Precision Measurements of Net-proton Number Fluctuations in Au+Au Collisions at 7.7 & 9.2 GeV at RHIC

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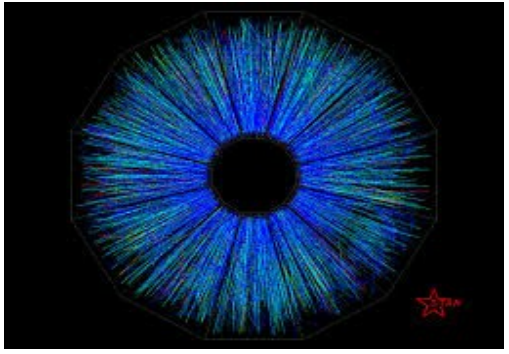
ALICE-STAR India collaboration meet
27th Jun, 2024

National Institute of Science Education and Research, Bhubaneswar, India



Outline

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2) Observables
3) STAR BES-II program
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राष्ट्रीय विज्ञान शिक्षा एवं अनुसंधान संस्थान
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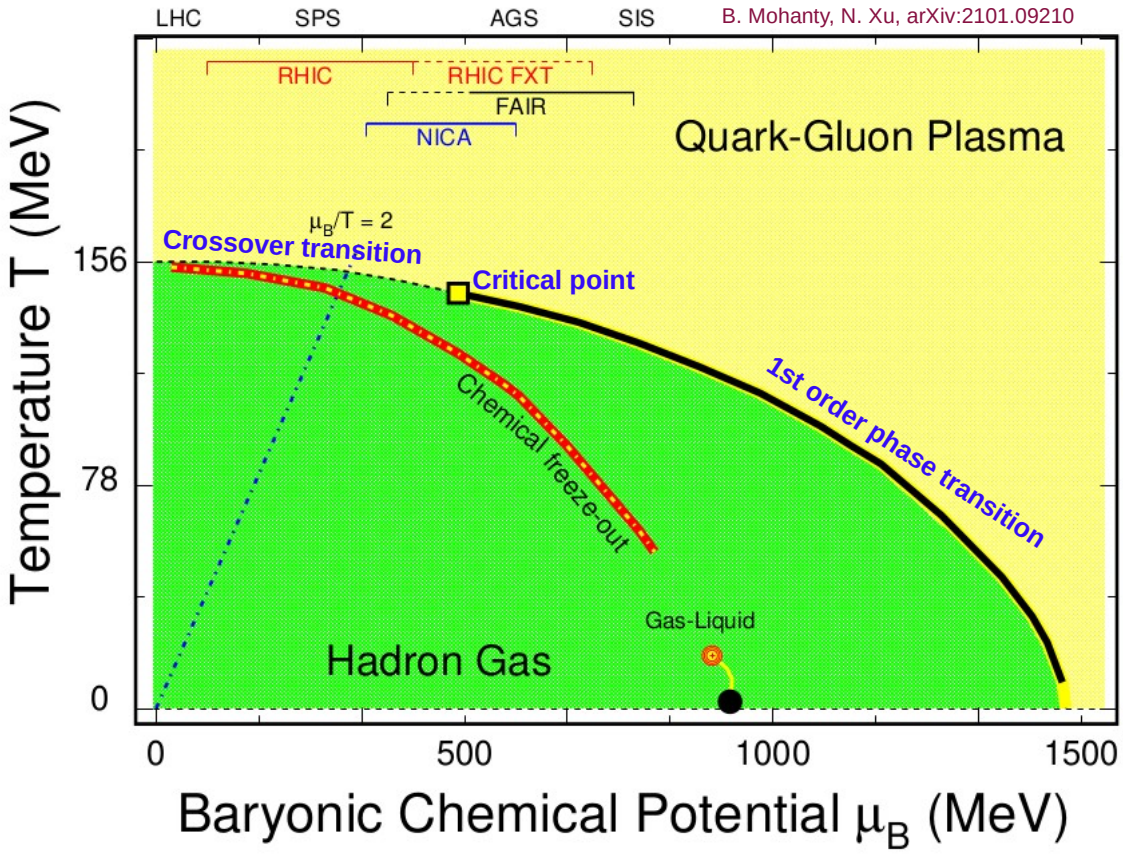
Introduction- QCD Phase Diagram



- ☑ **Goal:** To study QCD phase diagram.
- ☑ Varying collision energy varies Temperature (T) and Baryon Chemical Potential (μ_B).
- ☑ Fluctuation of conserved quantities are sensitive observables to study QCD phase structure.

Y. Aoki et al, Nature 443 (2006) 675.
S. Ejiri, Phys. Rev. D 78, 074507 (2008).
P. Braun-Munzinger, J. Stachel, Nature 448 (2007) 302
A. Pandav et. al. Prog.Part.Nucl.Phys. 125 (2022) 103960

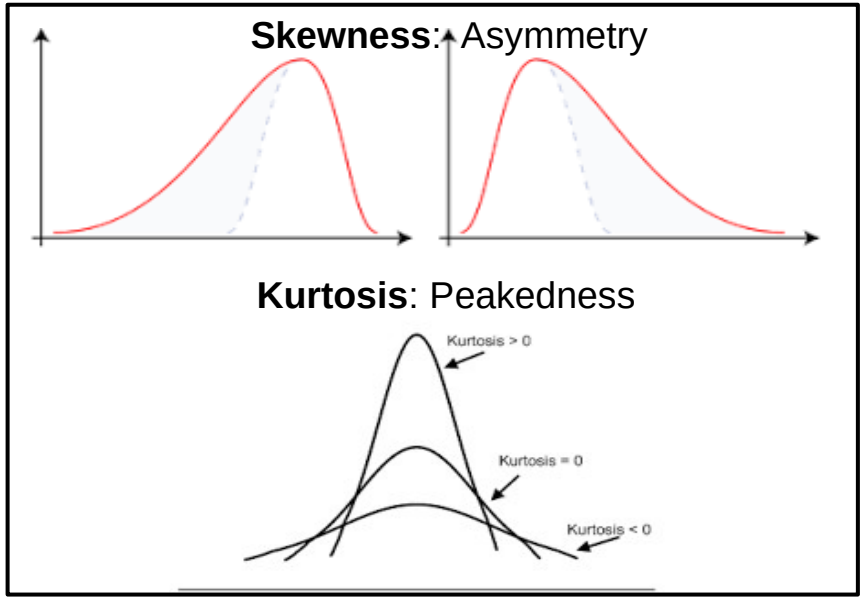
Observables (Net-proton Cumulants)

☑ Higher order cumulants of net proton (proxy for net-baryon) distribution.

$$C_1 = \langle N \rangle$$
$$C_2 = \langle (\delta N)^2 \rangle$$
$$C_3 = \langle (\delta N)^3 \rangle$$
$$C_4 = \langle (\delta N)^4 \rangle - 3\langle (\delta N)^2 \rangle^2$$
$$\kappa_1 = C_1, \quad \kappa_2 = -C_1 + C_2,$$
$$\kappa_3 = 2C_1 - 3C_2 + C_3, \quad \kappa_4 = -6C_1 + 11C_2 - 6C_3$$

here, N = *number of net proton*

here, $\delta N = N - \langle N \rangle$



☑ Higher order cumulants are sensitive probes for the CP and nature of phase transition.

☑ Direct comparison with lattice QCD, HRG, QCD-based model calculations.

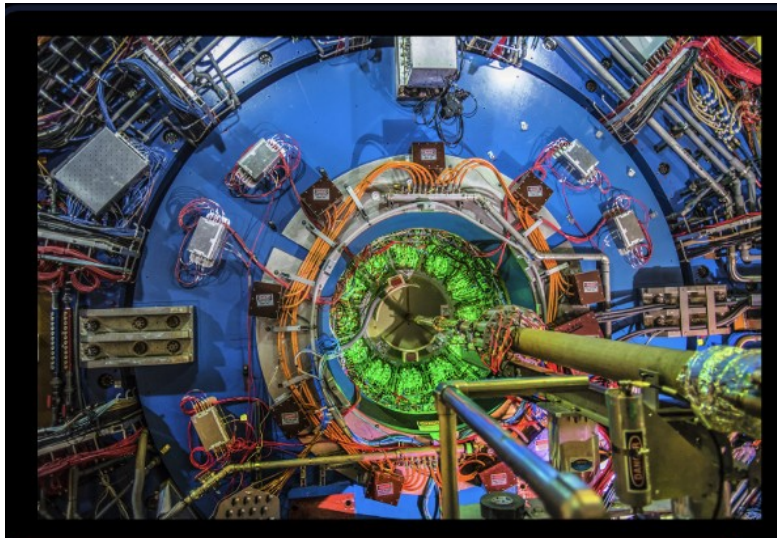
$$\frac{C_3}{C_2} = S\sigma \qquad \frac{C_4}{C_2} = \kappa\sigma^2 \qquad S = Skewness,\ \kappa = Kurtosis$$

M. A. Stephanov, Phys.Rev.Lett. 107 (2011) 052301
Y. Hatta ,M. A. Stephanov, Phys.Rev.Lett. 91 (2003) 102003

STAR BES-II program

- ☑ Two new collider energy: 9.2 & 17.3 GeV.
- ☑ In BES-II, about 10 – 18 times increase in statistics for Au + Au collision.

Energy (GeV)	7.7	9.2	11.5	14.5	17.3	19.6	27
Events BES-I (10^6)	3	-	7	20	-	15	30
Events BES-II (10^6)	45	78	110	178	116	270	220



iTPC

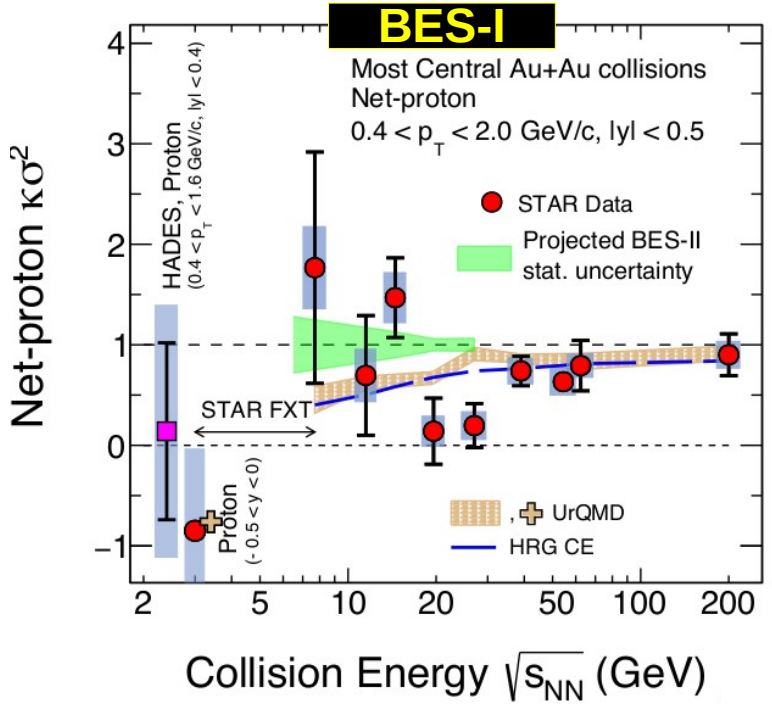
- ☑ Major detector upgrade related to current work.
- ☑ Improves dE/dX measurements.
- ☑ Extend η coverage: $|\eta|<1.0$ to $|\eta|<1.6$
- ☑ Lower p_T threshold: From 125 MeV to 60 MeV.

Data set details

- ☑ Au + Au at $\sqrt{s_{NN}}$ = **7.7** GeV (BES-II)
- ☑ Run ID : 22031042 – 22121018 (total 2696 runs)
- ☑ Production tag : P22ia
- ☑ Total data size : 45 million events

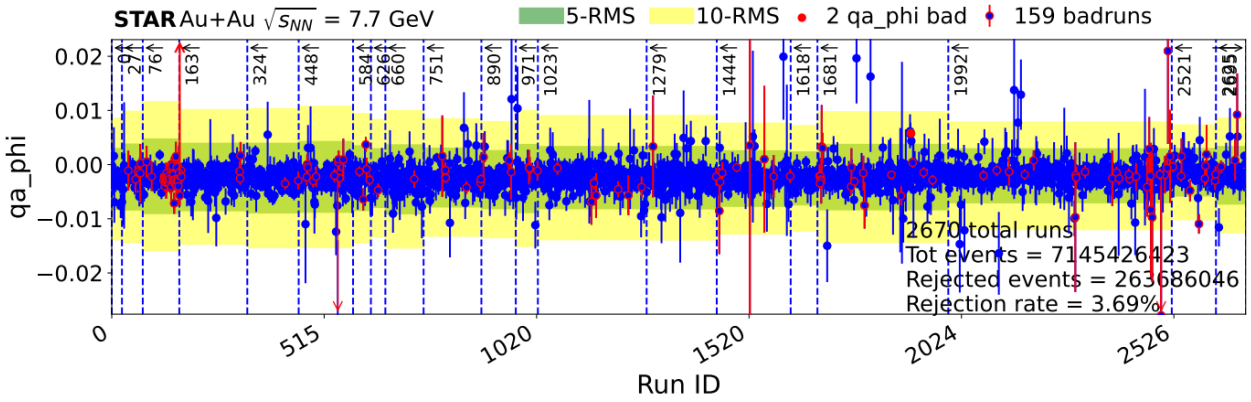
- ☑ Au + Au at $\sqrt{s_{NN}}$ = **9.2** GeV (BES-II)
- ☑ Run ID : 21169035 – 21245010 (total 1535 runs)
- ☑ Production tag : P23ia
- ☑ Total data size : 78 million events

Last collab. Meeting (Jammu): mentioned to work on two energies for thesis: 7.7 GeV & 9.2 GeV.

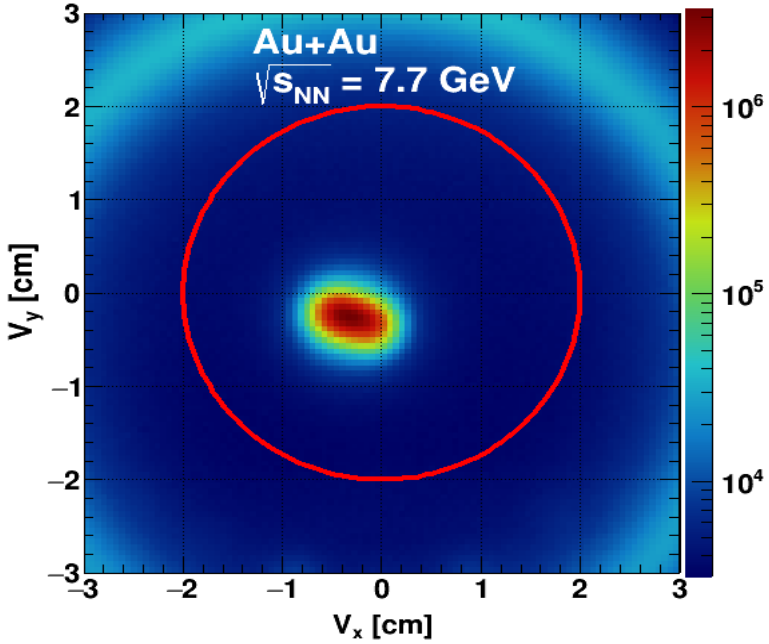


Run-by-run & Event level Quality Assuarance (QA) Check

Run QA:

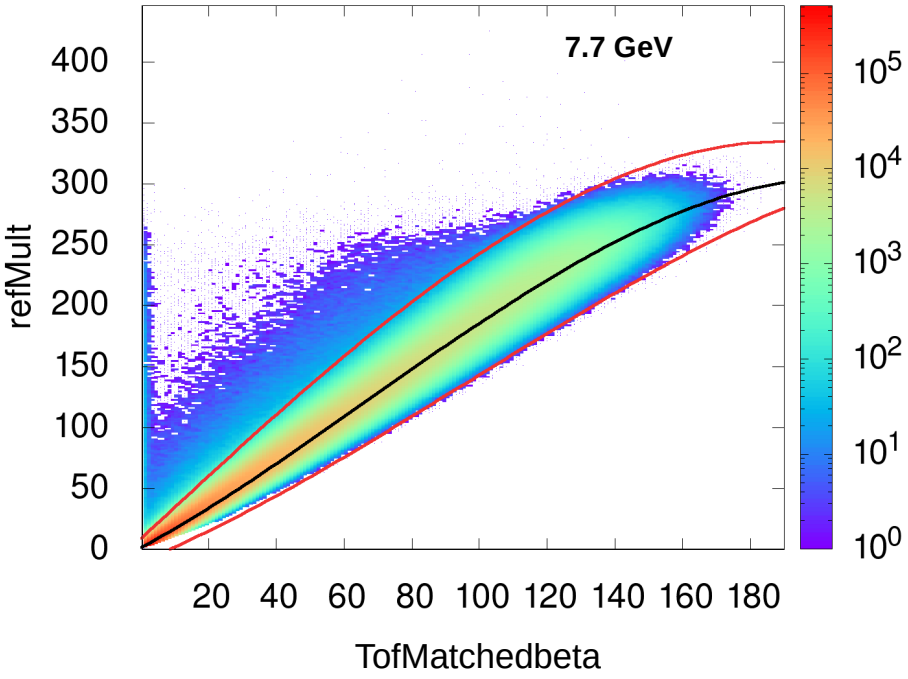


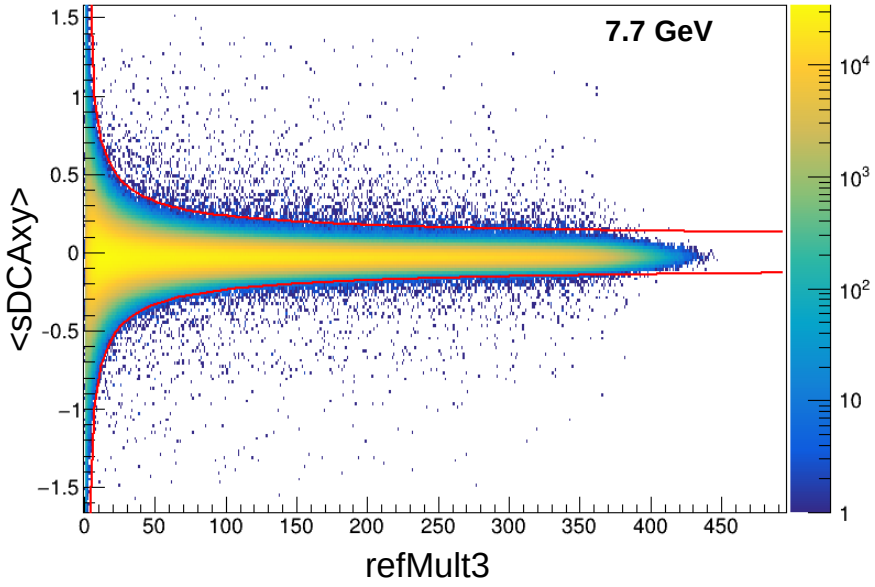
Event QA:



- ☑ QA variable: refmult, tofmult, tofmatched, tofmatchedbeta, zdc, bbc, vx, vy,vz, vr, dca, nhitsfit, nhitsdedx, pt, eta, phi, dcaxy, sdcaxy.
- ☑ Combining with STAR official bad run list.
- ☑ $|V_z| < 50$ cm & $V_r < 2$ cm is used for event selection.

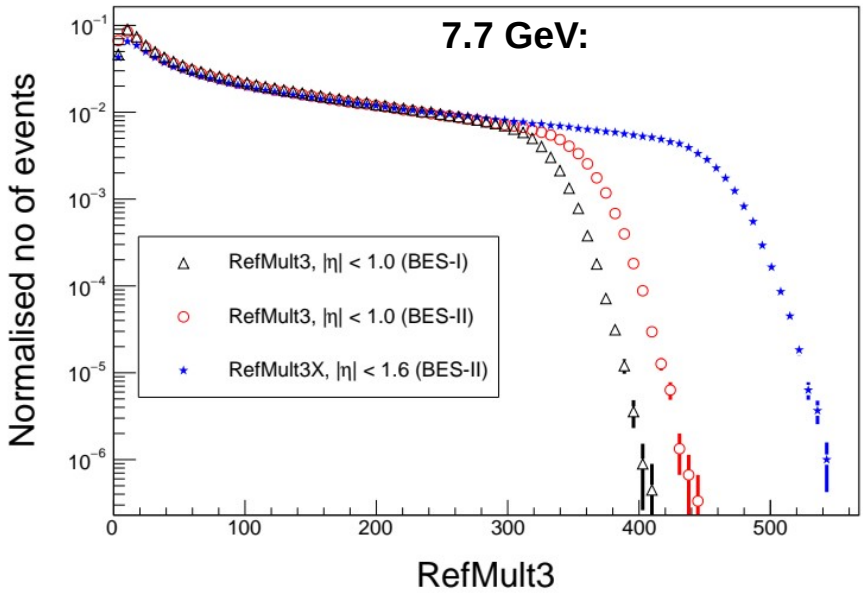
Pileup events & bad sDCA events

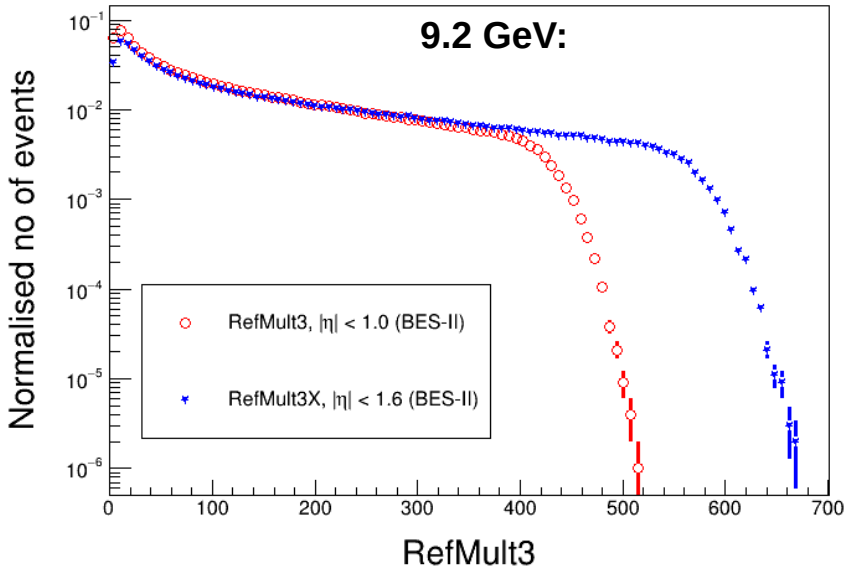




- ☑ RefMult: Charge particle multiplicity ($|\eta| < 0.5$).
- ☑ RefMult3: Charge particle multiplicity excluding protons ($|\eta| < 1.0$).
- ☑ TofMatchedbeta: TofMatched with $\beta > 0.1c$
- ☑ Bad events rejected using sDCAz & sDCAxy cut.

Centrality definition





- ☑ **Refmult3:** (Charge particle multiplicity with **|η|< 1.0** excluding protons and anti protons) distribution for centrality determination
- ☑ **Refmult3X:** same with **|η|< 1.6**
- ☑ Divide into 9 centrality classes: 0-5%, 5-10%, 10-20%, 20-30, ... 70-80%
- ☑ Resolution: Refmult3X (BES-II) > Refmult3 (BES-II) > RefMult3 (BES-I)

Analysis Cut

☑ **Track quality cuts:** DCA <1 cm, NhitsFit > 20 , NhitsDedx > 5, nHitsFit/(nHitsPoss)>0.52

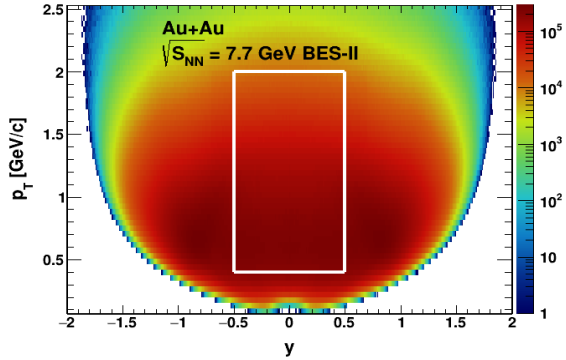
☑ **Proton selection: (7.7 & 9.2 GeV)**

- $|y| < 0.5$ & $0.4 < p_T < 0.8$ GeV/c : TPC ($|n\sigma_p| < 2$)
- $|y| < 0.5$ & $0.8 < p_T < 2$ GeV/c : TPC+TOF ($|n\sigma_p| < 2$, $0.6 < m^2 < 1.2$ Gev^2/c^4)

☑ **Anti-proton selection: (7.7 GeV)**

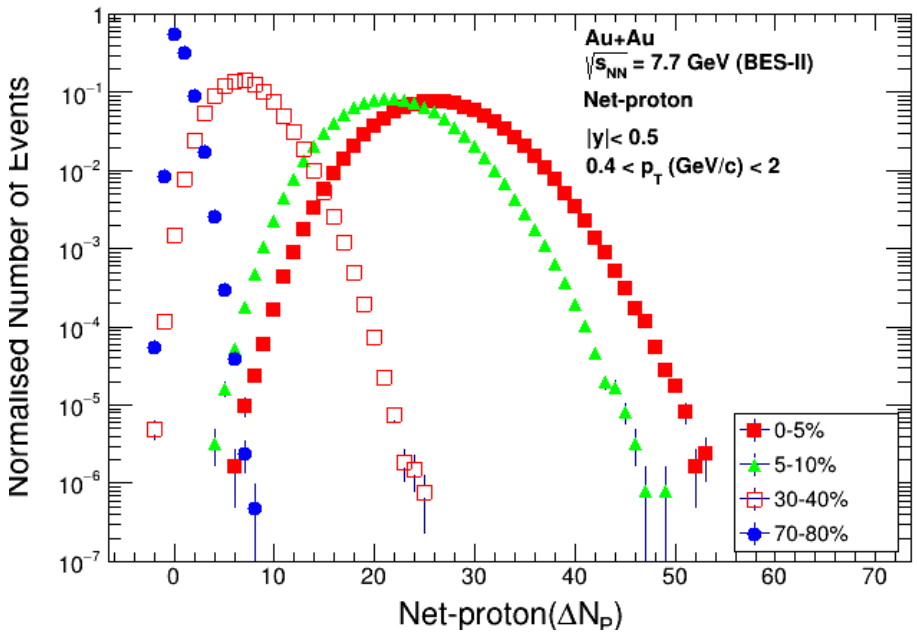
- $|y| < 0.4$, $0.4 < p_T < 0.7$ GeV/c use TPC ($-2 < n\sigma_p < 2$)
  $0.7 < p_T < 2.0$ GeV/c use TPC + TOF
- $0.4 < |y| < 0.5$, $0.4 < p_T < 0.8$ Gev/c use TPC ($0 < n\sigma_p < 2$)
  $0.8 < p_T < 2.0$ Gev/c use TPC + TOF

*PID purity > 95%

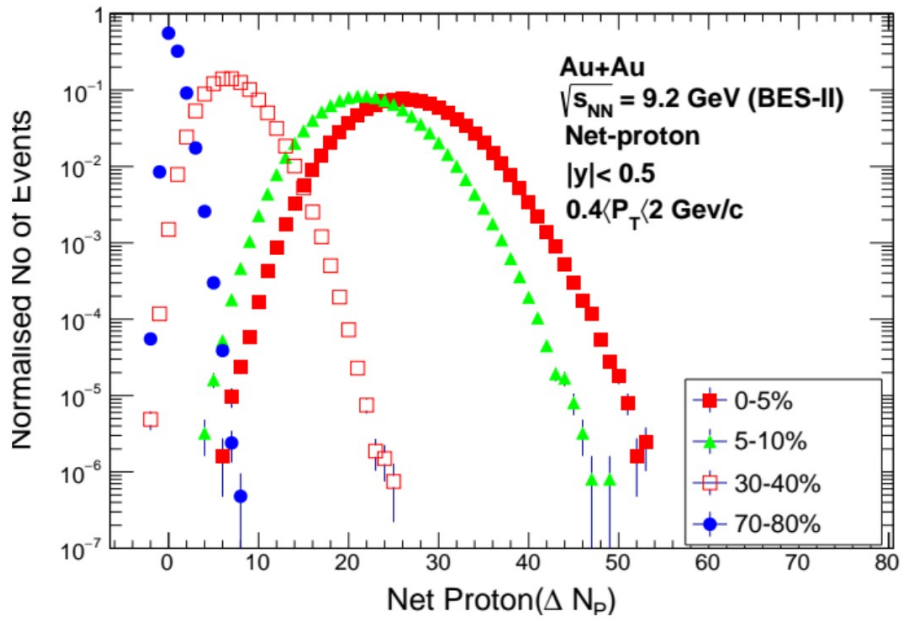


Event by event net-proton multiplicity distribution

7.7 GeV

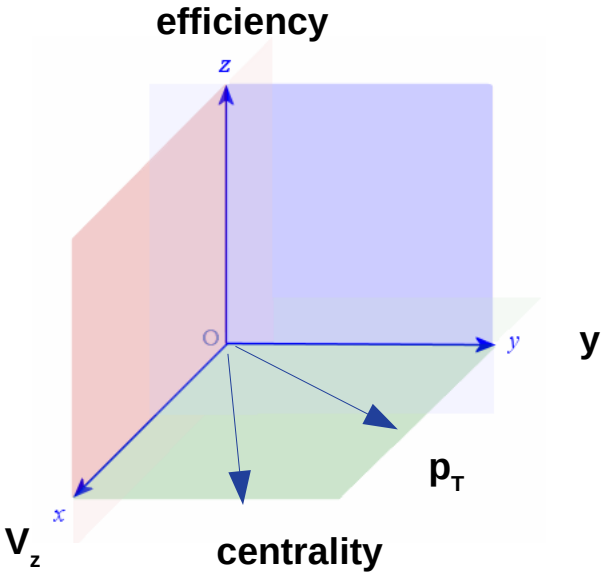


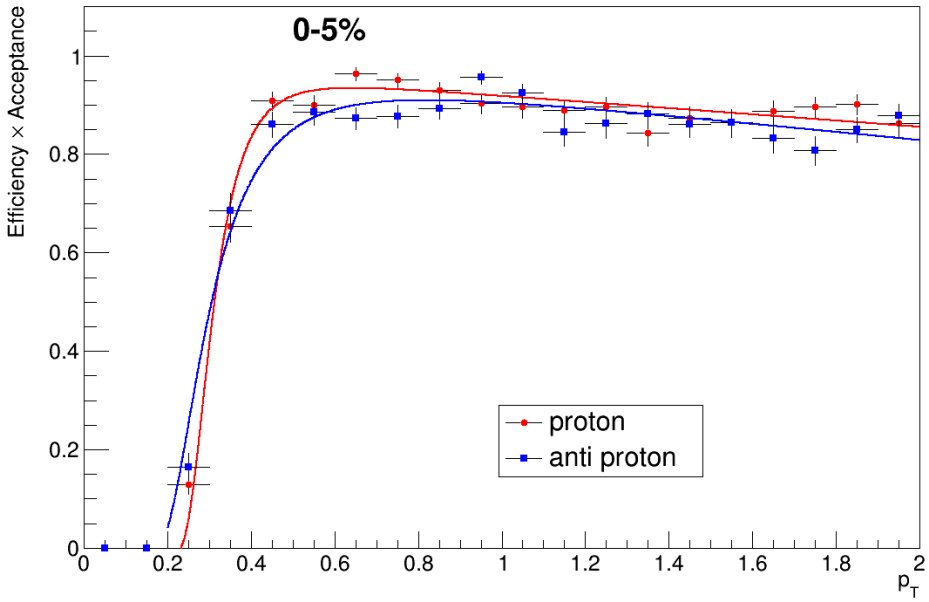
9.2 GeV



- ☑ Distributions are not corrected for proton and antiproton reconstruction efficiency in TPC and TOF.
- ☑ Mean & sigma of the distributions decreases from central to peripheral.

Correction for efficiency





- ☑ Divide full V_z window into 5 segment (-50, -30, -10, 10, 30, 50 cm)
- ☑ Divide full rapidity window into 9 segment (-0.5,-0.4,-0.3,-0.2,-0.1,0.1,0.2,0.3,0.4,0.5)

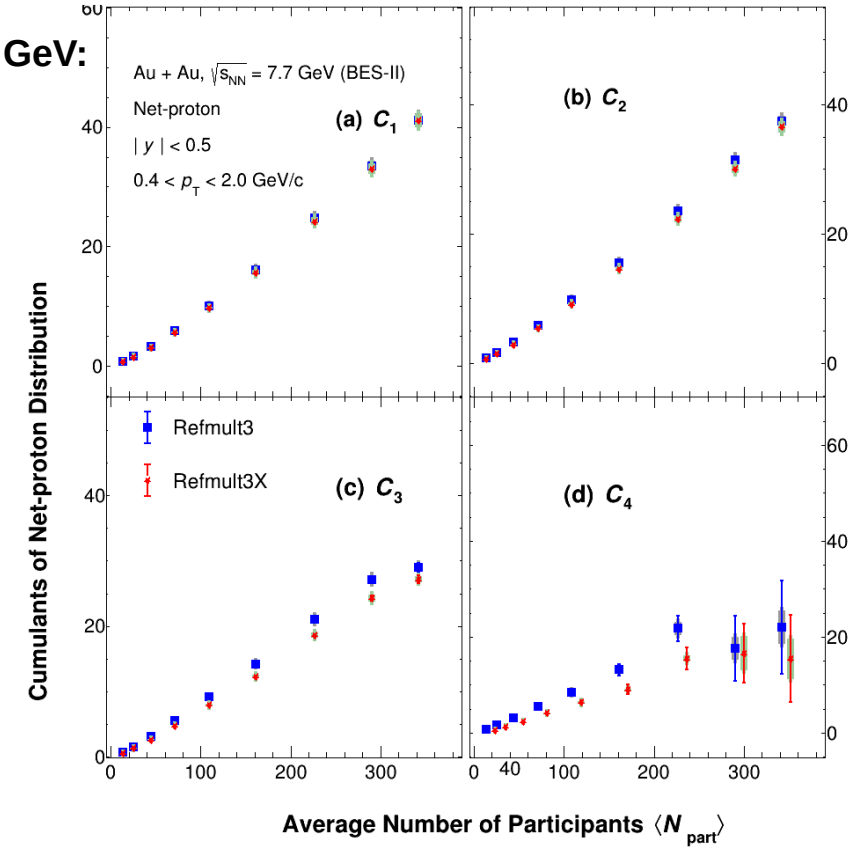
- ☑ Efficiency for proton and anti proton
- ☑ Shown for: -10< V_z (cm) < 10, -0.1< y < 0.1
- ☑ Efficiency applied on track-by-track basis

Results (7.7 & 9.2 GeV)

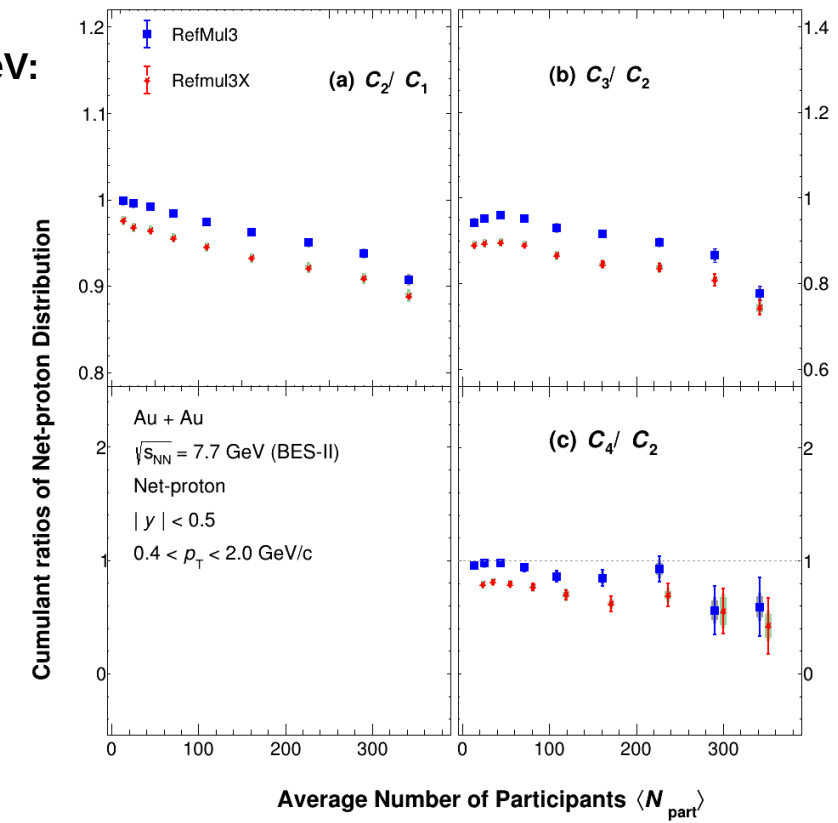
- ☑ Efficiency corr. (detector eff & PID eff) cumulants
- ☑ Stat. error using bootstrap method
- ☑ Centrality bin width correction applied

Centrality dependence: net proton Cumulant (7.7 GeV)

7.7 GeV:



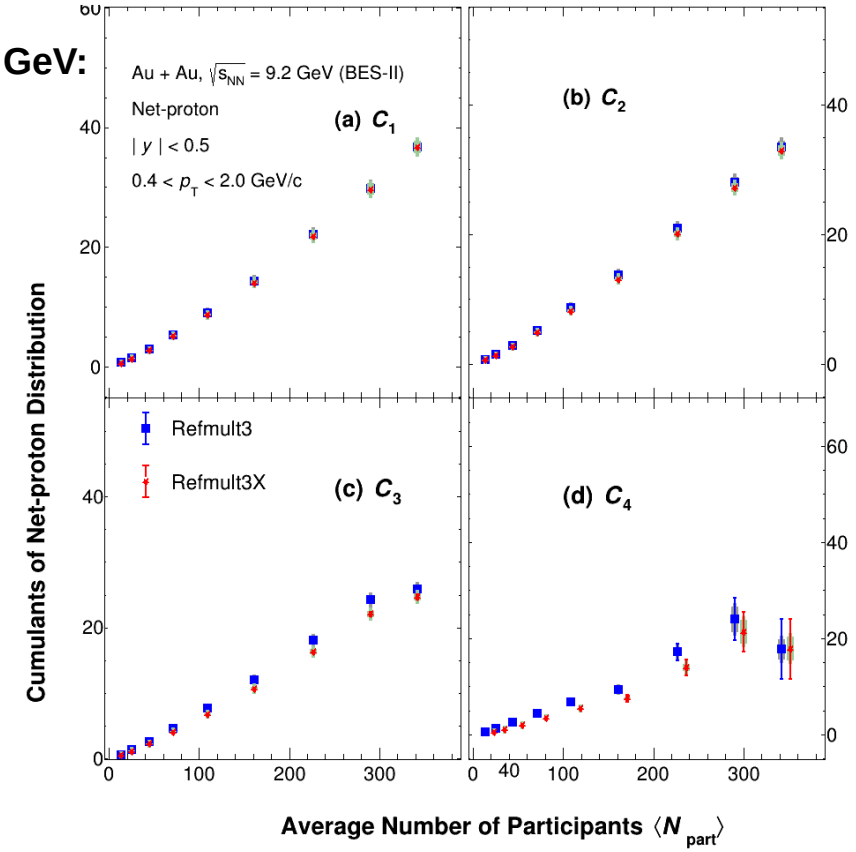
7.7 GeV:



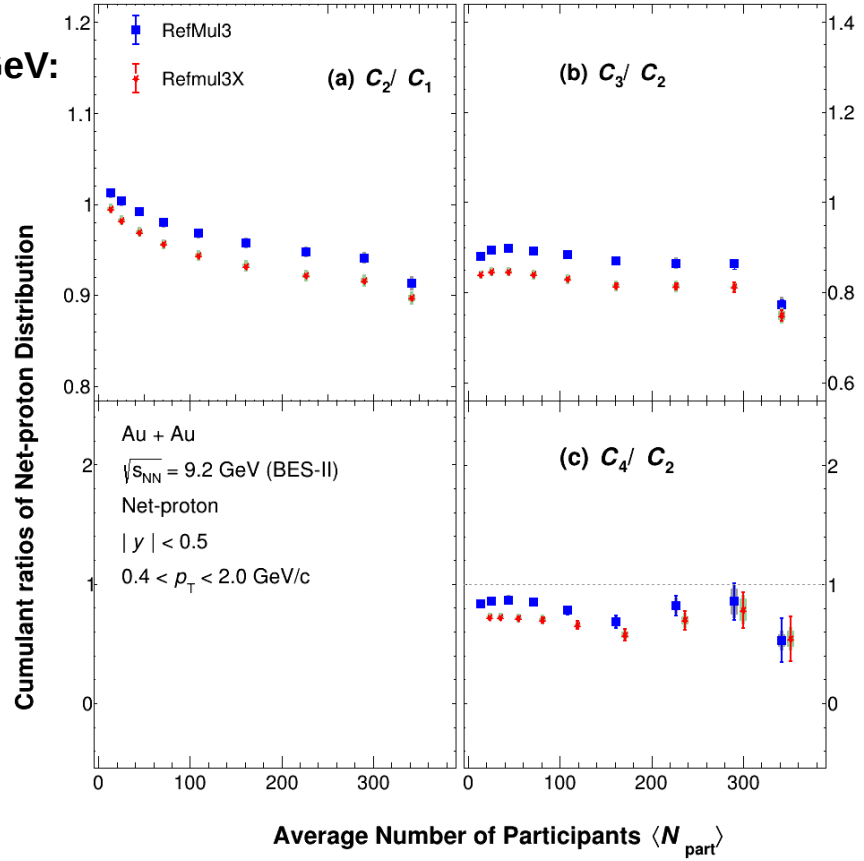
- ☑ Cumulant shows increasing trend over centrality.
- ☑ Weak dependence for cumulant ratios.
- ☑ Refmult3X always lower than Refmult3 result.

Centrality dependence: net proton Cumulant (9.2 GeV)

9.2 GeV:



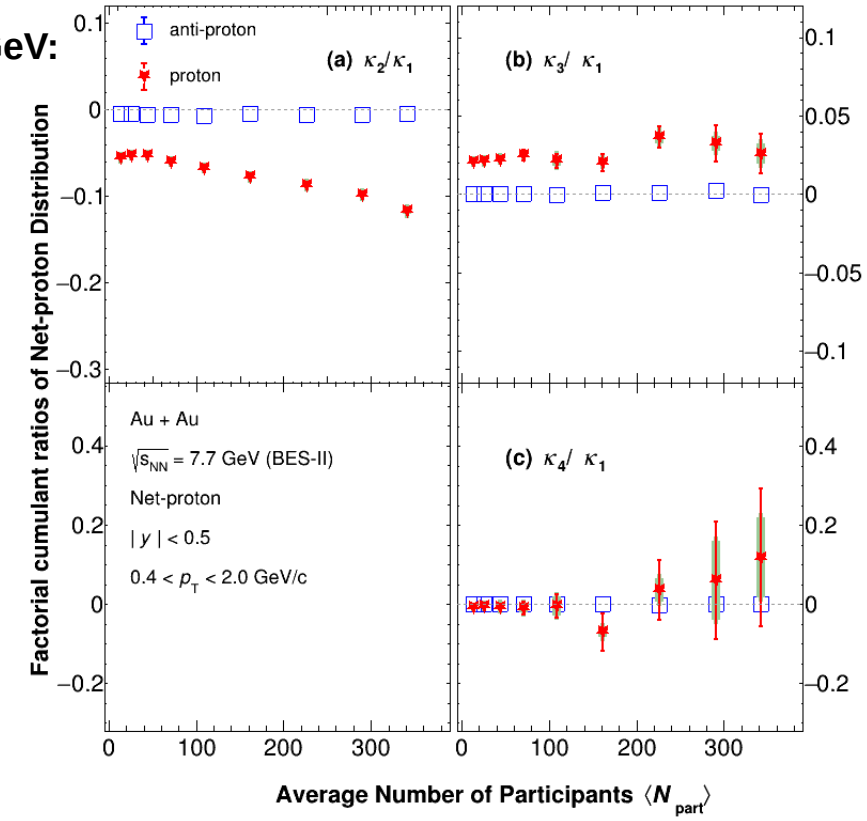
9.2 GeV:



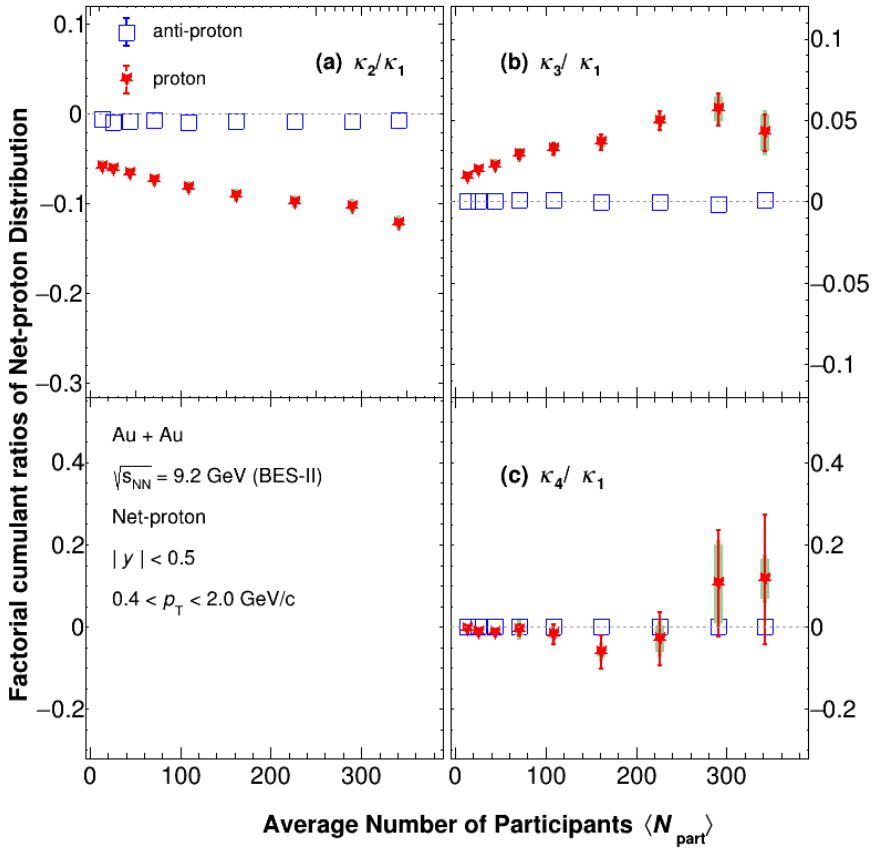
- ☑ Cumulant shows increasing trend over centrality.
- ☑ Weak dependence for cumulant ratios.
- ☑ Refmult3X always lower than Refmult3 result.

Centrality dependence: Factorial Cumulant (7.7 & 9.2 GeV)

7.7 GeV:



9.2 GeV:



- ☑ Results are shown for Refmult3X definition.
- ☑ Anti proton κ_3/κ_1 & κ_4/κ_1 close to zero.

Summary and Outlook

Summary:

☑ Net-proton cumulants & factorial cumulants done for 7.7 & 9.2 GeV.
☑ Results shown at CPOD, SQM, RHIC-AGS meeting.

Outlook:

☑ Study of higher order fluctuations (C_5, C_6 , κ_5, κ_6).
☑ Rapidity & P_T dependence study to follow soon.