IDEA muon system based on μ-RWELL technology
2025 Planning: Detector, FEE, Simulation, TB

Riccardo Farinelli
on behalf of INFN – FCC group

FCC Papers & EOI documents

FCC-PED-Final-Report-Detector-Concepts-branch completed

(Paper on all technology suitable for FCC)

Future Circular Collider

Physics and Experiments

I N W O R K

7 July 2024

Contents

Muon System

Several technologies are under consideration for use in detector muon systems at the FCC-ee, including μ-RWELL, resistive plate chambers, resistive Micromegas, scintillators, drift tubes and combinations thereof. Apart from muon identification, these systems can offer capabilities for tail catching of calorimeter showers, identification of long-lived particles by providing tracking with good position resolution, or independent triggers.

[Original contribution by: M. Poli Lener]

The IDEA muon system baseline foresees three layers of μ-RWELL detectors for both barrel and endcap regions, housed within the iron yoke that closes the solenoidal magnetic field. In order to benefit from industrial production capabilities of this technology, a modular design has been adopted with basic μ-RWELL "tiles" with an active area of 50×50 cm^2, and a readout strip pitch of about 1 mm, enabling sufficient spatial resolution of about 400 μm while limiting the number of readout channels to 1000 per tile. The choices of detector tile size, strip pitch and width is a compromise between the largest μ-RWELL detector that can be industrially mass-produced and the maximum input detector capacitance that can be tolerated in terms of signal over noise ratio by the front-end electronics.

Table 3 lists the dimensions, the number of basic μ-RWELL tiles and the readout channels of the three muon stations of the IDEA detector. In total, including the barrel and the end-cap muon stations, the system comprises about 5800 μ-RWELL tiles with about 6 million readout channels.

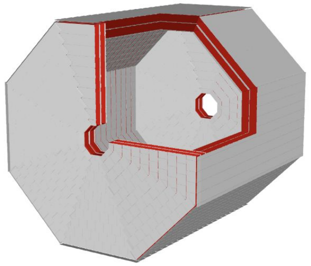


Fig. 26: The IDEA muon detection system generated by DD4hep and visualized using ROOT.

The geometries and material of both barrel and end-cap have been implemented in the Geant4 full simulation for the muon system (see Fig. 26), and the implementation of algorithms for digitisation and clustering will follow. Since the μ-RWELL technology has not yet been used to build a full detector system, a vigorous R&D program to study integration issues will be carried out in the coming years. The detailed layout of the detector, together with all its services, will have to be accurately developed. The optimization of the basic μ-RWELL tile, including gas gap, DLC resistivity and gas amplification has started [34, 35] and is expected to be finalised to match the requirements of the IDEA muon system

Table 3: Dimensions of the three IDEA barrel muon stations, together with the number of detector tiles and the corresponding number of readout channels.

Station	Radius [m]	Length [m]	Strip Pitch [mm]	Strip Length [mm]	Area [m^2]	# of tiles	Channels
1	4.52	9.0	1	500	260	1040	1040000
2	4.88	9.0	1	500	280	1120	1120000
3	5.24	10.52	1	500	350	1400	1400000

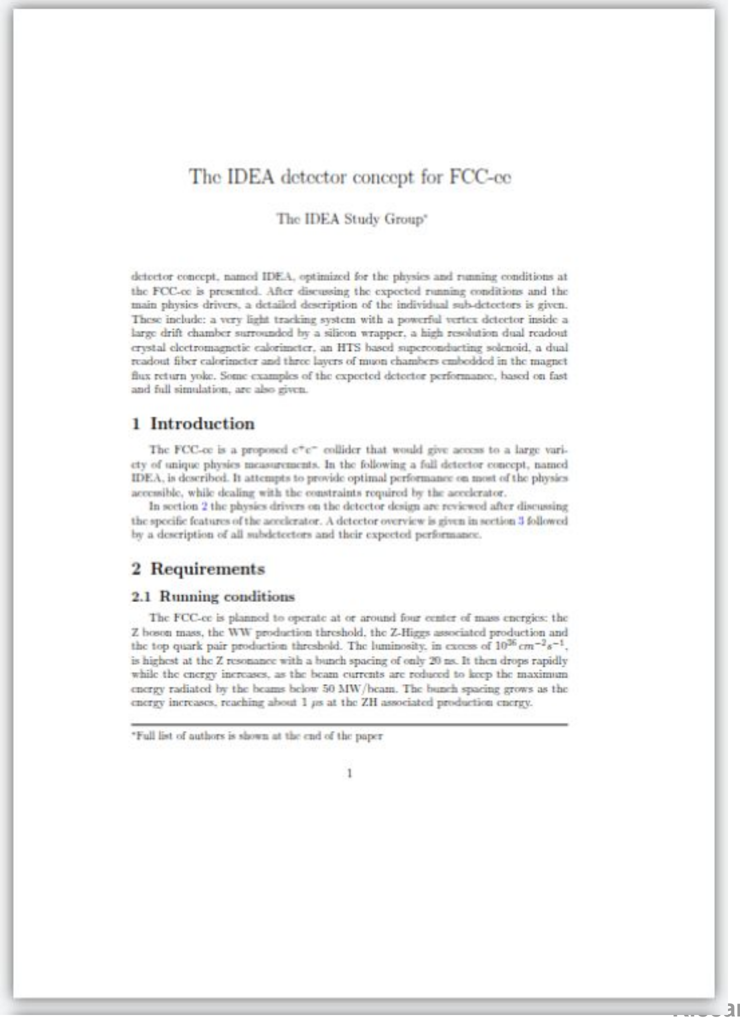
by 2027. R&D on the μ-RWELL is performed in synergy with WP1 of DRD1 [36]. Another important aspect of the R&D program will be the design and development of dedicated front-end electronics based on a custom-made ASIC.

1 page for the Muon apparatus

FCC Papers & EOI documents

IDEA_Detector_EUupdate2026 □ completed

Paper of IDEA in FCC


The IDEA detector concept for FCC-ee

The IDEA Study Group*

detector concept, named IDEA, optimized for the physics and running conditions at the FCC-ee is presented. After discussing the expected running conditions and the main physics drivers, a detailed description of the individual sub-detectors is given. These include: a very light tracking system with a powerful vertex detector inside a large drift chamber surrounded by a silicon wrapper, a high resolution dual readout crystal electromagnetic calorimeter, an HTS based superconducting solenoid, a dual readout fiber calorimeter and three layers of muon chambers embedded in the magnet flux return yoke. Some examples of the expected detector performance, based on fast and full simulation, are also given.

1 Introduction

The FCC-ee is a proposed e^+e^- collider that would give access to a large variety of unique physics measurements. In the following a full detector concept, named IDEA, is described. It attempts to provide optimal performance on most of the physics accessible, while dealing with the constraints required by the accelerator.

In section 2 the physics drivers on the detector design are reviewed after discussing the specific features of the accelerator. A detector overview is given in section 3 followed by a description of all subdetectors and their expected performance.

2 Requirements

2.1 Running conditions

The FCC-ee is planned to operate at or around four center of mass energies: the Z boson mass, the WW production threshold, the Z-Higgs associated production and the top quark pair production threshold. The luminosity, in excess of $10^{36}\ cm^{-2}s^{-1}$, is highest at the Z resonance with a bunch spacing of only 20 ns. It then drops rapidly while the energy increases, as the beam currents are reduced to keep the maximum energy radiated by the beams below 50 MW/beam. The bunch spacing grows as the energy increases, reaching about 1 μs at the ZH associated production energy.

*Full list of authors is shown at the end of the paper

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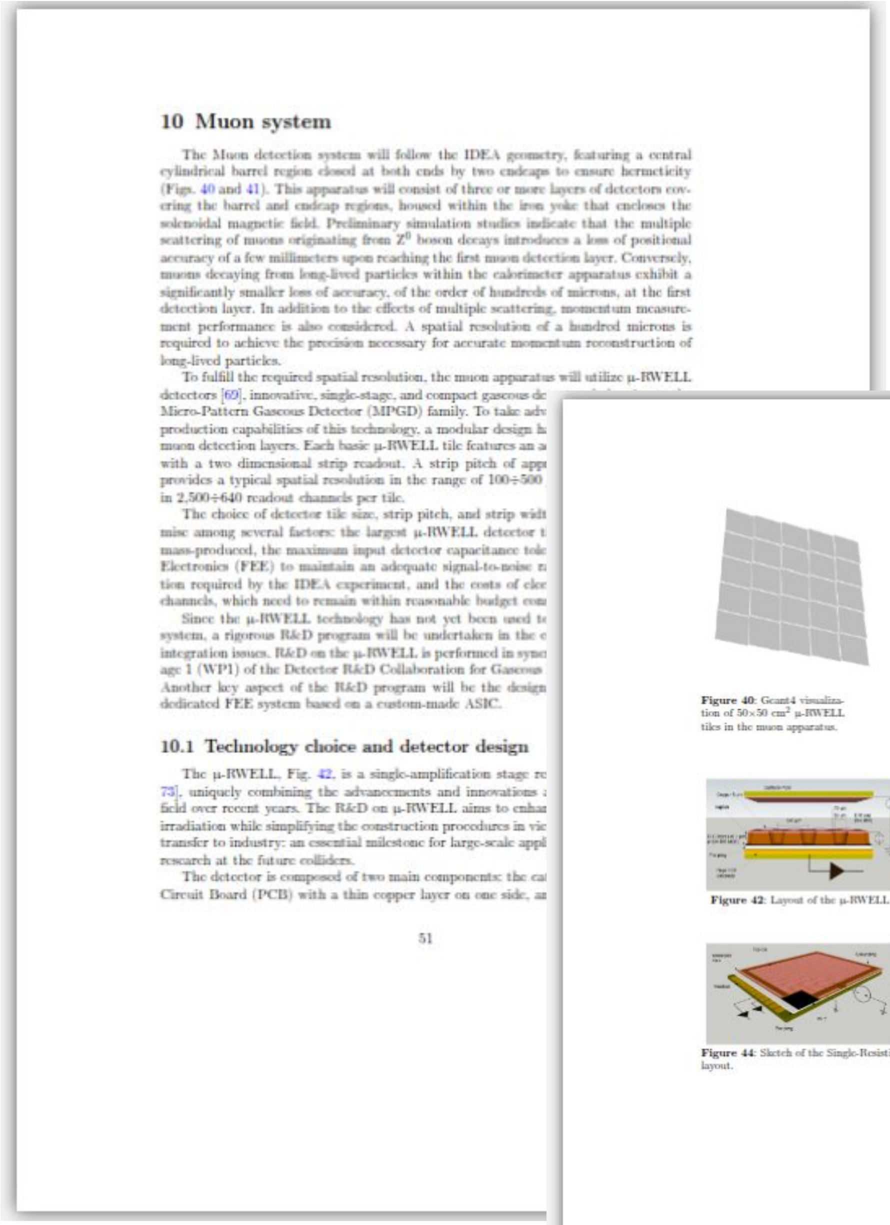
10 Muon system

The Muon detection system will follow the IDEA geometry, featuring a central cylindrical barrel region closed at both ends by two endcaps to ensure hermeticity (Figs. 40 and 41). This apparatus will consist of three or more layers of detectors covering the barrel and endcap regions, housed within the iron yoke that encloses the solenoidal magnetic field. Preliminary simulation studies indicate that the multiple scattering of muons originating from Z^0 boson decays introduces a loss of positional accuracy of a few millimeters upon reaching the first muon detection layer. Conversely, muons decaying from long-lived particles within the calorimeter apparatus exhibit a significantly smaller loss of accuracy, of the order of hundreds of microns, at the first detection layer. In addition to the effects of multiple scattering, momentum measurement performance is also considered. A spatial resolution of a hundred microns is required to achieve the precision necessary for accurate momentum reconstruction of long-lived particles.

To fulfill the required spatial resolution, the muon apparatus will utilize μ-RWELL detectors [69], innovative, single-stage, and compact gaseous de…
Micro-Pattern Gaseous Detector (MPGD) family. To take adv…
production capabilities of this technology, a modular design h…
muon detection layers. Each basic μ-RWELL tile features an a…
with a two dimensional strip readout. A strip pitch of appr…
provides a typical spatial resolution in the range of 100÷500…
in 2,500÷640 readout channels per tile.

The choice of detector tile size, strip pitch, and strip widt…
mise among several factors: the largest μ-RWELL detector t…
mass-produced, the maximum input detector capacitance tole…
Electronics (FEE) to maintain an adequate signal-to-noise r…
tion required by the IDEA experiment, and the costs of elec…
channels, which need to remain within reasonable budget con…

Since the μ-RWELL technology has not yet been used to…
system, a rigorous R&D program will be undertaken in the c…
integration issues. R&D on the μ-RWELL is performed in sync…
age 1 (WP1) of the Detector R&D Collaboration for Gaseous…
Another key aspect of the R&D program will be the design…
dedicated FEE system based on a custom-made ASIC.

10.1 Technology choice and detector design

The μ-RWELL, Fig. 42, is a single-amplification stage re…
73], uniquely combining the advancements and innovations…
field over recent years. The R&D on μ-RWELL aims to enhan…
irradiation while simplifying the construction procedures in vie…
transfer to industry: an essential milestone for large-scale appl…
research at the future colliders.

The detector is composed of two main components: the ca…
Circuit Board (PCB) with a thin copper layer on one side, an…

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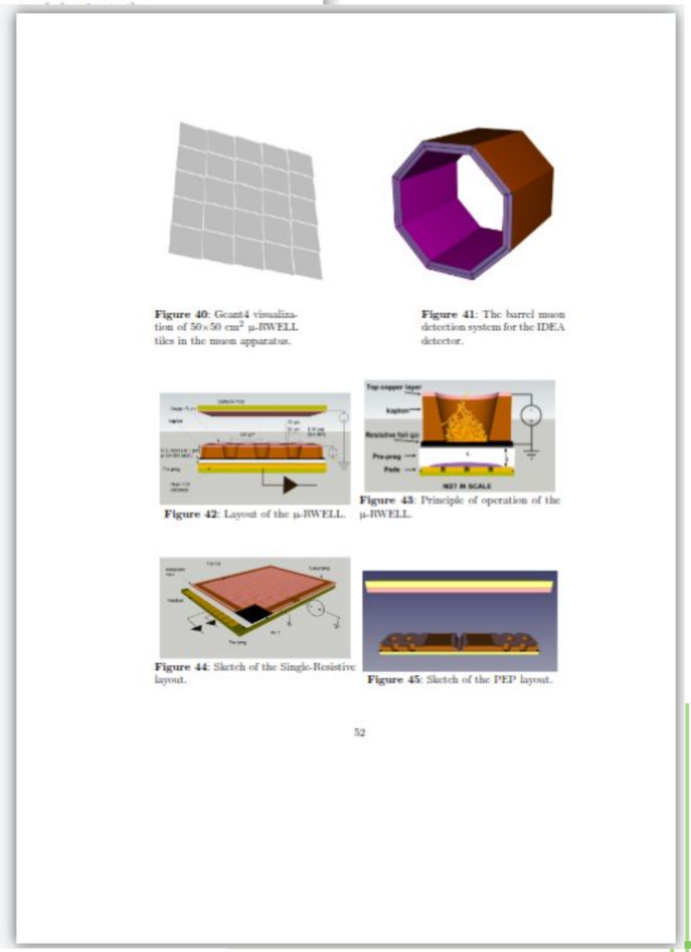

Figure 40: Geant4 visualization of 50×50 cm² μ-RWELL tiles in the muon apparatus.

Figure 41: The barrel muon detection system for the IDEA detector.

Figure 42: Layout of the μ-RWELL.

Figure 43: Principle of operation of the μ-RWELL.

Figure 44: Sketch of the Single-Resistive layout.

Figure 45: Sketch of the PEP layout.

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FCC Papers & EOI documents

<ID 0076> Development of micro-RWELL technology for the Muon system

Contact Persons:

- Marco Poli Lener, marco.polilener@lnf.infn.it
- Riccardo Farinelli, riccardo.farinelli@bo.infn.it

Collaborating Institutes & expertise/facilities:

- Laboratori Nazionali di Frascati
  - Expertise in detector design, construction and testing
  - Facility: Large cleanroom class 100 with granite tables, electronics & mechanics workshop, Detector Lab with X-ray guns, Bema Test Facility (BTF) line
- INFN Sez. Torino and Ferrara
  - Expertise on electronics development and integration
  - Facility: Cleanroom,electronics & mechanics workshop, Detector Lab.
- INFN Sez. Bologna
  - Expertise in simulation and validation of detector performance using GARFIELD++ and analysis data
  - Facility: Cleanroom,electronics & mechanics workshop, Detector Lab.

Connections with DRDs:

- DRD1, WP1: development of novel detector architectures for future collider experiments,
- DRD1, WP8: knowledge-sharing and testing campaigns in collaboration with DRD1 partner institutions

Connections with Concept Groups:

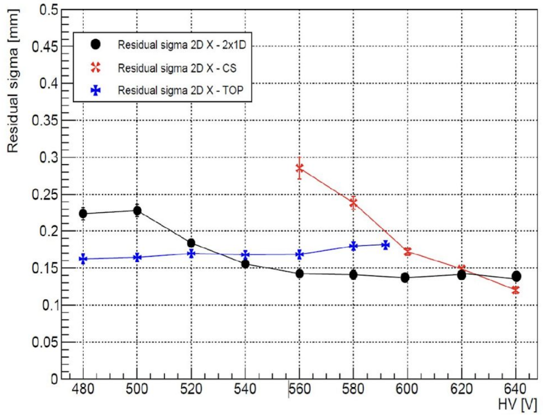
- Engineering/Simulation studies with concept IDEA

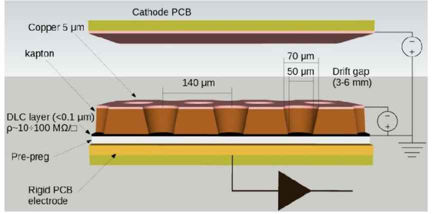
2 slides presented @ 8th FCC Physics Workshop – 17 January 2025
https://indico.cern.ch/event/1439509/timetable/#b-597055-satellite-meeting-pre

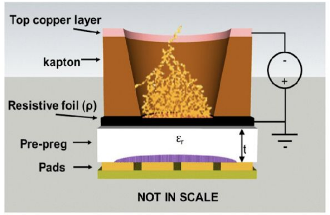
<ID 0076> Development of micro-RWELL technology for the Muon system

Planned activities for the next 3-5 years

- 2025: 1. Optimization of Detector Performance
  2. Simulation Detector performance
- 2026: 1. Characterization and Beam Tests
  2. Validation of the simulation with experimental data
  3. Design of new front-end electronics
- 2027-29: 1. Development of Modular and Scalable Designs
  2. Production of the front-end electronics
  3. Electronics Integration and Readout Optimization







References: [1]: G. Bencivenni et al., The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD, 2015 JINST 10 P02008

FCC Papers & EOI documents

The EOI (2 pages) is sent to FCC organization

Expression of Interest (EOI)
R&D Program on the μ-RWELL Detector Technology for future Muon Apparatus at FCC

Introduction

The μ-RWELL (micro-Resistive WELL) is a promising Micro-Pattern Gaseous Detector (MPGD) technology that combines construction simplicity, operational robustness, and excellent performance, making it ideal for large-scale applications in particle physics experiments. This document outlines the R&D program for μ-RWELL technology over the next 3-5 years, the institutions involved, and the connections to ongoing research activities, including those within the DRD1 collaboration framework at CERN.

R&D Program Goals

Over the next 3-5 years, the R&D program will focus on the following objectives:

1. **Optimization of Detector Performance:**
    - Enhance operational stability at low-medium particle fluxes (<100 kHz/cm2).
    - Validate the detector performance in terms of spatial resolution and long-term stability under irradiation.
2. **Characterization and Beam Tests:**
    - Characterize the detectors in the laboratory to assess the detector gas gain and the rate capability.
    - Carry out beam tests to study the detector response under realistic operational conditions and validate their performance in high-energy physics environments.
3. **Development of Modular and Scalable Designs:**
    - Design modular prototypes for large-scale applications.
    - Integrate cost-effective manufacturing solutions for technology transfer to industry.
4. **Electronics Integration and Readout Optimization:**
    - Develop custom front-end electronics, including ASICs optimized for μ-RWELL, in collaboration with specialized electronics teams.
    - Test and integrate custom front-end electronics, based on TIGER, FATIC, or TORA front-end, with μ-RWELL detectors for enhanced signal processing.
5. **Simulation and Validation:**
    - Use the GARFIELD++ simulation framework to model and optimize the detector's response to different experimental conditions.
    - Compare simulation results with experimental data to refine detector designs.

Collaborating Institutions and Key Contacts

The R&D program will be carried out by an international team of researchers from the following institutions:

- **Laboratori Nazionali di Frascati:** Expertise in detector design, construction and testing.
- **INFN Sez. Torino, Ferrara:** Expertise in electronics development and integration.
- **INFN Sez. Bologna:** Expertise in simulation and validation of detector performance using GARFIELD++ and analysis data.

The primary contacts for this program are:

- **Dr. Marco Poli Lener, Laboratori Nazionali di Frascati** (Project Lead)
    - Email: marco.polilener@lnf.infn.it
- **Dr. Riccardo Farinelli, INFN Sez. Bologna** (Electronics and Analysis Development Lead)
    - Email: riccardo.farinelli@bo.infn.it

Connections to DRD1 Collaboration at CERN

The μ-RWELL R&D aligns closely with the DRD1 framework at CERN (WP 1), which focuses on advanced MPGD technologies. Our program will contribute to:

- The development of novel detector architectures for future collider experiments.
- Knowledge-sharing and testing campaigns in collaboration with DRD1 partner institutions.

Synergies with GARFIELD++ Simulations

The GARFIELD++ framework will play a pivotal role in:

- Simulating electron avalanche processes within the μ-RWELL detector.
- Validating the detector spatial response under different experimental scenarios.
- Supporting the design of optimized gas mixtures.

Conclusion

This EOI outlines an ambitious yet achievable roadmap for advancing μ-RWELL technology. Through collaboration with leading institutions and integration into the DRD1 framework, the program aims to establish μ-RWELL as a reliable and scalable solution for muon apparatus at future experiments at future circular collider.

μ-RWELL in IDEA

μ-RWELL for muon apparatus in IDEA

The **IDEA detector** is a general purpose detector designed for experiments at future e^+e^- colliders.
The Muon system are designed to be instrumented with μ-RWELL technology.

Muon requirements:

μ-RWELL pre-shower replace with EC cristalls

Tiles: 50x50 cm² with X-Y readout

Efficiency ≥ 98%

Space resolution

≤ 100 ÷ 400 μm (Muon) → **to reduce the number of FEE**

Particle Flux

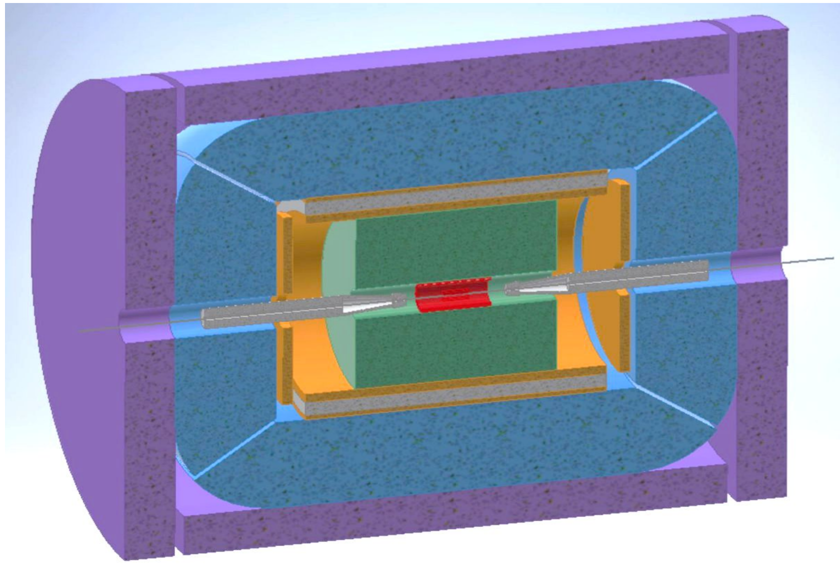
< 1 HZ/cm² (Muon) → **average over the whole solid angle w/out machine background**

Instrumented Surface/FEE:

1500 m², 6000 det., 5×10⁶ ch. (1.2 mm strip pitch)

Mass production → **Technology Transfer to Industry**

FEE Cost reduction → **custom made ASIC (TIGER, TORA,…..)**

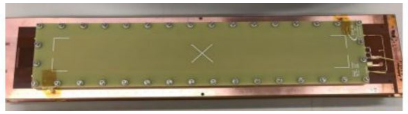


Muon system
Reconstruct and tag the muon with 3 - 4 layers in between the iron return yoke and reconstruct LLP

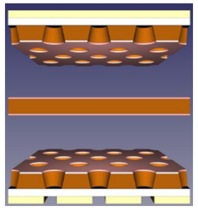
Italian Institute involved: Laboratori Nazionali di Frascati, Bologna, Ferrara, Torino

History of μ-RWELL R&D for IDEA

1D Layout optimization

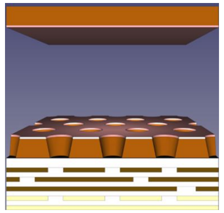


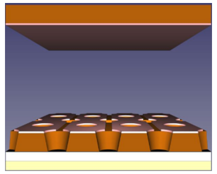
2D layouts optimization



2x1D layout

Capacitive Sharing layout



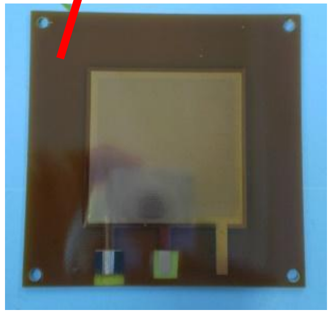


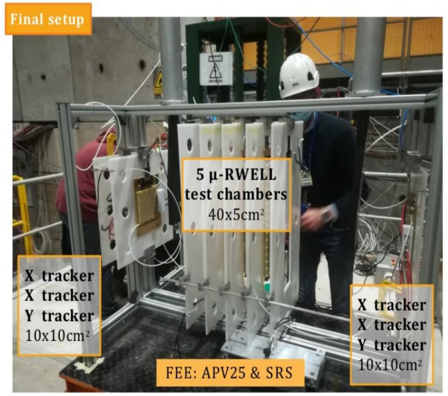
TOP layout

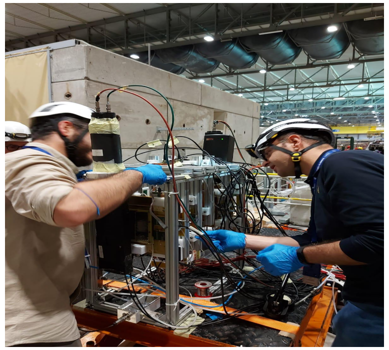
New u-RWELL ideas (in collaboration with RD51)

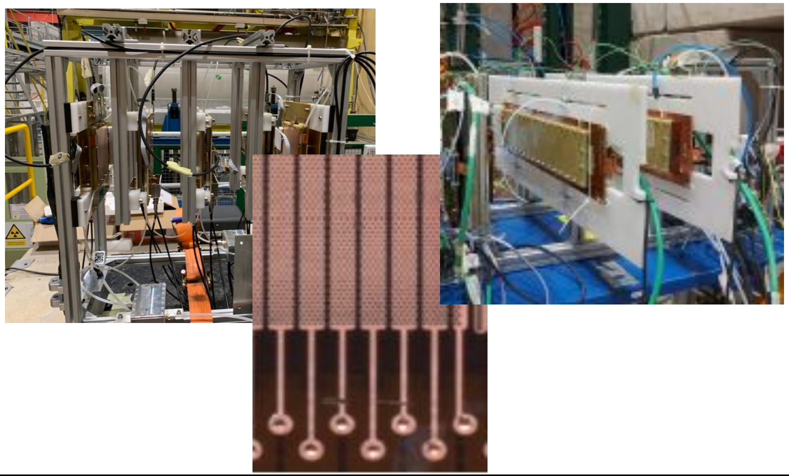
R&D for FCC start

2009 · 2020 · 2021 · 2022 · 2023 · 2024









electronics optimization

IDEA slice test: DC + pre-shower + dual_calo + muon

Research lines for μ-RWELL in IDEA

μ-RWELL technology

- Baseline design with reliable performance (2x1D)
- Large area R&D to validate design and performance
- New μ-RWELL design under evaluation to improve the performance and define cutting-edge technology for the muon apparatus

Electronics integration

- Evaluation of the performance with existing readout systems
- Minimize the noise in existing readout systems
- Simulate the detector response and study the performance with different configuration of detector/electronics
- Defines the μ-RWELL needs to optimize its integration with the readout system to improve performance
- Extend the acquired know-how to new readout systems

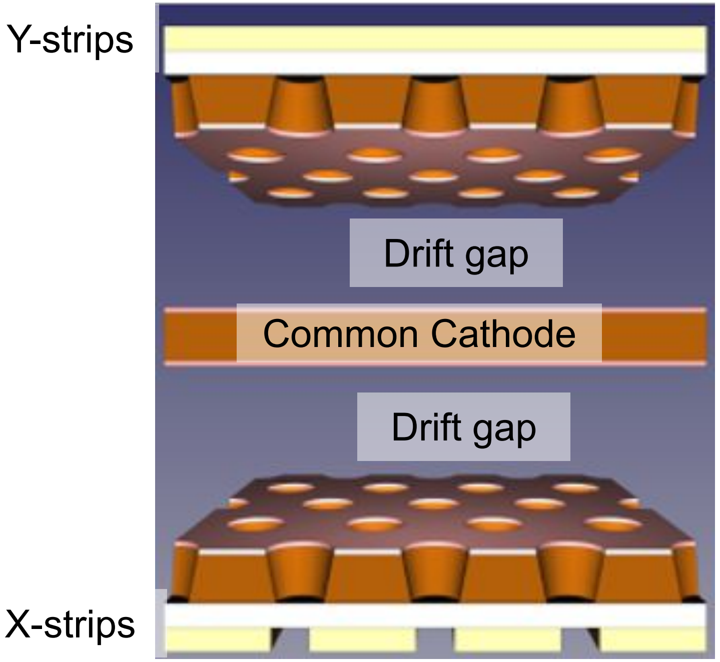
Muon system simulation in IDEA

- Description of the baseline design in IDEA fast and full simulation
- Evaluation of the stand-alone tracking performance for muons
- Suggest possible layout of the muon system and the needed performance

DETECTORS LAYOUT

TB Analysis finalization -2D layouts – 10x10 cm^2

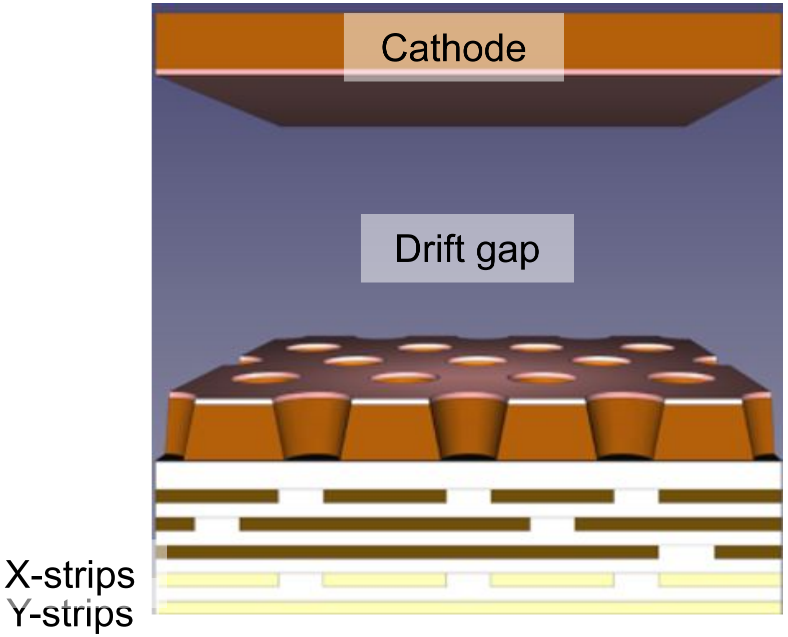
n.2 μ-RWELL 1D [2×1D]



- Lower gas gain w.r.t. the "COMPASS R/O" (X / Y are not sharing any charge)
- Tested @ TB2022

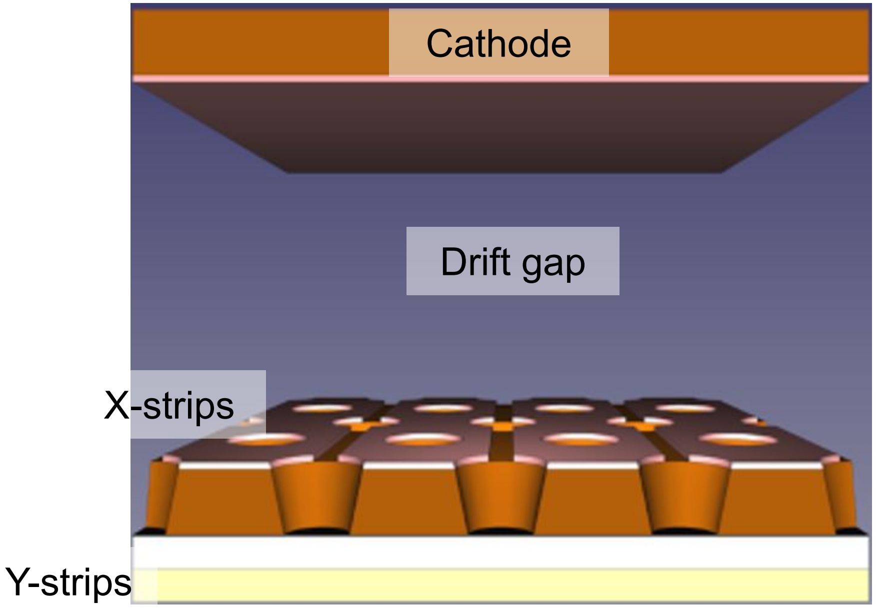
Capacitive Sharing [*]

[*] K. Gnanvo et al., NIM A 1047 (2023) 167782



- Stack of layers of pad
- Reduce the FEE channels
- The charge is divided between X and Y → Higher gas gain required w.r.t. 1D
- Tested @ TB2023

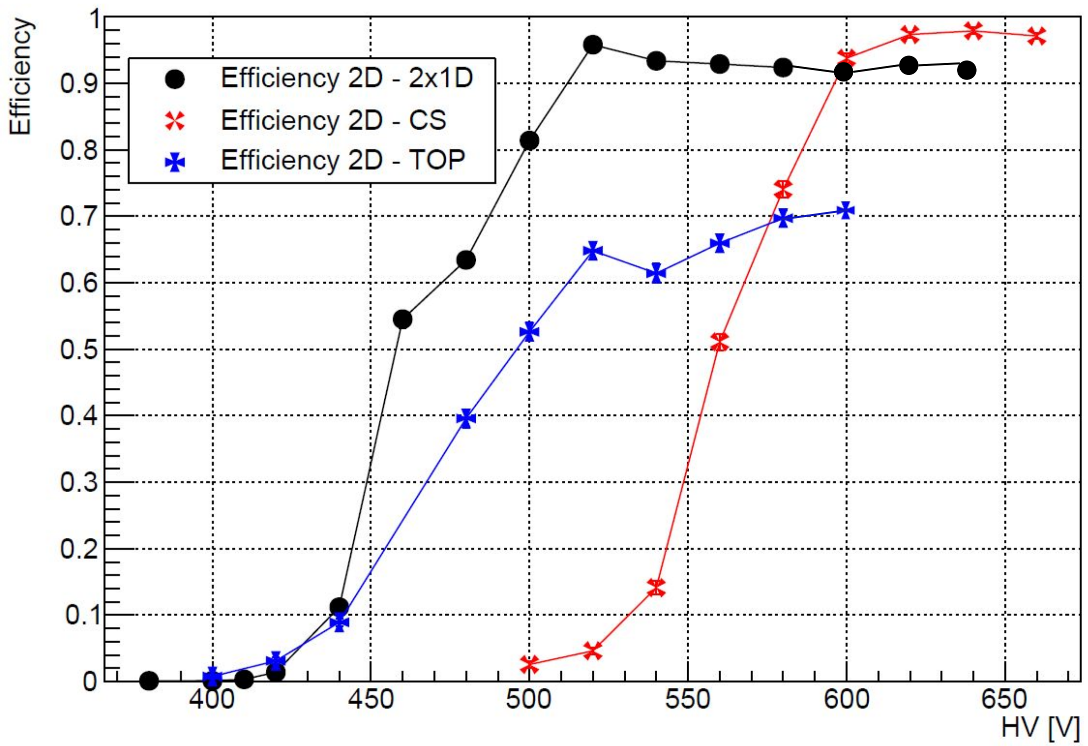
Top R/O



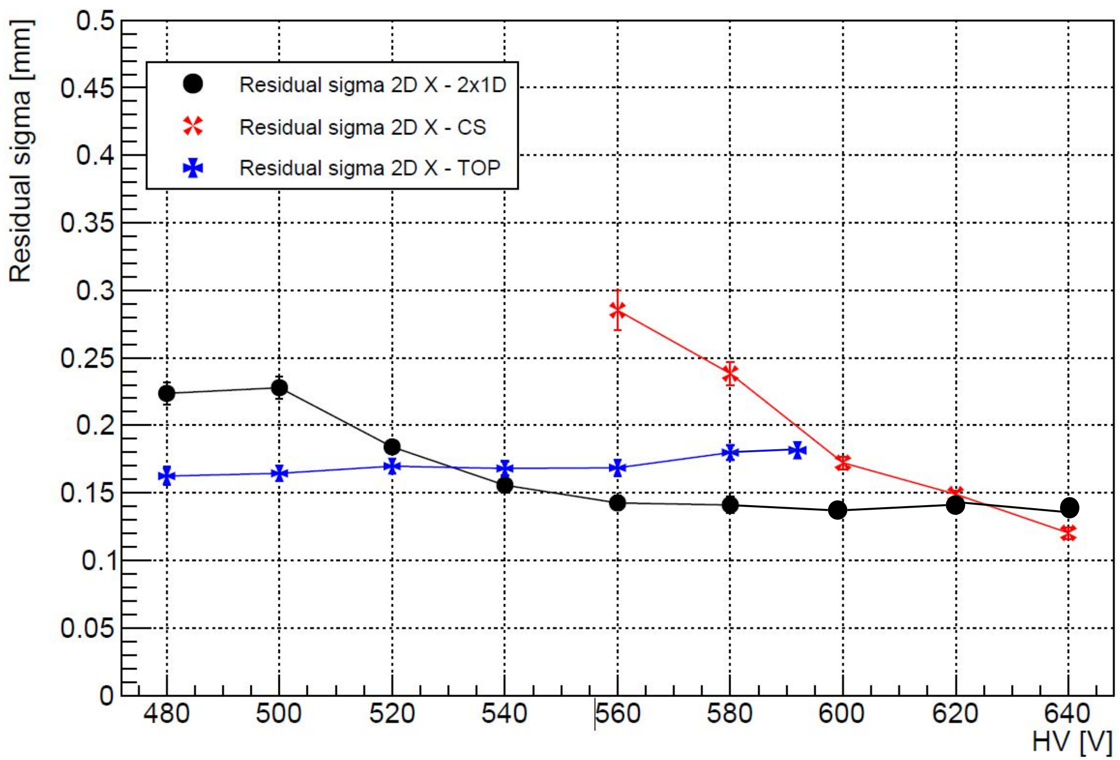
- Lower gas gain w.r.t. the "COMPASS R/O" (X / Y are not sharing any charge)
- The "Top" coordinate introduces dead zone in the active area
- Tested @ TB 2023

TB Analysis finalization -2D layouts @ TB

2D layouts – 10x10 cm^2



2D layouts – 10x10 cm^2



The results of TB-22-23, where the 2D layouts have been compared, gaving the following results:

2x1D layout: spatial resolution < 200um (pitch 0.8 mm), low voltage operating point ~520V, efficiency ≥98% (large eff. plateau)

CS layout: spatial resolution <200um (with pitch 1.2 mm), very high voltage operating point, ≥ 600V, efficiency ≥98%

Top layout: spatial resolution < 200um (pitch 0.8 mm), low voltage operating point ~520V, efficiency ~ 70% (dead-zone)

R&D program 2025

The production of the 2024 layouts has been delayed due to the increased workload at the Rui's workshop

Solution under study to increase detector stability:

1. **μ-RWELL "well optimization"**
   - This study was done with GEM detectors but never with uRWELL well pitch from 140 μm to 90 μm with an increase in gain of about a factor of 2
   - **ARRIVED**

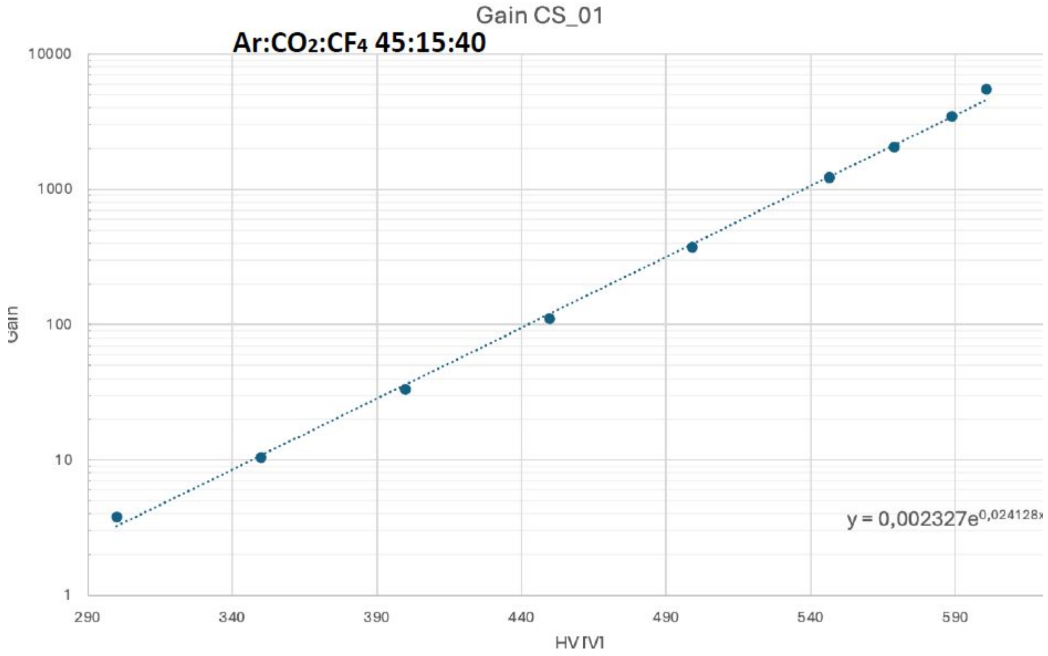
New layouts under study for Muon systems:

1. **(Hybrid) CS μ-RWELL 50X50 CM2**
   - **GEMs PRODUCED IN THE FIRST PART OF 2025**

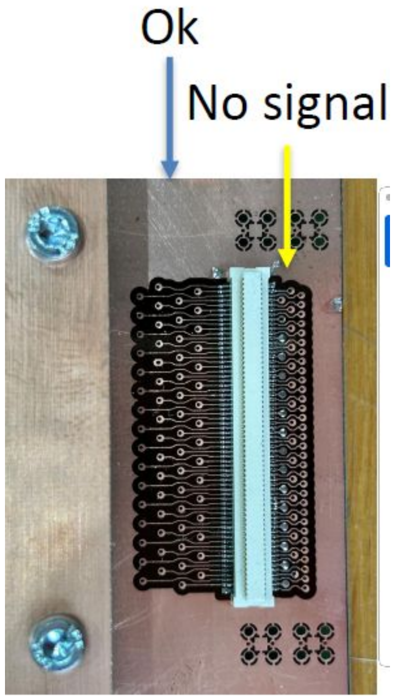
2. **μ-RGroove layout**
   - new layout, where the amplification stage is not based on the **«wells» but on the «grooves».** This facilitates the realization of the strip readout on the top, without introducing dead-zones (introduced by Z. Yi in RD51).
   - **ARRIVED with 2 different layouts (3 OR-STRIPS, 2 OR-STRIPS both with 400 um)**

3. **"GEM + μ-RWELL CS" (strip)**
   - GEM pre-amplification stage, to lower the operating point, greatly improving the RWELL stability and maintaining high spatial performance with millimetric pitches.
   - **GEMs PRODUCED IN THE FIRST PART OF 2025**

CS µ-RWELL layout - 50x50 cm2



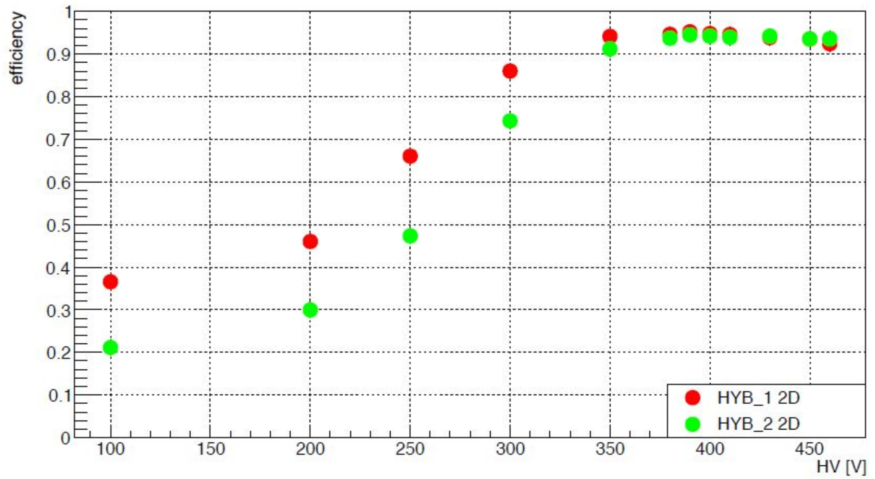
During the test we observed that only the half of the strip are connected to FEE due a problem in the production of the detector send the detector to Rui's workshop to repair

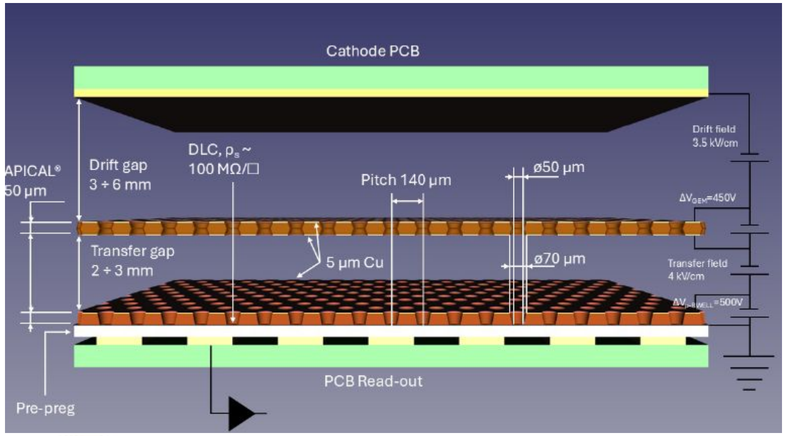


X-Ray characterization

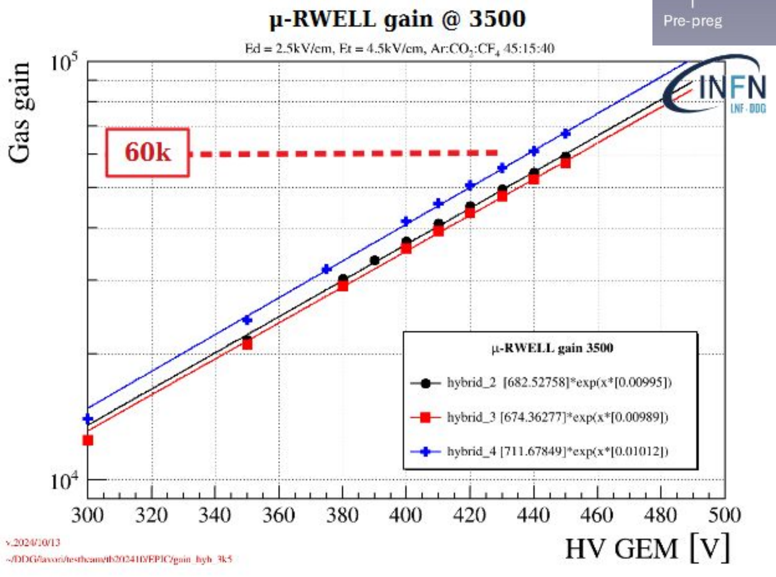
Hybrid µ-RWELL @ preliminary TB

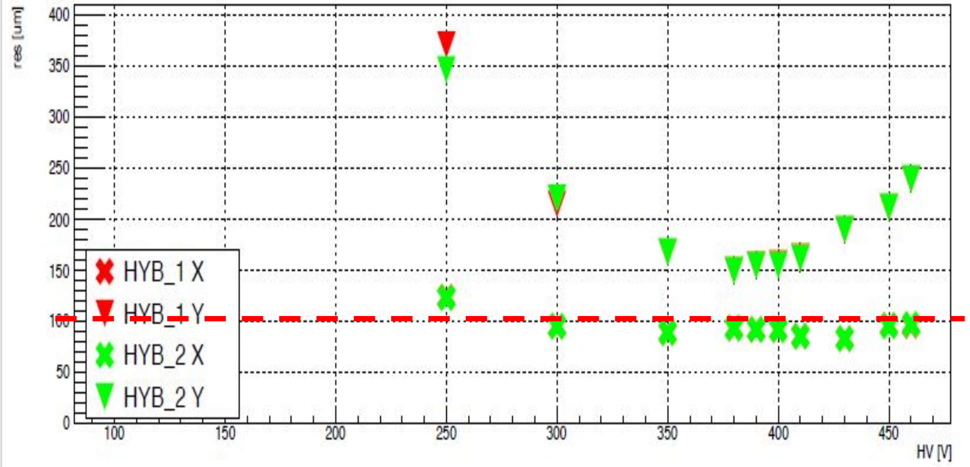
GEM+ μ-RWELL hybrid (G-RWELL) uses a GEM as pre-amplifier and allows to reach gas gain larger than 10^4.





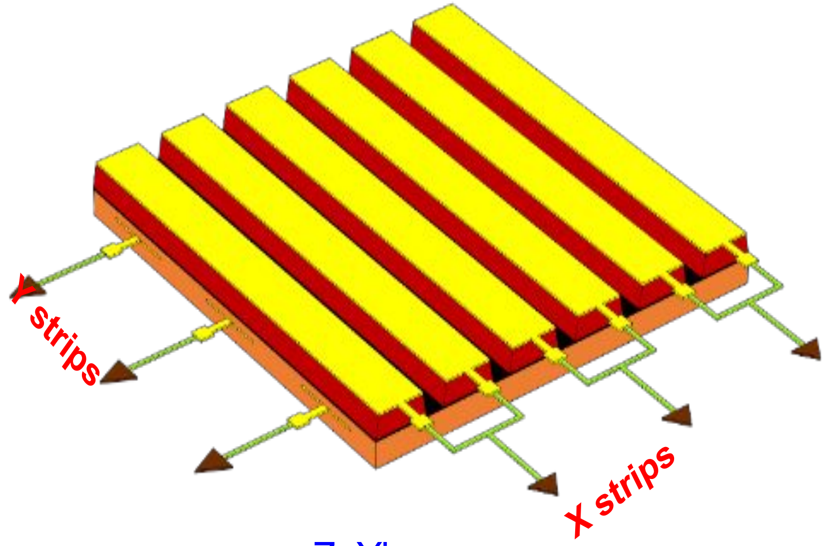
No good sharing between views: wrong strip width ratio



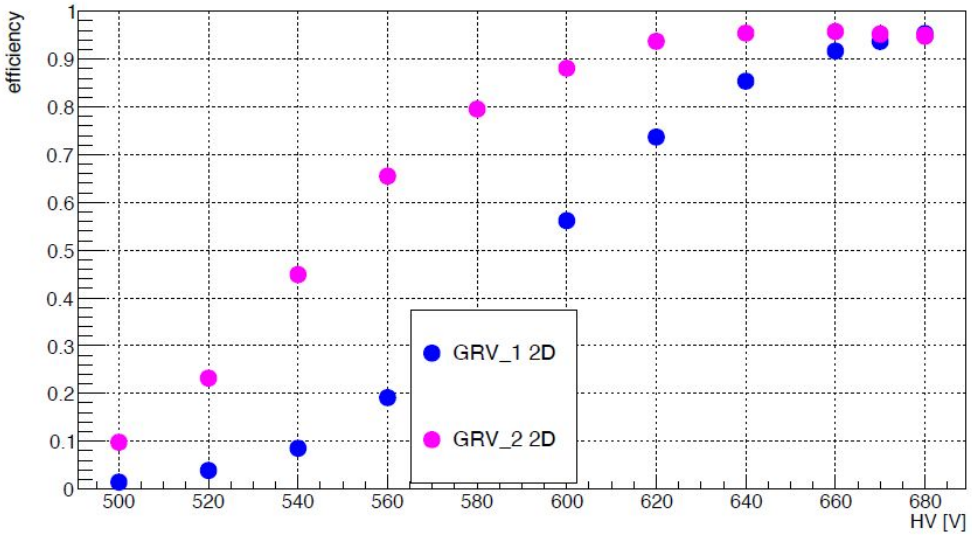


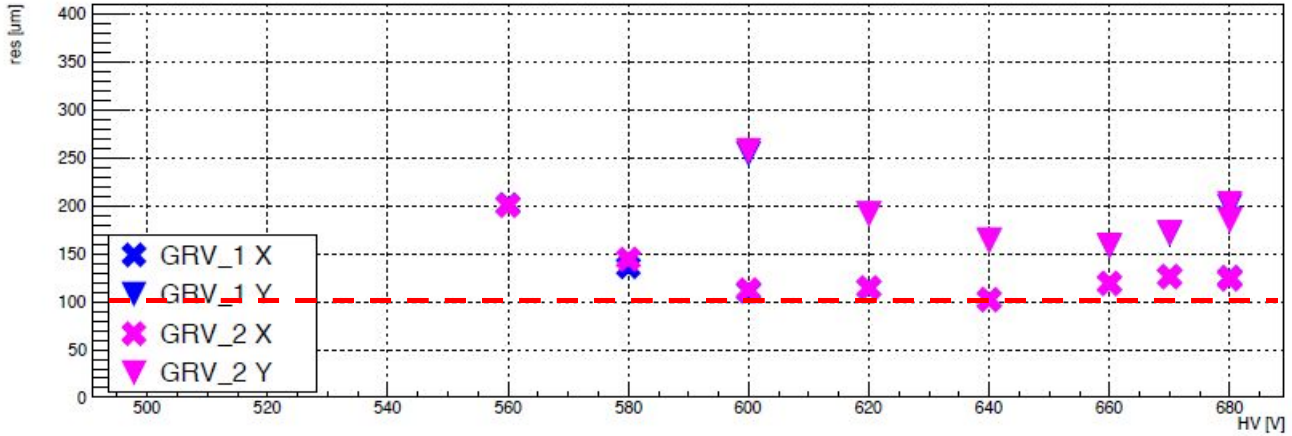
μ-RGroove @ preliminary TB

μ-RGroove is the development of the “TOP” layout without dead-zone and no sharing between X/Y strips



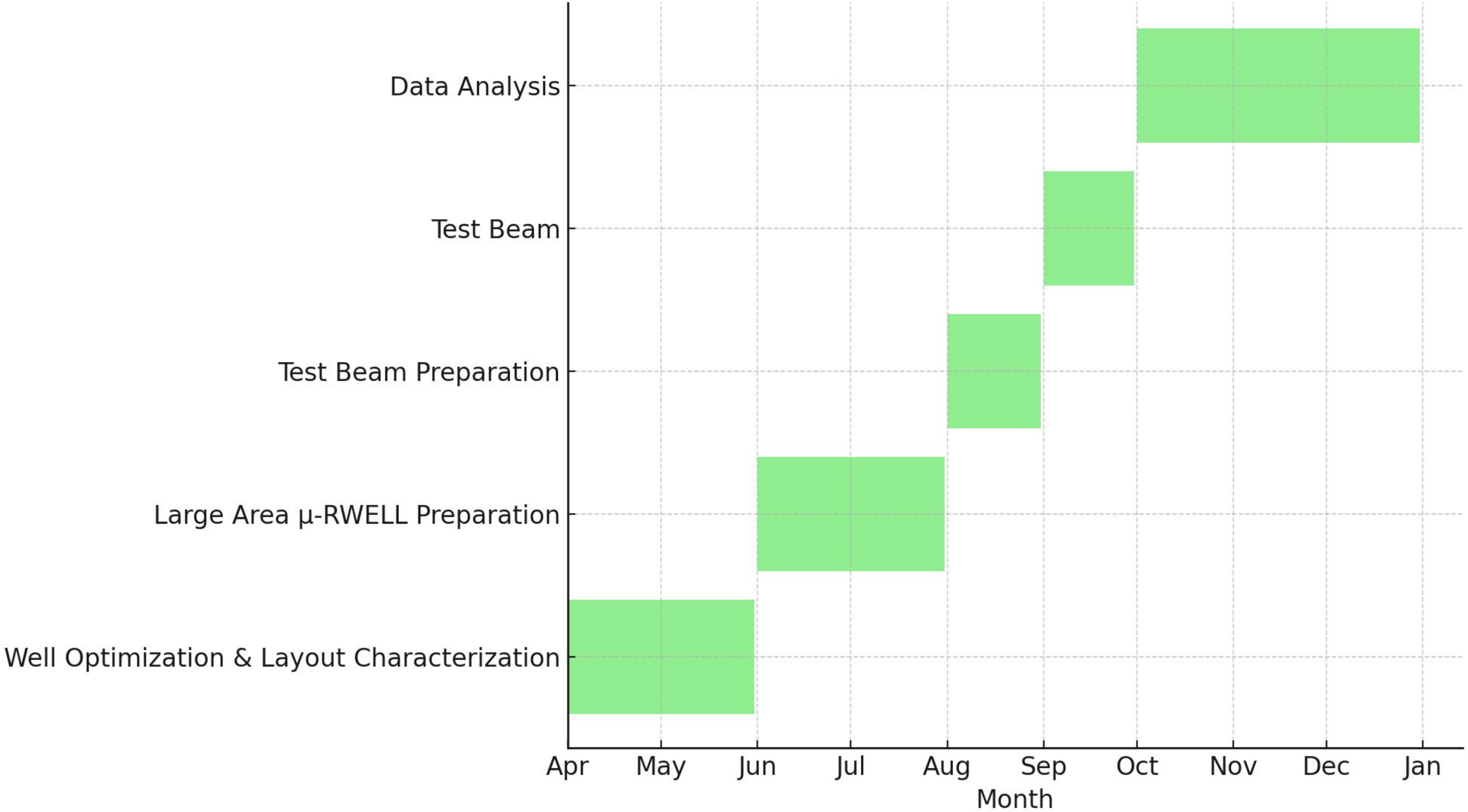
Z. Yi





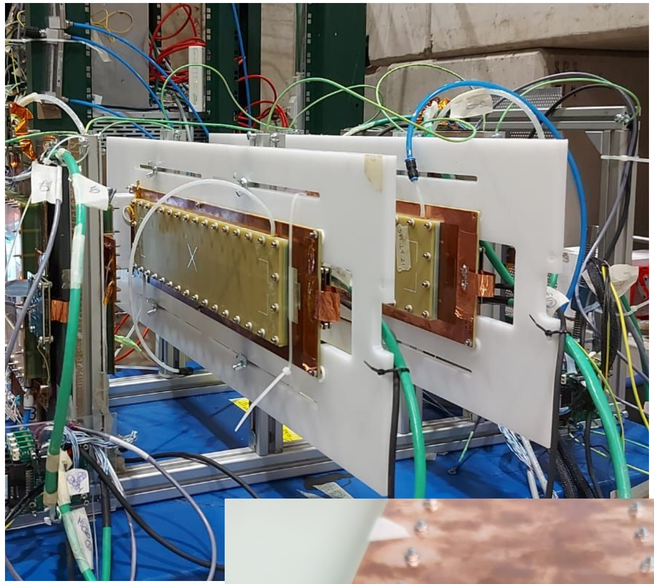
No good sharing between views: wrong strip width ratio

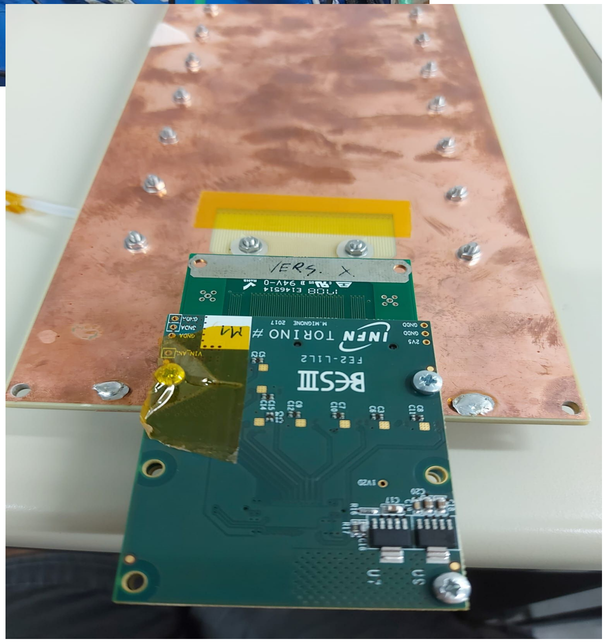
Detector layout plans 2025



FRONT END

Performance with TIGER electronics





Detector under test:
- 4 μRWELL w/ 40 cm strip length
  1D strip pitch of 0.4/0.8/1.2/1.6 mm

Readout under test:
- TIGER FEE (INFN-TO)
- GEMROC FPGA (INFN-FE)

Goals of the testbeam:
- Define the state of art of μRWELL+TIGER for IDEA Muon system optimization studies
- Compare the APV-25 performance studies with TIGER
- Performance in Ar:CO2 and Ar:CO2:CF4 comparison
- Collect data to compare experimental measurement and simulation

Measurements:
- Gain scan to evaluate the amplification/saturation/performance
- Drift scan to evaluate the signal collection
- Threshold scan to optimize S/N

TIGER electronics

• The readout chain consists of **ON-detector** and **OFF-Detector** electronics

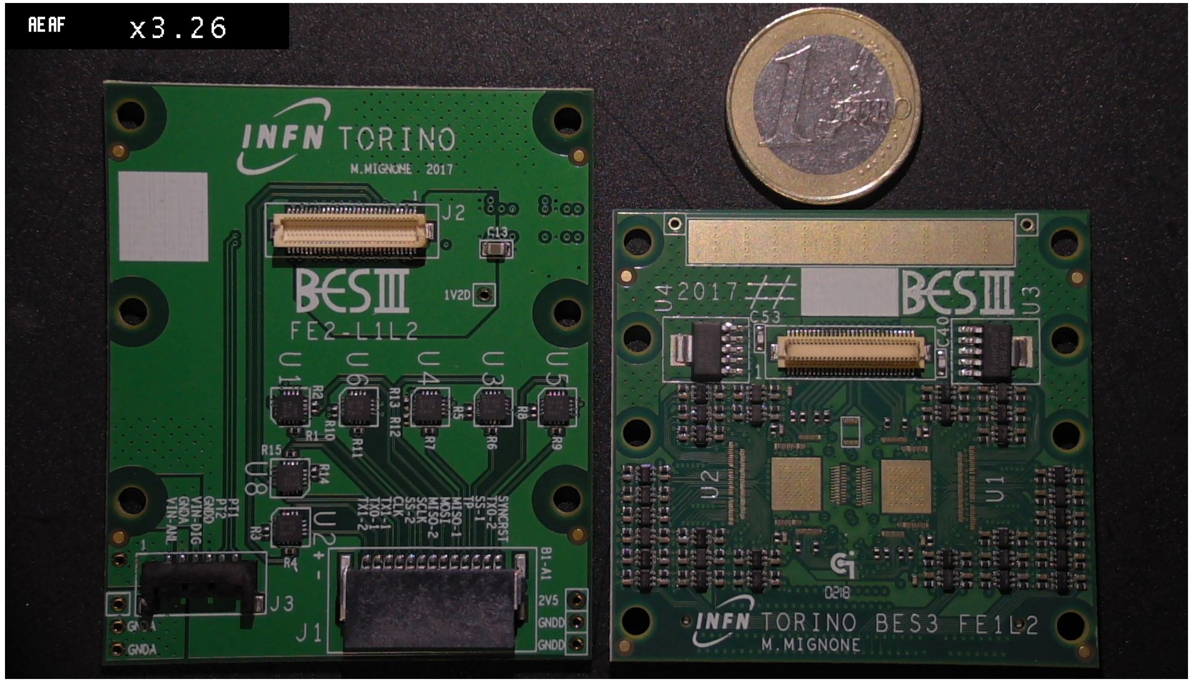
• The OFF-detector electronics is based on GEM Read-Out Cards (**GEMROC**) and Data Low Voltage Patch Cards (DLVPC)

• GEMROC is an FPGA based back-end module for configuring the ON-detector electronics, powering it, and managing data flow during acquisition

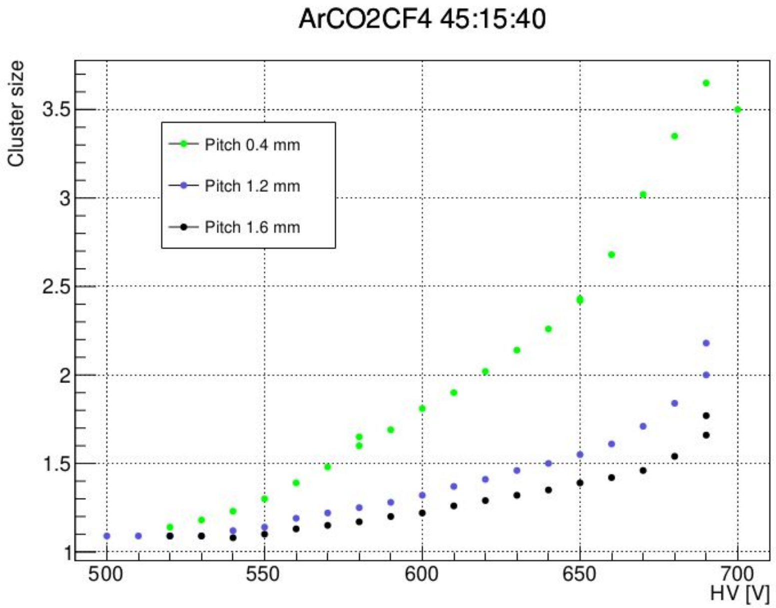
The ON-Detector electronics is composed by Front-End-Boards (FEBs). Each FEB host two **TIGER** ASIC chip

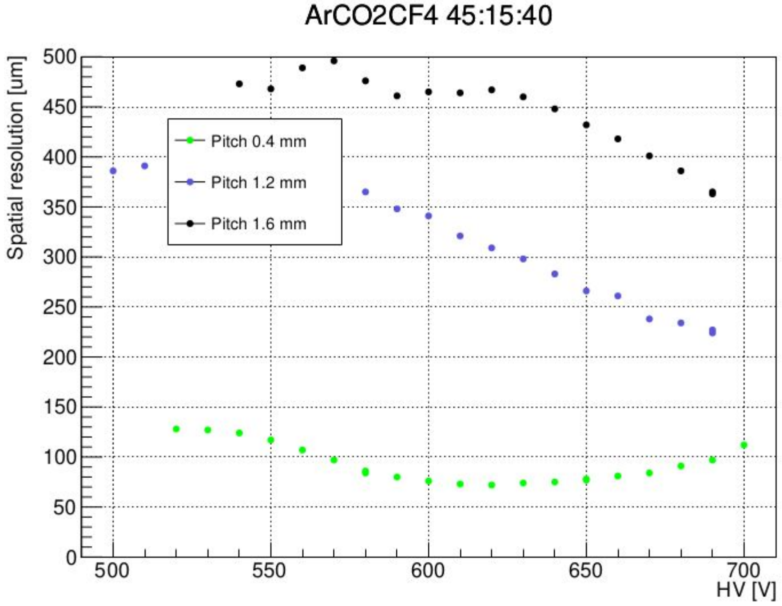
• TIGER (Torino Integrated GEM Electronics for Readout) is a 64-channel mixed signal ASIC capable of performing simultaneous charge and time
Measurements

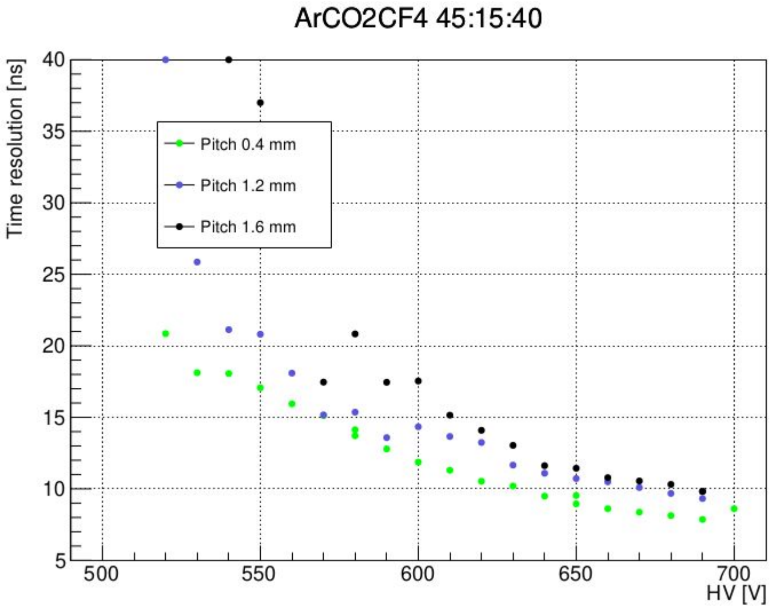
• A cooling system ensures a constant operating temperature

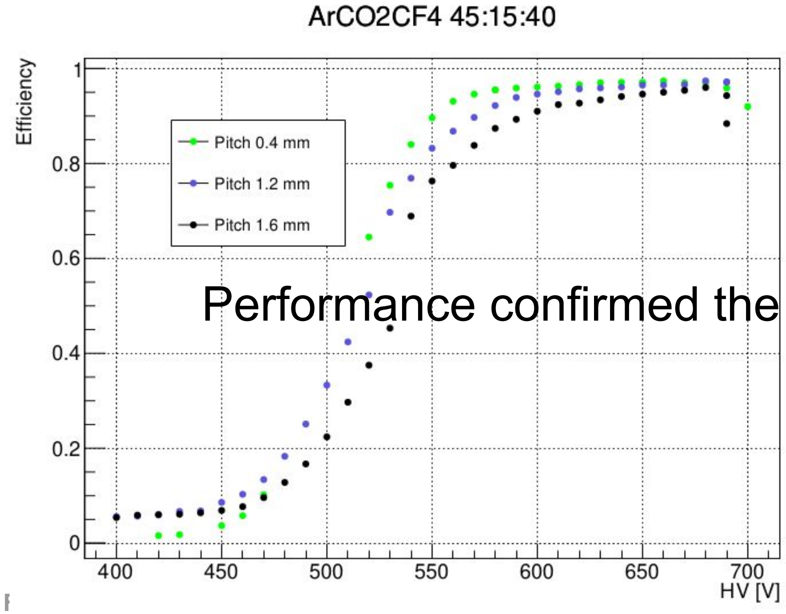


Performance with TIGER electronics @ TB



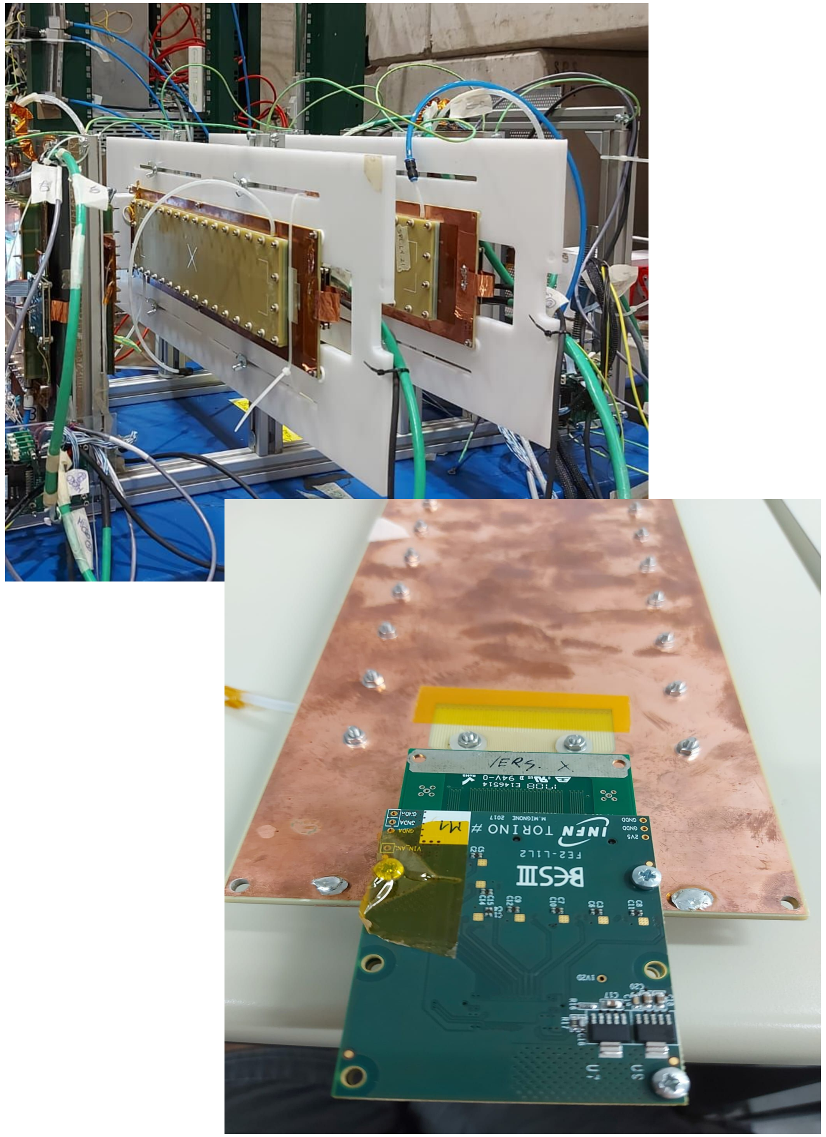




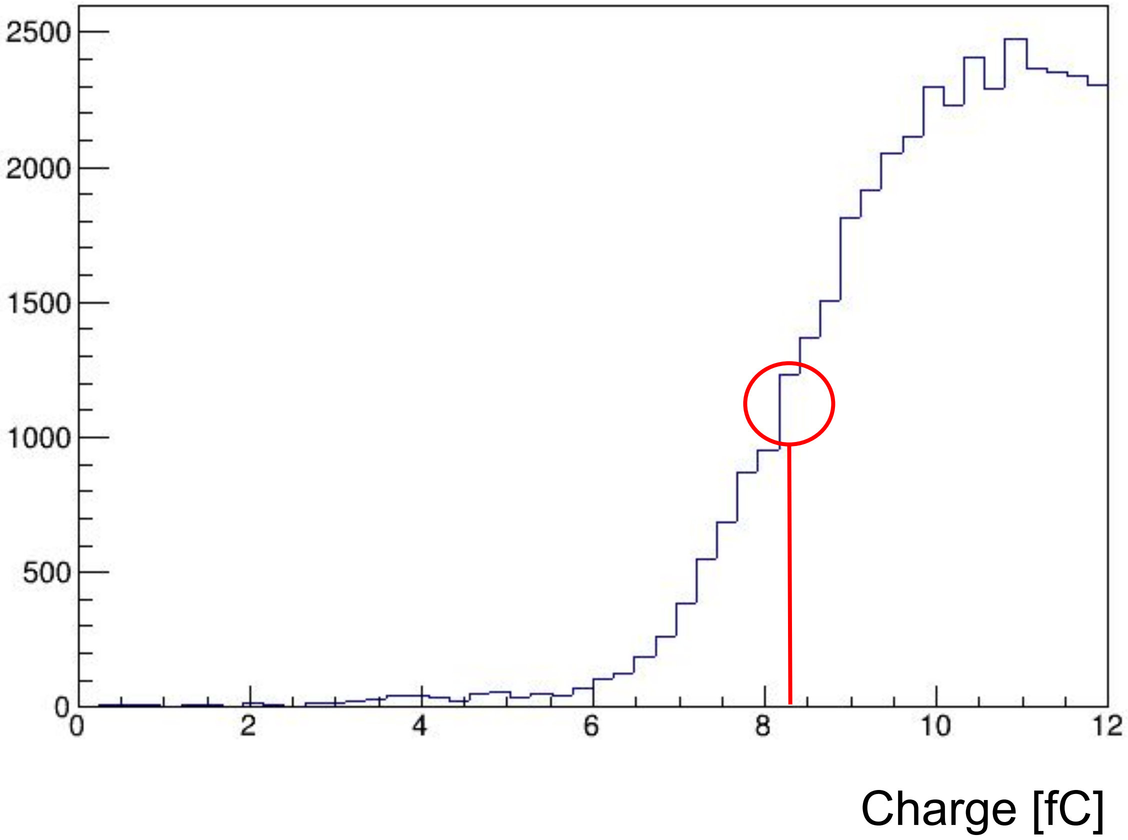


Performance confirmed the ones evaluated with APV 25

Performance with TIGER electronics



Effective threshold of 8 fC -> to be optimized



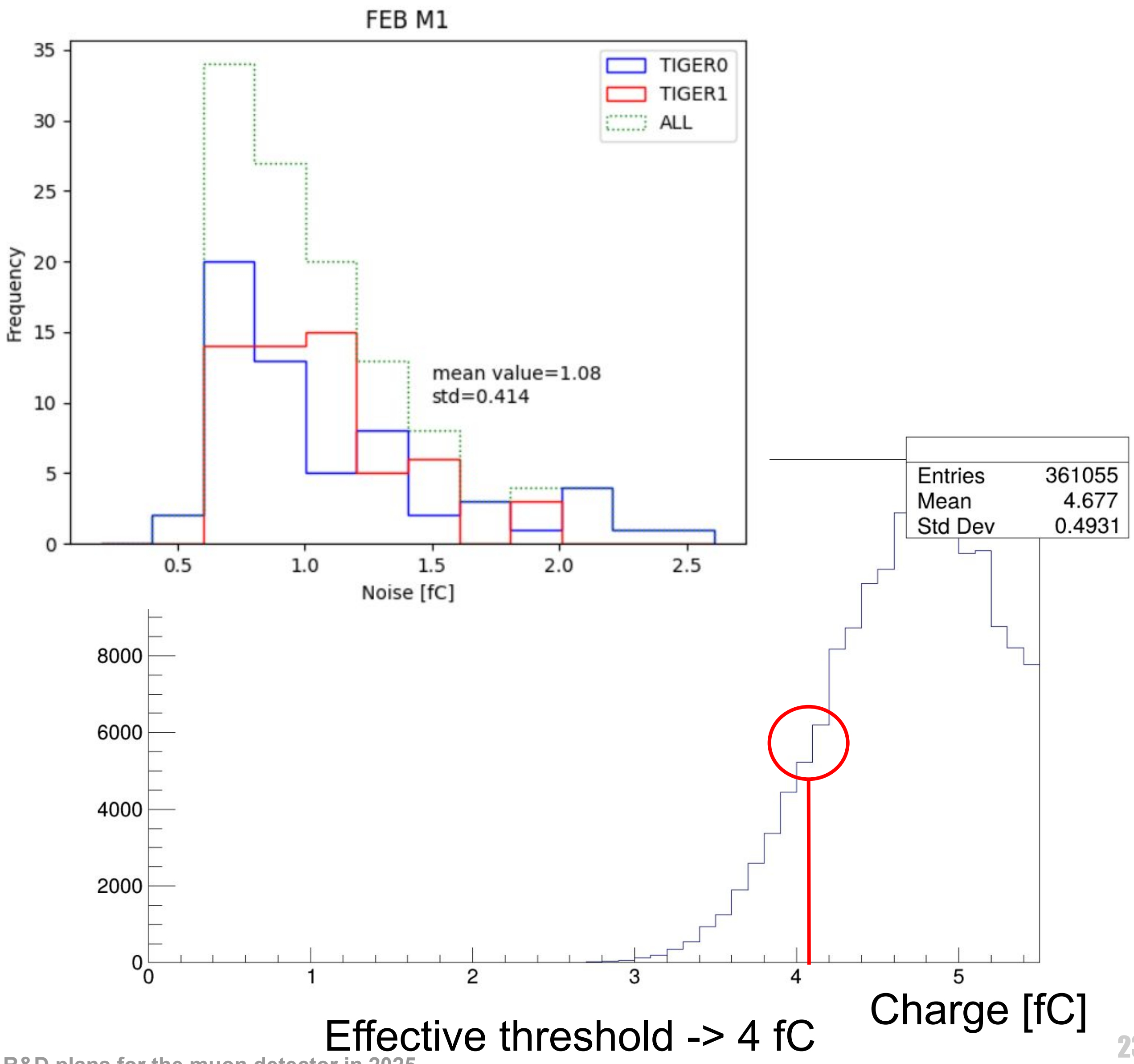
Noise campaign for TIGER studies

Test of TIGER coupled with micro-RWELL detectors

- Studies of sensible components of the setup
- Noise studies with different ground-scheme
- Noise studies with different shielding of sensible components

The test are performed in a simplified system composed of one GEMROC e one FEB. The study is still ongoing, but some good promising results has been achieved.

An electronic noise of 1 fC is measured on average on the channels and an effective threshold improved of a factor 2 is achieved.

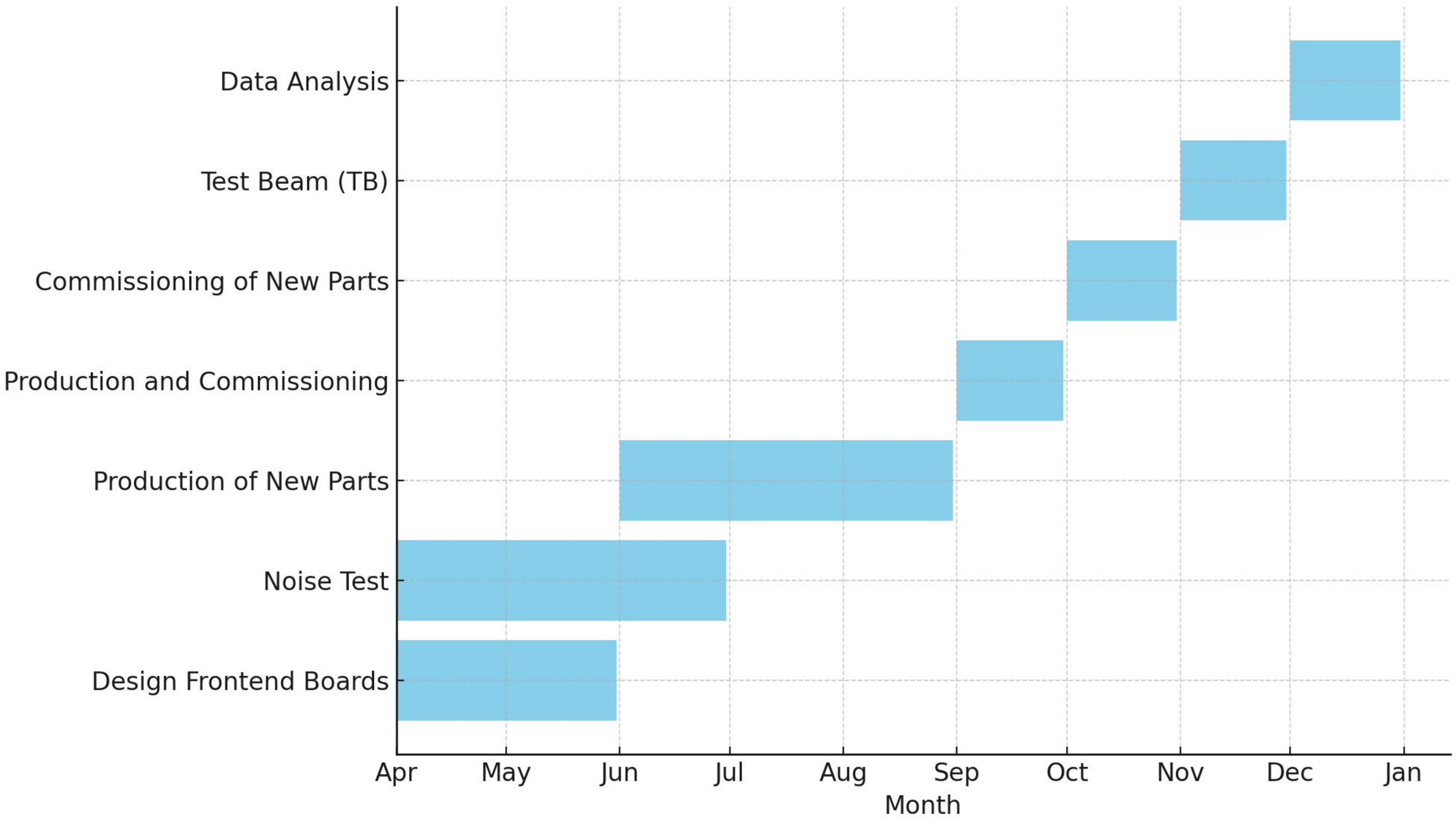


Readout chain HW improvement

1. Frontend board design upgrade
   - better grounding connections
   - remove external protection net (needed for GEM detector)
   - simpler design
   - more stable connectors

2. Improve and test the grounding scheme
   - cleaner scheme with possibility to separate different reference GND (e.g. frontend and readout)
   - improve shielding
   - improve connection with HV
   - test different configuration

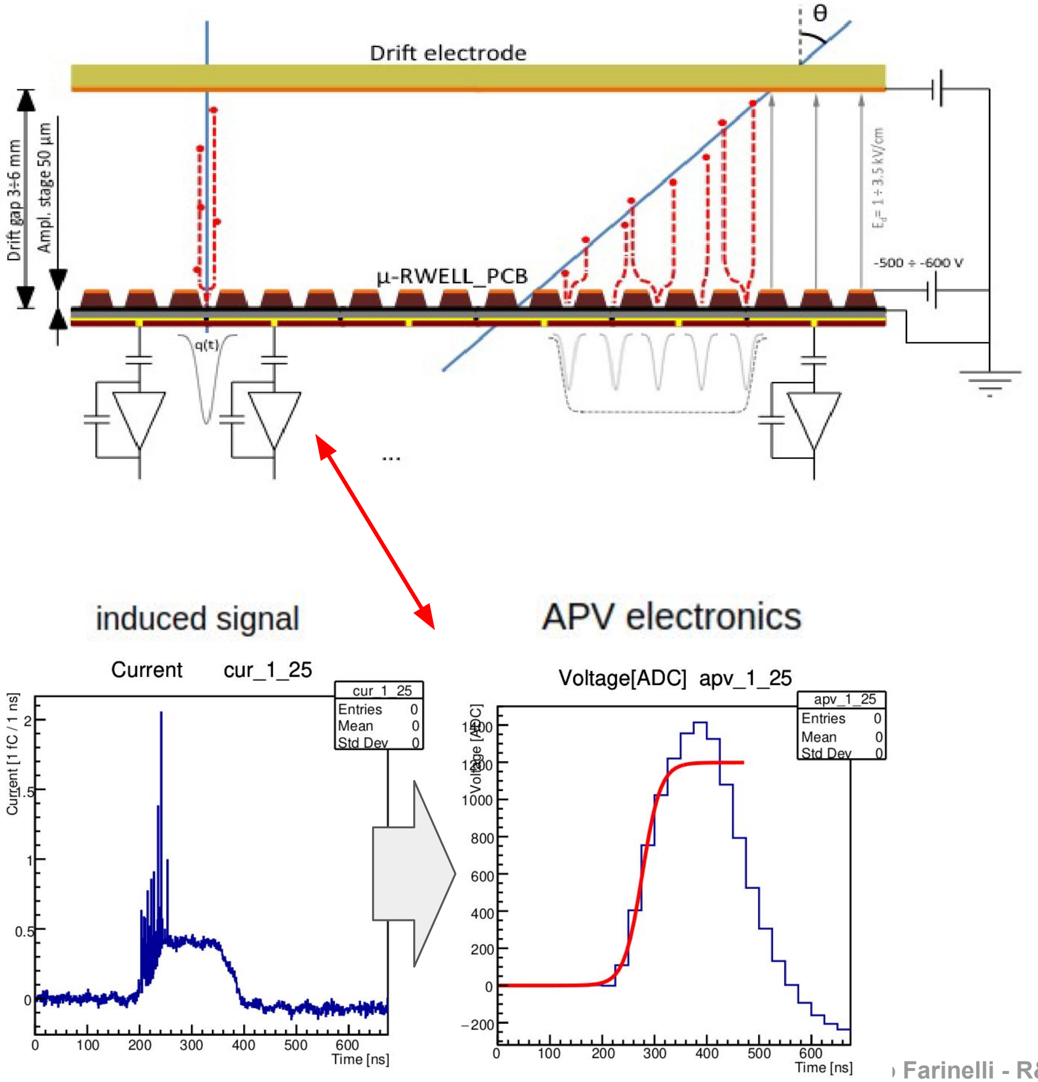
Front-End plans 2025



DETECTOR SIMULATION

μ-RWELL detector simulation

from the generation of the electrons…



Ionization

Electron Drift

Amplification

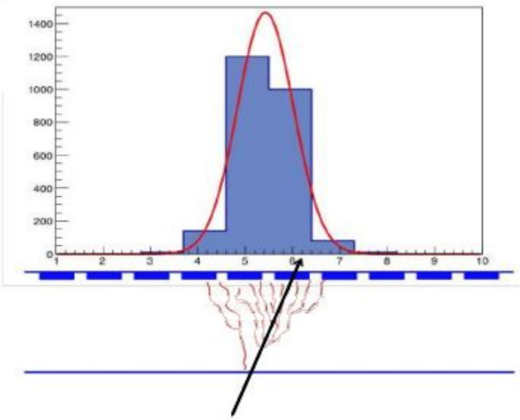
Resistive

Induction

Readout

Reco

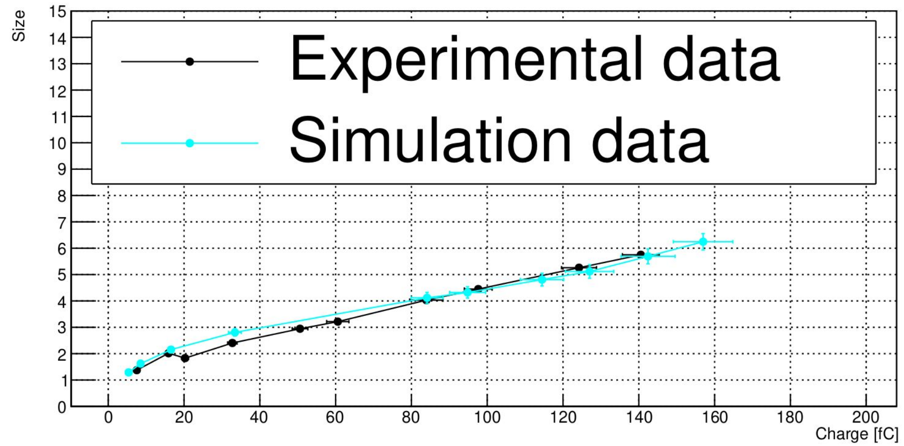
…to the signal formation

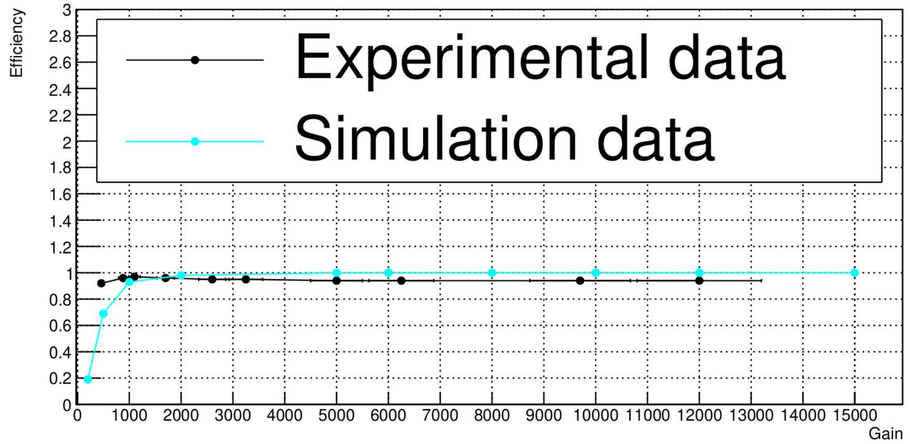


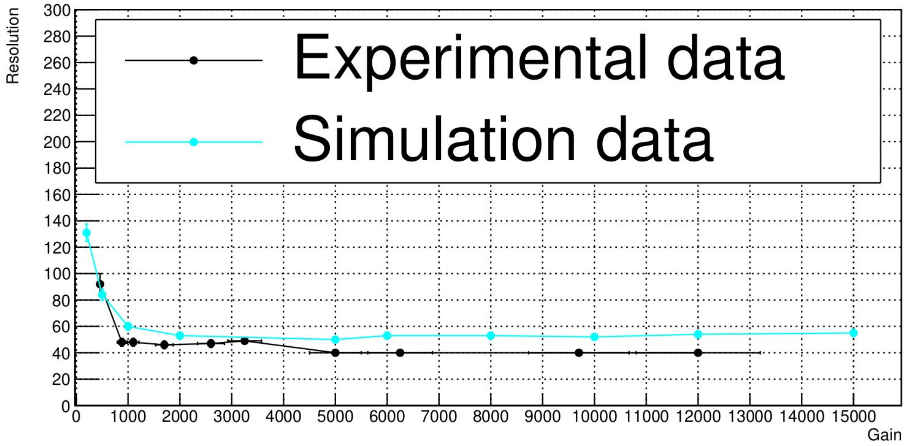
µ-RWELL simulation results

A simulation with tuned parameters can reproduce the APV results looking at the following parameters:

- Total charge collected
- Number of readout channel above threshold
- Efficiency
- Spatial resolution
- and many others







μ-RWELL simulation plans

Extend the simulation to the TIGER electronics

Scan the parameter of interest to evaluate optimization in a new ASIC, i.e.

- Noise value
- Saturation level (dynamic range)
- Shaping time

And explore new possible sampling methods:

- Double threshold for Time-Walk correction
- Constant fraction discriminator
- Peak finder
- Multi-sampling

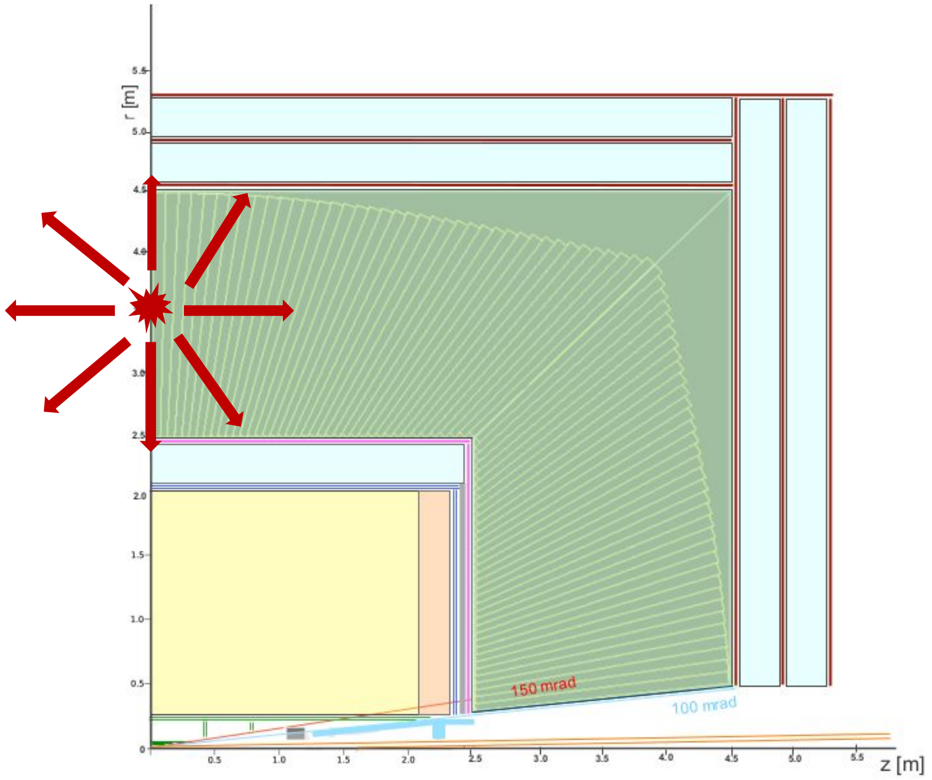
Muon Apparatus SIMULATION

Delphes study: Tracks from Standalone Muon-system

- Tests have been done by emulating LLPs decays in two muons in the calorimeter volume @ 3.5 m away from the IP, muon maximum P_T =45 GeV.
- 10 K events 20 k muons.
- Cuts on the selected events:

  - Choosing only events have two muons at final states.

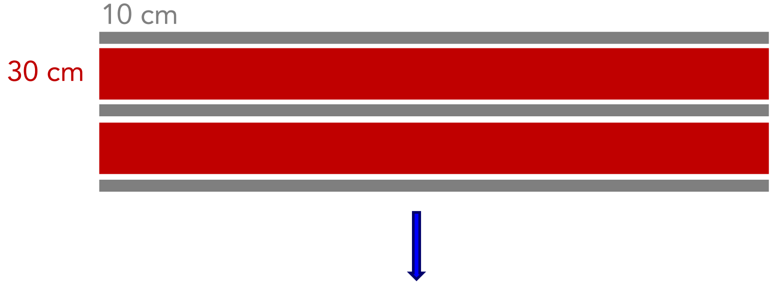
  - Maximum P_T =100 GeV for combined two muons.

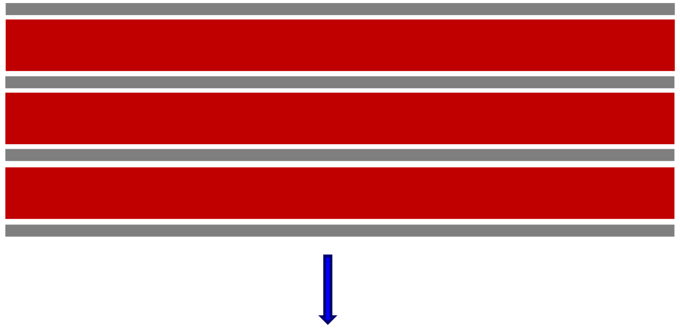


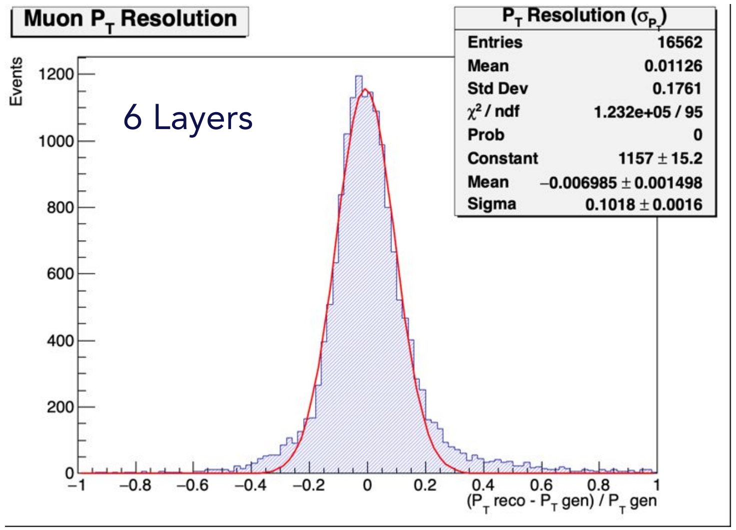
Delphes study: Tracks from Standalone Muon-system
Varying number of Detector layers:

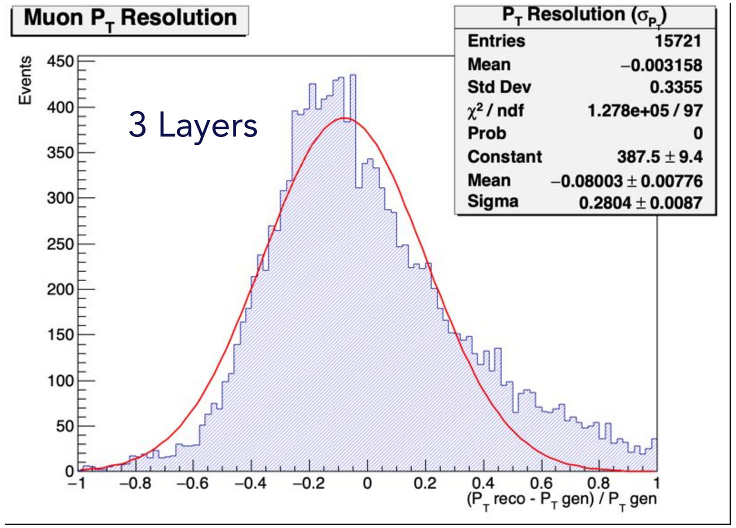
- The primarly design of IDEA muon-system consists of 3 detector layers and 2 return yokes.

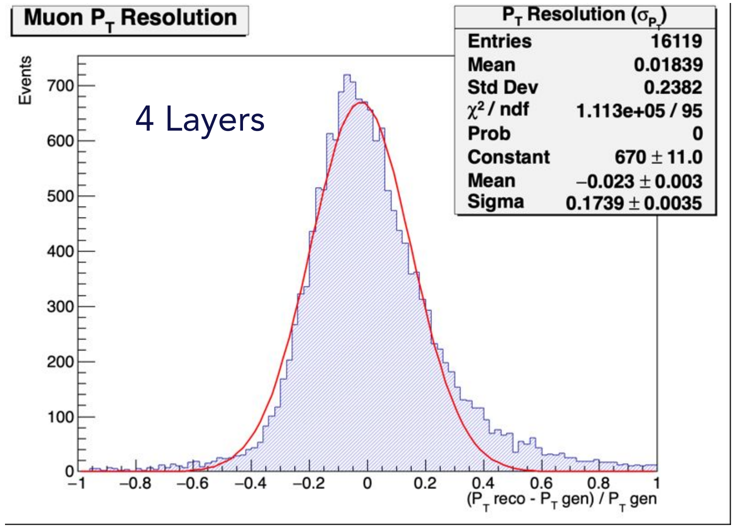
- All 400 μm space resolution

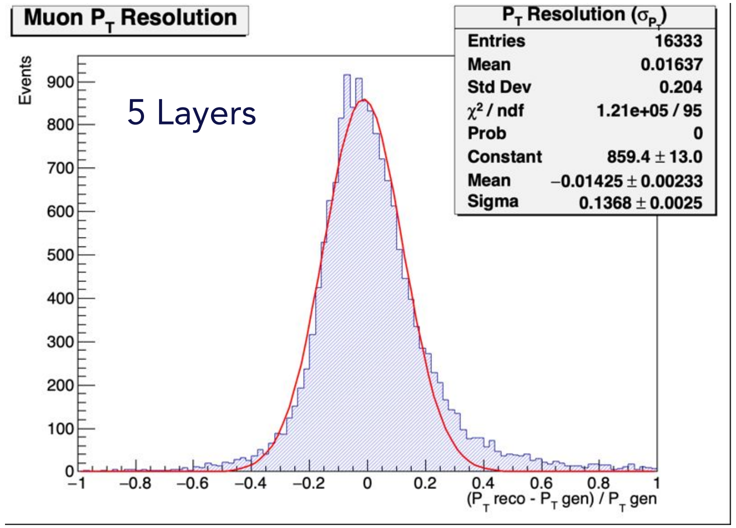










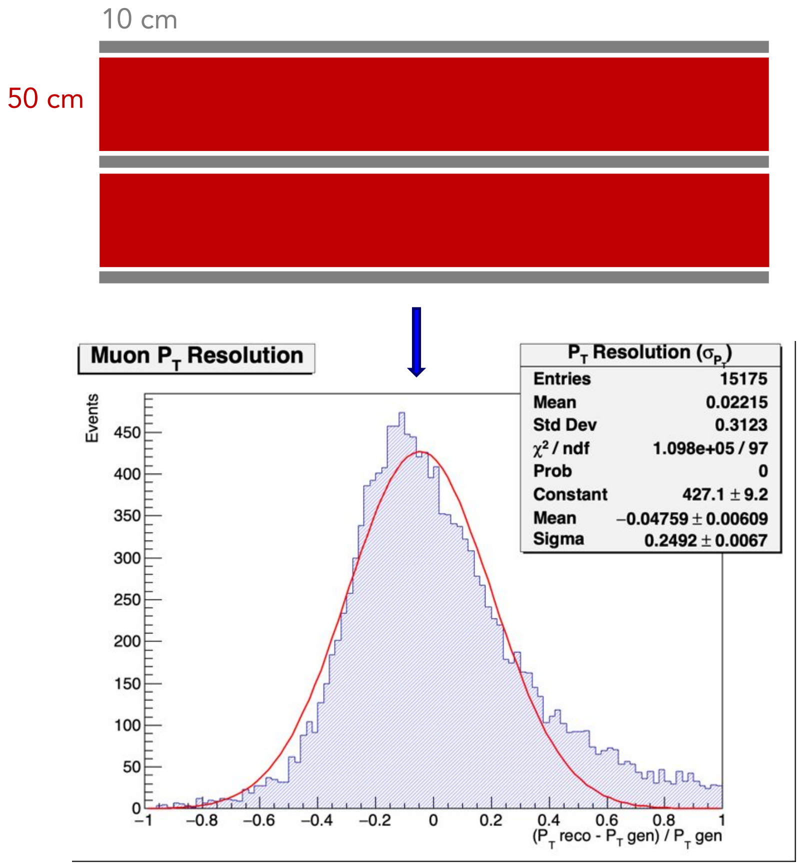


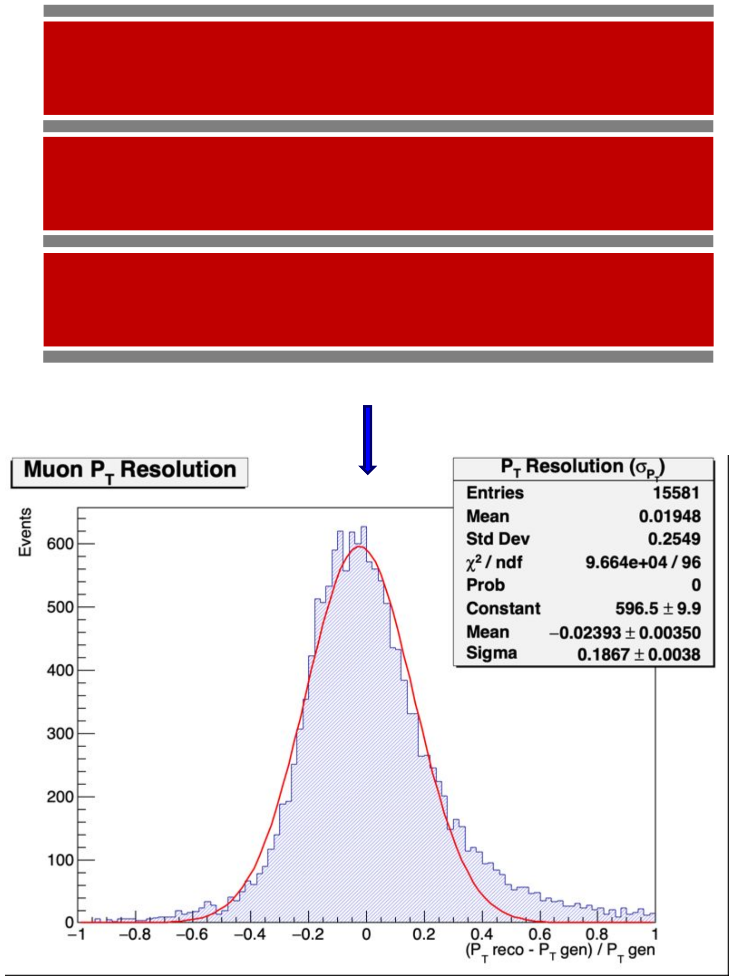
Delphes study: Tracks from Standalone Muon-system

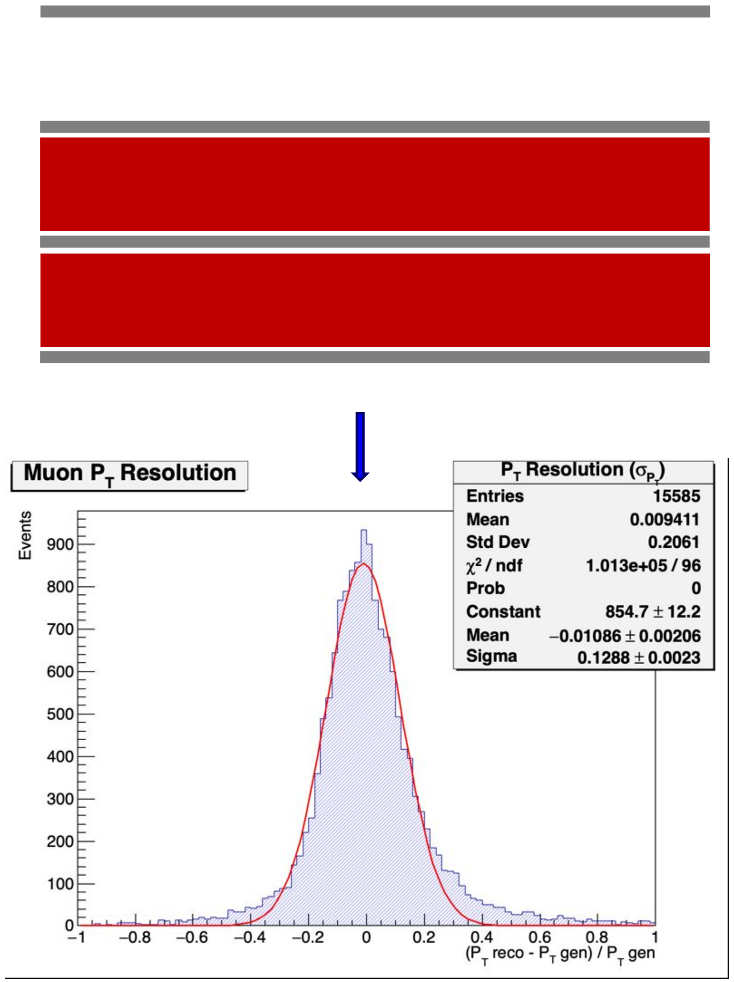
- All 400 µm space resolution

Varying level arm distance:

- The distance between every two detectors layers

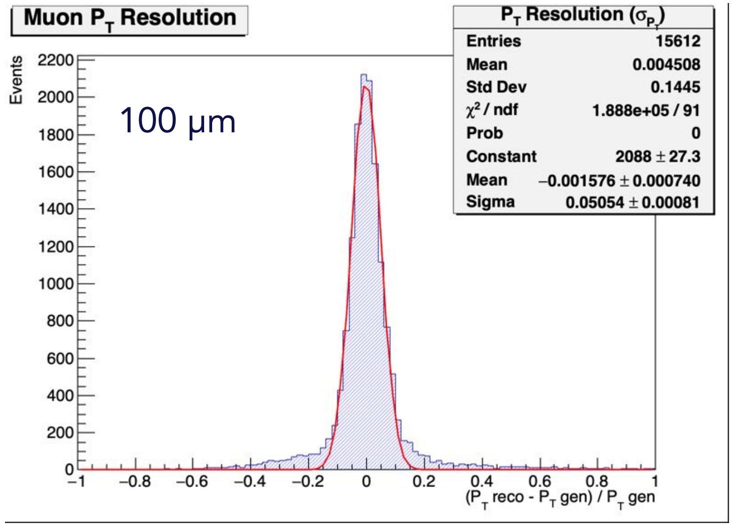


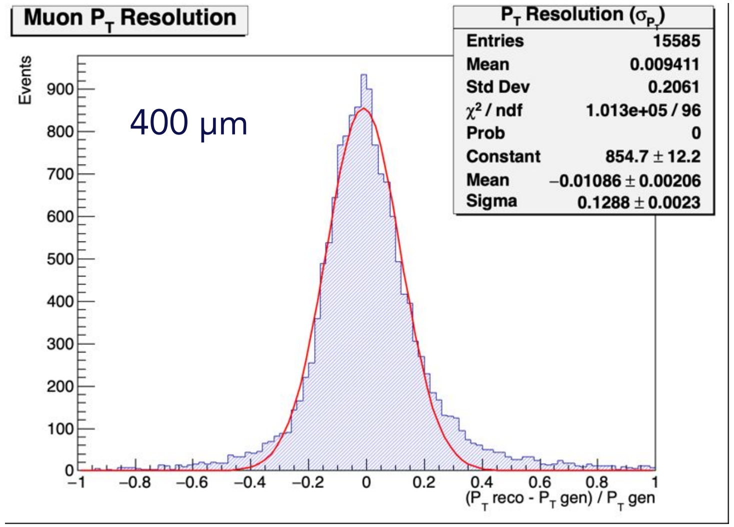


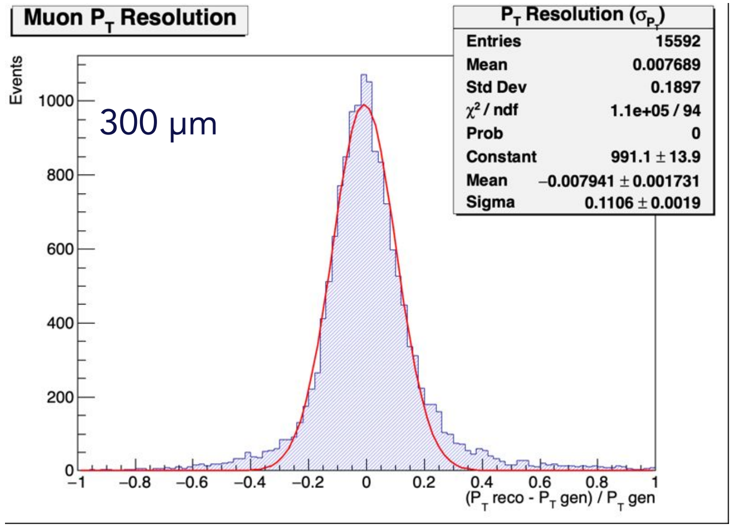


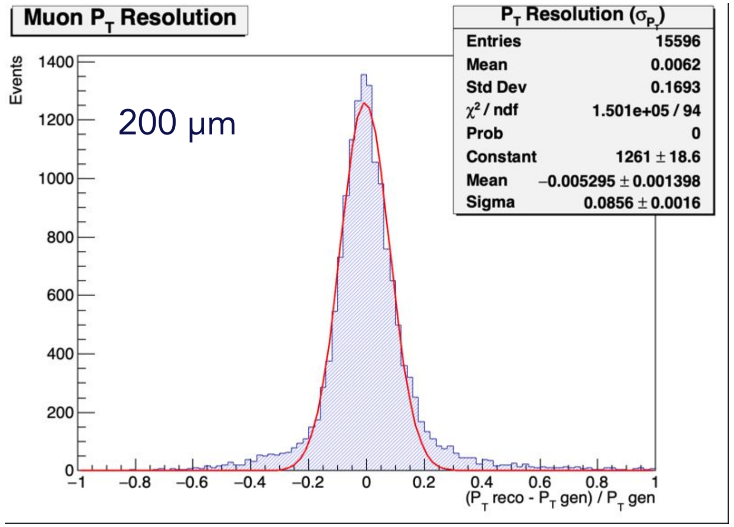
Delphes study: Tracks from Standalone Muon-system
Varying detector space resolution:

- 4 Layers with level-arm = 50 cm, and only two yokes.



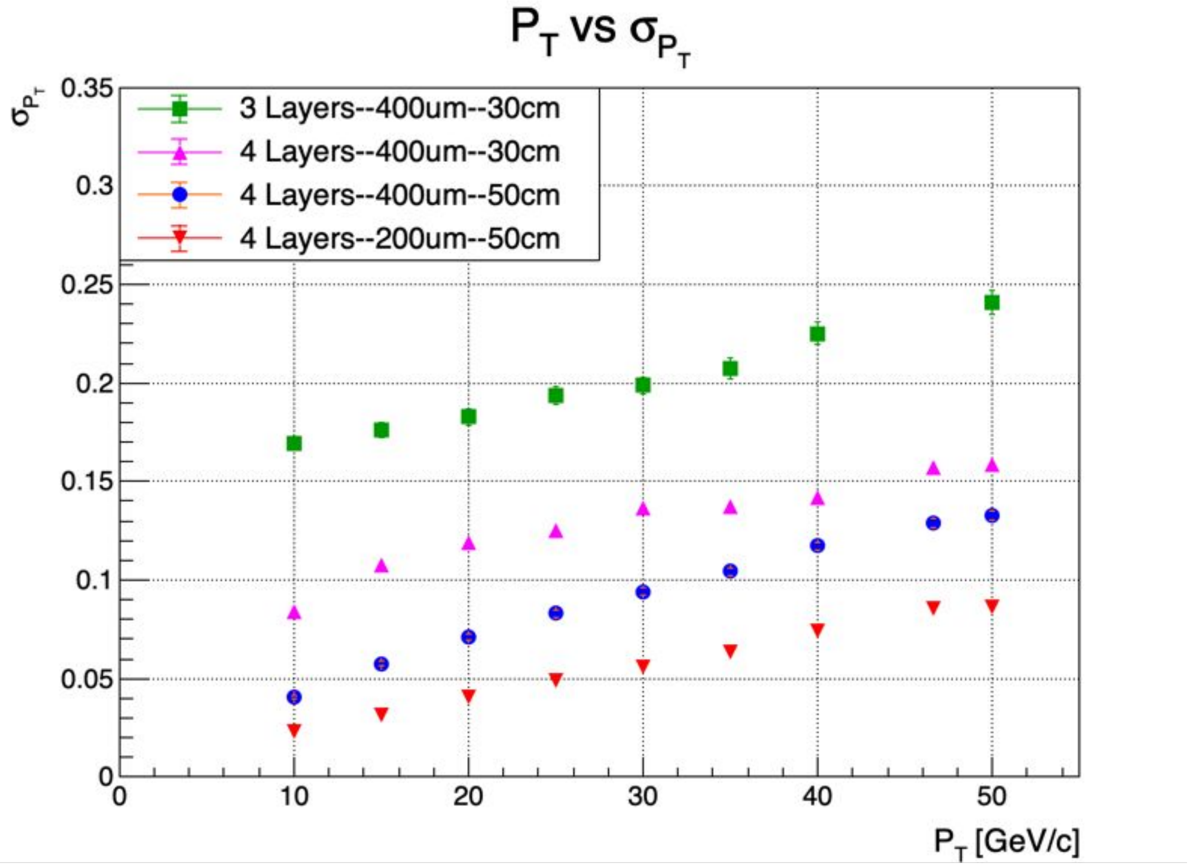






Scanning over transverse momentum:

- To summarize, 4 different muon-system apparatuses in comparison.
- # Layers – detector space resolution- level-arm distance(cm).



Full-Sim study: Tracks from Standalone Muon-system

Implementation of a tracking algorithm adopted for IDEA Muon system and displaced tracks, Key features of the algorithm:

Triplet Seeding Approach

The code implements a triplet-based seeding strategy:

1. Hits are grouped by their layer IDs

Triplet Selection

2. The algorithm then forms triplets by selecting hits from three different layers
3. Systematically iterating through all possible combinations (3 nested loops)
4. For each potential triplet, it calls createTripletSeed to evaluate if the hits form a valid track seed

Triplet Validation

5. Distance check: Ensures hits aren't too far apart (> 100 cm)

6. Angle consistency: Verifies that the vectors between consecutive hits maintain a consistent direction

7. Circle fitting: Attempts to fit a circle through the projected hit positions in the x-y plane

Full-Sim study: Tracks from Standalone Muon-system

Track Parameter Extraction

When a valid triplet is found, the algorithm:

1. Fits a circle through the hits in the transverse plane using **Sagitta** method (which measures the "bow" of three points)

2. Calculates track parameters:
   - **I. Momentum (pT)**: Using the relation pT = 0.3 × B × R (where B is magnetic field in Tesla and R is radius in meters)
   - **II. Phi angle**: From circle center and hit positions
   - **III. Charge sign**: Based on clockwise/counterclockwise determination
   - **IV. Z component**: Linear fit along the track path to get theta/eta
   - **V. Impact parameters**: Using calculateImpactParameter which models field transitions

Track extrapolation: Starting from the seed and extrapolate it to the following layers (using Kalman Filter) to find more compatible hits

Further developments:

3.Track fitting: Using GenFit to fit the track, taking into account the effect of multiple scattering to enhance the measurements

4.Vertex fitting: Integrate displaced vertex reconstruction

Conclusion

μ-RWELL technology

- There is always room to optimize the technology, and cutting-edge results could significantly enhance its performance. Several solutions are currently being developed and they will be tested in a test beam

Electronics integration

- The development of electronics and detector technologies must progress in parallel to fully exploit their combined potential. Research activities are currently on going to optimize both the front-end board and the readout chain. The test beam planned is expected to validate the proposed layout

Muon system simulation in IDEA

- A full simulation of the muon system is of fundamental importance for defining the detector layout and performance requirements within the IDEA concept. The development of dedicated tracking and vertexing algorithms will enable a comprehensive characterization of the muon system and its potential capabilities