# EMITTANCE PAPER

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CM45
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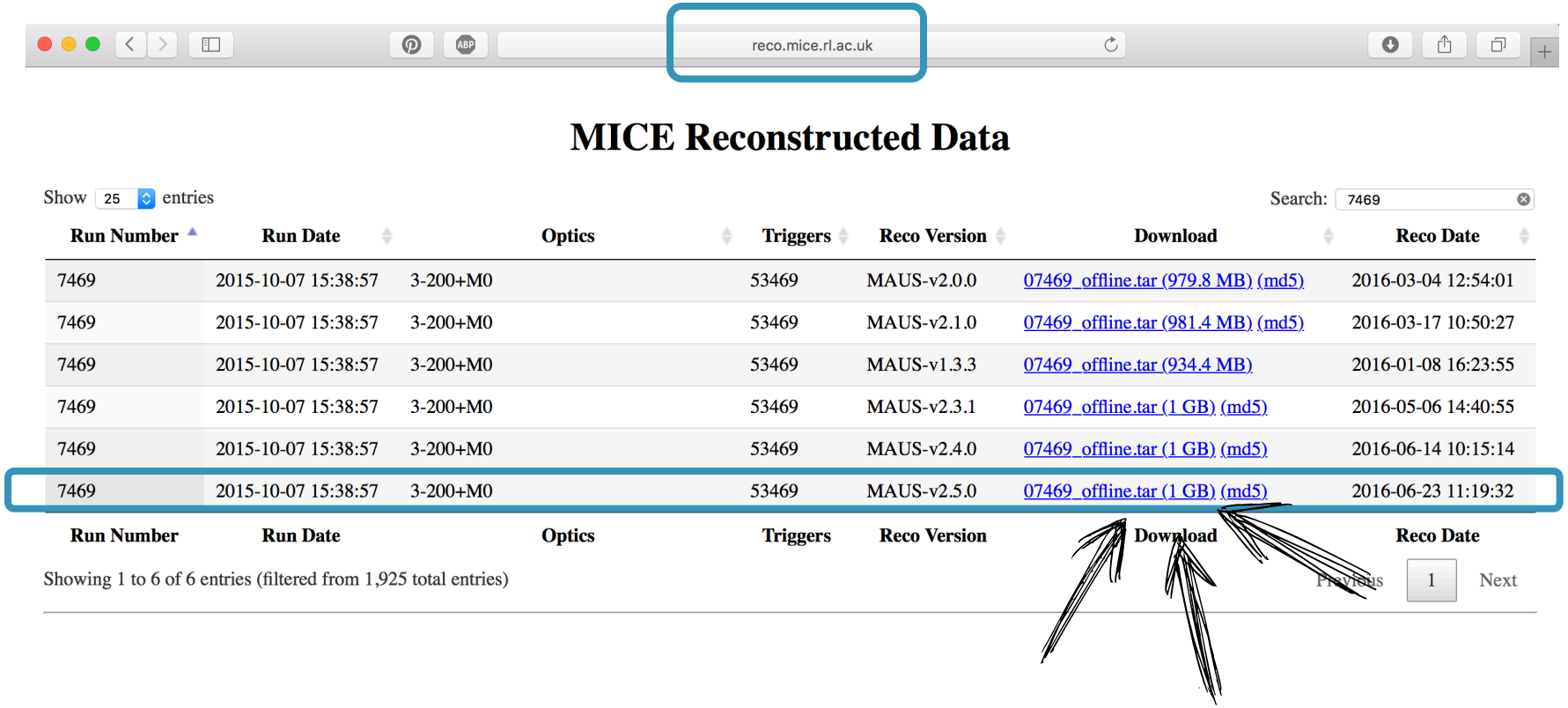
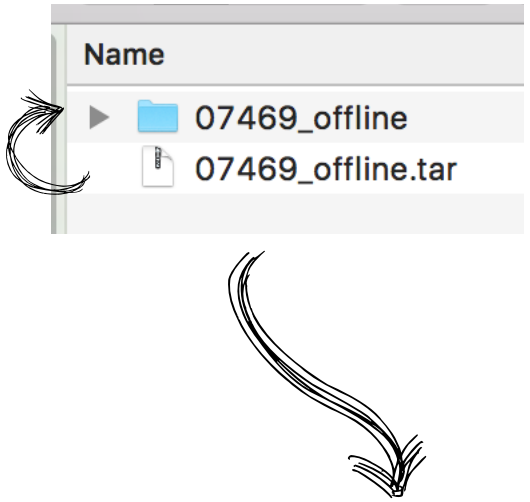
# CONTENTS

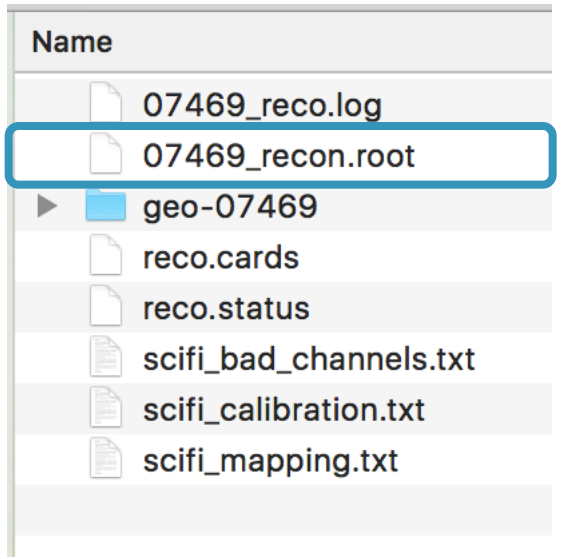
**Goal:** Everything you ever wanted to know about this analysis but were (never) afraid to ask.

1. Getting data
2. Extracting data, TOF-processing
3. Applying cuts
4. Covariance matrices & emittances
5. Error estimates
6. Ongoing analyses

# GETTING DATA

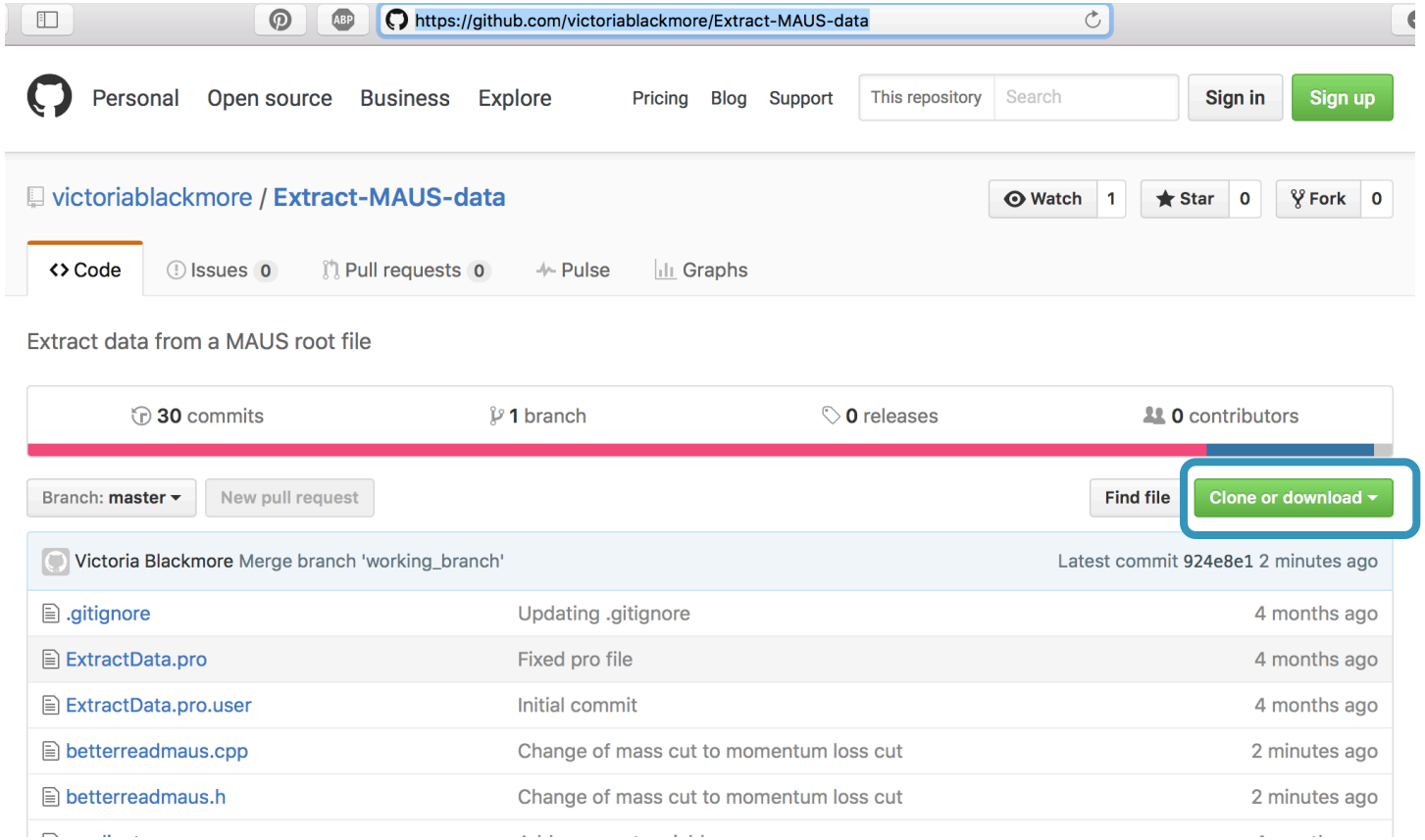


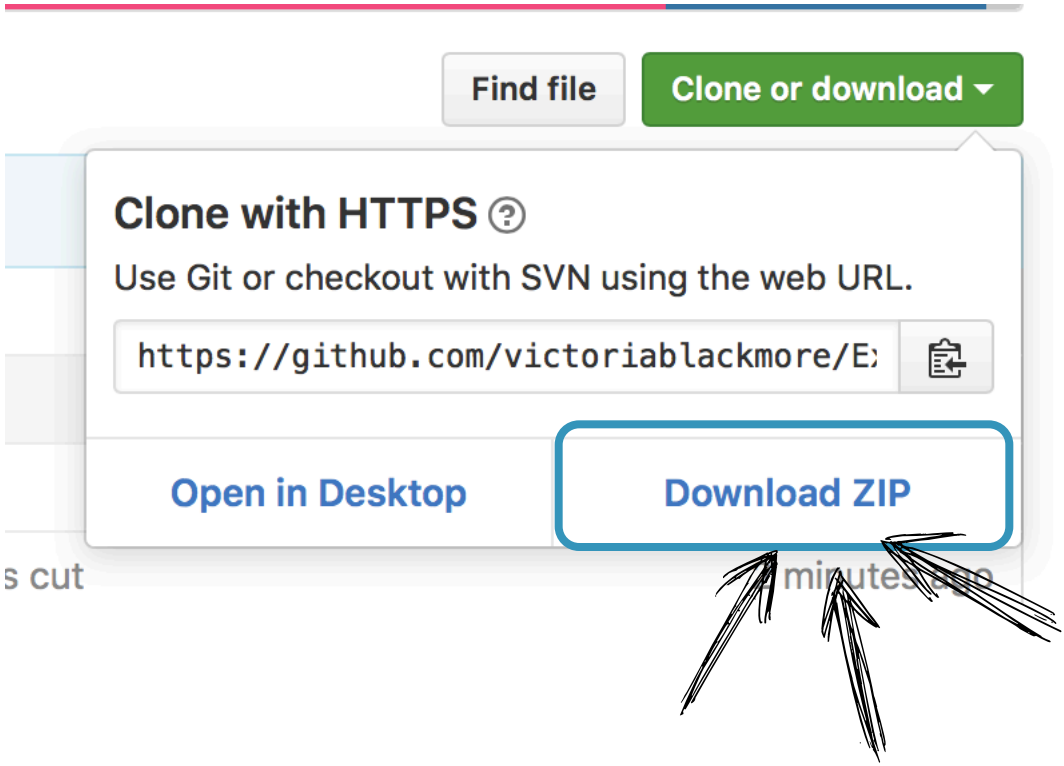



Not necessary for run 7469 (see later), **but** I'm including this here in case it's useful for other analyses...

# EXTRACT-YOUR-OWN...



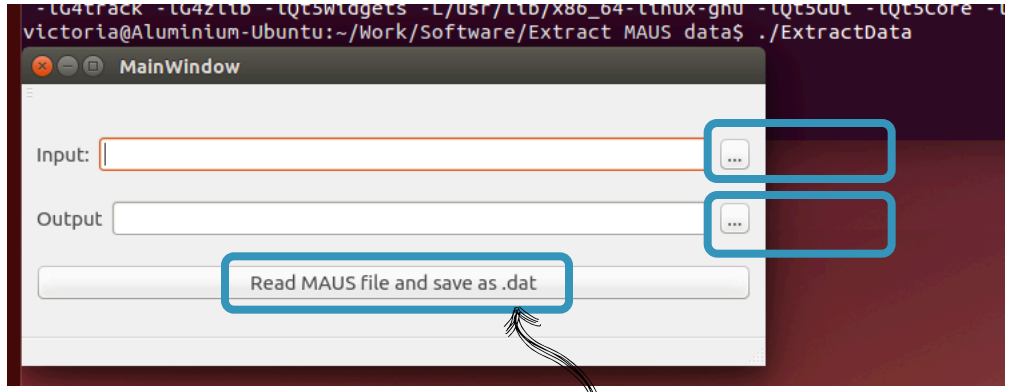
Not necessary for run 7469 (see later), **but** I'm including this here in case it's useful for other analyses...

# EXTRACT-YOUR-OWN...

```
victoria@Aluminium-Ubuntu: ~
victoria@Aluminium-Ubuntu:~$ source WorkPrograms/maus/env.sh
INFO: Using third party libraries from /home/victoria/WorkPrograms/maus
MAUS web front-end directory: /home/victoria/WorkPrograms/maus/third_party/install/lib/maus-apps-0.2
    Database directory: /home/victoria/WorkPrograms/maus/third_party/install/lib/maus-apps-0.2/db
    Media directory: /home/victoria/WorkPrograms/maus/third_party/install/lib/maus-apps-0.2/media
    Media directory (raw images): /home/victoria/WorkPrograms/maus/third_party/install/lib/maus-apps-0.2/media/raw
SUCCESS: MAUS setup
victoria@Aluminium-Ubuntu:~$
```

```
victoria@Aluminium-Ubuntu:~$ cd Work/Software/Extract\ MAUS\ data/
victoria@Aluminium-Ubuntu:~/Work/Software/Extract MAUS data$ qmake
victoria@Aluminium-Ubuntu:~/Work/Software/Extract MAUS data$ make
```

```
victoria@Aluminium-Ubuntu:~/Work/Software/Extract MAUS data$ ./ExtractData
```




*Oh look... a typo I just spotted.*
*It will save it as a **.root** file*

The extraction code requires you have a recent(ish) install of Qt. It's often pre-installed on many linux distributions, but if 'qmake' does nothing for you, I can walk you through that extra hoop.

1. Source your MAUS installation (NB: Your MAUS install must be of a version **at least** equal to what the data(MC) was reconstructed with)
2. Extract the downloaded source code from GitHub to your directory of choice. Here I put it in 'Extract MAUS data'. Then do:
    1. qmake
    2. make
3. Run the program with:
    1. ./ExtractData
4. Use the "highly intuitive" GUI to select your input reconstructed data or MC file, and pick a location and name for the output.
5. Click the button and wait.

# … OR BE LAZY.

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- **File** deleted (~~*run7469_extracted_data__MAUS2pt3pt1_c_tighterMassCut.root*~~)

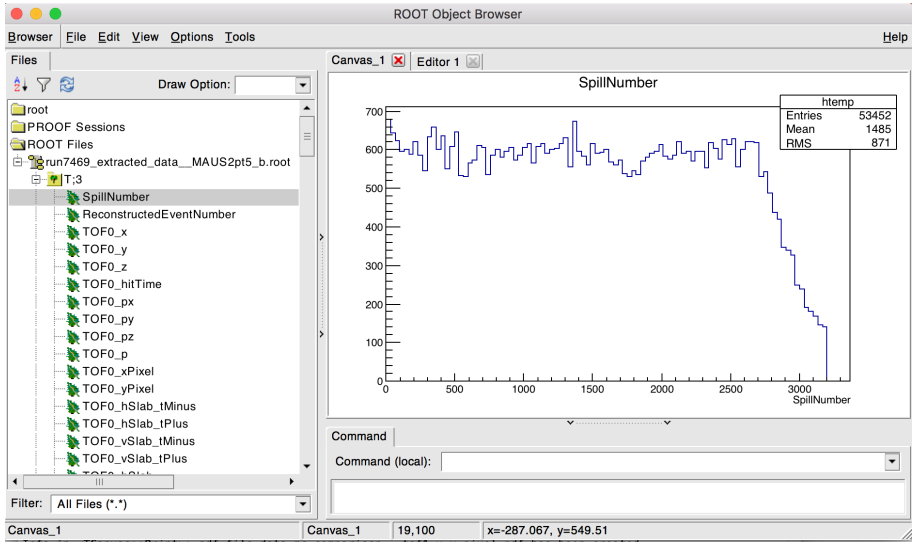
**Updated by Blackmore, Victoria 4 days ago** **#34**

- **File** run7469_extracted_data__MAUS2pt5_b.root added

Updating extracted data file:

- cut_allPassed has been modified to remove the mass cut (added in the last update) and replace it with a cut on the momentum lost between TOF1 and TKU.
  - removed: cut_muon_mass branch
  - added: cut_momentum_loss branch
  - modified: cut_allPassed now depends on cut_momentum_loss and not cut_muon_mass

```
Aluminium:Data run 7469 Victoria$ root -l run7469_extracted_data__MAUS2pt5_b.root
root [0]
Attaching file run7469_extracted_data__MAUS2pt5_b.root as _file0...
root [1] TBrowser b;
```



# BRANCHES IN EXTRACTED DATA FILE

| Branch name | Type | Unit | Description |
|---|---|---|---|
| SpillNumber | Int | -- | … as it sounds. |
| ReconstructedEventNumber | Int | -- | … as it sounds. Particles can be ID'd by (spill, event) |
| TOF0_x, TOF0_y, TOF0_z | Double | mm | Position at TOF0 (x, y) according to PMT-based position measurement |
| TOF0_px, TOF0_py, TOF0_pz, TOF0_p | Double | MeV/c | Momentum at TOF0 according to M. Rayner reconstruction |
| TOF0_xPrime, TOF0_yPrime | Double | rad | Reconstructed angle at TOF0 according to M. Rayner reconstruction |
| TOF0_xPixel, TOF0_yPixel | Double | mm | Position of the TOF pixel crossed, i.e. crossing point of slabs |
| TOF0_hitTime | Double | ns | Time particle crossed TOF0 |
| *TOF0_hSlab_tMinus, *TOF0_hSlab_tPlus | Double | ps | Time recorded at horizontal slab PMTs at positive (plus) and negative (minus) x |
| *TOF0_vSlab_tMinus, *TOF0_vSlab_tPlus | Double | ps | Time recorded at vertical slab PMTs at positive (plus) and negative (minus) y |
| TOF0_hSlab, TOF0_vSlab | Double | -- | Horizontal (hSlab) and vertical (vSlab) numbers hit |

* These are used to get the position of the particle at TOF0 according to the PMT times

# BRANCHES IN EXTRACTED DATA FILE

| Branch name | Type | Unit | Description |
|---|---|---|---|
| TOF1_x, TOF1_y, TOF1_z | Double | mm | Position at TOF1 (x, y) according to PMT-based position measurement |
| TOF1_px, TOF1_py, TOF1_pz, TOF1_p | Double | MeV/c | Momentum at TOF1 according to M. Rayner reconstruction |
| TOF1_xPrime, TOF1_yPrime | Double | rad | Reconstructed angle at TOF1 according to M. Rayner reconstruction |
| TOF1_xPixel, TOF1_yPixel | Double | mm | Position of the TOF pixel crossed, i.e. crossing point of slabs |
| TOF1_hitTime | Double | ns | Time particle crossed TOF1 |
| *TOF1_hSlab_tMinus, *TOF1_hSlab_tPlus | Double | ps | Time recorded at horizontal slab PMTs at positive (plus) and negative (minus) x |
| *TOF1_vSlab_tMinus, *TOF1_vSlab_tPlus | Double | ps | Time recorded at vertical slab PMTs at positive (plus) and negative (minus) y |
| TOF1_hSlab, TOF1_vSlab | Double | -- | Horizontal (hSlab) and vertical (vSlab) numbers hit |

* These are used to get the position of the particle at TOF1 according to the PMT times

# BRANCHES IN EXTRACTED DATA FILE

| Branch name | Type | Unit | Description |
|---|---|---|---|
| TKU_s1_x, TKU_s1_y, TKU_s1_z | Double | mm | Position at tracker station 1 from MAUS::SciFiTrackPoint->pos().x() |
| TKU_s1_px, TKU_s1_py, TKU_s1_pz, TKU_s1_p | Double | MeV/c | Position at tracker station 1 from MAUS::SciFiTrackPoint->mom().x() |
| TKU_s1_pull | Double | | Pull at tracker station 1 from MAUS::SciFiTrackPoint->pull() |
| TKU_s1_x_error, TKU_s1_y_error | Double | mm | Error on position from track fit (MAUS::SciFiTrackPoint->errors() ) |
| TKU_s1_px_error, TKU_s1_py_error | Double | MeV/c | Error on momentum from track fit (MAUS::SciFiTrackPoint->errors() ) |
| TKU_s1_kappa_error | Double | T/GeV* | kappa = qBz/Pz (in GeV), error from track fit (as above) |
| TKU_PValue | Double | | P-value from MAUS::SciFiTrackPoint->P_value() |
| TKU_chiSquare | Double | | Chi-squared from MAUS::SciFiTrackPoint->chi_2() |
| TKU_pattRec_r | Double | mm | Radius of patt. rec. circle from MAUS::SciFiHelicalPRTrack->get_R() |
| TKU_pattRec_dipAngle | Double | rad | Angle of helix from MAUS::SciFiHelicalPRTrack->get_dsdz() |
| TKU_pattRec_x0, TKU_pattRec_y0 | Double | mm | Centre of patt. rec. circle from MAUS::SciFiHelicalPRTrack->get_circle_x0() and MAUS::SciFiHelicalPRTrack->get_circle_y0() |

Replace ‘s1’ with ‘s2’ for station 2, ‘s3’ for station 3, etc...

# BRANCHES IN EXTRACTED DATA FILE

## Cuts

*cut = 1, particle passed*
*cut = 0, particle failed*

| Branch name | Type | Unit | Description (or pass condition if branch begins with 'cut_') |
|---|---|---|---|
| TKU_mass | Double | MeV/$c^2$ | Calculated particle mass using time-of-flight and TKU momentum |
| TKU_good | Int | -- | If there were 5 station hits, this is 1. Otherwise, 0. |
| TKU_station_hits | Int | -- | The number of station hits in the track |
| cut_TOF0_goodPMTPosition | Int | -- | TOF0_xPixel – slabWidth <= TOF0_x <= TOF0_xPixel + slabWidth |
| cut_TOF1_goodPMTPosition | Int | -- | TOF1_xPixel – slabWidth <= TOF1_x <= TOF1_xPixel + slabWidth |
| cut_goodRaynerReconstruction | Int | -- | M. Rayner reconstruction converges |
| cut_TKU_hitAllStations | Int | -- | TKU_station_hits == 5 |
| cut_TimeOfFlight | Int | -- | 27 <= (TOF1_hitTime - TOF0_hitTime) <= 40 |
| cut_hit_all_detectors | Int | -- | cut_TOF0_goodPMTPosition && cut_TOF1_goodPMTPosition && cut_TKU_hitAllStations |
| cut_TOF0_singleHit | Int | -- | MAUS::TOFEventSpacePoint->GetTOF0SpacePointArray()->size() ==1 |
| cut_TOF1_singleHit | | | MAUS::TOFEventSpacePoint->GetTOF1SpacePointArray()->size() ==1 |

# Cuts

*cut = 1, particle passed*
*cut = 0, particle failed*

# BRANCHES IN EXTRACTED DATA FILE

| Branch name | Type | Unit | Description |
|---|---|---|---|
| cut_TKU_singleTrack | Int | -- | MAUS::SciFiTrack->size() == 1 |
| cut_TKU_PValue | Int | -- | TKU_PValue >= 0.01 |
| cut_momentum_loss | Int | -- | min_tracker(beta*gamma) <= tof(beta*gamma) <= max_tracker(beta*gamma) |
| cut_allPassed | Int | -- | cut_TOF0_goodPMTPosition && cut_TOF1_goodPMTPosition && cut_goodRaynerReconstruction && cut_TKU_hitAllStations && cut_TimeOfFlight && cut_hit_all_detectors && cut_TOF0_singleHit && cut_TOF1_singleHit && cut_TKU_PValue && cut_momentum_loss |

$$\text{min\_tracker}(\beta\gamma) = (p + p_{\text{min}})/m_\mu$$
$$\text{max\_tracker}(\beta\gamma) = (p + p_{\text{max}})/m_\mu$$

$p_{\text{min}} = 5$ MeV/c
$p_{\text{max}} = 43.4$ MeV/c

These are $3\sigma$ away from the mean total momentum difference between TOF1 and TKU

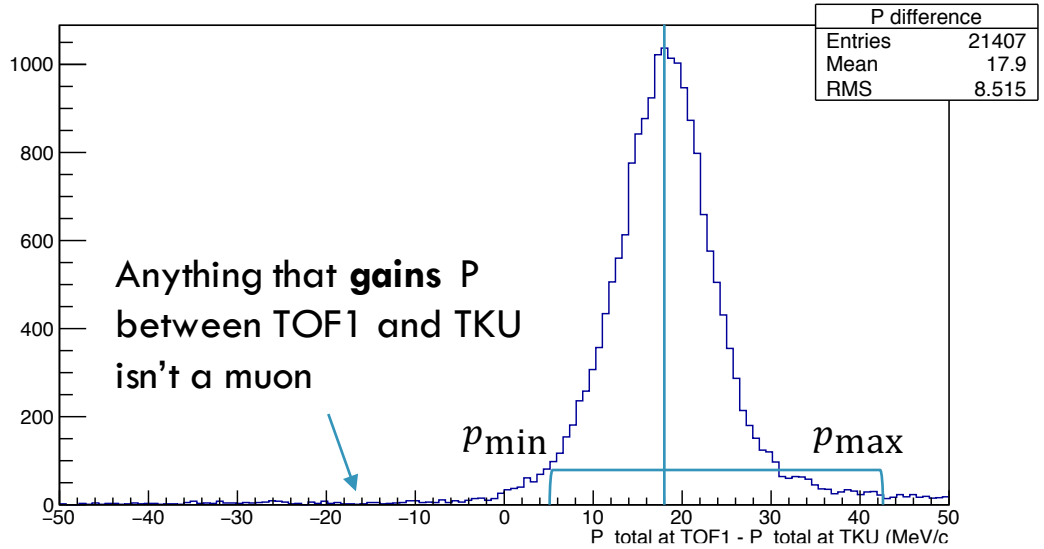
$$\text{tof}(\beta) = t_e/t_\mu$$
$$\text{tof}(\gamma) = 1/\sqrt{1 - \beta^2}$$

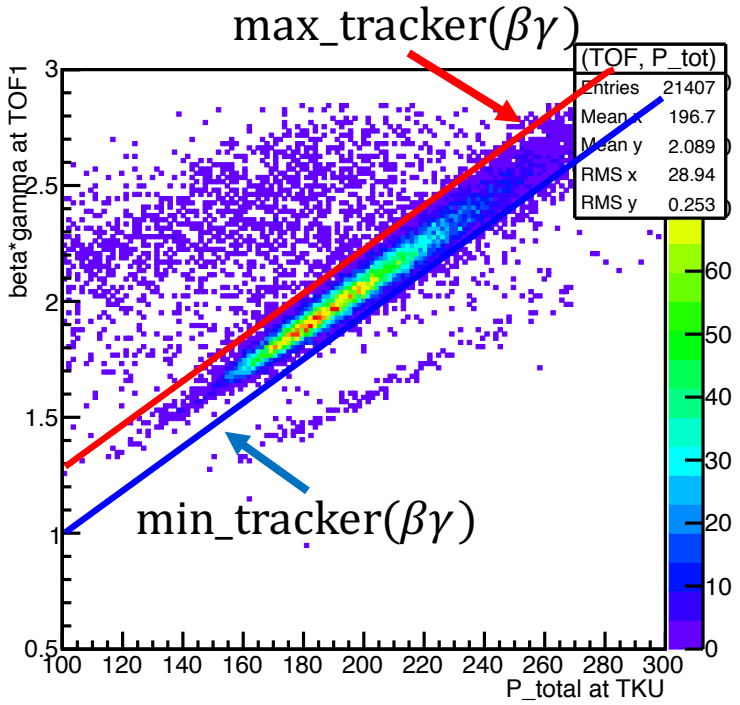
*(P evaluated at tracker station 1)*

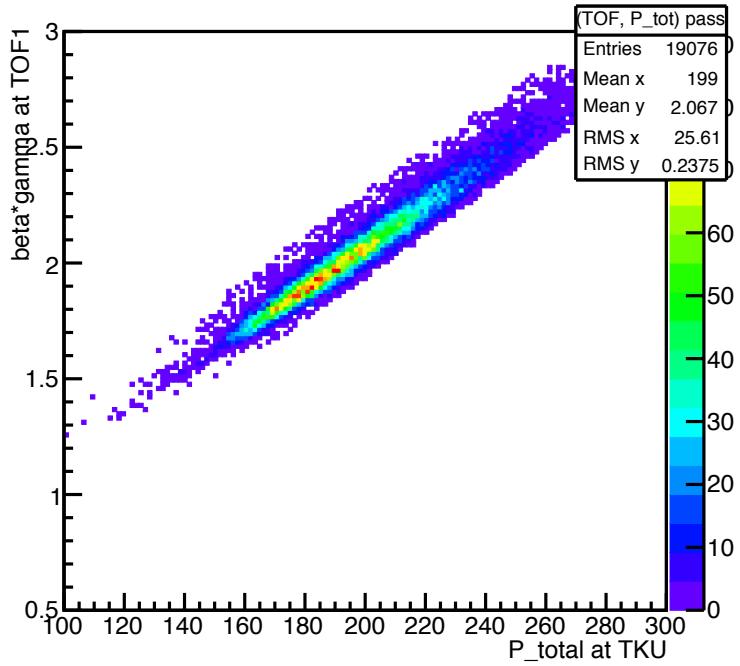
# CUT_MOMENTUM_LOSS

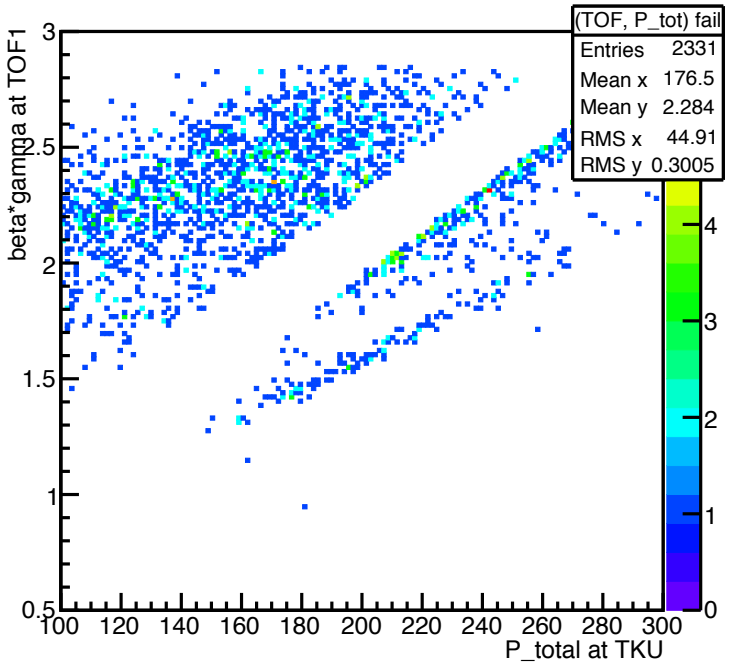
$$\text{min\_tracker}(\beta\gamma) = (p + p_{\text{min}})/m_{\mu}$$

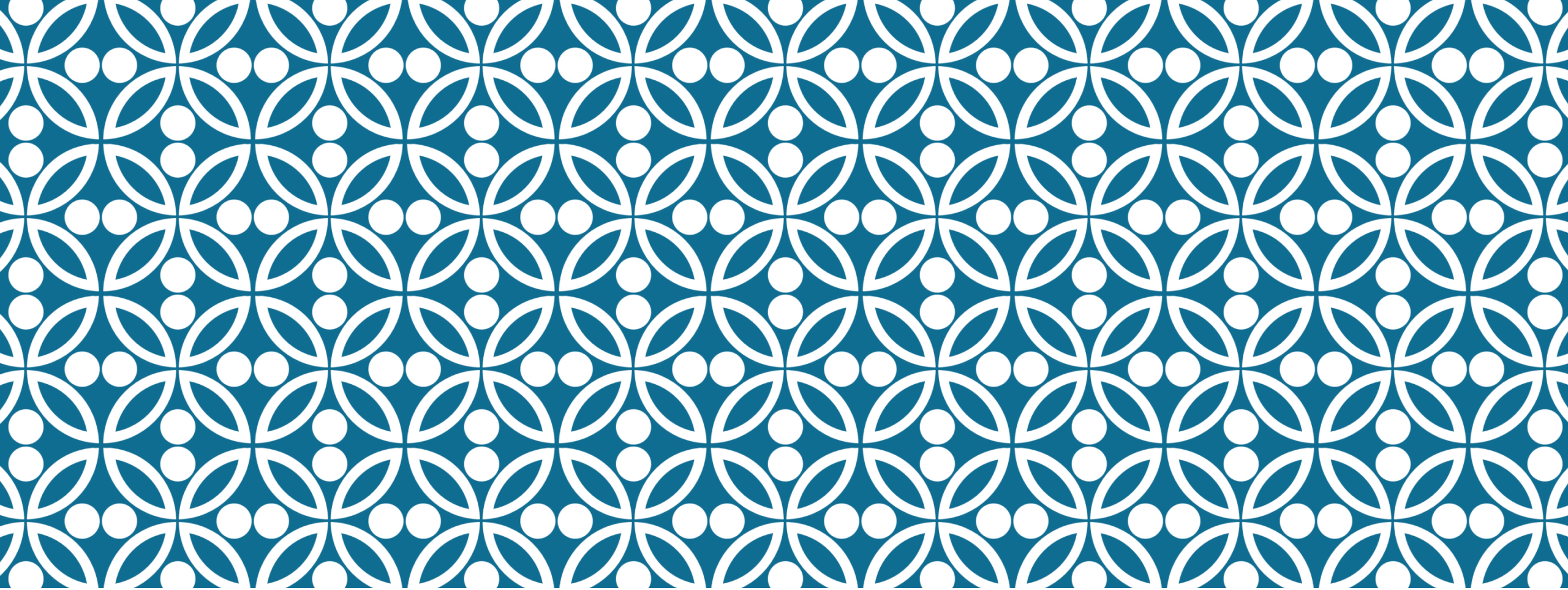
$$\text{max\_tracker}(\beta\gamma) = (p + p_{\text{max}})/m_{\mu}$$





# WHAT'S WITH ALL THE CUTS?

Compare distributions:

- with all cuts applied
- with all but cut-of-interest applied

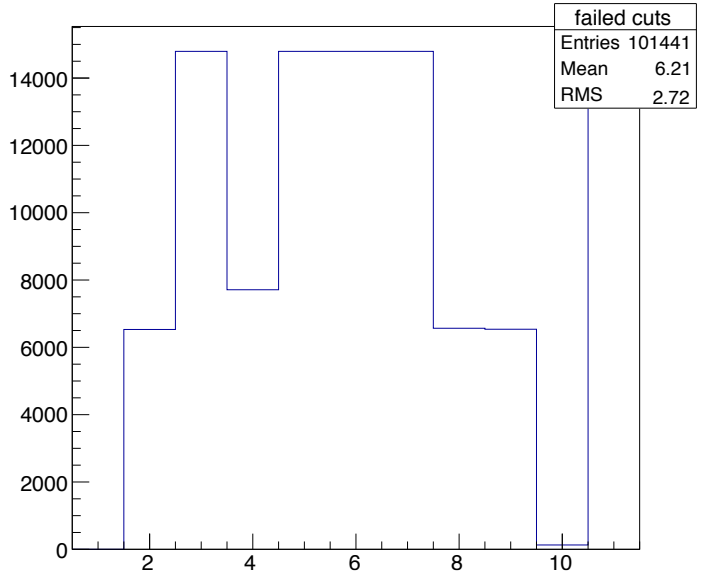
# A THOUGHT EXPERIMENT ON CUTS

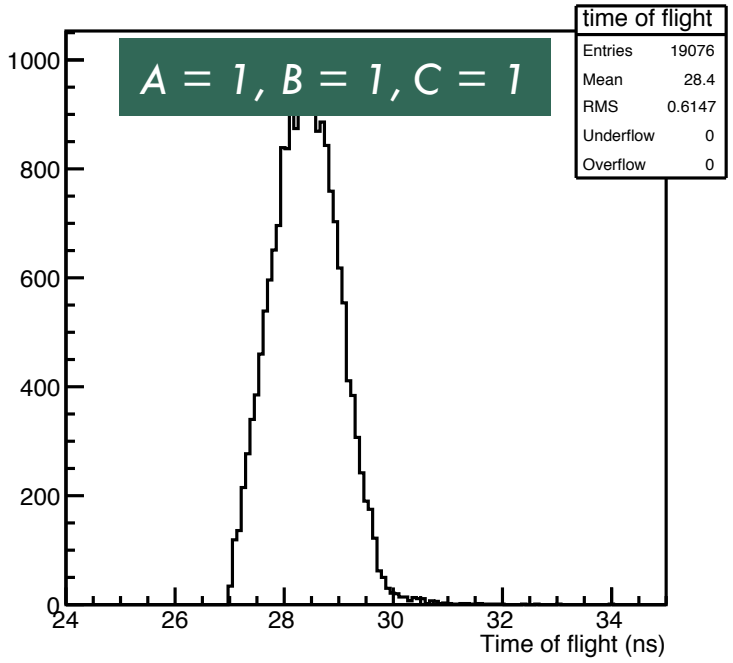
- Say we have 3 cuts: A, B & C
  - We want to accept particles that pass all 3 cuts, so we introduce a shorthand ‘D’
  - D = 1 if A = B = C = 1
  - D = 0 otherwise
- We want to test the effectiveness of cut A:
  - Look at particles that have D = 1
  - Look at particles that have A = 0, B = 1, C = 1
  - Look at particles that have A = 0, regardless of what B & C do
  - If a particle fails A, see if it also fails B or C
- … and now extend this to the 11 cuts we have

# A THOUGHT EXPERIMENT ON CUTS

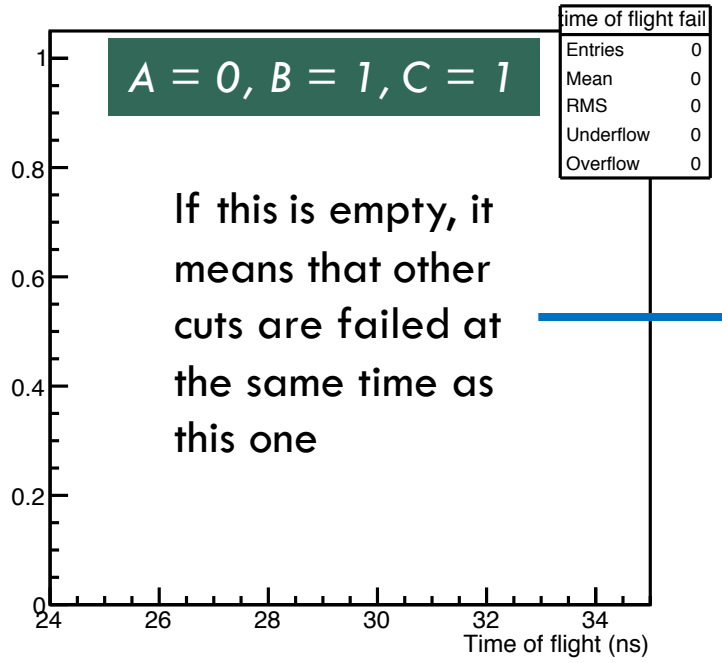
A pseudo-example of what's to come...

If **this cut** is failed, fill histogram with the other cuts that failed (so #entries ≠ #particles)



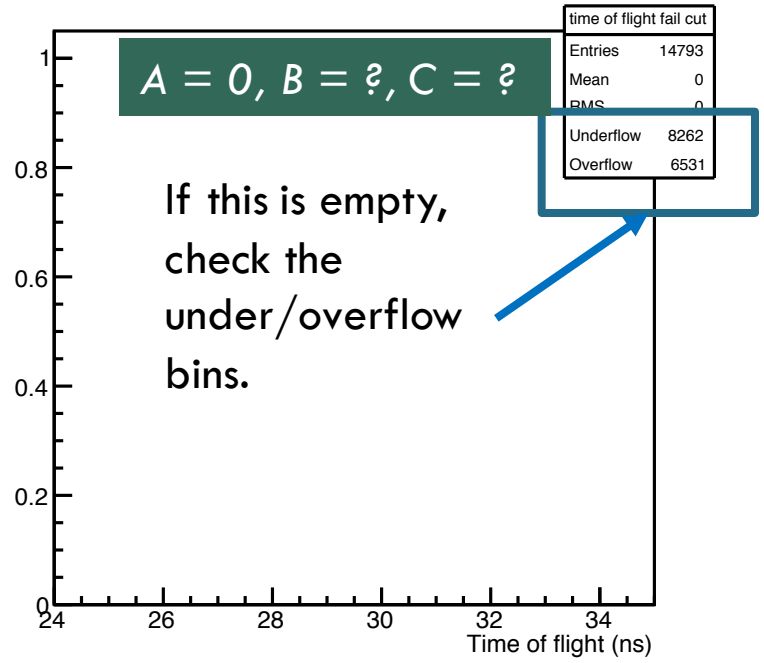




These particles pass **all cuts**




If this is empty, it means that other cuts are failed at the same time as this one

These particles pass **all cuts except this one**



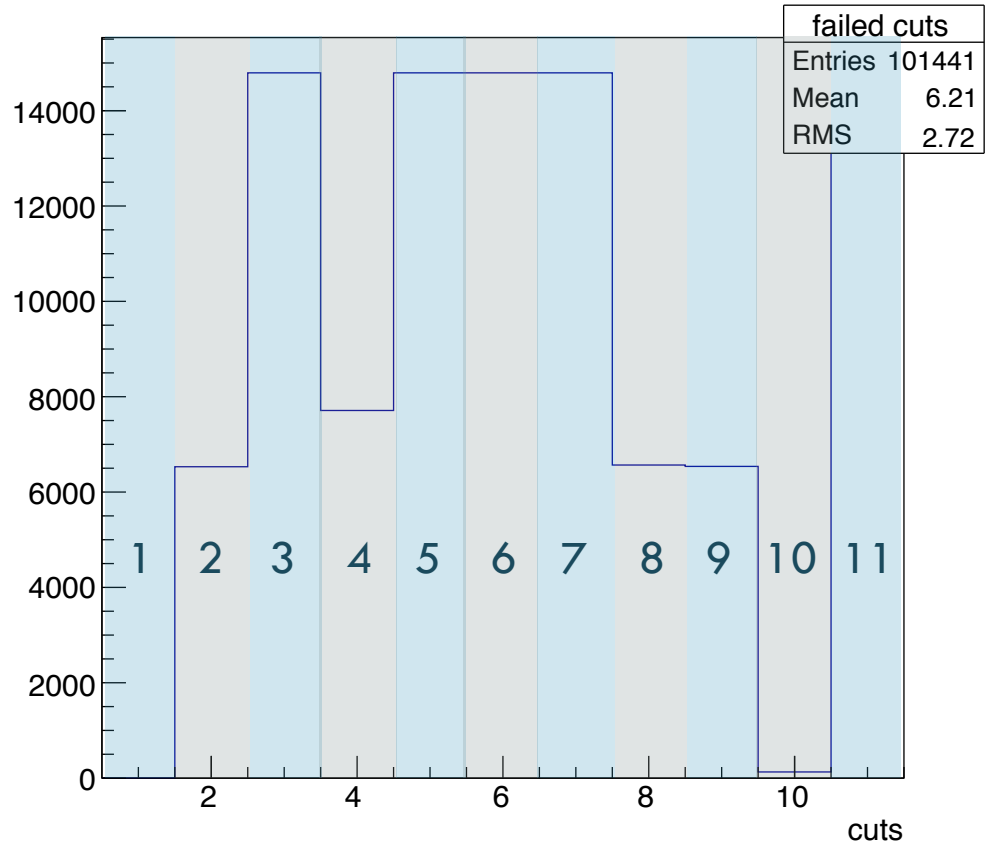

If this is empty, check the under/overflow bins.

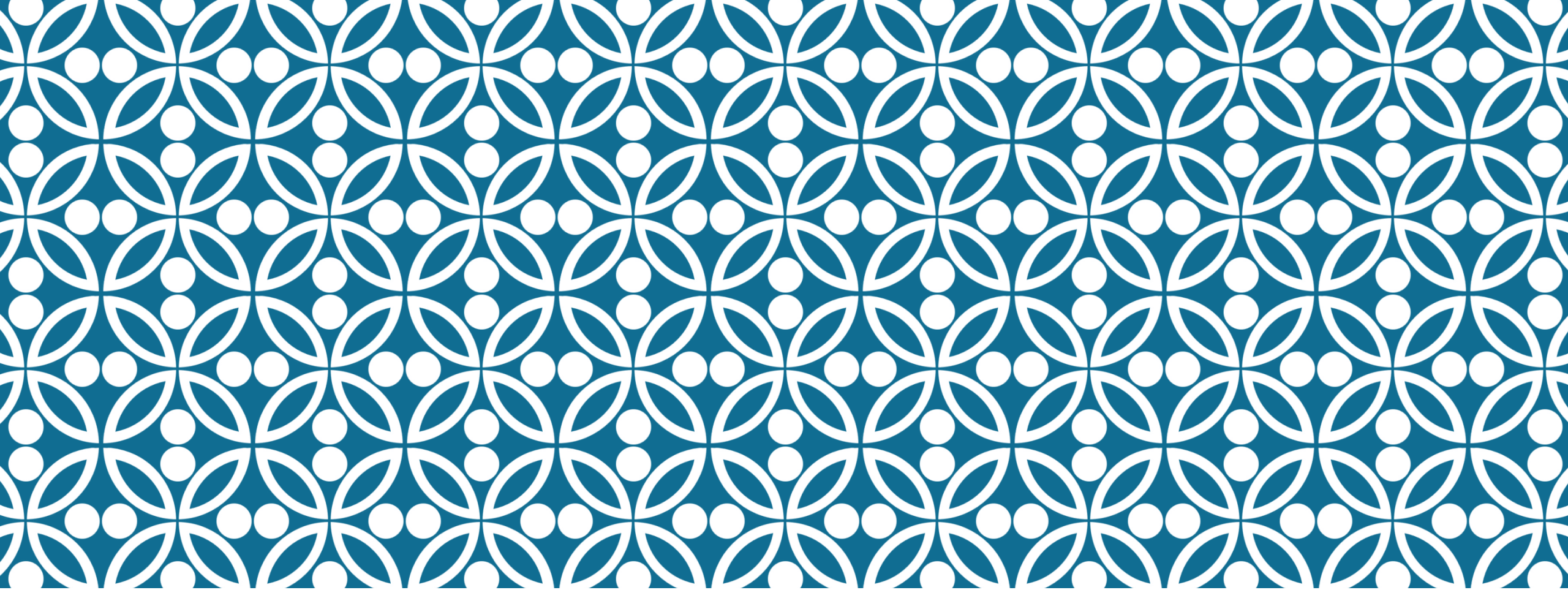
These particles **fail this cut**

# A THOUGHT EXPERIMENT ON CUTS

A pseudo-example of what's to come...

| 'Cut number' | Cut |
|---|---|
| 1 | cut_TOF0_goodPMTPosition |
| 2 | cut_TOF1_goodPMTPosition |
| 3 | cut_goodRaynerReconstruction |
| 4 | cut_TKU_hitAllStations |
| 5 | cut_TimeOfFlight |
| 6 | cut_hit_all_detectors |
| 7 | cut_TOF0_singleHit |
| 8 | cut_TOF1_singleHit |
| 9 | cut_TKU_singleTrack |
| 10 | cut_TKU_PValue |
| 11 | cut_momentum_loss |

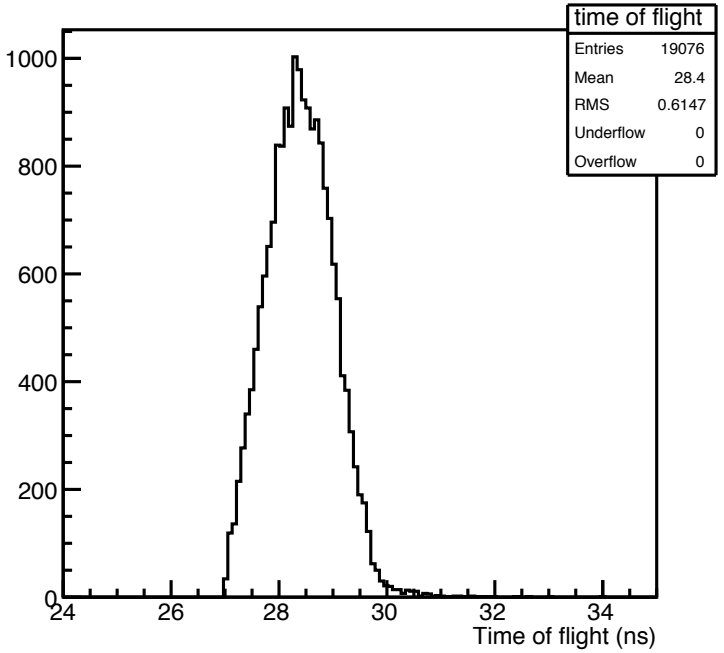


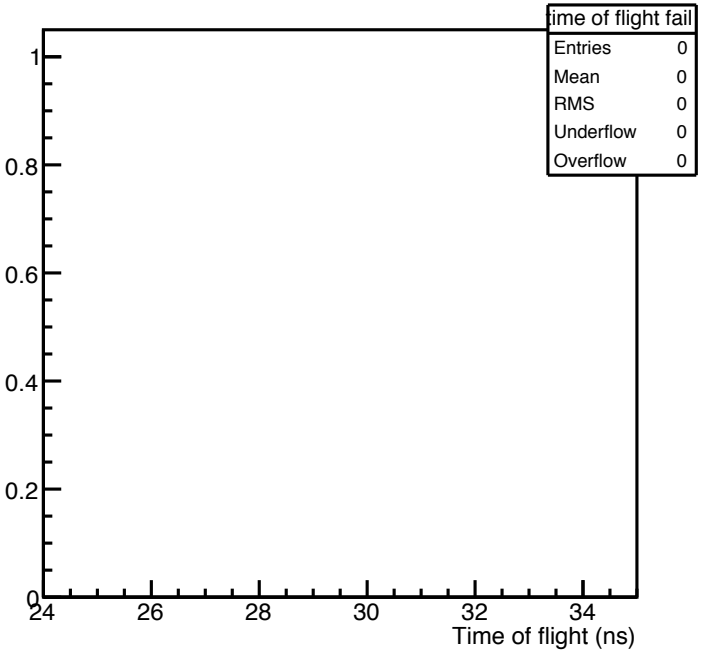


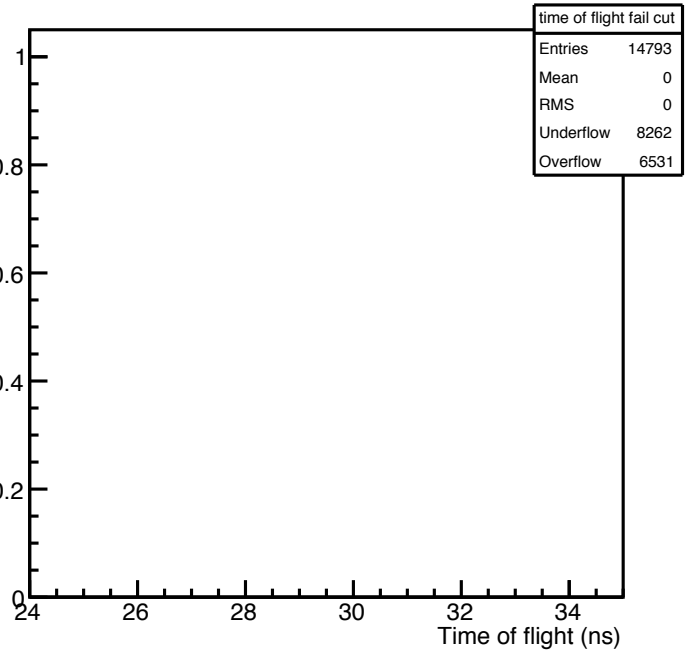
# CUT_TOF0_GOODPMTPOSITION

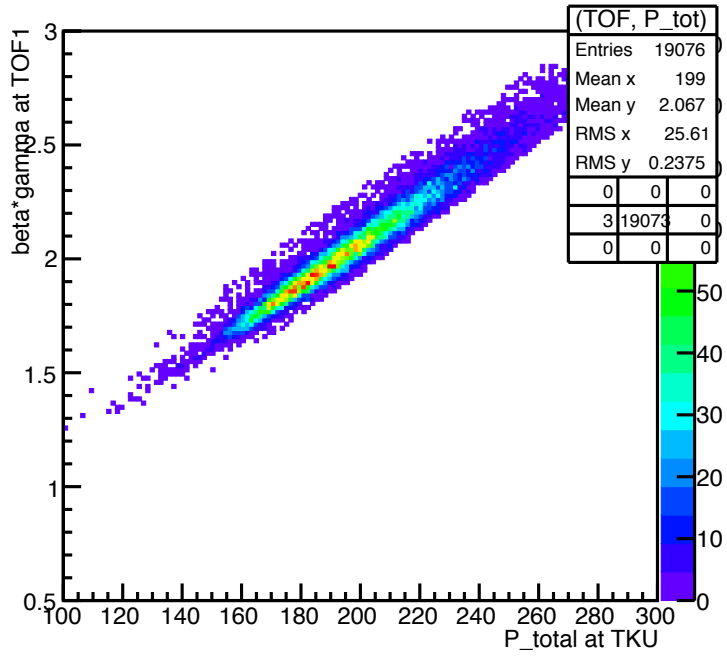
AKA ‘cut 1’

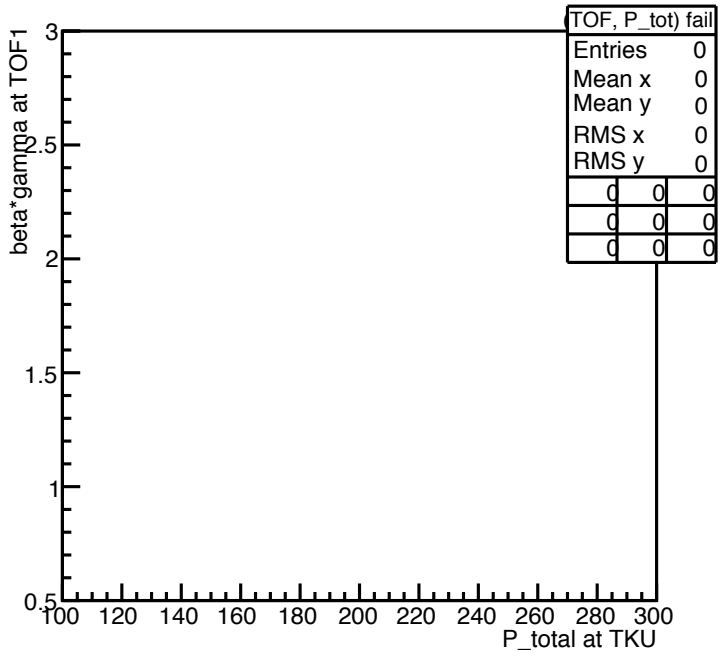
*cut_TOF0_goodPMTPosition (cut 1)*

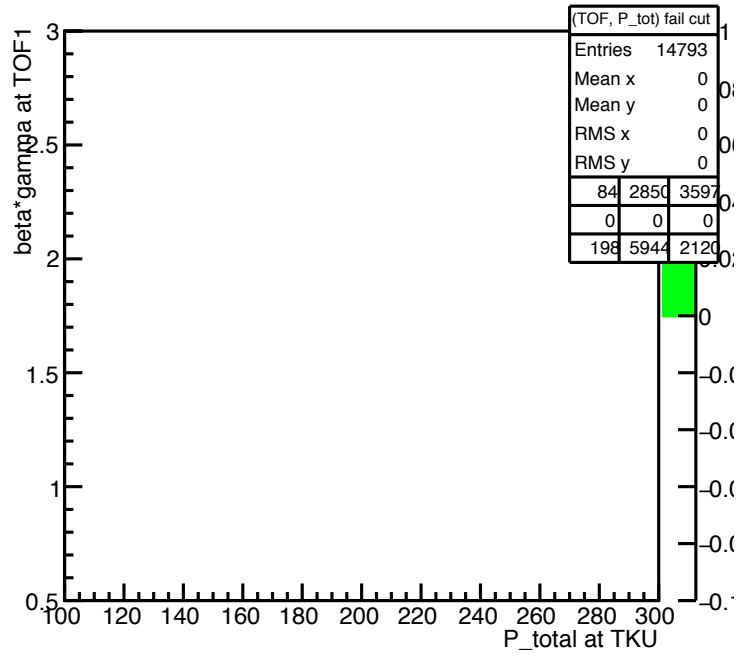


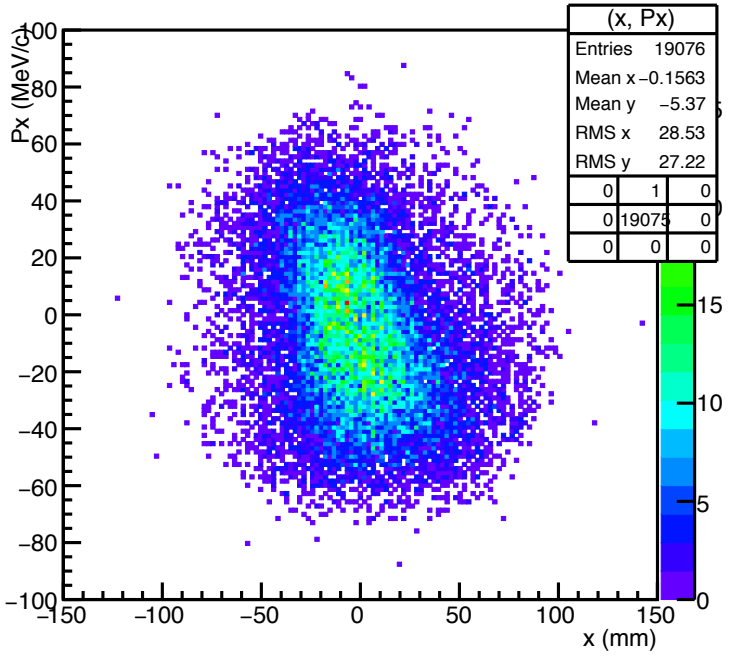



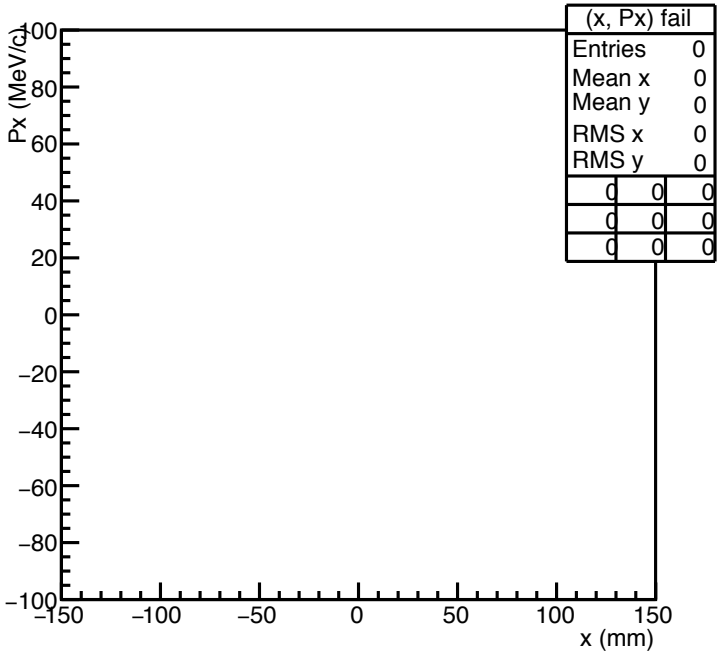



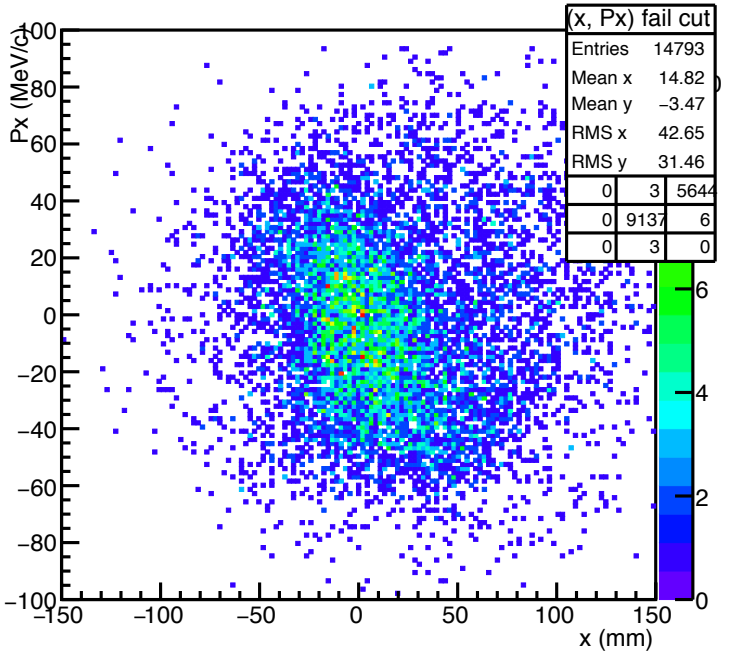



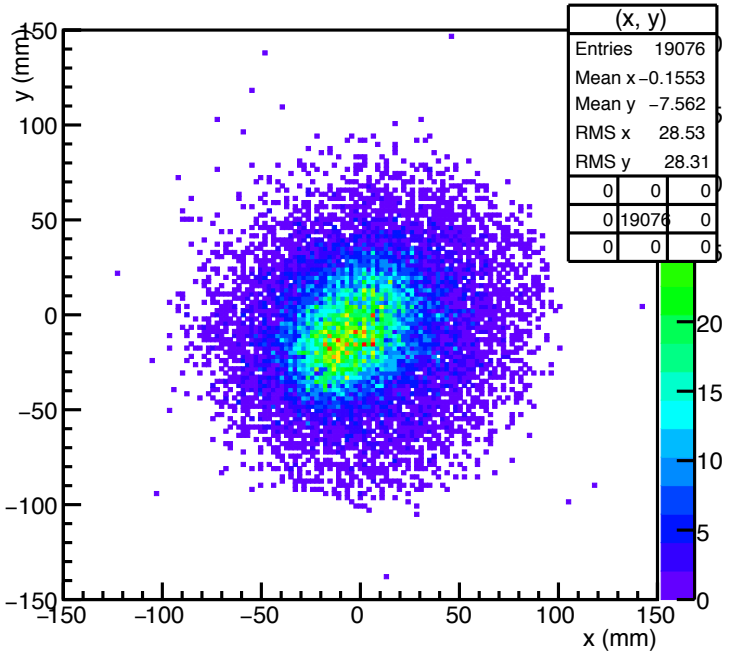



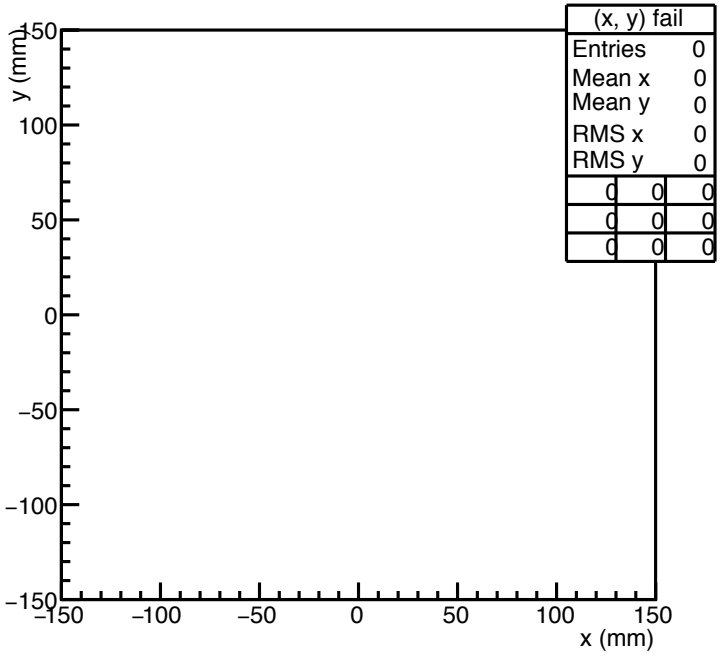
*cut_TOF0_goodPMTPosition (cut 1)*

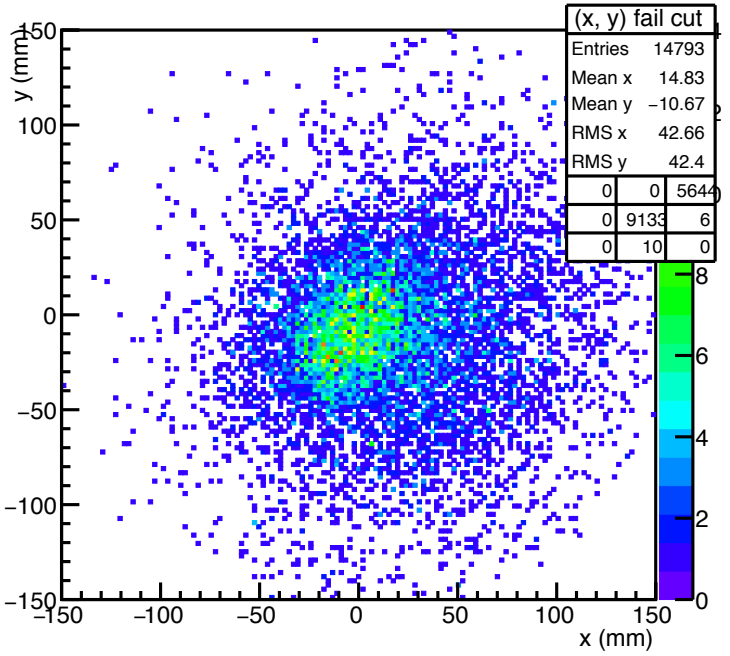


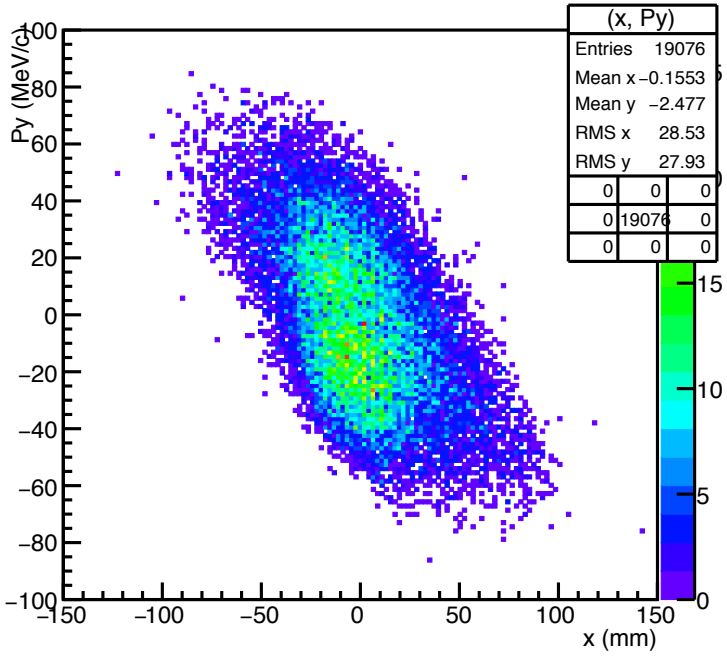



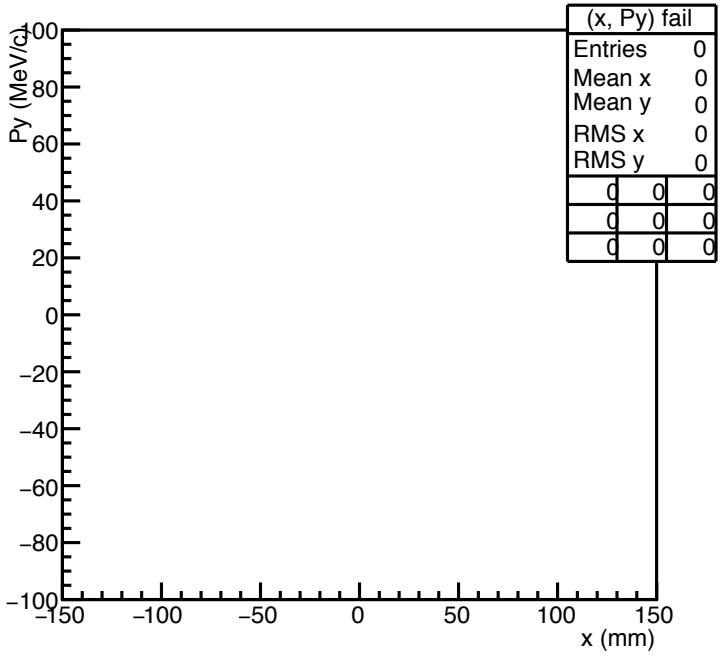



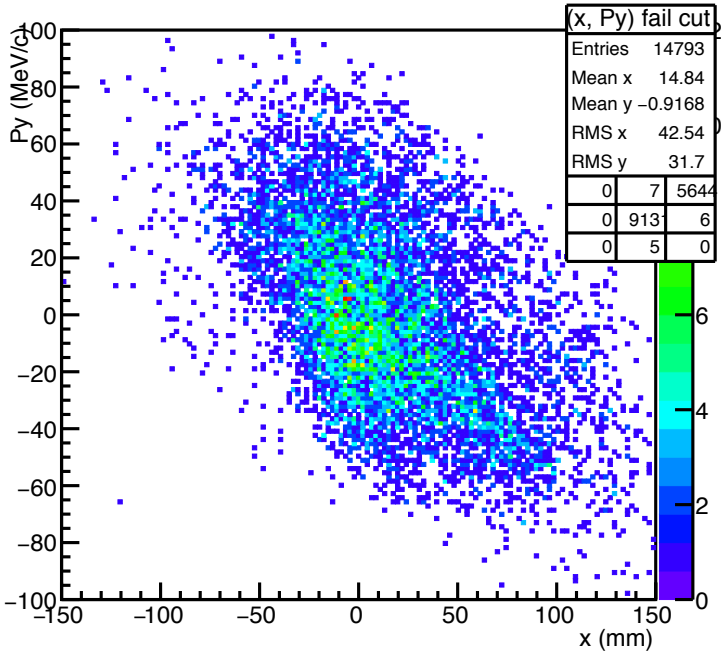



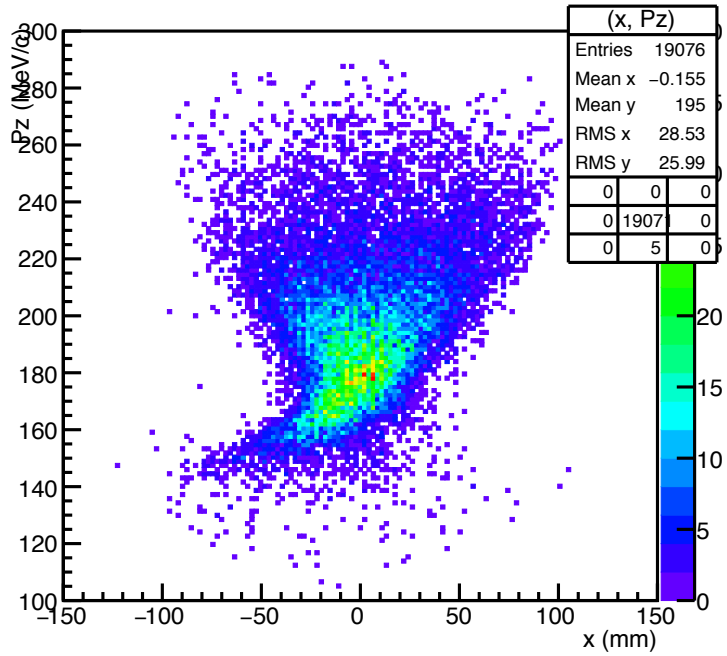



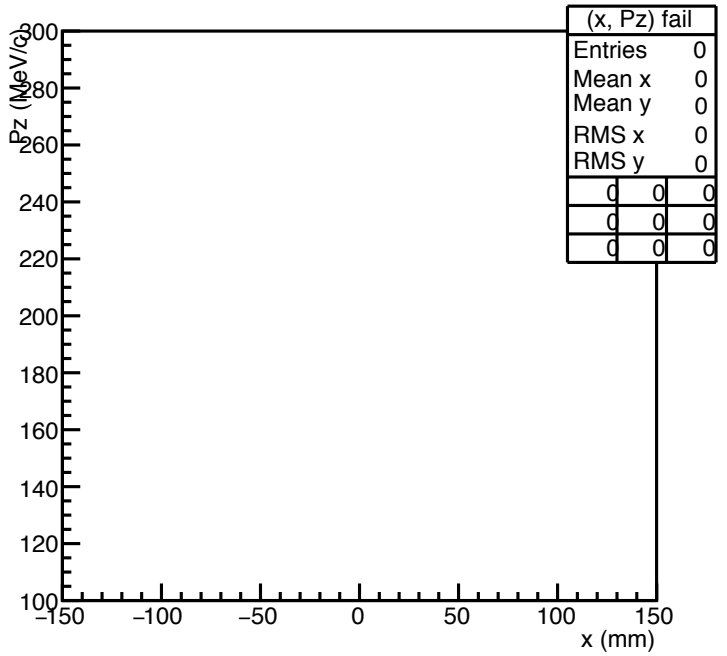
*cut_TOF0_goodPMTPosition (cut 1)*

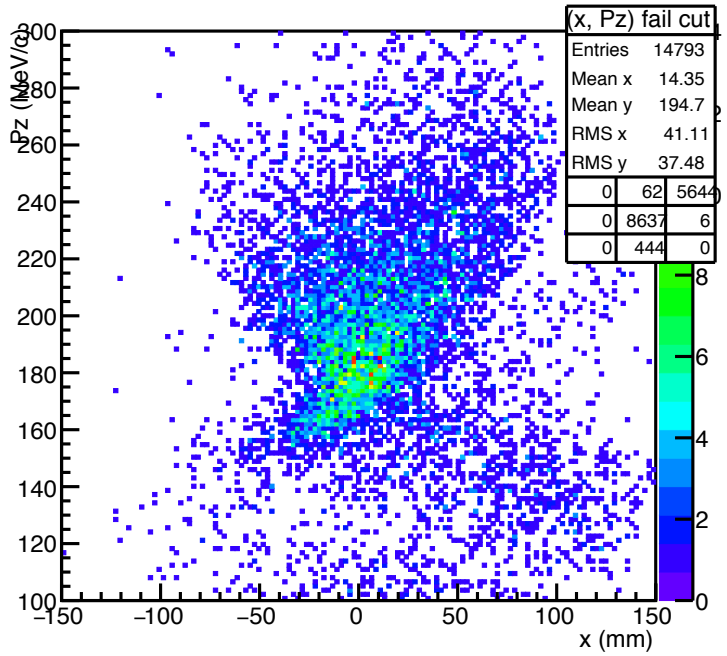


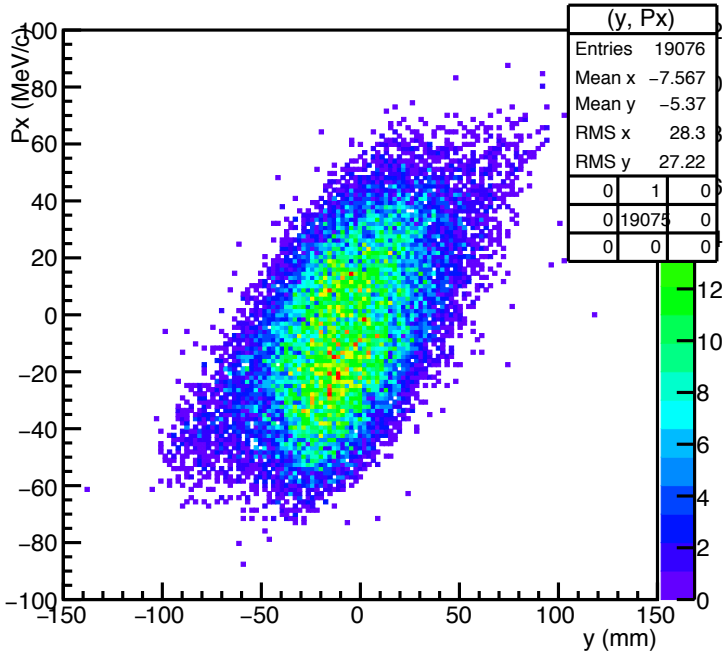



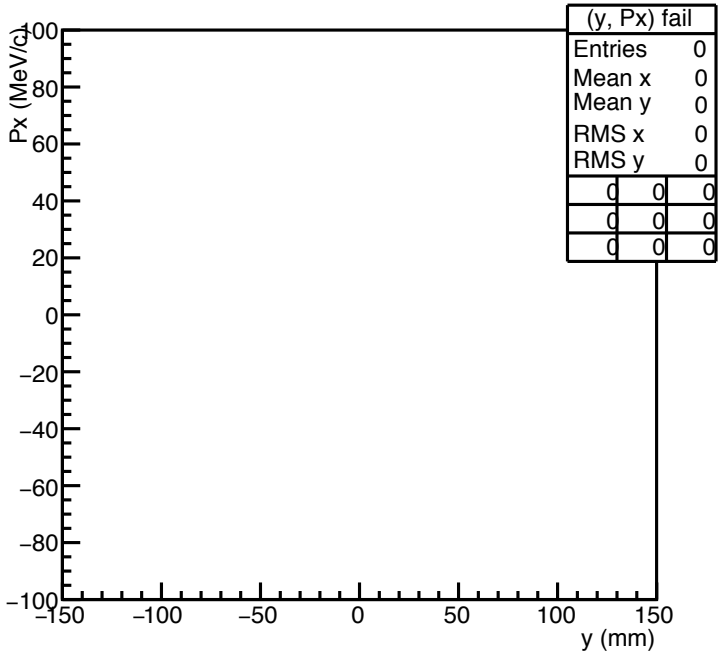



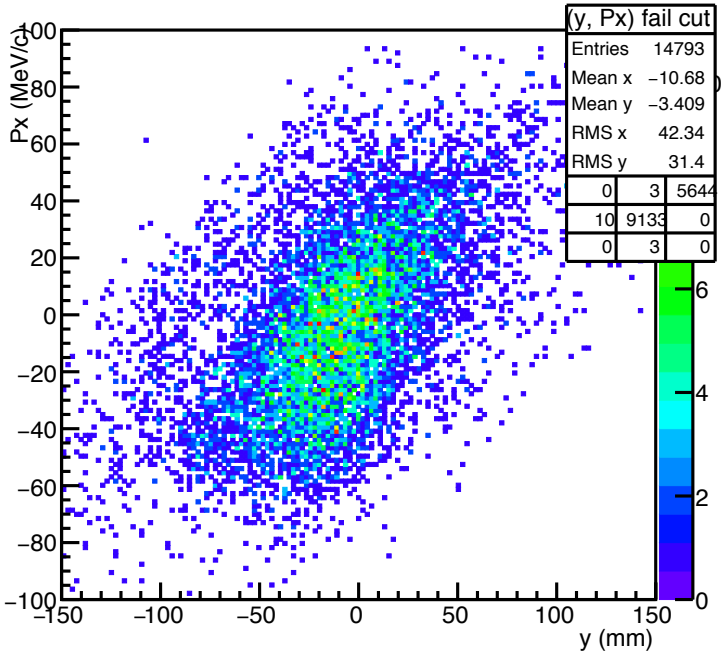



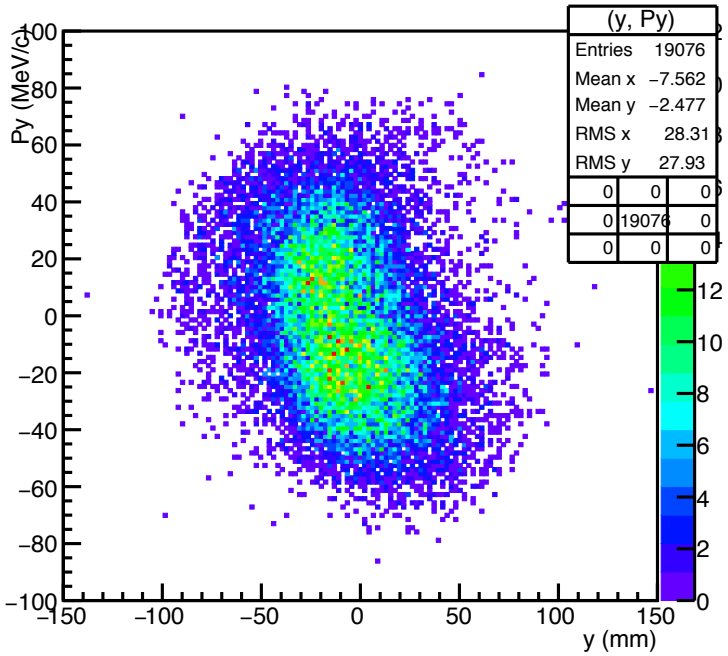



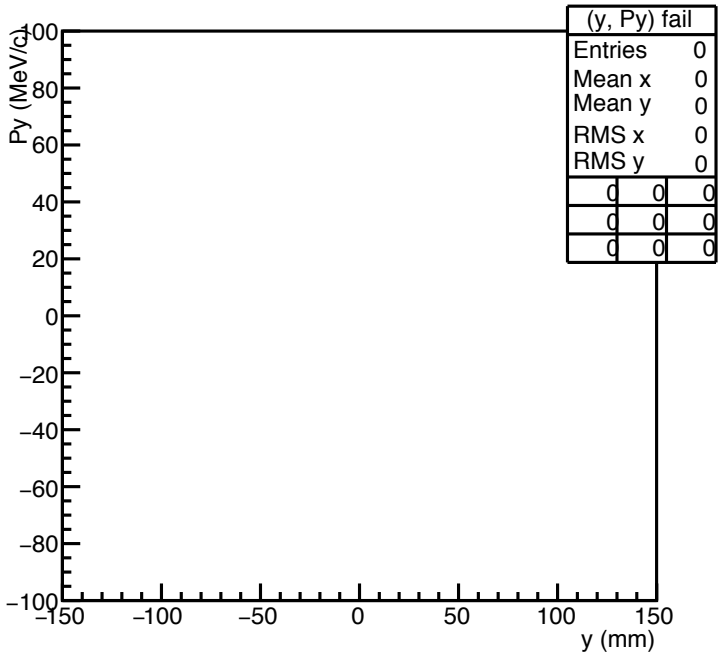
*cut_TOF0_goodPMTPosition (cut 1)*

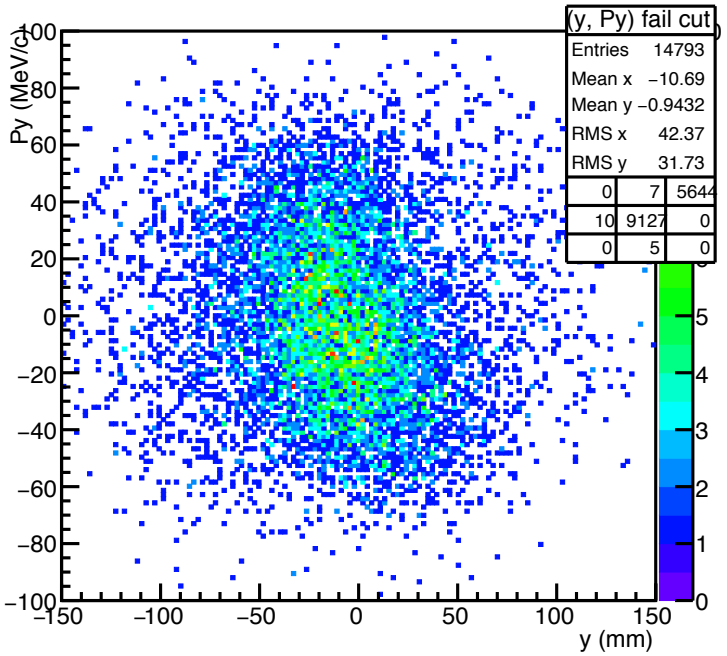


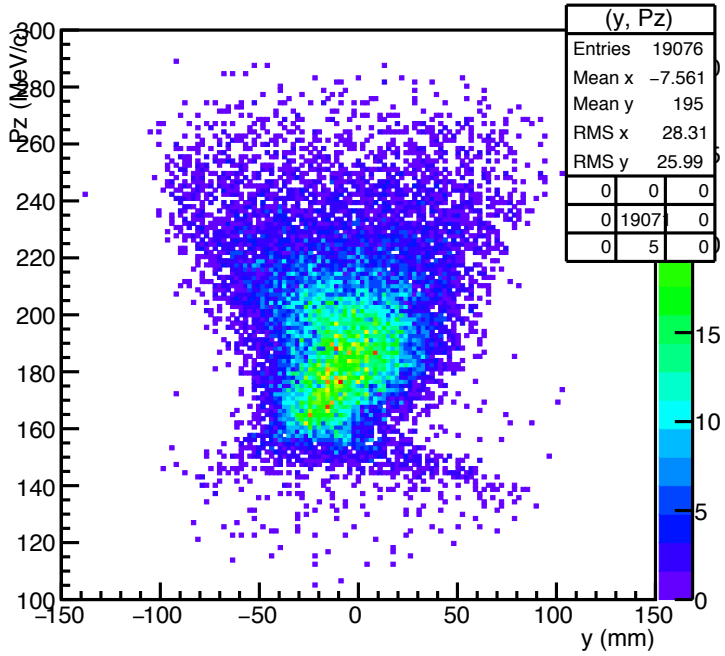



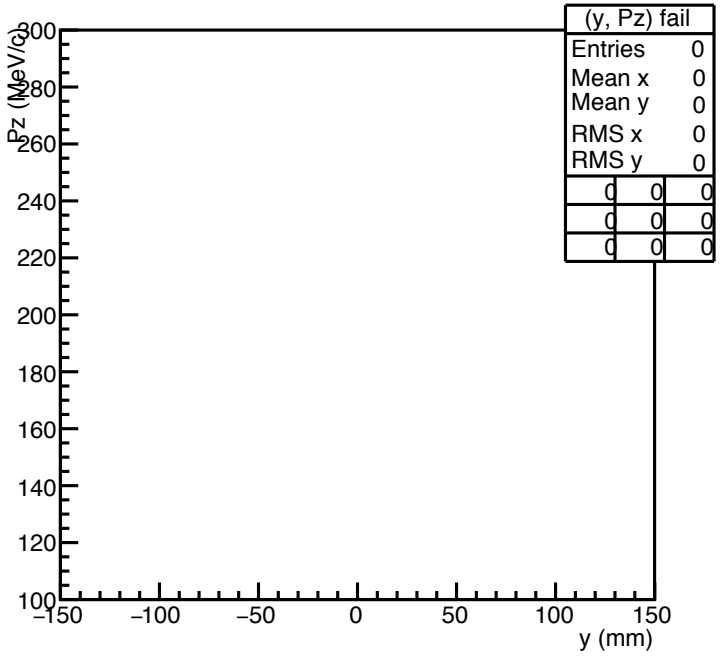



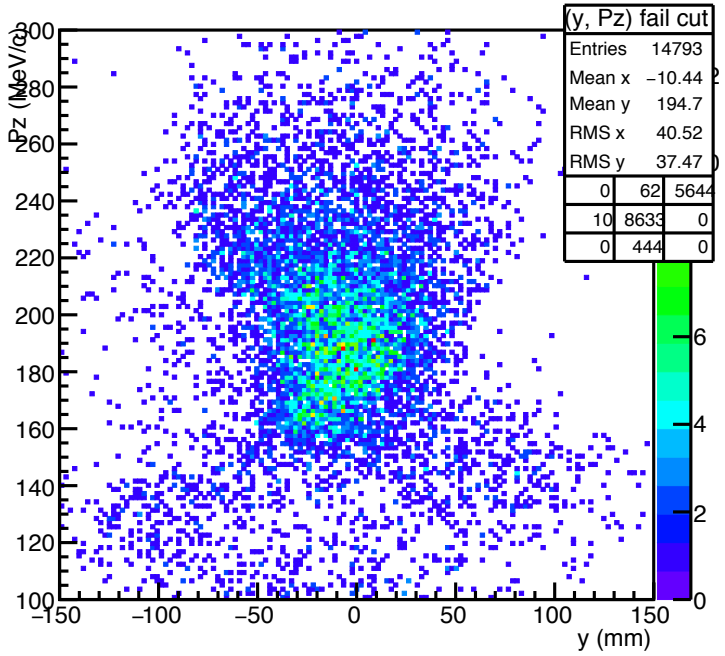



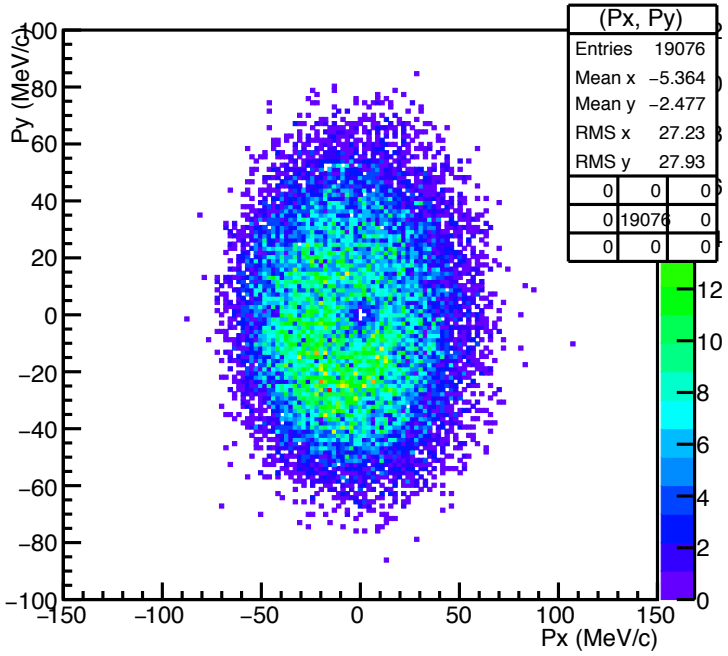



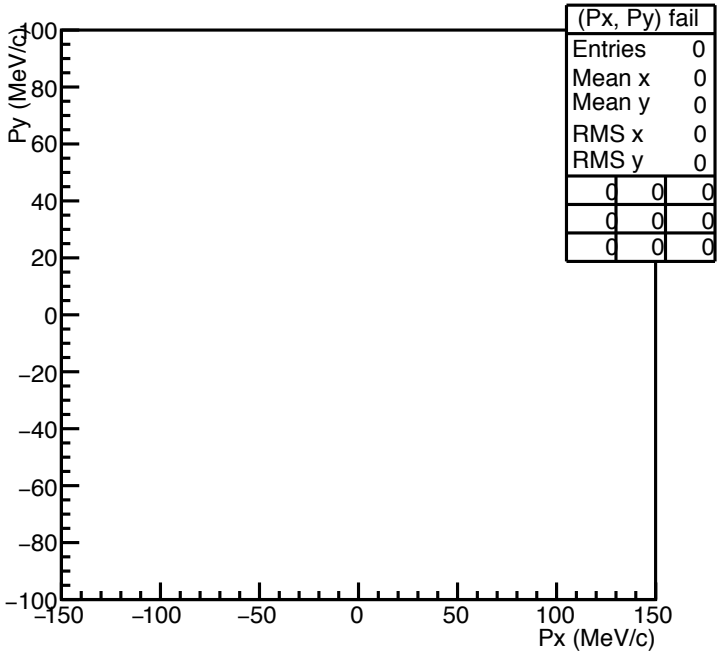
*cut_TOF0_goodPMTPosition (cut 1)*

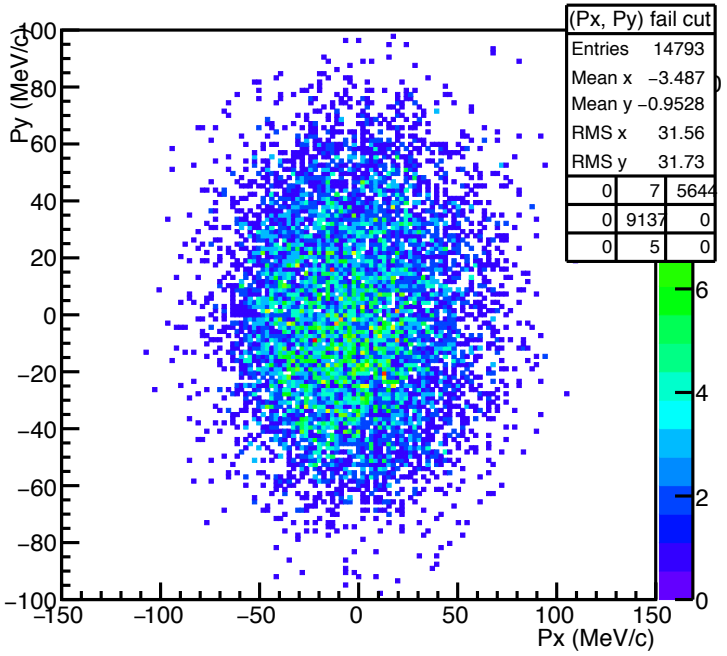


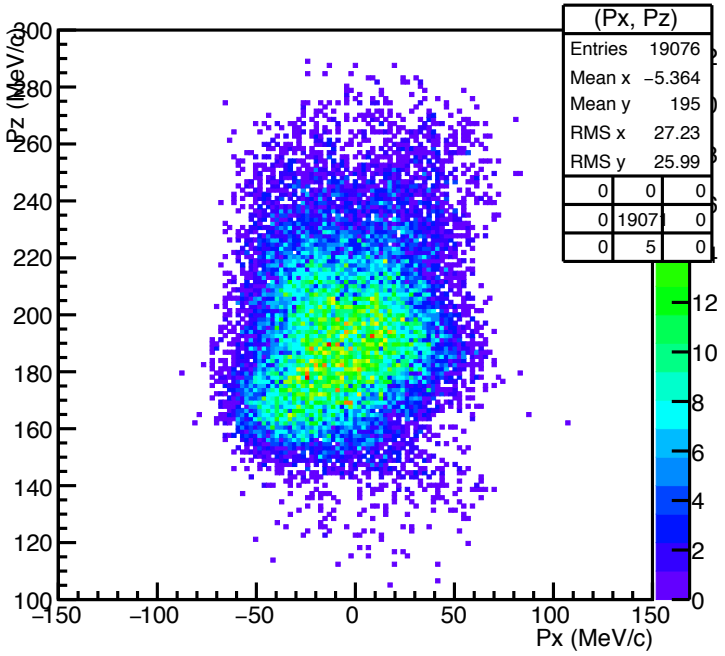



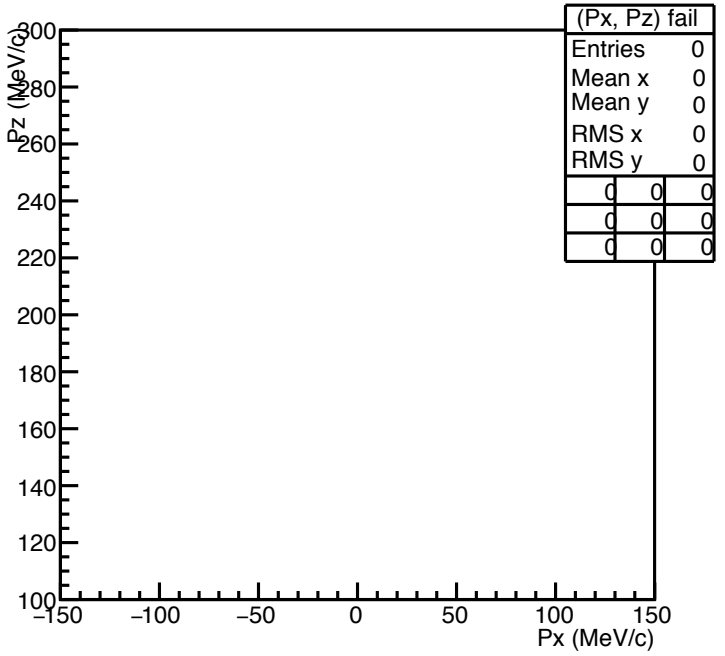



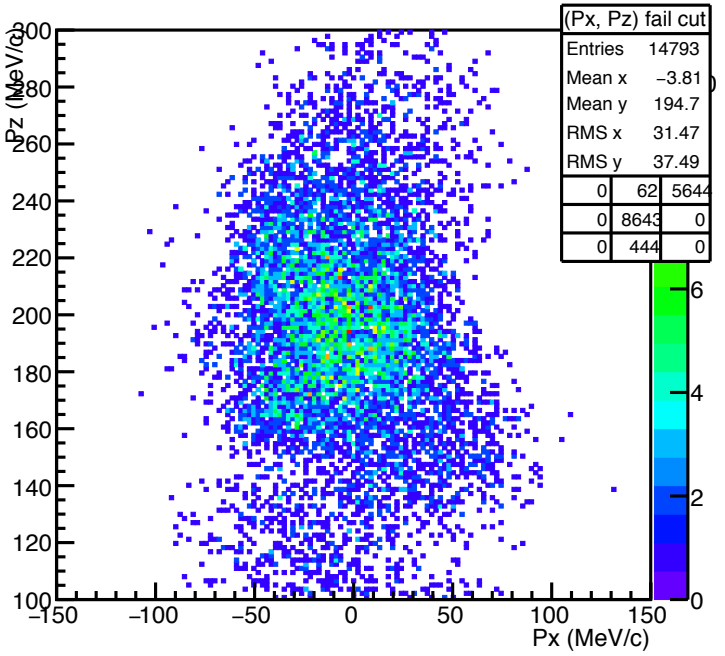



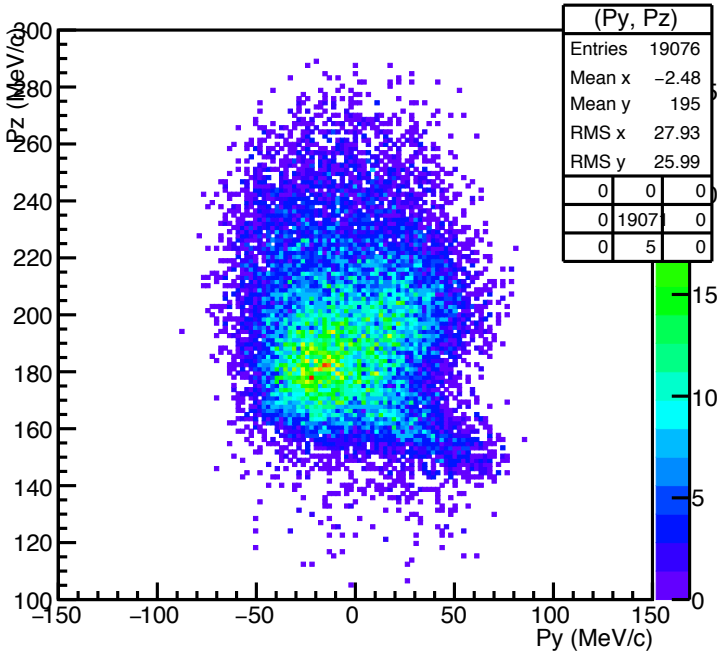



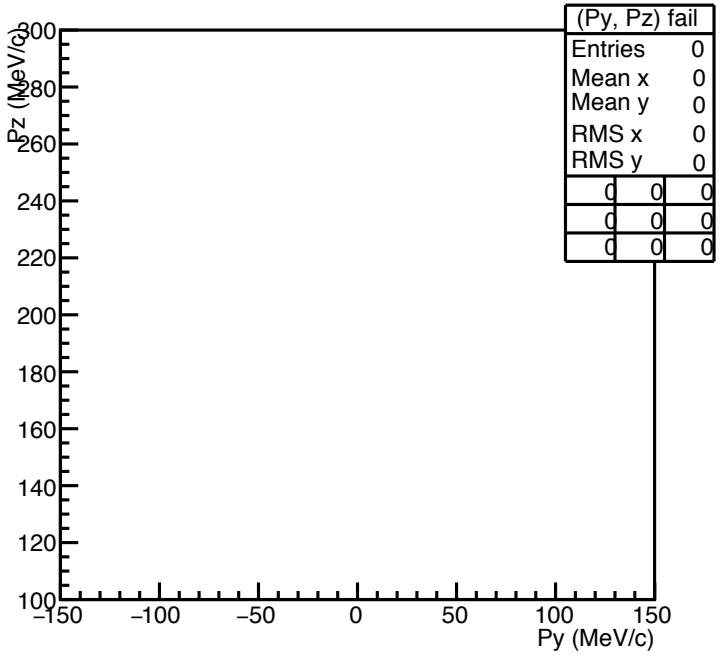
*cut_TOF0_goodPMTPosition (cut 1)*

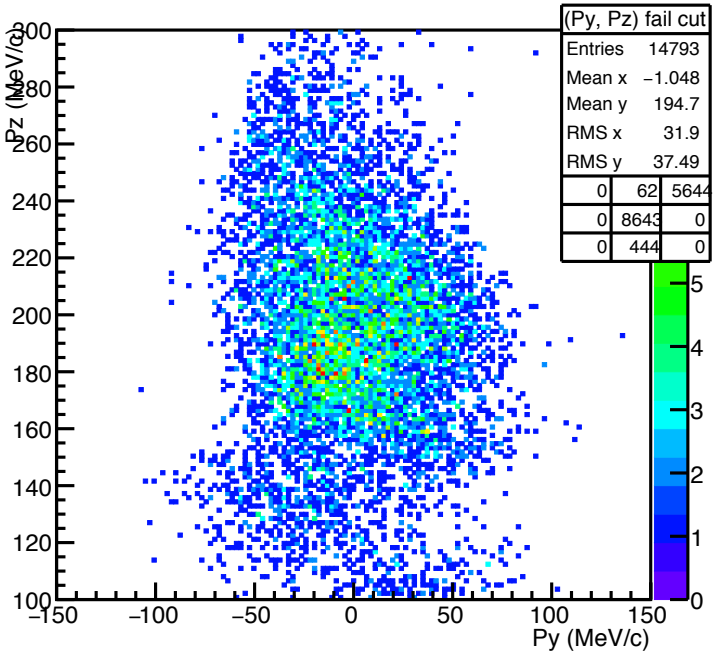


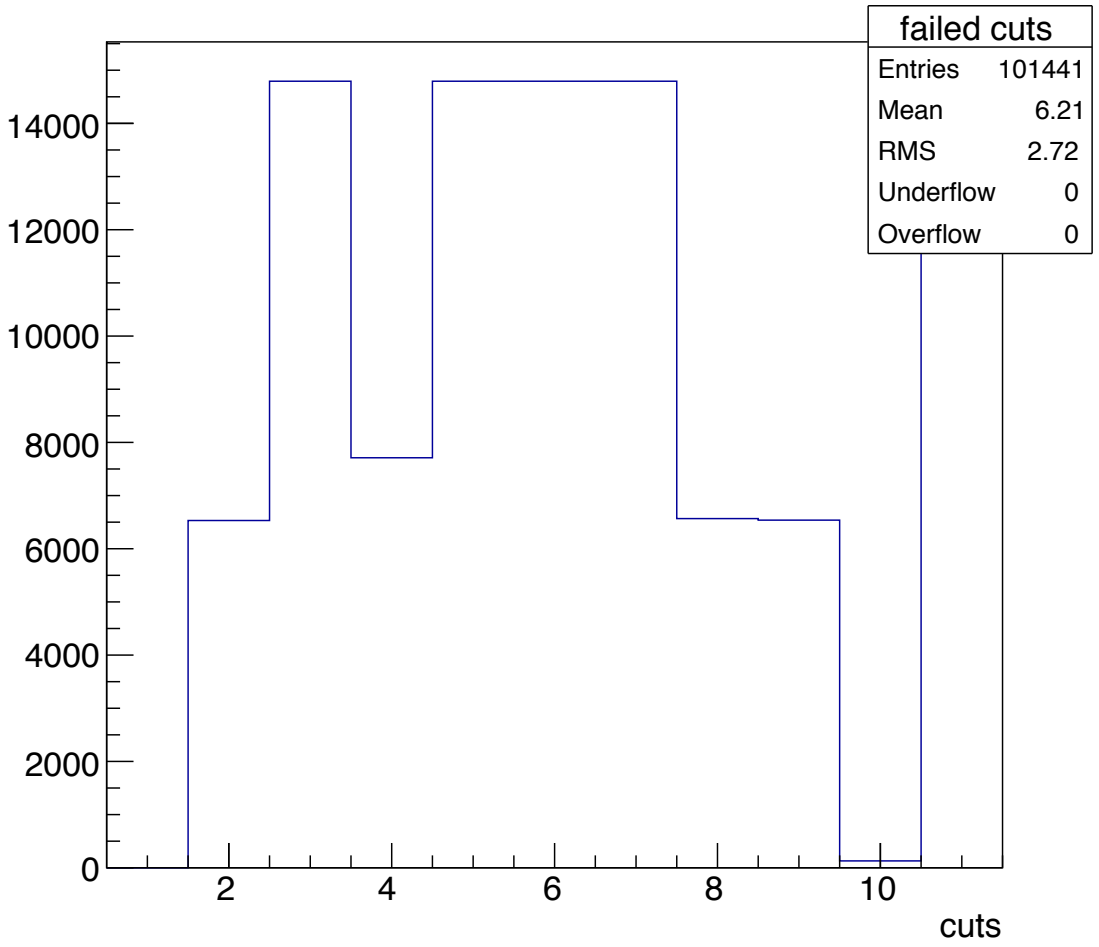



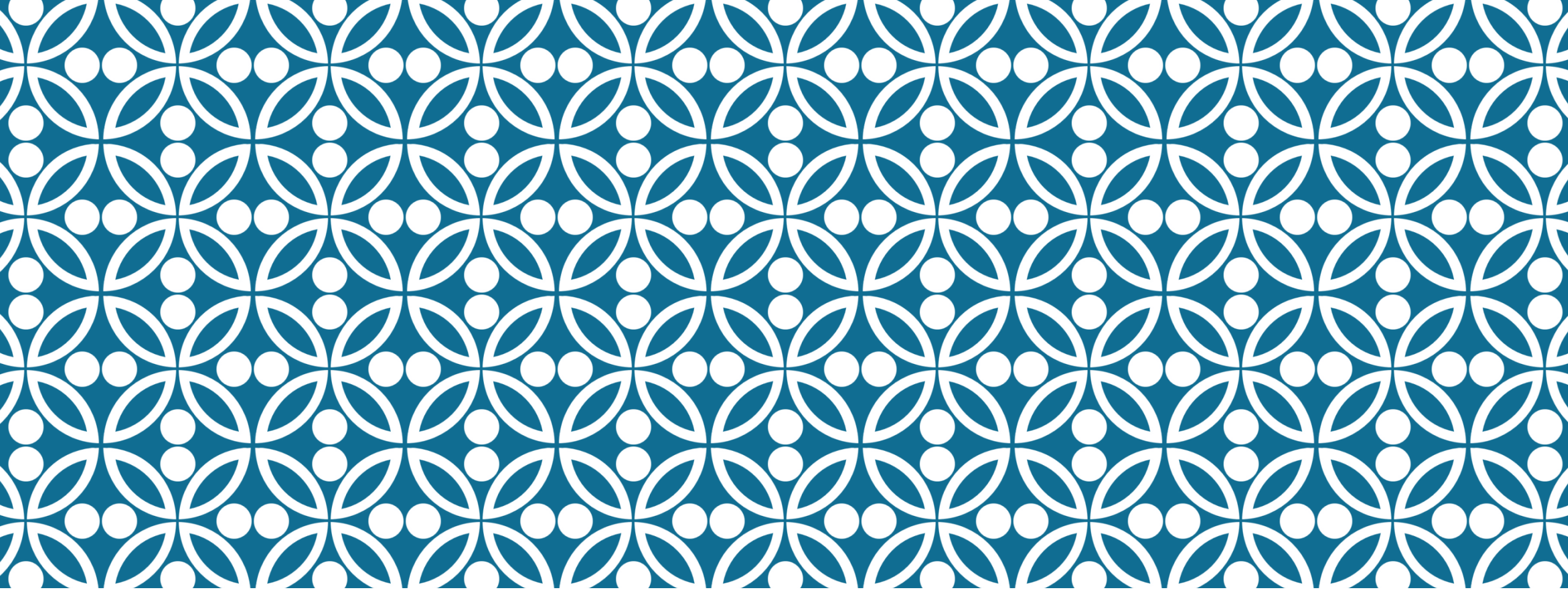



*cut_TOF0_goodPMTPosition (cut 1)*



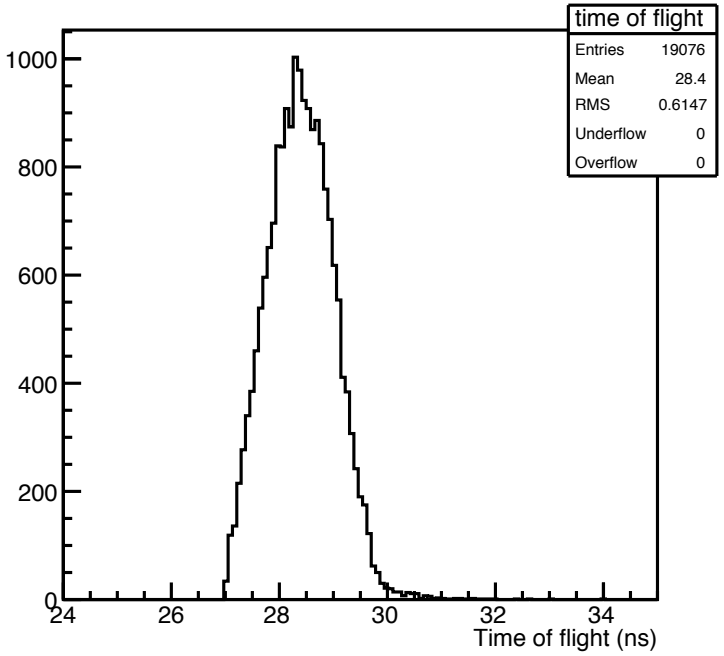

| 'Cut number' | Cut |
|---|---|
| 1 | cut_TOF0_goodPMTPosition |
| 2 | cut_TOF1_goodPMTPosition |
| 3 | cut_goodRaynerReconstruction |
| 4 | cut_TKU_hitAllStations |
| 5 | cut_TimeOfFlight |
| 6 | cut_hit_all_detectors |
| 7 | cut_TOF0_singleHit |
| 8 | cut_TOF1_singleHit |
| 9 | cut_TKU_singleTrack |
| 10 | cut_TKU_PValue |
| 11 | cut_momentum_loss |

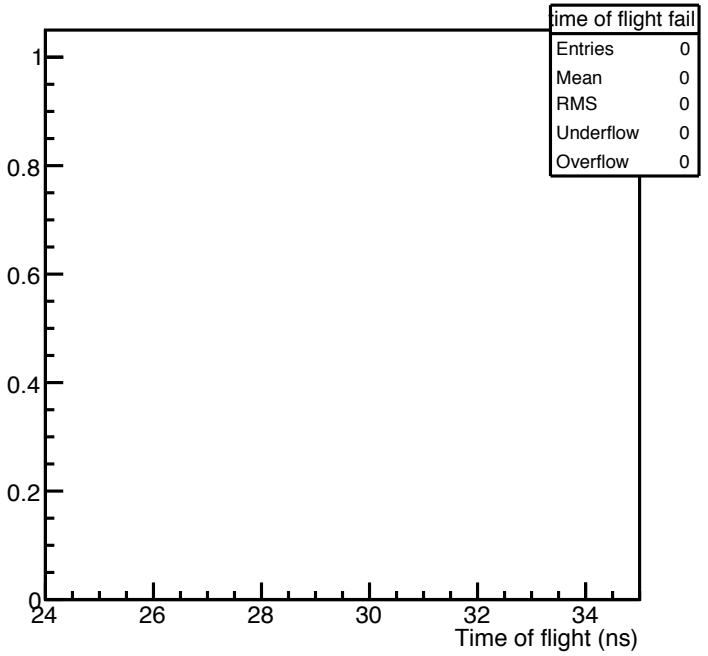


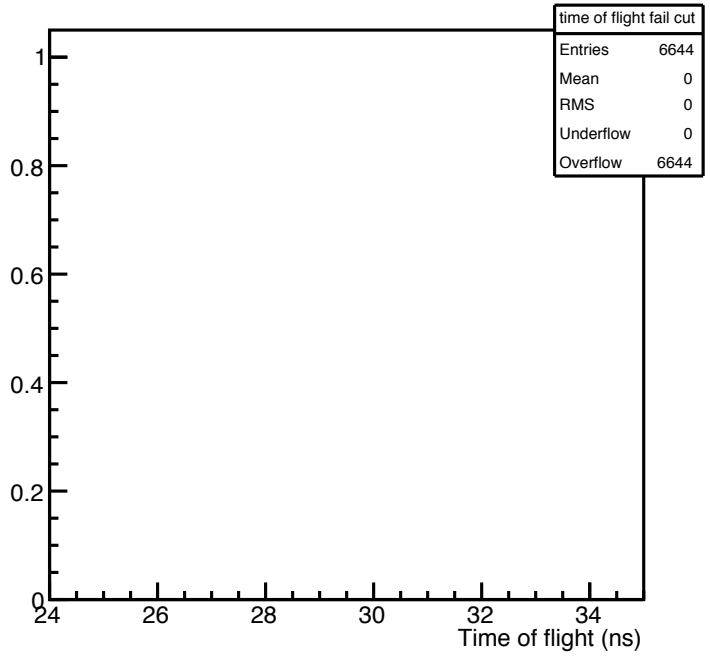
# CUT_TOF1_GOODPMTPOSITION

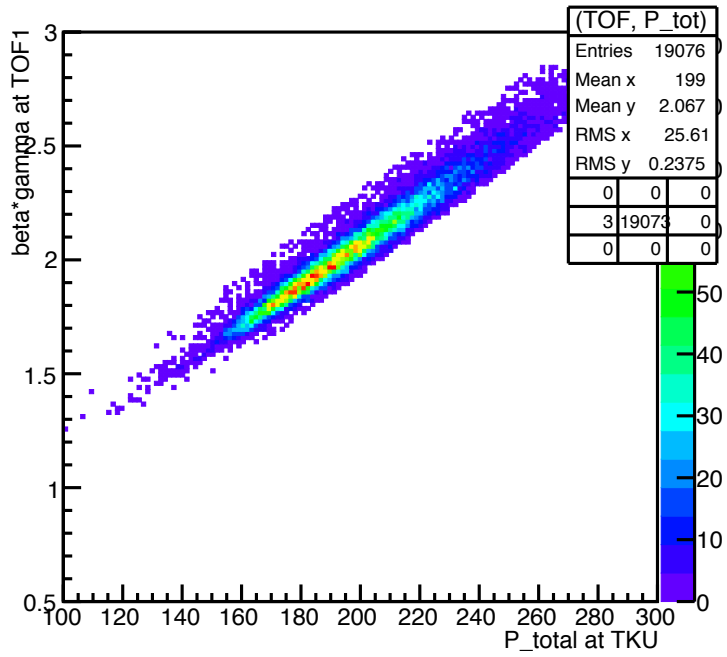
AKA ‘cut 2’

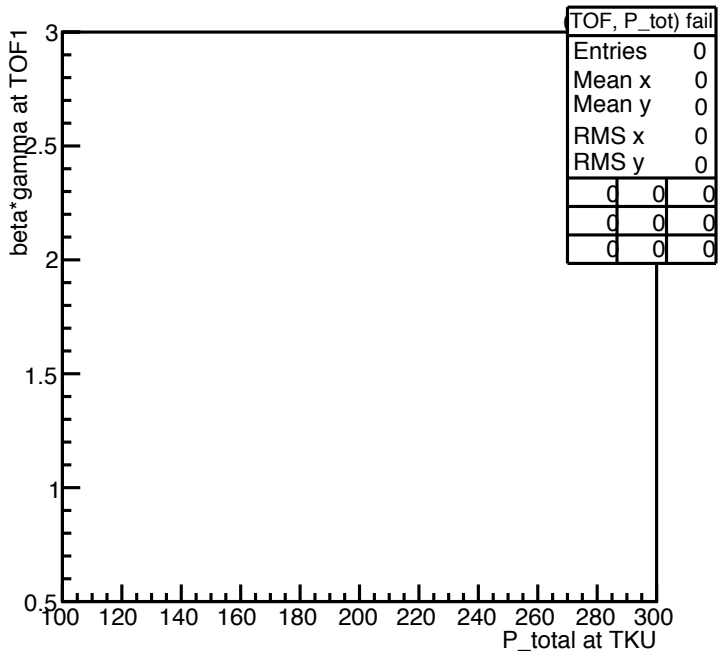
*cut_TOF1_goodPMTPosition (cut 2)*

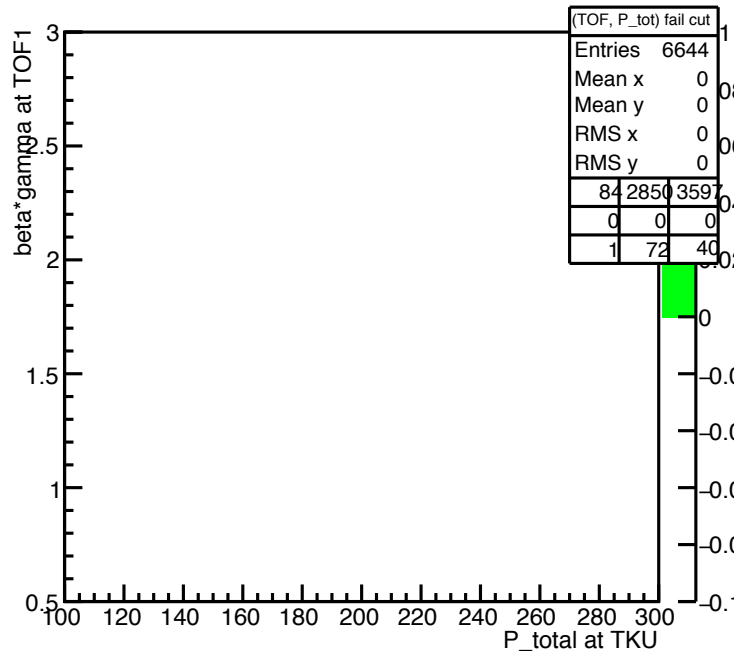


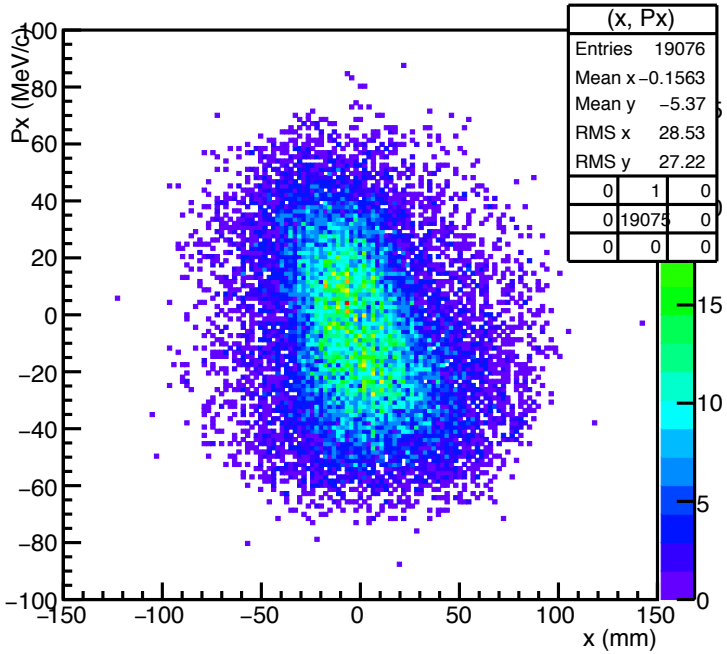



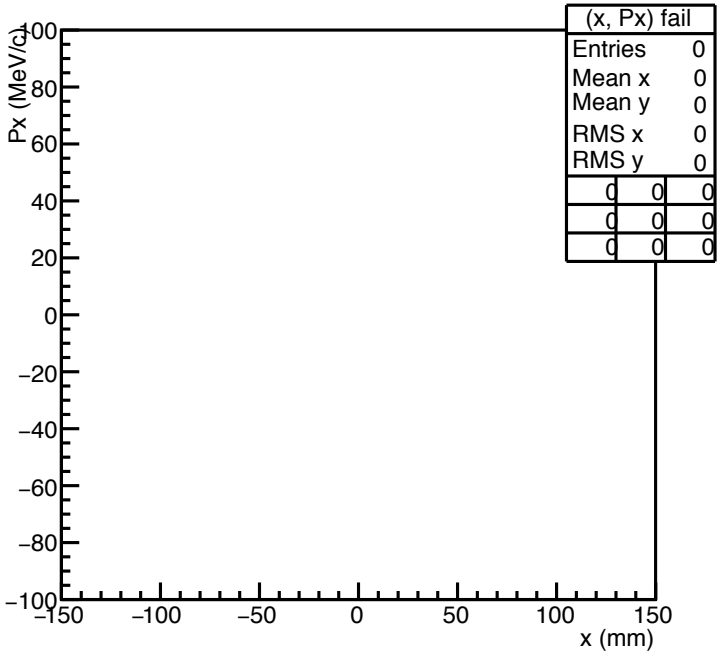



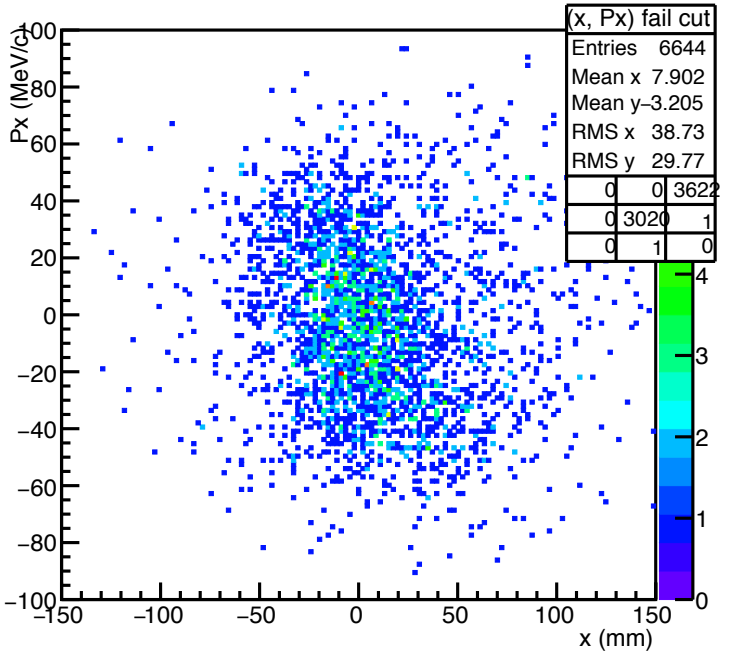



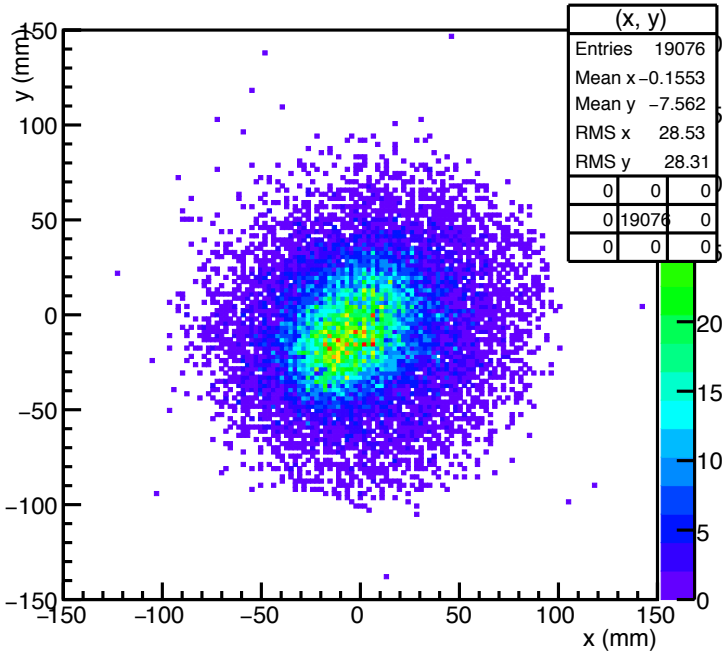



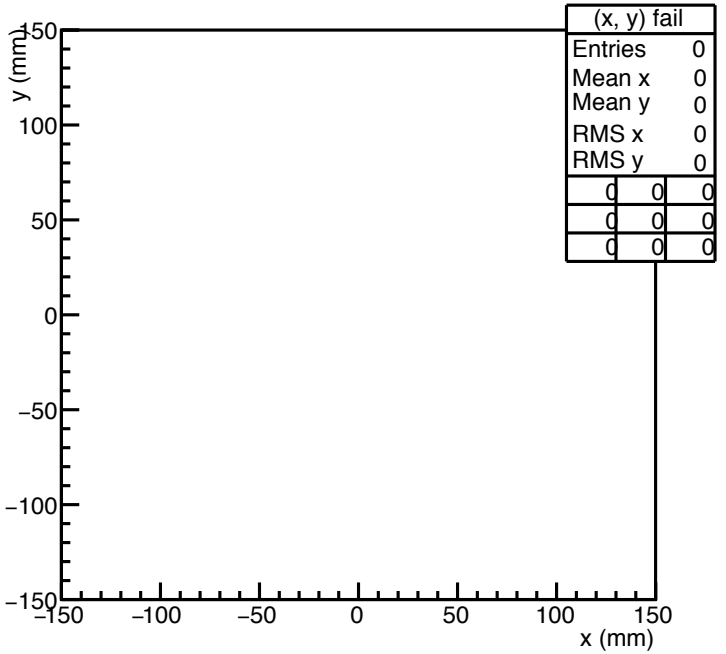
*cut_TOF1_goodPMTPosition (cut 2)*

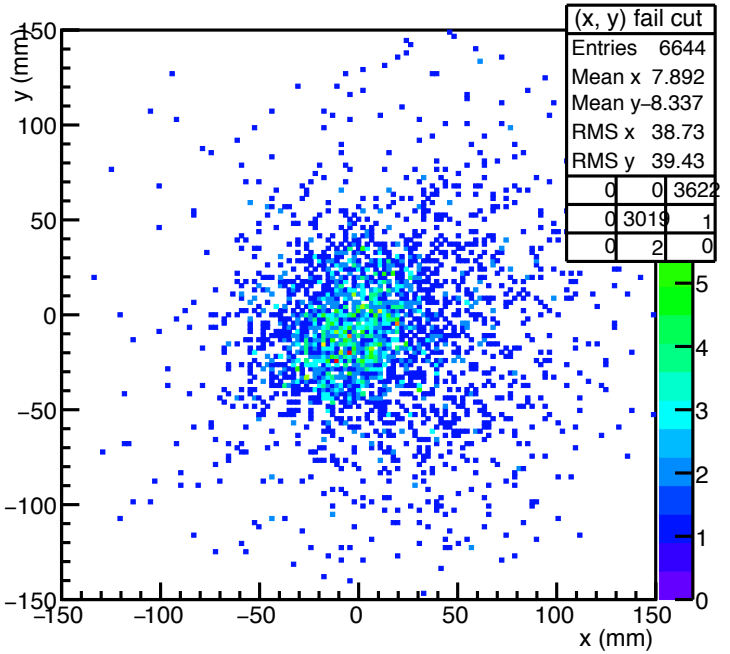


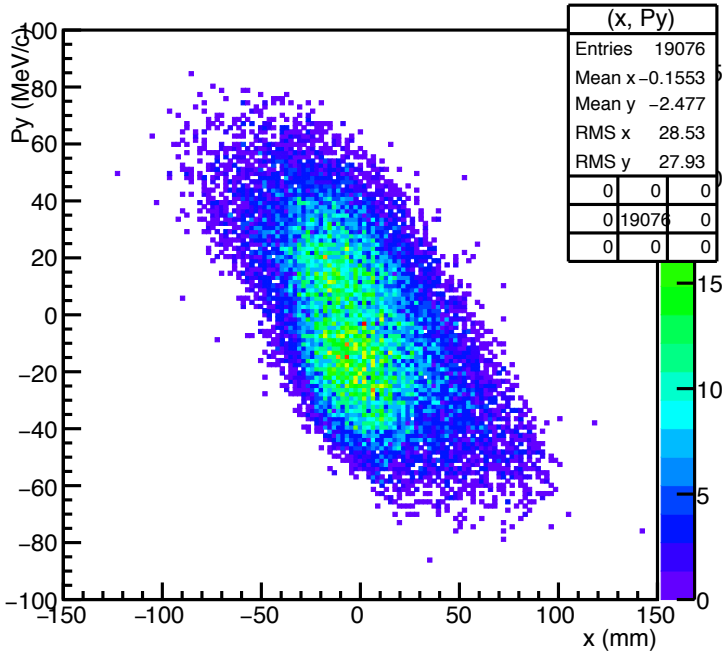



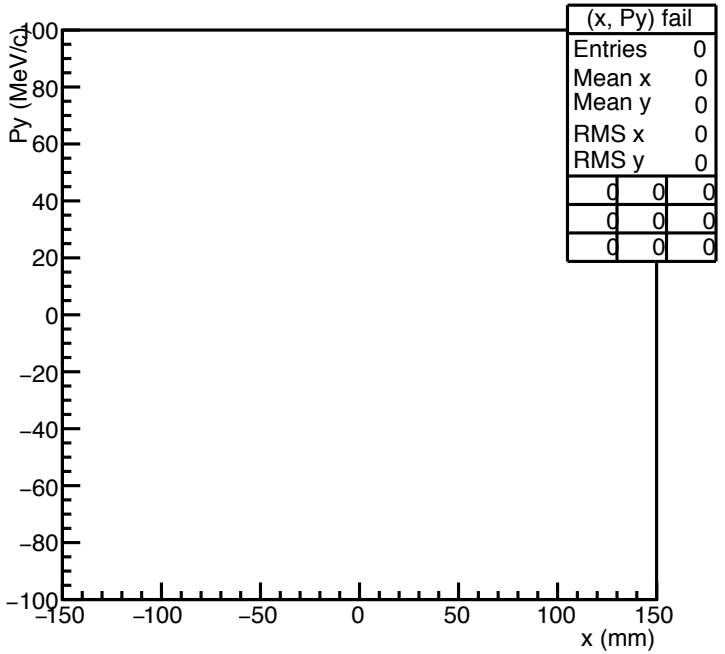



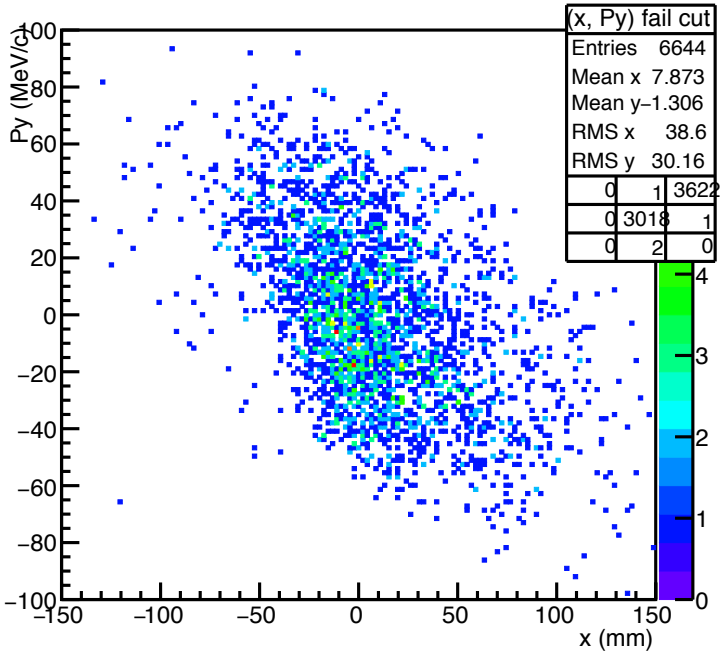



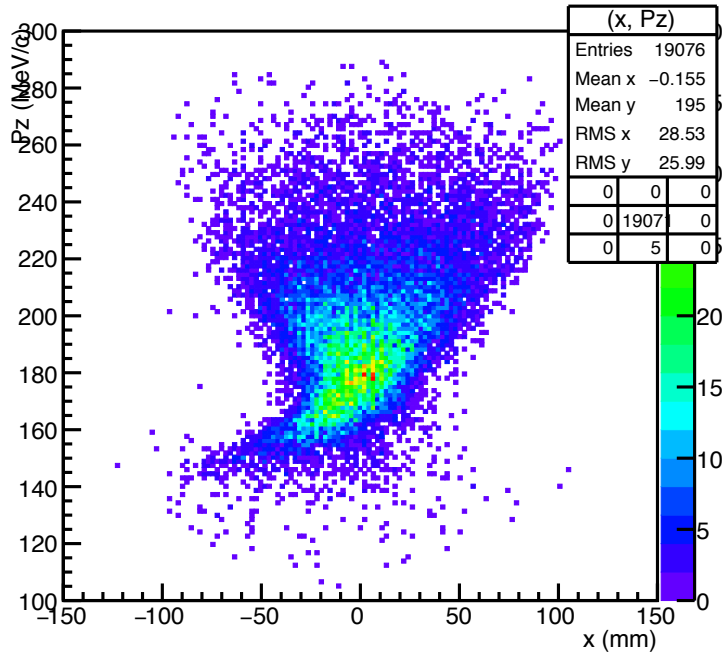



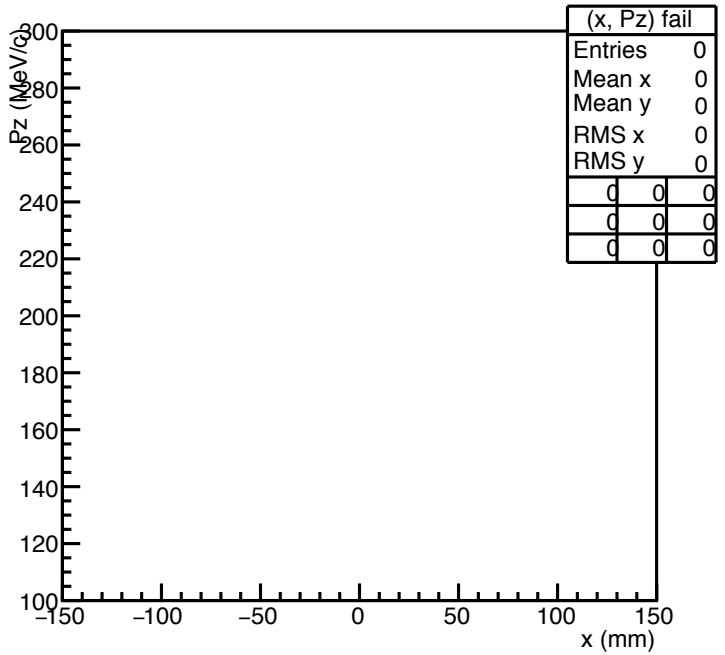
*cut_TOF1_goodPMTPosition (cut 2)*

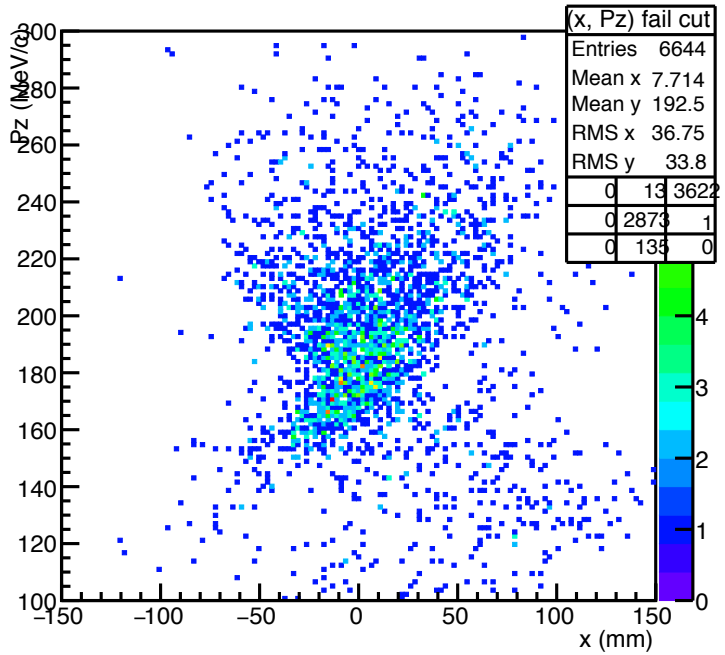


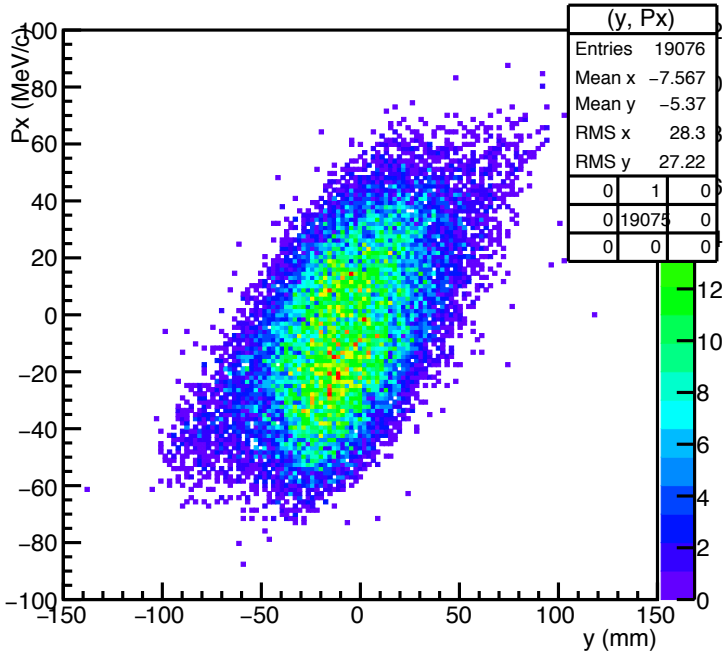



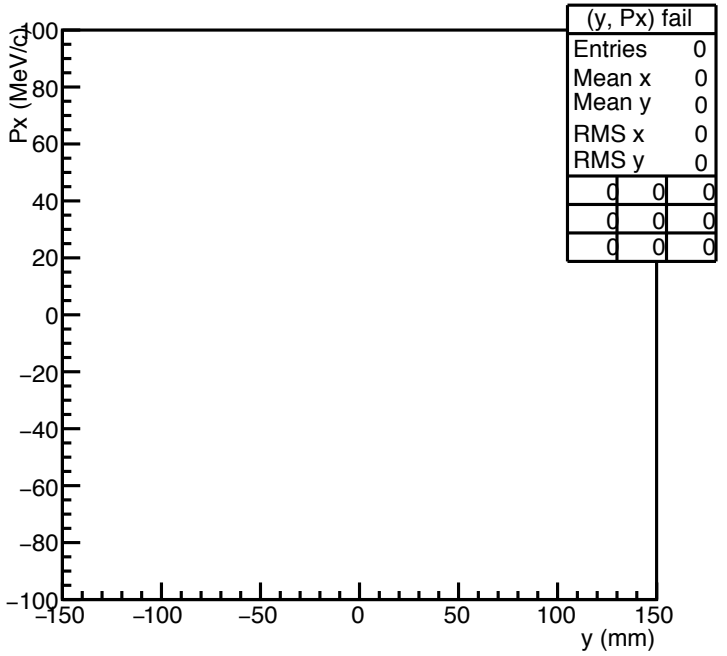



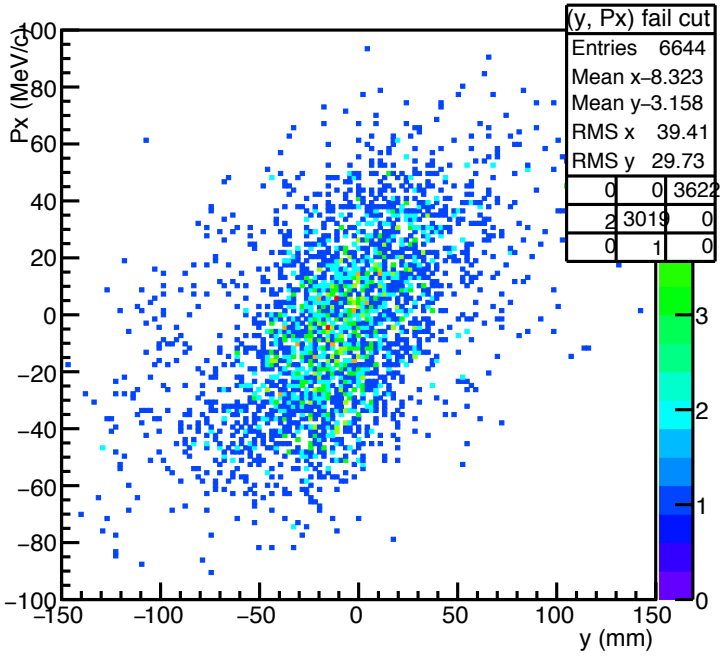



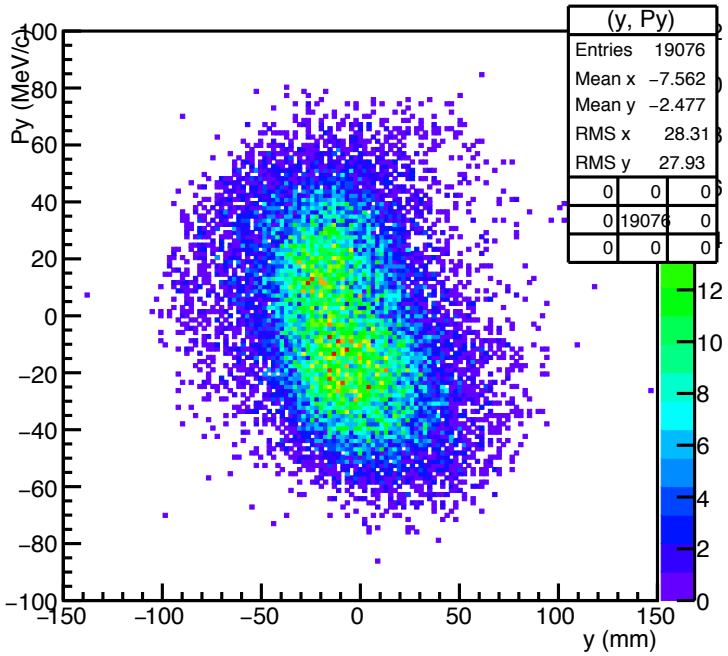



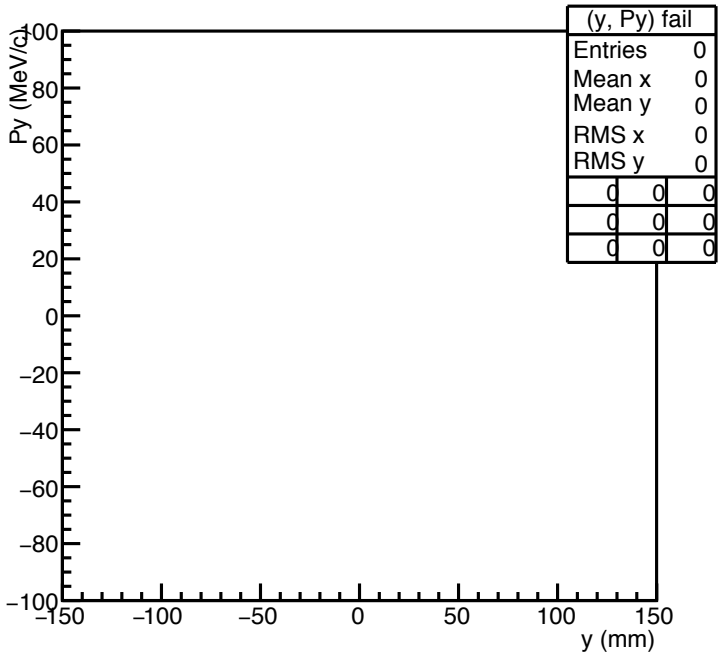
*cut_TOF1_goodPMTPosition (cut 2)*

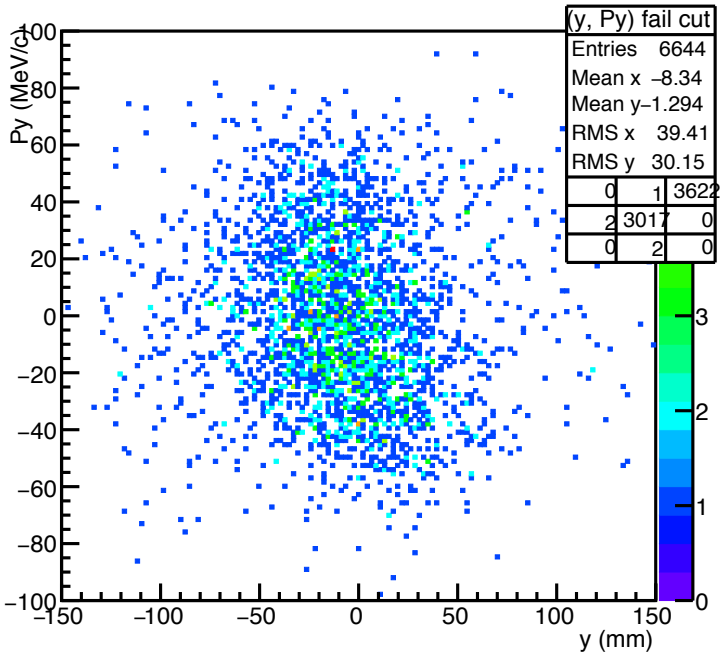


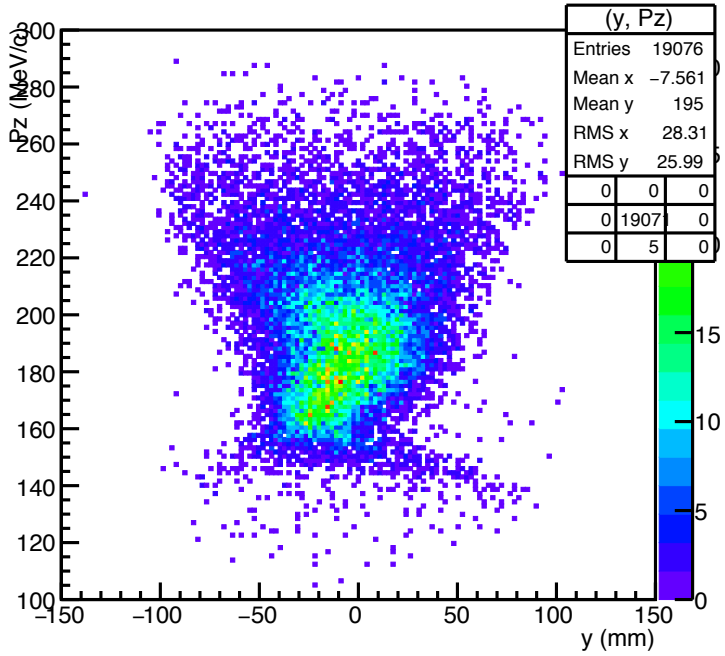



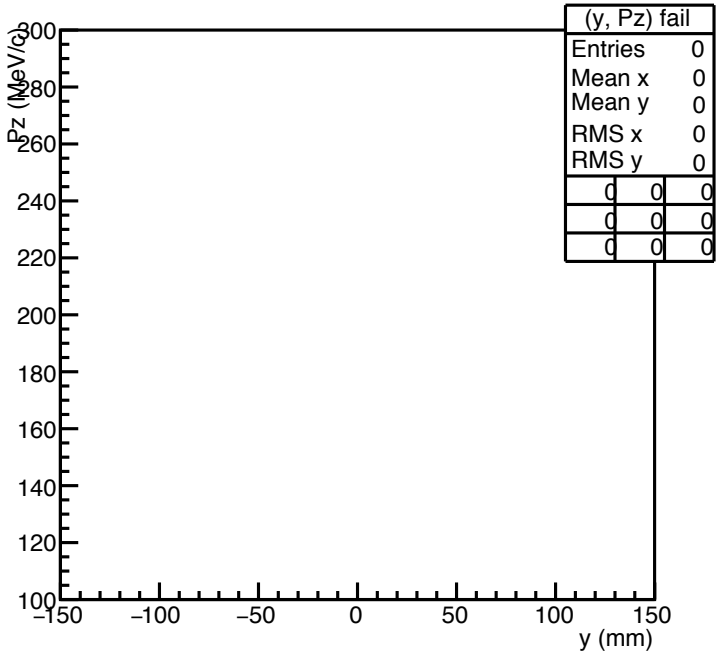



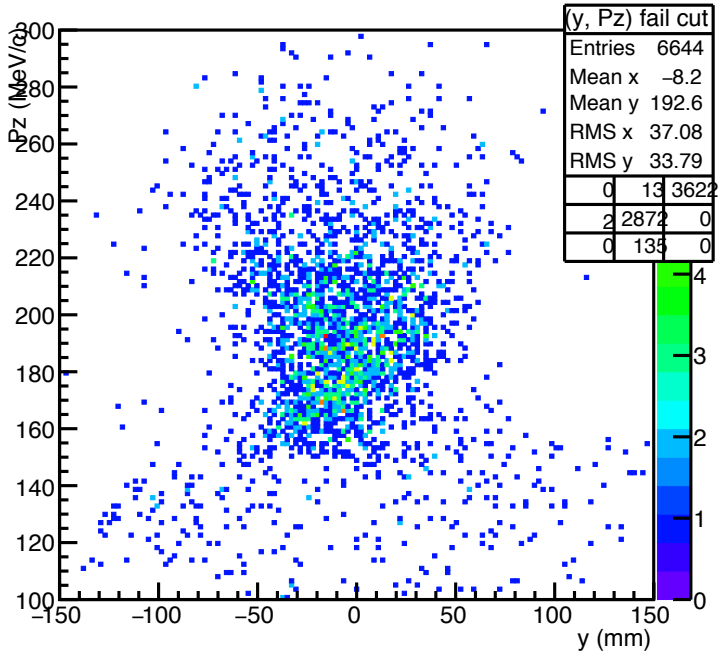



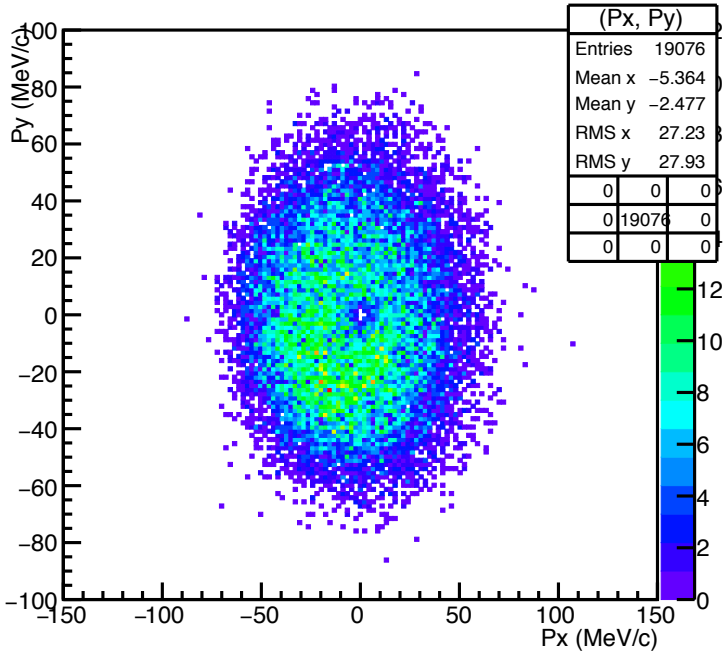



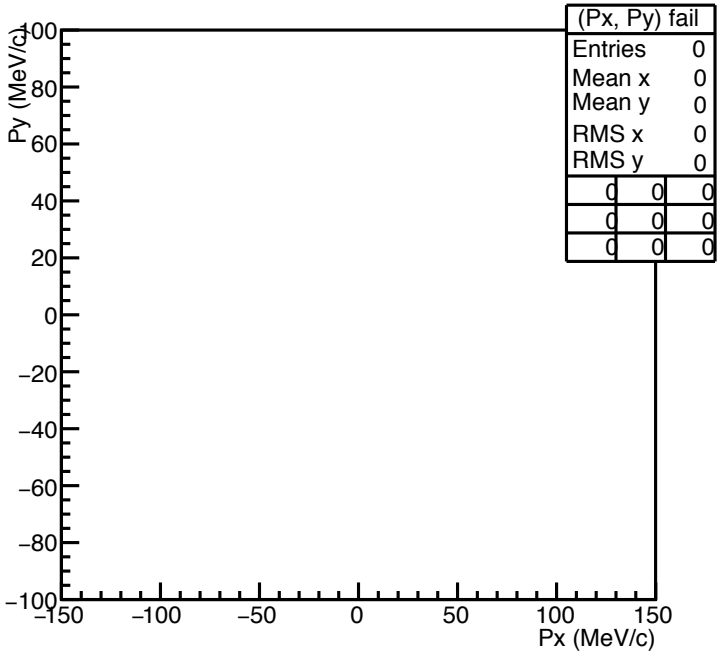
*cut_TOF1_goodPMTPosition (cut 2)*

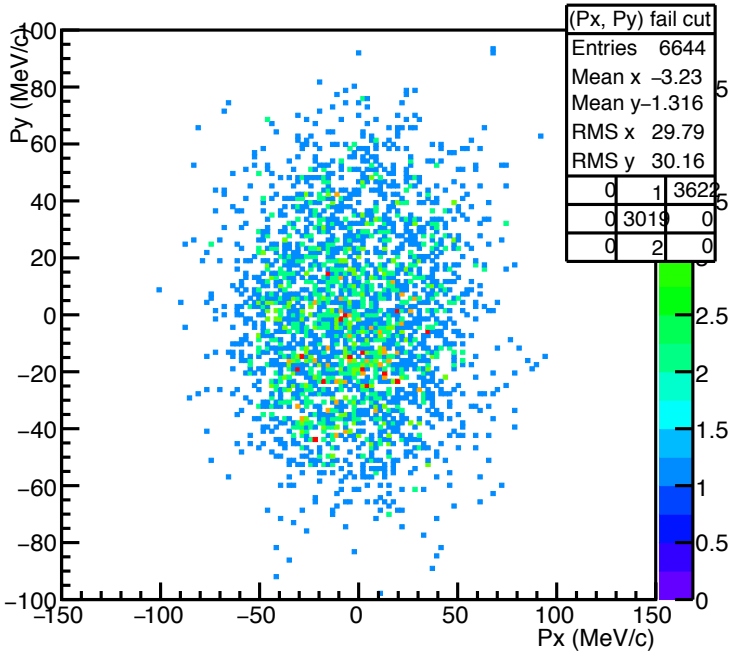


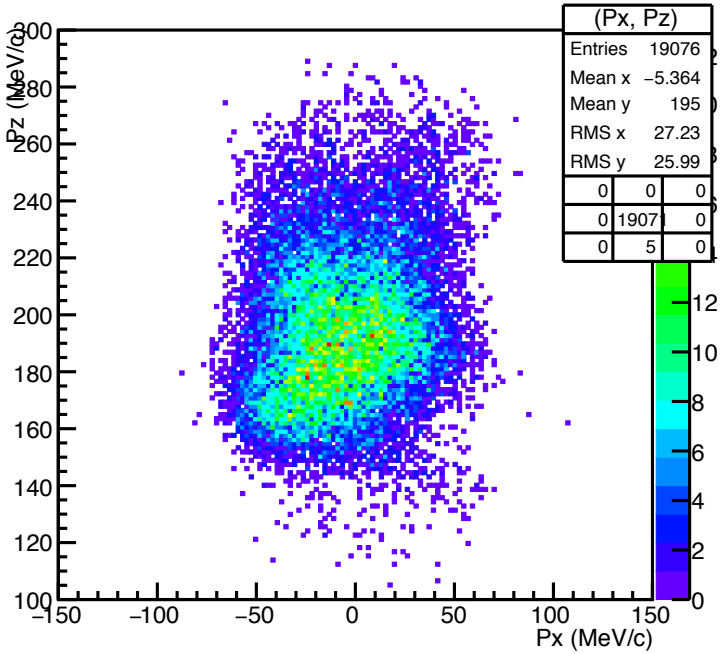



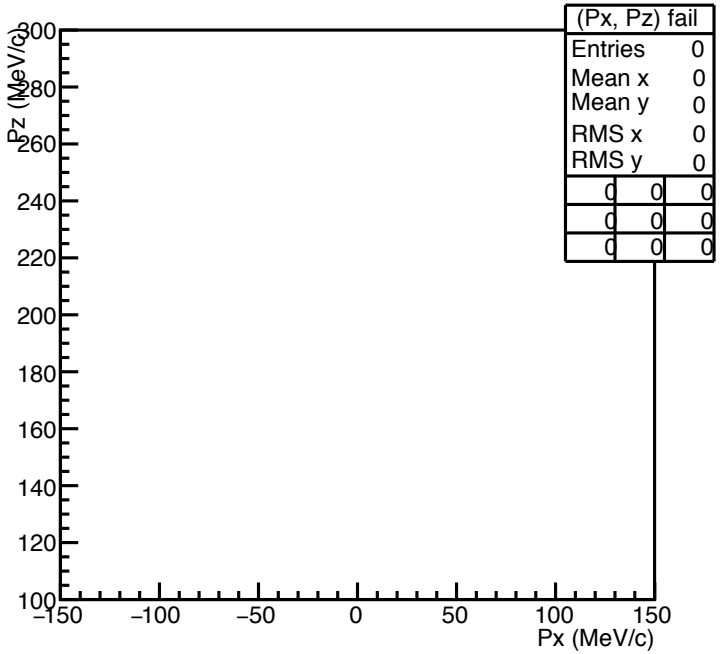



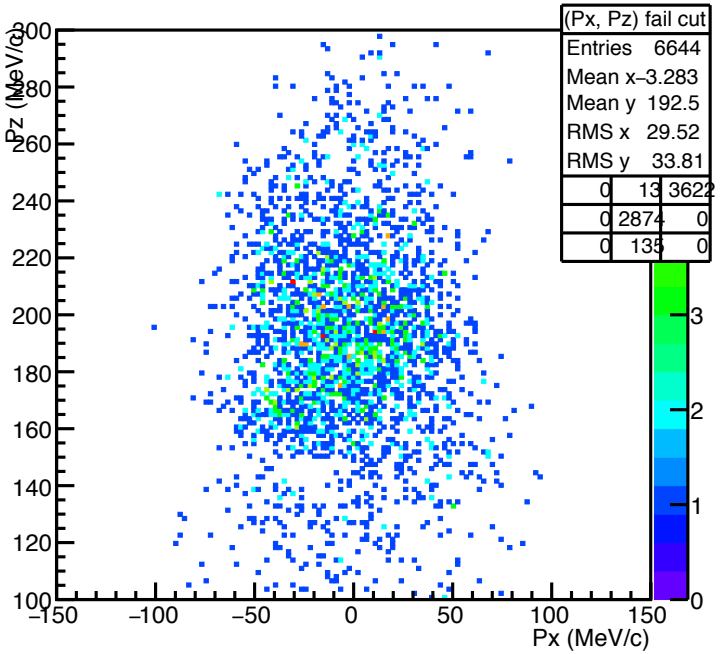



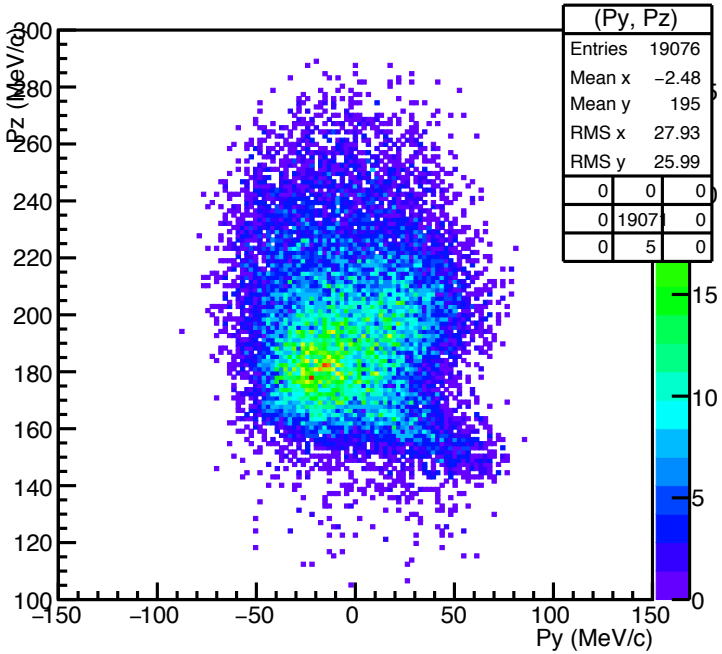



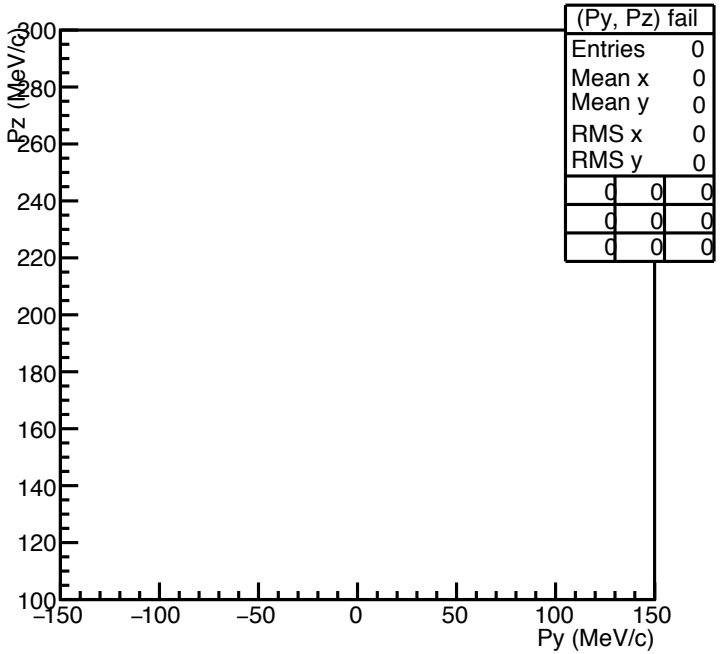
*cut_TOF1_goodPMTPosition (cut 2)*

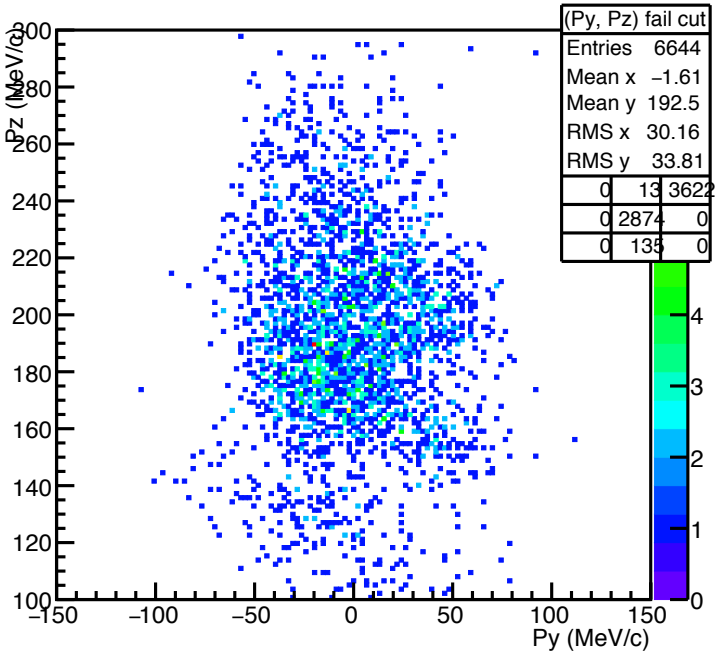


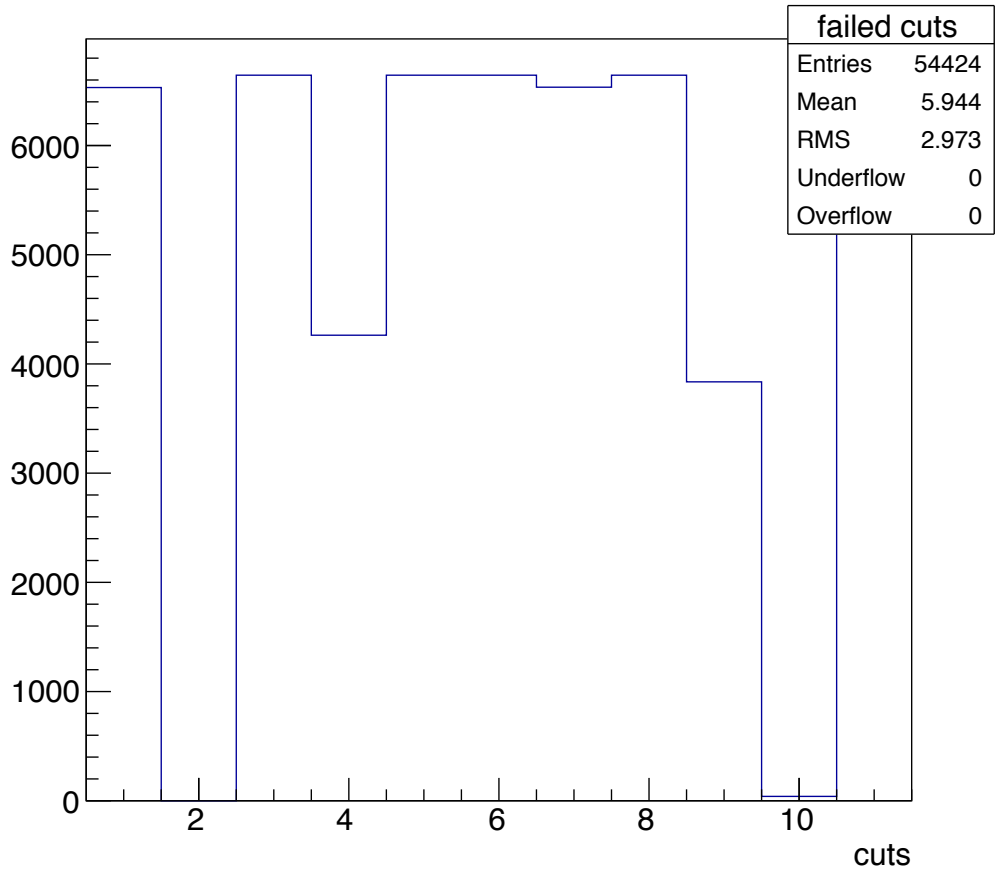



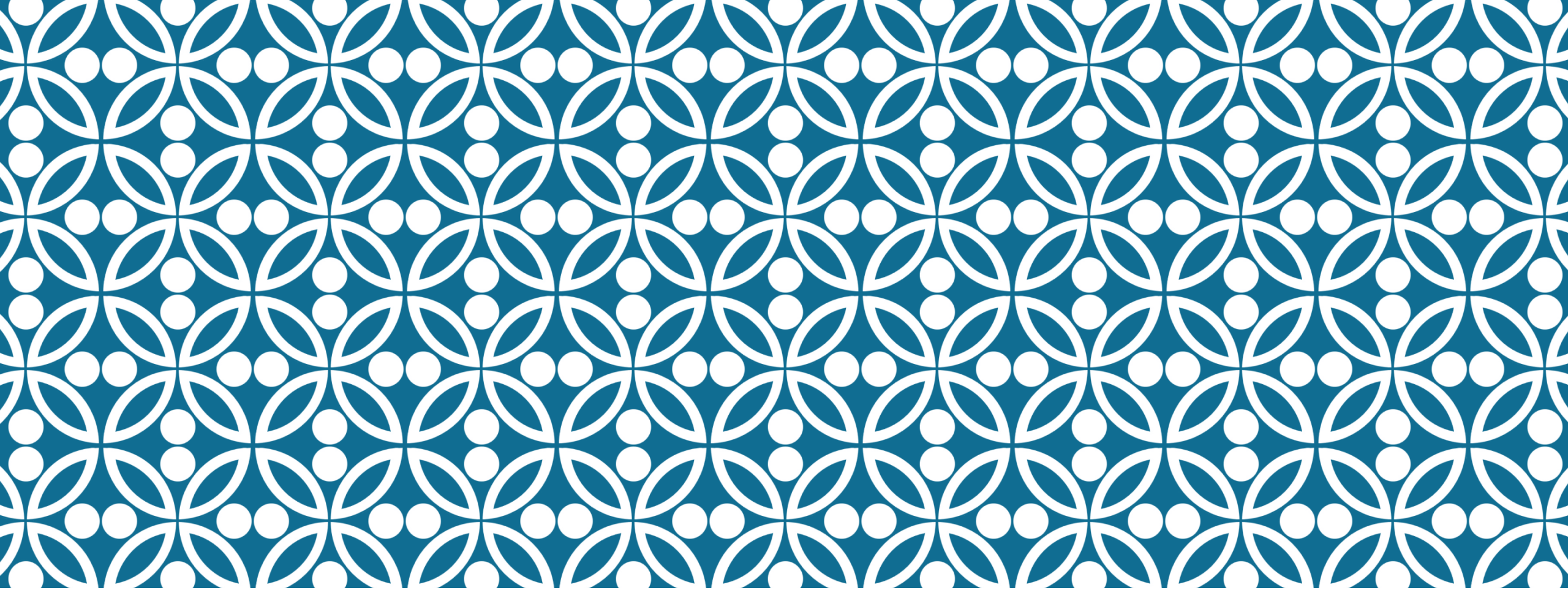





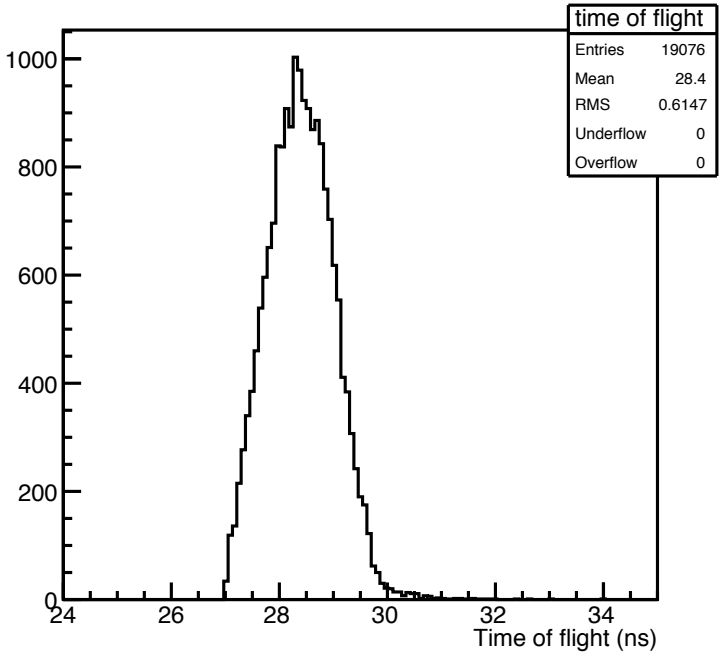

| ‘Cut number’ | Cut |
|---|---|
| 1 | cut_TOF0_goodPMTPosition |
| 2 | cut_TOF1_goodPMTPosition |
| 3 | cut_goodRaynerReconstruction |
| 4 | cut_TKU_hitAllStations |
| 5 | cut_TimeOfFlight |
| 6 | cut_hit_all_detectors |
| 7 | cut_TOF0_singleHit |
| 8 | cut_TOF1_singleHit |
| 9 | cut_TKU_singleTrack |
| 10 | cut_TKU_PValue |
| 11 | cut_momentum_loss |

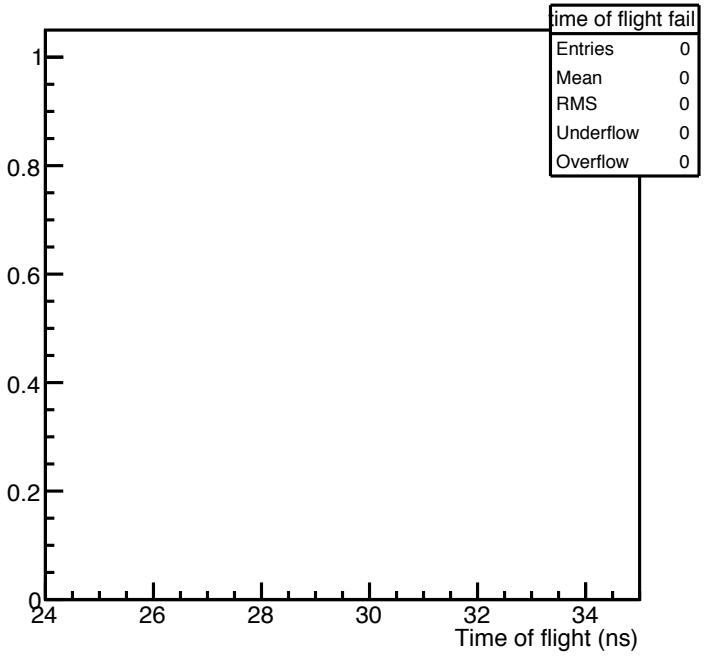


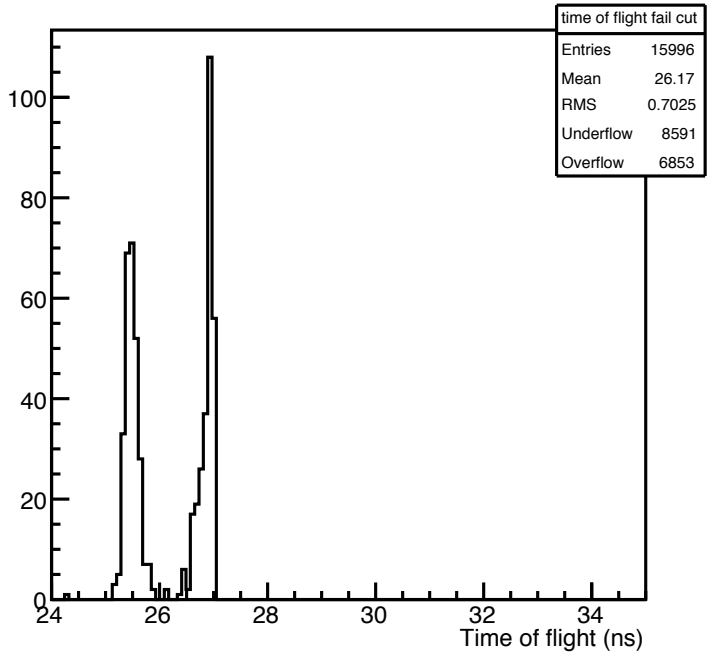
# CUT_GOODRAYNERRECONSTRUCTION

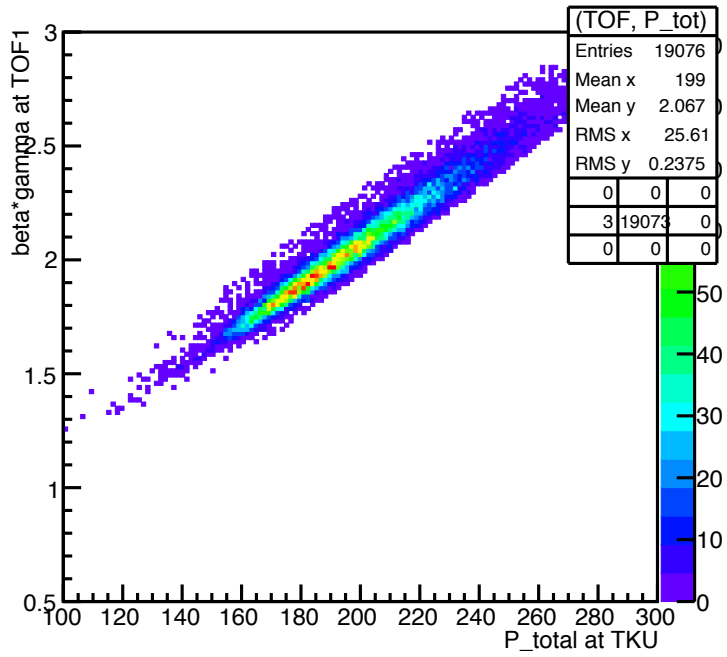
AKA ‘cut 3’

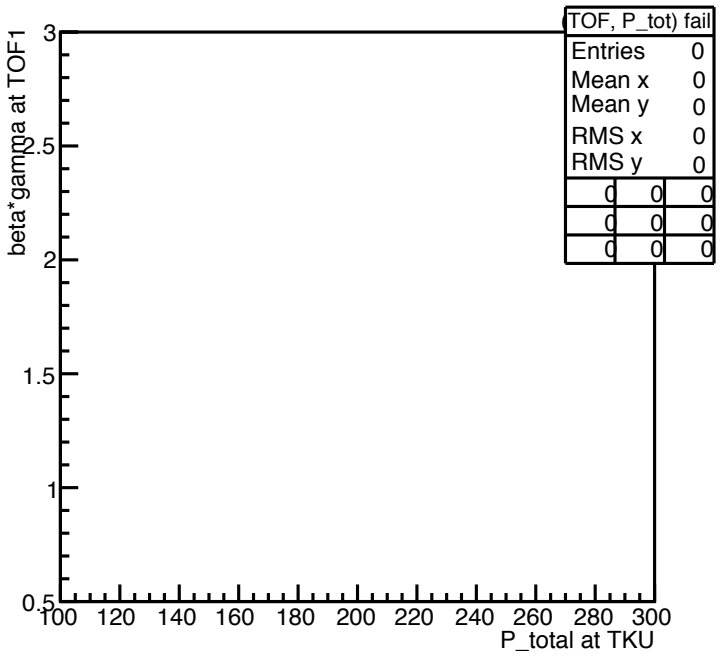
*cut_goodRaynerReconstruction (cut 3)*

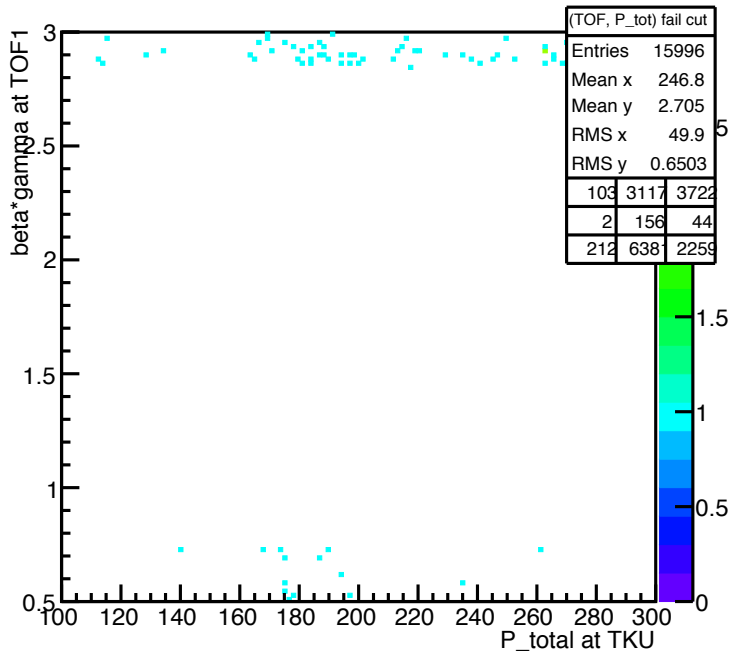


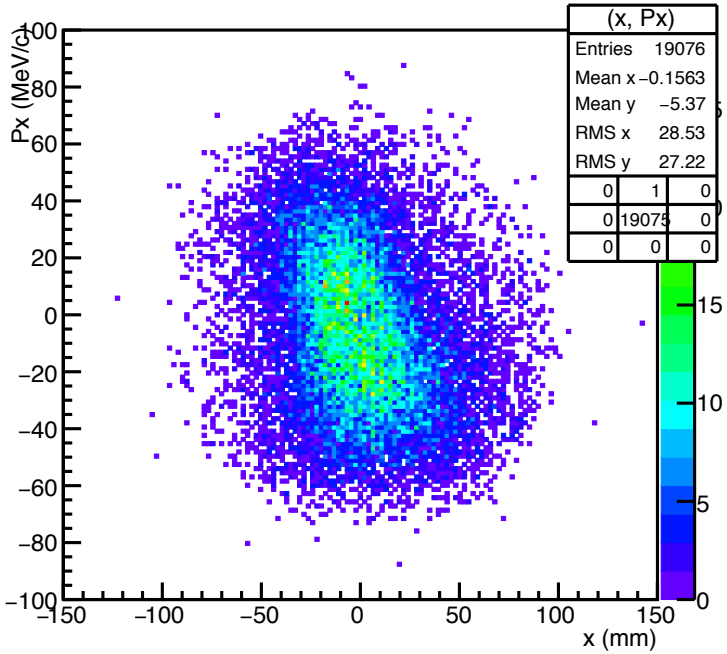



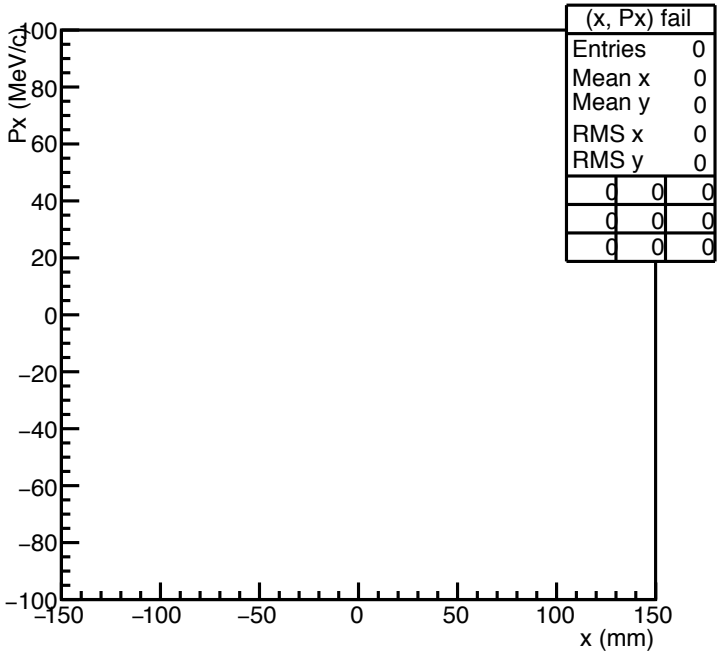



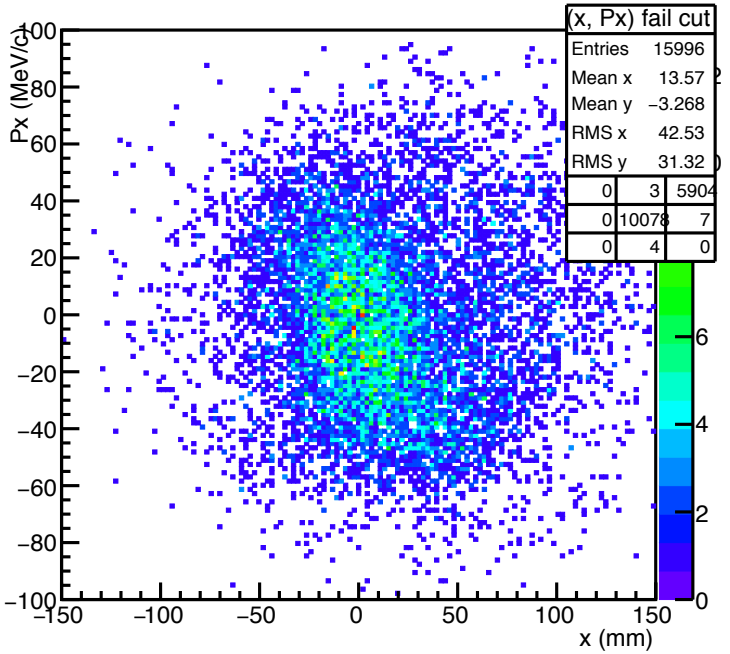



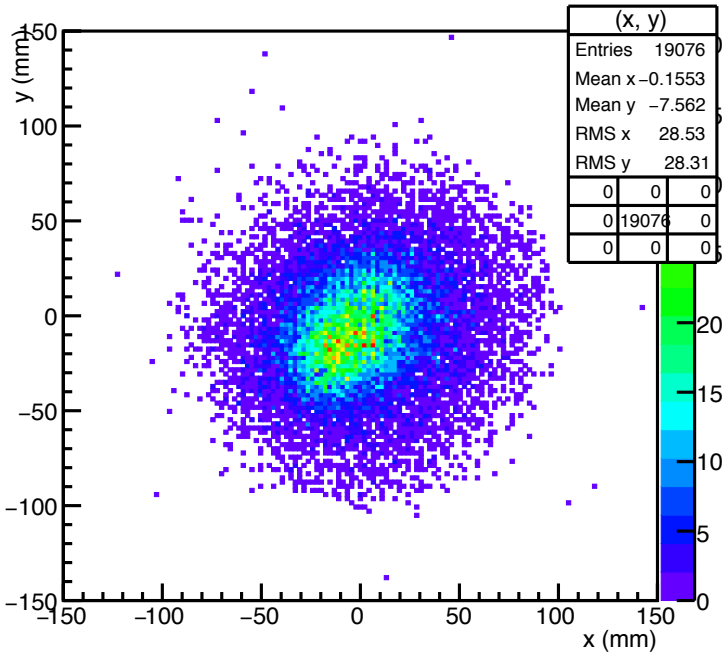



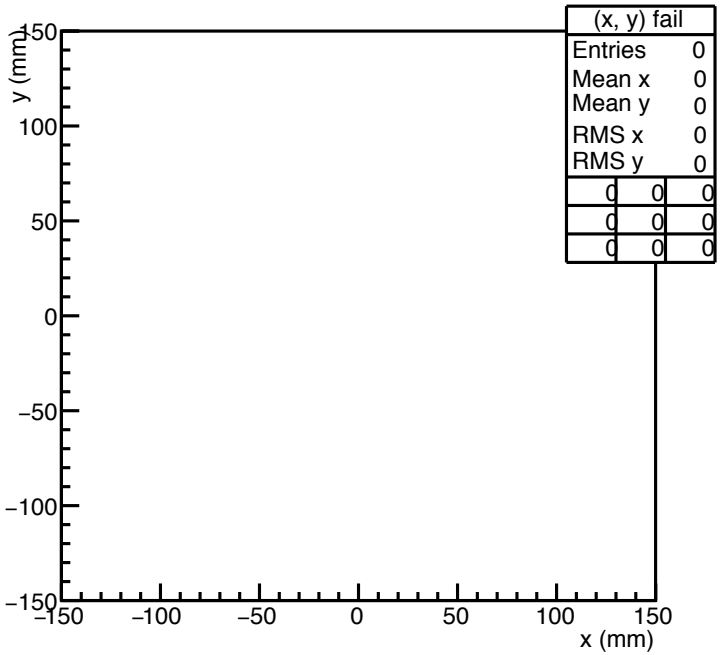
*cut_goodRaynerReconstruction (cut 3)*

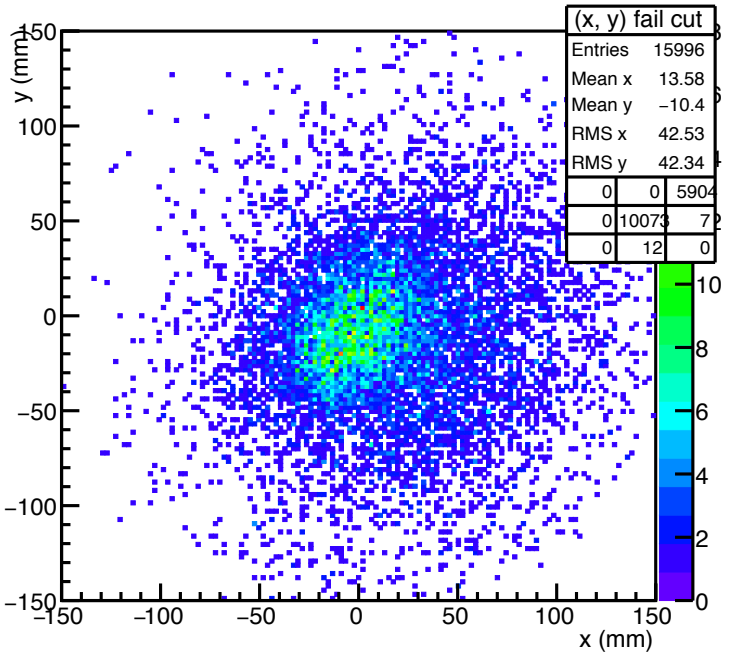


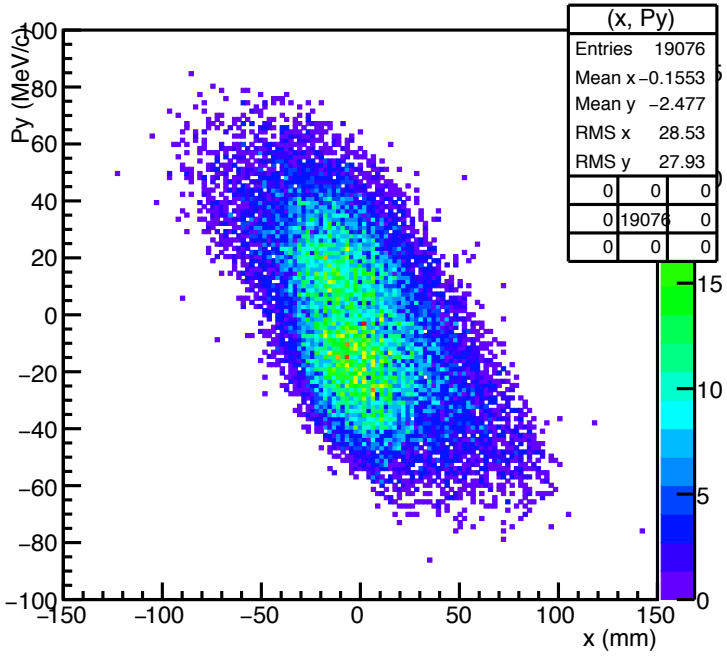



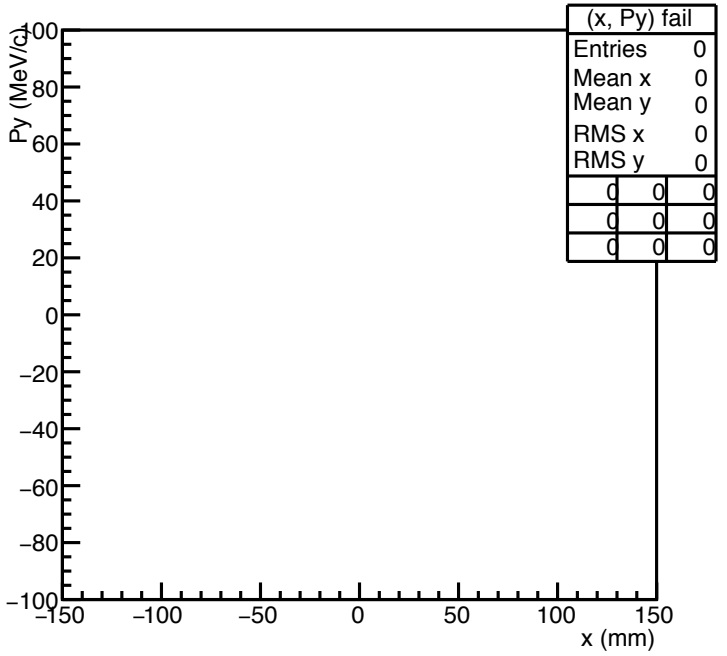



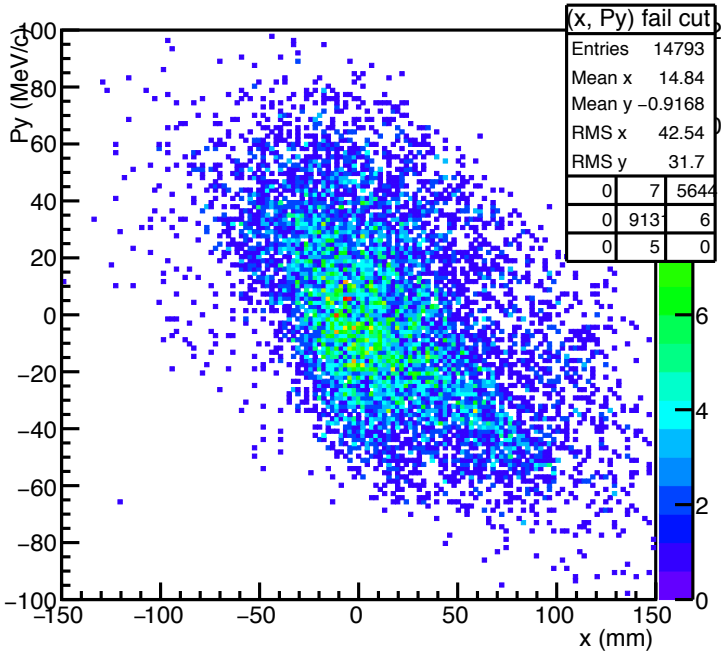



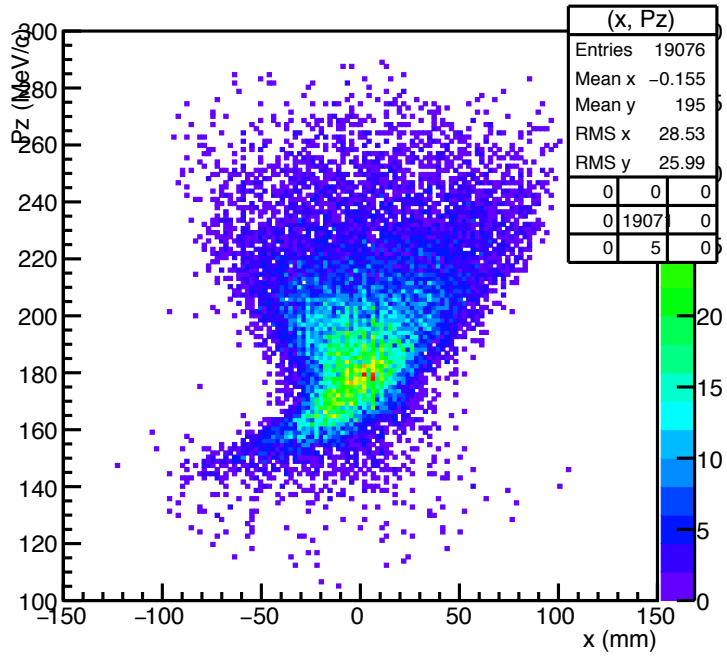



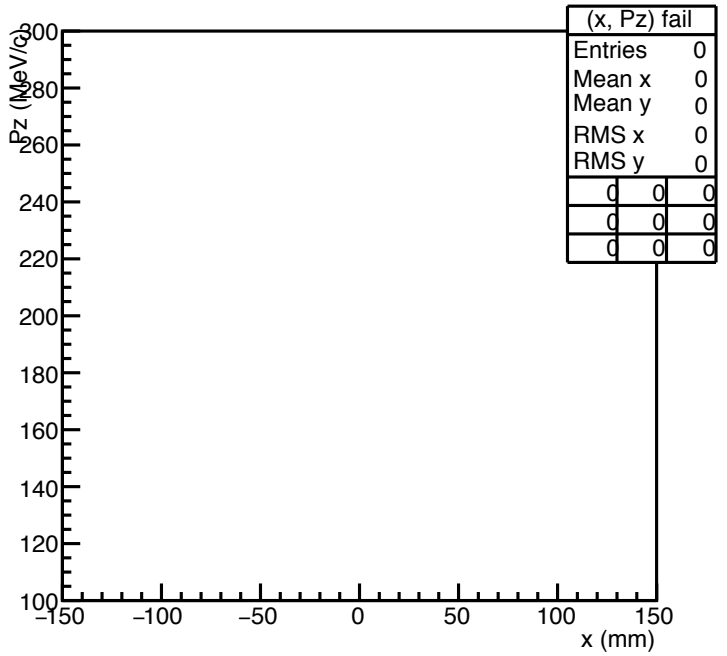
*cut_goodRaynerReconstruction (cut 3)*

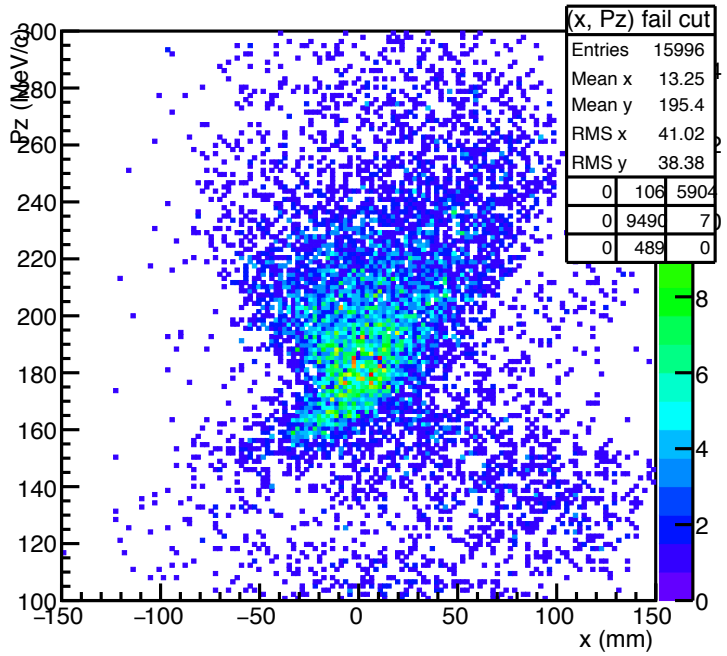


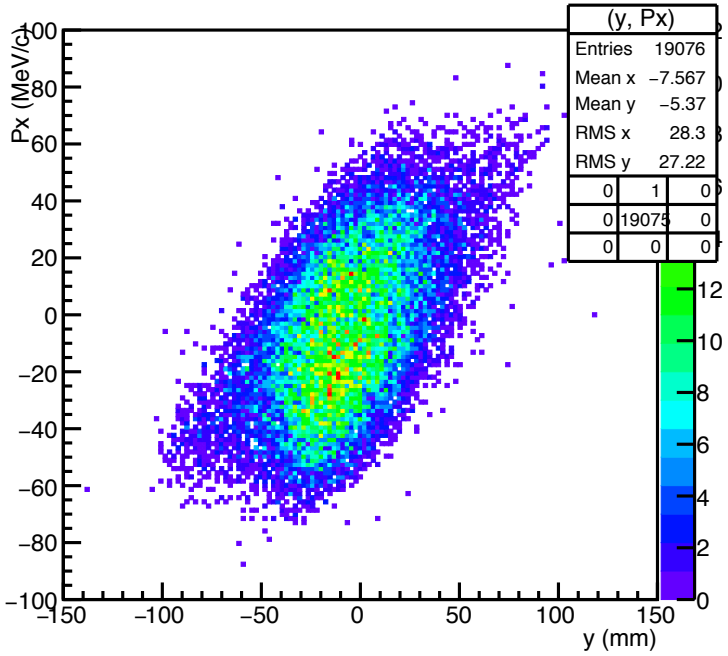



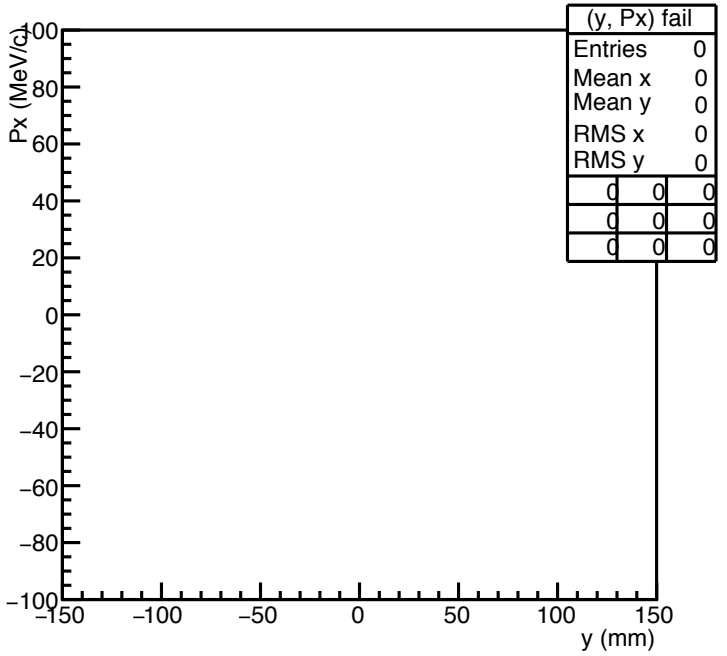



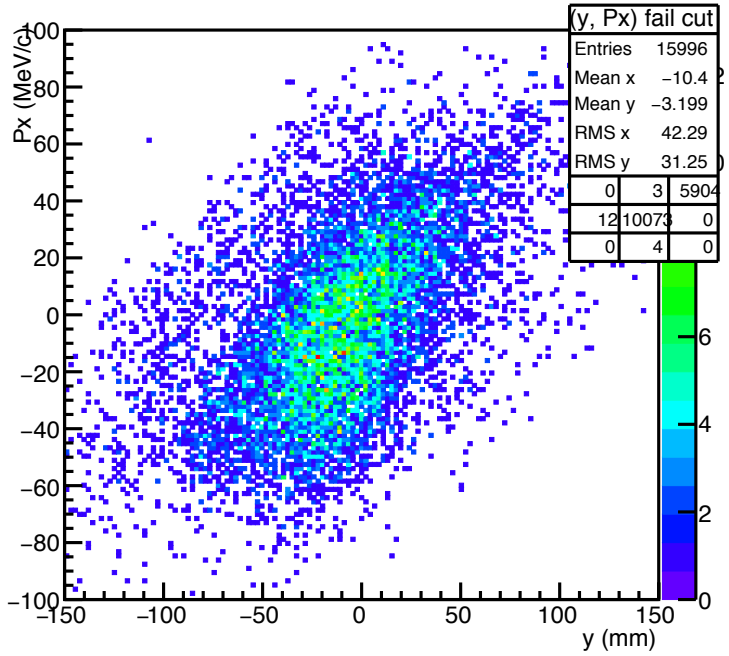



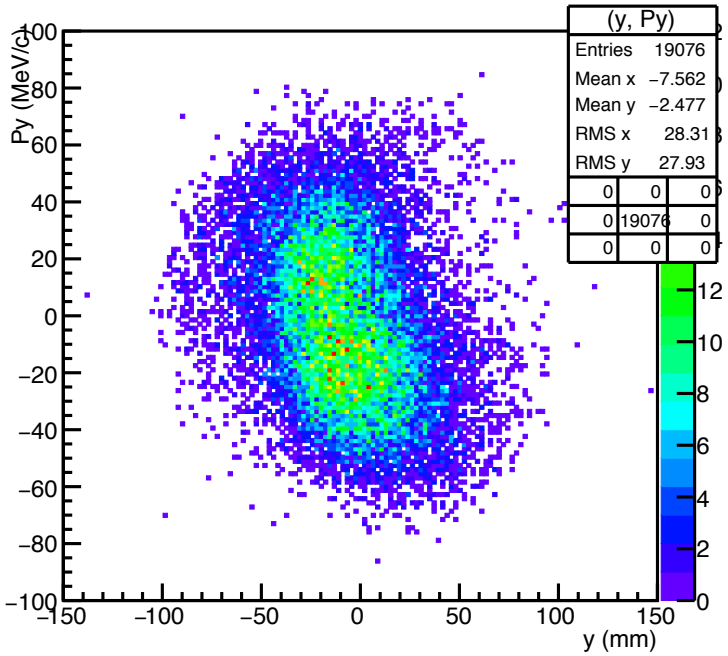



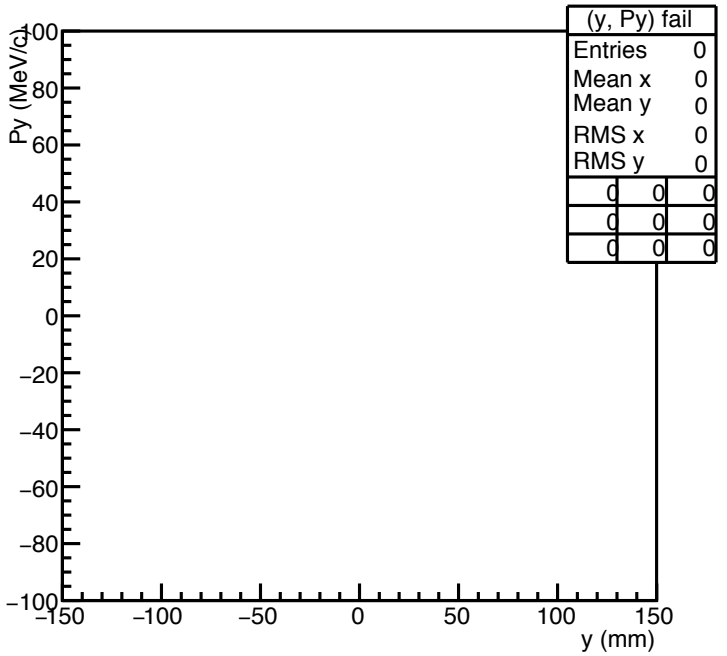
*cut_goodRaynerReconstruction (cut 3)*

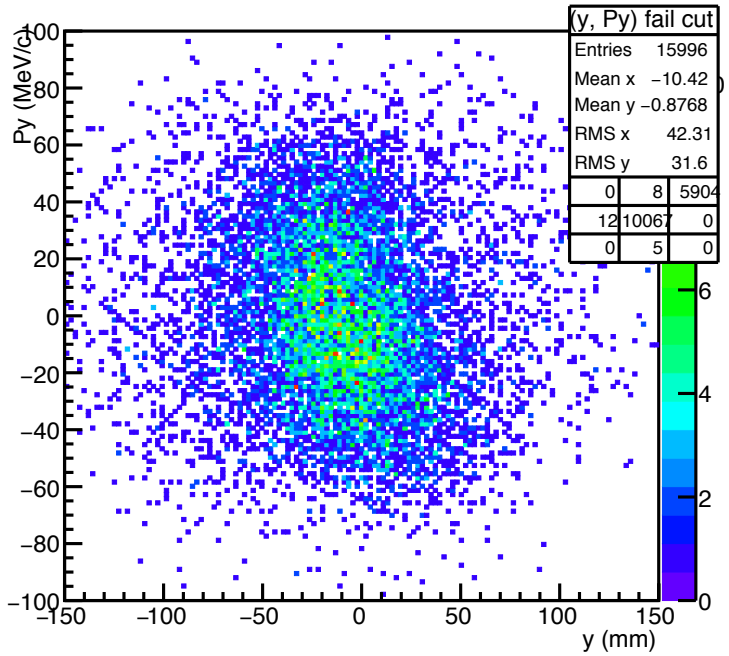


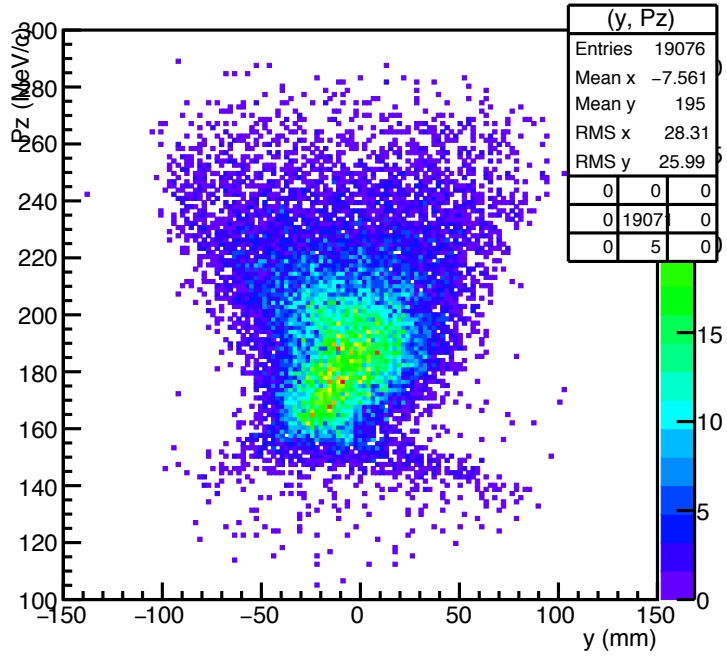



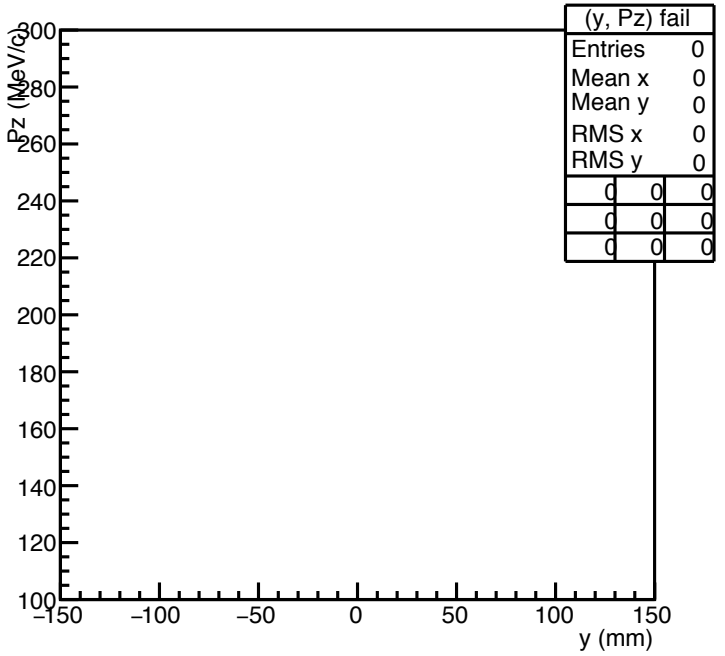



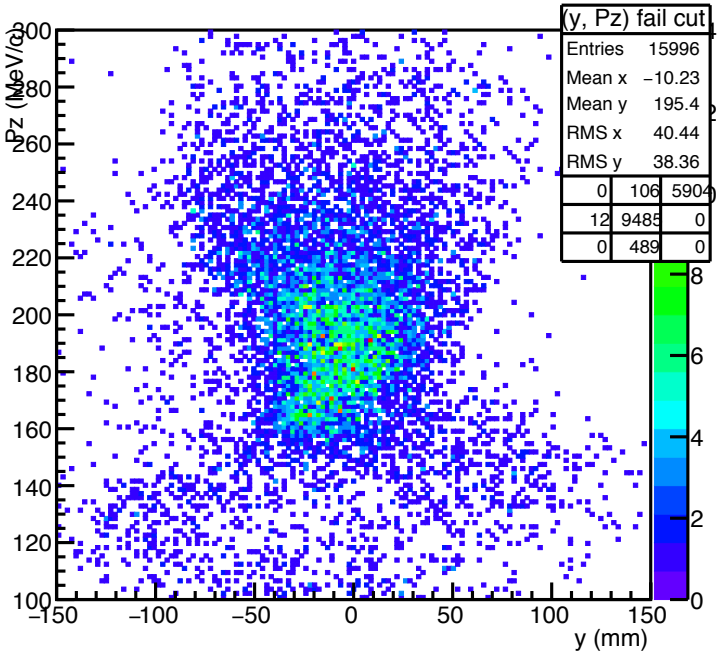



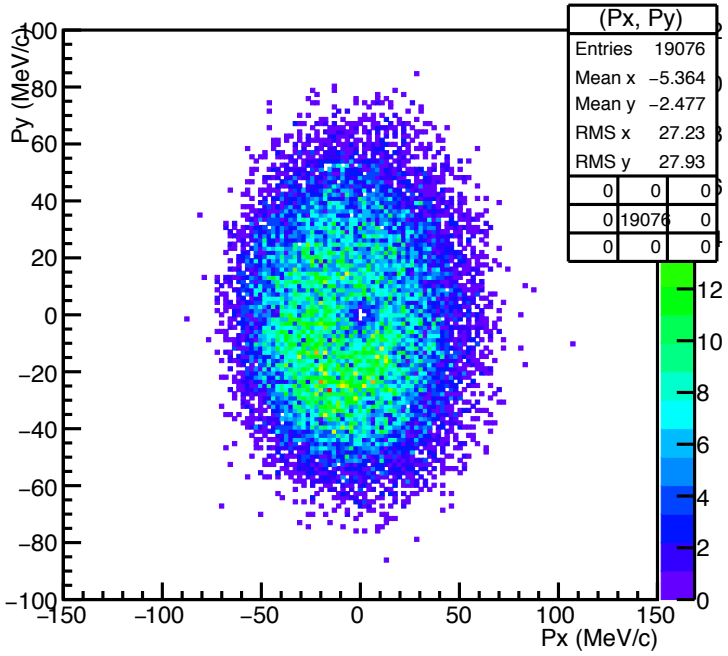



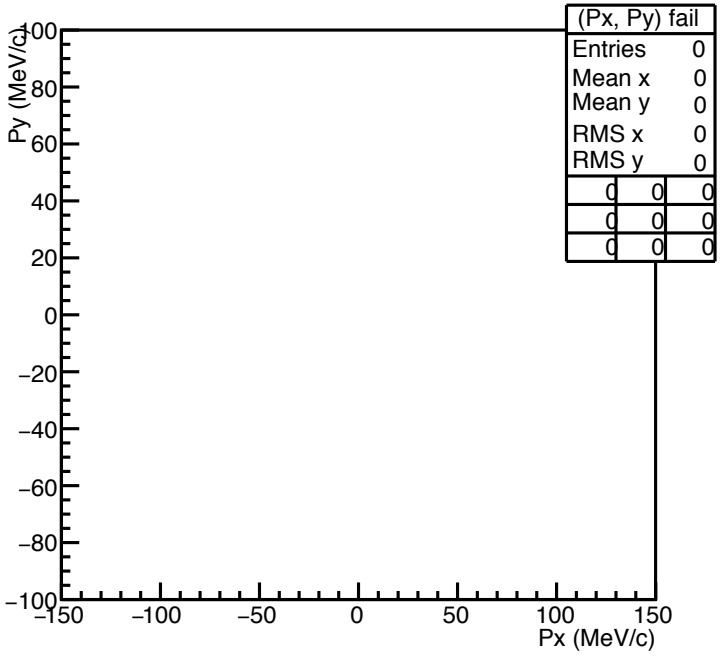
*cut_goodRaynerReconstruction (cut 3)*

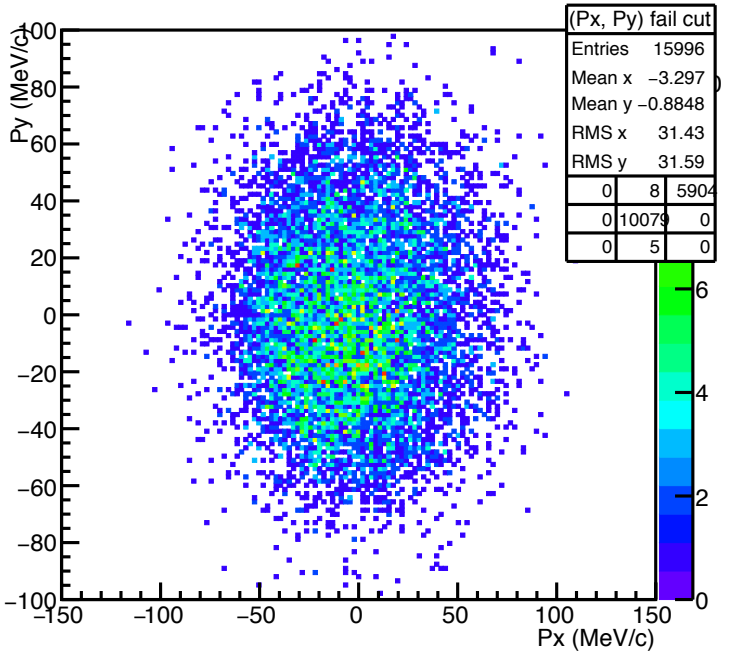


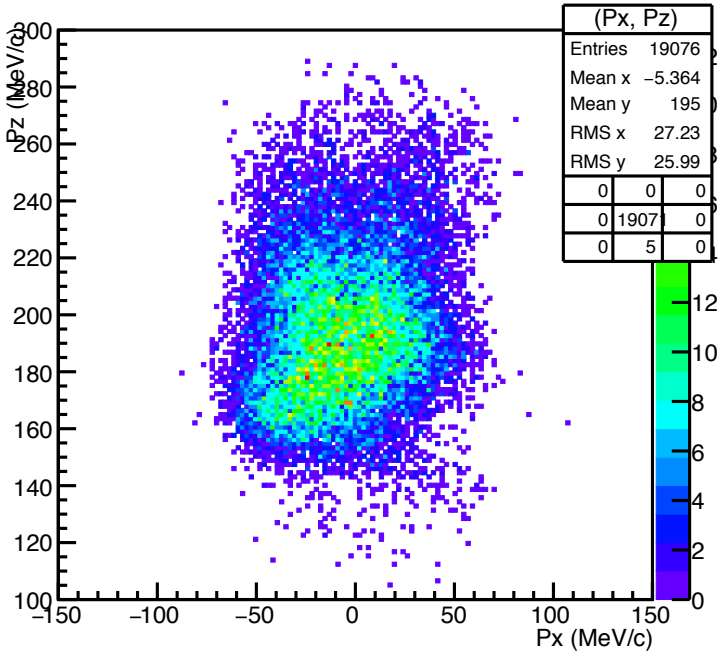



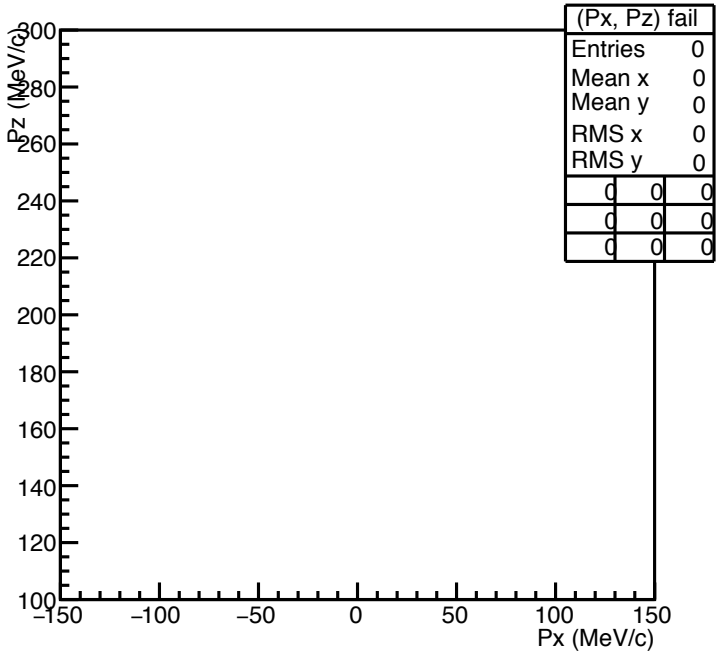



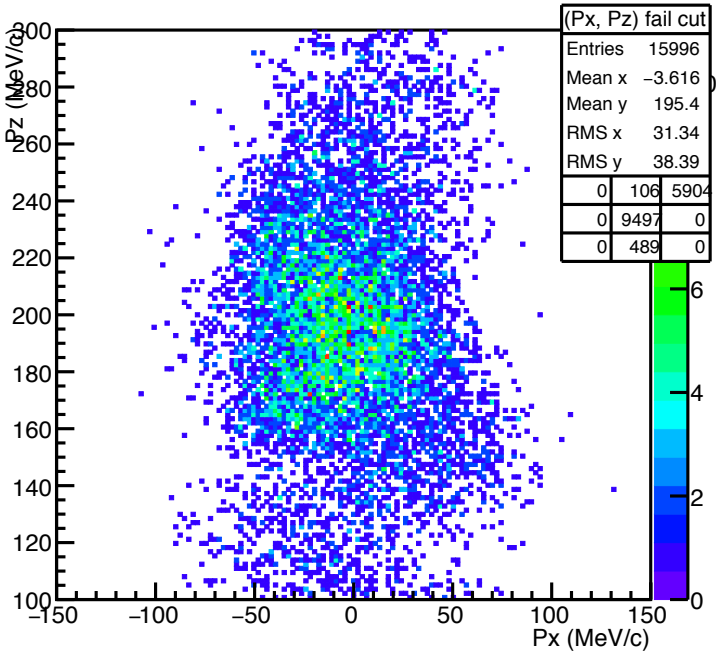



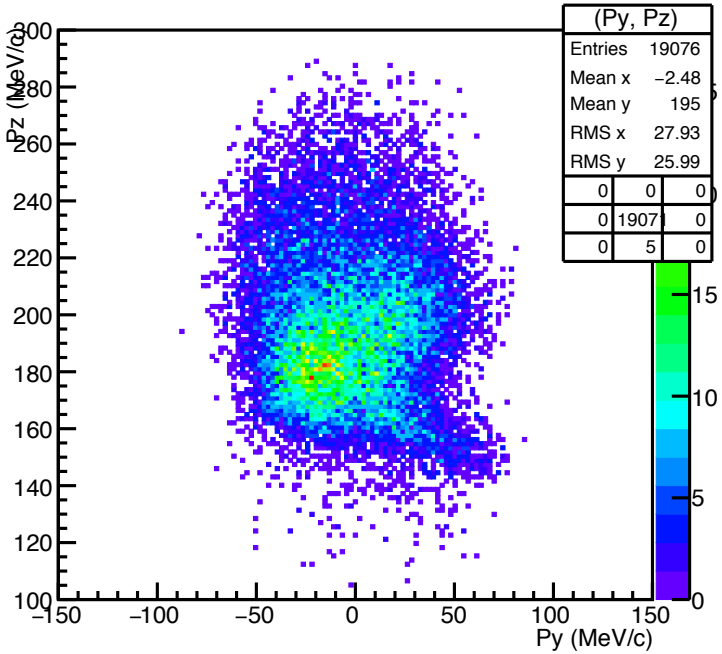



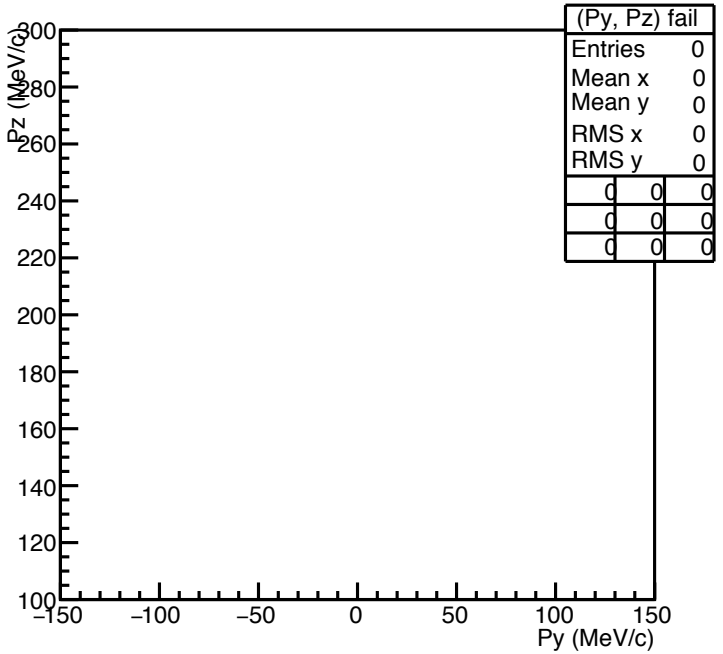
*cut_goodRaynerReconstruction (cut 3)*

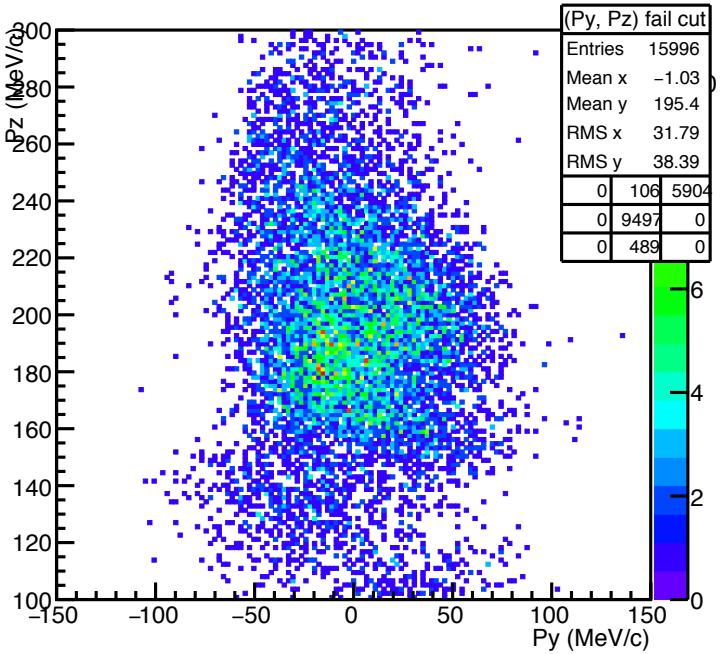


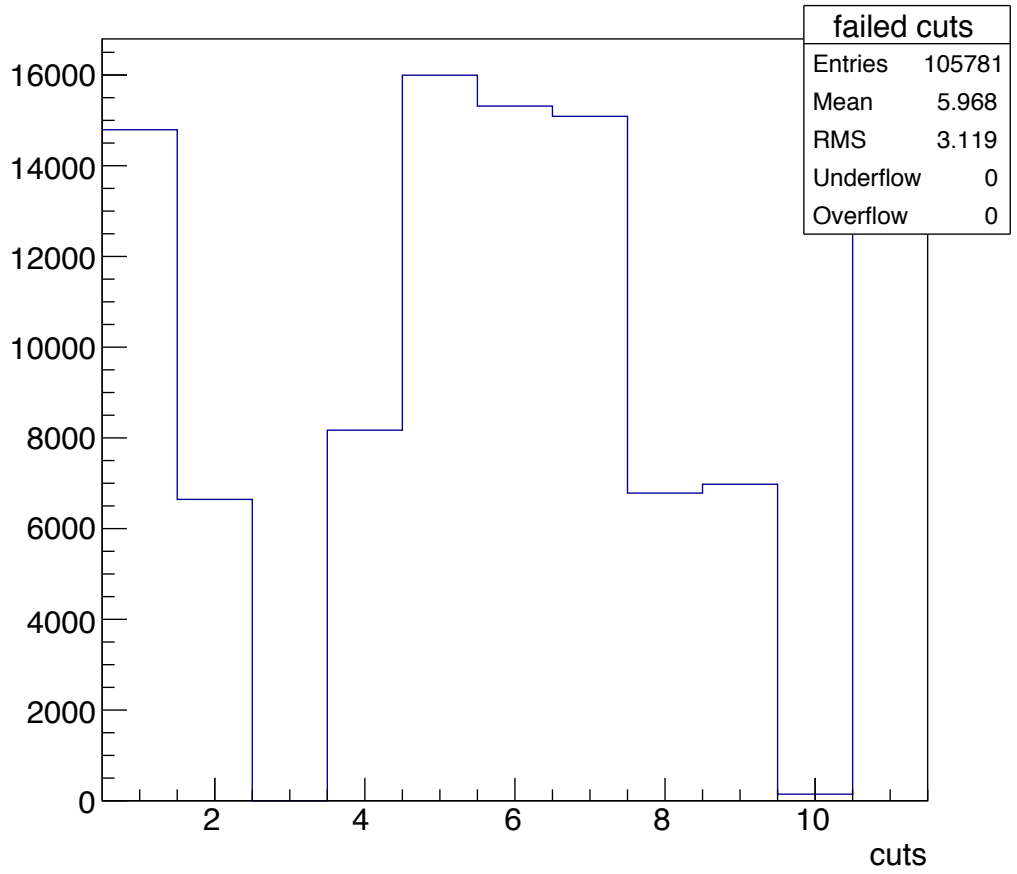



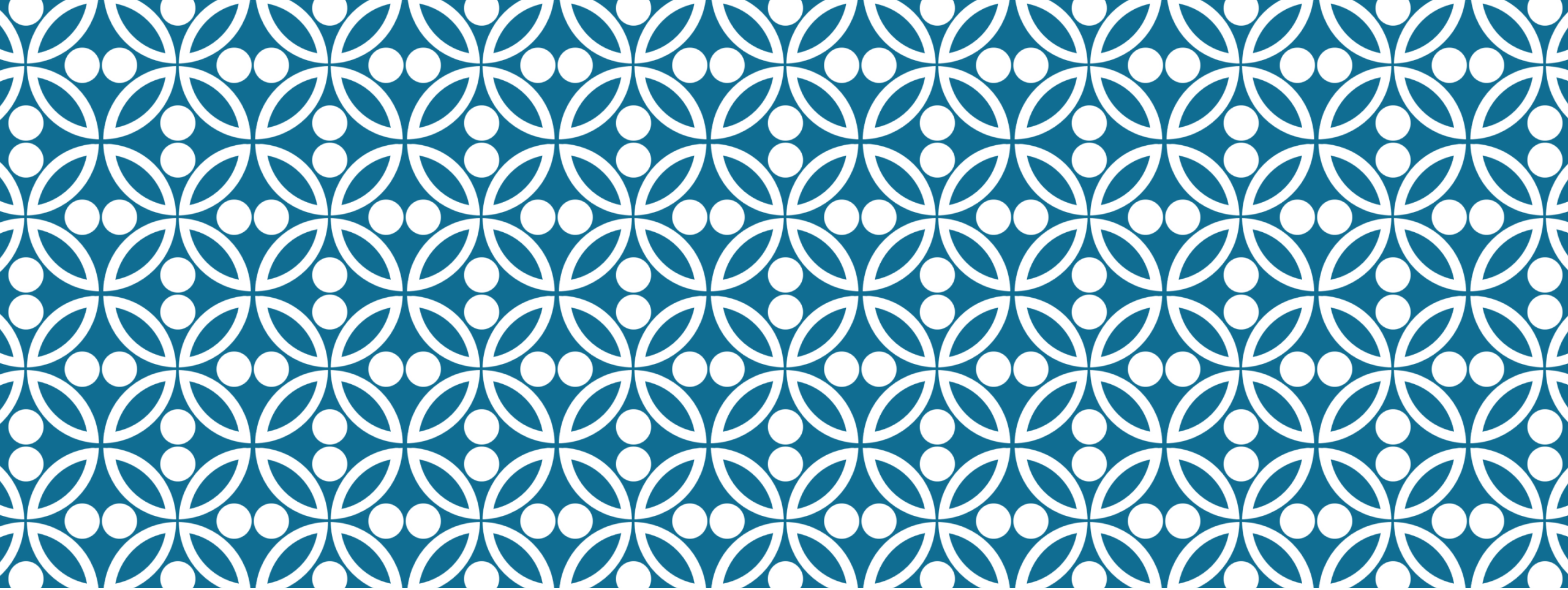





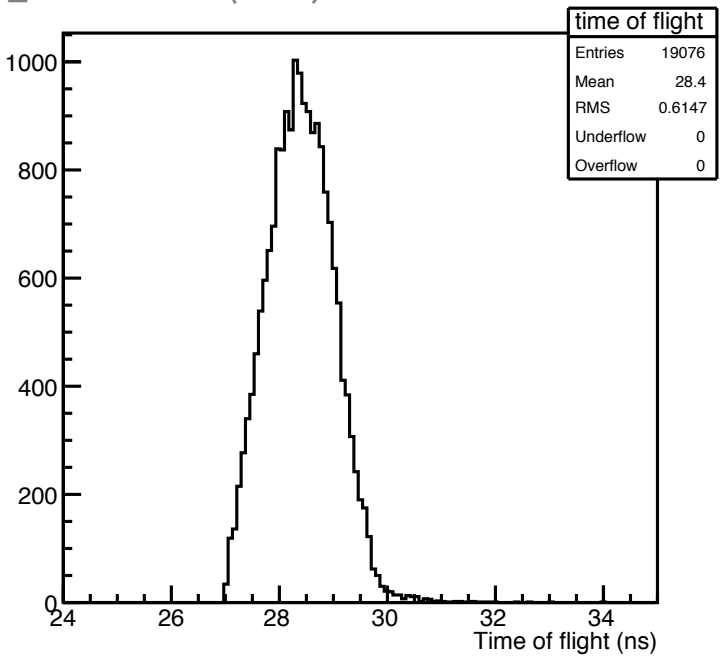

| 'Cut number' | Cut |
|---|---|
| 1 | cut_TOF0_goodPMTPosition |
| 2 | cut_TOF1_goodPMTPosition |
| 3 | cut_goodRaynerReconstruction |
| 4 | cut_TKU_hitAllStations |
| 5 | cut_TimeOfFlight |
| 6 | cut_hit_all_detectors |
| 7 | cut_TOF0_singleHit |
| 8 | cut_TOF1_singleHit |
| 9 | cut_TKU_singleTrack |
| 10 | cut_TKU_PValue |
| 11 | cut_momentum_loss |

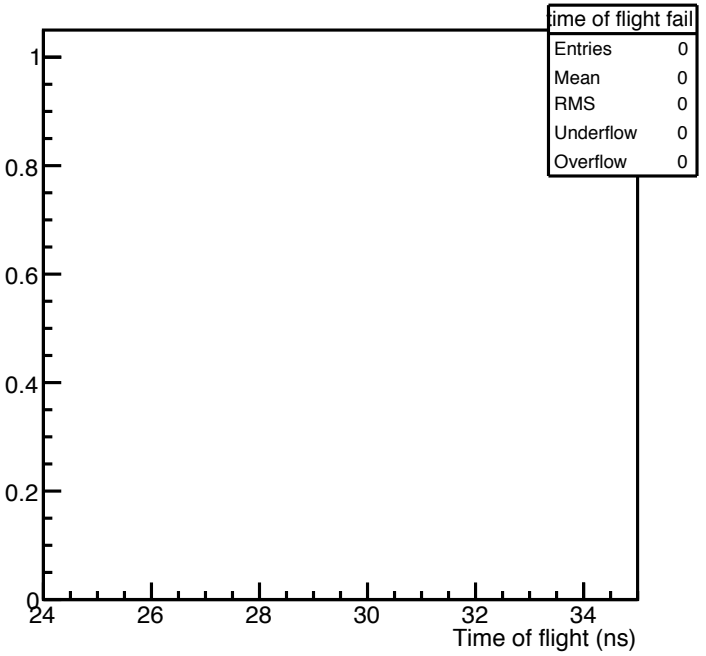


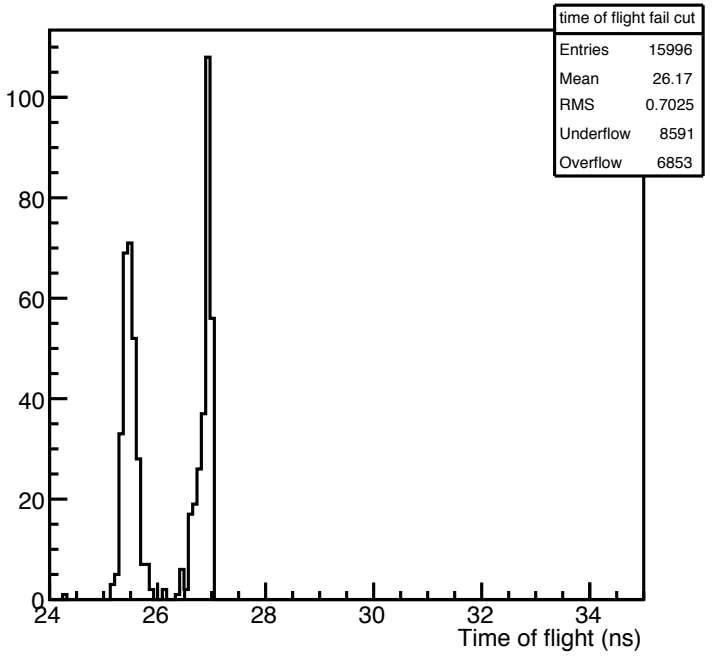
# CUT_TKU_HITALLSTATIONS

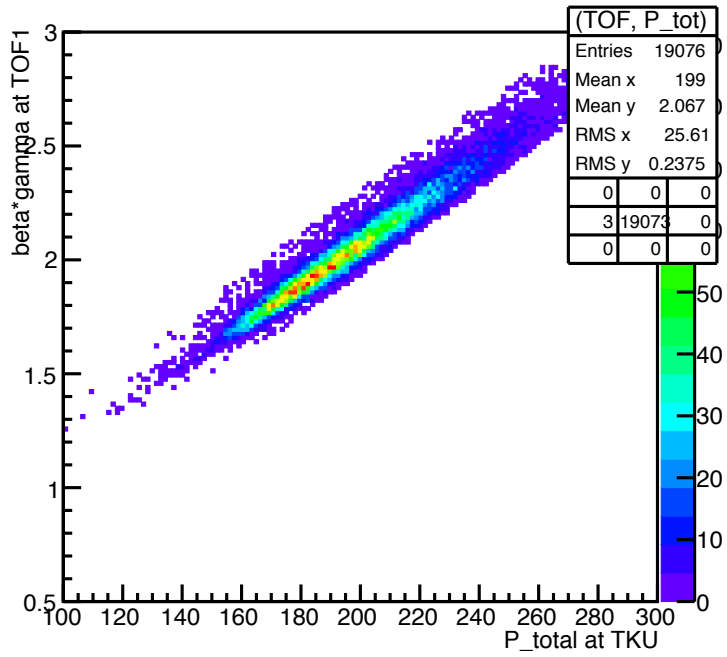
AKA ‘cut 4’

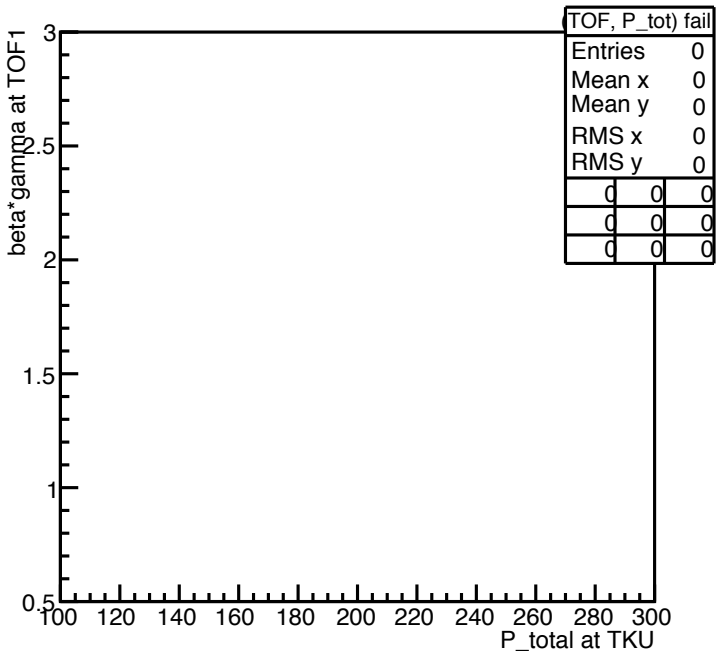
*cut_TKU_hitAllStations (cut 4)*

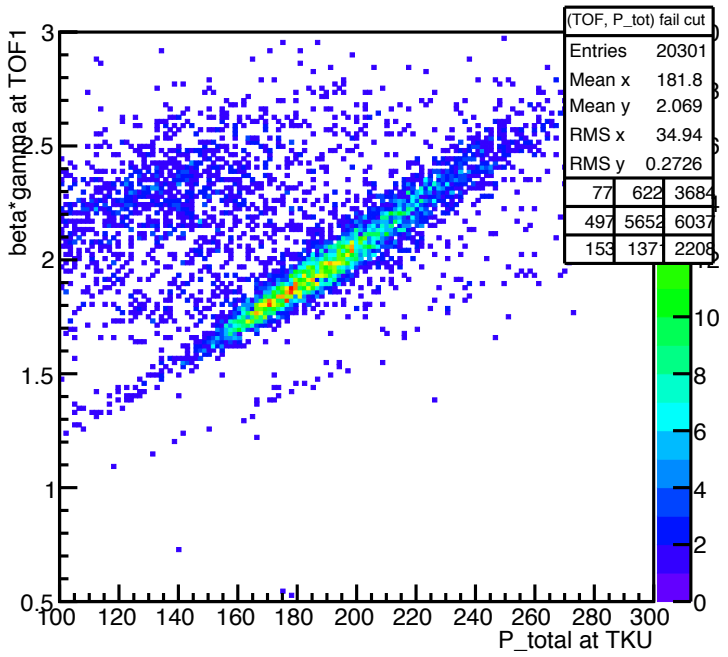


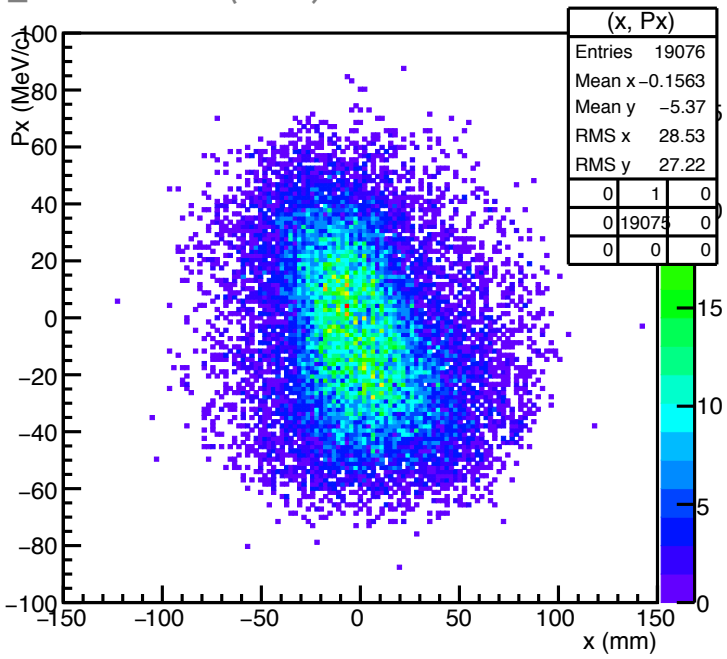



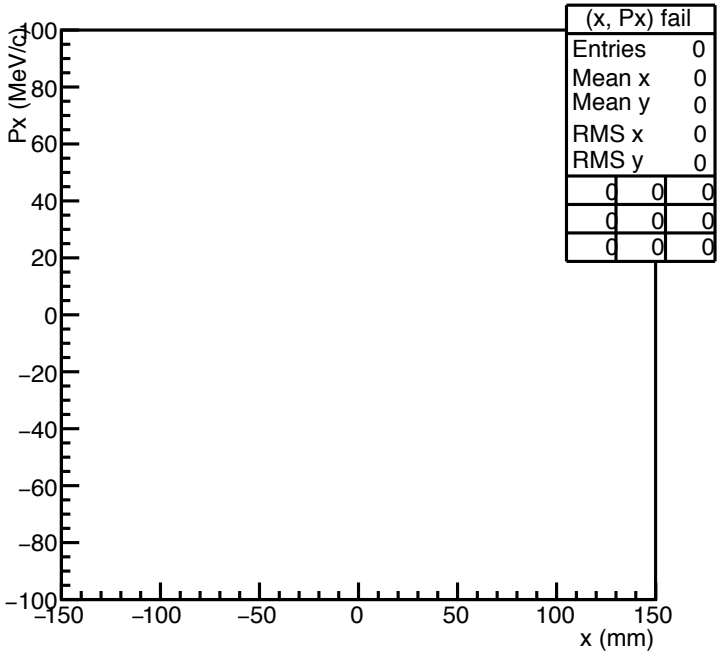



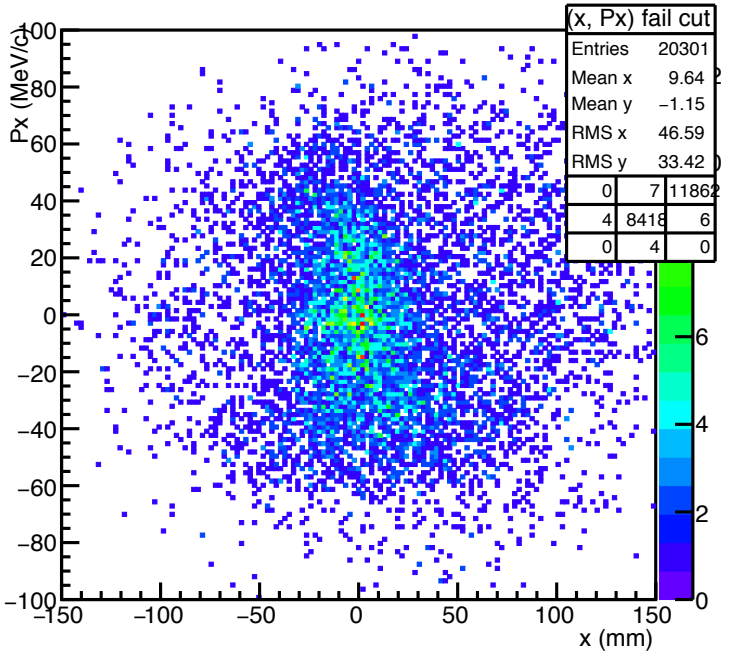



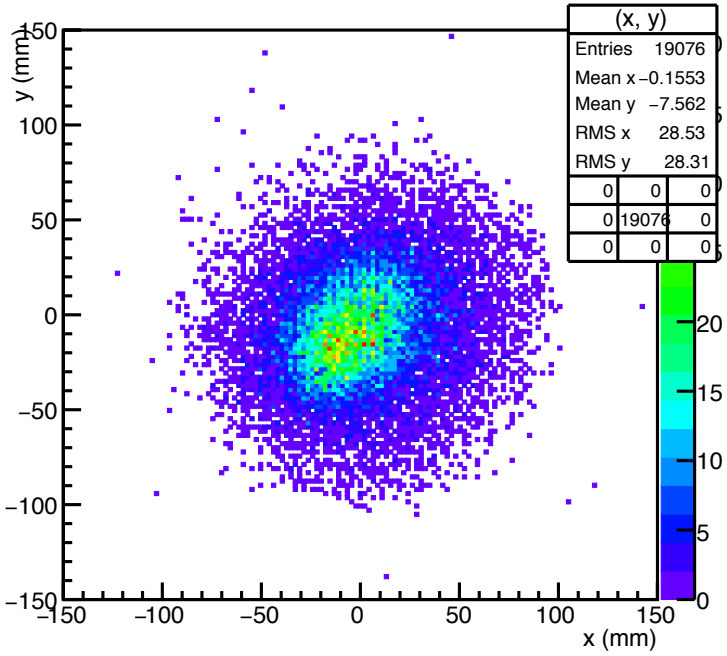




(x, Px)
Entries 19076
Mean x −0.1563
Mean y −5.37
RMS x 28.53
RMS y 27.22
Px (MeV/c)
x (mm)


(x, Px) fail
Entries 0
Mean x 0
Mean y 0
RMS x 0
RMS y 0
Px (MeV/c)
x (mm)


(x, Px) fail cut
Entries 20301
Mean x 9.64
Mean y −1.15
RMS x 46.59
RMS y 33.42
Px (MeV/c)
x (mm)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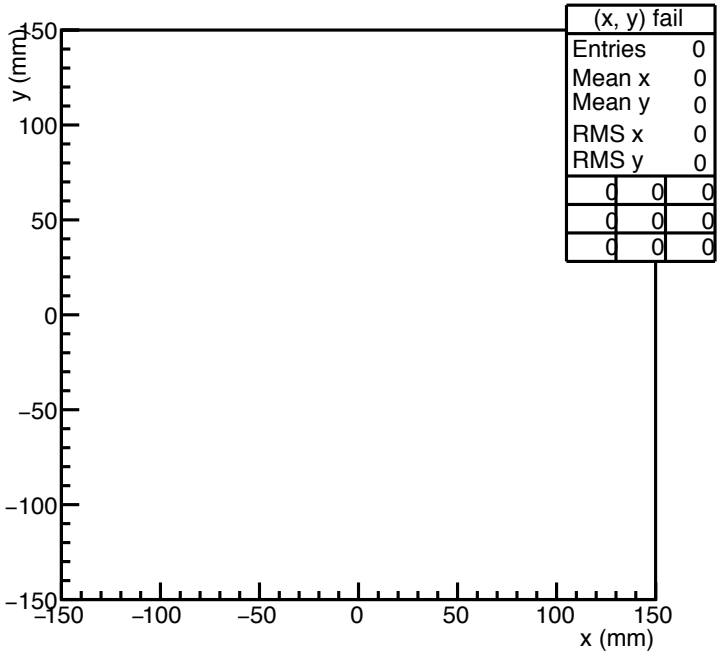
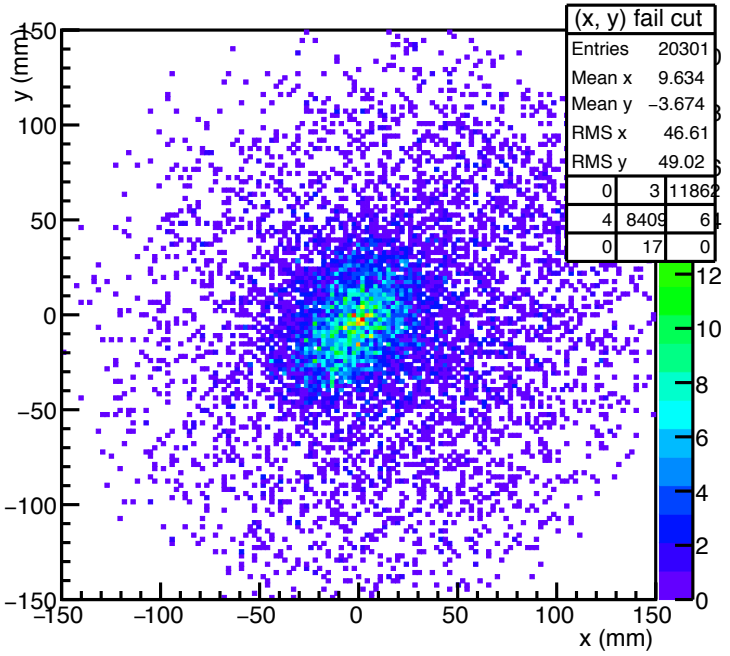
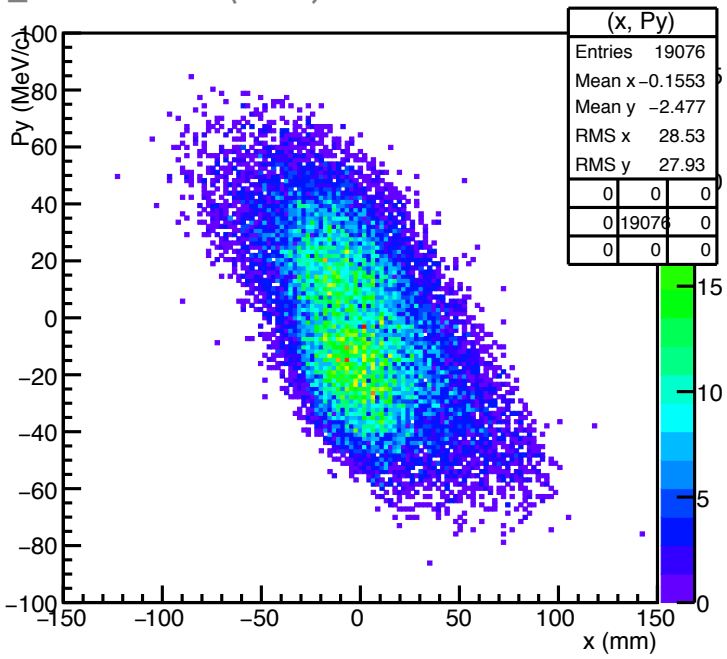
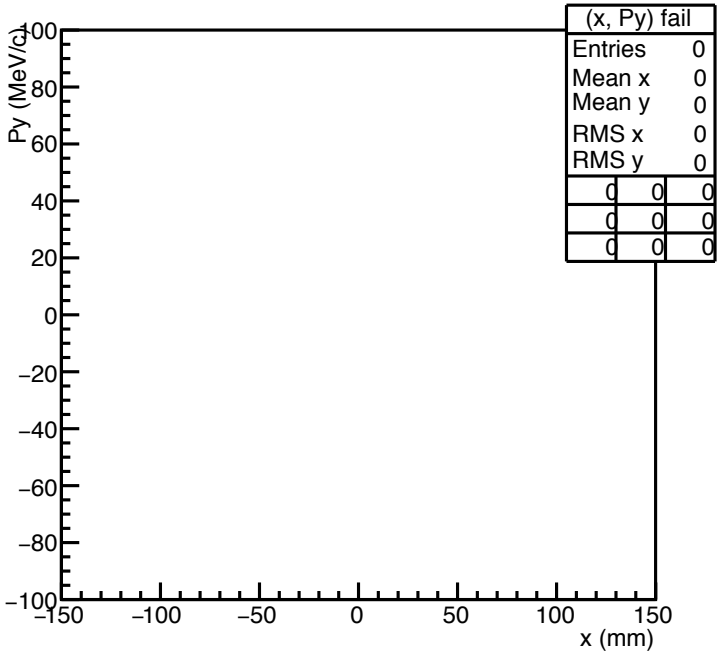
Mean y −7.562
RMS x 28.53
RMS y 28.31
y (mm)
x (mm)

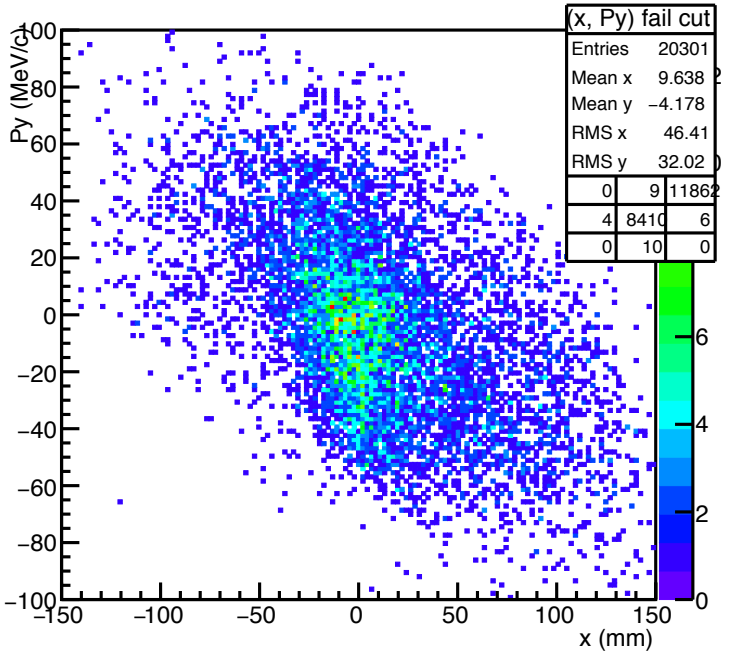

(x, y) fail
Entries 0
Mean x 0
Mean y 0
RMS x 0
RMS y 0
y (mm)
x (mm)

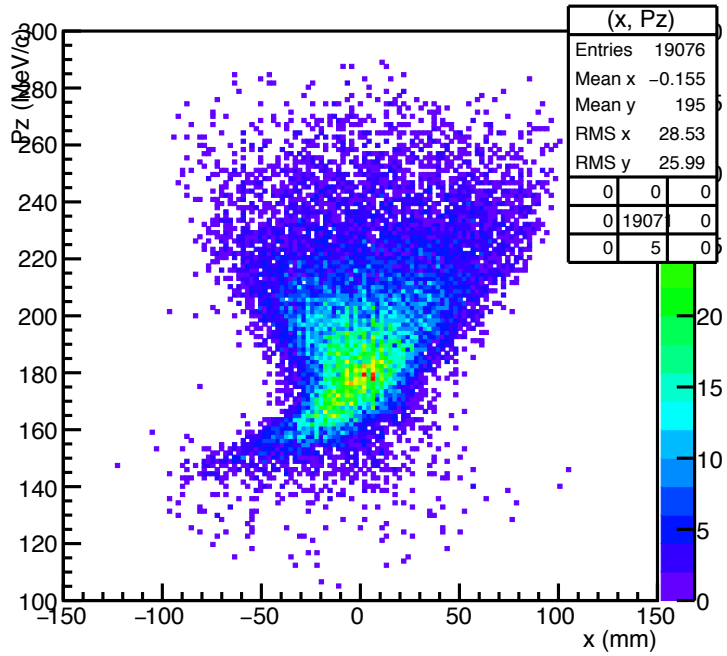

(x, y) fail cut
Entries 20301
Mean x 9.634
Mean y −3.674
RMS x 46.61
RMS y 49.02
y (mm)
x (mm)

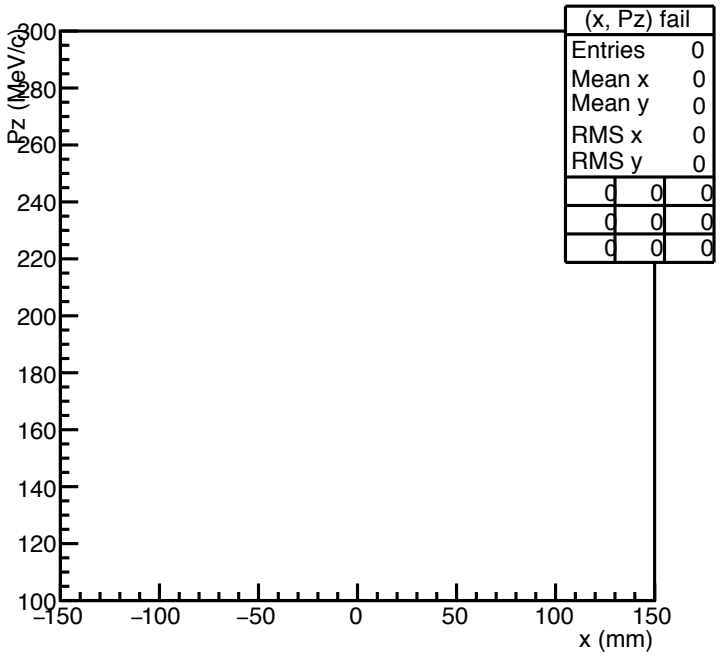
*cut_TKU_hitAllStations (cut 4)*

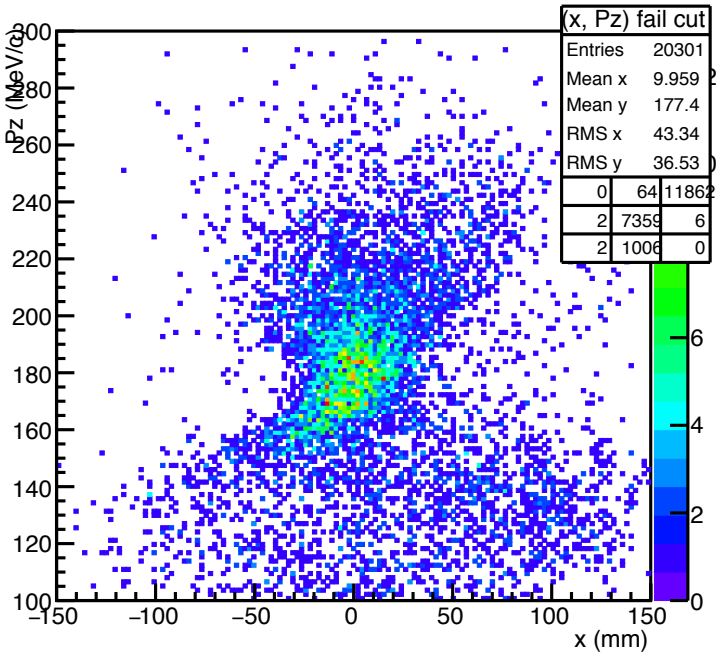


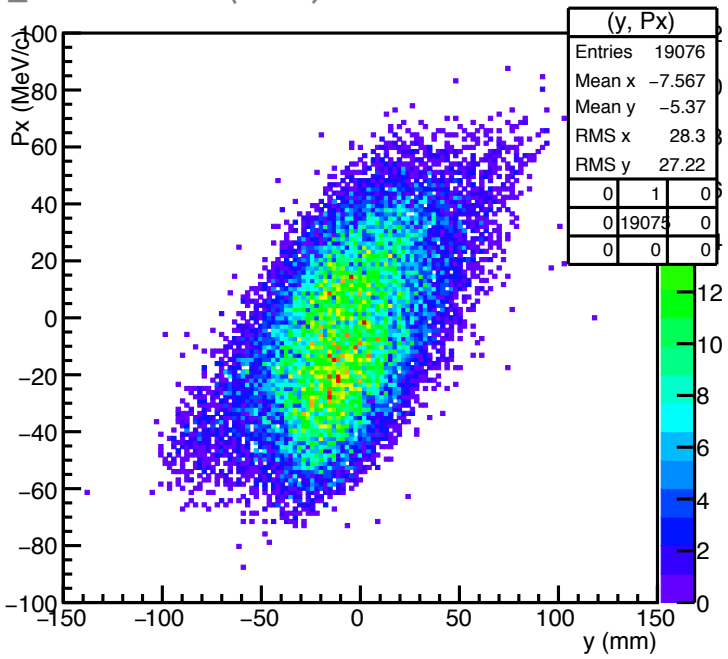



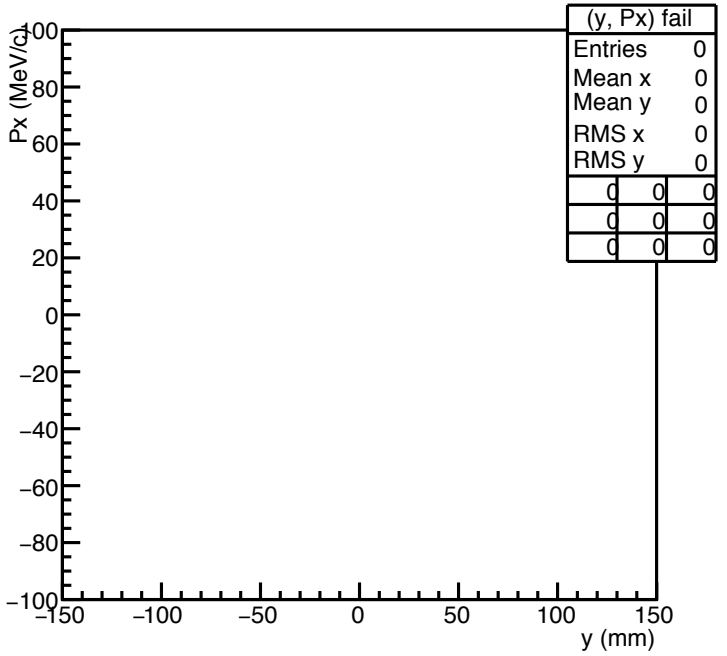



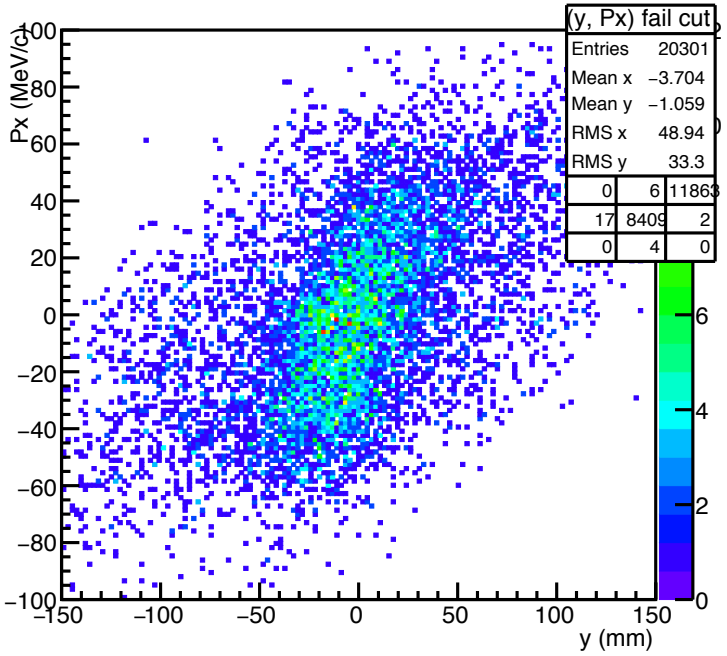



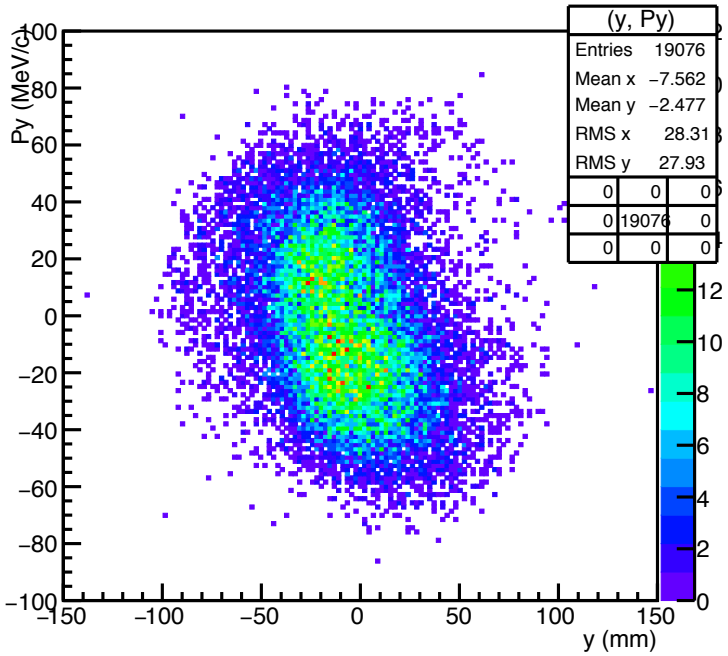



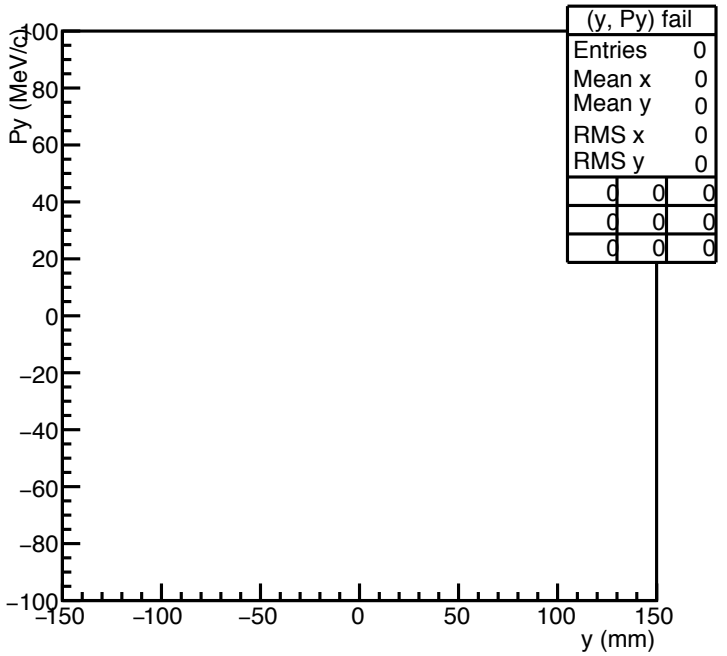
*cut_TKU_hitAllStations (cut 4)*

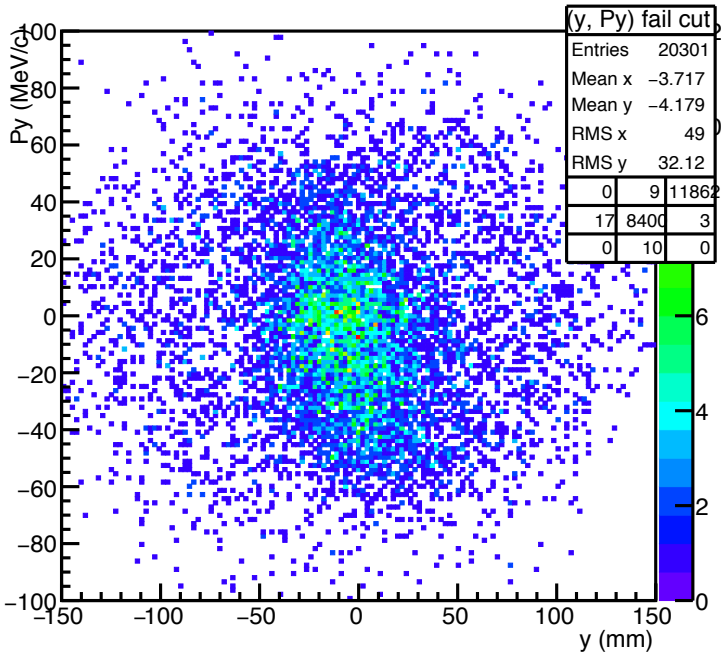


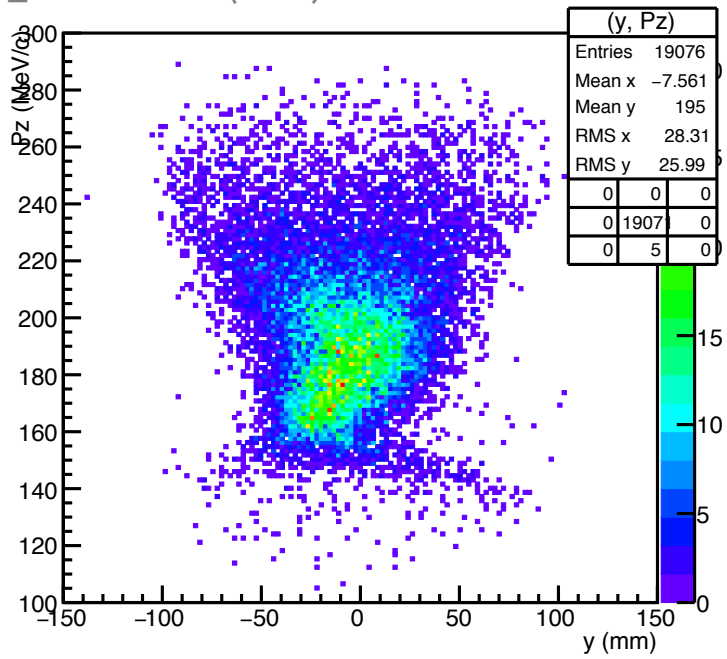



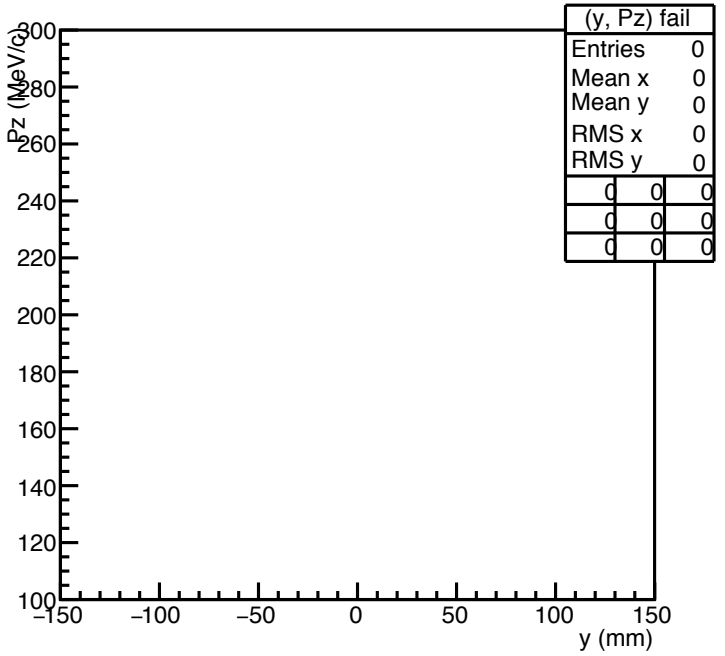



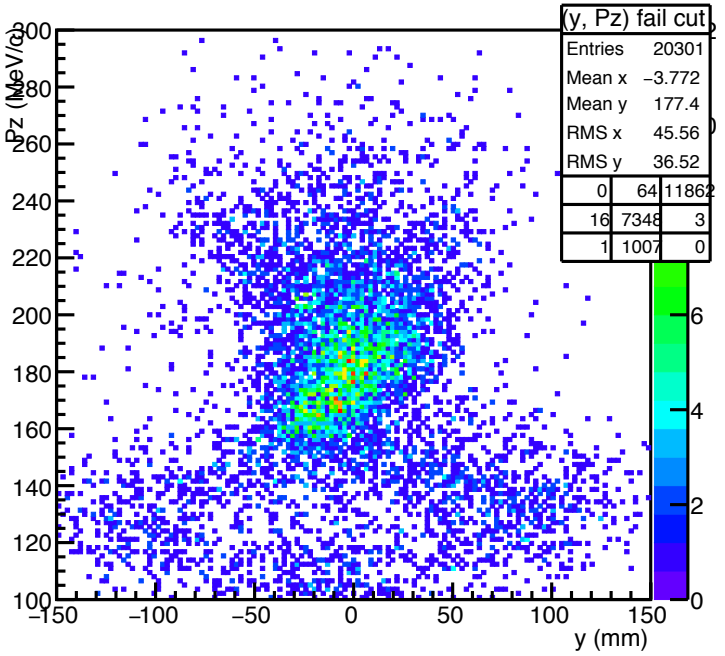



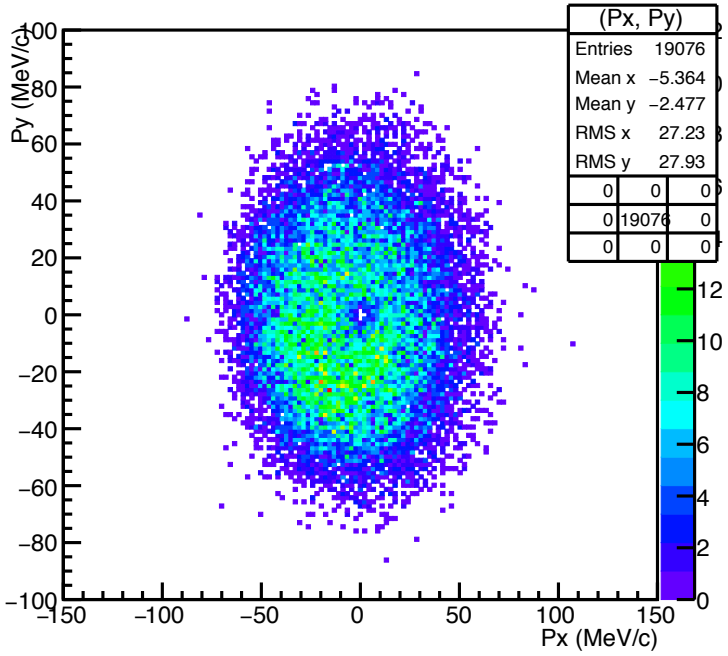



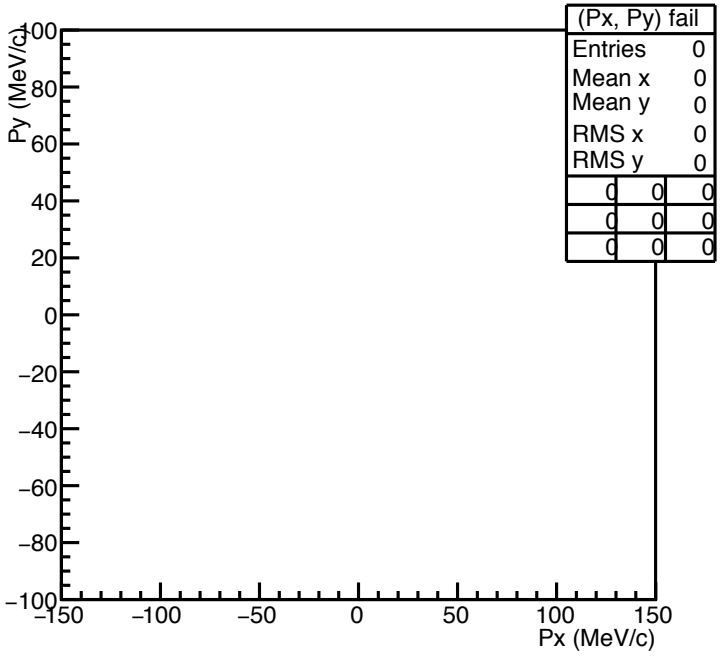
*cut_TKU_hitAllStations (cut 4)*

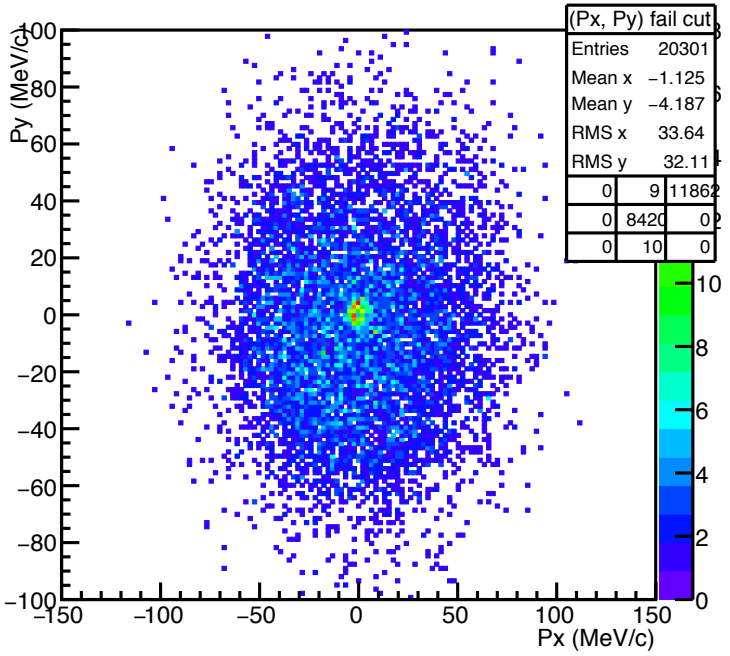


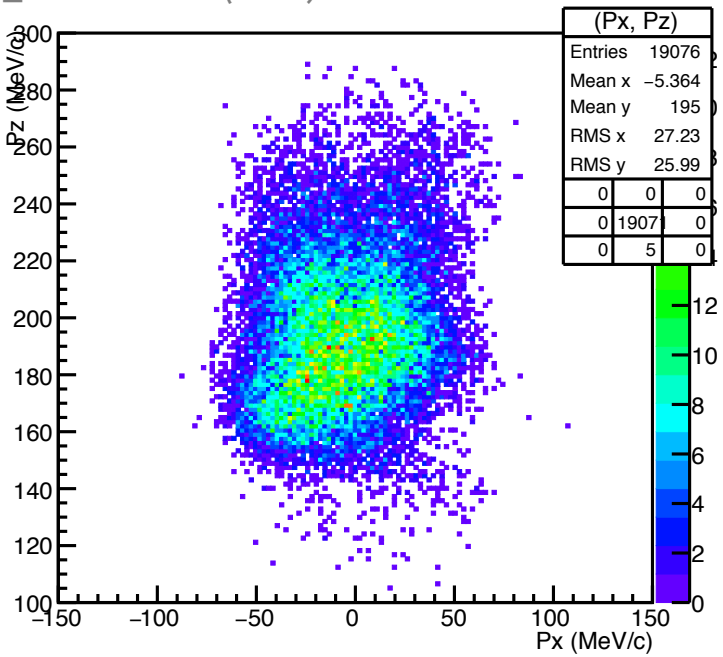



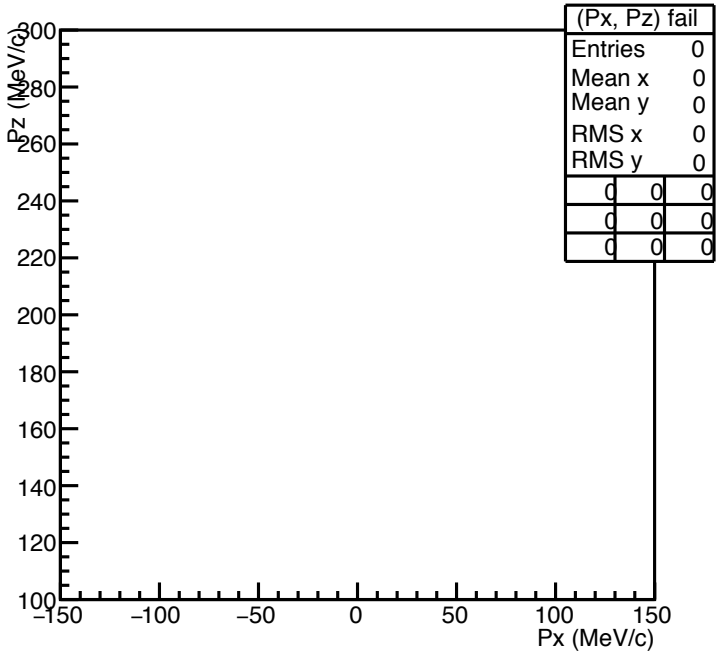



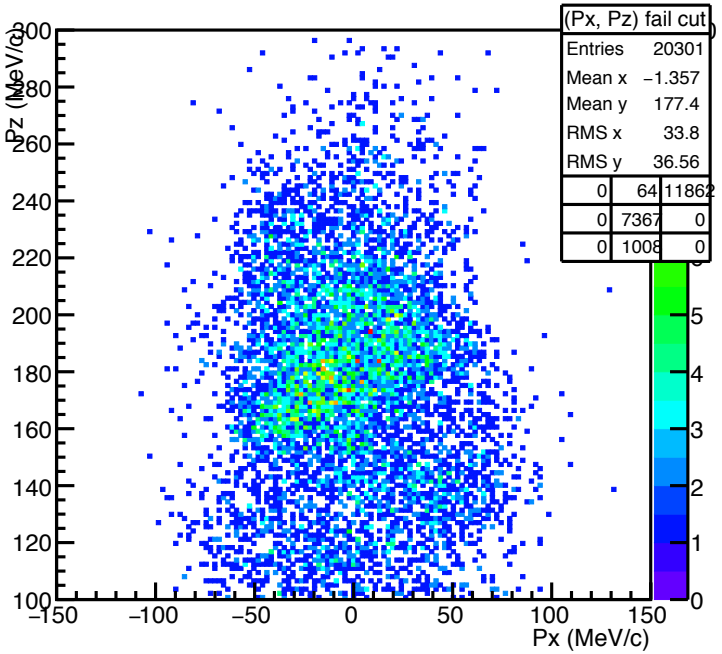



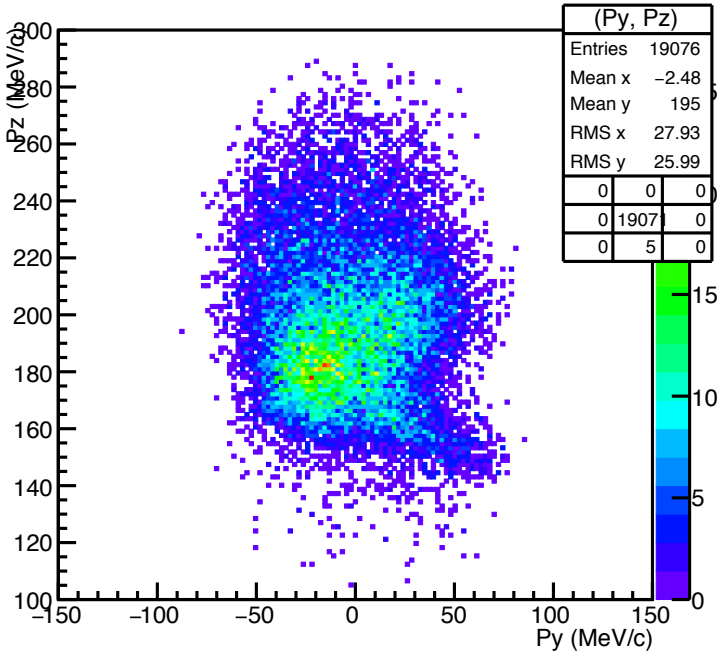



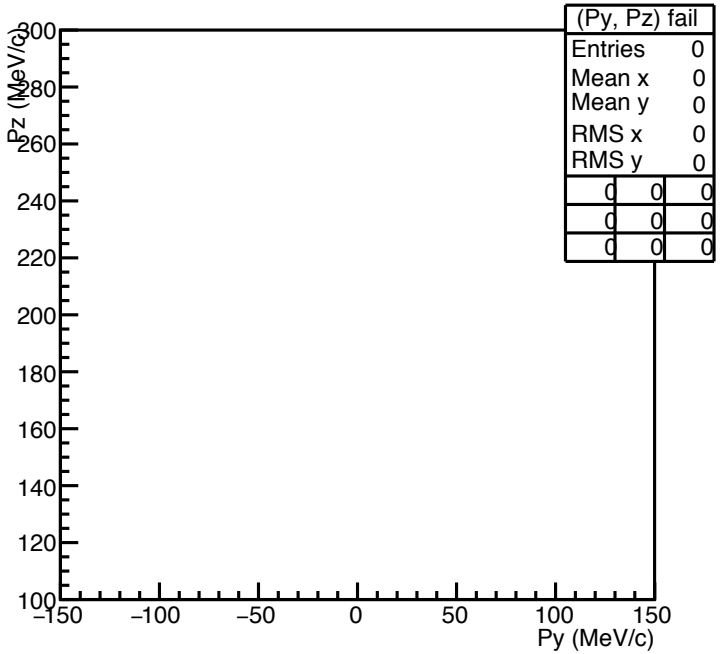
*cut_TKU_hitAllStations (cut 4)*

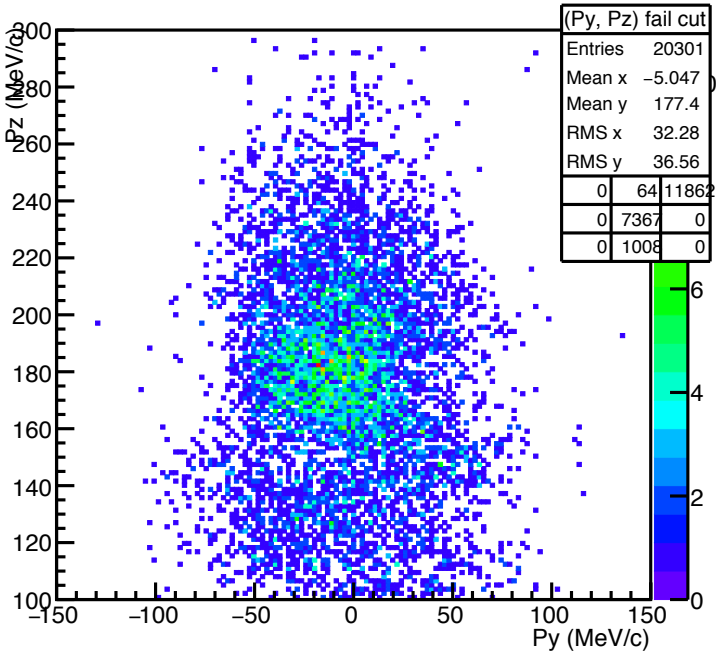


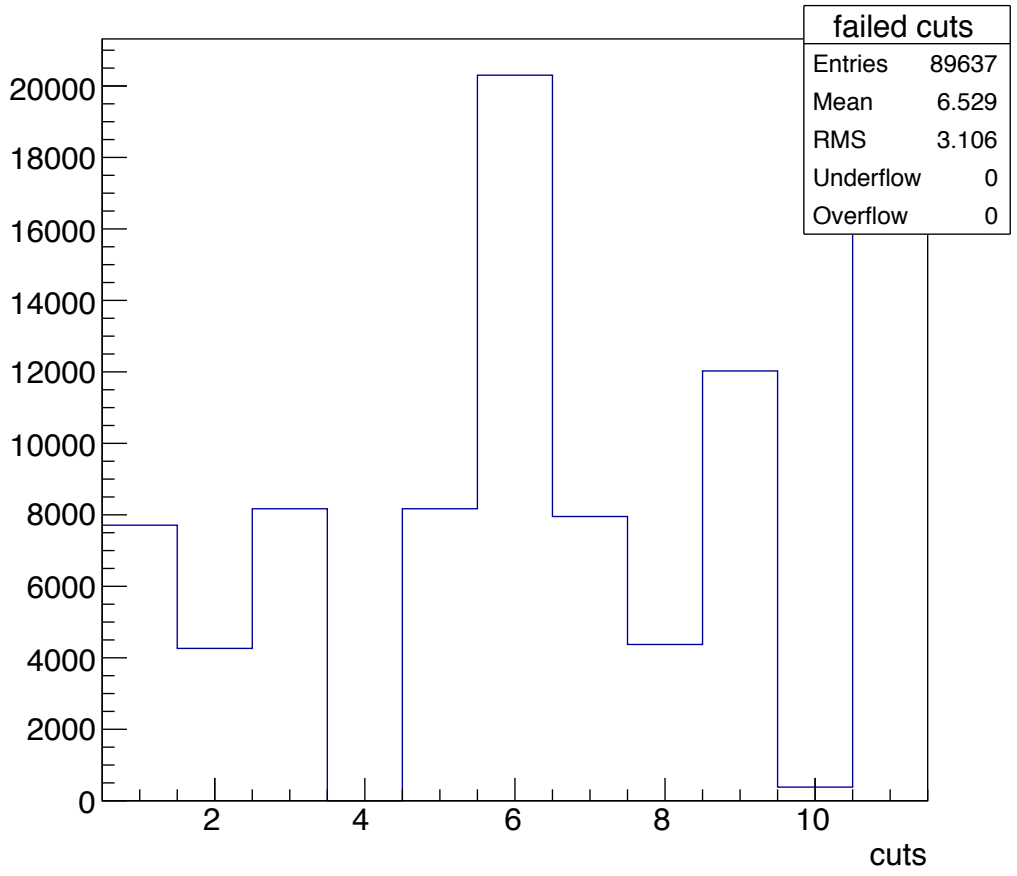



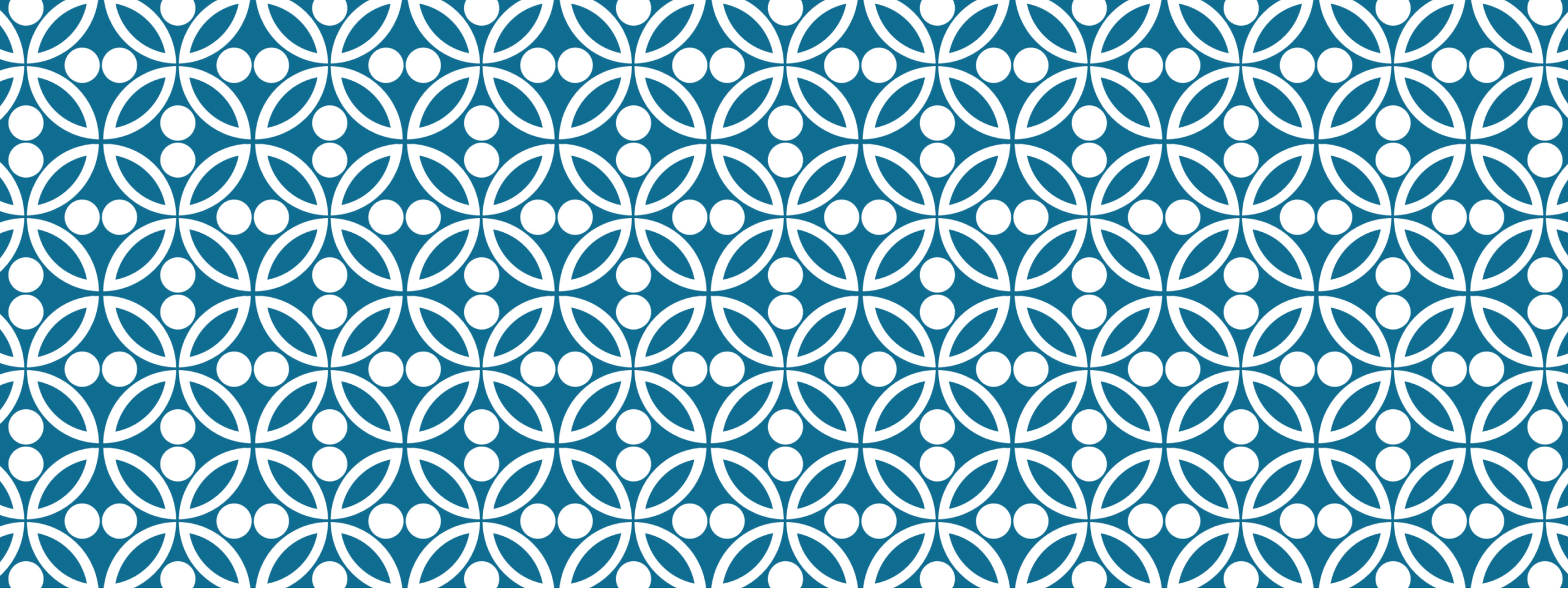





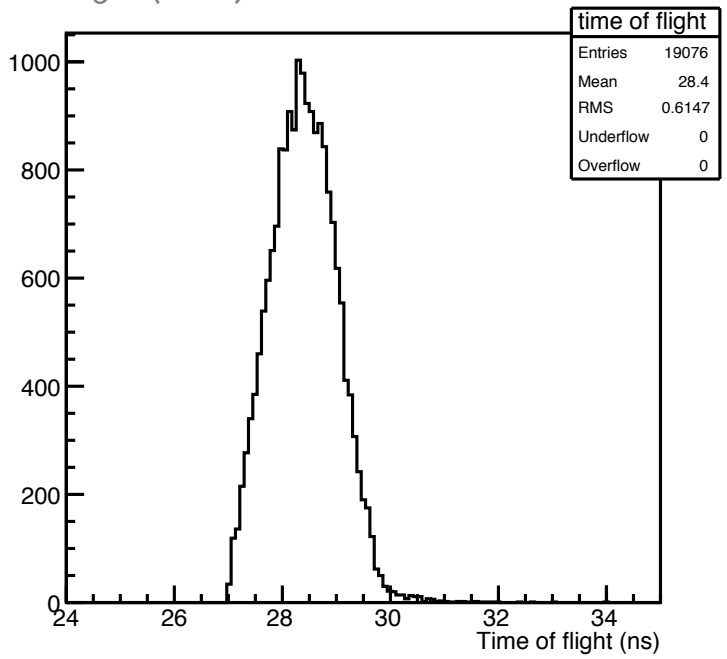

| 'Cut number' | Cut |
|---|---|
| 1 | cut_TOF0_goodPMTPosition |
| 2 | cut_TOF1_goodPMTPosition |
| 3 | cut_goodRaynerReconstruction |
| 4 | cut_TKU_hitAllStations |
| 5 | cut_TimeOfFlight |
| 6 | cut_hit_all_detectors |
| 7 | cut_TOF0_singleHit |
| 8 | cut_TOF1_singleHit |
| 9 | cut_TKU_singleTrack |
| 10 | cut_TKU_PValue |
| 11 | cut_momentum_loss |

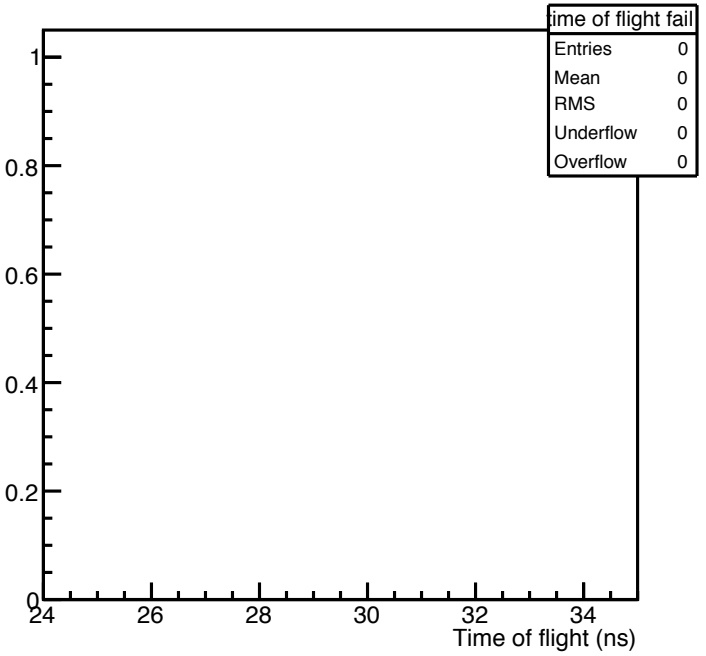


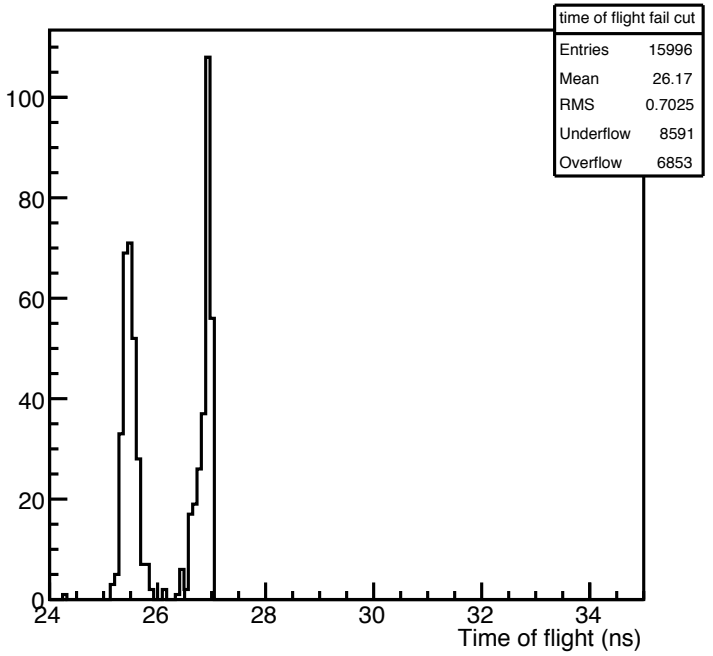
# CUT_TIMEOFFLIGHT

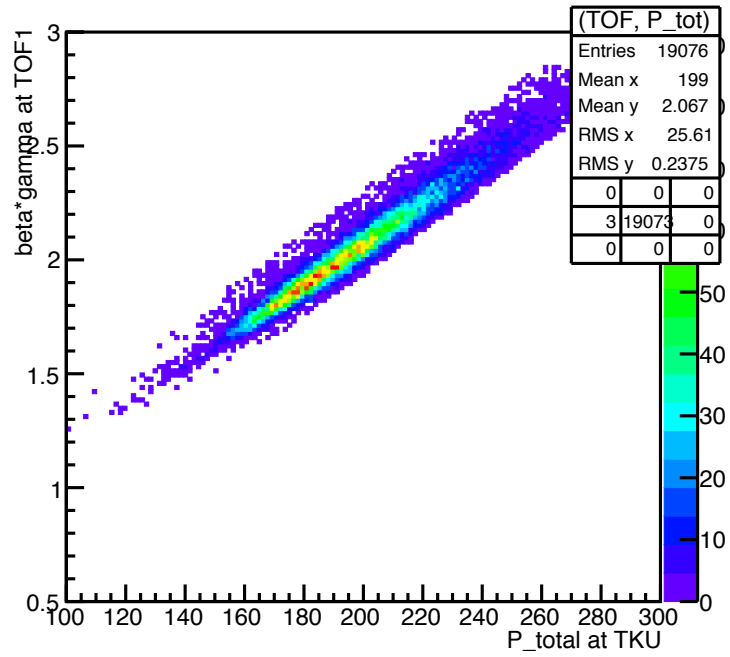
AKA ‘cut 5’

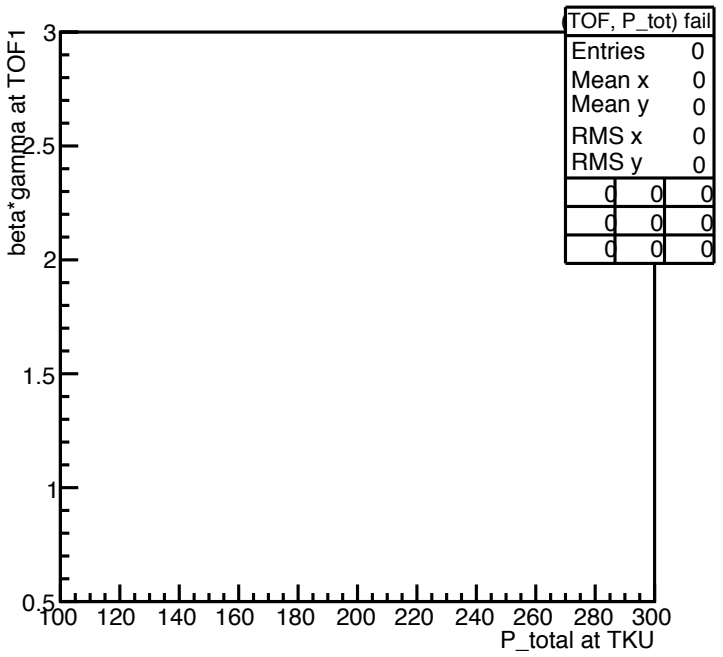
*cut_TimeOfFlight (cut 5)*

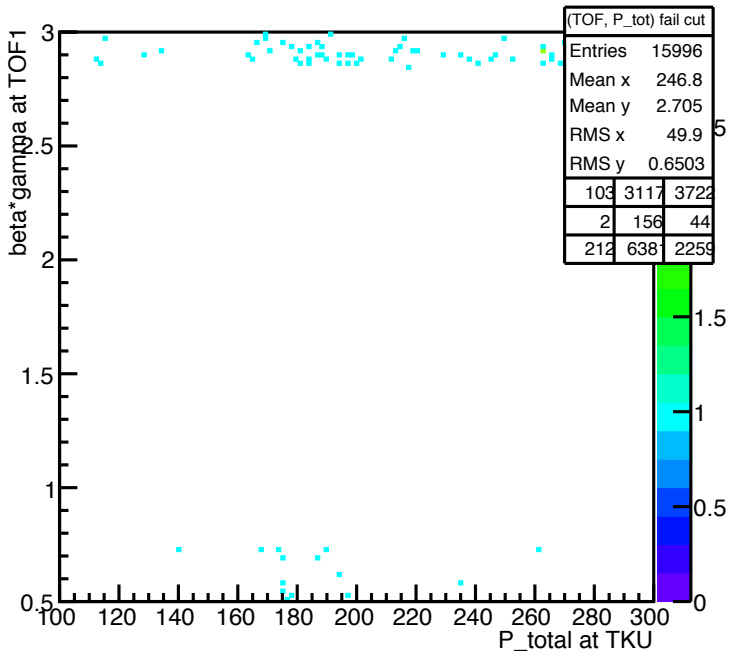


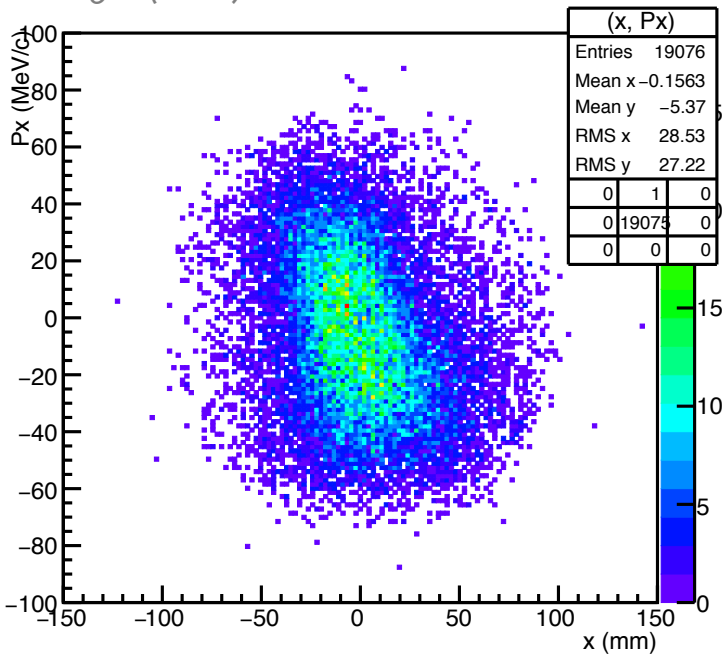



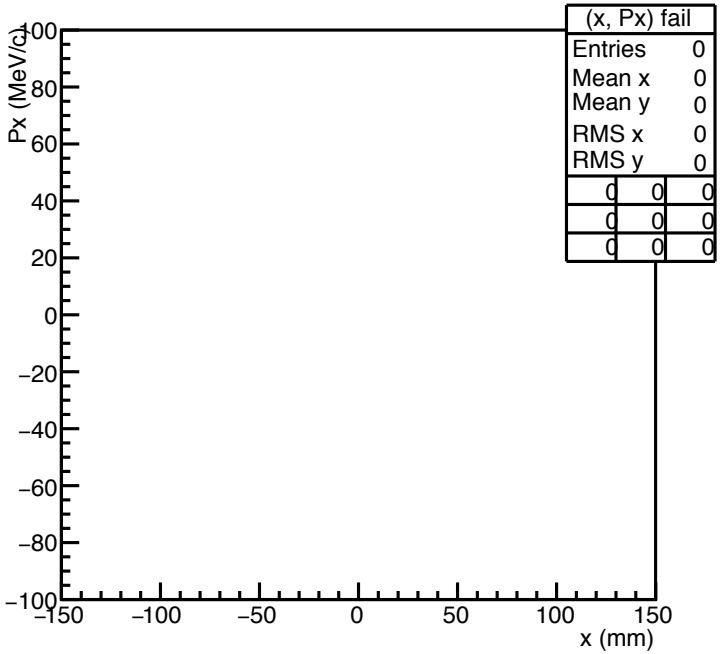



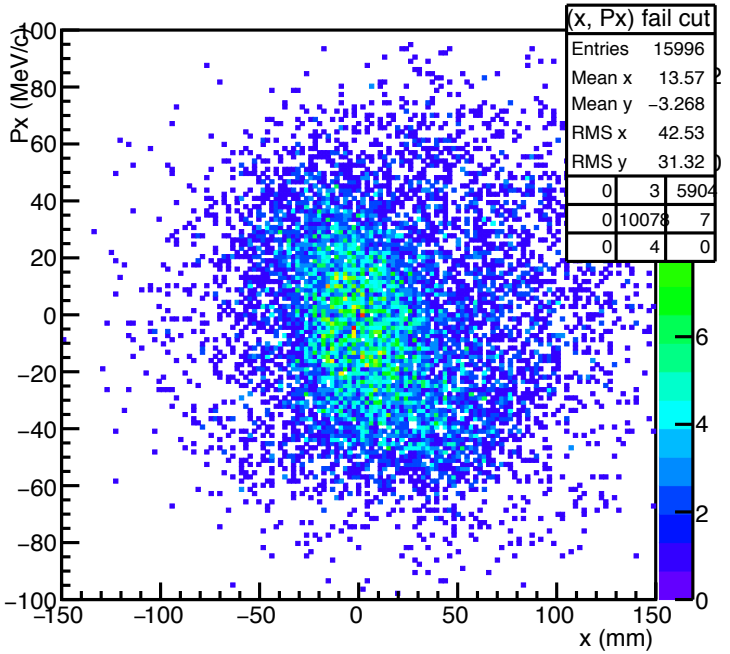



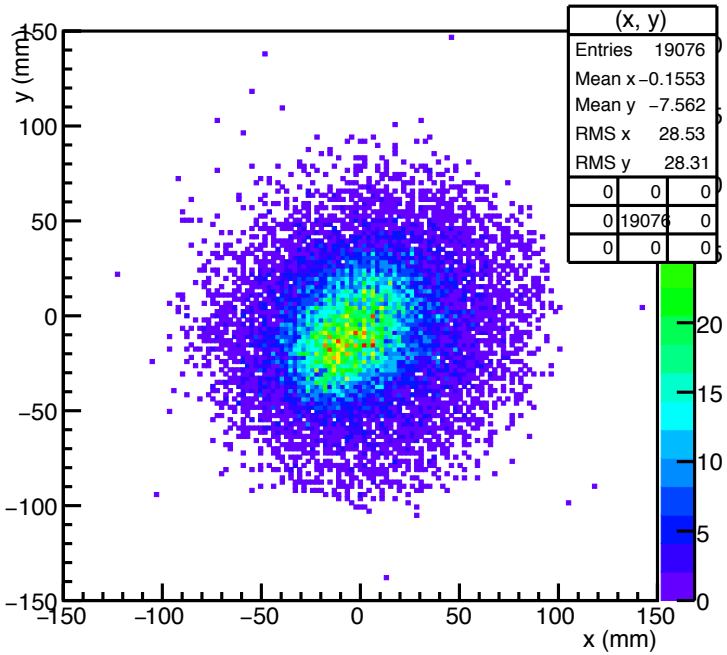



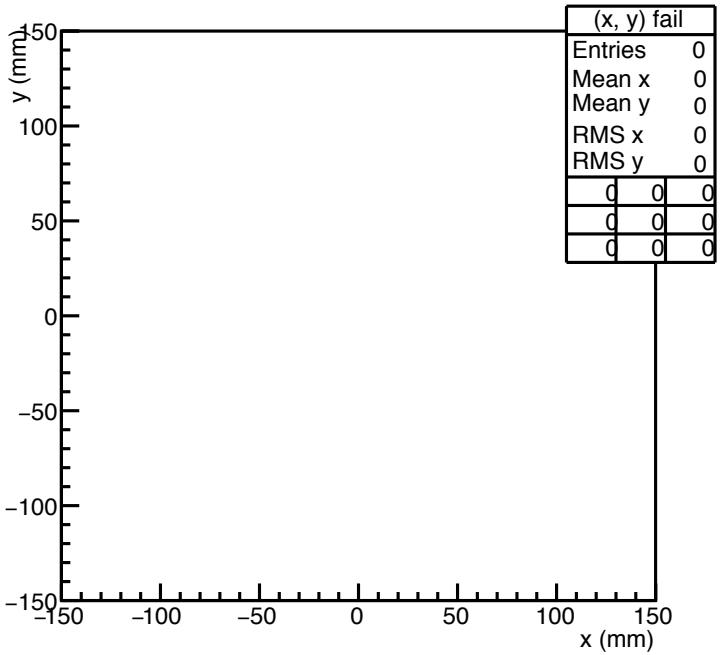



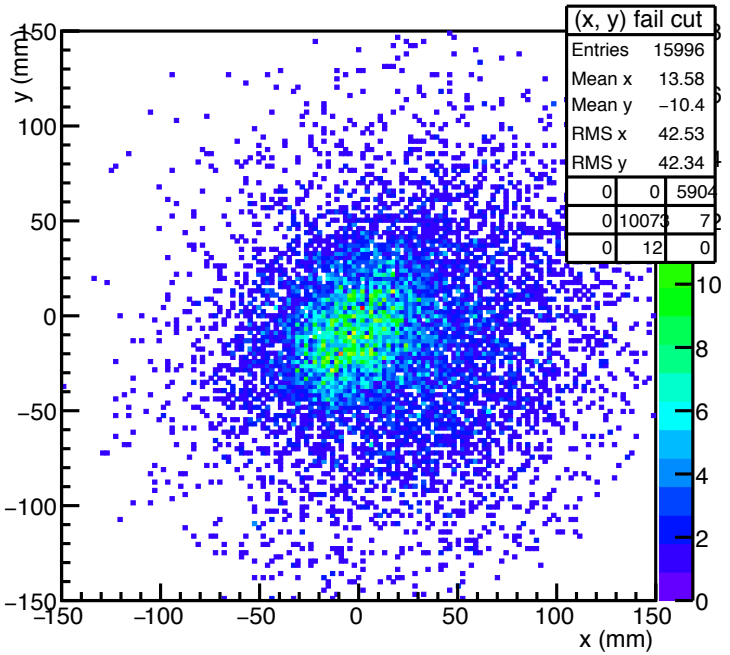

(x, Px)
Entries 19076
Mean x −0.1563
Mean y −5.37
RMS x 28.53
RMS y 27.22
Px (MeV/c)
x (mm)


(x, Px) fail
Entries 0
Mean x 0
Mean y 0
RMS x 0
RMS y 0
Px (MeV/c)
x (mm)

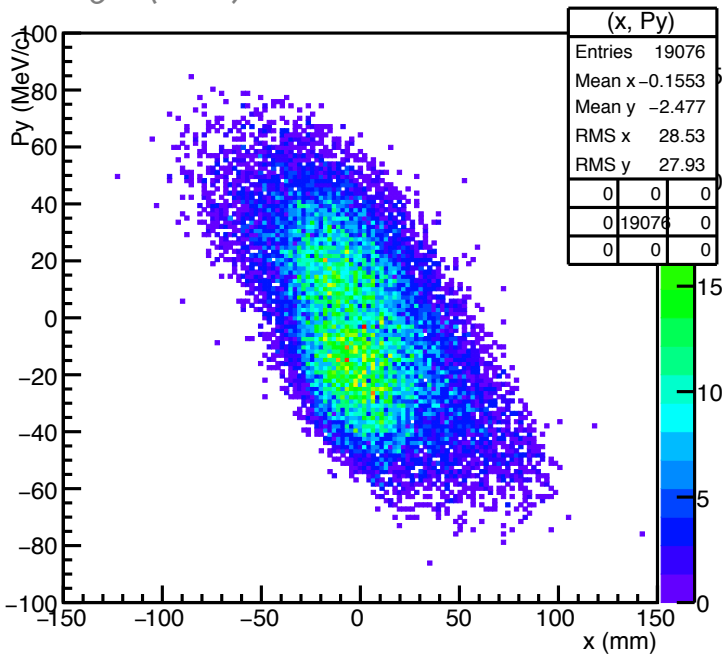

(x, Px) fail cut
Entries 15996
Mean x 13.57
Mean y −3.268
RMS x 42.53
RMS y 31.32
Px (MeV/c)
x (mm)

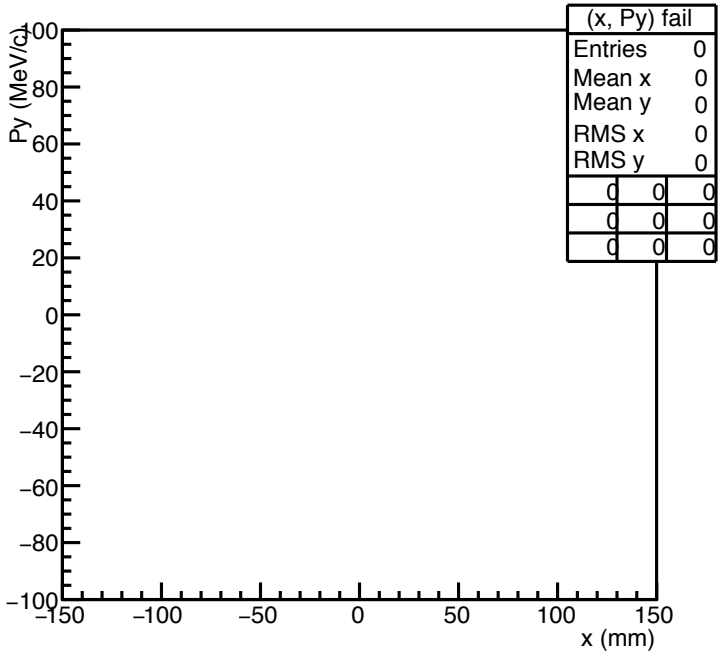

(x, y)
Entries 19076
Mean x −0.1553
Mean y −7.562
RMS x 28.53
RMS y 28.31
y (mm)
x (mm)

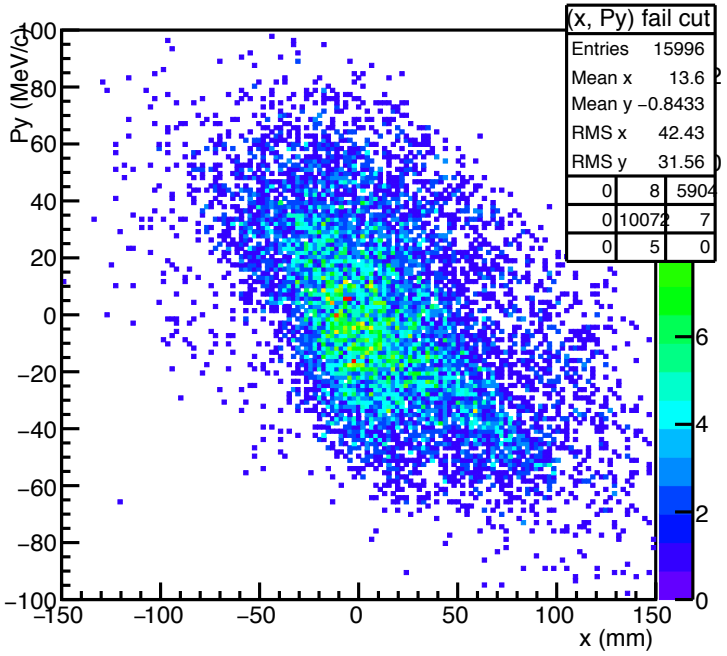

(x, y) fail
Entries 0
Mean x 0
Mean y 0
RMS x 0
RMS y 0
y (mm)
x (mm)

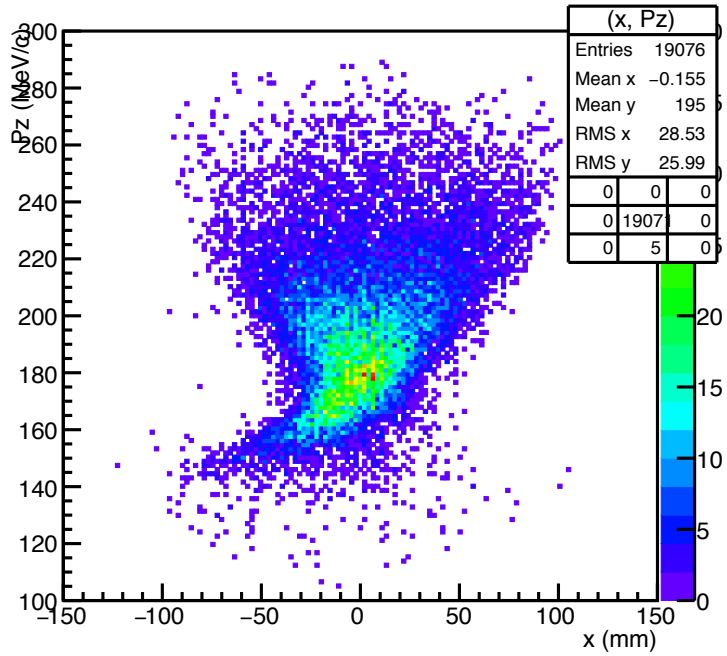

(x, y) fail cut
Entries 15996
Mean x 13.58
Mean y −10.4
RMS x 42.53
RMS y 42.34
y (mm)
x (mm)

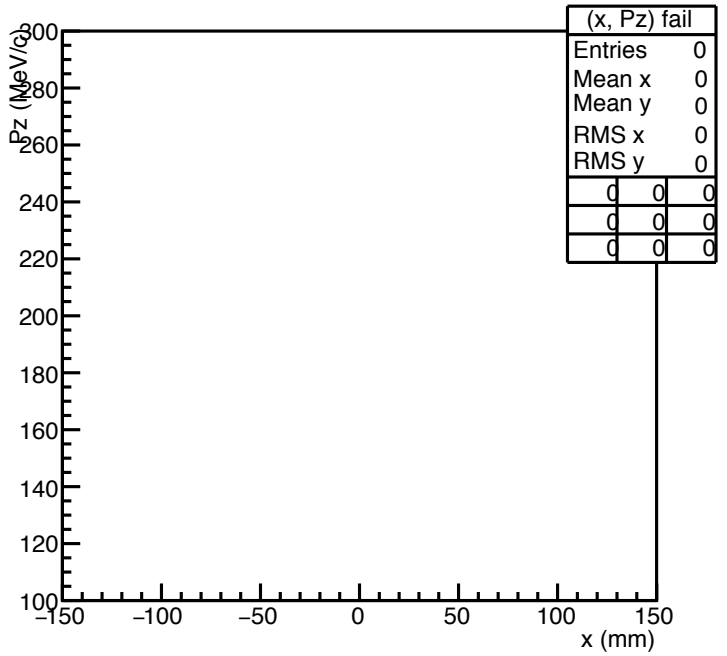
*cut_TimeOfFlight (cut 5)*

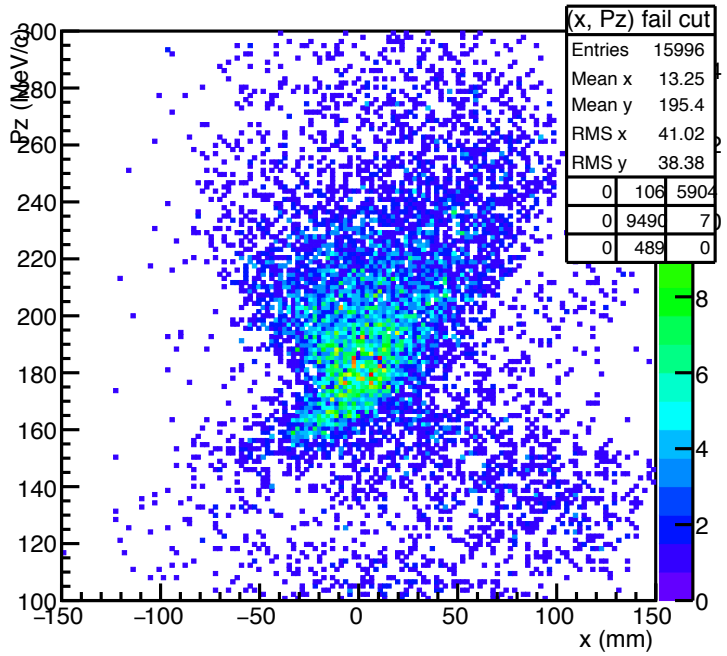


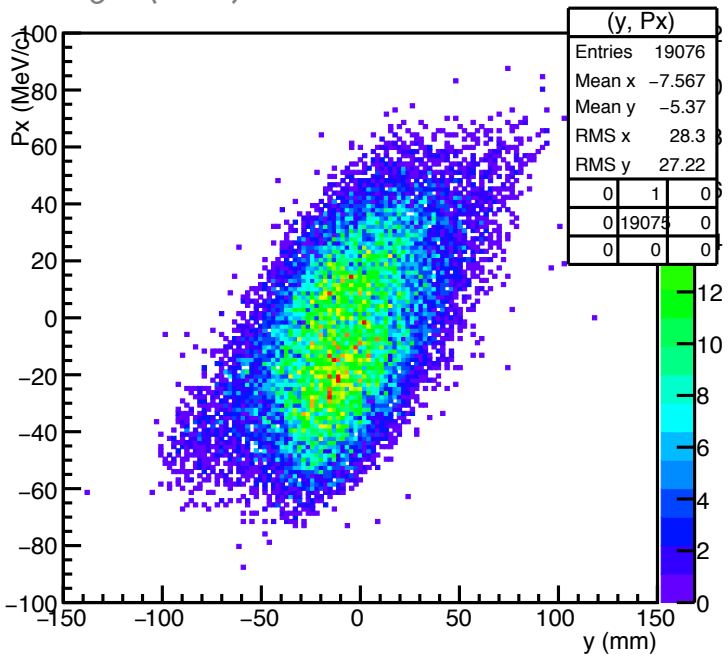



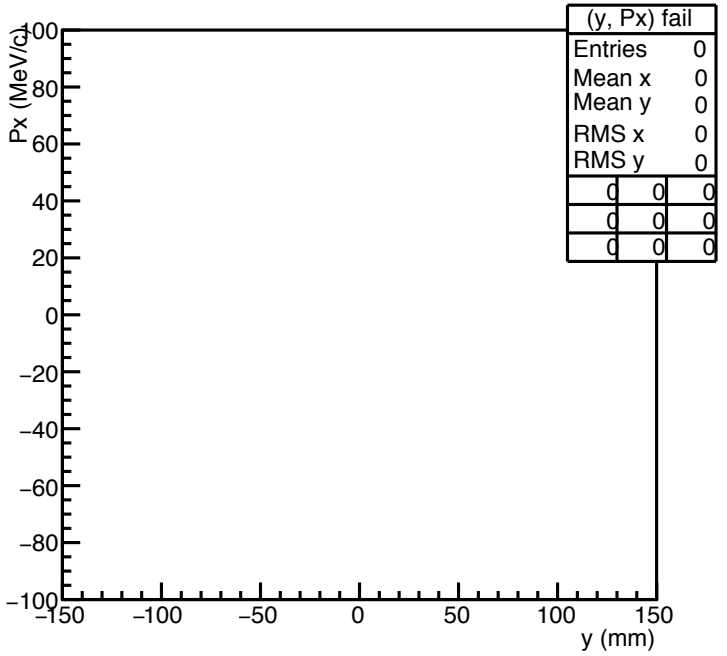



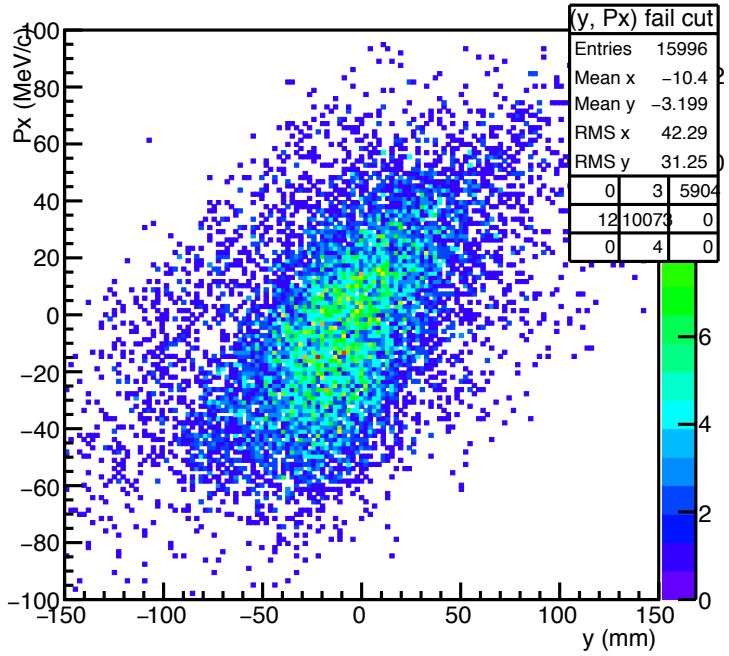



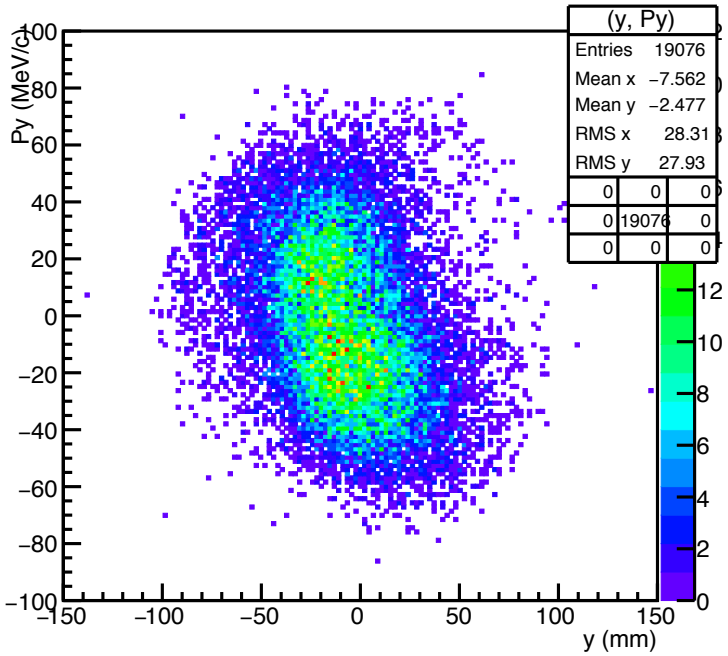



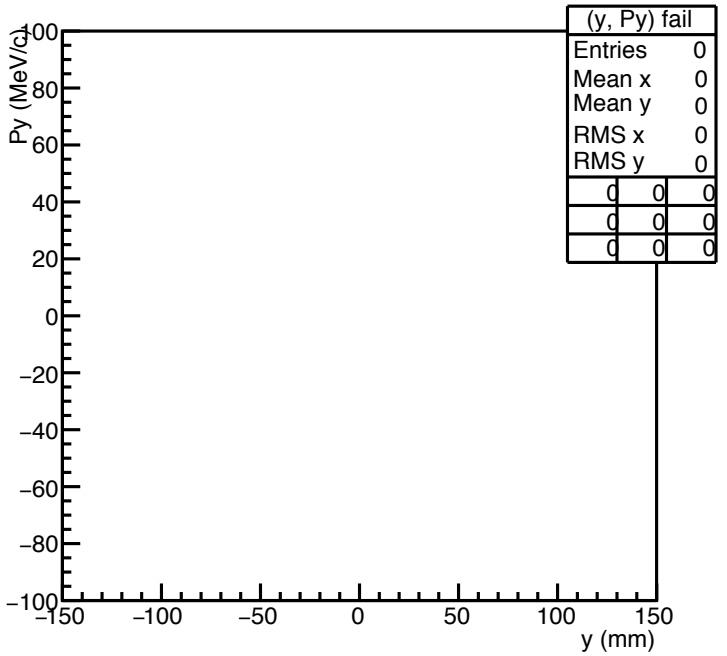



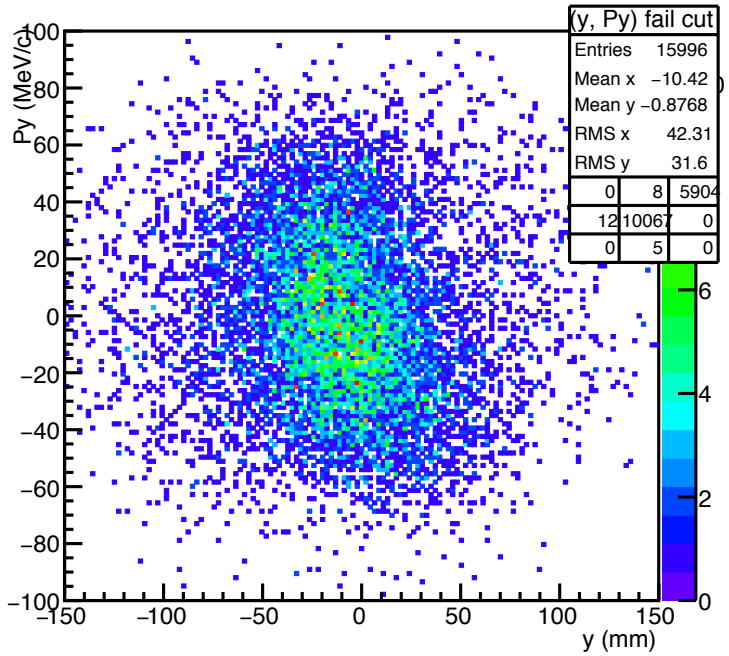

(y, Px)
Entries 19076
Mean x −7.567
Mean y −5.37
RMS x 28.3
RMS y 27.22
Px (MeV/c)
y (mm)


(y, Px) fail
Entries 0
Mean x 0
Mean y 0
RMS x 0
RMS y 0
Px (MeV/c)
y (mm)

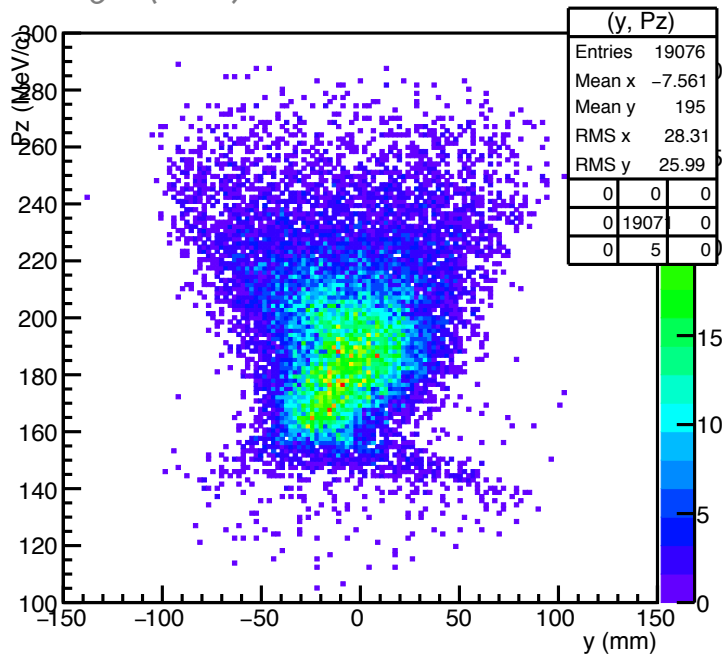

(y, Px) fail cut
Entries 15996
Mean x −10.4
Mean y −3.199
RMS x 42.29
RMS y 31.25
Px (MeV/c)
y (mm)

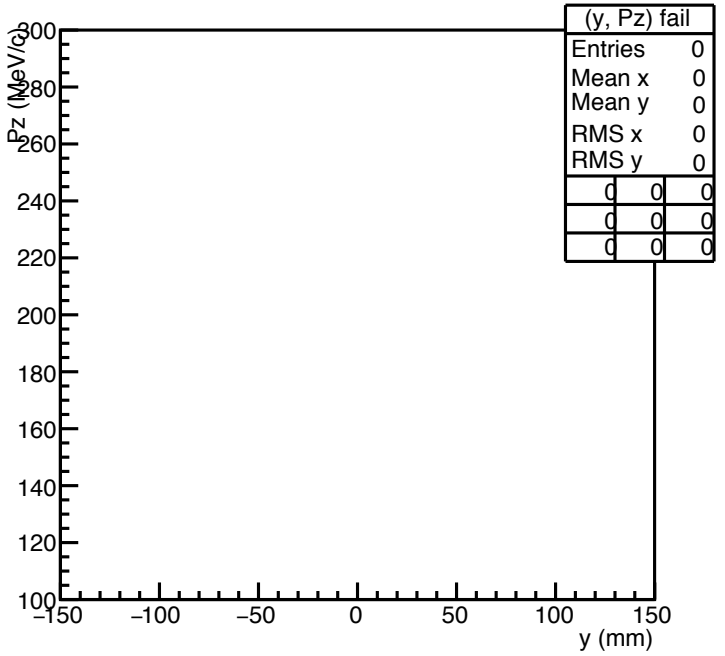

(y, Py)
Entries 19076
Mean x −7.562
Mean y −2.477
RMS x 28.31
RMS y 27.93
Py (MeV/c)
y (mm)

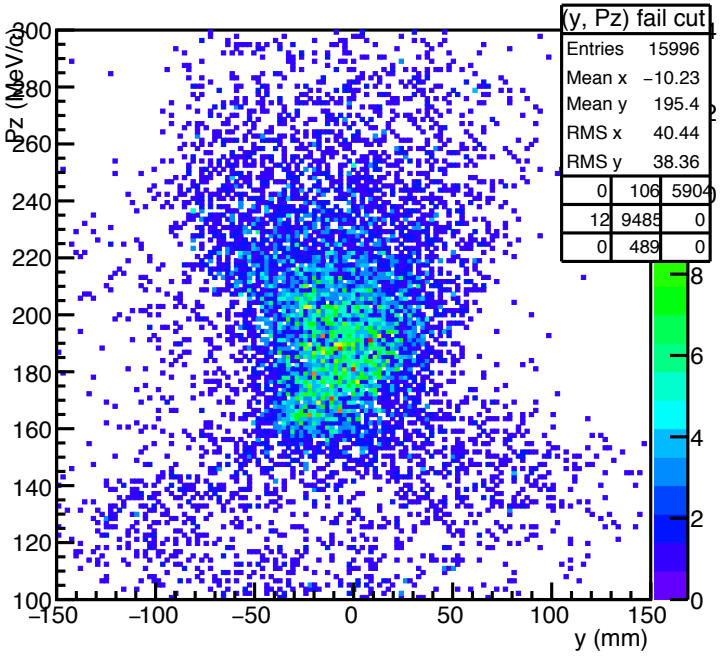

(y, Py) fail
Entries 0
Mean x 0
Mean y 0
RMS x 0
RMS y 0
Py (MeV/c)
y (mm)

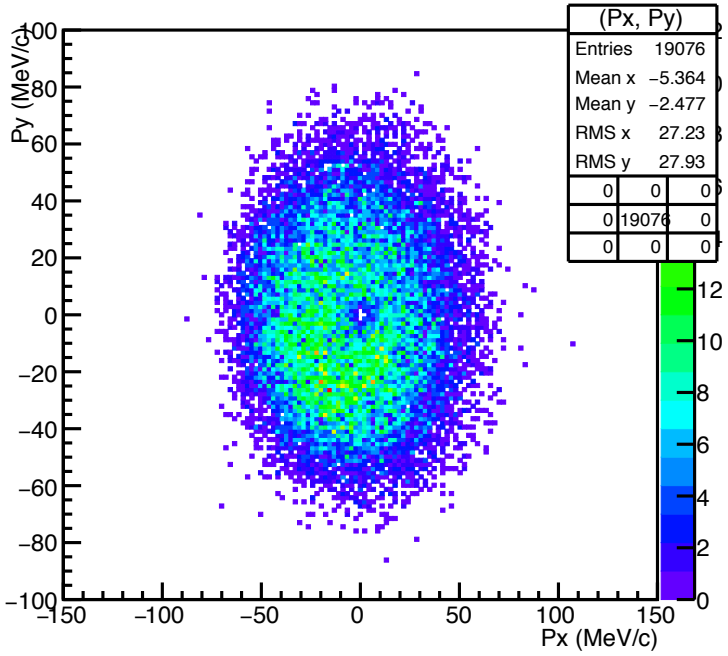

(y, Py) fail cut
Entries 15996
Mean x −10.42
Mean y −0.8768
RMS x 42.31
RMS y 31.6
Py (MeV/c)
y (mm)

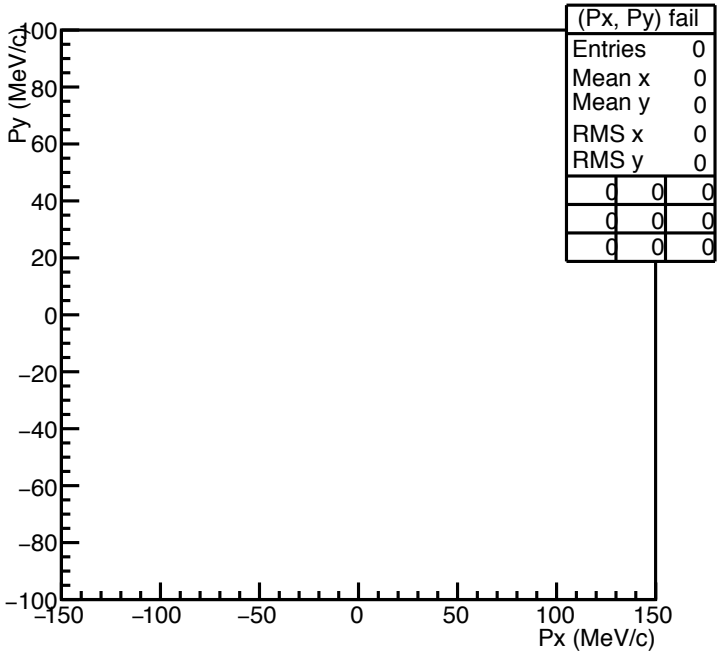
*cut_TimeOfFlight (cut 5)*

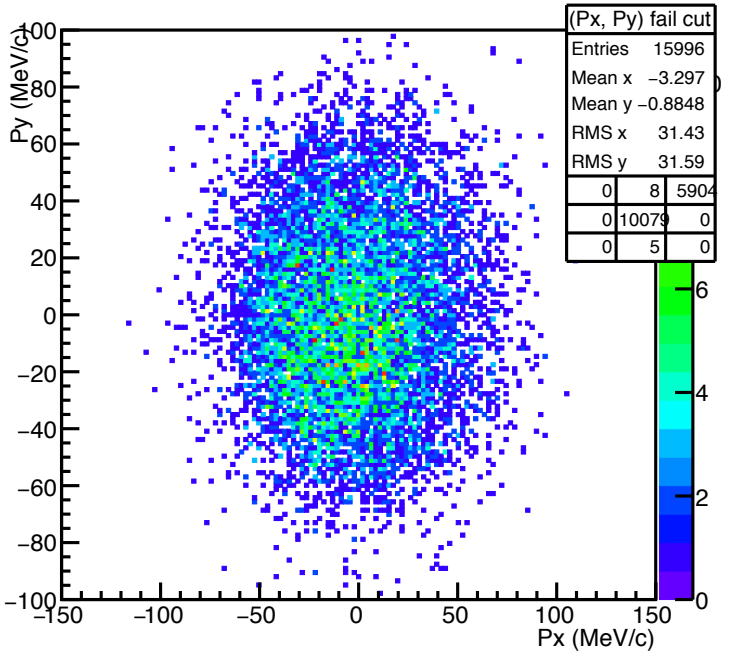


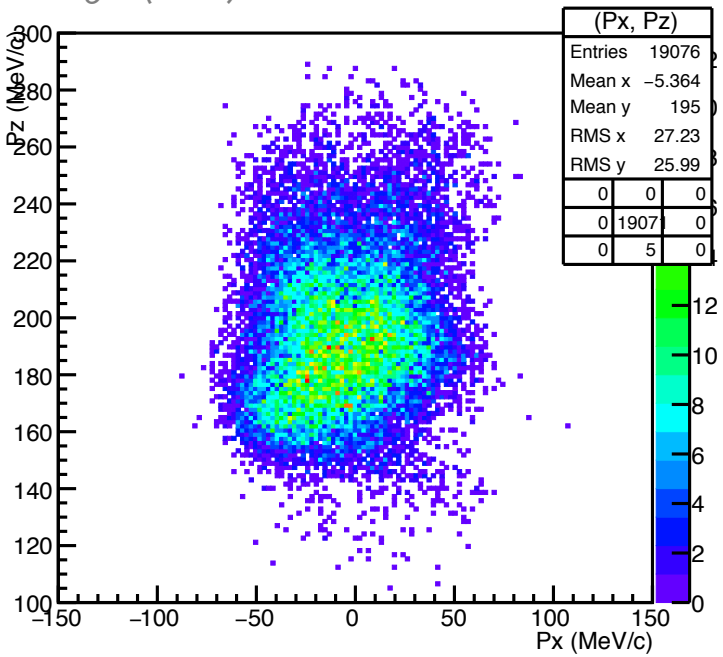



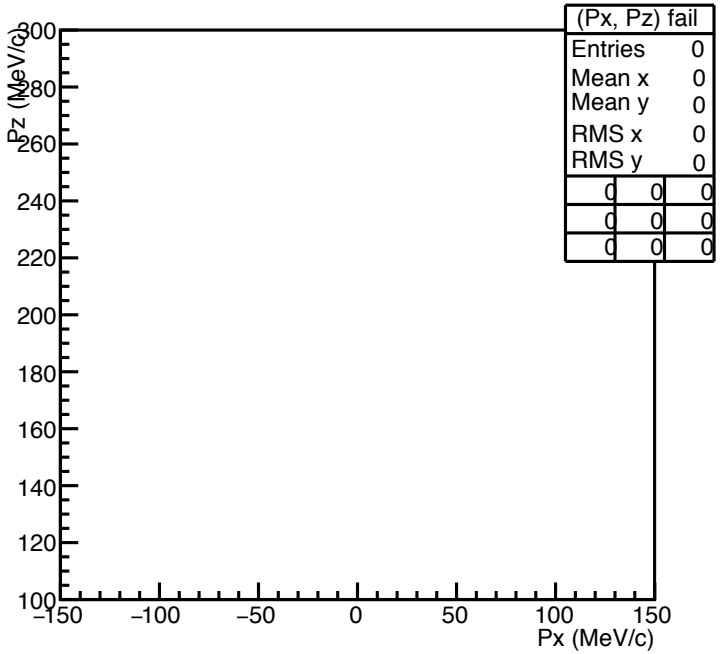



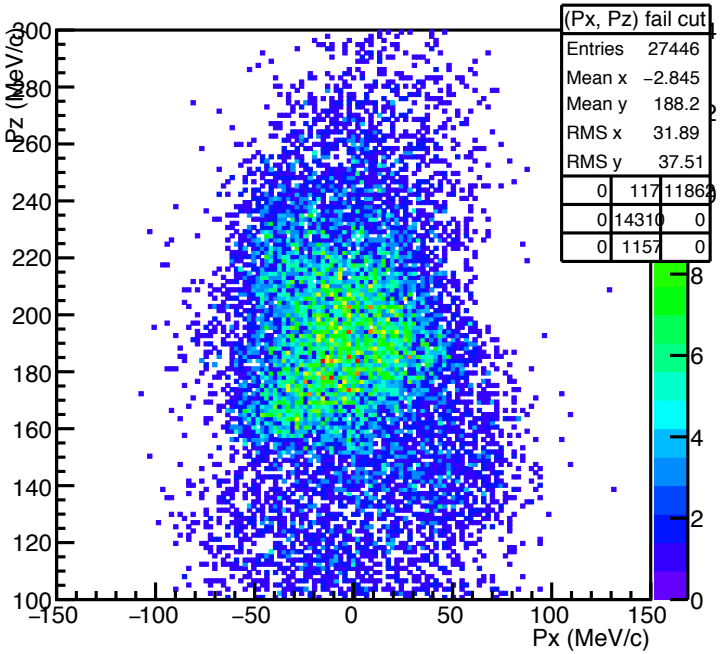



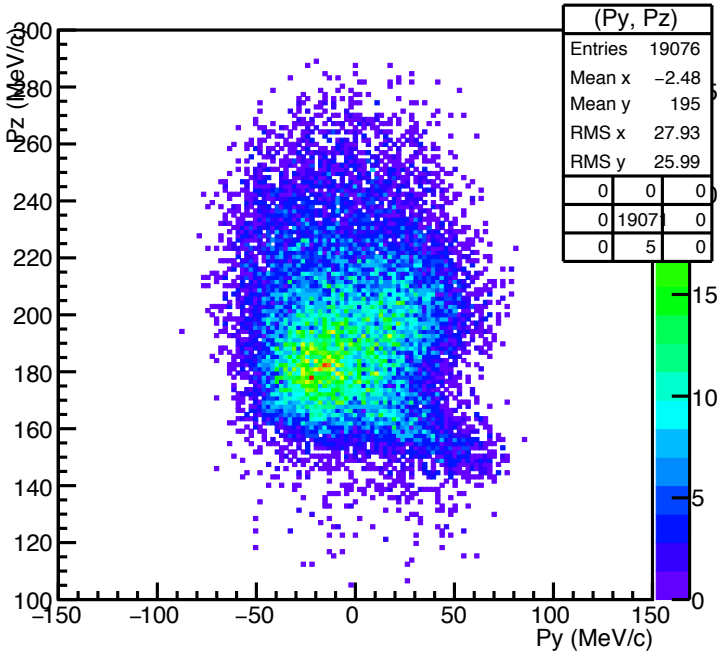



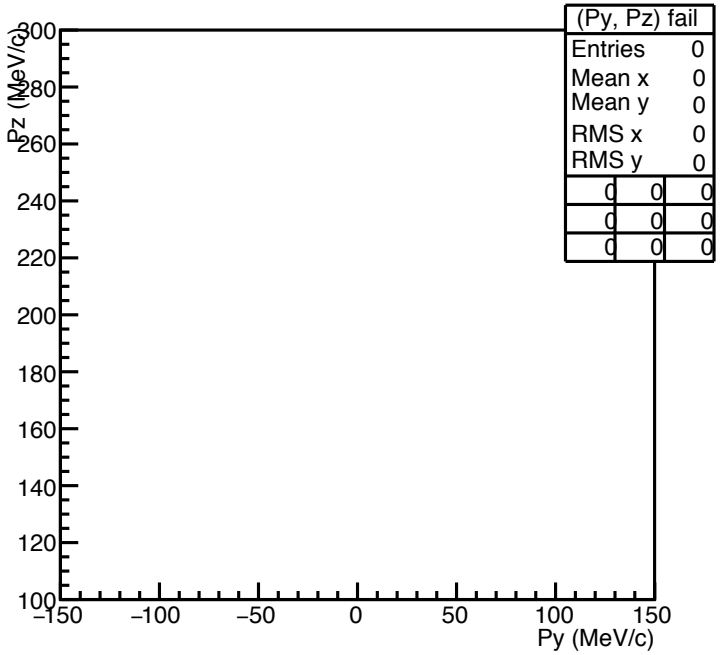
*cut_TimeOfFlight (cut 5)*

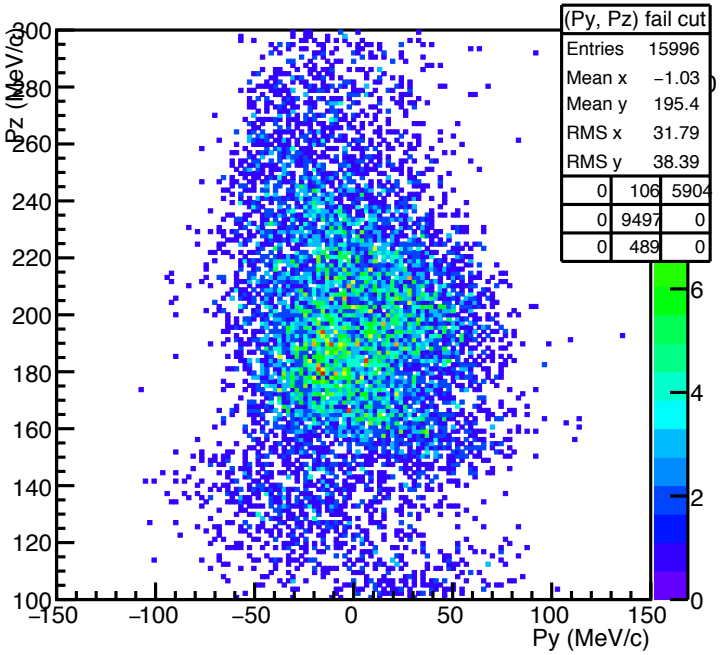


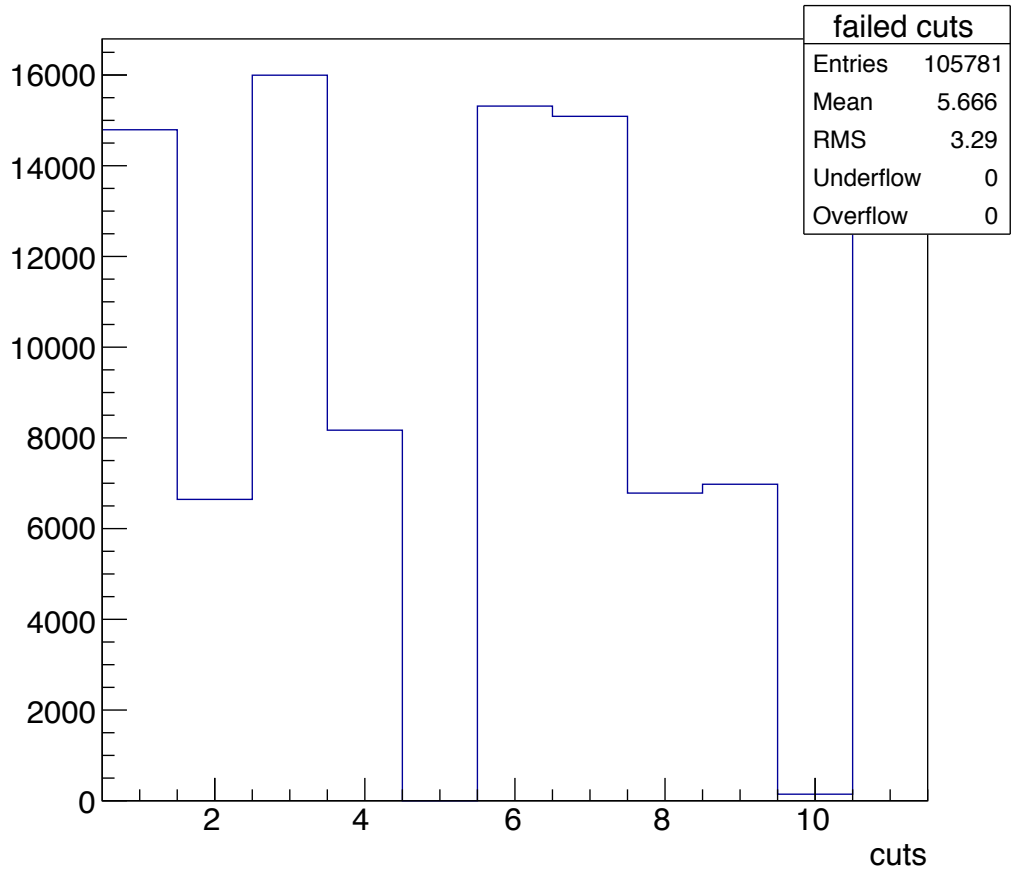



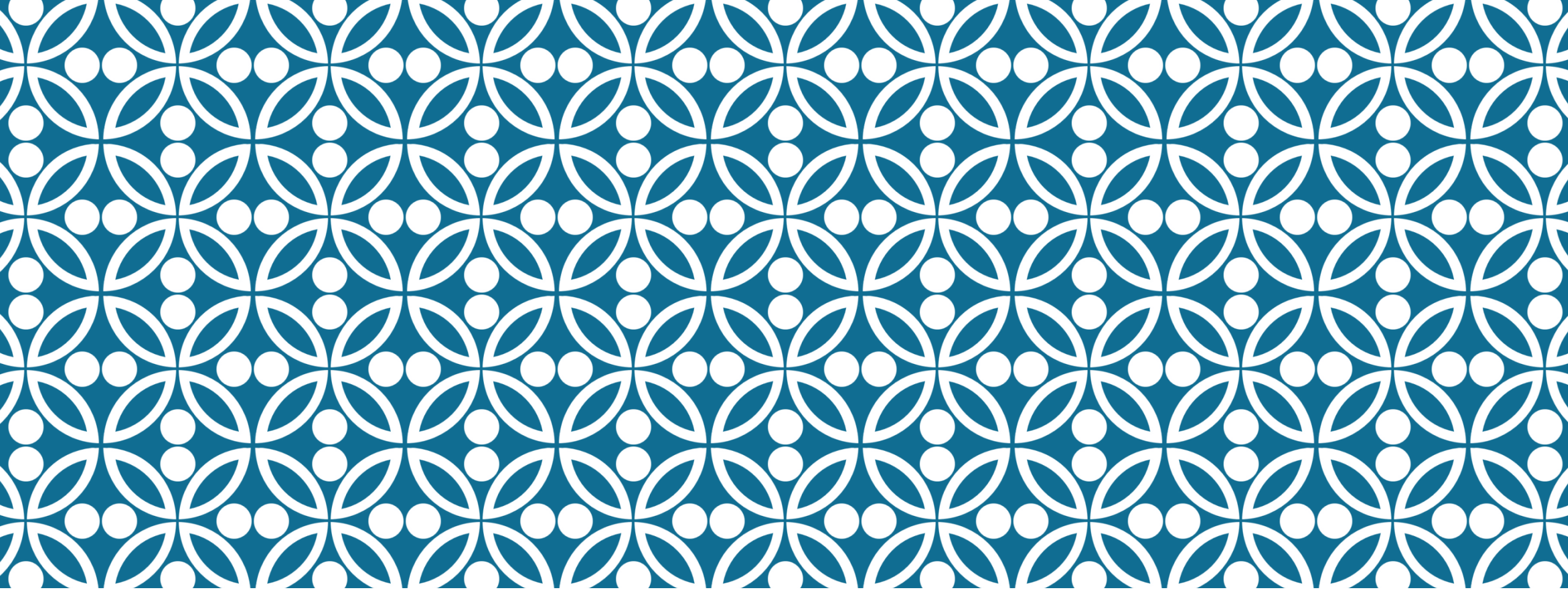





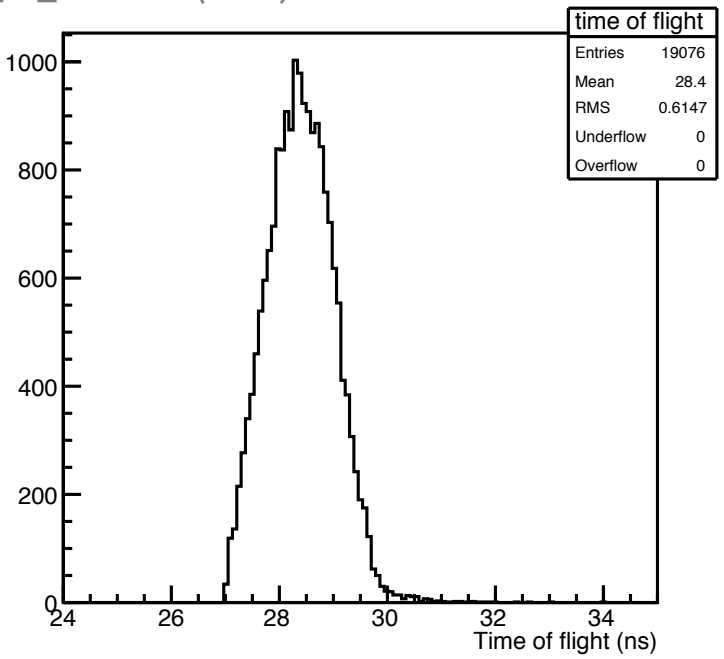

| 'Cut number' | Cut |
|---|---|
| 1 | cut_TOF0_goodPMTPosition |
| 2 | cut_TOF1_goodPMTPosition |
| 3 | cut_goodRaynerReconstruction |
| 4 | cut_TKU_hitAllStations |
| 5 | cut_TimeOfFlight |
| 6 | cut_hit_all_detectors |
| 7 | cut_TOF0_singleHit |
| 8 | cut_TOF1_singleHit |
| 9 | cut_TKU_singleTrack |
| 10 | cut_TKU_PValue |
| 11 | cut_momentum_loss |

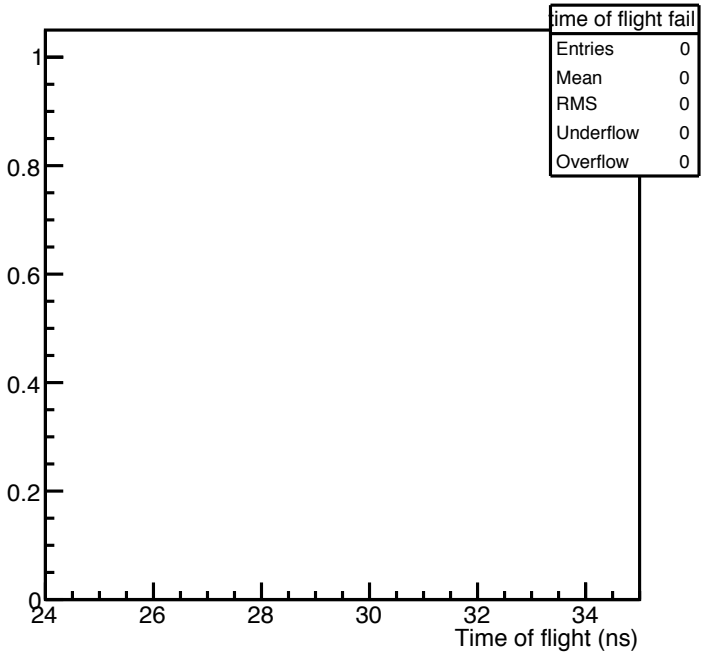


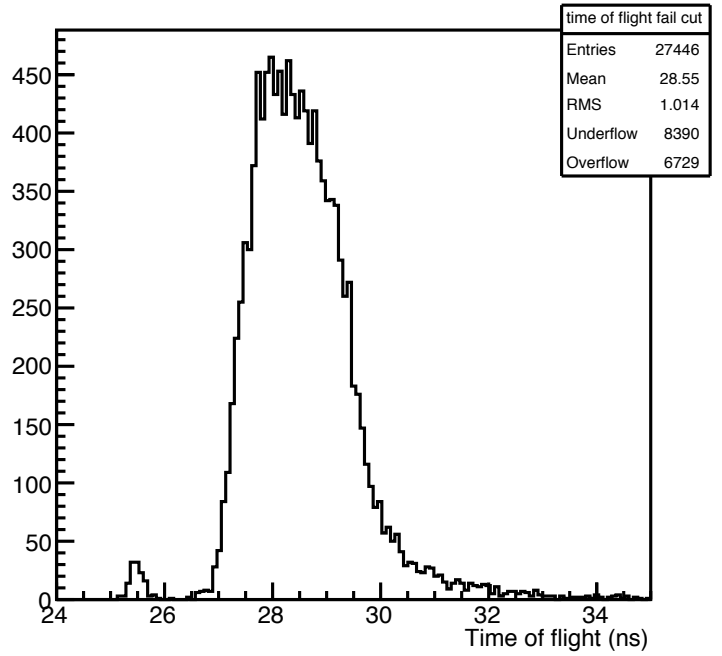
# CUT_HIT_ALL_DETECTORS

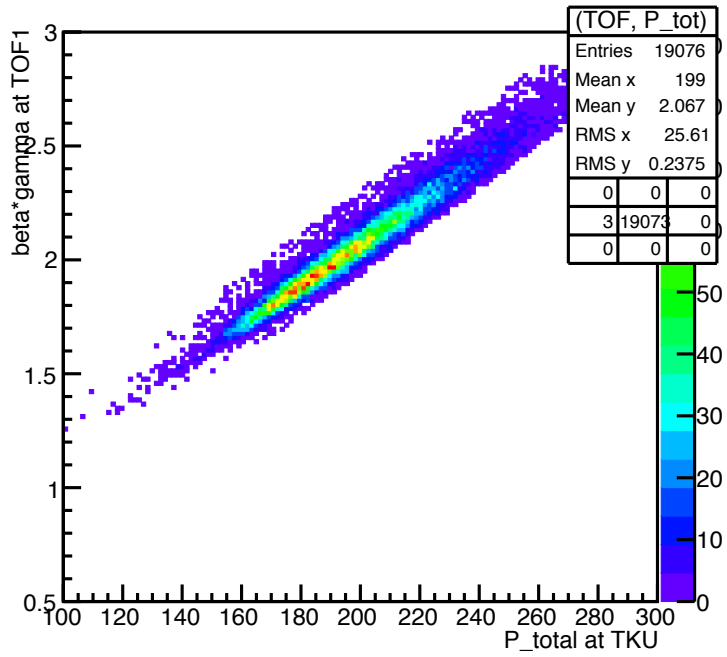
AKA ‘cut 6’

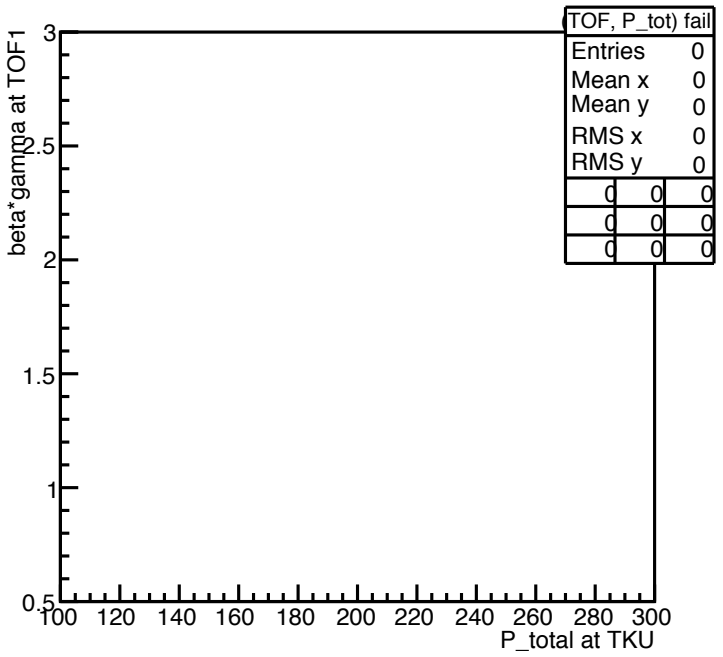
*cut_hit_all_detectors (cut 6)*

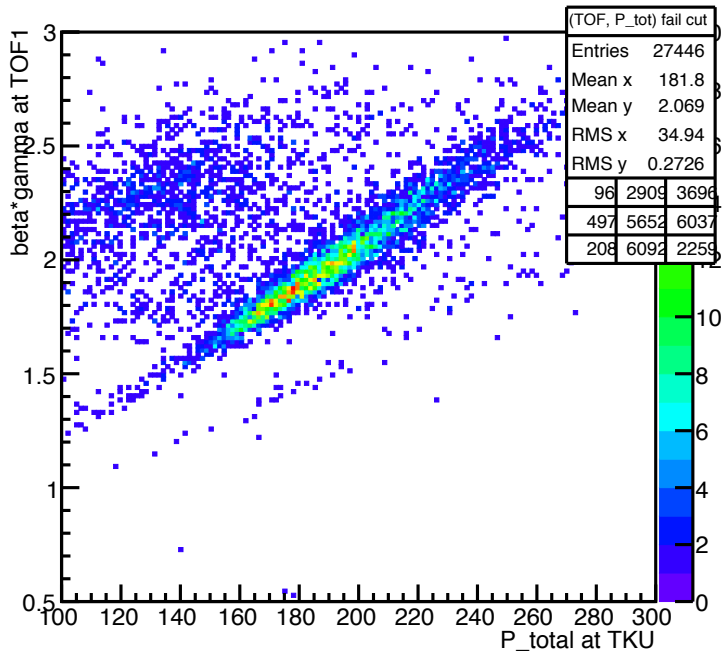


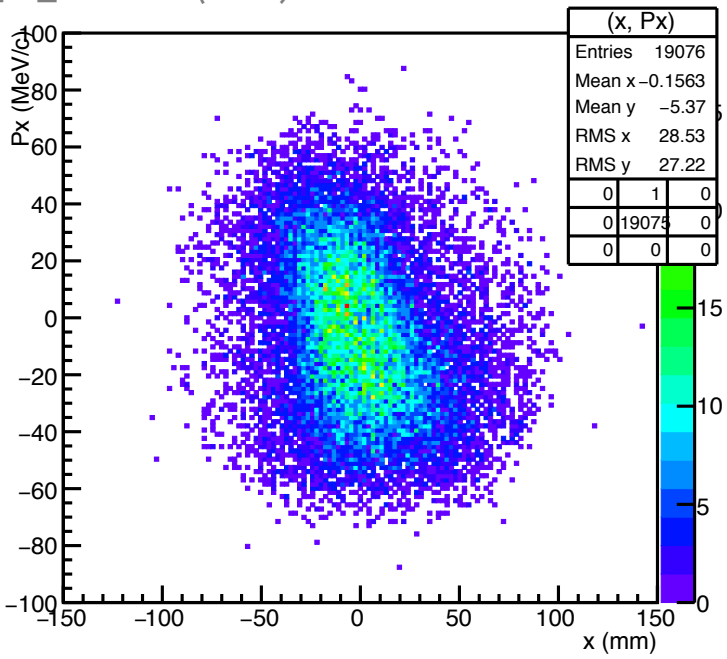



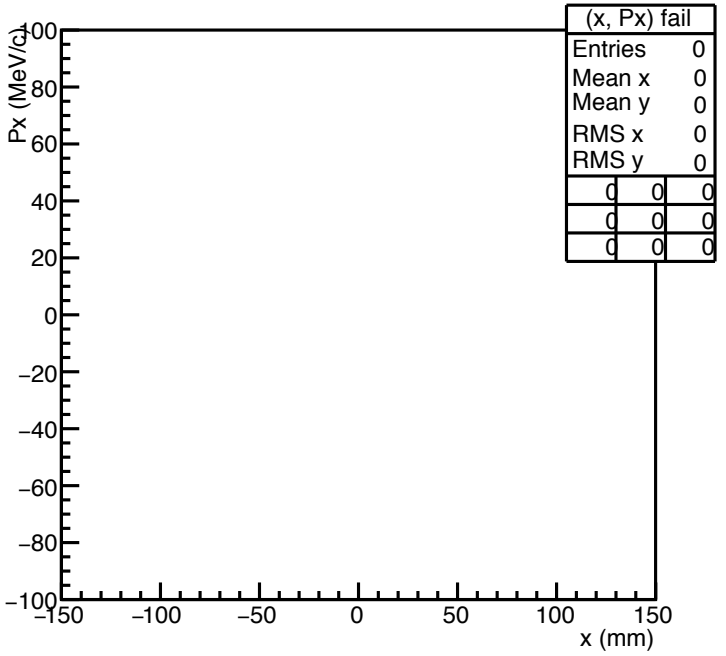



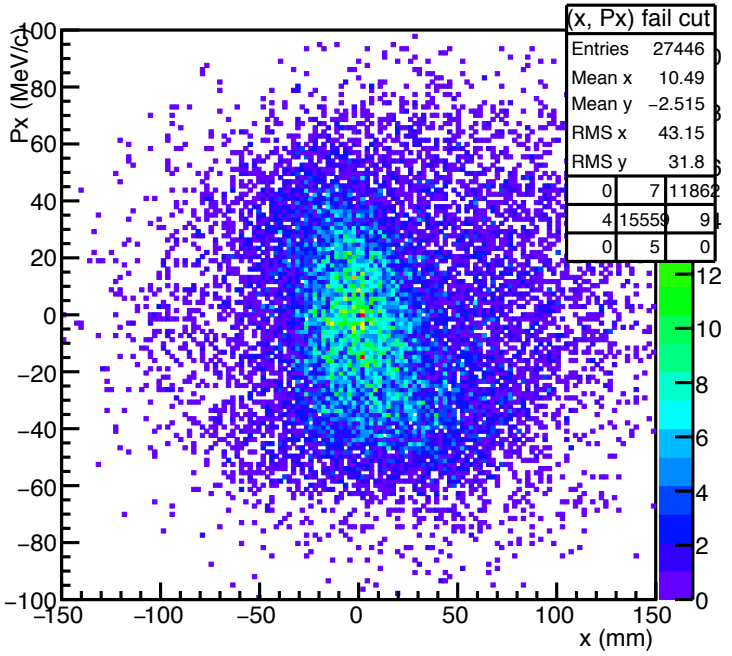



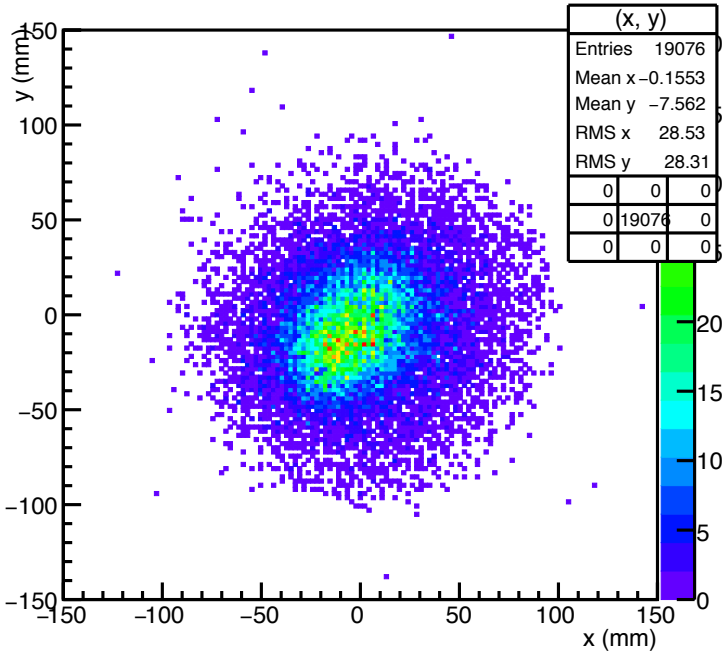



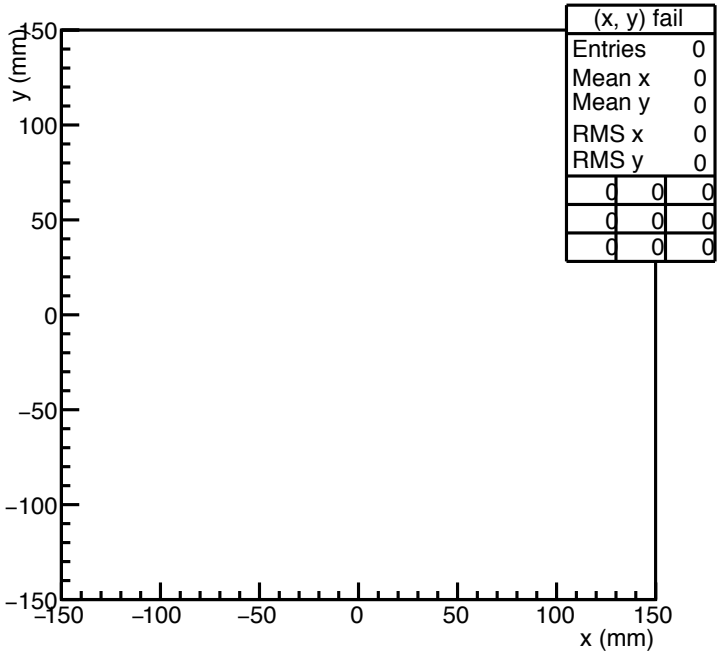
*cut_hit_all_detectors (cut 6)*

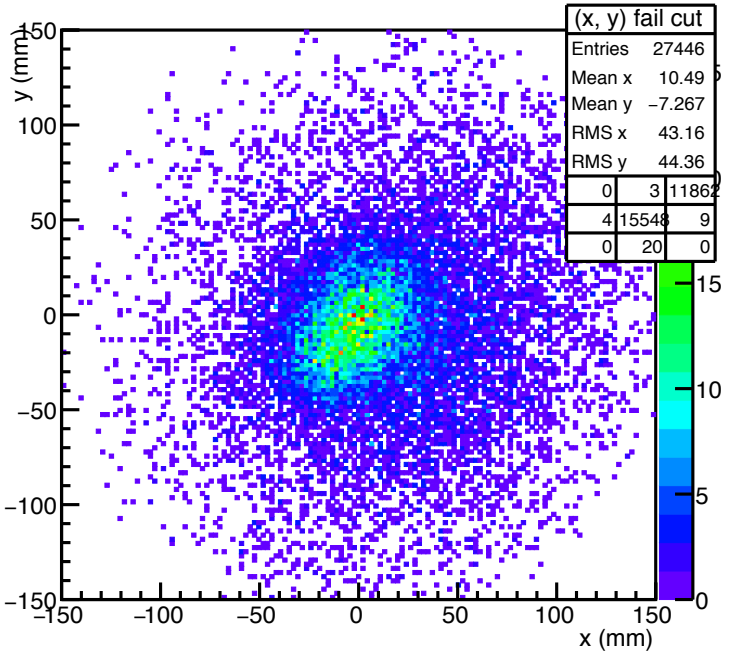


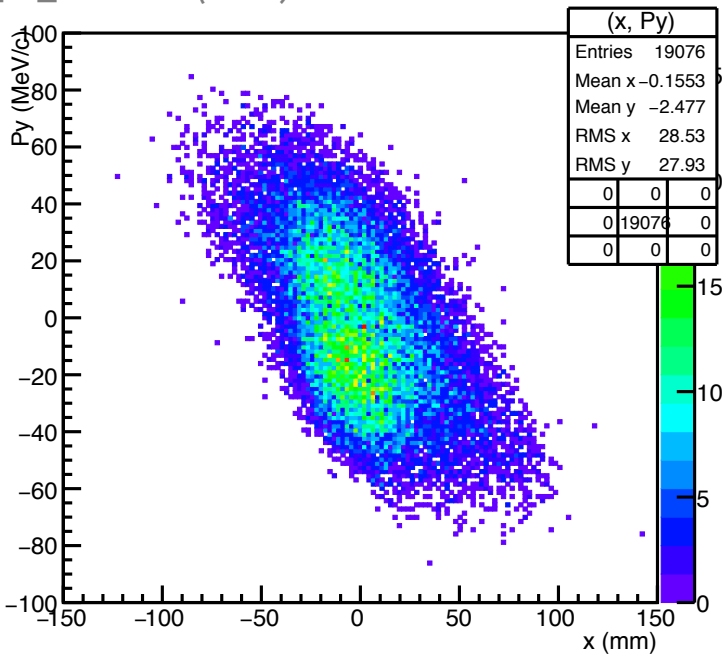



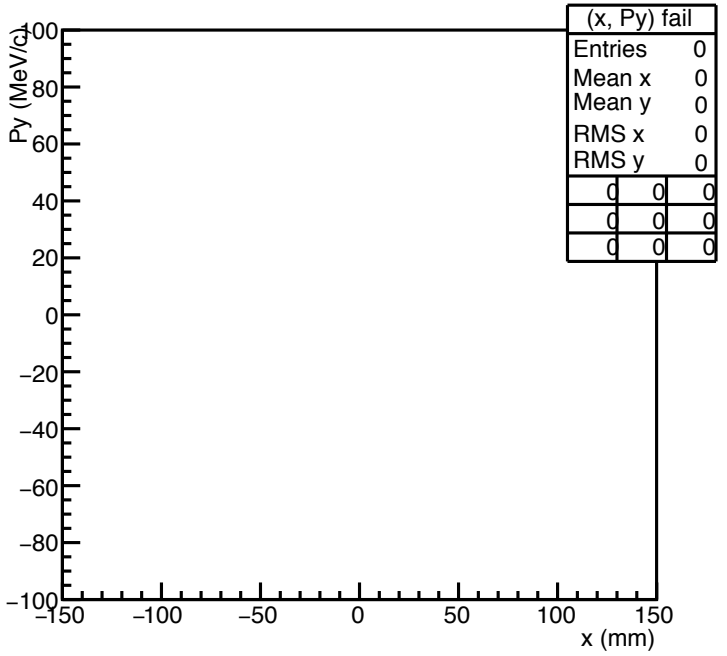



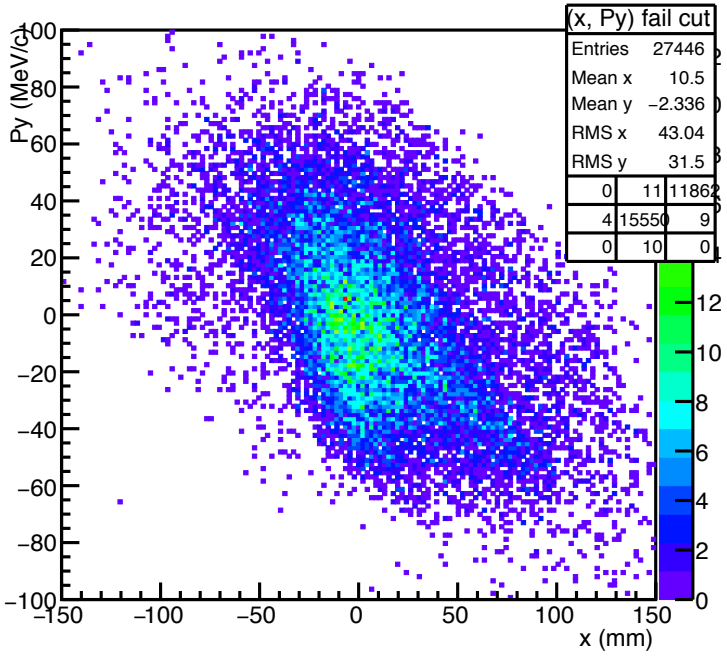



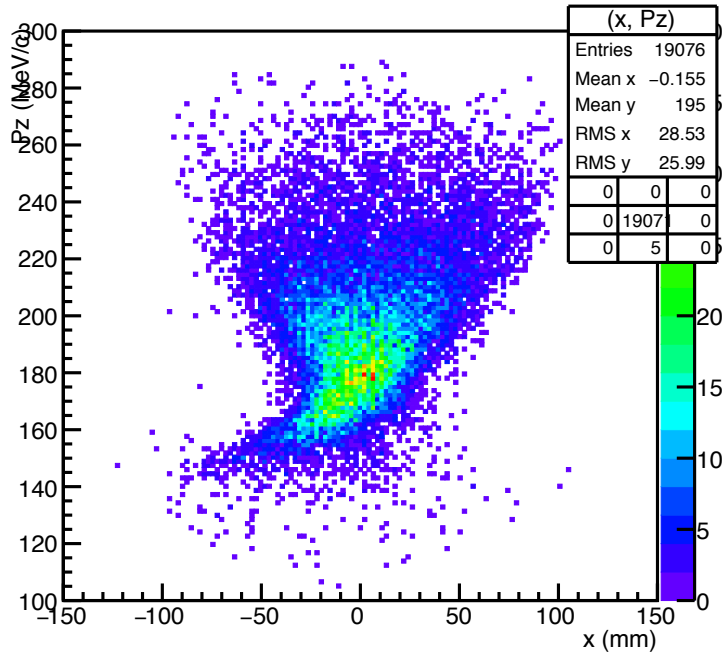



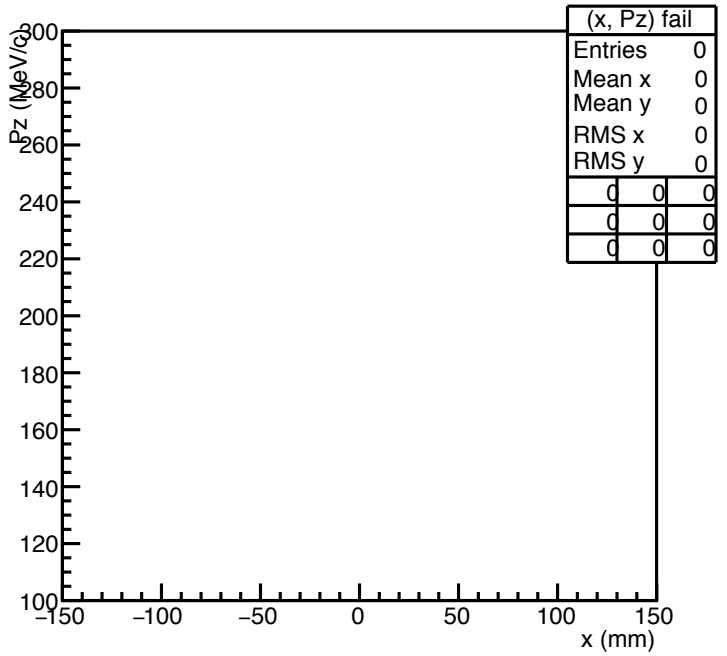
*cut_hit_all_detectors (cut 6)*

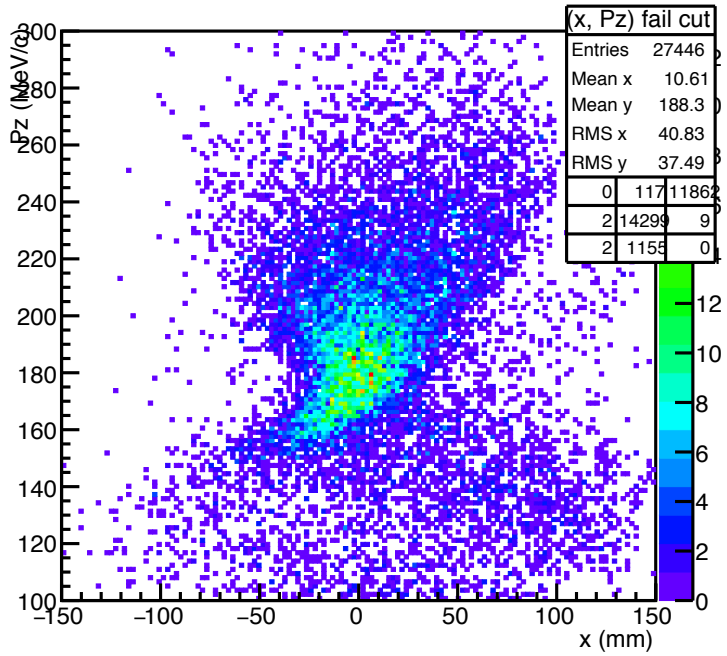


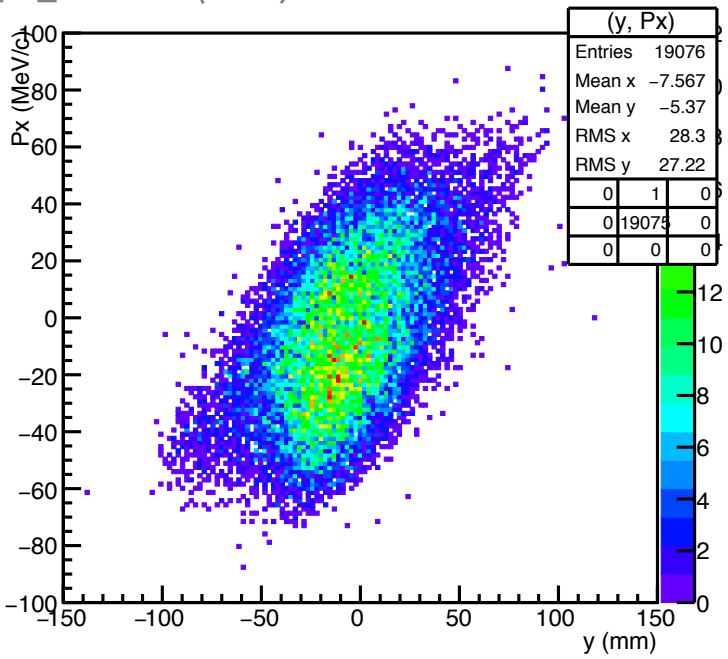



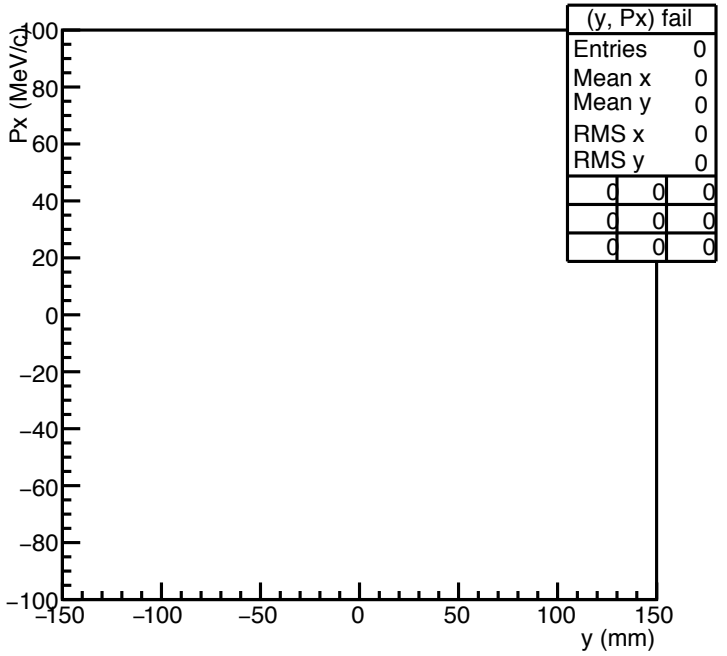



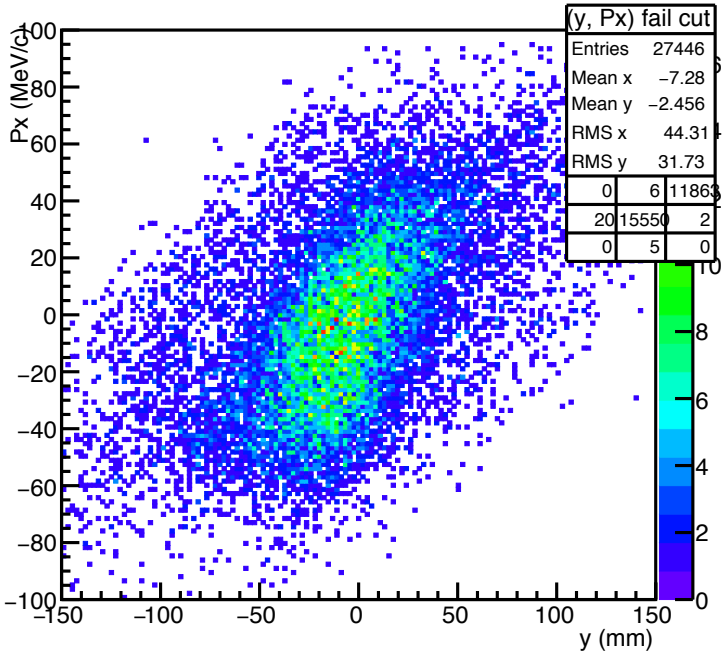



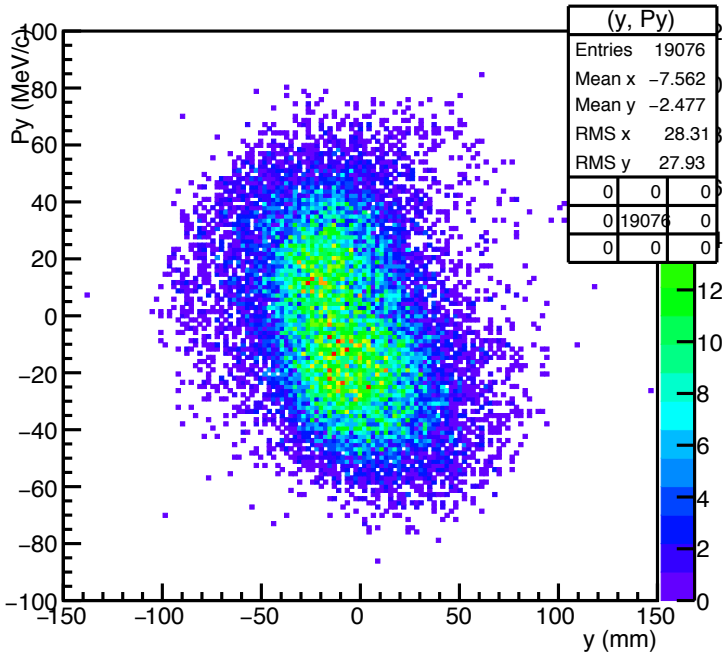



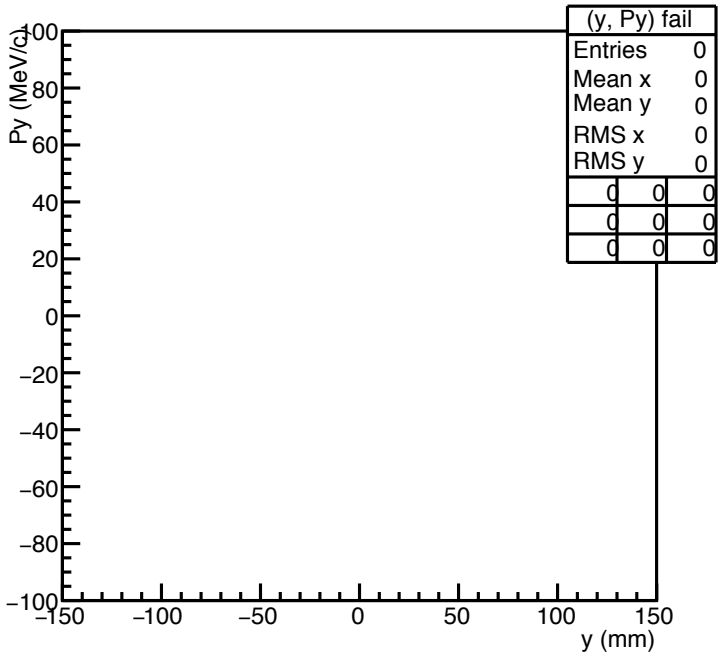
*cut_hit_all_detectors (cut 6)*

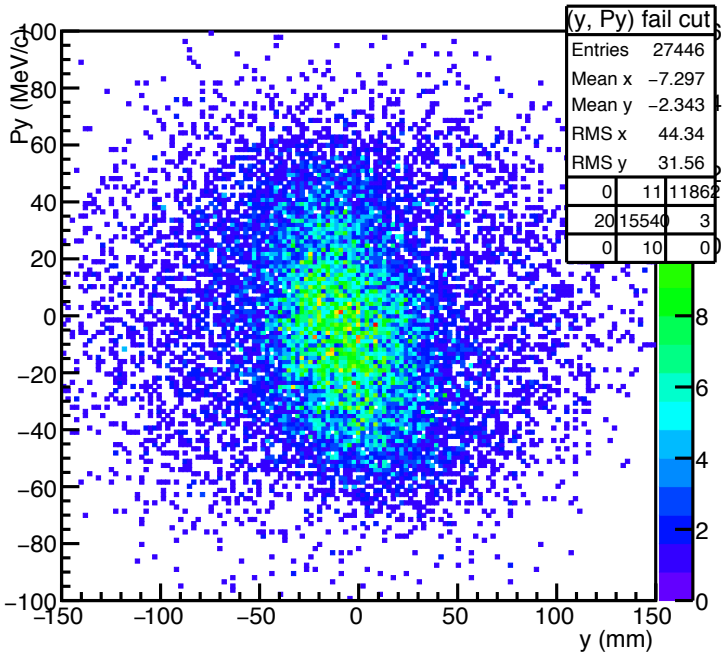


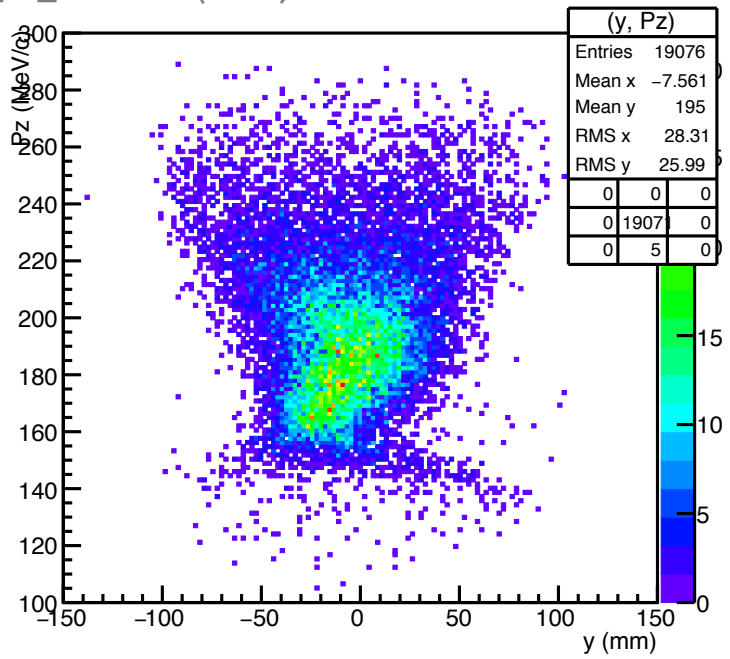



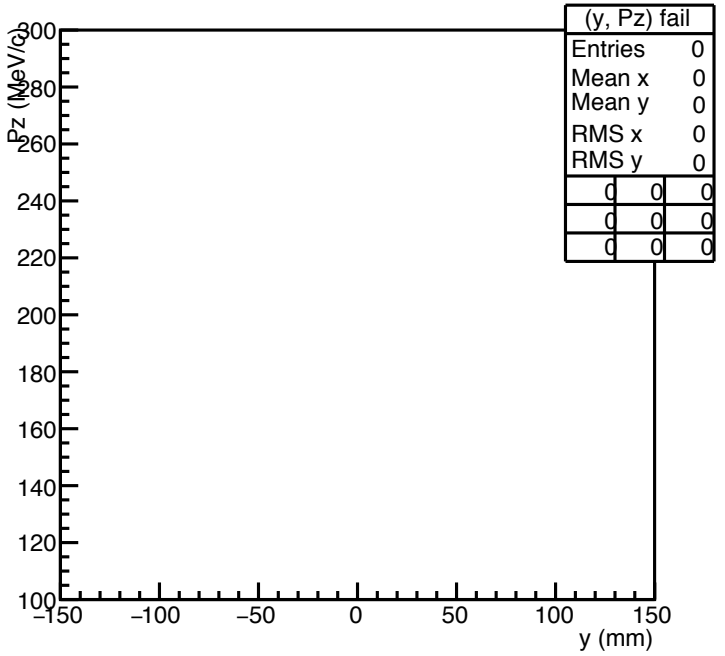



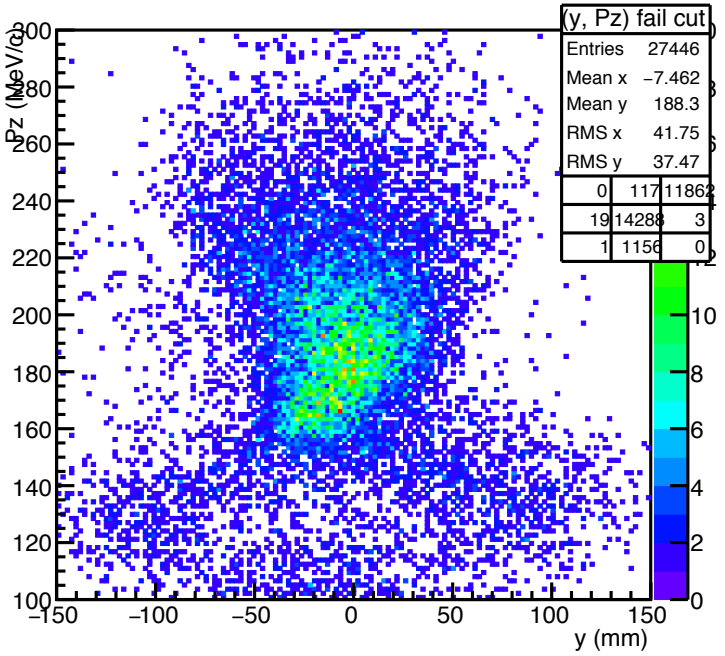



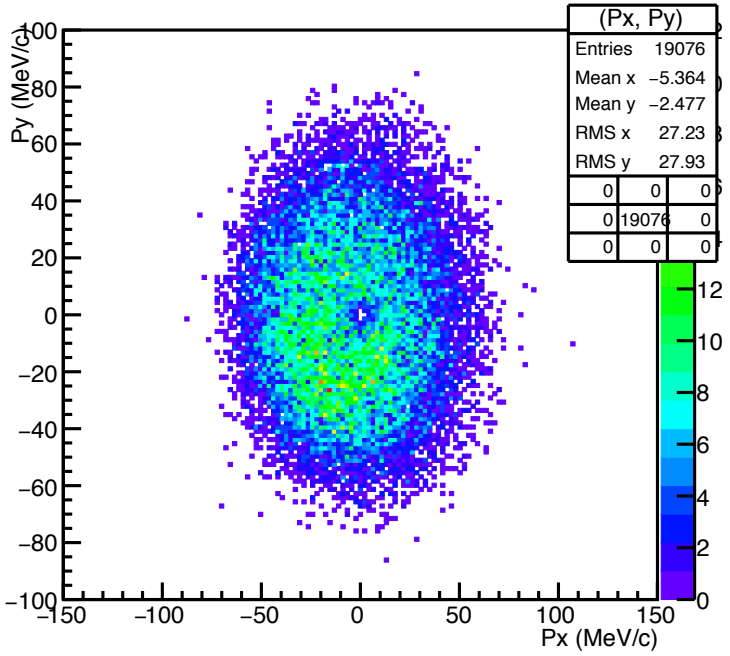



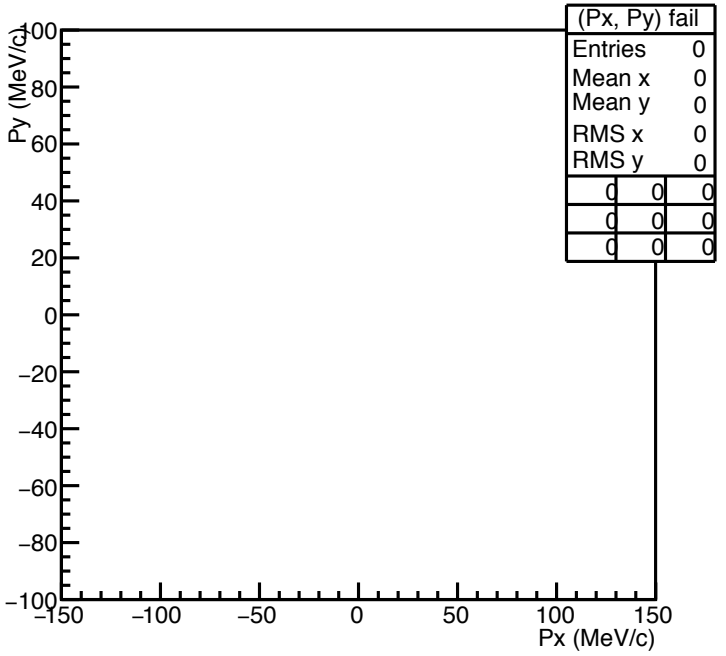
*cut_hit_all_detectors (cut 6)*

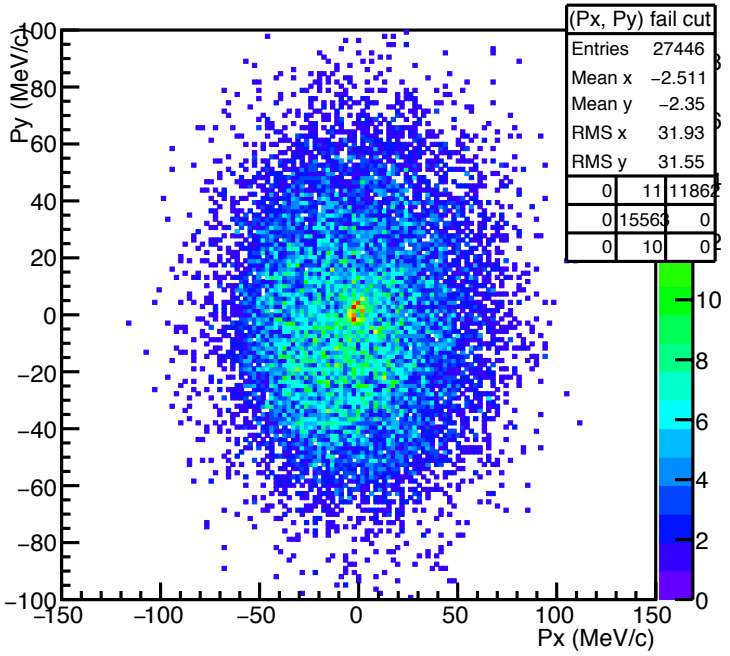


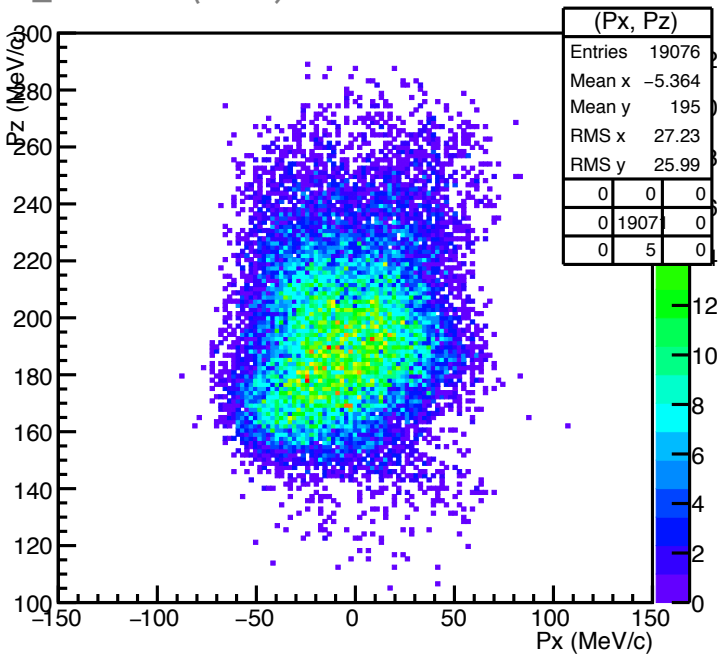



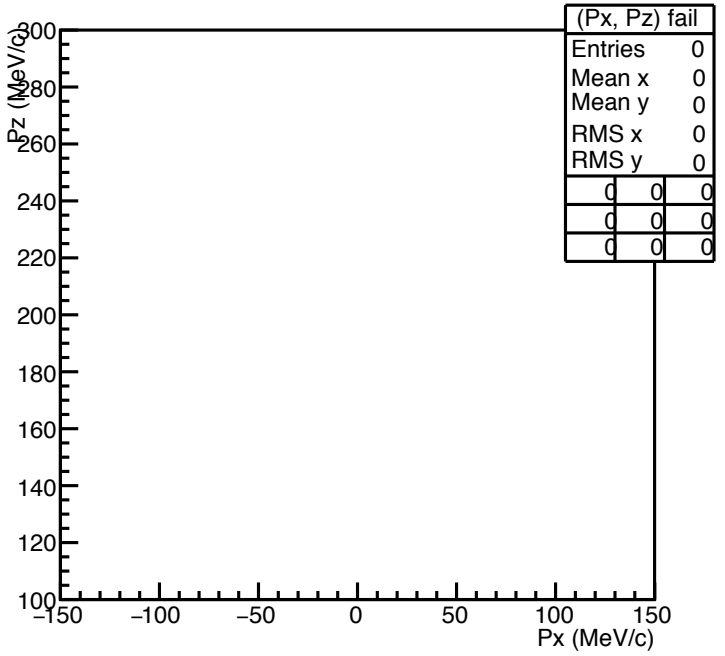



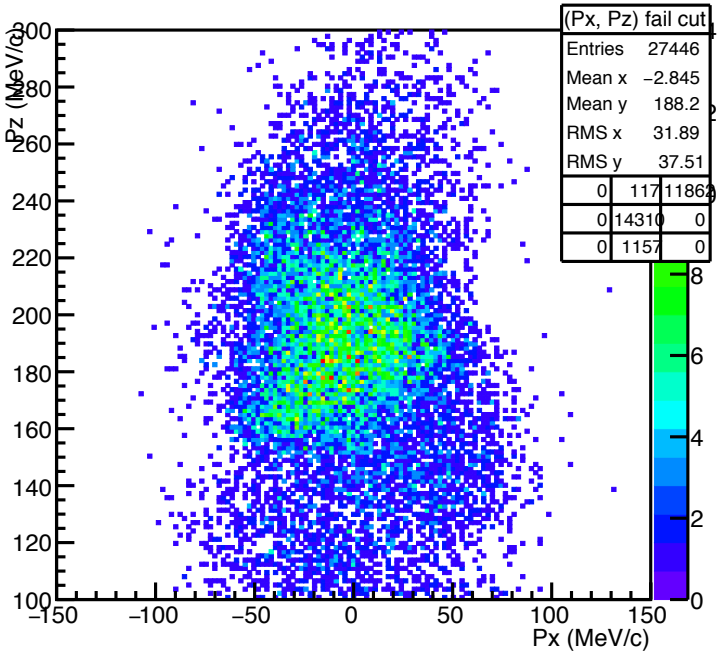



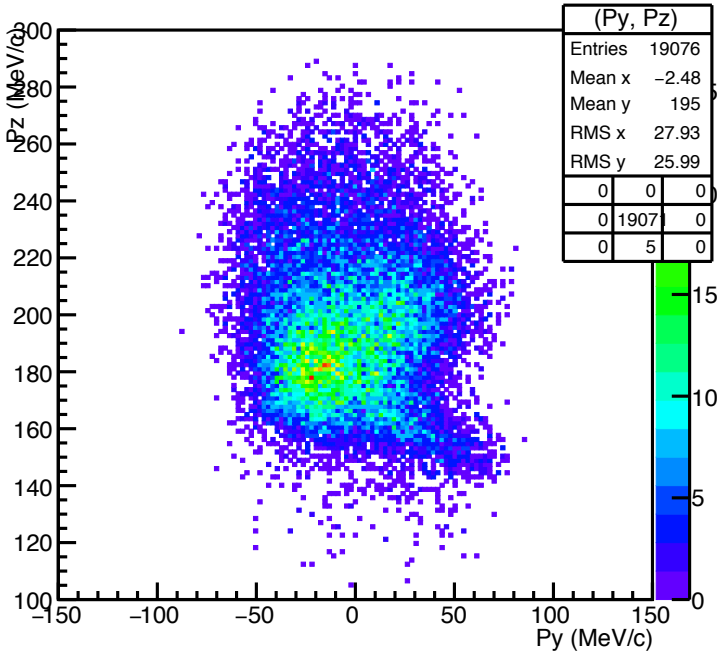



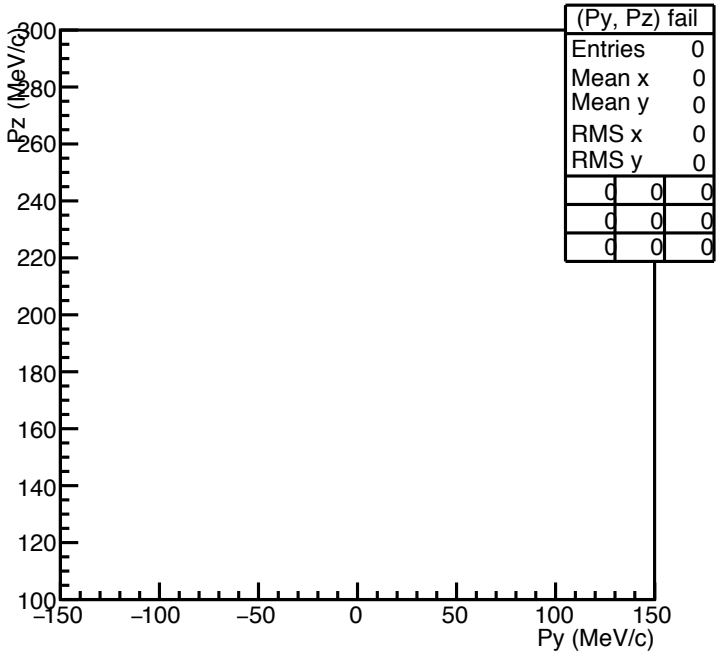
*cut_hit_all_detectors (cut 6)*

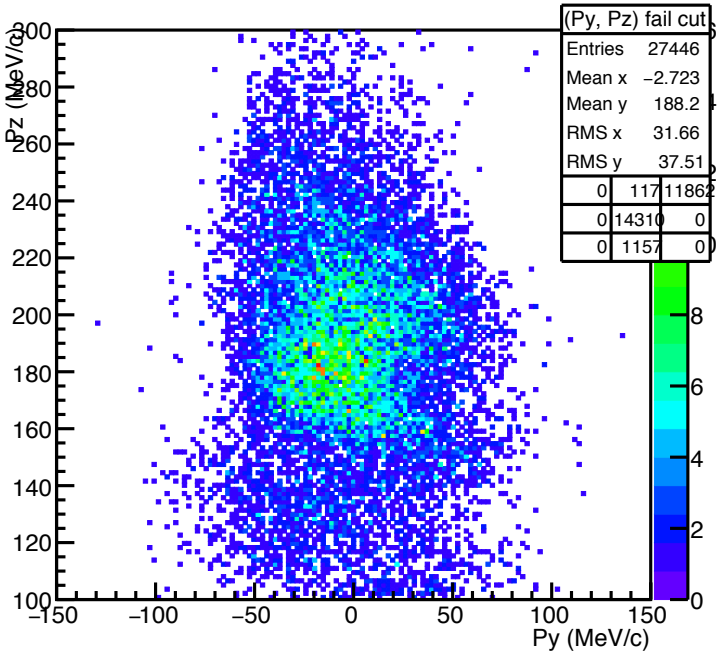


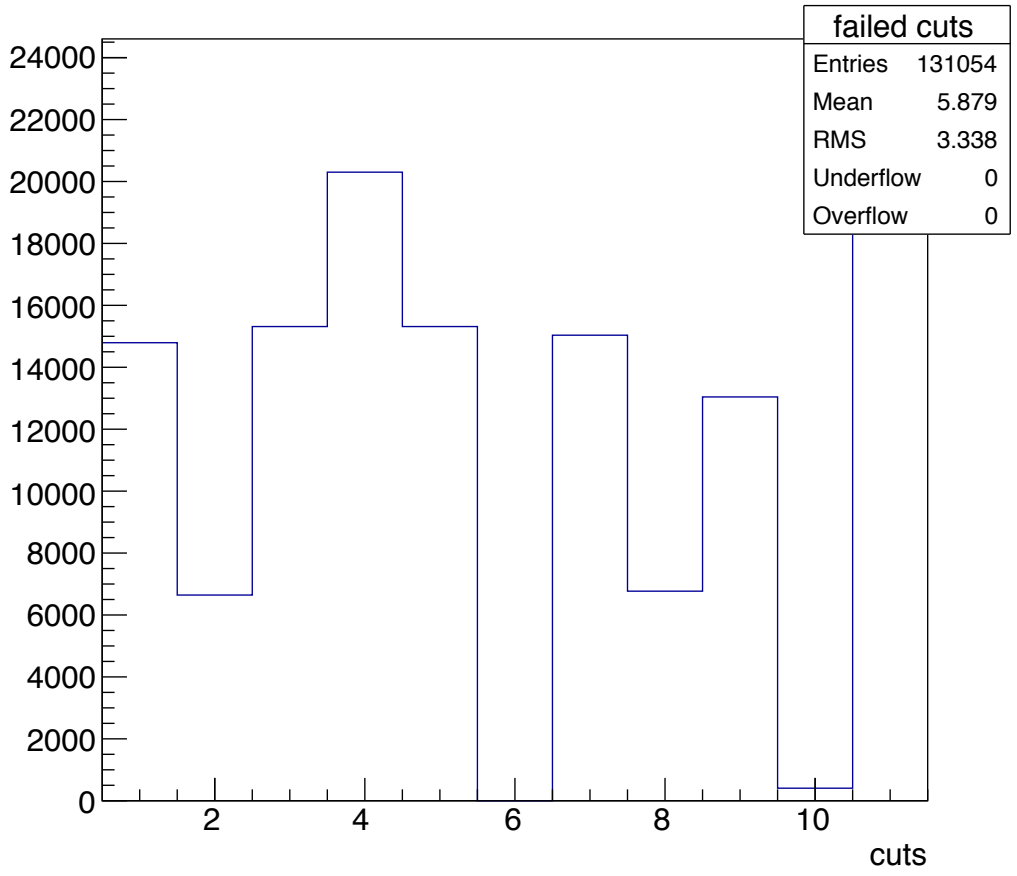



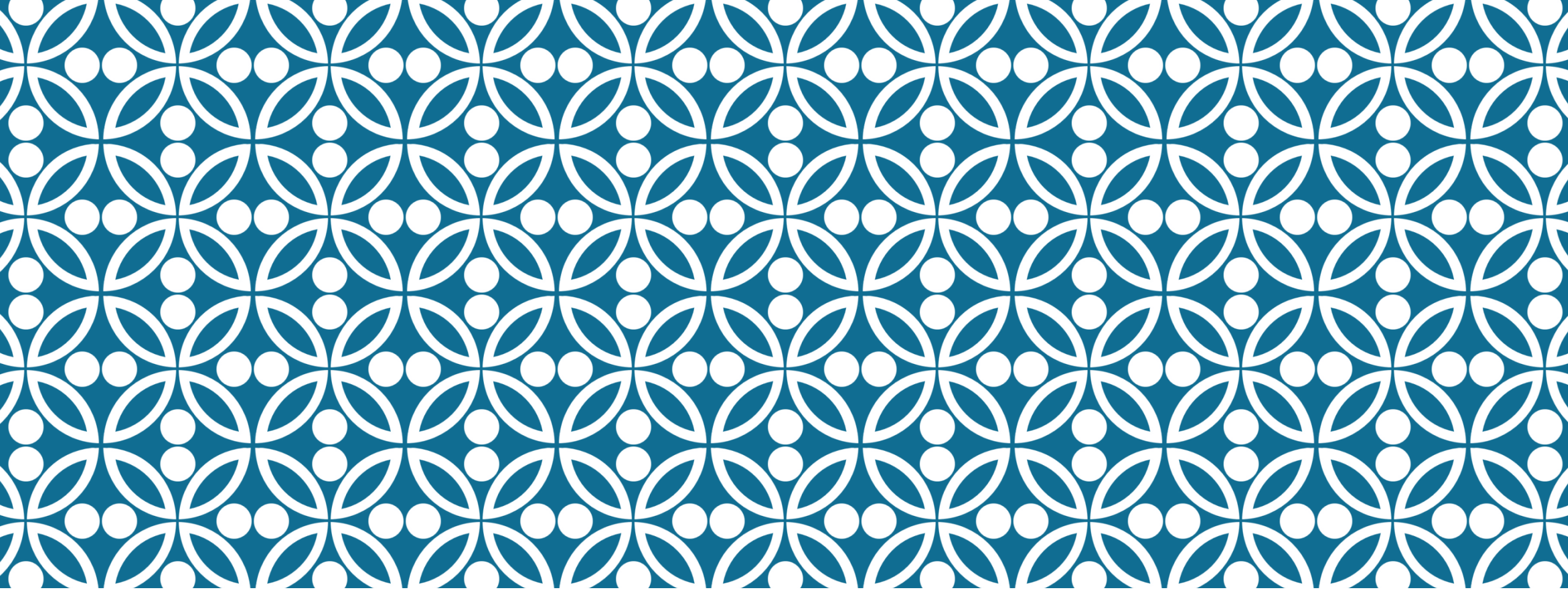



*cut_hit_all_detectors (cut 6)*



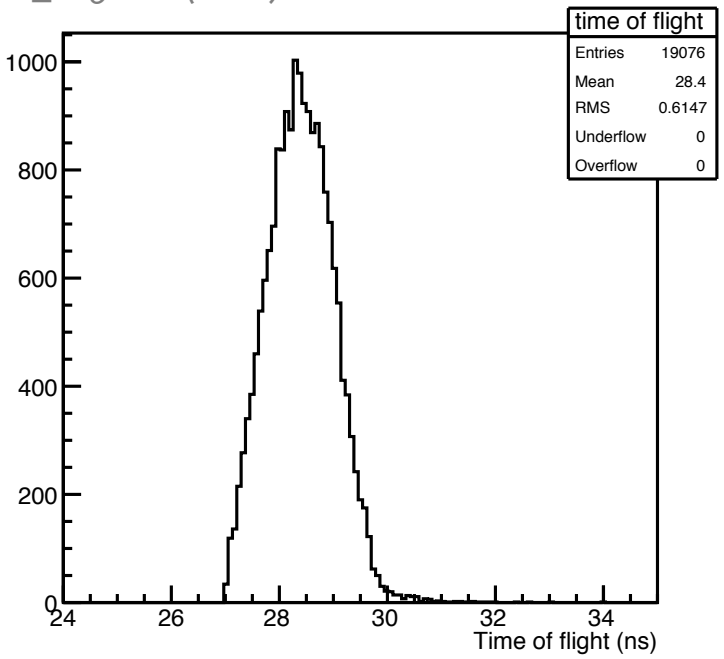

| 'Cut number' | Cut |
|---|---|
| 1 | cut_TOF0_goodPMTPosition |
| 2 | cut_TOF1_goodPMTPosition |
| 3 | cut_goodRaynerReconstruction |
| 4 | cut_TKU_hitAllStations |
| 5 | cut_TimeOfFlight |
| 6 | cut_hit_all_detectors |
| 7 | cut_TOF0_singleHit |
| 8 | cut_TOF1_singleHit |
| 9 | cut_TKU_singleTrack |
| 10 | cut_TKU_PValue |
| 11 | cut_momentum_loss |

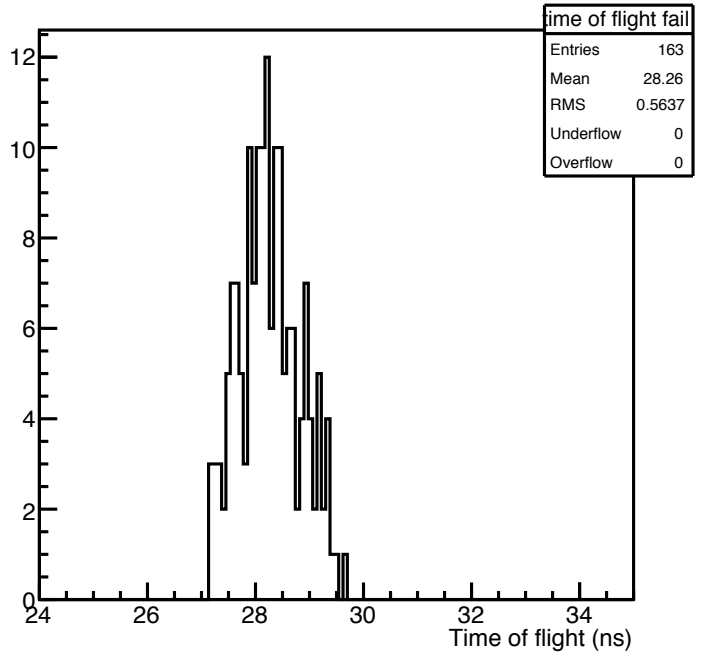


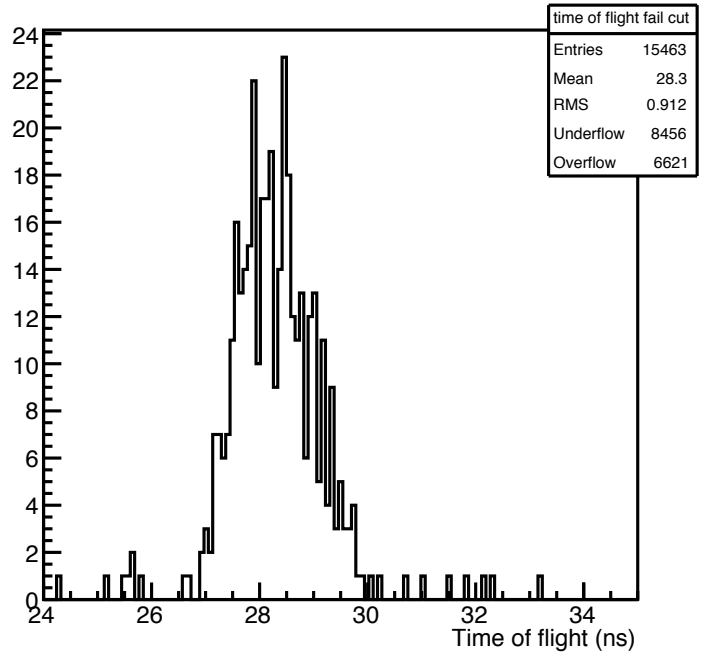
# CUT_TOFO_SINGLEHIT

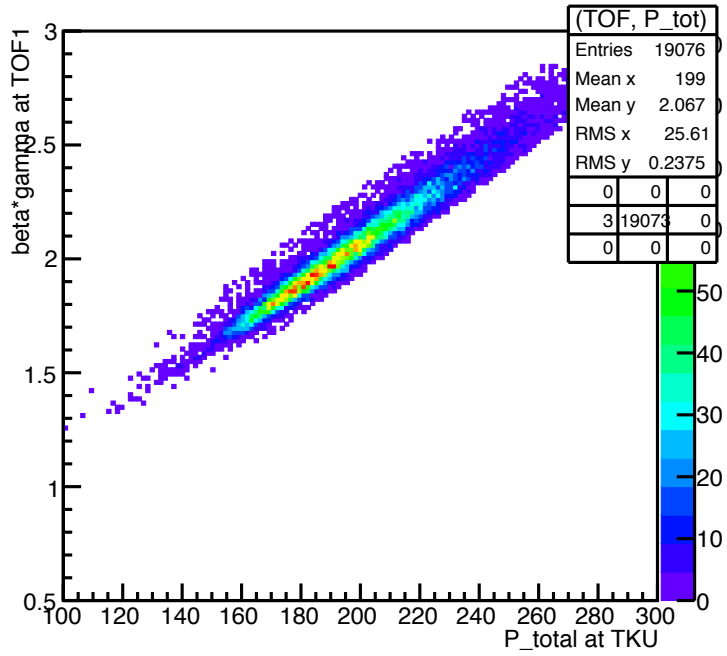
AKA ‘cut 7’

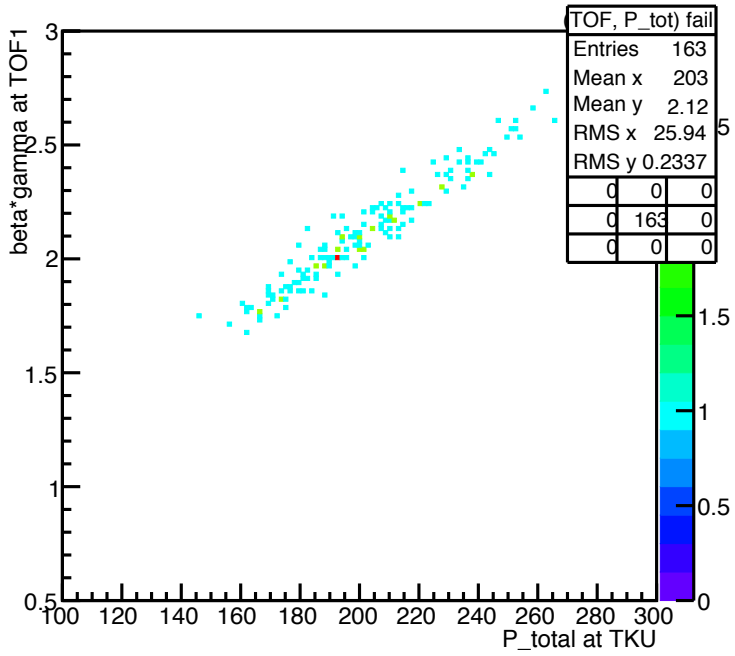
*cut_TOF0_singleHit (cut 7)*

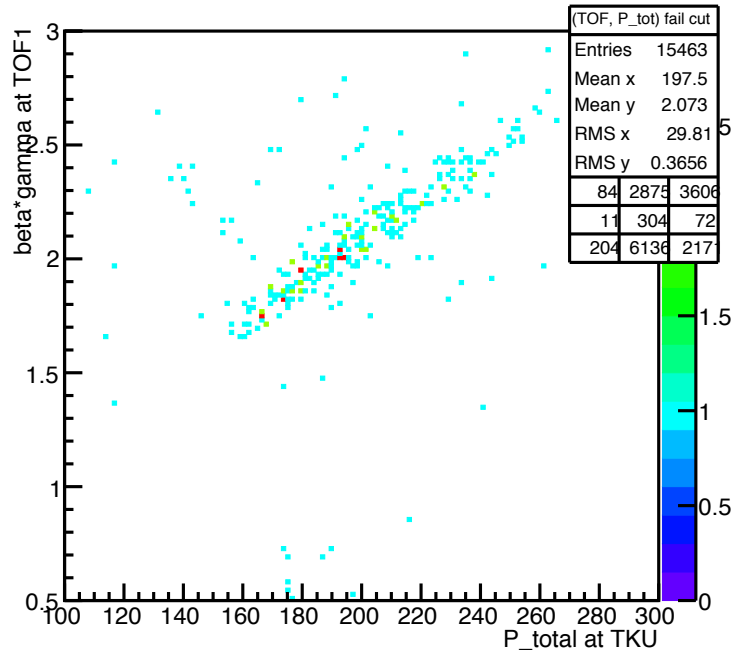


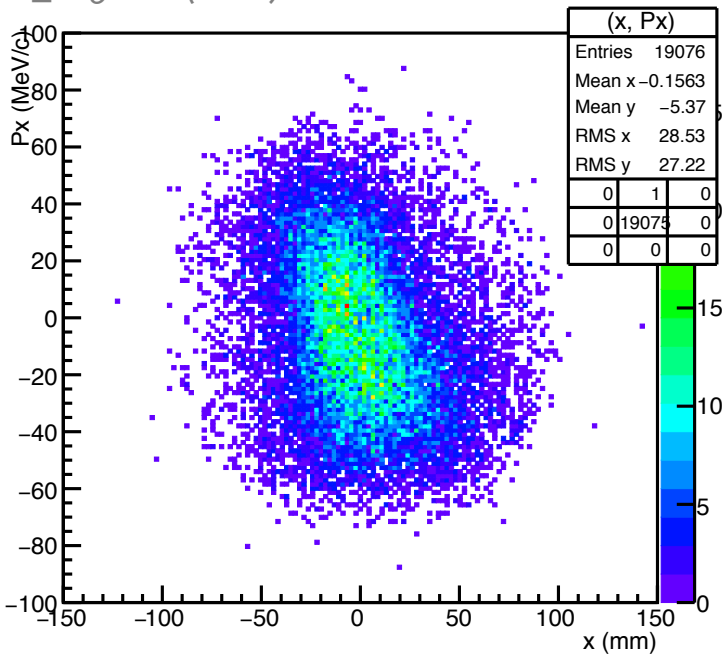



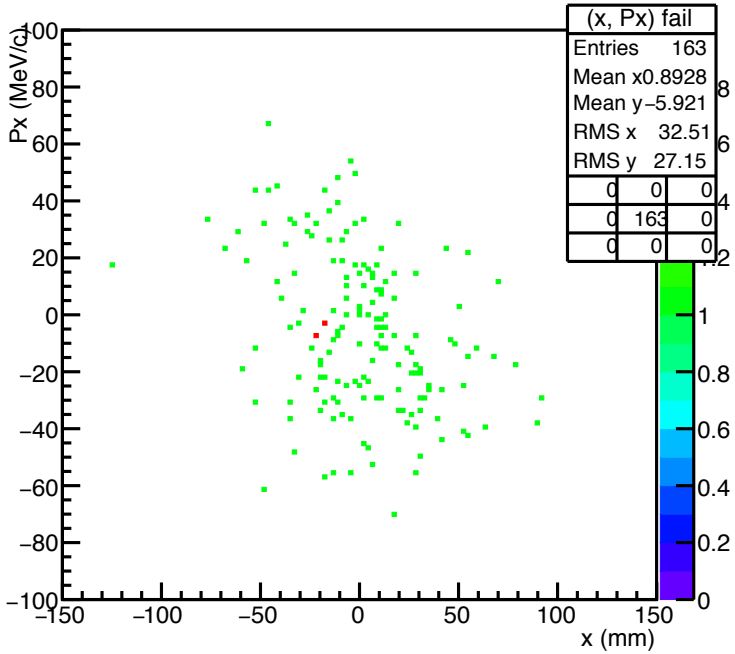



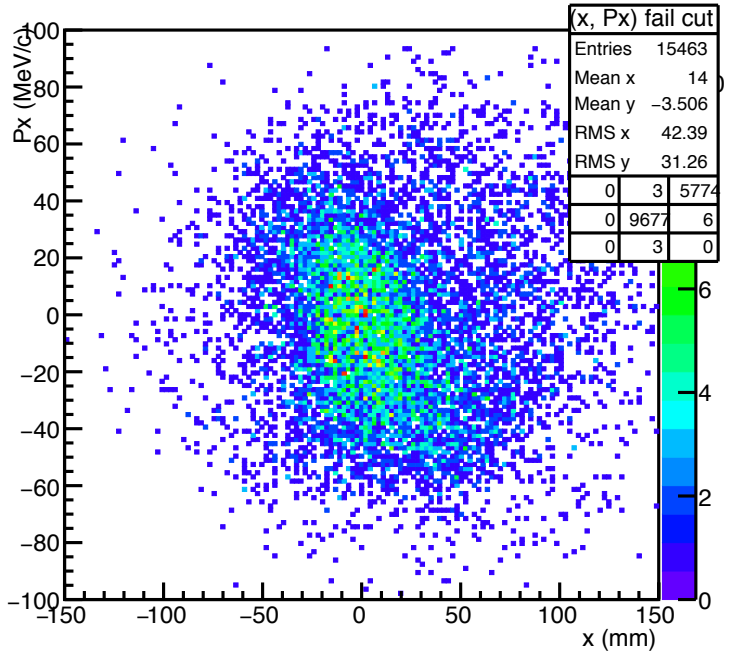



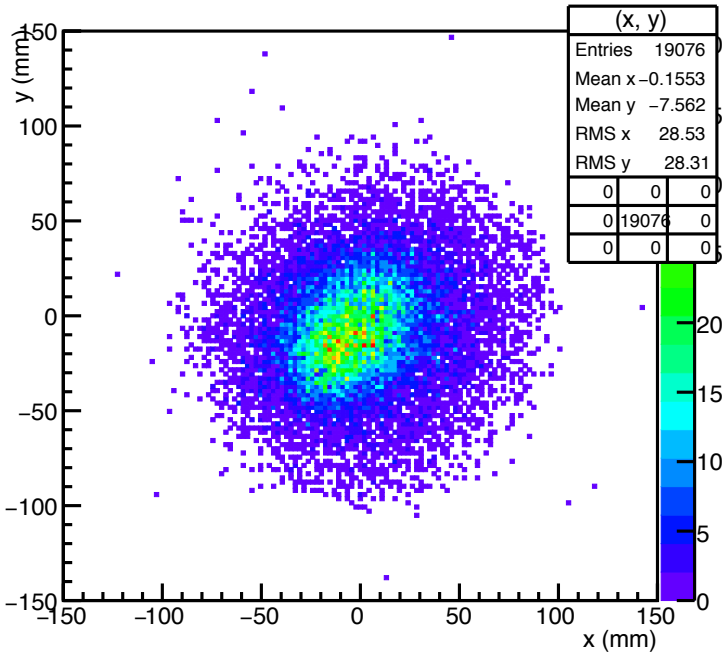



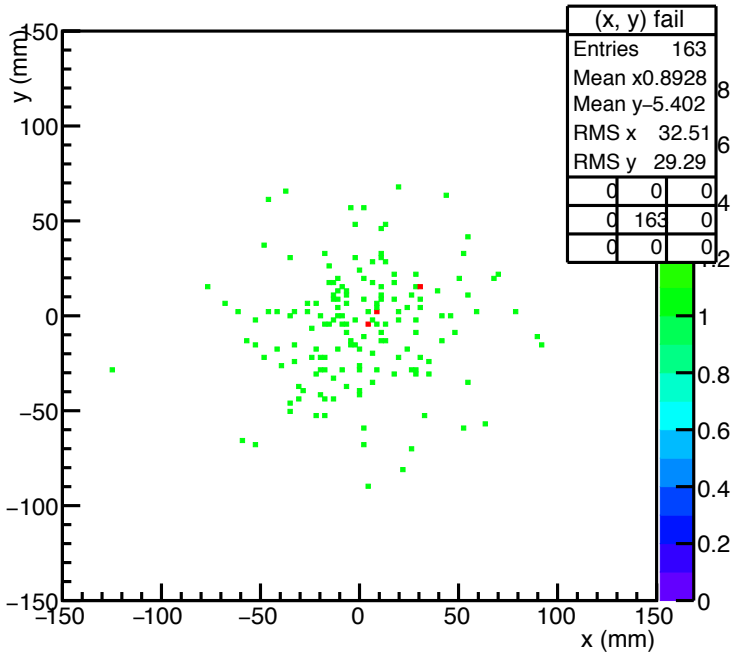
*cut_TOF0_singleHit (cut 7)*

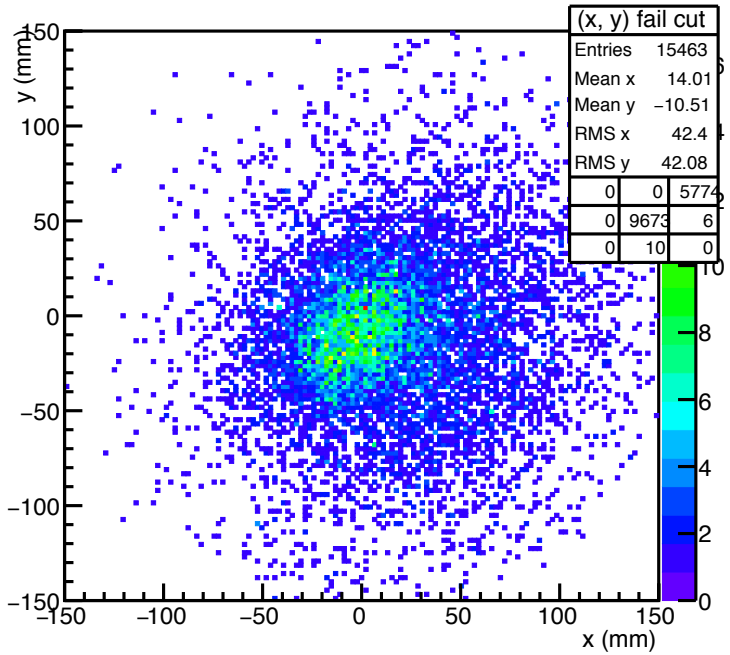


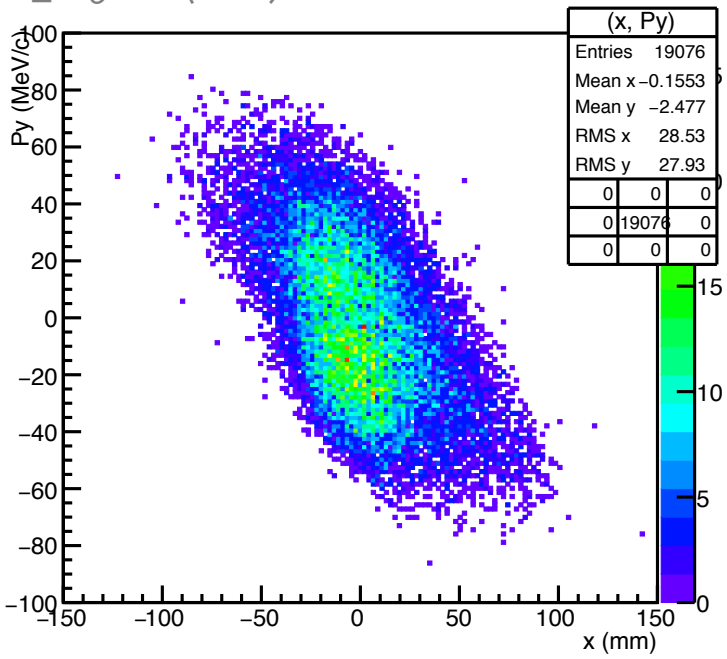



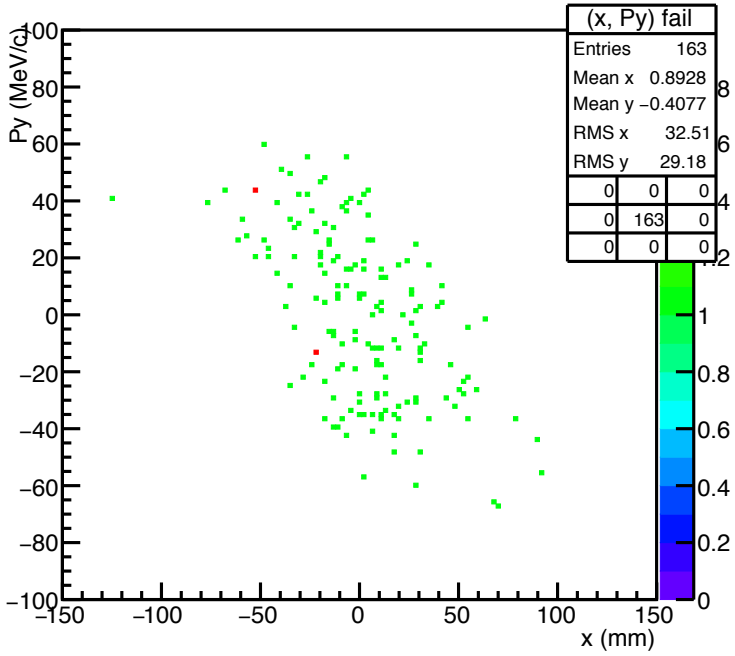



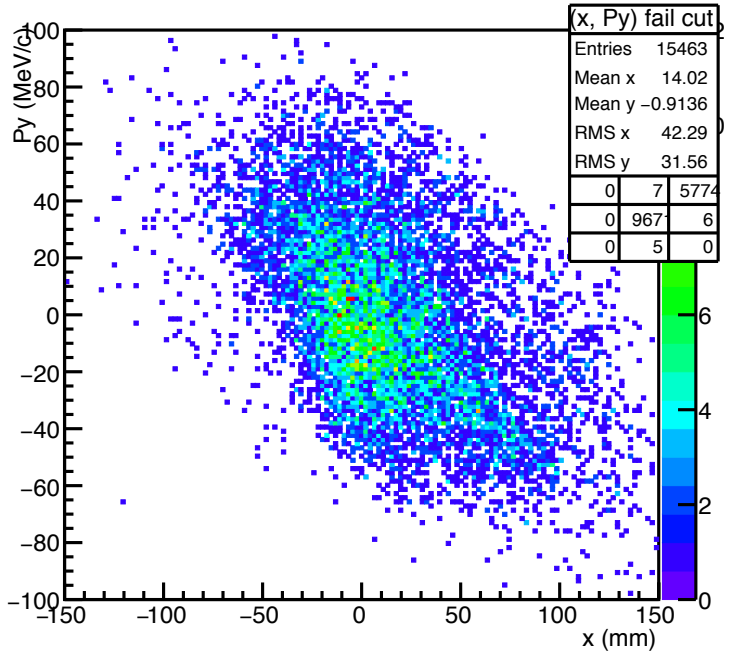



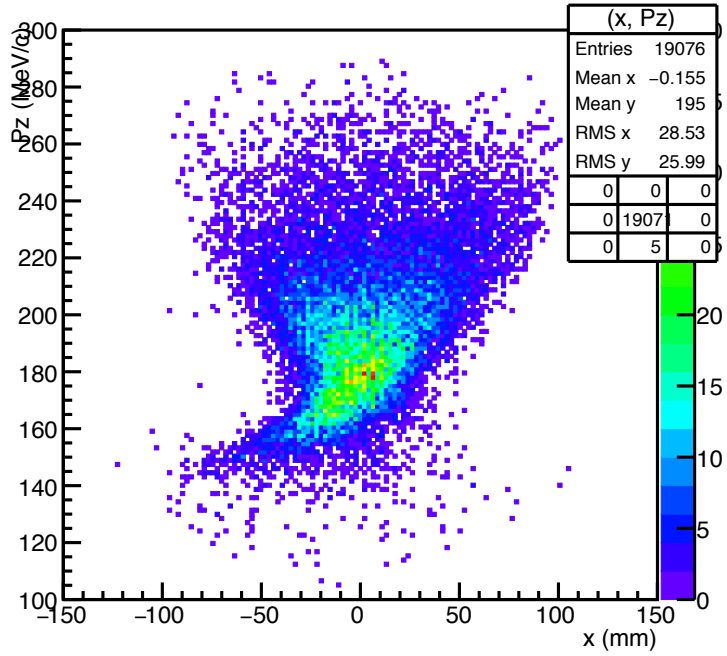



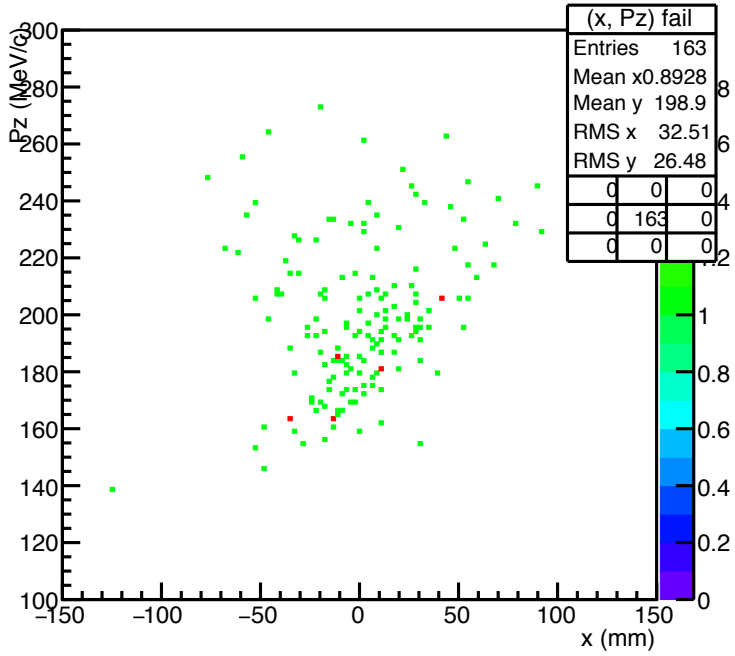
*cut_TOF0_singleHit (cut 7)*

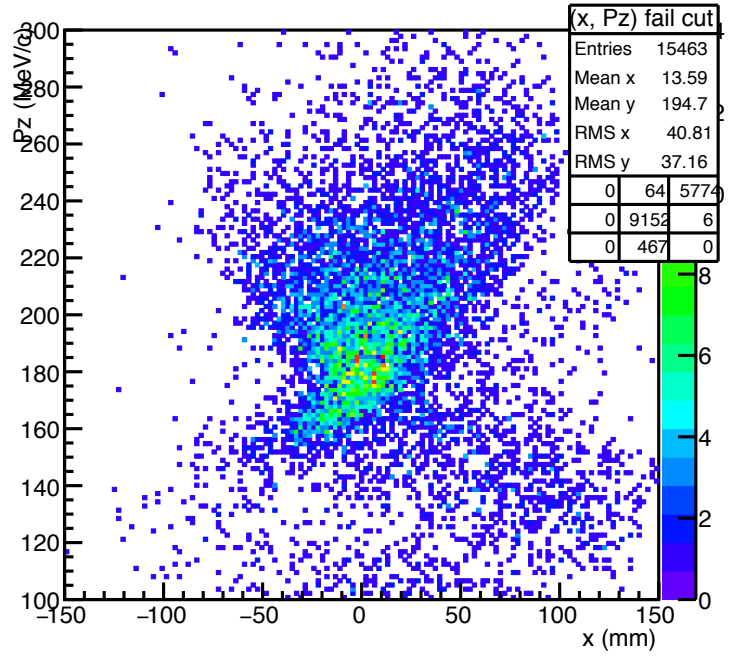


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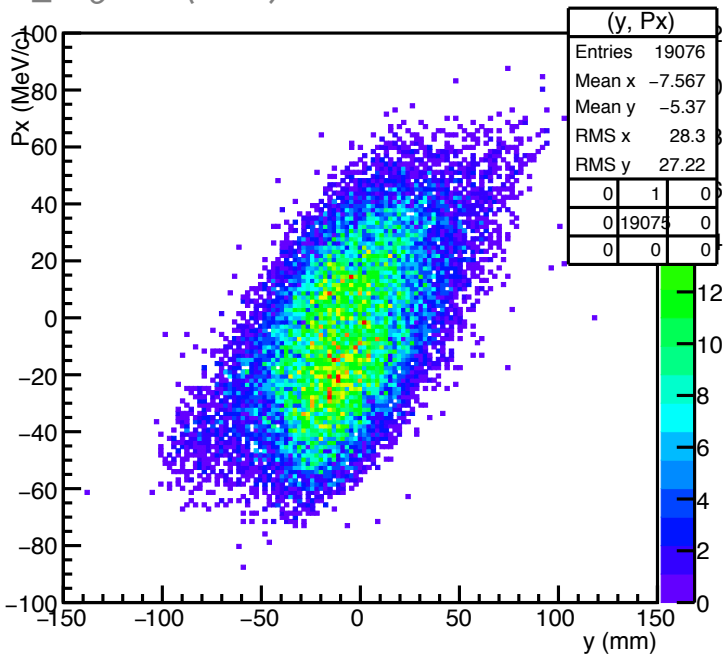
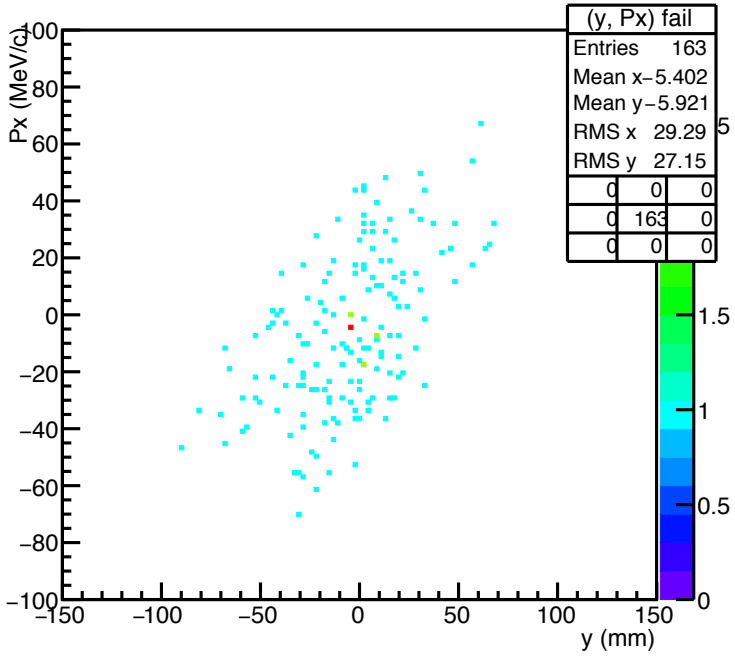
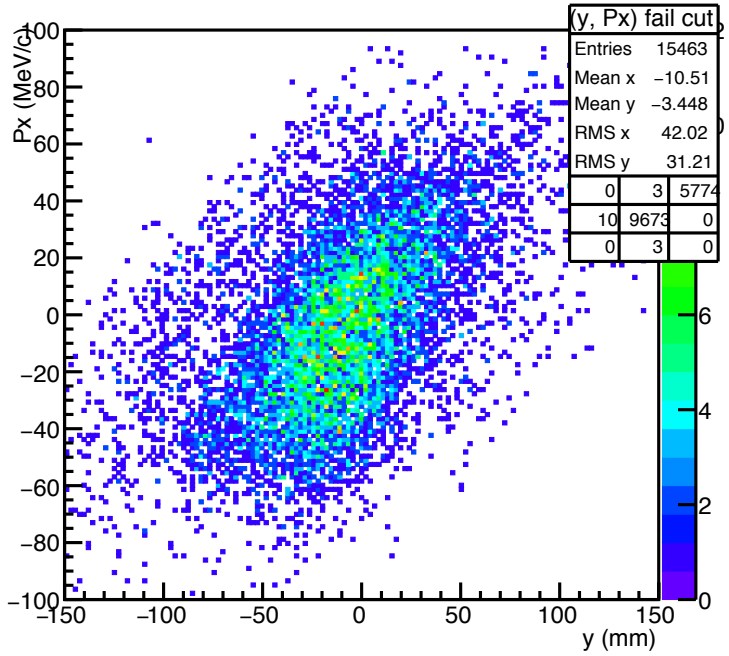
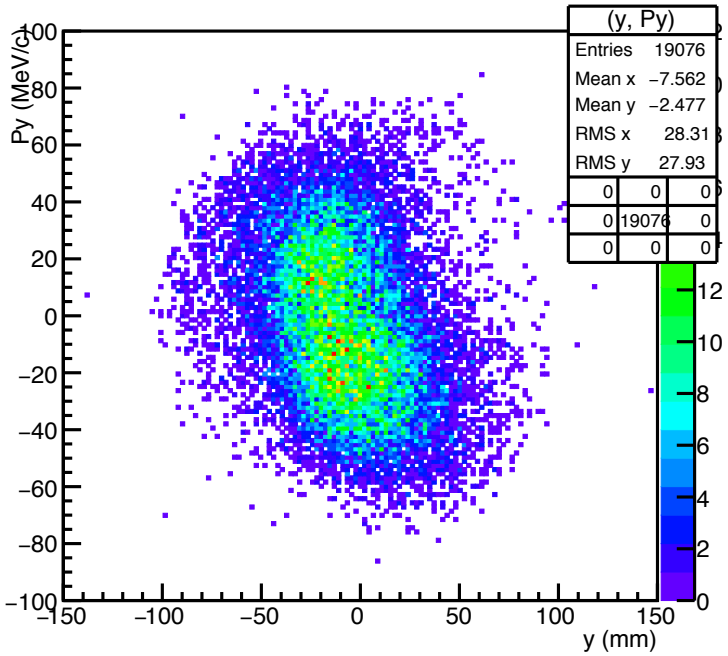
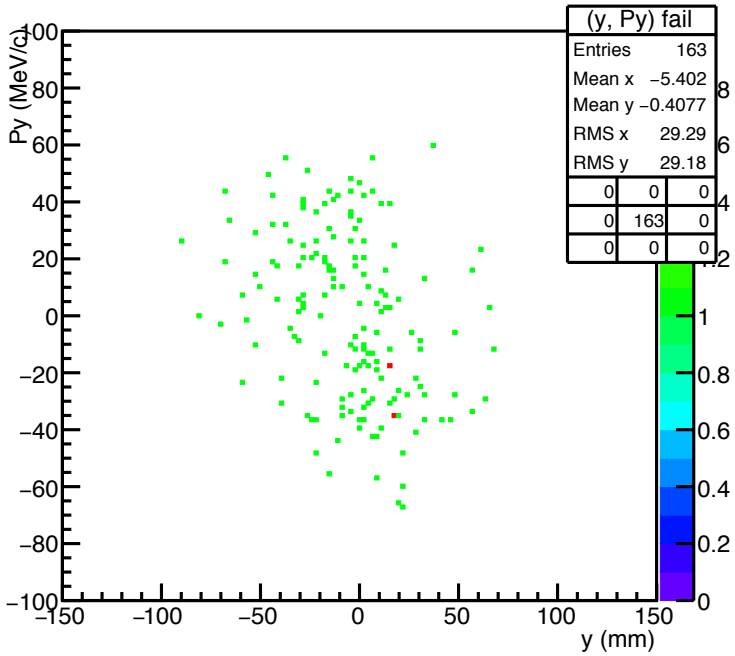
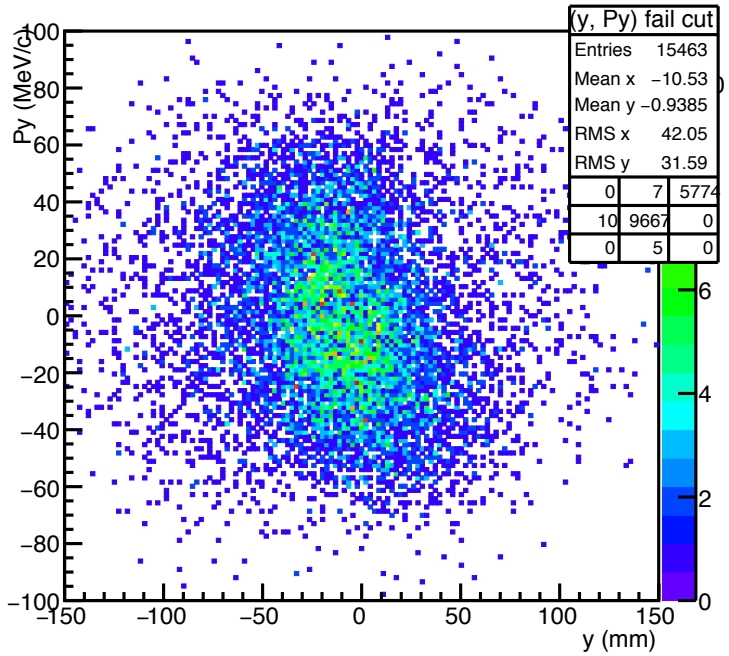


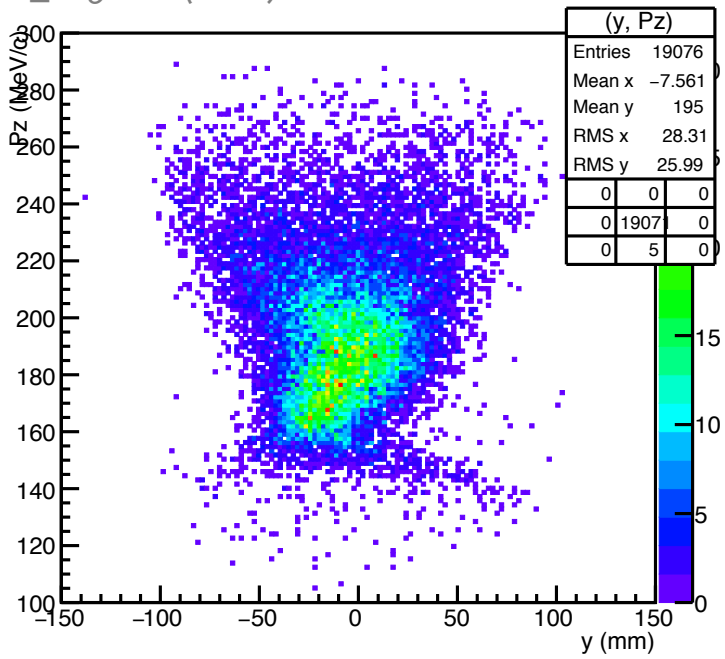



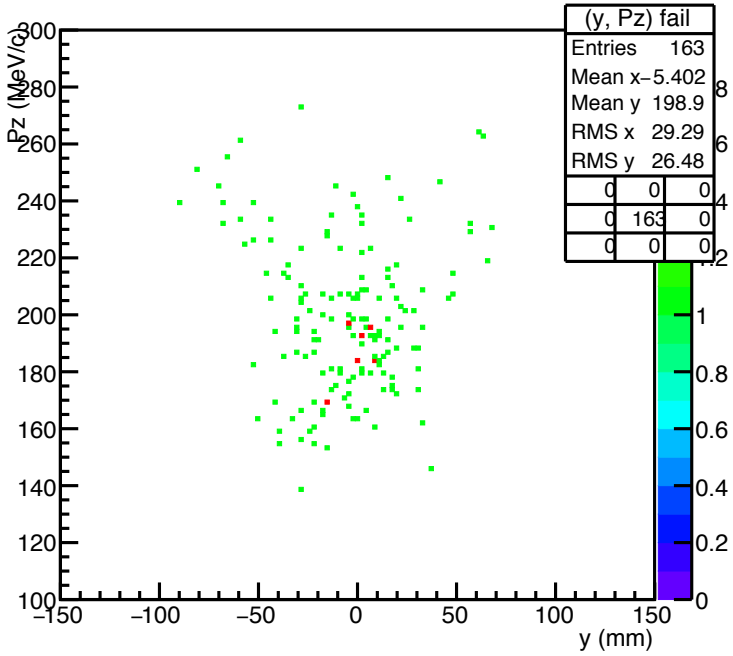



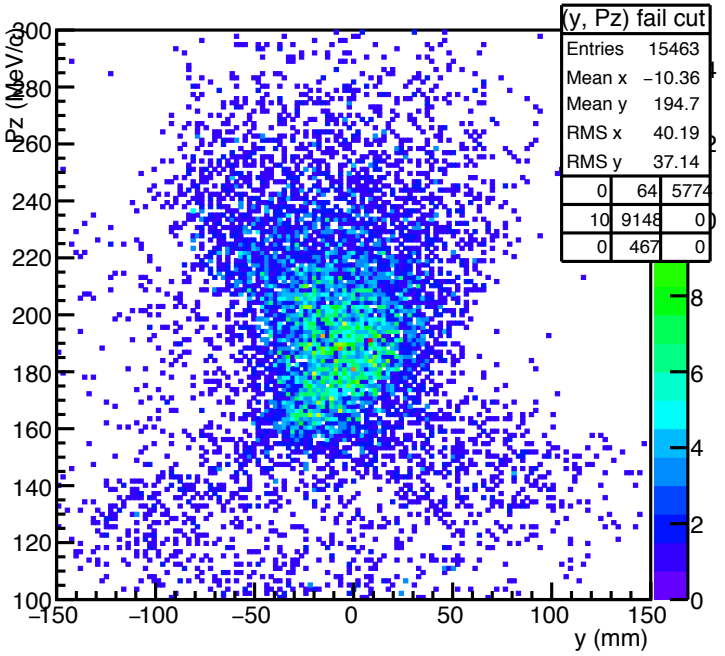



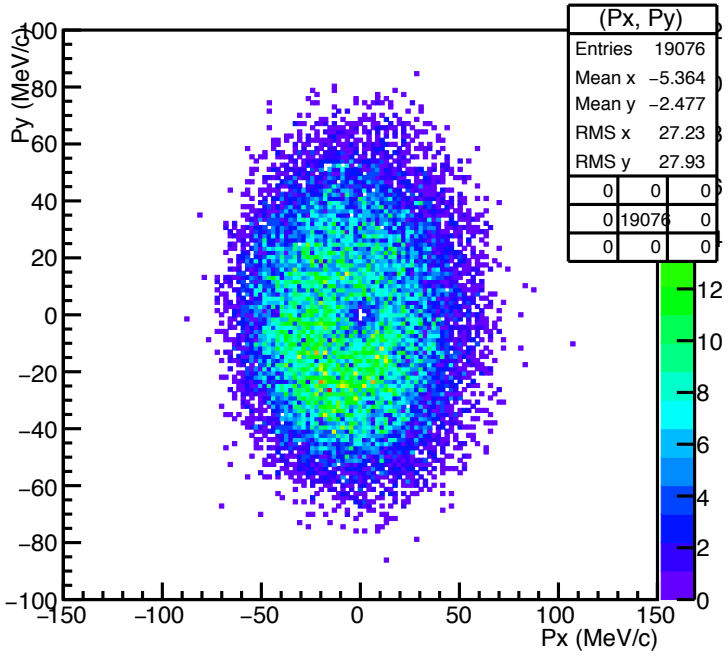



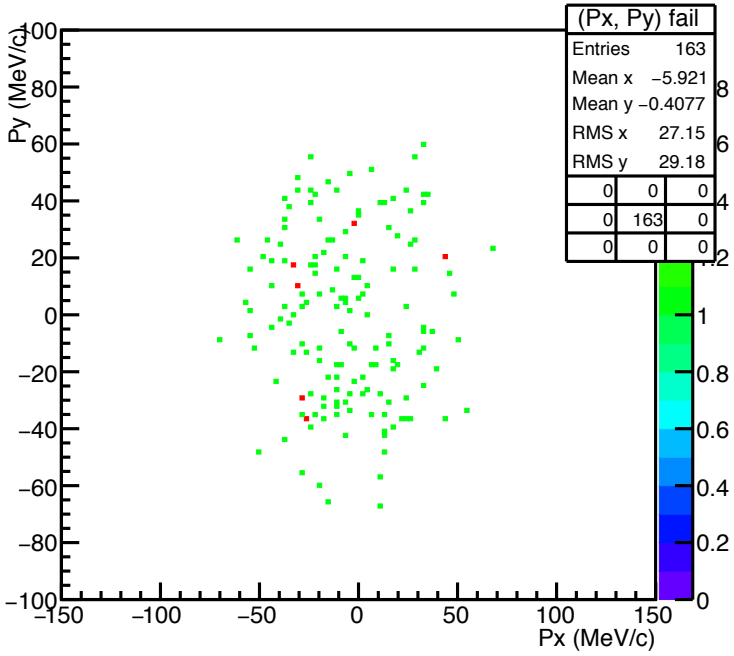
*cut_TOF0_singleHit (cut 7)*

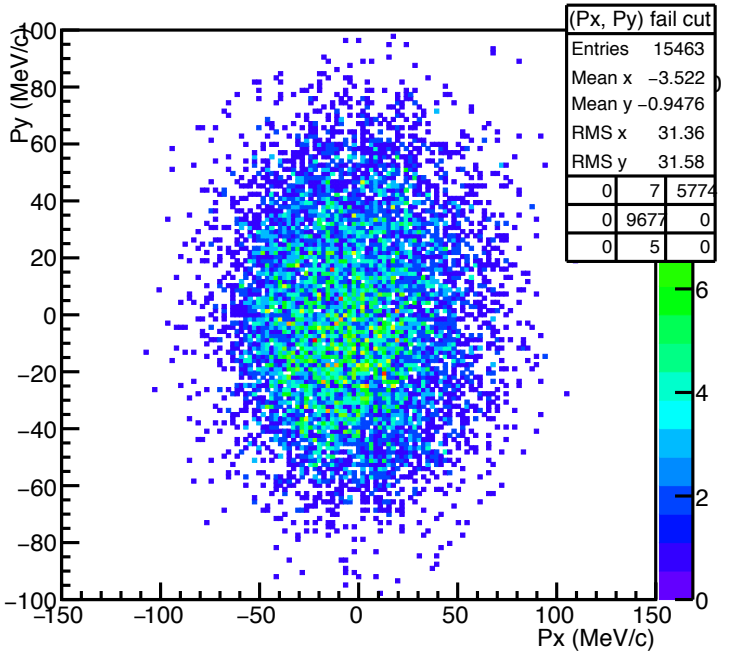


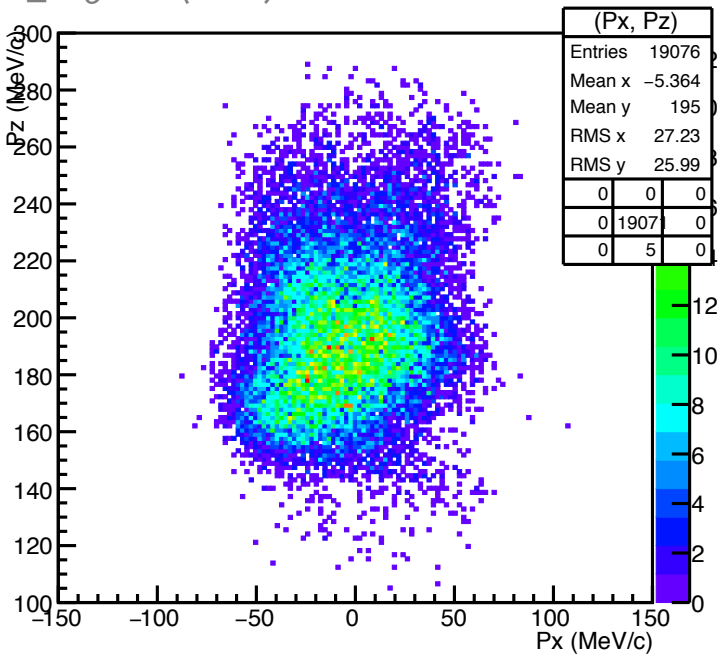



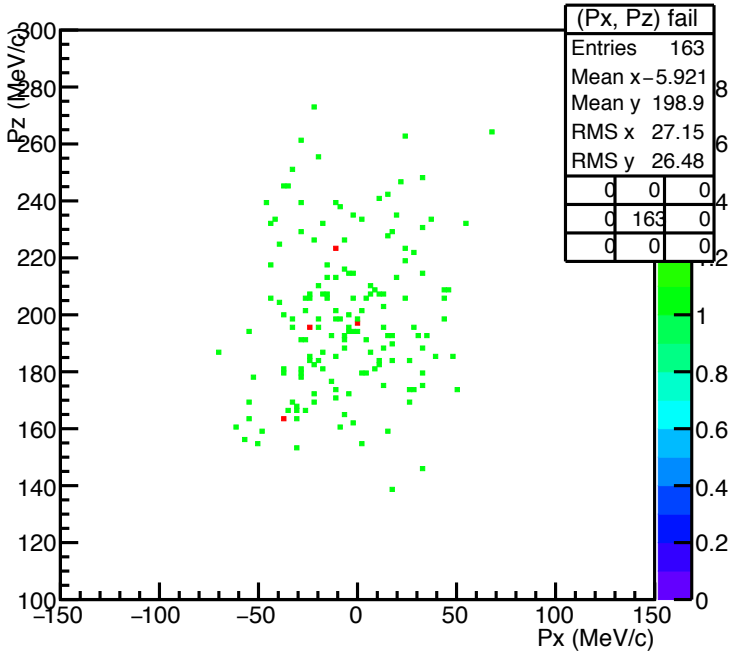



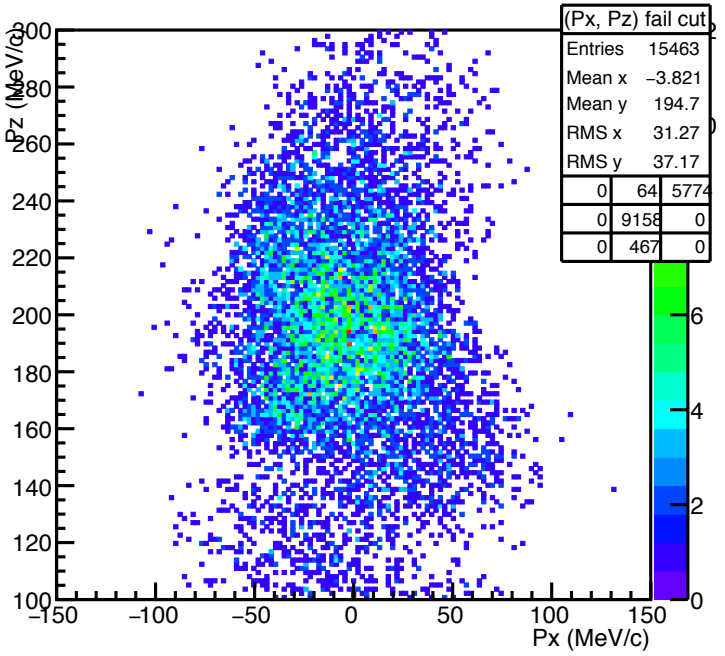



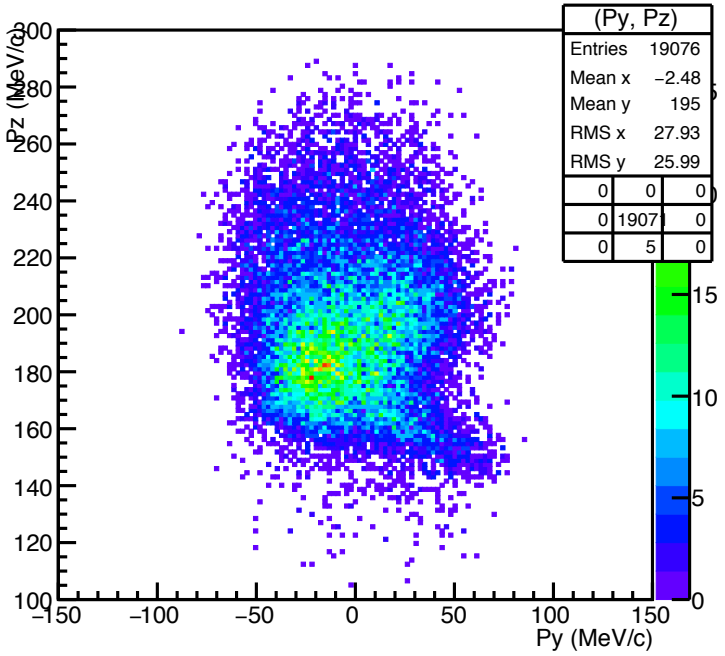



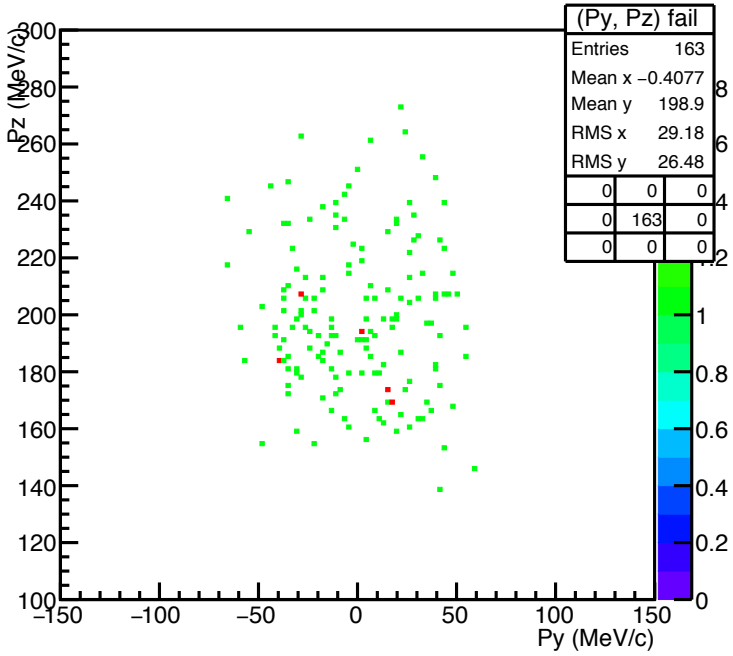
*cut_TOF0_singleHit (cut 7)*

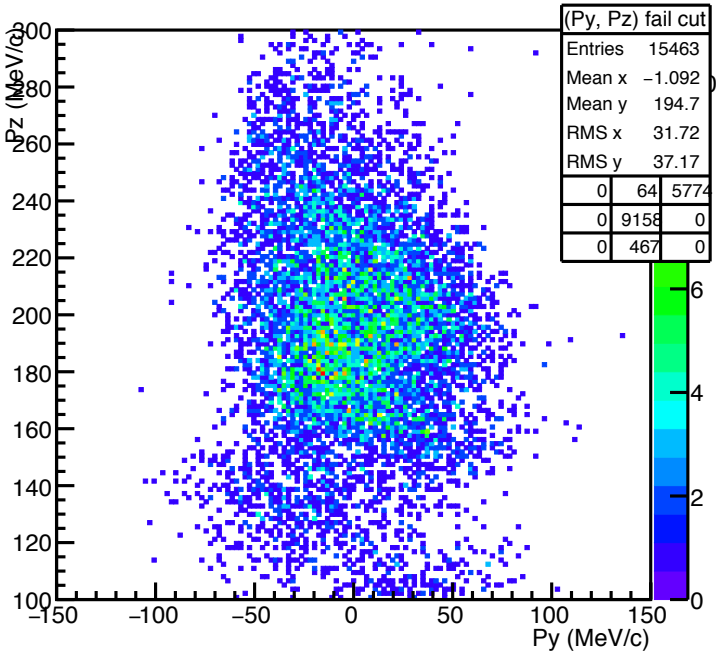


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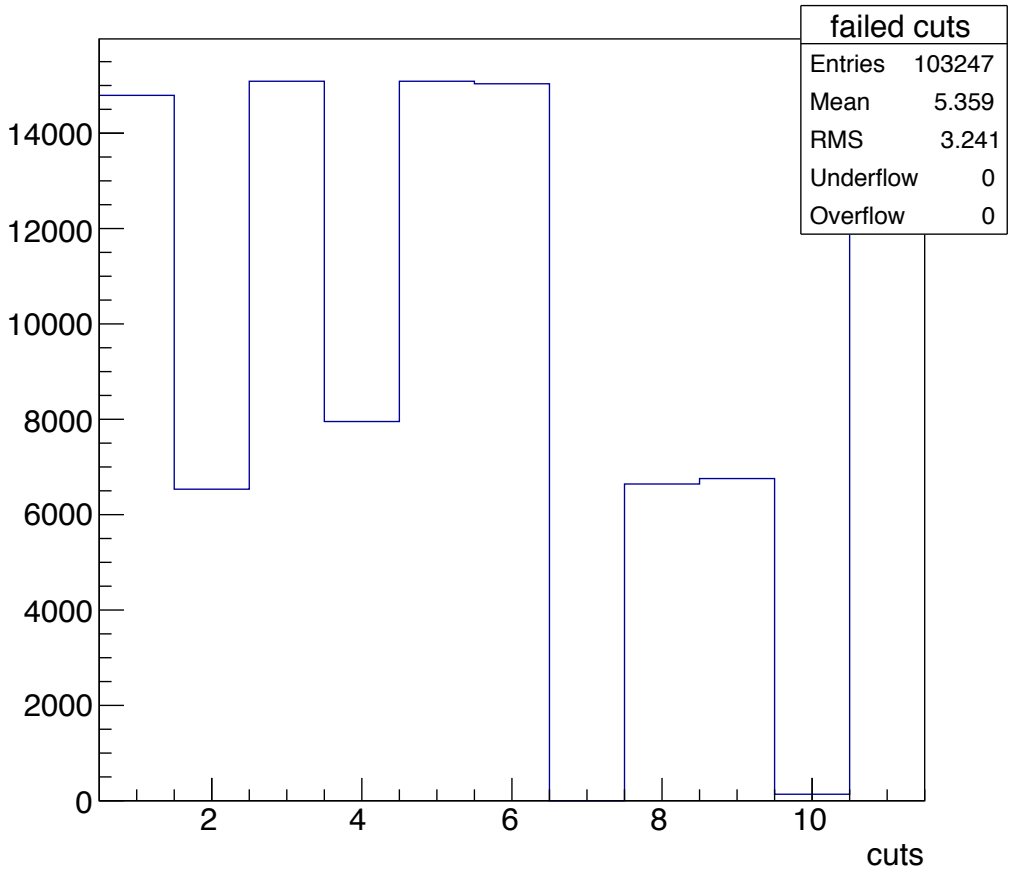
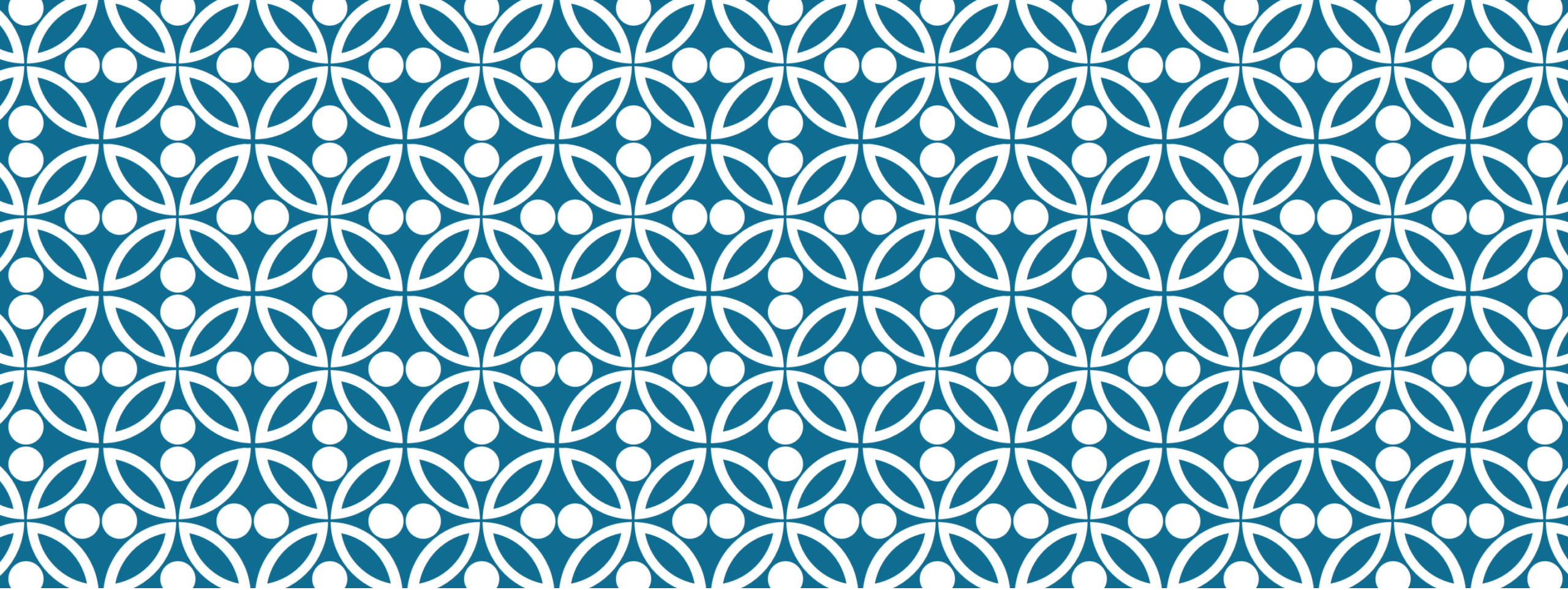


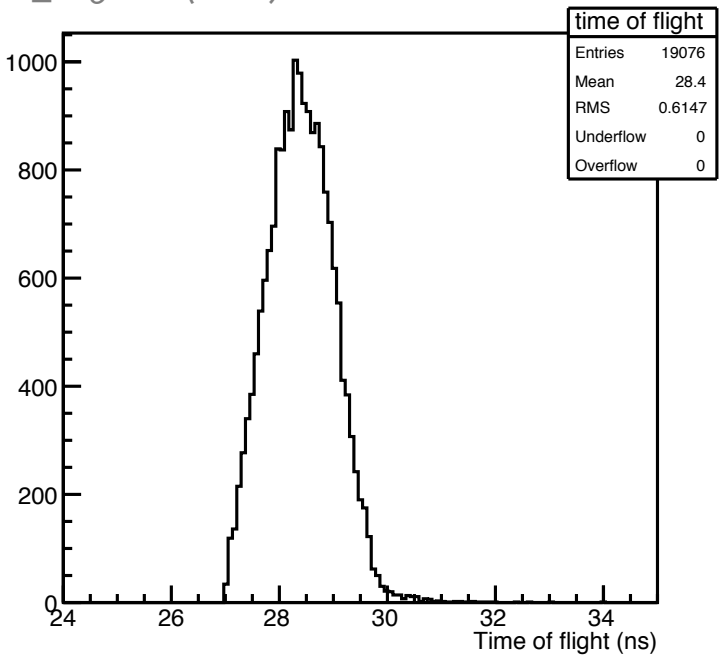

| ‘Cut number’ | Cut |
|---|---|
| 1 | cut_TOF0_goodPMTPosition |
| 2 | cut_TOF1_goodPMTPosition |
| 3 | cut_goodRaynerReconstruction |
| 4 | cut_TKU_hitAllStations |
| 5 | cut_TimeOfFlight |
| 6 | cut_hit_all_detectors |
| 7 | cut_TOF0_singleHit |
| 8 | cut_TOF1_singleHit |
| 9 | cut_TKU_singleTrack |
| 10 | cut_TKU_PValue |
| 11 | cut_momentum_loss |

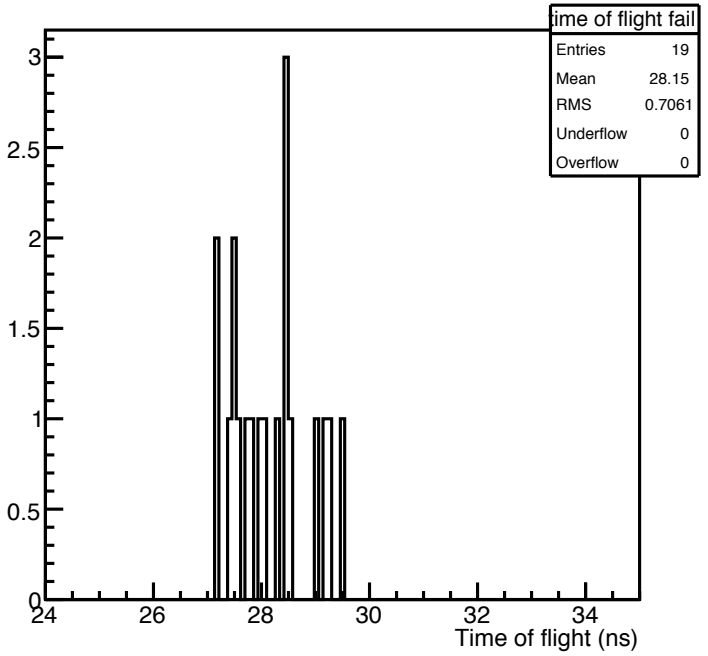


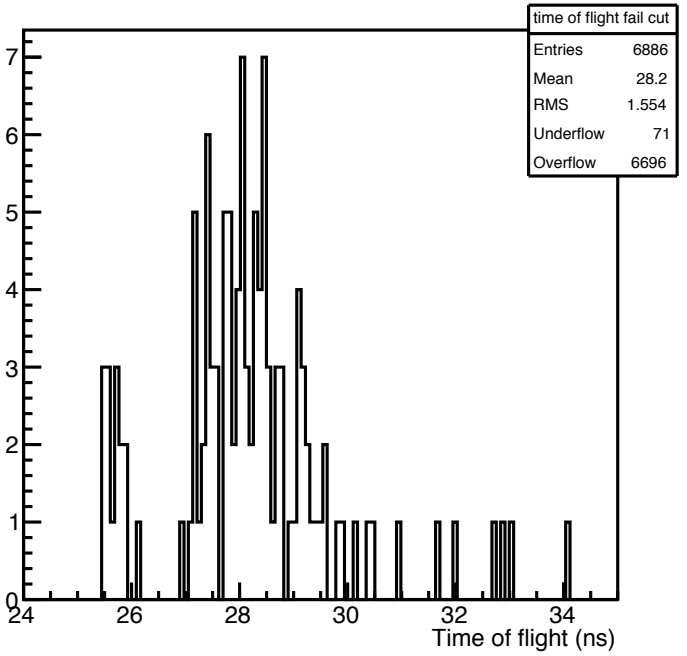
# CUT_TOF1_SINGLEHIT

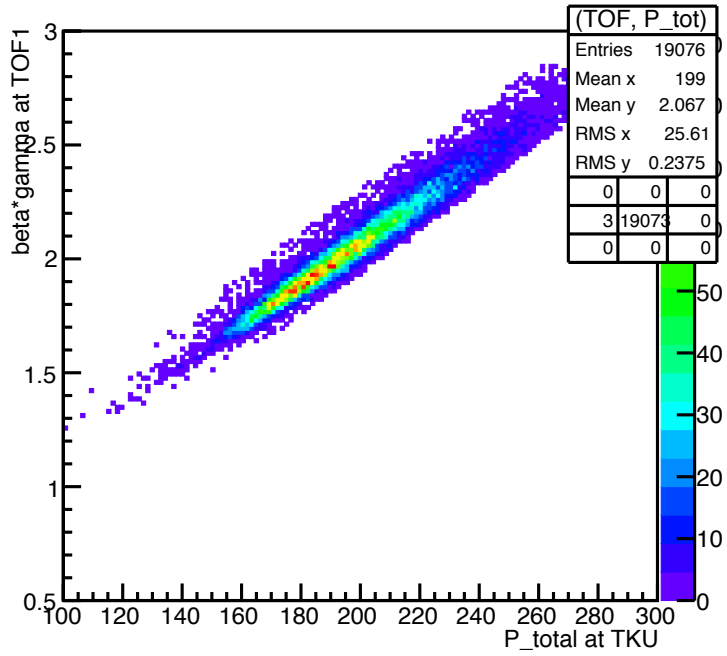
AKA ‘cut 8’

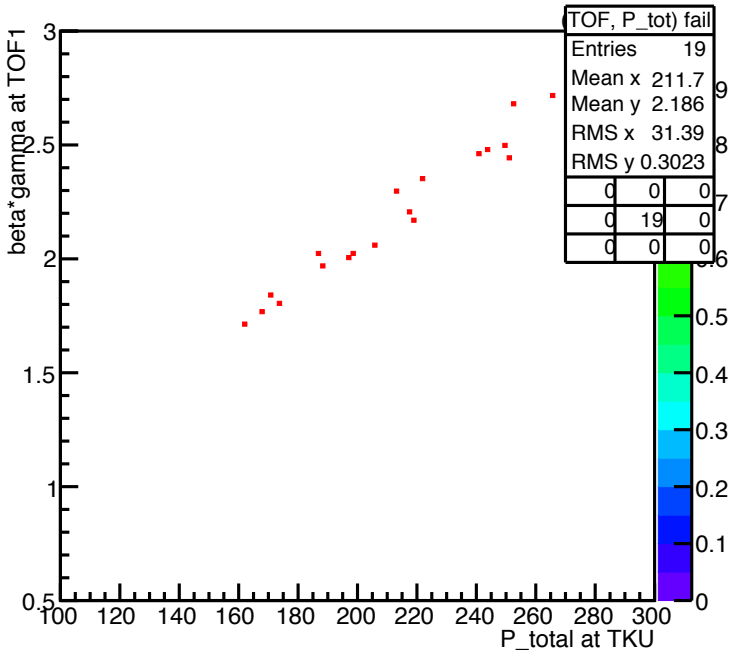
*cut_TOF1_singleHit (cut 8)*

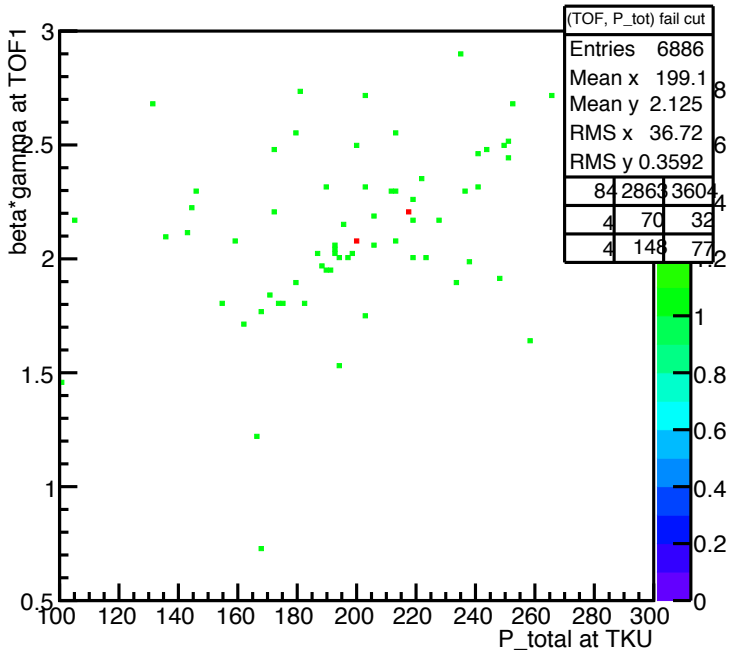


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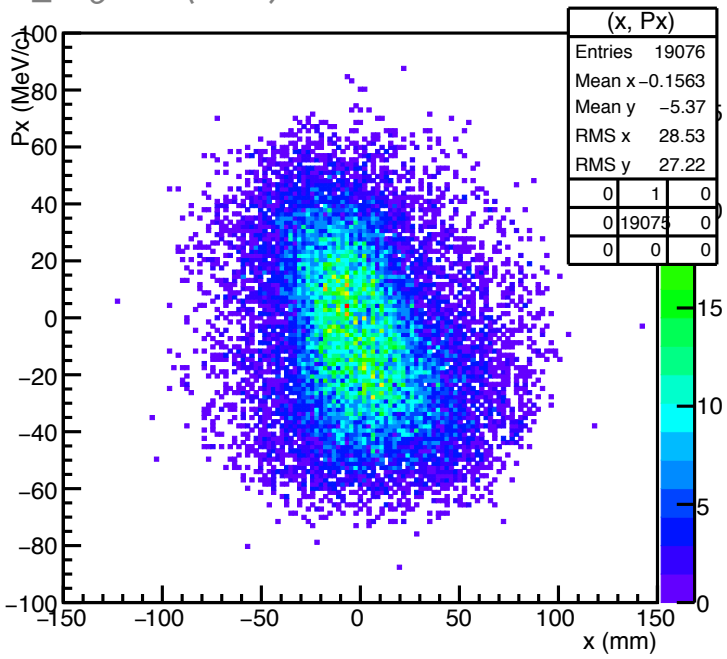


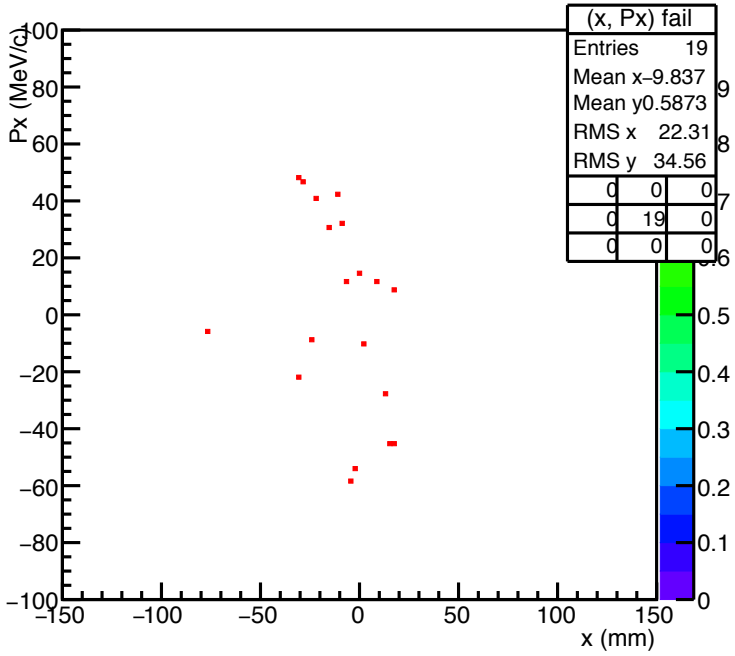


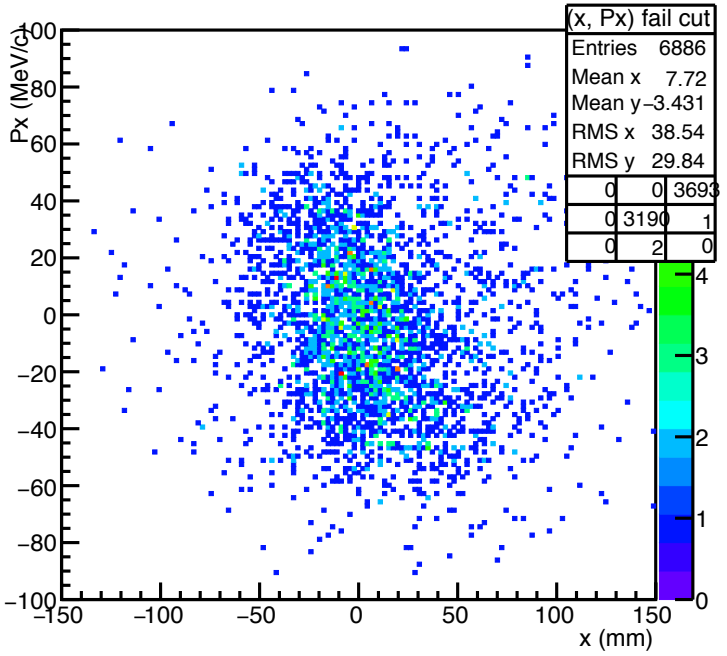


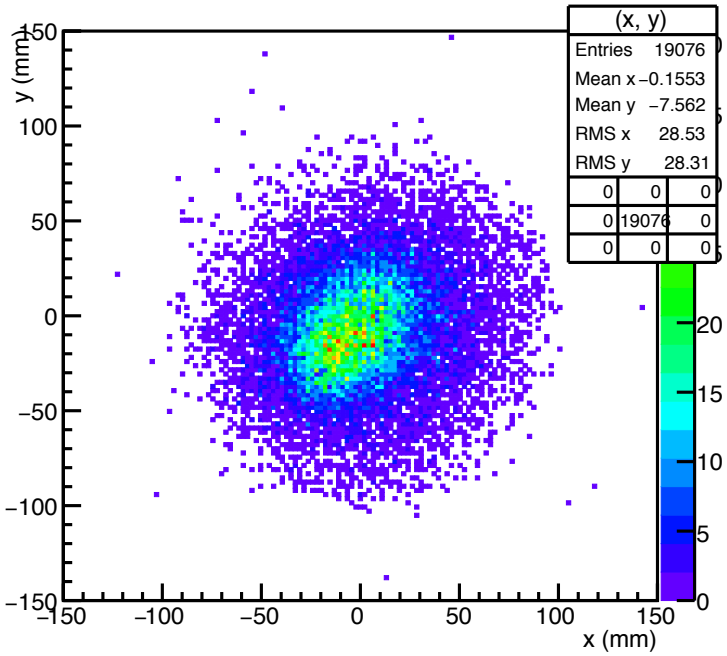


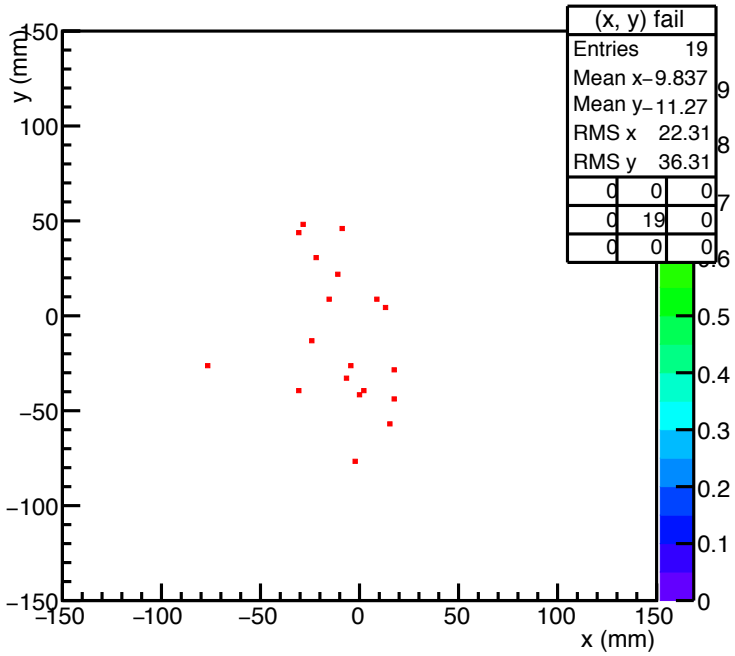


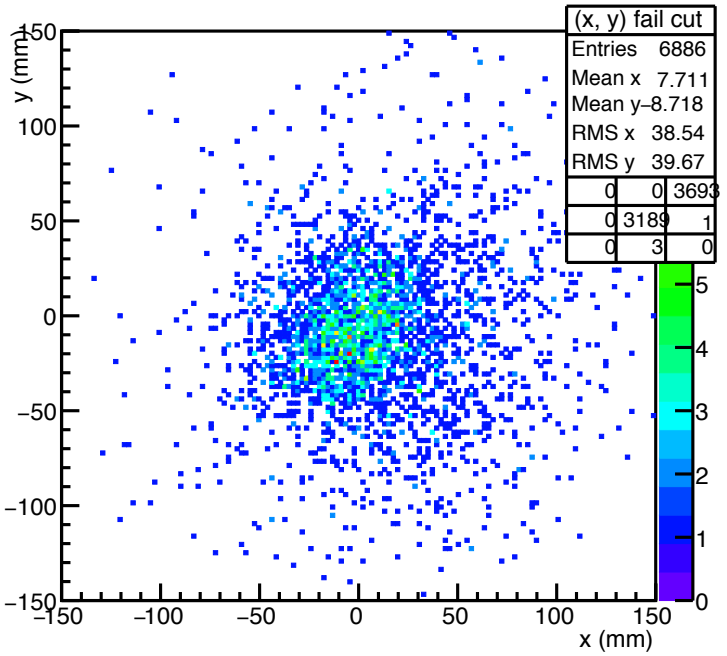

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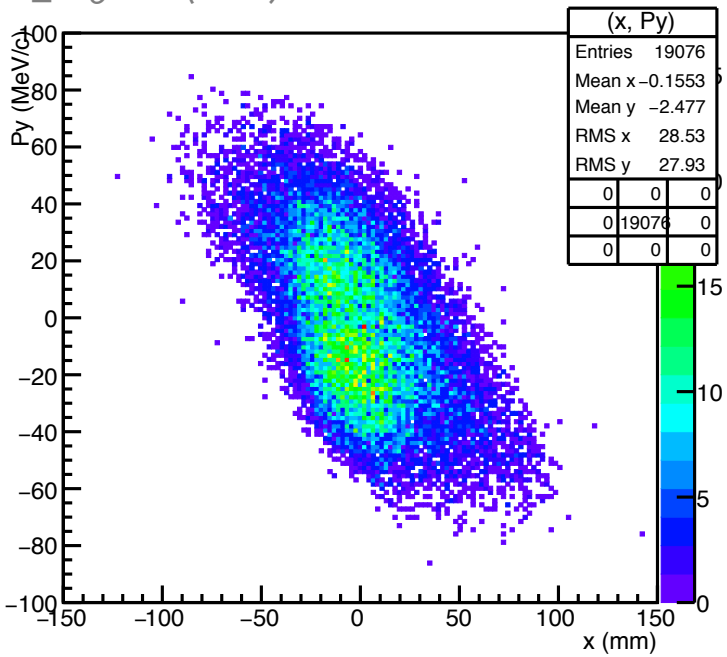
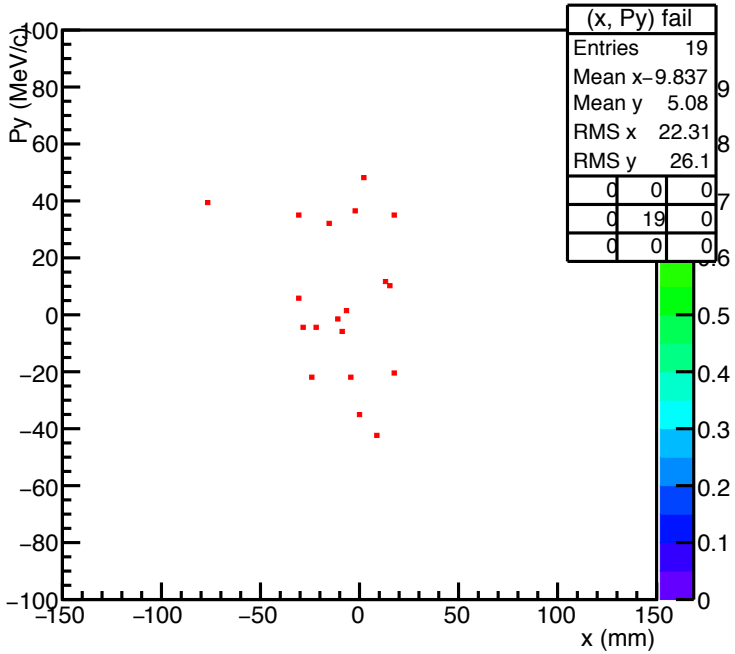
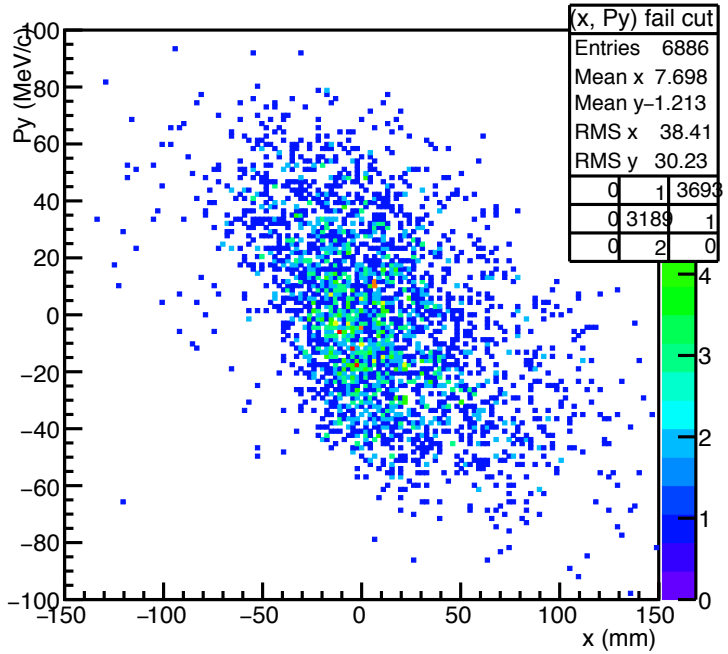
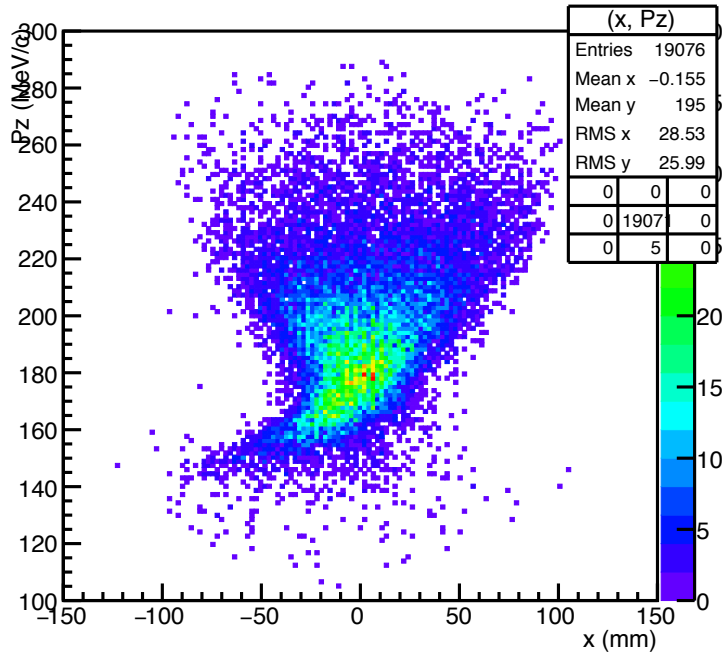
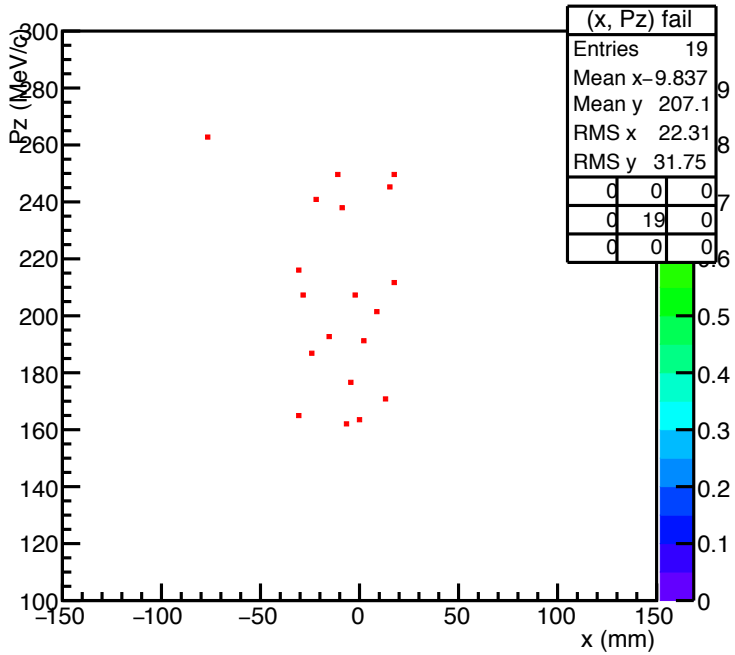
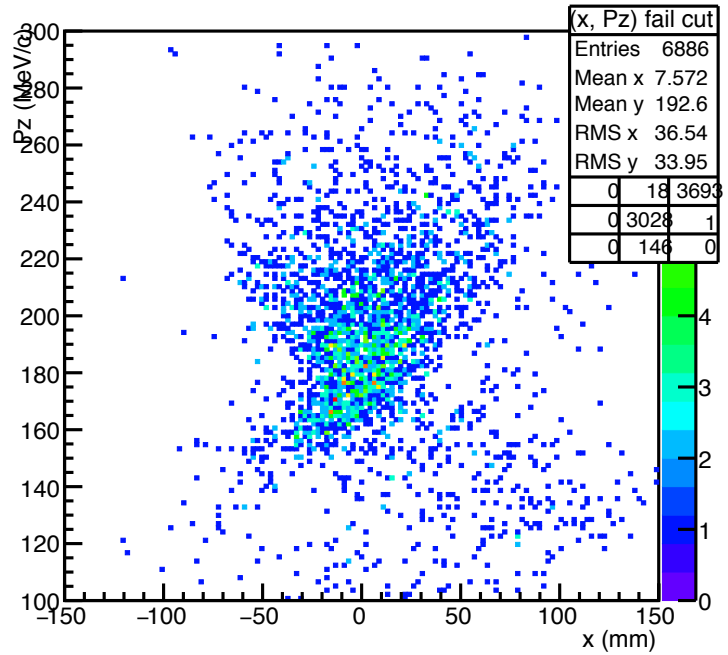


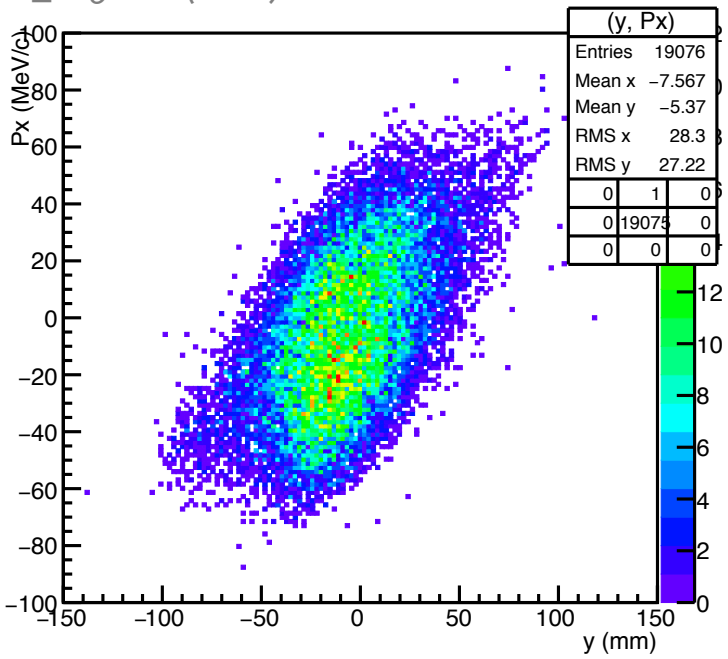



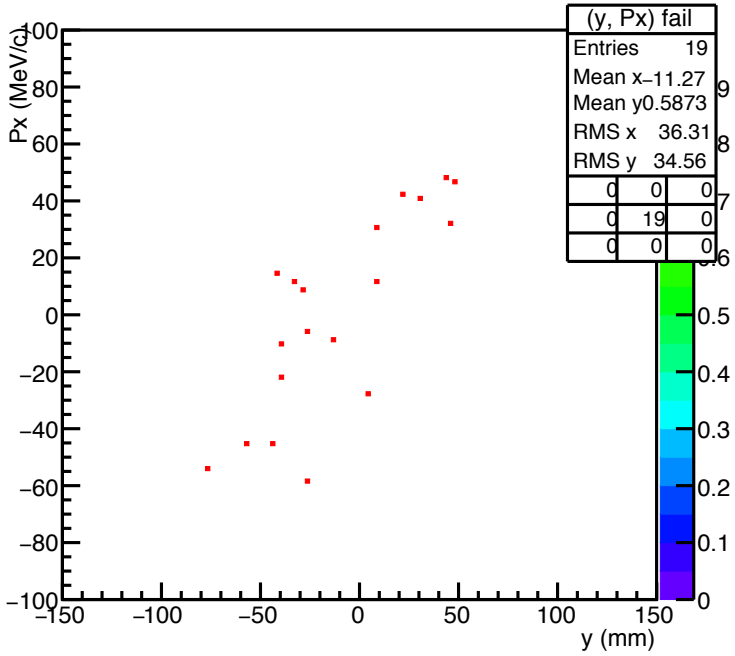



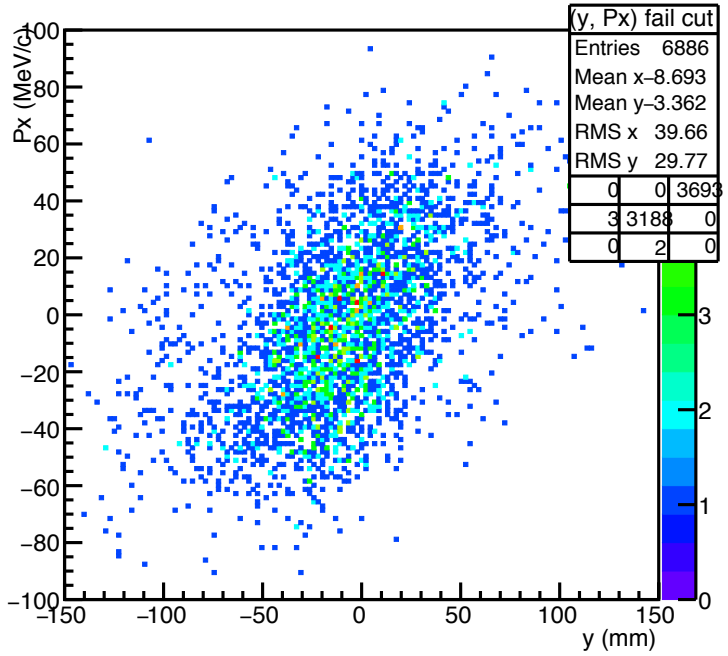



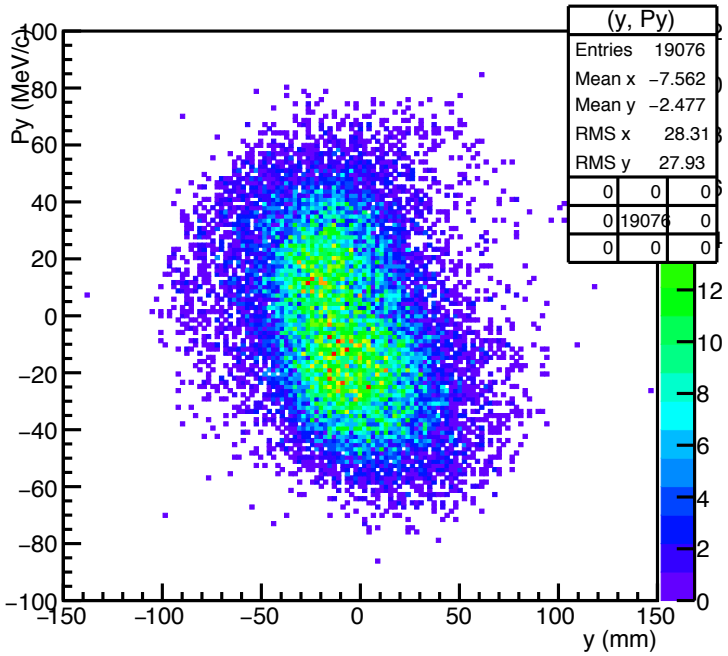



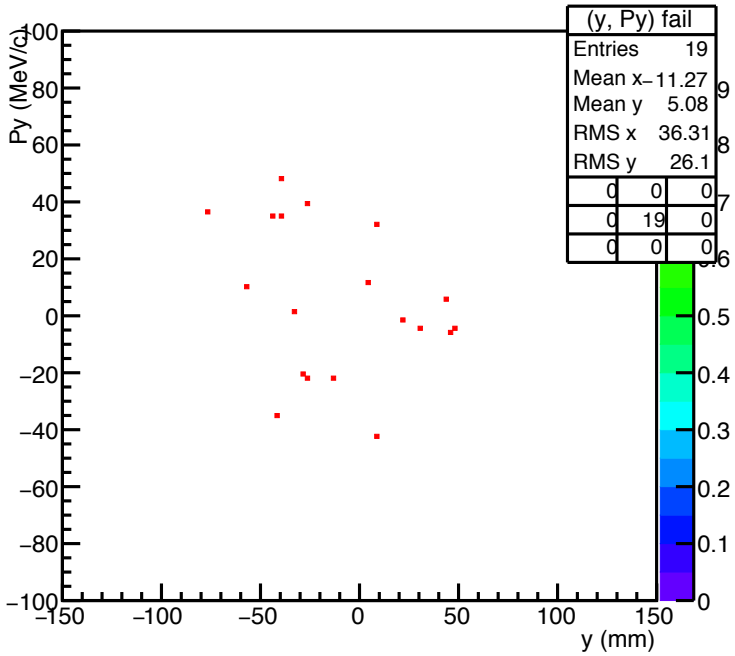
*cut_TOF1_singleHit (cut 8)*

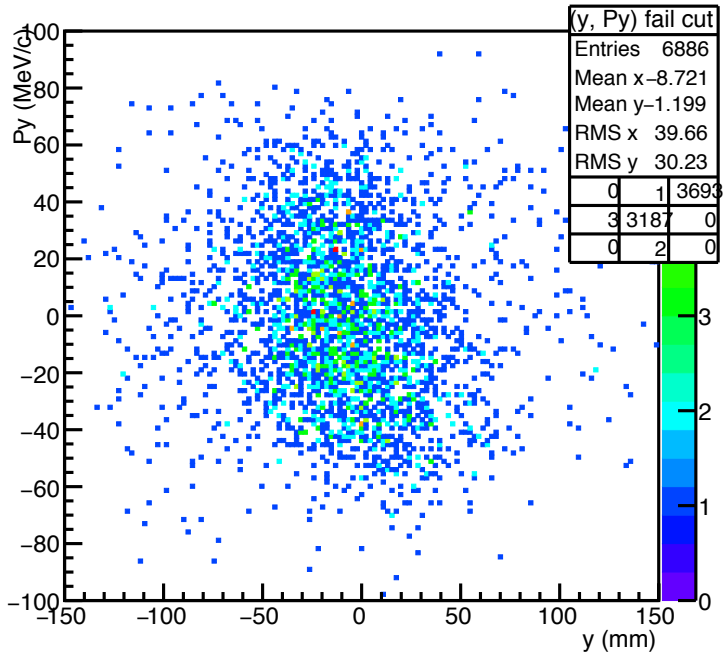


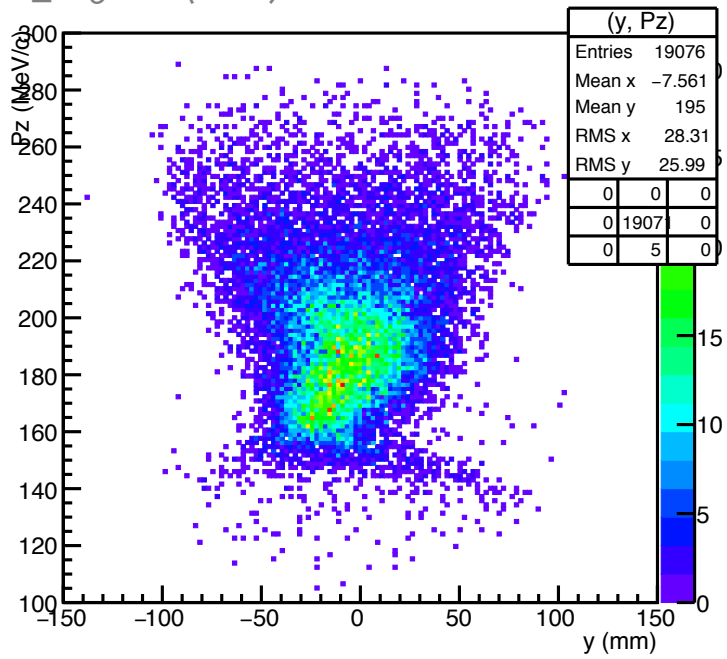



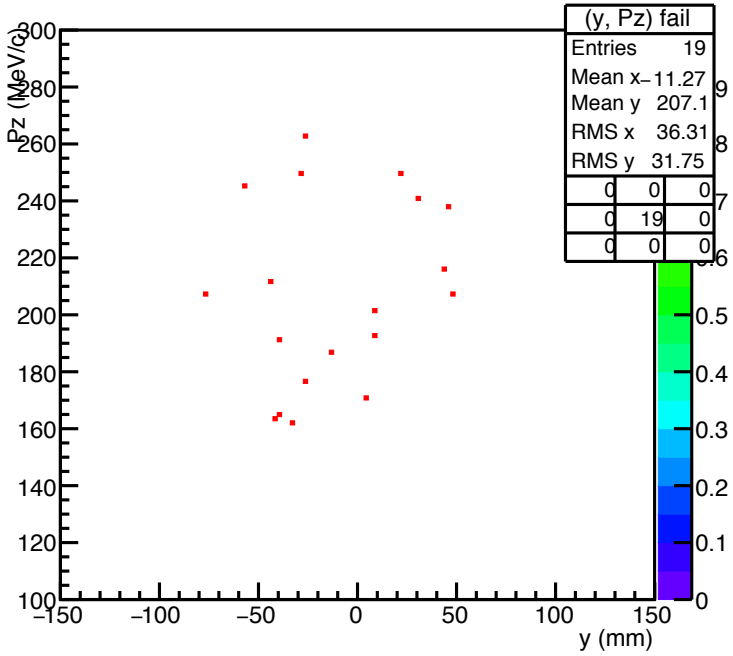



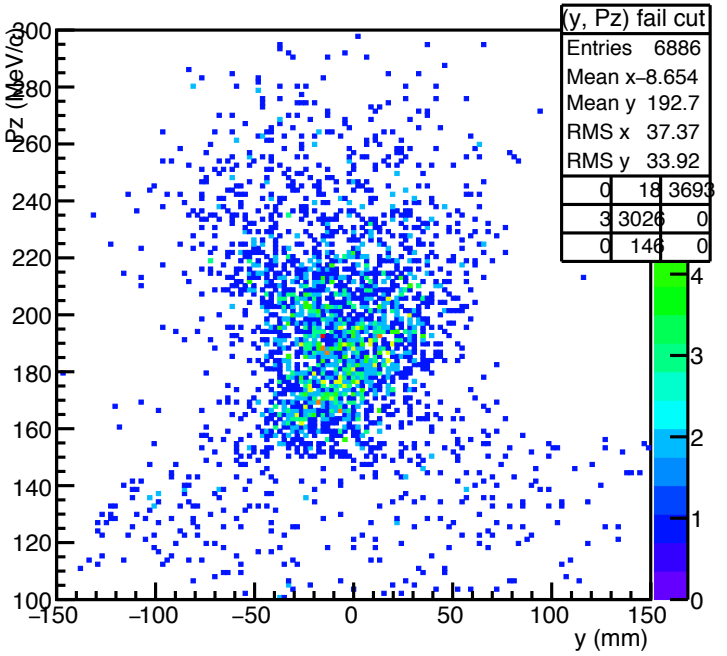



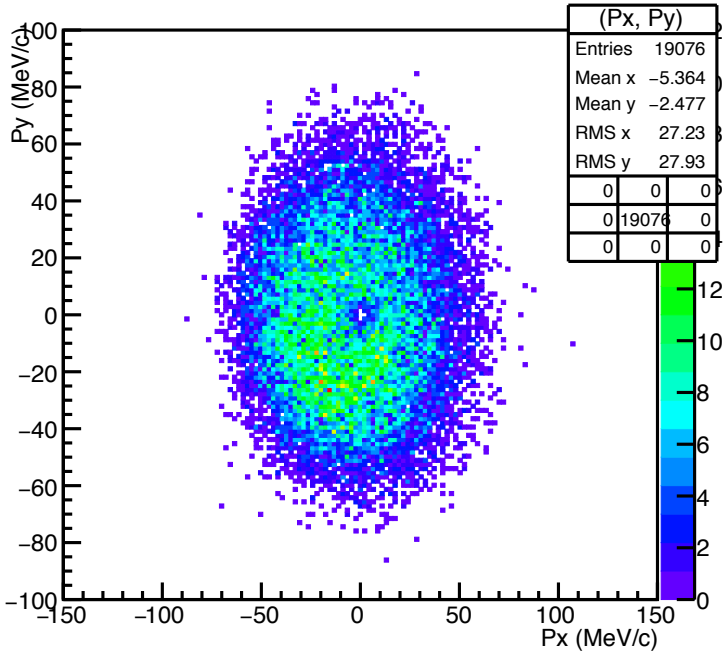



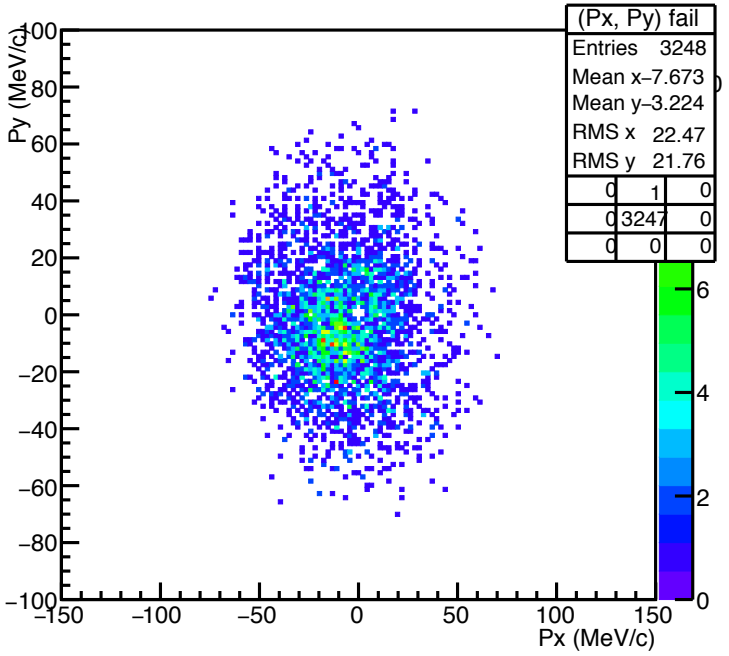
*cut_TOF1_singleHit (cut 8)*

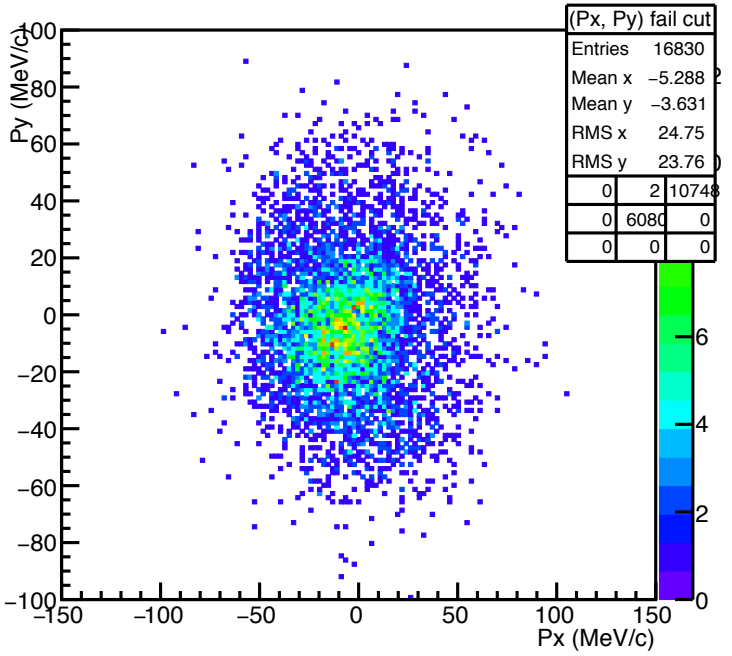


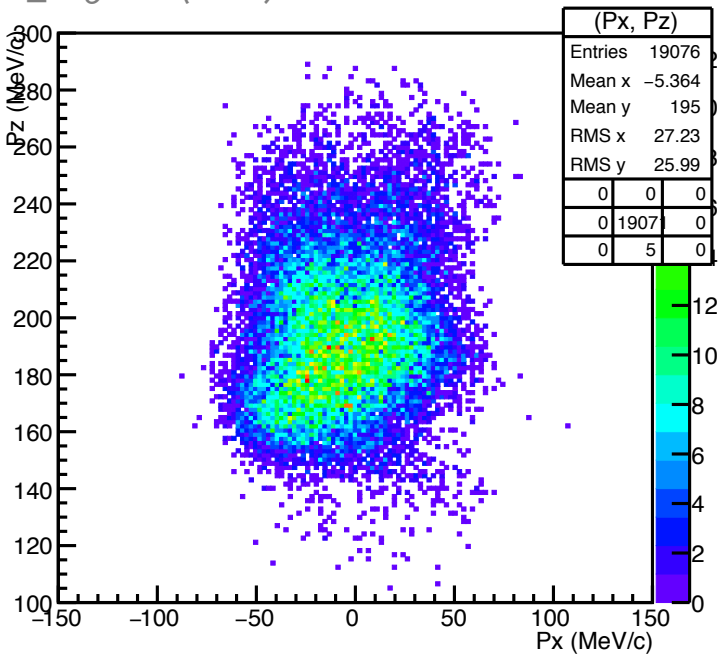



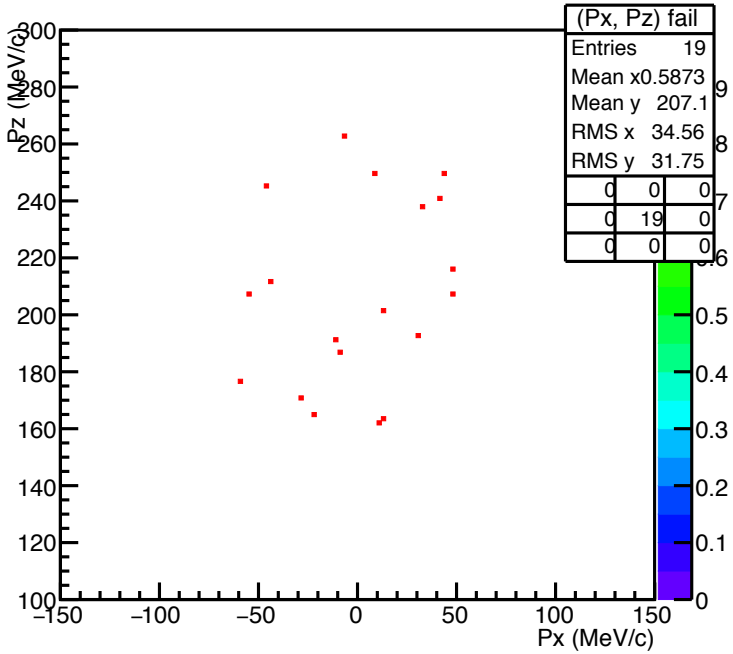



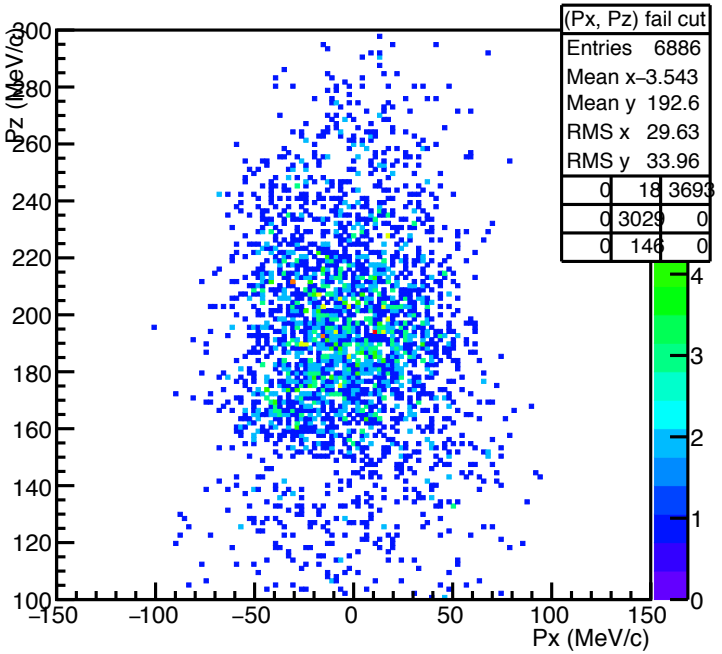



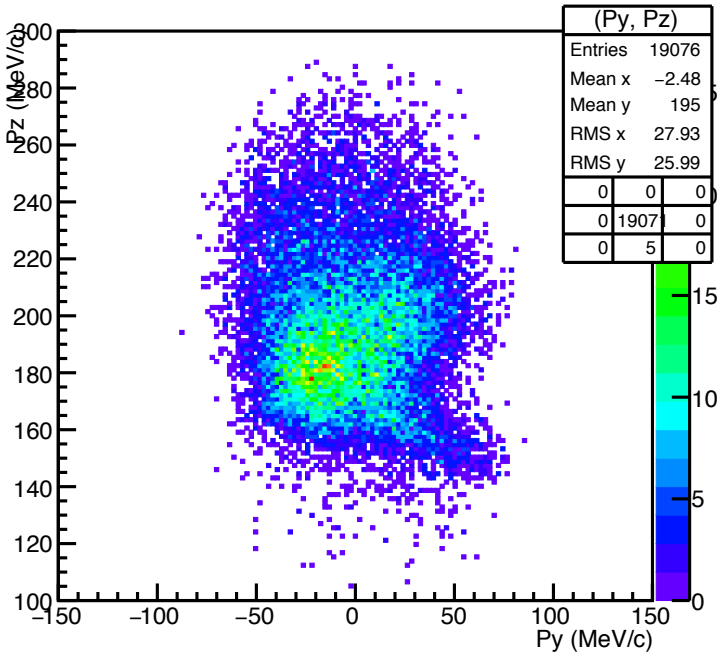



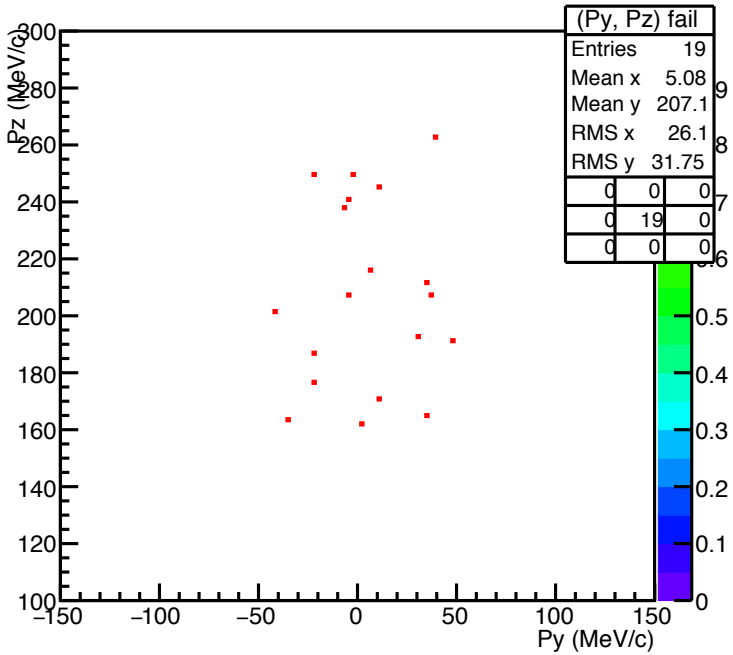
*cut_TOF1_singleHit (cut 8)*

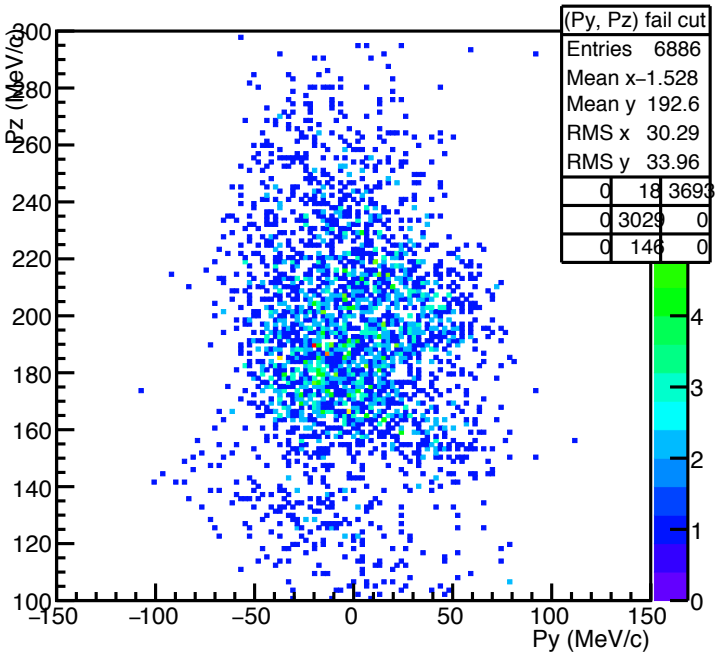


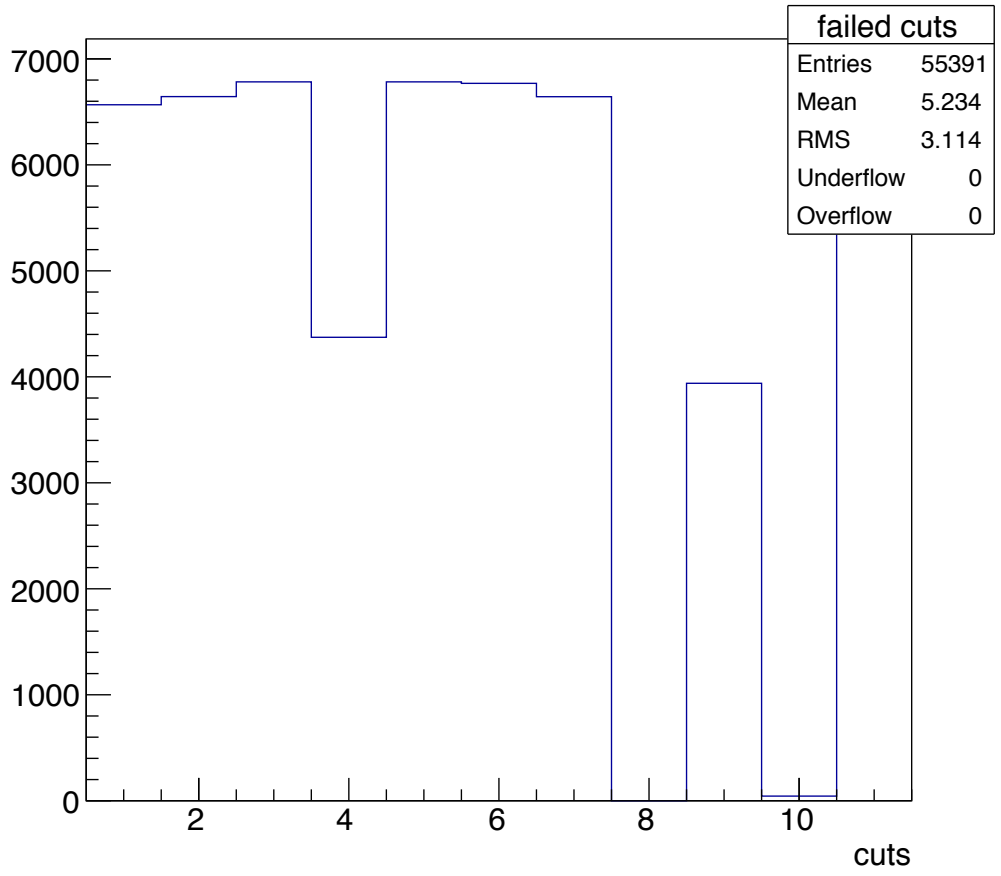



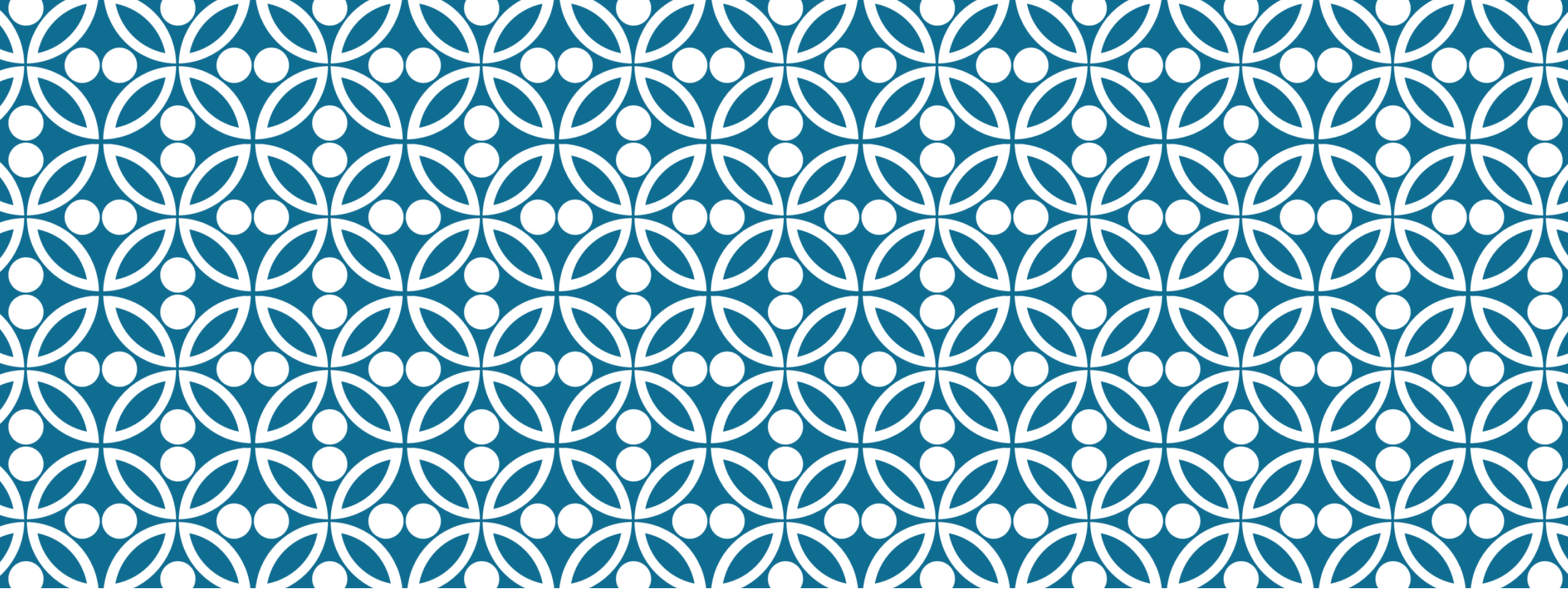



*cut_TOF1_singleHit (cut 8)*



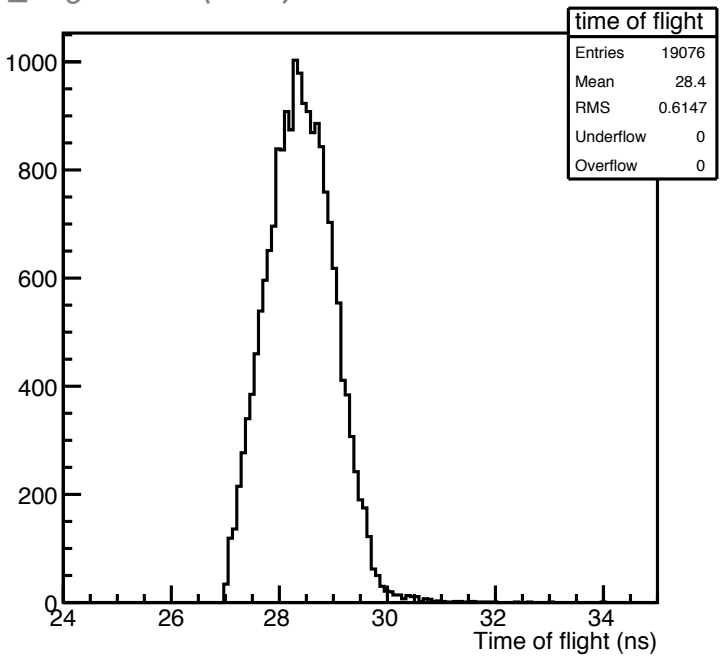

| 'Cut number' | Cut |
|---|---|
| 1 | cut_TOF0_goodPMTPosition |
| 2 | cut_TOF1_goodPMTPosition |
| 3 | cut_goodRaynerReconstruction |
| 4 | cut_TKU_hitAllStations |
| 5 | cut_TimeOfFlight |
| 6 | cut_hit_all_detectors |
| 7 | cut_TOF0_singleHit |
| 8 | cut_TOF1_singleHit |
| 9 | cut_TKU_singleTrack |
| 10 | cut_TKU_PValue |
| 11 | cut_momentum_loss |

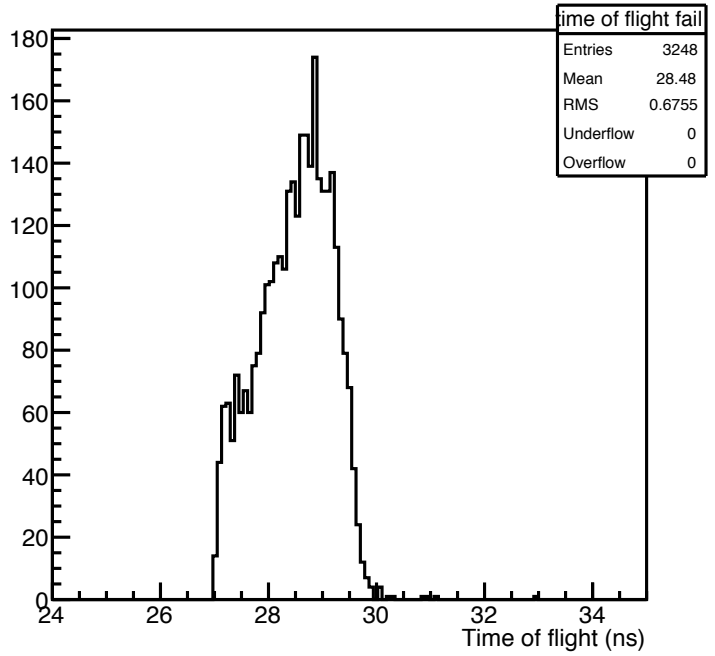


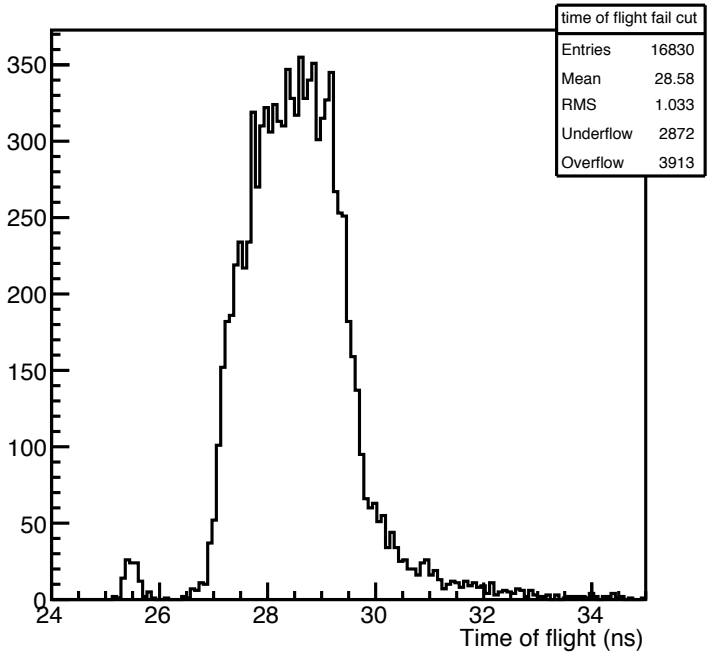
# CUT_TKU_SINGLETRACK

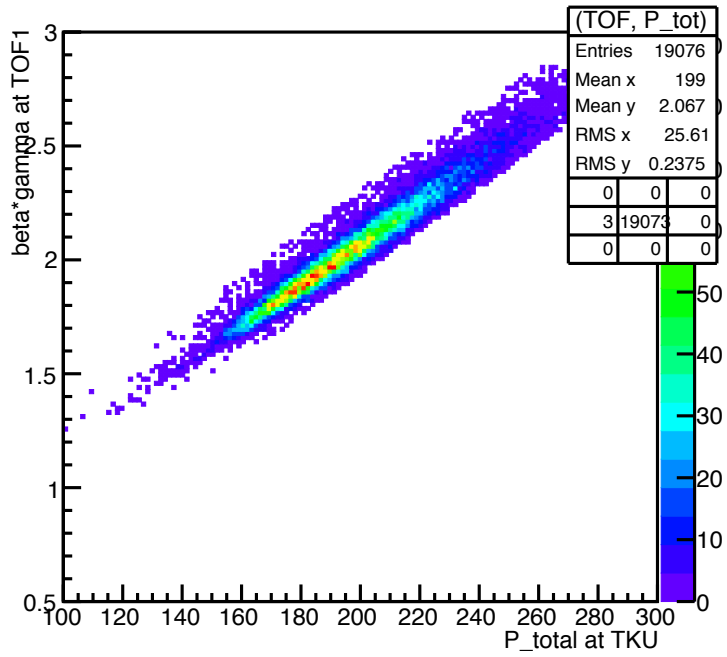
AKA ‘cut 9’

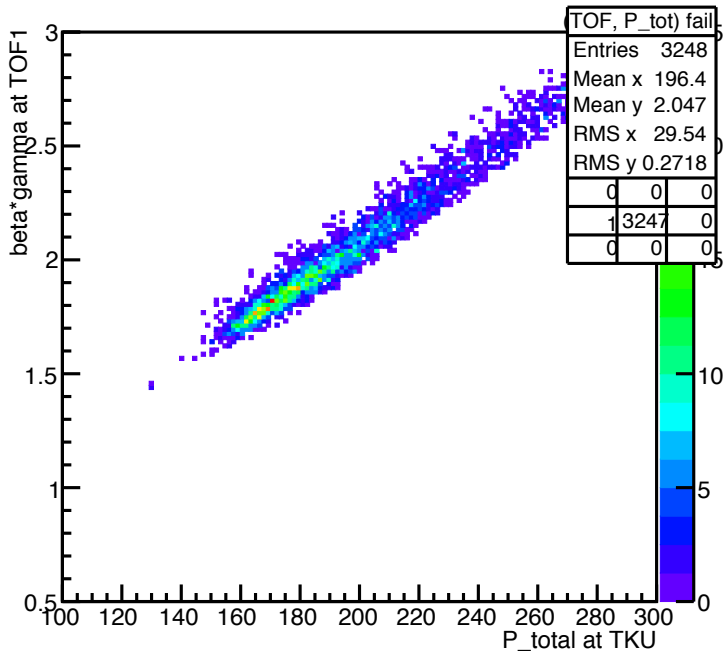
*cut_TKU_singleTrack (cut 9)*

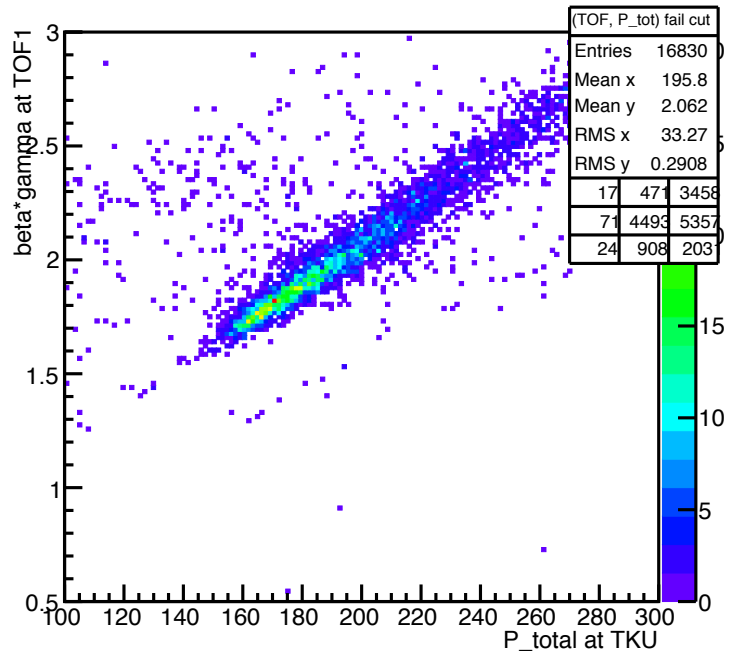


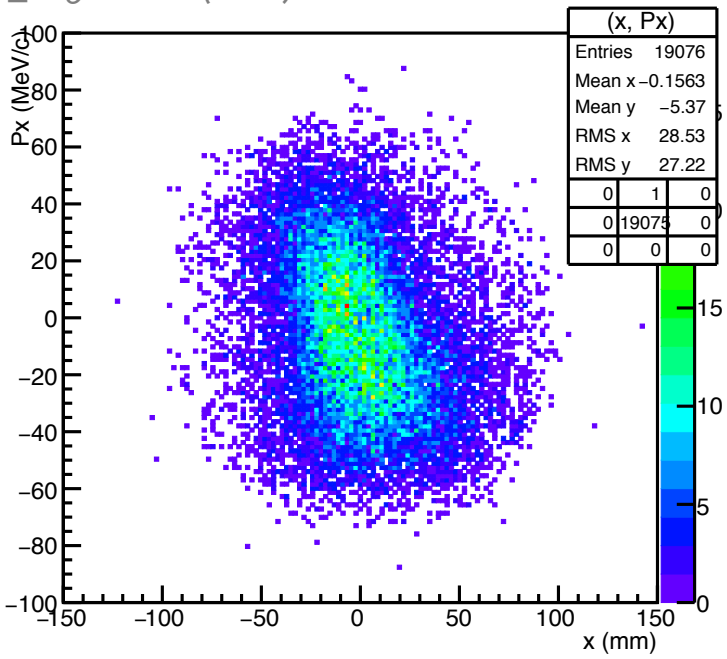



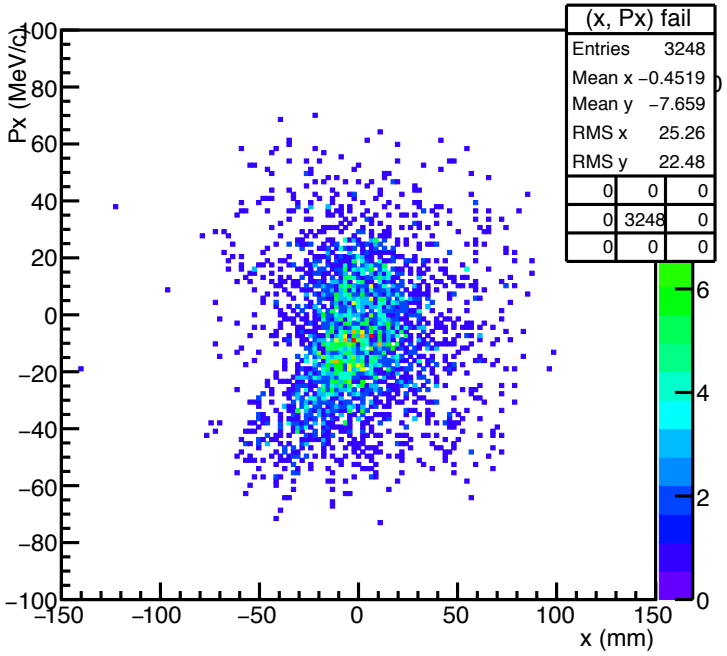



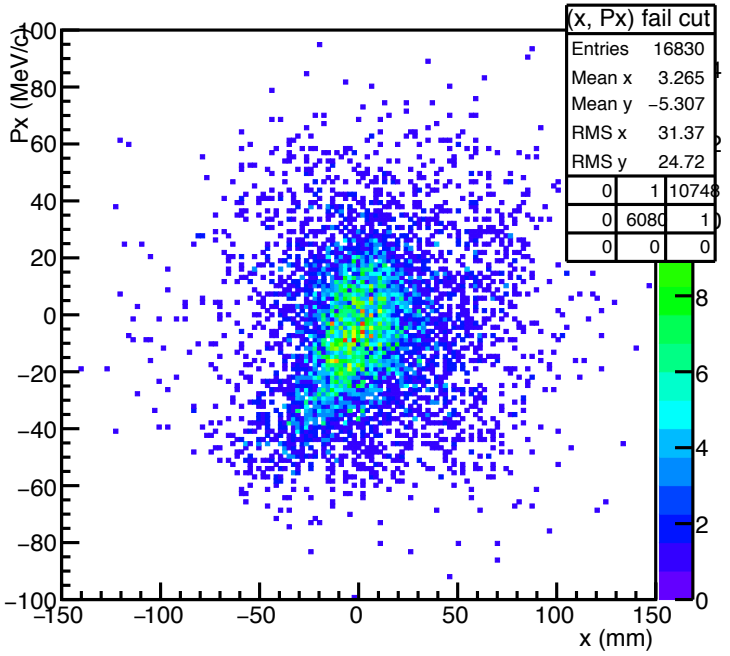



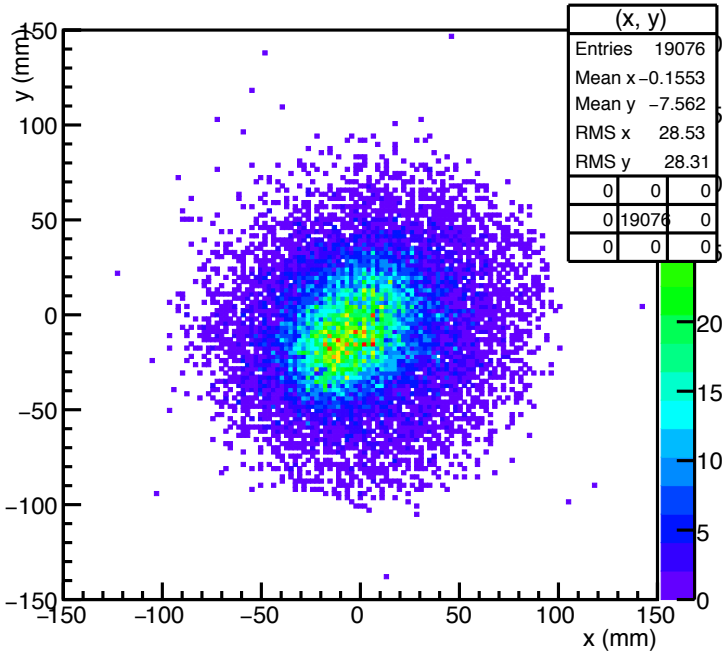



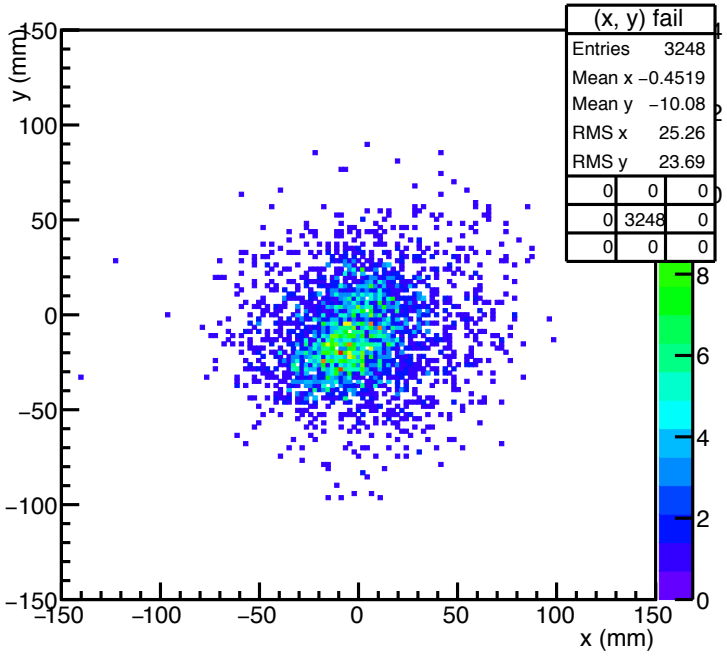



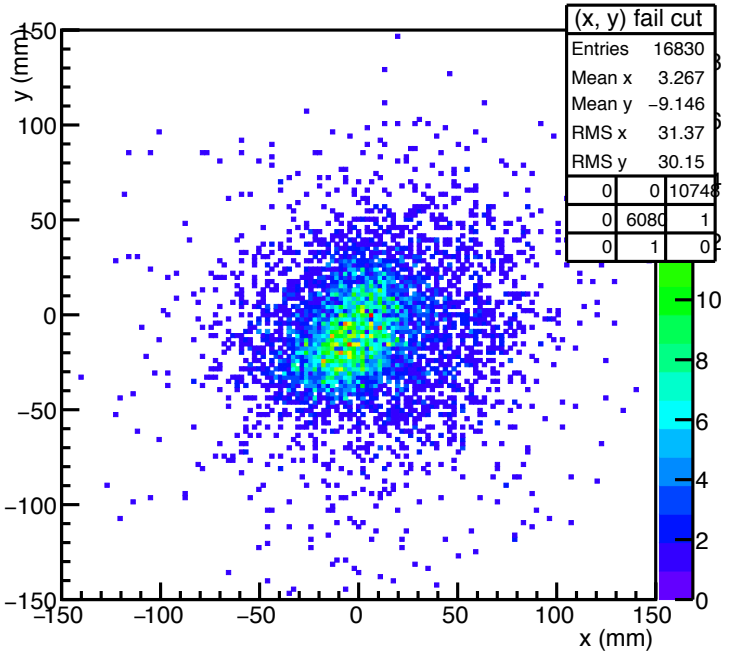

(x, Px)
Entries 19076
Mean x −0.1563
Mean y −5.37
RMS x 28.53
RMS y 27.22
Px (MeV/c)
x (mm)


(x, Px) fail
Entries 3248
Mean x −0.4519
Mean y −7.659
RMS x 25.26
RMS y 22.48
Px (MeV/c)
x (mm)

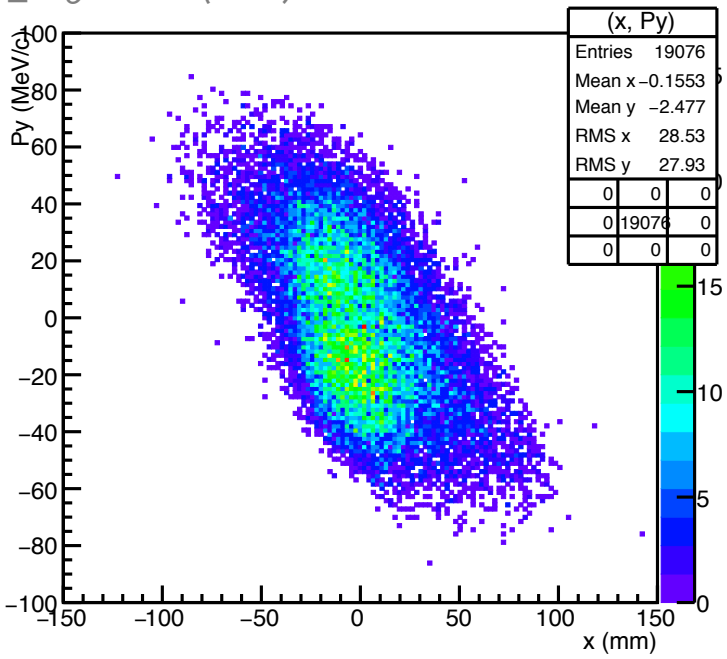

(x, Px) fail cut
Entries 16830
Mean x 3.265
Mean y −5.307
RMS x 31.37
RMS y 24.72
Px (MeV/c)
x (mm)

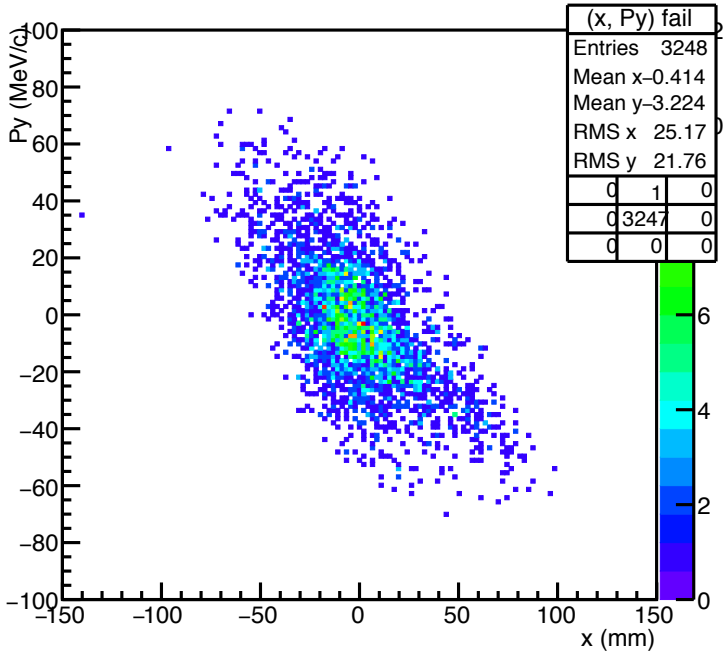

(x, y)
Entries 19076
Mean x −0.1553
Mean y −7.562
RMS x 28.53
RMS y 28.31
y (mm)
x (mm)

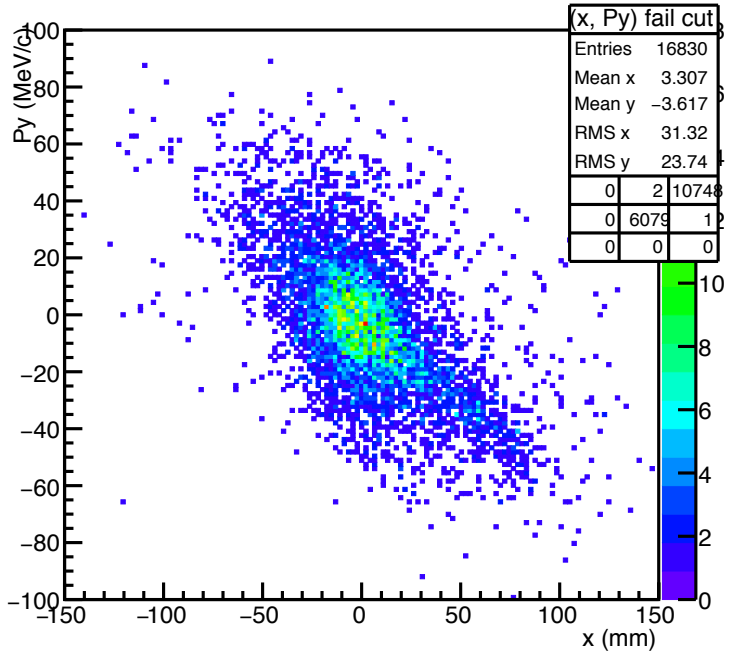

(x, y) fail
Entries 3248
Mean x −0.4519
Mean y −10.08
RMS x 25.26
RMS y 23.69
y (mm)
x (mm)

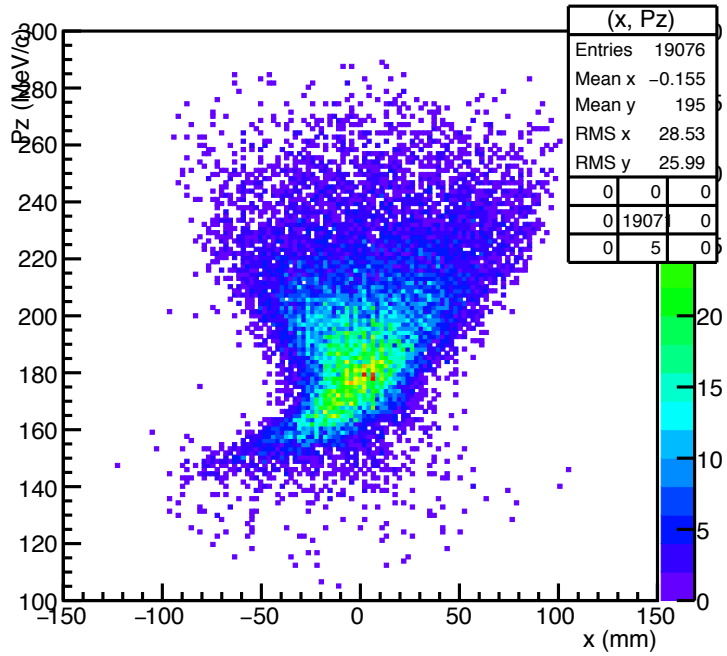

(x, y) fail cut
Entries 16830
Mean x 3.267
Mean y −9.146
RMS x 31.37
RMS y 30.15
y (mm)
x (mm)

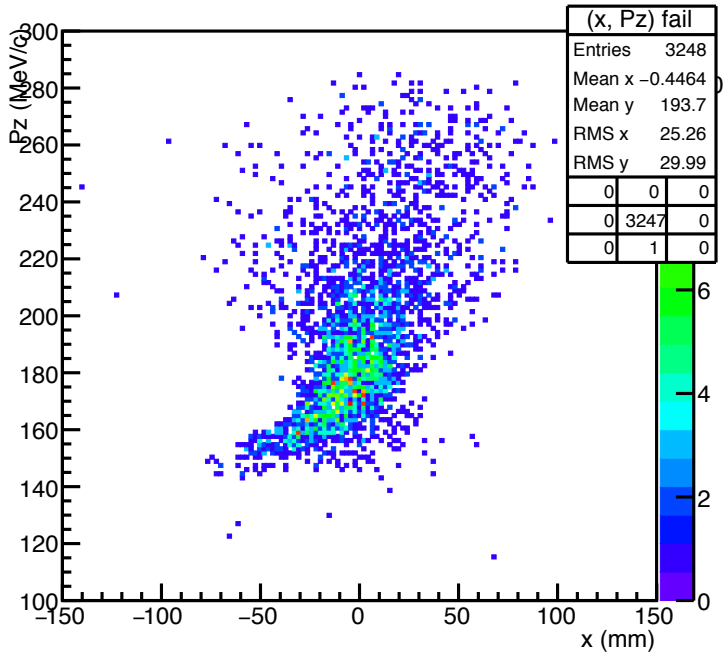
*cut_TKU_singleTrack (cut 9)*

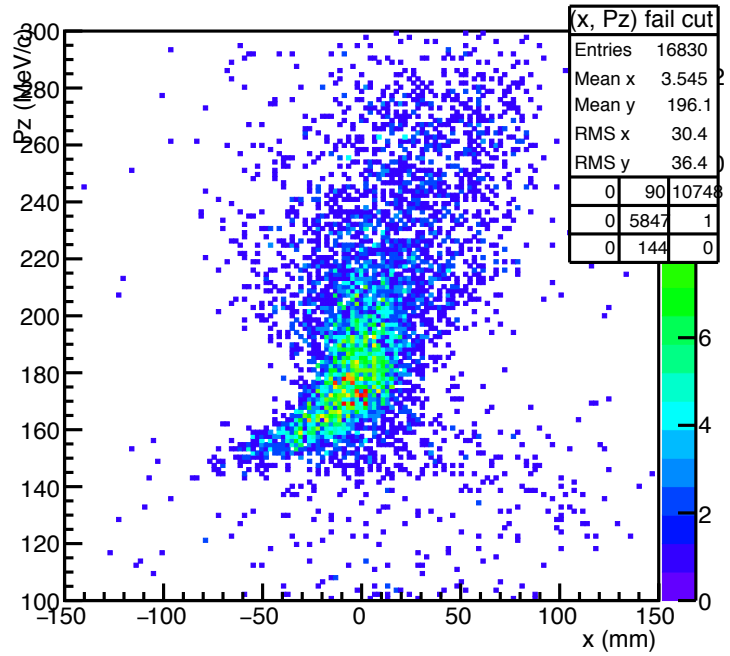


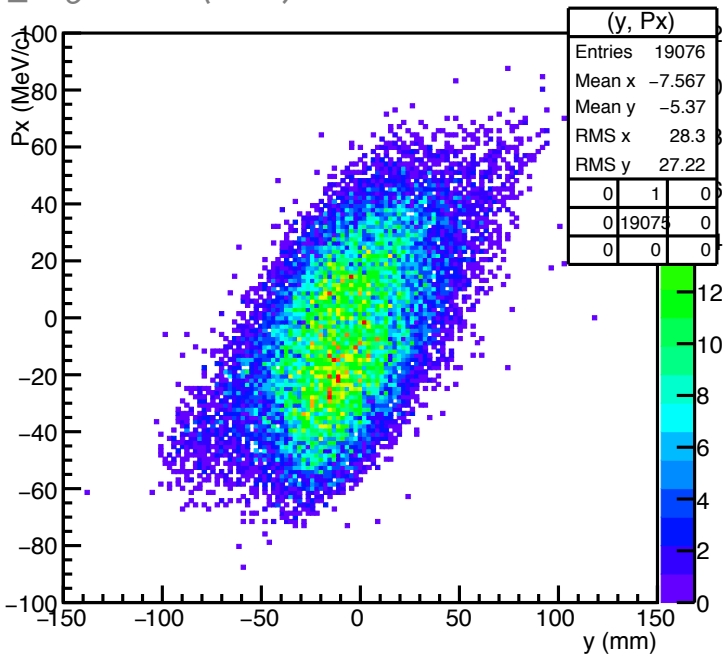



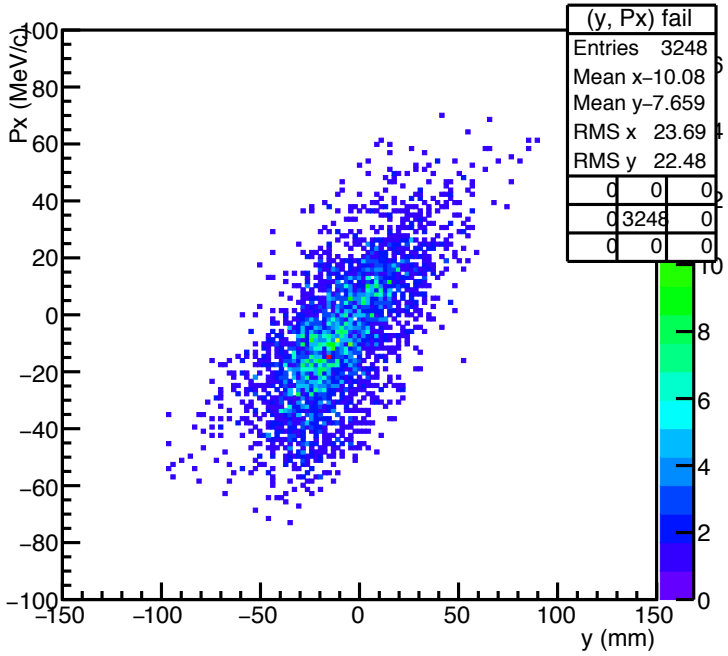



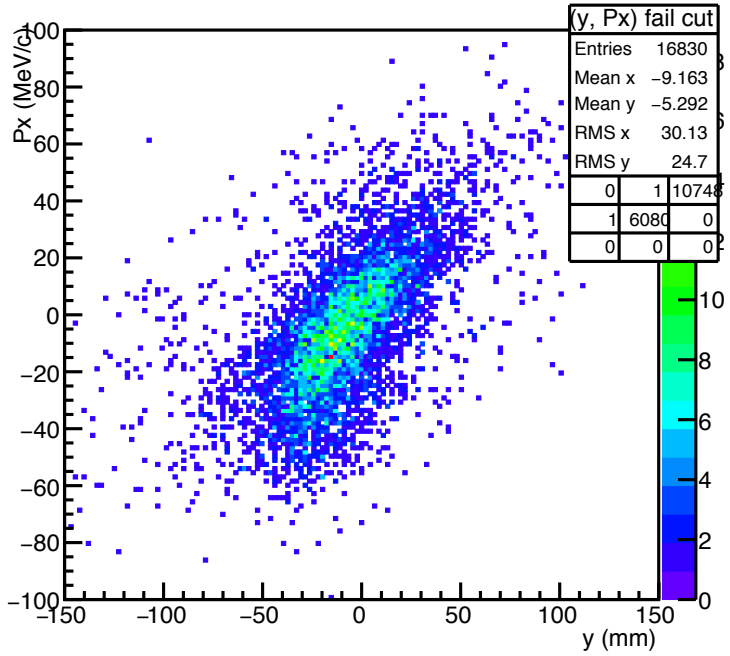



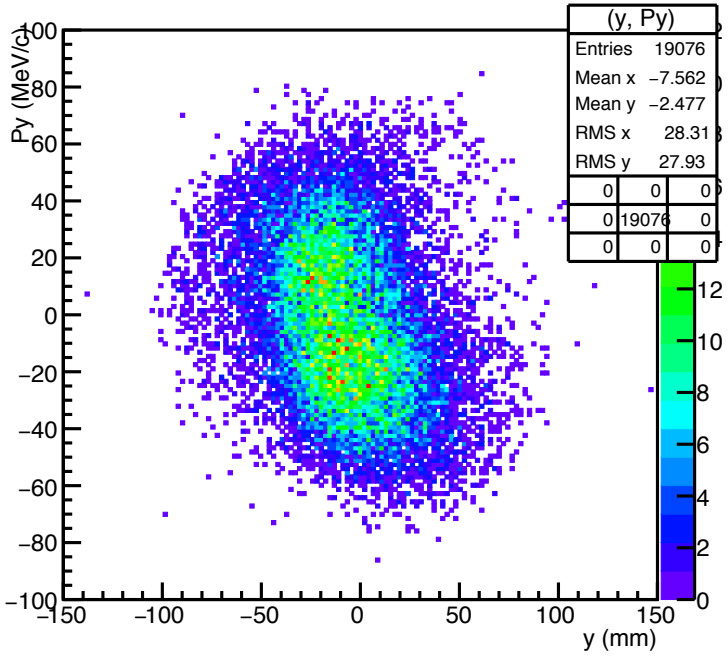



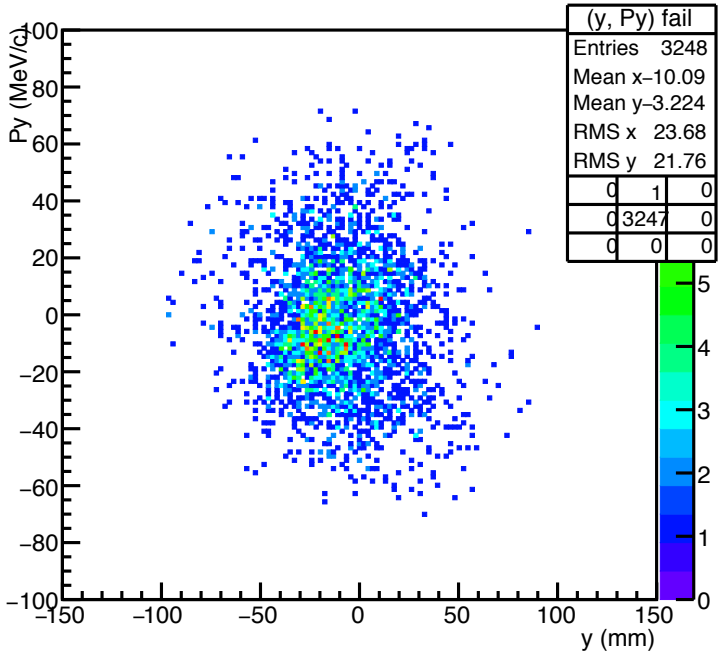
*cut_TKU_singleTrack (cut 9)*

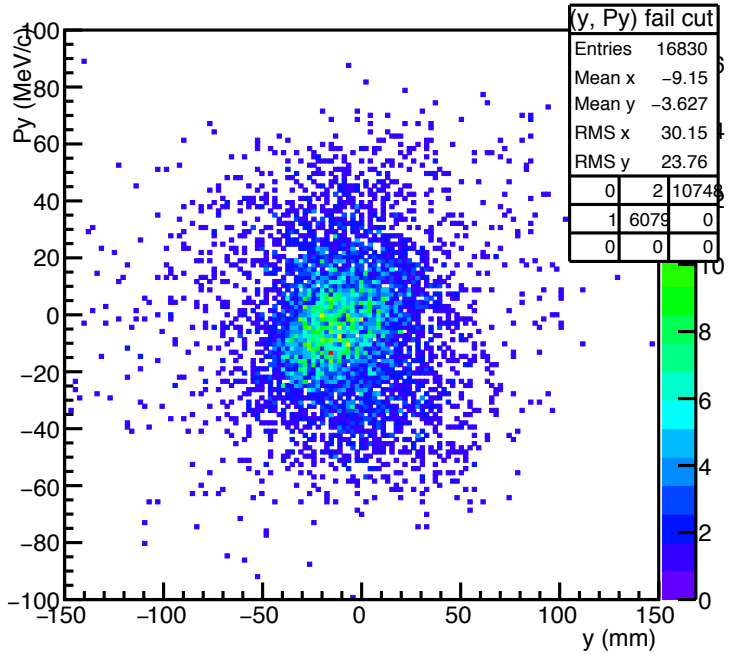


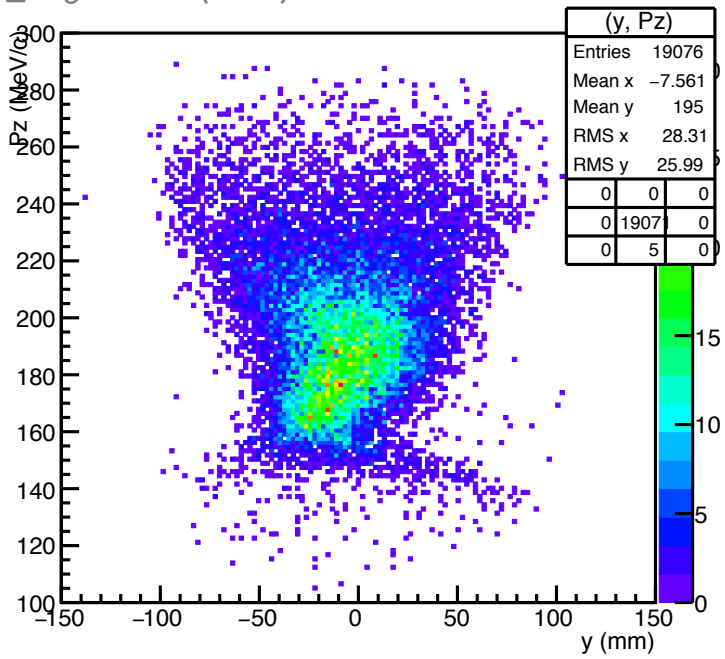



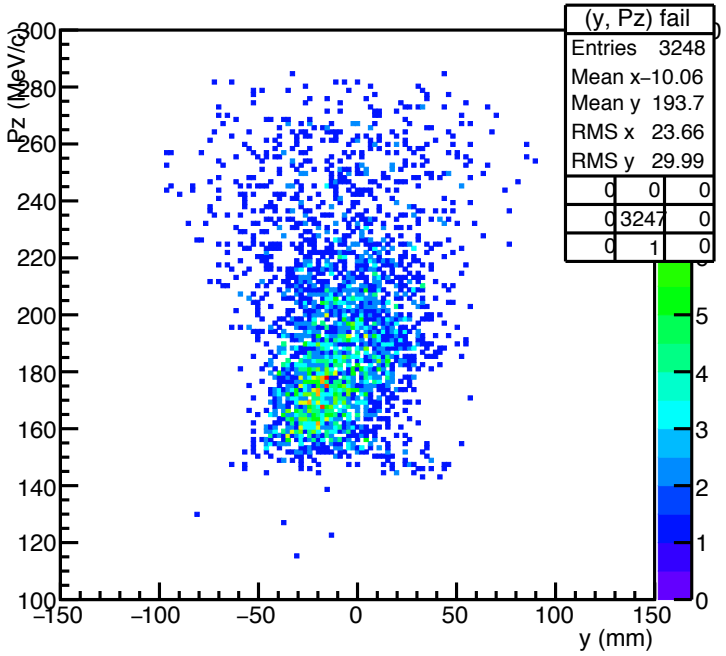



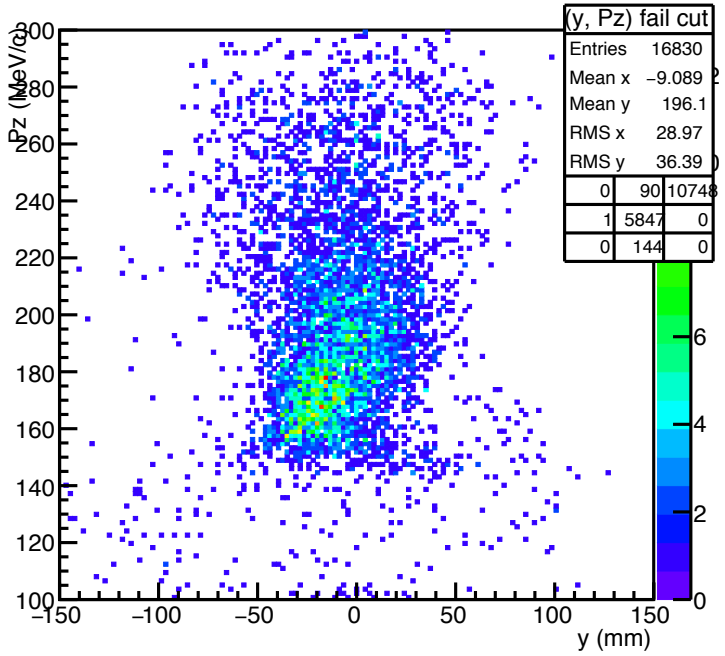



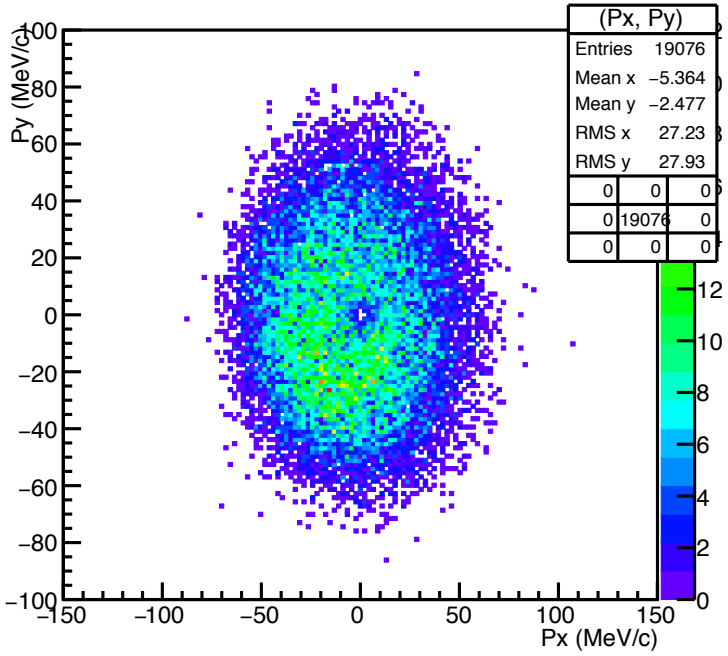



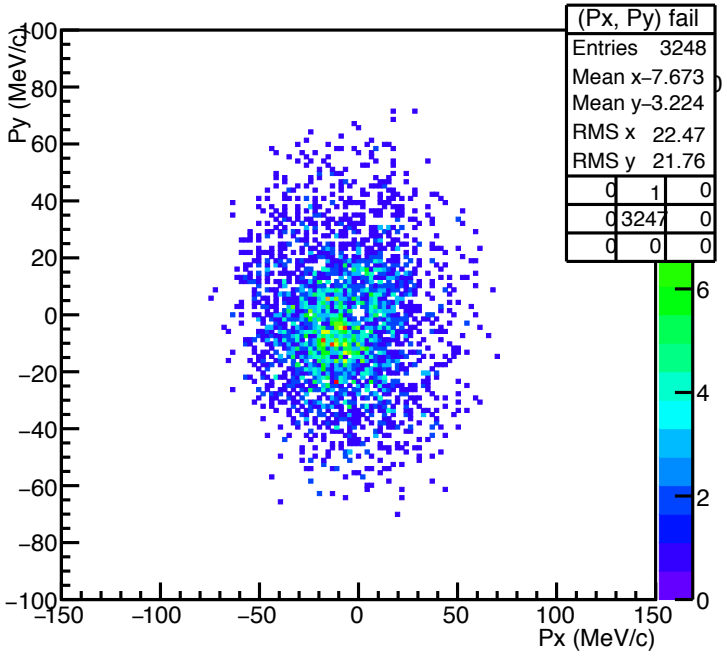
*cut_TKU_singleTrack (cut 9)*

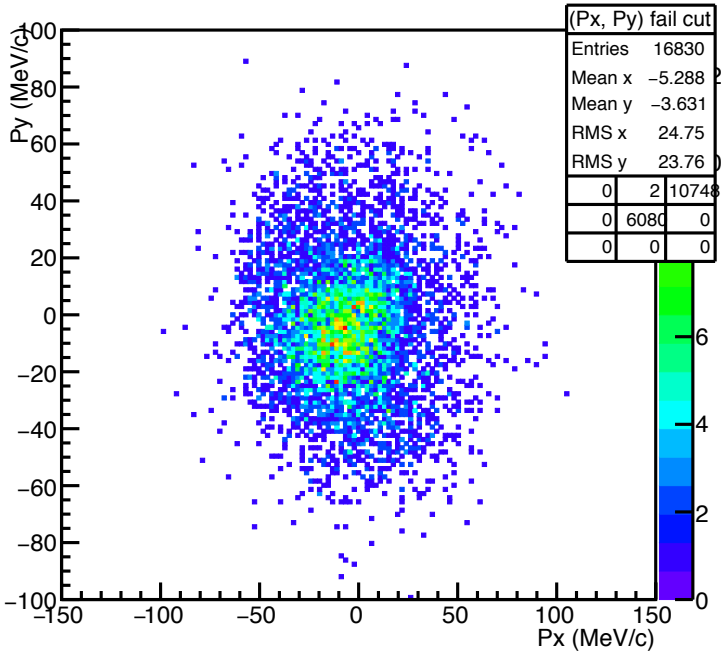


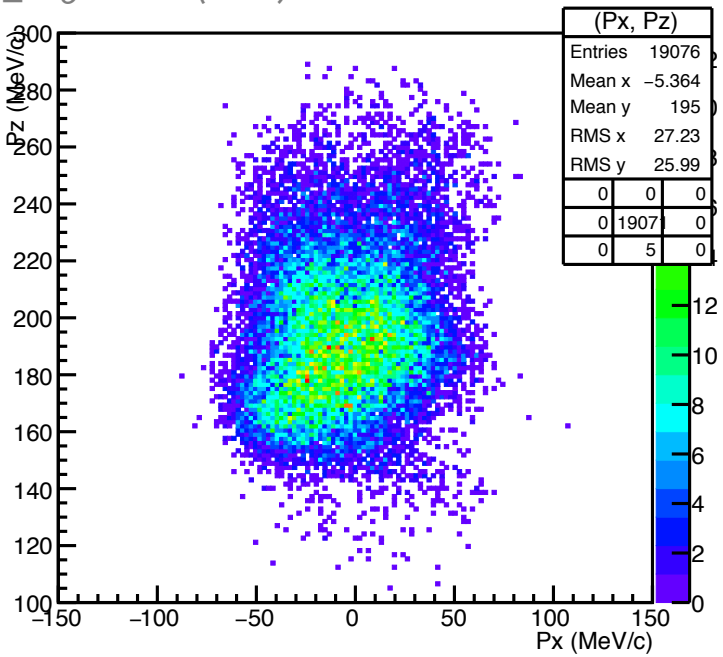



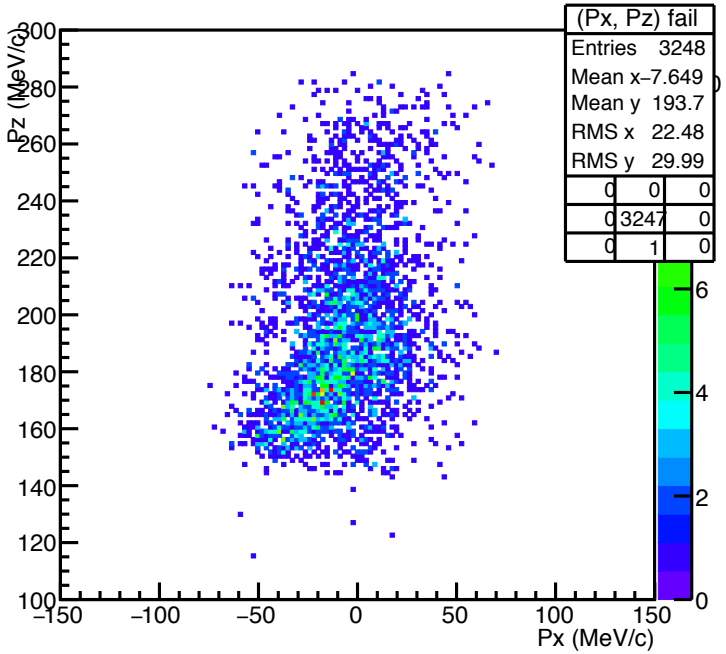



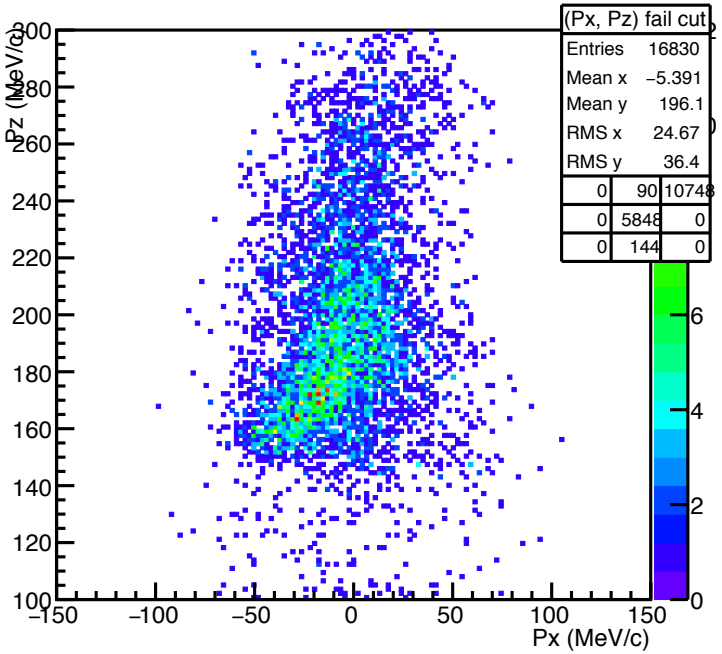



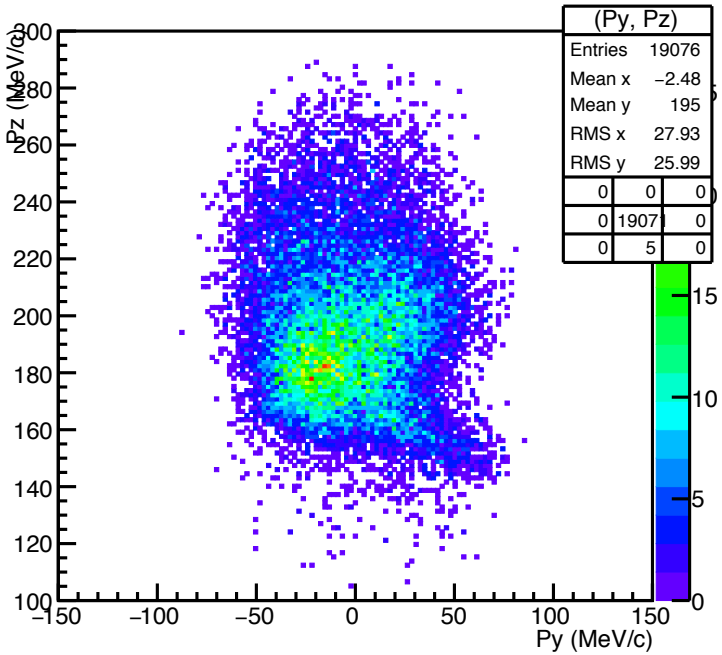



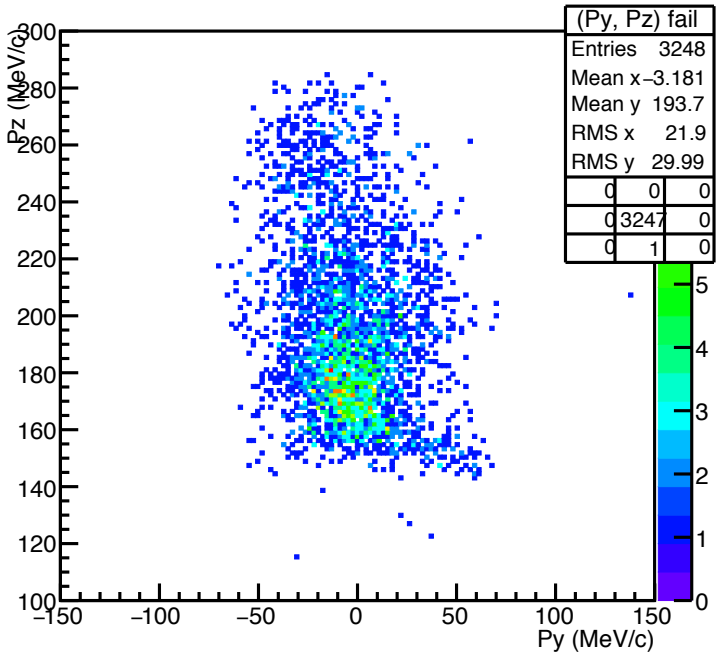
*cut_TKU_singleTrack (cut 9)*

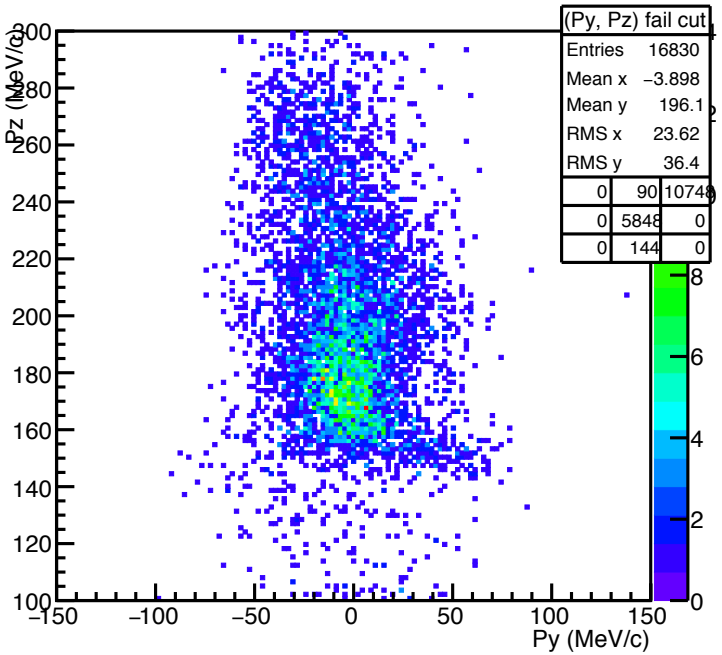


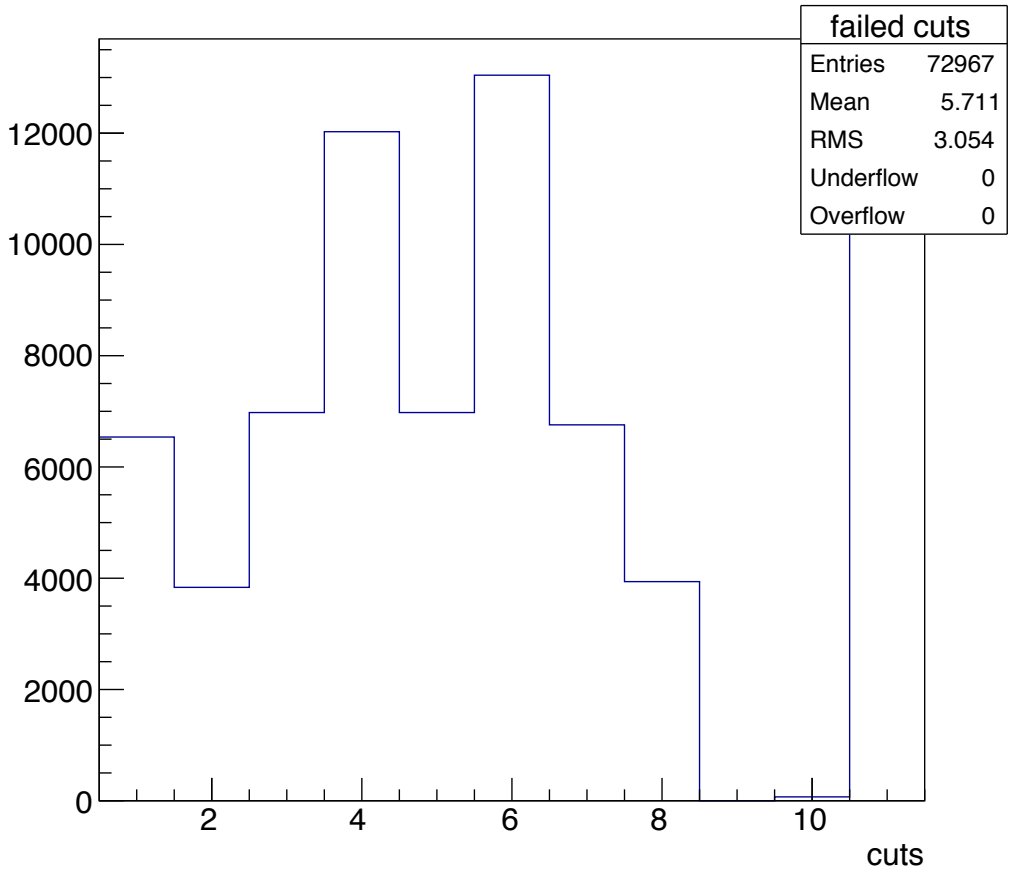



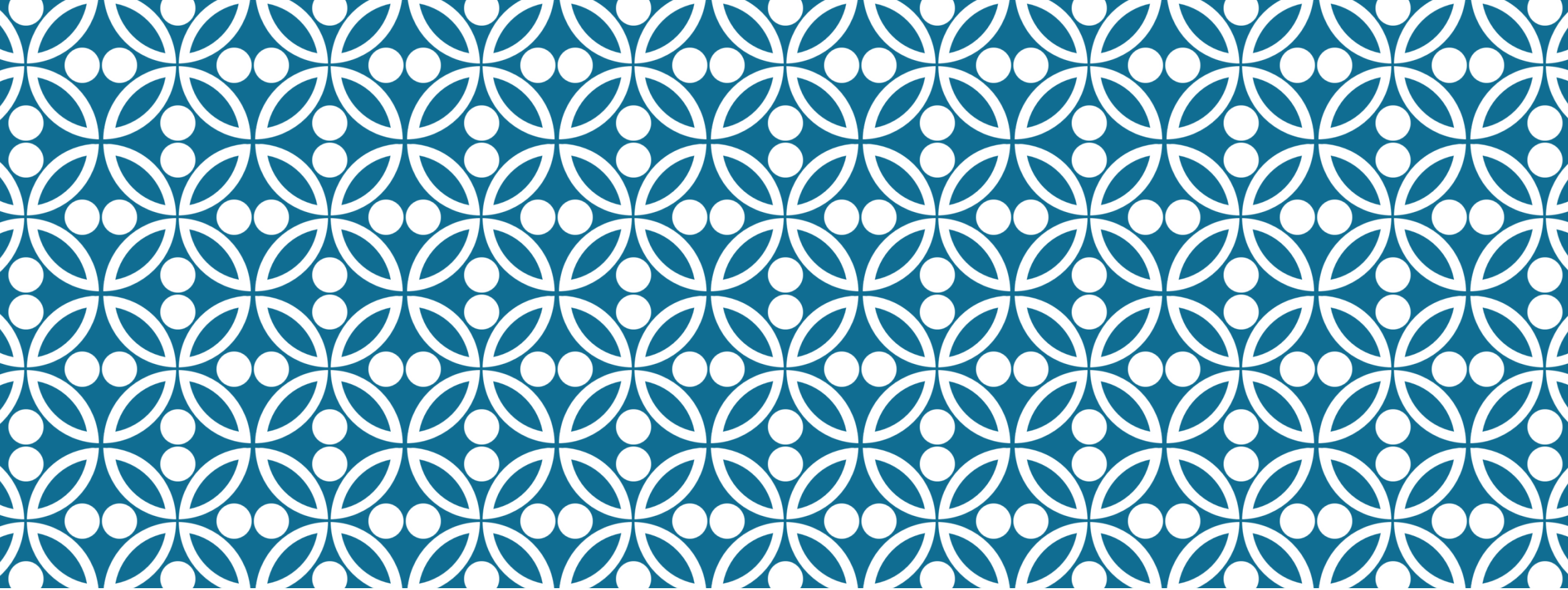





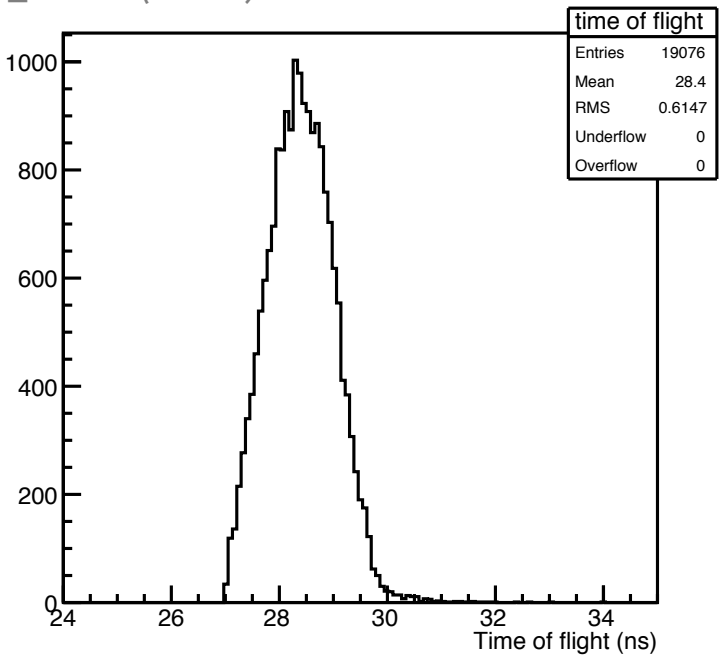

| 'Cut number' | Cut |
|---|---|
| 1 | cut_TOF0_goodPMTPosition |
| 2 | cut_TOF1_goodPMTPosition |
| 3 | cut_goodRaynerReconstruction |
| 4 | cut_TKU_hitAllStations |
| 5 | cut_TimeOfFlight |
| 6 | cut_hit_all_detectors |
| 7 | cut_TOF0_singleHit |
| 8 | cut_TOF1_singleHit |
| 9 | cut_TKU_singleTrack |
| 10 | cut_TKU_PValue |
| 11 | cut_momentum_loss |

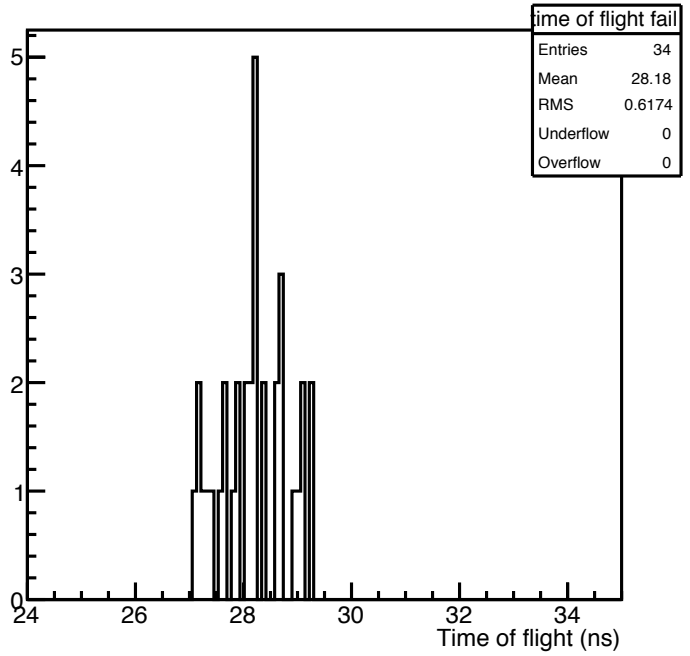


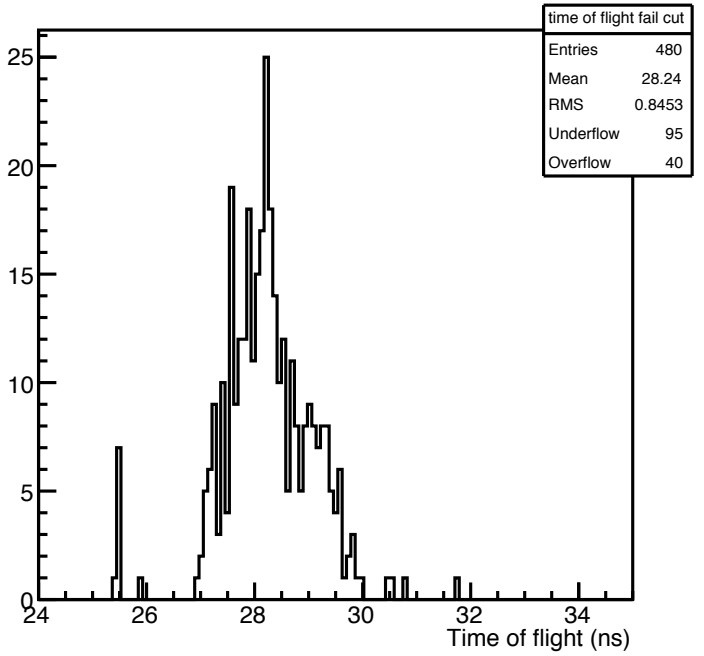
# CUT_TKU_PVALUE

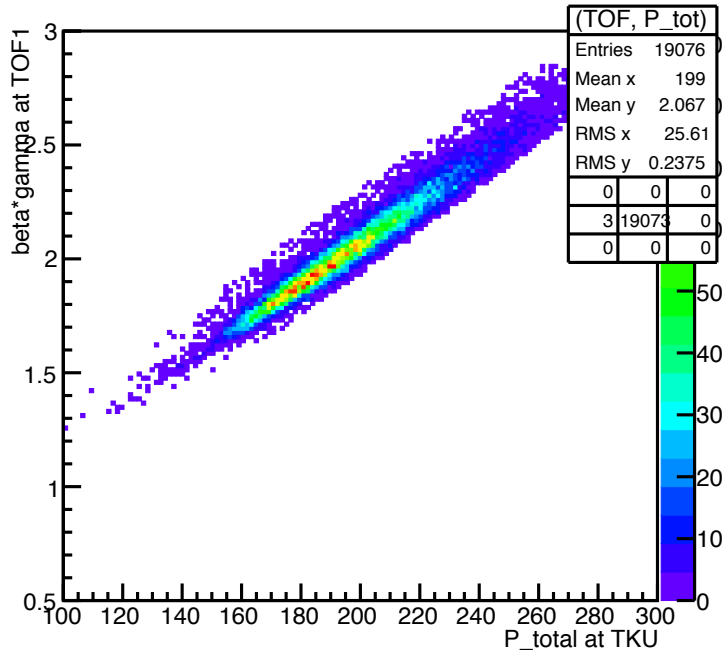
AKA ‘cut 10’

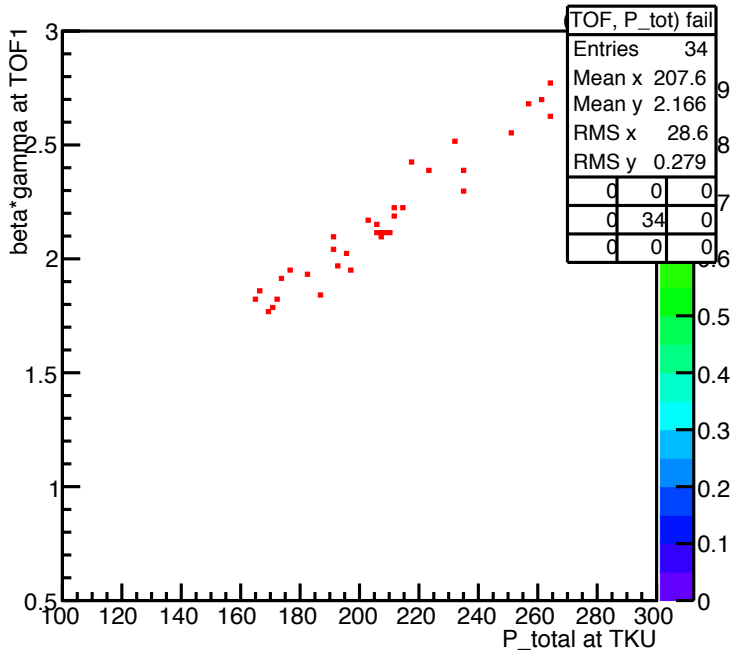
*cut_TKU_PValue (cut 10)*

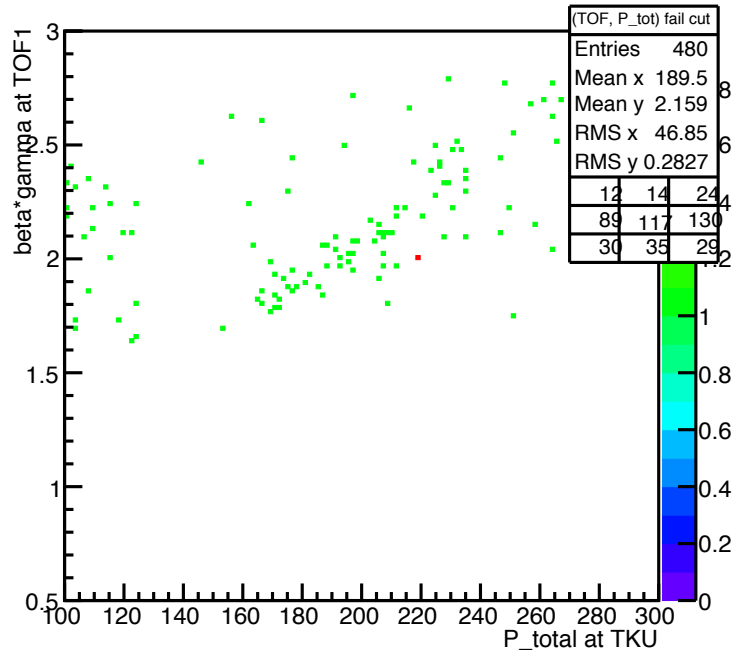


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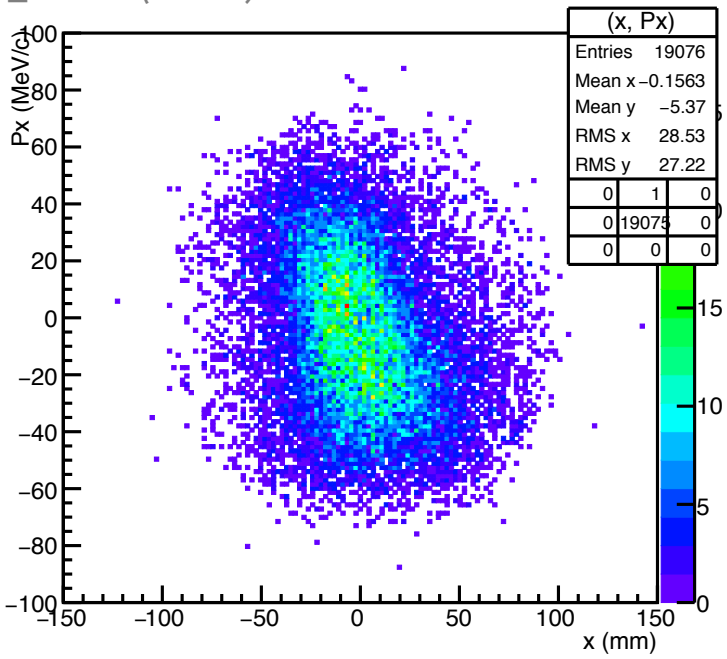


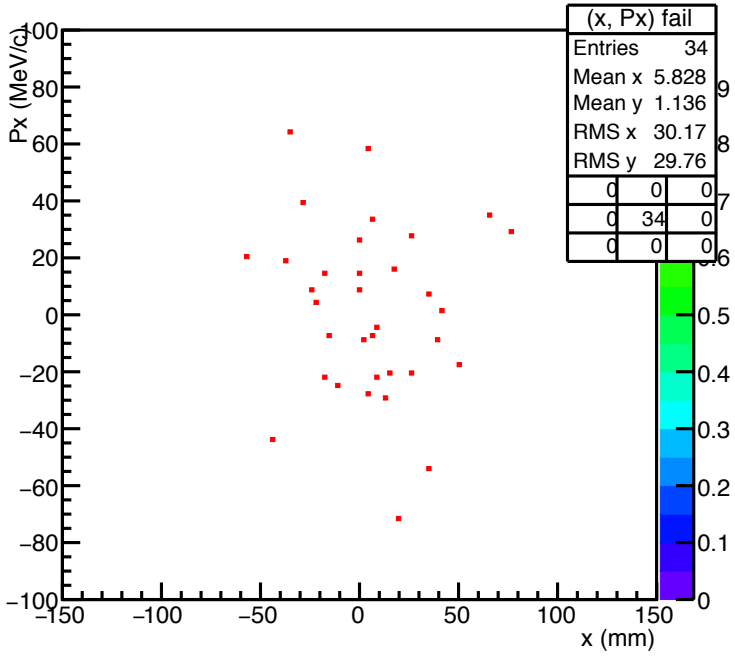


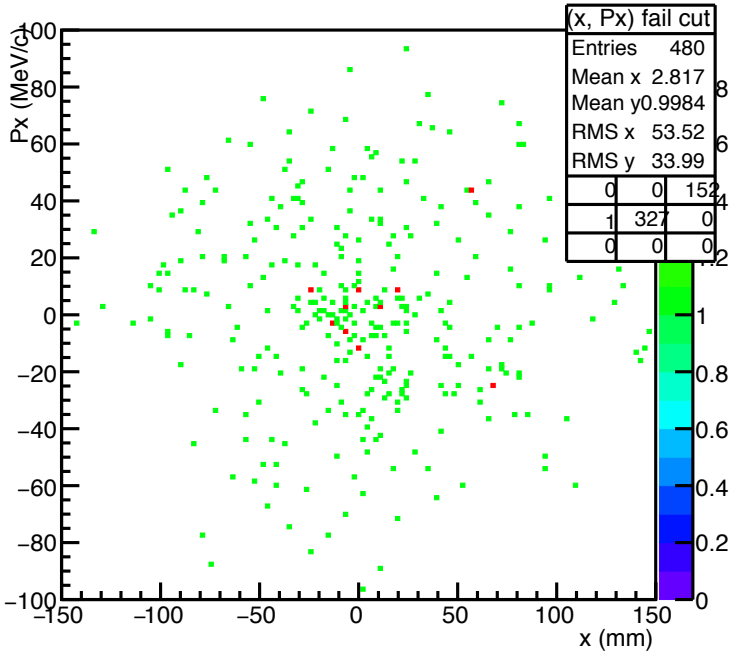


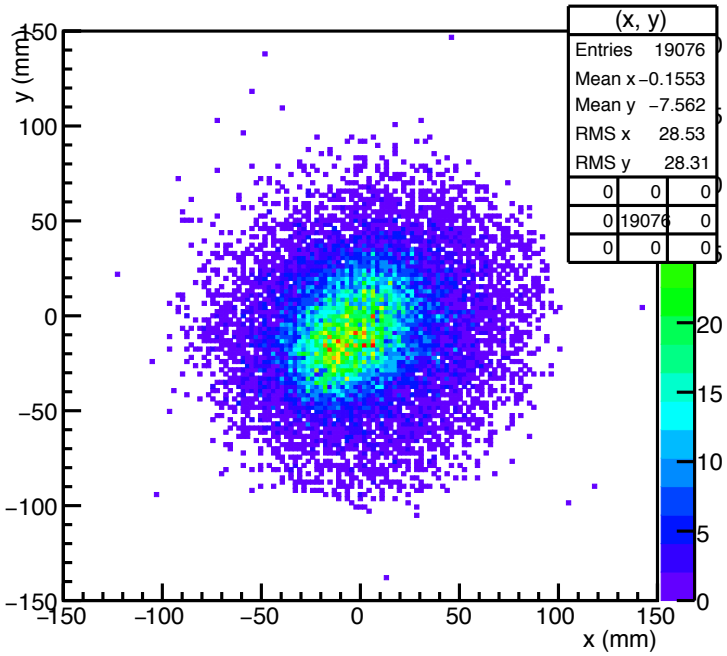


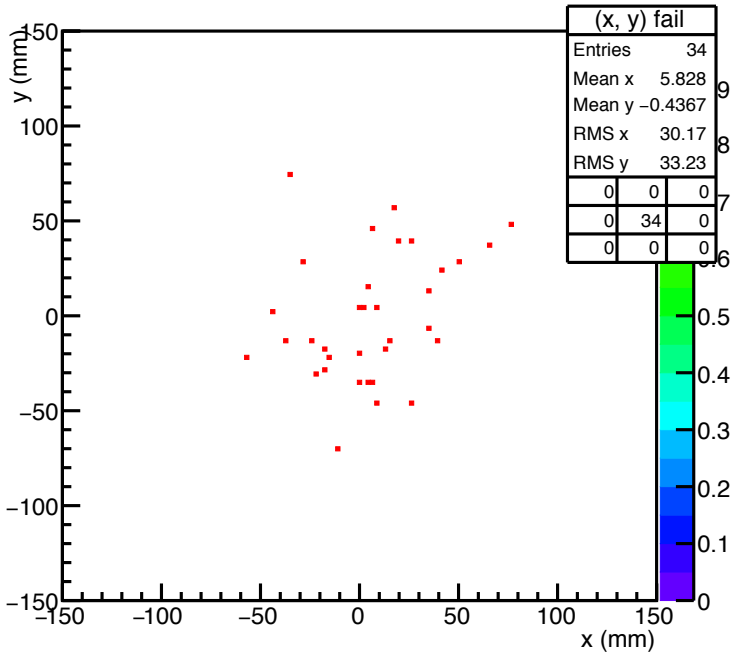


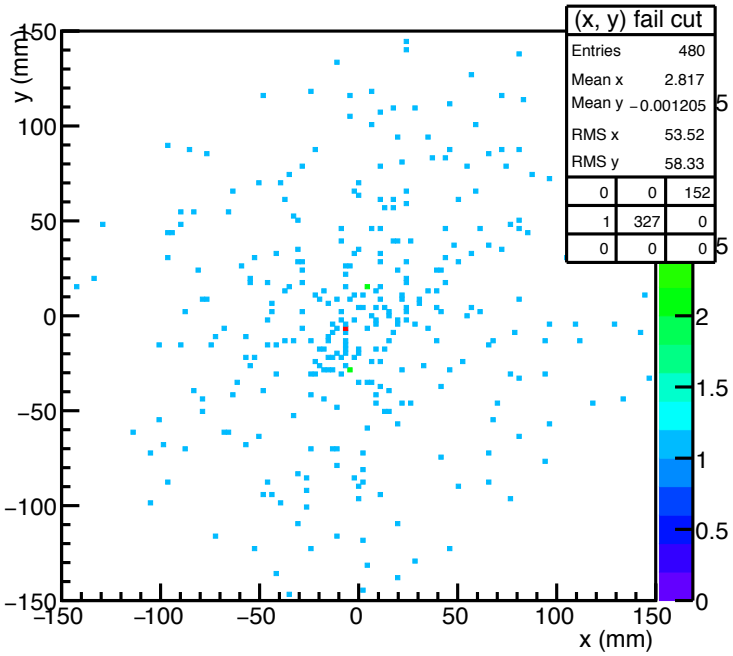

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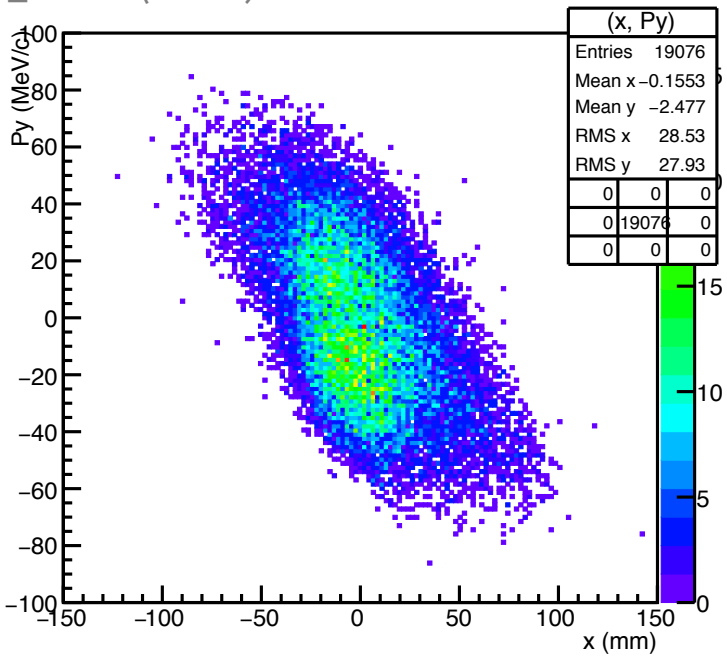


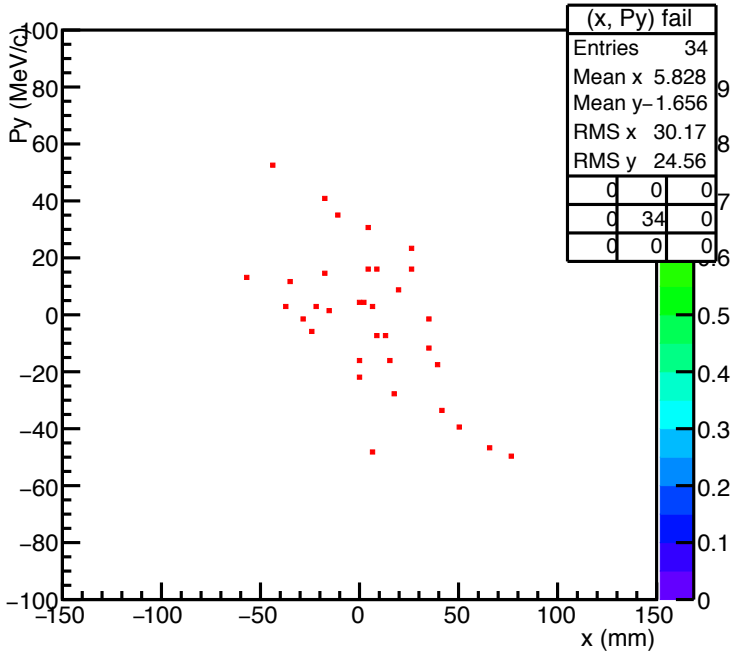


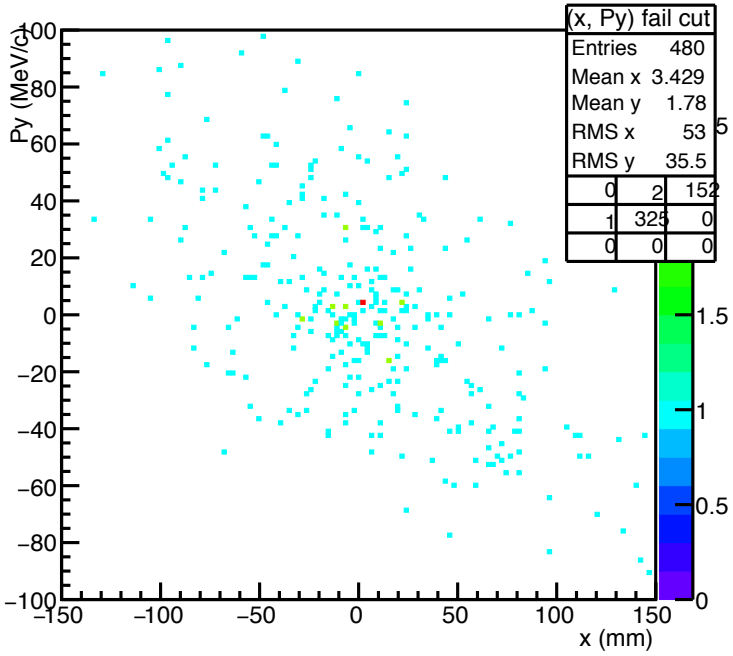


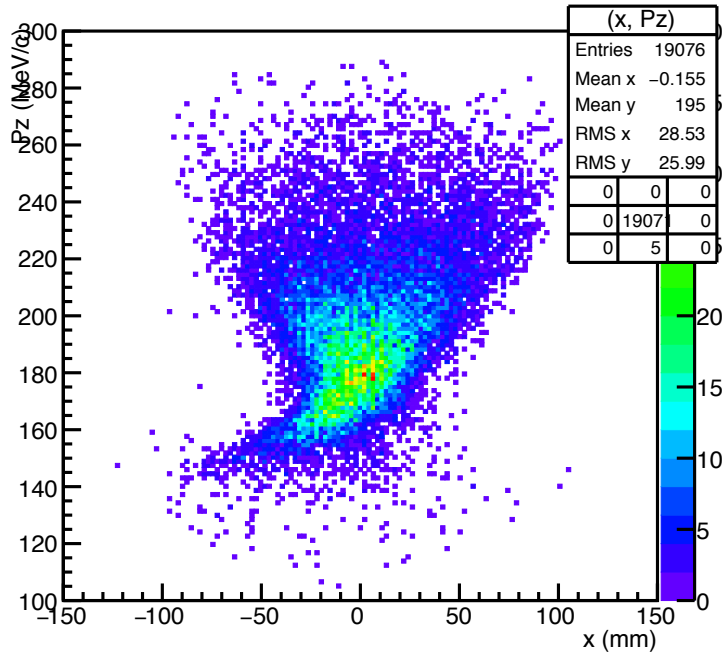


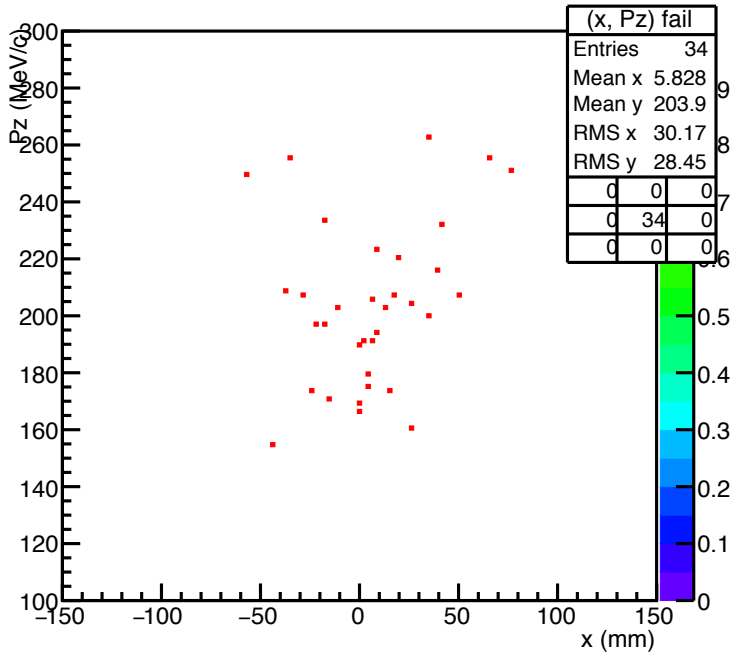


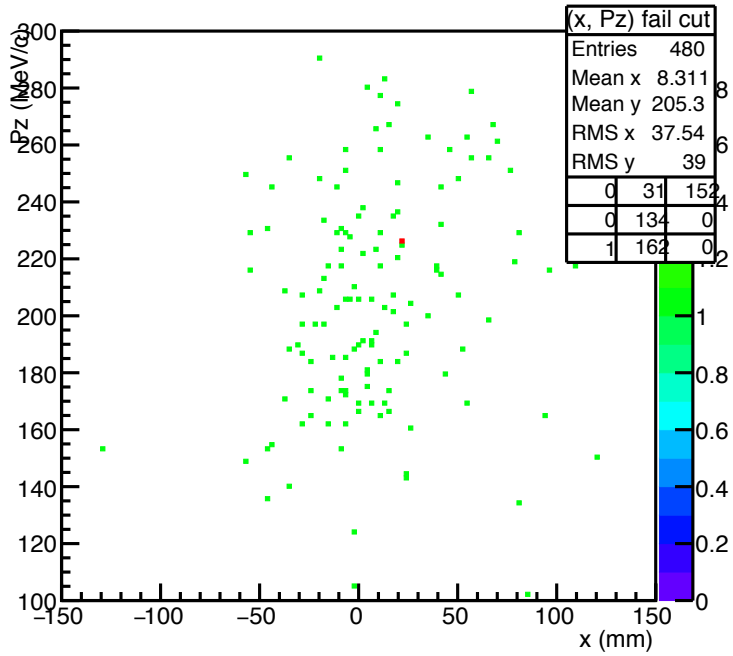

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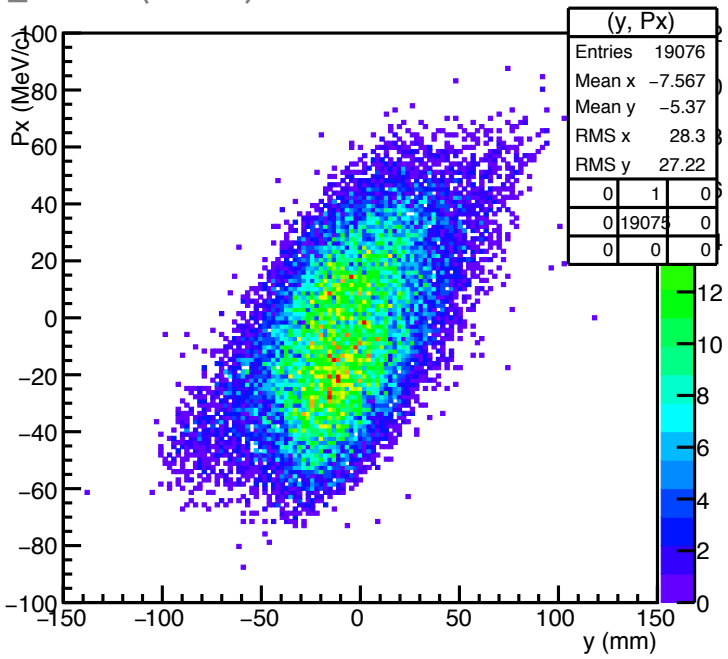


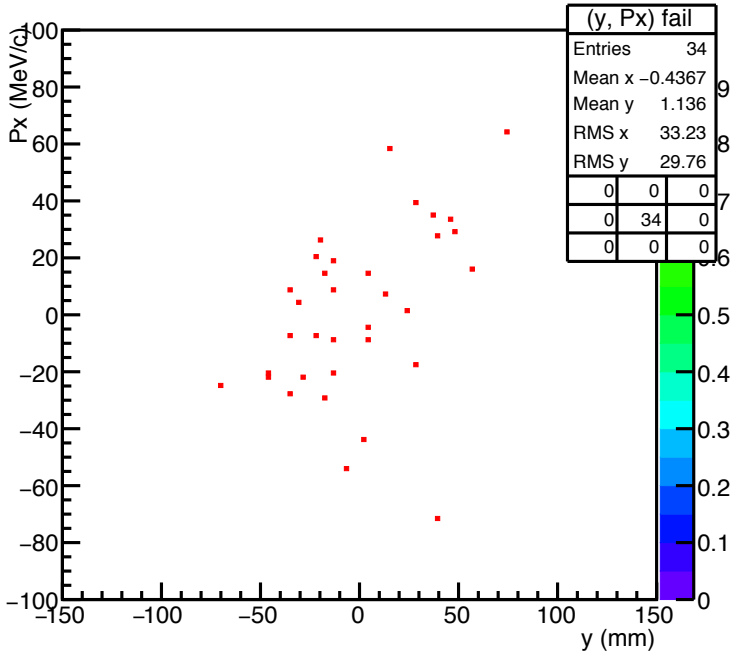


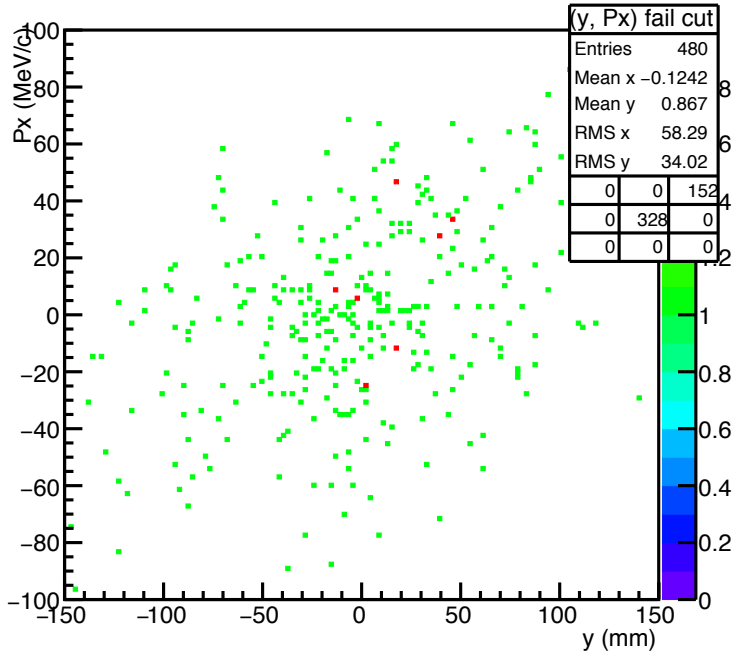


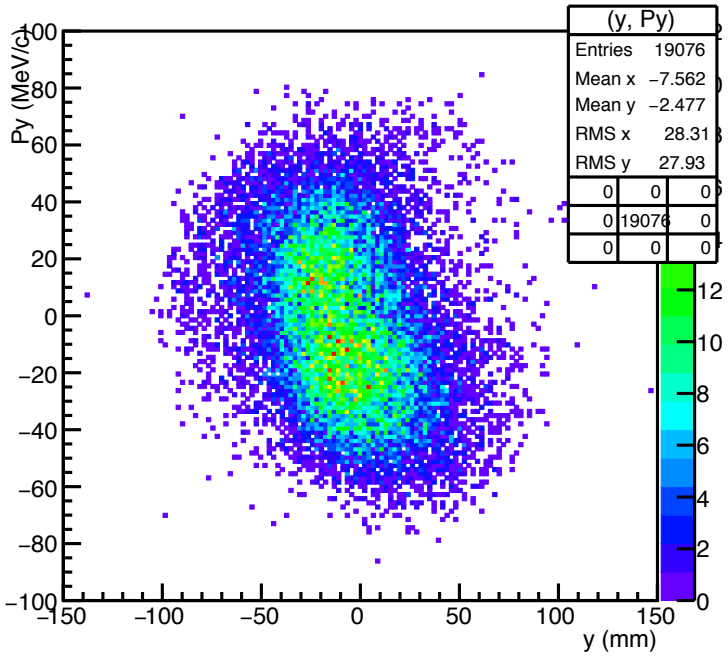


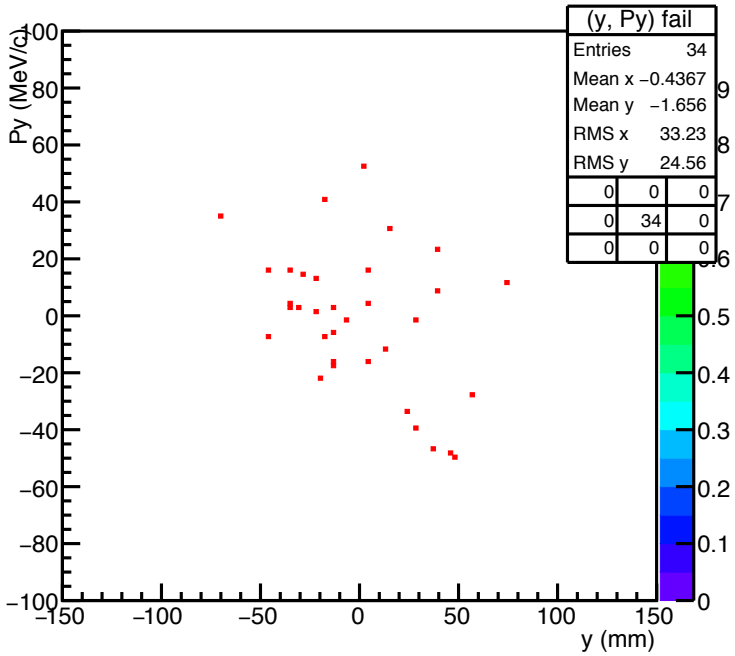


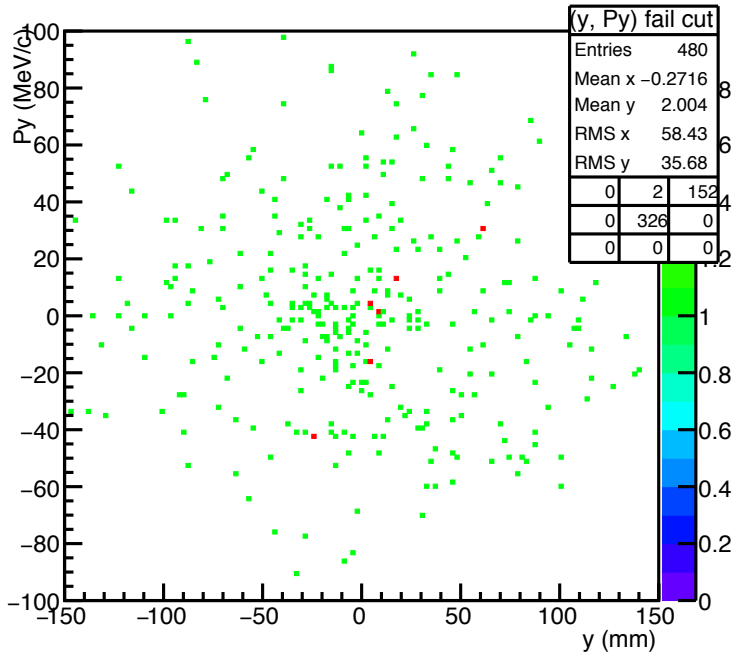

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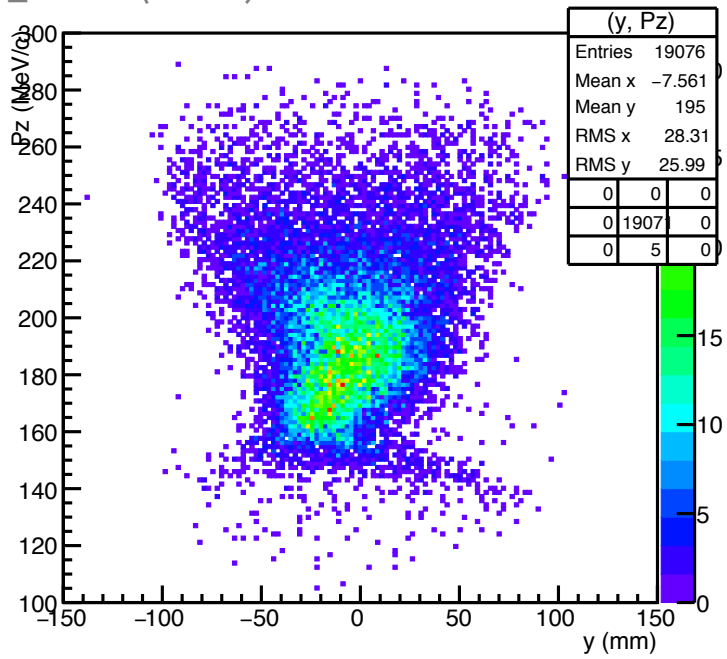


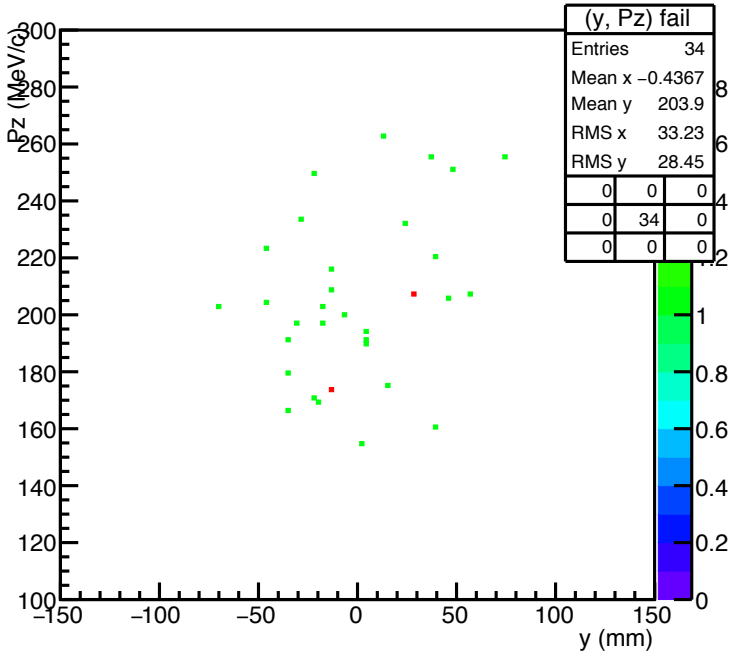


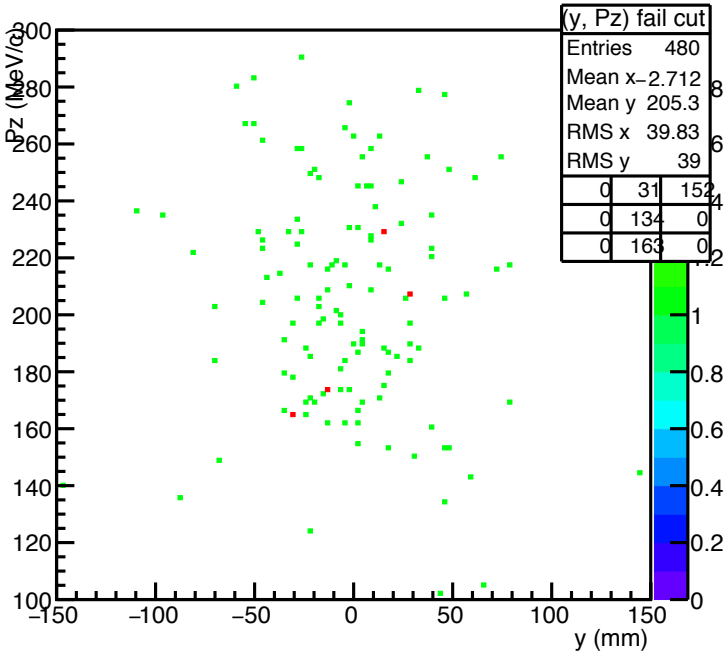


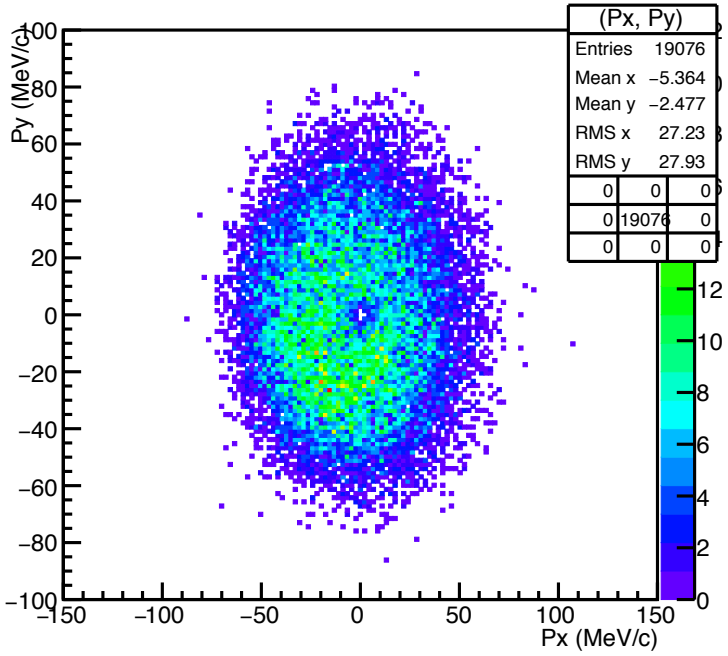


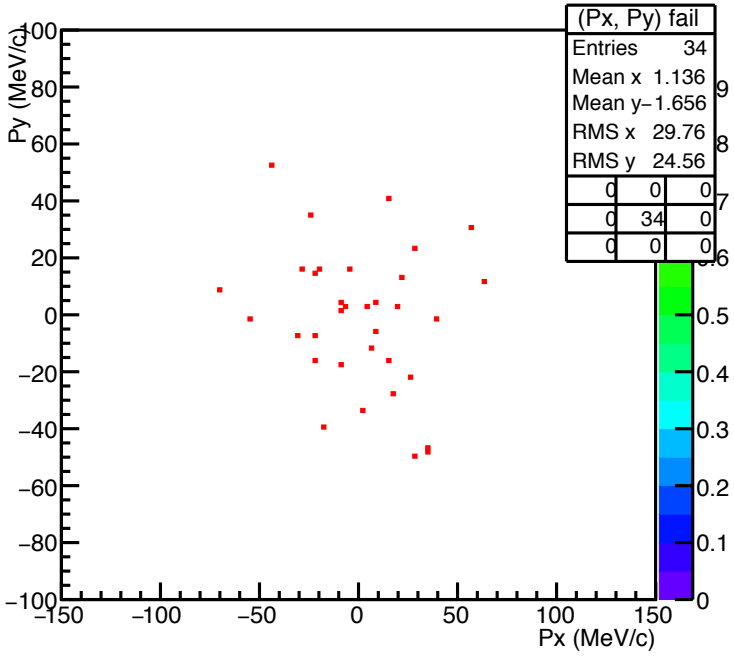


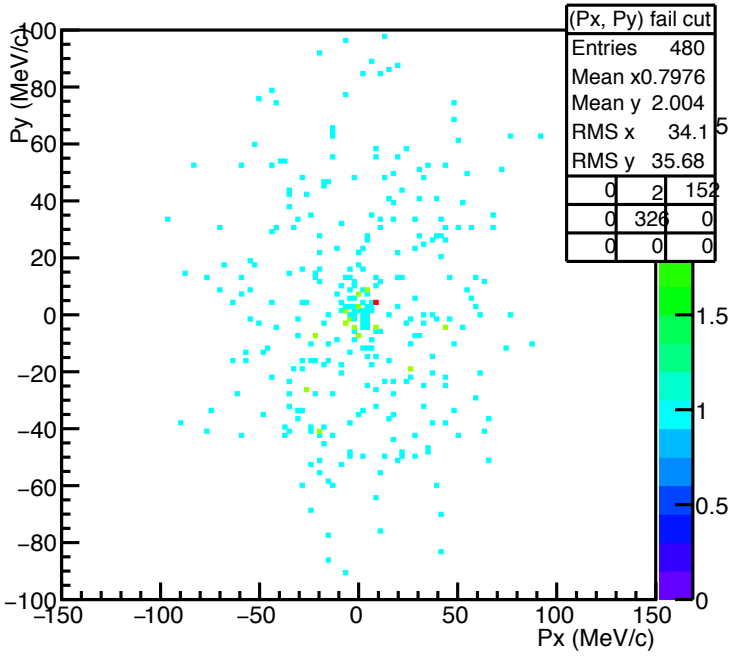

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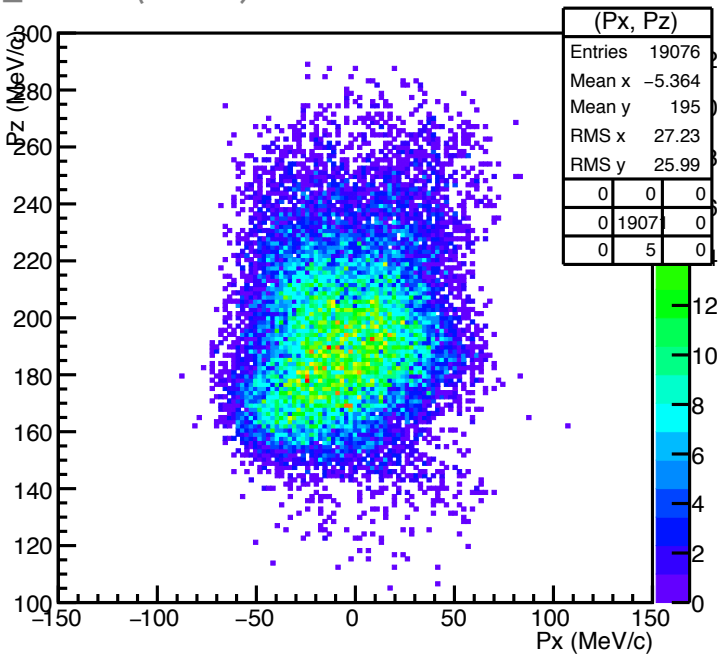


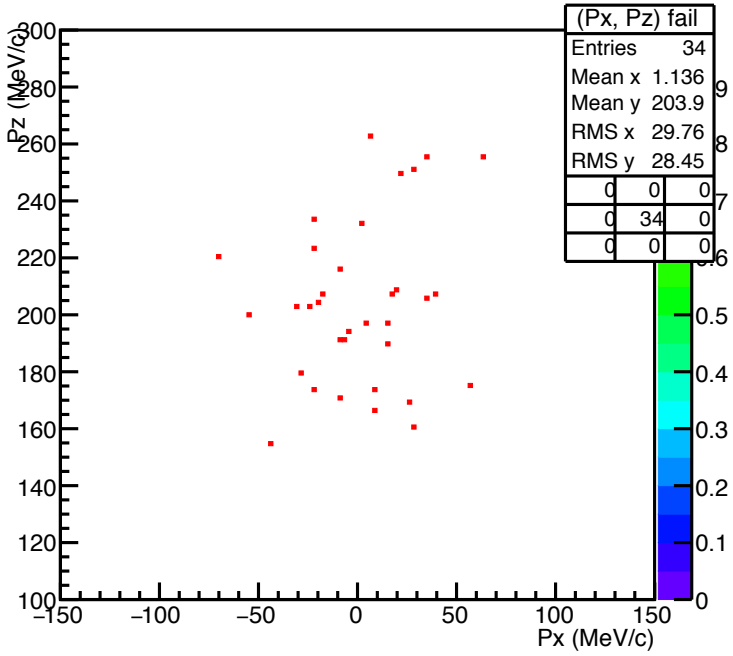


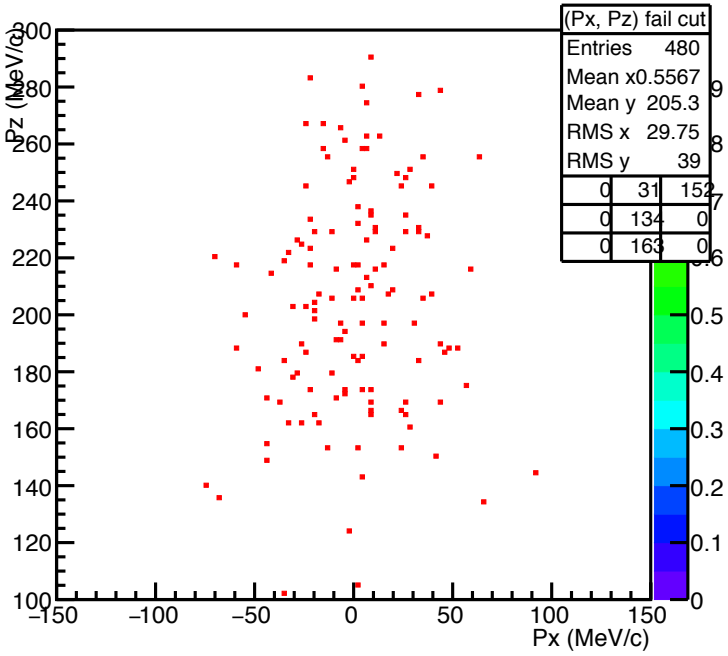


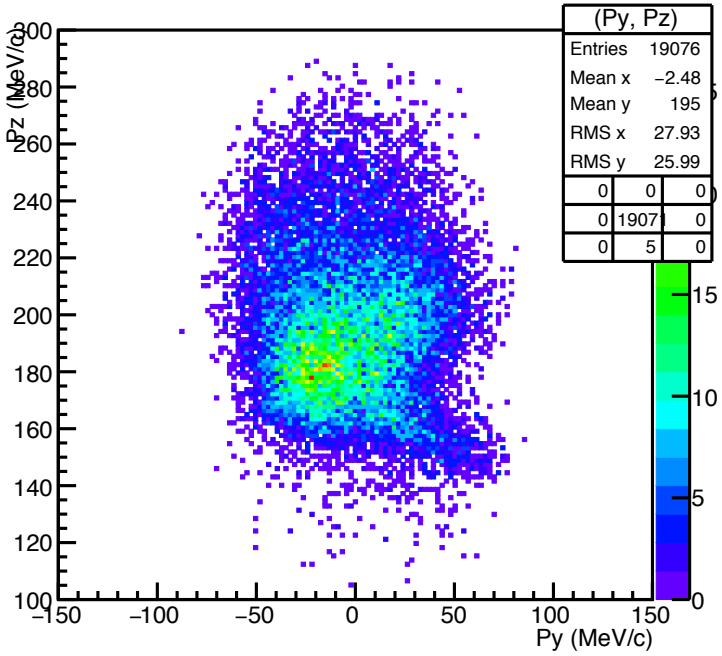


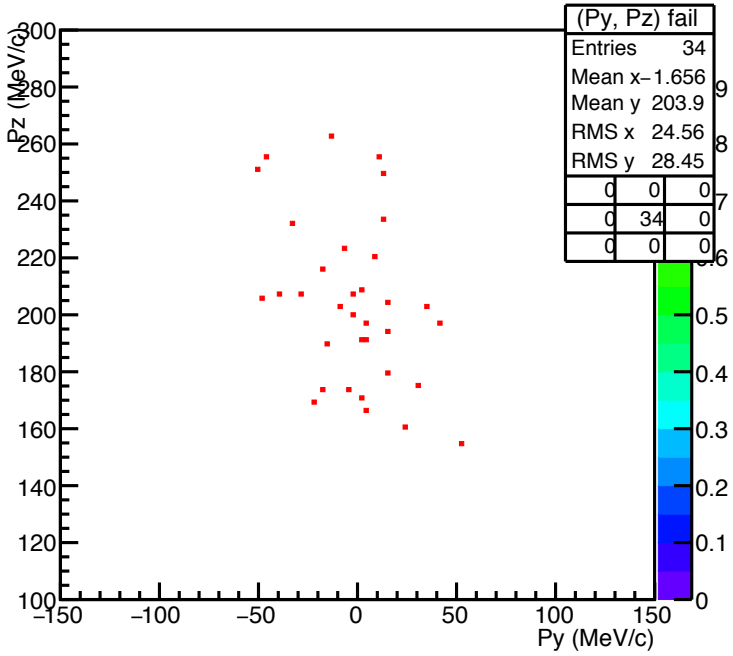


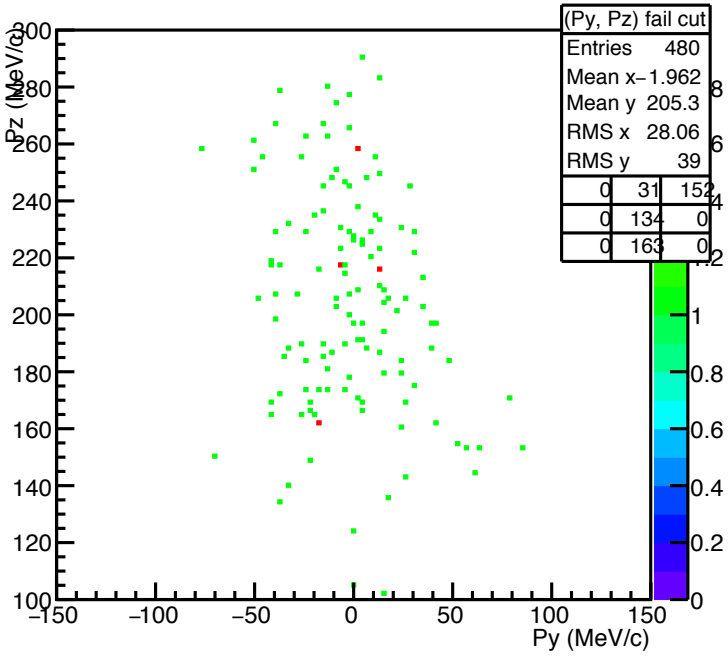

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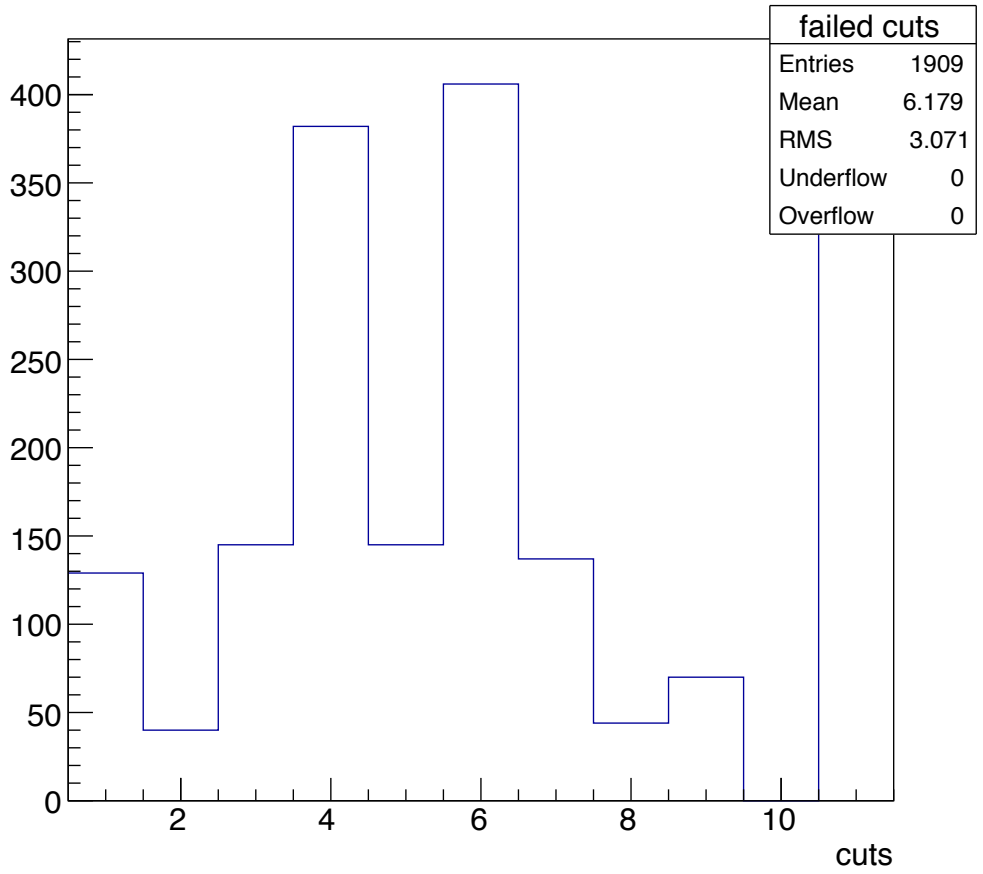
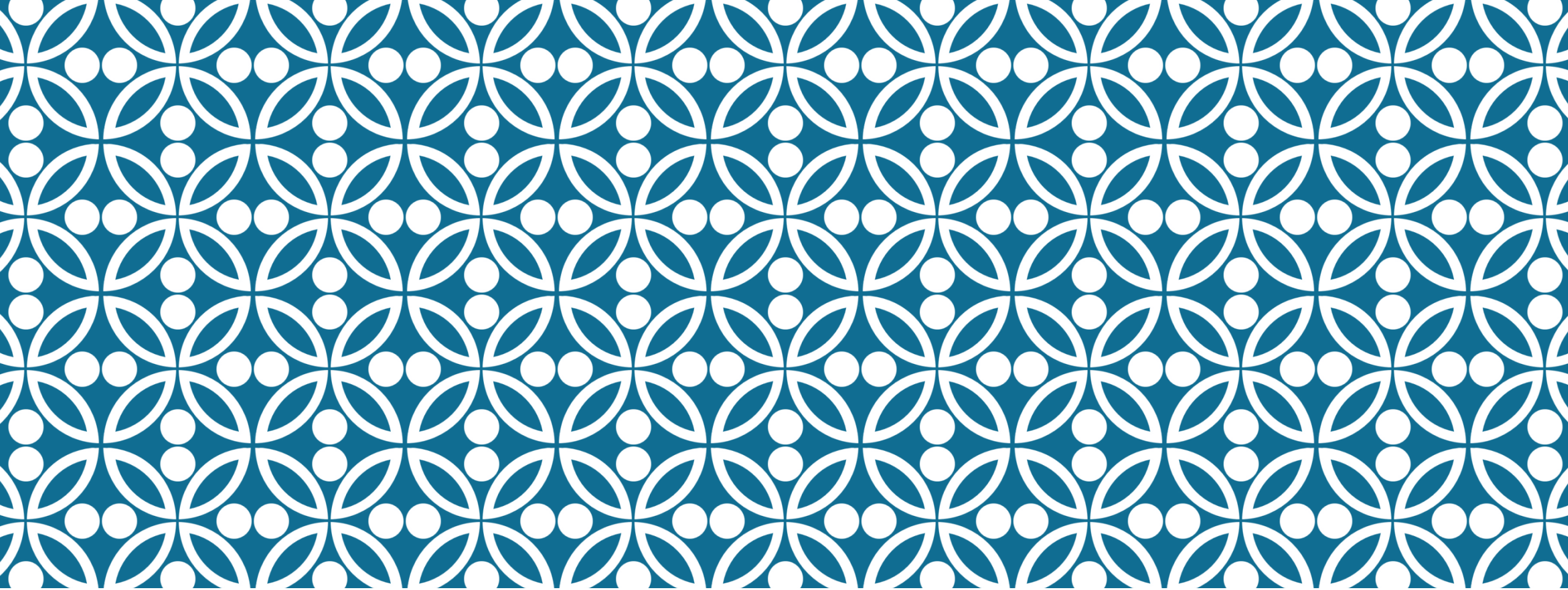



| 'Cut number' | Cut |
|---|---|
| 1 | cut_TOF0_goodPMTPosition |
| 2 | cut_TOF1_goodPMTPosition |
| 3 | cut_goodRaynerReconstruction |
| 4 | cut_TKU_hitAllStations |
| 5 | cut_TimeOfFlight |
| 6 | cut_hit_all_detectors |
| 7 | cut_TOF0_singleHit |
| 8 | cut_TOF1_singleHit |
| 9 | cut_TKU_singleTrack |
| 10 | cut_TKU_PValue |
| 11 | cut_momentum_loss |



# CUT_MOMENTUM_LOSS

AKA ‘cut 11’

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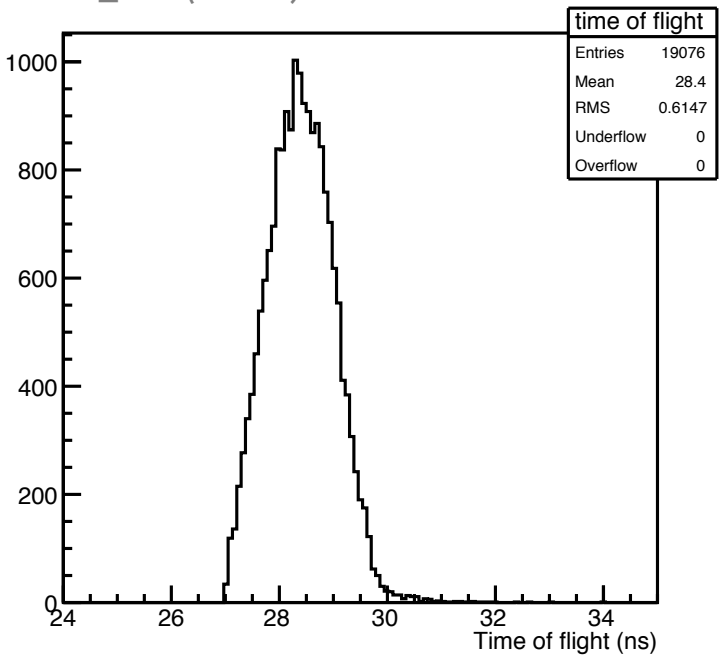
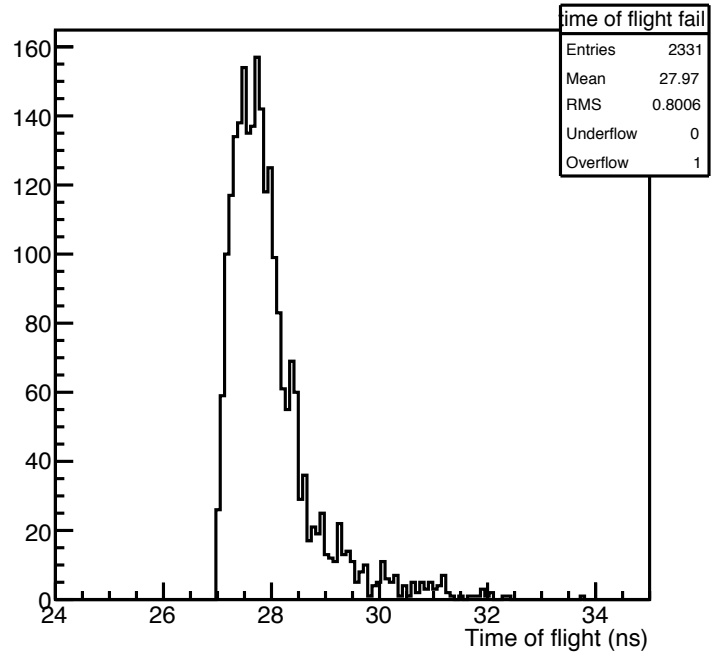
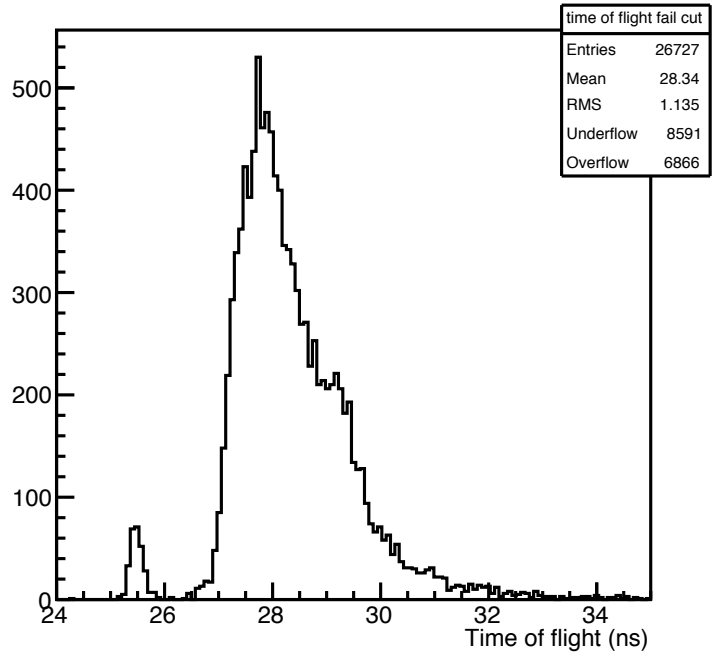
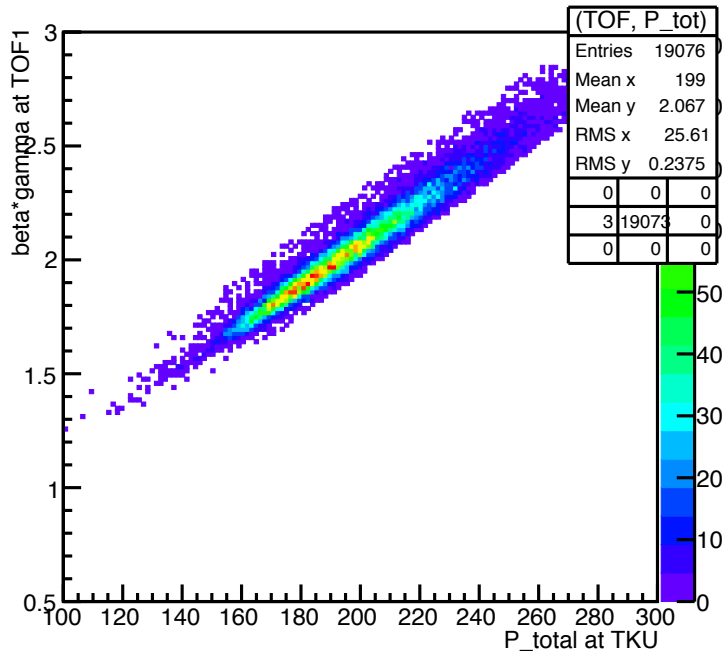
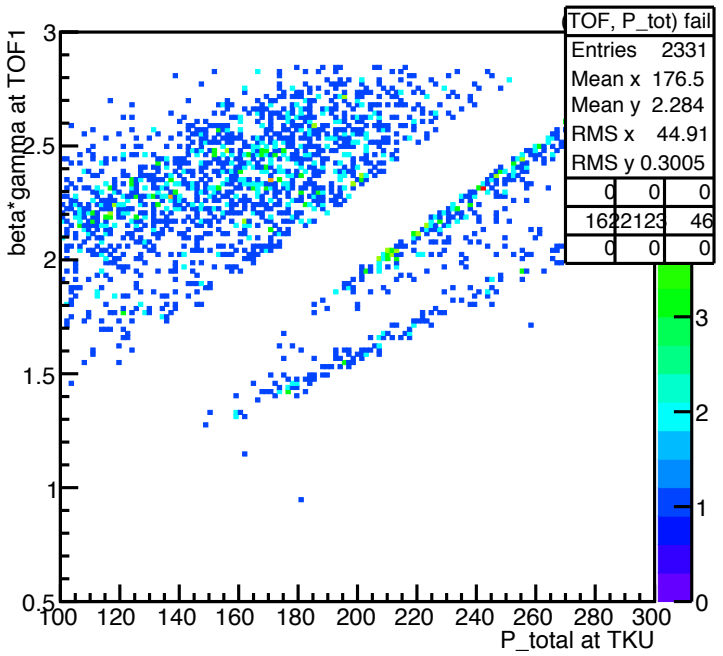
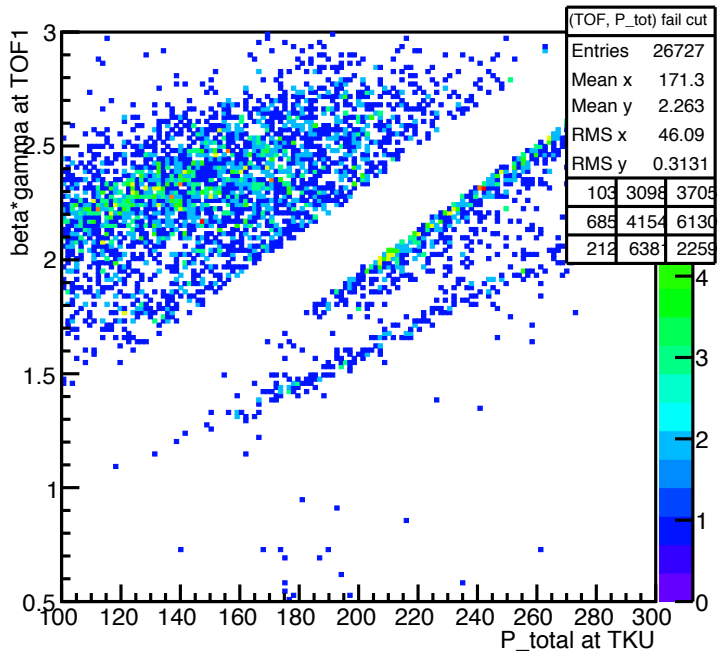


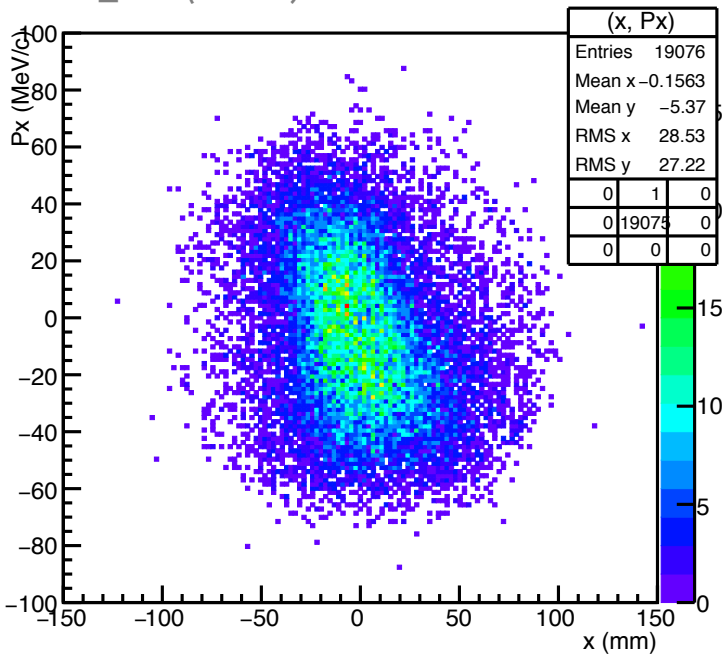



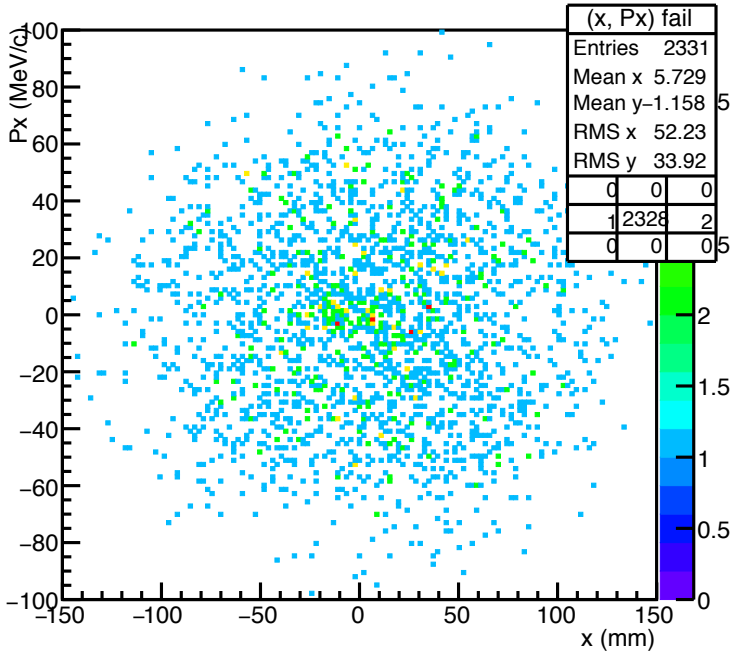



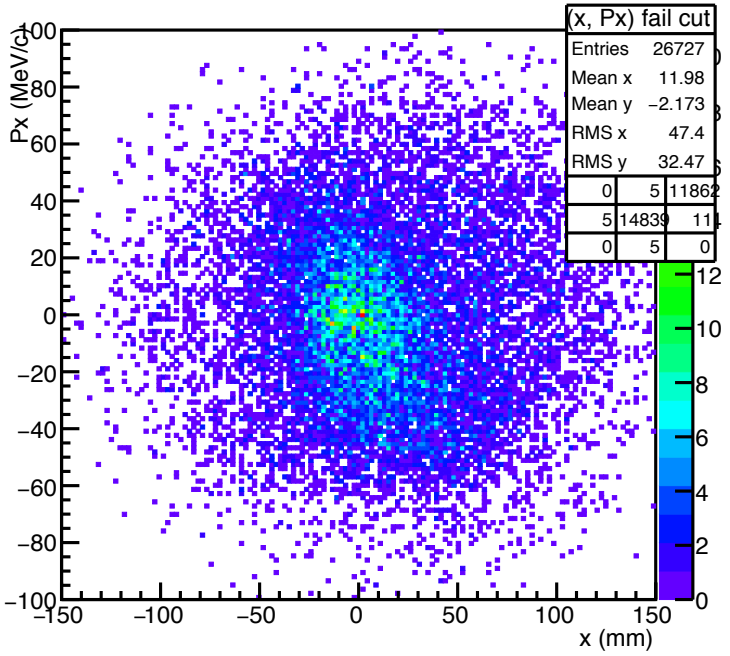



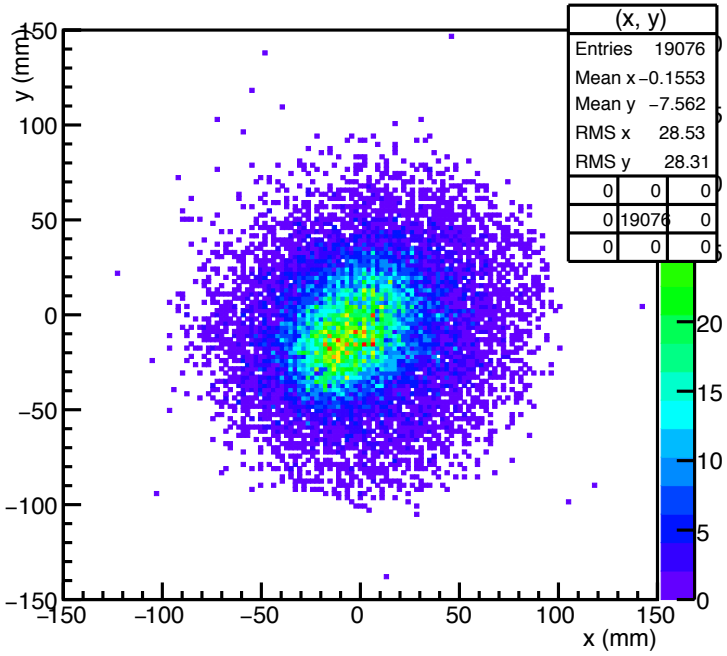



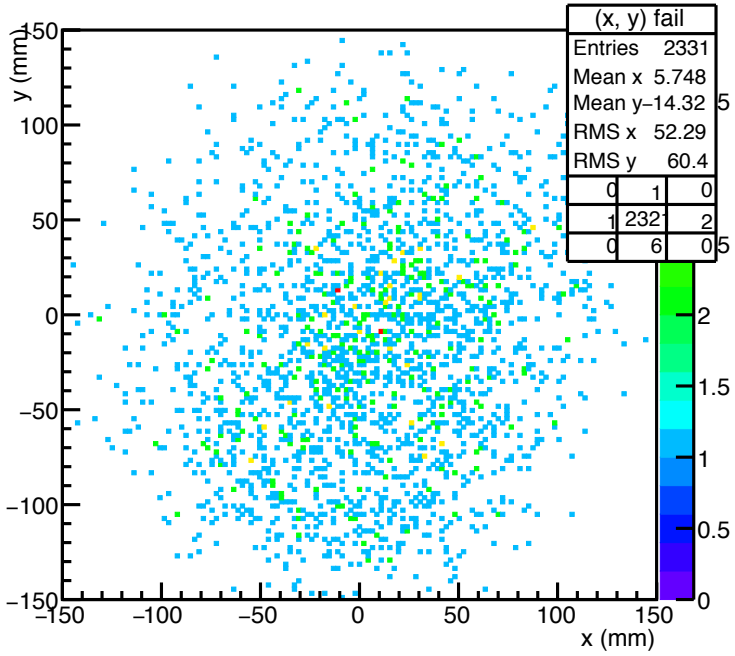
*cut_momentum_loss (cut 11)*

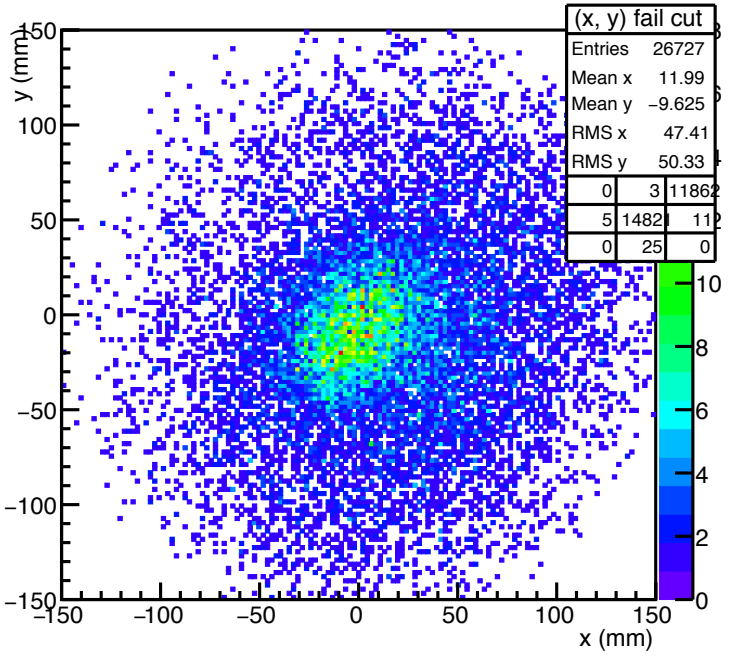


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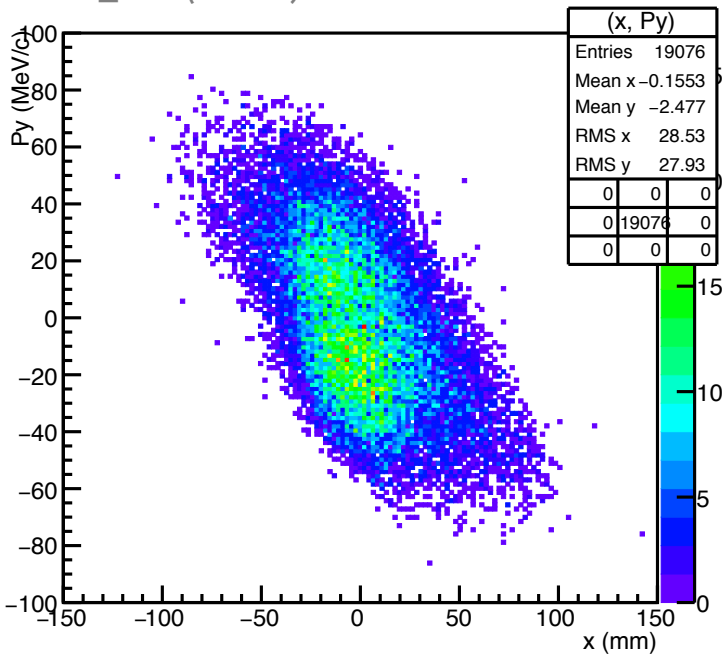
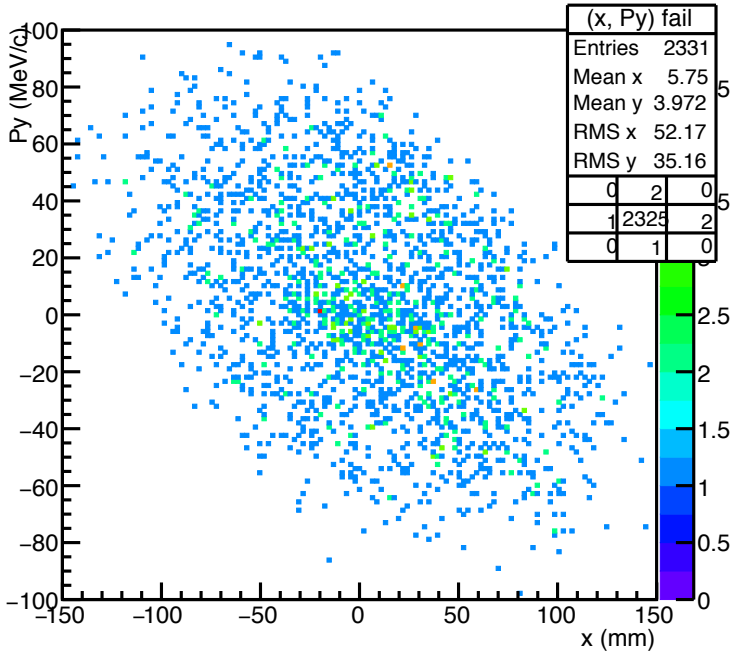
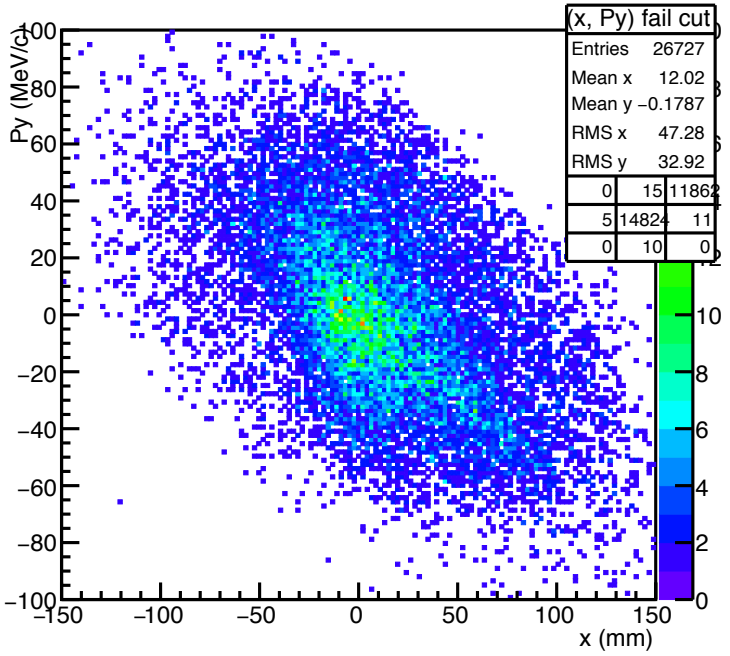
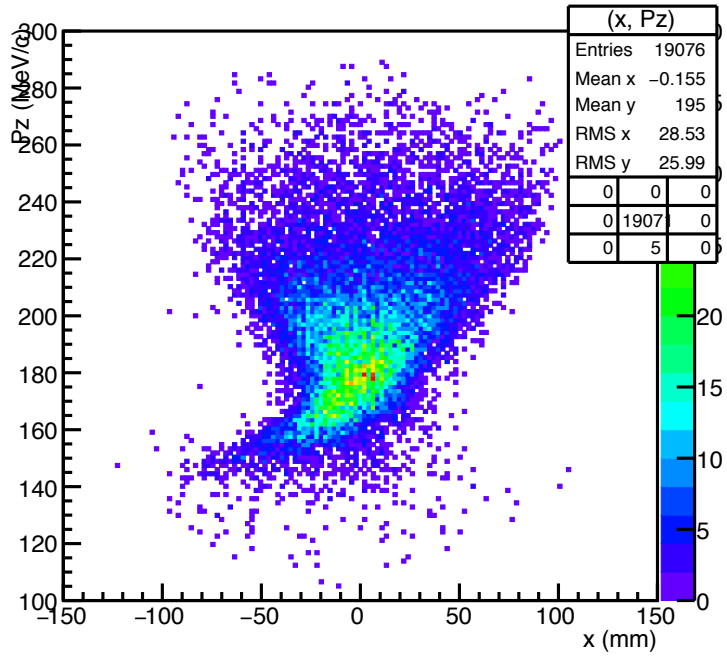
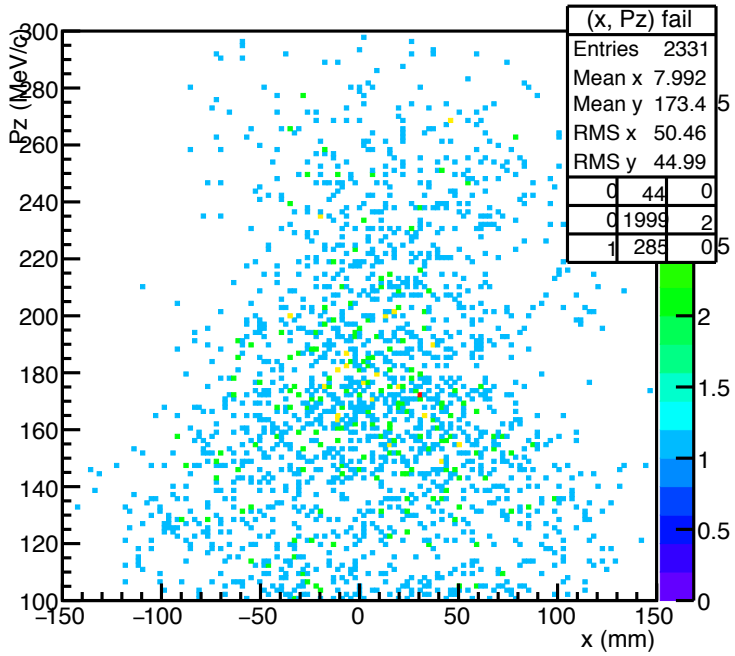
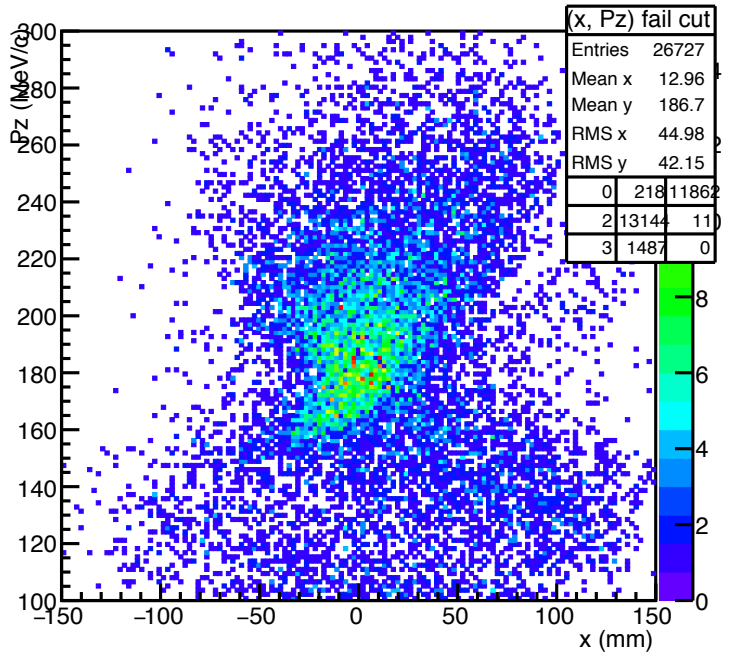


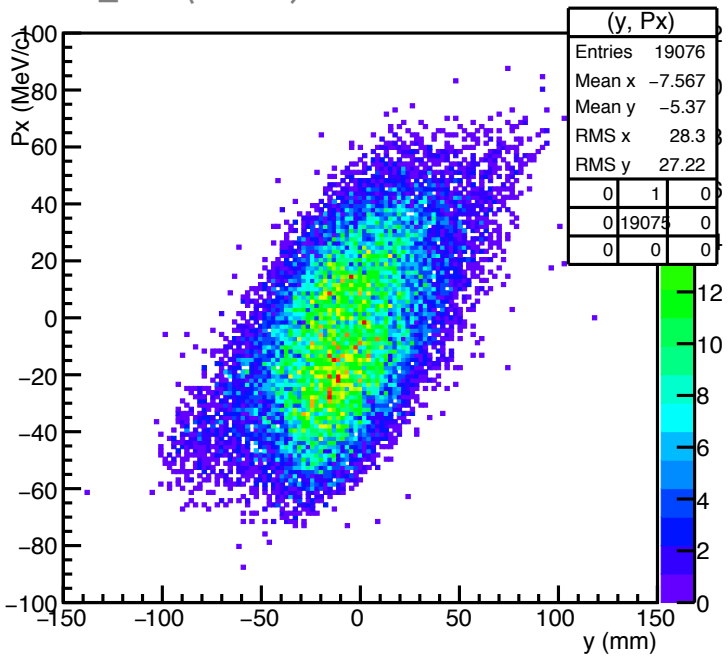



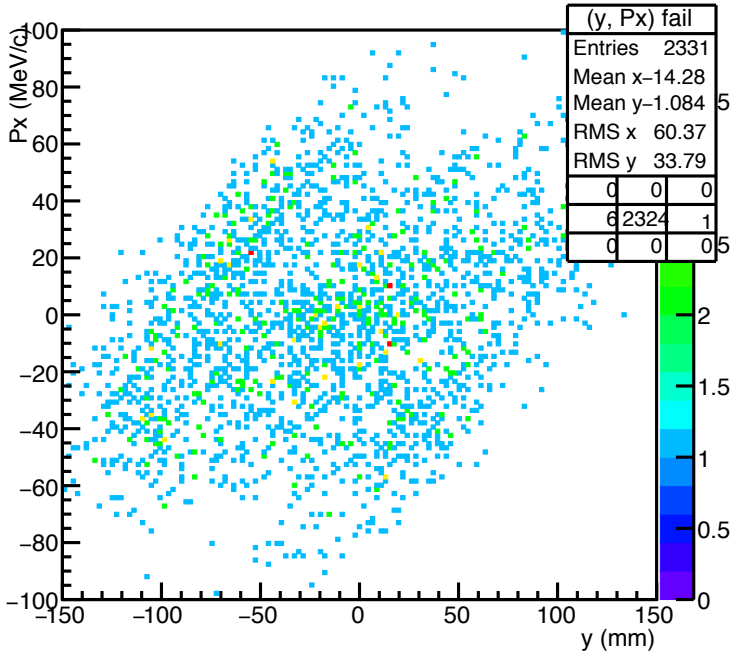



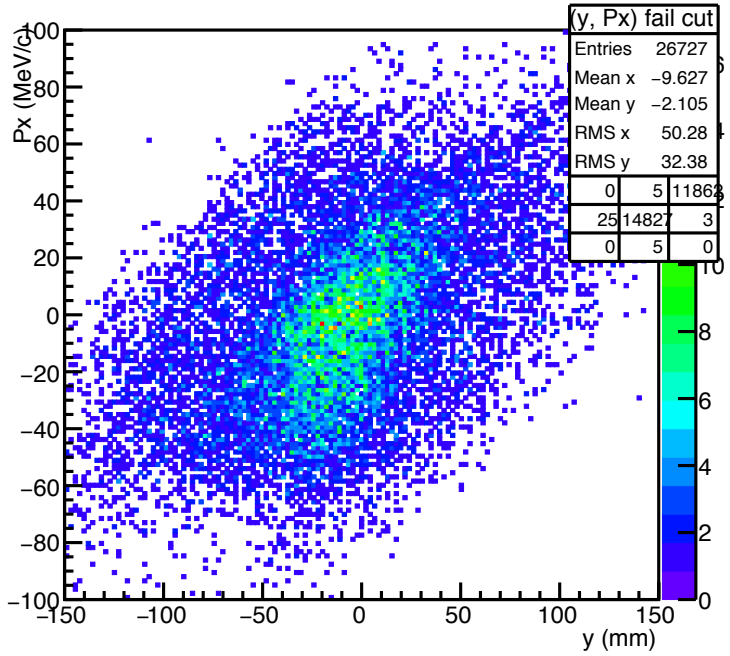



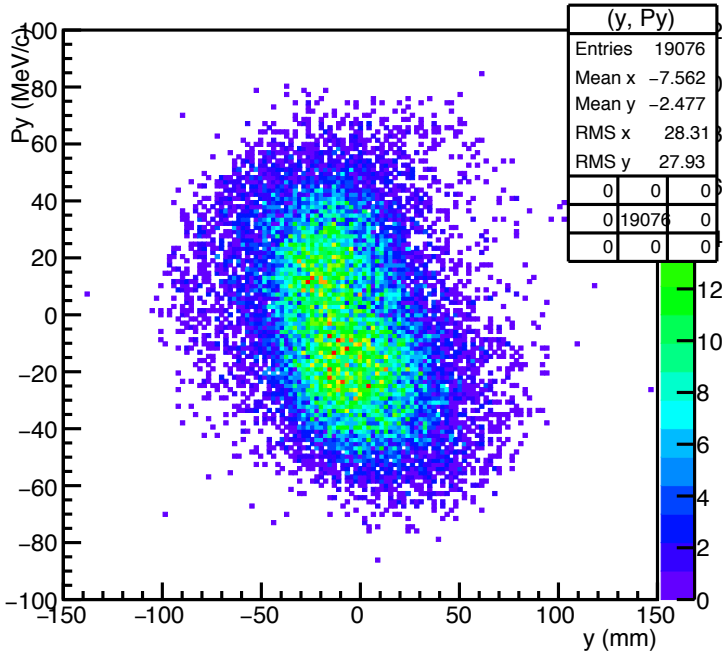



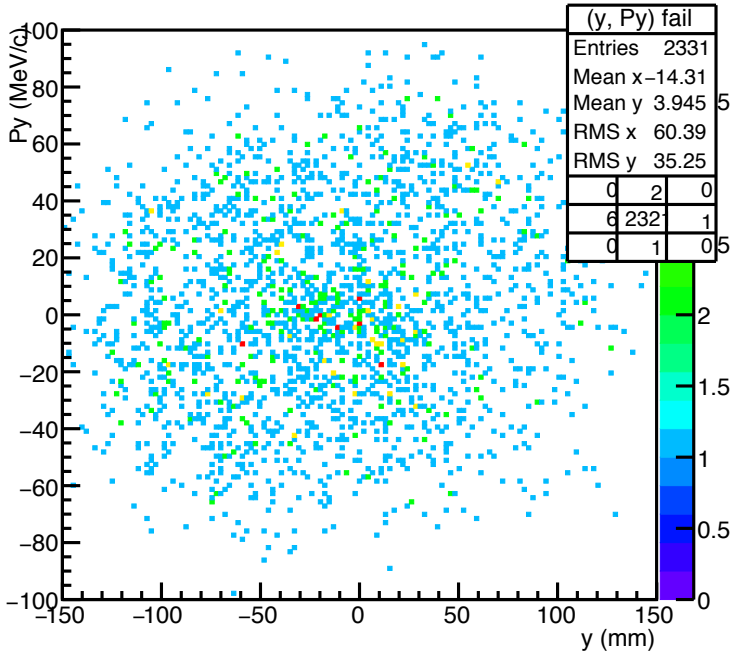
*cut_momentum_loss (cut 11)*

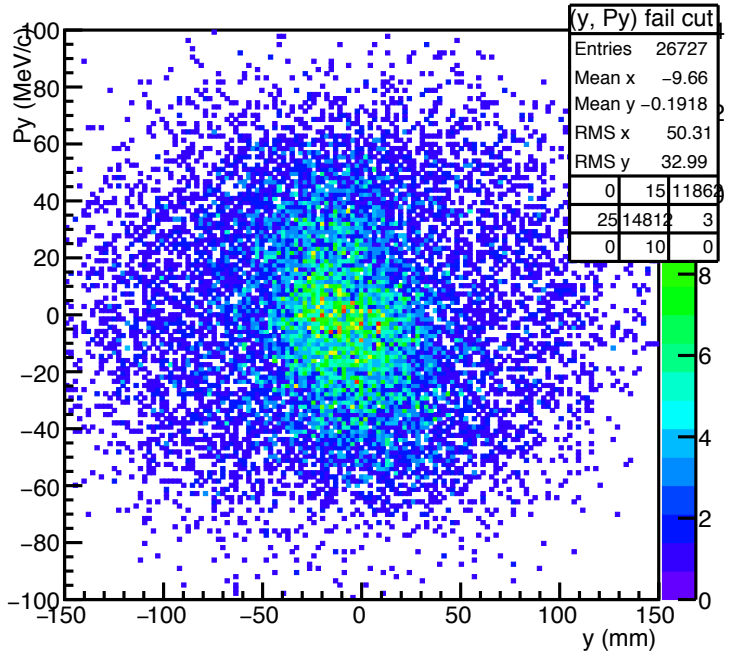


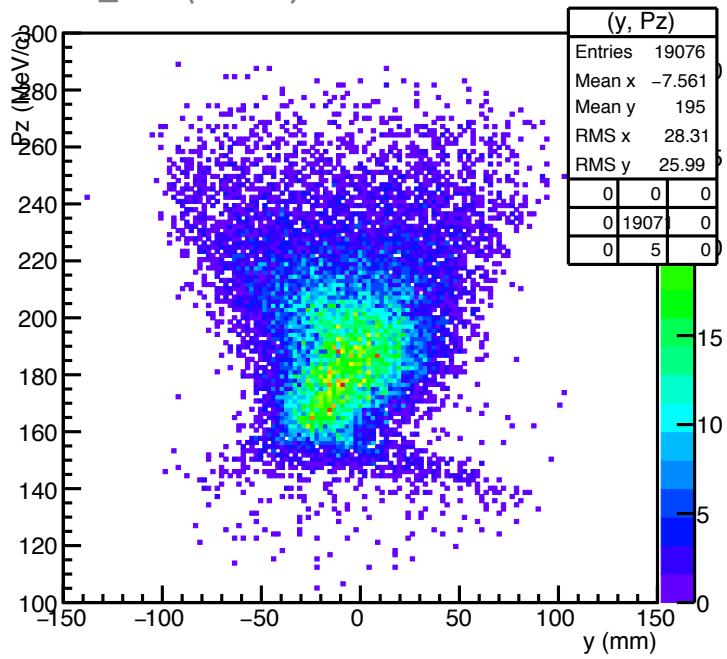



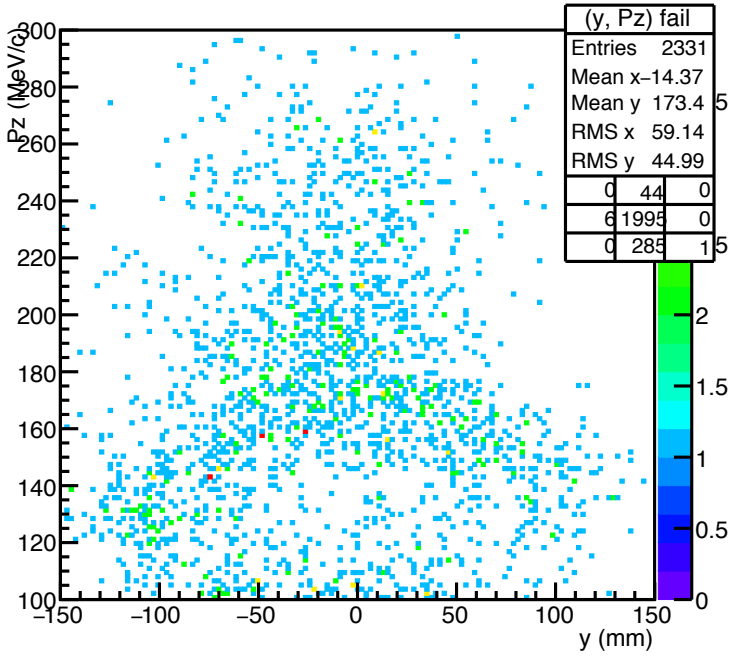



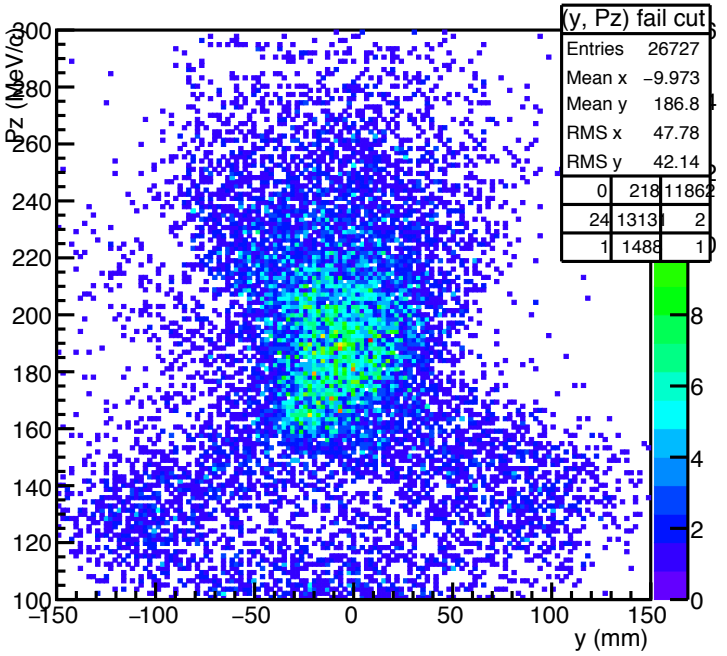



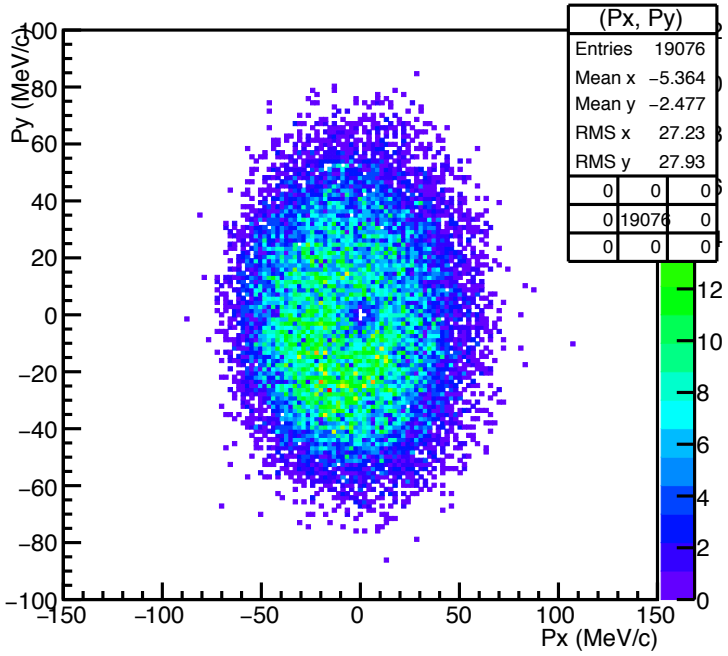



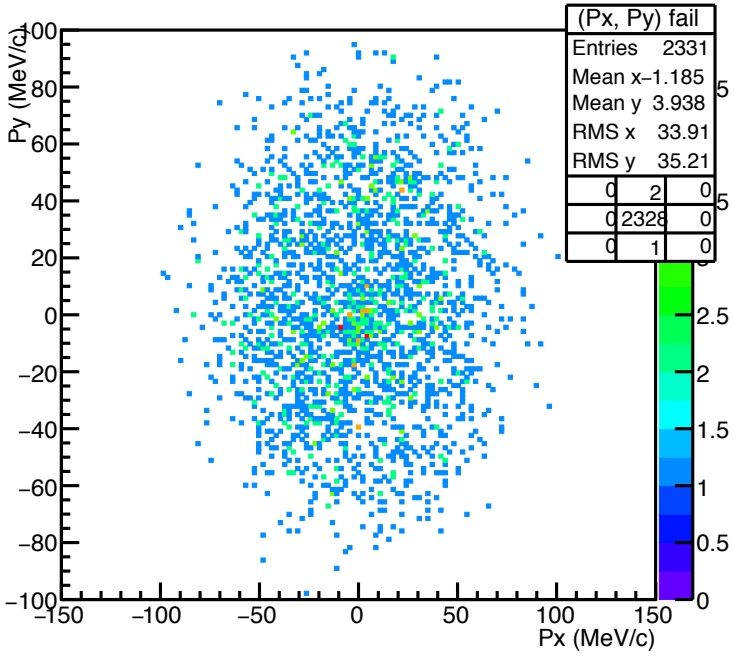
*cut_momentum_loss (cut 11)*

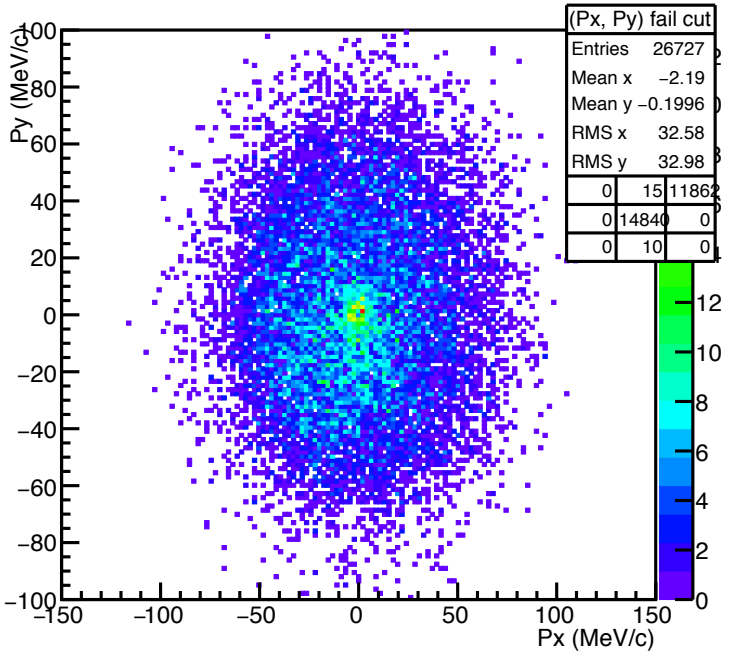


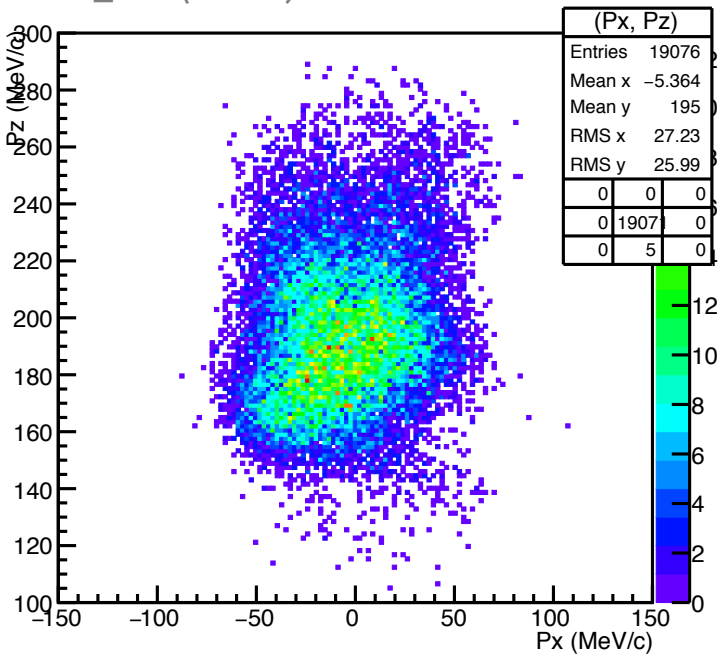



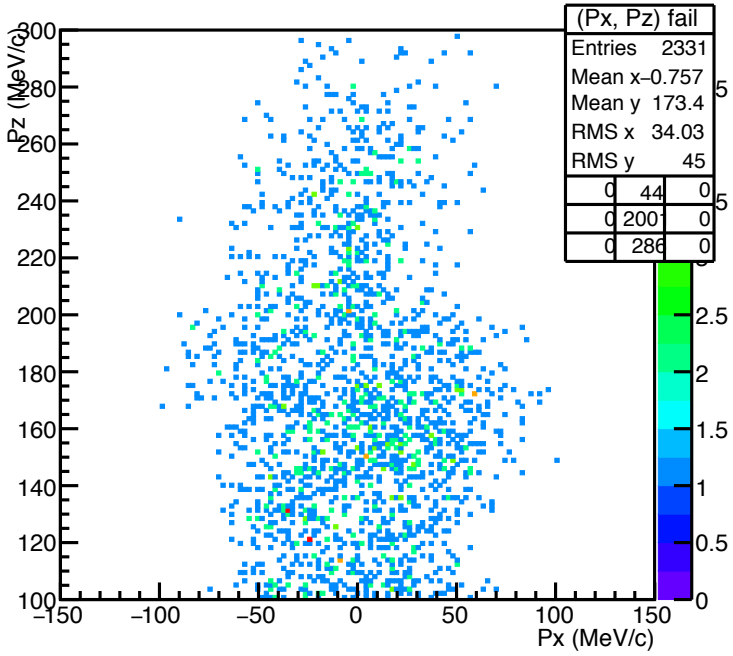



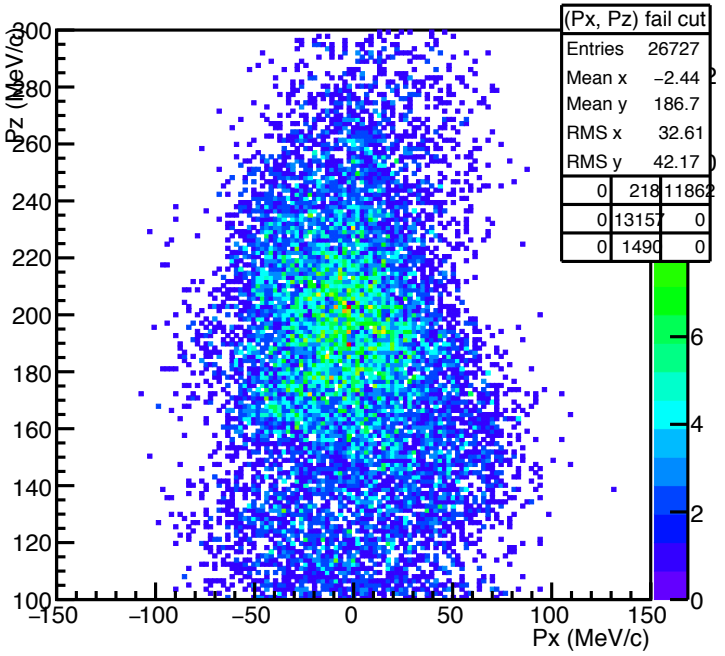



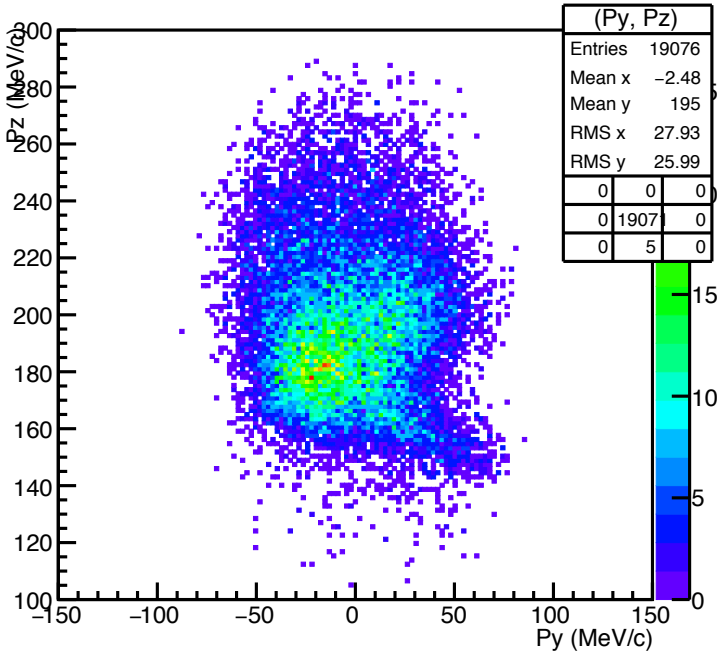



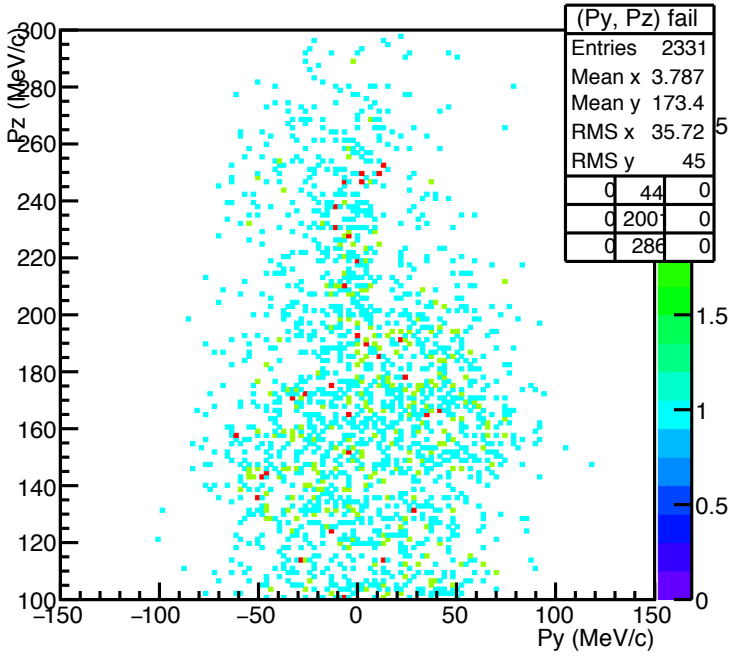
*cut_momentum_loss (cut 11)*

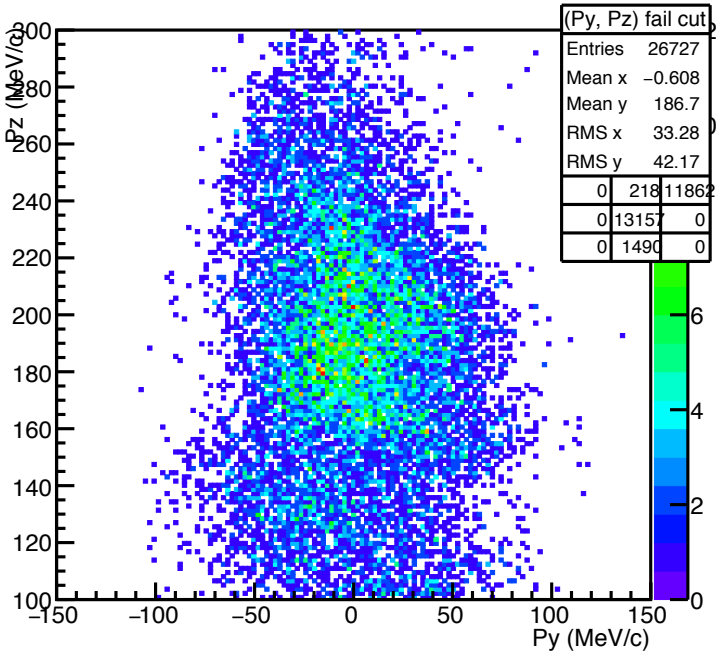


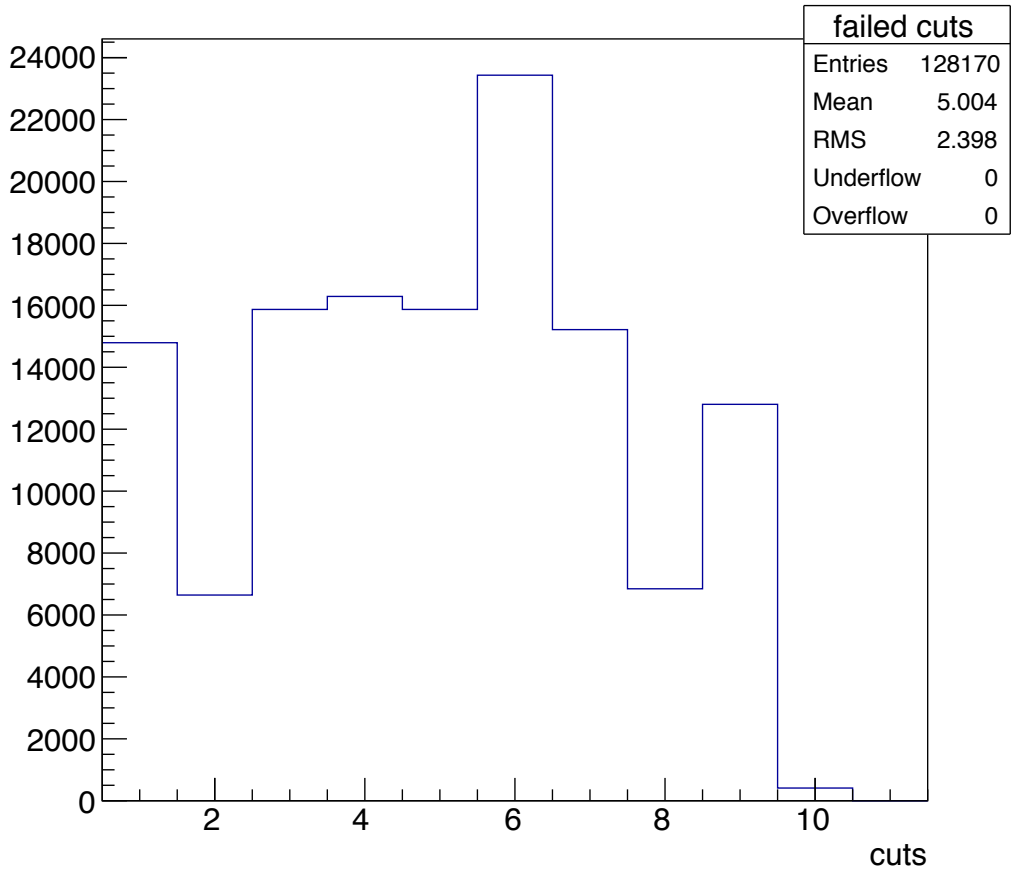



*cut_momentum_loss (cut 11)*



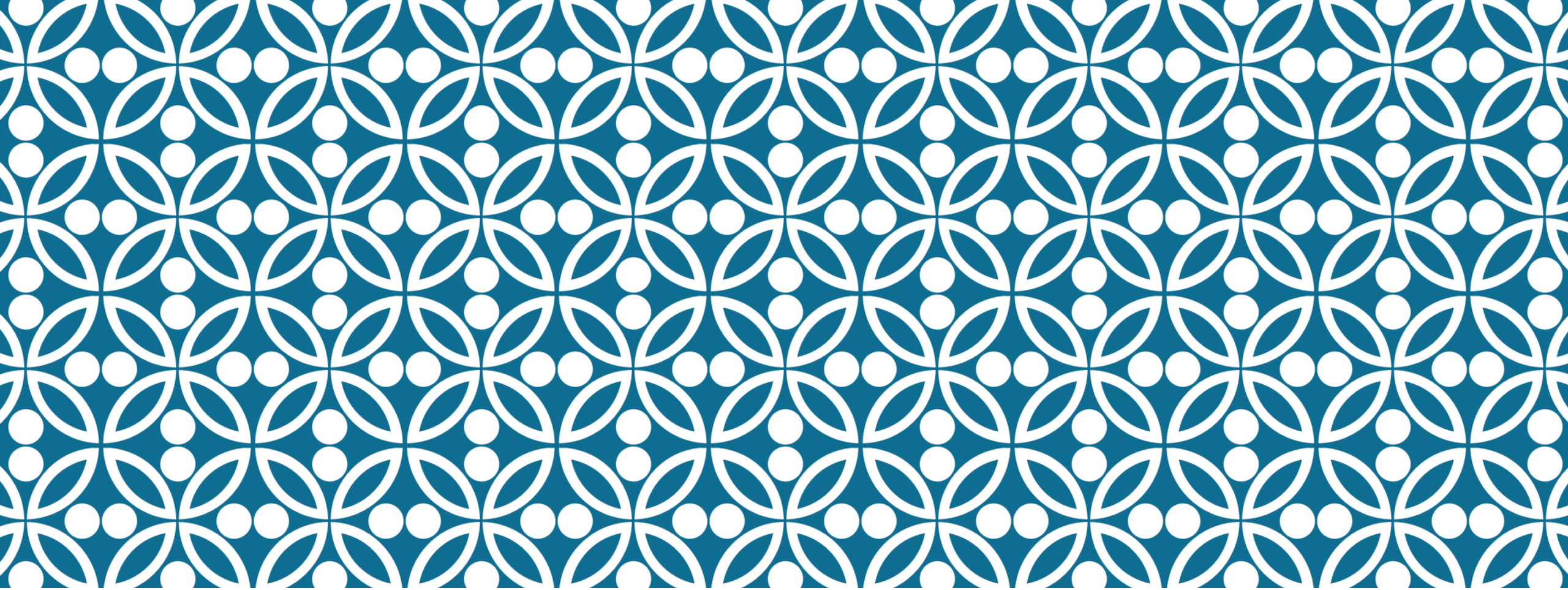

| 'Cut number' | Cut |
|---|---|
| 1 | cut_TOF0_goodPMTPosition |
| 2 | cut_TOF1_goodPMTPosition |
| 3 | cut_goodRaynerReconstruction |
| 4 | cut_TKU_hitAllStations |
| 5 | cut_TimeOfFlight |
| 6 | cut_hit_all_detectors |
| 7 | cut_TOF0_singleHit |
| 8 | cut_TOF1_singleHit |
| 9 | cut_TKU_singleTrack |
| 10 | cut_TKU_PValue |
| 11 | cut_momentum_loss |

# CUTS SUMMARY

- Data: 19076 surviving muons
- MC: 23398 surviving muons

- Extracted data file: http://micewww.pp.rl.ac.uk/attachments/6700/run7469_extracted_data__MAUS2pt5_b.root
- TOF PMT calibration for data: http://micewww.pp.rl.ac.uk/attachments/5896/run7417.dat
- Cut plots for data: http://micewww.pp.rl.ac.uk/attachments/6720/data_cut_comparisons.zip

- Extracted MC file: http://micewww.pp.rl.ac.uk/attachments/6724/mc_3mm200_07469_MAUS2pt5_extracted_data_c__withMCTOFCalib.root
- TOF PMT calibration for MC: http://micewww.pp.rl.ac.uk/attachments/6723/run7417_calibration_file_MC.txt
- Cut plots for MC: http://micewww.pp.rl.ac.uk/attachments/6722/mc_cut_comparisons.zip

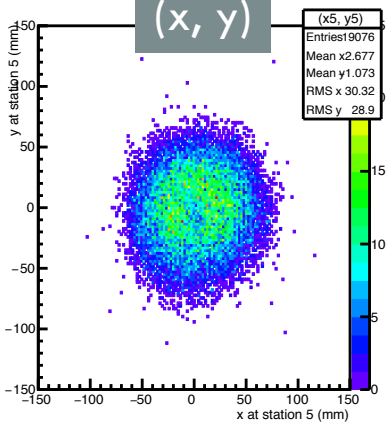


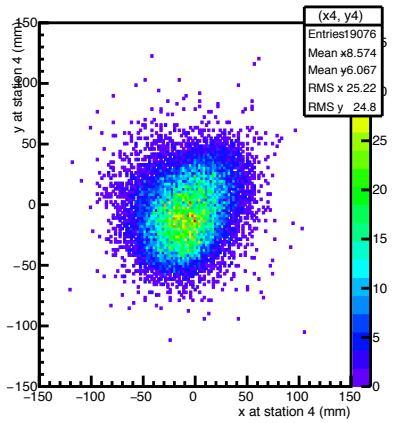
# EVOLUTION OF PHASE SPACE ACROSS TRACKER

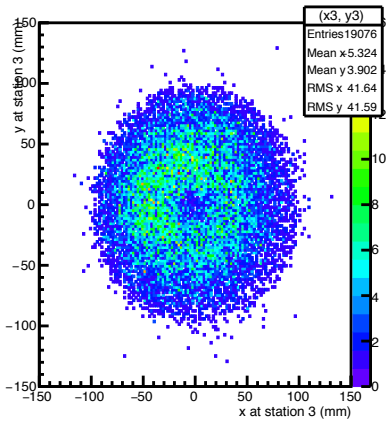
Upstream

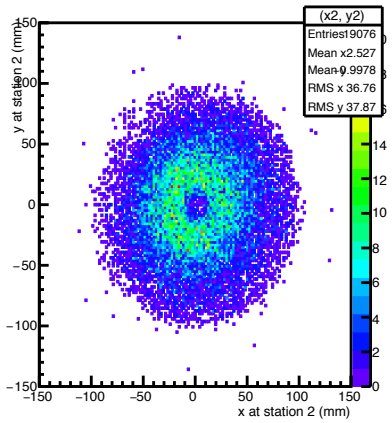
Downstream

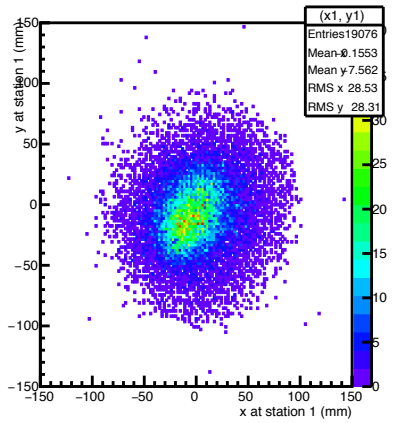
(x, y)



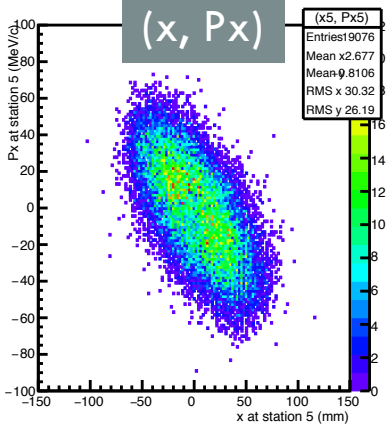



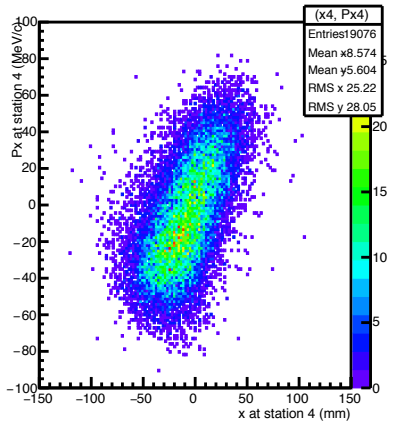



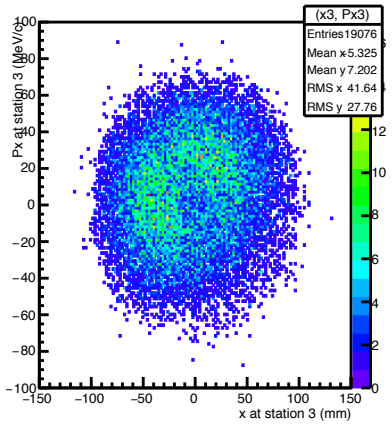



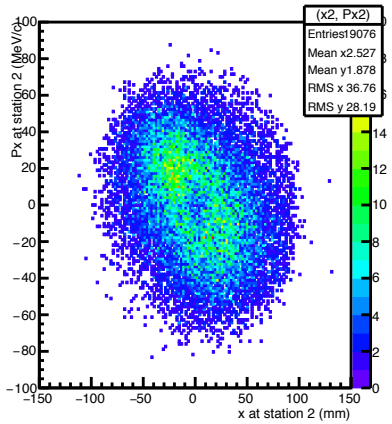



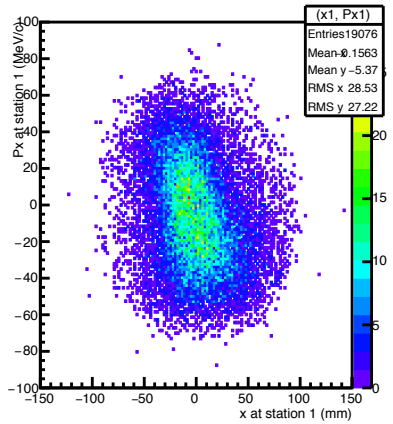

(x, Px)



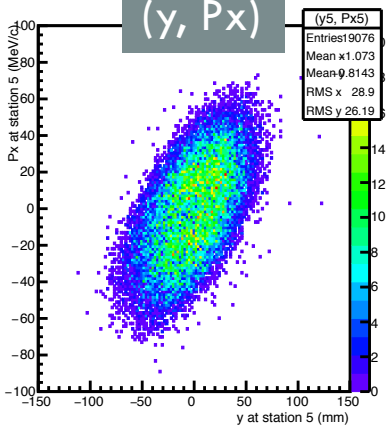



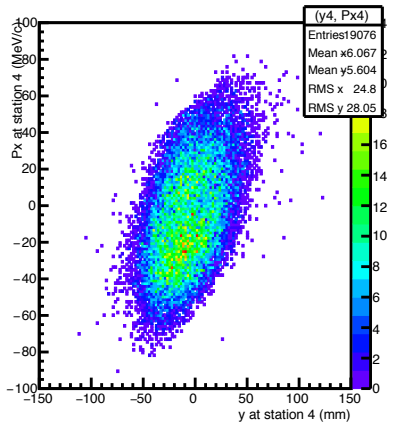



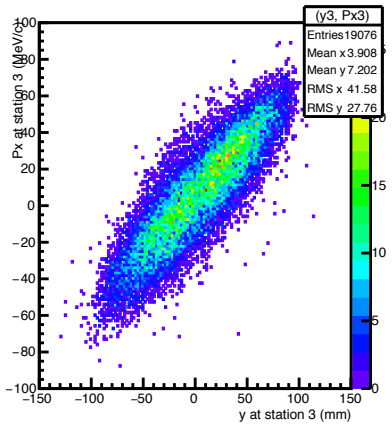



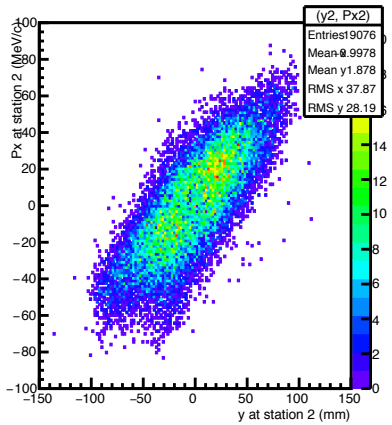



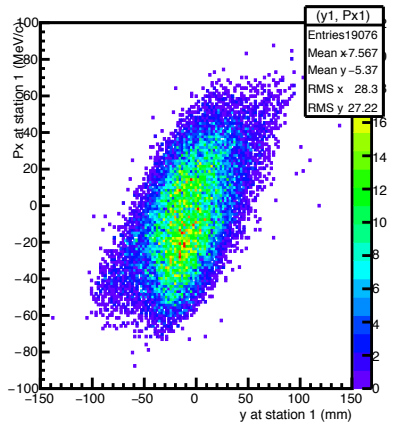

(y, Px)



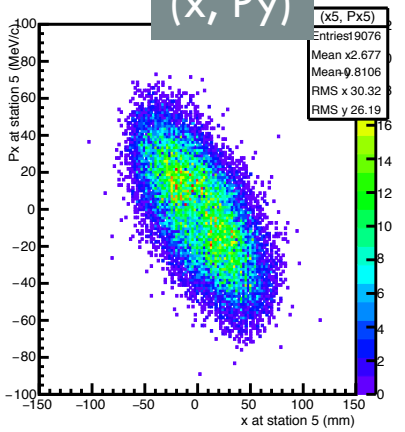



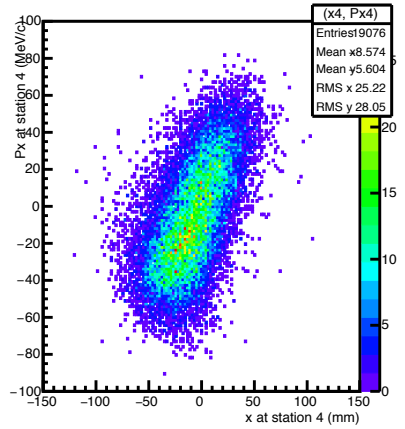



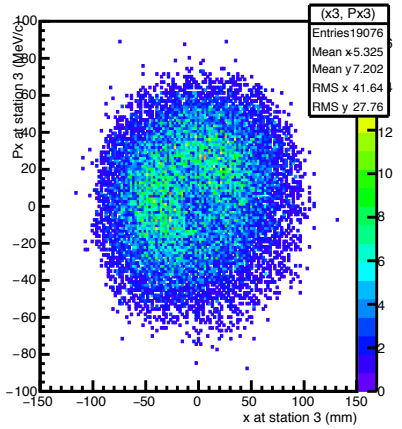
Upstream

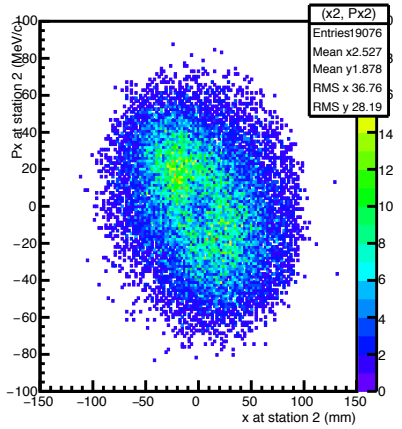
Downstream

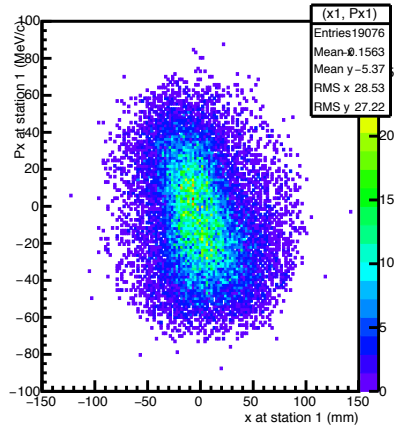
(x, Py)



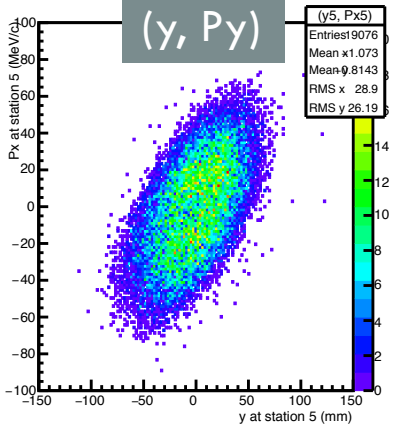



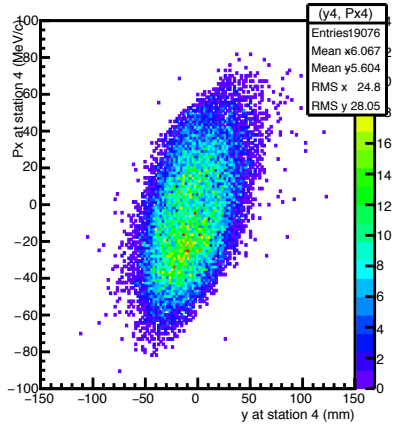



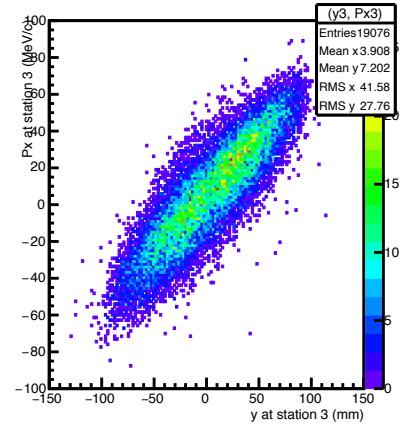



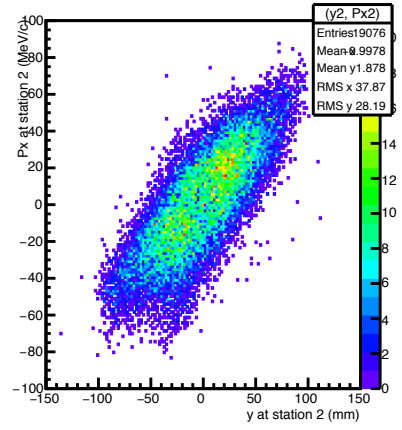



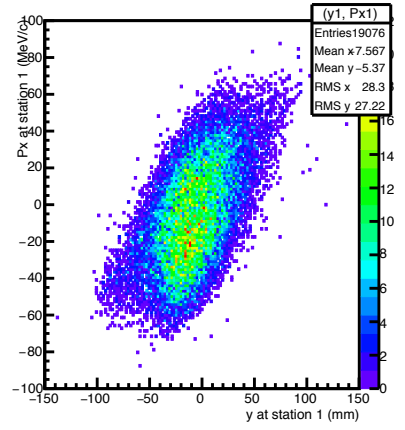

(y, Py)



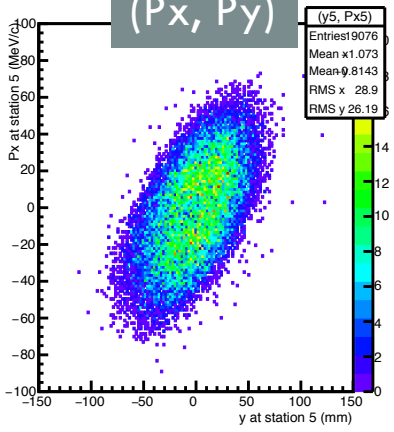



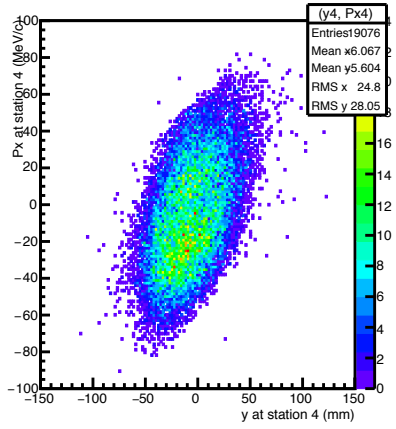



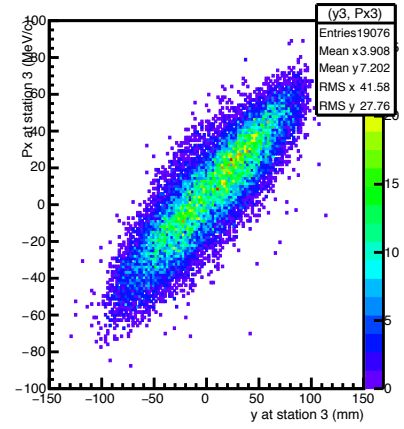



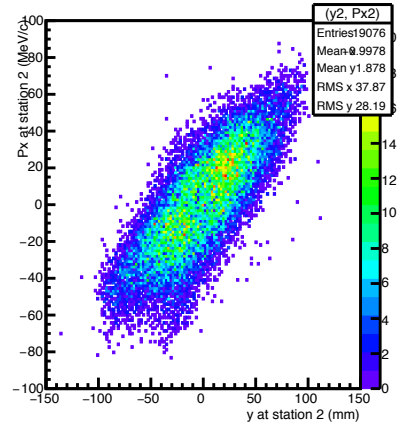



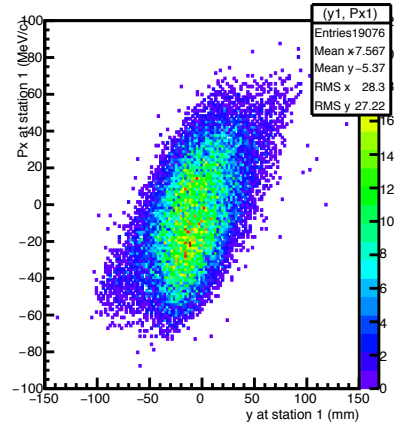

(Px, Py)



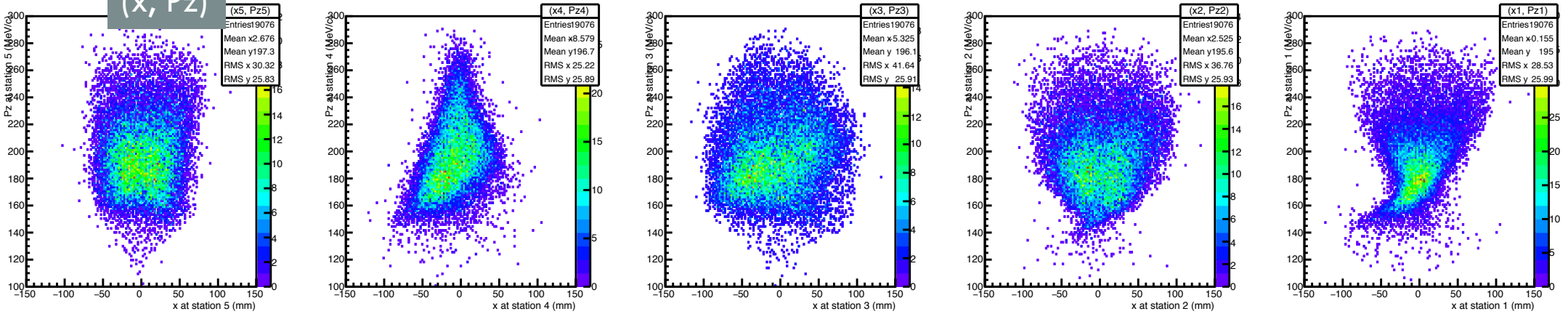



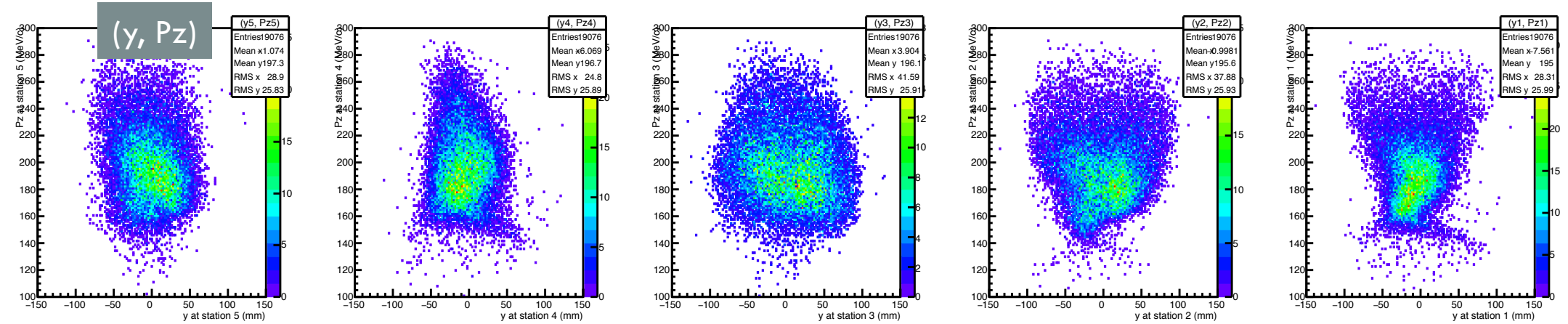



Upstream

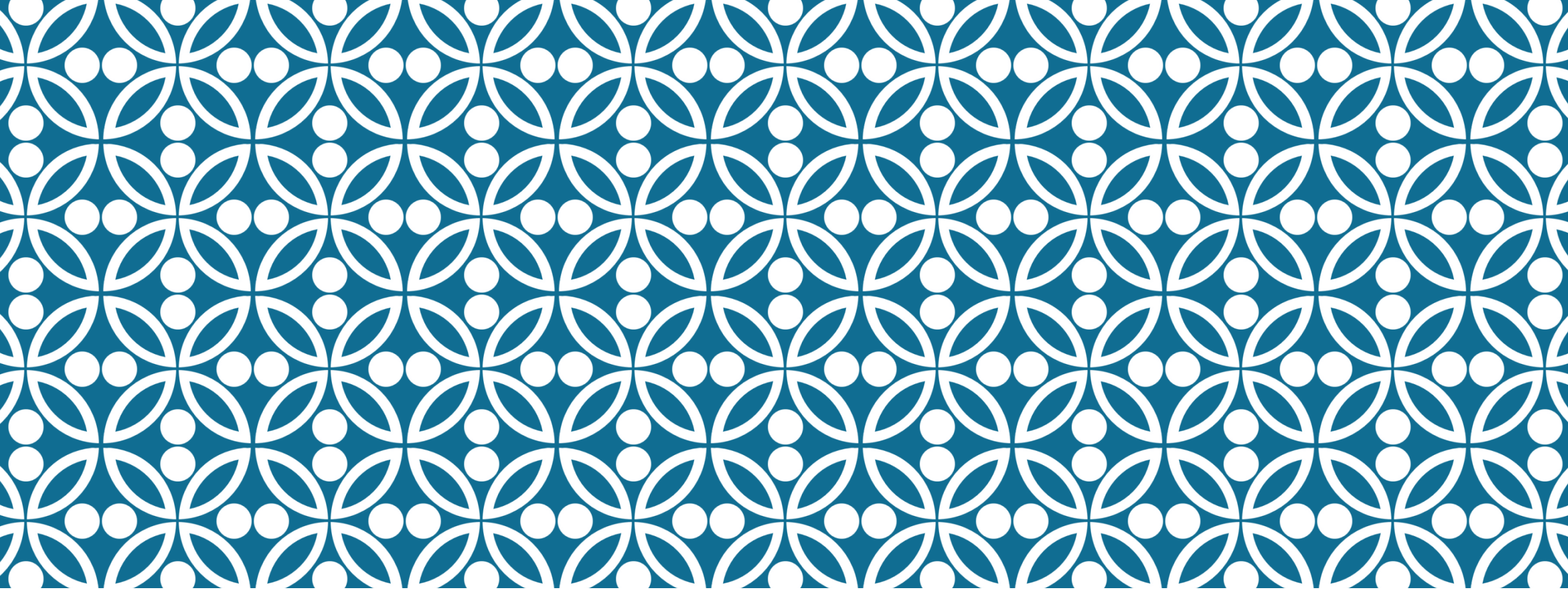
(x, Pz)




(y, Pz)



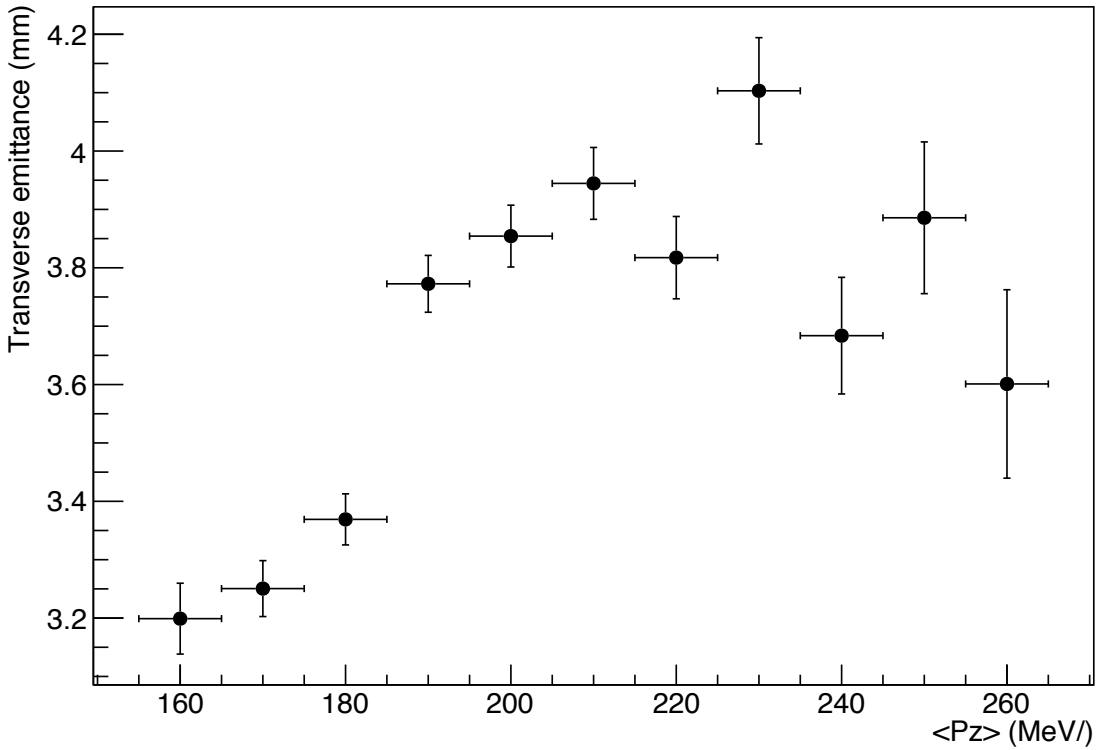

Downstream



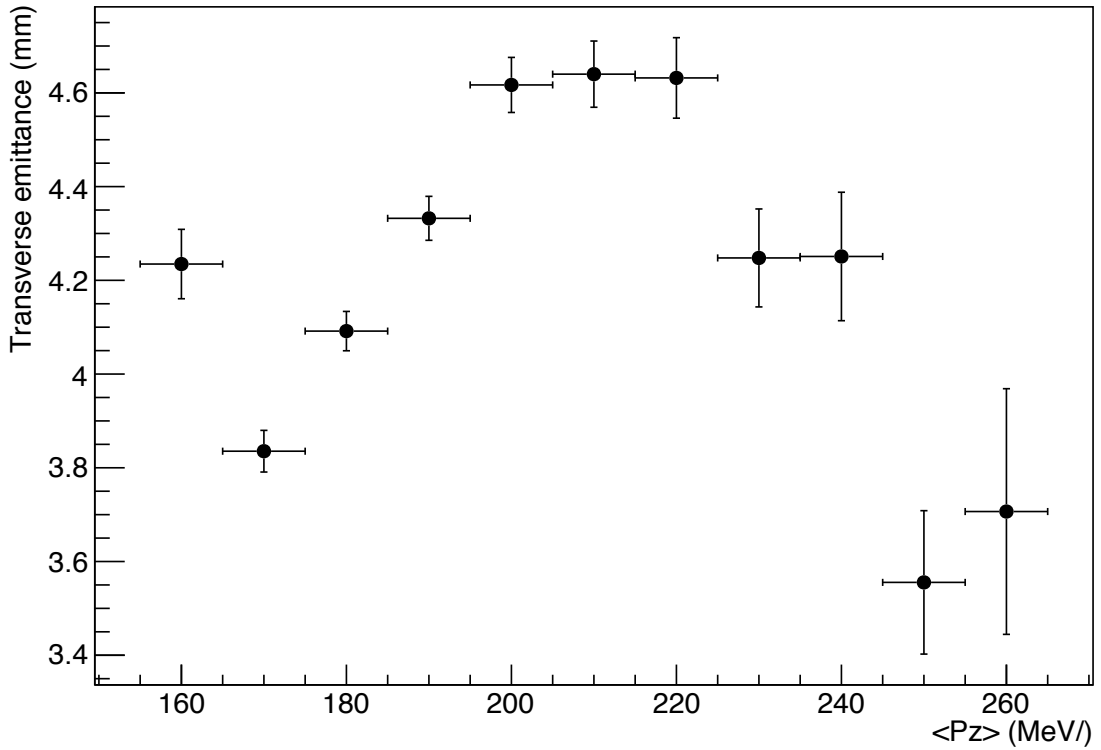
# COVARIANCE MATRICES & EMITTANCES

... because we're not done yet!

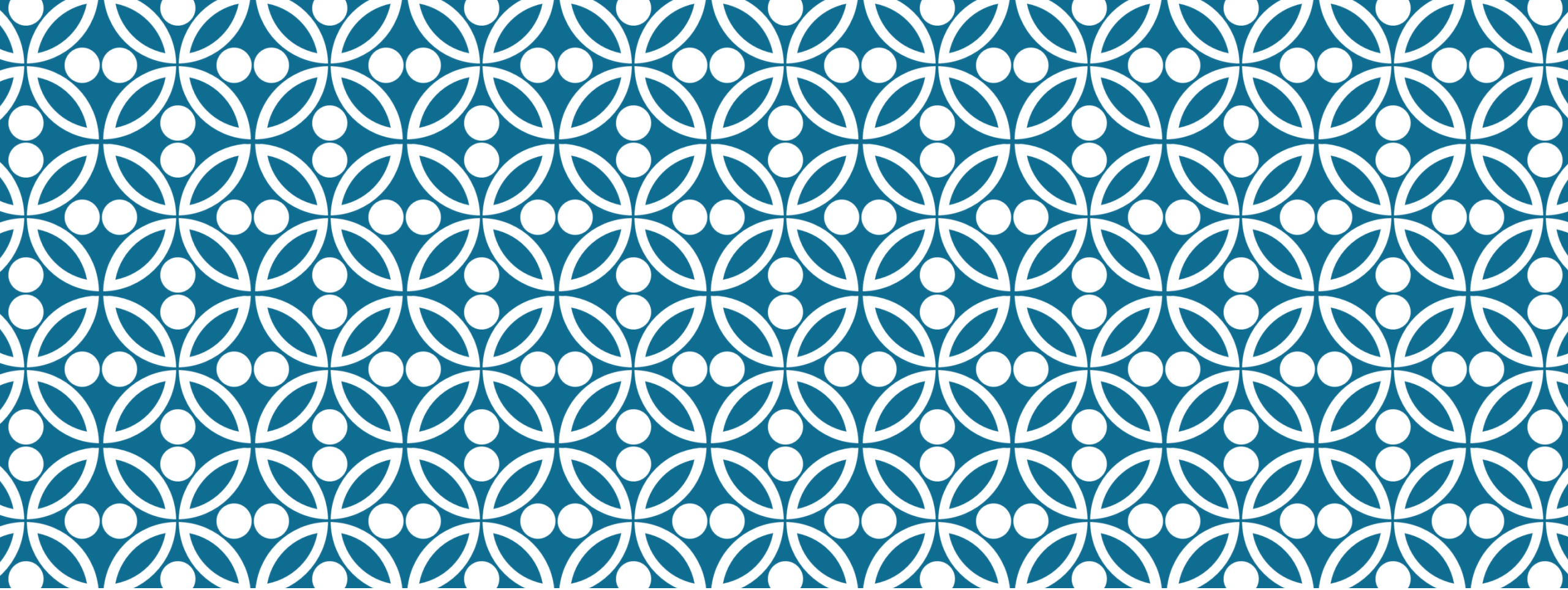
# EMITTANCE




Data




MC

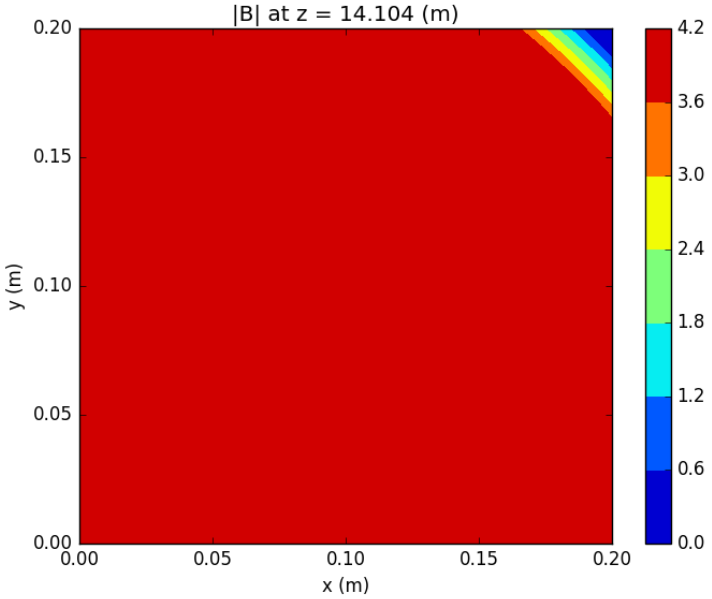


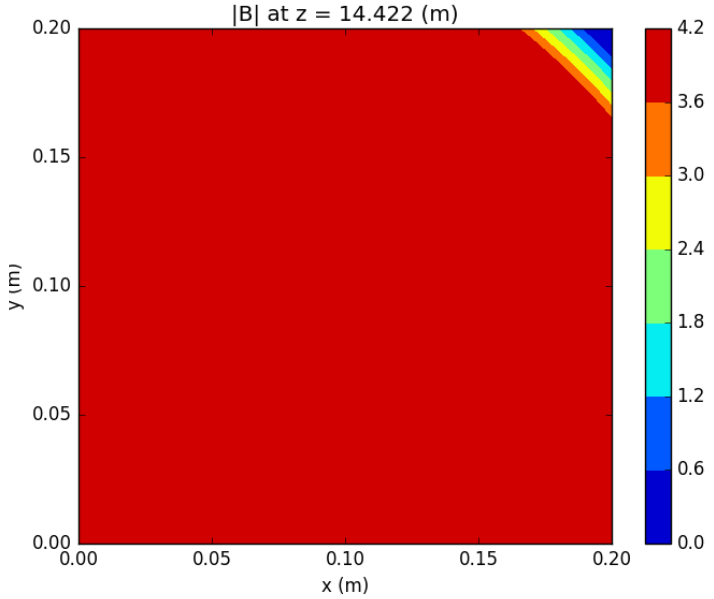
# FIELDS

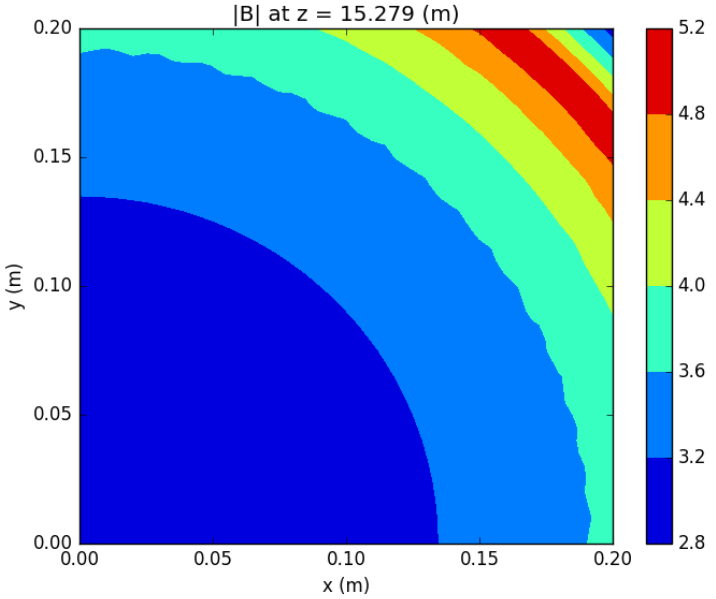
* Looking at **non-rotated** OPERA field map. MAUS applies a rotation & translation ($dx$ = 0.00759 mm, $dy$ = 0.1810 mm, $\theta_x$=-0.0458 deg, $\theta_y$=0.0196 deg

# HALL PROBE/OPERA COMPARISON (MAUS COORDS)

| Probe # | z (mm) ±5 | x (mm) | y (mm) | Average \|B\| measured (T) | \|B\| from OPERA map (T) |
|---|---|---|---|---|---|
| 65 | 14422 | 138.6 | 80.0 | 4.05 | 4.03 |
| 67 | 15279 | -138.6 | 80.0 | 3.80 | 3.33 |
| 77 | 14104 | 138.6 | 80.0 | 4.08 | 4.06 |
| 79 | 14422 | 0.0 | -160.0 | 4.05 | 4.03 |



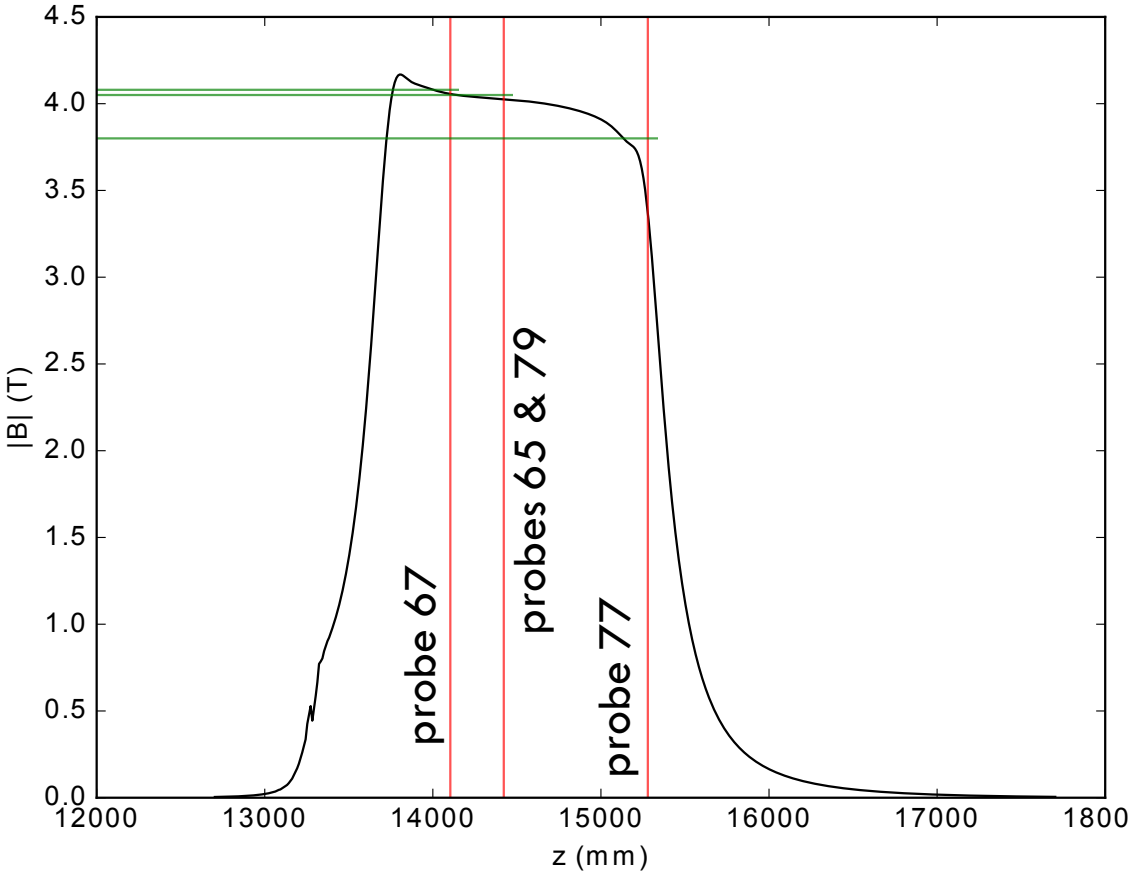



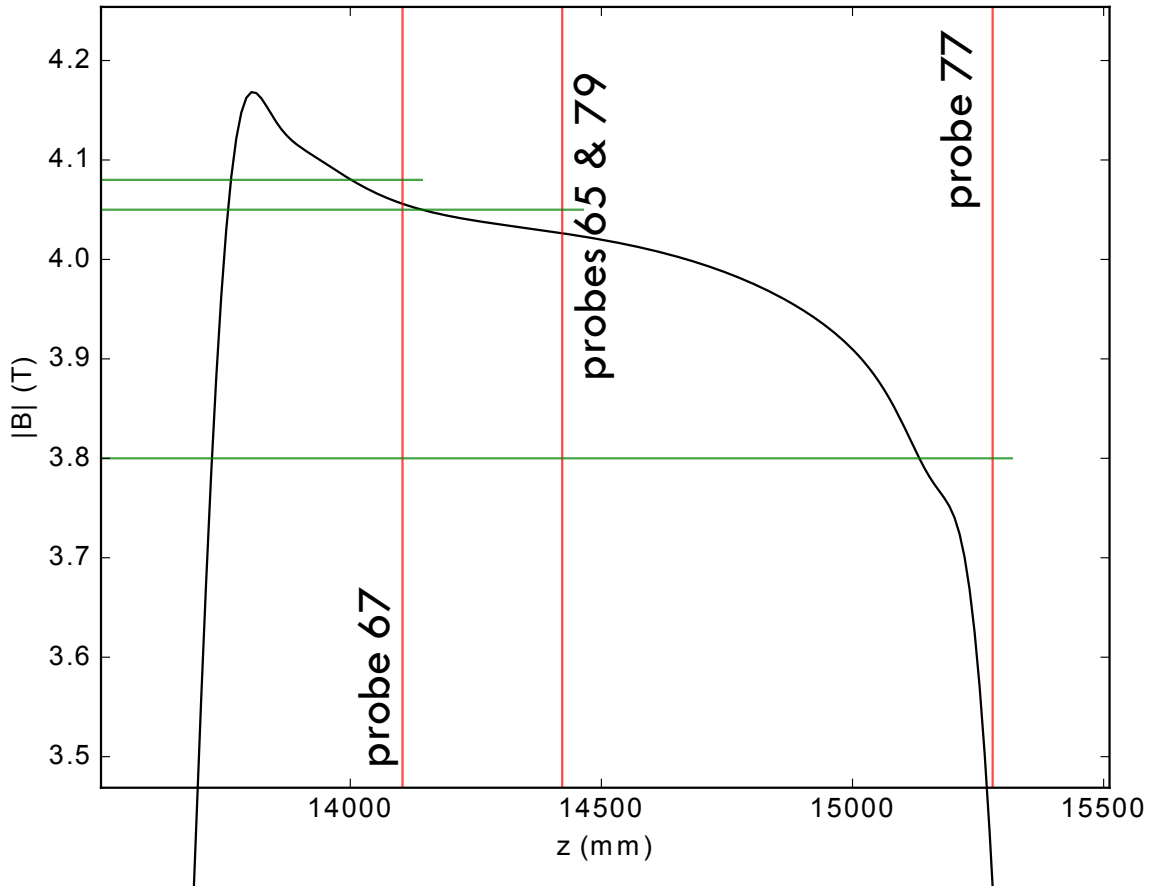



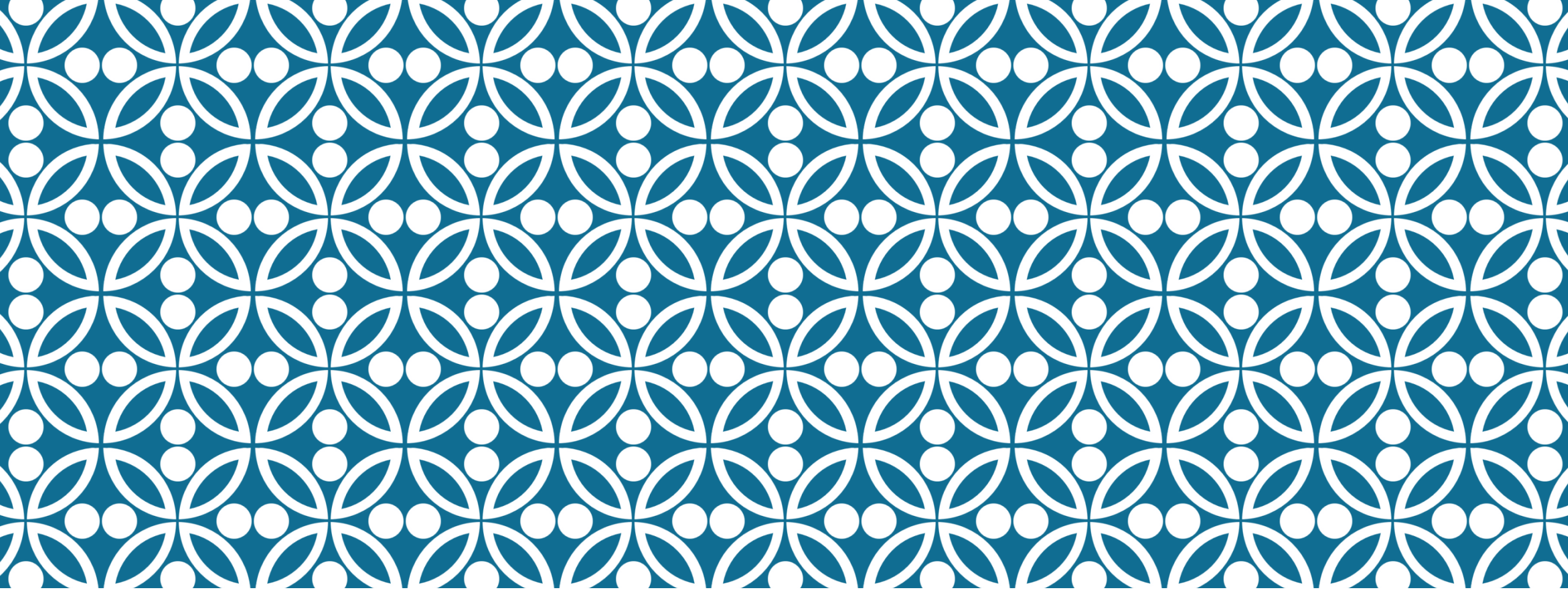
* Looking at **non-rotated** OPERA field map. MAUS applies a rotation & translation ($dx$ = 0.00759 mm, $dy$ = 0.1810 mm, $\theta_x$=-0.0458 deg, $\theta_y$=0.0196 deg

# HALL PROBE/OPERA COMPARISON (MAUS COORDS)

At r = 160 mm, same radius as Hall probes





# TOF—TRACKER COMPARISON

# TRACKER→TOF1 EXTRAPOLATION

- Propagate tracker tracks back to TOF1
- Compare with Rayner reconstruction
- Offsets in means point to misalignment of field map when tracking?

- Red: Propagated tracks from Chris Rogers
- Black: TOF1 reconstruction using Mark Rayners method (i.e. Step I paper)
- Green: 1000 ellipses generated using errors on Rayner recon

# TRACKER→TOF1 EXTRAPOLATION