



STAR Collaboration Meeting Spring 2023

Proton fluctuations at 3.9 GeV

Fan Si

University of Science and Technology of China

Feb. 28th, 2023

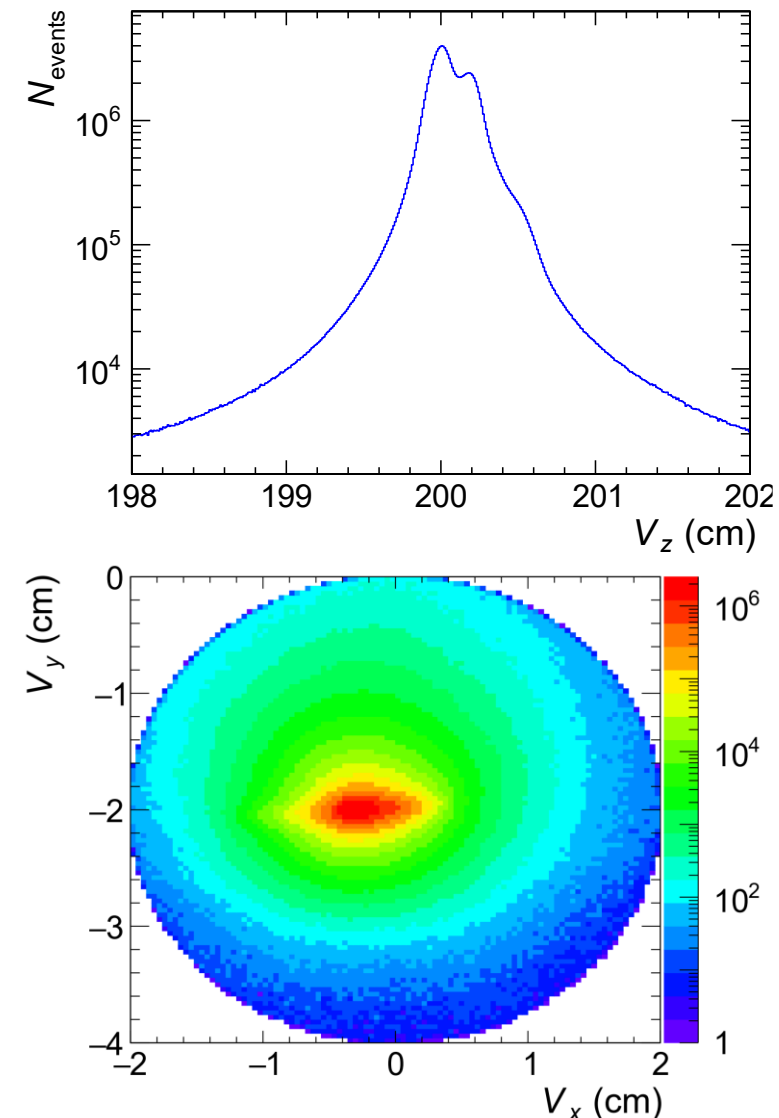
Previous presentations: https://drupal.star.bnl.gov/STAR/system/files/FanSi_CFmeeting_220428.pdf,
https://drupal.star.bnl.gov/STAR/system/files/FanSi_CFmeeting_220421.pdf, https://drupal.star.bnl.gov/STAR/system/files/FanSi_CFmeeting_220414.pdf,
https://drupal.star.bnl.gov/STAR/system/files/FanSi_CFmeeting_220303.pdf, https://drupal.star.bnl.gov/STAR/system/files/FanSi_CFmeeting_220127.pdf

Outline

- Dataset
- Run-by-run QA
- TPC recalibration
- Centrality determination
- Proton cumulants
- UrQMD study

Dataset

- Au+Au @ 3.9 GeV (7.3 GeV FXT, Run 20)
- Trigger setup: production_7p3GeV_fixedTarget_2020
- Stream: st_physics(_adc)
- Production: P21id
- Library: SL21d
- Run ID: 21035003 – 21036013 (32 runs)
- Events: 127M (accessible PicoDst)



Run-by-run QA

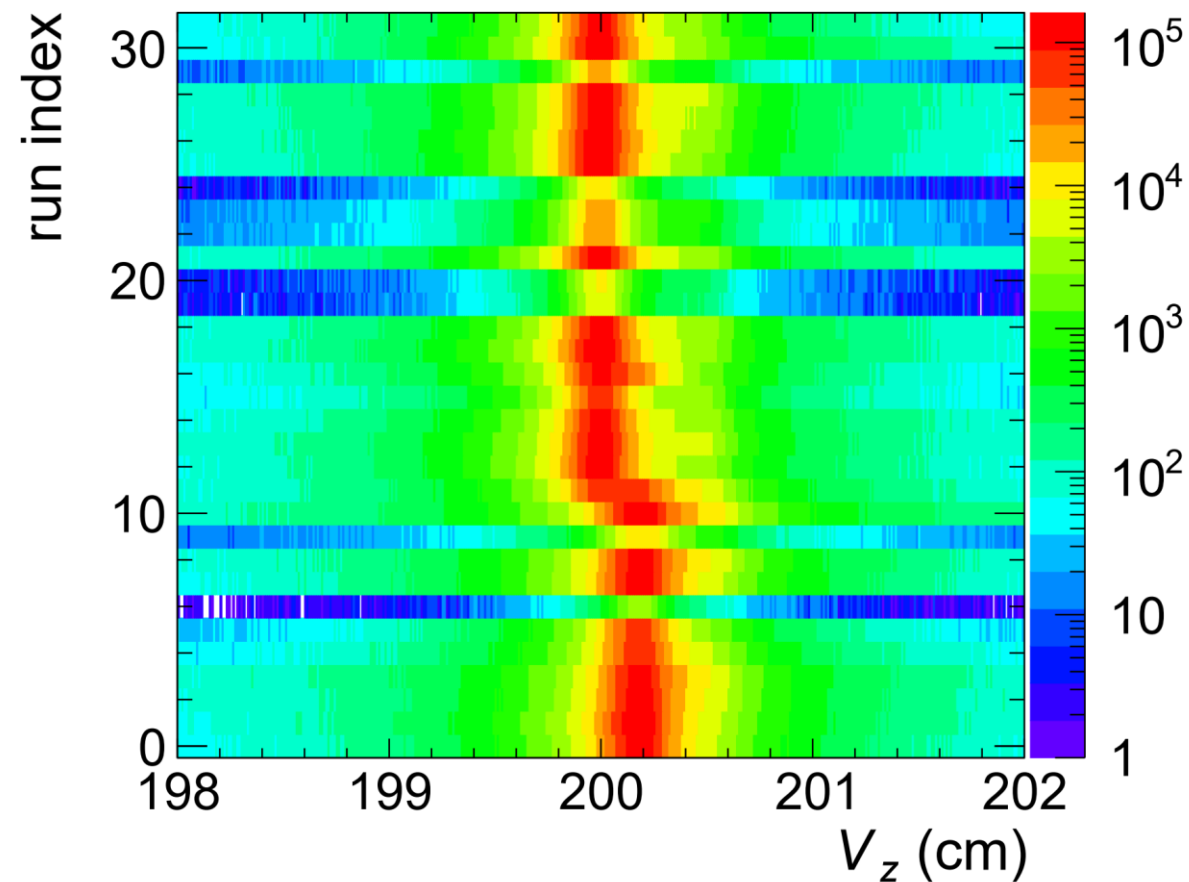
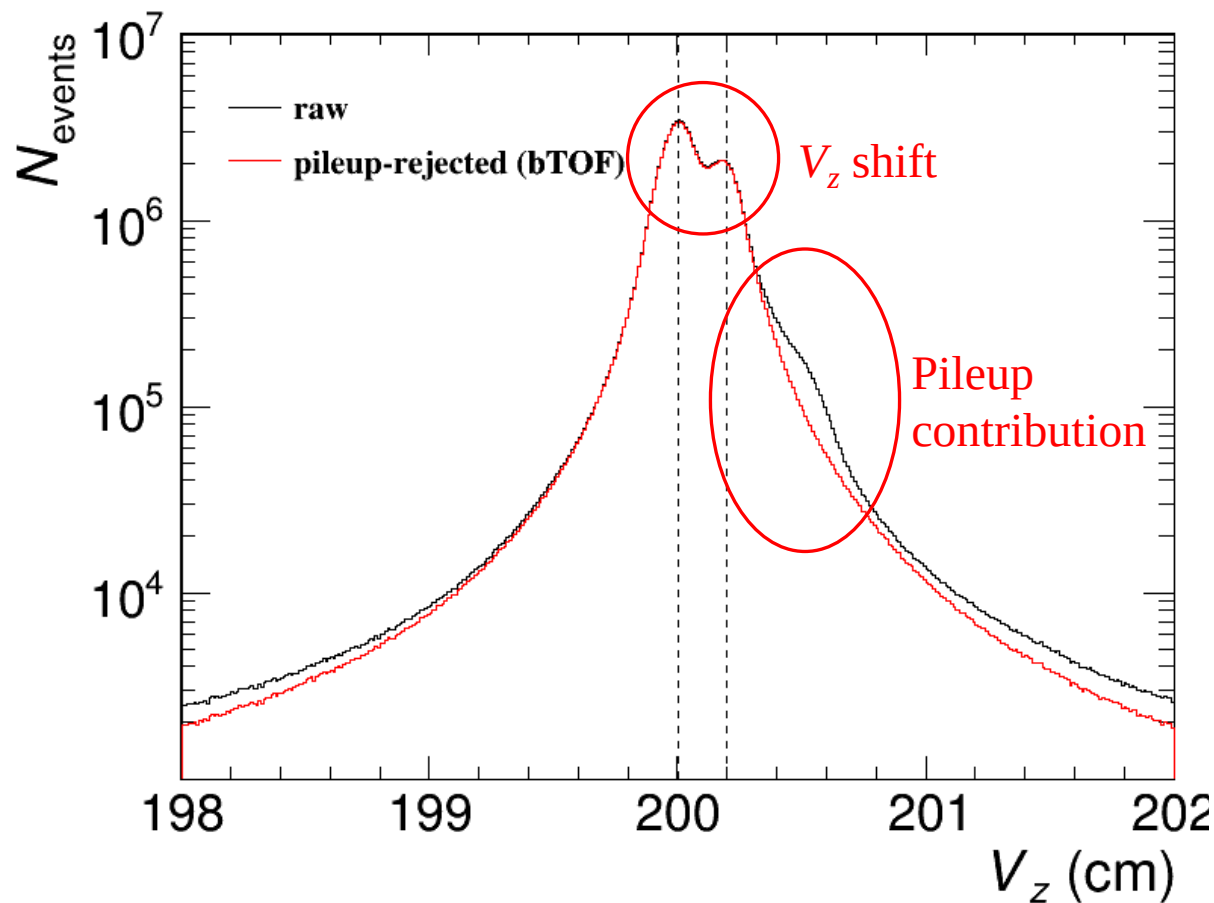
- Variables

Detector	Event level	Track level
TPC	V_x, V_y, V_z, V_r , FxtMult, FxtMult3	gDca, gDca _{xy} , signed gDca _{xy} , gDca _{φ} , gDca _z , nHitsFit, nHitsFit/nHitsPoss, nHitsDedx, p_T , φ , η , dE/dx
bTOF	nBTofMatches, nBTofHits	bTOF $1/\beta$

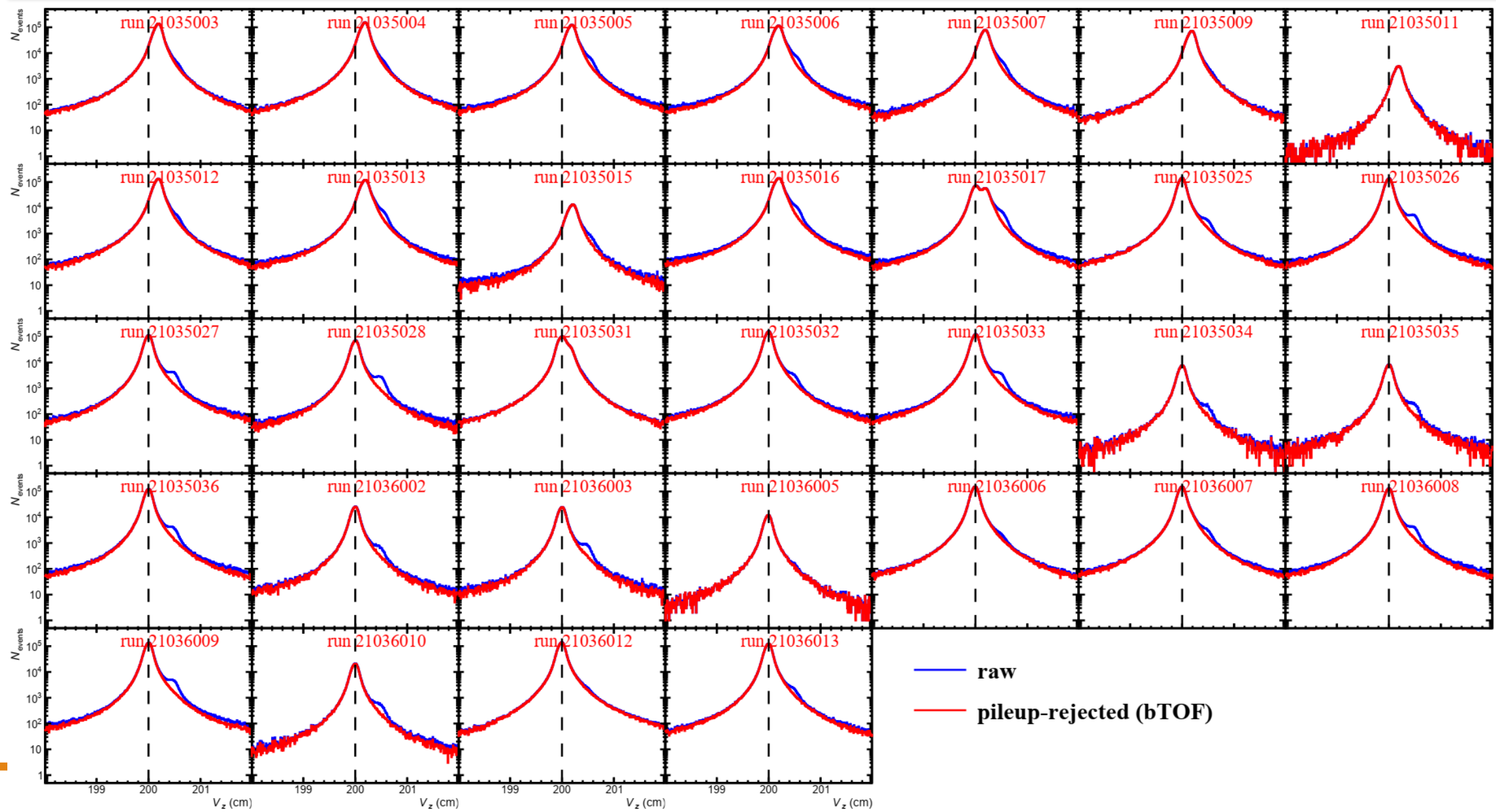
- Iteratively remove empty bins and 3- σ outliers until no new bad runs
 - Averages and standard deviations weighted by # events or tracks
- Bad runs [7]
 - 21035011, 21035015, 21035016, 21035027, 21036005, 21036010, 21036012

V_z distribution issue

- A small structure from pileup events at $V_z \sim 200.5$ cm
- A small peak at 200.2 cm seems from a V_z shift from a certain run



V_z distribution issue

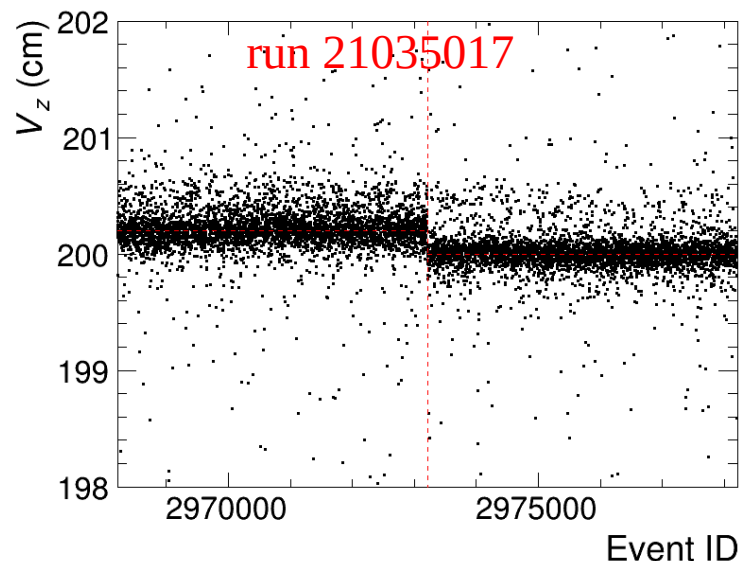
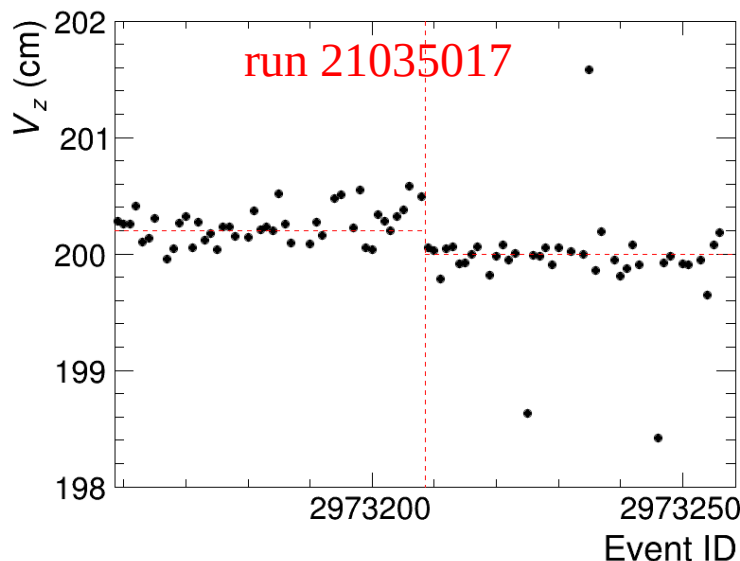
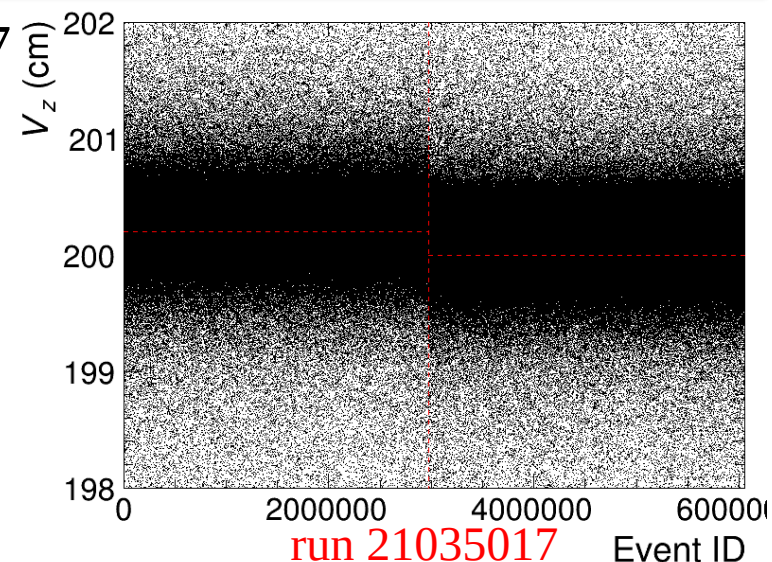


V_z distribution issue

- Clear shift (~ 0.2 cm) from event 2973209 of run 21035017

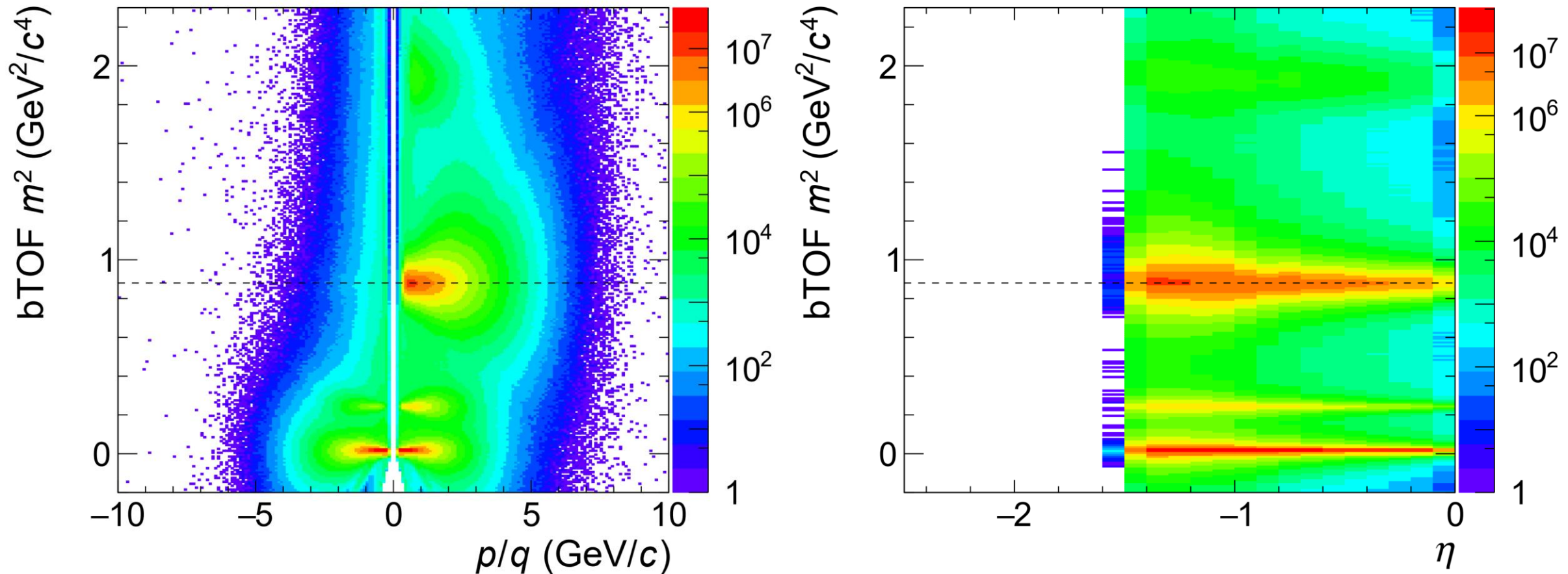
- V_z cut in following analysis

- $200 \text{ cm} < V_z < 200.4 \text{ cm}$
 - Run < 21035017 , or event < 2973209 for run 21035017
- $199.8 \text{ cm} < V_z < 200.2 \text{ cm}$
 - Event ≥ 2973209 for run 21035017, or run > 21035017



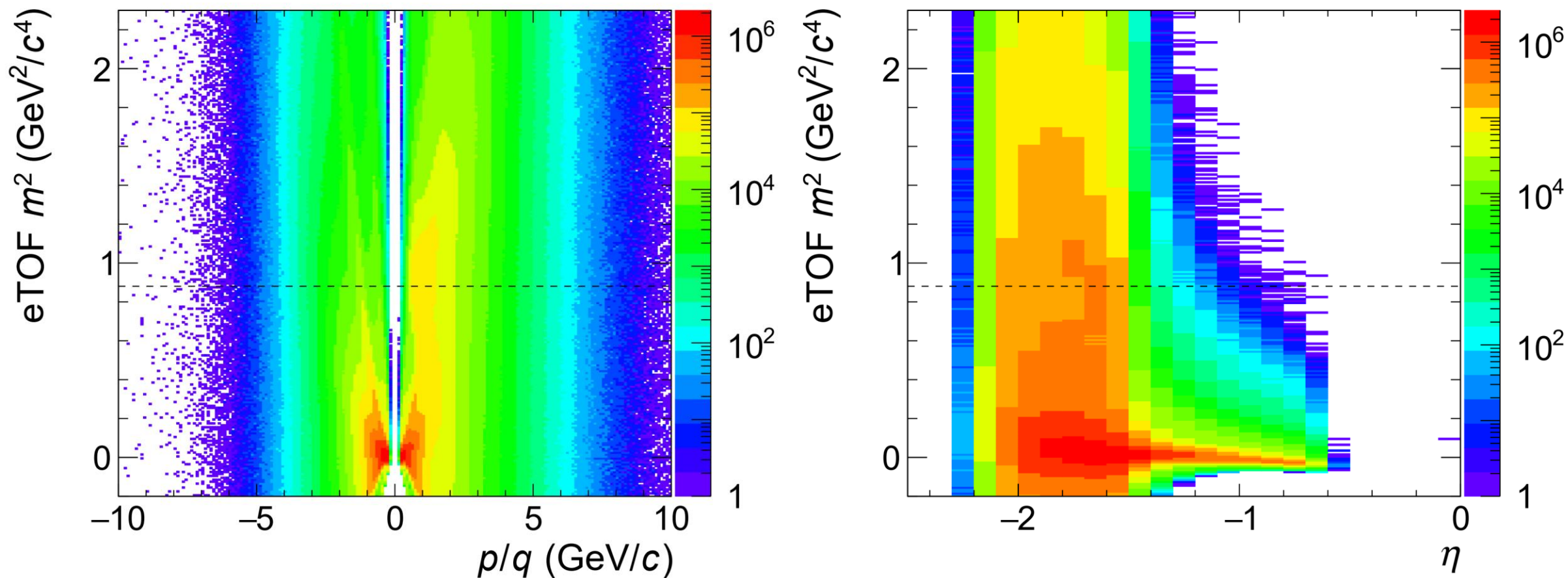
bTOF PID plots

- Excellent PID



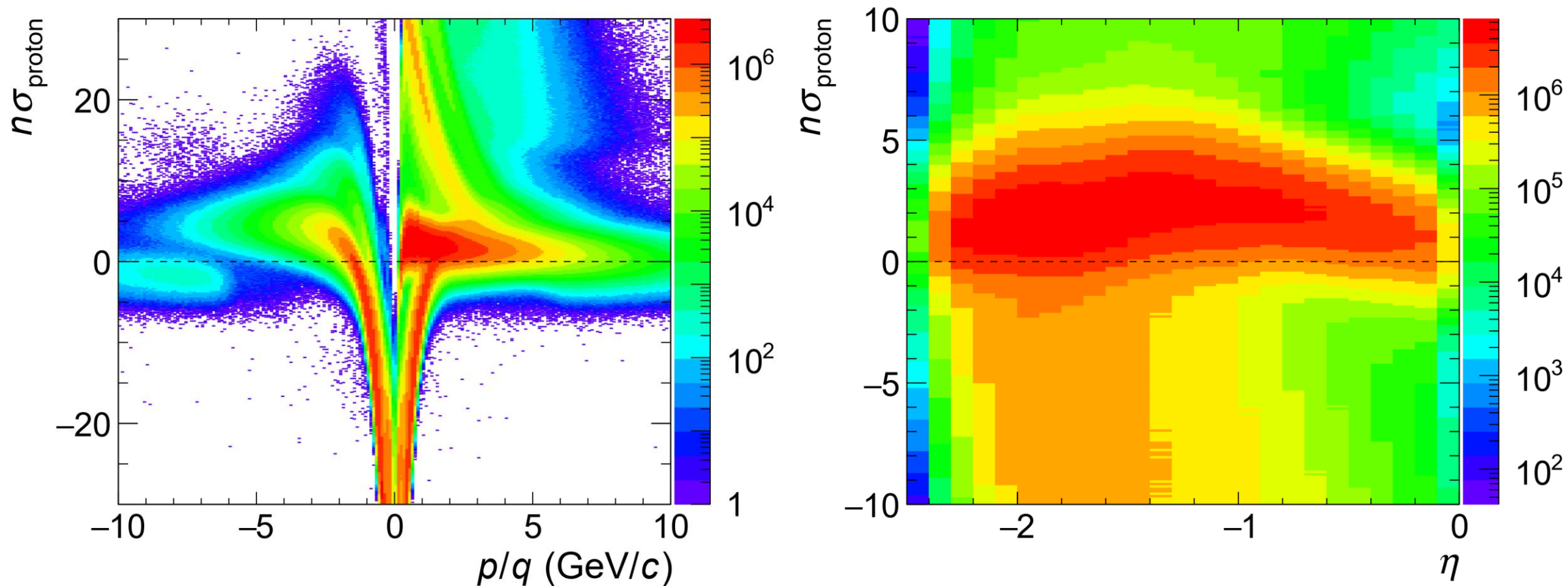
eTOF PID plots

- Unavailable PID



TPC PID plots

- Recalibration required

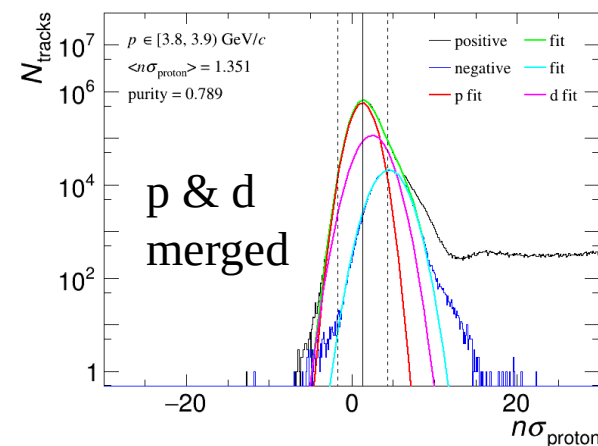
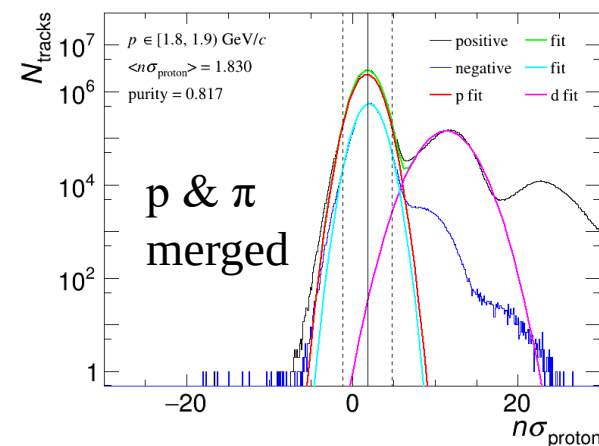
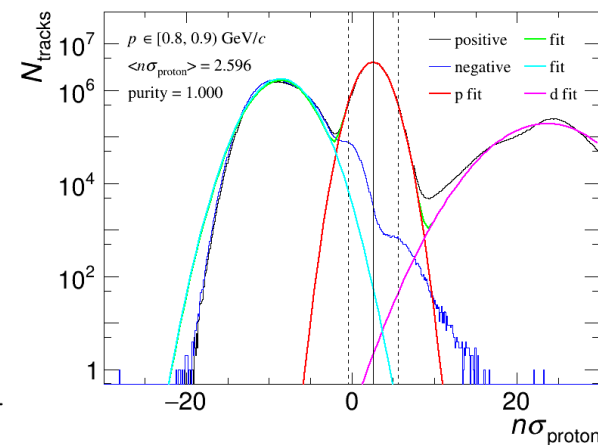
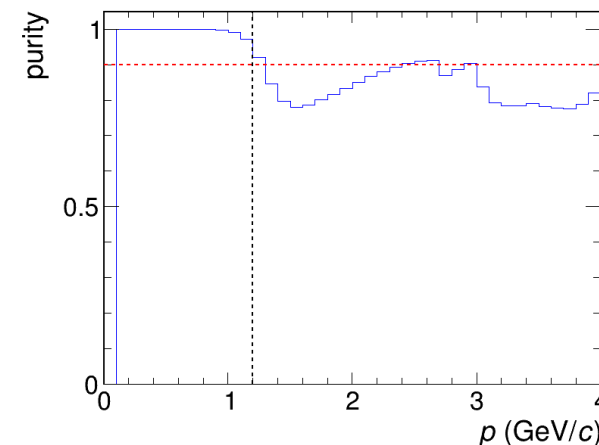
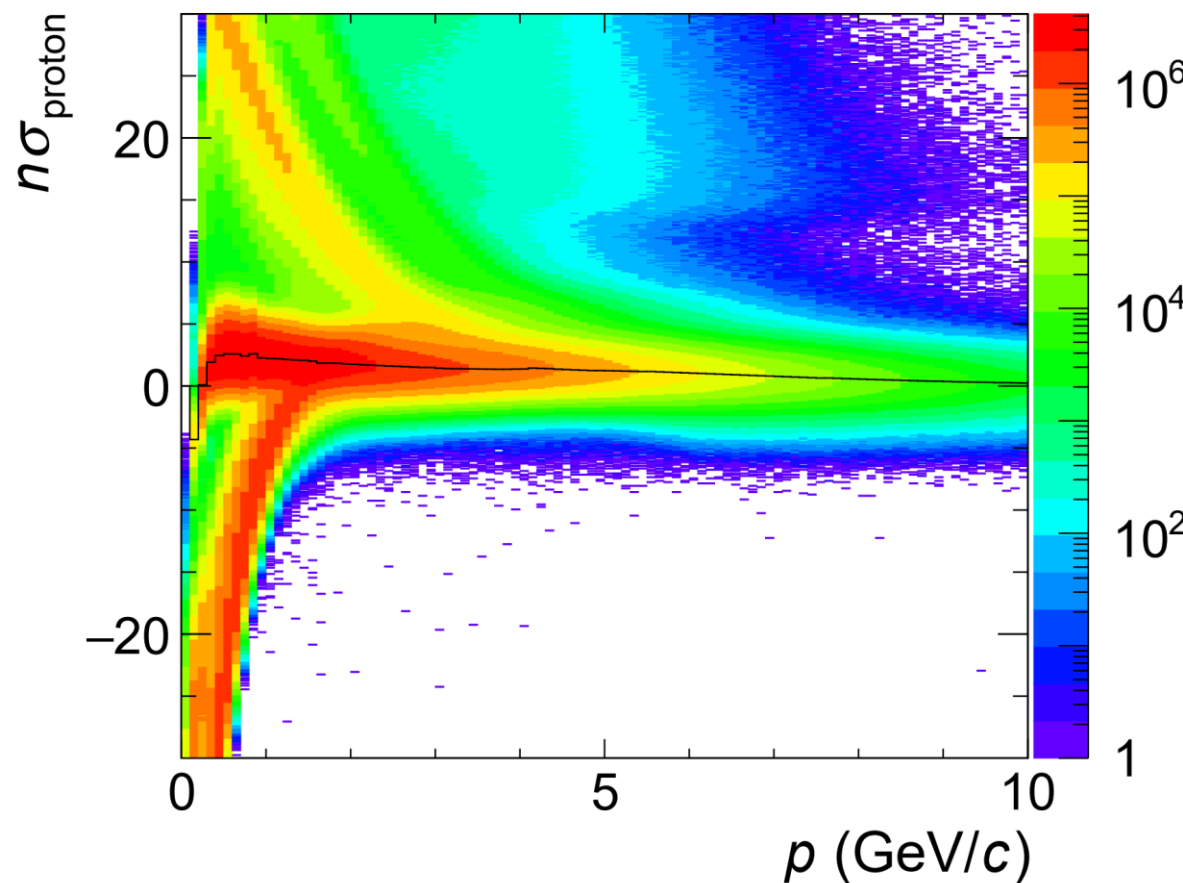


TPC recalibration

- Black curve: $\langle n\sigma_{\text{proton}} \rangle$
- Multi-Gaussian fits in p slices

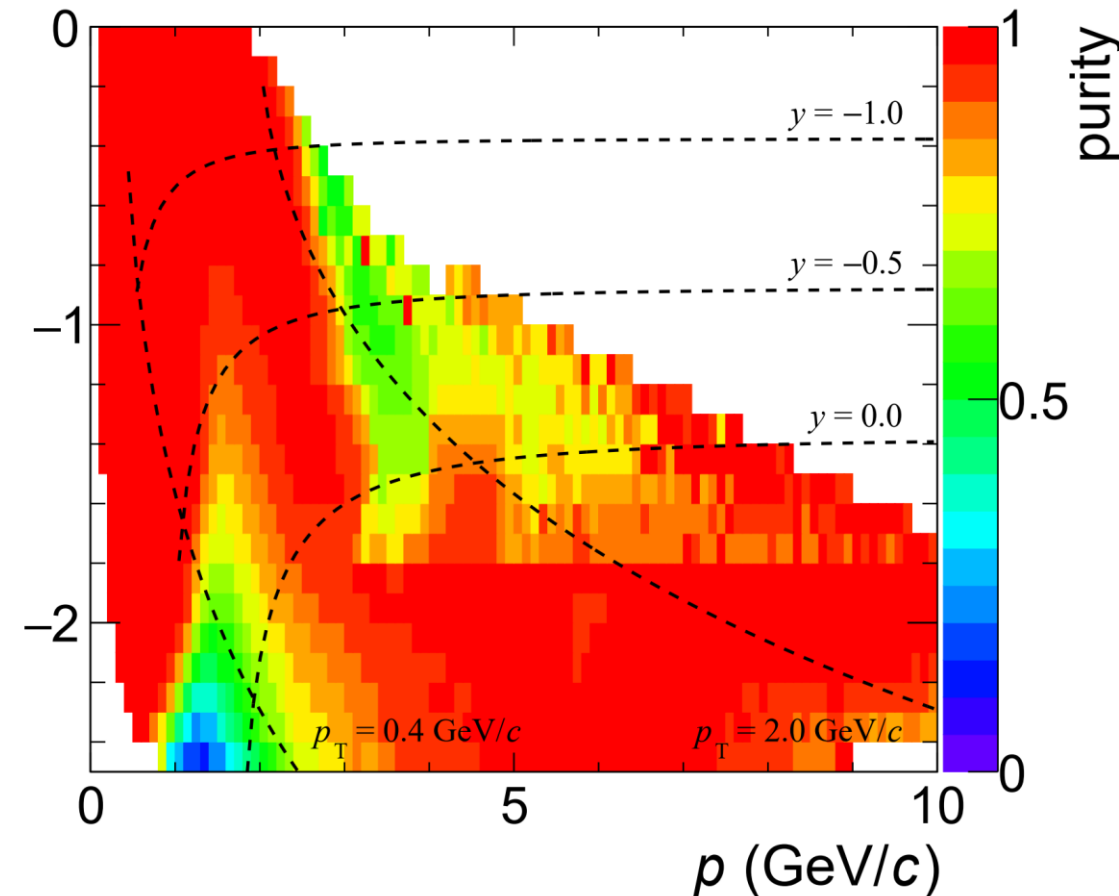
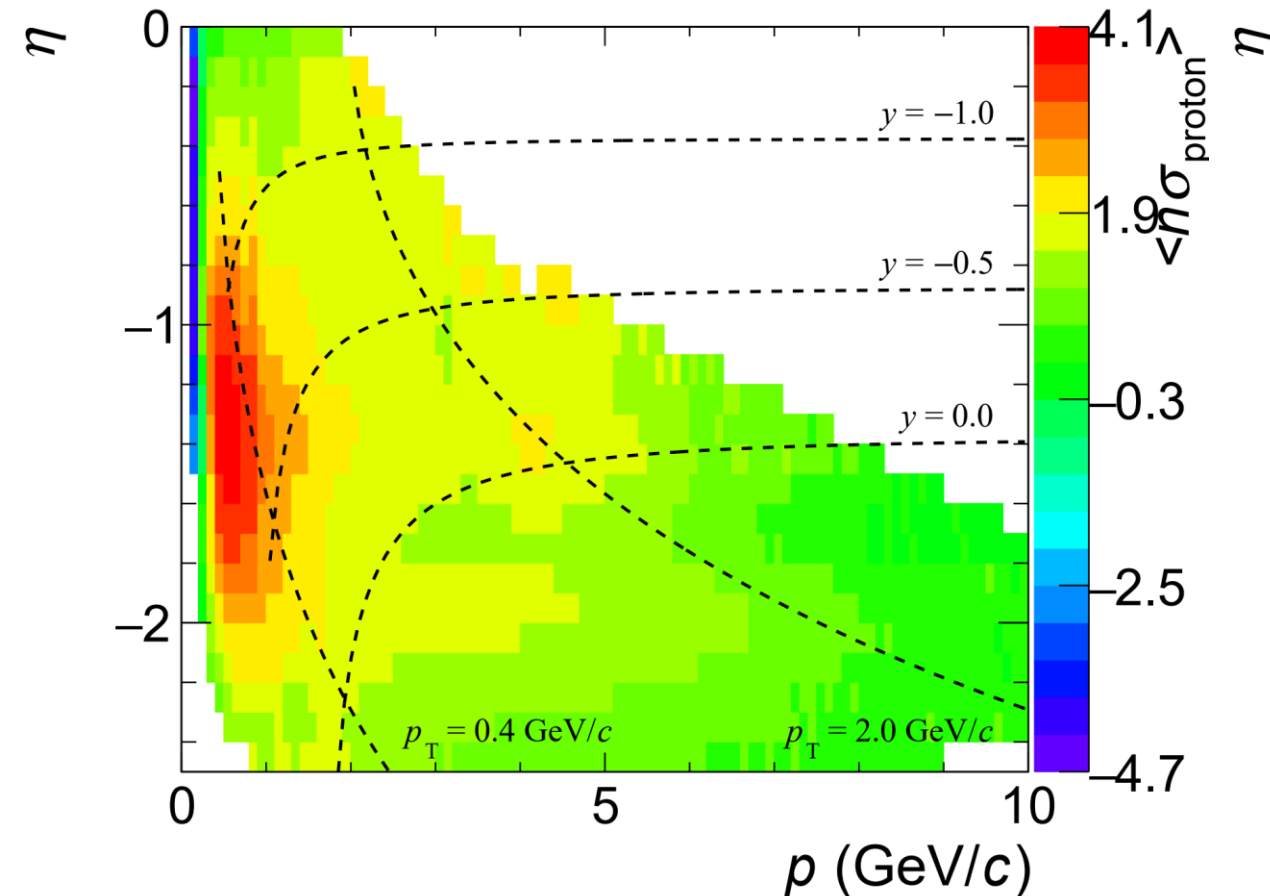
- Purity = $1 - (N_{\pi^-} + N_d)/N_{\text{pos}}$
- In range $|n\sigma_{\text{proton}} - \langle n\sigma_{\text{proton}} \rangle| < 3$

Purity > 90% @ $p < 1.2 \text{ GeV}/c$



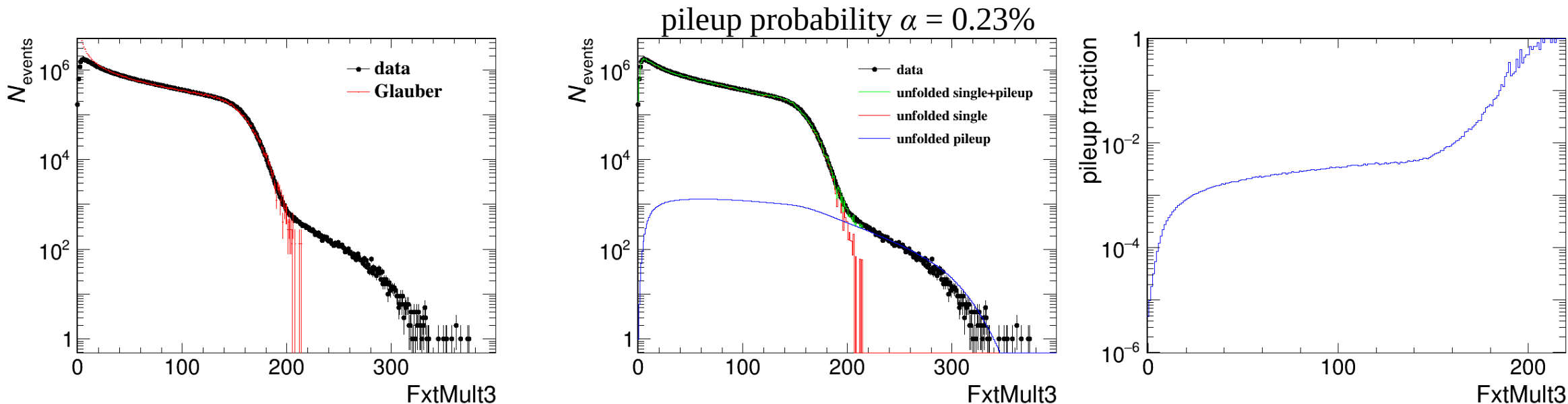
TPC recalibration

- Multi-Gaussian fits in 2D p - η bins



Centrality determination

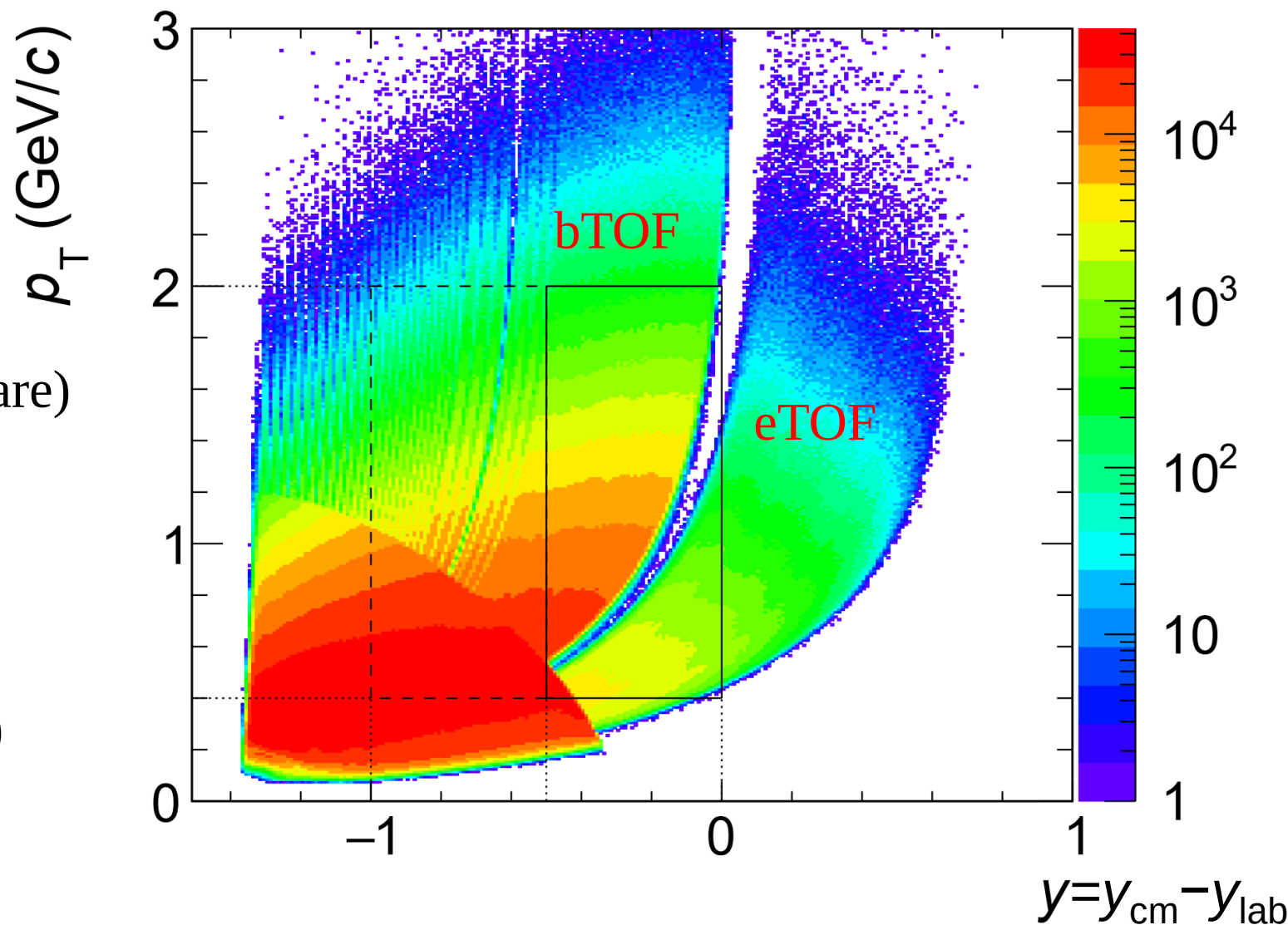
- FxtMult3 definition: basic cuts (for neg. tracks), + proton exclusion (for pos. tracks)
 - Basic cuts: primary, $p > 0.1$ GeV/c, $|gDca| < 3$ cm, $nHitsFit \geq 10$ (according to RefMult3 def.)
 - Proton exclusion: $n\sigma_{\text{proton}} - \langle n\sigma_{\text{proton}} \rangle(p, \eta) < -3$



Centrality	70-80%	60-70%	50-60%	40-50%	30-40%	20-30%	10-20%	5-10%	0-5%
FxtMult3 (>)	2	4	9	17	29	46	70	104	127

Acceptance

- Center-of-mass $y_{\text{cm}} = -1.375$
- Only TPC: $p < 1.2 \text{ GeV}/c$
- TPC+TOF: $p > 1.2 \text{ GeV}/c$
- Aimed acceptance (solid square)
 - $0.4 \text{ GeV}/c < p_{\text{T}} < 2 \text{ GeV}/c$
 - $-0.5 < y < 0$
 - Unavailable eTOF PID
- This analysis (dashed square)
 - $0.4 \text{ GeV}/c < p_{\text{T}} < 2 \text{ GeV}/c$
 - Backward $-1.0 < y < -0.5$

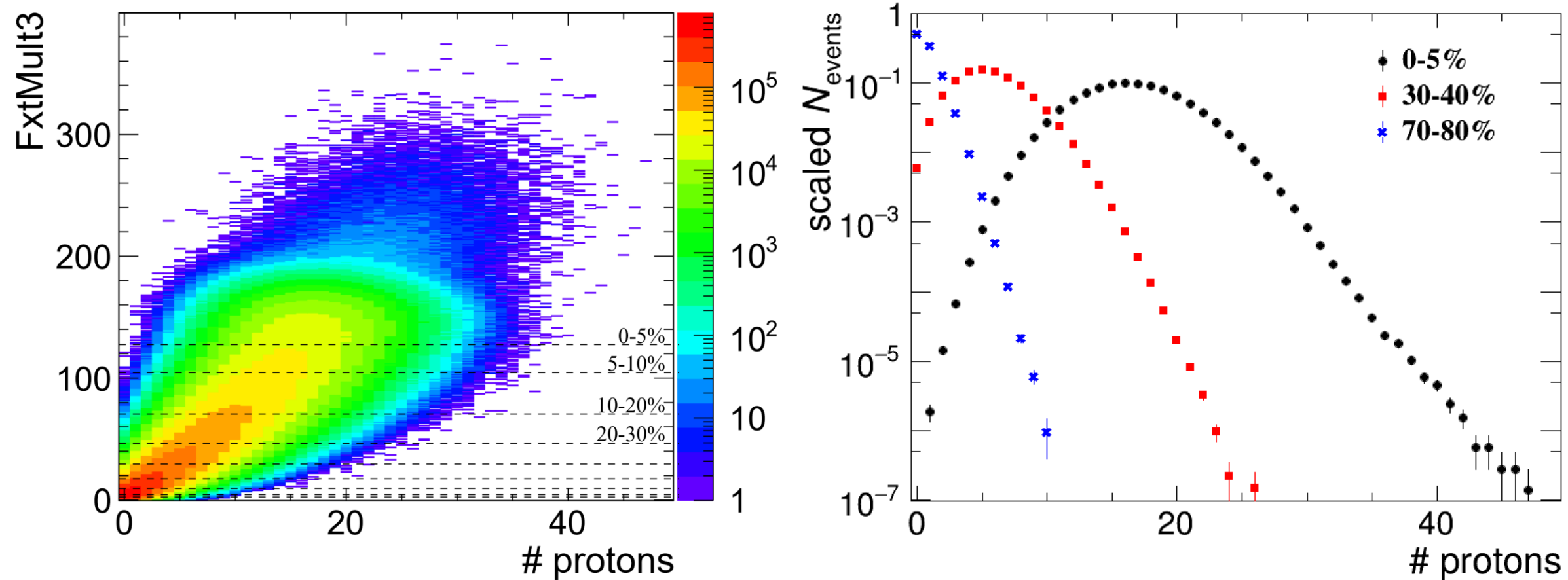


Analysis cuts

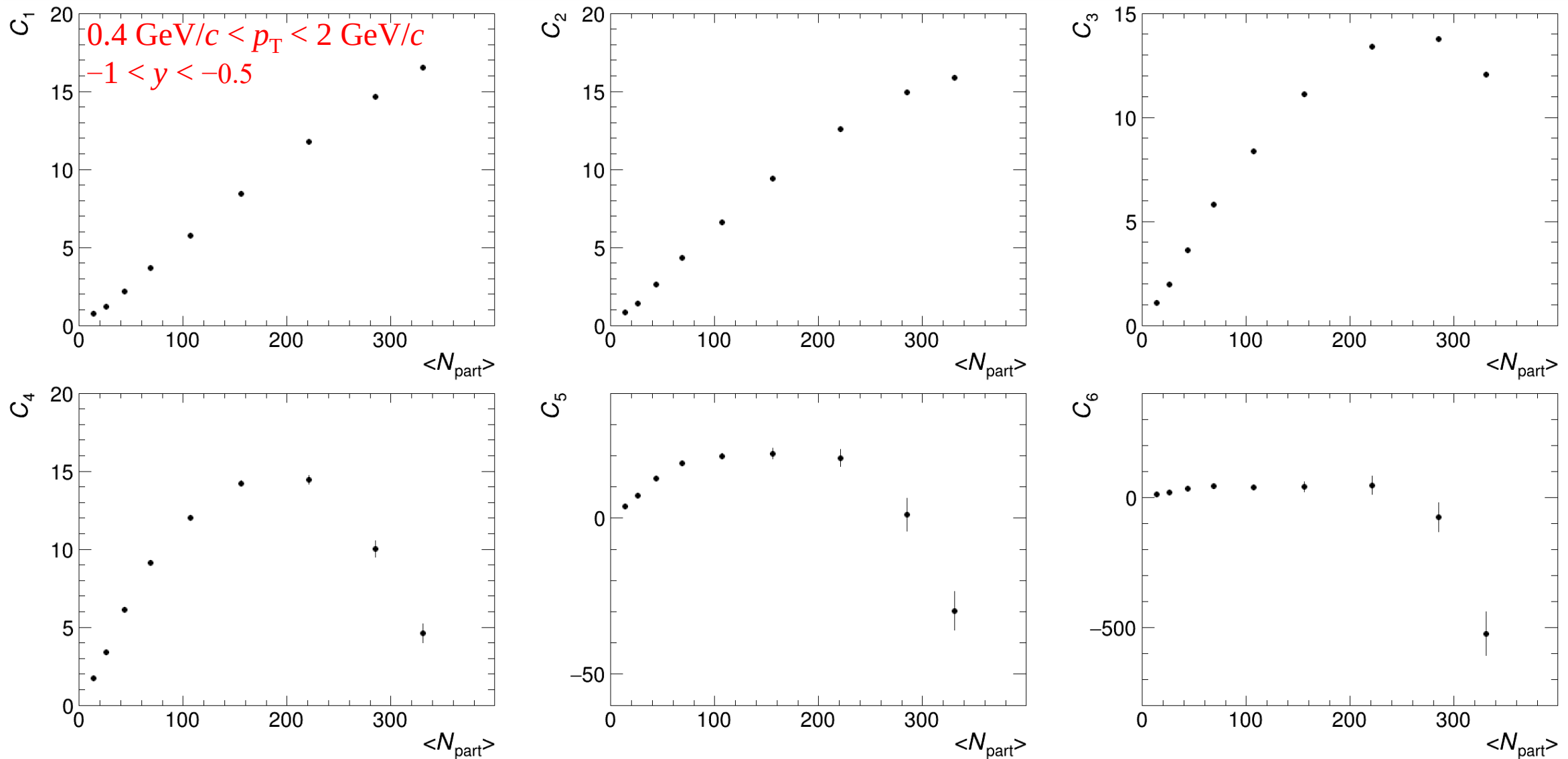
- Trigger ID
 - 730000 (epde-or-bbce-or-vpde-tof1)
- Run cuts
 - Bad run rejection
- Event cuts:
 - $200 \text{ cm} < V_z < 200.4 \text{ cm}$ (run < 21035017, or event < 2973209 for run 21035017)
 - $199.8 \text{ cm} < V_z < 200.2 \text{ cm}$ (other events)
 - $|V_r| < 2 \text{ cm}$, with center (0, -2) cm
- Events: 92M
- Track cuts
 - Primary
 - $|gDca| < 3 \text{ cm}$
 - $n\text{HitsFit} > 10$
 - $n\text{HitsFit}/n\text{HitsPoss} > 0.52$
 - $n\text{HitsDedx} > 5$
 - $0.4 \text{ GeV}/c < p_T < 2 \text{ GeV}/c$
 - Backward $-1.0 < y < -0.5$ ($y_{\text{cm}} = -1.375$)
 - Charge = 1
 - $|n\sigma_{\text{proton}} - \langle n\sigma_{\text{proton}} \rangle(p, \eta)| < 3$
 - $0.6 \text{ GeV}^2/c^4 < \text{bTOF } m^2 < 1.2 \text{ GeV}^2/c^4$
 - Only for $p > 1.2 \text{ GeV}/c$

Measured distributions

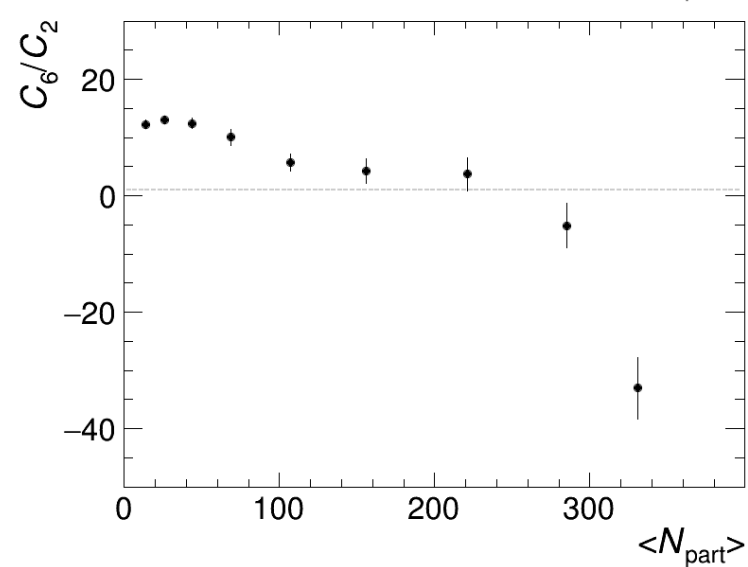
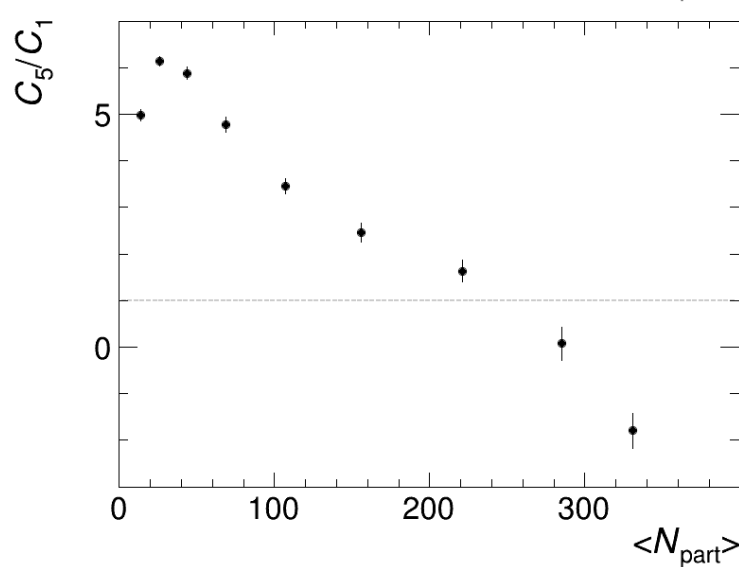
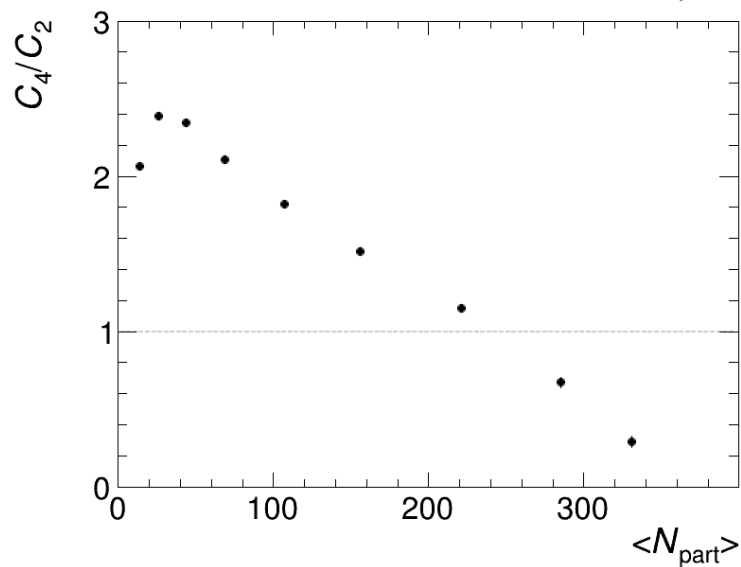
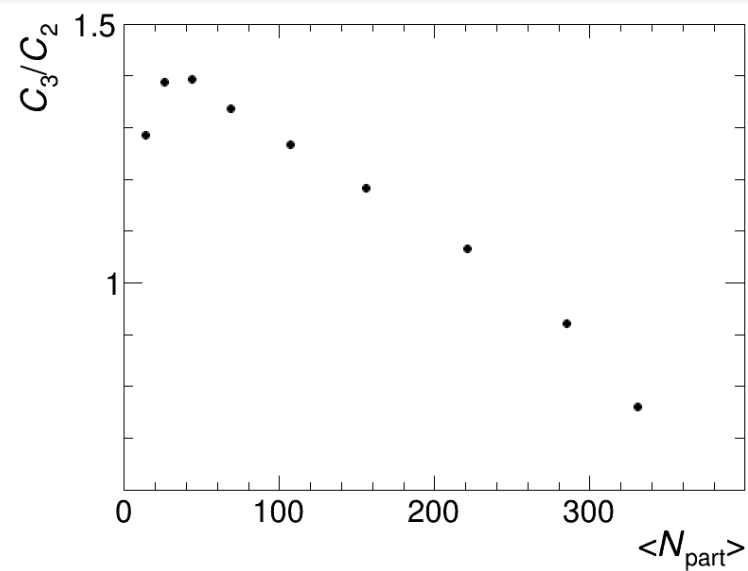
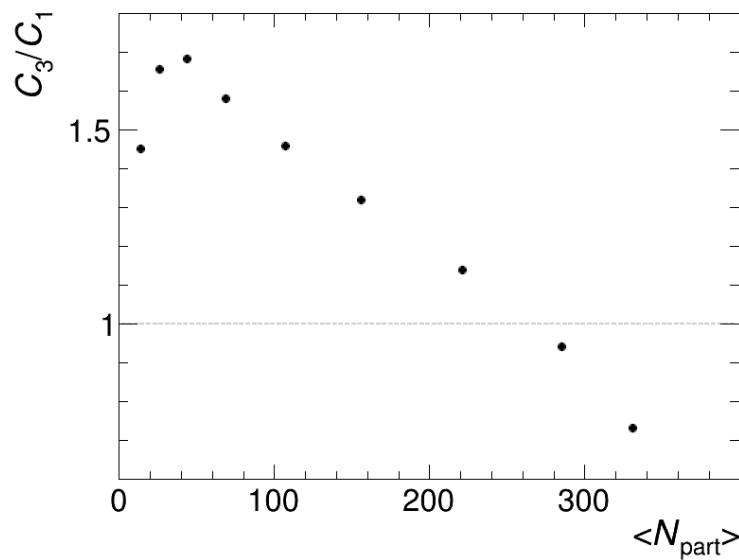
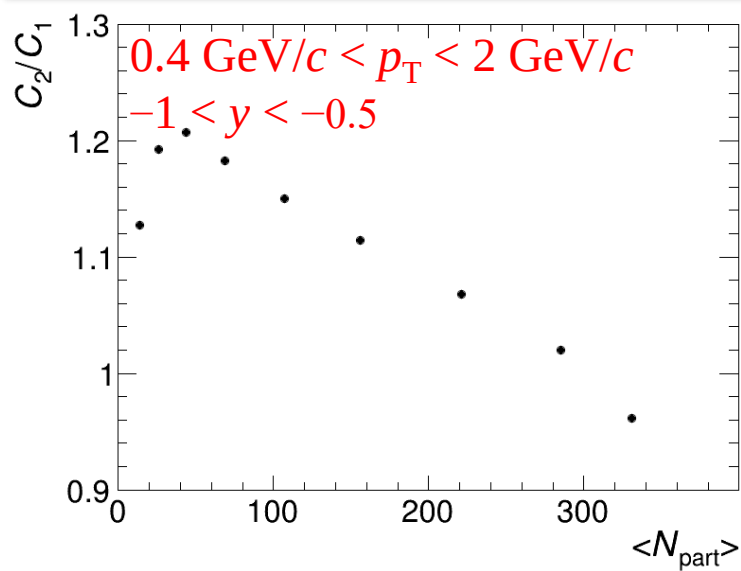
- Efficiency-uncorrected
- Centrality-dependent means and widths observed



Efficiency-uncorrected cumulants

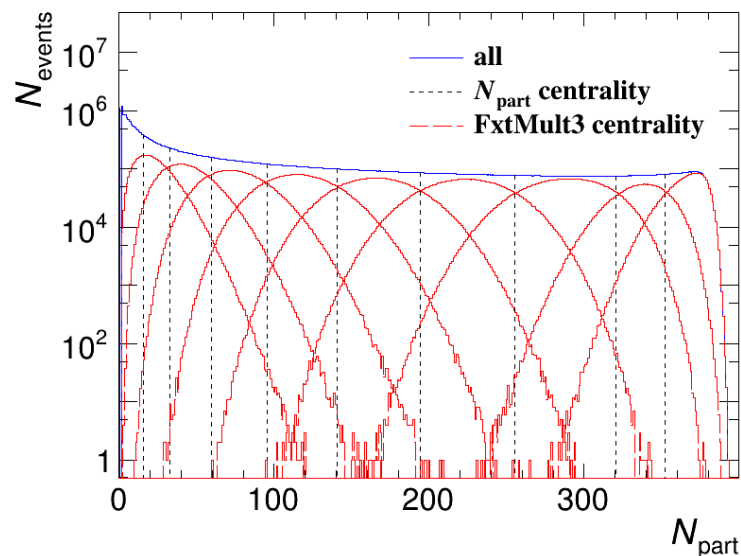
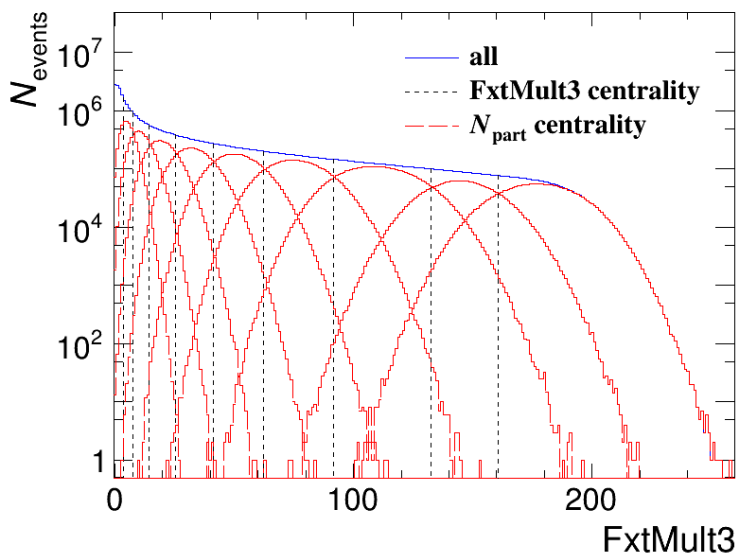
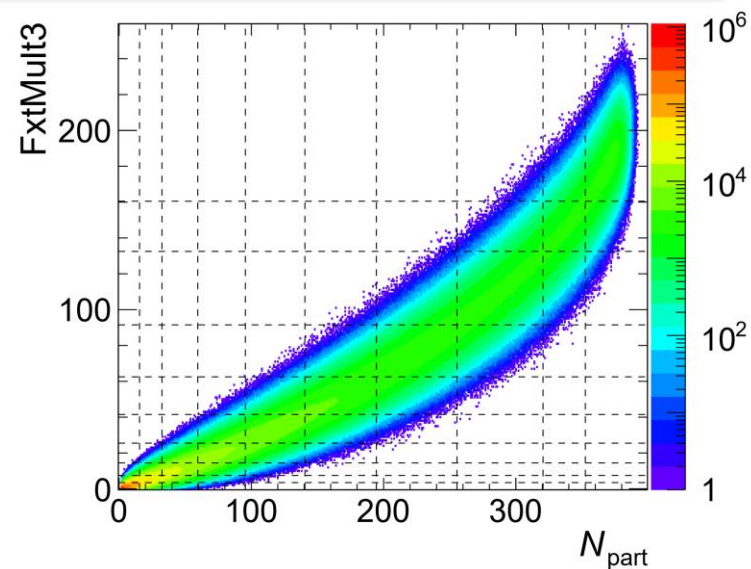
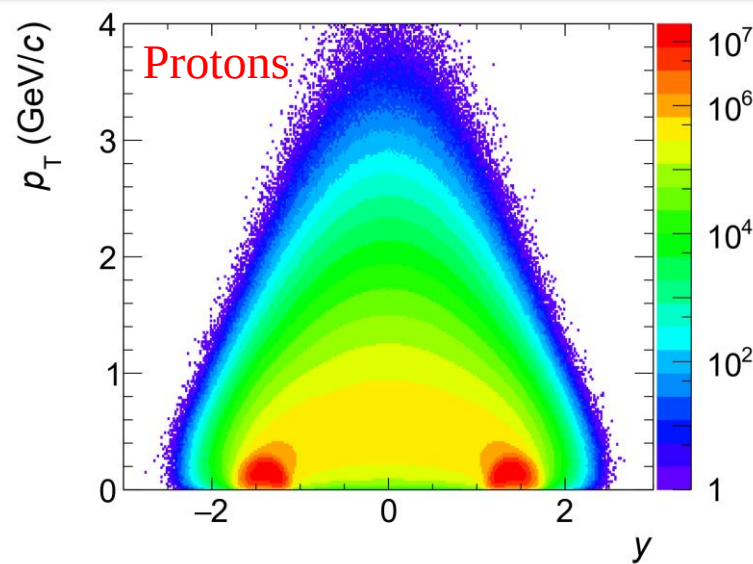


Efficiency-uncorrected cumulant ratios



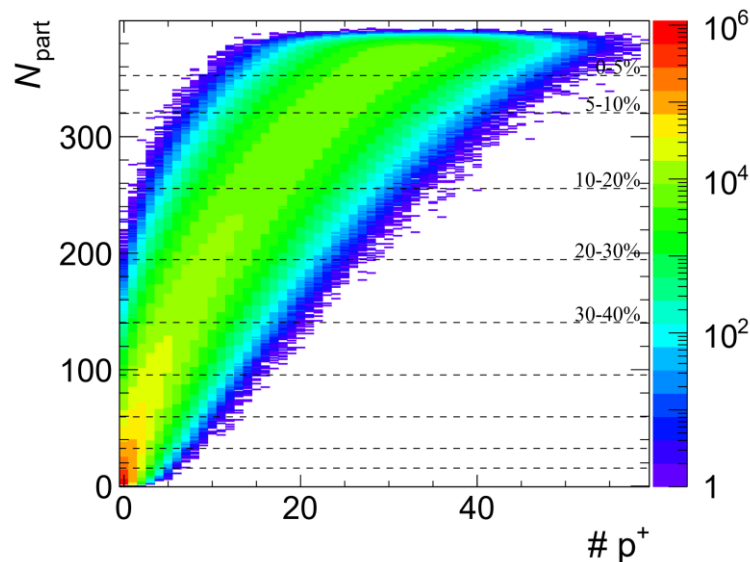
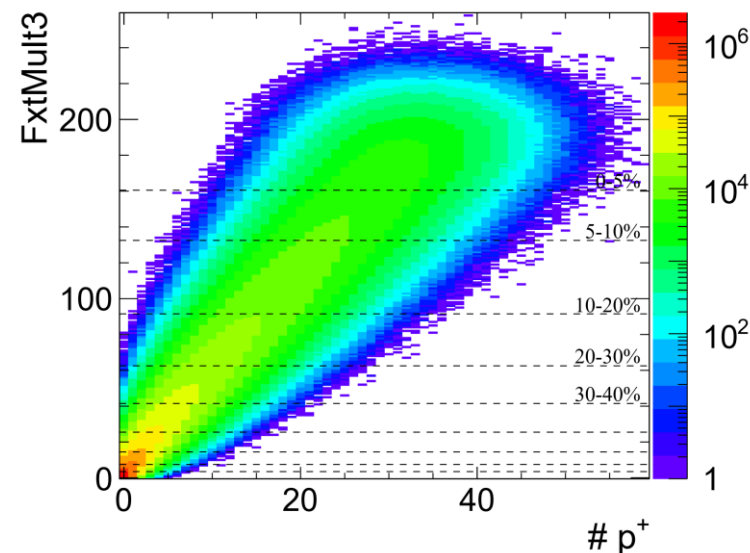
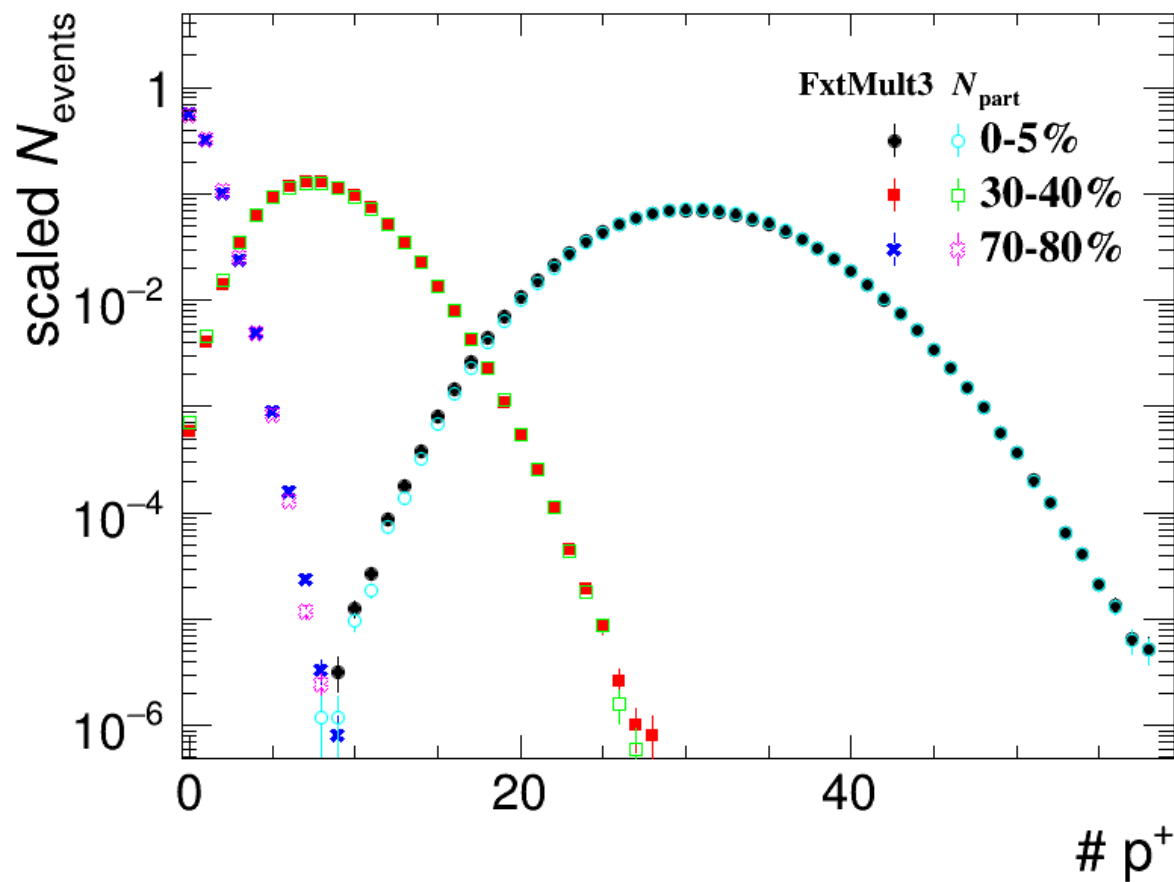
UrQMD simulation

- Au+Au @ $\sqrt{s_{\text{NN}}} = 3.9$ GeV
- # events: 50M
- b : 0 – 16 fm
- $t = 50$ fm/c
- Frame: center of mass
- FxtMult3 definition
 - $p > 0.1$ GeV/c
 - $-2.5 < \eta_{\text{lab}} < 0$
 - Boost: $y_{\text{lab}} = -1.375 - y$
 - Negative particles & π^+ , K^+

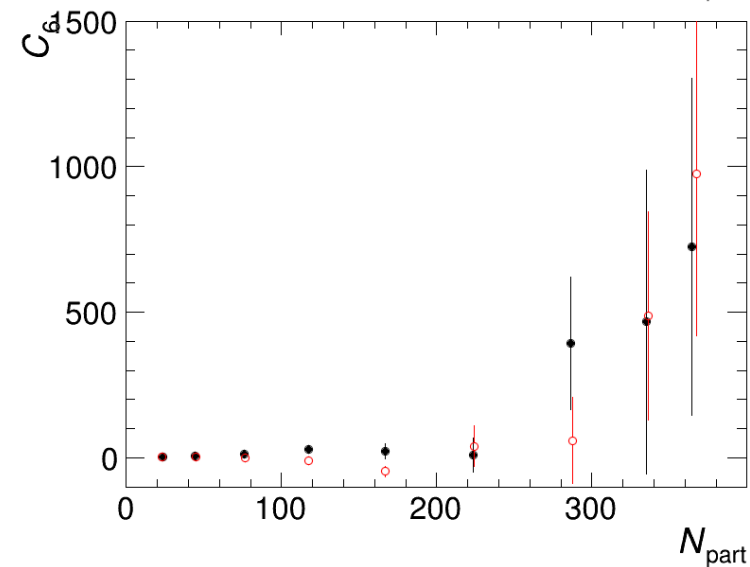
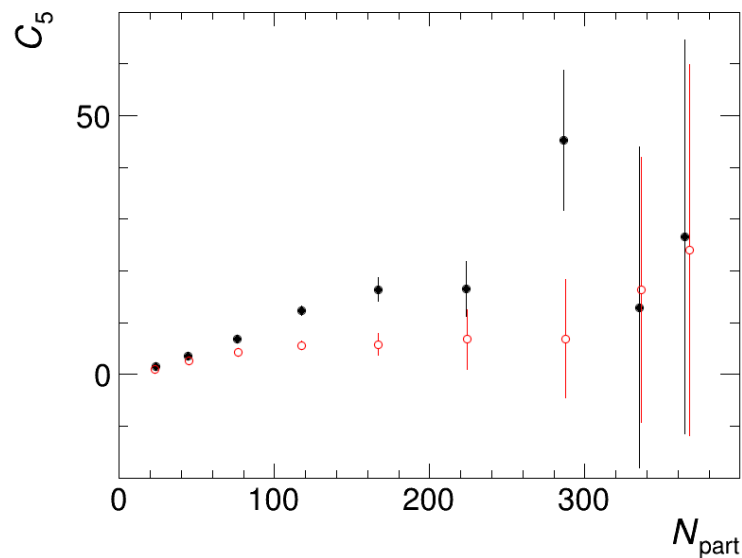
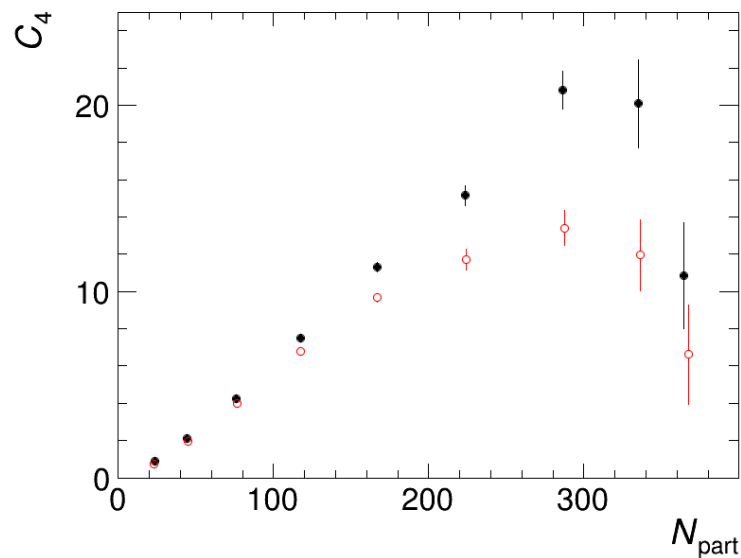
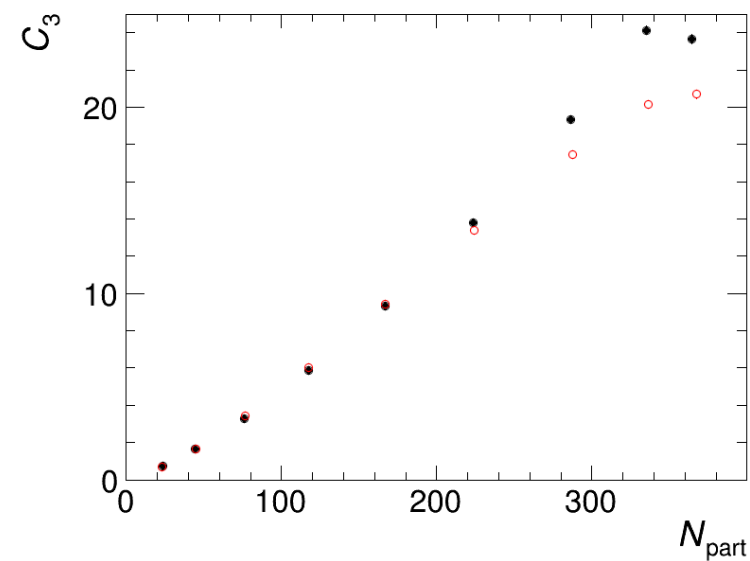
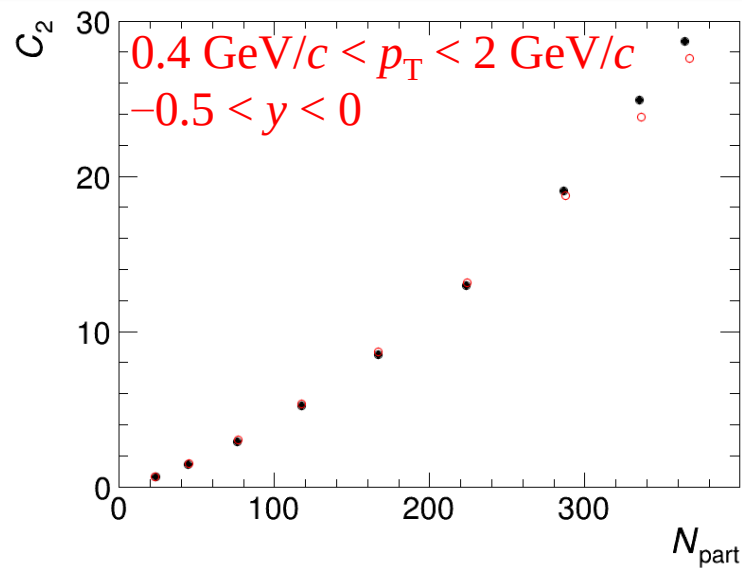
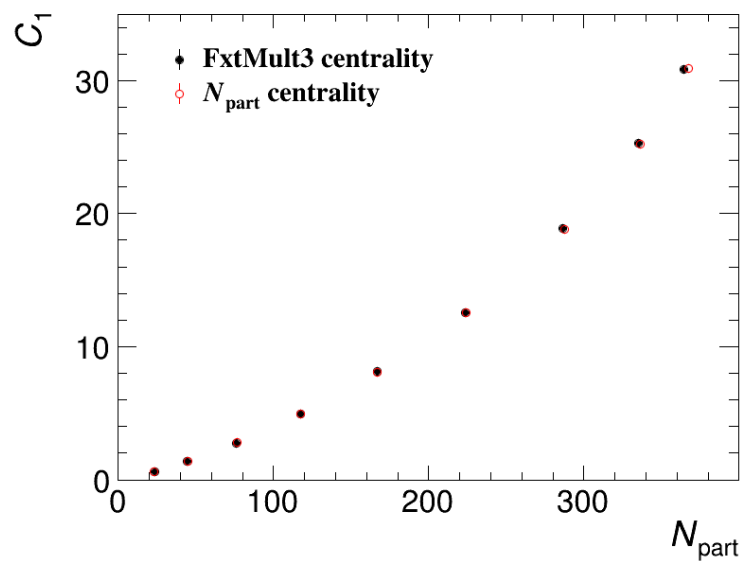


Proton number distributions in UrQMD

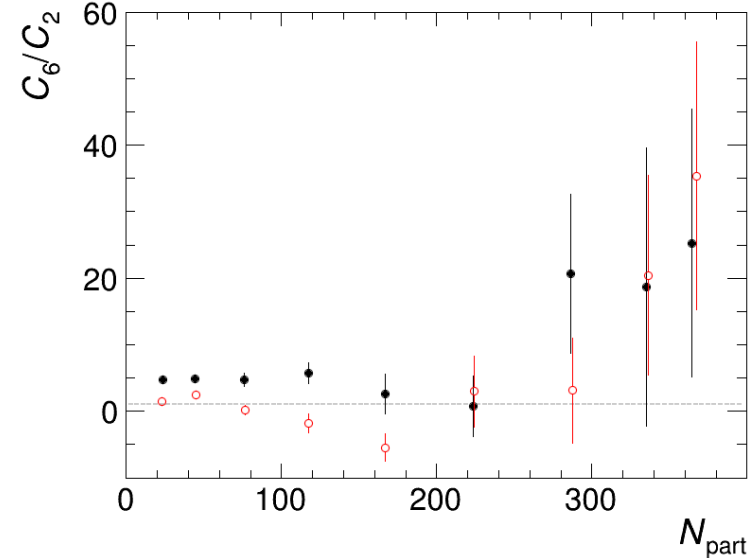
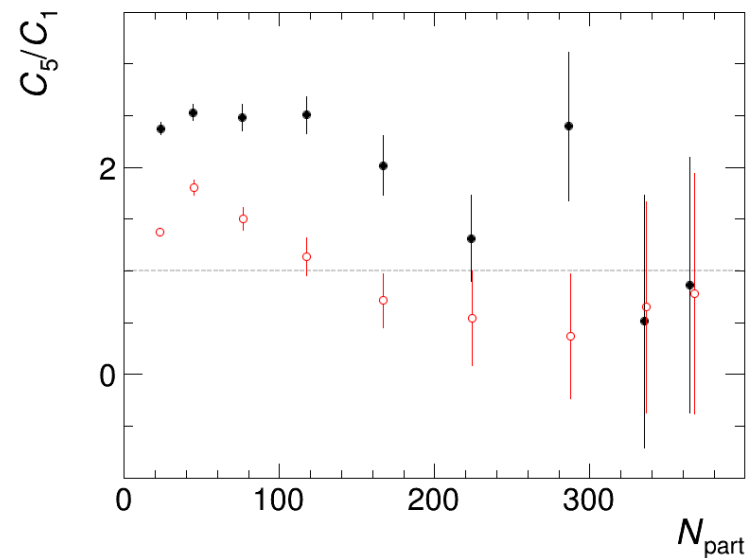
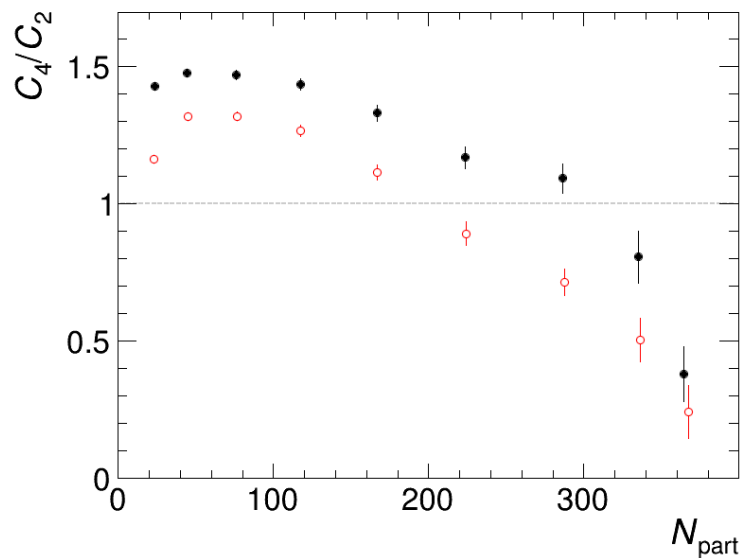
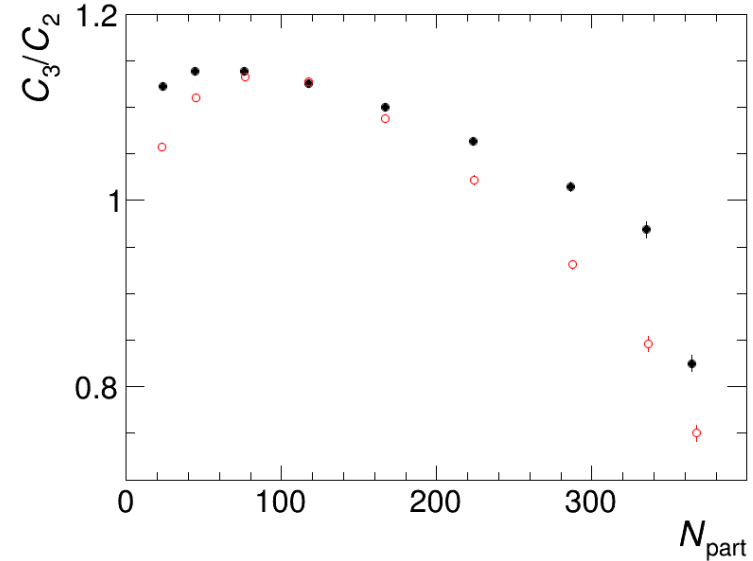
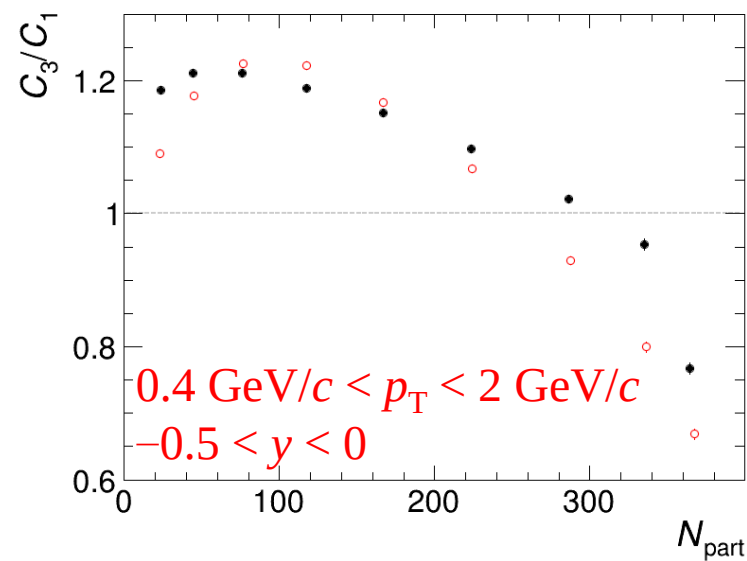
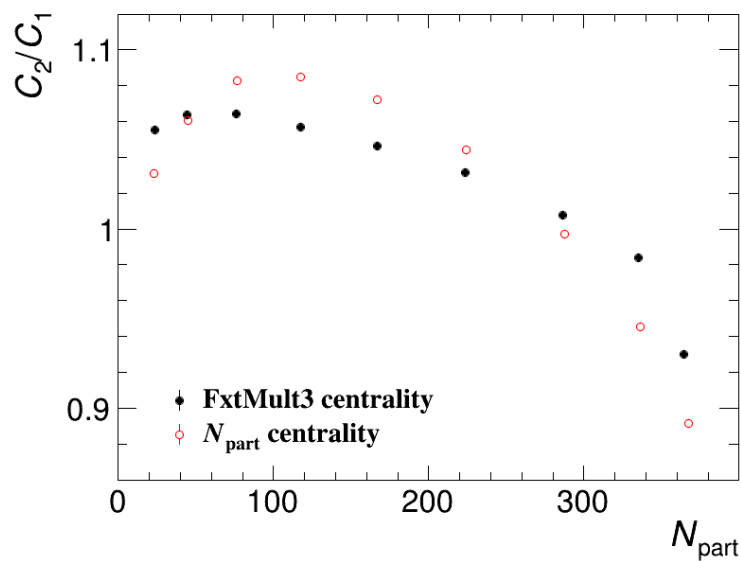
- Acceptance
 - $0.4 \text{ GeV}/c < p_T < 2 \text{ GeV}/c$
 - $-0.5 < y < 0$



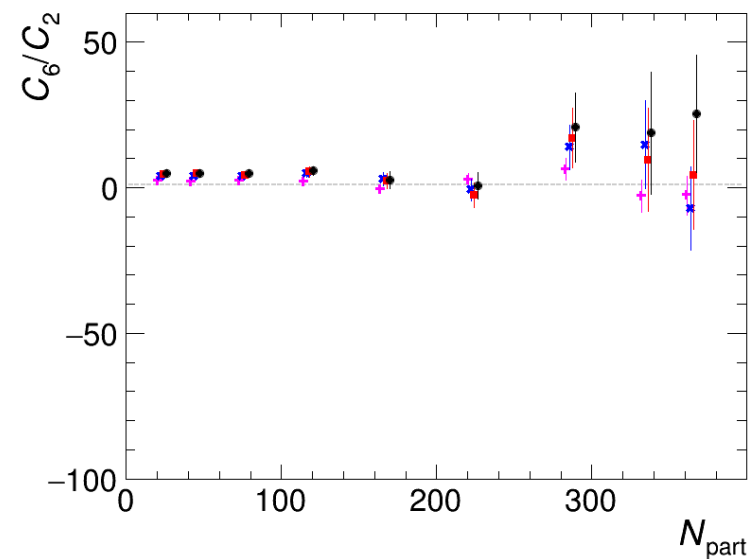
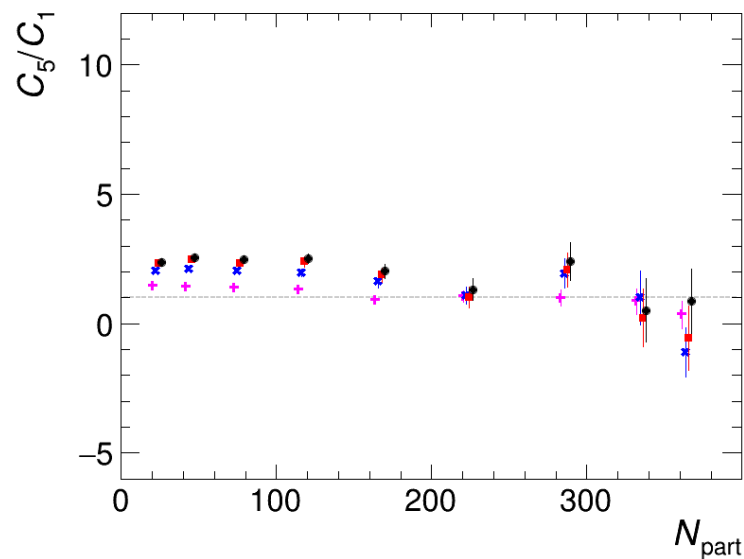
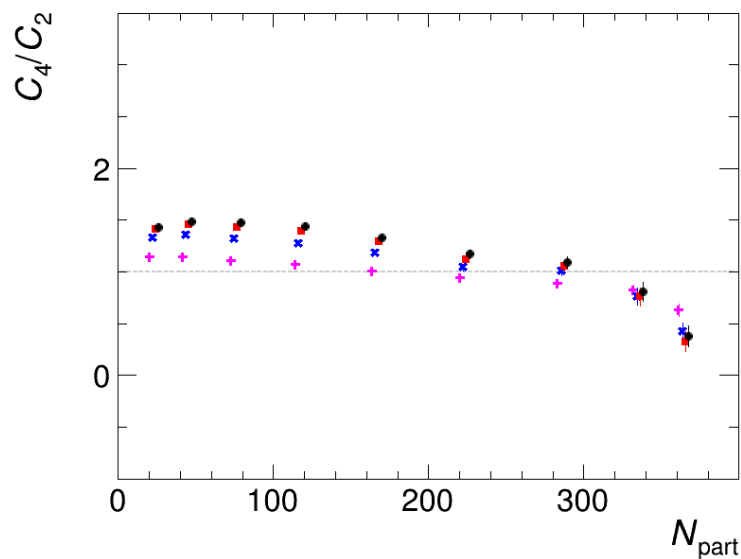
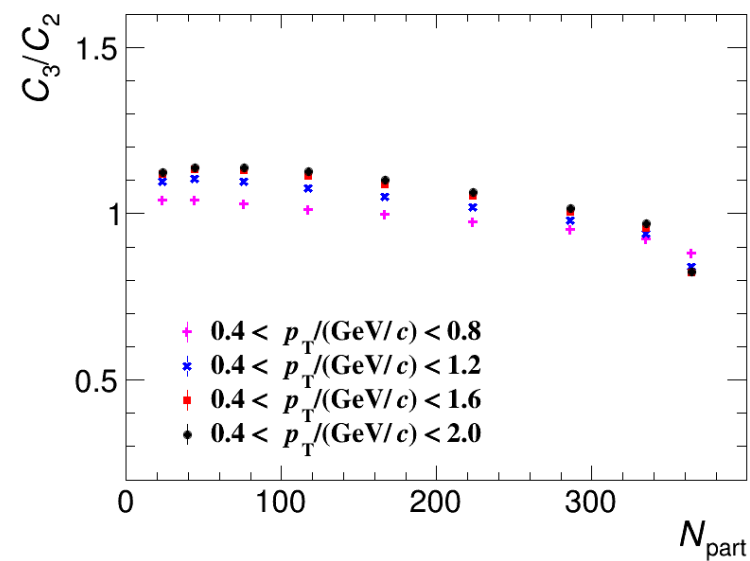
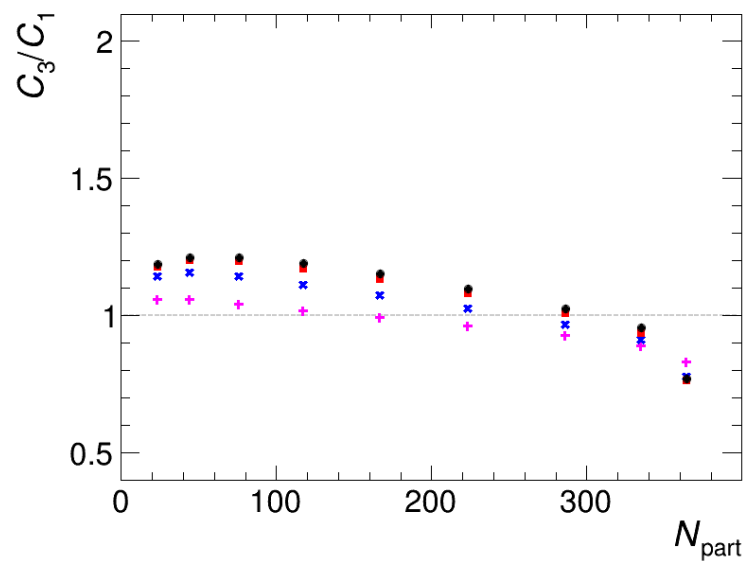
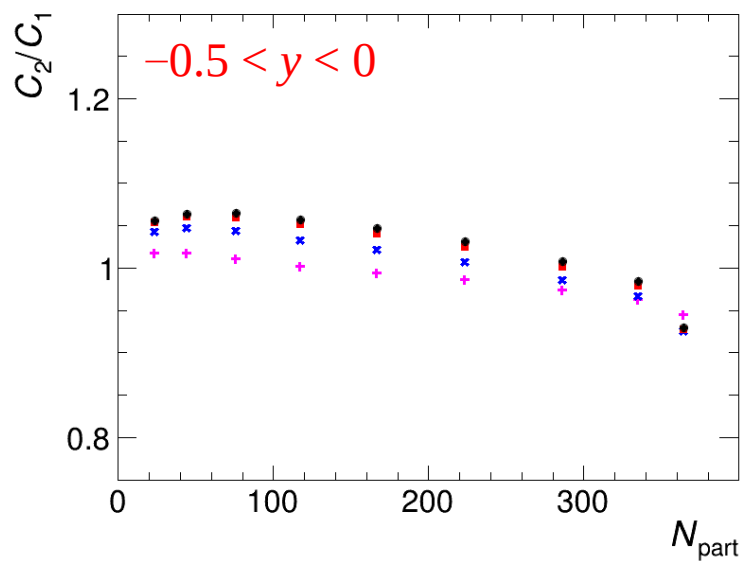
Cumulants in UrQMD



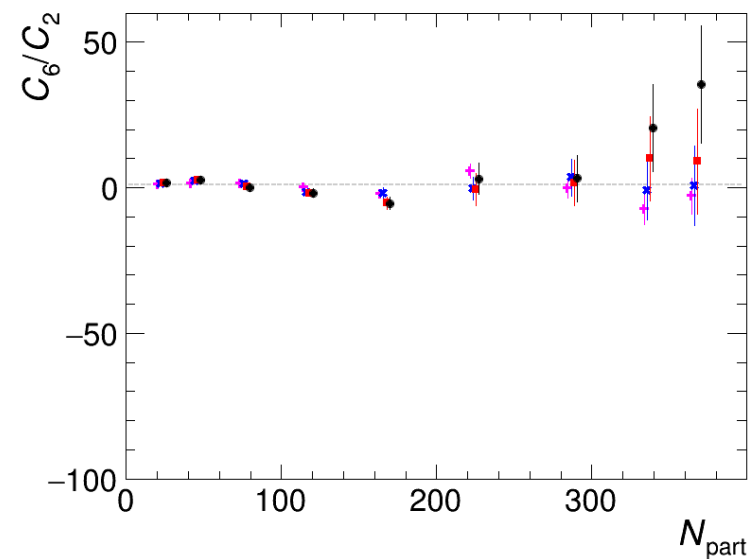
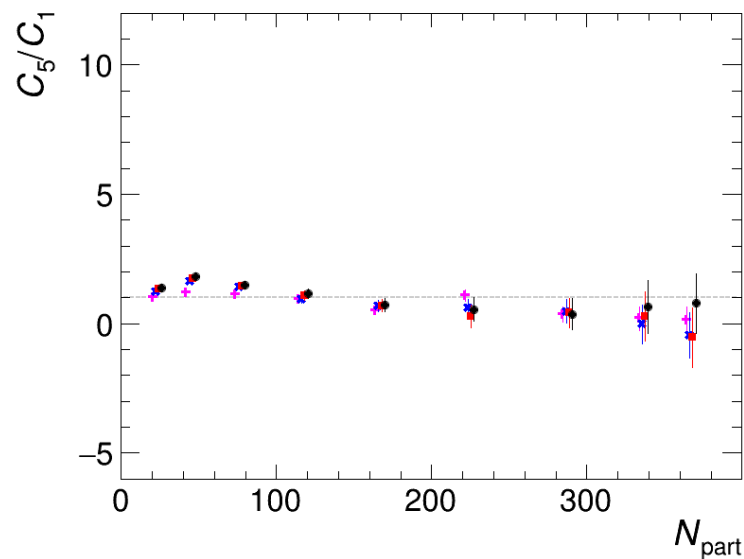
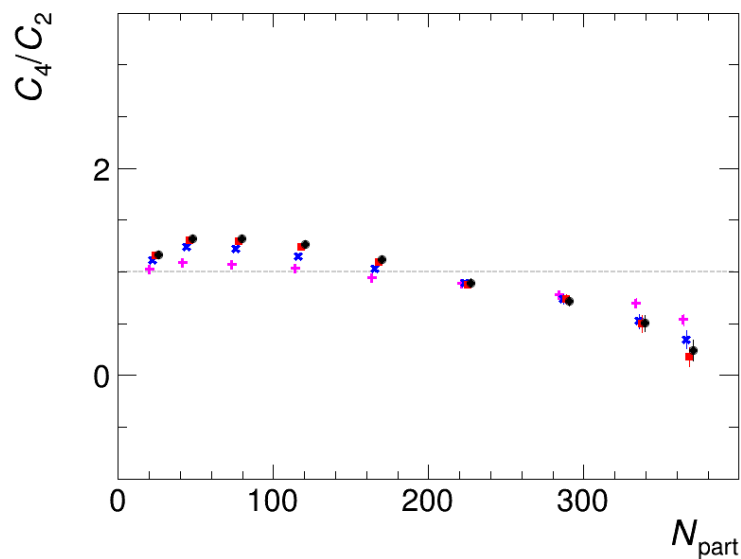
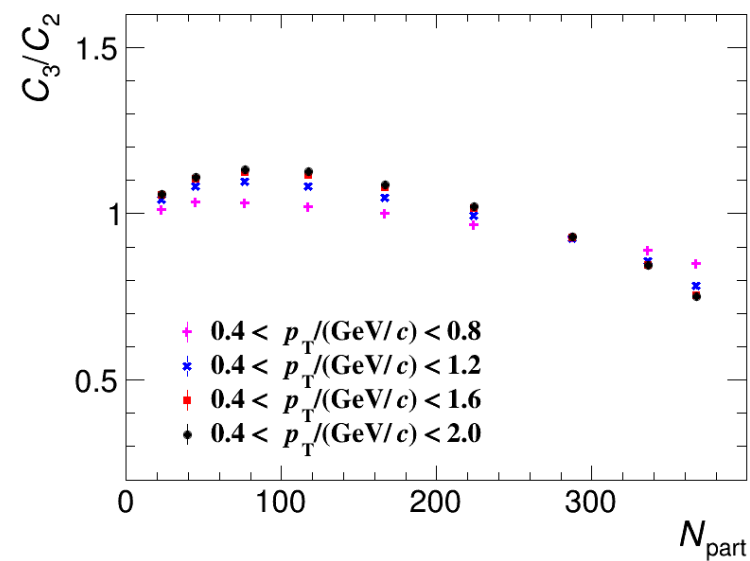
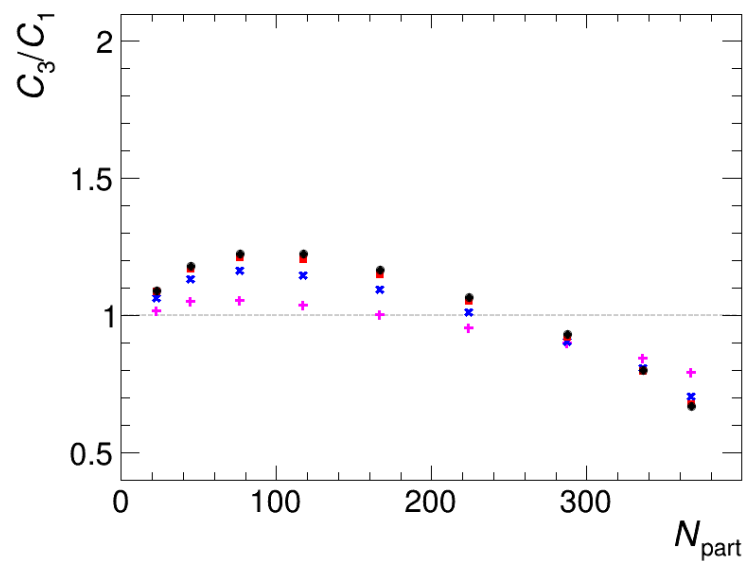
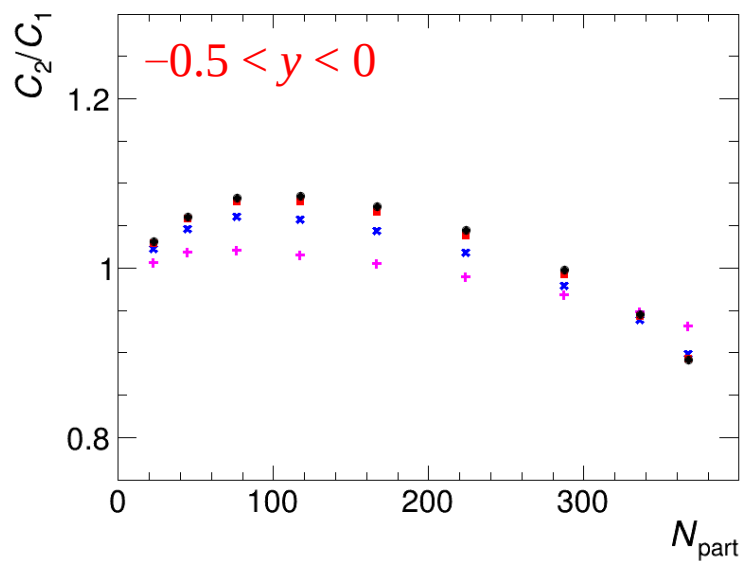
Cumulant ratios in UrQMD



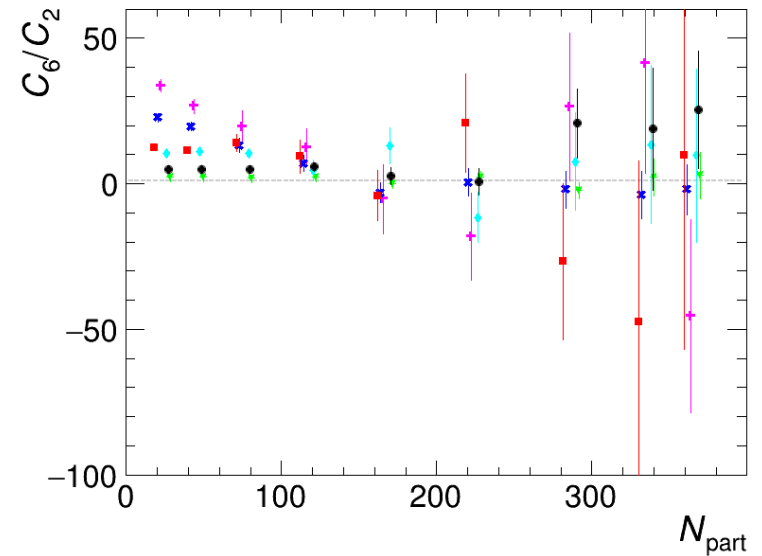
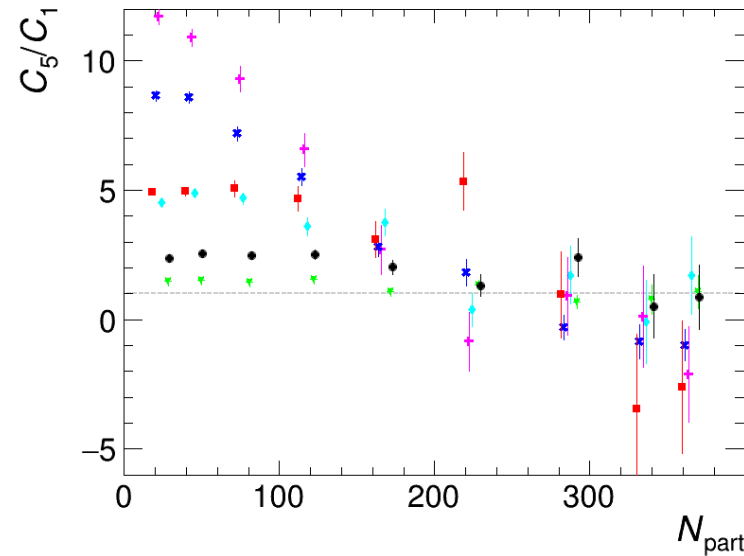
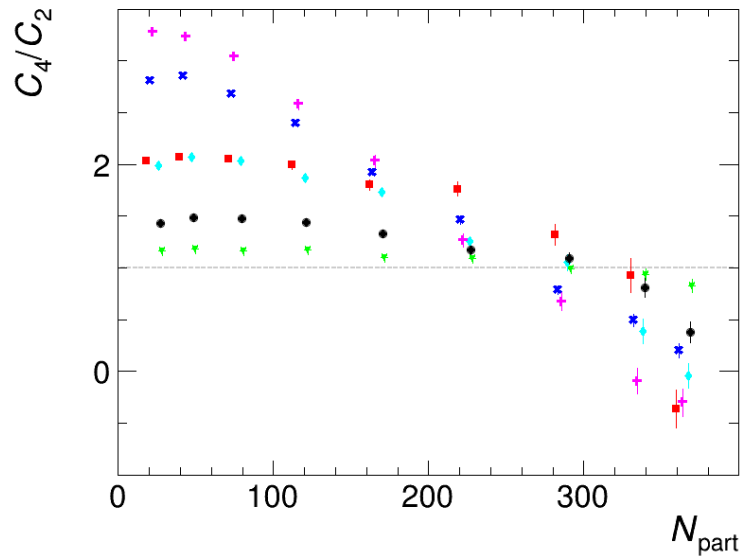
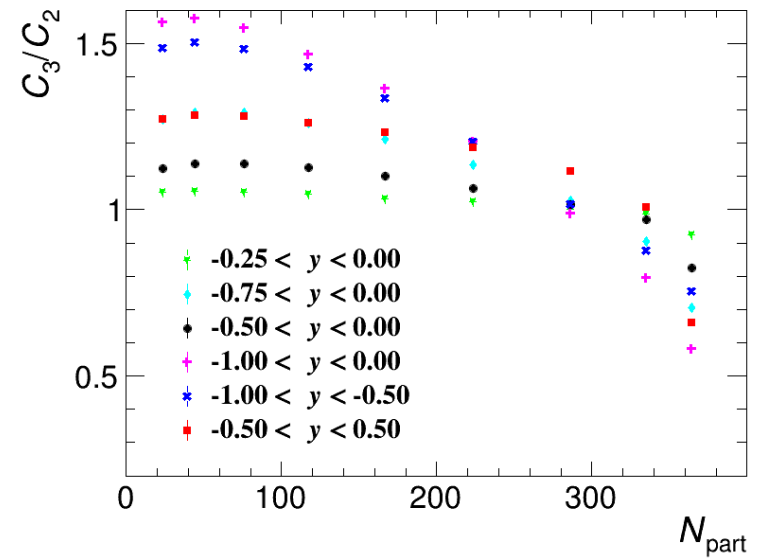
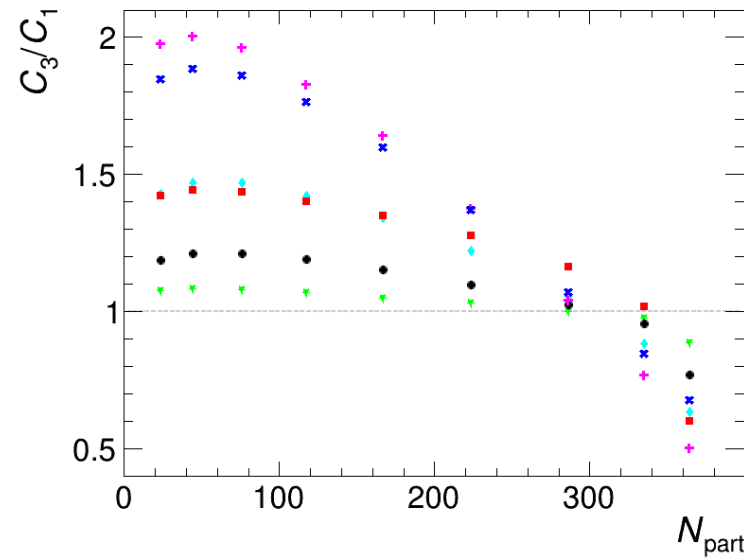
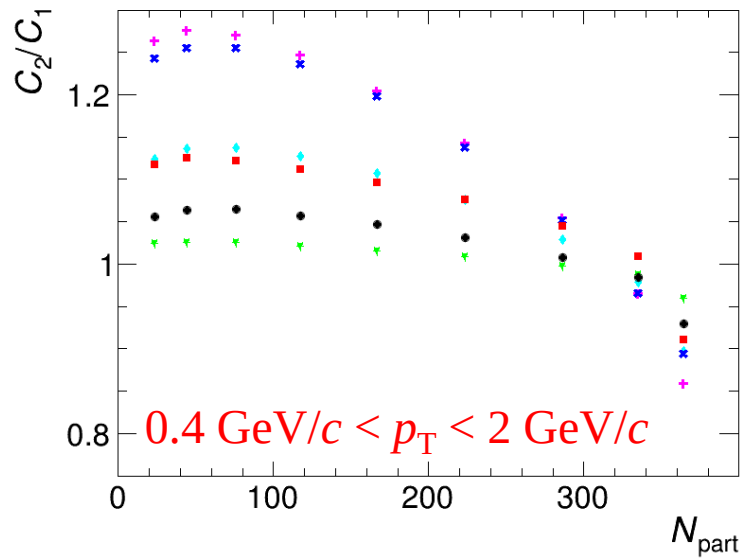
p_T dependence (FxtMult3 centrality)



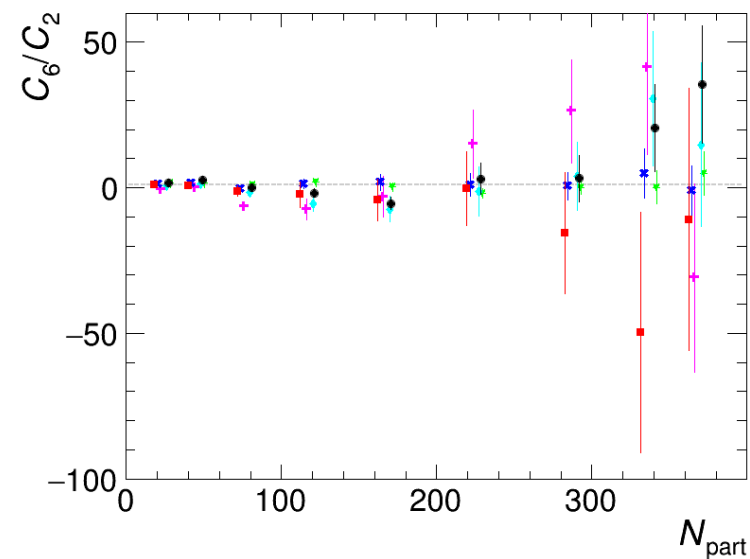
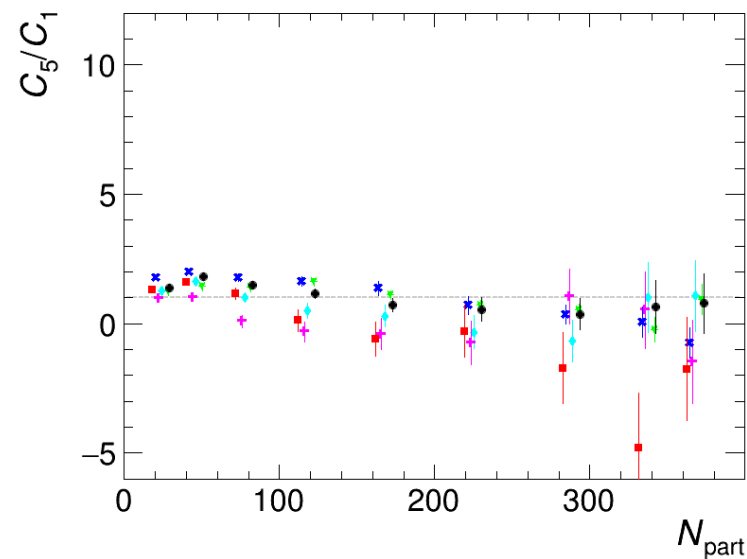
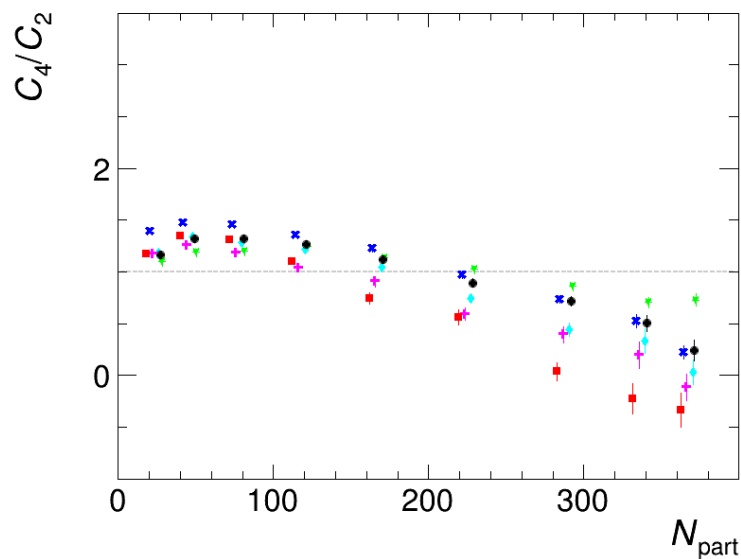
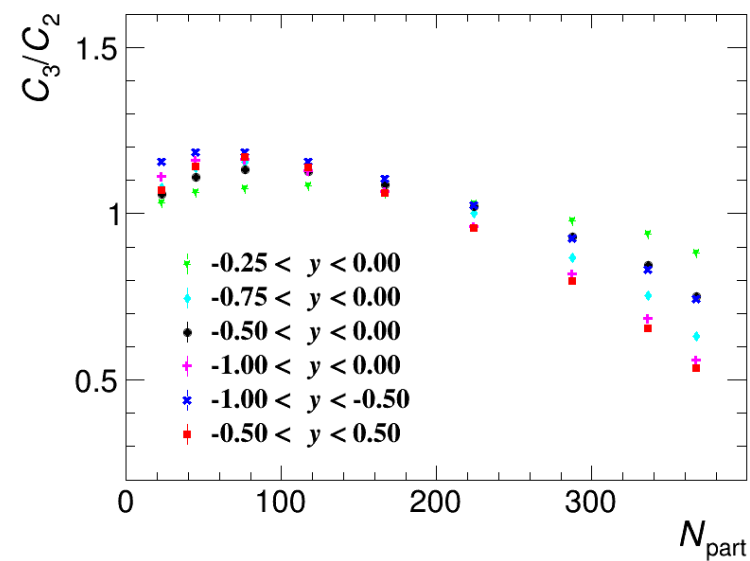
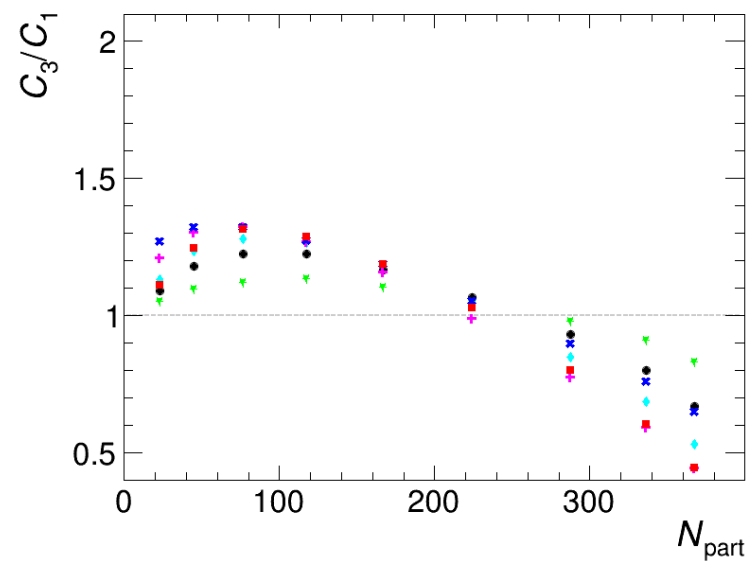
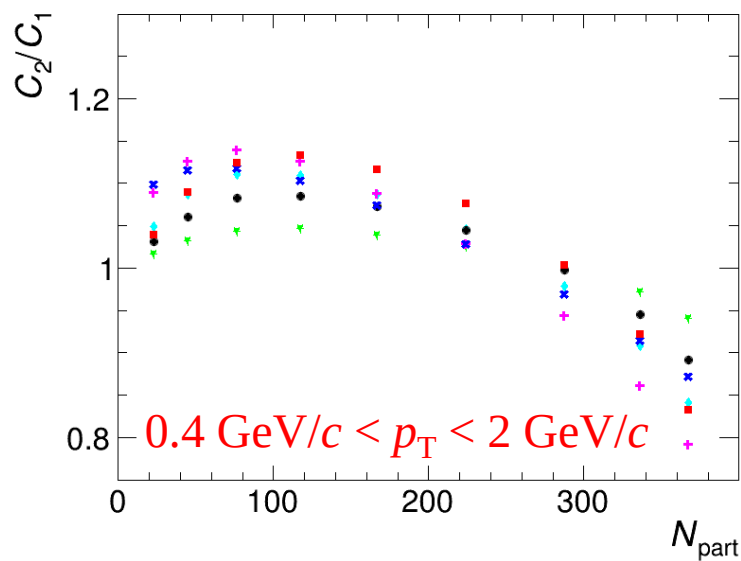
p_T dependence (N_{part} centrality)



y dependence (FxtMult3 centrality)



y dependence (N_{part} centrality)



Summary and outlook

- Summary

- Bad runs obtained, run-dependent V_z shift observed, and TPC $\langle n\sigma_{\text{proton}} \rangle$ recalibrated
- FxtMult3 and centrality defined, and pileup event unfolded
- Efficiency-uncorrected proton cumulants measured
- Acceptance and centrality-definition dependence of cumulants in UrQMD extracted

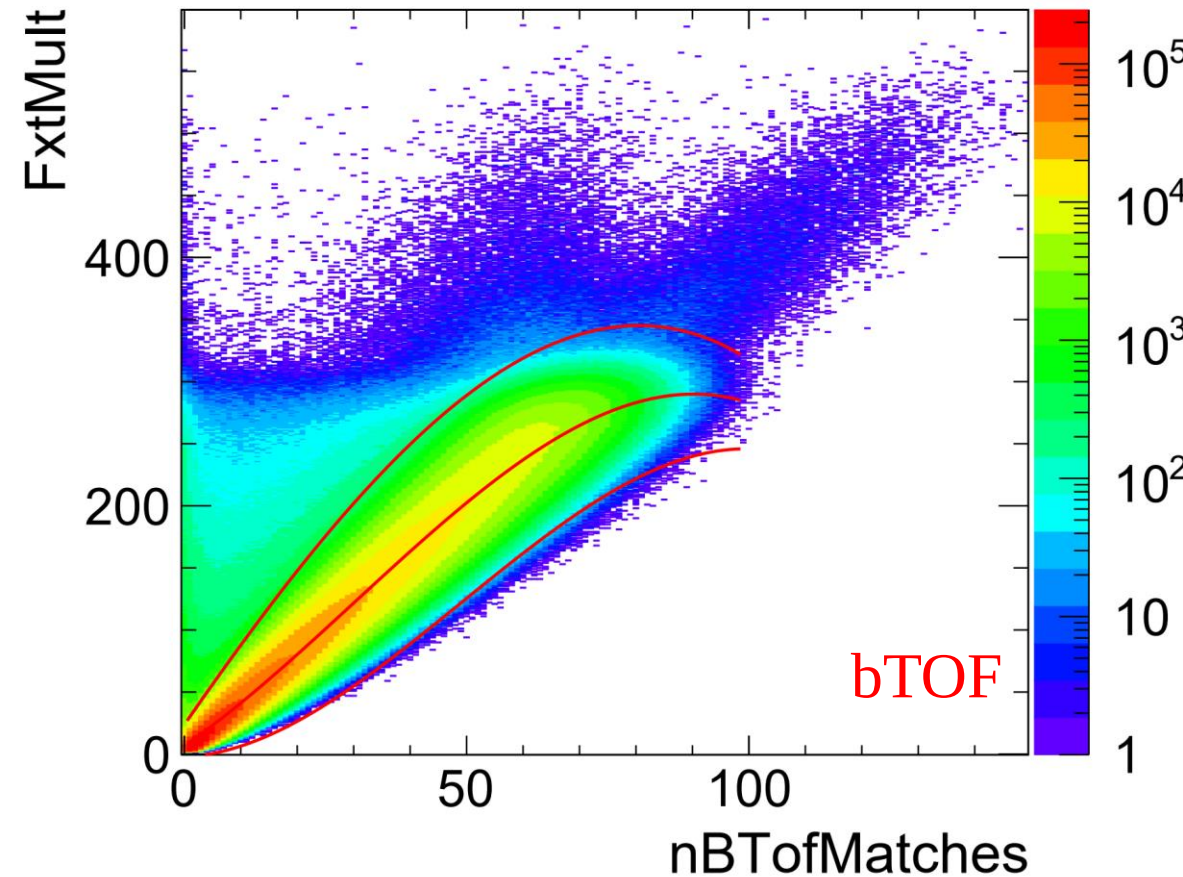
- Outlook

- Volume fluctuation correction
- Systematic uncertainty estimation
- Waiting for eTOF recalibration
- Waiting for embedding sample

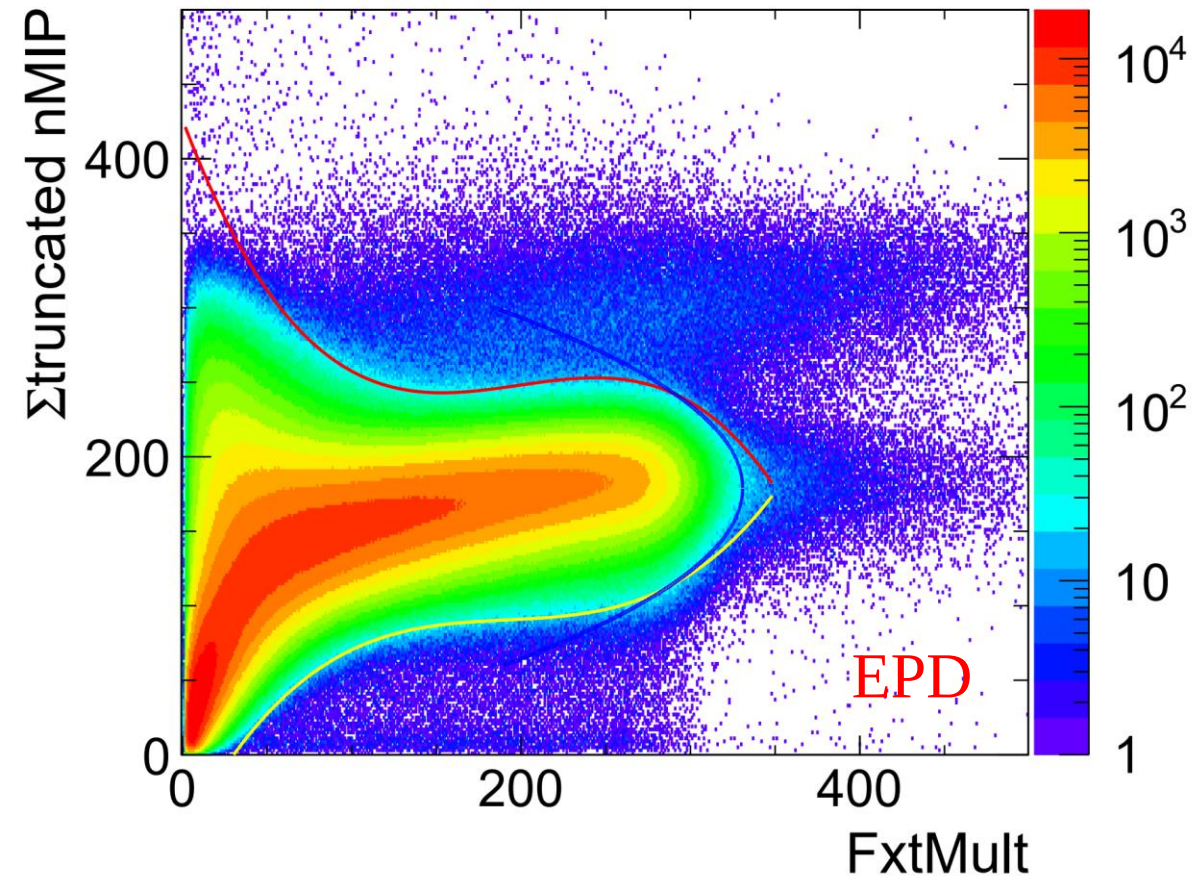
Thank you!

Pileup rejection

- Correlation between FxtMult & nBTofMatches

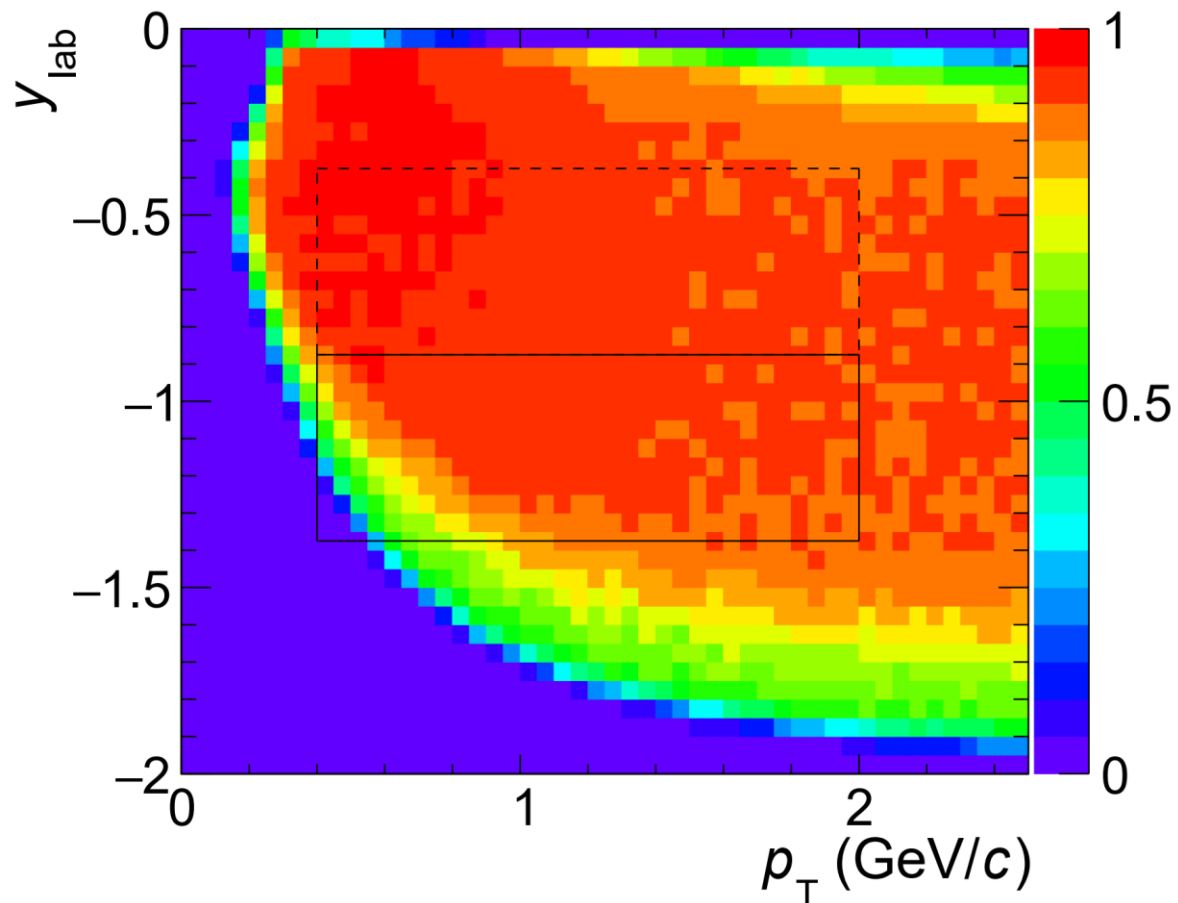


- Truncated nMIP =
$$\begin{cases} 2, & \text{nMIP} \geq 2 \\ \text{nMIP}, & 0.3 \leq \text{nMIP} < 2 \\ 0, & \text{nMIP} < 0.3 \end{cases}$$

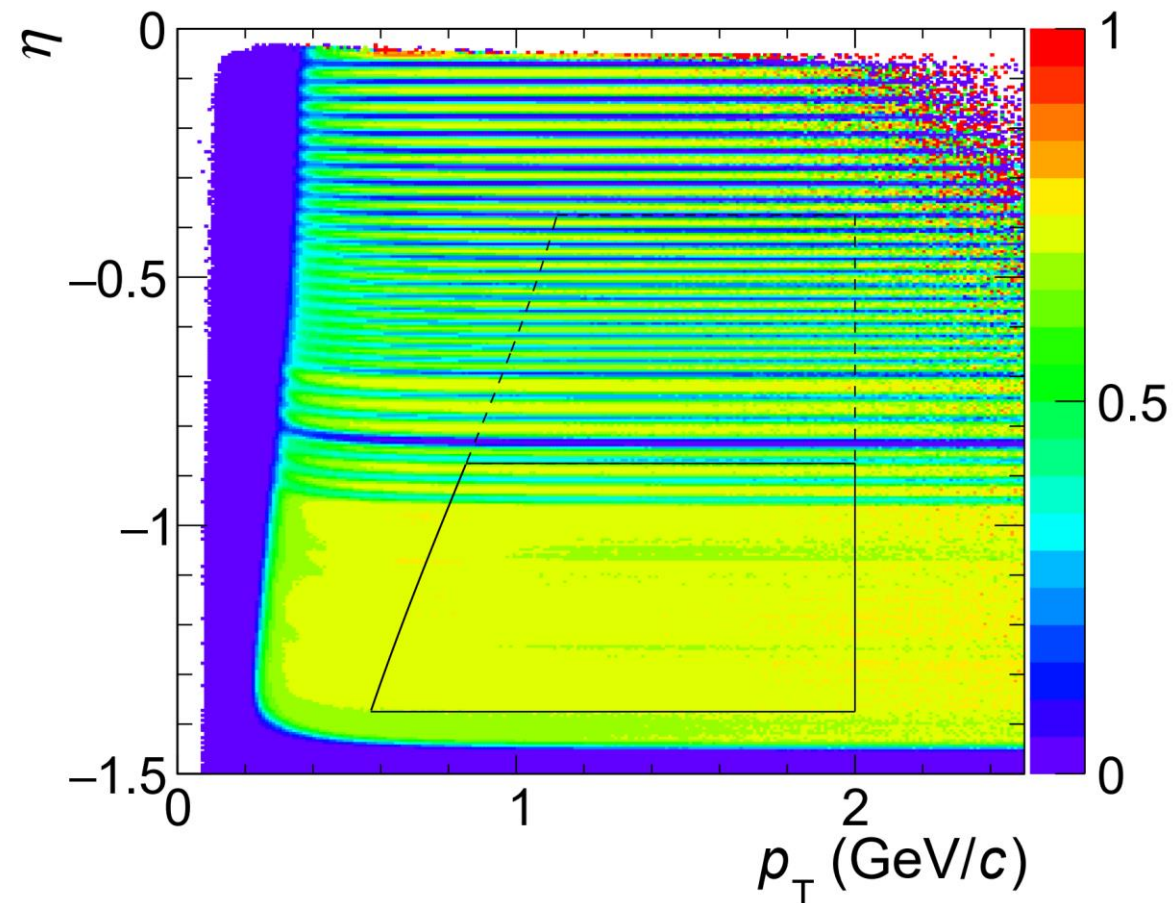


Efficiency

- TPC tracking efficiency
 - From 3.0 GeV embedding sample
 - No iTPC information



- TOF matching efficiency
 - $\varepsilon = \frac{N(\text{TPC PID \& TOF-matched})}{N(\text{TPC PID})}$



Analysis techniques

- Track-by-track efficiency correction
- Pileup correction
 - Pileup fraction and response matrix obtained from unfolding
- Centrality bin width correction (CBWC)
 - $C_k = \sum_r n_r C_{k,r} / \sum_r n_r$
- Bootstrap uncertainty estimation
 - 200 resamplings

$$q_{(r,s)} = \sum_{j=1}^{n_{\text{tot}}} \frac{a_j^r}{\varepsilon_j^s}$$

$$\begin{aligned} \langle Q \rangle_c &= \langle q_{(1,1)} \rangle_c, \\ \langle Q^2 \rangle_c &= \langle q_{(1,1)}^2 \rangle_c + \langle q_{(2,1)} \rangle_c - \langle q_{(2,2)} \rangle_c, \\ \langle Q^3 \rangle_c &= \langle q_{(1,1)}^3 \rangle_c + 3\langle q_{(1,1)} q_{(2,1)} \rangle_c - 3\langle q_{(1,1)} q_{(2,2)} \rangle_c \\ &\quad + \langle q_{(3,1)} \rangle_c - 3\langle q_{(3,2)} \rangle_c + 2\langle q_{(3,3)} \rangle_c, \\ \langle Q^4 \rangle_c &= \langle q_{(1,1)}^4 \rangle_c + 6\langle q_{(1,1)}^2 q_{(2,1)} \rangle_c - 6\langle q_{(1,1)}^2 q_{(2,2)} \rangle_c \\ &\quad + 4\langle q_{(1,1)} q_{(3,1)} \rangle_c + 3\langle q_{(2,1)}^2 \rangle_c + 3\langle q_{(2,2)}^2 \rangle_c \\ &\quad - 12\langle q_{(1,1)} q_{(3,2)} \rangle_c + 8\langle q_{(1,1)} q_{(3,3)} \rangle_c \\ &\quad - 6\langle q_{(2,1)} q_{(2,2)} \rangle_c + \langle q_{(4,1)} \rangle_c - 7\langle q_{(4,2)} \rangle_c \\ &\quad + 12\langle q_{(4,3)} \rangle_c - 6\langle q_{(4,4)} \rangle_c, \end{aligned}$$

$$\langle N^r \rangle_m^t = \frac{\langle N^r \rangle_m - \alpha_m C_m^{(r)}}{1 - \alpha_m + 2\alpha_m w_{m,0}},$$

with

$$C_m^{(r)} = \mu_m^{(r)} + \sum_{i,j>0} \delta_{m,i+j} w_{i,j} \langle N^r \rangle_{i,j}^{\text{sub}},$$

and

$$\mu_m^{(r)} = \begin{cases} 2w_{m,0} \sum_{k=0}^{r-1} \binom{r}{k} \langle N^{r-k} \rangle_0^t \langle N^k \rangle_m^t & (m > 0), \\ \sum_{k=1}^{r-1} \binom{r}{k} \langle N^{r-k} \rangle_0^t \langle N^k \rangle_0^t & (m = 0). \end{cases}$$

PRC 99, 044917
NIMA 984, 164632
NIMA 1026 166246
JPG 40 105104