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

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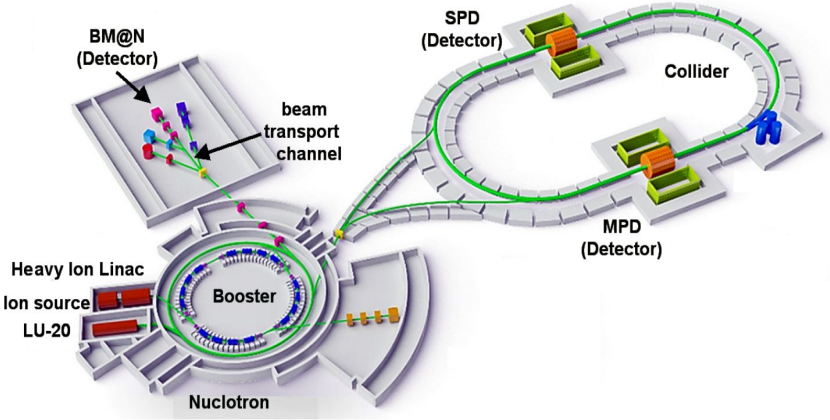
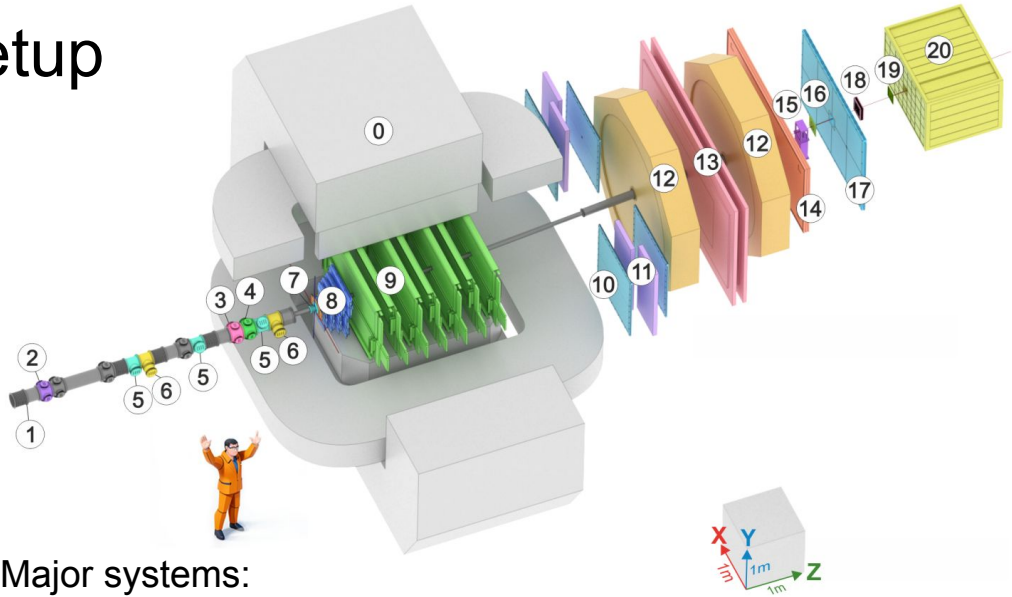
The BM@N experiment setup



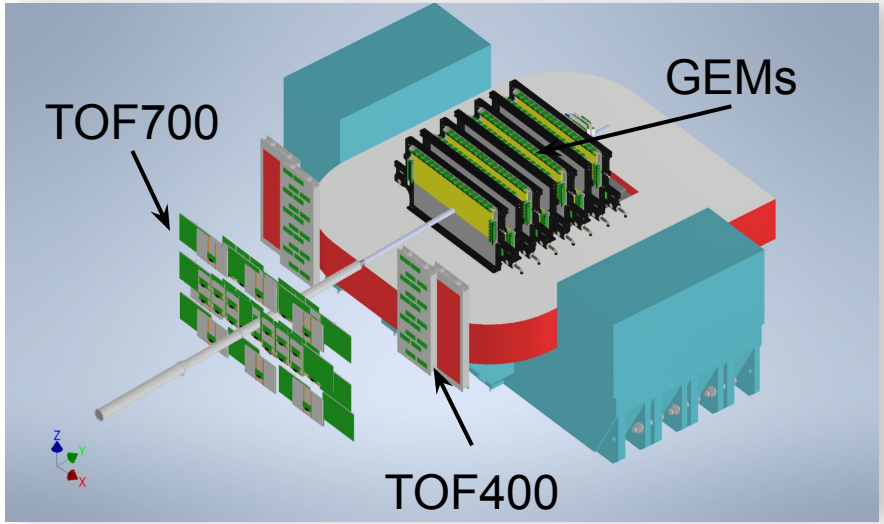


The first physics Run was carried out at the BM@N experiment in December, 2022 - February, 2023:
Xe+CsI, 3.0 AGeV (53M events), 3.8 AGeV (580M events).

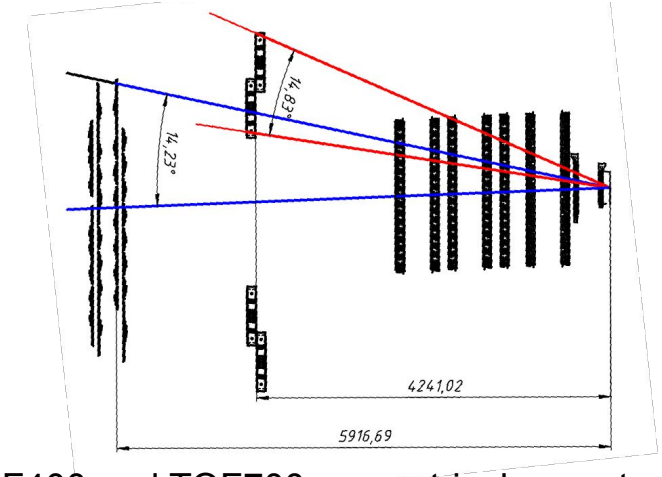
Major systems:

- ❏ 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



BM@N tracking and TOF systems

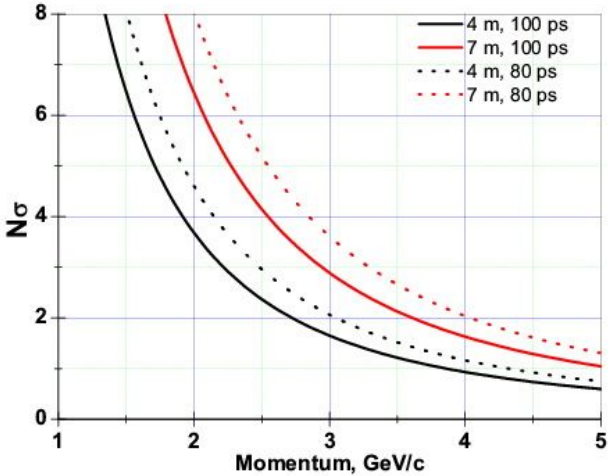


TOF400 and TOF700 geometrical acceptance

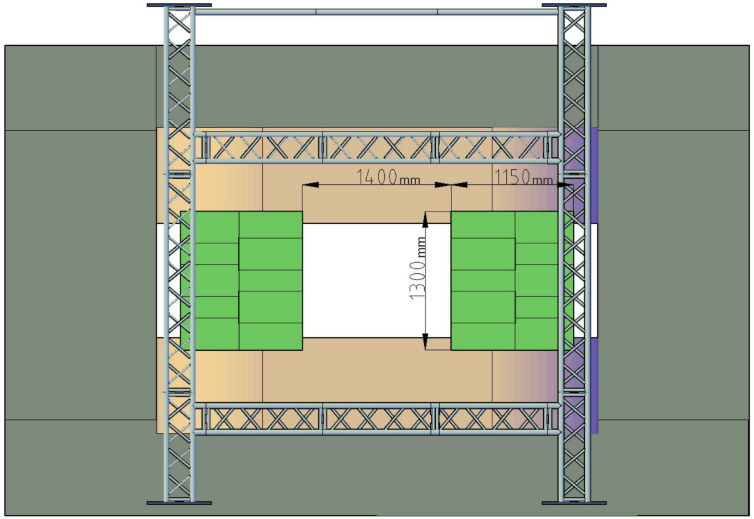
$$\Delta t = \frac{L}{c}\left(\sqrt{1+\frac{m_1^2}{p^2}} - \sqrt{1+\frac{m_2^2}{p^2}}\right)$$

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

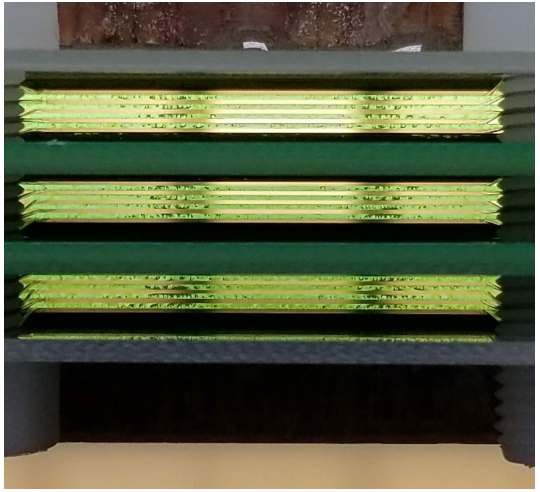
TOF separation power as a function of momentum for different flight path lengths and time resolutions

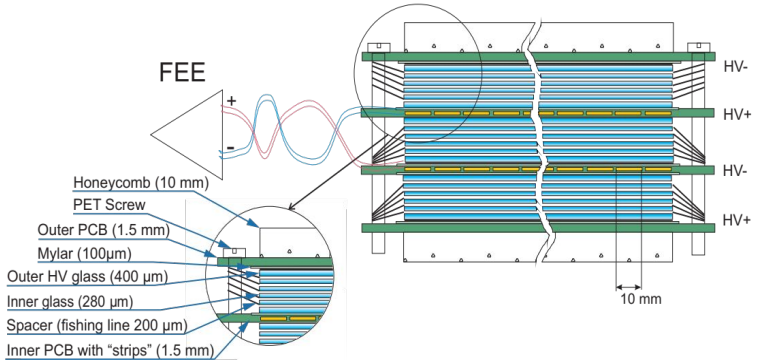


TOF400 subsystem



TOF400 layout

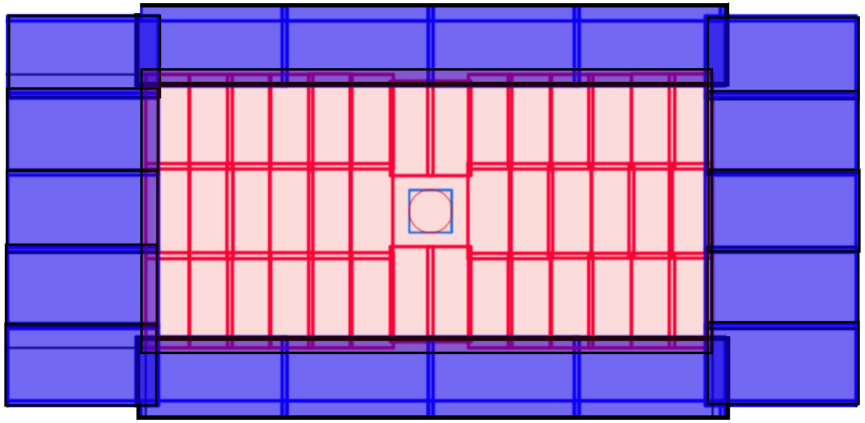




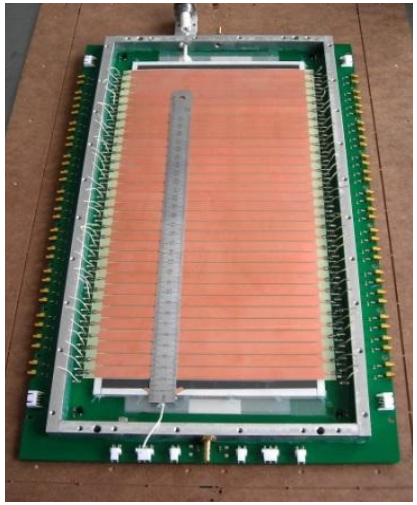
TOF400 mRPC cross section

Two arms of 10 mRPC detectors each (30×60 cm2)
48 readout strips of 1×30 cm2 in one mRPC
960 Readout strips
1920 channel of FEE
Active area 2×1.1×1.3 m2
90%C2H2F4 + 5% SF6 + 5% i-C4H10
11.5 kV working point

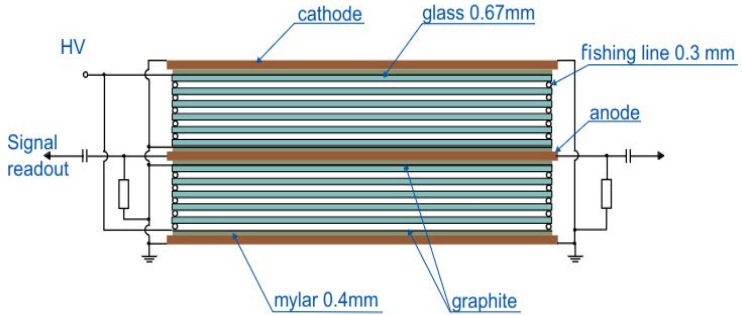
TOF700 subsystem



TOF700 layout

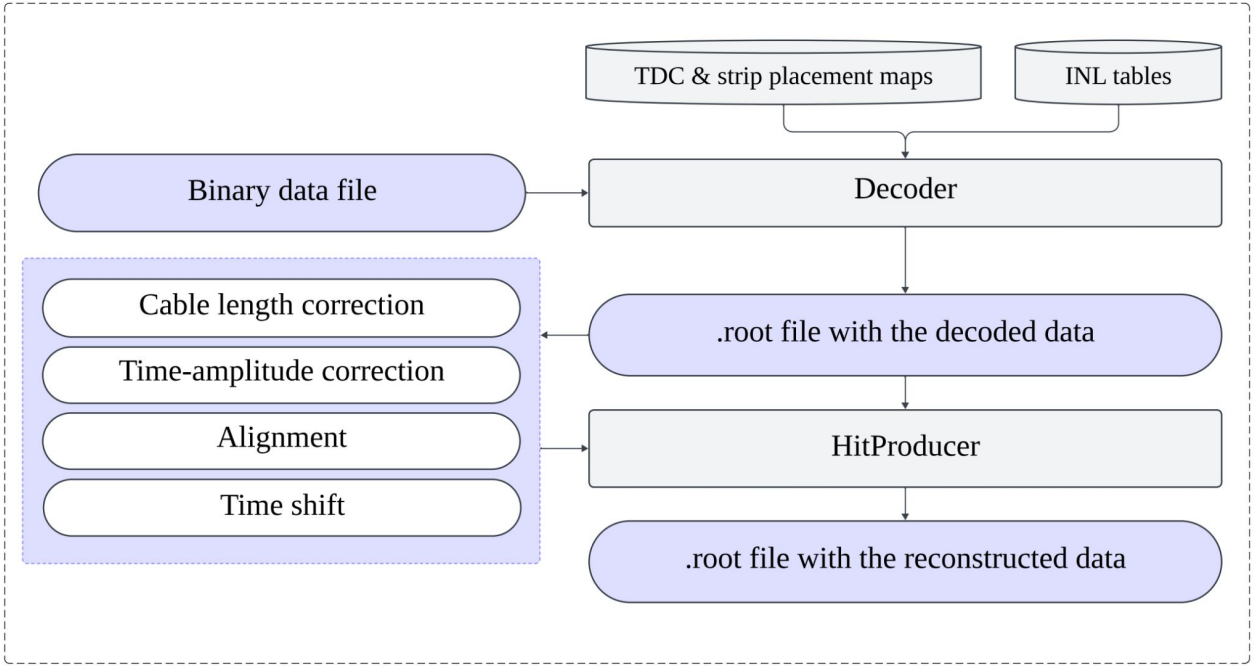


58 mRPC detectors of 2 sizes (30×56 cm2; 35×16 cm2)
16 (32) readout strips of 1.8×56 (1.×16) cm2 in one mRPC
1600 Readout strips
3200 channel of FEE
Active area 3.15×1.56 m2
90%C2H2F4 + 5% SF6 + 5% i-C4H10
15 kV working point



TOF700 mRPC cross section

Data reconstruction procedure



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

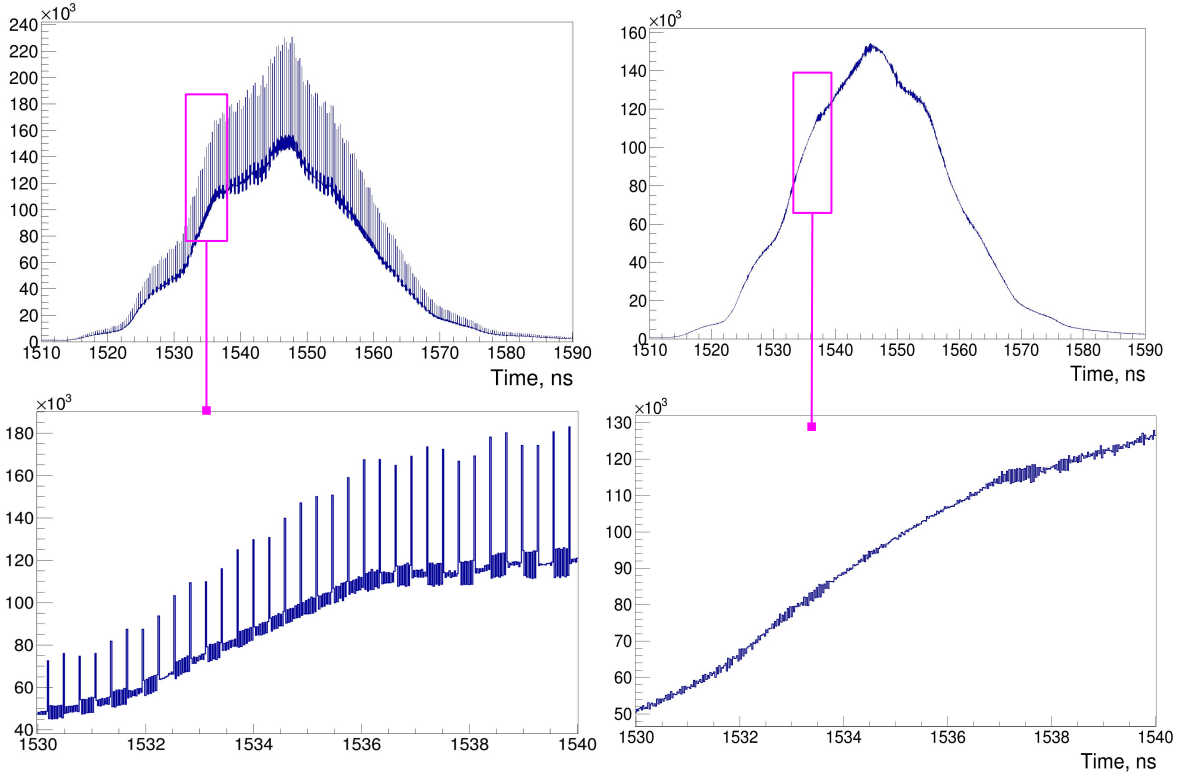
Integral Non-Linearity correction

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

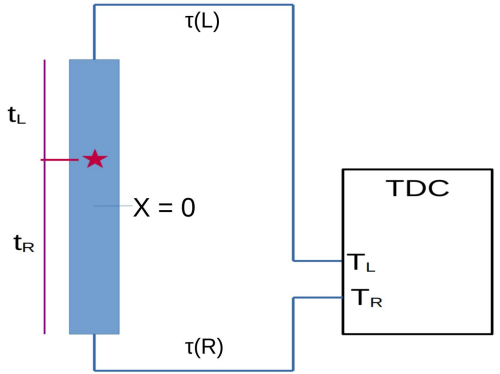
$$t = (N_{bin} + INL_{Nbin}) \times \ Width_{bin},$$



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



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

$$T_L = t_L + \tau_L$$

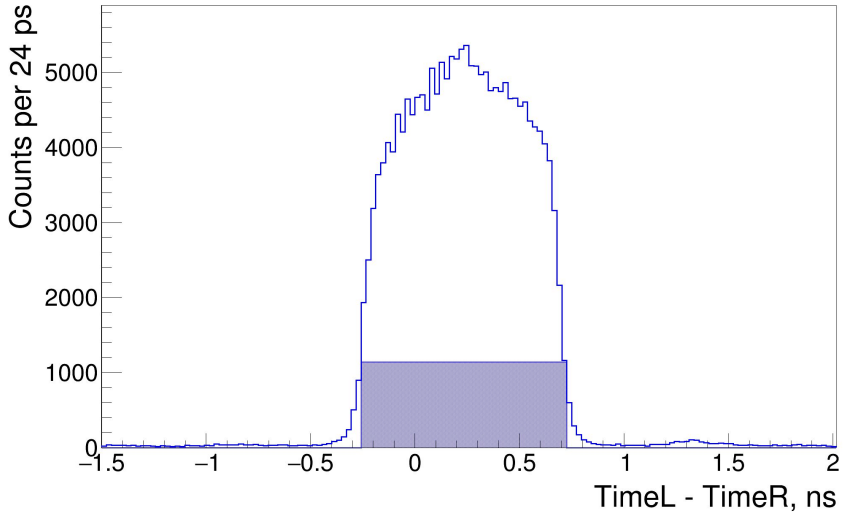
$$T_R = t_R + \tau_R$$

if $\tau_L = \tau_R$, then

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

otherwise

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



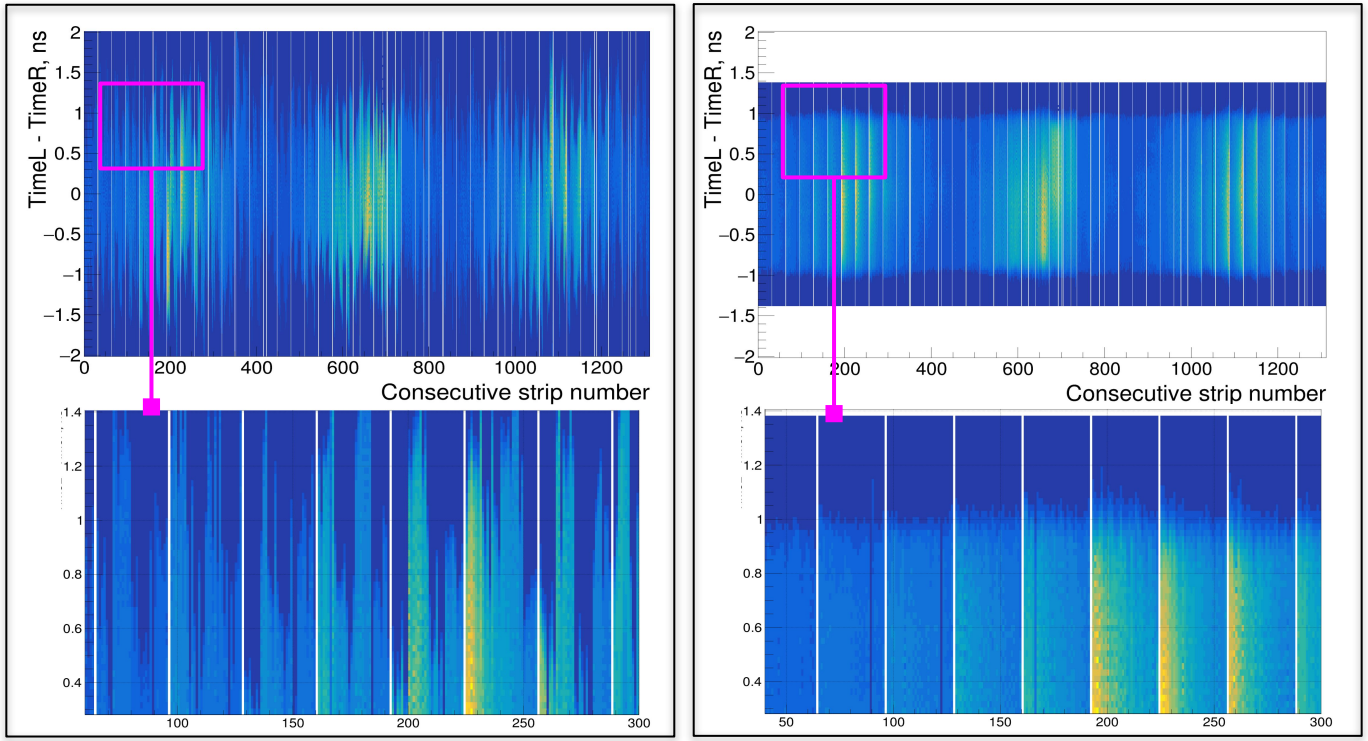
TimeL - TimeR distribution for a single strip.
Mean of the solid rectangle — the CL correction.

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

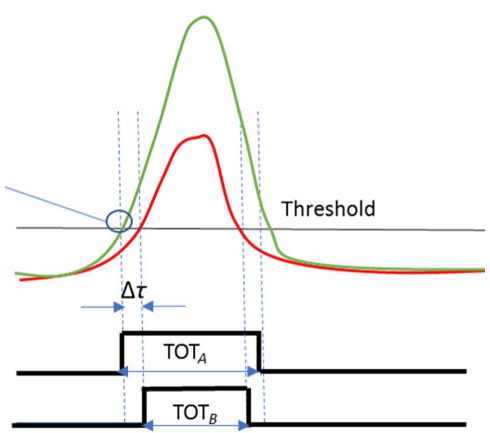
before

after



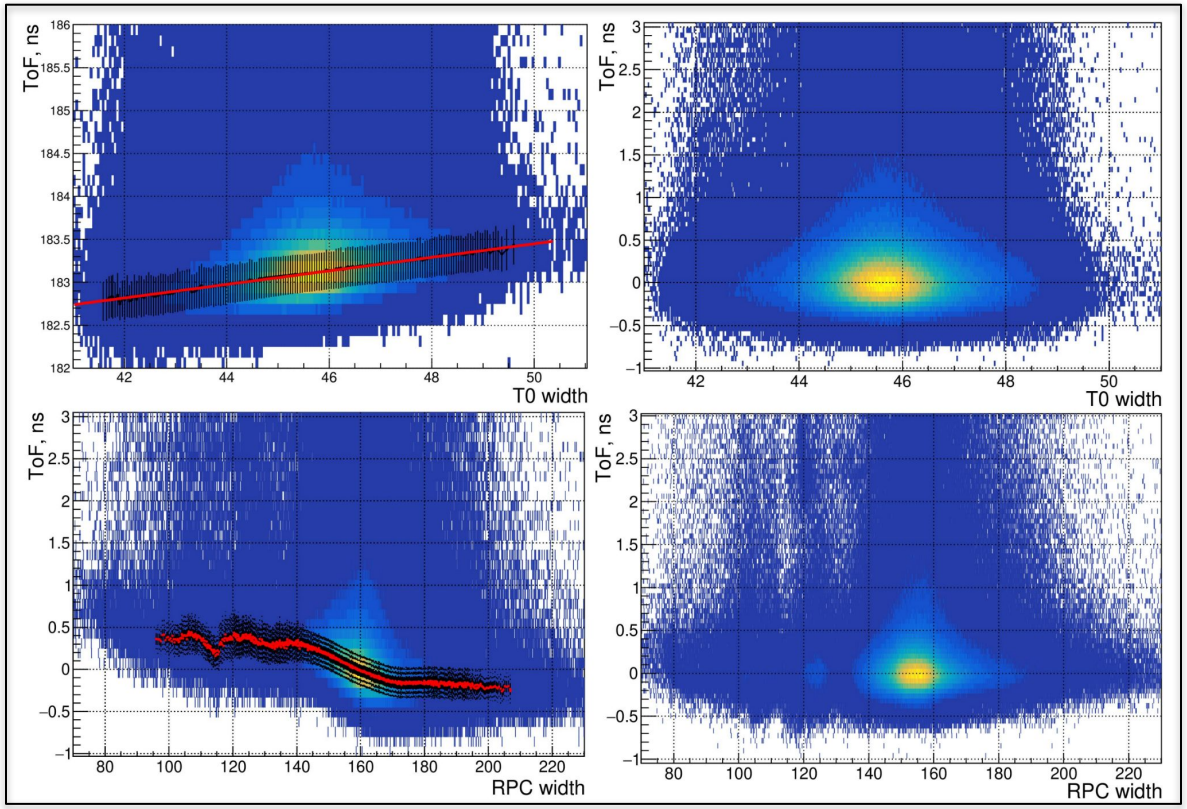
TimeL - TimeR (ns) distributions for all the strips in consecutive number

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.

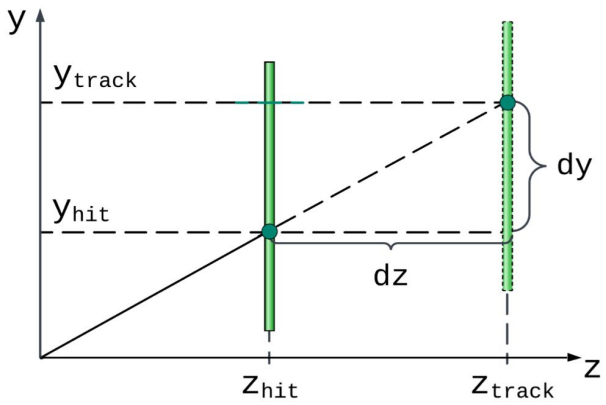


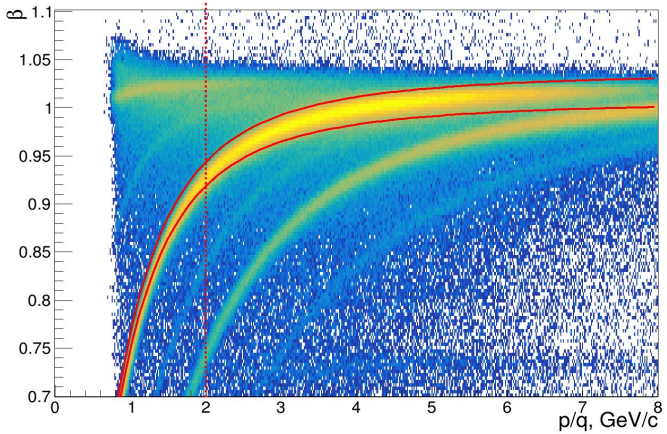
Time of flight *versus* signal amplitude before TA correction

Time of flight *versus* signal amplitude after TA correction

Alignment

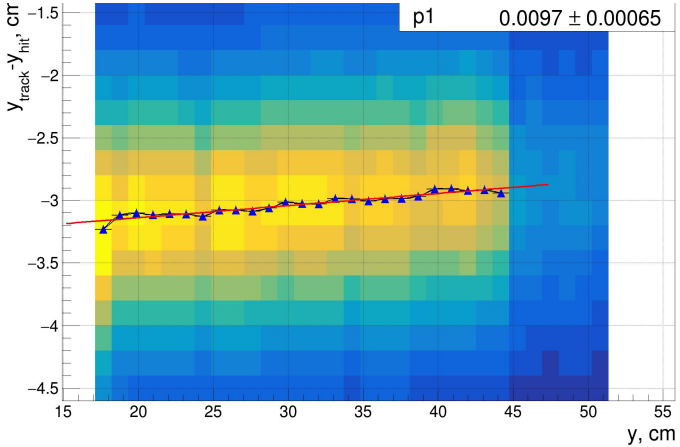
Alignment is performed using protons with momentum above 2 GeV/c

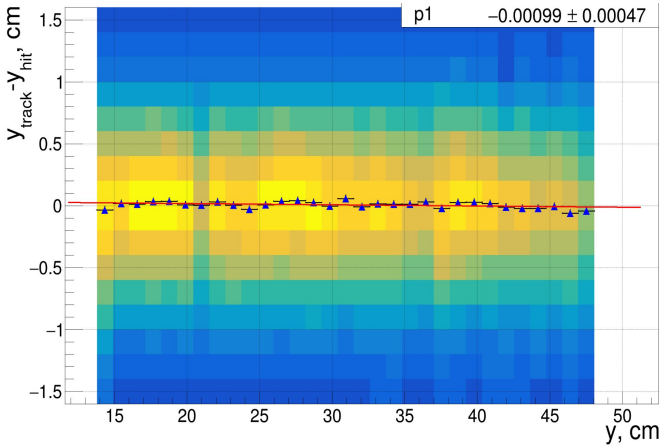




$$dy = y_{track} - y_{hit}$$

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

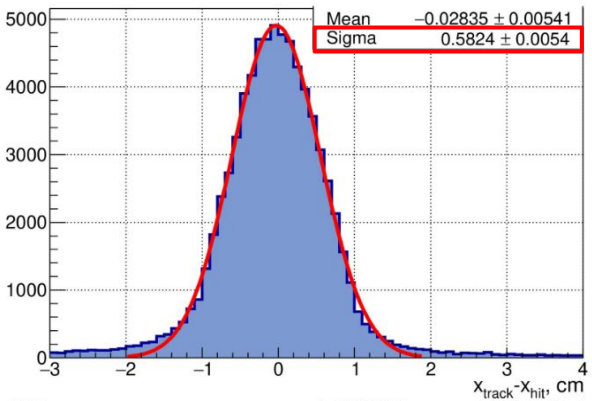


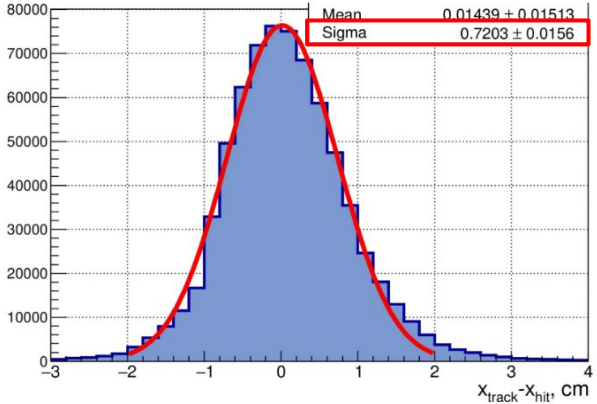


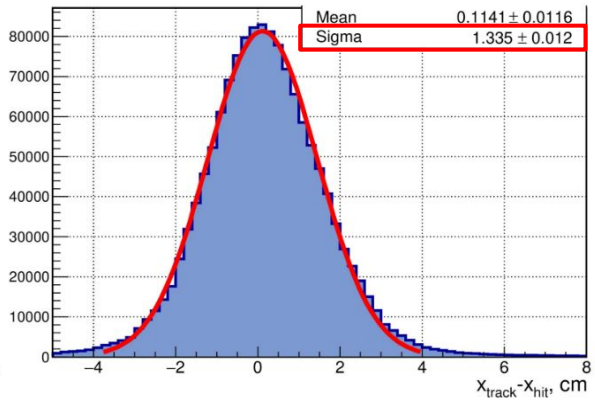
dy *versus* y for a single mRPC before and after alignment

Alignment. Matching resolution

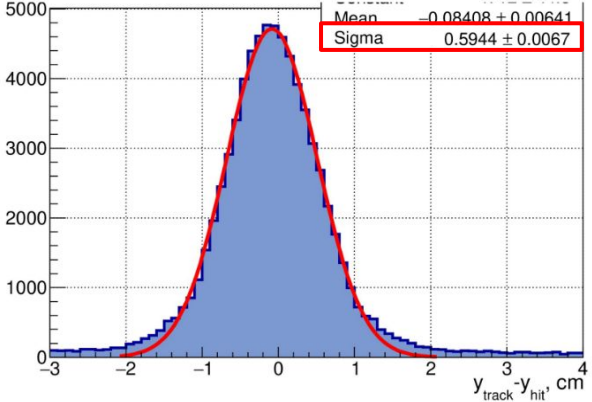
σ_x

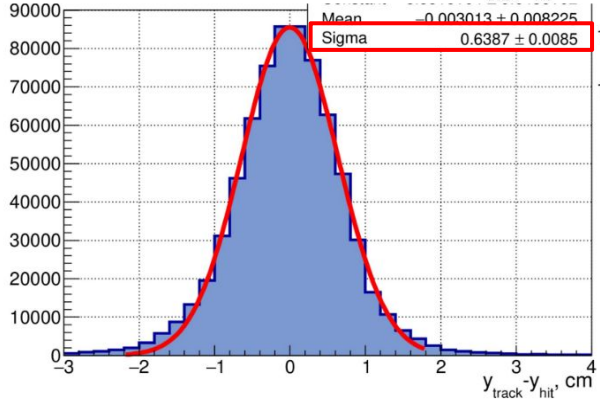


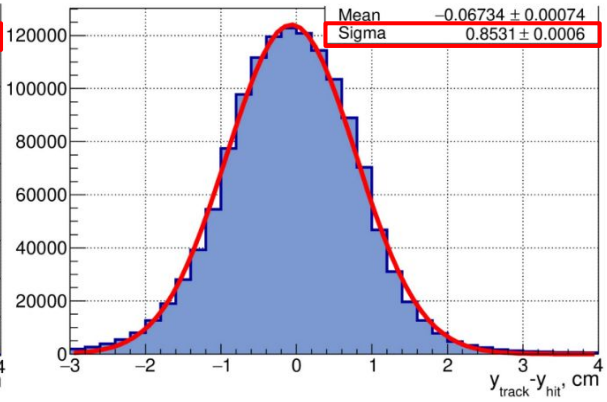




σ_y







TOF400 residual distributions

TOF700 residual distributions (small mPRCs)

TOF700 residual distributions (big mPRCs)

Time shift correction

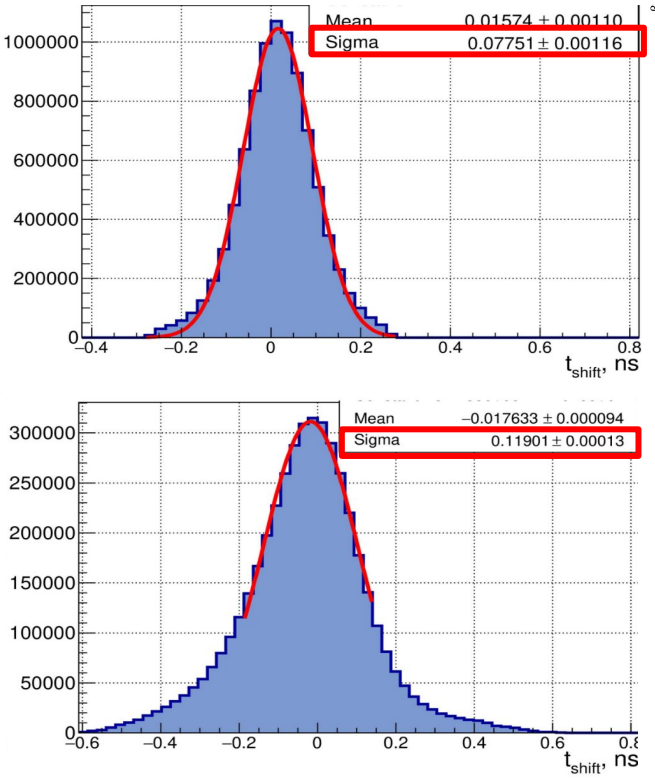
After the TA correction ToF peak is placed at zero → need to add a time constant corresponding to a particle ToF for each strip.

- 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:

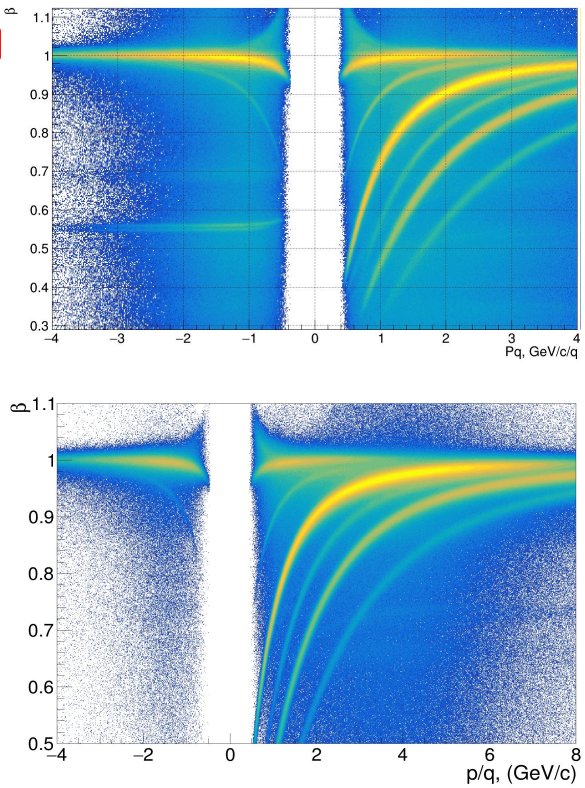
$$t_{theor} = \frac{L}{c}\sqrt{\frac{m^2}{(p/q)^2} + 1}$$

- 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

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: σ_x = 5.8 mm, σ_y = 5.9 mm.

   For the TOF700: σ_x = 7.2 mm, σ_y = 6.4 mm (small mRPCs);

   σ_x = 13.4 mm, σ_y = 8.5 mm (big mRPCs);
4. Time resolution of the TOF400+T0 system is 78 ps.

   For the TOF700+T0 this is 119 ps.

Thank you for your attention!