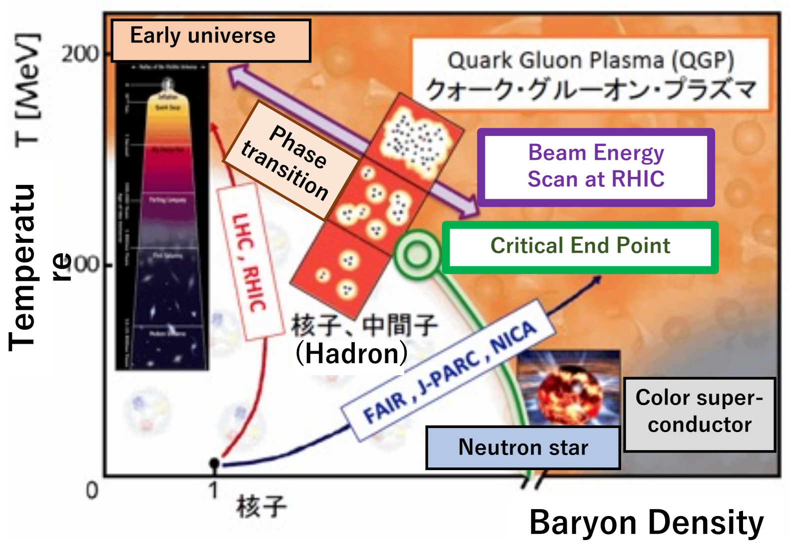
Fluactuation analysis and results from STAR BES-I including results from Fixed Target (FXT) Run



ShinIchi Esumi

Institute of Physics, University of Tsukuba
Tomonaga Center for the History of the Universe (TCHoU)

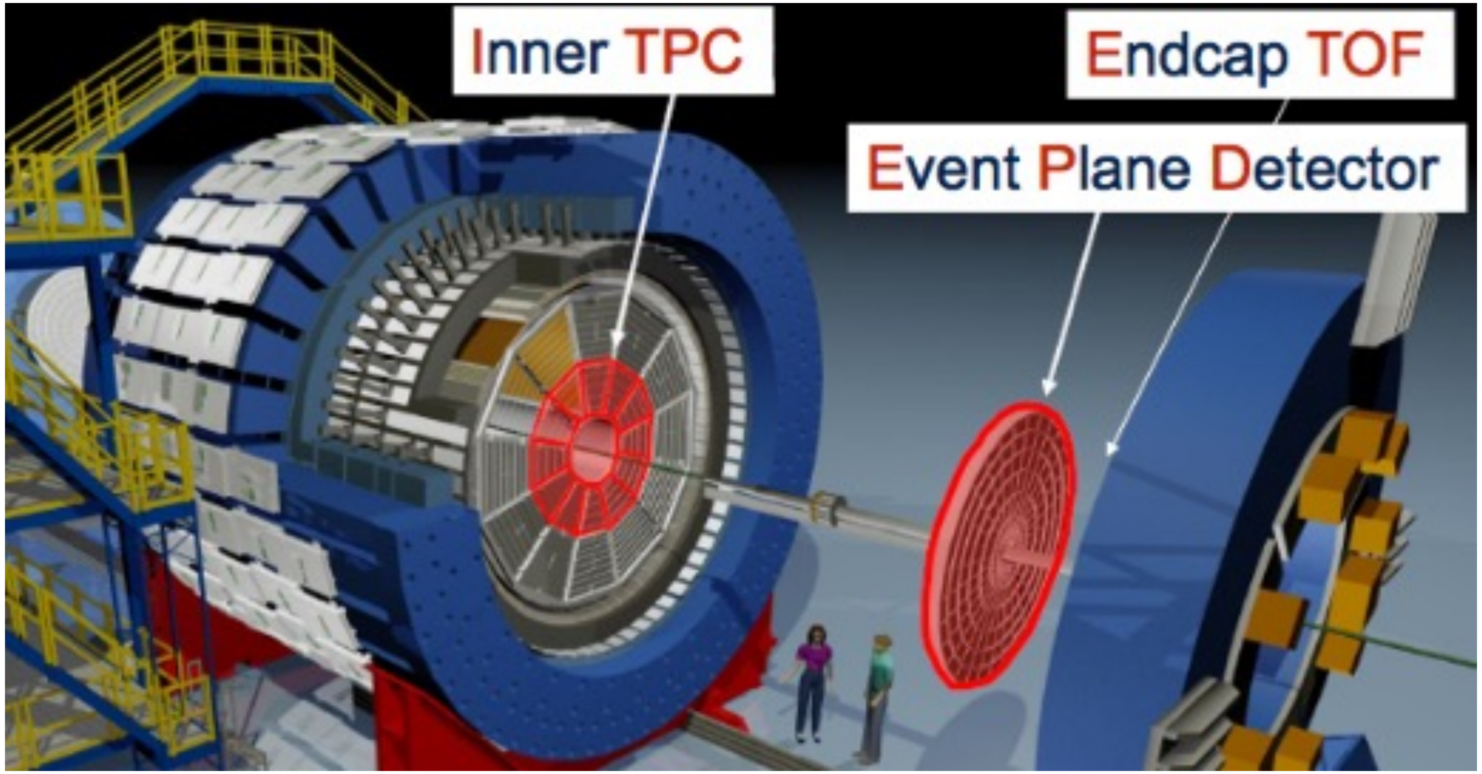
- Experimental pile-up removal and/or correction
- Tracking efficiency corrections
- Centrality determination and volume fluctuation
- Acceptance and beam energy dependence

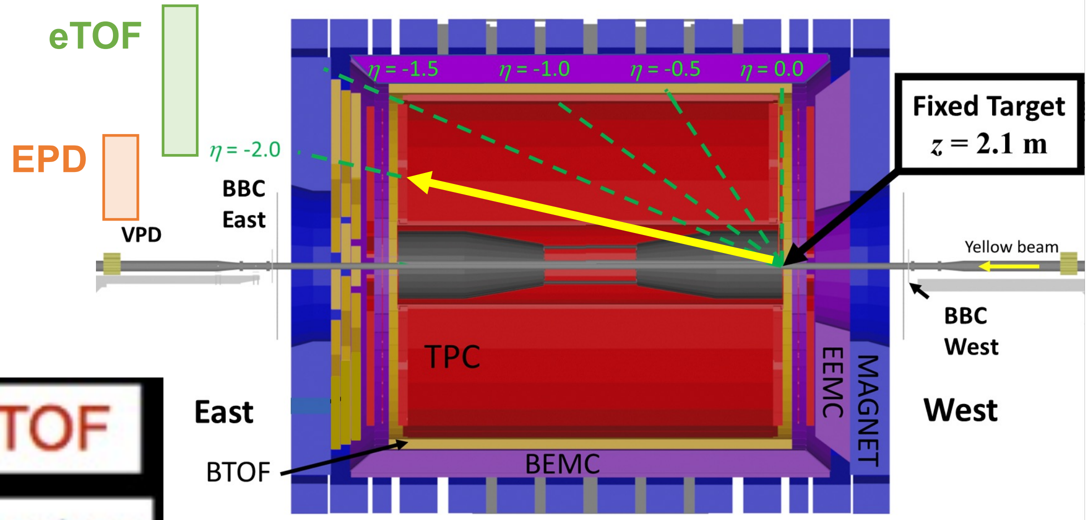
The STAR experiment at the Relativistic Heavy Ion Collider, Brookhaven National Laboratory

筑波大学 宇宙史研究センター Tomonaga Center for the History of the Universe

筑波大学 University of Tsukuba

STAR experiment and BES-II upgrades

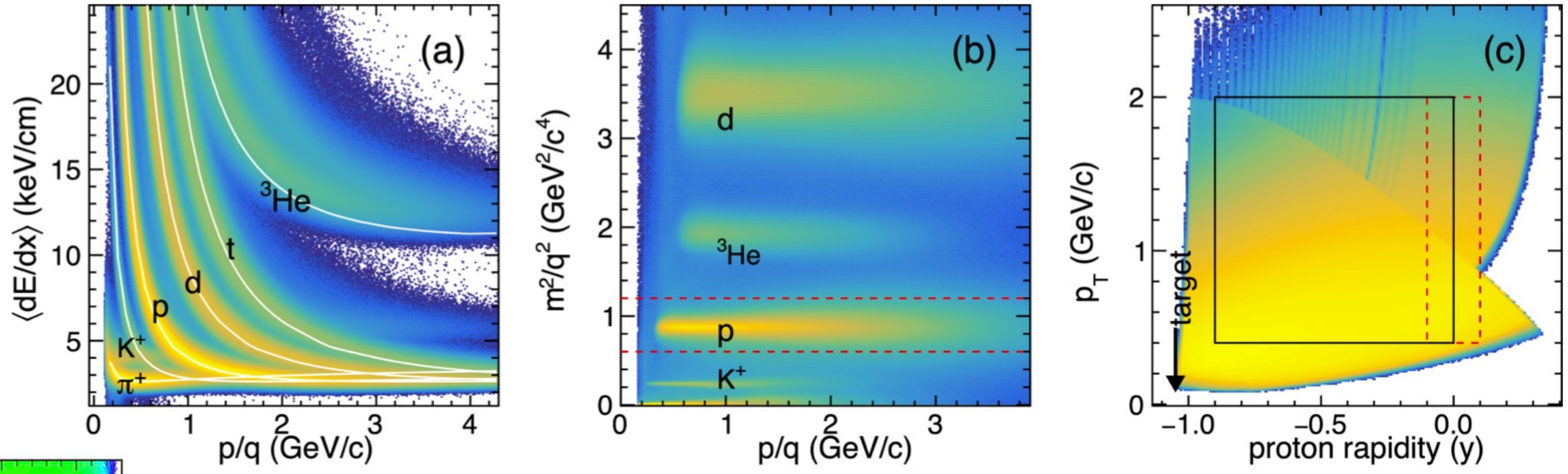




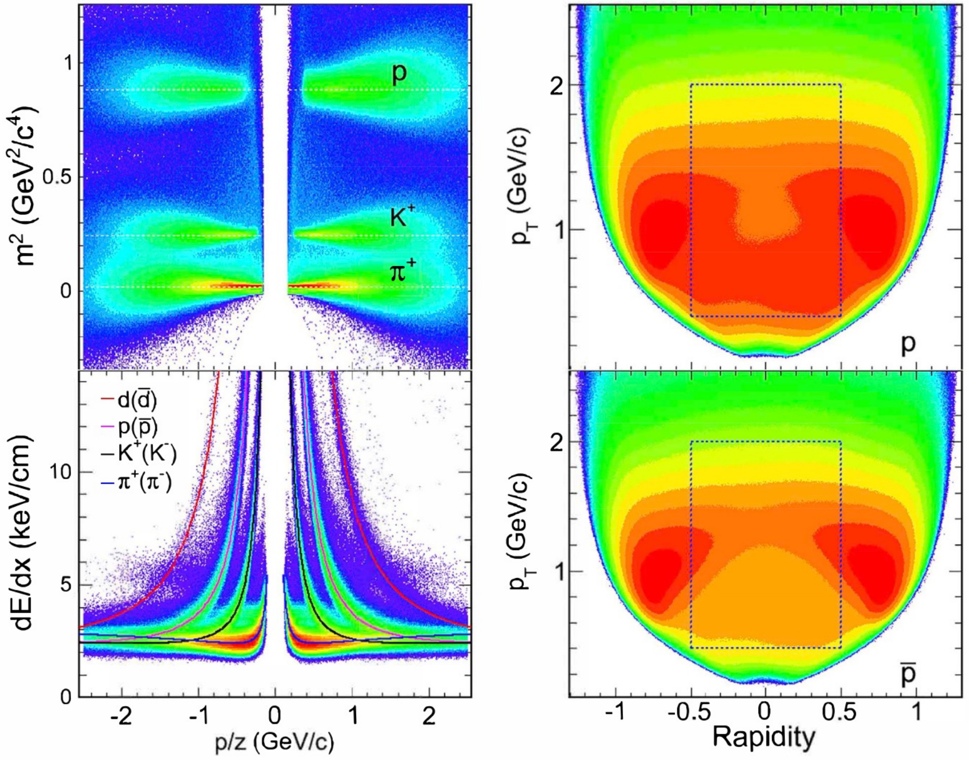
FXT mode experimental setup

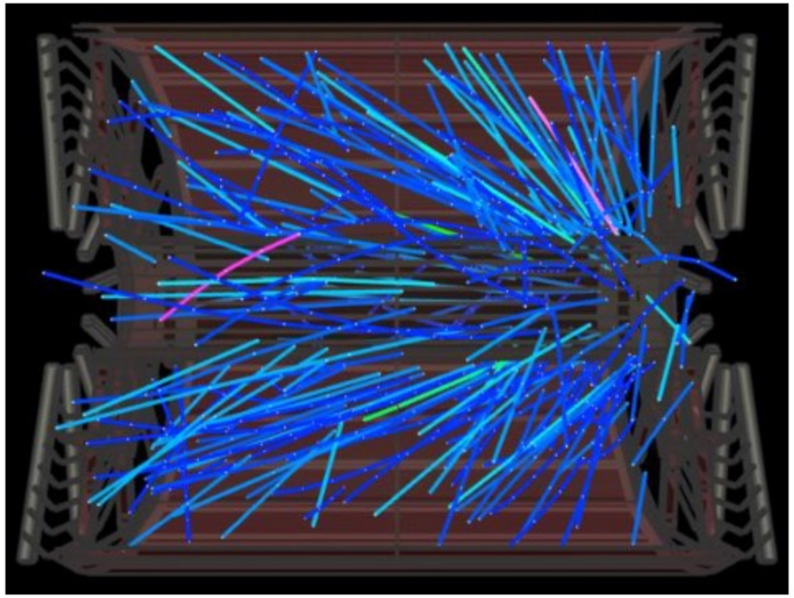
Particle identification and acceptance

Au+Au 3 GeV



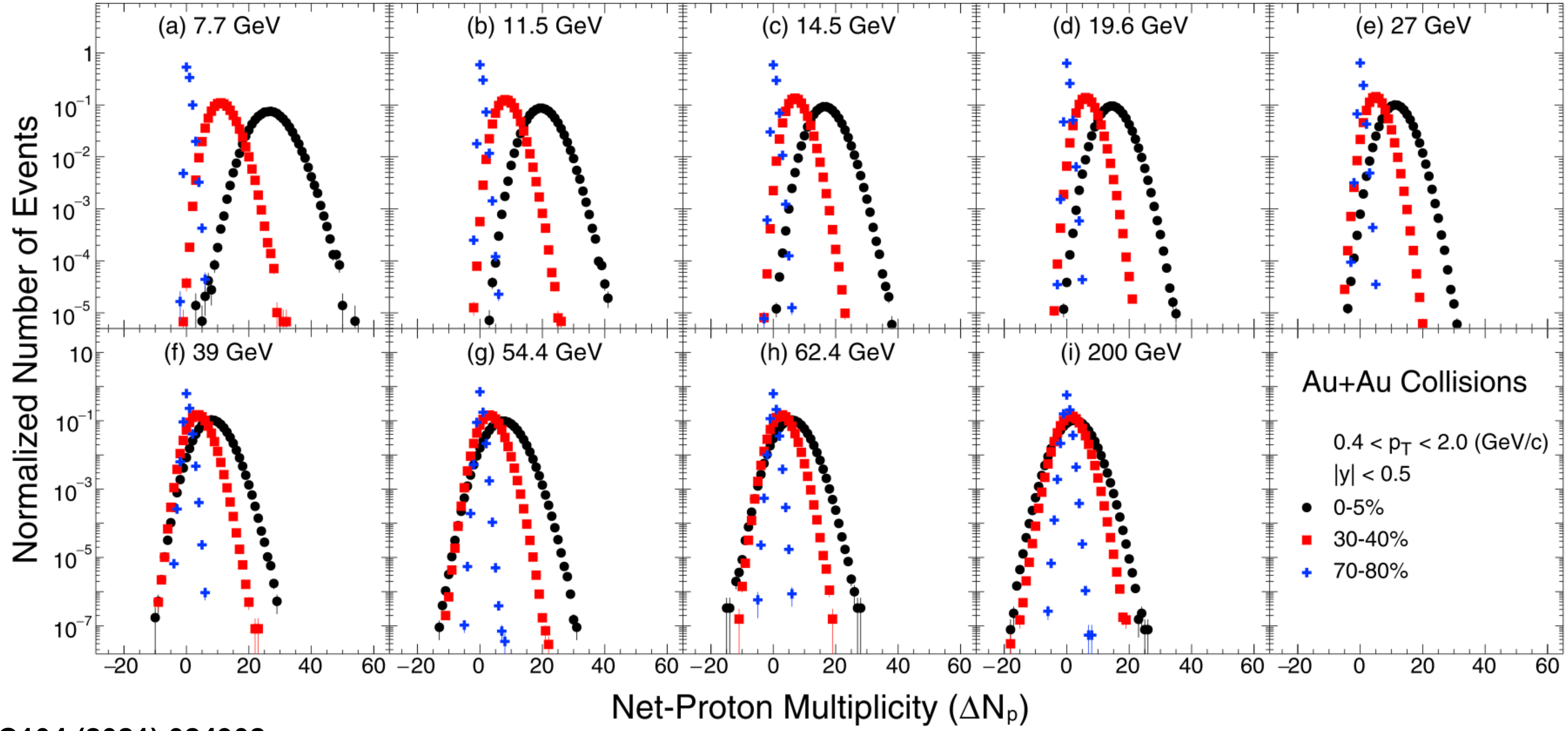
Au+Au 39 GeV





Measured (un-corrected) (net-) proton distribution

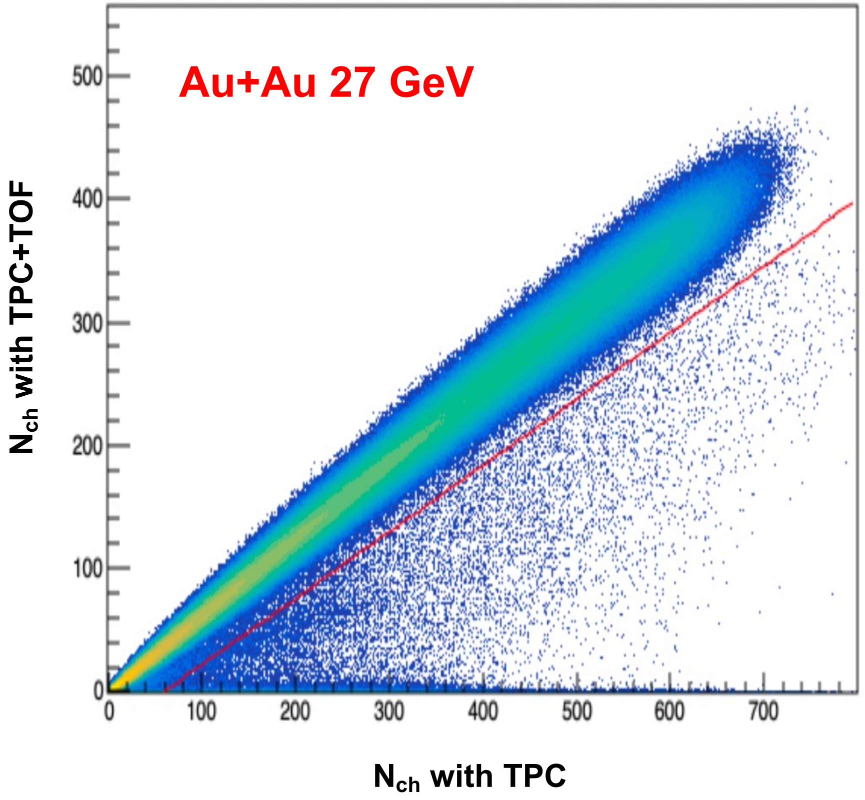
BES-I

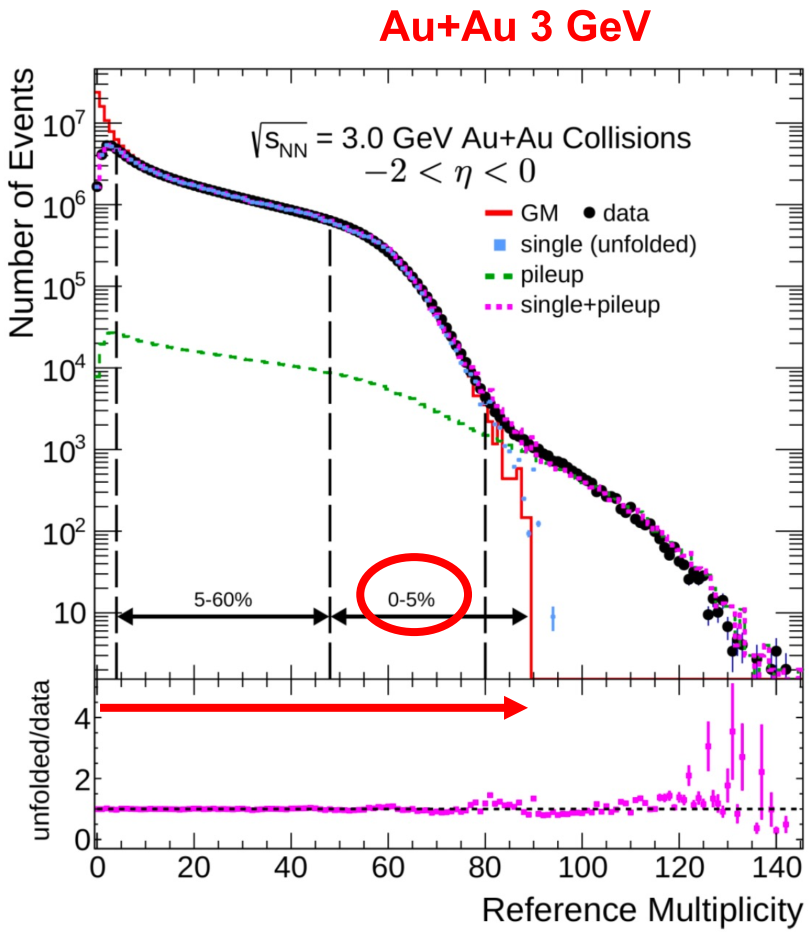


PRC104 (2021) 024902

PRC107 (2023) 024908
NIM A 984 (2020) 164632
NIM A 1026 (2022) 166246

Pile-up events from high rate measurements

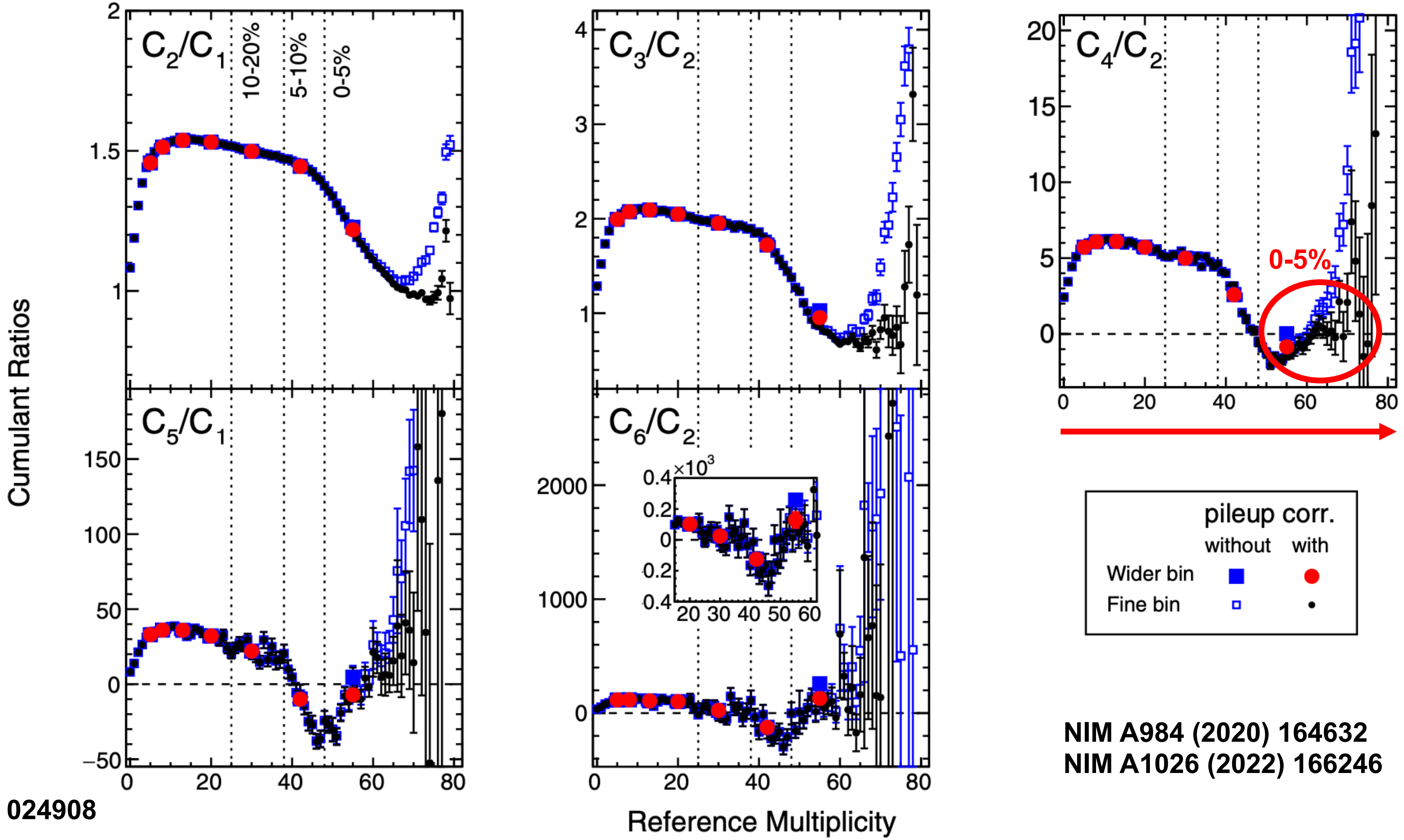




- independent superposition of two collisions
- with/without TOF hit requirement
- pile-up correction (next slide)

With/without pile-up correction on cumulant ratio

Au+Au 3 GeV

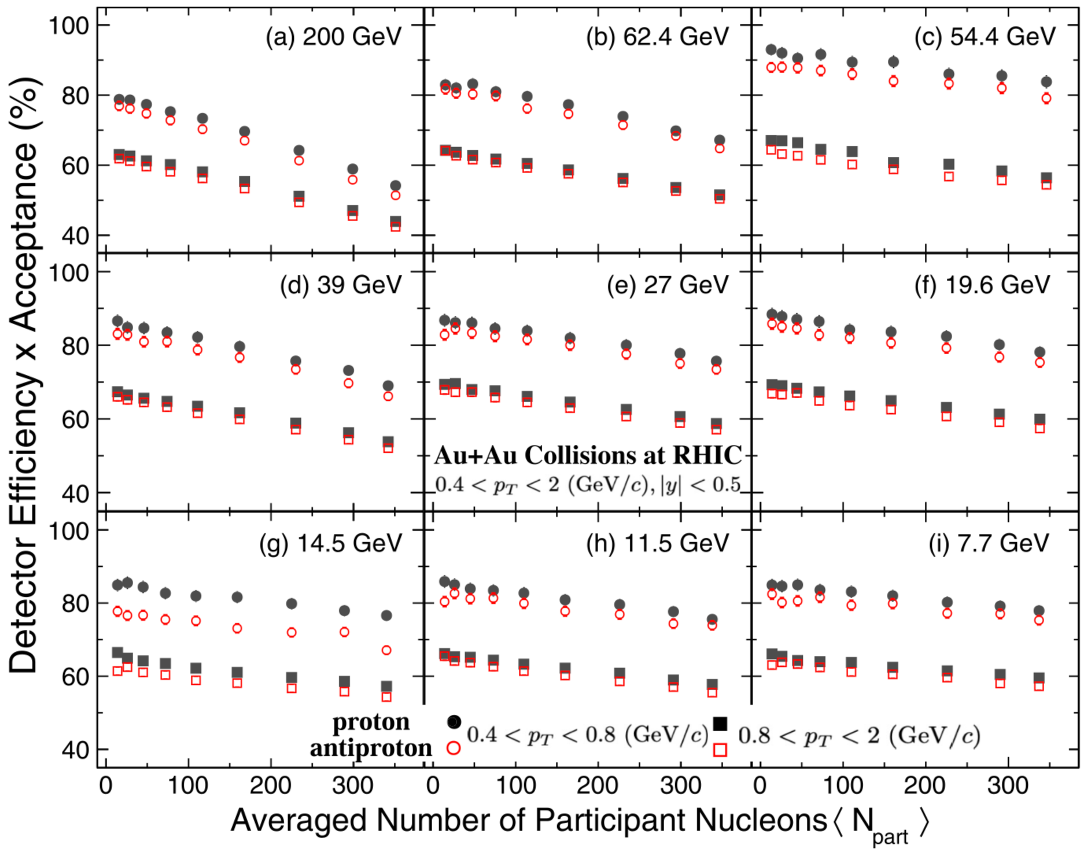


NIM A984 (2020) 164632
NIM A1026 (2022) 166246

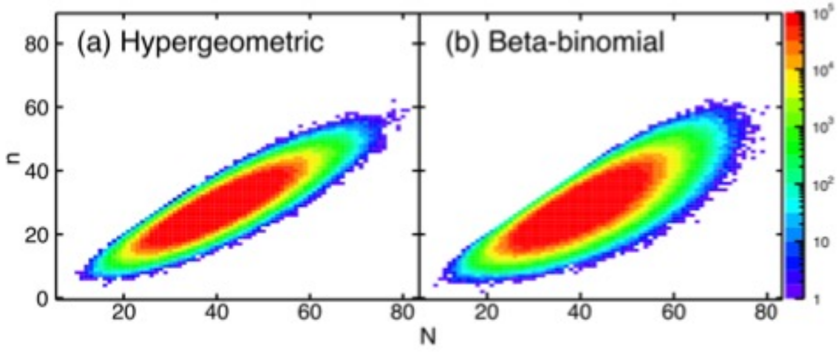
PRC107 (2023) 024908

Tracking efficiency and response matrix for unfolding correction

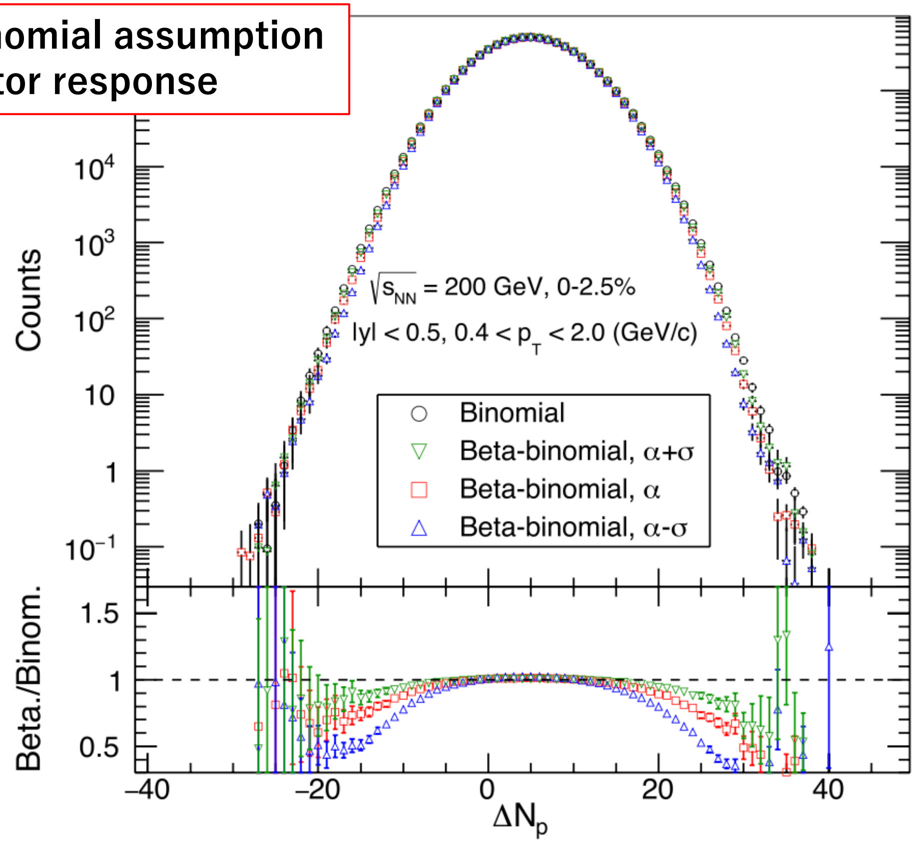
BES-I **PRC104 (2021) 024902**



based on embedding simulation



unfolded



(Non-)binomial assumption for detector response

detector efficiency for multi-particles detection with full Geant simulation

Non-binomial efficiency correction
(Unfolding method)

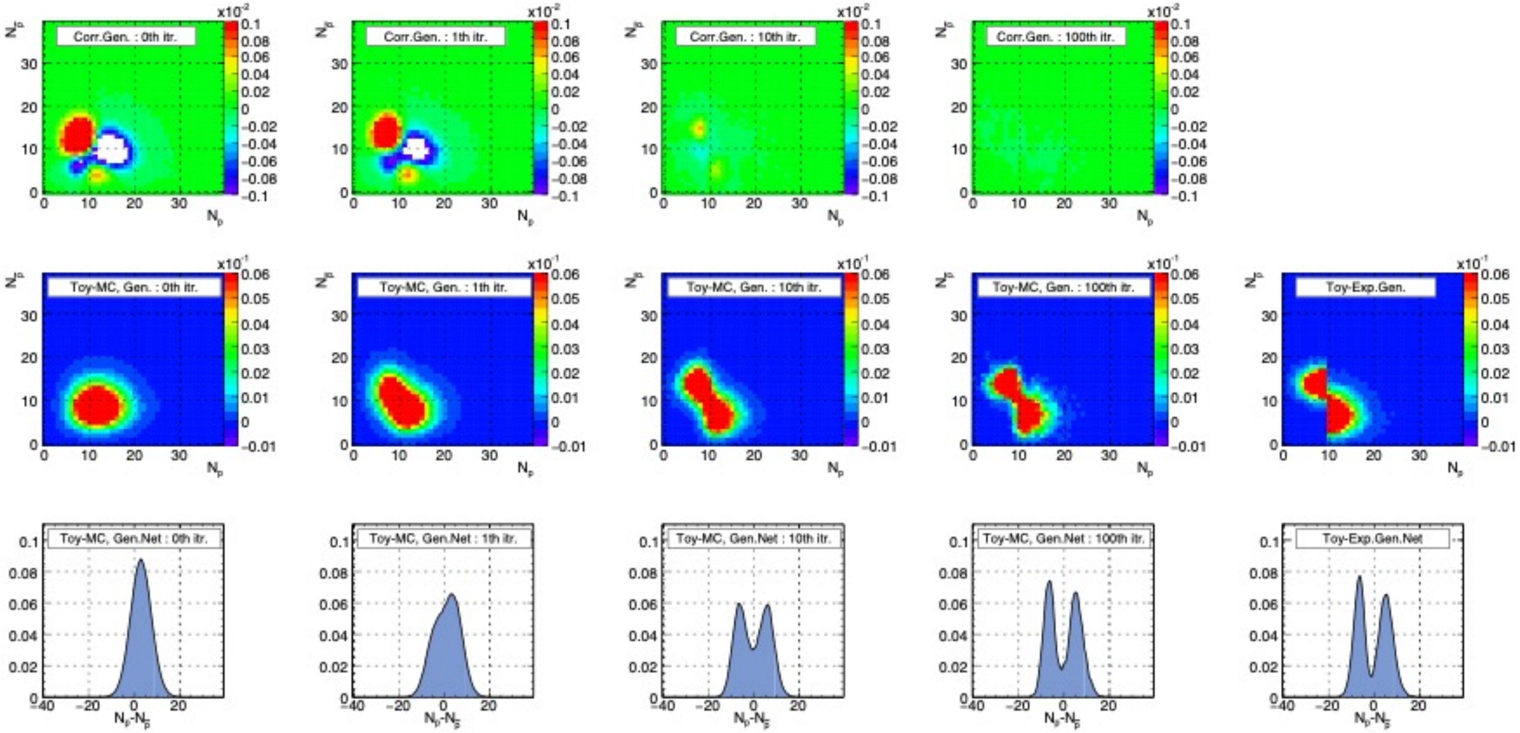


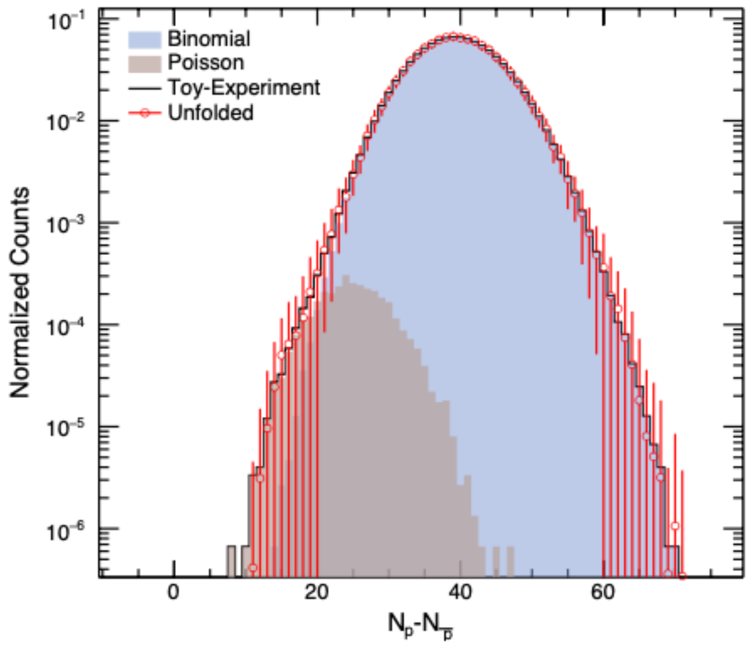
FIG. 4. (Top) Correction functions in the generated coordinates. White-colored bins represent the large negative value outside the z-axis range. (Middle) Toy-MC distributions in the generated coordinates. (Bottom) Toy-MC net-particle distributions in the generated coordinates. The 1st to 4th row from left to right show distributions at the 0th (initial condition), 1st, 10th and 100th iteration. The most right panels show distributions for the toy-experiment sample.

Reconstructing particle number distributions with convoluting volume fluctuations

ShinIchi Esumi,[1,*] Kana Nakagawa,[1] and Toshihiro Nonaka[1,2,†]
[1] Tomonaga Center for the History of the Universe, University of Tsukuba, Tsukuba, Ibaraki 305, Japan
[2] Key Laboratory of Quark & Lepton Physics (MOE) and Institute of Particle Physics, Central China Normal University, Wuhan 430079, China

We propose methods to reconstruct particle distributions with and without considering initial volume fluctuations. This approach enables us to correct for detector efficiencies and initial volume fluctuations simultaneously. Our study suggests such a tool could investigate the possible bimodal structure of net-proton distribution in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 GeV as a signature of first-order phase transition and critical point of hadronic matter [1, 2].

NIM A987, 164802 (2021)

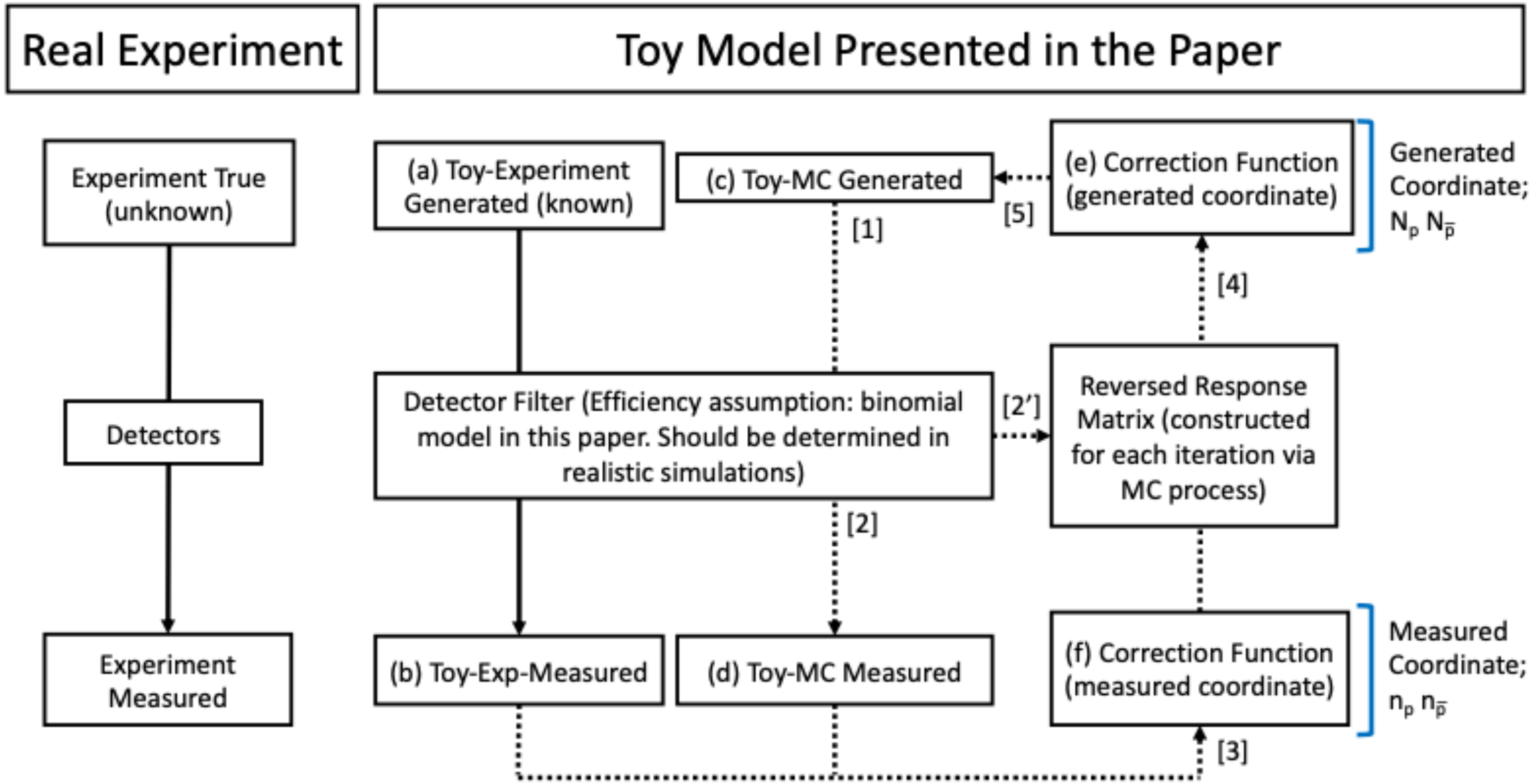


A general procedure for detector-response correction of higher order cumulants

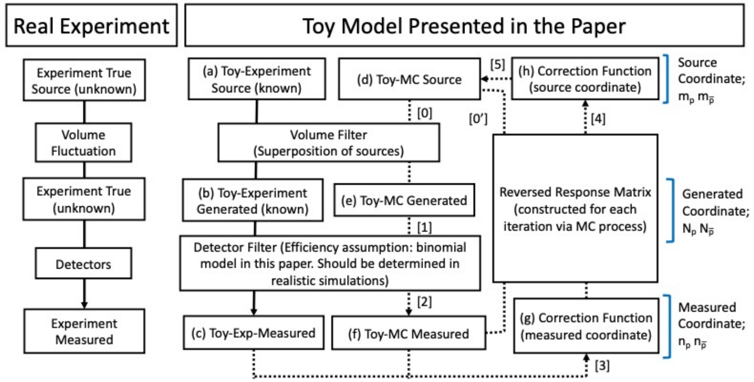
Toshihiro Nonaka,[1,2,*] Masakiyo Kitazawa,[3,4,†] and ShinIchi Esumi[2,‡]

alternative method with moment expansion
NIM A906, 10 (2018)

Unfolding procedure



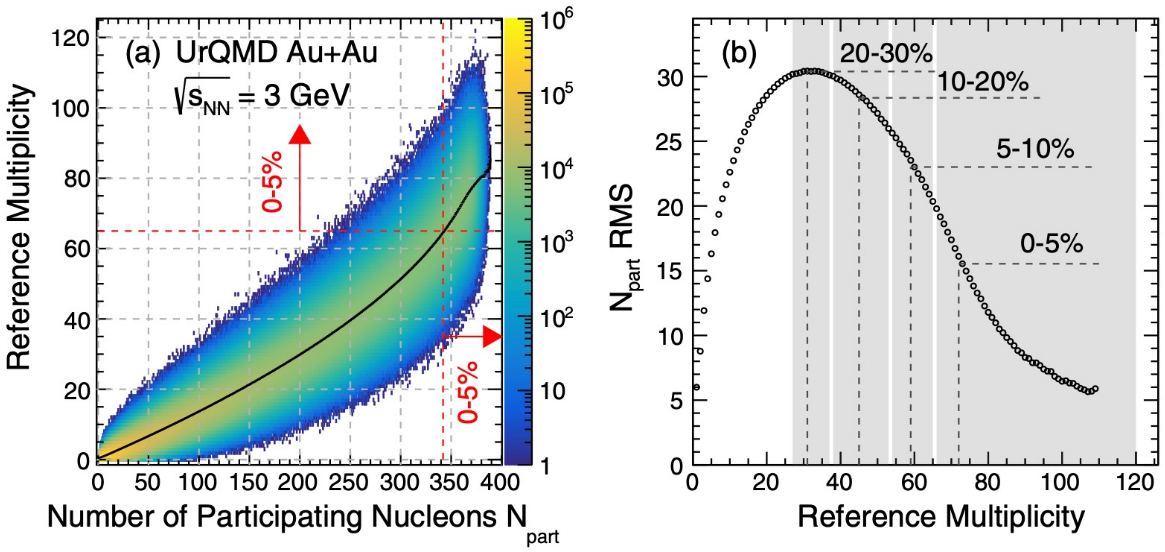
Volume fluctuation as a part of response matrix (**volume filter** in addition to the experimental "non-linear" **detector filter**)



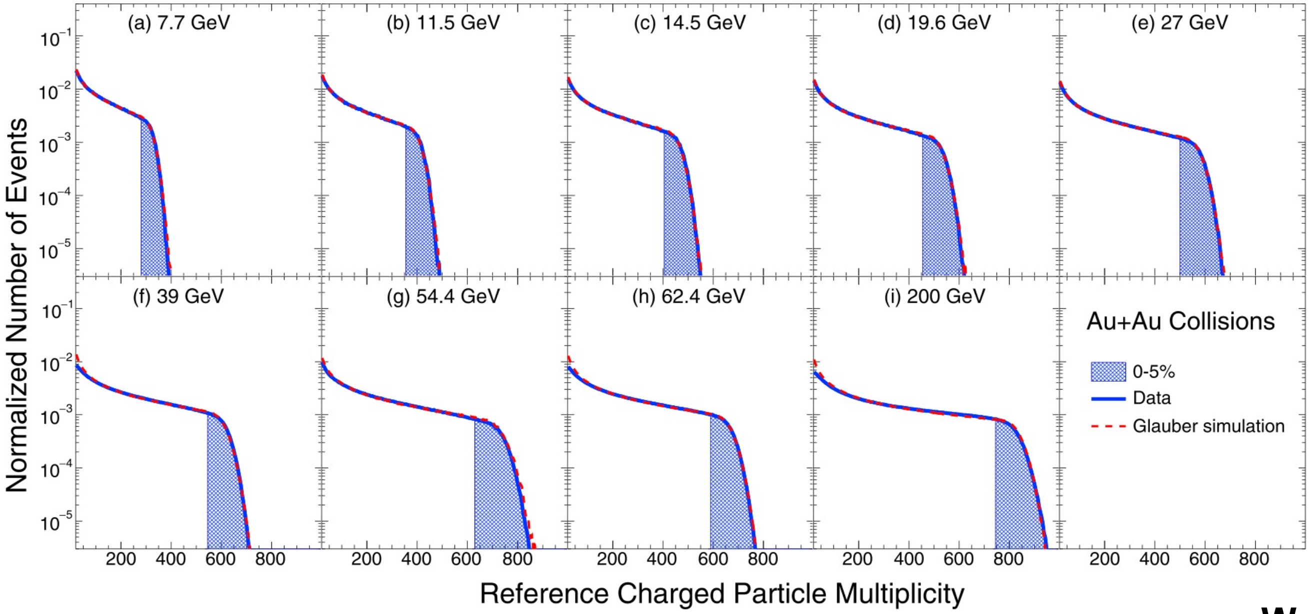
4D-unfolding (N_p, N_{pbar}, T_p, T_{pbar}) net-proton and their temperatures is ongoing…

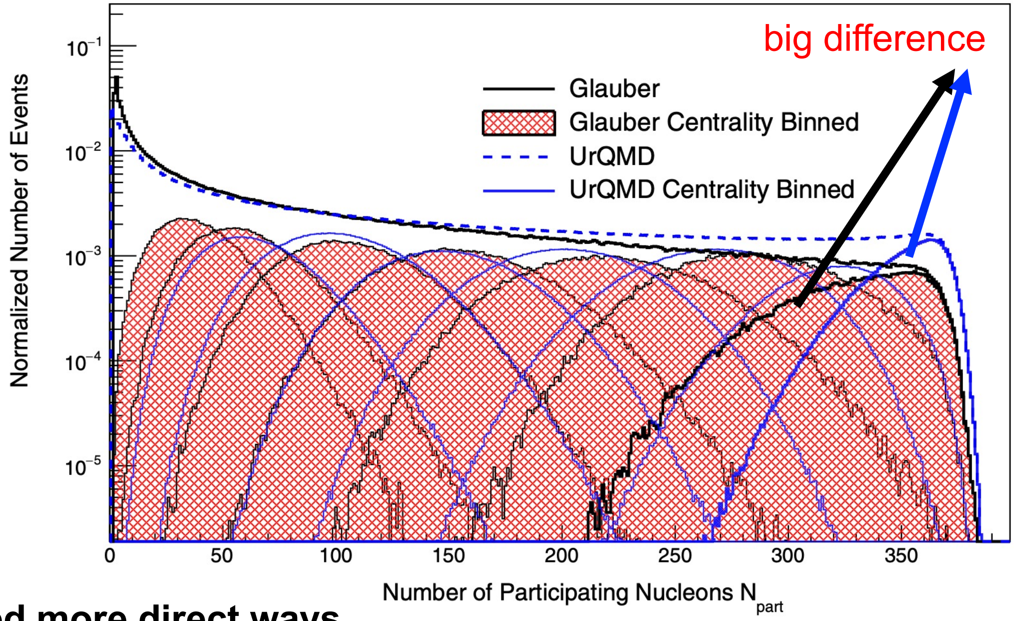
Centrality determination

trying to improve the centrality resolution by increasing the number of charged particle (as much as in the TPC even in the case of Fixed target mode) excluding protons with Centrality Bin Width Correction (CBWC)



BES-I





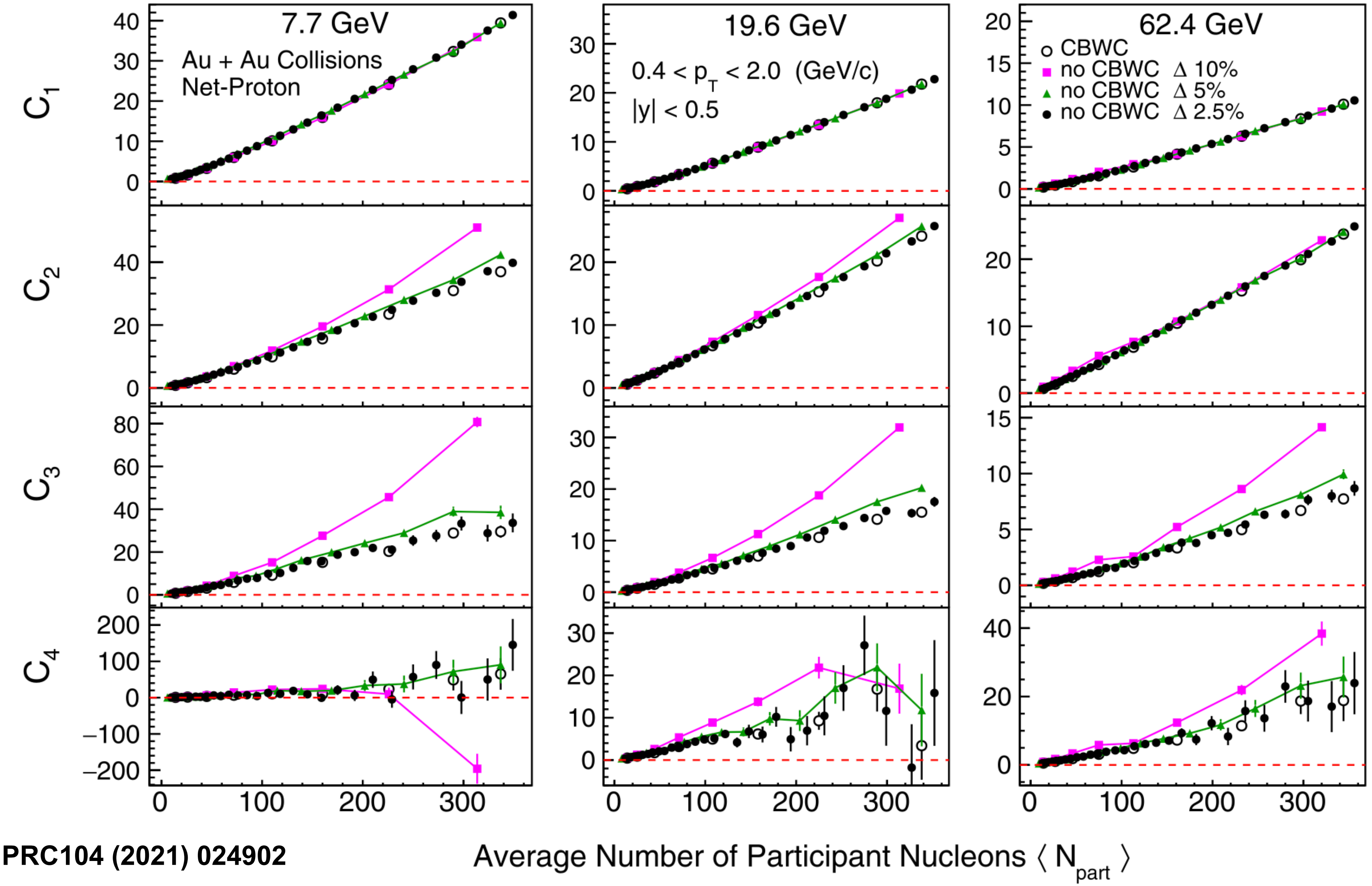
PRC104 (2021) 024902

We need more direct ways to determine N_{part} experimentally.

PRC107 (2023) 024908

Test of Centrality Bin Width Correction (CBWC)

BES-I



PRC104 (2021) 024902

The results approach to the CBWC result.

It does not mean the volume fluctuation is excluded, as centrality resolution limits.

Over correction, because of the use of same rapidity acceptance information. (The model test indicates the effect is small, though.)

Volume fluctuation, centrality resolution and auto-(self-) correlation

UrQMD model simulation

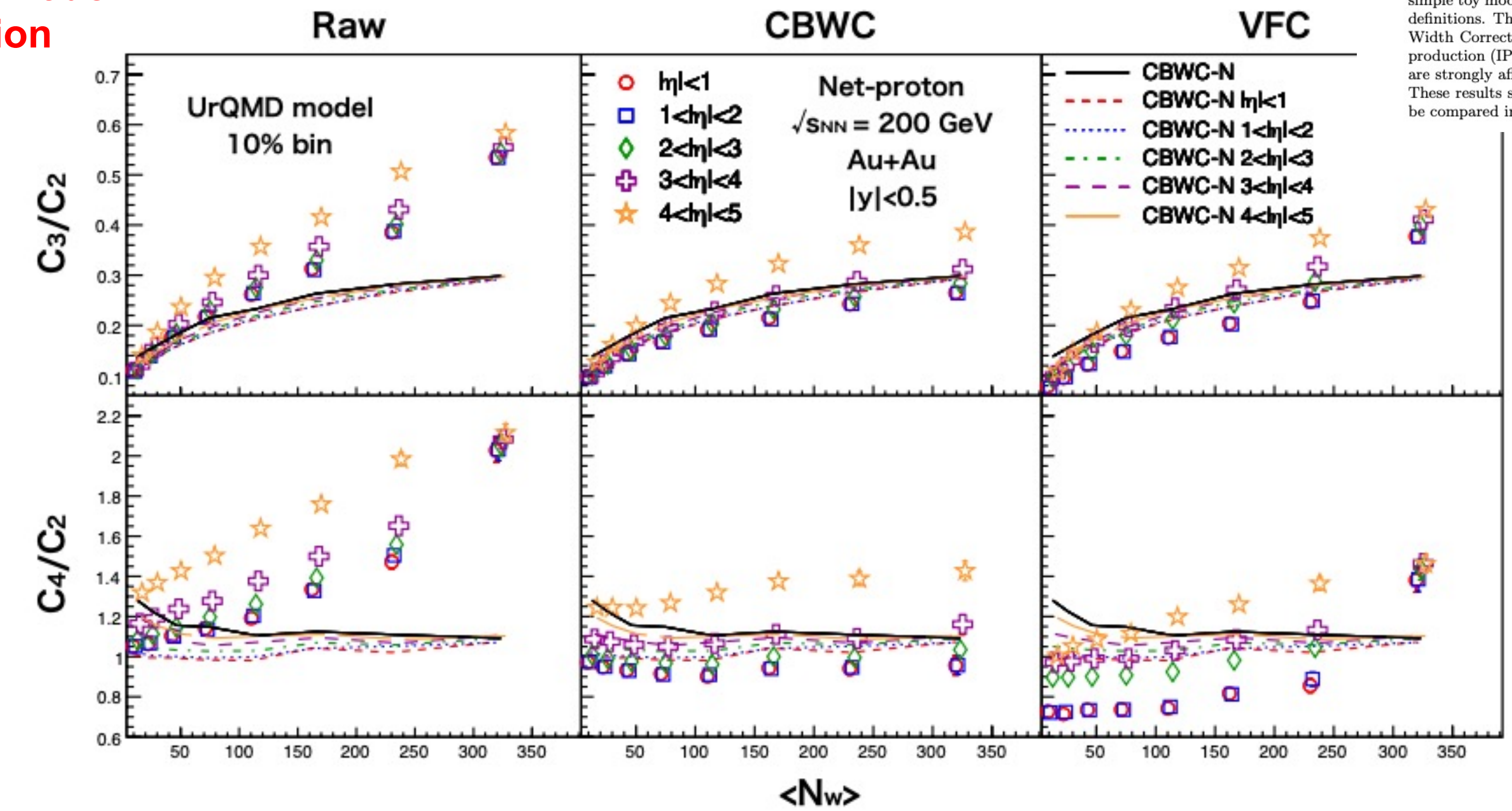


FIG. 6. C_3/C_2 and C_4/C_2 of net-proton distributions as a function of $\langle N_W \rangle$ by using UrQMD model simulation for 10% centrality divisions for different centrality definitions drawn in different markers. Centralities are determined in $|\eta| < 1$, $1 < |\eta| < 2$, $2 < |\eta| < 3$, $3 < |\eta| < 4$ and $4 < |\eta| < 5$ excluding proton (anti-proton) drawn in different colors. Raw, CBWC and VFC results are shown from left to right. CBWC-N results by definition2 and definition1 are shown in black solid lines and colored dotted lines, respectively.

Volume fluctuation and multiplicity correlation on higher-order cumulants

Tetsuro Sugiura,[1,*] Toshihiro Nonaka,[2,†] and ShinIchi Esumi[1,‡]

[1] Tomonaga Center for the History of the Universe, University of Tsukuba, Tsukuba, Ibaraki 305, Japan
[2] Key Laboratory of Quark & Lepton Physics (MOE) and Institute of Particle Physics, Central China Normal University, Wuhan 430079, China

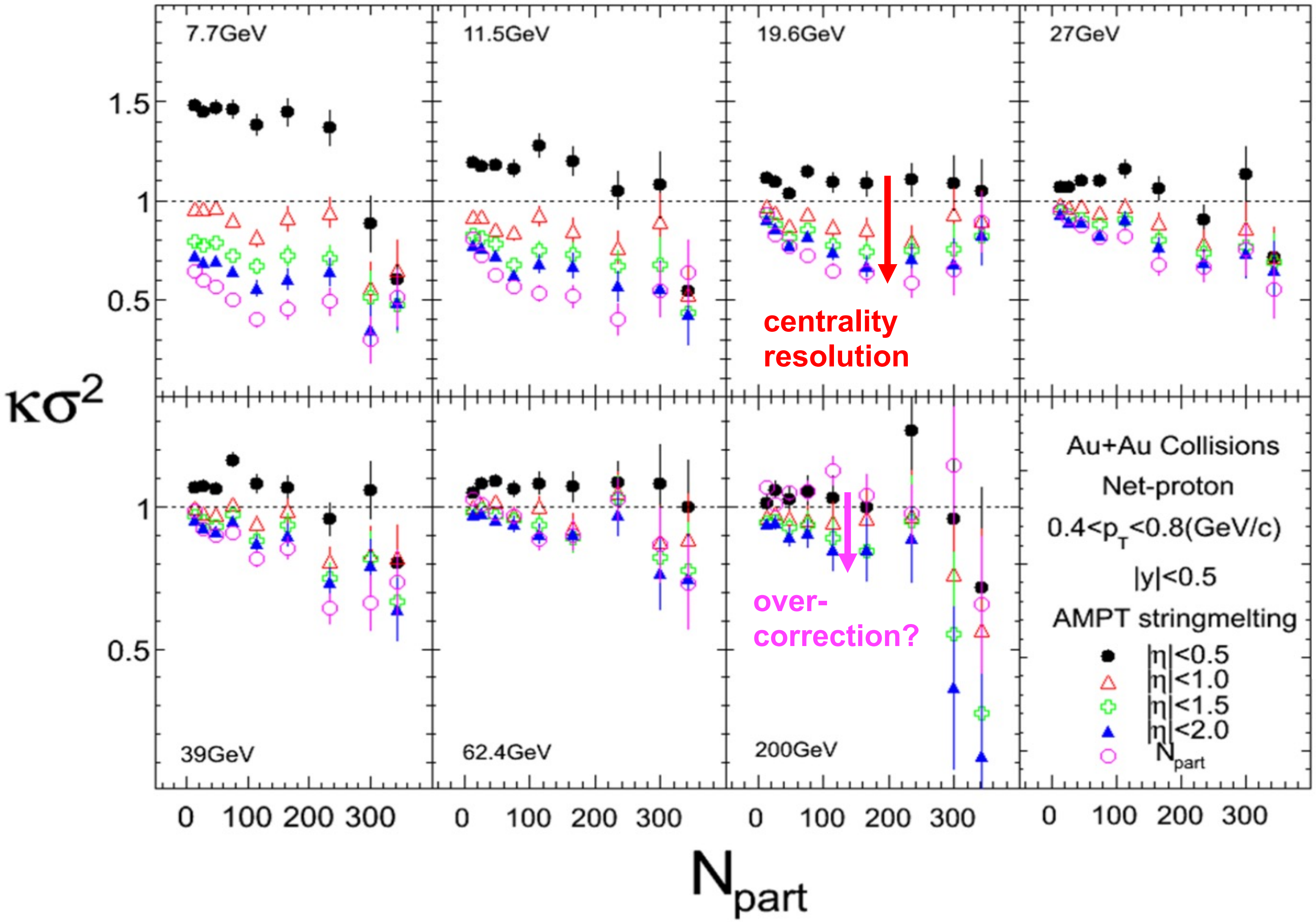
Initial volume fluctuation (VF) arising from the participant fluctuation would be the background which should be subtracted experimentally from the measured higher-order cumulants. We study the validity of the Volume Fluctuation Correction (VFC) on higher-order net-proton cumulants by using simple toy model and UrQMD model in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV for various centrality definitions. The results are compared to the conventional data driven method called Centrality Bin Width Correction (CBWC). We find VFC works well in toy model assuming independent particle production (IPP), but does not seem to work well in UrQMD model. It is also found that cumulants are strongly affected by the multiplicity correlation effect as well as the centrality resolution effect. These results show that neither VFC nor CBWC are perfect method. Thus, both methods should be compared in the real experiment.

PRC 100 (2019) 044904

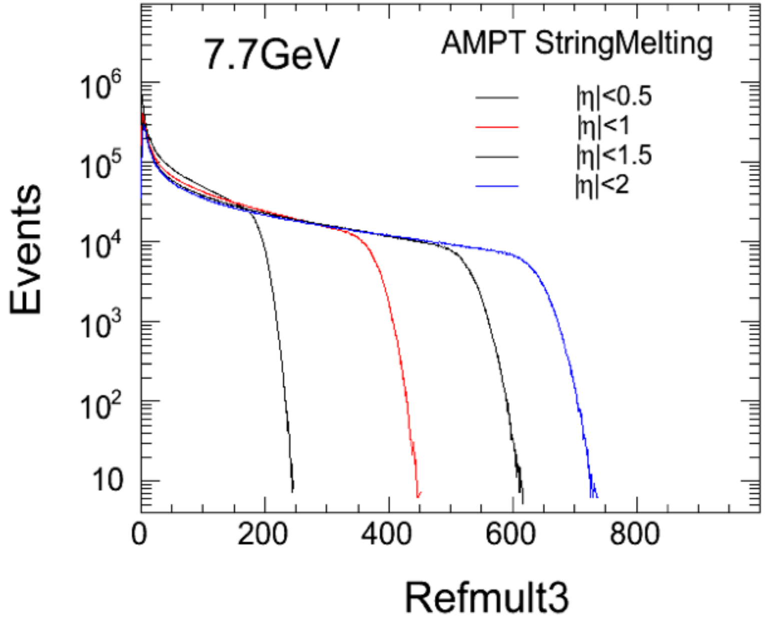
CBWC
- centrality resolution limits
- possible over-correction by auto-correlation

VFC
- independent particle production assumption based on N_{part}

AMPT model simulation



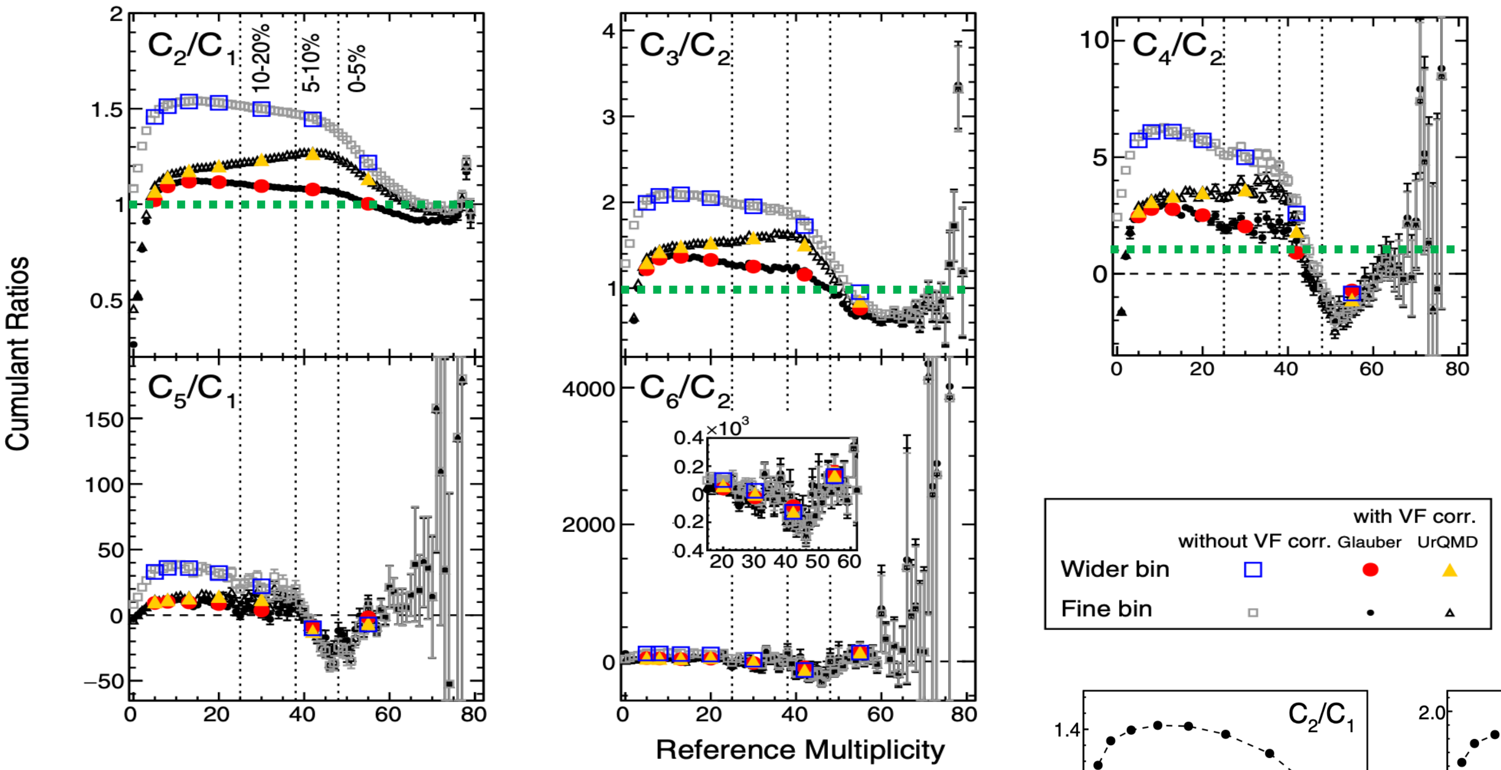
Xiaofeng Luo (CCNU)



different "CBWC" corrections with various reference multiplicity including N_{part}-CBWC

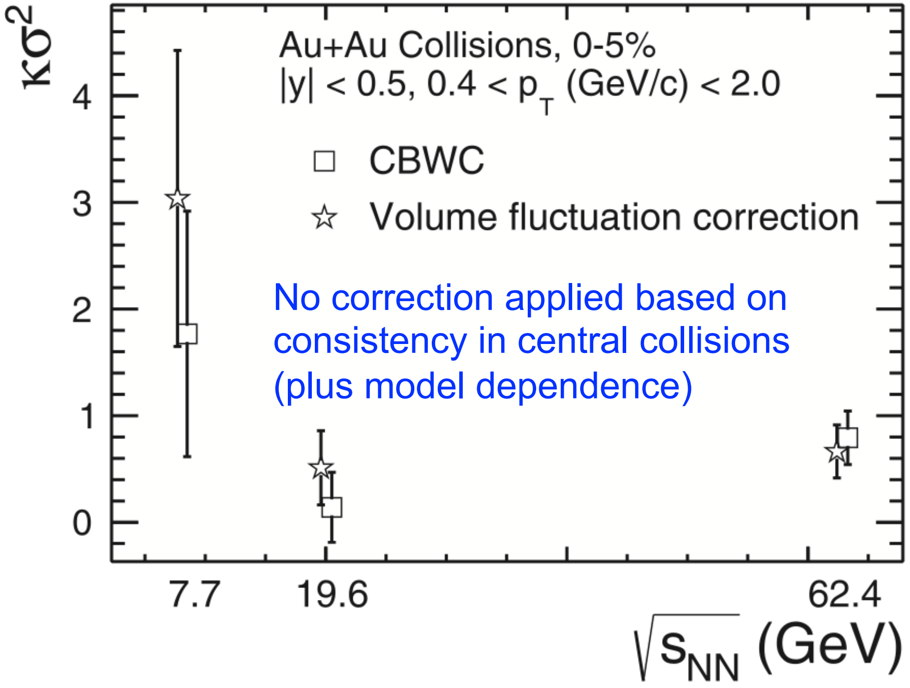
Au+Au 3 GeV

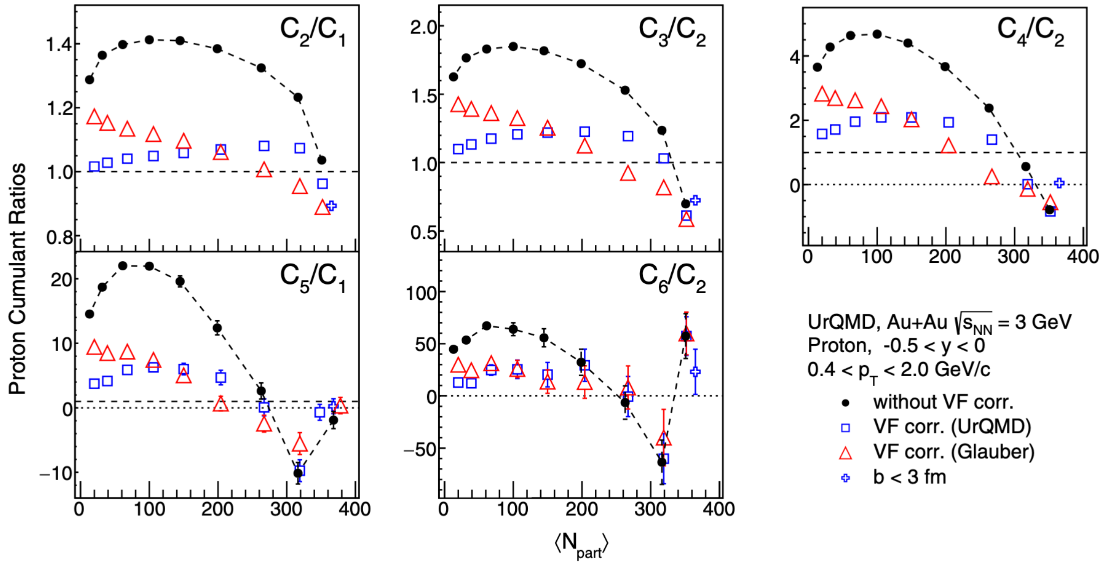
PRC107 (2023) 024908



BES-I

PRC104 (2021) 024902





UrQMD

Cumulant Ratio with/without VF corrections

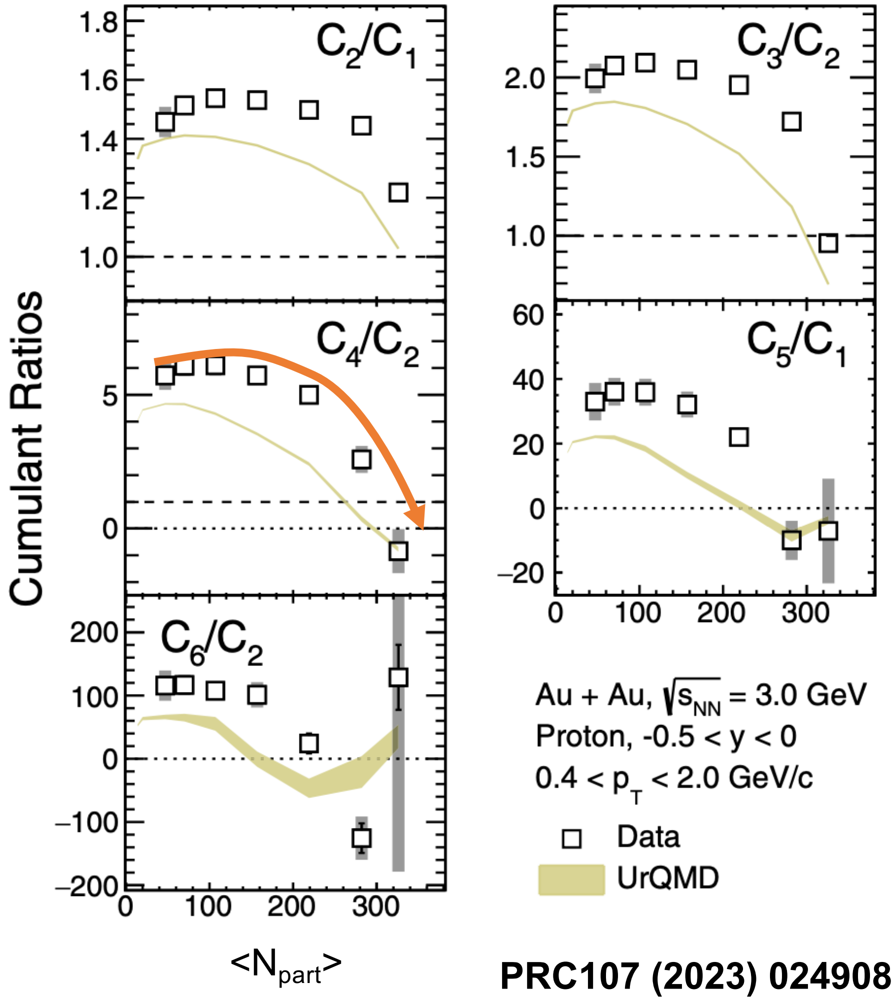
- The model dependent volume effects are mostly reproduced.
- The final results are given without correction.

Centrality dependence of cumulant ratio

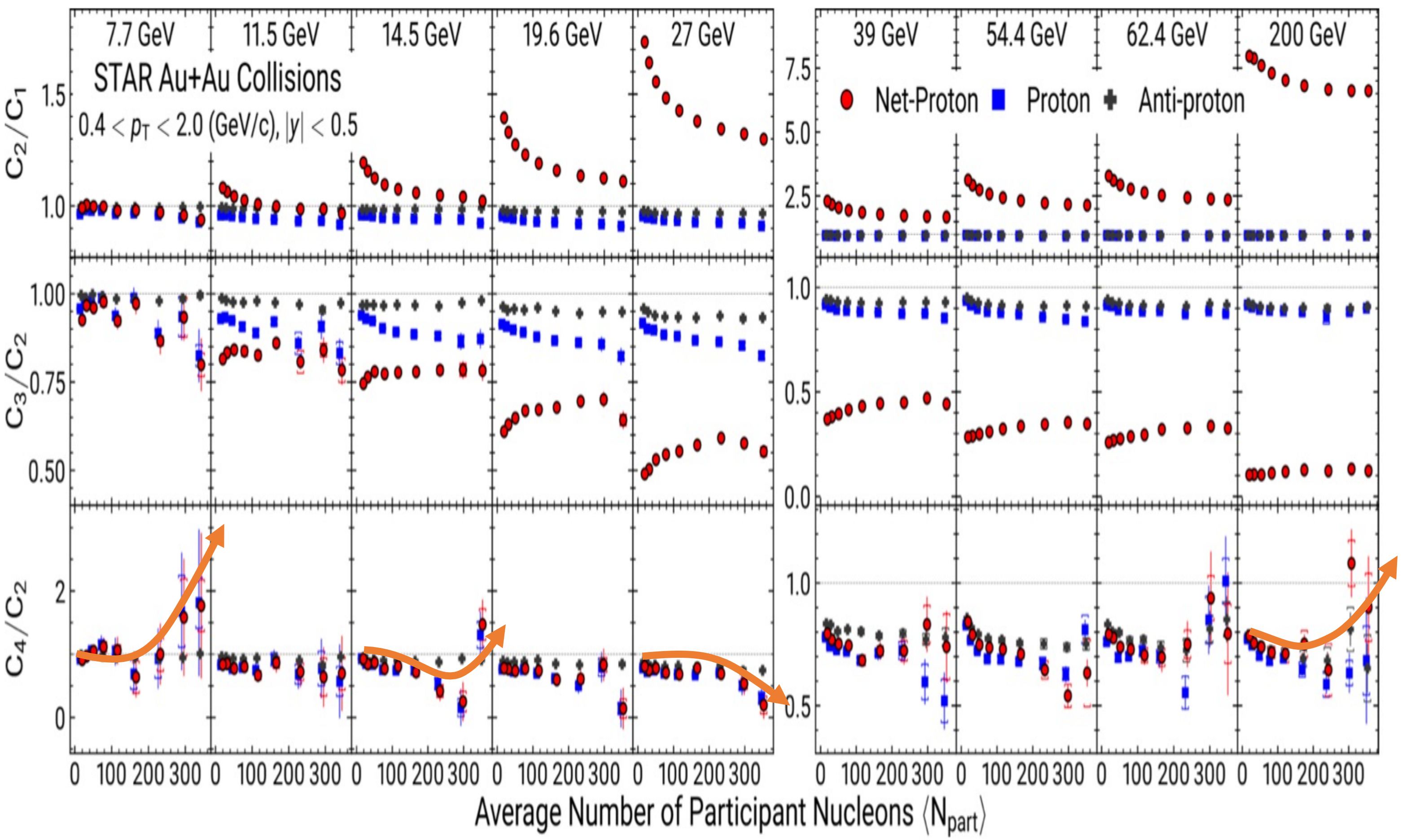
with participant based centrality
without volume correction

Au+Au 3 GeV : CBWC only

BES-I : CBWC only



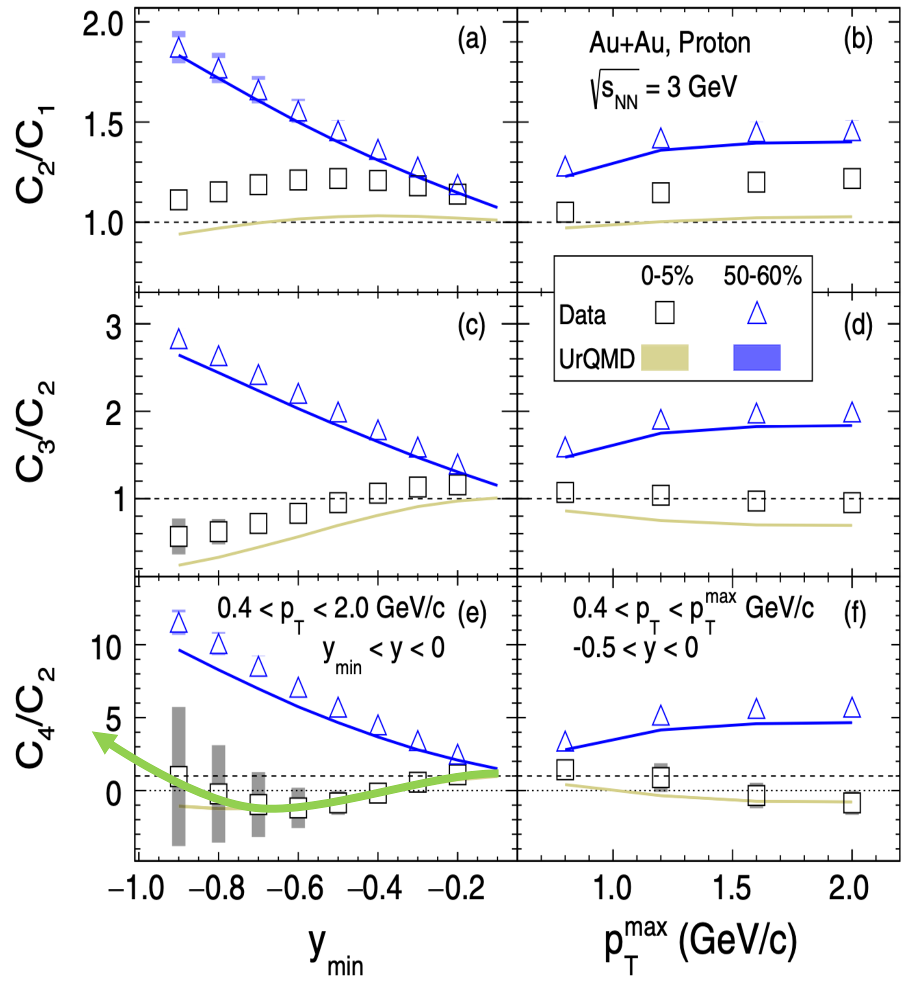
PRC107 (2023) 024908



PRC104 (2021) 024902

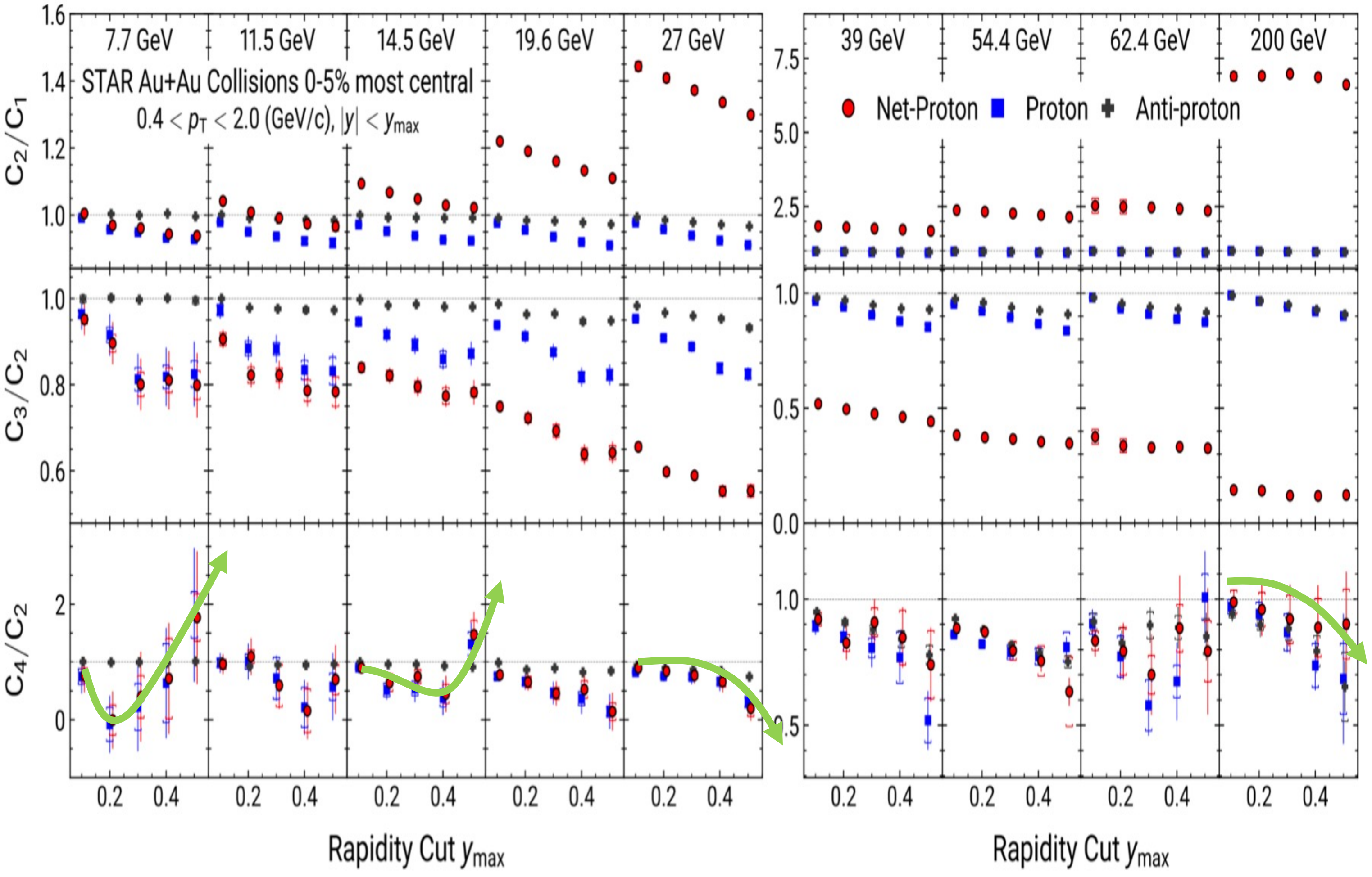
Acceptance dependence of cumulant ratio

Au+Au 3 GeV : CBWC only



PRC107 (2023) 024908

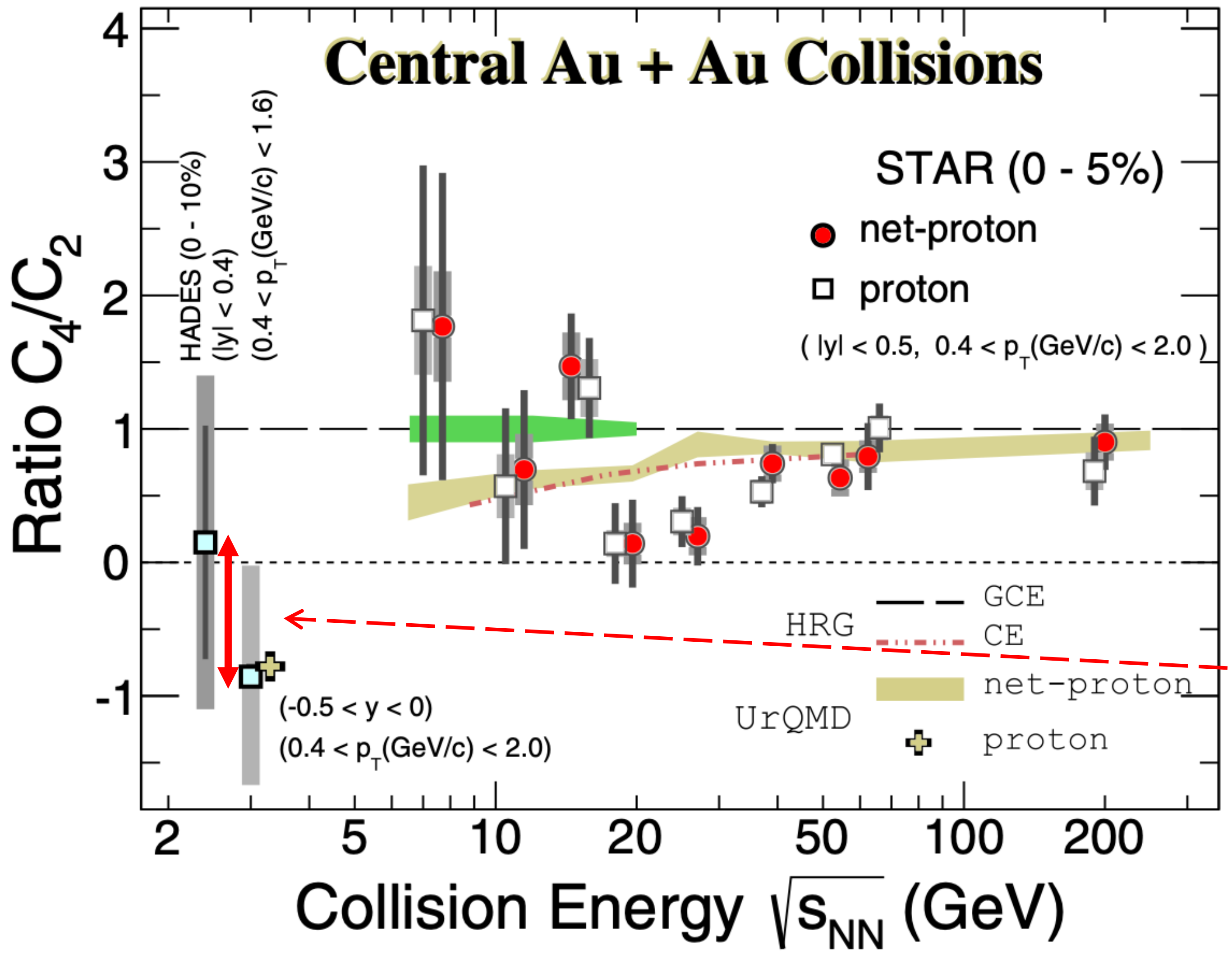
BES-I: CBWC only

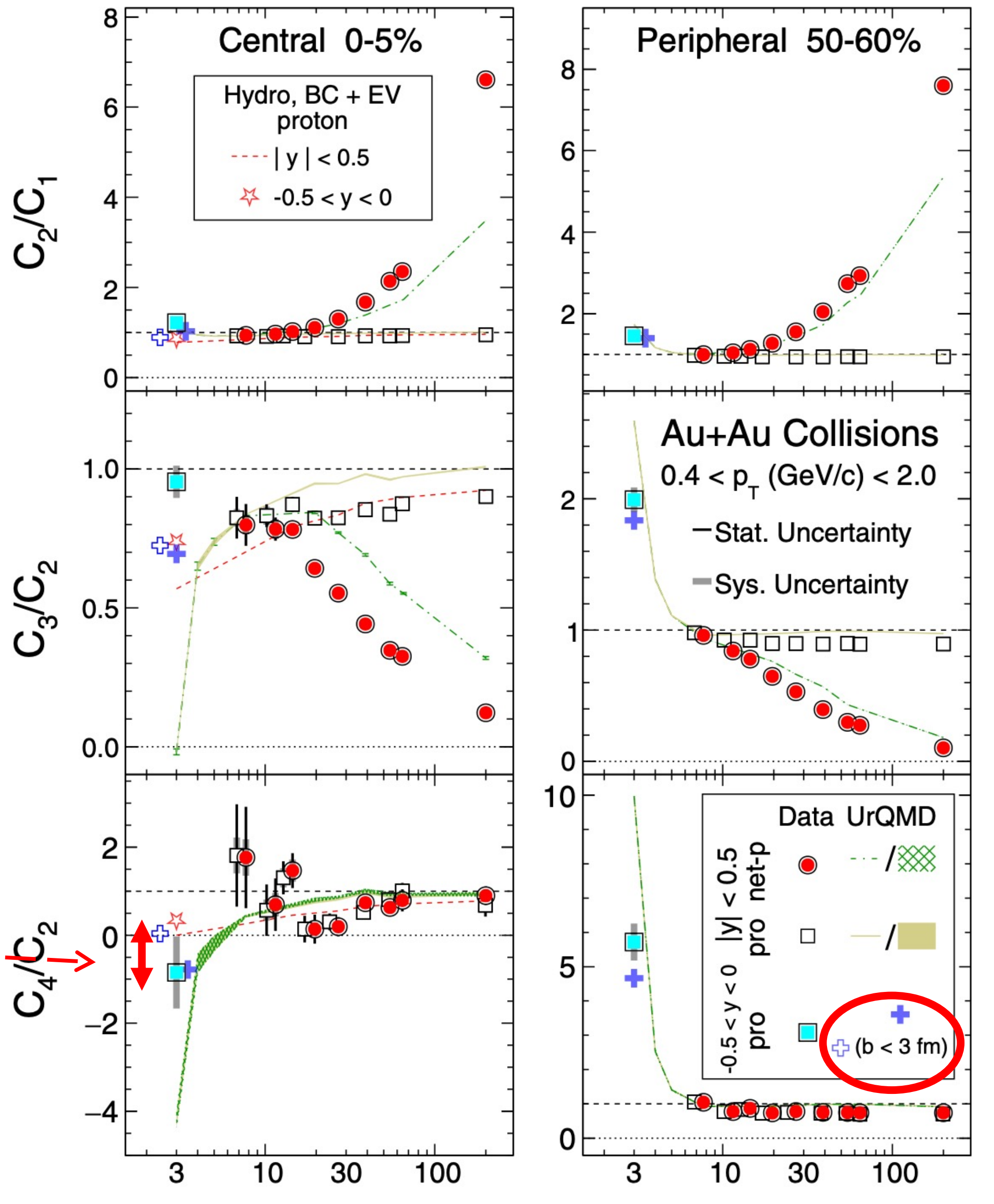


PRC104 (2021) 024902

Beam energy dependence of cumulant ratio

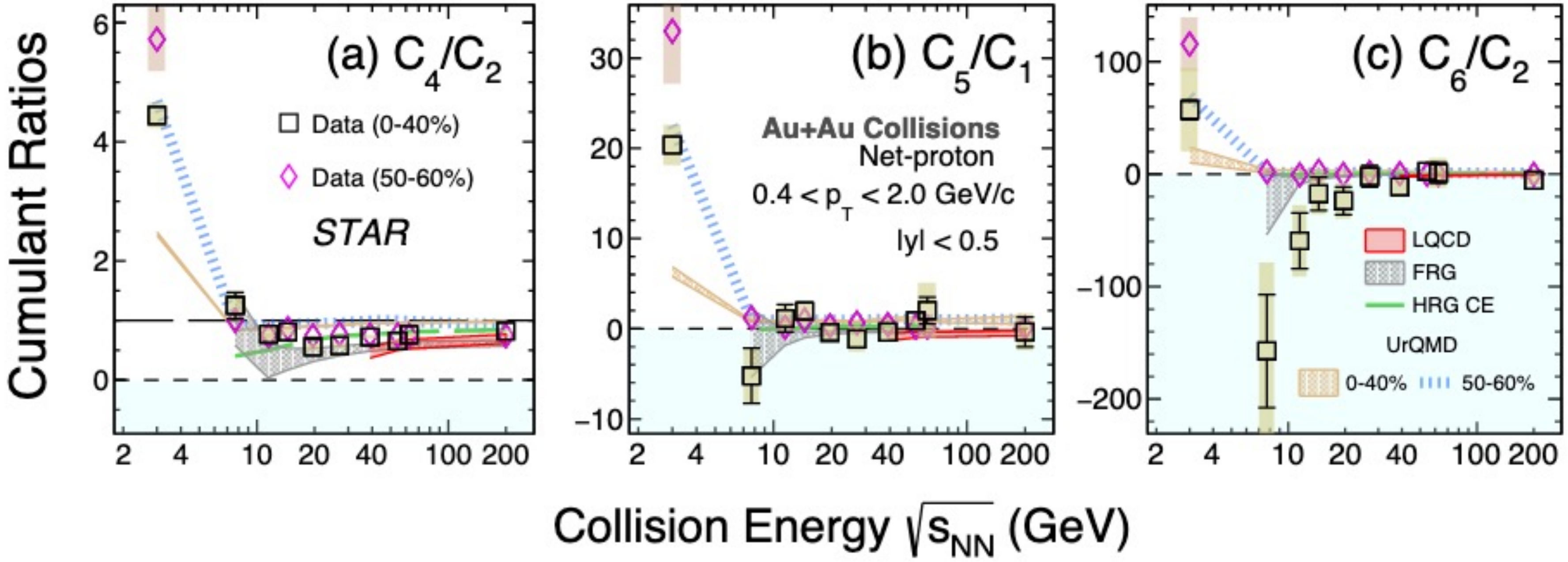
PRL128 (2022) 202303





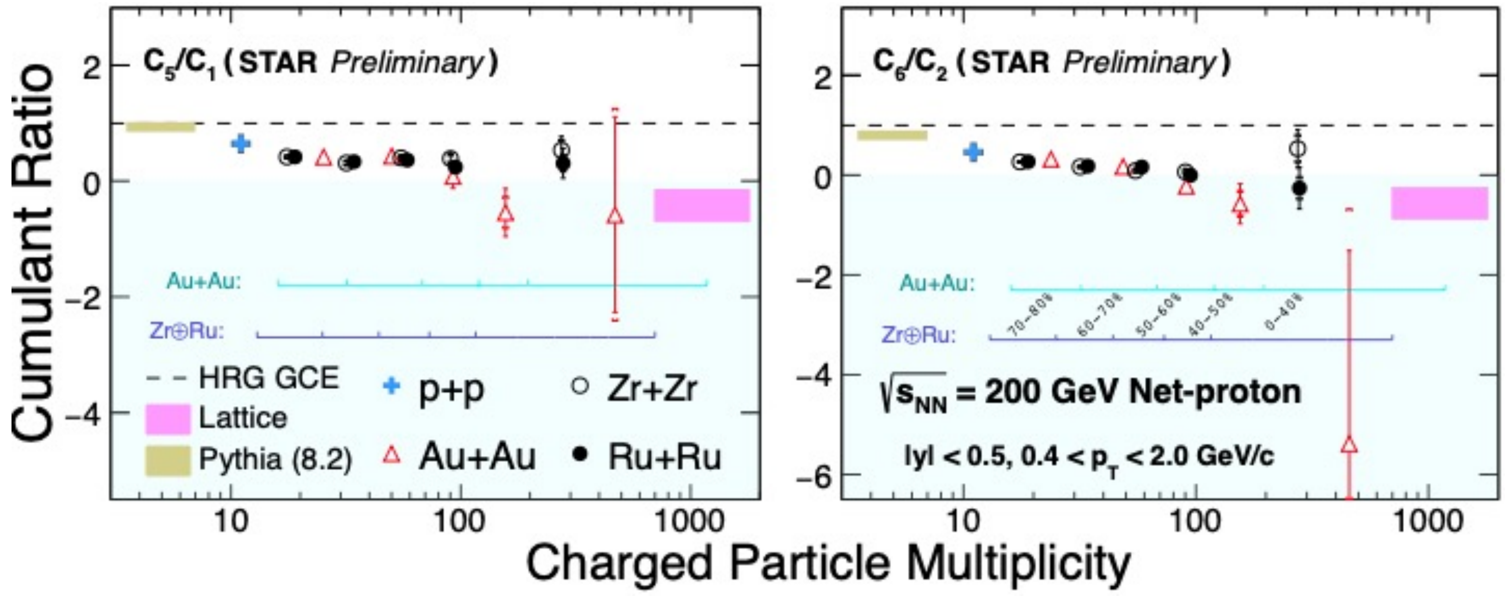
PRC107 (2023) 024908

PRL130 (2023) 82301



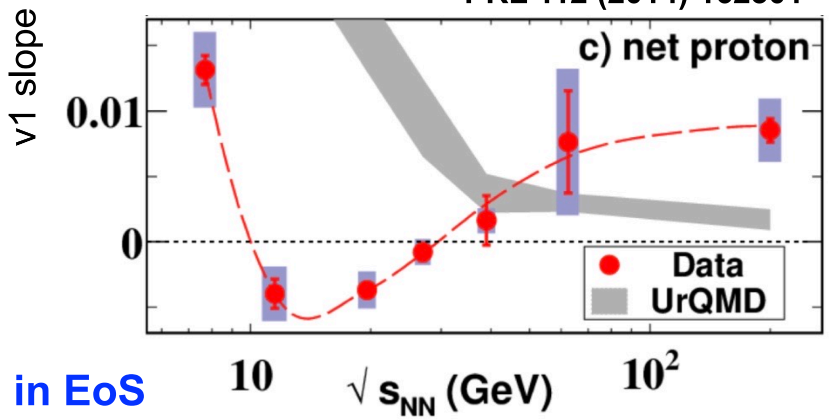
Higher order net-p fluctuation up to 5th and 6th order

- **energy dependence**
- **multiplicity dependence**



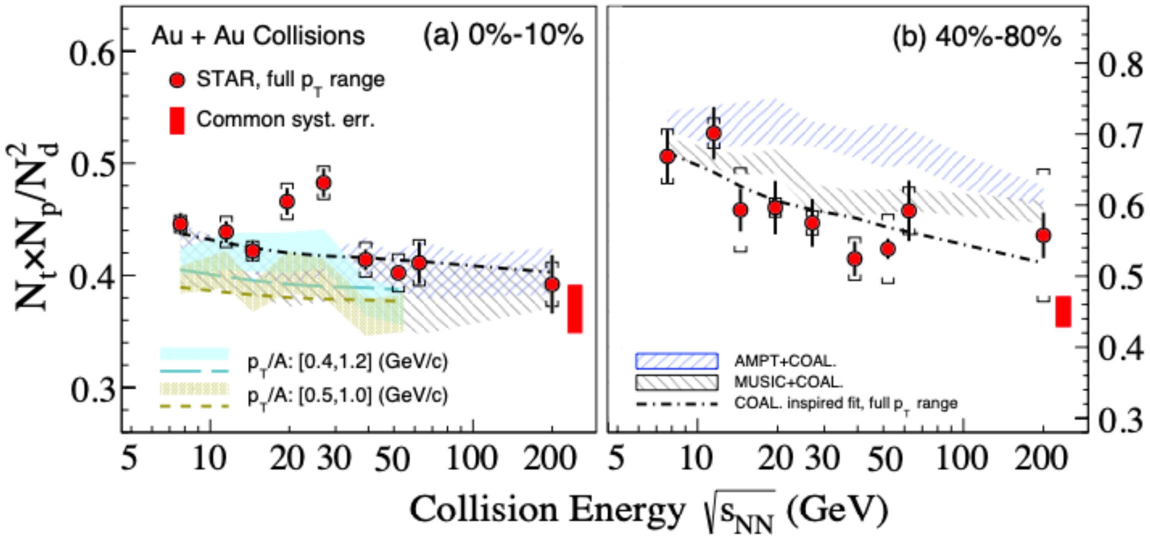
A few more possibly related observations

PRL 112 (2014) 162301



- change in EoS
- 1^{st} order phase trans.

PRL130 (2023) 202301

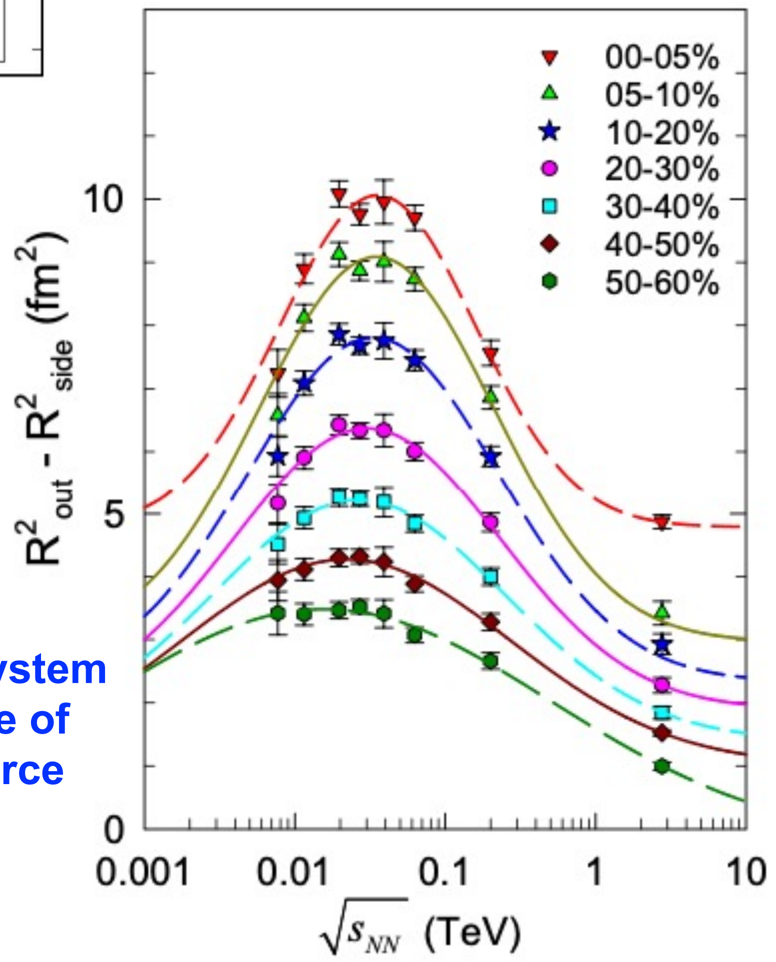


- local density fluctuation of neutron

(pnn * p) / (pn * pn)

Roy Lacey, et. al.

PRL 114 (2015) 142301



- lifetime of system
- duration time of emitting source

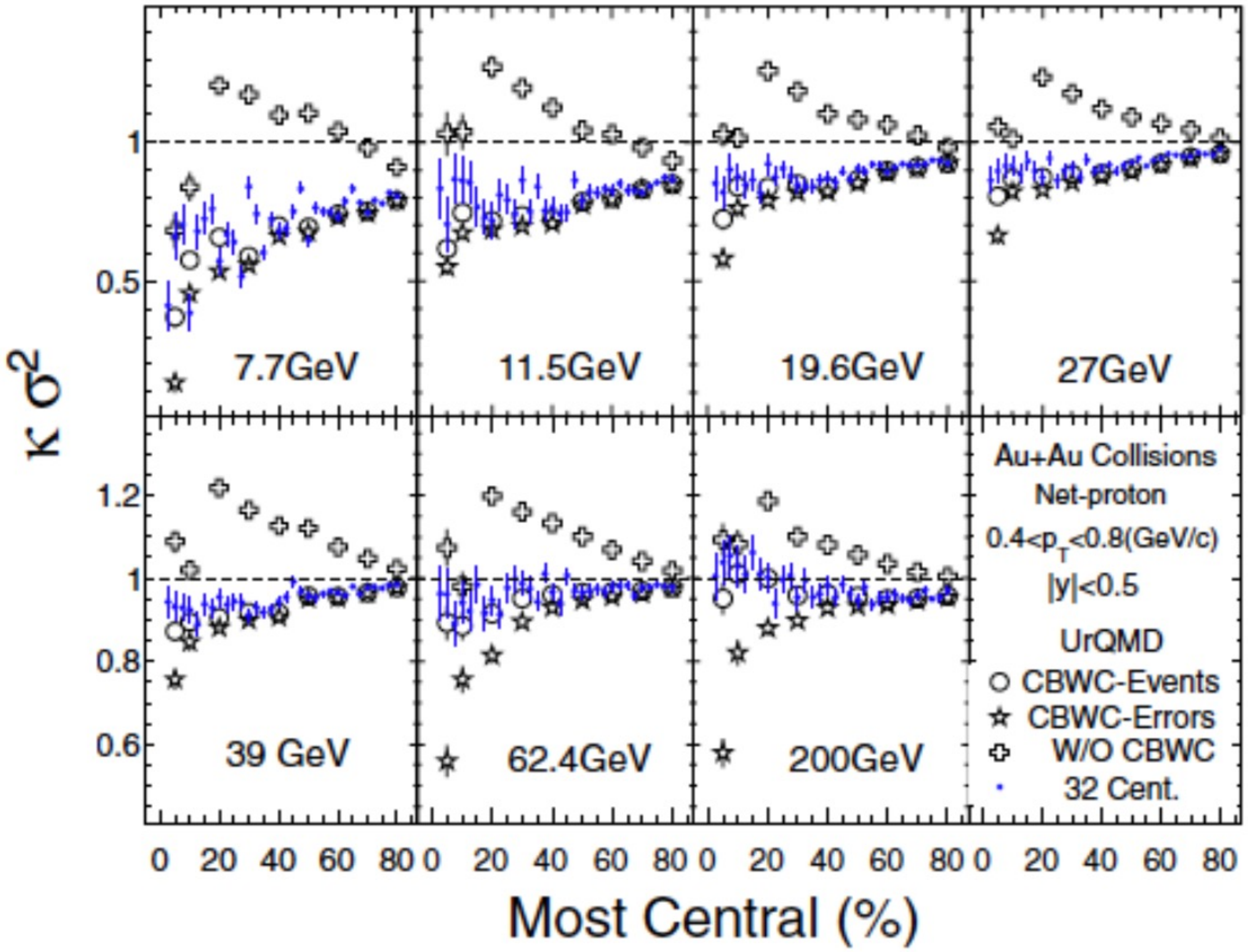
Summary

- STAR BES-I and BES-II measurments including fix target mode
- Experimental pile-up removal and/or correction
- Tracking efficiency corrections
- Centrality determination and volume fluctuation
- Acceptance and beam energy dependence

Many thanks to my STAR colleagues
especially in fluctuation focus group members

UrQMD model simulation

X.Luo, J. Xu, B. Mohanty and N. Xu. J. Phys. G 40,105104(2013).



with/without CBWC

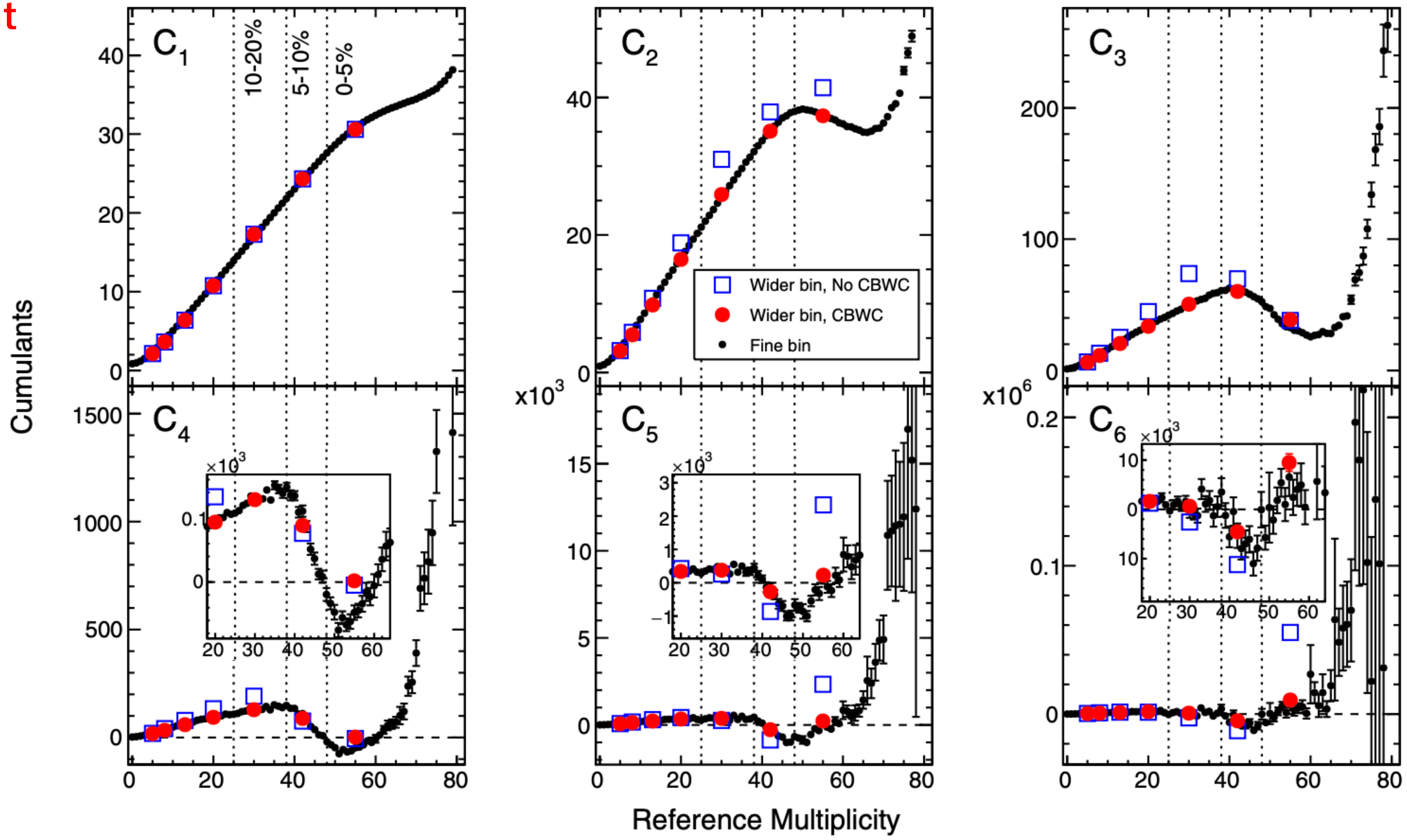


FIG. 4. Proton cumulants as a function of reference multiplicity (black circles) from $\sqrt{s_{NN}} = 3$ GeV Au+Au collisions. Centrality-binned results with and without centrality bin width corrections are represented by red circles and blue squares, respectively. Vertical dashed lines indicate the centrality classes, from right to left: 0–5%, 5–10%, 10–20%. Data points in this figure are only corrected for detector efficiency but not for the pileup effect, which will be discussed in a later section.

with/without pile-up correction

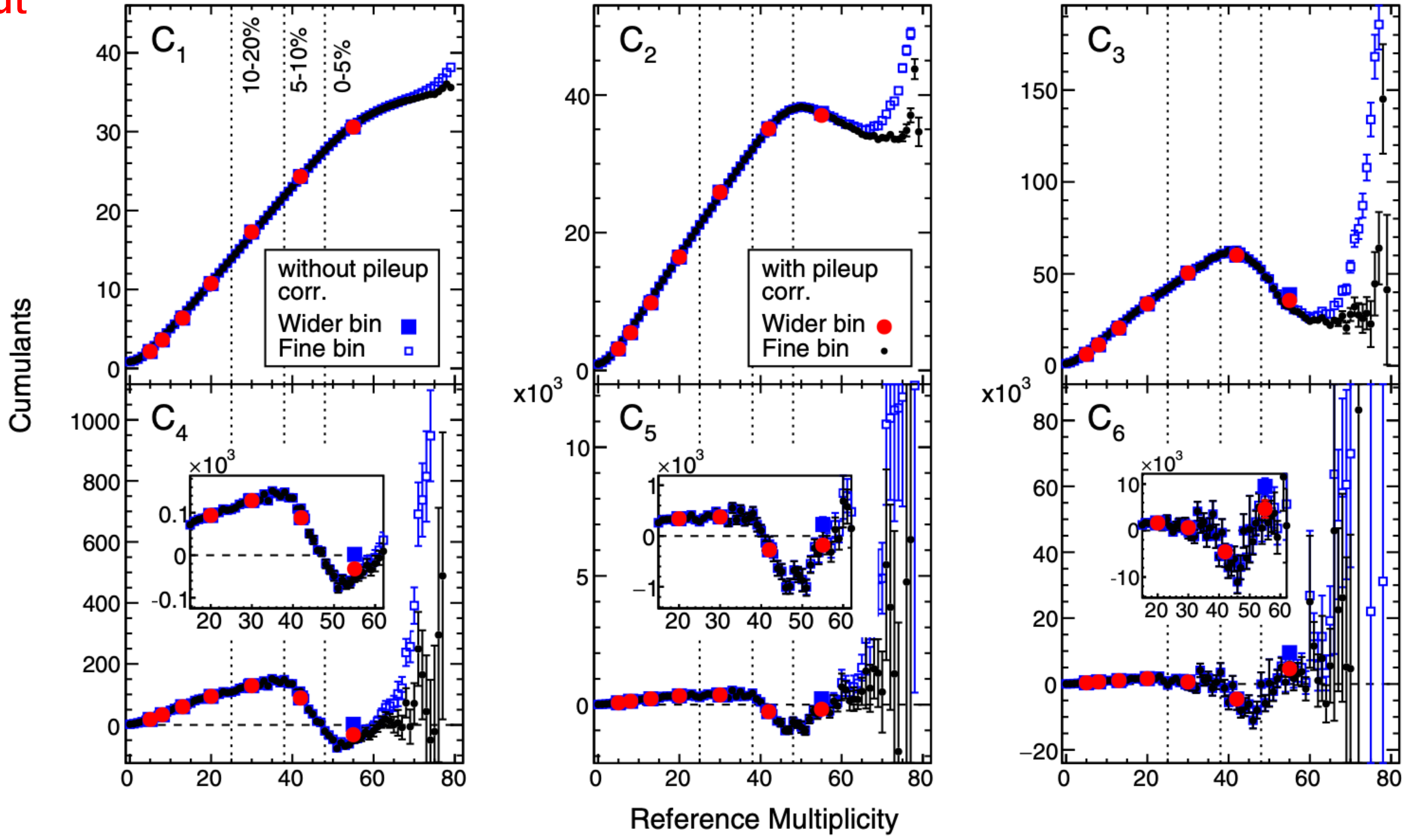


FIG. 6. Proton cumulants as a function of reference multiplicity from $\sqrt{s_{NN}} = 3$ GeV Au+Au collisions. Pileup corrected and uncorrected cumulants as a function of reference multiplicity are represented by black circles and blue open squares, respectively. Red circles and blue-filled squares represent the results of centrality binned data.

with/without volume fluc. correction

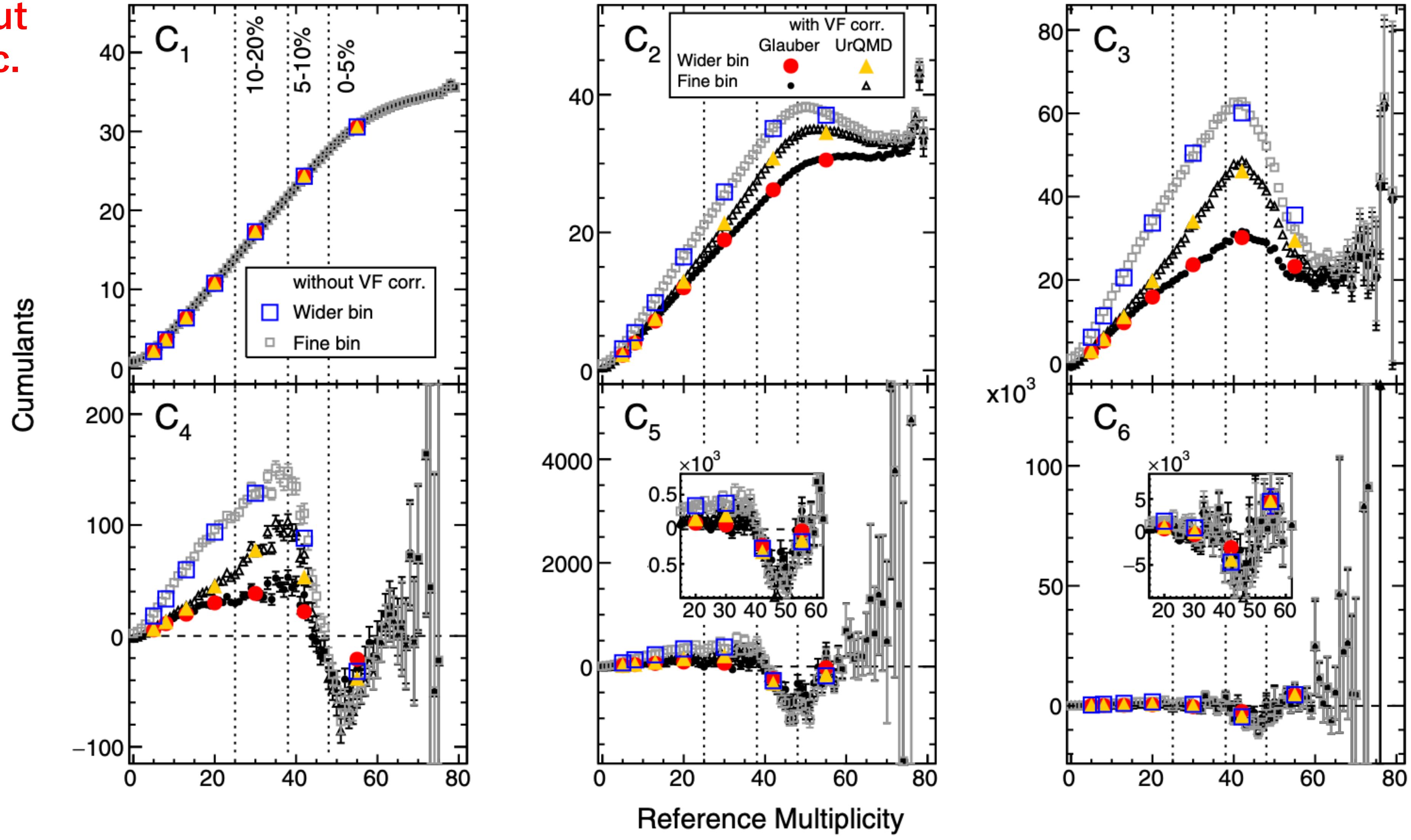
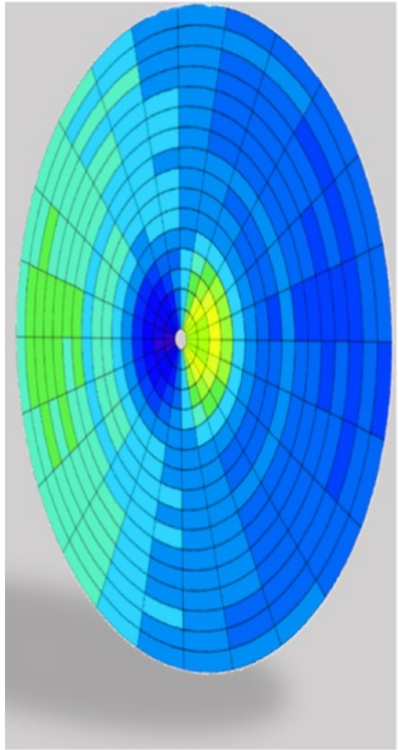
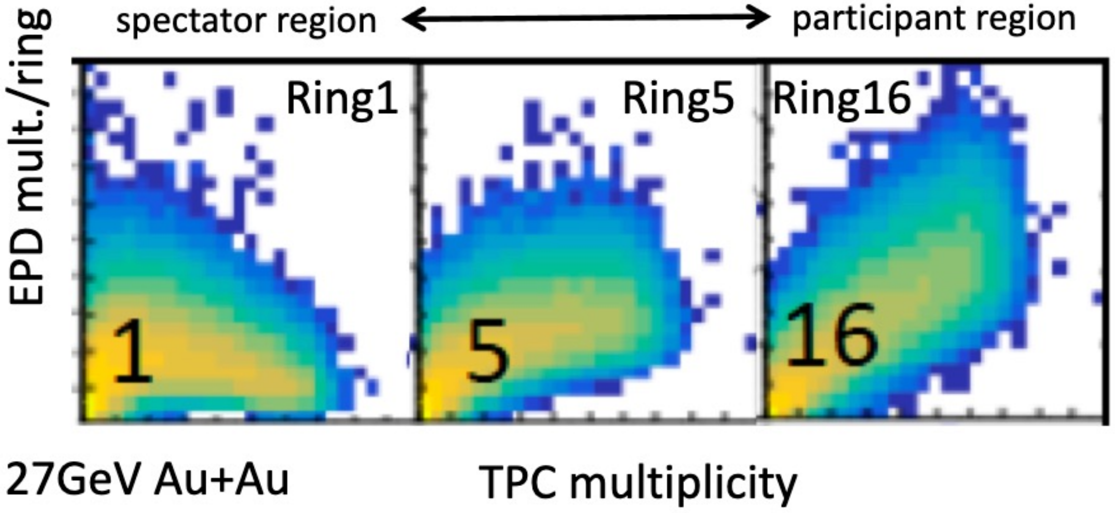


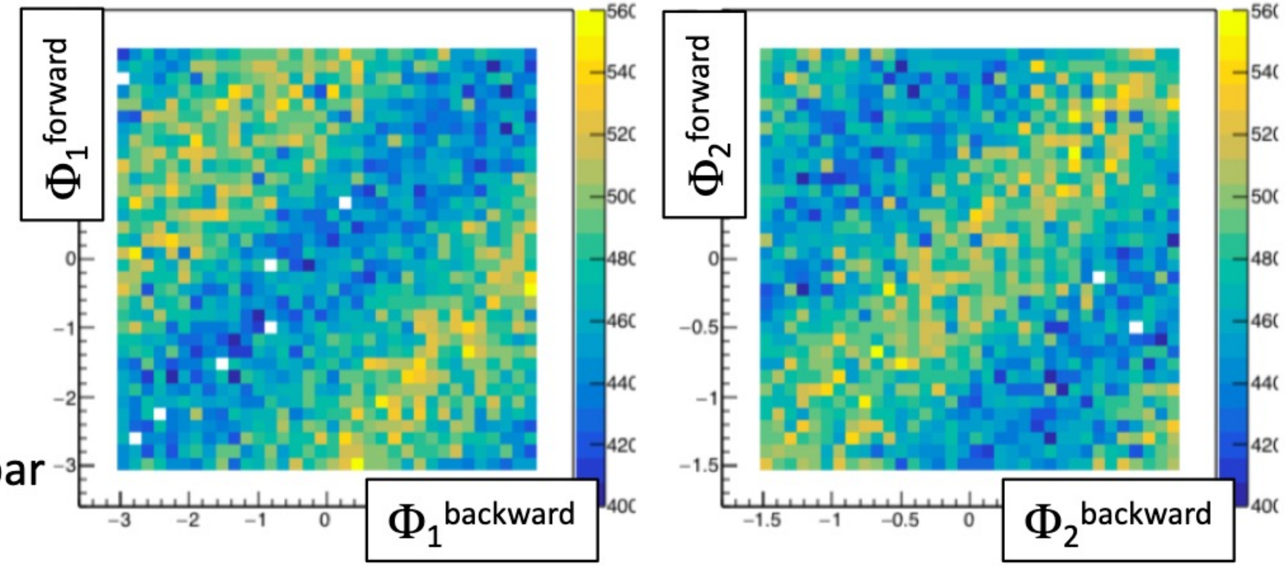
FIG. 11. Proton cumulants up to sixth order in $\sqrt{s_{NN}}$ = 3 GeV Au+Au collisions. Data without volume fluctuation correction is shown as grey open squares while data with volume fluctuation correction using N_{part} distributions from Glauber and UrQMD models are shown as black circles and black open triangles, respectively. The corresponding centrality binned cumulants are shown in blue squares, red circles, and orange triangles, respectively. Similarly to Fig. 6, the vertical dashed lines indicate the centrality classes.

STAR collider mode :
EPD (|eta| = 2 ~ 5)
TPC (|eta| = 0 ~ 1.5)
(for zvtx ~ 0 cm)

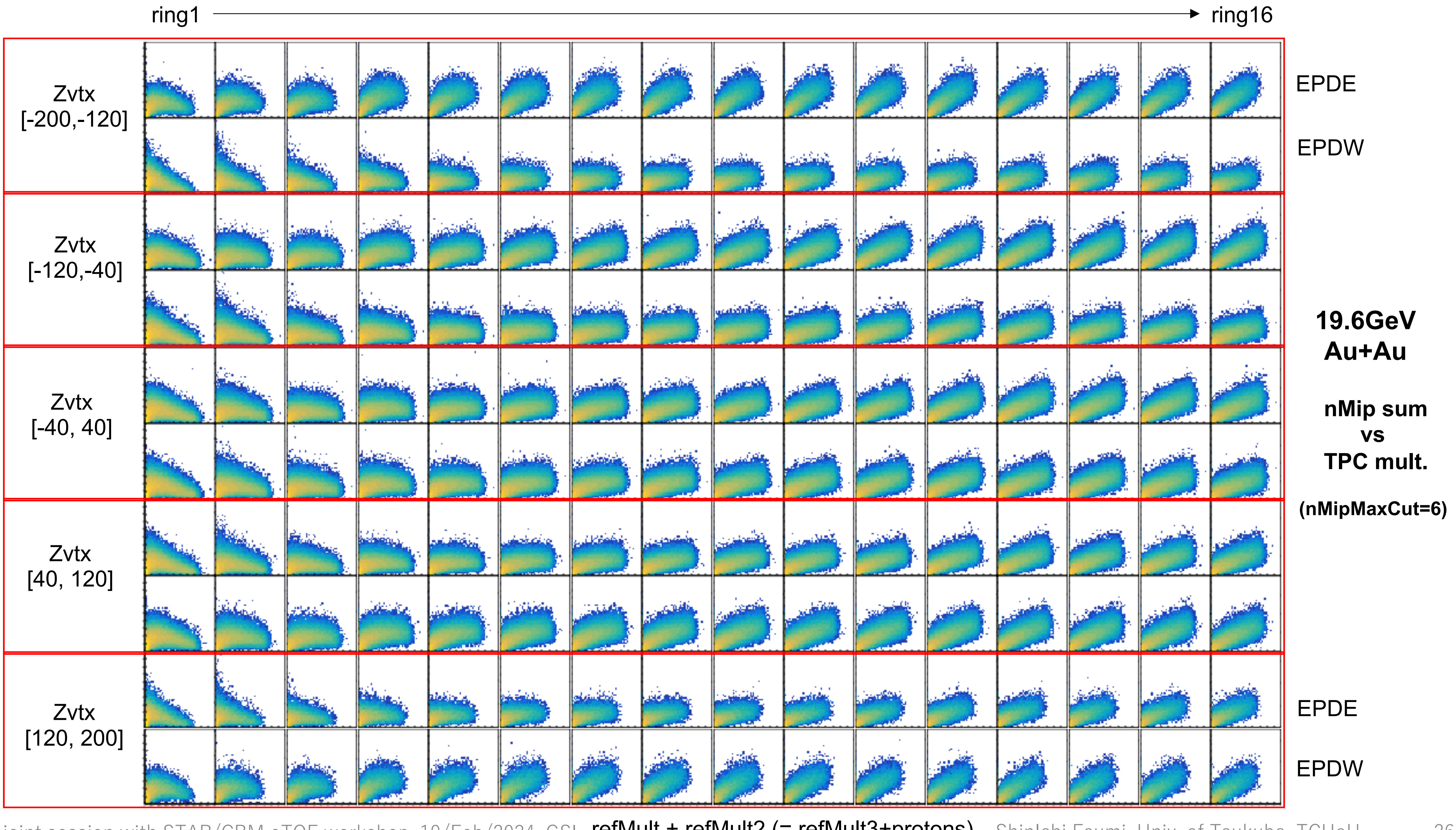




Forward-backward event-plane correlation



200GeV isobar



ring1
ring16
Zvtx
[-200,-120]
Zvtx
[-120,-40]
Zvtx
[-40, 40]
Zvtx
[40, 120]
Zvtx
[120, 200]
EPDE
EPDW
EPDE
EPDW
19.6GeV
Au+Au
nMip sum
vs
TPC mult.
(nMipMaxCut=6)
refMult + refMult2 (= refMult3+protons)