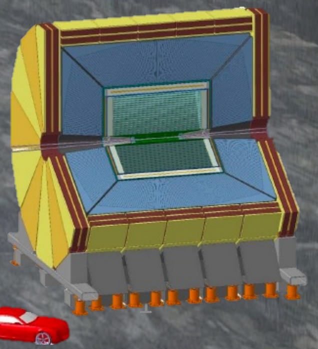
The IDEA drift chamber at FCC-ee and CEPC and related electronics

IFD 2022: INFN Workshop on Future Detectors
17th-19th October Bari, Italy
Speaker: **Brunella D'Anzi**

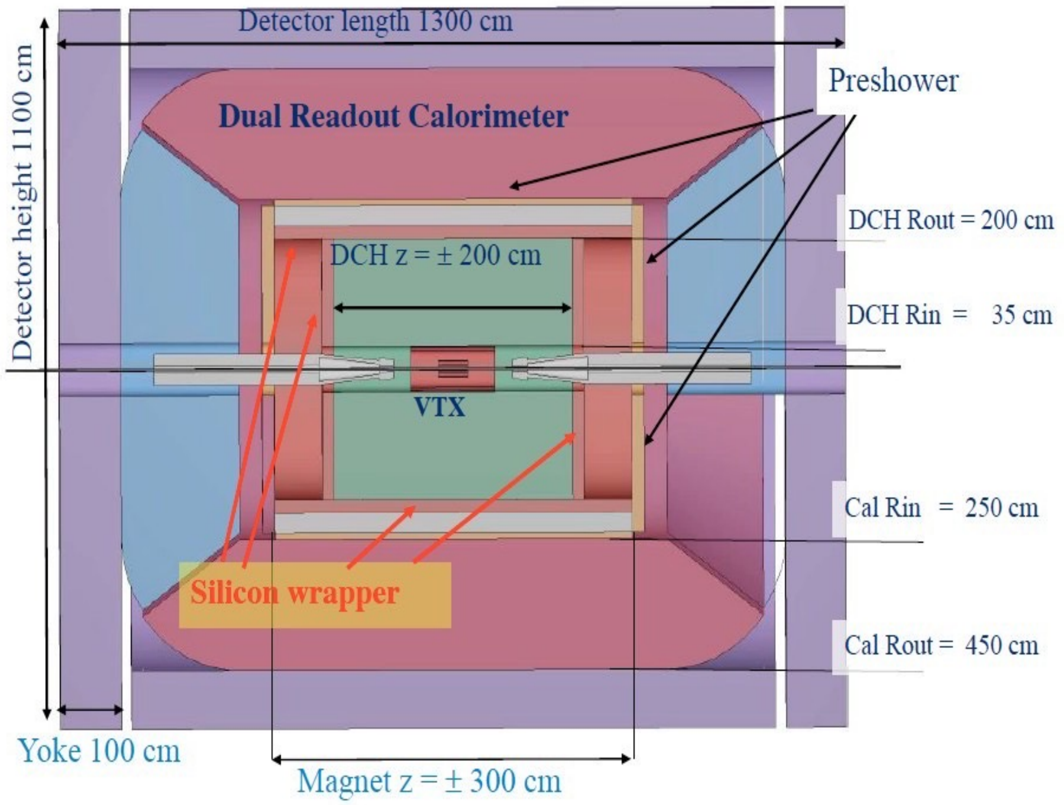


The detector concept IDEA

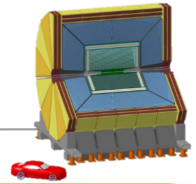
- The **IDEA** (**Innovative Detector for E+e- Accelerator**) **general-purpose detector concept** has been designed to study **electron-positron collisions** in a wide energy range provided by a very large (~**100 km**) circular leptonic collider (e.g. **FCC-ee** at **CERN, CEPC** in **China**) for **high luminosity Higgs**, **precision electroweak physics** at the **Z pole** and **flavour physics**.
- Its detectors sub-systems (**inside-out**) are:

  - **Silicon pixel vertex** detector
  - Large-volume, extremely-light, high transparency, high granularity **drift wire chamber (DCH)**
  - Surrounded by a layer of **silicon micro-strip detectors**
  - A thin low-mass **superconducting solenoid coil**
  - A preshower detector based on **μ-WELL technology**
  - A **Dual Read-out calorimeter**
  - Muon chambers inside the magnet return yoke, based on **μ-WELL technology**

- Low field detector solenoid (optimized at 2 T) **to maximize luminosity**

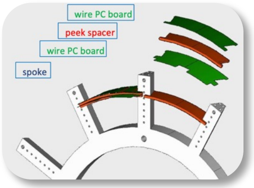


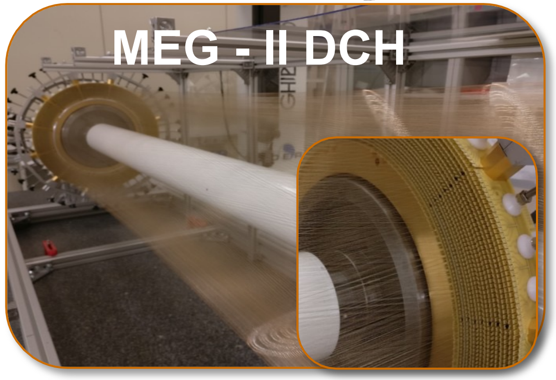
The IDEA drift chamber (DCH)

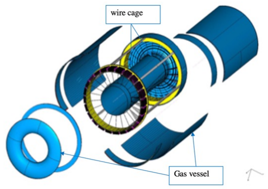


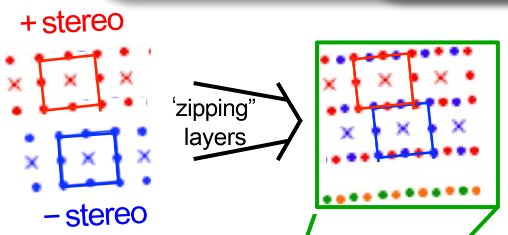
Goal: **efficient tracking** + **high precision momentum measurement** + **excellent particle identification** by applying the **Cluster Counting (CC) technique** (more details in the Talk *The cluster counting/timing techniques in drift chambers*).

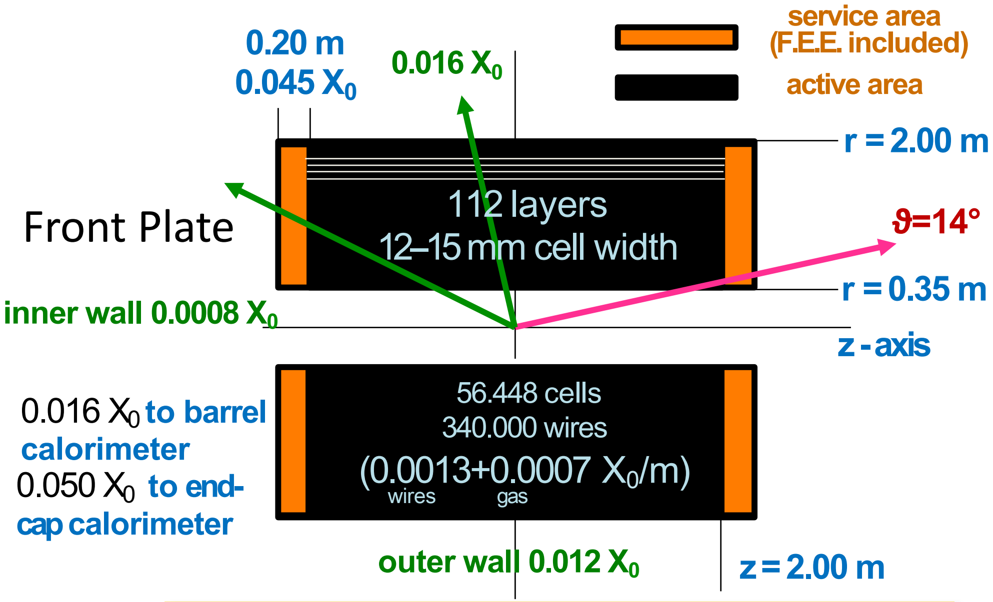
- New **concept of construction** allows to reduce material to **≈ 10^{-3} X_0** for the **barrel** and to a **few x 10^{-2} X_0** for the **end-plates.**
- The **wire net** created by the combination of + and - orientation generates a **more uniform equipotential surface.**
- High wire number requires a **non standard wiring procedure** and needs a **feed-through-less wiring system** already developed for the construction of the ultra-light MEG-II drift chamber.







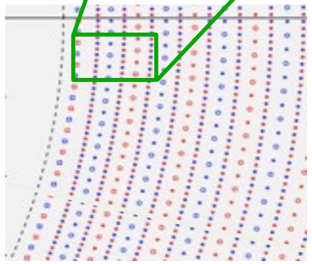




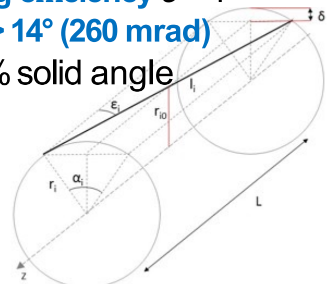
sense wires: 20 mm diameter W(Au) => 56.448 wires
field wires: 40 mm diameter Al(Ag) => 229.056 wires
f. and g. wires: 50 mm diameter Al(Ag) => 58.464 wires
► **343.968** wires in total

IDEA DCH parameters

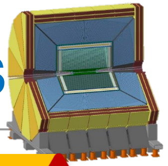
- **Gas mixture:** Helium-based
- 12 ÷15 mm wide **square cells** 5:1 field to sense wires ratio
- 4 m long, a_{xy} < 100 µm, a_z < 1 mm, **drift length (time)** ~1 cm (150 ns), **rise time signals** ~1 ns
- 14 co-axial super-layers, 8 layers each (**112 total**) in 24 equal azimuthal (15°) sectors ($N_i = 192 + (i - 1) \times 48$)
- **alternating sign stereo angles** ranging from 50 to 250 mrad



tracking efficiency ε ≈ 1 **for ϑ > 14° (260 mrad)** 97% solid angle



Data reduction and pre-processing of DCH signals



High speed digitization (2 GSa/s) for CC ⟹ Transfer rates in excess of TB/s at the Z–pole running !

- **Data reduction strategy:** transfer, for each hit drift cell, only the minimal information relevant to apply the **Cluster Counting/Timing (CCT) techniques**, i.e. the **amplitude** and the **arrival time of each peak** associated with **each individual ionization electron** ⟹ **CCT algorithms!**

  ► Use of a **FPGA** for the **real-time data analysis** of drift chamber signals **digitized by an ADC.** Acquire the signals converted ⟹ process with cluster counting algorithms (aimed also at **reducing the data throughput**) ⟹ send the processed information to a back-end computer via an Ethernet interface.

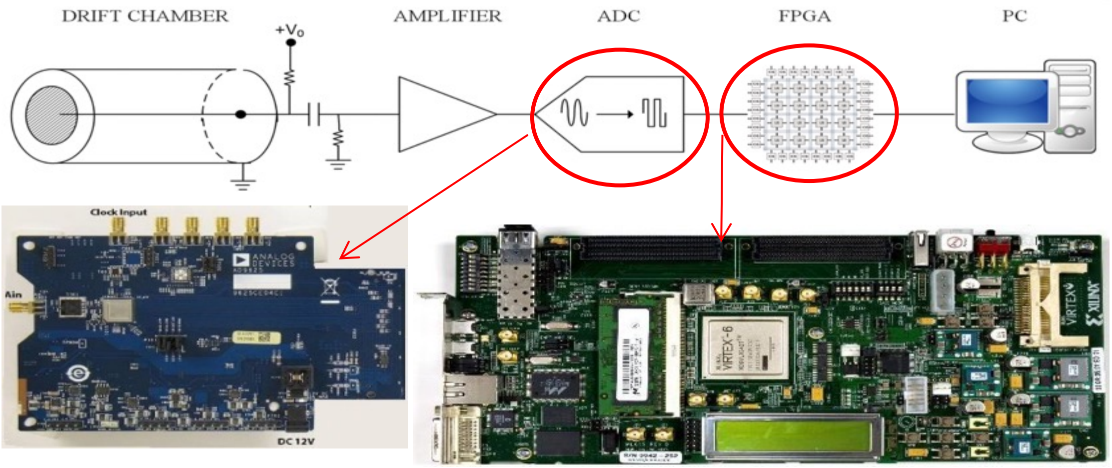
- A fast read-out CCT algorithm has been developed as **VHDL/Verilog** code implemented on a **Virtex 6 FPGA (maximum input/output clock switching frequency of 710 MHz).** The hardware setup includes also a **12-bit monolithic pipeline sampling ADC** at conversion rates up to **2.0 GSPS.**

Goal

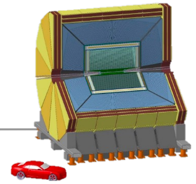
To implement on FPGA more sophisticated peak finding algorithms for the **parallel pre-processing** of **many ADC channels**:

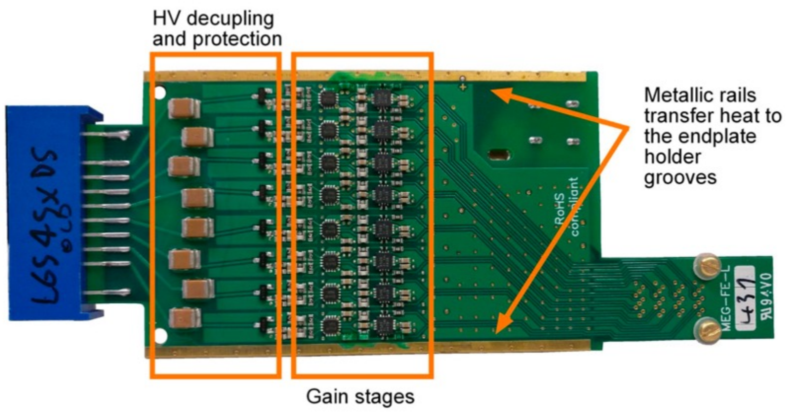
- **reduce costs** and **system complexity**
- **gain on flexibility in determining proximity correlations** among hit cells for track segment finding and triggering purposes.

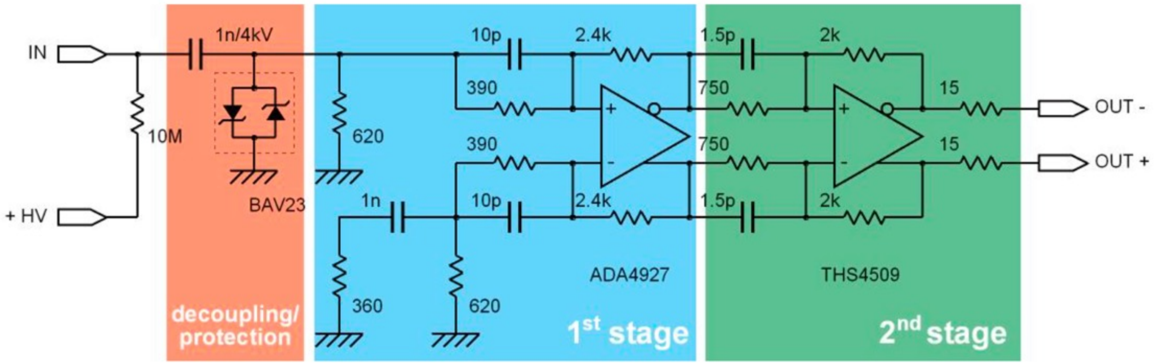
Implemtend using a **single channel ADC**



The read-out for DC (1/2)





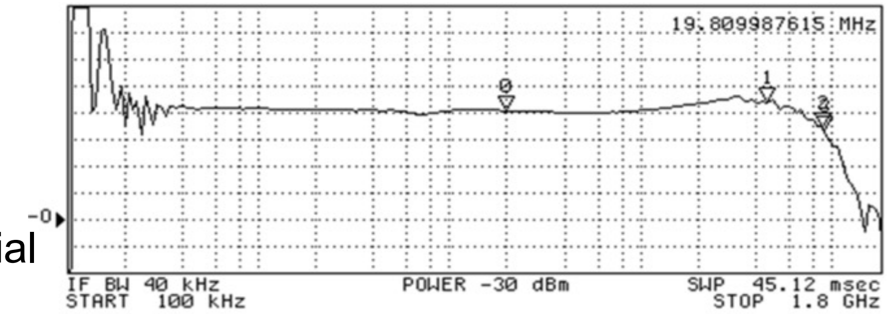


Amplifier used in MEG-II Cylindrical DCH

- **Two stage amplifiers** based on commercial devices:
  - **ADA4927 (AD)** **Ultralow distortion** current feedback
  - **THS4509 (TI)** Wideband **low noise** fully differential amplifier (driver for the ADC)

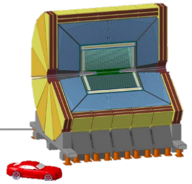
- **Pre-emphasis implemented** on both stages to balance the attenuation of output cable
- High overall bandwidth (F.E. input to DRS WD input): **~1 GHz**
- Low power: **50 mW @ ±2V**

Gain and Bandwidth after cable



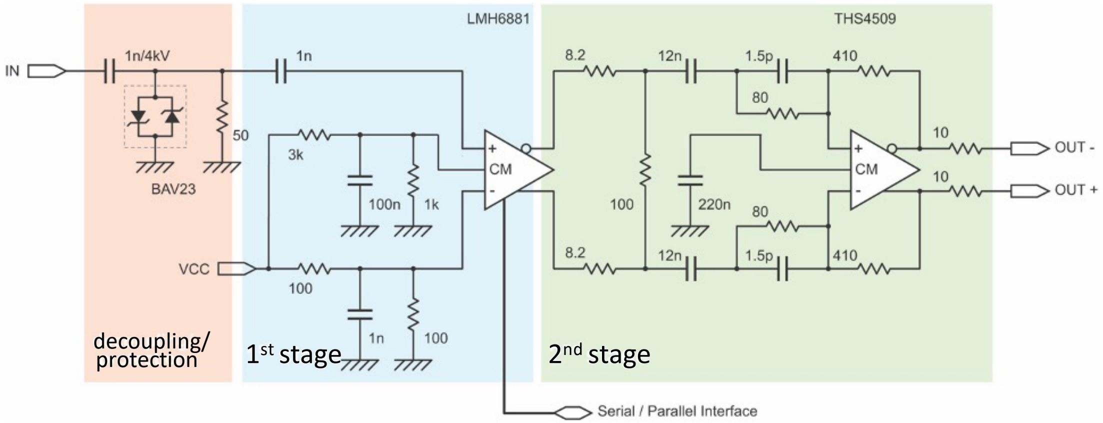
N	SWP PARAM	VAL
0	19.809987615 MHz	20.279 dB
1	456.600249532 MHz	21.773 dB
2	884.527480154 MHz	17.094 dB
3	899.750691731 MHz	16.686 dB

The read-out for DC (2/2)

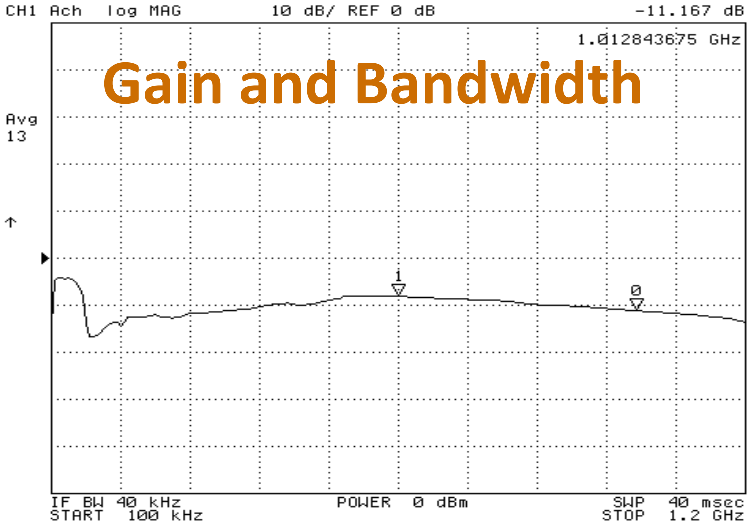


New Amplifier

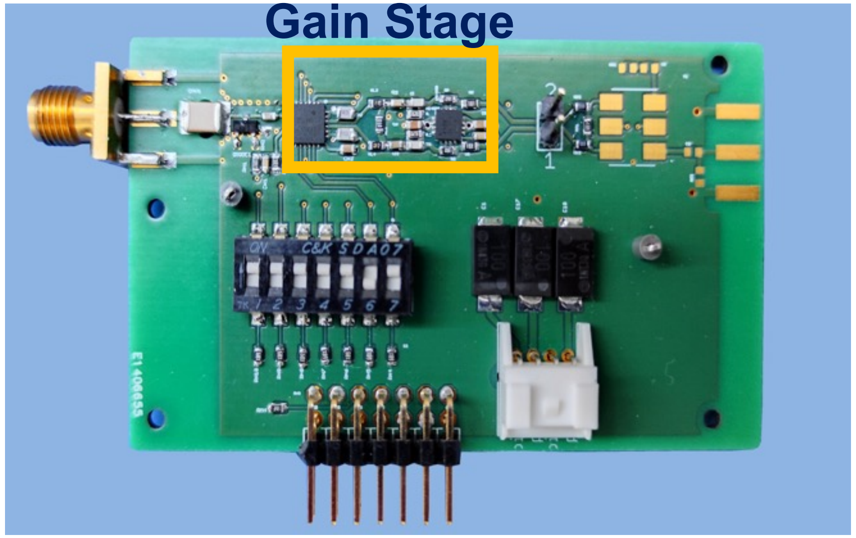
- Two stage amplifiers based on commercial devices:
  - **Variable gain LMH6881** is a high-speed, high-performance fully differential programmable amplifier (remote control via SPI)
  - **THS4509 (TI)** Wideband low noise fully differential amplifier



- The gain stage supports **gain settings** up to about **50 dB** with small accurate **0.25 dB gain steps**. The VGA can be also parallel programmed.



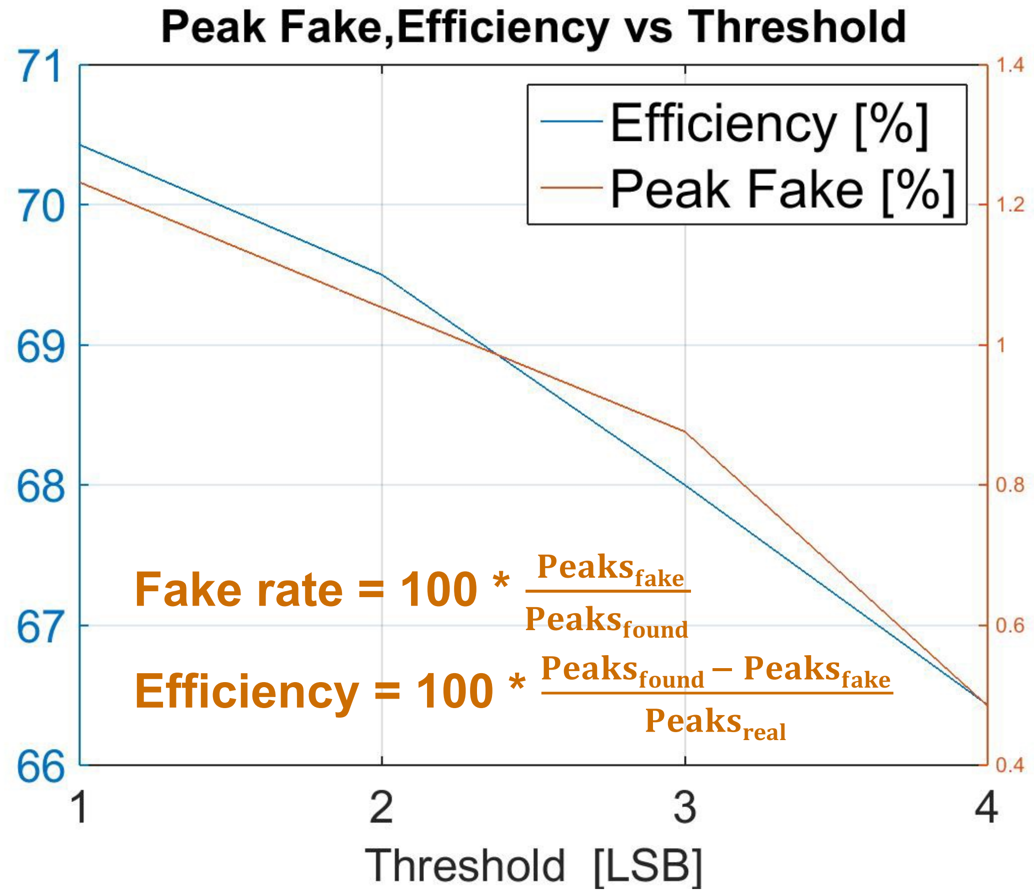
Prototype PCB



Mode/Gain programming. Through these dip switches it is possible to select the way to **control the gain of the first stage**, serial or parallel, in the **20 dB ÷ 49 dB** range.

Single-channel ADC results

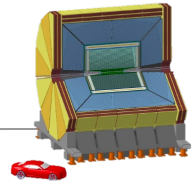
The CCT algorithm (DERIV) performances on FPGA



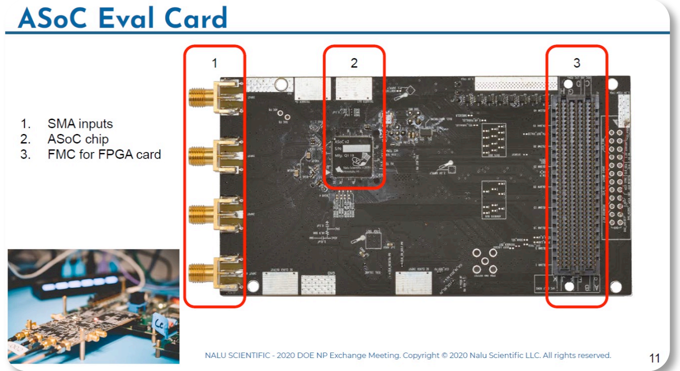
- Efficiency can be improved by using a **higher resolution ADC**
  - To recognize **smaller peaks.**
  - To increase the signal to noise ratio by filtering and amplifying the analog input signal.

- Using an **FPGA** with **better** performances (**temporal and powering**) allows us to reduce the **processing time** and manage **multichannel ADCs**.

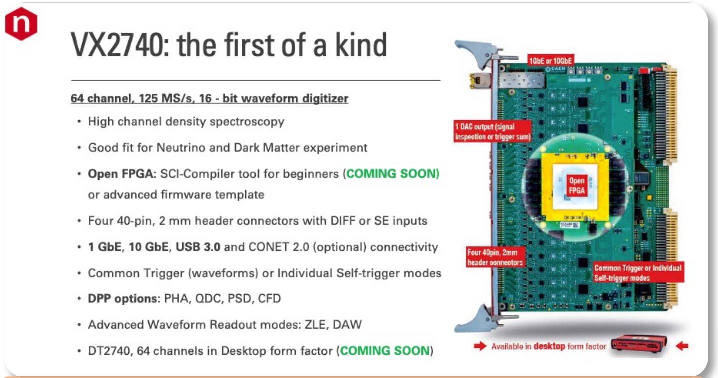
Conclusions and future strategy



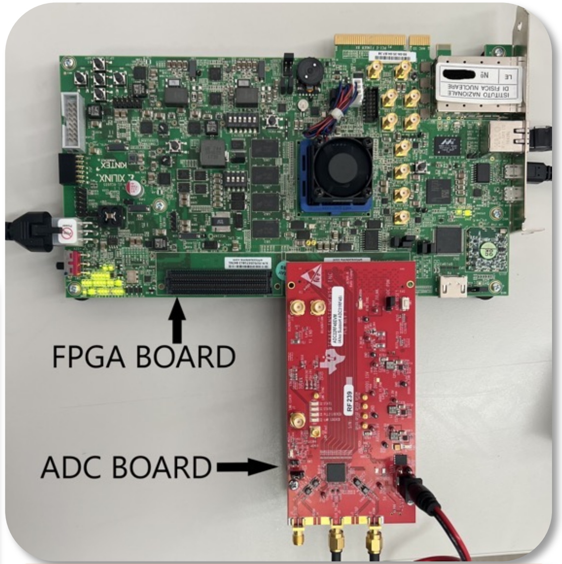
- We implemented successfully the CCT technique on **a single-channel ADC**
- To implement the **multi-channel DCH signals** reading, different digitizers are under test:
  1) ADC TEXAS INSTRUMENT **ADC32RF45**
  2) CAEN **digitizer**
  3) NALU SCIENTIFIC **ASoCv3**



4 Channel and Analog Bandwidth 850 MHz



OPEN FPGA system

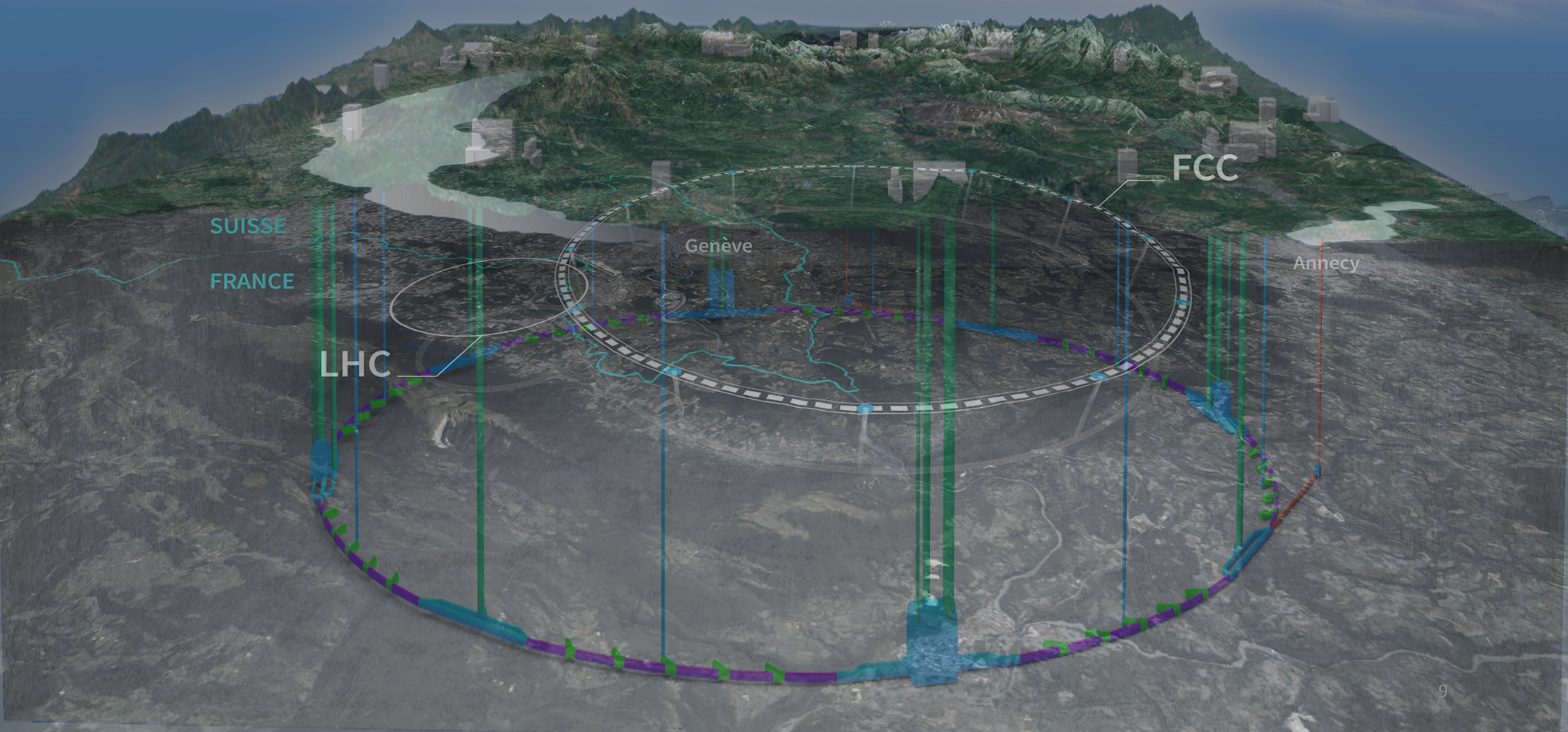


Xilinx Kintex UltraScale **FPGA** KCU105 Evaluation Kit **+ ADC dual channel** ADC32RF45EVM

- Understand how to best implement the data transfer to the DAQ, using **optical fiber with SFP + connectors** or **SFP + to RJ45 adapters** to use the new **10Gbit/s standard** (especially for (1) and (2)).

- Investigate the best way **to save information before the transfer** (we need it if a bottleneck during the transfer happens).

Backup



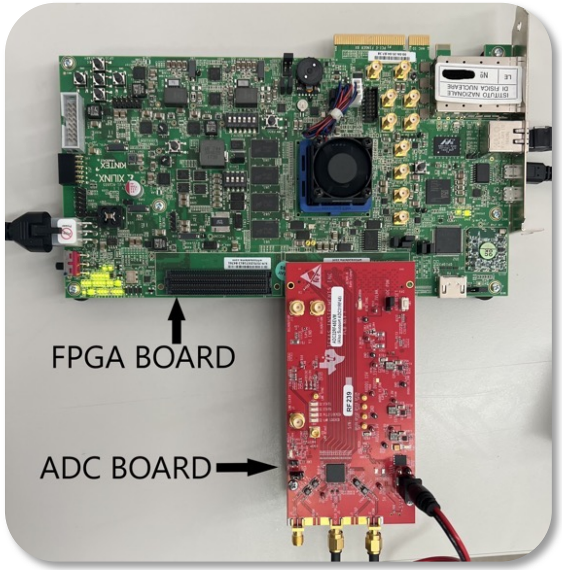
ADC TEXAS INSTRUMENT ADC32RF45

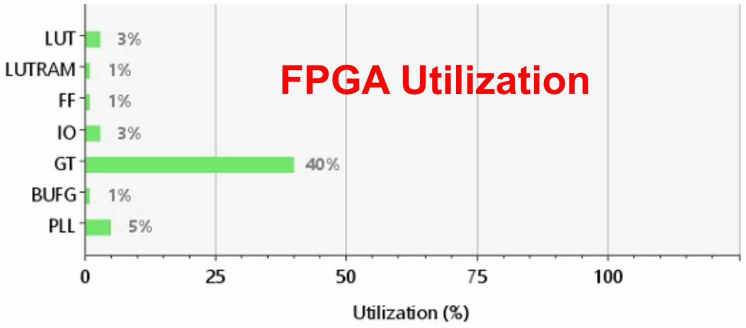
- The new hardware to test the algorithm is:
  - **Xilinx Kintex UltraScale FPGA KCU105 Evaluation Kit**
  - **ADC dual channel ADC32RF45EVM**

- The choice of the FPGA and ADC was made by choosing the **ADC** that ensured **good resolution** and **transfer capacity**.

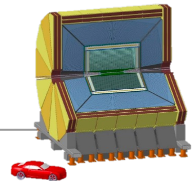
- The new FPGA allows to have **better time constraints**.

- The ADC has a **higher resolution** than the previous one and also it allows the reading of **two channels simultaneously.**

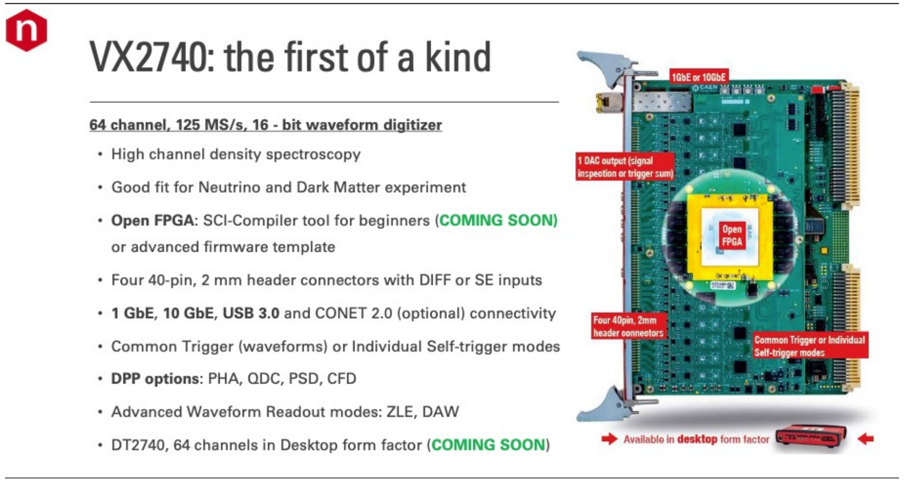


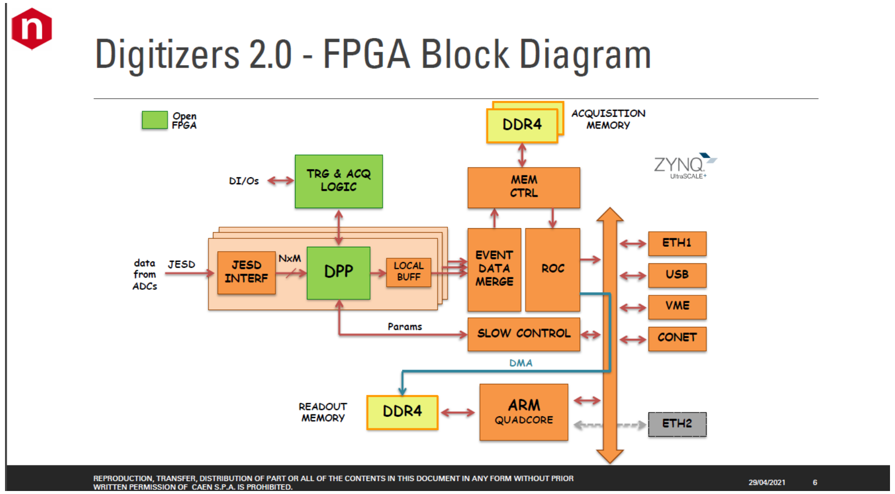


CAEN digitizers

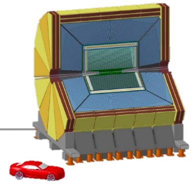


- Test with the **new high performance CAEN digitizers**:
  - start testing their **lower performance digitizer VX2740** (waiting for the **board VX2751**)
  - Use the **"OPEN FPGA" system**
- Using the CAEN HW we do not have access to the **whole firmware infrastructure** but only in the **green areas** (in the figure), where we will implement the cluster counting algorithm.





Contact with Caen

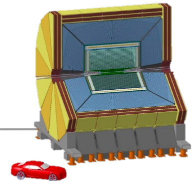


Model	# channels	MS/s	# bit	Applications
x2740	64	125	16	64 MCAs for high channel density spectroscopy Good fit for Neutrino and Dark Matter exp. Currently available
x2745 Advanced version of x2740	64	125	16	Variable gain input stage Designed for Si detectors readout COMING SOON
x2725/x2730	32	250/500	14	Medium-fast detectors Sub-ns timing combined with high energy resolution Optimal trade off between cost and performances
x2751	16	1000	14	Ultra-fast detectors (diamond, MPCs, SiPMs) with ps timing application Potential upgrade to higher sampling rate
x2724	32	125	16	Spectroscopy & MCA Advanced Front-End (gain, shaping, AC/DC coupling ...) Semiconductor detector (HPGe, Clover, SDD ,...) Typically connected to charge Sensitive Preamplifier

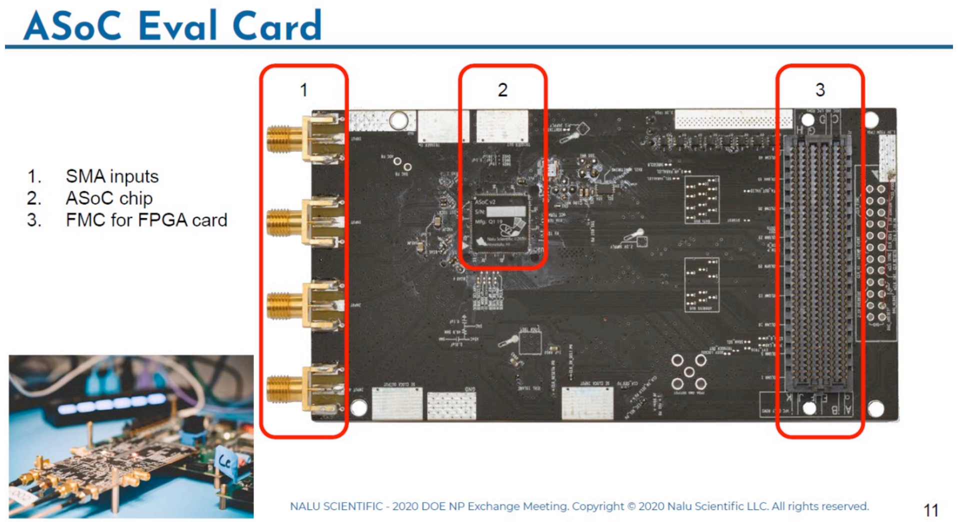
Birdseye view – what's coming

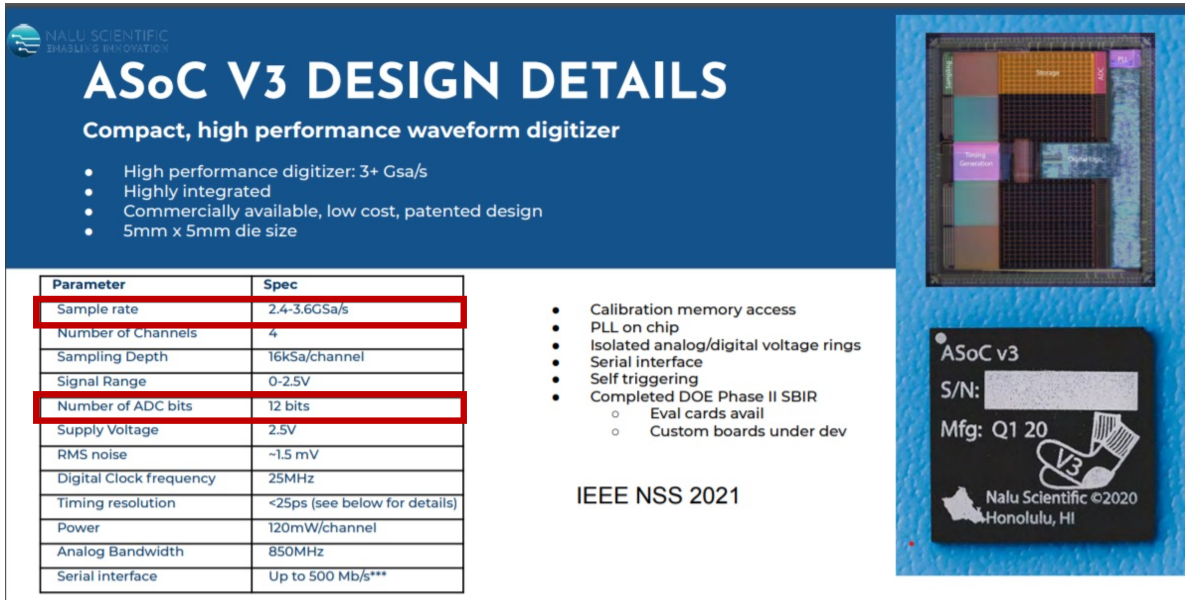
Target Digitizer

Naluscienfic ASoCV3 (1/2)



- Naluscientific is providing us the card with the **ASoCV3 chip**:
  - **4 channel**
  - **Analog Bandwidth 850 MHz**





NALU SCIENTIFIC
ENABLING INNOVATION

ASoC V3 DESIGN DETAILS

Compact, high performance waveform digitizer

- High performance digitizer: 3+ Gsa/s
- Highly integrated
- Commercially available, low cost, patented design
- 5mm x 5mm die size

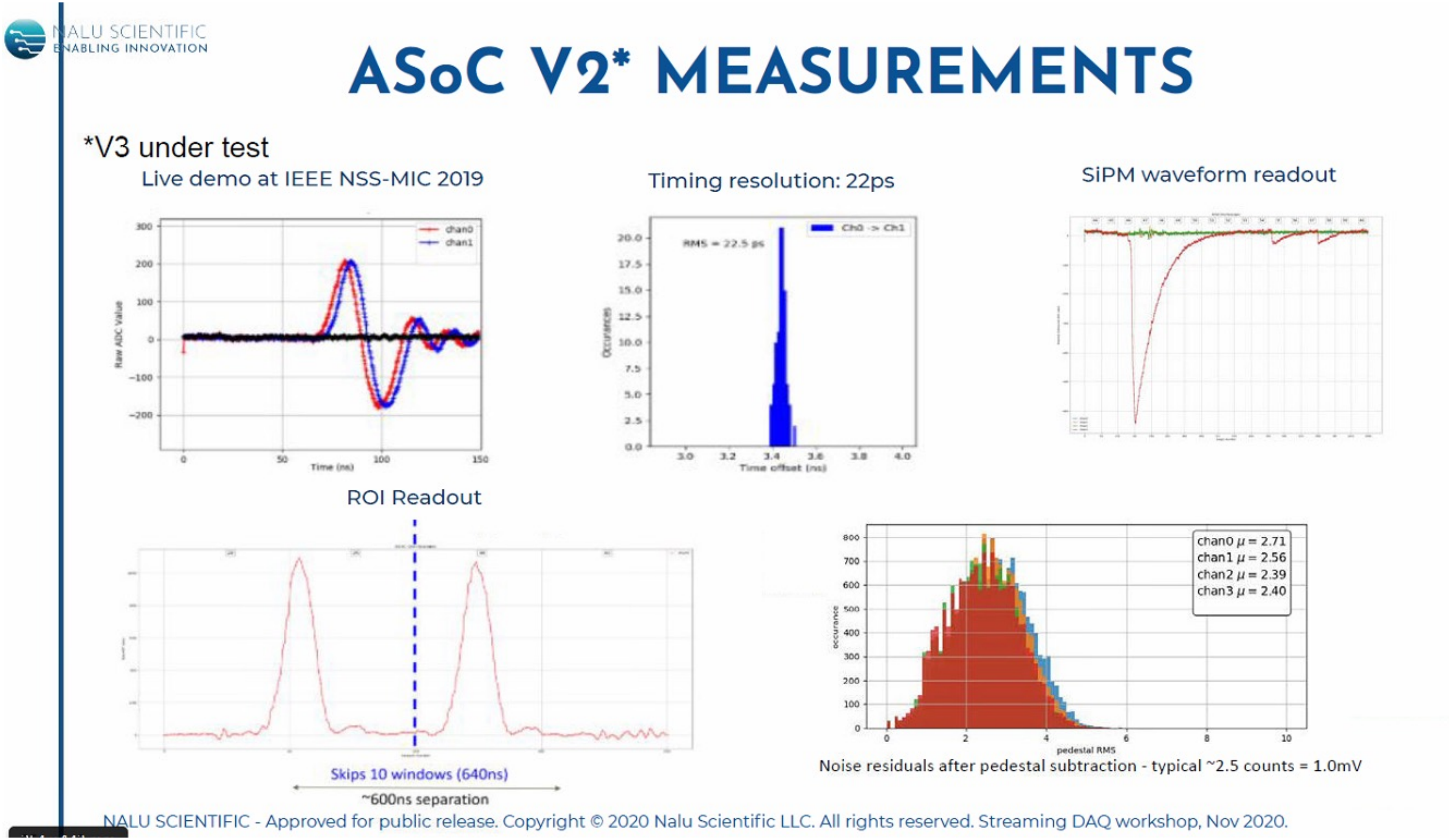
Parameter	Spec
Sample rate	2.4-3.6GSa/s
Number of Channels	4
Sampling Depth	16kSa/channel
Signal Range	0-2.5V
Number of ADC bits	12 bits
Supply Voltage	2.5V
RMS noise	~1.5 mV
Digital Clock frequency	25MHz
Timing resolution	<25ps (see below for details)
Power	120mW/channel
Analog Bandwidth	850MHz
Serial interface	Up to 500 Mb/s***

- Calibration memory access
- PLL on chip
- Isolated analog/digital voltage rings
- Serial interface
- Self triggering
- Completed DOE Phase II SBIR
  - Eval cards avail
  - Custom boards under dev

IEEE NSS 2021

Naluscienfic ASoCV3 (2/2)

- Some **performances of the tests** made by Naluscientific on the **old-version chip V2**



RPC with Gallium Arsenide electrodes, a solution for medium sized high-rate detectors

A. Rocchi and R. Cardarelli

IFD2022 - INFN WORKSHOP ON FUTURE DETECTORS

OCT 17 – 19, 2022

BARI, VILLA ROMANAZZI CARDUCCI

DETECTOR DESCRIPTION

✓High Rate RPC

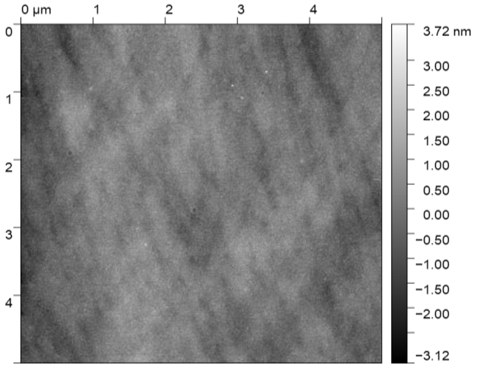
$$V_{gas} = V_{gen} - \rho d\bar{Q}\phi$$

State of the art: $\bar{Q} \sim 6\ pC$; $Q_{th} \sim 2 - 4\ fC$; **d=1.25 mm;** $\rho \sim 10^{10}\ \Omega\ cm$ **;**

-> ϕ **~7 kHz/cm²** ϕ **~1 MHz/cm²**

The HPL electrodes guarantee stable operation up to a total integrated charge of 0.3 C/cm² **--> Effective rate capability significantly limited by the experiment lifetime and background radiation**

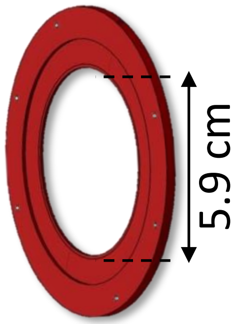
Material	Semi Insulating undoped GaAs
Thickness	$640 - 643;\ \mu m$
Diameter	3″
Resistivity	$1.4 \times 10^{8}\ \Omega cm$
Surface treatment	both polished
Growth method	VGF
Orientation	$(100) \pm 0.01°$
Mobility	$5300\ cm^{2}/Vs$



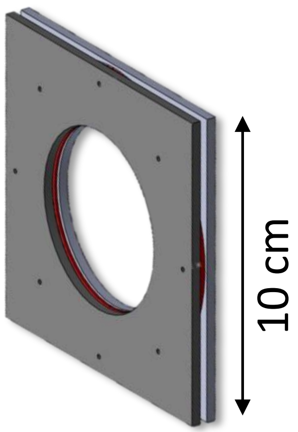
Thanks to Prof. M. Lucci for the GaAs metallization

A new material immune to the ageing effect should improve the effective rate capability of a factor ten, just with $10^{10}\ \Omega cm$ **resistivity**

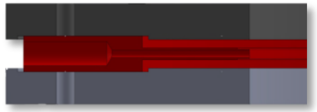
Wafers spacer 1 mm



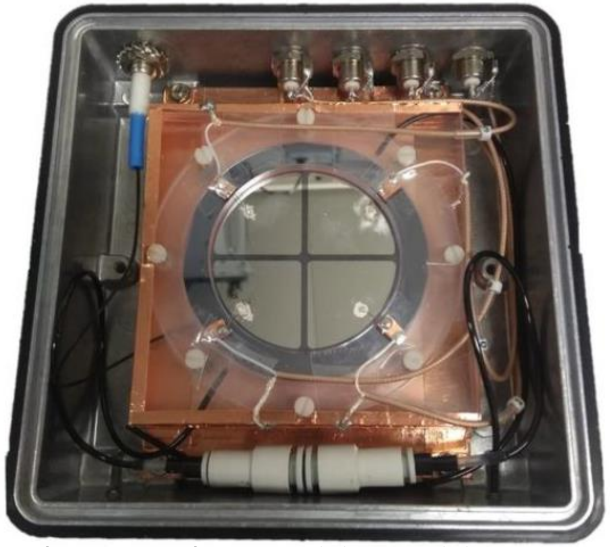
Wafers holder



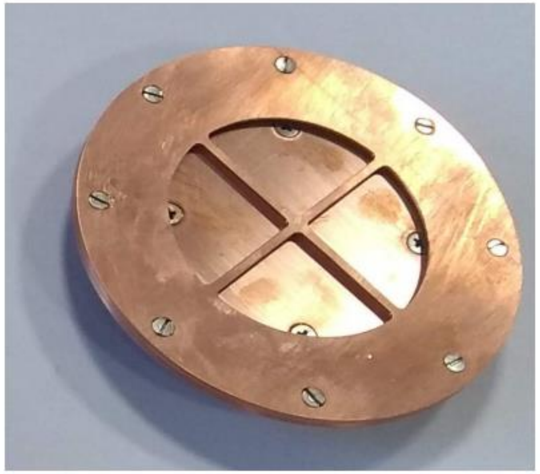
Voltage supply	3–5 Volt
Sensitivity	2–4 mV/fC
Noise (independent from detector)	4000 e^{-} RMS
Input impedance	100–50 Ohm
B.W.	10–100 MHz
Power consumption	10 mW/ch
Rise time $\delta(t)$ input	300–600 ps
Radiation hardness	1 Mrad, 10^{13} n cm^{-2}



Gas inlet ø 2 mm -> ø 0.6 mm



Wafers sputtering holder



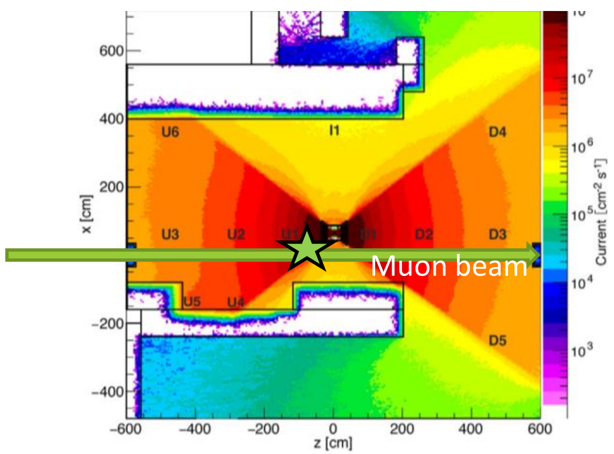
[R. Cardarelli et al, "Performance of RPCs and diamond detectors using a new very fast low noise preamplifier"]

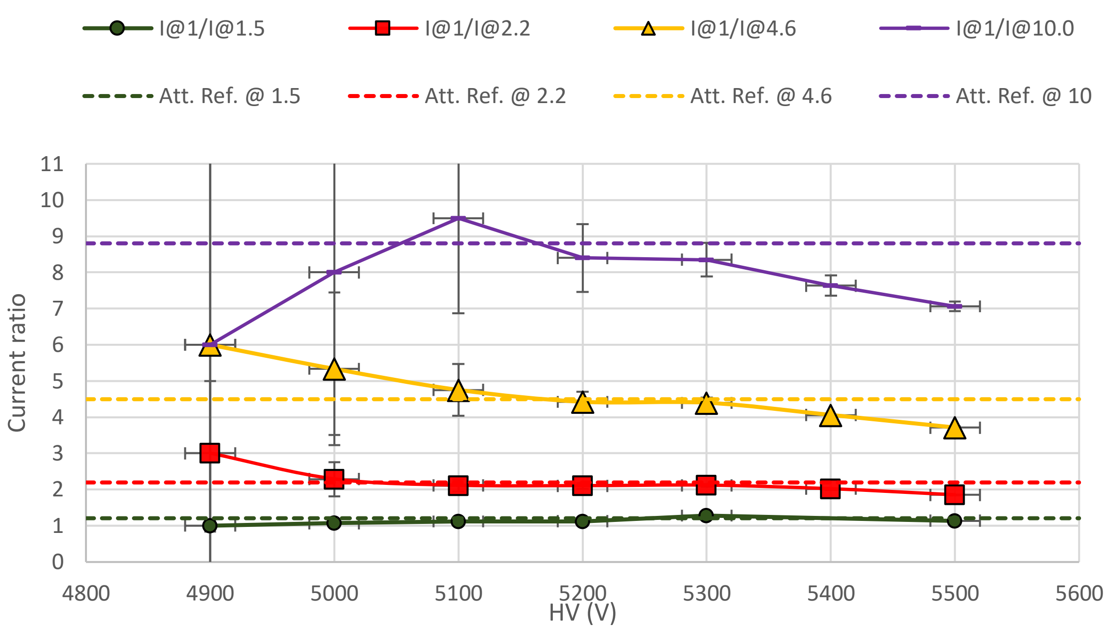
HIGH-RATE TESTS

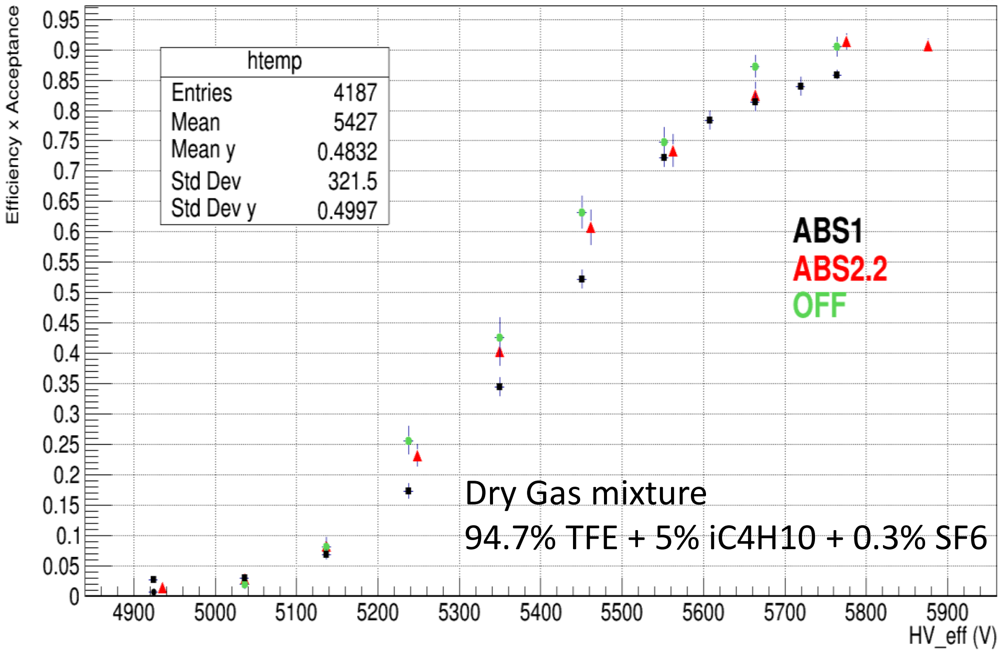
The rate capability was measured at GIF ++ at CERN. The detector efficiency response is constant up to the maximum observable flow at the Facility.

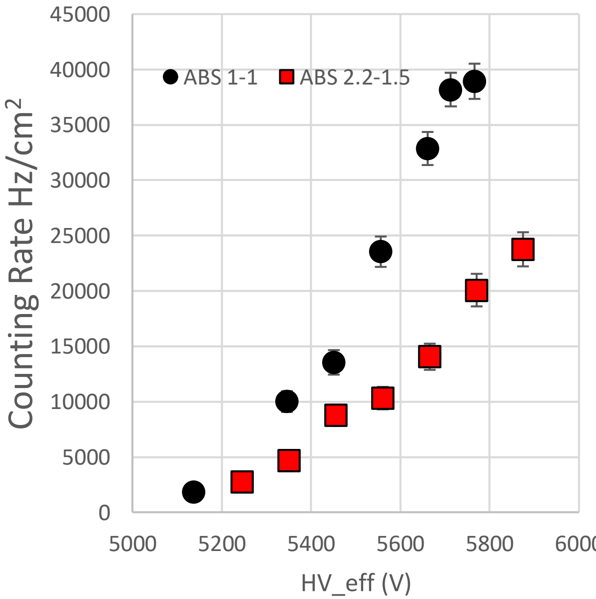
The maximum counting rate measured is 39 kHz/cm_2, a value consistent with the photon current if we consider a photon conversion efficiency approximately 1-2‰

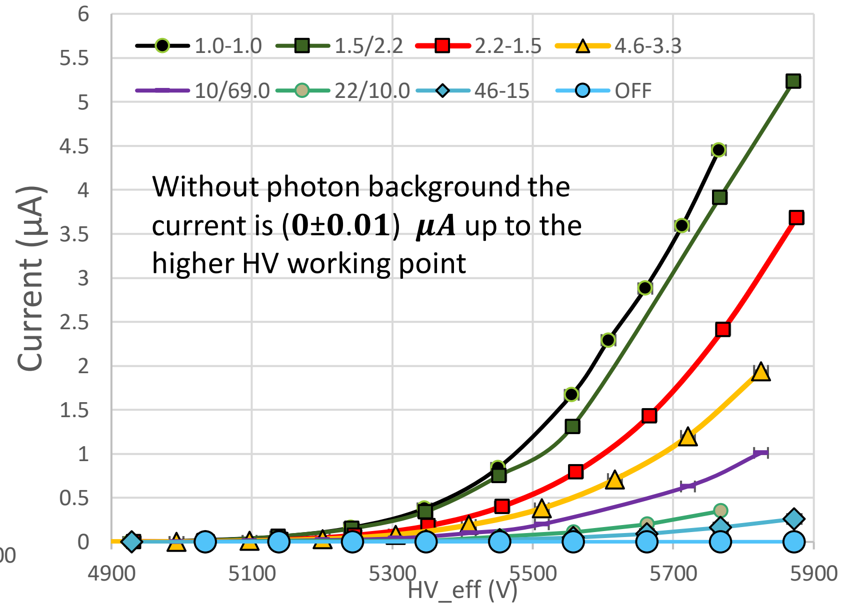
The measured attenuation of the source is consistent with the reference values





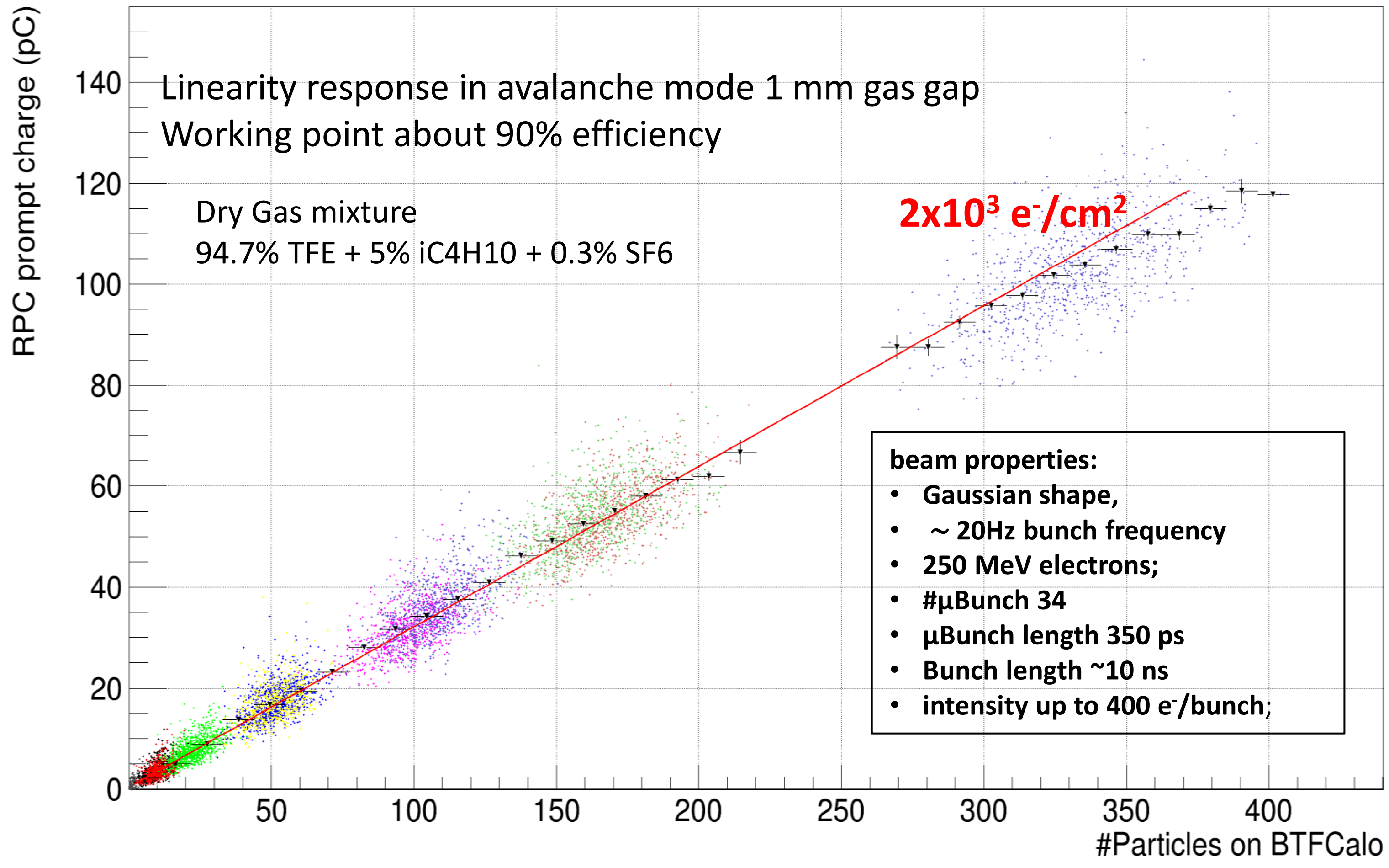






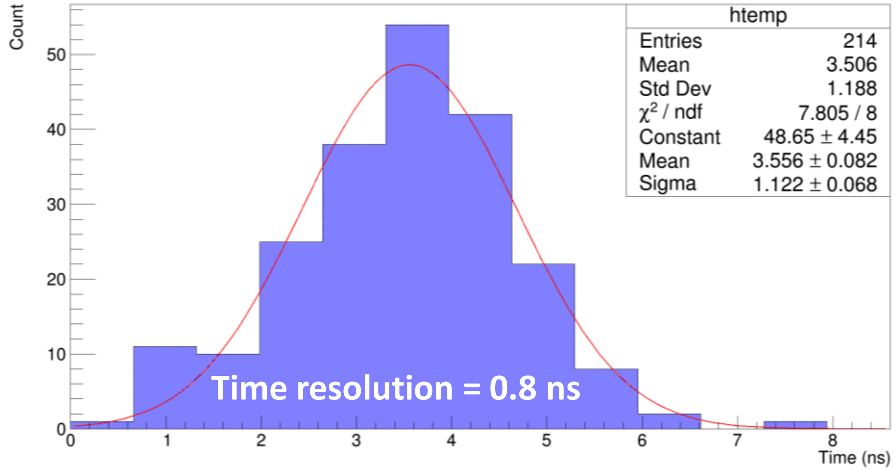
Bunched particles response:

Linearity and time resolution

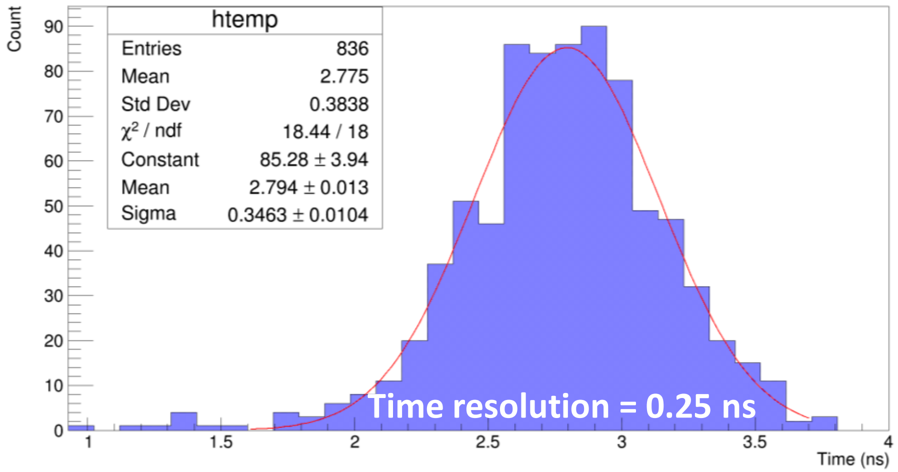


Time resolution with bunched particles improves as $\frac{1}{\sqrt{synchronous\ particles}}$

1 e⁻/bunch



~300 e⁻/bunch (10 e⁻/µbunch)



[B. Buonomo, G. Mazzitelli and P. Valente "Performance and Upgrade of the DAFNE Beam Test Facility (BTF)"]

[A. Rocchi et al "Linearity and rate capability measurements of RPC with semi-insulating crystalline electrodes operating in avalanche mode"]

Conclusions

- The functionality of the detector has been extensively demonstrated: thanks to the **high sensitivity of the FE electronics** and to the **surface quality of the new GaAs wafers** the detector is stable up to full efficiency.
- The detector **performance is constant up to the maximum photon flux available at the GIF ++** facility, and the maximum counting rate **measured** is **39 kHz / cm^2** (**about 1-2 ‰ photon efficiency**).
- **Negligible random counting rate, negligible dark current**

Open question:

- What changes in the physics of the detector when passing from an amorphous electrode to a semiconductive crystal?
- What role does electron mobility play?
- Does the resistivity of the electrode change with irradiation?
- What is the maximum rate capability of the detector?
- What is the aging damage of the detector?

Costs

3-inch Undoped GaAs wafer about 100 $/pz, 6-inch Undoped GaAs wafer about 200 $/pz.

Electrode sputtering?

The Resistive Cylindrical Chamber, a new detector based on the generalization of the RPC detectors to the quasi-planar field

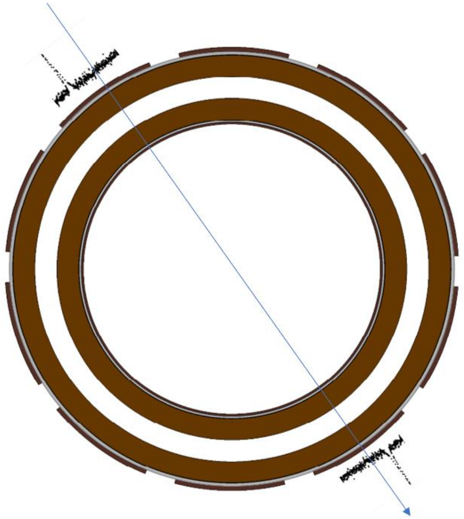
A. Rocchi and R. Cardarelli on behalf of RCC collaboration

IFD2022 - INFN WORKSHOP ON FUTURE DETECTORS

OCT 17 – 19, 2022

BARI, VILLA ROMANAZZI CARDUCCI

The Resistive Cylindrical Chamber



The RCC detector is a device consisting of two concentric cylinders of resistive material. The detector's stratigraphy is like that of an RPC, but the cylindrical geometry introduces new control parameters on the detector's response, as well as extending its use to hostile environments thanks to the high strength mechanical structure

Gas pressurization :

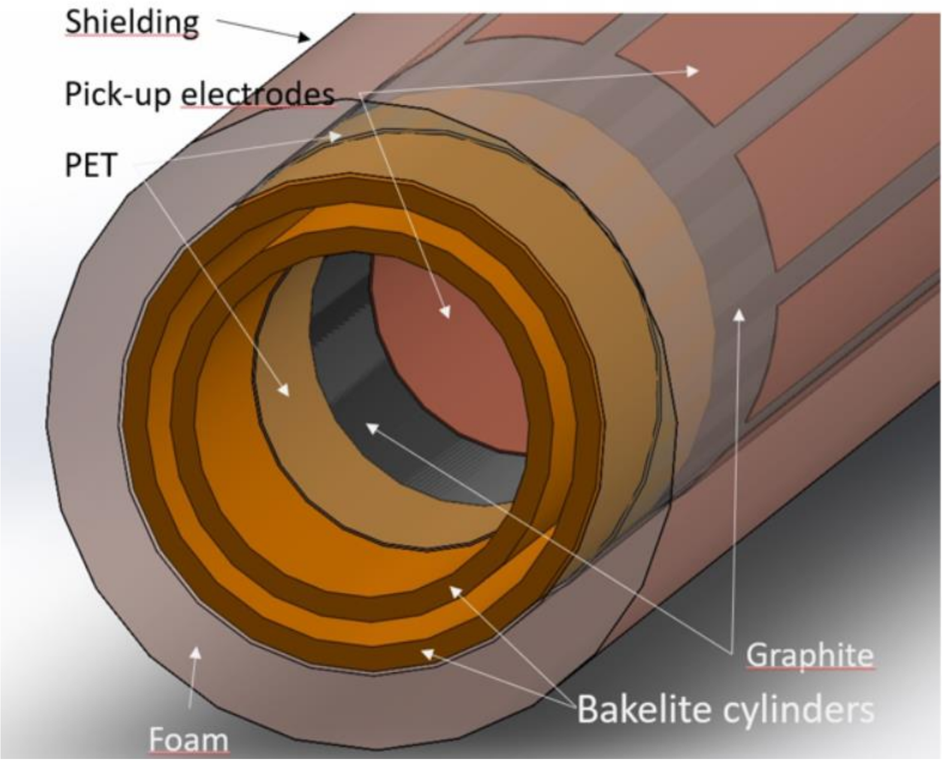
1. Increase the gas target density, with a consequent increase in intrinsic efficiency
   → MRPC time response with thin single gap configuration
   → light eco-friendly CO_2 based gas mixtures
2. Use the detector in hostile environments

The electric field gradient, depending on the polarization allows to

1. Contribute to the gas discharge quenching
   → new eco-friendly gas components
2. Increase the charge collection efficiency enhancing the multiplication in the initial part of the gas gap
3. Study the dependencies and optimize the time resolution

Double gap:

1. Tracking capability
2. Improvement in time resolution and efficiency



SIMULATION: ELECTRIC FIELD GRADIENT AND PRIMARY IONIZATION

In the RCC detector the electric field has a cylindrical geometry and is much more approximable to a planar field as the gas-gap is negligible with respect to the radius of the internal electrode. This feature allows to design detectors with different responses according to the experimental needs:

- it is possible to reproduce the same performances of an RPC in an easily pressurized cylindrical structure;
- it is possible to design a detector with a non-negligible field gradient to increase the time resolution and suppress the transition to the streamer regime

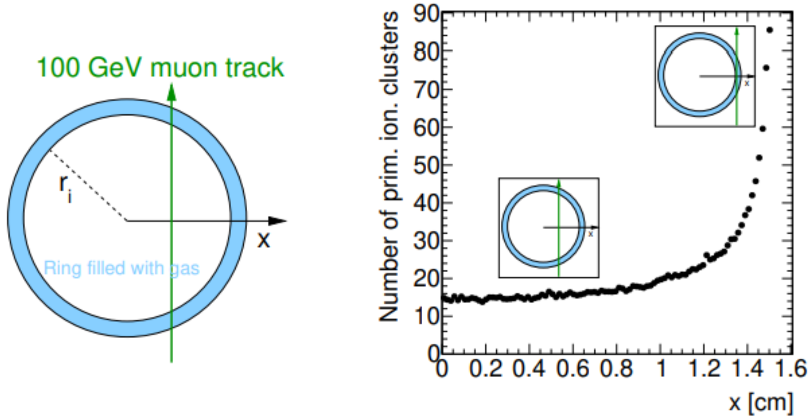
$$E(r) = \frac{V}{r\,ln\frac{R_o}{R_i}} \sim \boxed{\frac{V}{R_i ln\frac{R_o}{R_i}}} - \frac{V}{R_i ln\frac{R_o}{R_i}}\frac{r-R_i}{R_i}$$

$$R_o - R_i \ll R_i$$

→ weak dependence on thin gas gaps

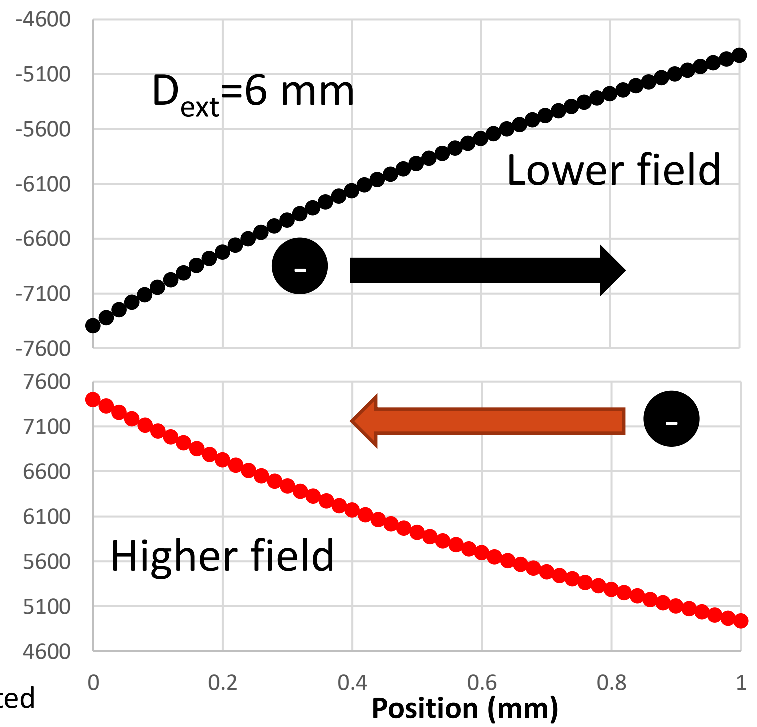
The RCC detector has a double gap structure, which can be exploited for tracking measurements and to increase efficiency and time resolution

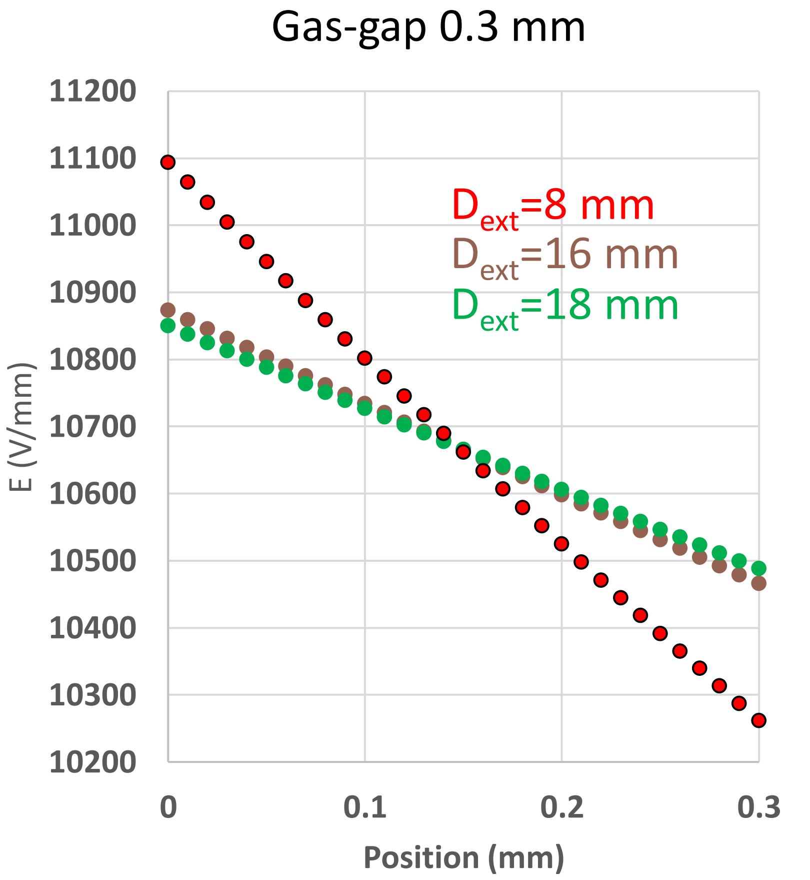
Primary ionization with pressurized CO_2



⇒ Small number of primary ionization clusters: ~14 for $r \lesssim r_i$.

[Simulation of the avalanche creation in resitive circular chambers Oliver Kortner, XVI Workshop on Resistive Plate Chambers and Related Detectors]



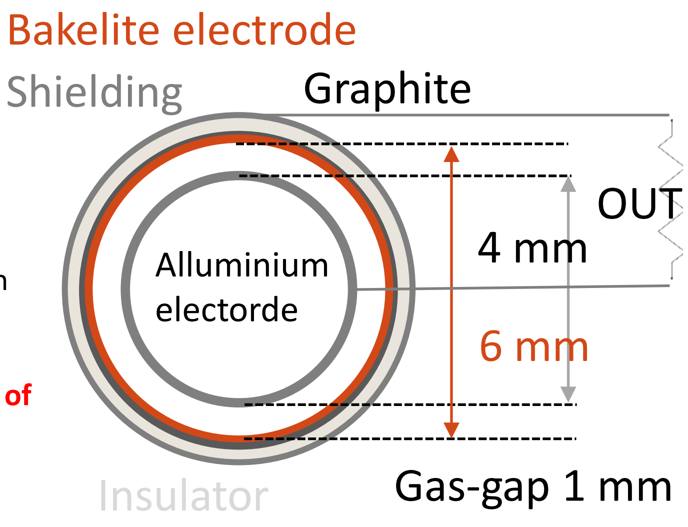


Detector description and reliminary results (1 mm gas-gap)

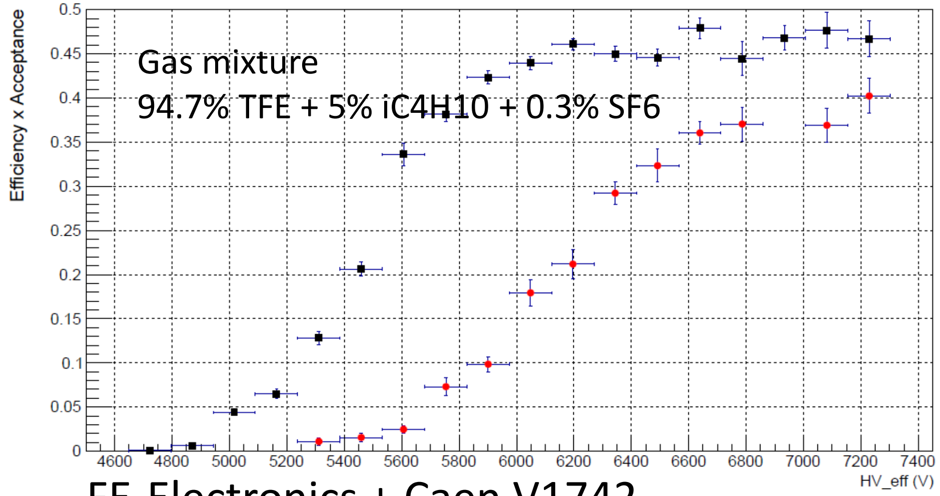
[Development of Resistive Cylindrical Chambers, R. Cardarelli, XVI Workshop on Resistive Plate Chambers and Related Detectors]
[Moderation of the avalanche gas discharge through a quasi-uniform electric field device: the Resistive Cylindrical Chamber, A. Rocchi, VCI2022]

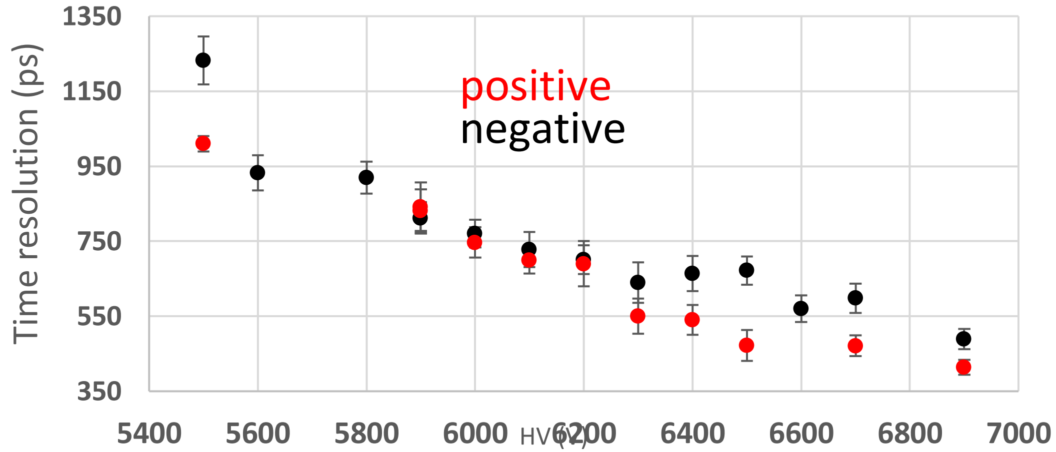
The response of a 1 mm gas-gap RCC was studied with the detector described in figure. The smaller radius electrode consists of an aluminum cylinder. A significant separation is observed between the working points of the detector in the different polarities. **The intrinsic efficiency is lower in the case of positive polarization as if the useful gas-gap decreases.**

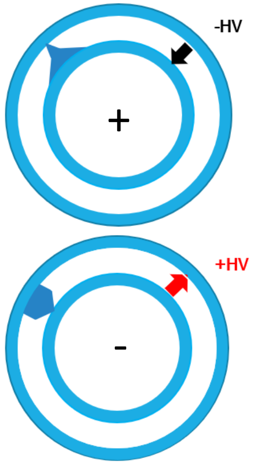
The time resolution was measured using an RPC detector with two coupled 0.2mm gaps as a reference.
The time resolution improve as the applied voltage increases and for high field values it **is systematically better in the case of positive polarization, in which multiplication occurs mainly near the cathode (behavior like that of a thinner gap**).



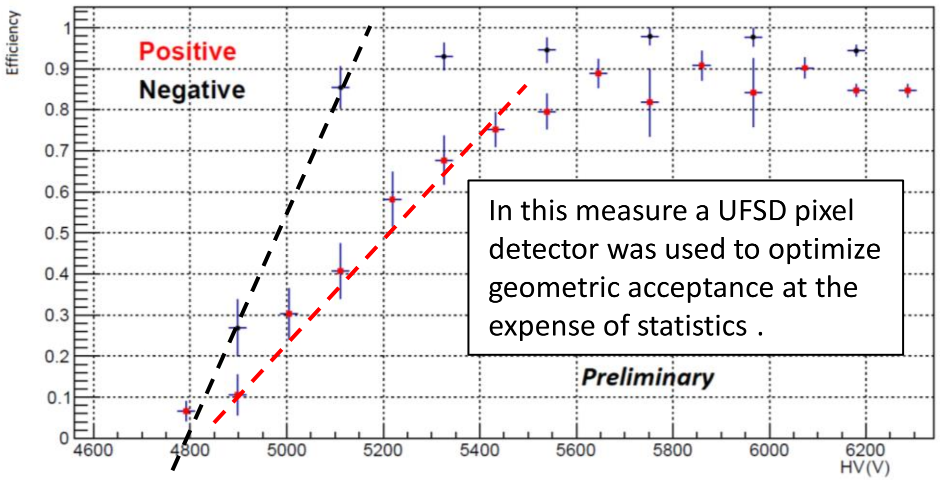
Caen V1742







FE-Electronics + Caen V1742

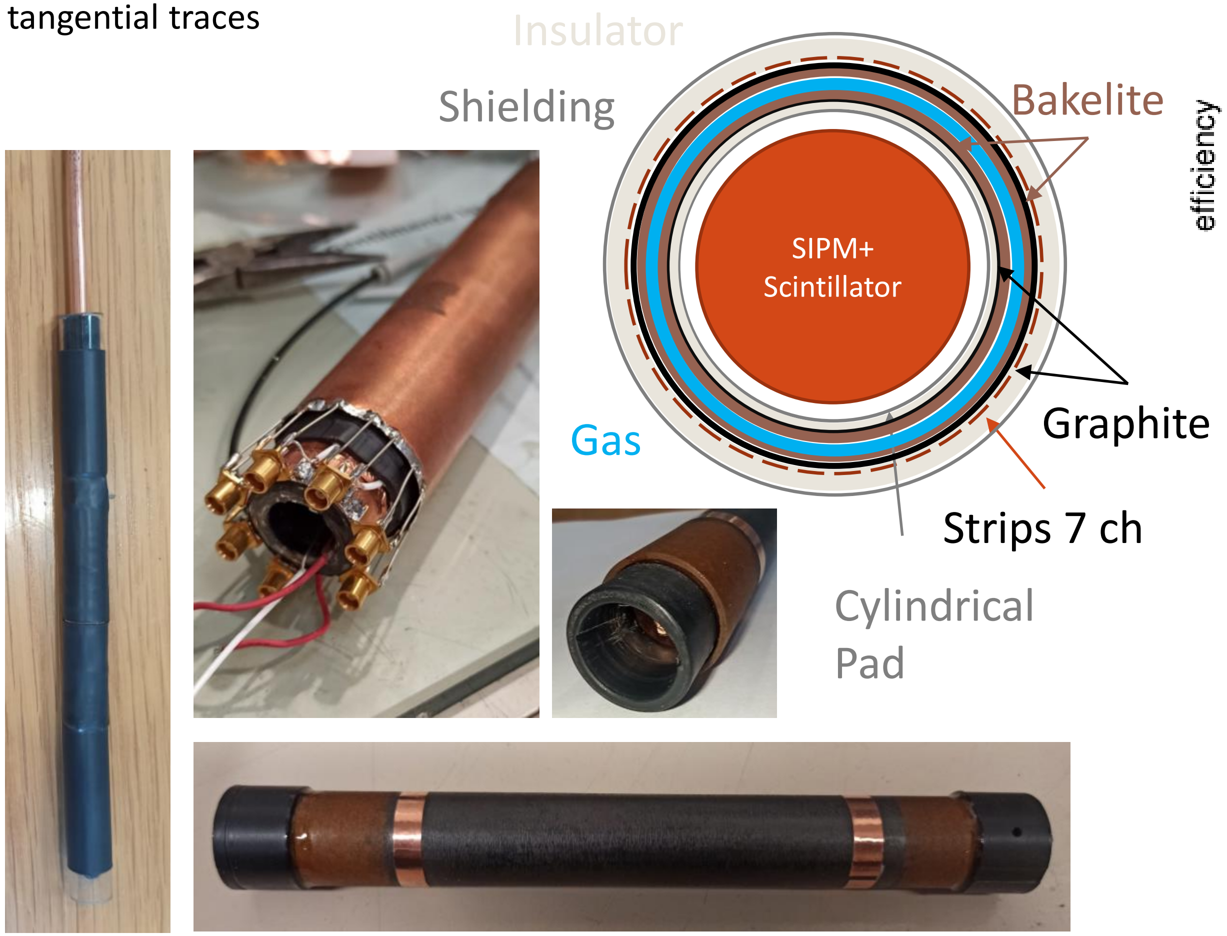


DETECTOR DESCRIPTION AND RELIMINARY RESULTS (0.3 mm GAS-GAP)

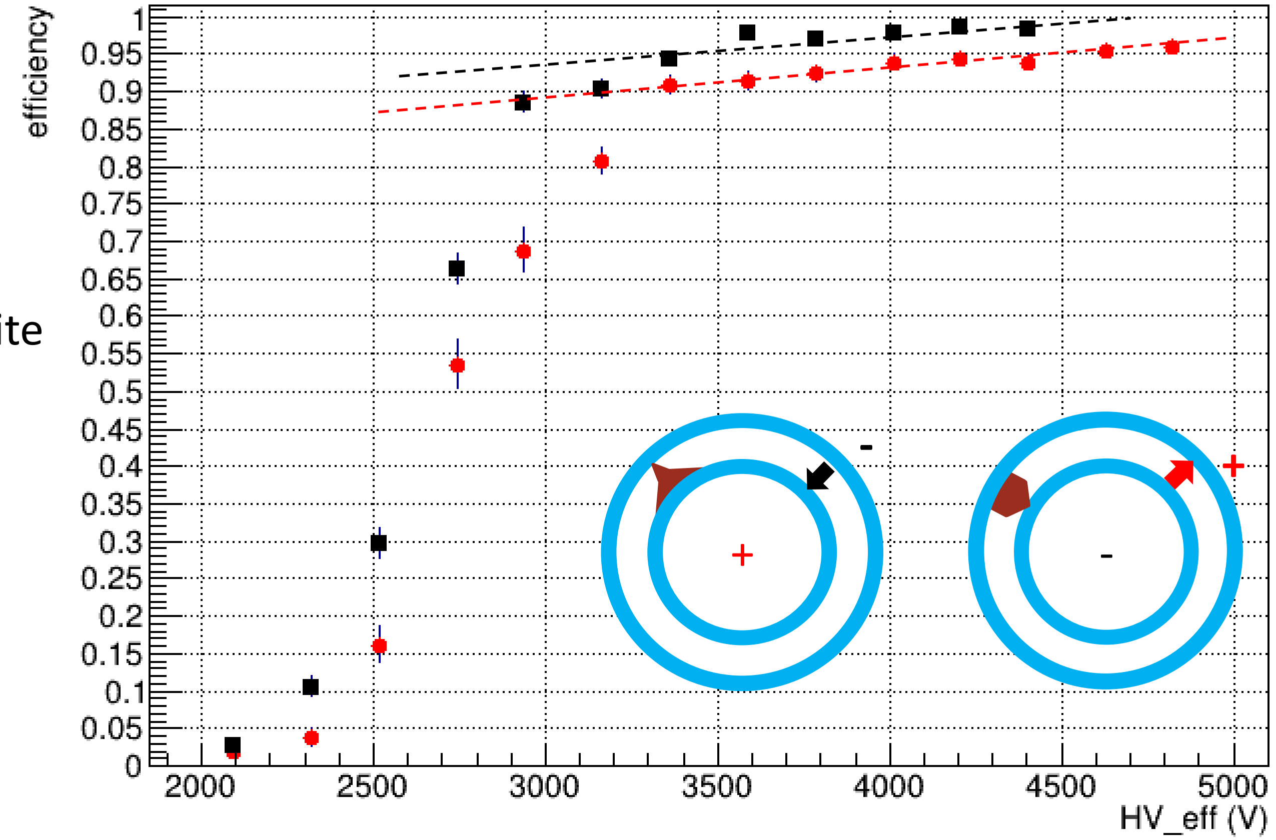
[Thanks to Alessandro Paoloni for the SIPM detector and electroinics]

The detector described in figure was characterized with muons of 180 GeV / c.
A small difference can be observed between the working points in different polarities. Also In this configuration the detector has a lower intrinsic efficiency in positive polarity.

The internal detector made it possible to close the angle of acceptance and discriminate the tangential traces



Gas mixture
94.7% TFE + 5% iC4H10 + 0.3% SF6

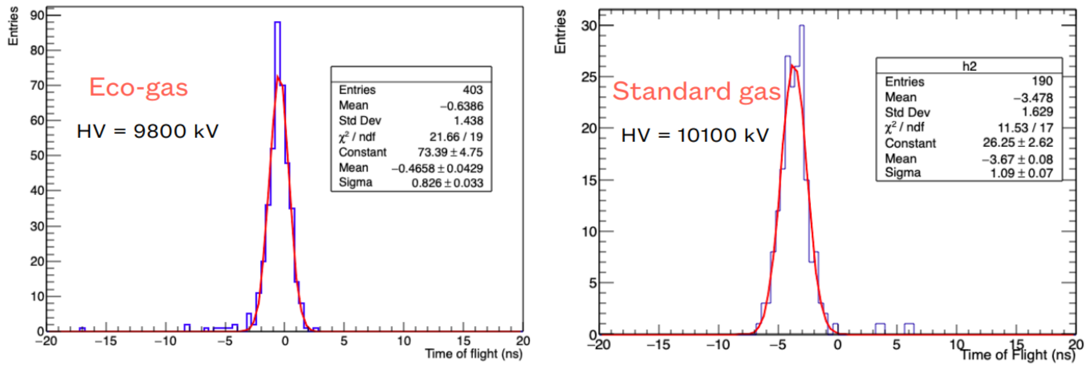


STUDY WITH HIGH PRESSURIZED CO_2

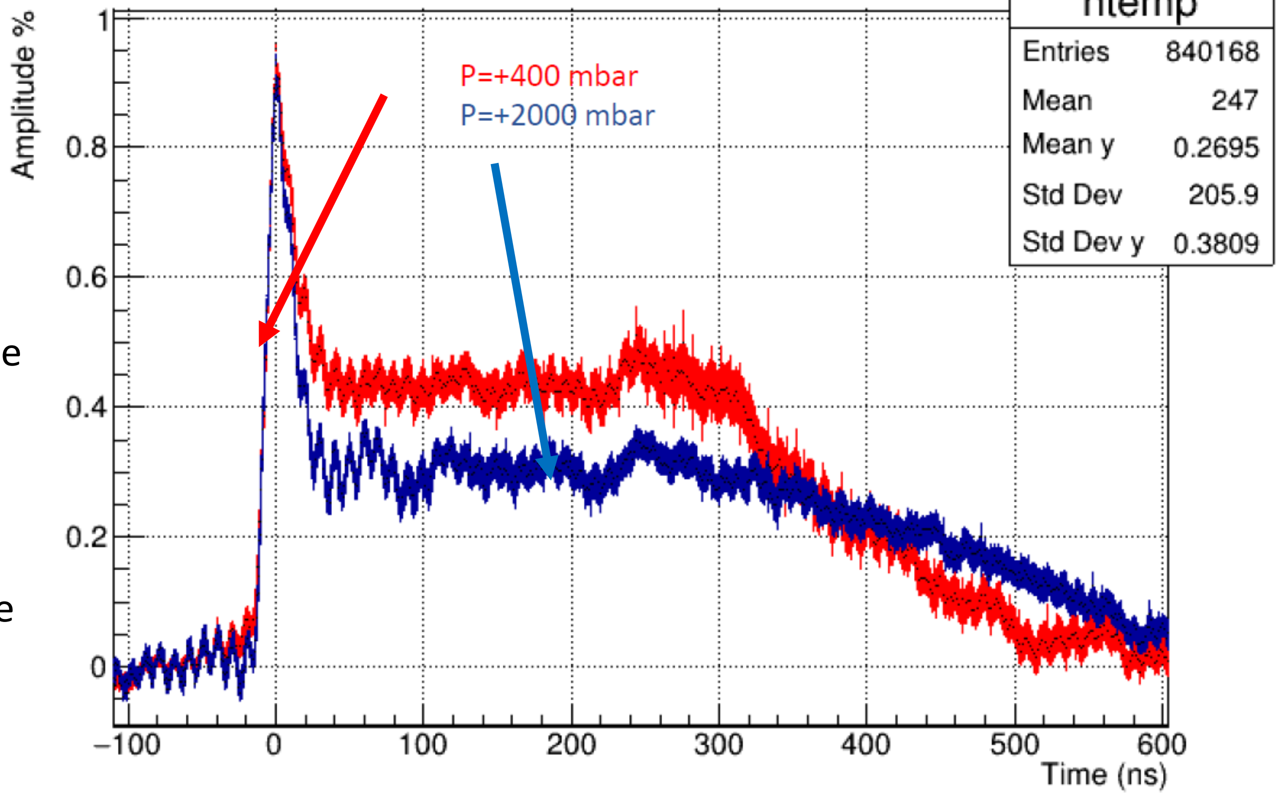
[On a new environment-friendly gas mixture for Resistive Plate Chambers, G. Proto, XVI Workshop on Resistive Plate Chambers and Related Detectors]

Studies on new eco-friendly gas mixtures show that mixtures with a high concentration of CO_2 lead to an improvement in the time resolution at expense of the intrinsic efficiency of the detector.

σ_{Eco} = (0.83 ± 0.03) ns
σ_{STD} = (1.09 ± 0.07) ns



Average profile of normalized signals



The RCC thanks to the pressurization of the gas-gap allows to increase the density of the gas recovering the loss of efficiency even for thin gas gaps

The effect of the pressure is visible from the ion signal profile: as the pressure increases, the instantaneous current decreases as the drift speed of the ions decreases and the duration of the signal increases accordingly. The amplitude of the electronic signal is unchanged

Conclusions

The functionality of the detector has been demonstrated with prototypes of different structures (1 mm gas-gap, 0.3 mm gas-gap)

As expected, the asymmetry in the detector response with respect to the polarity of the applied voltage increases when the thickness of the gap increases with respect to the internal radius

The effect of suppression of the avalanche in positive polarization leads to a reduction of the intrinsic efficiency but to an improvement in the time resolution, as if the useful gas-gap were thinner

This effect can also be studied to suppress the transition to the streamer regime in gas mixtures with low quenching potential

Perspectives

Systematic study of RCC detectors with different radius and gas-gaps

Study of the response with high concentration of CO_2

INFN BARI
Istituto Nazionale di Fisica Nucleare
Sezione di Bari

AIDA innova

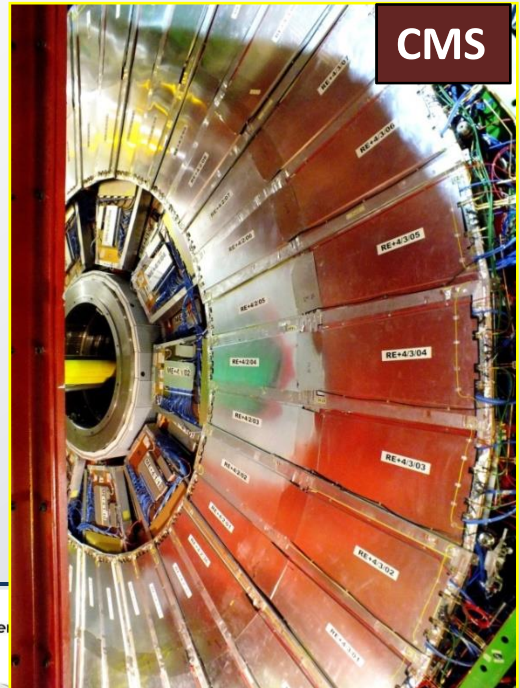
Green Resistive Plate Chamber detectors for HEP applications

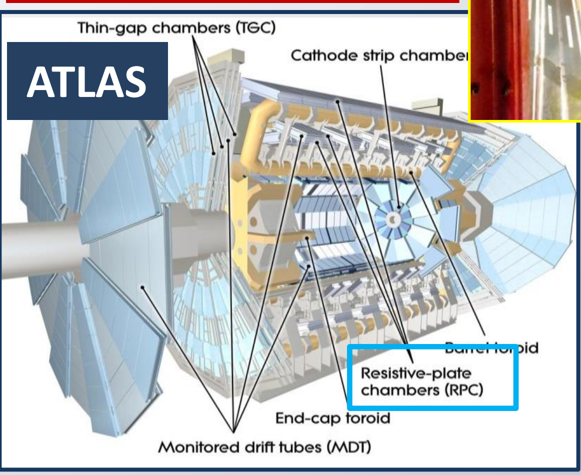
Alessandra Pastore *(INFN Bari)*

on behalf of the **RPC EcoGas@GIF++ Collaboration**,
born within the ALICE, ATLAS, CMS, LHCb/SHiP and CERN EP-DT RPC Communities

Resistive Plate Chambers in HEP

RPC technology continuously improved, aiming at more and more challenging applications





- *In HEP, typically operated in avalanche mode*
- *"standard" gas mixture is a perfect match:*

CH_2FCF_3 (> 90%)/ C_4H_{10} / SF_6

BUT

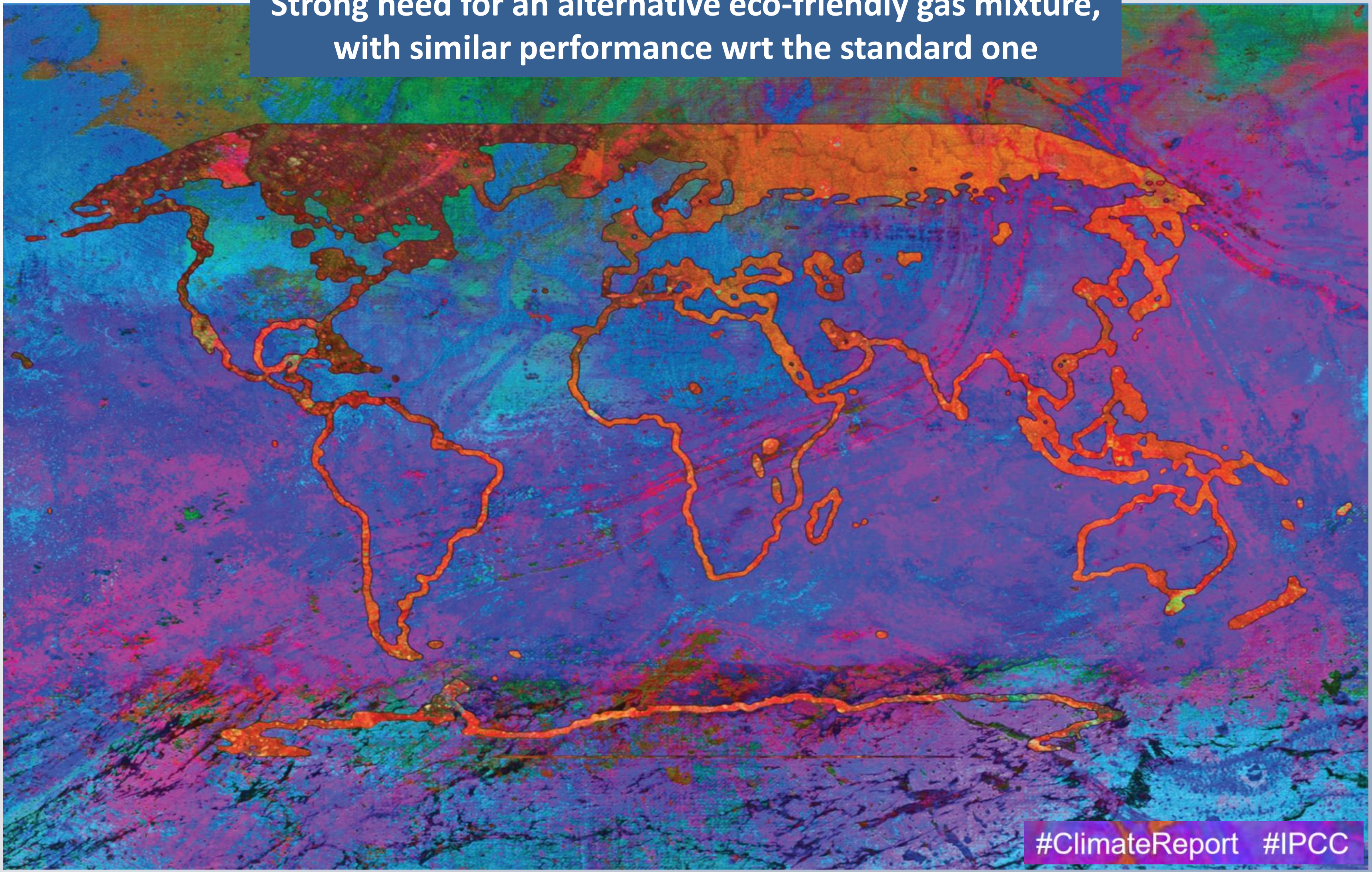
Gas	GWP* values 100-year time horizon
CO_2	1
CH_2FCF_3	1300
SF_6	23500

www.ipcc.ch, AR5

*Global Warming Potential = measure of the heat trapped in the atmosphere by a ton of a given gas, if compared to a ton of CO_2

Eco-compatibility of RPC detectors

Strong need for an alternative eco-friendly gas mixture, with similar performance wrt the standard one

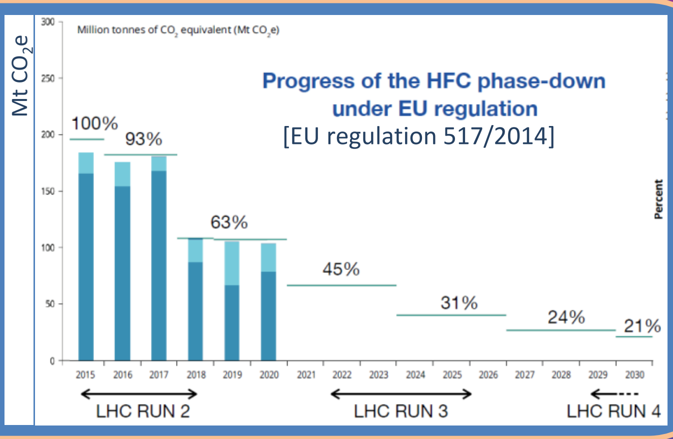


Eco-compatibility of RPC detectors

Strong need for an alternative eco-friendly gas mixture, with similar performance wrt the standard one

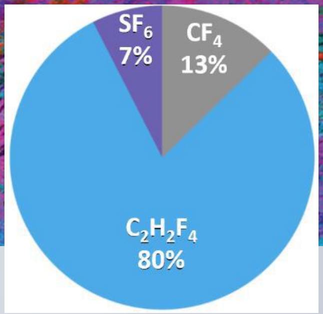
EU "F-gas regulation"

- **Limiting the total amount** of the most important F-gases that can be sold in the EU.
- **Banning the use** of F-gases where less harmful alternatives are widely available.
- **Preventing emissions** of F-gases from existing equipment.



B. Mandelli, VCI2022

relative contribution to GHGs emissions from particle detectors at CERN LHC experiments



Concerns about environment, F-gases availability and costs

f.e. **CH_2FCF_3** in **early LHC Run 3** expectation:

~ 90 ktCO2e/year emitted

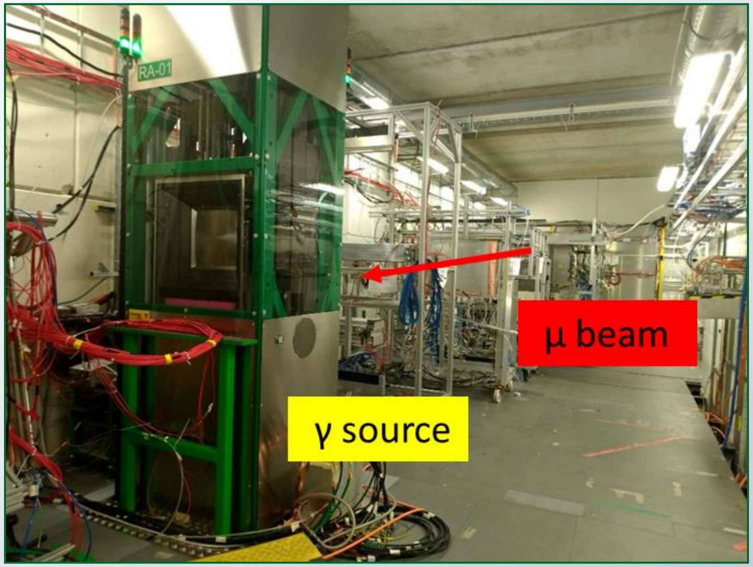
price increase of ~2.5 times w.r.t to 2015

#ClimateReport #IPCC

The RPC EcoGas@GIF++ Collaboration

- recently born within the **ALICE, ATLAS, CERN EP-DT, CMS and LHCb/SHiP RPC Communities**

- shares **person-power, instrumentation, ideas** in order to **search for potential eco-friendly gas mixtures** in home-laboratories and at CERN, and **assess the performance of RPCs in different irradiation conditions** at the CERN Gamma Irradiation Facility GIF++



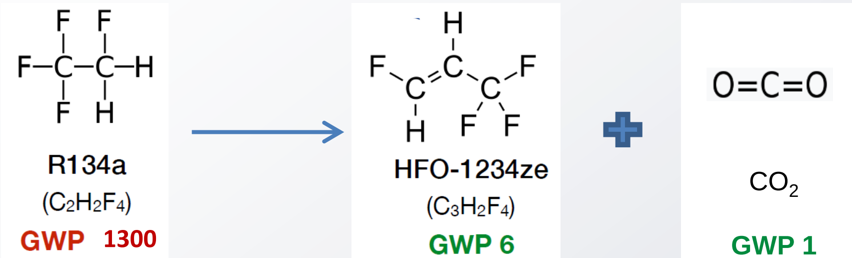
View of the setups inside the GIF++ bunker

Group	Dimension (cm^2)	# of gaps	Gap/electrodes Thickness (mm)	Readout	# of strips
ATLAS	500	1	2 / 1.8	Digitizer	1
CMS	4350	2	2 / 2	TDC	128
EP-DT	7000	1	2 / 2	Digitizer	7
ALICE	2500	1	2 / 2	TDC	32
ShiP/LHCb	7000	1	1.6 / 1.6	TDC	64

Summary table of all the RPCs of the collaboration

The ‘HFO’ option for avalanche RPC detectors

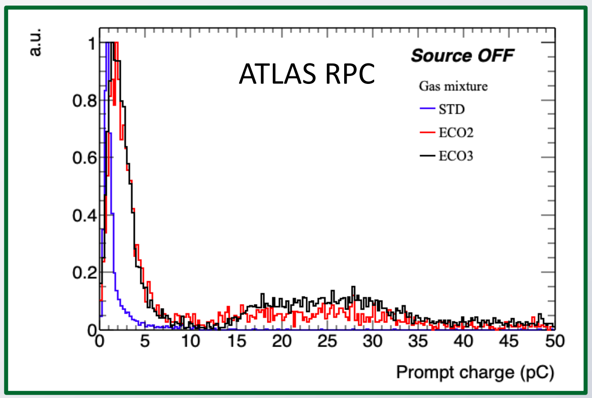
Several gas mixtures have been tested. Two of them have shown to be very promising:

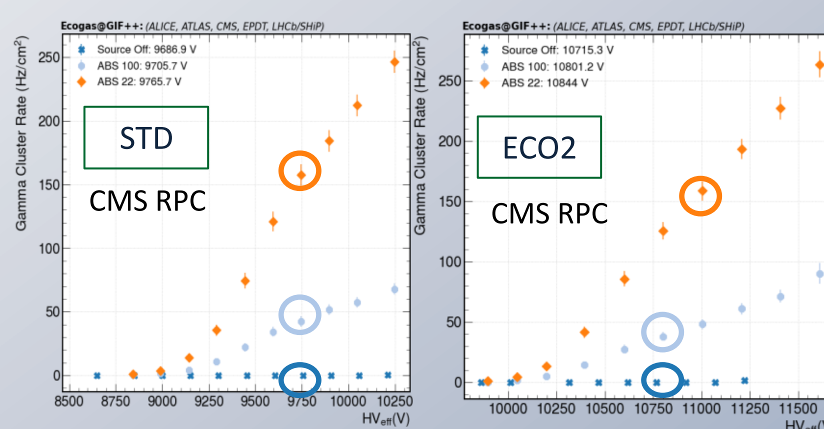


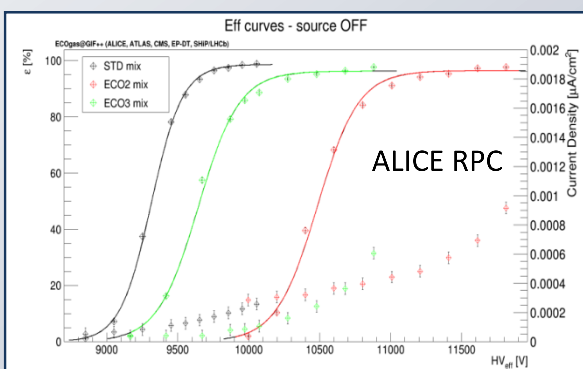
ECO2 = $CO_2/C_3H_2F_4$/i-C_4H_{10}/SF_6=(60/35/4/1)%

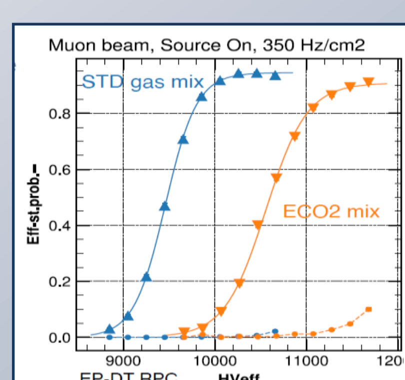
ECO3 = $CO_2/C_3H_2F_4$/i-C_4H_{10}/SF_6=(69/25/5/1)%

impact on the environment reduced of ~ 80% wrt STD mix



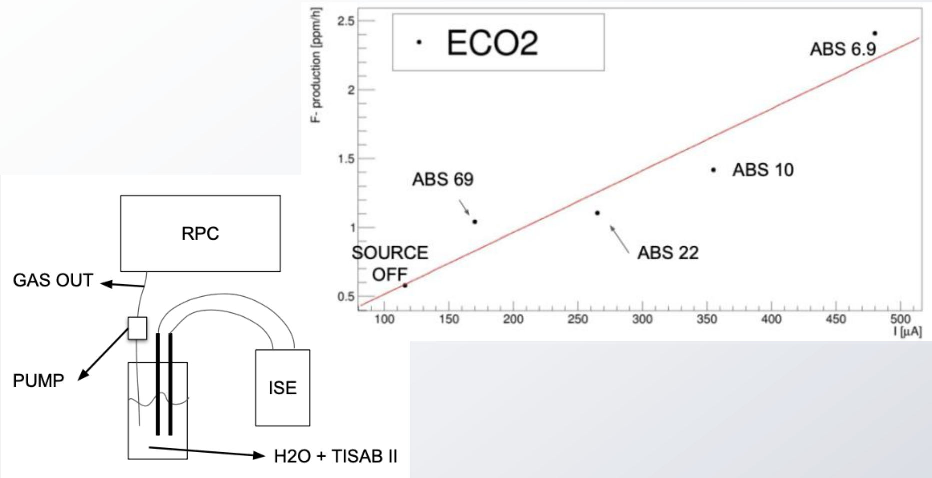






comparable performance at working point

Long term performance studies

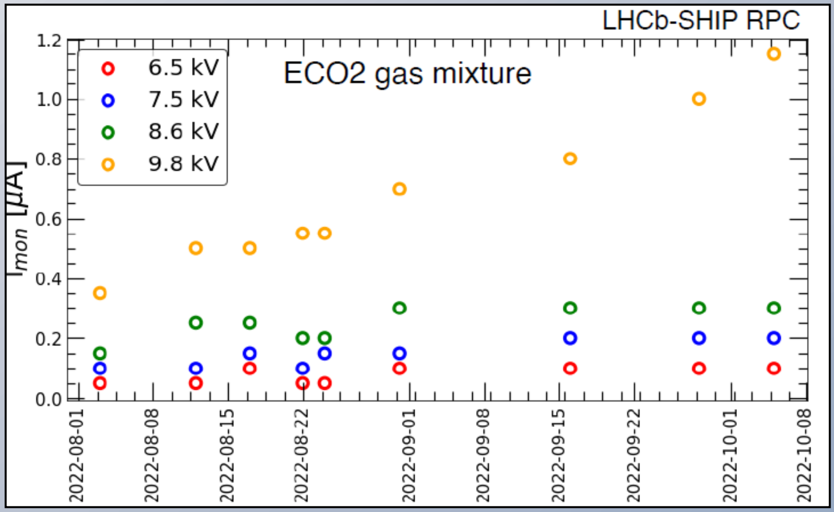


F⁻ produced from the C2H2F4 and C3H2F4 molecules, expecially in high irradiation conditions and high electric fields, combines with H_2O, producing HF acid

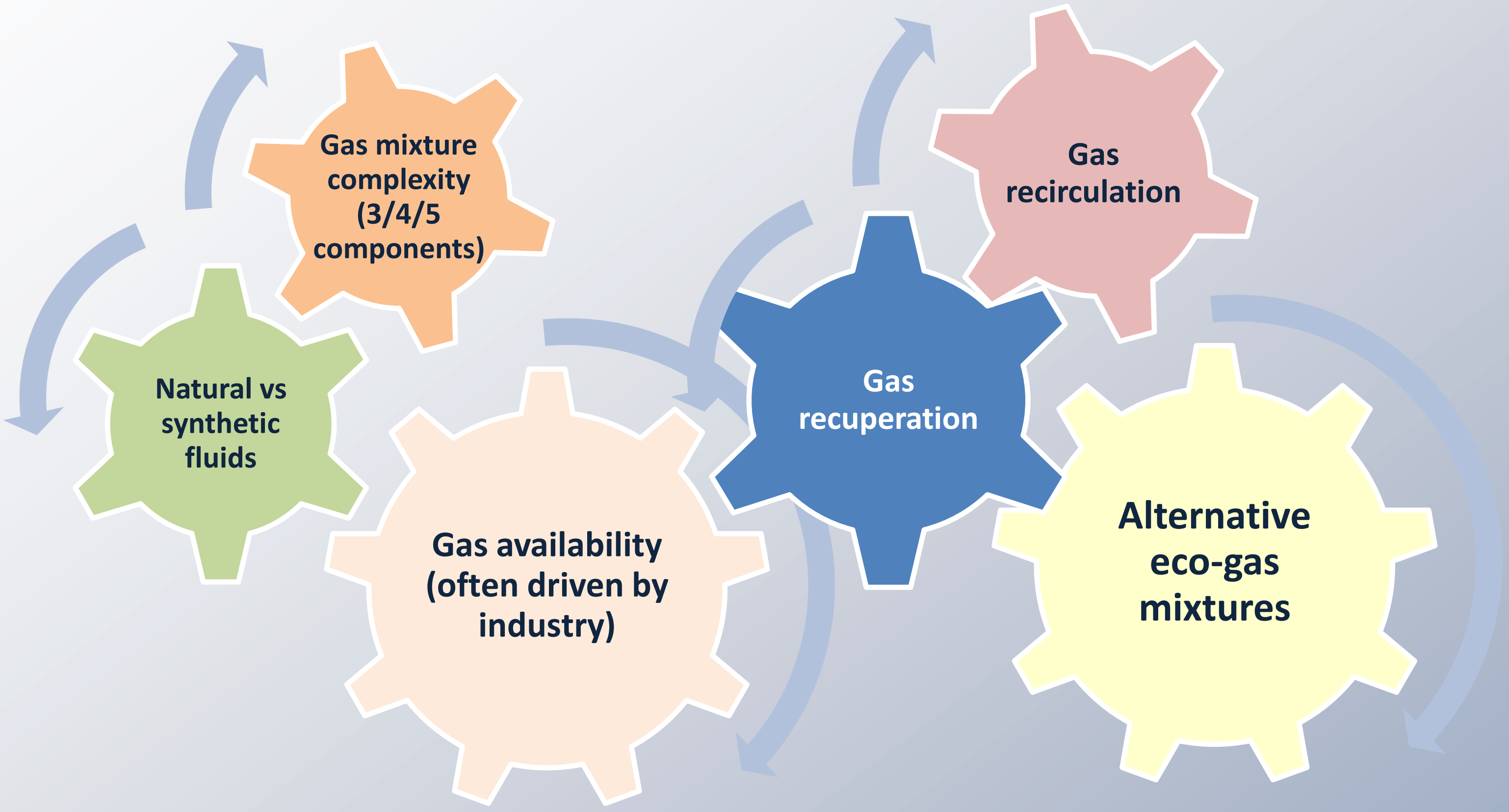
→ **Ion Selective Electrodes (ISE) at CERN**

Irradiation campaign of RPCs to accumulate an equivalent charge of the HL-LHC Phase

Fundamental for the validation of new eco-friendly gas mixtures



towards future …



Rapid fire

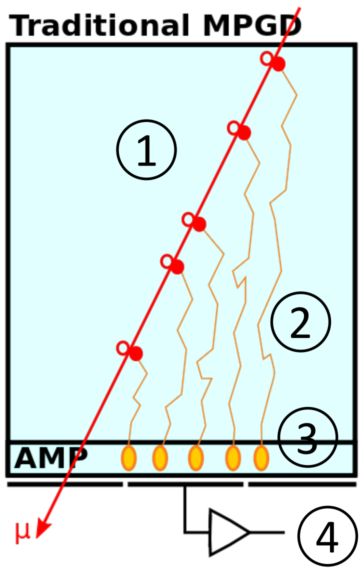
Fast Timing MPGD

INFN Workshop on Future Detectors (IFD)

October 18th 2022

Piet Verwilligen – INFN Bari
Antonello Pellecchia, Marcello Maggi & many others ….

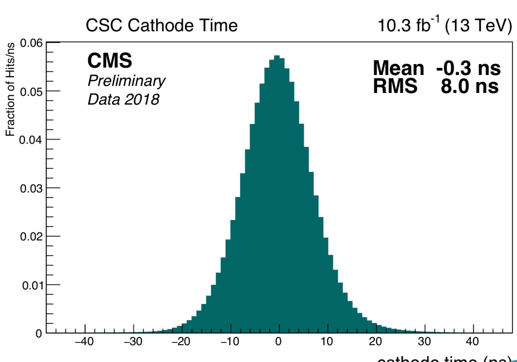
Timing with Gaseous Detectors in Proportional Mode (wires, MPGDs)

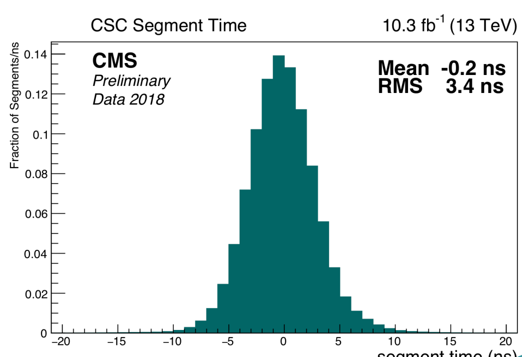


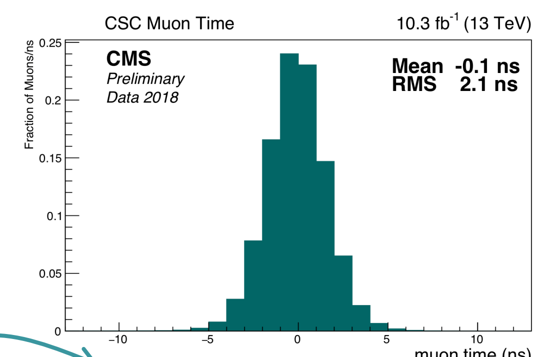
- with primary electron creation in gas ("Primary Ionization") typically in a so-called "Drift Volume" is limited to 5-10ns [1]
- Independent of Electric Field: parallel or circular wire detector
- Time resolution limited due to fluctuations in primary ionization
- Typical Fluctuation of closest primary electron to amplification structure. Example: Triple-GEM in **$Ar:CO_2$ (70:30)** λ~ 2.8mm^{-1} $\langle d \rangle$ = 350μm, v_{drift} = 70μm/ns (3kV/cm) → $\sigma_t^{primaries} = 5$ ns ①
- Next factors that influence time resolution in these detectors are:
  - Long diffusion flucts: σ_t^{drift} = few 10s – few 100 ps ②
  - Avalanche flucts: $\sigma_t^{avalanche}$ = few 10s – few 100ps ③
  - *Electronics jitter, system time distribution, start time,…* ④

Better time resolution obtained: $\sigma_t/\sqrt{N}$

Example at LHC: CMS CSC





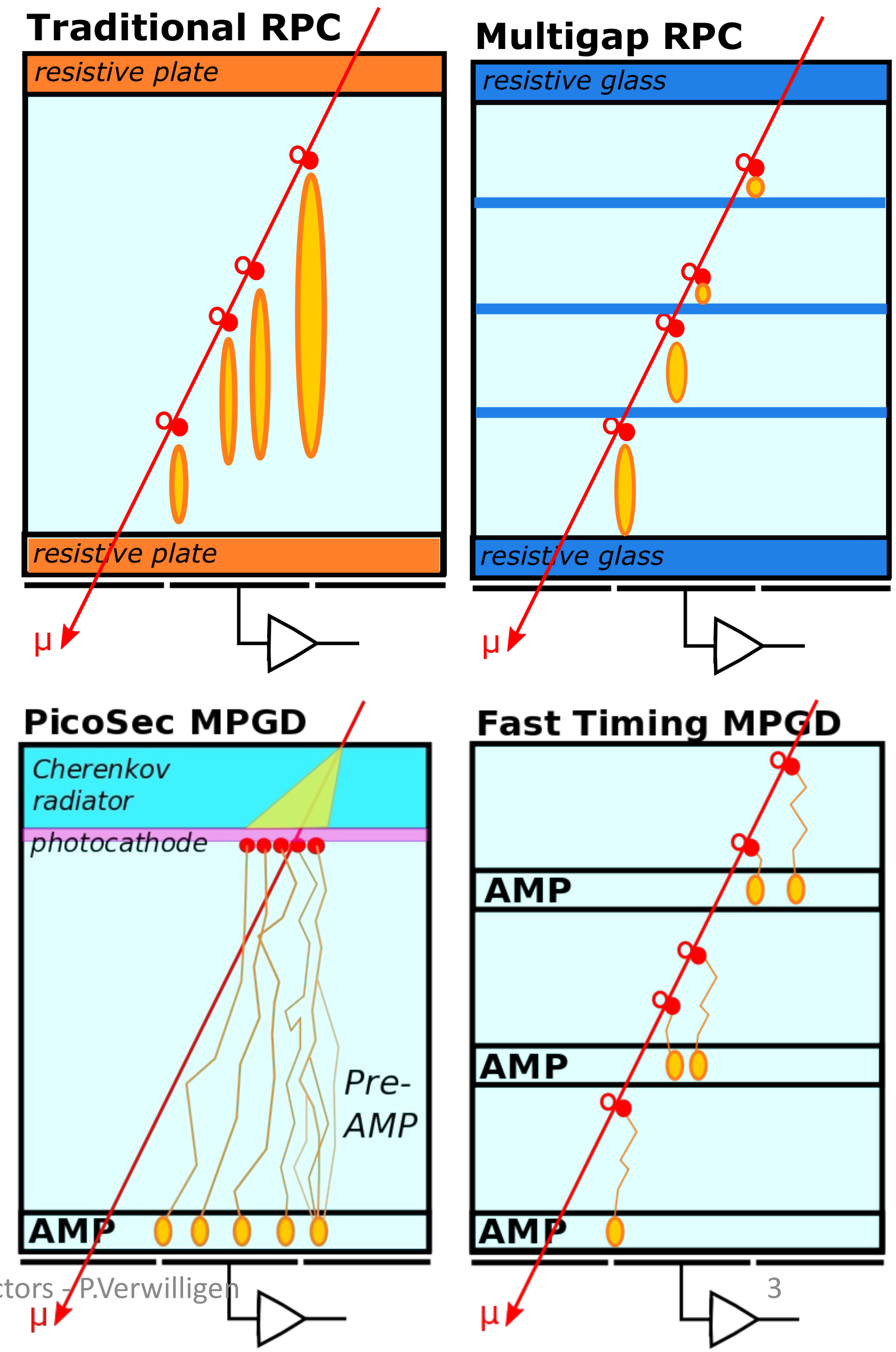


Single-hit $\sigma_t = 8$ns → 6-hit stub $\sigma_t = 3.4$ns → 4-stub muon $\sigma_t = 2.1$ns

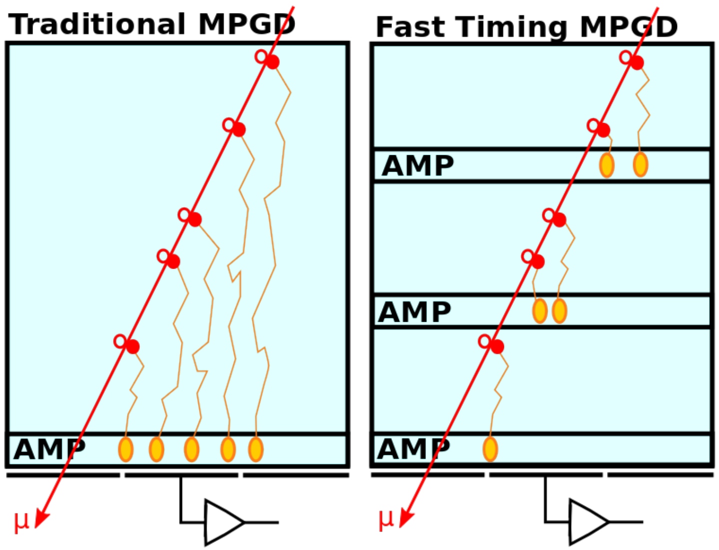
Overcome limits time-resolution

Possible Solutions:

- No drift volume, amplify immediately: **Resistive Plate Chamber**(2ns – 300ps)
  - at cost of loss of Proportionality, reduced Rate Capability & σ_x
- Reduce gap width with order of magnitude and use multiple gaps: **Multigap-RPC (100ps – 20ps)**
  - same as RPC, but difficult for large area
- Create all primary electrons at same place (use Radiator+PC): **PicoSec** (<25ps)
  - but expensive radiators (Quartz, MgF2) & non rad-hard photo-cathodes (CsI)
- Sample the fluctuations in primary electron creation: **Fast Timing MPGD** (~300ps – *not proven yet*)
  - resistive MPGD: spark protection but reduced rate capability



Fast Timing with MPGDs: FTM

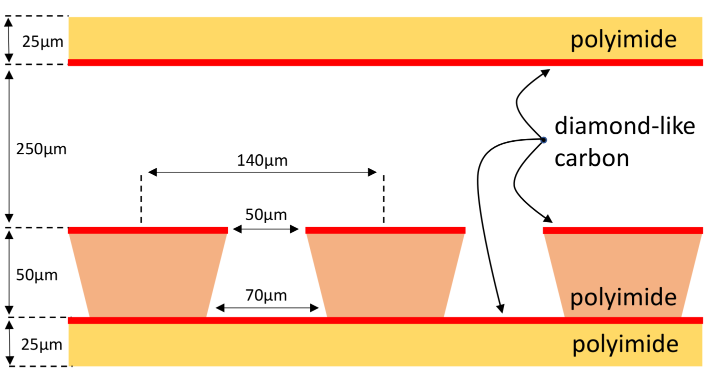


Fast Timing MPGD (FTM): Principle

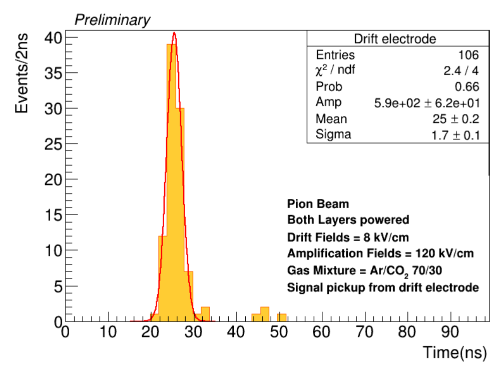
- Divide drift in multiple layers, each w/ own Amplification
- Resistive electrodes => Electrode Transparency
- Signal induced in External Pick-Up strips
- Closest primary electron => Fastest Signal
- Time Resolution $\sigma_t = 1/(\lambda \cdot v_{drift} \cdot N)$, where N = layers
- Observed: 2ns with 2 layer detector [4] (→ OK)

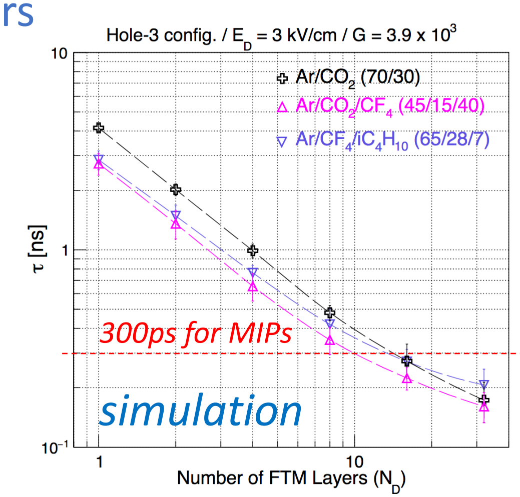
Fast Timing MPGD: Challenges:

- Detect single-electron (or single cluster) instead of many clusters
- **Requires High Gain Structures**
- **Requires sensitive front-end electronics**



Test Beam Results (2 layers)





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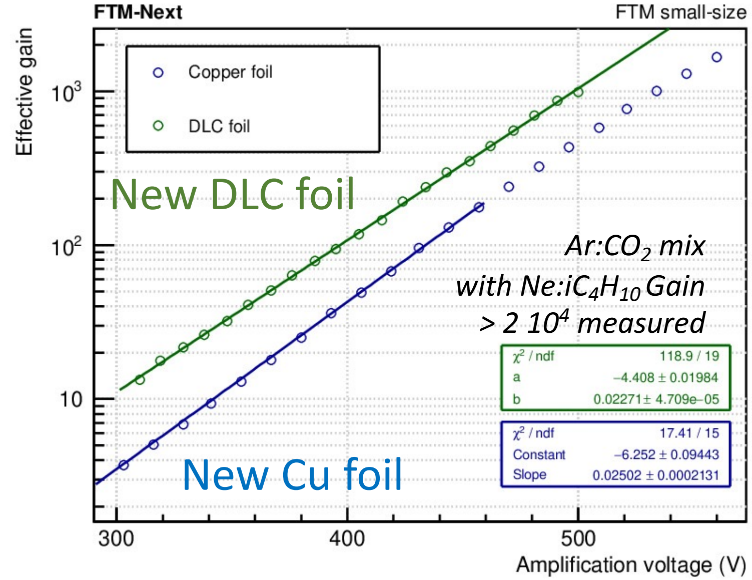
[4] I.Vai *et al.* NIM A 845 (2017) 313

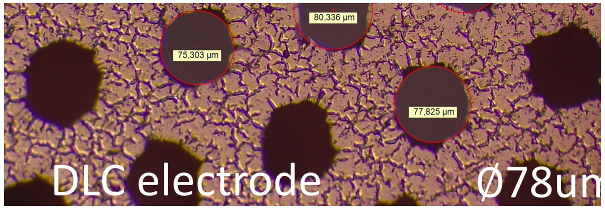
FTM: Technological Challenges

Single gain structure capable of gain > 10^4

- *with non-greenhouse, non-GWP, non-flammable gas*
- Main Challenge: production of high quality Amplification foils
  - Requires well adherent 2-sided Cu-DLC foils
  - CERN – INFN DLC Sputter machine is coming
  - In past years: collaboration with solid state physicist (INFN CSN-V)
    - High quality DLC production on small size prototypes 1-50cm^2
    - Strategies pioneered small scale can be brought to large scale production
- Side: understand details of capacitive signal induction in readout (first time for small Q)
- Future: 125um well height – Plasma Etching

⇒ Require technological advancements to make high quality detectors





Development of Fast and Sensitive electronics

Single-Stage MPGD have typical gain of 3 · 10^3 – max 10^4.

Assume signal not dispersed over strips, signals of 0.5-1fC

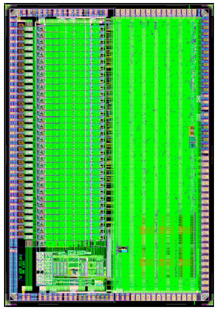
Fast Timing typically done for large signals:

$\sigma_t = \sigma_{noise}$ / dV/dt = t_{rise} / SNR

=> Now bring fast timing to smaller signals. Need very low noise amplifiers

FATIC (130nm Si CMOS)

- 32 channels + 1 test
- Gain: 10mV/fC & 50mV/fC
- ENC: 500e$^-$ @ 15pF
- Rise time: 7.5ns
- Analog: time & Charge
- Digital: TDC (100ps)



Want to develop new version in: AIDA innova

Backup

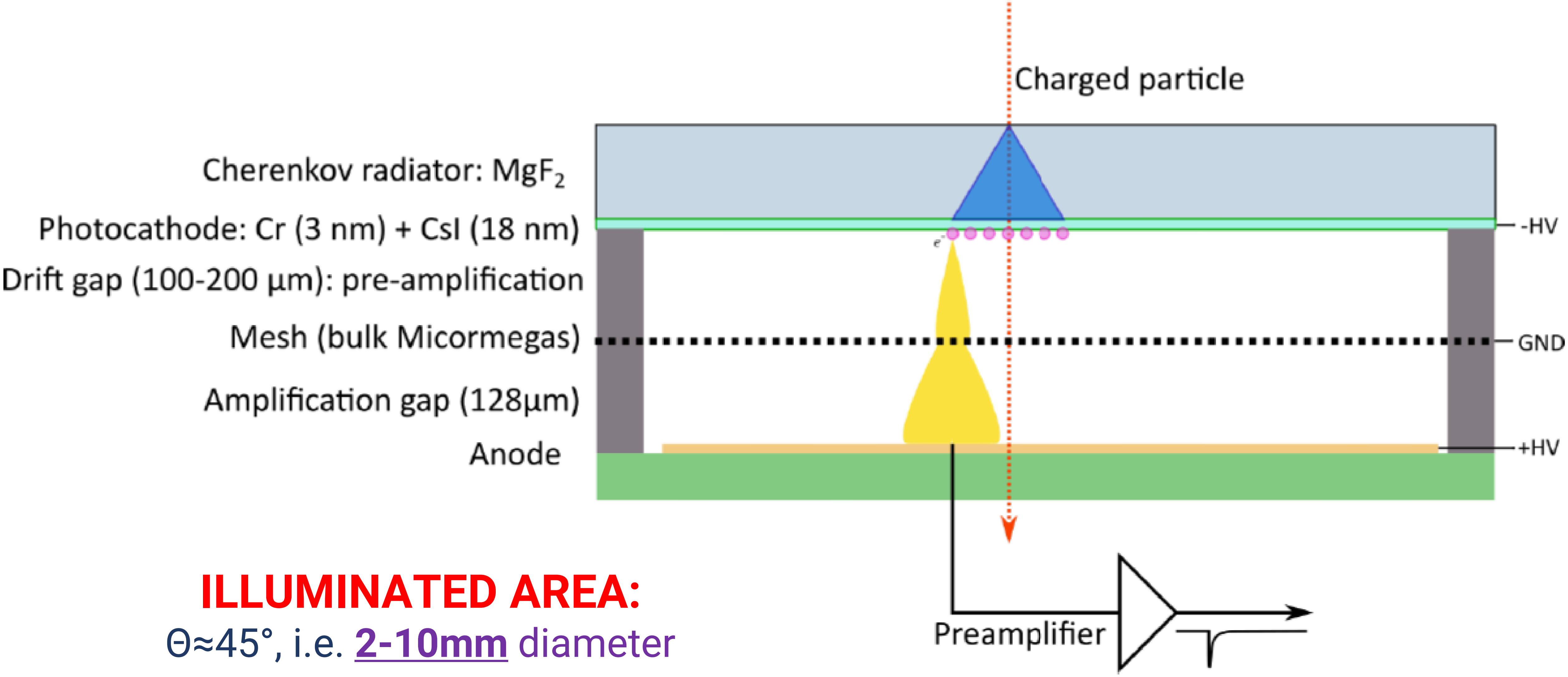
Picosec Micromegas: a fast-timing MPGD for MIP detector in the Muon Collider detector

Davide Fiorina – INFN Pavia

on behalf of the Muon Collider Physics and Detector working group

IFD Workshop, Bari 17-19 Oct

Picosec Micromegas concept

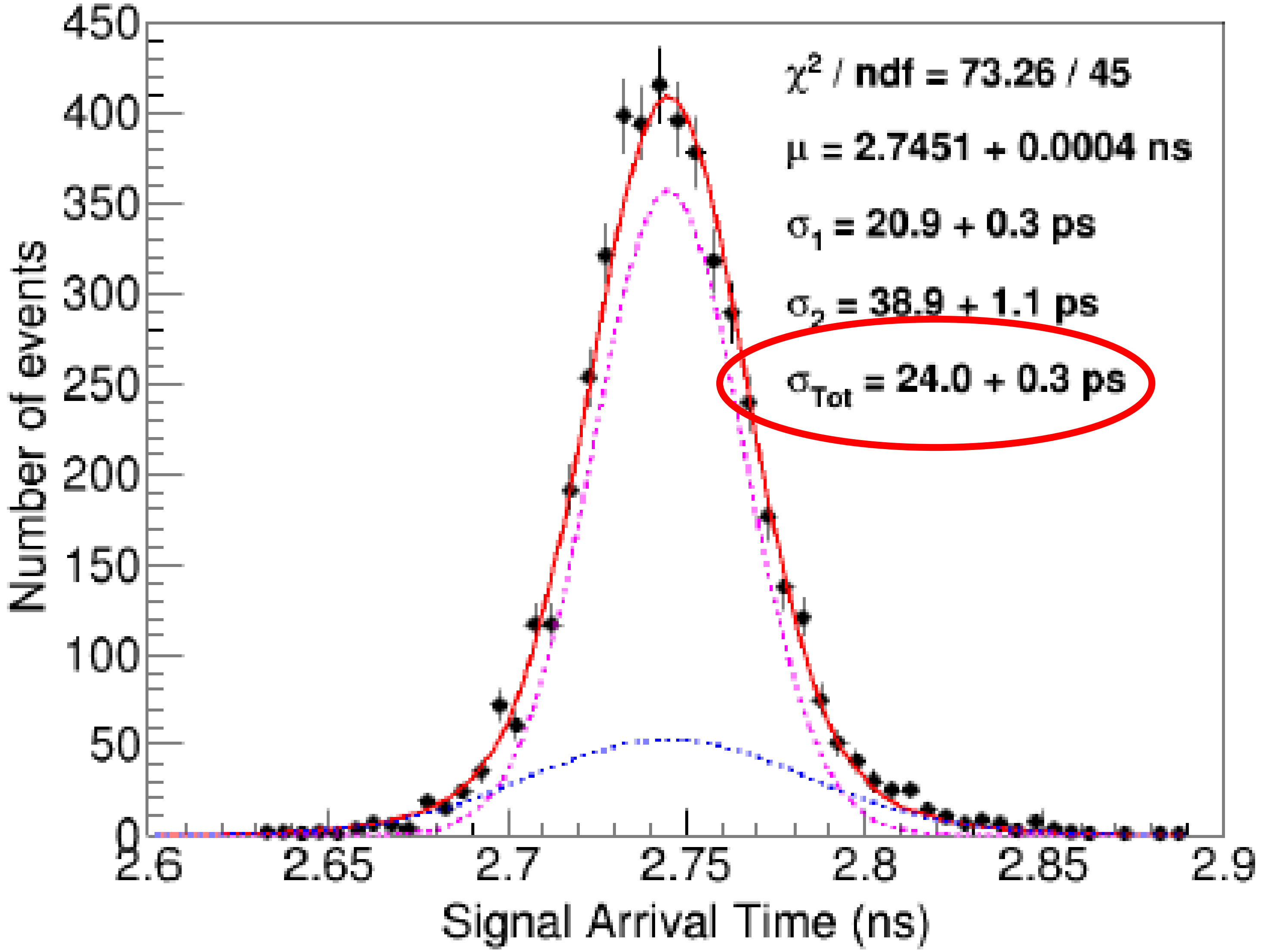


ILLUMINATED AREA:

Θ≈45°, i.e. **2-10mm** diameter

Picosec Micromegas concept

Bortfeldt, J., et al. "PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector."*Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*903 (2018): 317-325.



BASELINE DETECTOR

24ps of time resolution!

Proved on multiple test beams!

Picosec and Muon Collider detector

C.Aime - Muon detectors performance
I.Vai - R&D studies on muon detector
Muon collider collaboration meeting 11,14 Oct 2022

Picosec+MPGD station proposed for the Muon endcap!

Muon tracking and timing

hadronic calorimeter

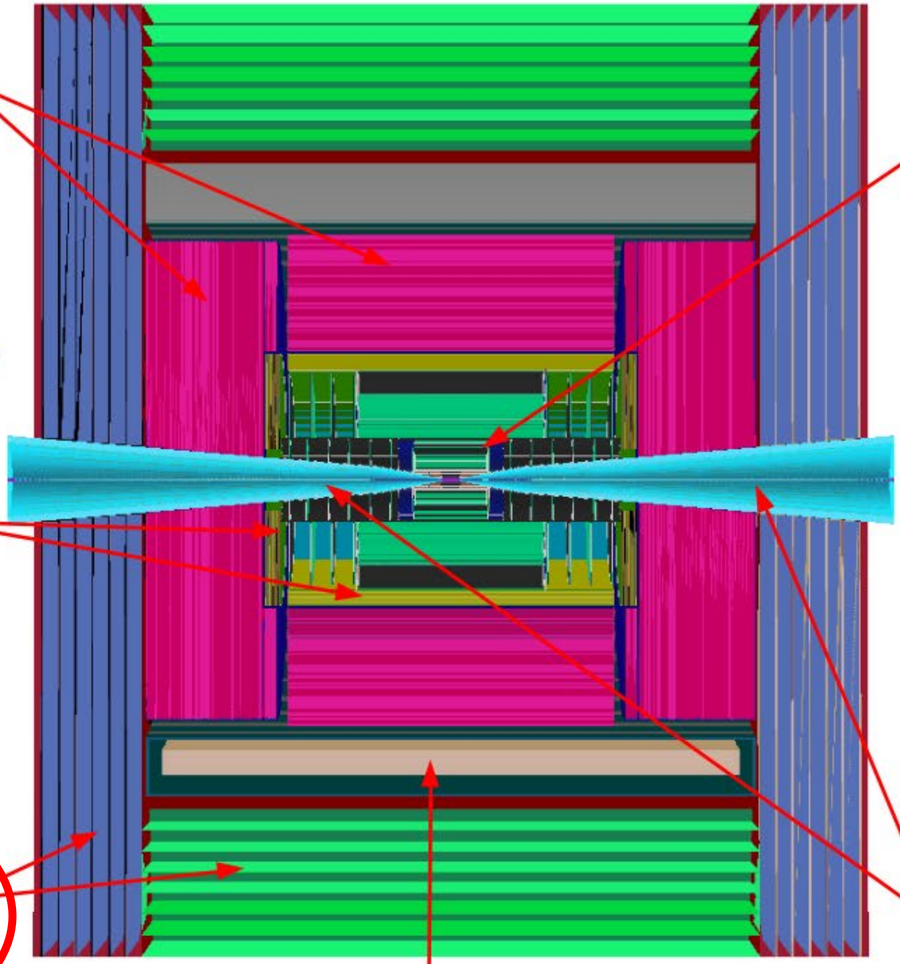
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm^2 cell size;
- 7.5 λ_I.

electromagnetic calorimeter

- 40 layers of 1.9-mm W absorber + silicon pad sensors;
- 5x5 mm^2 cell granularity;
- 22 X_0 + 1 λ_I.

muon detectors

- 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- 30x30 mm^2 cell size.



superconducting solenoid (3.57T)

tracking system

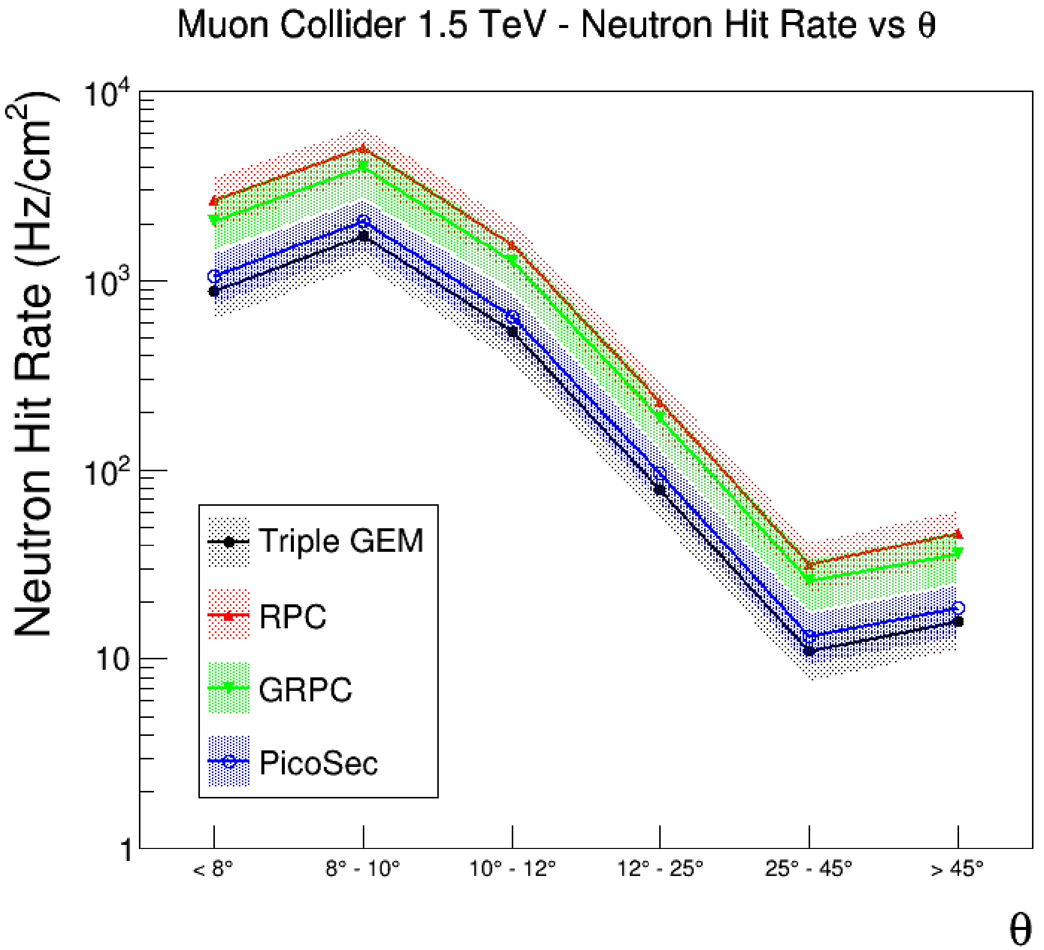
- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 25x25 μm^2 pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 50 µm x 1 mm macro-pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 50 µm x 10 mm micro-strip Si sensors.

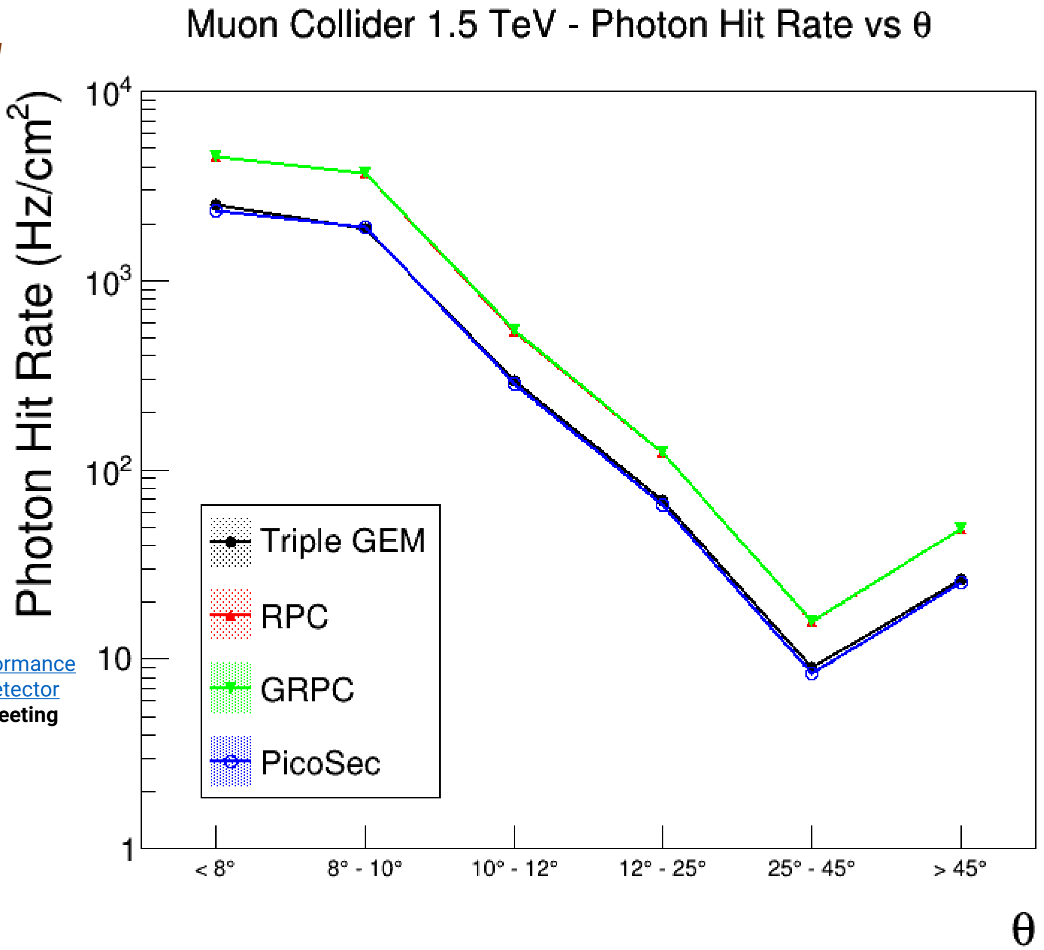
shielding nozzles

- Tungsten cones + borated polyethylene cladding.

Picosec and Muon Collider detector

Simulated Hit rate



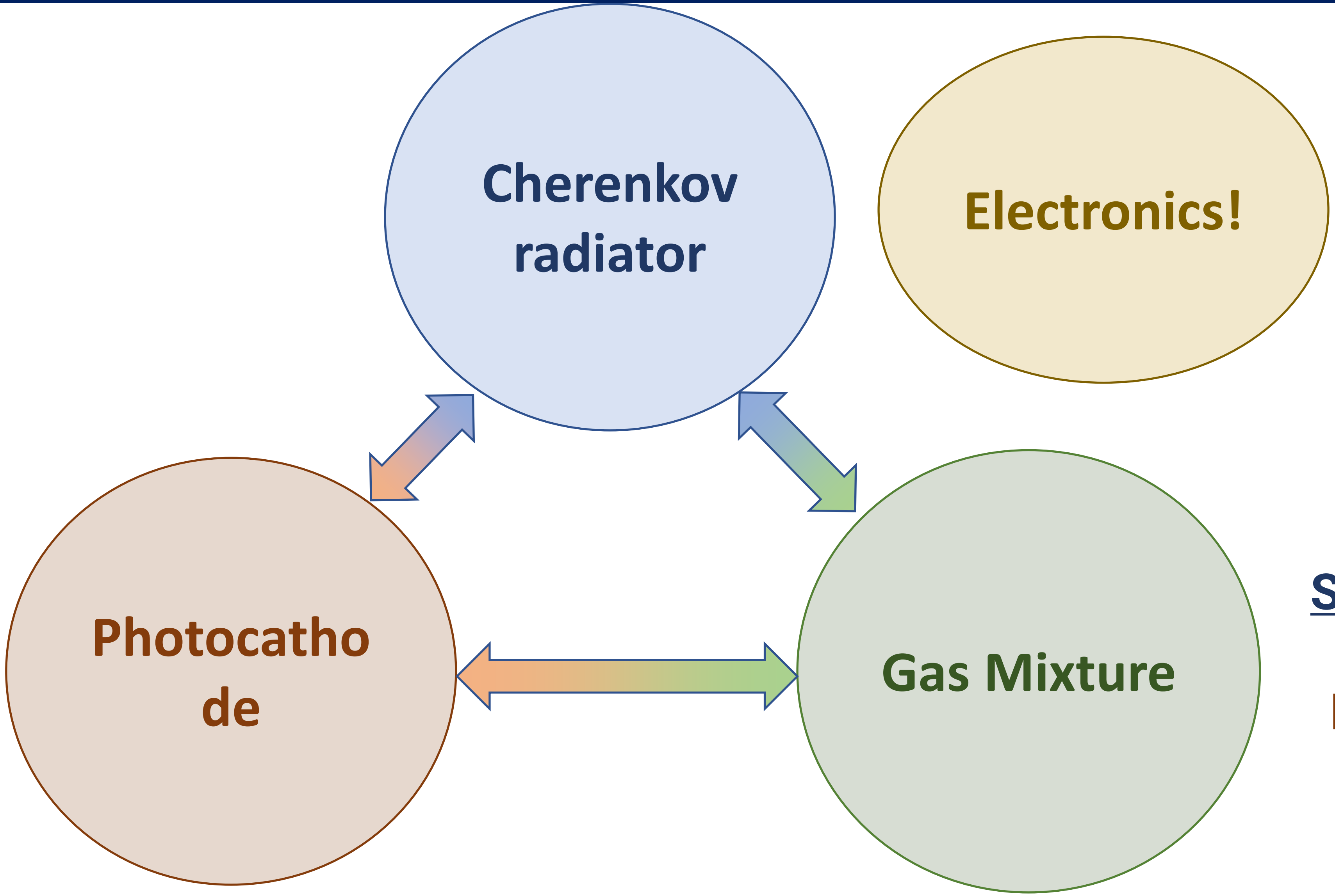


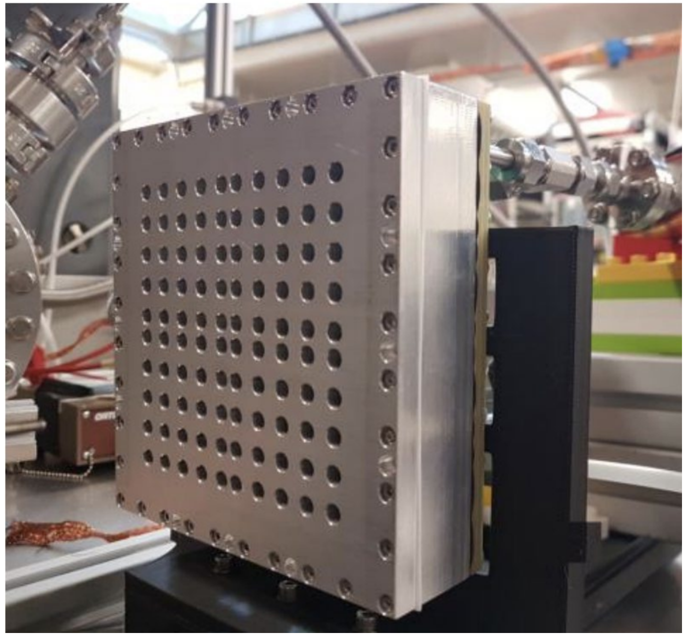
C.Aime - Muon detectors performance
I.Vai - R&D studies on muon detector
Muon collider collaboration meeting
11,14 Oct 2022

Picosec can operate in high-rate environments and give timing information with higher precision wrt other technologies

POTENTIALLY

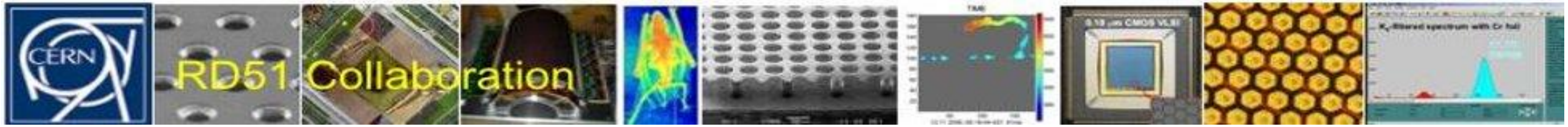
R&D perspective





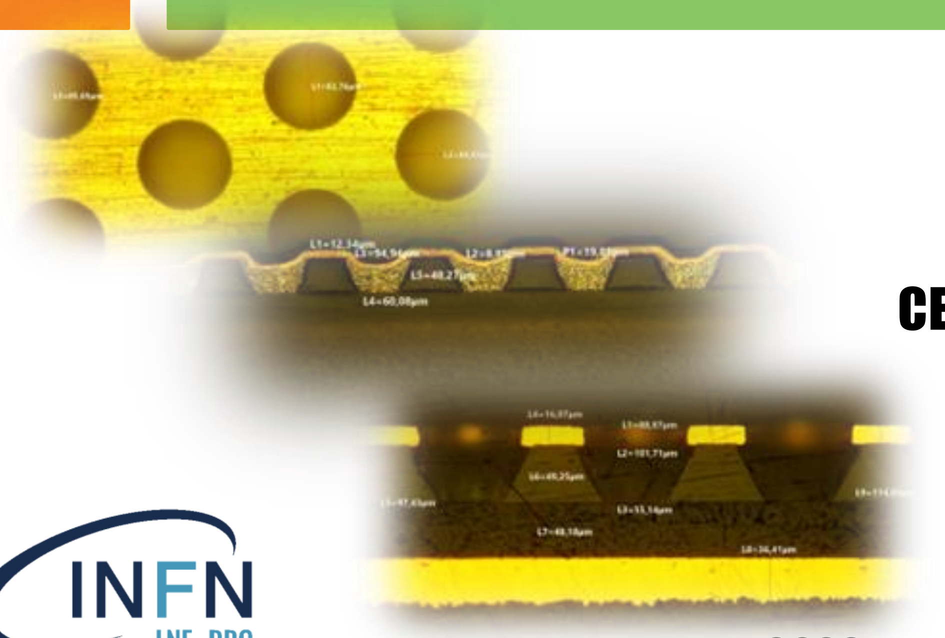
Still, a lot of work to do!

BASELINE DETECTOR engineered up to a 10x10!!!



The micro-RWELL technology:

from the R&D to the technology transfer towards Industry

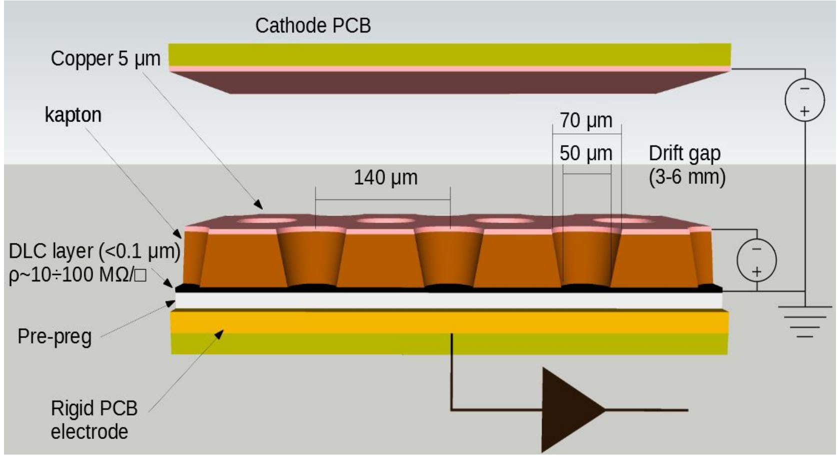


G. Bencivenni
on behalf of
DDG - LNF-INFN
CERN-CH, INFN – Bologna, INFN – Ferrara, ELTOS SpA

IFD2022 – INFN Workshop on Future Detectors, Bari- 17-19 Oct. 2022

The µ-RWELL

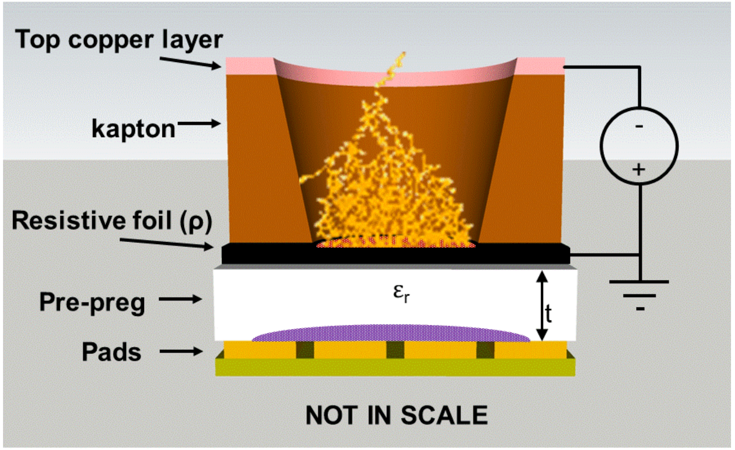
G. Bencivenni et al., The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD, 2015 JINST 10 P02008



The **µ-RWELL** is a **resistive MPGD** composed of two elements:

- **Cathode**
- **µ-RWELL_PCB:**
  - a **WELL** patterned **kapton foil** (w/**Cu-layer on top**) acting as **amplification stage**
  - a **resisitive DLC** layer(*) w/ **ρ~10÷100 MΩ/□**
  - a standard **readout PCB** with **pad/strip** segmentation

(*) DLC foils are currently provided by the Japan Company – BeSputter

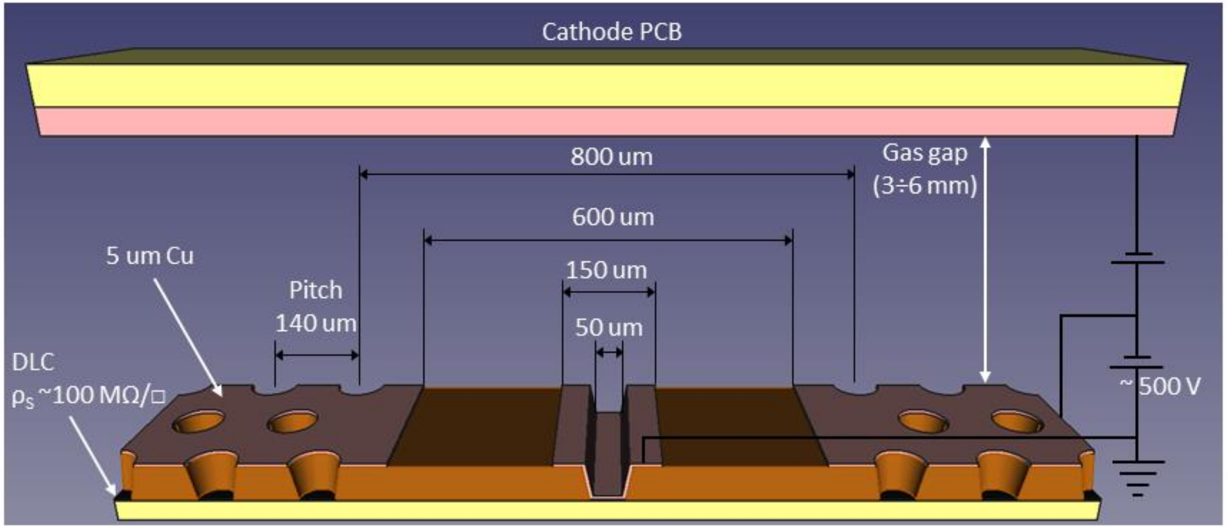


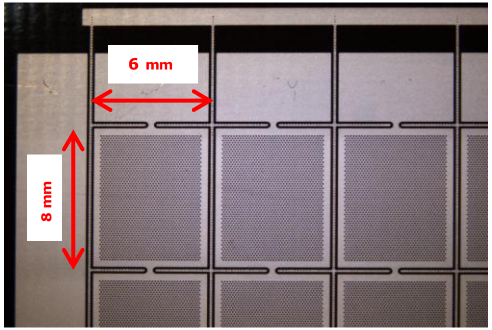
The **"WELL"** acts as a **multiplication channel** for the ionization produced in the drift gas gap.

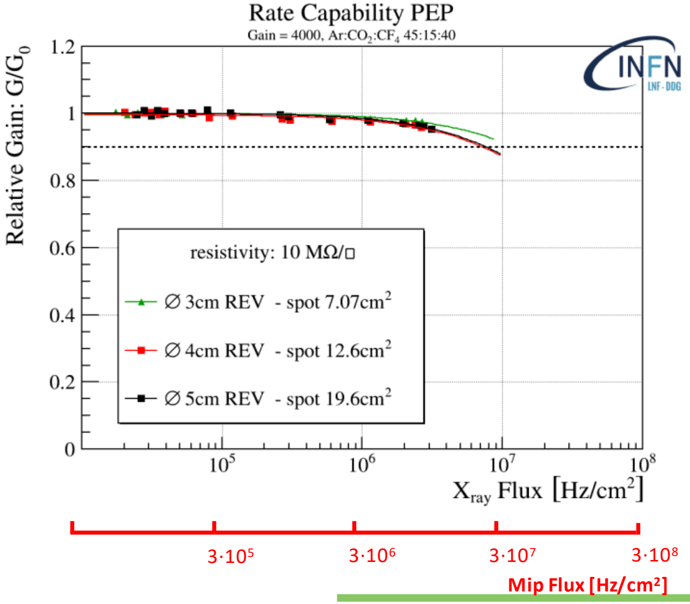
The **resistive stage** ensures the **spark amplitude quenching.**

Drawback: capability to stand high particle fluxes reduced, but **largely recovered** with appropriate **grounding schemes** of the **resistive layer**

The HR layout







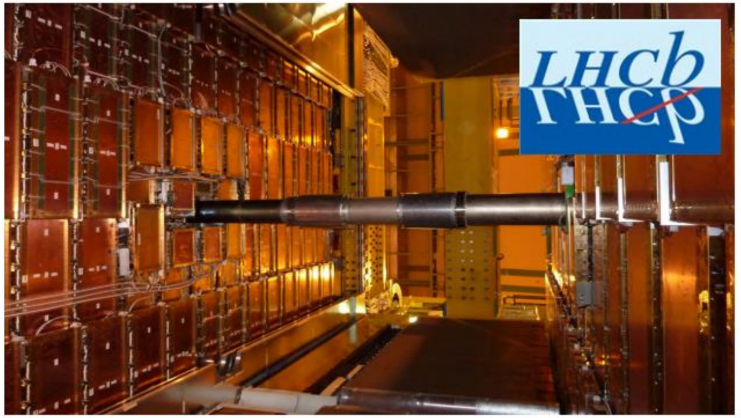
The PEP layout (Patterning – Etching – Plating) is the state of art of the high rate layout of the μ-RWELL

- Single DLC layer
- Grounding line from top by kapton etching and plating (pitch 1/cm)
- No alignment problems
- High rate capability
- **Scalable to large size** (*up to 1.2x0.5 m for the upgrade of CLAS12*)

LHCb upgrade II (Run5 – Run6)

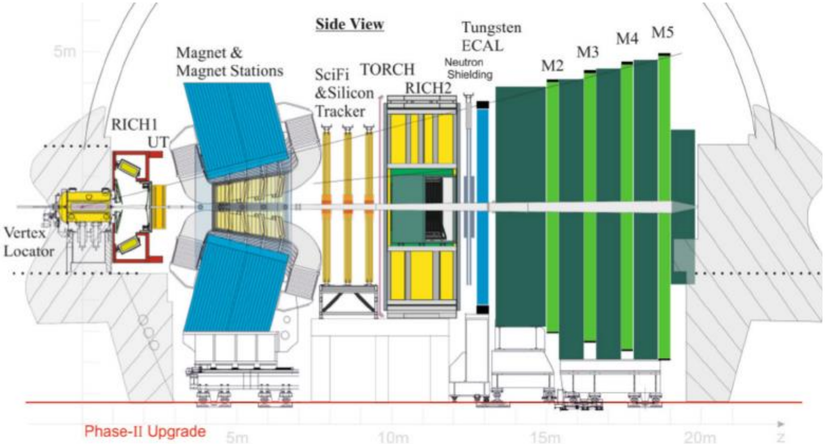
LHCb muon apparatus Run5 – Run6 option detector requirements

- Rate up to **1 MHz/cm²** on detector single gap
- Rate up to **700 kHz** per electronic channel
- Efficiency quadrigap >=99% within a BX (25 ns)
- Stability up to **1C/cm²** accumulated charge in 10 y of operation (M2R1, G=4000)



Detector size & quantity (4 gaps/chamber - redundancy)

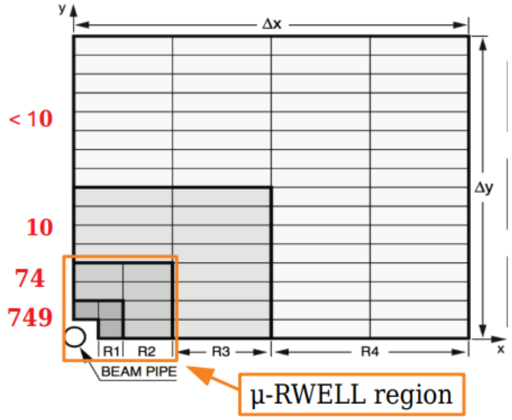
- **R1÷R2: 576 detectors, size 30x25 to 74x31 cm², 90 m² detector (130 m² DLC)**
- ~~R3: 768 detectors, siz 120x25 to 149x31 cm², 290m² det.~~
- ~~R4 : 3072 detectors, size 120x25 to 149x31 cm², 1164 m² det.~~



Rates (kHz/cm²)	M2	M3	M4	M5
R1	749	431	158	134
R2	74	54	23	15
R3	10	6	4	3
R4	8	2	2	2

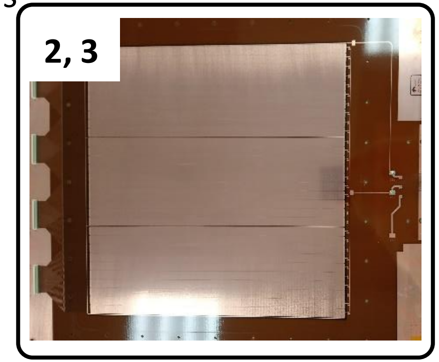
Area (m²)	M2	M3	M4	M5
R1	0.9	1.0	1.2	1.4
R2	3.6	4.2	4.9	5.5
R3	14.4	16.8	19.3	22.2
R4	57.6	67.4	77.4	88.7

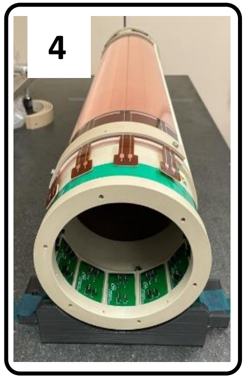
M2 station - max rate (kHz/cm²)

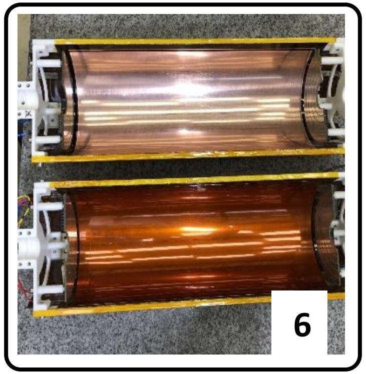


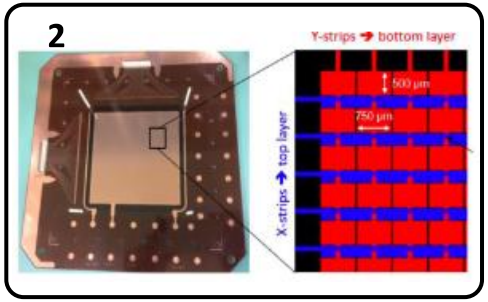
µ-RWELL in HEP/NP & beyond

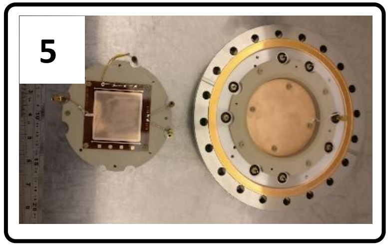
1. **FCC-ee**: pre-shower & muon systems of the IDEA apparatus → *large area (~4000m^2) to be instrumented w/tracking detectors*
2. **CLAS12 @ JLAB:** upgrade of the muon spectrometer → *large area (1.2x0.5m^2) low-mass tracking detectors*
3. **X17 @ n_TOF EAR2**: small -TPC for the detection of the X17 boson → *low mass tracking detectors*
4. **EURIZON**: R&D on IT based on cylindrical micro-RWELL for a SCTF → *low mass tracking detectors*
5. **UKRI:** thermal neutron detection with pressurized ^{3}He-CF4 gas mixtures → *neutron tracking device*
6. **TACTIC @ YORK Univ.:** radial TPC for nuclear reactions w/astrophysical significance → *low mass flexible tracking detectors*
7. **URANIA-V**: funded by CSN5 for neutron detection → *large pad (10x10cm^2) tile detectors for radiation portal monitor*
8. **Muon collider:** HCAL R&D → *pad tile detectors*

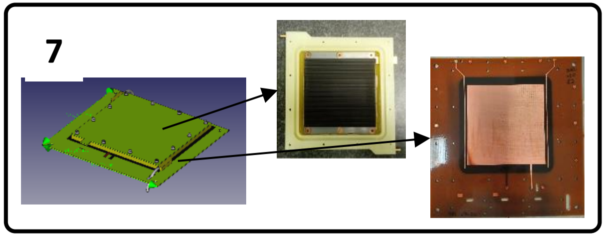












Technology transfer (I)

layout design

INFN LNF Istituto Nazionale di Fisica Nucleare

μ-RWELL technology transfer

AIDA innova EU-project

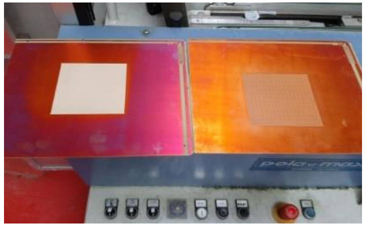
ELTOS

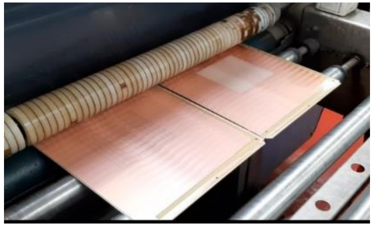
DLC sputtering know-how

DCL foil production (*)

CERN INFN Istituto Nazionale di Fisica Nucleare

PCB production





PCB shipping

CERN

Detector manufacturing

μ-RWELL_PCB shipping

*DLC Magnetron Sputtering machine co-funded by INFN-CSN1

Technology transfer (II)

Step 0 - Detector PCB design @ **LNF**

Step 1 - CERN_INFN DLC sputtering machine @ **CERN (+INFN)**

- delivery foreseen by the end of Oct. 2022
- **INFN** crew tbd & trained

Step 2- Producing readout PCB by **ELTOS**

- pad/strip readout

Step 3 - DLC patterning by **ELTOS**

- photo-resist $\oplus$ patterning with BRUSHING-machine

Step 4 - DLC foil gluing on PCB by **ELTOS**

- double 106-prepreg ~2x50µm thick
- PCB planarizing w/ screen printed epoxy $\oplus$ single 106-prepreg

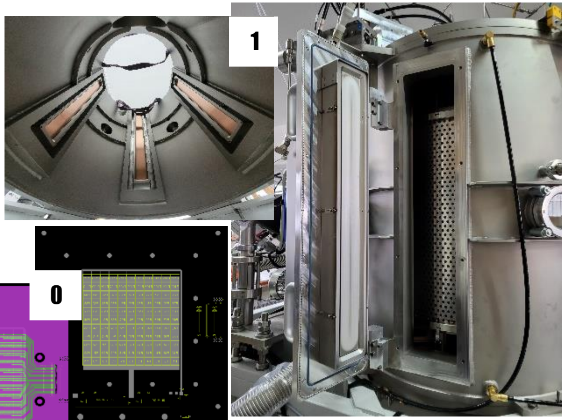
Step 5 - Top copper patterning by **CERN** (in future by **ELTOS)**

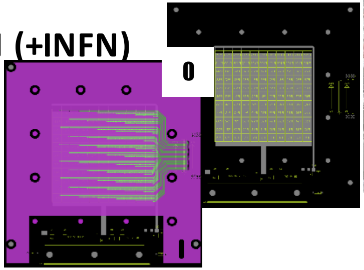
- Holes image and HV connections by Cu etching

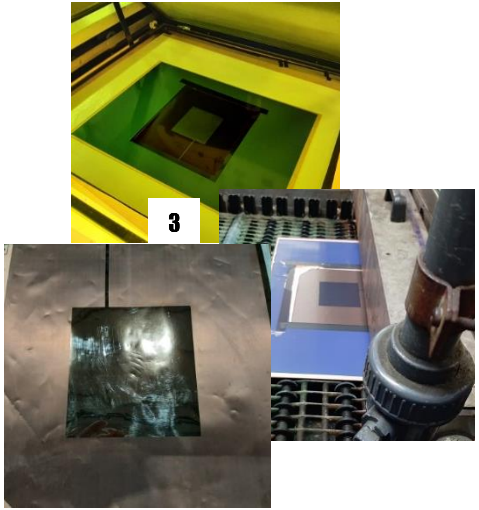
Step 6 - Amplification stage patterning by **CERN**

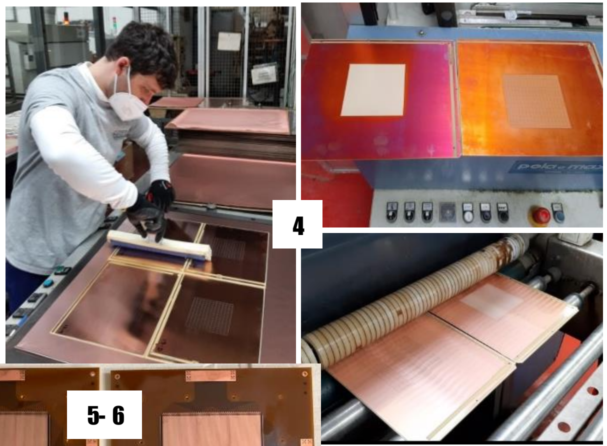
- PI etching $\oplus$ plating $\oplus$ ampl-holes

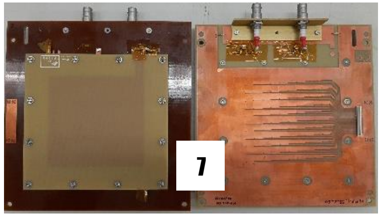
Step 7 – Electrical cleaning and detector closing @ **CERN**

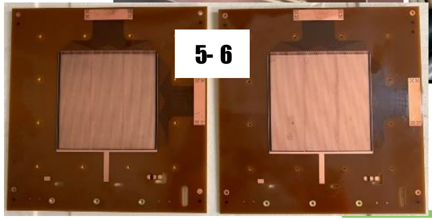








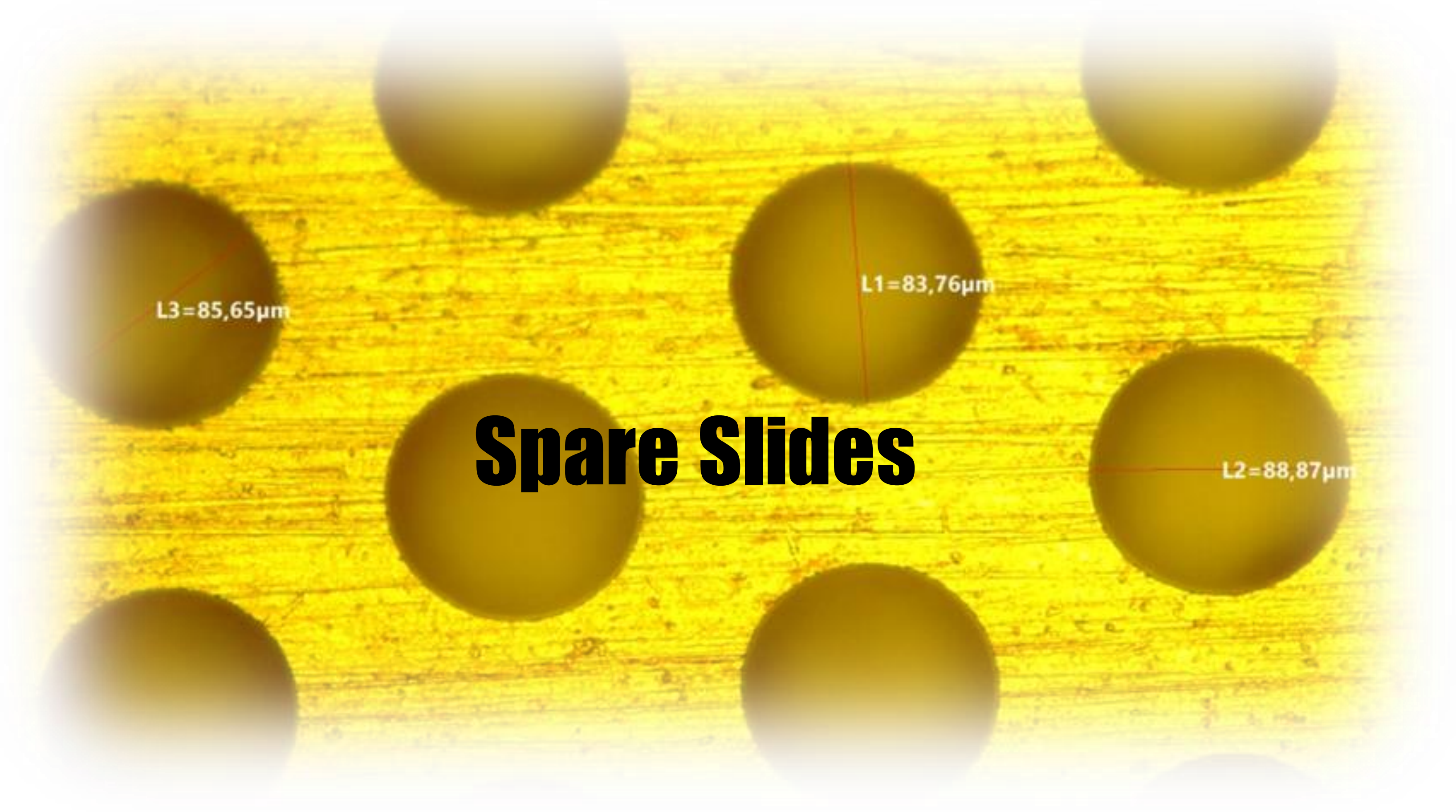




Summary

- The **driving force** behind the development of the **resistive MPGDs** is the **spark quenching** and **charge spreading** technique to optimize readout plane
- **DLC coatings** opened the way to develop new detector structures.
  The **μ-RWELL** is one of the examples of **emerging MPGD** technologies that are evolving and profiting from the on-going developments on DLC
- The challenge for the next years is the **TT of resistive-MPGD technology** to PCB industry
- **Key-point of the industrialization** has been the acquisition of a **DLC magnetron sputtering machine co-funded by CERN and INFN** that will enter in operation in 2023
- Other items that still need to be investigated:
  - **2D strip readout** → 2D w/top readout, 2D with capacitive sharing
  - **Global irradiation** (GIF, X-ray tube, Calliope source)
  - **Eco-gas fast mixtures** (*essentially for LHCb*)
  - **APV25** is a user-friendly electronics for testing MPGD.
    The **Bari group** (*G. De Robertis, F. Iaciulli, F. Loddo*) is developing a new ASIC **(FATIC)** that will be tested for the μ-RWELL (LHCb)
- **Sinergy** among **different groups** working on different resistive MPGD technologies (μ-RWELL/MM) for common tooling (DLC machine) should be promoted for the development of **high-performance hybrid structures**

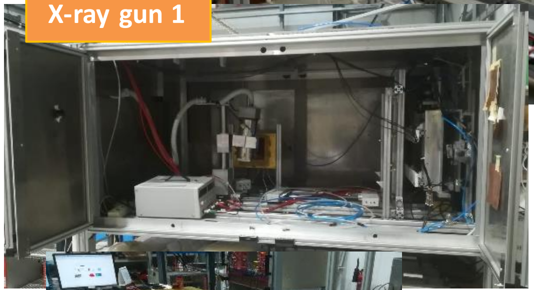
Spare Slides



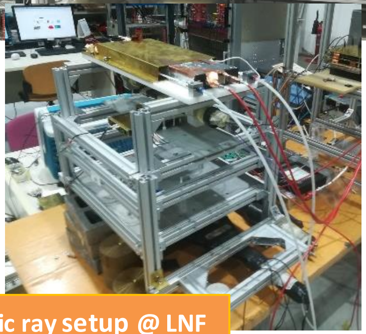
Test facilities

X-ray setup @ LNF

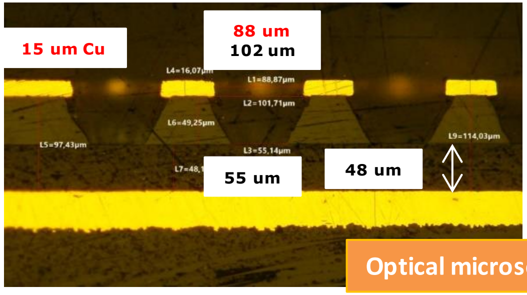
X-ray gun 1



X-ray gun 2

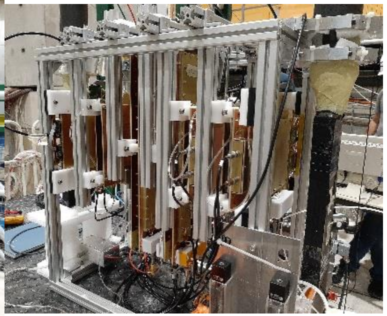


Cosmic ray setup @ LNF



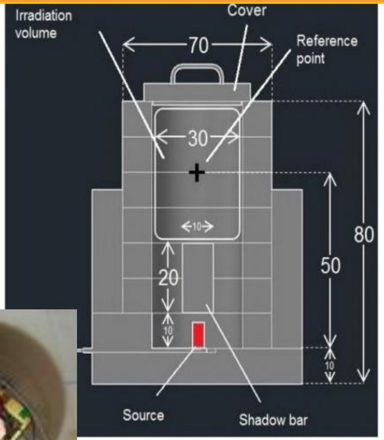
Optical microscope survey

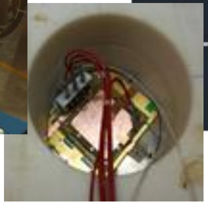
CERN – SpS H8C



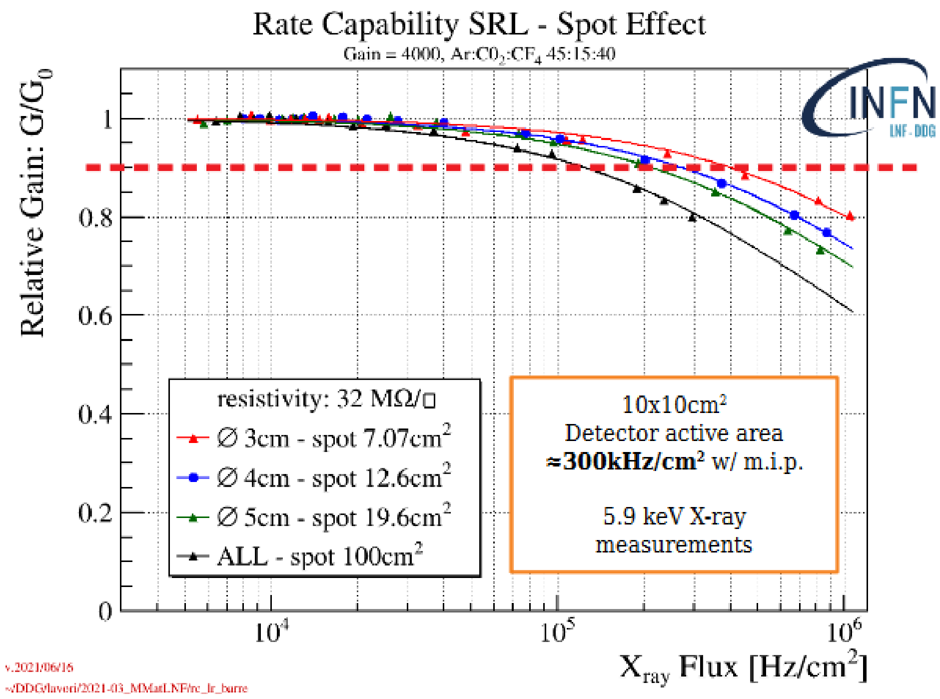
PSI – π-M1

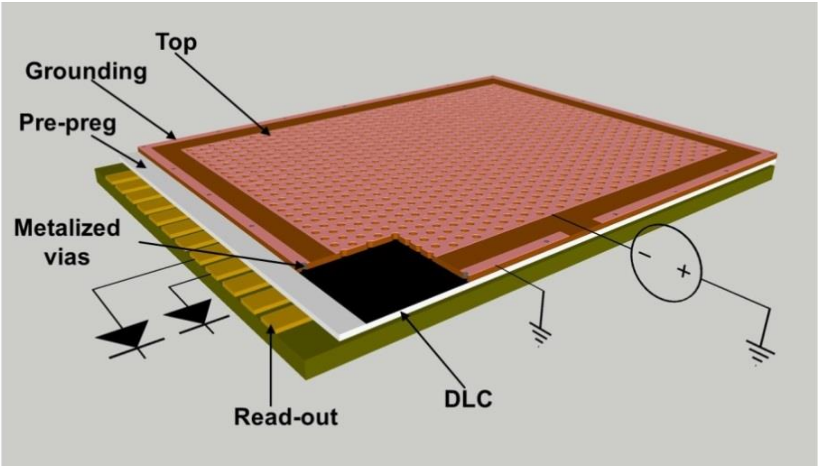
ENEA HOTNES thermal neutron facility





The low-rate layout

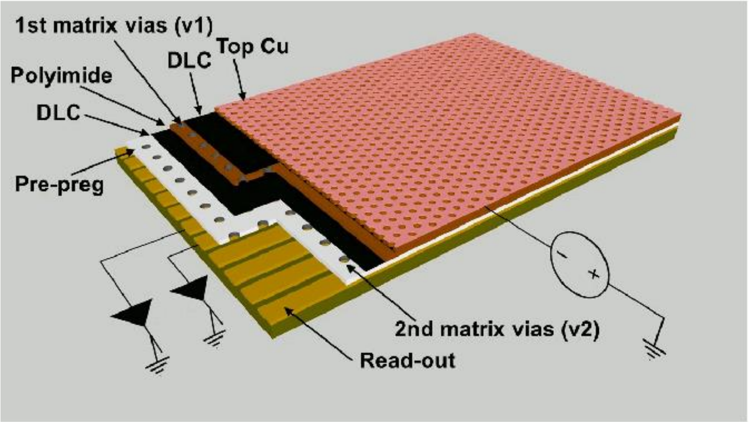




Single Resistive Layer (SRL)

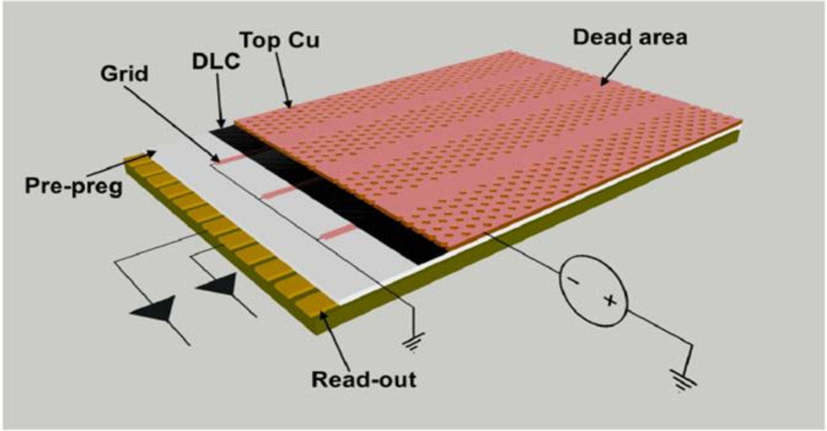
- **2-D current evacuation** scheme based on a single resistive layer
- **grounding** around the **perimeter** of the active area
- **limited rate capability <100 kHz/cm²**

High-rate layouts



Double Resistive Layer

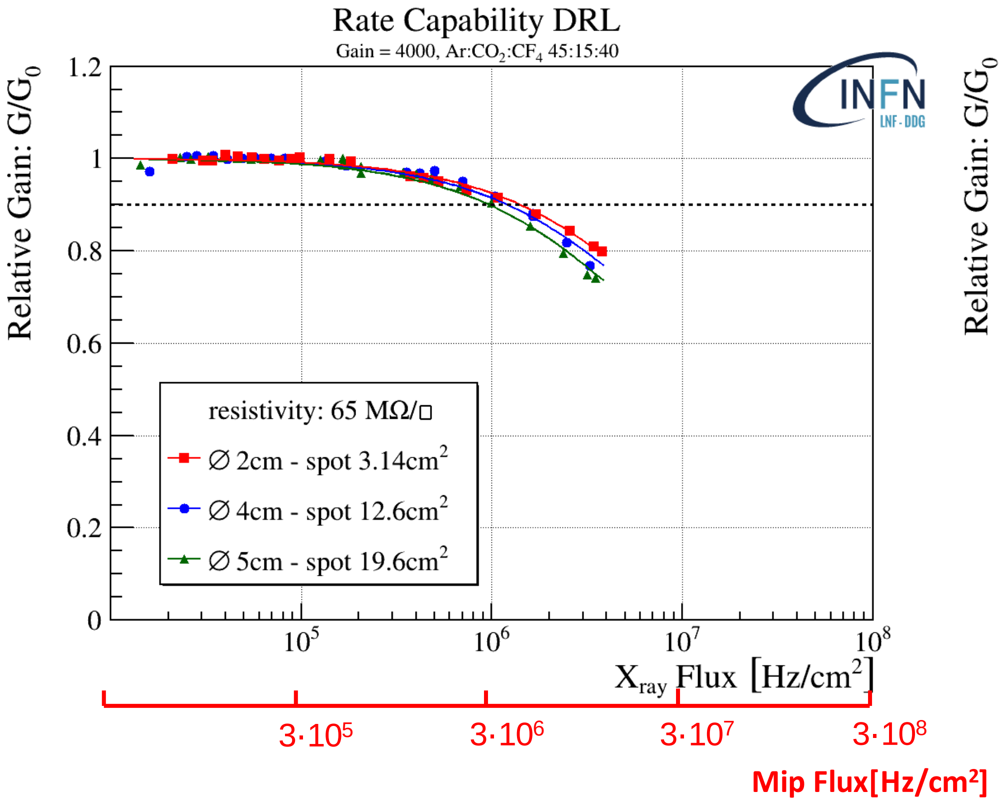
- **3-D current evacuation** scheme
- two stacked resistive layers connected through a matrix of conductive vias
- Resistive stage grounding through a further matrix of vias to the underlying readout electrodes
- pitch of the vias with a density less than 1/cm^2

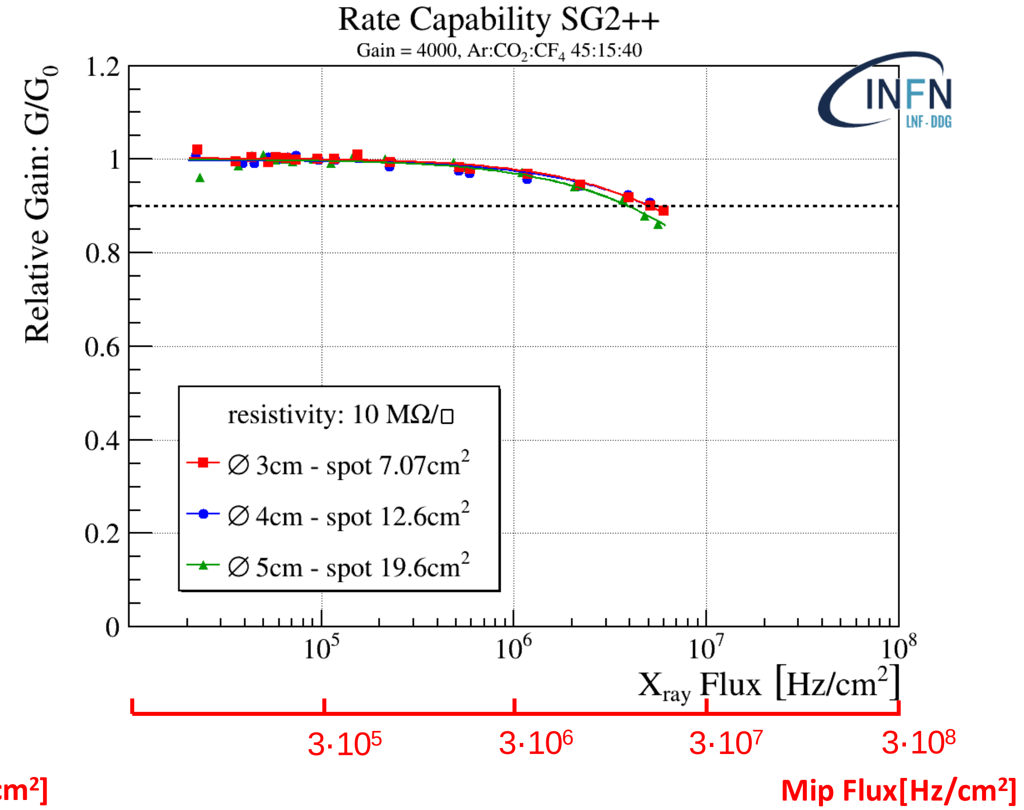


The Silver Grid

- simplified HR scheme based on SRL
- **2-D evacuation scheme** by means a conductive grid realized on the DLC layer
- grid lines can be screen-printed or etched by photo-lithography
- pitch of the grid lines of the order of 1/cm

High-rate layouts: performance w/X-rays

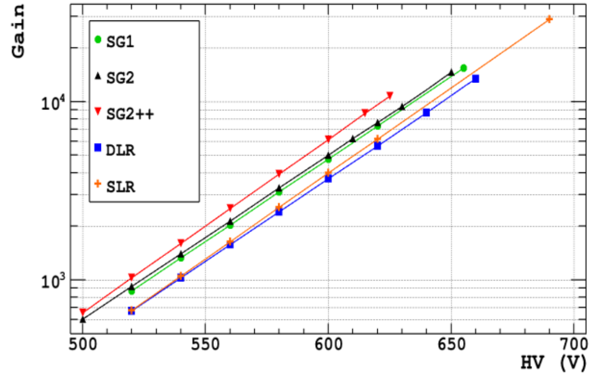




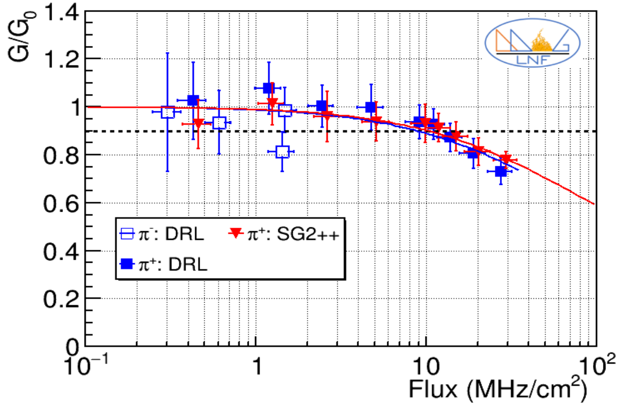
Rate capability w/m.i.p. ~ 3 times X-rays

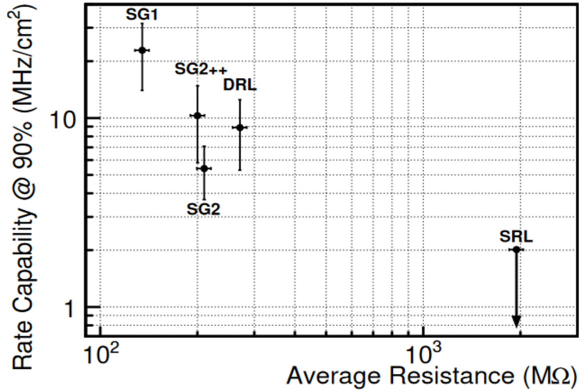
High-rate layouts performance w/m.i.p.

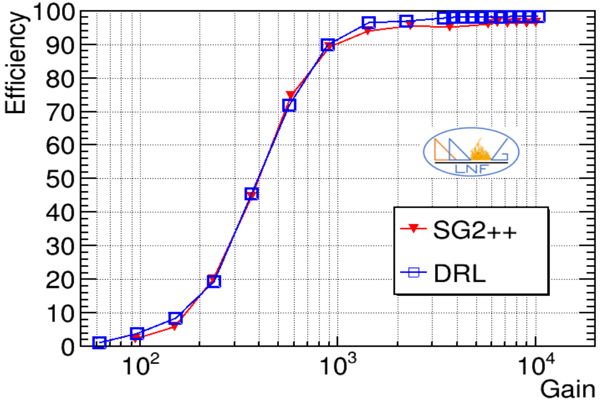
Gain up to ~10^4



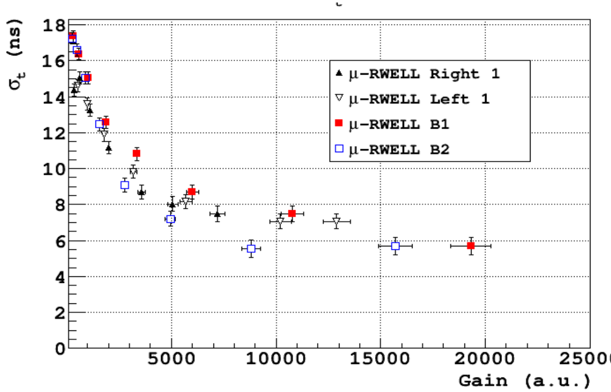
Rate capability up to 10 –20 MHz/cm^2



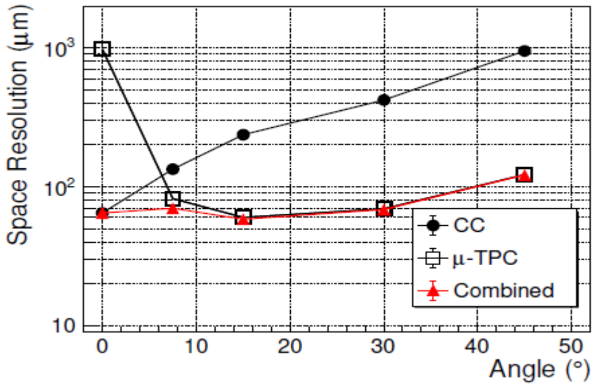




Efficiency ~97%



Time resolution 5-6 ns



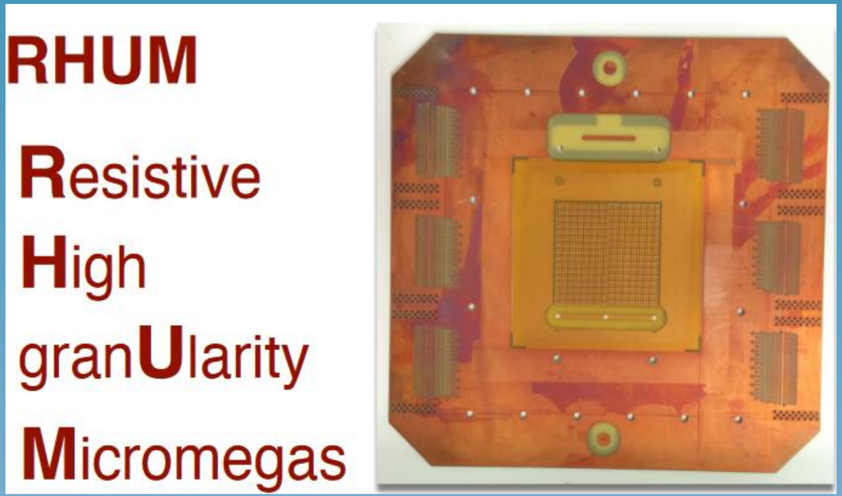
Space resolution down to 60 μm

The micro-RWELL layouts for high particle rate, G. Bencivenni et al., 2019_JINST_14_P05014

CID: the CERN-INFN DLC machine

… some infos extract from the machine Contract

- The machine shall be able to coat **flexible substrates** with areas of **up to 1.7 m × 0.6 m**
- The machine shall be able to coat **rigid substrates** with areas of up to **0.2 m × 0.6 m**
- **Five cooled target holders,** arranged as two pairs face to face and one on the front, equipped with five shutters
- The machine shall be able to **sputter or co-sputter different materials,** in order to create a coating layer by layer or an adjustable gradient in the coating
- The Contractor shall provide **training for the CERN-INFN personnel** concerned, at the CERN site. The aim of the training course is to ensure that personnel is able to:
    - Program and pilot the process with the machine
    - Conduct a failure analysis on the machine



Joint project of INFN Napoli and Roma Tre

New Resistive Micromegas structures for future detectors

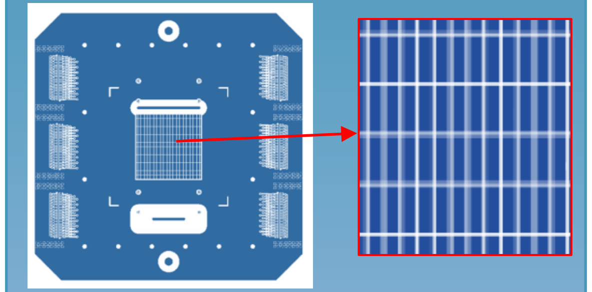
M.T. Camerlingo[1], M. Alviggi[1,2], M. Biglietti[3], M. Della Pietra[1,2], C. Di Donato[1,4], R. Di Nardo[3,5], P. Iengo[1], M. Iodice[3], F. Petrucci[3,5], G. Sekhianidze[1], M. Sessa[3,5]

1 INFN Napoli
2 Univ. di Napoli «Federico II»
3 INFN Roma Tre
4 Univ. di Napoli «Parthenope»
5 Univ. Roma Tre

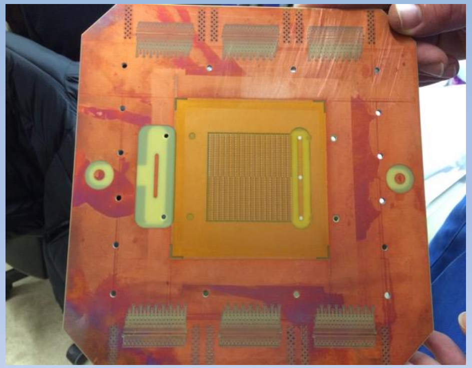
IFD2022: 17-19 October 2022

Small-Pad resistive Micromegas detectors

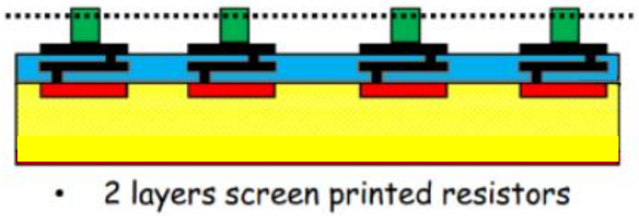
PIXELATED ANODIC PLANE



Pixelated readout:
5x5 cm^2 anodic plane,
pads of **0.8 x 2.8 mm^2**

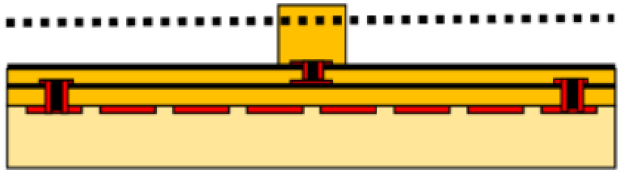


Resistive spark protection schemes



- **PAD-P**:
  micro-mesh (dot line) + pillars (green)
  Embedded pad resistors (black)
  Coverlay insulator (blue)
  Copper readout pads (red) on PCB (yellow)
  O(10) MΩ resistance btw top pad resistor and ground;

Ref [1] Construction and test of a small-pad resistive Micromegas prototype (https://iopscience.iop.org/article/10.1088/1748-0221/13/11/P11019)



- **DLC-like** (Diamond-Like-Carbon)
  micro-mesh (dot line) + pillars (orange)
  DLC foils with 20-50 MΩ/sq (black)
  Polymide insulator (orange);
  6-12 mm vias pitch side;
  Copper readout pads (red) on PCB (beige)

Ref. [2] Alviggi et al. - NIM Research Sec. A, Vol. 936, 21 Aug 2019, pp 408-411 (https://doi.org/10.1016/j.nima.2018.10.052)

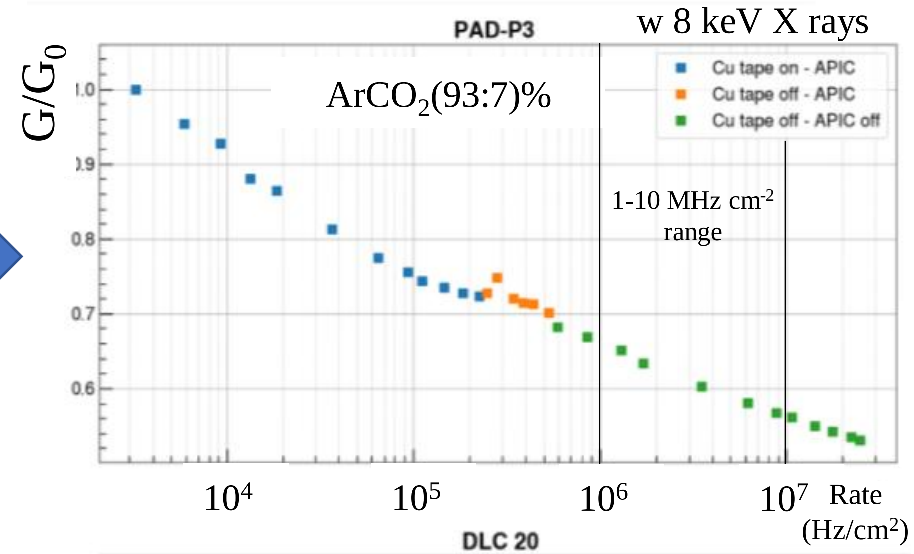
Studies of rate capability

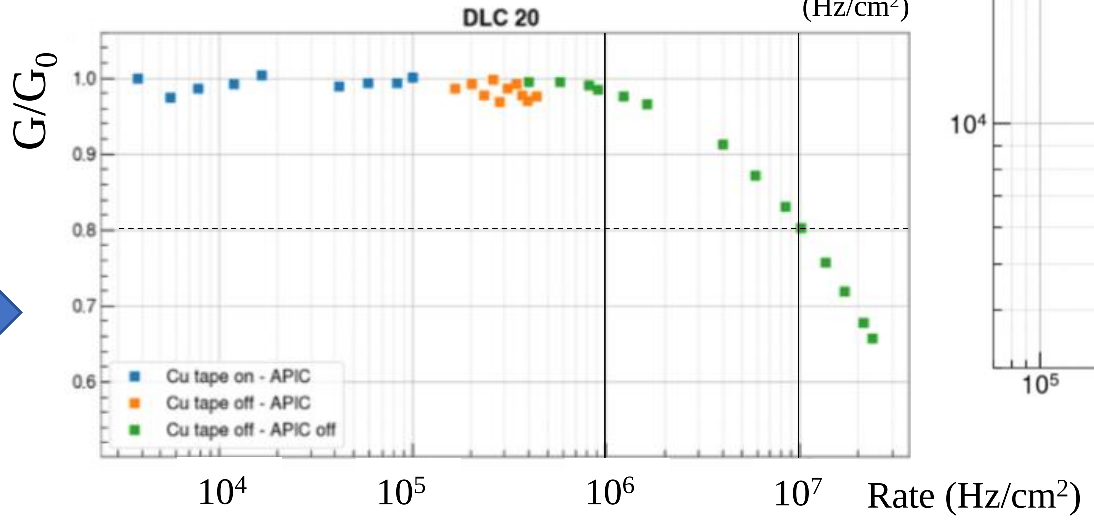
PAD-P scheme

- Relatively fast loss for rate < 0.1 MHz/cm^2 due to charging-up;
- Slower ohmic voltage drop through the individual pads at higher rates;

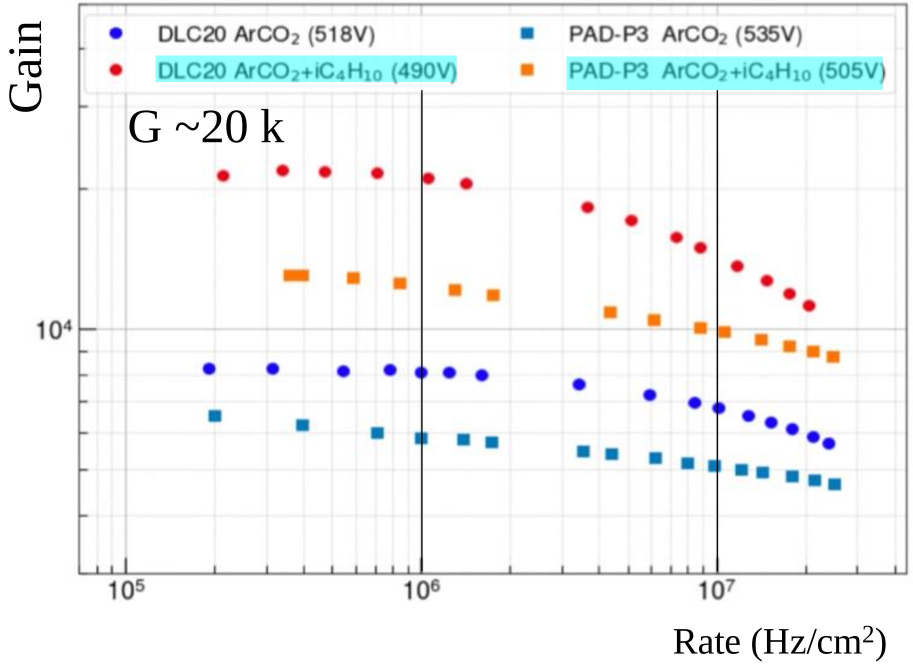
DLC-like scheme

- Negligible charging-up effects.
- Gain stable up to 1-2 MHz/cm^2, and at higher rates, gain drop due to ohmic contribution.
- At 10 MHz/cm^2, gain drop of ~20%



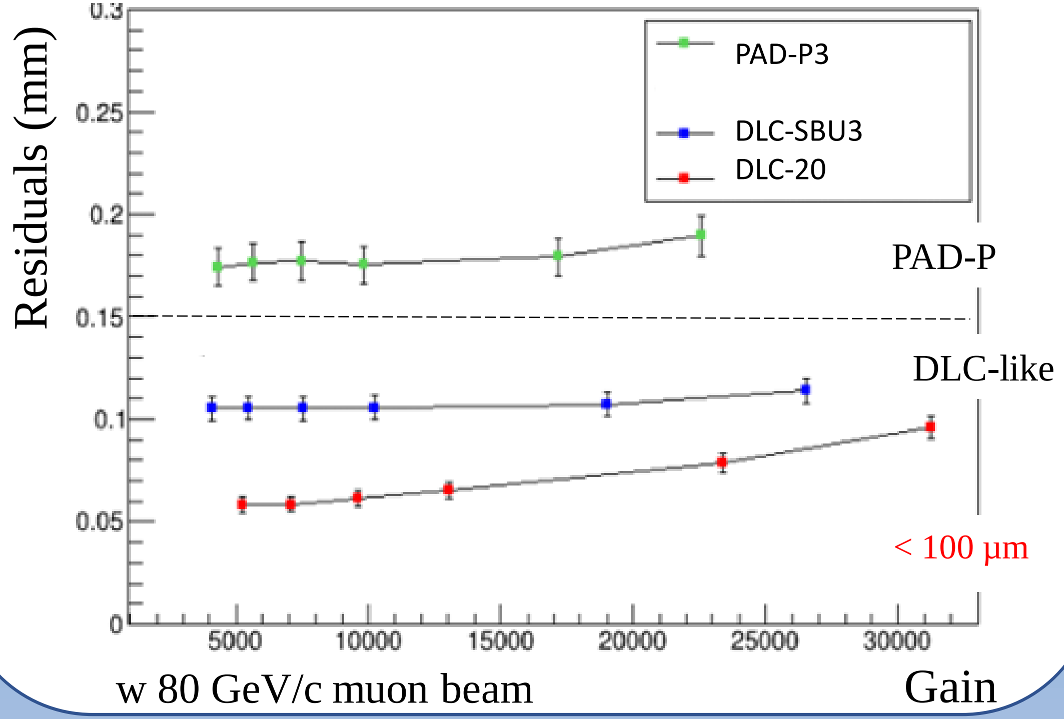


With the two mixtures, we observed compatible drops, **$ArCO_2iC_4H_{10}$(93:5:2)%** lets to work at a **higher gain** and to a **larger spark quenching.**



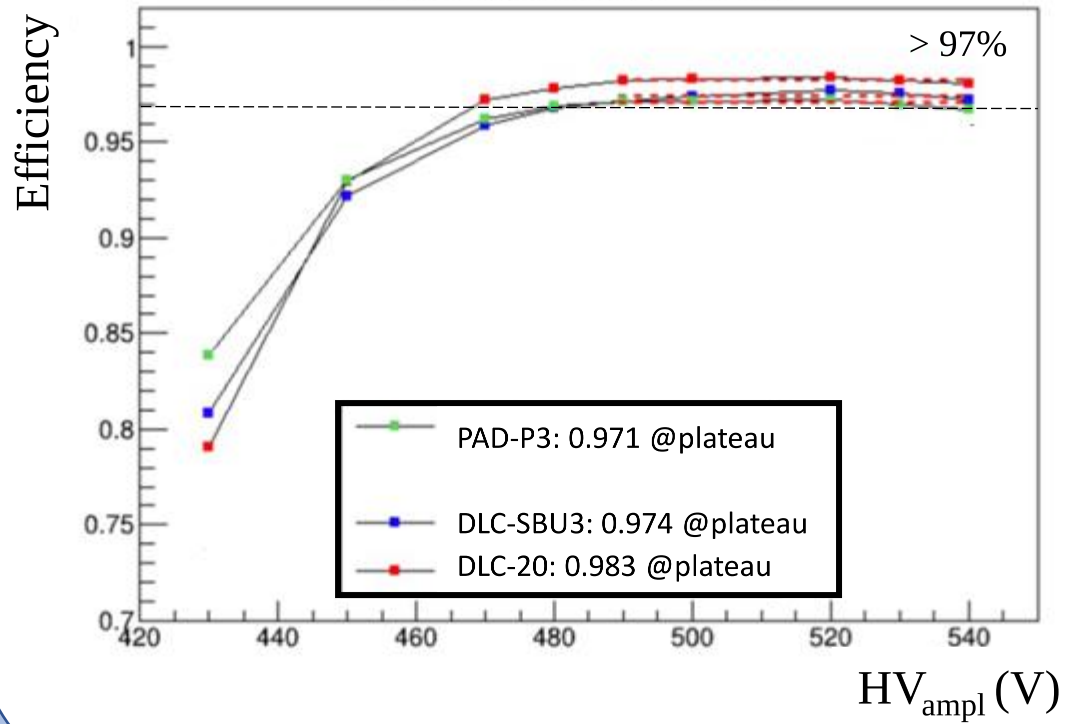
Studies of tracking performances ($ArCO_2iC_4H_{10}$(93:5:2)%)

Spatial resolution (along pad short side)



Tracking efficiency

based on cluster search within 1.5 mm fiducial range along the extropated track position in the pad short side



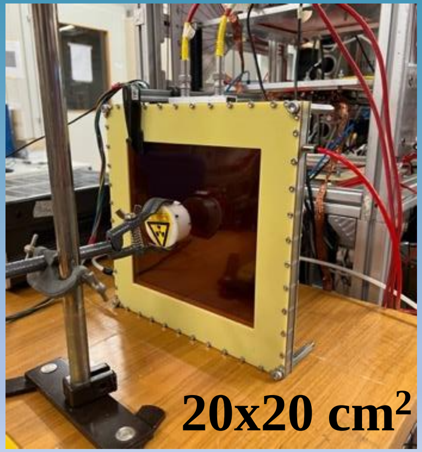
On going studies of **time resolution:**

with the investigated gas mixtures and APV25 FE chips, detectors have similar time performances (O(10 ns)). To improve

- «Faster» gas mixtures (with a small fraction of CF_4);
- New FE chips as VMM, tiger, fatic (in touch with the respective groups).

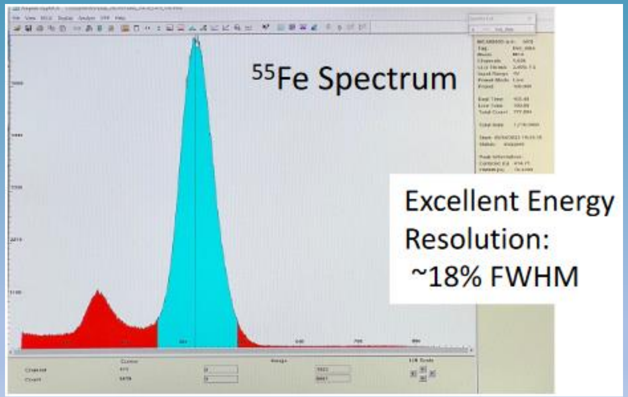
plots from Master thesis of C. Gimmillaro (Univ. Roma Tre)

Towards large areas

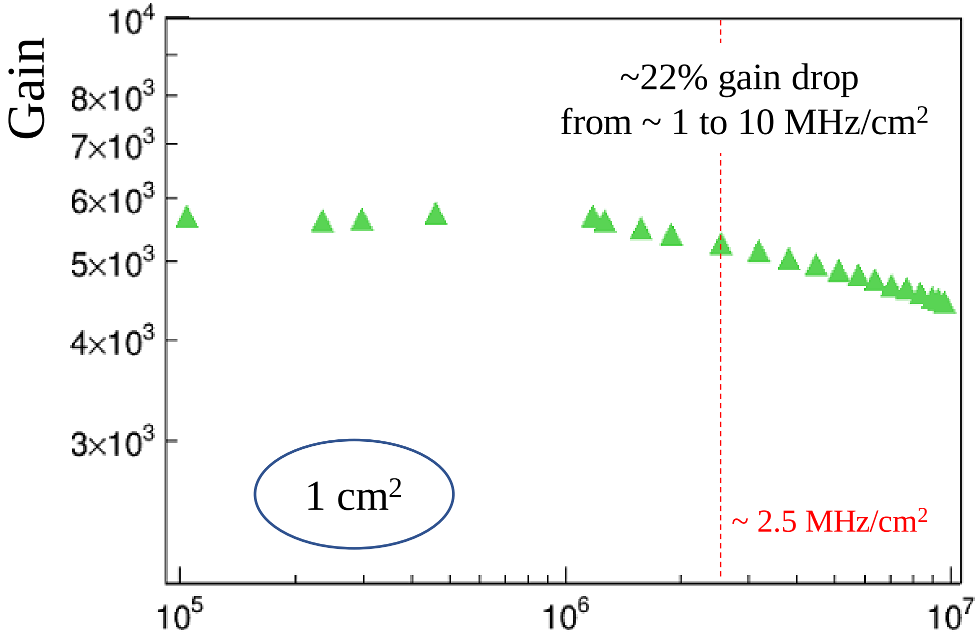


- **Pad size:** 1x8 mm^2
- **Number of Pads:** 4800
- **DLC-like layout** w 8 mm grounding vias pitch
- FE connectors on the back of the detector (partial readout)

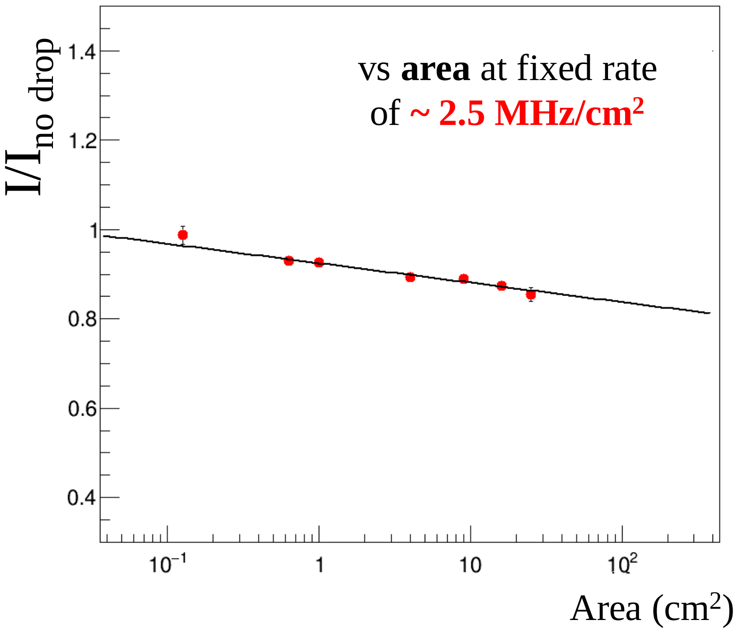
Tomorrow in TB



Repeated gain/rate capability studies with $ArCO_2$(93:7)%, varying irradiated area up to 25 cm^2 max area until now.



Area dependence tends to saturate,



as already observed for smaller areas in previous study
https://indico.cern.ch/event/868940/contributions/3813865

Conclusions

The results show that small-Pad resistive Micromegas:

are **excellent candidates for particle tracking and trigger operation** up to rate O(1-10 MHz cm^{-2}) with

- **stable HV behaviour,**
- **O(100 um) spatial resolution;**
- **O(10 ns) time resolution**

reached a consolidated constructive techniques for large area detectors, in touch with ELTOS company for the technological transfer

Optical Readout TPC for low energy event tracking

F.D.Amaro, E.Baracchini, L.Benussi, S.Bianco, C.Capoccia, M.Caponero, D.S.Cardoso, G.Cavoto, A.Cortez, I.A.Costa, R.J.d.C.Roque, E.Dané, G.Dho, F.Di Giambattista, E.Di Marco, G.Grilli di Cortona, G.D'Imperio, F.Iacoangeli, H.P.Lima Júnior, G.S.Pinheiro Lopes, A.d.S.Lopes Júnior, G.Maccarrone, R.D.P.Mano, M.Marafini, R.R.Marcelo Gregorio, D.J.G.Marques, G.Mazzitelli, A.G.McLean, A.Messina, C.M.Bernardes Monteiro, R.A.Nobrega, I.F.Pains, E.Paoletti, L.Passamonti, S.Pelosi, F.Petrucci, S.Piacentini, D.Piccolo, D.Pierluigi, D.Pinci, A.Prajapati, F.Renga, F.Rosatelli, A.Russo, J.M.F.dos Santos, G.Saviano, N.J.C.Spooner, R.Tesauro, S.Tomassini, S.Torelli

18 October 2022, Bari, IFD2022

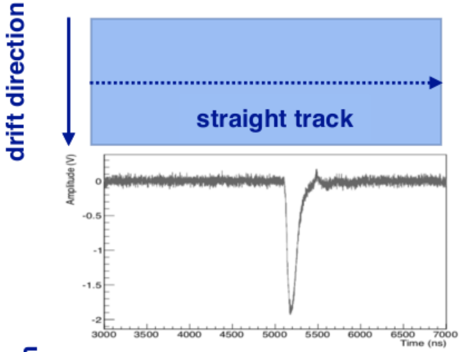
The CYGNO* approach: gaseous TPC with optical readout

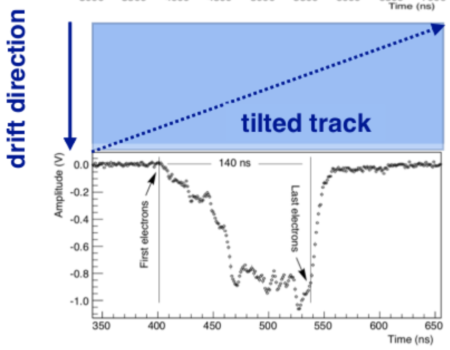
*Instruments 2022, 6(1), 6

- Gaseous TPC for **directional** Dark Matter search, He:CF_4 60:40
- Triple GEM amplification + optical readout (sCMOS cameras + PMT)
- **3D track reconstruction**
  - Directionality (axial+sense)
  - Background rejection
  - Particle identification
  - Fiducialization

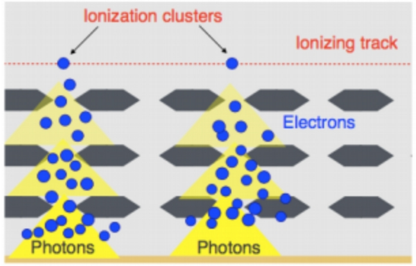
Optical readout:

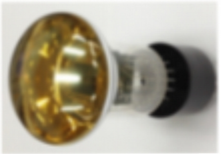
- With suitable lenses we can image **large areas** O(1m^2) **with single sensor**, with O(100 µm) effective pixel size
- **sCMOS**: high granularity, low noise, single photon sensitivity (energy + **xy** position)
- **PMT**: energy + **z** component

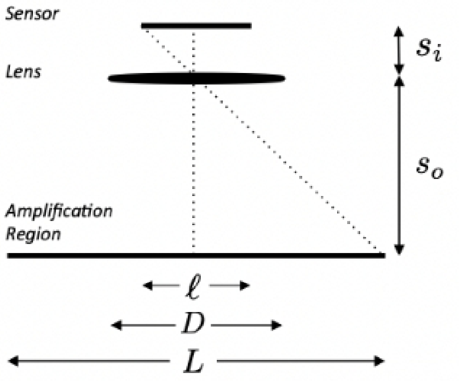




JINST 13 (2018) 05, P05001

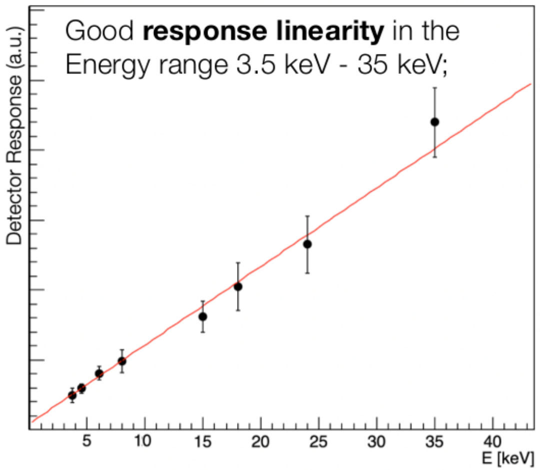


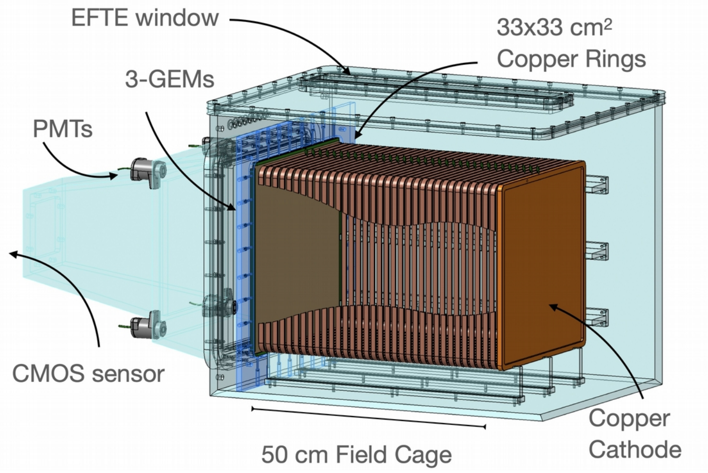


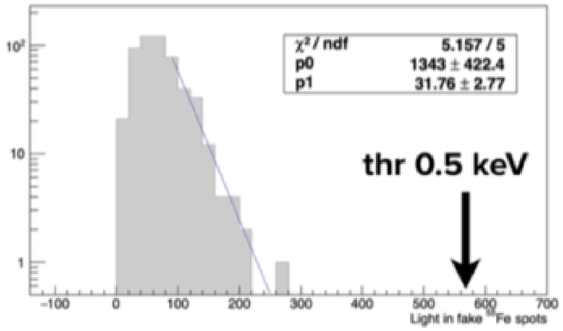


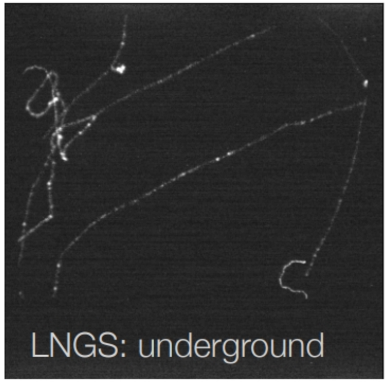
LIME (Long Imaging ModulE)

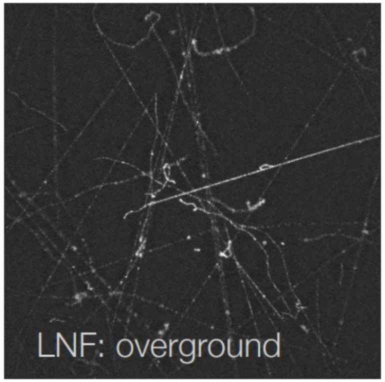
- 50 liters sensitive volume
- $He:CF_4$ 60/40, atm.pressure
- Triple GEM amplification
- 33x33 cm^2 readout area, 50cm drift
- 1sCMOS camera + 4 PMTs
- Now installed underground at LNGS







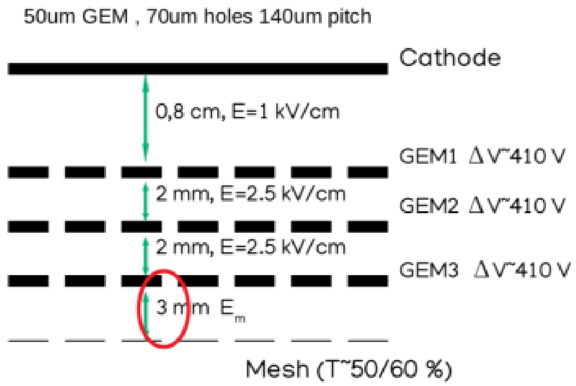


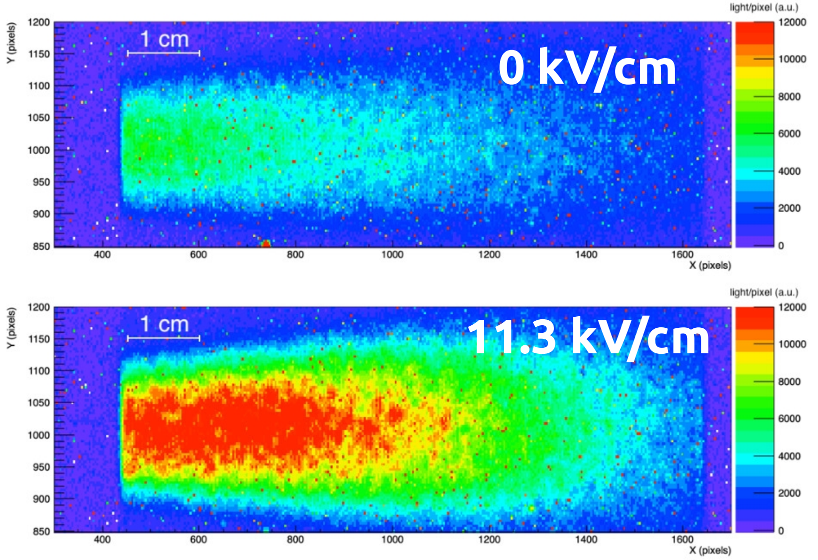


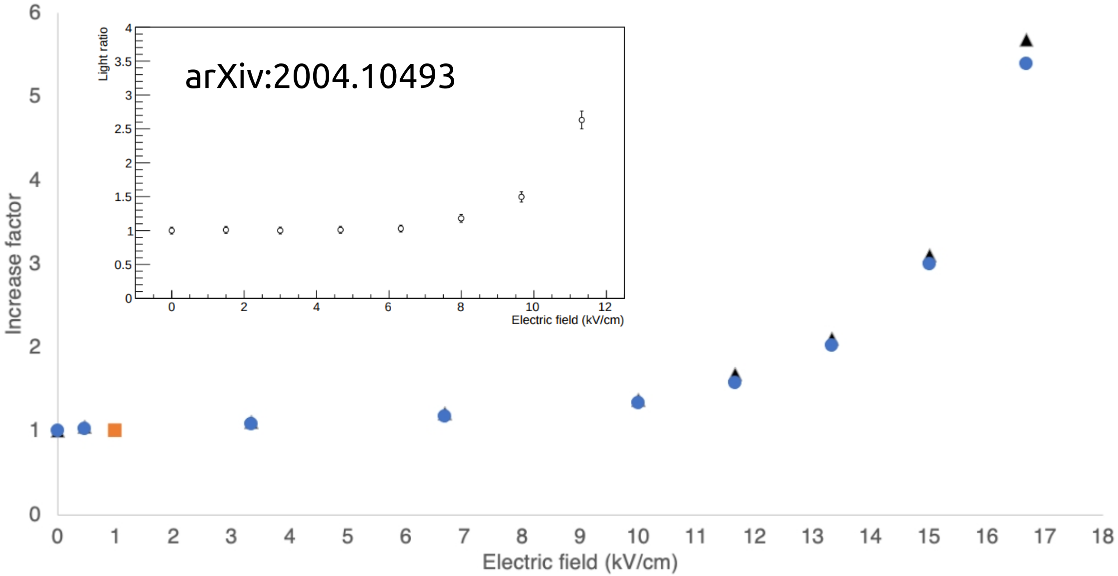
Electroluminescence studies

JINST 15 (2020) 08, P08018

- Add a mesh (or ITO glass) 3 mm after last GEM
- Apply drift field between GEM and mesh
- Electrons travelling in the GEM-mesh gap produce additional light with no (or relatively low) further ionisation
  - More light without degrading resolution (lower threshold)







Hydrocarbons studies

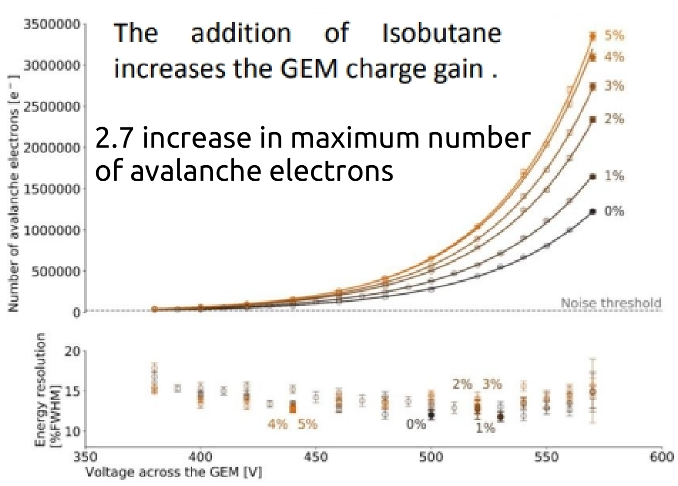
High hydrogen content extends sensitivity to lower WIMP masses

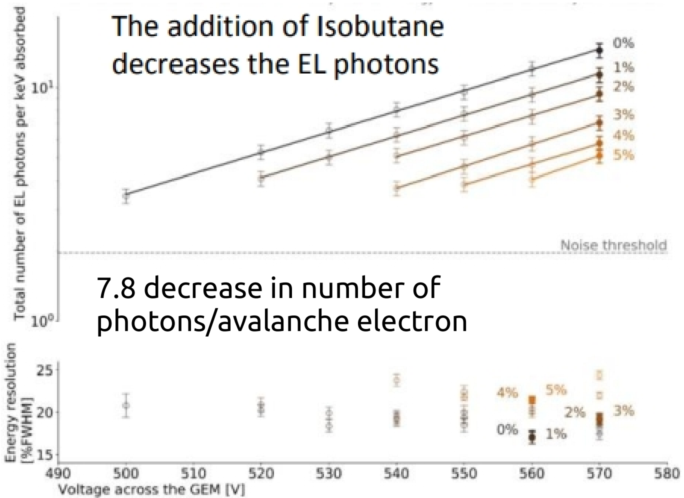
We studied for the first time the light yield of hydrocarbons gas mixtures

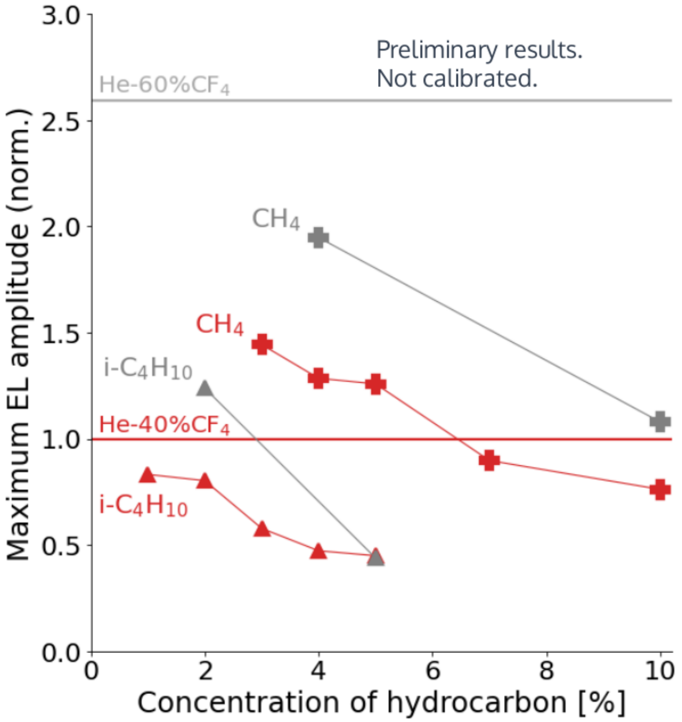
Adding between 0% and 5% of $\mathbf{iC_4H_{10}}$ to He:CF_4 mix:

- Overall only 2.8 decrease in photons/keV
- Energy resolution independent from iC_4H_{10} content

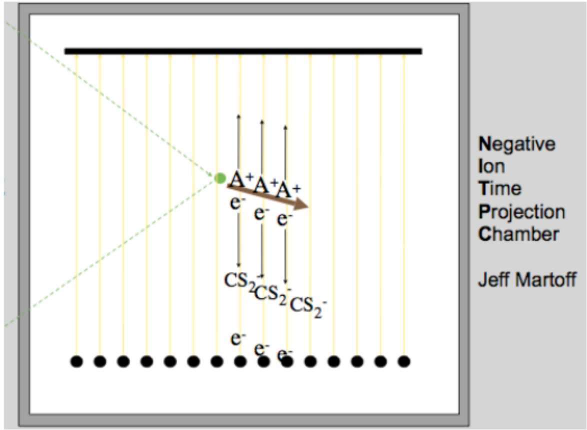
Adding between 3% and 5% of $\mathbf{CH_4}$ increases the light yield without degrading the energy resolution (ongoing)







Negative ion drift operation

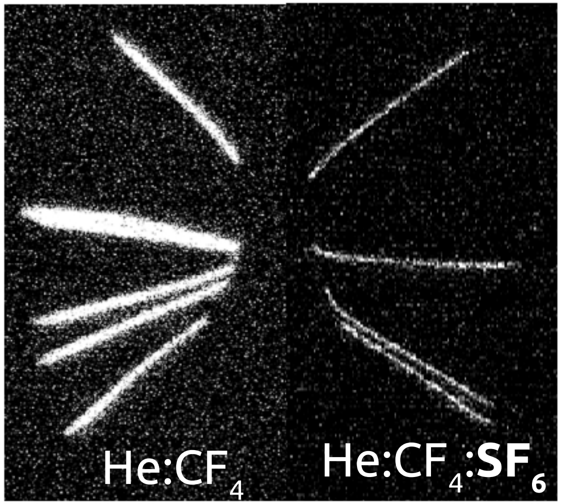


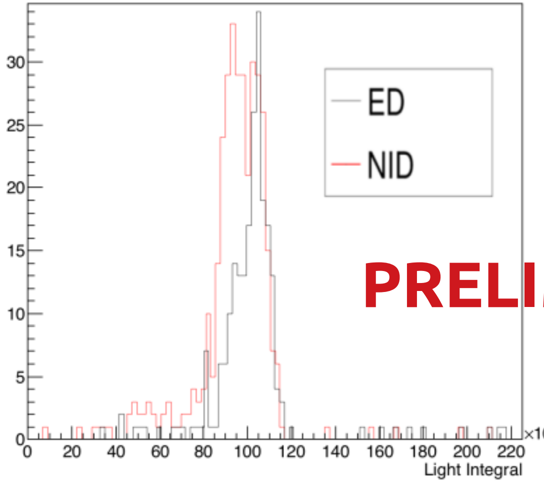
- **Electronegative** dopants added to the gas mixture
- Primary ionization electrons captured by electronegative gas molecules at O(100) um
- Negative ions act as image carriers instead of electrons – **reduced diffusion** allows larger volume TPCs with same (or better) tracking
- Tests ongoing on small prototype with SF_6 – promising results!

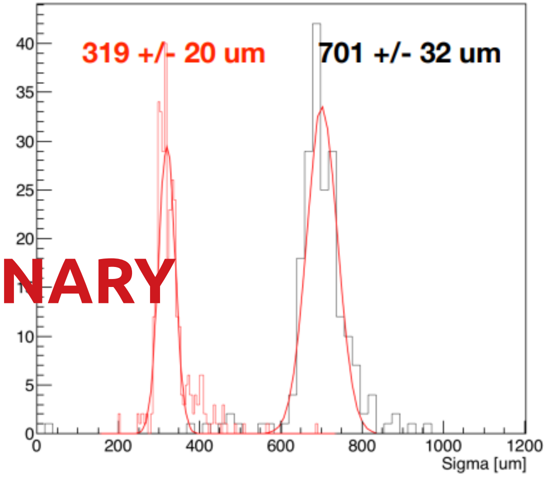
J. Martoff et al., NIM A 440 355

T. Ohnuki et al., NIM A 463

E. Baracchini et al., 2018, JINST 13 P04022

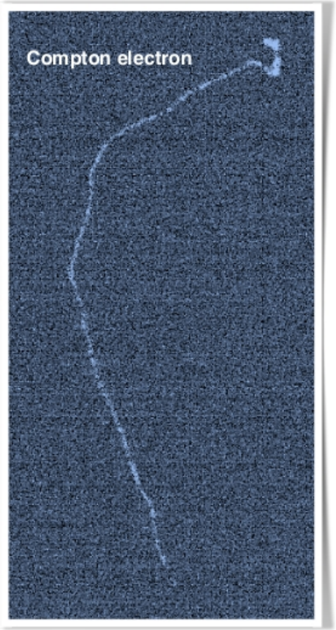


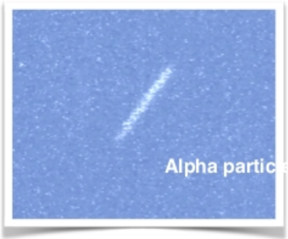


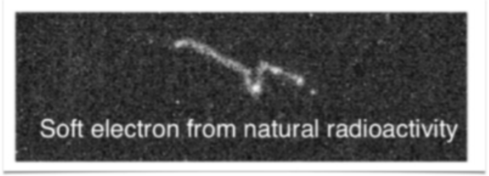


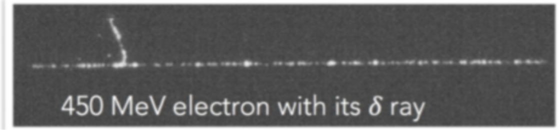
Photographing tracks

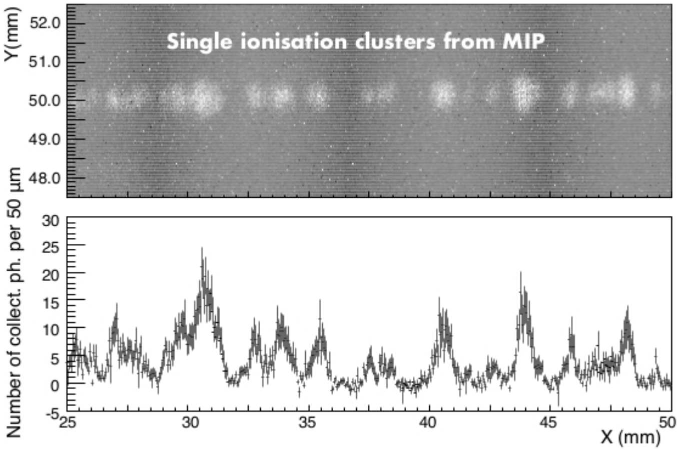
https://www.facebook.com/cygno.experiment
https://web.infn.it/cygnus/cygno

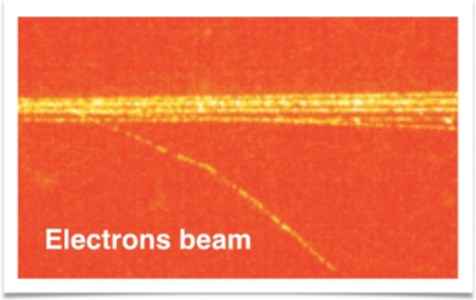


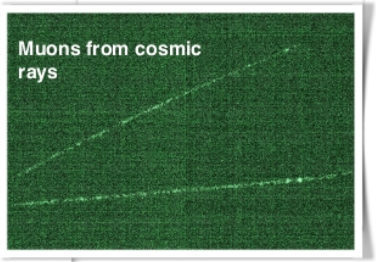


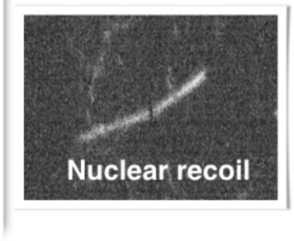




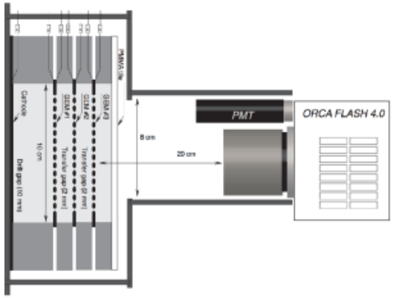




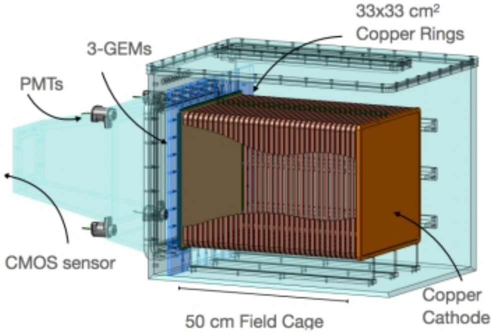




Beyond Dark Matter

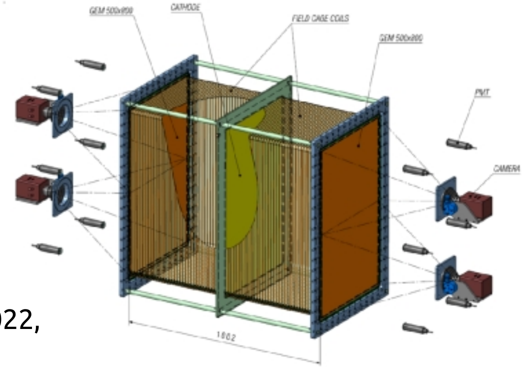


Small O(1L)

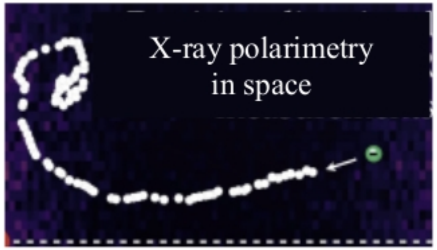


Medium O(50L)

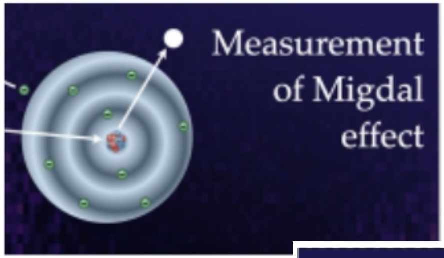
“The CYGNO experiment”, Instruments 2022, 6(1), 6



Large O(30-1000 m^3)

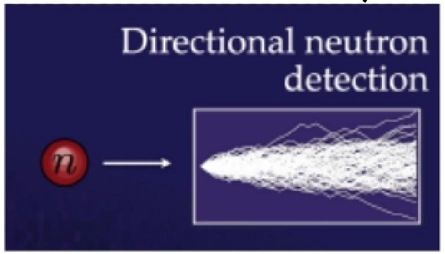


Funded!
“HypeX: High Yield Polarimetry Experiment in X-rays”
(PRIN 2020 Prot. 2020MZ884C)

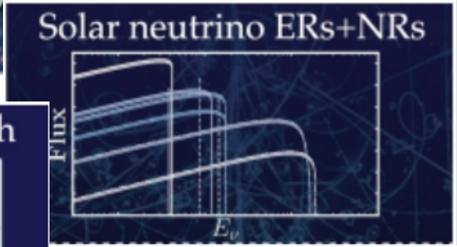


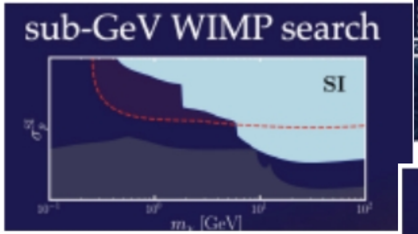
Funded!
“FINEM: Full Imaging of Nuclear recoils for Experimental Migdal measurement”
(FARE 2020 Prot. R208LP3A4C)

Funded!
“Zero Radioactivity for Future Experiments”
(PRIN 2017 Prot. 2017T54J9J)



S.E.Vahsen et al., arXiv:2008.12587





C. A. J. O’Hare et al., 2022 Snowmass Summer Study, arXiv:2203.05914

Beyond Dark Matter

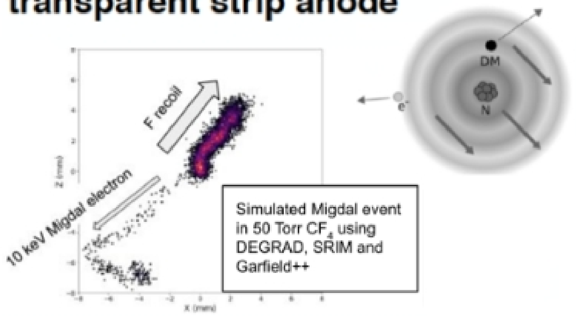
MIGDAL
Migdal In Galactic Dark mAtter expLoration

CERN 2020

Low-pressure TPC with optical+electronic readout

Migdal effect search in low-pressure CF_4 for DM searches in

CMOS + electronic readout of **transparent strip anode**



P. Majewski, RD51 Mini-Week 2020, https://indico.cern.ch/event/872501/contributions/3730586/attachments/1985262/3307758/RD51_mini_week_Pawel_Majewski_ver2.pdf

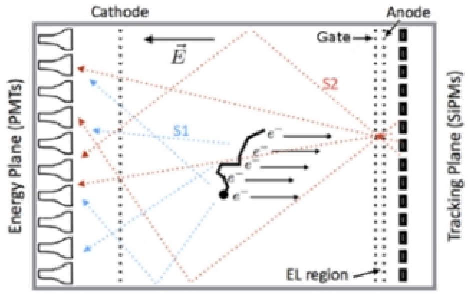
next

CANFRANC 2019

High Pressure Xe gas TPC with electroluminescent amplification

Neutrinoless double beta decay searches in ^{136}Xe

PMTs for energy measurement & t_0 from S1, **SiPM-based tracking** plane recording electroluminescence



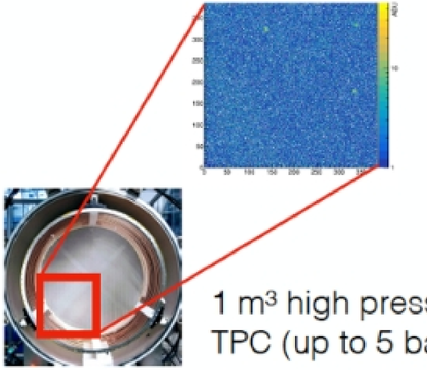
https://next.ific.uv.es/next/experiment/detector.html
L. Arazi, Status of the NEXT project, https://doi.org/10.1016/j.nima.2019.04.080

High Pressure TPC

DUNE COLLABORATION 2021

Towards a neutrino-nucleus cross section experiments

Stitched optical readout (4 CCD cameras) + **electronic signals** from meshes used for amplification



1 m³ high pressure TPC (up to 5 bar)

A. Deisting, HPTPC, https://arxiv.org/pdf/2102.06643.pdf

Thank you