Study on measurement of cumulants of net-proton distributions for Au +Au collisions at $\sqrt{s_{NN}}$ = 7.7 GeV in BES-II

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ALICE-STAR India collaboration meet
24th Nov, 2023

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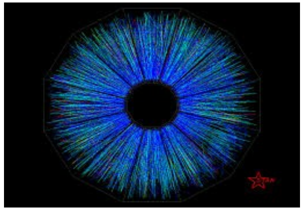
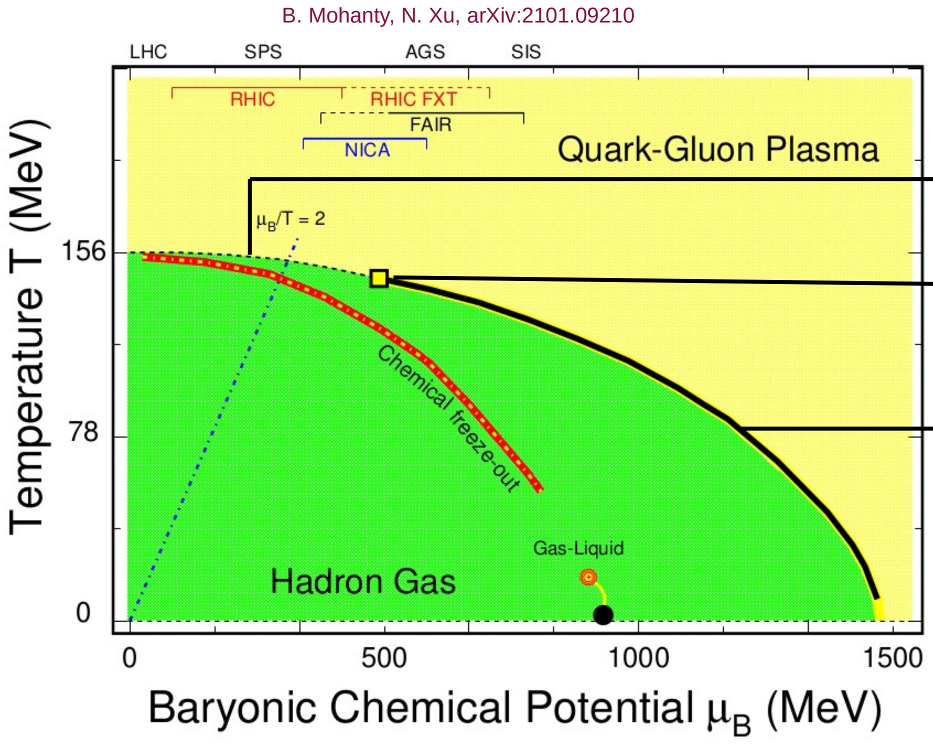


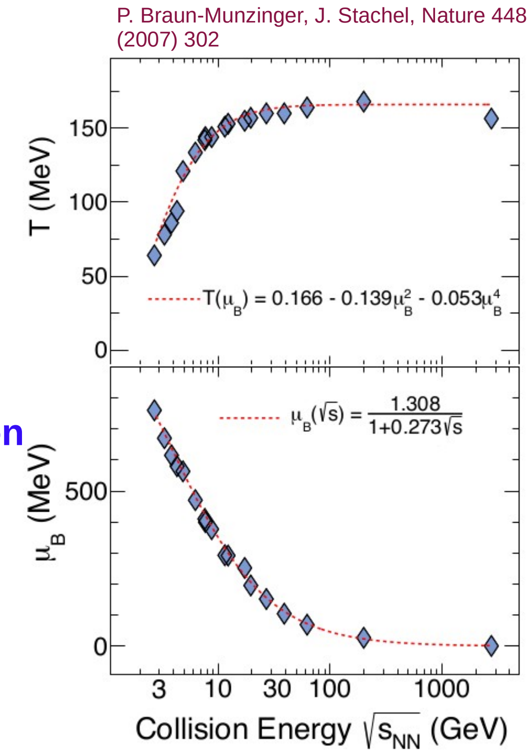
Outline

1) Motivation
2) Observables
3) Previous results
4) Current Analysis status
5) Summary & Outlook

Motivation



- **Crossover transition (from Lattice QCD)**
  Y. Aoki et al, Nature 443 (2006) 675.
- **QCD critical point (CP)**
- **1st order phase transition (from models)**
  S. Ejiri, Phys. Rev. D 78, 074507 (2008).



- **Goal:** To search for QCD critical point
- Varying collision energy varies Temperature (T) and Baryon Chemical Potential (μ_B).
- Fluctuation of conserved quantities are sensitive observable to study QCD critical point

Observables

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

$C_1 = \langle N \rangle$ $\quad$ $here, \delta N = N - \langle N \rangle$

$C_2 = \langle (\delta N)^2 \rangle$

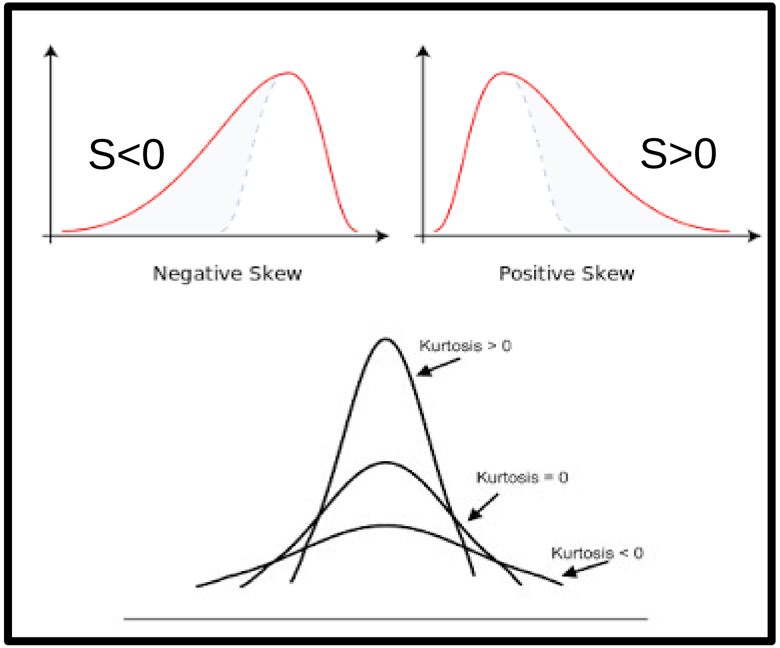
$C_3 = \langle (\delta N)^3 \rangle$

$C_4 = \langle (\delta N)^4 \rangle - 3\langle (\delta N)^2 \rangle^2$

$C_5 = \langle (\delta N)^5 \rangle - 5\langle (\delta N)^3 \rangle \langle (\delta N)^2 \rangle$

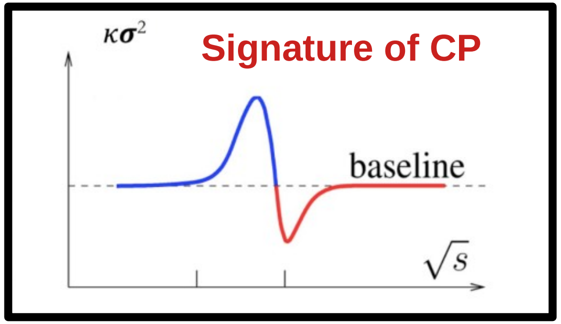
$C_6 = \langle (\delta N)^6 \rangle - 15\langle (\delta N)^4 \rangle \langle (\delta N)^2 \rangle - 10\langle (\delta N)^3 \rangle^2 + 30\langle (\delta N)^2 \rangle^3$

$\frac{C_2}{C_1} = \frac{\sigma^2}{M}$ $\quad$ $\frac{C_3}{C_2} = S\sigma$ $\quad$ $\frac{C_4}{C_2} = \kappa\sigma^2$ $\quad$ $M = Mean, \sigma^2 = Variance$, $S = Skewness, \kappa = Kurtosis$



- Higher order cumulants of net proton multiplicity distributions are sensitive observables for QCD crirtical point
- Related to correlation length $C_2 \sim \xi^2$ $\quad$ $C_4 \sim \xi^7$

- In presence of critical point: Non-monotonic collision energy dependence of C_4/C_2

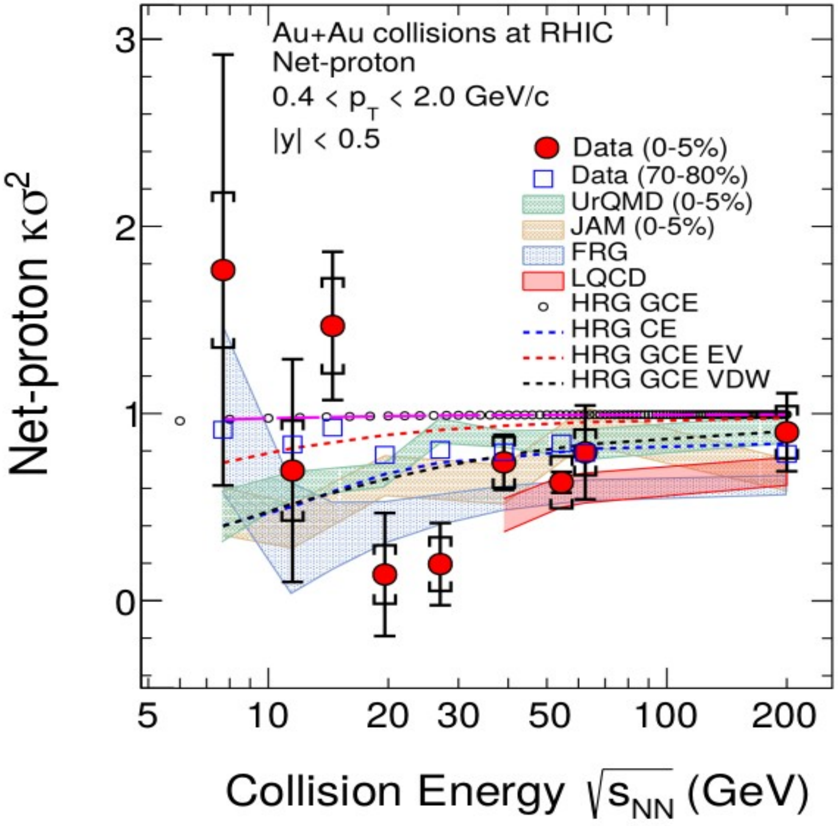


M.A. Stephanov, Phys.Rev.Lett. 107 (2011) 052301

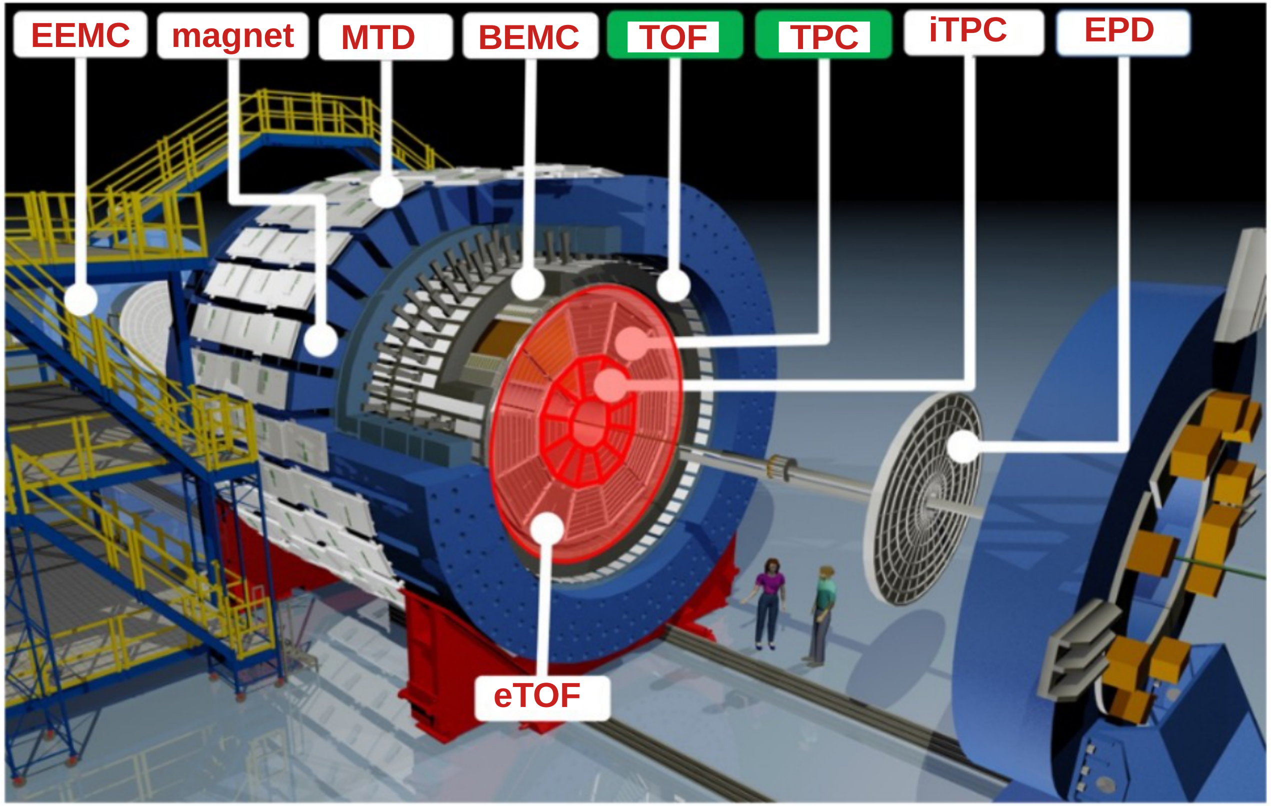
Previous result from BES-I

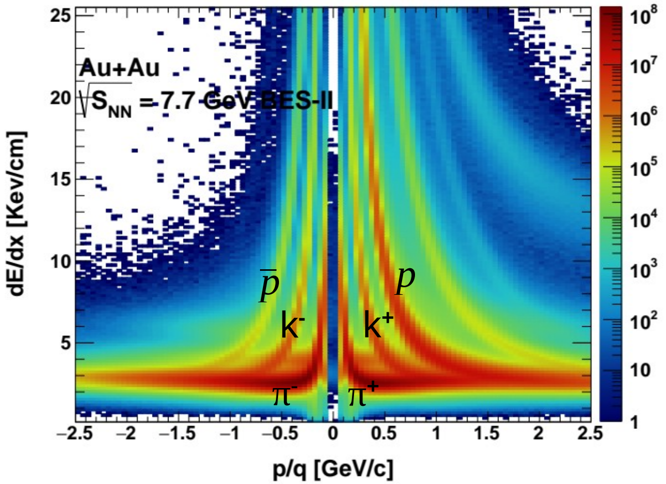
- Collision energy dependence of ratio of fourth to second-order cumulant of net-proton distribution (from BES-I) shown here
- Measurements are shown for 0-5% and 70-80% Au+Au collision centrality class as a function of various collision energies
- Non monotonic dependence over collision energy
- However at lower energy larger statistical uncertainty
- Analysis in BES-II needed for higher statistical precision
- Here we only focus on higher statistics data collected at 7.7 GeV collision energy in BES-II

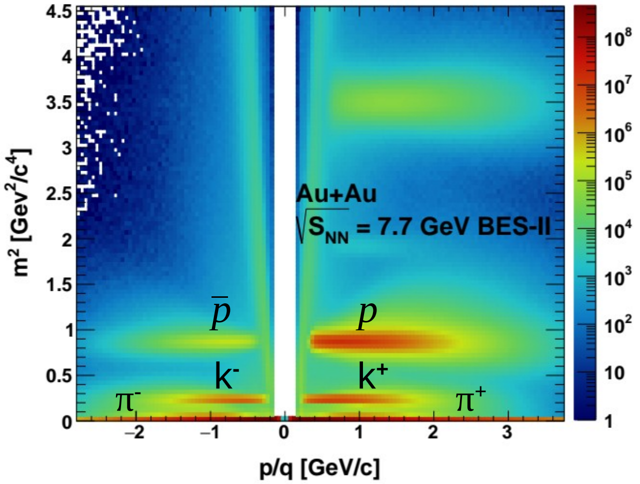
https://doi.org/10.1016/j.ppnp.2022.103960



STAR Detector







- Two main detectors for current analysis: Time Projection Chamber & Time of Flight

Analysis procedure

1/ Data set details

2/ Run-by-run Quality Assurance (QA)

3/ Event level QA

4/ Track level QA

5/ Bad event remove

6/ Centrality determination

7/ Analysis acceptance

8/ Cumulants result (efficiency uncorrected)

9/ Extended centrality *

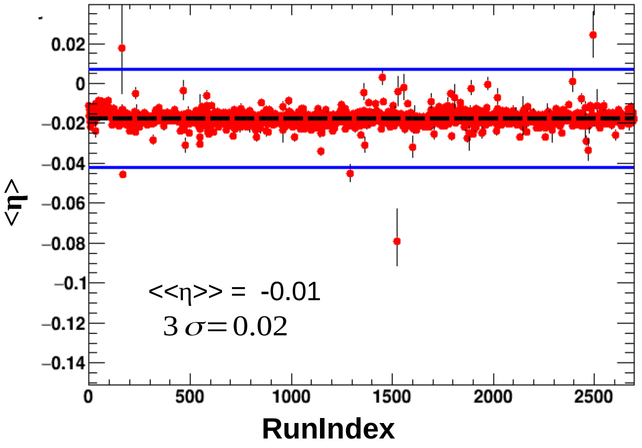
10/ Summary & Outlook

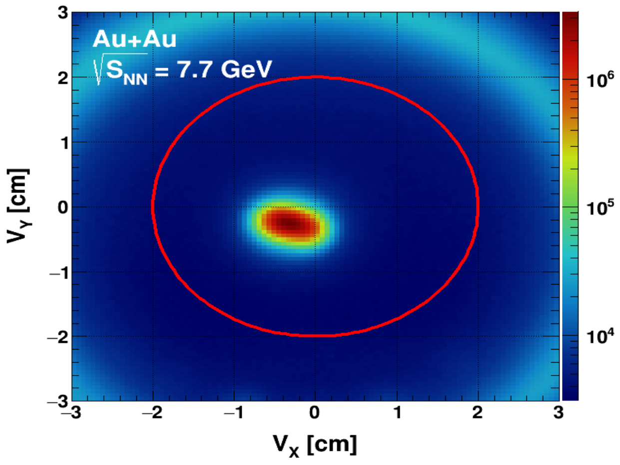
* To improve on centrality resolution

Data sets details

- Au + Au at $\sqrt{s_{NN}}$ = 7.7 GeV (BES-II)
- Run ID : 22031042 – 22121018 (total 2696 runs)
- Trigger ID : 810010,810020,810030 (minimum bias)
- Production tag : P22ia
- Total data size : 52 million events (with $|V_z| < 50$ cm & $V_r < 2$ cm)

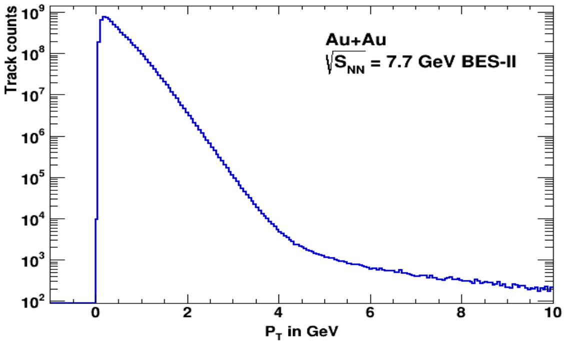
Run by run QA & event QA check

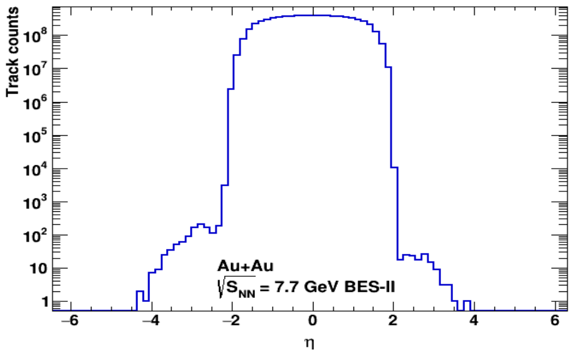


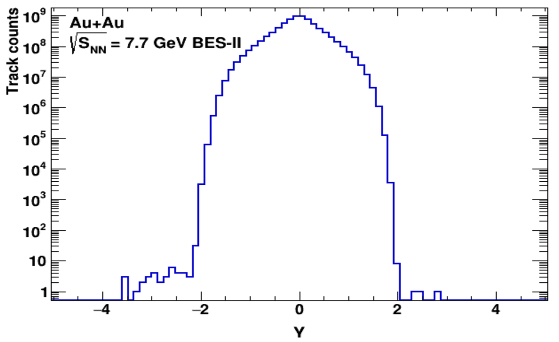


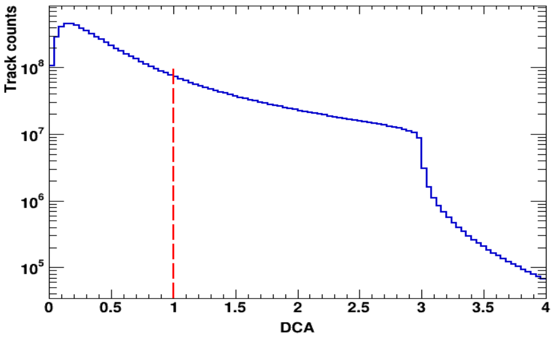
- V_x, V_y, V_r, ZDC, tofmult, tofmatched, p_T, nhitsfit, nhitsdedx, $n\sigma_p$ etc are also considered for QA check ==> 4.9 million events (379 bad run) excluded
- $|V_z| < 50$ cm & $V_r < 2$ cm is used for event selection

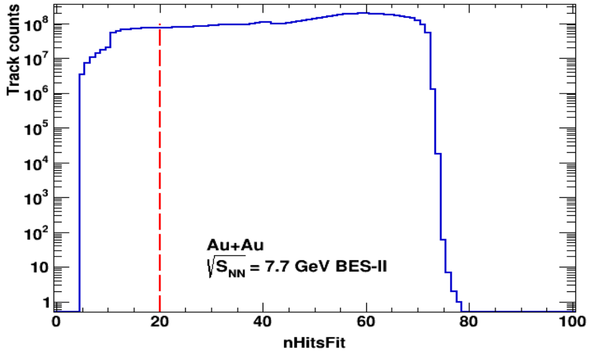
Track QA

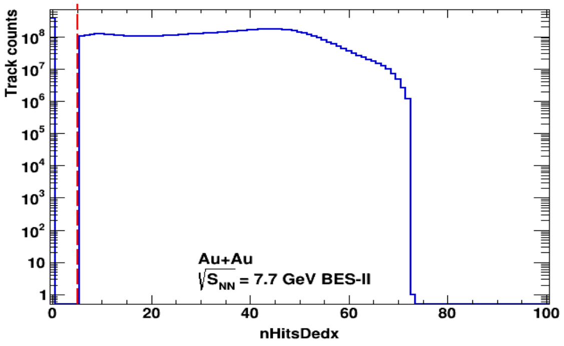








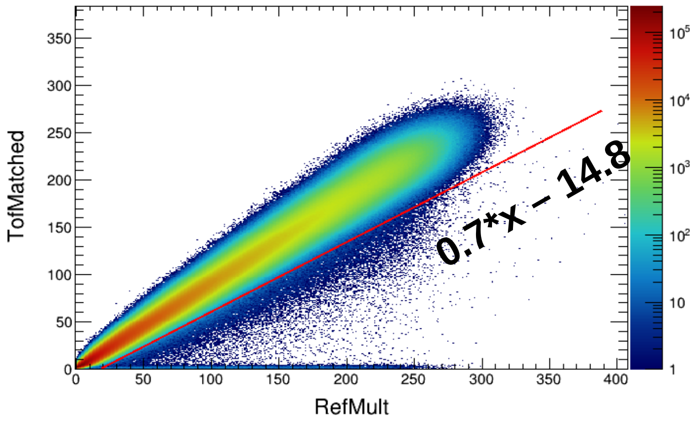


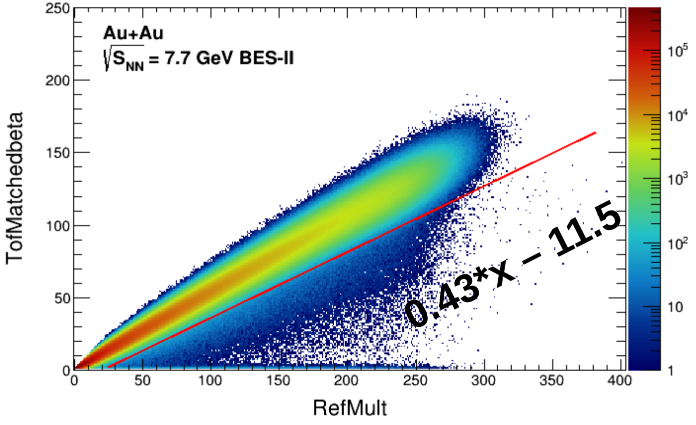


Track quality cut:

- DCA < 1
- NhitsFit > 20
- NhitsDedx > 5
- nHitsFit/(nHitsPoss) > 0.52

Pileup event removal

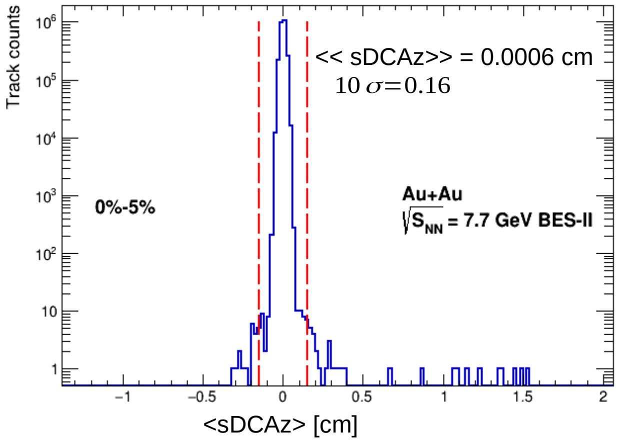


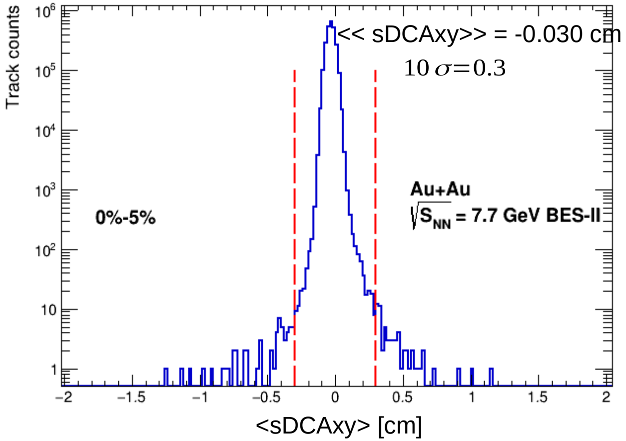


- RefMult: Charge particle ($|\eta| < 0.5$)
- TofMatched : Number of tracks that matched TOF
- TofMatchedbeta: TofMatched with $\beta > 0.1c$

- Neglected those events below red line
- pileup events removed: 64,766 events

Bad events from sDCAxy & sDCAz

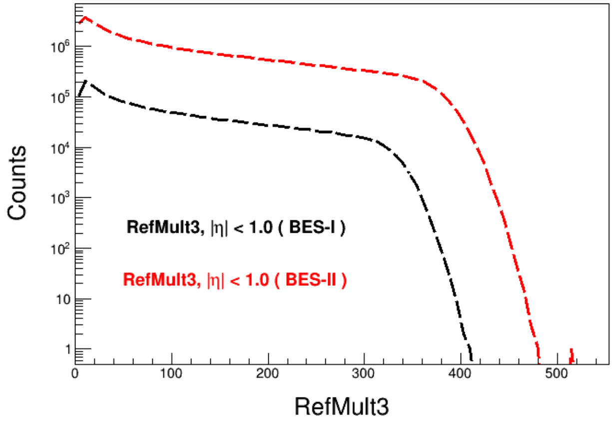




- Obtain mean and sigma of <sDCAz>, <sDCAxy> for 9 individual centrality

- Events 10 sigma (σ) away from mean value are removed. 1524 events rejected

Centrality definition



- **Refmult3:** (Charge particle multiplicity with |η|< 1.0 excluding protons and anti protons) distribution for centrality determination
- Compare with BES-I result

Centrality class (%)	0-5	5 - 10	10-20	20-30	30-40	40-50	50-60	60-70	70-80
RefMult3 cut (BES-I)	270	225	155	105	68	41	23	11	5
RefMult3 cut (BES-II)	307	254	173	116	74	45	26	13	6

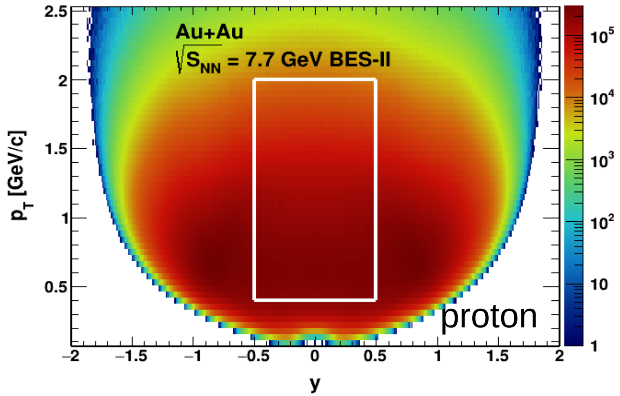
Analysis cut

Proton selection

- $|y| < 0.5$ & $0.4 < p_T < 0.8$ 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)

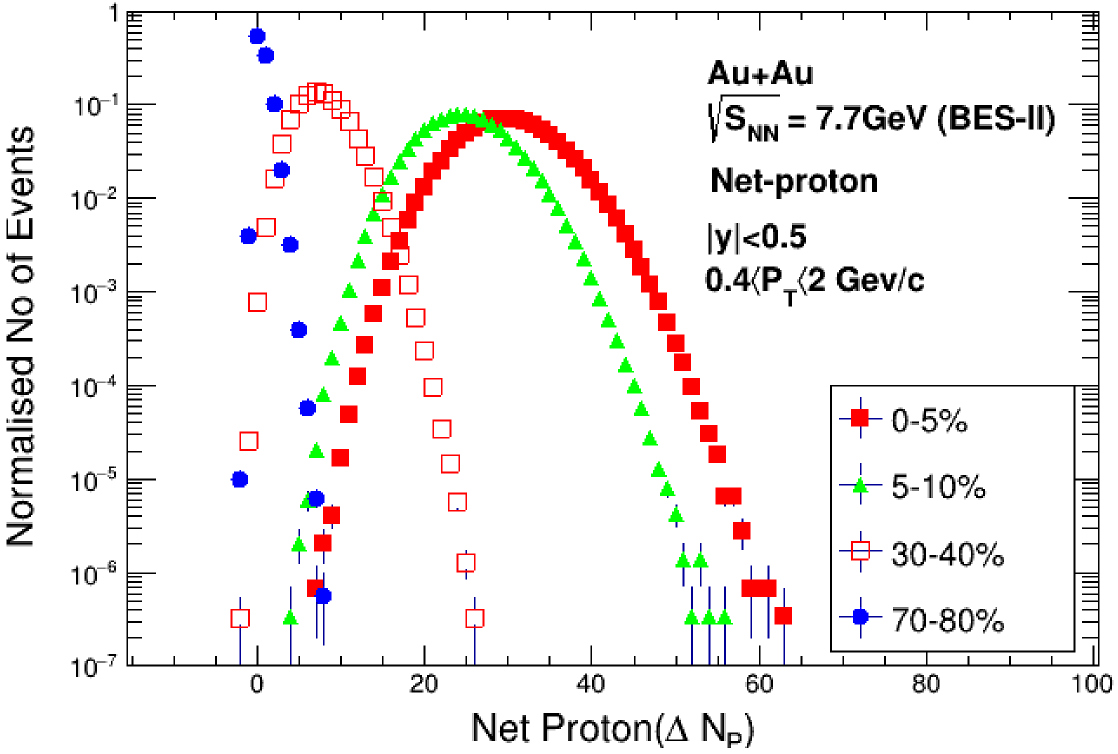
Anti-proton selection

- $|y| < 0.4$: $0.4 < pt < 0.7$ GeV/c use TPC ($-2 < n\sigma_p < 2$)
  $0.7 < pt < 2.0$ GeV/c use TPC +TOF
- $0.4 < |y| < 0.5$: $0.4 < pt < 0.7$ Gev/c use TPC ($-1 < n\sigma_p < 2$)
  $0.7 < pt < 2.0$ use TPC + TOF



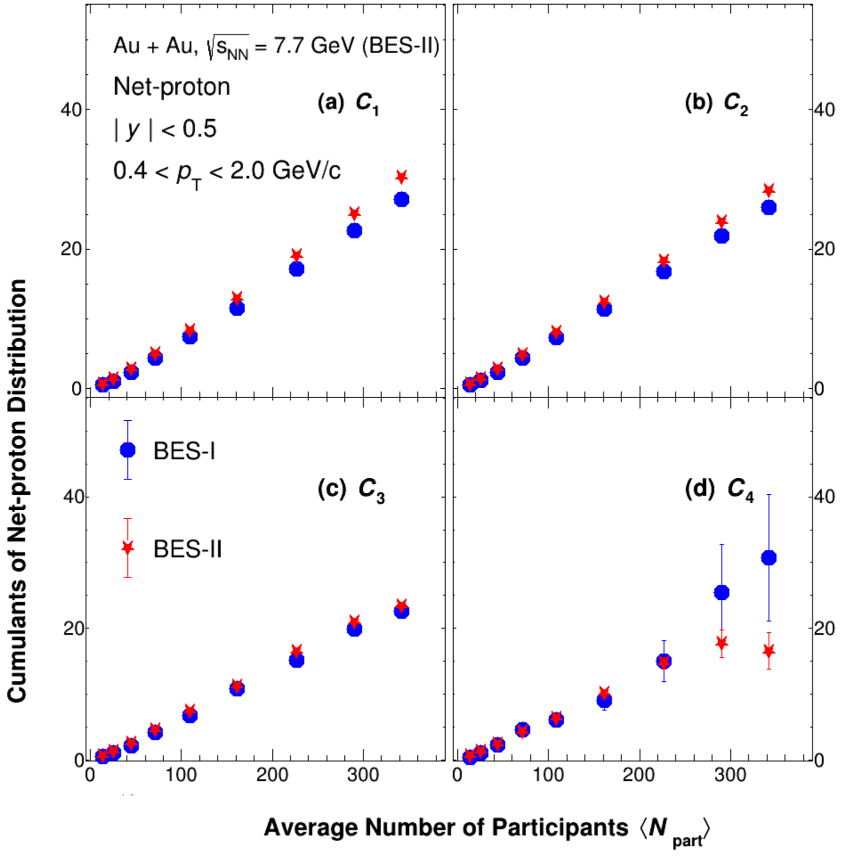
- PID purity > 90%
- Good events: (45 million)

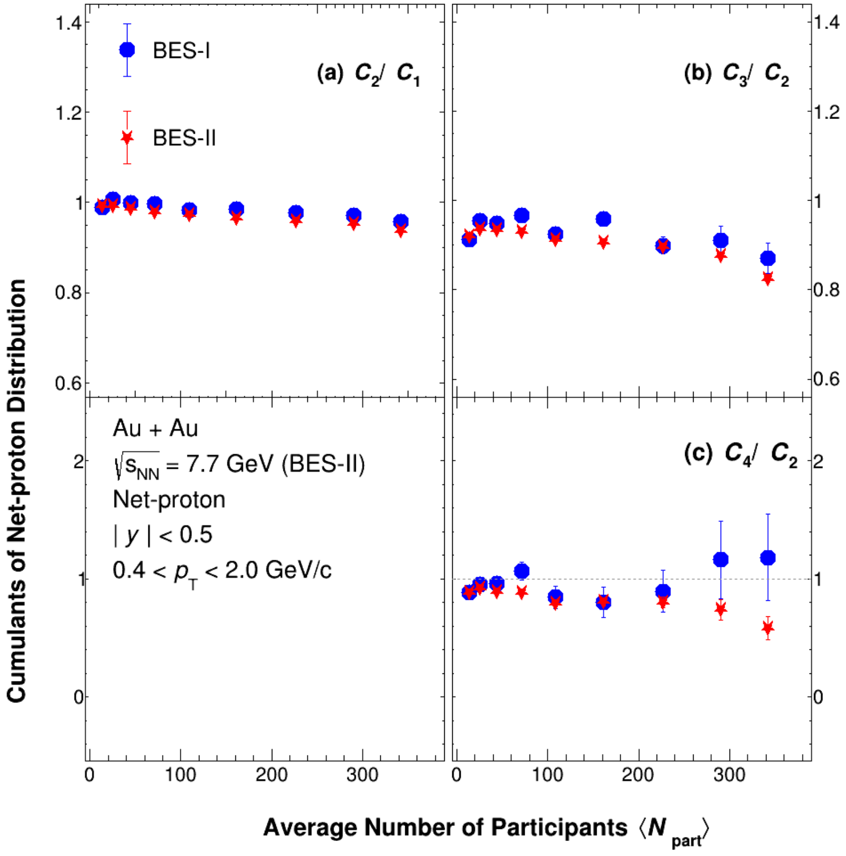
Centrality dependence of net proton multiplicity distribution



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

Centrality dependence of net proton cumulants (eff. uncorr.)

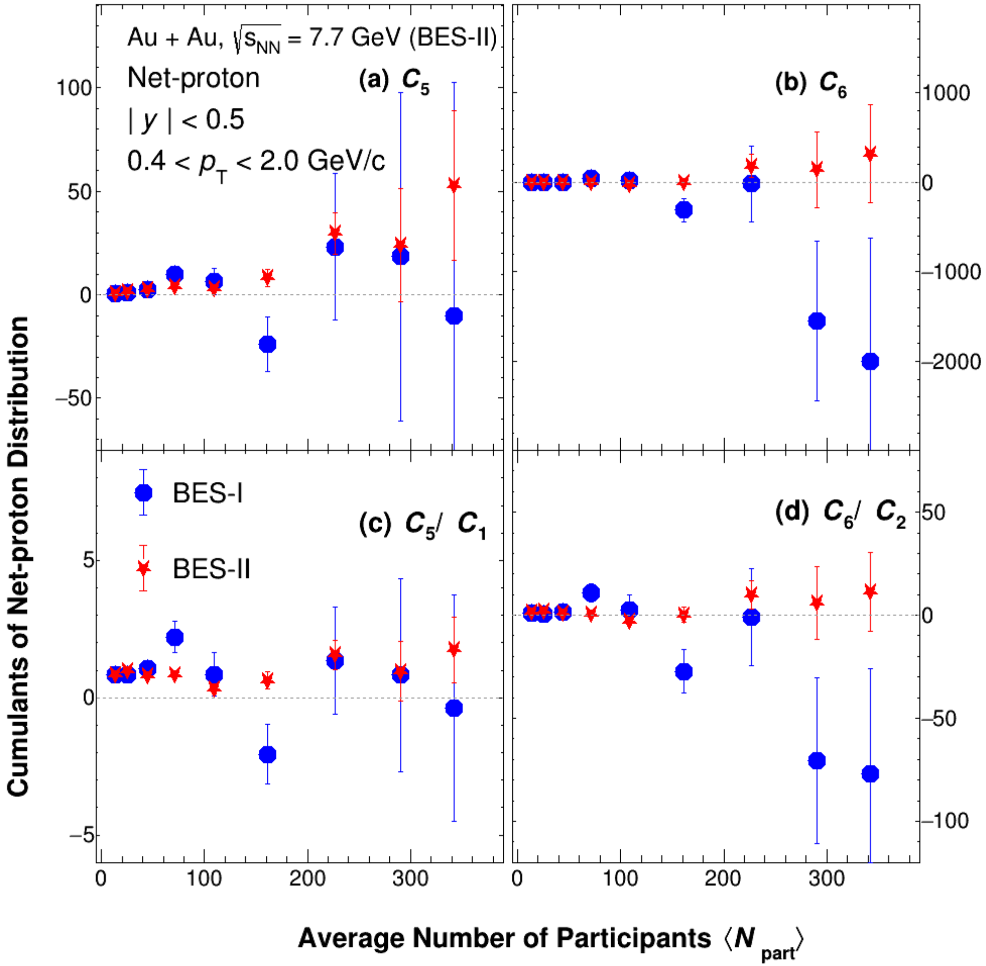




- Efficiency uncorr. cumulants
- Statistical error, obtained using bootstrap.
- Centrality bin width correction applied

- Increasing trend for cumulants as a function of centrality
- Cumulants ratios show weak dependece over centrality

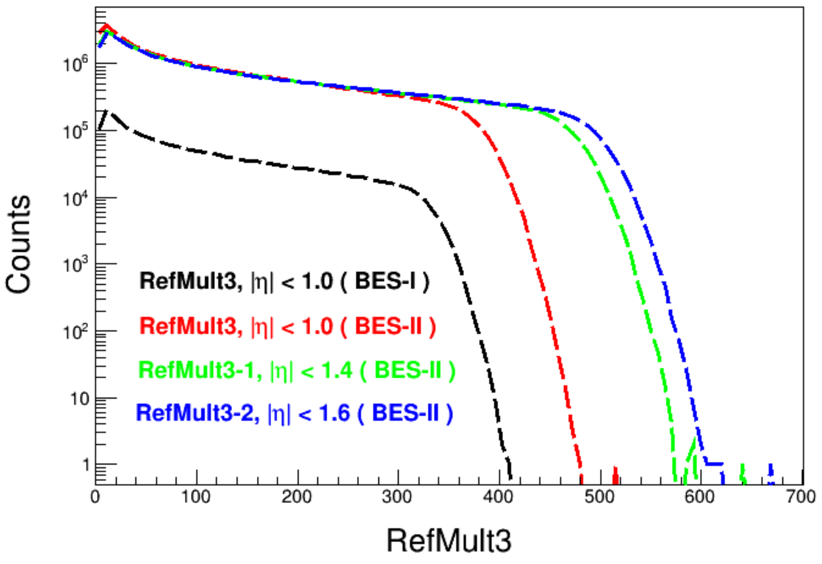
Centrality dependence of net proton cumulants (eff. uncorr.)



- Efficiency uncorr. Cumulants
- Centrality bin width correction applied applied
- C_5 & C_5/C_1 consistent within uncertainty
- C_6 & C_6/C_2 (of BES-II) have values close to zero as compared to BES-I

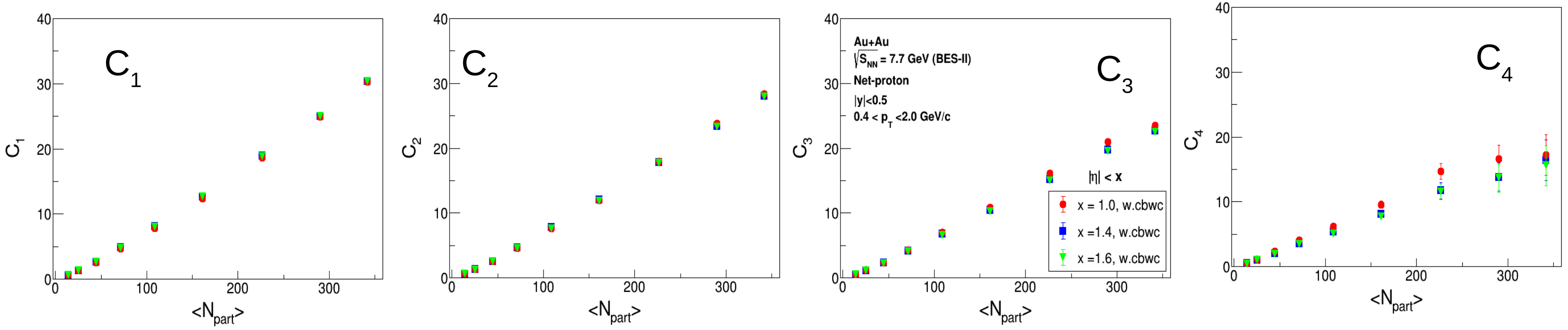
Study the effect of different centrality definitions on net-proton cumulants

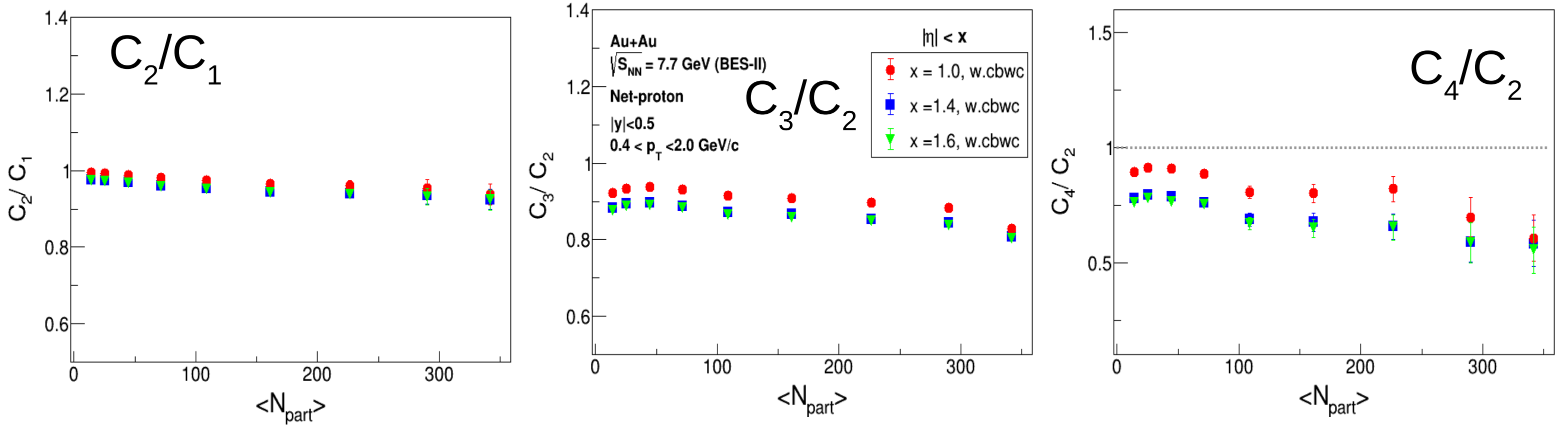
1. Three centrality definition :
   - RefMult3 (default) ($|\eta|< 1.0$)
   - RefMult3-1 ($|\eta|< 1.4$)
   - RefMult3-2 ($|\eta|< 1.6$)
2. Study centrality dependence of cumulants using these three centrality definitions.
3. Cumulants are efficiency uncorrected & CBW corrected



- RefMult3 distributions for three different definitions are plotted here
- Compare with BES-I result

Centrality dependence of cumulants for different centrality definitions (efficiency uncorr.)





- Cumulants are cbw corrected & efficiency uncorrected
- Error from bootstrap method
- Decrease and show saturation around |η|< 1.6

Summary & outlook

1.Shown basic QA plots, centrality determination

2. Presented centrality dependence of efficiency uncorrected net proton cumulants upto sixth order

3. Good improvement in centrality resolution as we widen charge particle acceptance for centrality selection from ||η|< 1.0 to |η|< 1.6.

4. For centrality definition (7.7 GeV) we plan to take RefMult3-2 (with |η|< 1.6) for better centrality resolution

5. Will focus on effciency corrected net-proton cumulants

6. For my thesis I will work on **7.7** and **9.2** GeV data set in BES-II

Acknowledgements

- We thank the STAR focus group and STAR collaboration for opportunity and support.

Thank You

Backup

CBWC

- $C_n = \quad w_r * C_{n,r}$
- $W_r = n_r / N$
- **For error :** $Err\,C_n = \sqrt{\left(\sum_r (W_r)^2 * (Err\,C_{n,r})^2\right)}$

C_n : is nth order cumulants
N_r :is number of events in rth refmutl3 bin
N :is total number of events

Bootstrap method

- Bootstrap method is a re-sampling method to estimate statistical error
- Does not involve the complexities of the standard error propagation method
- It uses Monte-Carlo algorithm to estimate the statistical error

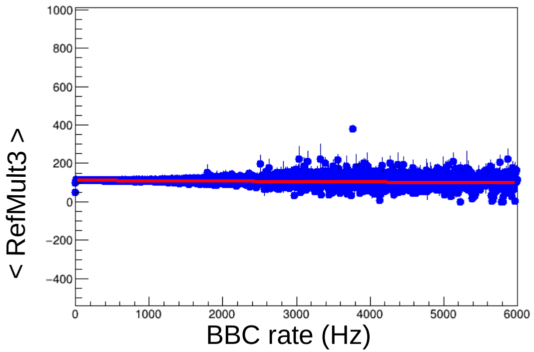
- Construct B number of independent bootstrap samples X_1' , X_2' , X_3' , ..., X_B' , each consisting of n data points randomly drawn from the random sample X with replacement
- Evaluate the estimator in each of these bootstrap samples: $\hat{e}_b' = \hat{e}(X_b') \qquad b = 1,2,3,\ldots,B.$
- The sampling variance of the estimator: $Var(\hat{e}) = \frac{1}{B-1}\sum_{b=1}^{B}(\bar{\hat{e}} - \hat{e}_b')^2$ where, $\bar{\hat{e}} = \frac{1}{B}\sum_{b=1}^{B}(\hat{e}_b')$

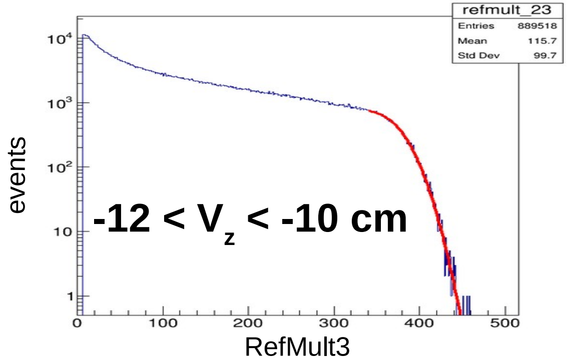
Centrality Definition

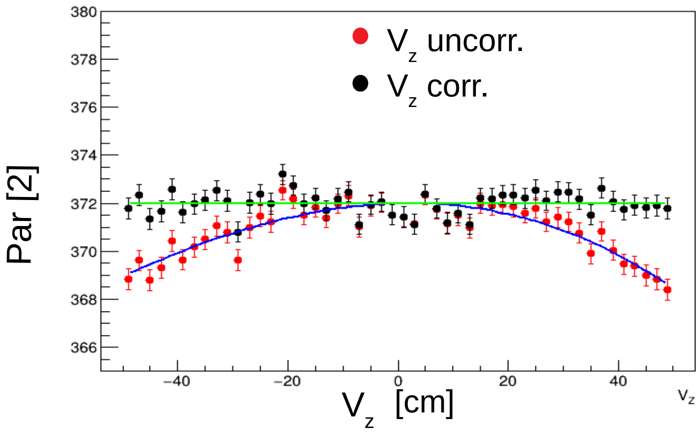
- **Refmult3:** (Charge particle multiplicity with |η|< 1.0 excluding protons and anti protons) distribution for centrality determination

- **Corr. to RefMult3:**
  - has a negligible dependence on luminosity
  - No luminosity corrections applied
  - V_z corrections applied

- Refmult3 is obtained for each V_z window (2 cm for my analysis).
- Fit function: **f(x) = [0]* Tmath::Erf(-[1]*(x-[2])) + [0]**
- After fitting par [2] is obtained for each V_z window

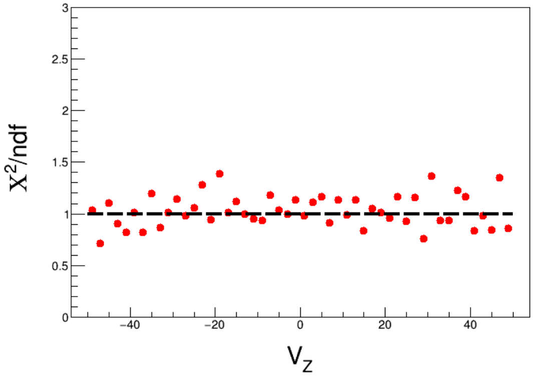




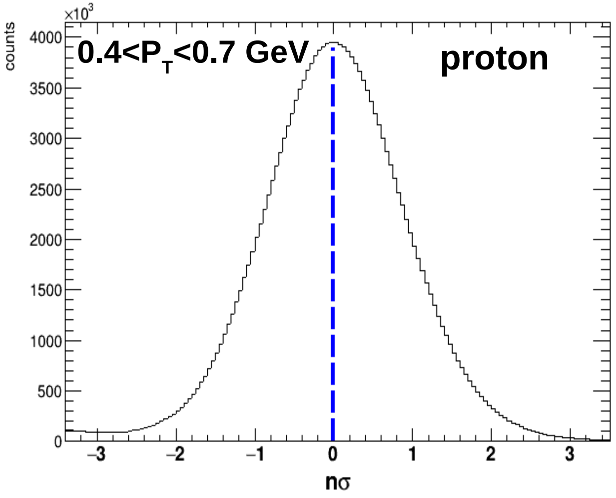


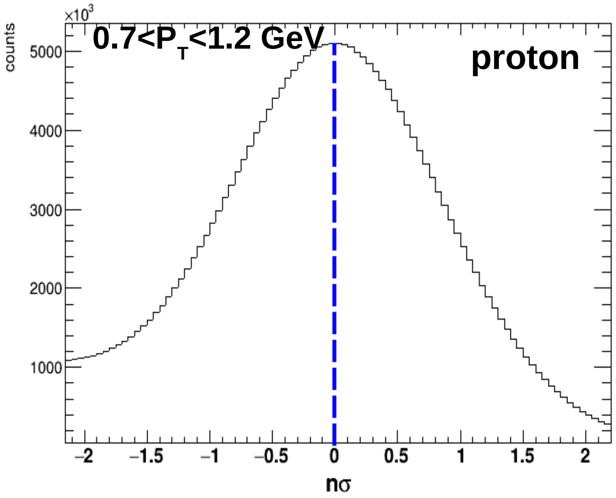
V_z correction factor:

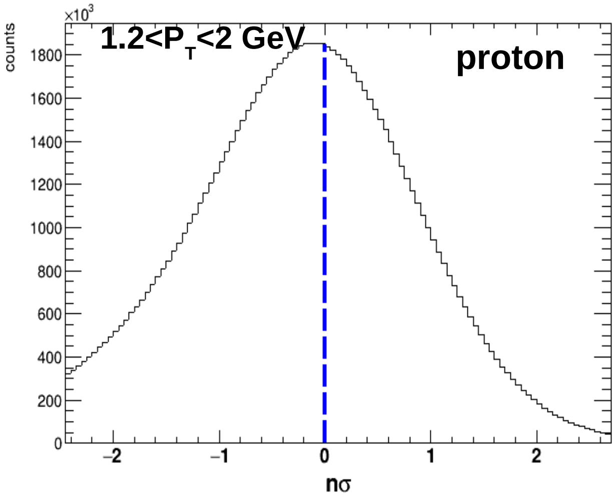
$$\frac{[0]}{[3]*x^3+[2]*x^2+[1]*x+[0]}$$



nsigma (nσ) shift







- Corrected nsigma (nσ) shift for the analysis
- nσ distribution is shifted as a funtion of rapidity and p_T bin