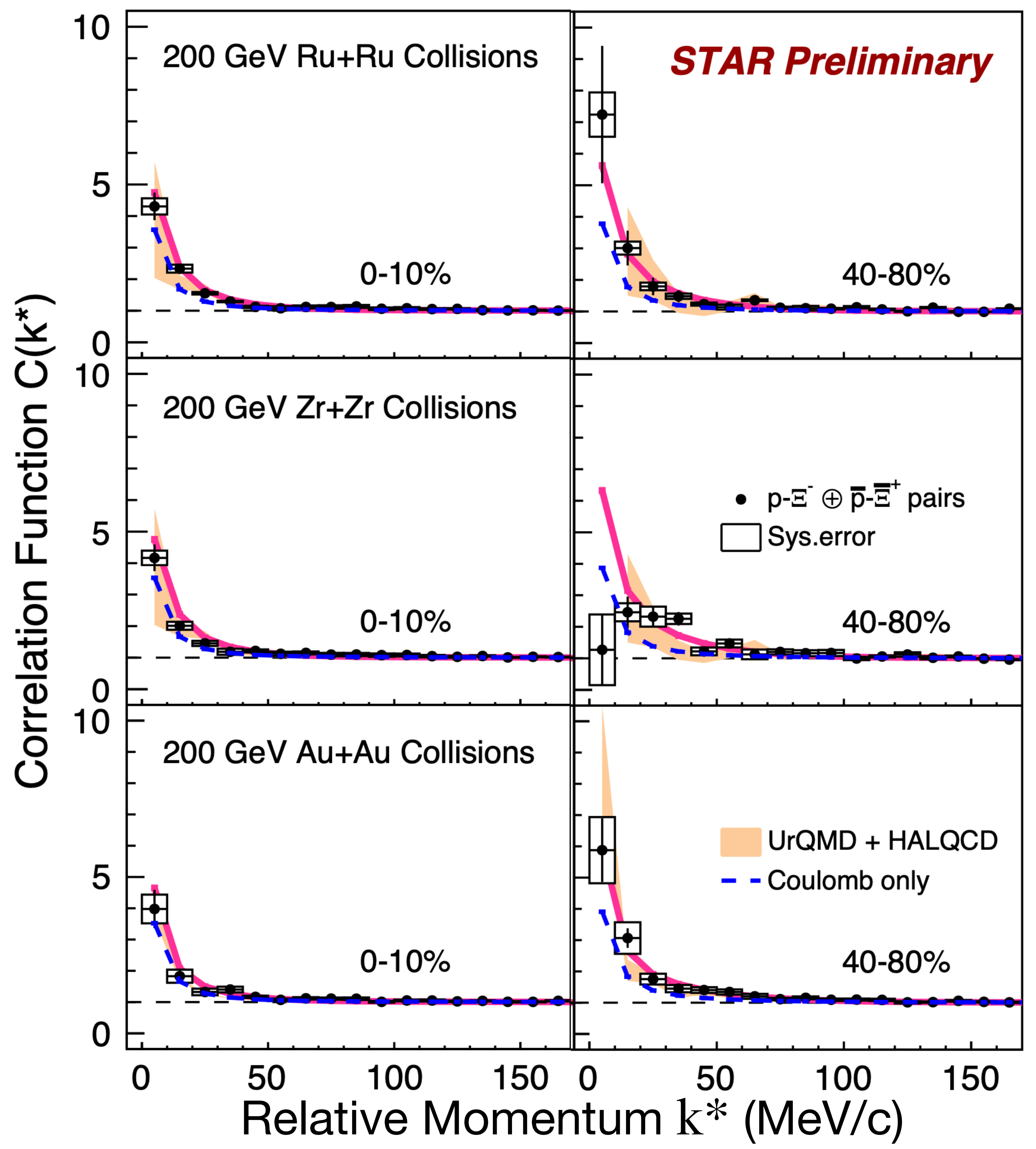
- v_1 slope: consistent with hadronic transport model (JAM2 mean field + Coalescence)

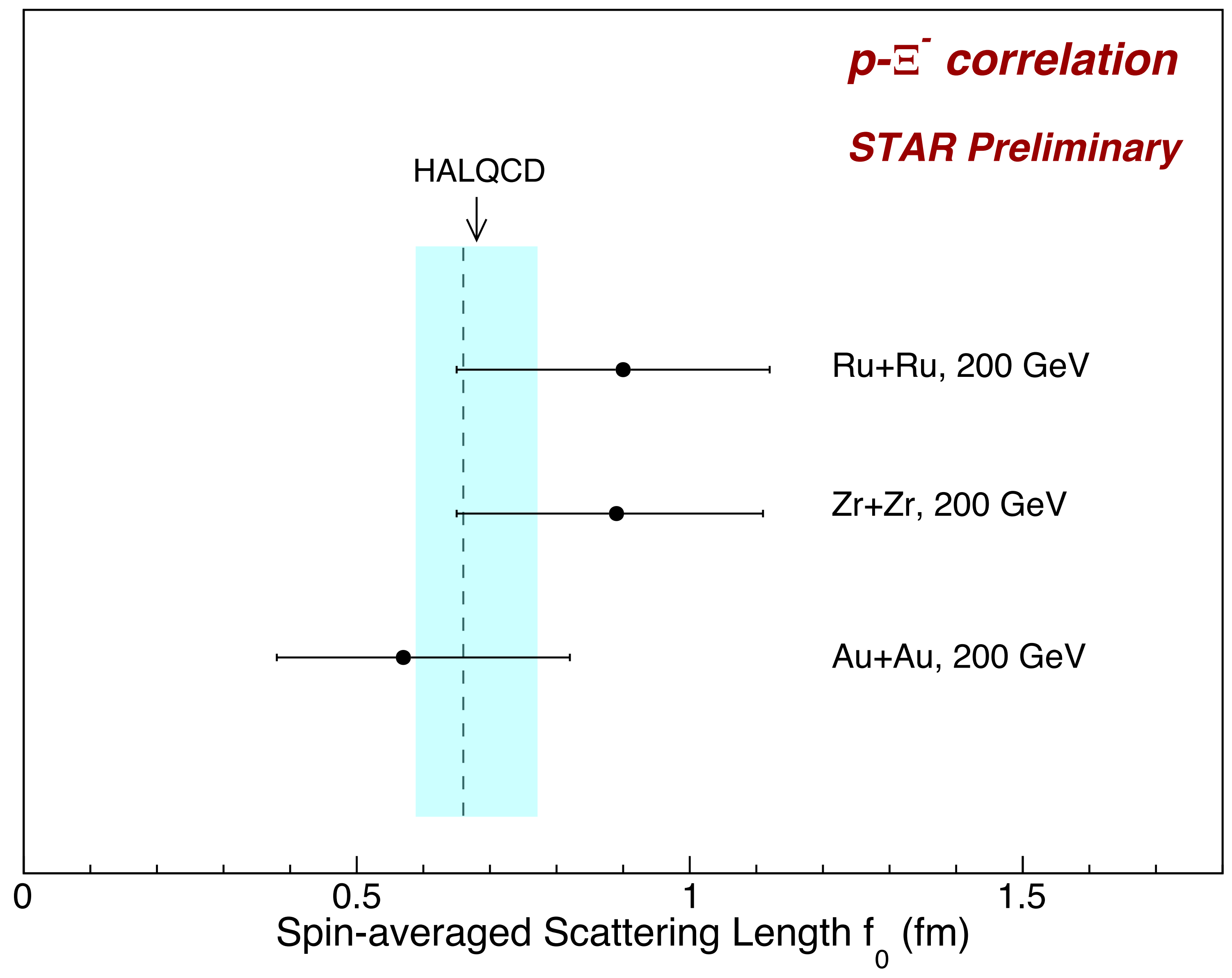
- Current measurements (particle yield ratio, $\langle p_T \rangle$ slope, and directed flow slope) support coalescence picture of light (hyper-)nuclei production

p-Ξ^- correlation function

Boyang Fu
05/06 9:10 AM

- Hyperon-nucleon(Y-N) interaction





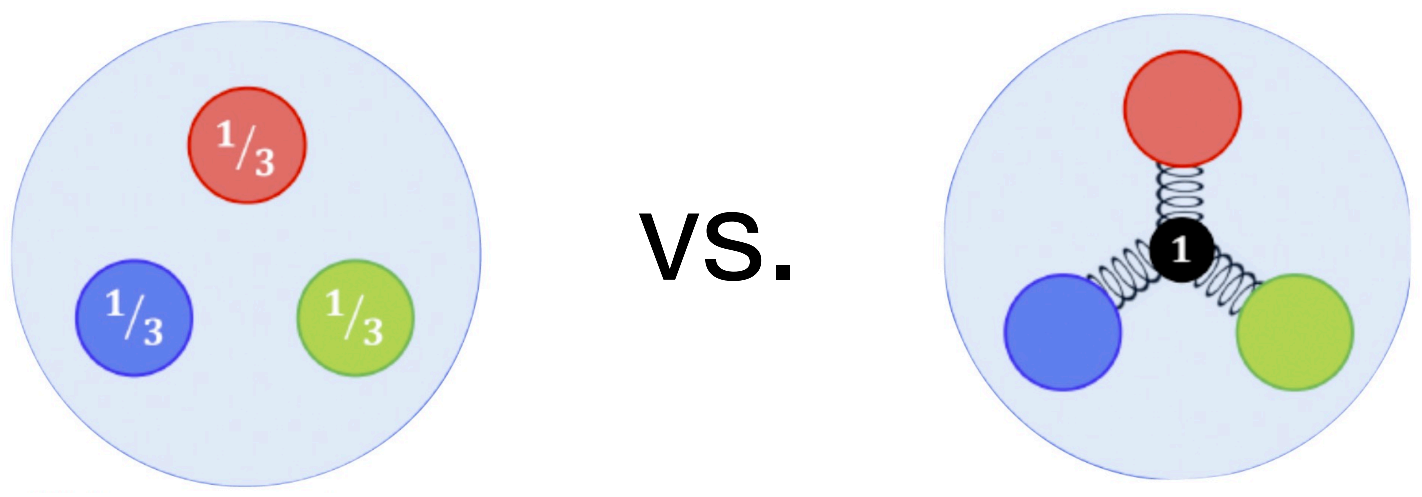
- CFs show enhancement at low k*

- The first experimental measurements of strong interaction parameters (f_0 , d_0) in p-Ξ^- pairs
  - The f_0 is consistent with HAL QCD predictions within 1σ
  - Weak attractive interaction in p-Ξ^- pairs

Baryon number carrier

Rongrong Ma
04/06 2:00 PM

What carries the baryon number?



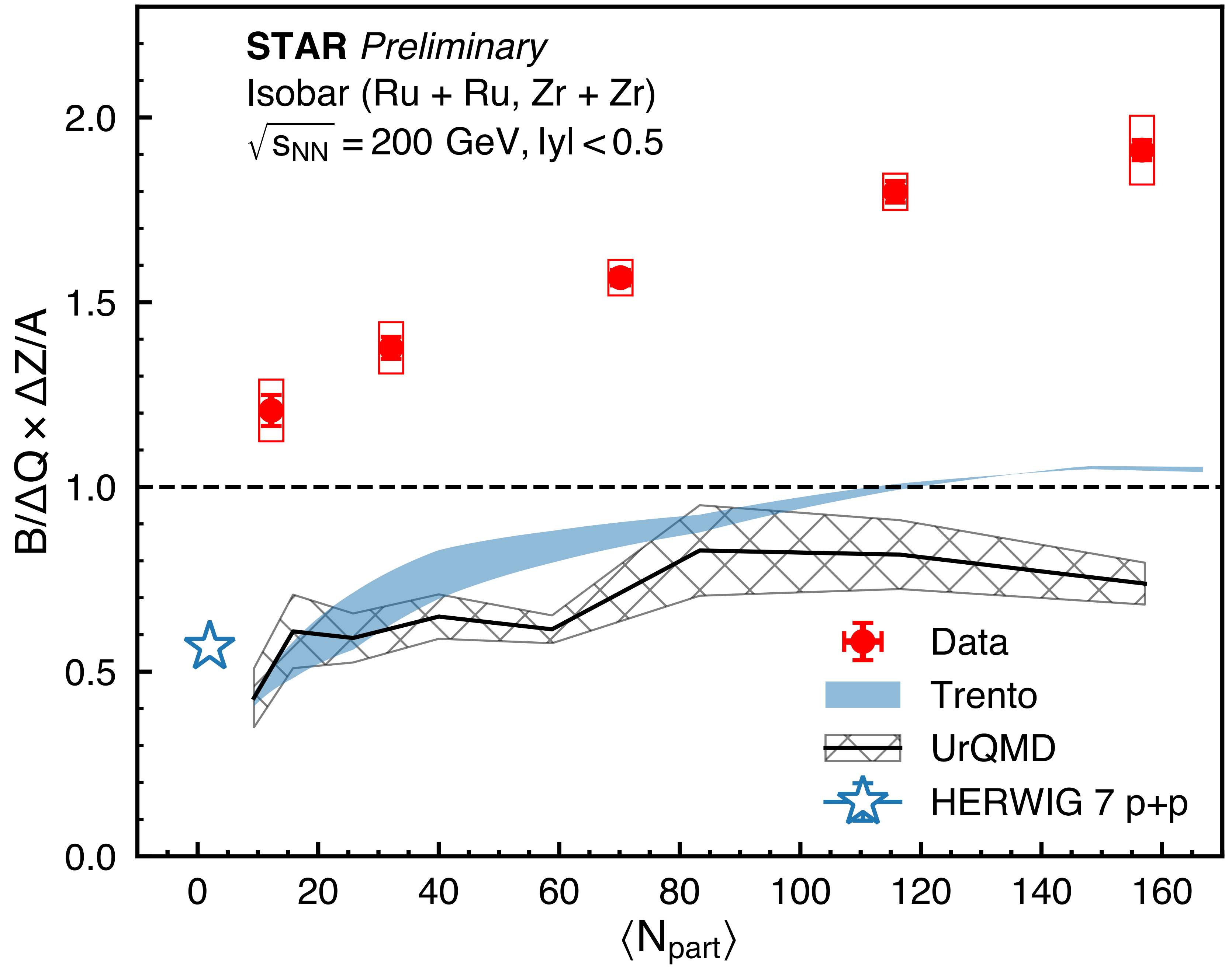
Valence Quarks:

- $Q \sim B \times Z/A$

Junctions:

- $Q < B \times Z/A$

$\langle B \rangle / \Delta Q \times \Delta Z/A$ vs. centrality



- $\langle B \rangle / \Delta Q \times \Delta Z/A$ ~ 2 in central collisions
  →higher than model calculations with valence quarks carrying baryon number

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Detector upgrades and future plan

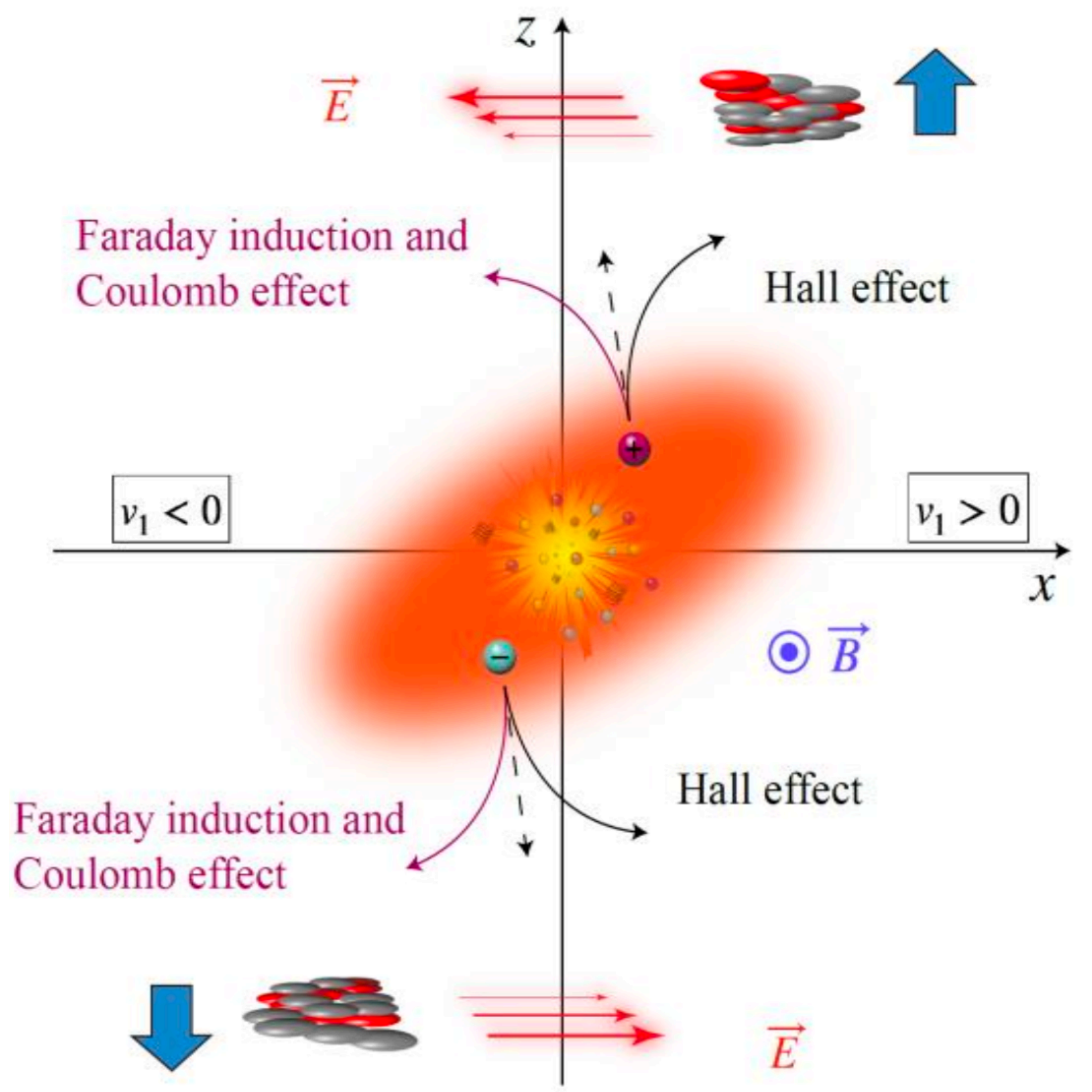
Charge-dependent directed flow in U+U

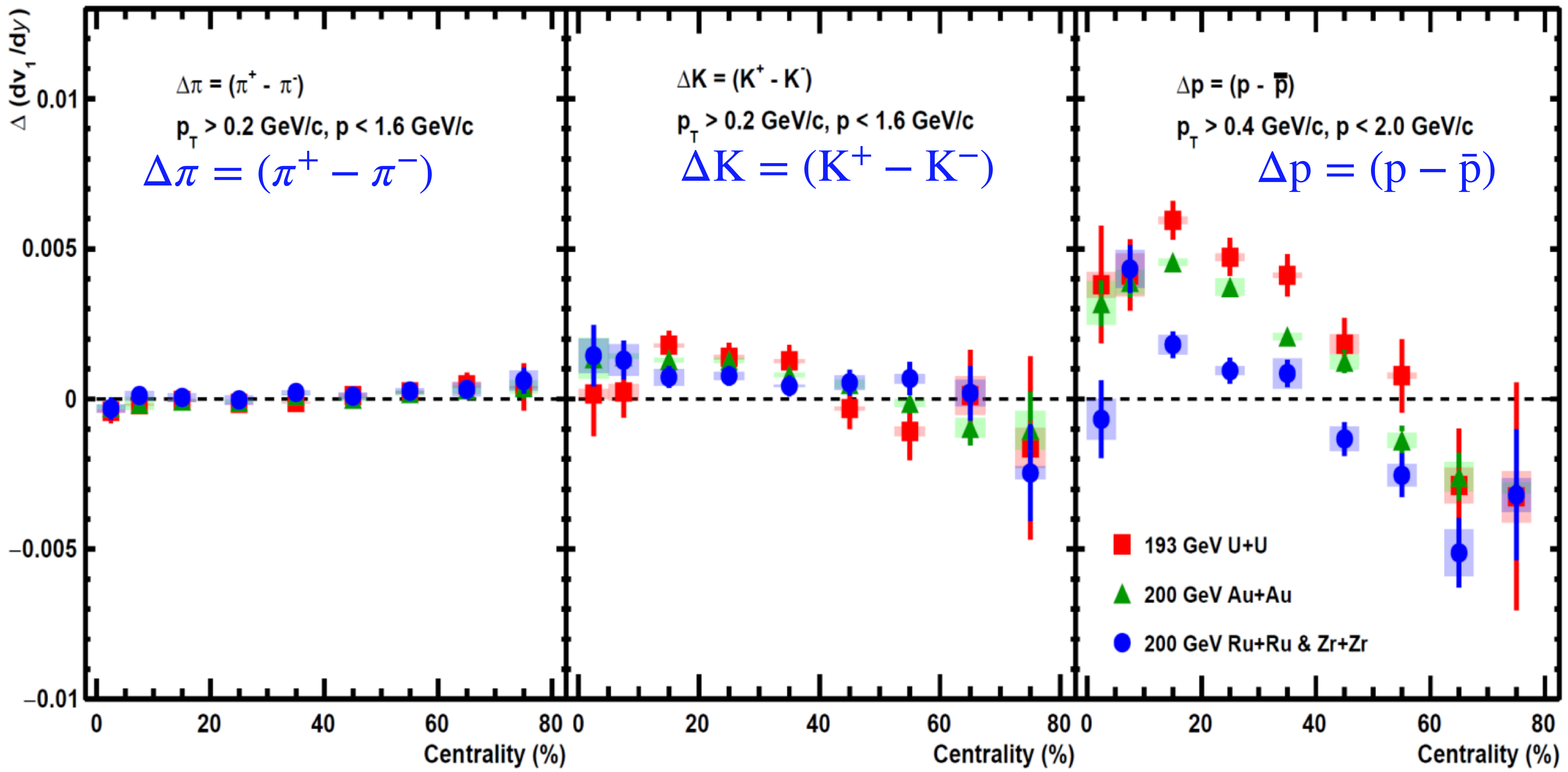
- Electromagnetic field could introduce charge-dependent directed flow

Muhammad F. T.
04/06 3:00 PM

$$\Delta(dv_1/dy) = [dv_1^+/dy - dv_1^-/dy]$$

STAR, PRX **14** (2024) 11028





$$I_{total} = I_{(Hall\ Effect)} + I_{(Faraday\ Effect)}$$

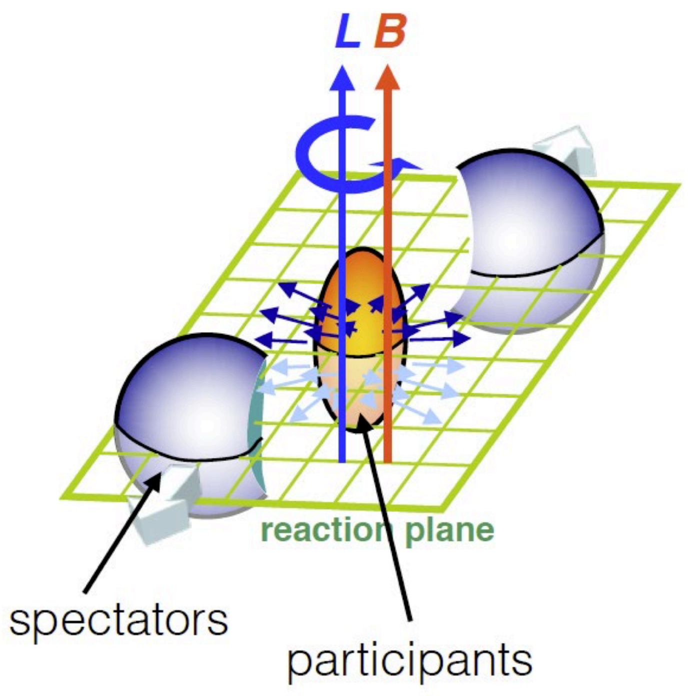
→ Directed flow difference(Δv_1)

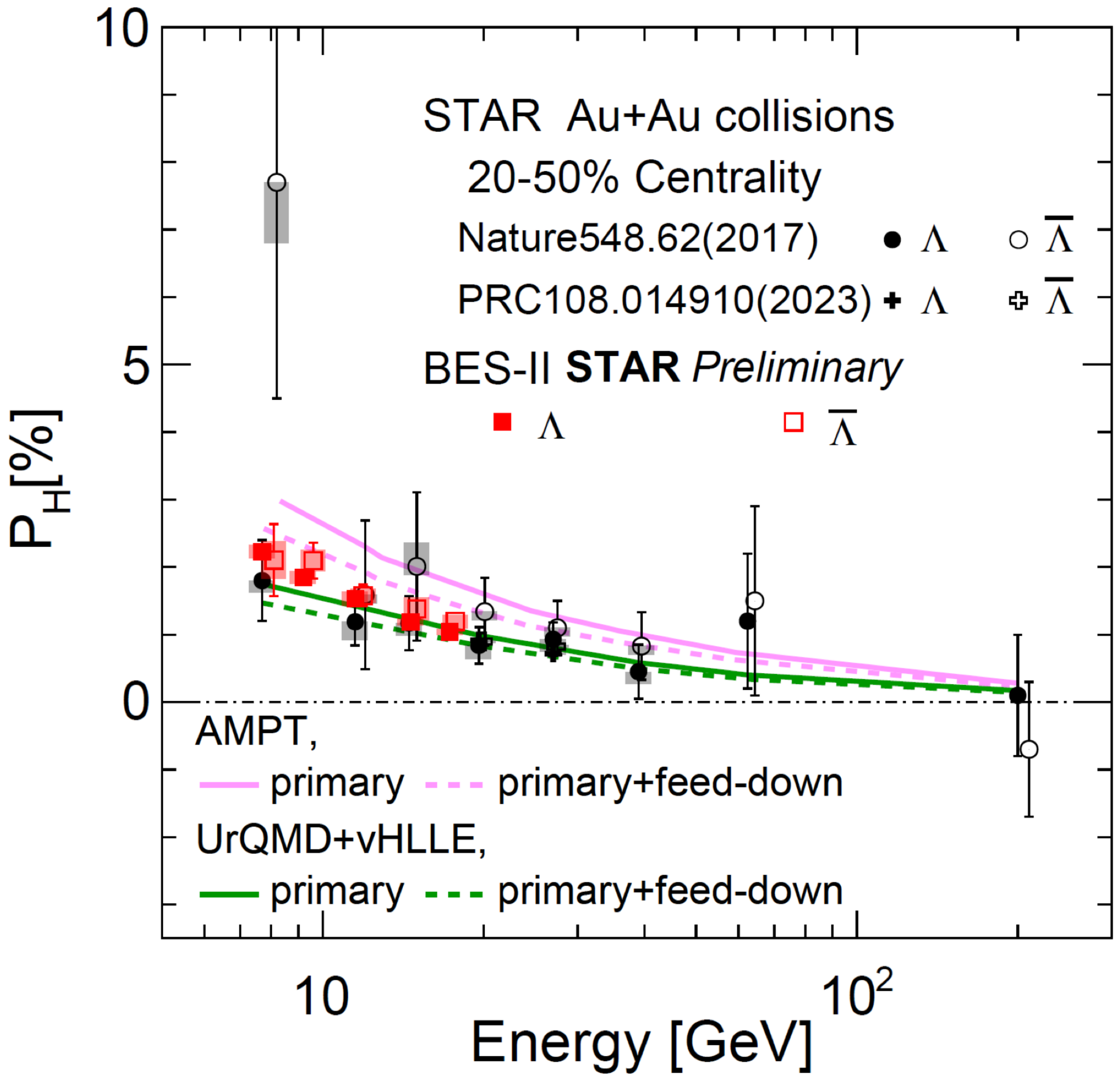
- Proton Δv_1: U+U > Au+Au > Isobar in 10-40% centrality
- Proton Δv_1 changes sign in peripheral collisions
  - Consistent with observation in Au+Au

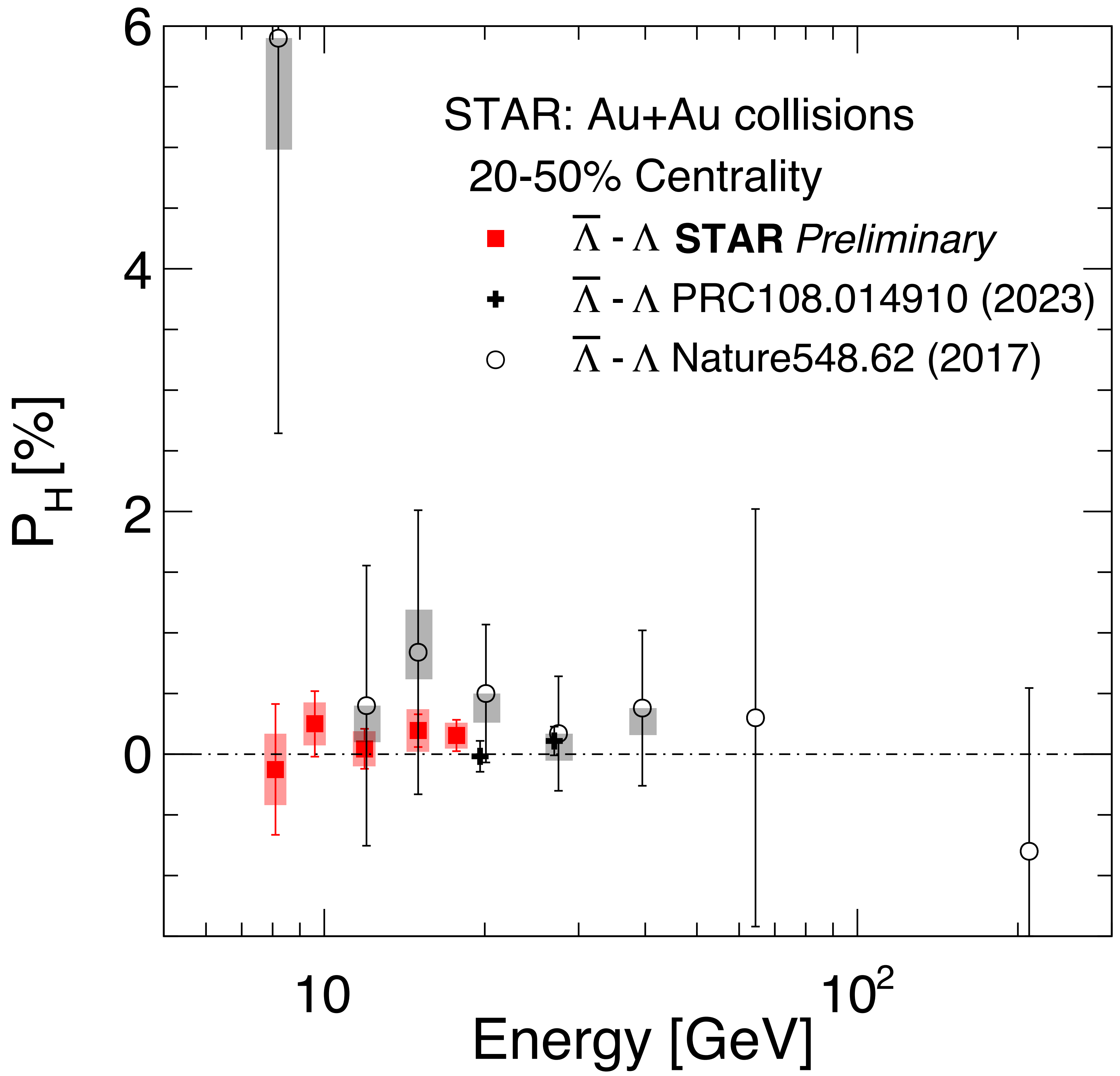
Global spin polarization of Λ

- Global polarization splitting and magnetic filed

Qiang Hu
05/06 9:10 AM



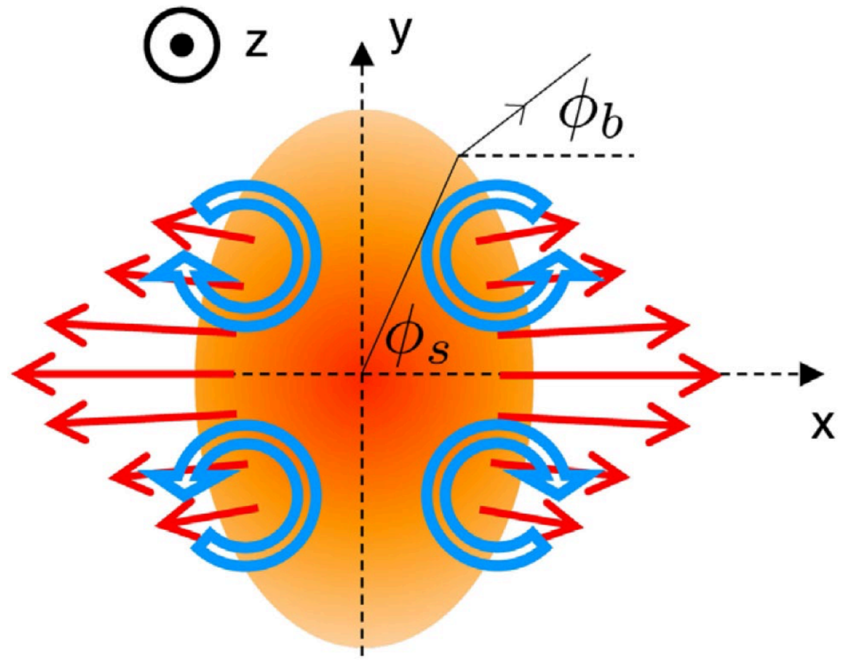


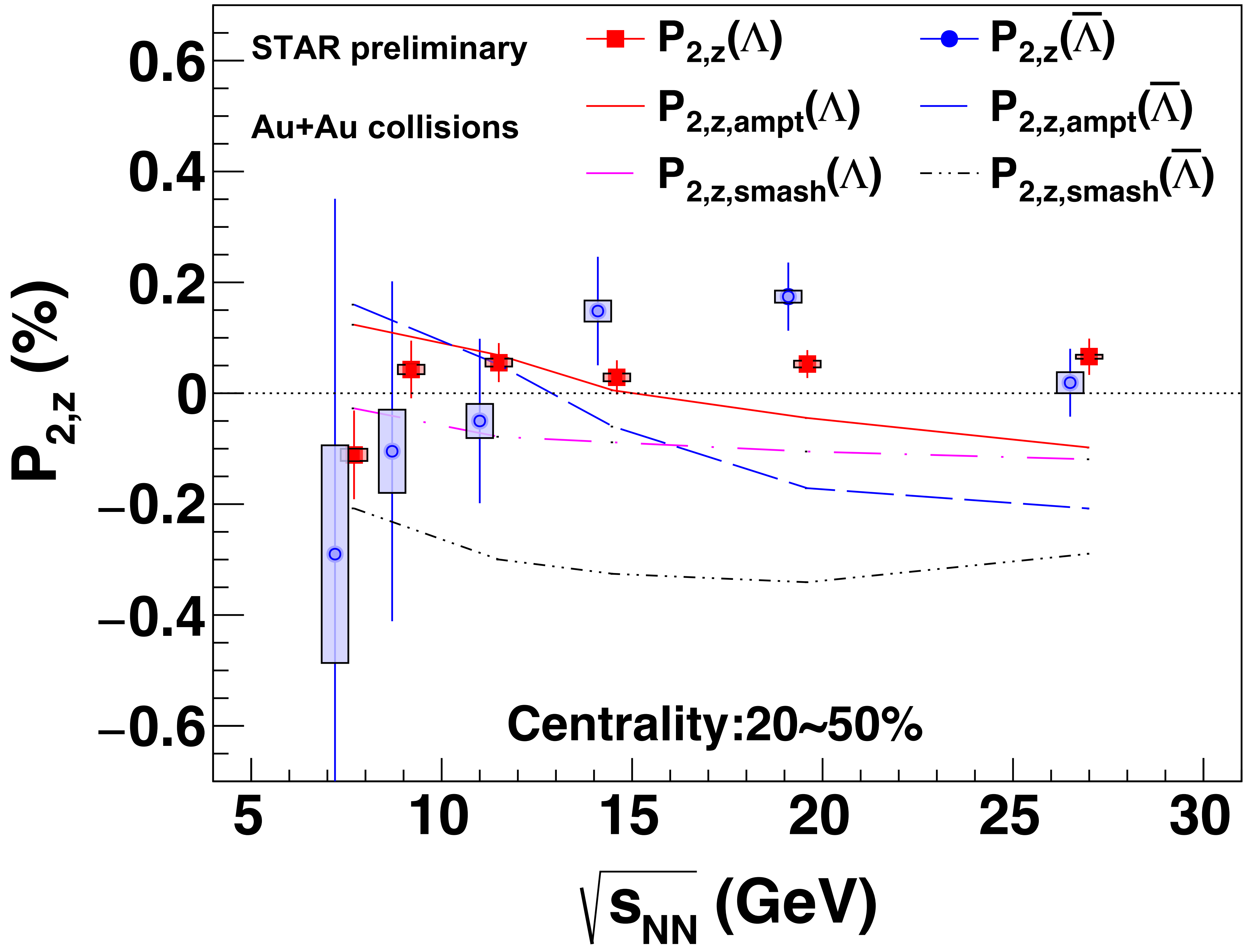


- Significant global polarization of Λ and $\bar{\Lambda}$ are observed
- No splitting between Λ and $\bar{\Lambda}$ global polarization within uncertainties

Local spin polarization of Λ

Qiang Hu
05/06 9:10 AM



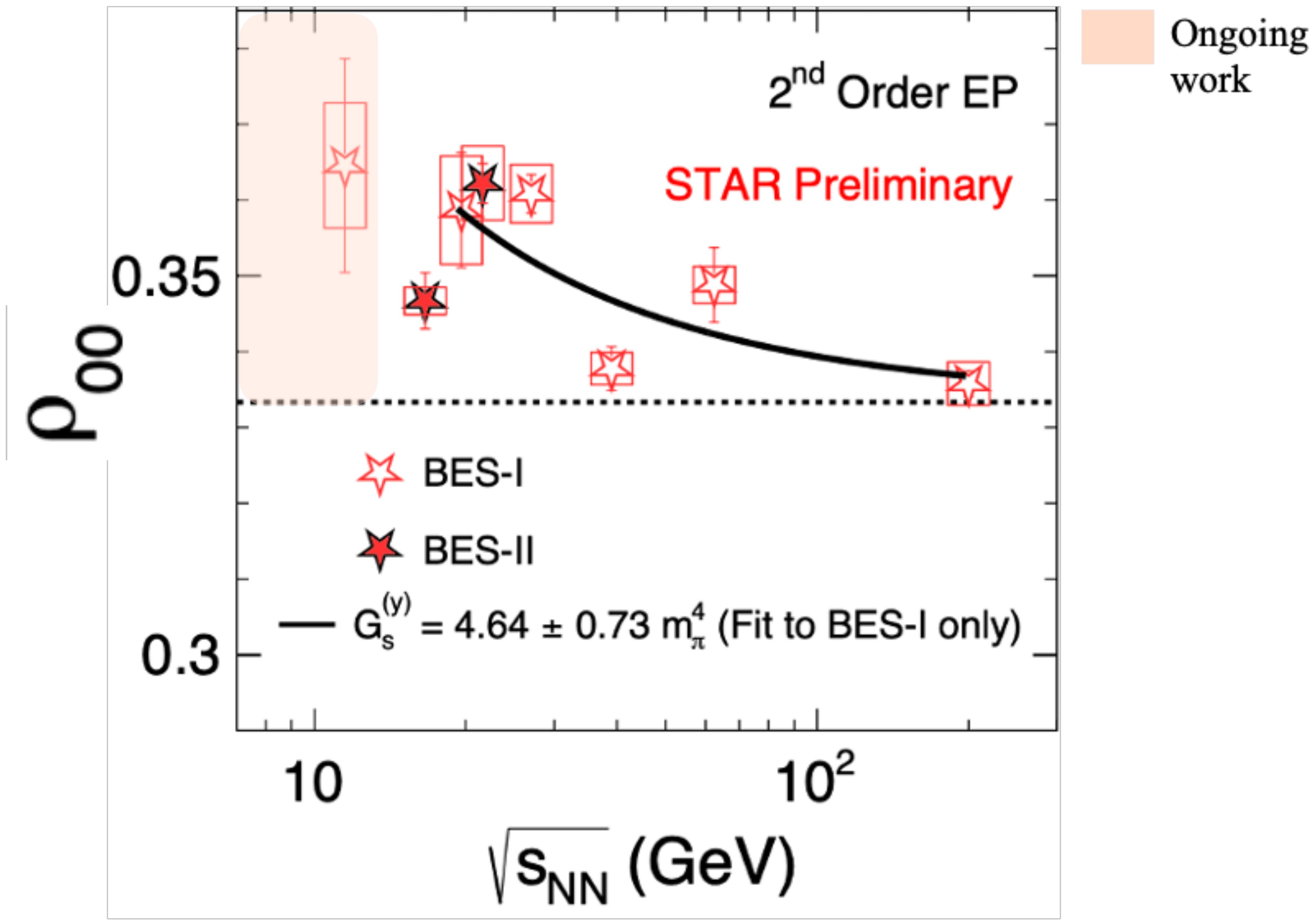


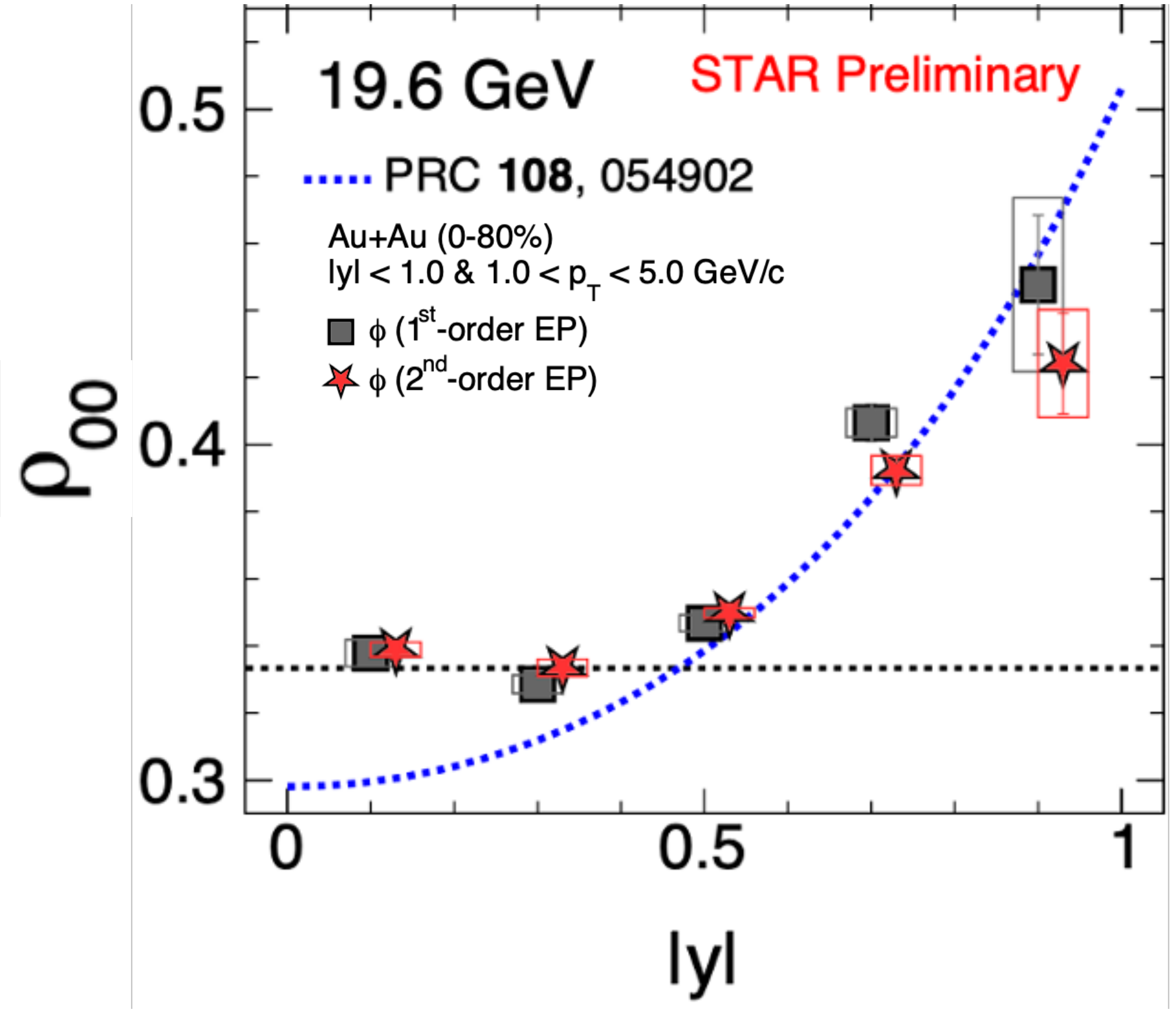
- Hint of sign change of $P_{2,z}$ at 7.7 GeV, measurement at lower energies underway

ϕ global spin alignment

- Probe the origin of ϕ global spin alignment

Gavin Wilks
05/06 11:20 AM



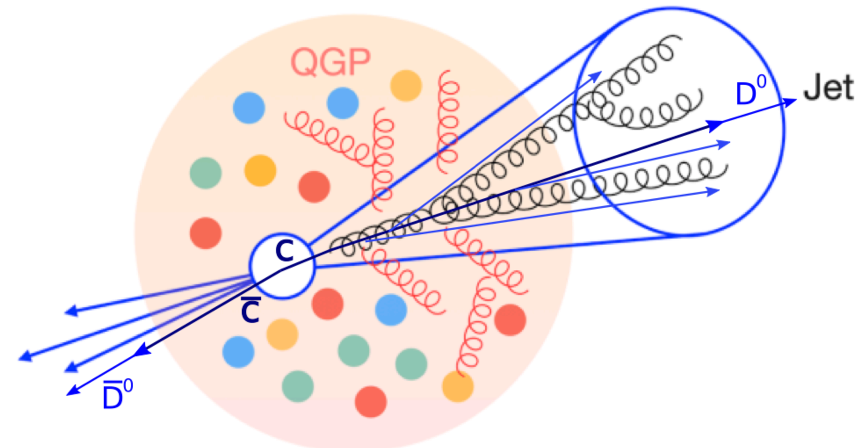


- Higher precision and first differential measurements with BES-II

D^0 tagged jet in heavy-ion collisions in Au+Au 200 GeV

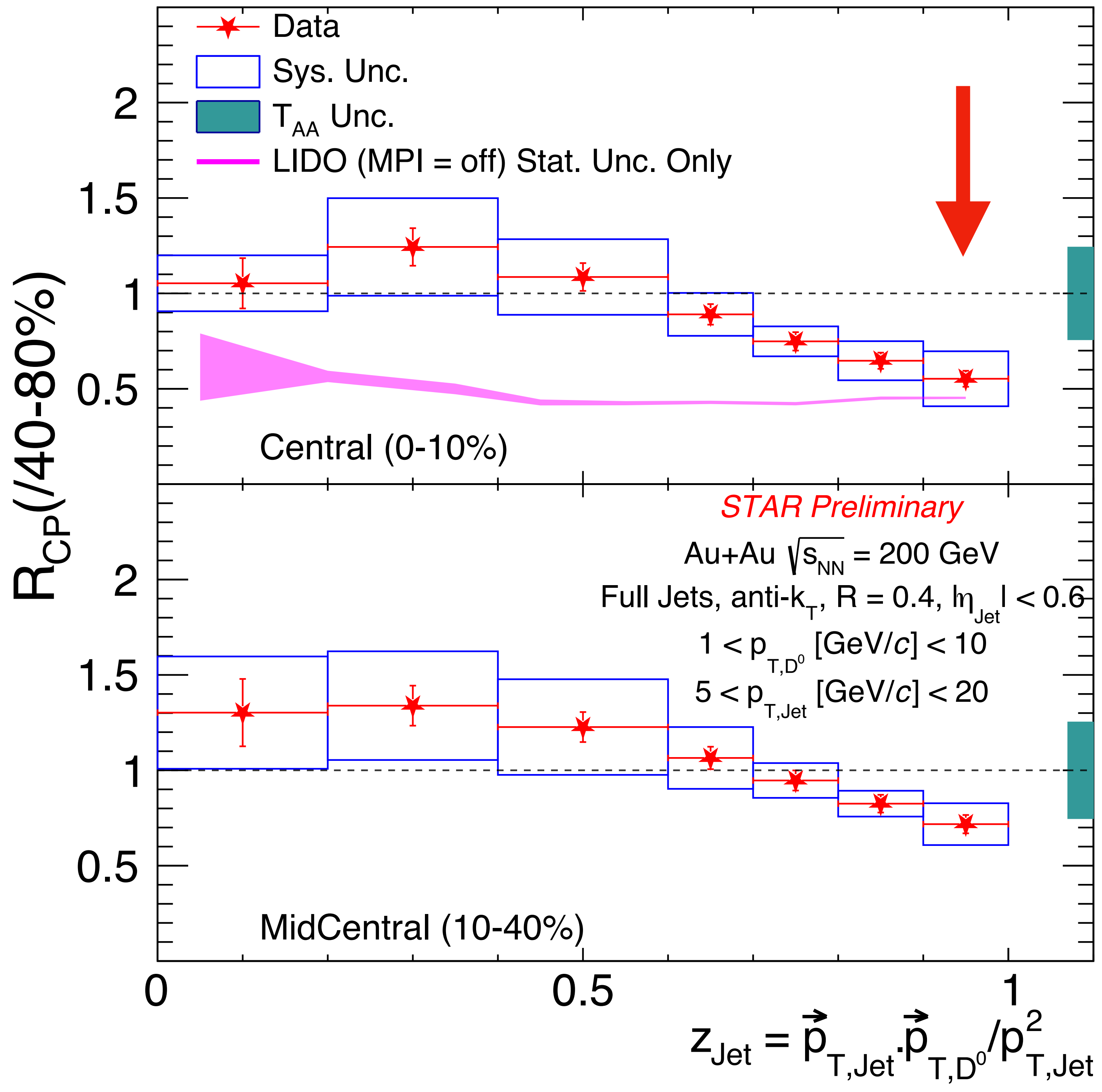
- Energy loss mechanism in medium

Ondrej Lomicky
05/06 8:30 PM

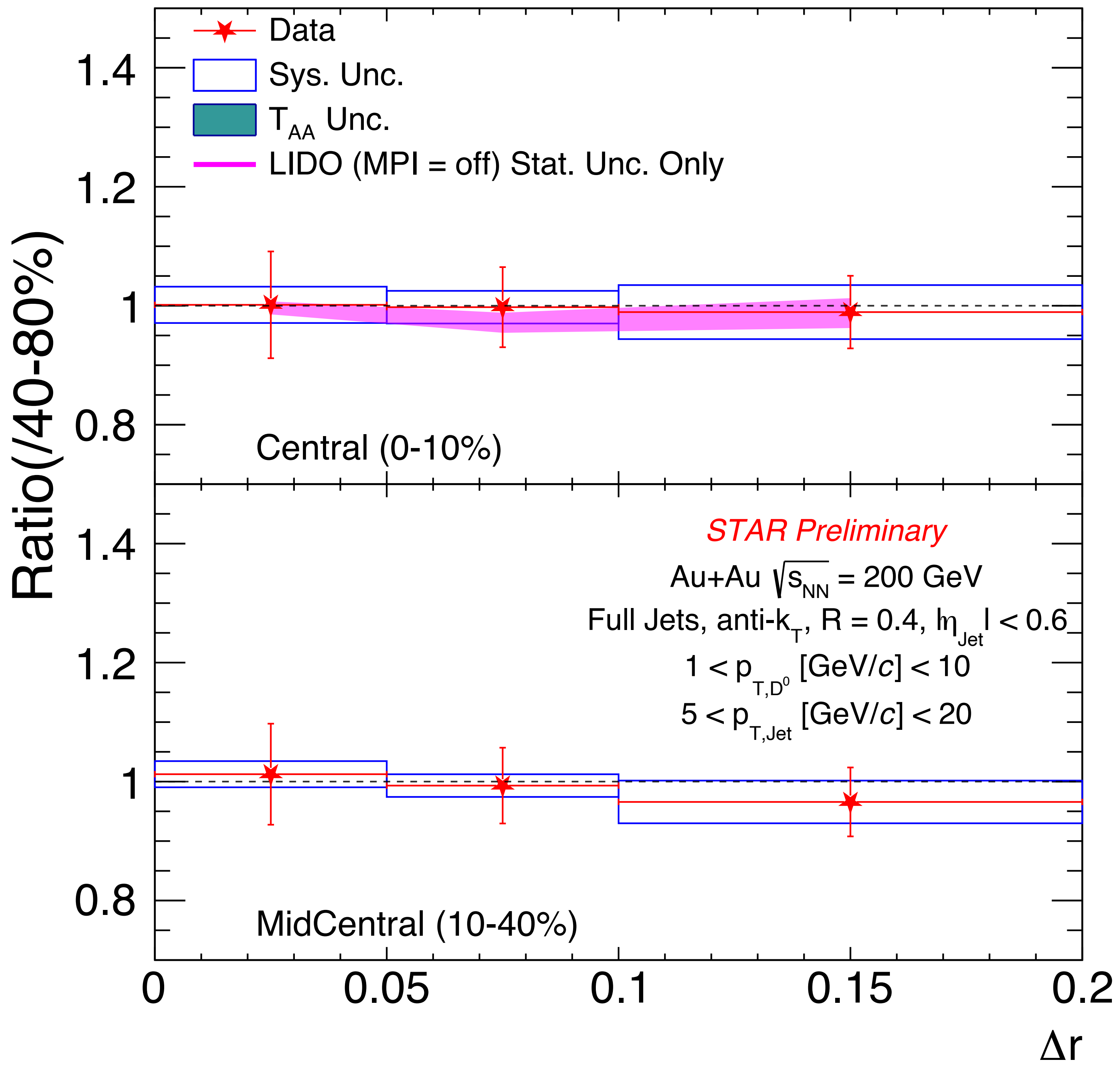


Modified, credit: https://www.int.washington.edu/node/776

Fragmentation function modification
(along jet axis)



Radial profile modification
(perpendicular to jet axis)

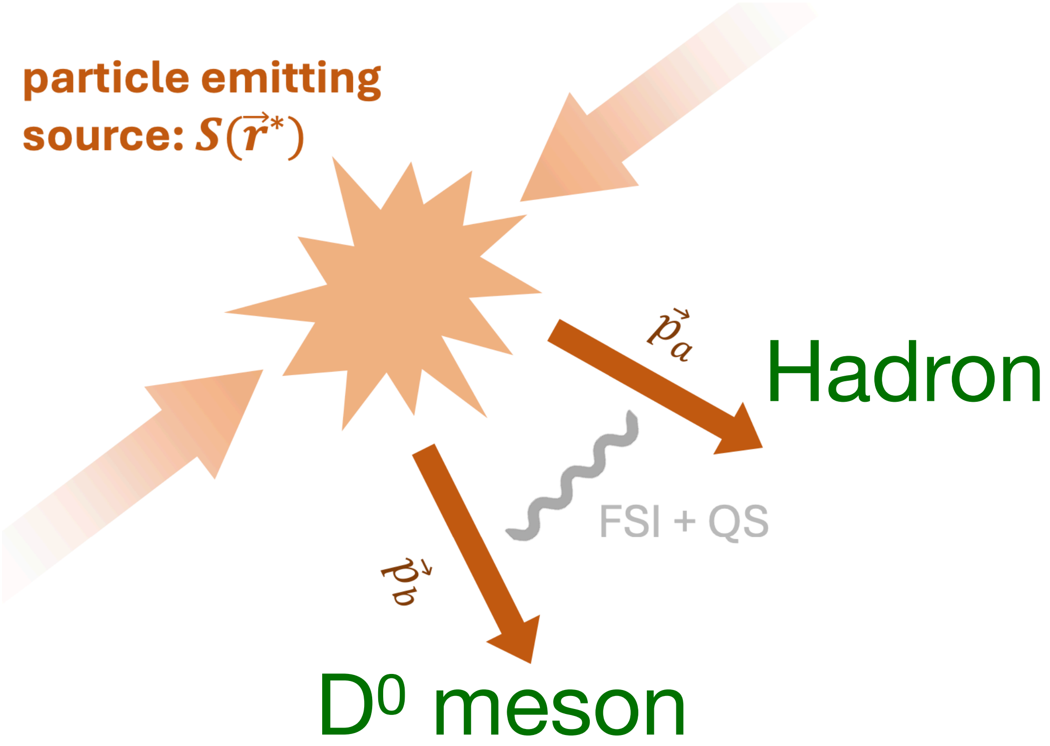


- Suppression for hard fragmented charm jets in central collisions
- Consistent radial profile from central to peripheral collisions

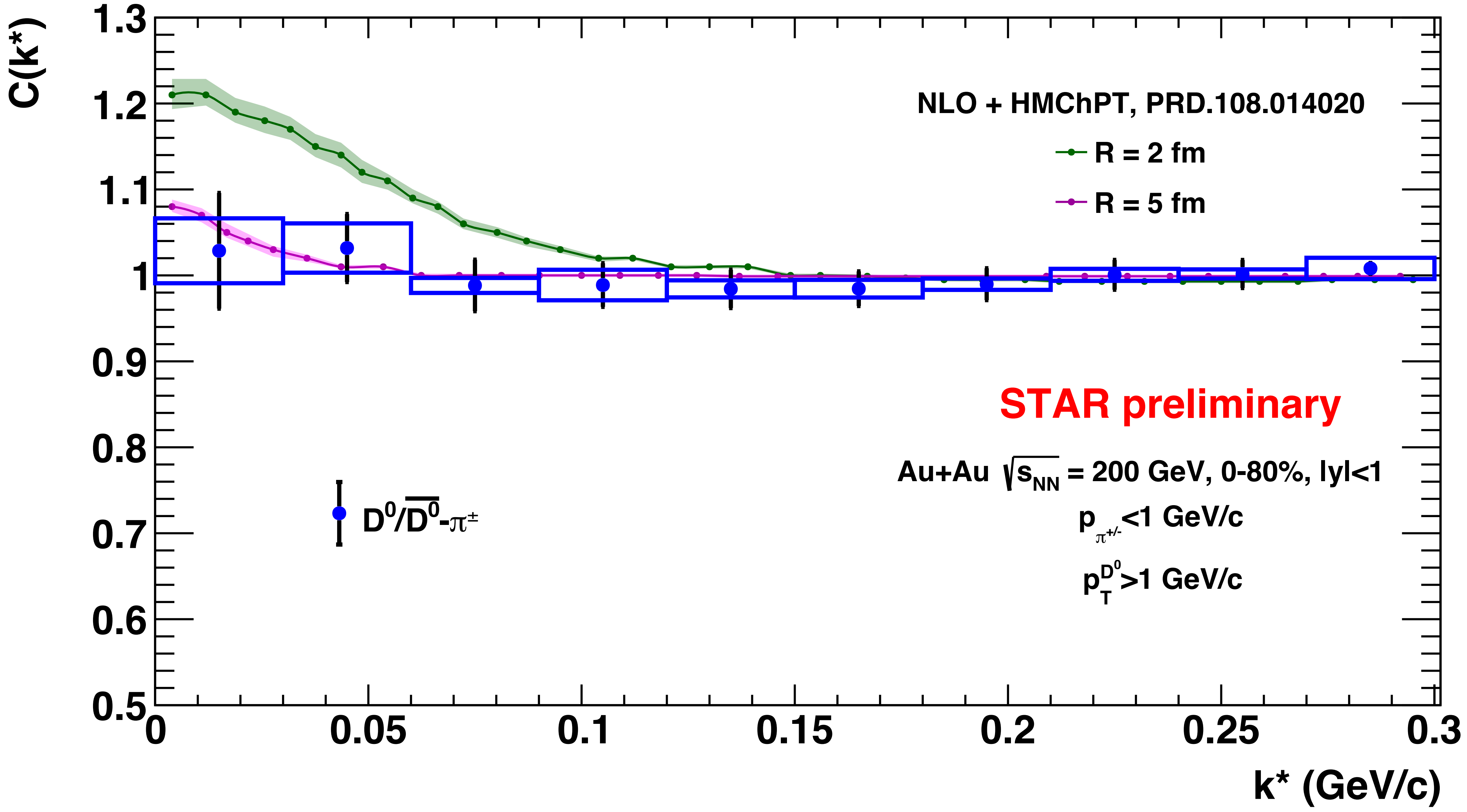
D^0-hadron femtoscopic correlations in Au+Au 200 GeV

- Freeze-out dynamics and final state interaction of charmed mesons

Priyanka Roy
04/06 5:10 PM



- Only strong interaction contribution to $\mathrm{D}^0/\bar{\mathrm{D}}^0 - \mathrm{h}^{\pm}$ femtoscopy



No significant correlation for D^0-π pair

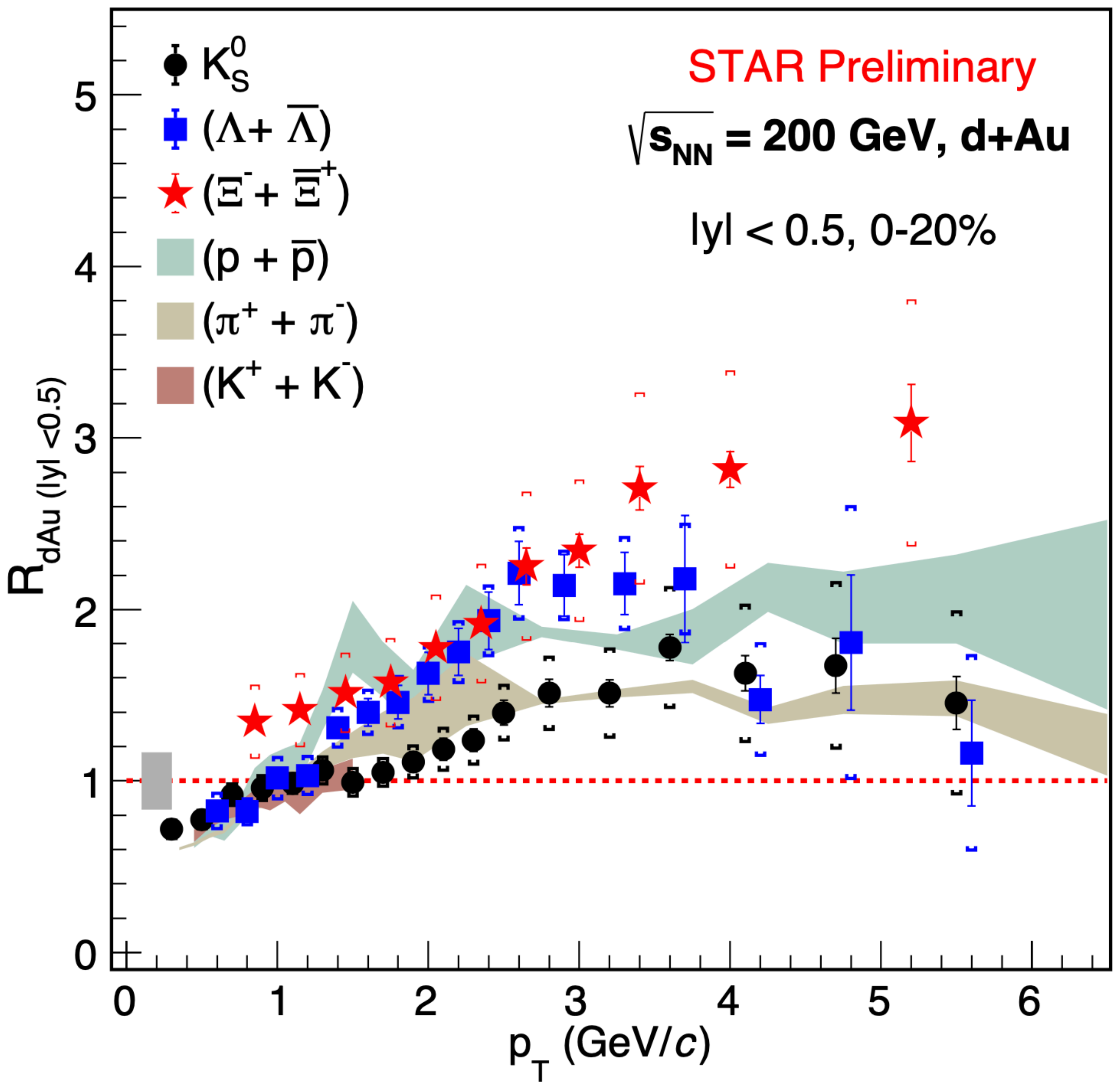
→consistent with calculations with a large emission source size

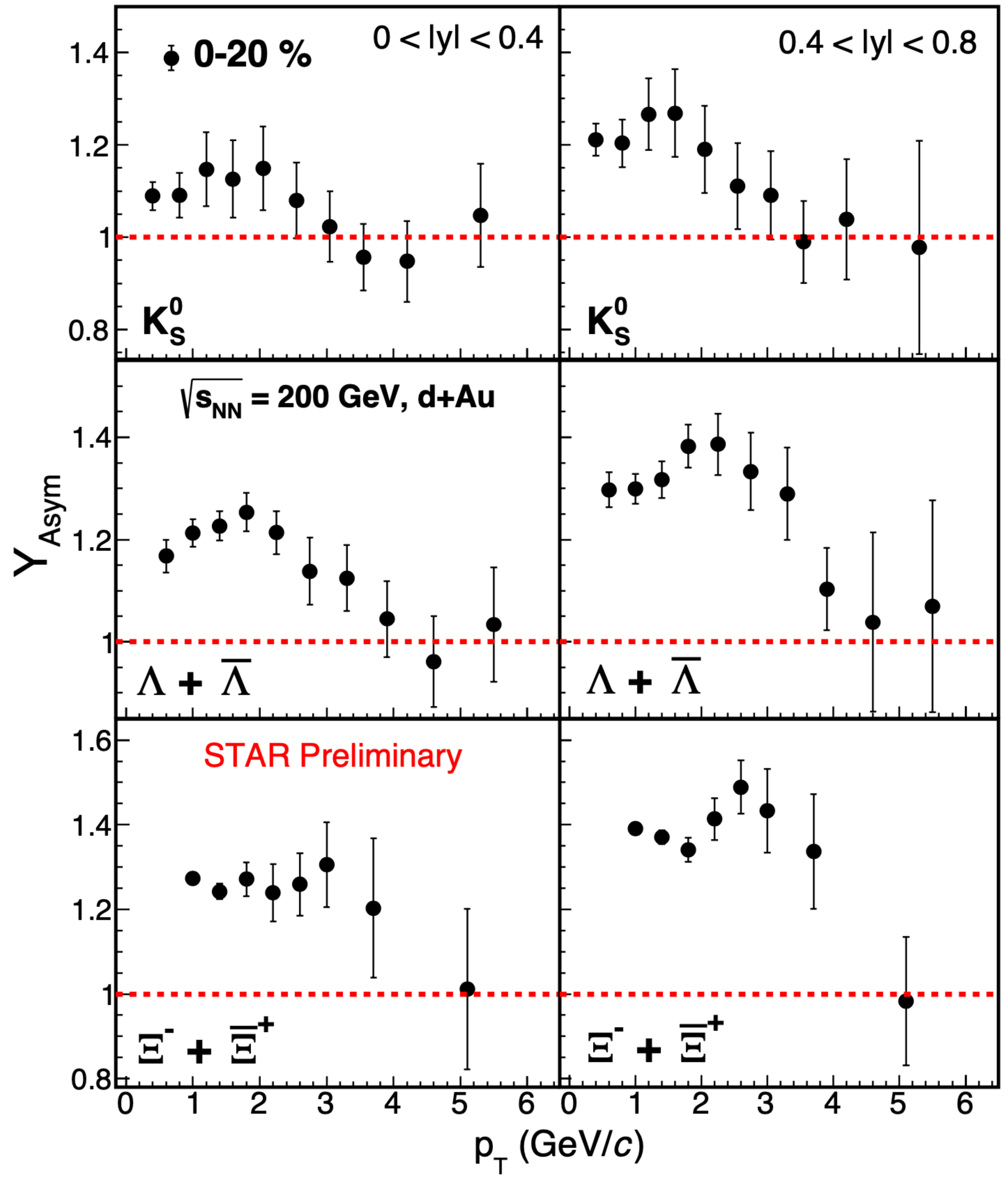
Strange hadrons production in d+Au collisions

Ishu Aggarwal
04/06 9:10 AM

d+Au @ 200 GeV

- Cold Nuclear Matter Effects





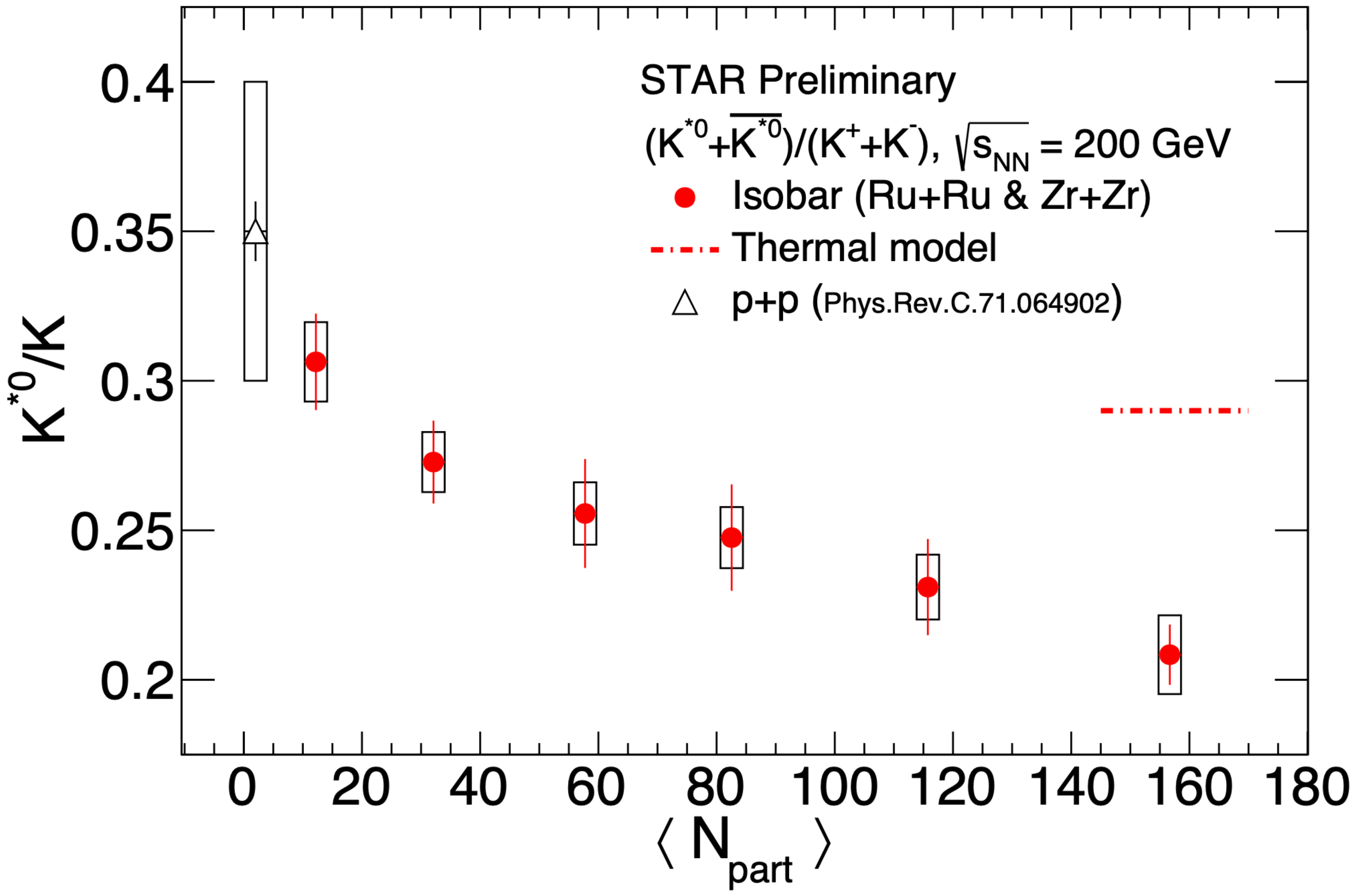
- Cronin like enhancement is observed for K^0_S, Λ, and Ξ at intermediate p_T

- Rapidity asymmetry for K^0_S, Λ, and Ξ
  - More noticeable in higher rapidity region and with heavier particles

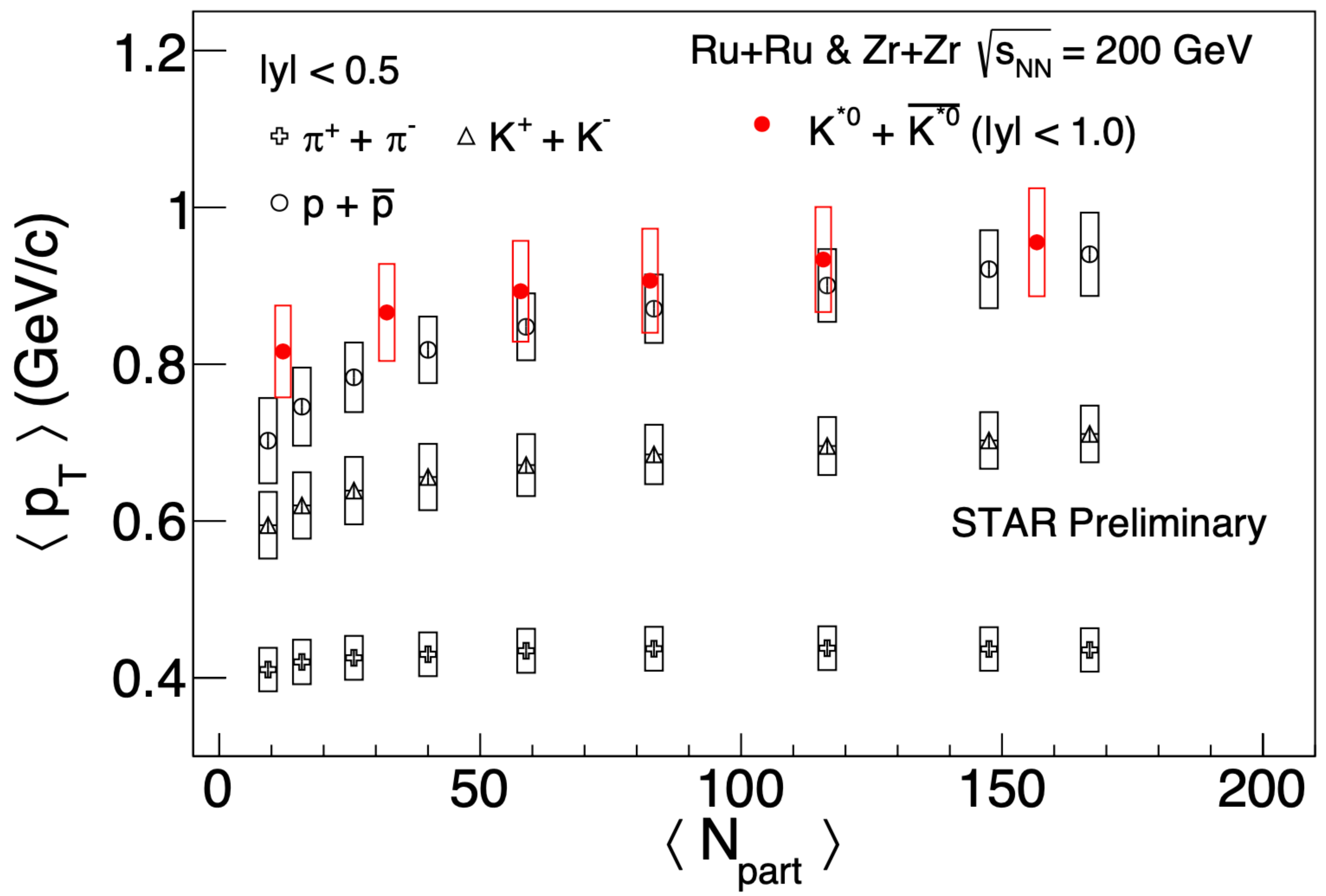
K^{*0} in Ru+Ru/Zr+Zr collisions

Subhash Singha
Poster ID: 191

- Re-scattering and regeneration effects at late stages of hadronic interactions



- Evidence of late stage hadronic re-scattering effect



- K^{*0} $<p_T>$ is consistent with that of protons (anti-proton)
  - Radial flow

Strangeness production at high energy

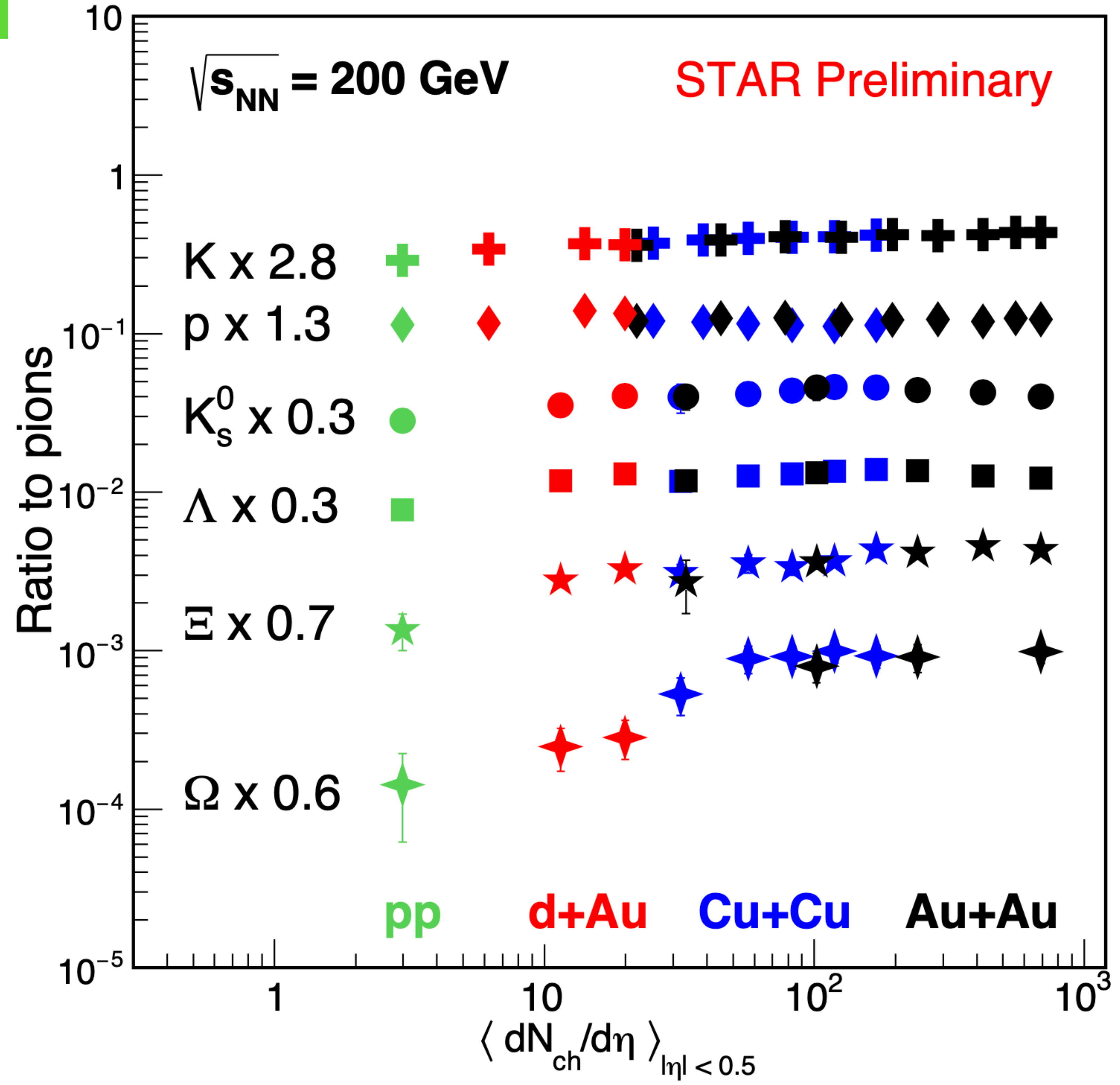
- Strangeness production at high energies

Isobar @ 200 GeV

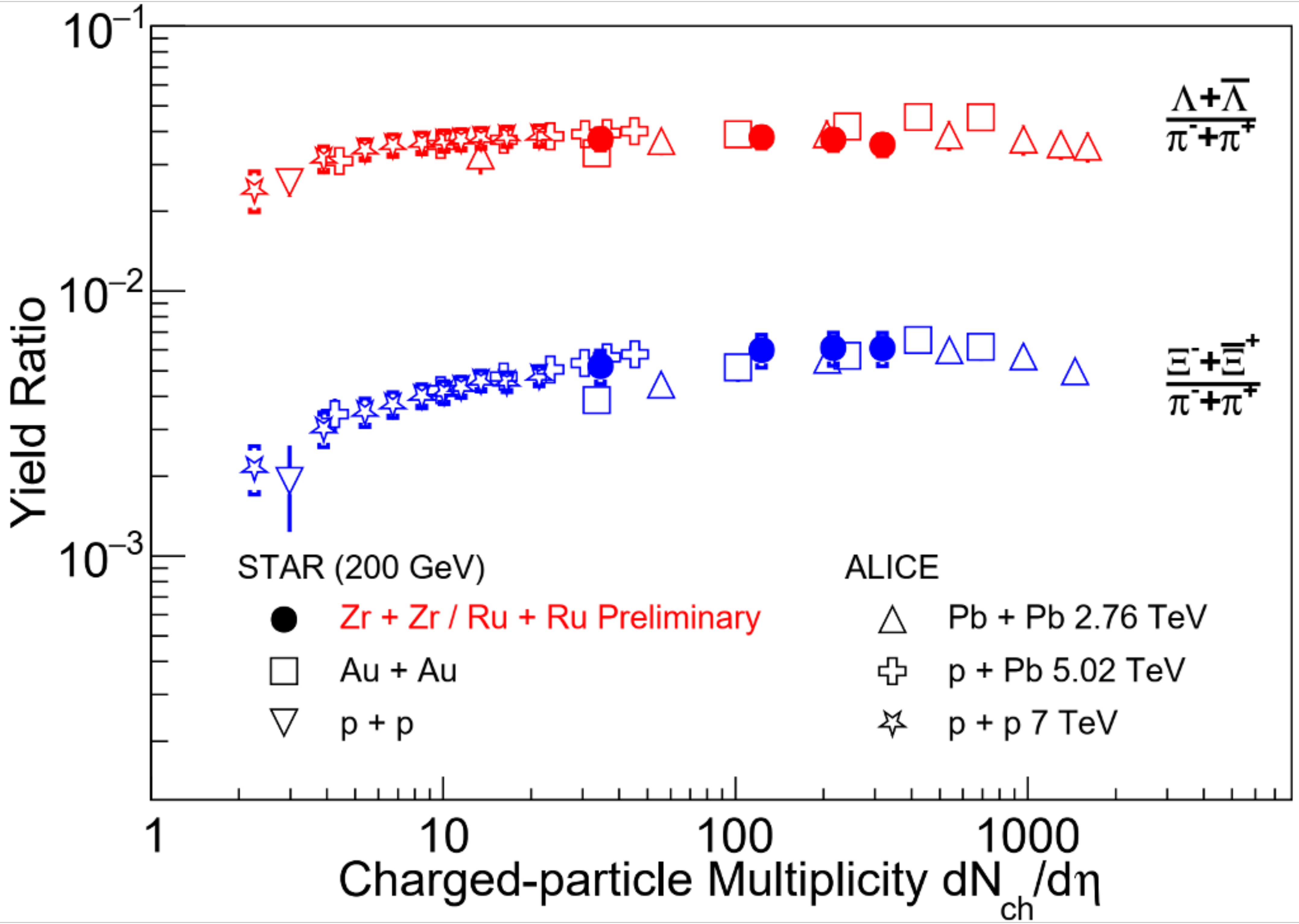
Dongsheng Li
05/06 11:40 AM

Ishu Aggarwal
04/06 9:10 AM

Strange hadron-to-pion yield ratio



Hyperon-to-pion yield ratio

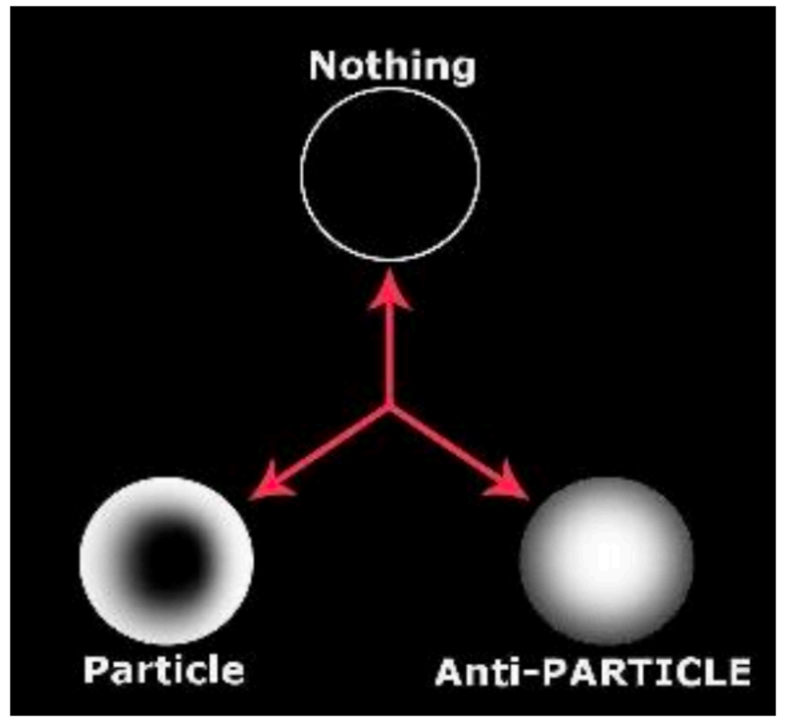


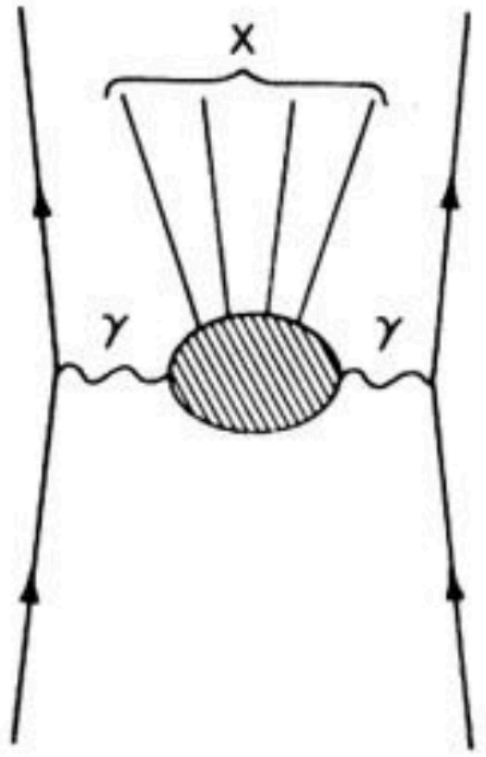
- Strangeness production seems follow a global trend mainly driven by event multiplicity

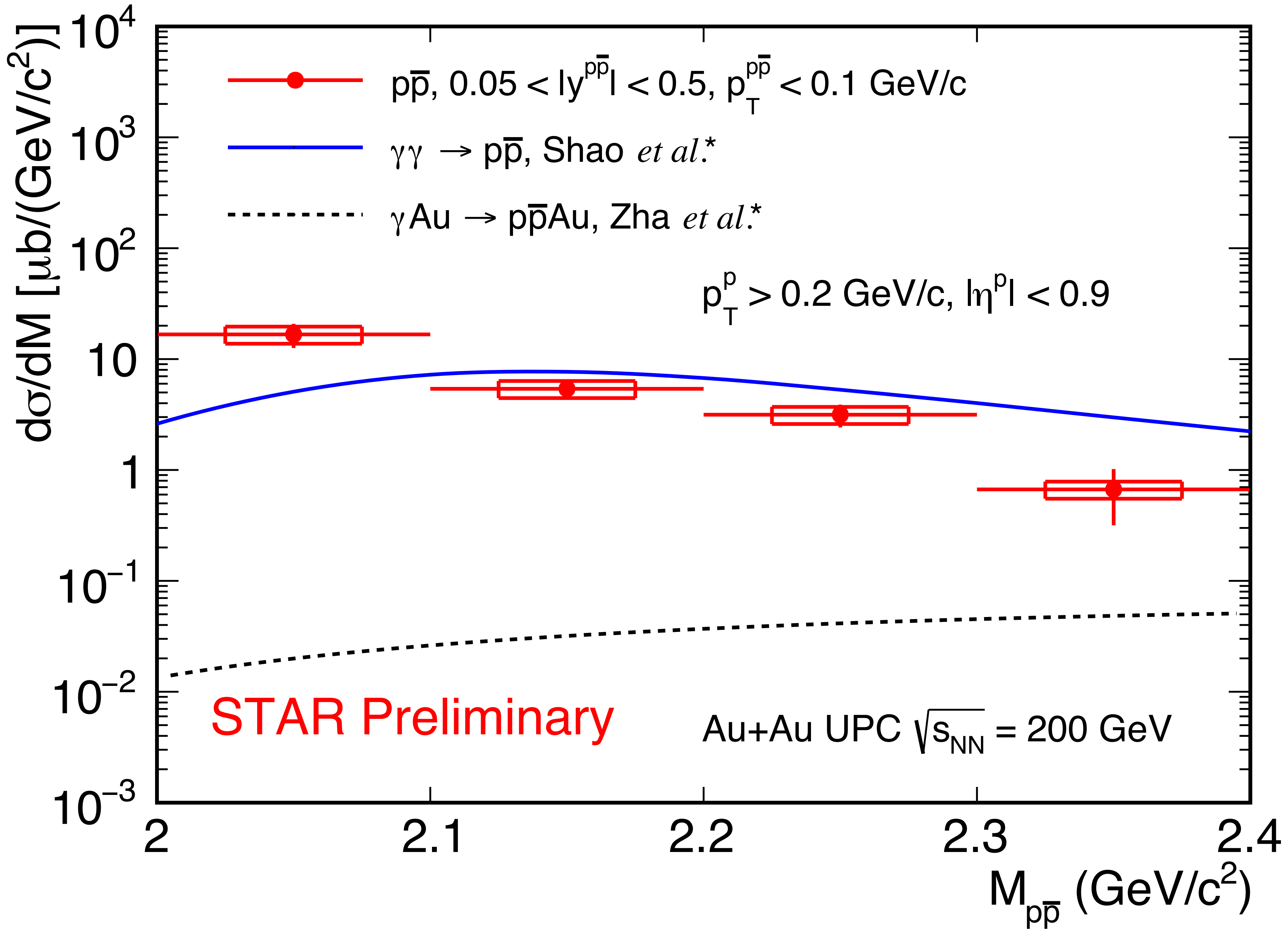
Di-hadron in UPC

- Electromagnetic excitation of the vacuum
  - Higher excitation mode of $\gamma\gamma \rightarrow hh$?

Xin Wu
Poster ID: 193







- Observed $\gamma\gamma \rightarrow \mathrm{p\bar{p}}$ process in UPC

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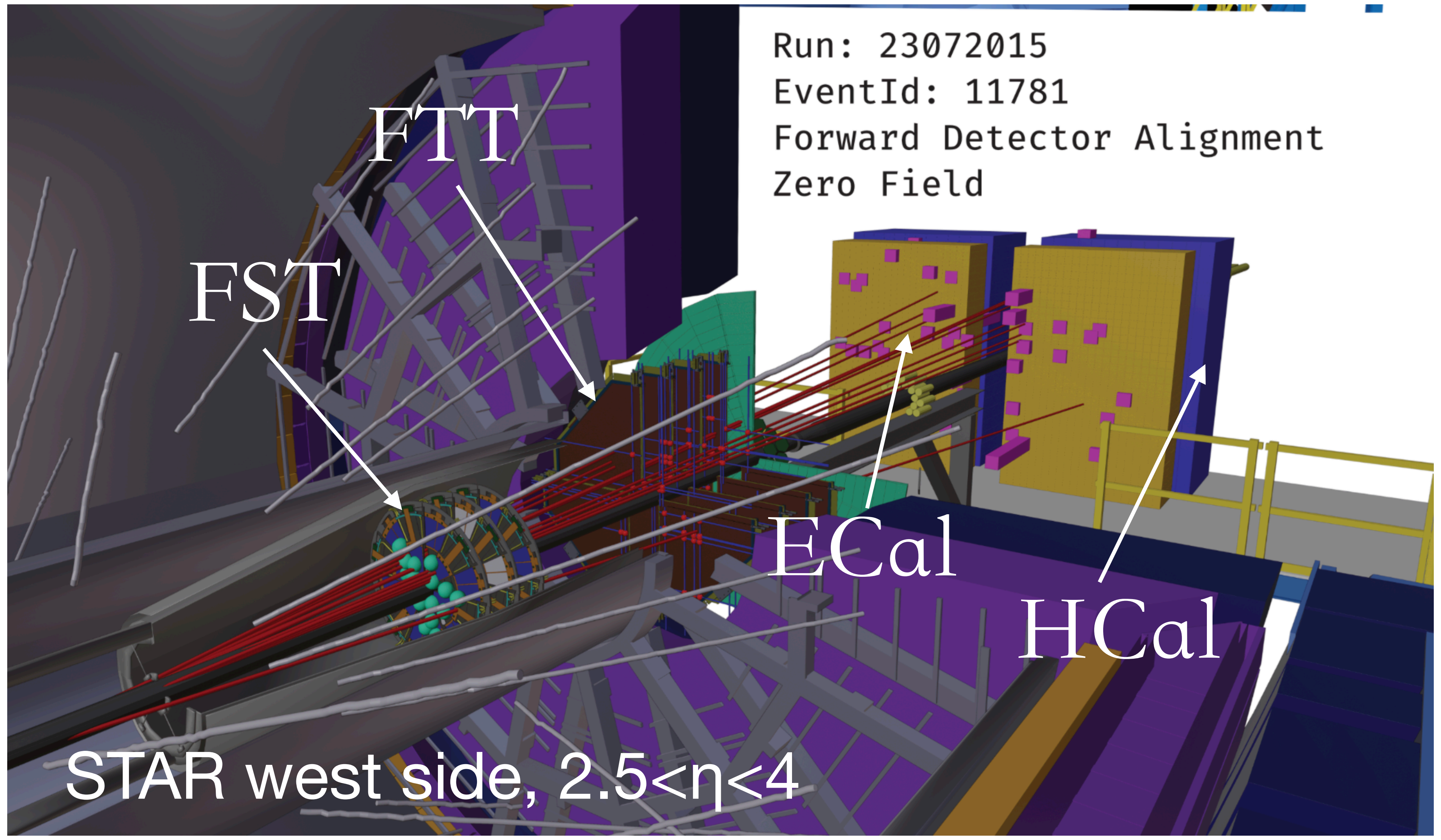
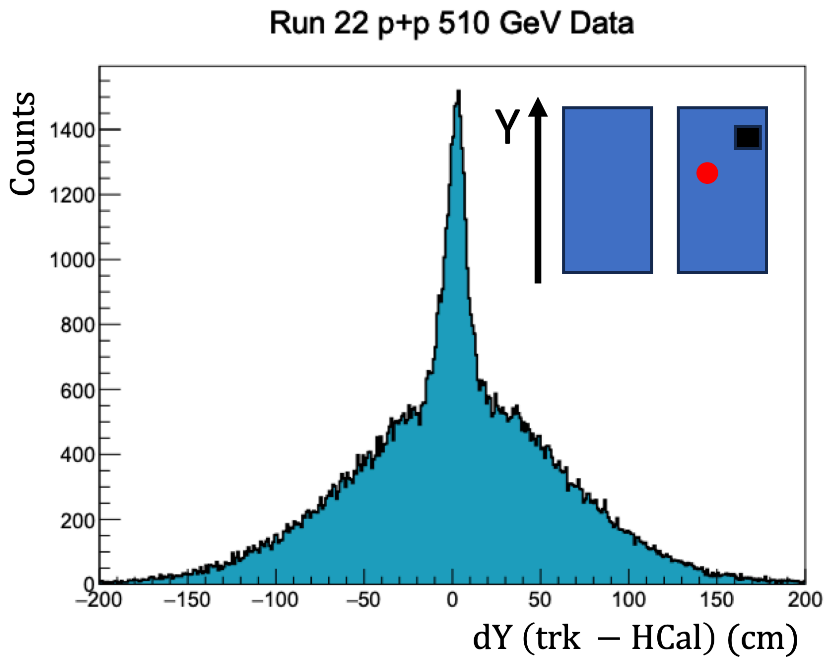
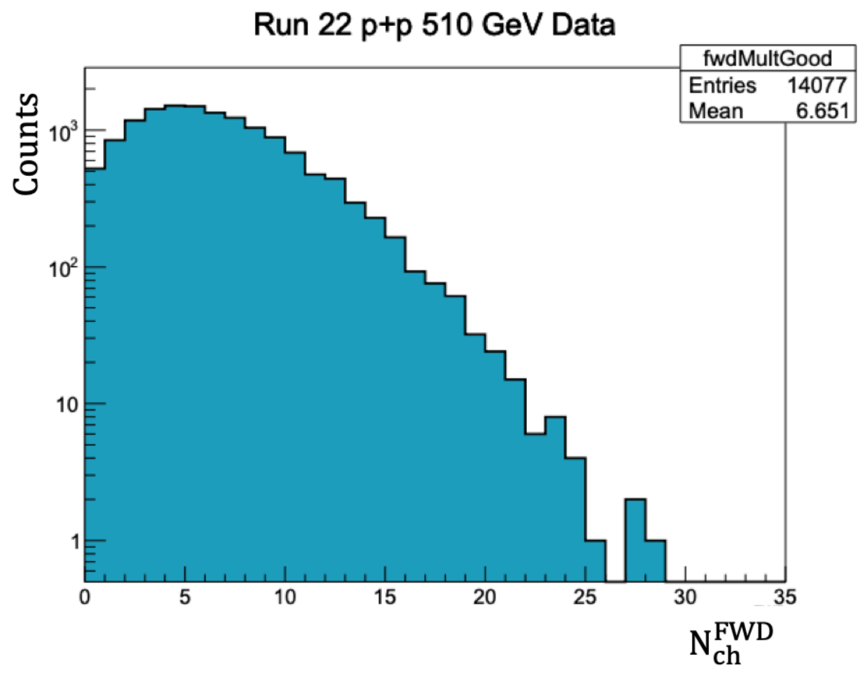
Detector upgrades and future plan

Forward upgrades

An event display at forward from 2023







Forward detector data taking since 2022

- Forward Tracking System (FTS)
  - Forward Silicon Tracker (FST)
  - Forward Small-strip Thin Gap Chambers Tracker (FTT)

Charge separation
$\delta p_T / p_T \sim$ 20-30% for 0.2 < p_T< 2GeV/c

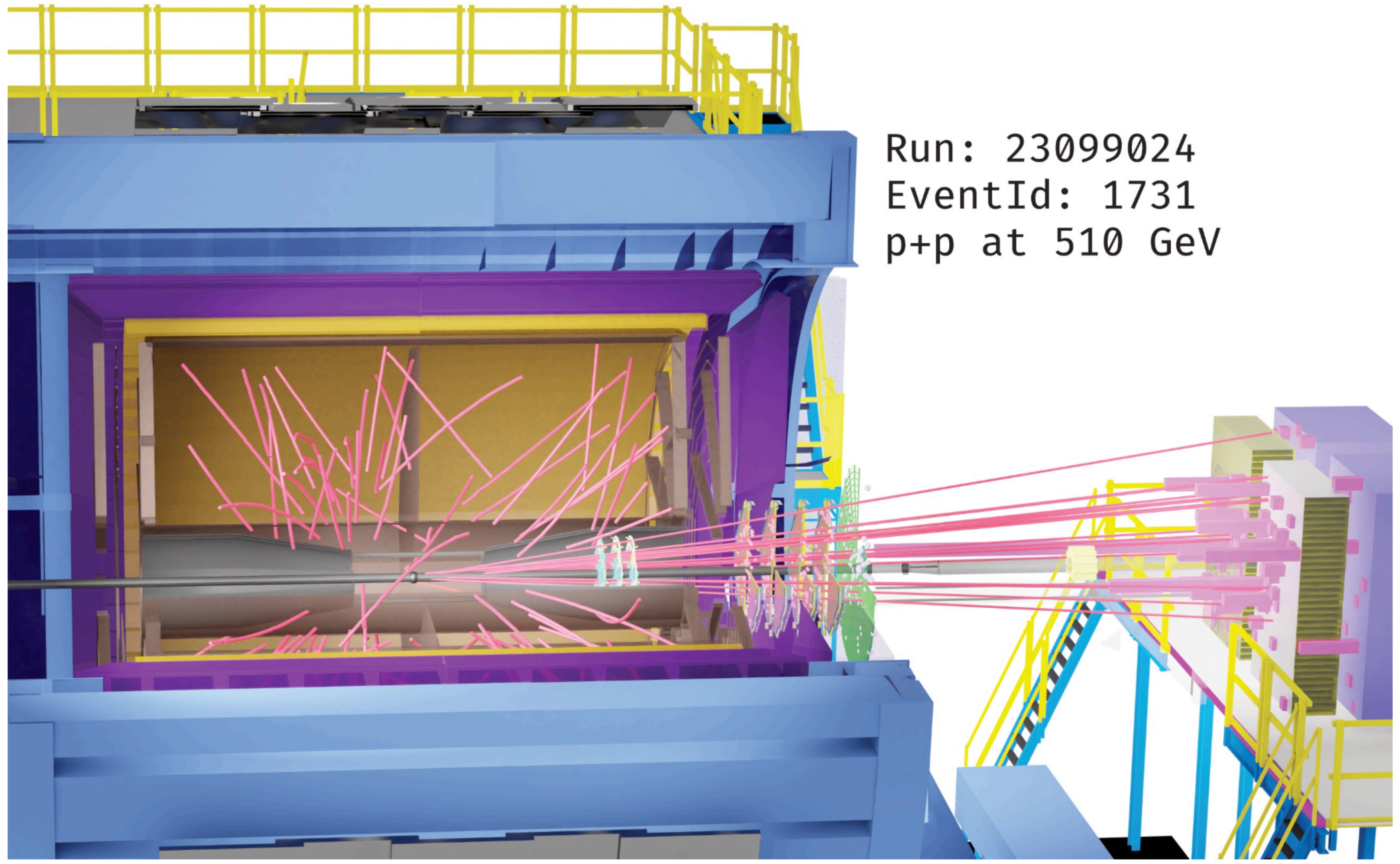
- Forward Calorimeter System (FCS)
  - Electromagnetic Calorimeter
  - Hadronic Calorimeter

Good e/h separation
Photon, π^0 identification
Ecal: ~10%/√E for pp and pA, ~20%/√E for AuAu
Hcal: ~50%/for pp and pA

Future physics opportunities

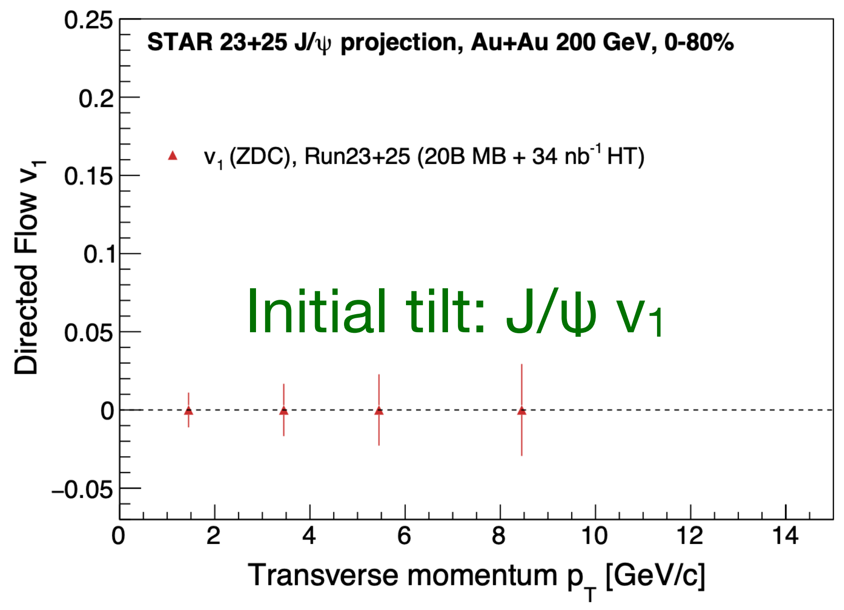
Projections as plans for 2023-2025

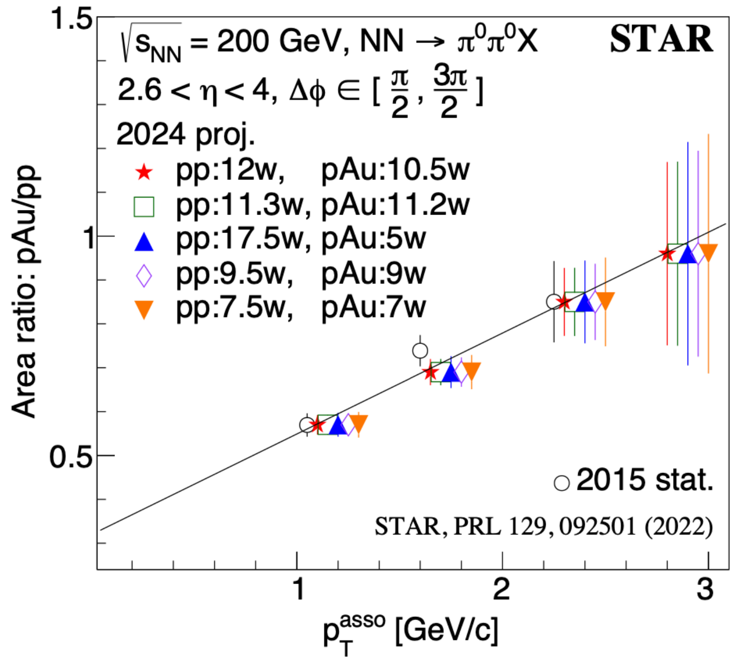
$\sqrt{s_{NN}}$ (GeV)	Species	Sampled Luminosity	Year
200	Au+Au&p+Au	AuAu 32.7 nb^{-1} / pAu 0.69 pb^{-1}	2023+2025
200	p+p	142 pb^{-1}	2024



Hot QCD physics: Explore the microstructure of QGP

- What is the Nature of the 3D Initial State?
- What is the Temperature of QGP and the Temperature Dependence of Viscosity?
- What can Charmonium Tell Us About Deconfinement?
- What are the Electrical, Magnetic, and Chiral Properties of the Medium?
- What are the Underlying Mechanisms of Jet Quenching?
- What is the Nature of the Phase Transition Near $\mu_B = 0$?
- What Can We Learn About the Strong Interaction?





Cold QCD physics: Establish the validity and limits of factorization and universality to understanding of QCD

- Forward Transverse-Spin Asymmetries
- Sivers and Efremov-Teryaev-Qiu-Sterman Functions
- Transversely, Collins Function and Interference Fragmentation Function
- Ultra-Peripheral Collisions

Summary

Physics results from multiple perspectives (18 talks and 6 posters)

Stay tuned for more to come from BES-II and future hot QCD and cold QCD studies!

SQM2024 STAR talks:

1. Proton-Xi correlation function: Boyang Fu, 05/06/24, 9:10AM
2. Strange hadron production: Hongcan Li, 05/06/24, 11:40AM
3. D0-meson tagged Jets: Ondrej Lomicky, 05/06/24, 8:30AM
4. D0 meson charged hadron femtoscopy, Priyanka Roy Chowdhbury, 04/06/24, 5:10PM
5. ${}^{4}_{\Lambda}\mathbf{H}$ and ${}^{4}_{\Lambda}\mathbf{He}$ yield measurement, Chenlu Hu, 05/06/24, 9:10AM
6. Hyperon and hypertriton yield in Isobar system, Dongsheng Li, 05/06/24, 11:40AM
7. Light nuclei production, Yixuan Jin, 05/06/24, 12:00PM
8. Kaon femtoscopy, Bijun Fan, 04/06/24, 5:30PM
9. CEP: net-proton cumulants, Yifei Zhang, 06/06/24, 8:30AM
10. Differential measurement of phi global spin alignment, Gavin Wilks, 05/06/24, 11:20AM
11. Charge-dependent directed flow, Muhammad Farhan Taseer, 04/06/24, 3:00PM
12. Lambda global and local spin polarization, Qiang Hu, 05/06/24, 9:10AM
13. Collective flow to explore QCD phase diagram, Shush Shi, 04/06/24, 11:20AM
14. Energy dependence of hypertriton production, Xiujun Li, 04/06/24, 4:30PM
15. Multi-strange hadrons production in d+Au collisions, Ishu Aggarwal, 04/06/24, 9:10AM
16. Lamba, H3L and H4L directed flow, Junyi Han, 04/06/24, 2:40PM
17. Bayon number carrier, Rongrong Ma, 04/06/24, 2:00 PM
18. QGP temperature from dielectron measurement, Zhen Wang, 04/06/24, 3:00PM

SQM2024 STAR posters:

19. K^0_s and $\Omega(\bar{\Omega})$ production in 7.7, 14.6, 19.6 GeV, Yi Fang, ID 102
20. Heavy-flavor electron production in Au+Au 54.4 GeV , Veronica Prozorova, ID 107
21. K* meson measurement in isobar and BES-II, Subhash Singha, ID 191
22. Strangeness production in Au+Au 7.7-19.6 GeV, Weiguang Yuan, ID 192
23. Di-hadron production in UPC, Xin Wu, ID 193
24. ${}^{4}_{\Lambda}\mathbf{He}$ lifetime measurement, Xiujun Li, ID 194

Thank you!