Pre-SQM 2026 Discussions

Higher order fluctuations

Observables:

- Cumulants:

$n =$ ***net-proton/proton multiplicity in an event***

$$C_1 = < n >$$

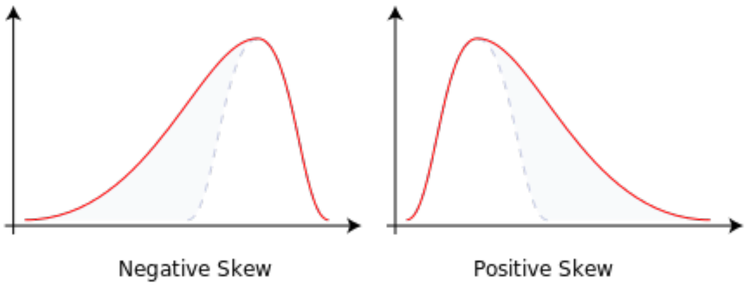
$$C_2 = < \delta n^2 >$$

$$C_3 = < \delta n^3 >$$

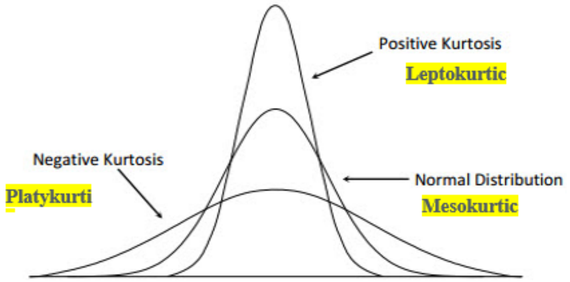
$$C_4 = < \delta n^4 > - 3 < \delta n^2 >$$

$$*\delta n = n - < n >$$

Skewness: Asymmetry



Kurtosis: Peakedness



- Factorial cumulants (irreducible correlation function):

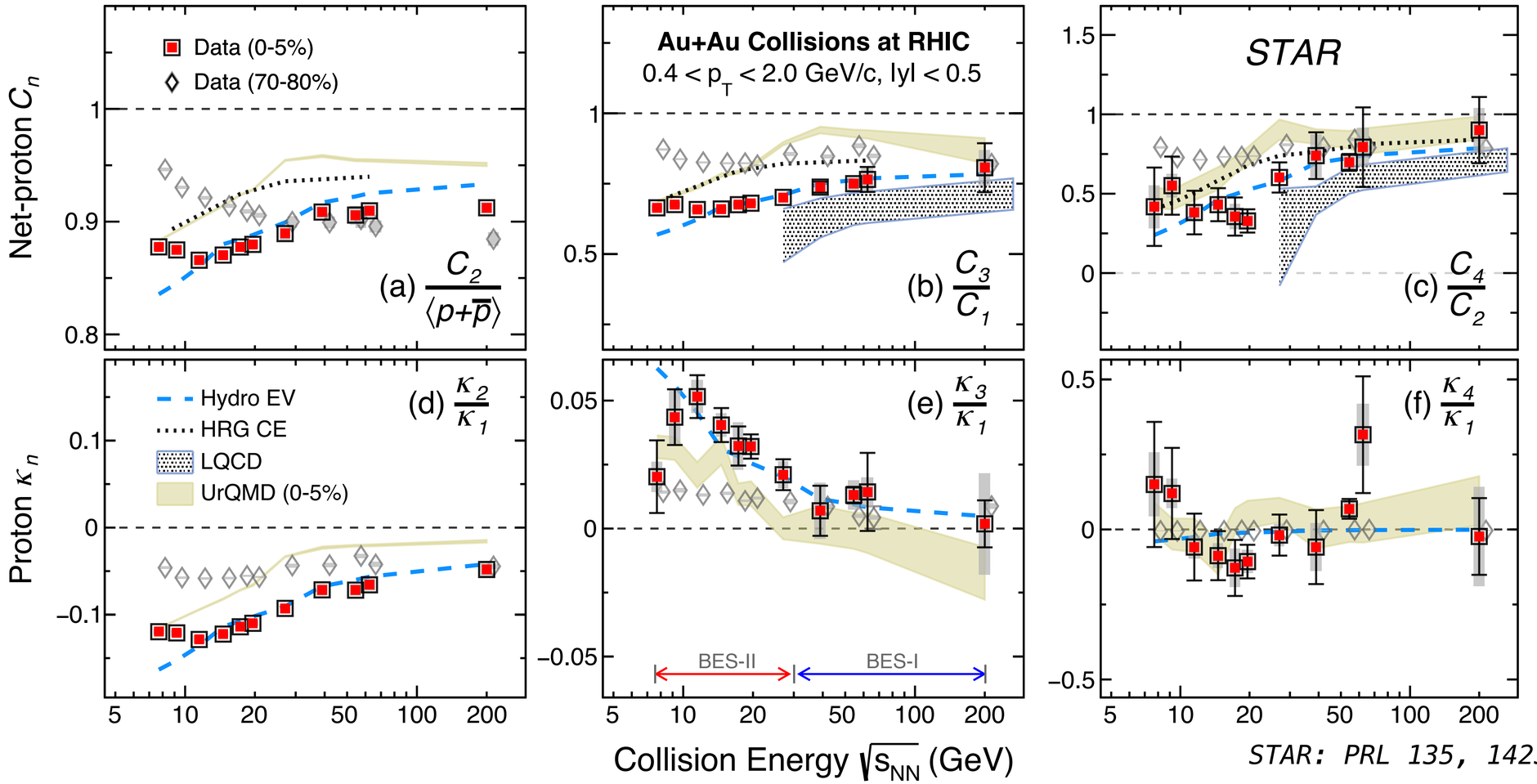
$$\kappa_1 = C_1$$

$$\kappa_2 = - C_1 + C_2$$

$$\kappa_3 = 2C_1 - 3C_2 + C_3$$

$$\kappa_4 = - 6C_1 + 11C_2 - 6C_3 + C_4$$

Energy dependence of Proton Fluctuations



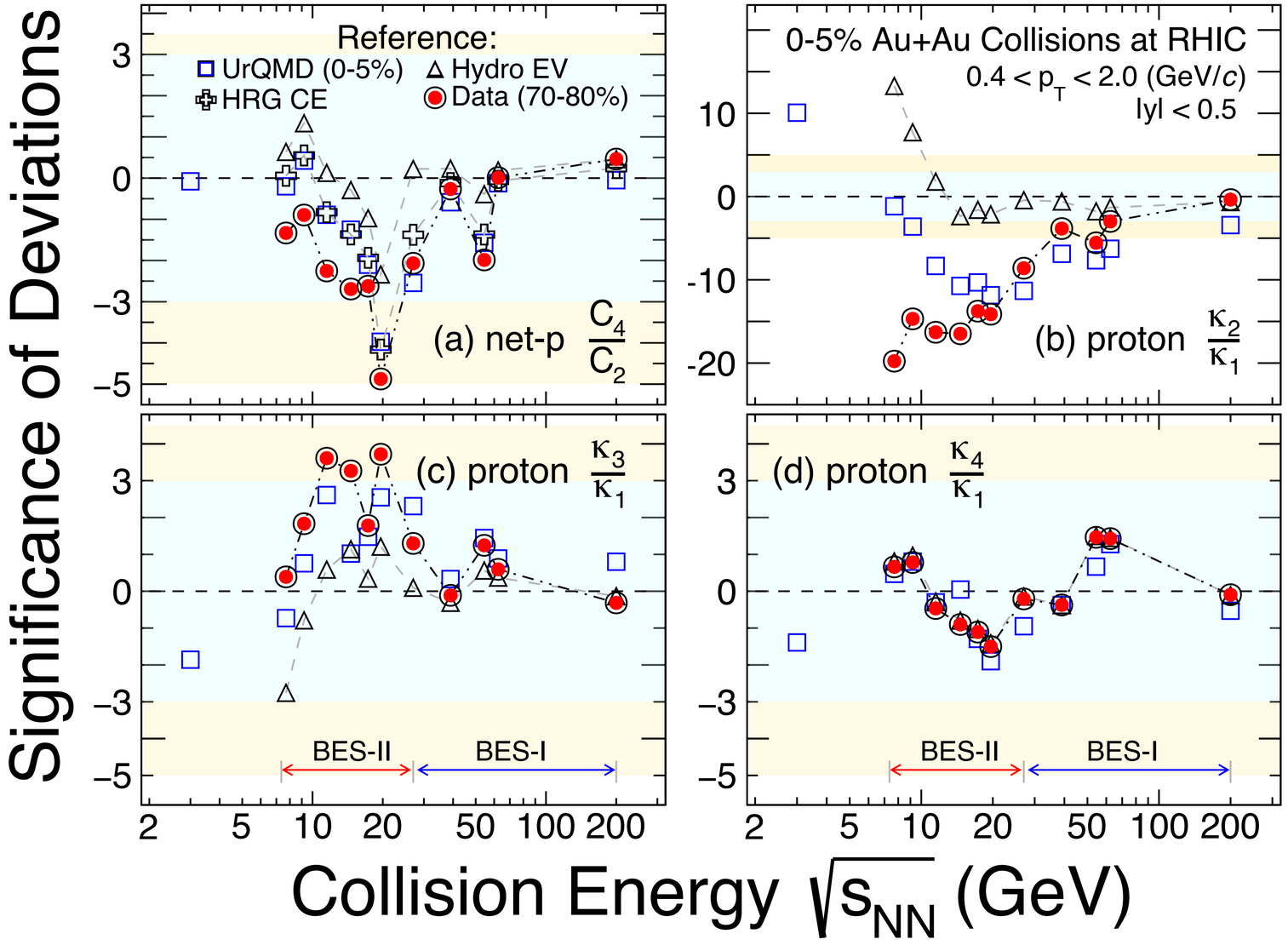
STAR: PRL 135, 142301 (2025)

Deviation between data and non-CP models seen in low collisions energies.

- Change of trends in $C_2/\langle p+\bar{p}\rangle$ and κ_2/κ_1 around $\sqrt{s_{NN}} \sim 10$ GeV. An opposite trend seen for κ_3/κ_1.
- A dip in C_4/C_2 (0-5%) at ~ 20 GeV compared to models.

All non-CP models (HRG, UrQMD, Hydro) are monotonic, do not capture the full energy dependence trends.

Deviations from Non-CP Baselines



Minimum in C4/C2 w.r.t. non-CP models at 2-5σ level ~ 20 GeV - aligns with the feature of the proposed CP signal.

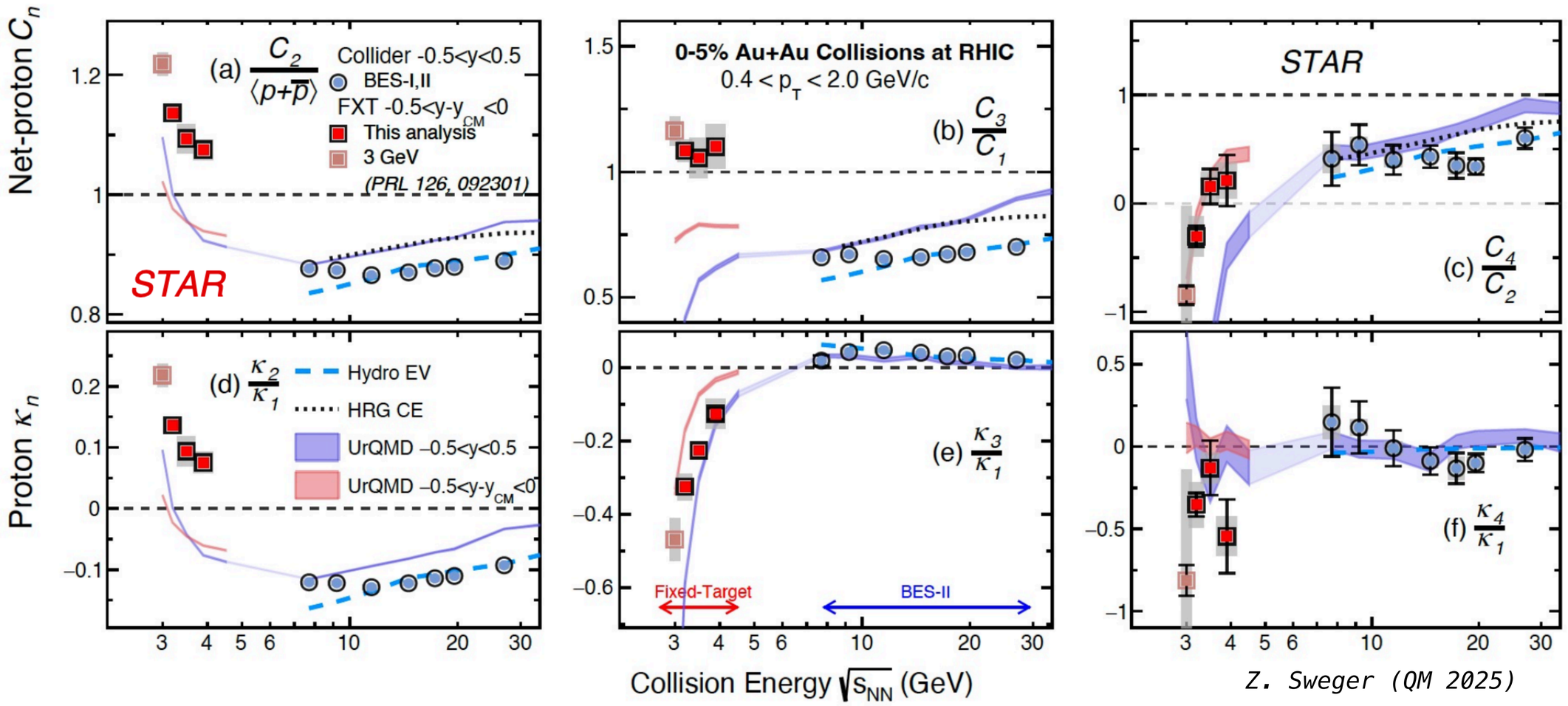
Similar trend seen in κ_4/κ_1, albeit within uncertainties.

Deviation also seen for other lower order ratios around similar collision energy range.

Dynamic models with a CP necessary for quantitive assessment of data.

STAR: PRL 135, 142301 (2025)

Energy dependence of Proton Fluctuations: FXT

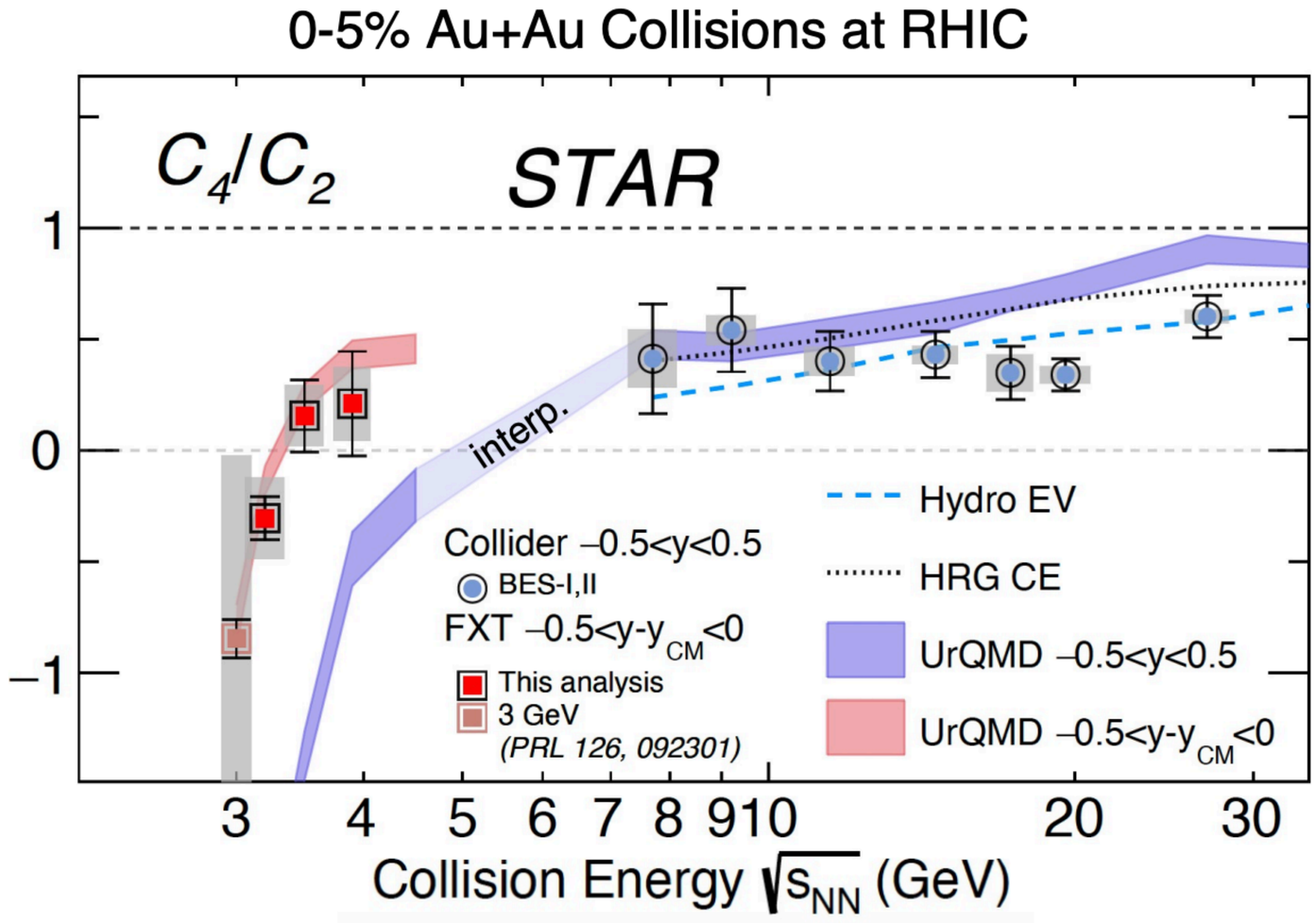


Energy dependence: STAR FXT results at $\sqrt{s_{NN}}$ = 3.2, 3.5, 3.9 GeV

Change in trends in lower order ratios

Kurtosis consistent with hadronic baseline UrQMD

Data from STAR FXT Collisions: C4/C2



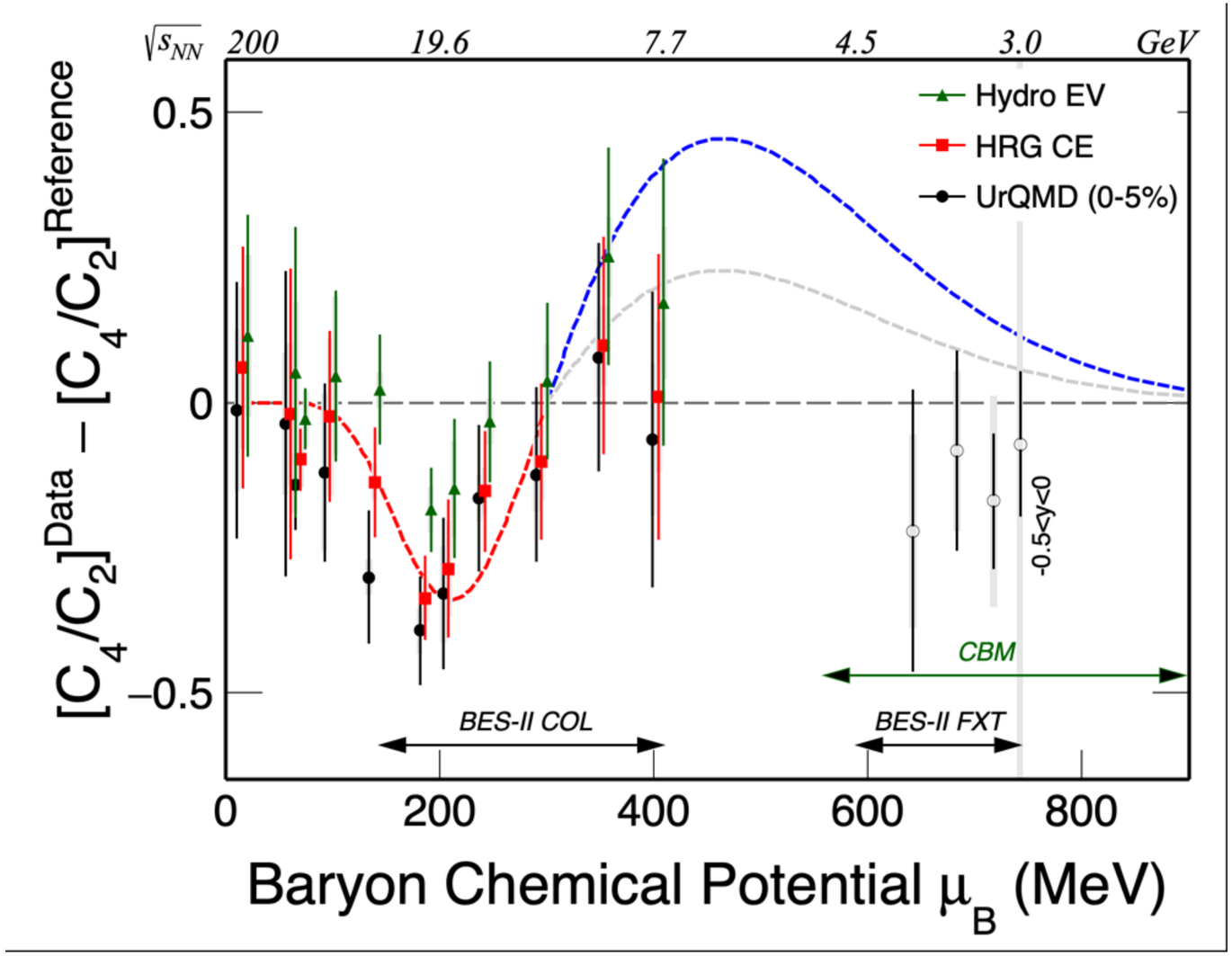
Search for a maximum in data relative to non-CP baseline at $\sqrt{s_{NN}} < 7$ GeV.

STAR FXT results at $\sqrt{s_{NN}} = 3.2, 3.5, 3.9$ GeV consistent with hadronic baseline UrQMD

Analysis at $\sqrt{s_{NN}} = 4.5$ ongoing.

Z. Sweger (STAR): QM25 talk

Deviations from Non-CP Baselines: C4/C2



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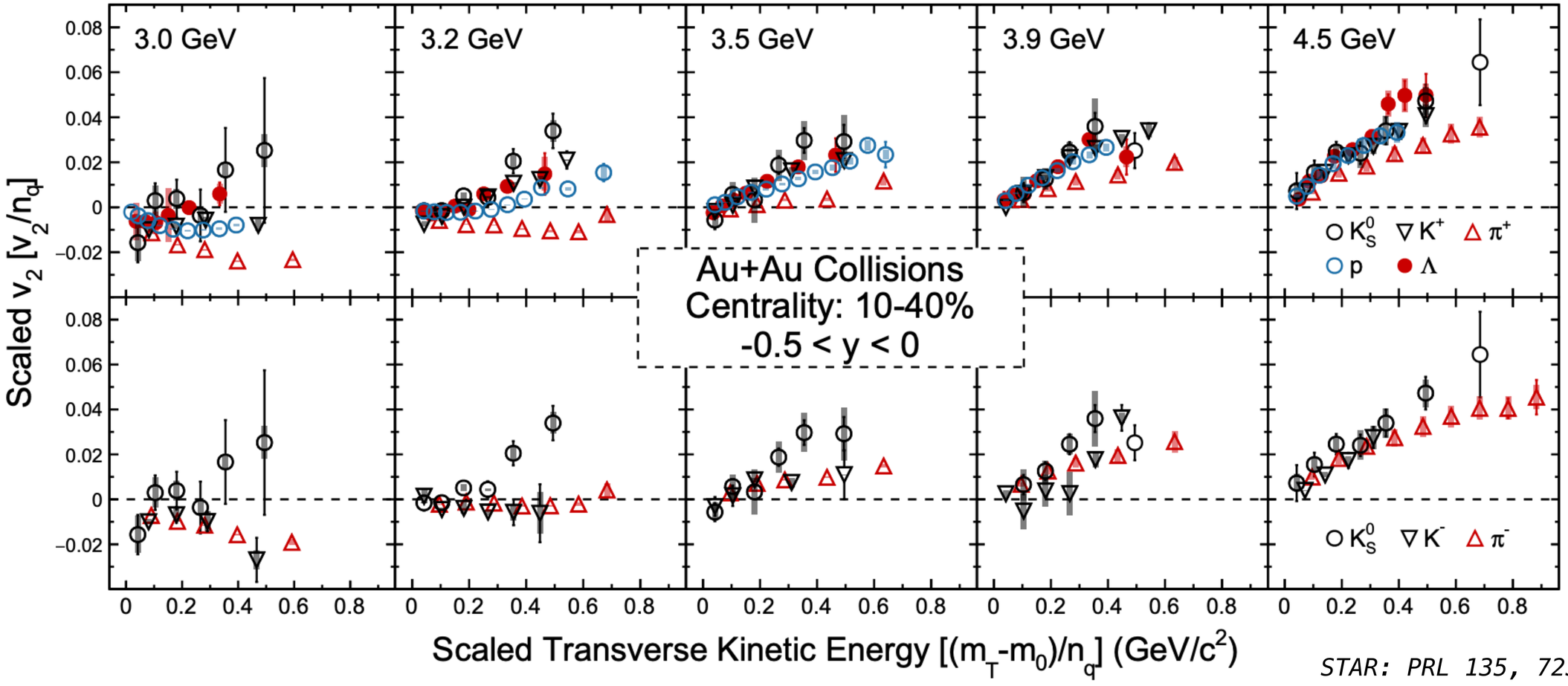
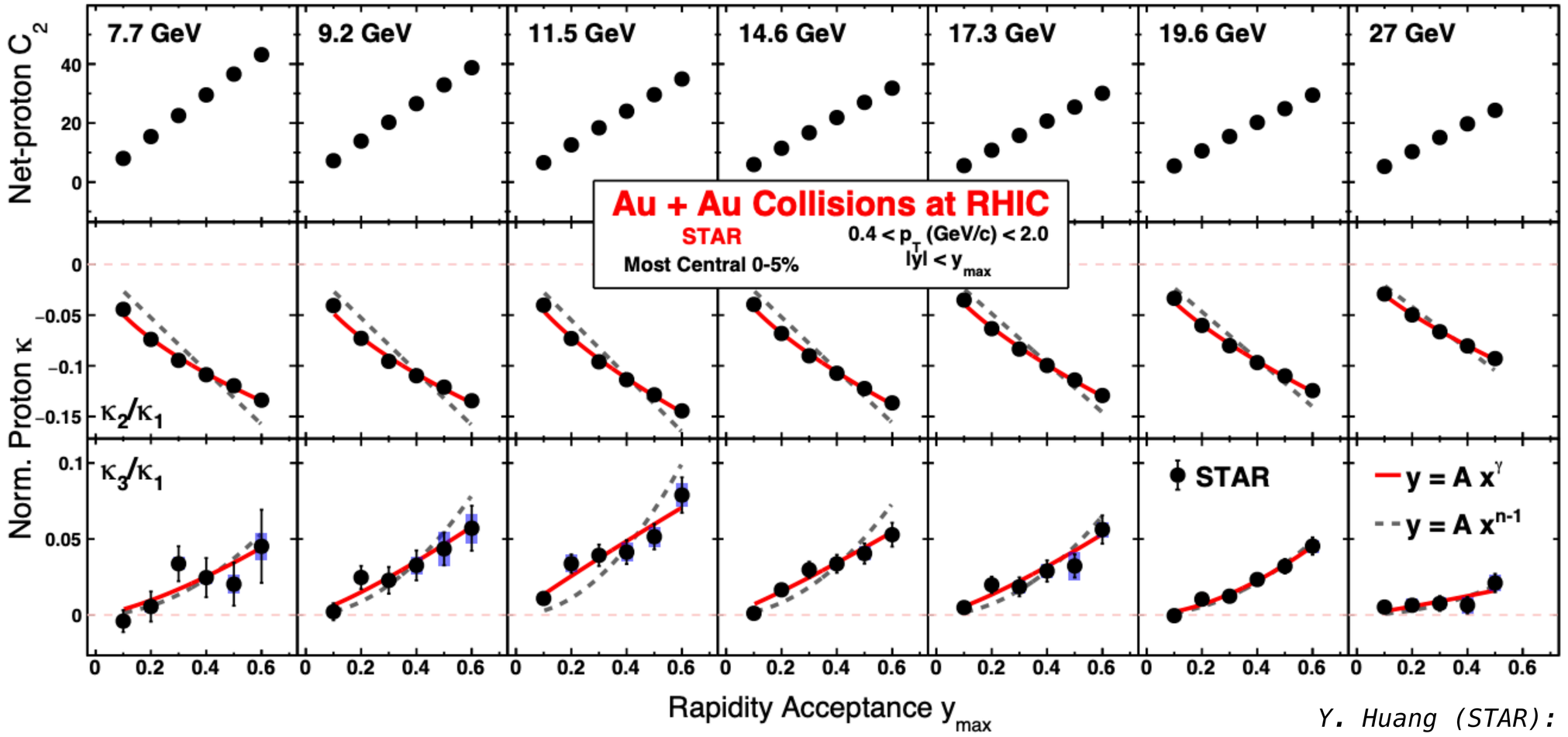
Onset of Deconfinement:



STAR: PRL 135, 72301 (2025)

v_2 measurements at FXT energies indicates restoration of ncq scaling at $\sqrt{s_{NN}}$ ~ 4.5 GeV - possible formation of QGP.

Rapidity Dependence:

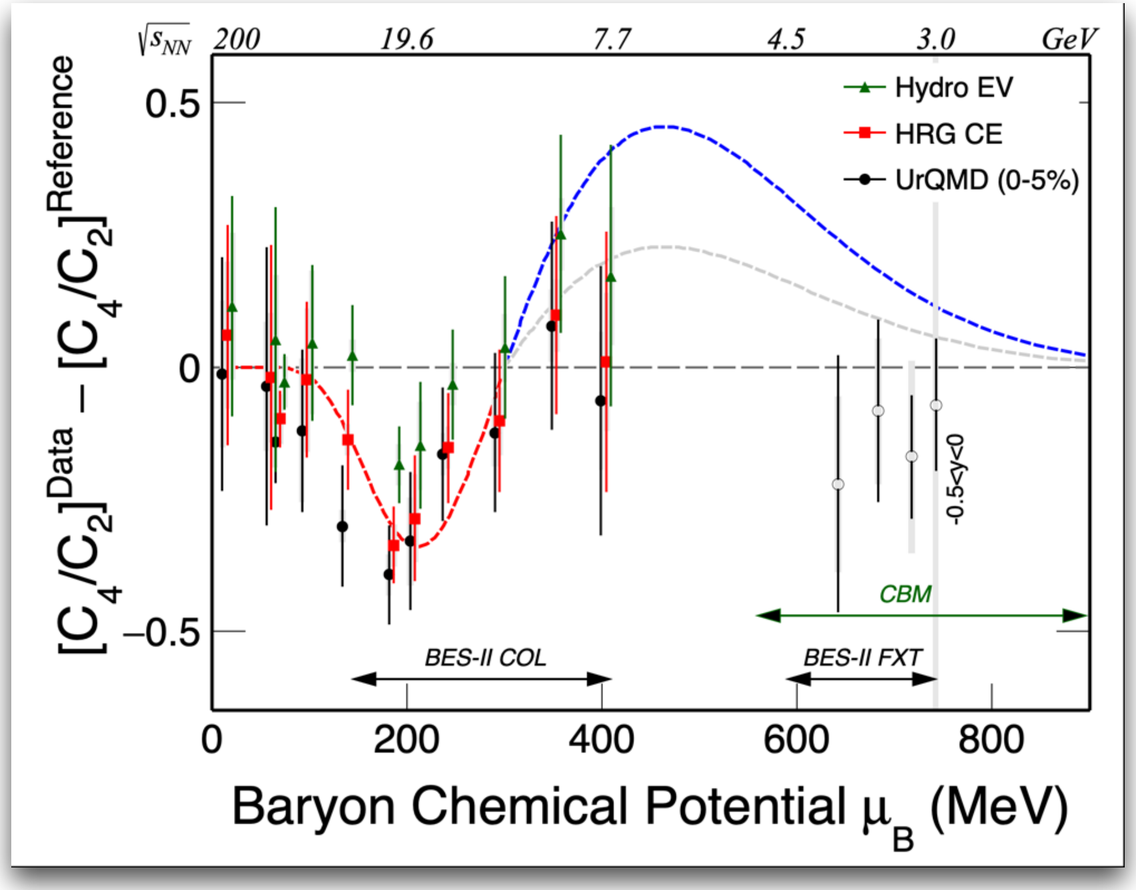


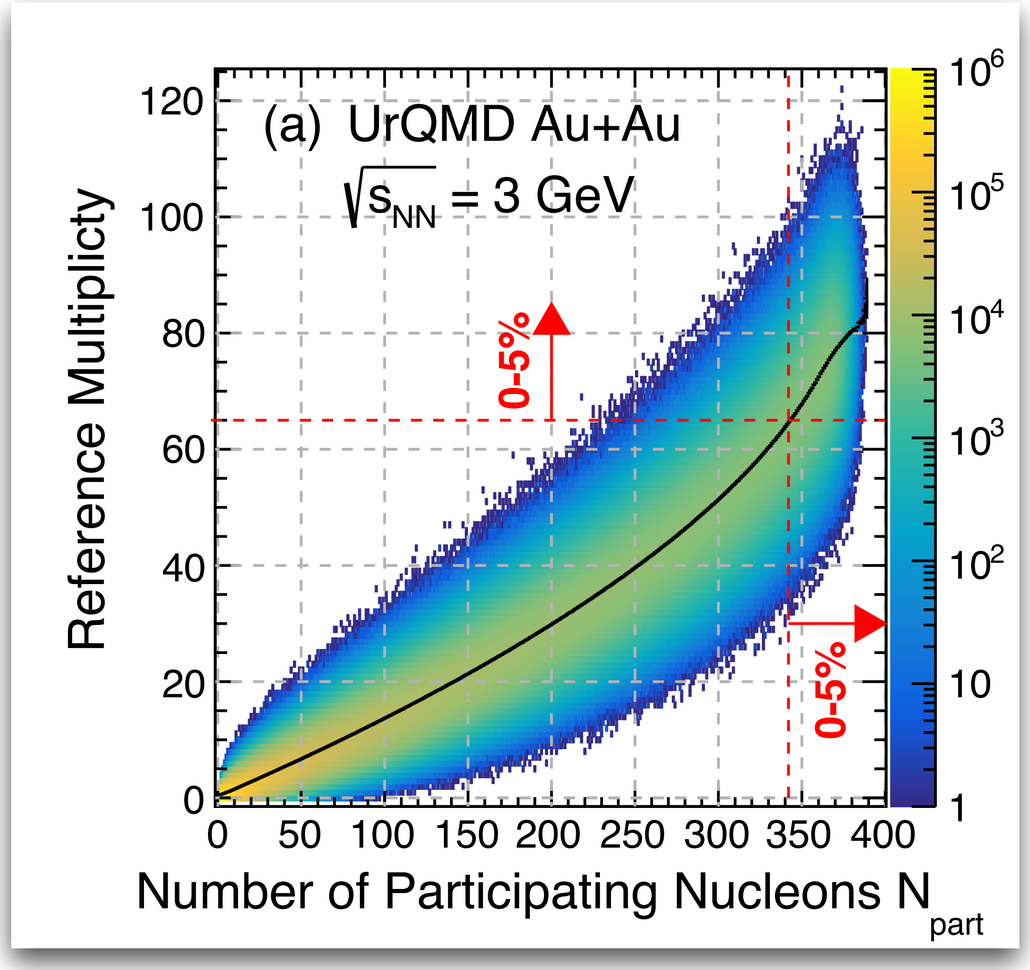
Y. Huang (STAR): QM25 talk

Rapidity dependence studies at collider energies yield smaller exponents than power law trend $\kappa_n/\kappa_1 \sim (\Delta y)^{n-1}$ expected for long-range correlation, such as a CP. *B. Ling, M. Stephanov Phys. Rev. C 93, 034915*

Finite size scaling studies done with 2nd-order cumulant data (as done by Sorensens), yield a critical region of $\mu_B \sim$ 550-650 MeV ($\sim \sqrt{s_{NN}} = 4.5$ GeV). *A.Sorensen and P.Sorensen: arXiv:2405.10278*

OUTLOOK:





-Understanding trend at $\sqrt{s_{NN}}$ = 4.5 GeV crucial. Analysis ongoing with 2020 dataset (19million events)

High statistic data taken this year: FXT data at $\sqrt{s_{NN}}$ = **4.5 GeV (~1B), 4.2 GeV(290M), 5.2 GeV (~370 M)**

-Understanding initial volume fluctuation effect at FXT energy important, new method currently being tested

Summary:

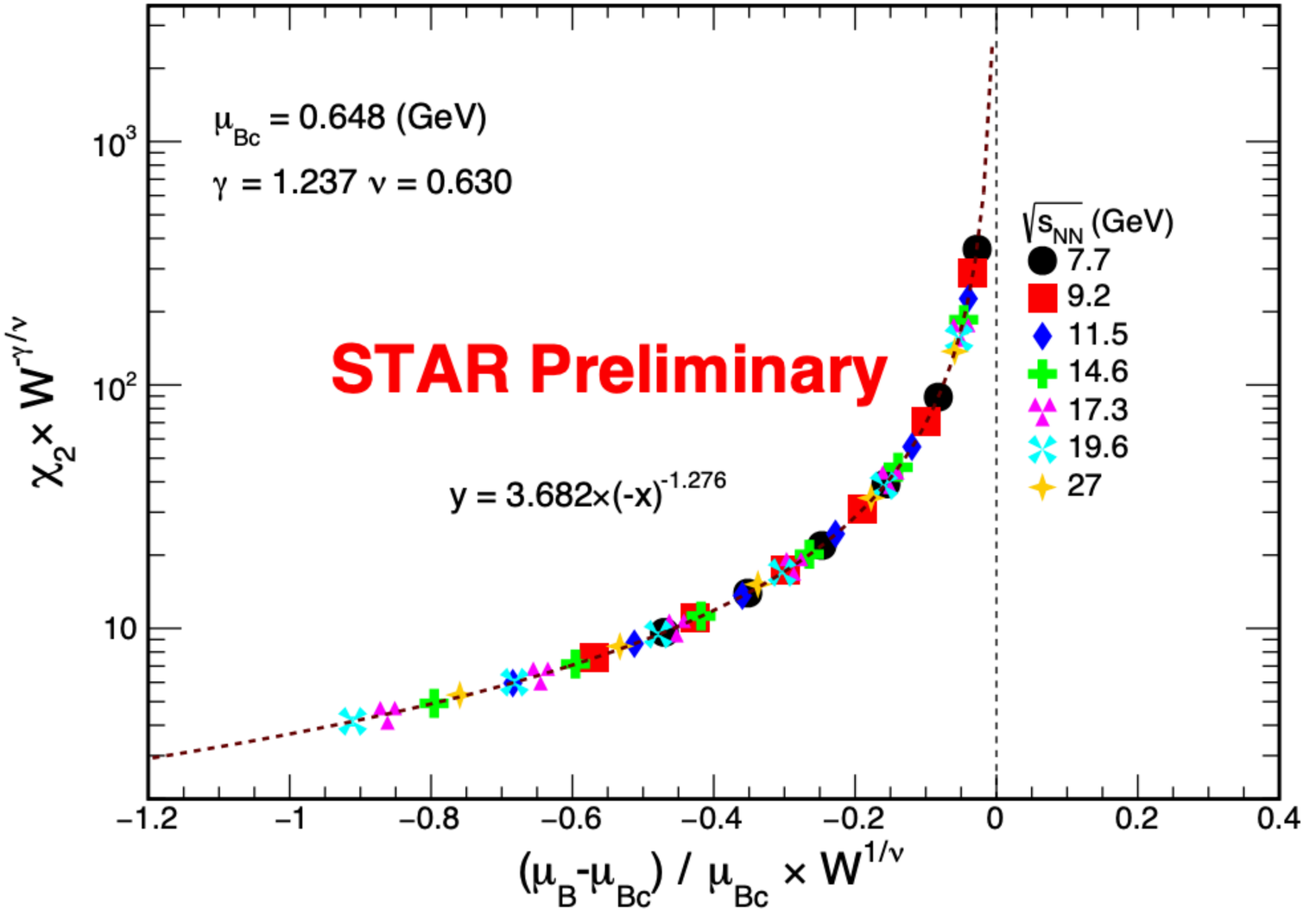
- Precision measurements of proton and net-proton fluctuations from $\sqrt{s_{NN}}$ = 3 - 27 GeV (BES-II). Large improvements seen in centrality resolution; PID; rapidity coverage; higher statistics.

- C4/C2 data shows show a minimum in energy dependence at 19.6 GeV compared to all considered non-CP references, especially with the peripheral data and UrQMD calculations.

- FXT data is being analyzed with a new method to suppress volume fluctuations.

- STAR collected high statistic data at $\sqrt{s_{NN}}$ = 4.2, 4.5, 5.2 GeV. Very important for CP search.

Backup:



1) Susceptibility: $\chi_2(W, \mu_{fo}) = \frac{C_2(W, \mu_{fo})}{T_{fo}^3 W dV_{fo}/dy}$
2) Binder cumulant: $U_4 = -3C_4/C_2^2$
3) Rapidity window size: W
4) Freeze out parameters[1][2]: T, μ, dV/dy
5) Critical exponents[3]: γ, ν
6) Uncertainty: $\sigma = \sqrt{\sigma_{\text{stat.}}^2 + \sigma_{\text{sys.}}^2}$

A.Sorensen and P.Sorensen: arXiv:2405.10278