Applications of Fast Time-of-Flight system

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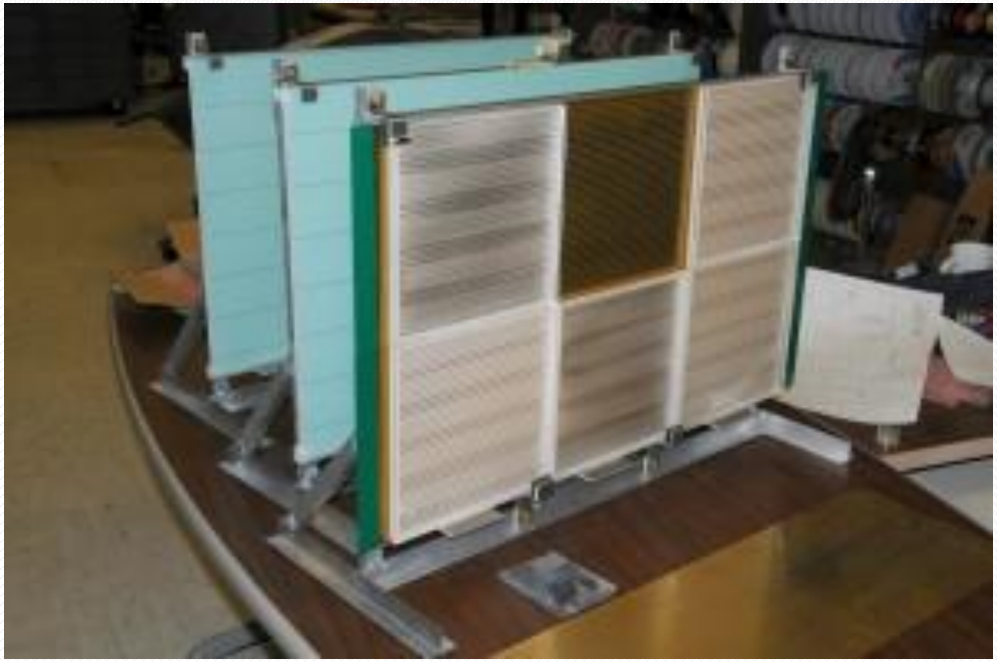
Research Background

- A next-generation of large-area, low cost time-of-flight (TOF) detectors with time resolutions ≤10 ps and space resolutions ≤1 mm is being developed for use in nuclear and particle physics experiments, as well as for medical and industrial applications.
- Prototype detectors with areas of ~1 m^2 are expected to become available for testing and early applications in the next year or two. Such detectors are being considered for use in muon cooling measurements for muon collider studies, TOF spectrometry, and particle identification in collider detectors.
- A concept for using such detectors for momentum determination is presented.

Prototype Detector

1 tile: 20 cm by 20 cm

1 tray: 2 tiles by 3 tiles

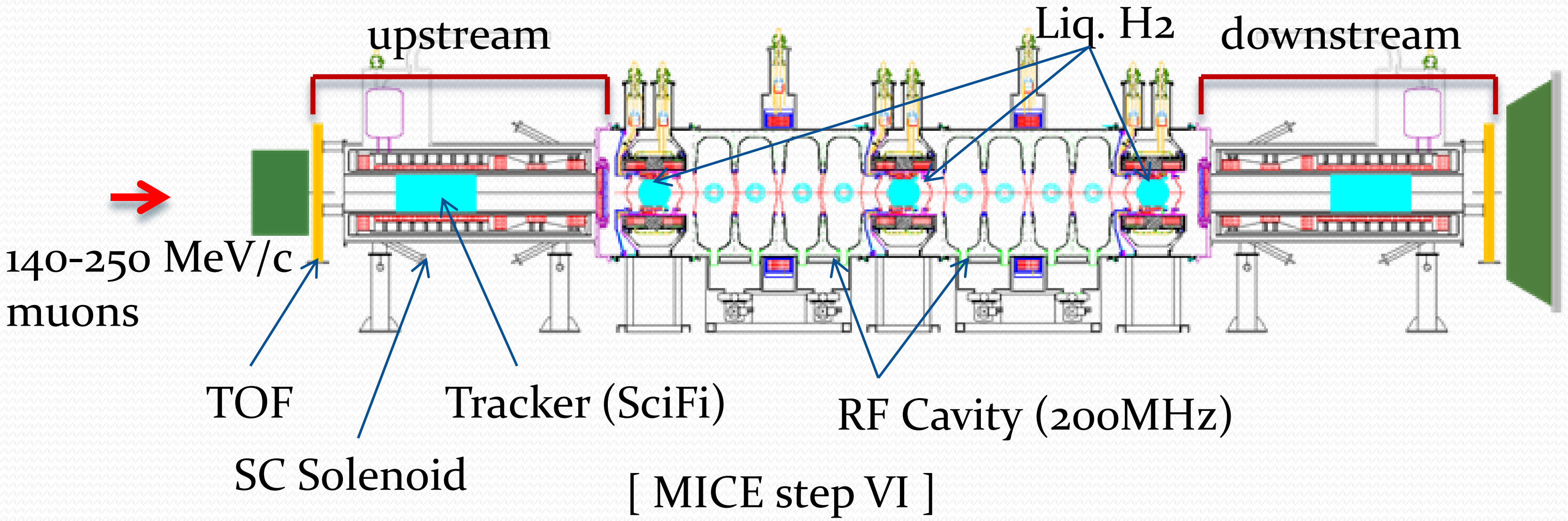


- Cherenkov radiator
- A pair of MCPs
- 80 electronics channels
- Transmission line readout

* Developed by LAPPD (Large Area Picosecond Photo-Detectors) collaboration, lead by the University of Chicago
* See LAPPD presentations at this conference

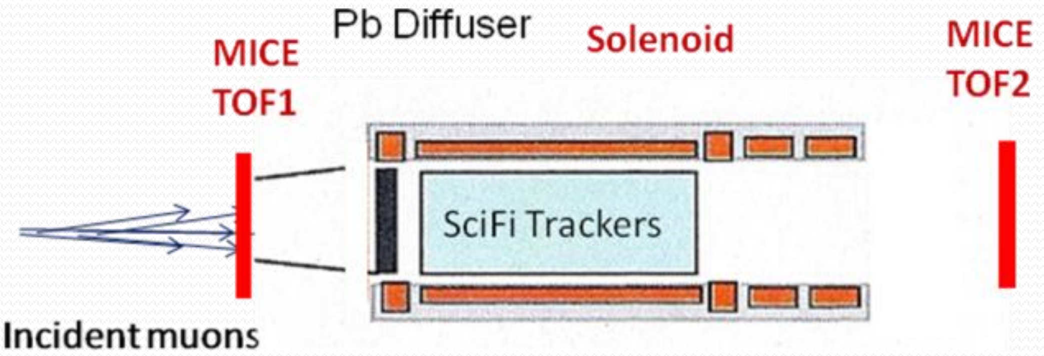
Application (1) - Muon Cooling test

- High performance muon cooling channel being studied for future muon collider
- First demonstration experiment - MICE (Muon Ionization Cooling Experiment) in the U.K.



Momentum and Emittance measurement with TOF and magnetic spectrometer

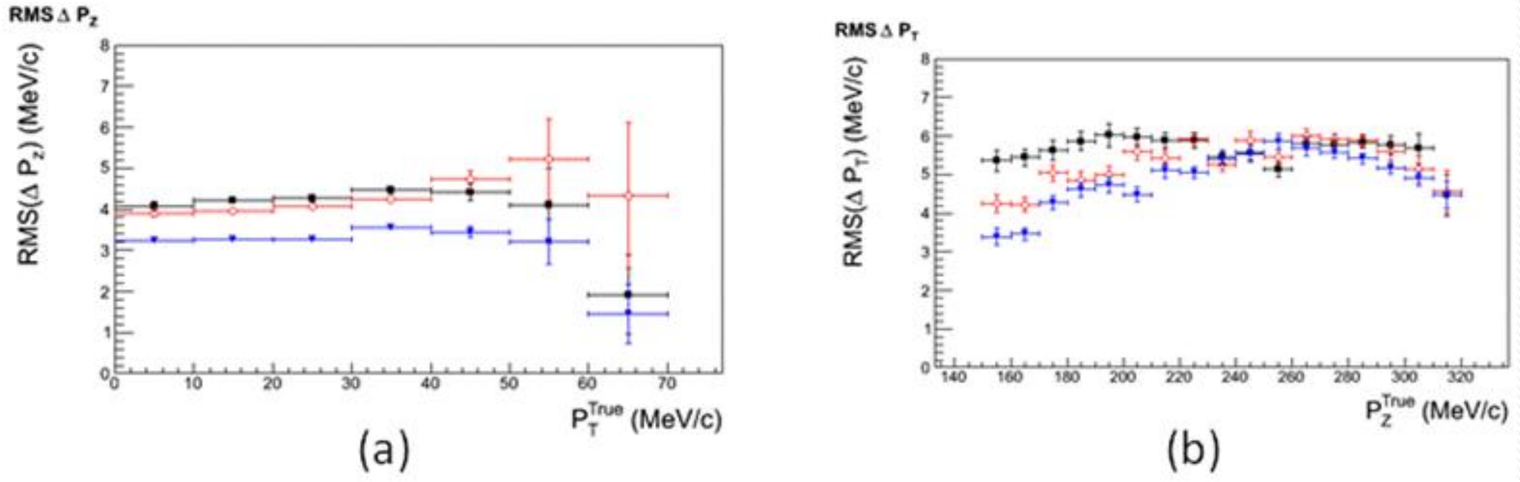
- In step II configuration, there is one solenoid spectrometer with two TOF counters (upstream and downstream)
- SciFi trackers have space resolution of 0.5 mm
- Current MICE TOF detectors have resolutions of 17 mm and 60 ps for space and time



Simulation of Momentum Resolution for MICE Phase II with Improved TOF Counters

- Transverse and longitudinal momentum resolution, as (a) P_Z resolution vs. P_T, and (b) P_T resolution vs. P_Z
- Three kinds of combinations: #1 AA(black), #2 AB (red), #3 BB (blue)

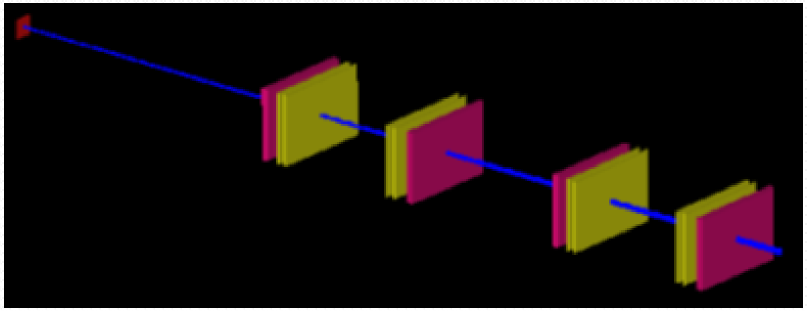
  A: Current MICE Detector (60 ps, 17mm) B: LAPPD Detector (10 ps, 0.3 mm)



- The plots show about a 20% improvement in the P_Z resolution for the case of the thinner LAPPD detectors over the thicker MICE TOFs.

Non-magnetic TOF spectrometer -Idea

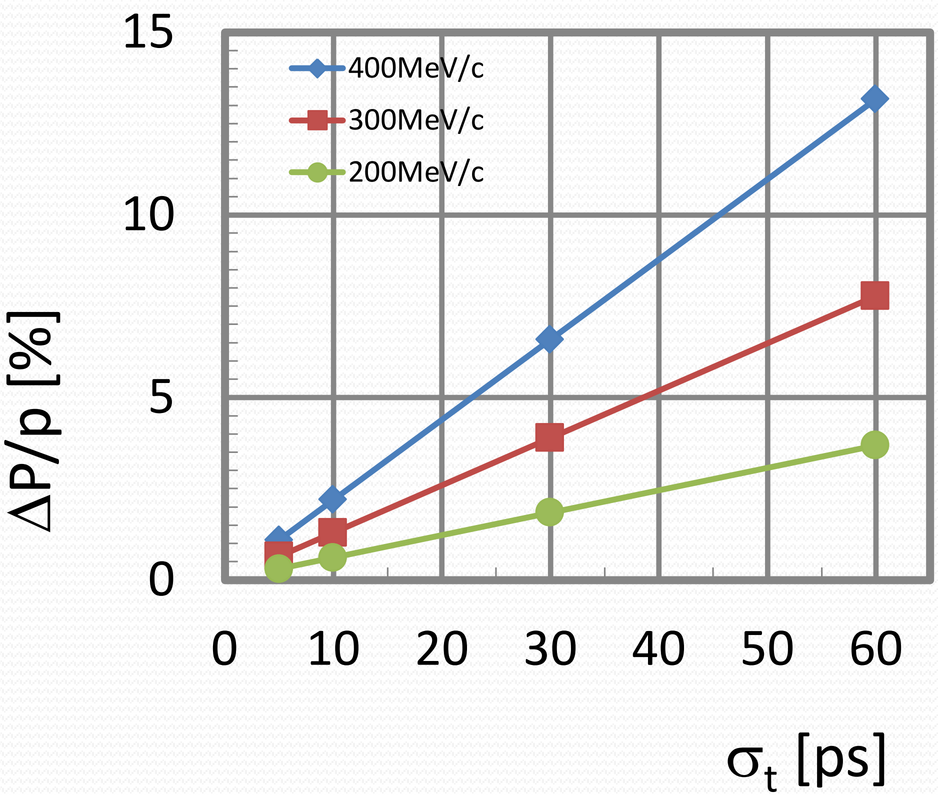
- Novel momentum measurement of muons for muon cooling not using a magnetic spectrometer can be used to measure emittance
- Time of flight between two detectors is related directly to the particle's velocity, $v = \Delta s/\Delta t$. The momentum is simply derived from Δt.



* Two arm non-magnetic TOF spectrometer

Non-magnetic TOF spectrometer - Resolution

Momentum resolutions



$$P = \gamma\beta m_0,$$

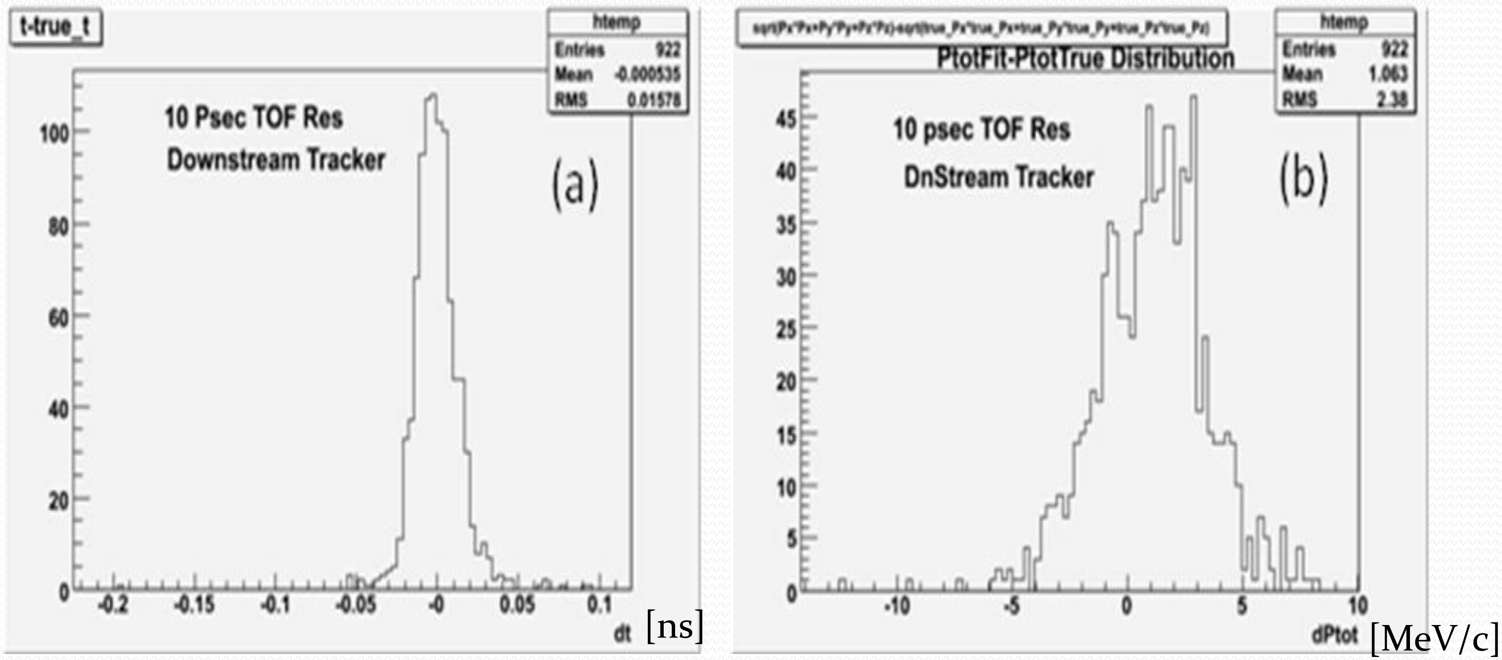
$$\Delta P = m_0 \beta\gamma^3 \sqrt{\left(\frac{\Delta s}{s}\right)^2 + \left(\frac{\Delta t}{t}\right)^2}$$

- 200, 300 and 400-MeV/c Muons
- s = 2 m between two counters
- Timing resolution from 60 ps to 6 ps

$\rightarrow \Delta P/P \leq 1\%$

Non-magnetic TOF spectrometer - Simulation

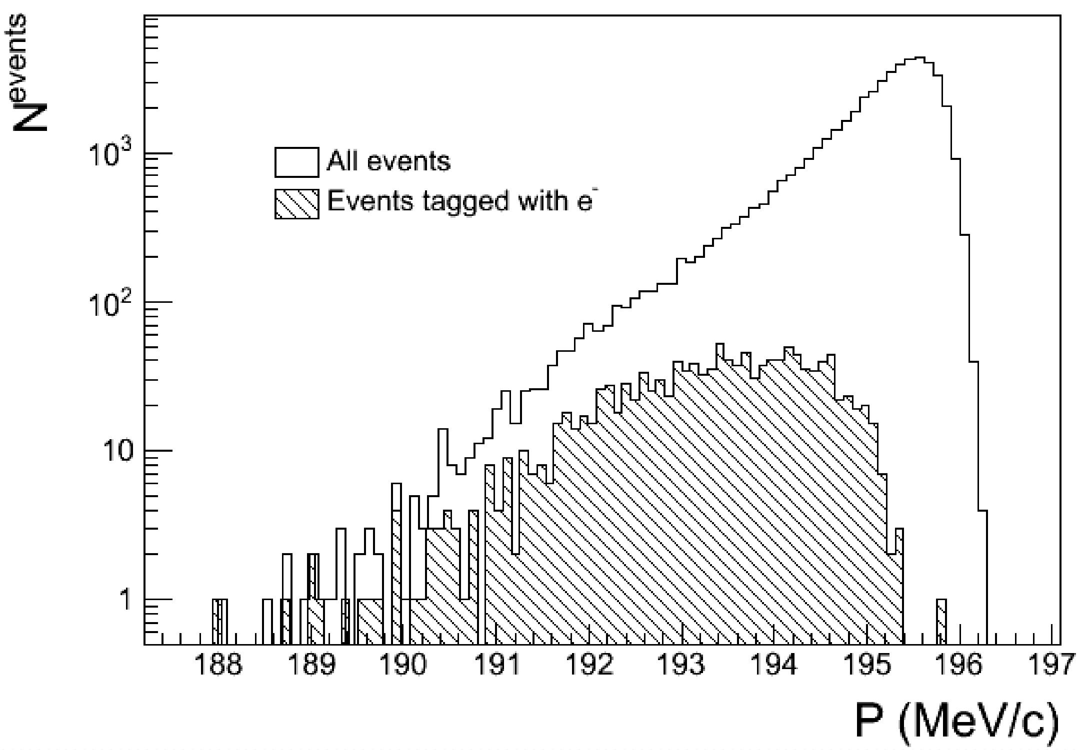
- The resolution limited by the thickness of the window



(a) Time and (b) momentum resolutions for the downstream arm of the spectrometer setup.

Non-magnetic TOF spectrometer – delta ray

- The low momentum tail (*P* < 192 MeV/c) is made up almost entirely of muons in which there is an electron present, and the distribution



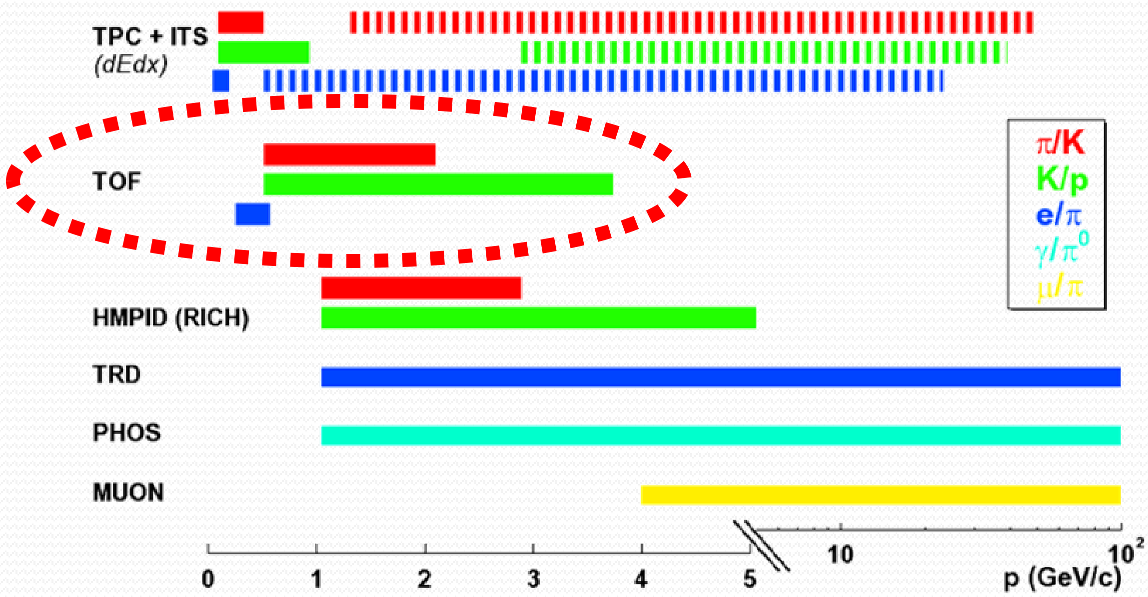
- The elimination of events with delta rays can reduce the tail of the muon momentum distribution.

Application (2) - Collider experiment

- TOF detector provides particle identification in general-purpose detectors at future collider experiments such as the ILC and muon collider.
- Background suppression – from intense beam hitting the beam pipe as well as the muon decay

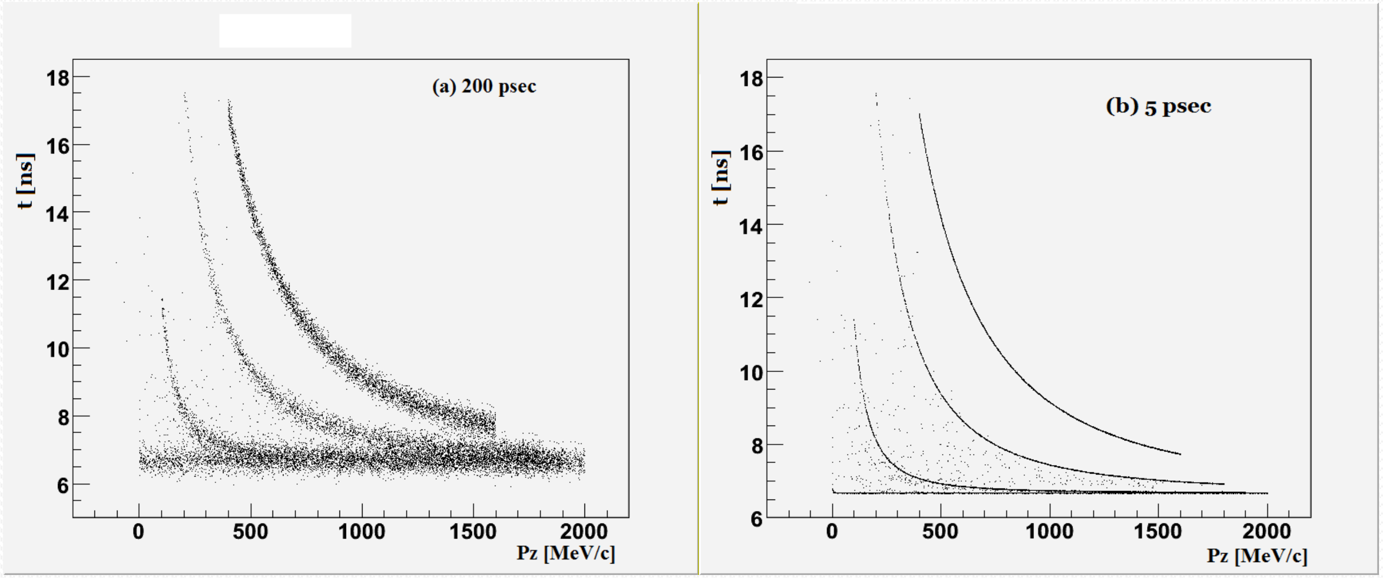
Typical reach of PID techniques

Ex.



* Each Detector performance for ALICE@LHC

Simulation of PID with TOF



Timing spectra of K, pi, proton and electron with various *Pz*

Particle discrimination with TOF

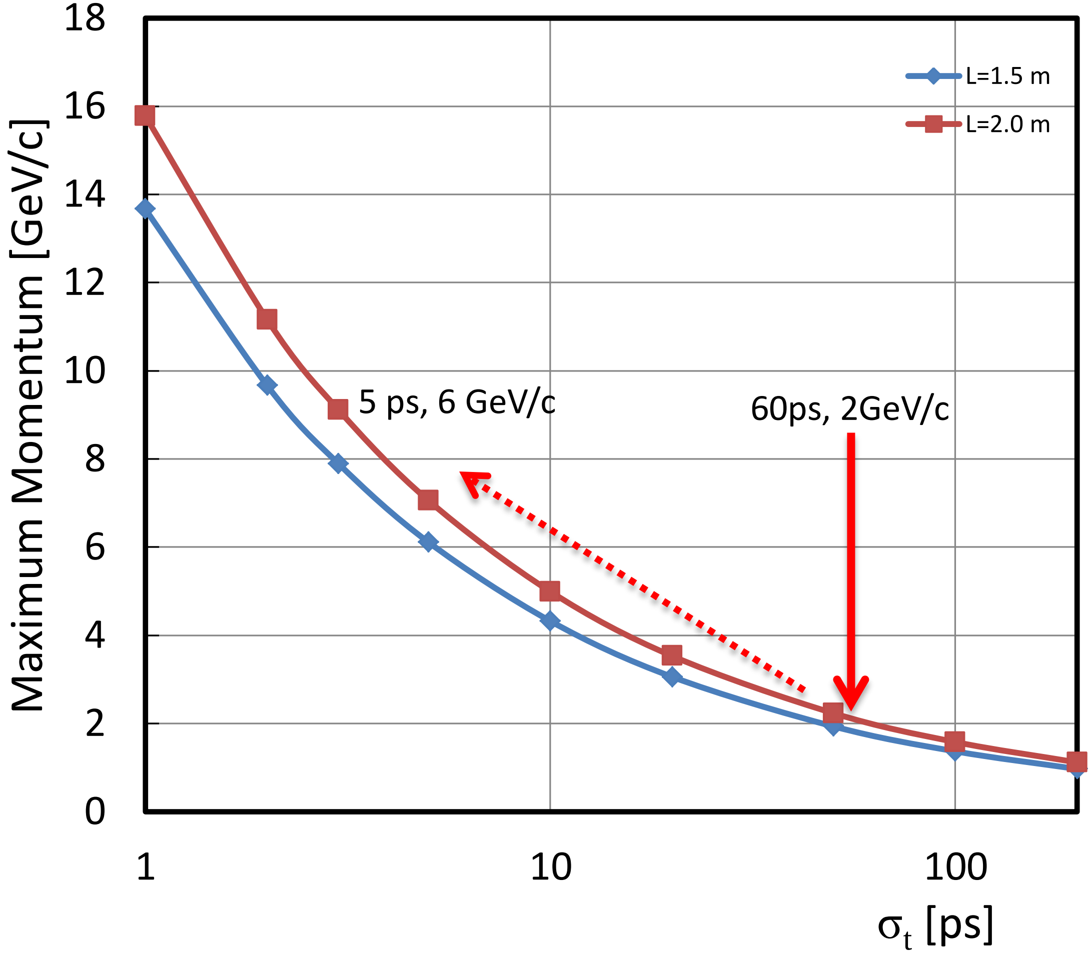
$$t = \frac{l}{v} = \frac{l}{\beta c}, \quad \beta = p/E, \quad \gamma = E/m, \; E = \sqrt{p^2 + m^2}$$

$$\Delta t = \frac{l}{v_1} - \frac{l}{v_2} = \frac{l}{c}\left(\sqrt{\frac{m_1^2}{p^2}+1} - \sqrt{\frac{m_2^2}{p^2}+1}\right)$$

For π-K separation, $\Delta \mathrm{m}^2 = m_1^2 - m_2^2 = 0.224\,\mathrm{GeV}^2$

If $\Delta p \approx 0$, $p = \sqrt{\frac{l \Delta \mathrm{m}^2}{2c\Delta t}}$ for high-energy particles ($p >> m$)

π-K separation



$\Delta T=3\sigma_t$

Improved TOF precision extends the measurement range of particle identification

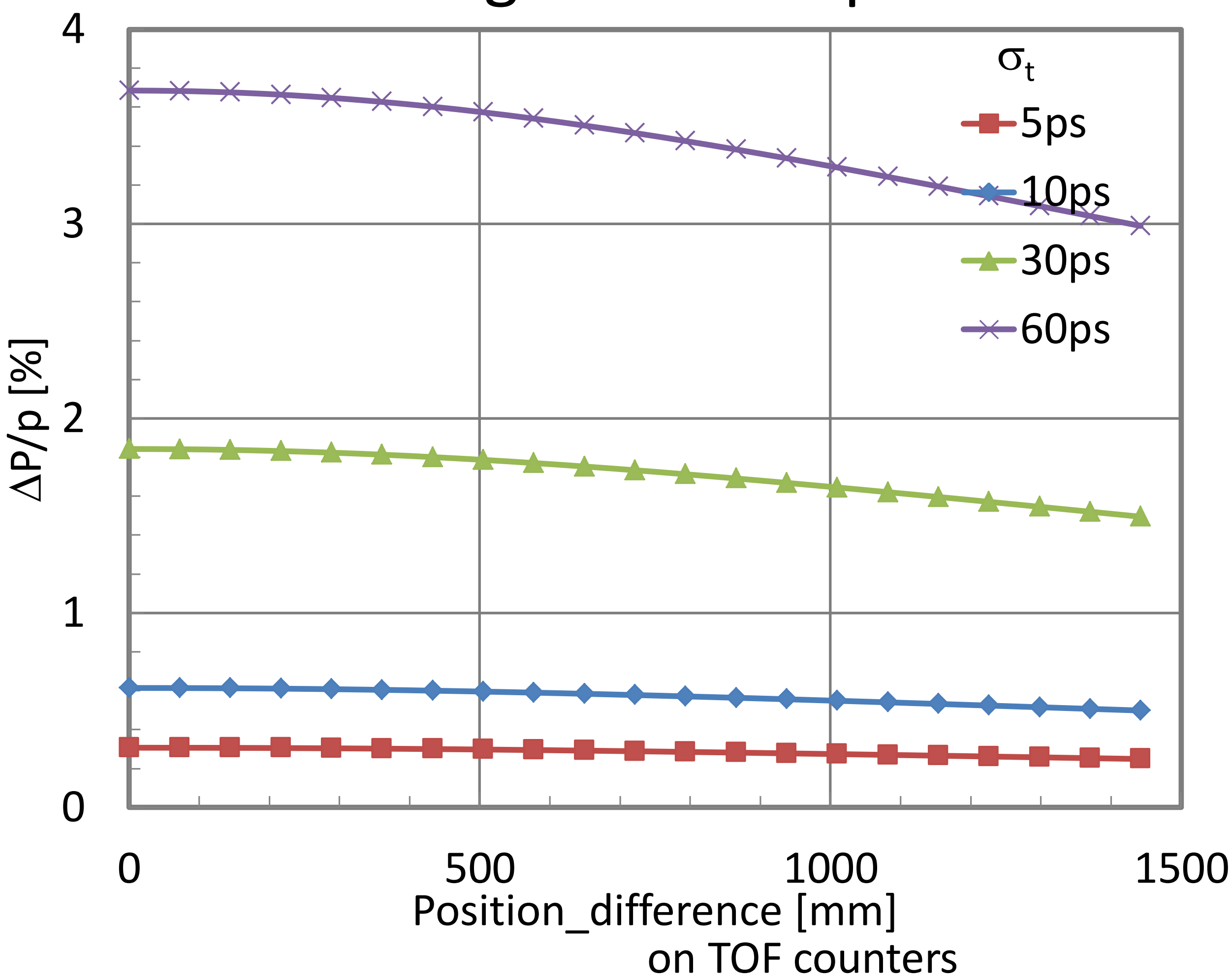
Summary and Conclusion

- Large area fast timing detectors with resolutions ≤10 ps are being developed
- Useful to various experiments such as muon cooling test for emittance measurement
- Also applicable for high-energy experiments in general-purpose collider detector (ILC, Muon collider)

Acknowledgements: This work has been supported in par by DOE SBIR Grant DE-SC00005445

Back up

Position Dependence (x, y) of Momentum Resolution on non-Magnetic TOF spectrometer



Details of Particle Discrimination

Mass separation

$$\delta m^2 = \frac{2p}{l^2}\sqrt{c^4 p^2 t^2 \Delta t^2 + (t^2 c^2 - l^2)^2 \Delta p^2}$$

ex. ALICE@CERN gives: $\Delta p / p^2 \approx 0.0006 GeV^{-1}$

The two terms give the following δm^2 for each at max-p:

σ_t [ps]	δm^2_1	δm^2_2
1	0.2240118	2.35E-05
2	0.2240235	2.35E-05
3	0.2240353	2.35E-05
5	0.2240588	2.35E-05
10	0.2241175	2.35E-05
20	0.2242349	2.35E-05
50	0.2245868	2.35E-05
100	0.2251721	2.35E-05
200	0.2263382	2.35E-05

$\Delta m^2 = m_1^2 - m_2^2 = 0.224 \mathrm{GeV}^2$

→ $\Delta p \approx 0$ approx. is ok.