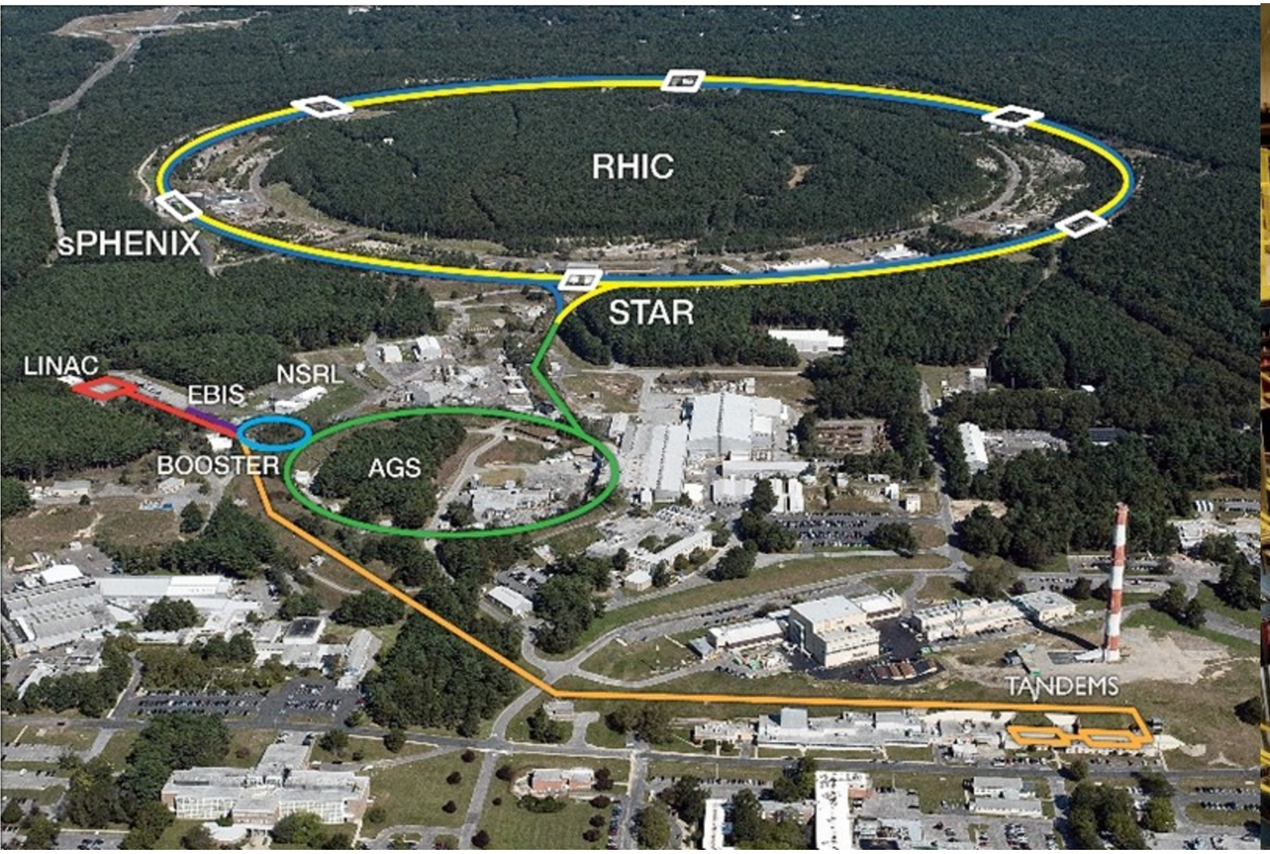
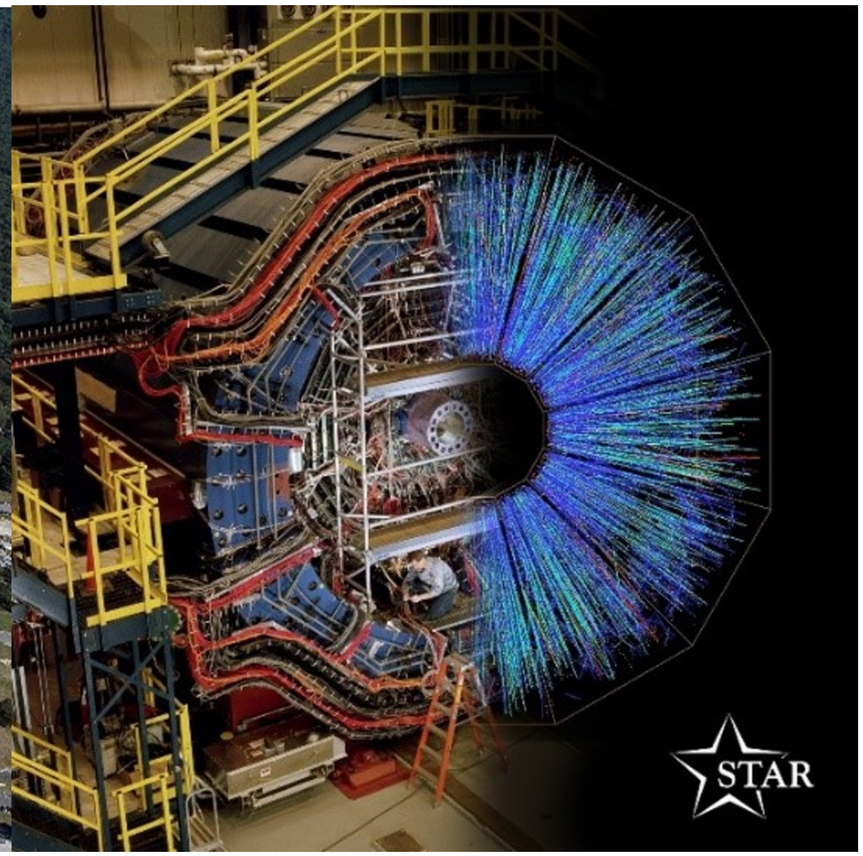
STAR Highlight I - Recent Results from Beam Energy Scan II

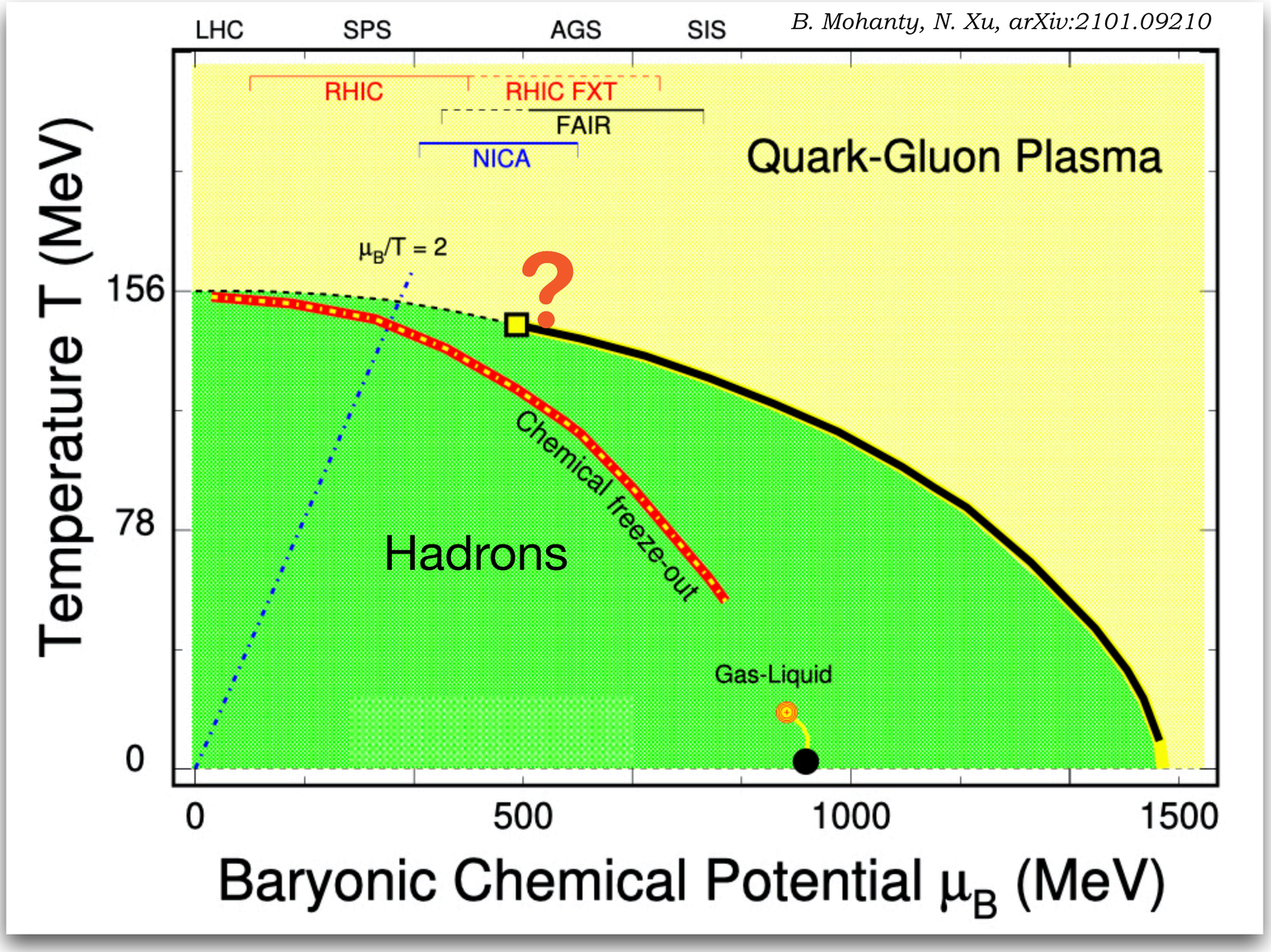
Ashish Pandav (for the STAR Collaboration)
Lawrence Berkeley National Laboratory





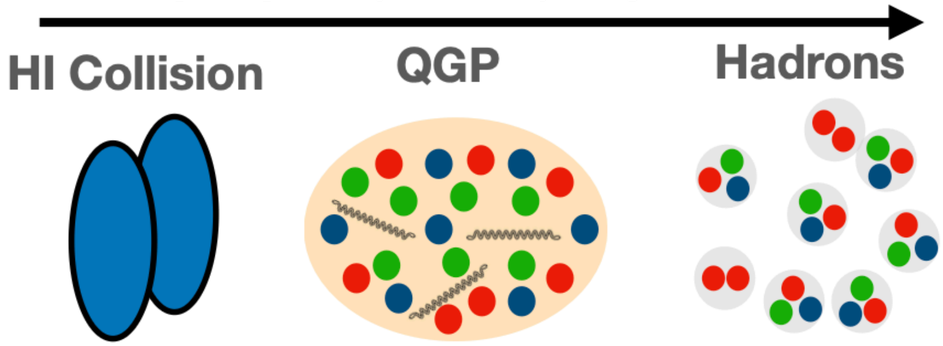
Supported in part by
U.S. DEPARTMENT of ENERGY
Office of Science

Studying QCD at STAR



B. Mohanty, N. Xu, arXiv:2101.09210

A simplistic picture of evolution of heavy ion collisions



Initial state correlations

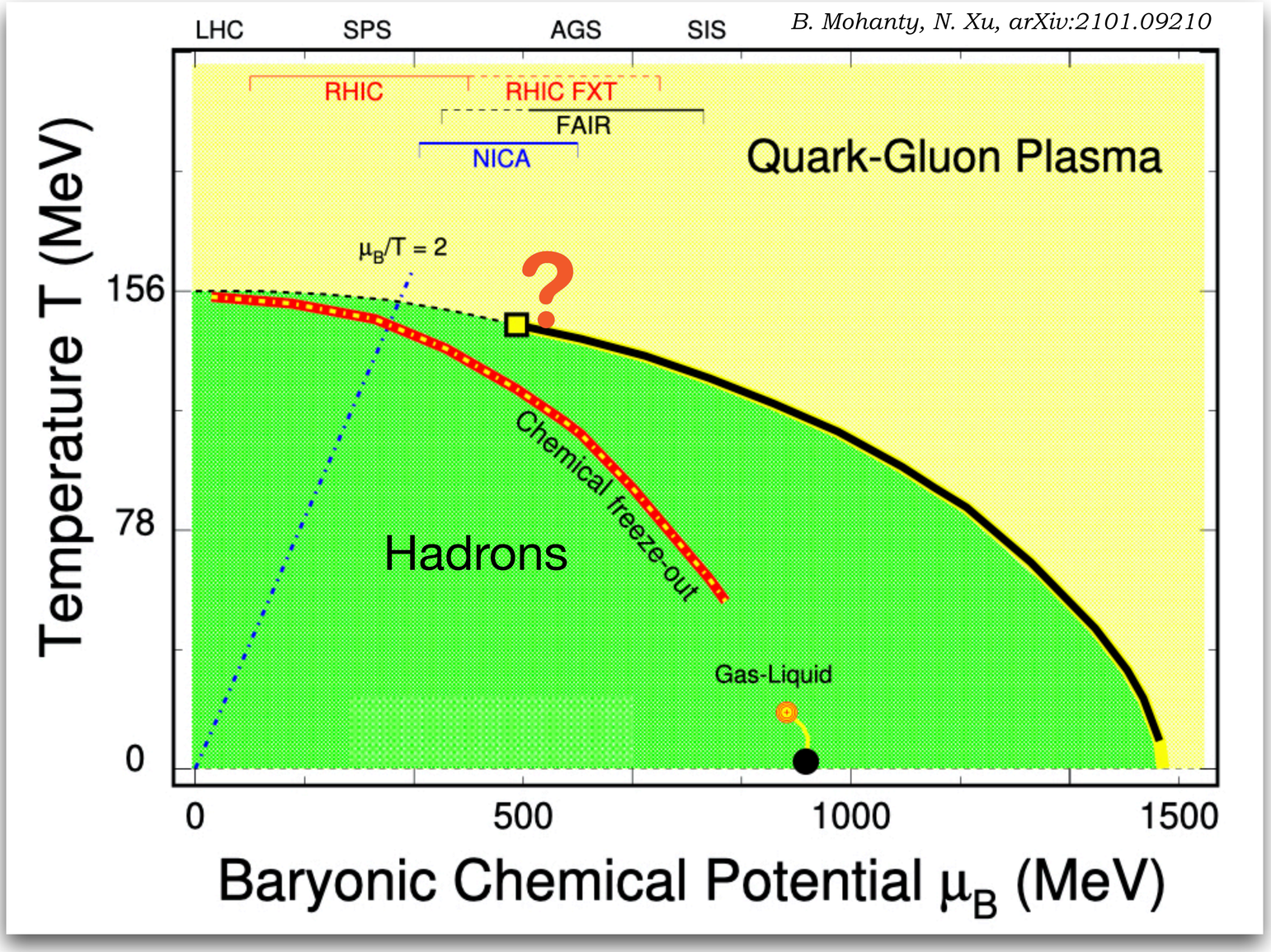
↓

Medium formation (QGP/hadronic)

↓

Emergent macroscopic phenomena

Studying QCD at STAR



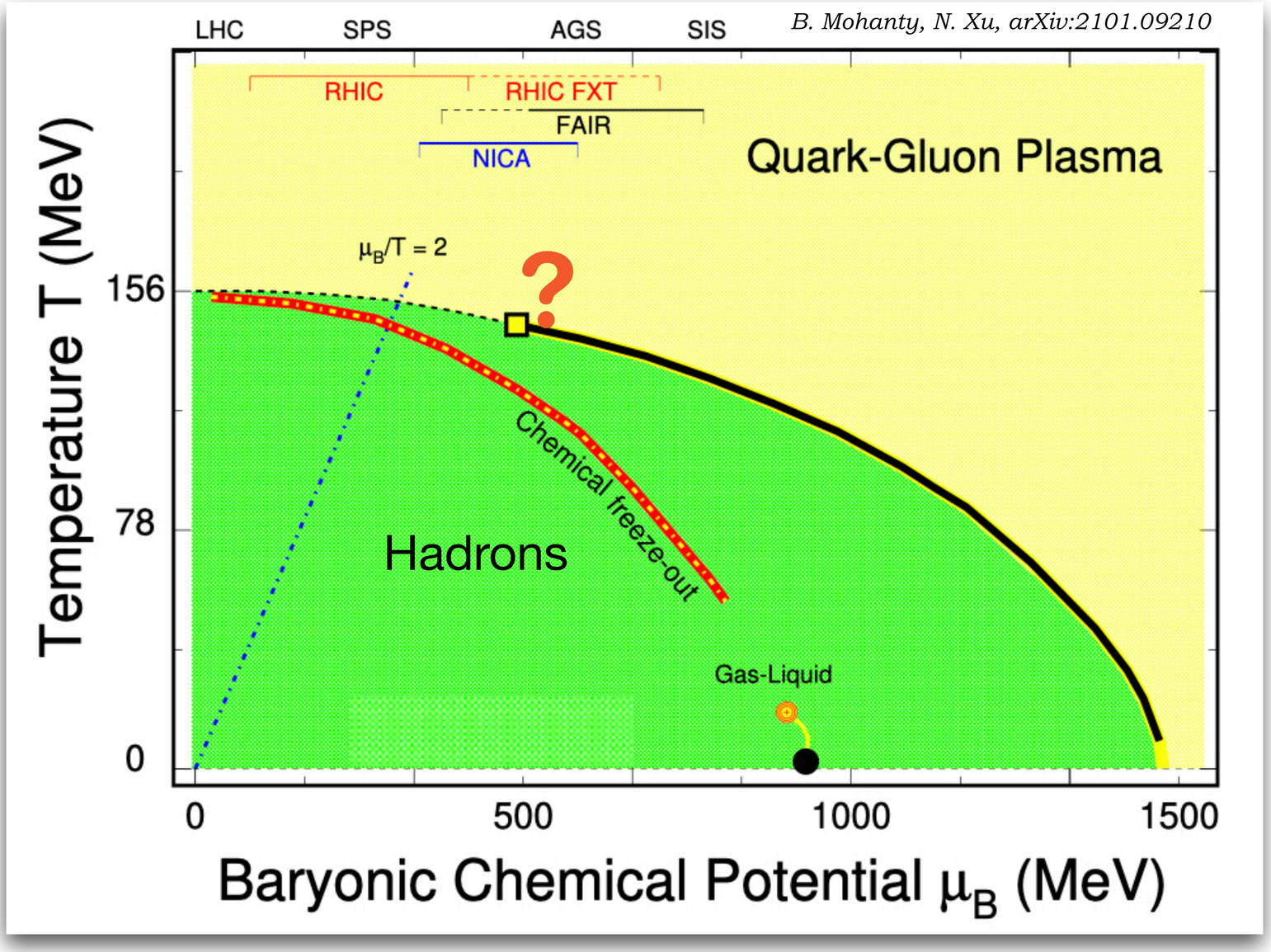
Medium formation

Characterizing the medium:
Study of hadron yields/spectra
Femtoscopic correlations

Emergent Macroscopic phenomena

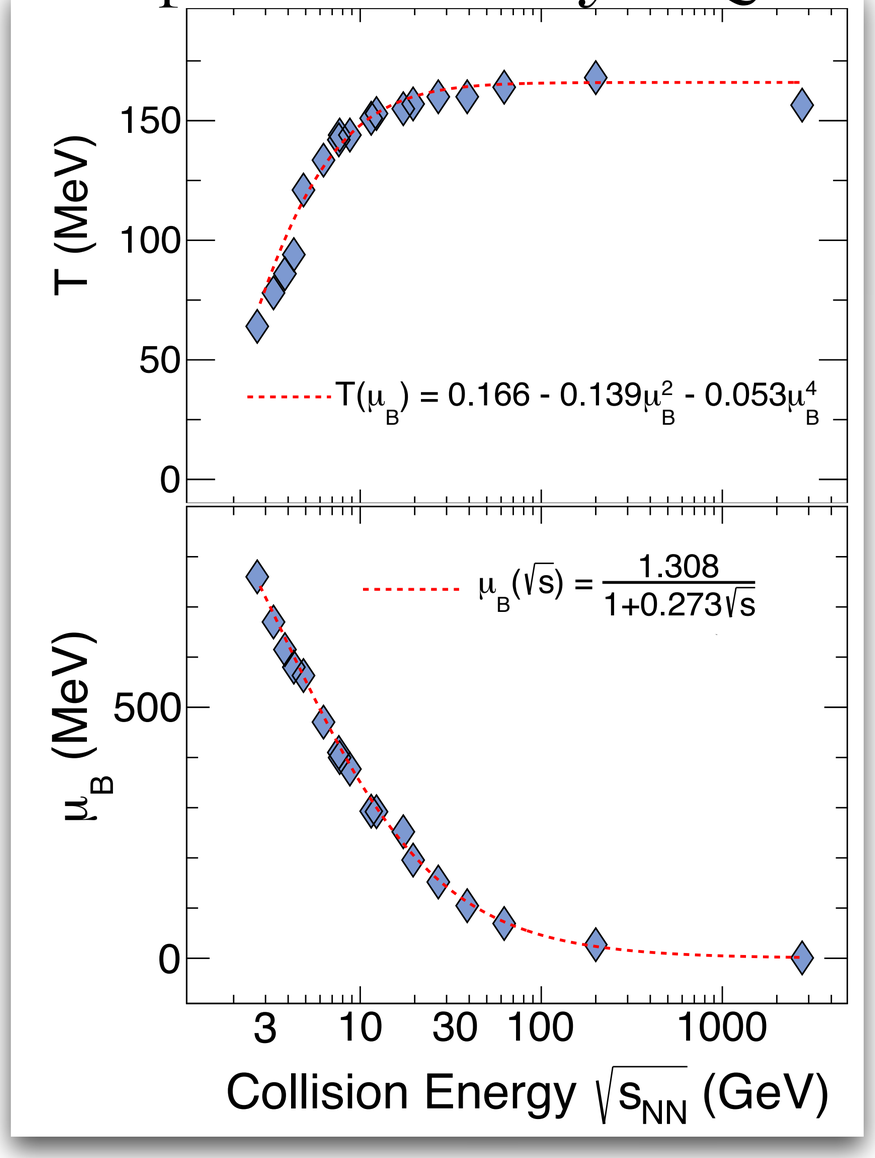
Emergent properties of medium:
Flow, vorticity, phase transitions, possible critical point?

Studying QCD at STAR



B. Mohanty, N. Xu, arXiv:2101.09210

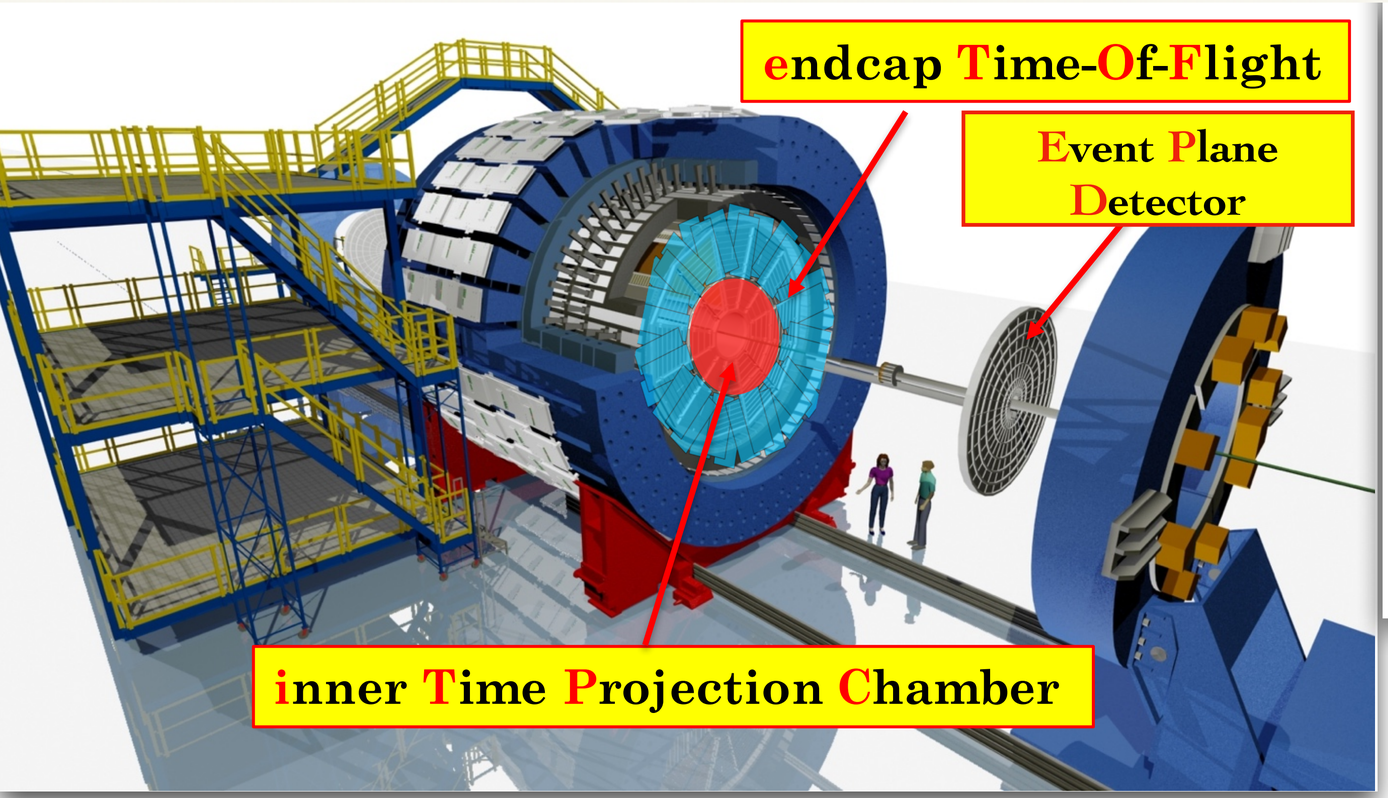
Experimental study of QCD

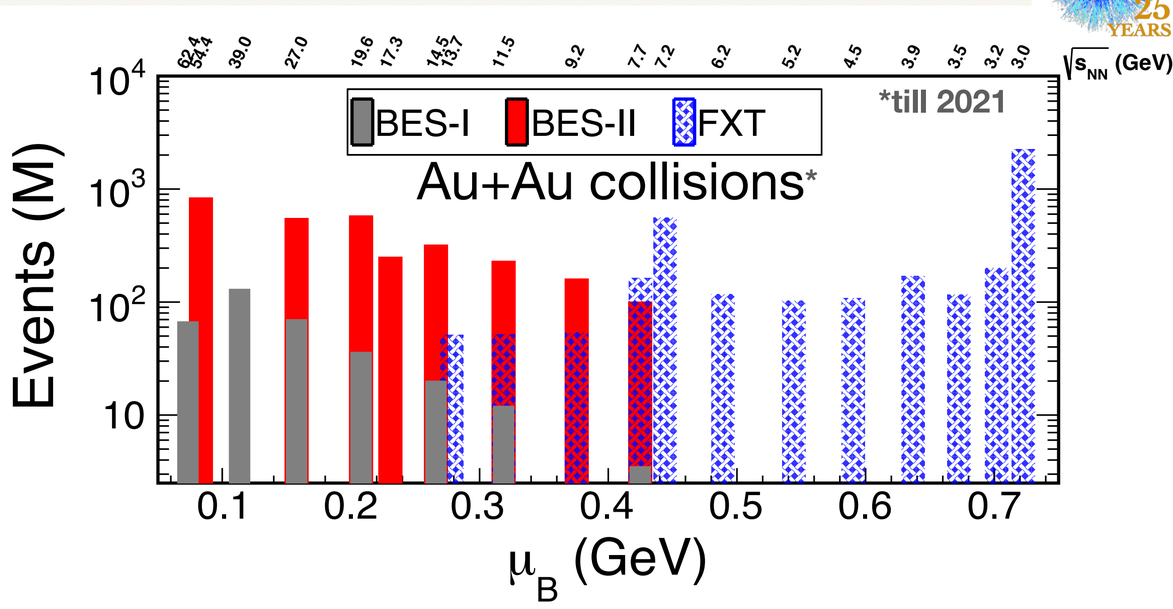


P. Braun-Munzinger, J. Stachel, Nature 448 (2007) 302

A. Pandav, D. Mallick, B. Mohanty, PPNP. 125, 103960 (2022)

The STAR at RHIC

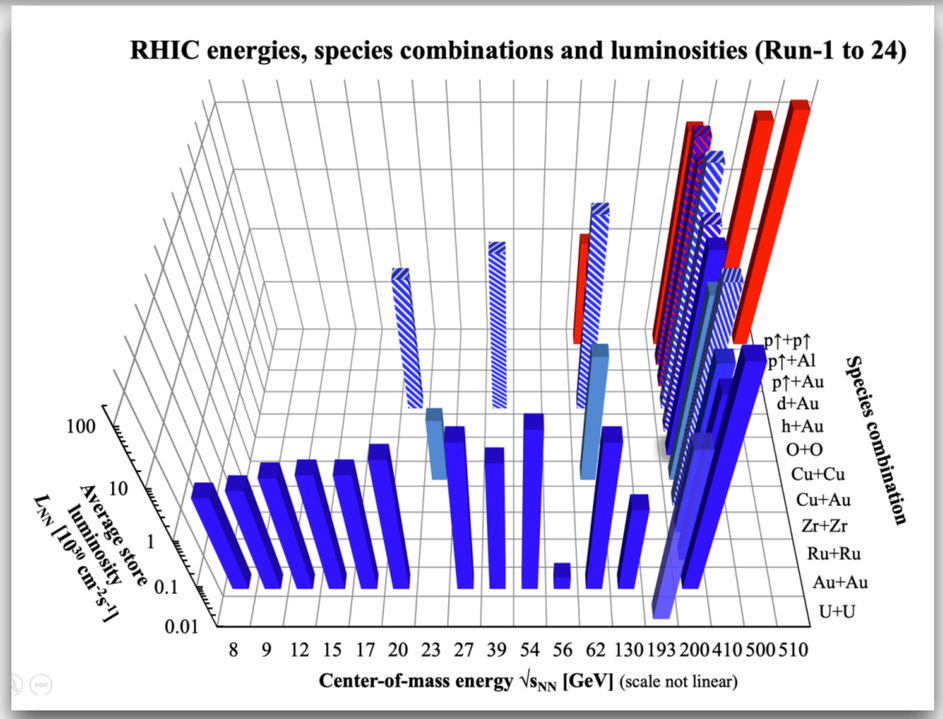




Completed its last run in 2026

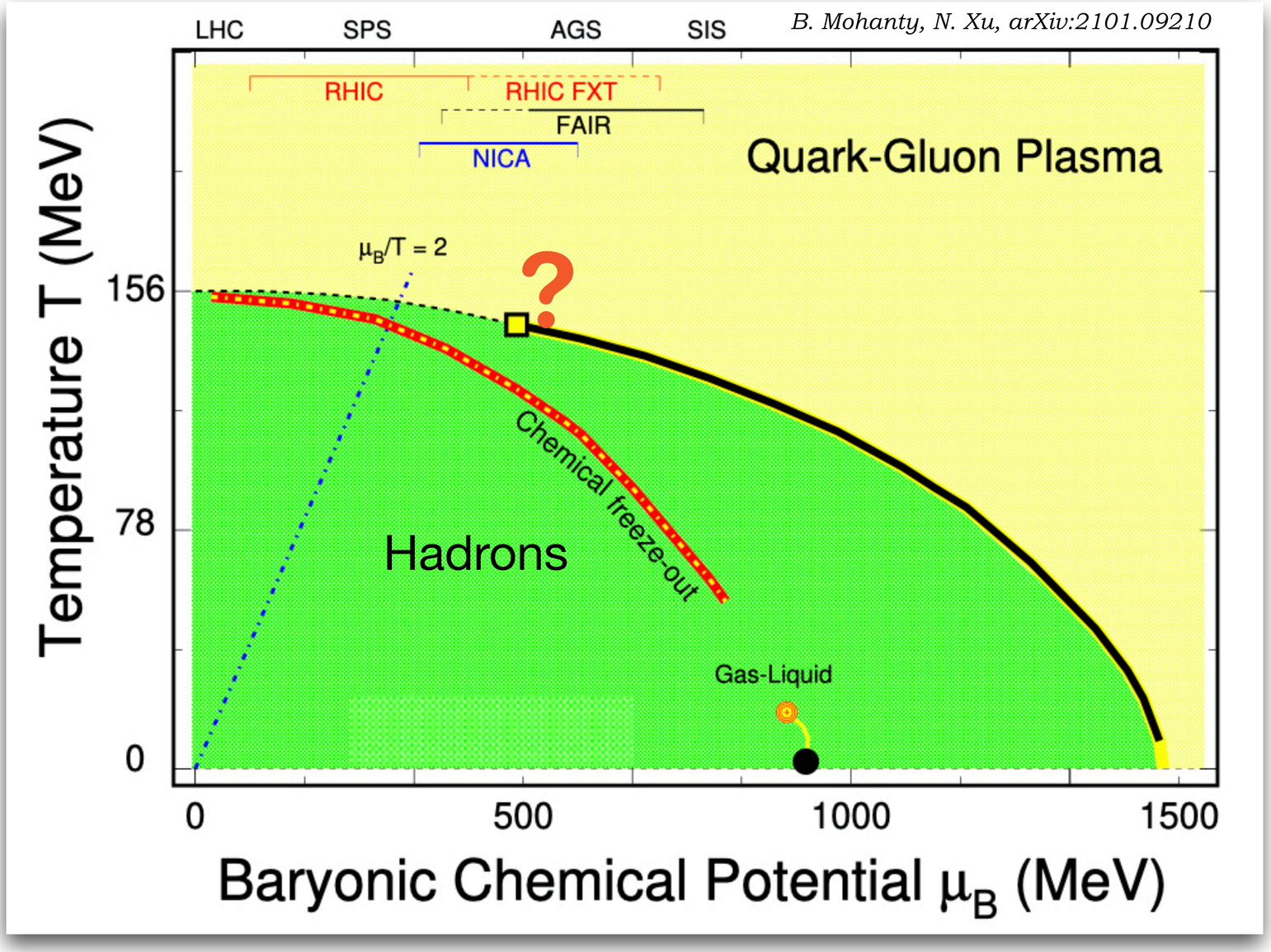
Access to wide range of QCD phase diagram

$3 \leq \sqrt{s_{NN}}\,(GeV) \leq 200 \;\rightarrow\; 25 \leq \mu_B\,(MeV) \leq 750$



Small systems and exotic physics:
STAR highlight talk II: Jiangyong Jia (today)

Studying QCD at STAR



Medium formation

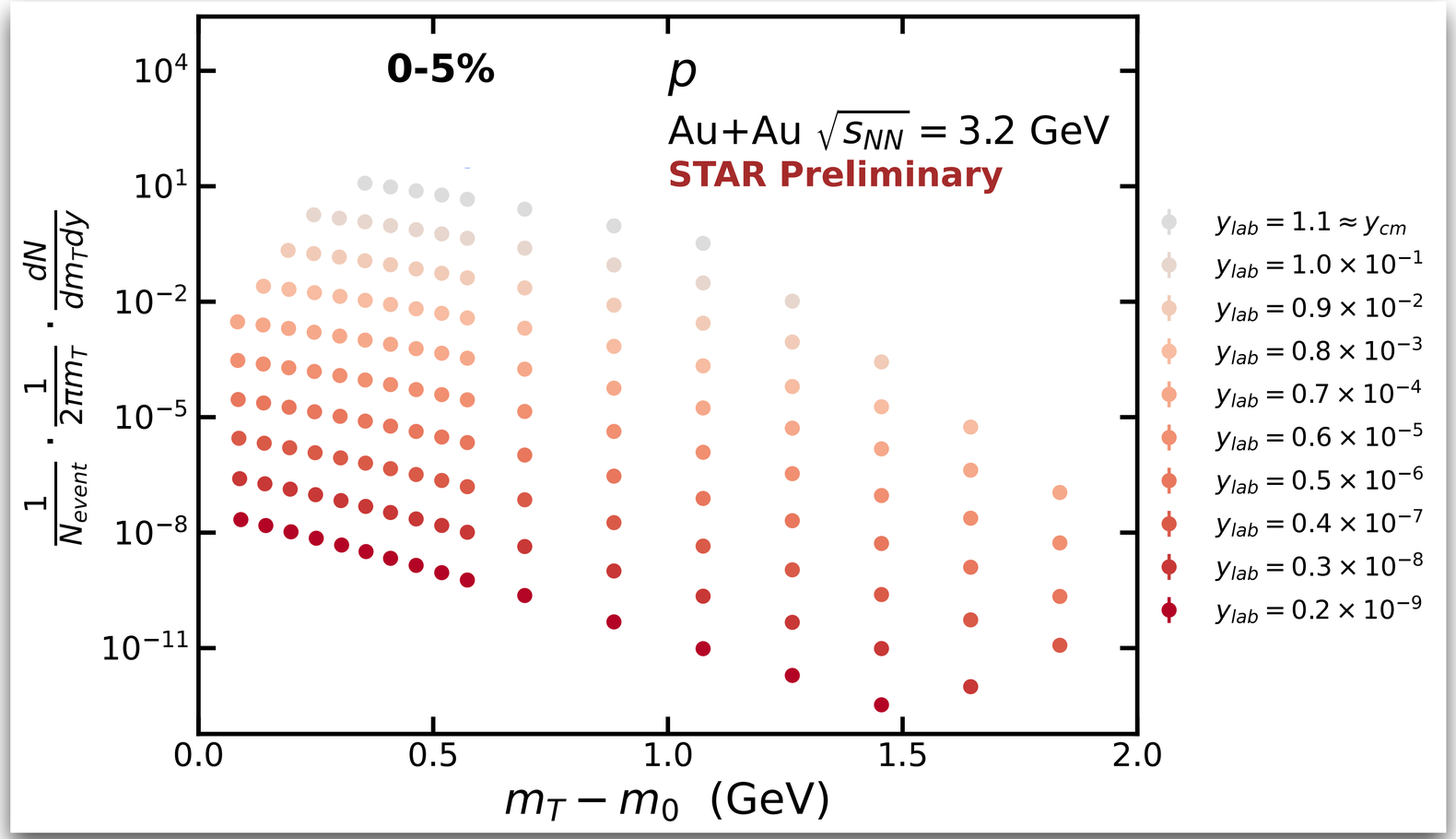
Characterizing the medium:

Study of hadron yields/spectra

Femtoscopic correlations

Hadron yield measurements

- Probing bulk properties via hadron yield measurements



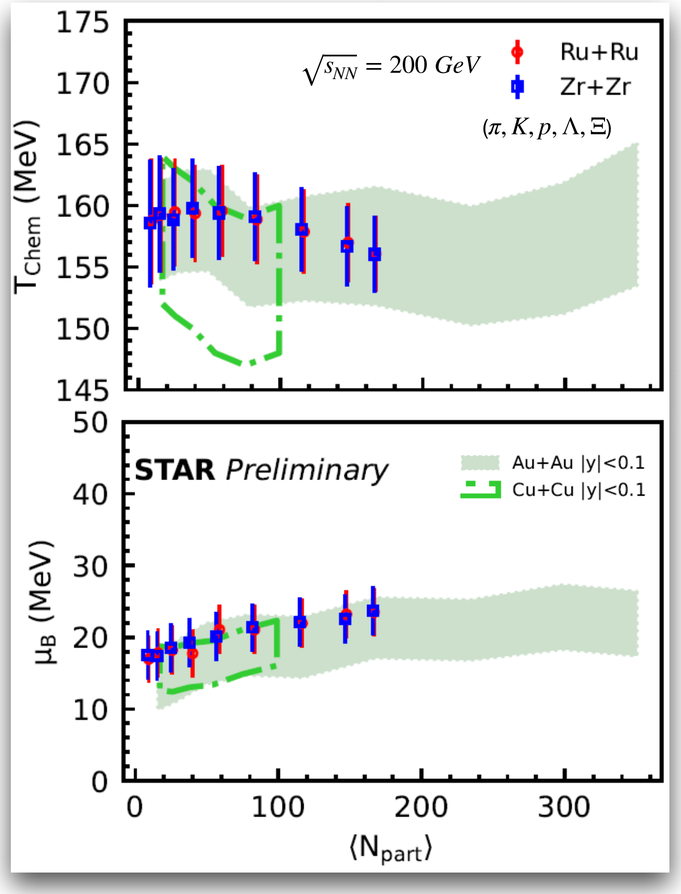
Talk: Mathias Labonte (Tue)

Poster: Chun Yuen Tsang (Wed)

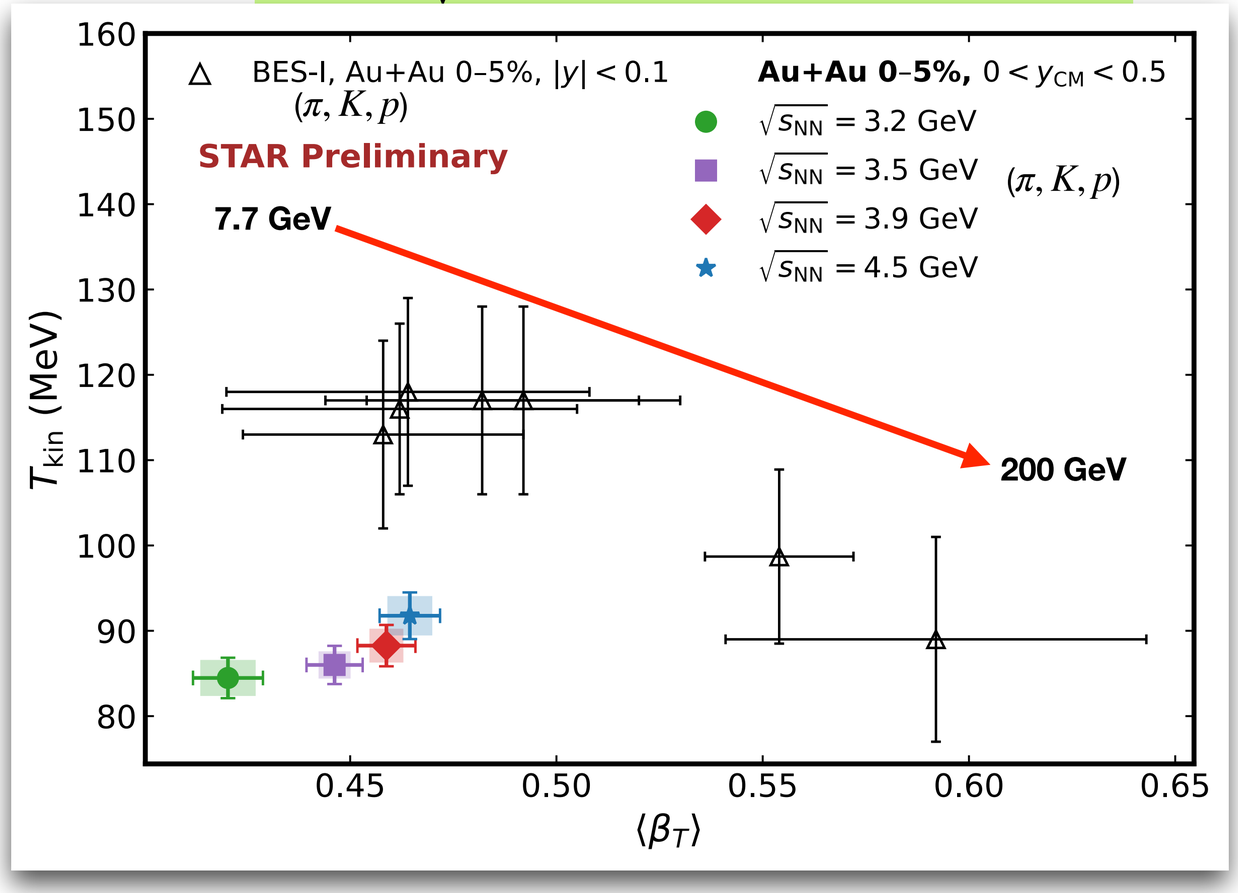
Hadron yield measurements

- Probing bulk properties via hadron yield measurements

Ru+Ru/Zr+Zr: $\sqrt{s_{NN}}$ = 200 GeV



Au+Au: $\sqrt{s_{NN}}$ = 3.2 – 4.5 GeV (STAR FXT)



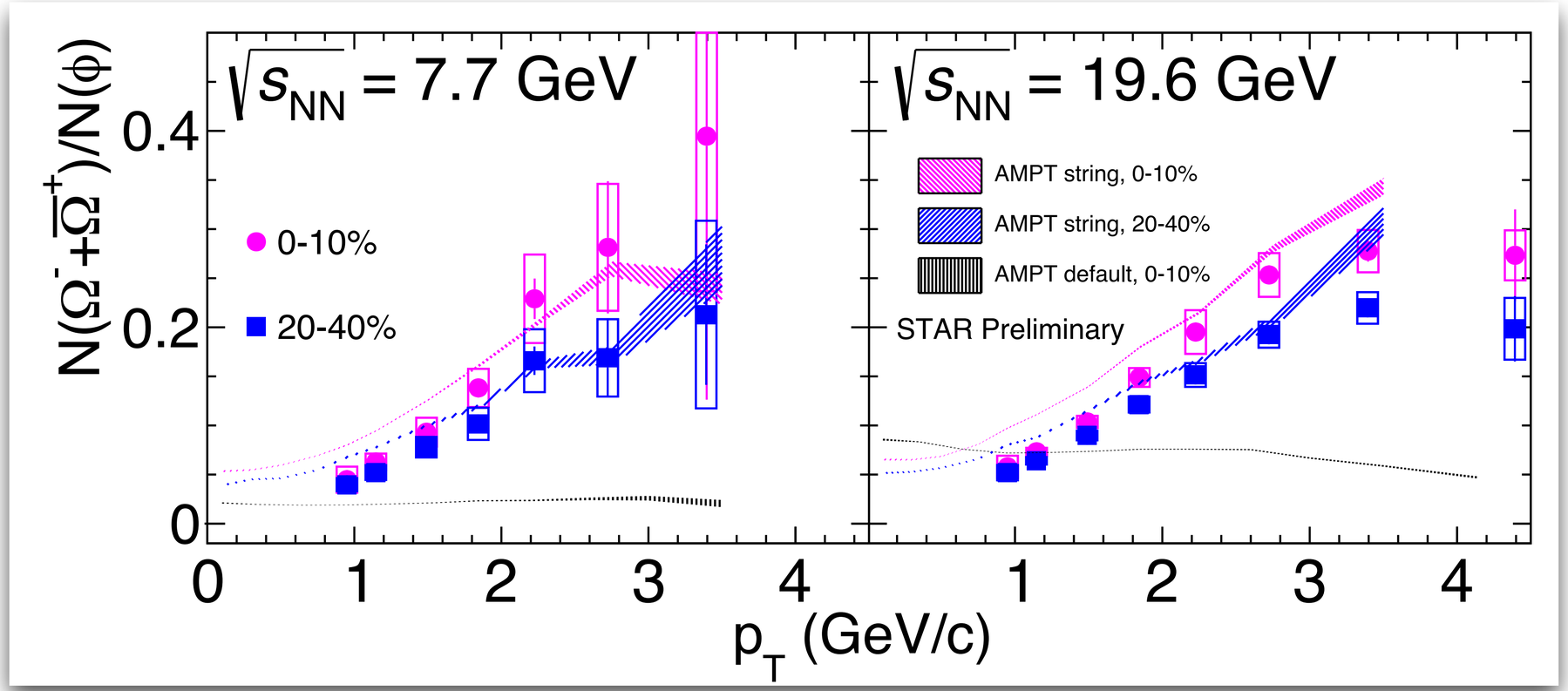
- Ru+Ru/Zr+Zr: Chemical and kinetic freezeout parameters follow Au+Au trend at 200 GeV
- Au+Au at FXT: T_{kin} and $\langle \beta_T \rangle$ extracted, increases with energy

Talk: Mathias Labonte (Tue)

Poster: Chun Yuen Tsang (Wed)

(Multi-)strange hadron production in BES

- Strange hadron yields are sensitive probes of QGP and hadronization mechanism

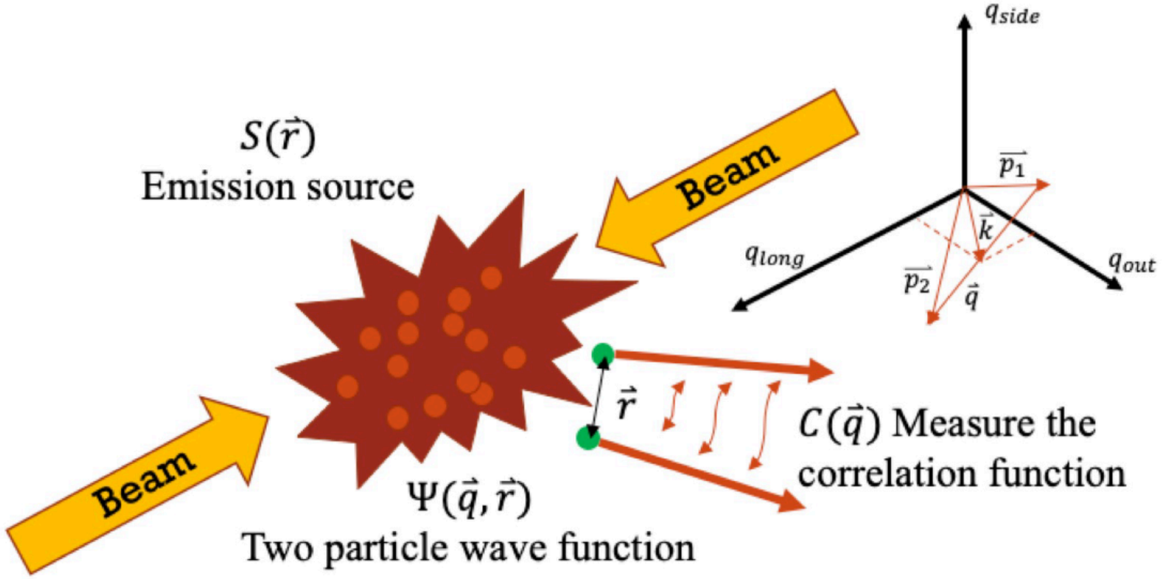


- Strong enhancement in Ω/ϕ ratio at intermediate p_T

- AMPT default version (string fragmentation) fails. String melting version(QGP-like quark-coalescence) reproduces the trend-> supports QGP formation for $\sqrt{s_{NN}} \geq 7.7$ GeV

Talk: Weiguang Yuan (Tue)

Femtoscopic correlations



Tool to probe space–time geometry of source and hadronic interactions

$$C(k^*) = \int dr^* \; S(r^*) \; |\Psi(r^*, k^*)|^2$$

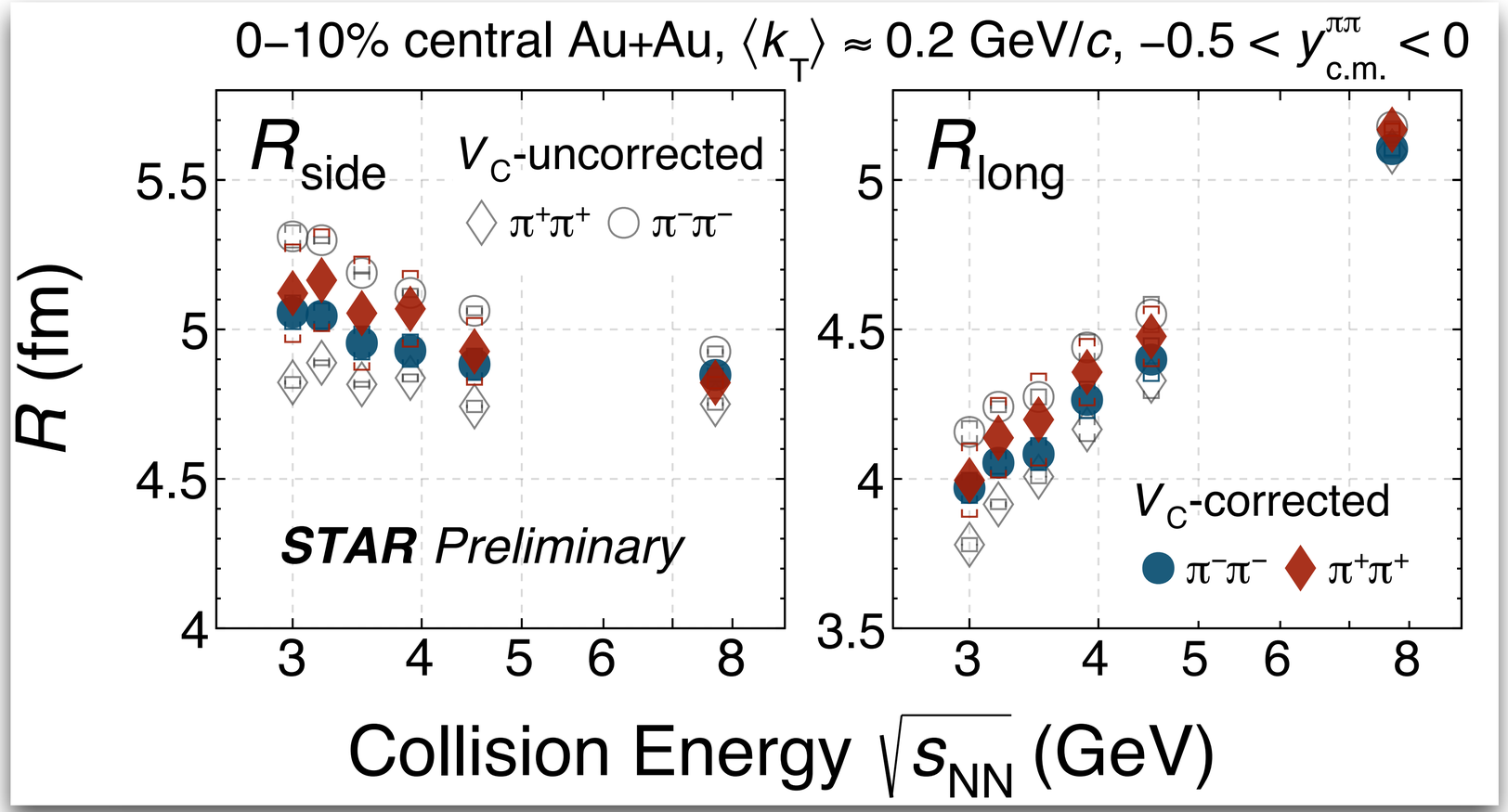
source *interaction*

$$= \frac{N_{same\ event}(k^*)}{N_{mixed\ event}(k^*)}$$

Identical pion correlations

- Understating 3rd-body coulomb effect

R_{side}, R_{long} ($\pi^+\pi^+$) < R_{side}, R_{long} ($\pi^-\pi^-$): 3rd-body coulomb effect or isospin asymmetry ?



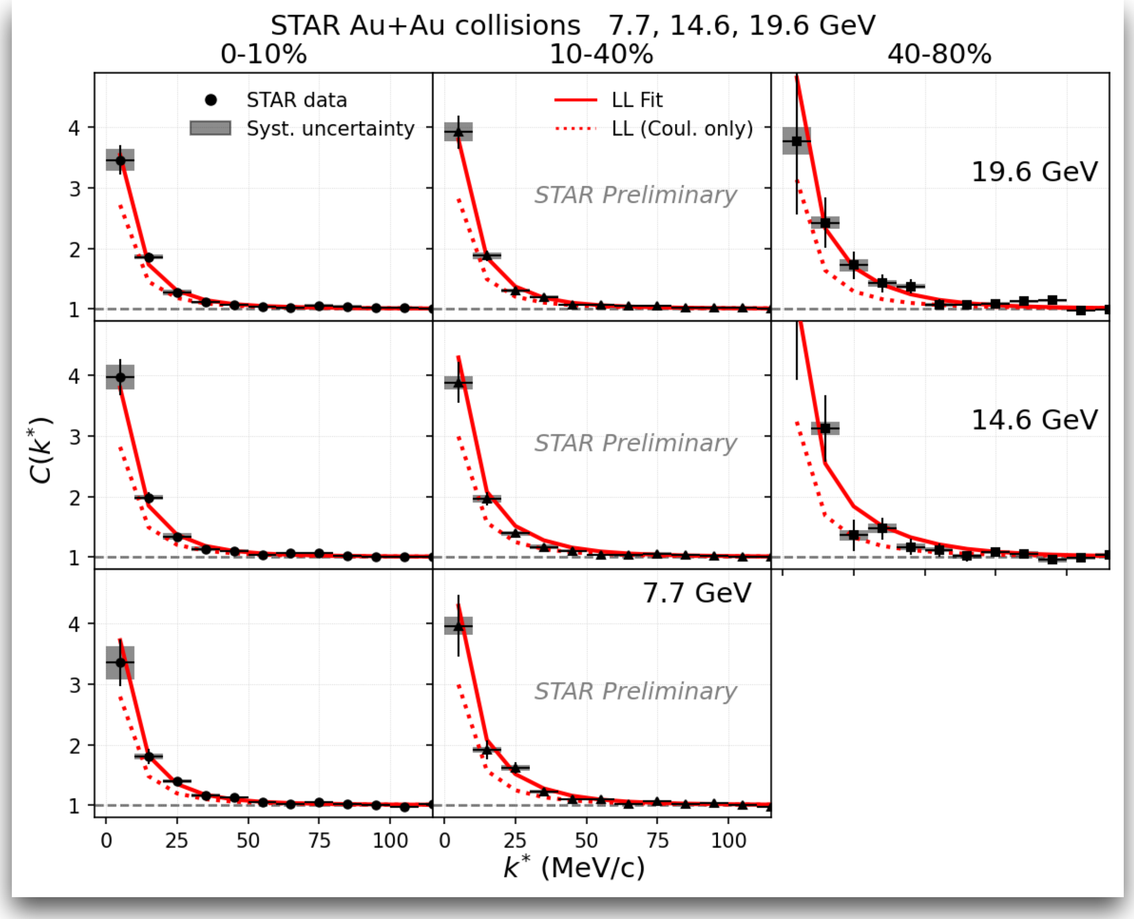
correction applied using coulomb potential energy extracted from pion p_T spectra

-$\pi^+\pi^+$ and $\pi^-\pi^-$ source radii consistent after accounting for coulomb correction

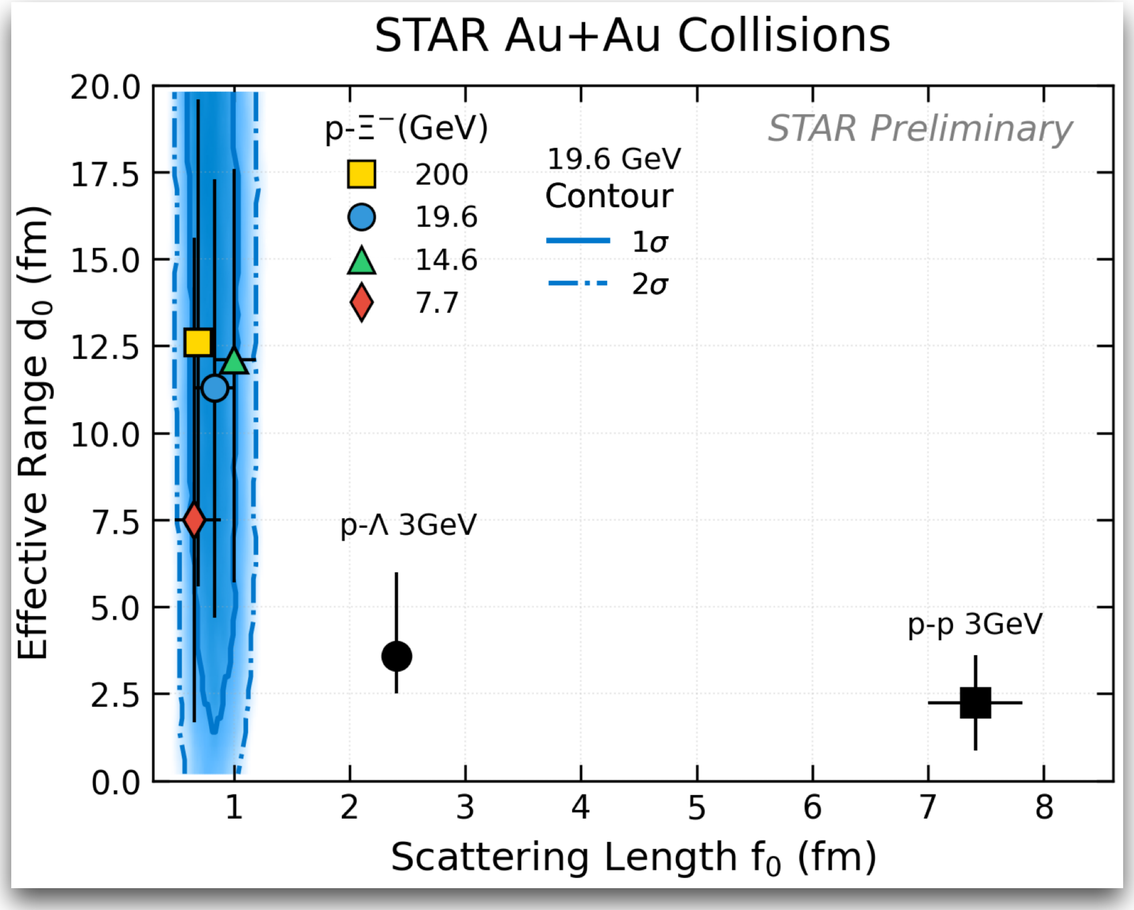
Talk: Youquan Qi (Tue)

p-Ξ⁻ correlations from BES-II

- Study of hyperon-nucleon (YN) interactions



Extracted strong interaction parameter using Lednický–Lyuboshitz formalism



- Strong interaction seen above coulomb interaction
- Observed hierarchy of strangeness content for f_0: $f_0(|s|=0) > f_0(|s|=1) > f_0(|s|=2) > 0$

Talk: Jing An (Tue)

p-p-Λ correlations in Au+Au at 3 GeV

- Constraining three body hyperon interactions: important for EOS and hyperon puzzle

$$C(Q_3) = \int \rho^5 d\rho d\Omega_\rho \, S(\rho, \rho_0) |\Psi(\rho, Q_3)|^2$$

Source Function

Wave function (interaction)

$$C(p_1, p_2, p_3) = C(Q_3) = N \frac{N_s(Q_3)}{N_m(Q_3)}$$

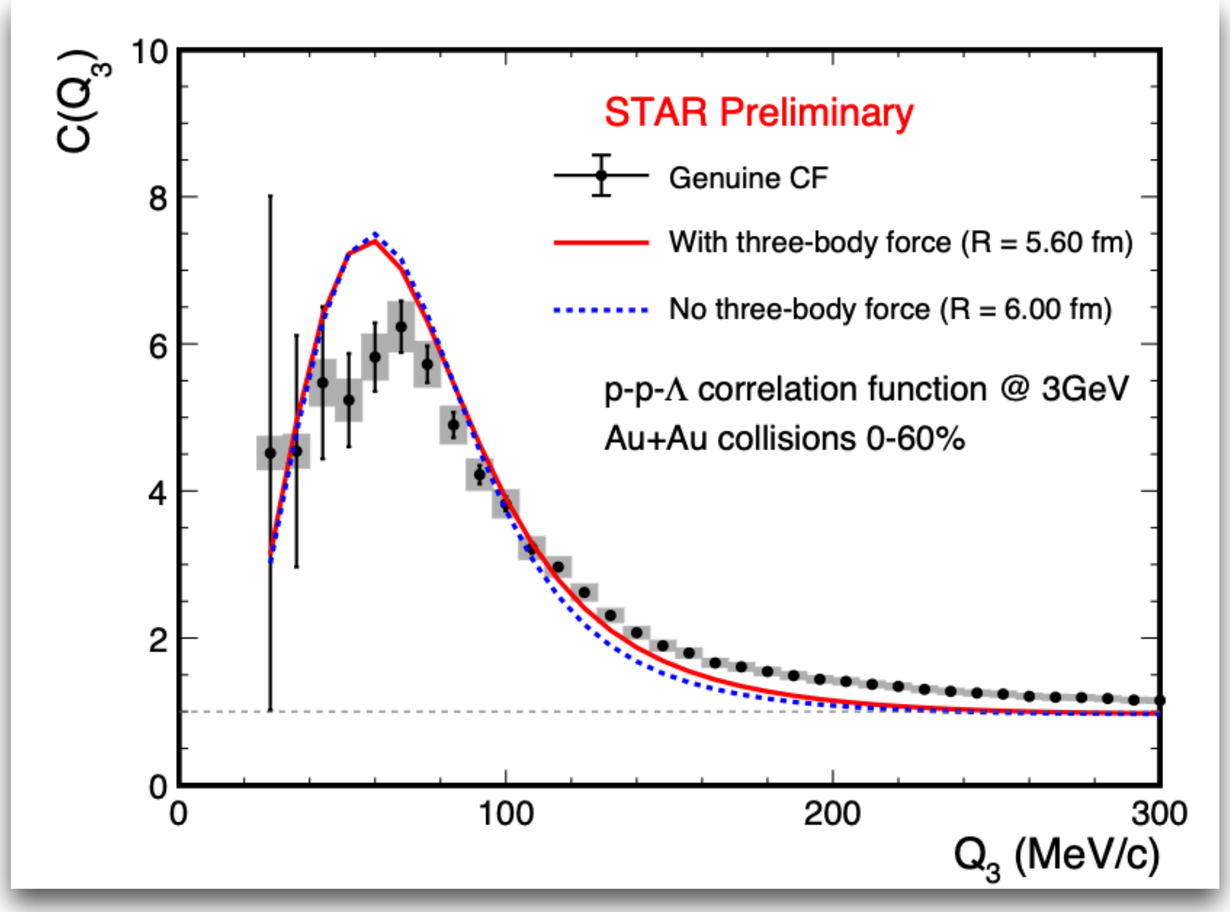
Signal

Background

Normalization factor

$$Q_3 = \sqrt{-q_{ij}^2 - q_{jk}^2 - q_{ki}^2}$$

E. Garrido et al, Phys. Rev. C 110, 054004



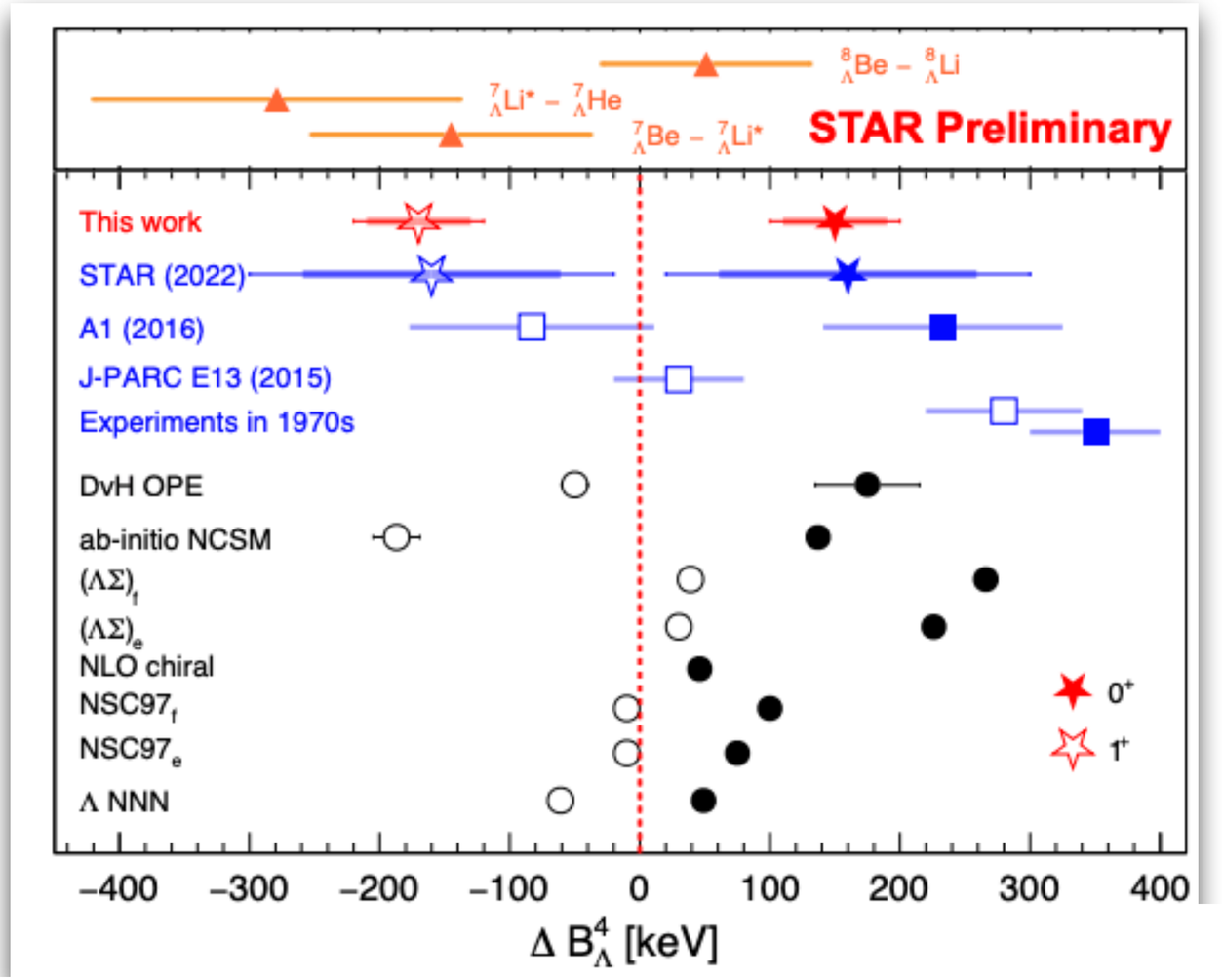
-First attempt at STAR, decent kinematic coverage down to relative momenta < 100 MeV (sensitive to final-state interactions)

-Theoretical modeling challenging. Need help from theorists.

Talk: Jing Gu (Tue)

Hypernuclei and charge symmetry breaking (CSB)

- Testing the charge dependence of Λ-nucleon (ΛN) interaction



Mirror hypernuclei

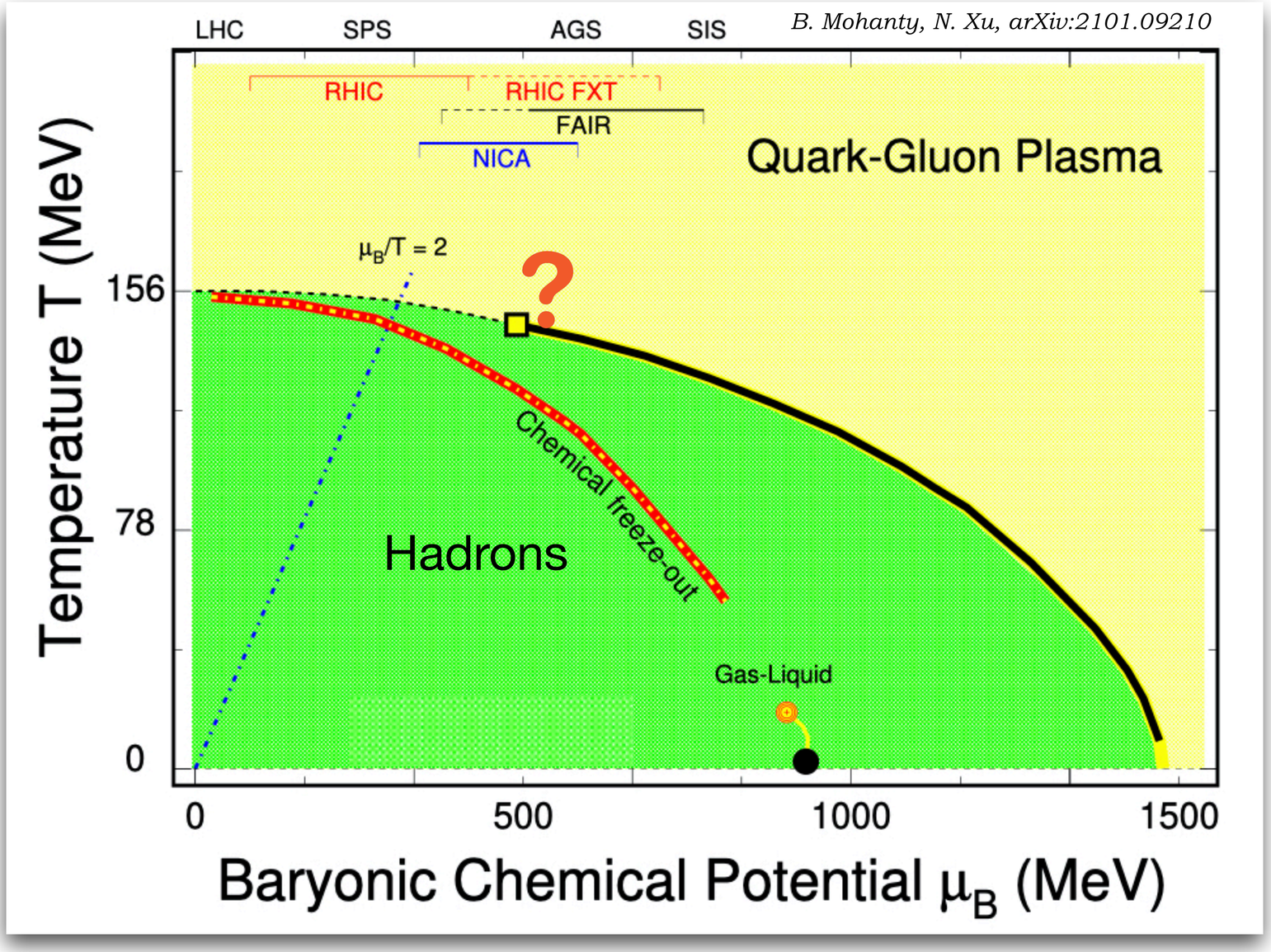
$^{4}_{\Lambda}$H $^{4}_{\Lambda}$He

CSB reflected in difference in binding energy.
Do CSB strength depend on quantum states: ground or excited?

- Most precise measurement of CSB so far
- Similar strength between ground and excited states but opposite sign

Talk: Tianhao Shao (Tue)

Studying QCD at STAR



Medium formation

Characterizing the medium:
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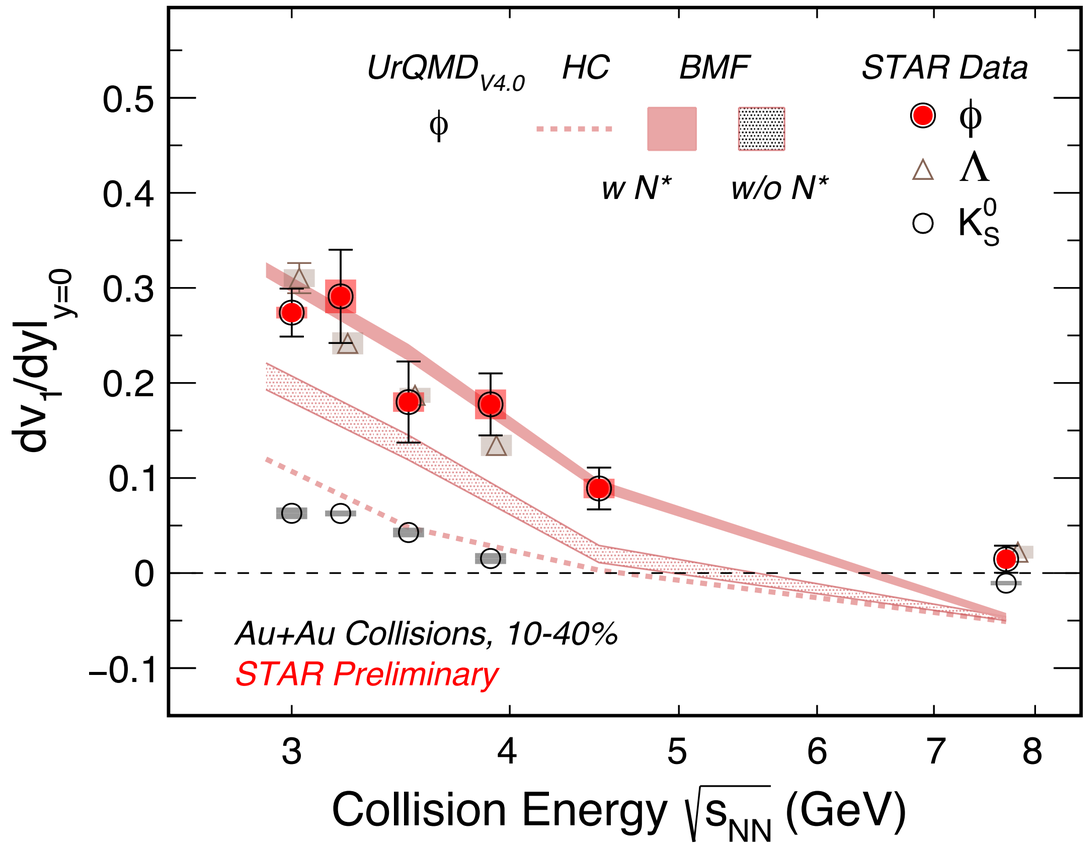
Emergent Macroscopic phenomena

Emergent properties of medium:
Flow, vorticity, phase transitions, possible critical point?

Directed flow of ϕ meson at high μ_B

- Understanding v_1 slope difference between baryons and mesons at high μ_B

ϕ unique probe: small hadronic cross section, longer lifetime



- ϕ shows large v_1 slope
- Including baryon resonance excitations ($N + N \rightarrow N^* + N \rightarrow N + \phi + N$), measurements reproduced by UrQMD:

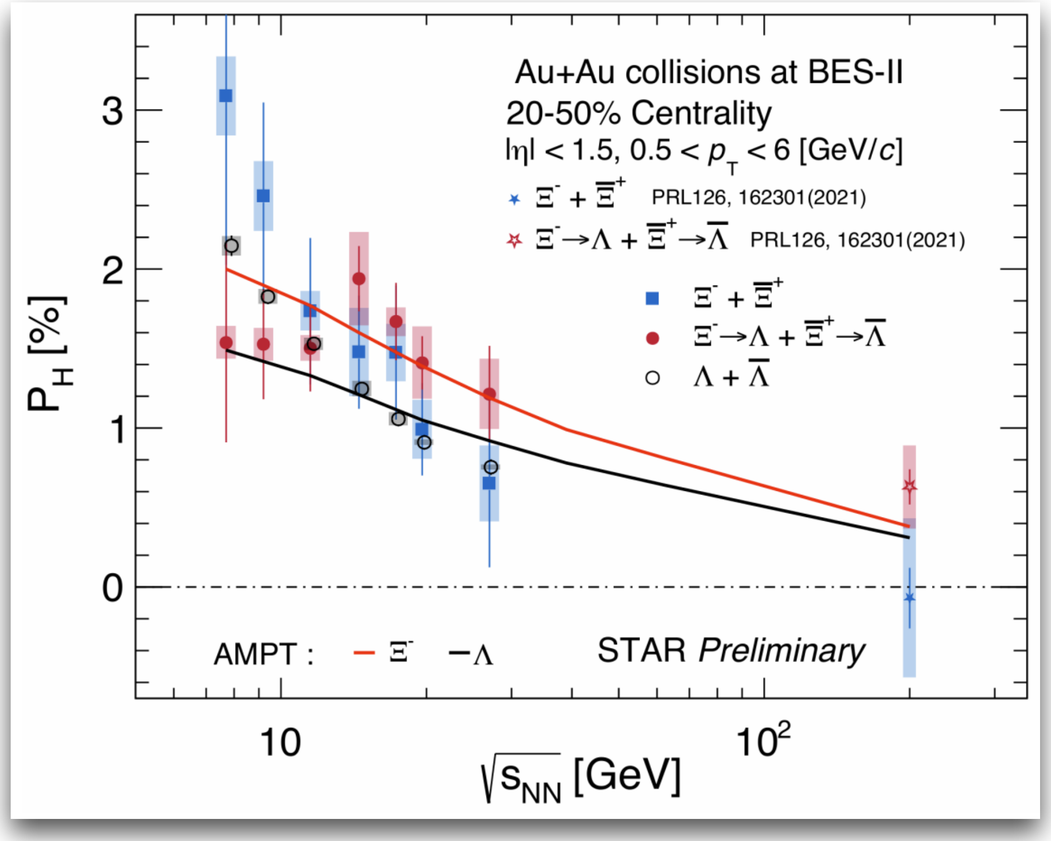
ϕ meson sensitive probes of baryon resonance production

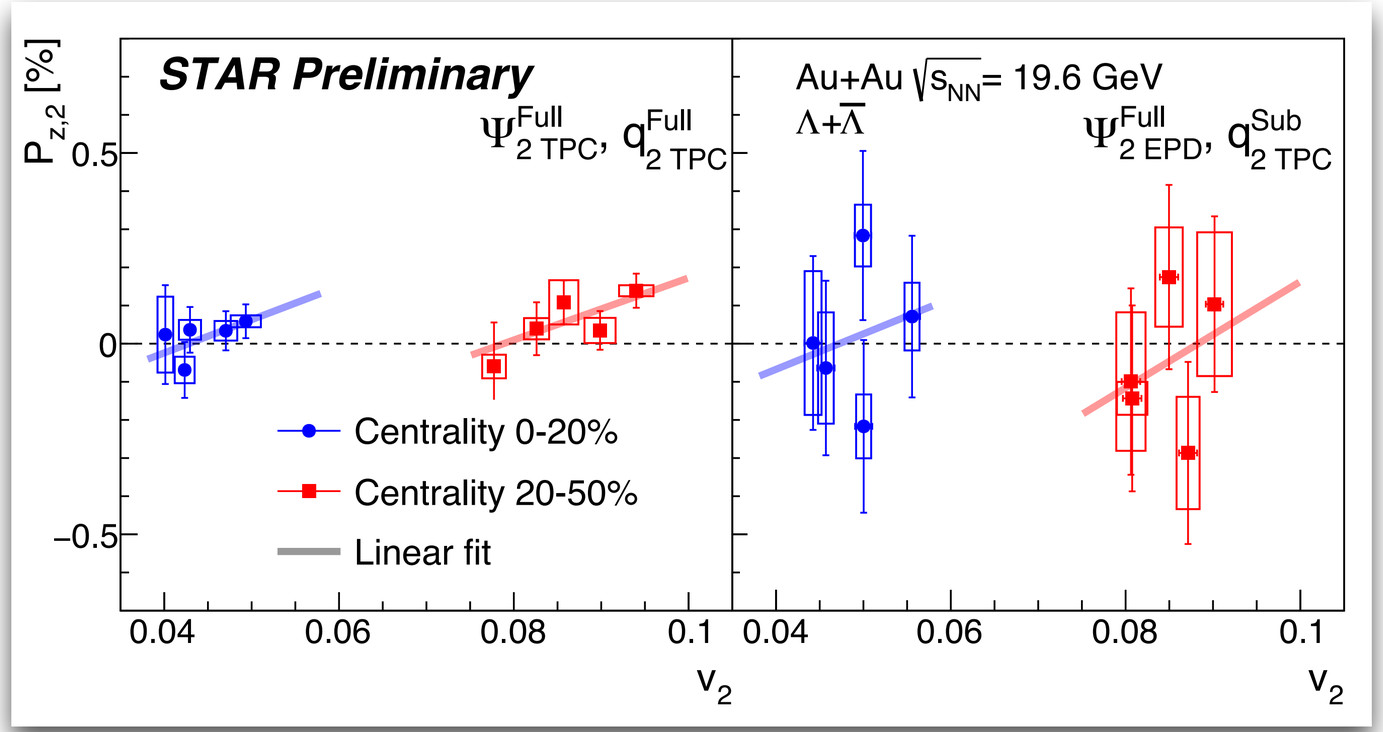
HC: Hadronic Cascade mode of UrQMD
BMF: Baryonic mean field included

Talk: Guangyu Zheng (Tue)

Polarization of hyperons

- Investigation of global and local hyperon polarization at BES-II





- Significant $P_H(\Xi^- + \bar{\Xi}^+)$ *also* $\simeq P_H(\Lambda + \bar{\Lambda})$ within errors. Hint of larger $\Omega^- + \bar{\Omega}^+$ polarization.

- First measurements of correlation between Λ+Λ̄ local polarization ($P_{z,2}$) and v_2
Slight dependence of $P_{z,2}$ on flow vector q_2 and v_2 within uncertainty(~2σ effect)

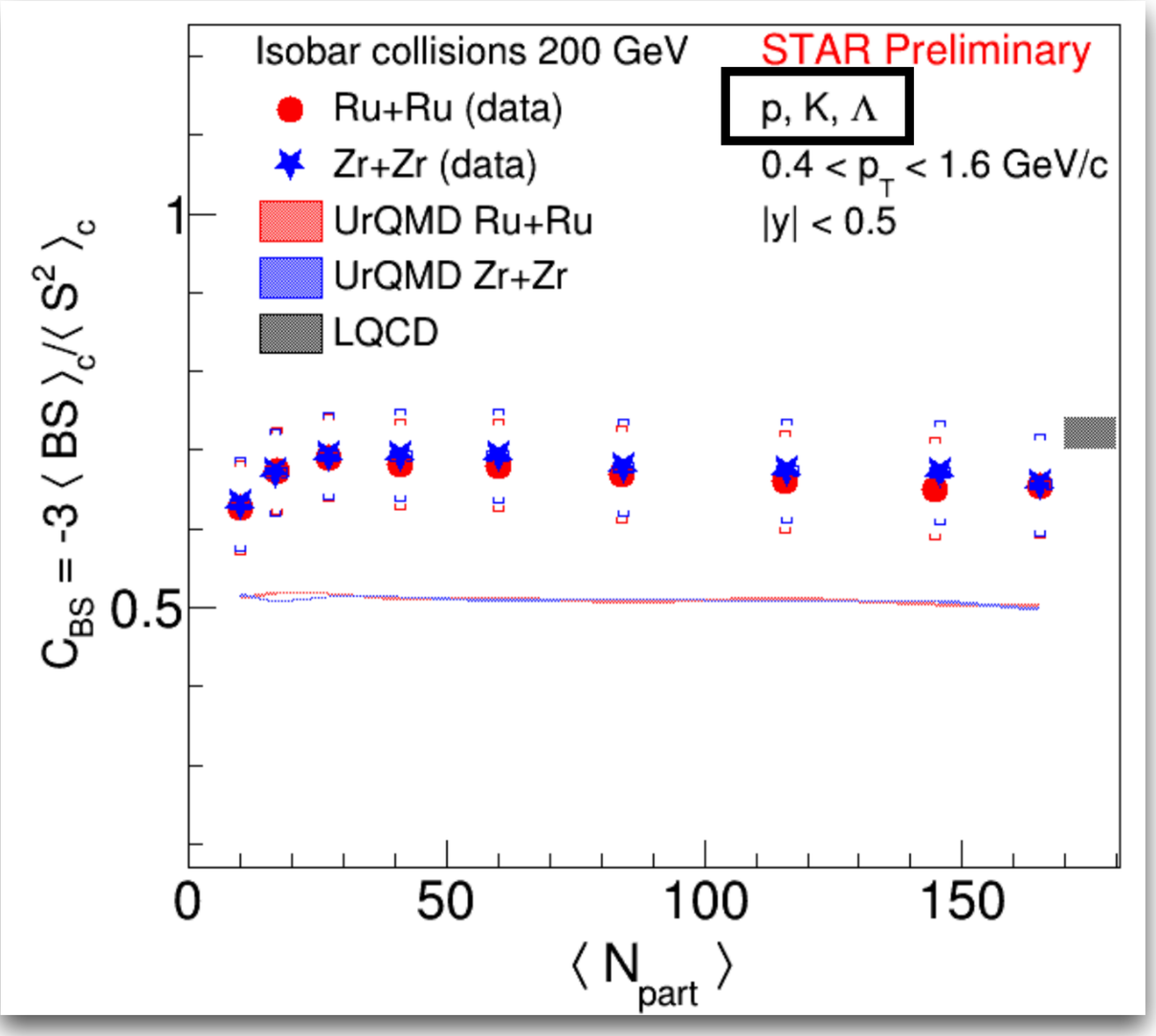
Talk: Tong Fu (Tue)

Talk: Taiki Kondo (Wed)

Probing QGP using Baryon-Strangess correlation

- BS correlation: sensitive probes of changes in degree of freedom of QCD matter

M. Asakawa, U. W. Heinz and B. Muller, Phys. Rev. Lett. 85 (2000)
V. Koch, A. Majumder and J. Randrup, Phys. Rev. Lett. 95, 182301 (2005)



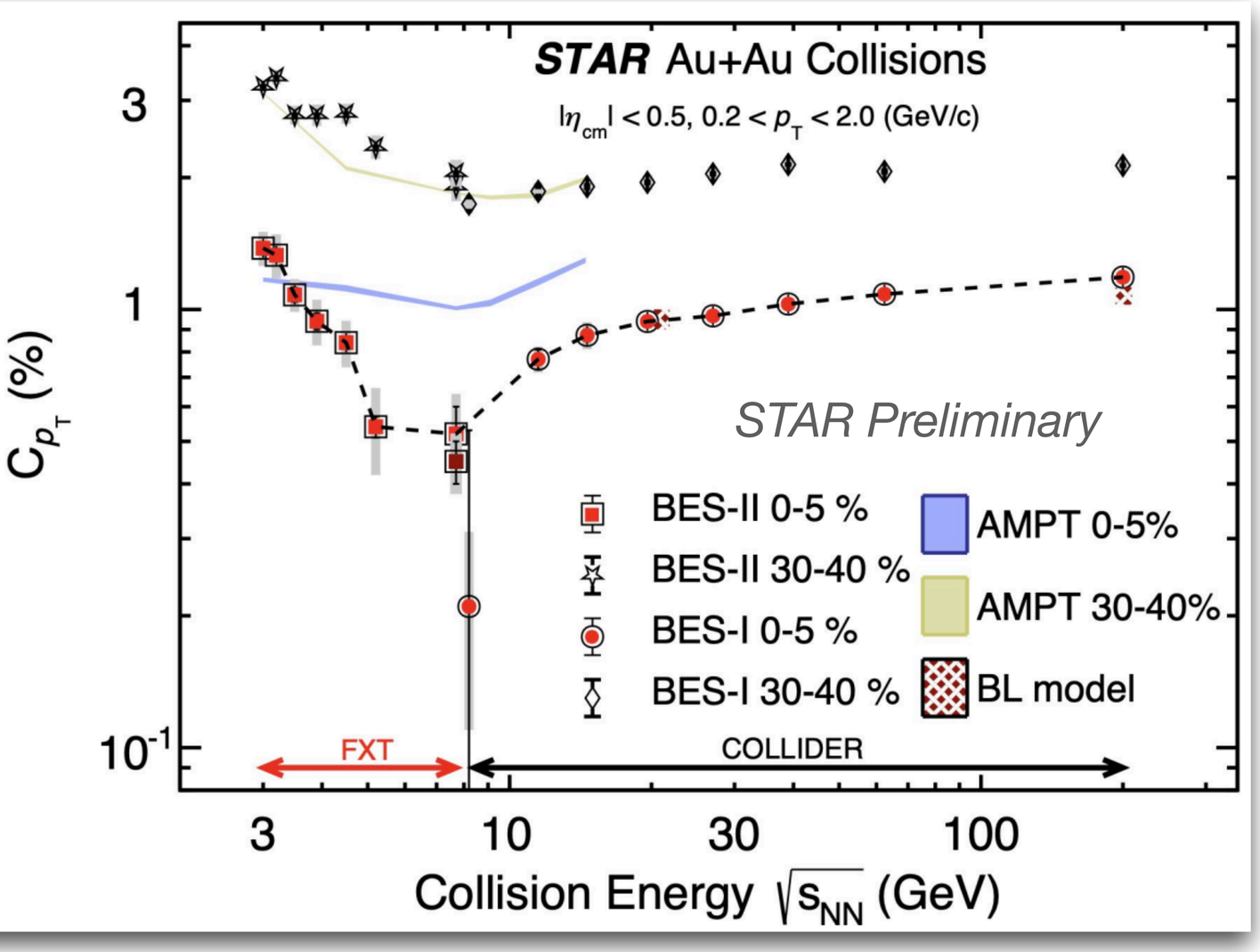
$$C_{BS} = -3\frac{\langle BS\rangle_c}{\langle S^2\rangle_c} = -3\frac{\langle BS\rangle - \langle B\rangle\langle S\rangle}{\langle S^2\rangle - \langle S\rangle^2}$$

-Measurements higher than UrQMD and consistent with lattice QCD within uncertainties.

Talk: Changfeng Li /Hanwen Feng(Wed)

Probing phase structure at high μ_B via p_T fluctuations

- Mean p_T fluctuations: sensitive to EOS



$$C_{p_T} = \frac{\sqrt{\langle \Delta p_{T,i} \Delta p_{T,j} \rangle}}{\langle \langle p_T \rangle \rangle}$$

-Robust observable to volume and efficiency effect

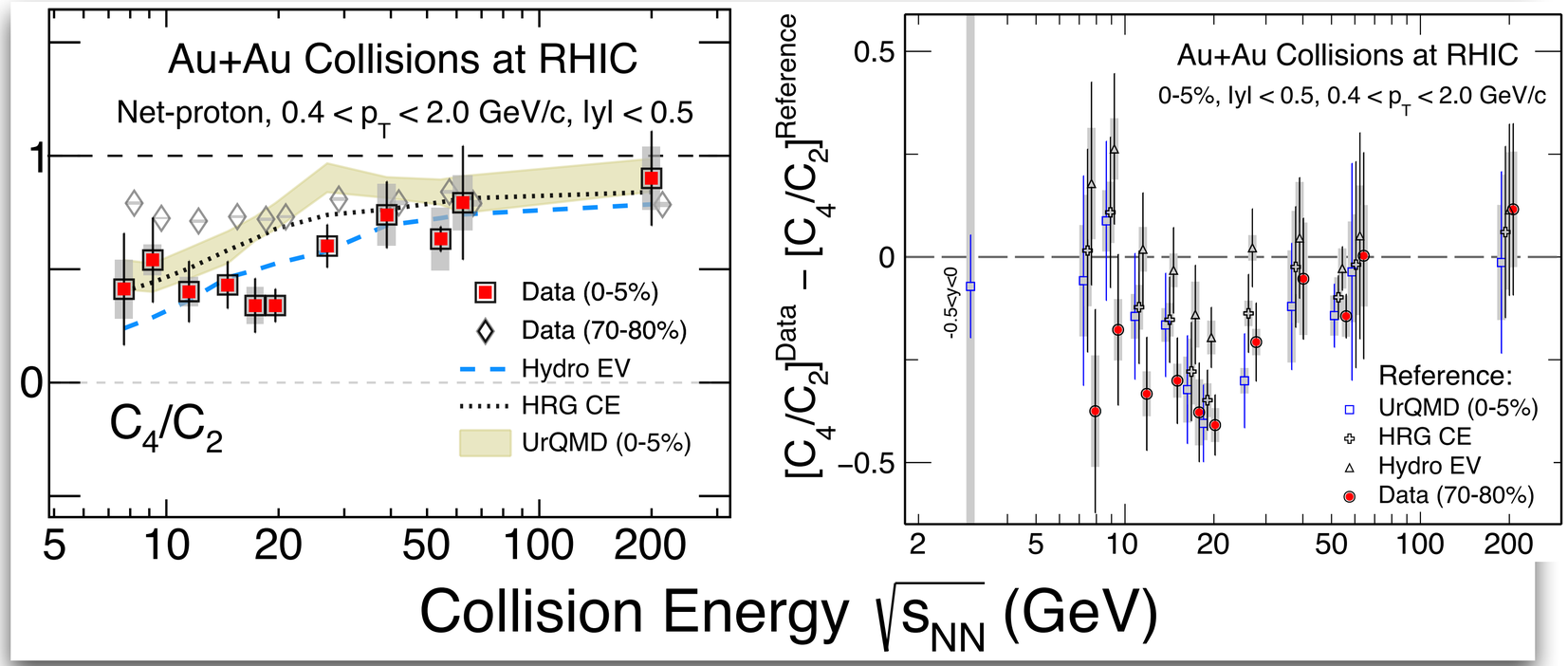
-Non-monotonic collision energy dependence (0-5% centrality). Minimum around 4.5- 7.7 GeV

-AMPT model (no phase transition) and 30-40% data do not show such stark trends

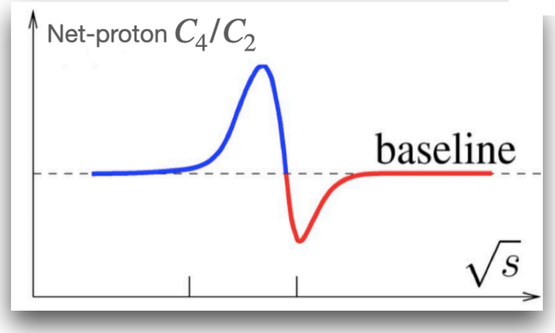
Talk: Rutik Manikandhan (Tue)

Search for QCD critical point

Net-proton C_4/C_2: Data vs. model



STAR: PRL 135, 142301 (2025)



M. A. Stephanov, Phys.Rev.Lett. 107 (2011) 052301

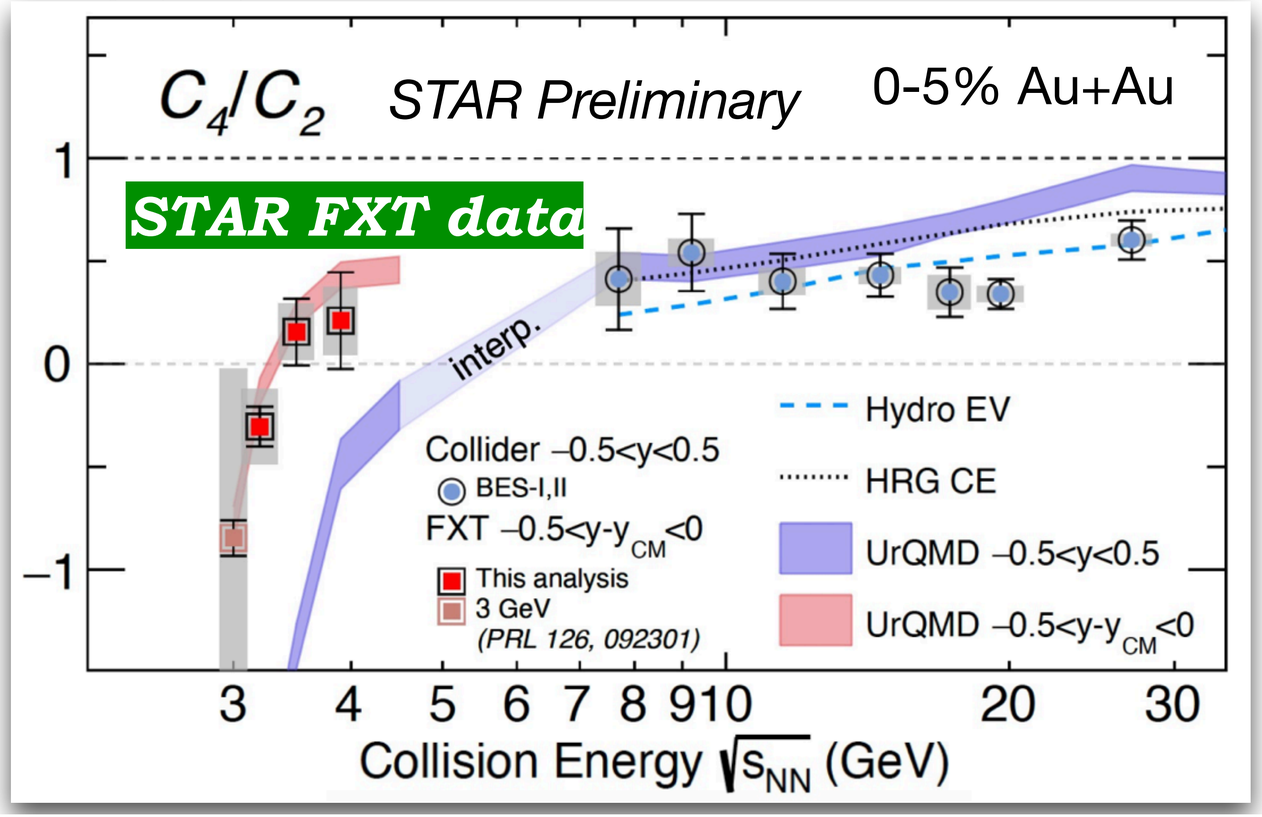
Qualitative feature near a CP

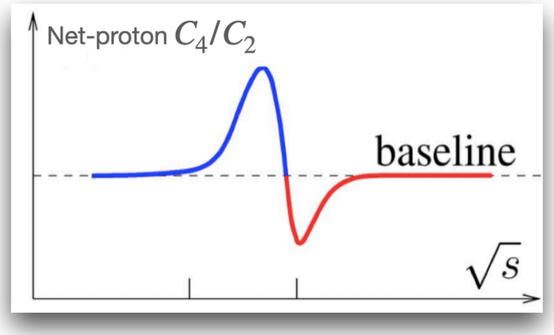
- A minimum in C_4/C_2 w.r.t. non-CP models and peripheral data at 2-5σ level around 20 GeV
- Consistency with non-CP baseline for data at $\sqrt{s_{NN}} \geq 27$ GeV

Search for QCD critical point

C_4/C_2: Data vs. model

Z. Sweger (STAR) at QM2025





M. A. Stephanov, Phys.Rev.Lett. 107 (2011) 052301

Qualitative feature near a CP

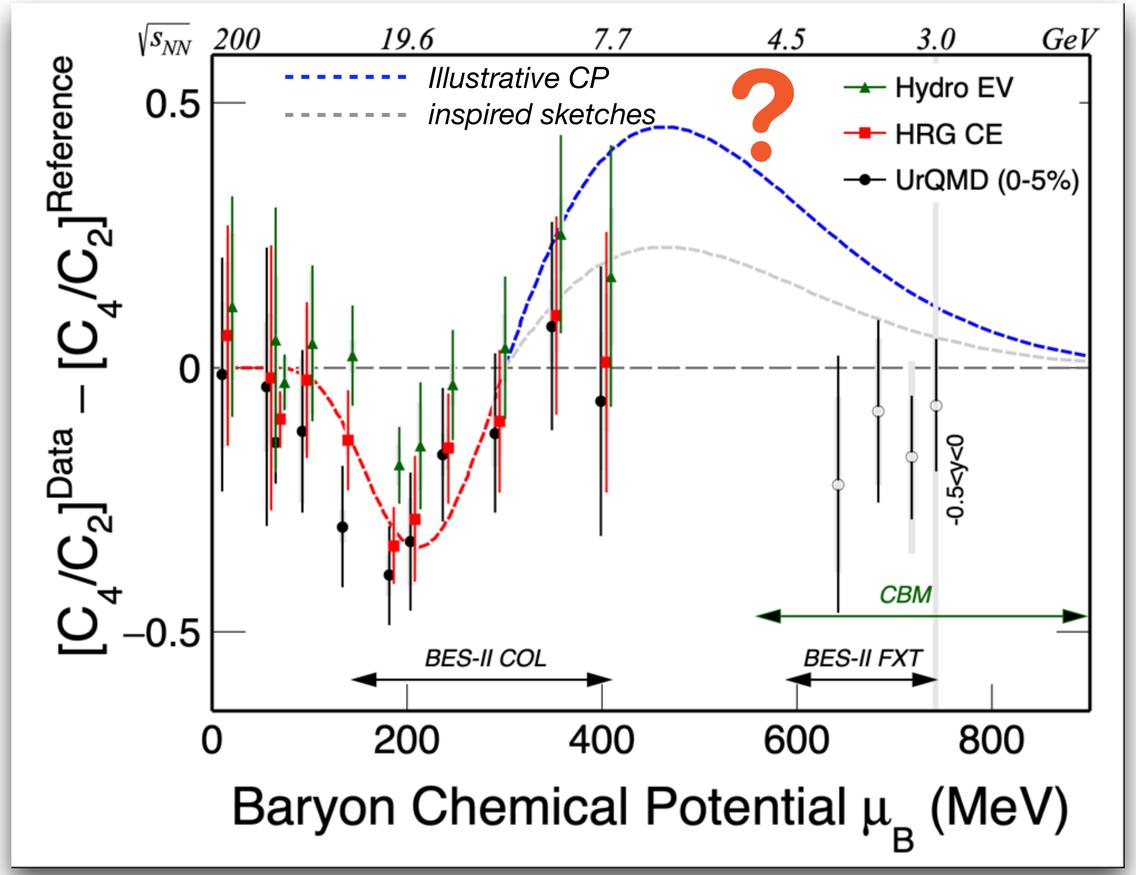
-A minimum in C_4/C_2 w.r.t. non-CP models and peripheral data at 2-5σ level around 20 GeV

-Consistency with non-CP baseline for data at $\sqrt{s_{NN}} \geq 27$ GeV

-Consistency also seen for FXT data for $\sqrt{s_{NN}} \leq 3.9$ GeV.

-Dynamic model calculation with a CP needed for quantitative assessment of data

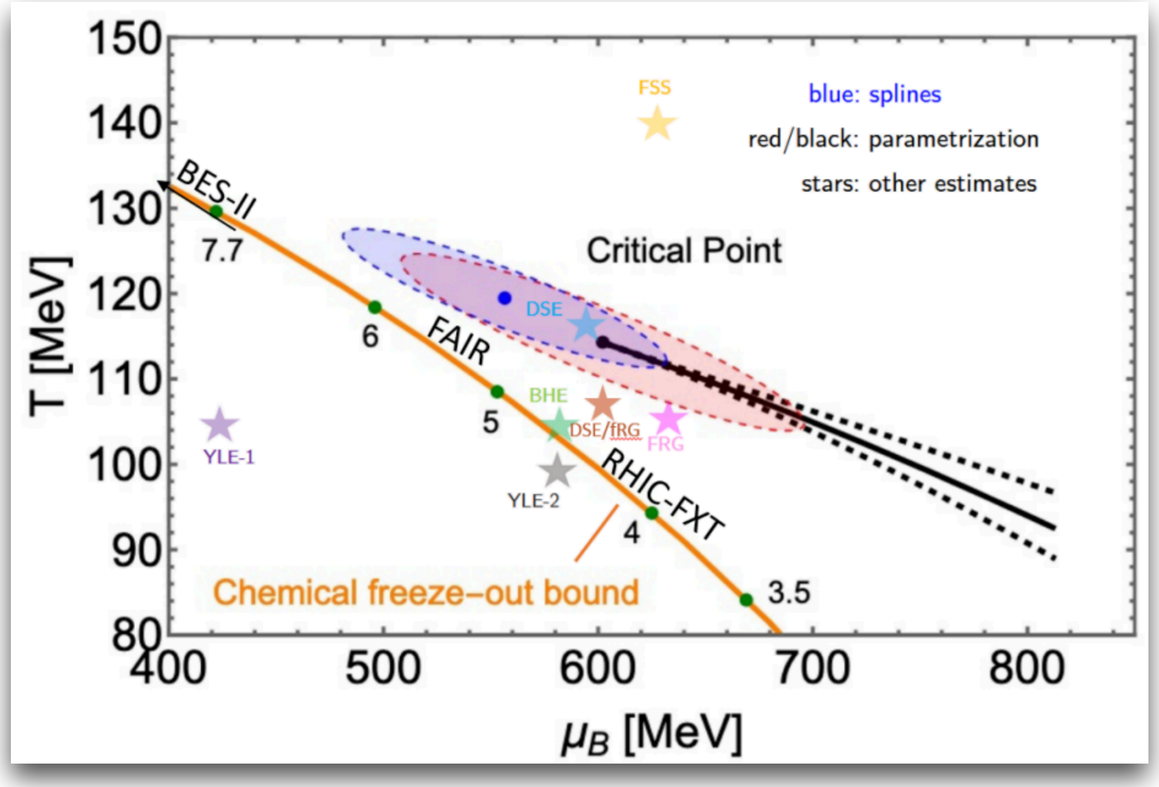
STAR future prospects (selected few):



STAR: PRL 135, 142301 (2025)

Understanding the trends at high μ_B

Recent theory predictions for CP



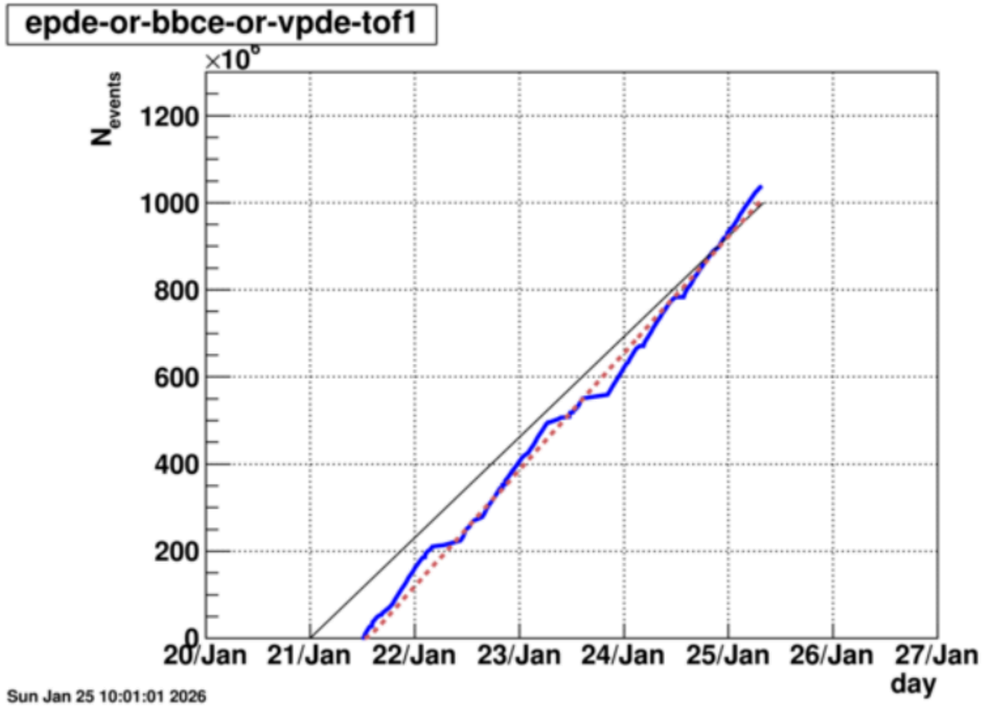
Recent CP estimates from diverse theory calculations suggest $\sqrt{s_{NN}} \sim 4$ - 5 GeV

Finite size scaling analysis of net-proton data(collider) points to above critical region

Y. Huang (STAR) at QM2025

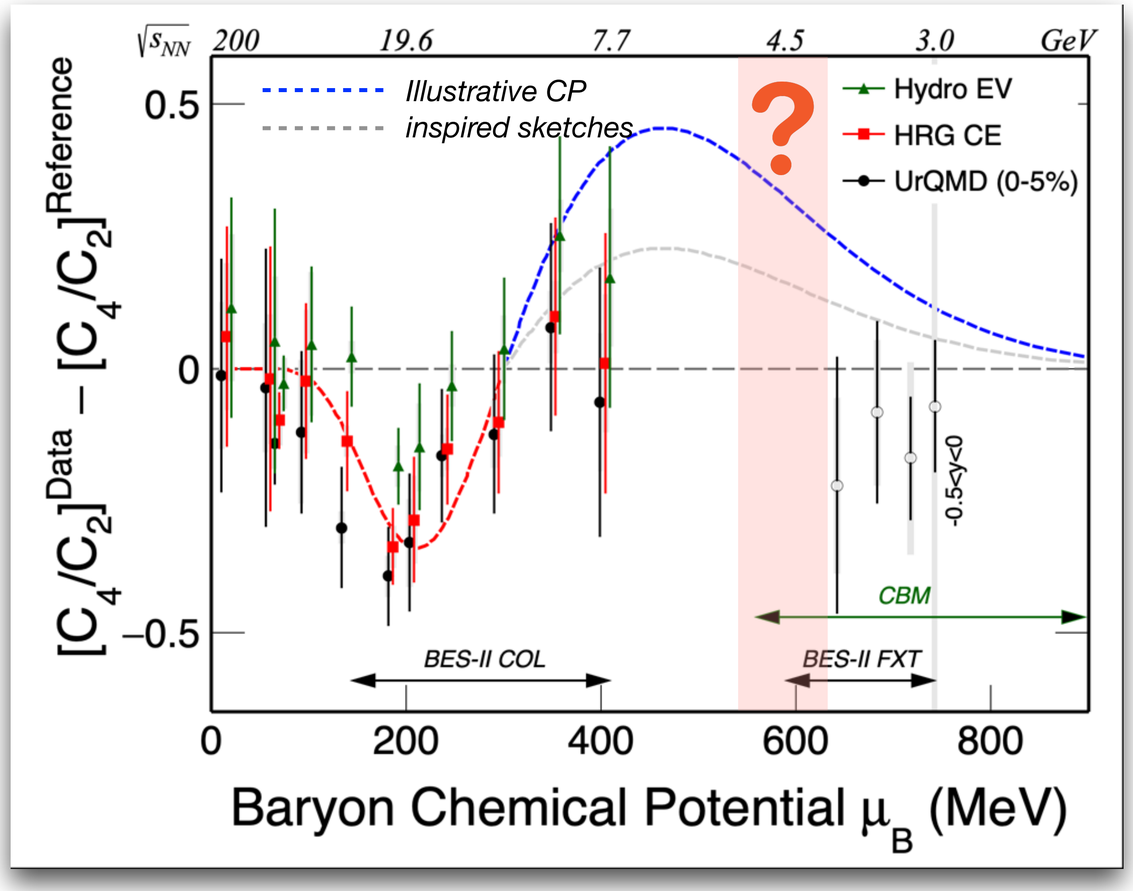
CP from different theories (References):
YLE-1: D.A. Clarke et al, arXiv:2405.10196
YLE-2: G. Basar, PRC 110, 015203 (2024)
BHE: M. Hippert et al., PRD 110, 094006 (2024)
FRG: W-J. Fu et al., PRD 101, 054032 (2020)
DSE: P.J. Gunkel et al., PRD 104, 052202 (2021)
DSE/fRG: Gao, Pawlowski., PLB 820, 136584 (2021)
FSS: A. Sorensen et al., arXiv:2405.10278

STAR future prospects (selected few):



Completed its last run in 2026

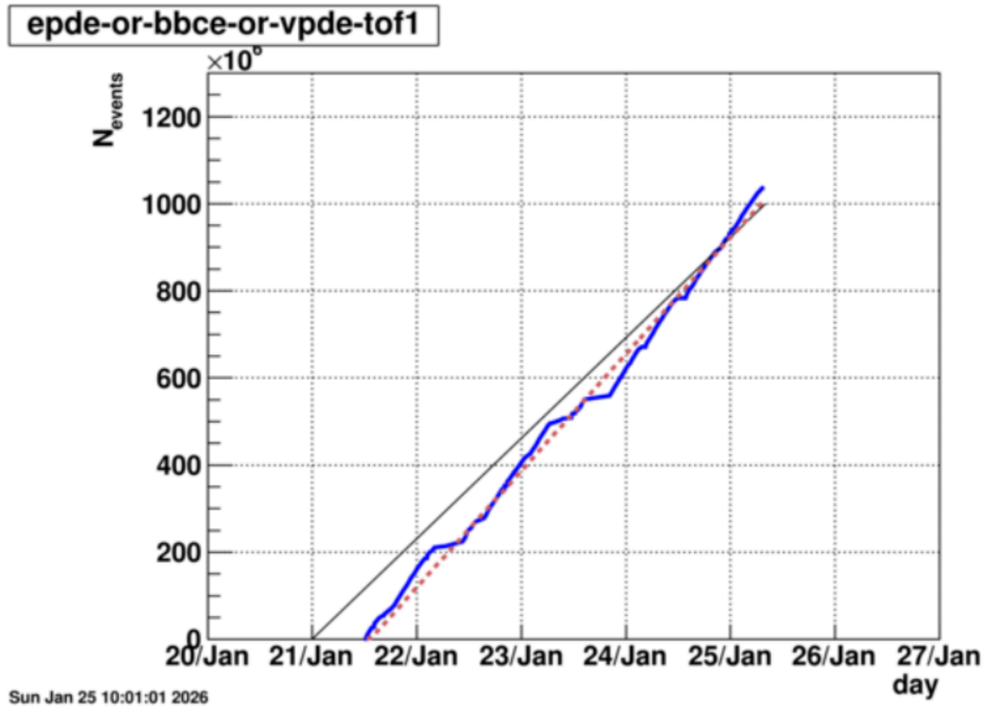
FXT data at $\sqrt{s_{NN}}$ = **4.5 GeV (~1B), 4.2 GeV(~290M), 5.2 GeV (~370 M) collected !**



STAR: PRL 135, 142301 (2025)

Precision data at $\sqrt{s_{NN}}$ = **4.2, 4.5, 5.2 GeV** in near future for CP search

STAR future prospects (selected few):



Completed its last run in 2026

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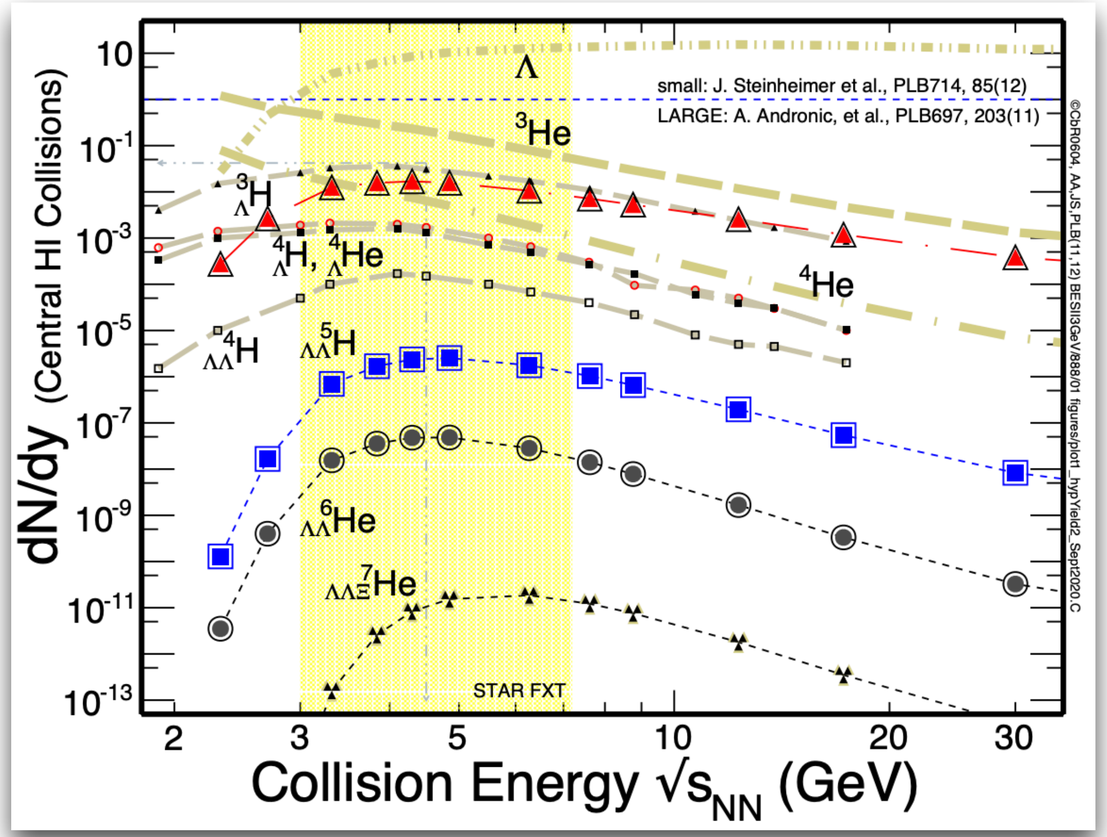
Model calculations

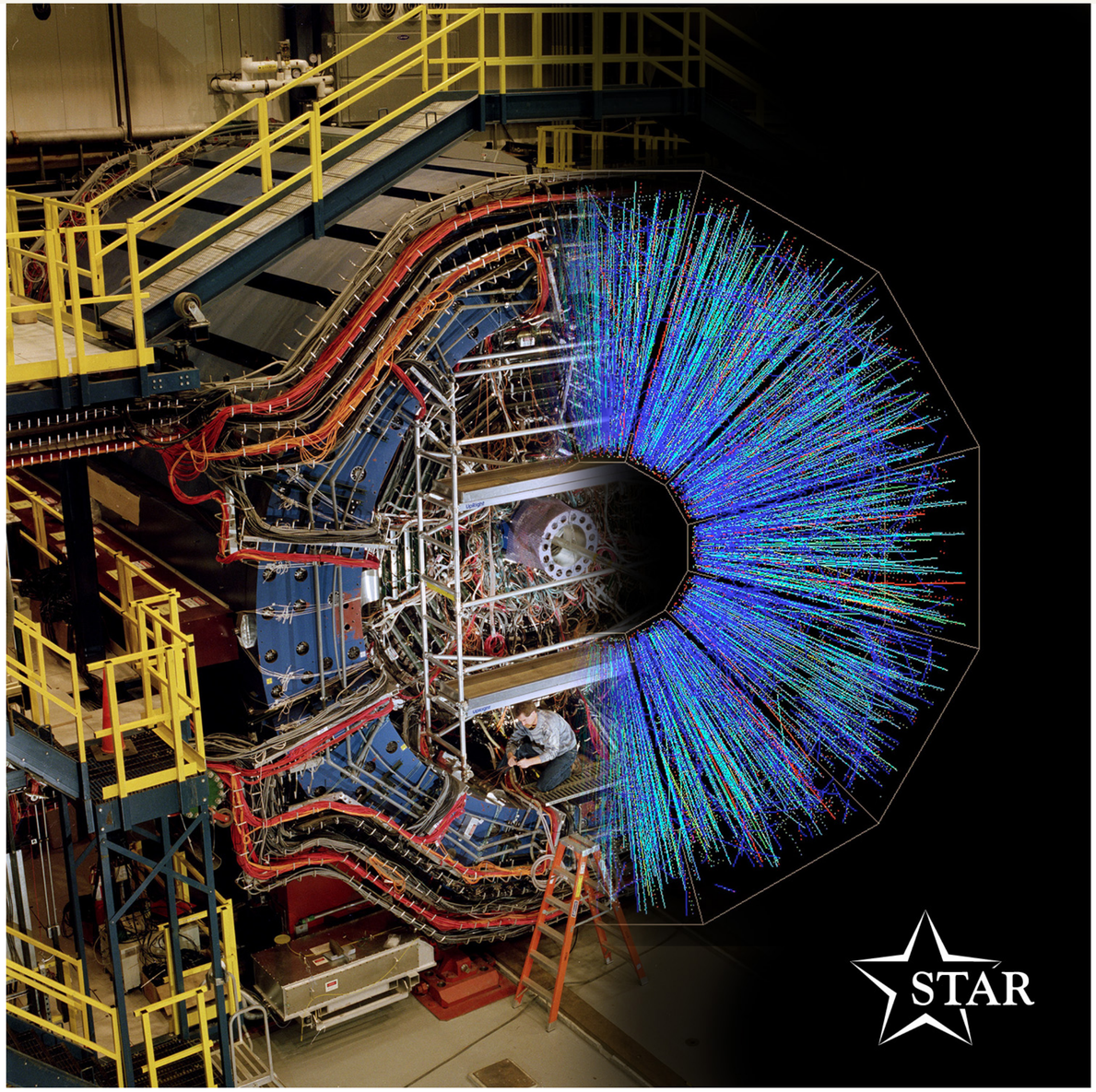


Andronic et al. Phys.Lett.B 697 203 (2011)
J. Steinheimer et al. Phys.Lett.B 714 85 (2012)

$${}^{4}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{4}_{\Lambda}\mathrm{He} + \pi^- \rightarrow {}^{3}\mathrm{He} + \mathrm{p} + \pi^- + \pi^-$$

Measurement of double-Λ hypernuclei possible at FXT (may reach 5σ significance)

Conclusion:



STAR delivering impactful results across key QCD physics frontiers

Systematic study of QCD phase structure with precision measurements

More exciting results are on the way.

A quarter century of discovery at STAR-RHIC and continuing……

List of STAR Presentations

Parallel Talks:

TITLES	PRESENTER	DAY/SESSION (with LINK)
1. Strange hadron production in different collision systems at sNN = 200 GeV at STAR Beam Energy Scan-II at STAR	Iris Ponce	Tue, PI
2. Exploring Strangeness Production across Beam Energies in Au+Au Collisions at STAR	Weiguang Yuan	Tue, PI
3. Measurement of Charge Symmetry Breaking in A = 4 hypernuclei in sNN = GeV Au+Au collisions at RHIC	Tianhao Shao	Tue, PI
4. Production of Unstable Light Nuclei in Au+Au Collisions at sNN = GeV with the STAR Detector	Chenlu Hu	Tue, PI
5. Light hadron production measurements with Au+Au Collisions from sNN = 3.2 -4.5 GeV with STAR	Mathias Labonte	Tue, PII
6. Extracting the Speed of Sound from Mean Transverse Momentum Measurements in Au+Au Collisions from RHIC-BESII	Caleb Broodo	Tue, PII
7. Radial Flow of Strange and Multi-strange Hadrons in Heavy-Ion Collisions at RHIC–STAR	Yuli Kong	Tue, PII
8. Collision Energy and System Size Dependent Radial Flow Fluctuations at RHIC	Zaining Wang	Tue, PII
9. Measurement of thermal dielectron production in O+O collisions at sNN = 200 GeV with the STAR experiment	Zihan Liu	Tue, PIII
10. Hyperon Spin Observables in Au+Au Collisions at RHIC BES-II: Global and Local Polarization, Spin Correlations	Tong Fu	Tue, PIV
11. Differential measurements of phi-meson global spin alignment and off-diagonal spin density matrix elements in Au+Au	Zhenyu Ye	Tue, PIV
12. Measurements of Local Polarization of Hyperons with Event Shape Engineering in Au+Au collisions at RHIC-STAR	Taiki Kondo	Tue, PIV
13. Non-Monotonicity of pT Correlations in Au + Au Collisions at RHIC	Rutik Manikandhan	Tue, PV
14. Observation of Strong Directed Flow for phi meson in High Baryon Density Region at RHIC	Guangyu Zheng	Tue, PV
15. Third-body-corrected Two-Pion Femtoscopic Correlations in Au+Au Collisions at high baryon density	Youquan Qi	Tue, PV
16. Measurements of p-Xi Correlation Functions in Au+Au Collisions from STAR Beam Energy Scan II	Jing An	Tue, PVI
17. p-p-Lambda Correlation in 3 GeV Au+Au Collisions with the STAR Detector	Jing Gu	Tue, PVII
18. Observation of a Strange Muonic Atom and Its Antimatter in Heavy-Ion Collisions at STAR	Zhangbu Xu	Tue, PVIII
19. Exploring System-Size and Energy Dependence of J/Psi production with the STAR experiment	Kaifeng Shen	Wed, PII
20. Fluctuations and Correlations of Conserved Charges in Isobar Collisions at sNN = 200 GeV with STAR Detector	Hanwen Feng	Wed, PVI
21. Measurement of coherent J/ψ and K^+K^– photoproduction in UPCs at = 200 GeV with STAR experiment	Zengzhi Li	Wed, PI

List of STAR Presentations

Posters:

TITLES	PRESENTER	DAY/SESSION (with LINK)
1. Search for dark photons in pi0/eta Dalitz decays with the STAR detector	Kaifeng Shen	Wed
2. Bulk Properties of the medium in Ru+Ru and Zr+Zr Collisions at sNN = 200 GeV with STAR detector	Chun Yuen Tsang	Wed
3. J/Psi production as a function of event activity in p+p collisions at s = 500 GeV at STAR	Brennan Schaefer	Wed
4. Accessing the shape of cluster pattern in O+ O and d+Au collisions from STAR experiment	Zaining Wang	Wed
5. Anisotropic Flow of Identified Hadrons in O+O Collisions at sNN = 200 GeV	Santanu Prodhan	Wed
6. Study of charge and baryon transport in O+O and Au+Au collisions at sNN = 200 GeV with STAR experiment	Wendi Lu	Wed
7. Search for Exotic Particles in Multi-Prong Central Exclusive Production in pp Collisions at the STAR Experiment	Aranya Giri	Wed
8. Measurement of coherent K+K- photoproduction in Au+Au ultra-peripheral collisions at sNN = 200 with the STAR	Luobing Wang	Wed
9. π/K/p/ϕ flow in O+O and d+Au collisions	Souvik Paul	Wed
10. Engineering the shapes of quark-gluon plasma droplets by comparing anisotropic flow in small symmetric and asymmetric collision systems	Chunjian Zhang	Wed
11. The underlying event and global event-structure observables in p+p collisions at STAR	Oliver Matonoha	Wed

Thanks!

SQM organizers and participants for your attention.

STAR Collaboration