

# Performance of the Time-of-flight system at the BM@N experiment

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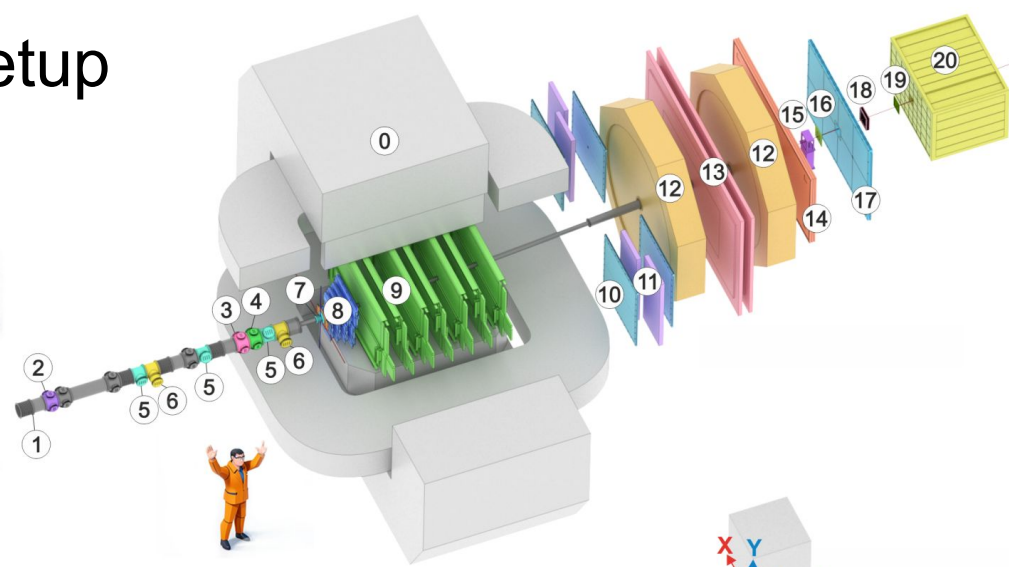
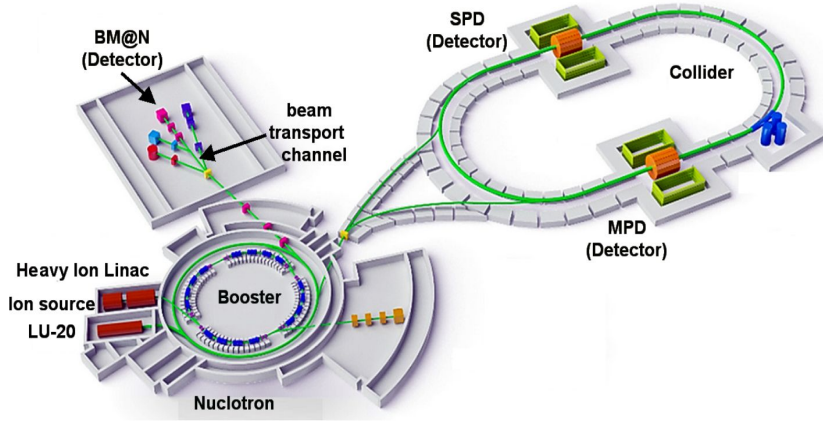
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Fundamental problems and applications  
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# The BM@N experiment setup

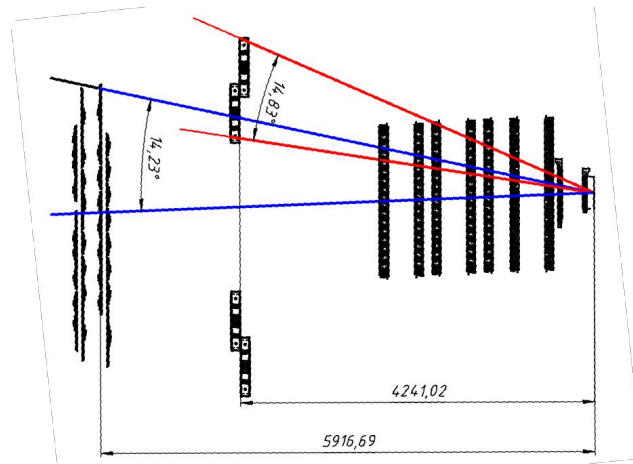
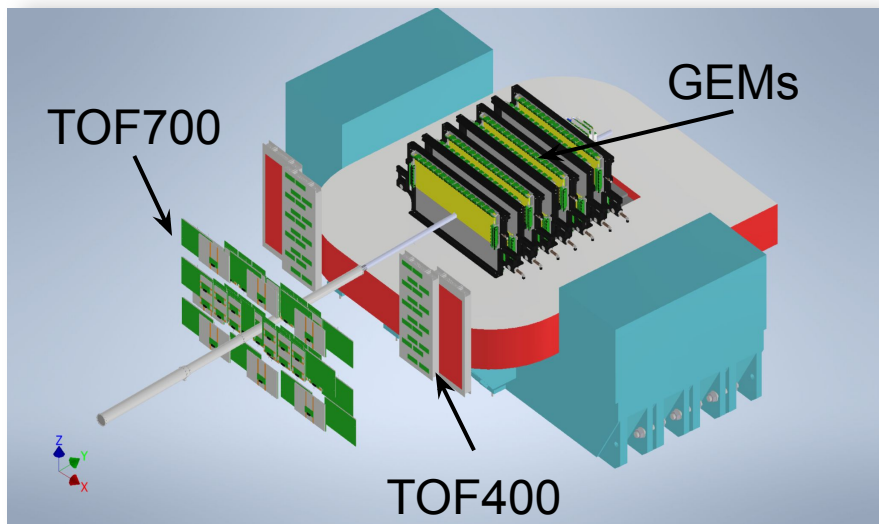


The first physics Run was carried out at the BM@N experiment in December, 2022 - February, 2023:  
Xe+CsI, 3.0 AGeV (53M events), 3.8 AGeV (580M events).

## Major systems:

- ❑ Inner tracking system FSD+GEM (Forward Silicon Detector + Gaseous Electron Multipliers, [8,9 on the scheme]);
- ❑ Outer tracking system CSC (Cathod Strip Chambers, big, small [10]);
- ❑ PID system TOF400 + TOF700, [11, 13];
- ❑ FHCAL (Forward Hadron Calorimeter, [20]) - centrality and reaction plane determination.

# Time-of-Flight systems



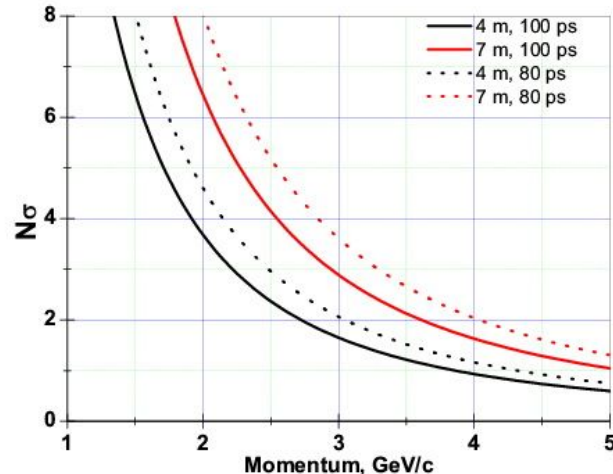
TOF400 and TOF700 geometrical acceptance

BM@N tracking and TOF systems

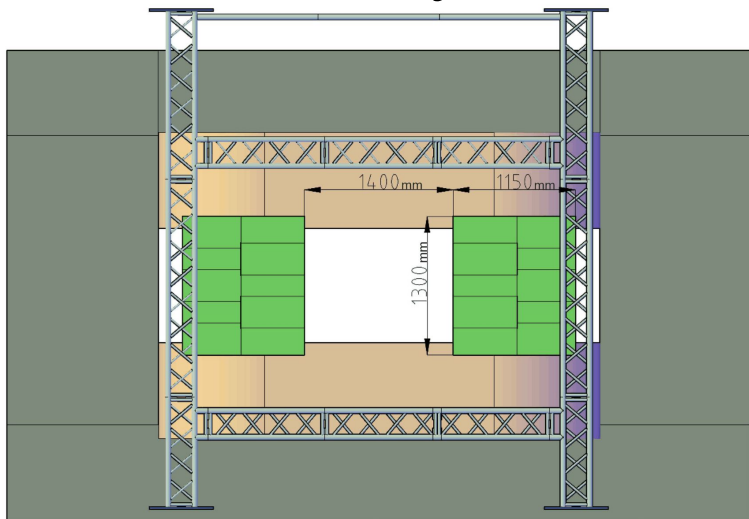
$$\Delta t = \frac{L}{c} \left( \sqrt{1 + \frac{m_1^2}{p^2}} - \sqrt{1 + \frac{m_2^2}{p^2}} \right)$$

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

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

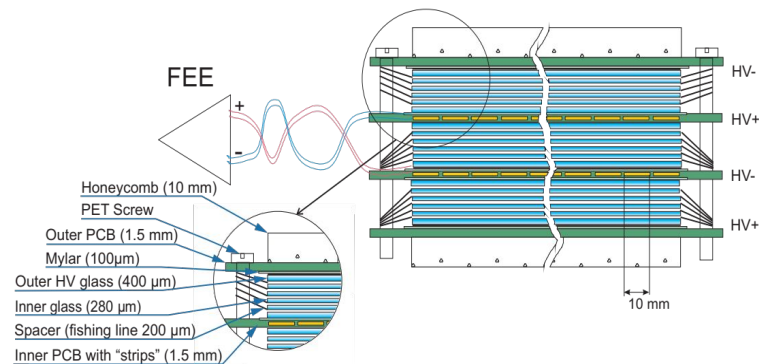
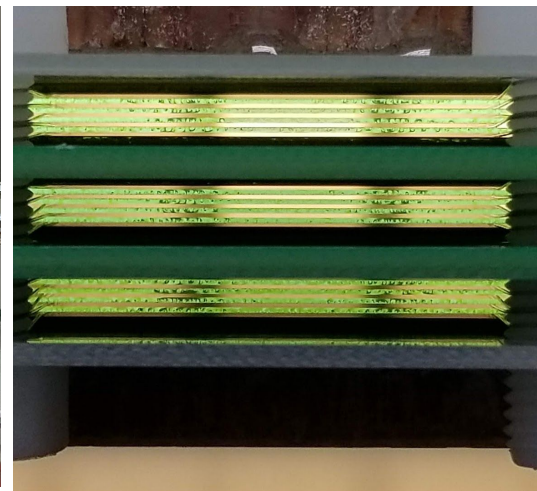


# TOF400 subsystem



TOF400 layout

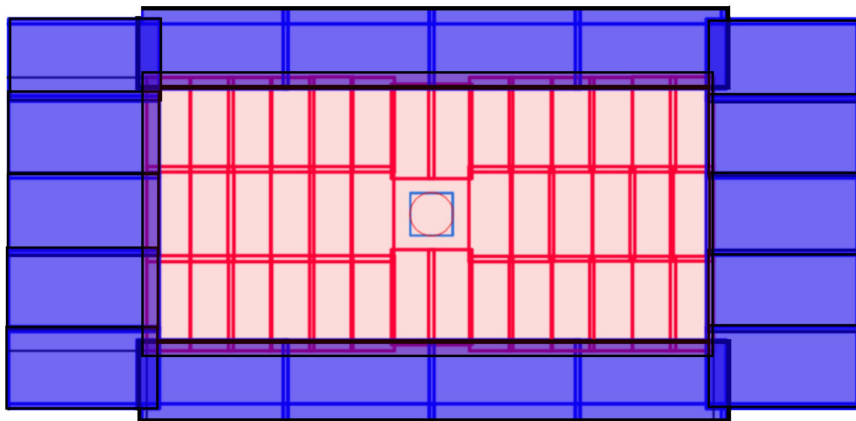
- Two arms of 10 mRPC detectors each (30×60 cm<sup>2</sup>)
- 48 readout strips of 1×30 cm<sup>2</sup> in one mRPC
- 960 Readout strips
- 1920 channel of FEE
- Active area 2×1.1×1.3 m<sup>2</sup>
- 90% C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> + 5% SF<sub>6</sub> + 5% i-C<sub>4</sub>H<sub>10</sub>
- 11.5 kV working point



TOF400 mRPC cross section

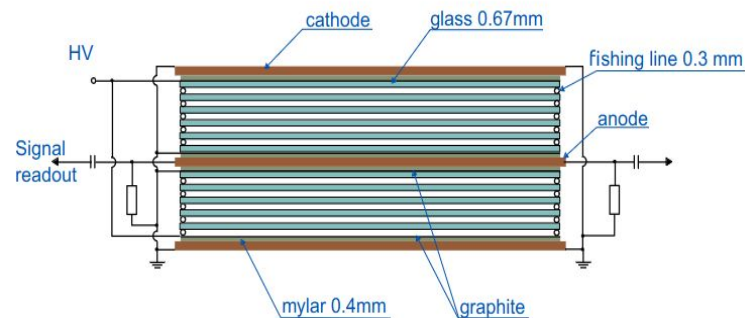
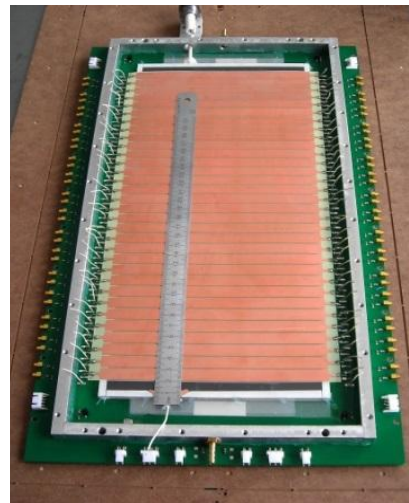


# TOF700 subsystem



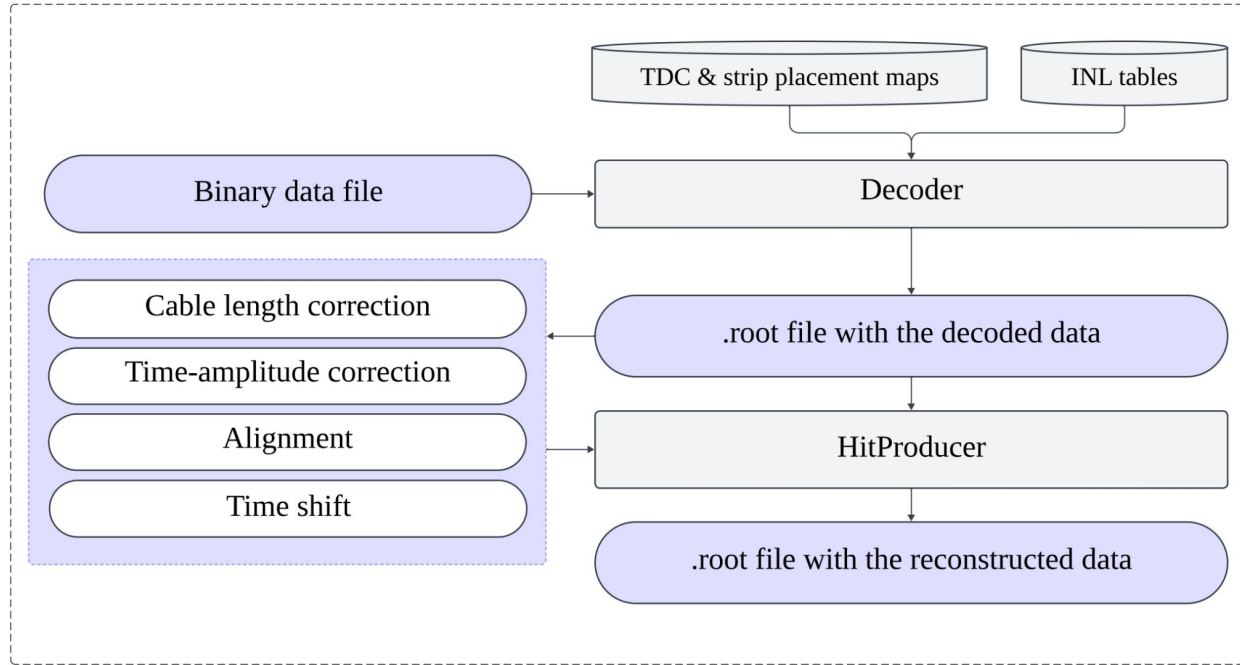
TOF700 layout

58 mRPC detectors of 2 sizes (30×56 cm<sup>2</sup>; 35×16 cm<sup>2</sup>)  
16 (32) readout strips of 1.8×56 (1.×16) cm<sup>2</sup> in one mRPC  
1600 Readout strips  
3200 channel of FEE  
Active area 3.15×1.56 m<sup>2</sup>  
90% C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> + 5% SF<sub>6</sub> + 5% i-C<sub>4</sub>H<sub>10</sub>  
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

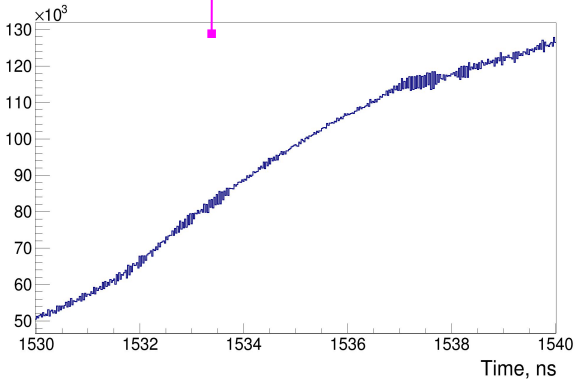
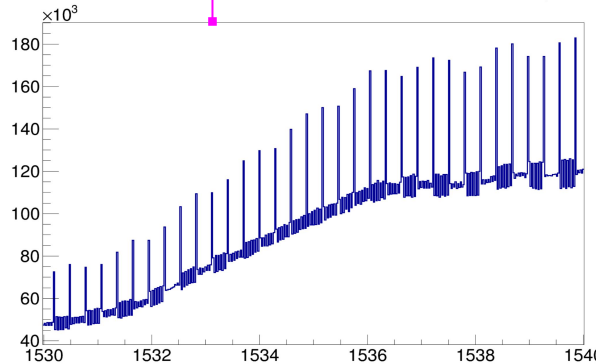
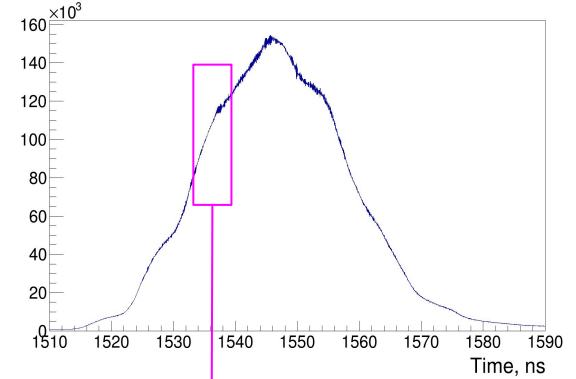
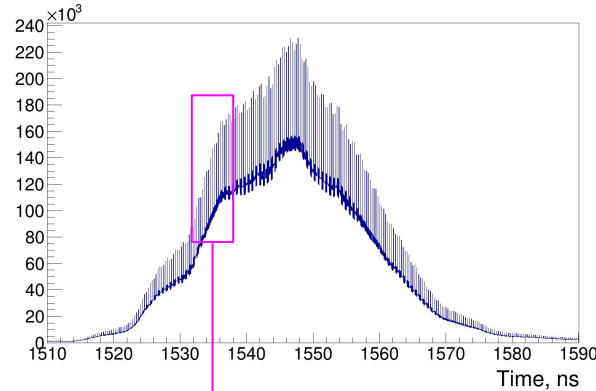
# Integral Non-Linearity correction

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

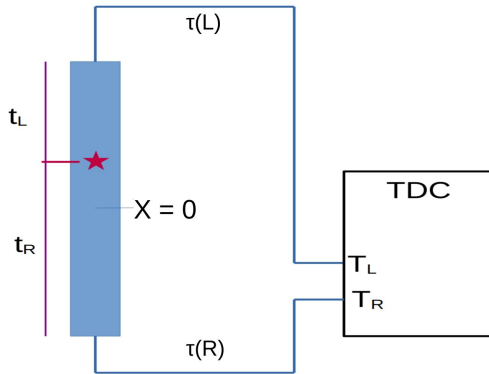
$$t = (N_{bin} + INL_{Nbin}) \times Width_{bin},$$



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



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

$$T_L = t_L + \tau_L$$

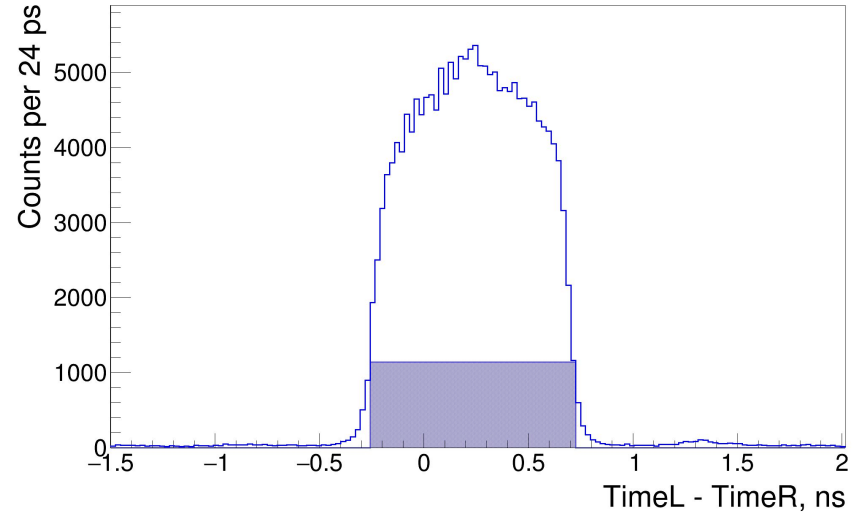
$$T_R = t_R + \tau_R$$

if  $\tau_L = \tau_R$ , then

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

otherwise

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

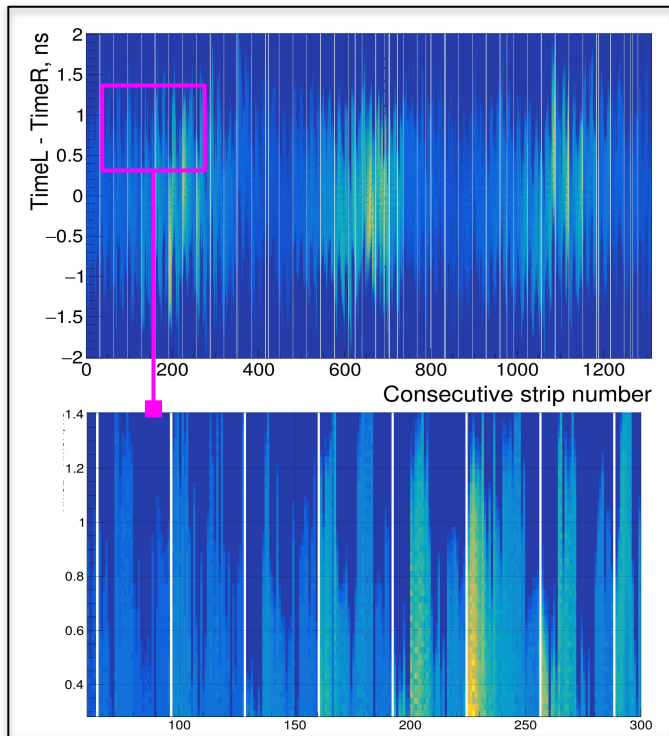


TimeL - TimeR distribution for a single strip.  
Mean of the solid rectangle — the CL correction.

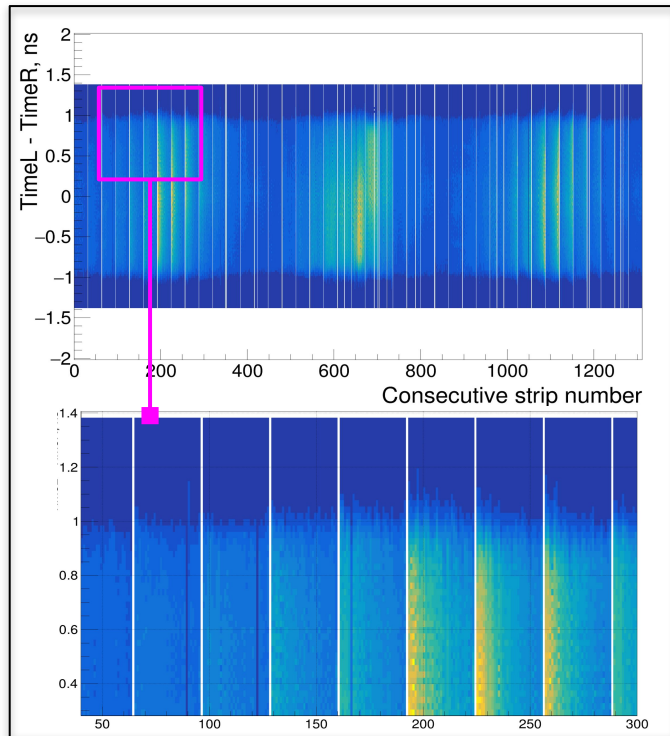
For TOF400 we are able to reconstruct **Y** hit coordinate (the strips are **vertically** oriented).  
For TOF700 — **X** hit coordinate (the strips are **horizontally** oriented).  
The procedure is the same.

# Cable length correction

before



after

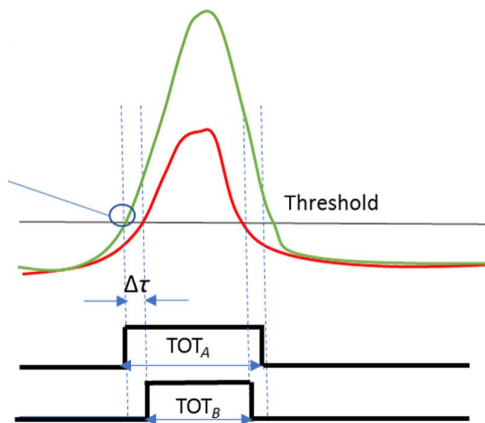


$\text{TimeL} - \text{TimeR}$  (ns) distributions for all the strips in consecutive number



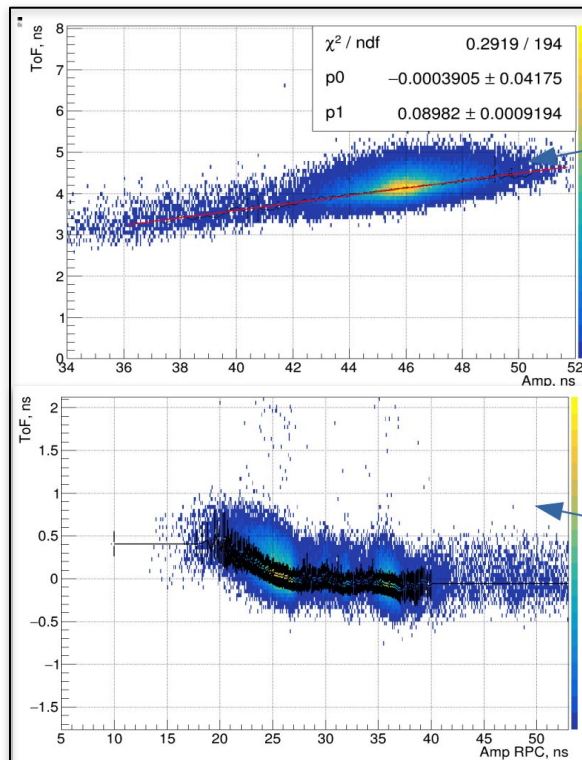
# Time-amplitude (TA) correction

TOF400

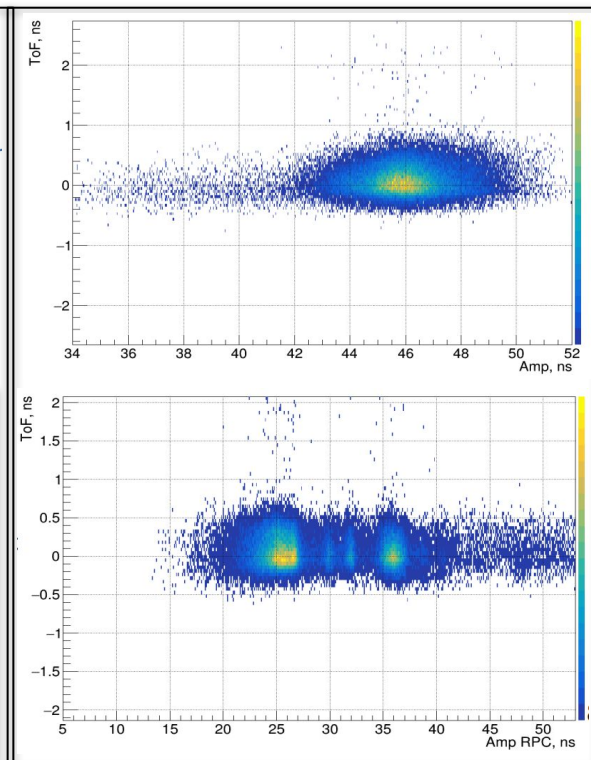


A particle's time of flight is the difference between the mRPC signal and the start T0 signal.

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



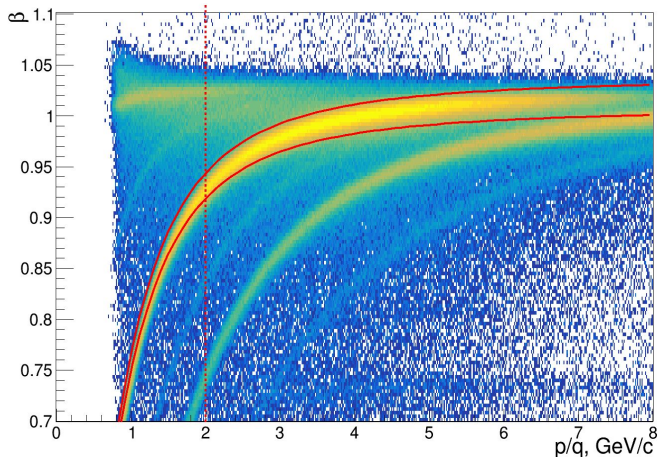
Before TA correction



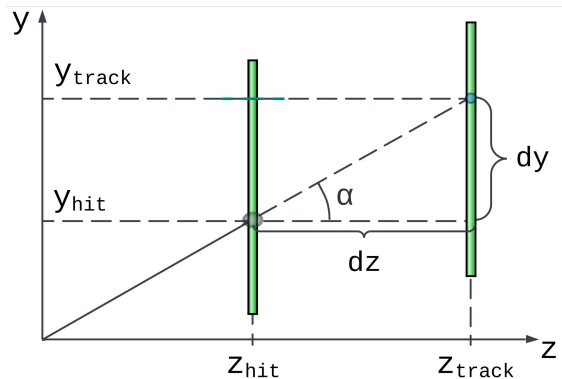
After TA correction

# Alignment

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



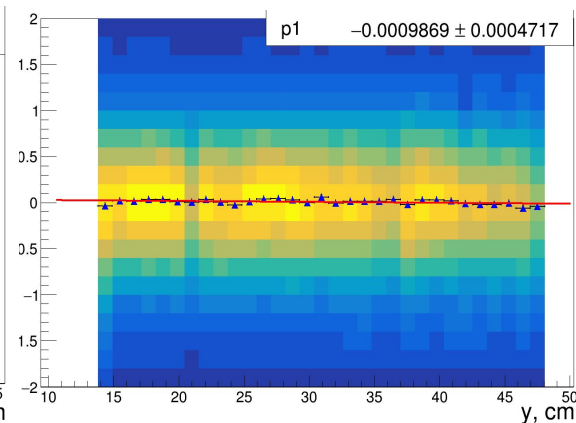
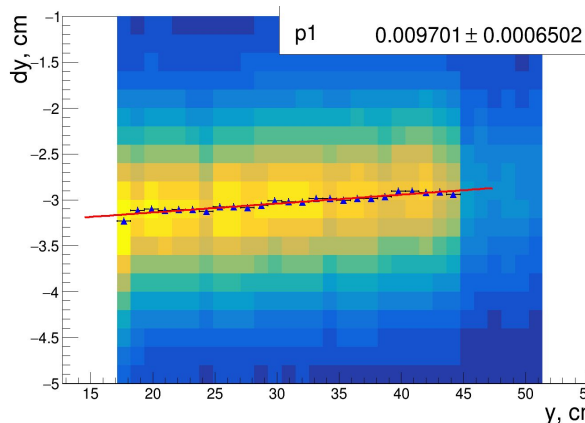
Relativistic speed versus rigidity distribution



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

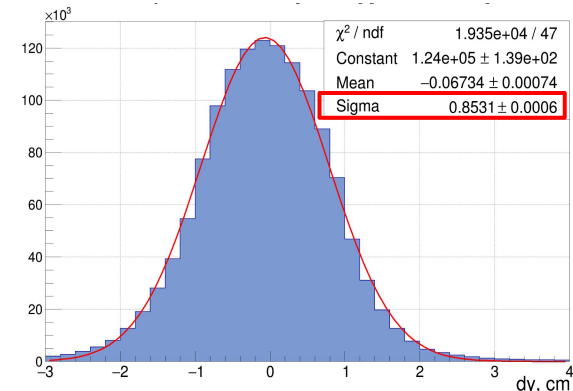
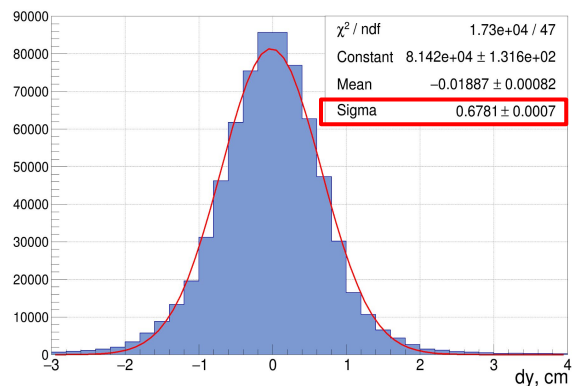
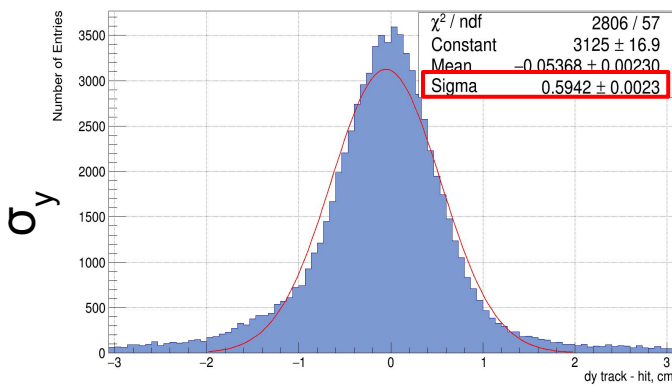
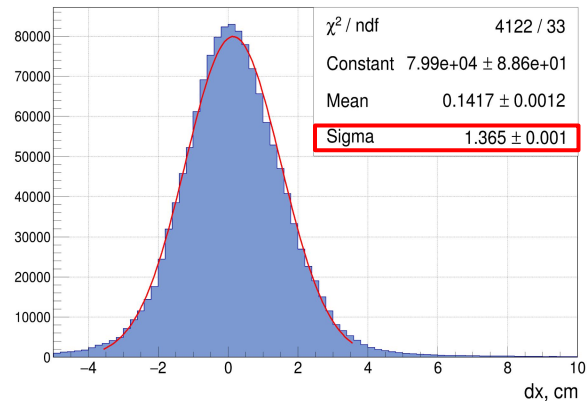
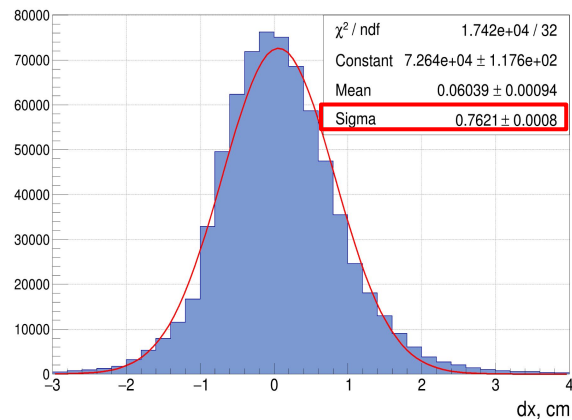
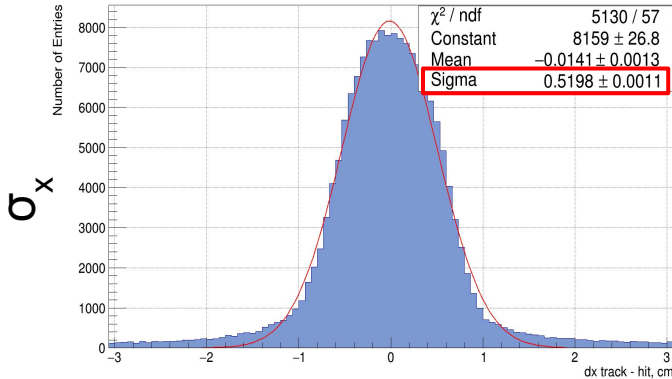
$$dy = \frac{dz}{z_{track}} y$$

Illustration to the idea of  $dy/y$  distribution use



$dy/y$  for a single mRPC (TOF700) before and after alignment

# Alignment. Matching resolution



TOF400 residual distributions

TOF700 residual distributions  
(small mPRC)

TOF700 residual distributions  
(big mPRC)

# Particles time shift correction

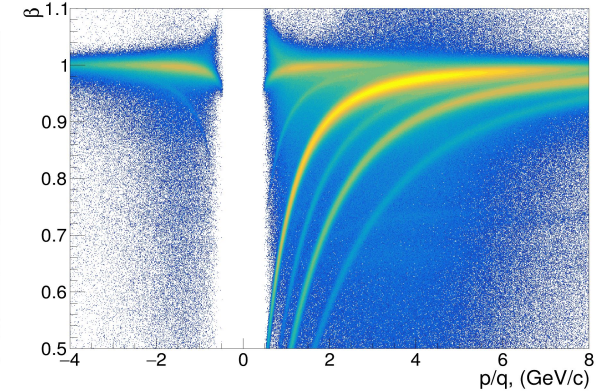
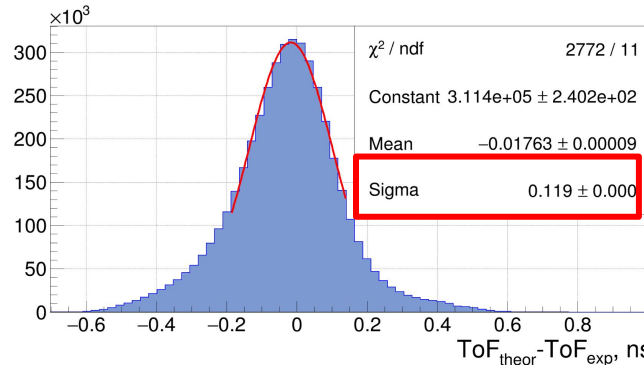
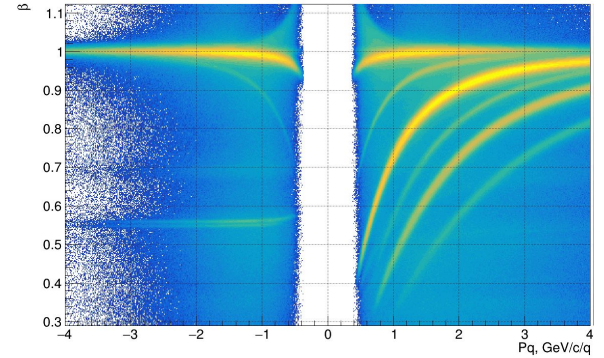
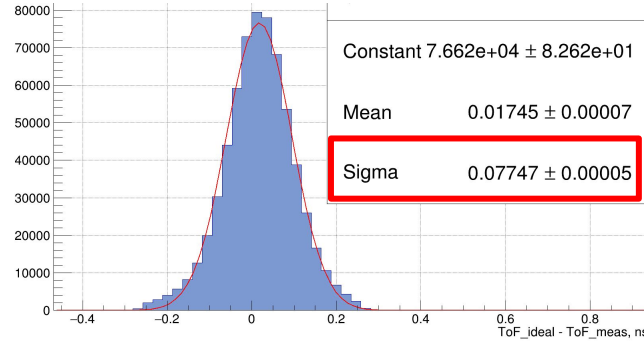
After the TA correction ToF peak is placed at zero → need to add a time constant corresponding to a particle ToF for each strip.

- 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)

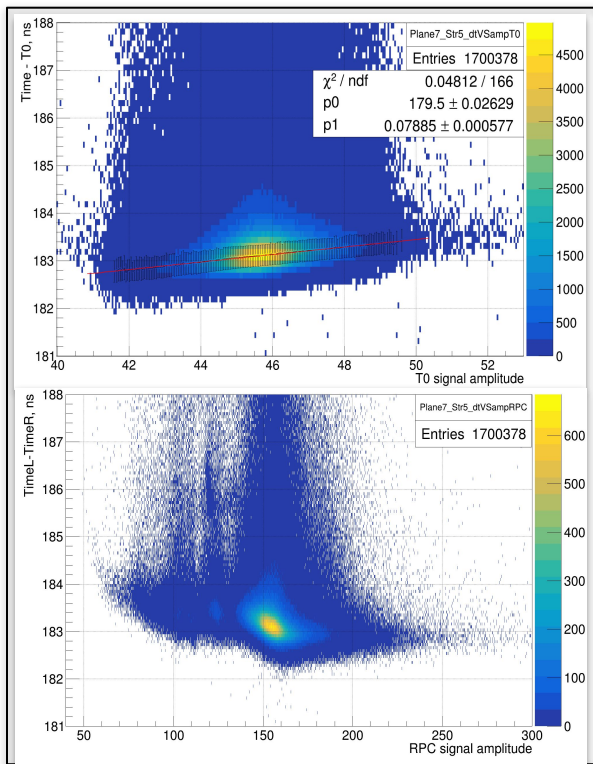
Relativistic speed versus rigidity distribution **after** time shift correction

# Conclusion

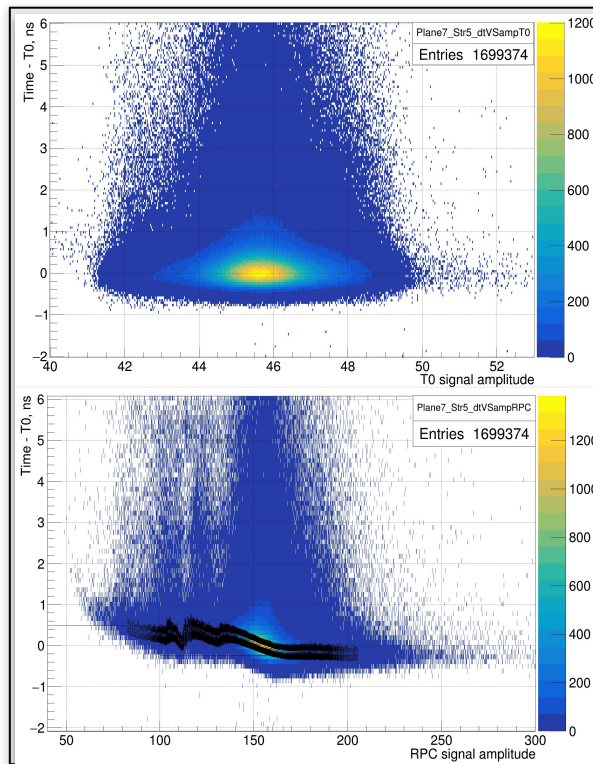
1. The TOF400 and TOF700 data flow procedures have been unified
2. Calibrations of the TOF400 and TOF700 systems were performed
3. Matching resolutions for the TOF400 are:  $\sigma_x = 5.2$  mm,  $\sigma_y = 6.9$  mm.  
For the TOF700:  $\sigma_x = 7.6$  mm,  $\sigma_y = 6.7$  mm (small mRPC);  
 $\sigma_x = 14.6$  mm,  $\sigma_y = 8.5$  mm (small mRPC);
4. Time resolution of the TOF400+T0 system is 77 ps.  
For the TOF700+T0 this is 119 ps.

Thank you for your attention!

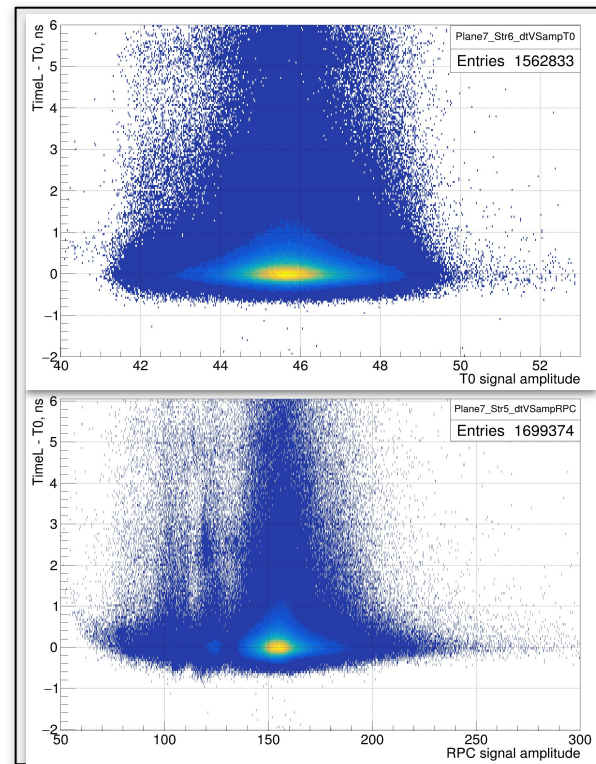




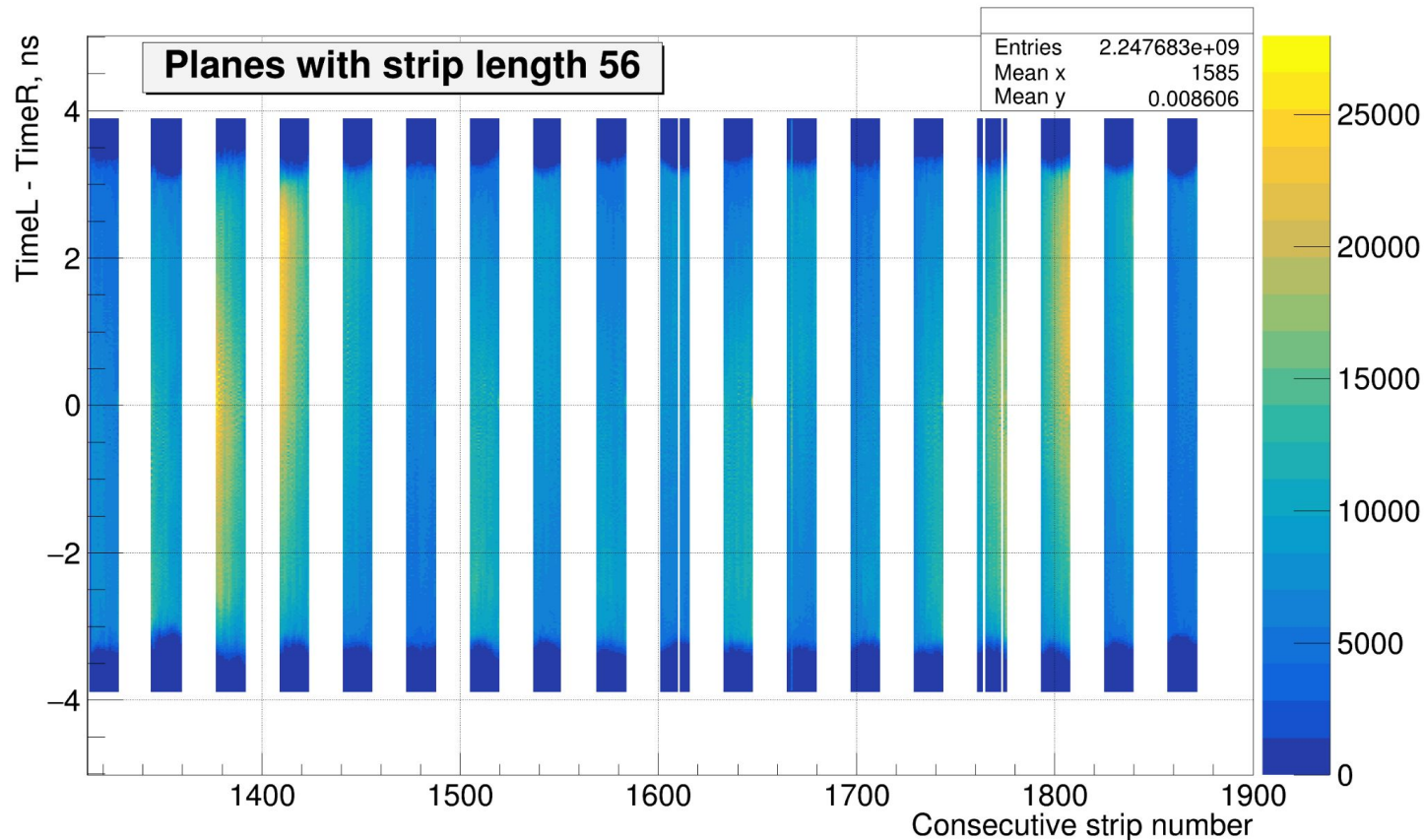
before slewing correction



after T0 slewing correction



after T0&RPC slewing  
correction



LR correction result for the big planes

Gaps are due to the fact that big planes have 16 strips, while numbering assumes 32