ePIC MPGD-DSC Workfest

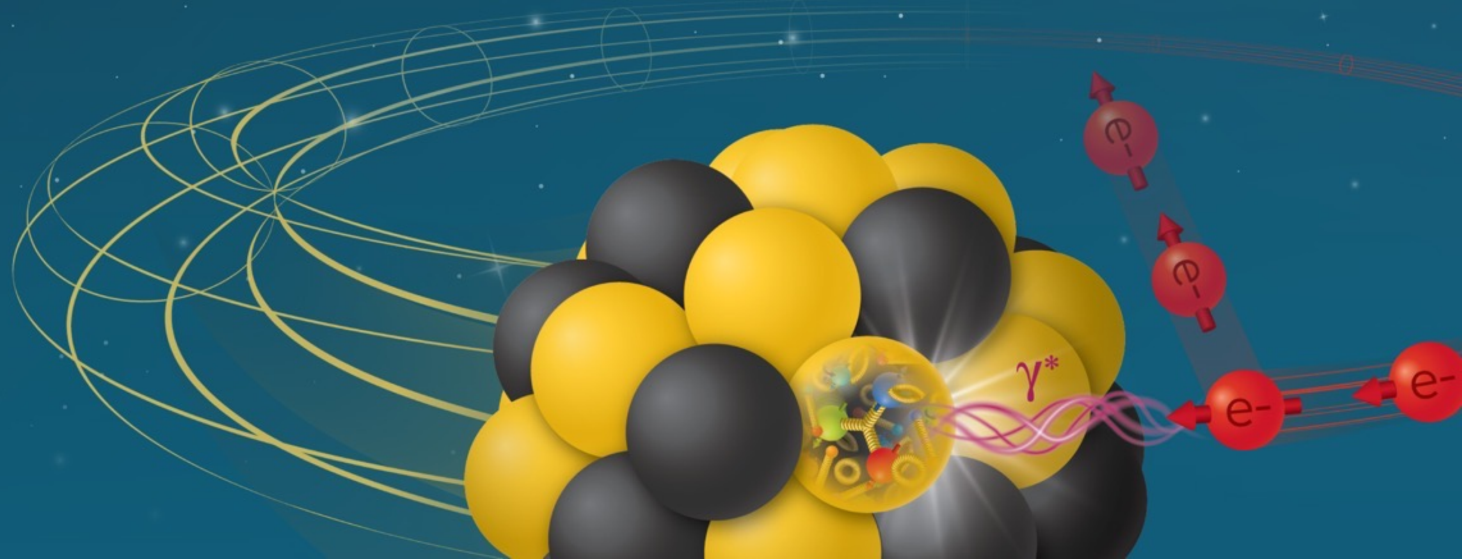
MPGD – BOT MPGD – CYMBALL MPGD - ECT

Kondo Gnanvo, Francesco Bossù, Sourav Tarafdar

Annalisa D’Angelo

ePIC Collaboration Meeting
July 25-26, 2024

Electron-Ion Collider



Highlights 2 half days divided into 4 sessions

Sessions Convener - Kondo Gnanvo

MPGD detectors stability	
Pietro Iapozzuto Florida Tech	Experience with µRWELL stability (assembly and operation) at Florida TechScope of the MPGD Endcap Trackers Detector
Florian Hauenstein JLab	Experience with µRWELL stability (assembly and operation) at Jefferson Lab
Matteo Giovannetti INFN-LNF	Experience with µRWELL stability (assembly and operation) at INFN Frascati
Fabien Jeanneau CEA Saclay	Experience with Resistive Micromegas stability (assembly and operation) at CEA Saclay
Rui de Oliveira CERN	Experience with resistive MPGDs at CERN MPGD workshop

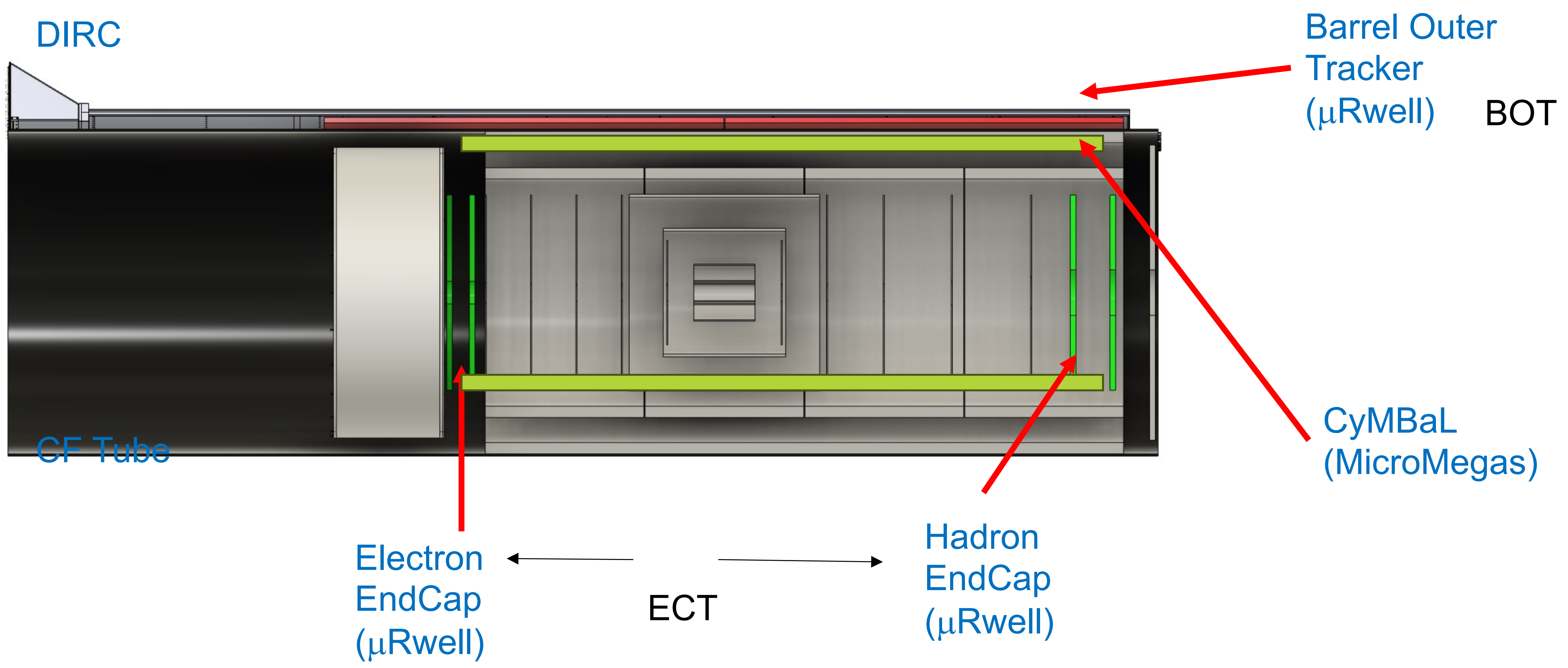
MPGD subdetectors status report	
Kondo Gnanvo JLab	Overview & status of µRWELL BOT
Annalisa D'Angelo INFN Roma TV	Overview & status of µRWELL ECT
Francesco Bossù CEA Saclay	Overview & status of CyMBaL
Prithwish Tribedy BNL	Digitization in ePIC framework: lessons from AC-LGAD subsystems

Sessions Convener – Sourav Tarafdar

MPGD Engineer and Electronics update	
Seung Joon Lee JLab	MPGD engineering design and integration
Roberto Ammendola INFN Roma TV	Electronics Development for the EndCap Tracker
Fernando Barbosa BNL	ePIC electronics development
Annalisa D'Angelo INFN Roma TV	uTPC and synergy with ePIC electronics development
Tim Camarda BNL	LV power regulation options with DC-DC converters

MPGD Gas Choice and Distribution	
Bern Surrow Temple U.	Gas system for the STAR Forward GEM tracke
Francesco Bossù CEA Saclay	CyMBaL-BOT-ECT Gas requirements
Matt Posick Temple U.	**Preparation of the TDR**

THE MPGD Detectors



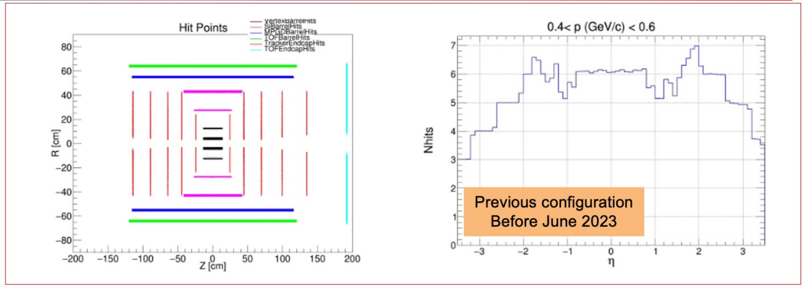
BOT - Highlights

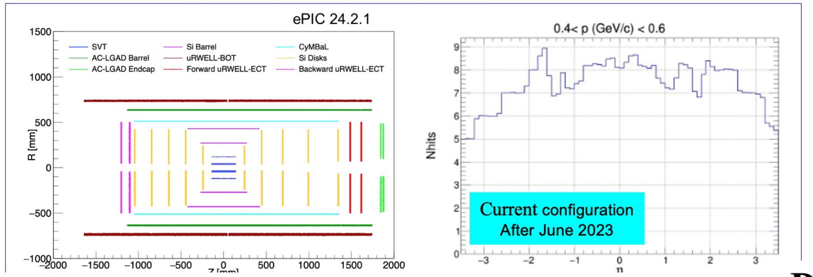
Kondo Gnanvo
JLab

Requirements for µRWELL-BOT : Pattern recognition & tracking redundancy

ePIC Barrel Outer Tracker (µRWELL-BOT)

- Outer layer for pattern recognition together with the TOF (AC-LGAD) and Inner barrel layer (CyMBaL) trackers
- Provide fast timing capability (~10 ns) to help the slow Si trackers with pattern recognition in high background.
- Provide additional hit point to tracking for redundancy

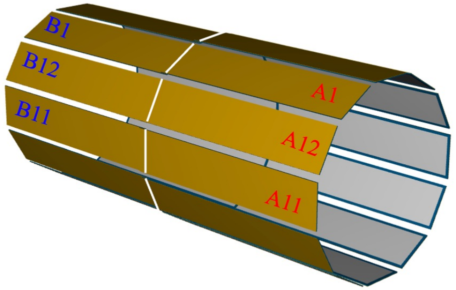


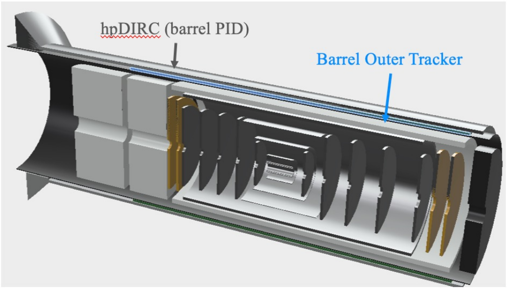


µRWELL-BOT Layout

µRWELL-BOT Layout

- 24 planar modules arrange in 12-sided polygon shape
  - L = 340 cm (−165 cm ≤ Z ≤ 175 cm)
  - R = 72.5 cm
- Segmented into
  - 2 sectors (A & B) in z along beam axis
  - 12 modules in phi azimuthal direction

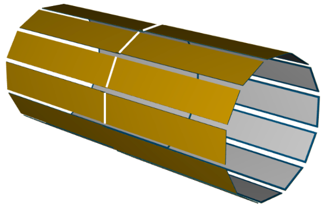


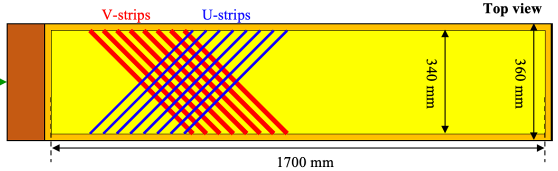


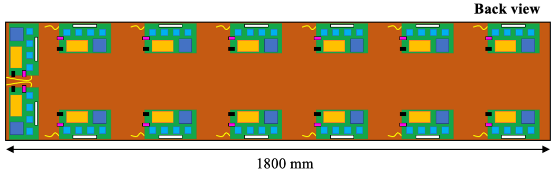
µRWELL-BOT specifications

- Thin-gap & double amplification (GEM & µRWELL)
- 2D-strip readout
  - Nominal 70 µm (perpendicular tracks)
  - On average 150 µm on for tracks in angle range [0, 45 degrees]
- Fast timing layer ~ 10 ns
- Radiation length < 2% in active area

µRWELL-BOT Module:





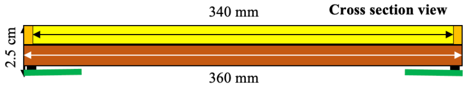


µRWELL-BOT module

- Thin-gap (1-mm drift) hybrid amplification GEM-µRWELL detector
- Capacitive-sharing U-V strips readout layers(45^O stereo angle)
- Pitch: 1.14 mm (1790 U-strips and 1790 V-strips per modules)

On-detector Front End Boards (FEBs) based on SALSA chips

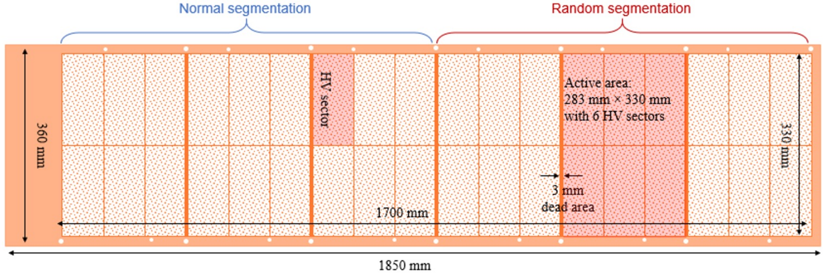
- 14 FEB / modules (assuming 4 SALSA chips i.e 256 e-ch / FEB)
- Direct connection on the back of the modules (no need for flex cables)

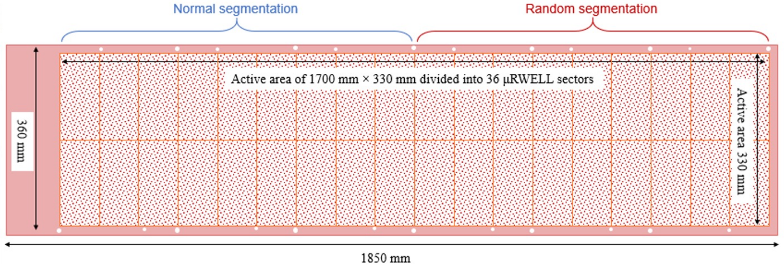


Design consideration – µRWELL and GEM foil design

GEM foil:

- foil divided into 36 HV sector ~ 156 cm^2
- Trade-off between active-to-dead area ratio for gap uniformity (~1% dead area)
- Final design ongoing in collaboration with CERN MPT workshop experts
- Procurement expected by 12/24





µRWELL PCB:

- Foil divided into 36 HV sectors ~ 156 cm^2
- Final design ongoing in collaboration with CERN MPT workshop experts
- Procurement by 12/24

BOT - Highlights

Kondo Gnanvo
JLab

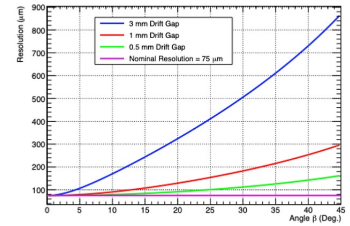
Technology choice: Thin-gap GEM-µRWELL Hybrid Detector

Challenges with standard (> 3-mm drift gap) MPGD

- ❖ Degradation of the spatial resolution with track angle .
- ❖ E × B in magnetic field negatively impact resolution

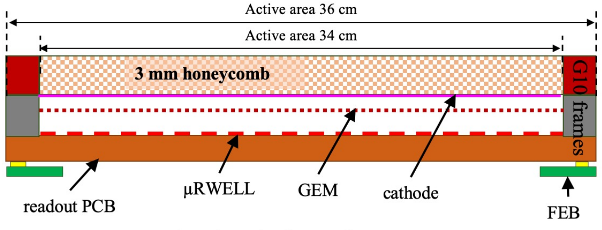
Development of Thin-gap MPGDs:

- ❖ Small drift gap improve spatial resolution at large angle
- ❖ Small gap ➔ minimize E × B effect in magnetic field
- ❖ Improve the detector timing performance



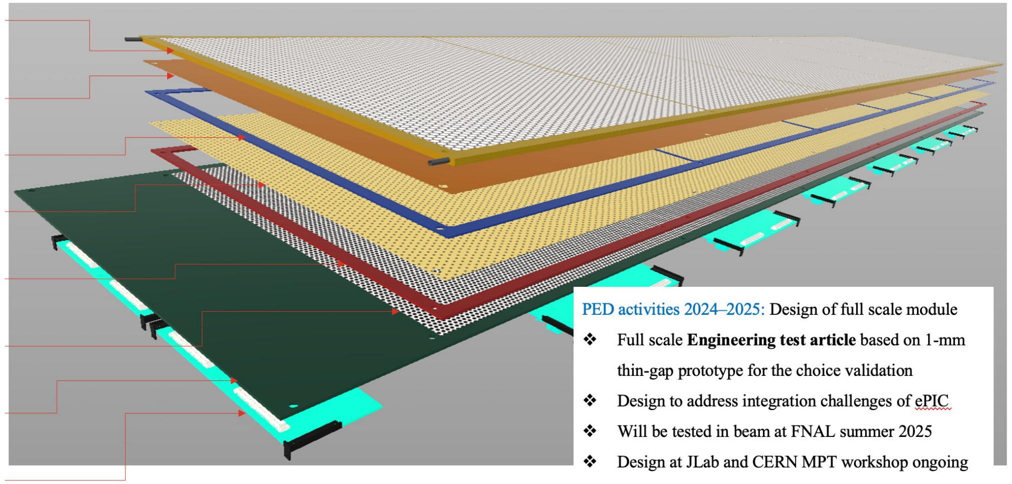
Thin-gap GEM-µRWELL detector concept

- ❖ hybrid amplification MPGD:
  - GEM (preamplification) and µRWELL (main amplification)
  - Allow large detector gain and stable operating HV
- ❖ Readout layer: 3-layer capacitive-sharing U-V strip readout
  - Achieve excellent spatial resolution with thin gap detector



cross-section view of thin-gap GEM-µRWELL detector

Design consideration: Breakdown of µRWELL-BOT module



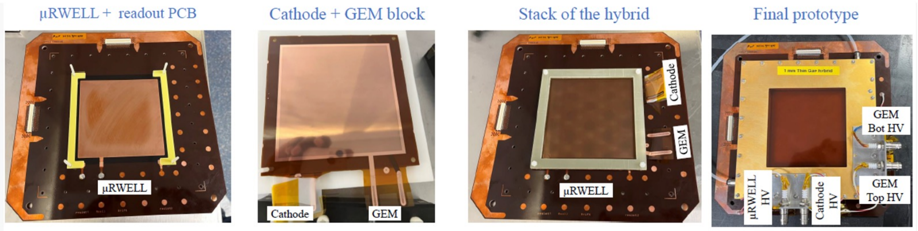
PED activities 2024–2025: Design of full scale module

- ❖ Full scale **Engineering test article** based on 1-mm thin-gap prototype for the choice validation
- ❖ Design to address integration challenges of ePIC
- ❖ Will be tested in beam at FNAL summer 2025
- ❖ Design at JLab and CERN MPT workshop ongoing
- ❖ Test article module fabrication completion 2024
- ❖ Will be tested in beam at FNAL summer 2025

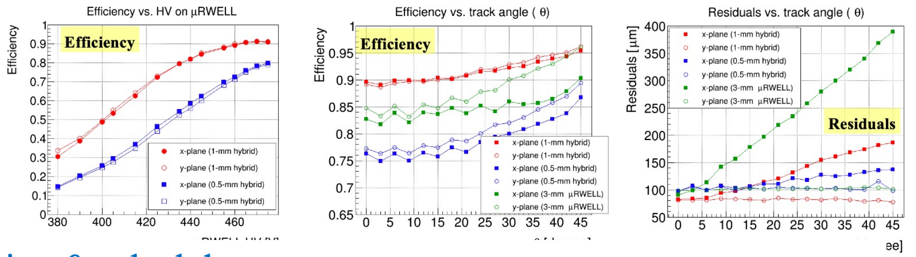
Technology choice: Thin-gap GEM-µRWELL Hybrid Detector

Proof of concept

- ❖ Concept of thin-gap GEM-µRWELL hybrid prototype demonstrated in beam test at the Fermilab Test beam Facility in Summer 2023 (red plots)
- ❖ Space resolution < 150 µm and efficiency of 92% on average for 1-mm thin-gap GEM-µRWELL prototype (red dots) and for track in an angle range between 0 – 45 degrees.
- ❖ **Baseline technology for ePIC outer MPGD tracker**



R&D funded by JLab administered DOE EIC Generic R&D Program as EICGENRandD_2022_23



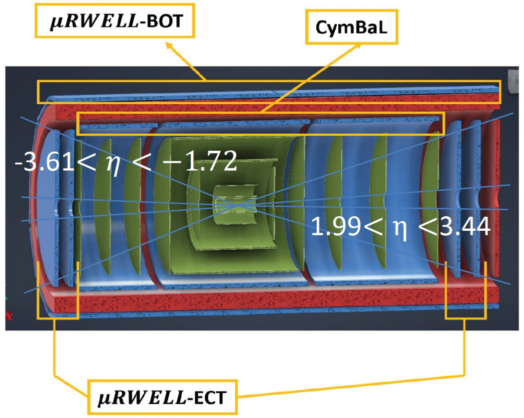
Assembly plans: Planning & schedule

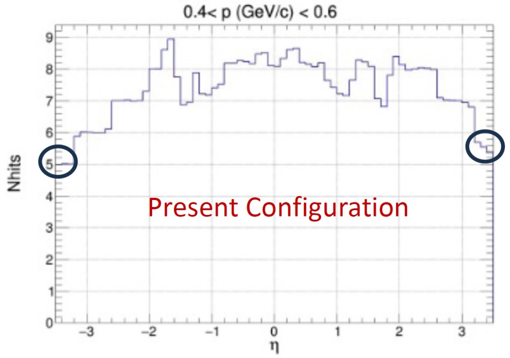
06/2025	06/2026	04/2029	06/2029	
PED & validation	Pre-production	Production	Shipment to JLab	Commissioning & Installation
▪ Ongoing design of full size µRWELL-BOT module ▪ Procurement of GEM foils, µRWELL PCB – **12 / 2024** ▪ Assembly at JLab test in at FNAL - **06/2025**	▪ Assembly of one pre-production module **(module#0)** ▪ Setup of infrastructure and equipment in assembly sites	▪ Assembly and QA of 9 production modules at assembly sites ▪ Full characterization at assembly sites of each module on cosmic stand and with radioactive sources	▪ Shipment of all 24 modules to BNL ▪ Commissioning at BNL cosmic test stand of all µRWELL-BOT as well as µRWELL-ECT	▪ Commissioning ▪ Installation

ECT - Highlights

Scope of the MPGD endcaps in ePIC detector tracking

- Adding **two MPGD Endcap Tracking (ECT) disks** both in the **hadronic** and in the **leptonic regions** increased the number of hits in the $|\eta| > 2$ region to improve pattern recognition.

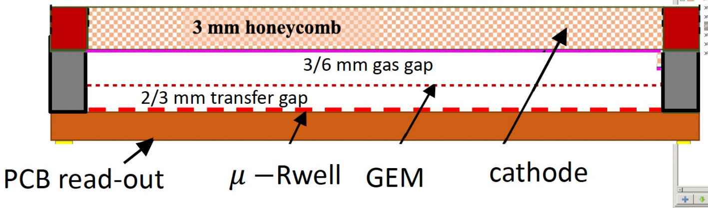


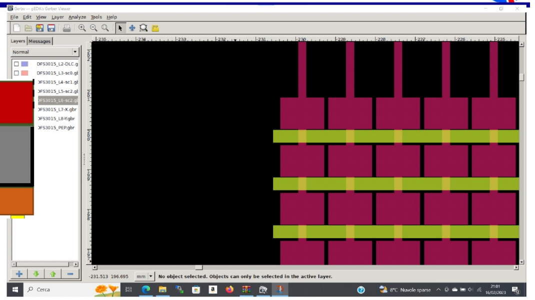


Present ePIC tracker geometry

Detector Technology Choices: GEM+μRwell

GEM - μRwell Technology





- 2D CS readout reduces the gain from 10^4 to 3-4 10^3 → the detector stability is put at risk
- GEM- μRwell hybrid configuration has been chosen to increase the gain in the 10 000 ÷ 20 000 range
- 2D strip read-out using a "COMPASS-like" scheme
- 500 μm pitch guarantees a spatial resolution better than 150 μm (no need of capacitive sharing))
- A gas gap lager than 3 mm is compatible with single detector efficiency larger than 96%

Technical Performance Requirements

AD
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Time resolution 10 ns or less to provide tracking timing
- Fast rise time ~ 20 ÷ 50 ns
- Peaking time 50 ns
- Sampling faster than 50 MHz

Low material budget
- 1-2 % X_0 - it will be the minimum compatible with the chosen technology

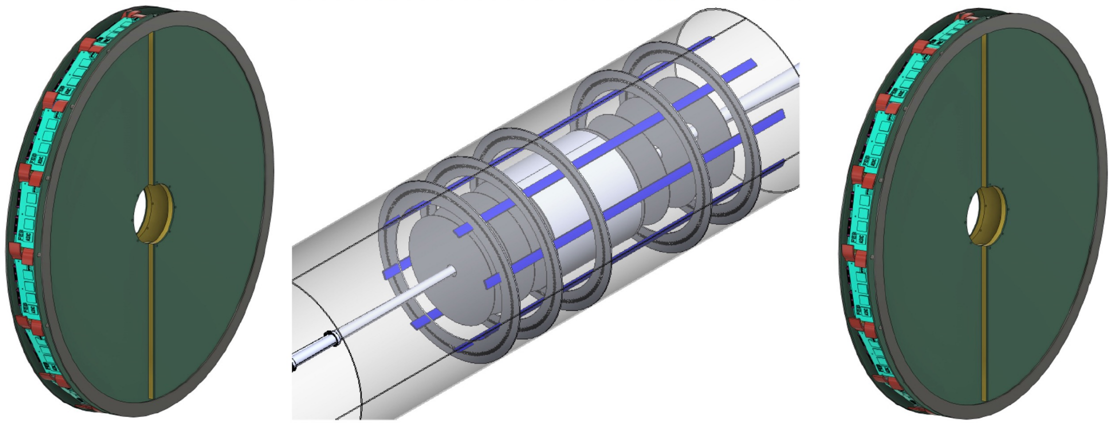
Spatial resolution: 150 μm or better
- <150 μm intrinsic spatial resolution for perpendicular tracks
- Technological optimizations to retain 150 μm resolution for inclined/curved tracks

High Efficiency
- Single detector efficiency ~ 96 –97 % → 92 –94 % combined efficiency for two disks

Endcap Detectors Integration in ePIC

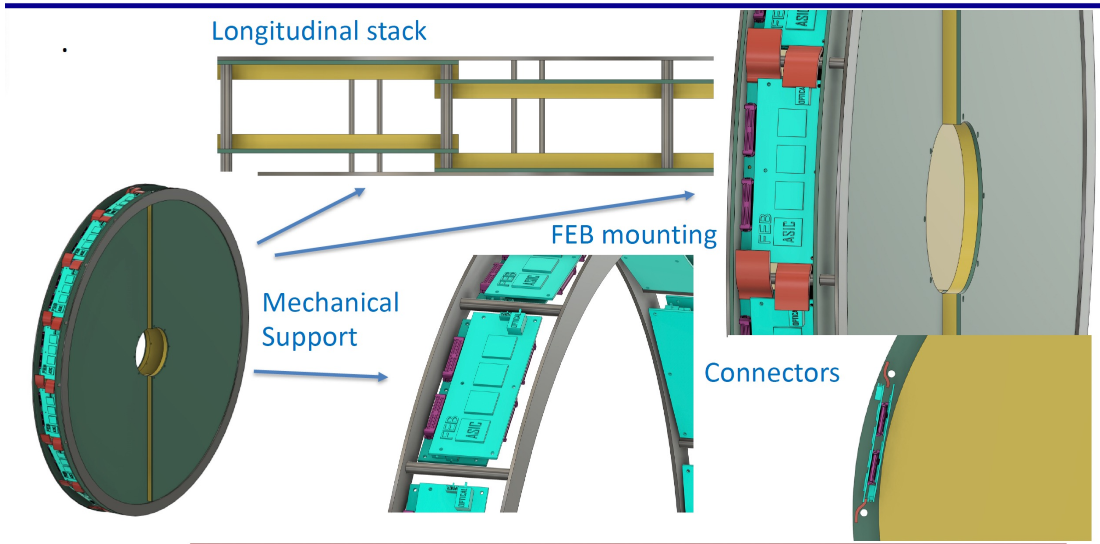
The assigned envelope will include the detectors and the FEB electronics.

The disks will be attached together and to the support frame under design.



ECT - Highlights

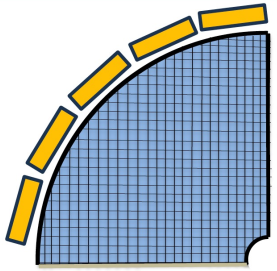
Endcap Detectors Mechanical design in progress



Detector Technology Choices: (X,Y) vs (R,φ) read-out

(X, Y) read-out geometry

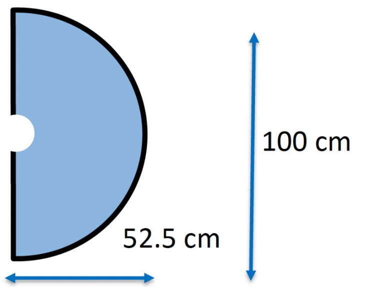
PROs	CONs
The strip length does not vary much along the active area	Alignment is critical
All readout FE hybrids may be located outside the active area	Routes to read-out connectors must be accurately studied



- (X, Y) readout is preferred vs (R,φ) – no FEB on the active area
- 500 μm pitch → better than 150 μm intrinsic position resolution
  - **Strips routing details is being studied**

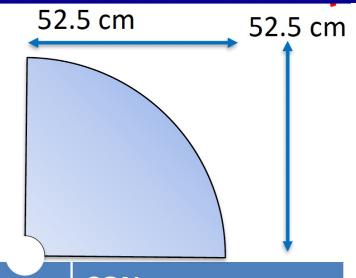
ePIC Endcaps – open options

2 semi-circles



PROs	CONs
One vertical/horizontal overlap only – less material	Larger detector surfaces are more difficult to handle.
The two endcaps may be rotated by 90° one respect to the other to recover overall symmetry	Longer strips: → Readout should be segmented into two sectors to avoid too long strips
	GEM foils need to be supported

4 Quadrants

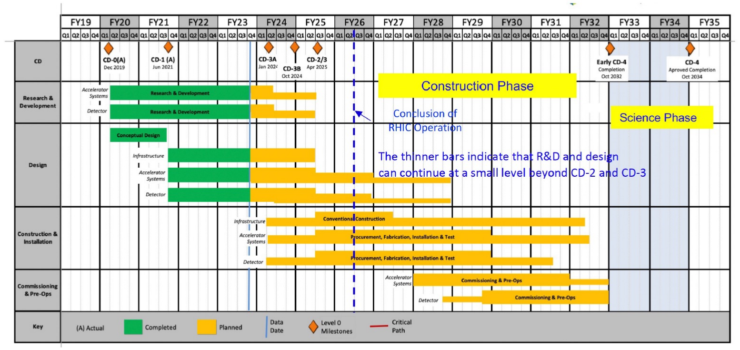


PROs	CONs
Smaller dimensions are easier to handle	Two vertical and horizontal overlapping regions – more material budget
Each endcap is intrinsically symmetric	We need to study how to attach two quadrants in a semi-circle
Strips length are shorter	
GEM foils easier to stretch	

Fabrication and Assembly Plans

- Design by end of 2024
- 2025 - 2026 Engineering Test Article and Pre-Production
- 2027 - 2029 production & QA
- 2030 Commissioning & Installation

AD
INFN Roma TV



MPGD Timeline			DURATION (years)
START DATE	END DATE	DESCRIPTION	
3/1/24	12/31/24	Detectors Overall Design	<1
1/1/25	12/31/26	Pre - Production	2
1/1/27	31/12/29	Production & QA	3
1/1/30	6/1/30	Commissioning & Installation	0.5

CyMBaL - Highlights

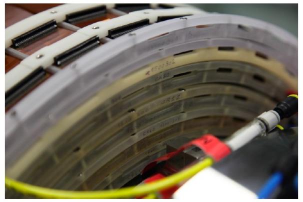
Requirements

Requirements:
- Provide redundancy and pattern recognition for tracking
- Spatial resolution: ~150µm
- Timing resolution ~10ns
- Peaking times: ~100ns
- Light detector: ~0.5%X0 in active areas
- Hermetic

External constraints:
- Tight space: about 5cm radial keeping zone
- Magnetic field ~2T
- Wrap around the SVT in the entire length

Solutions:
- Cylindrical resistive Micromegas technology developed for CLAS12 BMT:
  - Material budget ~0.4%
  - Working in high radiation environment and in B=5T
- Modular design
  - Possibly, just a single module design to pave the whole surface

Ongoing R&D:
- 2D readout with small number of channels

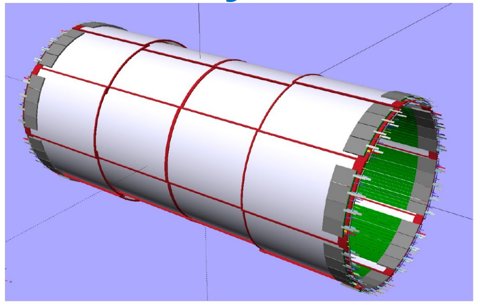


Close up of the BMT: fits in a tight space

CyMBaL – Design principles

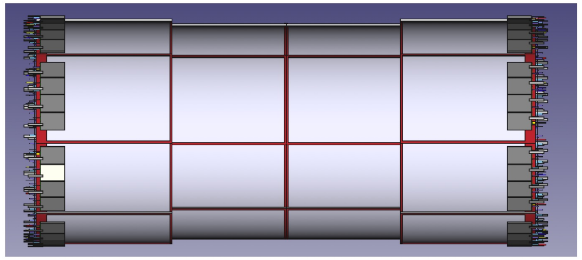
Francesco Bossù
CEA Saclay

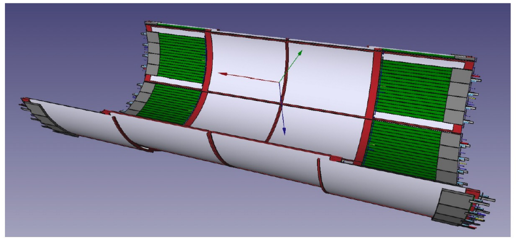
- A **single (or few) module PCB readout design**, with two curvature radii (55cm and 57.5cm)
  - **Simplify production, reduce costs**
  - **Industrial PCB production (Elvia, ...)**
  - **Micromegas bulking possible at several sites, example Saclay, Elvia, CERN, ...**
- Overlaps in phi and z allow for hermeticity
- Front end boards (FEBs) on system edges to reduce material budget



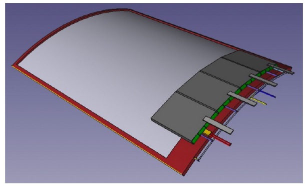
Some numbers:
- 32 module: 8 modules in ϕ times 4 modules in z
- 1024 readout channels/module
- 32K readout channels

CyMBaL – Layout

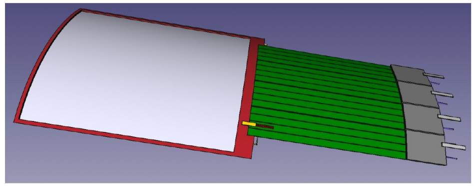




- Four modules in length
- Eight modules in phi
- Overlap in phi and z
- FEB to the periphery
- Inner modules connected to FEB with flex cables



Outer module

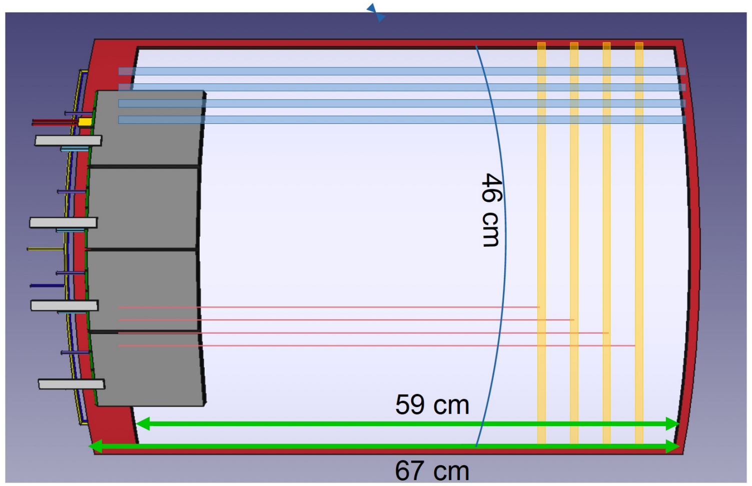


Inner module

CyMBaL – Module

Module dimensions
Z = 67 cm
R*phi = 48 cm
Active zone dimensions
Z = 59 cm
R*phi = 46 cm

Z; (r phi)
C; (z)
return trail for C strips



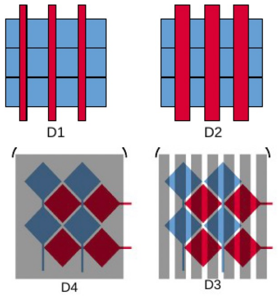
CyMBaL - Highlights

Francesco Bossù
CEA Saclay

CyMBaL – R&D 2D

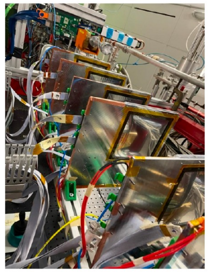
- Upgrade CLAS12 Micromegas technology from 1D → 2D readout
- Small number of readout channels
- Tests of different patterns with different resistive layers

Designs

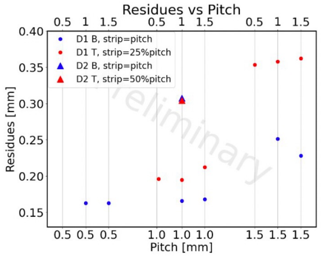


- Pitch and interstrip variation
- ASACUSA like motifs
- Variation of resistive layer (full, strips, grid)

Tests



Test beam in MAMI



Cosmics in Saclay

- Test in MAMI affected by large multiple scattering.
- Upgraded cosmics test bench
- Preparing a new test beam

Tests and analysis lead by Samy Polcher Rafael and Dylan Neff

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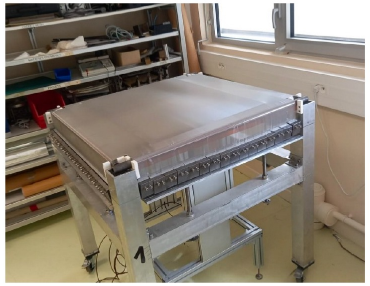
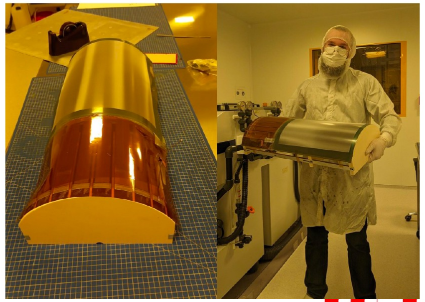
CyMBaL – Cylindrical prototype

- Refurbishing and re-learning the production of resistive cylindrical Micromegas
  - Refurbishing of the tensioning system
  - Change of photoresistive material for the bulk process
  - Bulking and bending tests using CLAS12 PCBs
- Design of the PCB is waiting for the choice of the 2D pattern
- Choice of the connector :
  - Identified a small form factor KEL connector with lightweight micro-coaxial cables
  - Tests will start in Fall





CyMBaL – Module

Module dimensions

Z = 67 cm

R*phi = 48 cm

Active zone dimensions

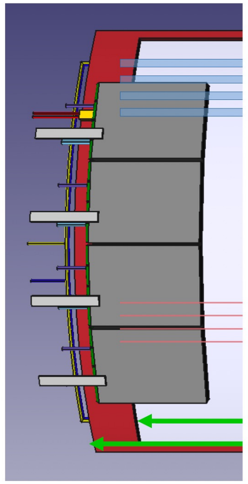
Z = 59 cm

R*phi = 46 cm

Z; (r phi)

C; (z)

return trail for C strips



Dimensions:
- Size: 65 x 46 cm^2
- Active area: 59x44 cm^2
- r/o strips: ~1 mm pitch in both directions
- Readout strips per module: 1024
- 32 channels per connector → 32 connectors

Services:
- HV: 2 channels (drift and resistive layer)
- Gas: 2 tubes (in and out)
  - Two tiles can be in series
- 4 FEBs per module
- 4 ASICs per FEB:
  - 1 4-lines bidirectional optical fiber FireFly to RDO
  - 2 short flex cables per ASIC (SALSA)
  - Low voltage
  - Cooling in and out, possibly in series

Outlook

- The R&D on 2D readout is progressing
  - Tests in MAMI affected by large multiple scattering
  - Ongoing tests with cosmics
  - Preparation of new prototypes with not-yet-tested combinations of resistive layer and 2D r/o
- Re-learning the cylindrical detector techniques ongoing and choice of the connector are preliminary steps towards the scale 1:1 prototype
- Saclay internal:
  - Internal review in November
  - A new and more formal structure of the CyMBaL + SALSA project
  - New people joining

MPGD Detectors Stability – INFN - LNF experience

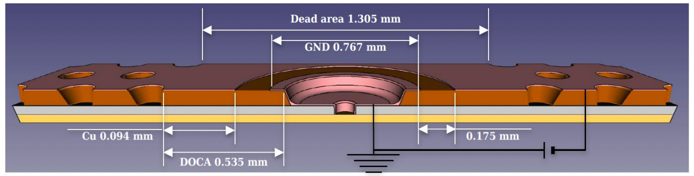
Matteo Giovannetti
INFN-LNF

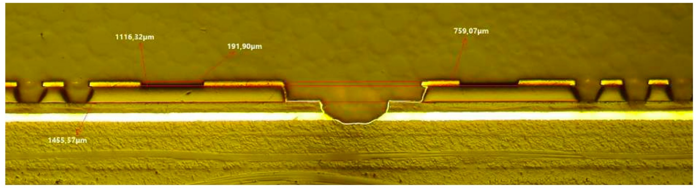
The PEP-DOT μ-RWELL

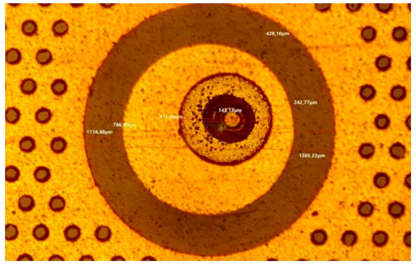
DLC-GND pitch [mm]	Dead Zone [mm]	GND width [mm]	Insulation gap [mm]	DOCA [mm]
9	1.3 (1.6%)	0.767	0.175	0.535

- The most recent high rate layout
  - **P**atterning-**E**tching-**P**lating
- The DLC ground connection is established by creating **metalized vias from the top Cu layer through the DLC**, down to the pad-readout of the PCB
- The dead zone is ~2%

Our main activity is R&D on **high-rate μ-RWELL with pad R/O** for LHCb U2.







Some critical construction aspects

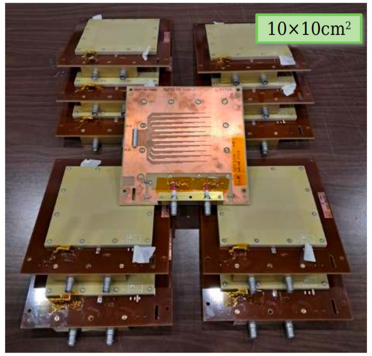
The **main parameters** of the detector, crucial **for stable and efficient operation**, are:

- The **resistivity of the DLC**, which is closely related to the quenching of the discharge amplitude.
- The **DOCA** (Distance of Closest Approach): the distance between conductive grounding elements of the DLC and the nearest amplification region (the wells of the amplification stage). This parameter is related to the DLC resistivity. **Optimizing this parameter ensures the safe operation of the detector.**
- The **distance between the DLC and the readout stage** (pads or strips), coinciding with the **prepreg thickness**, which determines the amplitude of the charge induced on the readout**. By maximizing this charge, the detector can operate at a low gas gain**, increasing the stability of the detector.

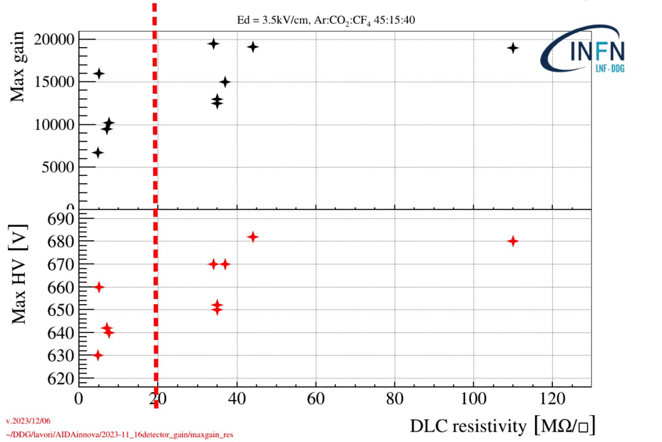
Further possible improvement of the detector stability can be done **optimizing the amplification stage** by **reducing the well pitch: 140μm, 110μm, 90μm** (work in progress)

Other important construction aspects include the **choice of materials**, such as using **PEEK instead of FR4** for frames, thus **minimizing hygroscopic and outgassing materials.** Since the base material for the cathode **must be made of FR4**, we have recently produced cathodes where **copper covers the entire surface facing the active area**, up to the inner edge of the PEEK frame.

Co-production pilot test – results

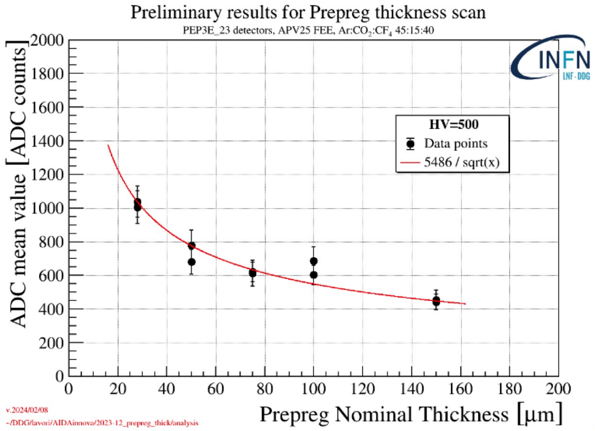


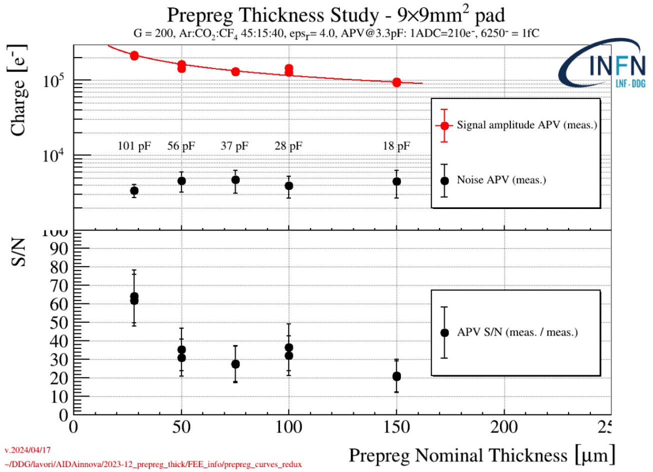
- **16** co-produced protos have been **produceded**
- **15/16 are fine → 94% yield**
- 1 should be re-cleaned



- Characterized with **X-ray gun → Gas gain** measurement
- **Next** step: measure of the **pulse amplitude** (APV25) vs Gas gain

Prepreg thickness optimization



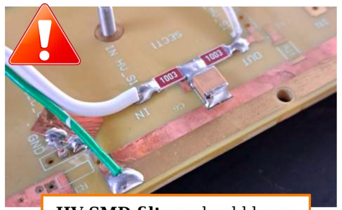


28μm thick prepreg maximize both the **amplitude of the signa**l induced on the pad readout, and **S/N ratio** (measurement done with APV25)

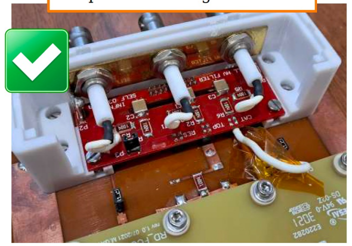
Electron-Ion Collider

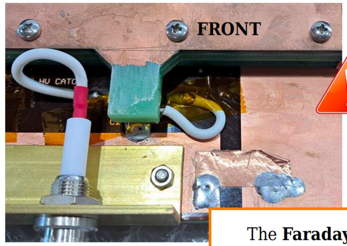
MPGD Detectors Stability – INFN - LNF experience

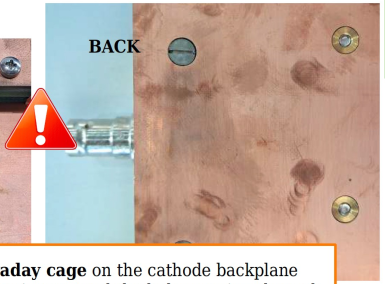
Two design good habits



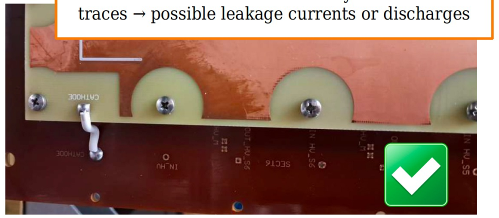
HV SMD filters should be on external board and not on kapton (FR4 is even worse) → possible leakage currents





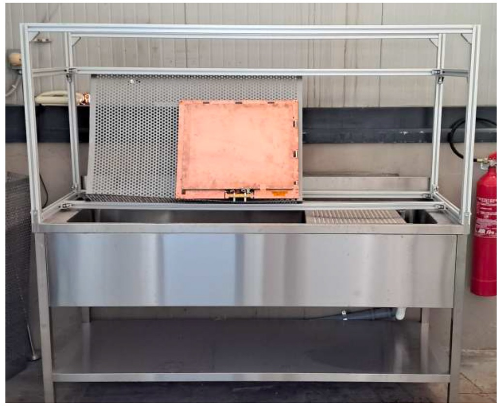


The **Faraday cage** on the cathode backplane should have rims around the bolts passing through the frame. Such bolts could be very close to the HV traces → possible leakage currents or discharges



Detector washing and electrical cleaning @ LNF

At LNF, we are installing a **detector washing station** with a stainless-steel tank and a high-pressure car-washing machine using deionized water.
After washing, the detector is placed in an **oven at 90°C**. After 24 hours, it is gradually powered by increasing voltage from 300V to 680V, following Rui's guidelines.



Detector warm up and operation

Initial power-up procedure:

At CERN, detectors undergo the Electrical Cleaning, a conditioning procedure at a temperature of 90°C where the HV is increased step by step from 100 V up to 680 V, essentially without current limitation.
This procedure allows for curing potential manufacturing defects by exploiting the current draw. Critical areas are deactivated by burning the thin layer of DLC at defect sites **(Rui will surely show some photos).**

Detectors are closed with their cathode at CERN and then delivered.

At LNF, an initial power-up procedure is followed according to the following steps:

- Test with a MEGGER up to 500V
- Flushing with the gas mixture at 100 cc/min for approximately 24-48 hours (depending on detector size) monitoring the humidity (ppm or %)
- Ramp-up of the HV: 100, 200, 300, 400, 450, 500, 520, ... 660 V
- Measuring gas gain with X-ray
- Readout test with APV with X-ray (using internal trigger)

See spare for additional info on both the Megger test and the first operation

Summary

CERN: μ-RWELL production + electrical cleaning
LNF: quality control w/ X-ray - gas gain measure + R/O control with APV25
in case of minor problems -> whashing station + oven

A great effort in R&D has been made in recent years. We are confident that we can set many of the detector's parameters to maximize its stability.

Detector parameters have been set to **maximize stability and gain**:
- **ρ_S > 50 MOhm/sq.** (taking into account 30% uniformity during sputtering)
- **DOCA** depending on ρ_S, **O(500μm)**
- **prepreg thickness 28μm** (depending on the FEE)
- (w.i.p.) ampl. stage optimization → protos under production

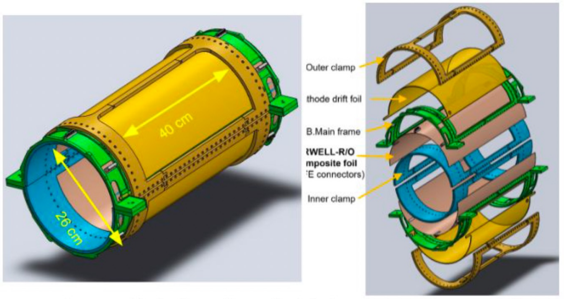
Detector materials optimization:
- **PEEK instead of FR4** whenever possible (e.g. frames) to minimize hygroscopic materials
- copper cathode closer as possible to the frame to minimize exposed FR4 in the active area
- metallic bolt: patterned faraday cage
- **HV filter NOT onboard** (passable for R&D, not suitable for experiment production)

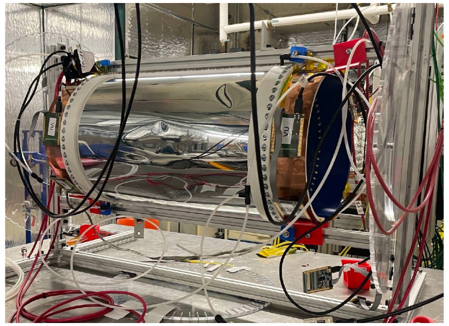
Detector production:
- **Standardizing** the production processes, including the **etching chemistry** and the selection of **parameters and materials**, is crucial because it ensures consistent quality, enhances reliability, and maximizes stability.
- **high rate** layout: The **PEP layout provides excellent results**, but the **SG layout**, already successfully characterized in terms of stability and high-rate performance, is likely to be **simpler and more reliable from a manufacturing process perspective** (less manufacturing steps, no exposed kapton, no ground electrodes in the active area, no plating holes yield)

Matteo Giovannetti
INFN-LNF

MPGD Detectors Stability – Florida Tech experience

Cylindrical μRWELL Introduction

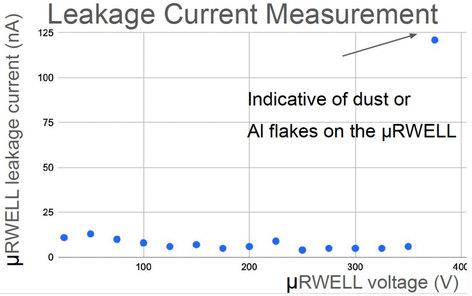




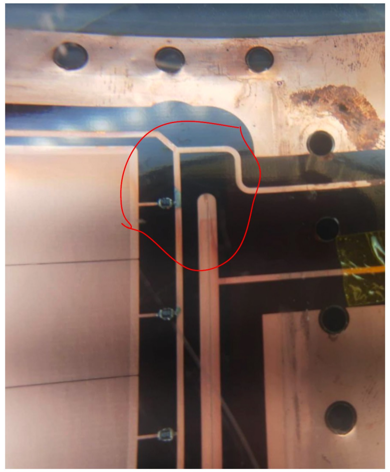
- Drift foil (Al-mylar) had developed dents during tests at FNAL

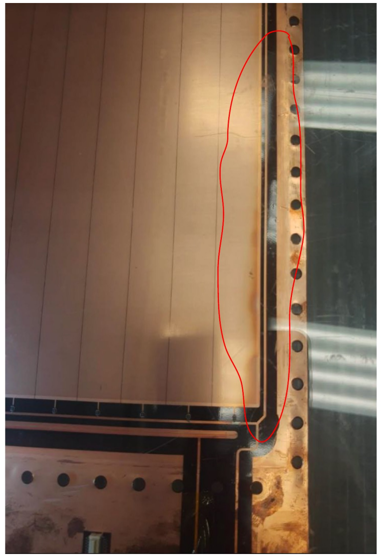
HV and gas leakage testing

- In a test assembly with drift foil & mock μRWELL foil,
  - pressure drops from 20 mbar to 10 mbar in one hour
  - the drift shows low leakage current up to 1000V
- In an assembly with drift foil & real μRWELL foil,
  - pressure drops from 20 mbar to 10 mbar in two min.
  - μRWELL has small leakage current up to 375V
  - above 350V, sudden current increase observed
  - This HV test was with ½ Honeycomb cylinder



uRWELL foil imperfections



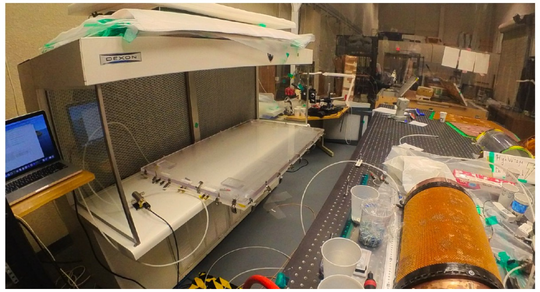


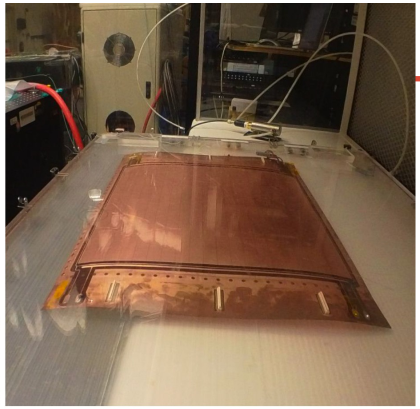
μRWELL Foil cleaning

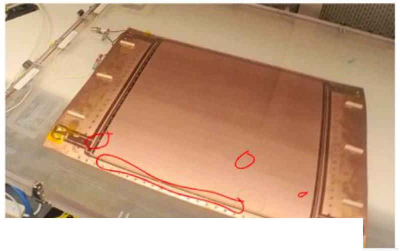
- Foil Inspection Testing (Acrylic box)
  - Heat discoloration side - 2-3 dark spot/red spot/ hole spot

Process for Cleaning

- Vacuum cleaning box, rollering box, rollering foil, 3 different rollers
- Nitrogen Flushing to acrylic box
- Dust counts with Kanomax : in counts/m^3 for .3um,.5um,5um)







Gas line schematic and particle counts

Nitrogen Gas Tank Regulator — 5um Dust filter — Flow Meter — 5um Dust filter — Acrylic Box

- Tested Nitrogen Line at various points with particle counter
- Added two dust filters to see if results improved
- Will Repeat Measurements with Co2

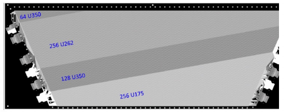
Pietro Iapozzuto
Florida Tech

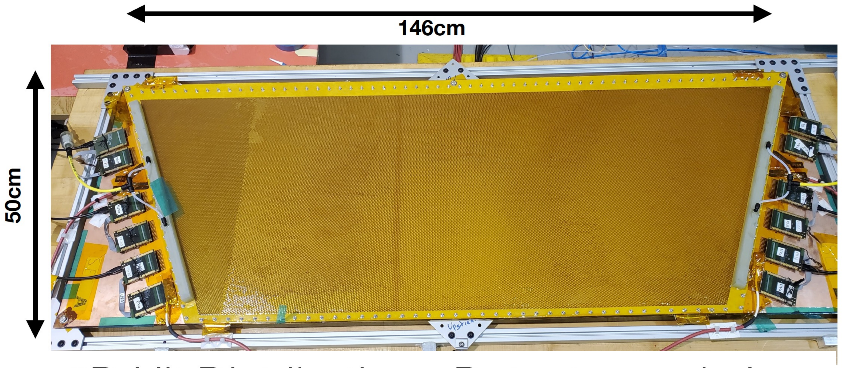
Kanomax location	Dust Counts/m^3 (.3um, .5um, 5um)
After regulator	(1.96E, 6.06E4, 3.7E3)
After flow meter	(1.51E3, 7.06E2, 1.59E3)
Before acrylic box	(2.47E3, 1.71E3, 3.53E2)
After acrylic box	(2.48E3, 1.41E3, 1.77E2)

MPGD Detectors Stability – JLab experience

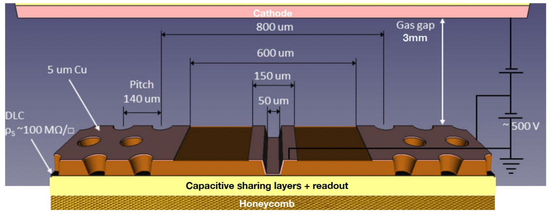
CLAS12 μRWELL Prototype - Overview

- 2D-U/V strip readout with 10 deg stereo angle
  - pitch 1mm
  - various strip widths (to find optimal combination)
- Capacitive sharing
- Electronics APV25 and SRS

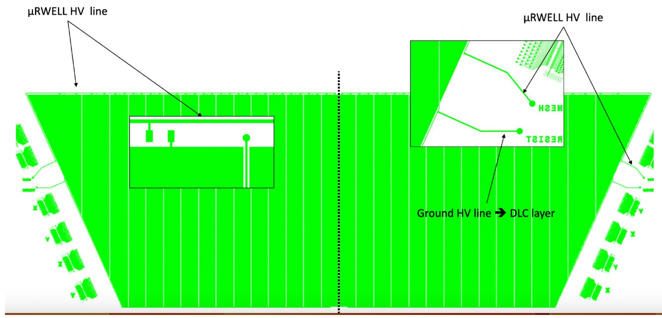




CLAS12 Prototype - Detector Structures



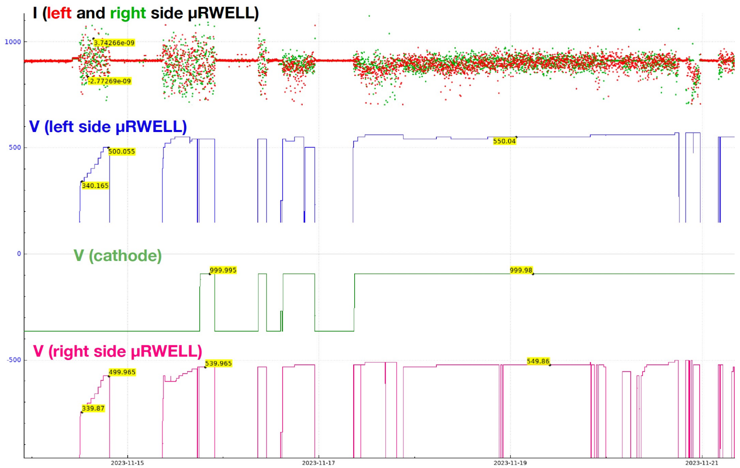
Cross section of prototype



μRWELL foil HV lines

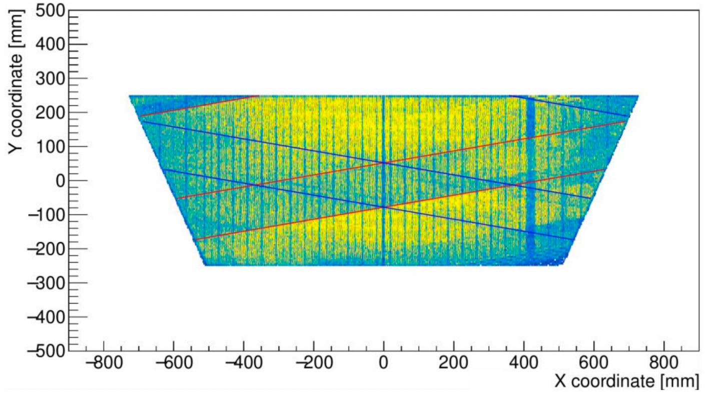
Split in two separate halfs

HV Test with Ar:CO_2 (80:20) and cosmic



- stable operation
- leakage currents <2-3nA up to 550V on μRWELL and 1kV on cathode

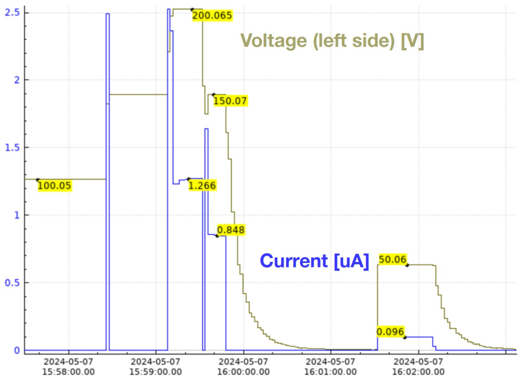
2D Hit Distribution - Detector works!



- μRWELL at 570V, cathode at 1020V, Ar:CO_2 (80:20)
- Substructure from strips, HV segmentation and APVs visible

But: Issues with cathode and connections required us to replace cathode —> done in cleanroom at UVA together with Nilanga Liyanage's group

Leakage seen after Cathode Replacement



- CO_2 gas
- Leakage current proportional to voltage up to 600V
- both sides have leakage
- decided to keep running with leakage and take data since current just increases linearly with voltage

Conclusions / Personal Take

- Large risk of bringing dust or other particles on the μRWELL or the drift region when it is open. We were very careful and had the expertise of GEM experts at UVA when we replaced cathode. Detector was opened for a very short time.
- Nevertheless, our μRWELL prototype runs so far quite stable even with high leakage from dust or other particles and we could get data.
- For the serial production of μRWELL for CLAS12, we prefer to glue the detector and build extra spares.
- Note: We can not remove individual HV sectors from the support without opening the detector fully because the connection is under the frame —> better to put these outside the frame so access is possible in case leakage occurs

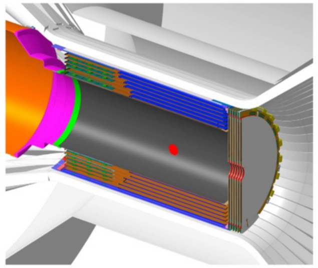
MPGD Detectors Stability – Saclay experience

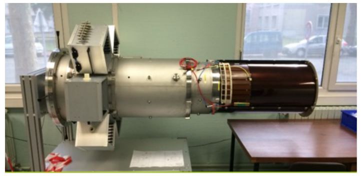
Fabien Jeanneau
CEA Saclay

MPGD facility @ Saclay

- Everything for the bulk process
- Masks and PCB ordered by industrial partner (Elvia)
- Serigraphy machine for resistive deposition
- R&D:
  - P2, EIC, … prototyping
  - Picosec, PIMENT
  - Bulk on glass substrate
  - …
- And small/medium productions:
  - TPOT for sPhenix
  - P2
  - EIC
- Investments:
  - New oven
  - Press
  - [Laser Direct Imaging (LDI)]

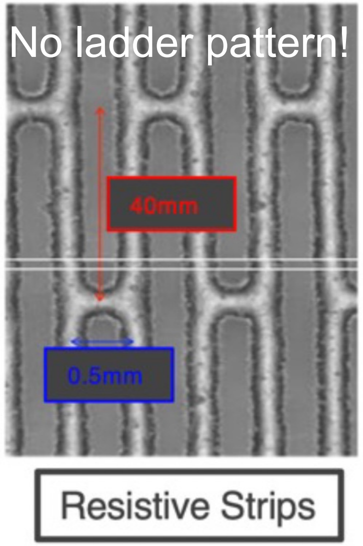
CLAS12



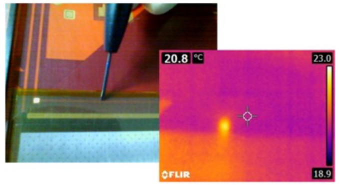


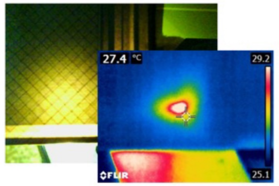
- Cylindrical Micromegas
  - Resistive strips
  - 6 Layers with different radius (18 det.)
  - 1D drift C or Z, 3mm drift
  - Very light : 0.5% of X0
- Forward Disk Micromegas
  - 20MHz integrate rate
  - 2 independent resistive zone
  - 1D strip design rotated at 60 deg
- Conditions
  - 5T Magnetic field, gas Ar/Iso (90/10)
  - 11GeV e⁻ beam up to 10^{35} cm^{-2}s^{-1}

- **PCB + resistive bulk produced at Cern**
- **Integration and tests in Saclay**



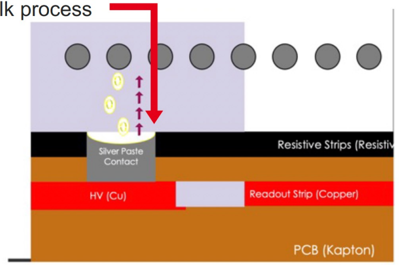
Silver paste migration

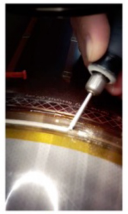




=> Thermal imaging shows that high current appeared on the silver paste connection between the resistive layer and the PCB

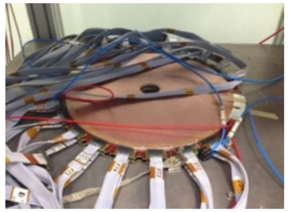
Add tape during bulk process

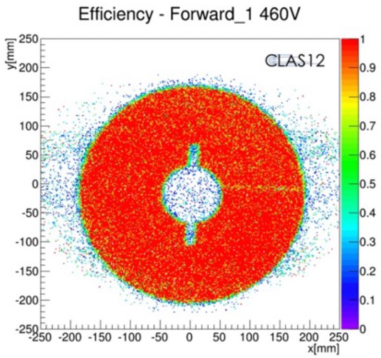




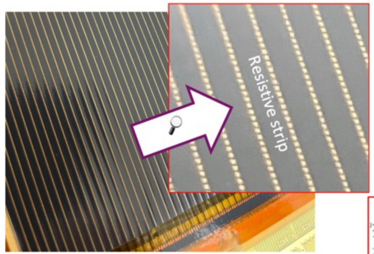
Solution: Remove the mesh over the full silver paste zone, and modify future layout

Nowadays:
- PCB are ordered with Kapton already pressed and glued
- Resistive paste serigraphy at Saclay
- No silver paste (robust HV contact)

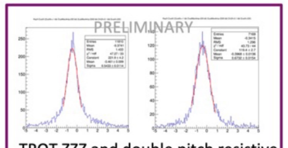




Zig zag readout



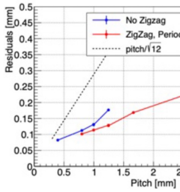
Large resistive strips over zigzag strips



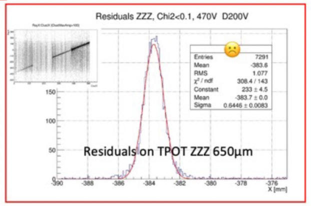
TPOT ZZZ and double pitch resistive
=> 2mm:620µm, 0.5mm:470µm

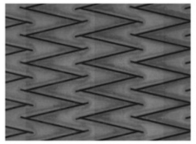
TPOT project

02/2022 : New TPOT Z Zigzag (ZZZ)
- Zigzag from LDRD program
⇒ Efficiency OK 98%
⇒ Resolution ~650µm



ZZ R&D from LDRD pro





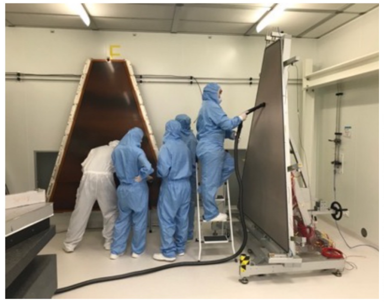
ZZ strips

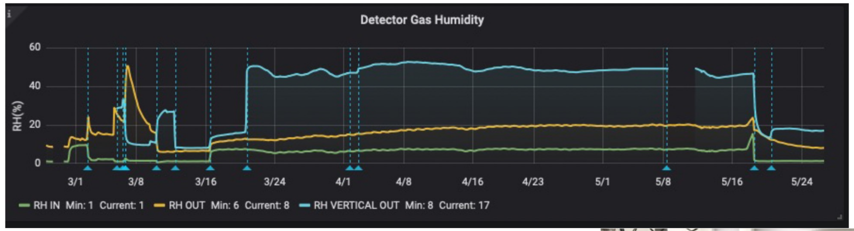
=> 470um resolution is good enough for the TPOT project since integration time can compensate resolution
=> Noise level are ok with SAMPA

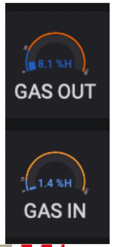
MPGD Detectors Stability – Saclay experience

HV instabilities: causes

- Residual ionic contamination → cleaning procedures reviewed
- Mesh mechanical imperfections → mesh polishing
- Humidity → monitor humidity, dry panels and modules, increase gas flux
- Low resistivity of anode resistive strips
- ~~Low quenching gas mixture~~

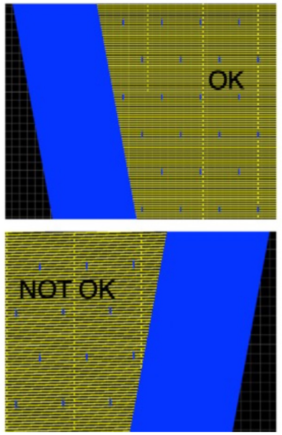




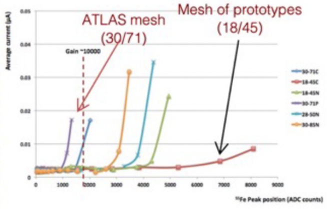


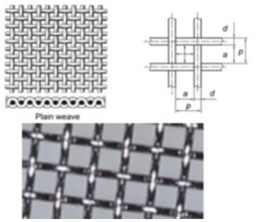
Issue causes ?

- Design issue
  Resistive interconnections extending to the edge: reduce R_{min} → Passivation

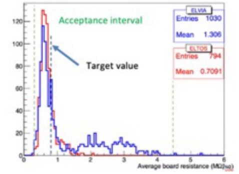


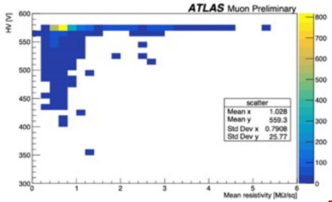
- Mesh selection
  The mesh used for ATLAS is the less performing for HV stability



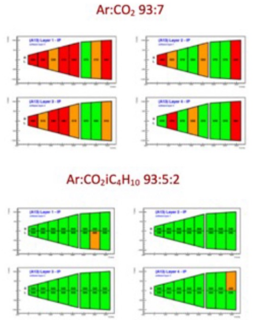


- Resistivity
  Target value too low (optimised on small bulk prototypes with 18/45 mesh). Min resistance not enough to quench discharged close to the edge
  → Process optimisation (when possible) + passivation



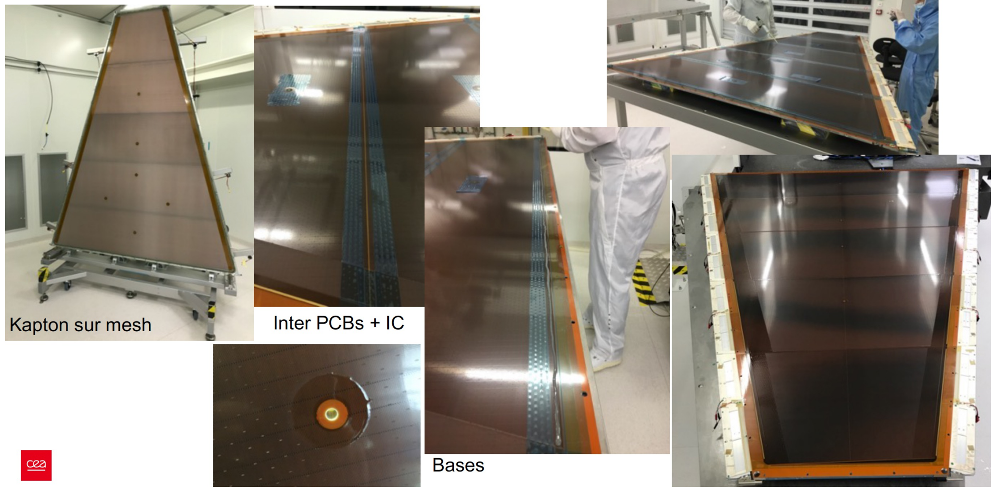


- Gas mixture
  Baseline gas mixture $Ar:CO_2$ 93:7 ok for prototypes not for final detectors. Big improvement by adding 2% of iC_4H_{10}
  → Gas changed



From P. Iengo – MPGD 2022

Example of Passivation

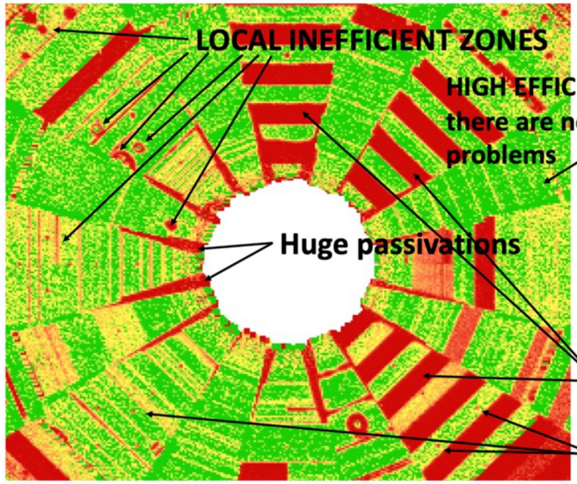


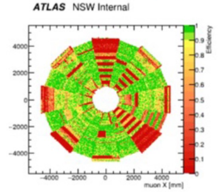
Kapton sur mesh

Inter PCBs + IC

Bases

MM- efficiency map (layer 2, side C)





Efficiency is high when no HV – DAQ problem are present

Green > 95%
Light green > 90%
< 95%

ZEBRA (animal) PATTERN – DAQ related problem which impact a lot the efficiency (46 / 256 sector-layer)

INTERCONNECTIONS

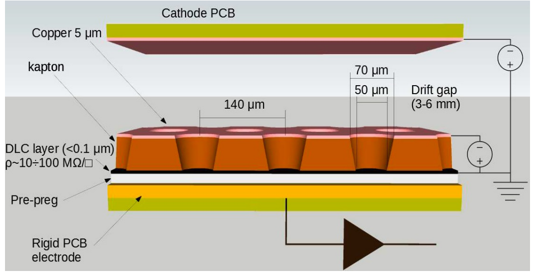
Fabien Jeanneau
CEA Saclay

MPGD Stability – CERN Workshop experience

Rui de Oliveira
CERN

Cause of instabilities in resistive detectors

- 1/ Dust → during the detector assembly
  - Detectors should be assembled under clean room condition
    - All parts must be rinsed with US DI water and dried , in the clean room .
    - In case of leakage current , tacky rollers can help but this is not always efficient.
    - In case of problem a new US or High-pressure DI water rinse should be performed.
    - In case of re-opening the user should be prepared to re-US clean the detector
    - Avoid copper alloys for screws or nuts , only SS
  - Gas filters
    - Putting gas filters prevents dust entering in the gas volume.



- 2/ Humidity → during operation
  - Part of the humidity comes with the gas
    - But gas RH is quite easy to measure and adjust.
  - The greater part comes from ambient Air humidity, passing through the materials !
    - Difficult to measure , difficult to estimate
    - And some polymers are strongly storing moisture (PI , Photoimageable coverlay)

Clean room

- Detectors are sensitive to dust ranging from 5um (invisible) up to 100um
- Clean room class → particles per cubic foot

	Federal Standard 209E Class Limits					
FS209E	Particles / ft³					ISO Equivalence
	≥0.1µm	≥0.2µm	≥0.3µm	≥0.5µm	≥5.0µm	
Class 1	35	7.5	3	1	N/A	ISO 3
Class 10	350	75	30	10	N/A	ISO 4
Class 100	N/A	750	300	100	N/A	ISO 5
Class 1,000	N/A	N/A	N/A	1,000	7	ISO 6
Class 10,000	N/A	N/A	N/A	10,000	70	ISO 7
Class 100,000	N/A	N/A	N/A	100,000	700	ISO 8

Too good
Too good
perfect
Possible
difficult
impossible

Detector qualification test at CERN

Detector open in oven @ 90deg
-1 hour drying time before applying any voltage
-apply voltage , massive electrical cleaning →10uA leakage current allowed
-after 1 day : air RH negligeable and detector humidity trapped negligeable → 660 to 680V (1nA)

Chemical removal of evaporated materials.
-Potassium permanganate followed by Chromic acid passivation

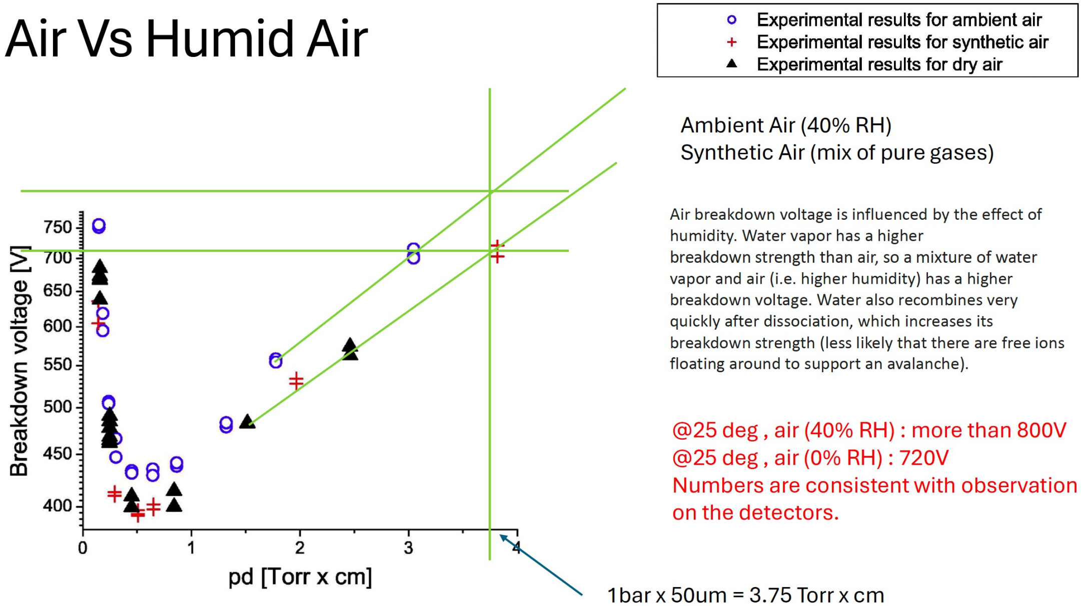
Detector closed in oven @ 50deg
-soft electrical cleaning allowed: 50 to 100nA during 5 sec max. More than 5 sec → reduction of 100V
-After 2 days : air RH stabilized at 15% and detector humidity stabilized at 15% → 760V (1nA)

Detector closed in oven @ 35deg
Immediate test : air RH immediately raise to 20% , detector (memory of 15%) → more than 800V (1nA)
After 2 days : air RH is stabilized at 20% , detector humidity is stabilized at 20% → 750V (1nA)

Detector closed out of the oven @ 25deg 50%RH
After 15 min : air RH immediately raise to 50% , detector (memory of 20%) → 790V (1nA)
After one day , we start to see a serious impact on the maximum voltage → 700V (1nA)
After 2 days → 650V (1nA)
After one week even at 500V the detector start to show dangerous instabilities (uA peaks)

Humid air seems to have a higher breakdown voltage
Moisture seems to come back in the detector within a day
Humidity trapped in materials is the main problem

Air Vs Humid Air



1bar x 50um = 3.75 Torr x cm

Ambient Air (40% RH)
Synthetic Air (mix of pure gases)

Air breakdown voltage is influenced by the effect of humidity. Water vapor has a higher breakdown strength than air, so a mixture of water vapor and air (i.e. higher humidity) has a higher breakdown voltage. Water also recombines very quickly after dissociation, which increases its breakdown strength (less likely that there are free ions floating around to support an avalanche).

@25 deg , air (40% RH) : more than 800V
@25 deg , air (0% RH) : 720V
Numbers are consistent with observation on the detectors.

MPGD Stability – CERN Workshop experience

Rui de Oliveira
CERN

Humidity absorption/desorption of PI

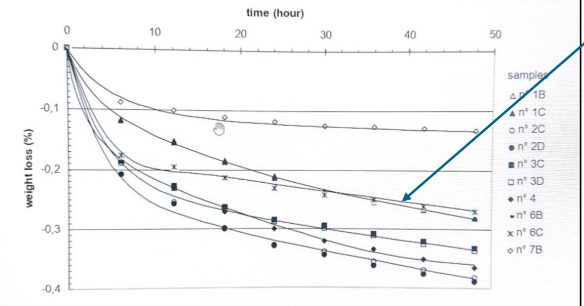


Figure 1: weight loss after baking at 105°C as a function of time (see equation 1).

- 2mm PI plate
  - Weight loss at 105 deg → around 0.3% after 48 Hours.
  - Weight loss at 120 deg → around 0.3% after 12 Hours.
  - Rule : multiply the time by 2 if you decrease the temperature by 7deg.
  - 0.3% weight recovery after 1 month .
- 50um PI
  - Thickness 40 time less than previous numbers
  - Same drying should be obtained after 1h at 105deg .
  - @ 50 deg , it should take 5 days to get the same drying.
  - weight recovery time for 50um PI should be 24h.

- looking at Air Vs Humid Air curves , humidity storage in PI and measurements with detectors

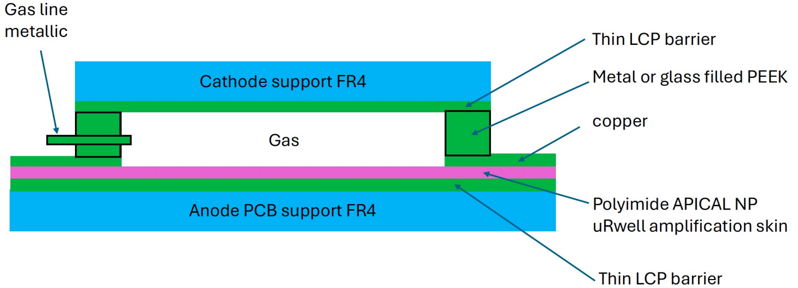
The conclusion is clear :
Instabilities are triggered by water in materials , not directly by gas RH !
At the opposite, some water in the gas improves the Vmax

Any detector must be dried before powering it (at least 50 deg-5 days).
Or stored a long time in air with RH below 20%.
The detector should be as hermetic as possible to ambient moisture penetration , such that the desired level of moisture is adjusted with the gas.

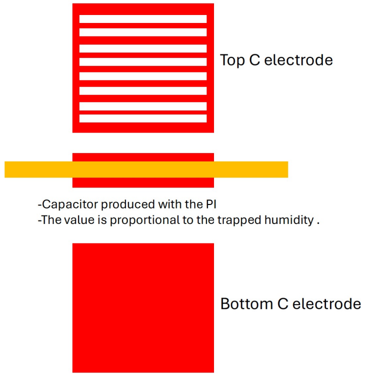
Moisture barriers

Copper : not measurable
Teflon 0.01%
LCP: 0.1%
Glass filled PEEK: 0.11%
Best Polyurethane : 0.3%
STD Epoxy : 0.4%
Best Polyamide : 0.7% (Rilsan tubes)
STD polyimide Apical NP: 3%

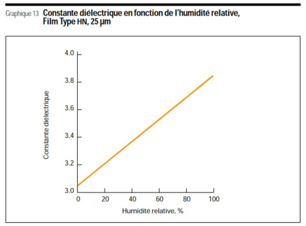
water absorption of different materials



Real time measurement of humidity trapped in materials



-Capacitor produced with the PI
-The value is proportional to the trapped humidity .



Between 10 and 40% RH
+10% variation on Dk

conclusion

- Dust is a problem but only during detector assembly
- Working gas moisture is not the main problem
- Moisture penetrating the detector through materials is the problem
- There is ways to limit the moisture penetration
- There is may be a way to do a real time measurement of the moisture of critical materials.

MPGD Digitization – AC- LGAD experience

Prithwish Tribedy
BNL

Quick summary of the current status

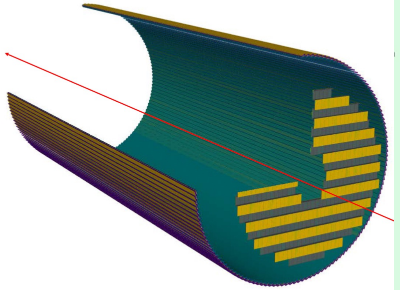
Files   EICrecon / src / detectors / BTOF /

Overview

The digitization model for AC-LGAD system has step:

- Conversion of GEANT deposited energy into ADC/TDC
- Implementation of a charge-sharing
- Incorporating noise due to full readout chain

In EICrecon has two modules:
1) Segmentation/neighbor finder,
2) Digitization/noise

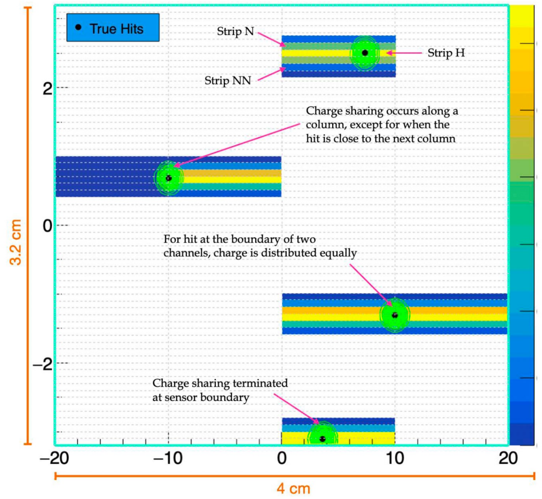


GEANT Hit → Segmenter module (Neighbor finder) → Digitization module (TDC/ADC) ⇄ Noise module (Jitter, slewing) → Reconstruction module

digi-block

Using BTOF as the reference example for digitization of AC-LGAD systems

Charge sharing: Strip geometry



Summary

Digitization

Energy deposited (From GEANT)
↓
Charge (MIP)
↓
Analog signal (Trial signal shape parameterized by rise time & width from AC-LGAD test beam, ASIC charge injection studies)
↓
ADC (8 bit), TDC (10 bit) (Using a 40 MHz clock)

Charge Sharing

Distribute in neighbour channels based on a Gaussian (trial) within sensor boundaries (Trial clustering using the center weight technique)

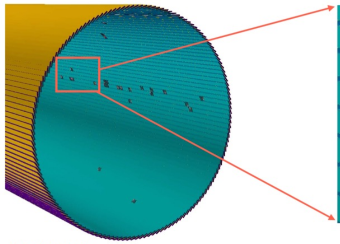
Detector Noise

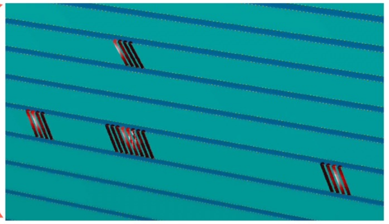
To do with input from ASIC testing data

Ext. parameters

Reference clock (T=25 n
Delay cells
Thresholds (Fixed gap)

Task at hand





GEANT hit

```
TOFBarrelRecHit.cellID = 18425070710973014364
TOFBarrelRecHit.position.x = 636.281799
TOFBarrelRecHit.position.y = 32.092369
TOFBarrelRecHit.position.z = 1077.500000
TOFBarrelRecHit.time = 4.227000
TOFBarrelRecHit.edep = 0.000184
```

Digitized hit with charge sharing

```
TOFBarrelADCTDC.cellID = 18425352185949725020, 18425070710973014364, 18424789235996303708, 18424507761019593052, 18424507782494429532...
TOFBarrelADCTDC.charge = 359, 785, 359, 34, 34 ...
TOFBarrelADCTDC.timeStamp = 197, 194, 197, 215, 215 ...
```

First challenge: Deciphering the cell ID

Cell ID helps to go to local co-ordinates & group cells together for signal sharing

1. Convert the ID to the 64-bit binary ID

$18423381384371622236_{(10)}$ Cell ID for a strip in Barrel ToF

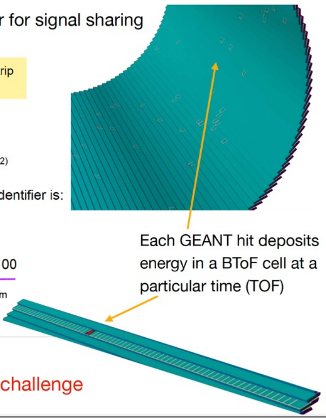
$1111111110101100111111111110000100000000010000001111010001010111100_{(2)}$

2. Split the binary ID based on the identifier in the xml code. For Barrel ToF, the identifier is:

<id>system:8,layer:4,module:12,sensor:2,x:32:-16,y:-16</id>

111111 11101011001111111111110000100000000 01 000000111101 0001 01011100

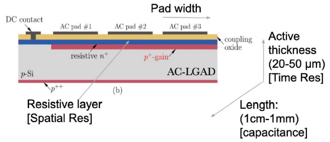
y   x   Sensor   Module   Layer   System

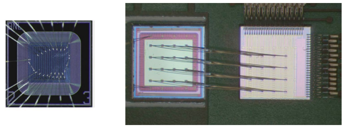


Each GEANT hit deposits energy in a BToF cell at a particular time (TOF)

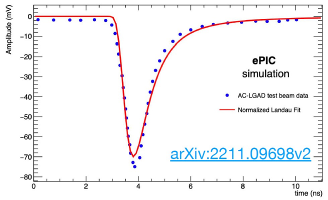
Deciphering the cell-id is the first step & was our major challenge

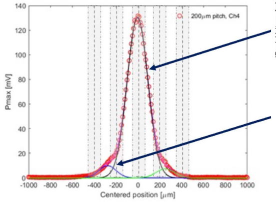
Input from sensor+asic+RDO

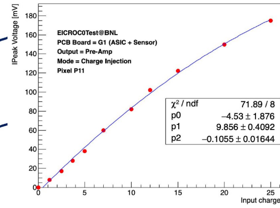




AC-LGAD   EICROC0





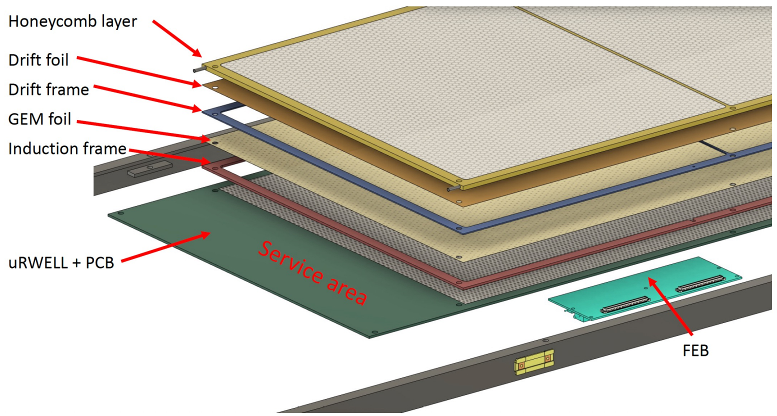


Input from hardware on signal shape, charge spread, pre-Amp output

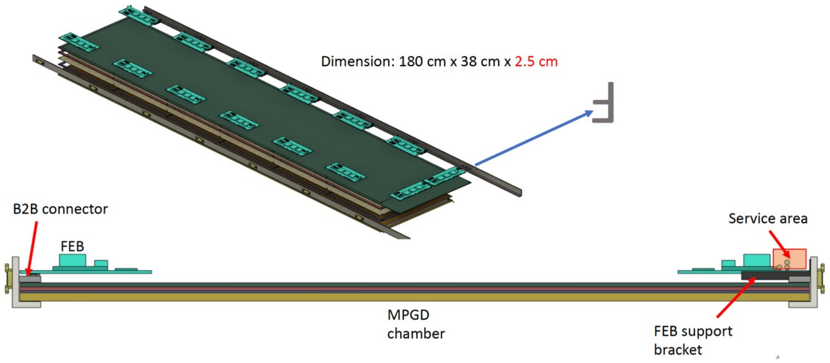
MPGD Engineering & Integration – BOT

Seung Joon Lee
JLab

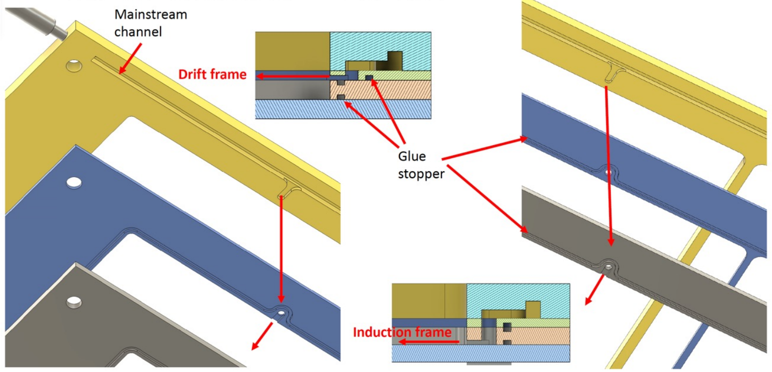
BOT structure



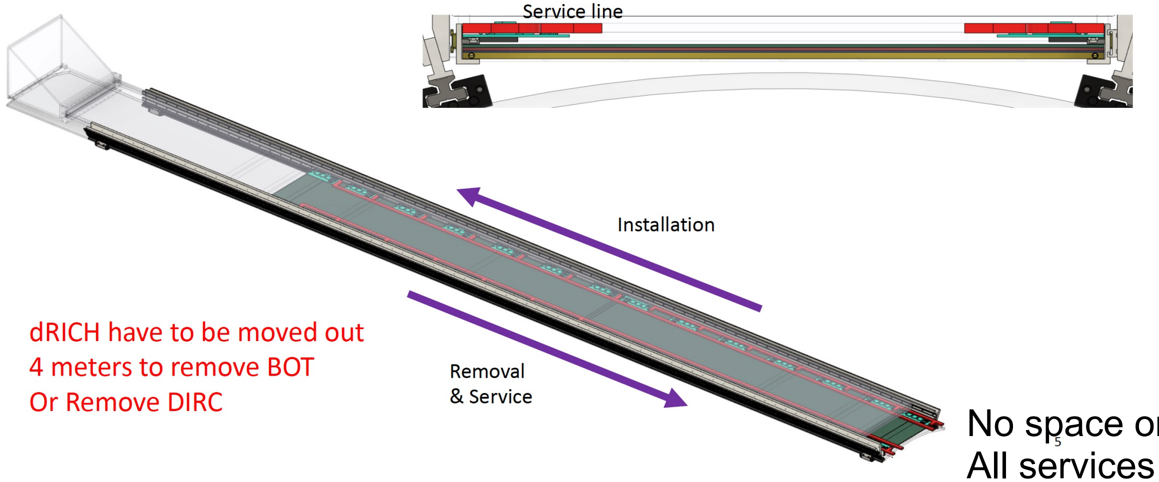
Detector Structure



MPGD chamber - Gas line

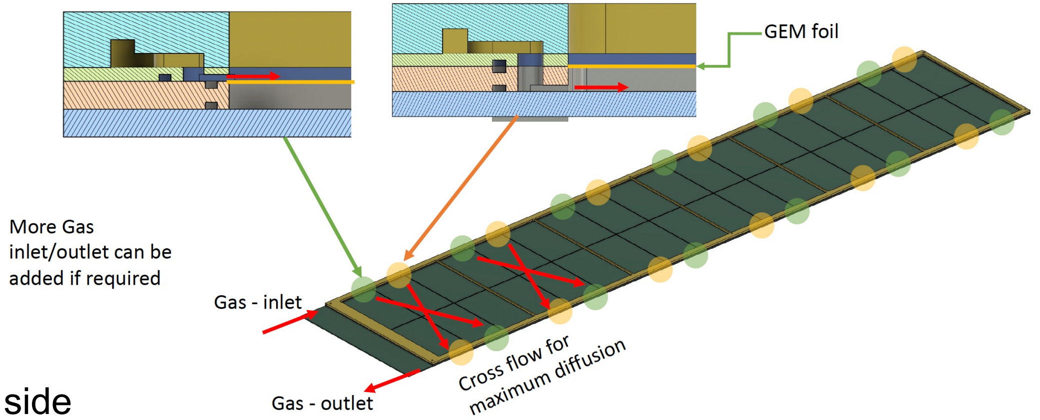


Service Line (BOT)



dRICH have to be moved out
4 meters to remove BOT
Or Remove DIRC

MPGD chamber - Gas line

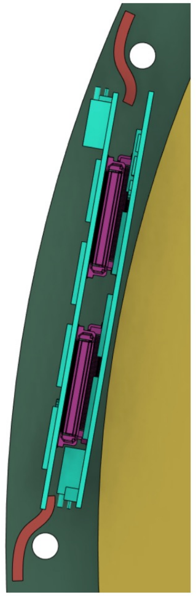


No space on the lepton side
All services need to exit at the hadron end ?!

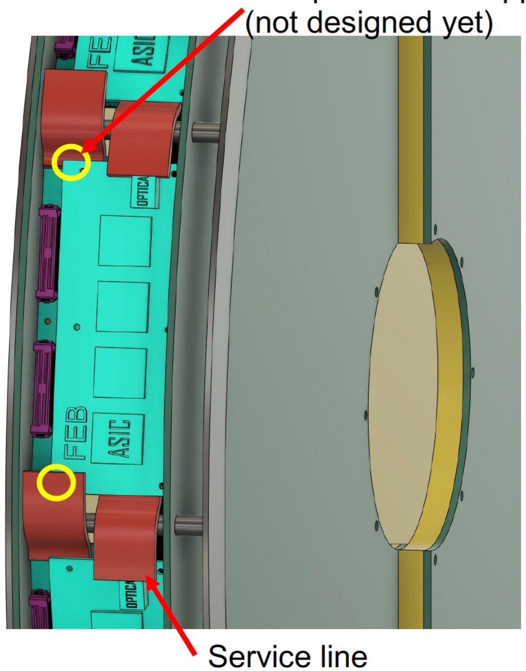
MPGD Engineering & Integration – ECT

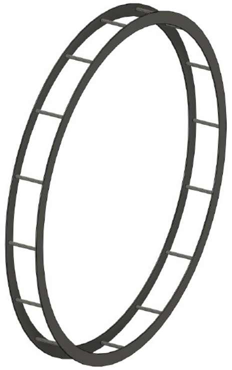
Seung Joon Lee
JLab

FEB and Service

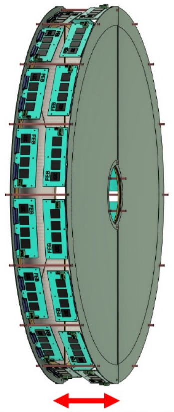


Front view without front disc





Double rim
support structure

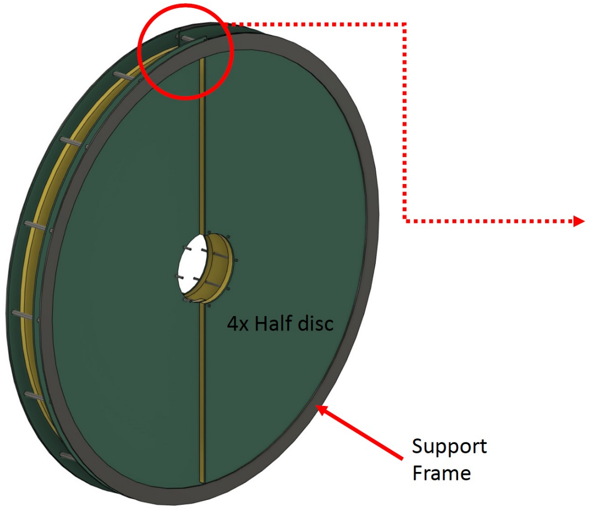


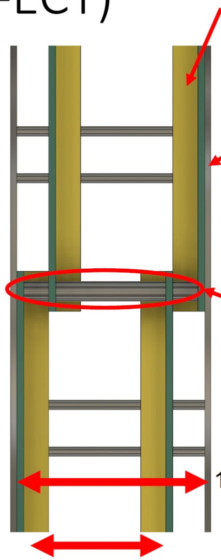
15+ cm for HD-ECT

Open problems:

- 32 FEB seem not to fit in the available space – to be optimized
- Impact of a support ring, FEB and services material budget on tracks reconstruction – to be simulated

Current Design of ECT (E-ECT)

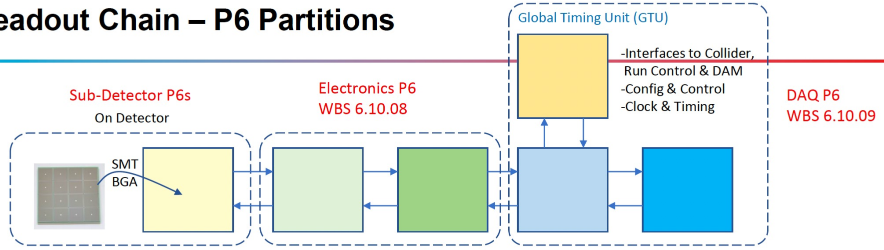




MPGD Electronics Read-out

Fernando Barbosa
BNL

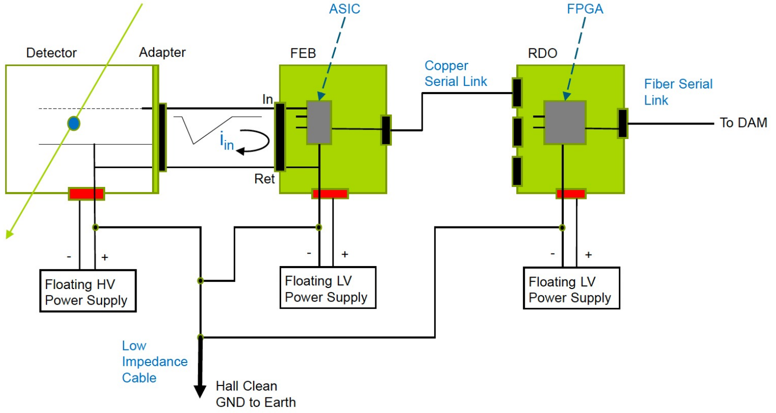
Streaming Readout Chain – P6 Partitions



Name	Sensor	Adapter	Front End Board (FEB)	Readout Board (RDO)	Data Aggregation Module (DAM)	Computing
Design	Detector Specific	Detector Specific	Detector Specific	Few Variants	Common	Common
Function	-Multi-Channel Sensor	-HV/Bias Distribution -HV divider -Interconnect Routing	-Amplification -Shaping -Digitization -Zero Suppression -Bias Control & Monitoring	-Communication -Aggregation -Formatting -Data Readout -Config & Control -Clock & Timing	-Computing Interface -Aggregation -Software Trigger -Config & Control -Clock & Timing	-Data Buffering and Sinking -Calibration Support -QA/Scalers -Collider Feedback -Event ID/Building -Software Trigger -Monitoring
Attributes	-MAPS -AC-LGAD -MPGD -MCP-PMT -SiPM -LAPPD	-Sensor Specific -Passive	-ASIC/ADC -Discrete -Serial Link	-FPGA -Fiber Link	-Large FPGA -PCIe -Ethernet	-COTS -Ethernet

❖ Nomenclature standardized after August 2022 Electronics & DAQ Review (PDR 1)

Interconnection Model



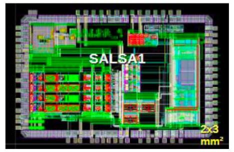
- Consider low impedance and multiple connections for input signal return currents.
- Floating power supplies allow for GND reference at the detector to the hall clean GND column in IP6.
- Make provisions for GND connections on PCBs and detectors.
- Consider segregating sub-detector systems' grounding.

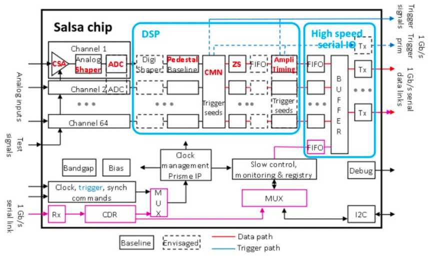
Charge 3

SALSA

MPGD – SALSA (CEA-Saclay, U. Sao Paulo)

- 64 Ch
- 65 nm CMOS
- Peaking time: 50 – 500 ns;
- Inputs: Cdin<200 pF; Dual polarity; Q: 3 – 250 fC
- ADC: 12 bits, 5 – 50 MSPS.
- Extensive data processing capabilities
- I2C configuration.
- Triggerless and triggered operation;
- Several 1 Gbps links.
- Power: 15 mW/Ch; Radiation Tolerant.





- Approximate quantities and costs.
- Costs include mask sets, fabrication and packaging, wrt quantities needed.

	#Ch	#Ch/Unit	#ASICs/ Wafer	#Wafers	Node (nm)	Packaging	Cost/ch ($)
SALSA	202 k	64	500	9	65	BGA	4.1

- Production
  - 65 nm: $750 k masks + $3.5 k per wafer
  - Packaging BGA: $3-$7.5 per chip.

- SALSA0 (IP blocks): FY23
- SALSA1: FY23 – FY24
- SALSA2: FY23 – FY25
- SALSA3: FY25 – FY26
- SALSA: FY27 – FY28

eRD102	eRD109	R&D Milestones	FEB QC Complete
Calorimeters	Discrete, CALOROC	30 September 2025	Mar 2028 – Jan 2030
AC-LGAD	EICROC, FCFD	30 September 2025	Nov 2027 – Jan 2029
dRICH	ALCOR	2 January 2026	Nov 2028
MPGD	SALSA	31 March 2026	Sep 2028 – Jun 2029
LAPPD/MCPMT	FCFD/EICROCx	23 December 2026	Sep 2028 – Jan 2029

- eRD102 – Electronics for detectors R&D.
- eRD109 – Readout R&D.
- R&D Milestones – ASICs ready for production.
- ASIC Production FY25 – FY28.
- FEB QA/QC Complete – Ready for integration.

FY23 – FY26 | FY25 – FY28

R&D (eRD109) | ASIC Production

11/2027 – 1/2030

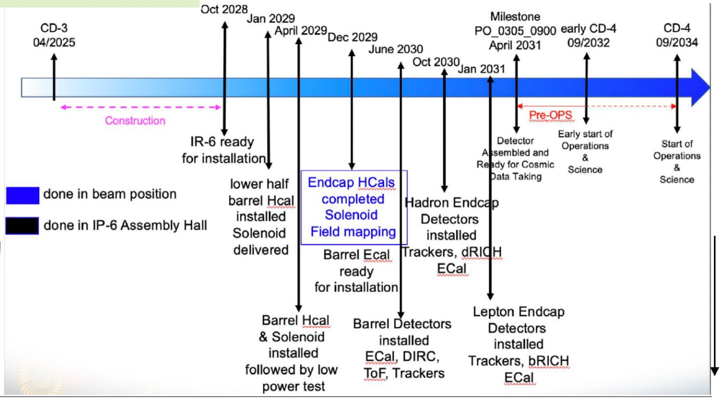
FY26 – FY29

Readout Production & QC

QC Complete

Installation

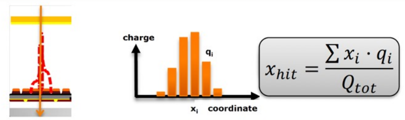
Jan 2029 – Jan 2031



MPGD synergic developments: μTPC

AD
INFN Roma Tor Vergata

μ-RWELL Position Resolution

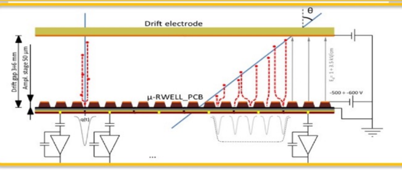


$$x_{hit} = \frac{\sum x_i \cdot q_i}{Q_{tot}}$$

Charge Centroid reconstruction method

The track position is determined as a weighted average of fired strips

GOOD FOR ORTHOGONAL TRACKS



FOR INCLINED TRACKS &/or HIGH B FIELD

the Charge Centroid method gives a very broad spatial distribution on the anode-strip plane.

μTPC reconstruction

The spatial resolution is strongly dependent on the impinging angle of the track → A non-uniform resolution in the solid angle covered by the apparatus → Large systematical errors.

The μTPC reconstruction algorithm: $z_k = v_{drift} \cdot (t_k - t_0)$

The μTPC algorithm requires knowledge of:

- the reference time t_0
- the strip charge arrival time t_k
- the charge drift velocity v_{drift}

It requires a fit for each hit strip

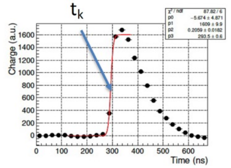
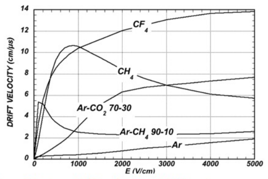


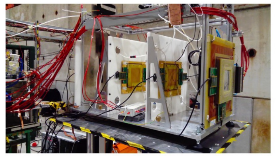
Figure 7. Charge signal as a function of the sampling time fitted with a Fermi-Dirac function:

$$f(t) = f_0 + \frac{q_k}{1 + e^{-(t-t_k)/\tau}}.$$



Electron drift velocity of different gasses, as a function of the applied electric field

PDG



1D 400 μm pitch
Ar:C02:CF4
40:14:45
Gas mixture

Figure 3. Experimental setup: all the detectors have a 10 × 10 cm² active area. The distance between the two μ-RWELL detectors is 30 cm.

- The reference time t_0 is provided by plastic scintillators providing the DAQ trigger

- The reconstructed track: $z = p_0 + p_1 x$ is used to provide the "measured" x at the middle plane of the detector: $x = \frac{z_C - p_0}{p_1}$

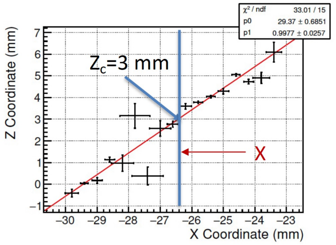


Figure 8. Example of a 45° track segment as reconstructed using the μTPC algorithm with the linear fit: $z = p_0 + p_1 \cdot x$. The smaller the charge collected on a strip, the larger the x coordinate error.

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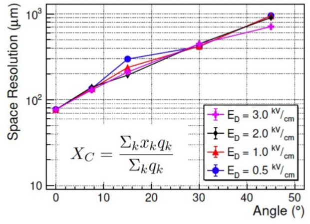
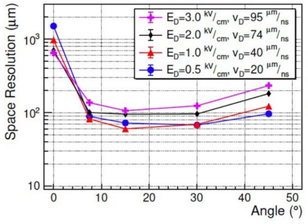


(a) CC space resolution.

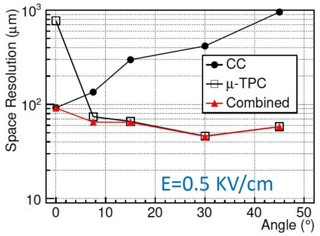


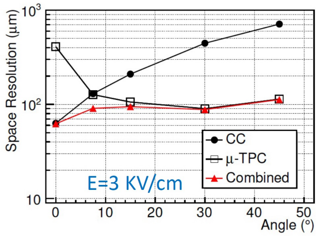
(b) μTPC space resolution.

1D 400 μm p
Ar:C02:CF4
40:14:45
Gas mixture

Figure 11. The results of the two reconstruction algorithms, over a large angular range, for various drift field values.

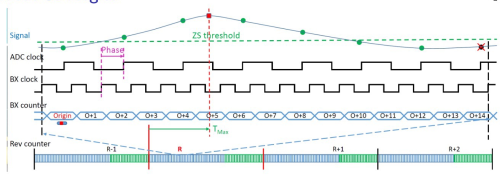
1D 400 μm pitch Ar:C02:CF4 40:14:45 Gas mixture



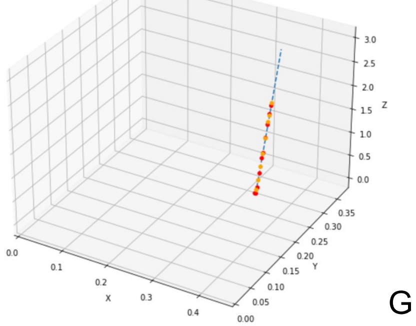


Combined results of 1D space resolution from charge centroid (CC) and μ-TPC algorithms

Readout Strategies



- Signal is continuously sampled with an ADC
- Signal samples above threshold are retained
- Nominal (physics data) readout: signal amplitude and timing is derived → Time of max (as on example) or time of arrival (fitting samples on rising edge)
- On demand readout: signal shapes or raw non ZS data are provided → Calibration, detector studies
- Guarantees best noise immunity and thus best S/N ratio → Allows on line common mode noise (CMN) subtraction before ZS



Requirements to the DAQ electronics

- Start time t_0
- Charge sampling at 50 MHz
- Number of sampling larger than the maximum drift time
- Precise t_k determination in the data stream: rise-time fit not the time of the maximum collected charge

PROs

The ***μ***-TPC algorithm provides:

- Improved position resolution for Inclined/bent tracks
- The timing information is embedded in the detector response

CONs

The ***μ***-TPC algorithm requires:

- Precise charge timing information
- A start timing information
- A fit for each strip signal
- A fit for each track
- Never systematically applied on 2D μ-Rwell detectors
- Never applied to 2D GEM- μ-Rwell detectors
- Very complicated for multiple tracks
- Is it compatible with charge sharing?

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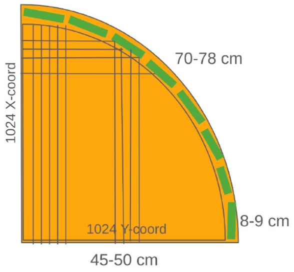
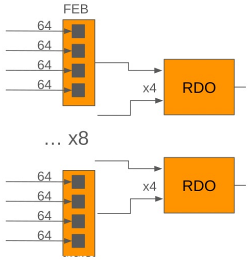
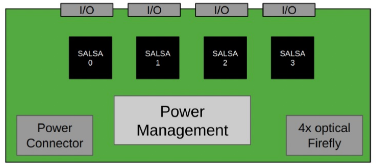
MPGD Electronics & Integration – Salsa signal emulation

Roberto Ammendola
INFN Roma Tor Vergata

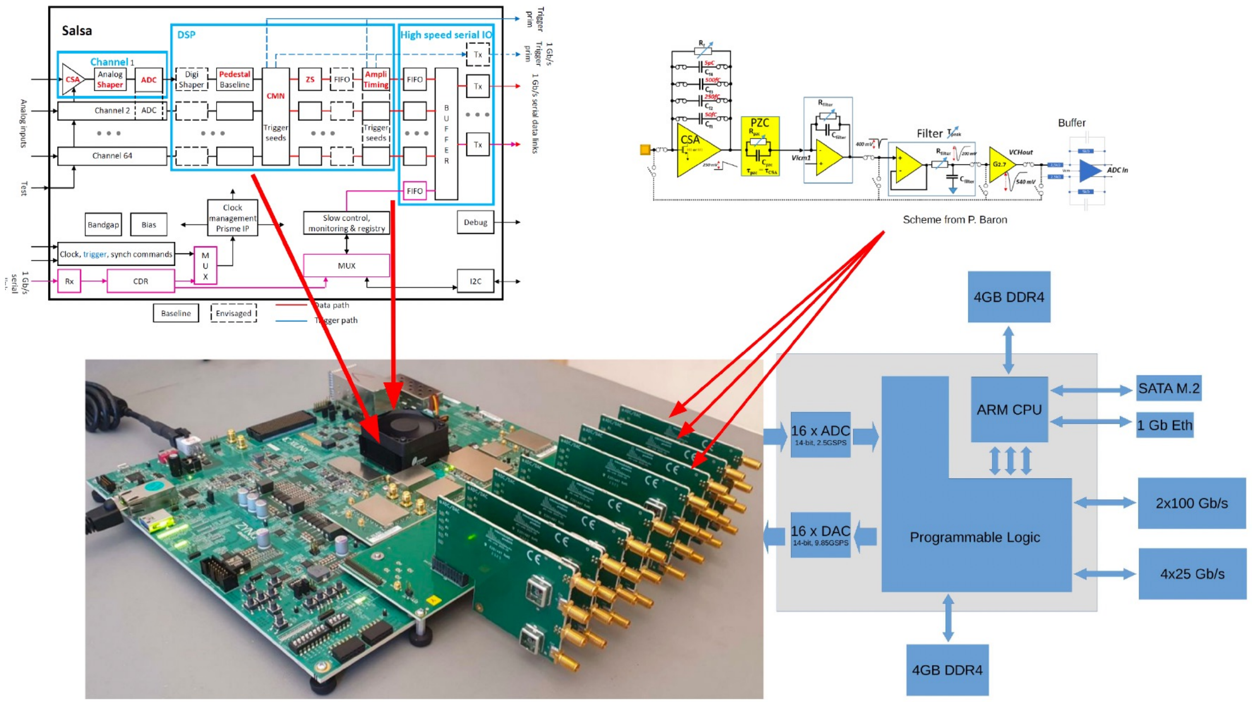
- Work started in order to understand:
  - Development of custom FE board
  - Possible development of custom RDO board
- First issues arising:
  - FE board length should be within 9 cm
  - how much is width constraint?
  - (x,y) computation should be performed at RDO level, this a single RDO should receive data from an entire quadrant







FE Emulation preliminary ideas



- SALSA chip could be available in late 2026 for first integration in Front-End boards
- interfacing with detector could happen even later
- Saclay group has already though to emulate (part of) SALSA logic on low-cost FPGAs, to perform design verification
- one can think of extending this activity in order to connect the detector to a multi-channel, high sampling rate integrated ADCs FPGAs (ZCU216 board)
- there is some glue logic needed (charge amplifier) we can think to develop in very short time eventually in a simplified version
- having a single box with 16 channel readout complete with charge amplifier, ADC, SALSA ASIC logic and instrumented readout through the on-chip Processing System can be a good solution to both test the detector in development and test the SALSA ASIC features directly on real detector data.

MPGD Electronics & Integration – LV

Tim Camarda
BNL

- Motivation to explore commercial parts (cost, performance, availability)
- Comparisons

Device (buck converter)	Vin (Vout = 1.2V)	Vout	Iout (80% derated)	Eff.	FSW as tested	Package mm²	Cost $USD
LTC3626	20V	0.6 – 6V	2.0A	~85% as tested (2.3W)	1.8MHz	12	5.05 (500)
bPOL12V	*10V	0.6 – 5V	3.2A	70% data sheet 75% as tested at 2.0A (3W)	1.5MHz	25	15.00(36)

*Highest voltage recommended for SOA & stability

Device (buck controller)	Vin (Vout = 1.2V)	Vout	Iout (as tested)	Eff.	FSW as tested	Package mm²	Cost
LTC7890 External GaN FETs	12V can be increased if FSW is lowered	0.8 – 60V	Tested for 12A / channel (2 ch) operate 180° out to reduce EMI	~80% tested 29W	2.0 MHz	36	4.01 (500)
bPOL48V External GaN driver/ FET	15V	0.6 – 24V	Tested at 8A	~78% tested 10W	1.5MHz	25	17.00(36)

Vin / Vout ratio & pulse switch time needs to be observed

Radiation testing criteria:
If commercial parts are tolerant of radiation environment after 10yr operation at full efficiency & machine luminosity...with 3x TID & fluence safety factor => COTS parts can be utilized

Specifications & Requirements for DC:DC Power regulation

Performance Requirements:
- Efficiency ≥ 70%
- Power Density (power / CM²) 500mW to 800mW / CM²
- Low noise/ ripple ≤ 0.5% of VOUT
- Temperature stability 35°C env.
- 1MeV fluence 1E12 n /cm² (ePIC upper bound 10yr operation)
- TID 10K rads / year
- Magnet tol. 2 Tesla field

Radiation tolerance if based on worst case upper bound Simulations for 10years of operation

Power Specifications
- VOUT (1.2V, *10V)
- V_{IN} ≥10V
- P_{OUT} 3W – 10W
- I_{OUT} 2.5A – 8A

Power Output & Current are based on cooling and space constraints
*10V if powering bPLO12V from bPOL48V

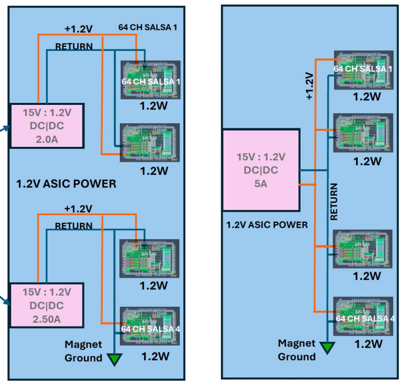
- Disk => 16K channels
- 64 channel SALSA
- 4 SALSAs / FEB
- Need to power 63 FEBs

MPGD DISK ASIC FEB POWER REQUIREMENTS

• SALSA: 1W @ 1.2V	≈ 1A (833ma) => 25% margin
• FEB w/ 4x SALSA ASICs	≈ 4A => 4.8W
• Efficiency losses (power in)	= 4.8W/ 0.7 ≈ 7W

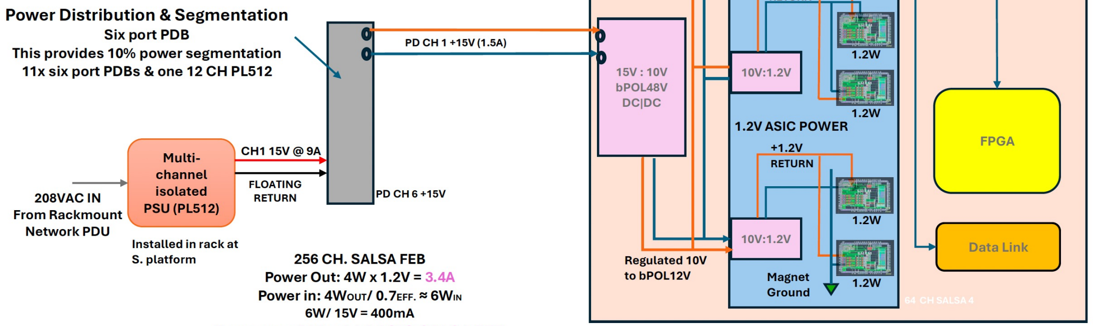
We could use CERN bPOL12V here but reduce Vin to 10V Lower Vin yields %50 increase in input current (470mA Vs 700mA)

- An option is to use bPLO48V for input regulation & power bPOL12V w/ 10V



Example with COTS LTC3626 Example with CERN bPOL48V

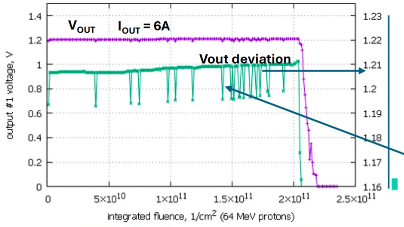
MPGD Trackers
Powering FEB & ASIC Boards
Power distribution from equipment platform to FEBs
Example



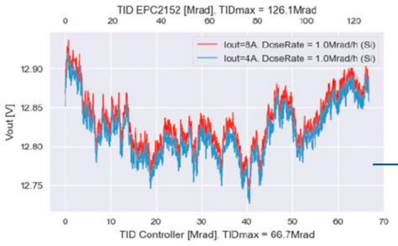
FEB + RDO power block example

SALSA ASIC, Sao Paulo University and CEA IRFU teams

MORE RADIATION TESTING BEING DONE ON COMMERCIAL PARTS



LTC7890 Vout Vs neutron fluence @ 25°C



bPOL48V Vout Vs TID @ 30°C

Radiation Type	Testing Notes	Comments
Fast Neutrons	Tested at UC Davis 64MeV proton facility at a flux of 2.5E8/sec cm² (45min) Note: this may of given us a higher TID rate that caused early failure. LTC7890 slight Vout deviation: could be SEE	Parts that survived ~ 30% of target fluence of 1.0E12 n/ cm² failed at 2.0E11 n/ cm² are being considered for further testing. LTC3600 (1.5A) output shorted LTC3626 (2.5A) output shorted LTC7890 (15A) output died...but recovered several hours later. Seems to be 100% now! (possibly annealed displacement damage G.V.)
TID	From our fast neutron test at UC Davis 64MeV beam, simulations indicated the TID < 100k rads	Testing to be done in July BNL gamma ray facility at < 10k rads/ hour
SEE		Single event effects will be studied if parts pass TID testing

The single event effects (SEE) have been evaluated for the controller using heavy ions on the bPOL48V in the Cyclotron Resource Center of UCLouvain. In these tests, the effect on the EPC2152 is negligible, as the range of the heavy ions is not large enough to deposit charge on the sensitive area of the EPC2152. The GaN power stage is being characterized by EPC Co.

From bPOL48V data sheet

MPGD Electronics & Integration – LV

Tim Camarda
BNL

MPGD Neutron Fluence & TID simulations referenced from distance

MPGD layer locations		Maximum EM Radiation dose [krads]	Maximum Hadron radiation dose [krads]	1 MeV neutrons equivalent fluence [cm^{-2}]	1 MeV protons equivalent fluence [cm^{-2}]
Barrel	R = 73 cm	0.3	0.1	2.8x 10^{10}	4.2x 10^{9}
	R = 55 cm	0.22	0.15	2.7x 10^{10}	6.5x 10^{9}
Hadron end cap	z = 148 cm	51.2	16.2	1.2x 10^{11}	2.3x 10^{11}
	z = 163 cm	52.6	14.1	1.1x 10^{11}	3.3x 10^{11}
Electron end cap	z = -112.5 cm	3.2	0.2	1.3x 10^{10}	5.2x 10^{8}
	z = -122.5 cm	4.2	0.2	1.4x 10^{10}	8.0x 10^{9}

TABLE1: e + p minimum-bias event @ 500 kHz event rate for 10 yrs EIC runs with 6 months run time/ yr and 100% efficiency

Layer	Distance cm	TID (k rads)	Fluence n/ sec / cm^2
Barrel	R=73	1.2	8.4E10
Barrel	R=55	1.2	8.4E10
Hadron endcap	Z=148	200	3.6E11
Hadron endcap	Z=163	200	3.3E11
Electron endcap	Z=112.5	10.2	4.0E10
Electron endcap	Z=122.5	13.2	4.2E10

TABLE 2: 1meV n. equivalent fluence & TID from table 1
With added 3x safety factor

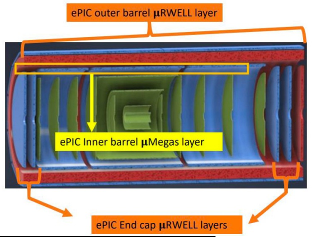
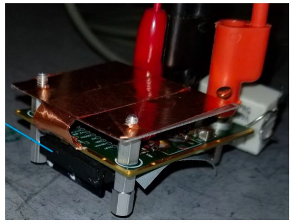


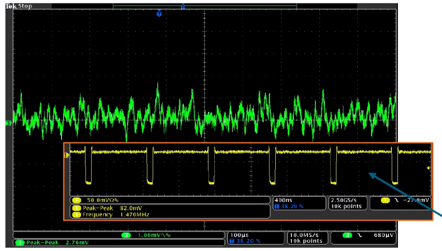
Image from Sourav Tarafdar (Jlab), Vanderbilt U. 2023

https://indico.slac.stanford.edu/event/8288/contributions/7884/attachments/3675/10024/CPAD_11_08_23.pdf

DC|DC performance testing bPOL48V (BUCK POINT OF LOAD) Vs LTC7890



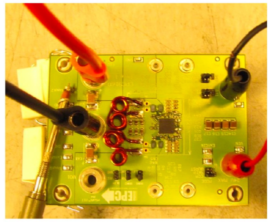
bPOL48V w/ bottom mount heat-sink, 300nH @ 1.5MHz



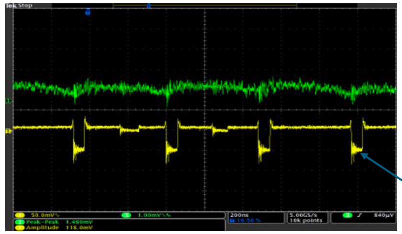
Vout Noise/ ripple ~3mV (1mV/div) h. 100us

V_{OUT}	1.2V
I_{OUT}	8.2A
V_{IN}	15V
P_{IN}	12.75
P_{OUT}	10.0W
P_{EFF}	78.0%
Noise 1gHz	<0.3%
Ripple 25MHz	<0.3%
On-time	~60ns
Fsw	1.5MHz

EMI (near field) 82.0mV p-p
Measured from bottom of the PCB
50mv/div h.400ns

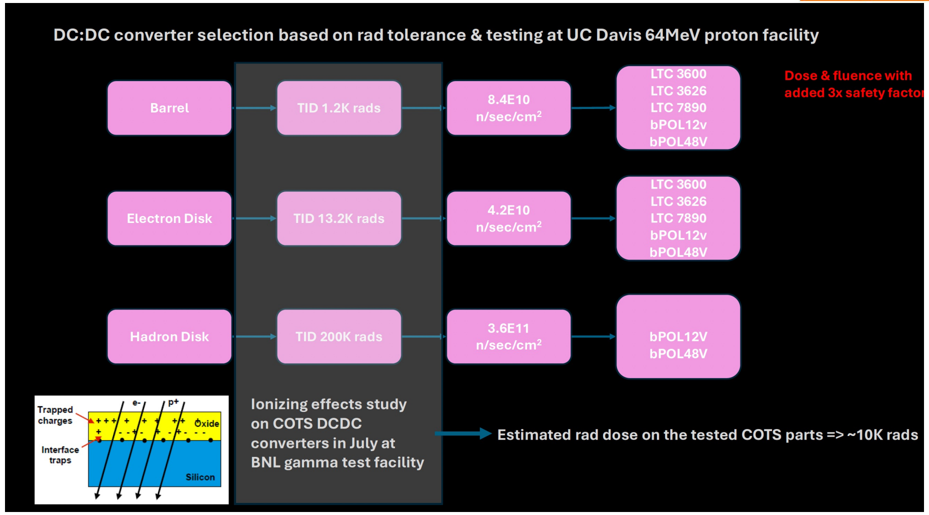


LTC7890, 27



$V_{OUT\ ch1,\ ch2}$	1.2V, 1.2V
$I_{OUT\ ch1,\ ch2}$	12A, 12A
V_{IN}	12V
P_{IN}	36W
P_{OUT}	28.8W
P_{EFF}	80.0%
Noise 1gHz	<0.3%
Ripple 25MHz	<0.3%
On-time	~60ns
Fsw	2.0MHz

EMI (near field) 118mV p-p



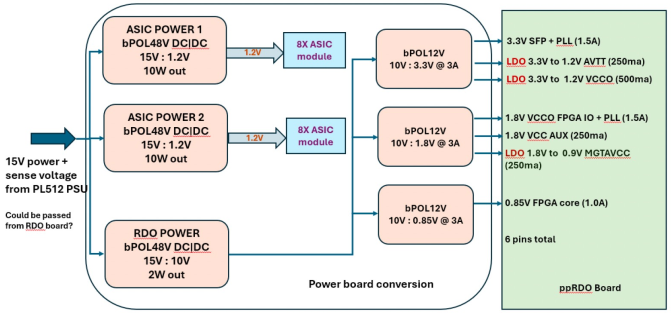
Conclusions

- All tested parts should meet pow
- CERN bPOL parts will meet radia
- More rad testing is needed for sel
- A good deal of vetting has been d

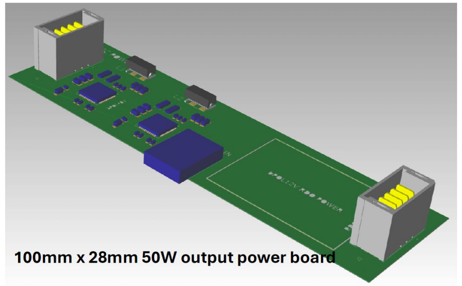
What's Next?

- Continue radiation studies for COT
- Build prototype power boards
- Power board design for fTOF EICR(
- Acceptance testing

EICROC FEB ASIC + RDO POWER BOARD EXAMPLE



Preliminary EICROC ASIC+RDO power board flow chart
Optimized for efficiency



100mm x 28mm 50W output power board

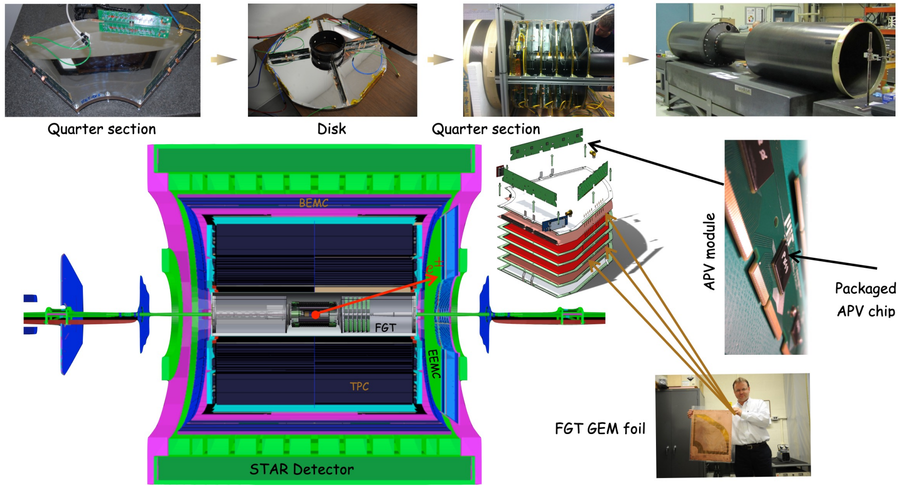
Layers:	4x to 6x
	2.0 mm thick
Copper Weight:	2oz top/bottom
Heat transfer:	Bottom copper w/ gold finish
	Thermal compound or sil-pad
	mount to plate w/2.0mm screws
Component Mount:	Top only
Power Dissipation:	~50W (~75% efficiency) 180mw / cm^2

Boards will range in size based on installed locations
(100x28mm is smallest PCB dimension)

MPGD Gas Systems – STAR experience

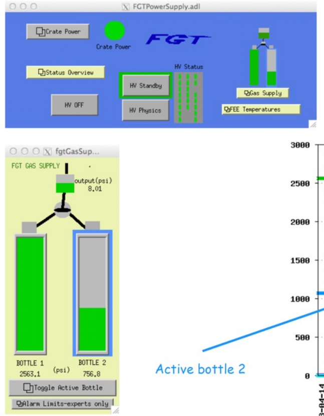
Bern Surrow
Temple U.

Forward GEM Tracker - Layout

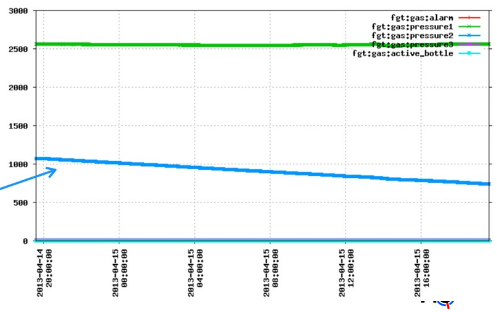


Gas system design Performance

- Status



- Smooth performance
- Two $ArCO_2$ (90/10) gas bottles connected to gas system (Gas consumption: ~350psi / day ⇒ 1 bottle / week)
- No issues!



Gas system design

- Overview

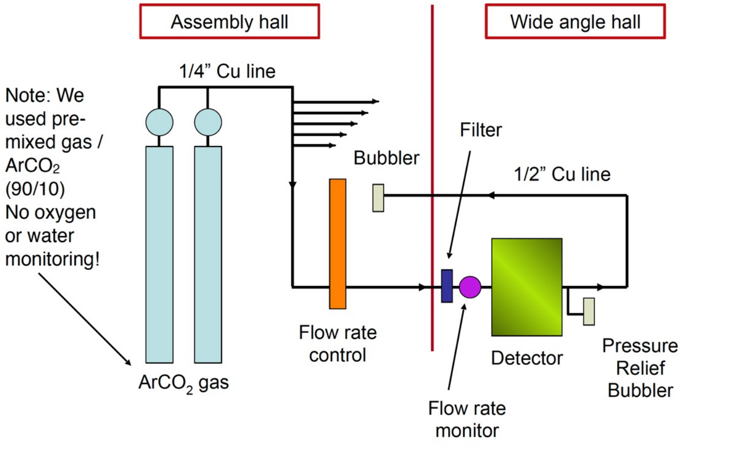
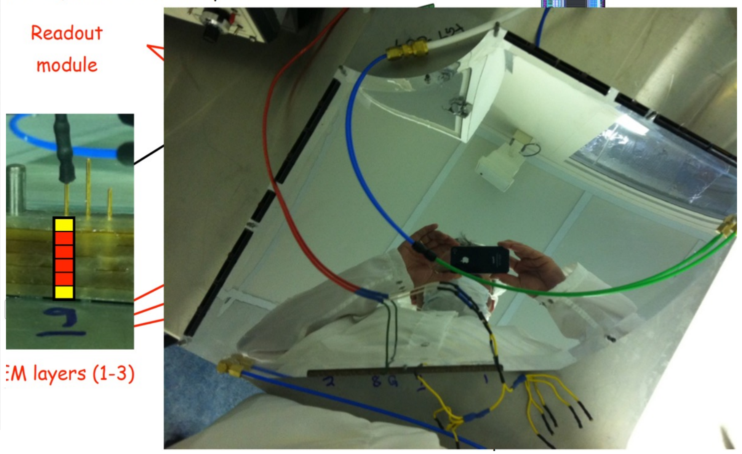


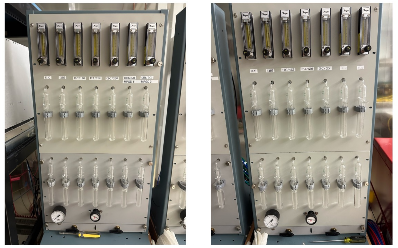
Photo album - Quarter section assembly (1)

FGT Quarter section layout



Summary

- FGT gas system was based on a pre-mixed gas system of $ArCO_2$ without oxygen or water content monitoring.
- The gas system was a standalone gas system, i.e. it was not part of another gas detector system. The pre-mixed gas bottles were located for simplicity outside the STAR gas room.
- Remote monitoring of pressure was included and was part of the slow-control system.
- Generally, the gas system was very robust and simple. It did not cause any issues!
- The full gas system is now at Temple Univeristy in our lab.



MPGD Gas Systems – Gas options and Constraints

μ-RWELL + GEM – Gain

ePIC

L. Shekhtman, Nuclear Inst. and Methods in Physics Research, A 936 (2019) 401–404

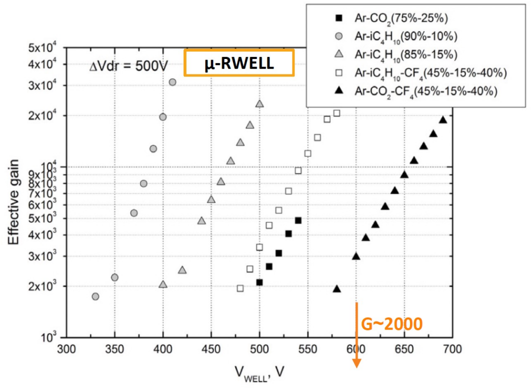


Fig. 4. Gain as a function of voltage on the top electrode of μ-RWELL for different gas mixtures. Voltage across the drift gap is 500 V.

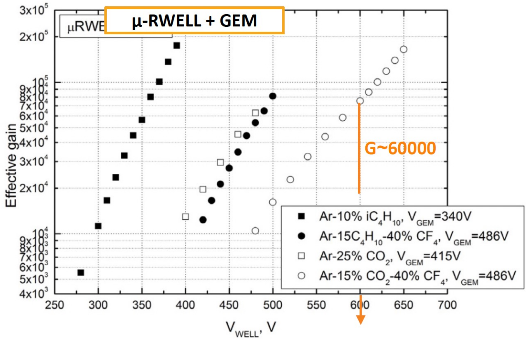
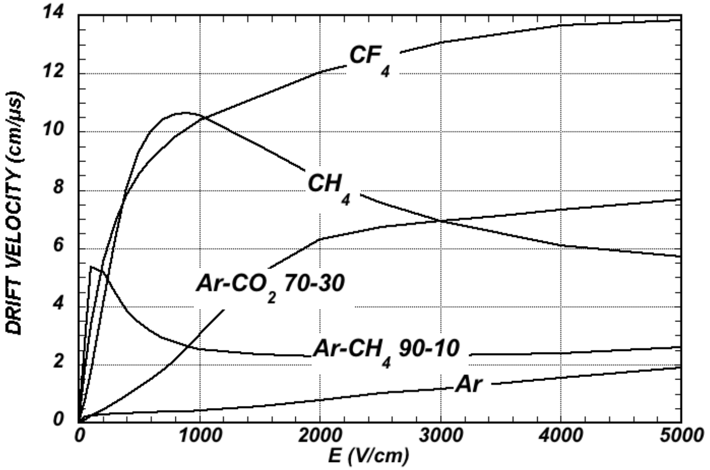


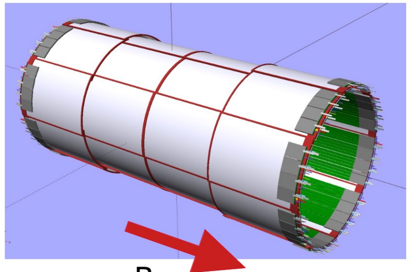
Fig. 5. Gain as a function of voltage on the top electrode of μ-RWELL for GEM voltages providing additional gain of 50–100 and for different gas mixtures. Voltage across the drift gap is 500 V.

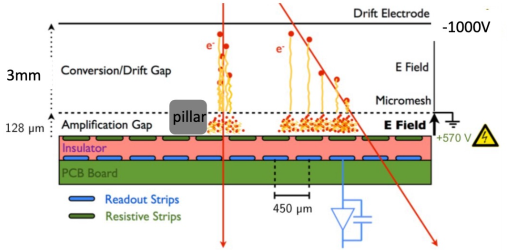


AD
INFN Roma TV

CyMBaL – Micromegas

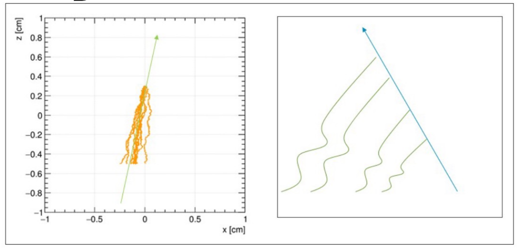
- Resistive Micromegas
- 3 mm conversion gap
- Single amplification stage
  - Larger Ar fraction
  - Strong quencher, isobutane
- Working in 1.7 T
- Lorentz angle affect cluster size and transparency





$$\tan(\theta_L) = \omega\tau = \frac{v_D B}{E}$$

B

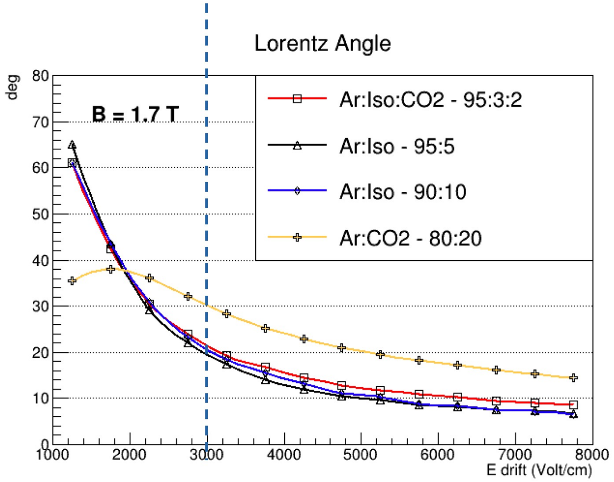


Effects depends on the sign of the charged particle

Francesco Bossù
CEA Saclay

Lorentz angle

- Simulations using Magboltz (thorough Garfield++)
- $Ar{:}iC_4H_{10}$ 95:5 mixture have lower drift velocities than $Ar{:}CO_2$ 80:20, i.e. smaller Lorentz angles
- To keep the Lorentz angle ~ 20 deg, Vdrift
  - ~1kV/3mm $Ar{:}iC_4H_{10}$ *(safer)*
  - ~1.6kV/3mm $Ar{:}CO_2$
- $Ar{:}iC_4H_{10}{:}CO_2$ 95:3:2 (NSW gas) similar behavior as $Ar{:}iC_4H_{10}$ 95:5



MPGD - Summary

- All MPGD subdetectors are in an advanced state of design – in line with the expected time schedule

- MPGD detectors instability causes has been addresses:
  - Construction parameters optimization
  - Dust minimization/elimination at the assembly phase
  - Moisture reduction and monitoring in the detector initial conditioning

- MPGD detectors engineering & integration
  - Space constraints for BOT have been identified
  - Design optimization in progress for ECT

- MPGD Electronics and Read-out
  - FEB will be based on SALSA chip developed at Saclay
  - The FEB design and connection to RDO still under consideration
  - SALSA chip emulation of the response to MPGD detectors will be useful to optimize its design
  - LV components are being characterized and selected

- MPGD Gas Choice and Distribution
  - Will work in the direction of using the same Gas mixture for all detectors, compatibly with performances
  - Gas distribution system should be kept simple and guarantee low moisture contamination

MPGD – TDR preparation