

The Detector Development Group

Resistive Gaseous Detector R&D at INFN Frascati
for Future Collider Experiments

M. Giovannetti¹

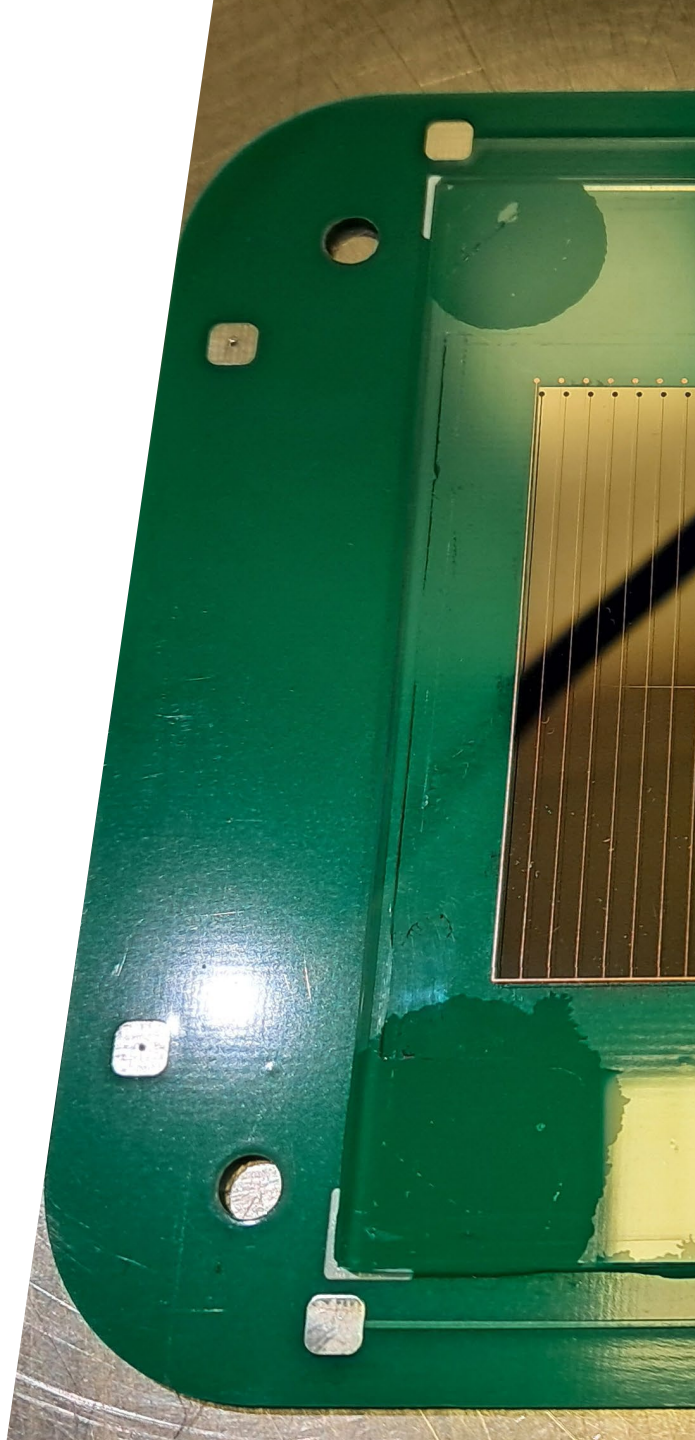
G. Bencivenni¹, G. Felici¹, M. Gatta¹, G. Morello¹, G. Papalino¹, E. Paoletti¹,
M. Poli Lener¹, S. Serafino¹, R. Tesauro¹, L. Torlai², G. Zunica¹

¹ INFN-LNF

² Università degli Studi di Roma “Tor Vergata”

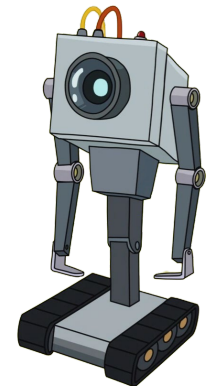
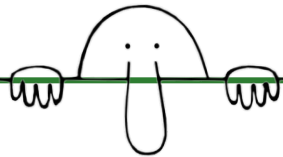


INSTR26, Hefei, 16th Oct. 2026



Purpose Robot – “What is my purpose?”

Rick Sanchez – “Test the pointer”



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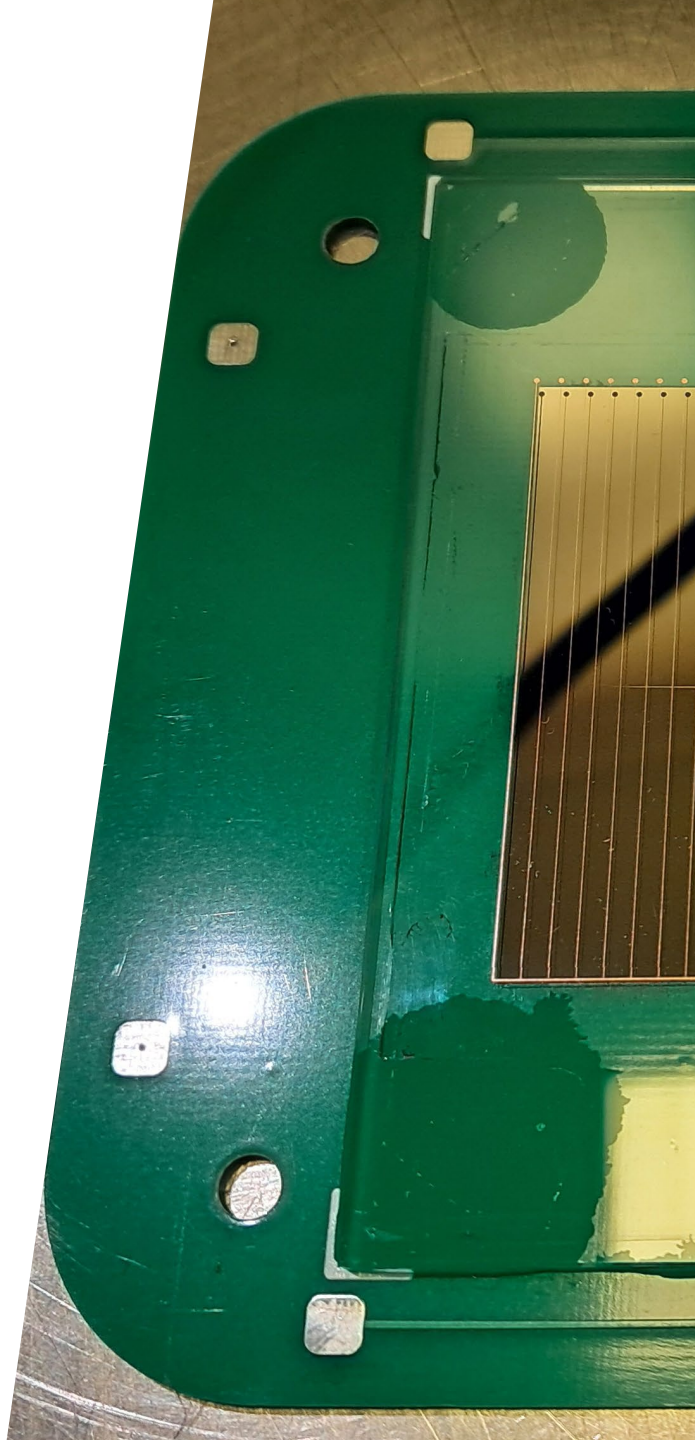
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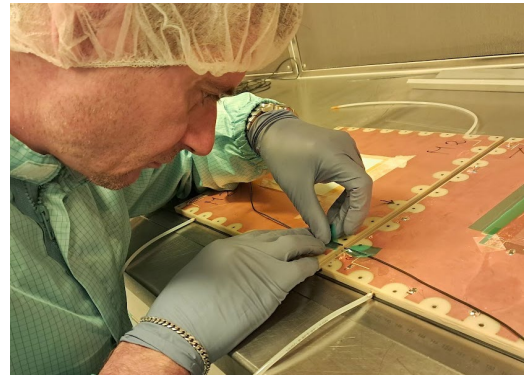
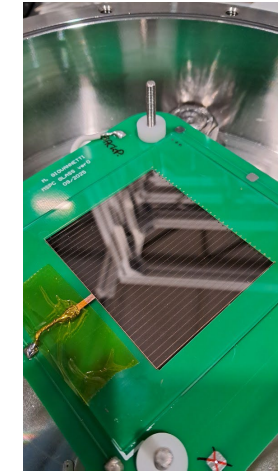
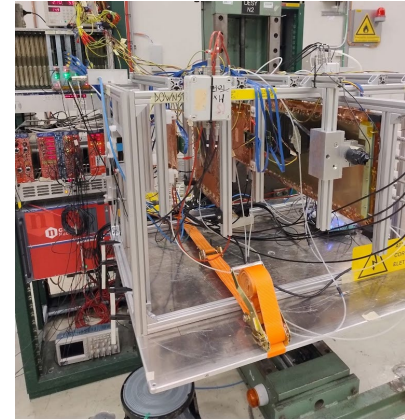
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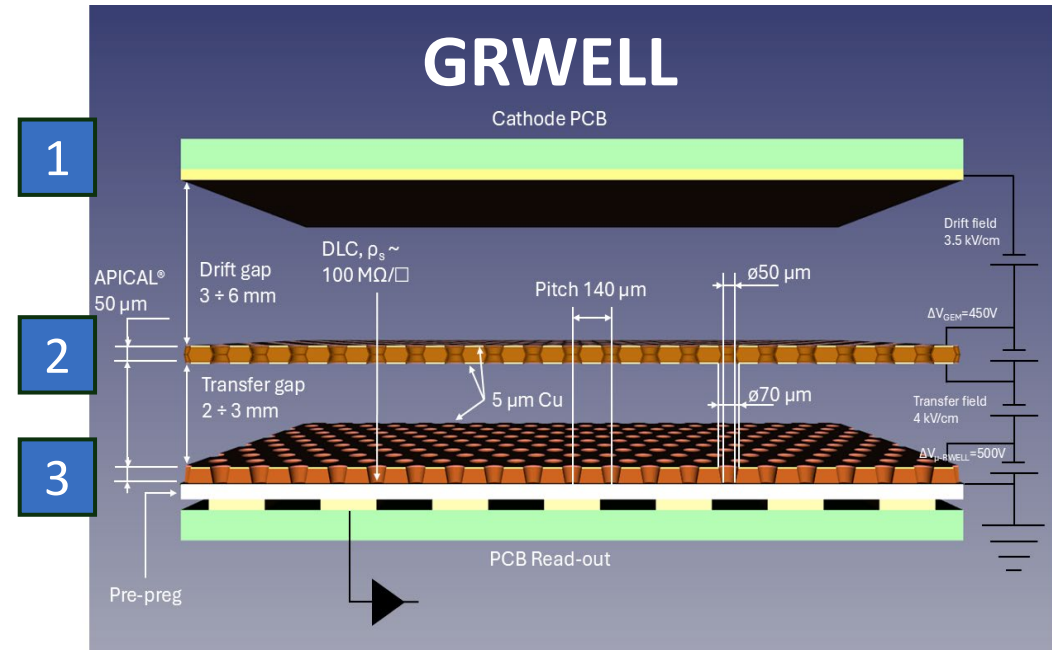
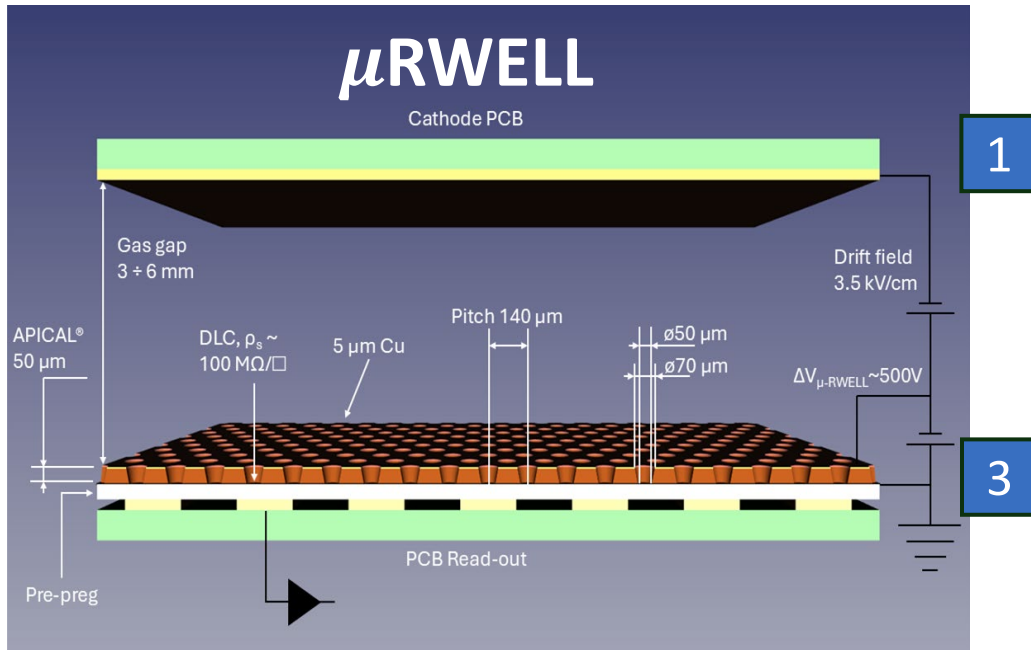
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The DDG activities



The μ -RWELL and G-RWELL detector



- Ar:CO₂:CF₄ 45:15:40**
- 1 Cathode PCB
 - 2 GEM foil - 50 μm Apical – 140 μm pitch
 - 3 μ -RWELL_PCB
 - 3.1 a **WELL** patterned Apical foil acting as **amplification stage**
 - 3.2 a **resistive DLC layer (Diamond-Like-Carbon)** for discharge suppression with surface resistivity $\sim 100 \text{ M}\Omega/\square$
 - 3.3 a standard **readout PCB**

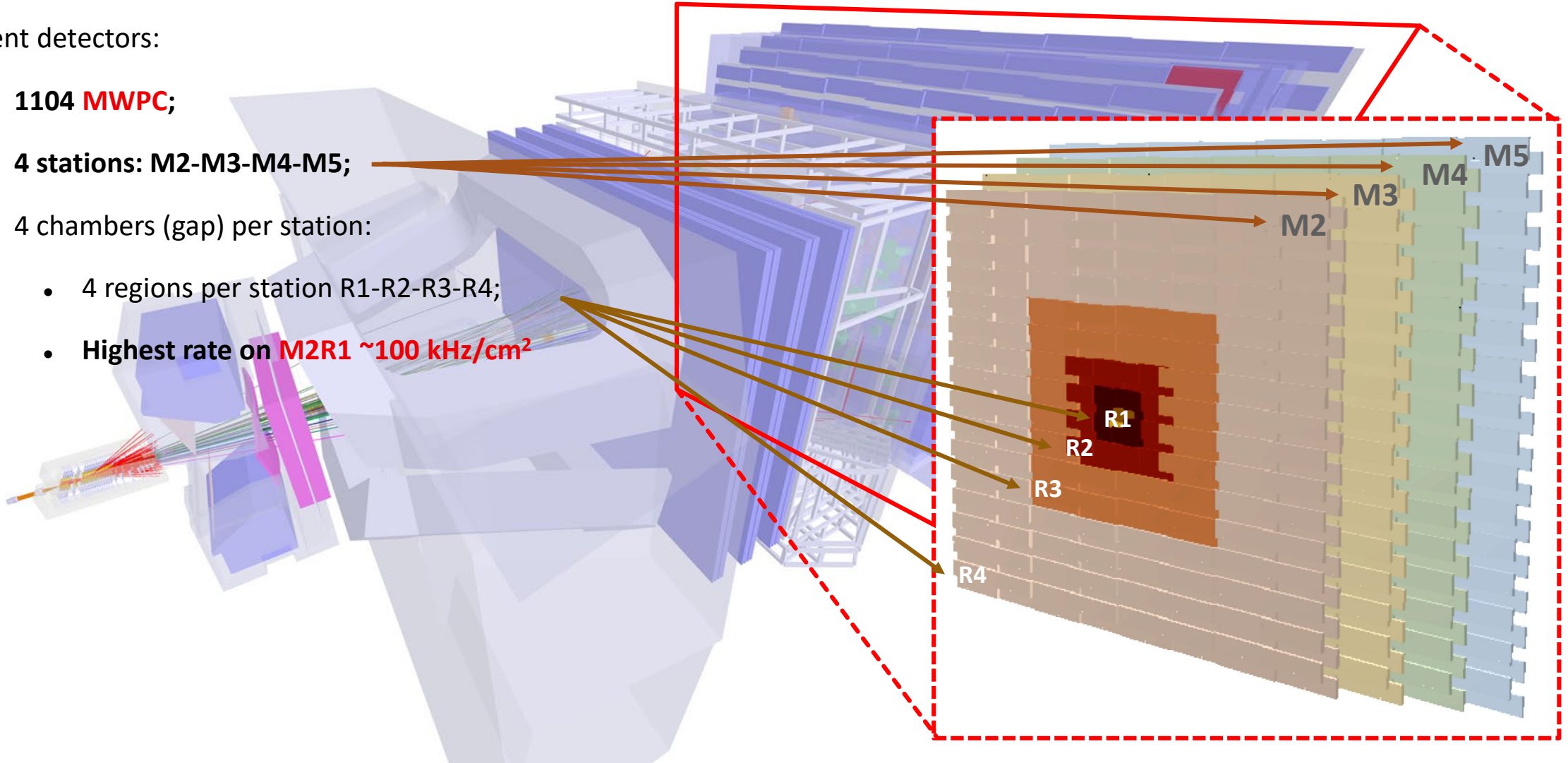
	Drift [mm]	Transfer [mm]
2024	6	3
2025	6	2
LHCb U2	3	2

The LHCb U2 Muon System

LHCb: the Muon System today

Current detectors:

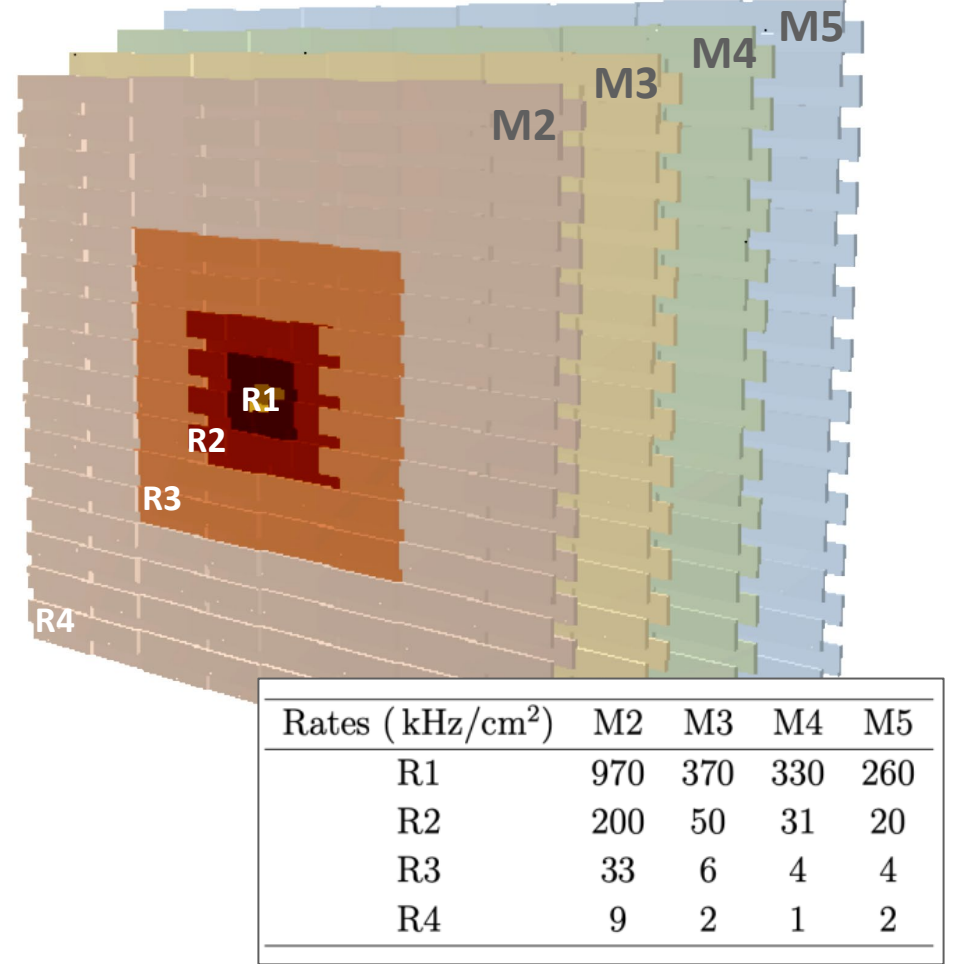
- 1104 **MWPC**;
- 4 stations: M2-M3-M4-M5;
- 4 chambers (gap) per station:
 - 4 regions per station R1-R2-R3-R4;
 - Highest rate on **M2R1** $\sim 100 \text{ kHz/cm}^2$



LHCb: requirements for Upgrade II

U2 requirements:

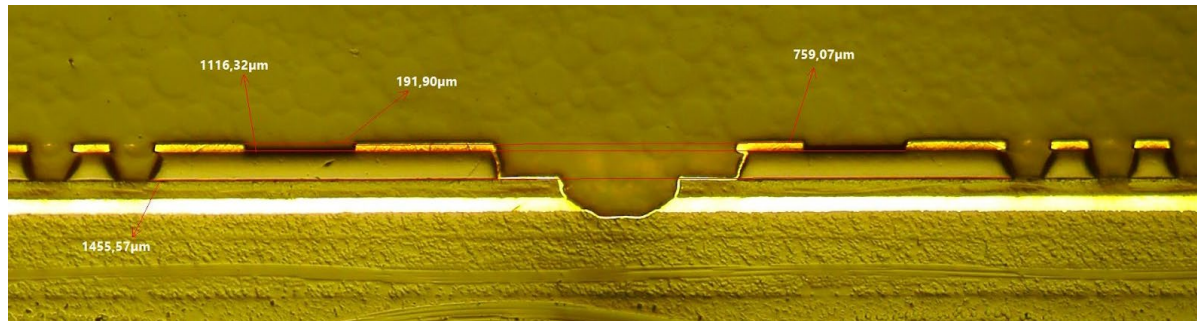
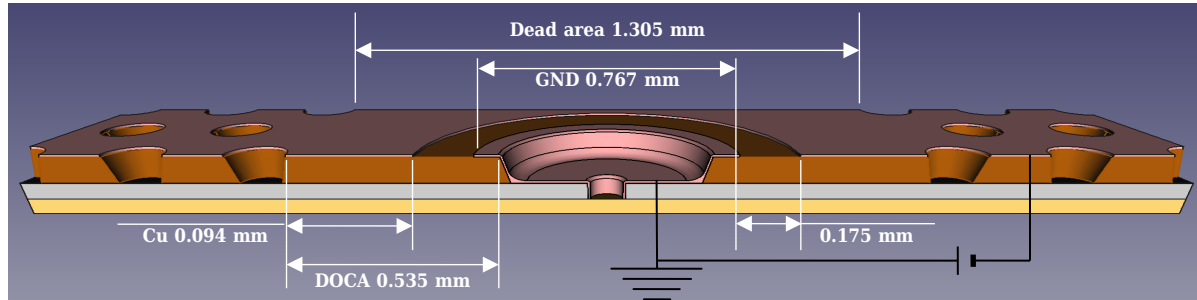
- Instantaneous luminosity $\Rightarrow 1.0 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$:
- Rate **M2R1 $\sim 1 \text{ MHz/cm}^2$** :
 - $\sim 800 \text{ kHz}$ for single RO pad;
 - Triggerless acquisition @ 40 MHz;
 - efficiency 25 ns time window:**
 - 98% on 4 gaps majority $\Rightarrow$ 90% single gap;
 - MWPC: the rate-induced dead time inefficiency would be a major limiting factor:
 - Replace all R1 & R2 with MPGD detectors**



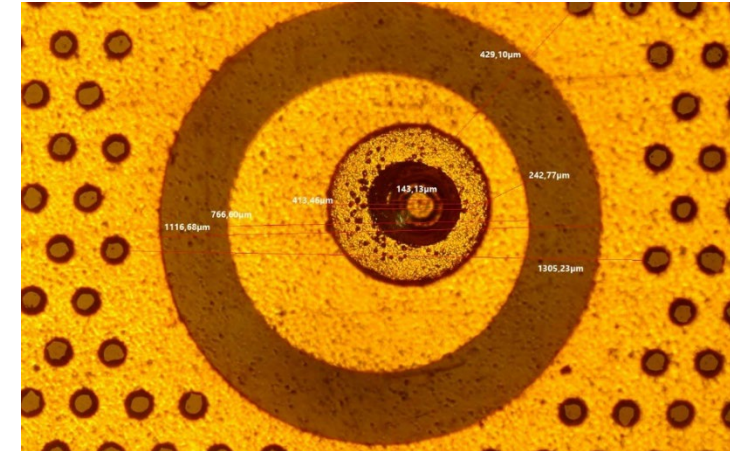
[Alessia Satta - Muon Parallel 22/06/2026](#)

The PEP-DOT μ -RWELL

DLC-GND pitch [mm]	Dead Area [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:
Patterning-Etching-Plating
- 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 area is $\sim 2\%$



As an alternative, a **Silver Grid** high-rate scheme is also **under investigation** but the PEP-DOT still remains the favorite option.

Efficiency in 25ns

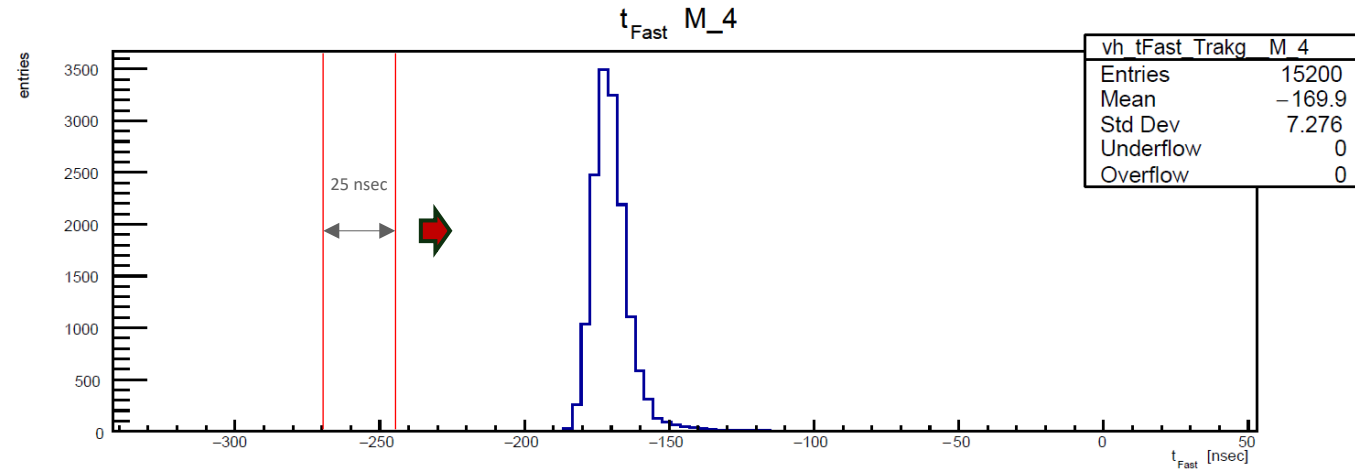
Raw Efficiency:

fraction of events in which a cluster is found within a Field of Interest (FoI) around the reconstructed track, restricted to the fiducial area.

The time distribution of the fastest hits in the selected clusters is then used to evaluate the

25 nsec Efficiency:

maximum fraction of events with the fastest cluster timestamps contained within a 25 ns time window.



Efficiency in 25ns

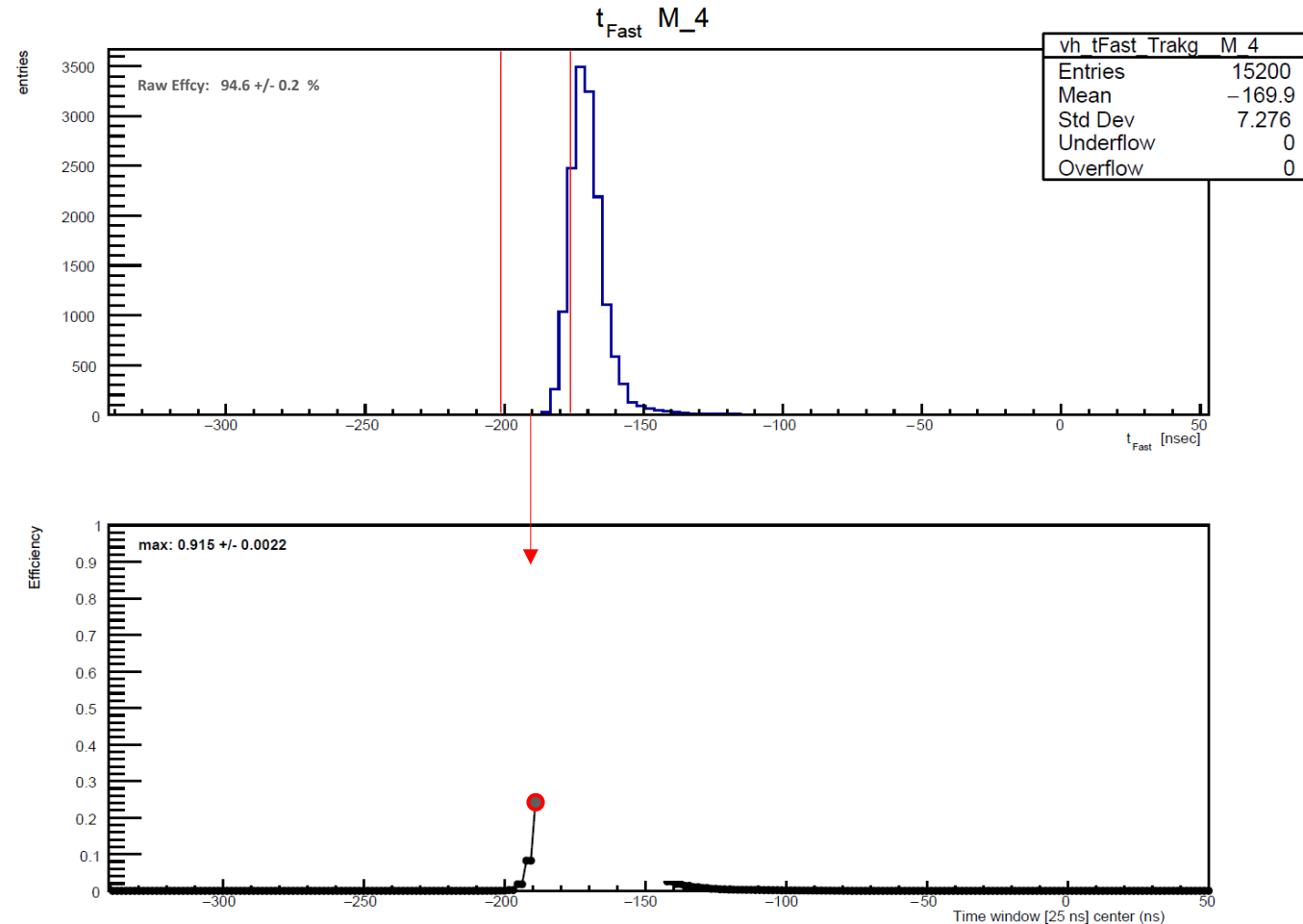
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Efficiency in 25ns

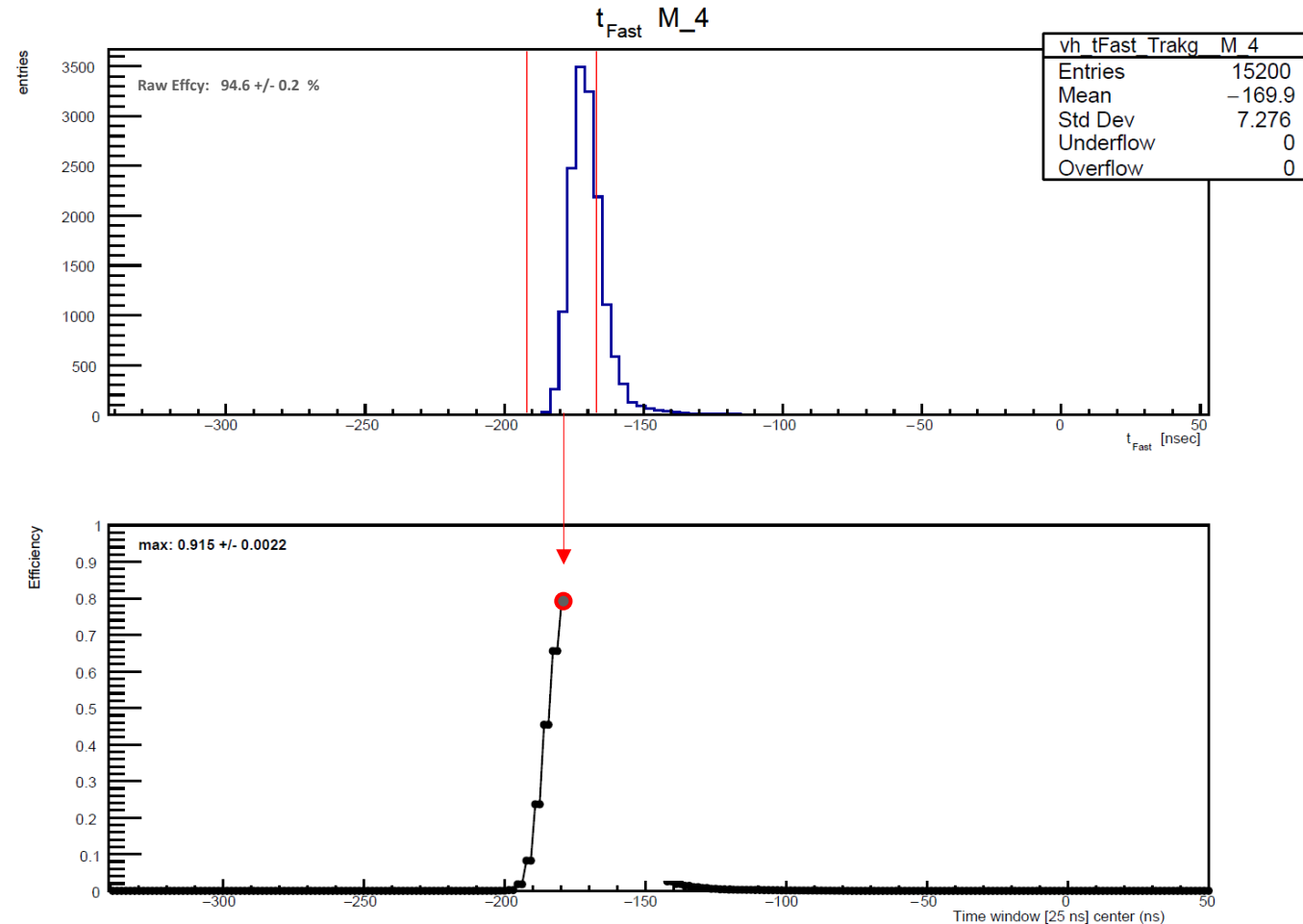
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Efficiency in 25ns

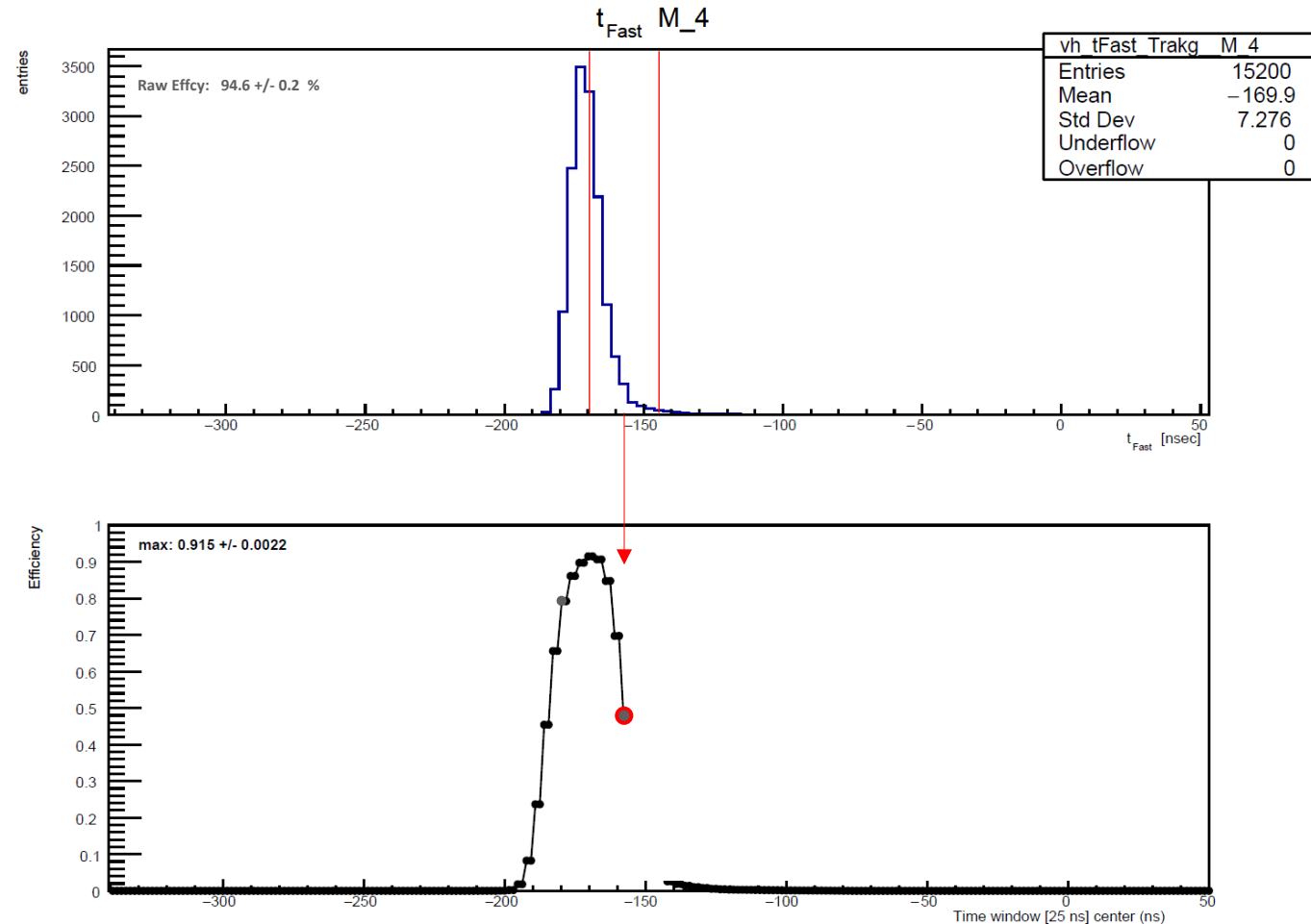
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Efficiency in 25ns

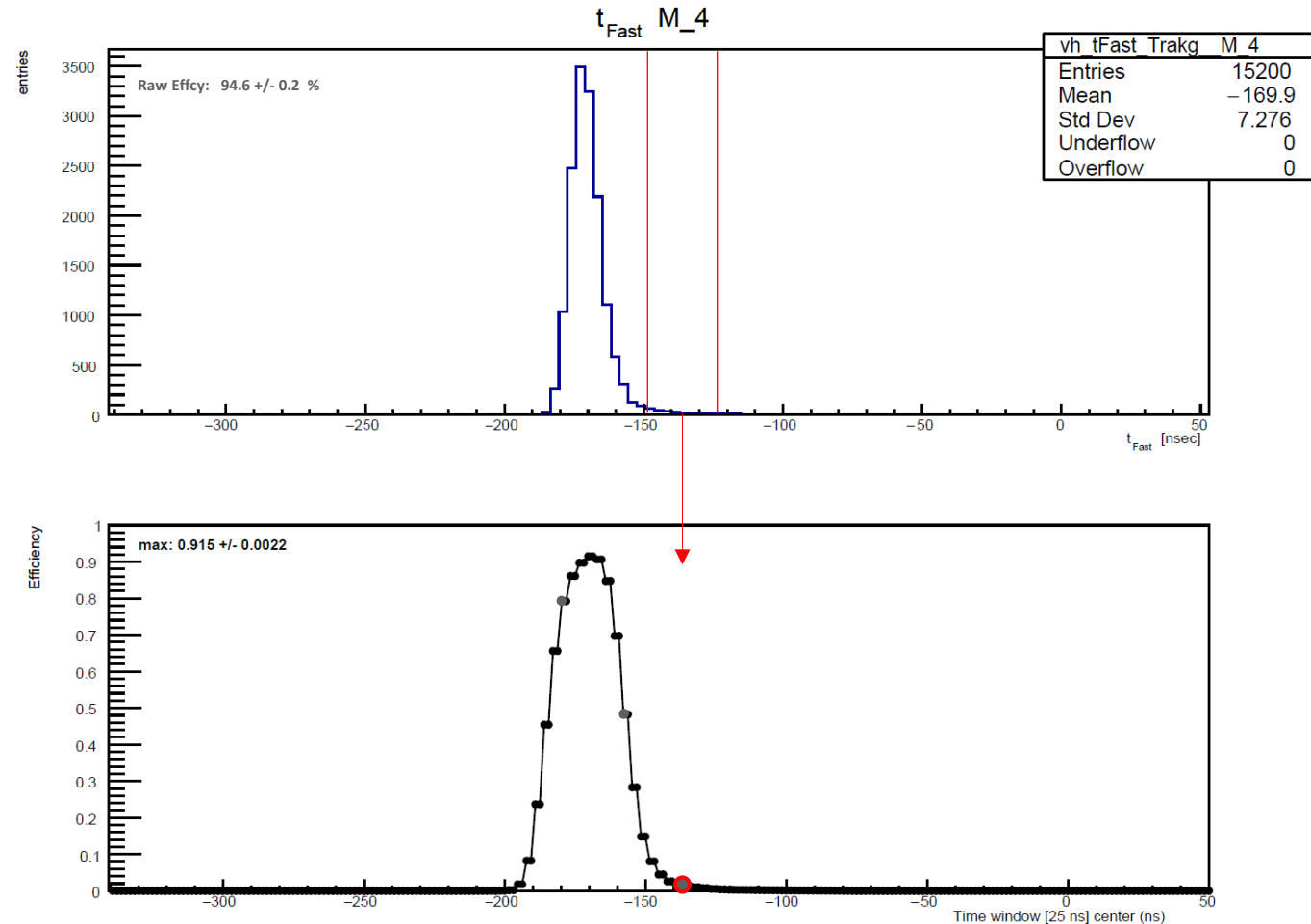
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Efficiency in 25ns

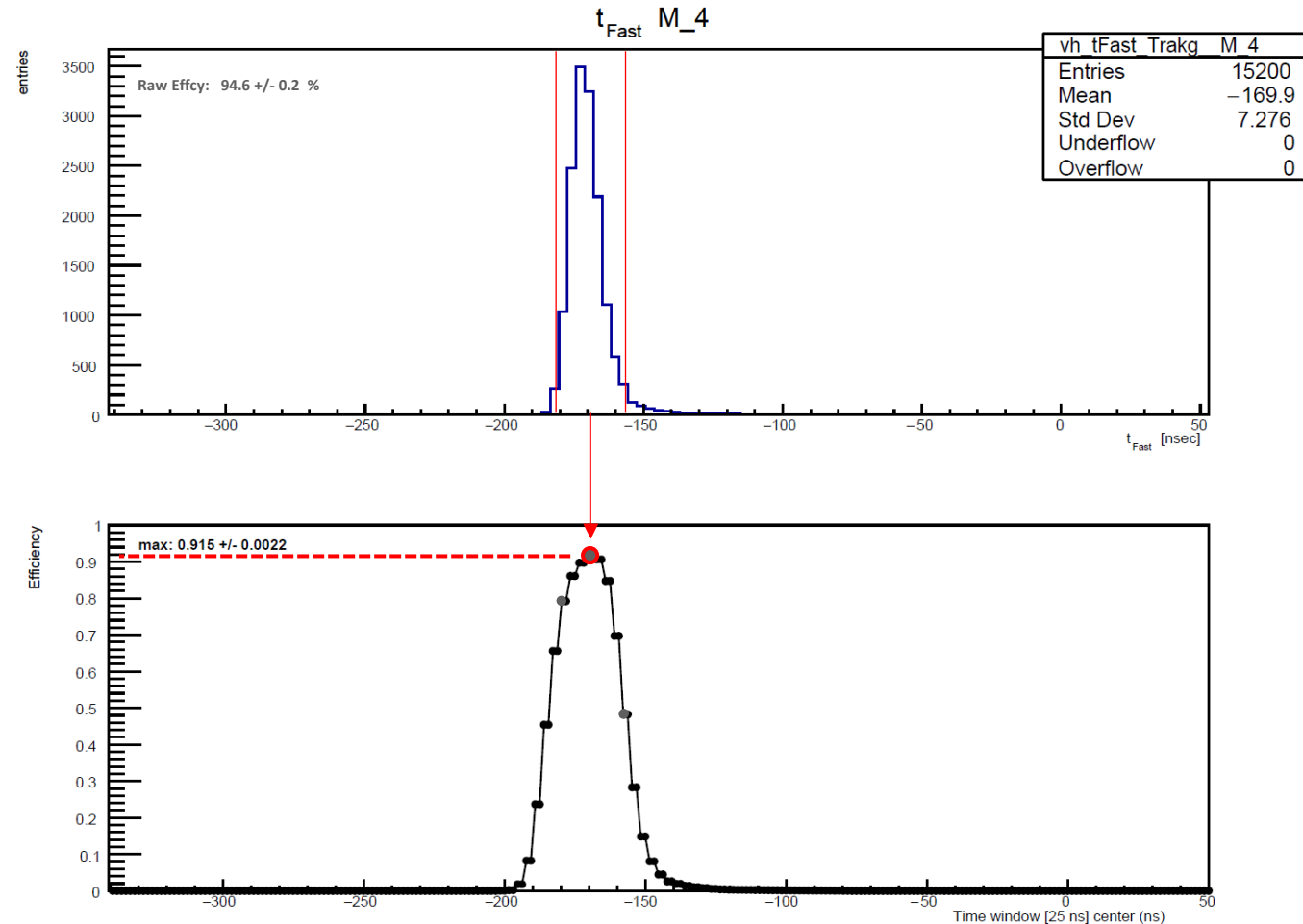
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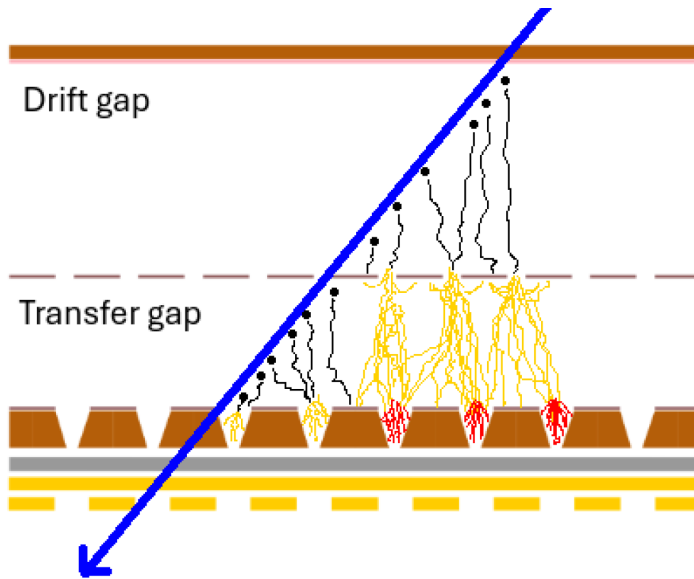
25 nsec Efficiency:

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G-RWELL: the Bi-Gap effect

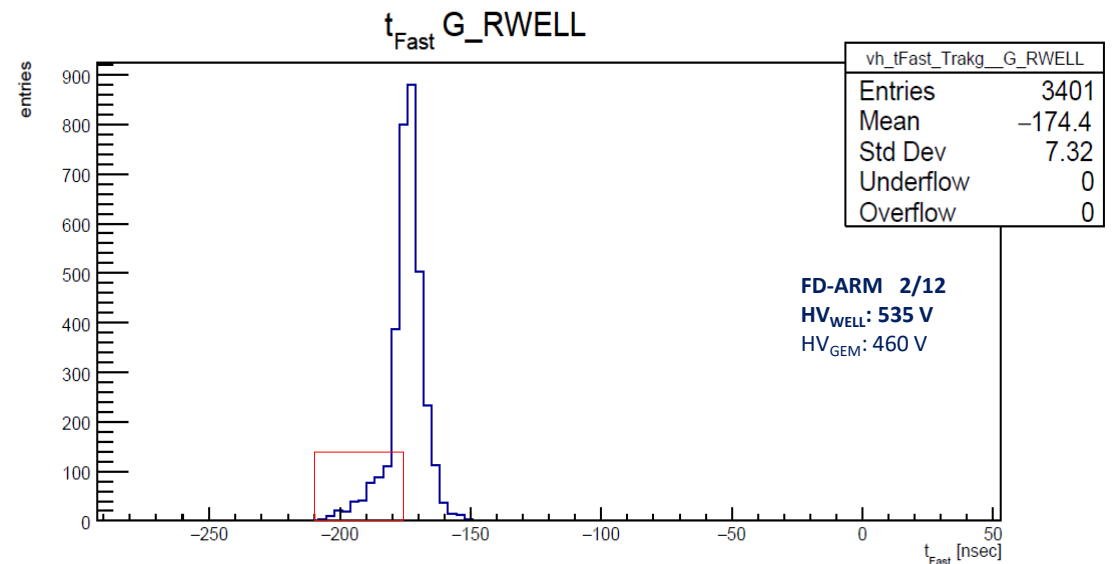
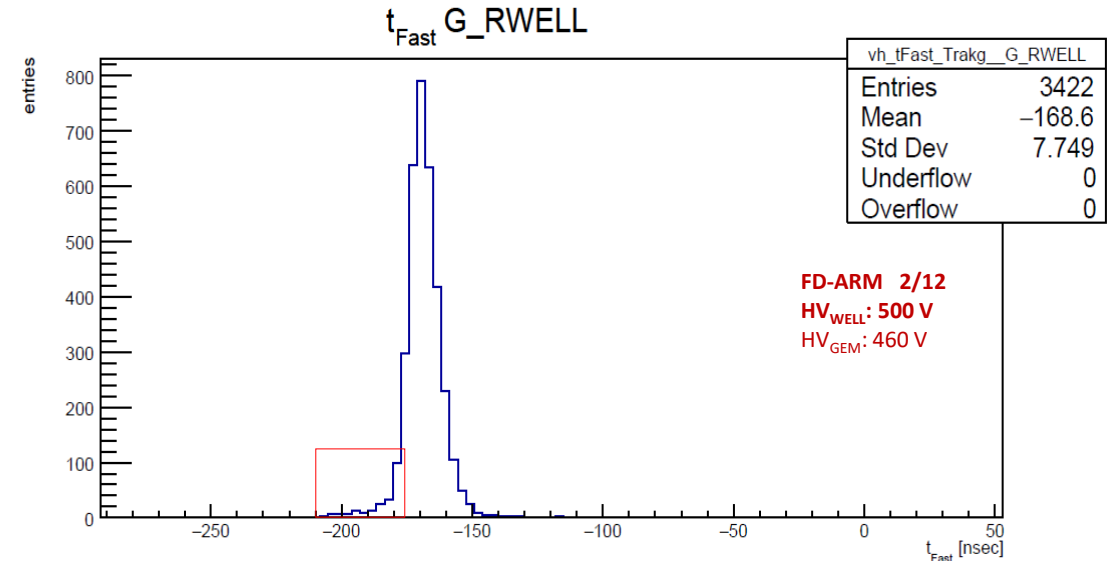
Ionization in the **transfer gap** may generate **early signals** due to amplification only by the μ RWELL:



At high μ -RWELL gain ($HV_{WELL} > 500$ V), this signal can exceed the threshold before the main signal characterized by two amplification stages.

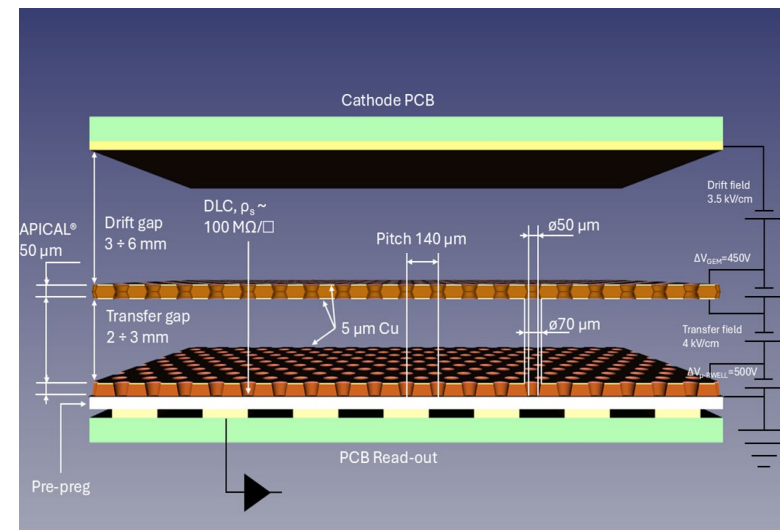
Early-time contributions degrading the time resolution.

An ongoing R&D program is investigating the mitigation of the **BI-GAP** effect by reducing the transfer gap size: the first G-RWELL degree of freedom.

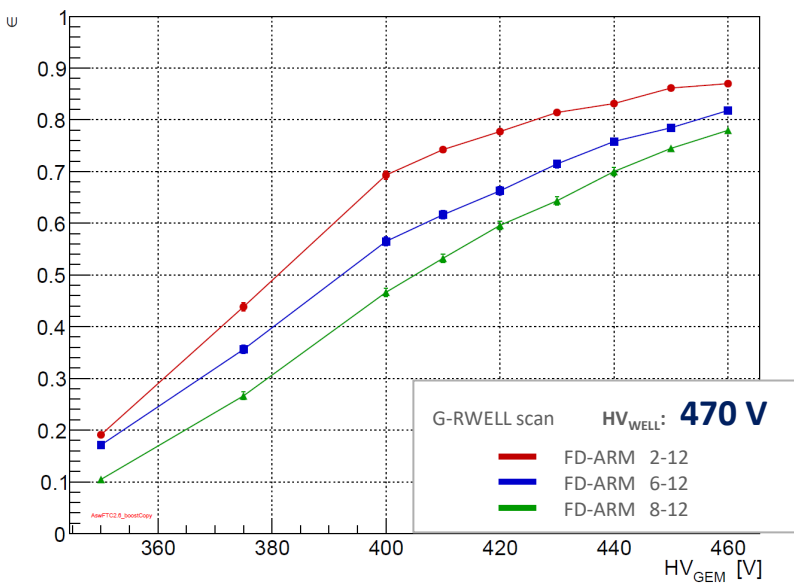


The G-RWELL optimization

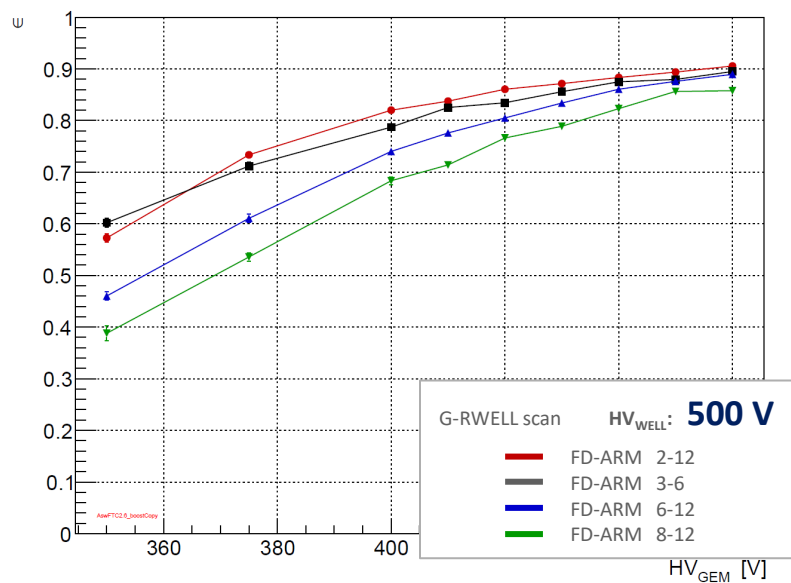
	HV _{GEM} = 460 V			
	THR: FD – ARM (fc)			
	2-12	3-6	6-12	8-12
470 V _{WELL} – G: 5×10 ³	87.0 ±0.6 %		81.8 ±0.7 %	78.0 ±0.7 %
500 V _{WELL} – G: 1×10 ⁴	90.6 ±0.5 %	89.5 ±0.5 %	88.9 ±0.5 %	85.8 ±0.6 %
535 V _{WELL} – G: 2×10 ⁴	87.3 ±0.6 %	87.0 ±0.6 %	89.0 ±0.5 %	89.4 ±0.5 %



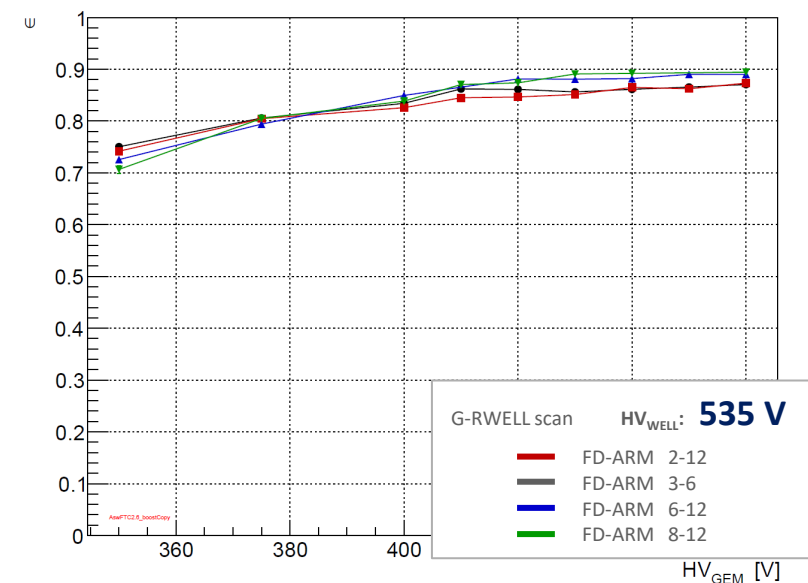
G-RWELL 25 nsec Efficiency



G-RWELL 25 nsec Efficiency



G-RWELL 25 nsec Efficiency

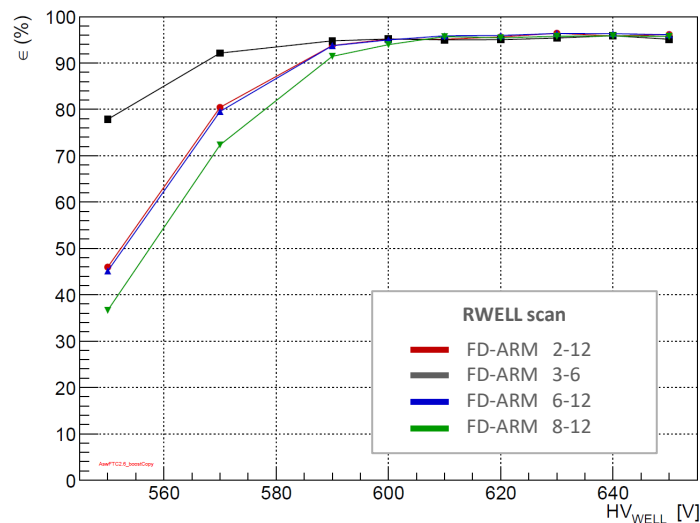


Gas: Ar/CO₂/CF₄ 45/15/40
FEE: FATIC3 (different THR_s)

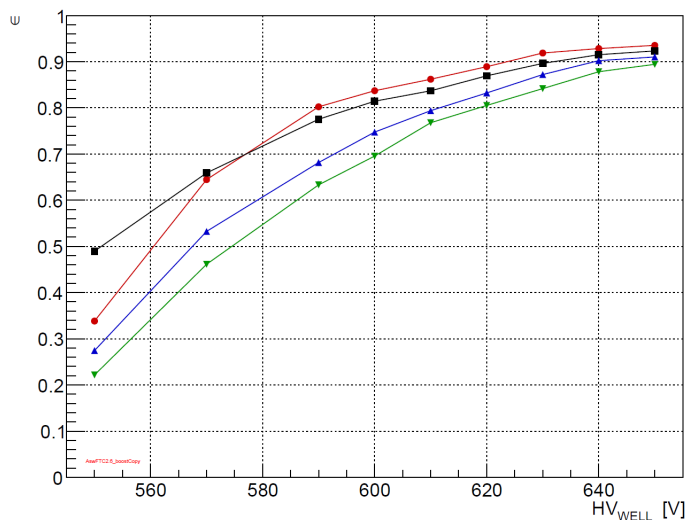
In collaboration with the LHCb U2-muon group,
thanks to INFN Tor Vergata and Bari

G-RWELL and μ -RWELL comparison

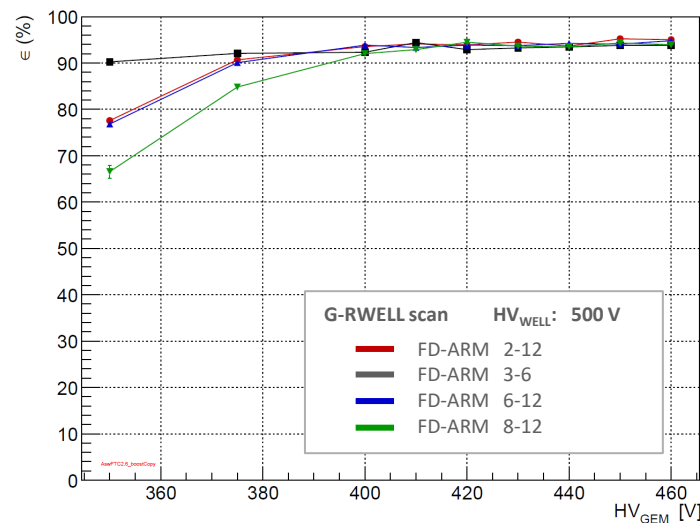
μ RWELL Raw Efficiency



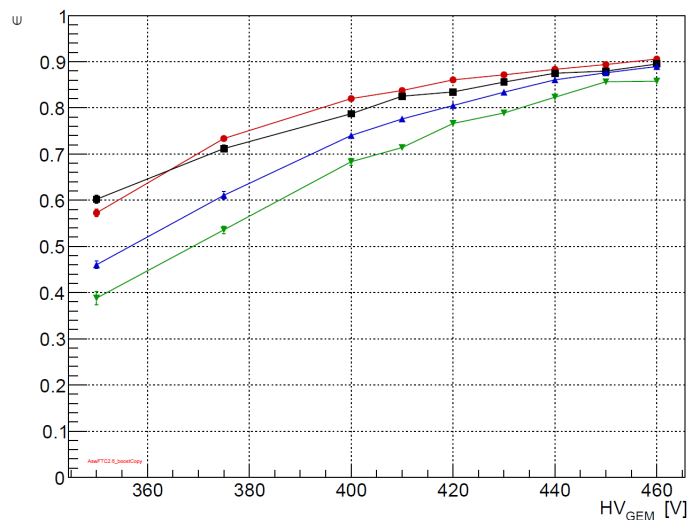
μ RWELL 25 nsec Efficiency



G-RWELL Raw Efficiency



G-RWELL 25 nsec Efficiency



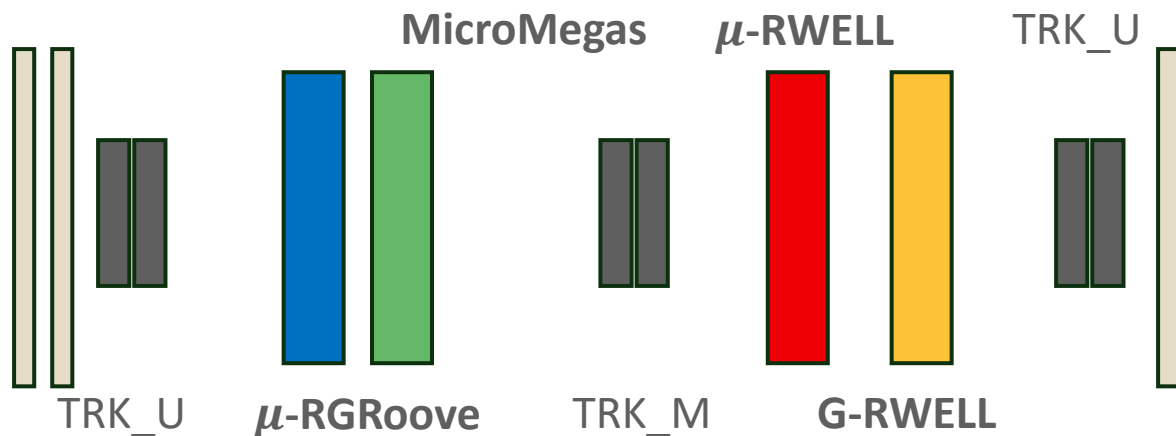
FD-ARM
2-12

	RWELL	G-RWELL
	HV _{WELL} : 650 V	HV _{WELL} : 500 V
	G: 1.1 x 10 ⁴	HV _{GEM} : 460 V
		G: 1. x 10 ⁴
Raw Eff. (%)	96.1 ± 0.3	95.0 ± 0.4
25 nsec Eff. (%)	93.5 ± 0.3	90.6 ± 0.5

The μ RWELL shows higher 25 ns efficiency compared to the G-RWELL.

The **BI-GAP** effect associated with the 3 mm transfer gap is evident in the G-RWELL 25 ns efficiency.

TB PSI 2026



Scintillator: 3 fast scintillators $16 \times 16 \text{ cm}^2$

Trackers: μ -RWELL $5 \times 5 \text{ cm}^2$ – 0.4mm strip R/O

μ -RWELL: $10 \times 10 \text{ cm}^2$ - $9 \times 9 \text{ mm}^2$ pad R/O – Drift 6mm

G-RWELL: $10 \times 10 \text{ cm}^2$ - $9 \times 9 \text{ mm}^2$ pad R/O – Transf 1mm, Drift 6mm

MicroMegas: $10 \times 10 \text{ cm}^2$ - $9 \times 9 \text{ mm}^2$ pad R/O – Drift 3.5mm

μ -RGRoove: $10 \times 10 \text{ cm}^2$ - $9 \times 9 \text{ mm}^2$ pad R/O – Drift 3mm

GOAL:

- raw efficiency & 25 ns efficiency
- rate capability through a measurement of the beam spot and of the rate in current mode
- long-operation performance and stability at max beam flux (we estimate $\sim 50 \text{ mC/cm}^2$ per day)

BEAM CHARACTERISTICS π M1:

- High intensity pion beam line with a momentum ranging between 100 and 500 MeV/c
- Quasi-continuous beam: bunch frequency 50 MHz
- Very high pion rate up to 200 MHz @ 350 MeV/c
- Proton contamination $< 10\%$ @ 350 MeV/c
- Spot size up to $4\text{-}5 \text{ cm}^2$

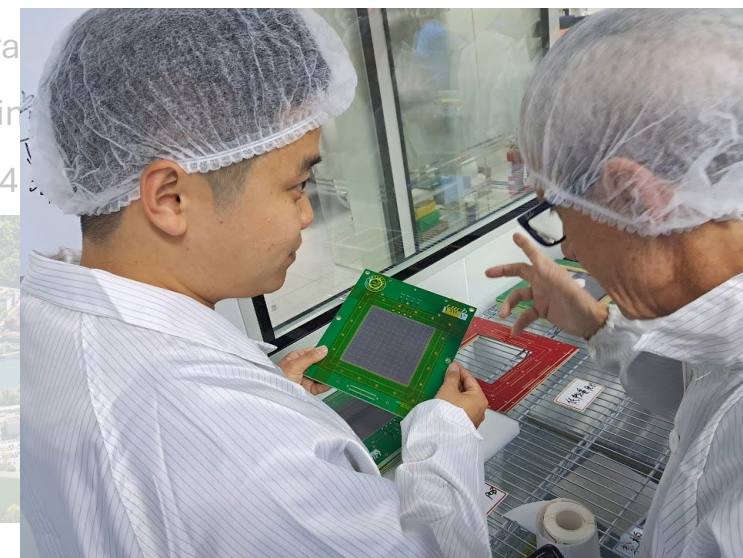


TB PSI 2026

USTC visit to LNF

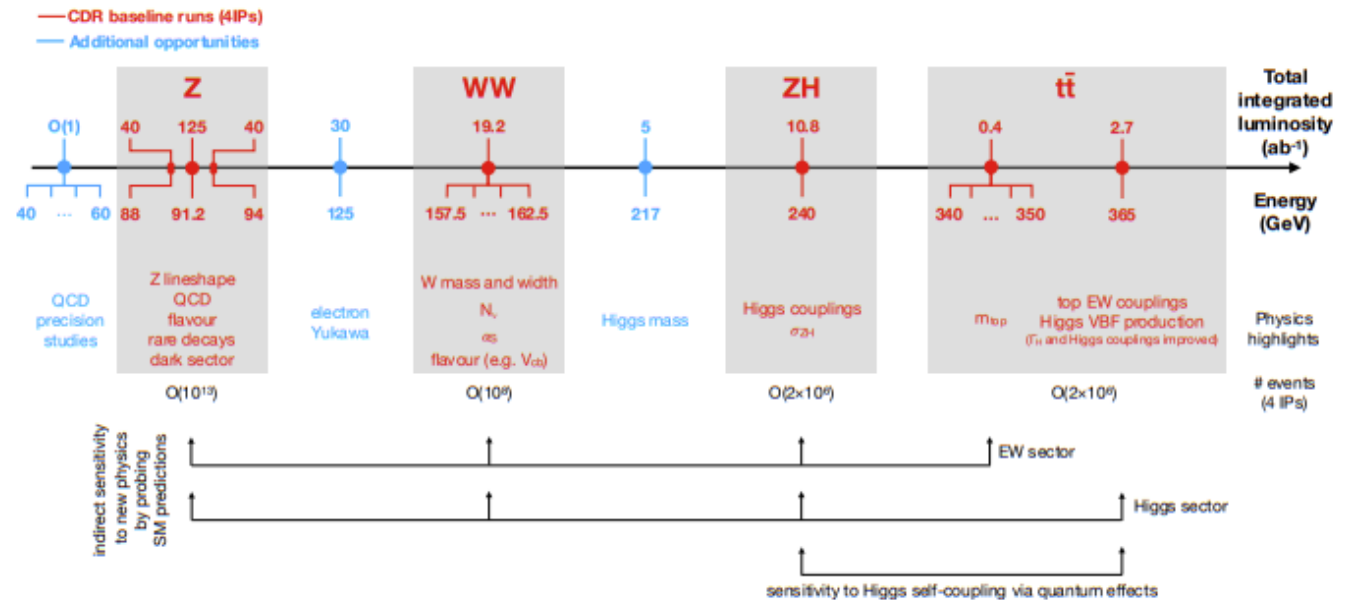


LNF visit to USTC



The Future Circular Collider

Operating across four energy stages, **FCC-ee is an ultra-high-luminosity factory** designed to stress-test the Standard Model with ultimate precision and directly uncover New Physics



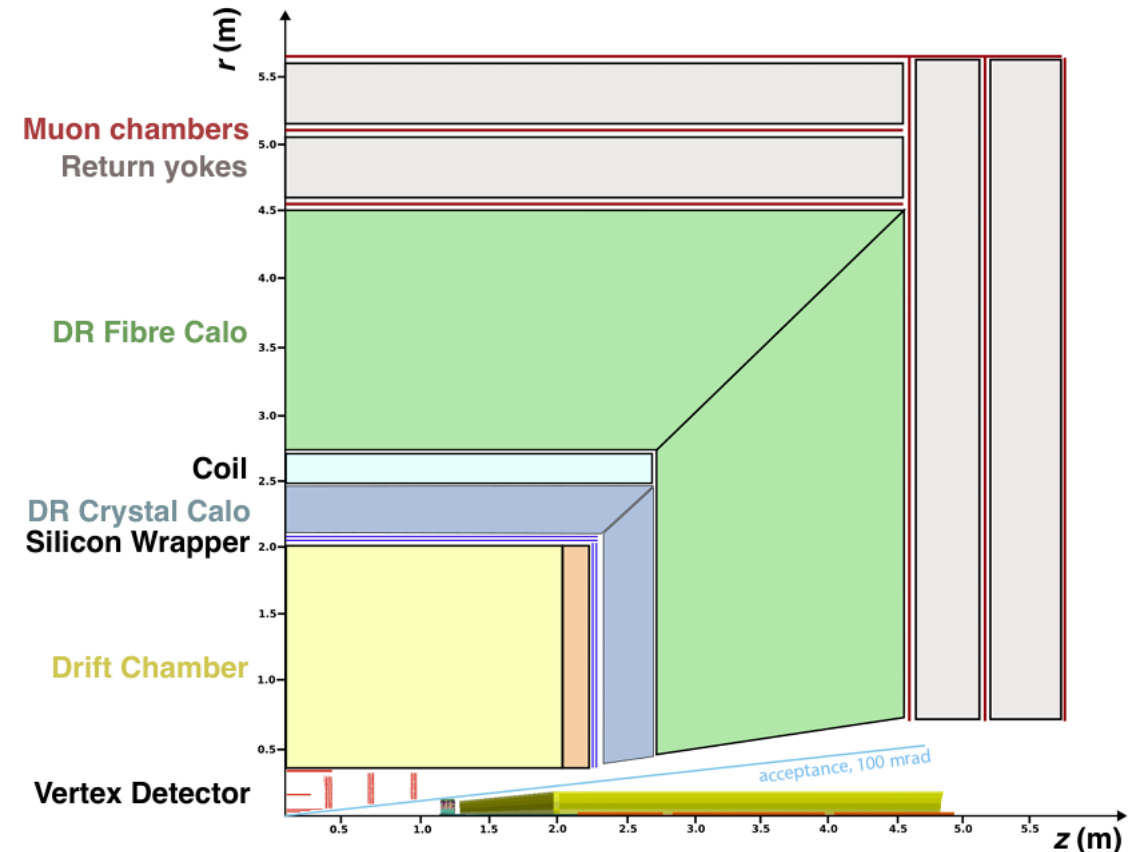
Innovative Detector for Electron-positron Accelerators

DETECTOR REQUIREMENTS

- Large solid angle coverage ($|\cos\theta| < 0.99$)
- Energy resolution 3% for 50 GeV jets
- Momentum resolution $O(0.15\%)$ for 50 GeV muons

SUBDETECTORS

- Silicon Pixel Vertex detector
- Drift Chamber
- Silicon Wrapper
- Crystal Dual-Readout ECAL
- Superconducting Solenoid
- Dual-Readout Fiber Calorimeter HCAL
- Muon Detection System → **μ -RWELL technology**



The IDEA Muon Detector

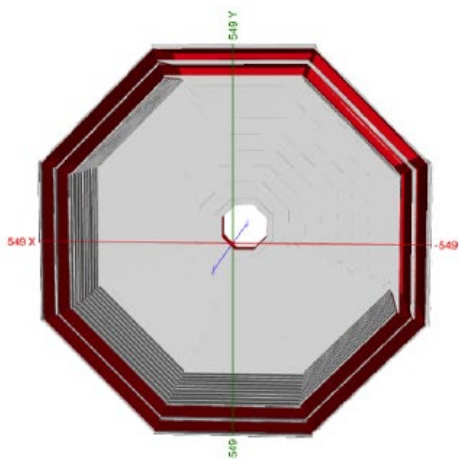
REQUIREMENTS

Reconstruct and tag the muon and detect LLP

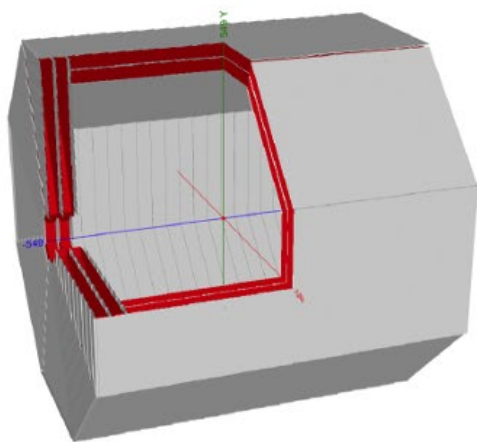
- Efficiency $> 98\%$
- Spatial Resolution $< 400 \mu\text{m}$ ($200 \mu\text{m}$ for LLP)
- Scalable Production
- Optimization of FEE channel cost

DETECTOR TECHNOLOGY: μ -RWELL

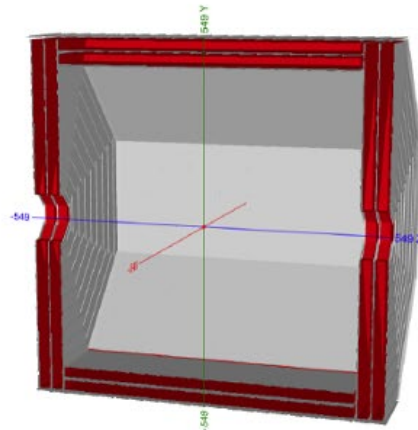
- 3 detection stations
- $50 \times 50 \text{ cm}^2$ 2D tiles to cover about 1525 m^2
- Strip Pitch = 1.2 mm
- FEE capacitance = 270 pF
- 5 million channels



(a) Transverse (x - y) cross-section



(b) 3D perspective (quarter section)



(c) Longitudinal (y - z) section

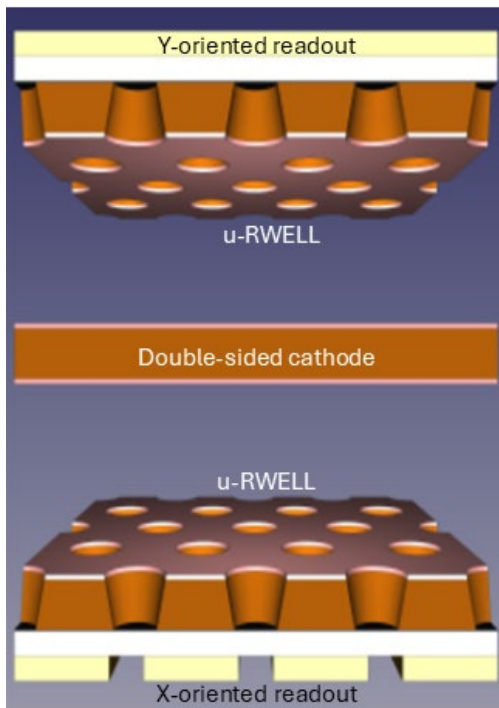
DD4hep geometry visualization of the IDEA Muon system. The μ -RWELL detection layers are shown in grey and the iron yoke segments in red

SIMULATION RESULT

For redundancy and LLP performances:

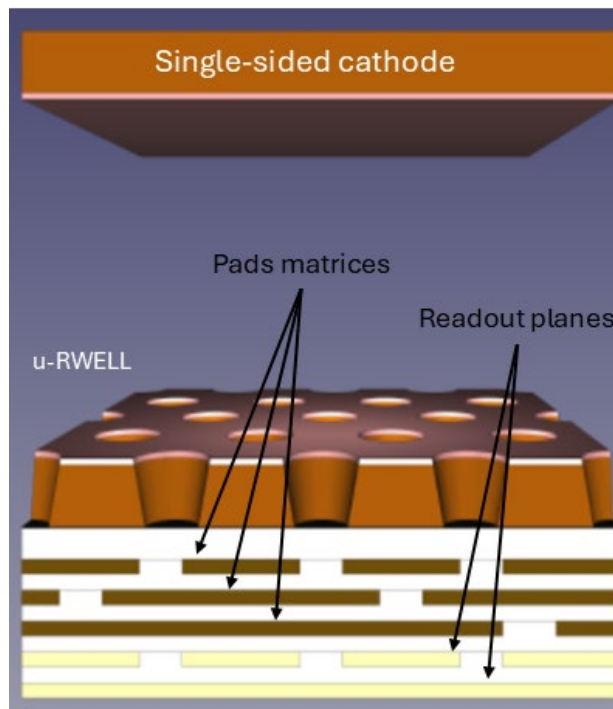
- Number of layers ≥ 4
- ~ 30 million channels

2D μ -RWELL Layouts



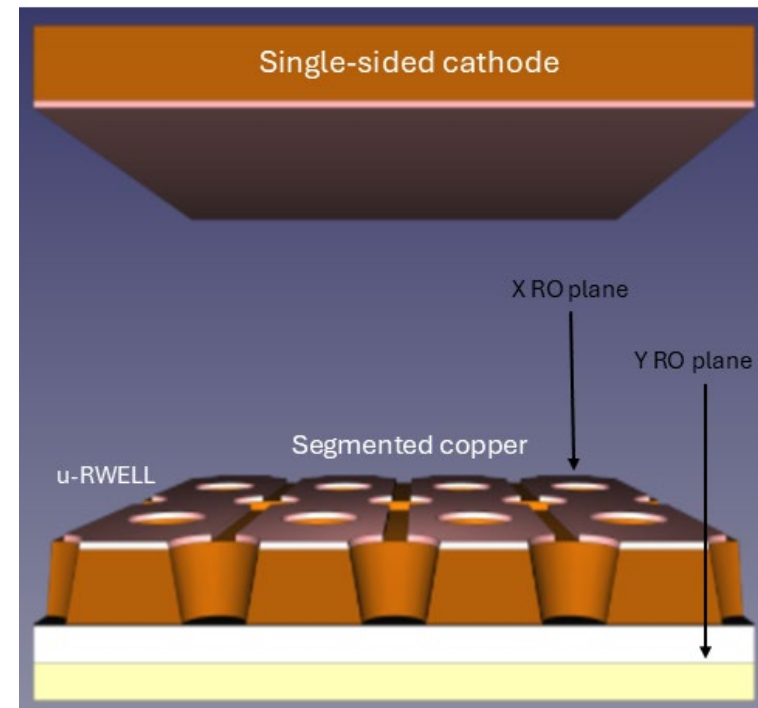
2x1D μ RWELL

- Shared cathode
- 1 view per μ RWELL
- Easy PCB construction
- Operation at lower gas gain



μ RWELL 2D: Charge Sharing r/out

- **Charge-Sharing** performed through the **capacitive coupling** between a **stack of layers of pads** and the readout board
- Good performance but needs **higher gain**
- **Reduce the FEE channels**, but the total charge is shared between the X and Y readout



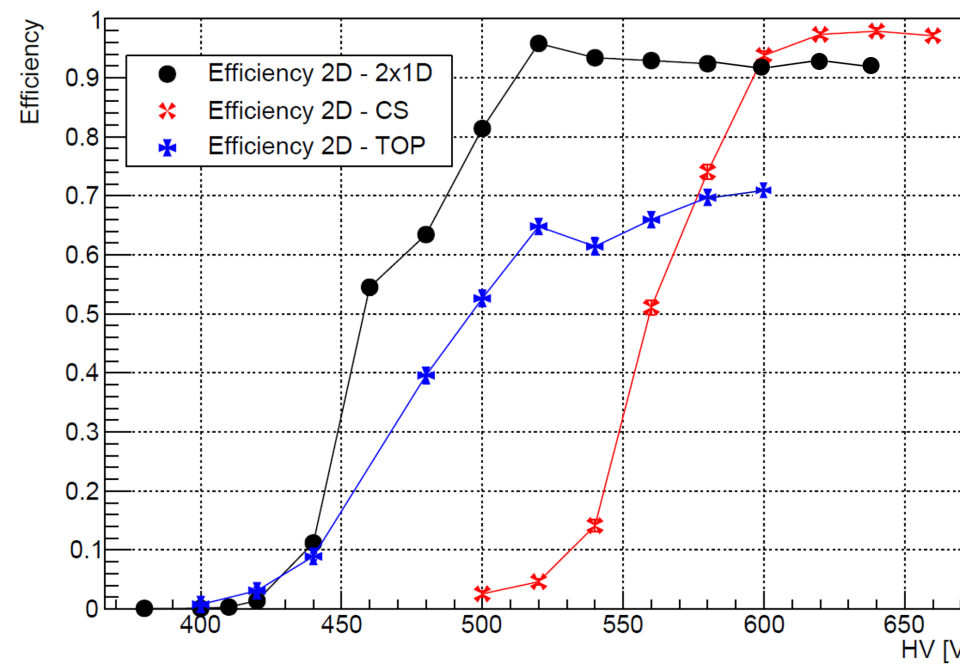
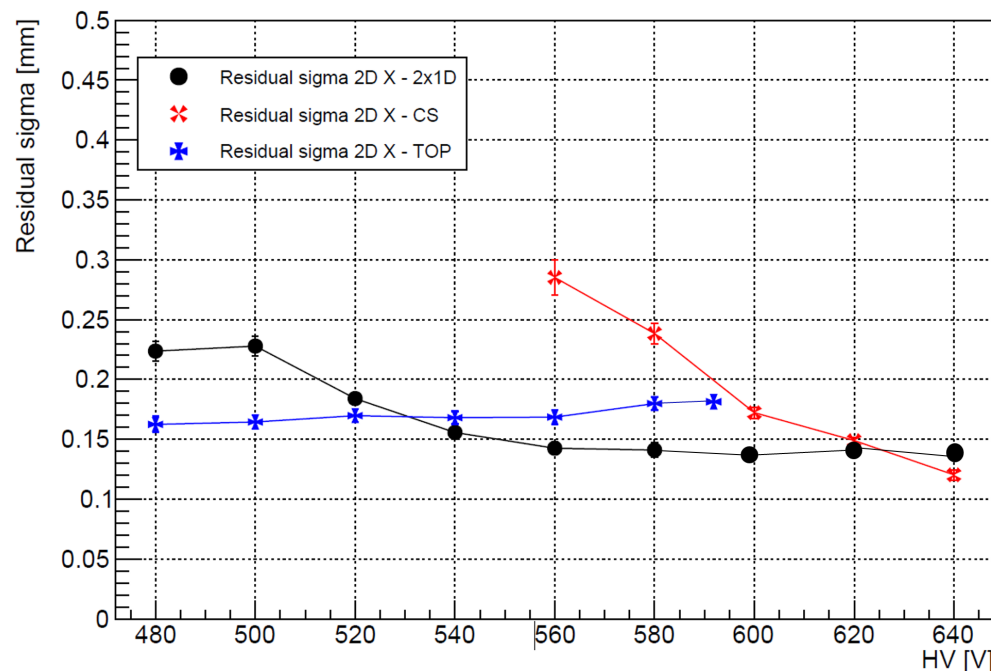
μ RWELL TOP r/out

- X strips patterned on the TOP of the amplification stage introduce a **dead zone in the active area**
- Operation at **lower gas gain**

K. Gnanvo et al., 2023,
NIM A 1047 167782

2D μ -RWELL: Layout Optimization

with APV25



2x1D μ RWELL
(pitch 0.8 mm)

- Spatial resolution < **200 μ m**
- Efficiency ~ **95%**

μ RWELL 2D: Charge Sharing r/out
(pitch 1.2 mm)

- Spatial resolution < **200 μ m**
- Efficiency ~ **98%**

μ RWELL TOP r/out
(pitch 0.8 mm)

- Spatial resolution < **200 μ m**
- Efficiency ~ **70%**

In collaboration with the IDEA muon group, thanks to INFN Bologna, Ferrara and Torino

A new entry: the Charge Dispersion μ -RWELL

With APV25
& TIGER

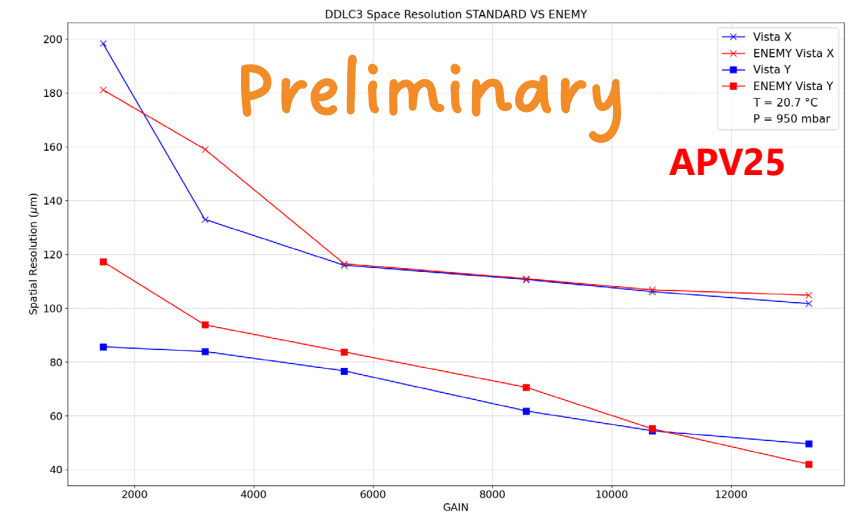
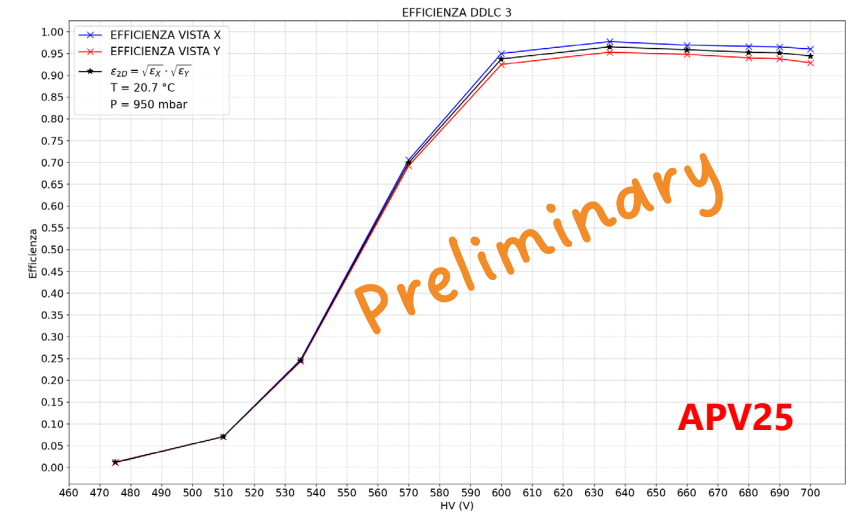
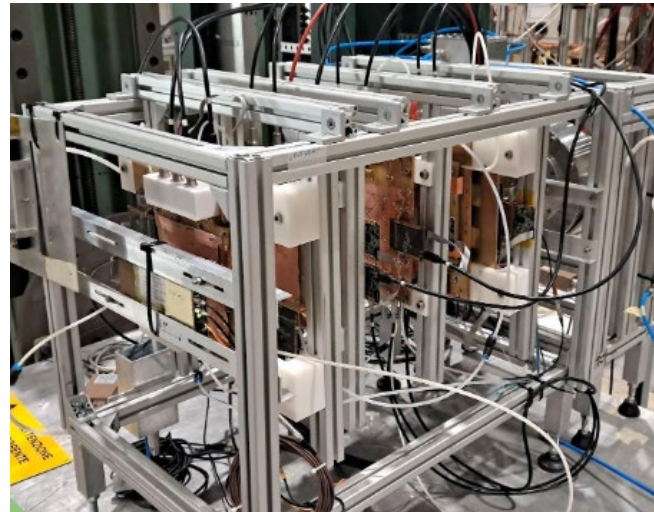
2D CD μ -RWELL

μ -RWELL with improved Charge Dispersion

- First DLC layer with high resistivity ($\rho = 100 \text{ M}\Omega/\square$) for higher spark quenching and detector stability
- Second DLC layer with low resistivity ($\rho < 1 \text{ M}\Omega/\square$) for signal spreading

CD μ -RWELL – First 2D prototype test (May '26)

- First **CD μ -RWELL prototypes** with 2D readout successfully built and tested at SPS-H8 beamline
- Production issue: second foil **resistivity** $\approx 20 \text{ M}\Omega/\square$ (non-optimal condition)
- Despite this, the **Charge Dispersion mechanism was clearly confirmed**
 - results consistent with expectations
- Overall performance was very encouraging
 - **strong support for further R&D development**



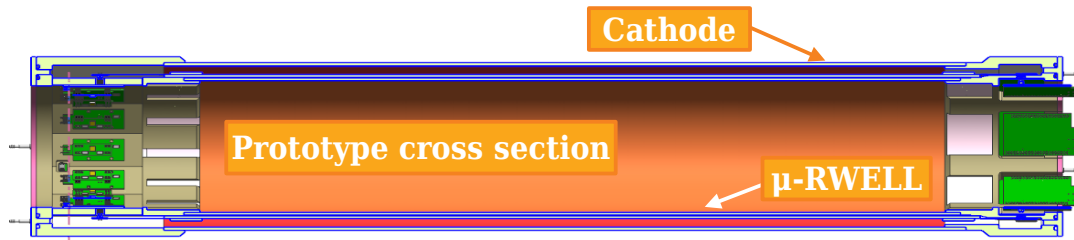
C-RWELL

Low X_0 Cylindrical μ -RWELL

Thanks to the LNF and INFN-Fe
Eurizon collaboration

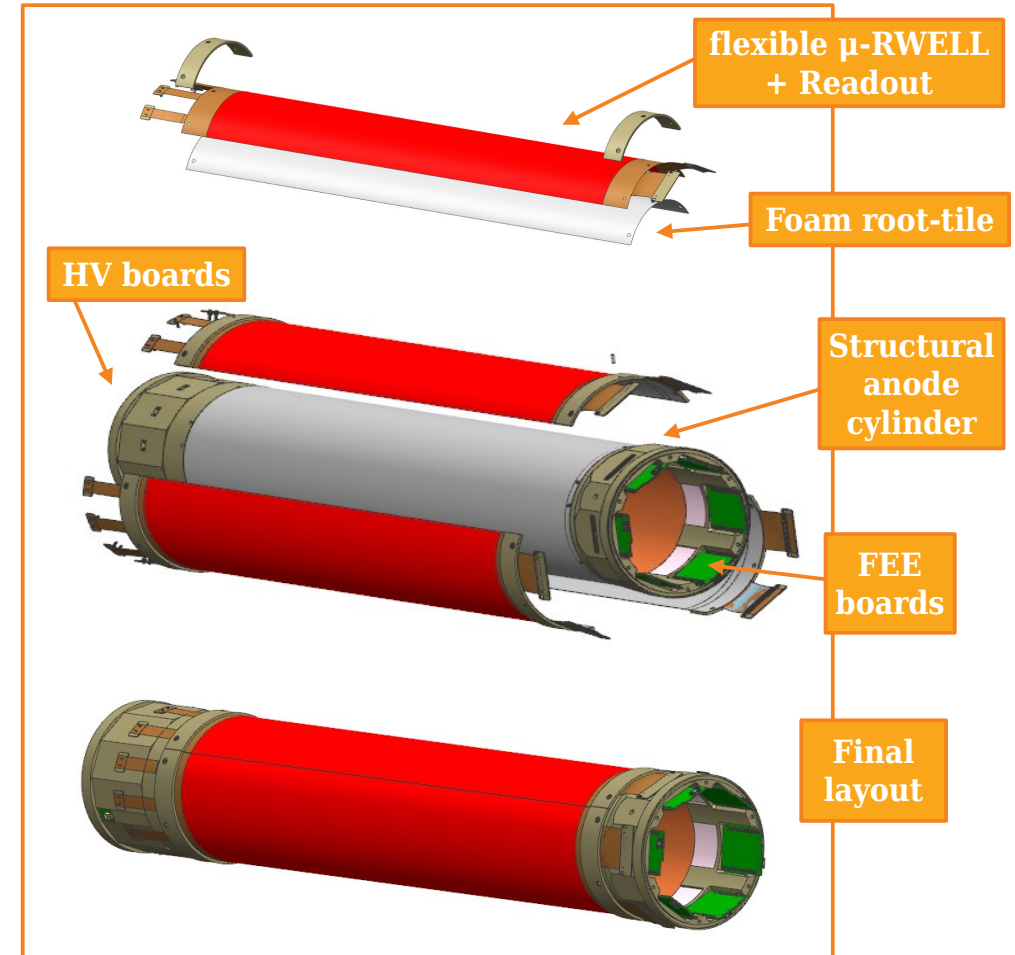
By exploiting the **flexibility** of both the μ -RWELL amplification stage and its readout, we are developing a **low-mass (0.6-1% X_0)**, **modular** inner tracker for low-energy e^+e^- colliders: the C-WELL.

- From standard μ -RWELL on rigid PCB supports → a **full flexible detector tile**
- **Three tiles** have been glued on composite/foam roof-tiles, then mounted on the anode cylindrical support
- A **full cylindrical-cathode** will close (externally) the detector



Detector size

- external **diameter** $\approx 20\text{cm}$
- global length $\approx 100\text{cm}$
- **active length** $\approx 60\text{cm}$



Final Assembly

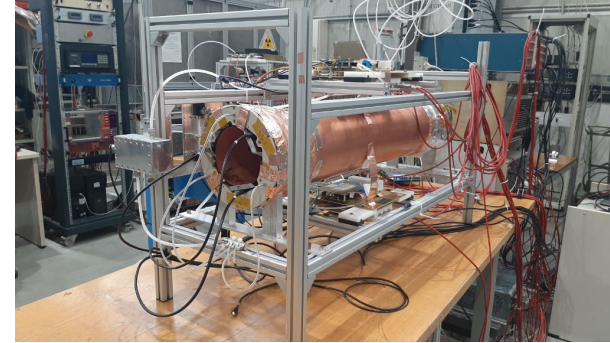
The final assembly **didn't require a highly sophisticated sliding machine**, thanks to the **large distance (10 mm)** between the roof tiles and the internal surface of the cathode.



The tile gluing and the detector assembly took **14 days**.

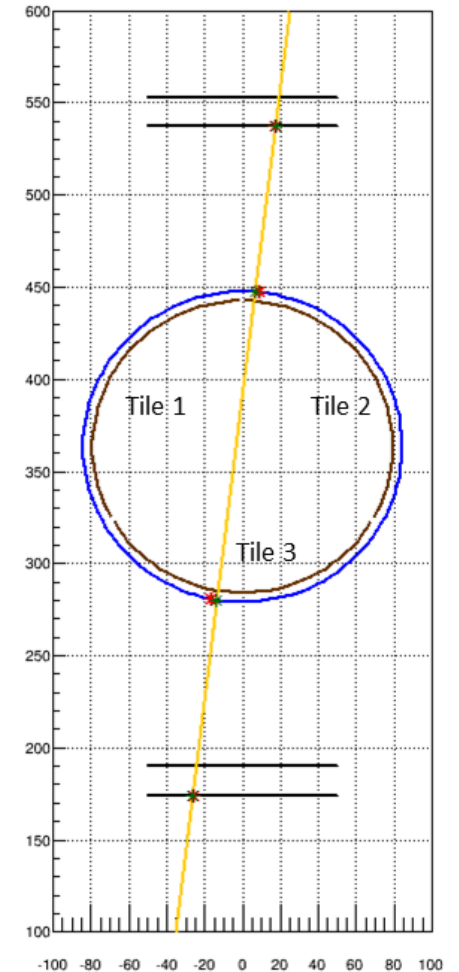
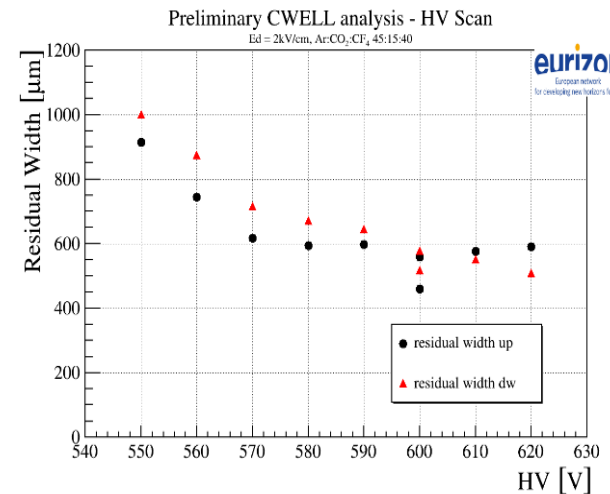


Cosmic Rays test



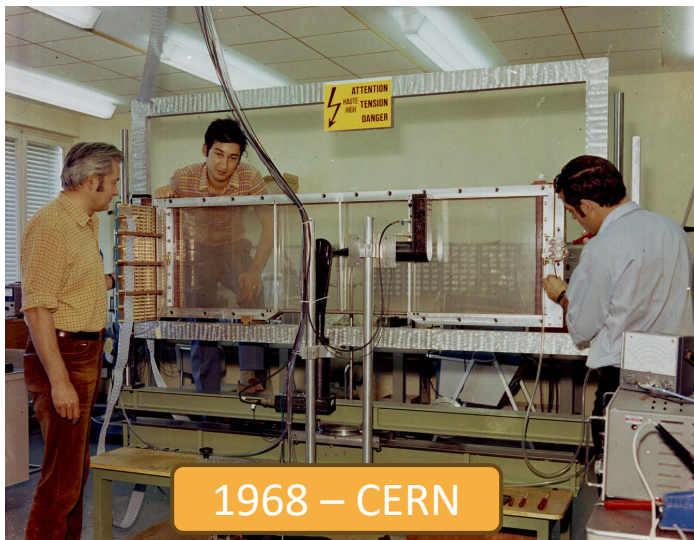
Tracking system: 4 1D μ -RWELLS
Gas: Ar:CO₂:CF₄ 45:15:40

→ large residuals due to inclined tracks



MSPC

Why



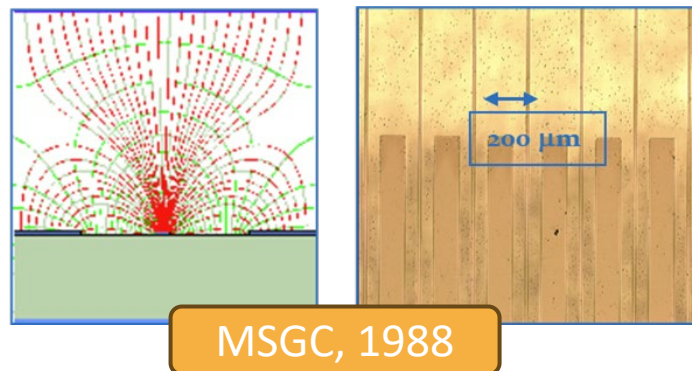
MWPC:
Reliable, Robust,
Good Performance

But have two
manufacturing problems:

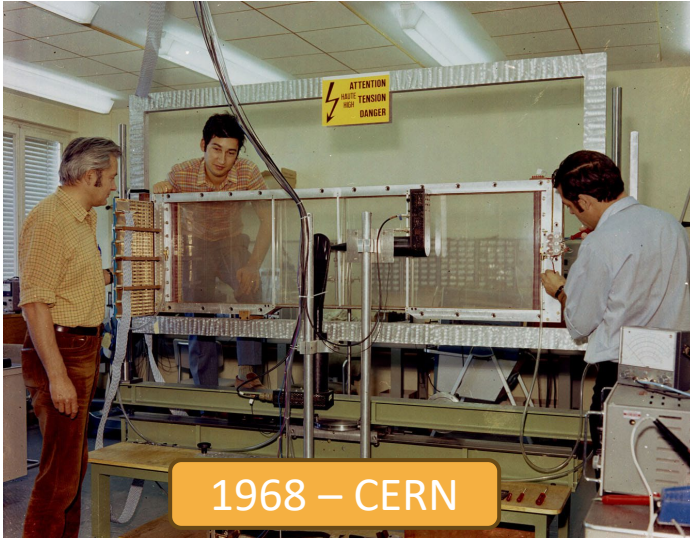
A **very high personpower** needed
for each detector

Very few production sites still
available in the world

But due to MWPC
time consuming manufacturing,
**even in low irradiated
applications sometimes
MPGDs are favoured**
since they are easier to build.



Why and How



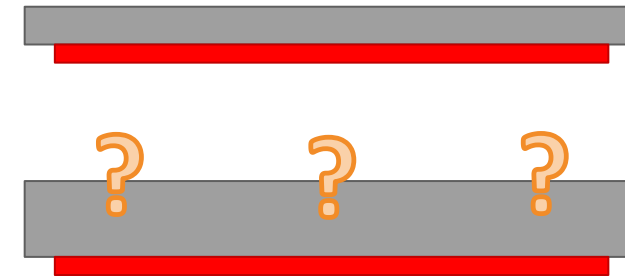
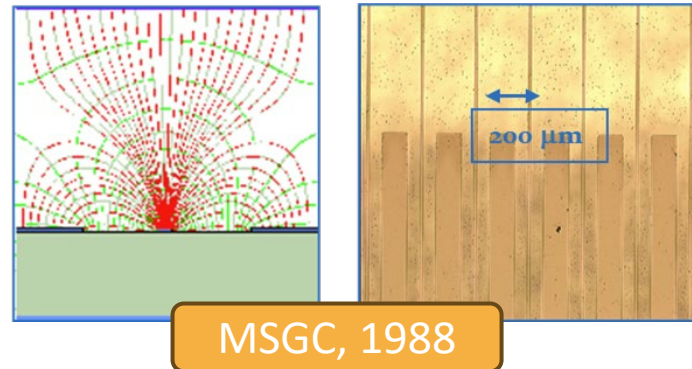
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Cathode

Amp. Stage

Support

Bias Backplane

Manufacturing simplicity

- ⇒ Photolithography
- ⇒ Anode: Cu strips (30μm)
- ⇒ Which substrate?

Spark Protection

- ⇒ **Cathode-Anode** distance: Drift Gap **O(2-6mm)**
- ⇒ **Anode strip pitch O(2mm)**
- ⇒ Are Cathodic strip (100μm) needed?
- ⇒ **HV bias Backplane** (as a «Virtual Cathode») ?

Gas

- ⇒ a simple gas mixture: **Ar:CO₂** is the target

Should be built like a «**MicroPattern**»
...**might** not be a «**MicroPattern**»!

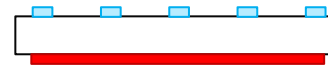
The MultiStrip Proportional Chamber

2026

5x6cm² Proof of Concept

10x10cm² Detector

Only SENSE



Sense Strip 30µm
GLASS
Bias Backplane

FIELD SENSE



Sense Strip 30µm
Field Strip 100µm
GLASS
Bias Backplane

GLASS

DLC



Sense Strip
Kapton
DLC



Sense Strip
Field Strip
Kapton
DLC



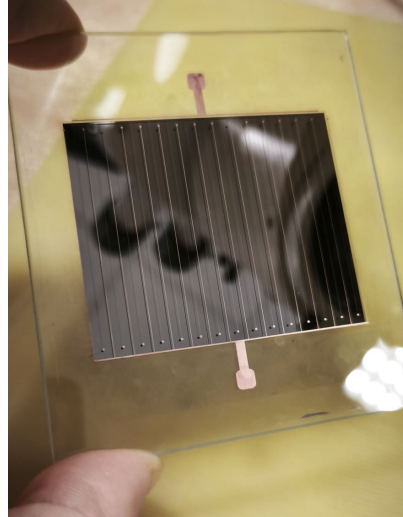
Gas mix used
Ar:CO₂ 90:10

MSPC GLASS – Manufacturing

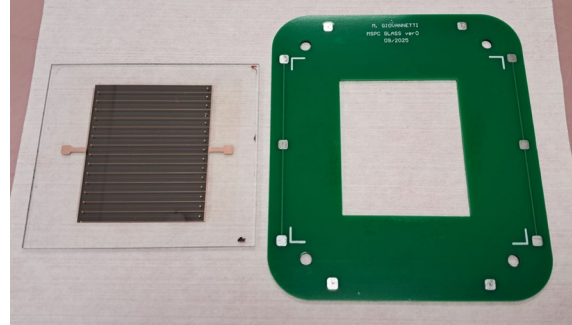
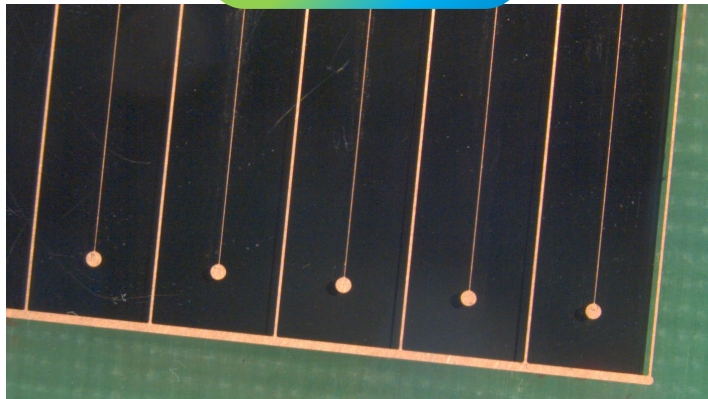
First small batch
produced

Detector Yield 20%
mainly due to calibration
of sputtering and etching

Strip Yield for a good
detector: 100%

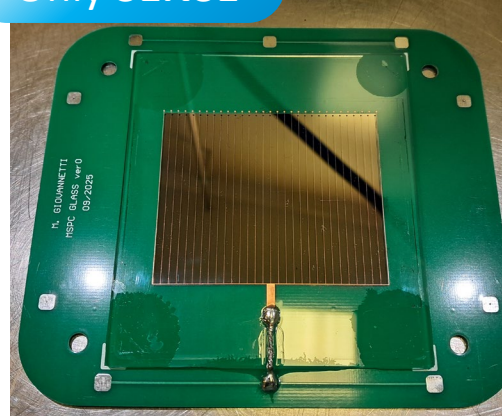


FIELD SENSE

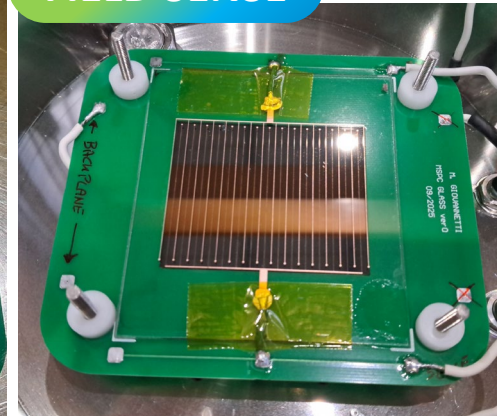


Detectors mounted on an FR4
support, useful for HV distribution

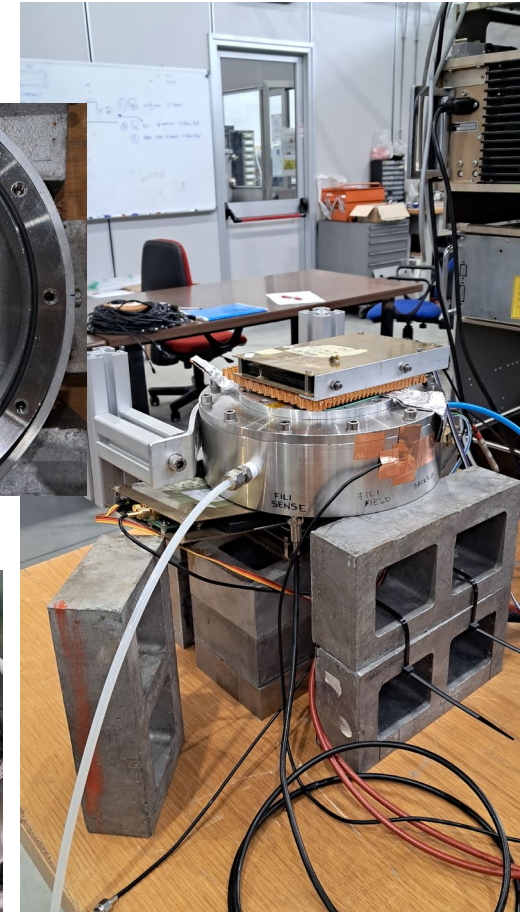
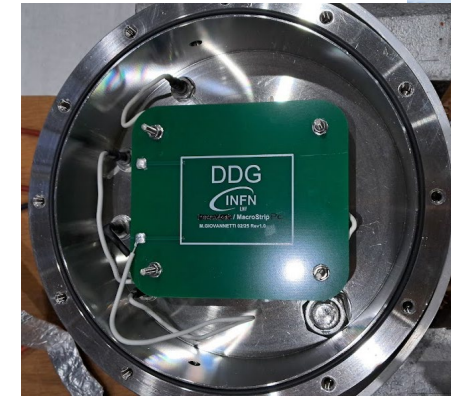
Only SENSE



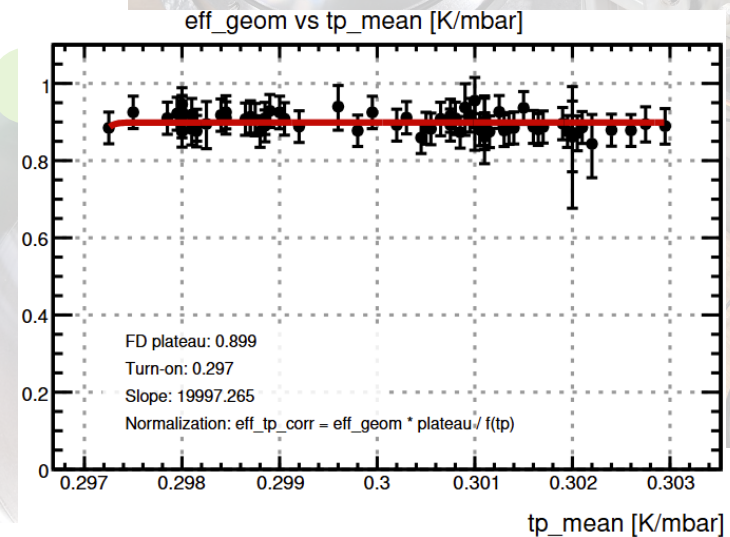
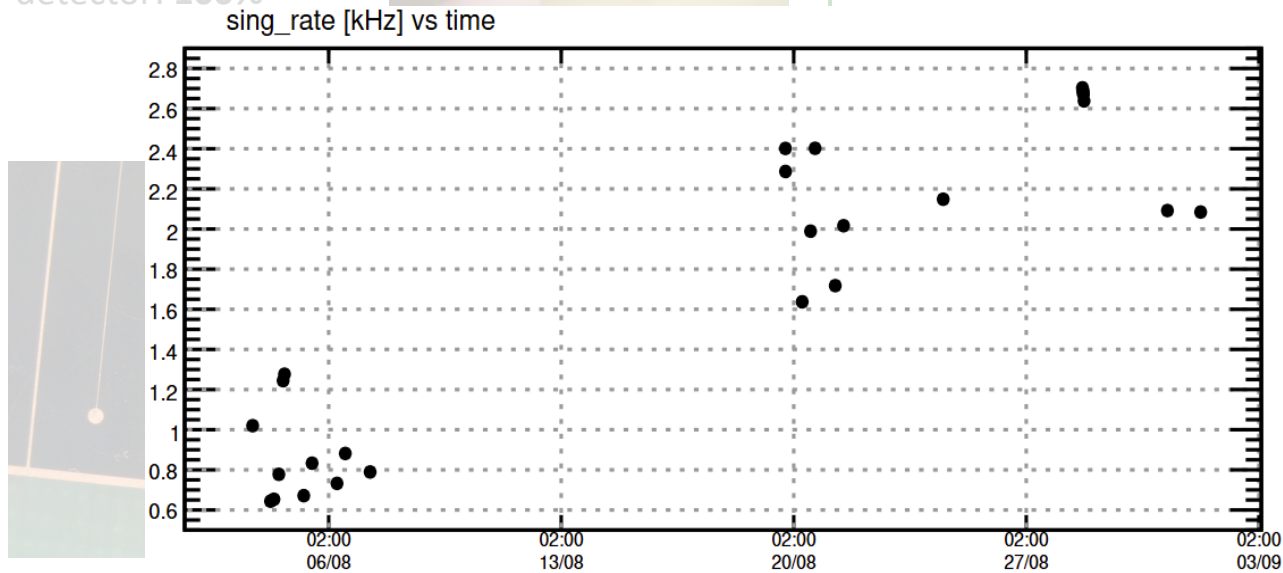
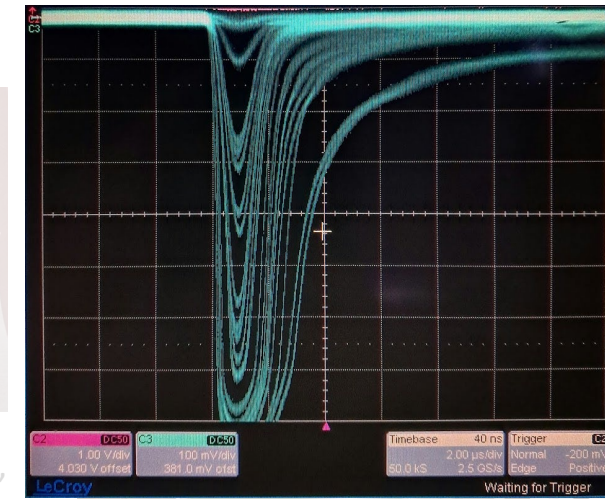
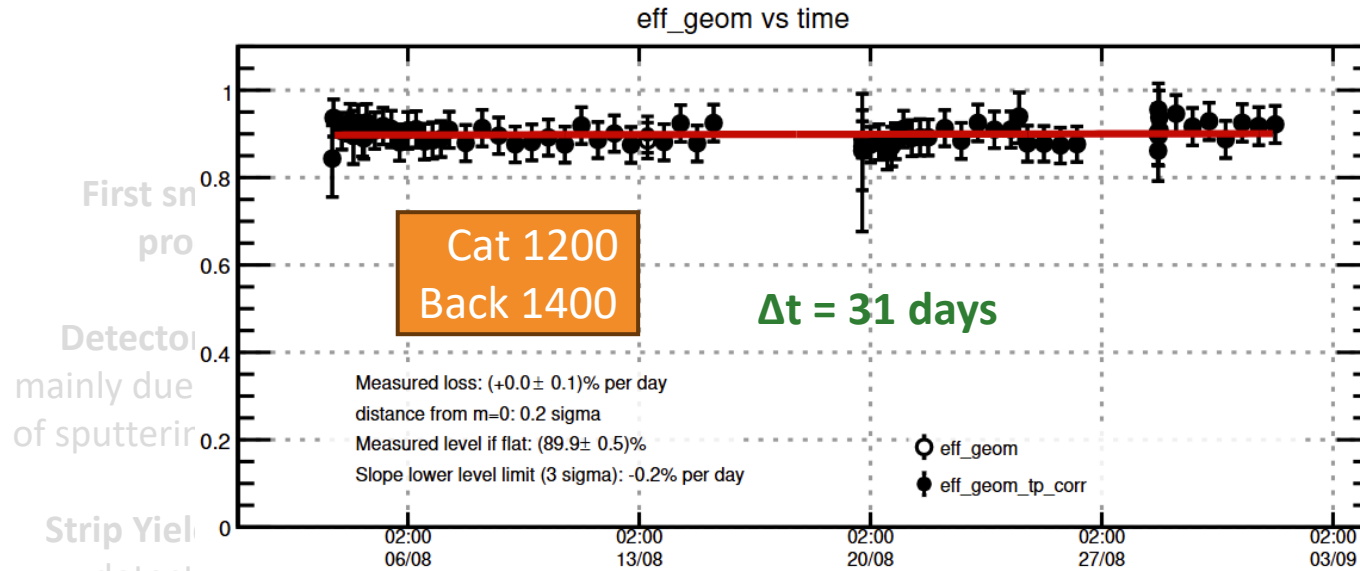
FIELD SENSE



Vessel top view
w/ closed cathode



MSPC GLASS – Stable Operation



Future Steps

- [2026] «Proof of Concept» 5x6 w/ single R/O ch.
 - **MSPC DLC** – under development



Two different Kapton thicknesses will be tested

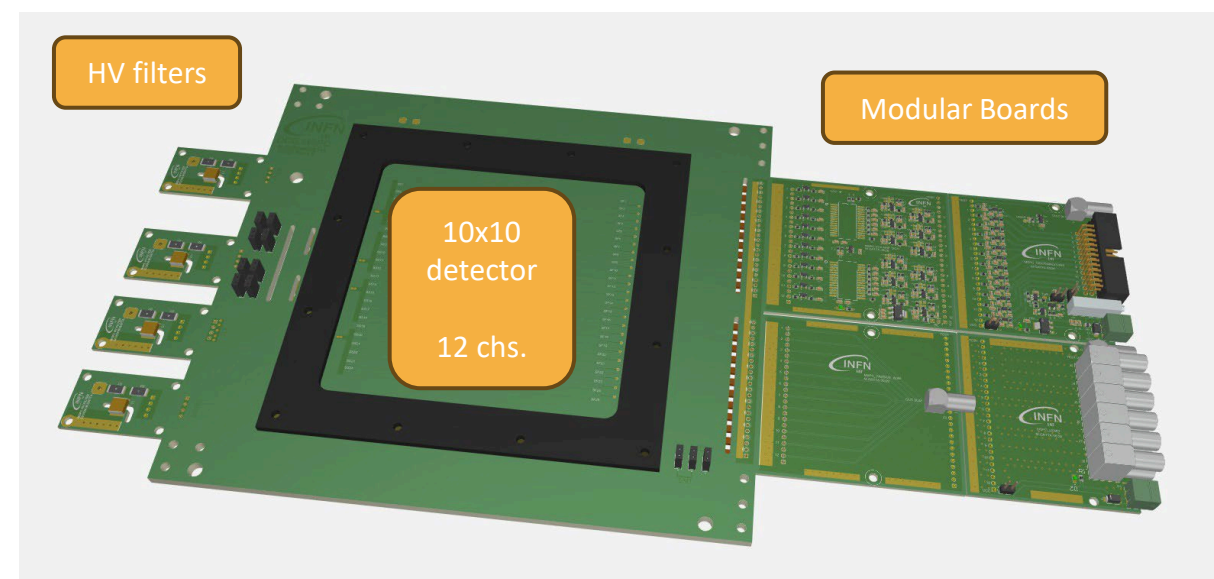
Future Steps

- [2026] «Proof of Concept» **5x6** w/ single R/O ch.
 - **MSPC DLC** – under development



Two different Kapton thicknesses will be tested

- Detector **10x10**, w/ integrated FEE
 - [2026] **MSPC DLC** – to be finalized after 5x6 protos.
 - [2027] MSPC GLASS – to be designed



Modular
Boards

Front-End Passive Sum: 12 chs. OR; **VTX-AMP**: 10mV/fC; **CSA-shaper**: 4 mV/fC 4us

Back-End Active Sum: VTX signals OR; **Discriminator**: for VTX signals; **x12 EMO**: output

Summary and Outlook

Future HEP experiments demand **gaseous detectors** combining **excellent spatial and time resolution**, high-rate capability, operational stability, and radiation resistance.

For over **30 years**, the **Detector Development Group (DDG)** at the **INFN Frascati National Laboratories** has been developing innovative gaseous-detector technologies to meet these challenges.

Summary and Outlook

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Our R&D efforts are primarily focused on the **μ -RWELL**, addressing different requirements:

- **LHCb U2**: operation in high rate environment, targeting time resolution $< 5\text{ns}$
- **FCC/IDEA**: large-area detectors providing high-precision tracking.
- **Low X_0 Cylindrical** detectors, for inner tracking systems

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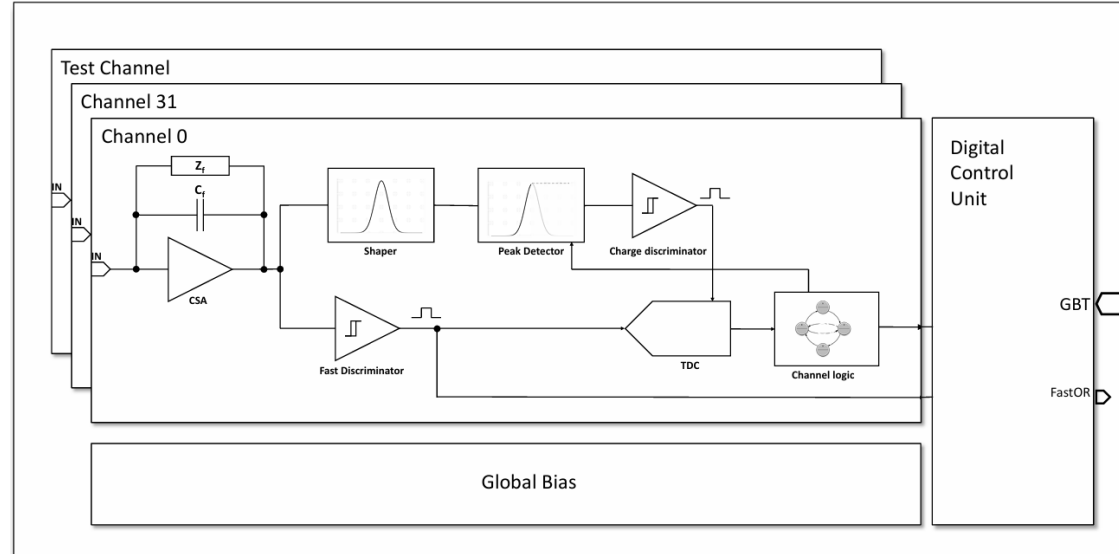
In parallel, the DDG continues to explore **new detector concepts**, most recently the **MSPC**, a promising, cost-effective solution for moderate-rate applications.

We look forward to the challenges ahead and are pleased to welcome our USTC colleagues, who have recently joined our LHCb R&D effort!



Spare

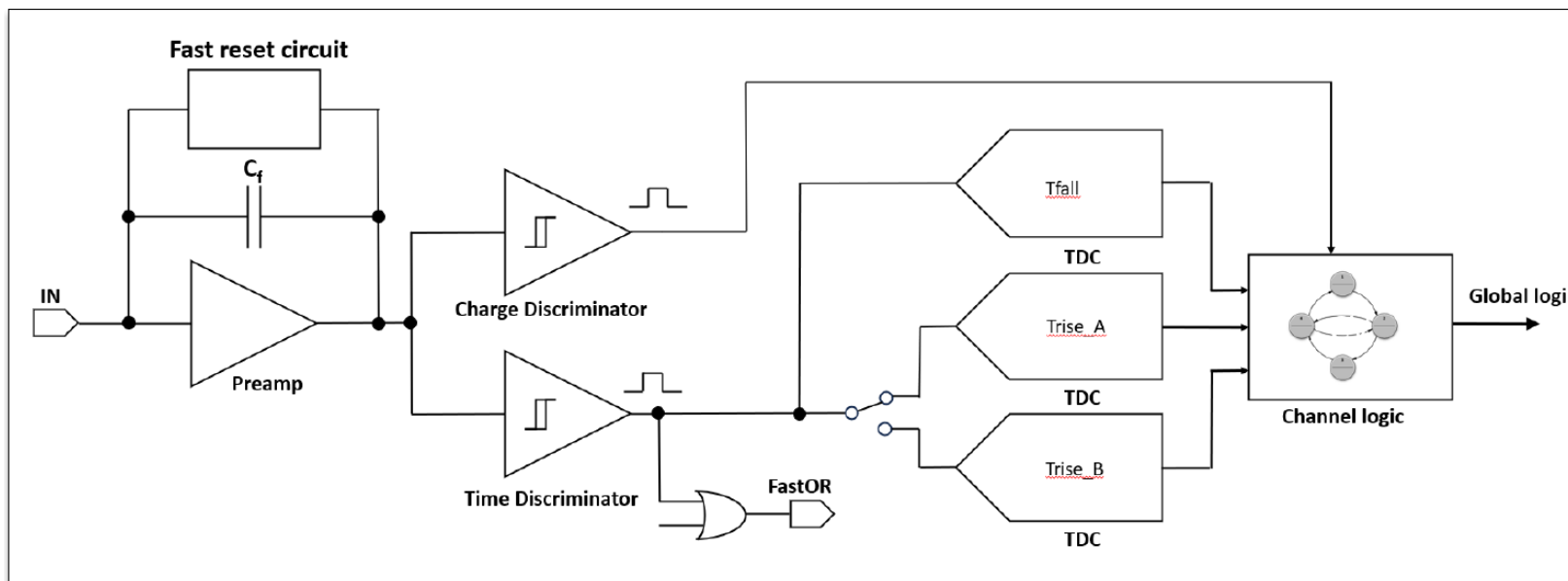
FATIC3 ASIC



- FAsT Timing Integrated Circuit (FATIC) designed in CMOS 130 nm technology
- CSA with programmable polarity, gain (10 mV/fC, 50 mV/fC) and recovery time of $\sim 1 \mu\text{s}$, ENC @150 pF: 1.2 fC
- Shaper with programmable peaking time: 25 ns, 50 ns, 75 ns, 100 ns
- Charge measurement with dynamic range $\leq 50 \text{ fC}$ and programmable charge resolution
- Time measurement (ToA) using 100 ps TDC
- 640 Mbps serial link, GBT compatible
- Power consumption $\sim 200 \text{ mW}$

FATIC4 ASIC

The FATIC3 chip has a dead time of $\sim 1\mu\text{s}$, mainly driven by the CSA, which should be reduced up to 100ns in order to guarantee efficient operations at the expected rates ($\sim 700\text{kHz/ch}$): a new FATIC version has been produced.

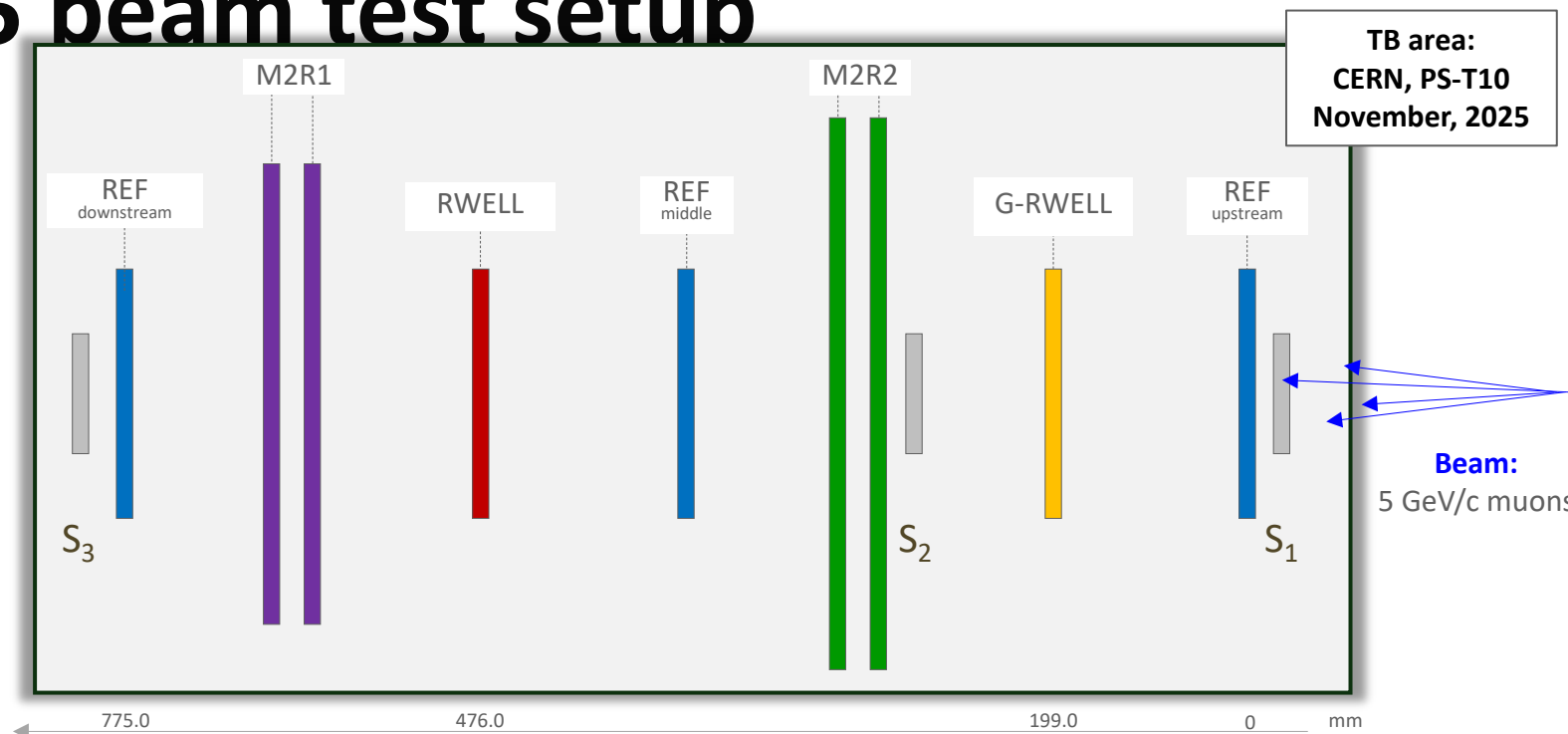


1. **CSA mode** (the same of the previous FATIC3 version): programmable MOS discharge resistor. Fixed gain (7mV/fC), adjustable recovery time.
2. **Fast reset** : speed-up the discharge process: **fast recovery** $< 100\text{ ns}$
3. **Leakage-current compensation circuit (LCC)** with two programmable parameters (filter capacitance and LCC bias current) can be activated to compensate a constant detector leakage current and/or an ion tail.

Charge branch: acknowledge of the input signal + filter noise. Charge threshold $\leq 50\text{fC}$.

Time branch: - measure of ToA (two switched channels capable of detecting 2 hits within few ns), resolution 100ps.
- measure of Time over Threshold, resolution 400ps.

LHCb 2025 beam test setup



Tracker:	M2R1:	RWELL:	Tracker:	M2R2:	G-RWELL:	Tracker:
<u>μRWELL</u>	<u>G-RWELL</u>	<u>μRWELL</u>	<u>μRWELL</u>	<u>G-RWELL</u>	<u>G-RWELL</u>	<u>μRWELL</u>
10x10 cm ²	60x25 cm ²	10x10 cm ²	10x10 cm ²	30x25 cm ²	10x10 cm ²	10x10 cm ²
Pad R/O, 9x9 mm ²	instrum. 12.6x15.3 cm ²	Pad R/O, 9x9 mm ²	Pad R/O, 9x9 mm ²	Instrum. 14.4x14.4 cm ²	Pad R/O, 9x9 mm ²	Pad R/O, 9x9 mm ²
Drift: 6 mm	Pad R/O, 9x9 mm ²	Drift: 6 mm	Drift: 6 mm	Pad R/O, 9x9 mm ²	Drift-Tran: 6-3 mm	Drift: 6 mm
TB2024: 1.2 mm pitch-strip	Drift-Tran: 6-2 mm			Drift-Tran: 6-2 mm		TB2024: 1.2 mm pitch-strip

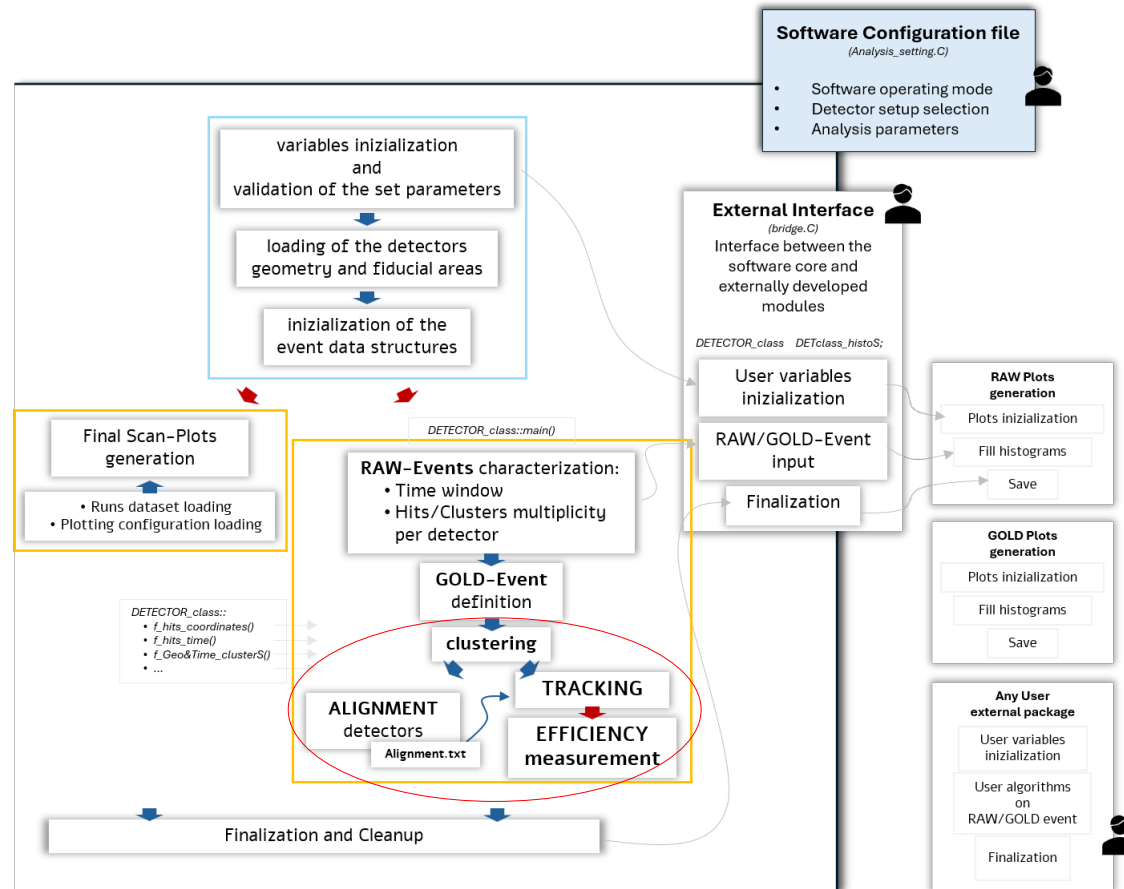
LHCb 2025 beam test software

Multi-purpose detector setups equipped with both strips and pads readout

- online data quality monitoring
- offline analysis

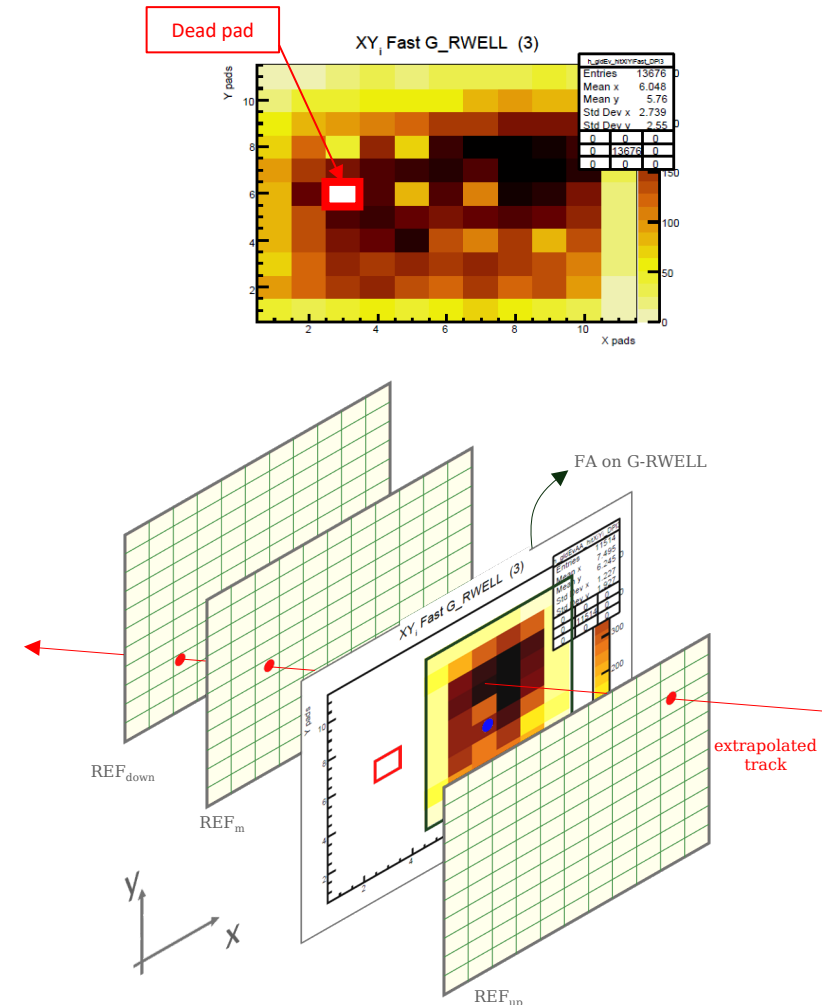
Main useful tools included:

- Event display
- HV-scan plots generation
- Clustering based on topology and time
- Detector alignment
- Track reconstruction



Also designed for collaborative use, featuring a user-friendly C++ interface for detectors configurations, final plot production and packages extensibility.

The tracking algorithm implements fiducial Areas on the μ /G-RWELLS, in order to exclude dead pads.



The G-RWELL

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

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Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima



Development of μ -RWELL detectors for the upgrade of the tracking system of CMD-3 detector

L. Shekhtman*, G. Fedotov, A. Kozyrev, V. Kudryavtsev, T. Maltsev, A. Ruban

Budker Institute of Nuclear Physics, 630090, Novosibirsk, Russia
Novosibirsk State University, 630090, Novosibirsk, Russia

ARTICLE INFO

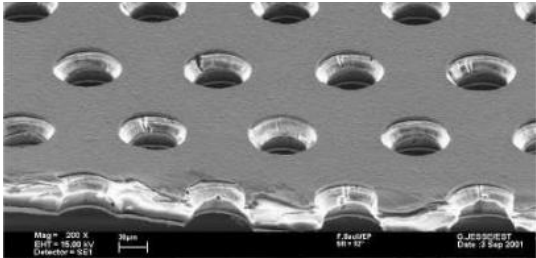
Keywords:
Tracking detectors
Micro-RWELL
Micro-pattern gas detectors

ABSTRACT

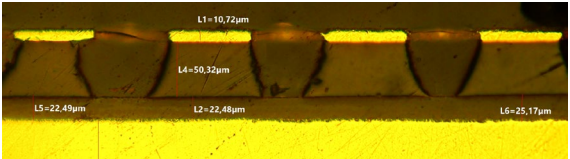
An upgrade of tracking system of Cryogenic Magnetic Detector (CMD-3) is proposed using microresistive WELL technology. CMD-3 is a general purpose detector operating at the VEPP-2000 collider at Budker Institute of Nuclear Physics and intended for studies of light vector mesons in the energy range between 0.3 GeV and 2 GeV. The new subsystem consists of double-layer cylindrical detector and the end-cap discs. Two prototypes, micro-RWELL and micro-RWELL-GEM were built and tested. Gas amplification of micro-RWELL detector was measured with several gas mixtures and maximum gain between 20000 and 30000 was observed. However, maximum gain is fluctuating from measurement to measurement by a factor of 2 and thus a safety margin of 2–3 is needed to provide reliable operation of the device. In order to increase the signal GEM was added to micro-RWELL, new prototype was tested with the same gas mixtures and gains above 10^5 have been demonstrated. Time resolution achieved for both prototypes are 7 ns for micro-RWELL and 4 ns for micro-RWELL-GEM.



Drift Gap: Shekhtman 3mm - LNF+Roma2 6mm



Transfer Gap: Shekhtman 3mm - LNF 3/2/1mm

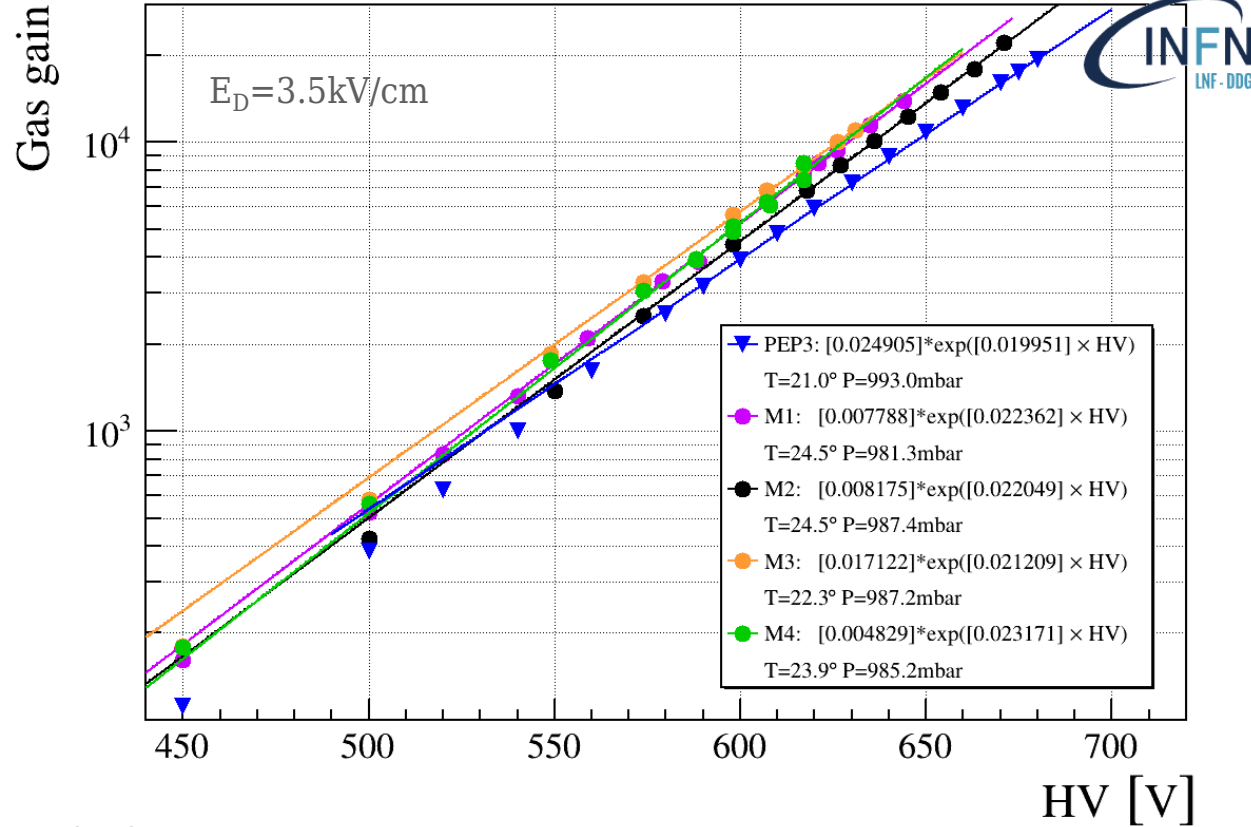


L. Shekhtman, Nuclear Inst. and Methods in Physics Research, A 936 (2019) 401–404

G-RWELL and μ -RWELL gas gain

M2R1

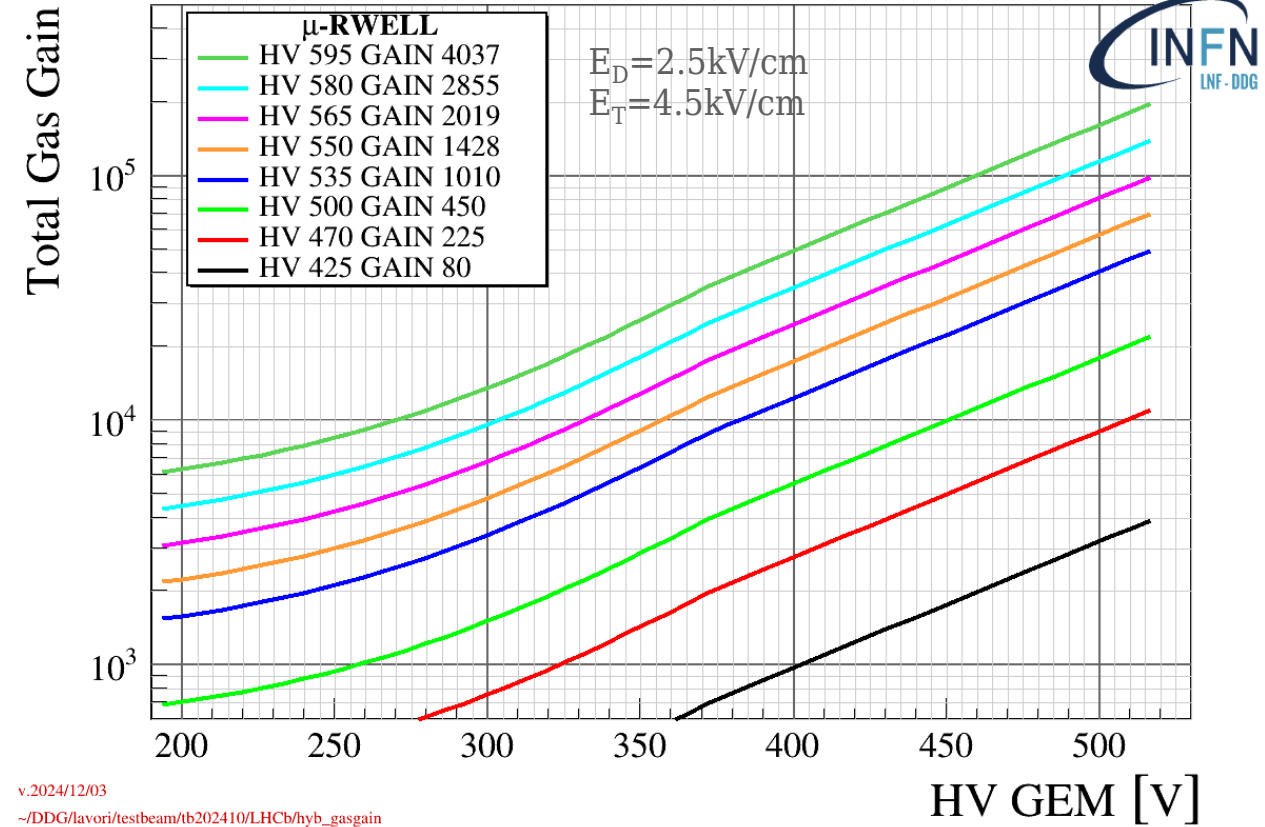
Ar:CO₂:CF₄ 45:15:40



```
// GAIN GEM:
TF1 *f_GEM = new TF1("f_GEM", "( (x<10)*1000+(x>10)*(x<375)*([0]*exp(x*[1])+[2]) + (x>375)*([3]*exp(x*[4])) )/[5]", -1, 540);
f_GEM->SetParameters(12.084448,0.017333,1186.539573,106.497361,0.011873,1000.000000);
// GAIN WELL_HYB:
TF1 *f_WELL_HYB = new TF1("f_WELL_HYB", "[0]*exp(x*[1])", 400, 700);
f_WELL_HYB->SetParameters(0.00436,0.02309);
// GAIN M2R1:
TF1 *f_M2R1 = new TF1("f_M2R1", "[0]*exp(x*[1])", 400, 700);
f_M2R1->SetParameters(0.008175,0.022049);
```

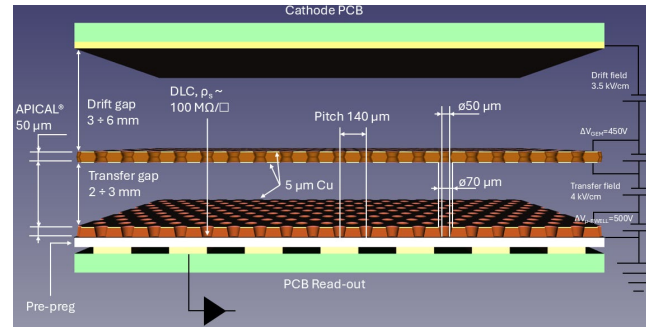
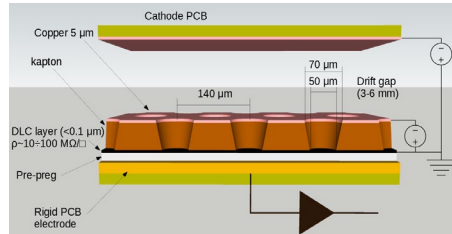
G-RWELL

Ar:CO₂:CF₄ 45:15:40



v.2024/12/03
~/DDG/lavori/testbeam/tb202410/LHCb/hyb_gasgain

It is possible to **extrapolate** the total gas gain for different WELL HV values.
The Hybrid gas gain should be considered **preliminary**.
The measurement will be **done again** soon as possible,
when the test beam setup will be shipped back.



Summary:

μ-RWELL

vs G-RWELL

	μ-RWELL	G-RWELL
Application	Standard MPGD - the everyday use	Very demanding scenarios in which extremely high gas gain is needed: e.g. time resolution <5ns, 2D uTPC reconstruction
Complexity : Production	Mid: low rate μ-RWELL are standards, high-rate ones need a bit more care	Low: GEMs are the MPT-Workshop “best sell item”
Complexity : Assembly	None: in principle they are ready to use after delivery from the MPT	Mid: it's an additional manufacture step, they need to be stretched/glued (more manpower)
Stability	Resistive: stable by design Single stage: operational gain 6-8k	Non-resistive: permanent damage Multi-stage: gain up to 100k
Timing	Down to 5ns	Down to 3.8ns bigap effect → possible source of stress for the GEM
Tracking	G. Bencivenni et al., 2020 <i>JINST</i> 16 P08036	See Elena's talk on thursday
Scalability	As large as the DLC foil (for the CID 170x60cm ²)	As large as the μ-RWELL

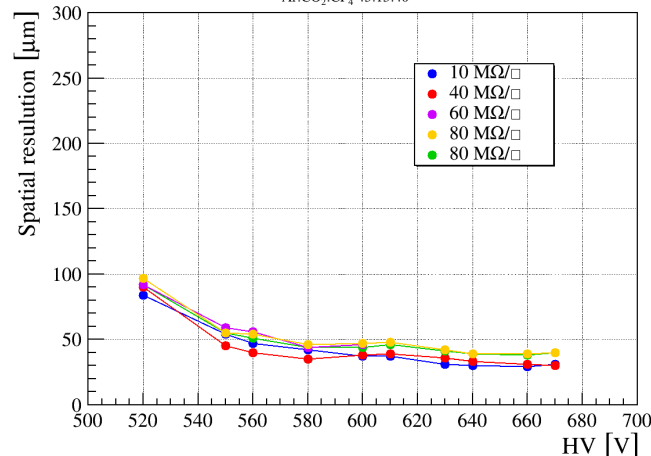
1D u-RWELL: DLC Resistivity

DLC RESISTIVITY SCAN

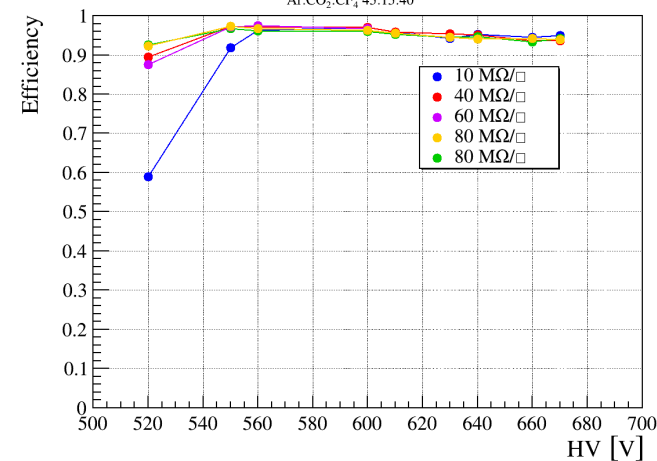
- Active area = $400 \times 50 \text{ mm}^2$
- Pre-preg thickness = $50 \text{ }\mu\text{m}$
- Resistivity** = [10, 14, 77, 80] $\text{M}\Omega/\square$
- Strip Pitch = 0.4 mm



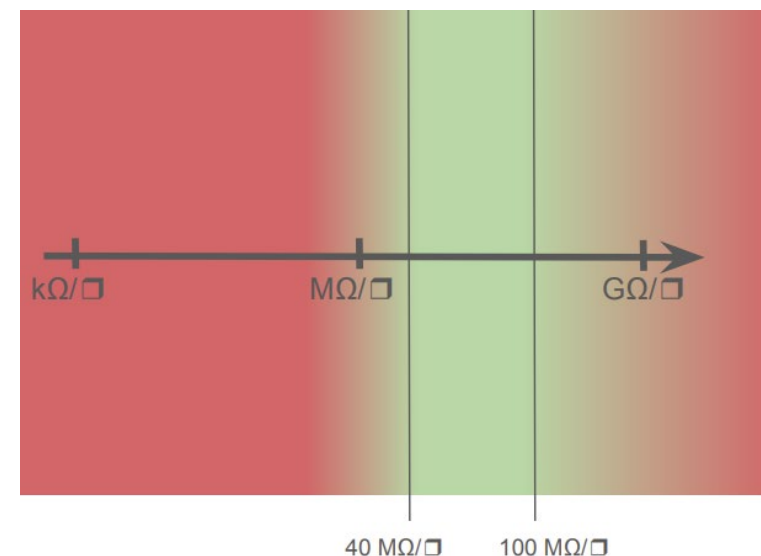
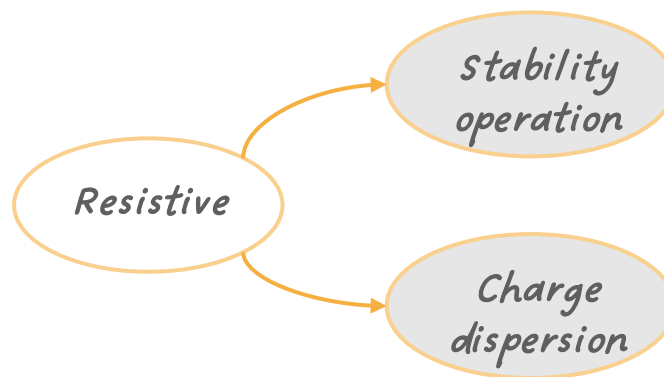
RD-FCC μ -RWELL, Residuals test resolution - 75ADC threshold
Ar:CO₂:CF₄ 45:15:40



RD-FCC μ -RWELL, DUT efficiency - 75ADC threshold
Ar:CO₂:CF₄ 45:15:40



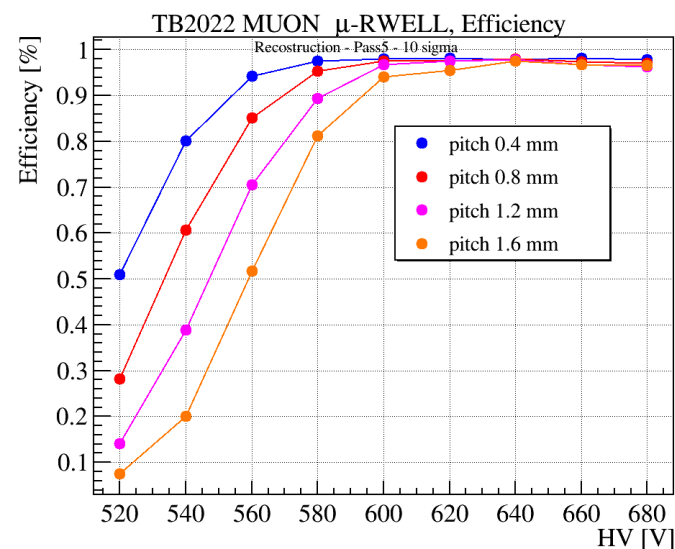
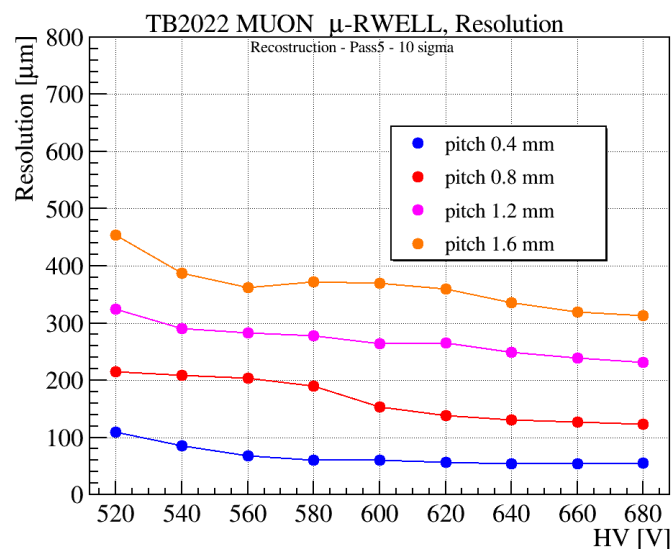
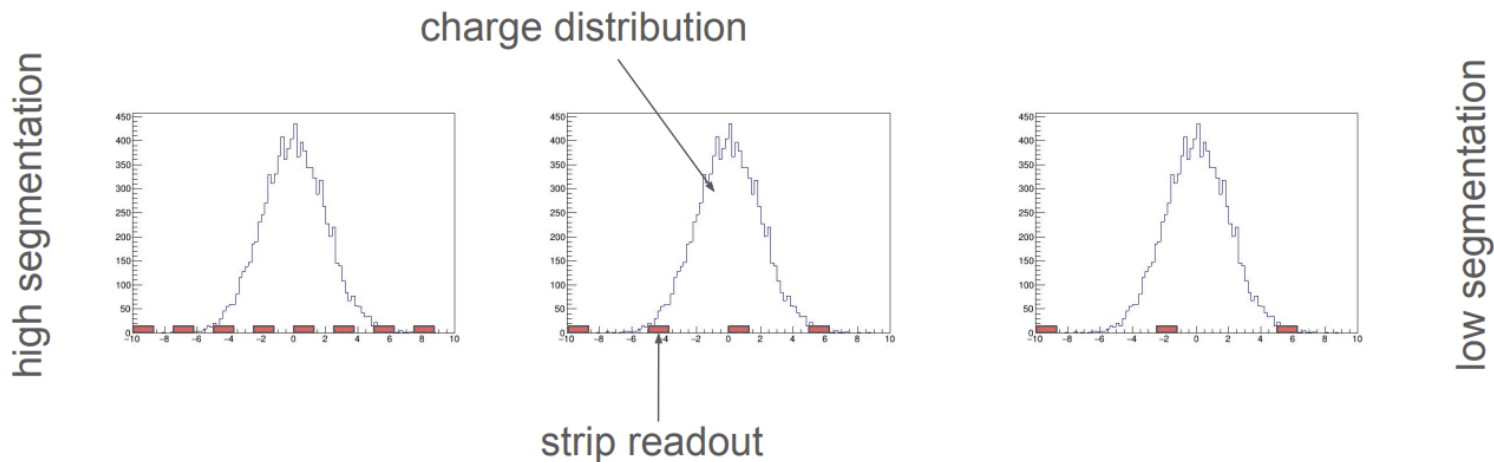
The dependence on the **DLC resistivity** is negligible for the spatial resolution. For resistivities below $40 \text{ M}\Omega/\square$, the spreading of the signal could introduce **inefficiency** since each of the strip will be below the detection threshold



1D u-RWELL: Strip Pitch

STRIP PITCH SCAN

- Active area = $400 \times 50 \text{ mm}^2$
- Pre-preg thickness = $50 \mu\text{m}$
- Resistivity = $10 \text{ M}\Omega/\square$
- Strip Pitch** = $[0.4, 0.8, 1.2, 1.6] \text{ mm}$

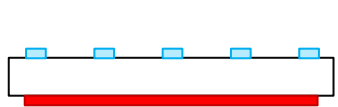


- The HV scan shows that cluster size scales with the strip pitch, plus threshold effects. The smaller the pitch, the better the resolution.
- Reaching the efficiency plateau requires a higher gain, with a 40 V shift observed between the 0.4 mm and 1.6 mm pitches.
- This voltage shift is driven by increased noise, resulting from a larger strip pitch and width, which results in a higher strip capacitance.

MSPC GLASS - Simulation

Only SENSE

Cat 1500 V
Back 1700 V



Sense Strip 30μm
GLASS
Bias Backplane

Two electrodes:

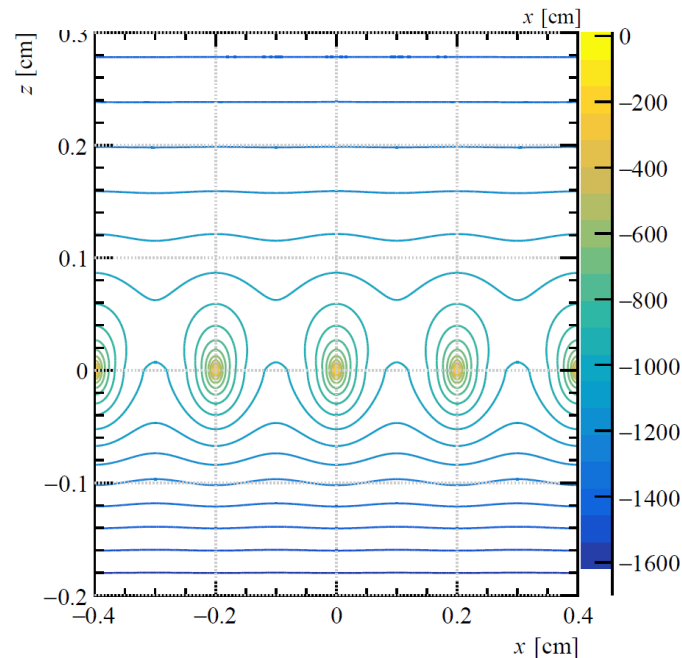
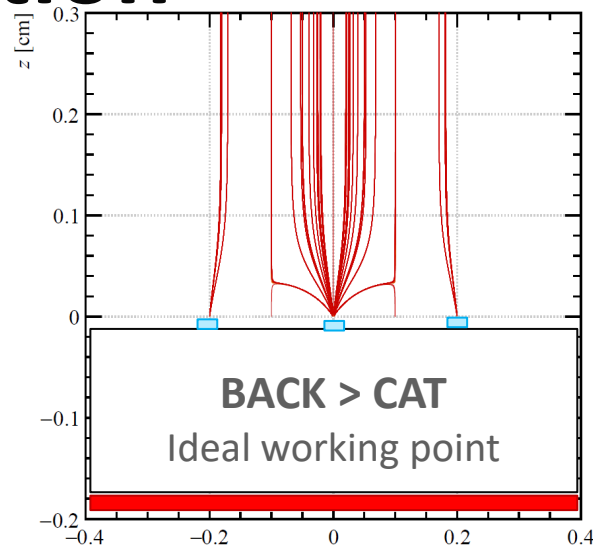
CAT – defines mainly drift field and gain

BACK – focus the field lines to SENSE, strongly impacting the gain

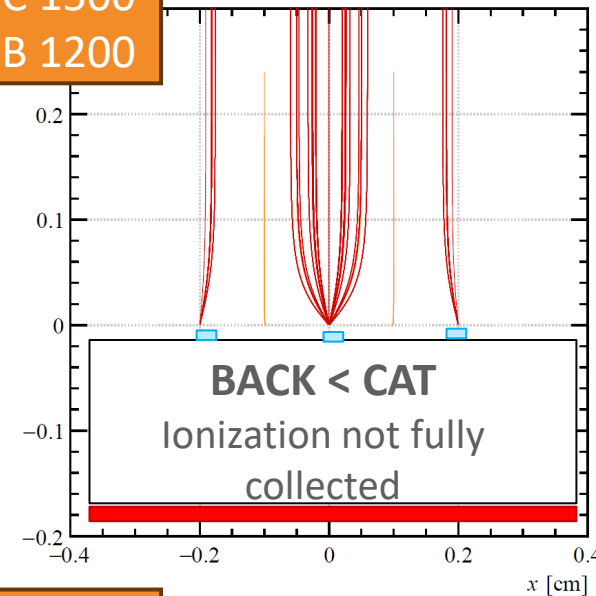
ATTENTION: if **BACK** >> **CAT**

⇒ Drift field will decrease

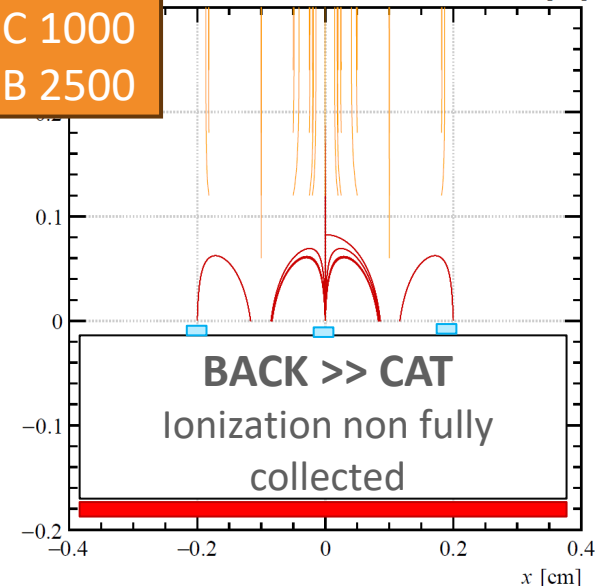
⇒ some of the ionization is pushed back to CAT



C 1500
B 1200



C 1000
B 2500



MSPC GLASS - Simulation

FIELD SENSE



Sense Strip 30 μ m
Field Strip 100 μ m
GLASS
Bias Backplane

Cat 1500 V
Back 2000 V
Field 1500 V

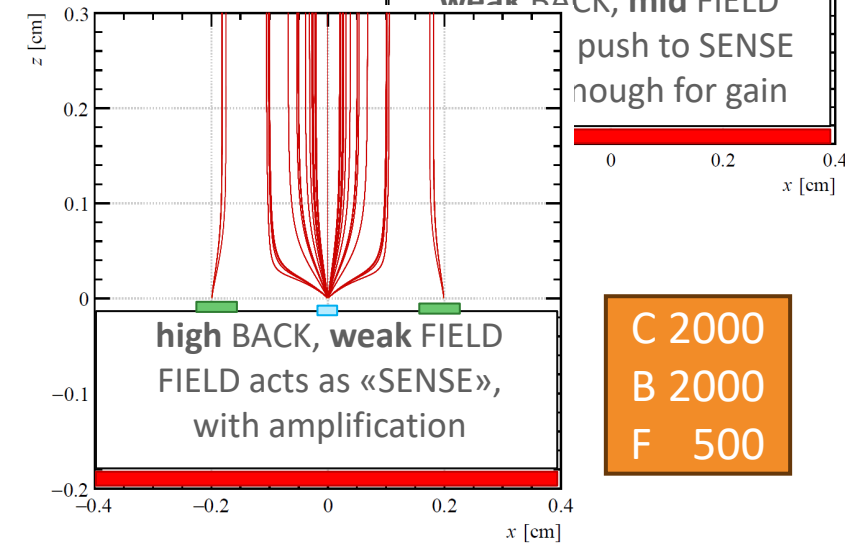
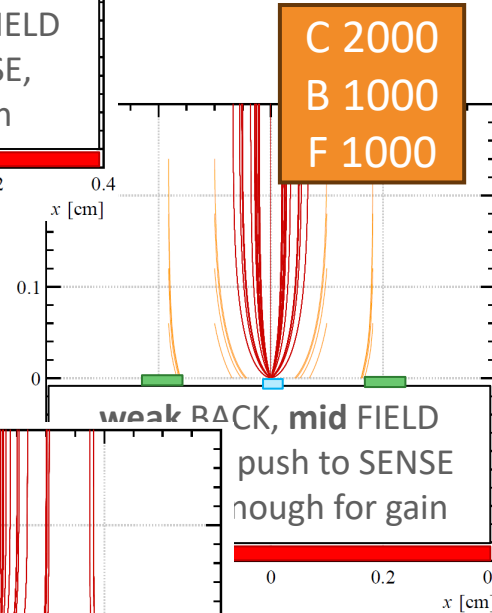
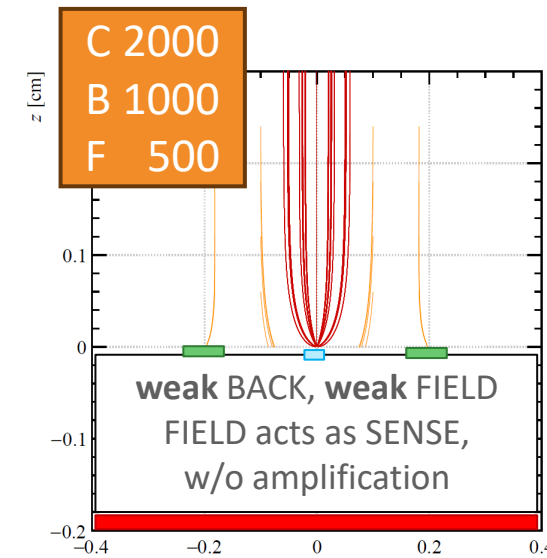
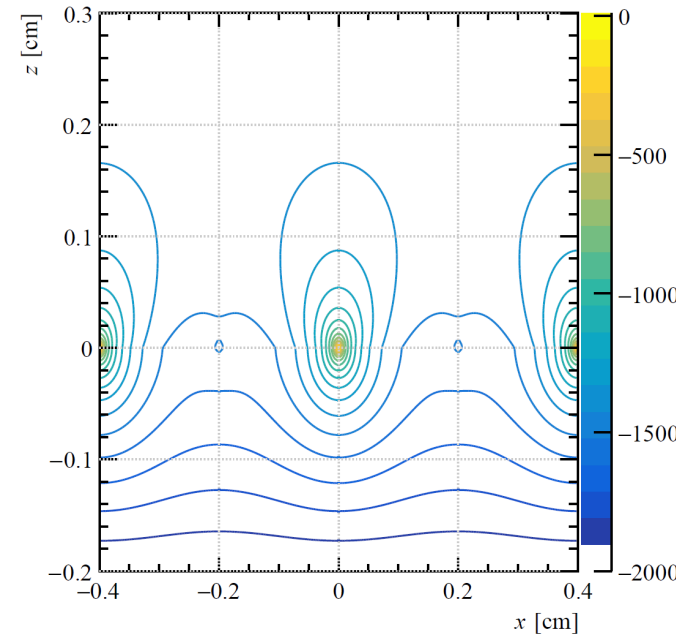
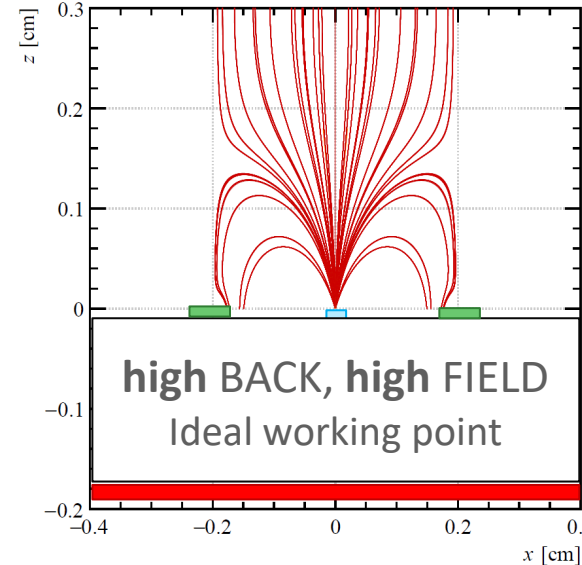
Three electrodes:

CAT – defines mainly drift field and gain

BACK & FIELD – focus the field lines to SENSE, strongly impacting the gain

Low FIELD $\Rightarrow$ ionization will drift to FIELD instead of SENSE

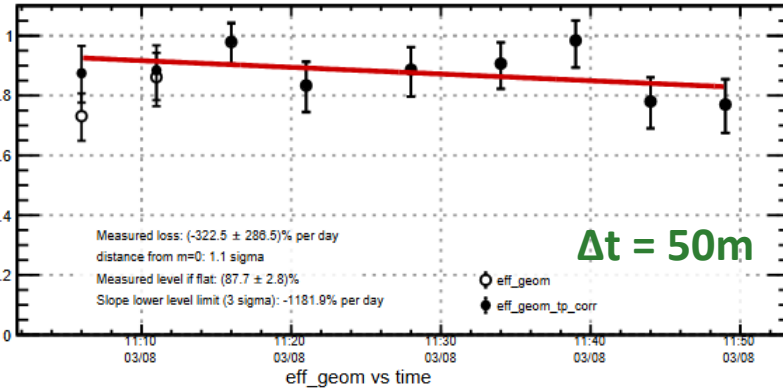
BACK $\gg$ CAT $\Rightarrow$ ionization pushed back to CAT



MSPC GLASS

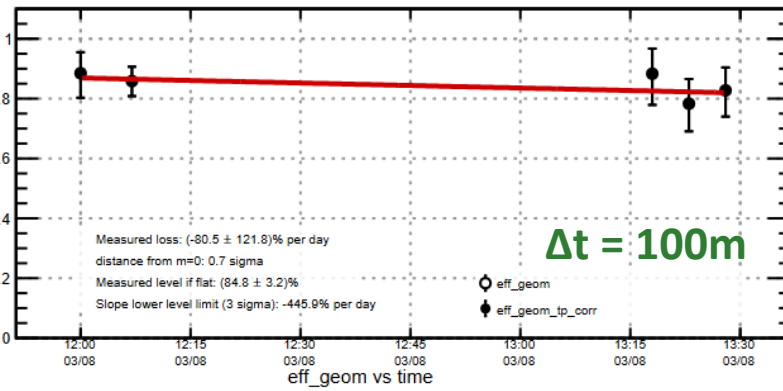
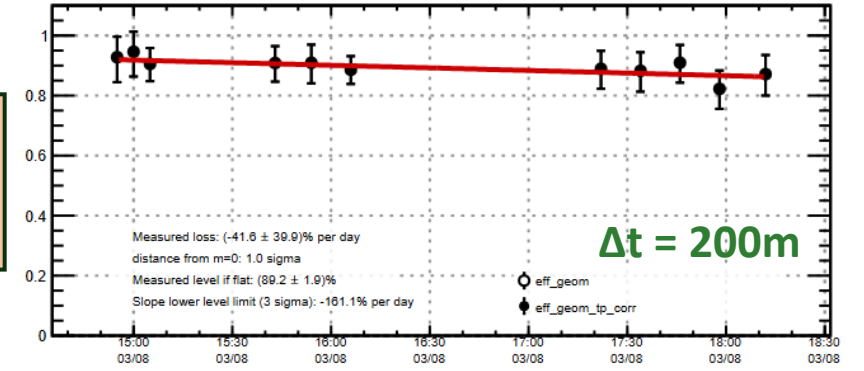
Only SENSE

Measurements



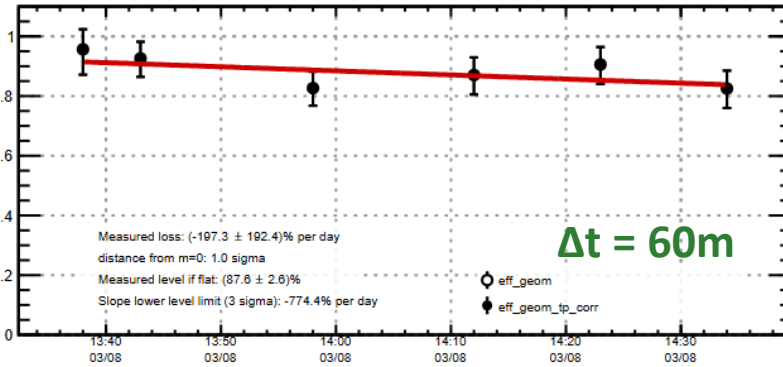
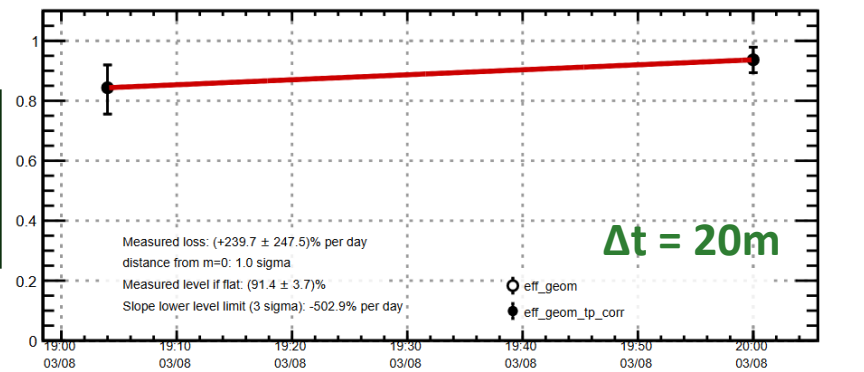
c 1500 b 1600
Start: 95%
End: 84%

c 1300 b 1500
Start: 92%
End: 86%



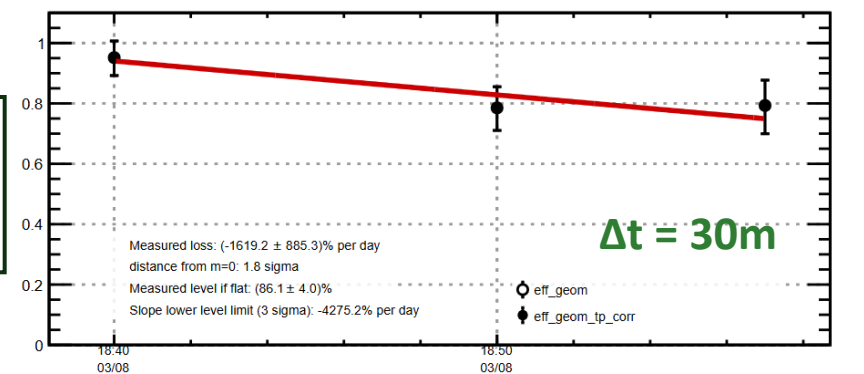
c 1400 b 1600
Start: 87%
End: 82%

c 1200 b 1400
Start: 85%
End: 95%



c 1400 b 1500
Start: 92%
End: 84%

c 1100 b 1300
Start: 95%
End: 75%

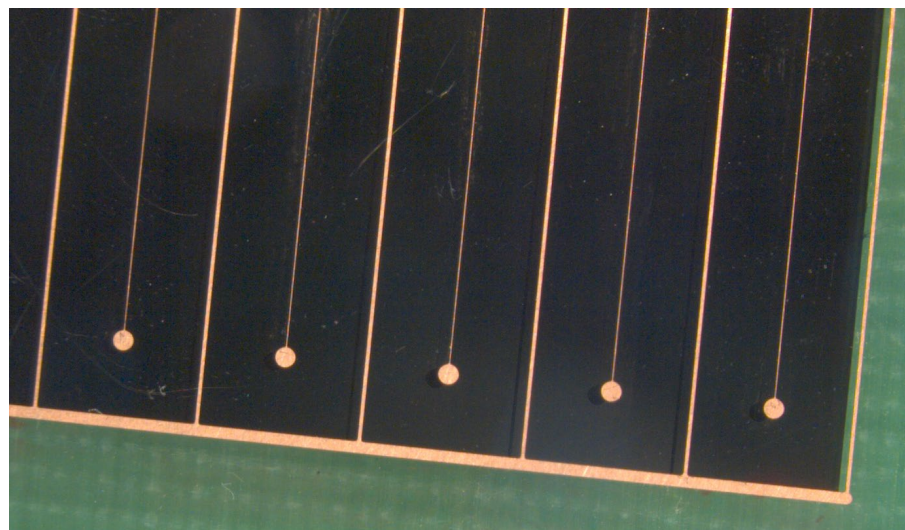
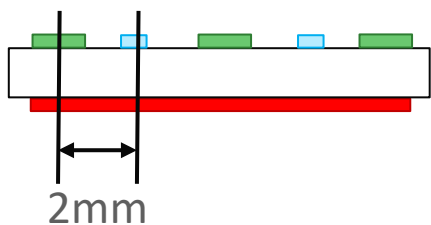
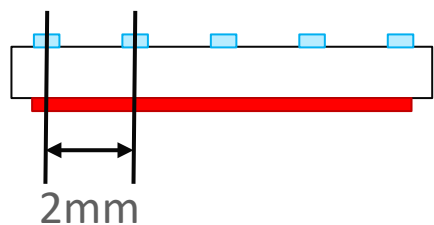


MSPC: comparison

Field Strip Sense Strip “Support” Backplane

Only SENSE

FIELD SENSE



2mm thick commercial float glass (10^{13} Ohm cm)
100% strip yield

1988
MSGC ([link](#))

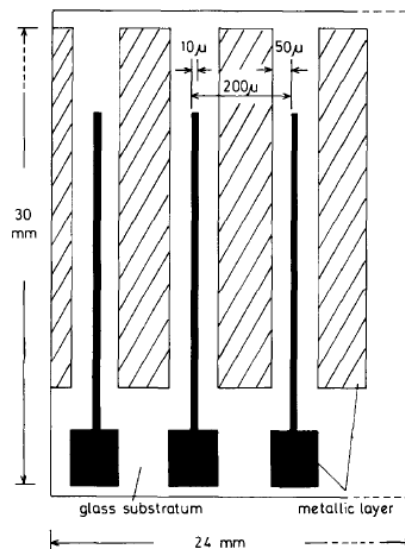
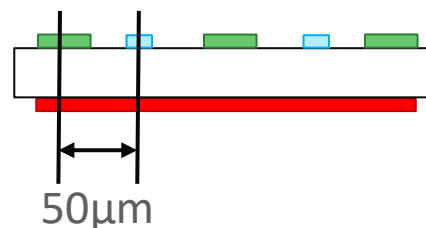


Fig. 1. Dimensions of the microstrip plate (MS-plate) used for the measurements. The chromium layer on the glass substrate is 300 nm in thickness.

1991
COated CAthode
COnductive LAYer
chamber ([link](#))

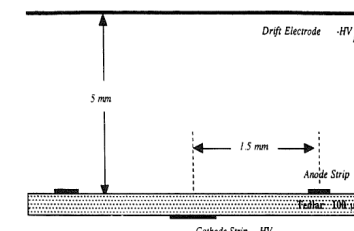
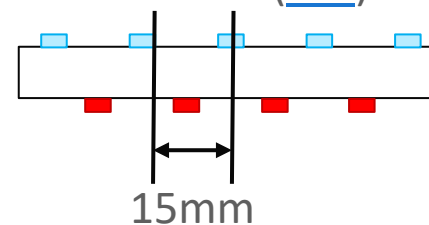


Fig. 1. Schematics of the COCA COLA chamber. Thin anode and cathode strips are placed on the two sides of a plastic foil. Ionization electrons released in the gas are drifted towards the anode strips, where avalanche multiplication occurs.

100 µm thick «Tedlar»
(10^{15} Ohm cm)

1997
Virtual Cathode
Chamber ([link](#))

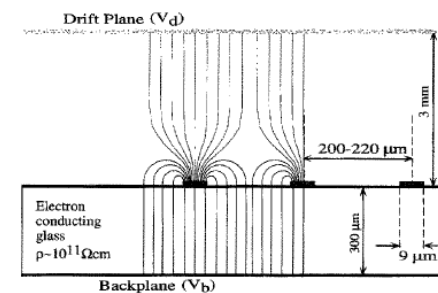
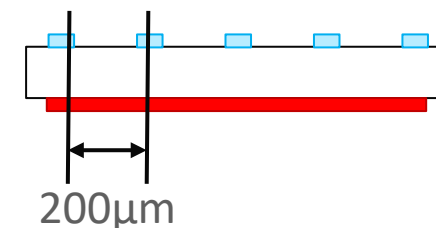


Fig. 4. Schematics of the Virtual Cathode Chamber with an approximated representation of the electric field.

Titanium strips
(low quality, with discontinuities)
300 µm thick conductive glass
(10^{11} Ohm cm)

CERN-INFN DLC (CID) sputtering machine



The **CID** (CERN-INFN-DLC) sputtering machine, a **joint project between CERN and INFN**. It is used for preparing the **base material for DLC-based detectors**. And various deposition over electrodes (Cu, Al, $^{10}\text{B}_4\text{C}$,...). The potential of the DLC sputtering machine is:

- **Flexible substrates** up to $1.7 \times 0.6 \text{ m}^2$
- **Rigid substrates** up to $0.2 \times 0.6 \text{ m}^2$

In **2023**, the activity on CID focused on the **tuning** of the **machine on small foils**: good results in terms of **reproducibility and uniformity**.

In **2024**, the goal has been the **sputtering of large foils**:

- **DLC+Cu sputtering on $0.8 \times 0.6 \text{ m}^2$ successfully done (May/June 2024)**
- **DLC on $1.7 \times 0.6 \text{ m}^2$ large 0/50/0 Apical foils successfully done (June 2024)**
- **DLC on $1.7 \times 0.6 \text{ m}^2$ large 5/50/0 Apical foils successfully done (July 2024)**

