Offline Data Processing of MRPC End cap TOF@BESIII

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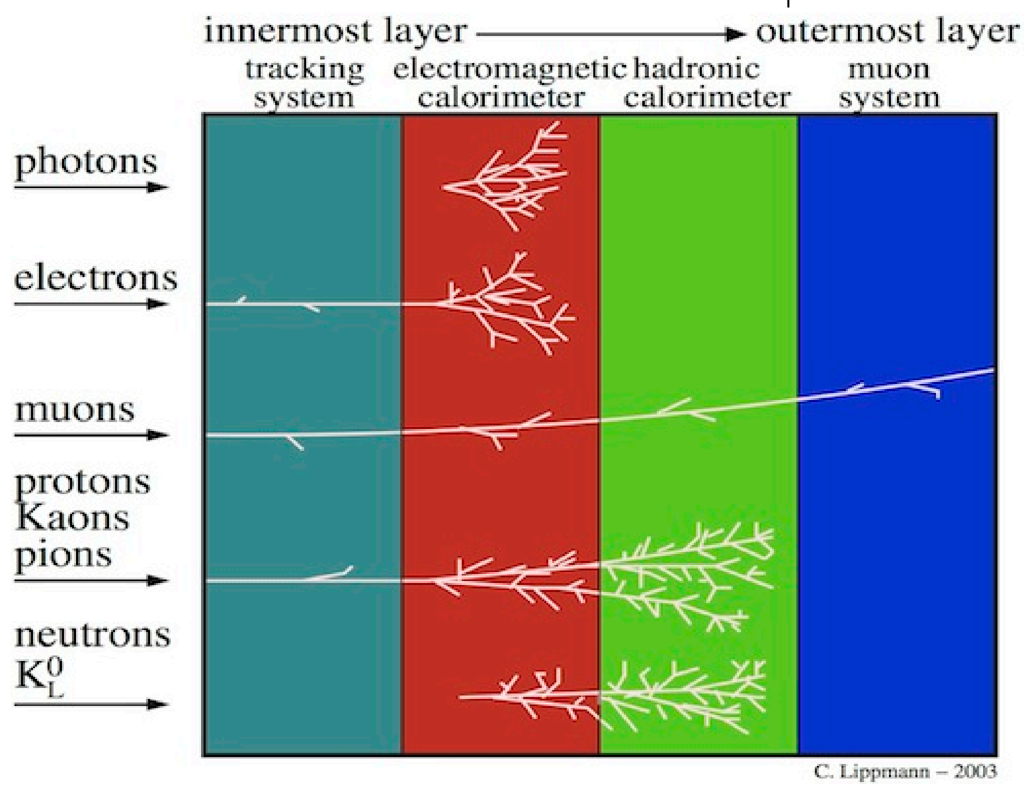
EPD Seminar
Dec. 27th, 2017

Outline

- Particle Identification (PID)
- Time-of-Flight Detector (TOF)
- Multi-gap Resistive Plate Chamber (MRPC)
- BESIII Endcap TOF system
  - Detector and Electronics
  - Multi-peak of Time-Over-Threshold (TOT)
  - Alignment of detector
  - Reconstruction and Calibration
- Summary

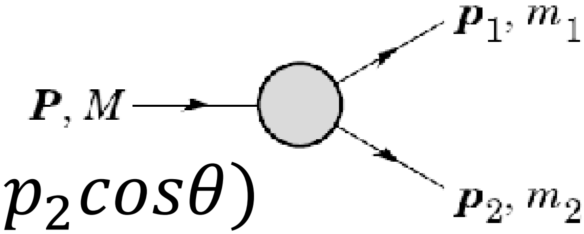
A “traditional” particle physics experiment

- Conceptual design of a “traditional” particle physics experiment
  - Tracking system
  - EM calorimeter
  - Hadron calorimeter
  - Muon system
- Particle identification is a crucial aspect.



$$r, e, \mu, \pi, K, p$$
$$(\vec{p}, E)$$

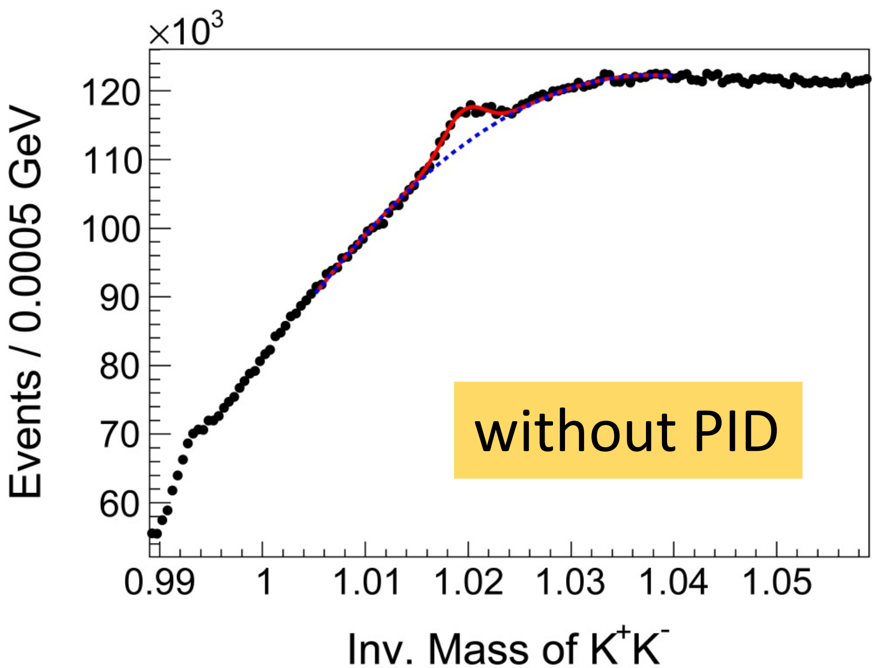
WHY PID is crucial?

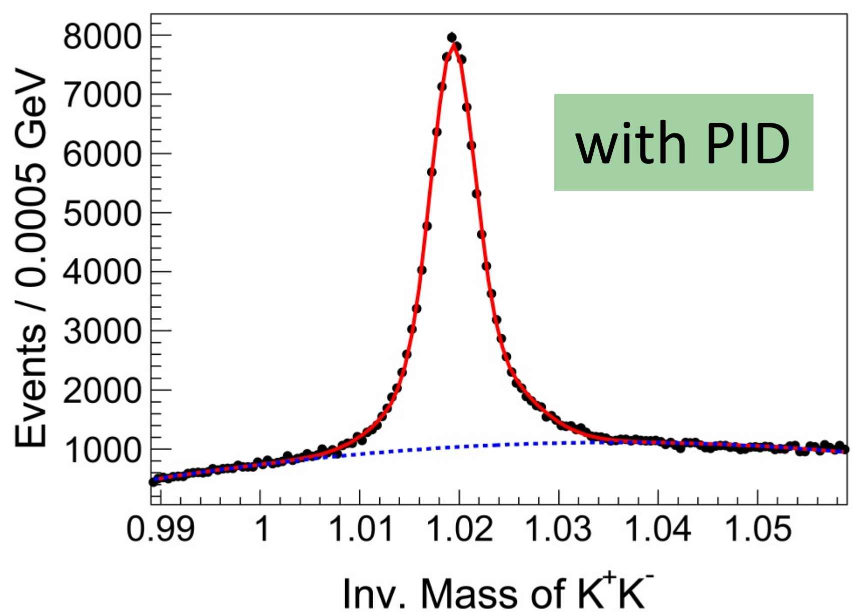


- Invariant mass

$$M^2 = m_1^2 + m_2^2 + 2(E_1E_2 - p_1p_2cos\theta)$$

- Improvement in the signal-to-background ratio





$$\phi \rightarrow K^+K^-$$

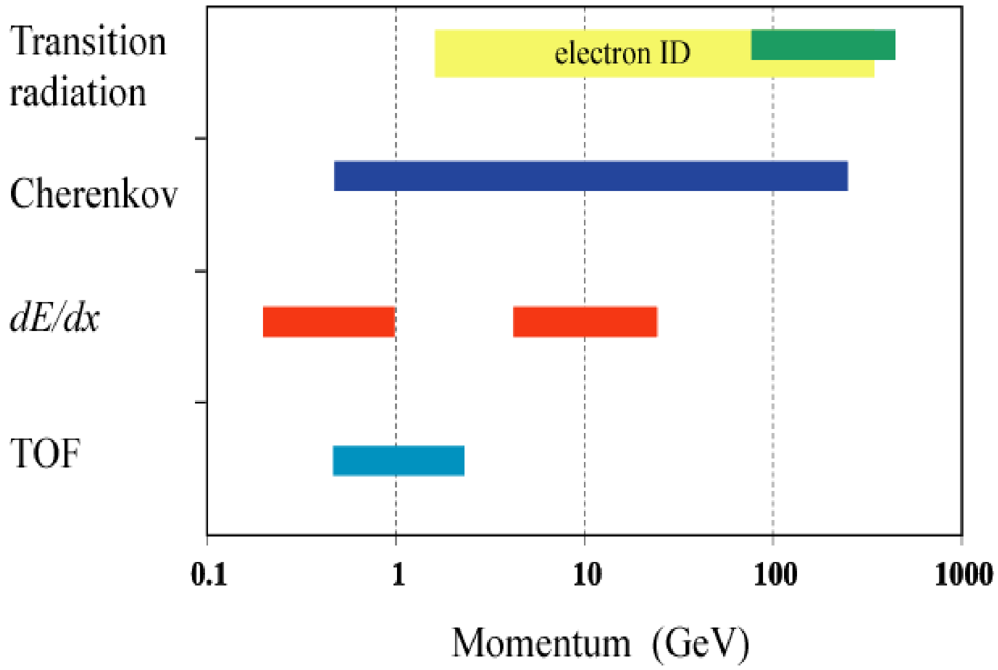
Particle Identification (PID)

- Measurement of the energy deposit by ionization
- Time-of-flight measurements
- Detection of Cherenkov radiation
- Detection of transition radiation

$$\beta \equiv \frac{v}{c} = \frac{|\vec{p}|c}{E}$$

$$\gamma \equiv \frac{1}{\sqrt{1-\beta^2}} = \frac{E}{mc^2}$$

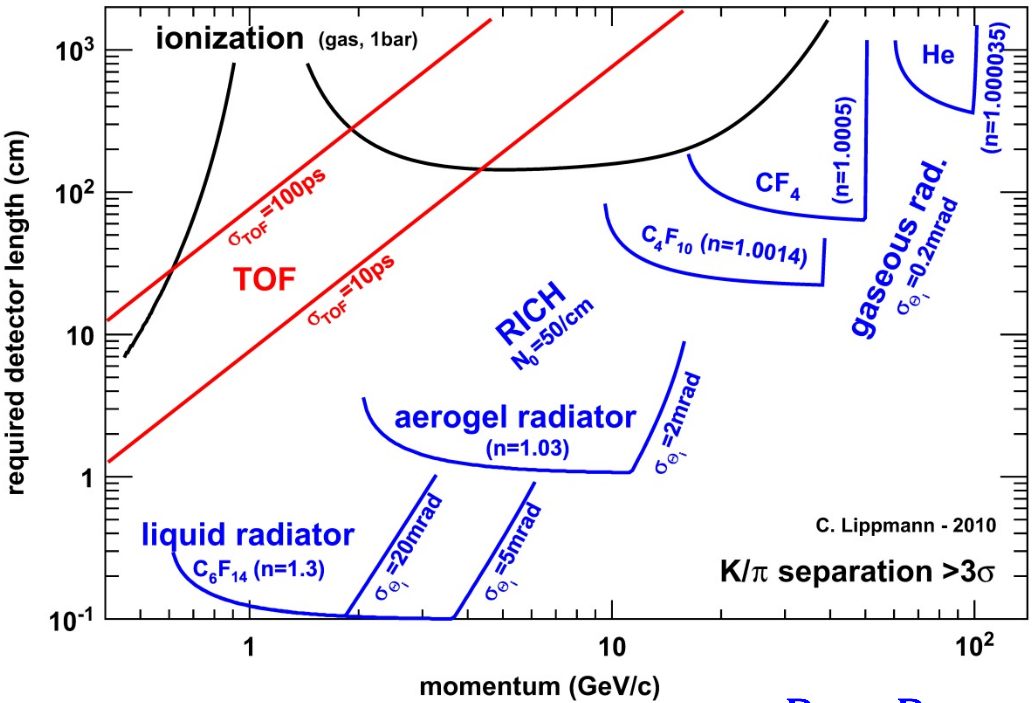
$$p = \gamma m v \rightarrow m = \frac{p}{c\beta\gamma}$$



Particle identification capability

$$p = \gamma m v \rightarrow m = \frac{p}{c\beta\gamma}$$

$$\left(\frac{dm}{m}\right)^2 = \left(\frac{dp}{p}\right)^2 + \left(\gamma^2 \frac{d\beta}{\beta}\right)^2$$



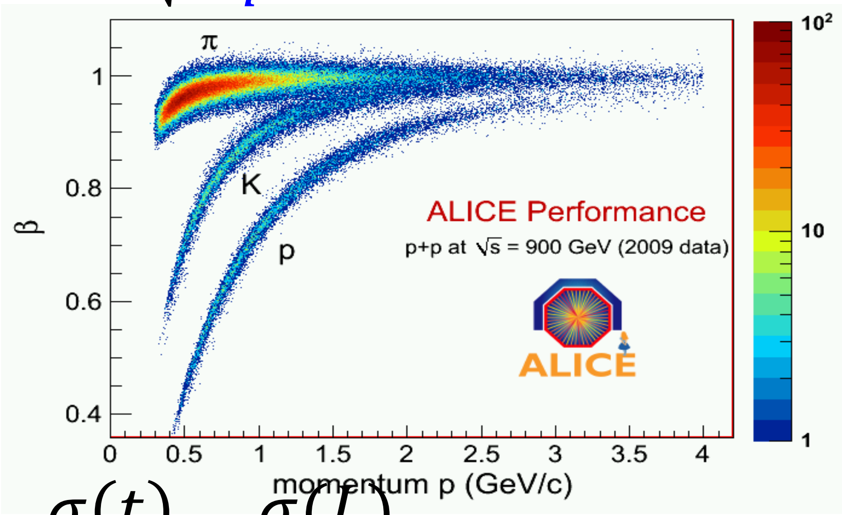
Separation power $n_\sigma = \frac{R_A - R_B}{<\sigma_{AB}>}$

Time-of-Flight detector

- 飞行时间探测器是通过测量带电粒子的飞行时间，结合径迹探测器测量的粒子的动量和飞行径迹长度，得到粒子的质量，实现粒子鉴别。

$$\frac{L}{c \cdot t} = \frac{v}{c} = \beta = \frac{p \cdot c}{E} = \frac{1}{\sqrt{\left(\frac{m \cdot c}{p}\right)^2 + 1}}$$

$$m = \frac{p}{c}\sqrt{\left(\frac{c \cdot t}{L}\right)^2 - 1}$$



- $p \uparrow$, $v \to c$,

  $\beta \to 1$

$$\frac{\sigma(m)}{m} = \frac{\sigma(p)}{p} + \gamma^2 \cdot \left(\frac{\sigma(t)}{t} + \frac{\sigma(L)}{L}\right)$$

TOF PID

- Comparison between measured and expected time:

$$t^{i}_{predict} = \frac{L}{c \cdot \beta_i}, \quad \beta_i = \frac{|\vec{p}|c}{E_i}, \quad E_i = \sqrt{m_i^2 + p^2}$$

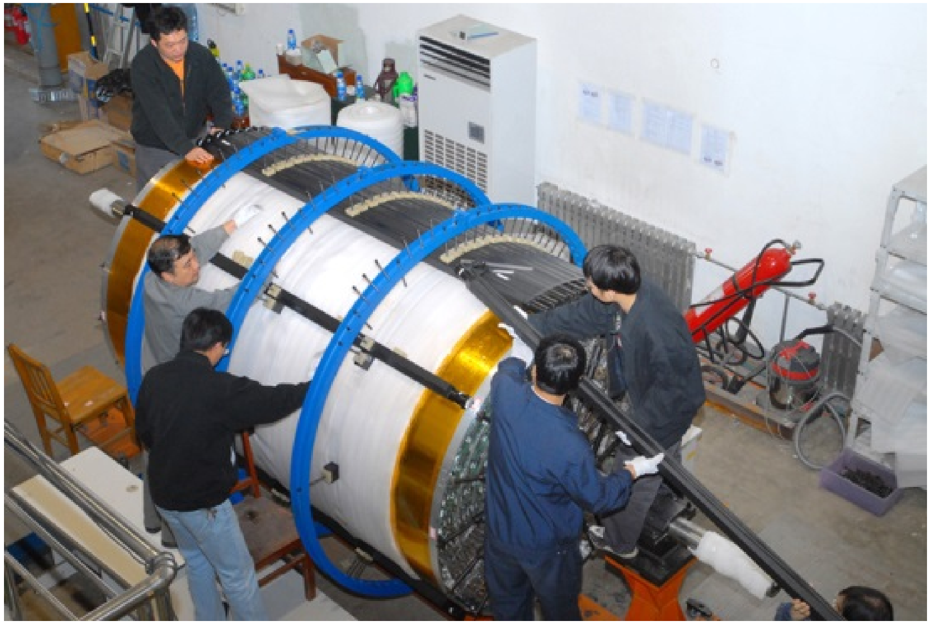
$$\chi = \frac{\Delta t}{\sigma} = \frac{t_{measure} - t^{i}_{predict}}{\sigma}$$ ➔ Normal distribution

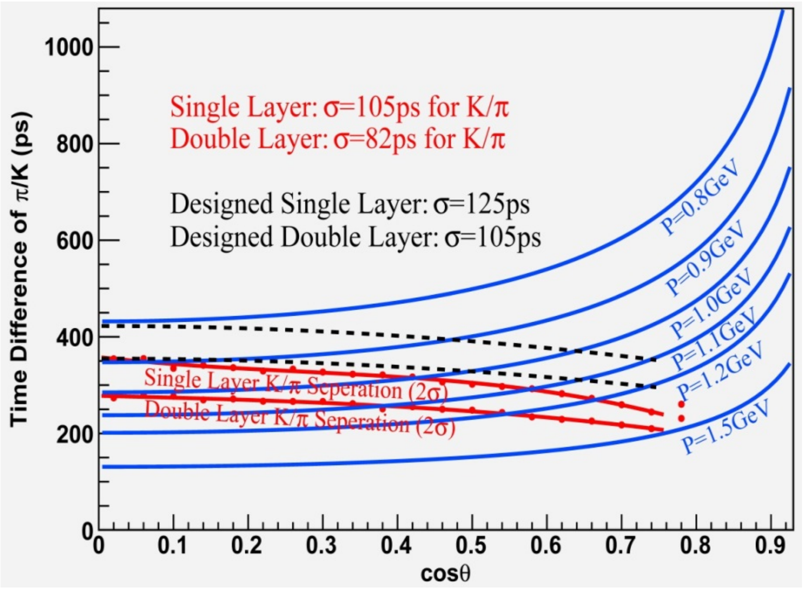
$$n_{TOF} = \frac{|t_A - t_B|}{\sigma_{TOF}} = \frac{Lc}{2p^2\sigma_{TOF}} |m_A^2 - m_B^2|$$

- Particle separation power of TOF depends on:
  - The flight time difference between different species particles with same momentum.
  - Time resolution

Scintillation TOF

- Scintillator bar coupled with PMT
  - Good time resolution
  - PMT under strong magnetic field
  - Increase of granularity





Multi-gap Resistive Plate Chamber

- MRPC-TOF

Charged particle → Primary ionization → Avalanche → Induced signal

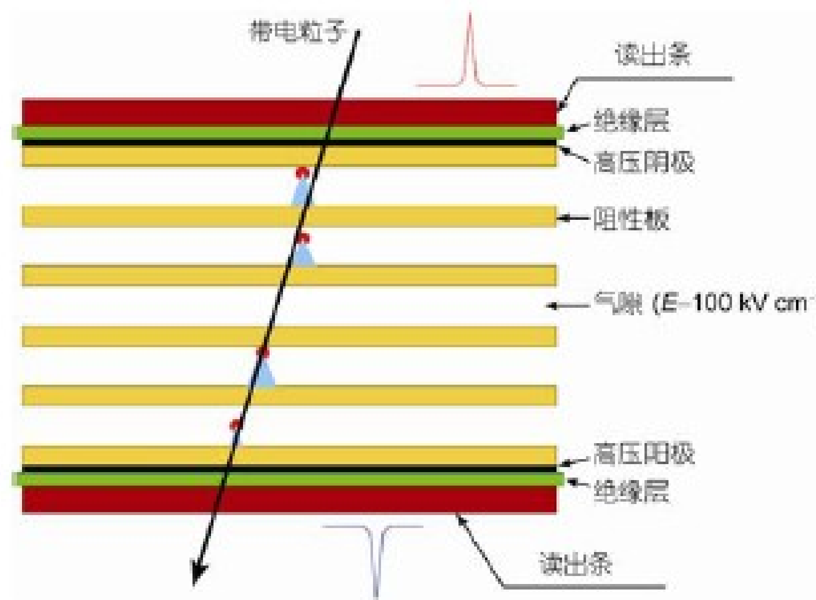
- Readout of scintillator is expensive, RPC is much cheaper.
- The RPC design was improved by Multi-gap RPC:
  - Reducing gap sizes

    restrict fluctuation of drift tim

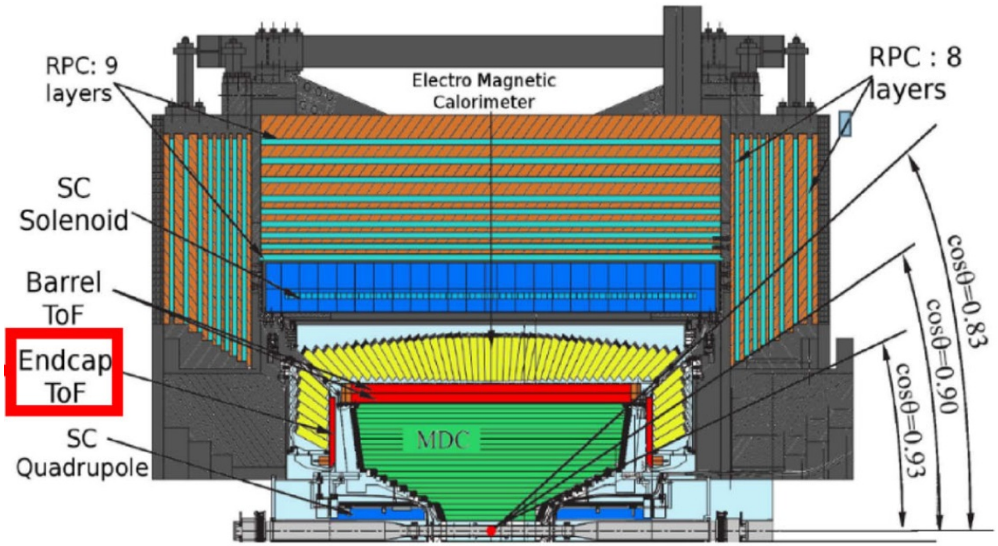
    improve time resolution
  - Increasing the electric field

    sum of the induced signals

    good detection efficiency



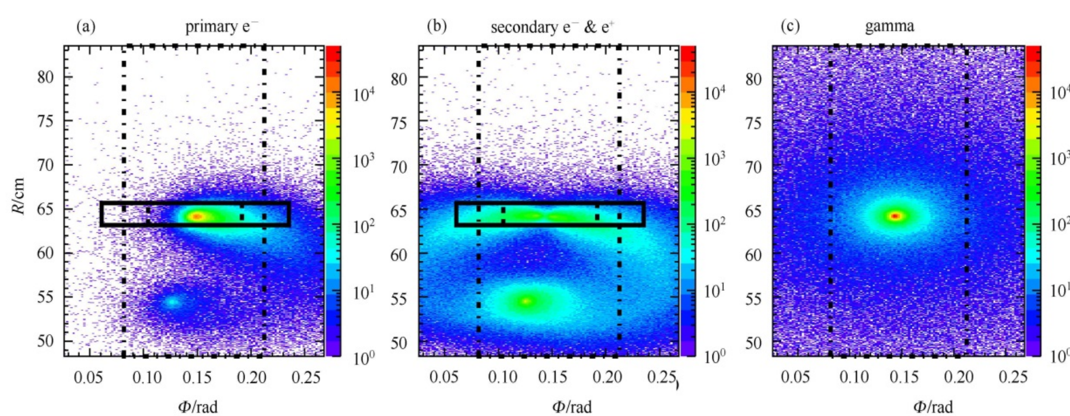
Scintillator End cap TOF @ BESIII



Intrinsic time resolution: 80 ps
Uncertainty of bunch time: 20 ps
Uncertainty of bunch length: 8-15mm
20—35ps
Extrapolation of track: 10mm
50ps
Electronics: 25 ps
Expected time: 30 ps
Time slewing: 10ps

Overall time resolution: 110—120 ps

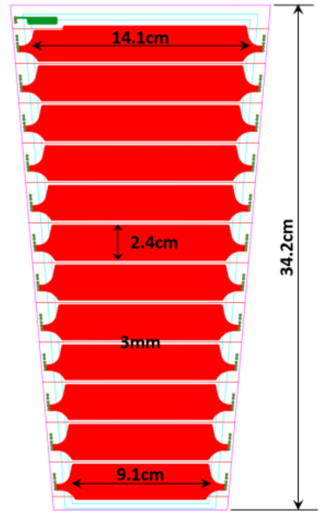
- The designed target is 110—120ps
- The time res for pions is 138ps.
- Multiple scattering has worsen the performance

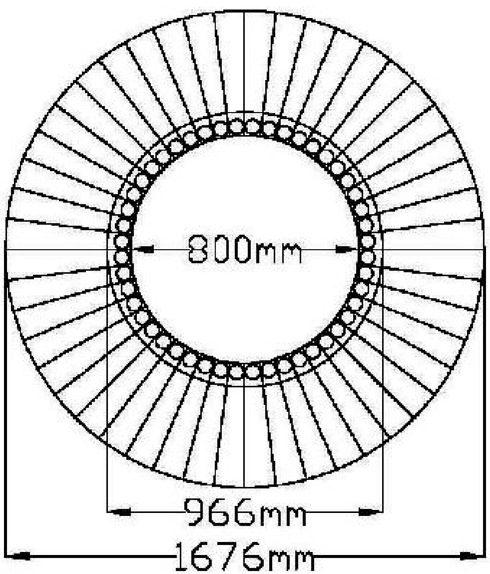


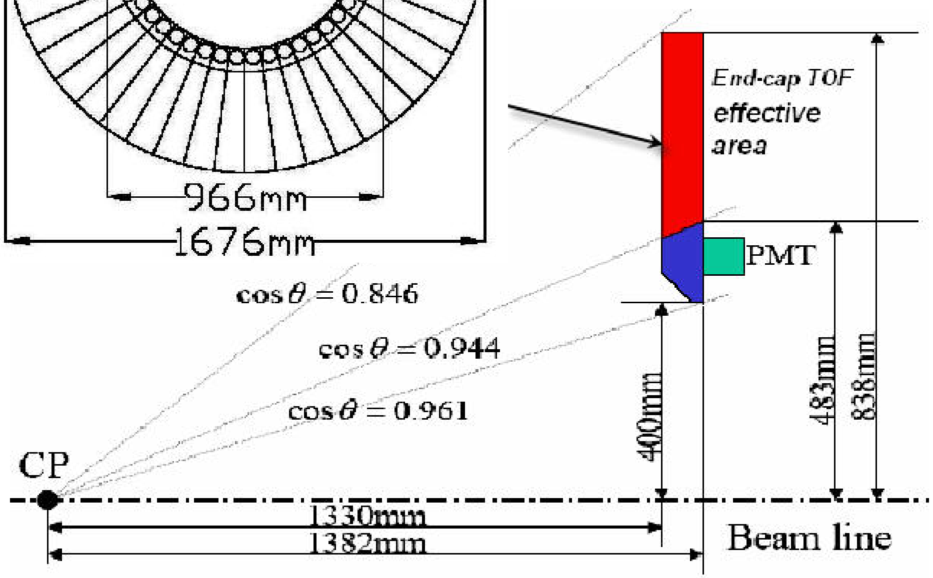
MRPC End cap TOF

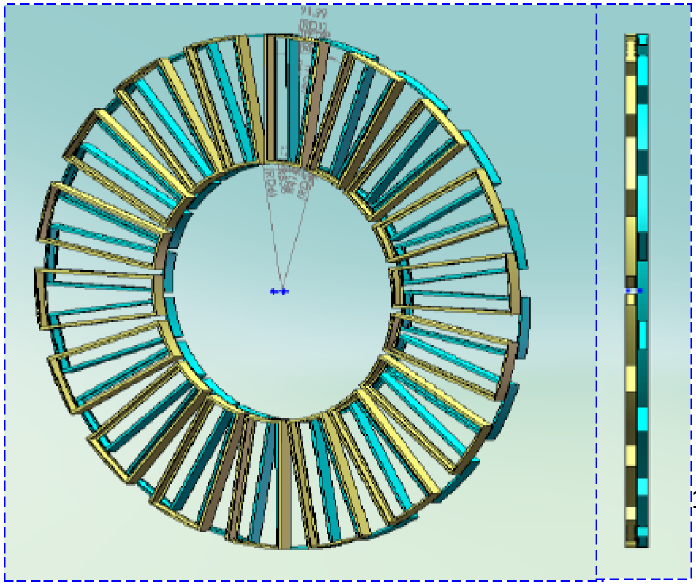
Intrinsic time resolution < 55 ps

	OLD	**NEW**
Detector	Scintillator	MRPC
Modules	96	72
Electronics	96	72×12×2=1728
Time Res	138ps	< 80~100ps

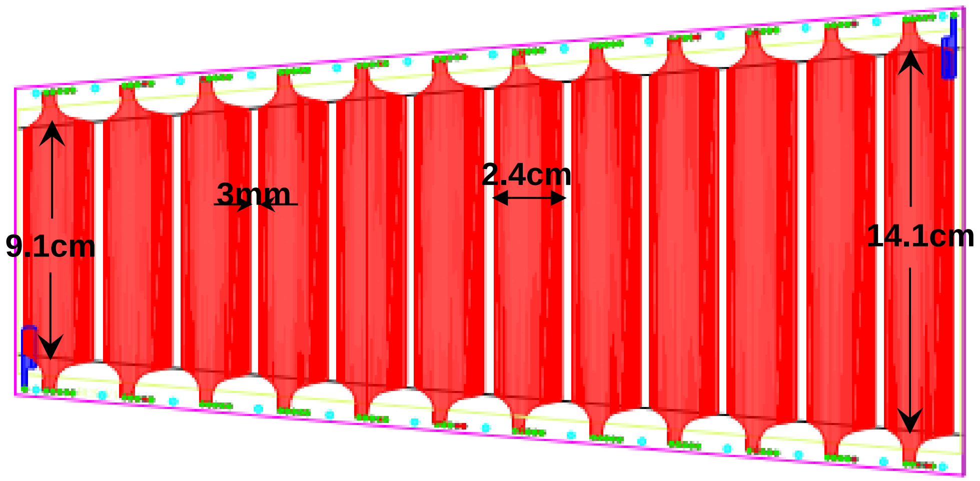




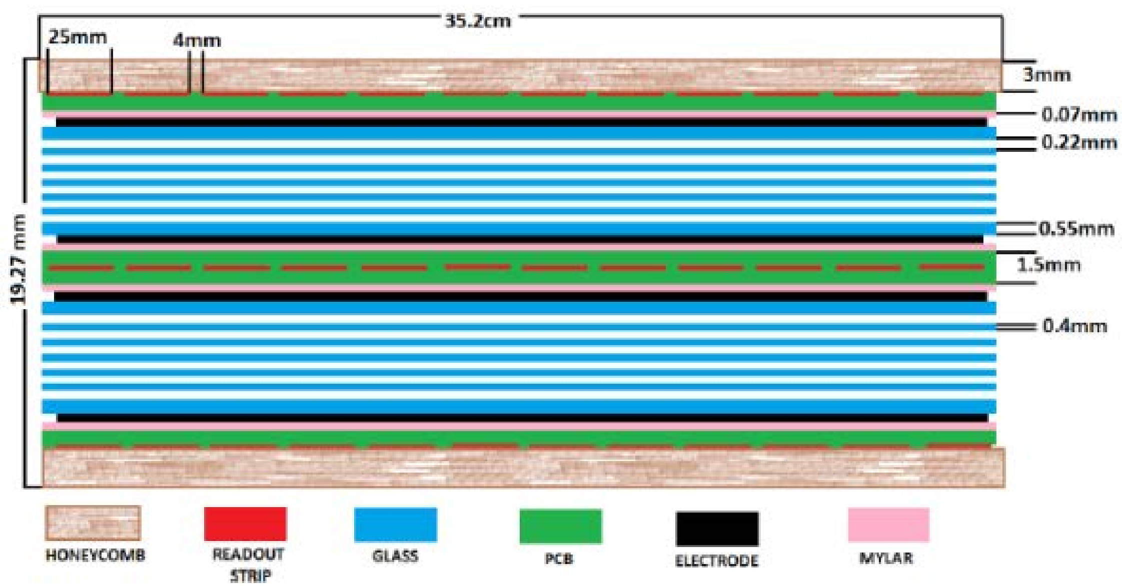




Structure of the MRPC

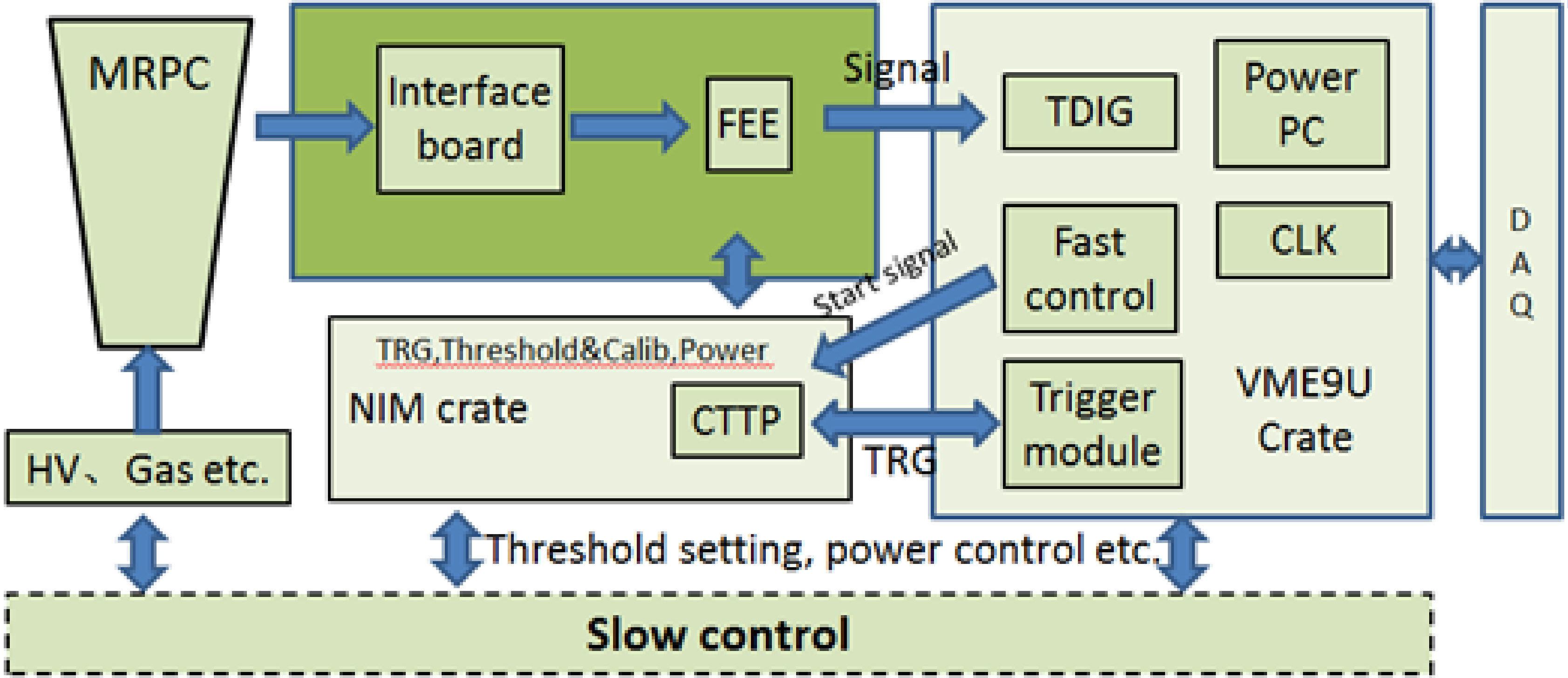


- Readout strip:
  - Width: 2.4 cm
  - Length: 9.1-14.1 cm



- Gas gap: 2 x 6
- Gap size: 0.22 mm
- Resistive plate: floating glass
- Total thickness: ~20 mm

Electronics

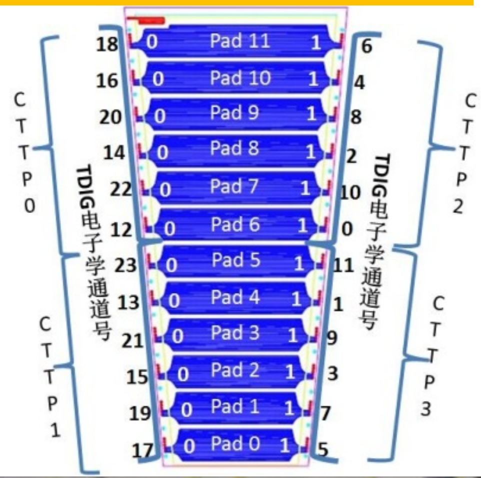


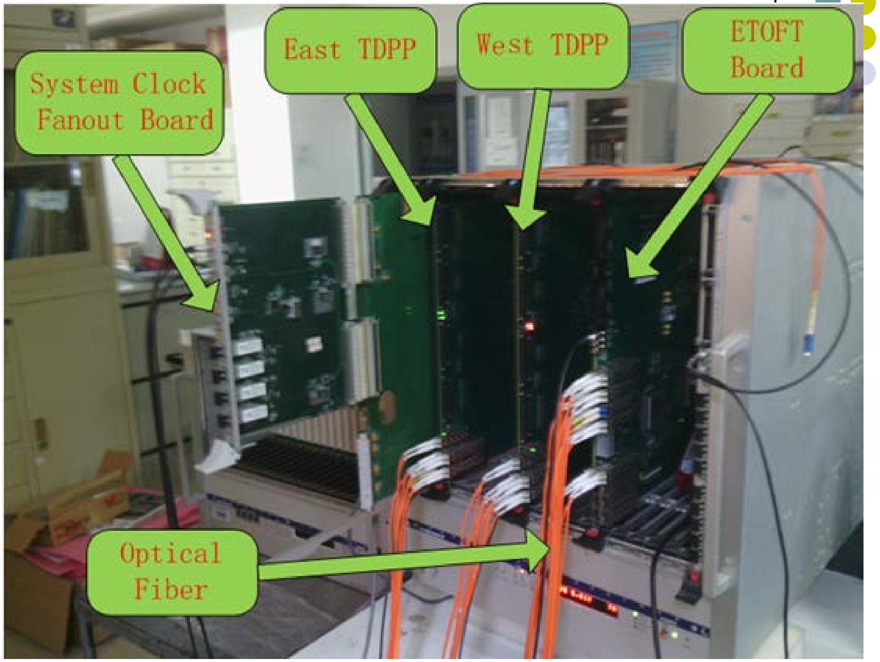
- FEE: Front_end electronics
- CTTP: Coincidence_Test_Threshold_Power
- TDIG: Time_to_Digital
- CLK: Clock

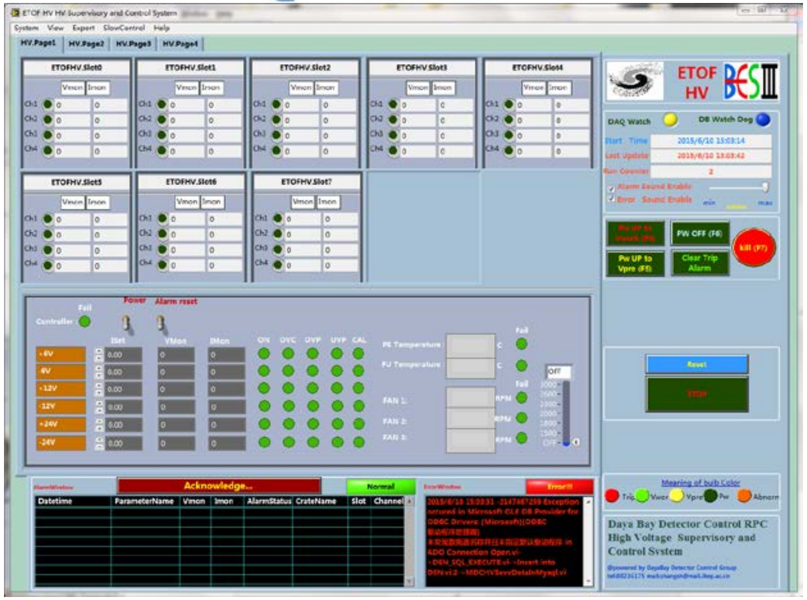
Time precision contributed by electronics (RMS) < 25ps

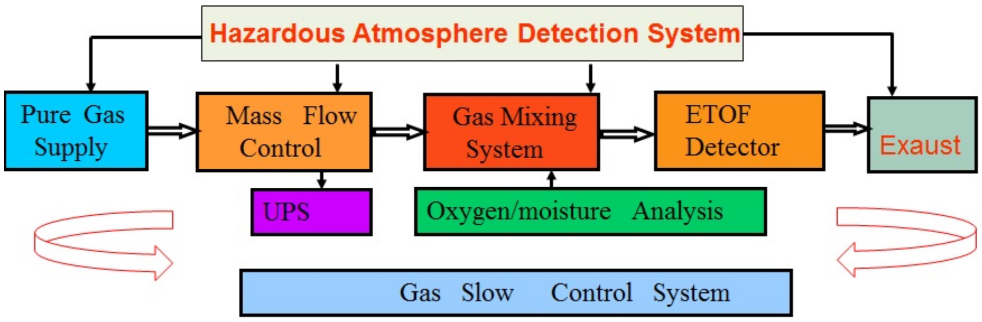
Trigger / Slow Control / Gas

Trigger conditions:
NETOF>=1, NETOF>=2,
Back to Back



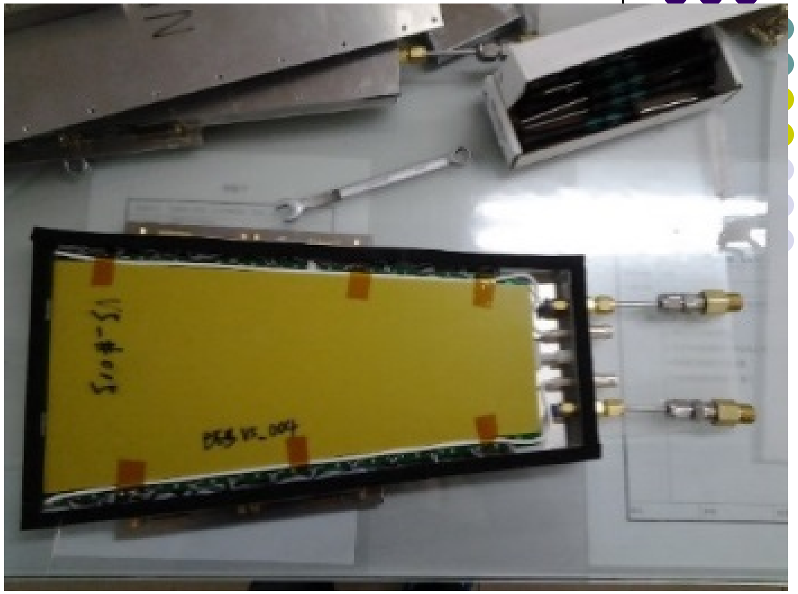


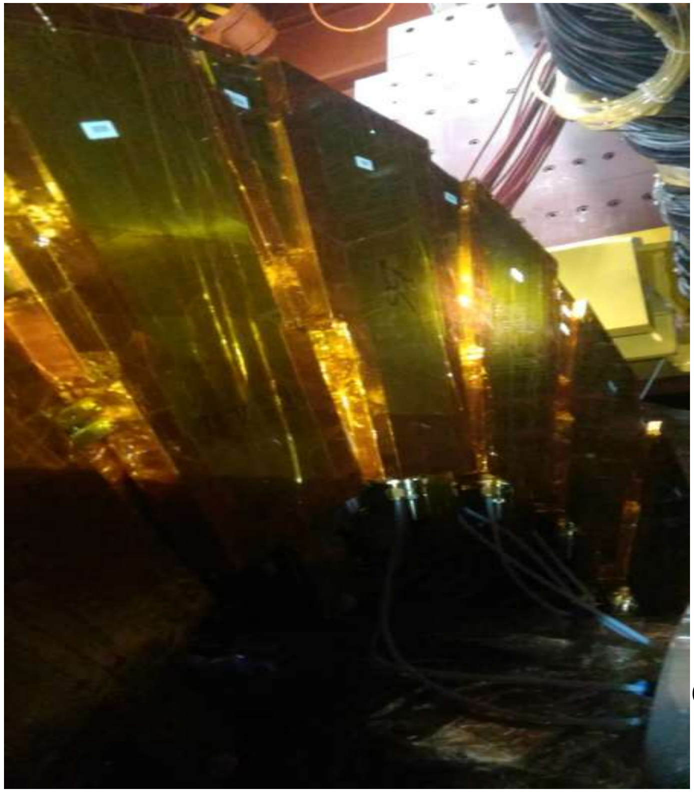




MRPC Installation

Oct. 2015, new MRPC End cap TOF
take place of scintillator endcap TOF
The total last about 60 days.





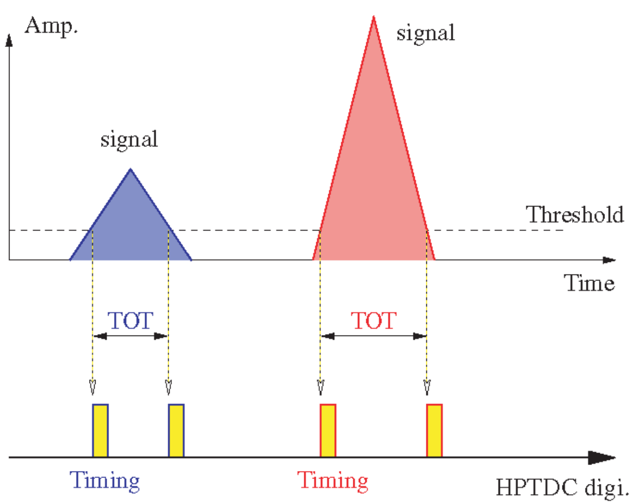
Procedure of MRPC Installation

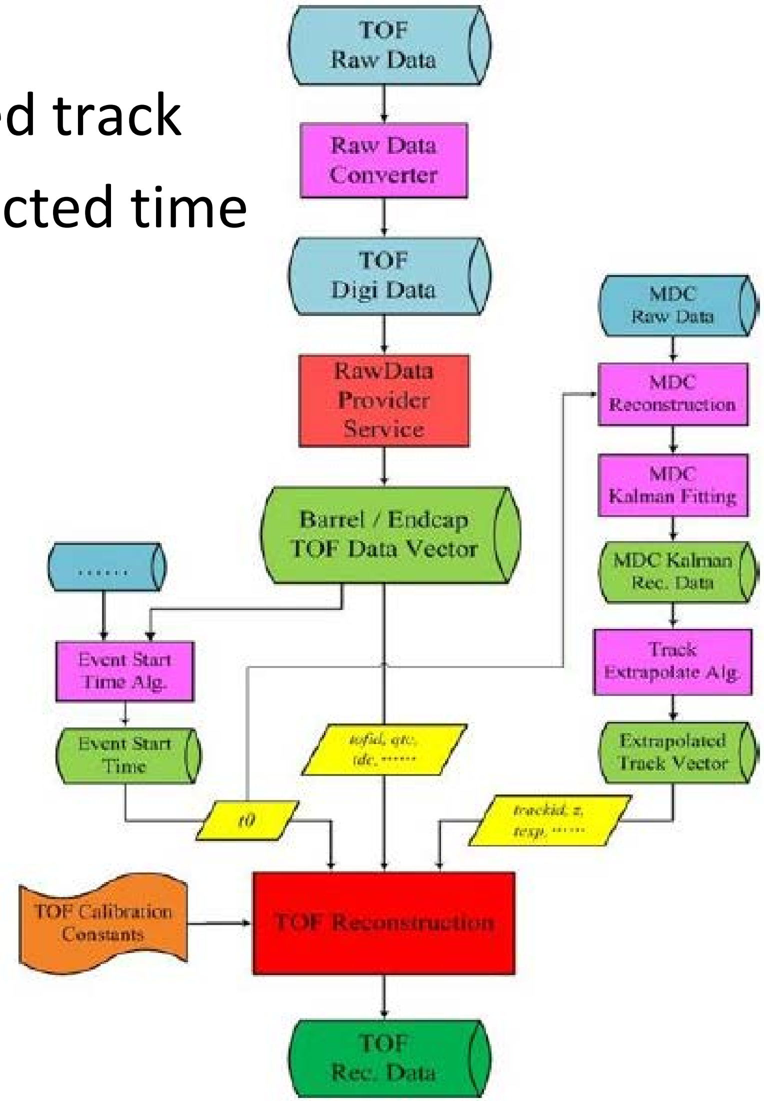
leakage Ratio check → electronics check → location guarantee

installation → gas pipes & HV wires → test with HV →

MRPC Endcap TOF Reconstruction

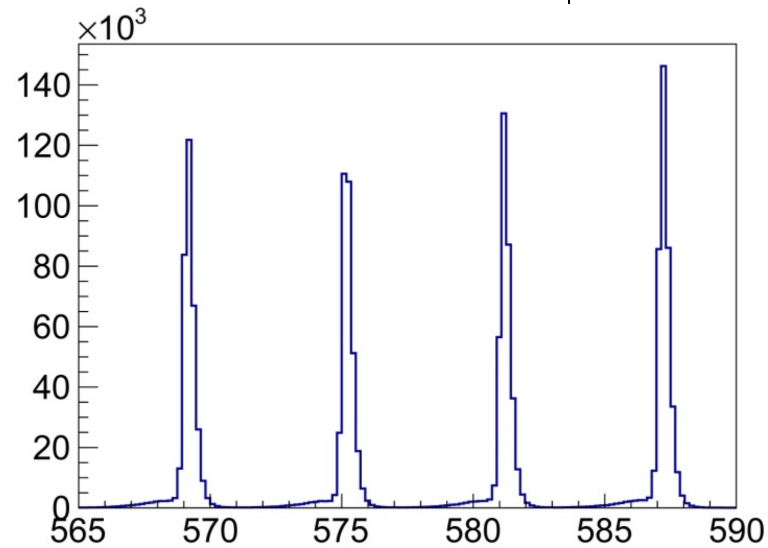
- Event Start Time t_0
- MDC Reconstruction ➔ Extrapolated track
  - Momentum, path length → expected time
  - Hit position
- TOF Raw Data
  - Leading time $t_{leading}$
  - Time-over-threshold (TOT)

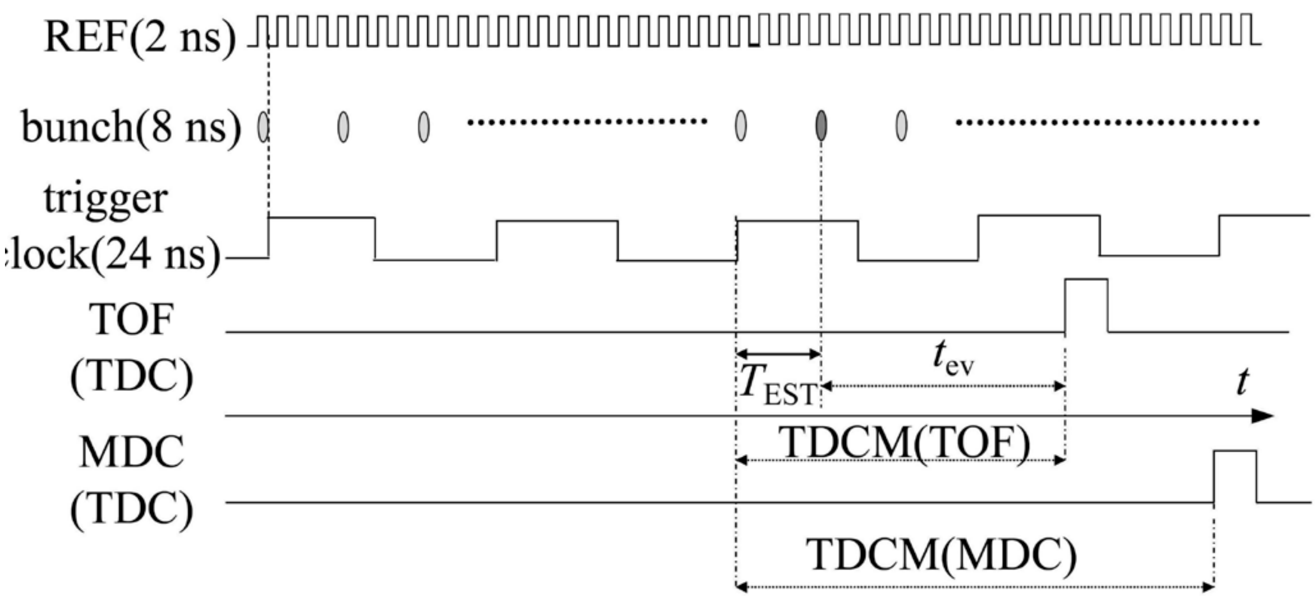




Event Start Time

$$\frac{1}{n}\sum_{i=1}^{n} t_{raw}^{i} - t_{corr} - t_{exp}^{i}$$



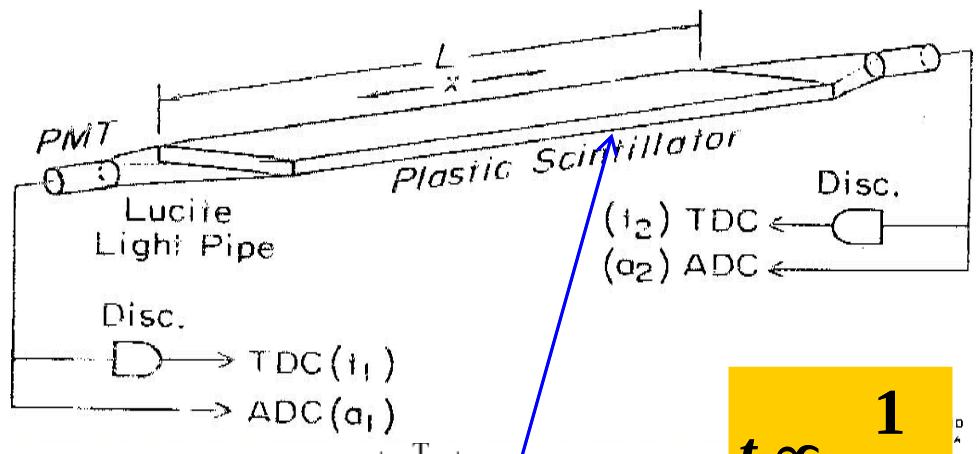


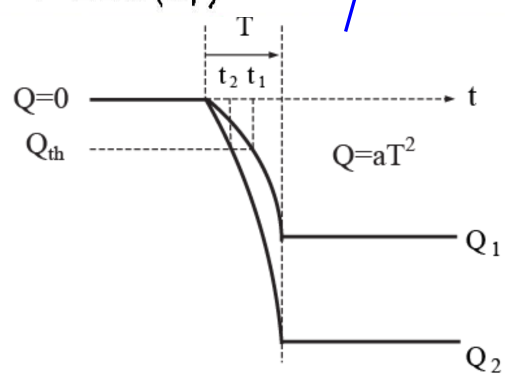
Signal of MRPC TOF

$$t_{cor} = t_{strip}^{pro}(z) + t_{time-walk}(q) + t_{delay}$$

$$\Delta t = t_{mea} - t_{exp}$$

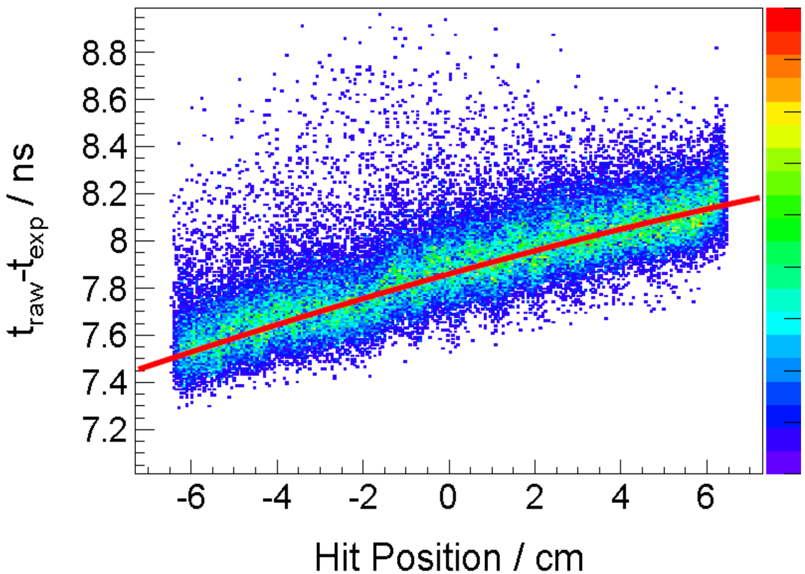
$$TDC = t_0 + t_{mea} + t_{cor}$$

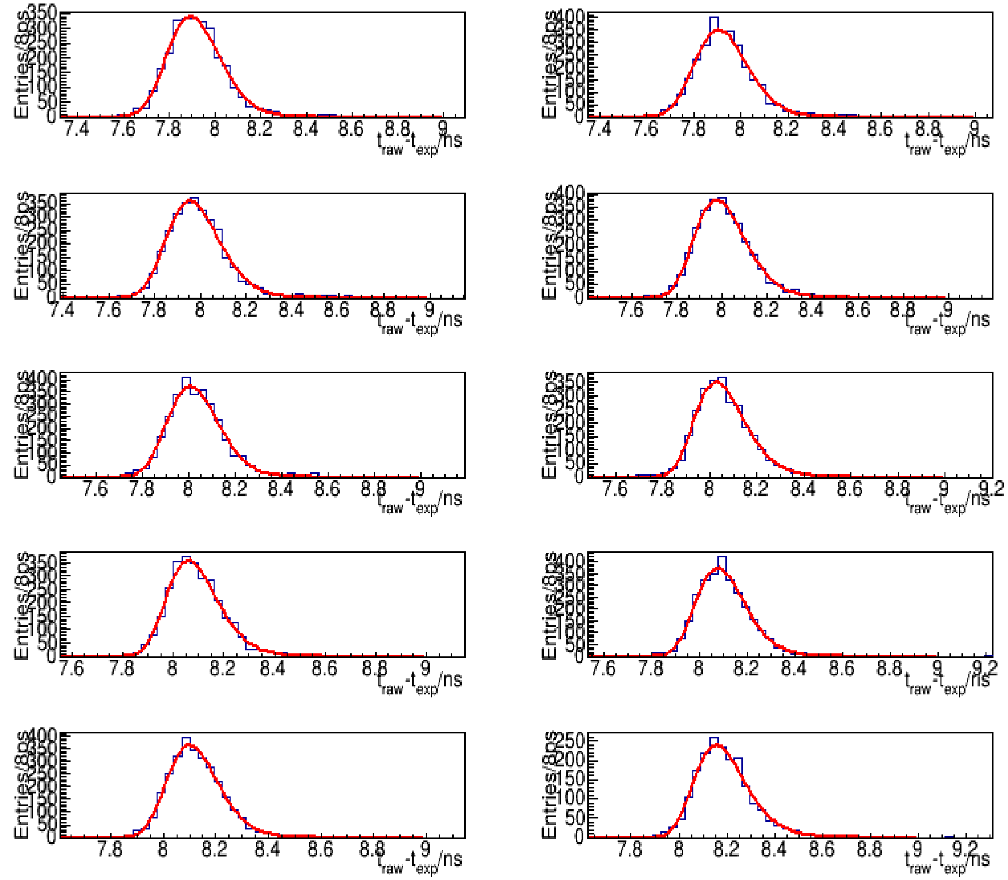




$$t \propto \frac{1}{\sqrt{Q}}$$

Transmission time on the strip

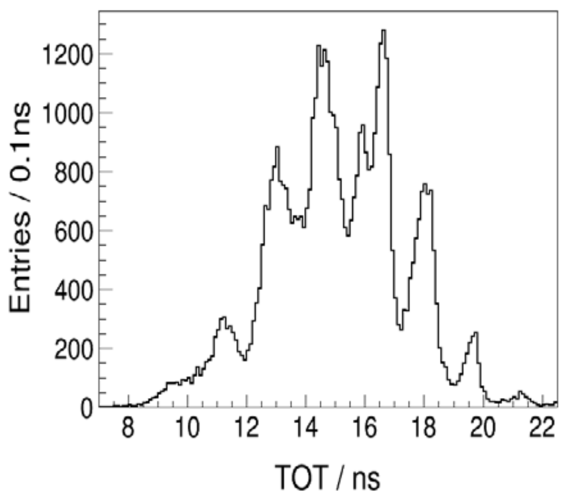


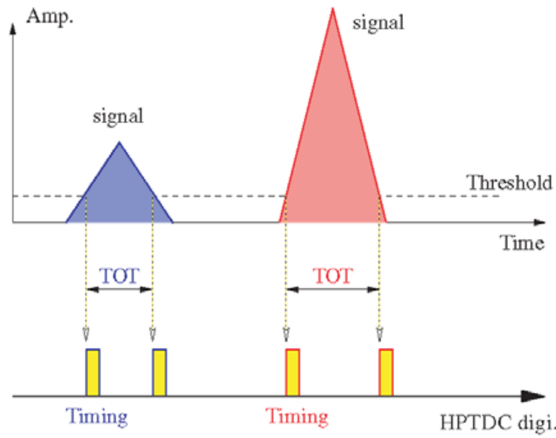


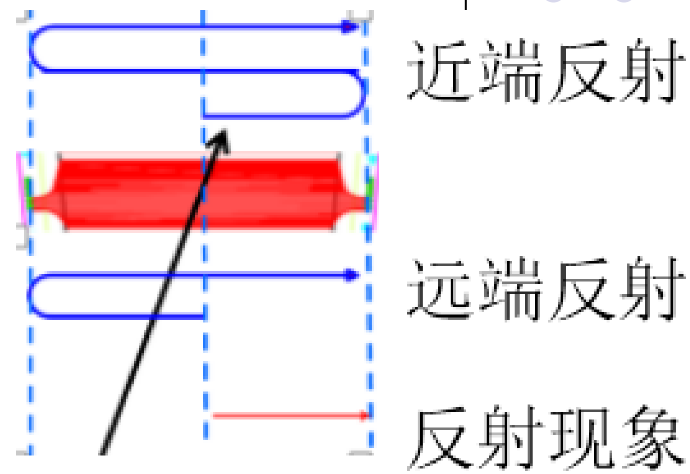
Dependence of measured time on the hit position

4-order polynomial function

Multi-peak TOT Distribution
Reflection of the signal in strip







$$t_{trailing} - t_{leading} = tot$$

$$t_{leading} = \frac{l/2 - z}{v} + t_{delay}$$

$$tot^{far} = tot + \frac{2 \cdot z}{v} + n \cdot t_{strip}$$

$$t_{trailing} = \frac{l/2 - z}{v} + tot + t_{delay}$$

$$tot^{near} = tot + 2n \cdot t_{strip}$$

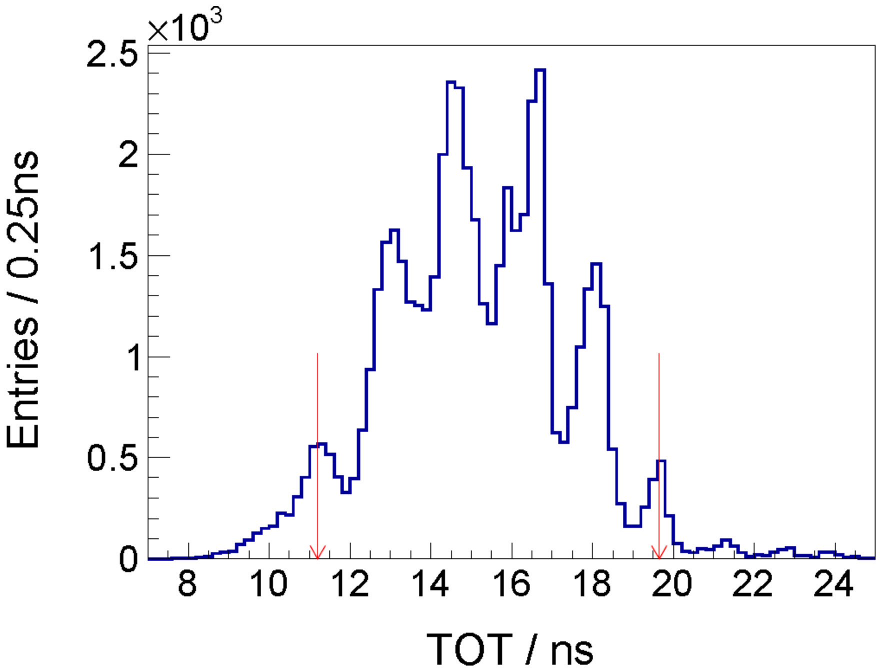
$$t_{trailing}^{far} = \frac{l/2 + z}{v} + tot + n \cdot t_{strip} + t_{delay}$$

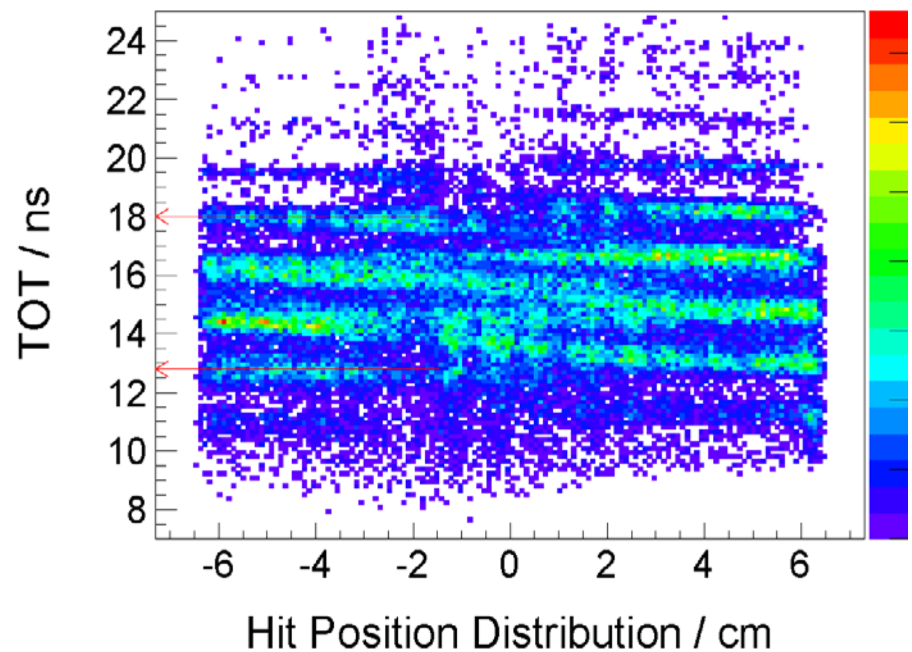
$$t_{trailing}^{near} = \frac{l/2 - z}{v} + tot + 2n \cdot t_{strip} + t_{delay}$$

Multi-peak TOT Distribution
Reflection of the signal in strip

Length of strip: 13 cm
Length of foot: 2.8 cm
Velocity of signal: 55ps/cm

Transmission time for total strip
(13+2.8)*55=869ps
869ps*2=1.738ns



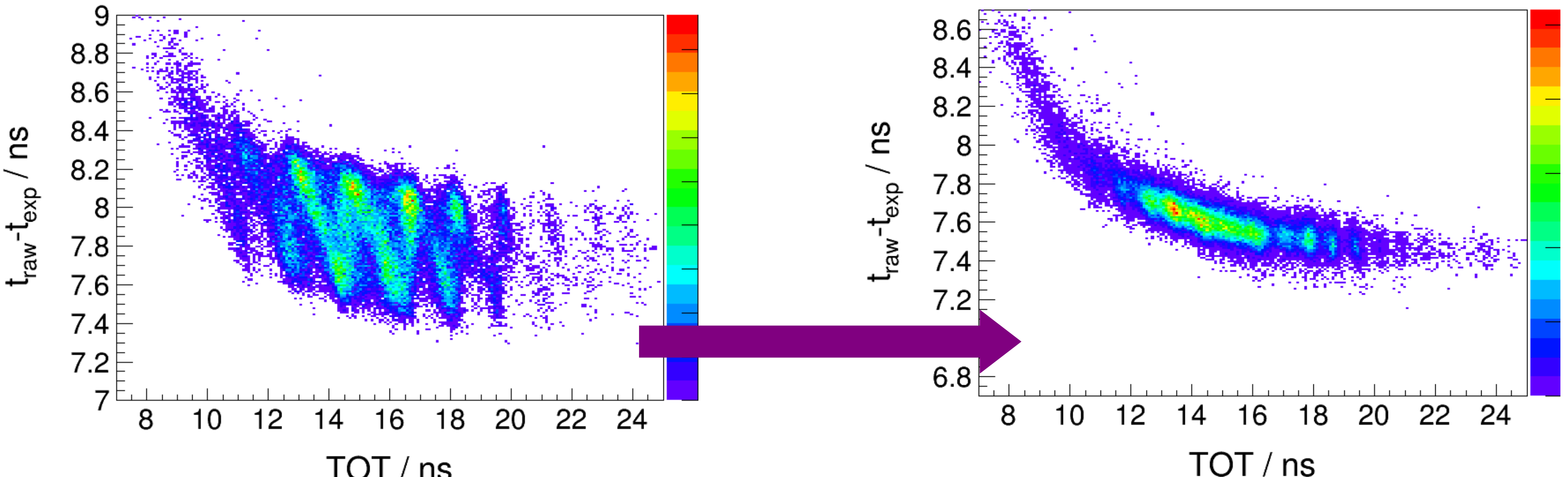


Time interval
(19.65ns-11.2ns)/5=1.69ns

Time interval
(18.0ns-12.8ns)/3=1.73ns;

Time Walk (Time Slewing)

- Measured raw time depend on hit position
- Multi-peak TOT partly depend on hit position



Hit position correction

MRPC TOF Calibration

- Bhabha events are used for calibration sample
- Empirical calibration function for single end of strip

$$t_{corr} = p_0 + \frac{p_1 + p_2 \cdot z}{\sqrt{Q}} + \frac{p_3 + p_4 \cdot z}{Q} + (p_5 + p_6 \cdot z) \cdot Q + p_7 \cdot Q^2 + p_8 \cdot Q^3 + p_9 \cdot Q^4 + p_{10} \cdot z + p_{11} \cdot z^2 + p_{12} \cdot z^3$$

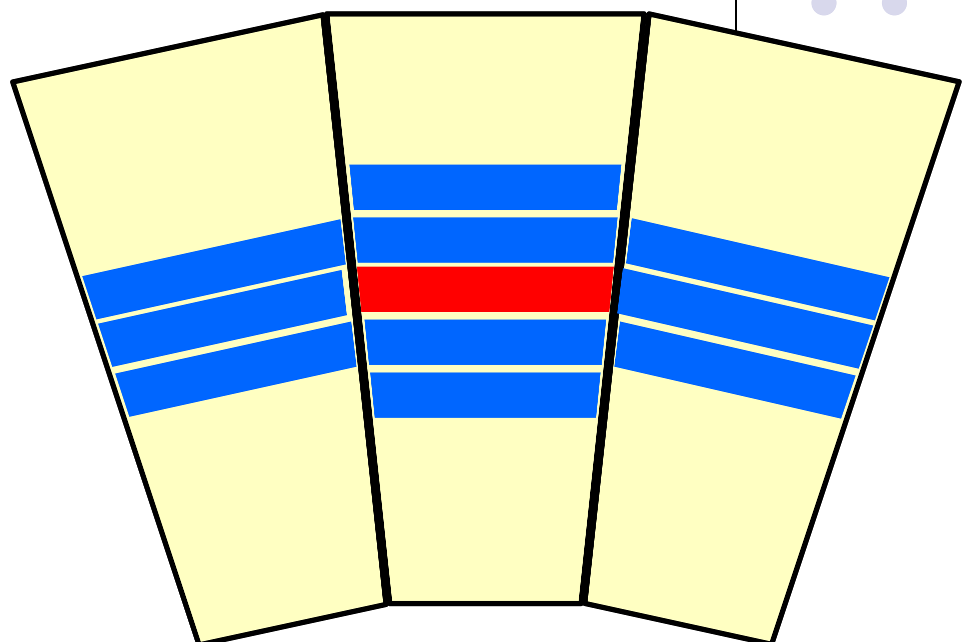
- Empirical calibration function for strip

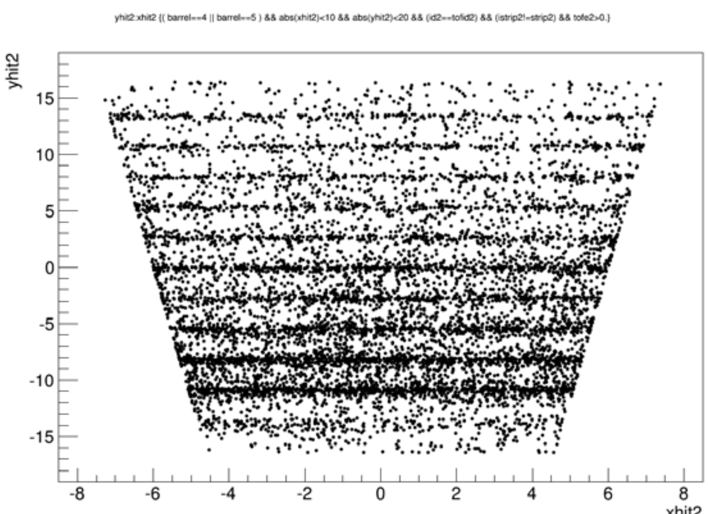
$$t_{corr} = p_0 + \frac{p_1}{\sqrt{Q}} + \frac{p_2}{Q} + p_3 \cdot Q + p_4 \cdot Q^2 + p_5 \cdot Q^3 + p_6 \cdot Q^4$$

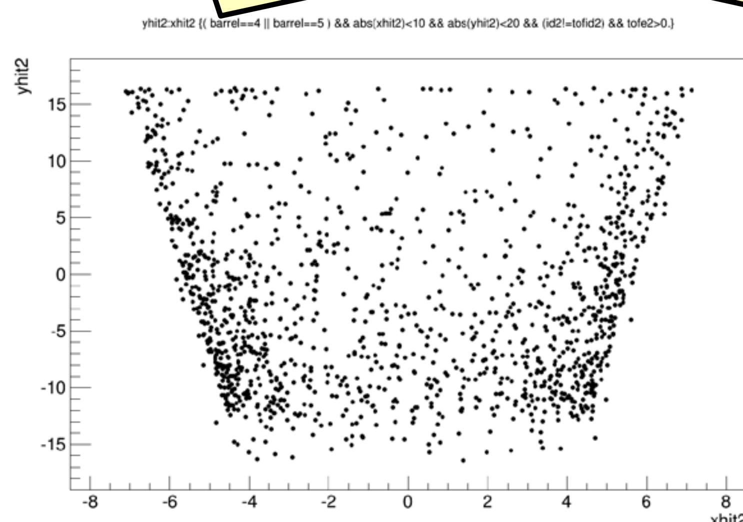
$$t_{corr}^{combine} = \frac{1}{2}(t_{corr}^{left} + t_{corr}^{right})$$

MRPC TOF Reconstruction

- Extrapolated strip as center, search signals in the range of 3+5+3 strips
- Multi-signals:
  - Match hit position
  - Compare TOT







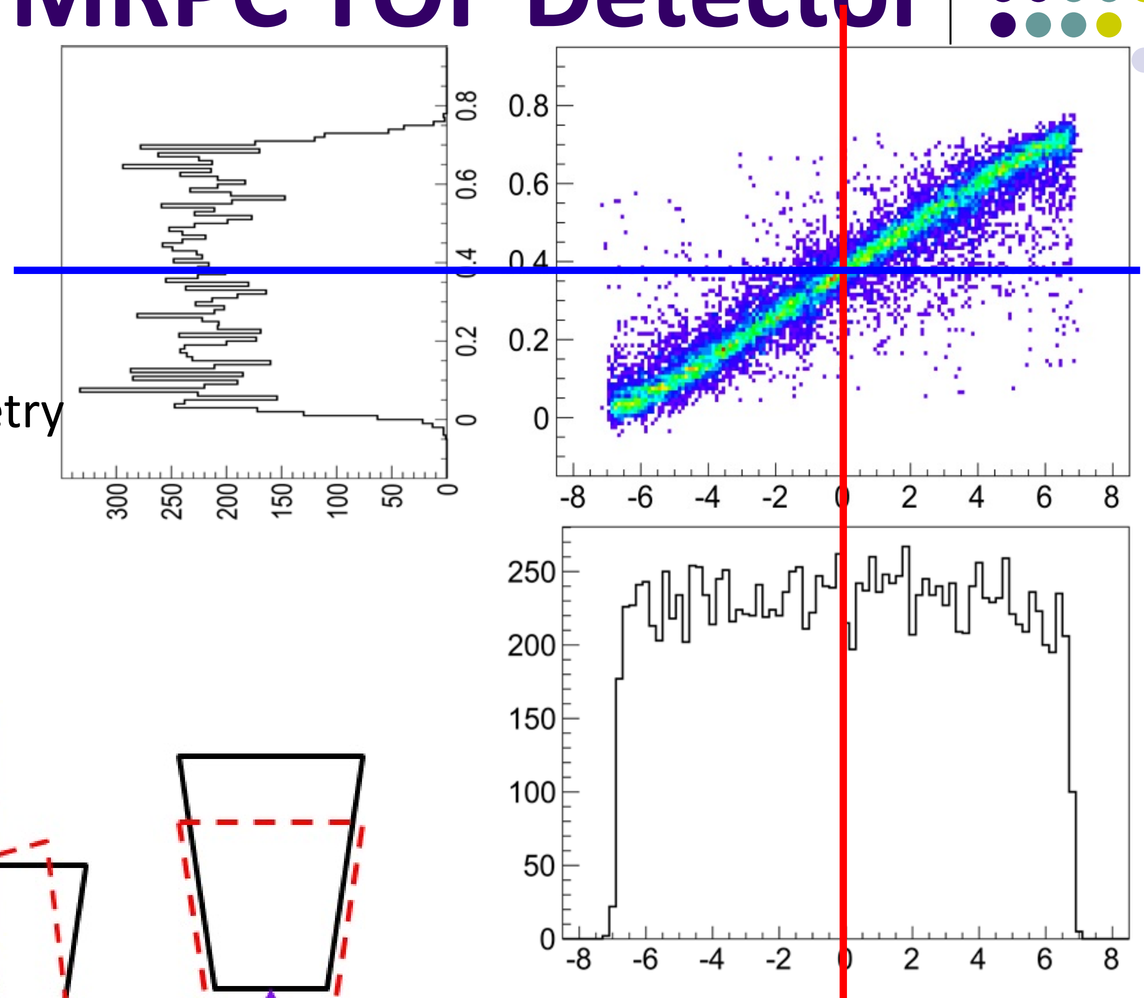
Alignment of MRPC TOF Detector

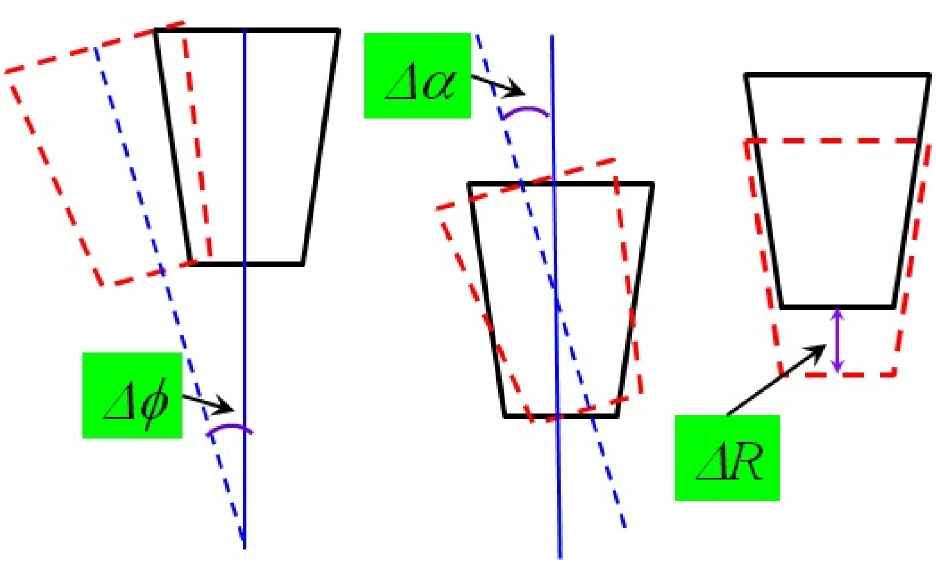
$$t_1 = \frac{l/2 - z}{v} + t^1_{delay}$$

$$t_2 = \frac{l/2 - z}{v} + t^2_{delay}$$

True Geometry   Ideal Geometry

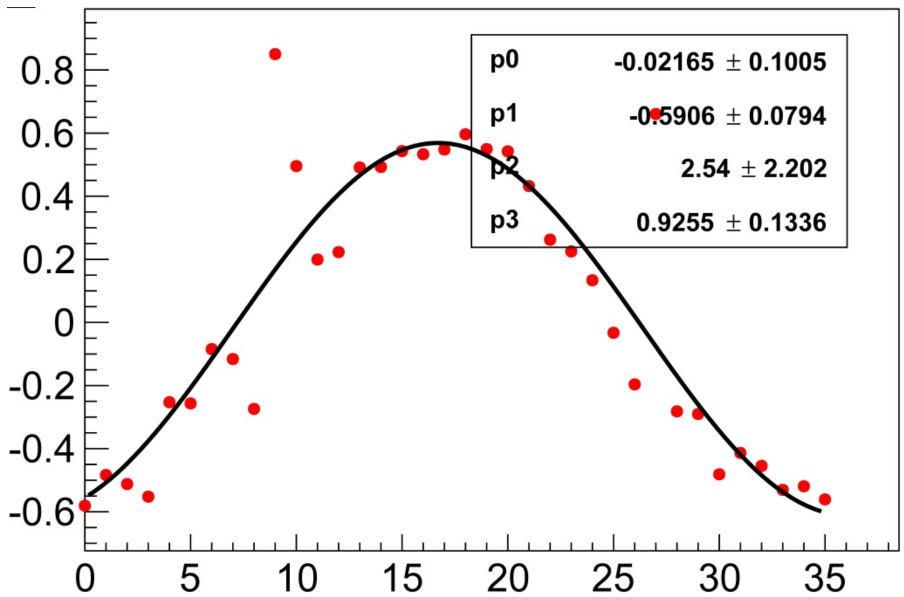
$$\frac{t_2 - t_1}{2} = \frac{z}{v} + c$$

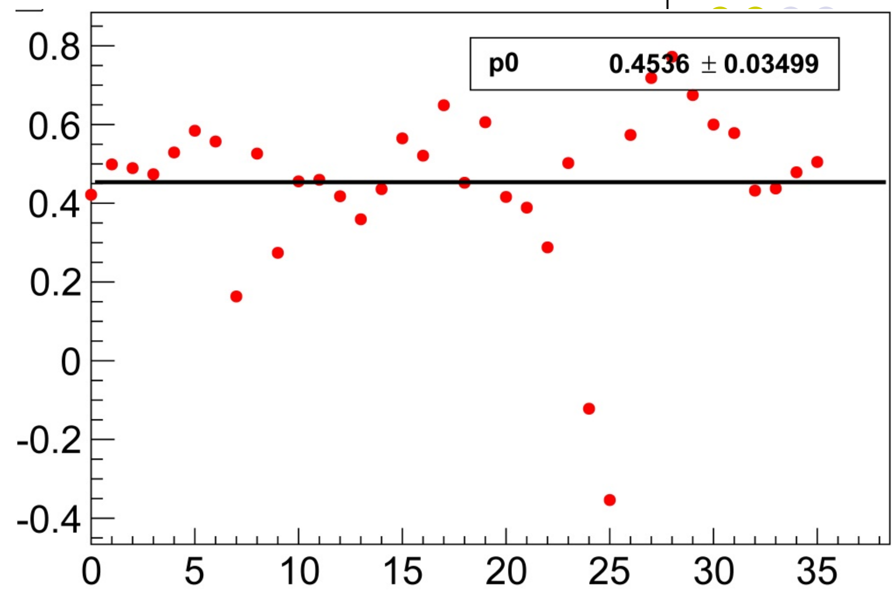




Assumption no misalignment along the beam direction

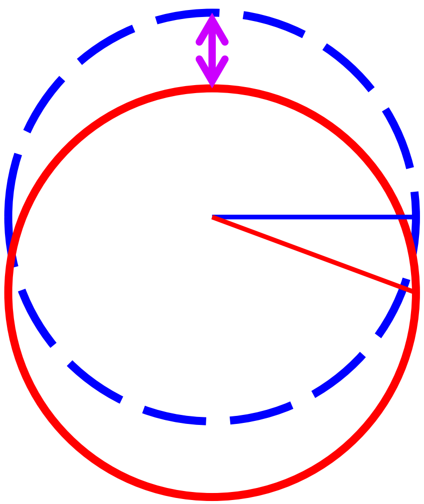
Alignment of MRPC TOF Detector



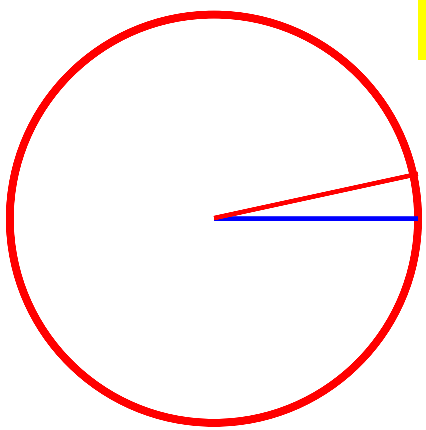


East Endcap

West Endcap

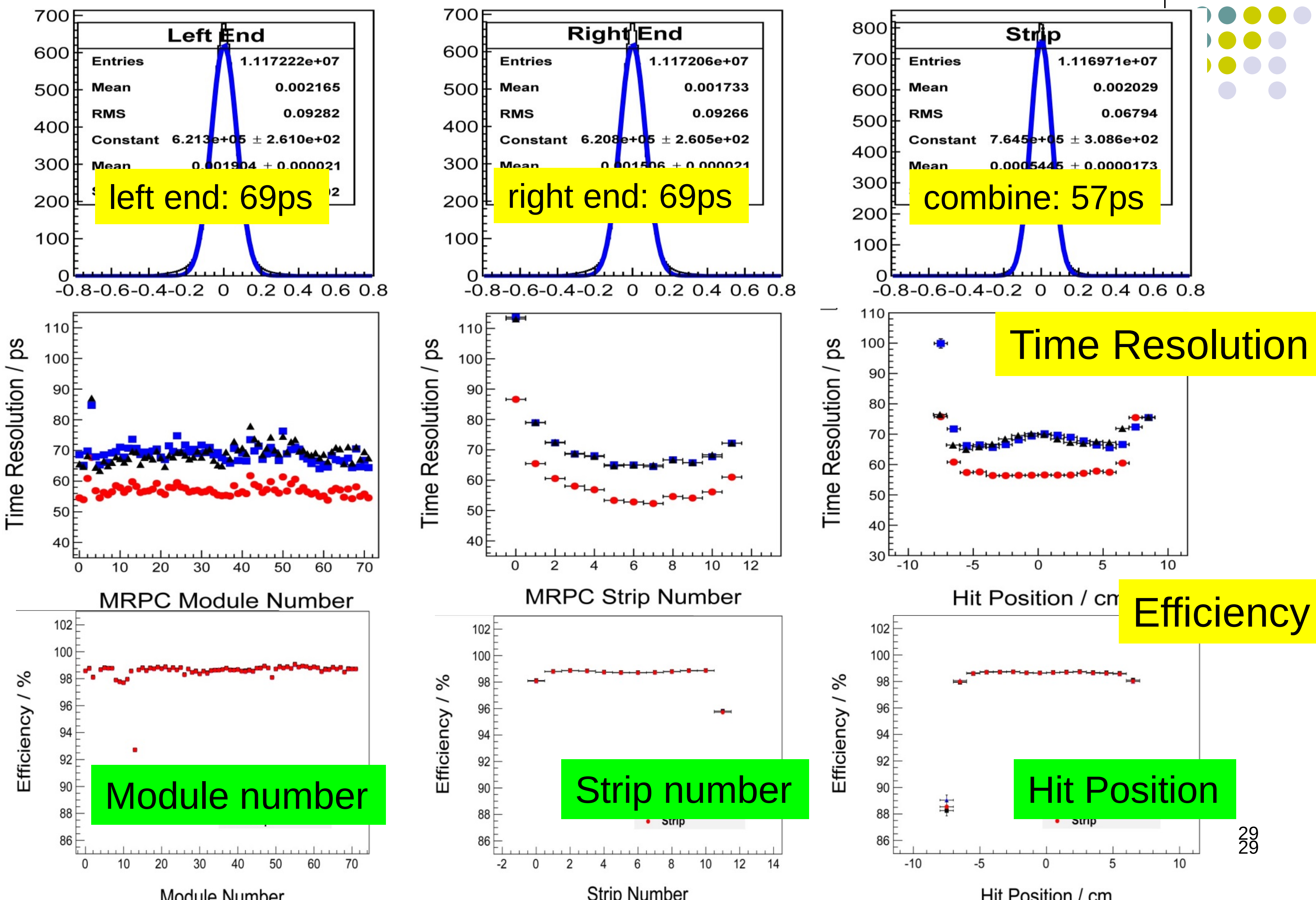


7mm



0.45 degree

Time Resolution and Efficiency of Bhabha



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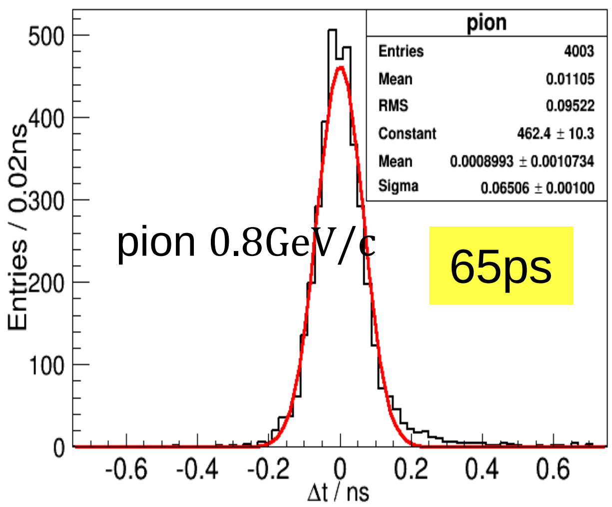
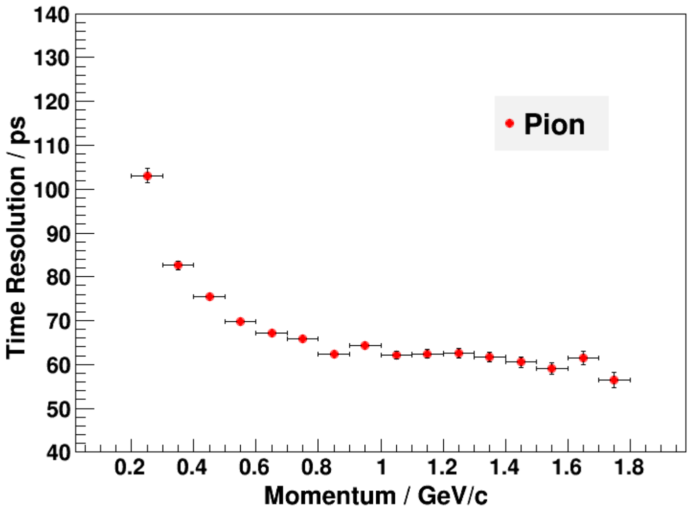
Time Resolution for π

Scintillator ETOF: 138 ps
Designed Target of MRPC ETOF: 80~100 ps
BESIII: 65ps



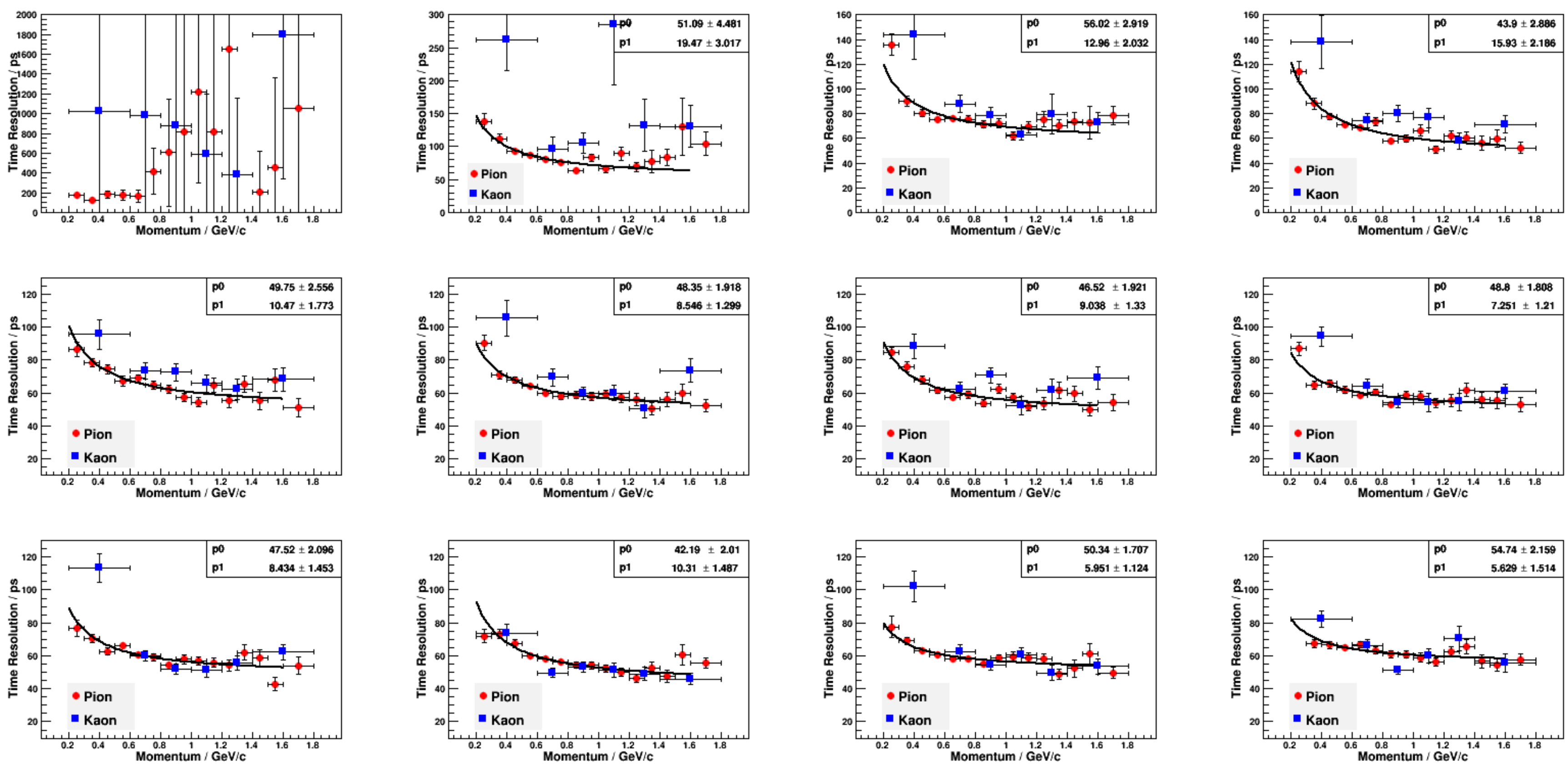


Accelator	Detector	Time Resolution(π)
RHIC	STAR	80ps
LHC	ALICE	86ps (Without t0)
BEPCII	BESIII	**65ps**

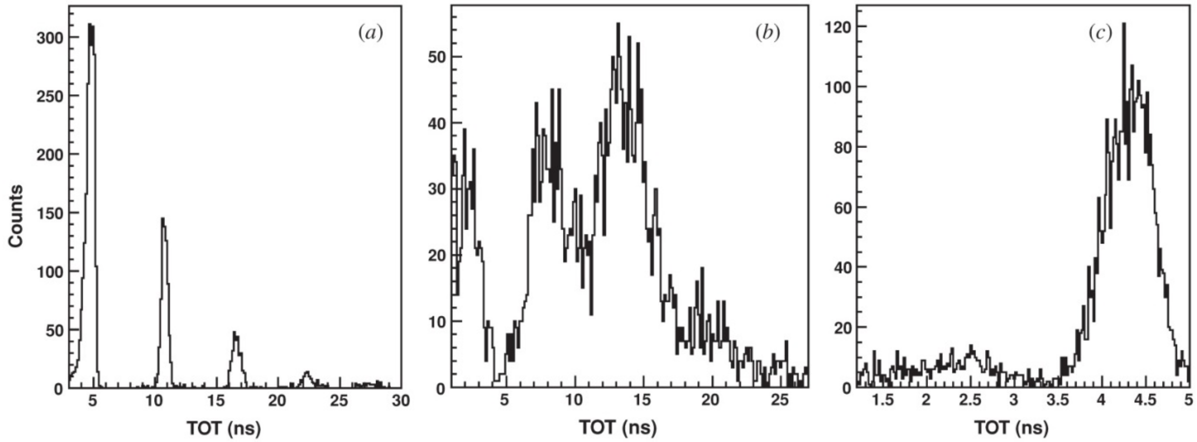
χ Calculation in PID Algorithm

- Time difference is not observed to depend on species of particle (?)
- Time difference depends on the momentum and polar angle.

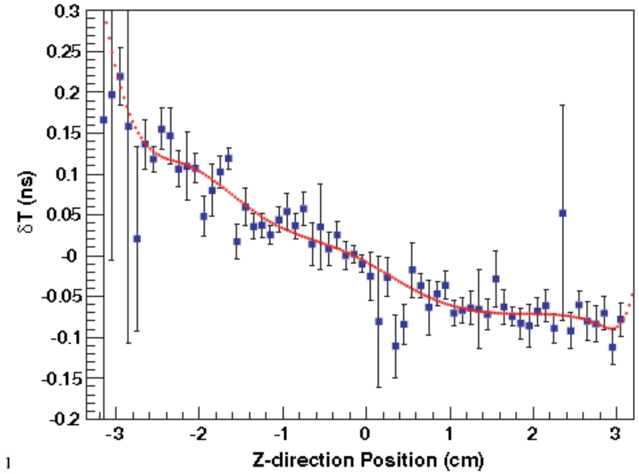
$$\chi_i = \frac{t_{mea} - -t^i_{exp}}{\sigma(strip, p)}$$



STAR Experiment --- Spline Fit



5. Three kinds of TOT distribution pattern of MRPCs measured by HPTDC. A clear ringing effect can be seen in the left and r
due to improper termination.



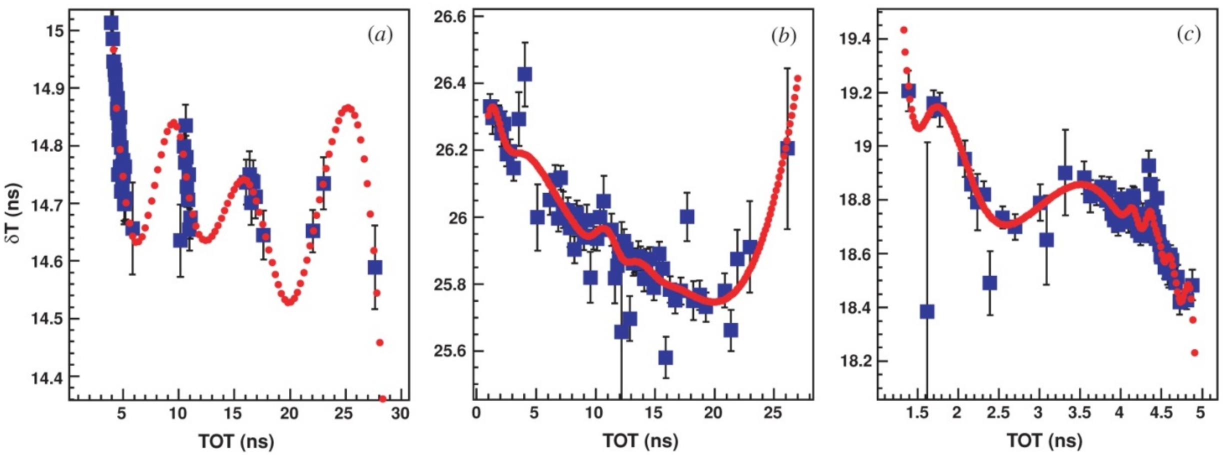
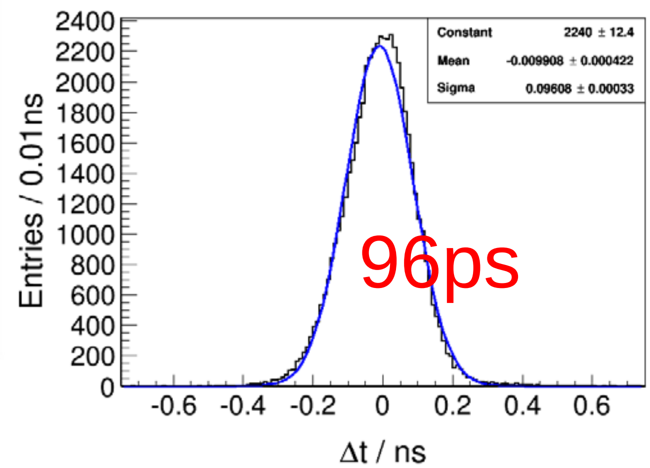
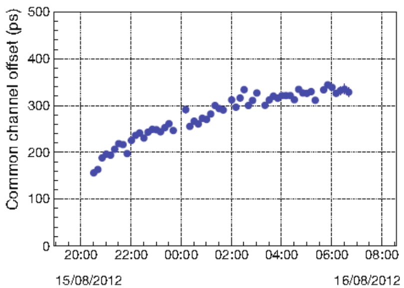
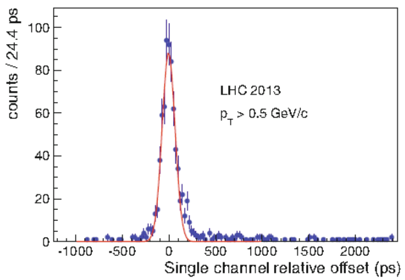


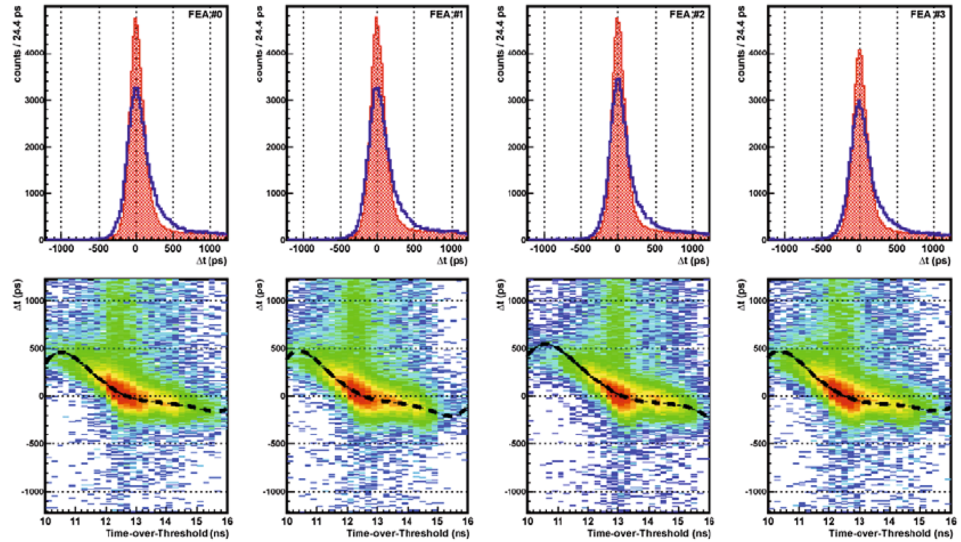
Figure 7. Spline fit results for different TOT distribution patterns.



ALICE Experiment







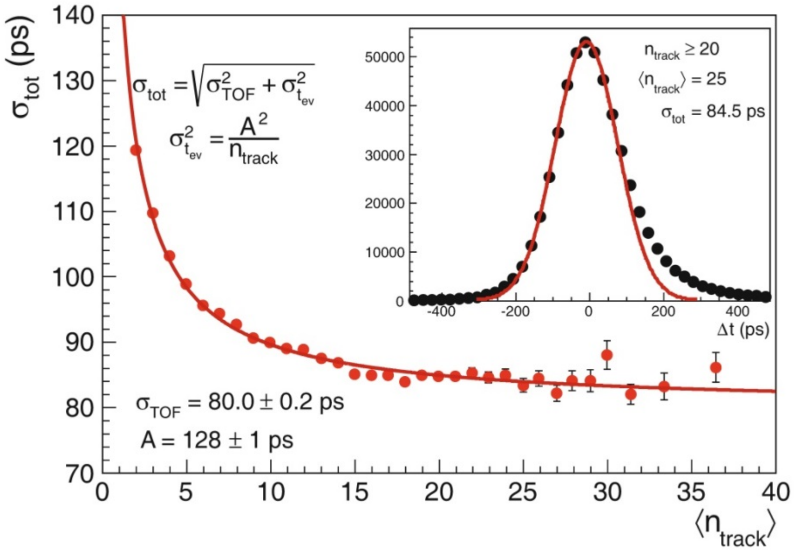


Fig. 7. Total time resolution for pion tracks on TOF with $0.95 < p < 1.05\,\mathrm{GeV}/c$ as a function of the number of tracks used to define the TOF event time. Data refer to p-Pb collisions. The inset shows the original distribution for a track multiplicity on TOF > 20 which corresponds to an average of 25.

Summary and Discussion

- Particle identification is crucial
- MRPC TOF: good time resolution, high efficiency and low cost
- Offline data processing of MRPC ETOF @ BESIII
  - Analysis of multi-peak TOT
  - Alignment of detector
  - Empirical calibration function.
- The time resolution of 0.8 GeV/c pion achieved 65 ps.

Thank you & Happy New Year!