Centrality, Rapidity and Energy Dependence of Proton Cumulants from UrQMD and PhQMD at High Baryon Density

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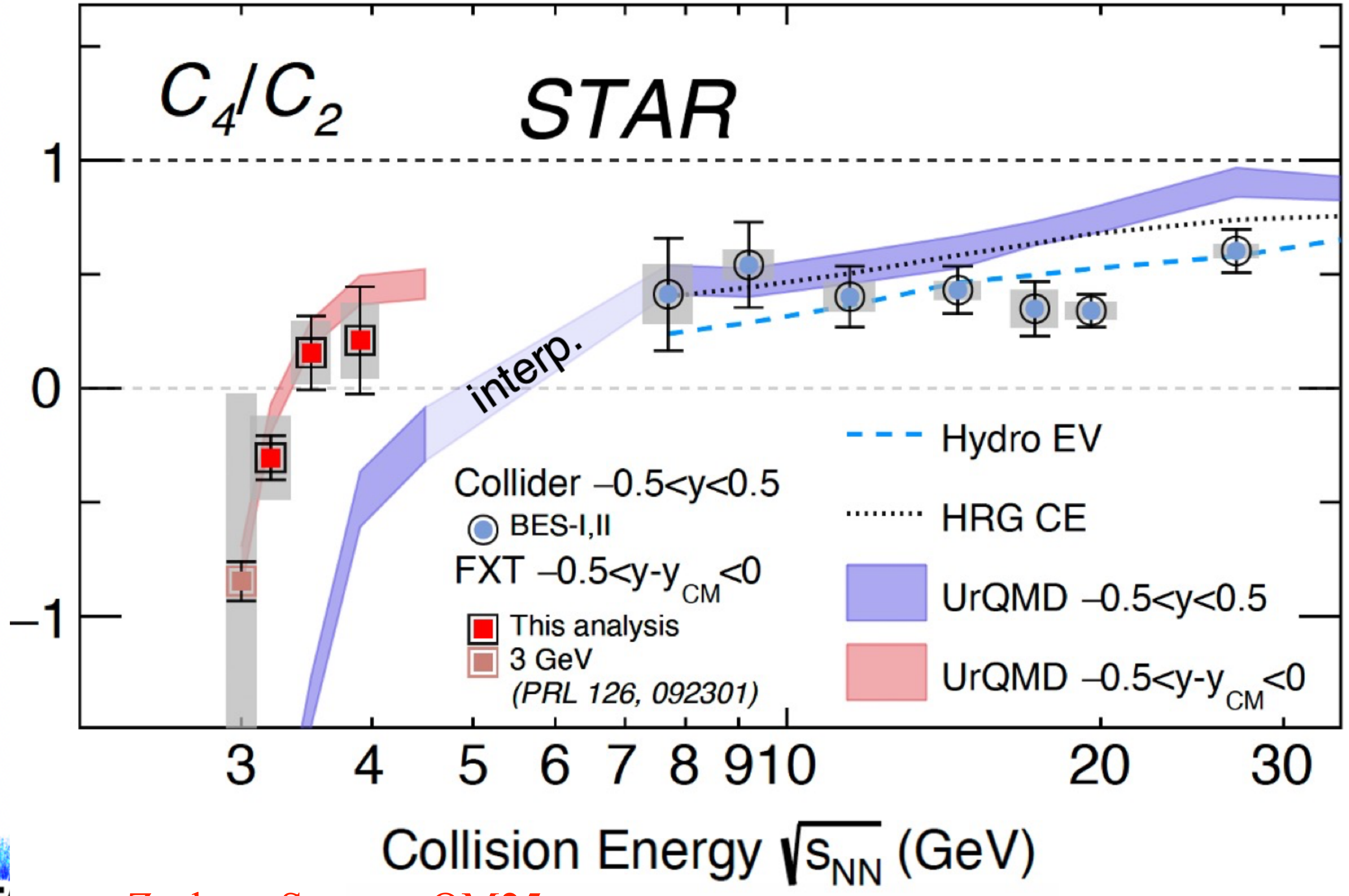
Outline:

1) Motivation
2) Observables
3) Results
4) Summary and To-Do List

Recent Results from STAR

1. Recent Results in collider energy ($\sqrt{s_{NN}}$ = 7.7 - 27 GeV) shows signals of the existence of the QCD critical point
2. Rapidity acceptance scan: may sensitive to the QCD critical point



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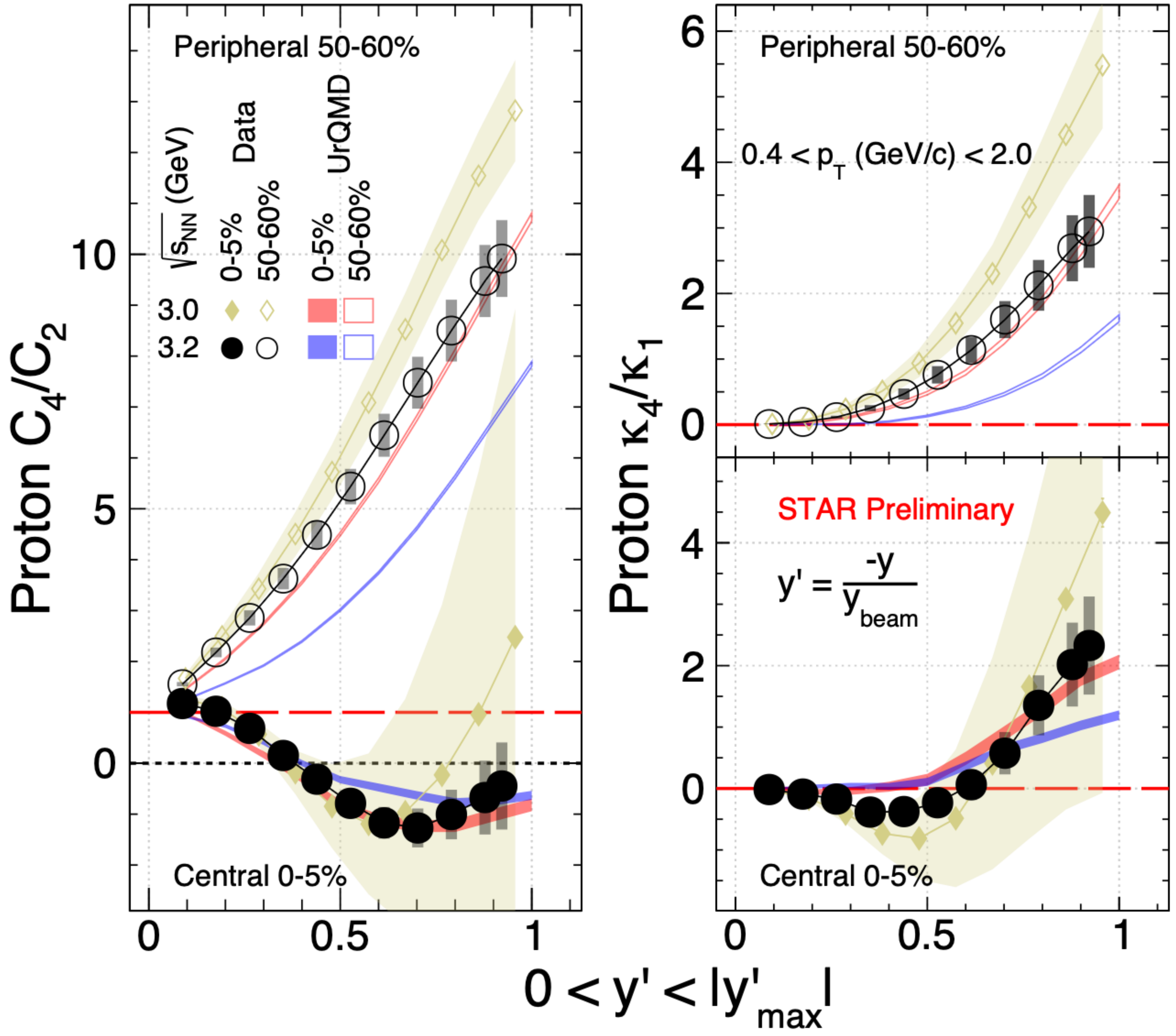

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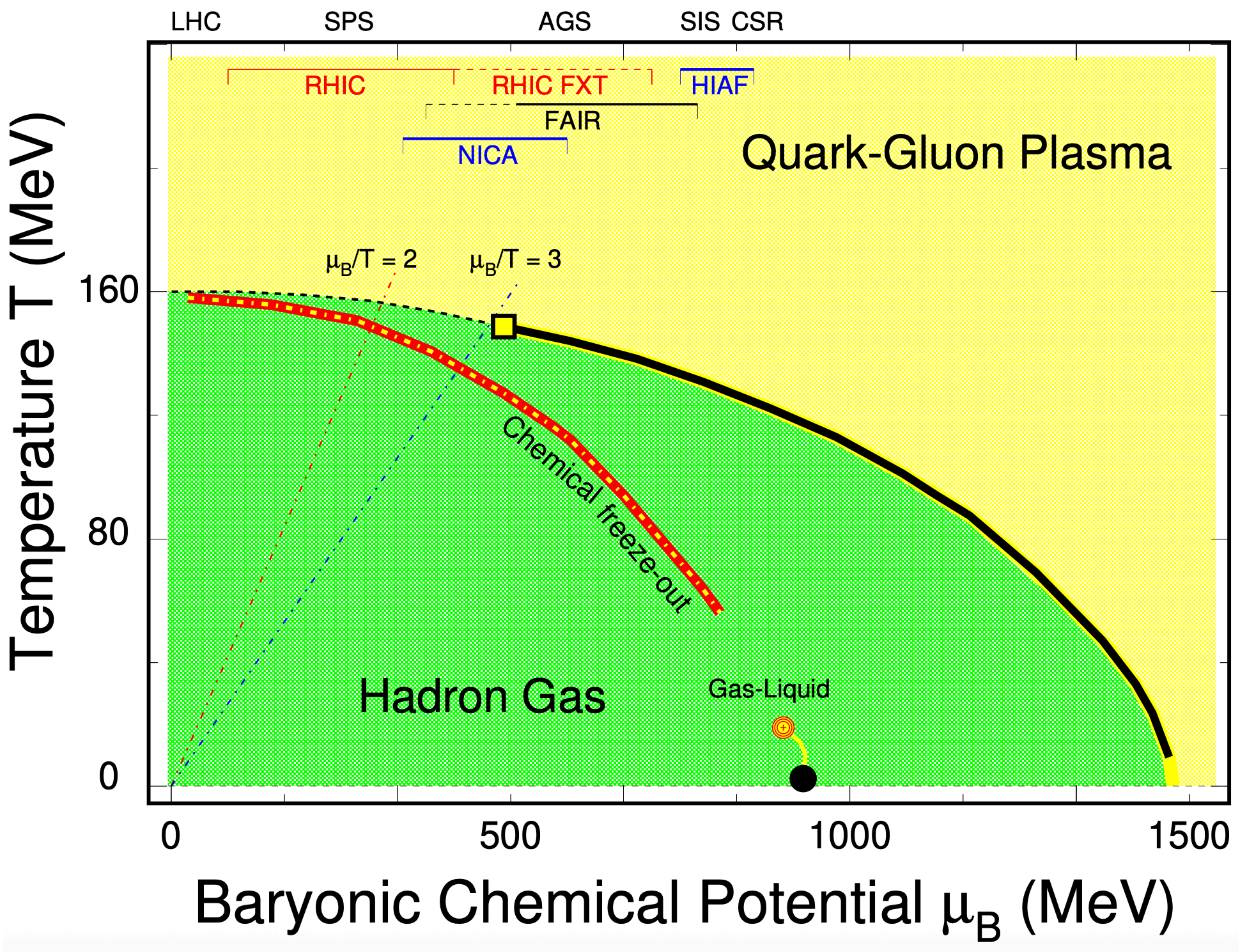
Motivation



B. Mohanty, N. Xu, arXiv:2101.09210

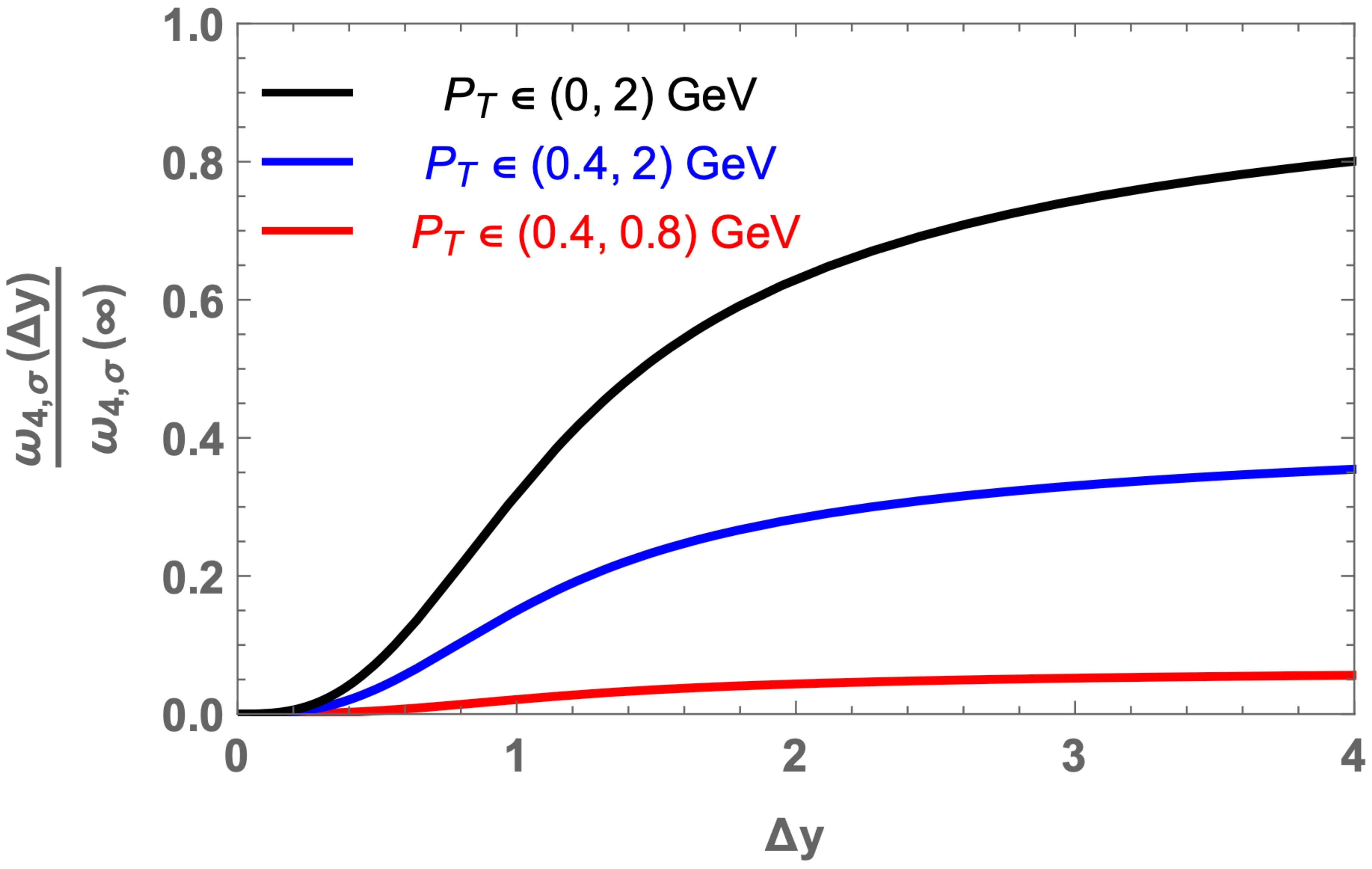
1. Smooth crossover at $\mu_B = 0$
2. Models predict 1st order phase transition at large μ_B
3. Possible QCD critical point and 1st order phase boundary
4. Scan phase diagram by varying collision energy

Goals of RHIC Beam Energy Scan Program:

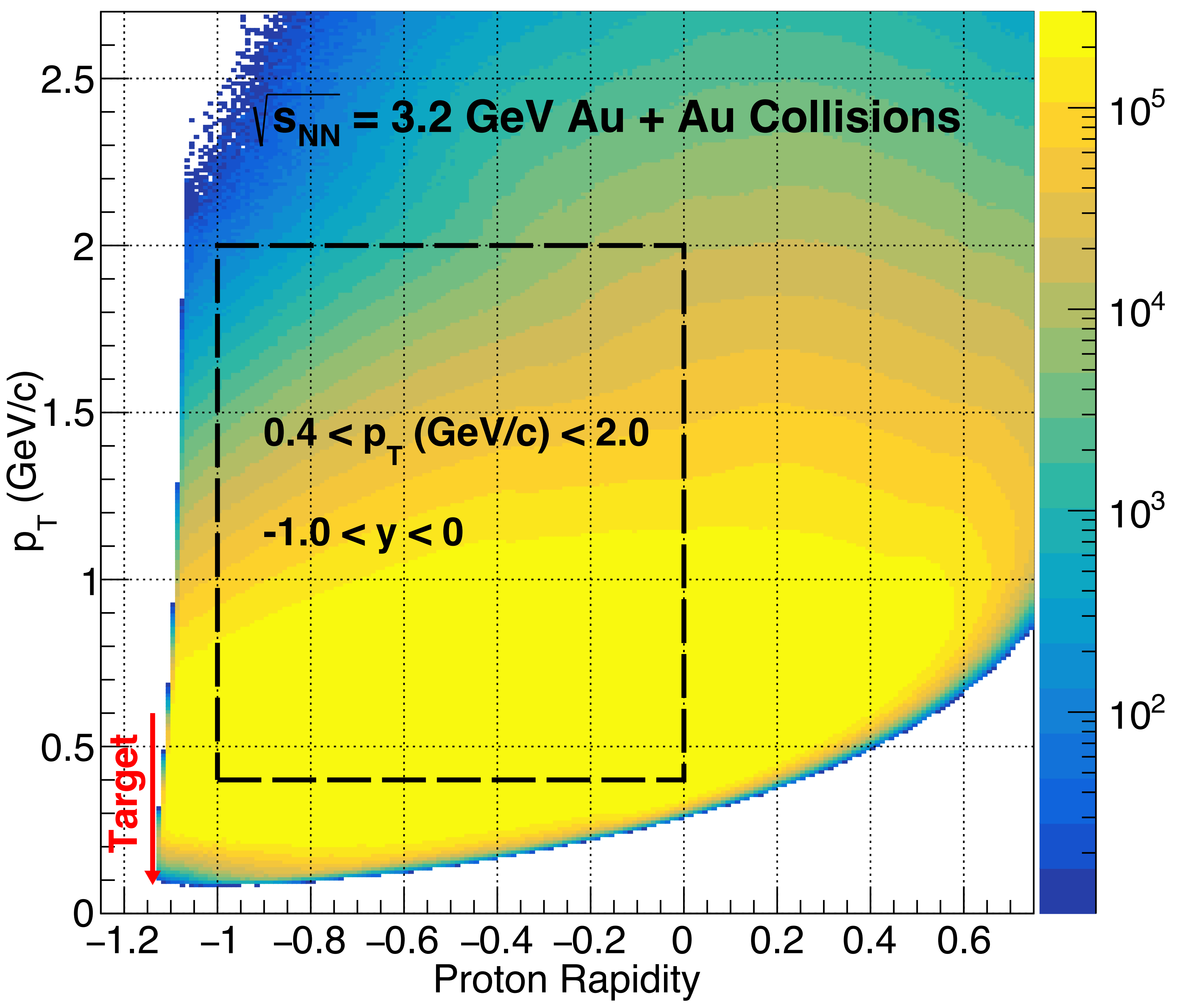
identify phase boundary and QCD critical point

Motivation

1. Should the critical behavior exist, a larger enhancement in fluctuations at wider rapidity and transverse momentum (p_T) bins is expected
   B. Ling and M. A. Stephanov, Phys. Rev. C 93, 034915 (2016)
2. STAR Fixed-Target (FXT) experiment: scan from mid-rapidity (hot medium) to target rapidity (cold nuclear matter)



Acceptance dependence of the critical contribution to the normalized cumulants of proton number



Experimental Observables

Fluctuation: Cumulant

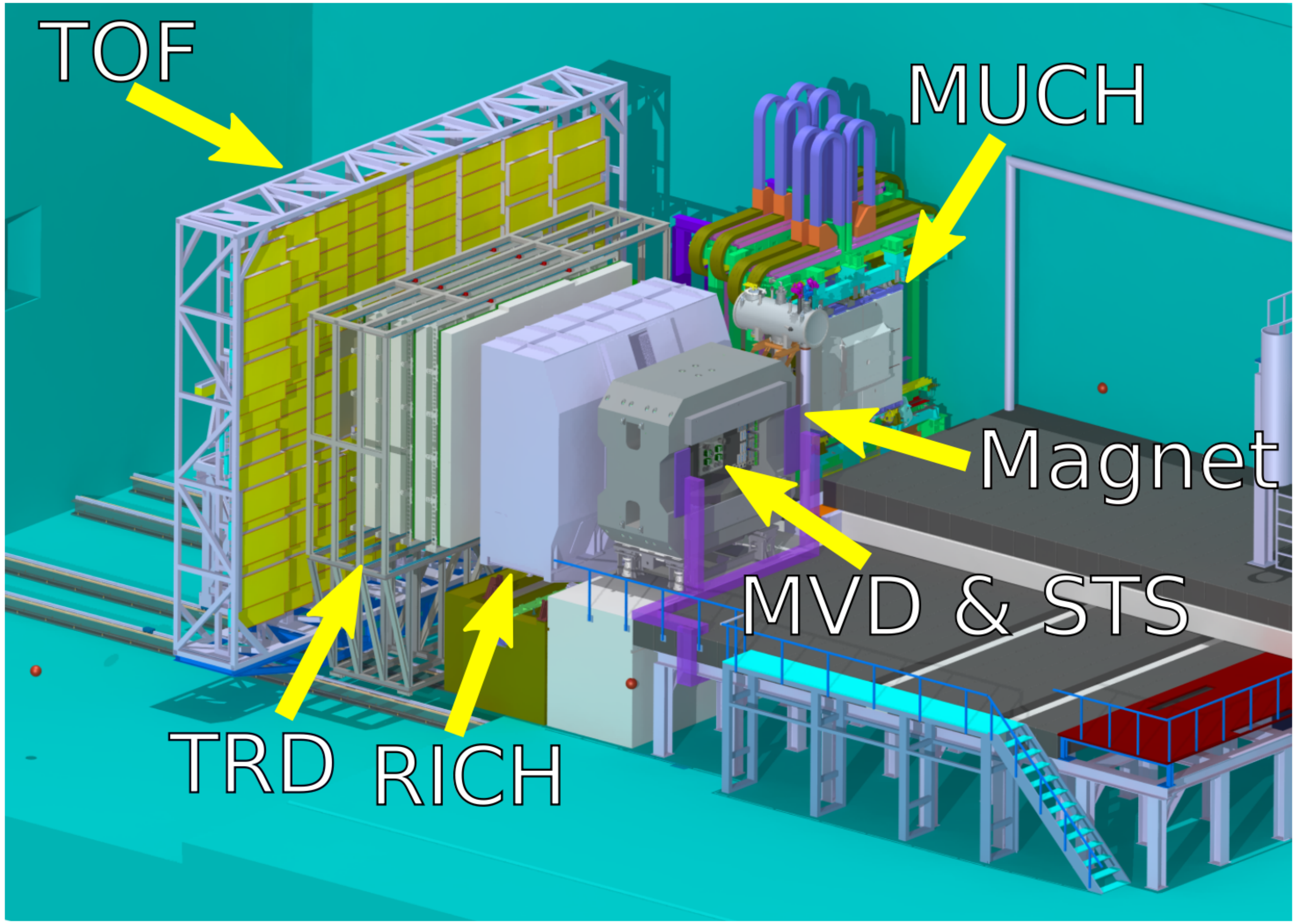
1. Measure non-Gaussian fluctuation
2. Extensive variables (intensive for ratios)

Conserved charges:

1. Net-baryon number (proton)
2. Net charge number
3. Net strangeness number (net-kaon)

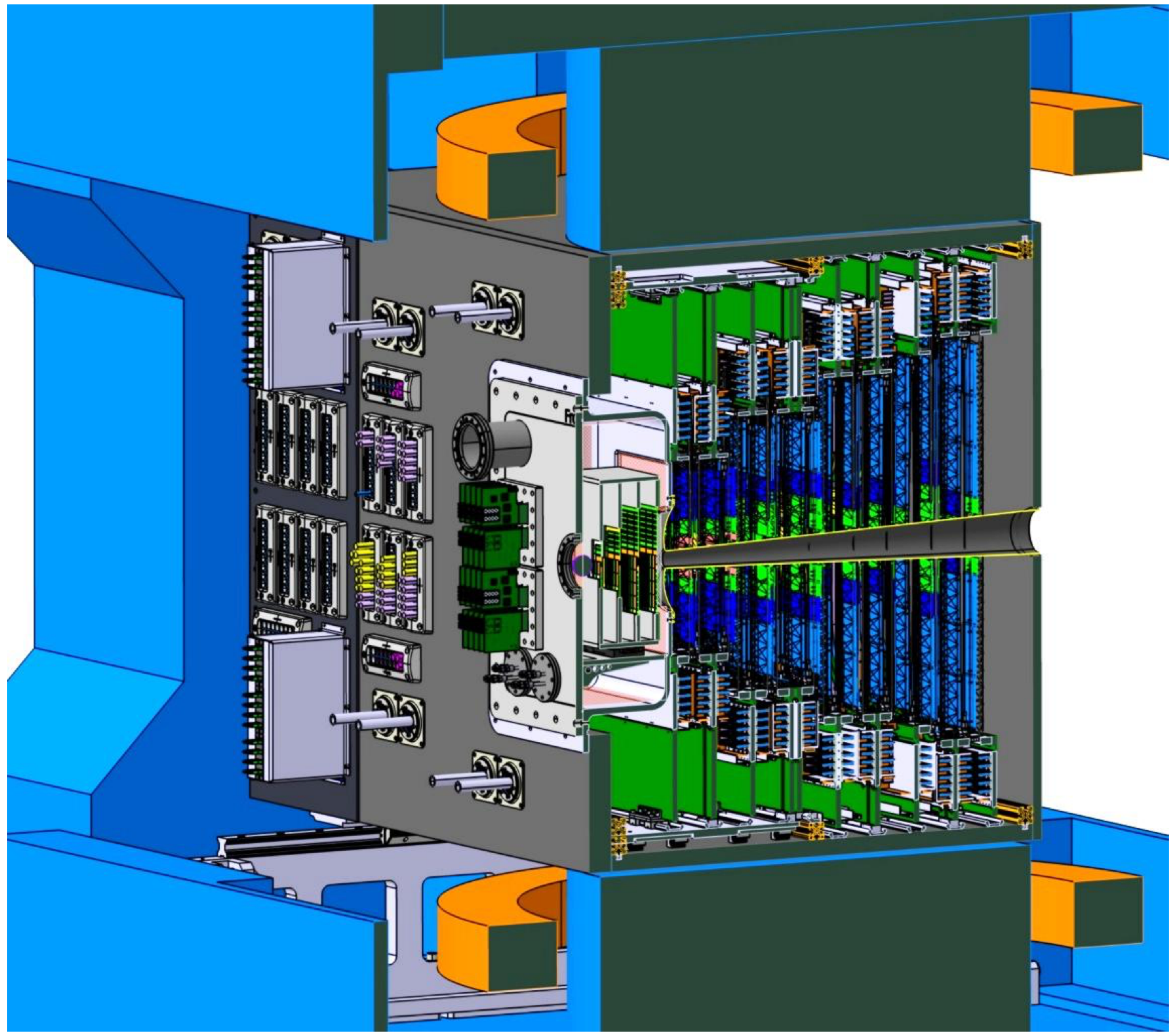
Cumulant:	**Factorial Cumulants:**
$\delta N = N - < N >$, *N is proton multiplicity in an event*	
$C_1 = \langle N \rangle$	$\kappa_1 = C_1$
$C_2 = \langle \delta N^2 \rangle$	$\kappa_2 = - C_1 + C_2$
$C_3 = \langle \delta N^3 \rangle$	$\kappa_3 = 2C_1 - 3C_2 + C_3$
$C_4 = \langle \delta N^4 \rangle - 3\langle \delta N^2 \rangle^2$	$\kappa_4 = - 6C_1 + 11C_2 - 6C_3 + C_4$

CBM Experiment



CBM detectors

1. Energy coverage $\sqrt{s_{NN}}$ = 2.4 - 4.9 GeV
2. Physics aperture of STS: $2.5 < \Theta < 25°$
   -> η acceptance: $1.5 < \eta < 3.8$



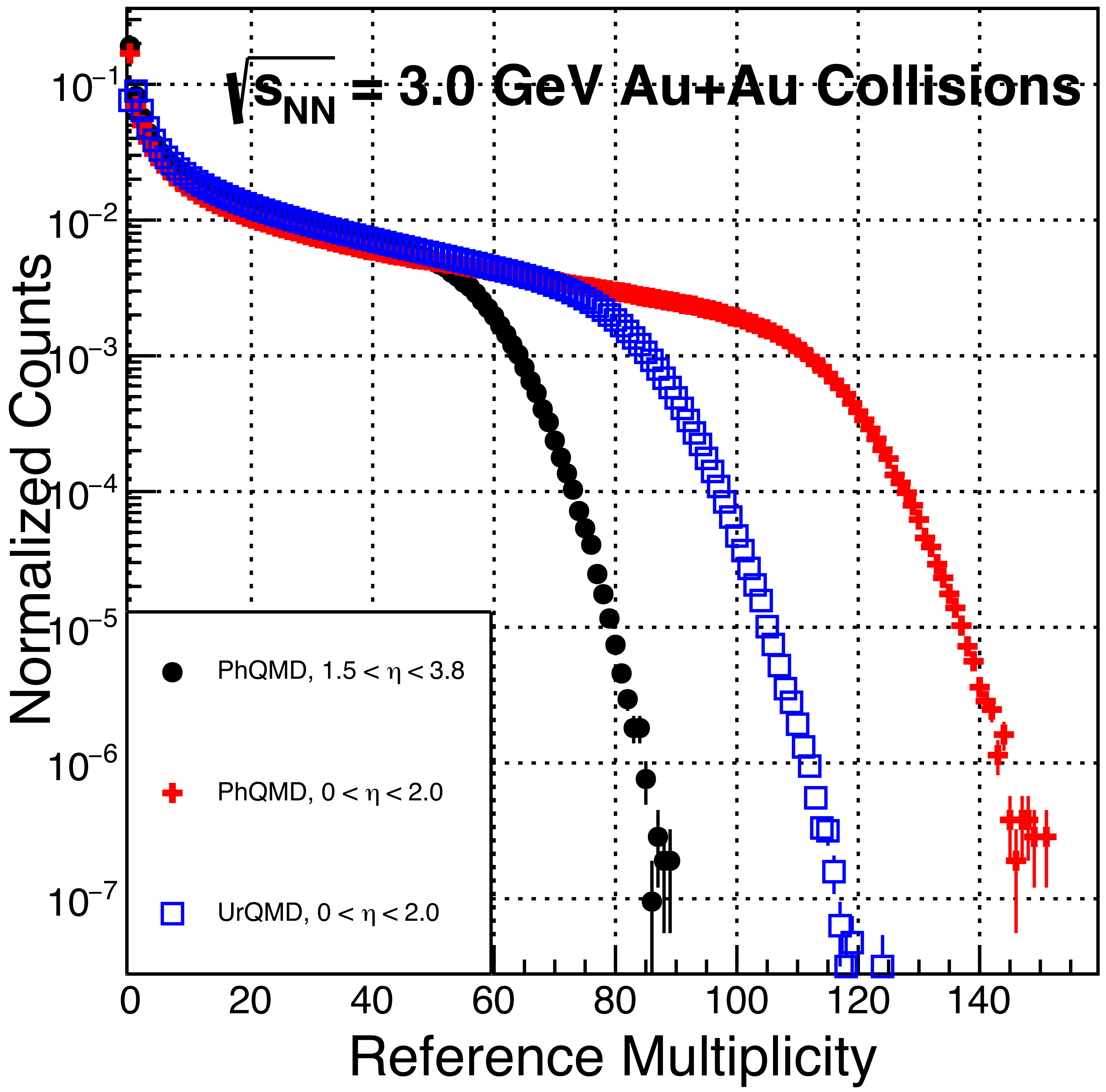
STS (Silicon Tracking System) detector

PhQMD and UrQMD Datasets

	PhQMD (Hard)	UrQMD
Mode	Meanfield	Cascade
Events	10M	60M
b (fm)	(0, 15)	(0, 16)

Collision Centrality Determination

CBM & STAR Eta Acceptance



Different centrality resolutions in each case!

Centrality	PhQMD		UrQMD
Eta	(1.5, 3.8)	(0, 2.0)	
	Reference Multiplicity		
0-5%	(49,-)	(93,-)	(67,-)
5-10%	(41,48)	(77,92)	(55,66)
10-20%	(28,40)	(53,76)	(38,54)
20-30%	(19,27)	(36,52)	(26,37)
30-40%	(12,18)	(23,35)	(17,25)
40-50%	(8,11)	(15,22)	(11,16)
50-60%	(5,7)	(9,14)	(7,10)

Reference multiplicity is all charged π and kaon

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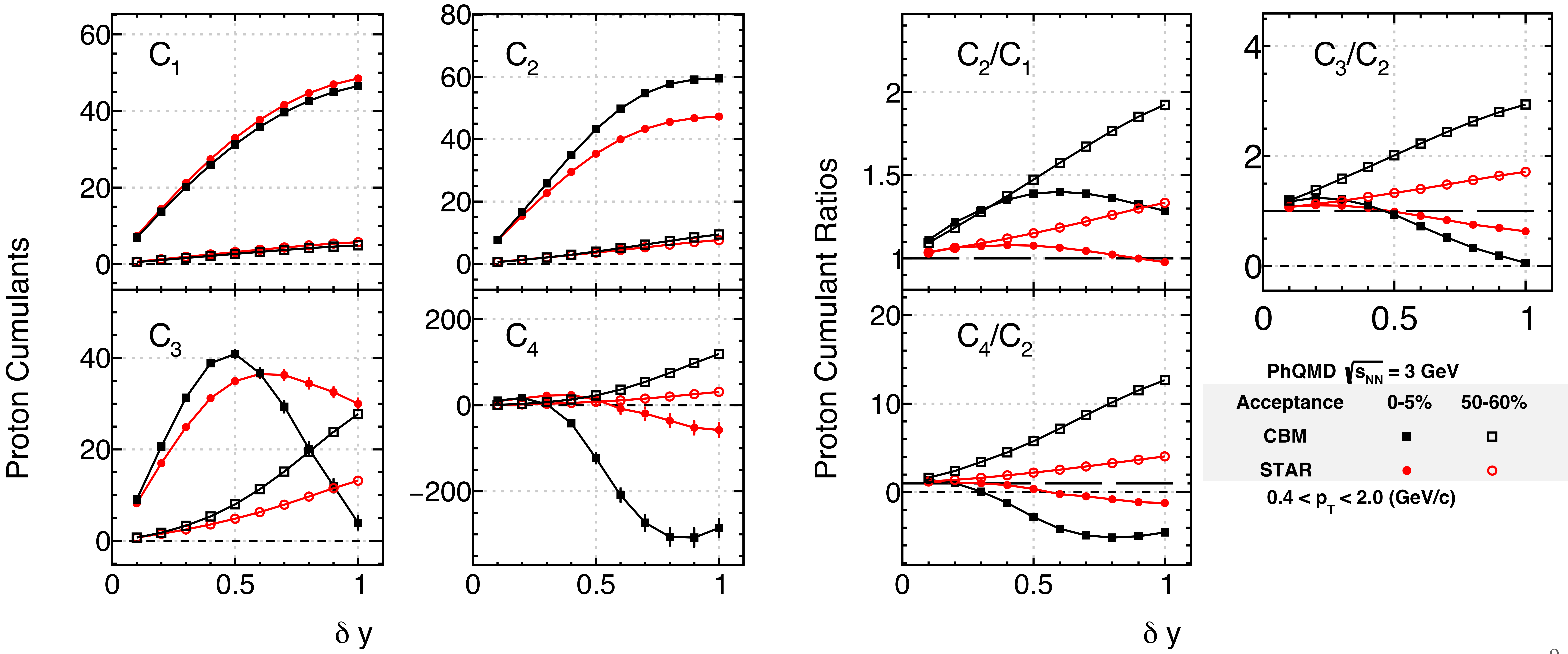
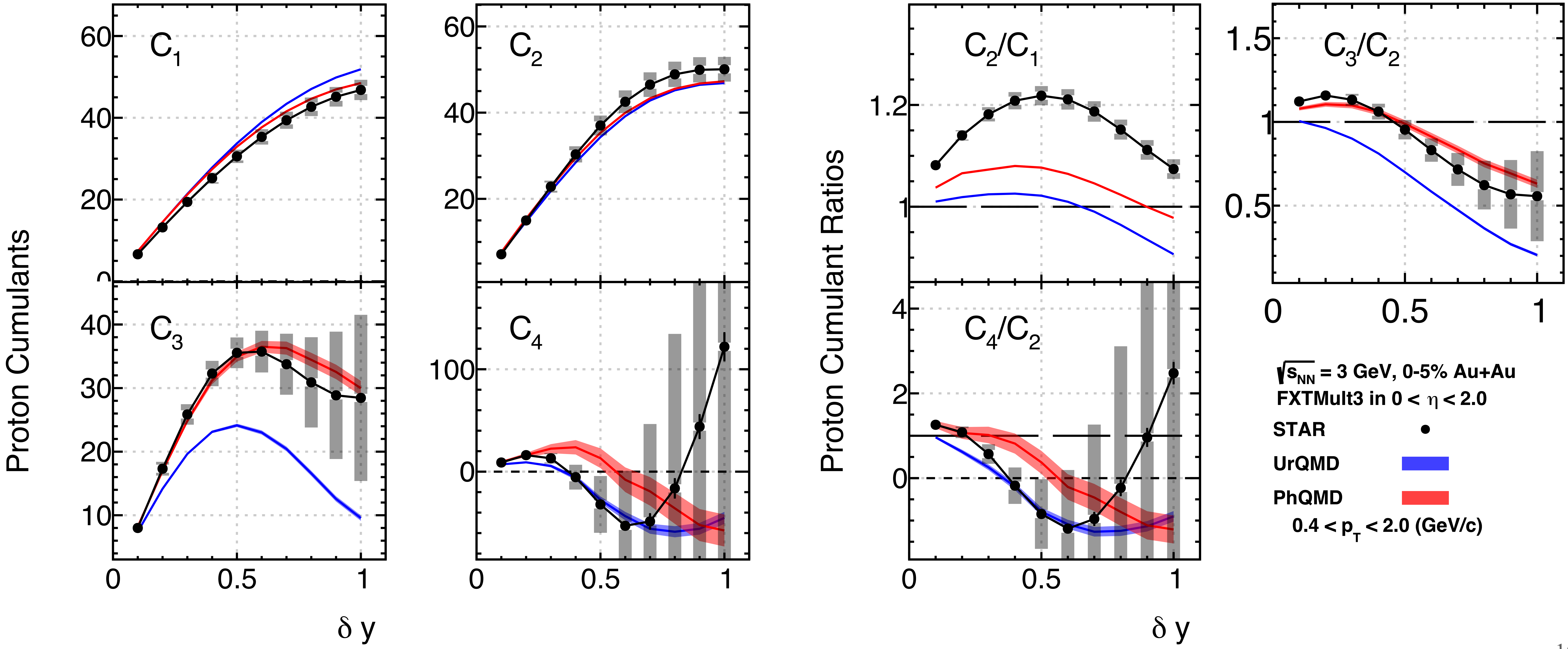
Rapidity Dependence of Proton Cumulants

1. Two results have a similar trend in rapidity dependence

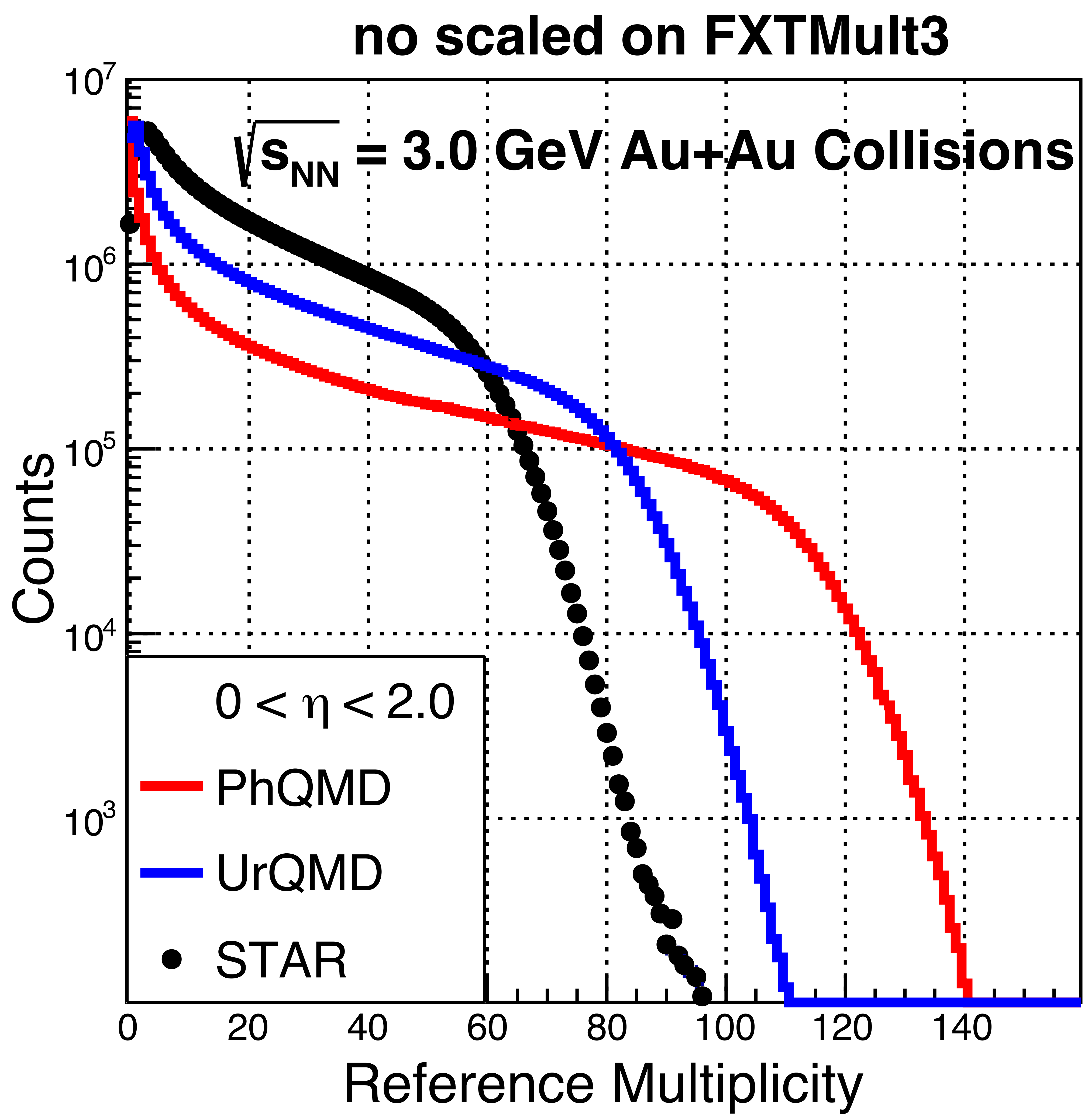


Rapidity Dependence of Proton Cumulants

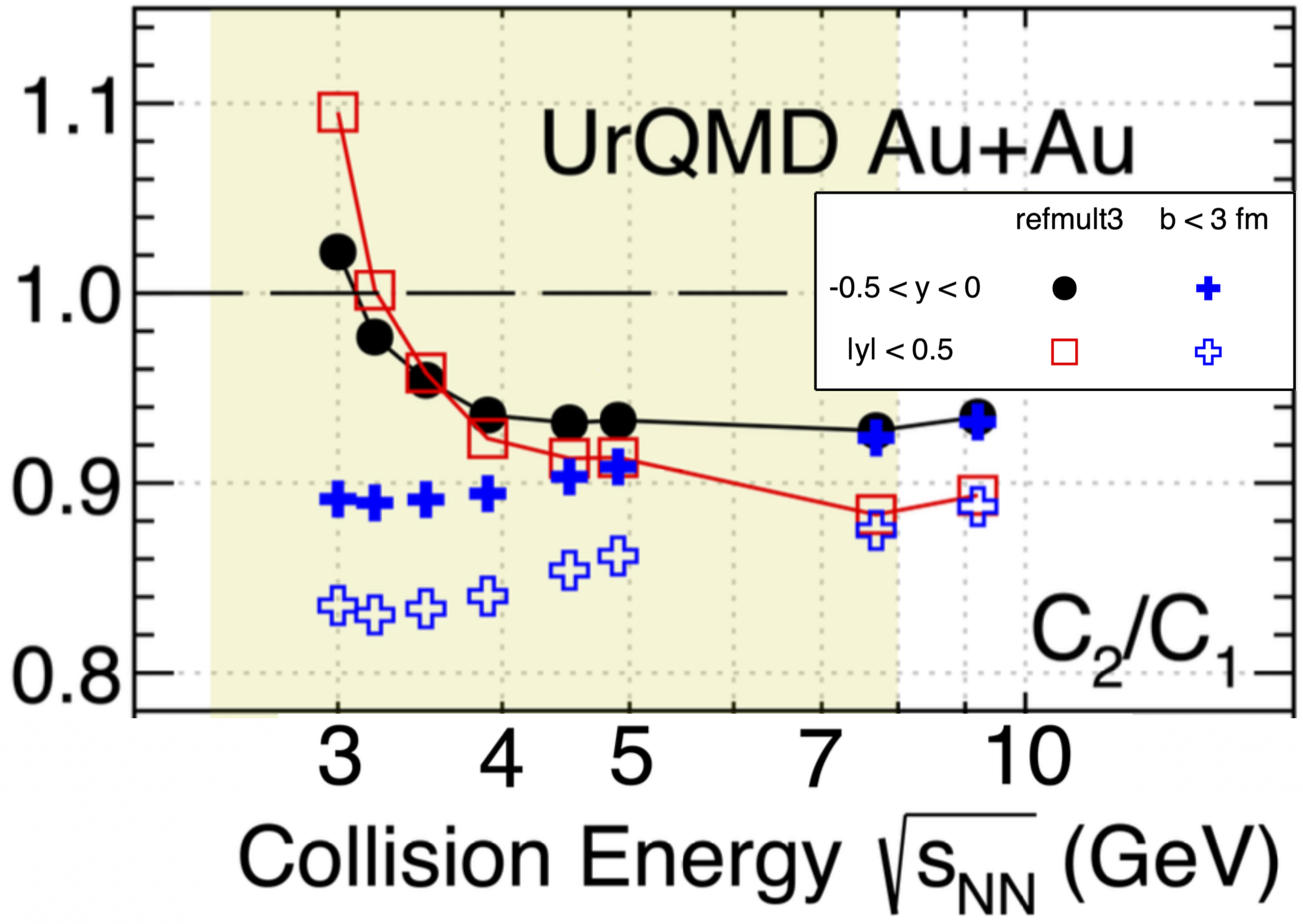
1. For both PhQMD and UrQMD models, two results also have a similar trend in rapidity dependence
2. Both PhQMD and UrQMD results can describe the trend of the data



Reference Multiplicity Distribution



1. Initial volume fluctuation is crucial, especially at $\sqrt{s_{NN}}$ = 3 GeV (high baryon density)



Reference multiplicity is all charged π and kaon

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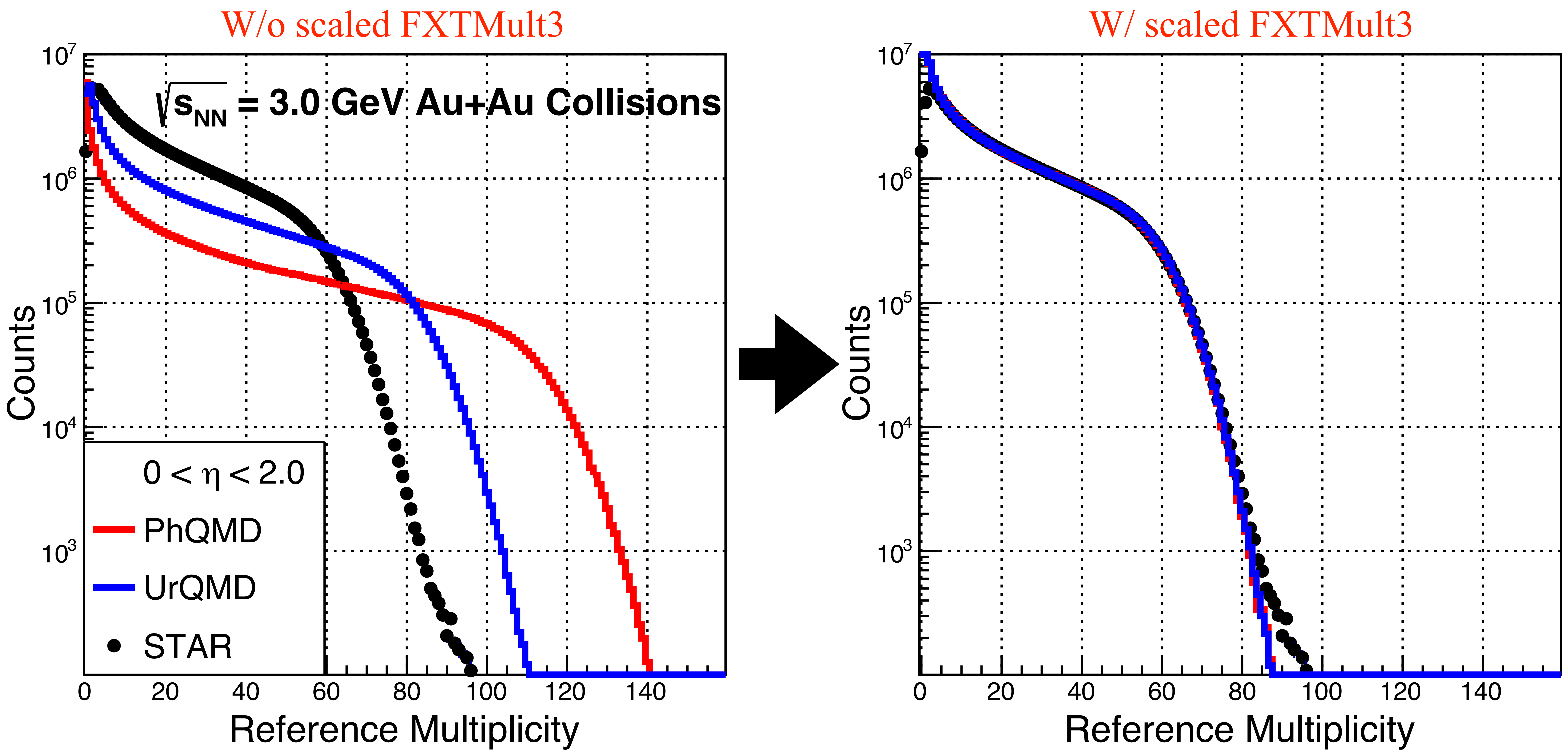
Reference Multiplicity Distribution

Scaled method:
For all pions and kaons in 0 < eta < 2.0
1. Sample a random number x in (0,1)
2. If x < best ratio, FXTMult3++

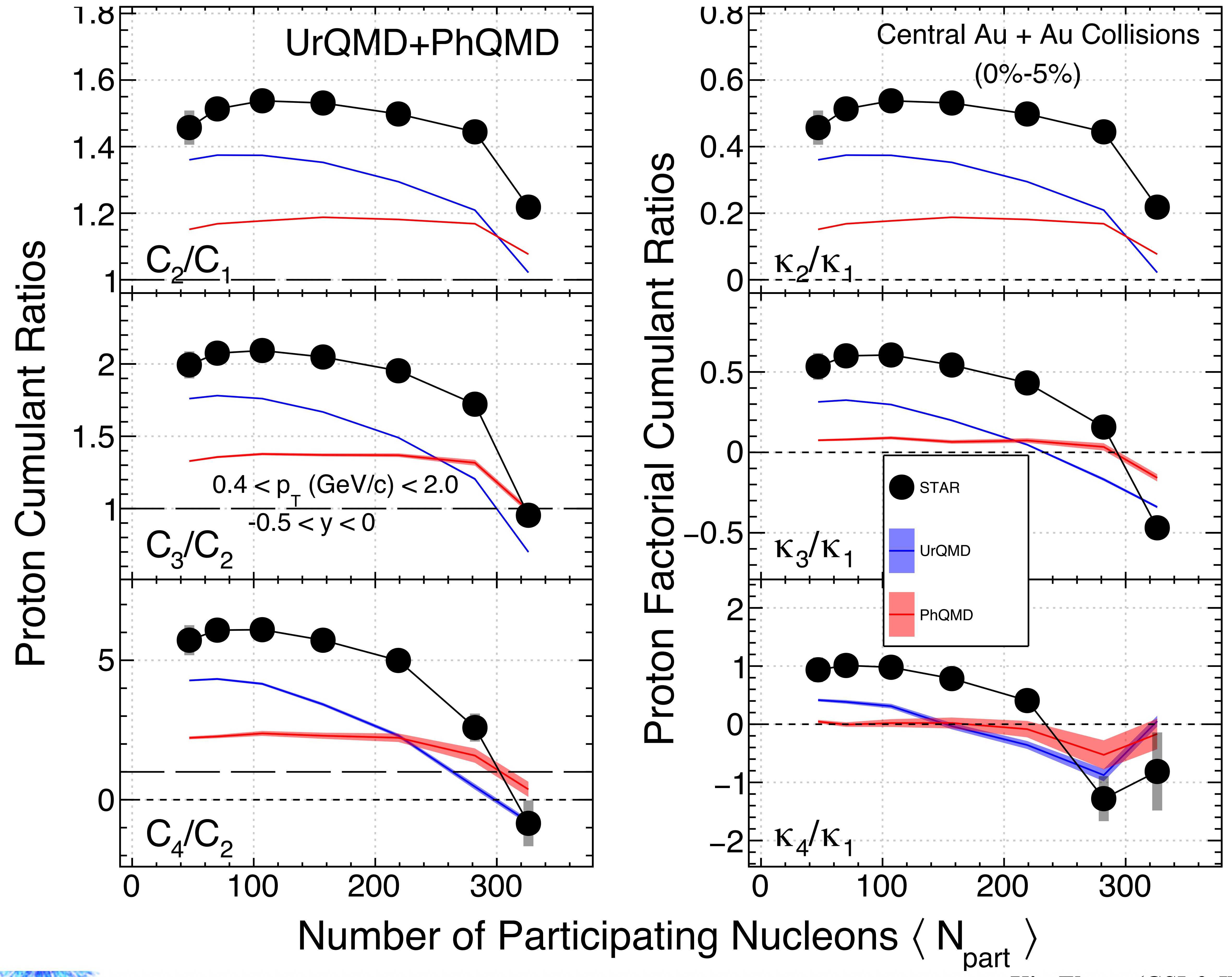
1. Reference multiplicity is scaled in order to make centrality resolution similar to experimental data



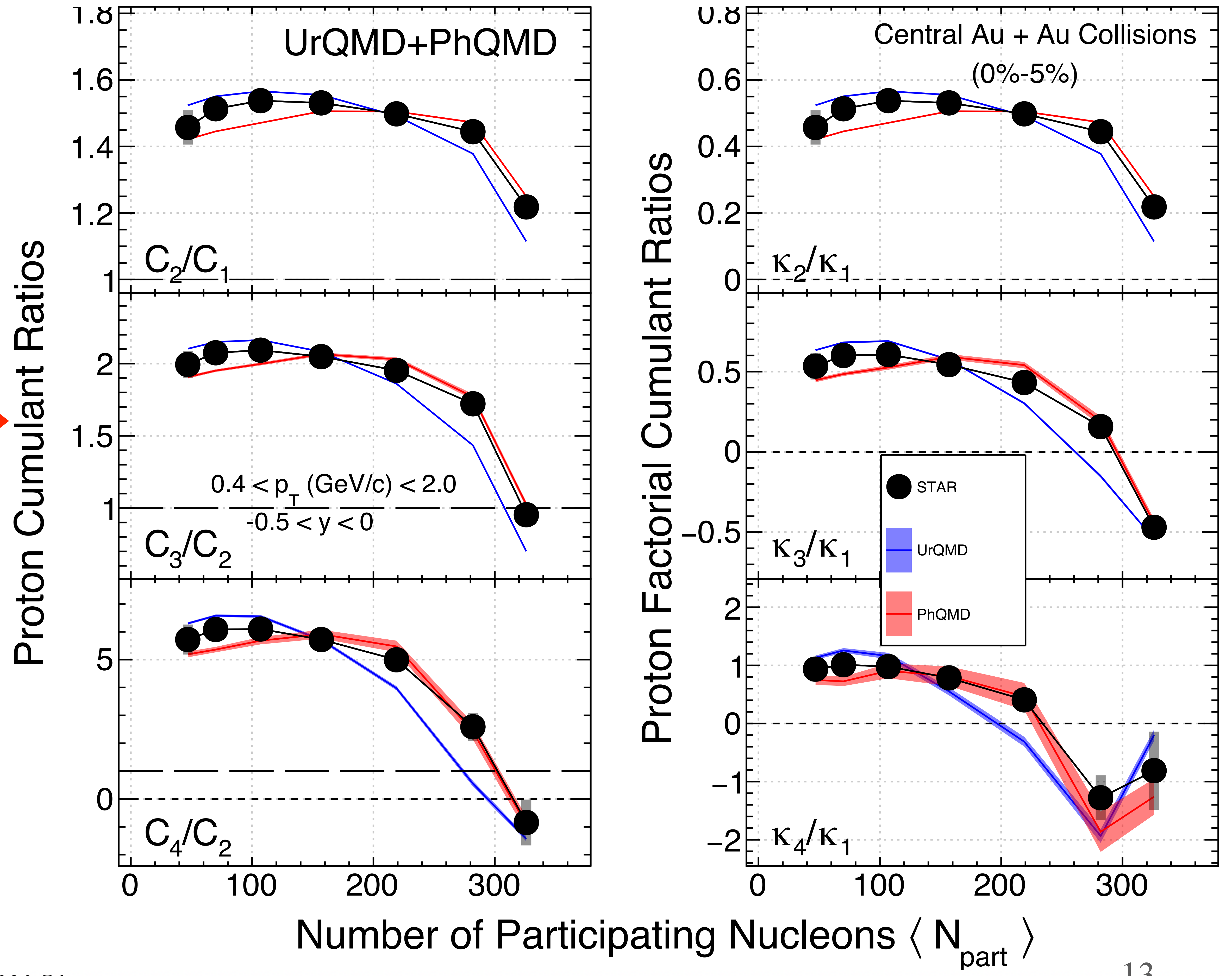
Centrality Dependence of Proton Cumulant and Factorial Cumulant Ratios

1. After scaling on FXTMult3, UrQMD and PhQMD can better describe the data

W/o scaled FXTMult3



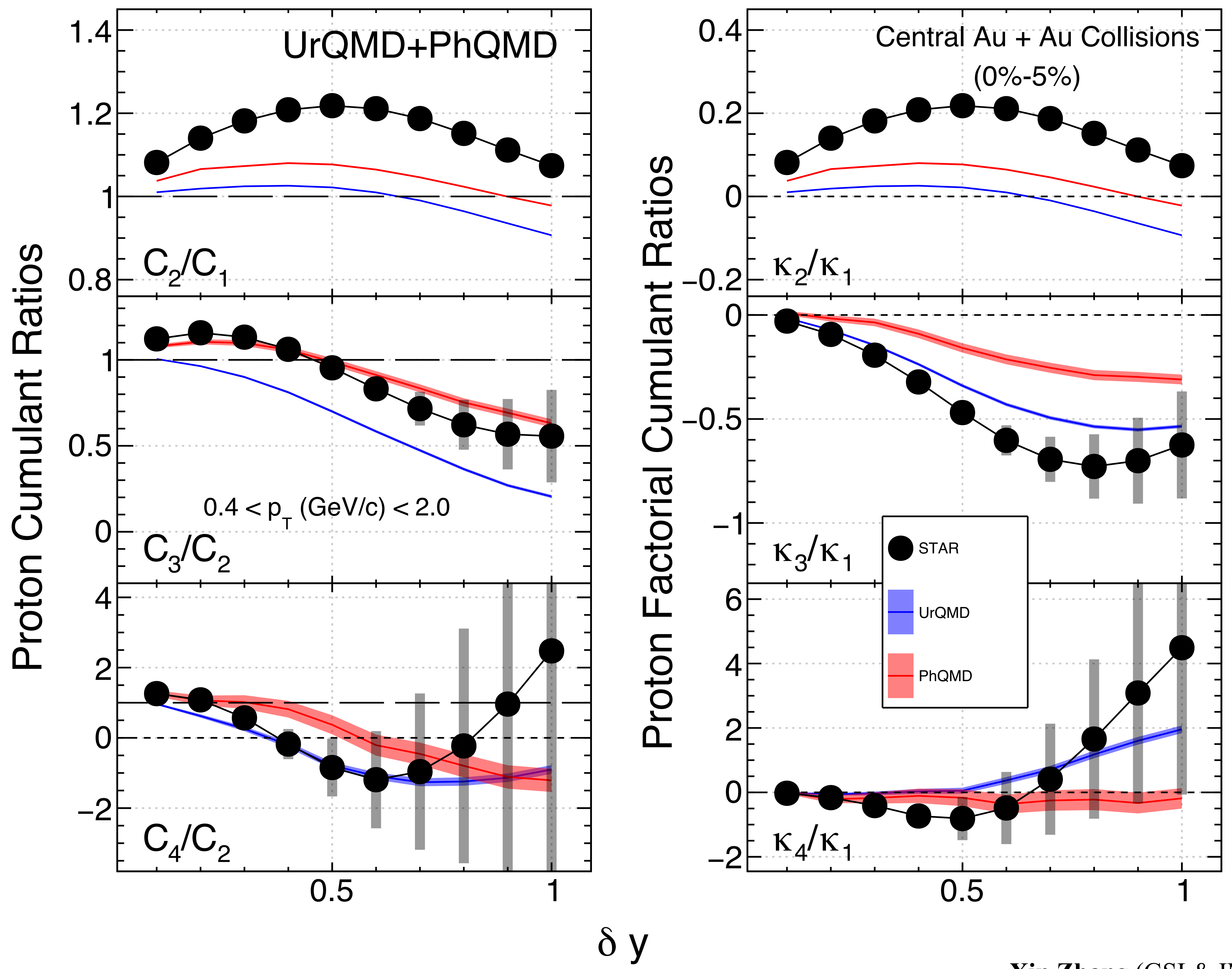
W/ scaled FXTMult3



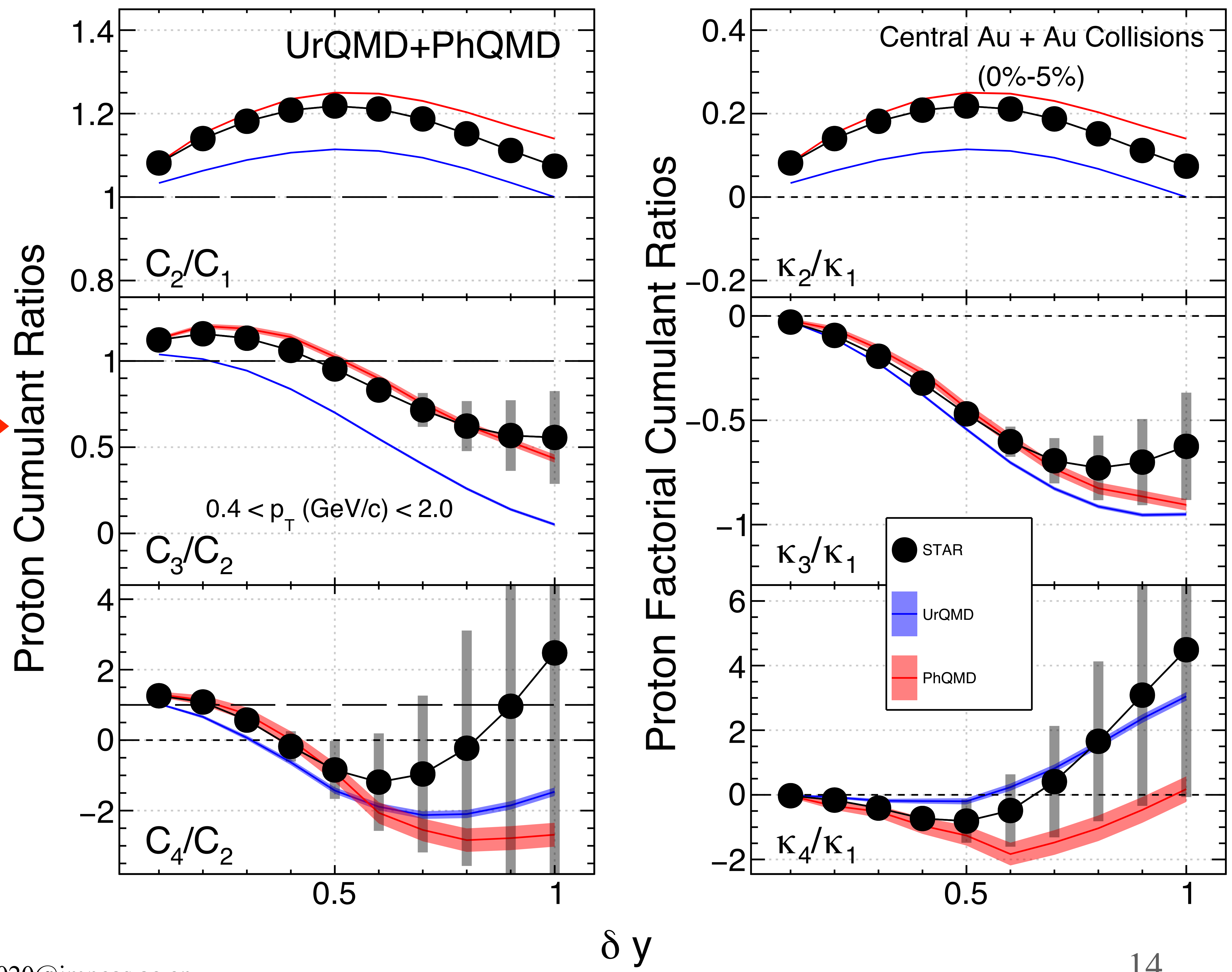
Rapidity Dependence of Proton Cumulant and Factorial Cumulant Ratios

1. After scaling on FXTMult3, UrQMD and PhQMD can better describe the data
2. Discrepancies are observed at large δy, where the data also have sizable systematic uncertainties

W/o scaled FXTMult3

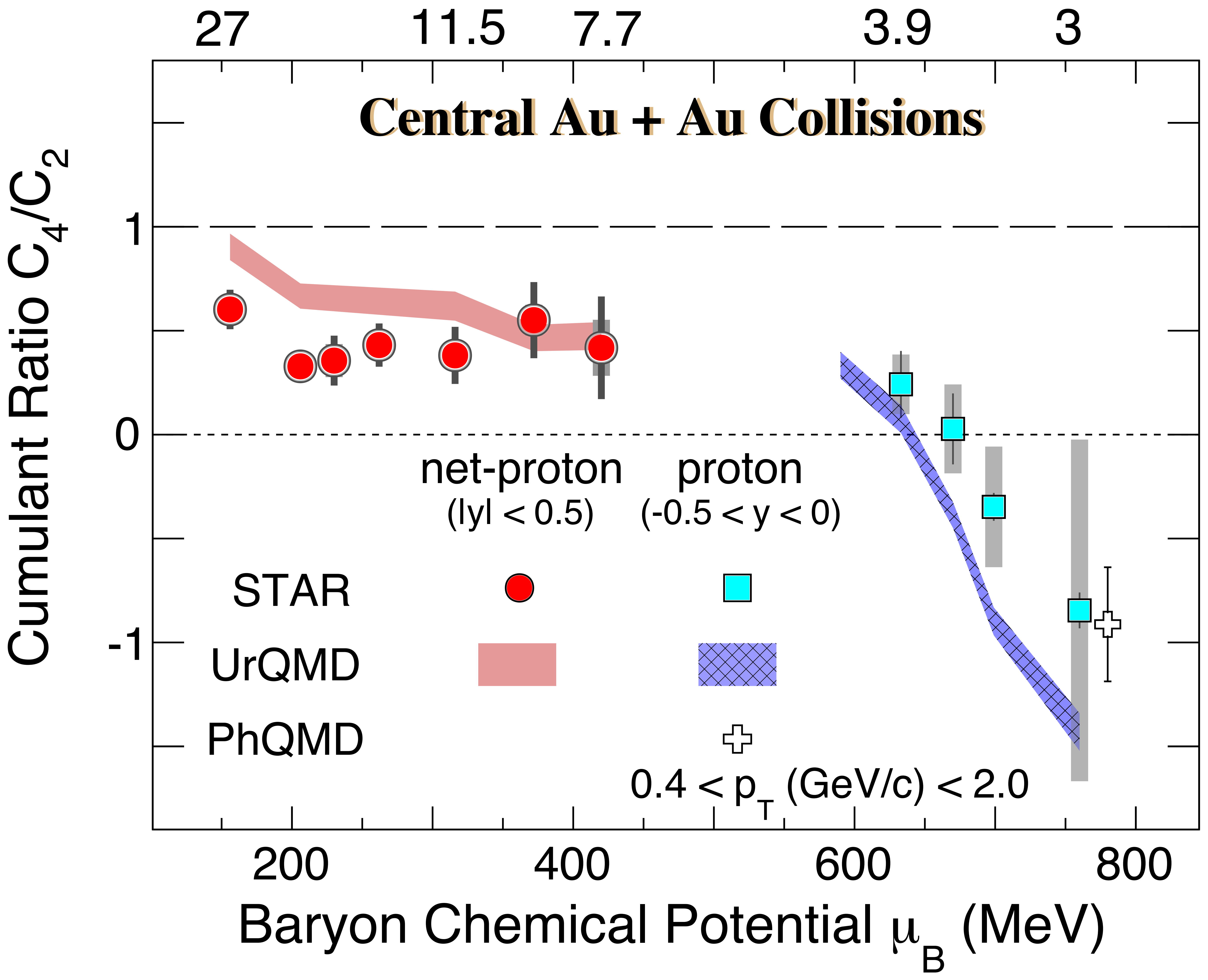


W/ scaled FXTMult3



Energy Dependence of (Net-) Proton C_4/C_2

1. Both UrQMD and PhQMD are consistent with data at $\sqrt{s_{NN}} = 3$ GeV, within the systematic uncertainty



Zachary Sweger, QM25

Summary and To-Do List

Summary:

1. We applied a new method in model (PhQMD and UrQMD) calculations: scale FXTMult3 in order to make centrality resolution similar to STAR data
2. In energy dependence, PhQMD and UrQMD are consistent with STAR data at $\sqrt{s_{NN}} = 3$ GeV
3. In rapidity dependence, discrepancies are observed at large δy, where the data also have sizable systematic uncertainties

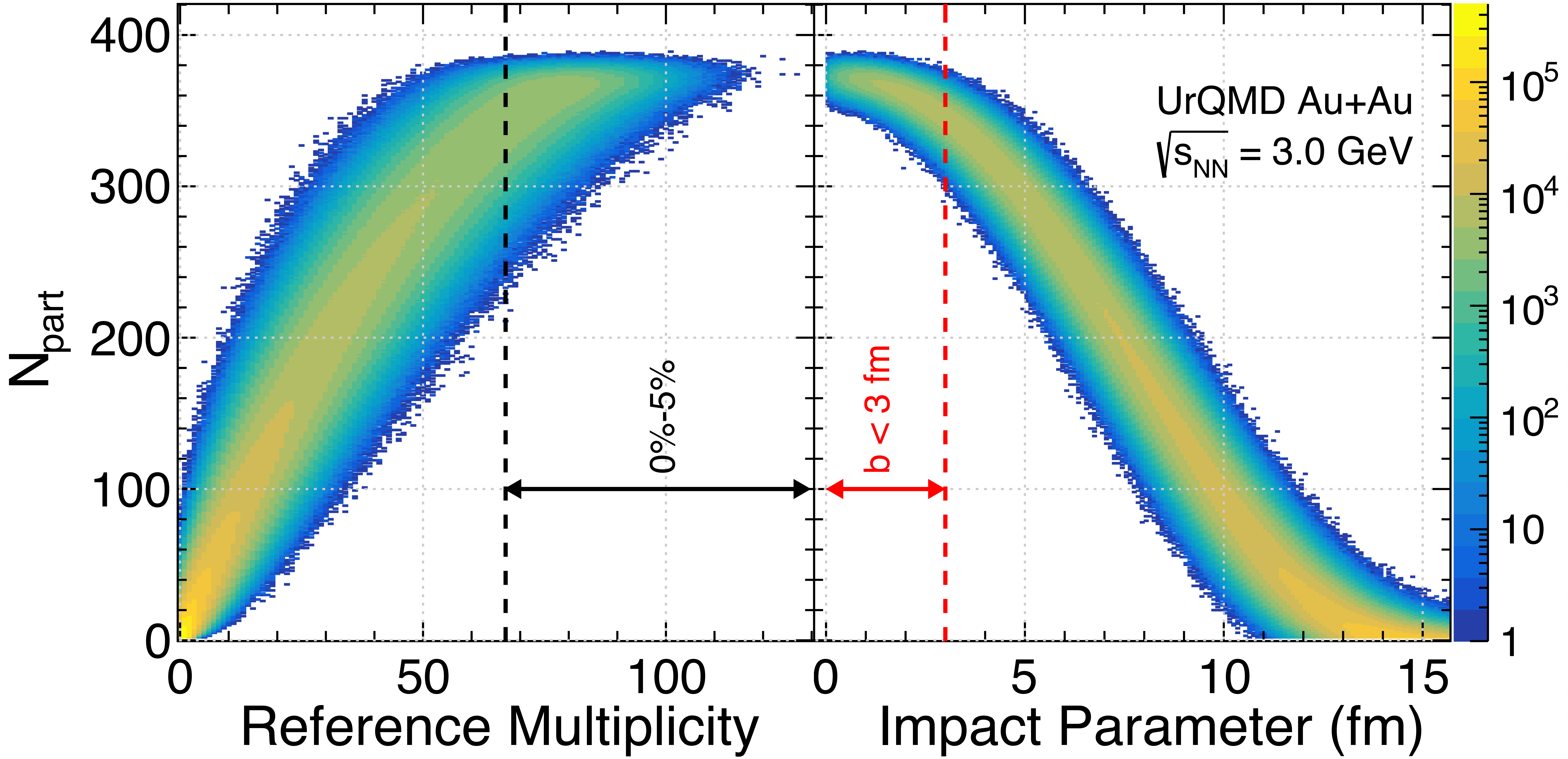
Thank you!

To-Do List:

1. PhQMD model calculations at $\sqrt{s_{NN}} = 3.2\text{-}19.6$ GeV
2. Initial Volume Fluctuation Correction in both UrQMD and PhQMD calculations

BACKUP

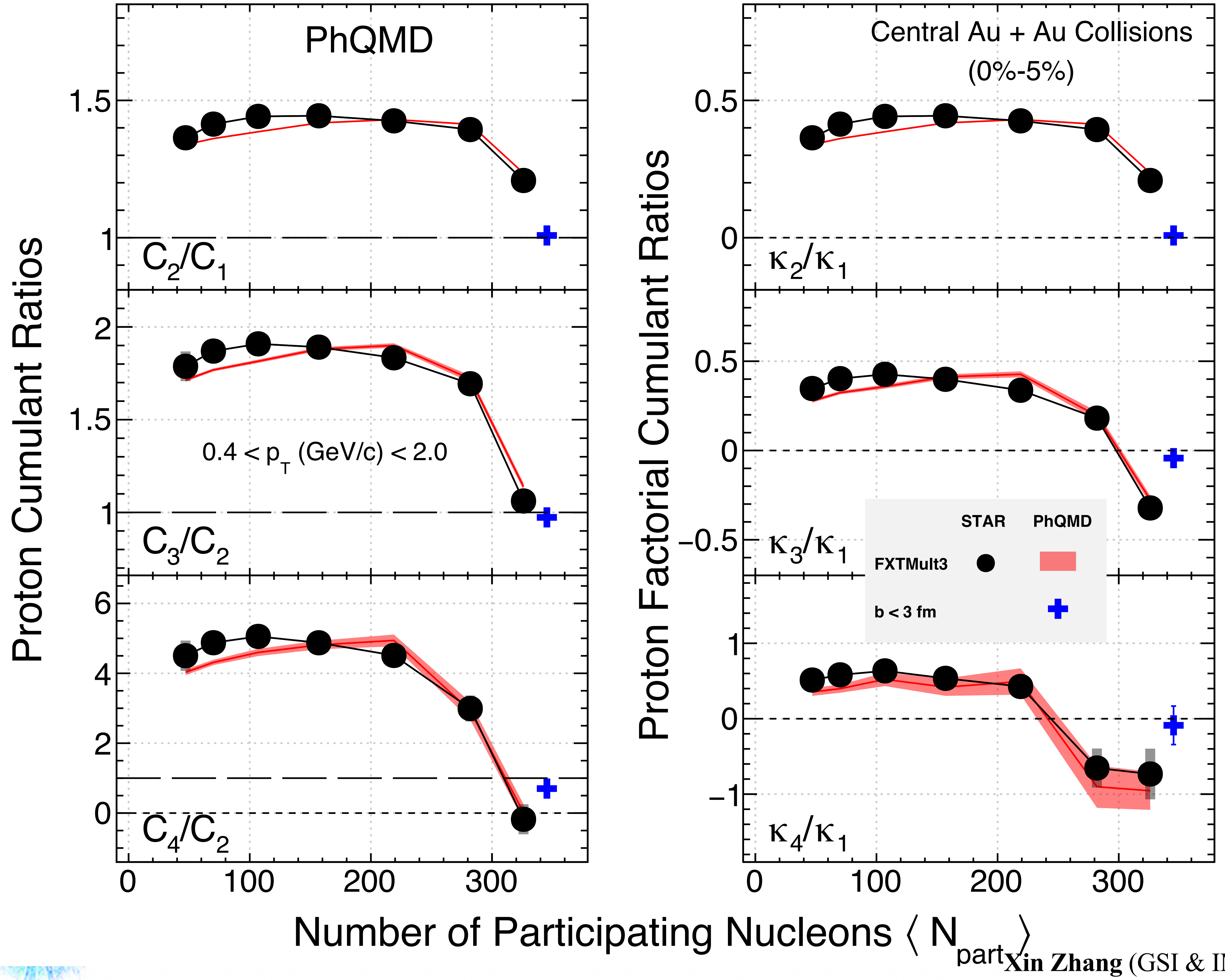
Npart Vs. Reference Multiplicity & Impact Parameter



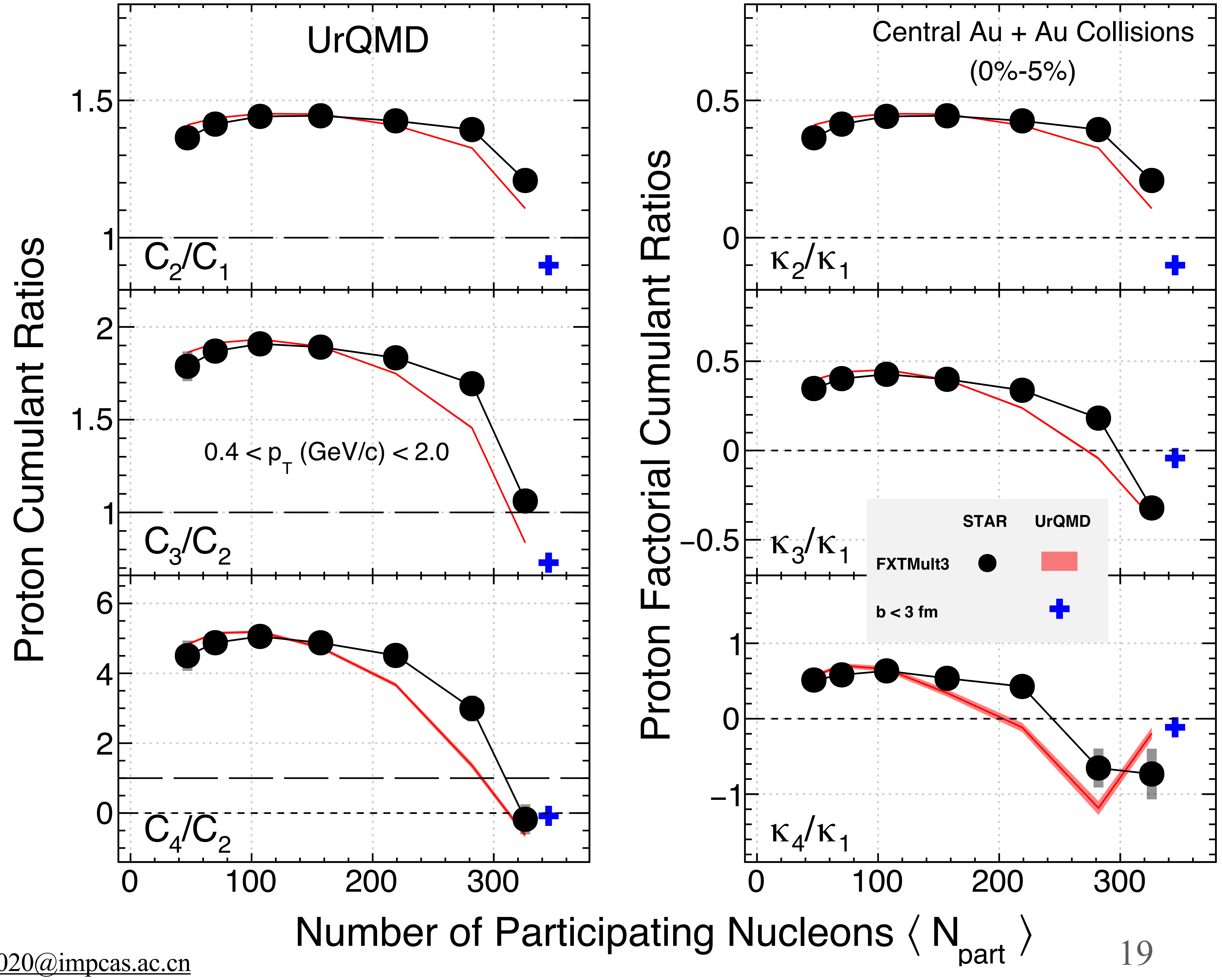
Centrality Dependence of Proton Cumulant and Factorial Cumulant Ratios

1. For ratio κ_2/κ_1, PhQMD b < 3 fm is positive, while UrQMD b < 3 fm is negative
2. For ratio C_4/C_2, PhQMD b < 3 fm is positive

PhQMD



UrQMD



Rapidity Dependence of Proton Cumulant and Factorial Cumulant Ratios

1. For ratio κ_2/κ_1, PhQMD b < 3 fm is positive while δy < 0.5 (While UrQMD b < 3 fm is always negative)

PhQMD

UrQMD