Simulation study of MPGD technique for CMS inner muon detector upgrade

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Outline

■ Introduction

- The CMS Muon System
- The CMS GE1/1,GE2/1 and ME0 Upgrade
- The GEM,FTM and μRWELL technique

■ Finite element analysis

- Multi-layer FTM
- Triple-GEM
- micro-Resistive WELL

■ Simulation & reconstruction

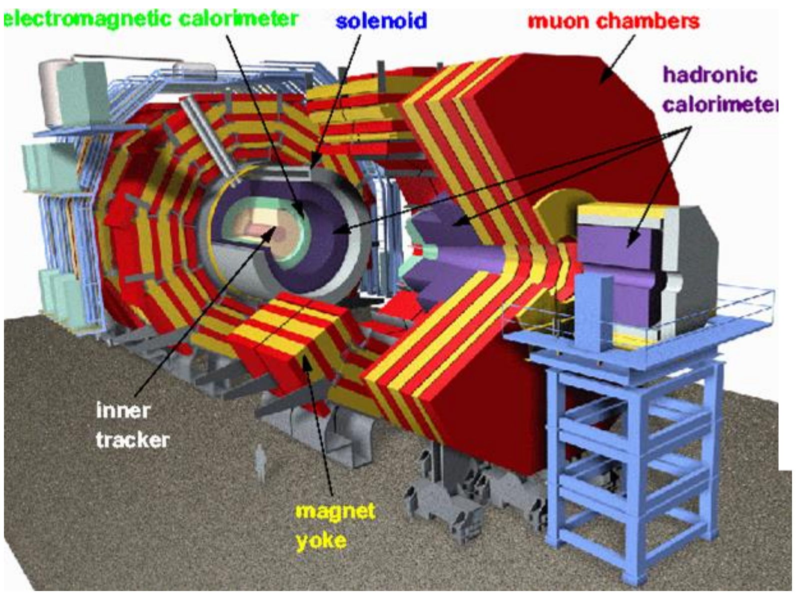
- Field, gas
- Heed and avalanche(geant4)
- Signal readout and storage

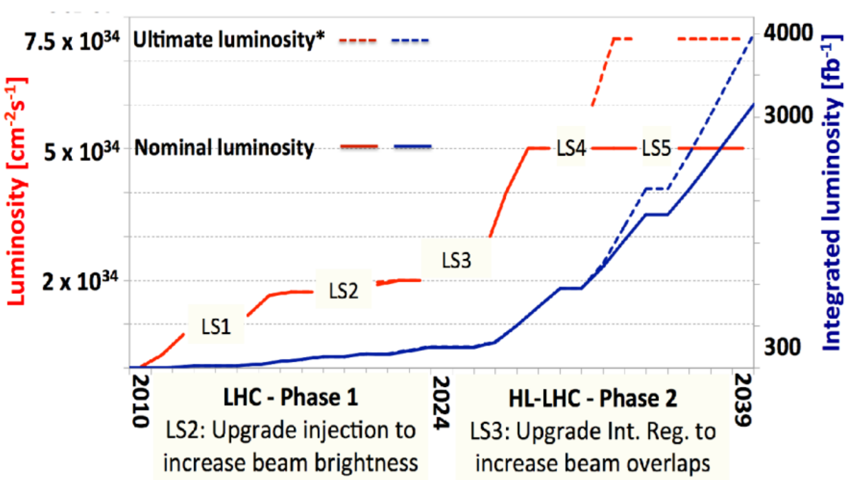
■ Data analysis

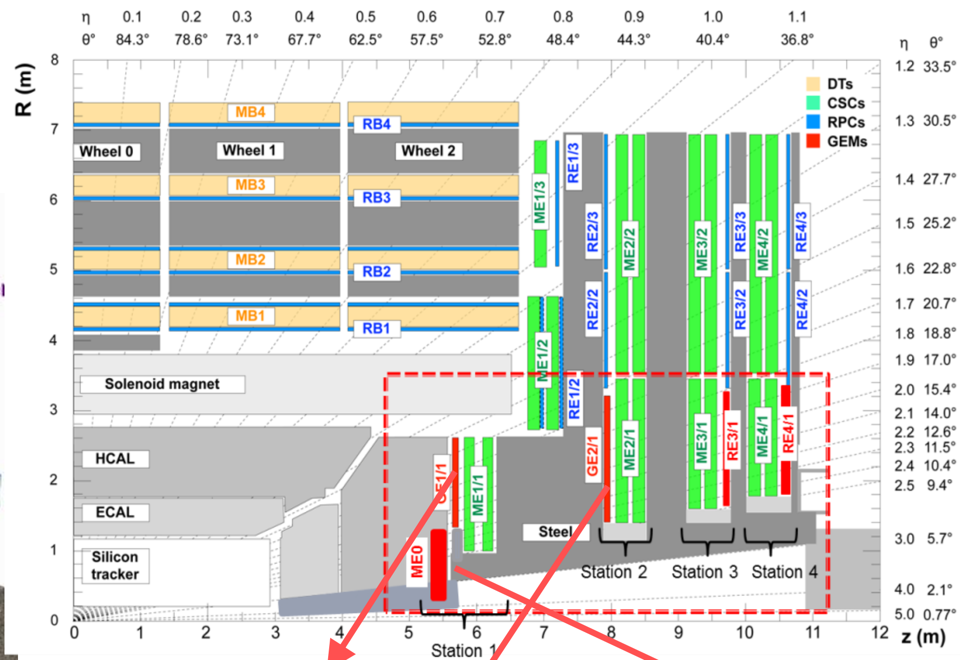
- Time resolution
- spatial resolution

■ Summary and Outlook

Introduction







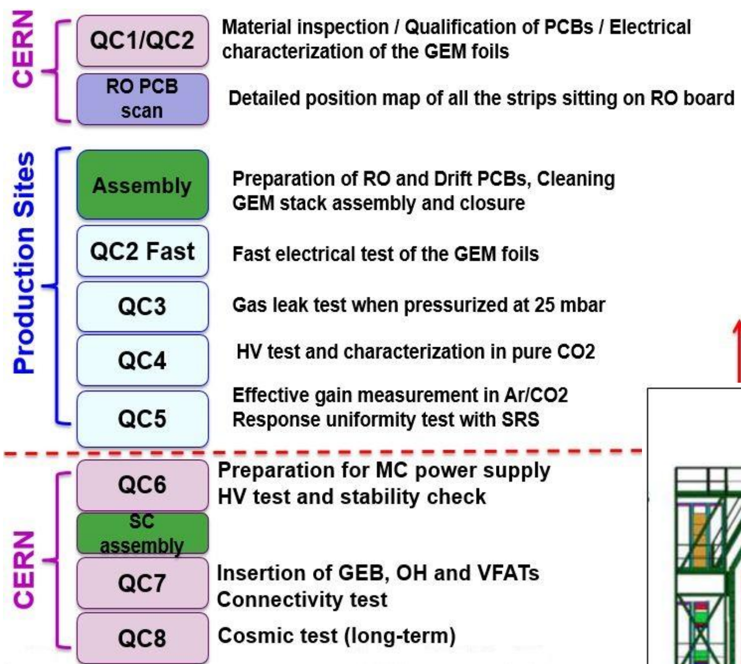
GEM Endcap GE1/1:
- station to be installed in LS2, 1.6 < |η| < 2.2
- GEM technology

GEM Endcap GE2/1:
- station proposed for LS3, η < 2.4
- 2 technologies considered:
- GEM technology - Baseline
- µRWELL-- Option

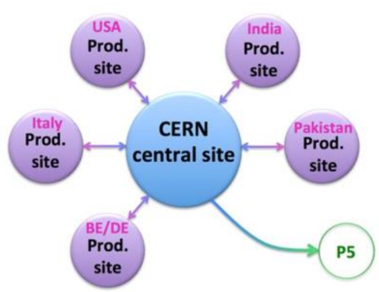
Muon Endcap ME0:
- station proposed for LS3, η < 3.8
- 2 technologies under consideration:
- GEM: GE1/1-like station, with more layers to reject background - Baseline
- FTM - Option

GE1/1 upgrade

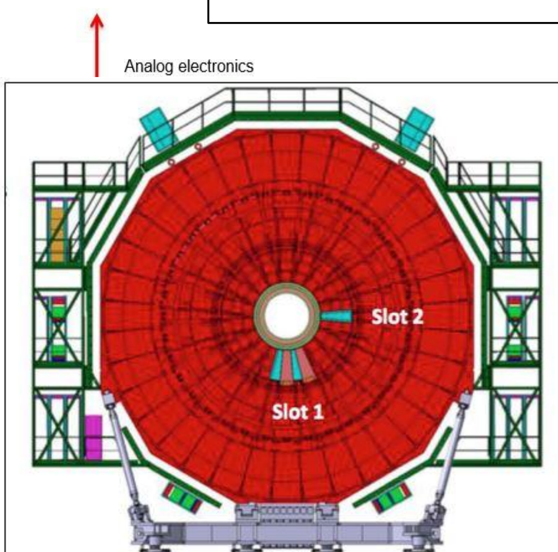
- Will be installed in LS2 (2018-2019)
- GEM chambers will be assembled and tested in 6 production sites
- 8 QC procedure were defined for GEM assembly and test
- China will provide front end board GEB (GEM Electronics Board)



GE1/1 assembly and test procedures



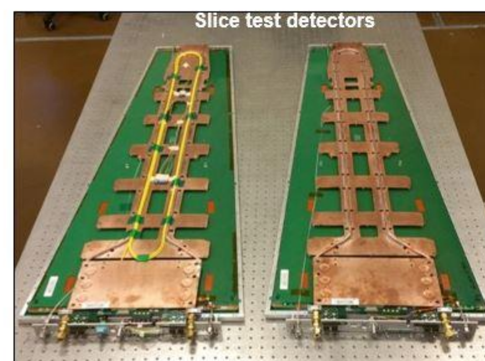
GE1/1 production sites



Slice test distribution in negative end-cap

- 10 GE1/1 slice test detectors installed in January 2017
- Chambers in operation since May 2017
- HV on in Ar/CO2 70:30
- Gas gain ~ 1×10^4
- 2 chambers with HV supplied individually to each of 7 electrodes
- 8 chambers with HV supplied through HV divider

- LHC delivered ~ 45 fb^{-1}
- Total area : 3×10^4 cm^2

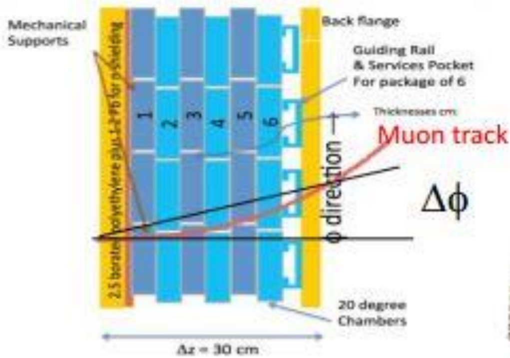


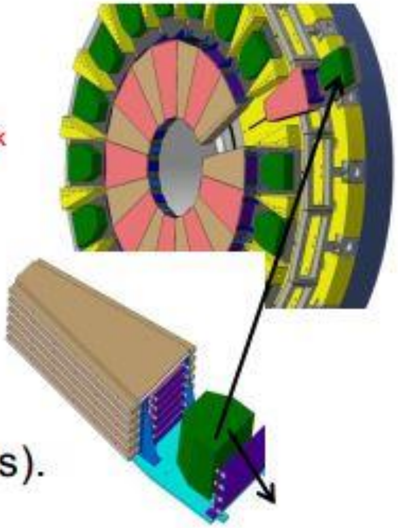
ME0 upgrade

- Extend muon tagging coverage up to $\eta \sim 2.9$ and enhance trigger to $\eta \sim 2.4$ range using space available in the back of the new endcap calorimeter
- ME0 baseline is 6 layers of triple-GEMs arranged in 20^0 super-module wedges.

High granularity spatial segmentation for:

- Position and bending measurement of the muon stubs for efficient matching of offline pixel tracks.





Multi-layered structure to:

- improve local muon track reconstruction
- discriminate muon (segment) against neutrons (uncorr hits).

Option: precision timing

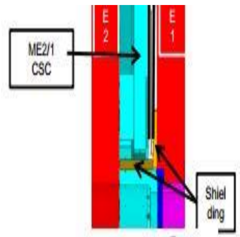
- Option for Fast Timing Micro-pattern (FTM) detector to reject background hits from pile-up and neutron background – small prototype under study

(**Maggi, De Oliveira, Sharma** arXiv:1503.05330v1)

GE2/1 upgrade

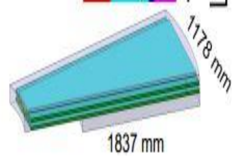
Baseline: GEM

The station GE2/1 consists of 72 triple-GEM chambers arranged in 36 20⁰ Super-chambers, covering 1.60<|η|<2.46.

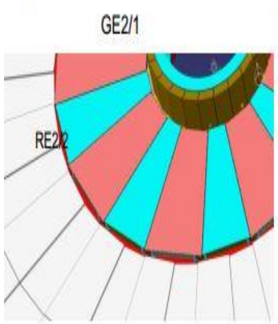


Layout is similar to GE1/1, but covering much larger surface:

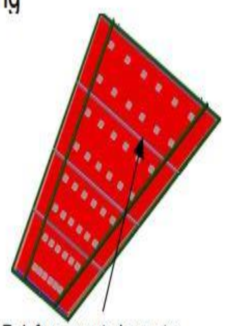
- ✓ Will be the largest triple-GEM chambers built



Optimization of engineering design for mass production on-going



- only 81 mm clearance including services
- four foil modules structure per 20-degree chamber, 6 ϕ-sectors × 8 η-sectors total



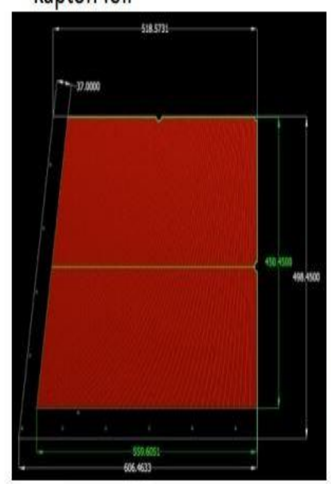
Reinforcement elements

- Option for μ-R-Well technology as compact and low cost large detector (G. Bencivenni et al., 2015_JINST_10_P02008)

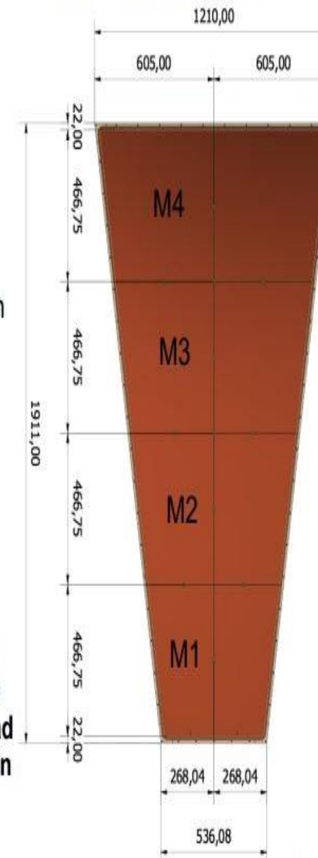
optional: μ-RWELL

We have built a full scale GE2/1 sector with 2 M4 μ-RWELL operating detectors.

1) M4 left and right are mirrored.
2) Size: 606.5 x 498.5 x 1 mm
3) Strip layout inspired to the GE2/1 GEM option
4) Final drawing finished (Gatta-LNF)
5) DLCed foils ready (Ochi-Kobe)
6) Preliminary tests at ELTOS done
7) PCB production at Eltos done, then glueing with kapton foil

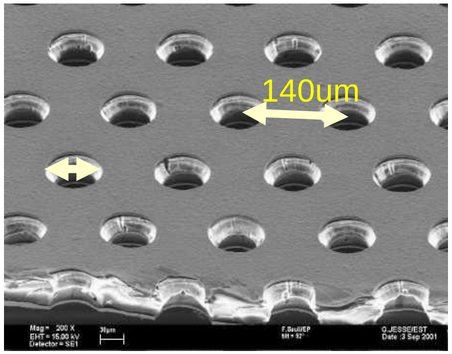


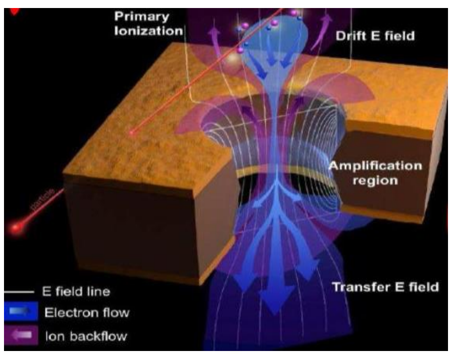
Modules fit within 74 mm splicing → dead space less than 0.01%

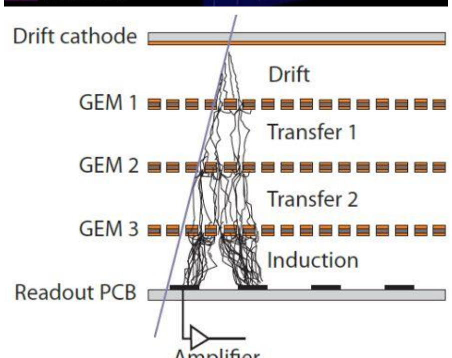


3 MPDG (Micro-Pattern-Gaseous-Detectors) techniques:

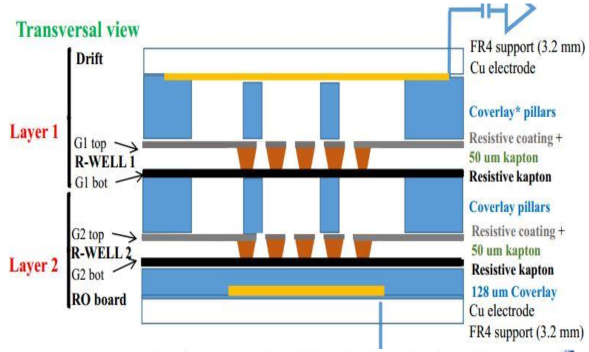
GEM

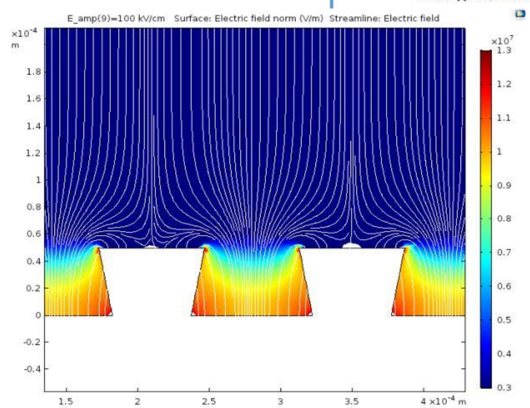


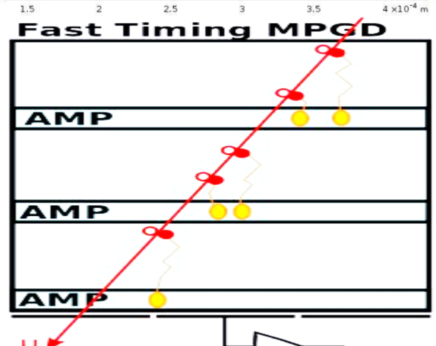




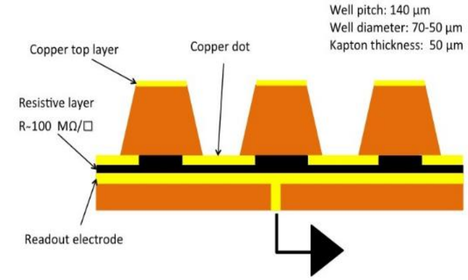
FTM

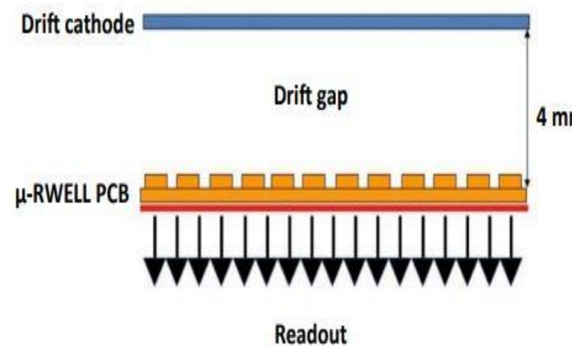


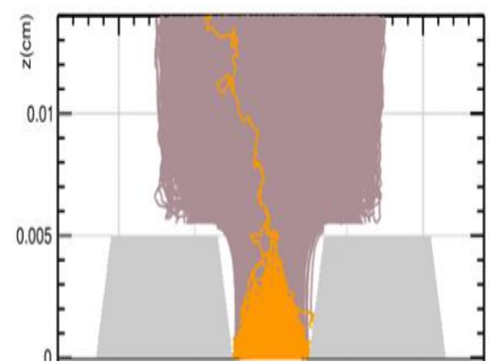




μ-RWELL







Simulation process

Gas and field preparation

Magboltz：gas property calculation

Ansys : electric field, material property, etc

Garfield++ initialization

Initialization : gas, field, sensor, particle, etc.

Preliminary ionization

Heed(Garfield++) or Geant4

avalanche

Give every electron a avalanche from a position, direction, energy

Weighting field readout

An additional electric field to calculate the induced signal

Data analysis

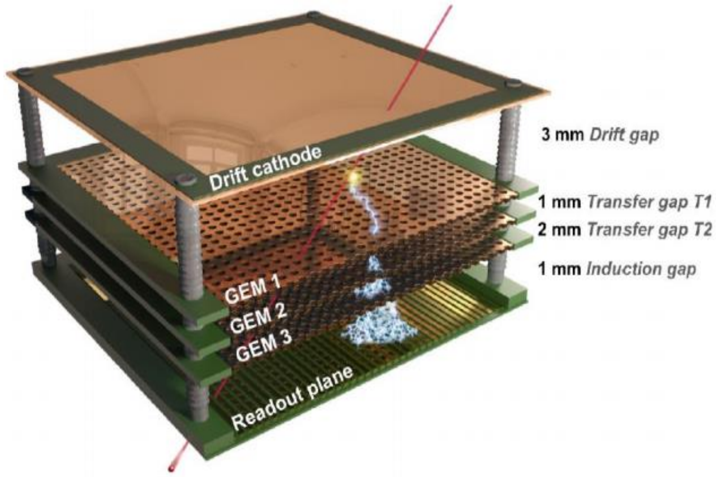
Time resolution, spatial resolution, etc.

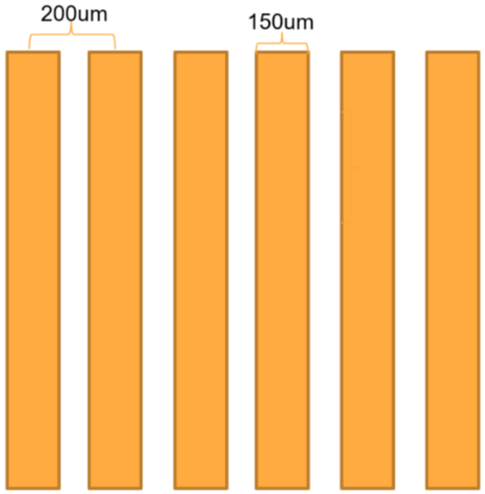
Finite element analysis: GEM

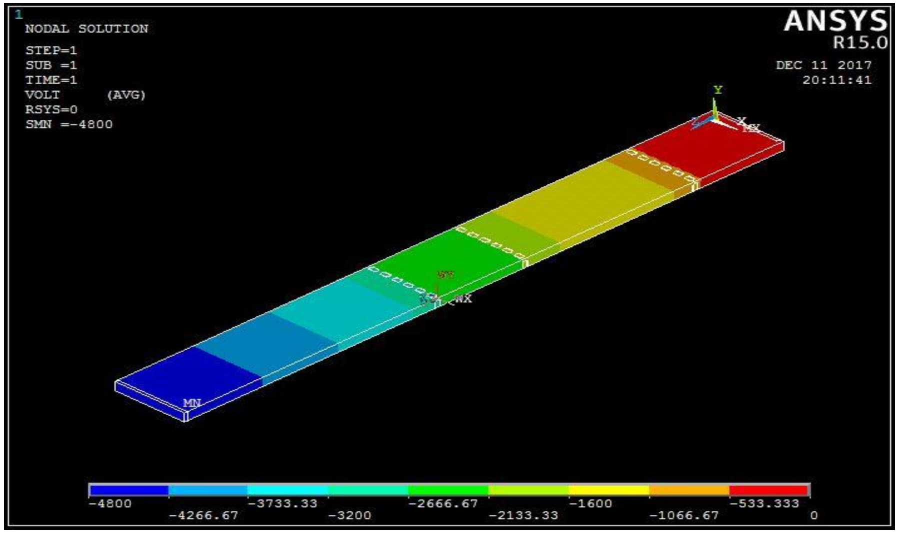
Triple-GEM

Drift: -4000V
G1UP: -3060V
G1DOWN:-2580V
G2UP: -2205V
G2DOWN:-1735V
G3UP: -985V
G3DOWN:-535V
READOUT: 0V

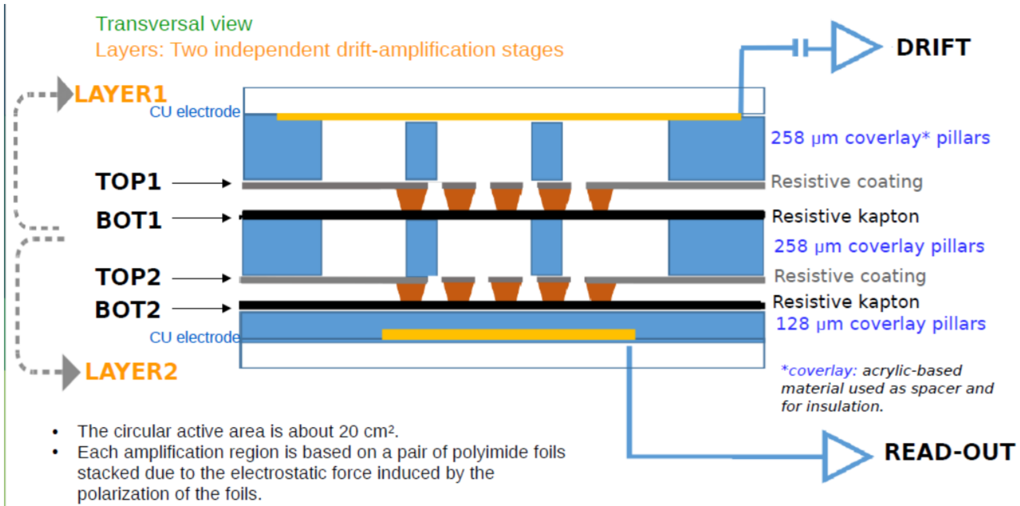
Gas: Ar:CO2=70:30
Temperature: 20°C
Drift filed :3kV/cm

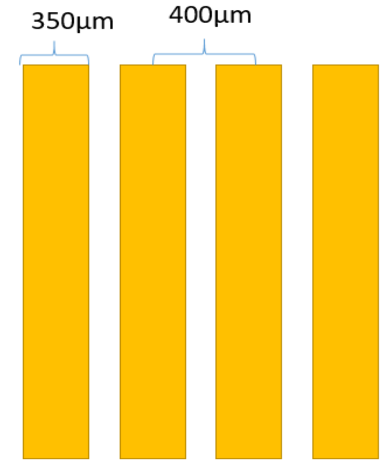






Finite element analysis: FTM





FTM:

Drift:-1300V

Top1: -1100V

Bot1: -650V

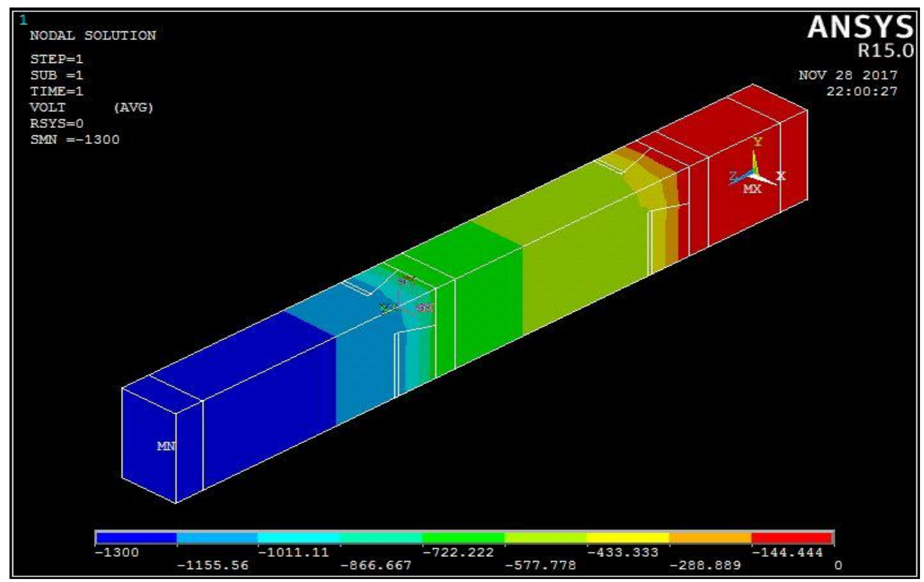
Top2: -450V

Bot2: 0V

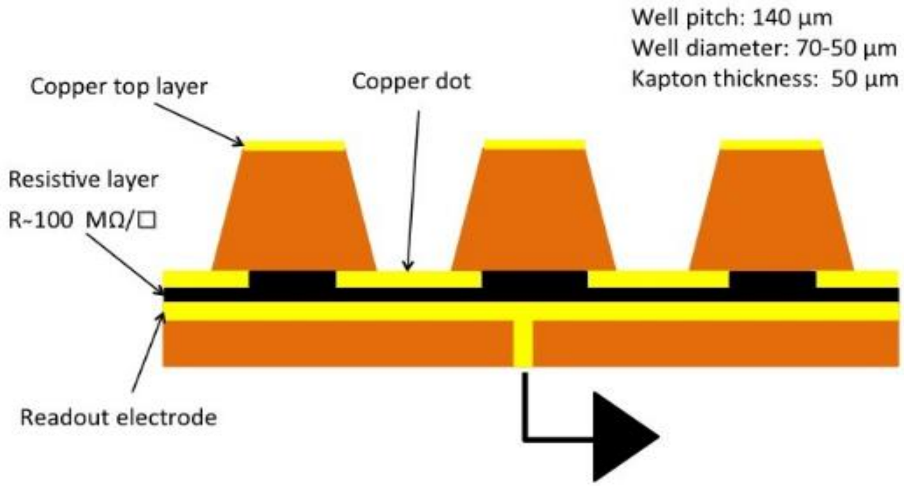
Gas: Ar:CO_2=70:30

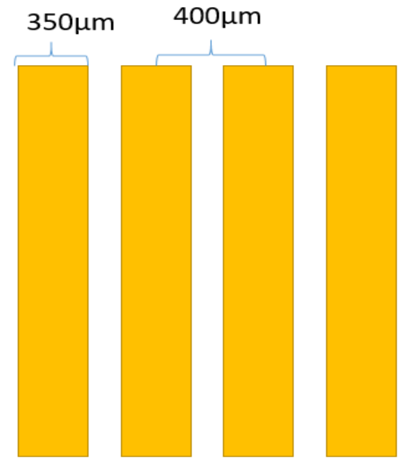
Temperature: 20℃

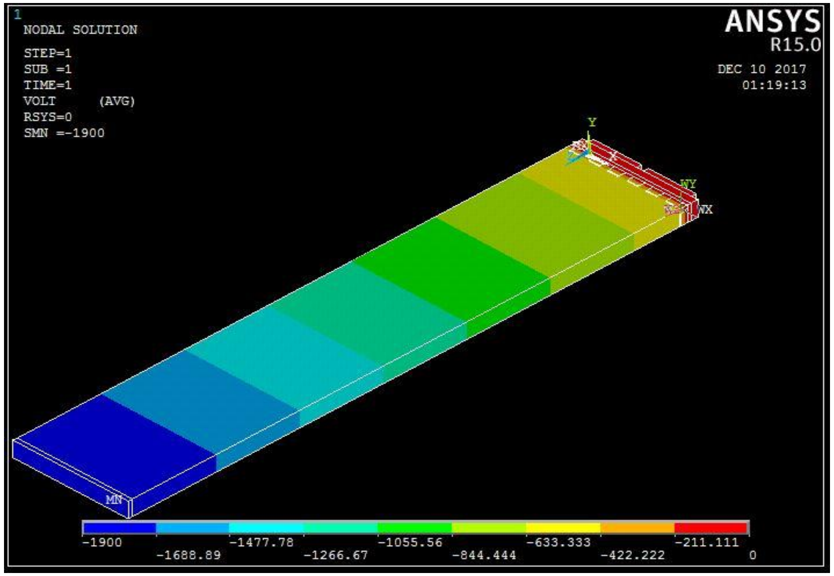
Drift Field： 8kV/cm

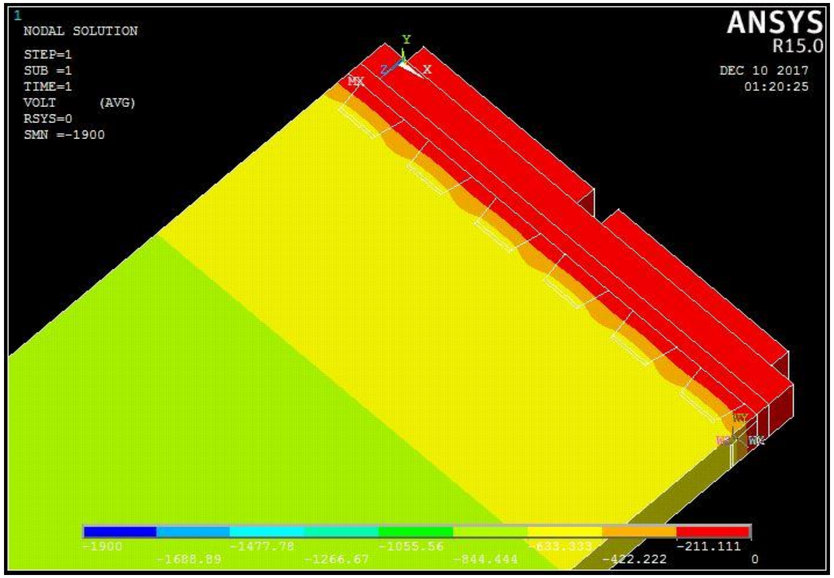


Finite element analysis: μ RWell





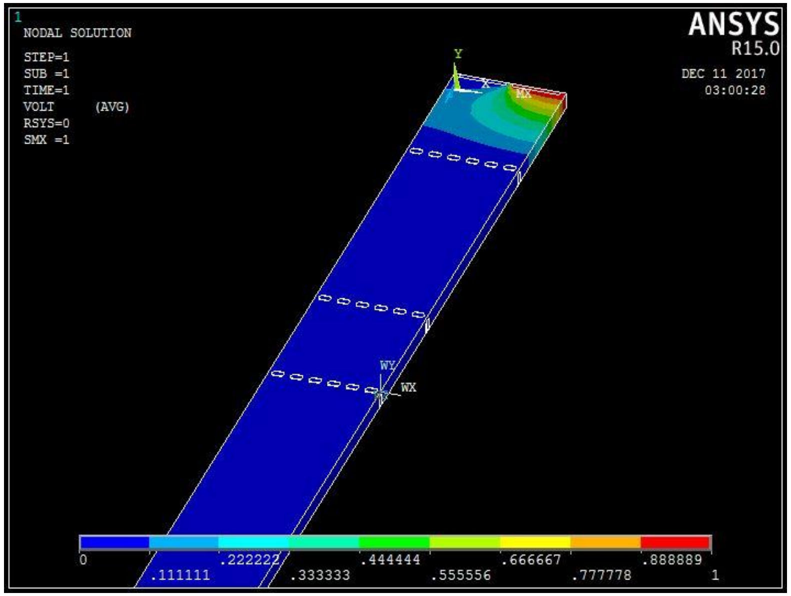


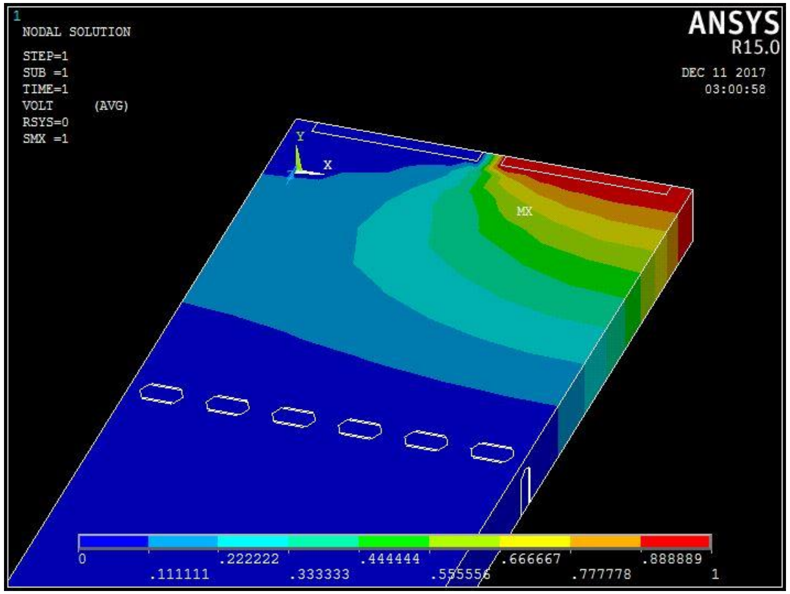


Weighting field readout

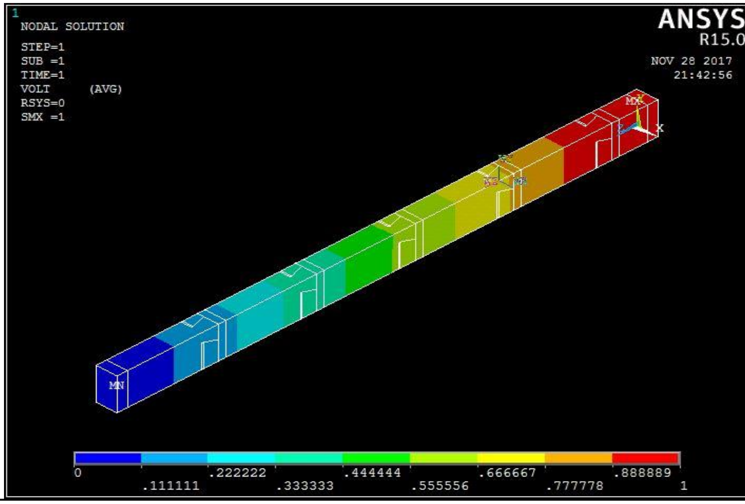
Ramo’ s Theorem :

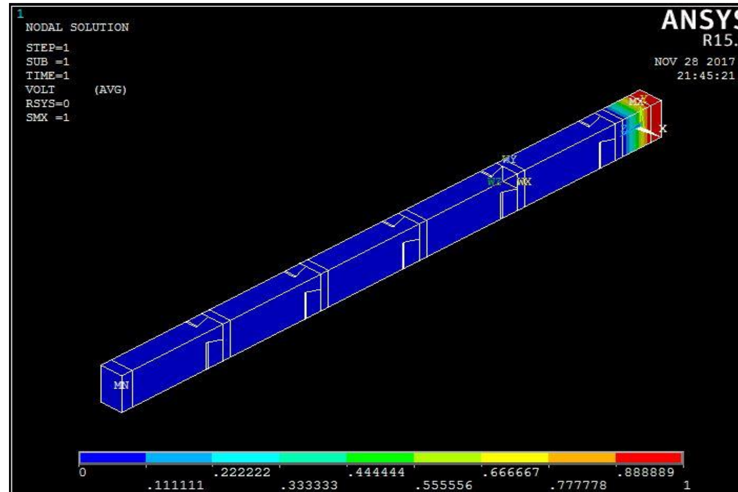
set the voltage of readout board to 1 and the other electrodes to 0, electrons drift in this weighting field and induce signal on the readout board.





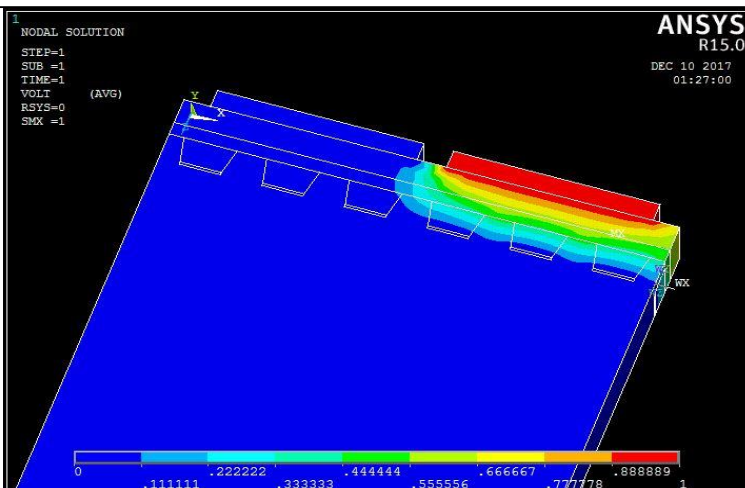
Effect of resistive electrode:

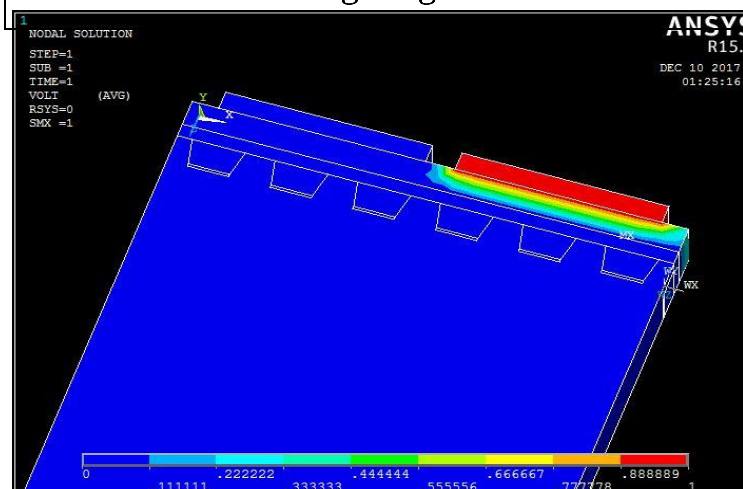




FTM: the effect of resistive electrode is ignored

FTM: the screening effect of resistive electrode is considered: no weighting electric field

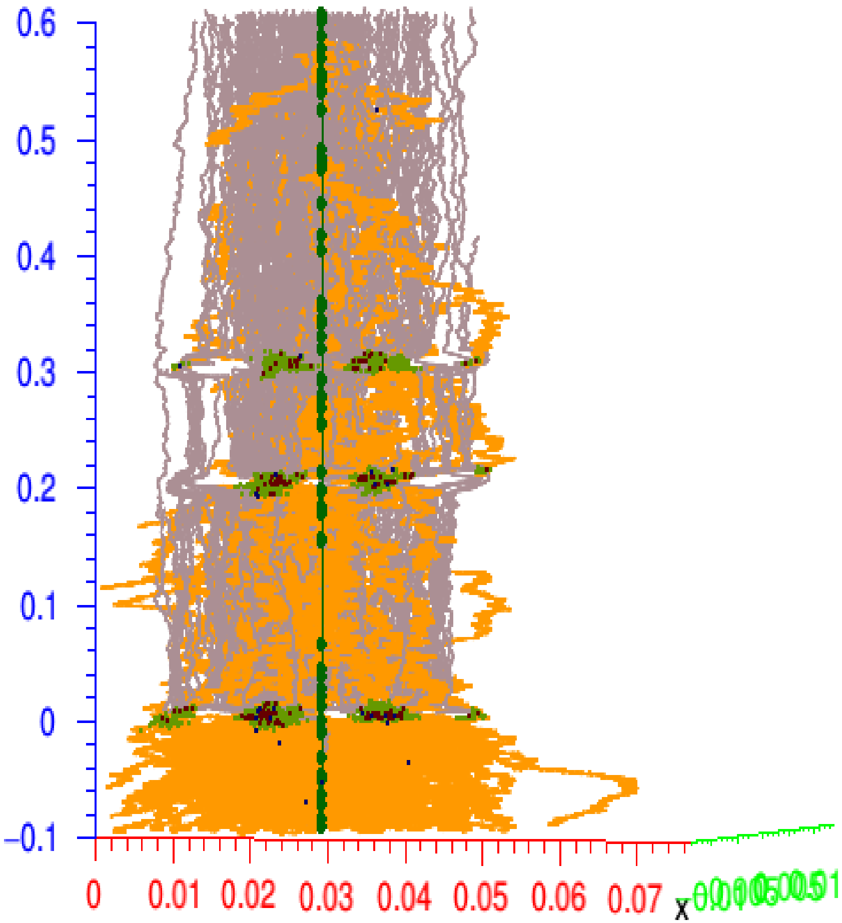




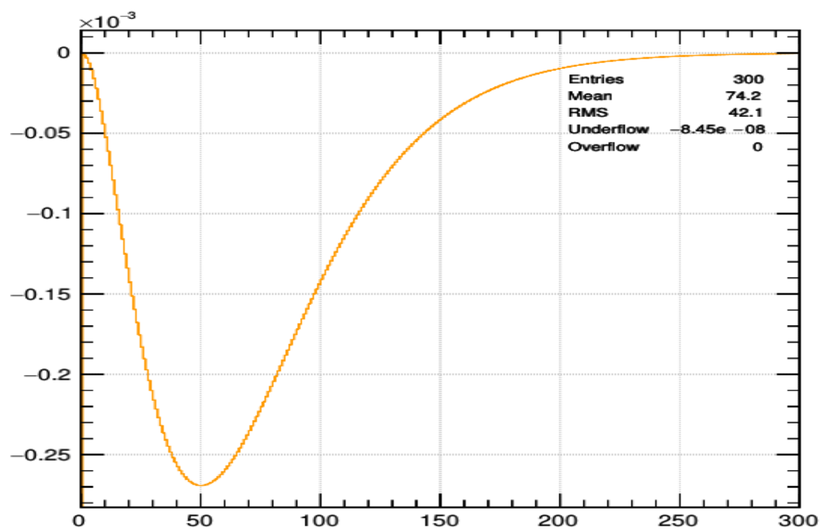
μRWell: the effect of resistive electrode is ignored

μRWell: the screening effect of resistive electrode is considered: no weighting electric field

GEM Reconstruction



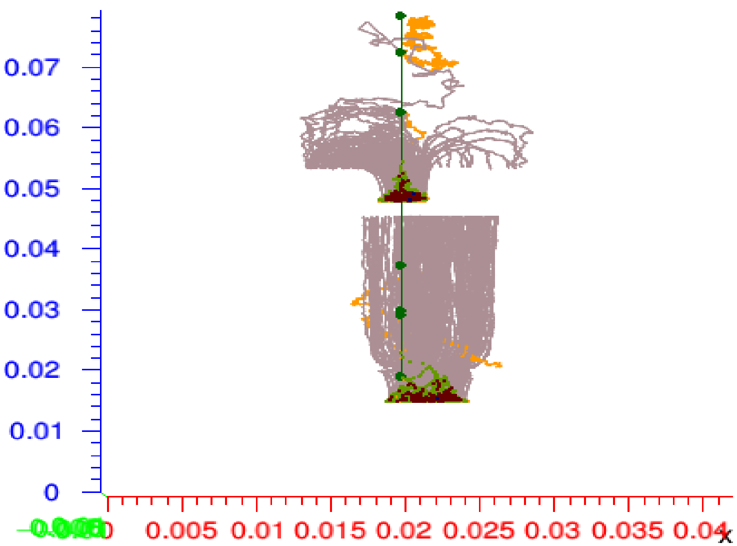
- Triple-GEM
- Particle: π-, μ-
- Energy :150GeV
- Direction : downstream
- Initial position(cm): (0.0385, 0, 0.6)
  in the center of the model
- RC: 30ns, 50ns
- Particle Time interval: 300ns



Induced time signal in GEM strips (ns)

FTM Reconstruction

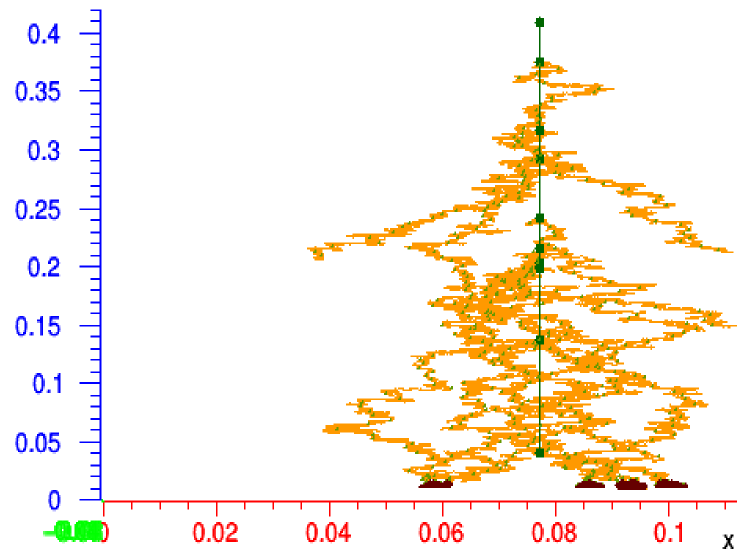
- Particle: π- , μ-
- Energy :150GeV
- Direction : downstream
- Initial position(cm): (0.02) , in the center of the model
- RC: 30ns,50ns
- Particle Time interval : 500ns



Avalanche process in FTM

μRWELL Reconstruction

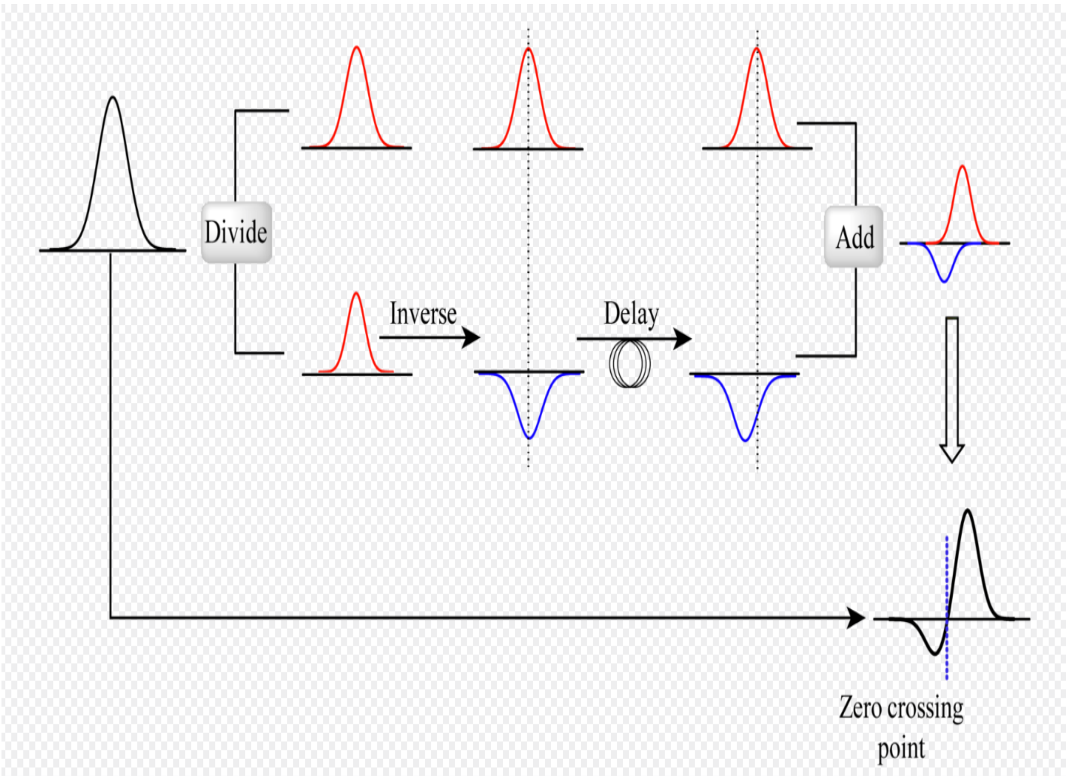
- Particle: π- , μ-
- Energy :150GeV
- Direction : downstream
- Initial position(cm): (0.0775) , in the center of the model
- RC: 30ns , 50ns
- Particle Time interval : 500ns



Avalanche process in μRWell

Data analysis

- Time resolution : Constant Fraction Timing
- Position resolution : The center-of-gravity method



$$X_0 = \frac{\sum_{i=1}^{n} X_i Q_i}{\sum_{i=1}^{n} Q_i}$$

X_i : Center position of the i-th strip,

Q_i : Charge of the signal in i-th strip,

X_0: position of the signal after center of gravity method.

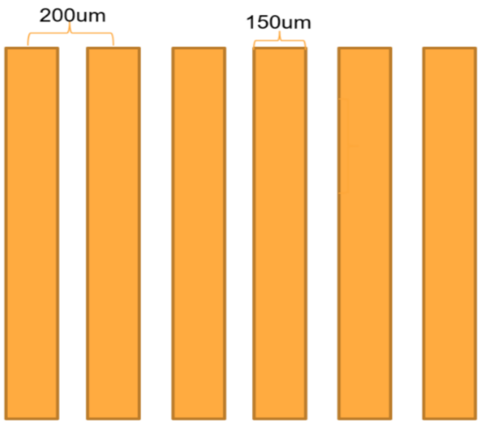
Results: Triple-GEM

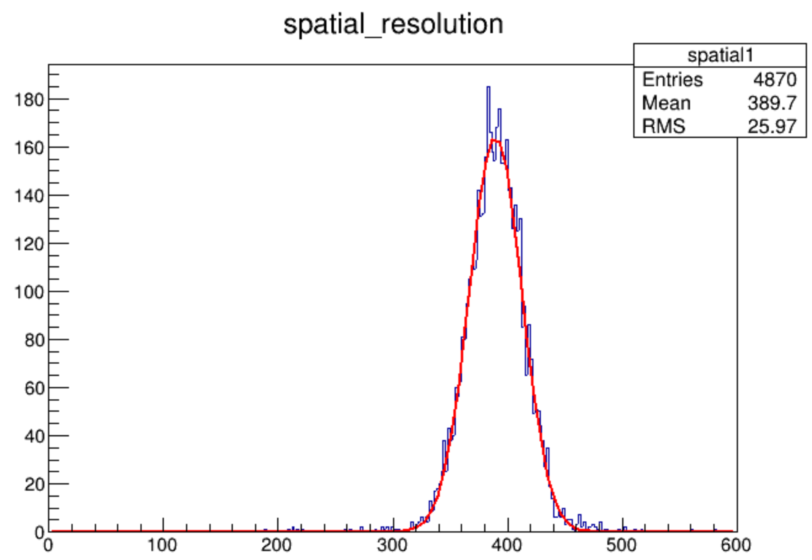
Particle: μ-

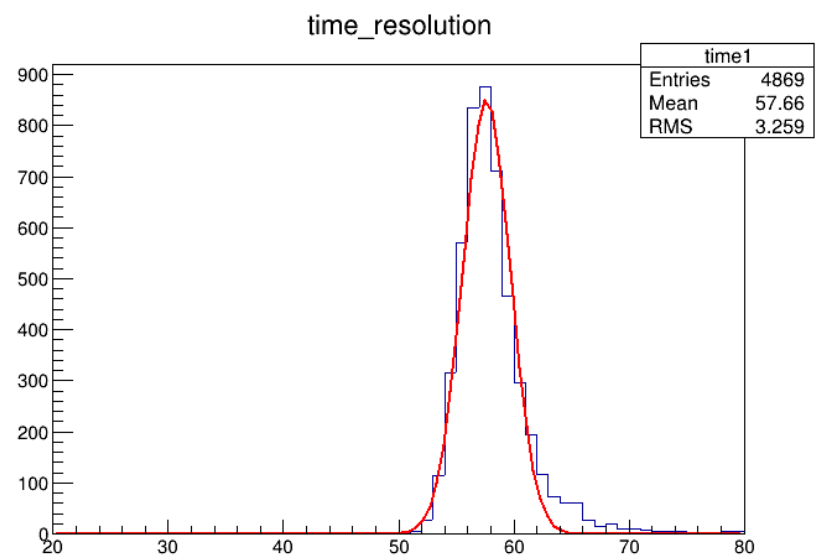
Energy: 150GeV

RC= 50ns

Gas: Ar/Co2/CF4=45/15/40



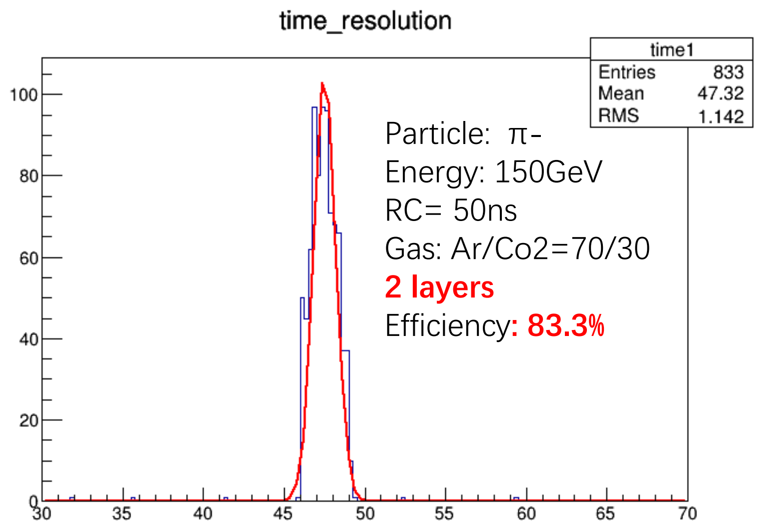


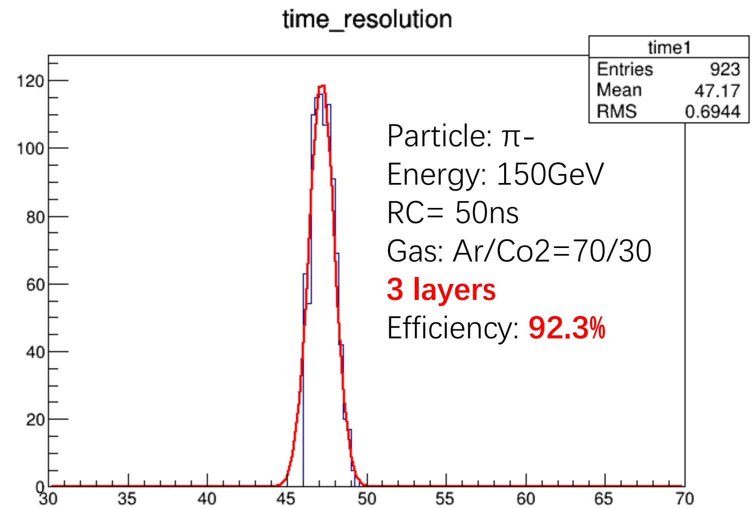


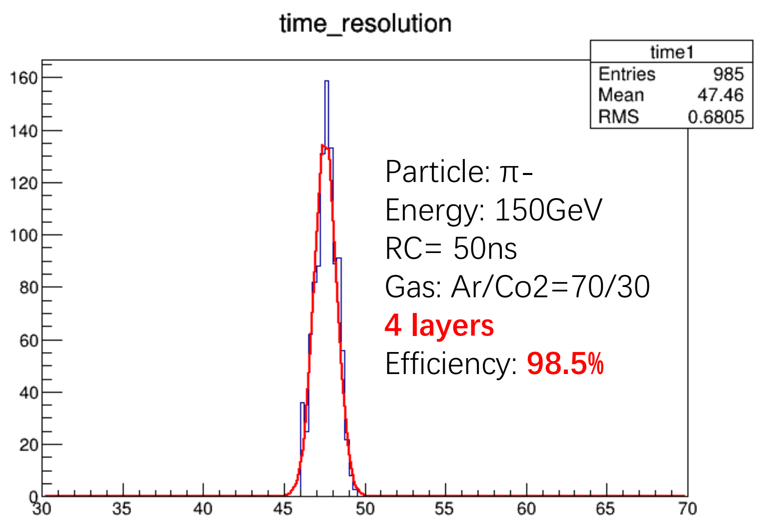
Spatial resolution: 29μm

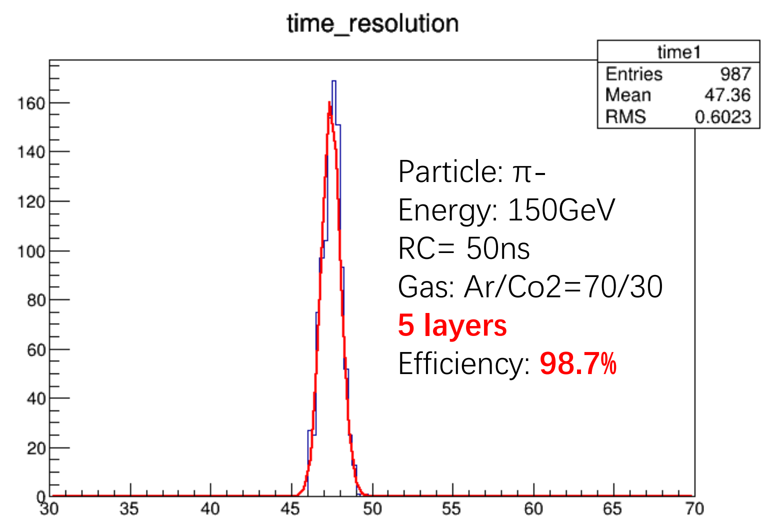
Time resolution: 2.19ns

Results: FTM



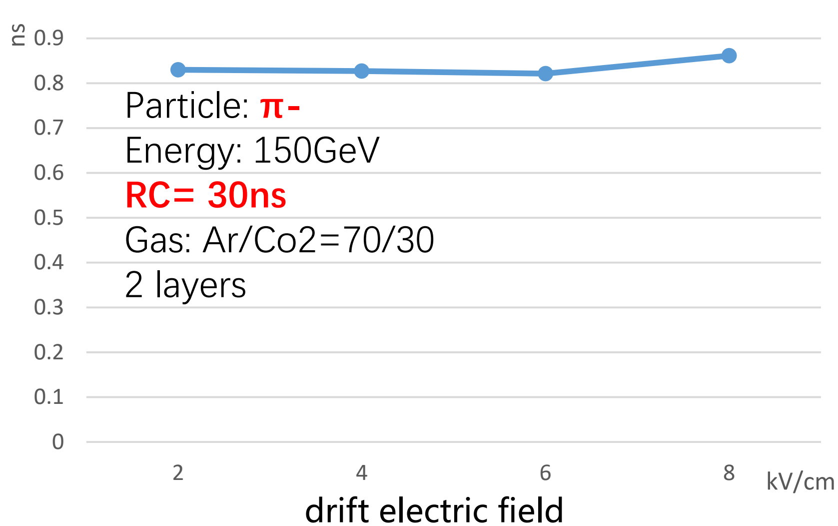


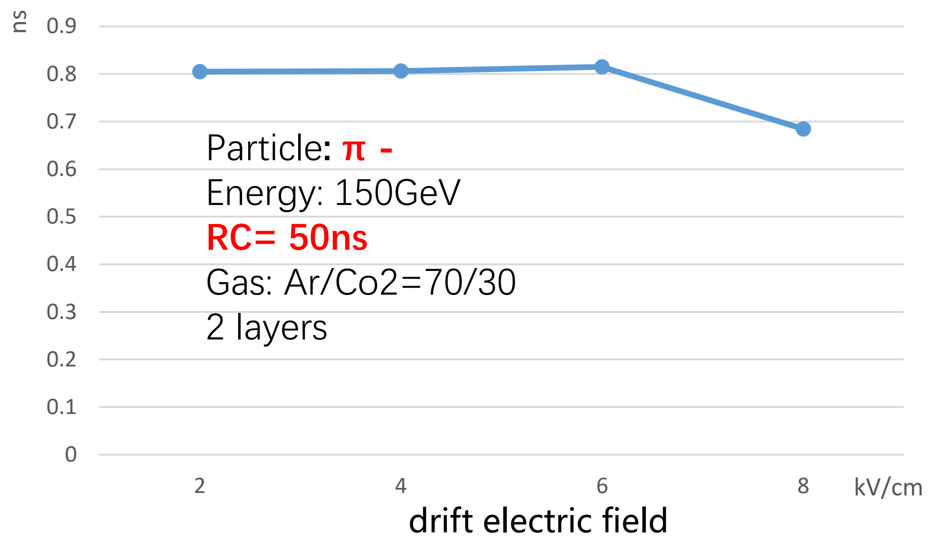


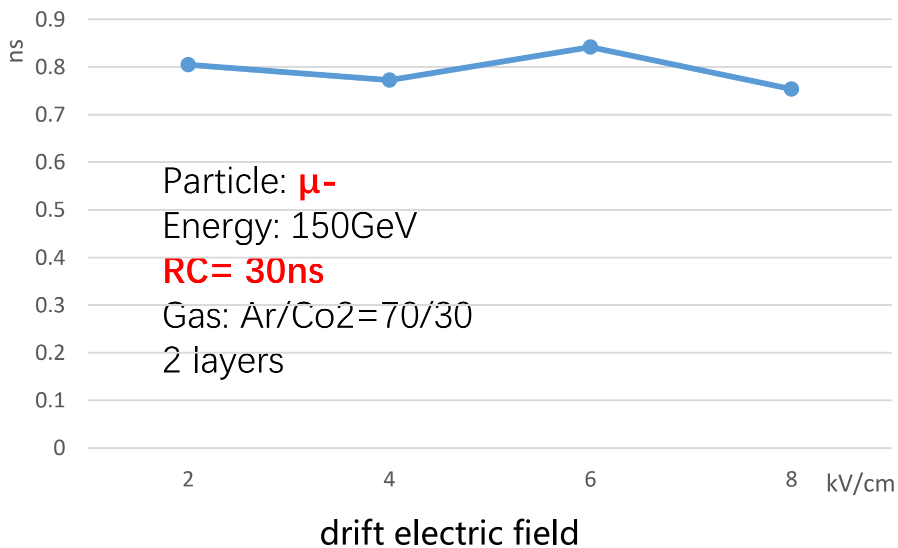


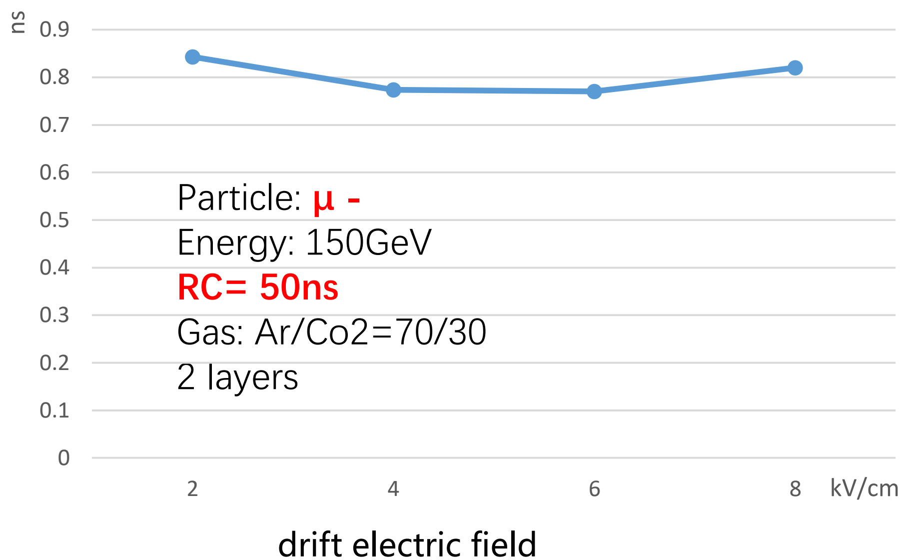
No doubt, efficiency is higher with more gas gaps.

FTM Result: time resolution at different incident particle and forming time, relative to the drift electric field

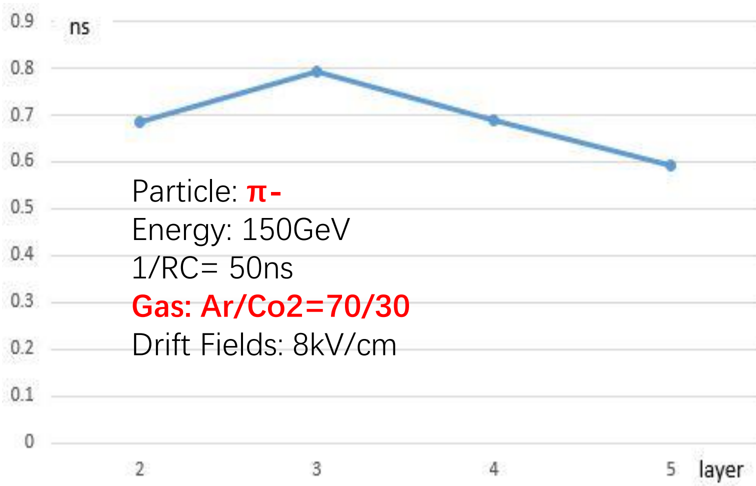


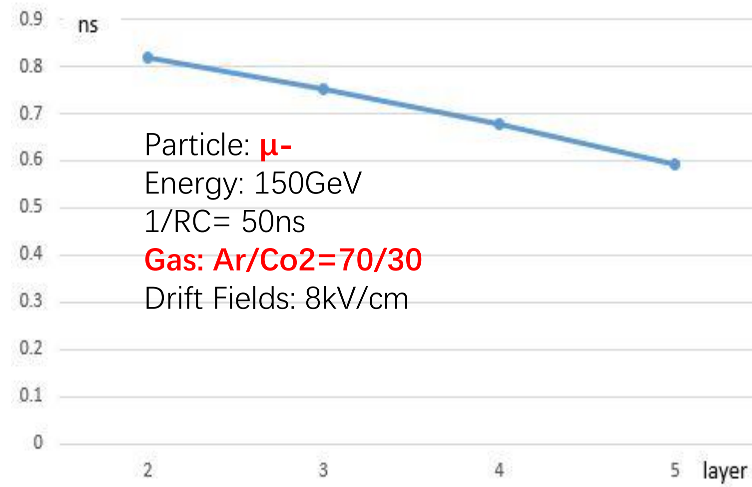


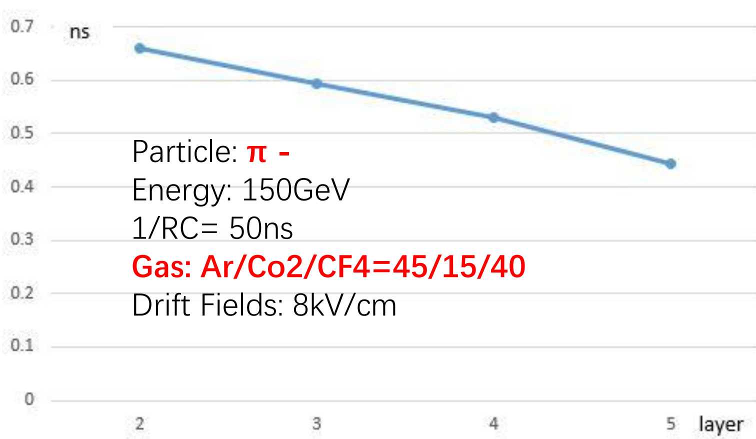


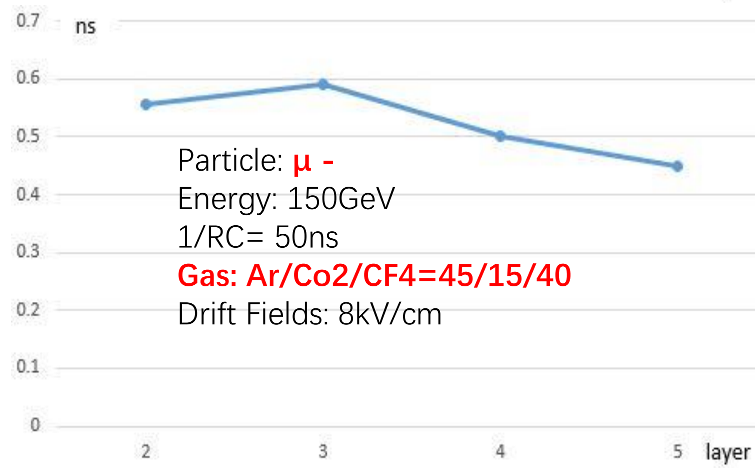


FTM Result: time resolution at different incident particle and gas composition, relative to the number of layers



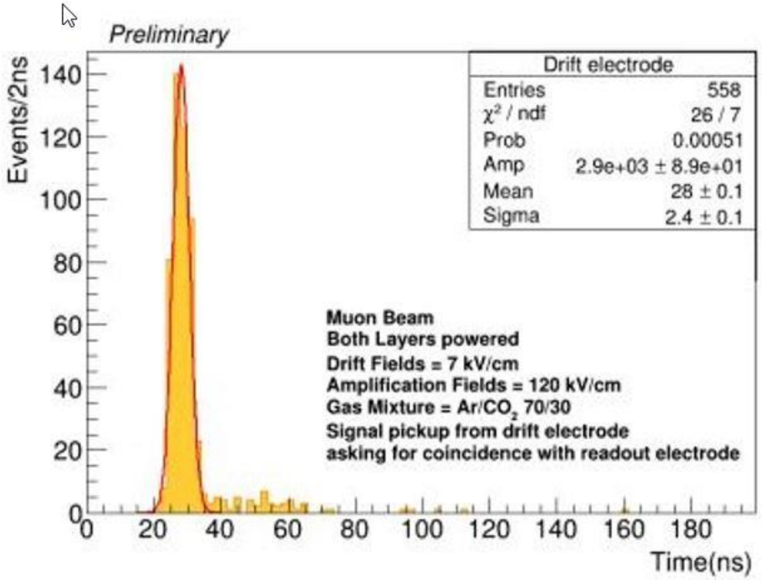


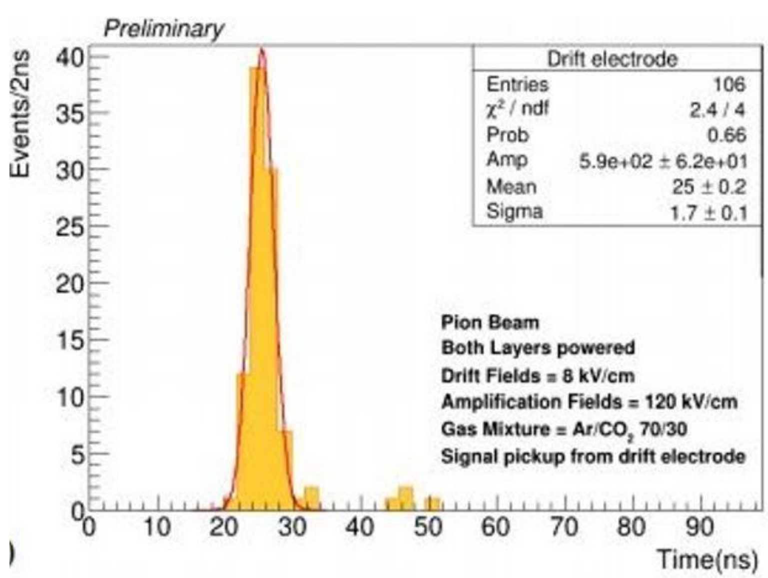


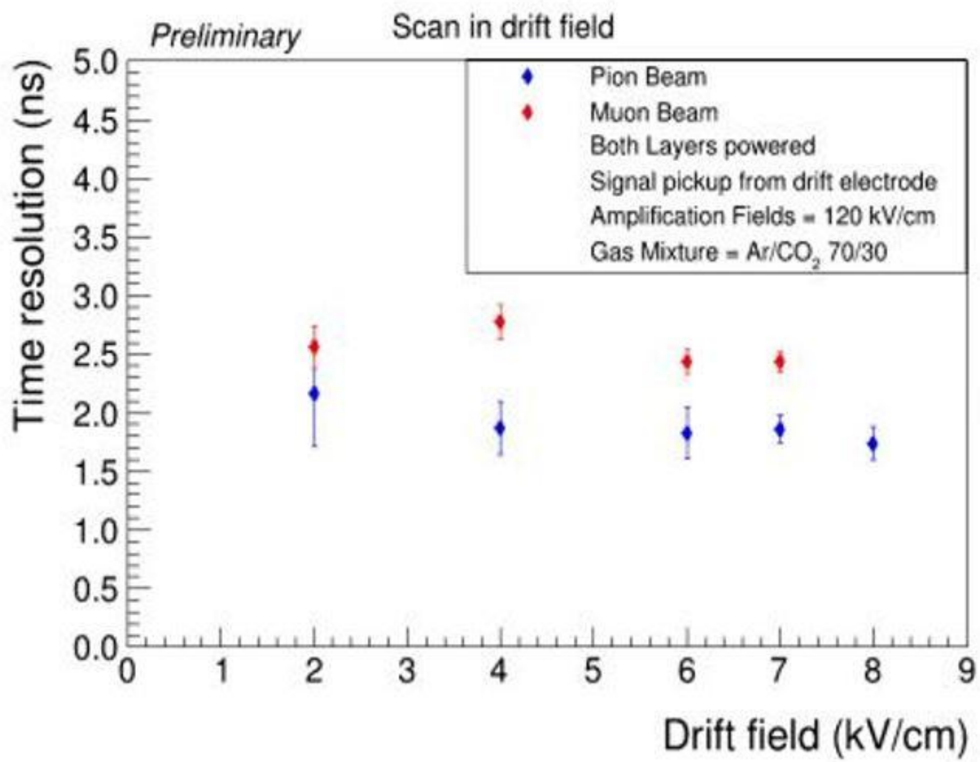


For different particles, time resolution does not change too much; Gas mixture with CF4 makes the resolution better.

FTM Result: compare with beam test

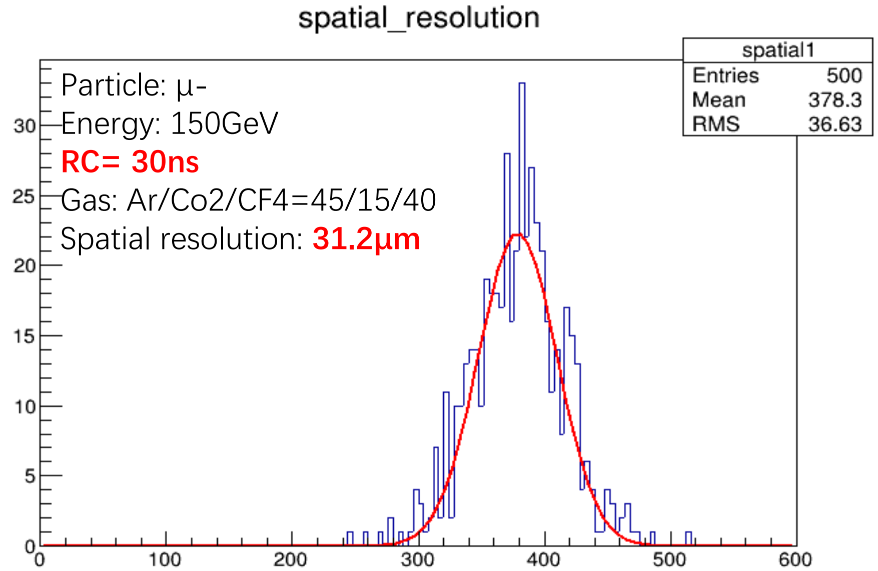


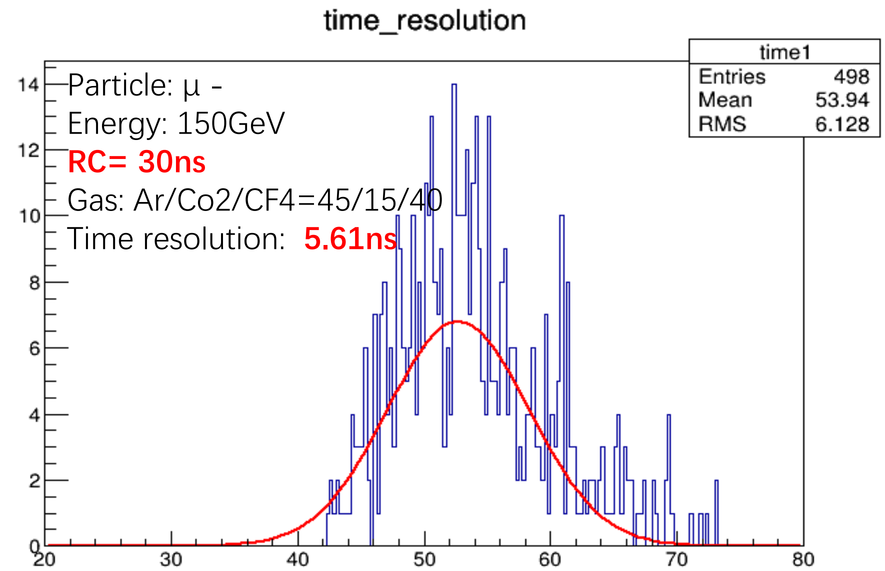


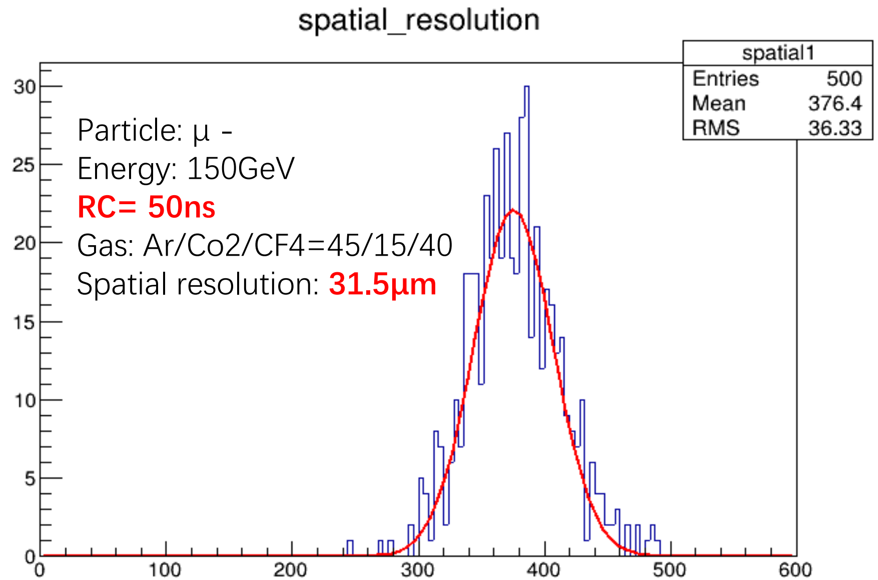


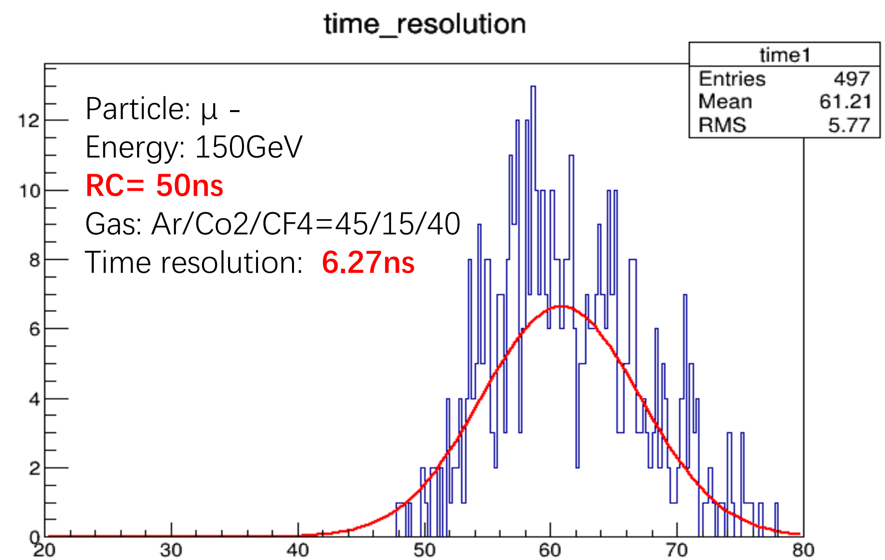
https://doi.org/10.1016/j.nima.2016.05.067

μRWell Results from different forming time



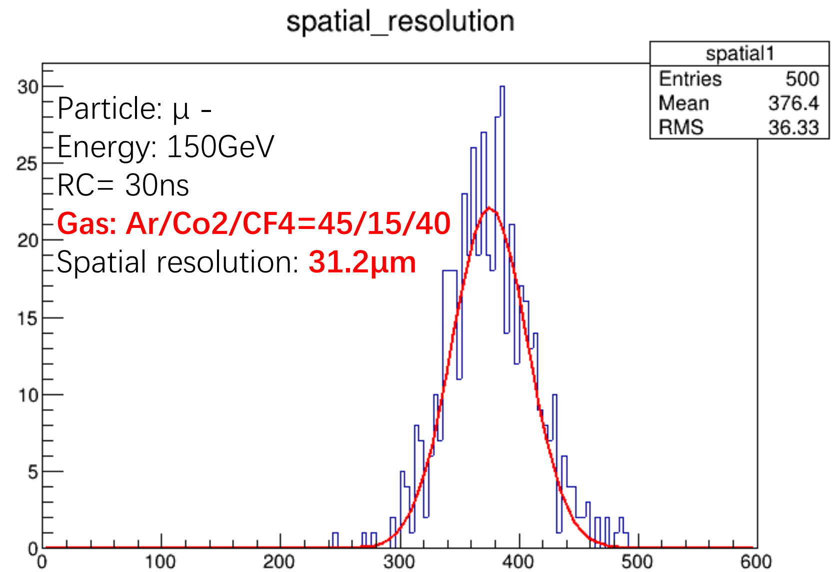


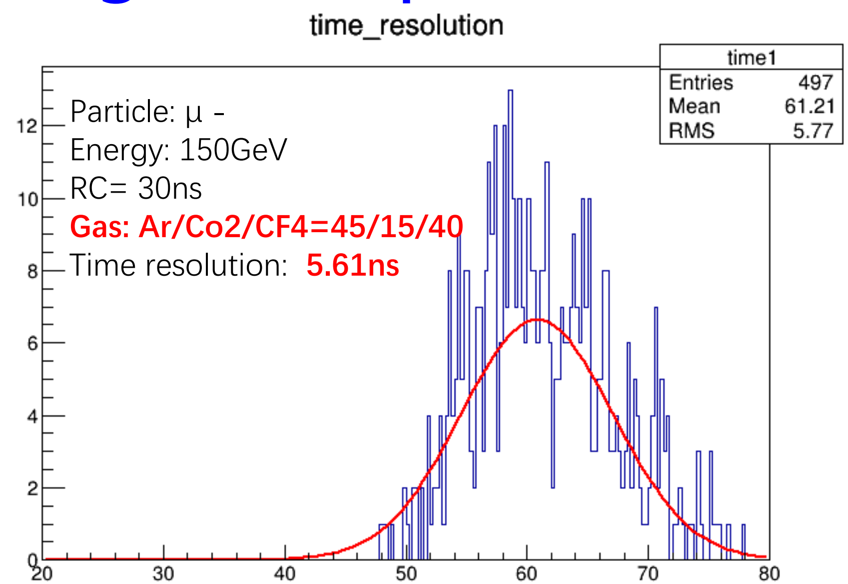


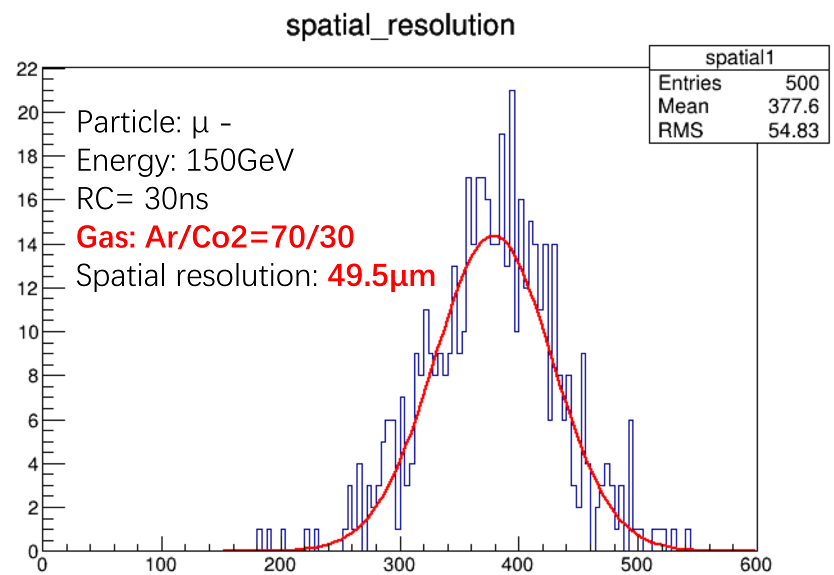


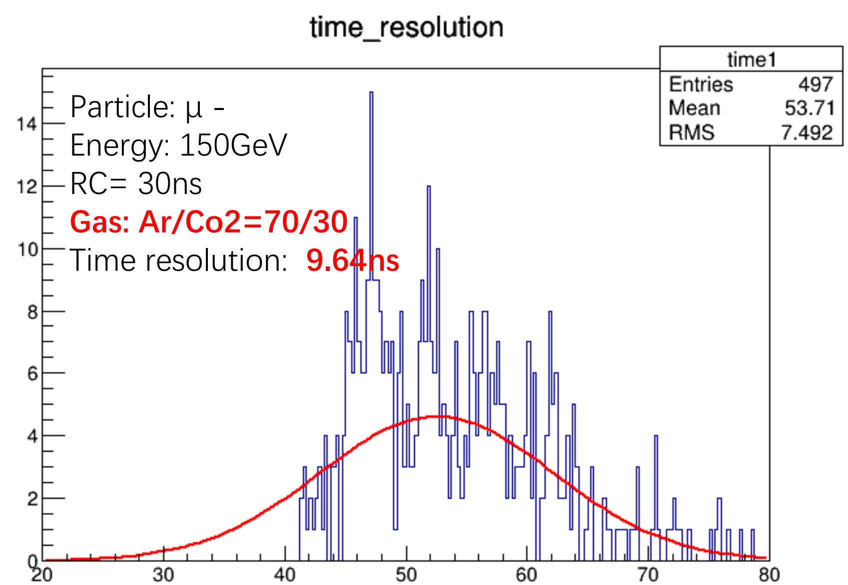
Forming time affect time resolution more than spatial

µRWell Result from different gas composition



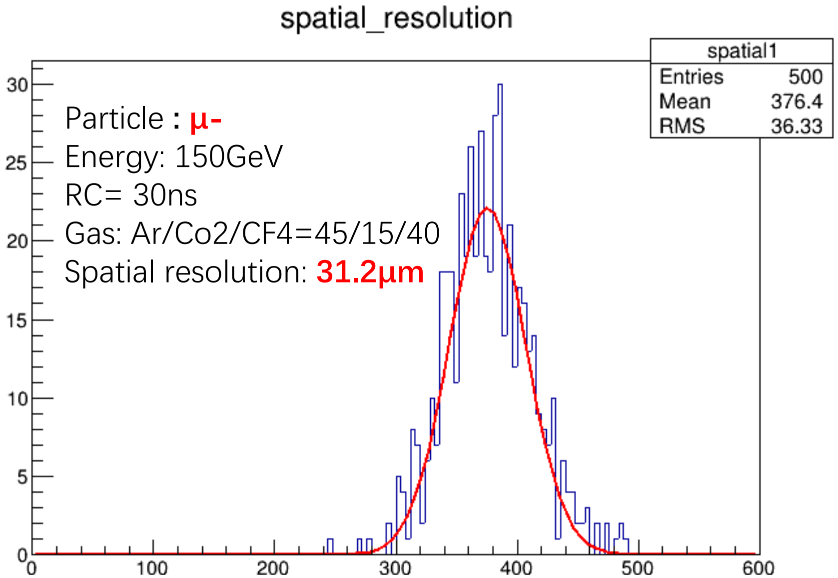


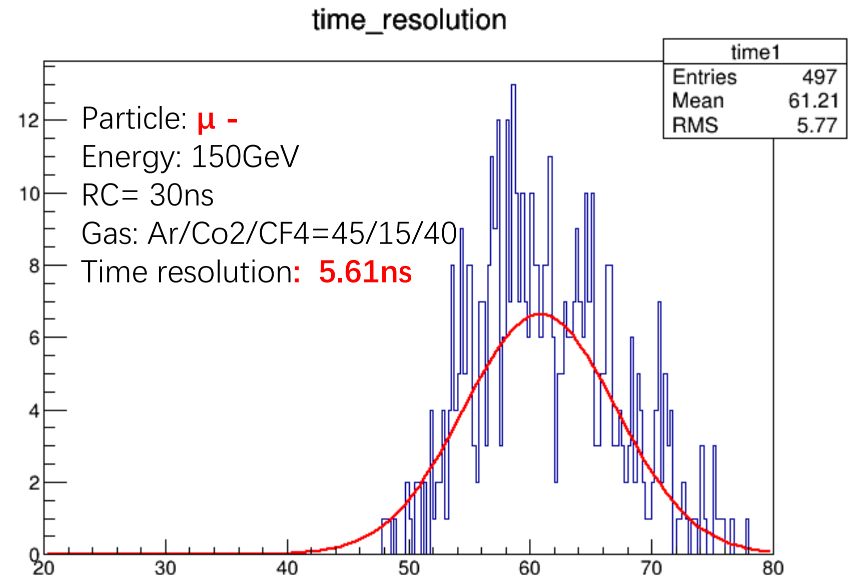


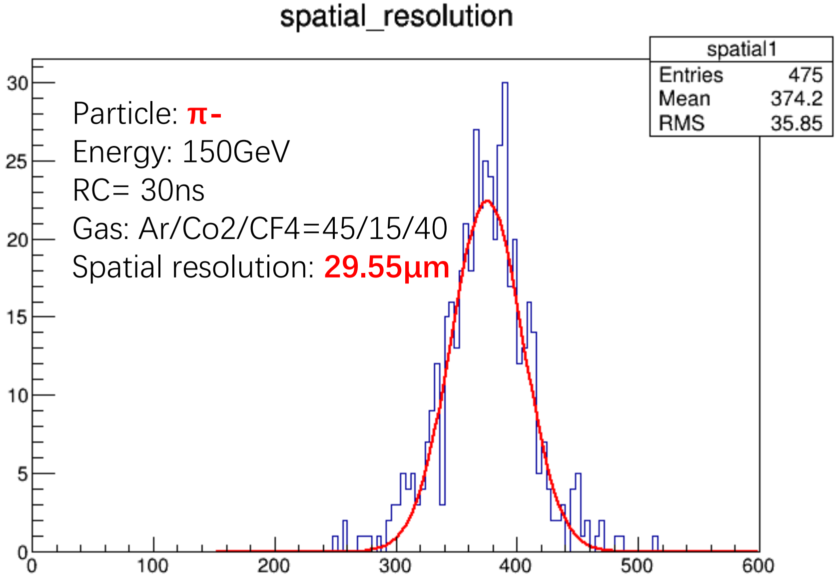


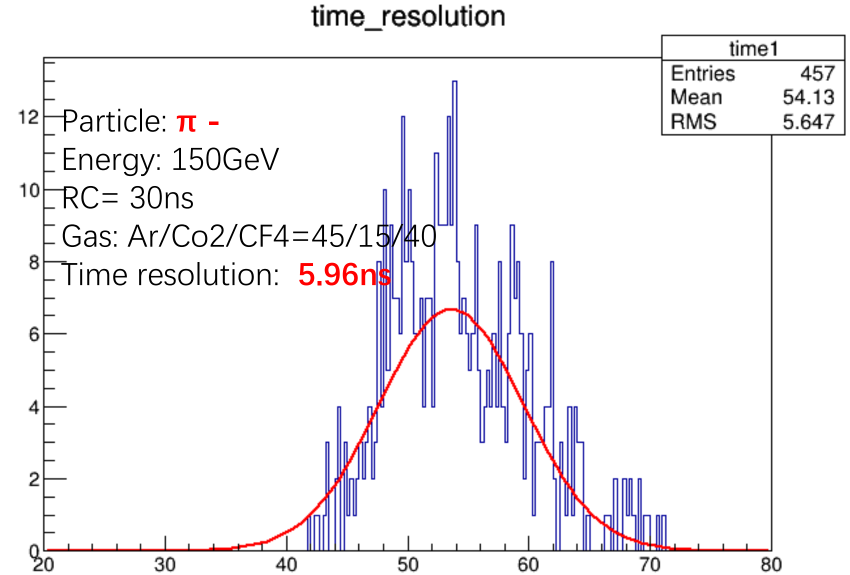
Gas mixture without CF4 makes both time and spatial resolution worse !

μRWell Result from different incident particles



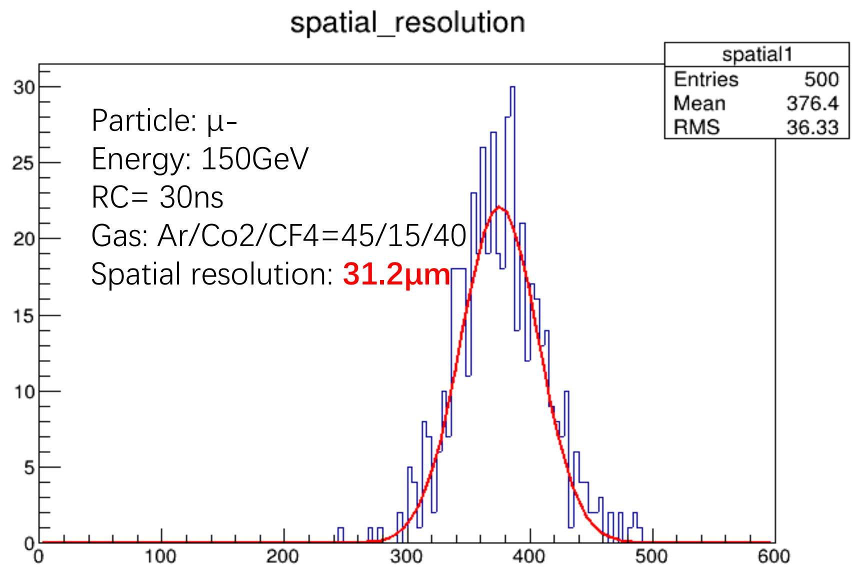


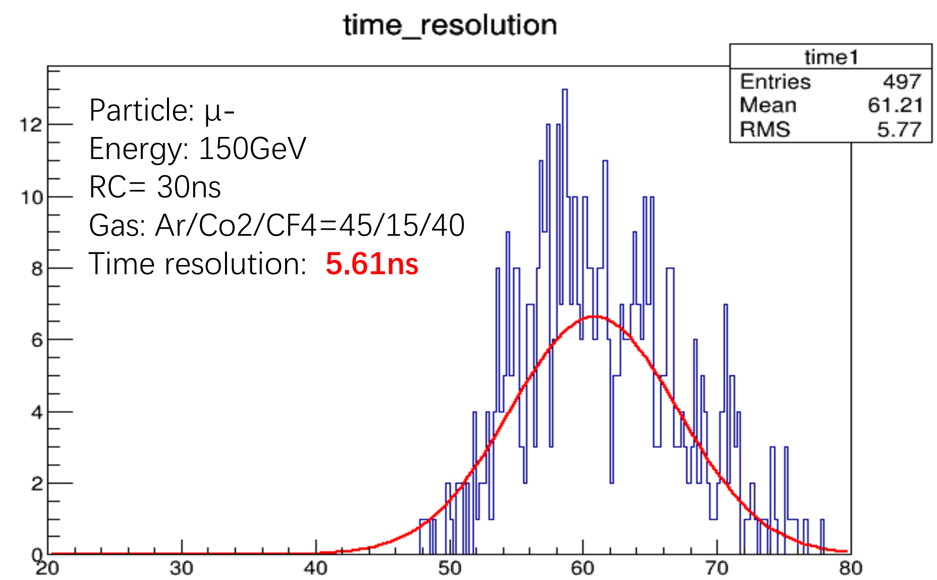


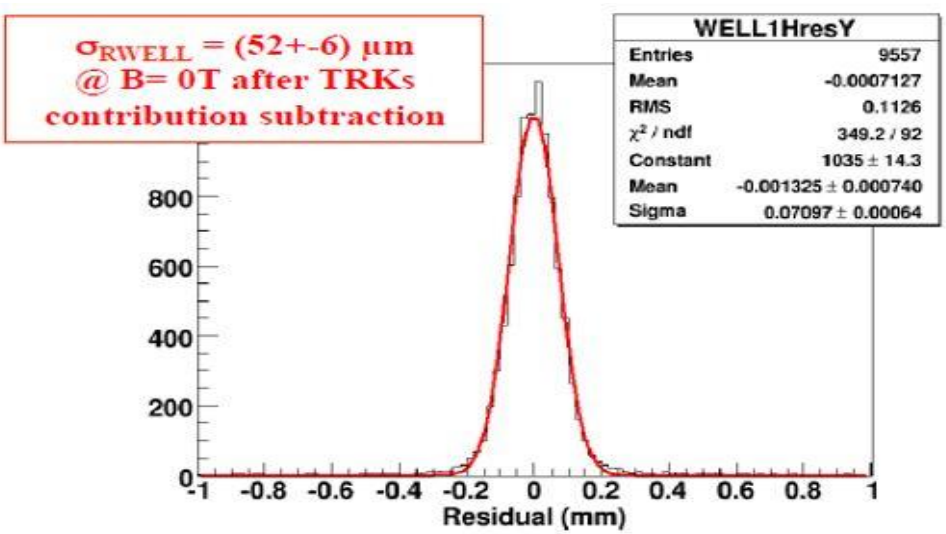


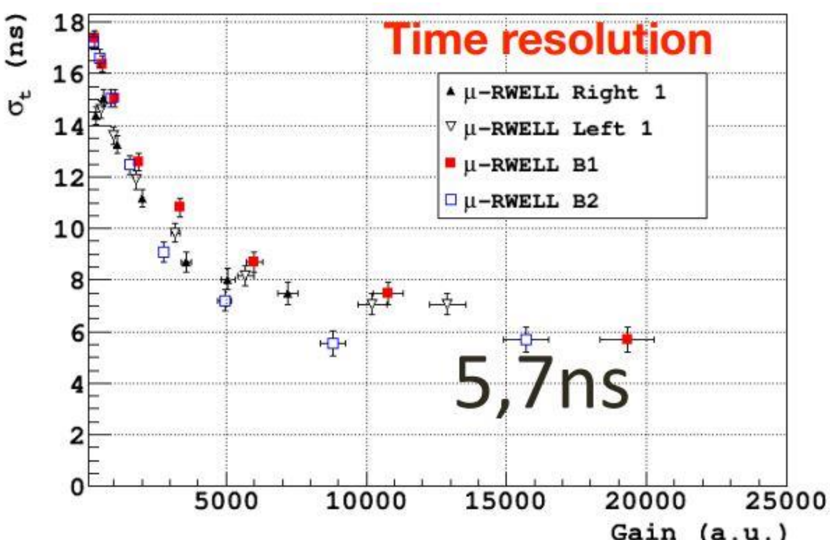
There is no much difference for different incident particles.

μRWell Result: compare with beam test









https://indico.mitp.uni-mainz.de/event/84/session/3/contribution/26/material/slides/0.pdf

Match quite well with each other !

Summary and Outlook

- We have carried out simulation study of different MPGD techniques for CMS muon detector upgrade, including triple-GEM,FTM and μRWell techniques.
- For each type of MPGD techniques, the simulation results are consistent with the experimental beam test results, in terms of time and space resolutions etc.
- Still some differences between MC and experimental results need to be studied and understood.
- More studies can been performed to understand how the working condition (detector structure, gas composition, number of layers, HV, forming time etc.) affect the performance of the detector, which will give references to the choice of the detector technique and the design of the detector.

Thank you !