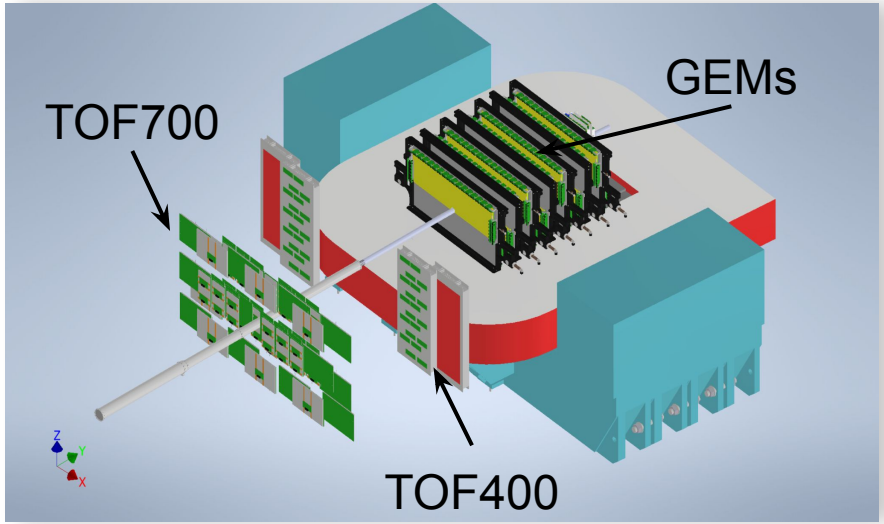
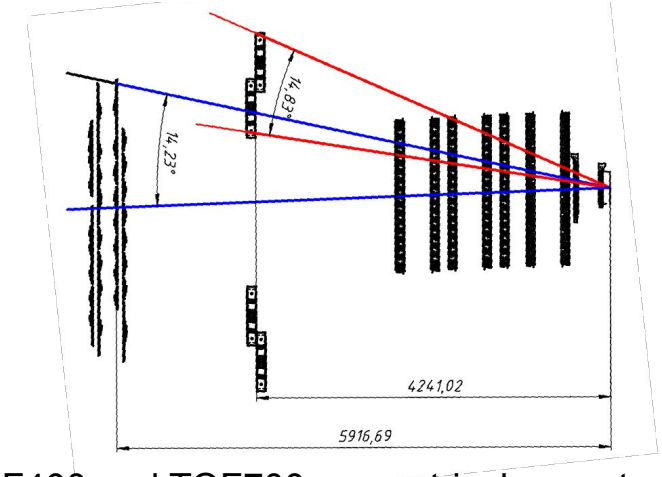
TOF detector calibration algorithm.
Strip-by-strip analysis.

Time-of-Flight systems



BM@N tracking and TOF systems

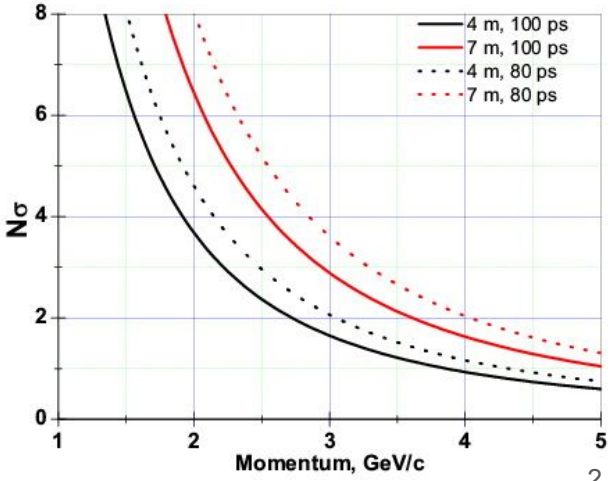


TOF400 and TOF700 geometrical acceptance

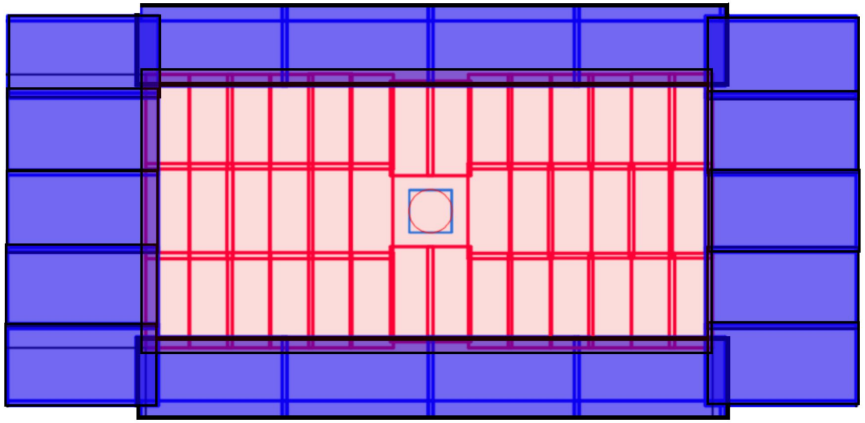
$$\Delta t = \frac{L}{c}\left(\sqrt{1+\frac{m_1^2}{p^2}} - \sqrt{1+\frac{m_2^2}{p^2}}\right)$$

$$\sigma_{m^2}^2 = 4m^4\left(\frac{\sigma_p}{p}\right)^2 + 4E^4\left(\frac{\sigma_t}{t}\right)^2 + 4E^4\left(\frac{\sigma_L}{L}\right)^2$$

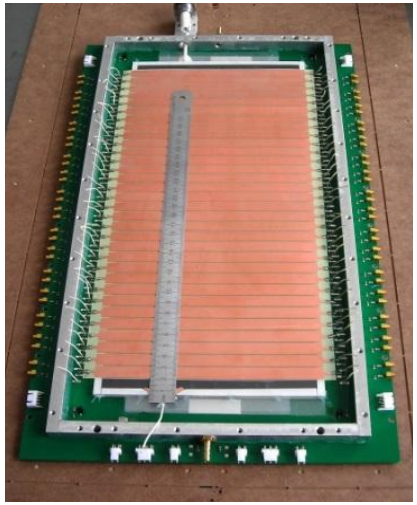
TOF separation power as a function of momentum for different flight path lengths and time resolutions



TOF700 subsystem

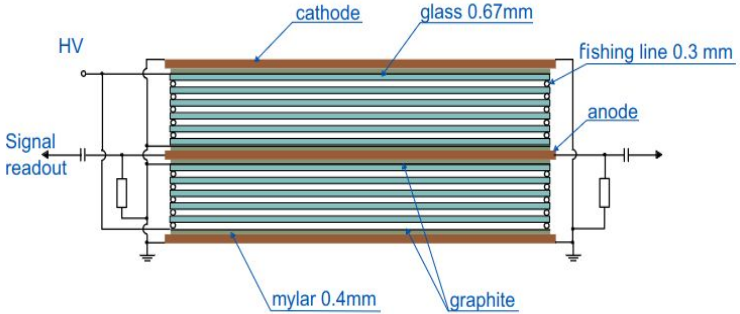


TOF700 layout



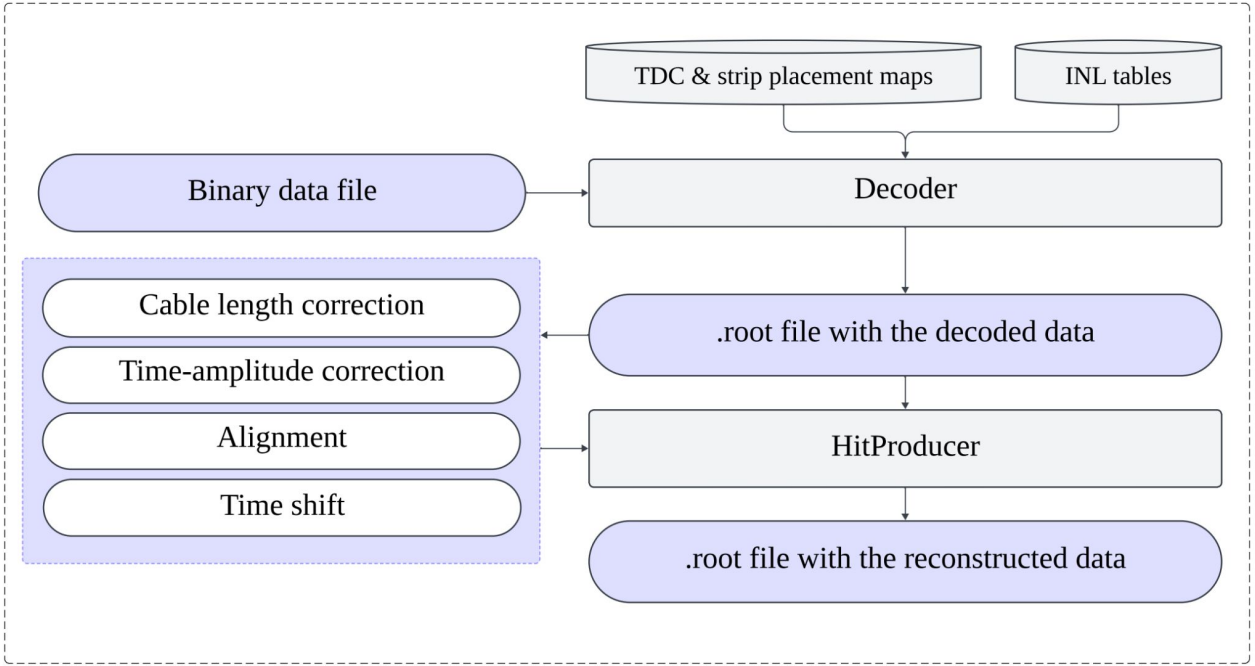


58 mRPC detectors of 2 sizes (30×56 cm2; 35×16 cm2)
16 (32) readout strips of 1.8×56 (1.×16) cm2 in one mRPC
1600 Readout strips
3200 channel of FEE
Active area 3.15×1.56 m2
90%C2H2F4 + 5% SF6 + 5% i-C4H10
15 kV working point



TOF700 mRPC cross section

Data reconstruction procedure



The TOF data flow diagram
The data reconstruction algorithm is the same for TOF400 and TOF700

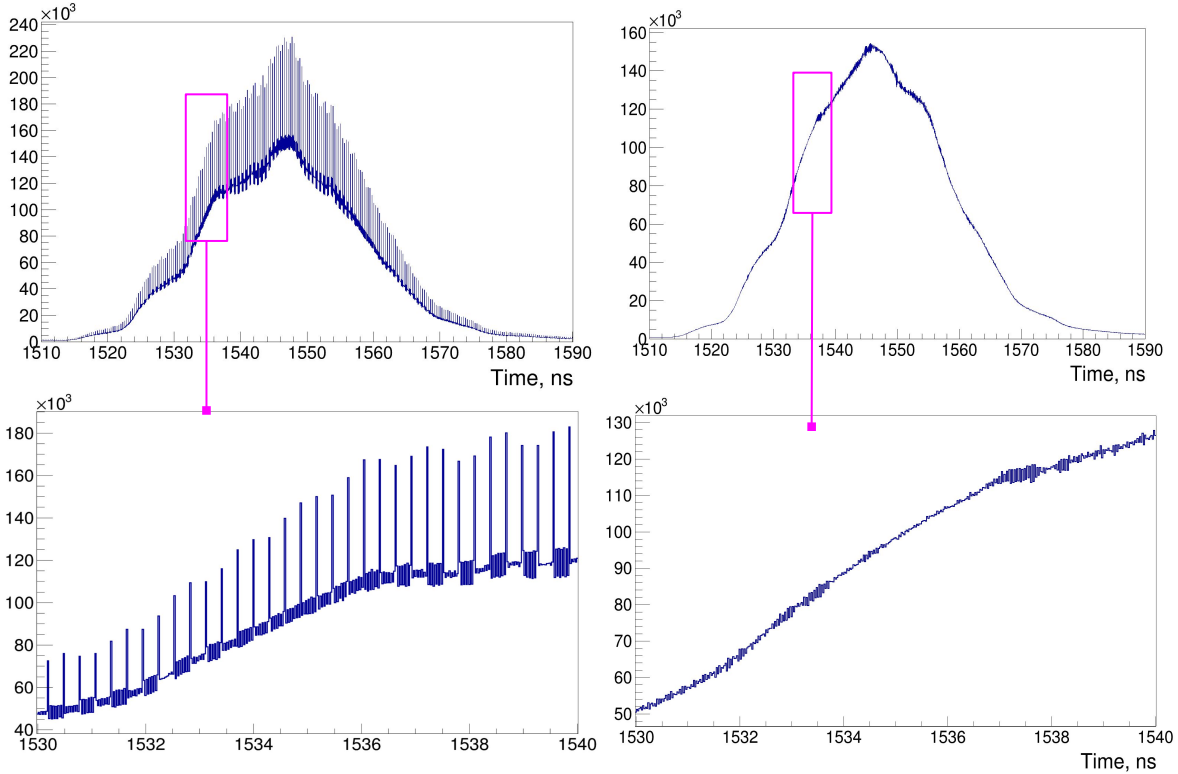
Integral Non-Linearity correction

Each channel encodes the signal with a specific sampling rate 1./Width$_{bin}$ Ideally,

$$t = N_{bin} \times Width_{bin}$$

In reality we need to correct for the INL as follows

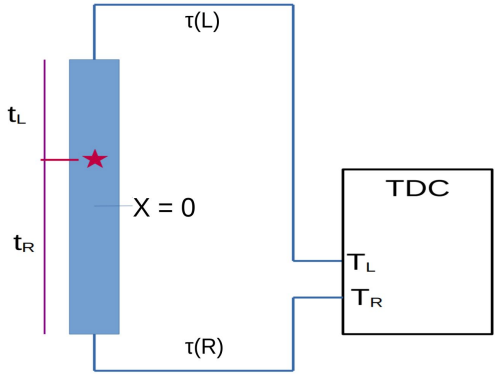
$$t = (N_{bin} + INL_{Nbin}) \times \ Width_{bin},$$



Signal time distribution before the INL correction (left plots) and after (right plots). Binning on both is the same - (1024 bins / 24 ns).

Cable length correction

To reconstruct hit coordinate along the strip one must know the time it took for the signal to pass from the hit to the sides of the strip. Different left and right cable lengths ⟶ delays in signal arrival time ⟶ coordinate reconstruction error



$$X = \frac{T_L - T_R}{2} * V_{sign}$$

$$T_L = t_L + \tau_L$$

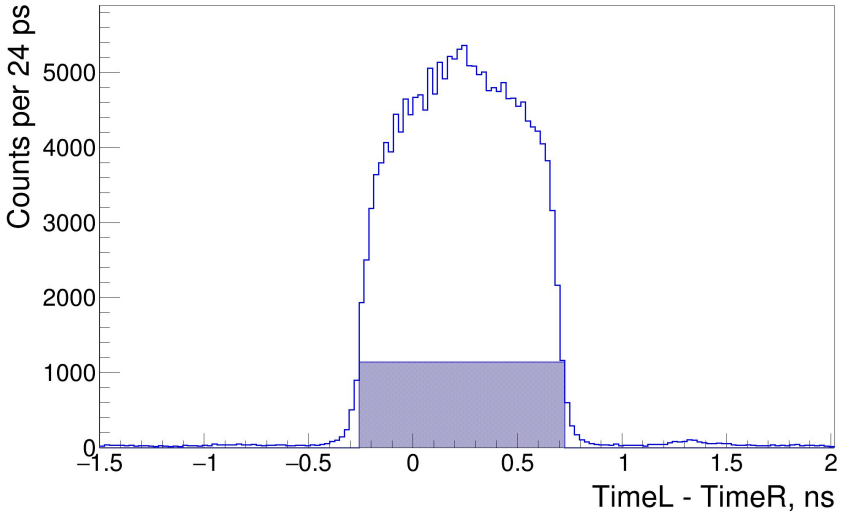
$$T_R = t_R + \tau_R$$

if $\tau_L = \tau_R$, then

$$X = \frac{t_L - t_R}{2} * V_{sign}$$

otherwise

$$X = \frac{t_L - t_R + C}{2} * V_{sign}$$



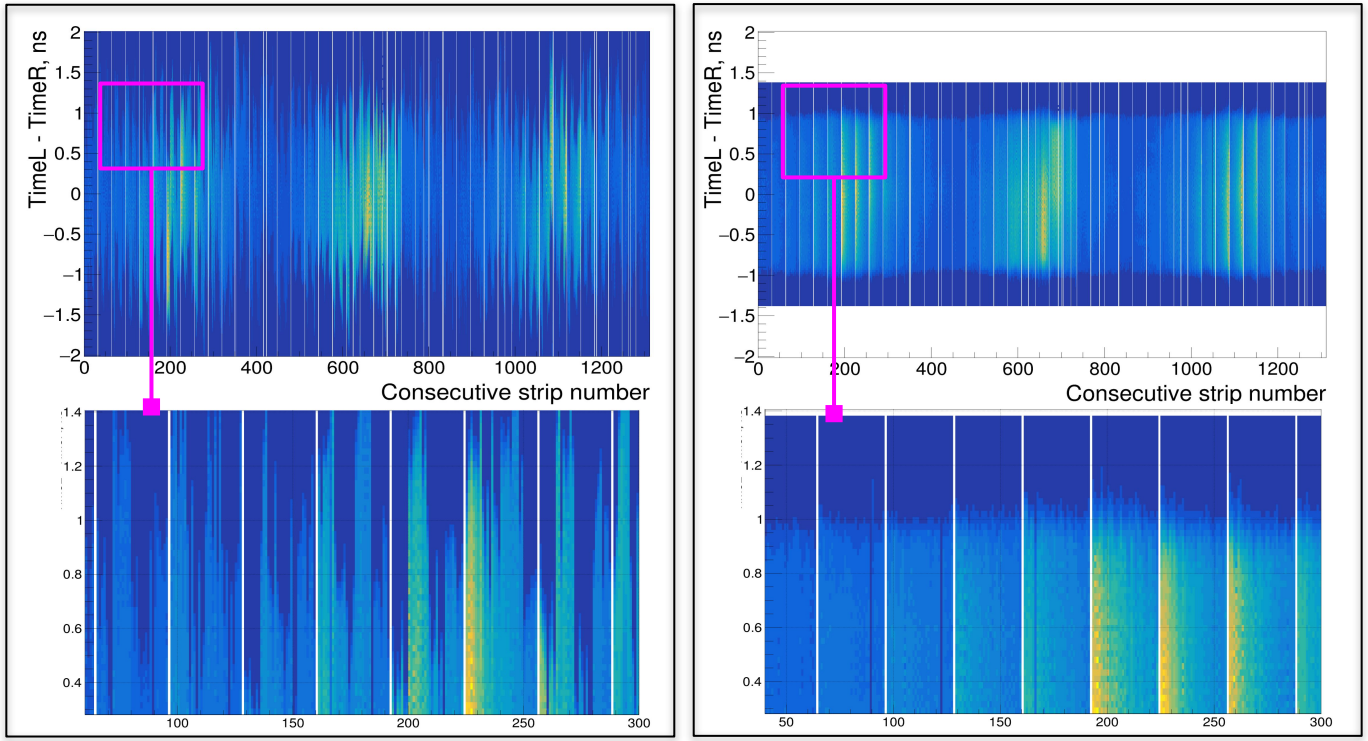
TimeL - TimeR distribution for a single strip.
Mean of the solid rectangle — the CL correction.

For TOF400 we are able to reconstruct **Y** hit coordinate (the strips are **vertically** oriented).
For TOF700 — **X** hit coordinate (the strips are **horizontally** oriented).
The procedure is the same.

Cable length correction

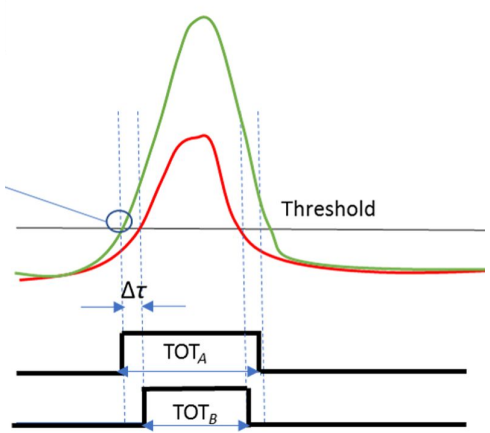
before

after



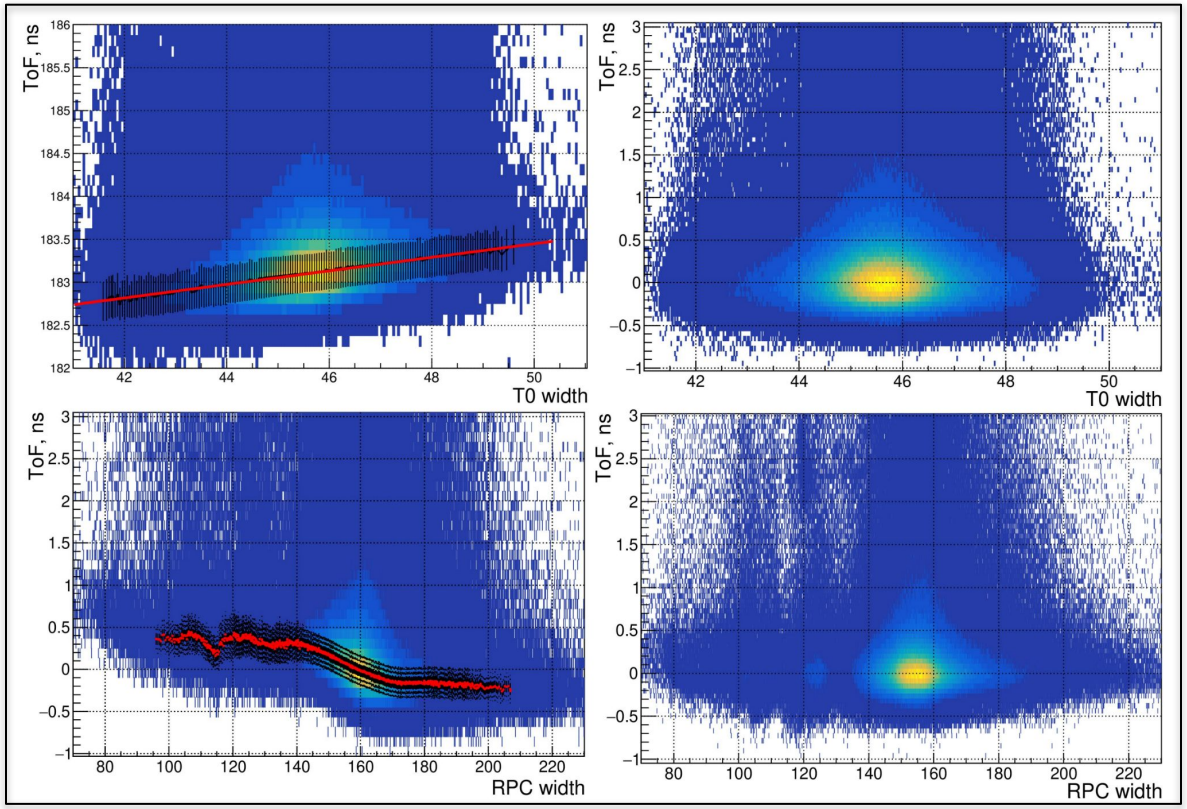
TimeL - TimeR (ns) distributions for all the strips in consecutive number

Time-amplitude (TA) correction



A particle's time of flight is the difference between the mRPC signal and the start T0 signal.

Time-amplitude dependence - signal's amplitude dependence on its moment of crossing the threshold. Appears for both T0 and mRPCs.

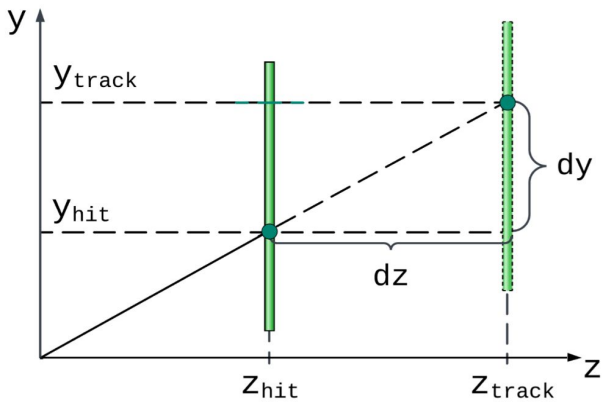


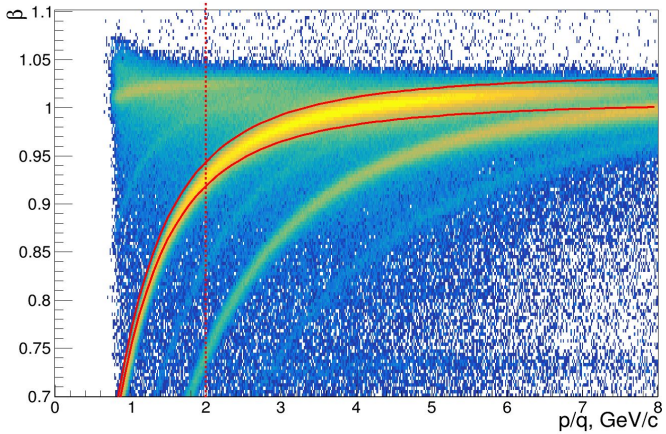
Time of flight *versus* signal amplitude before TA correction

Time of flight *versus* signal amplitude after TA correction

Alignment

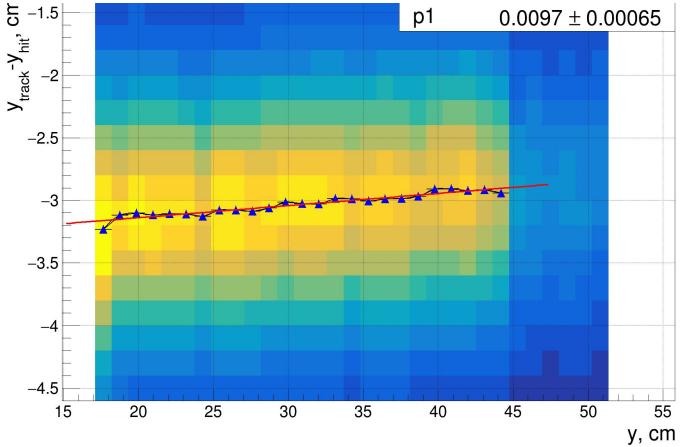
Alignment is performed using protons with momentum above 2 GeV/c

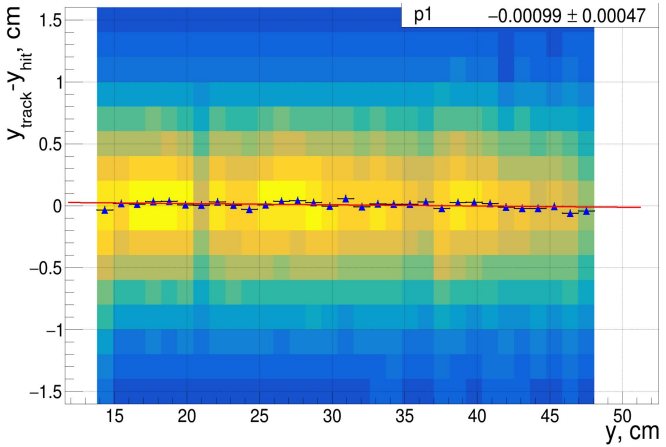




$$dy = y_{track} - y_{hit}$$

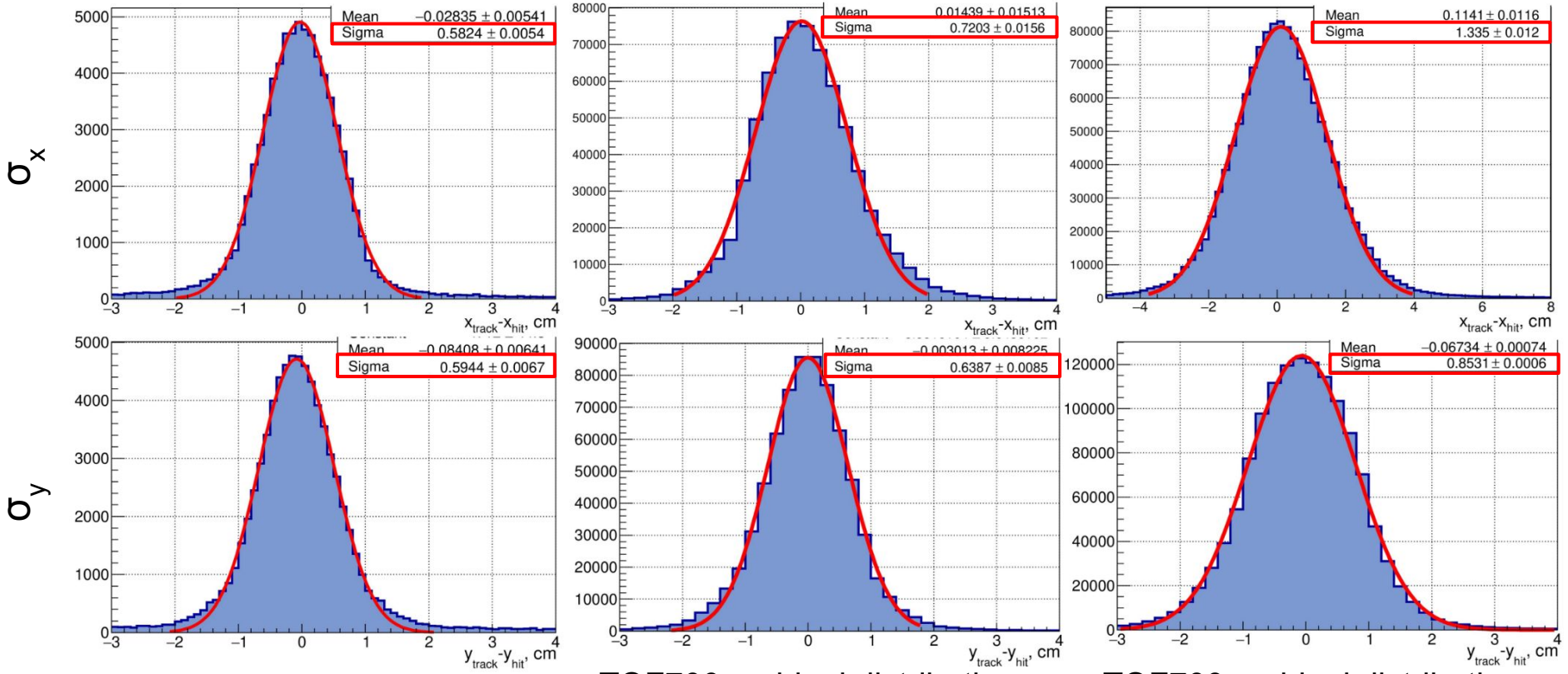
$$dy = \frac{dz}{z_{track}} y$$





dy *versus* y for a single mRPC before and after alignment

Alignment. Matching resolution



TOF400 residual distributions

TOF700 residual distributions (small mPRCs)

TOF700 residual distributions (big mPRCs)

Time shift correction

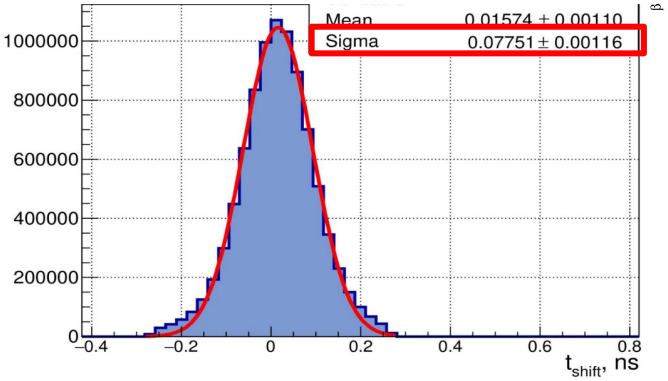
After the TA correction ToF peak is placed at zero → need to add a time constant corresponding to a particle ToF for each strip.

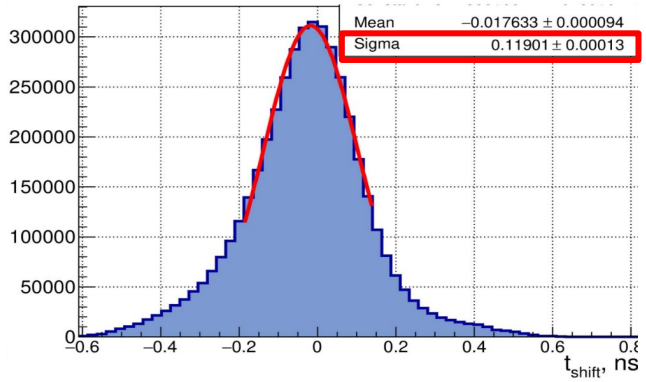
- Select particles (pions or protons) by mass in a narrow momentum range
- Calculate theoretical ToF having the L and momentum known from the tracking system:

$$t_{theor} = \frac{L}{c}\sqrt{\frac{m^2}{(p/q)^2} + 1}$$

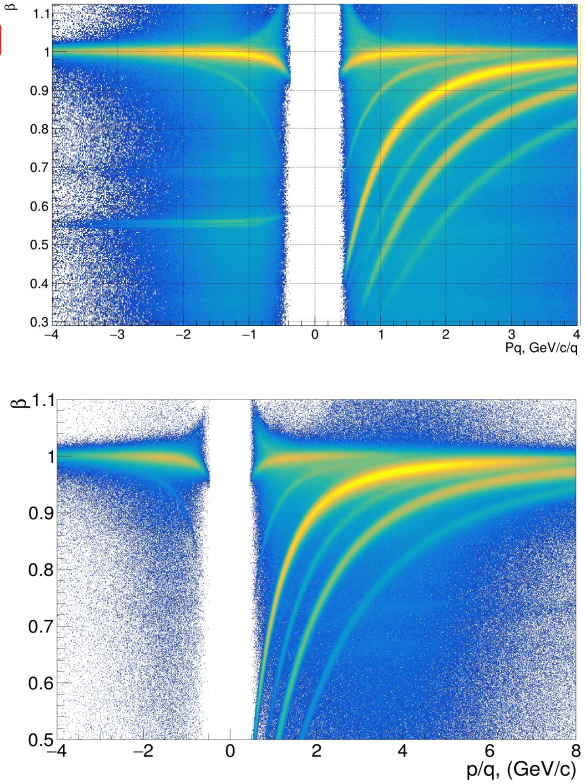
- Calculate time shift as

$$t_{shift} = t_{theor} - t_{exp}$$



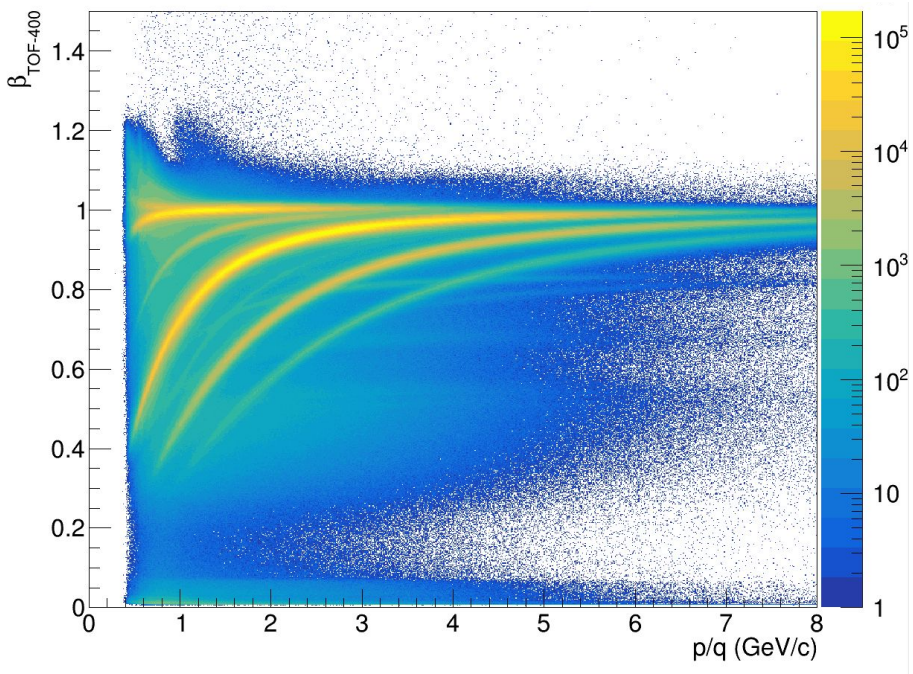


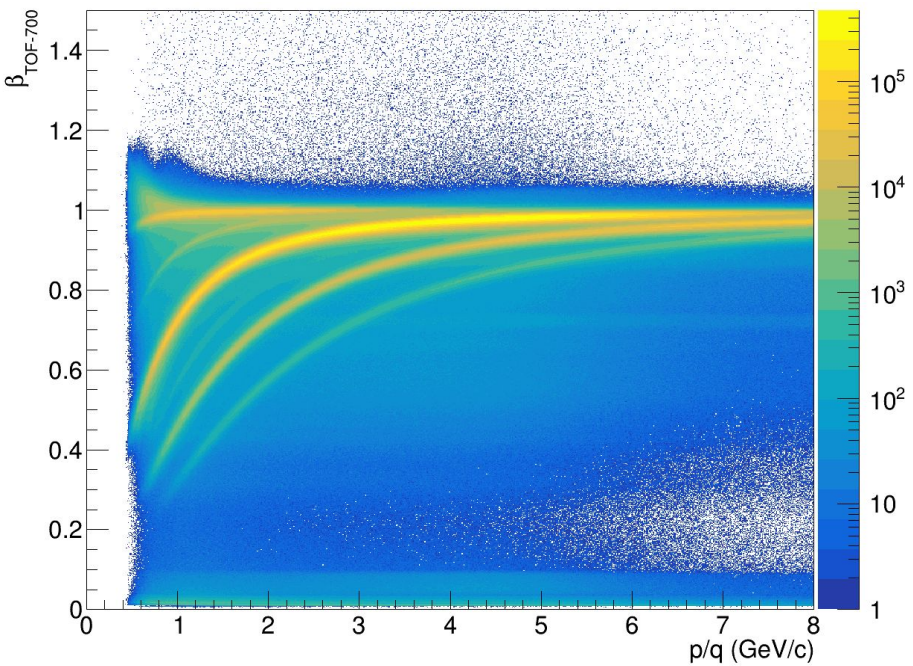
Time shift distributions for the TOF400 (top) and TOF700 (bottom)



Relativistic speed *versus* rigidity distribution **after** time shift correction

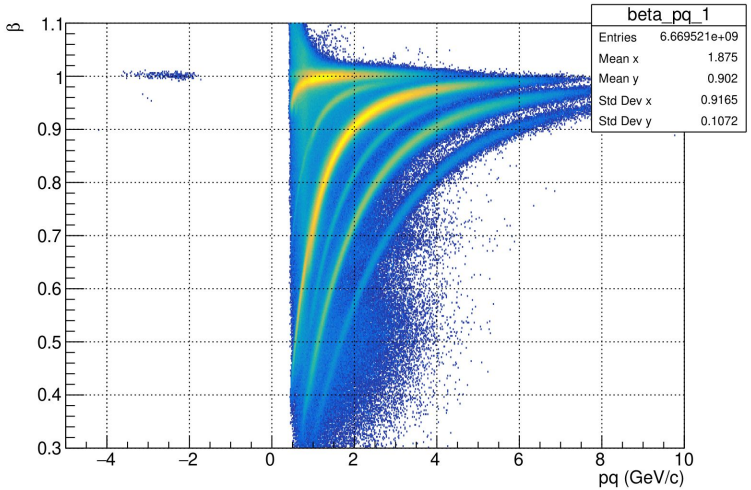
TOFs strip-by-strip examination

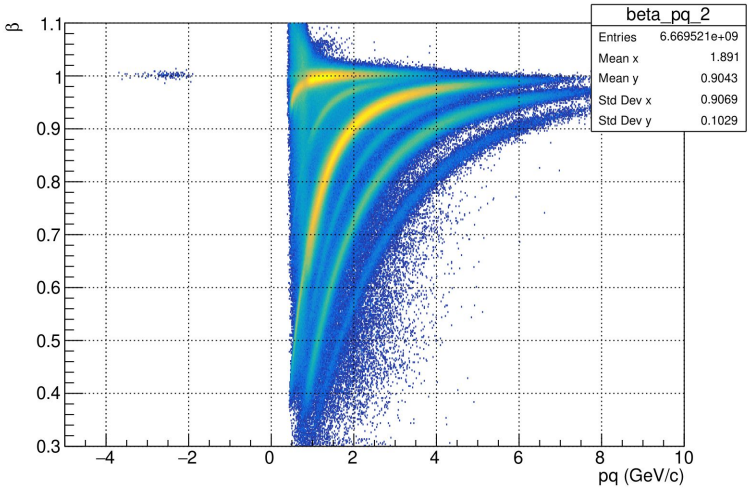


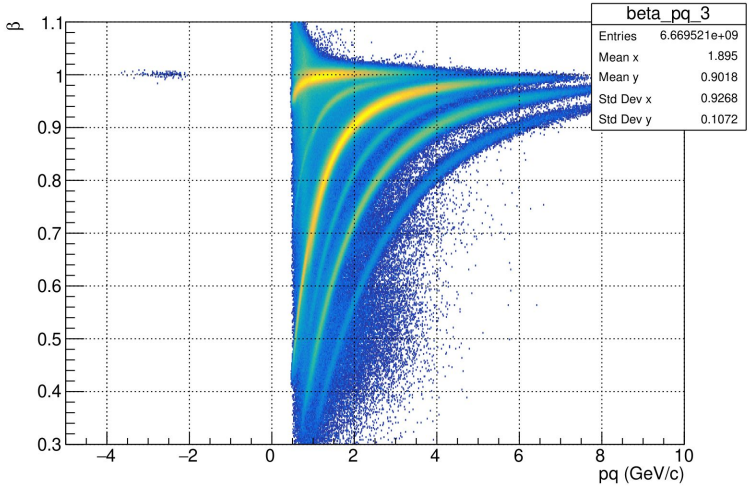


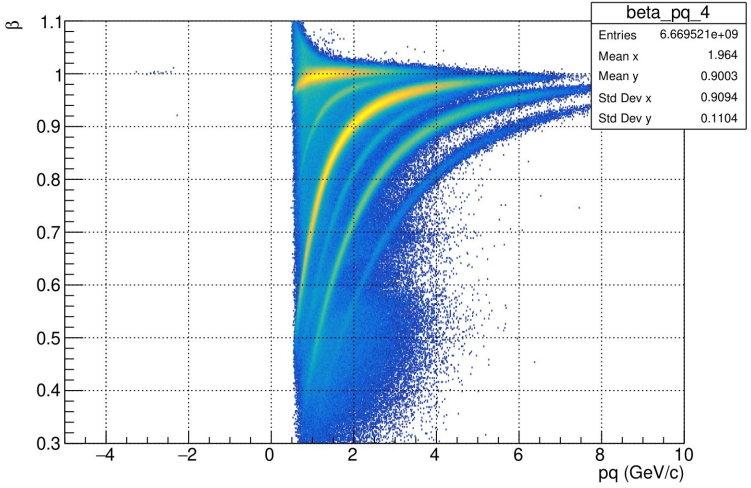
The hypothesis for the strange bands in pid plots - wrong TS correction values for some strips.
Strip-by-strip beta-pq distibutions have been plotted for TOF400 and TOF700 (the pdfs attached). Some strips indeed look “bad”.

An example of several **planes** in TOF400 where nothing criminal is going on.

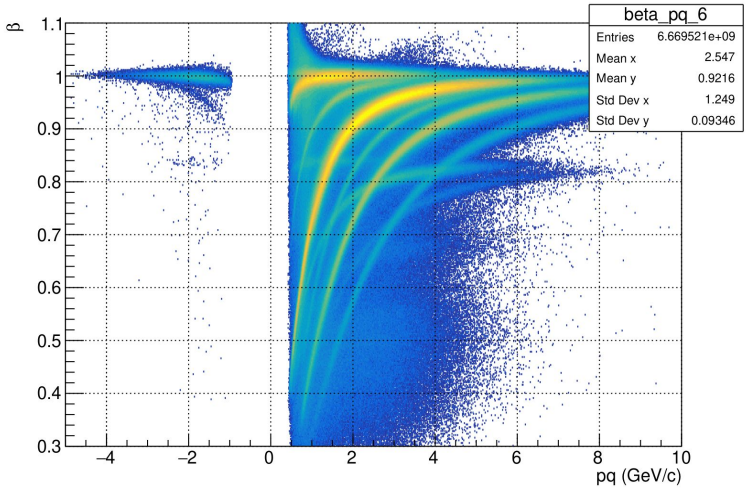


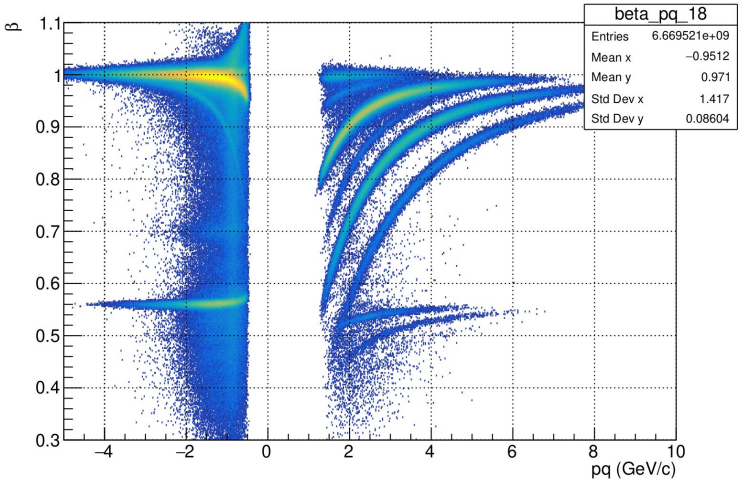




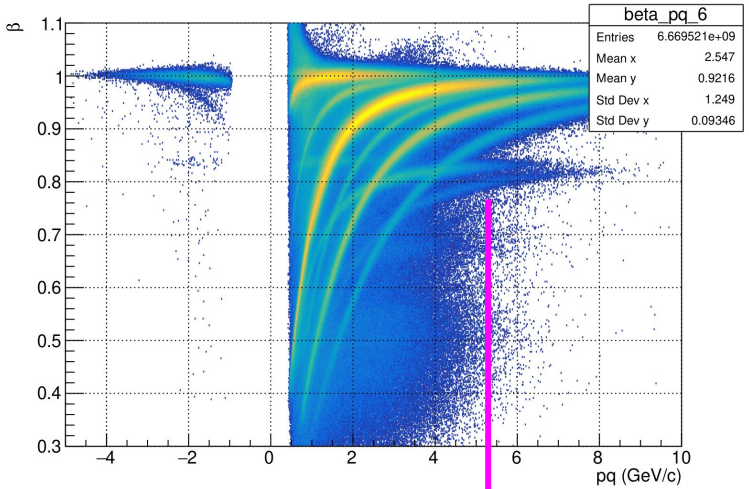


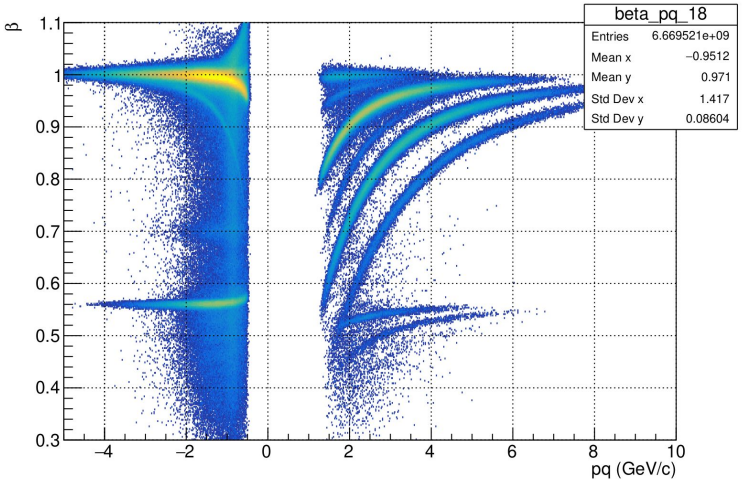
Planes with the bands of concern.

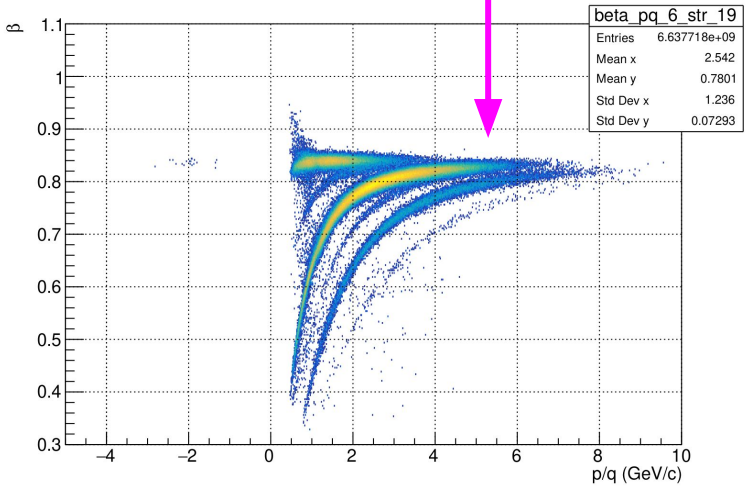




Planes with the bands of concern.

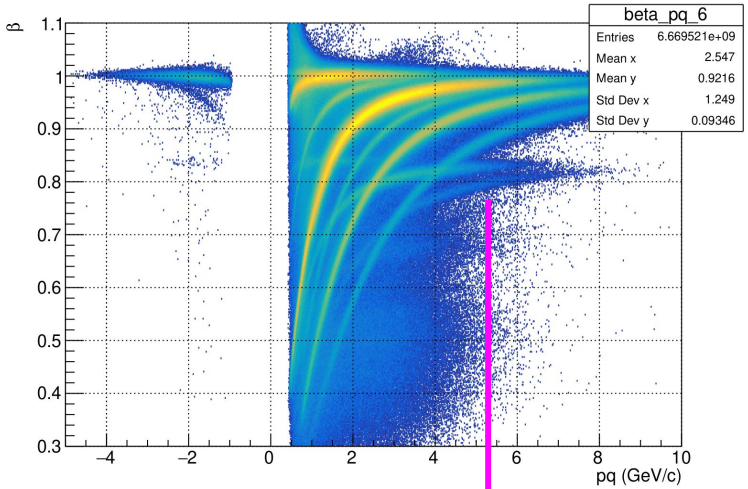


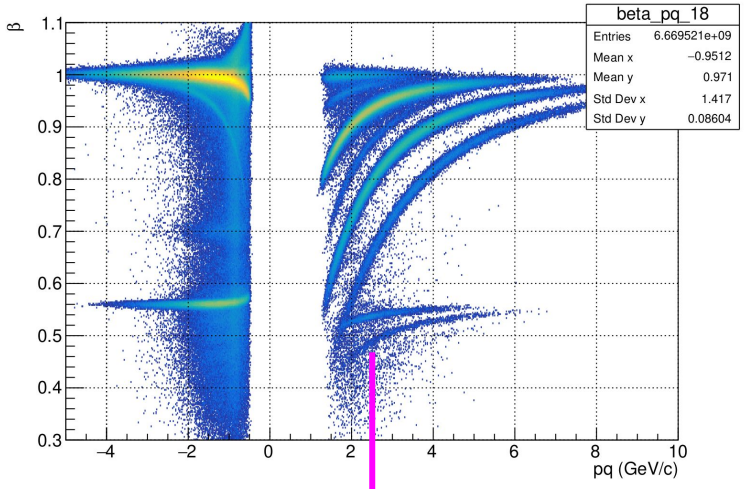


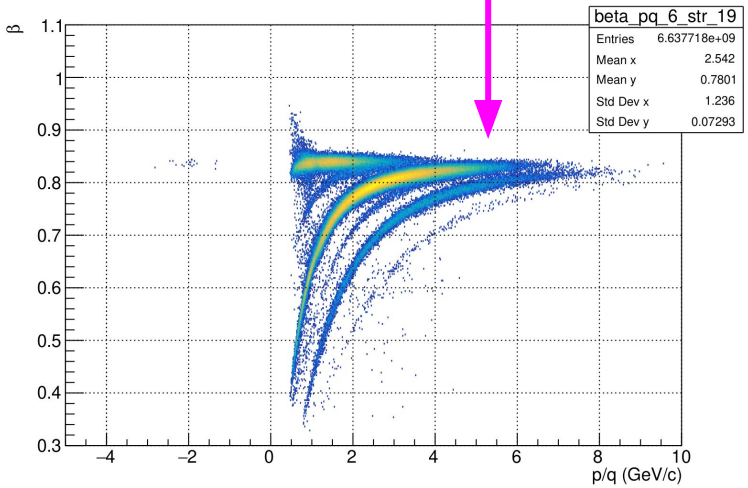


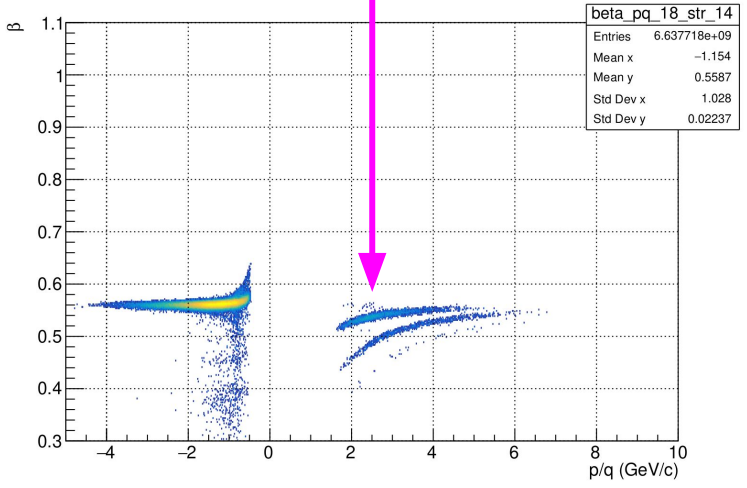
Planes with the bands of concern.

Strips like these needs to be excluded.

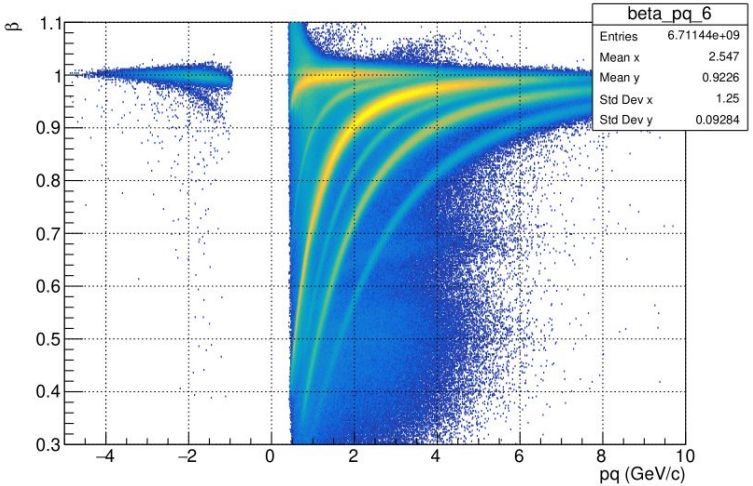


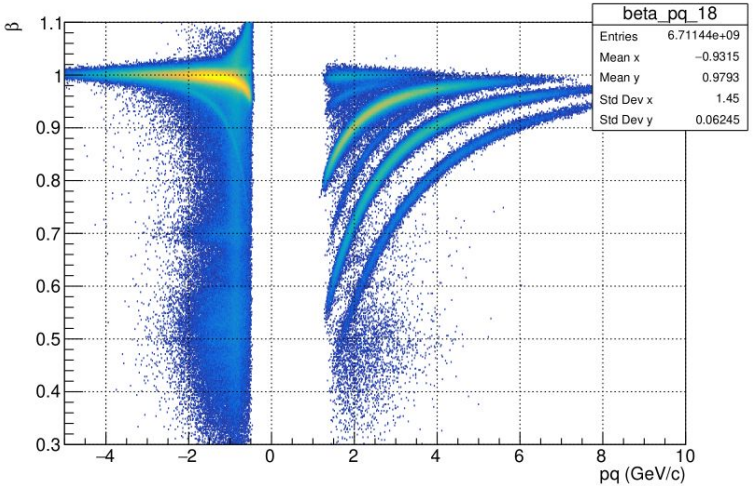


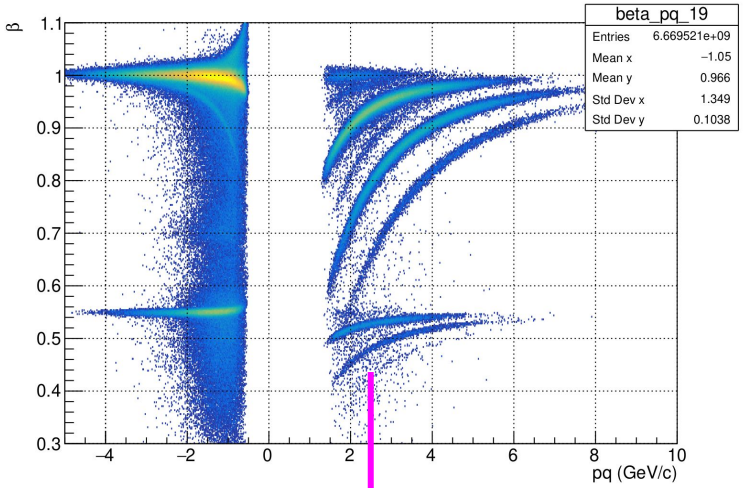


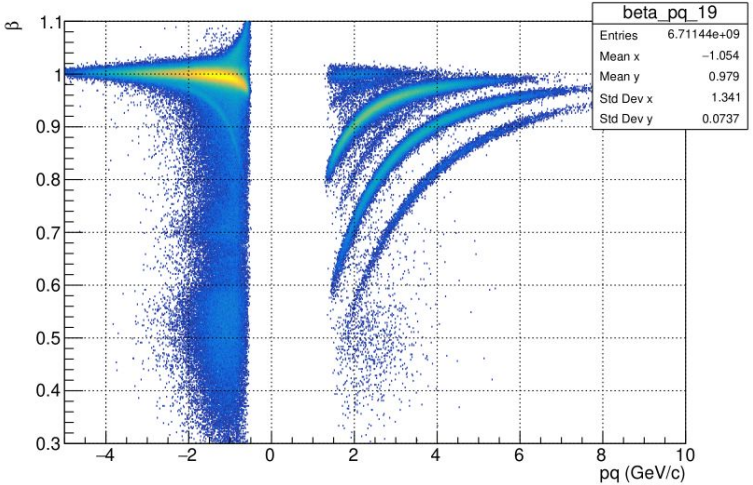


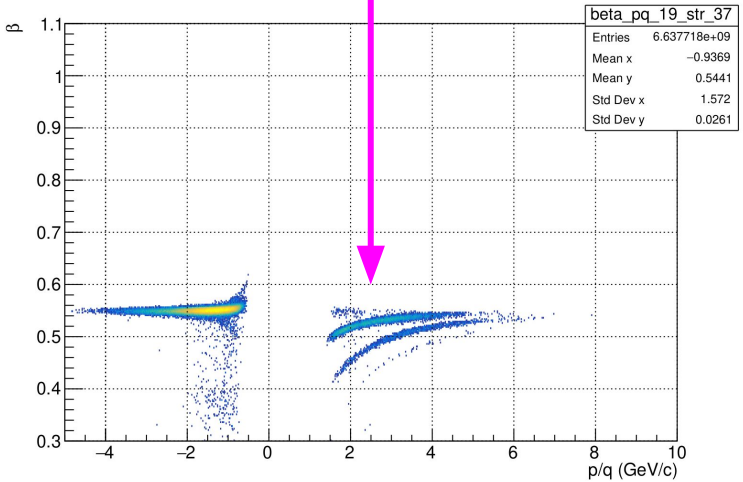
Planes with the bands of concern.

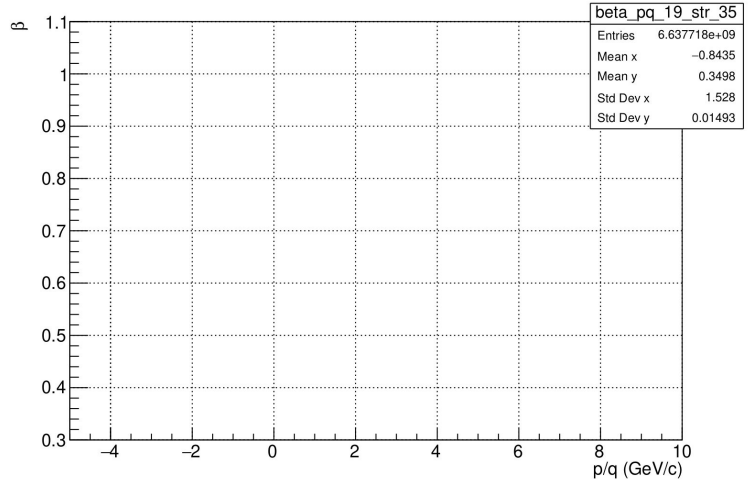




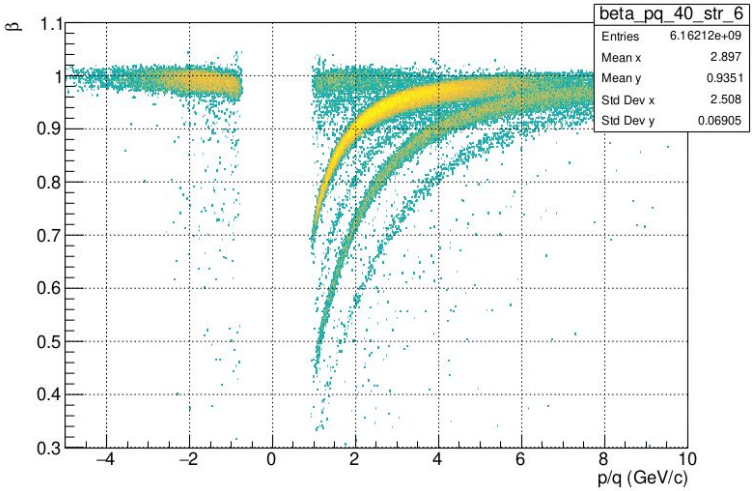

beta_pq_19
Entries 6.669521e+09
Mean x −1.05
Mean y 0.966
Std Dev x 1.349
Std Dev y 0.1038
β
pq (GeV/c)

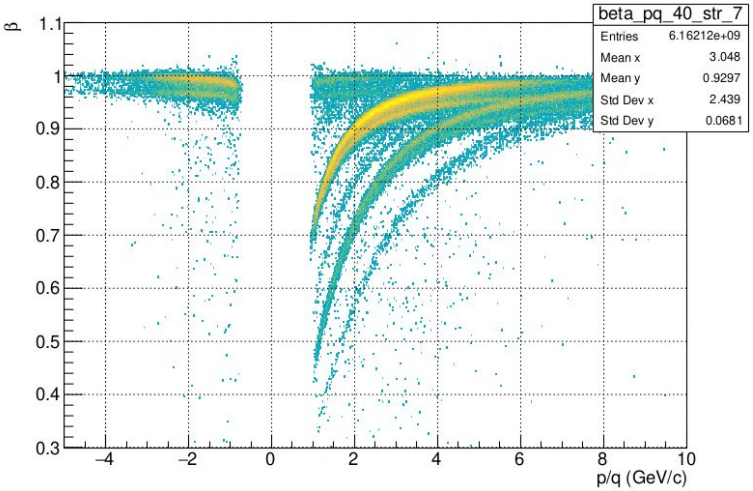

beta_pq_19
Entries 6.71144e+09
Mean x −1.054
Mean y 0.979
Std Dev x 1.341
Std Dev y 0.0737
β
pq (GeV/c)

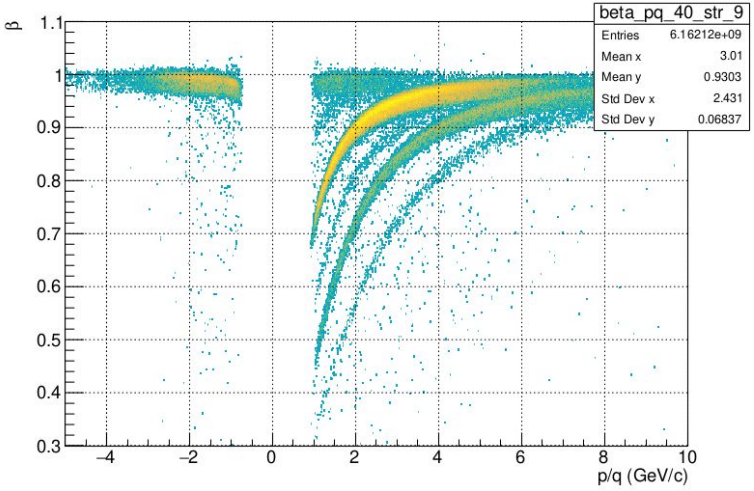

beta_pq_19_str_37
Entries 6.637718e+09
Mean x −0.9369
Mean y 0.5441
Std Dev x 1.572
Std Dev y 0.0261
β
p/q (GeV/c)

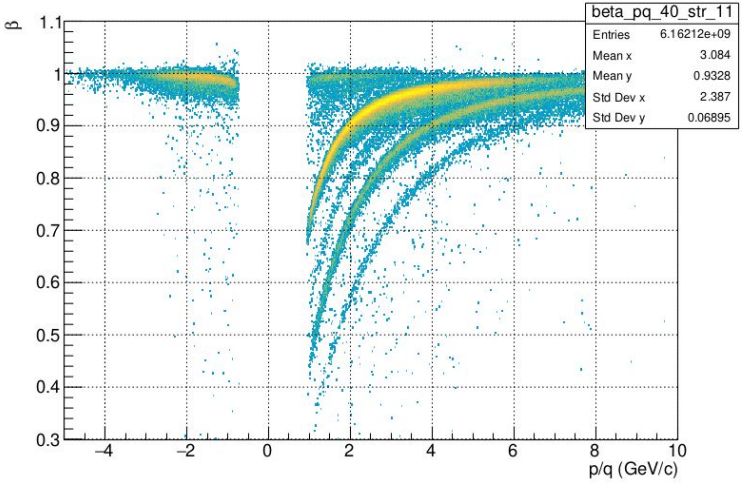

beta_pq_19_str_35
Entries 6.637718e+09
Mean x −0.8435
Mean y 0.3498
Std Dev x 1.528
Std Dev y 0.01493
β
p/q (GeV/c)

As for the TOF700, no such severely troubled strips are observed, but some strips show too wide bands, which is not ideal, may be excluded as well.









The strips found poorly calibrated can be excluded during the next processing of the dst-to-tree converter:

```
std::map<int, std::vector<int>> tof400_strips_to_exclude{
  {0, {39, 40, 41, 42}}, {6, {19}}, {8, {29,30,31}}, {9, {15,16,26,27,28}},{12, {40}},
  {18, {4, 13, 14, 15}}, {19, {35, 37}}
};

std::map<int, std::vector<int>> tof700_strips_to_exclude{
  {2, {25,26,}}, {3, {31}}, {5, {31}}, {6, {31}}, {8, {7,11,15,31}}, {9, {31}}, {10, {28,31}}, {12, {31}},
  {13, {18,19,20,21,22,23,24,25,26,27,228,29,30,31}}, {14, {31}}, {16, {31}}, {17, {31}}, {19, {31}}, {20,{31}},  {22, {31}}, {24, {31}},
  {25, {31}}, {26, {6, 31}}, {27, {31}}, {28, {31}}, {29, {8,31}}, {30, {15,17,31}}, {31, {31}}, {32, {31}}, {33,{22,23,24,25,31}},
  {34, {24,25,31}}, {35,{31}}, {36, {31}}, {37, {31}},
  {38, {31}}, {39, {31}}, {40, {1,2,3,4,5,6,7,8,9,11,17,18,19,20,26,27,31}}, {45, {11,12,13,15}}, {49, {15}}, {52, {3}}, {55, {8,9}},
  {57, {0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15}}
};
```

```
.Define("trBetaTof400_clean", remove_beta400_from_bad_strips, {"trBetaTof400", "trTof400Hit", "tof400Plane", "tof400Strip"})
.Define("trBetaTof700_clean", remove_beta700_from_bad_strips, {"trBetaTof700", "trTof400Hit", "tof700Plane", "tof700Strip"})
.Define("trM2Tof400", trM2, {"trMom", "trBetaTof400_clean"})
.Define("trM2Tof700", trM2, {"trMom", "trBetaTof700_clean"})
```

Residual dependence on pq and m2

Graphs are for the **mean** and **3*sigma** of the gaussian as fitted in pq slices.

Apparently no need to apply cut on the residual values.

