Estimation of Time Resolution for the PIONEER Tracker

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In collaboration with
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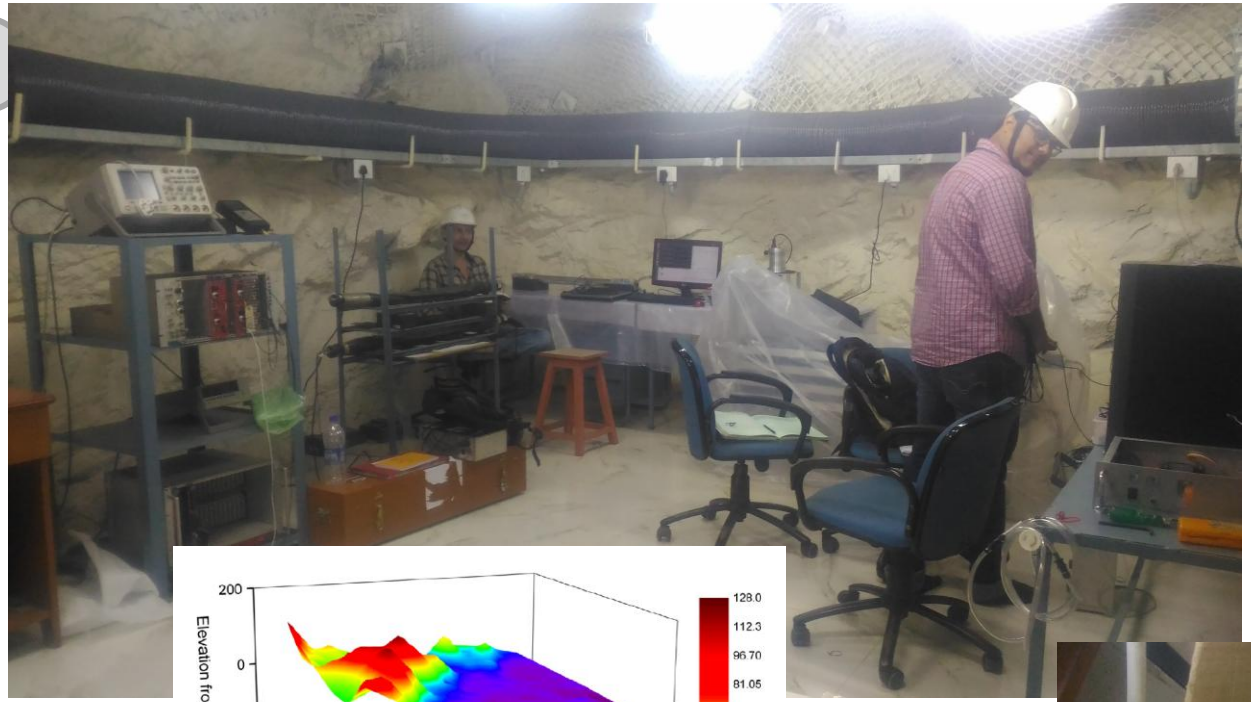
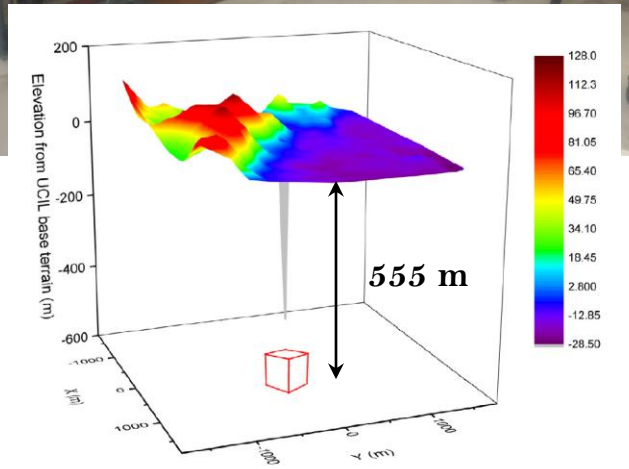
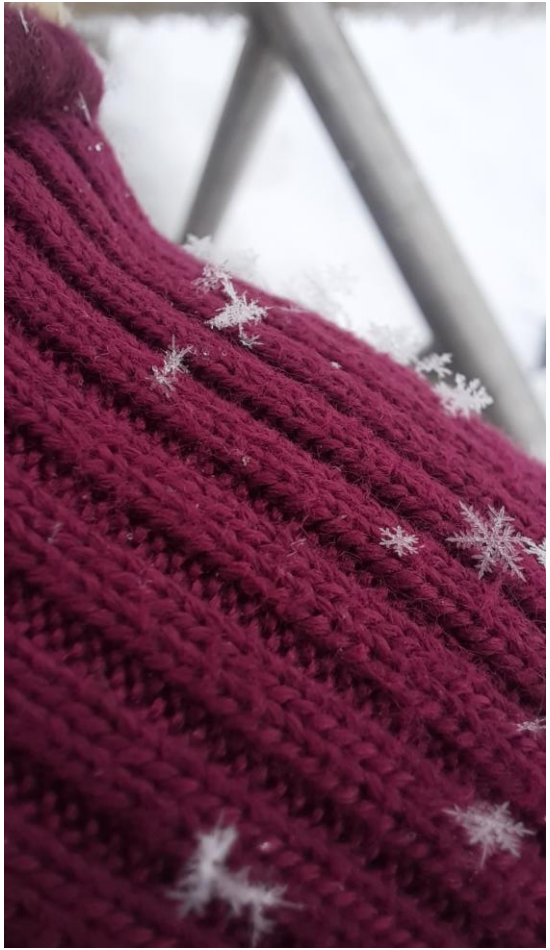
Dec 23, 2025




200
0
-200
-400
-600
Elevation from UCIL base terrain (m)
555 m
128.0
112.3
96.70
81.05
65.40
49.75
34.10
18.45
2.800
-12.85
-28.50
X (m)
Y (m)

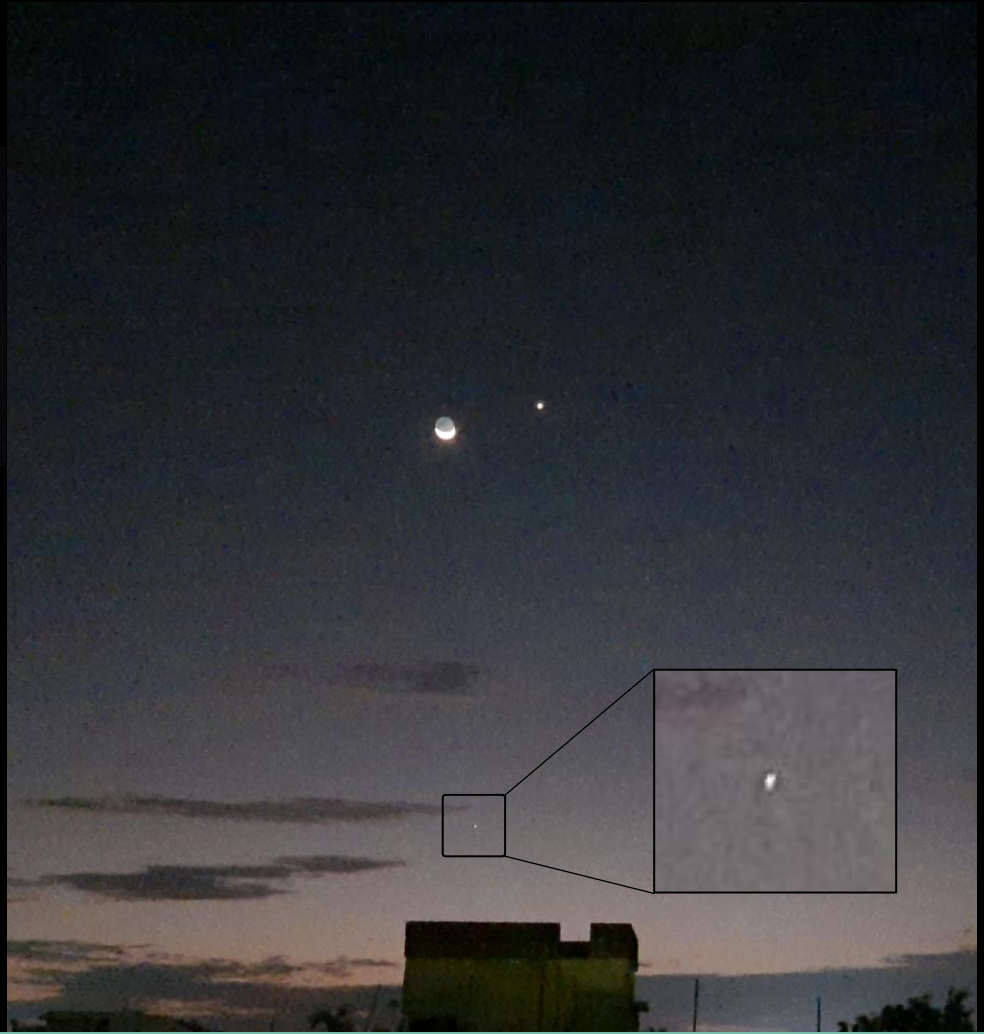

CMS


HMC-3
PAKISTAN




GOLIATH


Lindt
HOME OF CHOCOLATE

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PIONEER

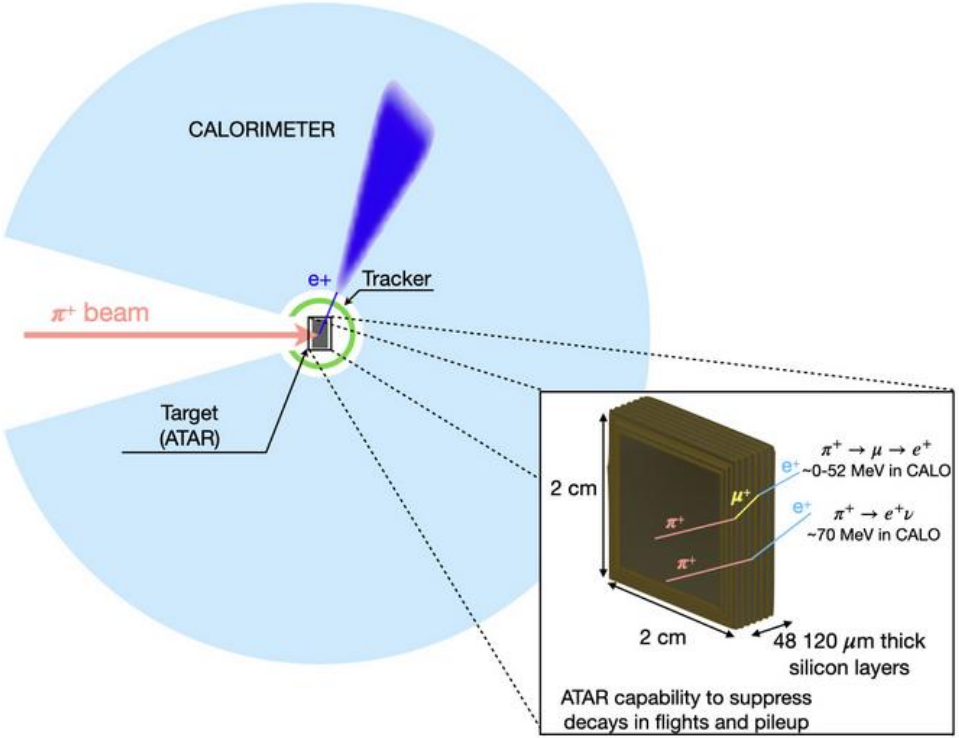
PIONEER : Introduction

- **Objective →** To test the Lepton Flavor Universality
- Aims to measure the BR of pion to electron and muon $\mathbf{R_{e/\mu}}$
- $\mathbf{R_{e/\mu}}$ → one of the most precisely known observable in the quark sector from SM
  - Decay to electron is suppressed in SM

$$\boldsymbol{R_{e/\mu}} = \frac{m_e^2}{m_\mu^2}\frac{(m_\pi^2 - m_e^2)^2}{(m_\pi^2 - m_\mu^2)^2} \approx 1.23524\,(15) \times 10^{-4}$$

- Currently best experimental value is $1.2327\,(23) \times 10^{-4}$

PIONEER : Strategy

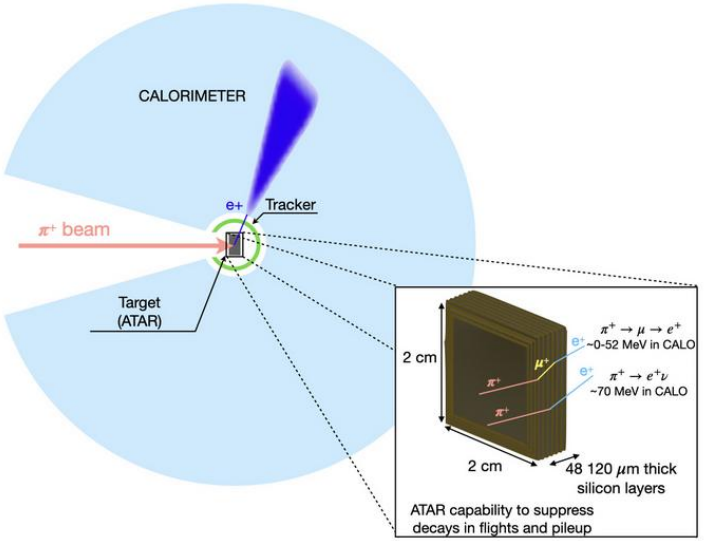


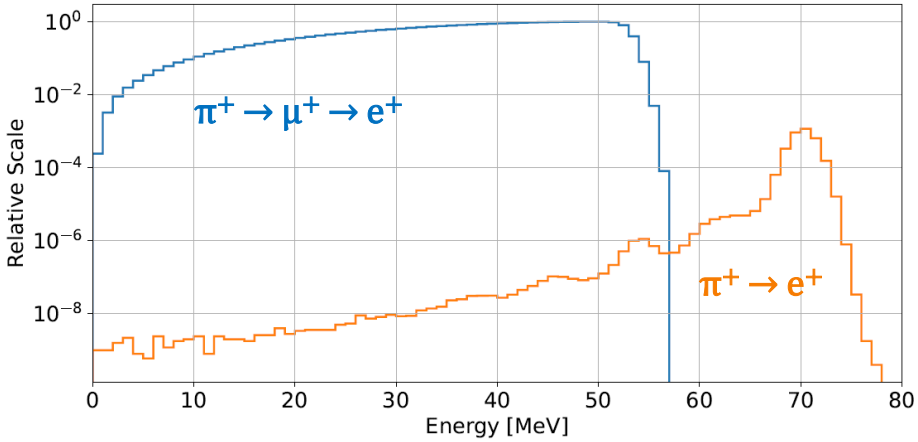
- ATAR → LGAD-based target to stop pions and record decay vertices
- Full event reconstruction required to distinguish between $\pi^+ \rightarrow e^+$ and $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ events
- Given the geometry of ATAR, possibility of missing hits in the perpendicular region

LGAD → Low Gain Avalanche Detector – silicon detectors with moderate internal gain having excellent time resolution (~100 ps)

Tracker

- **Tracker** required to cover the blind-spots of ATAR
- Aid in reconstruction of the event-topology → crucial to tackle the Albedo problem, as well as distinguish events in the overlapping region of positron spectra
- Provide trigger logic and mitigate pile-up events

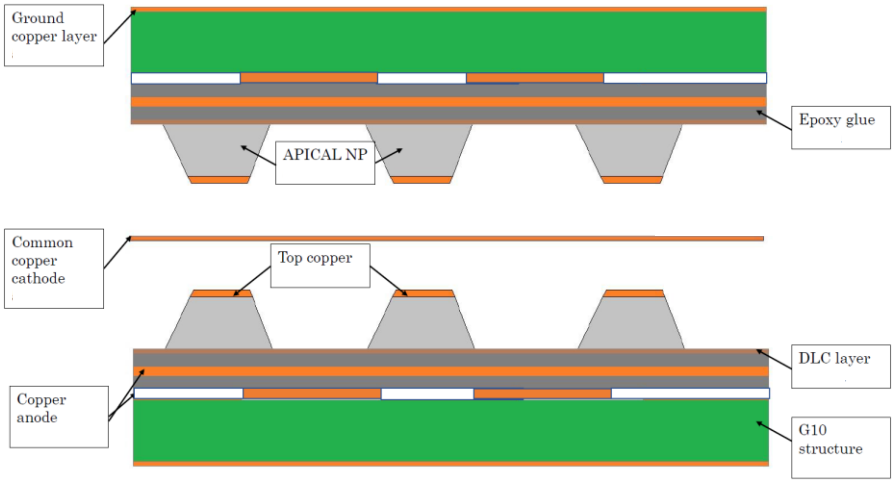


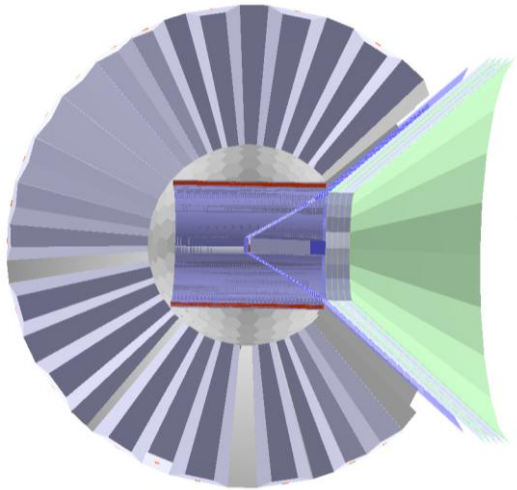


arXiv:2203.05505

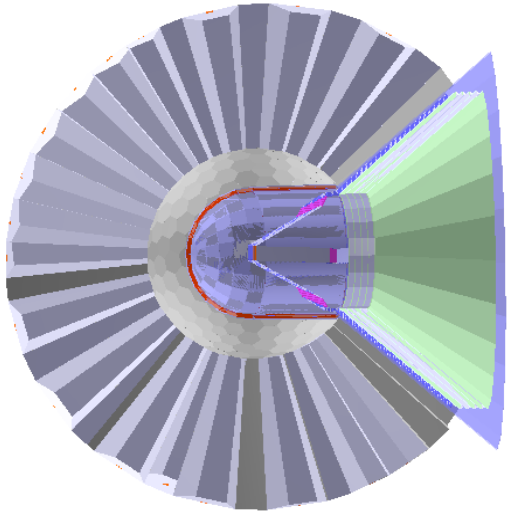
Tracker

- Two layers of **μRGroove Detector** with **common cathode**
- Cylindrical geometry for current studies
- Goal is to develop **bullet-shaped geometry** for covering forward region





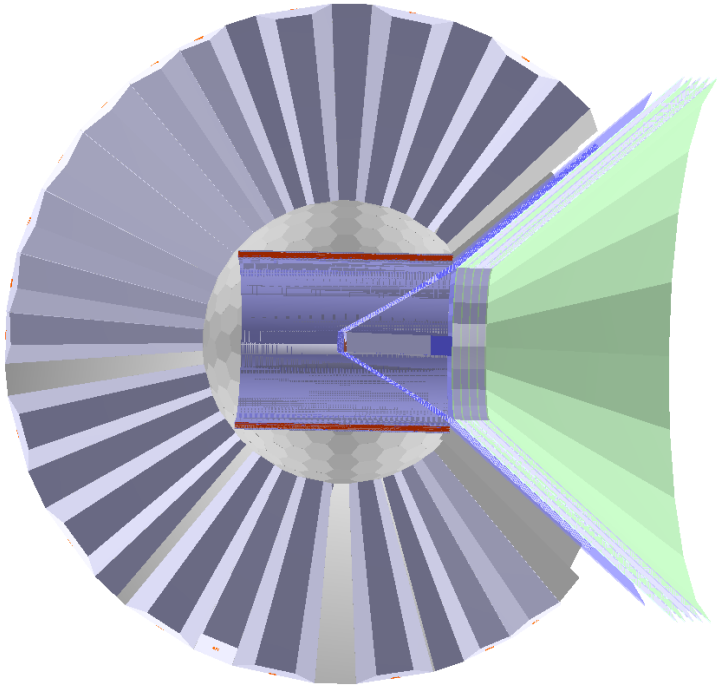
Current Study



Goal

Tracker

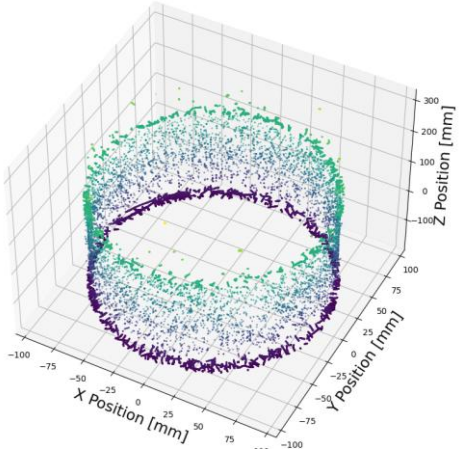
- Two layers of **µRGroove Detector** with **common cathode**
- Cylindrical geometry for current studies
- Goal is to develop **bullet-shaped geometry** for covering forward region
- Signal amplitude proportional to energy deposited
- Front-end DAQ – **SAMPA** (assumed for current simulation studies)
- Estimation of **time resolution using CFD** method (**0.3 fraction**)



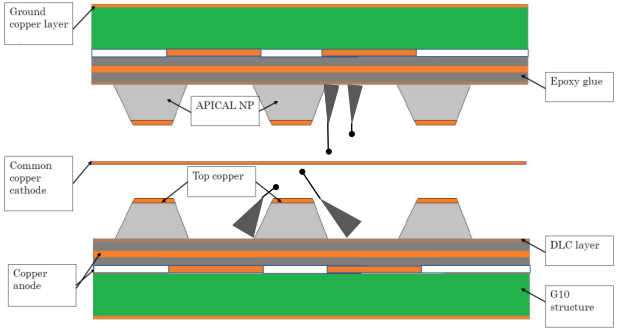
Current Study

Methodology

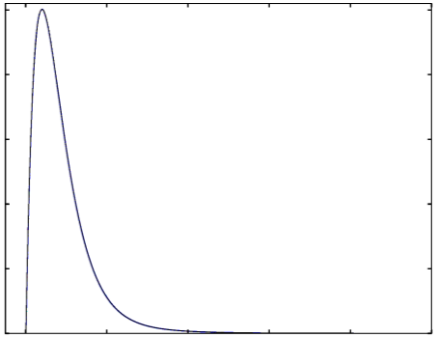
Information of primaries from GEANT4 simulation by shooting π^+ beam of 65 MeV/c



Parametric method for amplification and charge-spread on strips

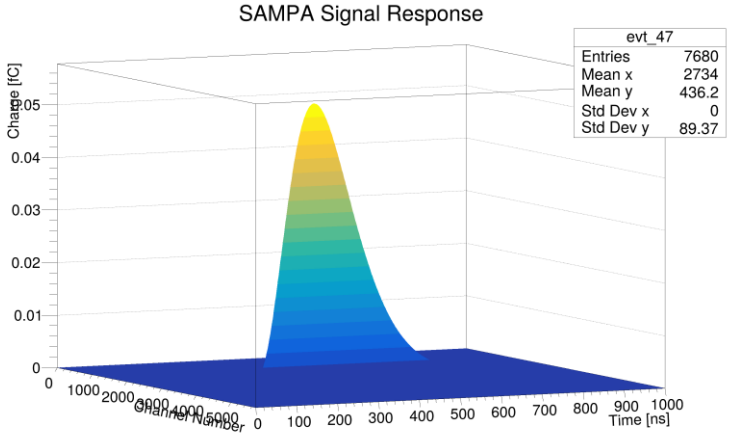


SAMPA simulation for signal shape

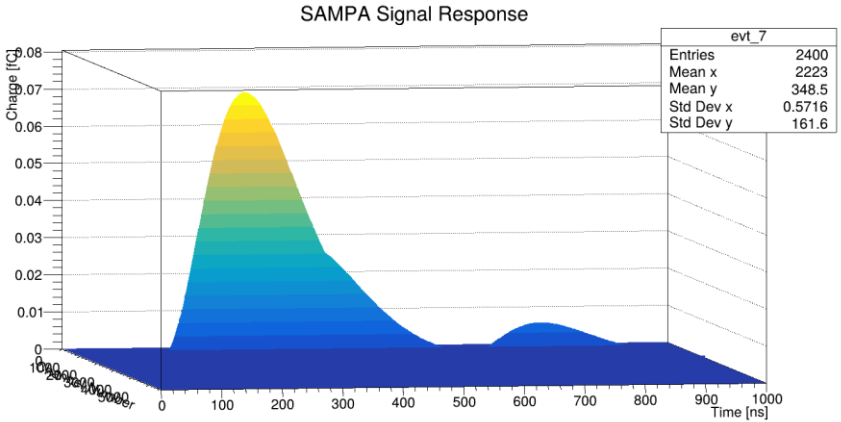


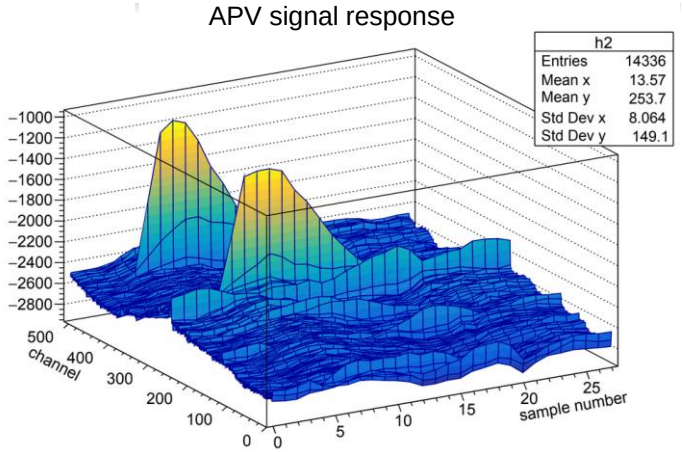
Estimation of time resolution using CFD method

SAMPA Signal

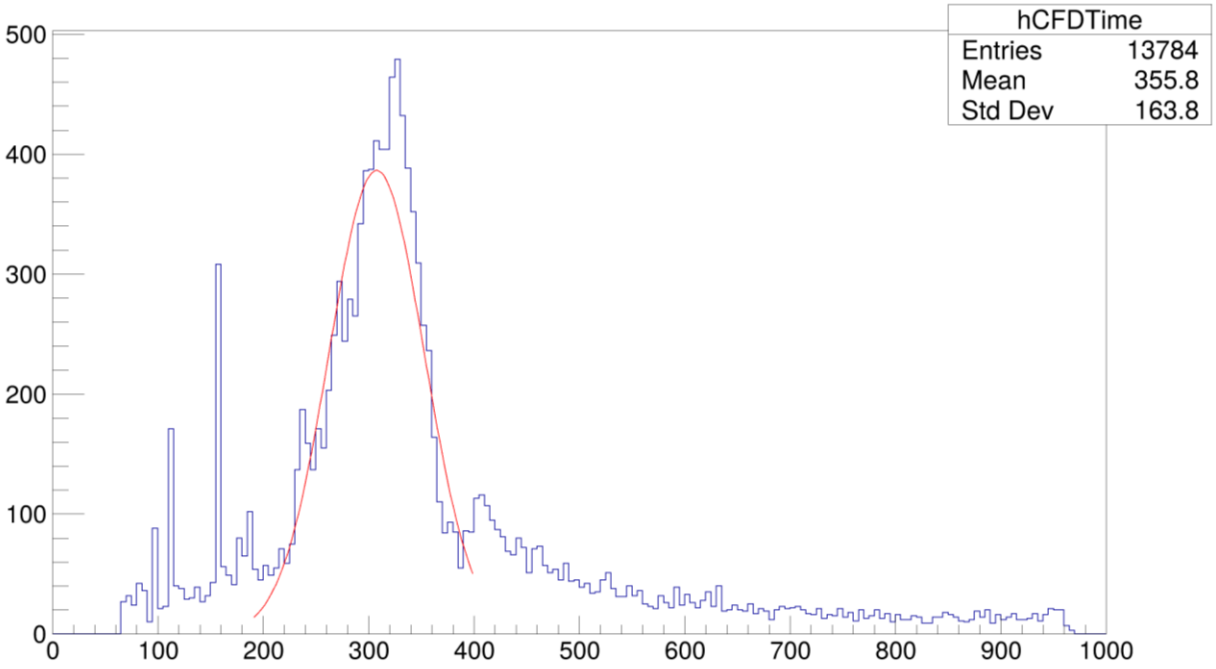


- SAMPA signal modelling for all strips (X-axis → channel number; Y-axis → time)
  - t=0, when first energy deposit occurs
- Comparison with APV signal shown below obtained experimentally from test-beam study



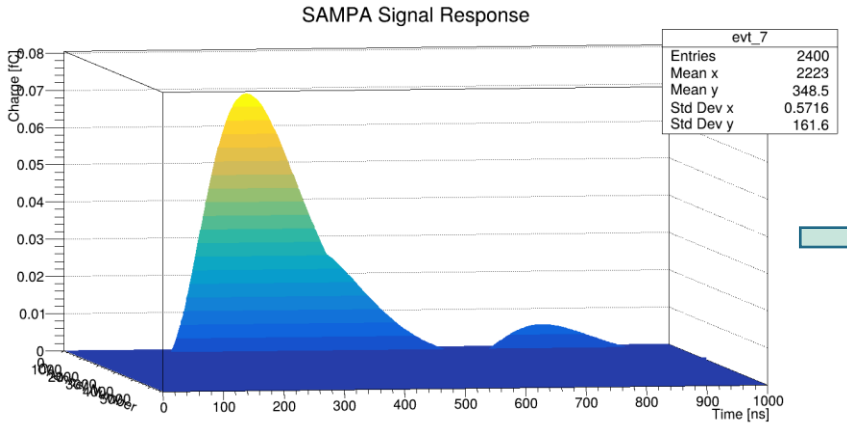


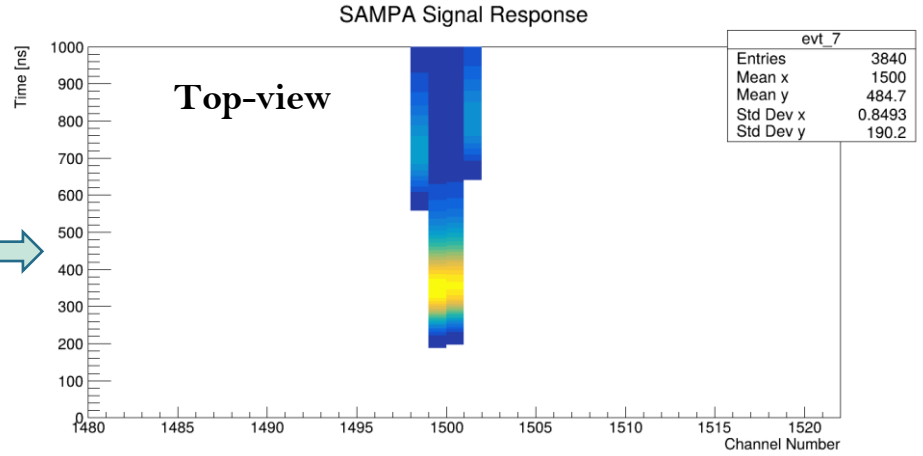
CFD Distribution

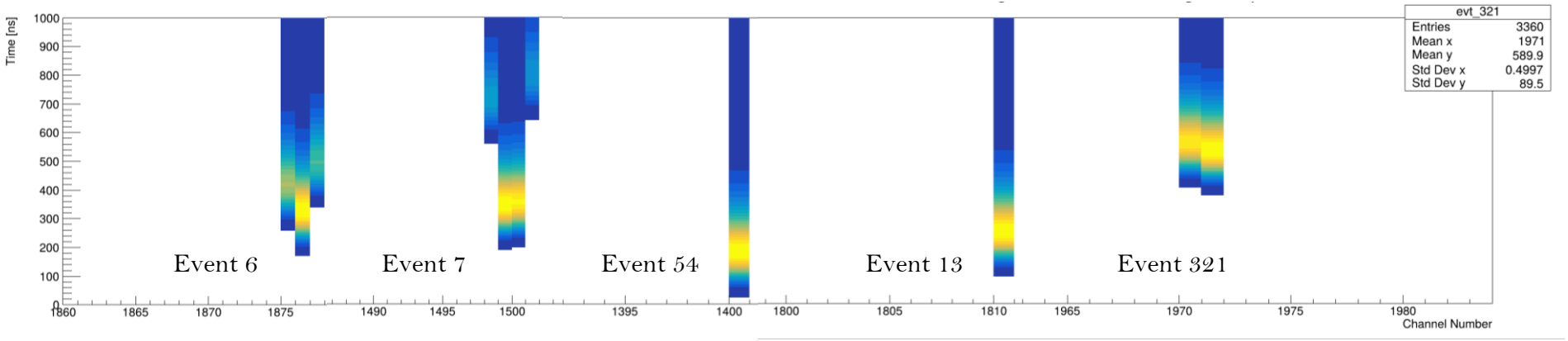


- From fit time resolution **~45 ns**
  (doesn't match experimental results from literature)

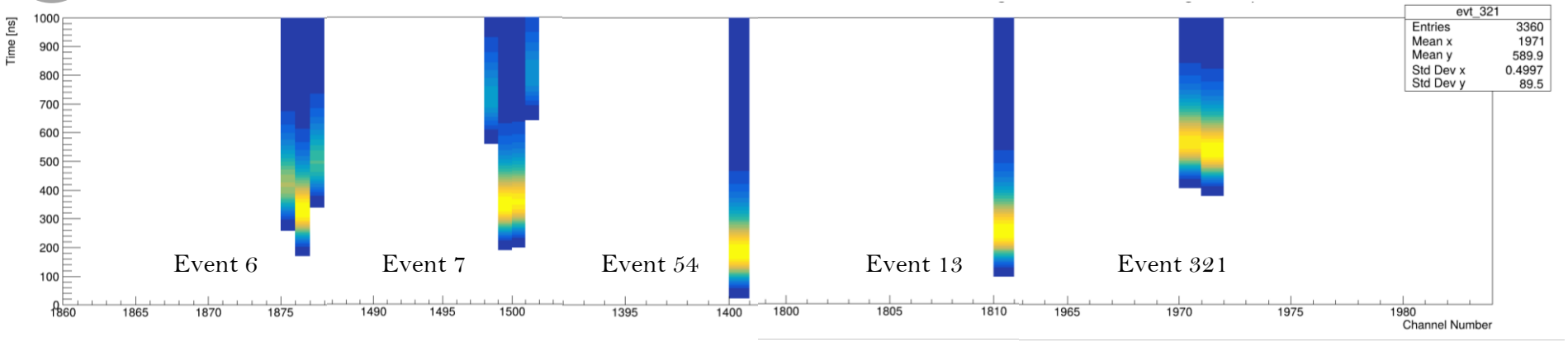
The Problem


SAMPA Signal Response
evt_7
Entries 2400
Mean x 2223
Mean y 348.5
Std Dev x 0.5716
Std Dev y 161.6
Charge [fC]
Time [ns]


SAMPA Signal Response
Top-view
evt_7
Entries 3840
Mean x 1500
Mean y 484.7
Std Dev x 0.8493
Std Dev y 190.2
Time [ns]
Channel Number

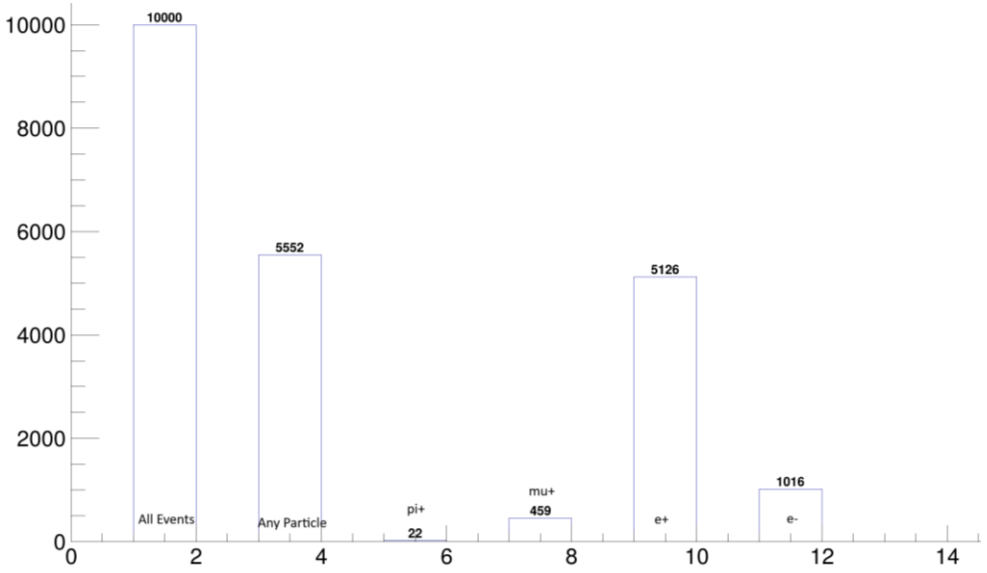

evt_321
Entries 3360
Mean x 1971
Mean y 589.9
Std Dev x 0.4997
Std Dev y 89.5
Time [ns]
Channel Number
Event 6
Event 7
Event 54
Event 13
Event 321

The Problem



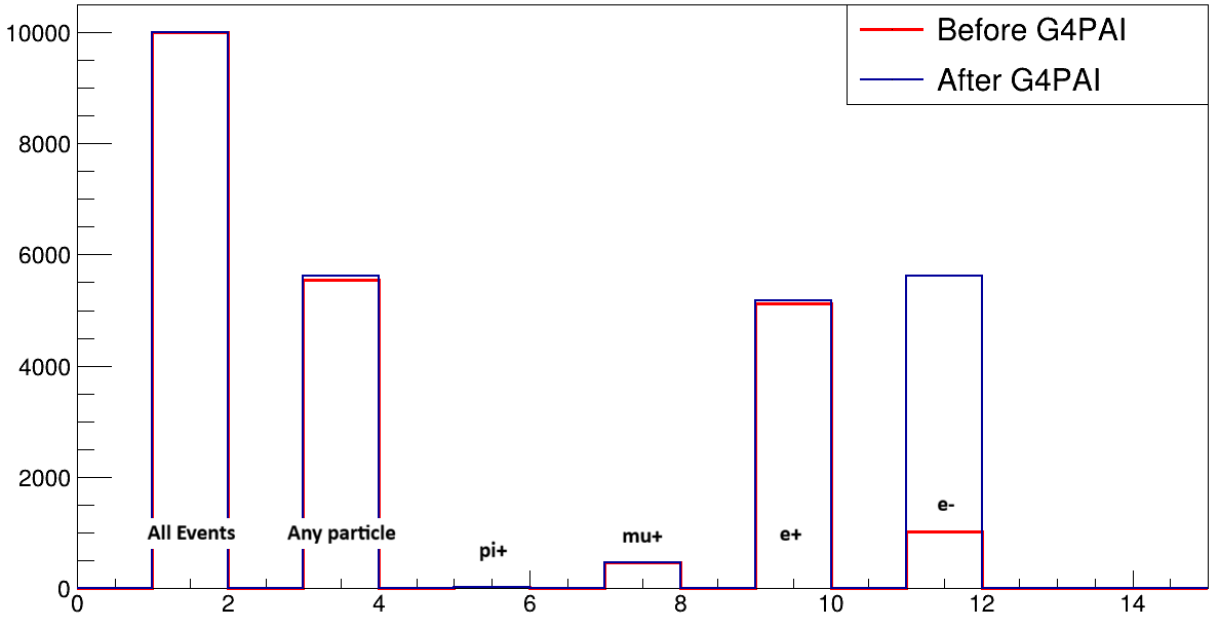
- Wide variation in the time is due to the fact that these are delta electrons
- Ionization electron tracks are not getting produced since they have low kinetic energy
- Modifying the simulation code to have ionization electron tracks produced within the gas volume only

The Problem



- 10K events simulated using GEANT4 : pion beam without contamination
- Selecting only those events that have electrons produced within the gas volume from muons and positrons
  - PDGID of the track is 11
  - Mother PDGID is -11 or -13
  - Track origin within gas volume
- After selection only 4385 events survived due to geometrical acceptance (cylindrical geometry)
- Estimation using Garfield : 99.9% events should have primary electrons

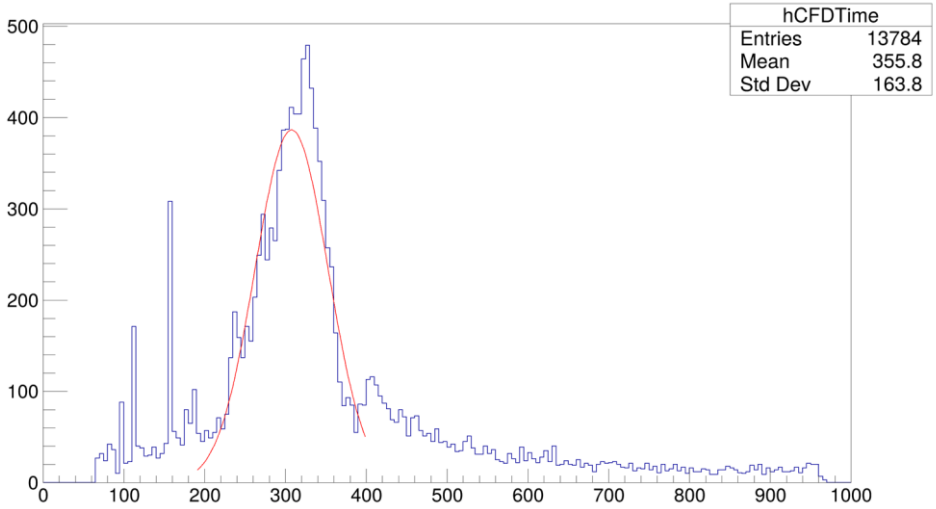
The Solution



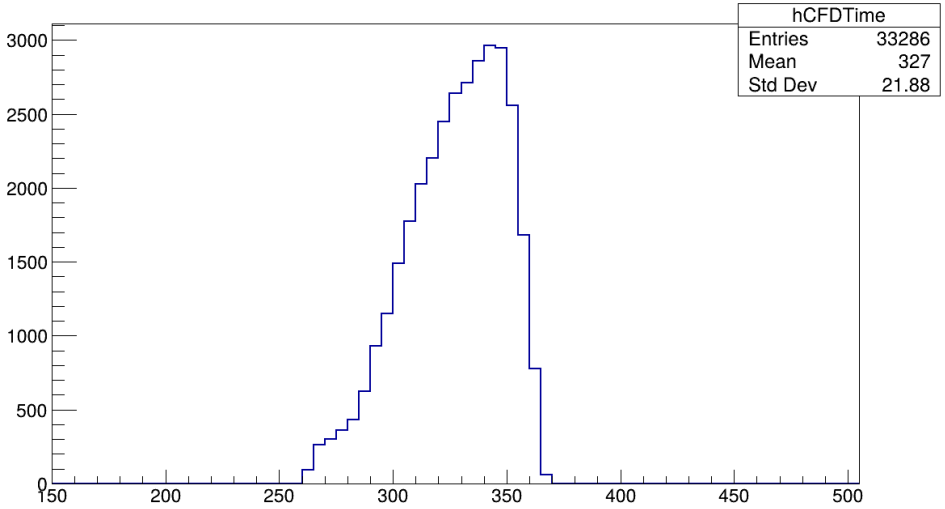
- CERN RD51 collaboration faced similar challenge
- They solved it by using G4PAI physics module for ionization in the gas region
- We did the same thing, and have given a cutoff for production at 15 eV for the electrons

CFD Distribution

Before G4PAI

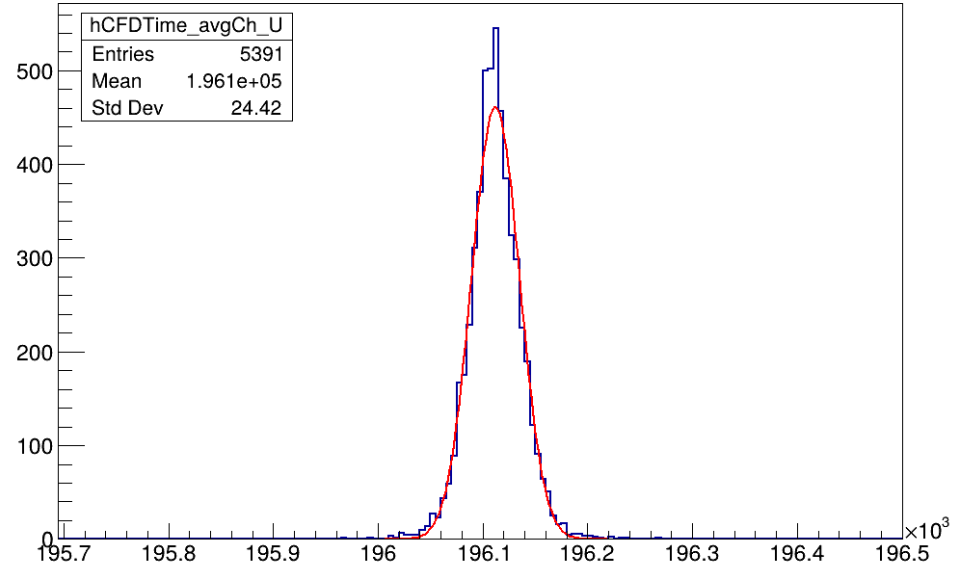


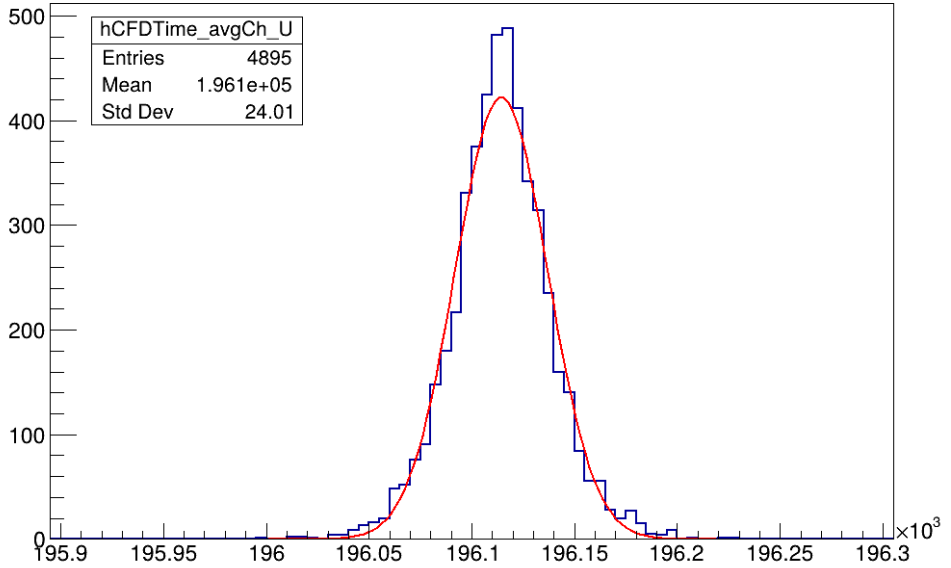
After G4PAI



From fit time resolution **~45 ns**

Result



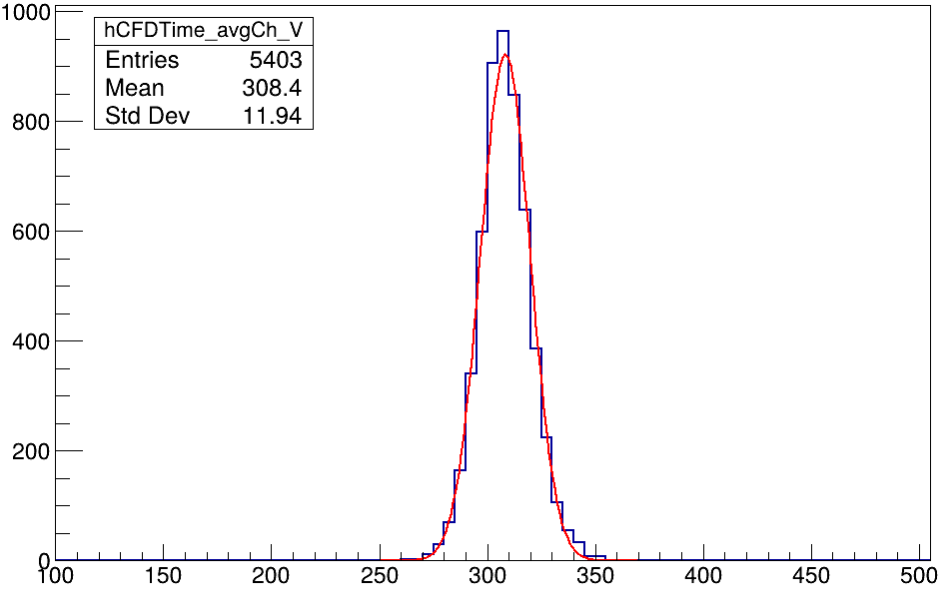


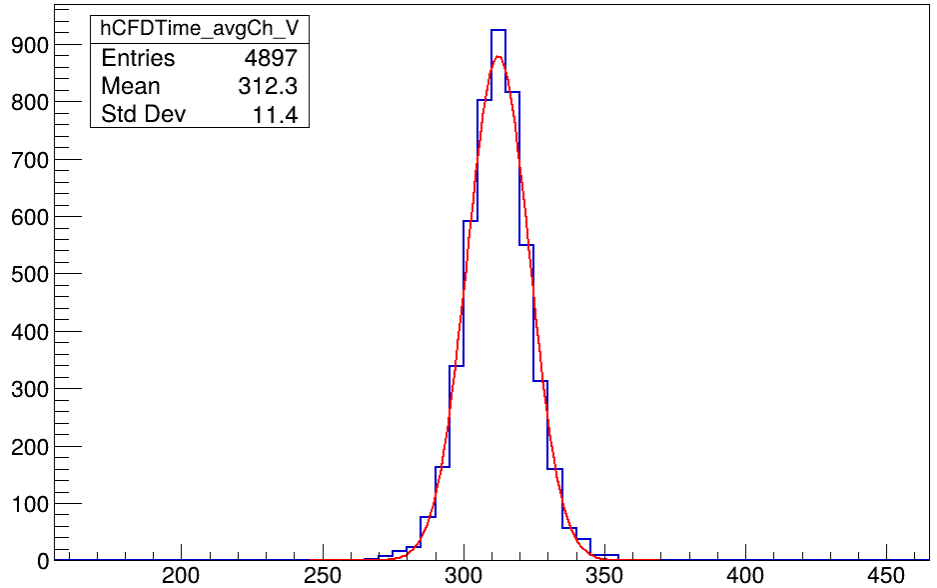
Time resolution from fit for U strips (ion signal)

200 um: 22.79 ± 0.27 ns

1 mm: 22.55 ± 0.30 ns

Result



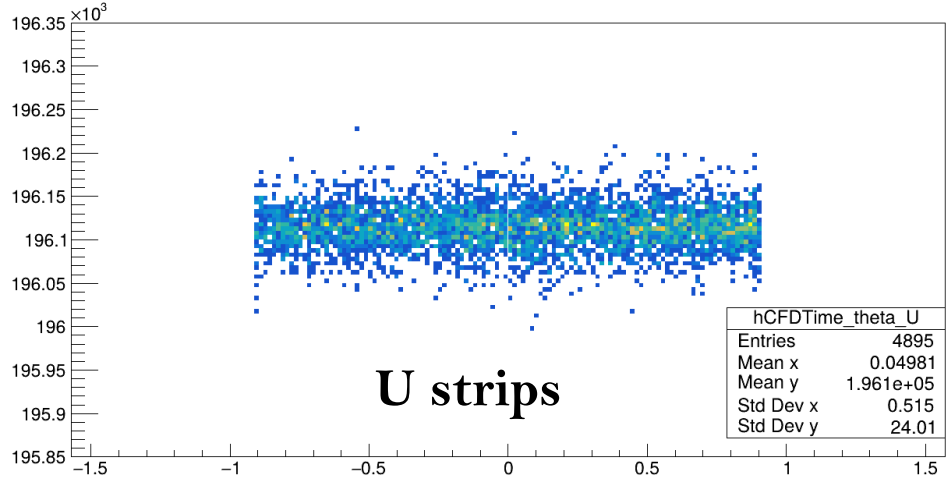


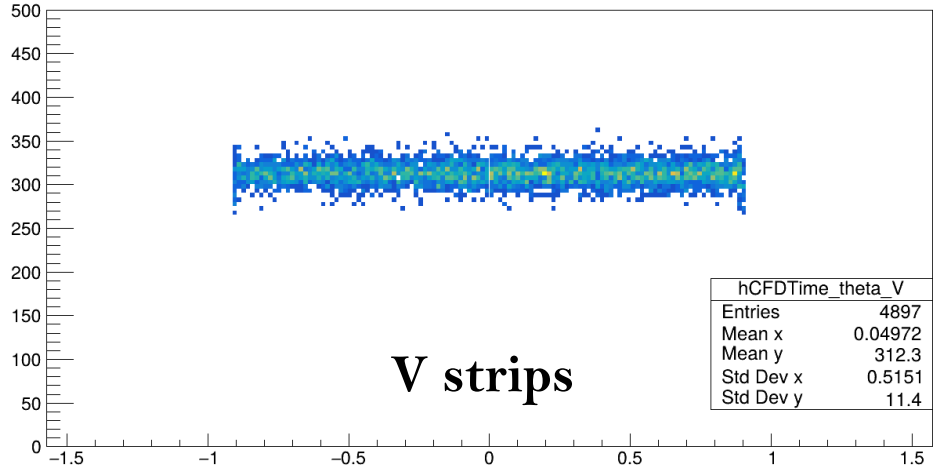
Time resolution from fit for V strips (electron signal)

200 um: 11.56 $\pm$ 0.13 ns

1 mm: 11.01 $\pm$ 0.13 ns

CFD time vs Theta





Time resolution for **1 mm strip width** configuration as function of **θ**

Summary

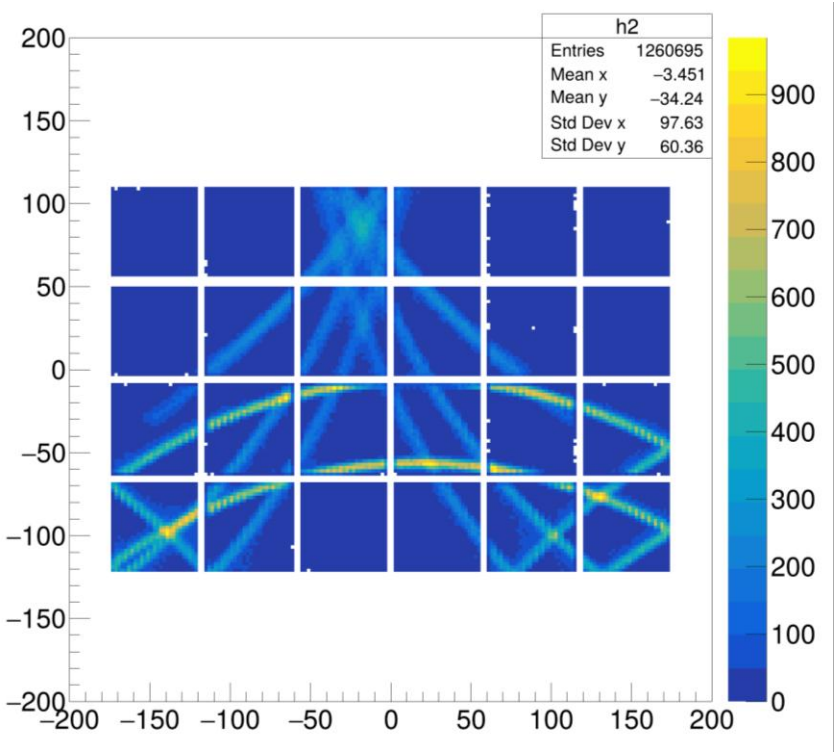
- Simulation studies conducted to estimate time resolution for tracker assuming SAMPA DAQ
- Amplification and charge spread on strips obtained using parametric method
- Signal shape is modelled and time distribution obtained using CFD method
- Time resolution was estimated to be about 11 ns with electronic signal.
- **Next step →** Estimate the spatial resolution

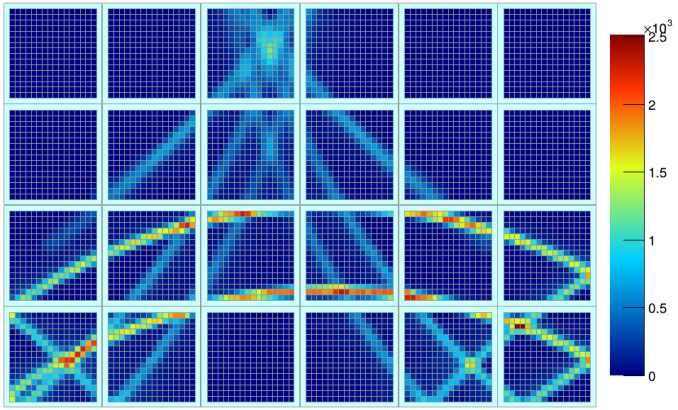
EIC

Standalone Framework

```
./eicdirc -r 0 -o data/sim_pi_6GeVc_30deg_25K.root -theta 30 -x "pi+" -p 6 -w 0 -g 1 -c
2031 -l 3 -trackingres 0.0005 -e 25000 -b 1
```

Particle → π^+ $\theta = 30^\circ$ Momentum = 6 GeV/c
tracking resolution = 0.5 mrad

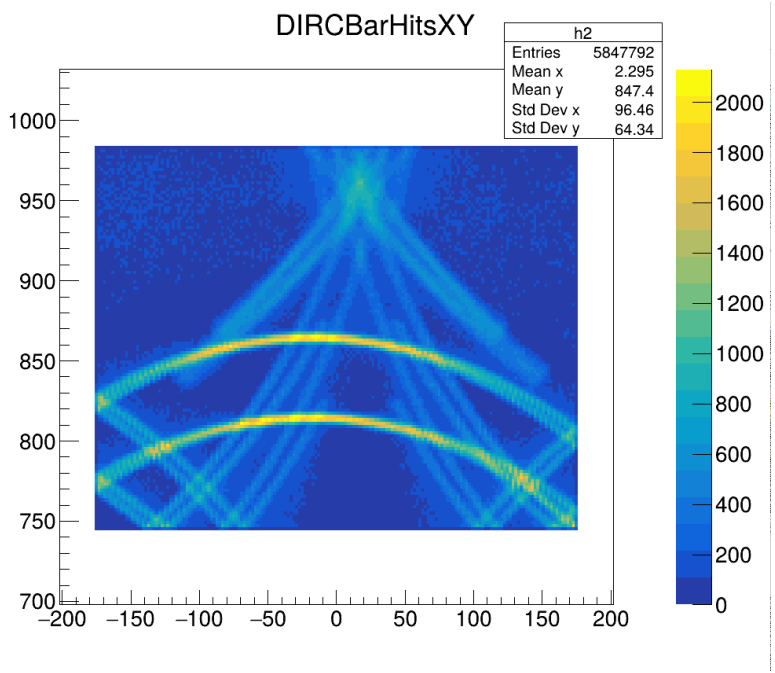


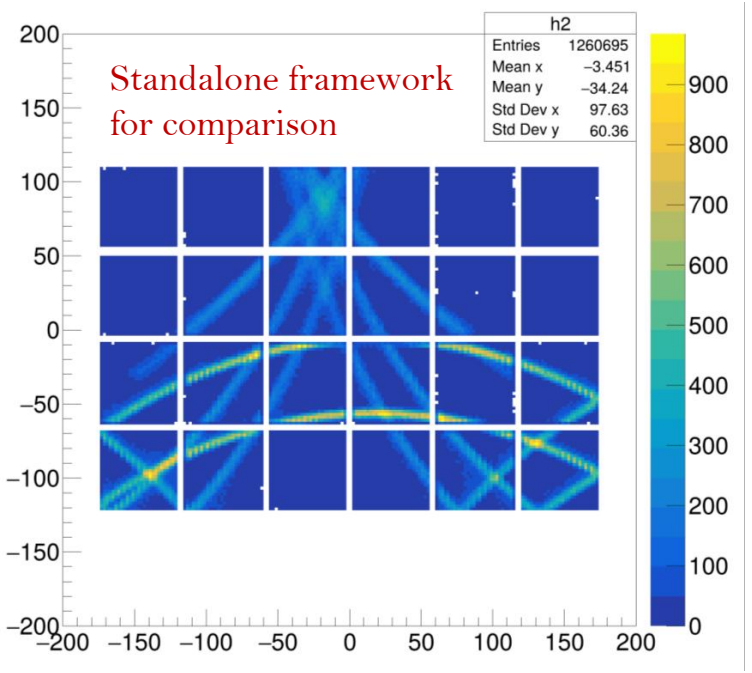


EPIC Framework

```
npsim --runType batch --compactFile $DETECTOR_PATH/epic_dirc_only.xml -G -N 25000 --gun.particle
"pi+" --gun.momentumMin 6*GeV --gun.momentumMax 6*GeV --gun.phiMin 355.334*deg --gun.phiMax
355.334*deg --gun.thetaMin 30*deg --gun.thetaMax 30*deg --gun.distribution uniform --gun.position
0*cm,0*cm,0*cm --part.userParticleHandler='' --outputFile
sim_dirconly_pi_6GeVc_30deg_25K.edm4hep.root
```

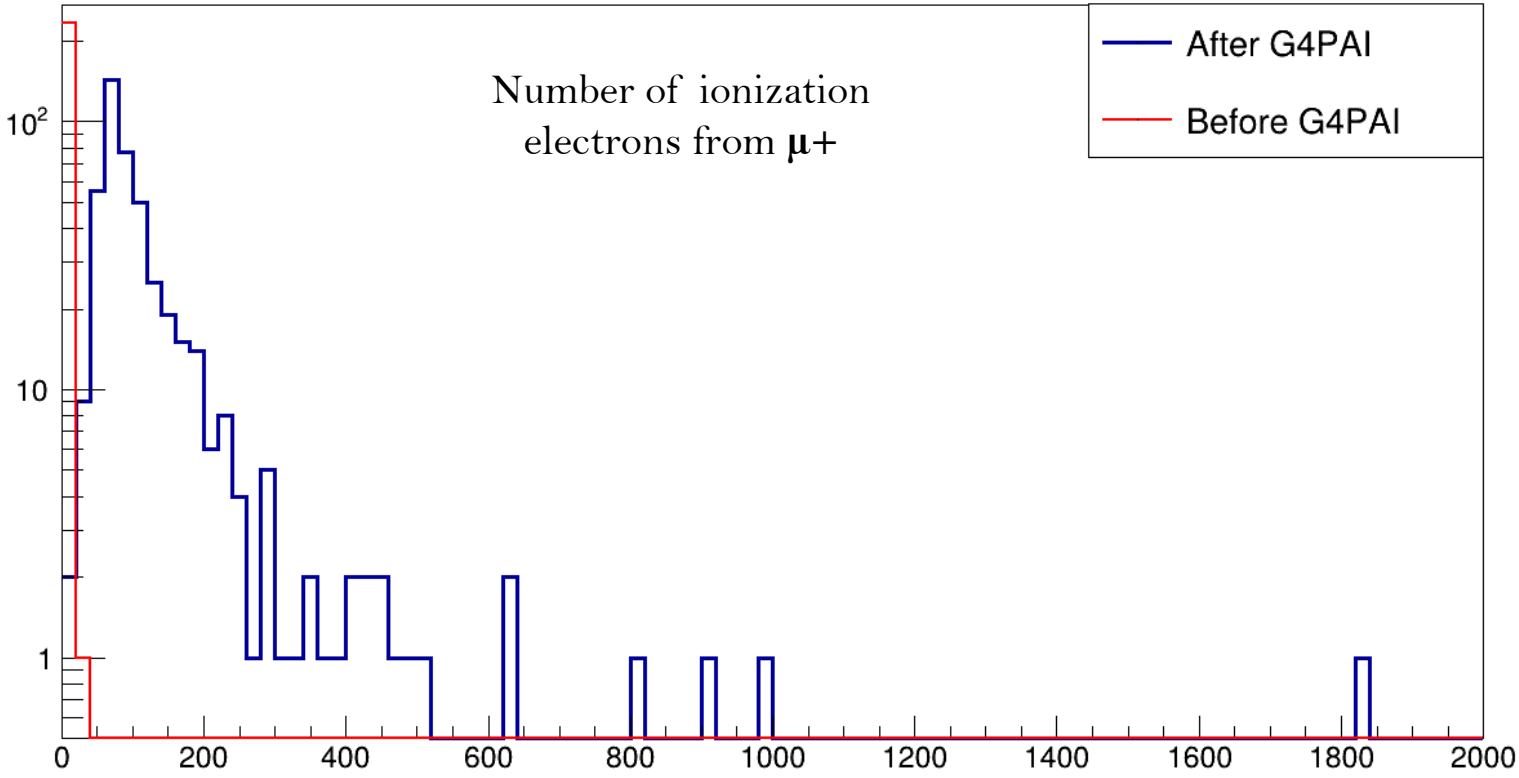
Particle → π^+ $\theta = 30^\circ$ Momentum = 6 GeV/c
tracking resolution = 0.5 mrad





BACKUP

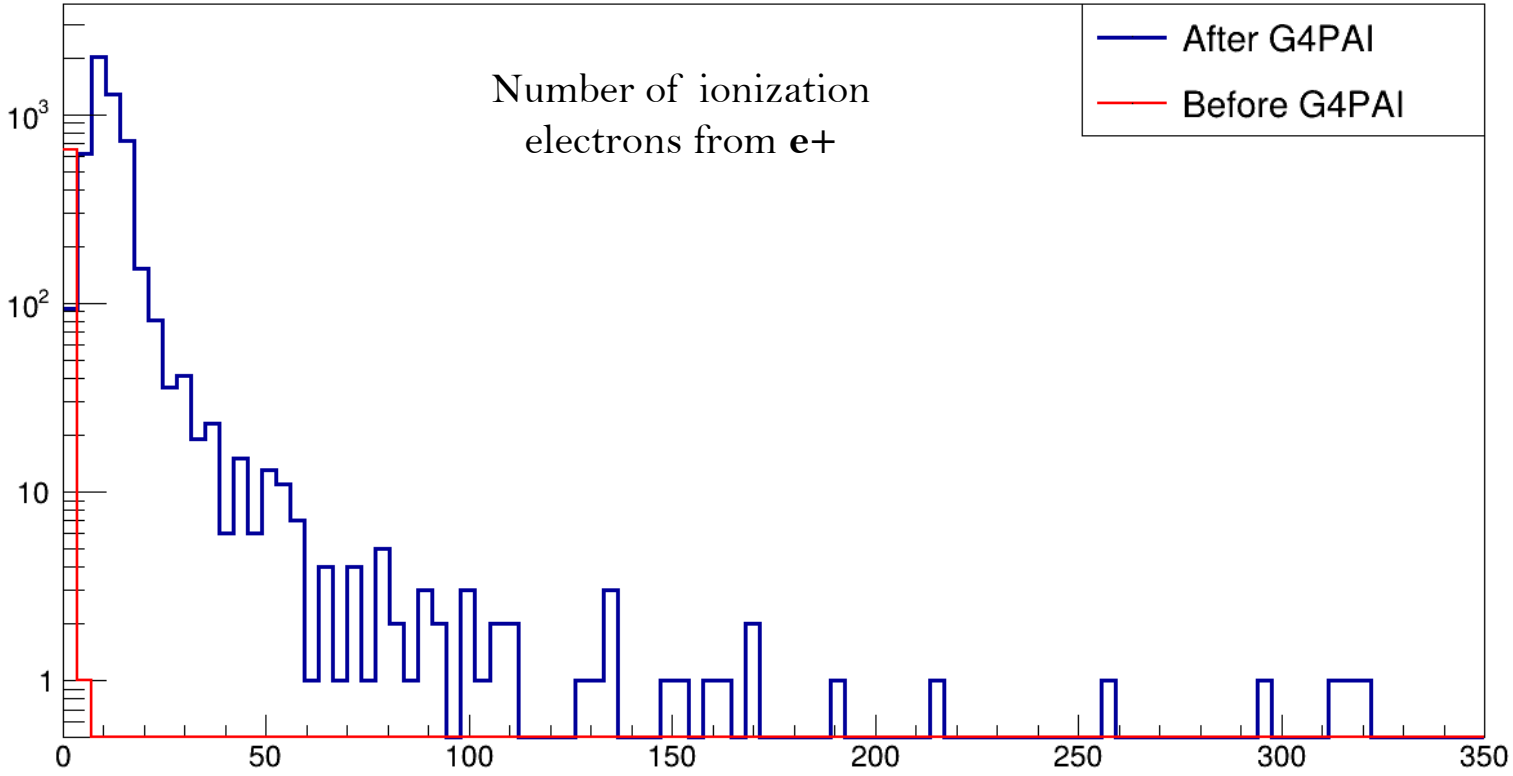
Number of Ionization Electrons



Before G4PAI
Mean: 1.66

After G4PAI
Mean: 119.2

Number of Ionization Electrons



Before G4PAI
Mean: 1.08

After G4PAI
Mean: 12.38