Proton fluctuation analysis at 3.2, 3.5, 3.9, 4.5 and 5.2 GeV

Fan Si

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Datasets

$\sqrt{s_{NN}}$ (GeV)	Trigger setup	Stream, Production, Library	Run ID	Events	Trigger ID (epde-or-bbce-or-vpde-tof1)
3.2	production_4p59GeV _fixedTarget_2019	st_physics(_adc), P21id, SL21d	20179040 − 20183025 (90 runs)	2.76×10^8	680001
3.5	production_5p75GeV _fixedTarget_2020		20355020 − 21045011 (31 runs)	1.51×10^8	720000
3.9	production_7.3GeV _fixedTarget_2019		20107029 − 20169055 (32 runs)	0.82×10^8	1 (epde-or-bbce-tof1 some runs)
3.9	production_7p3GeV _fixedTarget_2020		21035003 − 21036013 (32 runs)	1.56×10^8	730000
4.5	production_9p8GeV _fixedTarget_2020		21029051 − 21032016 (40 runs)	1.81×10^8	740000, 740010
5.2	production_13p5GeV _fixedTarget_2020		21033026 − 21034013 (24 runs)	1.34×10^8	750000

Run-by-run QA cuts

- Trigger
  - epde-or-bbce-or-vpde-tof1
- Event cuts:
  - 198 cm < V_z < 202 cm
  - $|V_r|$ < 2 cm, with center (0, −2) cm
- Track cuts
  - Primary
  - |gDca| < 3 cm
  - nHitsFit > 10
  - nHitsFit/nHitsPoss > 0.52
  - nHitsDedx > 5
- QA Quantities (averaged values)

Detector	Event level	Track level
TPC	V_x, V_y, V_z, V_r, FxtMult, FxtMult3 (w/o $\langle n\sigma_p \rangle$ shift), N_+, N_-	Dca, Dca_{xy}, Dca_{φ}, Dca_z, signed Dca_{xy}, nHitsFit, nHitsFit/nHitsPoss, nHitsDedx, p_T, φ, η, dE/dx
bTOF	bTofMatchMult, bTofTrayMult,	bTOF 1/β, bTofYLocal, bTofZLocal

Bad run rejection

- Iteratively remove empty bins and 3-σ outliers until no new bad runs
  - Weighted μ & σ

Dataset	Bad/total runs	Left/total PicoDst files
3.2 GeV	24/90 (26.7%)	7242/8949 (80.9%)
3.5 GeV	10/31 (32.3%)	4242/4868 (87.1%)
3.9 GeV (2019)	11/32 (34.4%)	2762/3328 (83.0%)
3.9 GeV (2020)	6/32 (18.8%)	5172/6004 (84.1%)
4.5 GeV	7/40 (17.5%)	7180/7847 (91.5%)
5.2 GeV	7/24 (28.0%)	4515/5644 (80.0%)

- FxtMult3 definition (according to RefMult3 in StPicoDstMaker/StPicoUtilities.h)
  - Basic cuts: primary, $p > 0.1$ GeV/c, Dca < 3 cm, nHitsFit ≥ 10
  - Proton exclusion (hybrid): $n\sigma_{\mathrm{p}} < -3$, bTOF $m^2 < 0.4$ GeV$^2/c^4$ (unavailable bTOF $m^2 = -999$)

Pileup event rejection (bTOF)

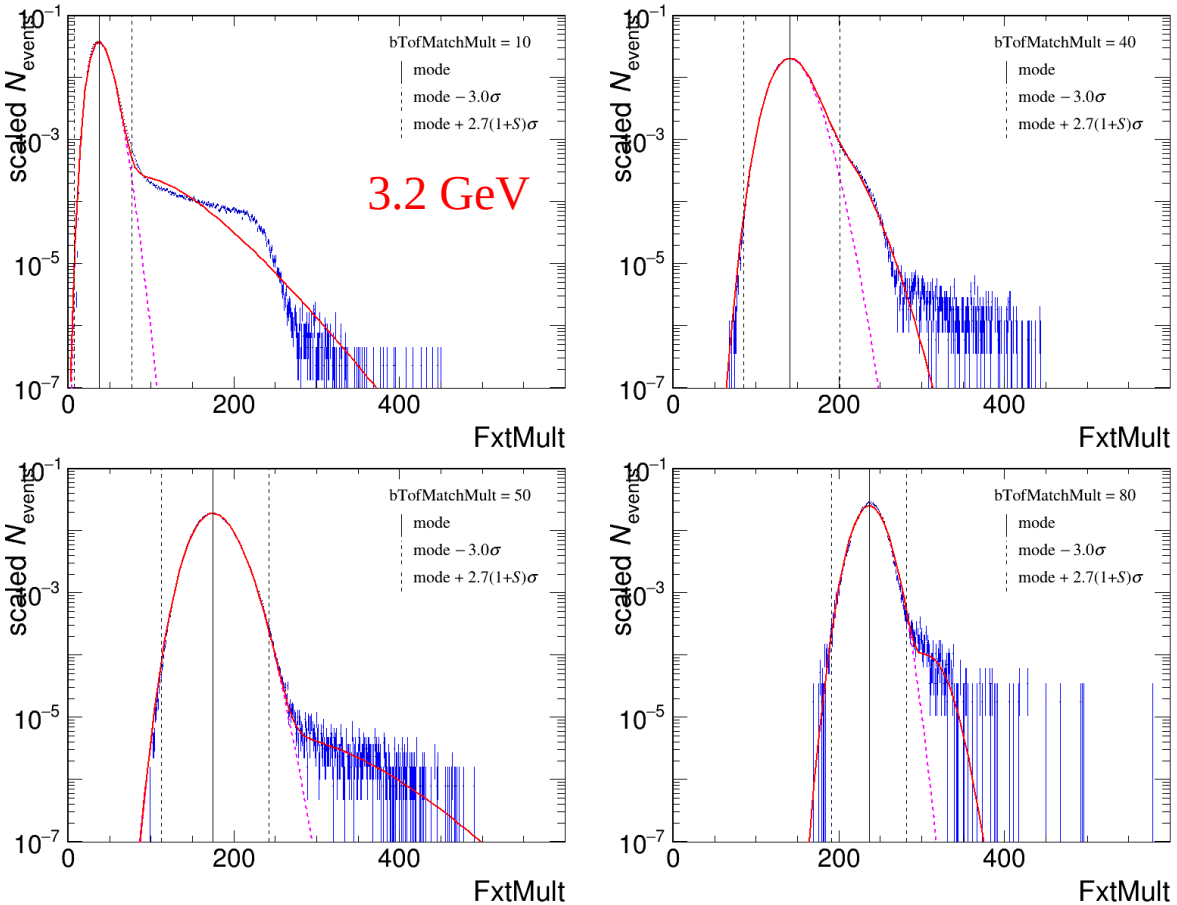
- Using procedures in isobar analysis
  - https://drupal.star.bnl.gov/STAR/system/files/isobar_analysis_note_v3.pdf
- Step 1: Obtain 2D FxtMult-bTofMatchMult distribution
  - After bad run removal
  - Same event cuts as run-by-run QA
- Step 2: Double-NBD fit in each bTofMatchMult slice
  - Determine central value, lower cut & higher cut for FxtMult
- Step 3: Cubic polynomial (pol3) fits for functions of bTofMatchMult

Double-NBD fit

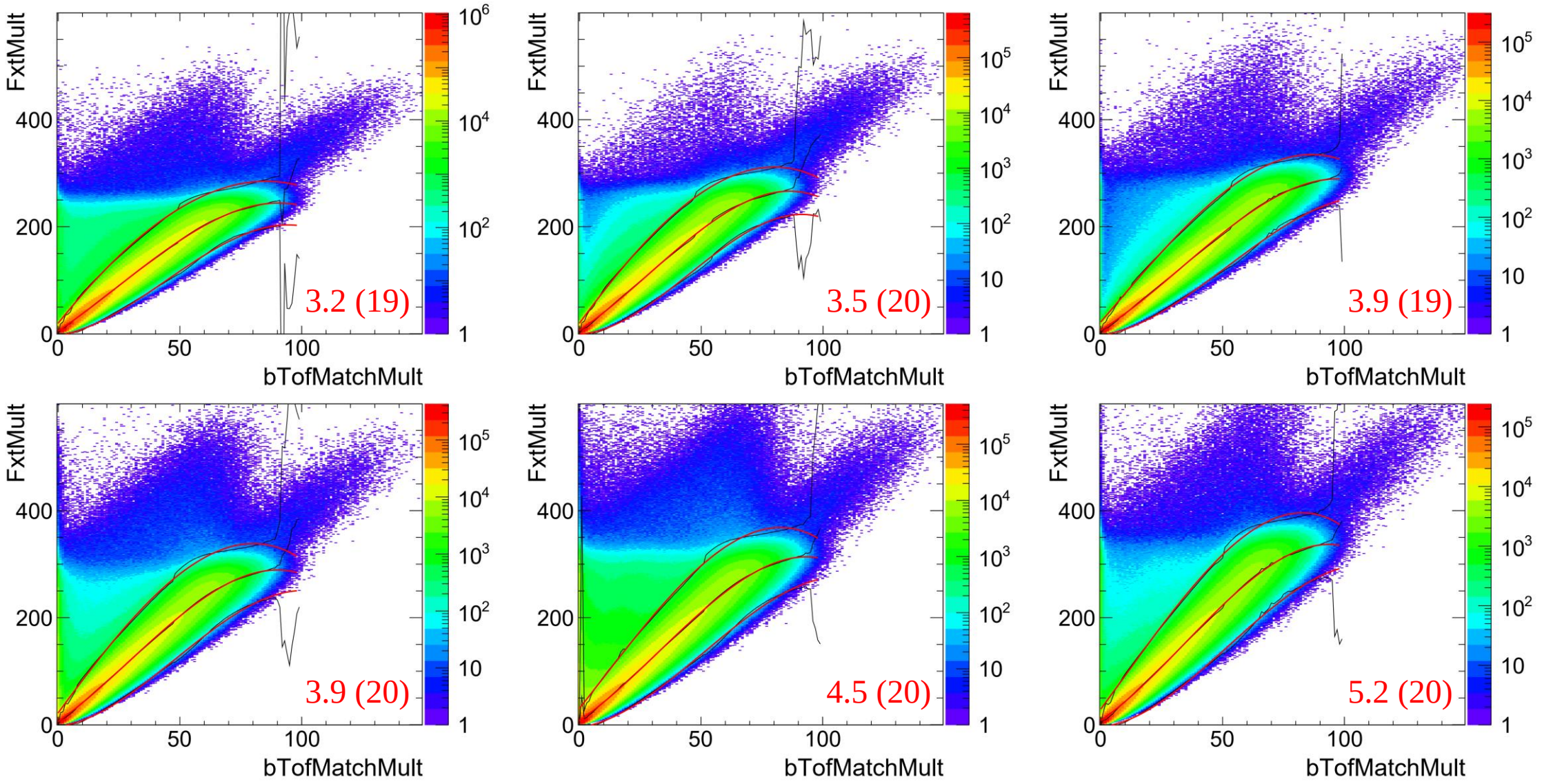
- Negative binomial distribution $f(x) = \binom{x+r-1}{r-1} p^r (1-p)^x = \frac{\Gamma(x+r)}{\Gamma(r)\Gamma(x+1)} p^r (1-p)^x$
  - Mode $m = \frac{(r-1)(1-p)}{p}$ (mean $\mu = \frac{r(1-p)}{p}$)
  - Sigma $\sigma = \frac{\sqrt{r(1-p)}}{p}$
  - Skewness $S = \frac{2-p}{\sqrt{r(1-p)}}$

- NBD1: main body of distribution
  - Central value: m
  - Lower cut: $m - 3\sigma$
  - Higher cut: $m + 2.7(1 + S)\sigma$

- NBD2: tail of distribution



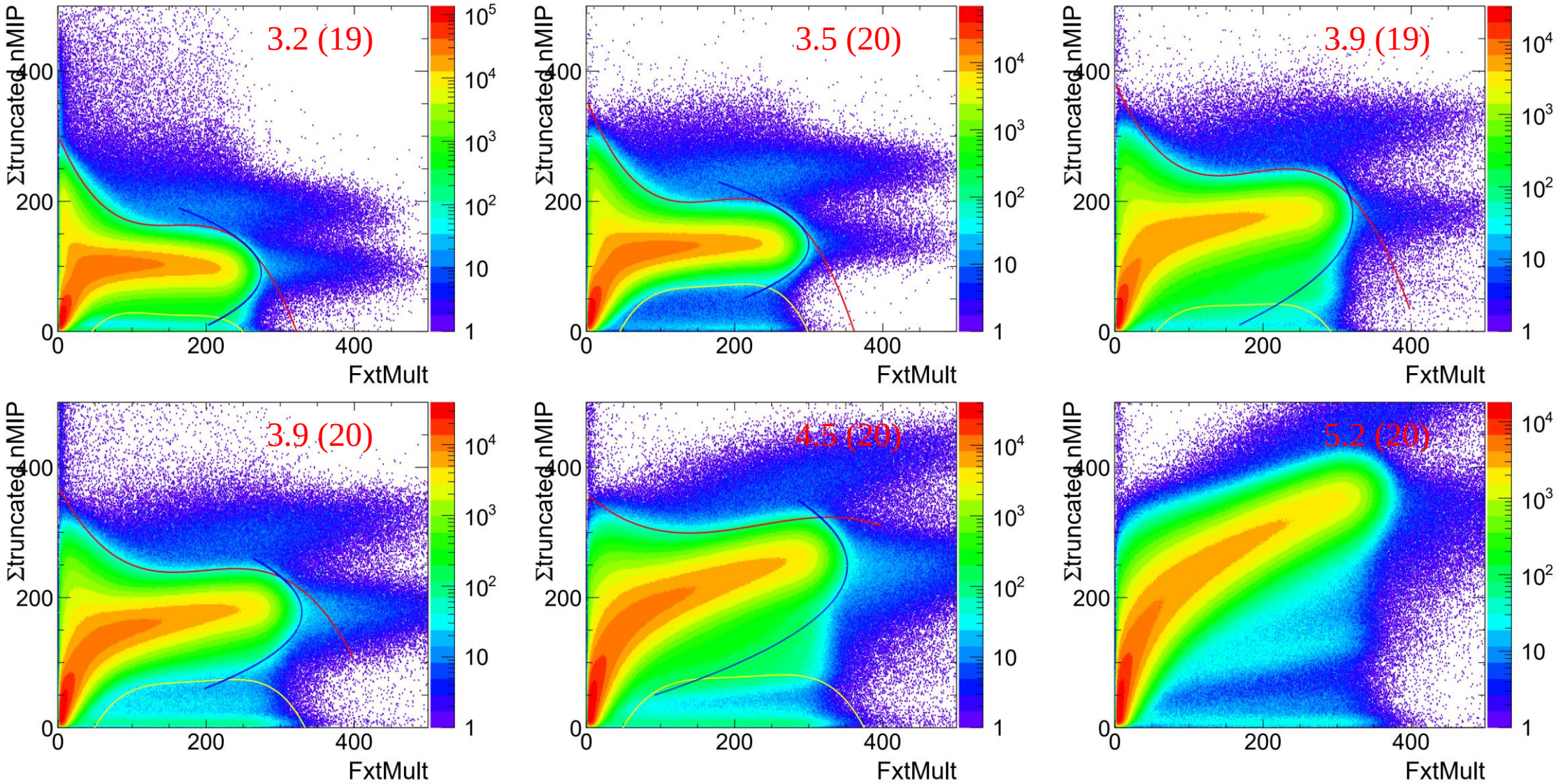
Pileup event rejection (bTOF)



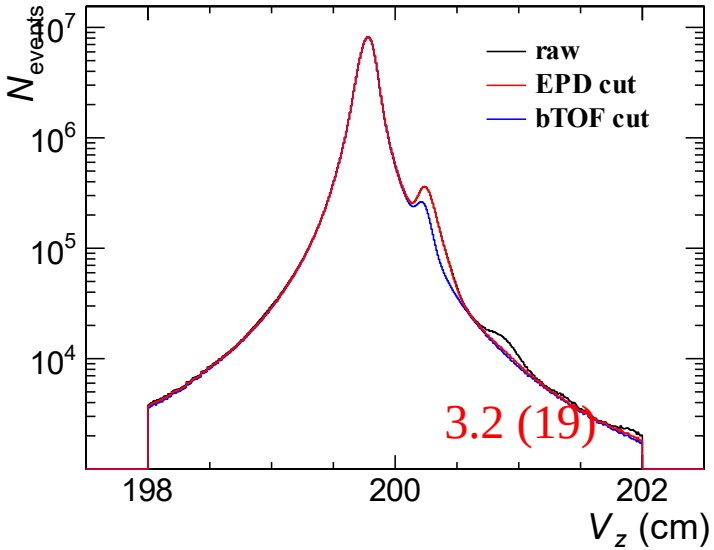
Pileup event rejection (EPD)

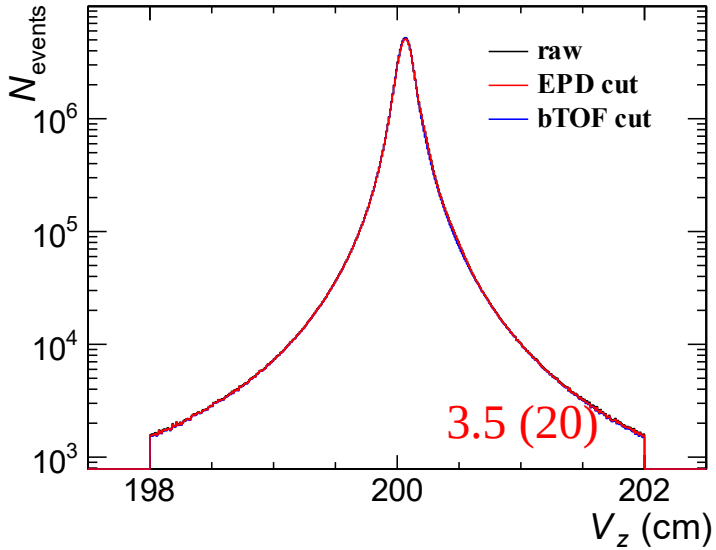
- Step 1: Obtain 2D FxtMult-∑TnMIP distribution
  - Truncated nMIP = StPicoEpdHit−>TnMIP(2, 0.3)
- Step 2: For 1D distribution of ∑TnMIP in each FxtMult slice
  - 2.1: Calculate bottom = $\mu - (3.5 - 0.2S)\sigma$ & top = $\mu + (3.5 + 0.8S)\sigma$ for ∑TnMIP
  - 2.2: Remove ∑TnMIP out of bottom to top, and recalculate bottom & top
- Step 3: Quartic polynomial (pol4) fit for bottom values, and cubic polynomial (pol3) fit for top values as functions of FxtMult
- Step 4: For 2D distribution
  - 4.1: Remove bins with value/integral out of 3.8e−7 to 4.2e−7
  - 4.2: Fit rest distribution with a “[0]*TMath::Gaus(x[0], [1], [2])+[3]” function of ∑TnMIP

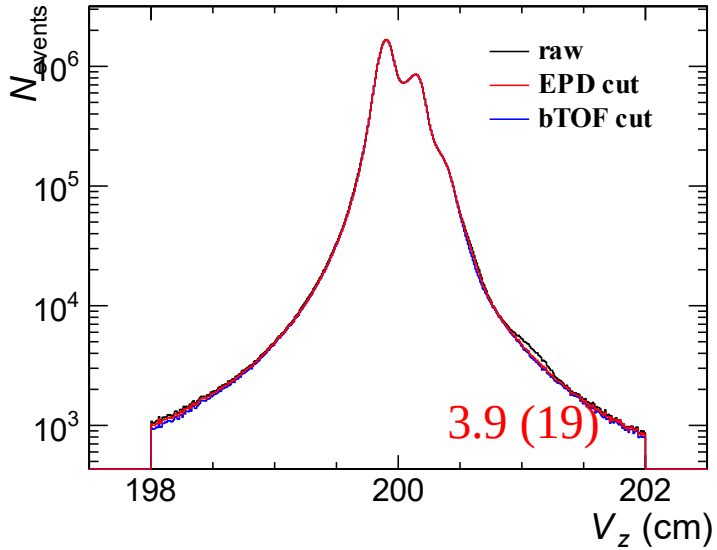
Pileup event rejection (EPD)

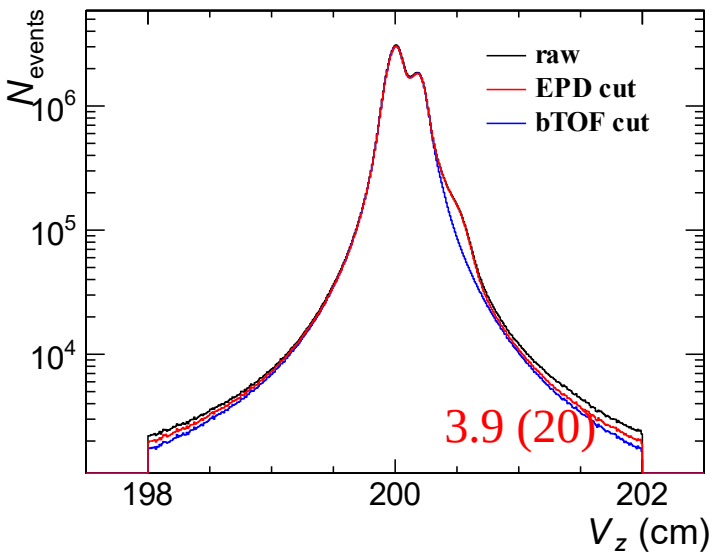


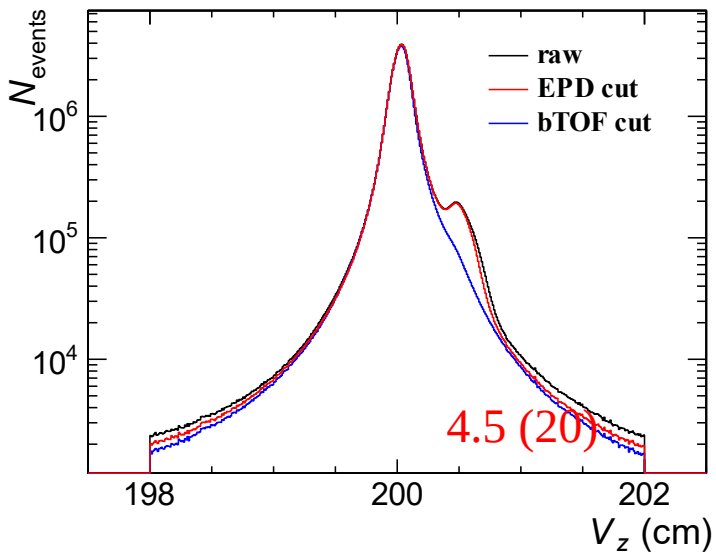
Effect of pileup event rejection

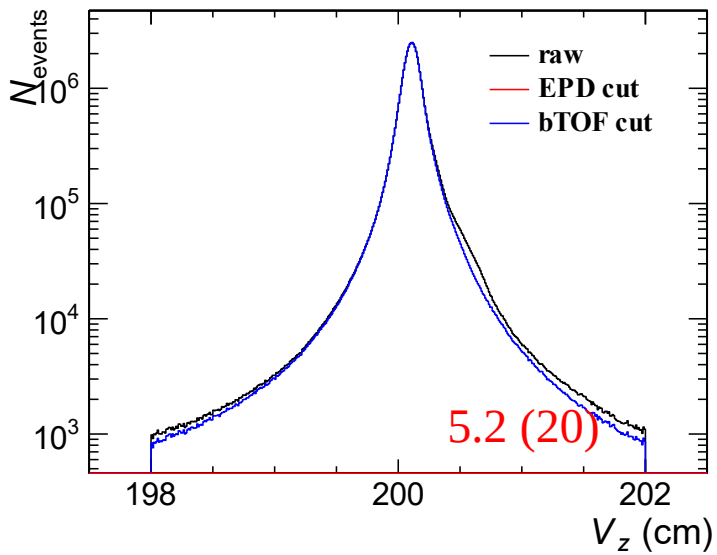




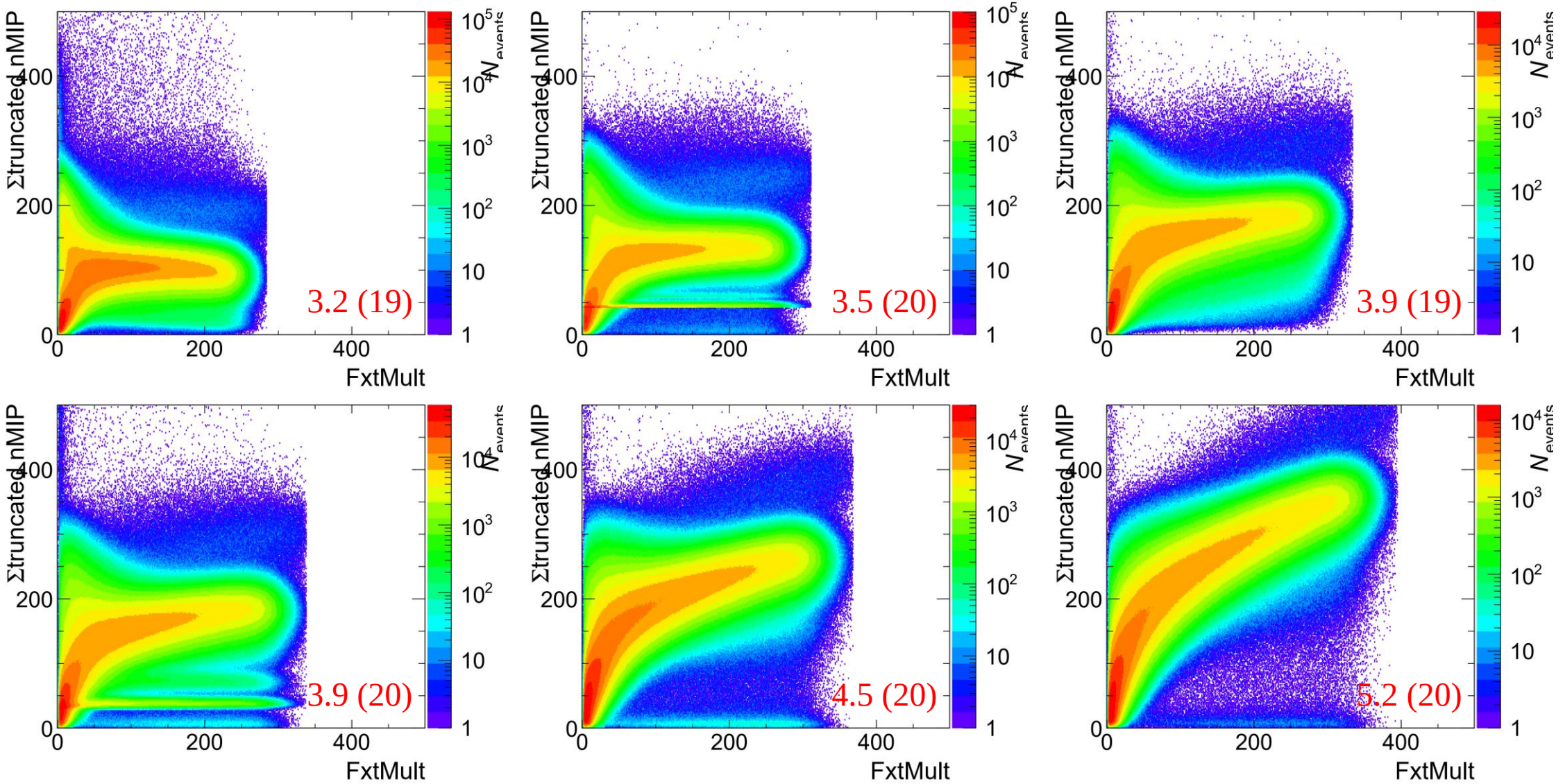




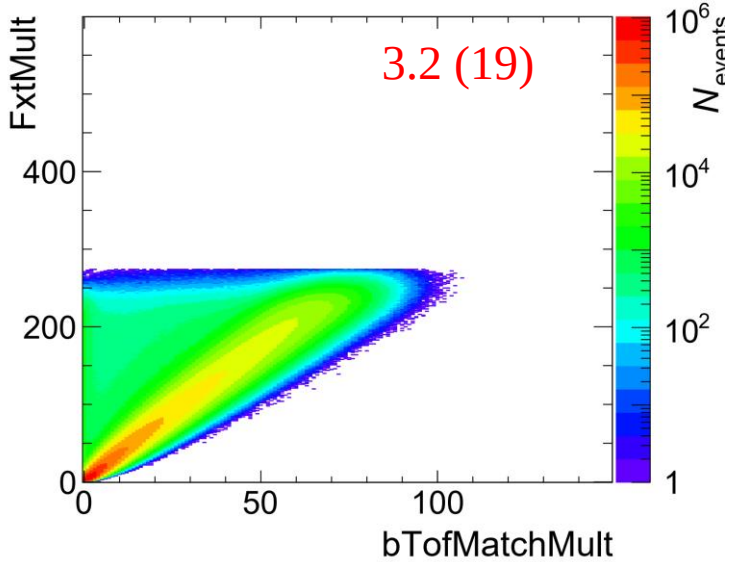


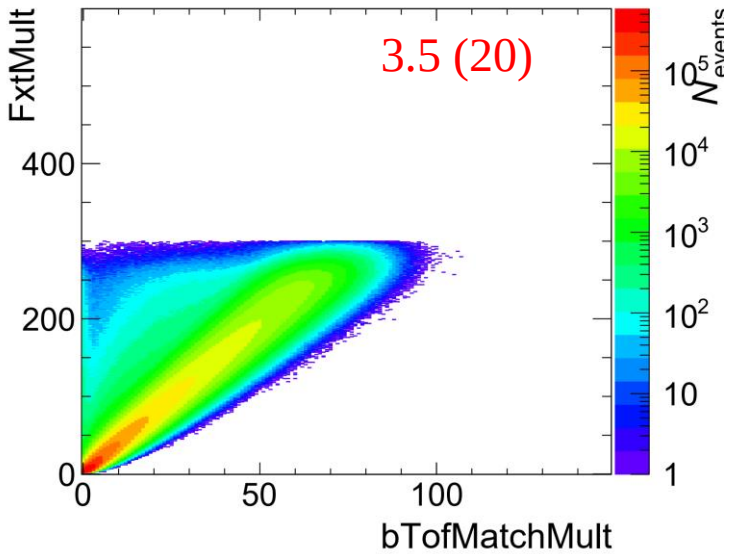


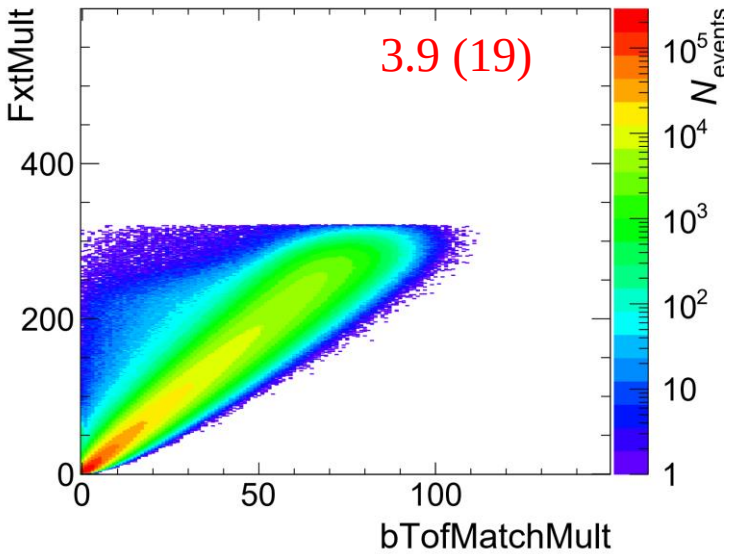
Effect of pileup event rejection (bTOF)

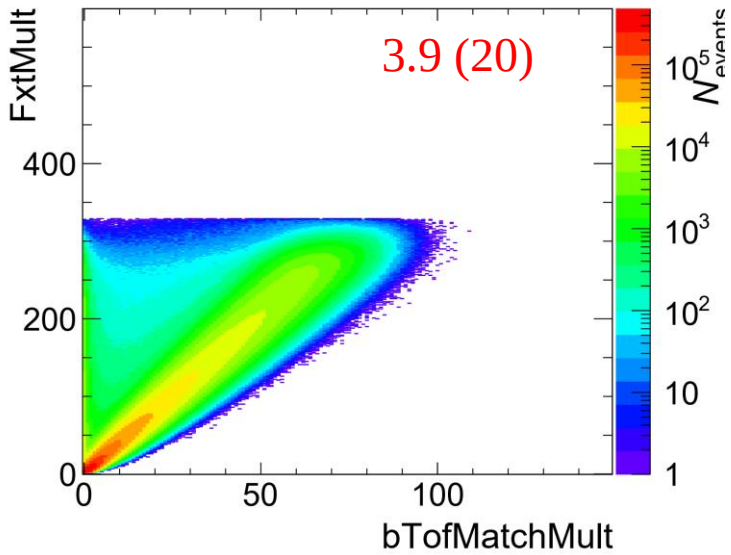


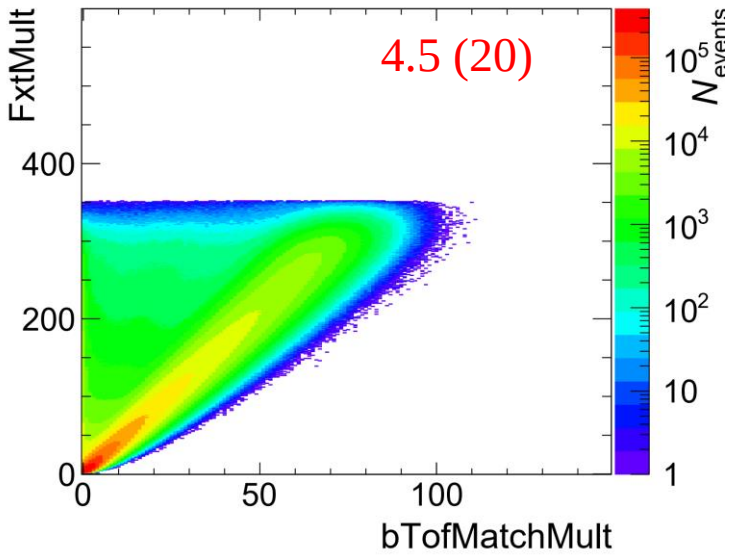
Effect of pileup event rejection (EPD)



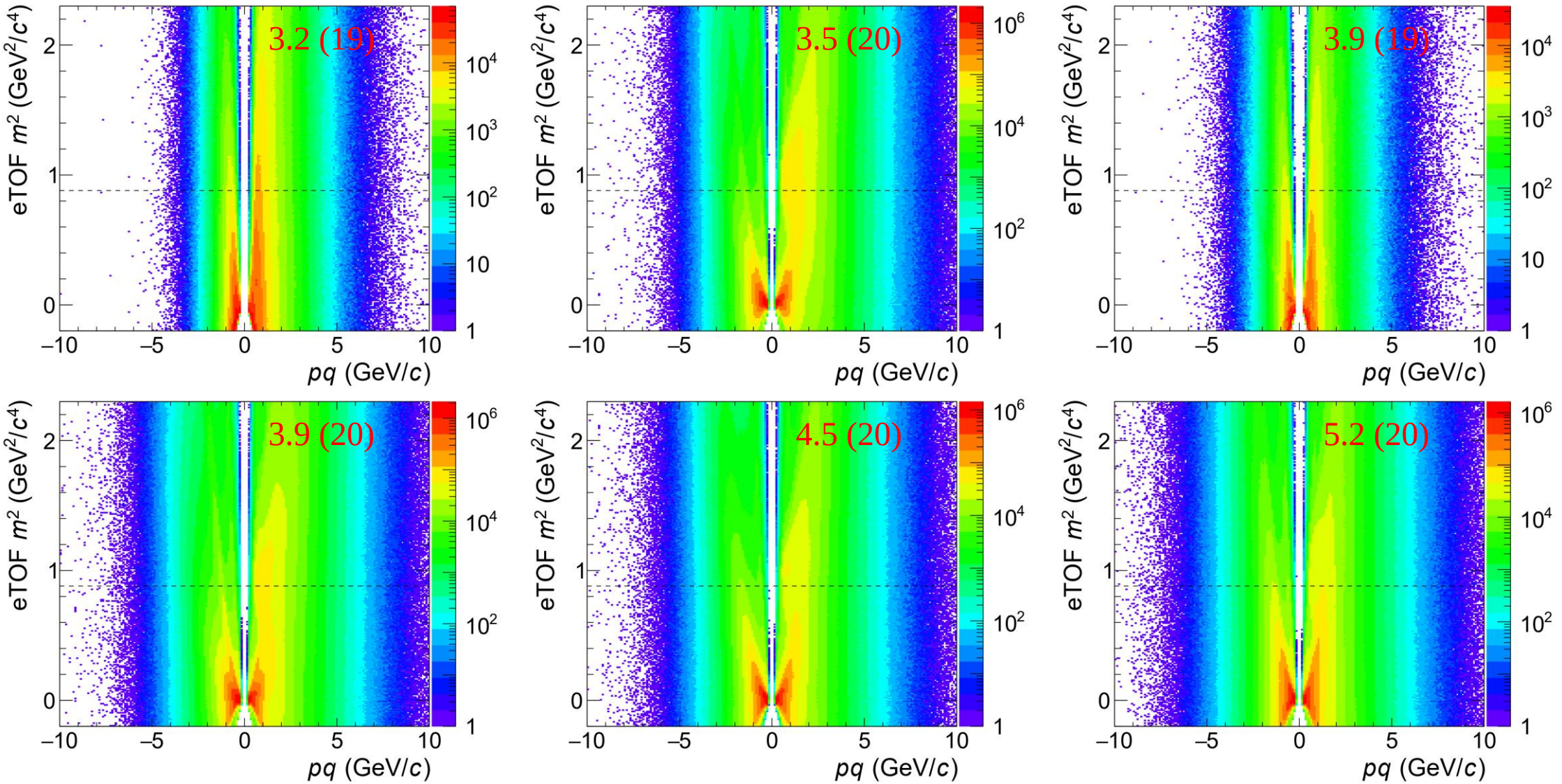




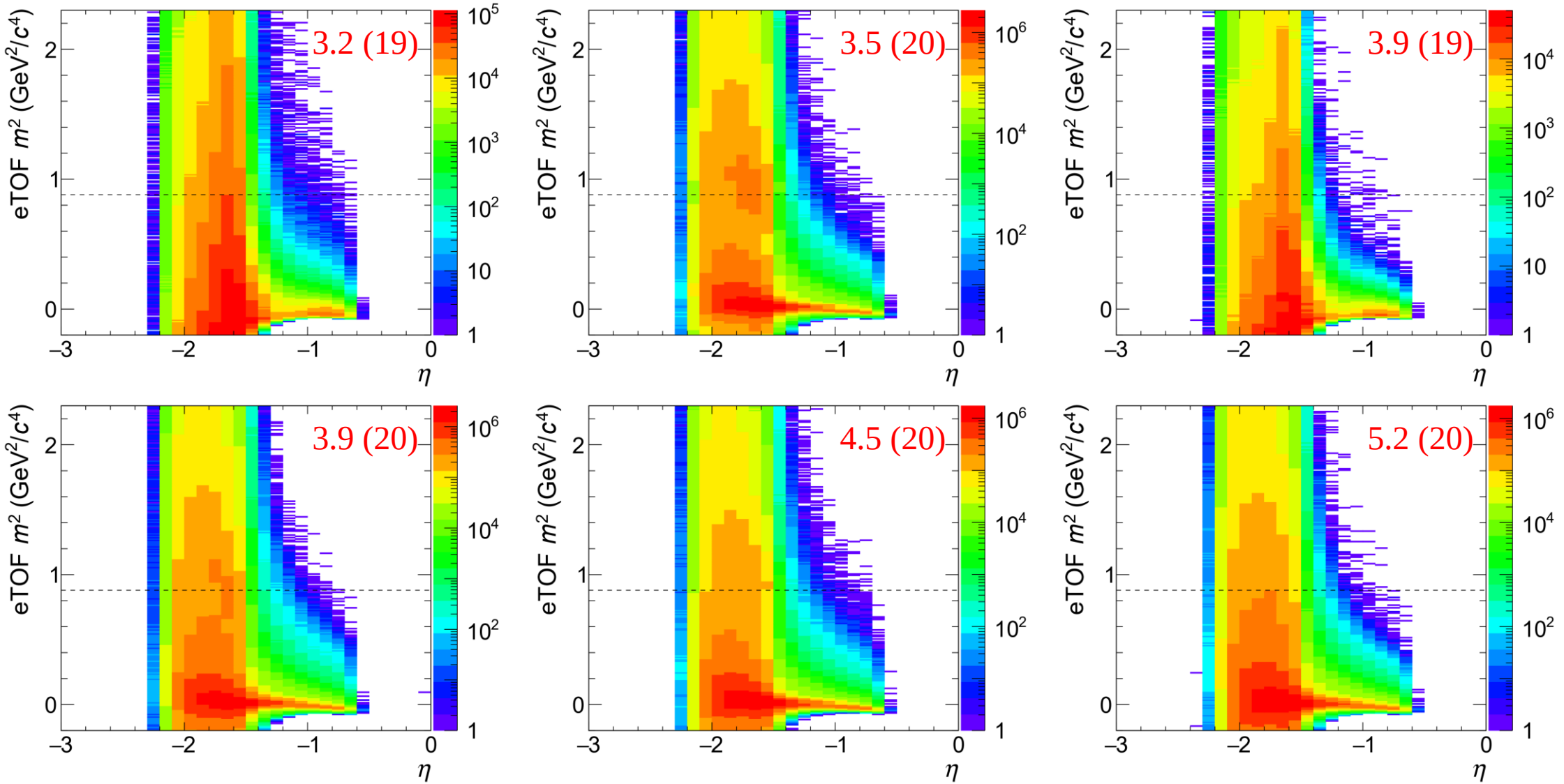




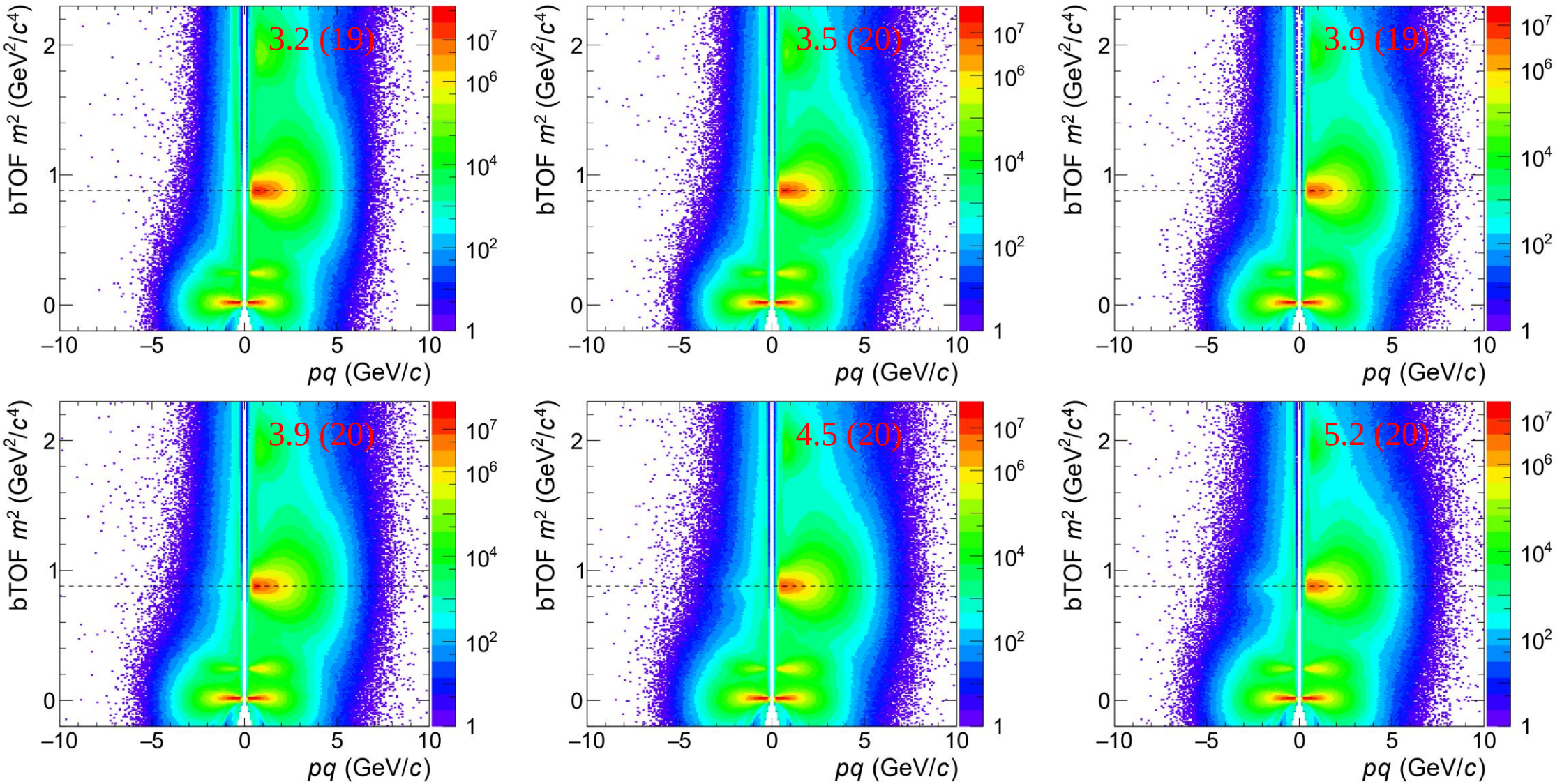
eTOF PID check



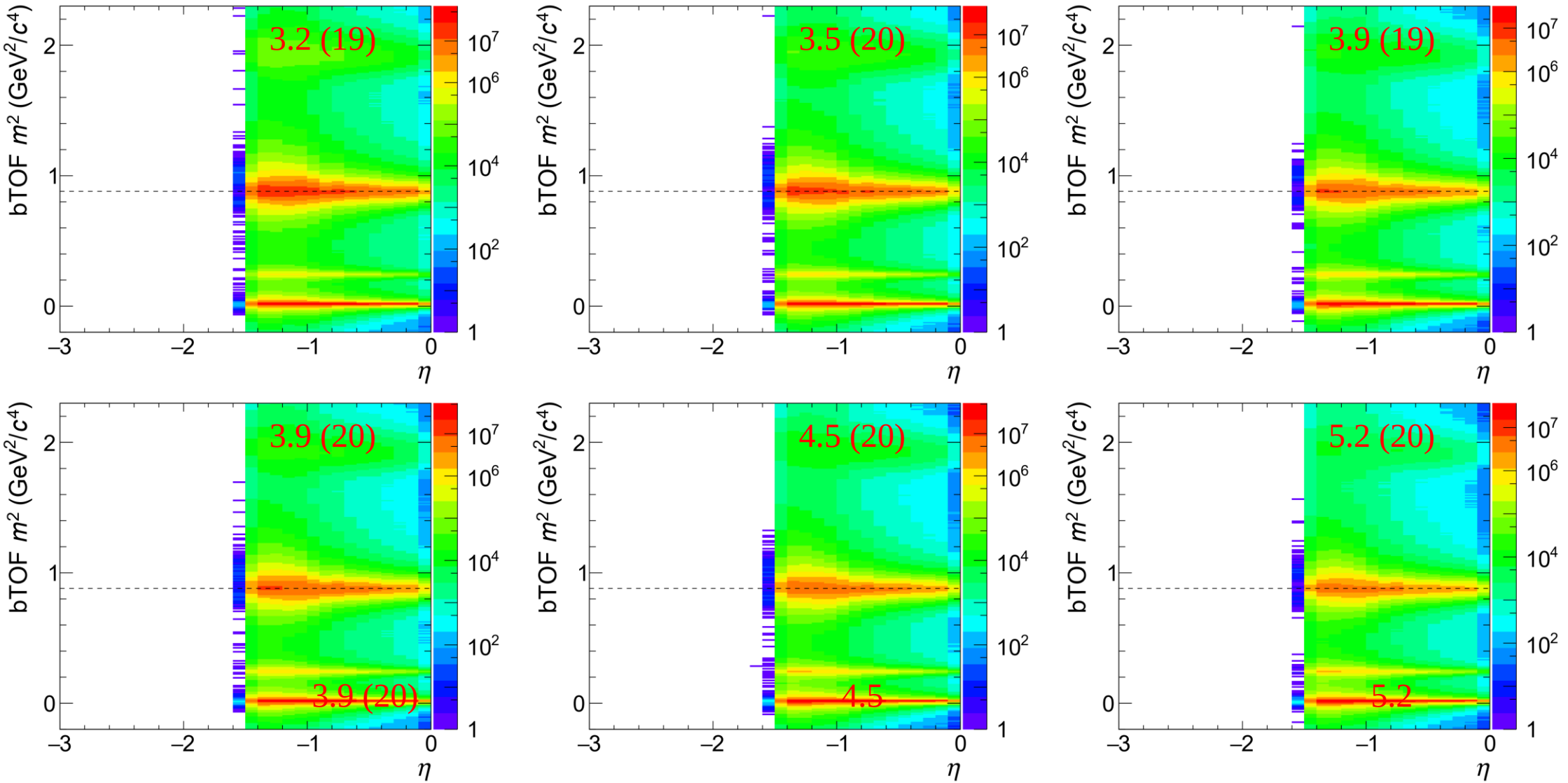
eTOF PID check



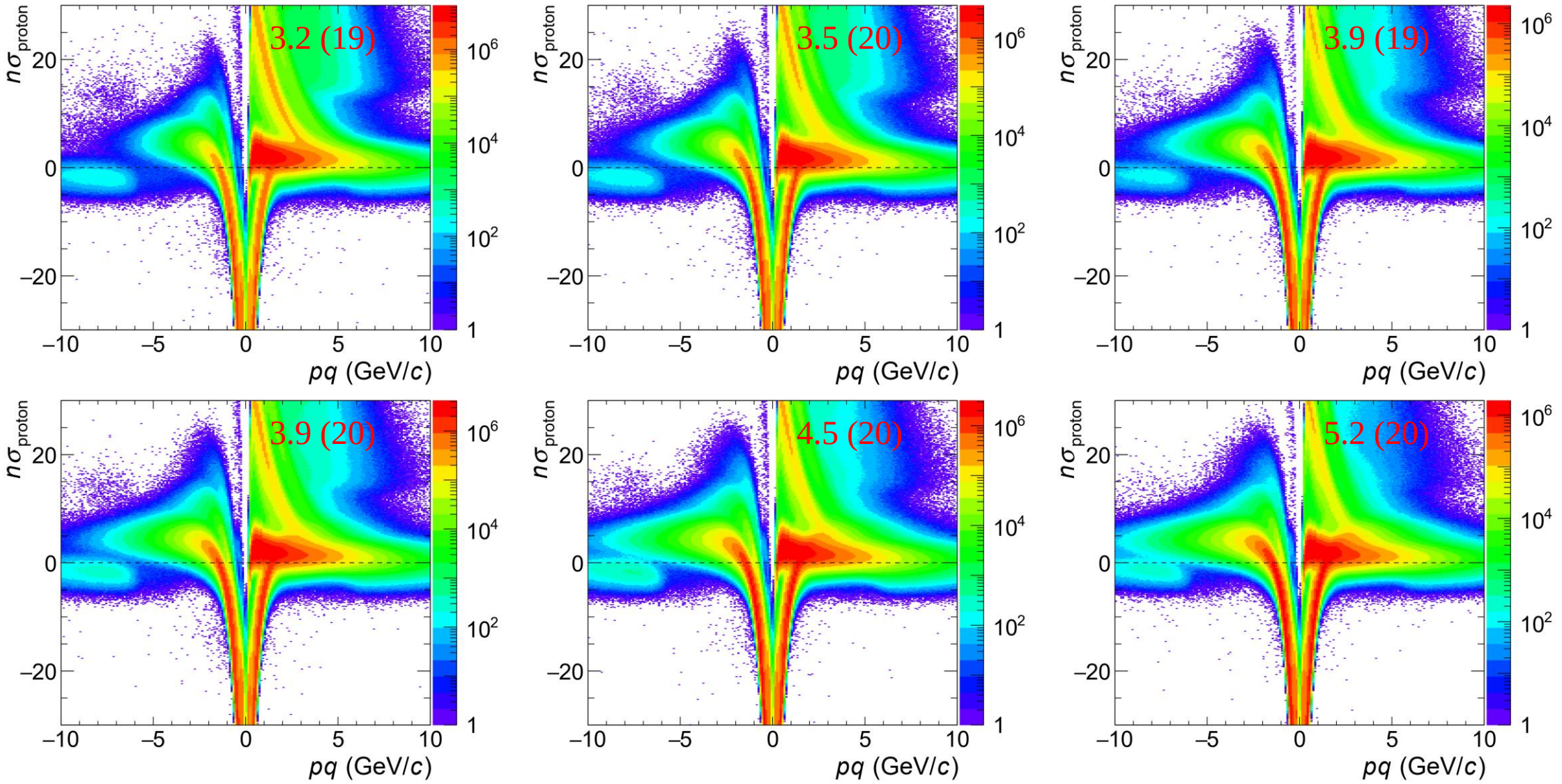
bTOF PID check



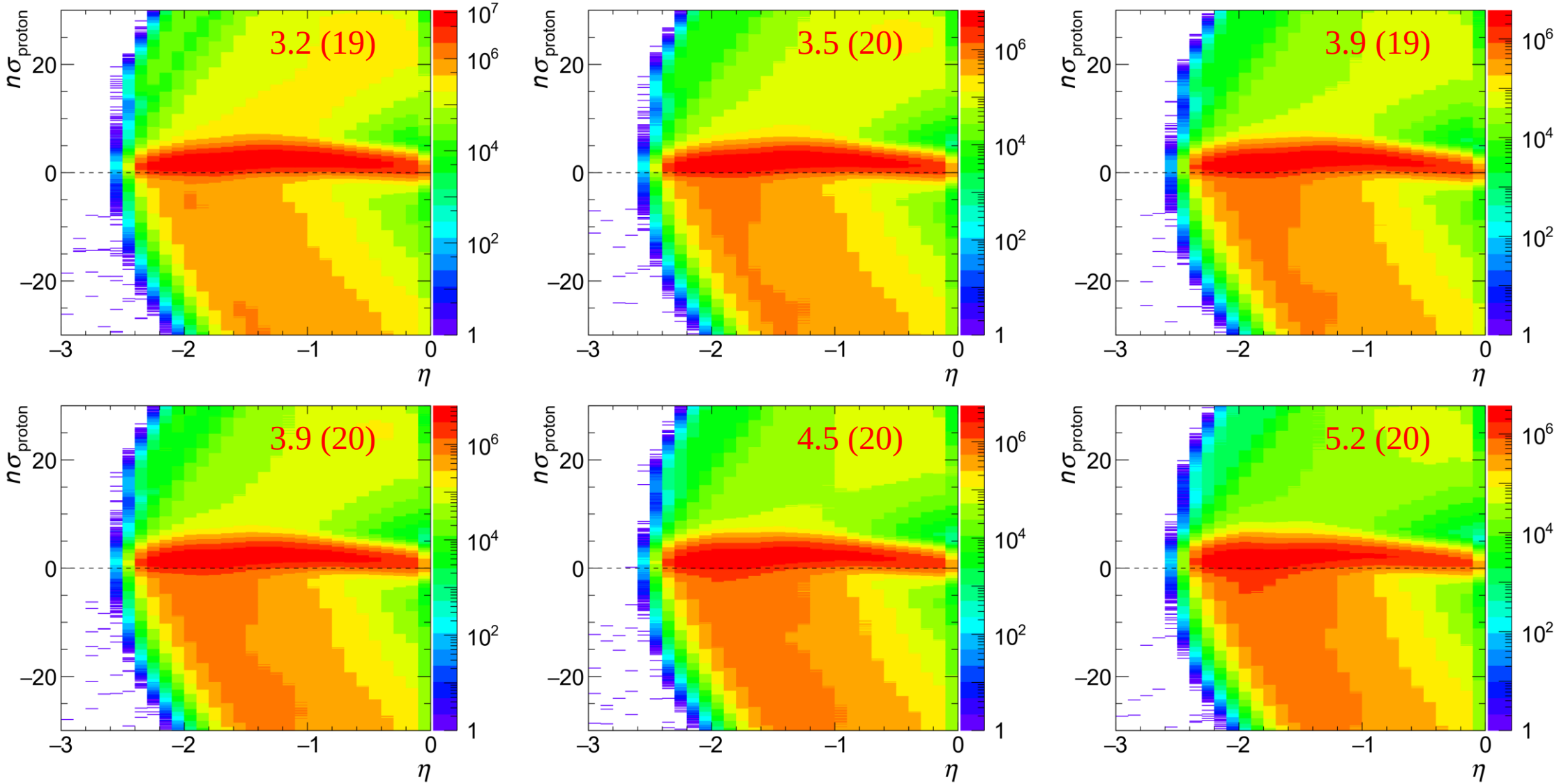
bTOF PID check



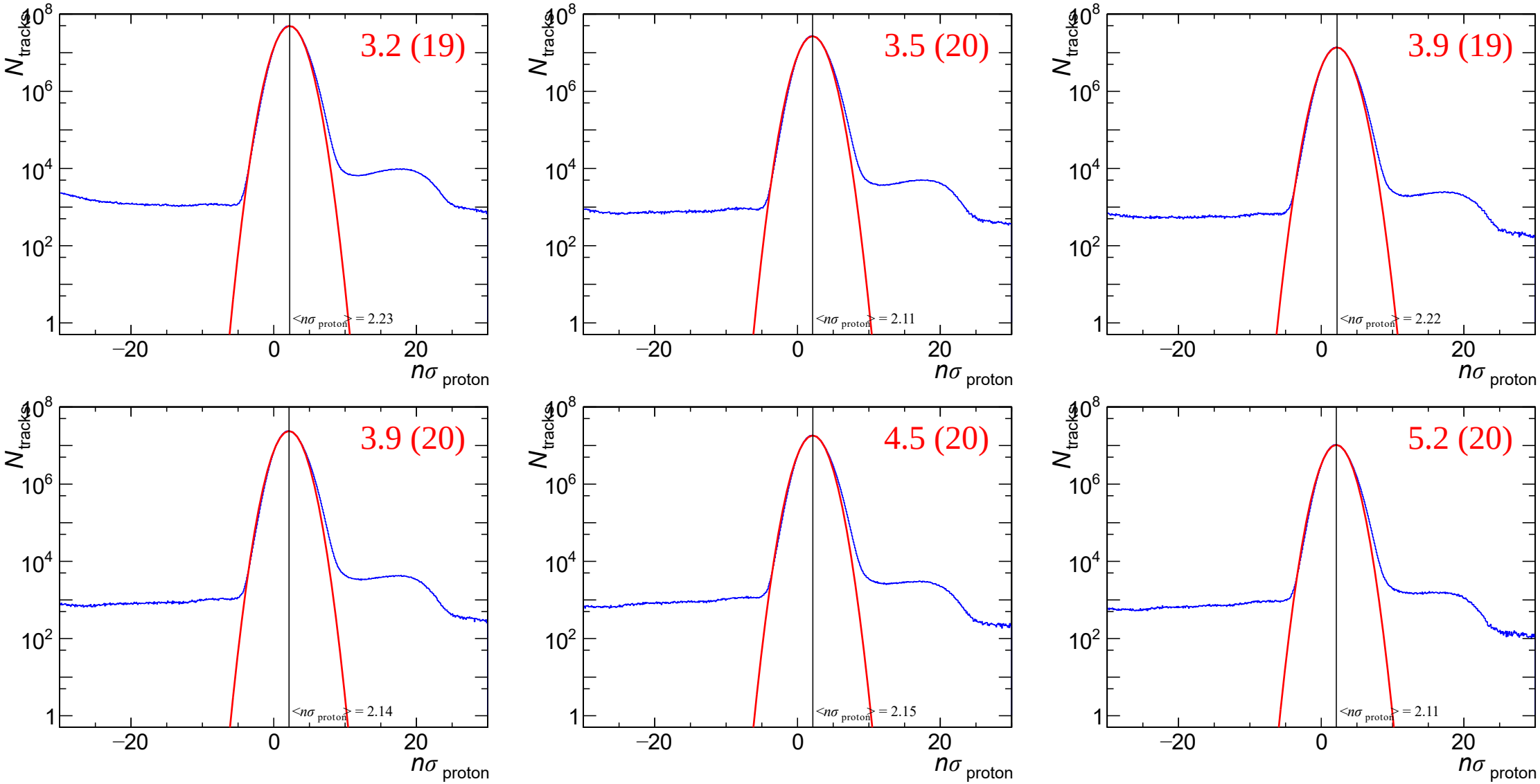
TPC PID check



TPC PID check



TPC PID recalibration (0.73 < bTOF m^2 < 1.03)



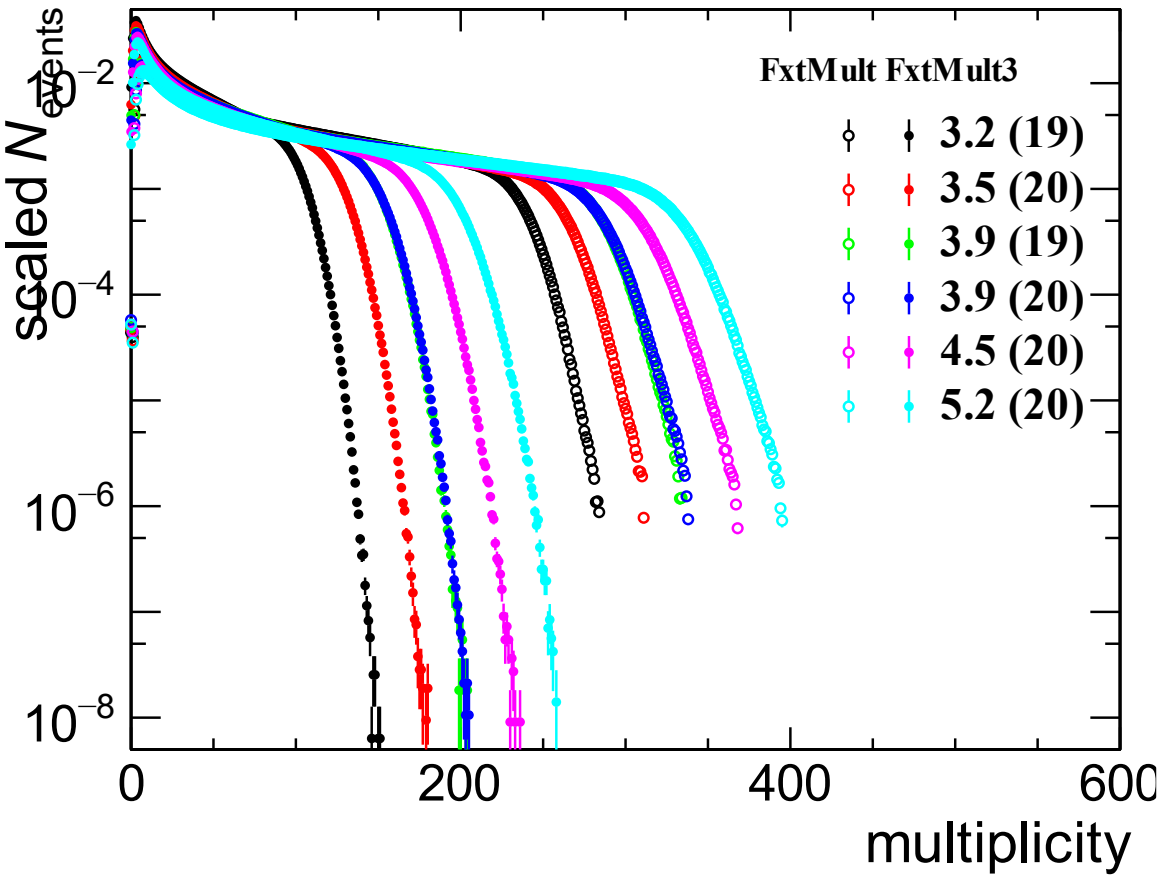
TPC PID recalibration

- Facts
  - η-dependence of $<n\sigma_p>$ and proton purity
  - Full acceptance required for FxtMult3 definition

- Difficulties
  - If only p-dependence considered
    - Suppose $<n\sigma_p> = -1$ & 1 in two η ranges (= 0 in full η range), $|n\sigma_p| < 2$ causes lower yield
  - If bTOF used for PID
    - Only $-1.5 < \eta < 0$ covered, η dependence contribution lost
  - If multi-Gaussian fit in each p-η bin
    - At mid-p (~ 1.5 GeV/c), π and p peaks merged
    - At high-p (> 3 GeV/c), p and d peaks merged
    - For 3.2 GeV, p_{max} = 3.67 GeV/c even only in analyzed acceptance (p_T = 2 GeV/c & y_{lab} = 0)
    - For 5.2 GeV, p_{max} = 6.06 GeV/c (and $\eta = -1.77$ out of bTOF coverage)

Centrality definition

- FxtMult3 definition (according to RefMult3 in StPicoDstMaker/StPicoUtilities.h)
  - Basic cuts: primary, $p > 0.1$ GeV/c, Dca < 3 cm, nHitsFit ≥ 10
  - Proton exclusion (hybrid)
    - $n\sigma_p - 2.2 < -3$ (constantly shifted)
    - bTOF $m^2 < 0.4$ GeV$^2/c^4$
      - Unavailable bTOF $m^2 = -999$



Doing

- Glauber fit for FxtMult3

- Try to determine how to recalibrate TPC $n\sigma_{\mathrm{p}}$