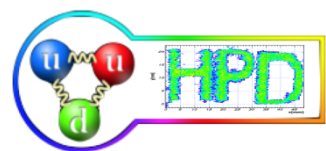


**High rate, high time resolution,
2D-position sensitive
and aging effect suppression
Multi-Strip Multi-Gap Resistive Plate Counter**

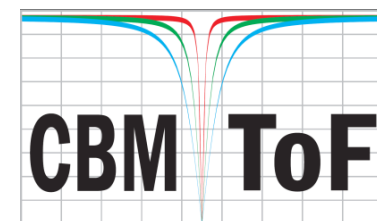
Mariana Petris

Hadron Physics Department

National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania



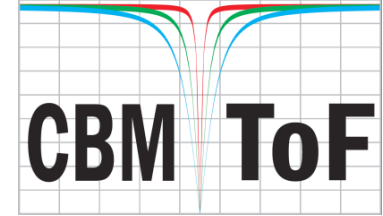
XVI Workshop on Resistive Plate Chambers and Related Detectors,
CERN, 26 – 30 September 2022



Outline

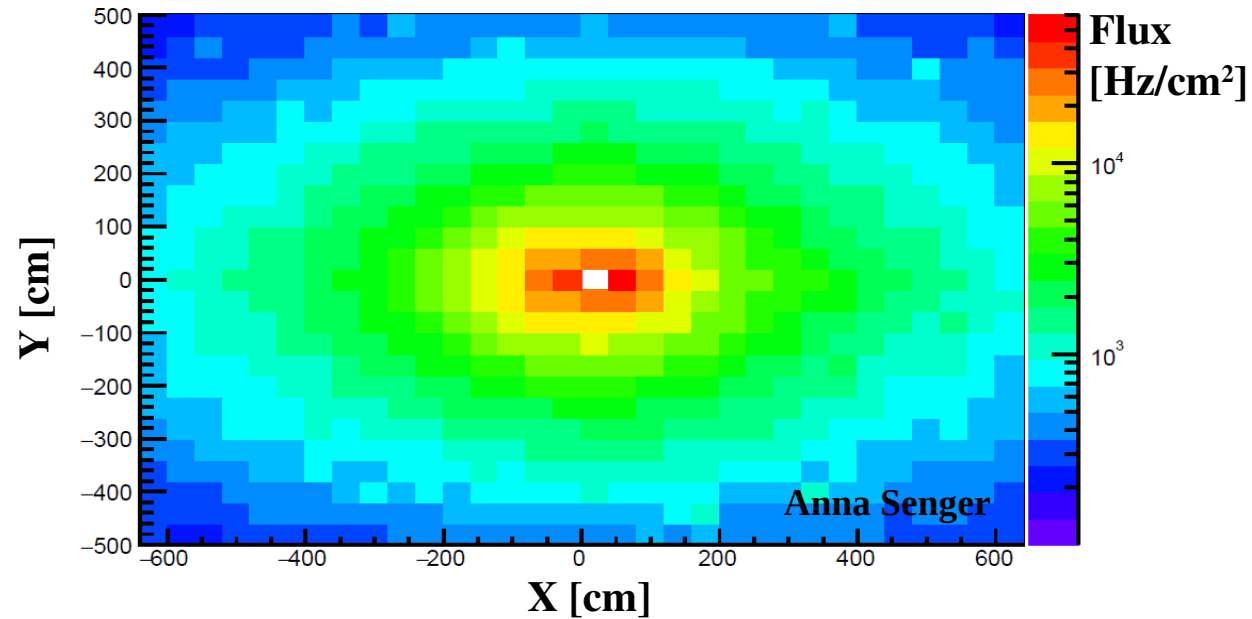
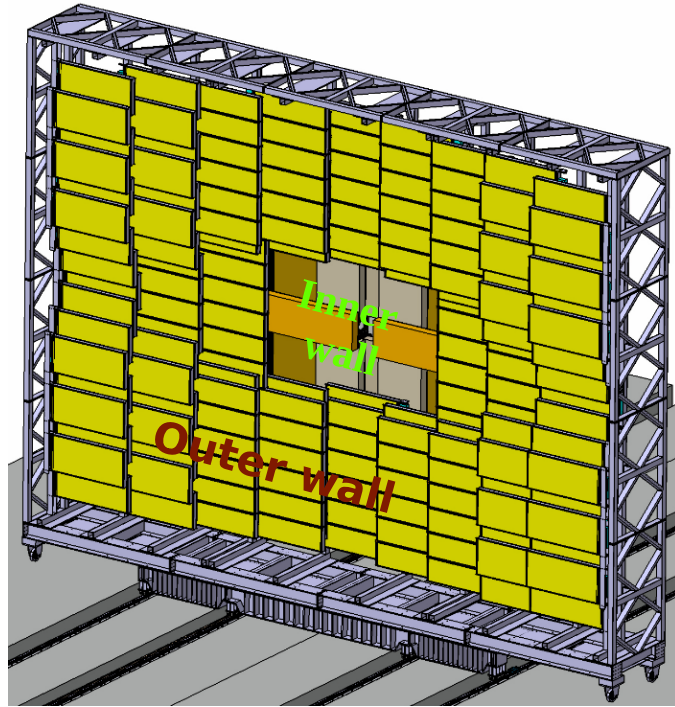
- **Motivation – next generation high counting rate, high multiplicity experiments, (e.g. CBM/FAIR, Darmstadt ->TOF inner wall)**
- **MSMGRPC with high granularity and impedance matching**
- **In-beam and high counting rate test of the MSMGRPC**
- **Aging investigations with high activity ^{60}Co source**
- **MSMGRPC prototype with direct gas flow – assembling & in-beam test**
- **X-ray tube aging studies**
- **Summary and Outlook**

CBM – TOF wall



→ see Ingo's talk on Monday

FLUKA simulation: Au + Au collisions at $E_{\text{kin}} = 11A$ GeV, 10^7 interactions/s
Charged particle flux at a distance of 8 m from the target



CBM-ToF Requirements

- Full system time resolution $\sigma_T \sim 80$ ps
- Efficiency $> 95\%$
- Rate capability ≤ 50 kHz/cm²
- Polar angular range $2.5^\circ - 25^\circ$
- Active area of 120 m²
- Occupancy $< 5\%$
- Low power electronics (~ 120.000 channels)
- Free streaming data acquisition

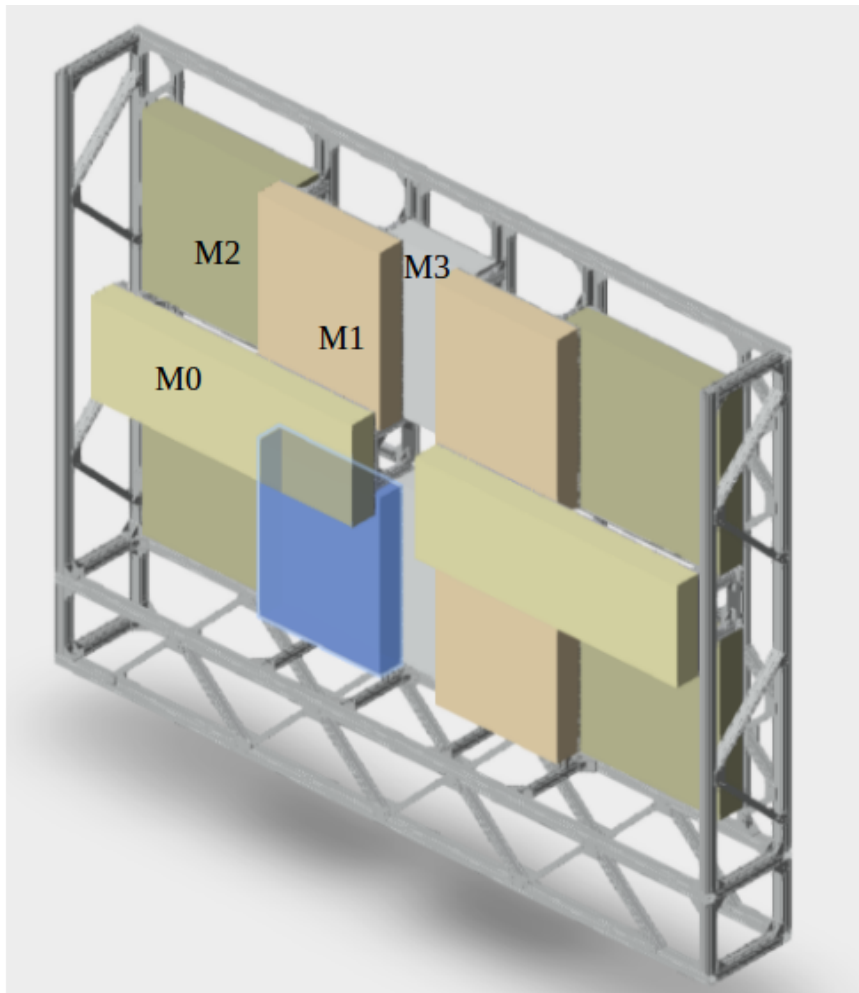
Detectors with different rate capabilities and granularities are needed as a function of polar angle

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

- highest counting rate
- highest granularity
- ~ 15 m² active area (up to $\sim 11^\circ$ polar angle)

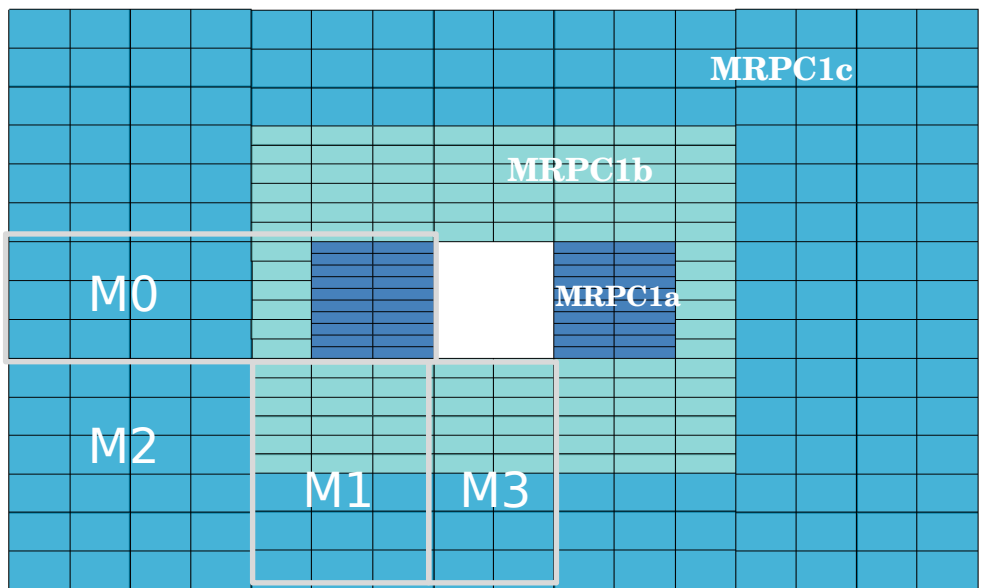
CBM – TOF Technical Desing Report, October 2014

CBM – TOF inner wall



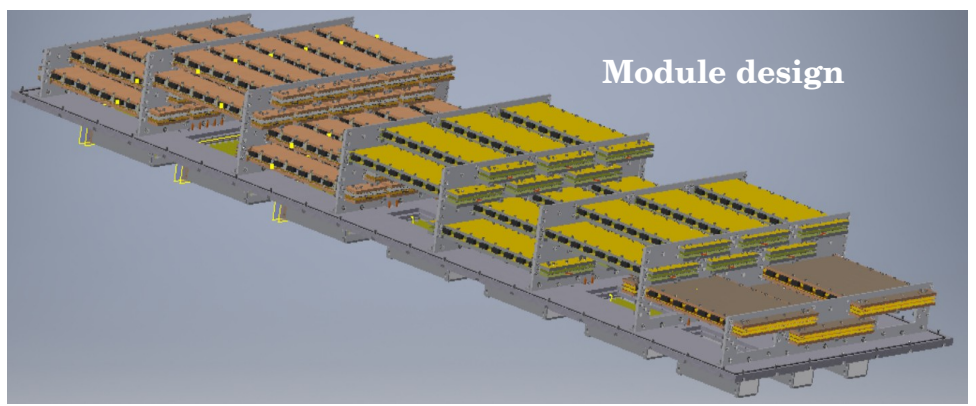
CBM-TOF inner zone

- ~15 m² active area
- modular architecture:
 - 12 modules
 - 4 types (M1, M2, M3, M4)

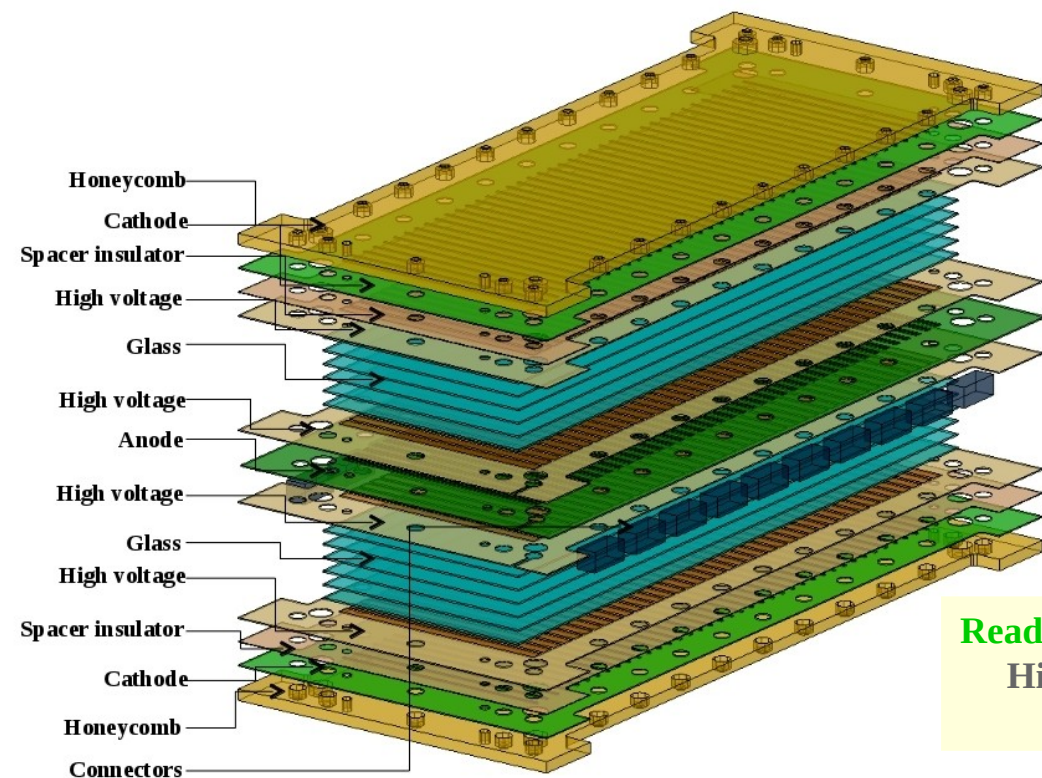


3 counter types: 60/100/200 mm (strip length) x 300 mm

	MRPC1c (200 mm)	MRPC1b (100 mm)	MRPC1a (60 mm)	Total
No. RPCs	168	92	40	300
No. channels	10752	5888	2560	19200

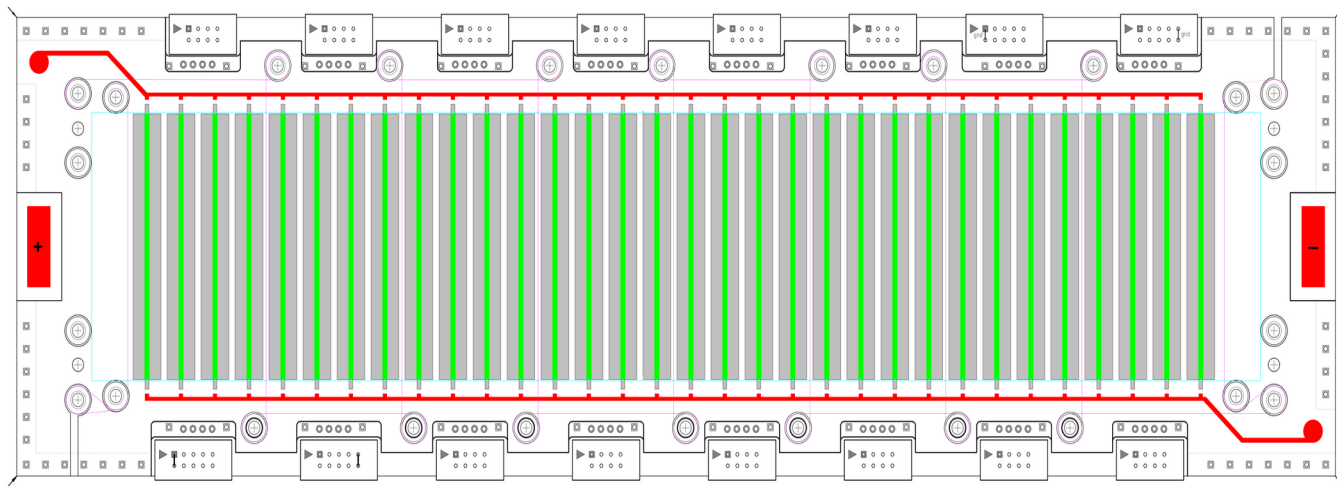
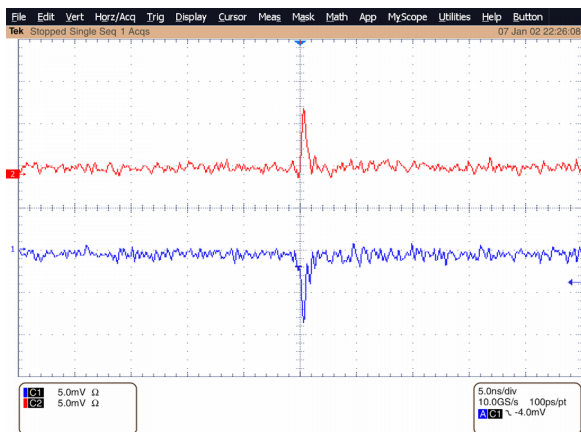


Prototype design considerations



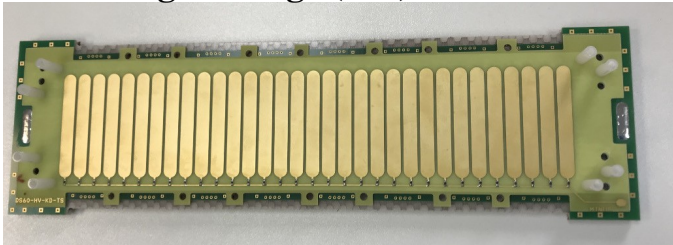
- ✓ Symmetric structure: 5 gaps x 2 stacks
- ✓ Gas gap thickness: 200 μm
- ✓ Active area 60/100/200 mm x 300 mm
- ✓ Resistive electrodes: $\sim 10^{10} \Omega\text{cm}$, 0.7 mm Chinese glass
- ✓ Strip structure for Readout & HV electrodes
- ✓ Differential readout

Readout electrode: 9.02 mm pitch = 1.27 mm w + 7.75 mm g
 High Voltage electrode: 9.02 mm pitch = 7.37 mm W + 1.65mm
 97 Ω signal transmission line impedance

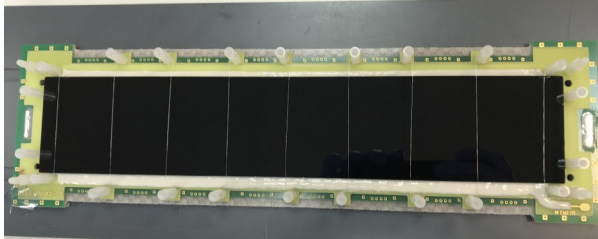


MSMGRPC prototype: 200 μm gas gap, 60 mm strip length

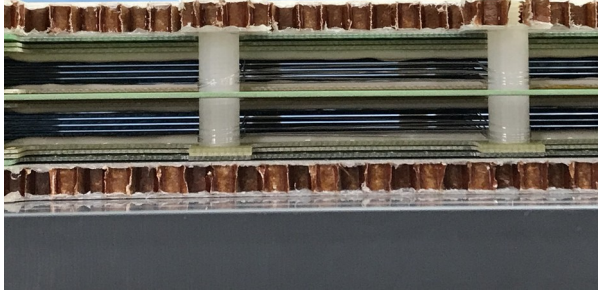
High voltage (HV) electrode



Spacer distribution across the surface



Two stacks



Two counters mounted on the back panel

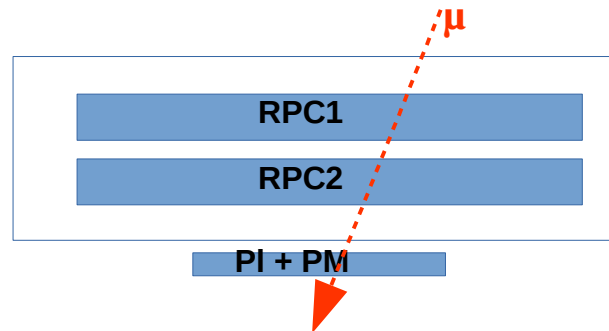
Laboratory cosmic rays test



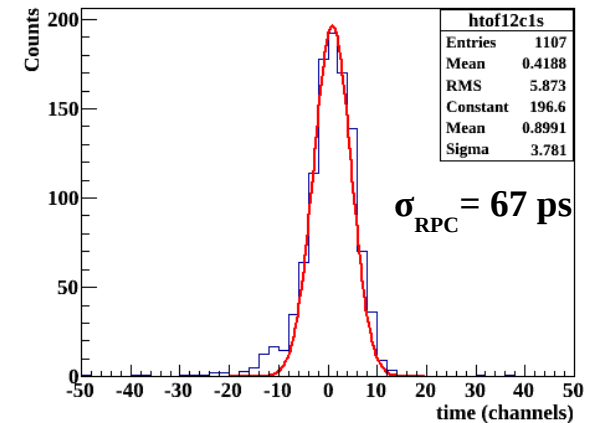
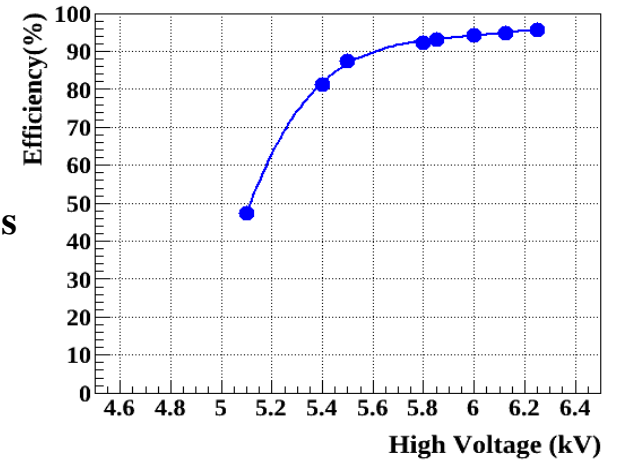
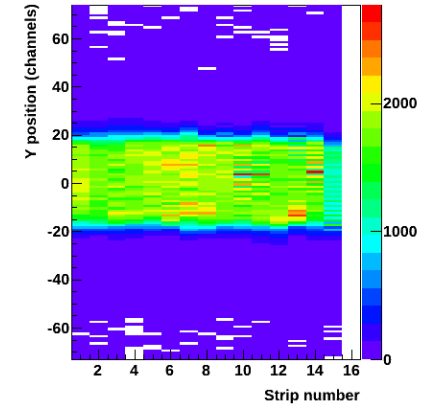
90% $\text{C}_2\text{H}_2\text{F}_4$ + 5% SF_6 + 5% iso- C_4H_{10}

NINO FEE (ALICE Coll.)+CAEN TDCs

MSMGRPC	I_{dark}	Dark rate
RPC1	< 1 nA	0.11 Hz/cm ²
RPC2	< 1 nA	0.14 Hz/cm ²



Self trigger cosmic rays 2D mapping



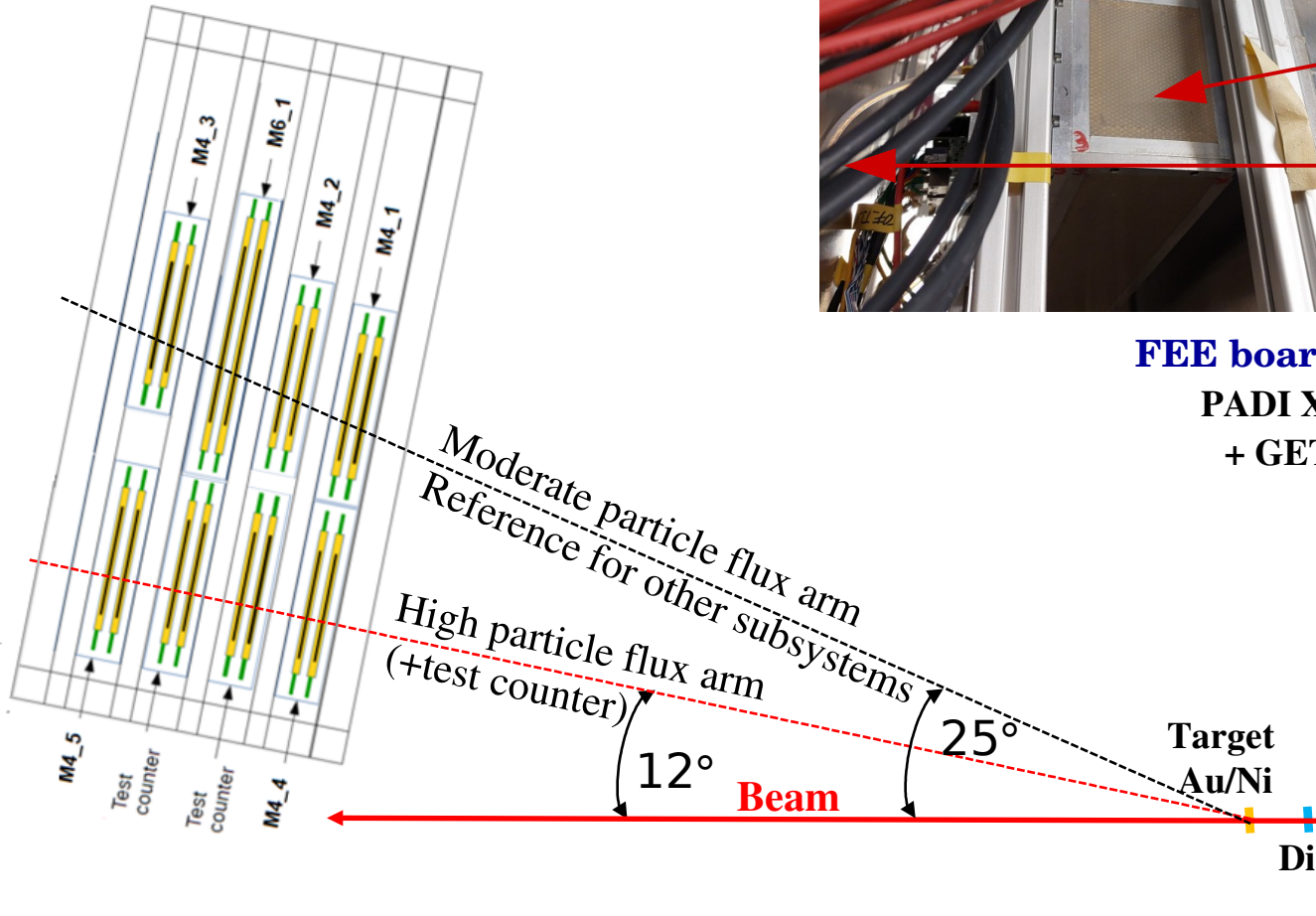
Prototype tests in mTOF -> mCBM@SIS18 2021 beam time

mCBM → see Ingo's talk on Monday

Setup and Tracking:

- 6 counter stations in stack
- Analysis → one station as DUT and 5 reference stations as tracking

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



Beam: ^{16}O , 2A GeV

Reference mTOF Counters (M4_4)

Test counters: USTC, Hefei, China

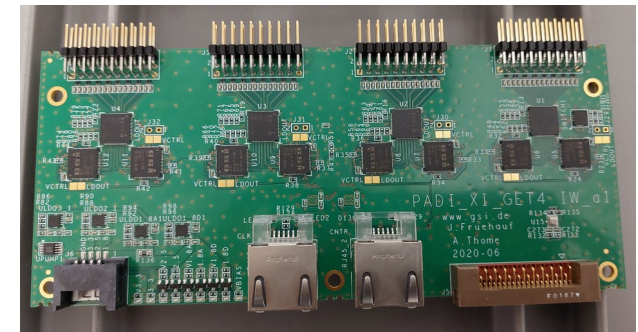
Test counters: IFIN-HH, Bucharest, Romania

Reference mTOF Counters (M4_5)

FEE board for the inner TOF wall (J. Frünhauf)

PADI XI (IEEE Trans. Nucl. Sci., vol. 68, no. 6, p. 1325)

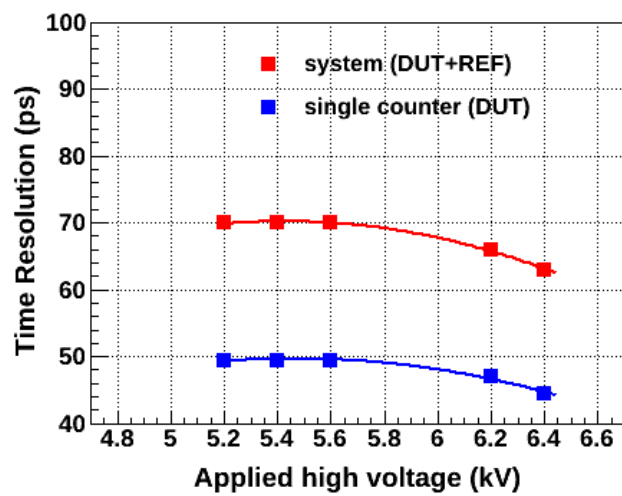
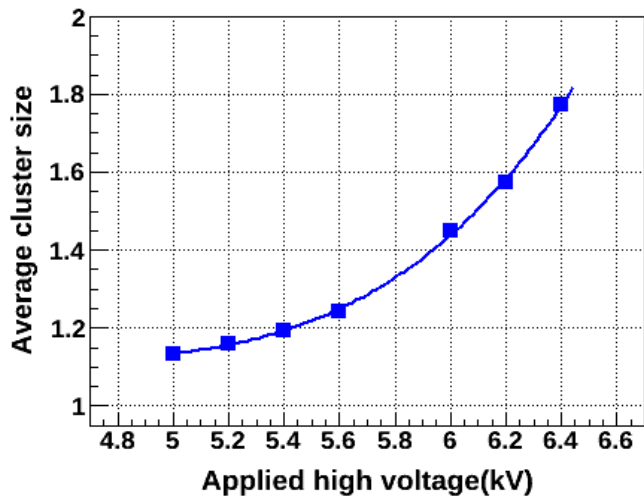
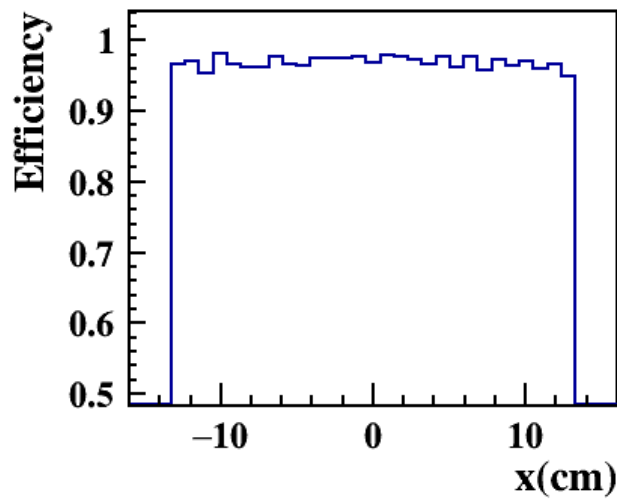
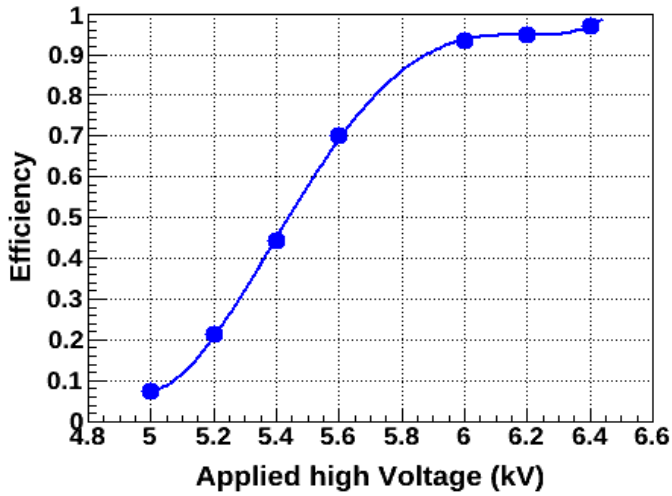
+ GET4 (IEEE Nucl. Sci. Sym. Conf. Rec. (2009) 295)



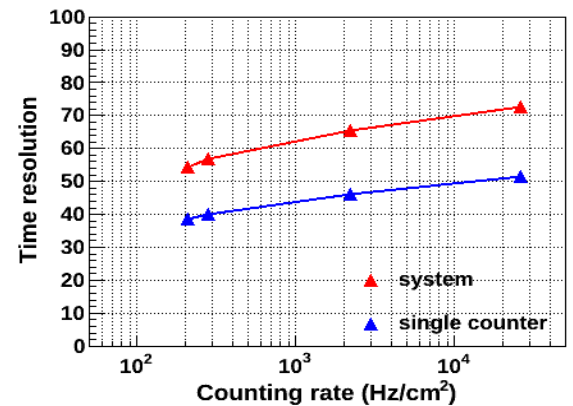
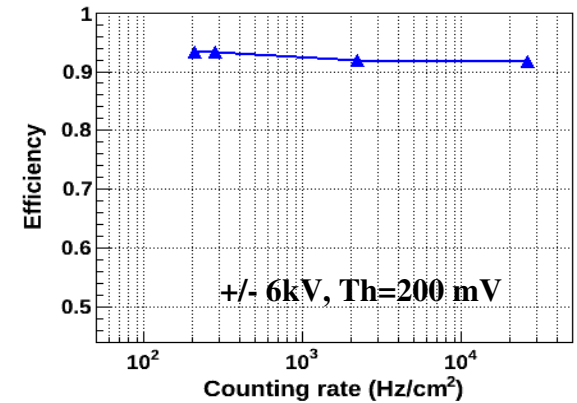
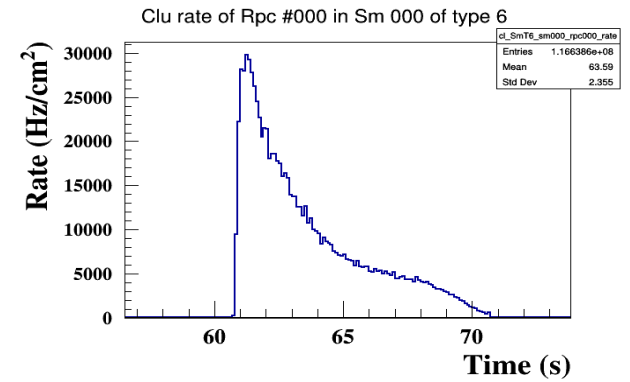
Diamond T0

In-beam test results

High voltage scan

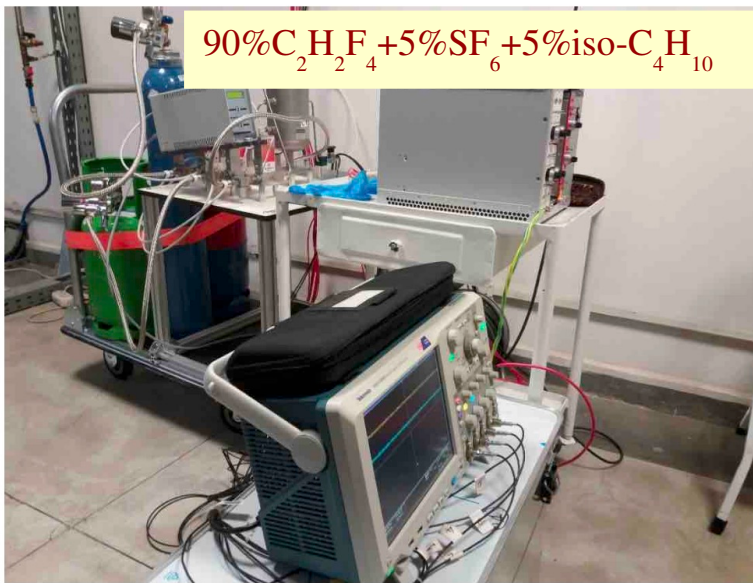


High counting rate scan



Aging investigations

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



Motivation: the detector will maintain its performance over the lifetime of the experiment

Date (dd/mm)	Gas flow (l/h)	Duration (hours)	I (μA)	$\langle Q \rangle$ (C)	Doze rate (kGy/h)	Cumulated dose (kGy)
10.11	4	3:45	105	1.4175	0.3267	1.225
11.11	4	2:30	125	1.125	0.3267	2.096
12.11	4	3:00	106	1.1448	0.3267	3.076
13.11	4	3:00	168	1.8144	0.3267	4.056
16.11	4	3:20	289	3.468	0.3222	5.130
17.11	4	3:30	363	4.5738	0.3222	6.258
18.11	8	6:35	254	6.0198	0.3222	8.379
20.11	4	4:00	397	5.7168	0.3145	9.637
23.11	4	3:10	233	2.6562	0.3145	10.633
23.11	8	3:00	288	3.1104	0.3145	11.577
24.11	8	4:30	246	3.990	0.3145	12.992
Total		40:33		35.0367		12.992

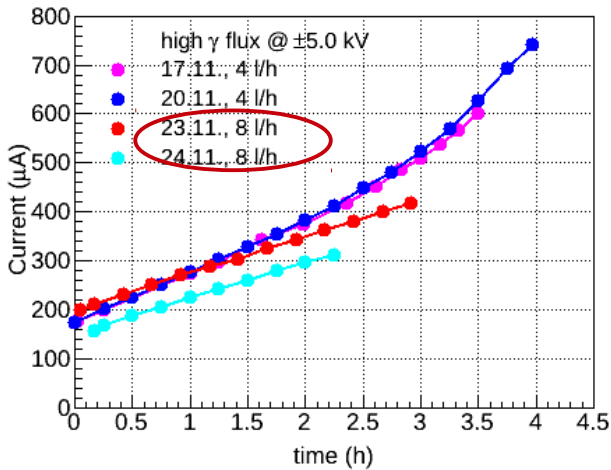
Total accumulated dose (w/o HV) = 77 kGy

Accumulated charge by the exposed MSMGRPC:
 $35.0367 \text{ C} / 276.5 \text{ cm}^2 = 0.127 \text{ C/cm}^2$

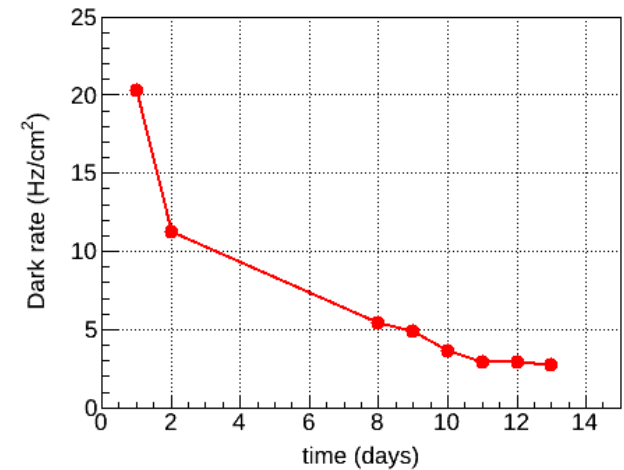
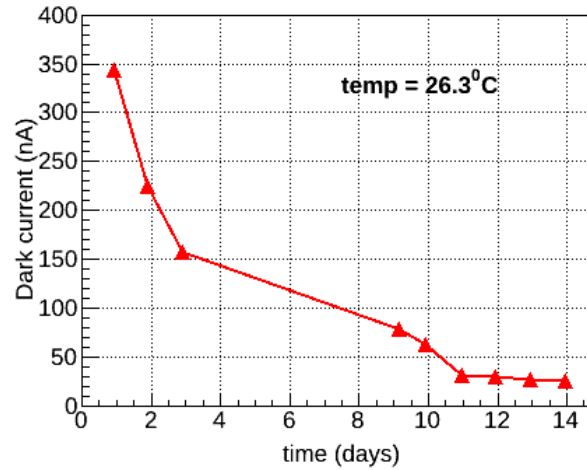
Equivalent particle flux = 80 - 310 kHz/cm²

Aging effects on MSMGRPC performance

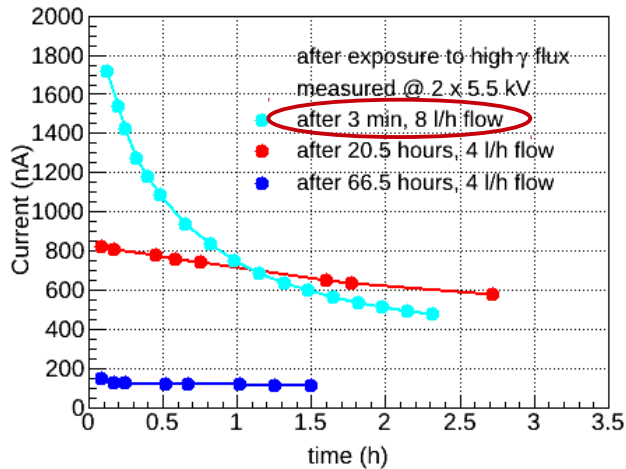
MSMGRPC under high γ flux



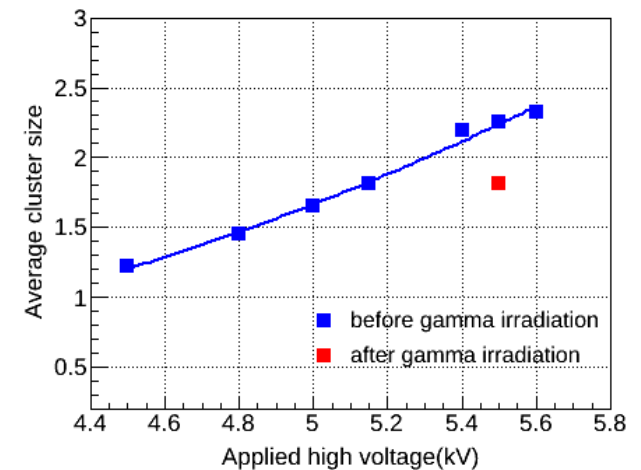
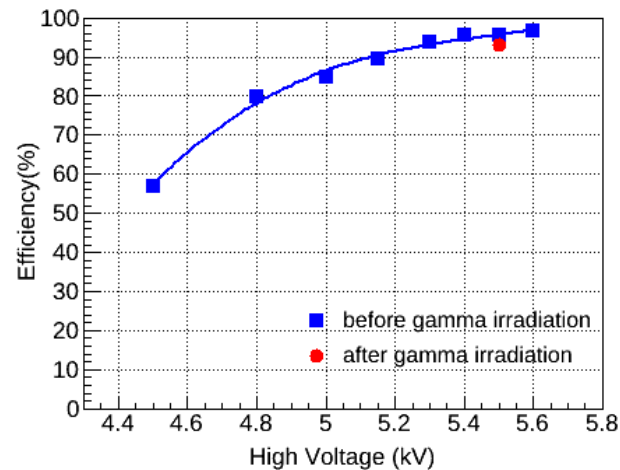
MSMGRPC “long” term recovery



MSMGRPC short term recovery



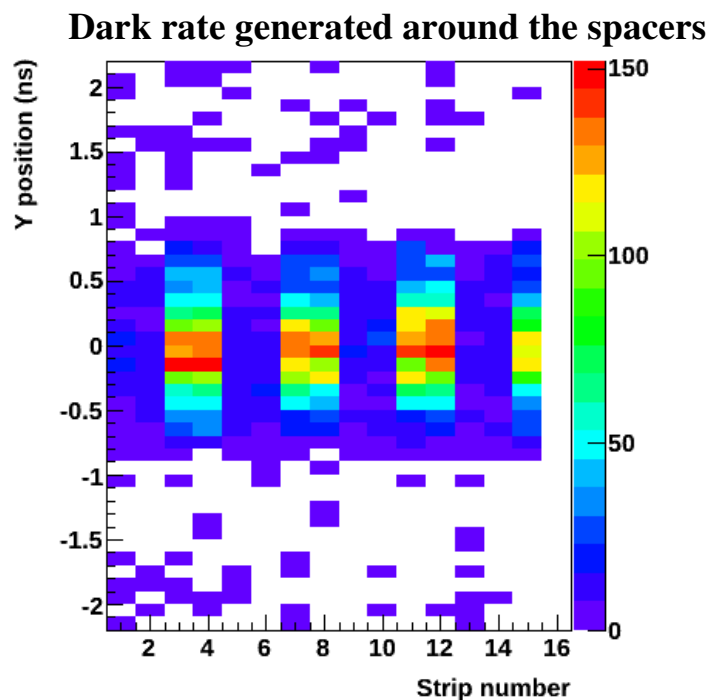
MSMGRPC performance before/after exposure



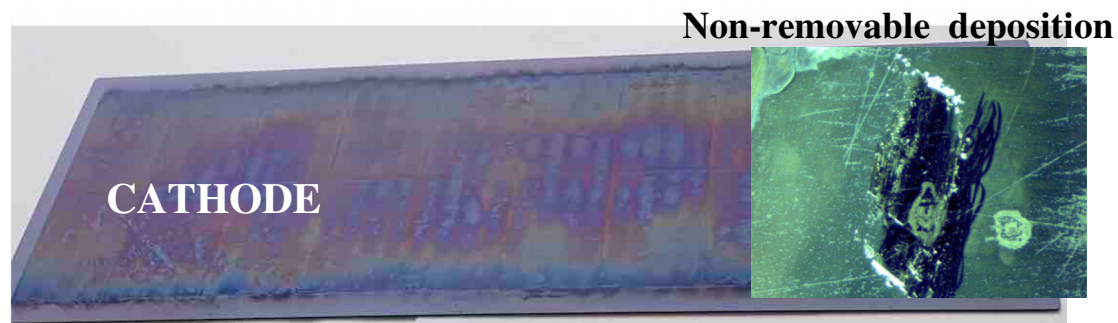
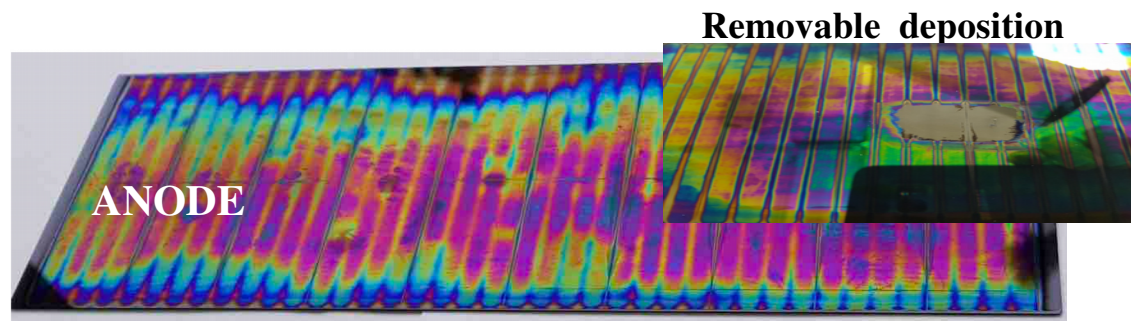
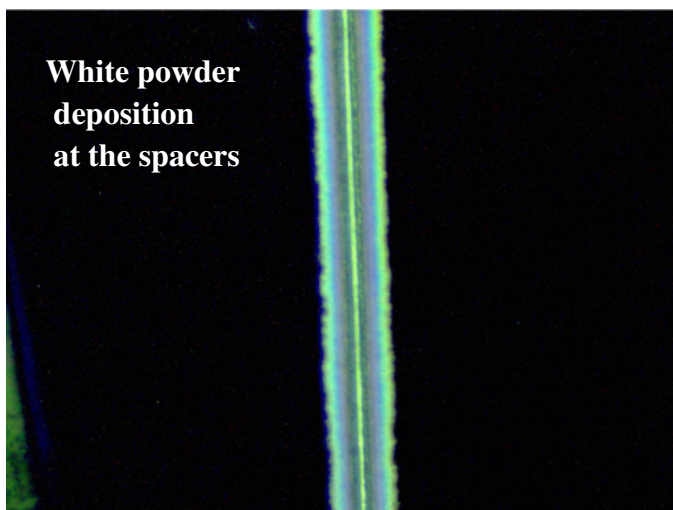
After flushing the counter with fresh working gas for two weeks:

- dark current and dark rate reached almost the same values as before the irradiation
- efficiency and cluster size were not significantly affected

Aging effects –deposited layers



Spacer – microscope photo

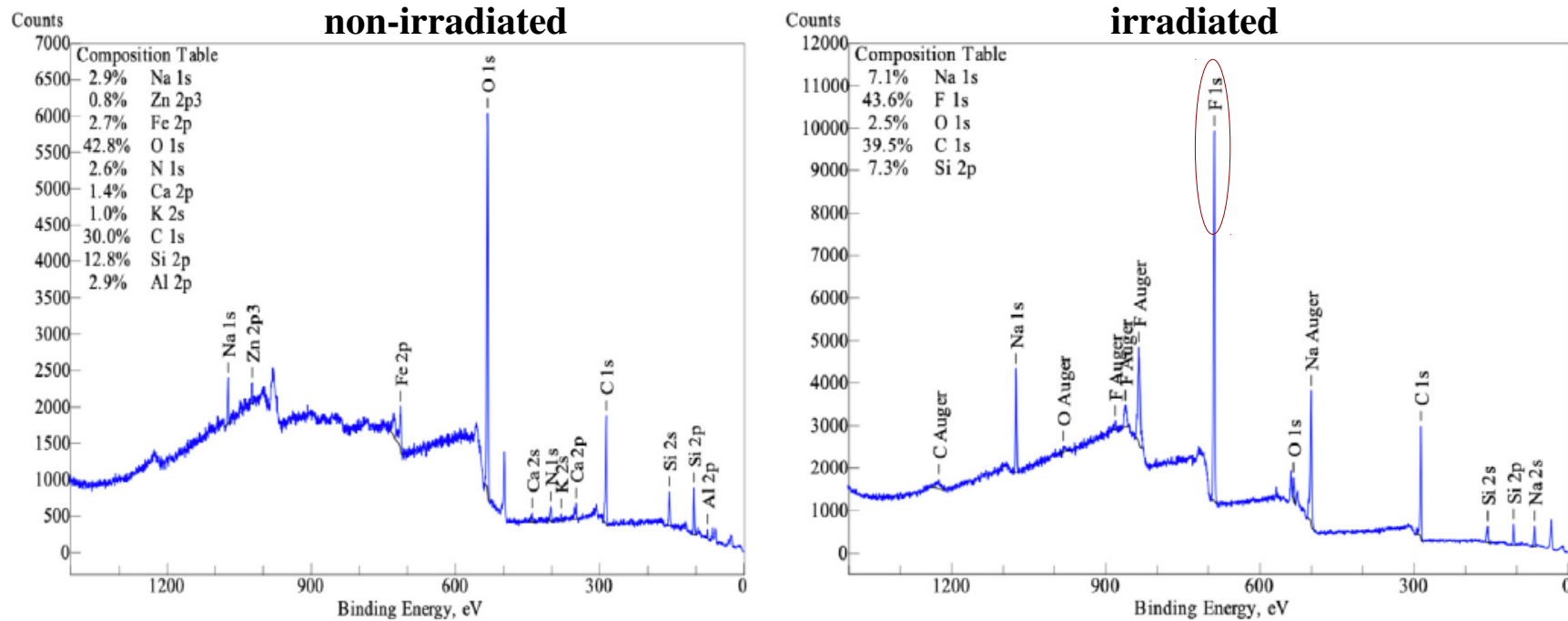


Glass resistivity measurements

Probe	R_V ($G\Omega\cdot\text{cm}$)	R_S ($G\Omega/\square$)
irradiated cathode surface	67.4	20.0
irradiated anode surface	61.5	21.1
non-irradiated glass	65.2	20.2

Aging effects – chemical composition of the deposited layers

X-ray photoelectron spectroscopy (XPS) analysis of the chemical composition of non-irradiated and irradiated glass plates

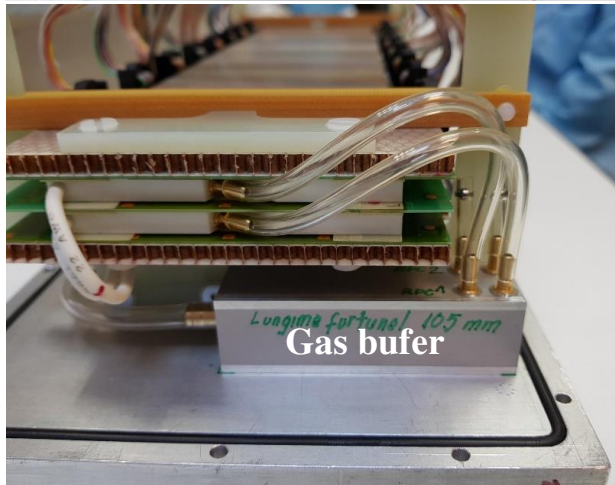
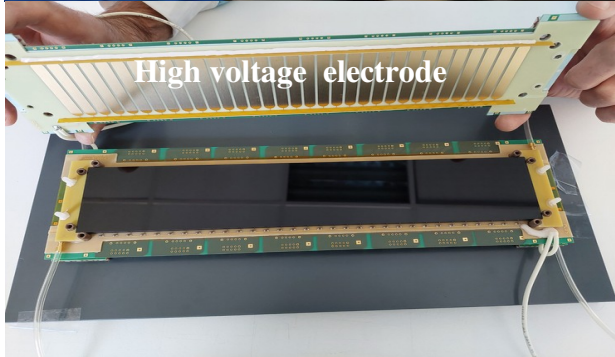
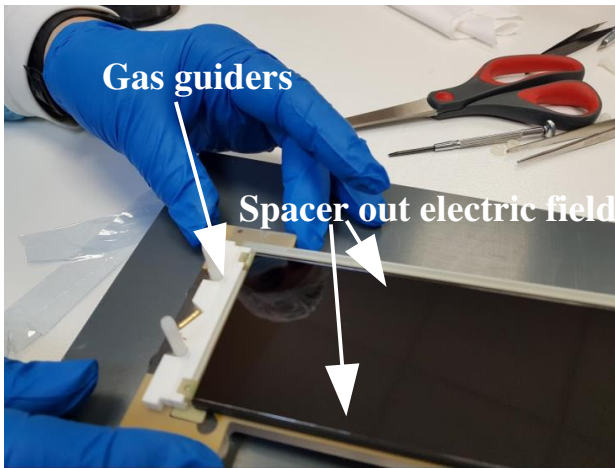


The fluorine percentage on the surface of the MSMGRPC glass electrodes exposed in high irradiation dose is significant. Not exposed glass does not contain fluorine.

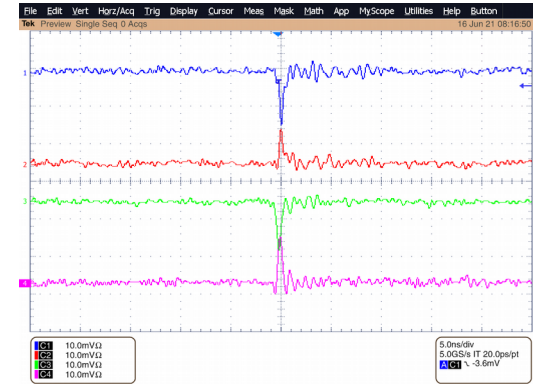
Other methods applied for chemical composition analysis: SEM, AFM, ERDA, RBS → Nucl. Inst. and Methods A 1024 (2022) 166122

Aging effect could limit the counter lifetime in the experiment → it is desirable to inhibit that processes keeping the electrodes surfaces as natural as possible.

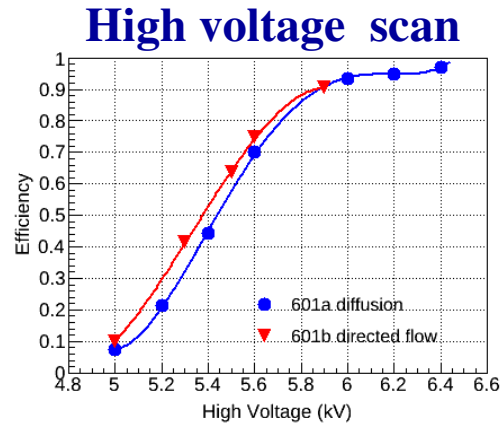
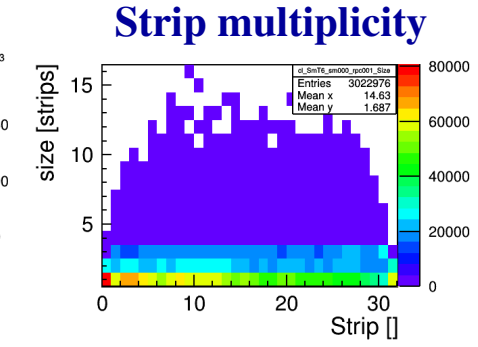
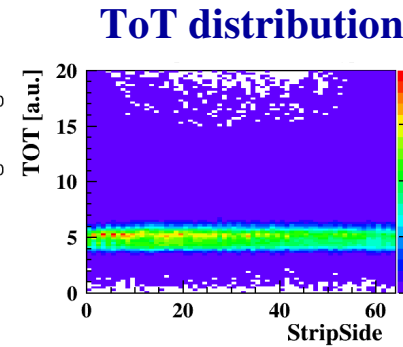
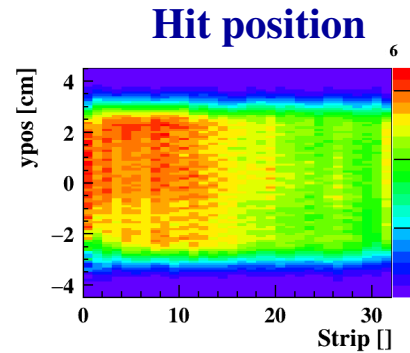
First prototype with a direct flow – 70% gas transmission



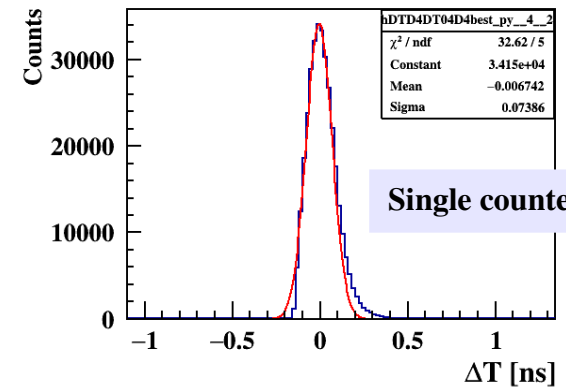
- Direct gas flow through the gas gaps.
- Spacers run across the strips
- Spacers outside electric field area.
- 5.6 cm strip length



mCBM@SIS18 July 2021 in-beam test results



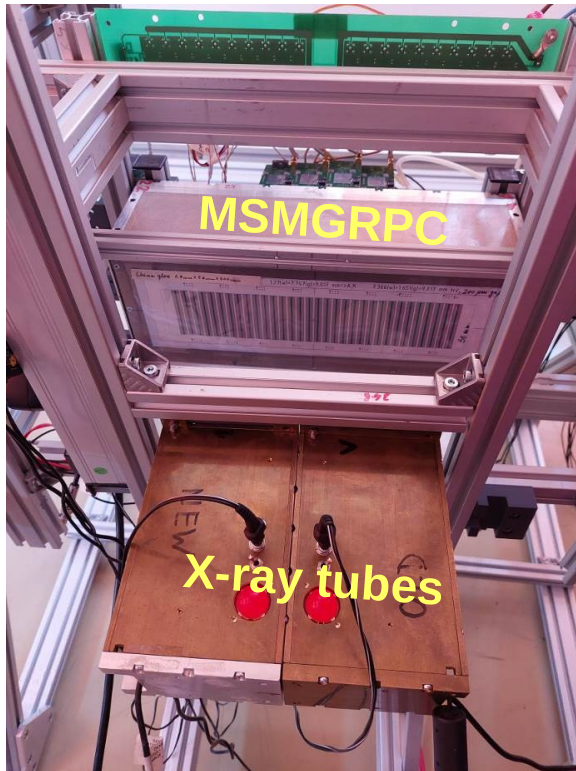
Time resolution @±5.9 kV



Single counter = 51 ps

High intensity X-ray irradiation of MSMGRPCs

Experimental Details



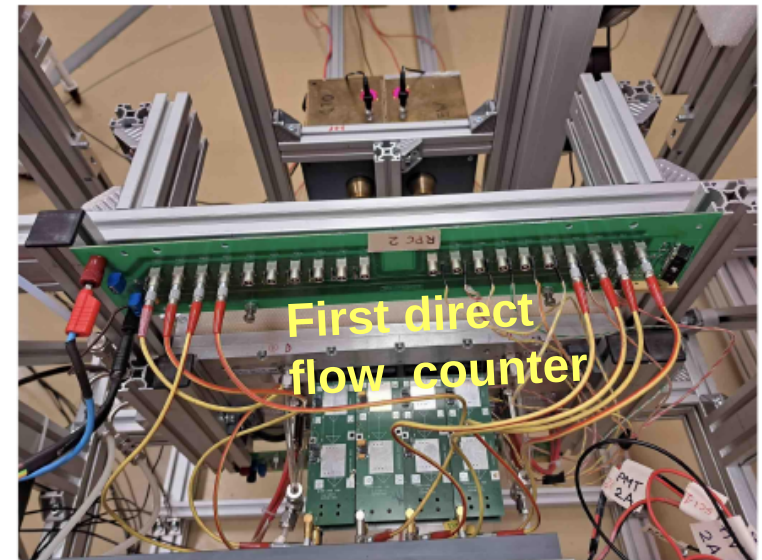
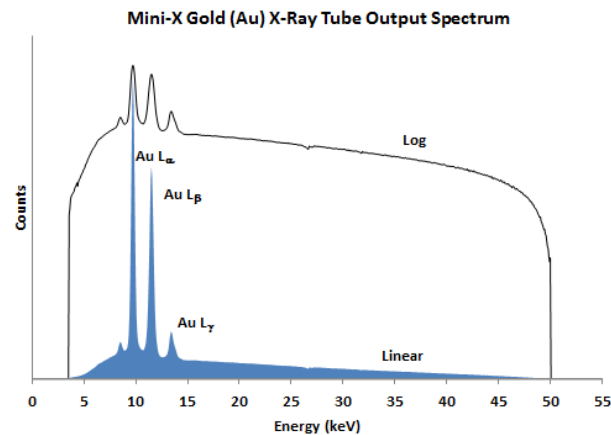
Mini X-ray tube Amptek

4 W output power

HV = 10 to 50 kV

I = 5 to 200 μ A

Au target



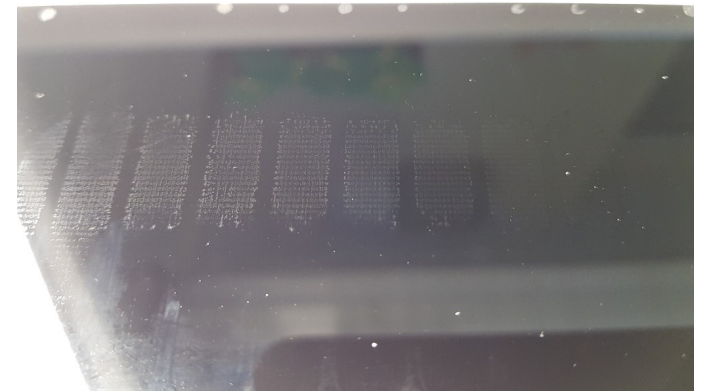
Deposition on the middle of the glass electrode

MSMGRPC operation

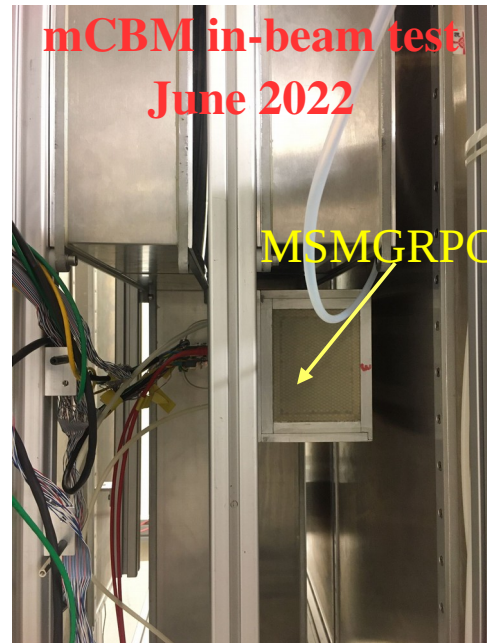
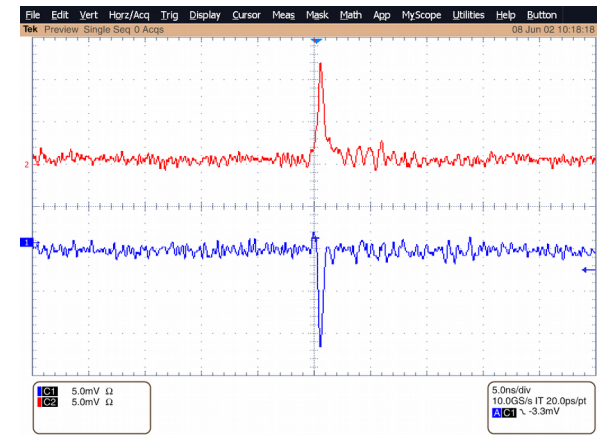
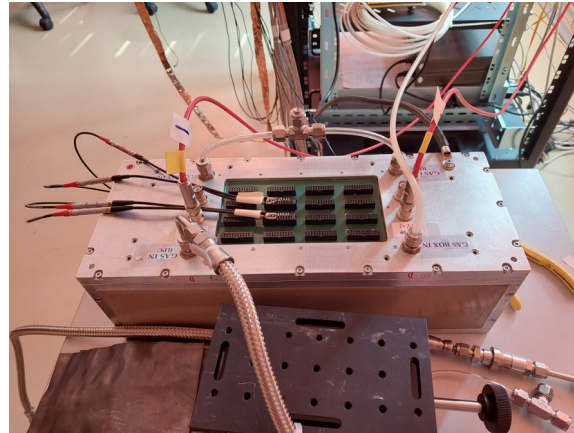
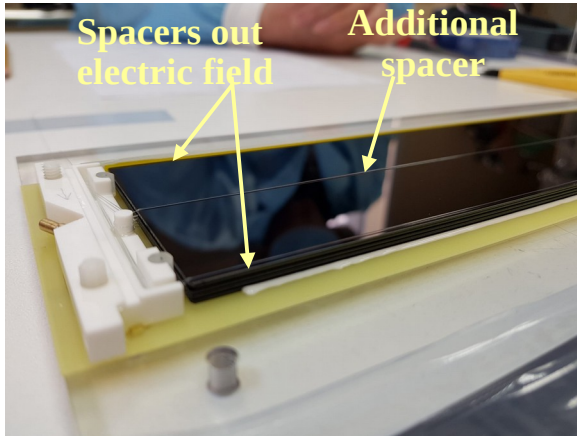
HV = \pm 6 kV

Gas mixture was of 97.5% C₂H₂F₄ + 2.5% SF₆

Gas flow rate was of 4 l/h.



Second prototype with a directed flow – 100% gas transmission



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

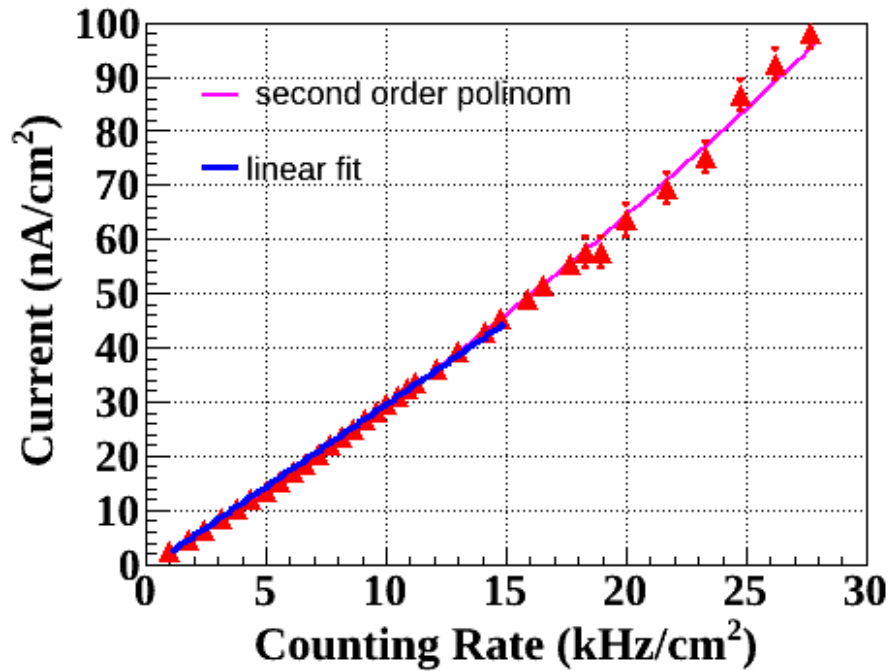
Negligible dark counting rate
after HR test

Data analysis in progress

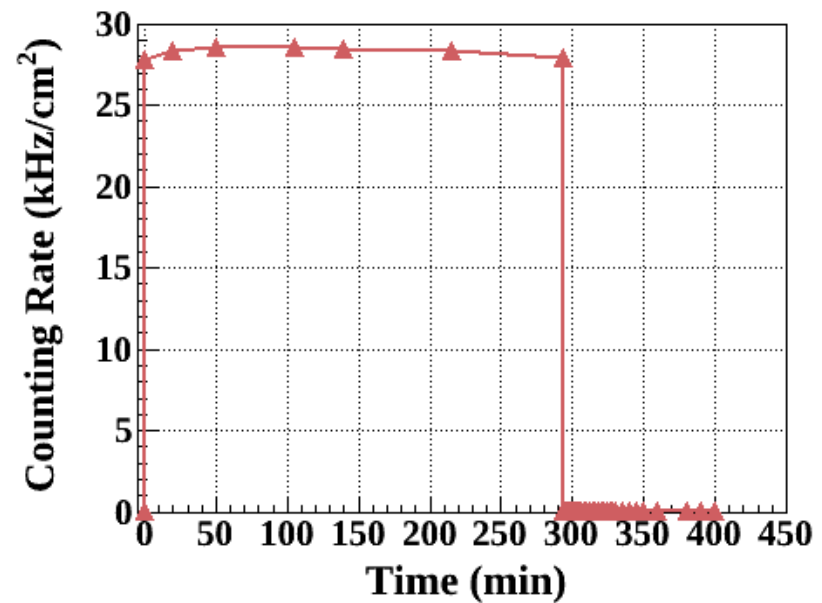
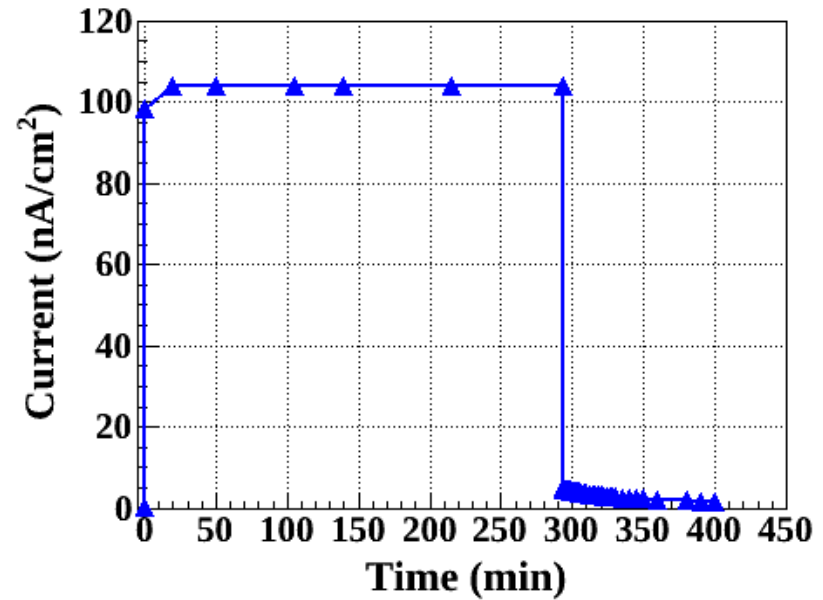


Au(65+) + Au at 1.13 AGeV, 2.5mm Au target/0.4mm/4mm Ni target
Rate scan (HR) -> intensity per spill: 1×10^7 , 3×10^7 , 1×10^8 , $3 \times$ to 4×10^8
Exposure to the highest delivered counting rate for ~8 hours

High intensity X-ray irradiation of MSMGRPCs

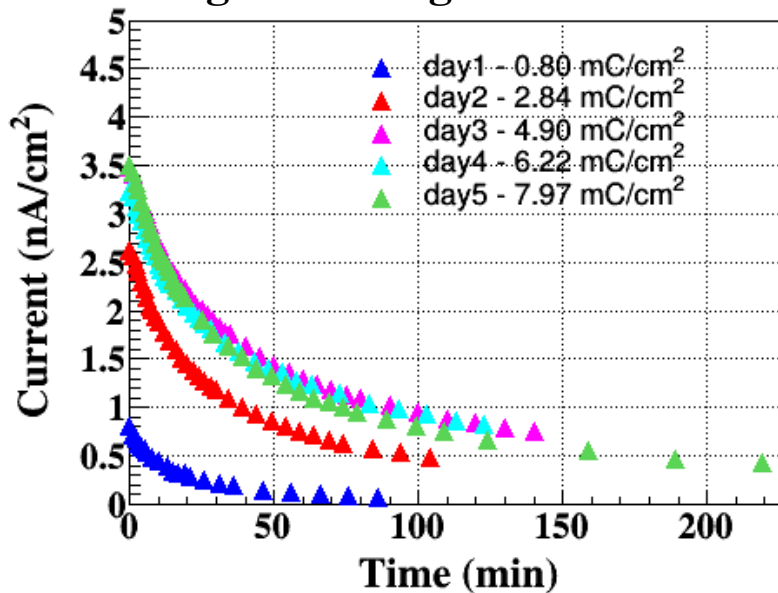


High voltage = 2 x 6.0 kV

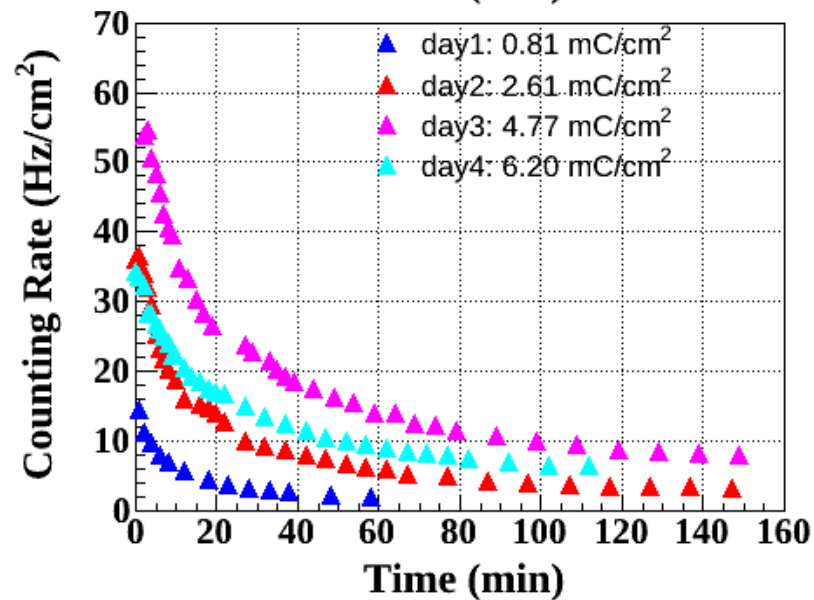
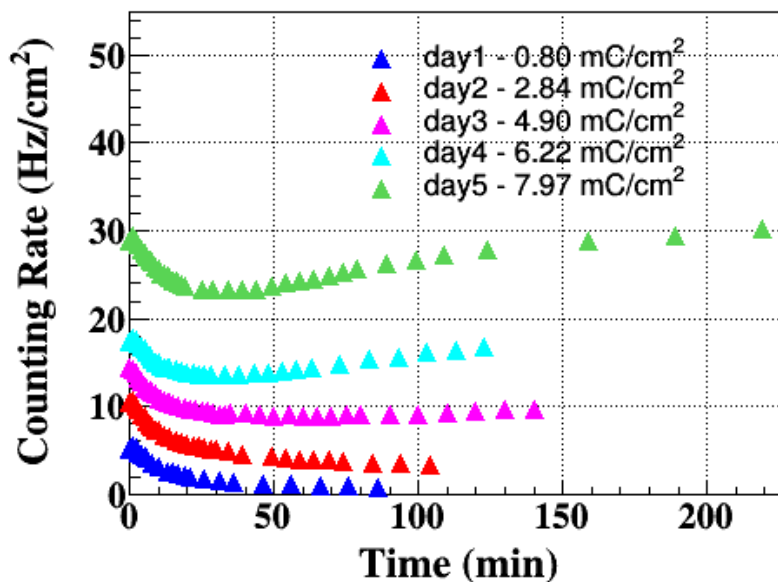
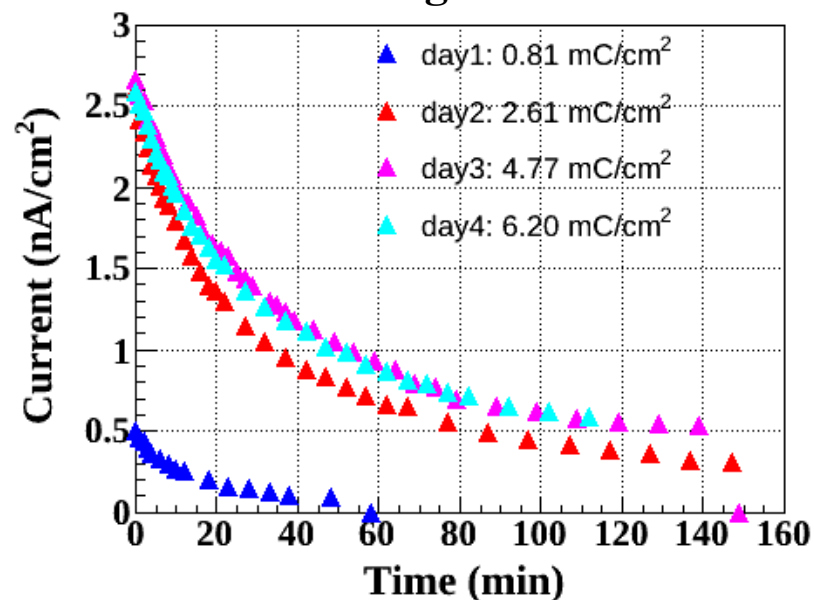


Dark current & dark counting rate after X-ray exposure @ 4 l/h gas flow rate

gas exchange via diffusion

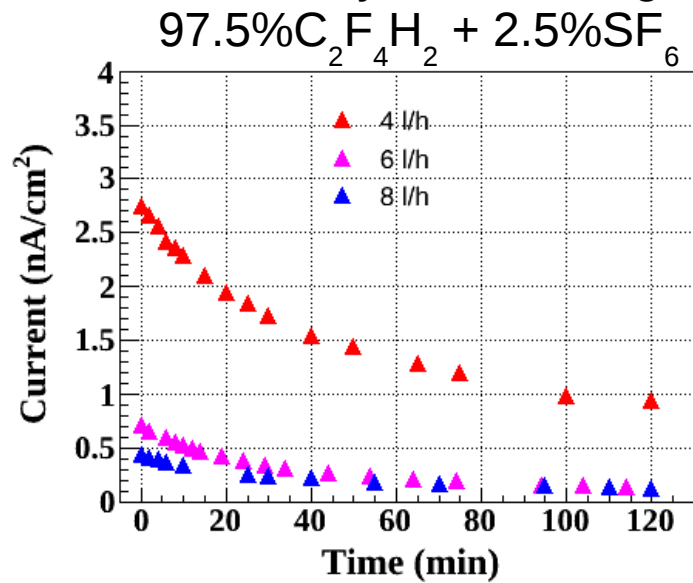


direct gas flow

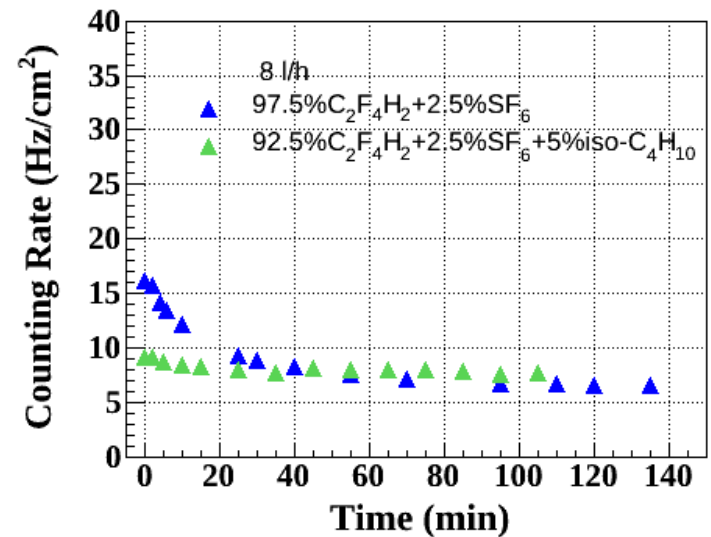
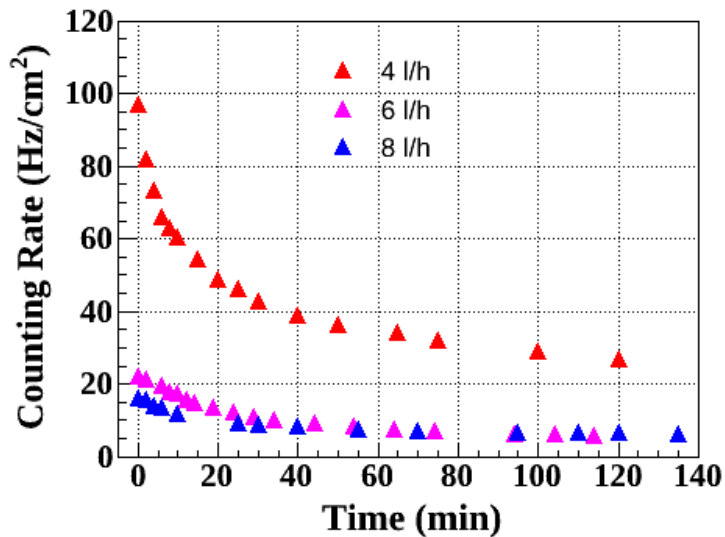
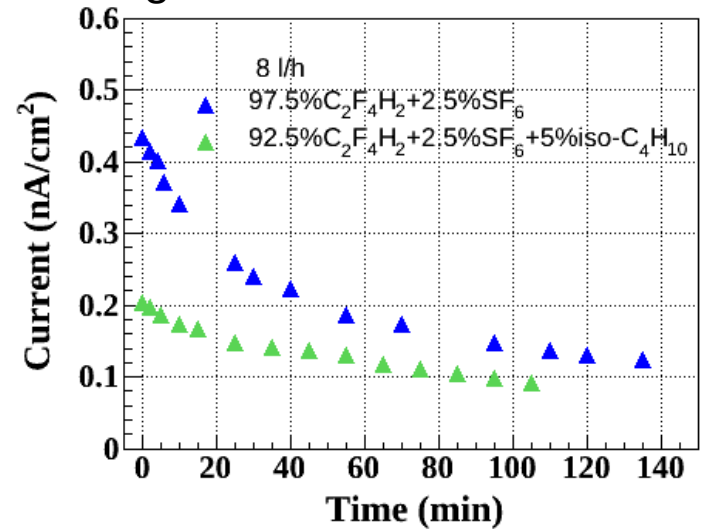


Dark current & dark counting rate after X-ray exposure for direct flow counter

Detector recovery at different gas flows

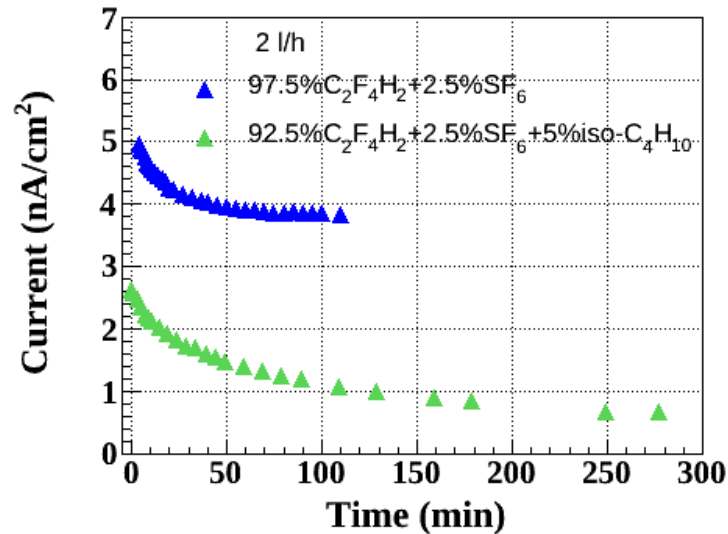


Detector recovery flushed with a gas mixture with isobutane

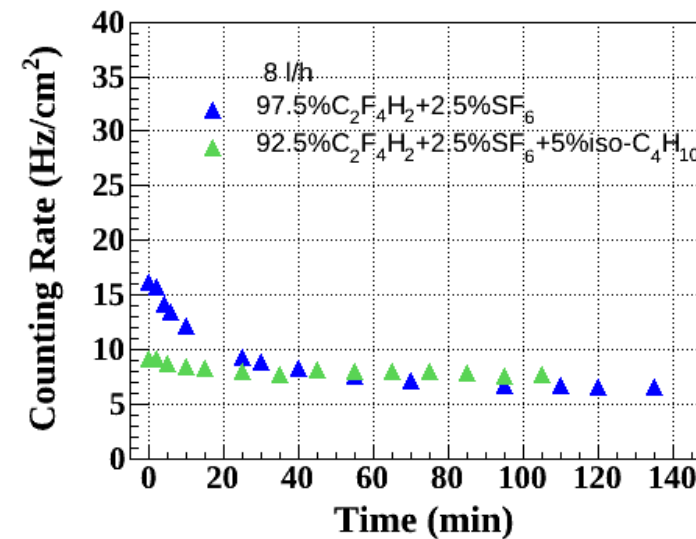
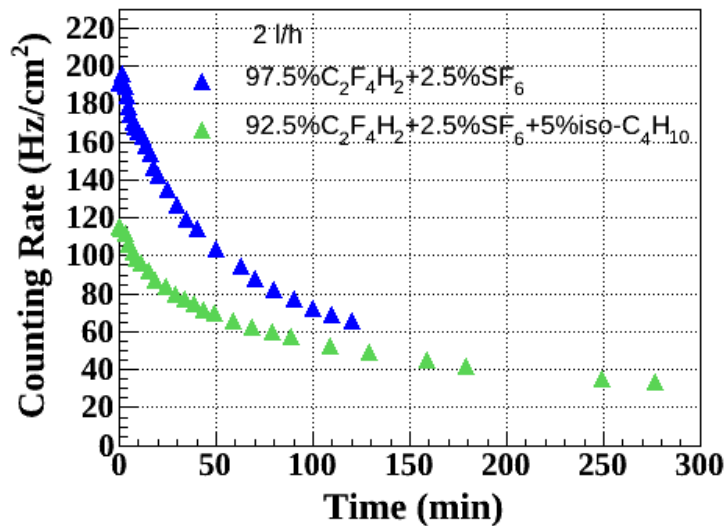
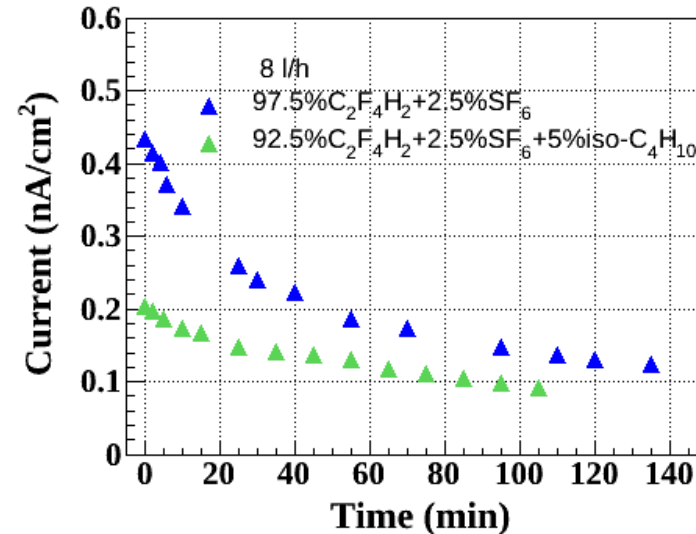


Dark current & dark counting rate after X-ray exposure for direct flow counter

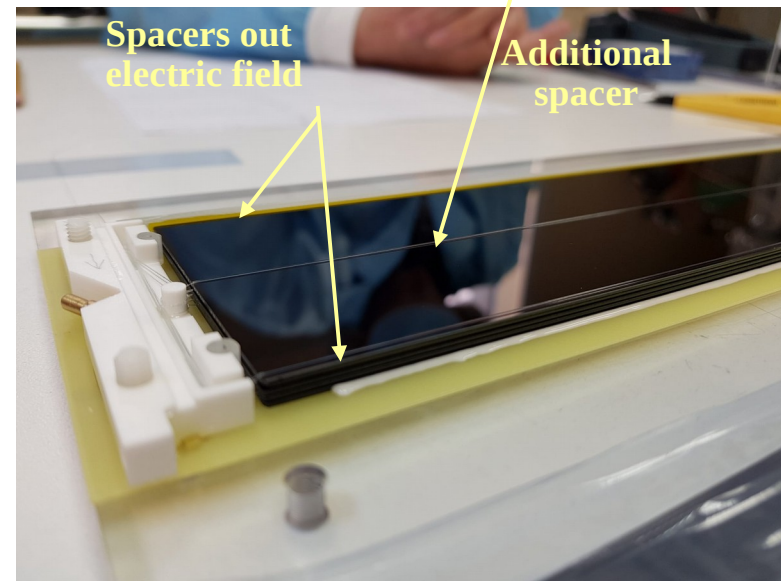
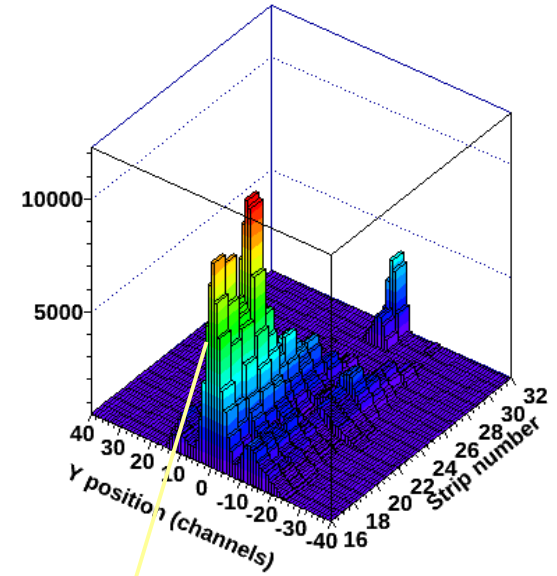
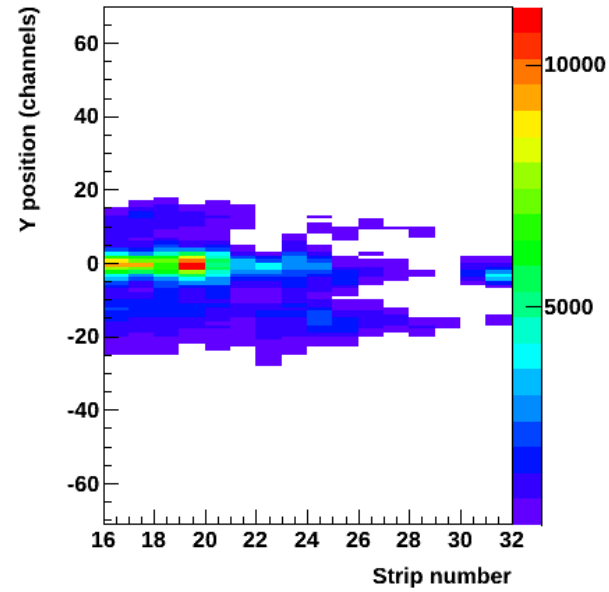
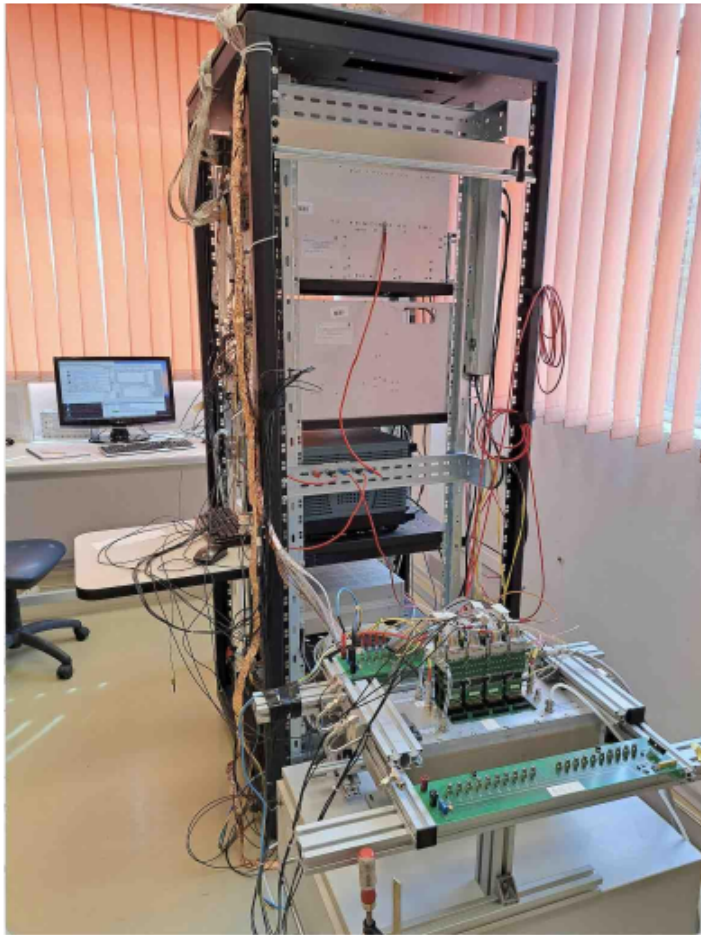
Detector recovery flushed with
2 l/h gas flow



Detector recovery flushed with
8 l/h gas flow



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



Summary & Outlook

- MSMGRPC prototypes with high granularity and impedance matched to the FEE input were assembled and tested in the Lab with cosmic rays proving very good efficiency and time resolution.
- In-beam tests in the mCBM setup confirmed the obtained results and showed that the efficiency and time resolution are still very good up to a counting rate ≥ 25 kHz/cm².
- The aging tests evidenced an important gas pollution effect which could limit the lifetime of the counter.
- Proposed mitigation solution is a MSMGRPC prototype with a direct flow through the gaps. It performed in the in-beam test in the mCBM/SIS18 setup in July 2021; A second prototype was tested in June 2022 (data analysis is in progress).
- Exposure to high intensity X-rays was used for:
 - current – counting rate calibration up to ~ 25 kHz/cm²;
 - studies of gas flow and gas composition for aging effect suppression.
- Aging tests using the high activity ⁶⁰Co source will be performed in the near future at a lower dose rate and longer exposure time.
- Direct gas flow wider counters (100/200 mm wide) will be assembled in the near future based on the already gained experience.

People involved in the presented activities

IFIN-HH Bucharest

Hadron Physics Department

V. Aprodu

D. Bartos

D. Dorobantu

V. Duta

M. Petris

M. Petrovici

L. Prodan

A. Radu

G. Stoian

GSI Darmstadt

Jochen Frühauf

Universität Heidelberg

Ingo Deppner

Norbert Herrmann

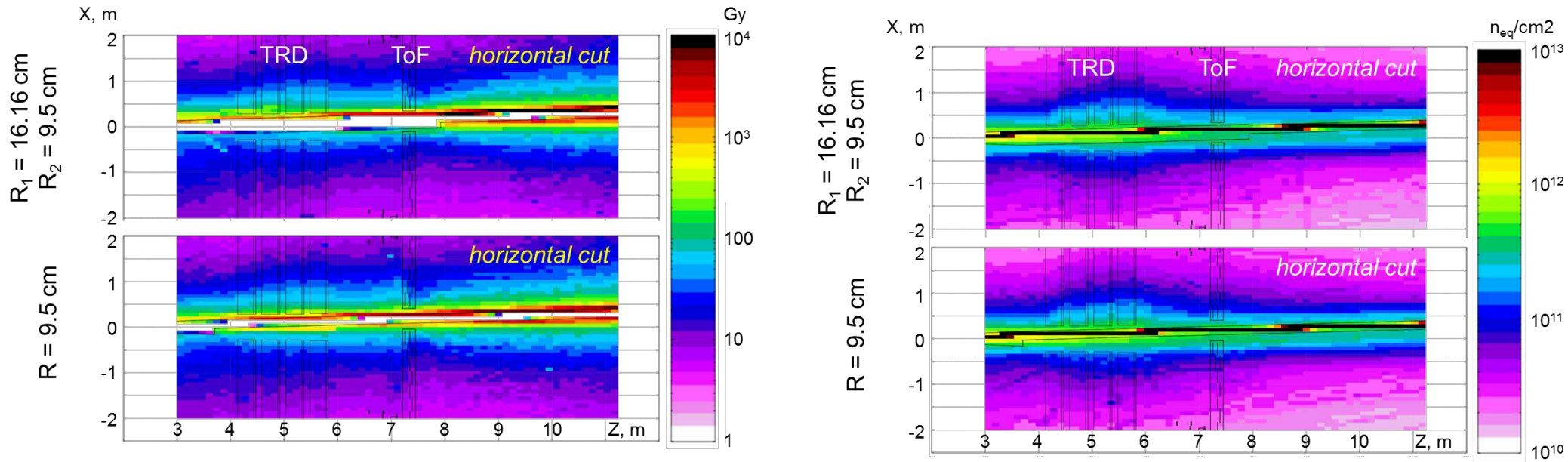
Thank you for your attention!



Back up

FLUKA simulations

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

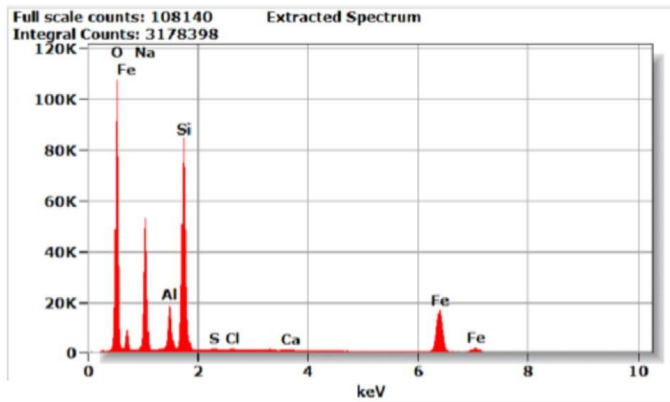


A.Senger, CBM-TN-18001

Aging effects – chemical composition of the deposited layers

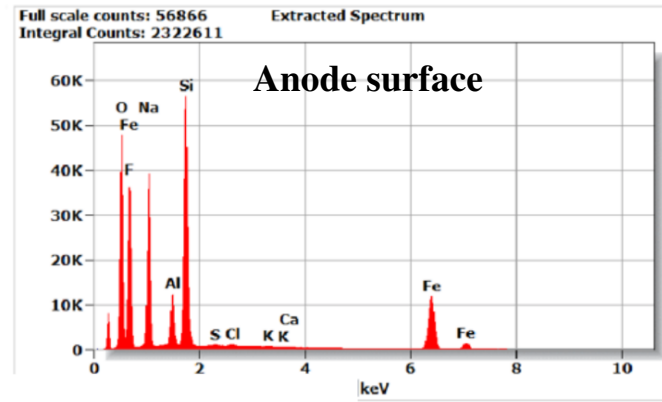
Energy- Dispersive X-ray (EDX) spectrometry analysis of the chemical composition of non-irradiated and irradiated glass plates

Non-irradiated glass plate

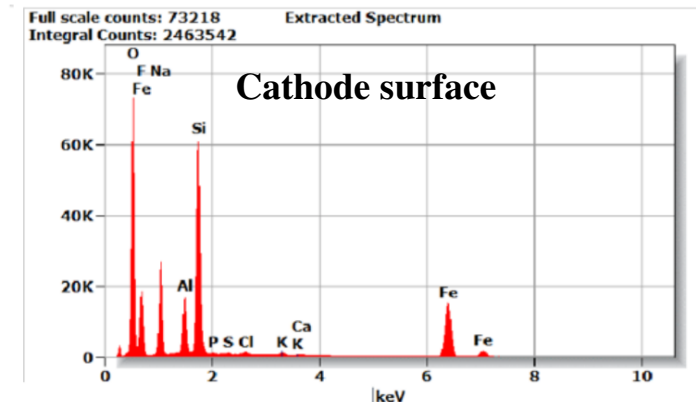


Element	Extracted Spectrum				
	Net Counts	Weight%	Weight% err	Atom %	Atom % err
O K	466449	31.25	0.09	46.10	0.28
Na K	407089	22.80	0.09	23.40	0.17
Al K	135440	4.35	0.03	3.80	0.05
Si K	741782	21.42	0.05	18.00	0.09
S K	6125	0.19	0.01	0.14	0.01
Cl K	6707	0.21	0.01	0.14	0.01
Ca K	9771	0.34	0.02	0.20	0.02
Fe K	267525	19.45	0.07	8.22	0.06
		100.00		100.00	

Irradiated glass plate



Element	Extracted Spectrum				
	Net Counts	Weight%	Weight% err	Atom %	Atom % err
O K	218509	15.88	0.07	23.12	0.19
F K	280231	25.87	0.10	31.73	0.25
Na K	270828	20.02	0.08	20.29	0.16
Al K	91370	3.59	0.03	3.10	0.05
Si K	499986	17.42	0.05	14.45	0.08
S K	3974	0.14	0.01	0.10	0.01
Cl K	5725	0.21	0.02	0.14	0.02
K K	1878	0.07	0.01	0.04	0.01
Ca K	1290	0.05	0.01	0.03	0.01
Fe K	192129	16.74	0.07	6.99	0.06
		100.00		100.00	



Element	Extracted Spectrum				
	Net Counts	Weight%	Weight% err	Atom %	Atom % err
O K	329097	24.64	0.09	36.42	0.25
F K	127222	15.11	0.08	18.81	0.20
Na K	197859	15.15	0.07	15.59	0.14
Al K	126132	4.77	0.03	4.18	0.05
Si K	539958	18.44	0.05	15.52	0.09
P K	1447	0.06	0.01	0.05	0.02
S K	4388	0.16	0.02	0.12	0.02
Cl K	7014	0.26	0.01	0.17	0.01
K K	7869	0.29	0.01	0.18	0.01
Ca K	3411	0.14	0.02	0.08	0.02
Fe K	245991	20.99	0.08	8.89	0.07
		100.00		100.00	

The fluorine percentage on the surface of the glass electrodes exposed in the MSMGRPC in high irradiation dose is significant and different for the two surfaces. Not exposed glass does not contain fluorine.

Refrigerant R 134a

Refrigeranti

Denumire / Identificare

Denumirea chimica 1,1,1,2-Tetrafluoretan

Formula chimica $\text{CF}_3\text{-CH}_2\text{F}$

Numar CAS 811-97-2

ADR UN 3159 Tetrafluoretan, 2.2
Clasa 2
Cod clasificare 2A

Identificare butelie



Ogiva:
Verde fluo

Caracteristici principale

Gaz lichefiat incolor, cu miros usor de eter, mai greu decat aerul

Pictograma de pericol

ATENTIE



Caracteristici fizice

Masa moleculara: 102 kg/kmol
Densitate la 20°C: 1,23 kg/l
Punct de fierbere (la 1,013 bar): -26,1 °C
Solubilitatea in apa la 25°C: 1 g/l
Presiunea de vapori la 25°C: 5,74 bar

Mai multe informatii gasiti in Fisa cu date de securitate

Ventil

Racordul la ventilul buteliei DIN 477 Nr. 6: W 21,8 x 1/14"

Specificatii / Forme de livrare

Compozitia

$\text{CF}_3\text{-CH}_2\text{F}$	≥	99,9	% masa
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Impuritati

Aciditate ca HCl	≤	1	ppm
H ₂ O	≤	10	ppm
Reziduu	≤	50	ppm
Gaze necondensabile	≤	1,5	% vol
Total olefine	≤	40	ppm

Recipient (litri)

12,5	12,5	kg
14,3	14,3	kg
20,0	20,0	kg
27,2	27,2	kg

Versionea: 1.1

MESSER 
Messer Romania Gaz SRL
Str. Delea Veche nr. 24
RO-0241 02 Bucuresti
Tel. +40213273624
Fax. +40213273626
www.messer.ro