Aging suppression timing Multi-Strip Multi-Gap Resistive Plate Chamber for high counting rate experiments

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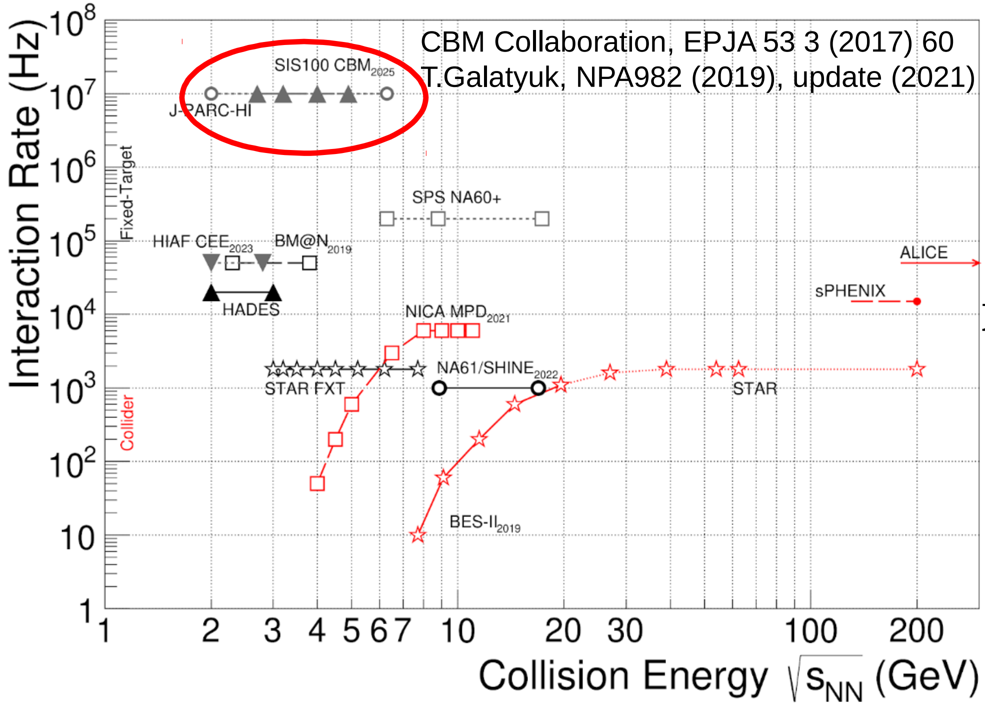
3rd International Conference on Detector Stability and Aging Phenomena in Gaseous Detectors, CERN, 06 – 10 November 2023

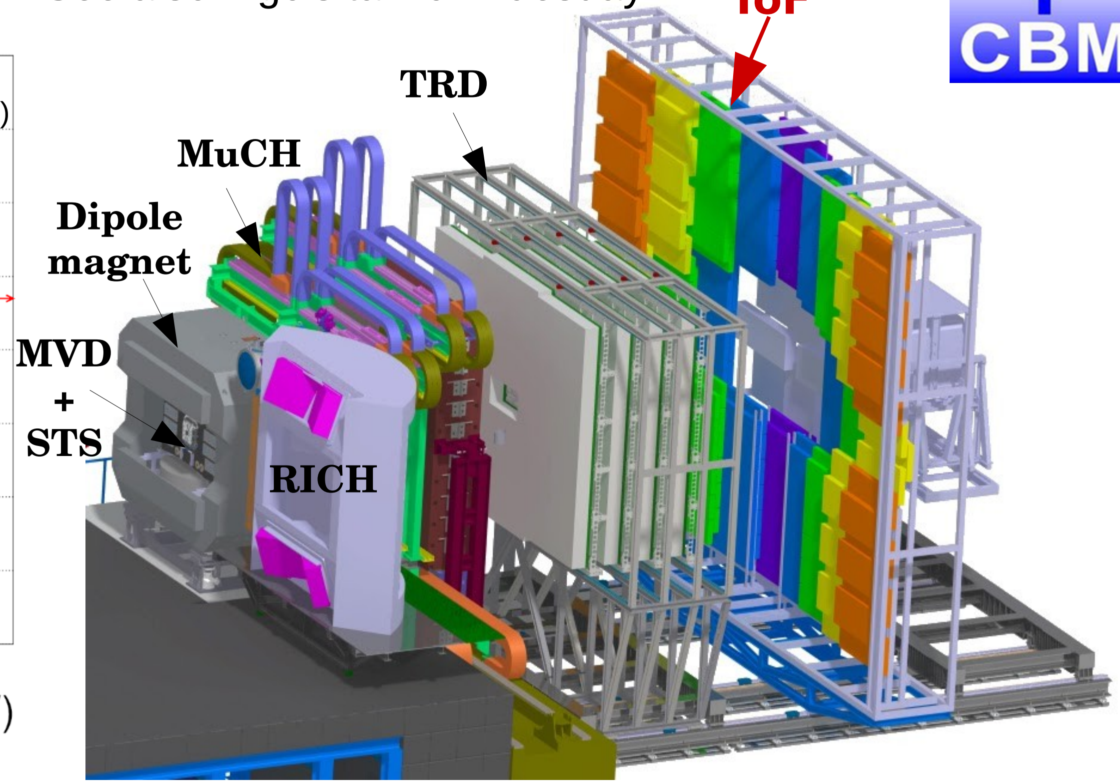
Outline

- **Motivation – next generation high interaction rate, high multiplicity experiments, (e.g. CBM/FAIR, Darmstadt ->TOF inner wall)**
- **MSMGRPC design considerations & high counting rate test of the MSMGRPC**
- **Aging investigations with high activity ^{60}Co source**
- **MSMGRPC prototype with direct gas flow & X-ray tube aging studies**
  - **Standard fishing line spacers**
  - **Discrete spacers - a new generation of direct flow MSMGRPC**
- **Summary and Outlook**

High interaction rate experiments -> CBM/FAIR

See also Ingo's talk on Tuesday





CBM experiment at FAIR/SIS100:

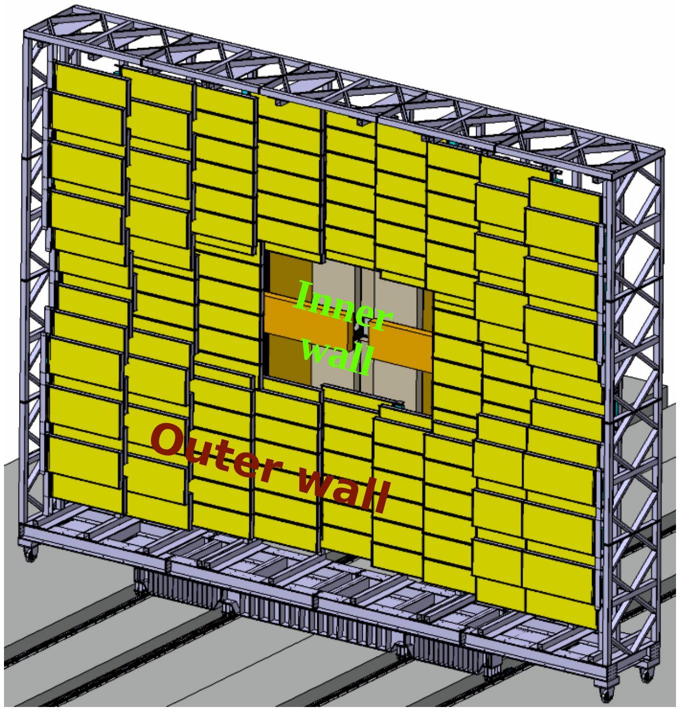
- A+A collisions, E_{kin} = 2.5A – 11A GeV
- Systematically explore QCD matter at large baryon densities with high accuracy and rare probes

MVD: Micro Vertex Detector*
STS: Silicon Tracking System*
* inside magnetic field
MuCh / RICH
Muon Chamber System /
Ring Imaging Cherenkov Detector
TRD: Transition Radiation Detector
ToF: Time-of-Flight Detector

- **Tracking acceptance: 2.5° < θ_{Lab} < 25°**
- **Peak R_{int} is 10 MHz for Au+Au**
- **Fast & radiation hard detectors**
- **Free-streaming DAQ**
- **4D tracking (space, time)**
- **Online event selection & reconstruction**
- **Data rate: 1 TB/sec**

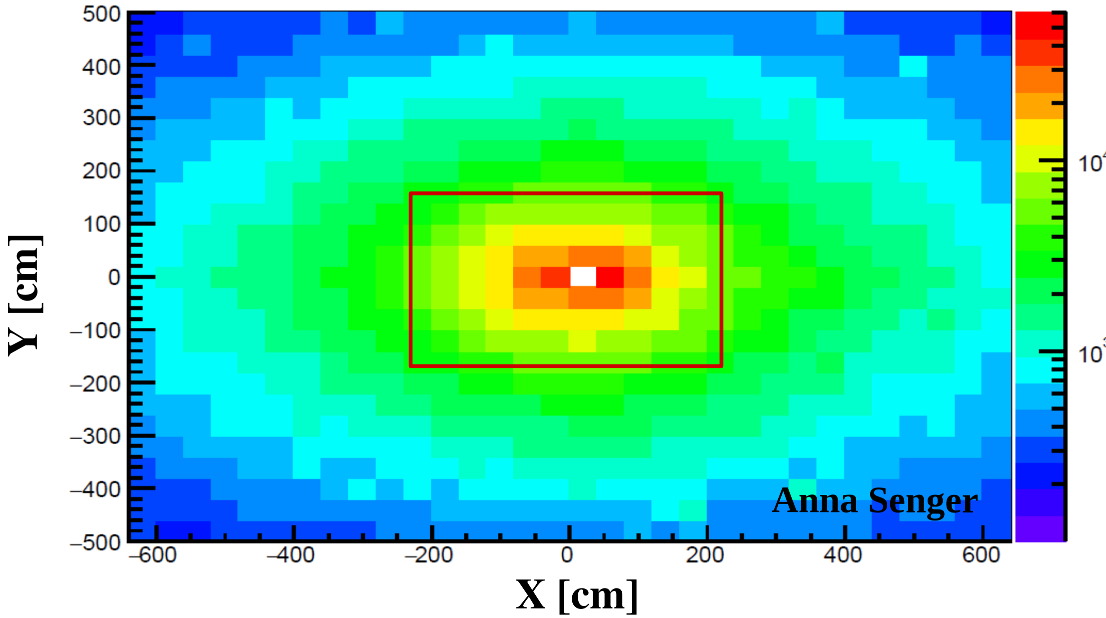
CBM – TOF wall

See also Ingo's talk on Tuesday



FLUKA simulation: Au + Au collisions at E_{kin} = 11A GeV, 10^7 interactions/s

Charged particle flux at a distance of 8 m from the target



CBM-ToF Requirements

- **Full system time resolution σ_T ~ 80 ps**
- **Efficiency > 95%**
- **Rate capability ≤ 50 kHz/cm^2**
- **Polar angular range 2.5° – 25°**
- **Active area of 120 m^2**
- **Occupancy < 5%**
- **Low power electronics (~120.000 channels)**
- **Free streaming data acquisition**

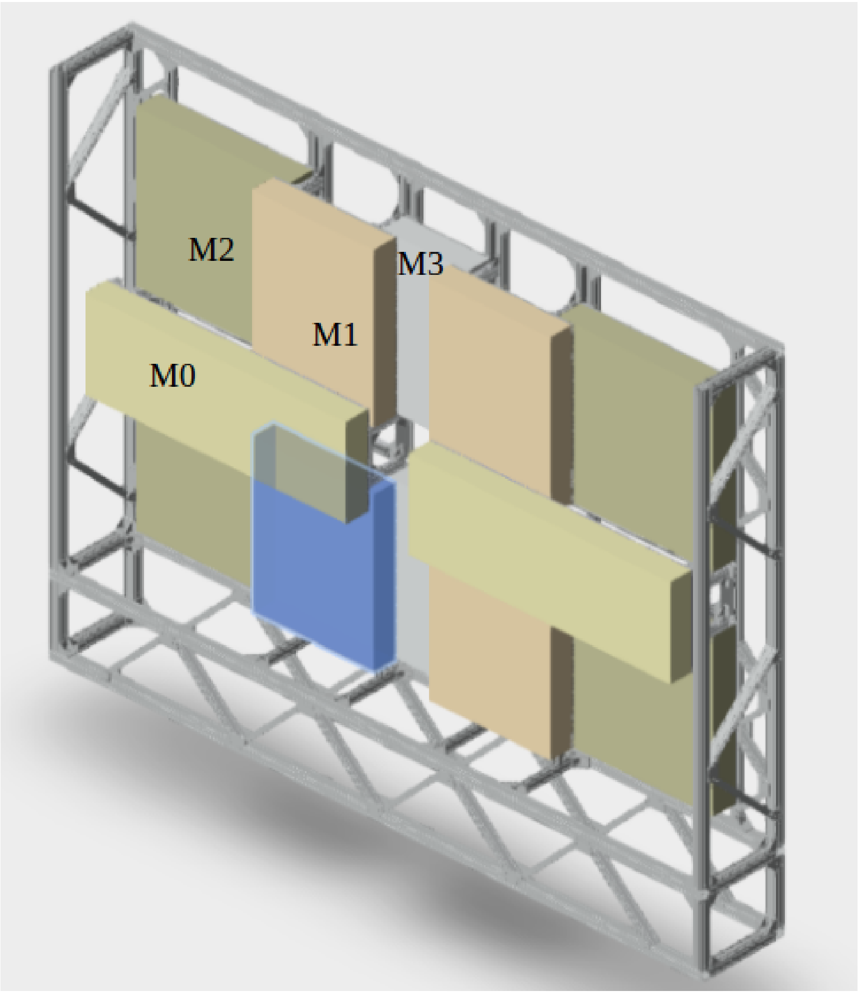
Detectors with different rate capabilities and granularities are needed as a function of polar angle

Our R&D activity → MSMGRPCs for the inner wall :

- highest counting rate
- highest granularity
- ~15 m^2 active area (up to ~ 11° polar angle)

CBM – TOF Technical Desing Report, October 2014

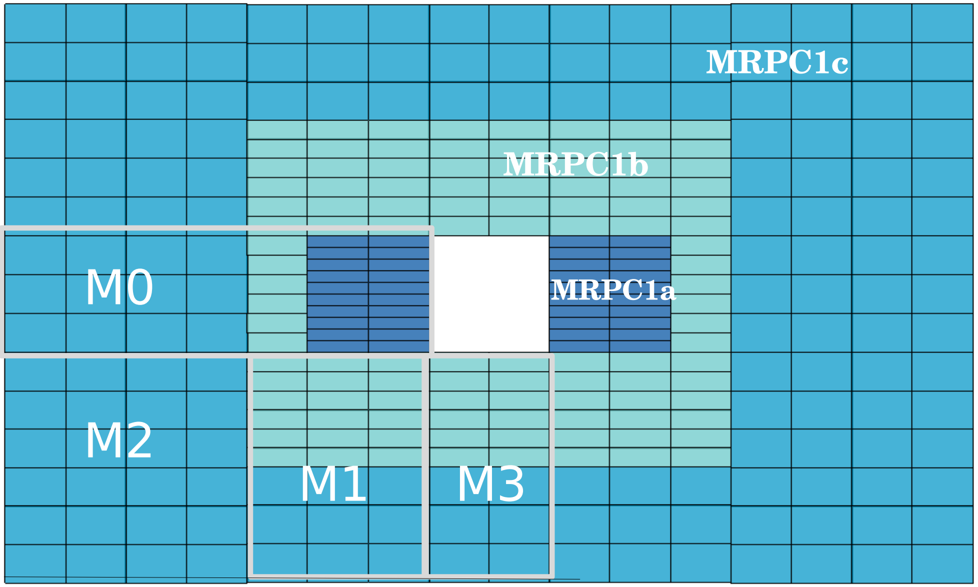
CBM – TOF inner wall

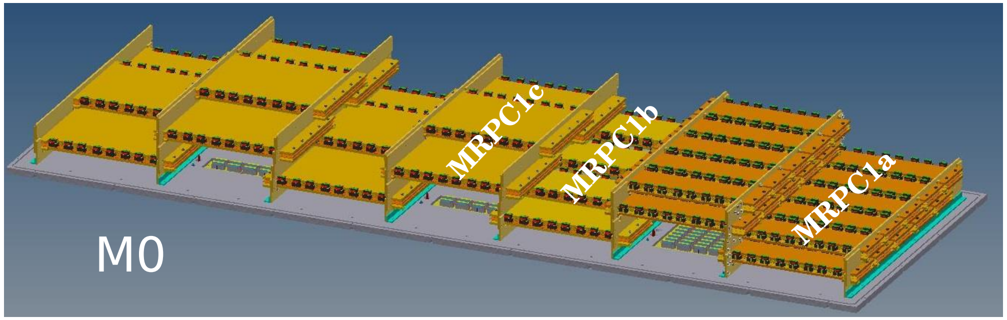


CBM-TOF inner zone

- *~15 m² active area, modular architecture:*
  - *12 modules*
  - *4 types (M0, M1, M2, M3)*

Counters with different granularities are used.

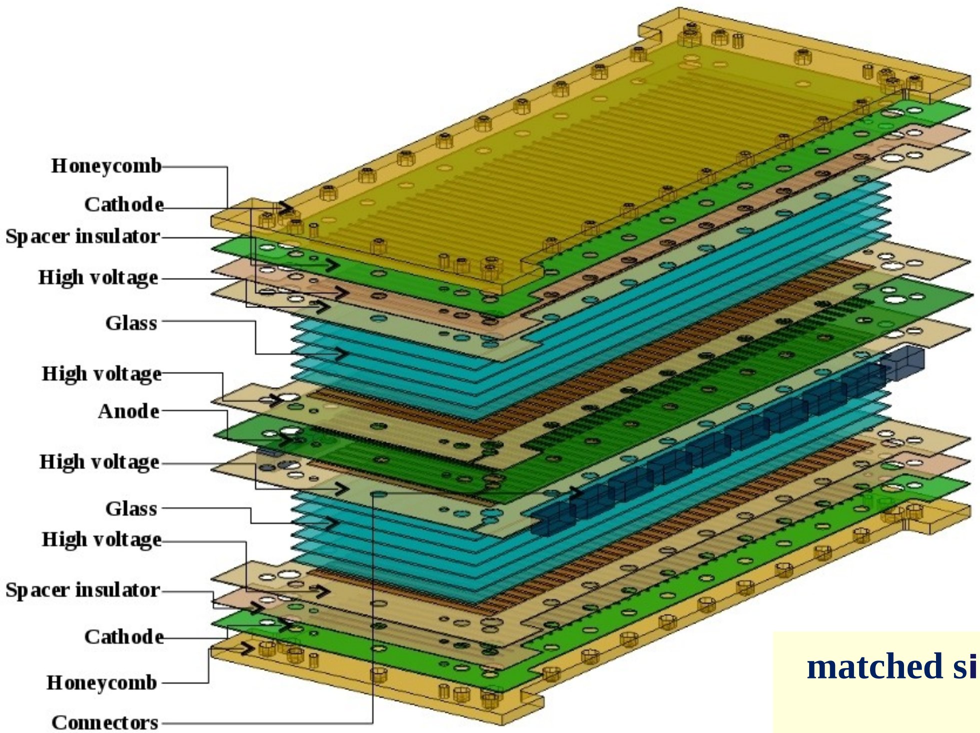




3 chamber types: 56/96/196 mm (strip length) x 300 mm

	MRPC1c (196 mm)	MRPC1b (96 mm)	MRPC1a (56 mm)	Total
No. MRPCs	168	108	40	316
No. channels	10752	6912	2560	20224

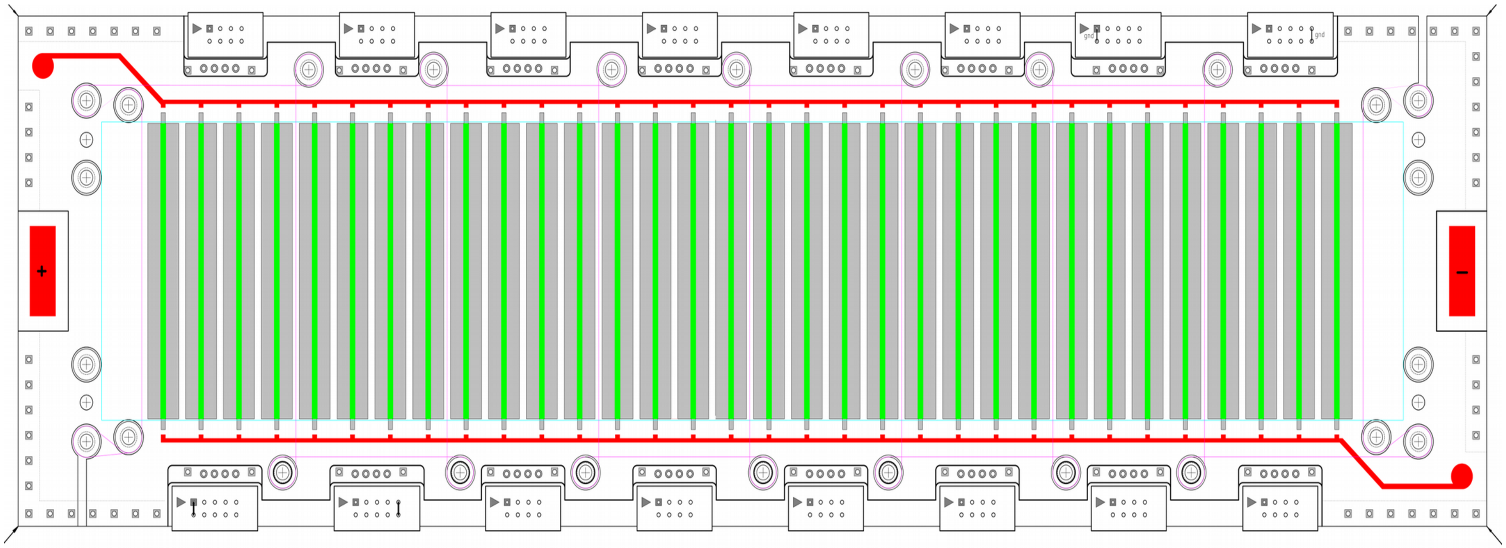
Chamber design considerations

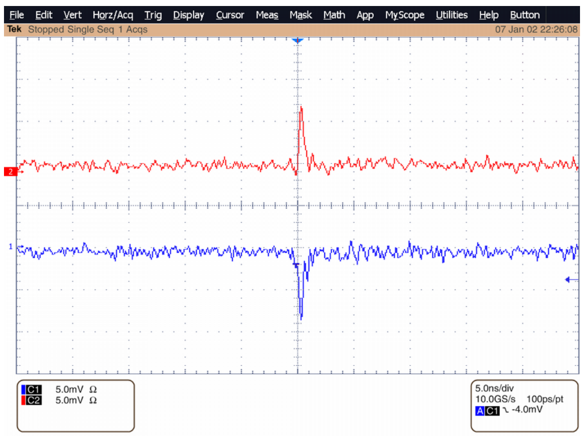


- ✓ Symmetric structure: 5 gaps x 2 stacks
- ✓ Gas gap thickness: 200 μm
- ✓ Active area 56/96/196 mm x 9 mm pitch x 32 strips
- ✓ Resistive electrodes: ~10^{10} Ωcm, 0.7 mm Chinese glass
- ✓ Strip structure for Readout & HV electrodes
- ✓ Differential readout
- ✓ Direct flow through the gas gaps

matched signal transmission line impedance to the input of the FEE

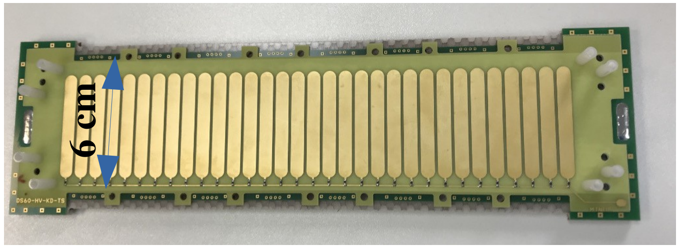
D. Bartos et al., Romanian Journal of Physics 63, 901 (2018)



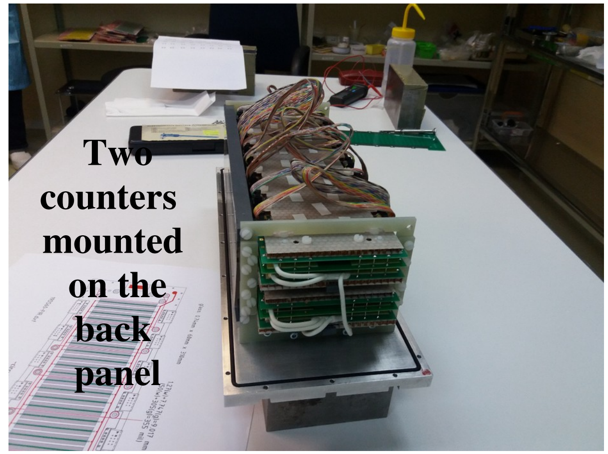


MSMGRPC prototype: gas exchange via diffusion

High voltage (HV) electrode

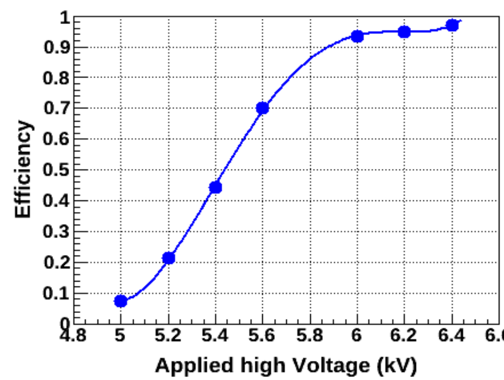


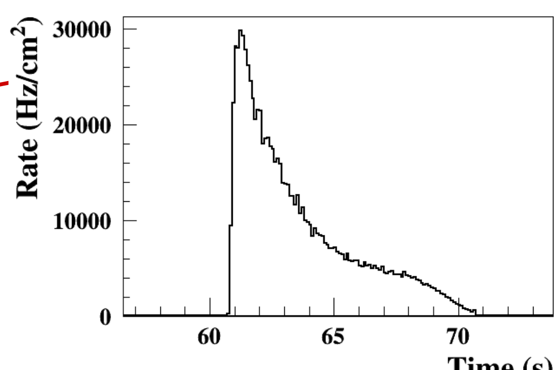
Spacer distribution across the surface

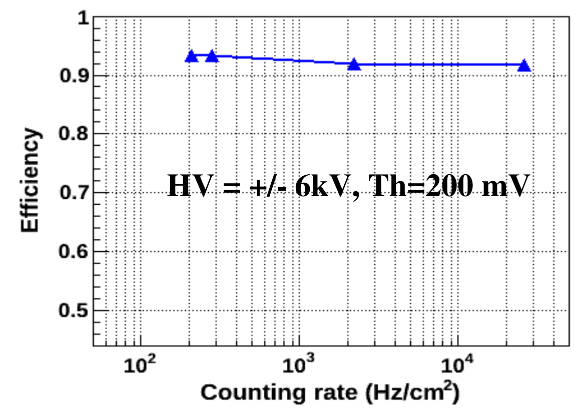


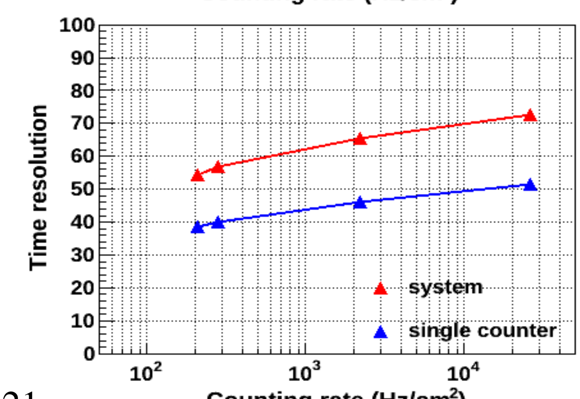
MSMGRPC	I_{dark}	Dark rate
RPC1	< 1 nA	0.11 Hz/cm²
RPC2	< 1 nA	0. 14 Hz/cm²

High Counting Rate Test in mCBM







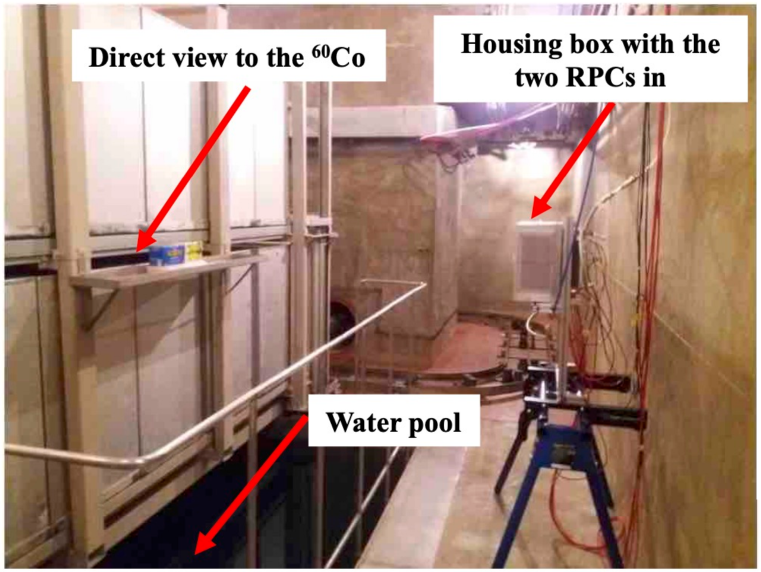


M. Petris et al., Nucl. Inst. and Methods A 1045 (2023) 167621

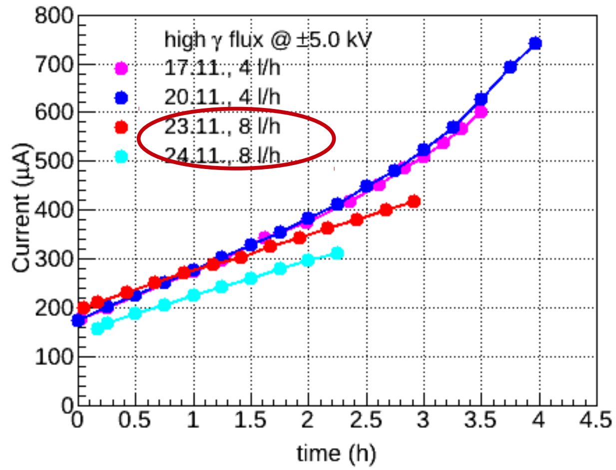
Aging investigations of MSMGRPC with gas exchange via diffusion

- **IRASM/IFIN-HH multipurpose irradiation center**
- **^{60}Co source: 360 kCi;**
- **Dose rate = 0.3 kGy/h**

D. Bartos et al., Nucl. Inst. and Methods A 1024 (2022) 166122



MSMGRPC under high γ flux

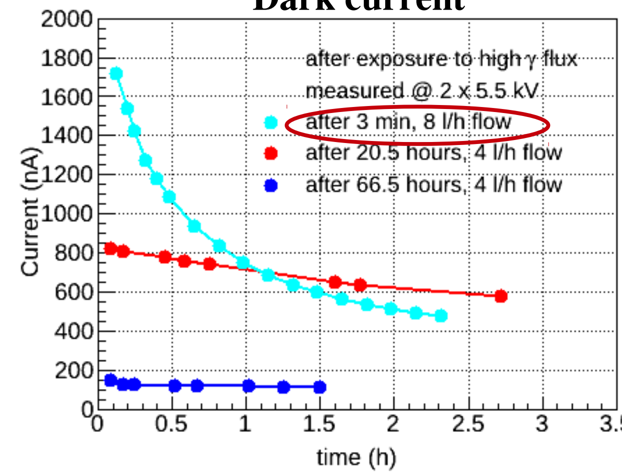


Accumulated charge: 0.127 C/cm^2

Chamber area = 9.6 cm x 30 cm

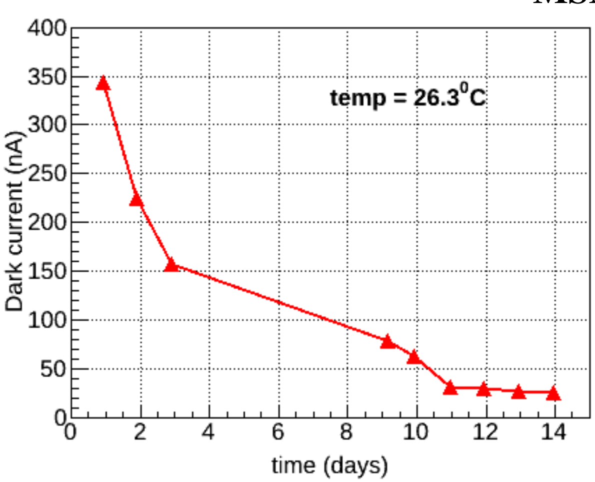
MSMGRPC short term recovery

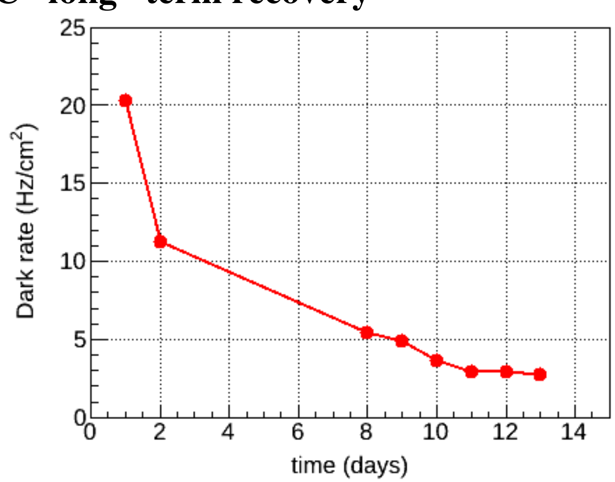
Dark current

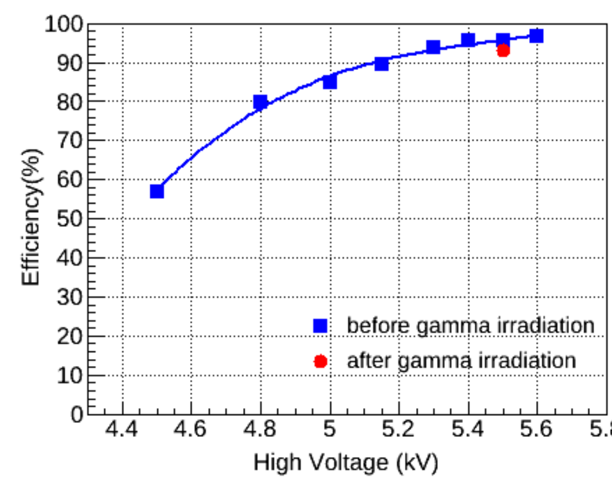


$90\%C_2H_2F_4+5\%SF_6+5\%iso\text{-}C_4H_{10}$

MSMGRPC "long" term recovery

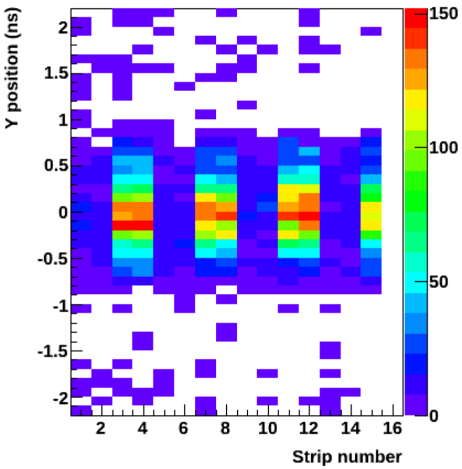


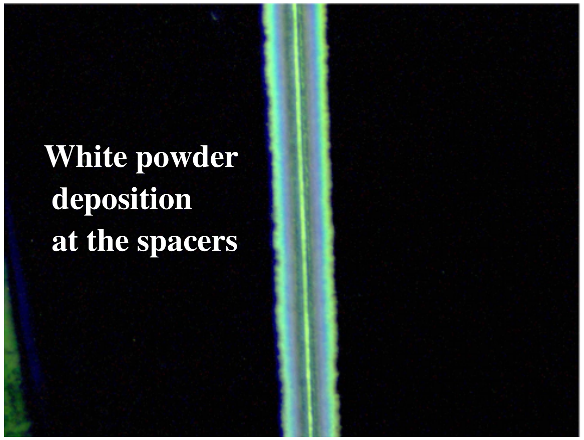




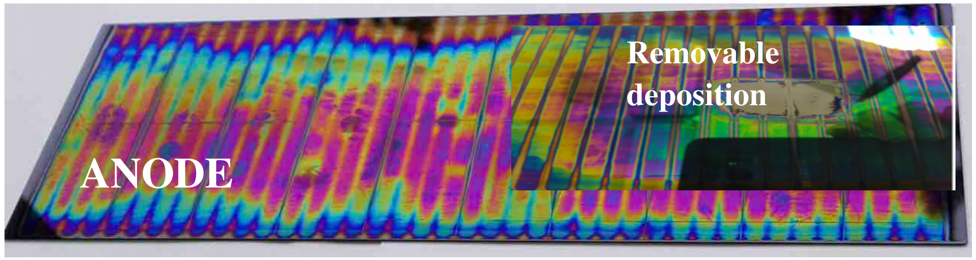
Aging investigations

Dark rate generated around the spacers





Glass inspections performed with various methods:
(SEM, XPS, AFM RBS, non-RBS, THz-TDS)



Glass resistivity remains unchanged

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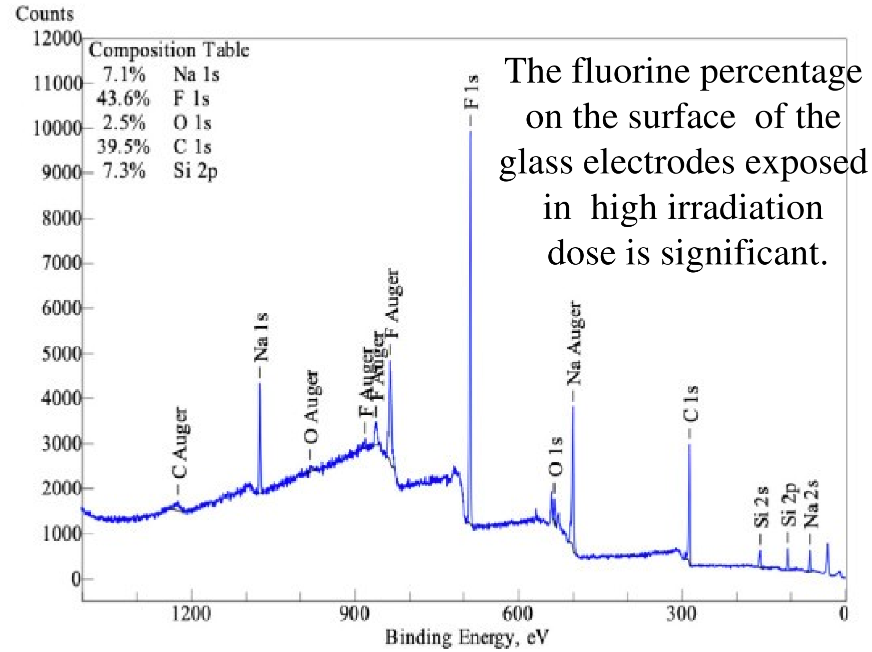
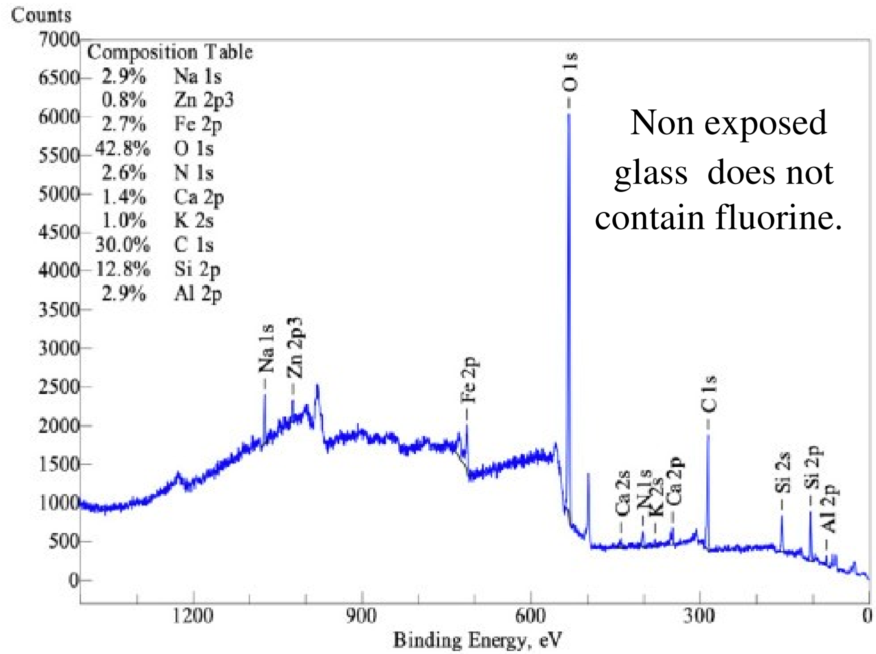
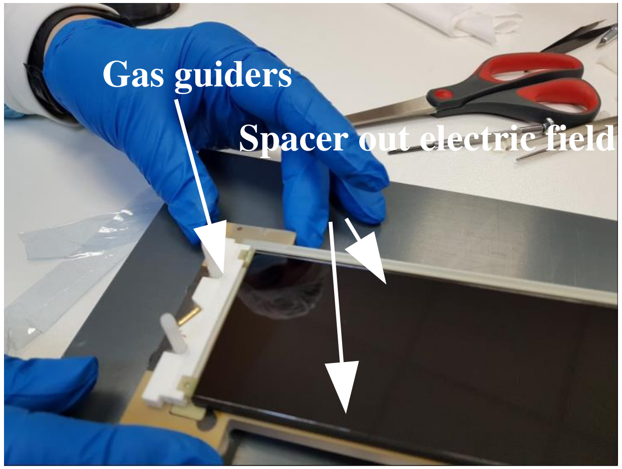
(XPS) analysis of the chemical composition of irradiated and non-irradiated glass plates

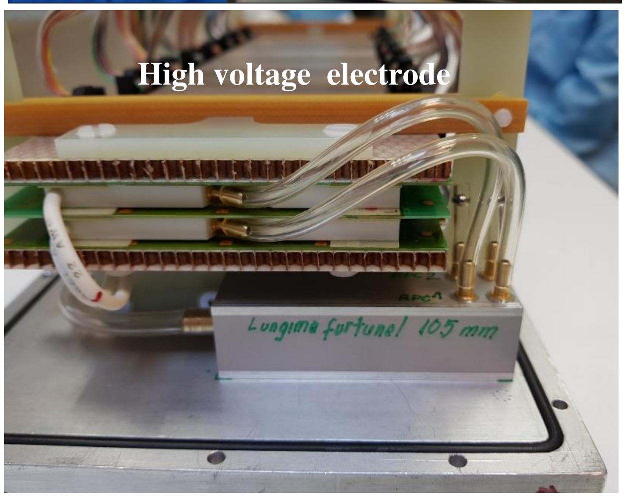




First MSMGRPC prototype with a direct flow – 70% gas transmission

Assembling of MRPC1a (56 mm strip length)

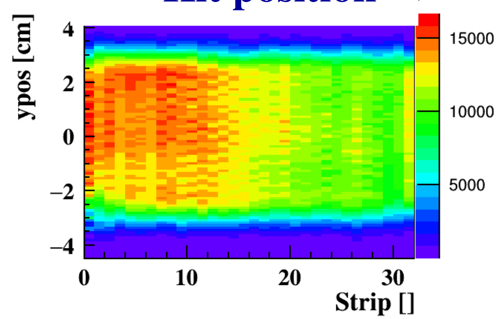




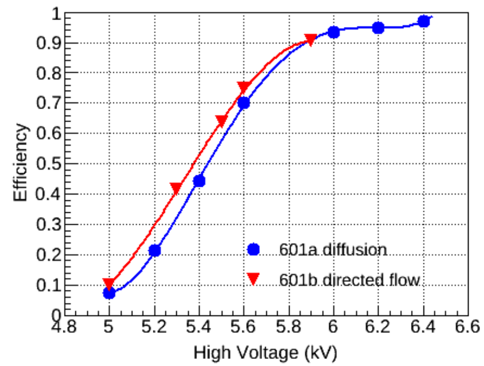
- **Direct gas flow through the gas gaps.**
- **Spacers run across the strips.**
- **Spacers outside electric field area.**

mCBM@SIS18 July 2021 in-beam test results

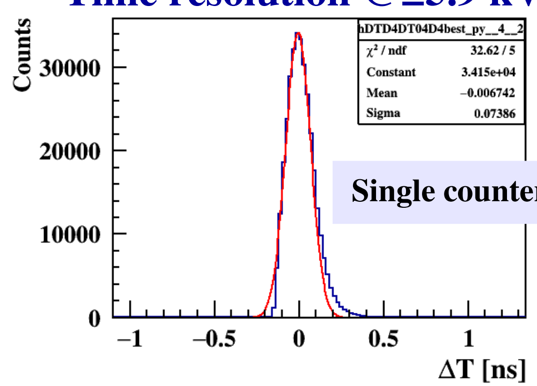
Hit position



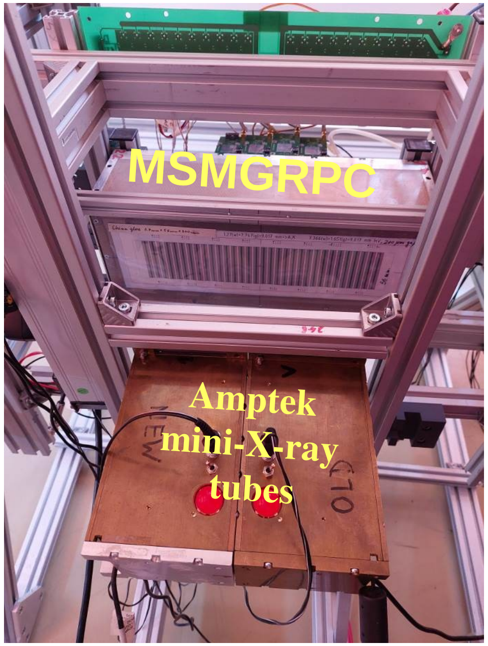
High voltage scan



Time resolution @±5.9 kV



High intensity X-ray irradiation

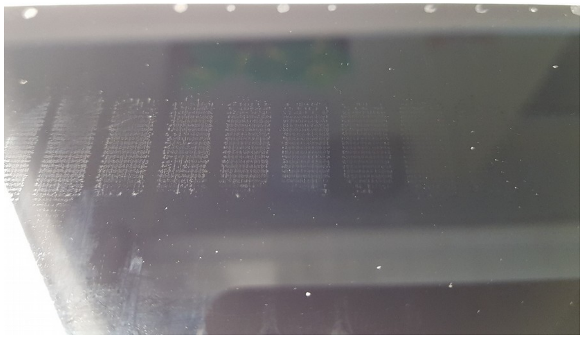


Gas mixture: 97.5% $C_2H_2F_4$ + 2.5% SF_6

Gas flow rate: 4 l/h

HV = +/- 6 kV

Deposition on the middle of the glass electrode



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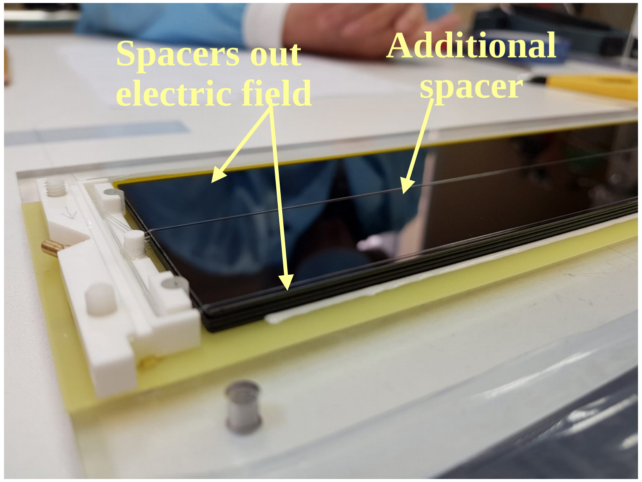
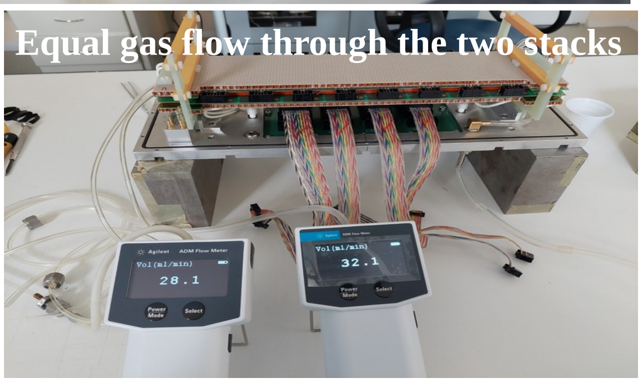
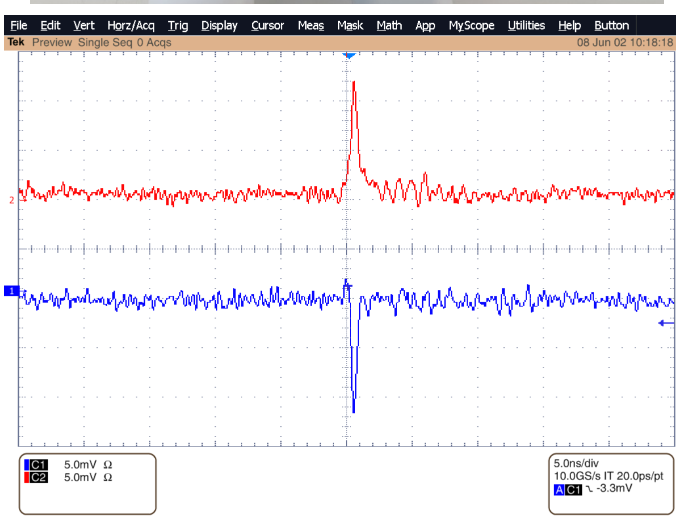
Second MRPC1a prototype with direct flow – 100% gas transmission

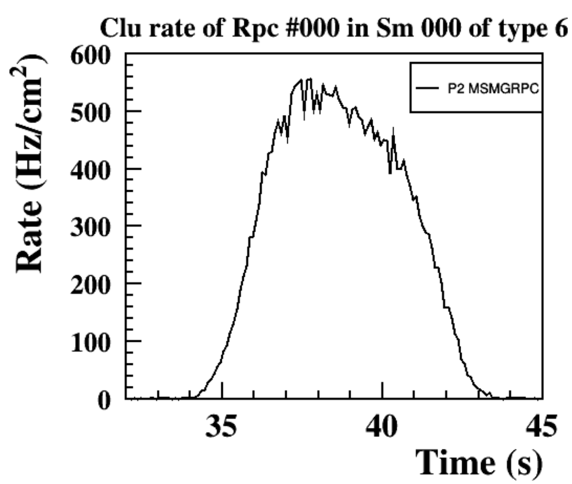


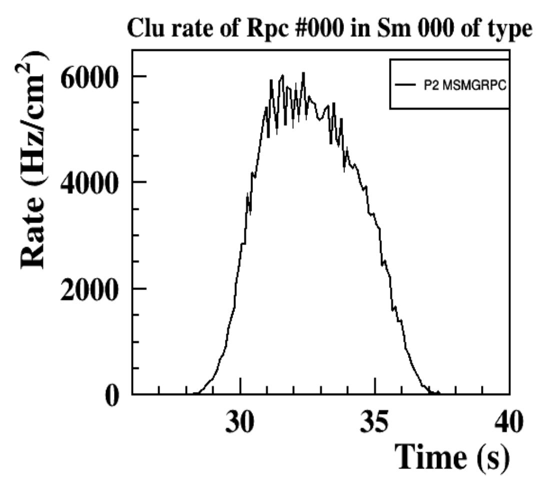




<u>Dark current up to 2 x 6.4 kV</u>
before HR test < 10 nA
after HR test <10 nA

Negligible dark counting rate after HR test

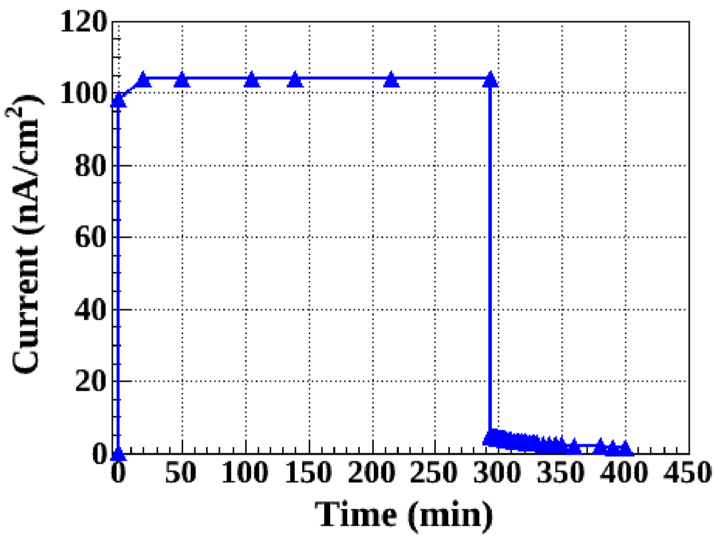


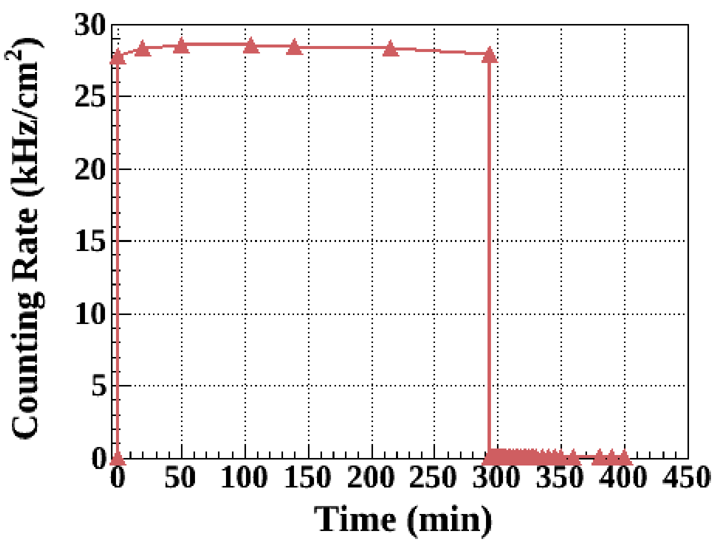


Au(65+) + Au at 1.13 AGeV, 2.5mm Au target/0.4mm/4mm Ni target
Rate scan (HR) -> intensity per spill: 1×10^7, 3×10^7, 1×10^8, 3x to 4×10^8
Exposed to the highest delivered counting rate for ~8 hours

High intensity X-ray irradiation of MRPC1a

Current & counting rate during high intensity X-ray flux exposure

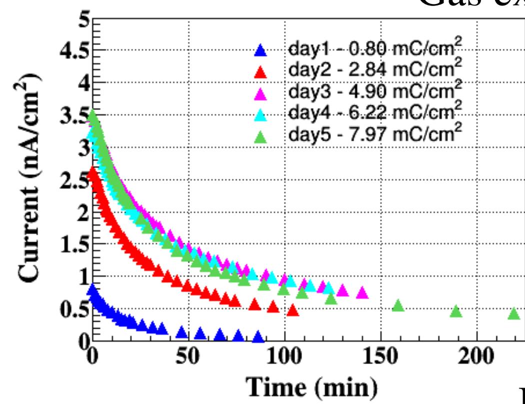


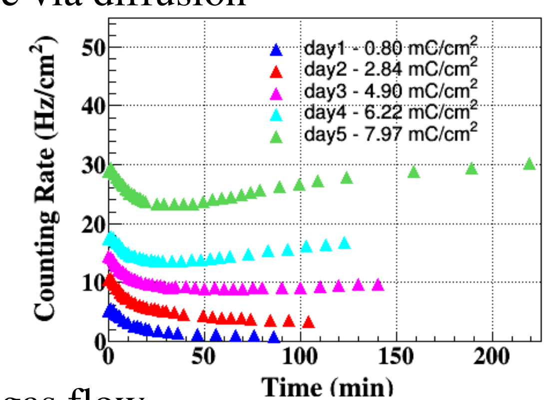


V. Aprodu et al., Nucl. Inst. and Methods A 1049 (2023) 168098

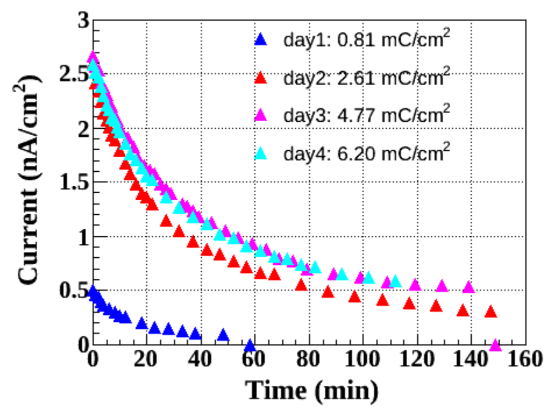
Dark current & dark counting rate after X-ray exposure

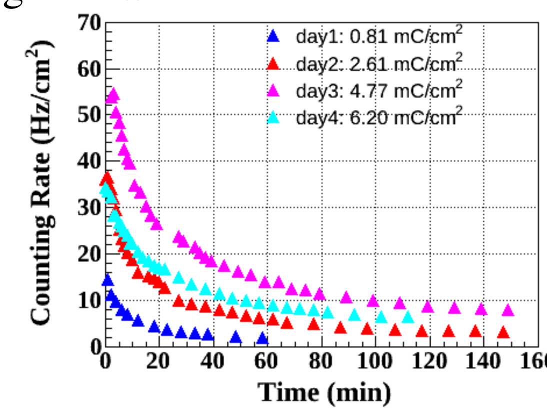
Gas exchange via diffusion



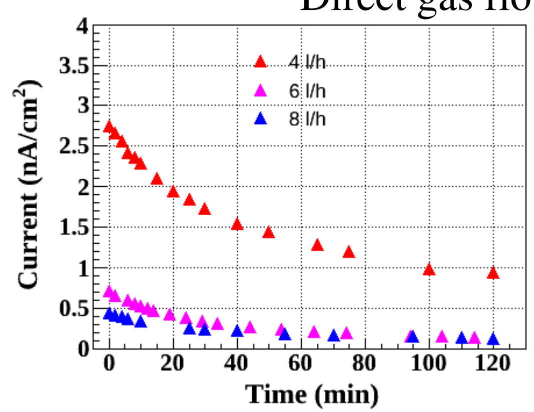


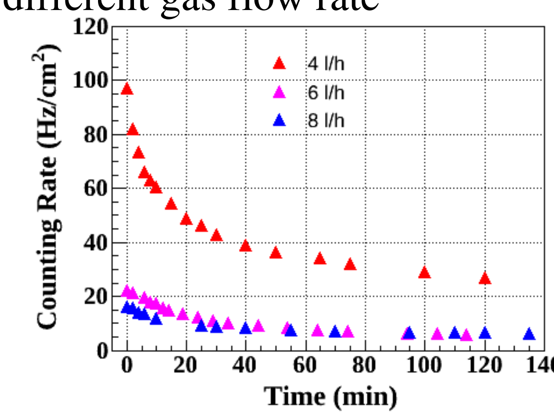
Direct gas flow



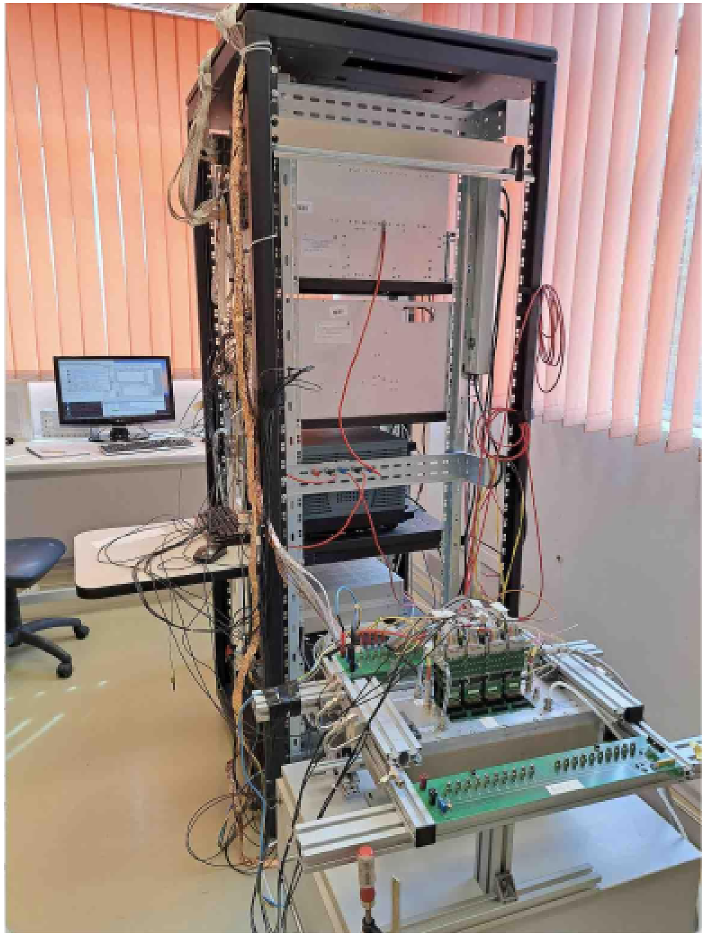


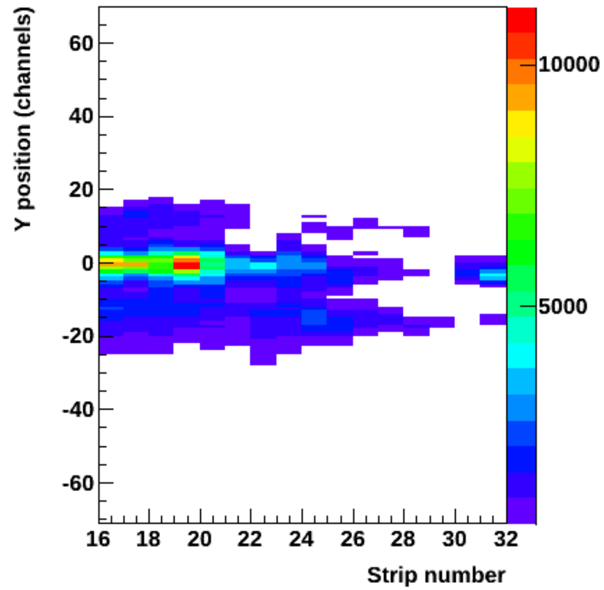
Direct gas flow at different gas flow rate

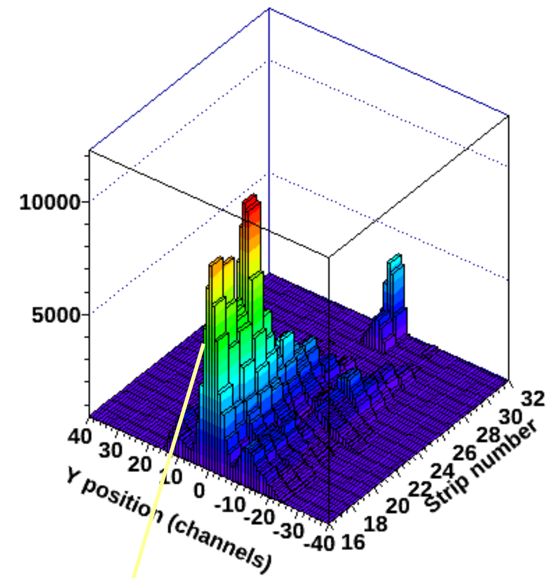


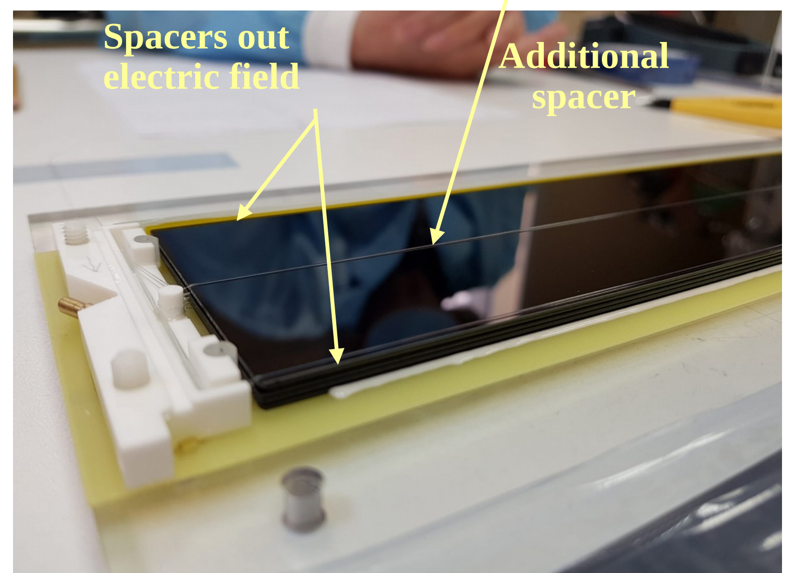


Mapping the direct flow counter with cosmic rays, in self – triggered mode, after X-ray exposure



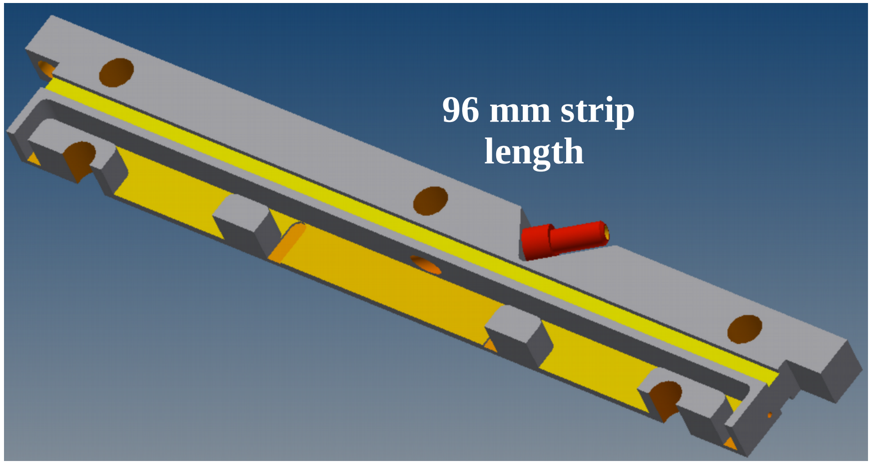




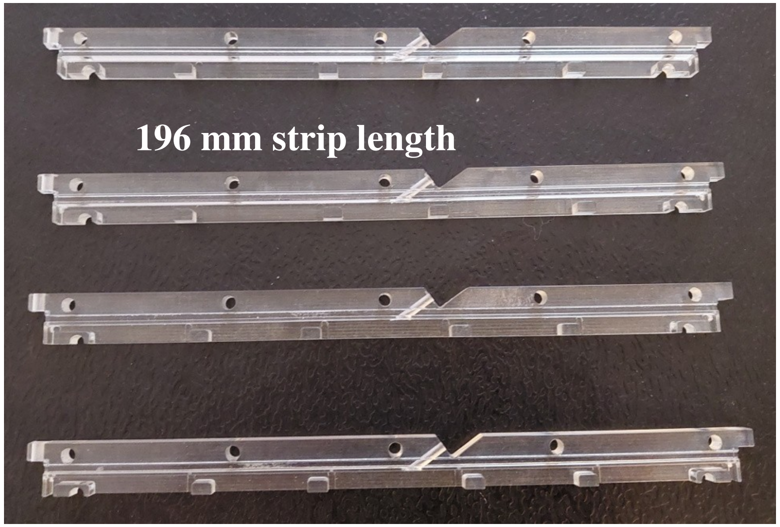


Direct gas flow counters MRPC1b

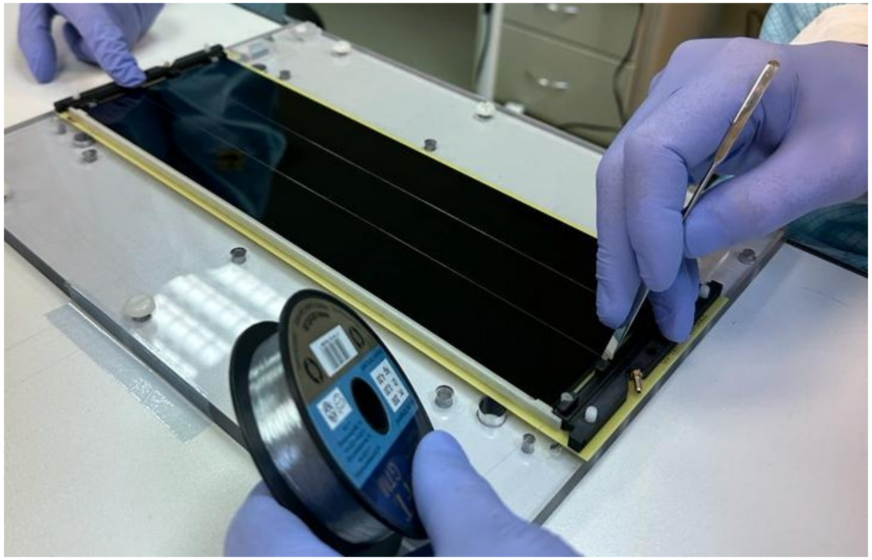
Gas guide design



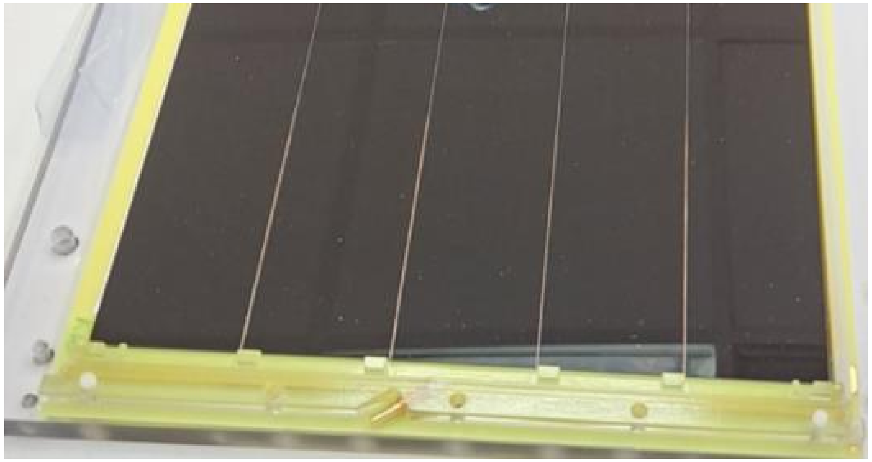
3D printed gas guide



Assembling of MRPC1b (96 mm strip length)

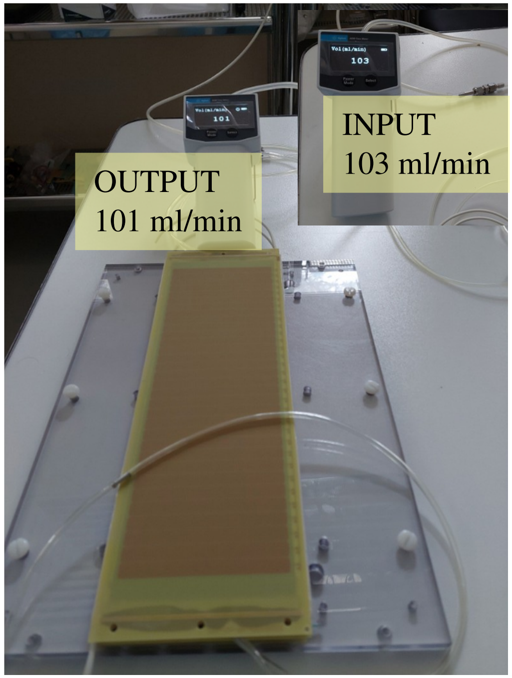


Assembling of MRPC1c (196 mm strip length

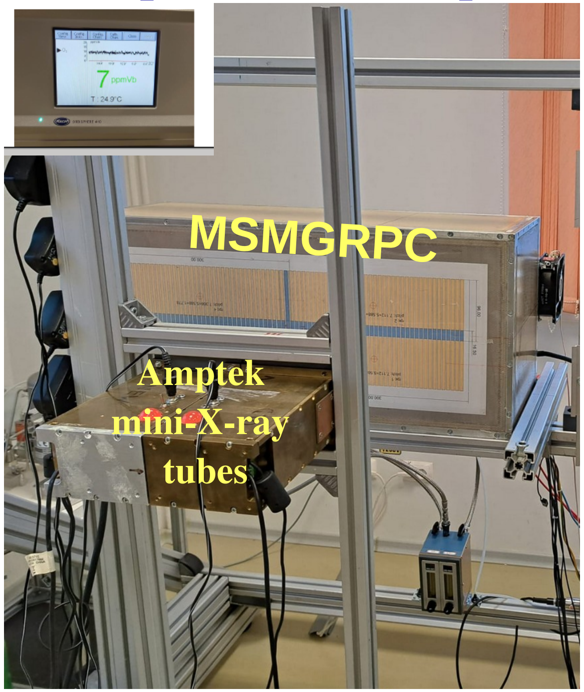


Aging tests, high X-ray flux MRPC1b & MRPC1c

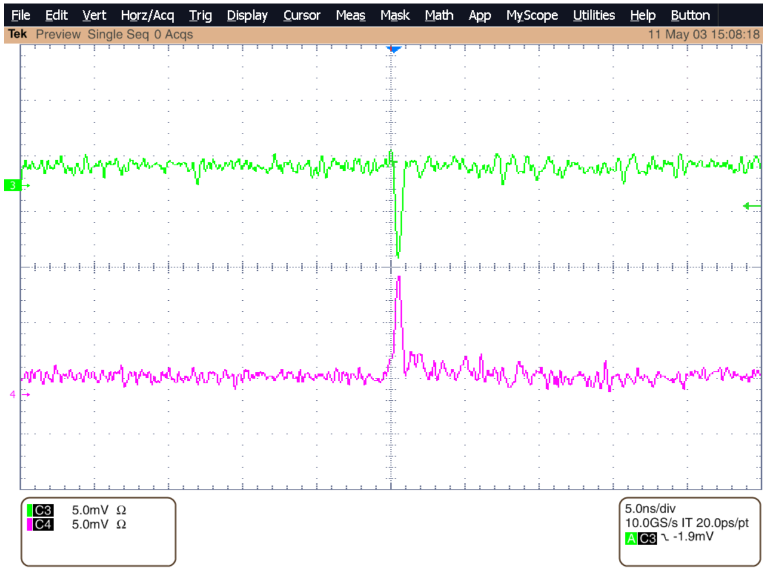
Chamber tightness



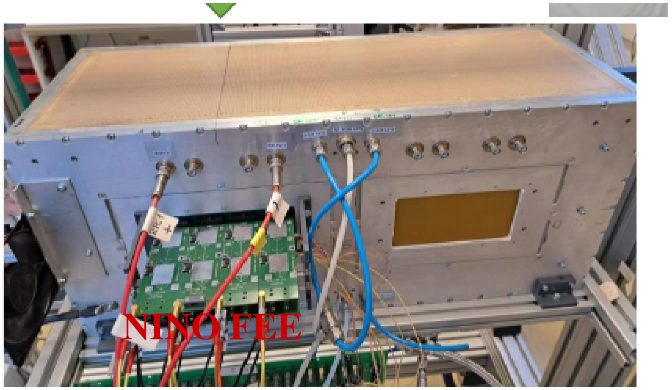
Experimental setup



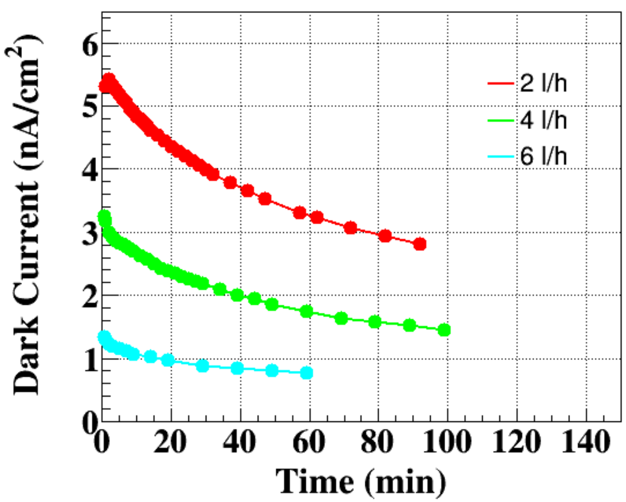
MRPC1b

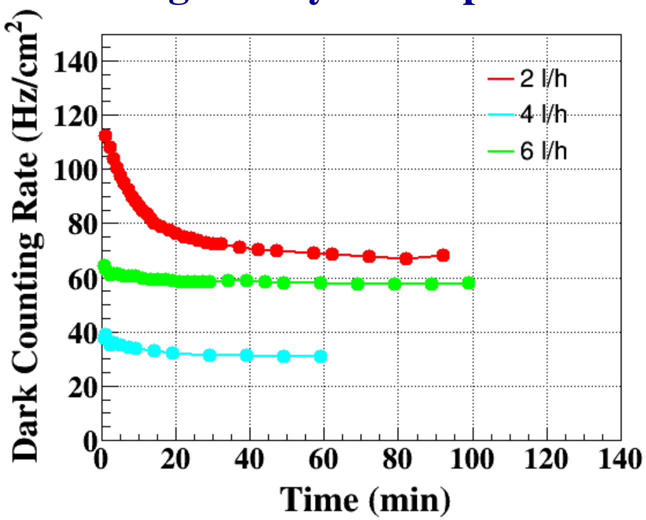


Gas mixture: 97.5% $C_2H_2F_4$ + 2.5% SF_6



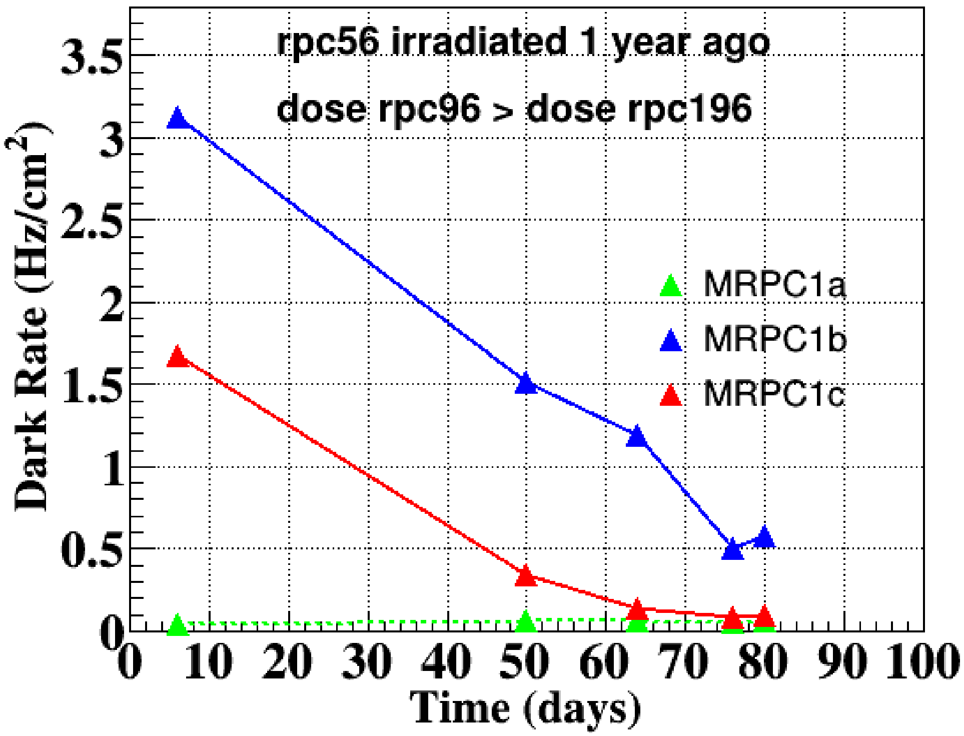
Dark current & dark counting rate after high X-ray flux exposure





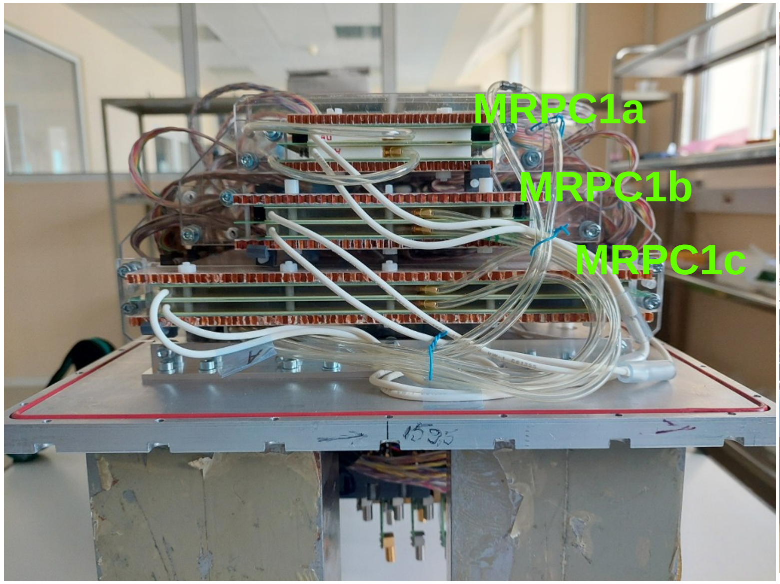
Dark rate long – term evolution

Counter	exposure
MRPC1a (56 mm)	End on 28.09.2022 (35 mC/cm^2)
MRPC1b (96 mm)	21.03 – 13.04.2023 9.4 mC/cm^2
MRPC1c (196 mm)	19.04 – 28.04 2023 2.4 mC/cm^2

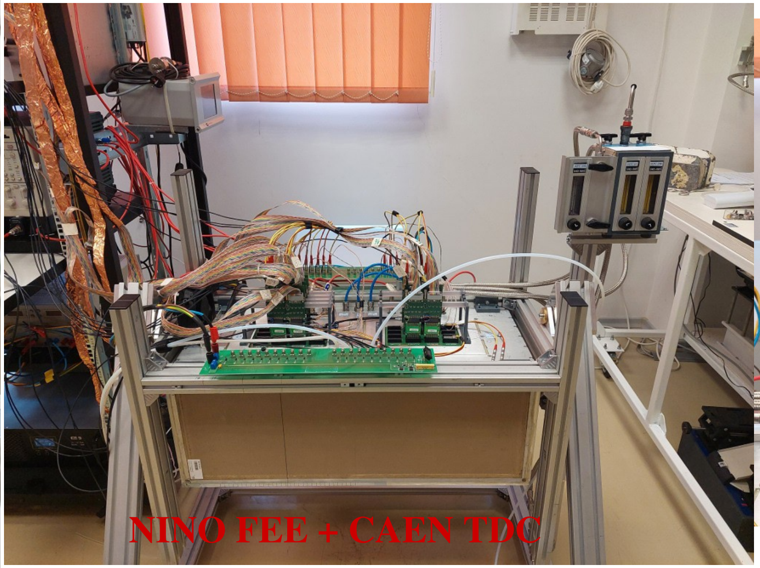


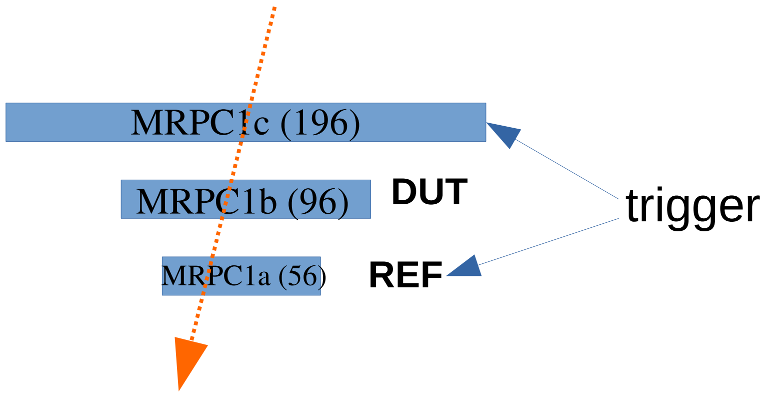
Cosmic - ray tests of the direct flow prototypes

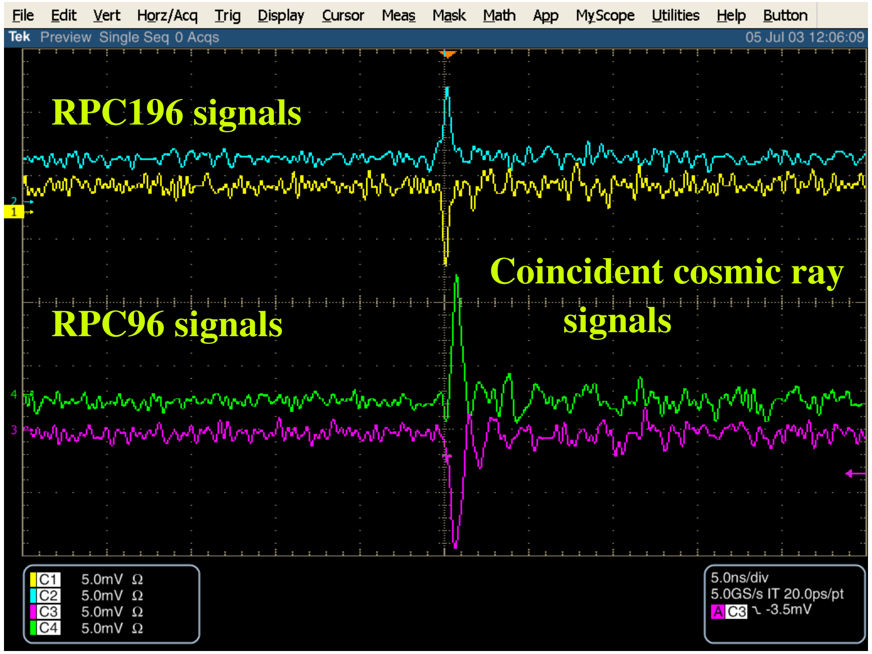
Direct flow MSMGRPC stack



Experimental setup for cosmic rays test



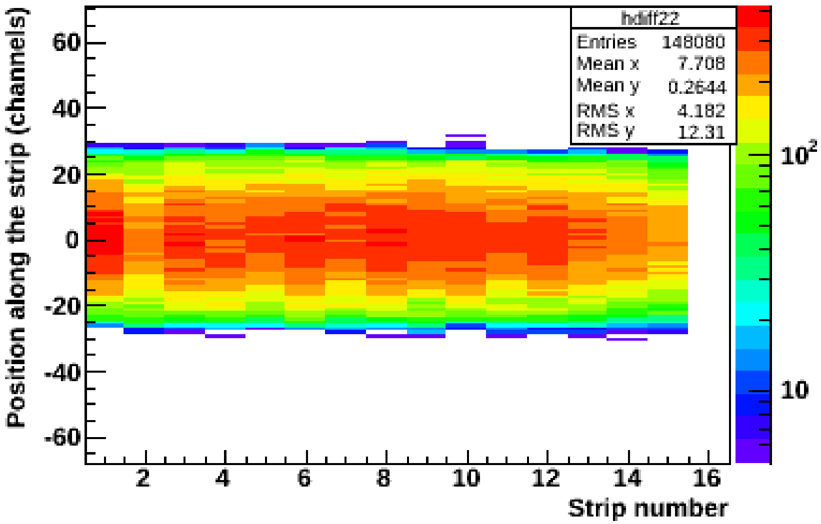




Cosmic - ray tests of the direct flow prototypes

Efficiency &time resolution after exposure to high X-ray flux

DUT



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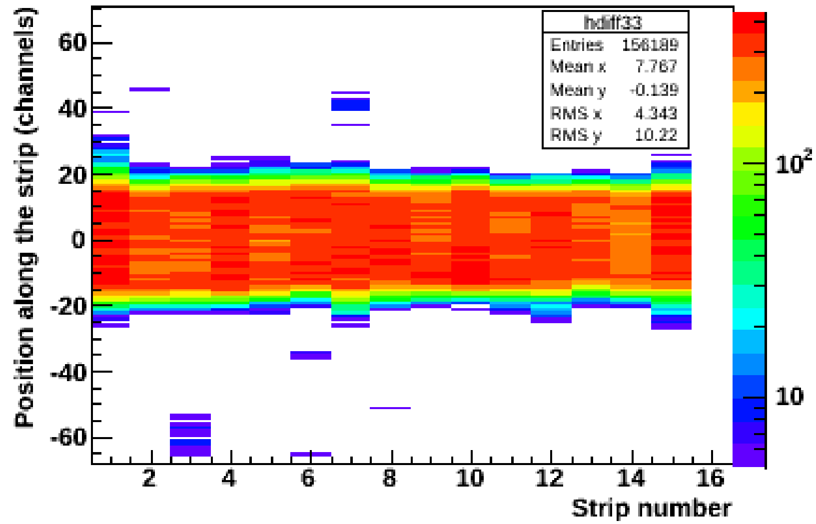
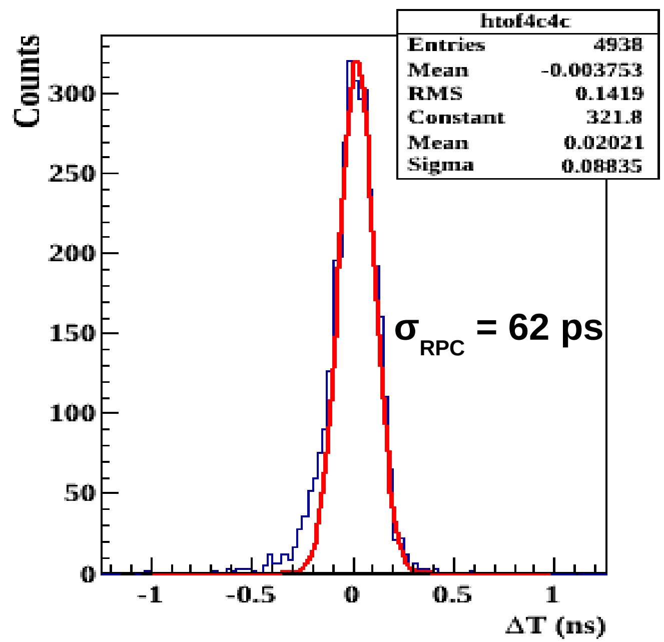
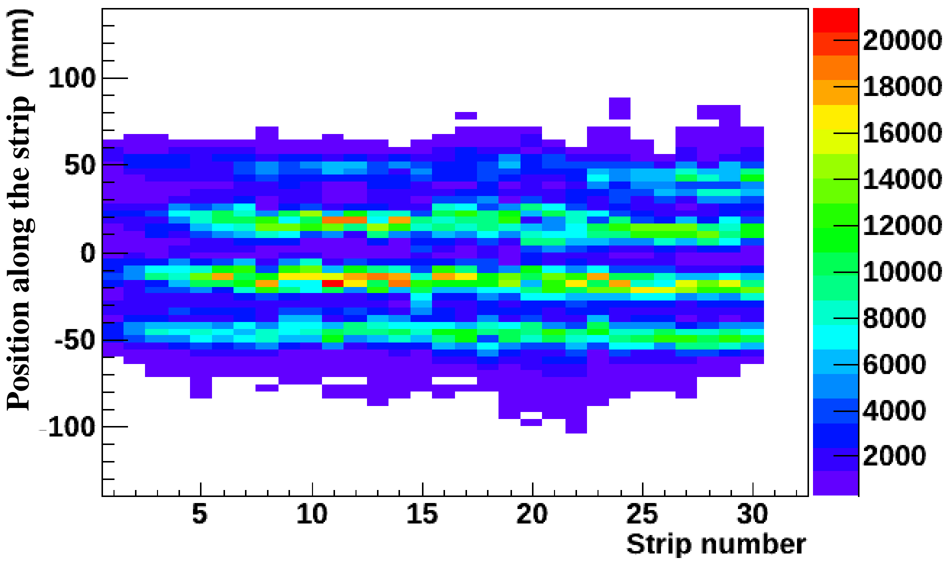
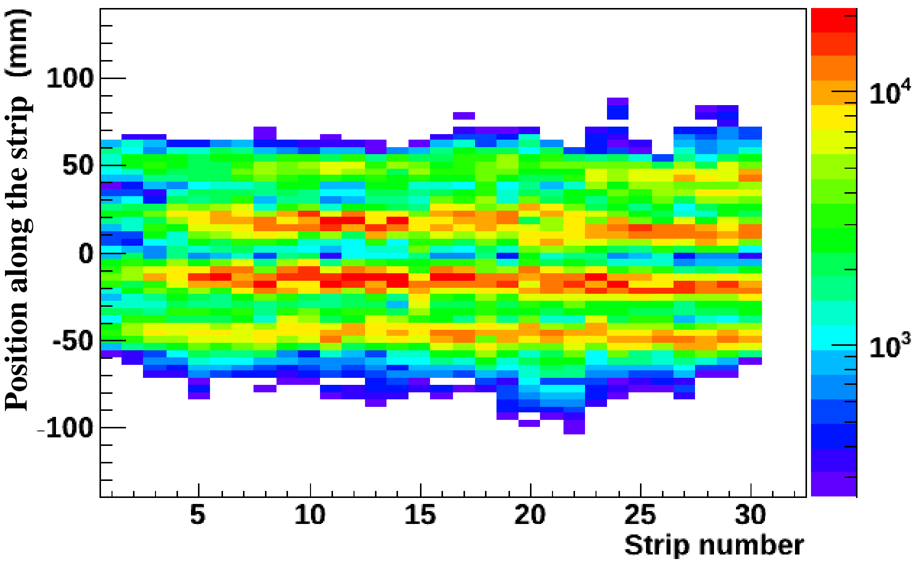


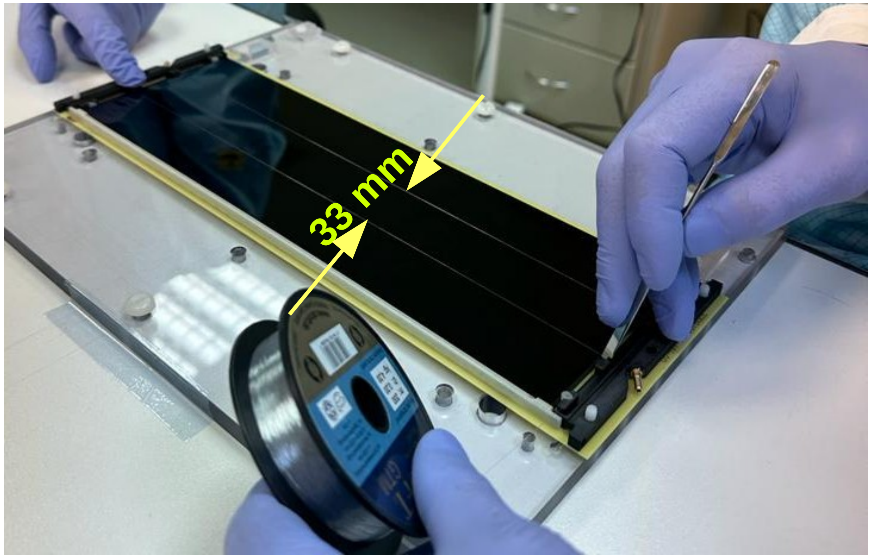
Efficiency = 94.8%

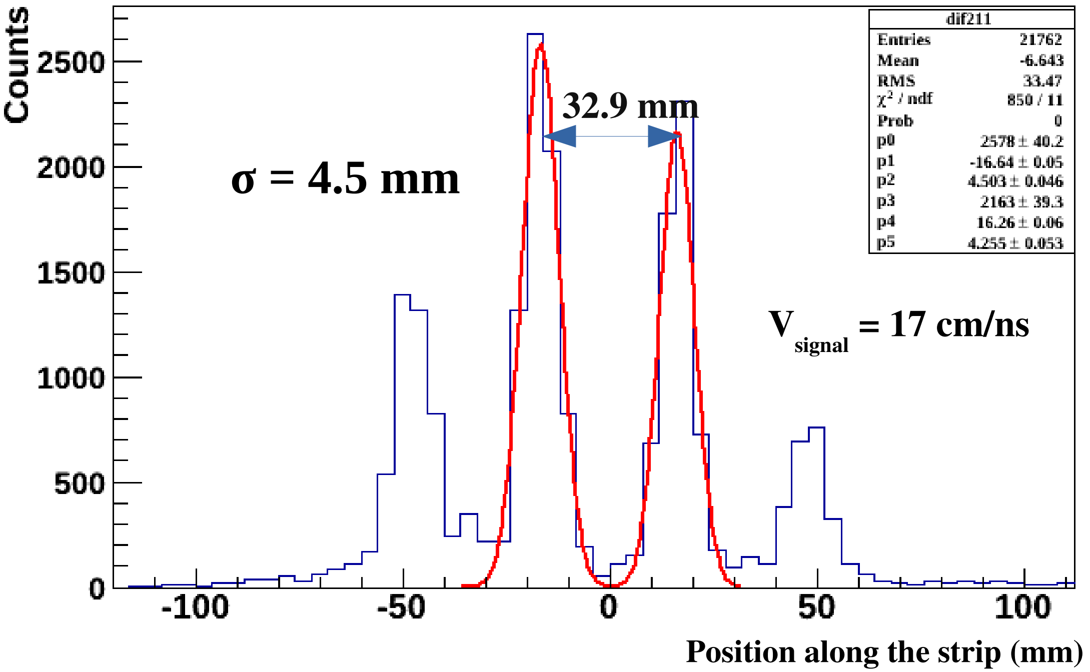


2D mapping of MRPC1b active area in self triggered mode

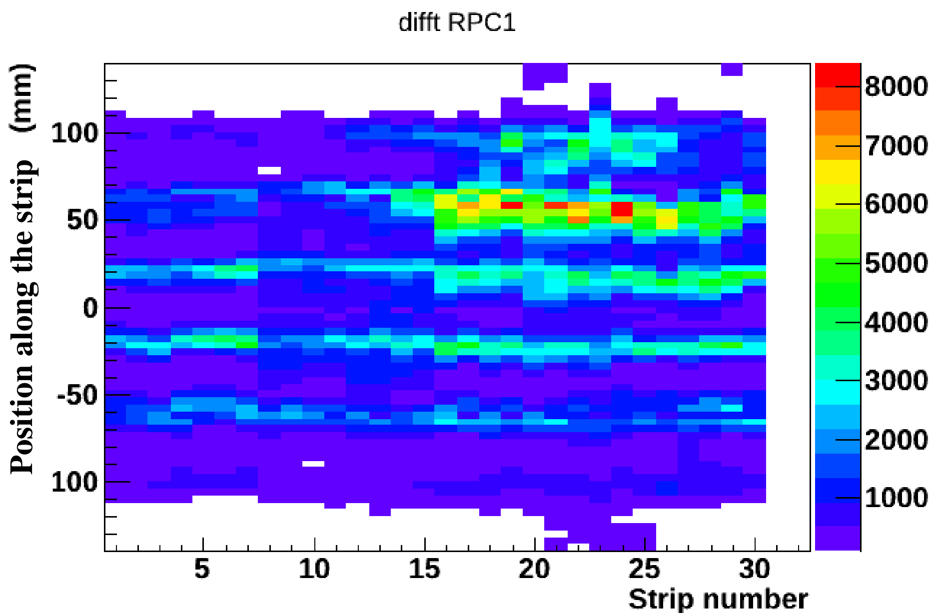


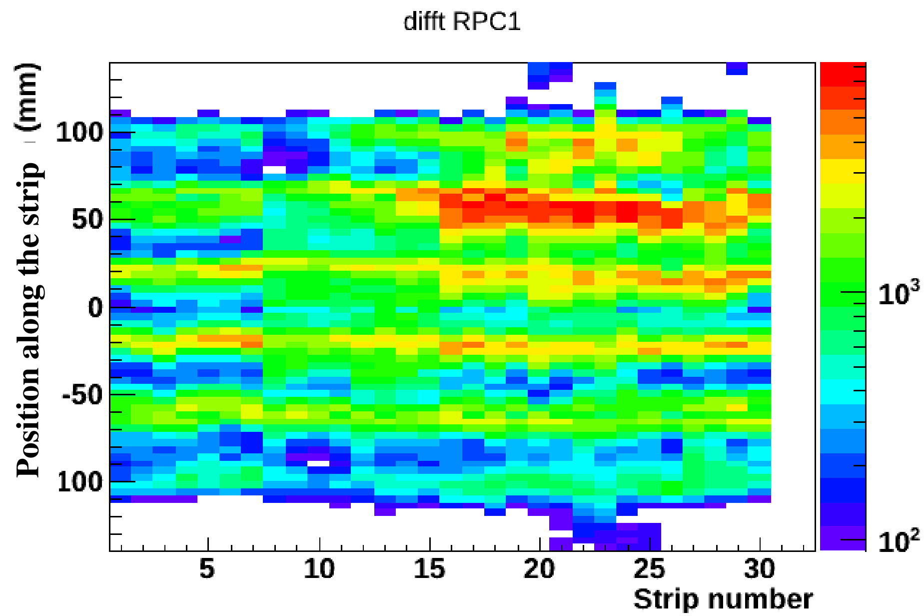


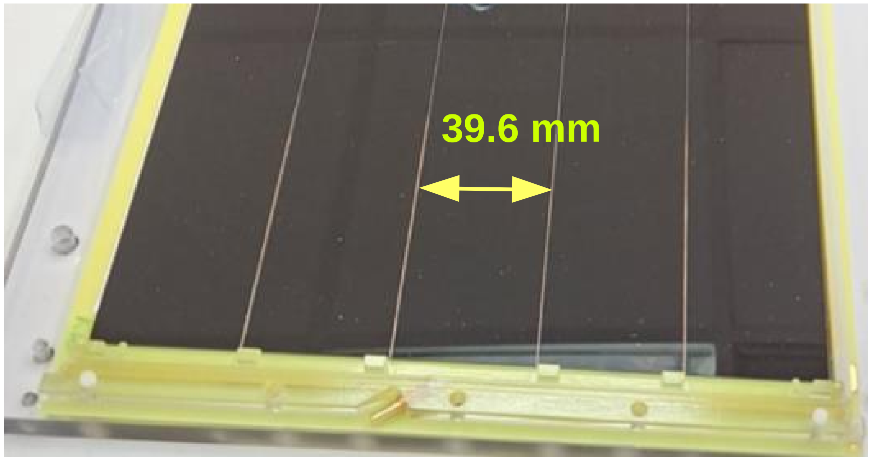


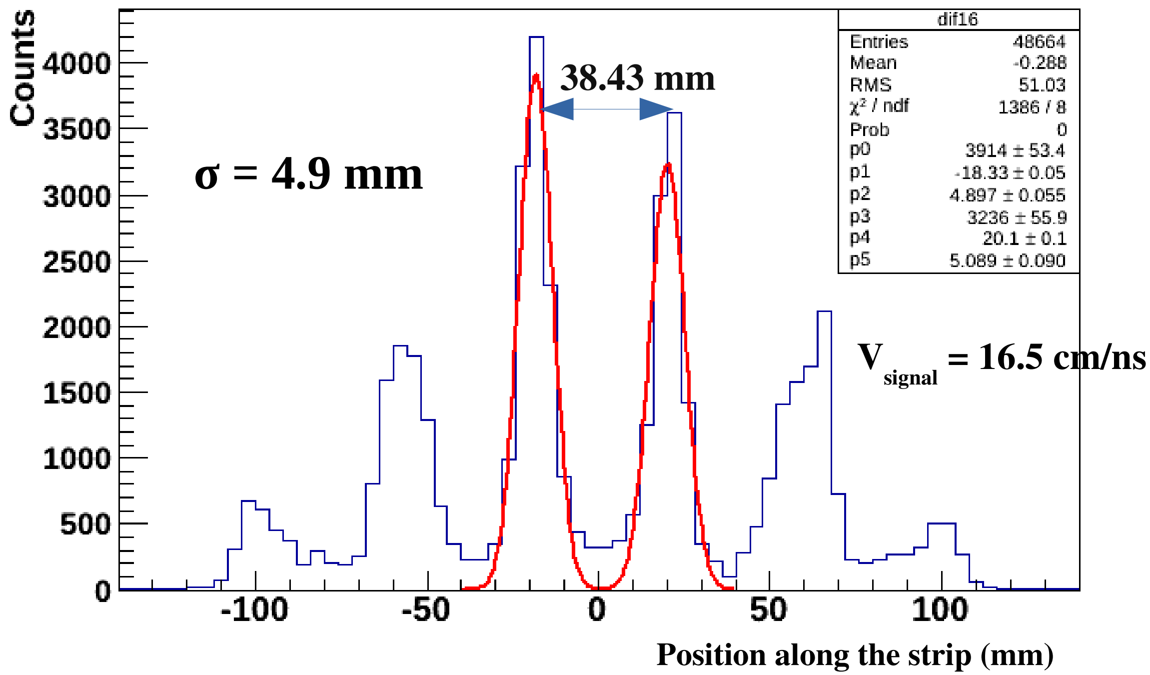


2D mapping of MRPC1c active area in self triggered mode



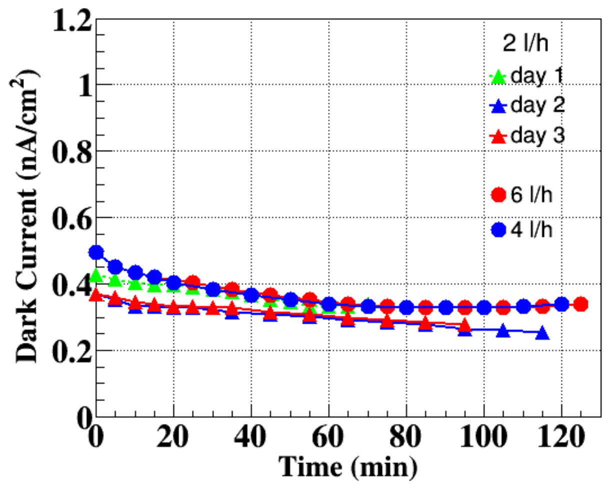


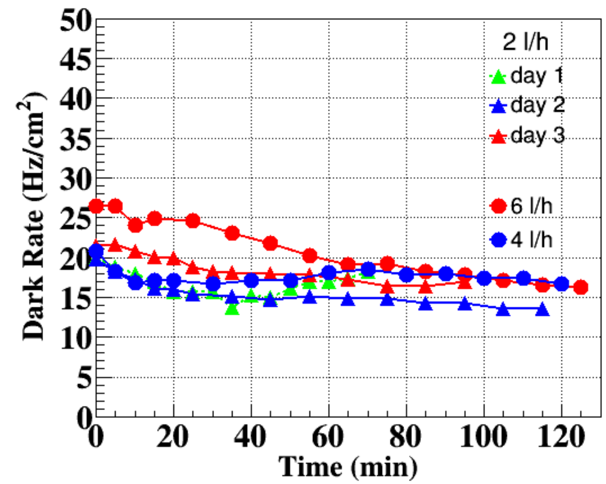




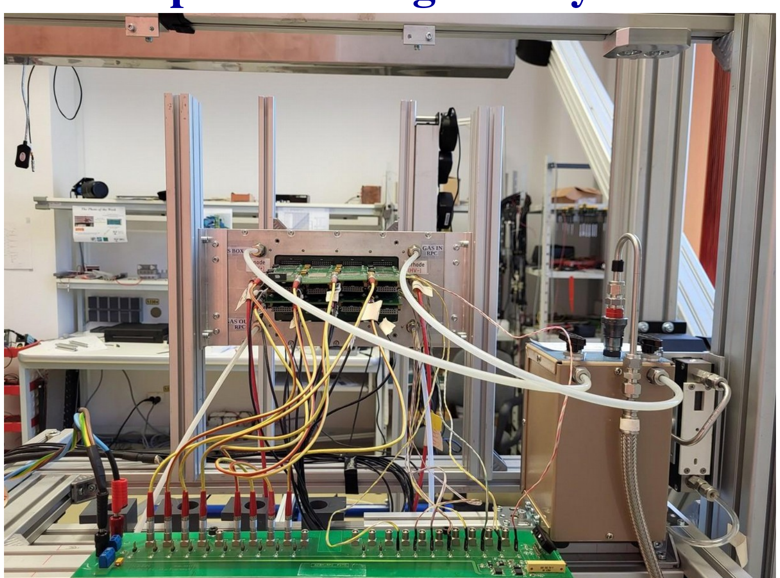
New generation direct flow MSMGRPC

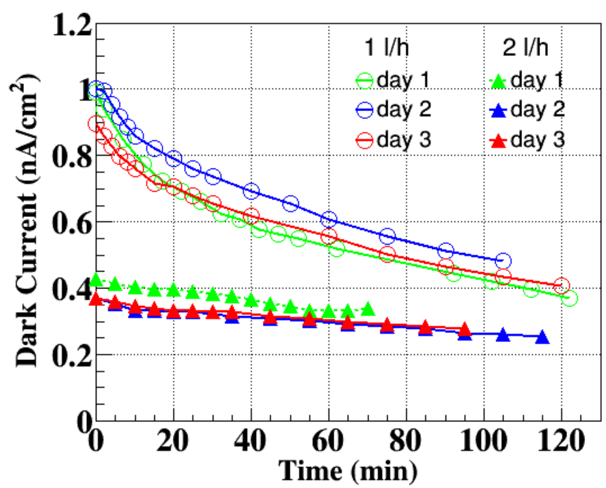
Dark current & dark counting rate after X-ray exposure

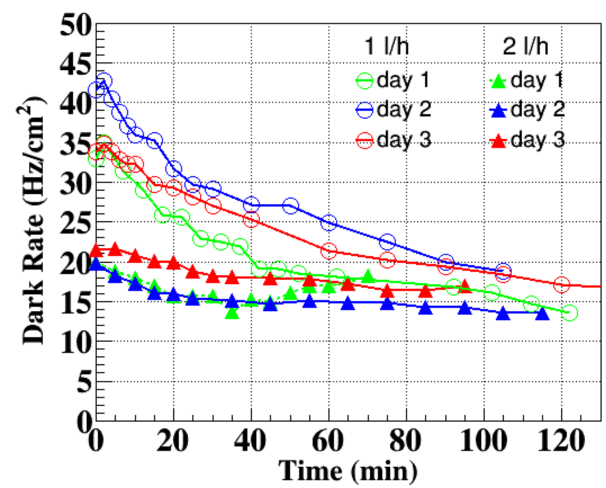




Exposure to high X-ray flux



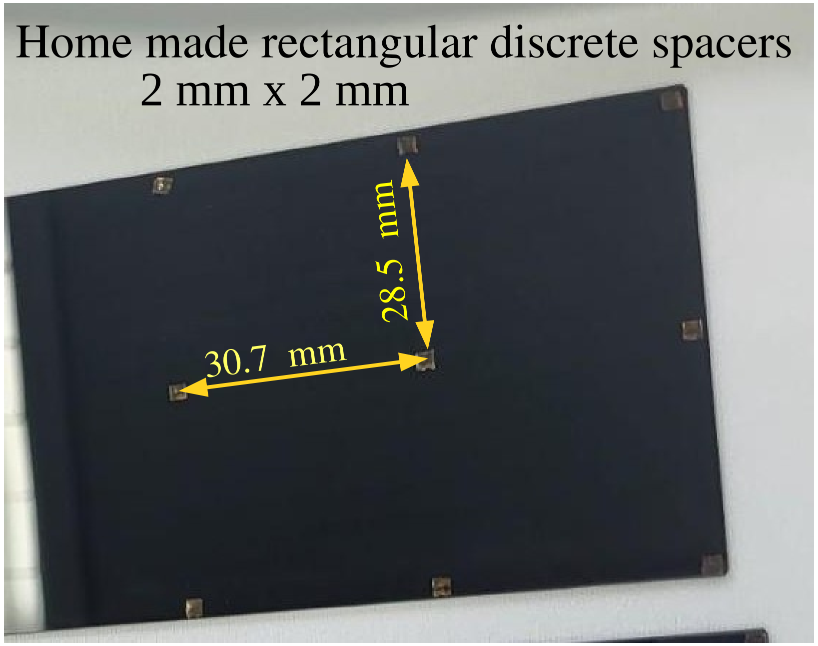


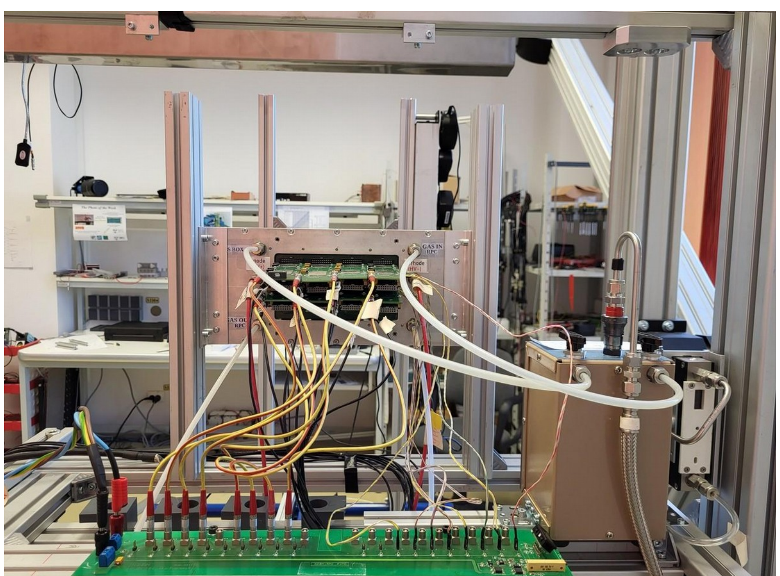


Gas mixture: 97.5% $C_2H_2F_4$ + 2.5% SF_6

New generation direct flow MSMGRPC – discrete spacers

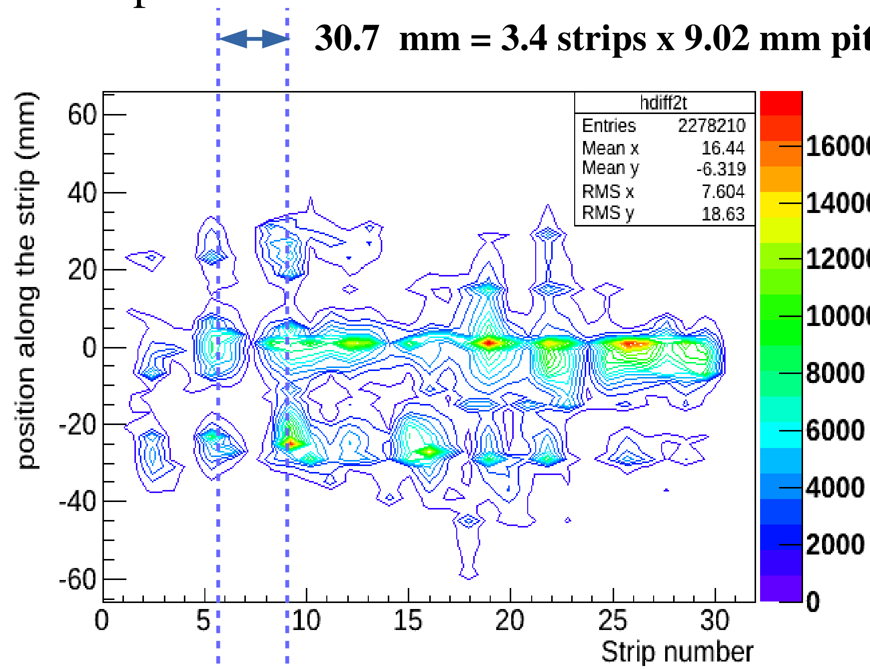
2D mapping in self triggered mode

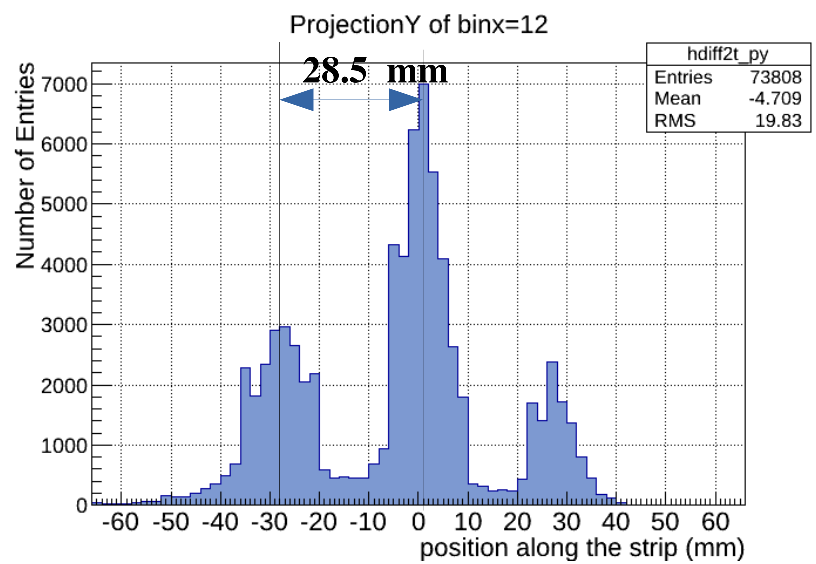




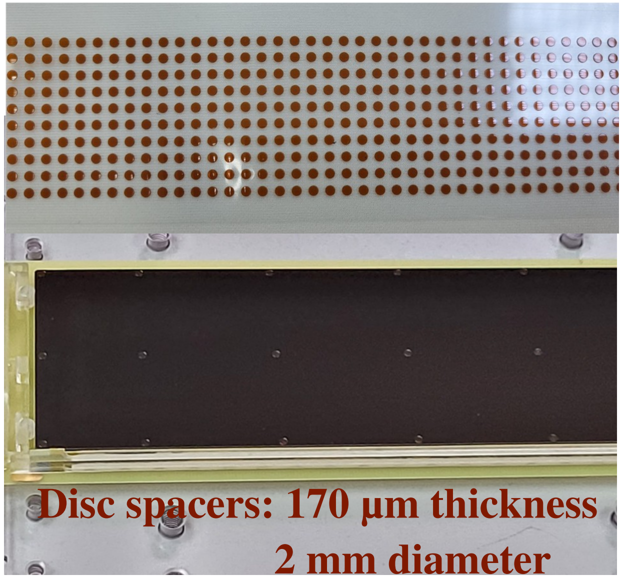
The spacers are the source of the measured dark rate

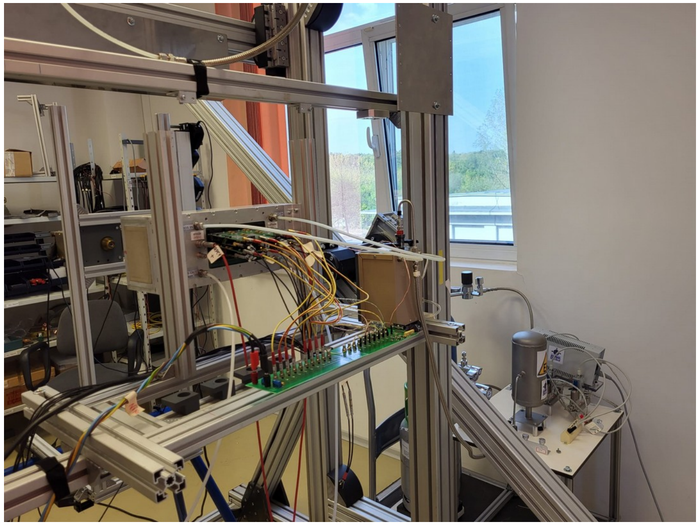
30.7 mm = 3.4 strips x 9.02 mm pitch



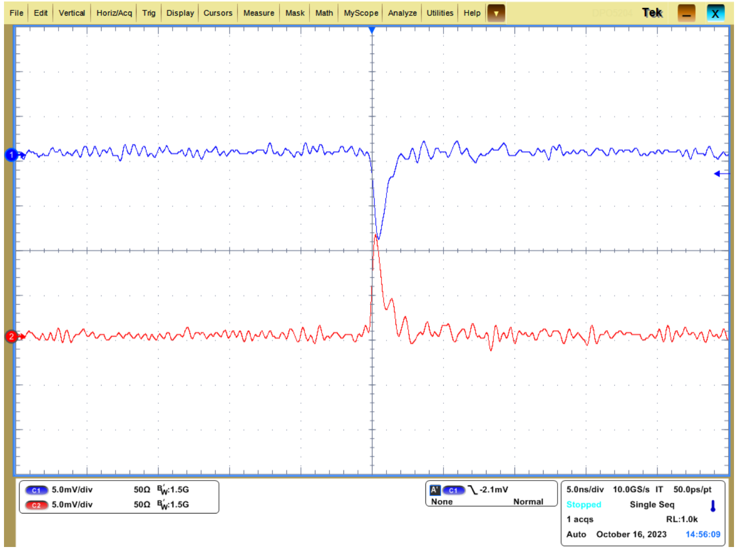


New generation direct flow MSMGRPC
based on commercial polyimide disc spacers

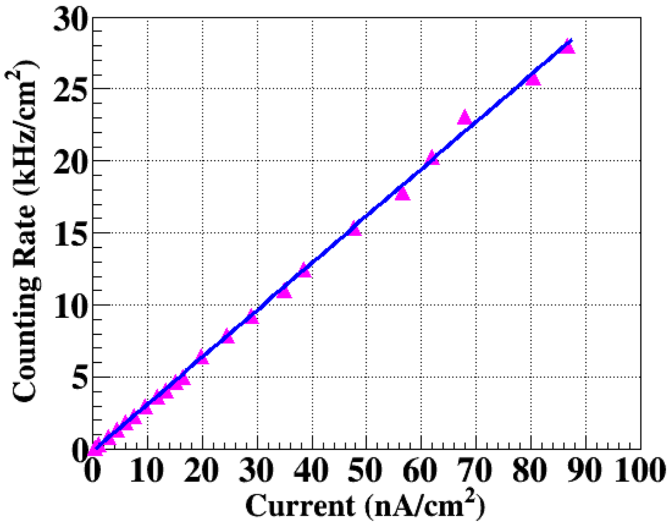


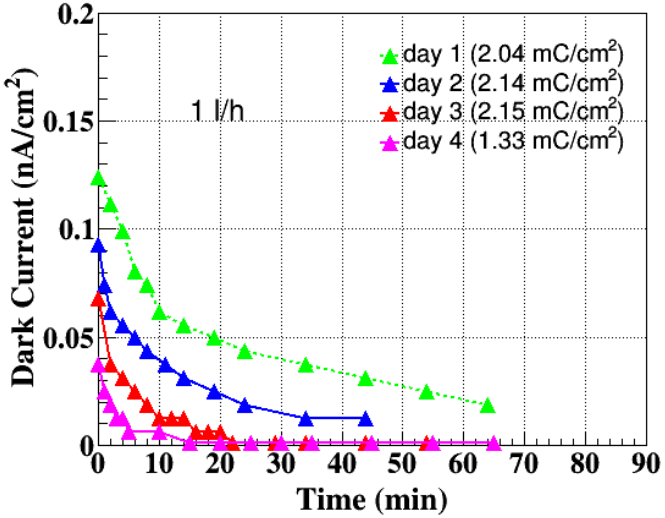


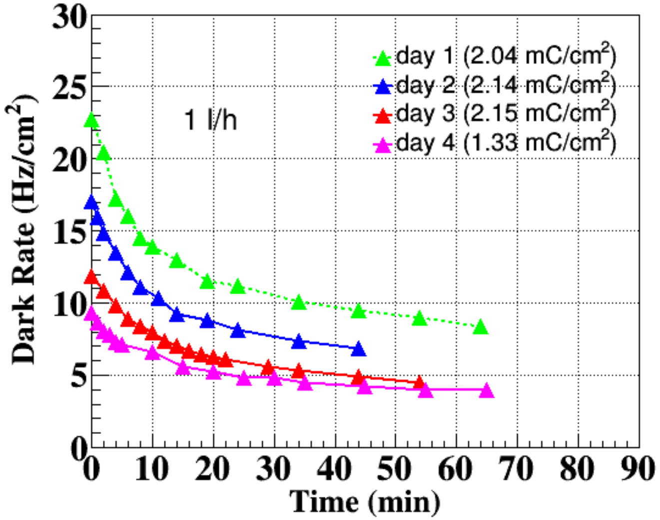
Gas mixture: 97.5% $C_2H_2F_4$ + 2.5% SF_6



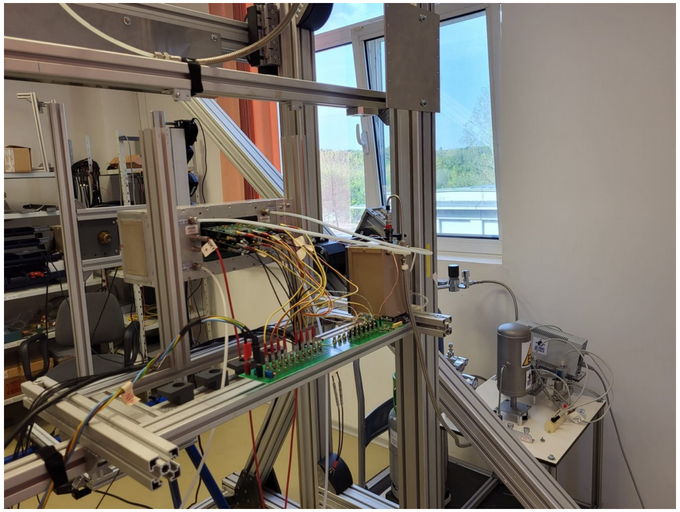
Exposure to high X-ray flux & recovery

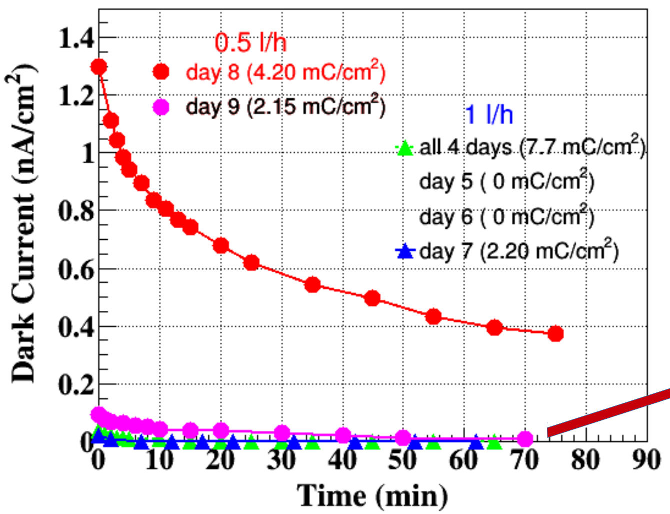


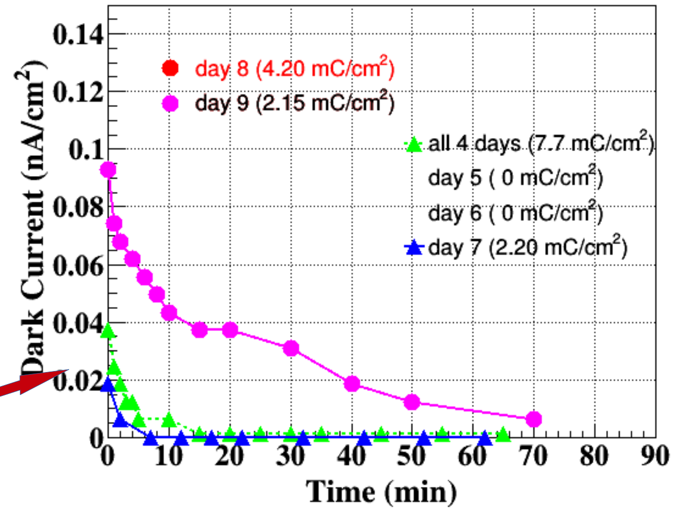




New generation direct flow MSMGRPC based on commercial polyimide disc spacers



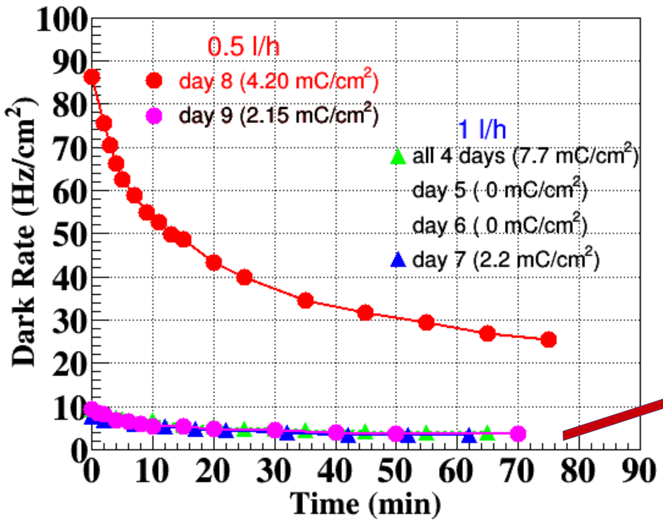


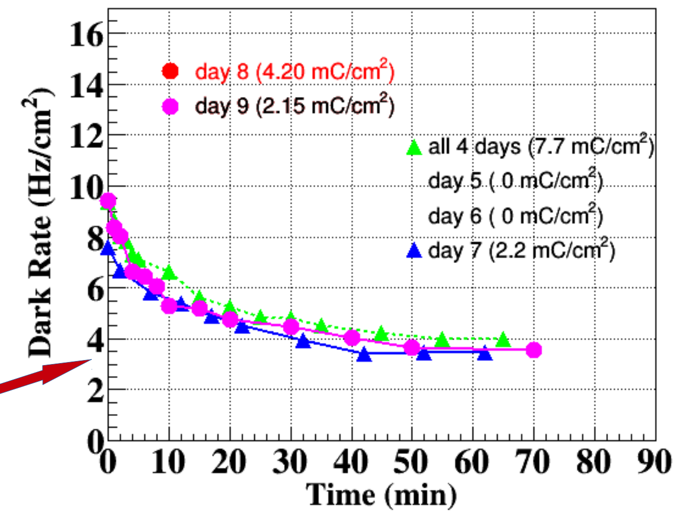


Chamber operation:

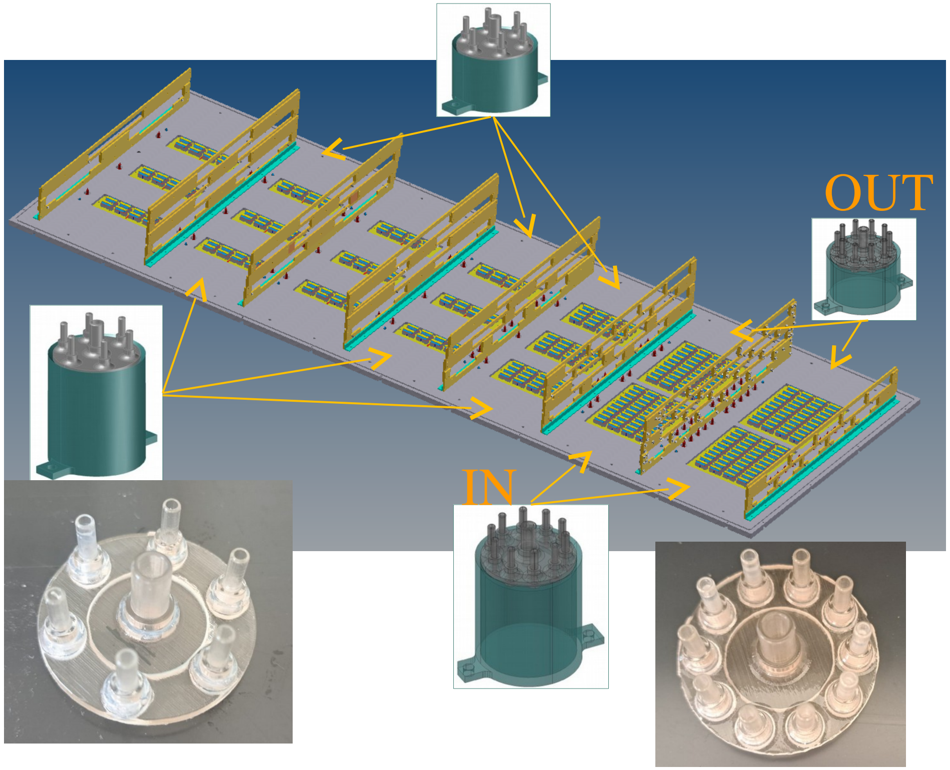
All days: 2 x 5.6 kV → 132 kV/cm
Counting rate = 28 – 30 kHz/cm^2

Day 8 : 2 x 6.0 kV → 141 kV/cm
Counting rate = 45 – 47 kHz/cm^2

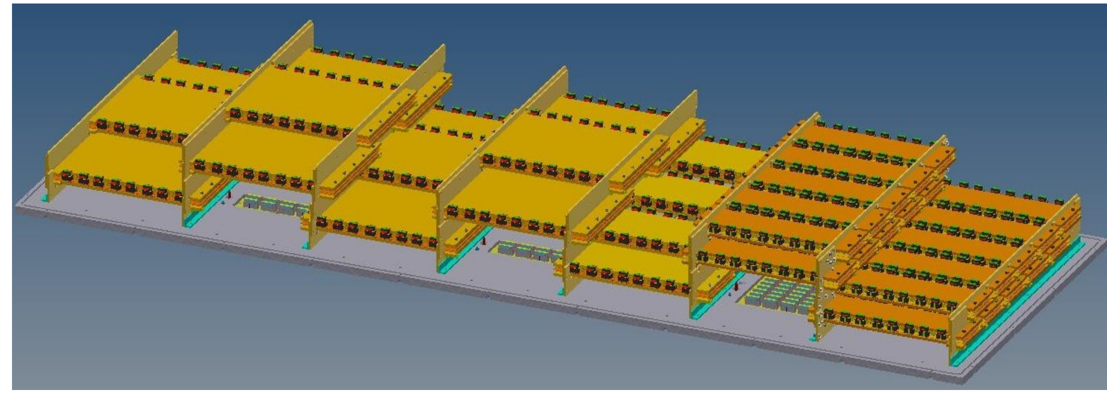


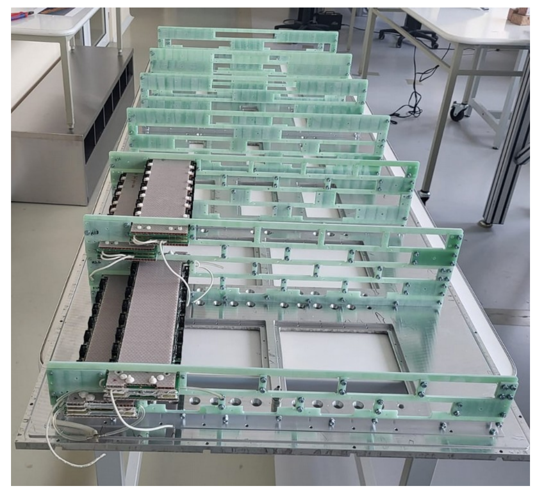


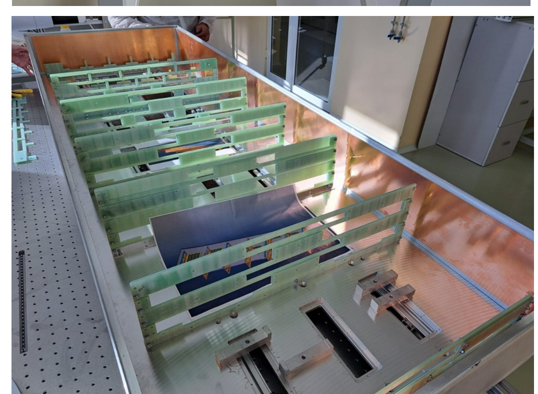
Implementation of the new generation direct flow MSMGRPC in the M0 module of the CBM-TOF inner zone



Six/ten gas pipes distributors printed 3D







Summary & Outlook

- The aging tests of MSMGRPCs for the CBM-TOF inner zone performed using a high intensity ^{60}Co source evidenced an important gas pollution effect which could limit the lifetime of the counter.

- Proposed mitigation solutions has been MSMGRPCs with direct flow through the gaps and reduced number of the fishing line spacers in the active area. Gas flow rate studies showed a minimization of the aging effects (dark current and dark counting rate) with the increase of the gas flow, its suppression being observed at 6 l/h.

- Due to the still high dark counting rate localized in the close vicinity of the spacer, a new architecture of the counters is proposed. The fishing line spacers were replaced with discrete spacers which minimize the active area in contact with spacers.

- The X-ray aging investigations showed very promising results: dark current and dark counting rate are independent of gas flow and goes to negligible values in hours, even at gas flow rate of 0.5 l/h.

- X-ray irradiated counters maintain their performance in terms of time resolution and efficiency after exposure.

- Dedicated high counting rate tests in mCBM and MIP aging tests are required and they will follow.

Acknowledgements

IFIN-HH Bucharest
Hadron Physics Department

V. Aprodu

D. Bartos

A. Caragheorgheopol

D. Dorobantu

V. Duta

M. Petris

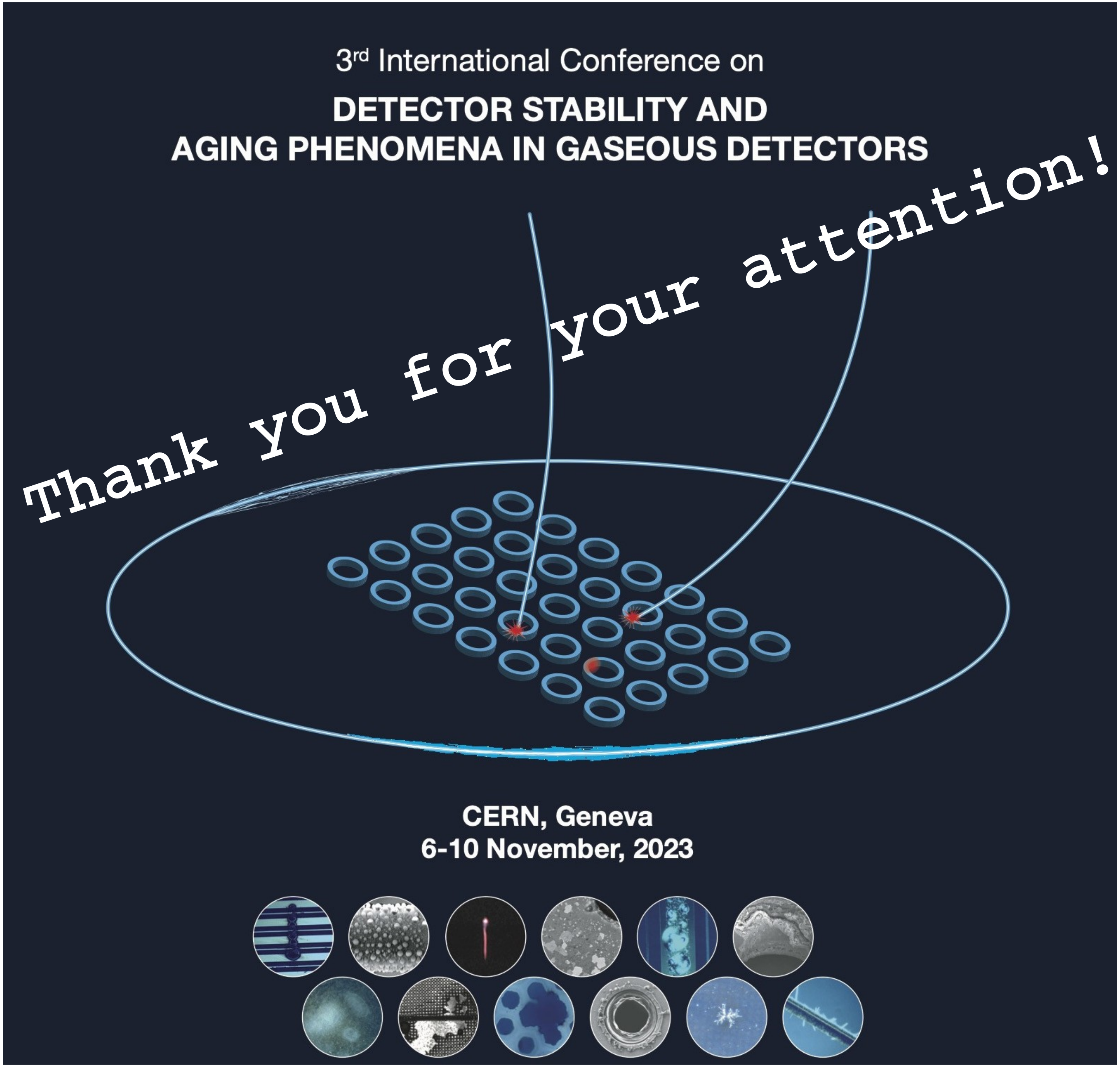
M. Petrovici

A. Radu

G. Stoian

GSI Darmstadt
Jochen Frühauf

Universität Heidelberg
Ingo Deppner
Norbert Herrmann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Thank you for your attention!
CERN, Geneva
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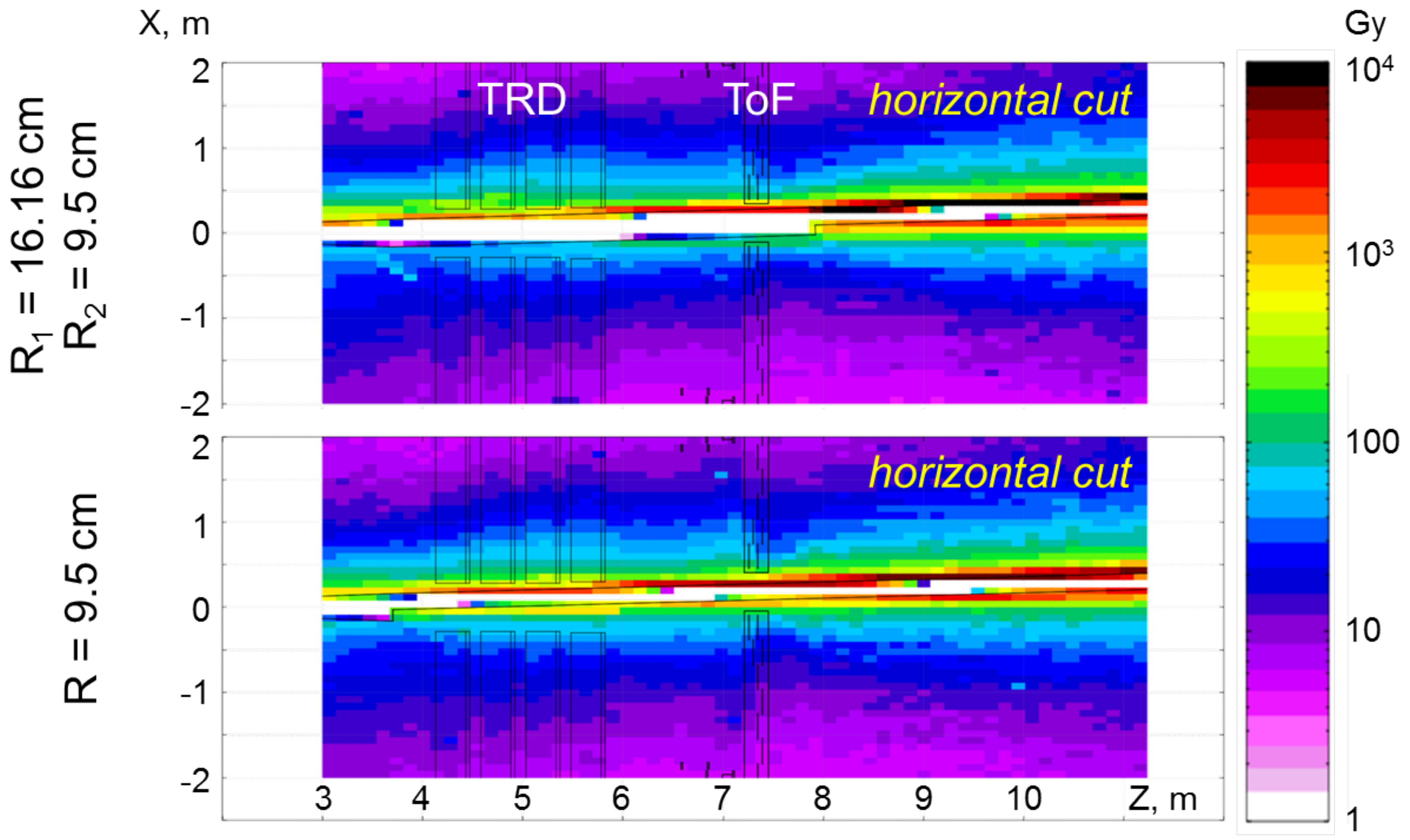
Back up slides

FLUKA simulations

Au beam with kinetic energy of 2A GeV, 10^7 interactions/s, over 2 months



A. Senger, Design simulations of beam pipe and radiation studies for the CBM experiment, CBM-TN-18001, 2018.

1D-position along 16 measured strips – self triggered mode MRPC1c fishing line spacers