66th INFN ELOISATRON WORKSHOP: New gas mixtures for RPC and MRPC detectors

Investigation on eco-friendly gas mixtures for Multigap-RPCs at CBM

Ingo Deppner

Physikalisches Institut, Heidelberg University

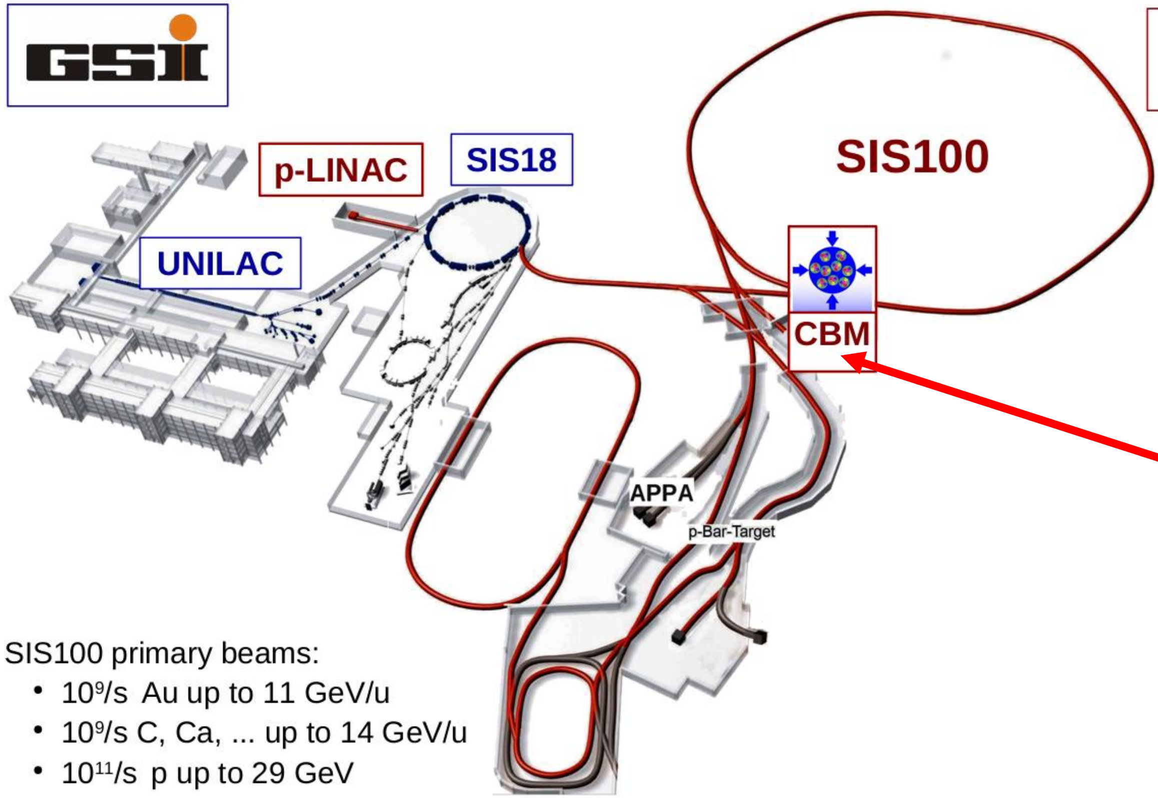
22.11.2022

Outline

- Introduction to FAIR/CBM/CBM-TOF
- Test results with standard gas mixture
- Investigation on eco friendly gas mixtures for timing MRPCs
- Gas-aging in a high rate environment
- Test results with modified gas mixture based on Tetrafluorethane
- Conclusions for the CBM TOF and its gas system
- Summary

Introduction FAIR

Facility for Antiproton and Ion Research



SIS100 primary beams:

- 10^9/s Au up to 11 GeV/u
- 10^9/s C, Ca, ... up to 14 GeV/u
- 10^{11}/s p up to 29 GeV

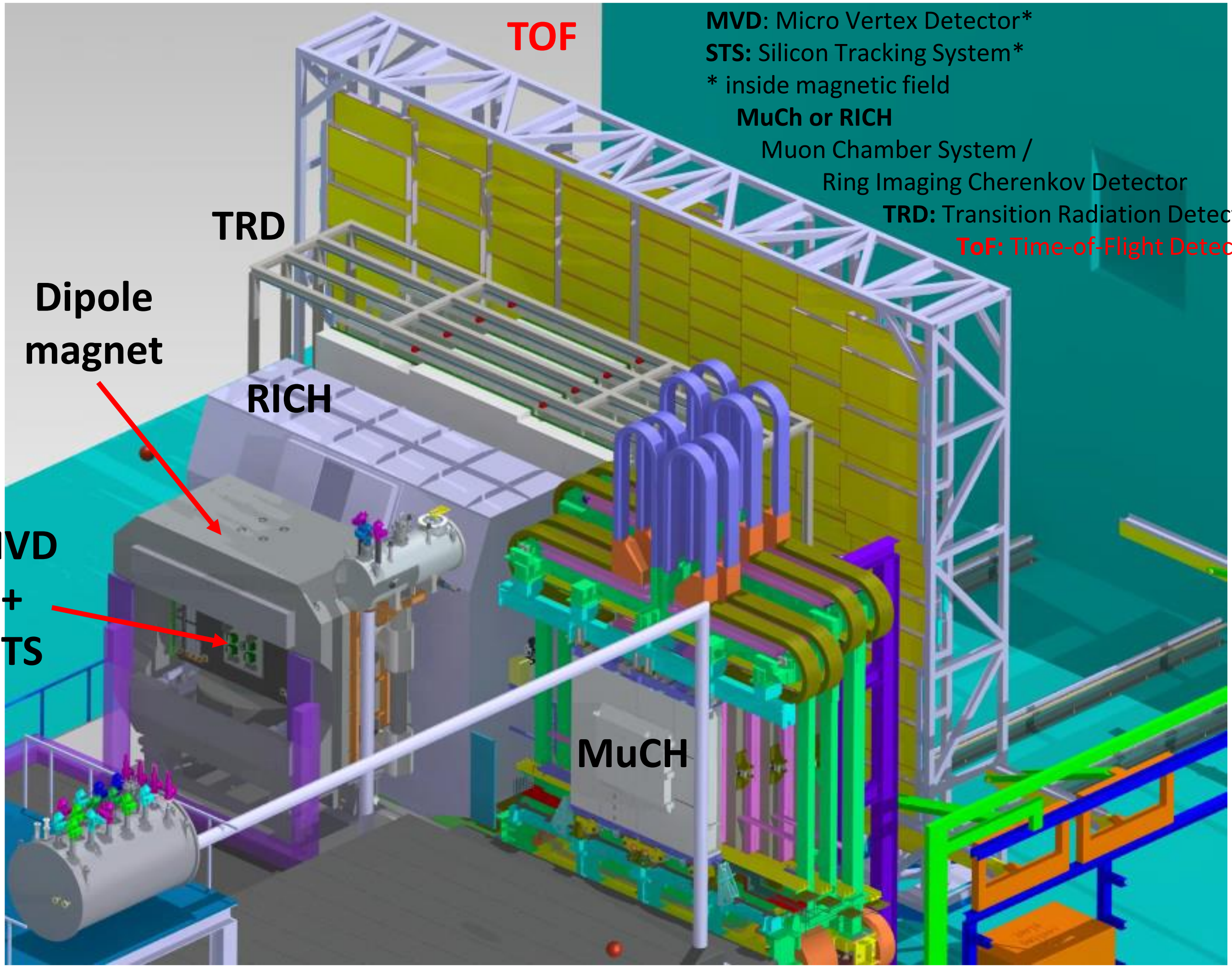
CBM Building Oct. 2022

Timeline

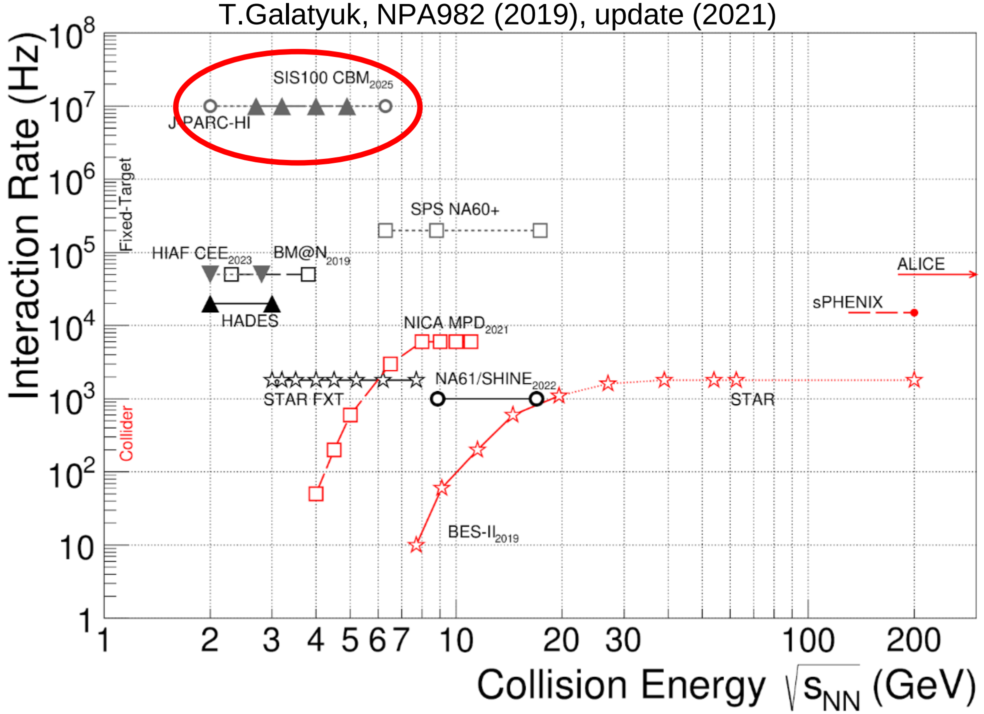
CBM building shell construction completed: Q1.2023
CBM ready for beam Q2.2027
SIS100 ready for beam 2028

Introduction CBM

Compressed Baryonic Matter (CBM) Experiment



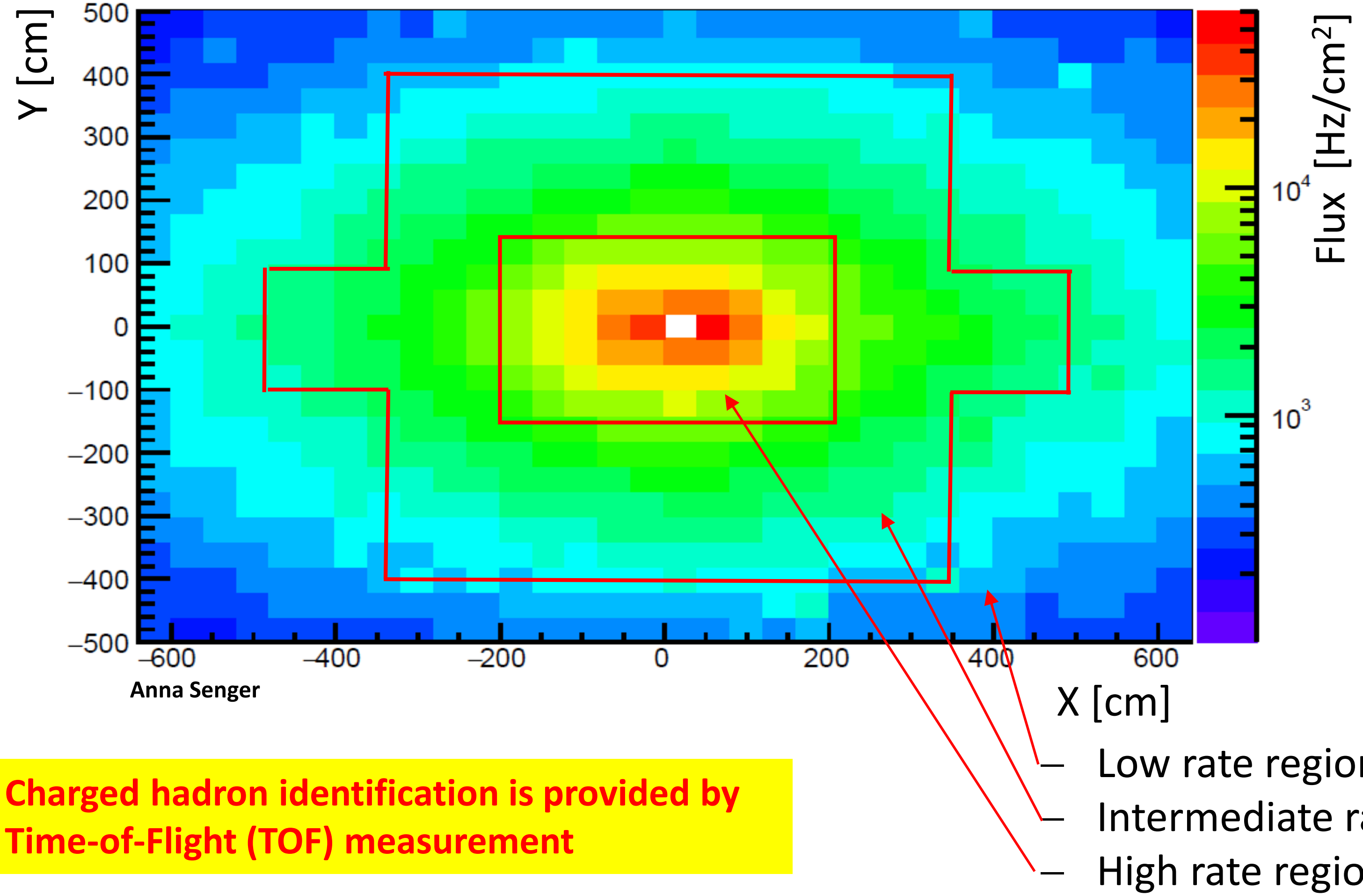
CBM Collaboration, EPJA 53 3 (2017) 60
T.Galatyuk, NPA982 (2019), update (2021)



- Tracking acceptance: $2.5^o < \theta_{Lab} < 25^o$
- Peak R_{int} is 10 MHz for Au+Au (300 kHz for MVD)
- Fast & radiation hard detectors
- Free-streaming DAQ
- 4D tracking (space, time)
- Online event reconstruction and selection
- Data rate: 1 TB/sec

Introduction CBM TOF

FLUKA simulation: Au + Au collisions at E_{kin} = 11 AGeV, 10^7 interactions
Charged particle flux at a distance of 8 m from the target



Charged hadron identification is provided by Time-of-Flight (TOF) measurement

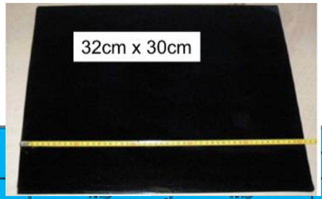
CBM-TOF Requirements

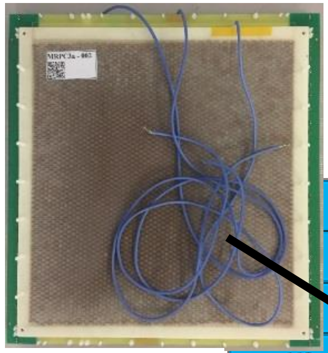
- **Full system time resolution σ_T ~ 80 ps**
- **Efficiency > 95 %**
- **Rate capability ≤ 50 kHz/cm²**
- **Polar angular range 2.5° – 25°**
- **Active area of 120 m²**
- **Occupancy < 5 %**
- **Low power electronics (~100.000 channels)**
- **Free streaming data acquisition**

Multi-gap Resistive Plate Chambers (MRPC) are the most suitable TOF detectors fulfilling our requirements

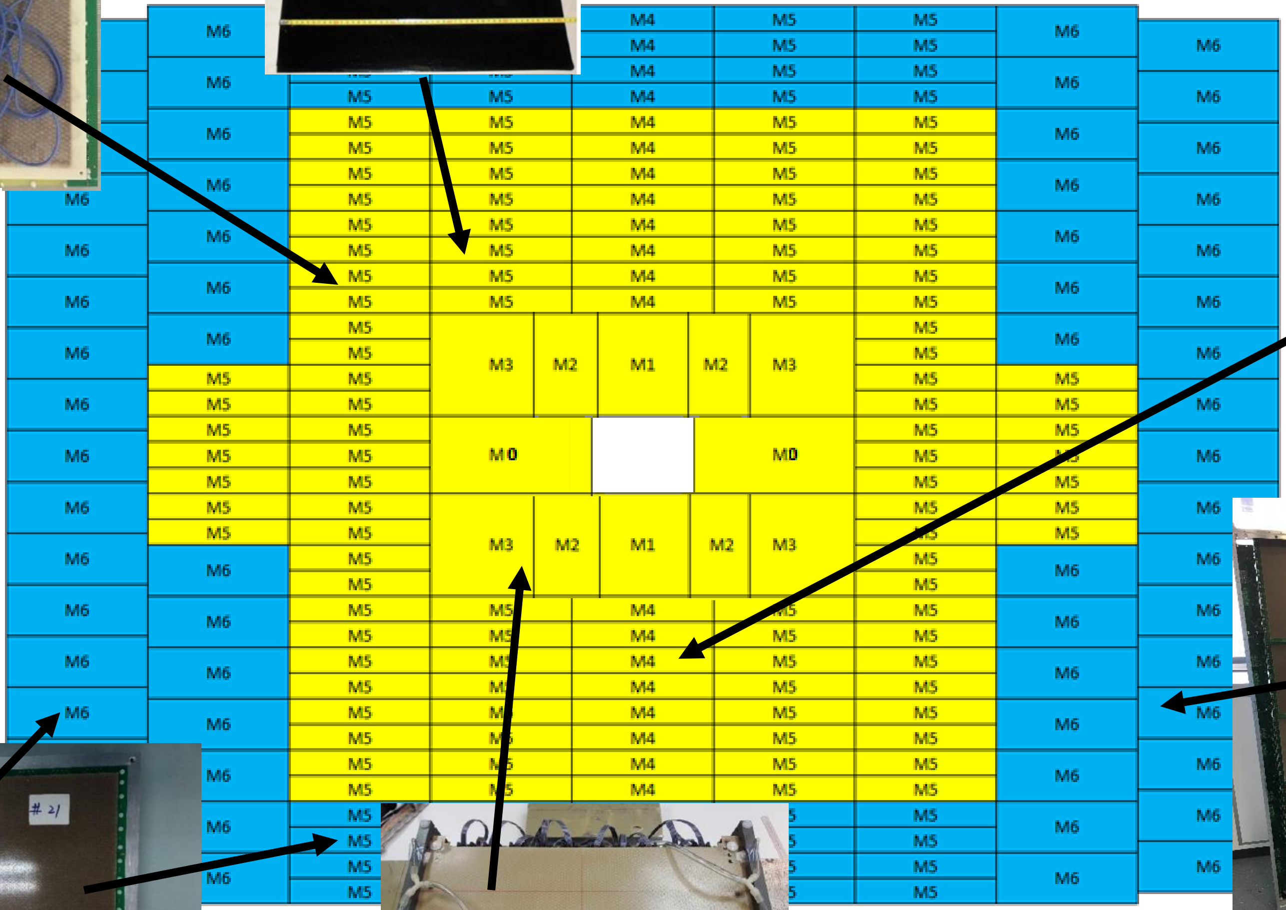
Introduction CBM TOF

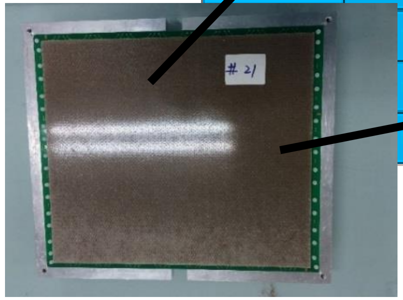
Low resistivity glass



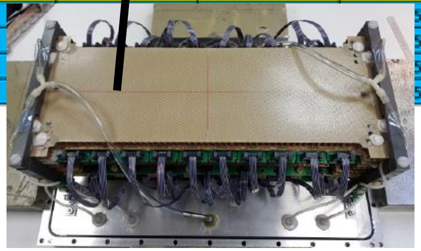


MRPC2
(Tsinghua)





MRPC3/4
(USTC)



MRPC1a - 1c
(NIPNE Bucharest)

M4 Module (HD)

- **Full size counter with close to final design for all regions build and tested**
- **M4 and M6 full size modules constructed and installed at mCBM**

M6 Module (HD)

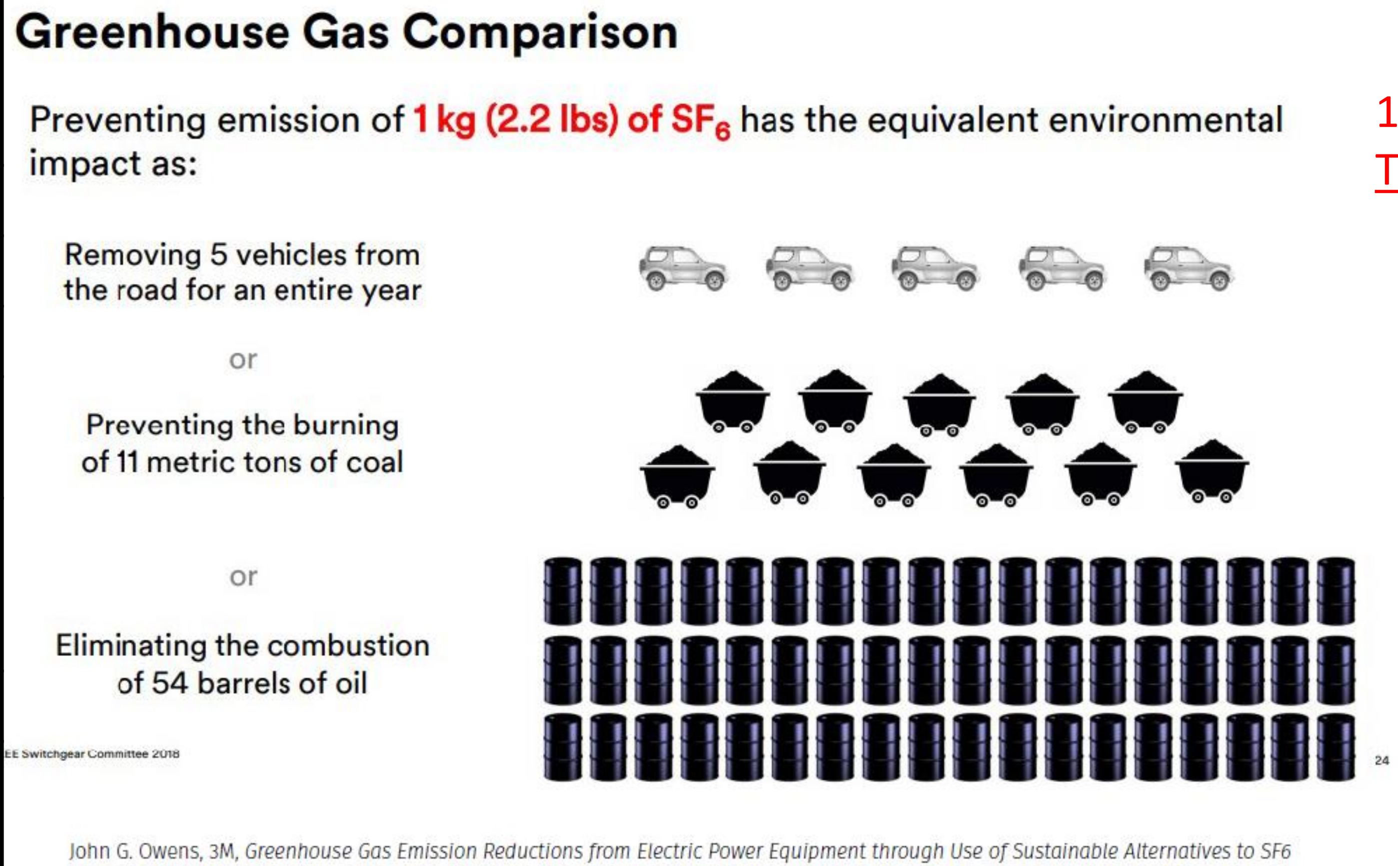
CBM-TOF MRPCs

- **230 Modules**
- **About 1500 MRPC**
- **About 100000 readout channel**
- **Multi-gap RPC with 8 – 10 gaps with gap size of 200 – 250 μm**
- **MRPC size ranging from 180 cm^2 up to 1700 cm^2**
- **Initially planed gas mixture: R134a/iso-Butan/SF_6: 90%/5%/5%**

Environmental impact of TOF gas

Parameters for one CBM TOF refill (125 m^3 gas)

gas	Isobu-tane	Reclin® R134a	Sulfur-hexafluoride
chemical structure	i-C_4H_{10}	$C_2H_2F_4$	SF_6
GWP	20	1430	22800
fraction	5%	90%	5%
partial volume [m^3]	6.25	112.5	6.25
density at 1013 mbar [kg/m^3] (15 °C)	2,5	4,4	6,2
portion [kg]	15.625	495	38.75
CO_2 equivalent [tons]	0.047	707.9	910.6
price [Euro]		11500 (23 Euro/kg)	



1 CBM-TOF refill

500

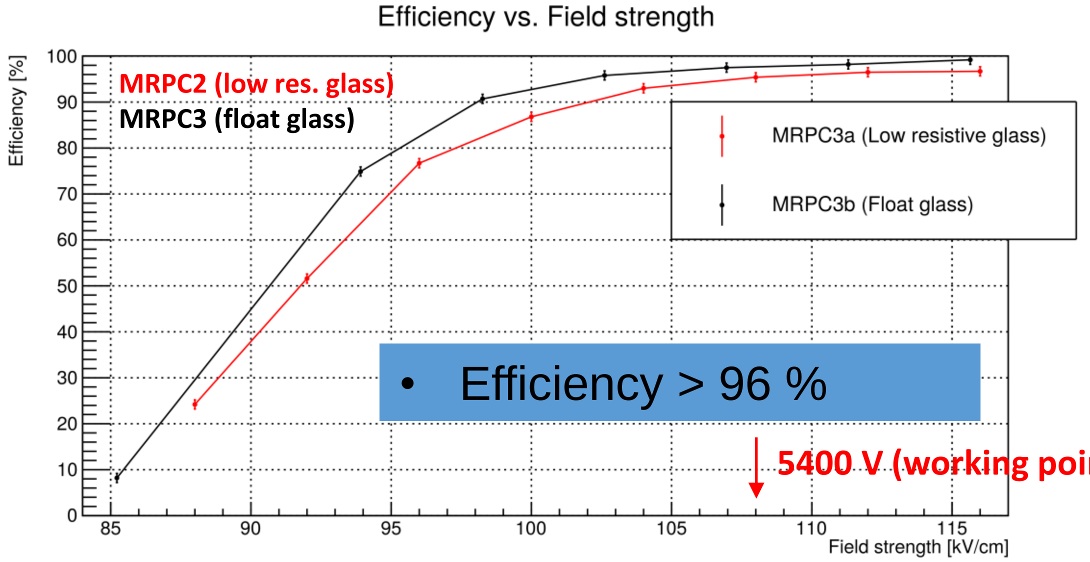
110

540

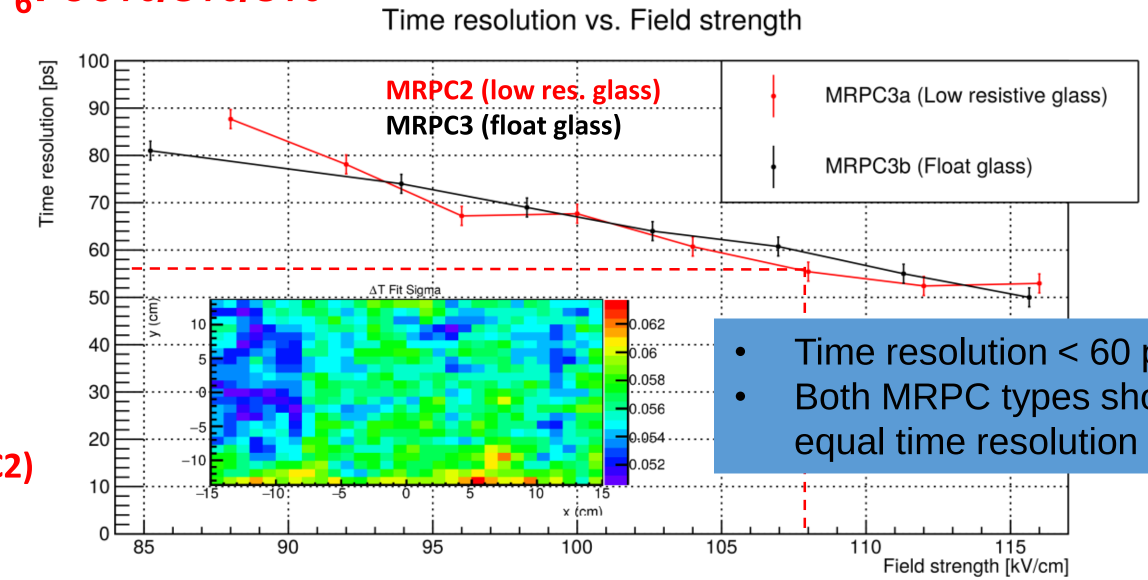
due to the high GWPs ⇒ - Alternative gases (HFO)
- Reduction of SF6
- Gas recycling

Cosmic test results (low rate)

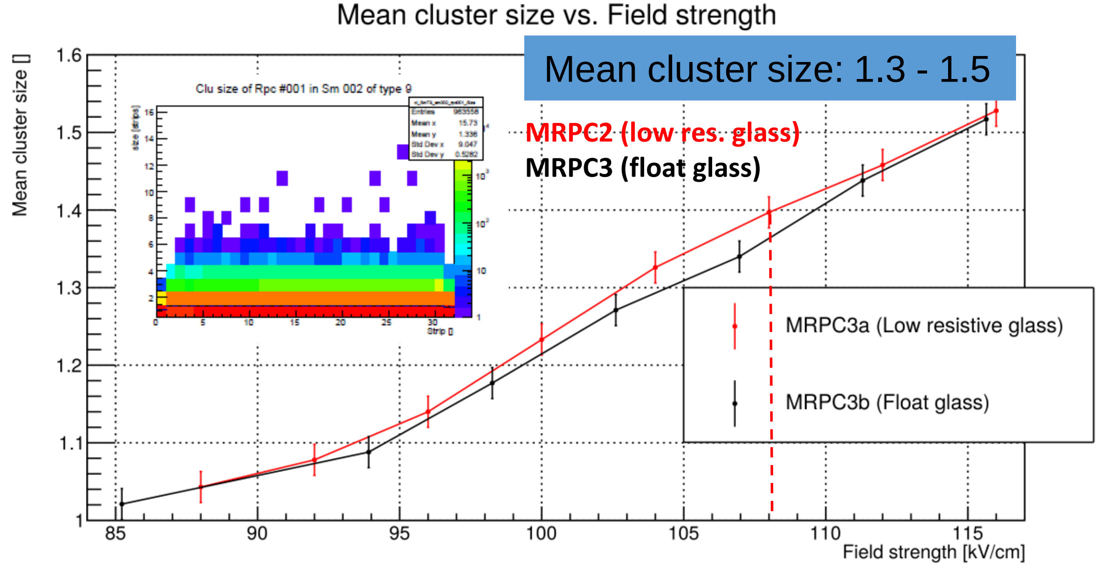
R134a/iso-Butan/SF_6: 90%/5%/5%



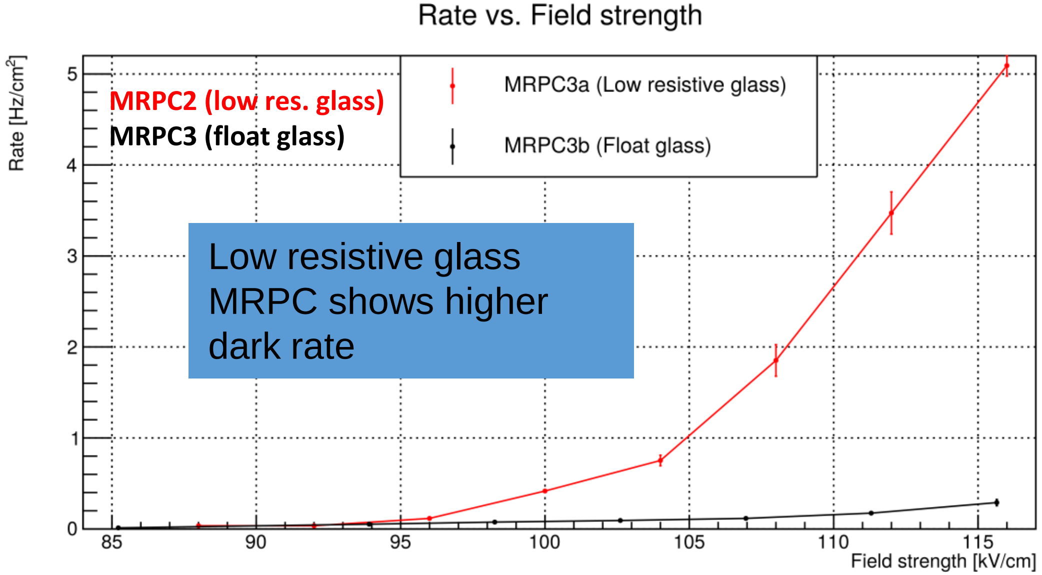
- Efficiency > 96 %



- Time resolution < 60 ps
- Both MRPC types show equal time resolution



Mean cluster size: 1.3 - 1.5

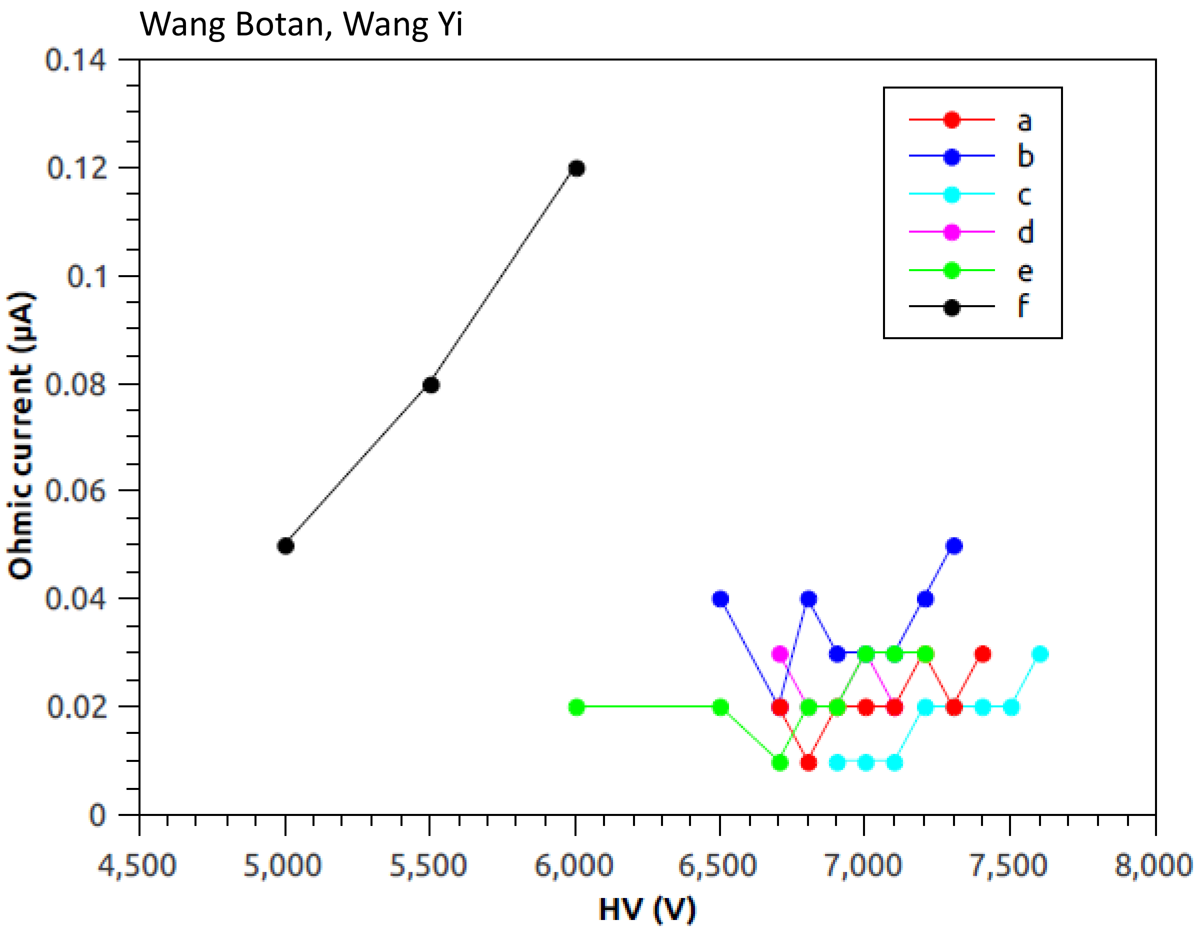


Low resistive glass MRPC shows higher dark rate

Alternative gas search in CBM TOF

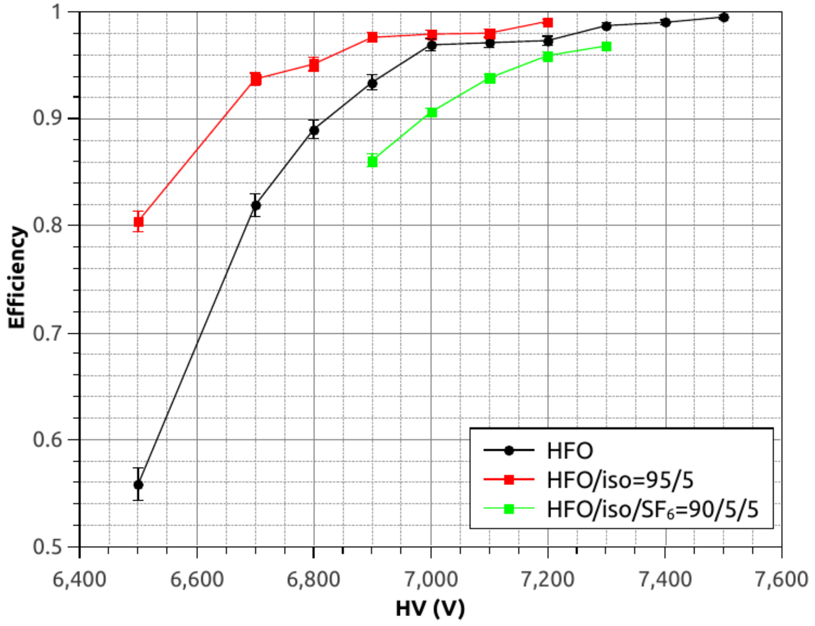
- Working point with standard gas mixture is at 5400 V

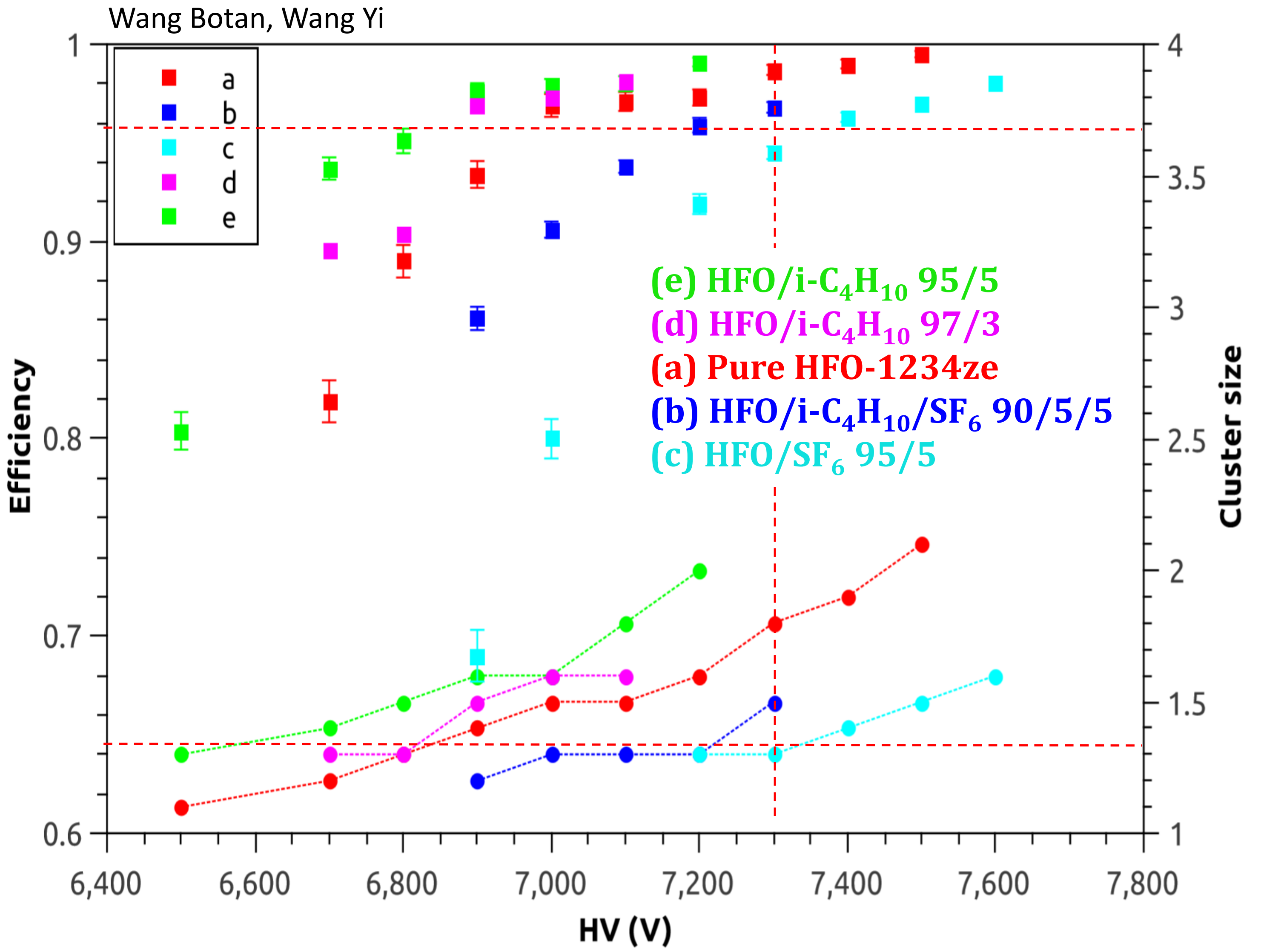
(a) Pure HFO-1234ze
(b) HFO/i-C_4H_{10}/SF_6 90/5/5
(c) HFO/SF_6 95/5
(d) HFO/i-C_4H_{10} 97/3
(e) HFO/i-C_4H_{10} 95/5
(f) HFO/i-C_4H_{10} 90/10



Alternative gas search in CBM TOF

- Working point with standard gas mixture is at 5400 V
- Working point is shifted by about 1900 V
- Gas mixtures with HFO fulfil our TOF requirements in terms of efficiency and cluster size

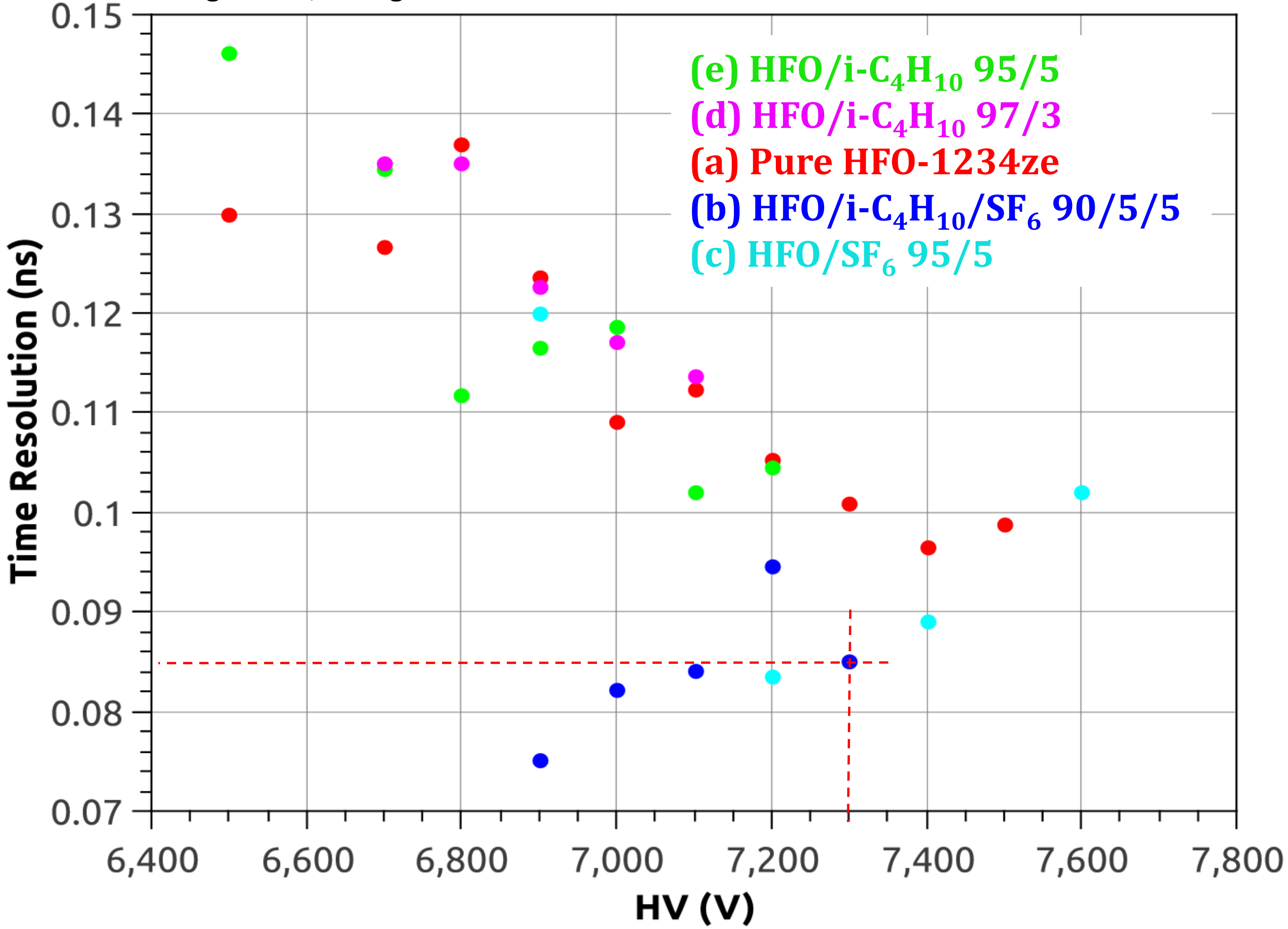


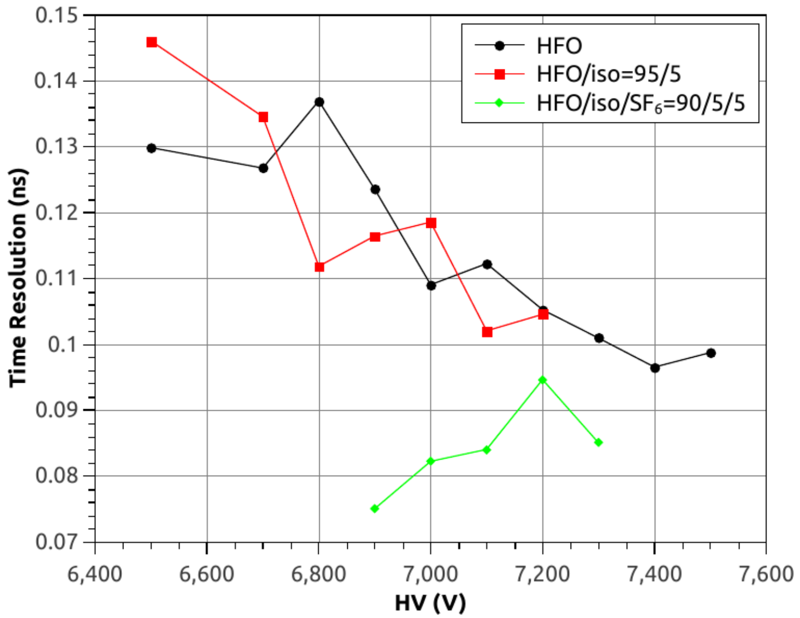


Alternative gas search in CBM TOF

- Working point with standard gas mixture is at 5400 V
- Working point is shifted by about 1900 V
- Time resolutions in the order of 80 ps to 100 ps were obtained
- Gas mixtures with HFO only in combination with SF_6 fulfil our TOF requirements

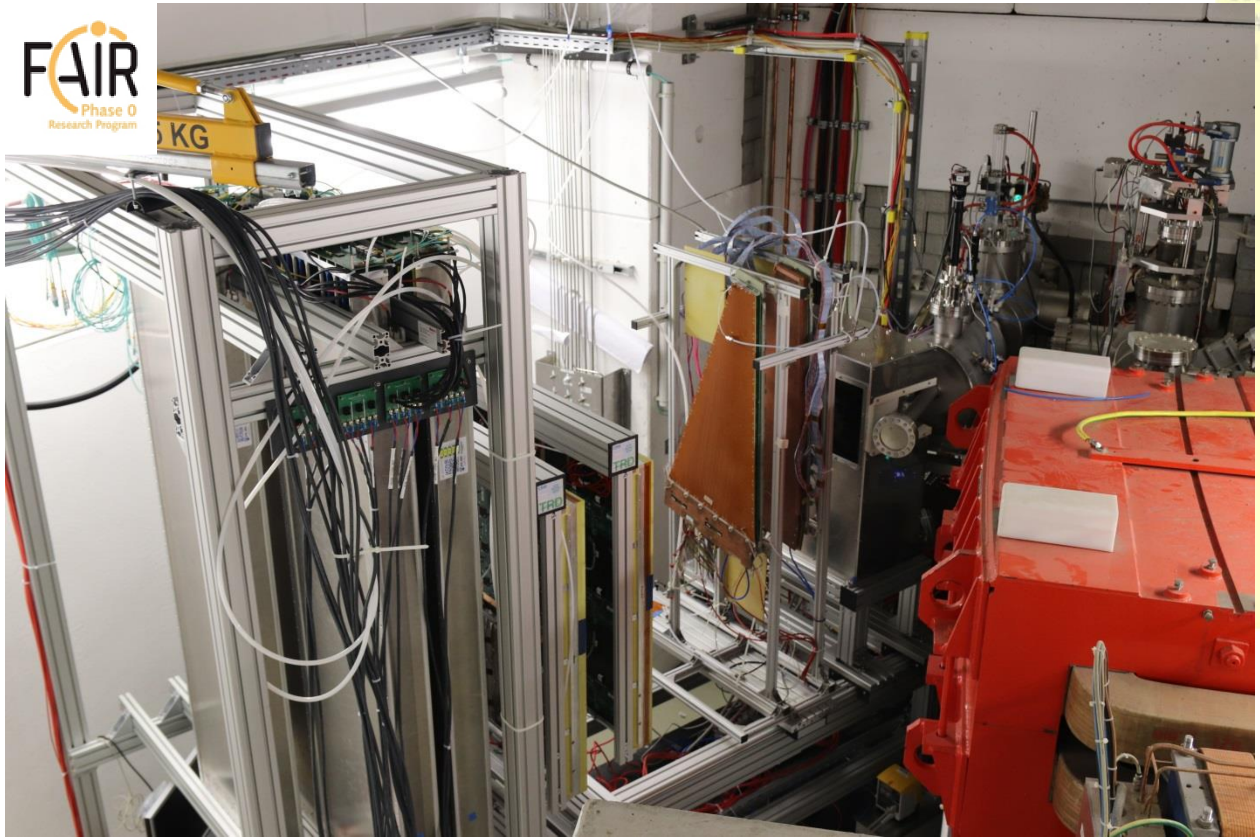
Wang Botan, Wang Yi

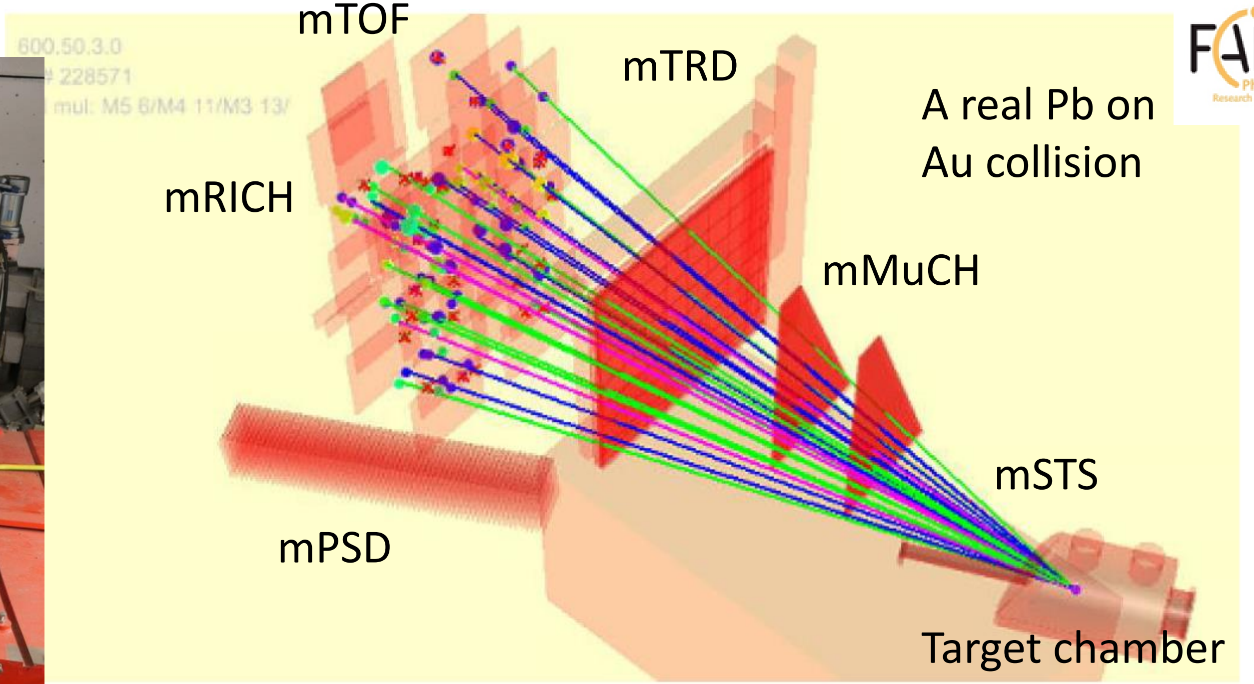


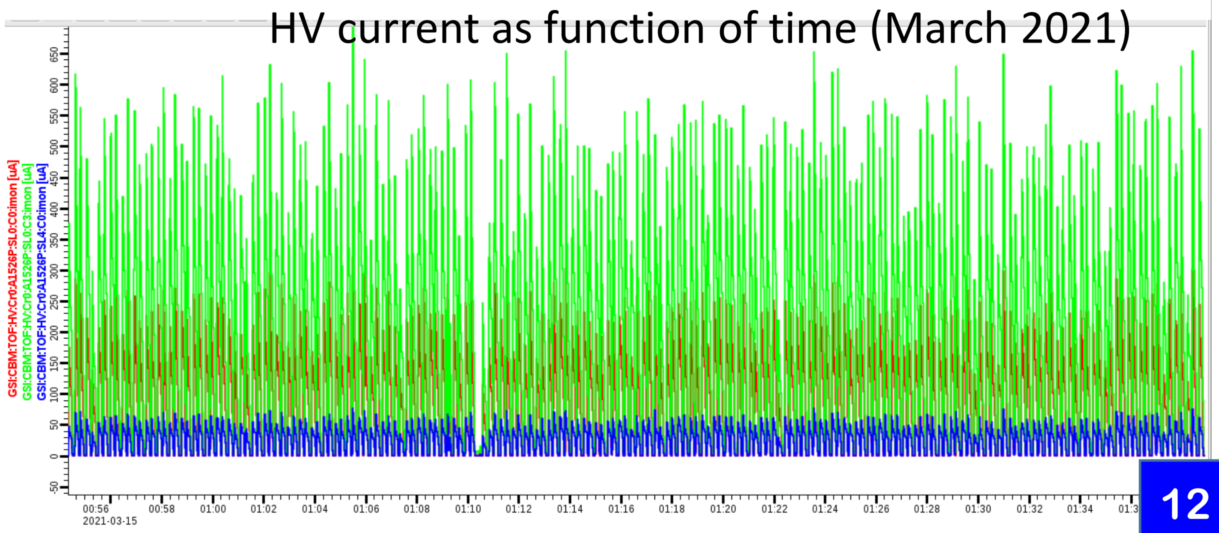


mCBM test setup at SIS18

FAIR Phase 0: mCBM setup @ SIS18





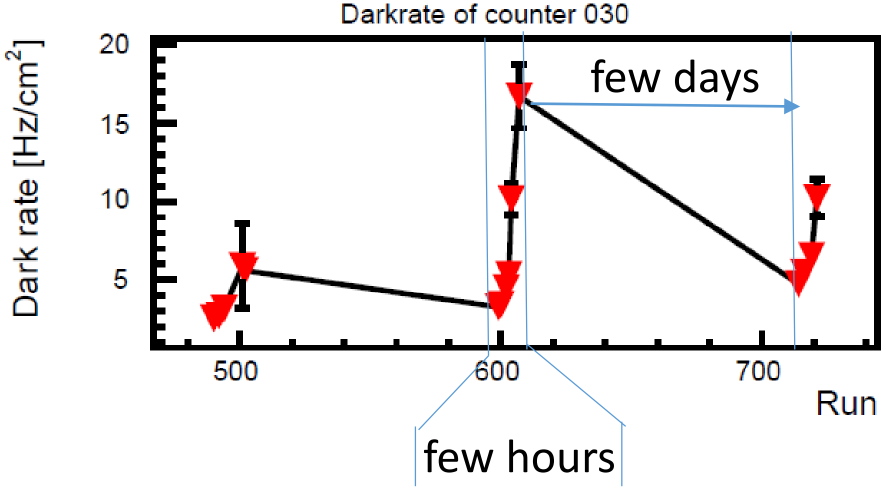


- mCBM is a full system test setup installed at SIS18/GSI dedicated for high rate detector and readout test including free streaming data acquisition and online event selection
- Charged particle fluxes of up to 30 kHz/cm^2

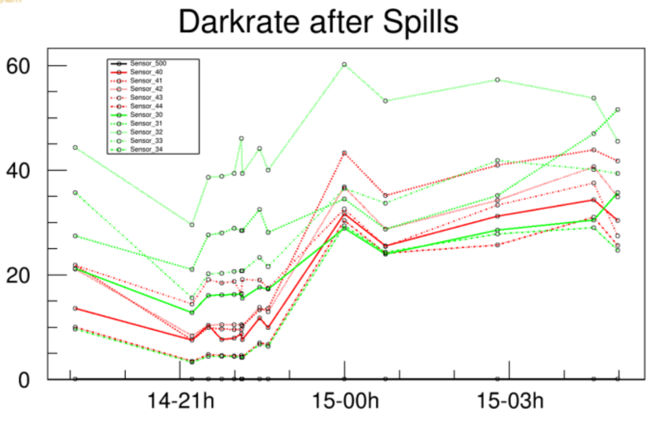
Aging & gas pollution

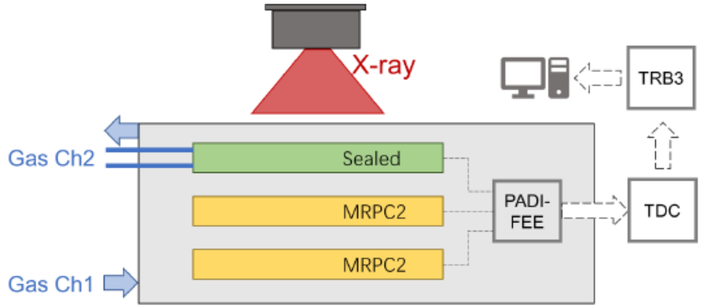
- Gas pollution effect observed at mCBM at high rate (above 10 kHz/cm²)
- Gas pollution effect was reproduced at IRASM (Bucharest) with high gamma flux
- X-Ray test at Beijing confirmed the gas pollution effect
- The effect was minimized by sealing the MRPC and increasing the gas flow

Observations @ mCBM 2020
rapid increase of dark rate

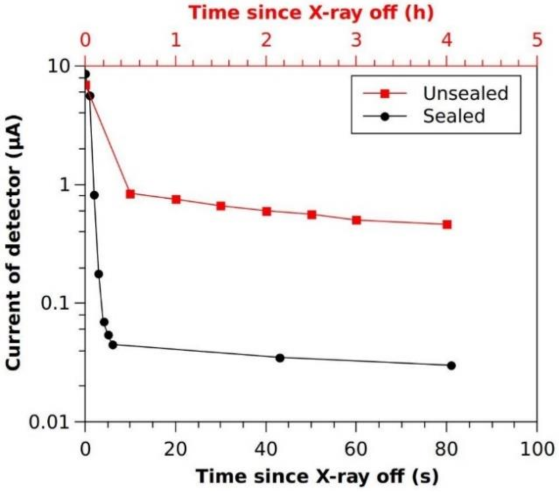


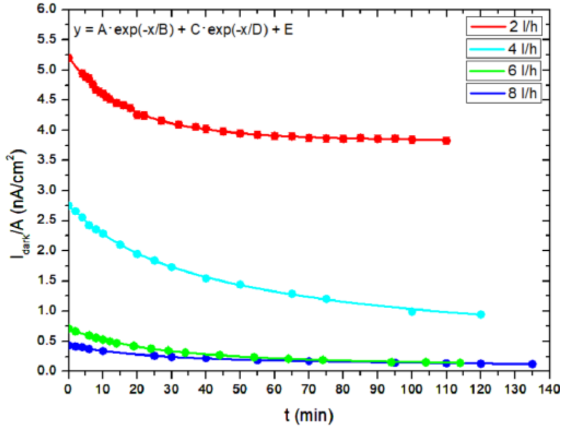
Observations confirmed @ mCBM 2021





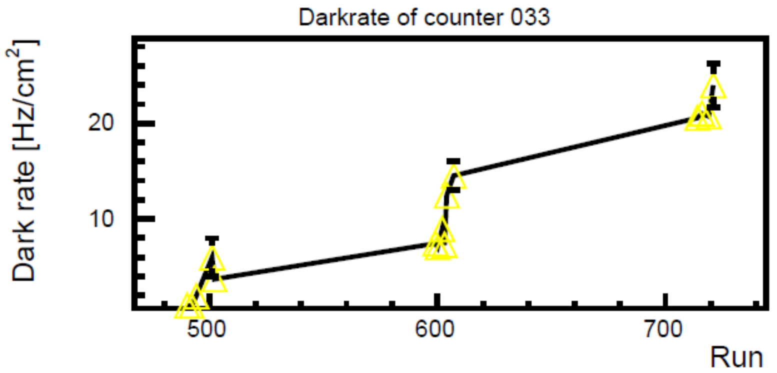
Dark current relaxation after irradiation

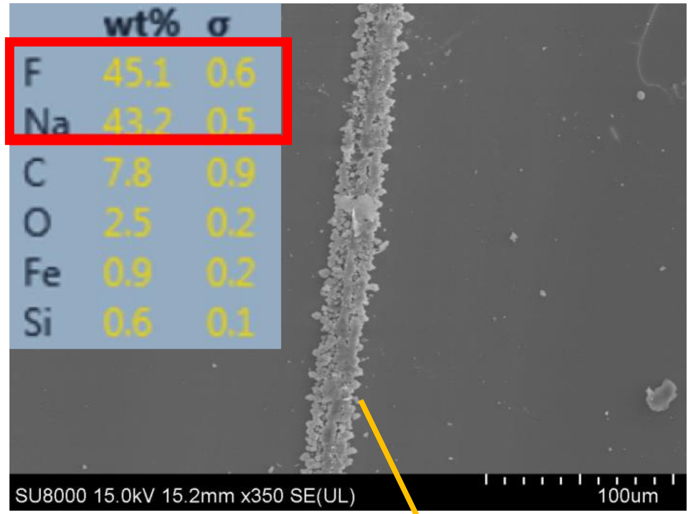


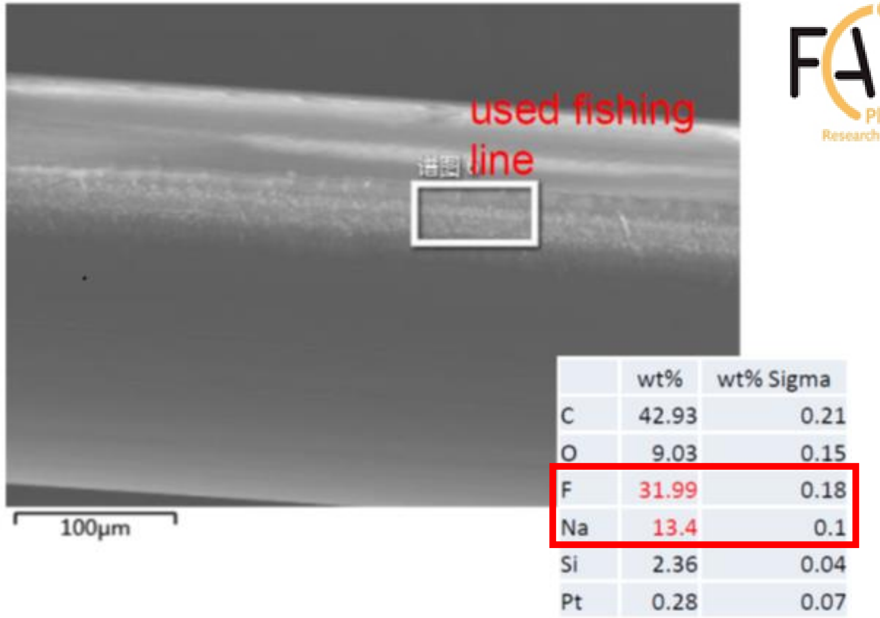


Aging & gas pollution

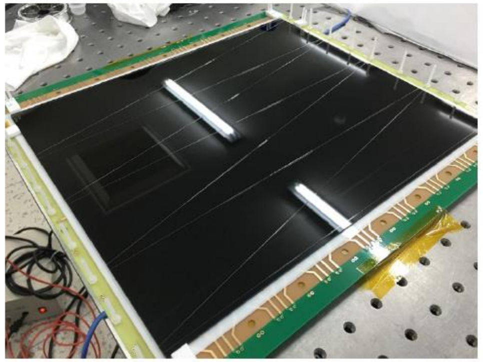
Observations: continuous increase in dark rate (permanent aging)

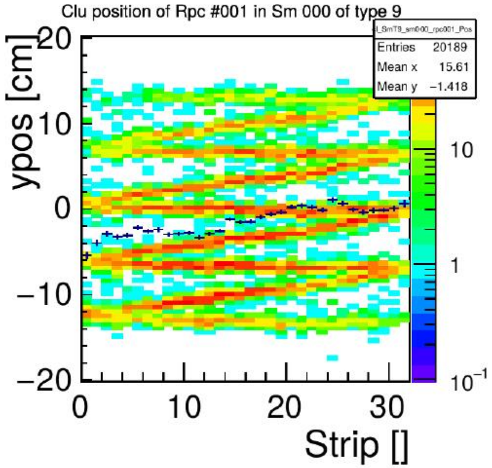


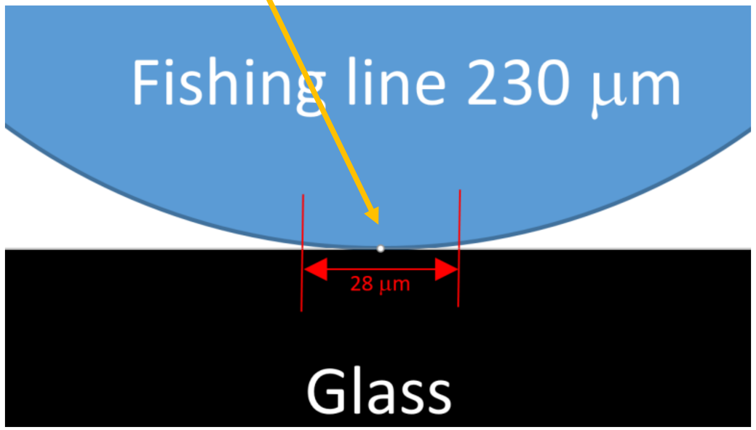




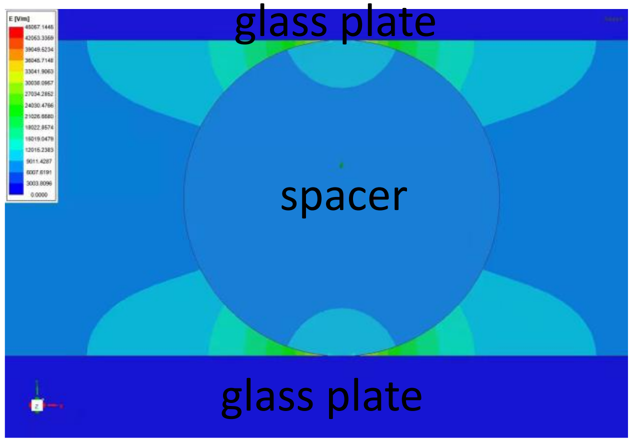
- Traces of NaF was found on the glass surface
- Dark rate (noise) is generated entirely on spacers
- Electrical field simulations performed







Electrical field simulations



Gas aging & pollution

CBM

CBM ToF

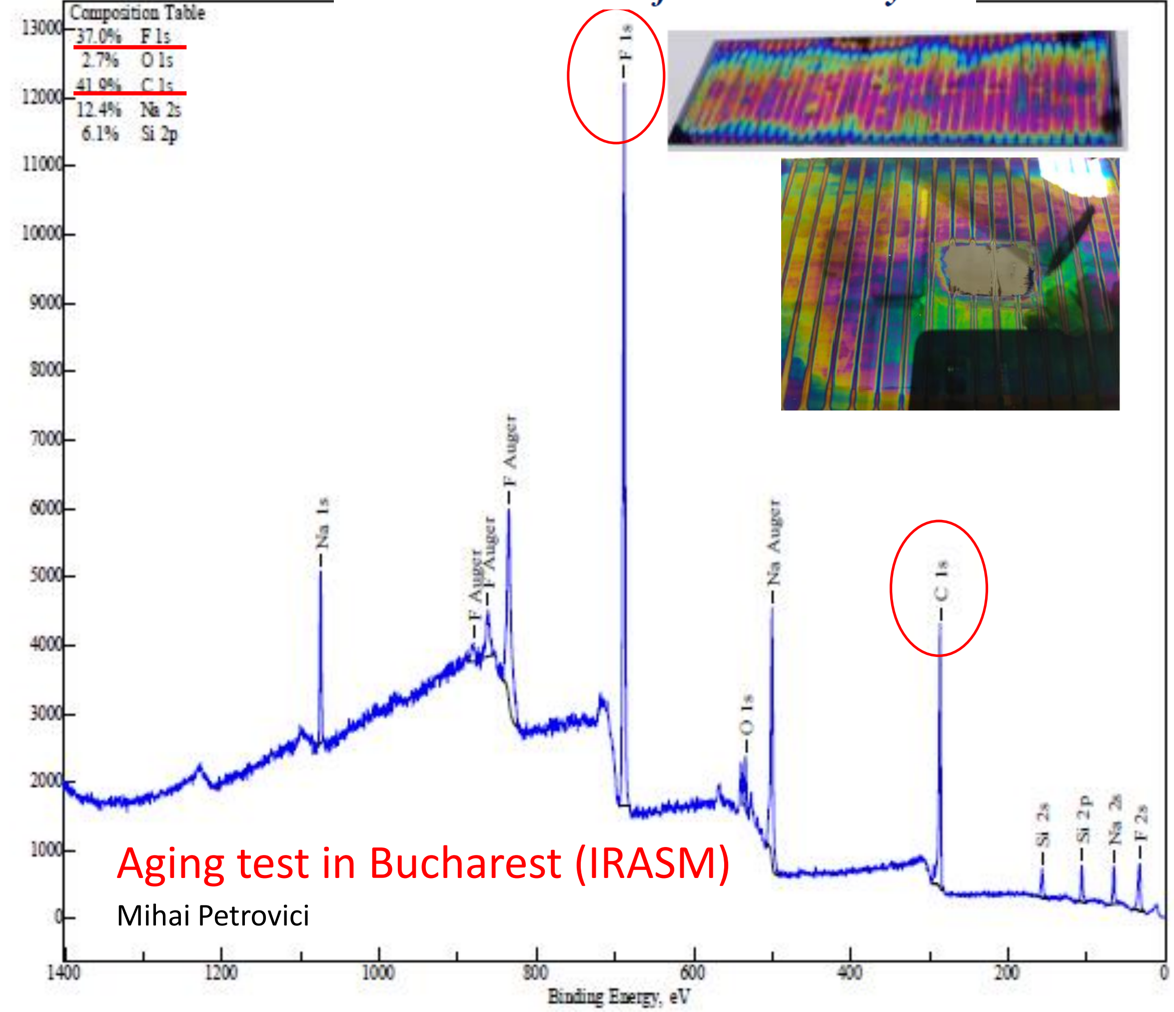
High intensity irradiation with gammas at IRASM

M. Petrovici at al. NIMA 1024 (2022) 166122

Surface facing the cathode

XPS analysis - thanks to C. Negrila

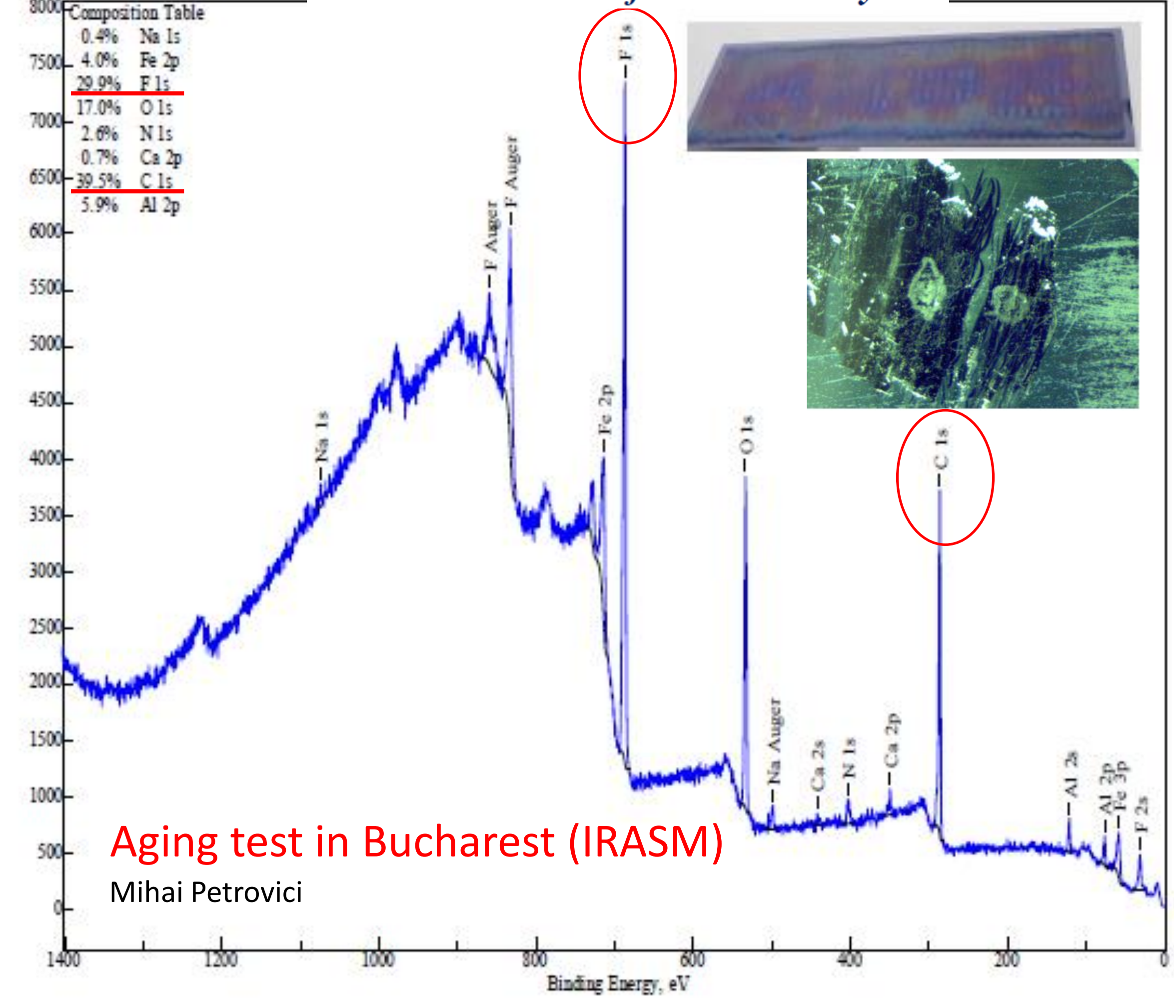
National Institute of Materials Physics



surface facing the anode

XPS analysis - thanks to C. Negrila

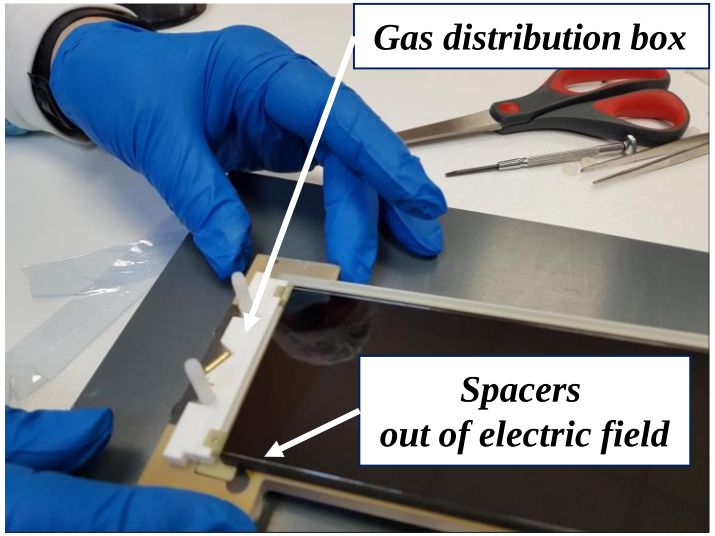
National Institute of Materials Physics

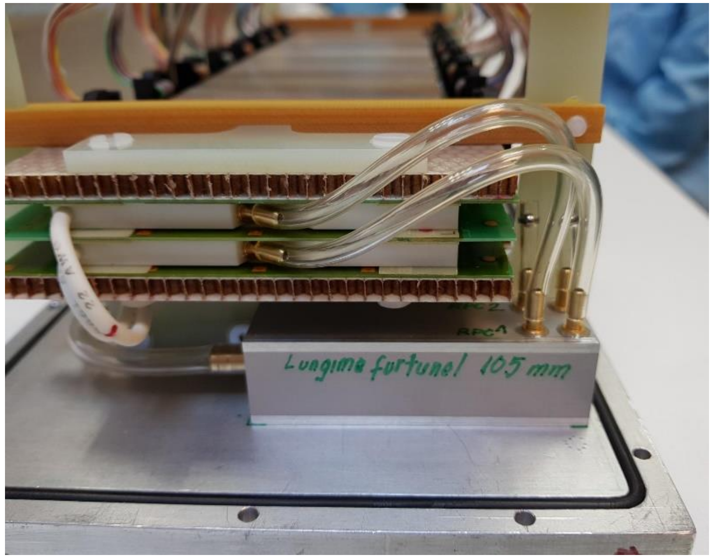


Mitigation of gas pollution and aging

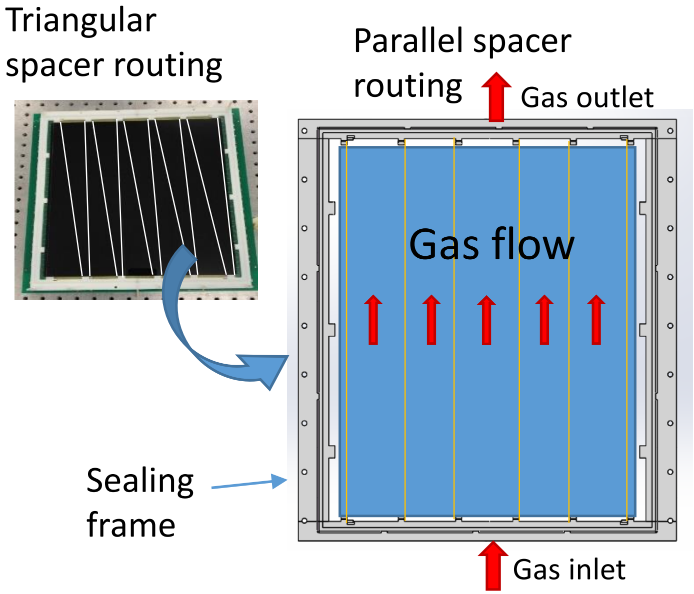
CBM ToF

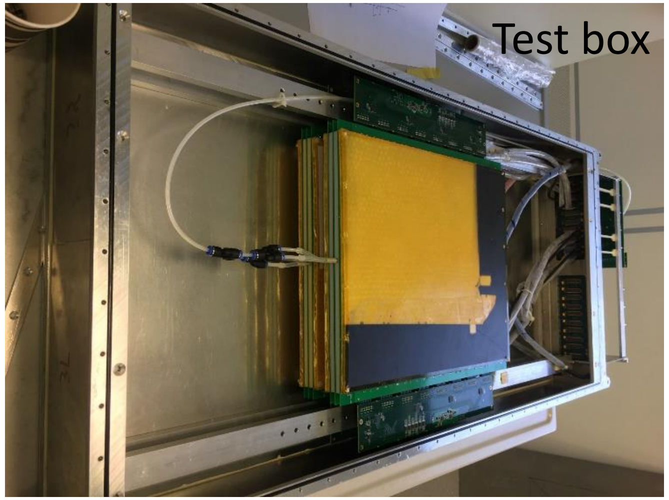
High rate counter (MRPC1)



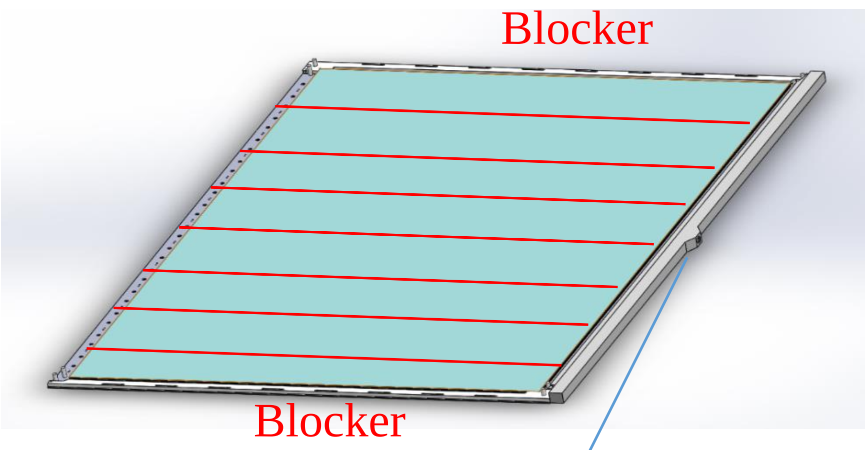


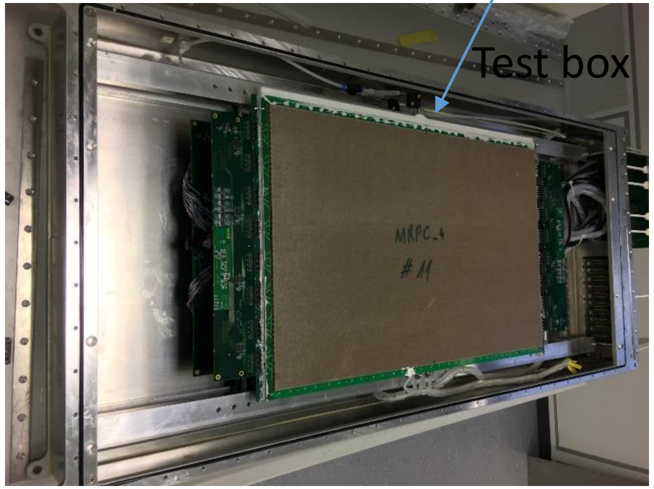
Intermediate rate counter (MRPC2)





Low rate counter (MRPC3/4)



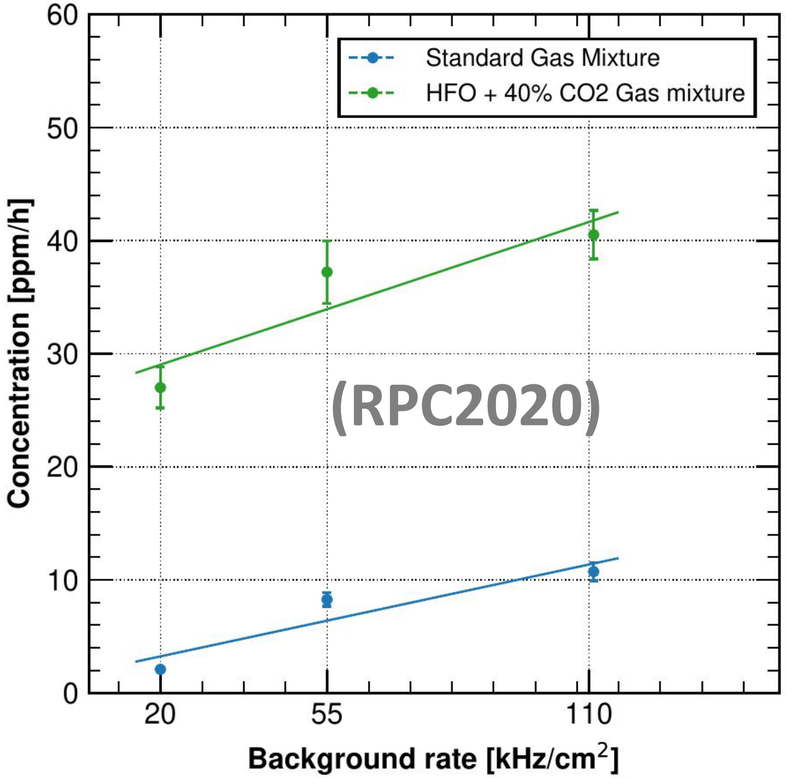


Gas stability comparison

https://agenda.infn.it/event/19942/contributions/108493/attachments/70618/88191/rigoletti_rpc2020.pdf

G. Rigoletti et al 2020 JINST 15 C11003

R. Guida. B. Mandelli. *G. Rigoletti*



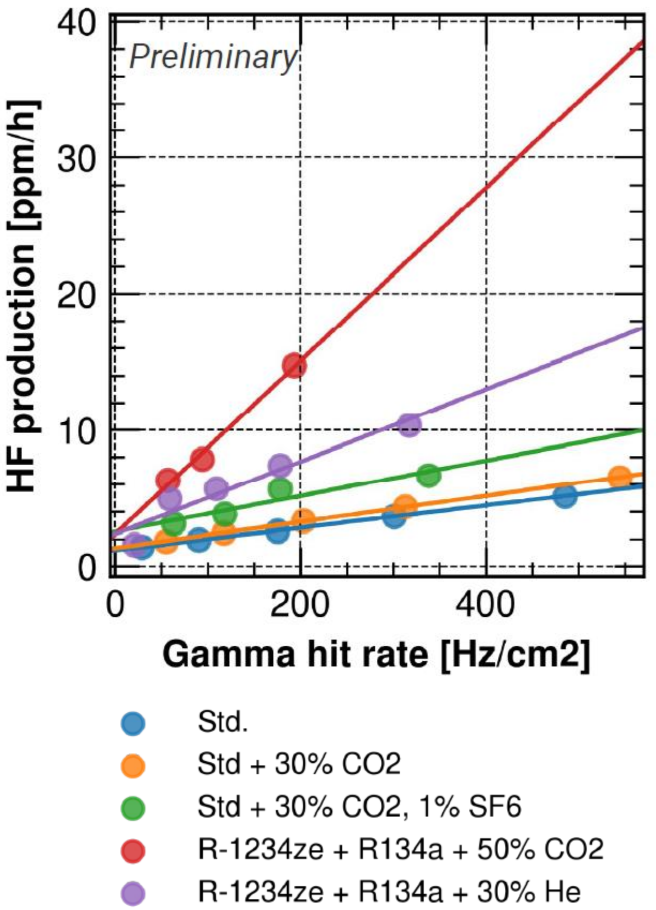
HFO is breaking ~10 times more easily than R134a

The instability of HFO in comparison to R134a is extremely counterproductive in a high rate environment as anticipated at CBM

- **The F^- production of the selected eco-friendly gas mixture is ~4 times higher than the standard gas mixture**

RPC2022: Measurements of fluoride production in Resistive Plate Chambers

HF Production @ w.p.

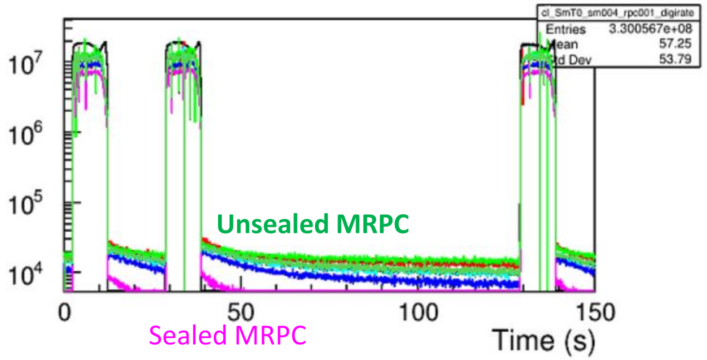


mCBM beam time results

Beamtime mCBM March 2021

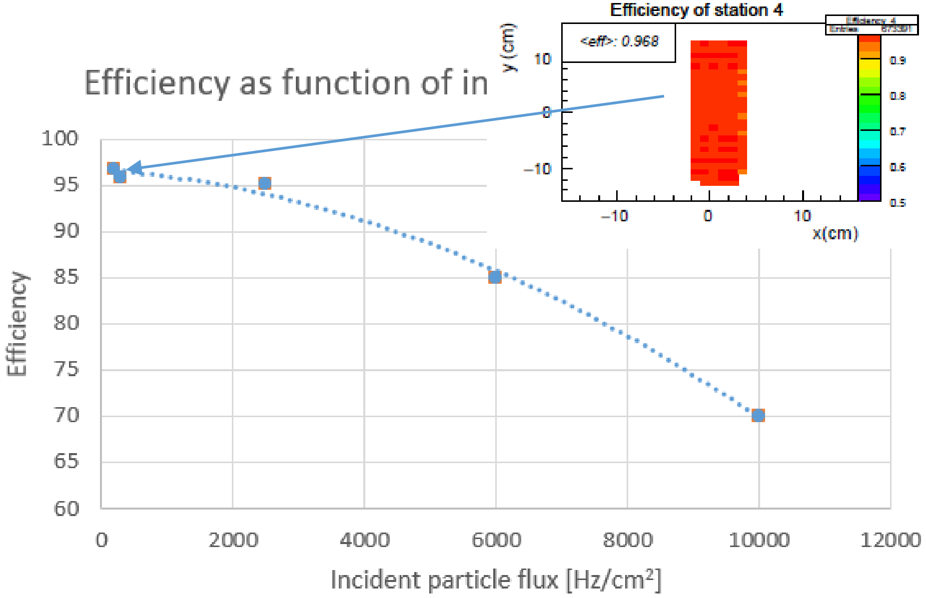
Gas Mixture:

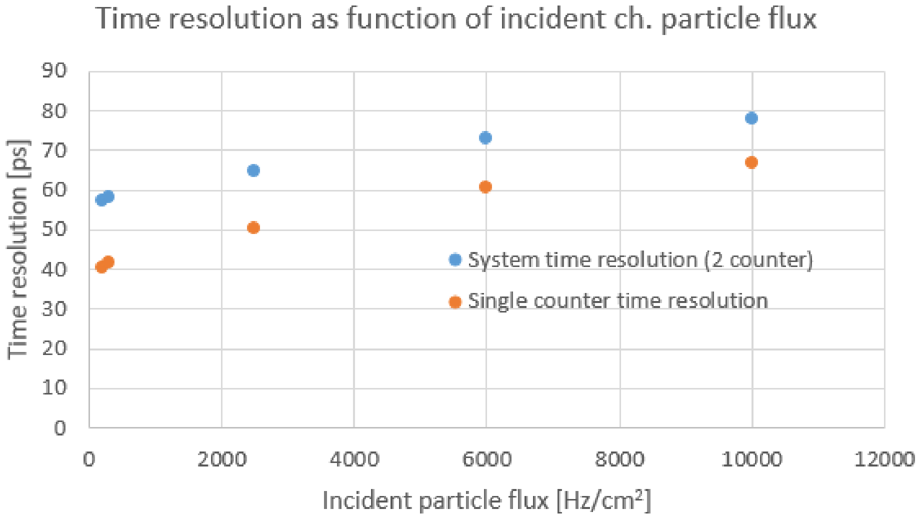
$R134a/SF_6$ - 97.5%/2.5%



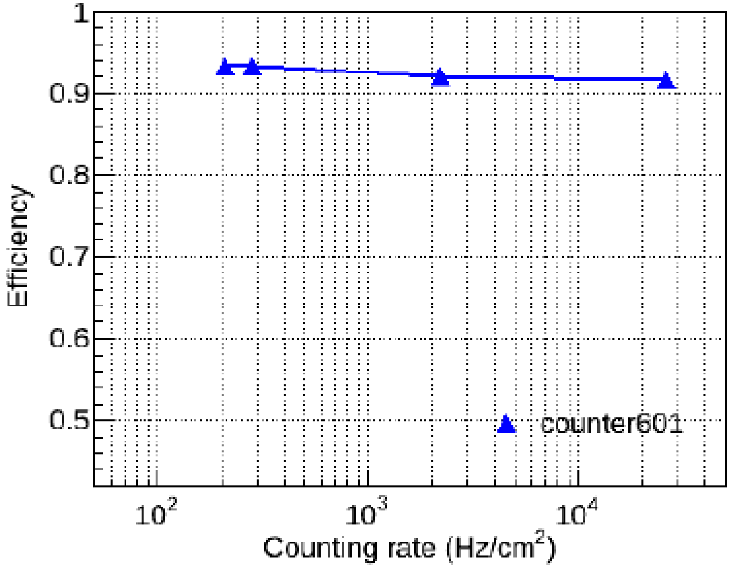
No significant change in performance with new gas mixture observed

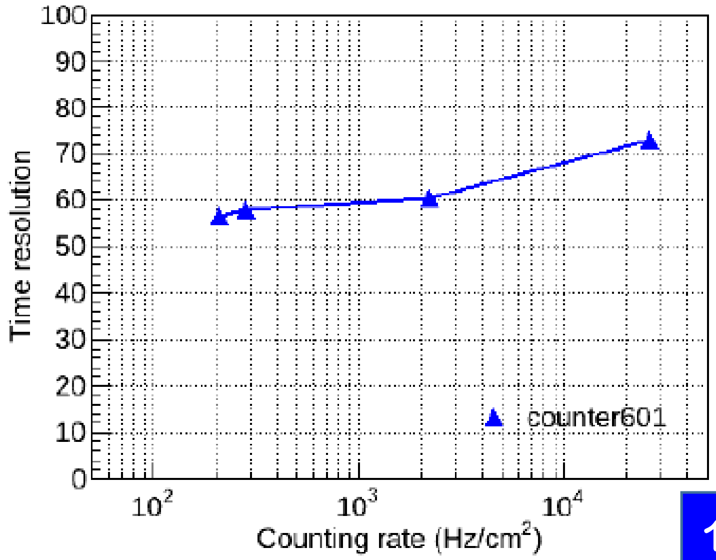
MRPC3 (low rate **thin float glass** counter)





MRPC1a (**low resistivity glass** counter)





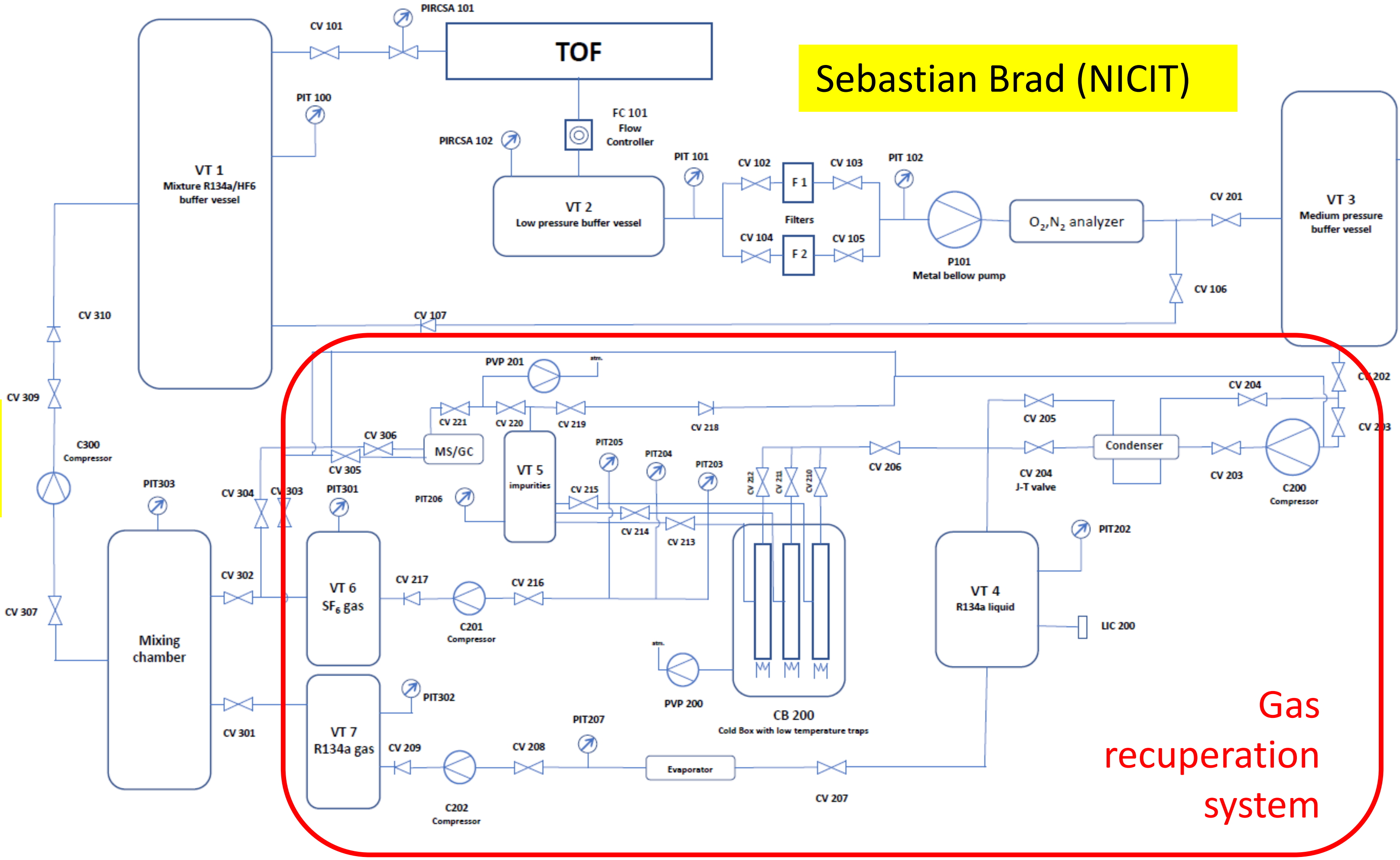
Conclusions for the CBM TOF gas system

R. Guida, B. Mandelli, G. Rigoletti

- Stay with Tetrafluorethane (R134a) (enhanced F-ion production for HFO in high rate environment)
- Abandon iso-Butan (aging , safety, difficult to recycle)
- Reduce fraction of SF_6 to 2.5% (reduction of GWP, difficult to recycle)
- Increase the flow rate
- Build a recuperation system (reuse of gas, cost reduction, GWP reduction)

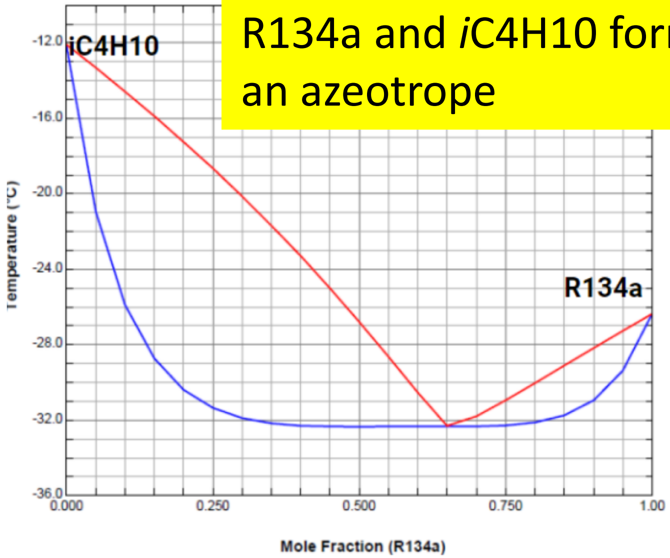
230 modules
Total gas volume 25 m^3

Sebastian Brad (NICIT)



Gas recuperation system

R134a and *i*C4H10 form an azeotrope



Summary

- In CBM hadron PID will be realized with the TOF method based on Multigap-RPCs
- With gas mixture based on Tetrafluorethane the counter fulfil the CBM TOF requirements
- At high particle flux gas aging effects were observed – mitigation on counters initiated
- Eco-friendly gas mixtures were investigated – however, HFO breaks faster than R134a which is not helpful in a high rate environment
- The conclusion for CBM TOF is to stay with R134a and recycle all gas components for reuse
- First concept of a recuperation system was proposed

Thank you for your attention

Contributing institutions:

Tsinghua	Beijing,
NIPNE	Bucharest,
GSI	Darmstadt,
TU	Darmstadt,
USTC	Hefei,
PI	Heidelberg,
ITEP*	Moscow,
CCNU	Wuhan,

*Cooperation suspended

Backup slides