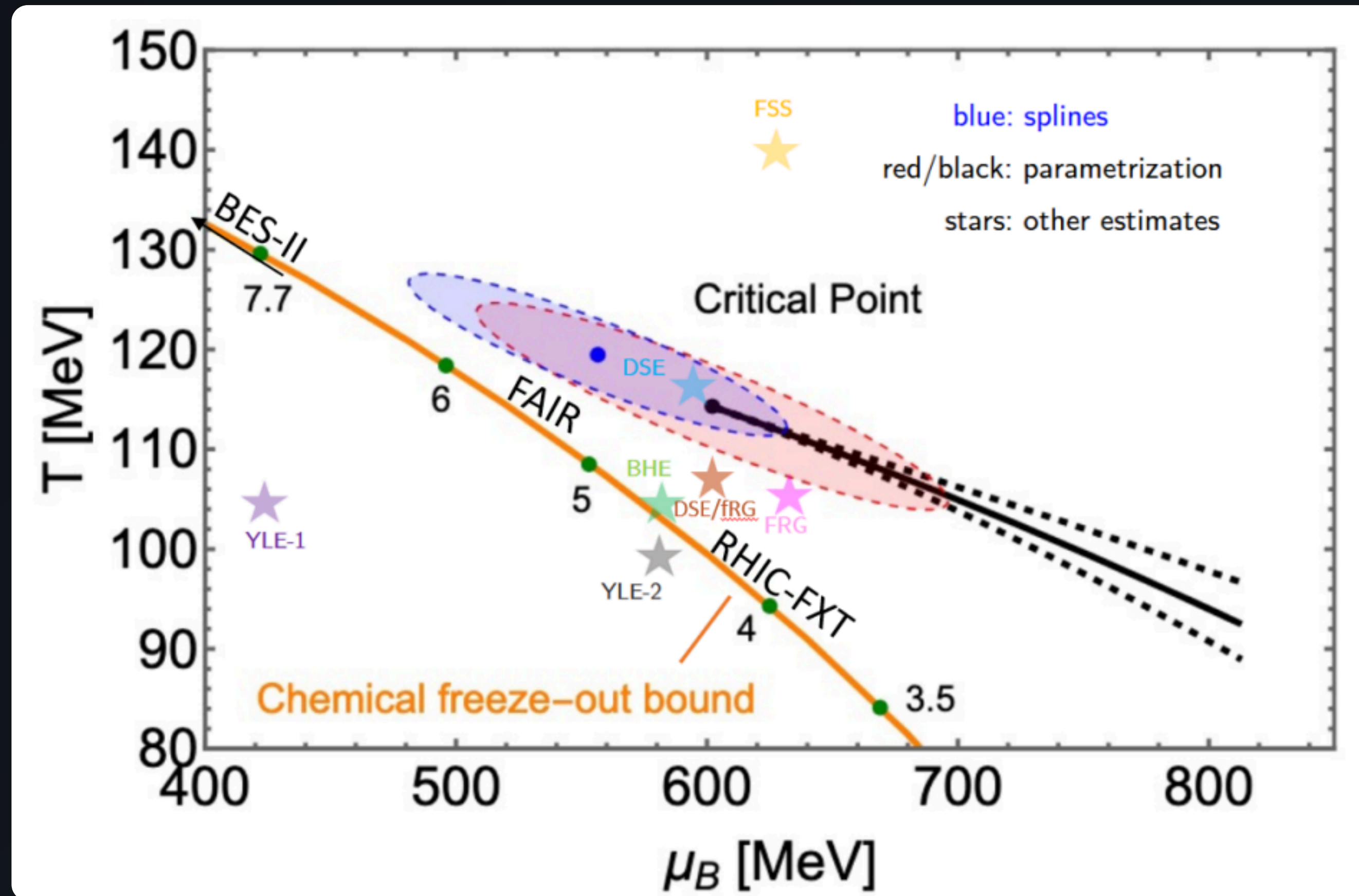


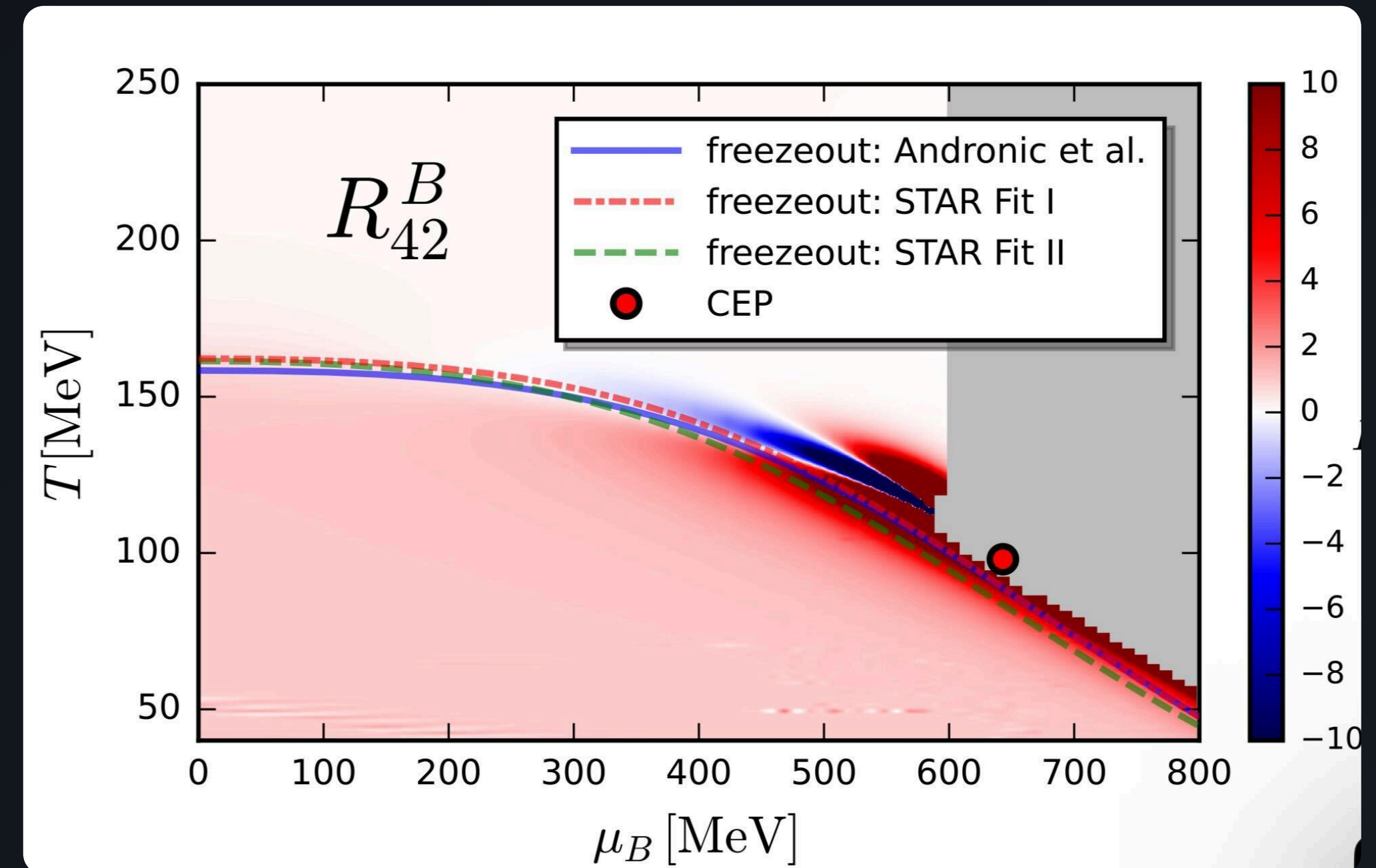
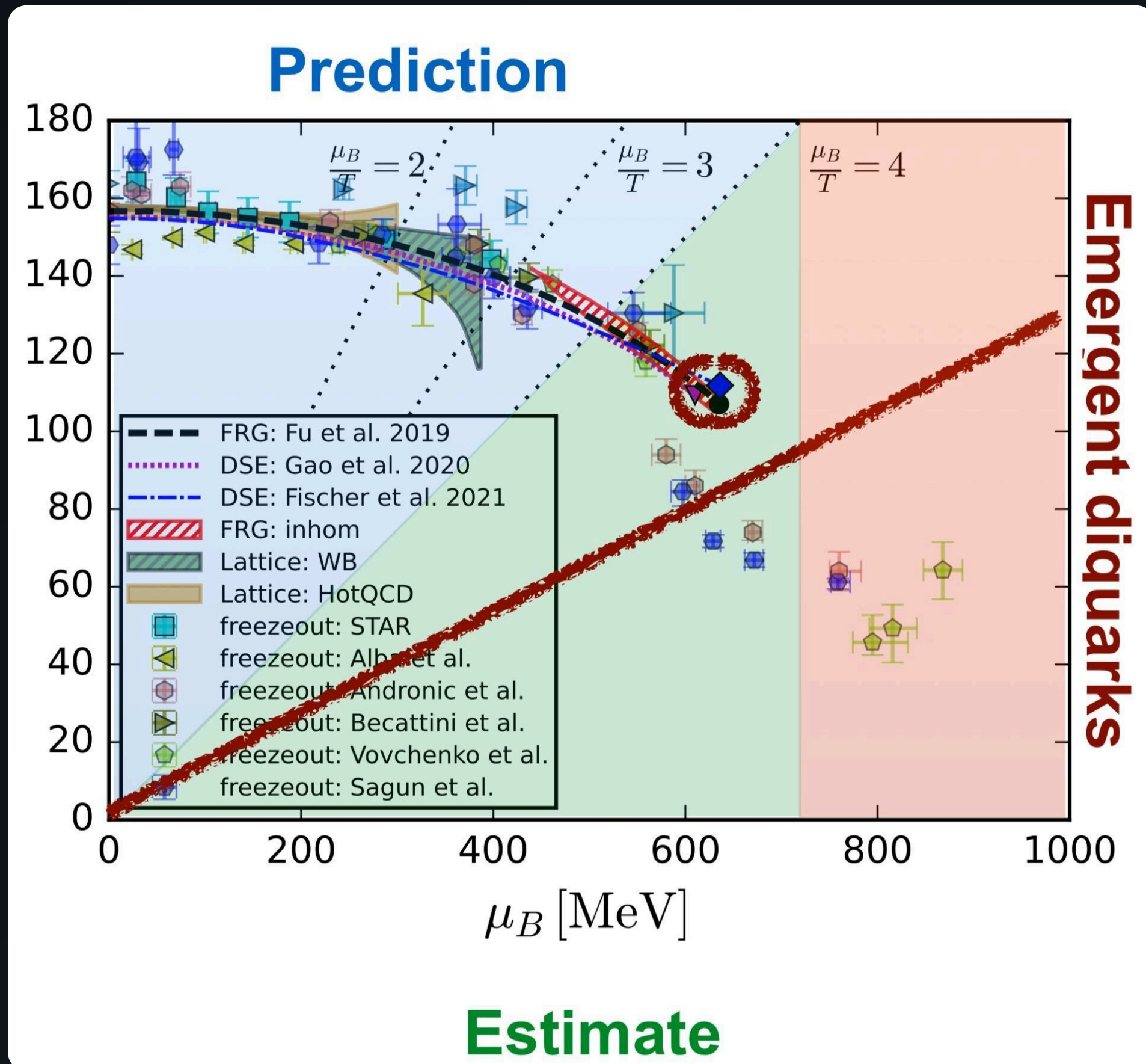
Summary and where to go from here

Critical points from various estimates



- YLE-1 extrapolated to continuum is at $\approx (90, 700)$ MeV
- FSS does not give definite T_c

FRG/DSE

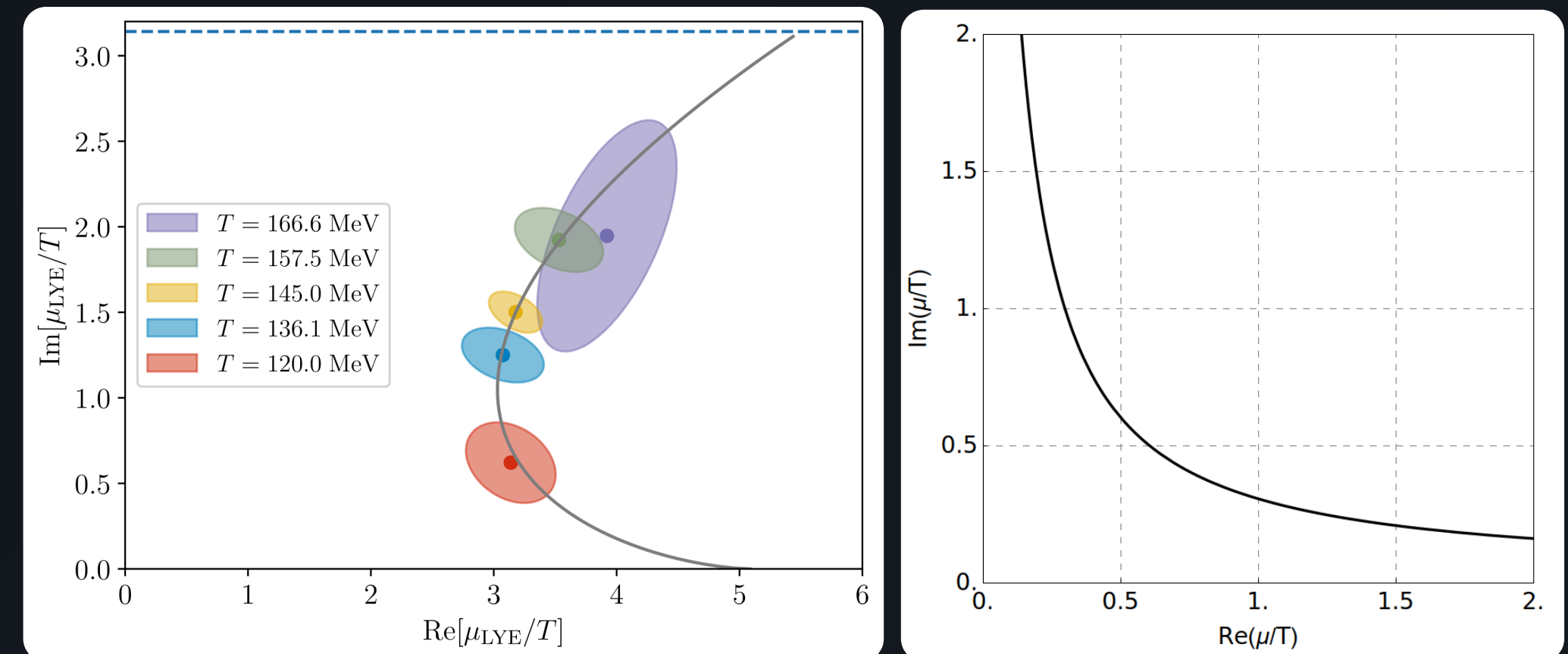
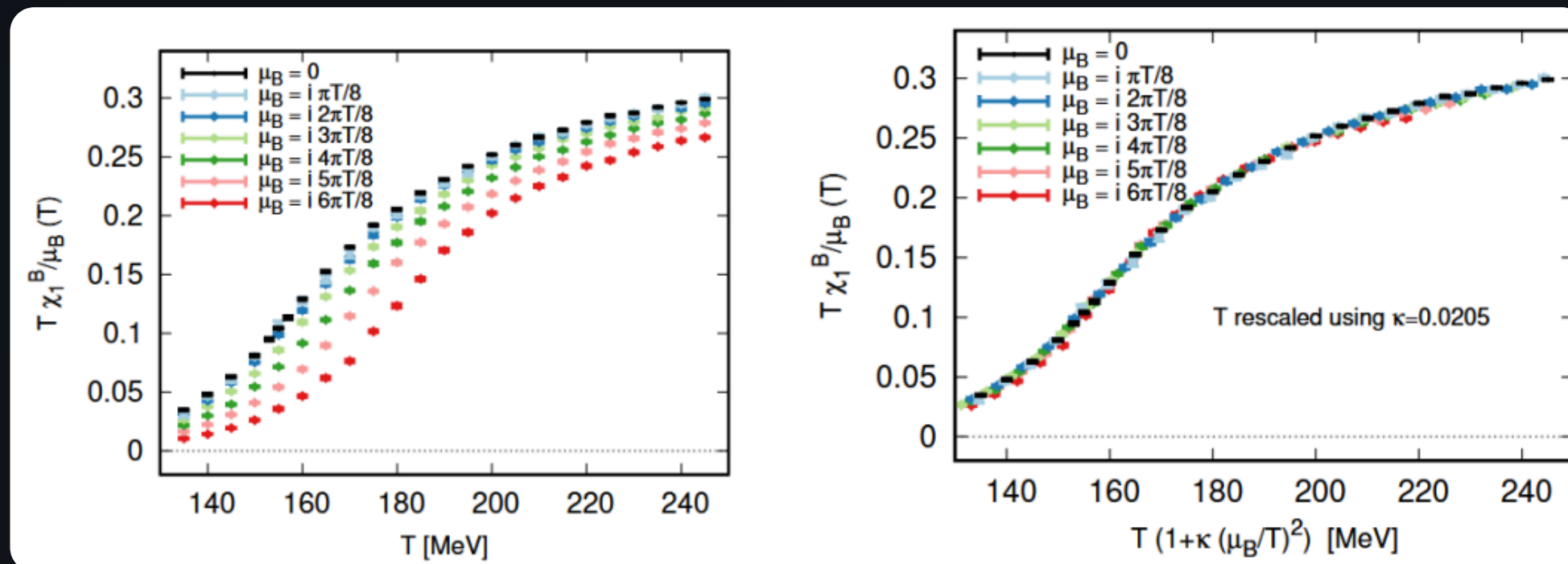


- FRG: estimate $\rightarrow$ prediction?
- Influence of CP extends by 40 MeV in T and 200 MeV in μ

YLE analysis in LQCD

- Most likely suffers from systematic uncertainties
- No clear improvement path without going to lower $T < 120$ MeV and collecting more statistics
- Tension with T' scaling observed in LQCD calculations

T' suggests $\Omega(T, \mu) = \Omega(T')$: applying to YLE, $T \left[1 + \kappa_2 \left(\frac{\mu_c}{T} \right)^2 \right] = T'_c = \text{complex number}$



(Critical) dynamics

Calculations in static equilibrium $\neq$ HIC:

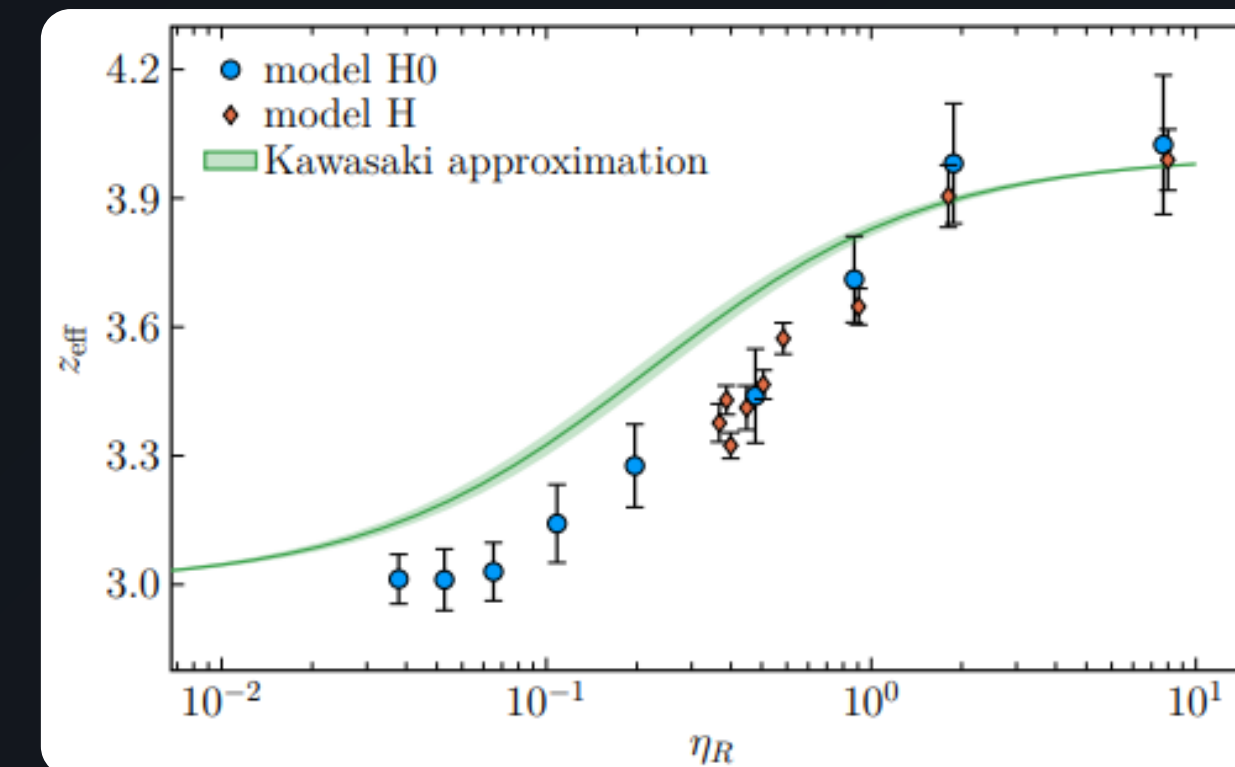
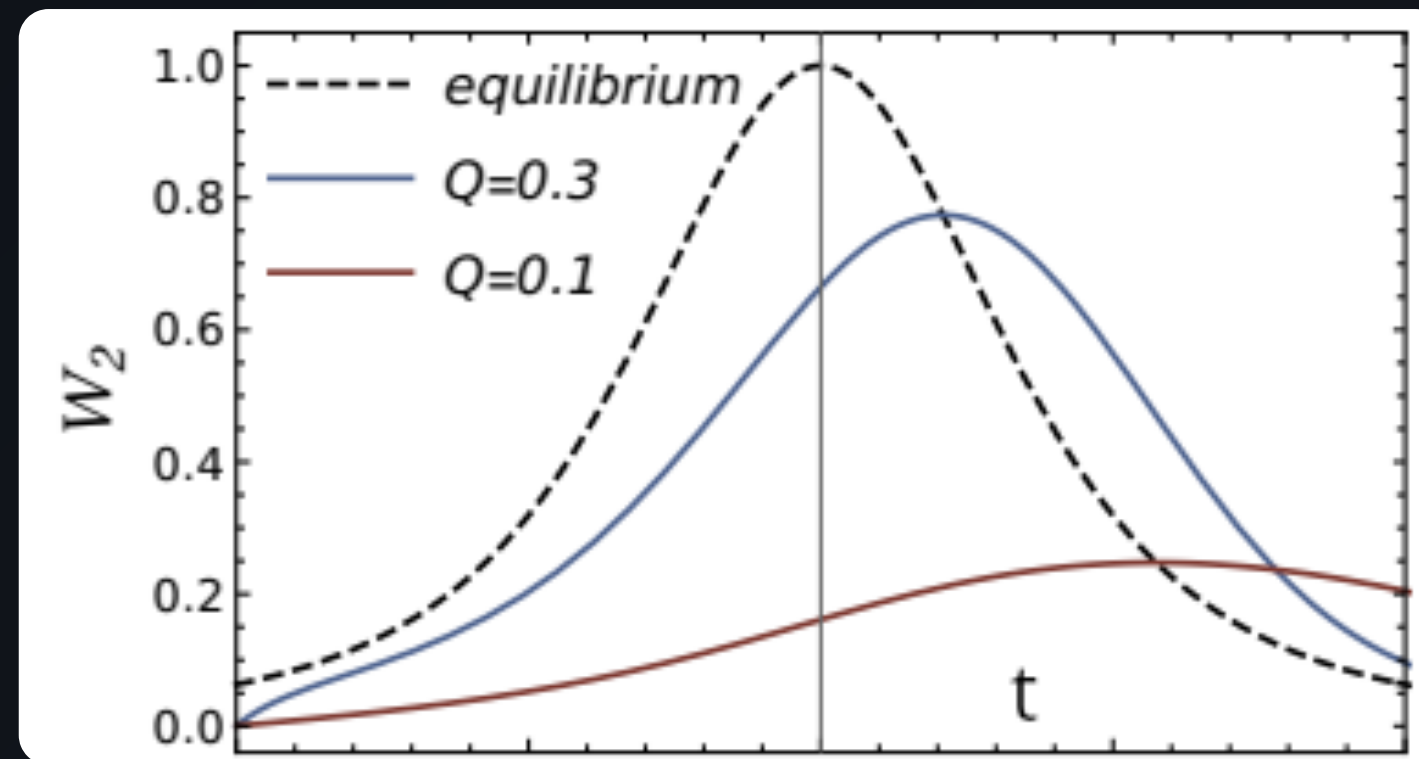
- Finite size effects, rapid expansion.
- Non-equilibrium effects (critical slowing, memory).
- Consistent treatment of fluctuations and dissipation.

Static box simulations of linear size L :

- Equilibration time is of order of $\tau_{eq} \sim L^z$, $z \approx 3$ in model H
- Start from a random initial conditions: location of apparent critical point $\neq T_c$ of static equilibrium

(Critical) dynamics

- There are two approaches to compute thermal fluctuations: Fluctuating hydro and hydro+.



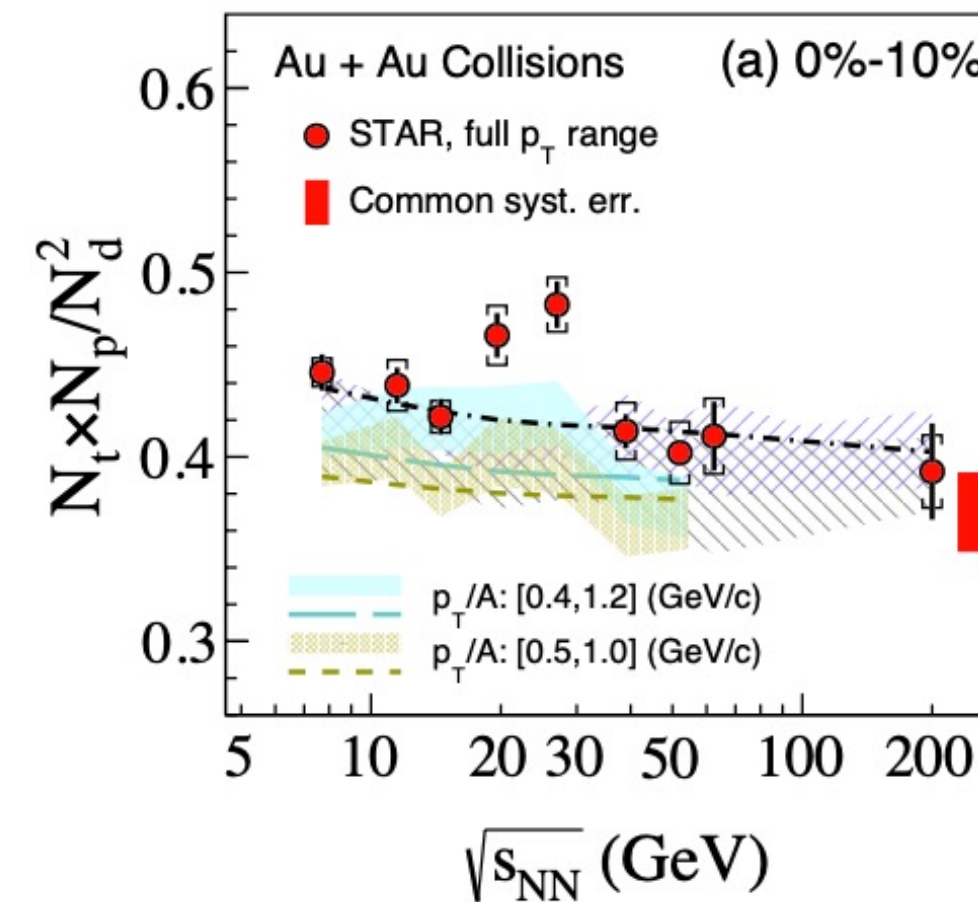
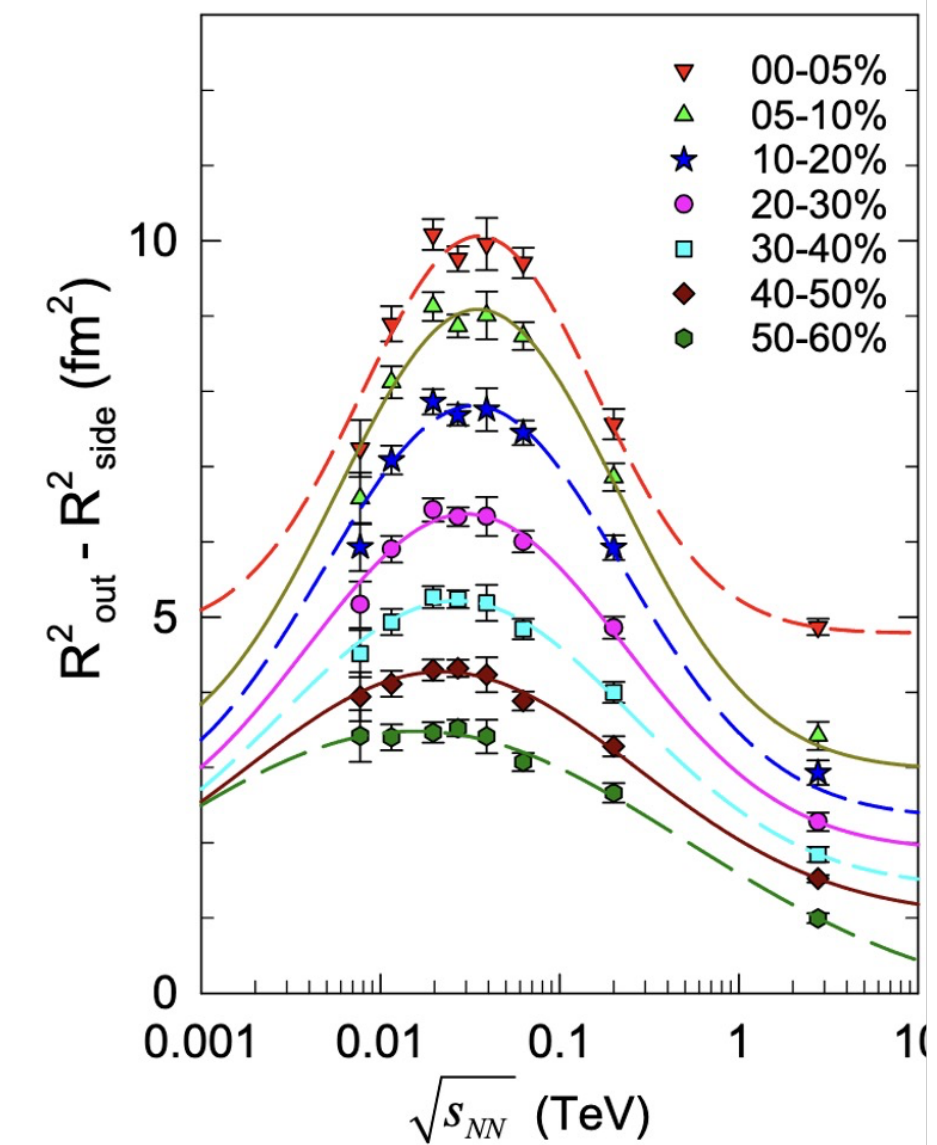
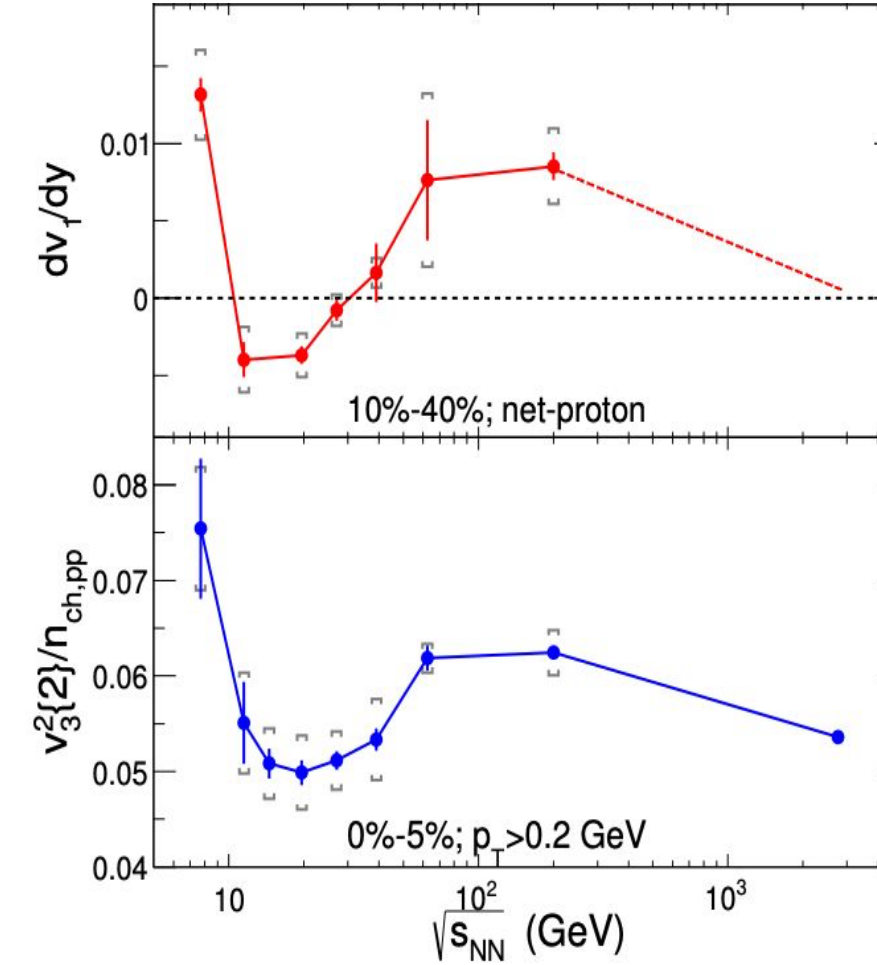
- Significant progress has been made in both directions; however, it is insufficient to quantitatively determine the magnitude of CP effects on observables.

Holes and bumps at ~20 GeV

- Flow $\frac{dv_1}{dy}, \frac{v_3^2}{n_{ch}}$ show minimum

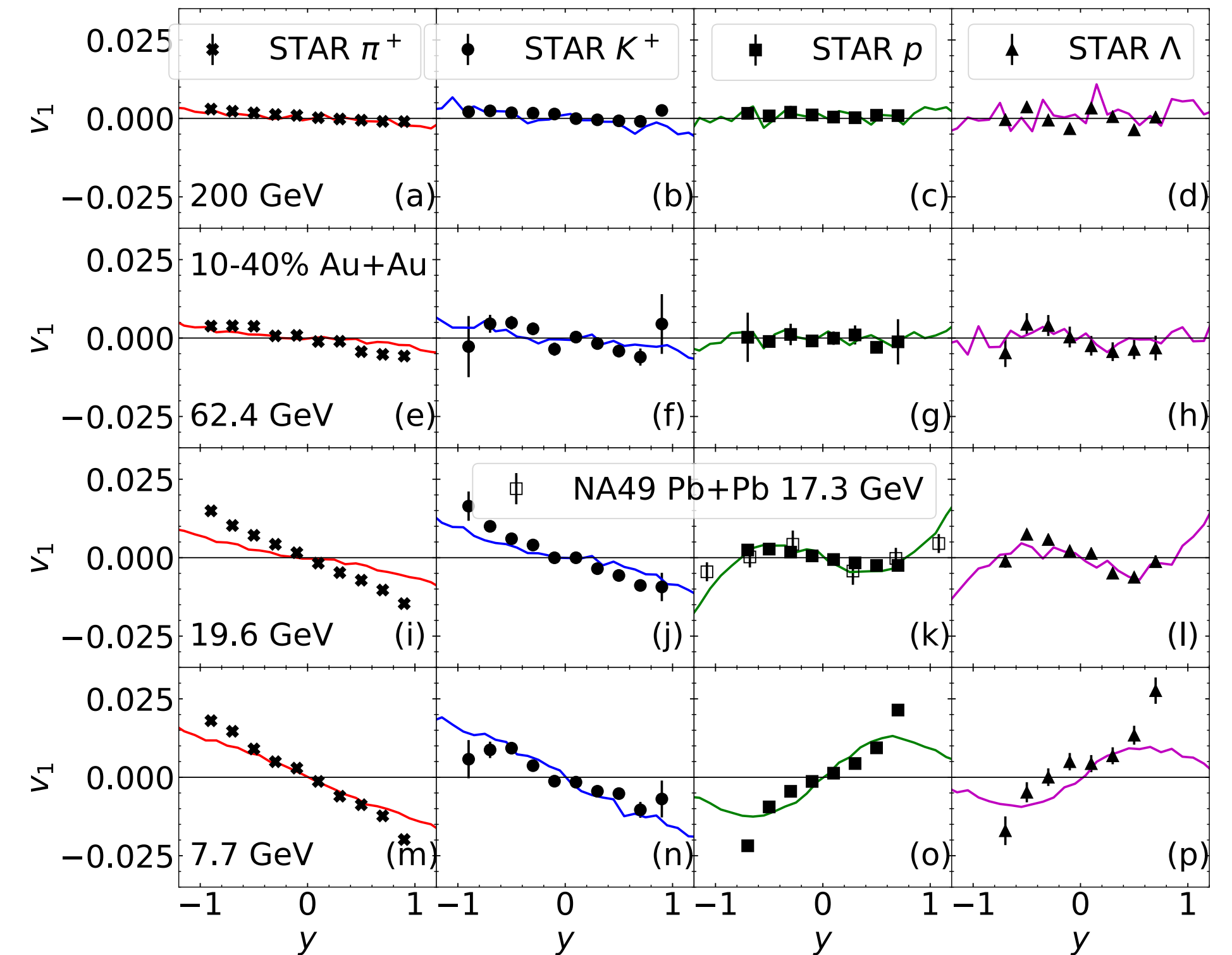
- HBT shows maximum

- Clusters $\frac{tp}{d^2p}$ show peak



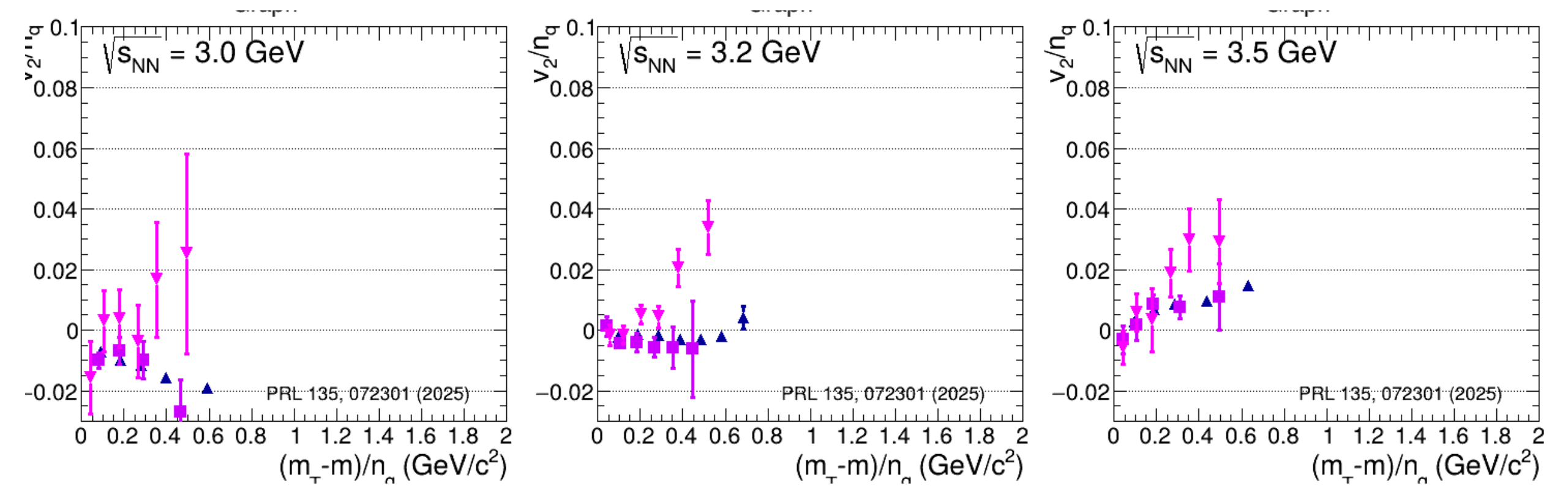
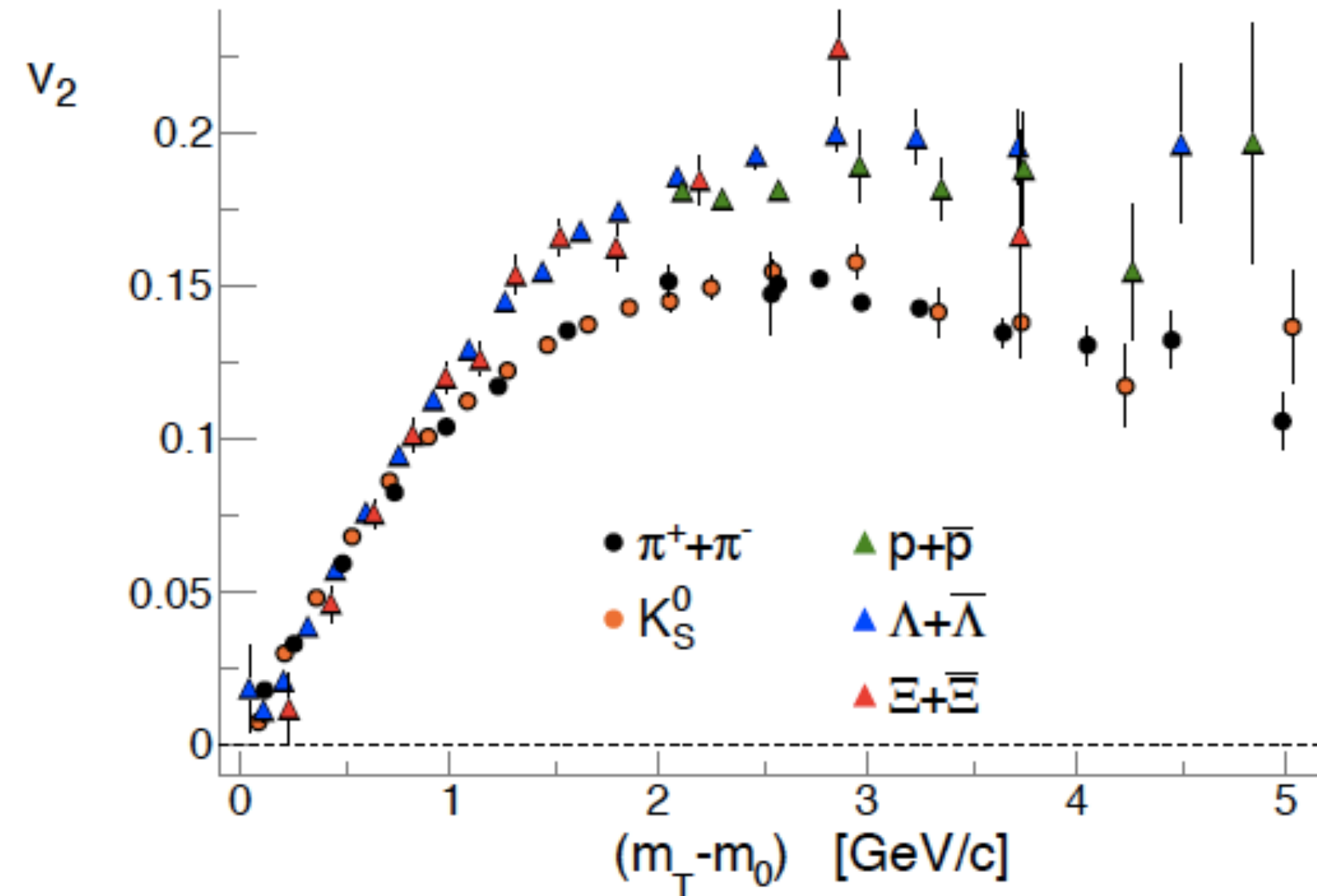
Holes and bumps at ~ 20 GeV

- Energy range is in the “hydro regime”
 - Flow and HBT should come out of hydro
- example: $\frac{dv_1}{dy}$ by Du et al (2211.16408) by guessing at initial conditions / stopping
- Can we do this also for HBT, $\frac{v_3^2}{n_{ch}}$
- Cluster likely beyond hydro
 - Spinodal? Probably not, requires phase co-existence at low μ . Also signal is very weak if phase co-existence is between QM and high density nuclear matter (Steinheimer et al)



But JAM-II also matches the data with a completely different explanation. Most models fail. Is this about baryon transport? Model space needs to be better constrained: data data data.

Quark number scaling



Splitting between baryons and mesons is only at $m_T - m_0 \geq 1$ GeV i.e. intermediate p_T

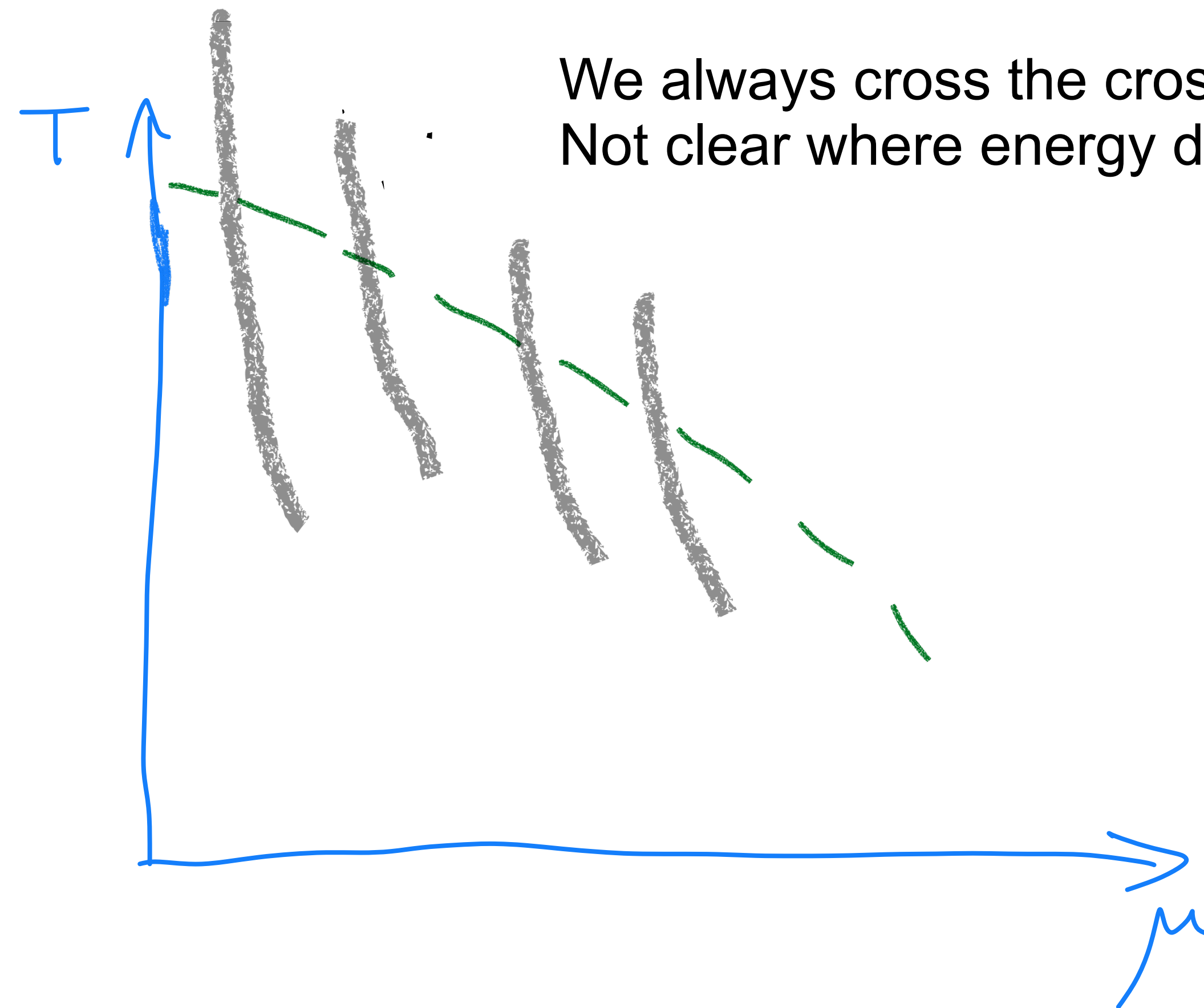
To test coalescence, you must have data in that range for mesons and baryons

Coalescence at all p_T : Problems with entropy!

What is the effect of shadowing from spectators?

Holes and bumps at ~ 20 GeV

Could it be due to the cross over transition?

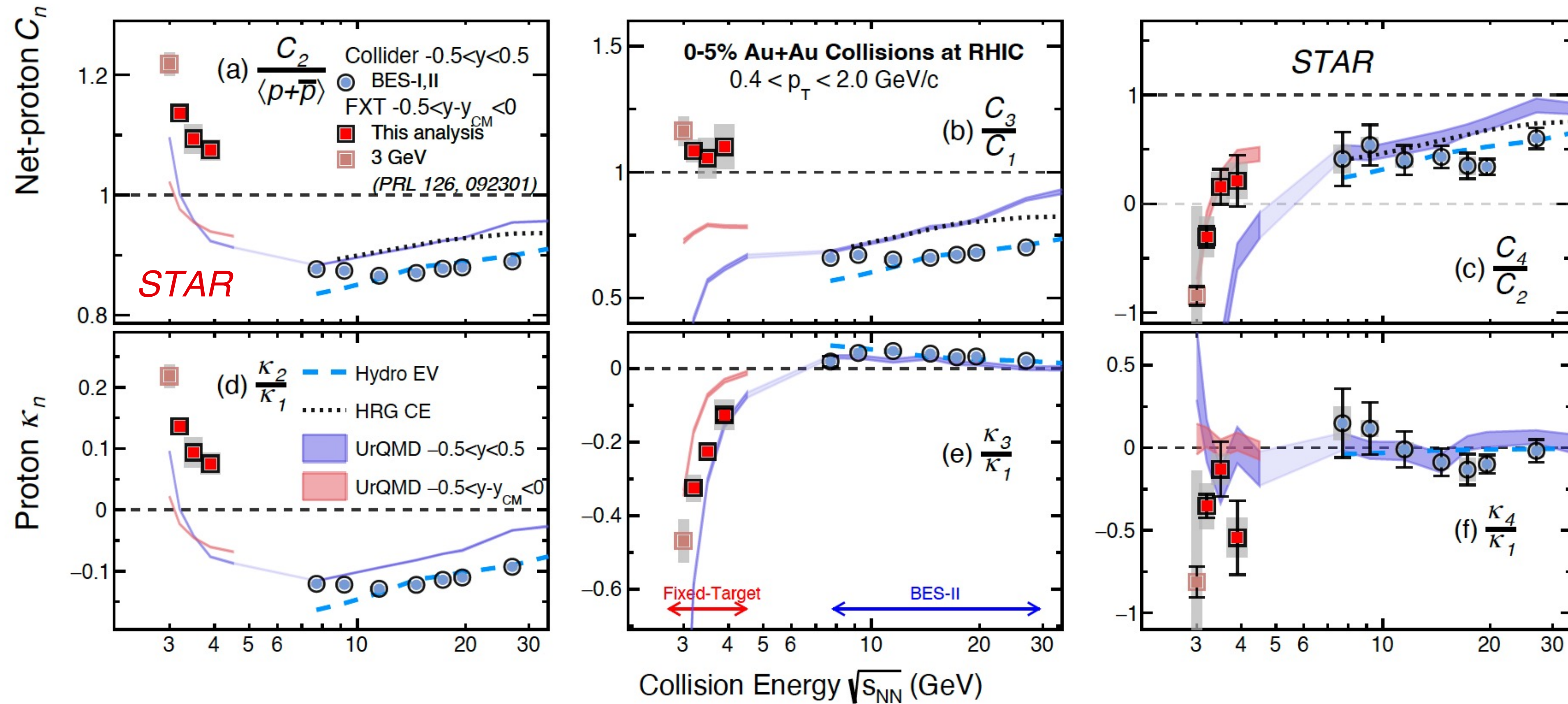


We always cross the cross over line
Not clear where energy dependence should come from?

What make the bumps/holes. Likely not the evolution though crossover

Cumulants

Zachary Sweger (for STAR) QM 2025



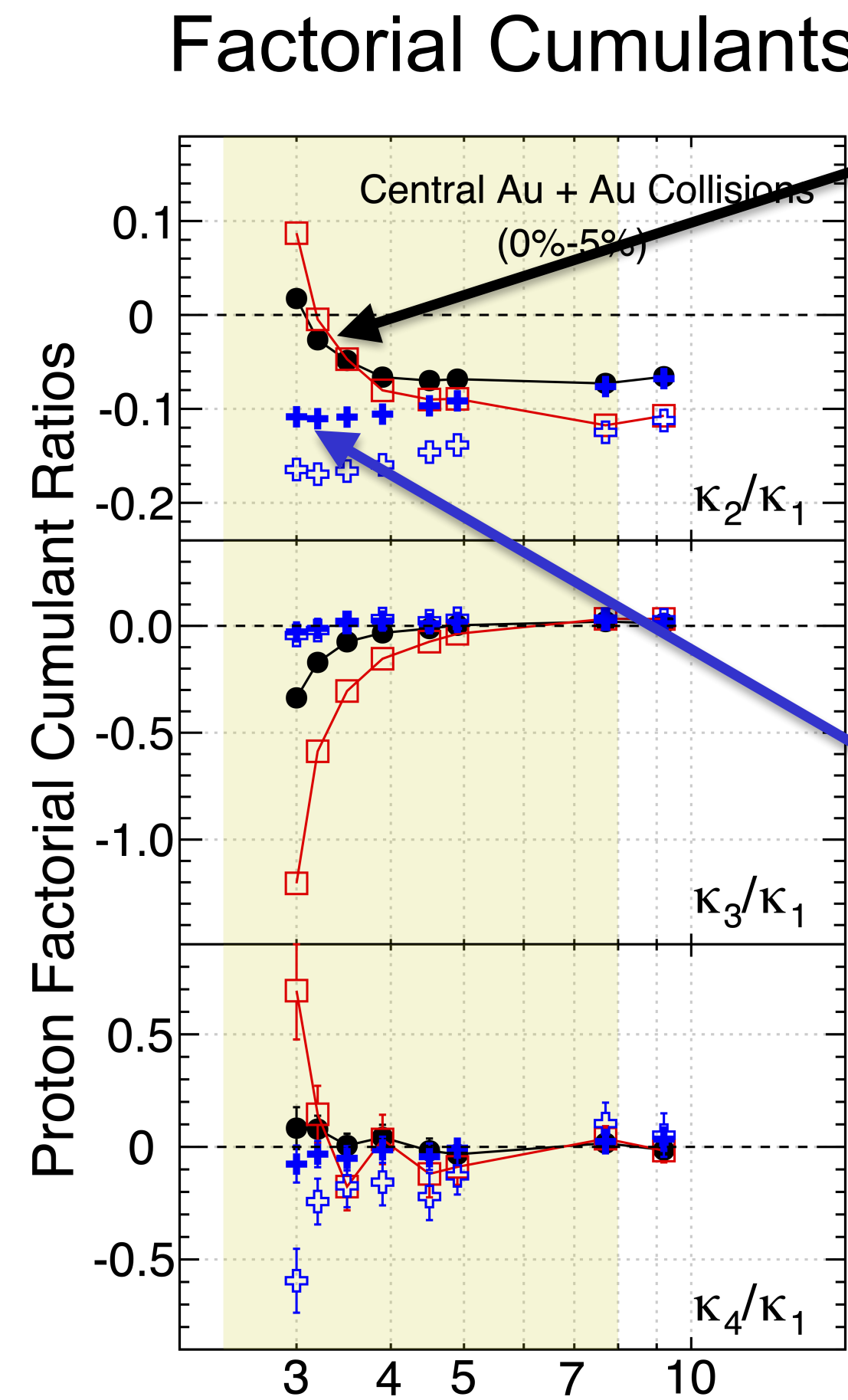
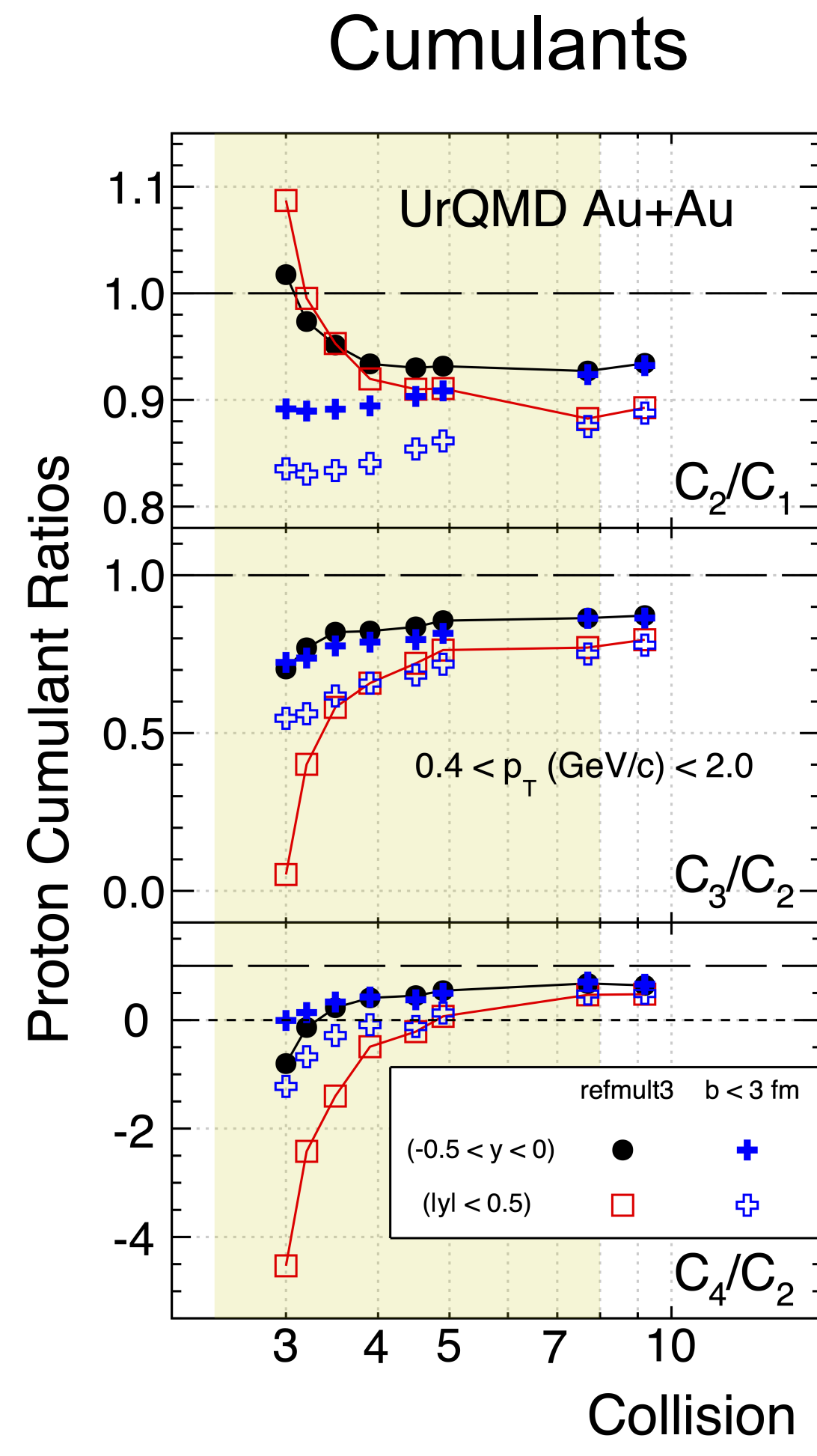
Cumulants

Factorial
Cumulants

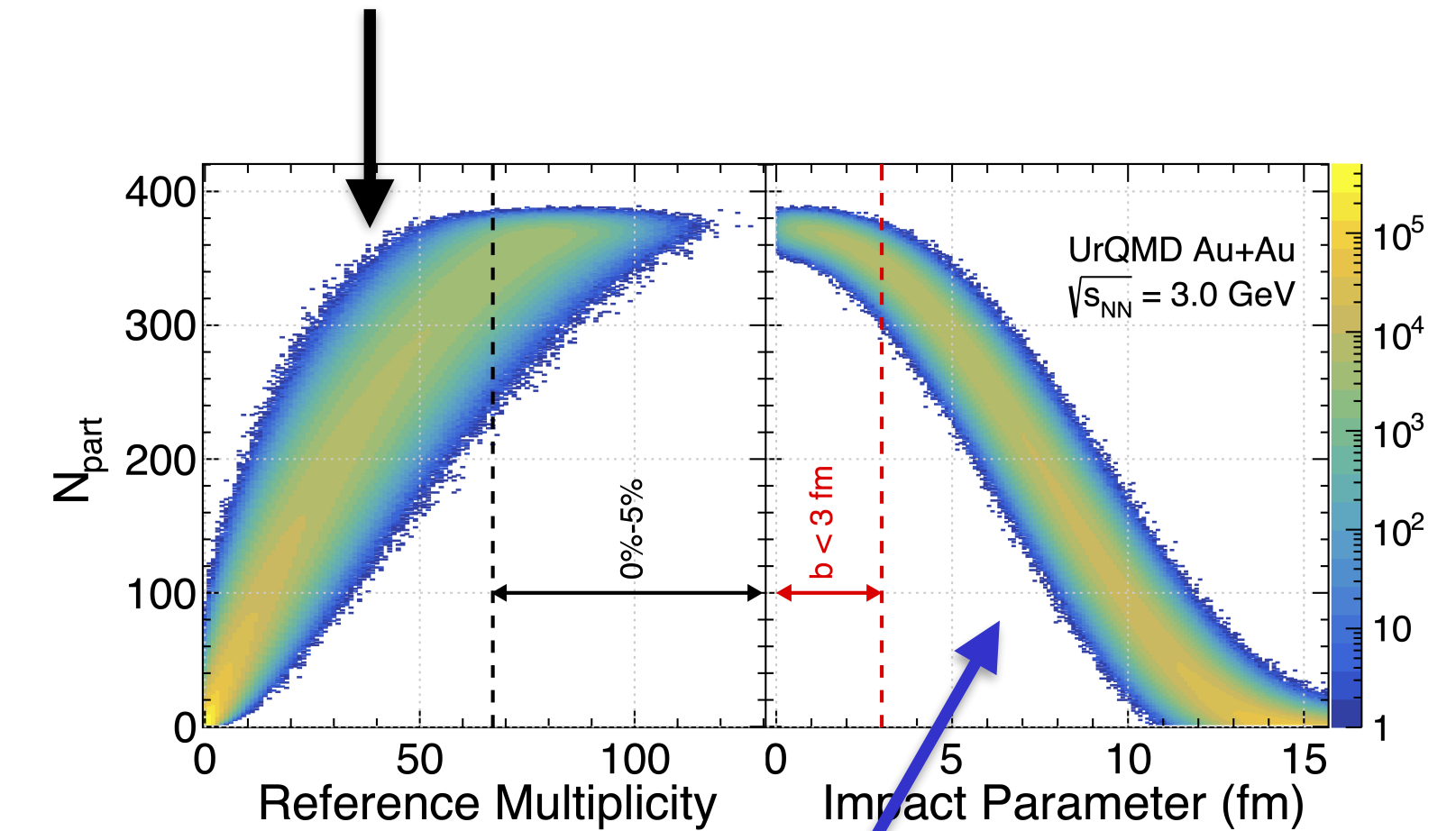
UrQMD (WITHOUT mean field) gets energy dependence qualitatively right!!!

The (possible) culprit

X. Zhang, Y. Zhang, X. Luo, N. Xu, arXiv: 2506.18832



Fluctuating impact parameter
STAR centrality selection

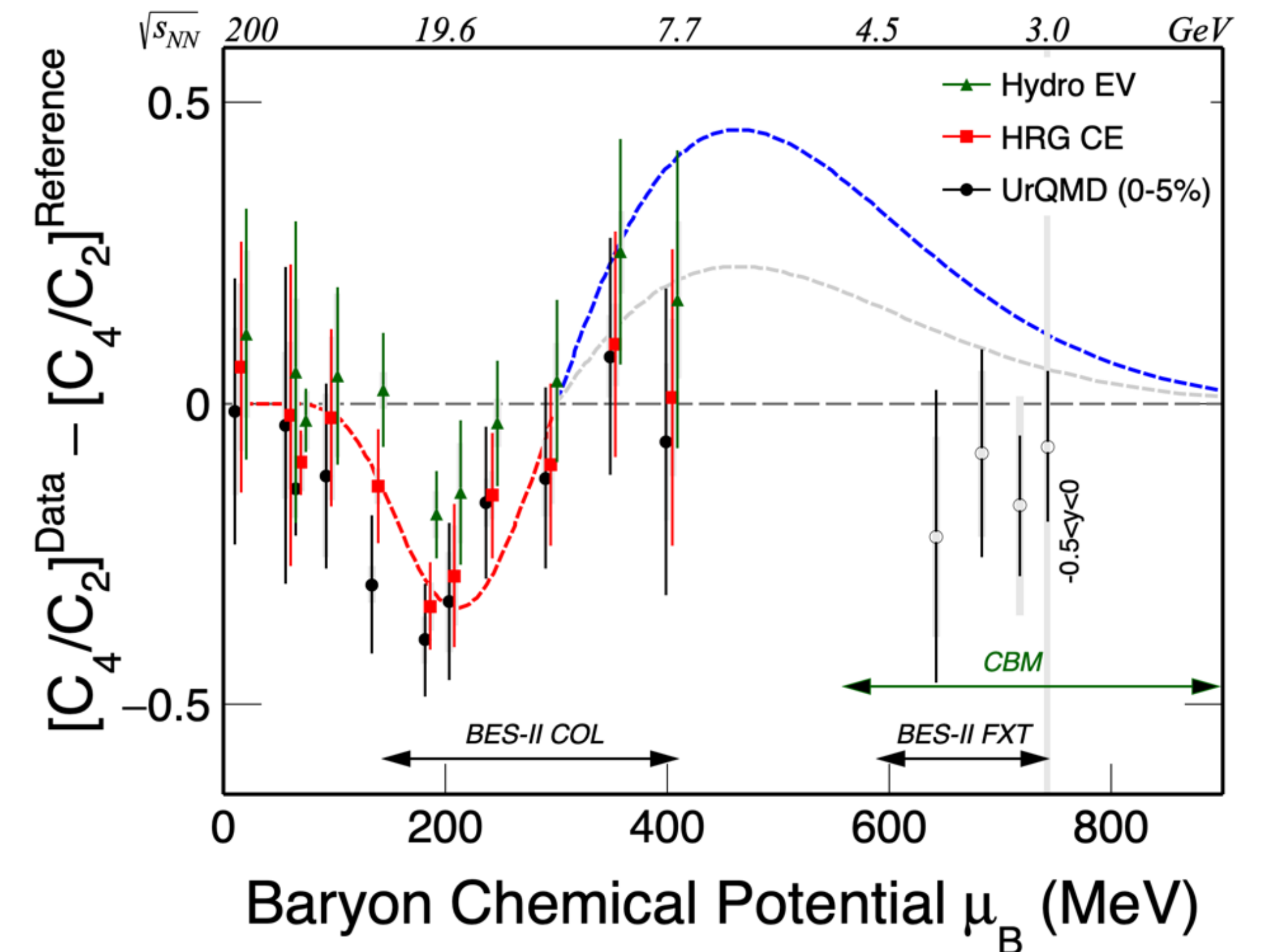
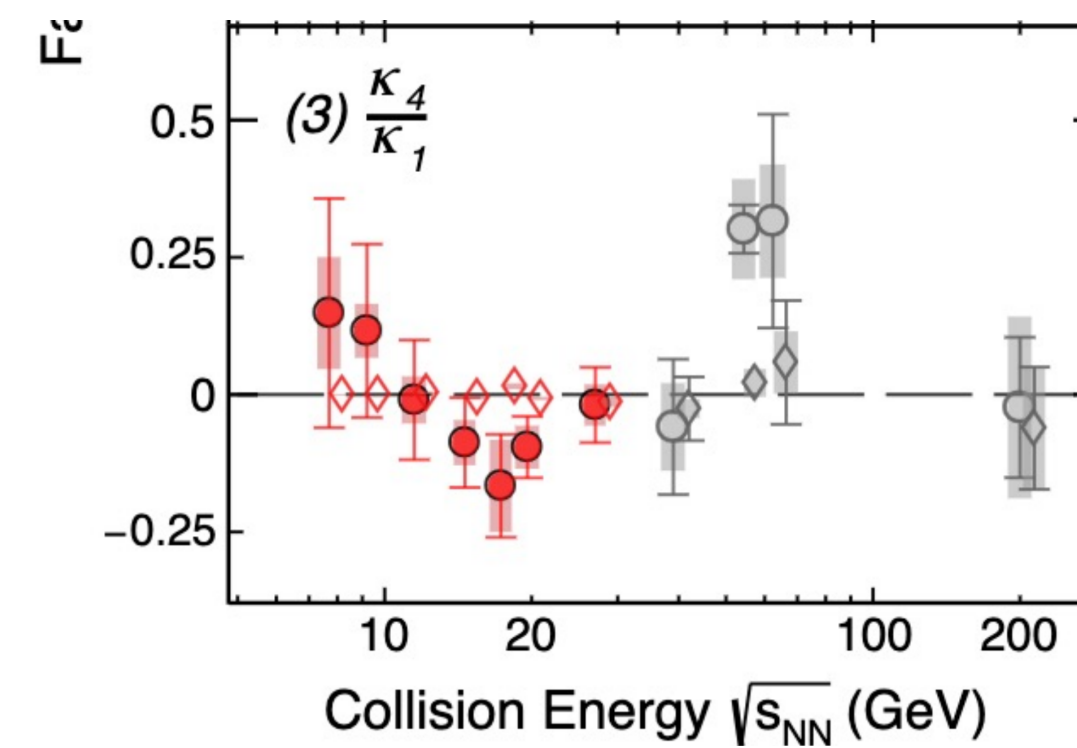
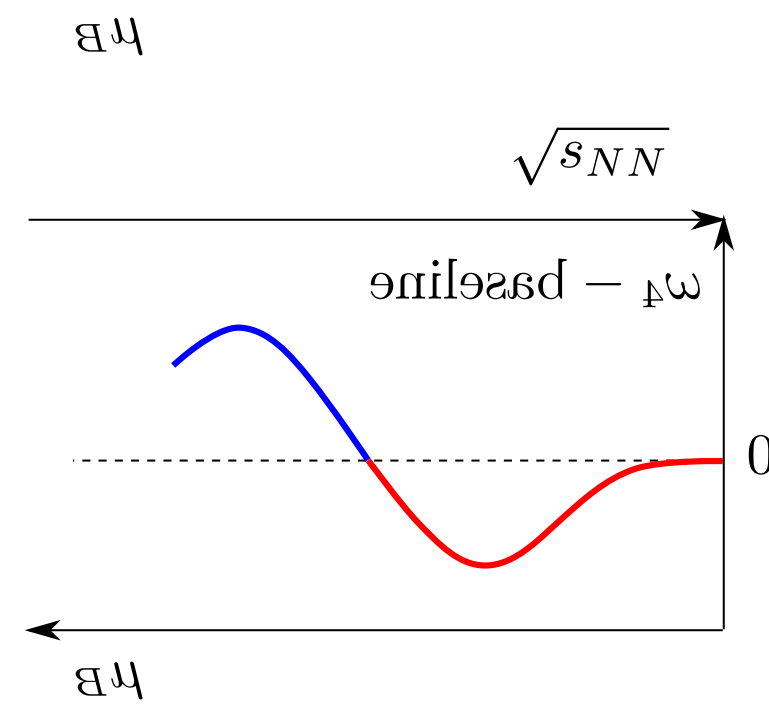


Fixed impact parameter ($b=3 \text{ fm}$)
minimal volume fluctuations.

N.B.: Centrality Bin Width Corrections
applied to both

Possible culprit:
volume (N_{part}) fluctuations

Higher order cumulants



Error bars are unfortunately sizable.
Theory has uncertainties as well!!!!
At best “supporting evidence”
Concentrate on 2 and 3 order!

Test of baseline: Reduce correlation functions

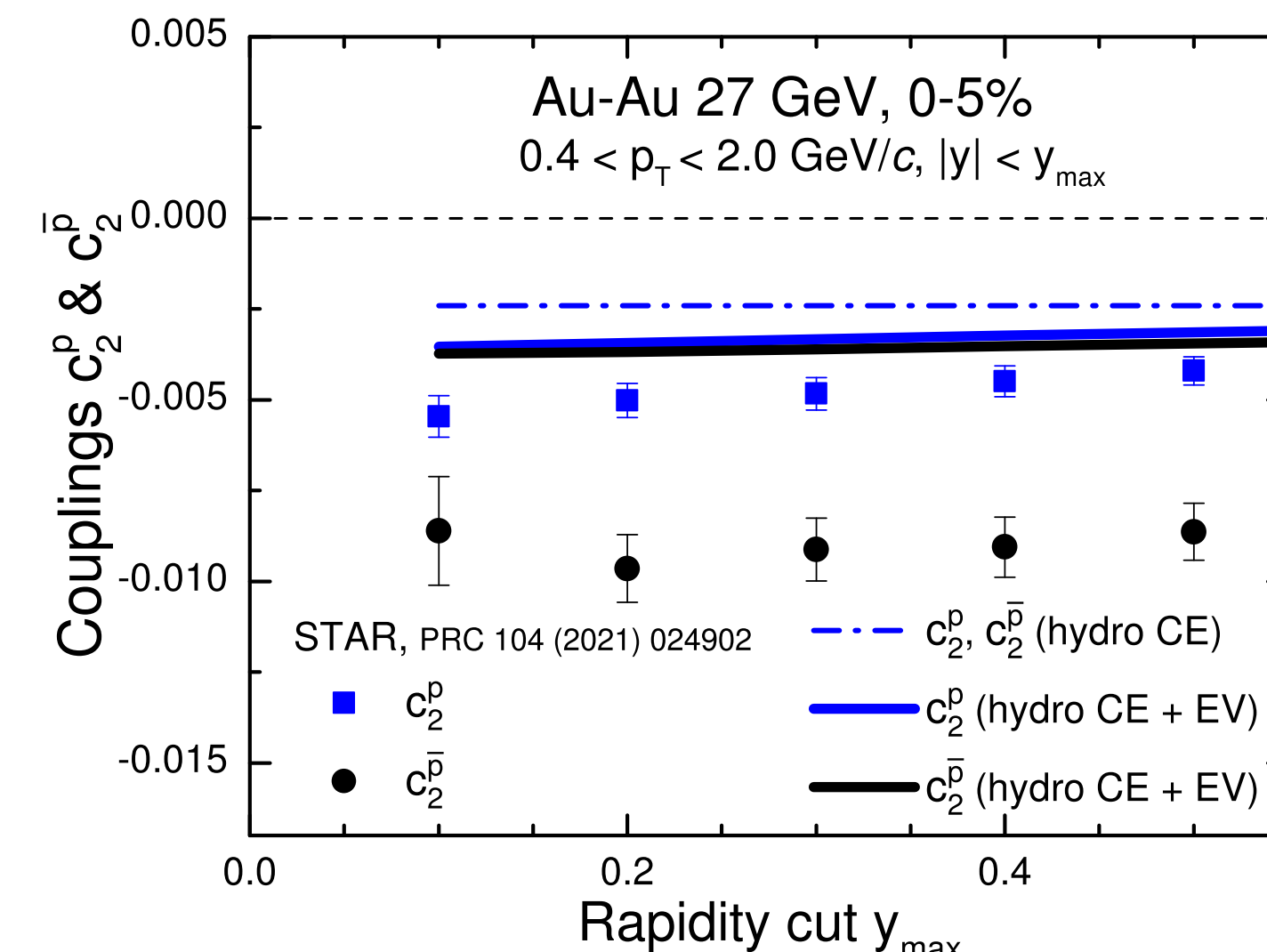
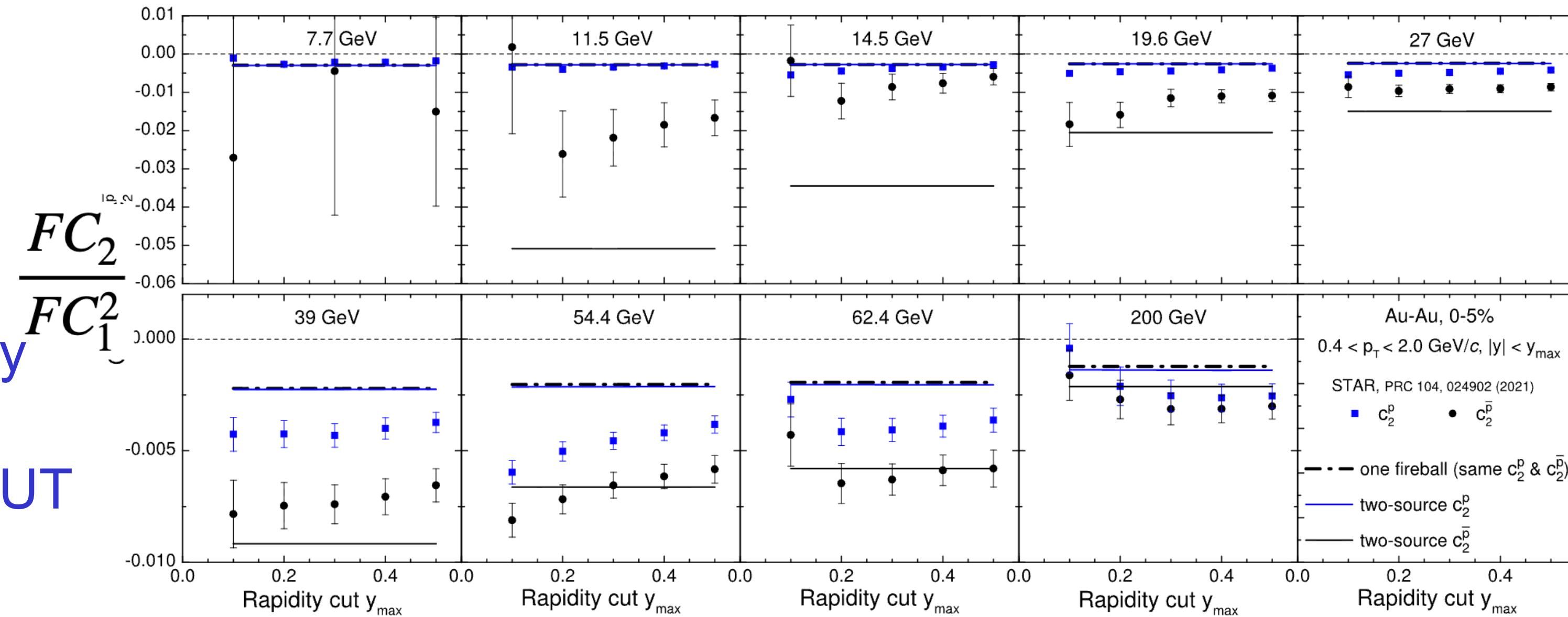
- reduced correlation functions

$$\hat{c}_k = \frac{\hat{C}_k}{\hat{C}_1^k} = \frac{\kappa_k}{\kappa_1^k} = \frac{FC_k}{FC_1^k}$$

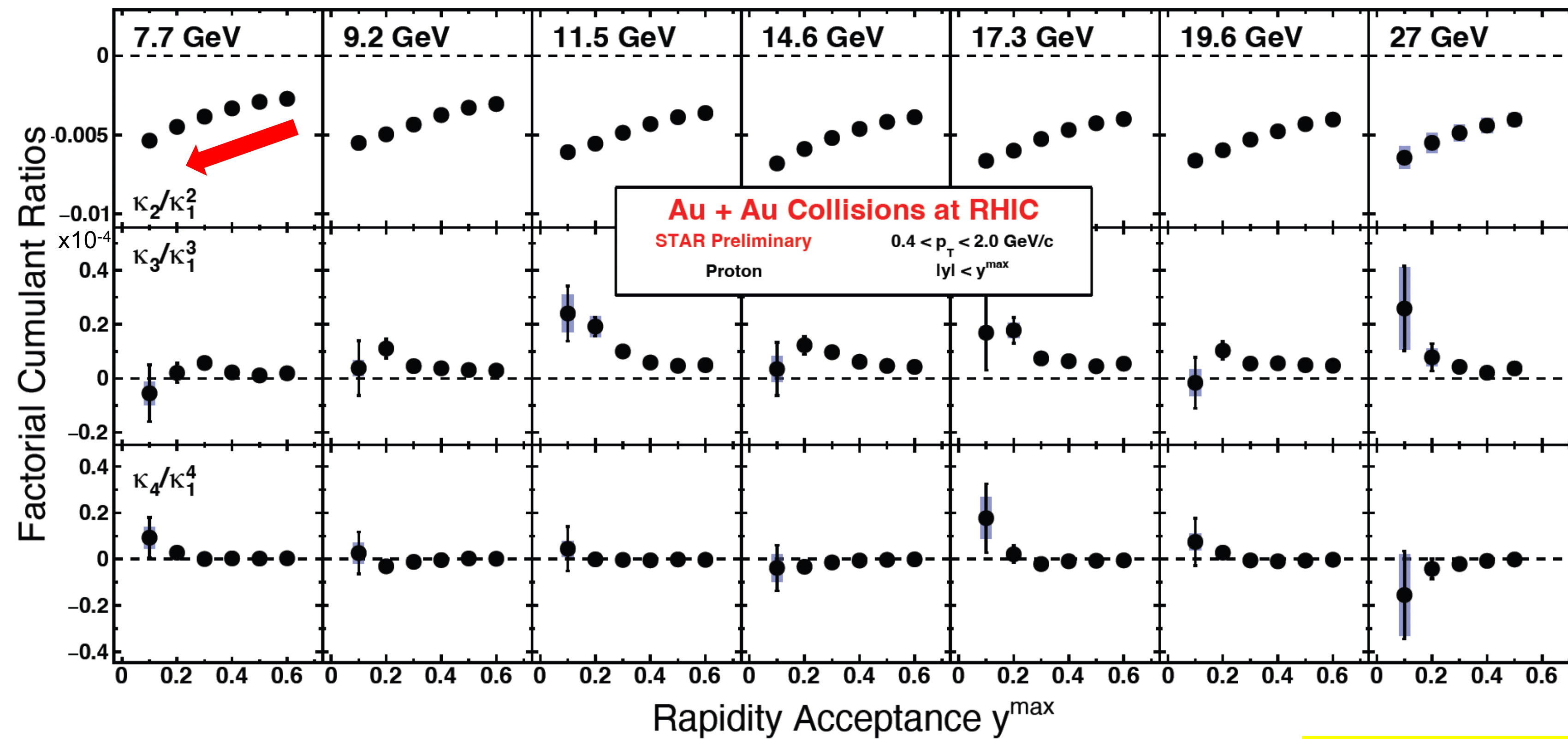
should be flat as a function of rapidity window

- Test with BES 2 data with AND WITHOUT CBWC corrections

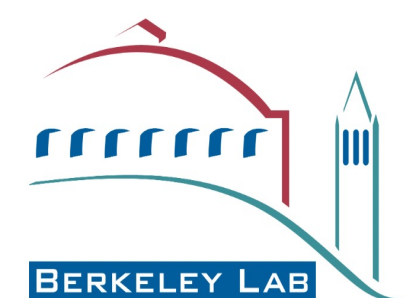
- Deviations may help to disentangle attractive/repulsive interaction from volume fluctuations
- Effect may be small
- (BES I) anti protons do NOT agree with baseline!!!!
- UrQMD (at 3 GeV) does NOT seem to give a flat curve



Acceptance Dependence



Yige Huang, PHD 25



Nov 5, 2025

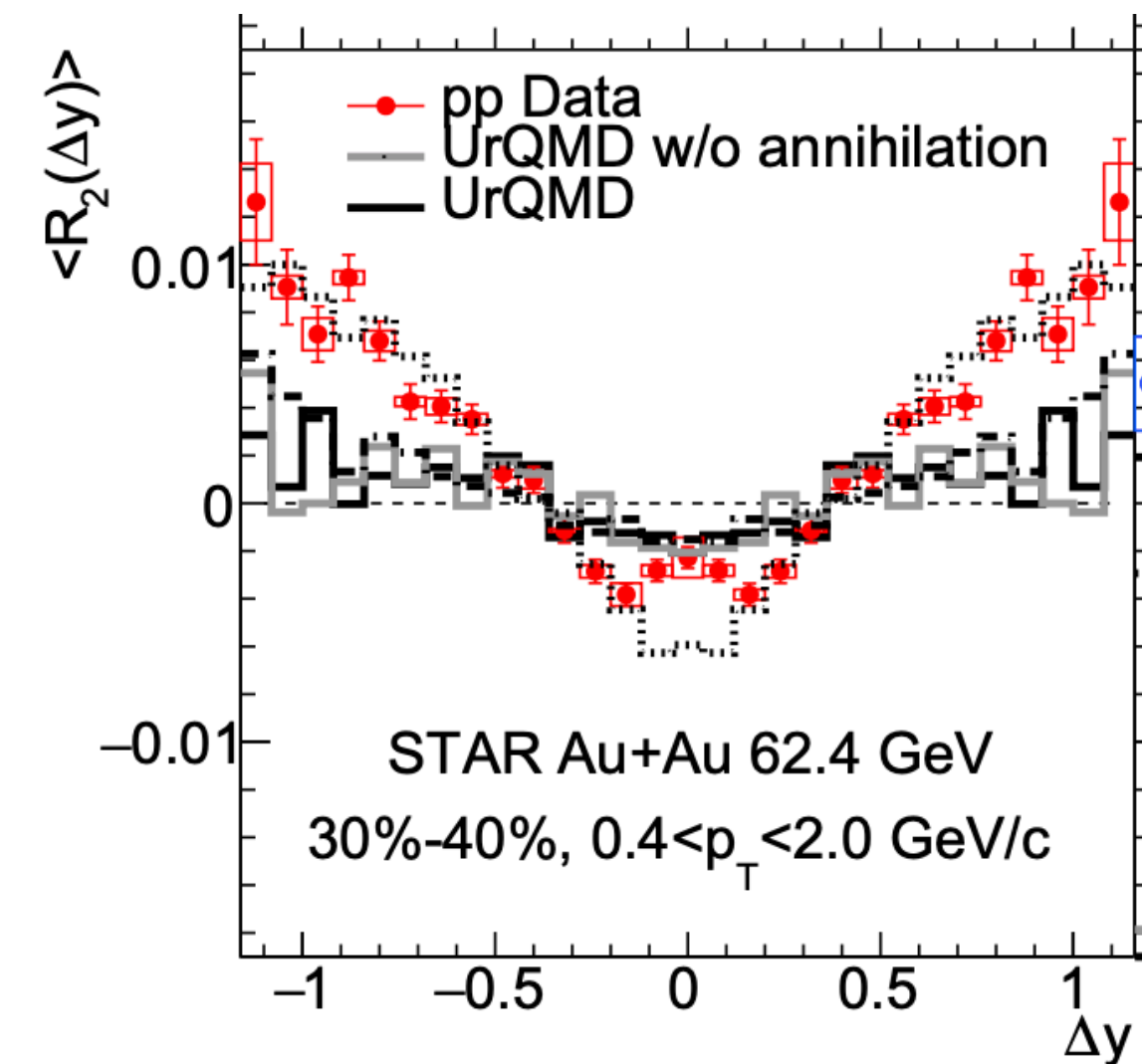
INT Workshop on "The QCD Critical Point Search: Are We There Yet"

X.Dong/LBNL

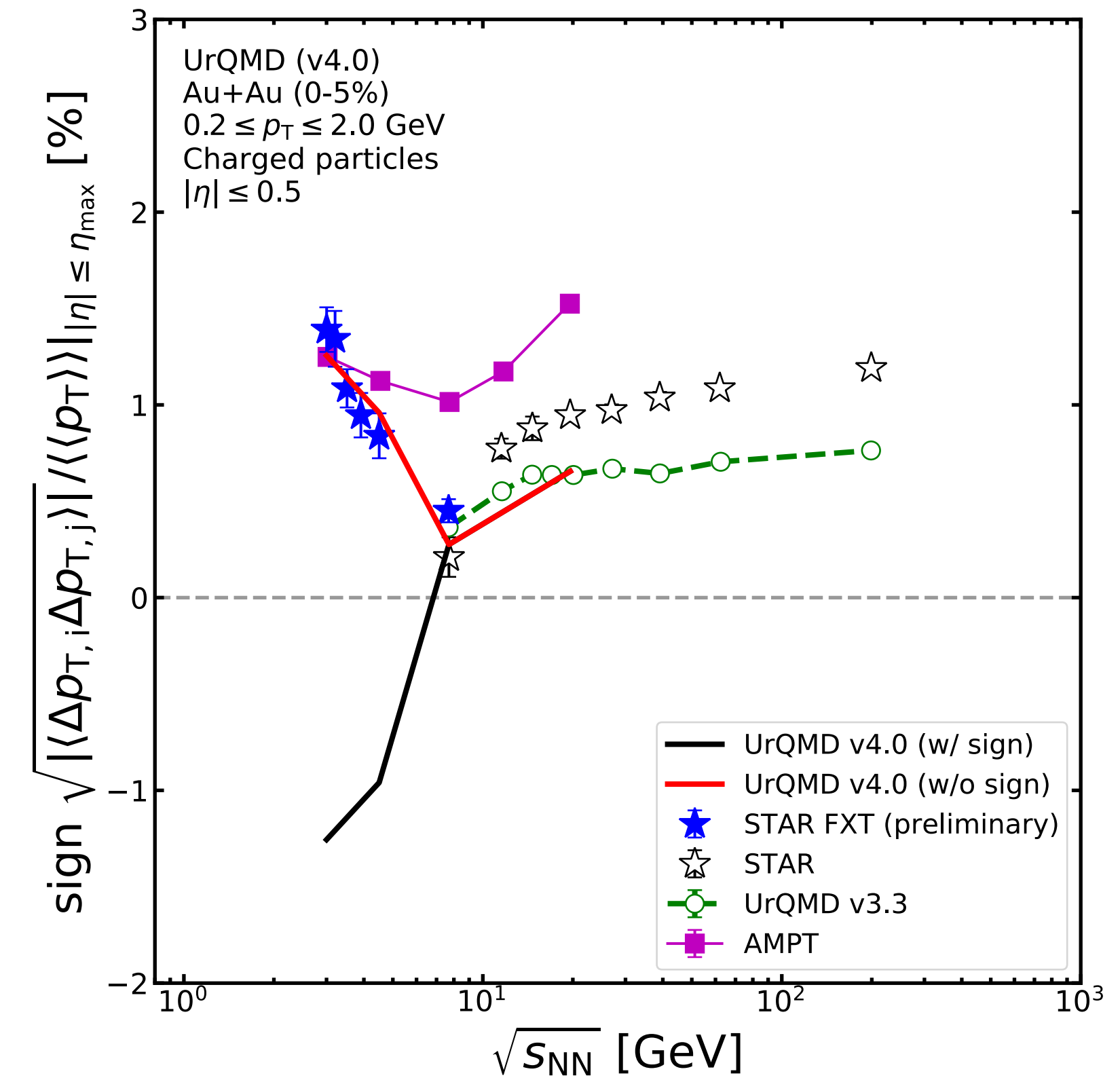
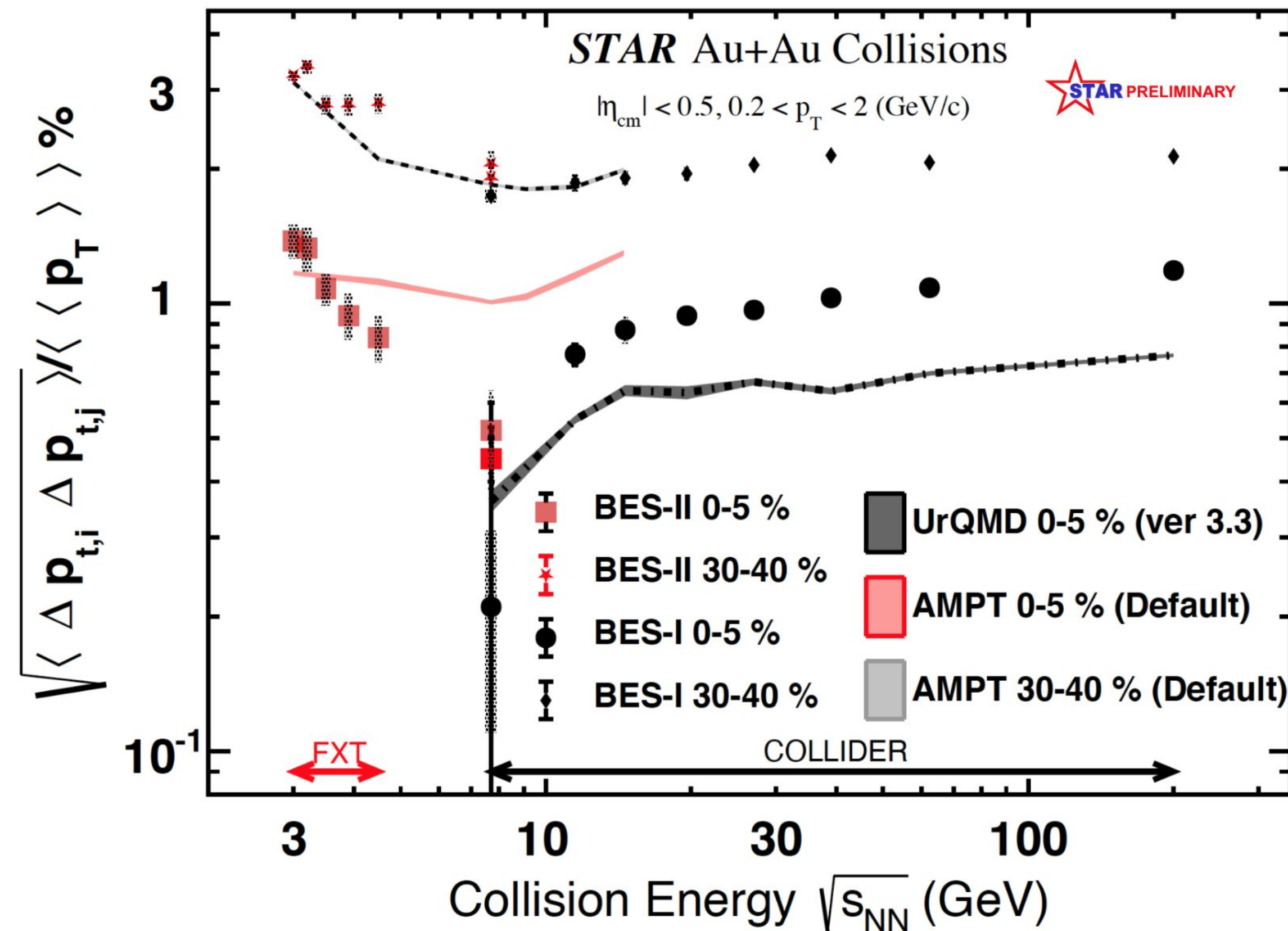
3

Cumulants

- Need to understand the UrQMD energy dependence before we conclude about attractive/repulsive
- Second order cumulants are integrals of 2 particle correlation functions which can/have been measured.
 - Plus side: Extra constraints
 - Possible issue: Sensitive to all kind of microscopic dynamics such as flow etc



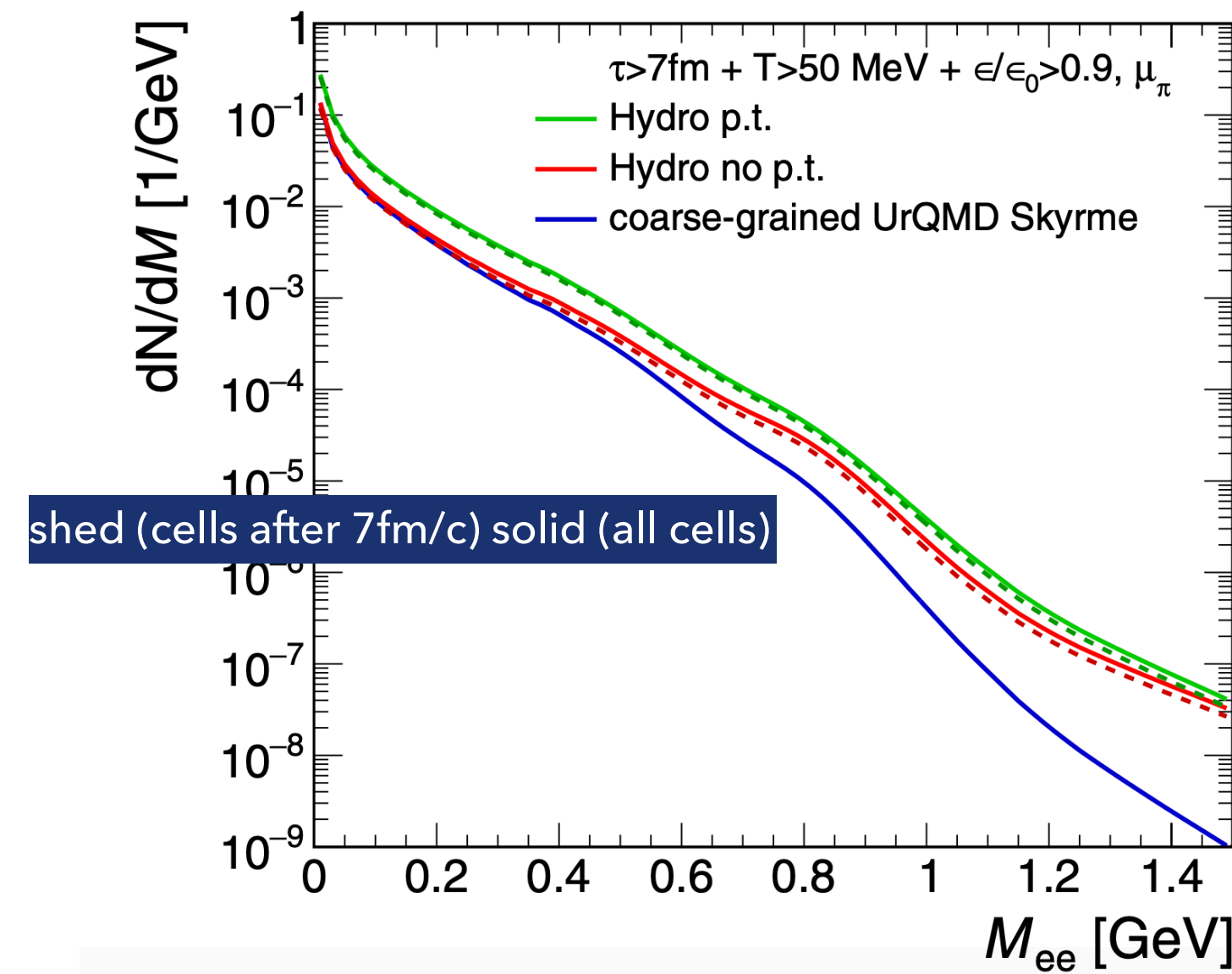
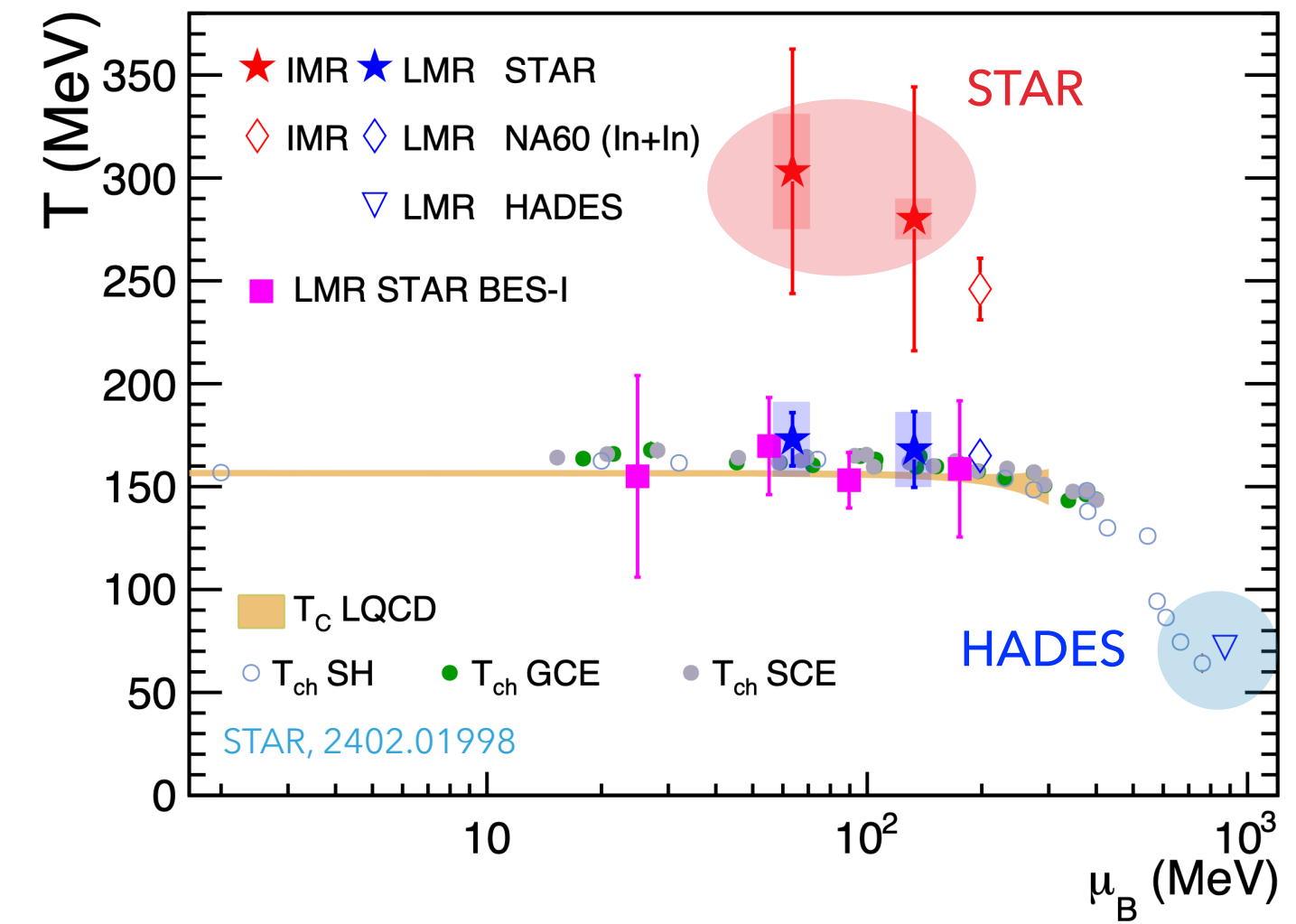
p_t fluctuations



Differential p_t correlations should help to resolve this issue

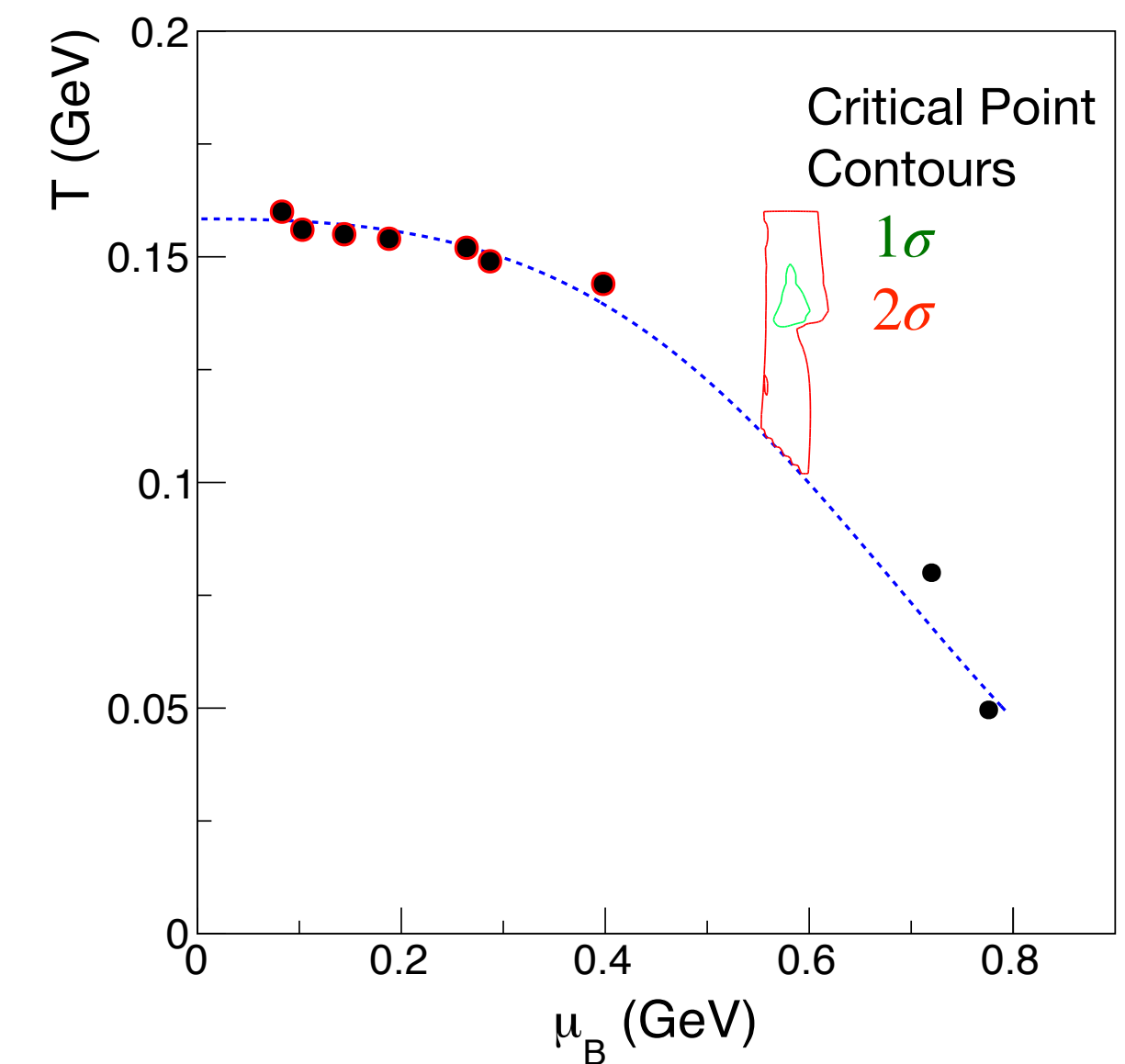
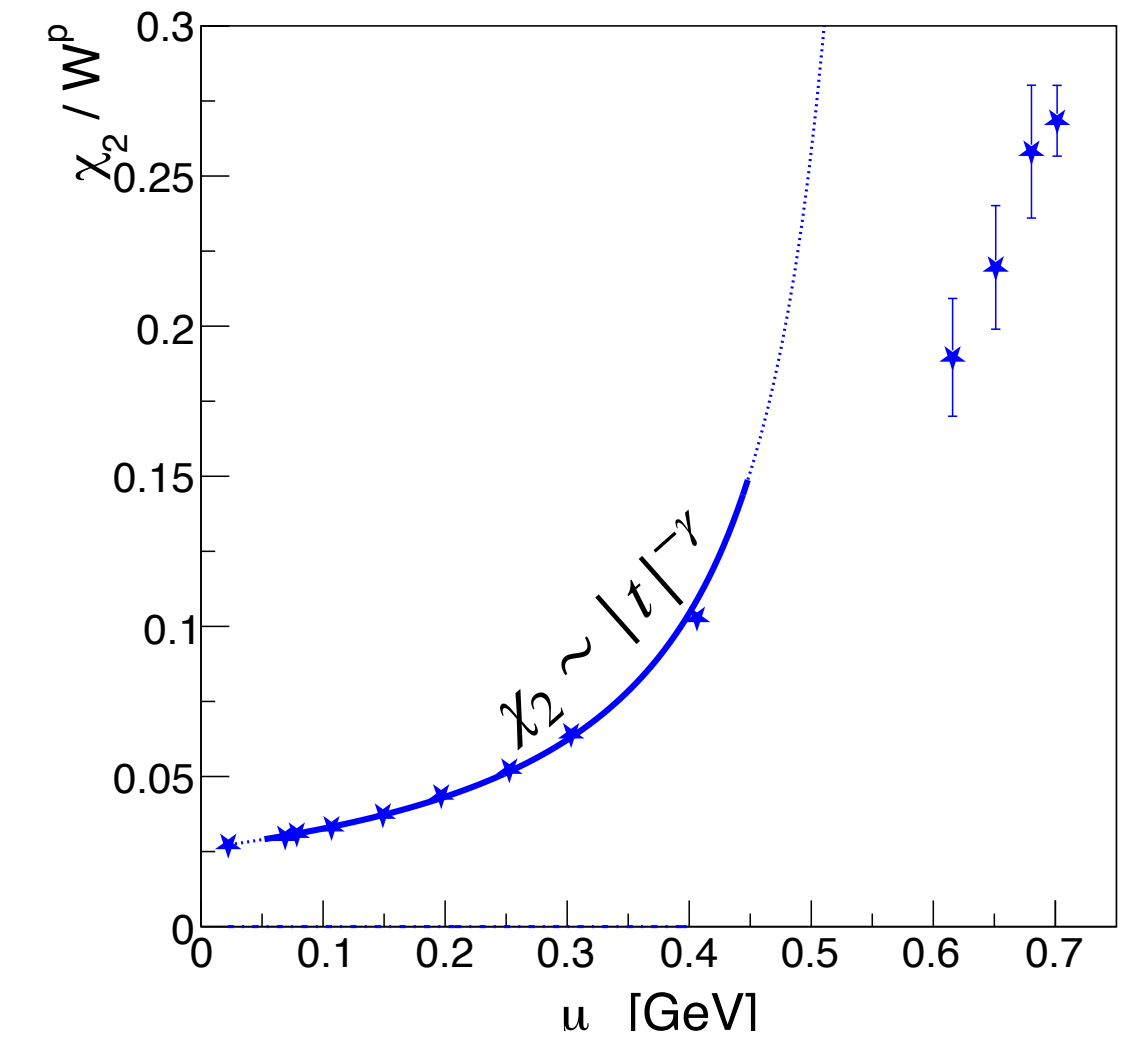
Dileptons

- Dileptons can provide info about the T reached and thus help calibrate the calculations.
- Signal from CP likely not measurable
 $m \leq 150 \text{ MeV}, p_t \sim 5 \text{ MeV}$
- 1st order PT may require absolute normalization of calculations. Is this possible?
- Chiral symmetry???



Finite size scaling

- Seems to work
 - gets critical chemical potential close to other approaches
 - fails for lower energies
 - works for Smash !?!
-
- TEST: will it work for HRG???

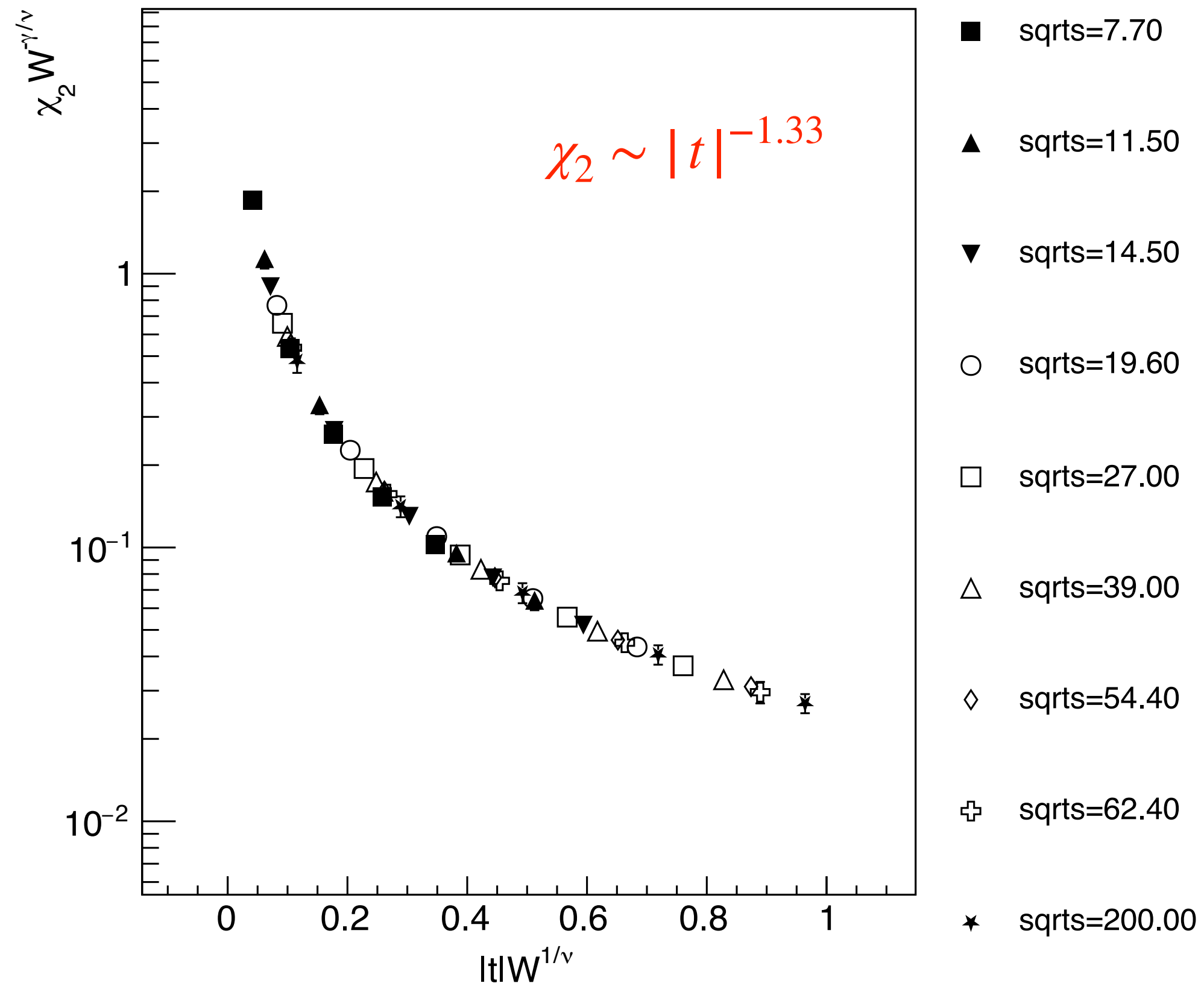


4D fit $\nu, \beta, \gamma, \mu_c$ for STAR data and SMASH cascade

STAR: χ_2

$$\nu = 0.76, \quad \beta = \text{N/A}, \quad \gamma = 1.33, \quad \mu_c = 622 \text{ MeV}$$

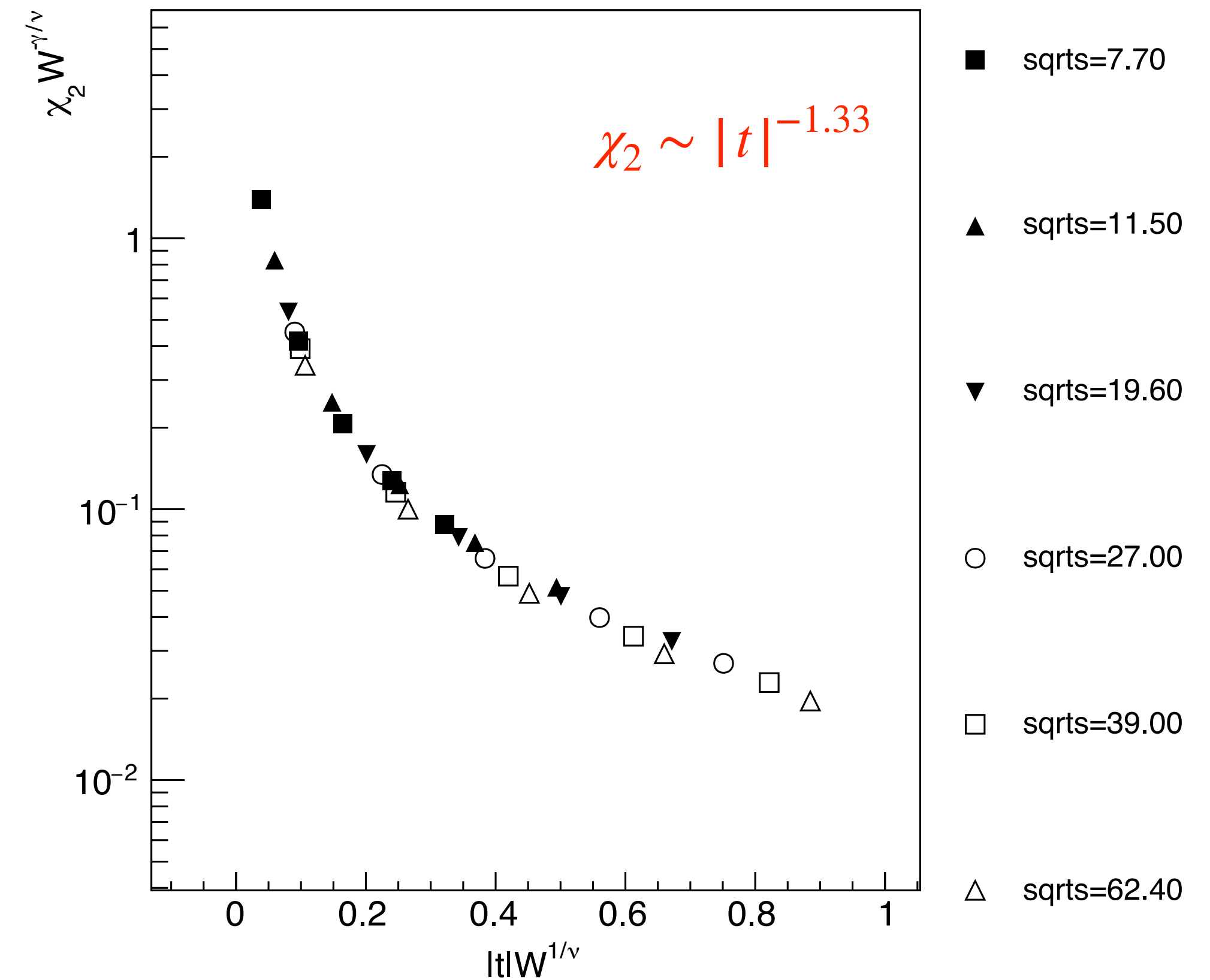
STAR_chi2_scaling_plot_nu=0.760_beta=0.120_gamma=1.330_muBc=0.622_Nybins=5_Ndata=9



SMASH: χ_2

$$\nu = 0.76, \quad \beta = \text{N/A}, \quad \gamma = 1.33, \quad \mu_c = 599 \text{ MeV}$$

SMASH_chi2_scaling_plot_nu=0.760_beta=0.120_gamma=1.330_muBc=0.599_Nybins=5_Ndata=6



MF: $\nu = 0.5, \quad \gamma = 1, \quad \beta = \frac{1}{2}, \quad \chi_2 \sim t^{-1}, \quad \chi_3 \sim t^{-2.5}, \quad$ 3D Ising: $\nu = 0.630, \quad \gamma = 1.237, \quad \beta = 0.326, \quad \chi_2 \sim t^{-1.237}, \quad \chi_3 \sim t^{-2.8}$

Neutron Stars

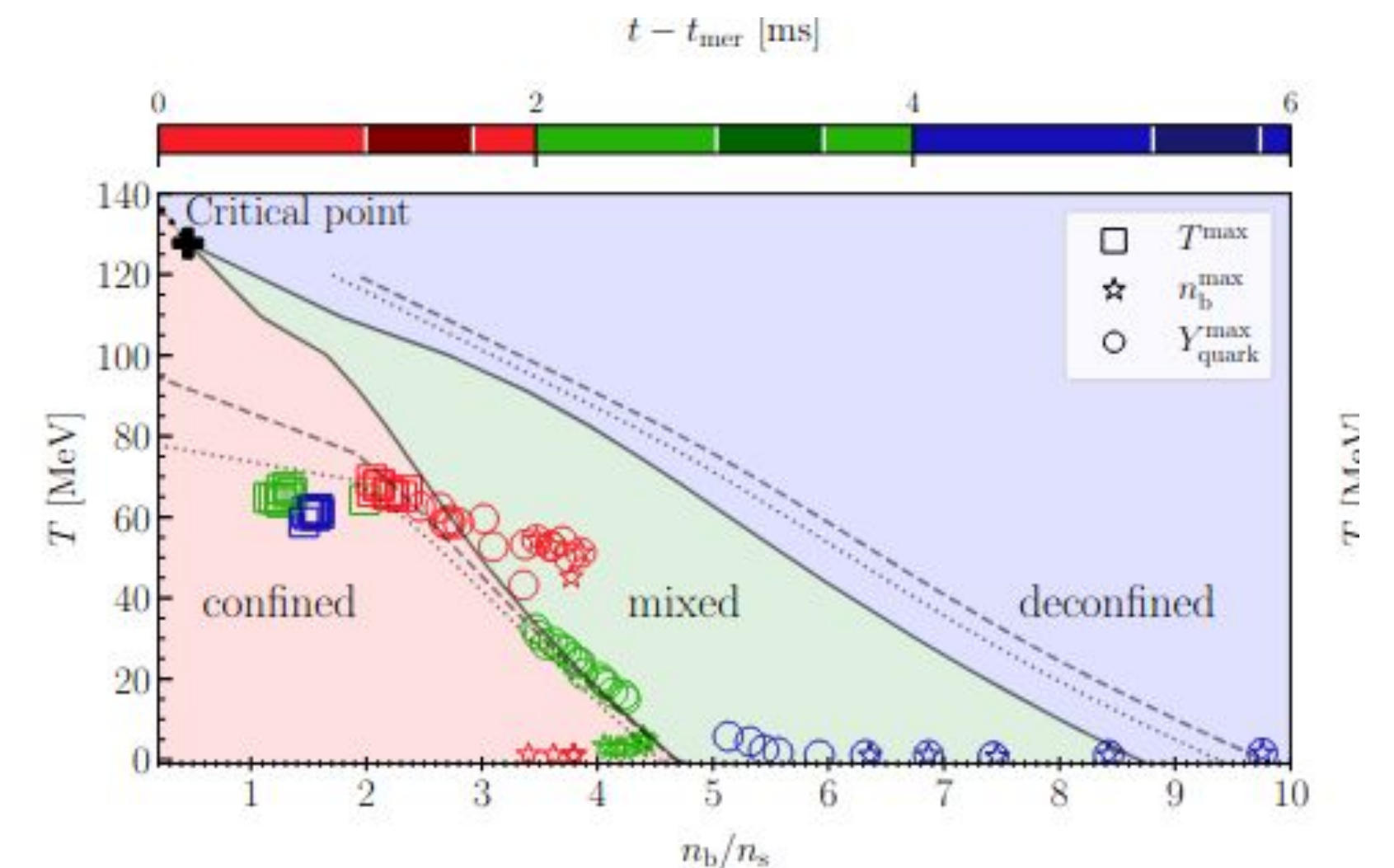
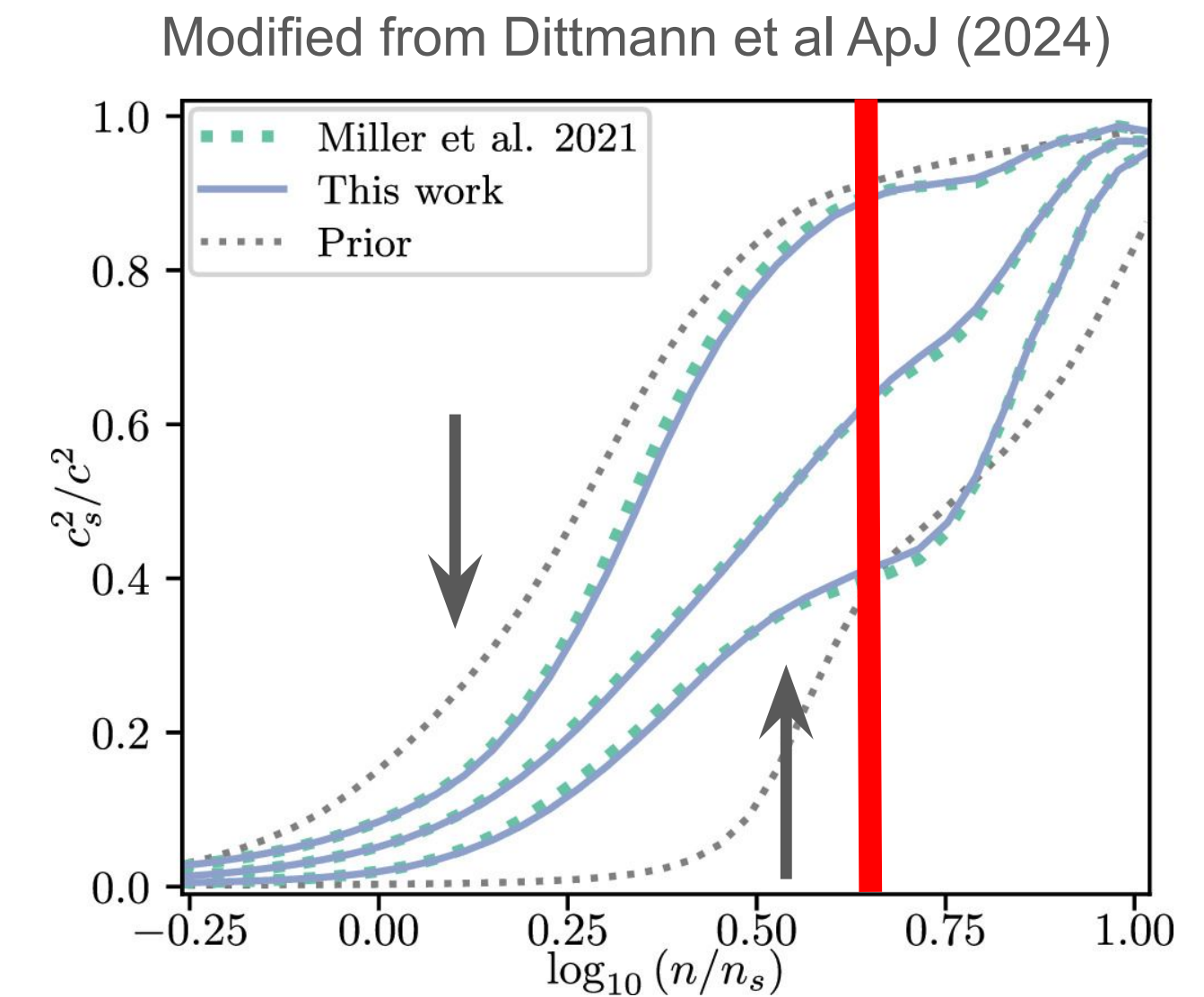
Neutron star studies put constraints on the QCD EOS

Yes

What can they tell us about the CP of nearly-isospin symmetric matter?

We all agree, right now, nothing.

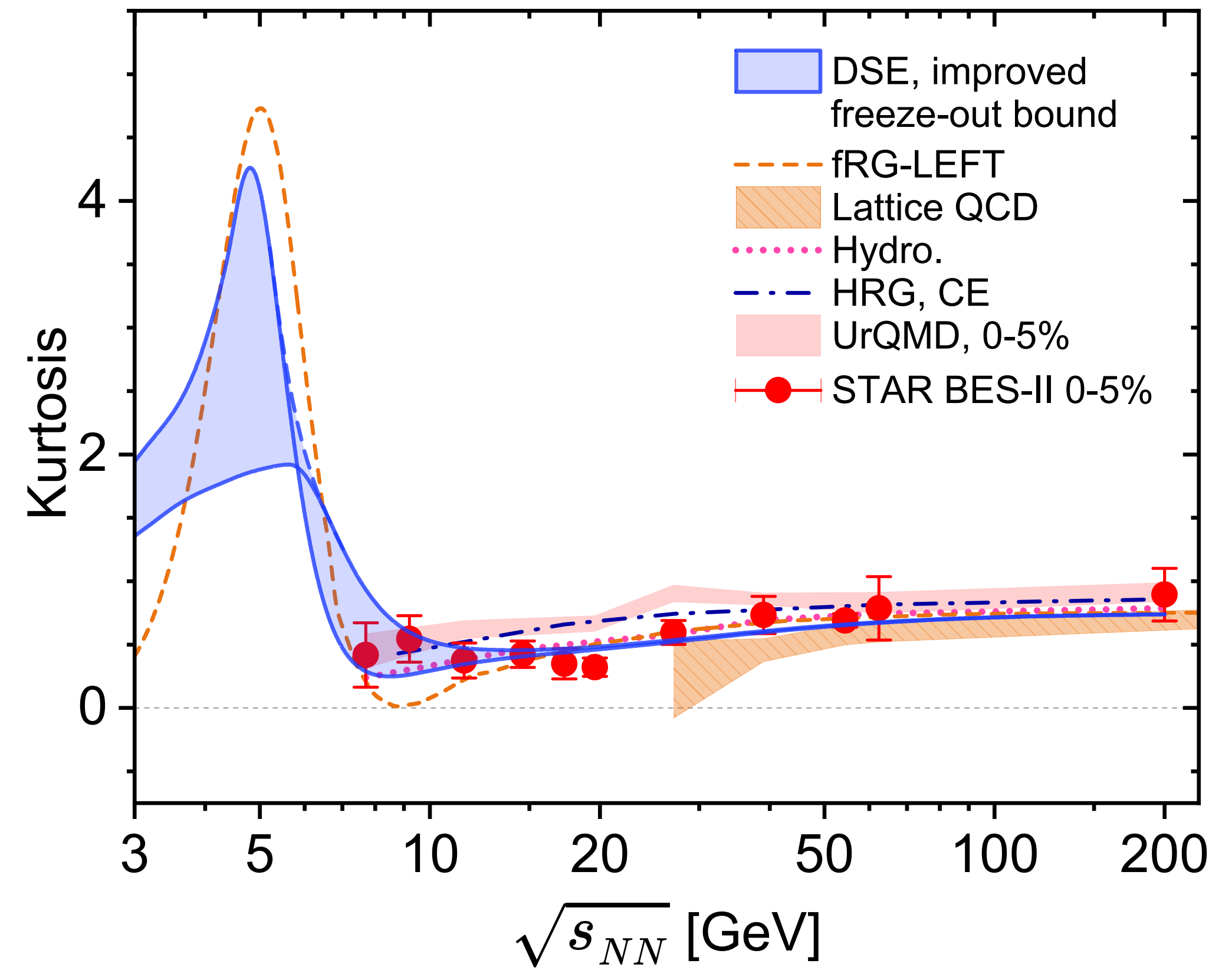
Well, maybe a bit?!



Going forward

Going forward

Option 1



Going forward

Option 2: “Homework problems”

- Is hydro (+ afterburner) able to reproduce the bumps and holes in flow and HBT?
 - _ What need to change in baryon transport in dynamical models to get e.g. $\frac{dv_1}{dy}$ etc
- Where does quark number scaling arise in a dynamical model which also reproduces all flow data? Relaxation time viscous correction effects??? (Teany et al)
 - Get the viscous correction from UrQMD and then plug into hydro (Thomas Schäfer)
 - Low energy: effect of shadowing???
- Check/verify that hydro with CP leads to same flow etc results as without CP
- BESII data for clusters
- Finite size scaling for HRG?
- BESII data for reduced correlation functions with and without CBWC
- Check if UrQMD gives constant reduced correlation functions
 - It seems not to. Why?
- Reduced correlations for anti protons from BESII. Still a problem w.r.t baseline?

Going forward

Option 2: “Homework problems”

- FRG, DSE, AdS:
 - ϵ, n_B, s, p along cross-over (and possibly co-existence) line
 - Slope of co-existence line at CP, streng of singularity, angle between t and h
 - Comparison with Lattice at imaginary chemical potential
 - Transport coefficients??
 - Dynamics??????
- Lattice, FRG, DSE, AdS: Please provide (net) proton cumulants with baryon number observations (for example using using Kitazawa et al (1107.2755) and SAM (2003.13905))
- Stochastic hydro/Hydro plus:
 - Calculation of expanding system (critical and non-critical)
 - provide upper limit of signal for CP ?

Homework

- List what is already done and send plot to Agnieszka
- Systematics for Cumulant baselines

The chef recommends



Backup