Net-proton fluctuations at 3.5 GeV

Fan Si

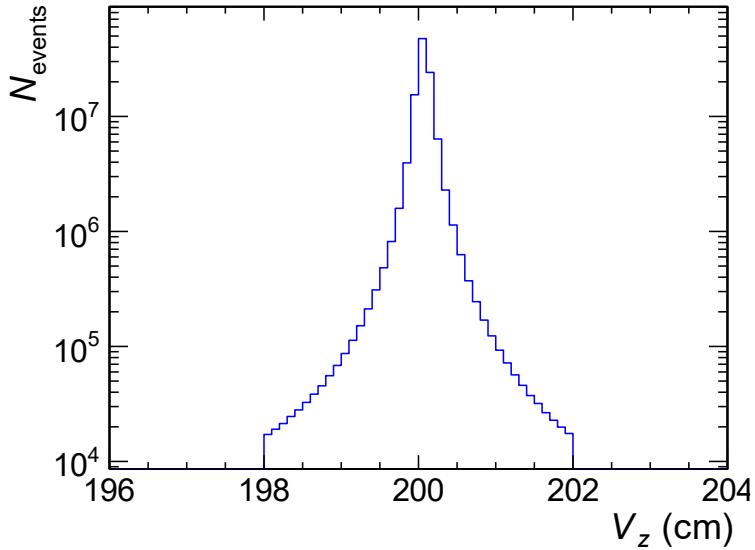
Apr. 18th, 2022

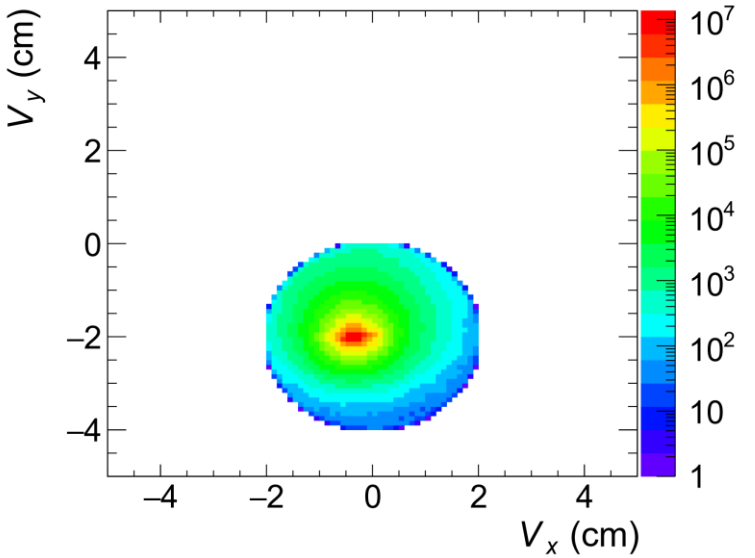
Dataset

- Au+Au @ 3.5 GeV (5.75 GeV FXT)

- Trigger setup: production_5p75GeV_fixedTarget_2020
- Stream: st_physics(_adc)
- Production: P21id
- Library: SL21d

- Run ID: 20355020 − 21045011 (31 runs)
- Events: 1.25×10^8

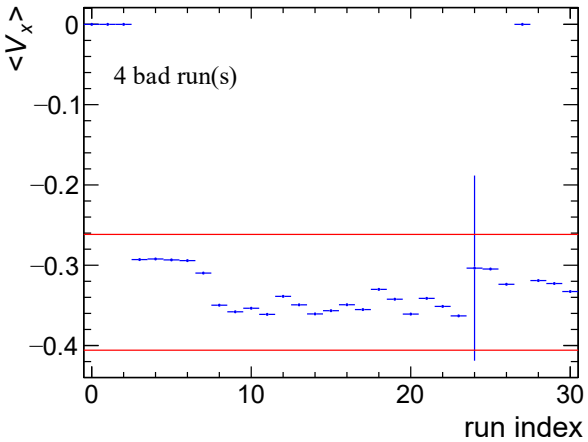


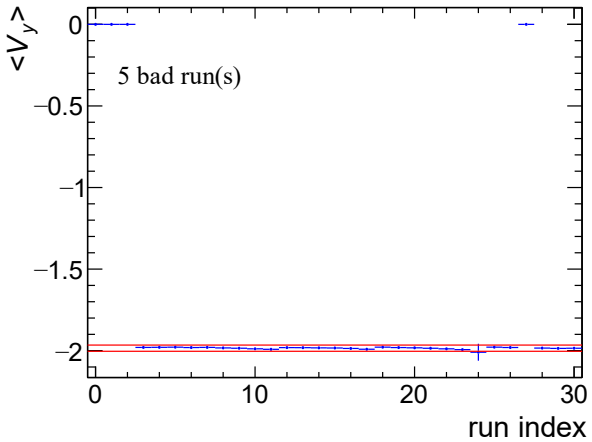


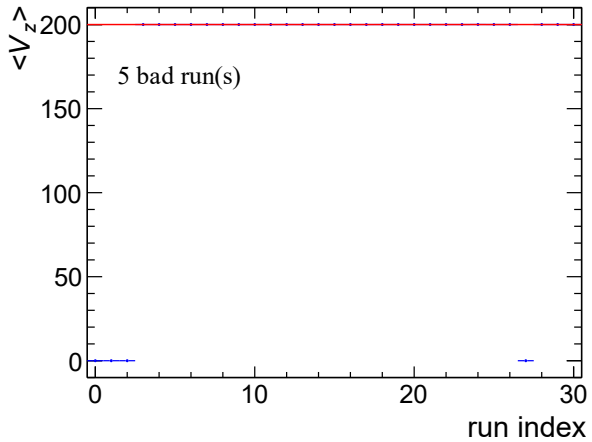
Run-by-run QA cuts

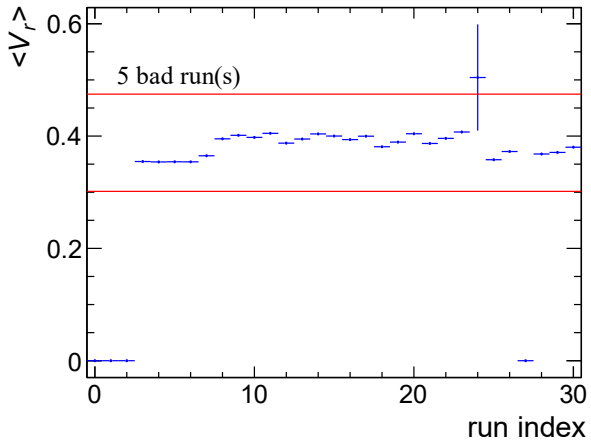
- Trigger ID
  - 720007 (epde-or-bbce-or-vpde-tof1-etof)
- Event cuts:
  - 198 cm < V_z < 202 cm
  - $|V_r|$ < 2 cm, with center (0, −2) cm
- Track cuts
  - Primary
  - |gDca| < 3 cm
  - nHitsFit > 10
  - nHitsFit/nHitsPoss > 0.52
  - nHitsDedx > 5
- Remove empty bins and 3-σ outliers
- Empty bins are not taken into account in σ calculation
- Bad run ID [7]: 20355020, 20355021, 21044023, 21044027, 21044031, 21045005, 21045008

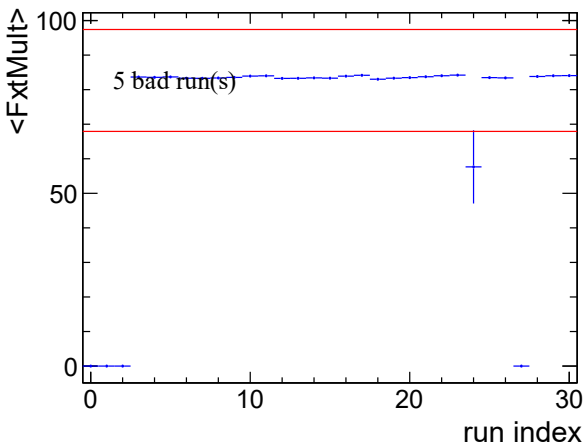
Run-by-run QA plots

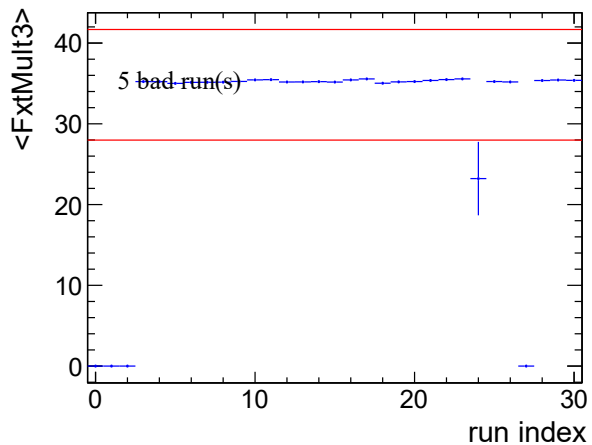


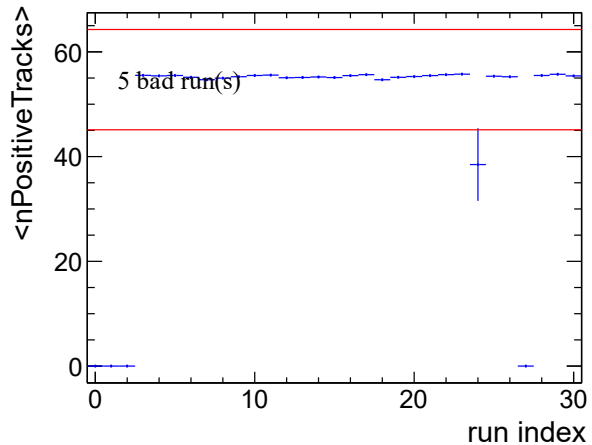


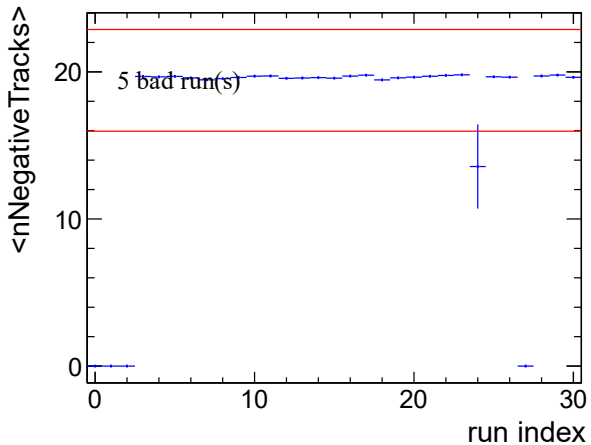




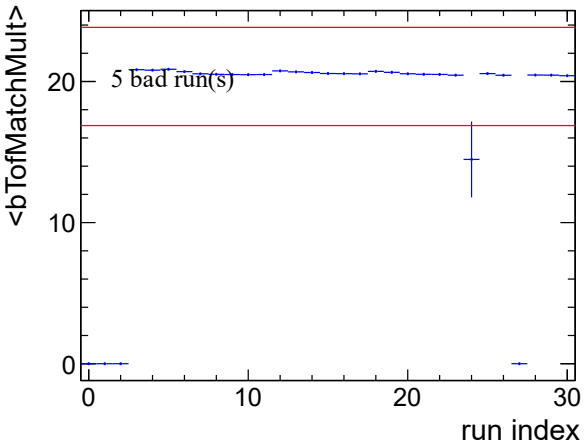


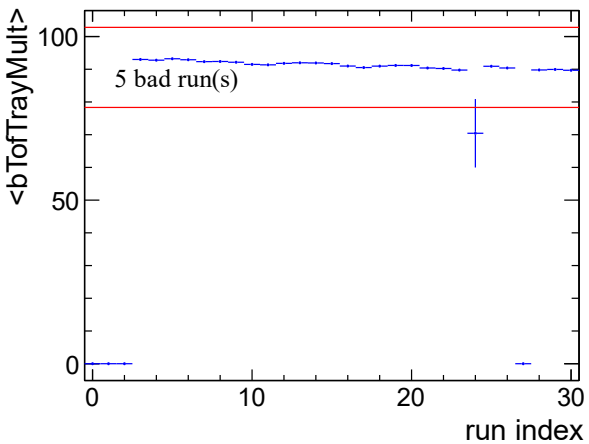


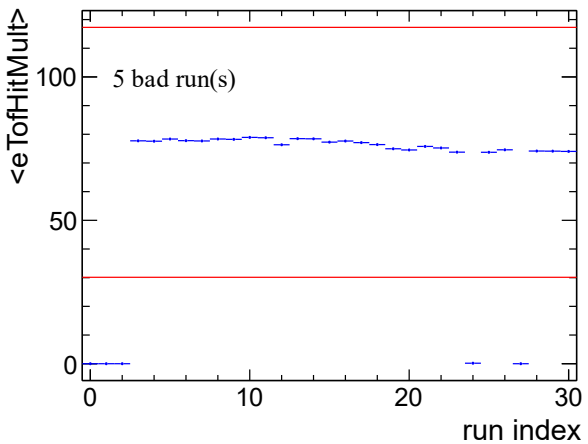


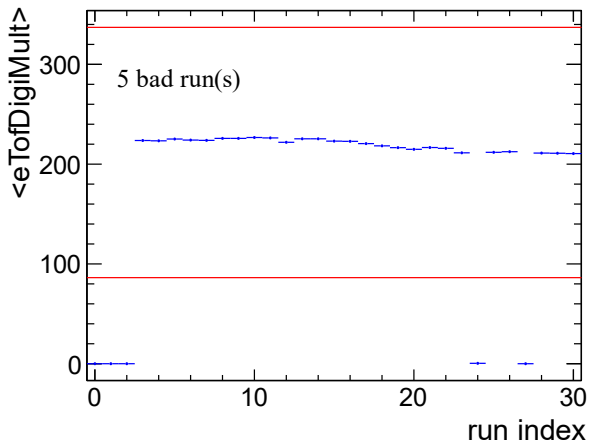


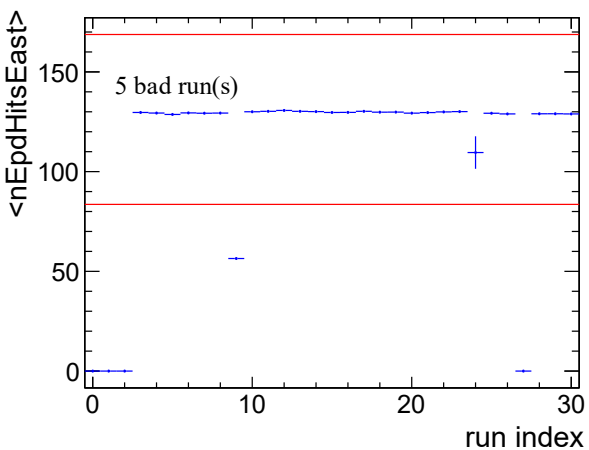
Run-by-run QA plots

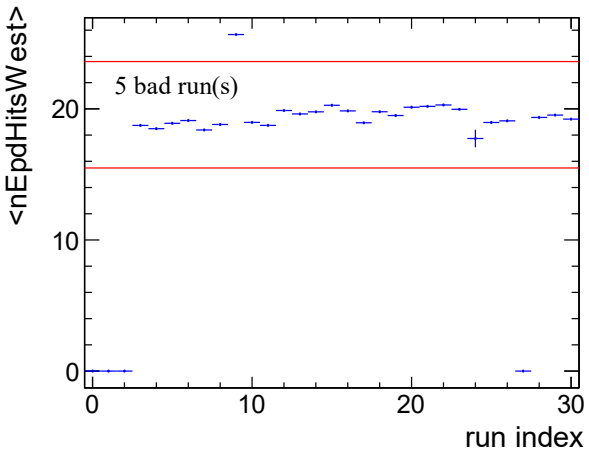


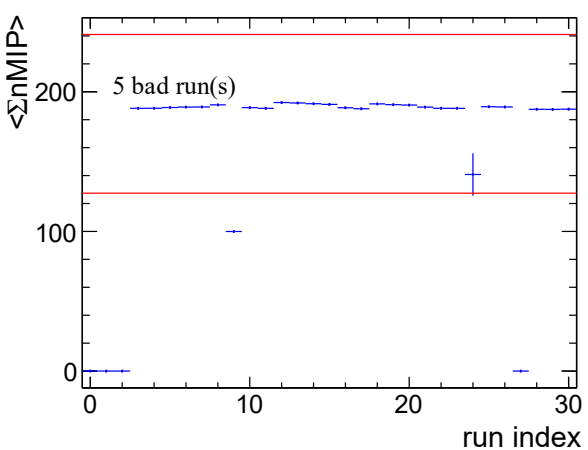


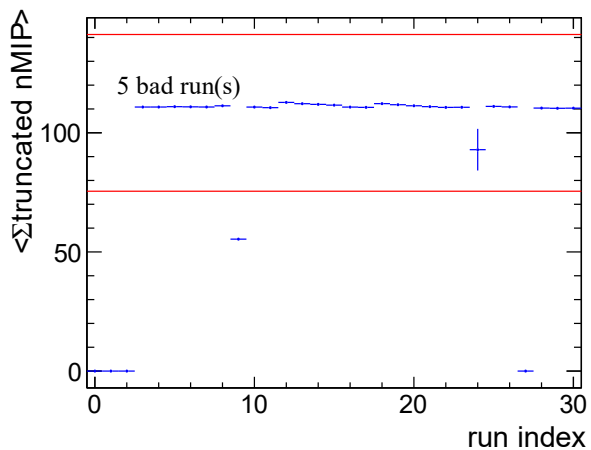




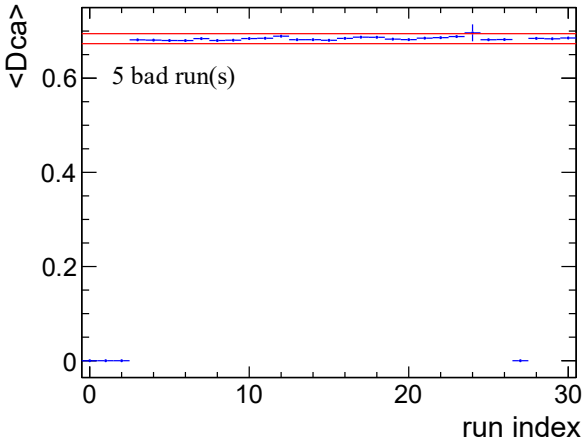


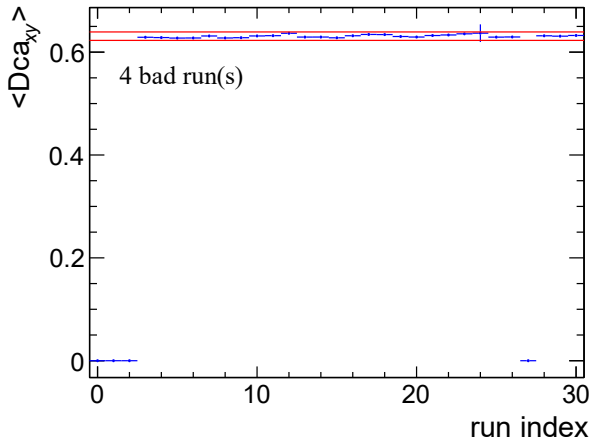


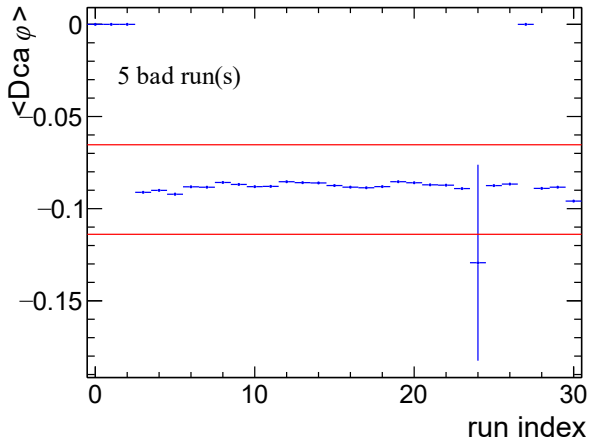


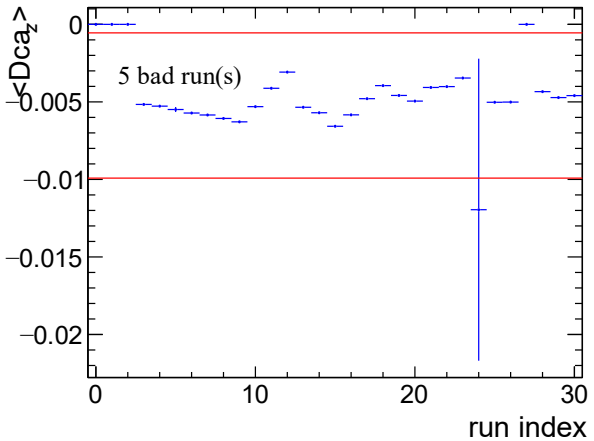


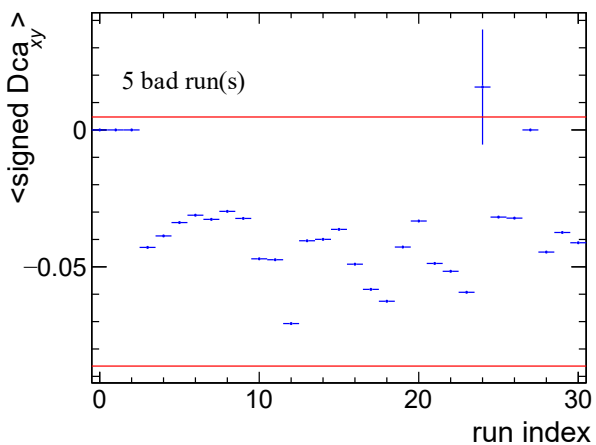
Run-by-run QA plots

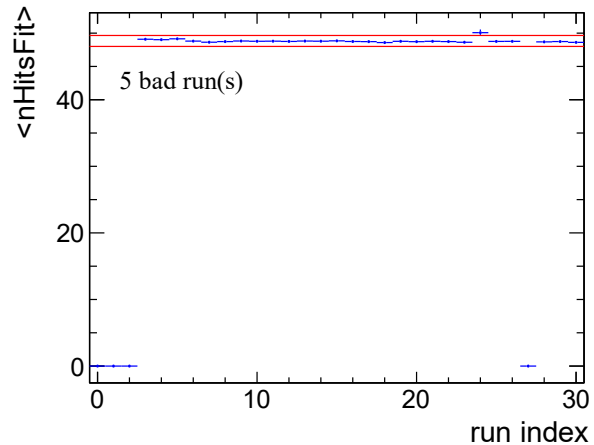


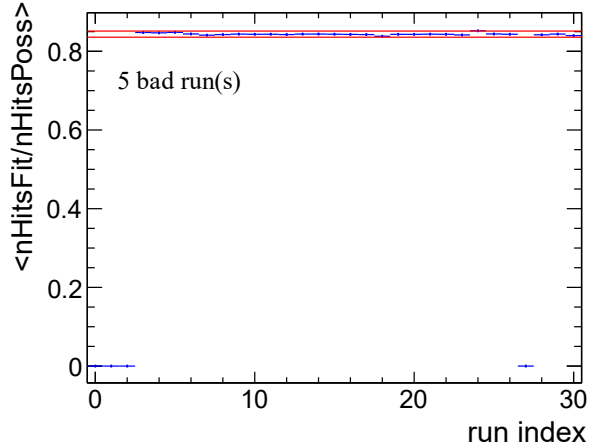


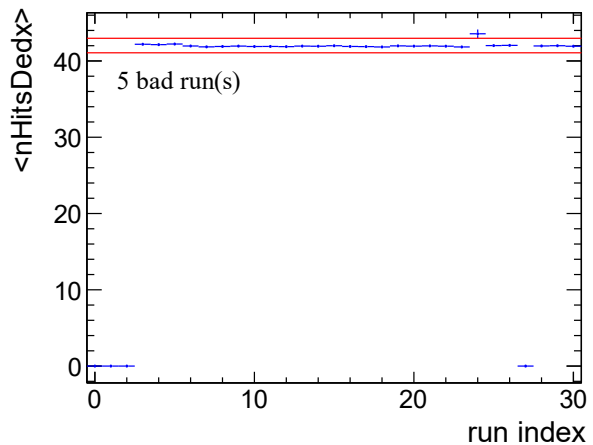




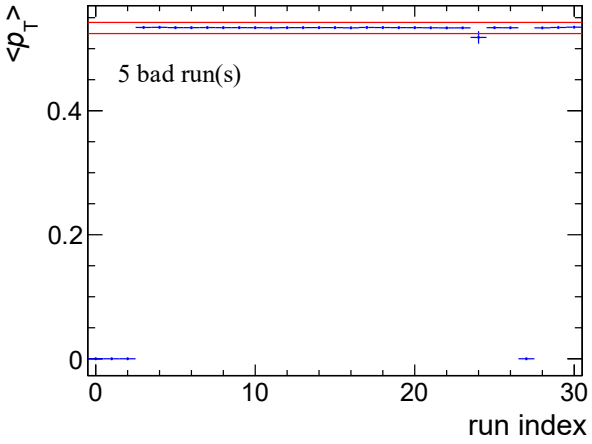


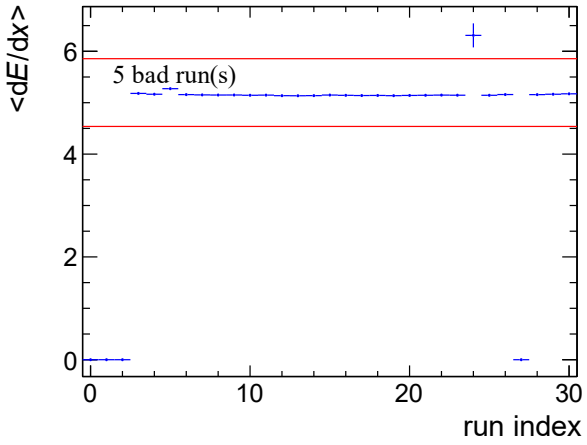


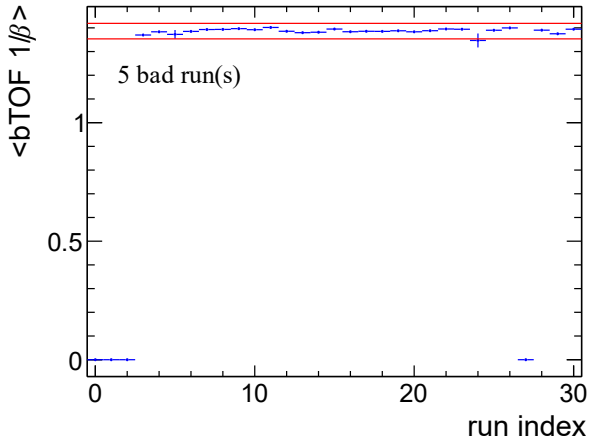


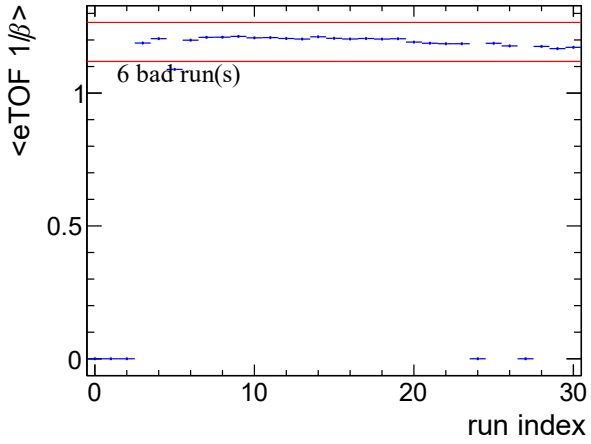


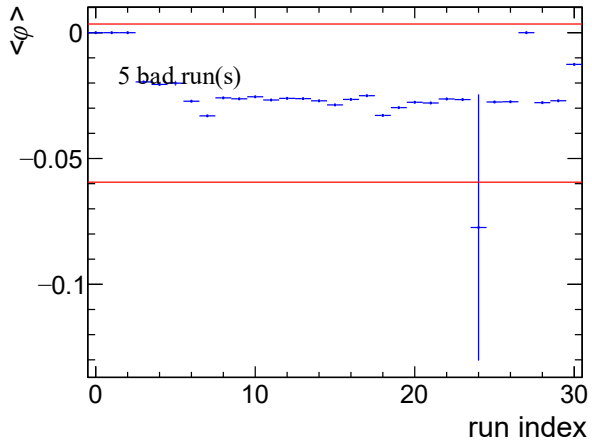
Run-by-run QA plots

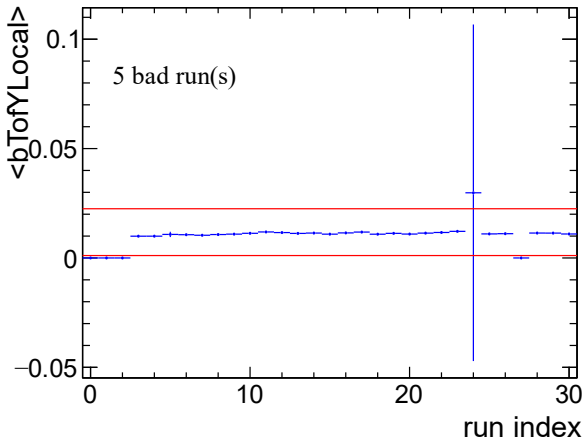


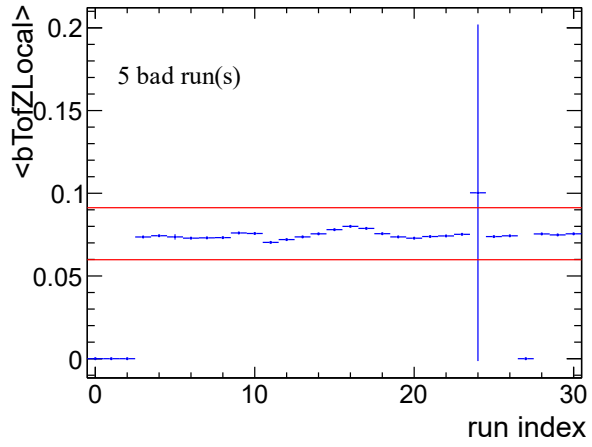


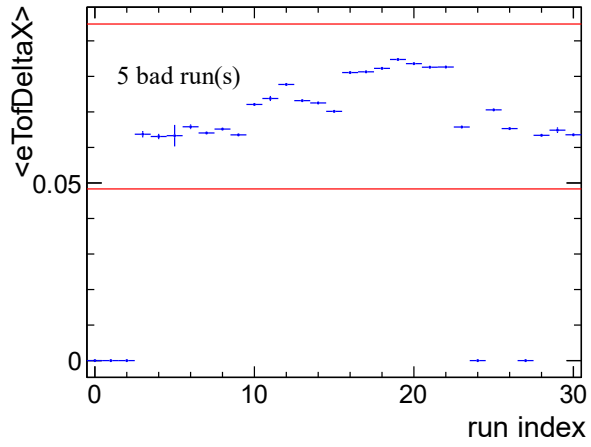


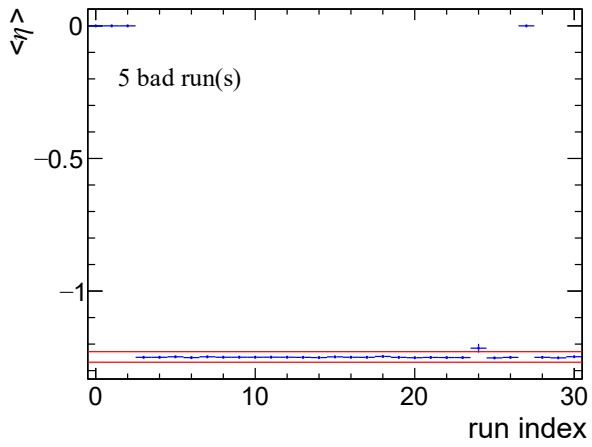


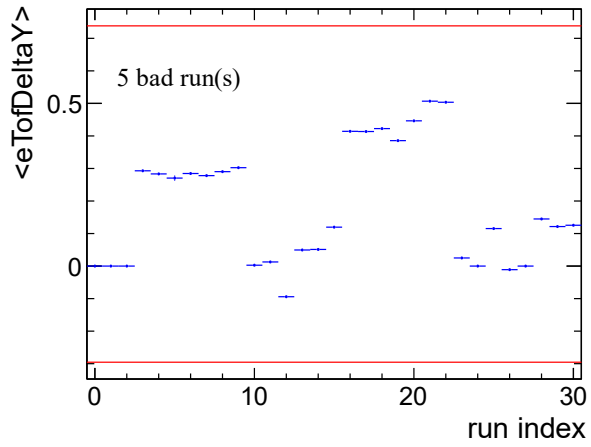








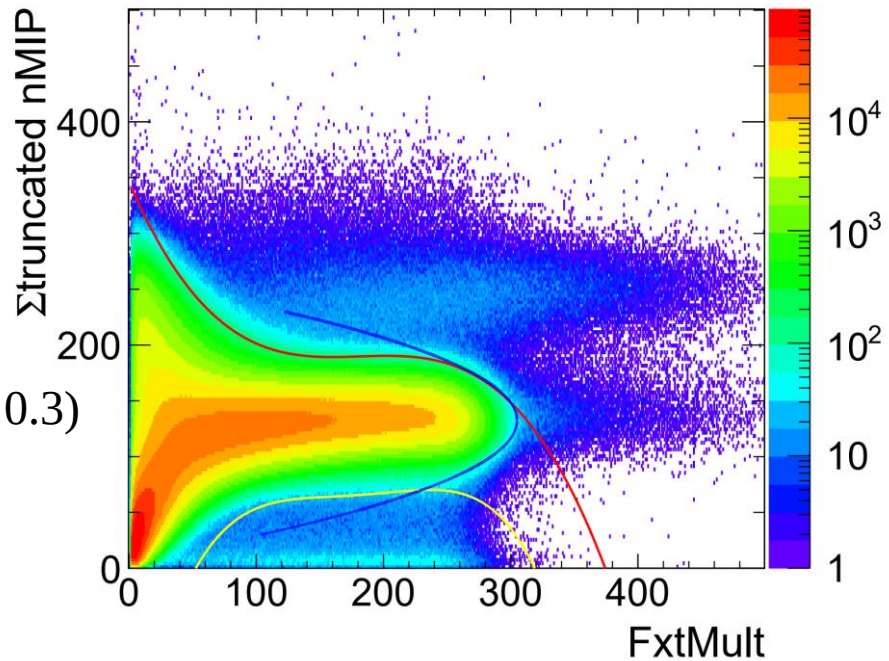




Pileup event rejection

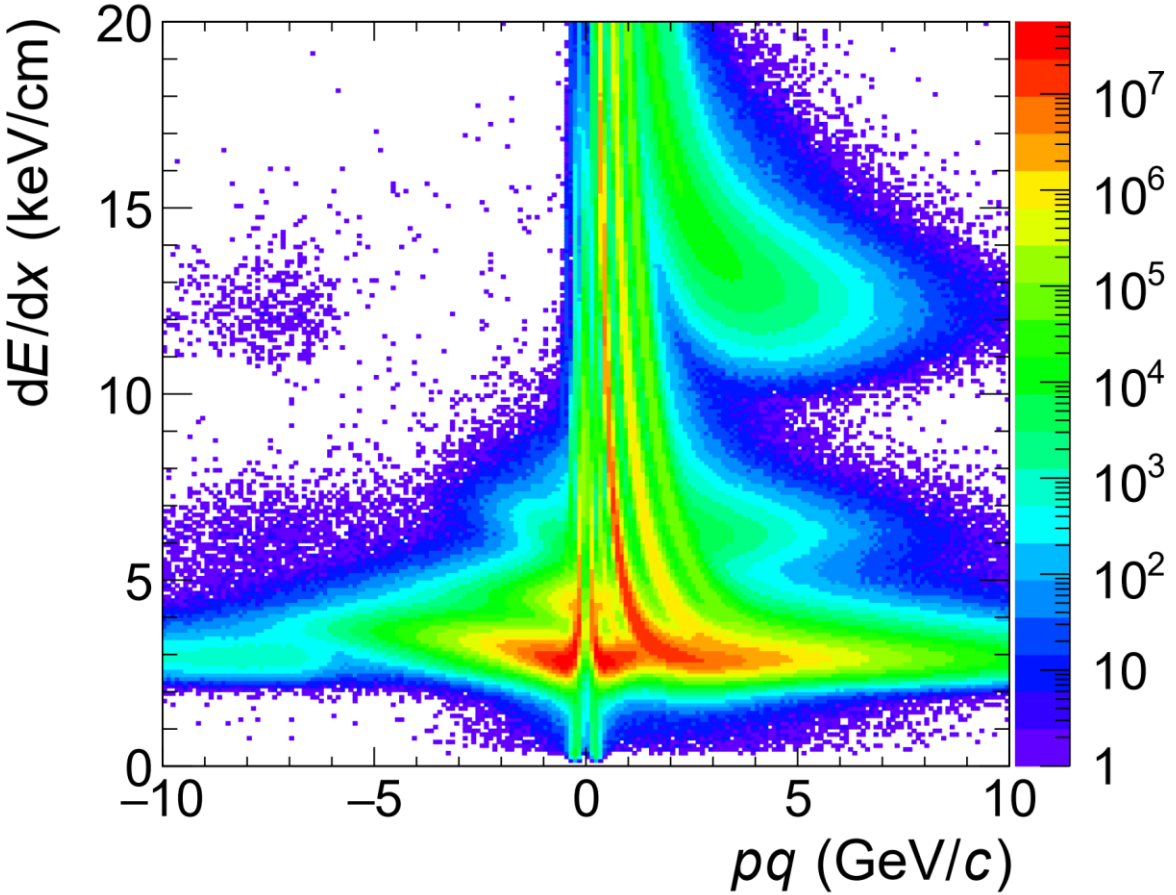
- (Red) ΣTnMIP < pol3(FxtMult): 3.463507e+02, −2.667239e+00, 1.492184e−02, −2.743280e−05
- (Yellow) ΣTnMIP > pol4(FxtMult): −1.932547e+02, 5.780245e+00, −4.894189e−02, 1.835858e−04, −2.539630e−07
- (Blue) FxtMult < [0]*TMath::Gaus(ΣTnMIP, [1], [2])+[3]: 9.394418e+04, 1.324599e+02, 1.563239e+03, −9.363926e+04, for FxtMult > 200

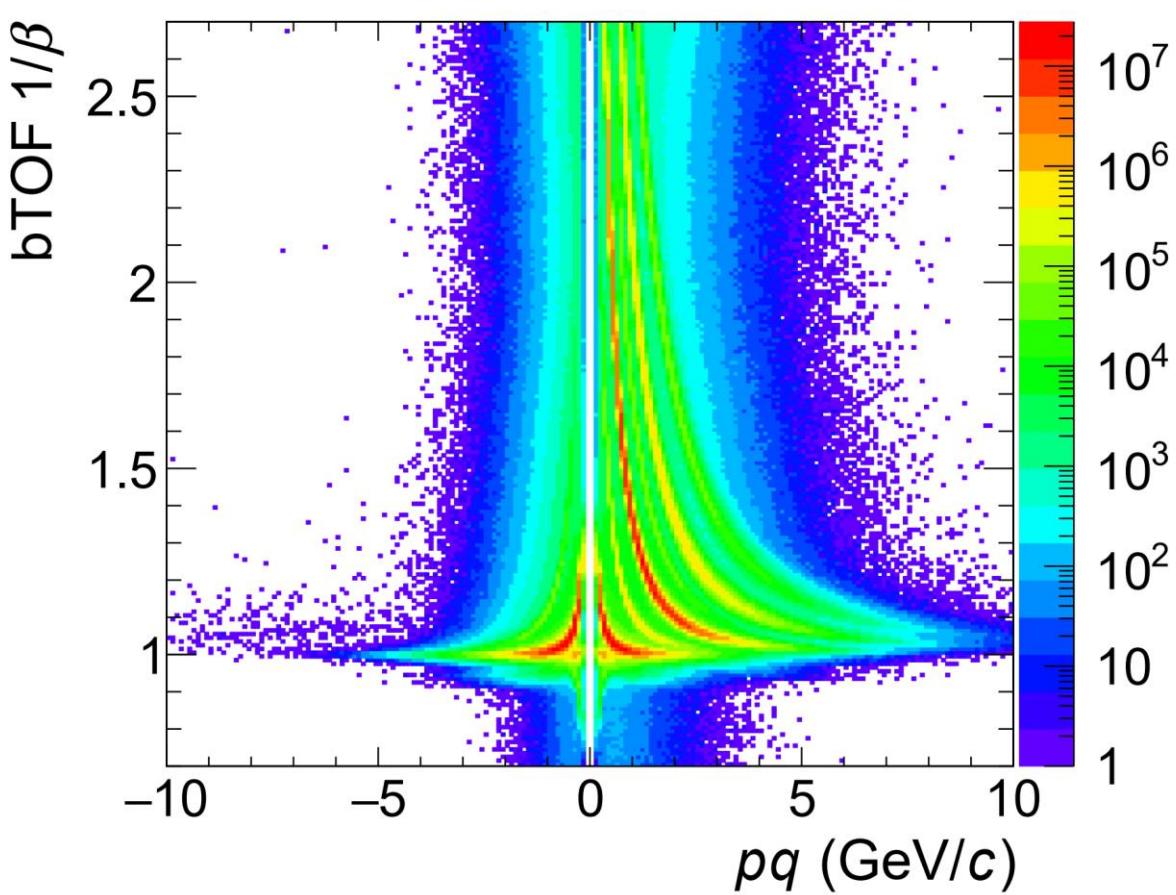
StPicoEpdHit−>TnMIP(2, 0.3)



PID plots

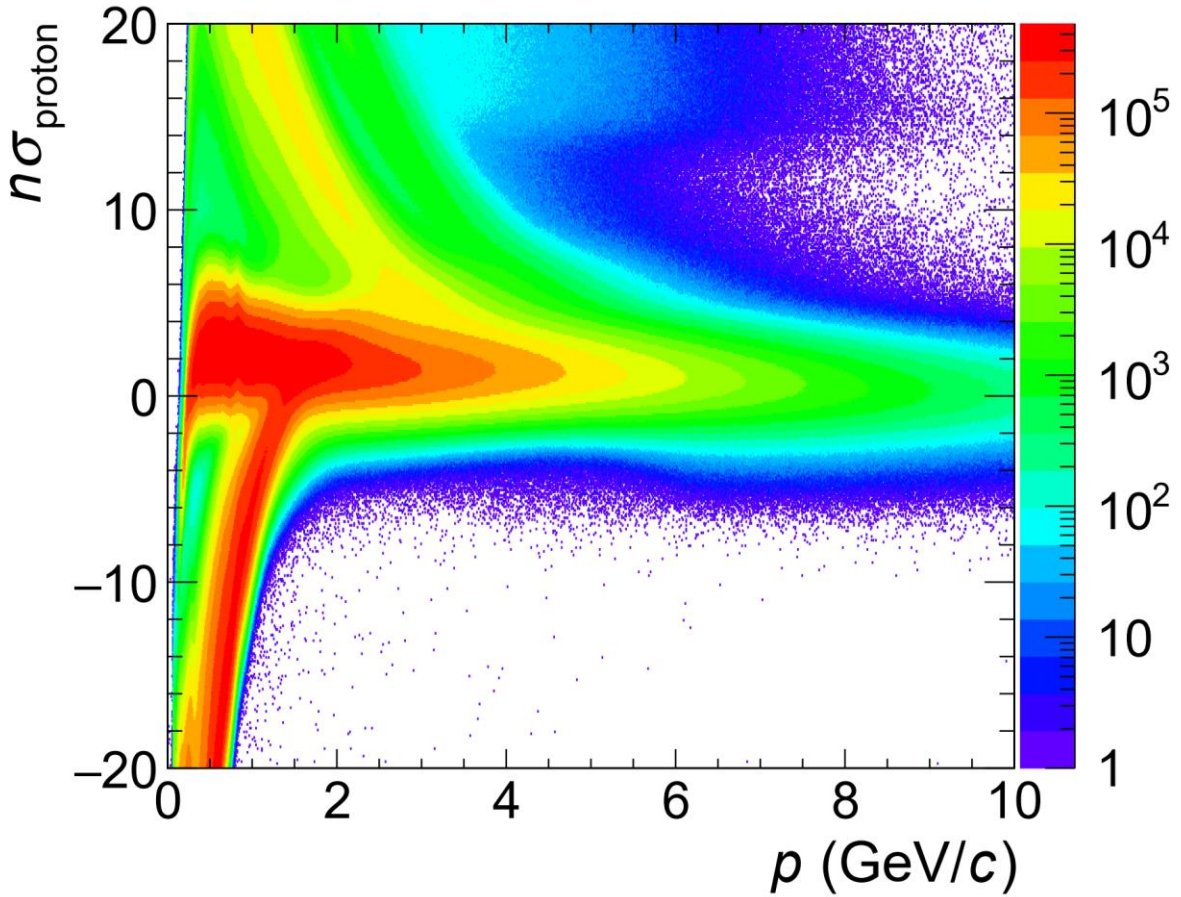
- TPC dE/dx
- bTOF $1/\beta$

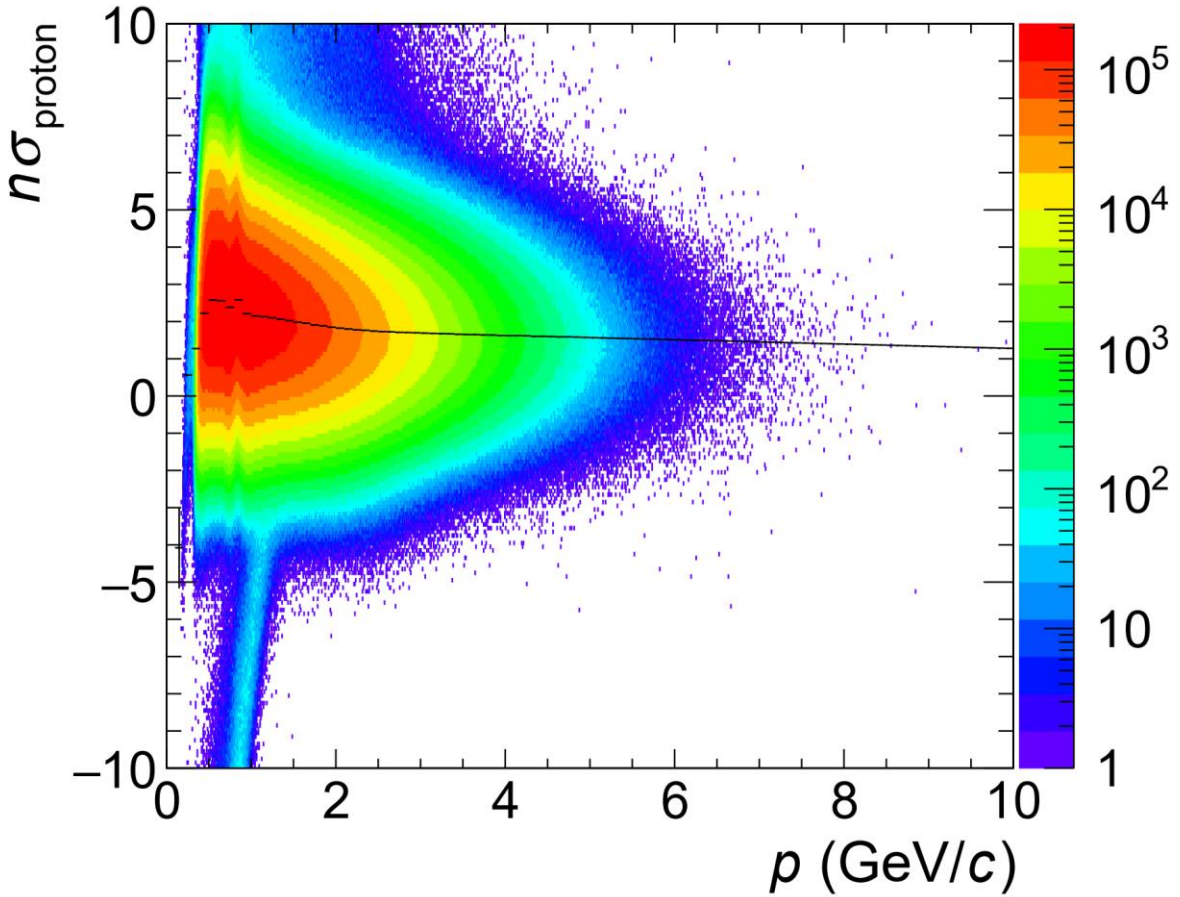




TPC PID check

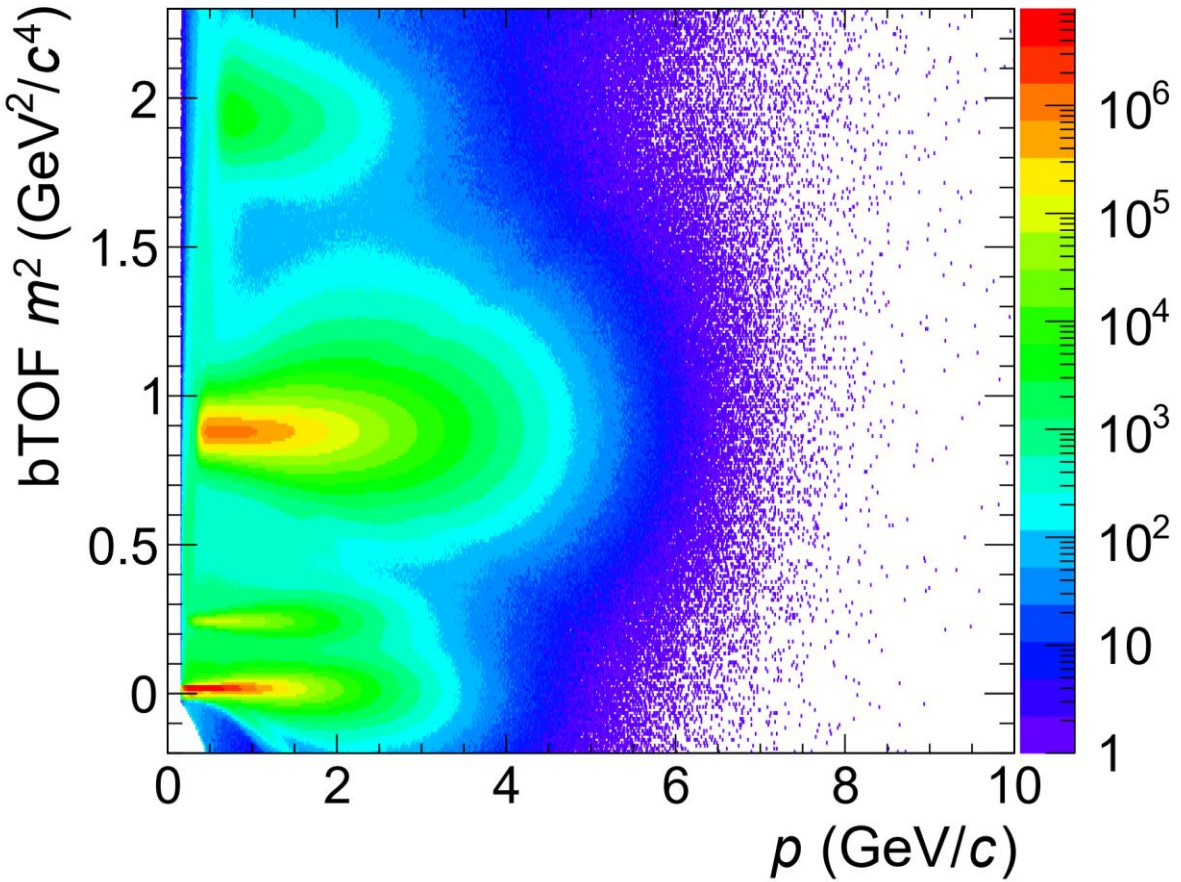
- No bTOF PID
- bTOF 0.73 GeV$^2/c^4$ < m^2 < 1.03 GeV$^2/c^4$
- Gaussian fit & <$n\sigma_{\text{proton}}$> shift in p bins

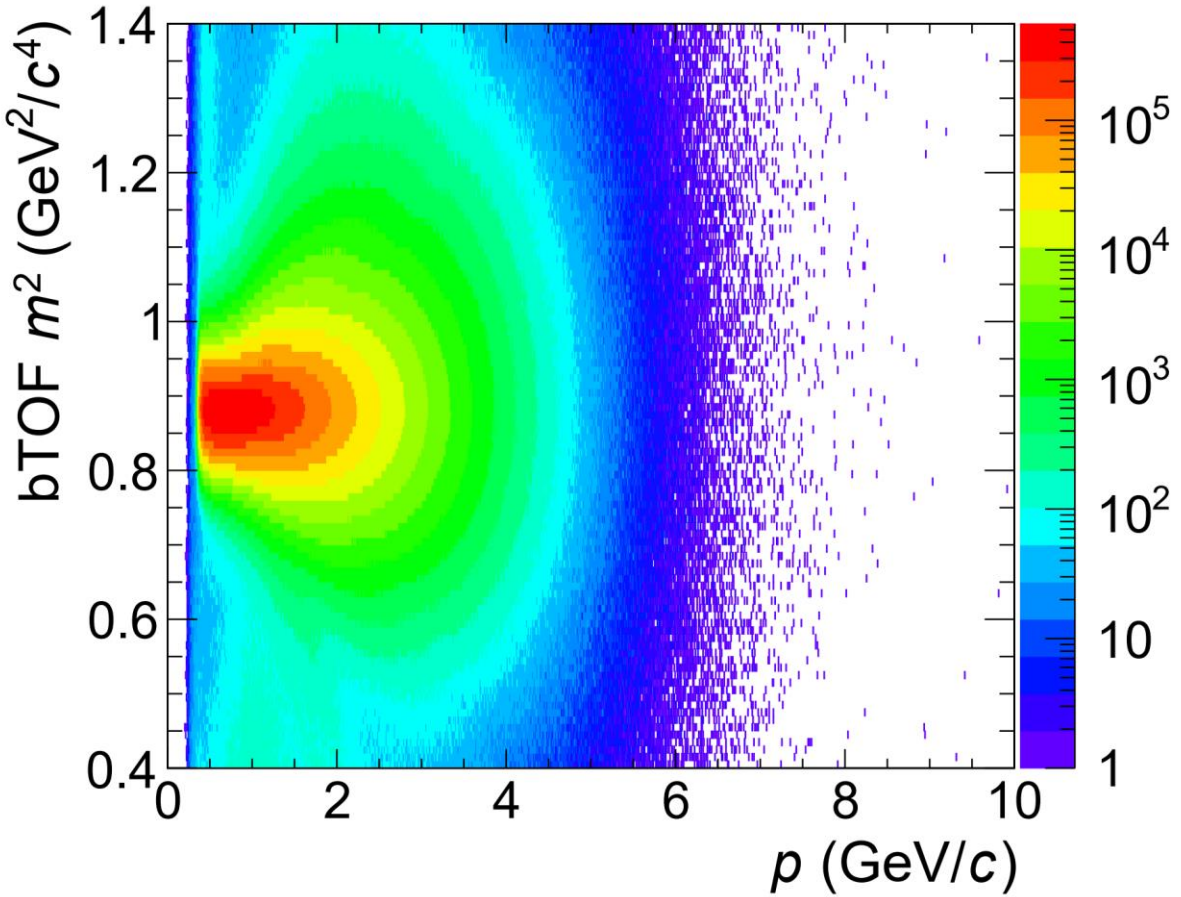




bTOF PID check

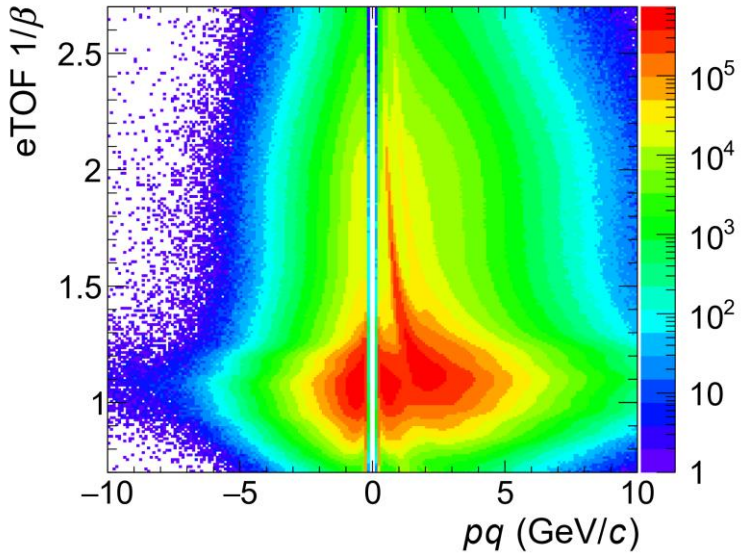
- No TPC PID
- TPC $|n\sigma_{\text{proton}} - 2.15| < 1$
- No mean shift required

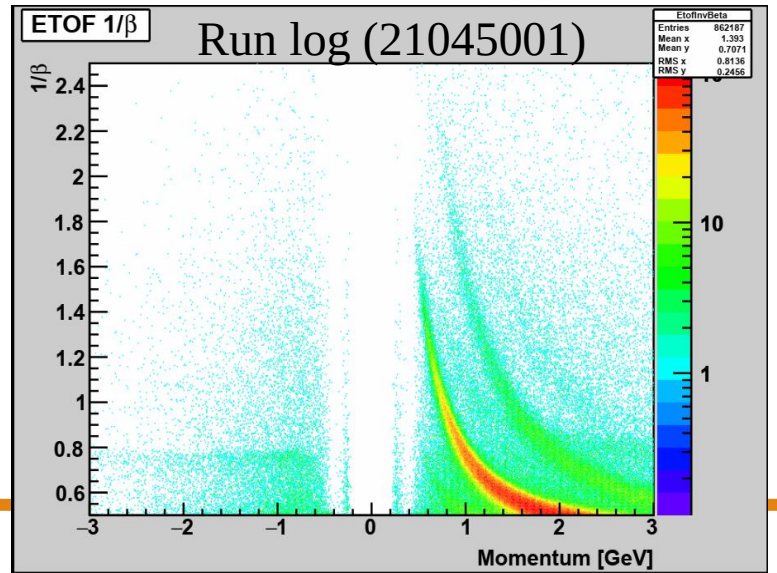




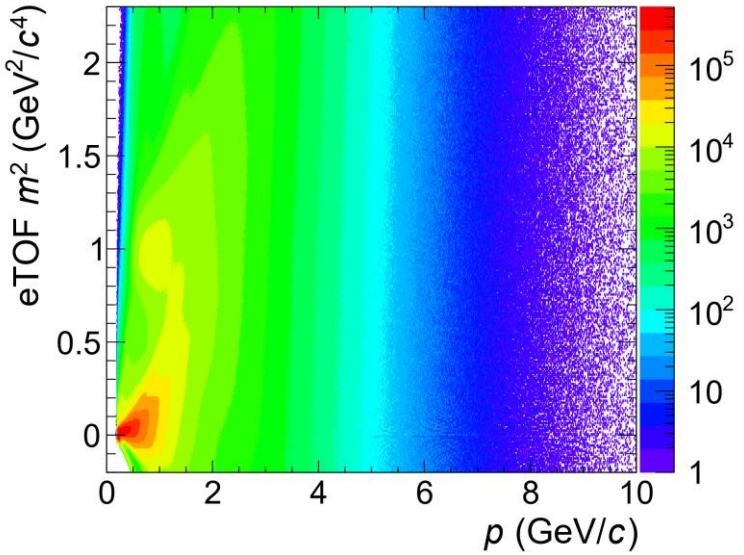
eTOF PID check

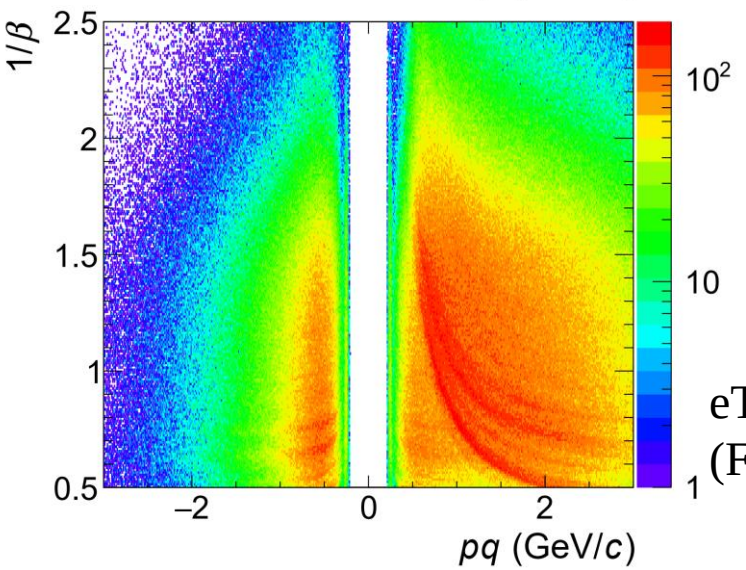
- No TPC PID



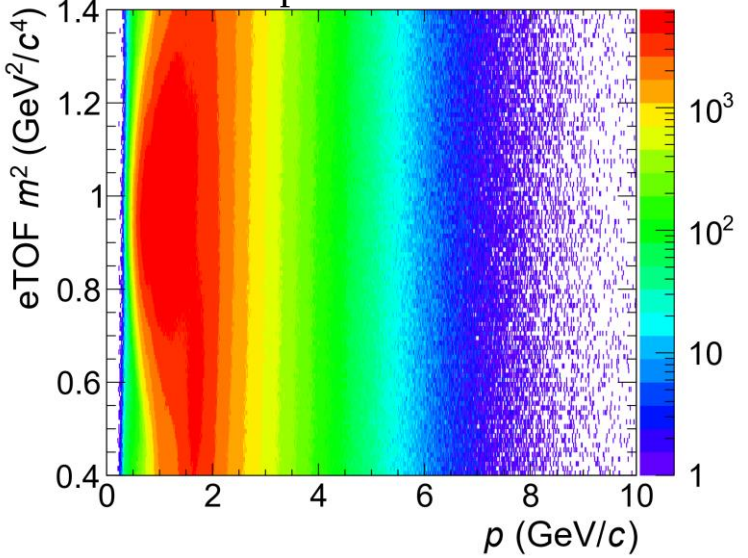


- No TPC PID





- TPC $|n\sigma_{\text{proton}} - 2.15| < 1$

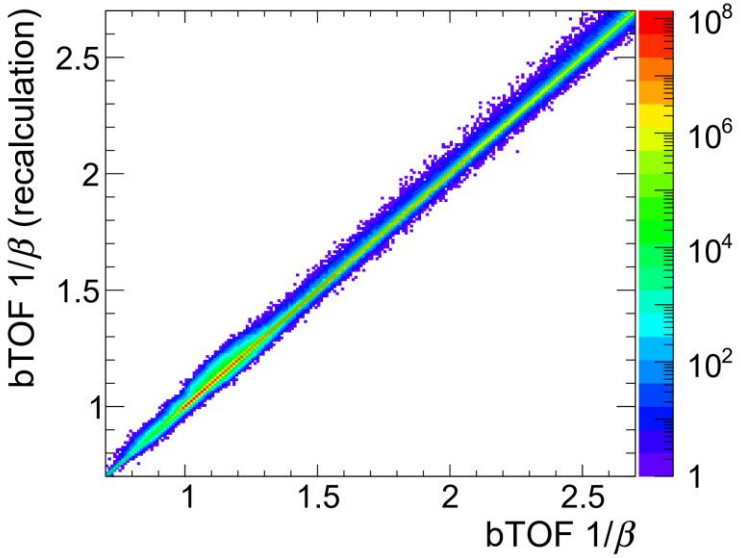


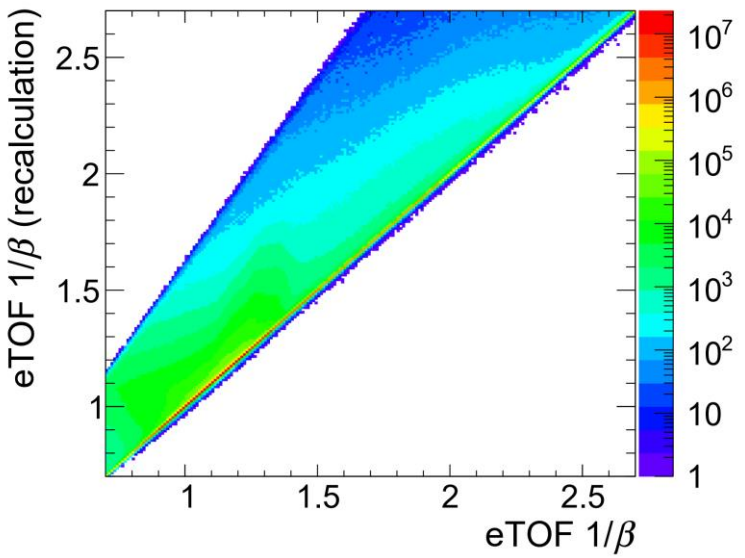
- Unavailable eTOF for PID
  - Further calibration required

eTOF @ 3.2 GeV
(FXT 4.59 GeV 2019)

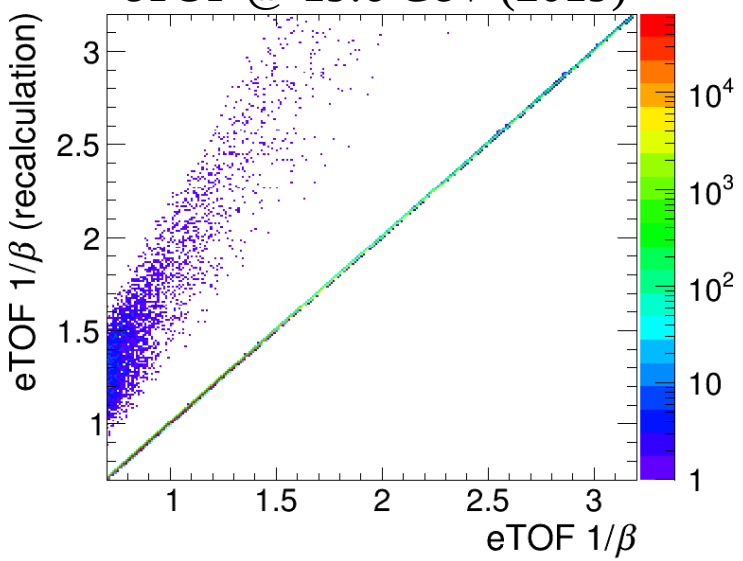
TOF β recalculation

- In StBTofUtil (or StTofUtil), tofPathLength(beginPoint, endPoint, curvature)
- bTOF β = tofPathLength(origin, bTofHitPos, helix(bField).curvature)/(bTofT*C_C_LIGHT/1.e9)
- eTOF β = tofPathLength(origin, eTofCrossingPos, helix(bField).curvature)/(eTofT*C_C_LIGHT/1.e9)



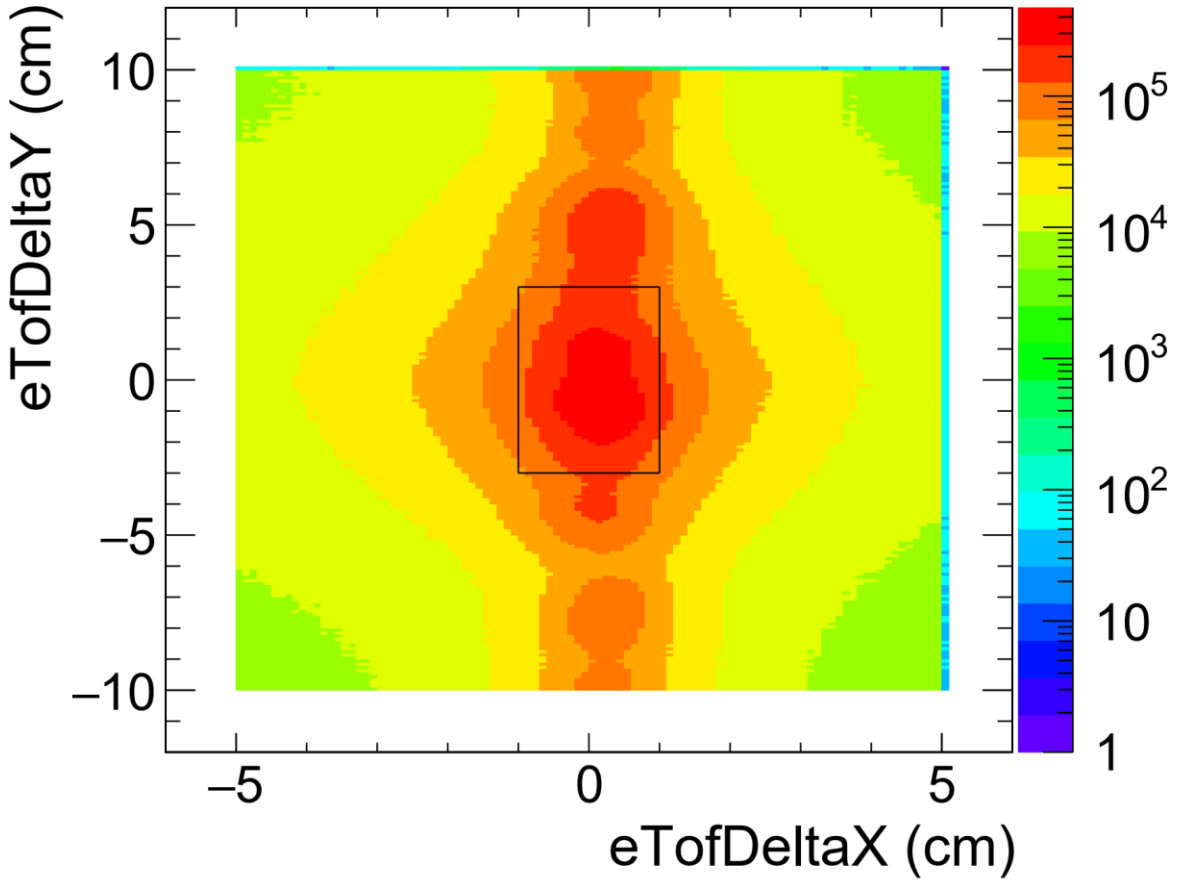


eTOF @ 19.6 GeV (2019)

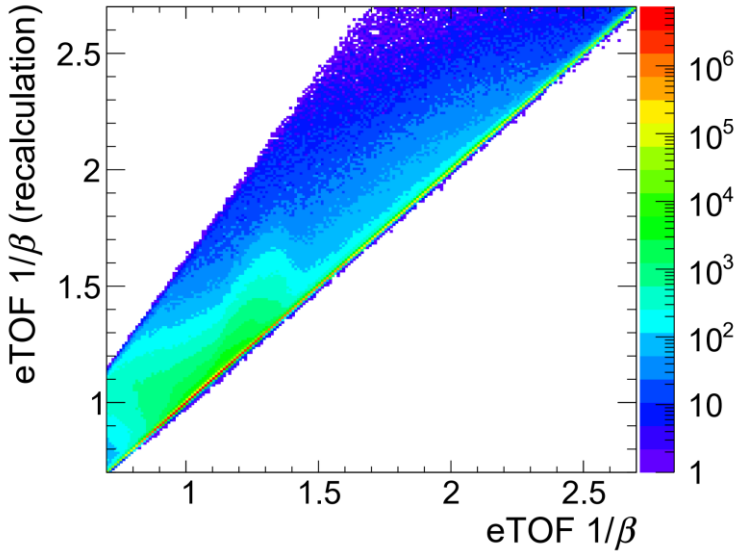


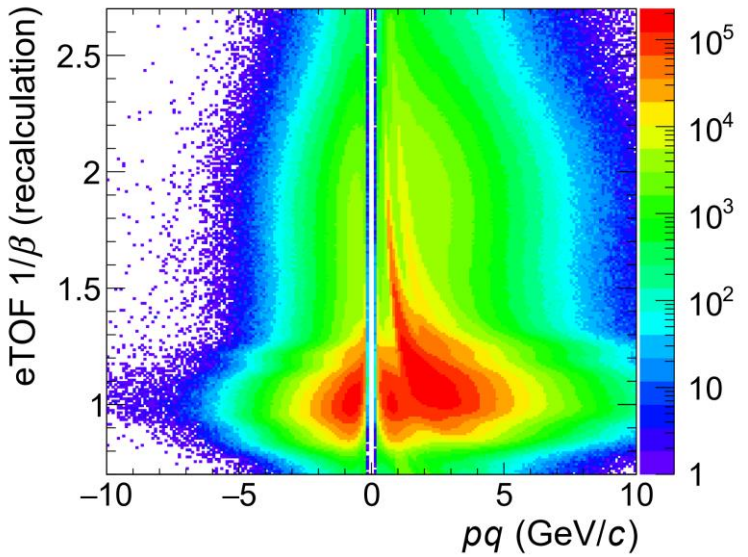
eTOF PID check

- DeltaX(Y): difference between track intersection and eTOF hit in local X(Y) coordinate (cm) across(along) strips

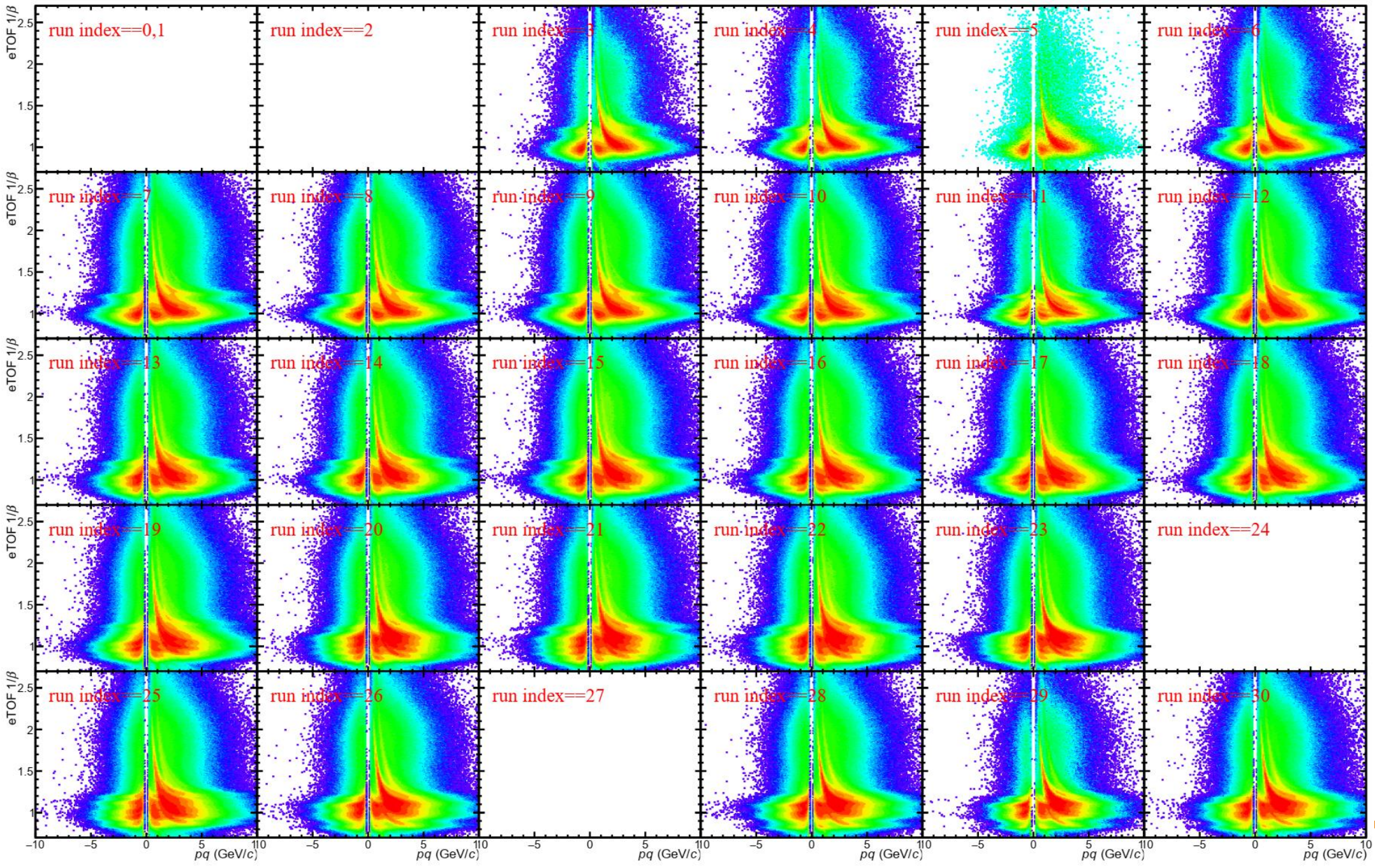


- |DeltaX| < 1
- |DeltaY| < 3

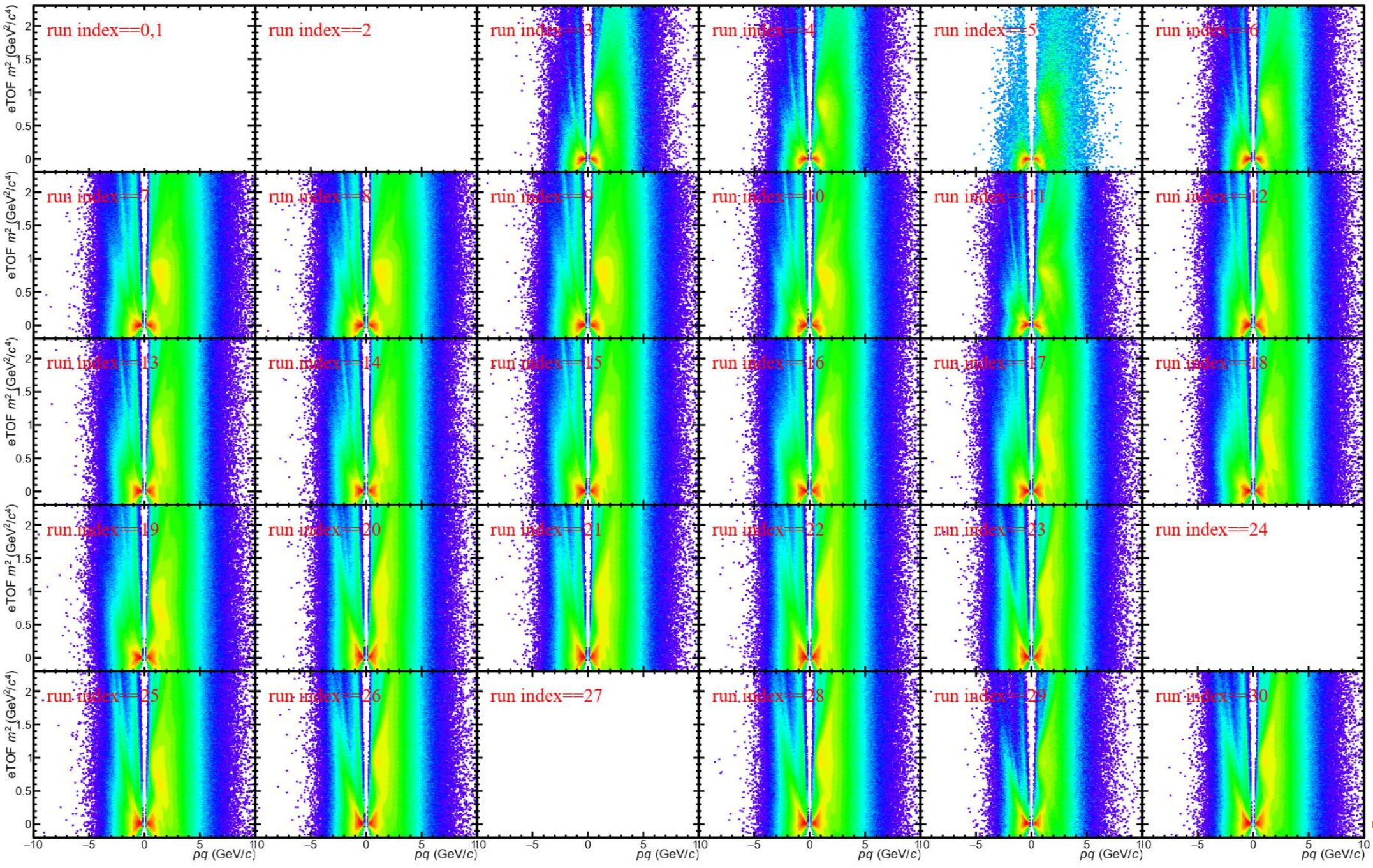




eTOF PID check (Δ cut)

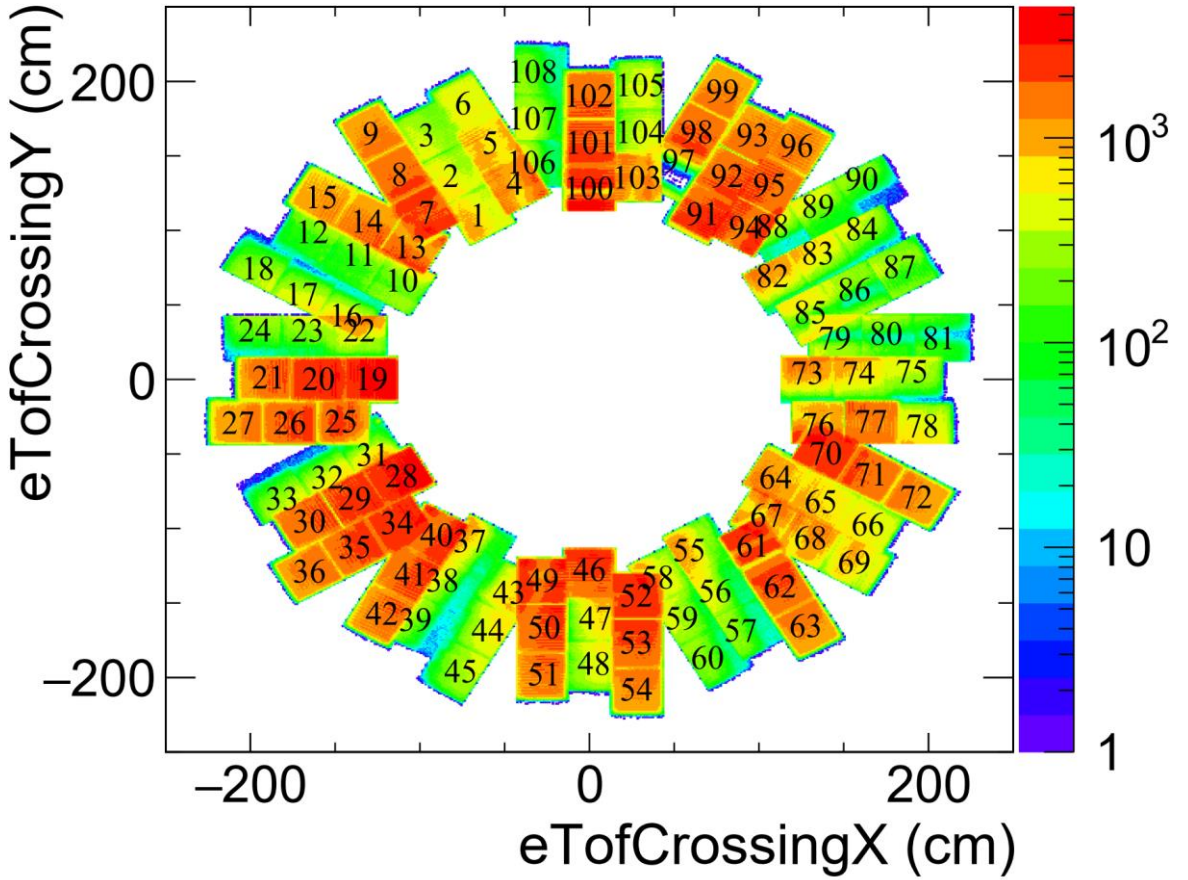


eTOF PID check (Δ cut)

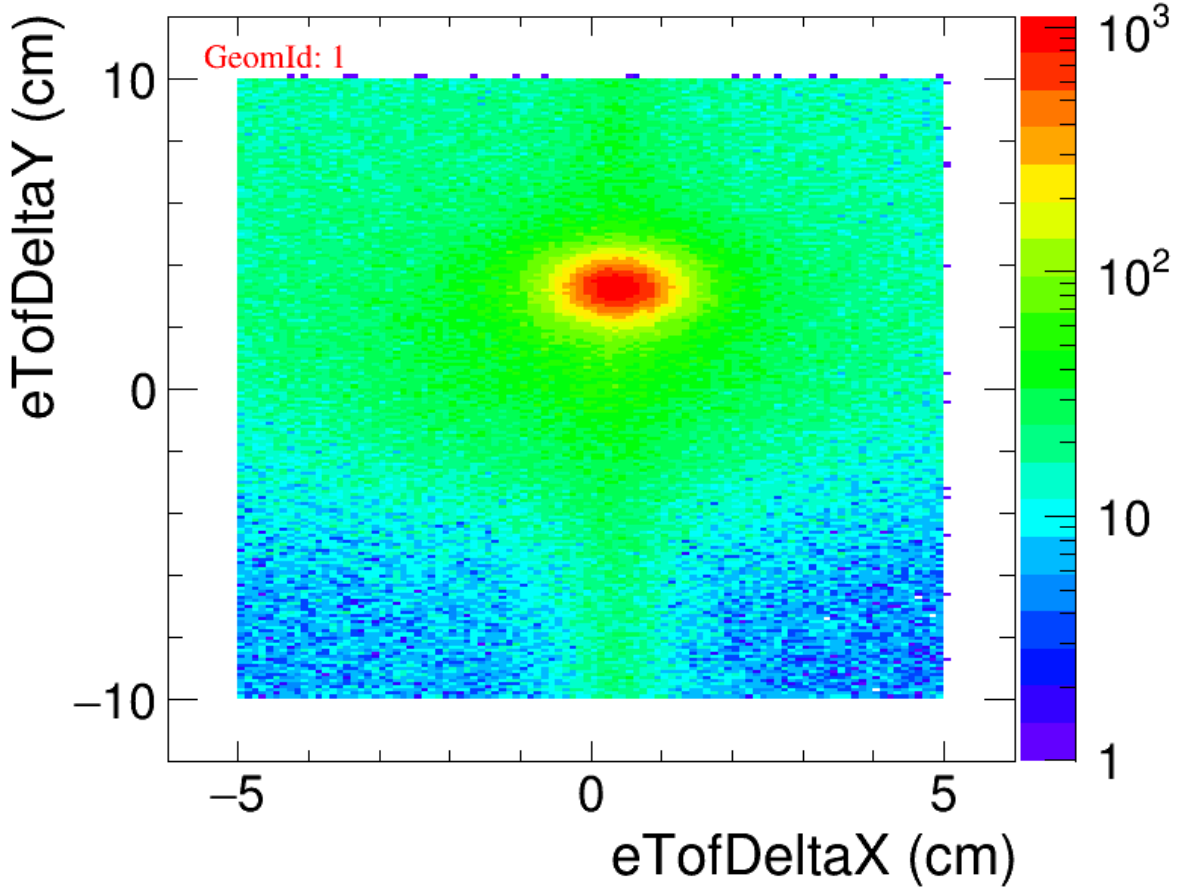


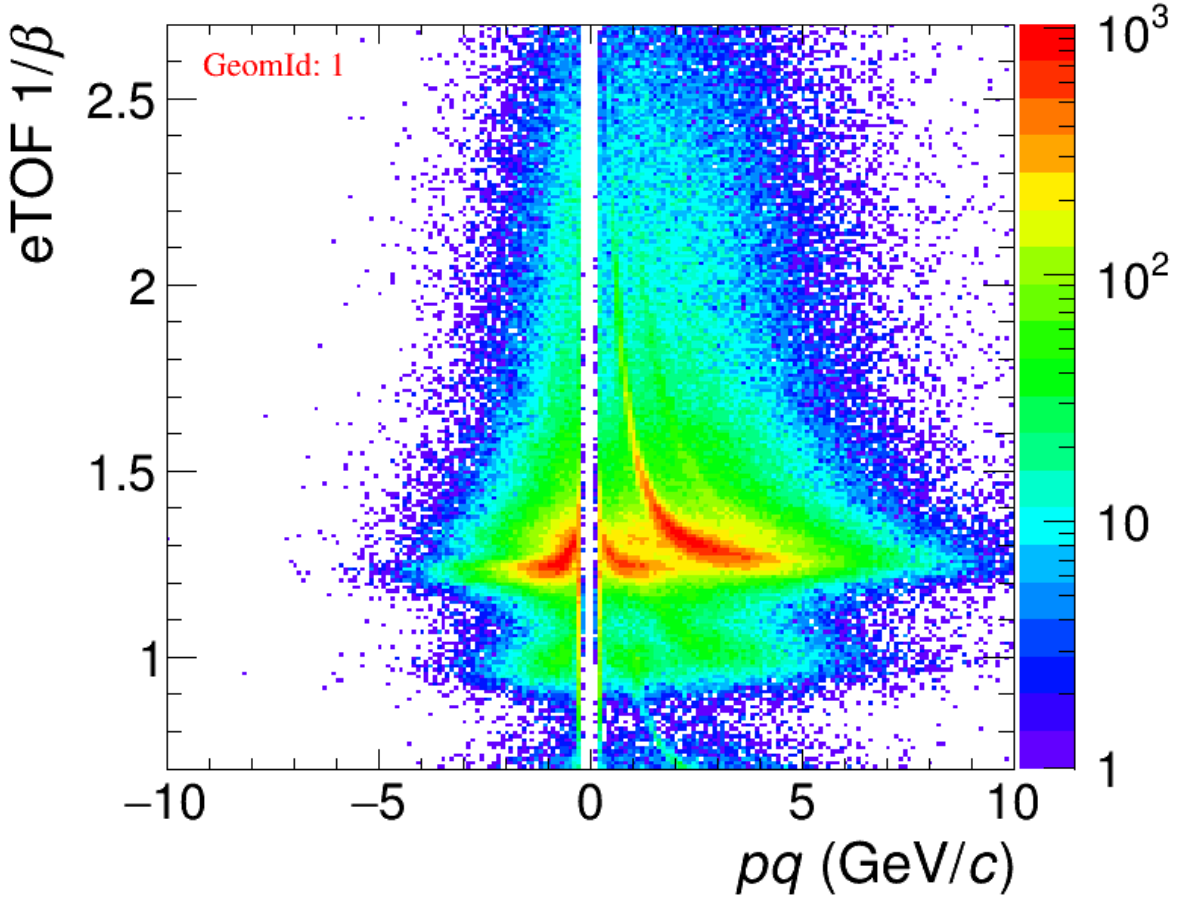
eTOF study

- 108 modules
  - 12 sectors (same as TPC)
  - 3 transverse planes along *z* axis
  - 3 counters along radial direction
- CrossingXYZ
  - Global XYZ coordinate (cm) of the track intersection with an eTOF volume
- GeomId drawn at <crossing>
  - Some numbers (37, …) are not at module center

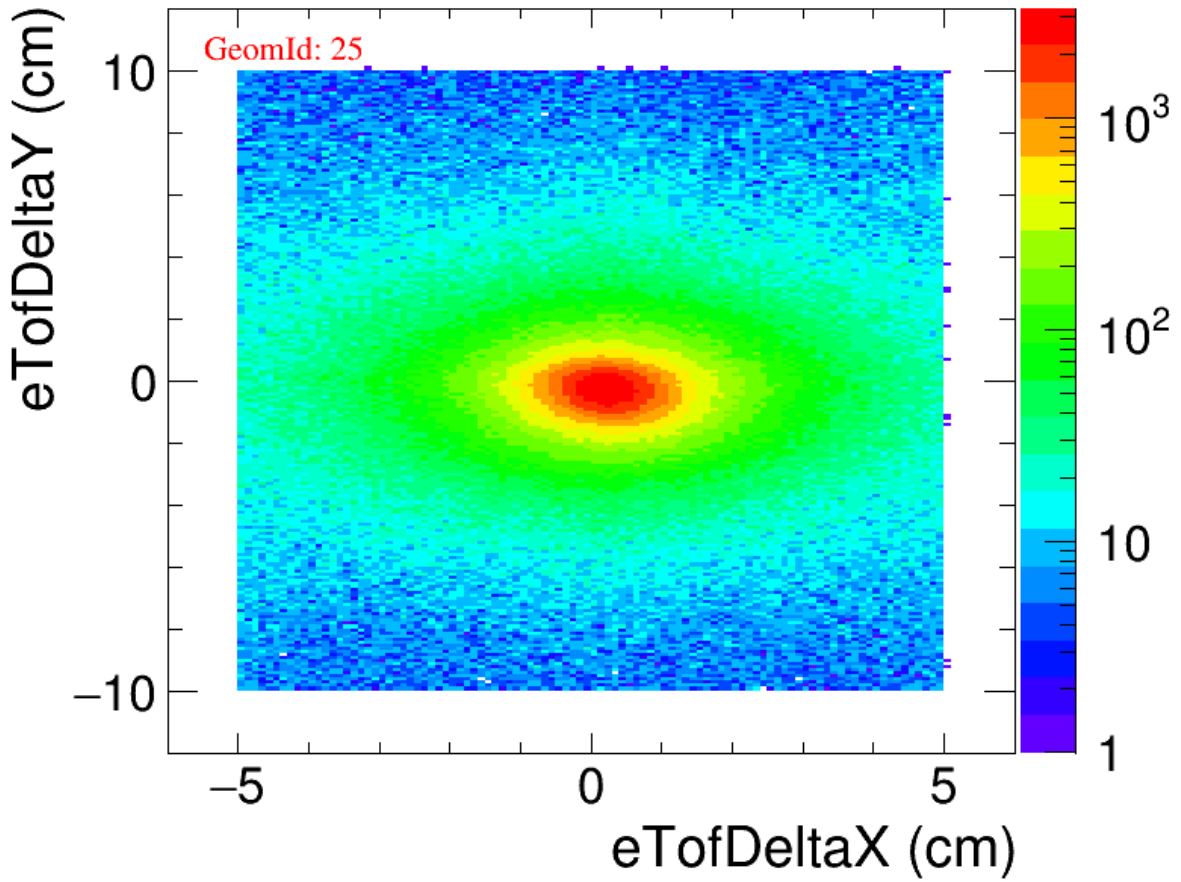


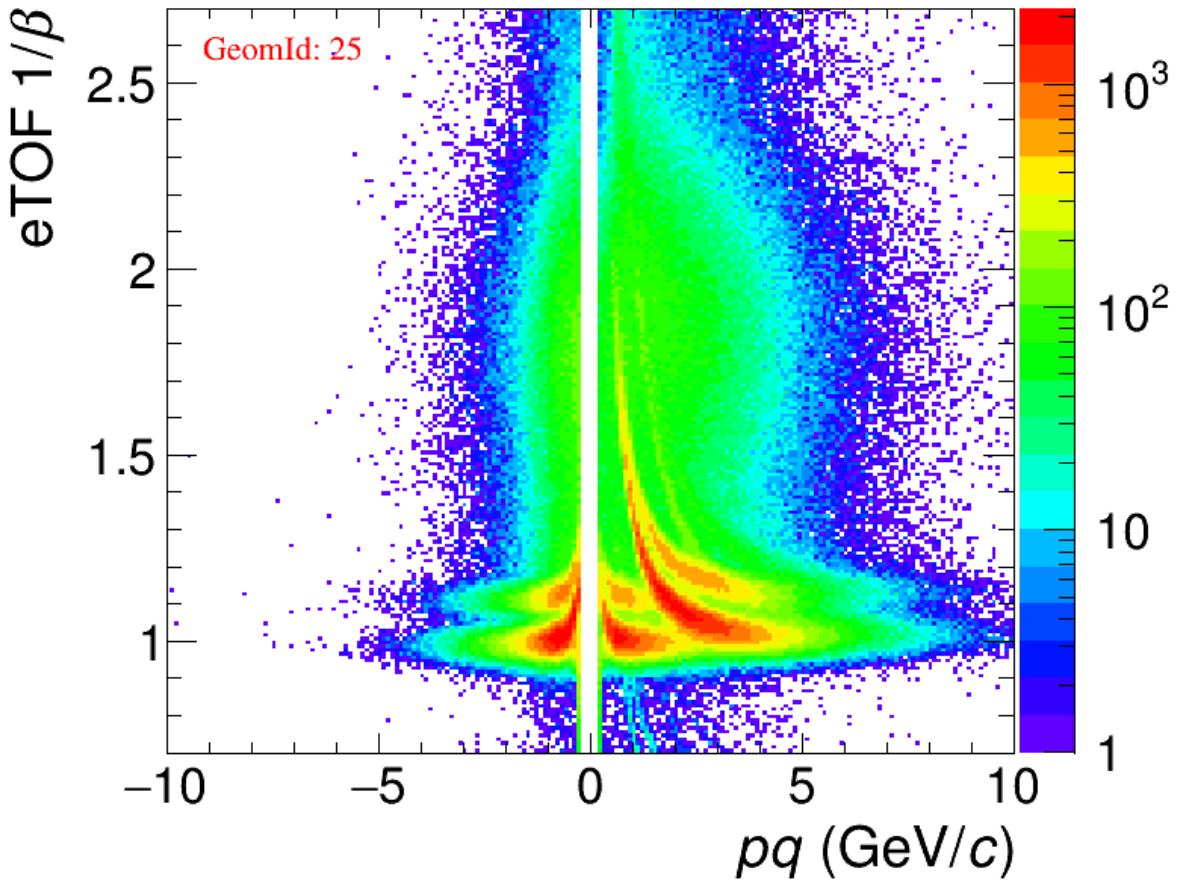
eTOF study


GeomId: 1
eTofDeltaY (cm)
eTofDeltaX (cm)
10
0
−10
−5
0
5
10^3
10^2
10
1

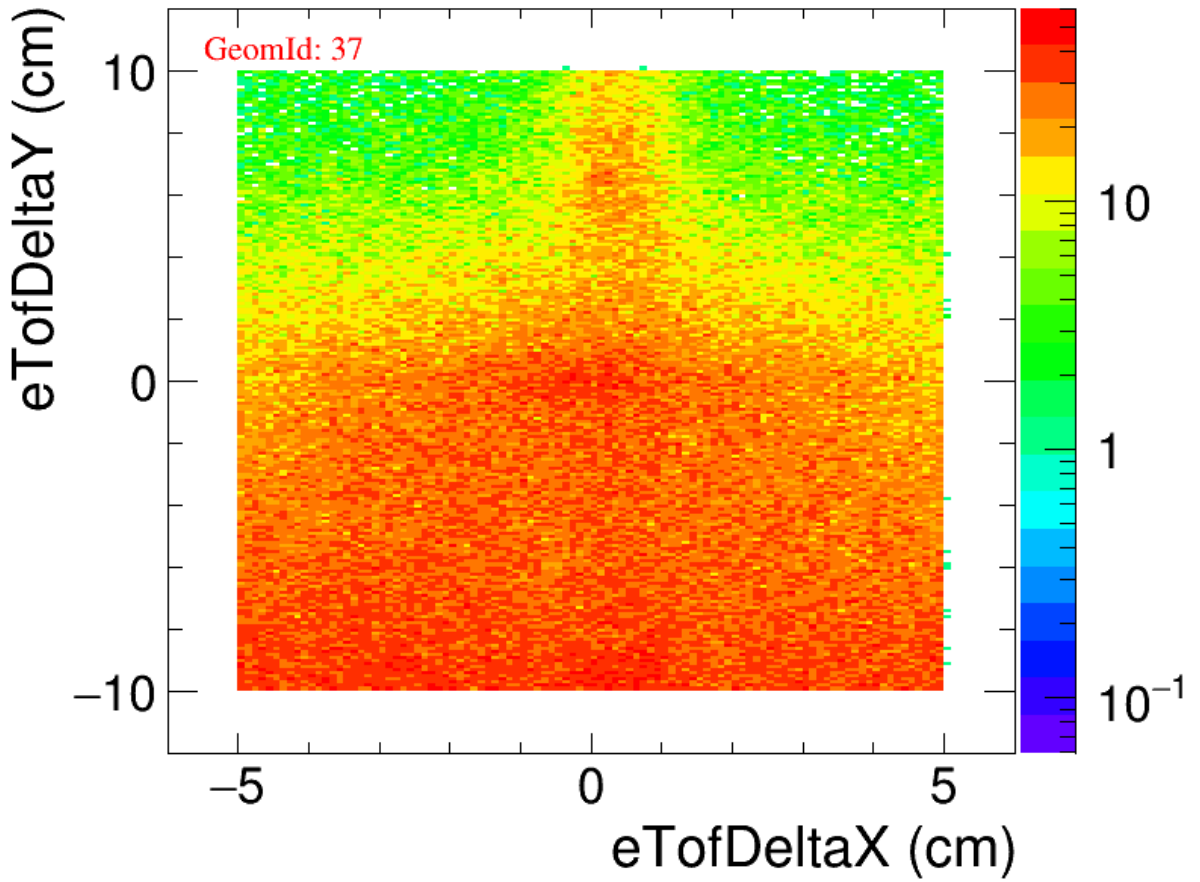

GeomId: 1
eTOF 1/β
pq (GeV/c)
2.5
2
1.5
1
−10
−5
0
5
10
10^3
10^2
10
1

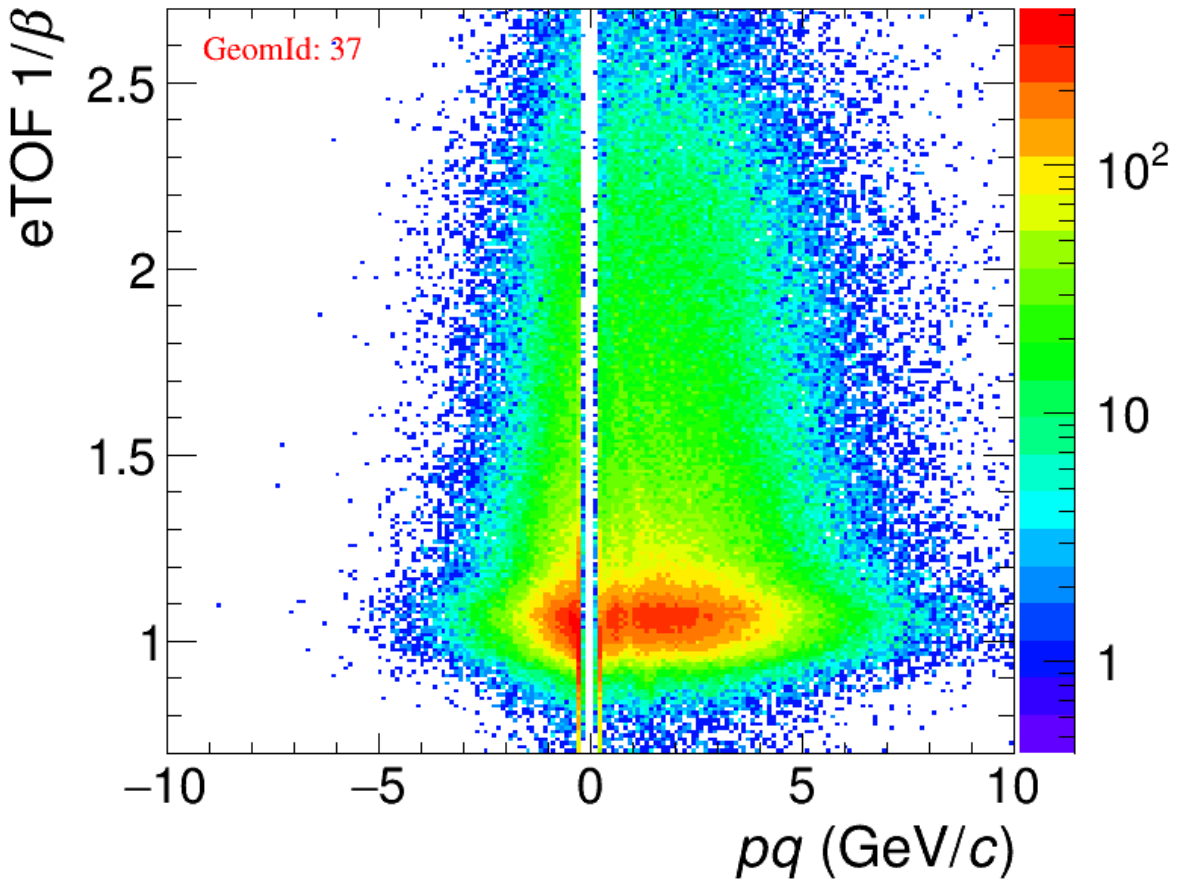
eTOF study


GeomId: 25
eTofDeltaY (cm)
eTofDeltaX (cm)
10
0
−10
−5
0
5
10^3
10^2
10
1

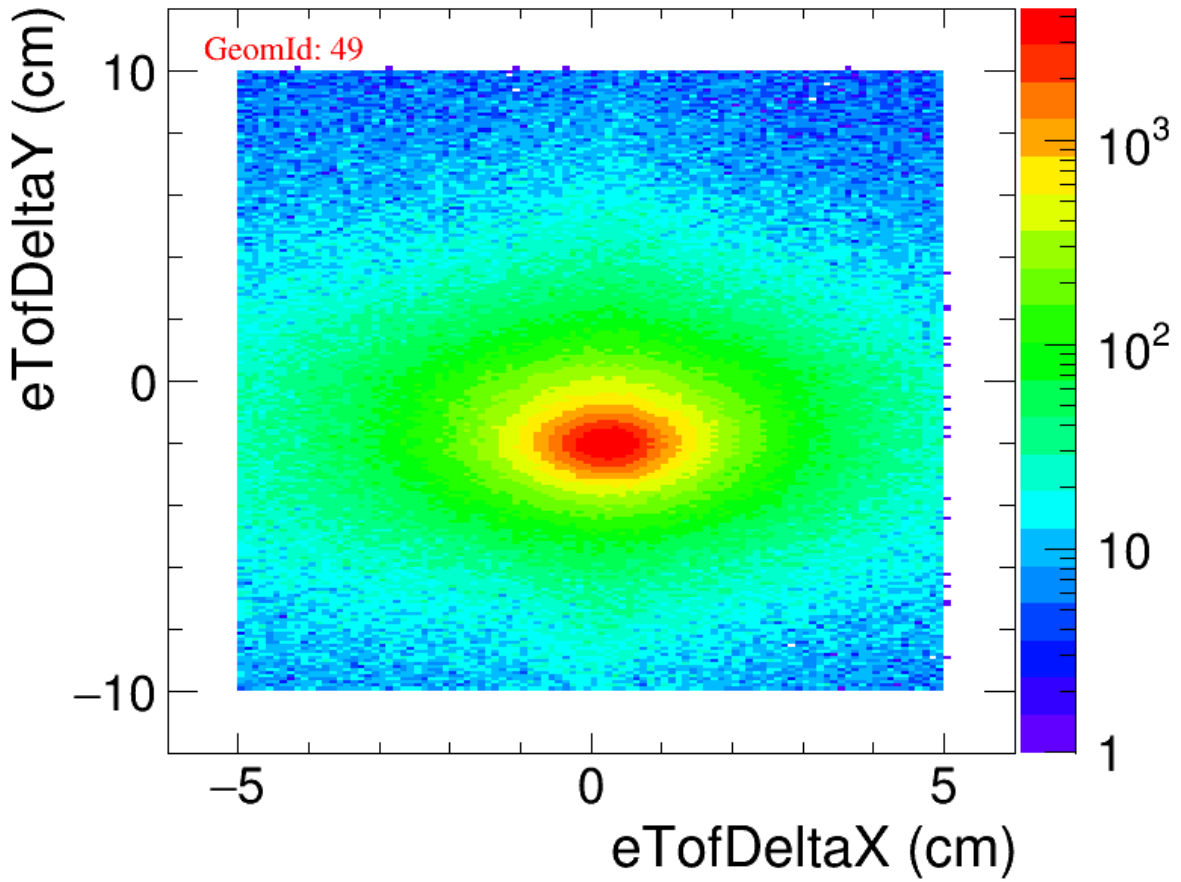

GeomId: 25
eTOF 1/β
pq (GeV/c)
2.5
2
1.5
1
−10
−5
0
5
10
10^3
10^2
10
1

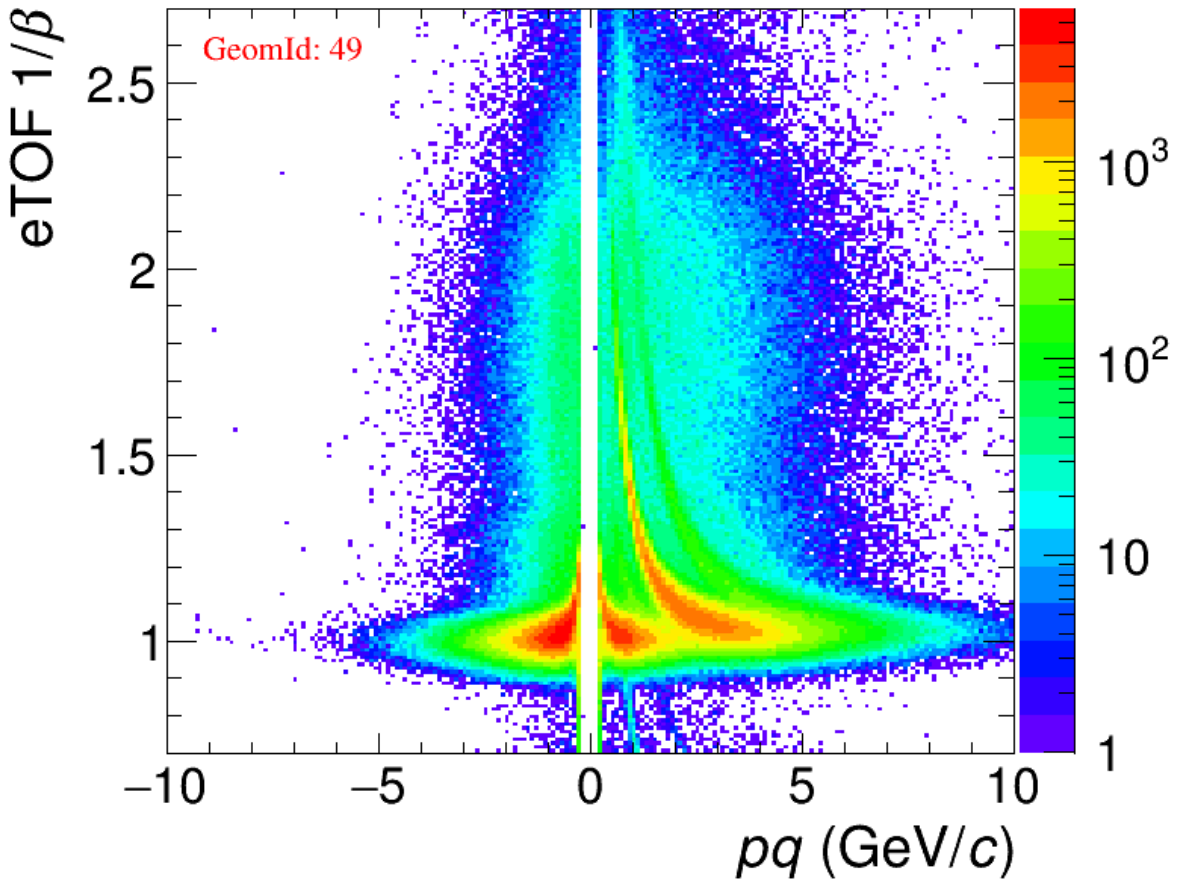
eTOF study


GeomId: 37
eTofDeltaY (cm)
eTofDeltaX (cm)
10
0
−10
−5
0
5
10
1
10^{-1}

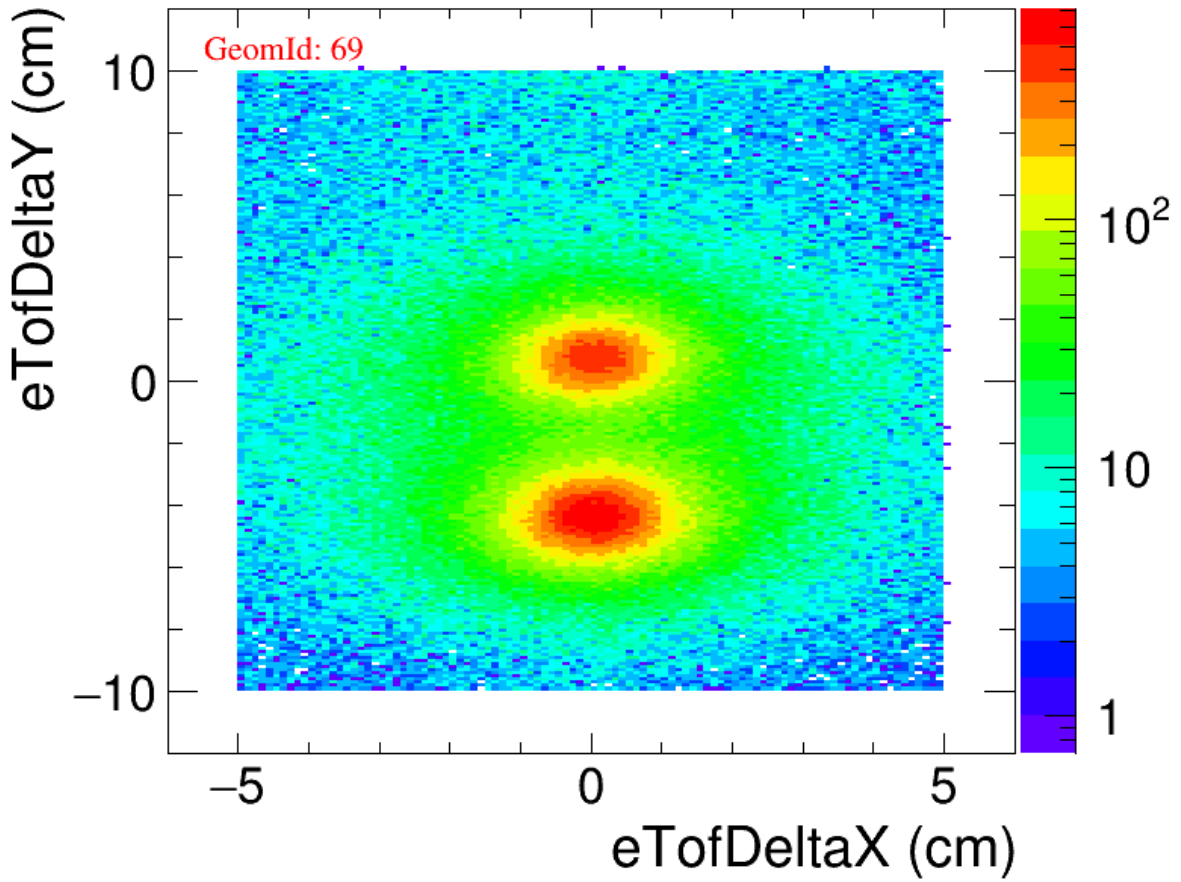

GeomId: 37
eTOF 1/β
pq (GeV/c)
2.5
2
1.5
1
−10
−5
0
5
10
10^2
10
1

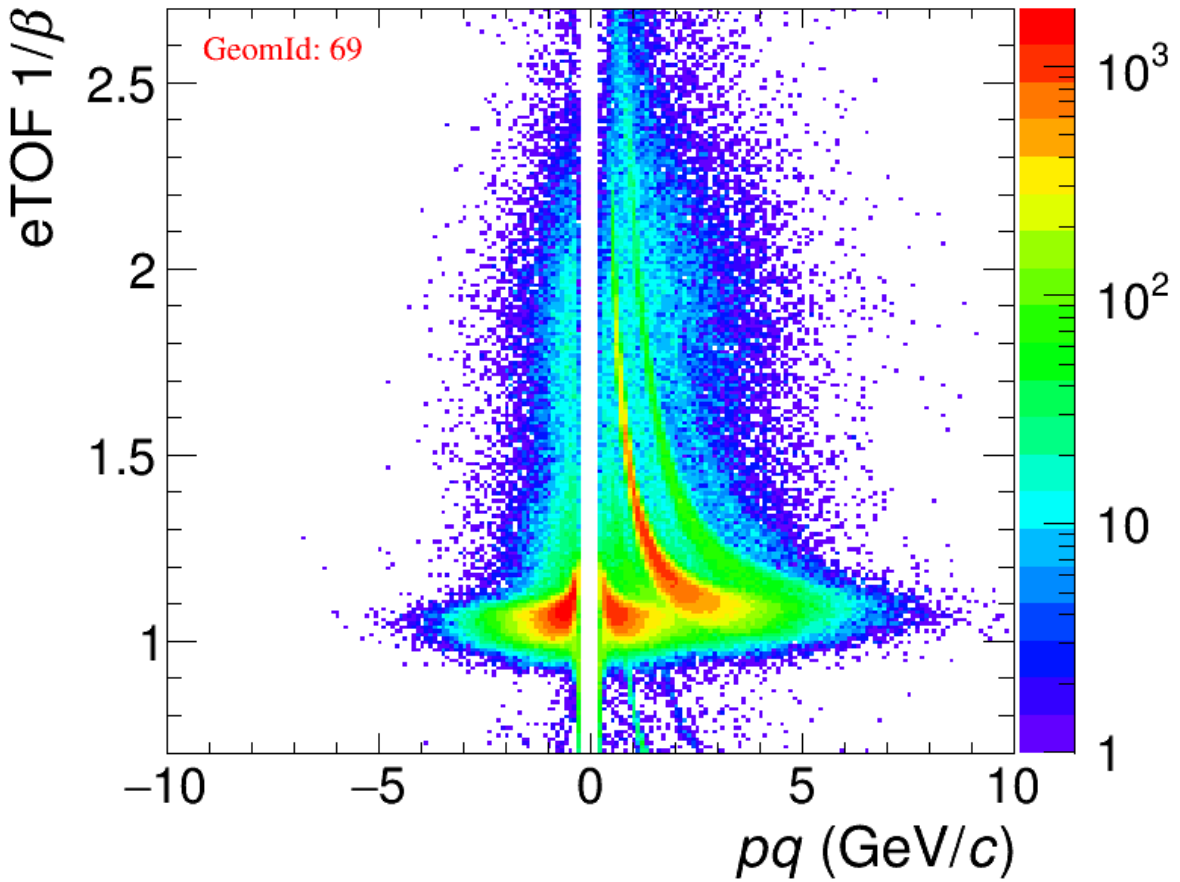
eTOF study


GeomId: 49
eTofDeltaY (cm)
eTofDeltaX (cm)
10
0
−10
−5
0
5
10^3
10^2
10
1


GeomId: 49
eTOF 1/β
pq (GeV/c)
2.5
2
1.5
1
−10
−5
0
5
10
10^3
10^2
10
1

eTOF study


GeomId: 69
eTofDeltaY (cm)
eTofDeltaX (cm)
10
0
−10
−5
0
5
10^2
10
1


GeomId: 69
eTOF 1/β
pq (GeV/c)
2.5
2
1.5
1
−10
−5
0
5
10
10^3
10^2
10
1

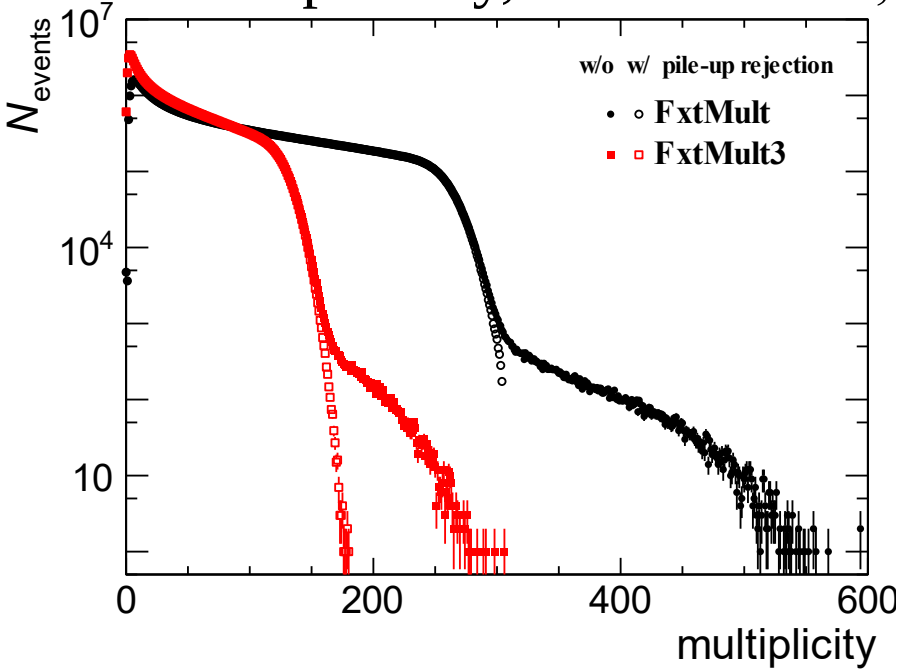
eTOF study

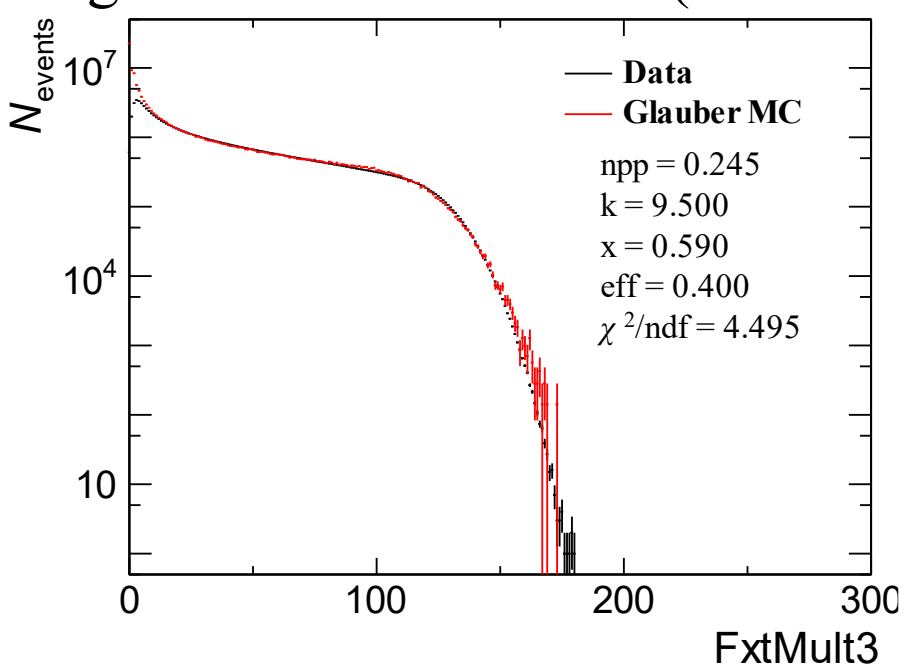
- Pre-cut of |DeltaX| ≤ 5 cm & |DeltaY| ≤ 10 cm in PicoDst
  - DeltaXY centers of some modules are not within the pre-cut

- Based on a sample of 3.5 GeV data (~1/8 statistics)
- Cuts: same as run-by-run qa cuts + bad run rejection + pileup event rejection
  - CrossingXY distribution
    - https://drupal.star.bnl.gov/STAR/system/files/hetofcrossingxy.pdf
  - DeltaXY distributions of 108 modules
    - https://drupal.star.bnl.gov/STAR/system/files/hetofdeltaxy_geomid.pdf
  - $1/\beta$ vs. pq distributions of 108 modules
    - https://drupal.star.bnl.gov/STAR/system/files/hpqetof1obeta_geomid.pdf

Centrality determination

- FxtMult: primary (branch of StPicoEvent)
- FxtMult3: primary, nHitsFit > 10, nSigmaProton−2.15 < −3 (constant $<n\sigma_{proton}>$ shift)





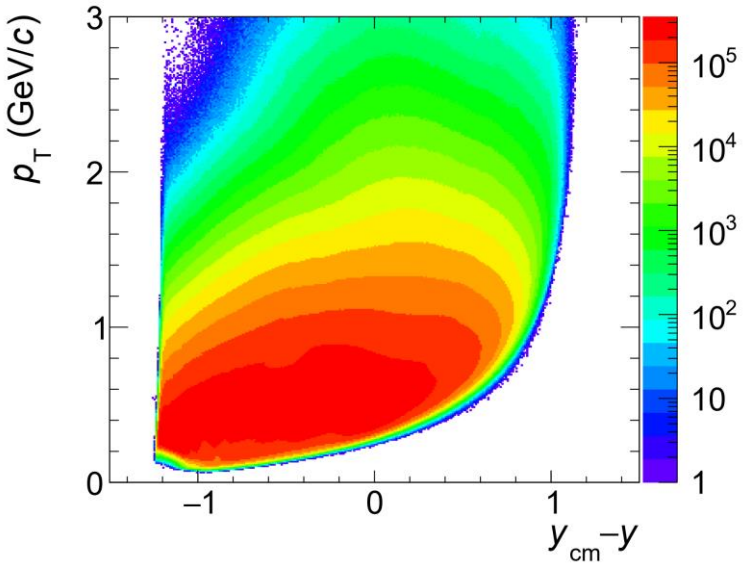
10^6 Glauber events
σ_{nn} = 29 mb

Fit @ FxtMult3 > 25

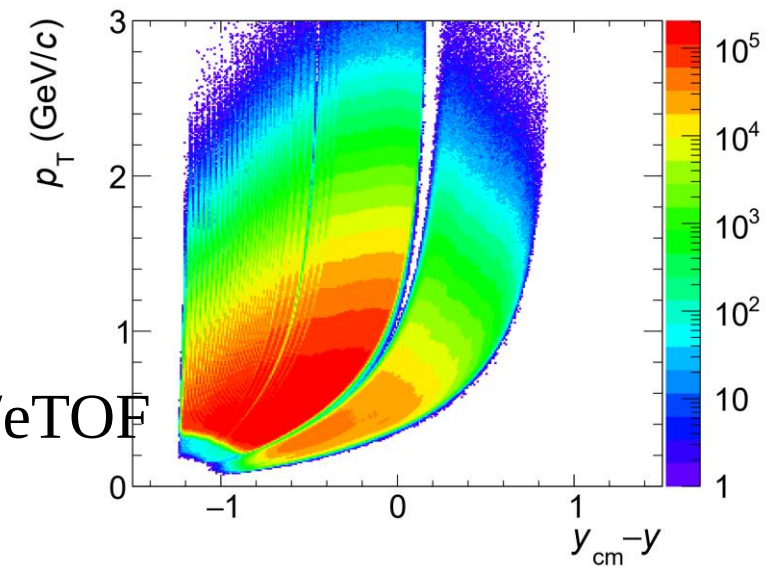
FxtMult3 >	1	2	3	4	6	8	11	15
Centrality	75-80%	70-75%	65-70%	60-65%	55-60%	50-55%	45-50%	40-45%
FxtMult3 >	21	27	34	43	54	67	82	101
Centrality	35-40%	30-35%	25-30%	20-25%	15-20%	10-15%	5-10%	0-5%

Acceptance

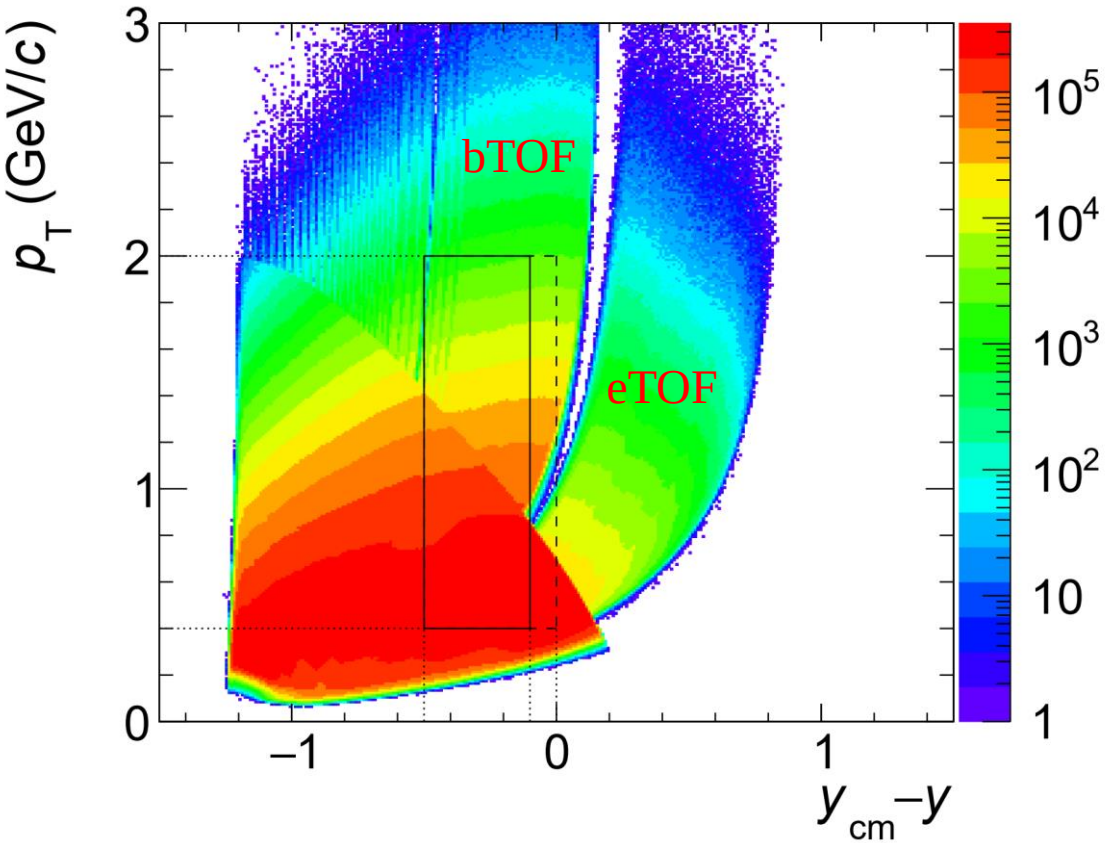
- Only TPC
- $y_{cm} = -1.250$



- TPC+bTOF/eTOF

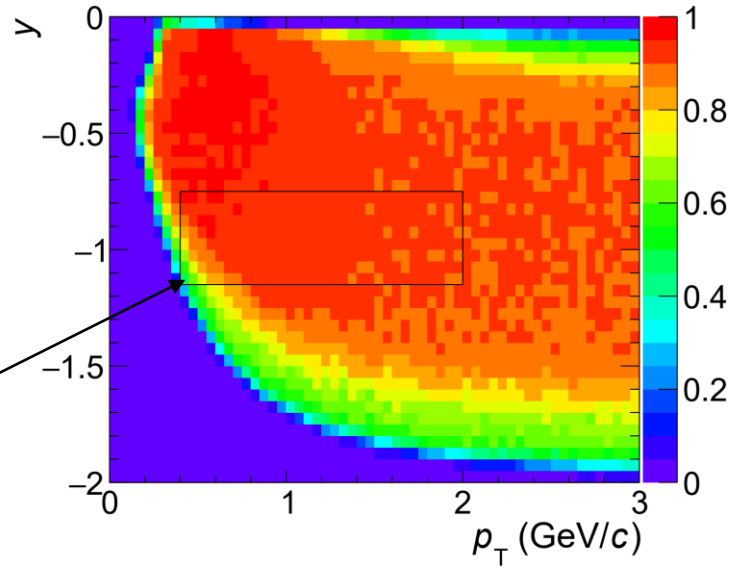


- Only TPC, $p < 2$ GeV/c
- TPC+bTOF/eTOF, $p > 2$ GeV/c

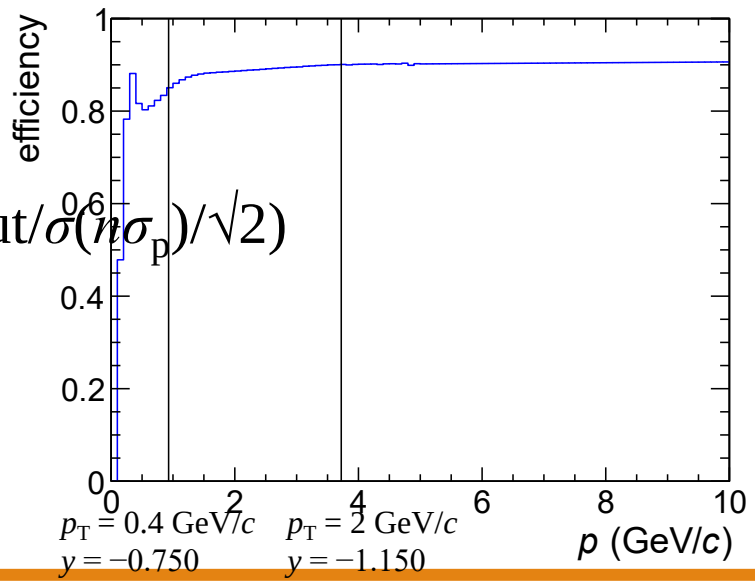


Efficiency

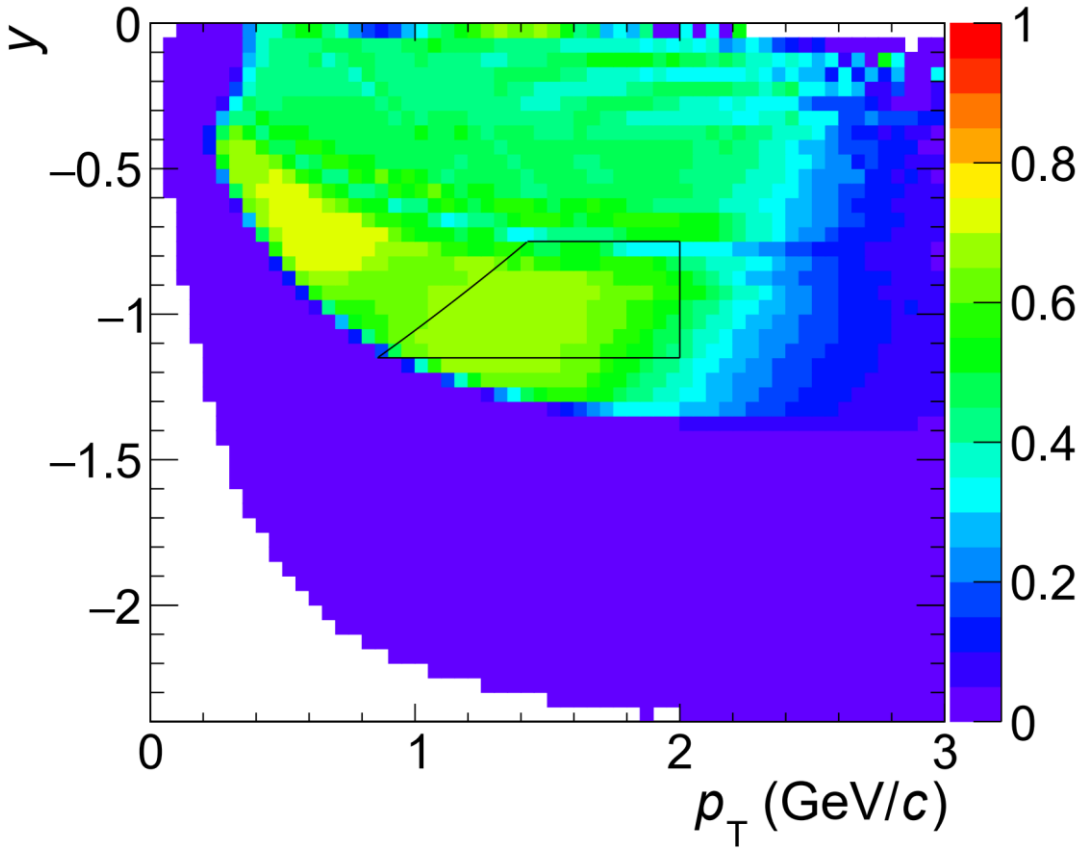
- TPC
- Tracking @ 3.0 GeV
- PID
  - $\varepsilon = \mathrm{erf}(n\sigma_p \text{ cut}/\sigma(n\sigma_p)/\sqrt{2})$



Edge of TPC (no iTPC)



- bTOF
  - $\varepsilon = N$(TPC+bTOF PID)/N(TPC PID)



Analysis cuts

- Trigger ID
  - 720007 (epde-or-bbce-or-vpde-tof1-etof)
- Run cuts
  - Bad run rejection
- Event cuts:
  - 198 cm < V_z < 202 cm
  - $|V_r|$ < 2 cm, with center (0, −2) cm
  - Pile-up event rejection
- Events: 0.98×10^8
- Track cuts
  - Primary
  - |gDca| < 3 cm
  - nHitsFit > 10
  - nHitsFit/nHitsPoss > 0.52
  - nHitsDedx > 5
  - 0.4 GeV/c < p_T < 2 GeV/c
  - $-0.5 < y_{cm} - y < -0.1$, $y_{cm} = -1.250$
  - $|n\sigma_{proton} - \langle n\sigma_{proton} \rangle(p)| < 2$
  - 0.6 GeV$^2/c^4$ < bTOF m^2 < 1.2 GeV$^2/c^4$
    - p > 2 GeV/c

Analysis techniques

- Track-by-track efficiency correction

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

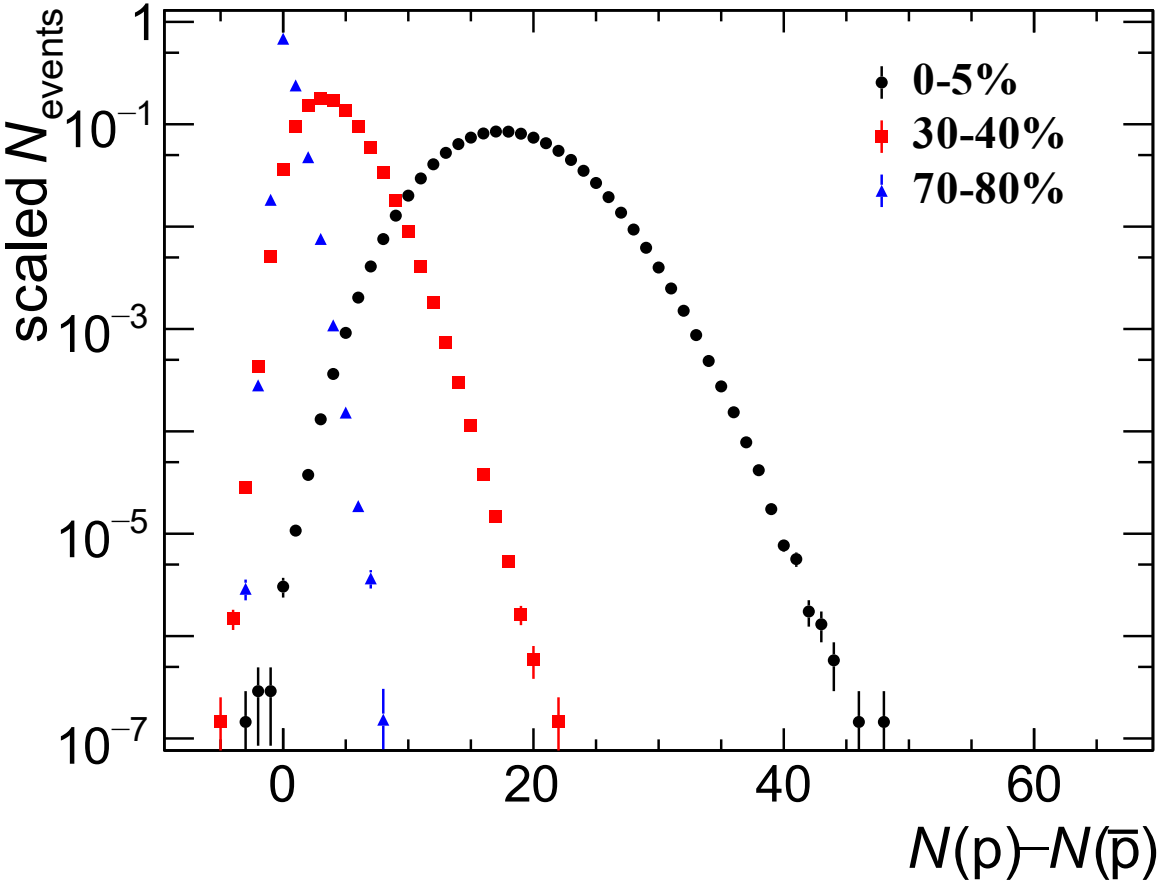
- Analytical statistical uncertainty estimation
  - Based on covariances of terms in track-by-track efficiency correction formulae

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

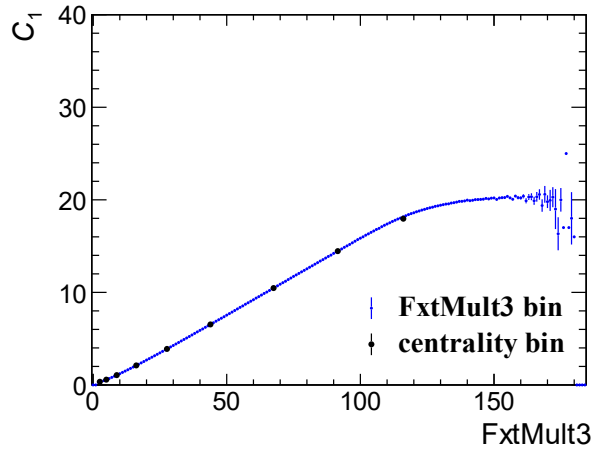
- Centrality bin width correction (CBWC)
  - $C_k = \sum_r n_r C_{k,r} / \sum_r n_r$
  - $\sigma(C_k) = \sqrt{\sum_r n_r^2 \sigma^2(C_{k,r}) / (\sum_r n_r)^2}$
  - $\sigma\left(\frac{C_k}{C_l}\right) = \sqrt{\sum_r n_r^2 \sigma^2\left(\frac{C_{k,r}}{C_{l,r}}\right) / (\sum_r n_r)^2}$

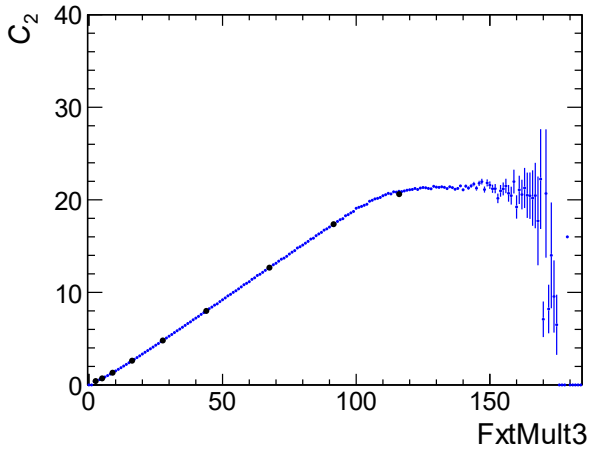
Measured distributions

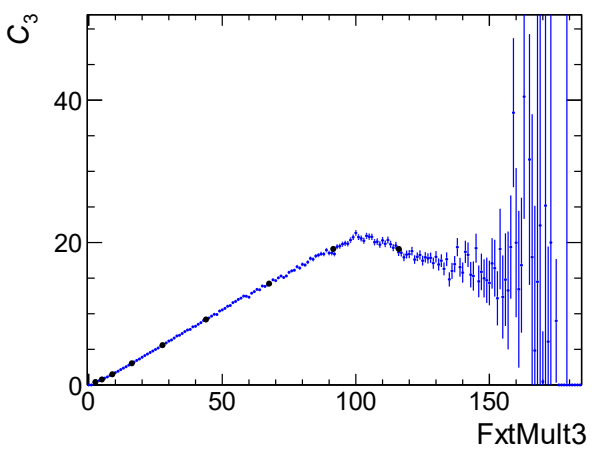
- Efficiency-uncorrected
- Centrality-dependent means and widths observed

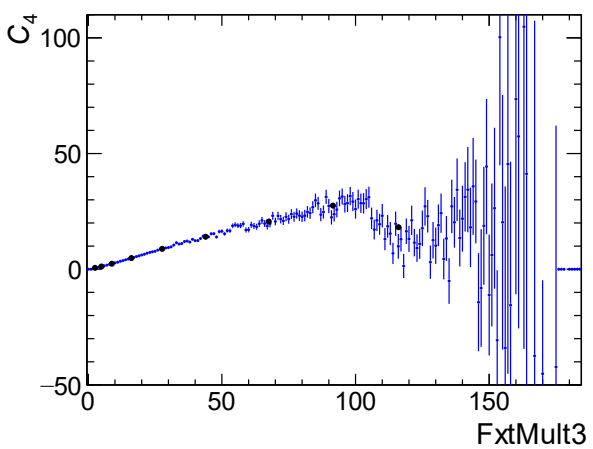


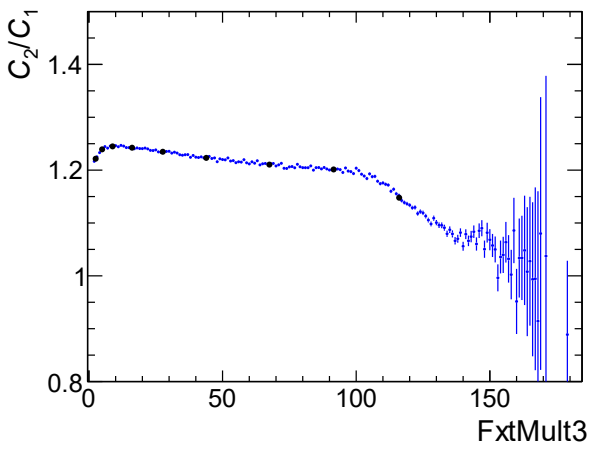
Efficiency-uncorrected cumulants

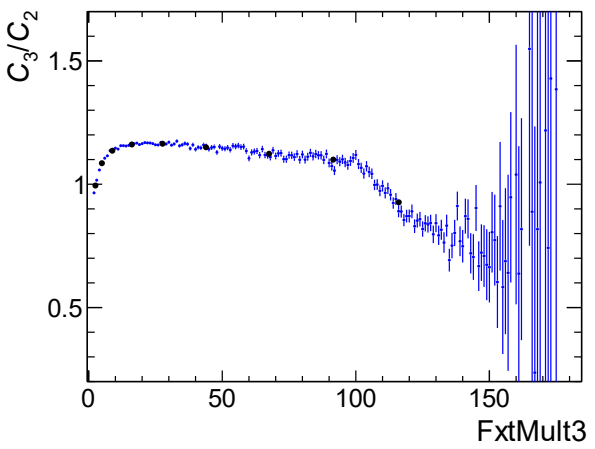


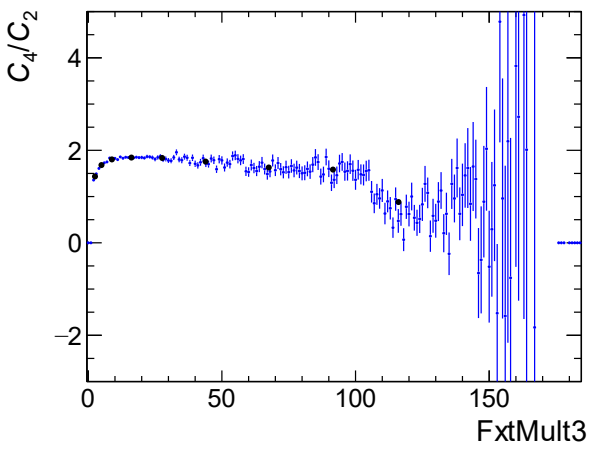




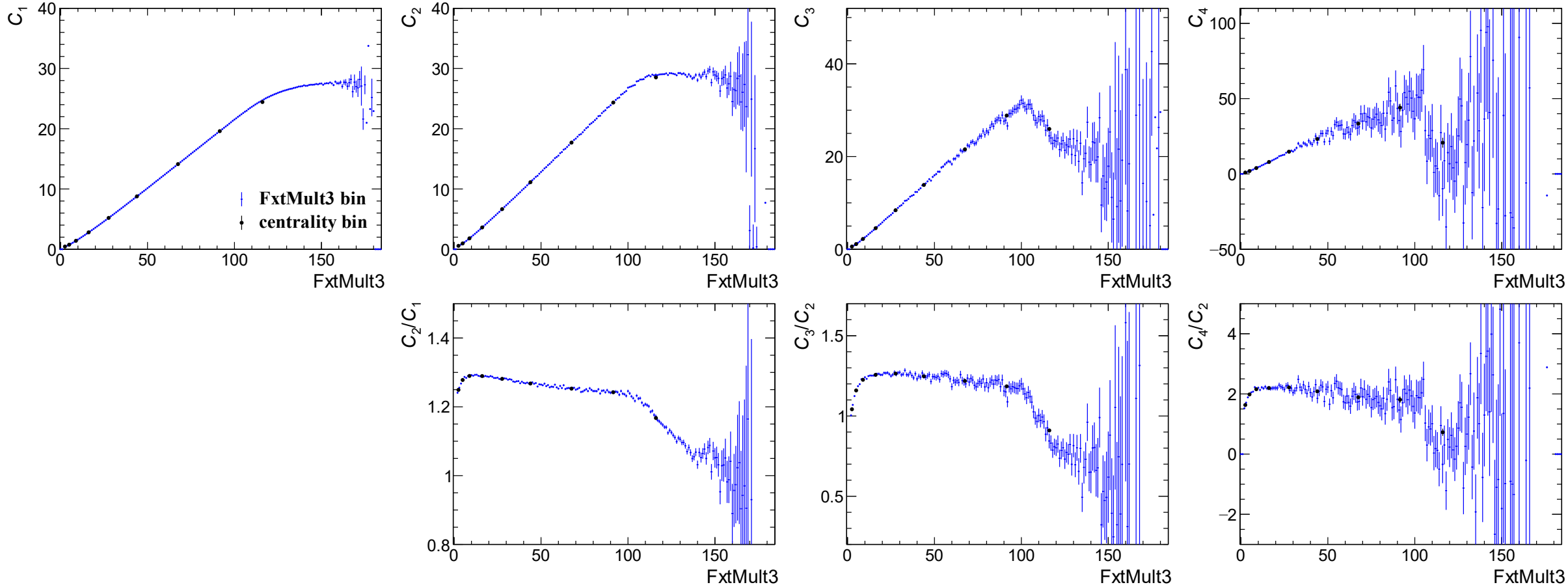






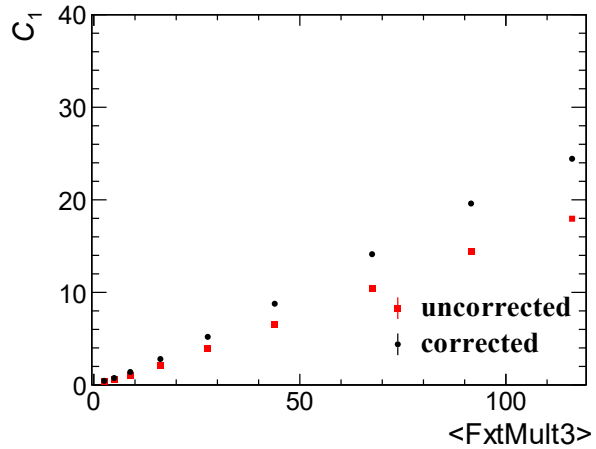


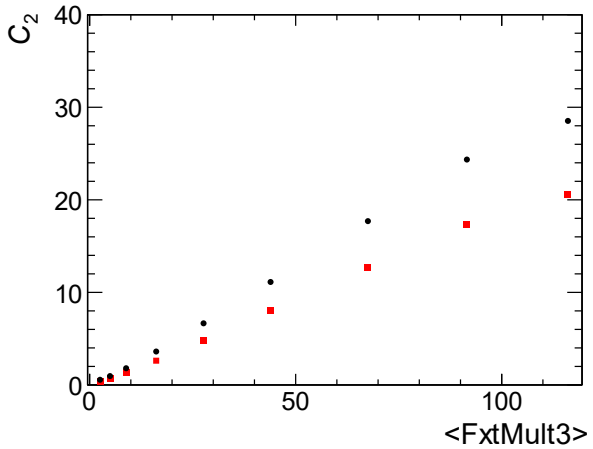
Efficiency-corrected cumulants

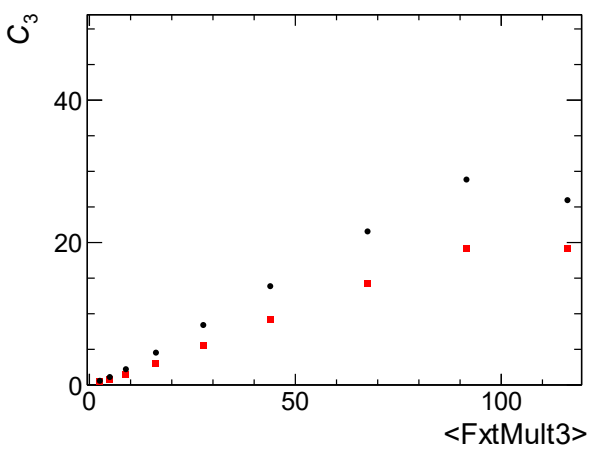


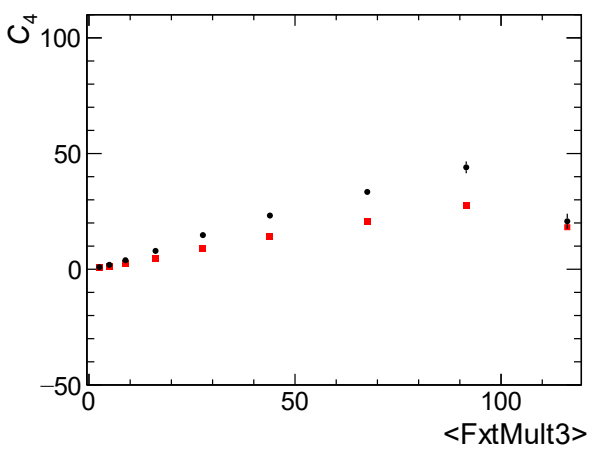
- Corrected with TPC tracking efficiency (@ 3.0 GeV), TPC PID efficiency and TOF efficiency

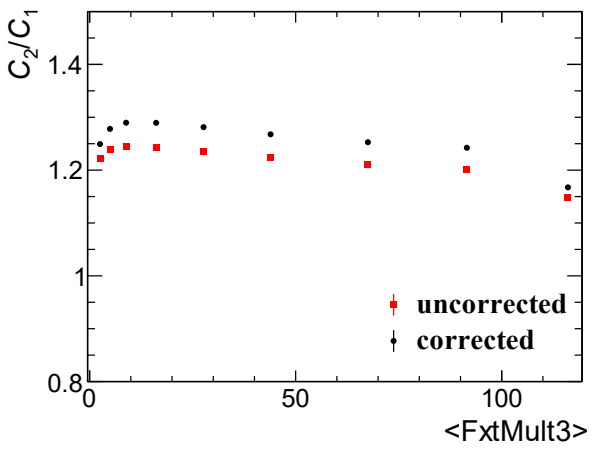
Comparison between (un)corrected results

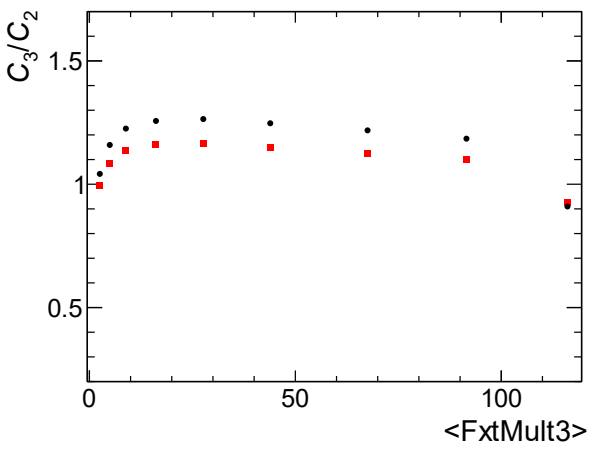


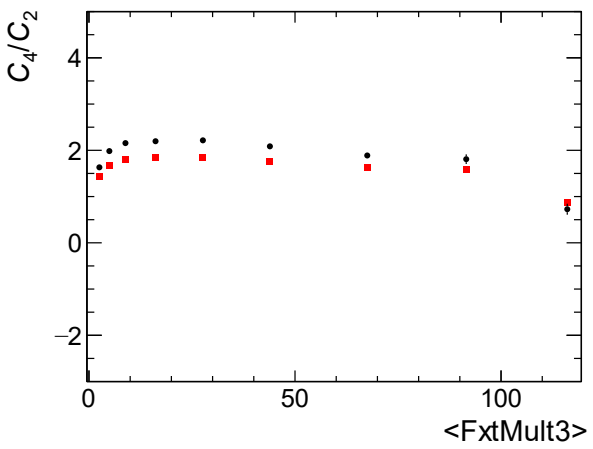






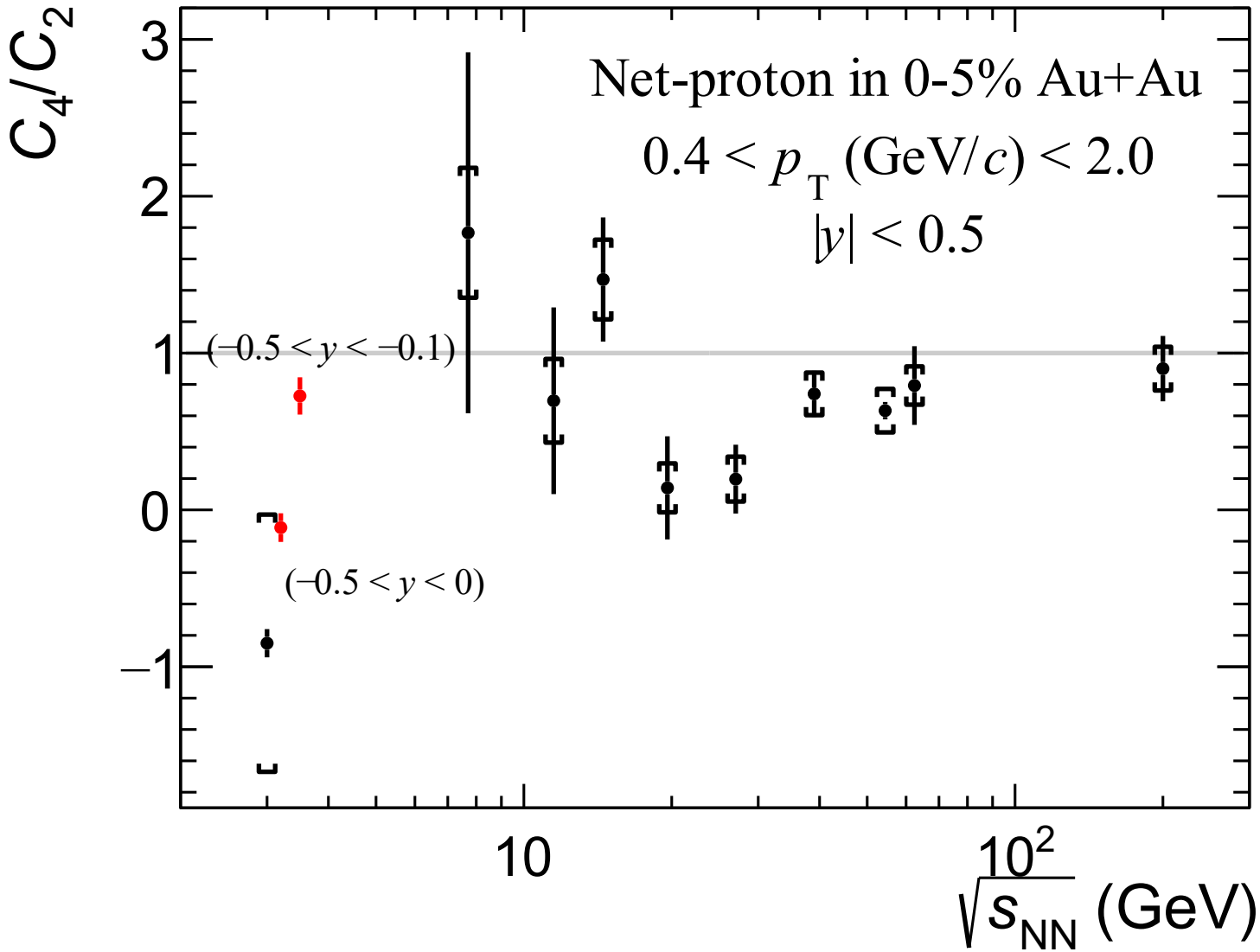






Energy dependence

- 3.2 GeV: last talk
- 3.5 GeV: this work
- With TPC tracking efficiency @ 3.0 GeV



Embedding request

- Protons in Au+Au @ 3.2 GeV

- Trigger setup: production_4p59GeV_fixedTarget_2019
- Stream: st_physics(_adc)
- Production: P21id
- Library: SL21d
- Trigger ID: 680001 (epde-or-bbce-or-vpde-tof1)
- 198 cm < V_z < 202 cm, 0 < p_T < 2.5 GeV/c (flat), −2.5 < η < 0, 0 < φ < 2π

- Run period: 20179040 − 20183025
- Bad run ID [12]: 20180005, 20180006, 20180010, 20180019, 20180025, 20181004, 20181016, 20182007, 20183010, 20183013, 20183014, 20183019
  - Or official bad run list

Summary & outlook

- Summary
  - Net-proton cumulants @ 3.5 GeV
  - Unavailable eTOF
    - Crucial for FXT @ 3.5 GeV and higher energies

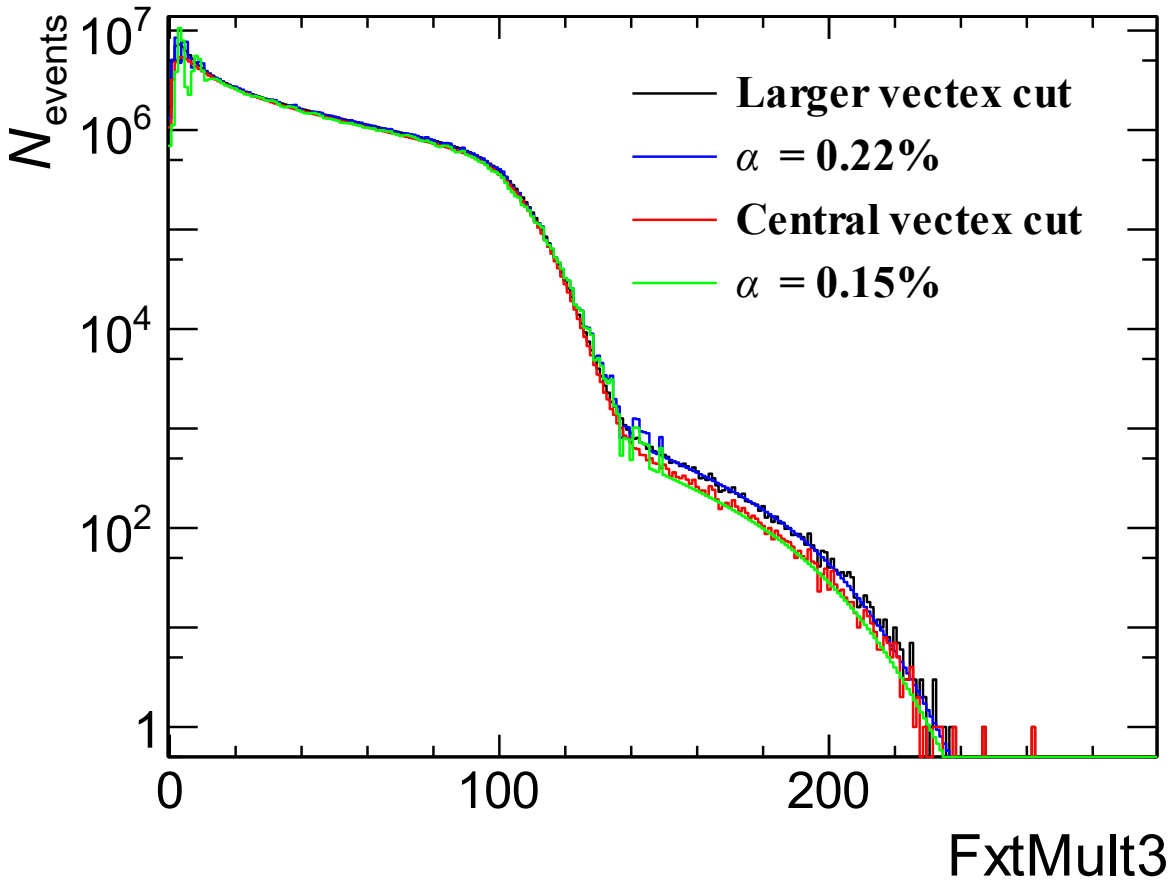
- Outlook
  - Further calibration of eTOF?
    - Or remove cuts for trigger and bad runs about eTOF
  - TPC tracking efficiency from embedding
  - Pileup correction
    - Cross-check with pileup rejection

Pileup study @ 3.2 GeV

- https://drupal.star.bnl.gov/STAR/system/files/3p2_PWG_xin.pdf
  - Pileup fraction α = 0.146%
  - 199.2 cm < V_z < 200 cm
  - $|V_r|$ < 1.5 cm, with center (−0.4, −2) cm
  - Unfolding code from Toshihiro

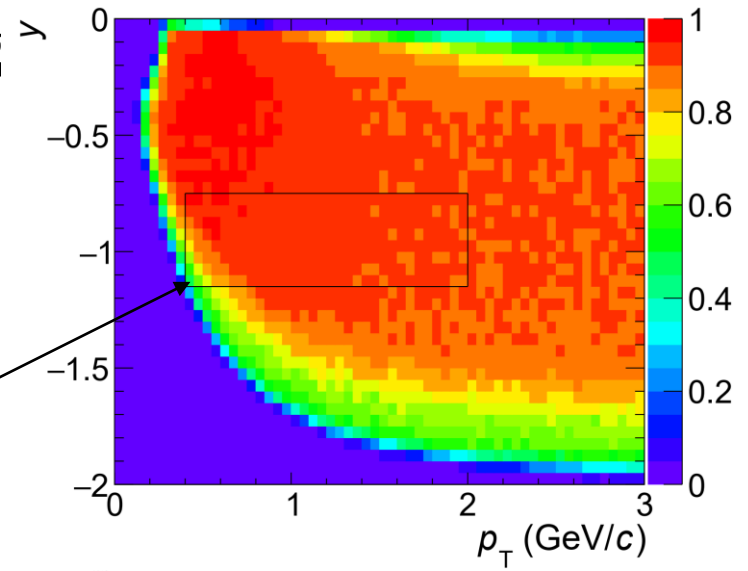
- My result
  - Pileup fraction α = 0.22%
  - 198 cm < V_z < 202 cm
  - $|V_r|$ < 2 cm, with center (0, −2) cm

- Vertex-dependent pileup fraction
- Valid unfolding code

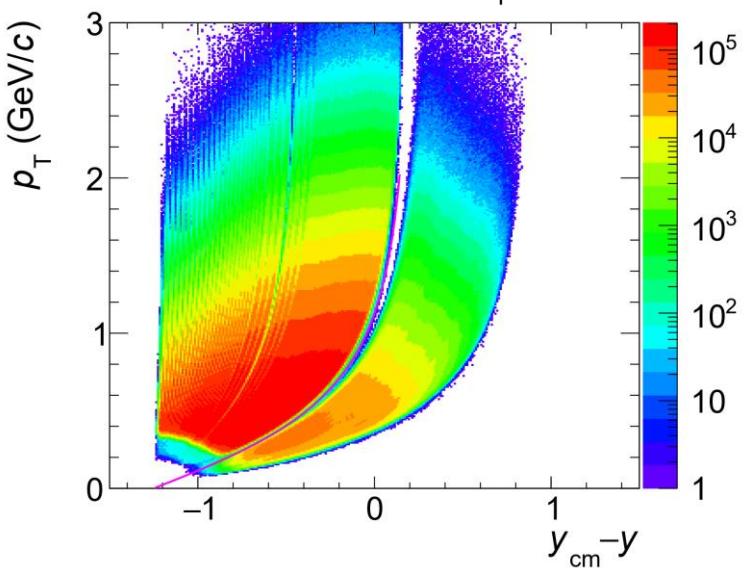


Acceptance extension

- TPC tracking efficiency

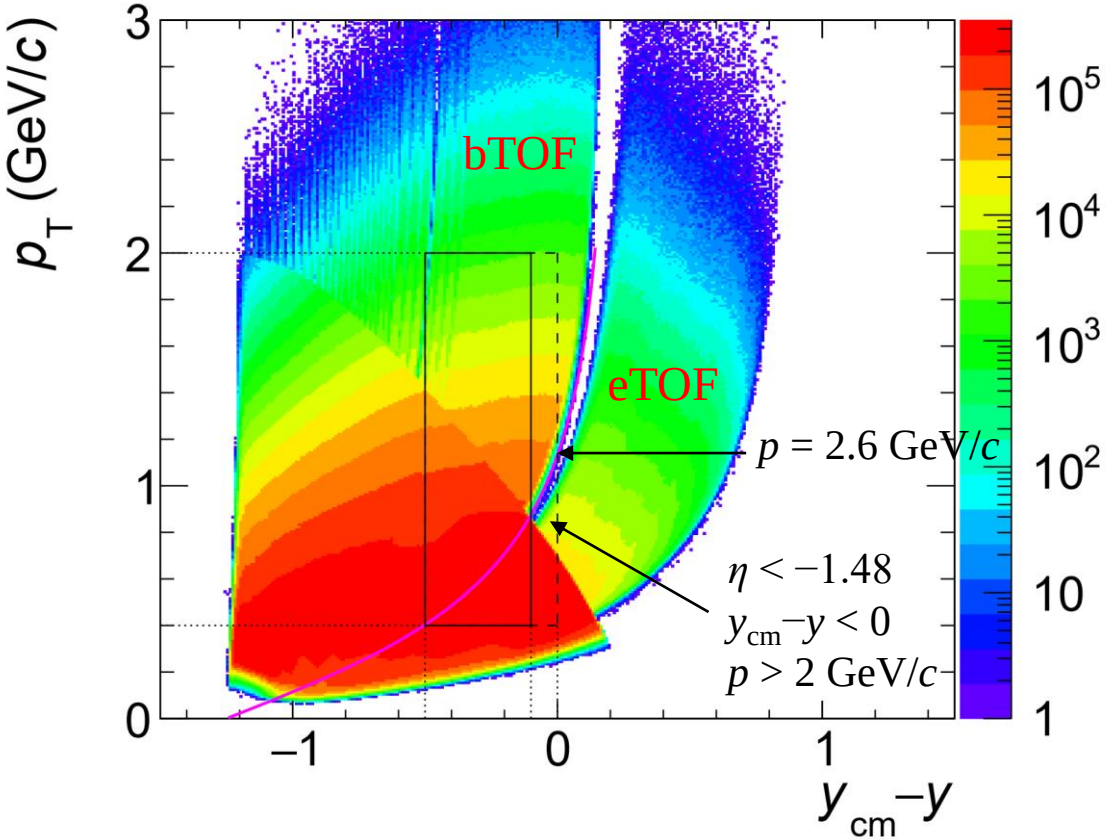


Edge of TPC (no iTPC)



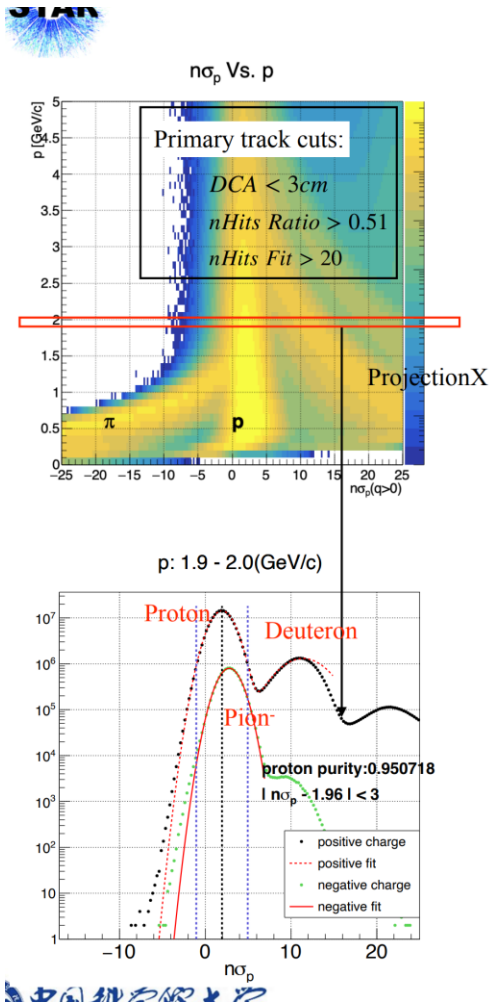
$$p_{\mathrm{T}} = \frac{m}{\sqrt{\left(\frac{\sinh \eta}{\sinh y}\right)^2 - 1}}$$

Curve: $\eta = -1.48$

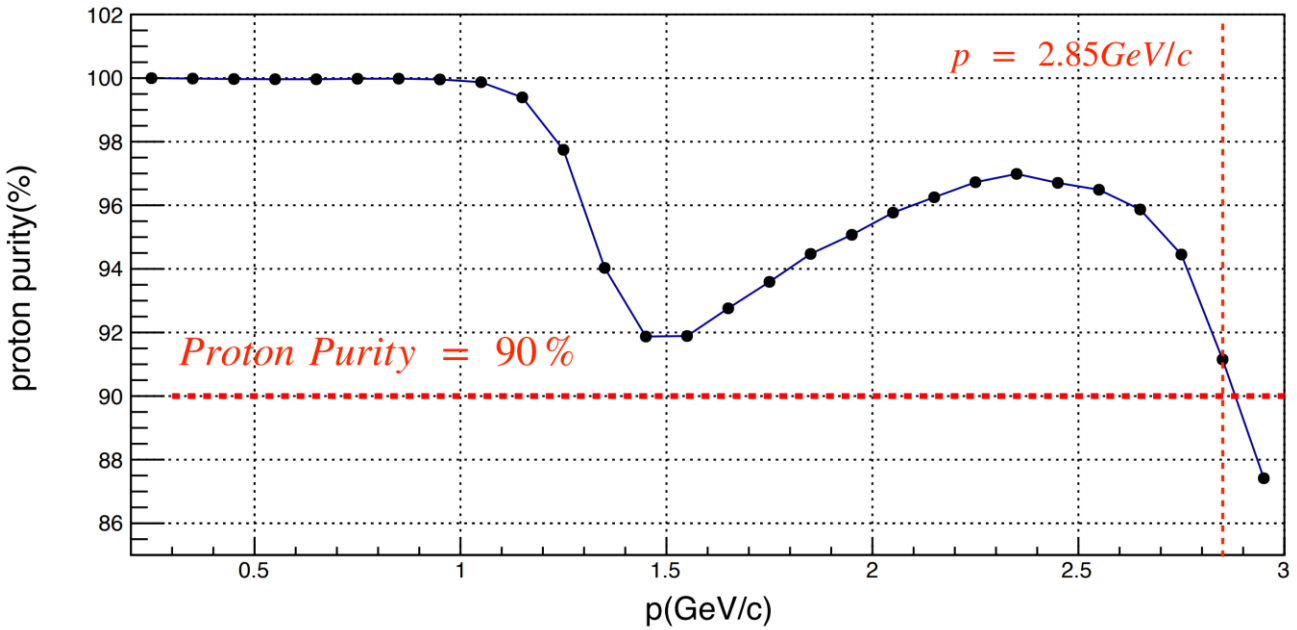


Proton purity estimtion

- Negatively charged particles are considered as pions



3. TPC Proton ID



$$proton\ purity = \frac{number_{proton}}{number_{all}} = \frac{number_{all} - \frac{number_{\pi^-}}{1.1} - number_D}{number_{all}}$$

To do

- Pileup study @ 3.5 GeV
- Purity estimation and acceptance extension for $-0.5 < y_{cm} - y < 0$
- Observation of p_T-y dependence of $n\sigma_{proton}$
- Some invalid modules of bTOF