# The CBM time-of-flight detector and the future perspective of (M)RPCs

**Ingo Deppner**

Physikalisches Institut, Heidelberg University

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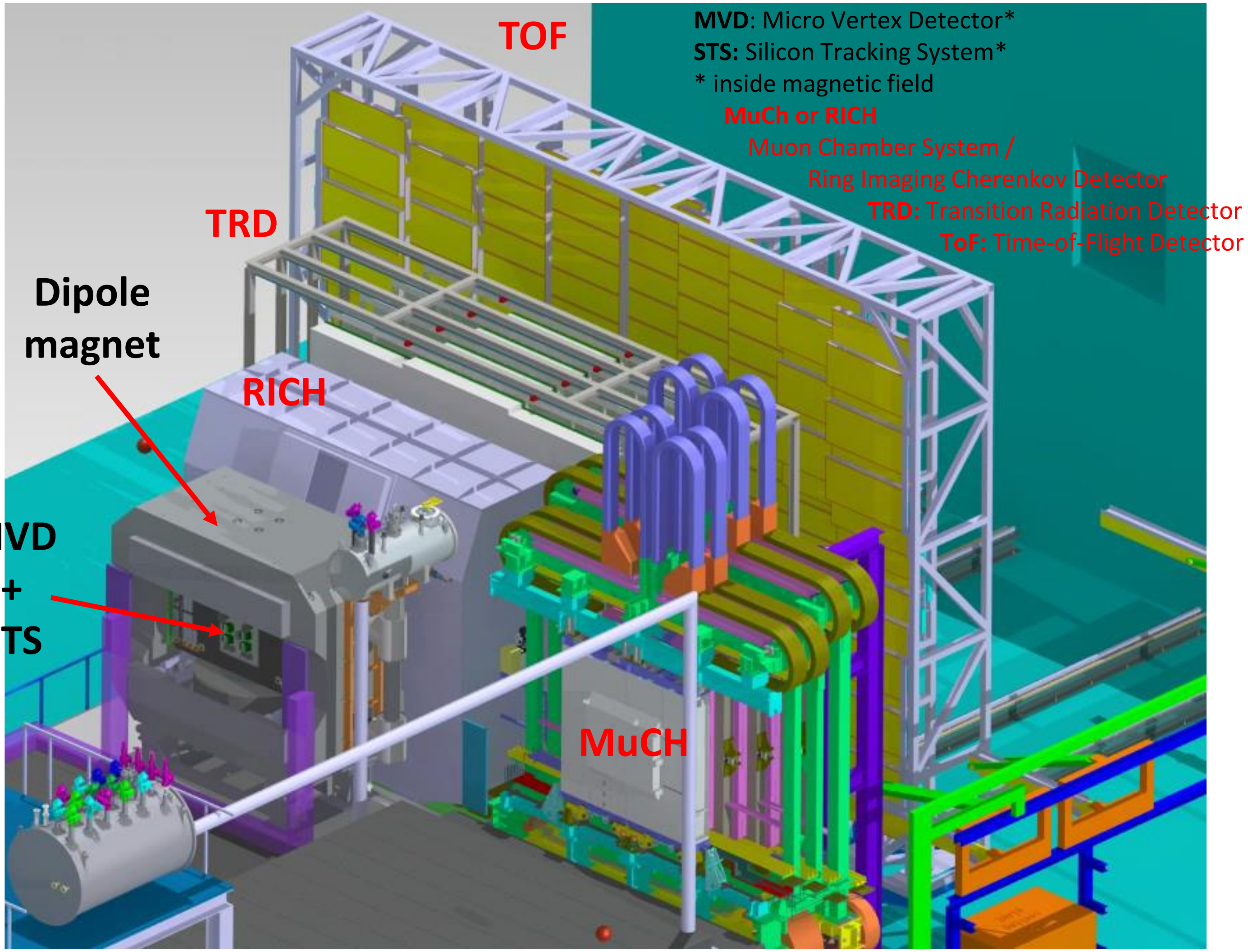
# Outline

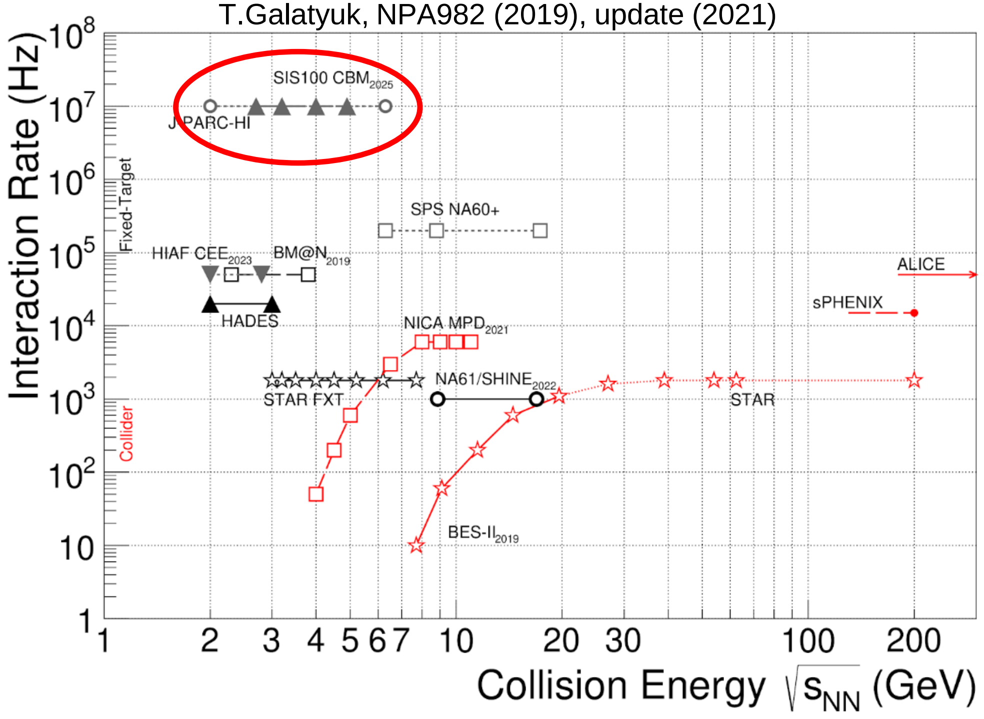
- Introduction to CBM and CBM-TOF
- mCBM@SIS18 test facility
- Performance results
- Gas-aging in a high rate environment
- Investigation on eco friendly gas mixtures for timing MRPCs
- Conclusions for the CBM TOF and its gas system
- ECFA road map and the DRD1 Collaboration
- Future perspective of RPCs and MRPCs in FAIR
- Summary

# Introduction CBM

## Compressed Baryonic Matter (CBM) Experiment




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

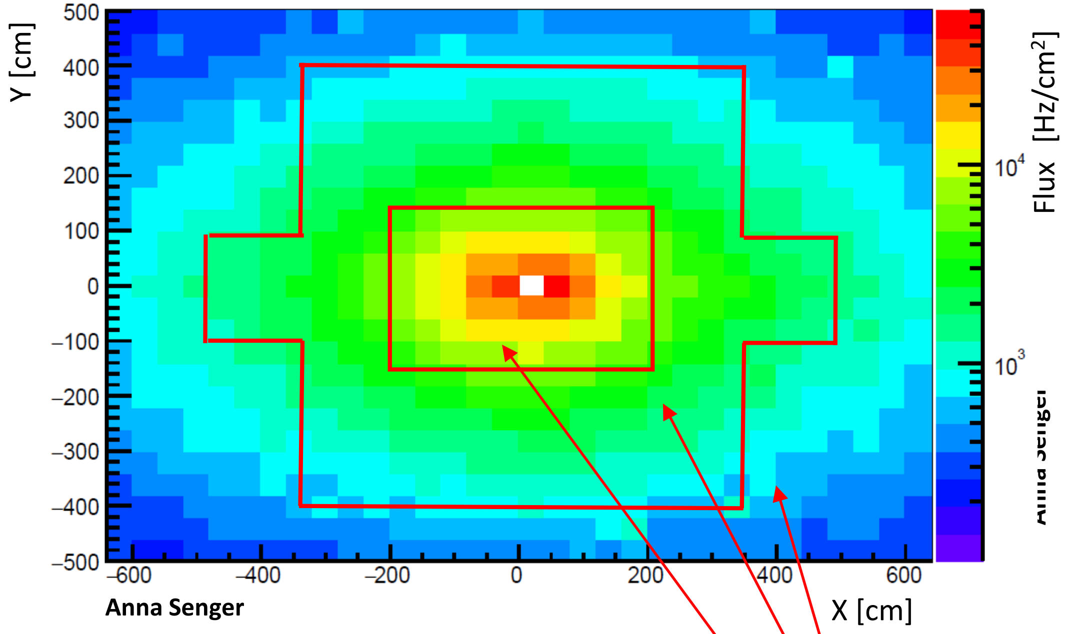



- Tracking acceptance: $2.5^o < \theta_{Lab} < 25^o$
- Peak $R_{int}$ is 10 MHz for Au+Au (300 kHz for MVD)
- Fast & radiation hard detectors
- Free-streaming DAQ
- 4D tracking (space, time)
- Online event reconstruction and selection
- Data rate: 1 TB/sec

# Introduction CBM TOF

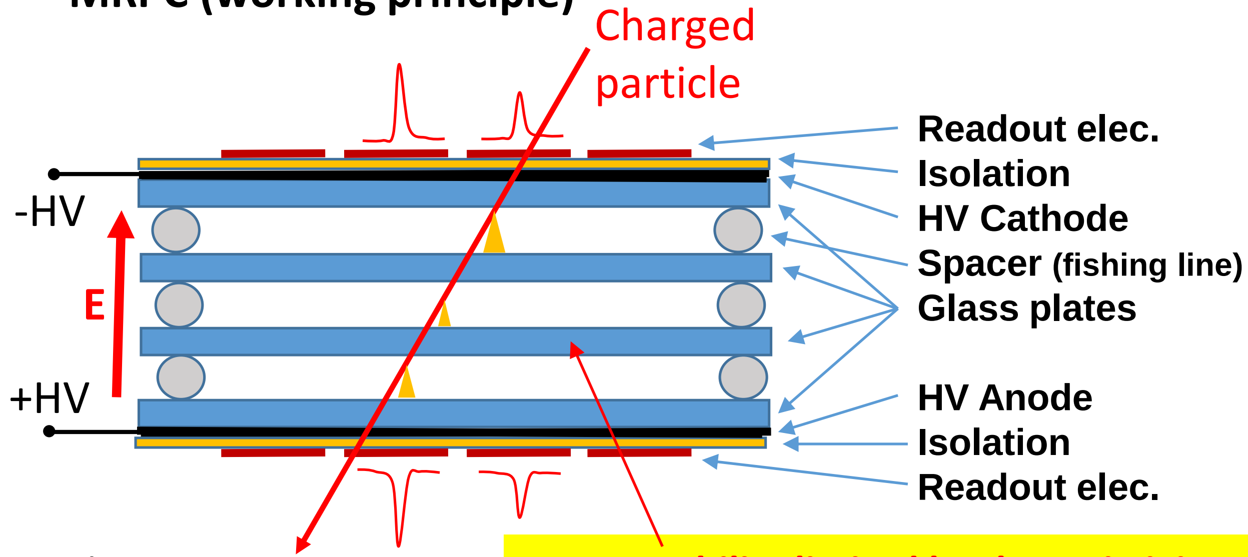
**Charged hadron identification is provided by Time-of-Flight (TOF) measurement**

FLUKA simulation: Au + Au collisions at $E_{kin}$ = 11 AGeV, $10^7$ interactions




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

**MRPC (working principle)**




**Rate capability limited by the resistivity of the electrodes (plates)** $\tau = \rho \varepsilon_0 \varepsilon_r$

## CBM-TOF Requirements

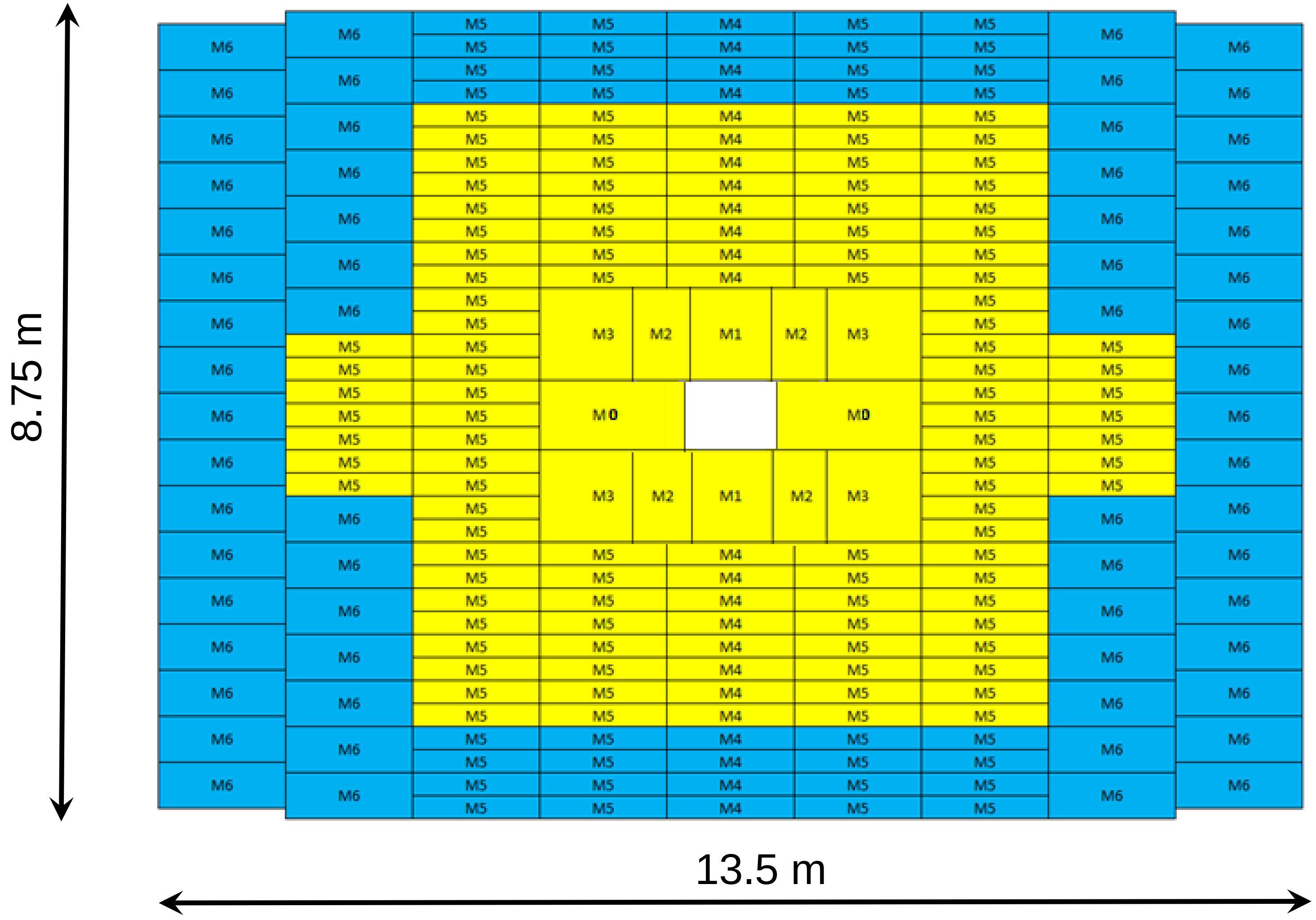
- Full system time resolution $\sigma_T$ ~ 80 ps
- Efficiency > 95 %
- Rate capability ≤ 50 kHz/cm²
- Polar angular range 2.5° – 25°
- Active area of 120 m²
- Occupancy < 5 %
- Low power electronics (~100.000 channels)
- Free streaming data acquisition

## CBM-TOF MRPCs

- About 1500 MRPC
- Multi-gap RPC with 8 – 10 gaps with gap size of 200 – 250 μm
- MRPC size ranging from 180 cm² up to 1700 cm²
- Gas mixture: Tetrafluorethane / $SF_6$: 97.5% / 2.5%

# Introduction CBM TOF

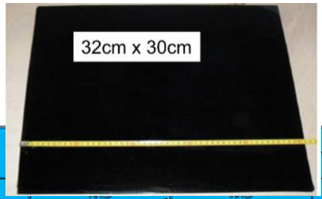
Active area



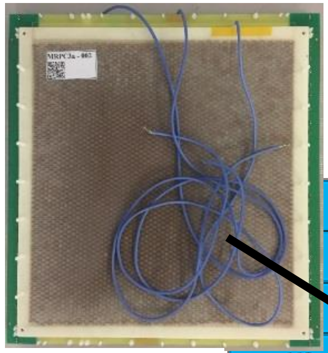

- A module contains several MRPC counters
- 230 modules
- Region containing counters equipped with thin float glass, $\rho \approx 10^{12}\ \Omega$ cm
- Region containing counters equipped with low resistivity glass, $\rho \approx 10^{10}\ \Omega$ cm

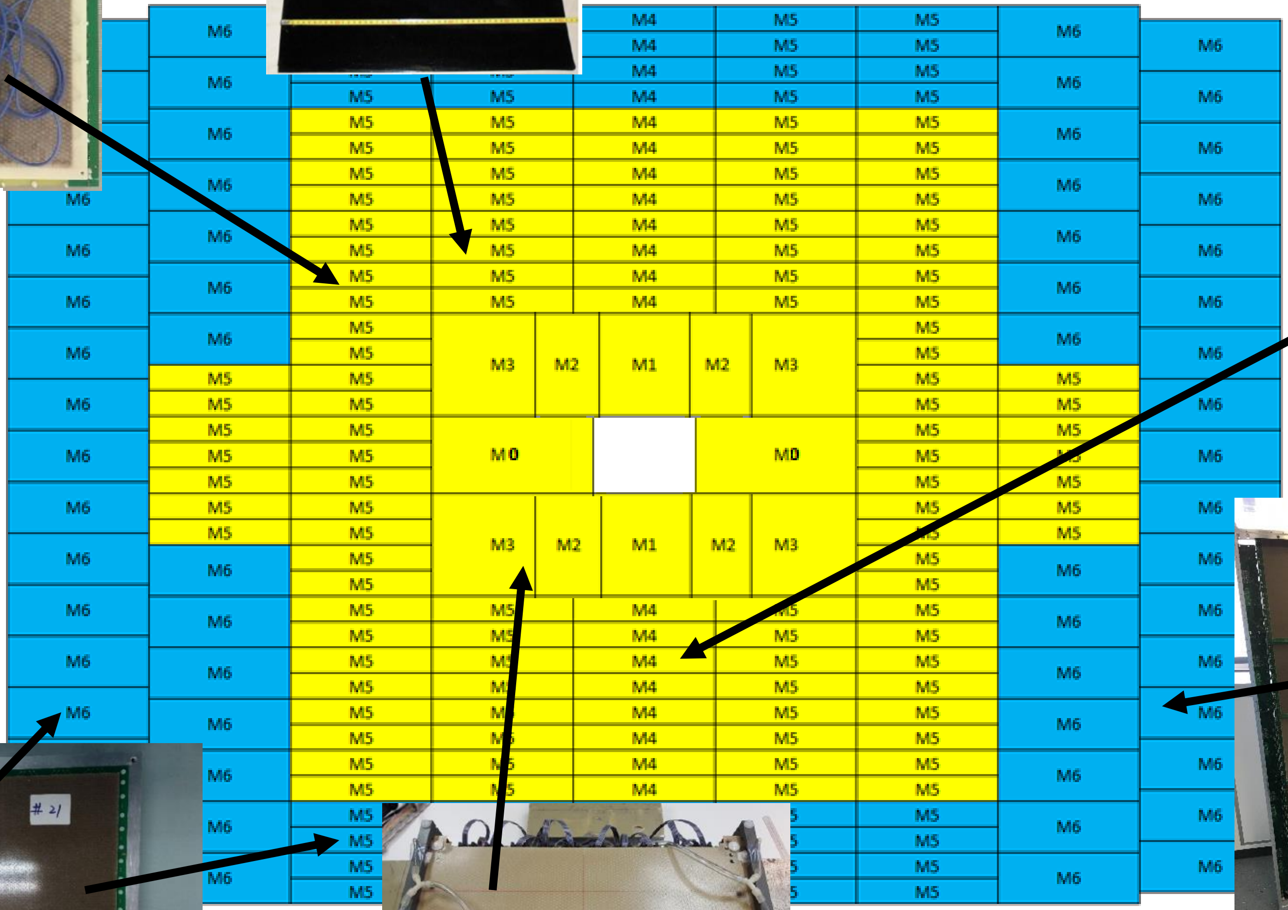
# Introduction CBM TOF

Low resistivity glass




MRPC2
(Tsinghua)

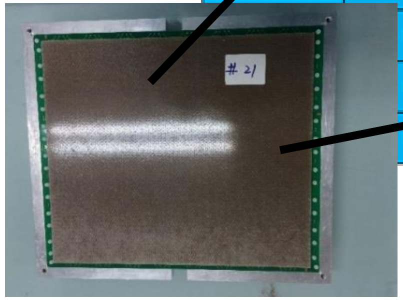


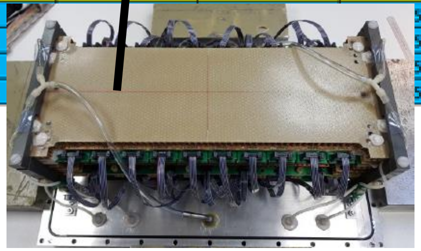



M4 Module (HD)

- **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**

MRPC3/4
(USTC)



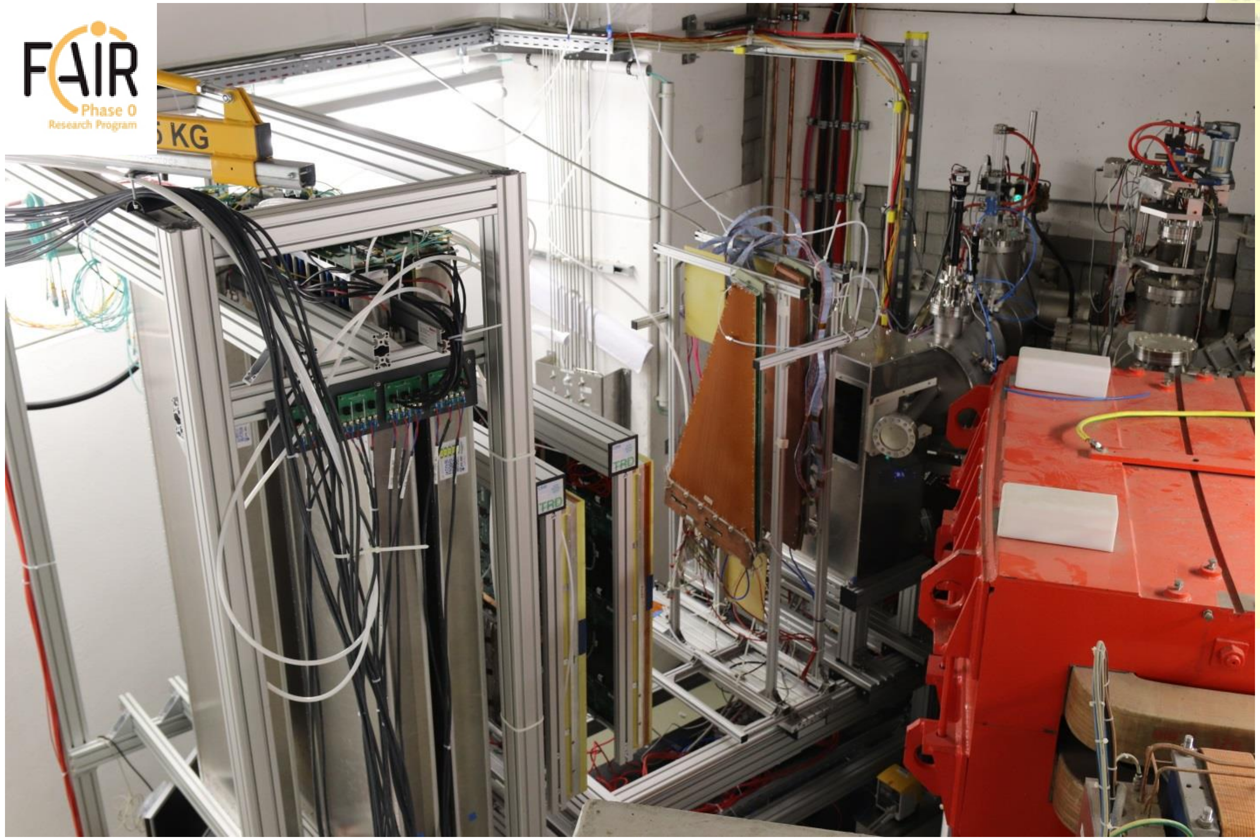


MRPC1a - 1c
(NIPNE Bucharest)

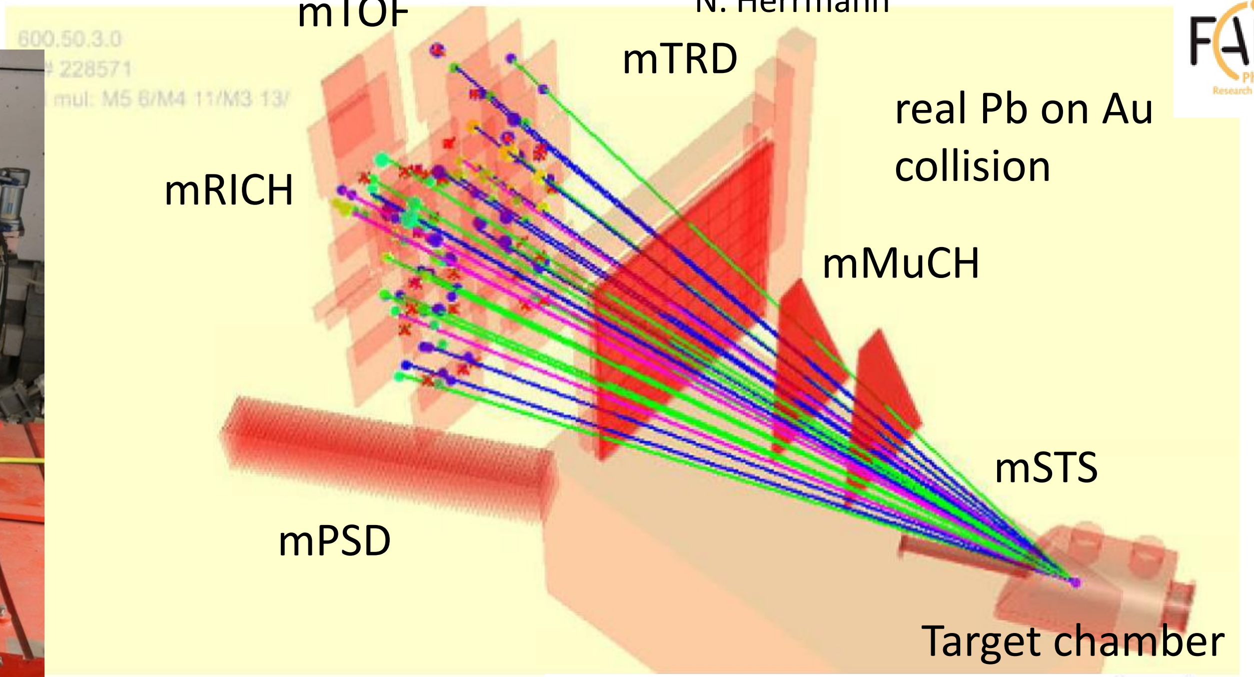
M6 Module (HD)

# mCBM @ SIS18

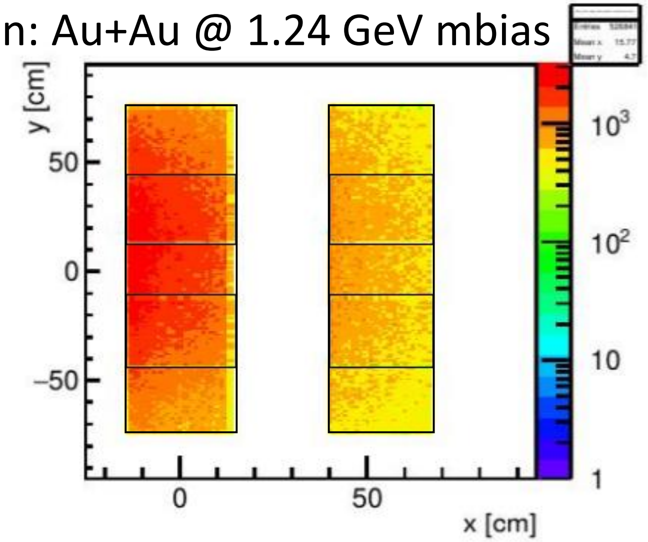
## FAIR Phase 0: mCBM setup @ SIS18



N. Herrmann




Simulation: Au+Au @ 1.24 GeV mbias



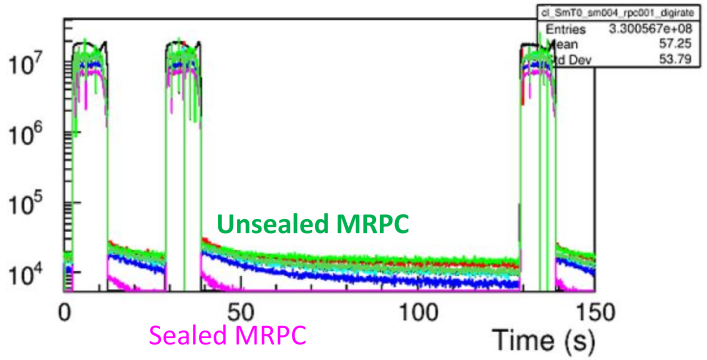

- mCBM is a full system test setup installed at SIS18/GSI dedicated for high rate detector and readout test including free streaming data acquisition and online event selection
- Charged particle fluxes of up to 30 kHz/cm$^2$
- Having a high rate test stand is highly important for detector development

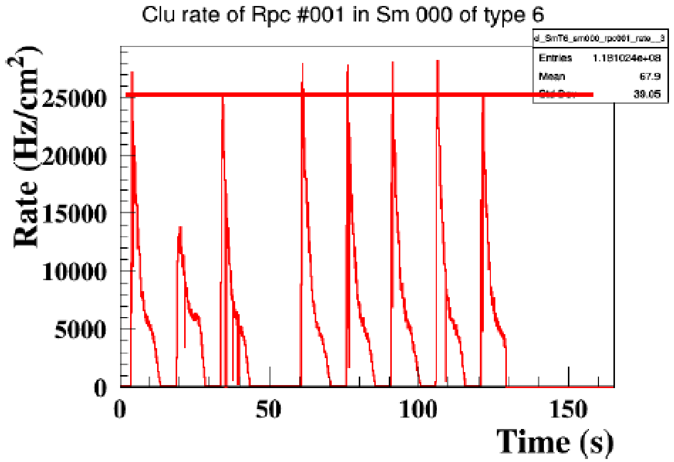
# mCBM beam time results

**Beamtime mCBM March 2021**

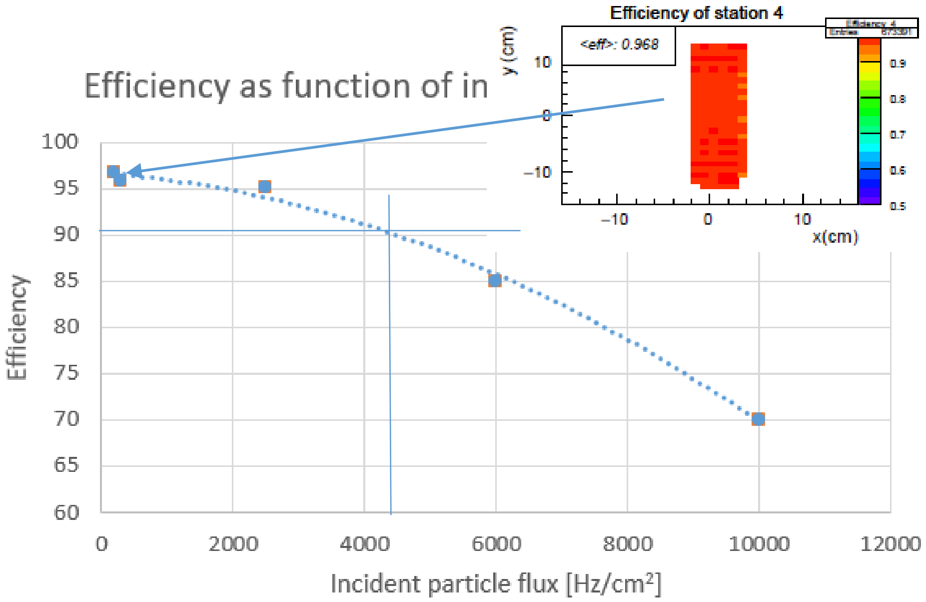
Gas Mixture:

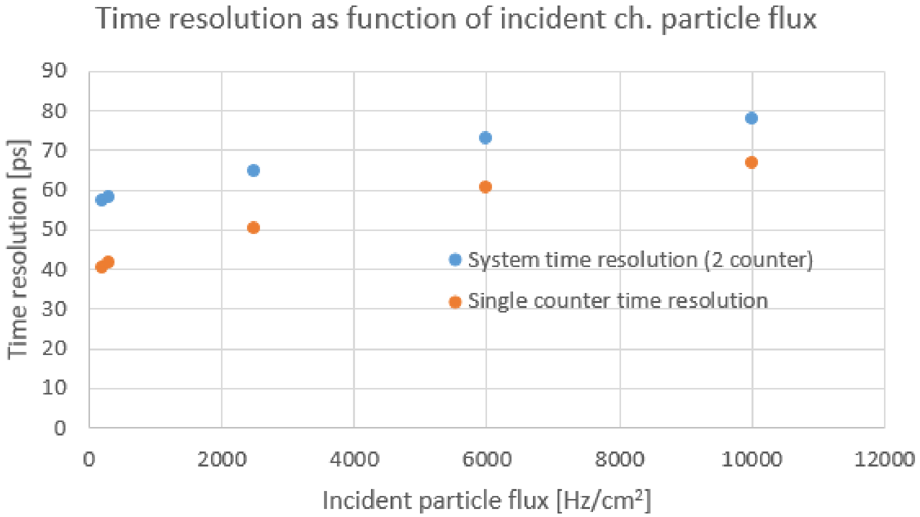
R134a/$SF_6$ - 97.5%/2.5%



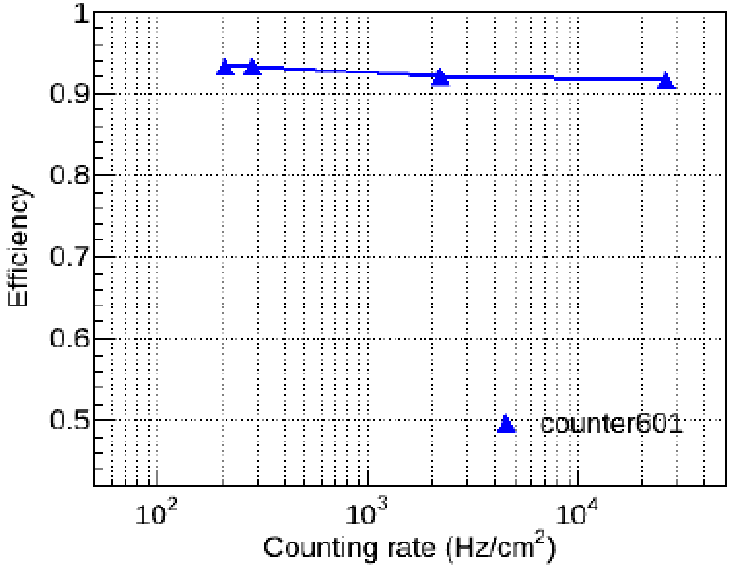



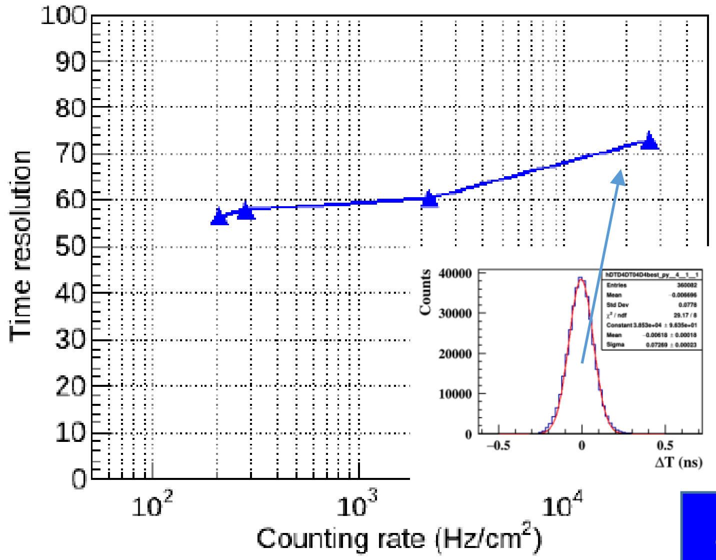

MRPC3 (low rate **thin float glass** counter)



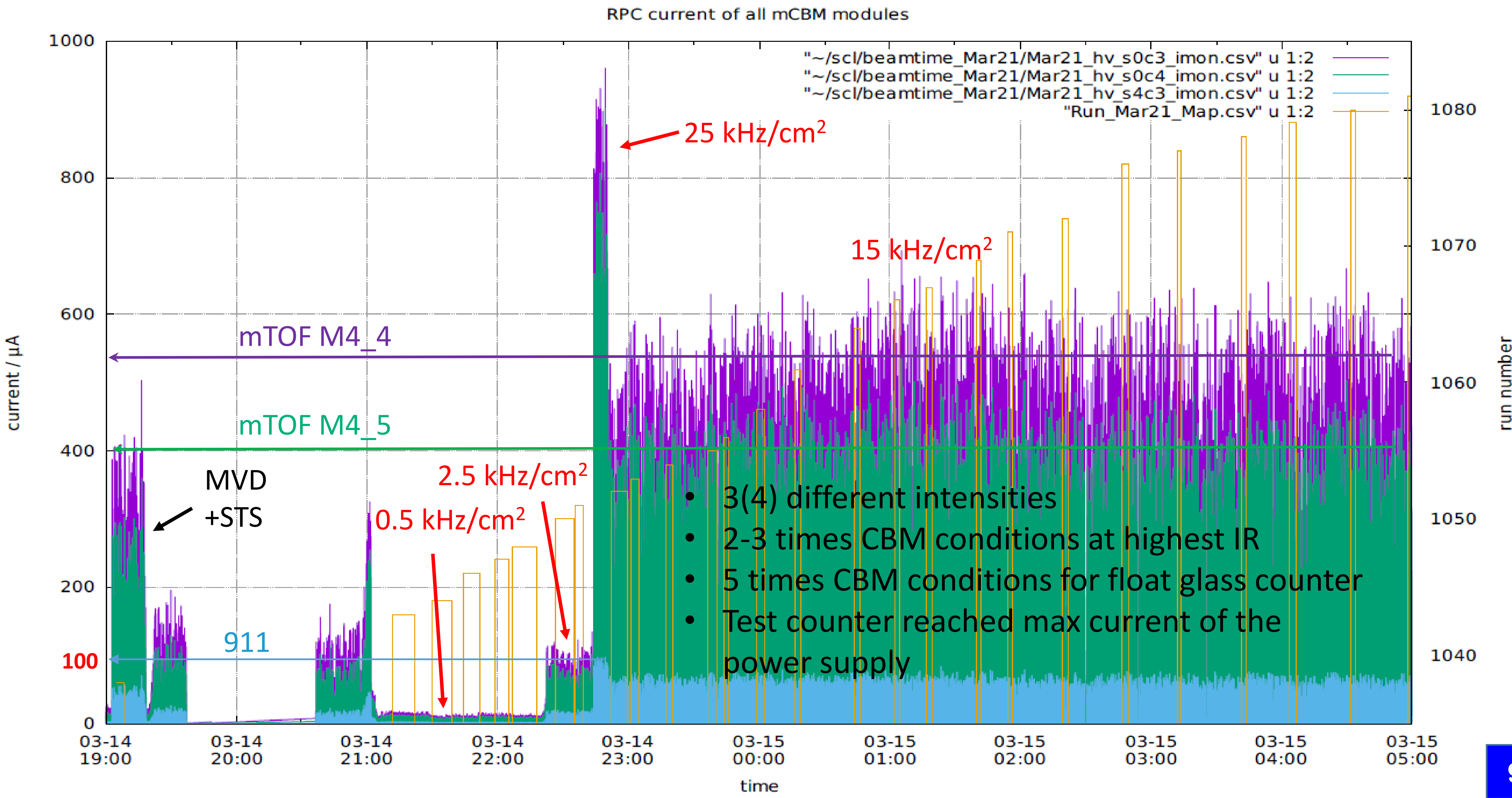




MRPC1a (**low resistivity glass** counter)



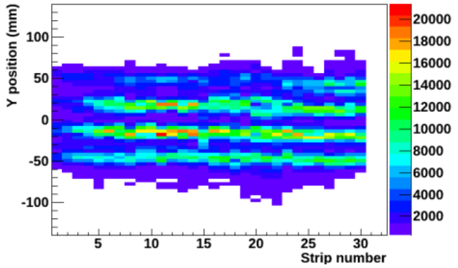



# Chamber HV currents (2020)

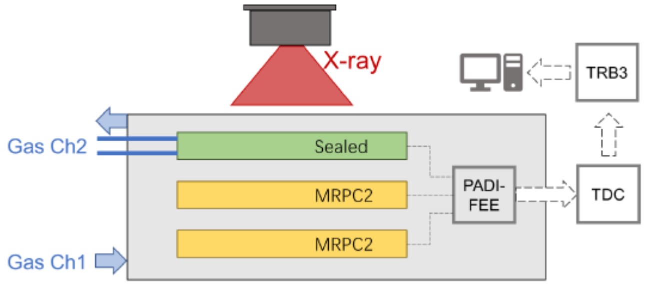


# Aging & gas pollution

- Gas pollution effect observed at mCBM at high rate (about 10 – 20 kHz/cm$^2$)
- Noise is generated on the spacers

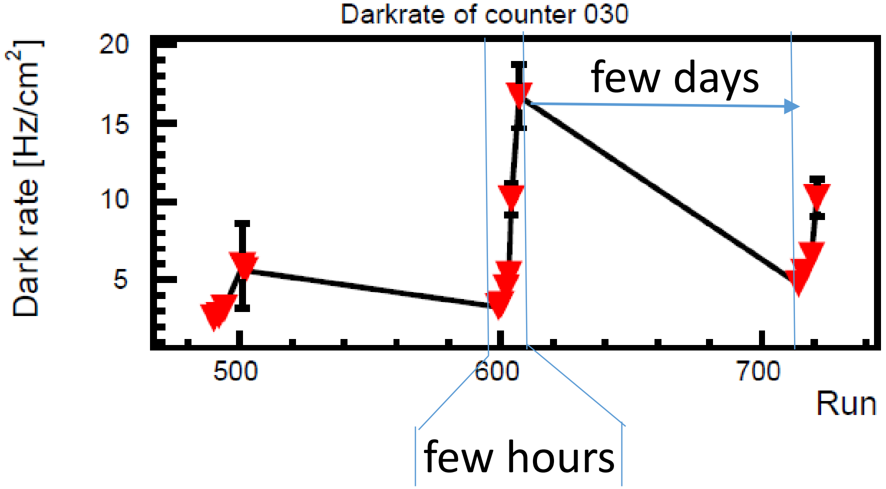



- Gas pollution effect was reproduced at IRASM (Bucharest) with high gamma flux
- X-Ray test at Beijing, Bucharest and USTC confirmed the gas pollution effect

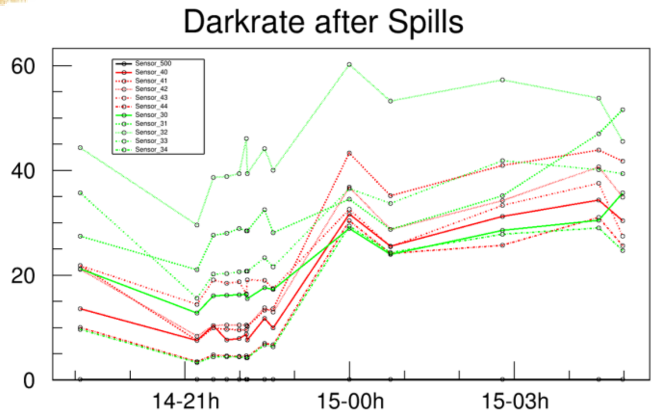


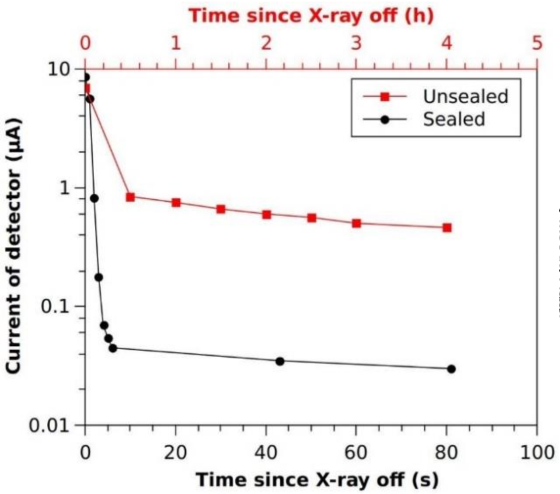

- The effect can be minimized by sealing the MRPC and increasing the gas flow
- Mitigation step not enough

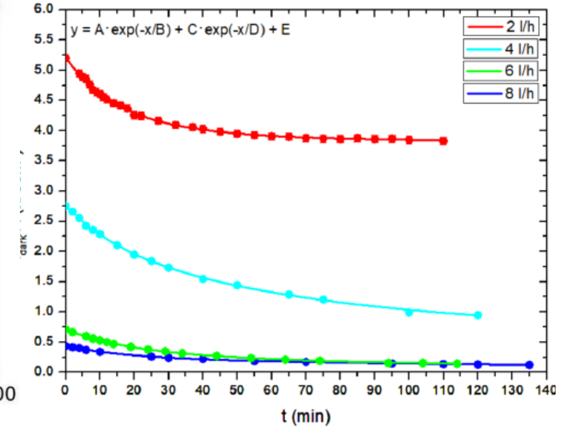
Observations @ mCBM 2020
rapid increase of dark rate

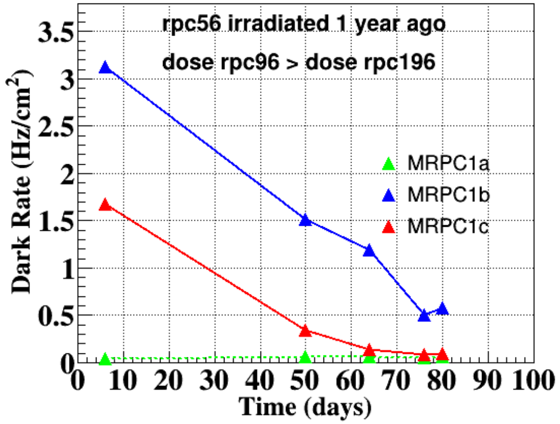



Observations confirmed @ mCBM 2021



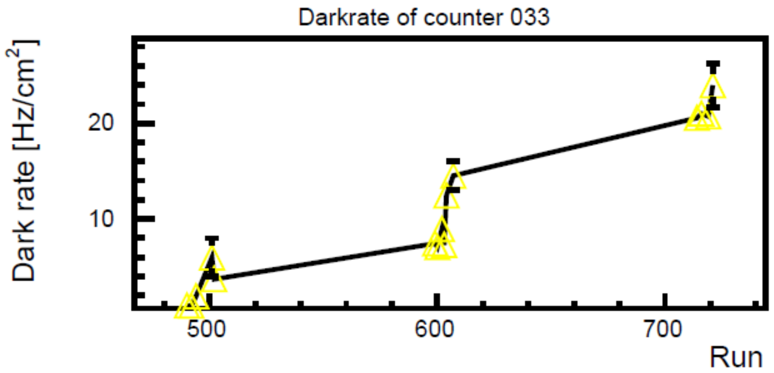



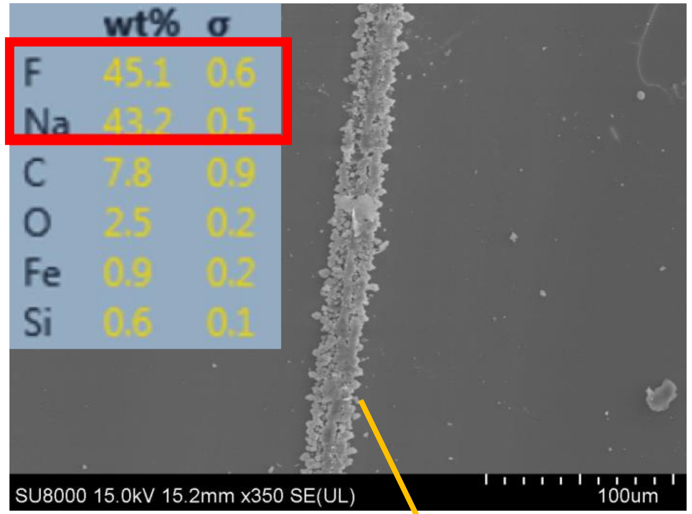



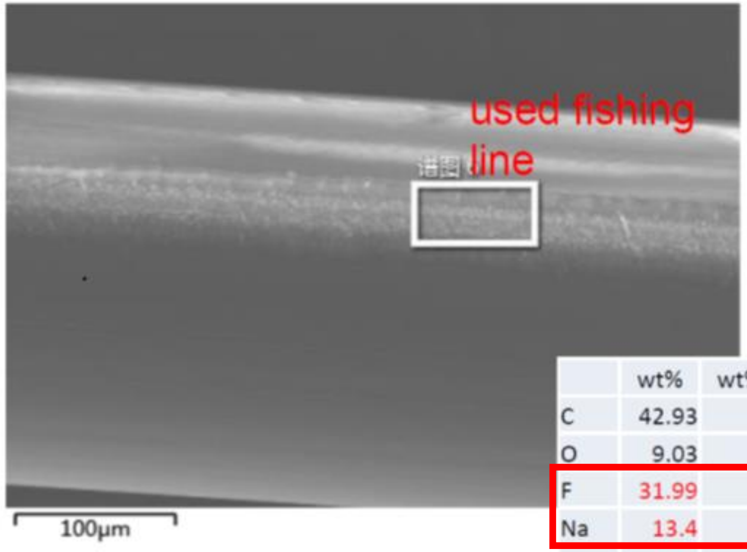

Dark current relaxation after irradiation

# Aging & gas pollution

Observations: continuous increase in dark rate (permanent aging)

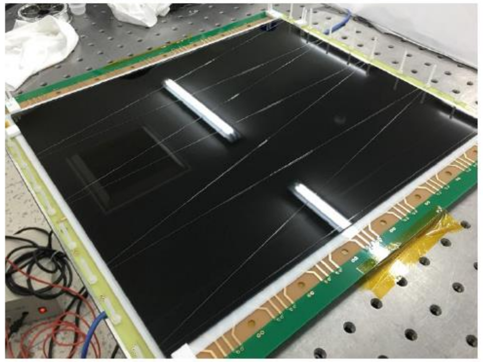


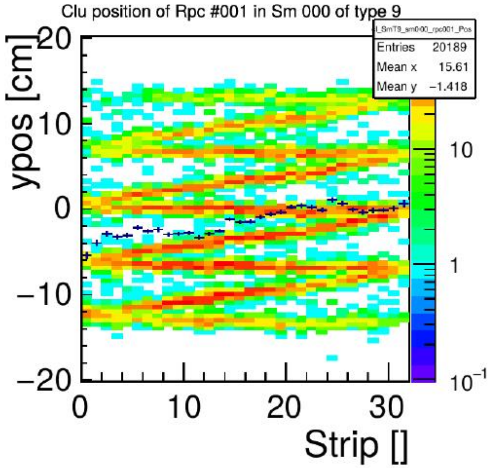



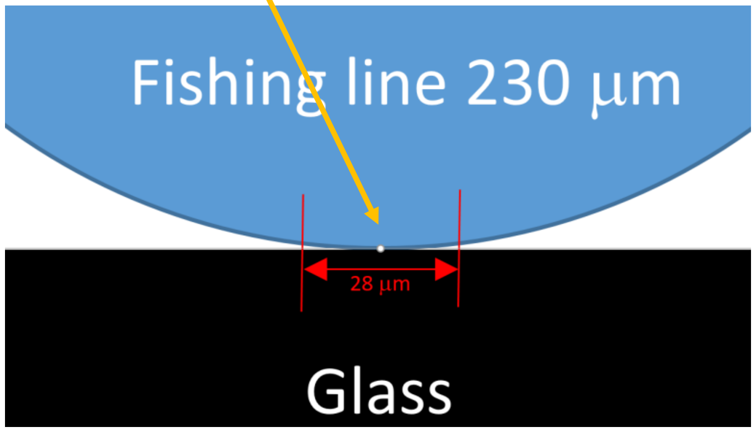




| | wt% | wt% Sigma |
|---|---|---|
| C | 42.93 | 0.21 |
| O | 9.03 | 0.15 |
| F | 31.99 | 0.18 |
| Na | 13.4 | 0.1 |
| Si | 2.36 | 0.04 |
| Pt | 0.28 | 0.07 |

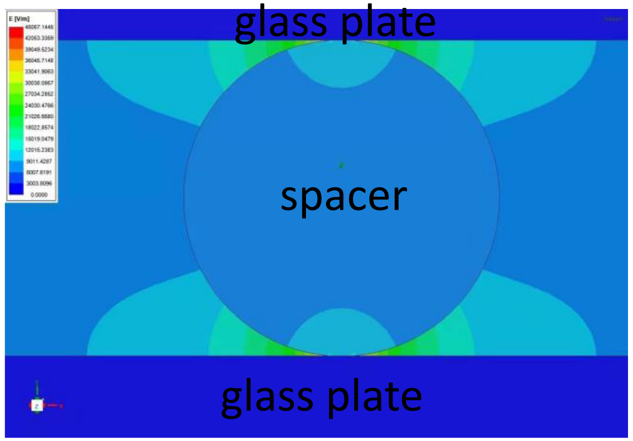
- Traces of NaF was found on the glass surface
- Dark rate (noise) is generated entirely on spacers
- Electrical field simulations performed





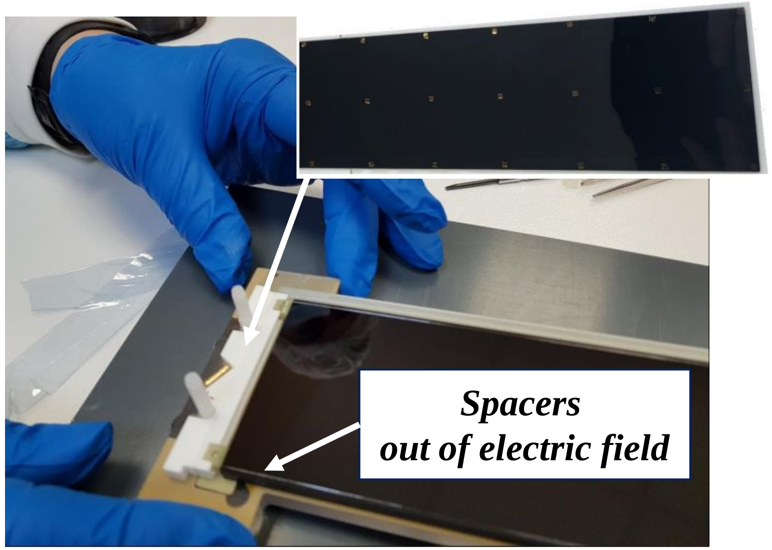



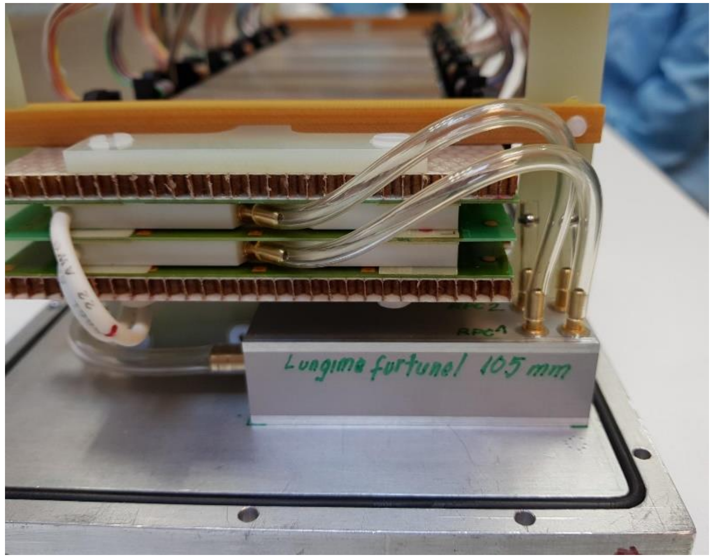

Electrical field simulations



# Mitigation of gas pollution and aging

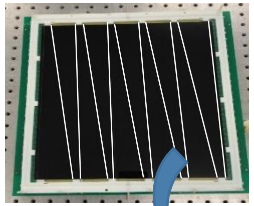
## High rate counter (MRPC1)



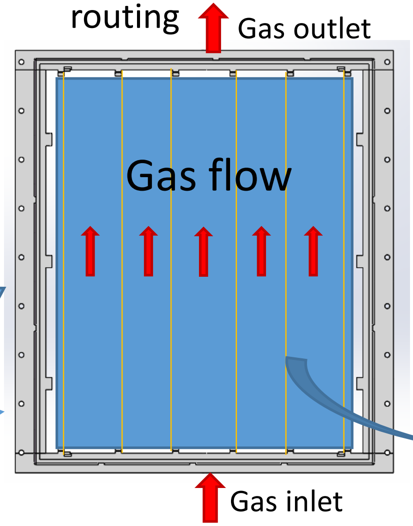




## Intermediate rate counter (MRPC2)

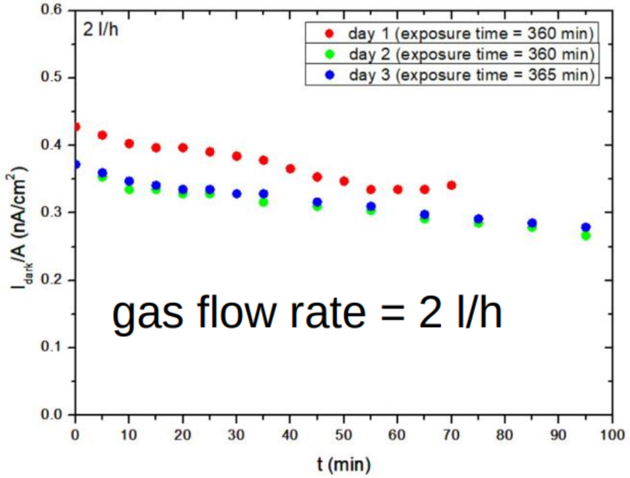
Triangular spacer routing



Parallel spacer routing

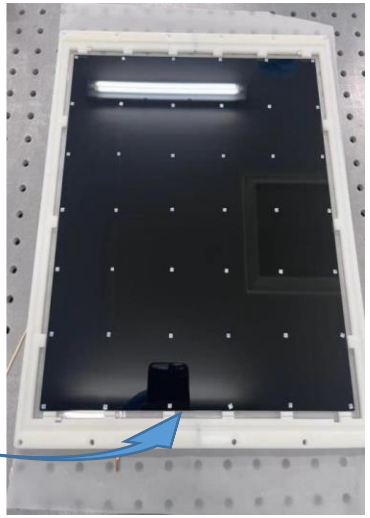



Sealing frame

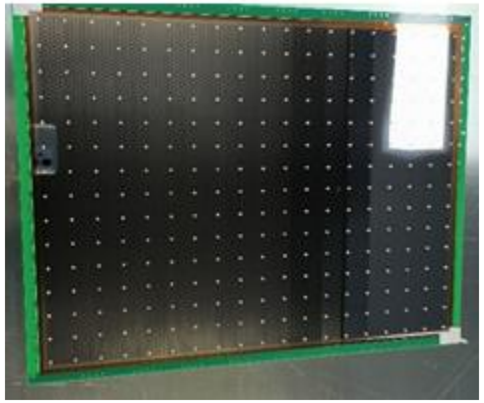


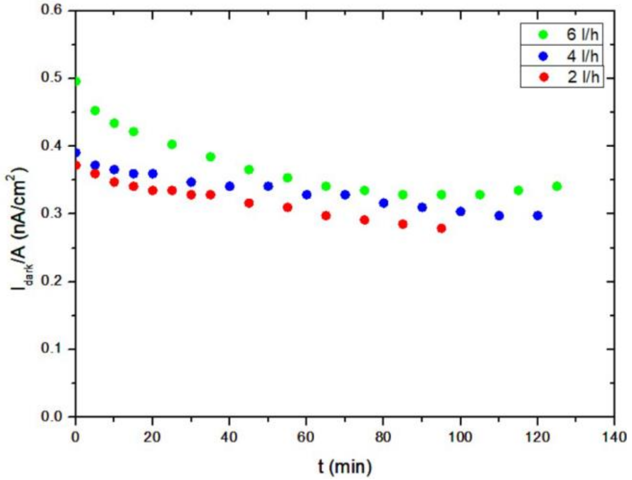

## Introduction of pad spacers

MRPC2



MRPC3

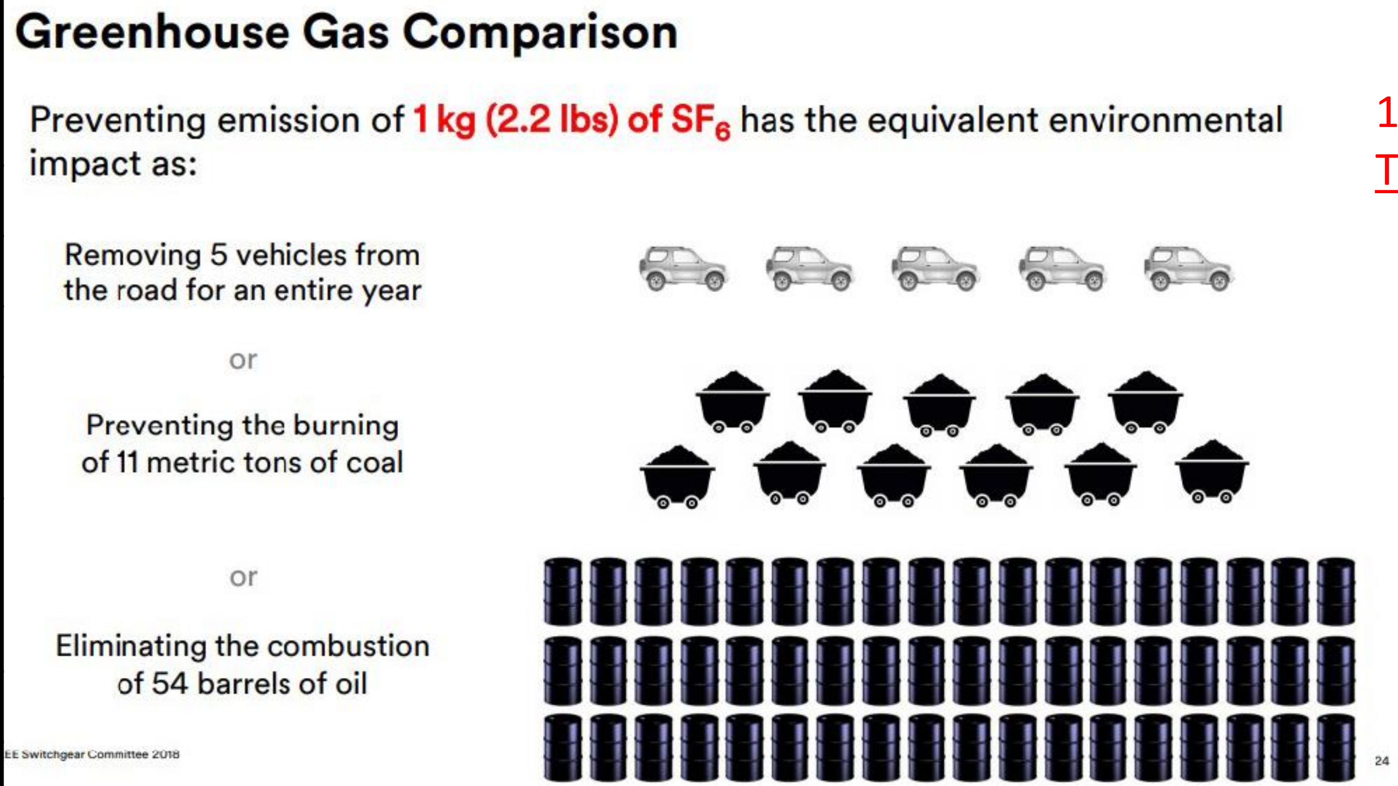




# Environmental impact of TOF gas

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] | | 23800 ( 47.62 Euro/kg) | |




John G. Owens, 3M, *Greenhouse Gas Emission Reductions from Electric Power Equipment through Use of Sustainable Alternatives to SF6*

1 CBM-TOF refill

500

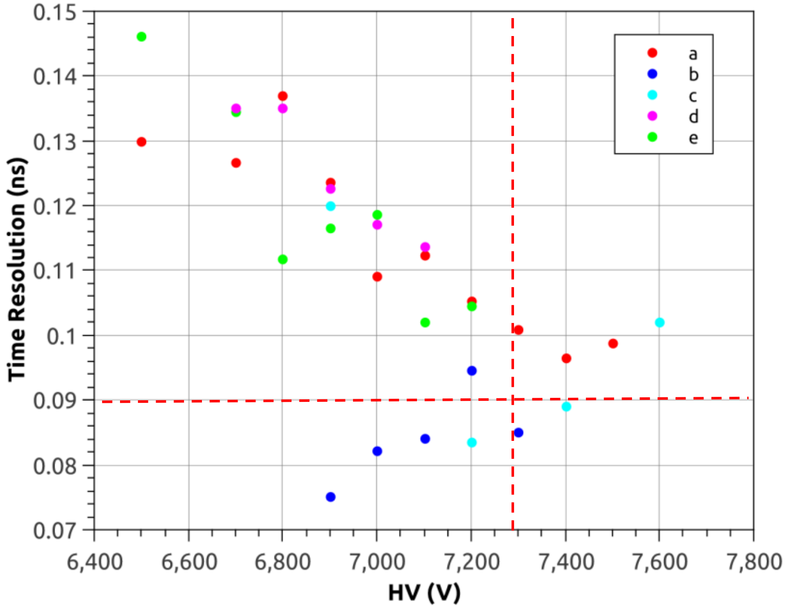
110

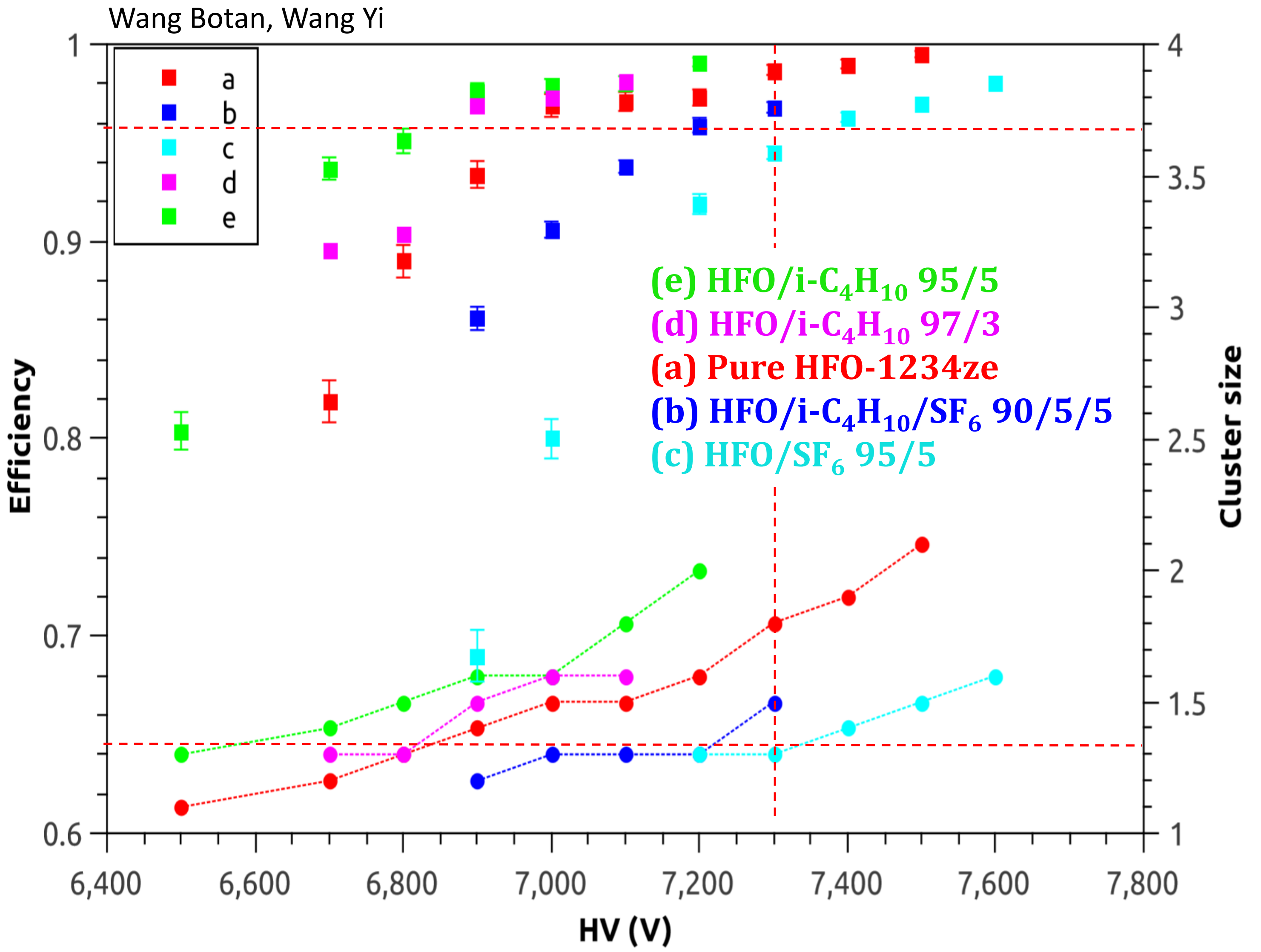
540

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

# 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
- Time resolution worse compared to std. gas mixture



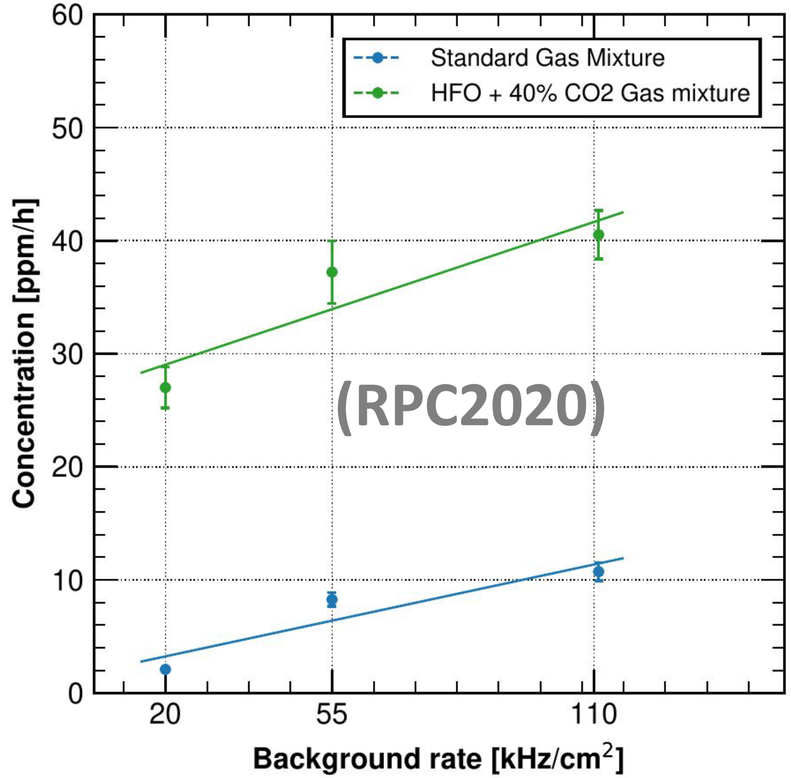



# Gas stability comparison

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*

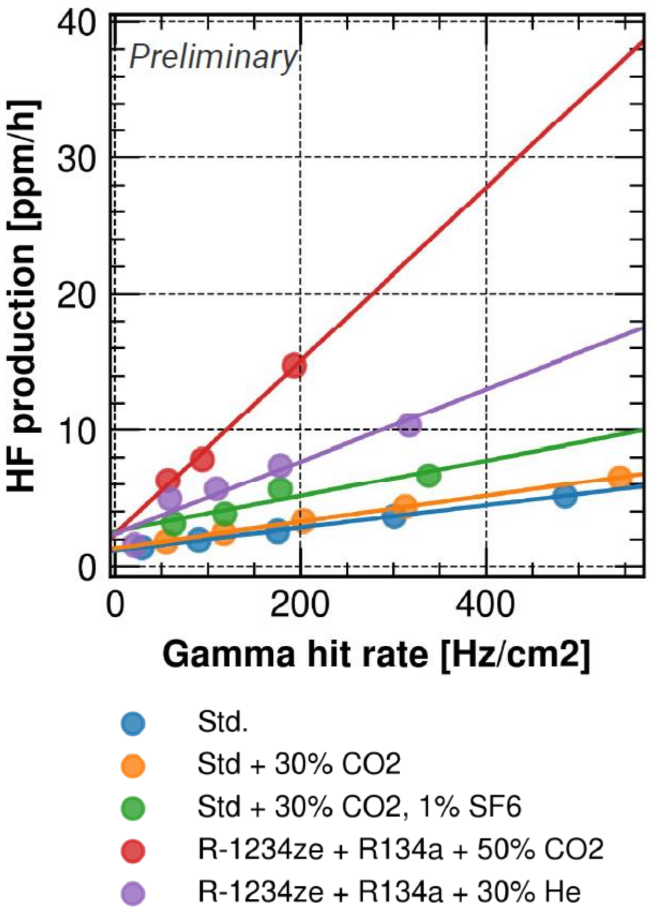



***HFO is breaking ~10 times more easily than R134a***

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

RPC2022: Measurements of fluoride production in Resistive Plate Chambers

**HF Production @ w.p.**




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

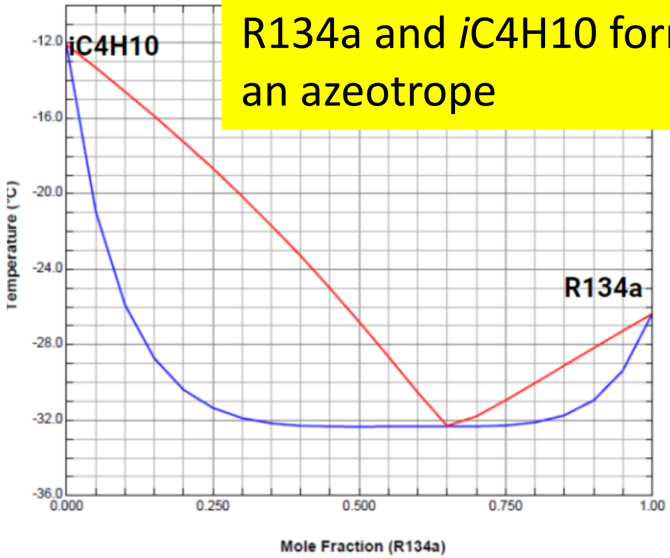
# Conclusions for the CBM TOF gas system

R. Guida, B. Mandelli, G. Rigoletti

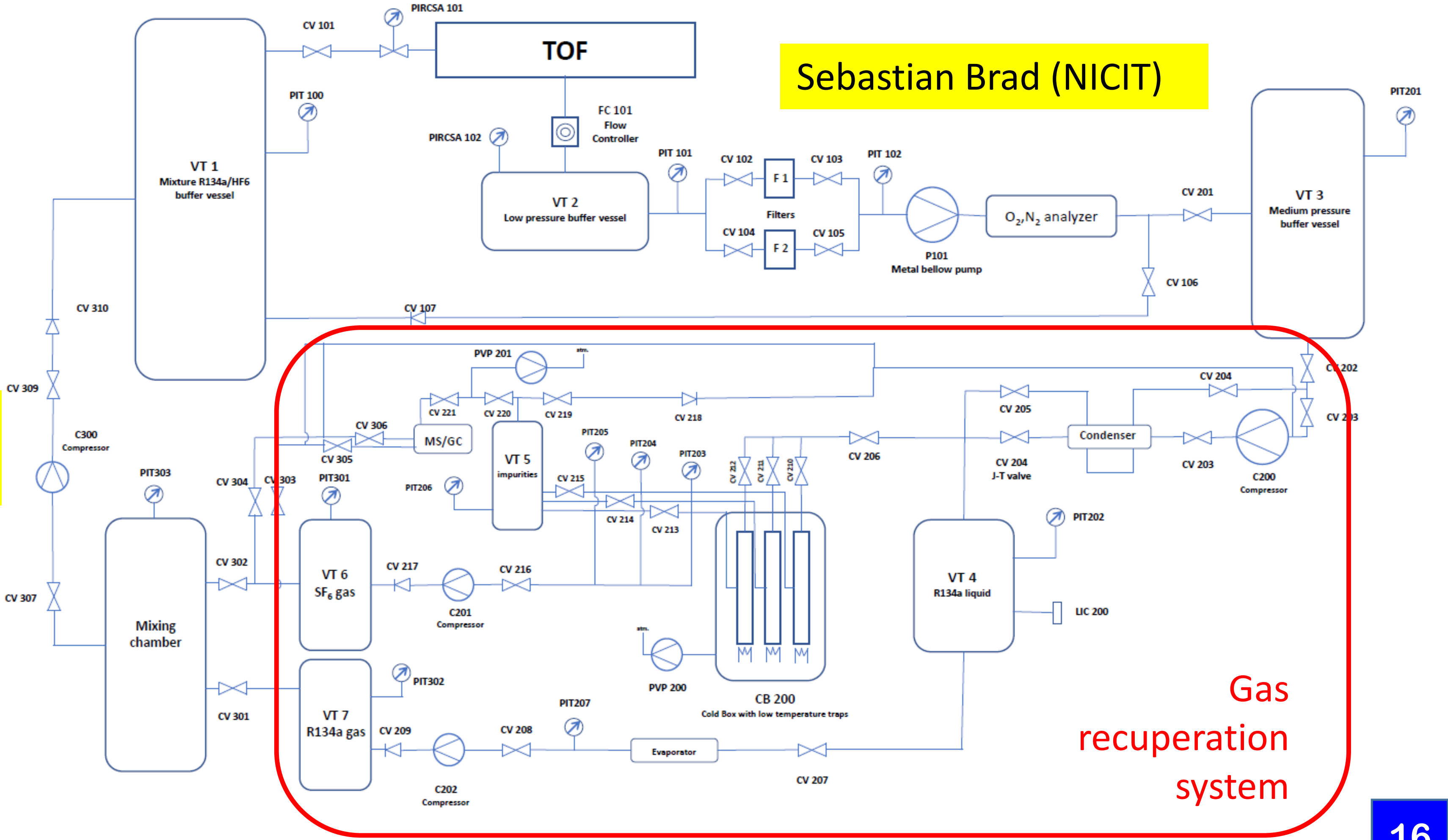
- Stay with Tetrafluorethane (R134a) (enhanced F-ion production for HFO in high rate environment)
- Abandon iso-Butan (aging , safety, difficult to recycle)
- Reduce fraction of $SF_6$ to 2.5% (reduction of GWP, difficult to recycle)
- Increase the flow rate
- Build a recuperation system (reuse of gas,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

230 modules
Total gas volume 25 $m^3$

Sebastian Brad (NICIT)

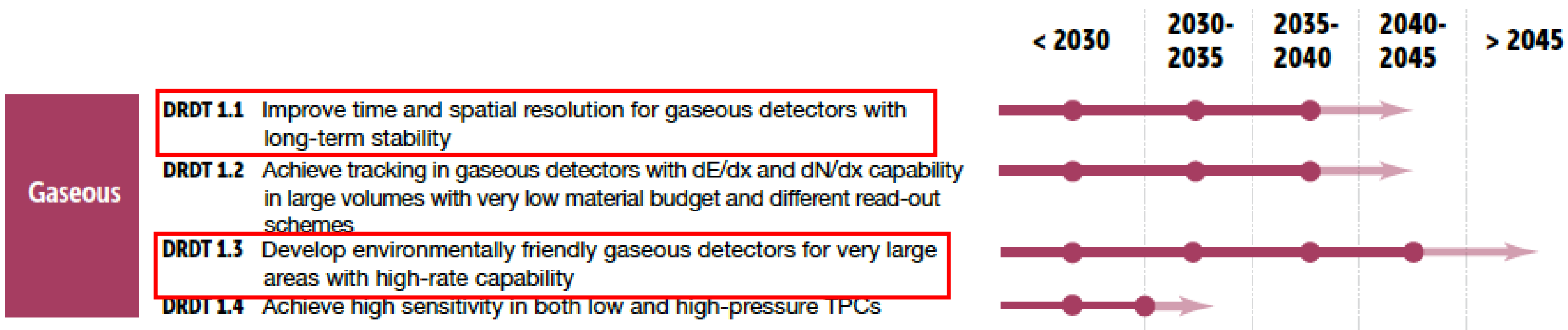


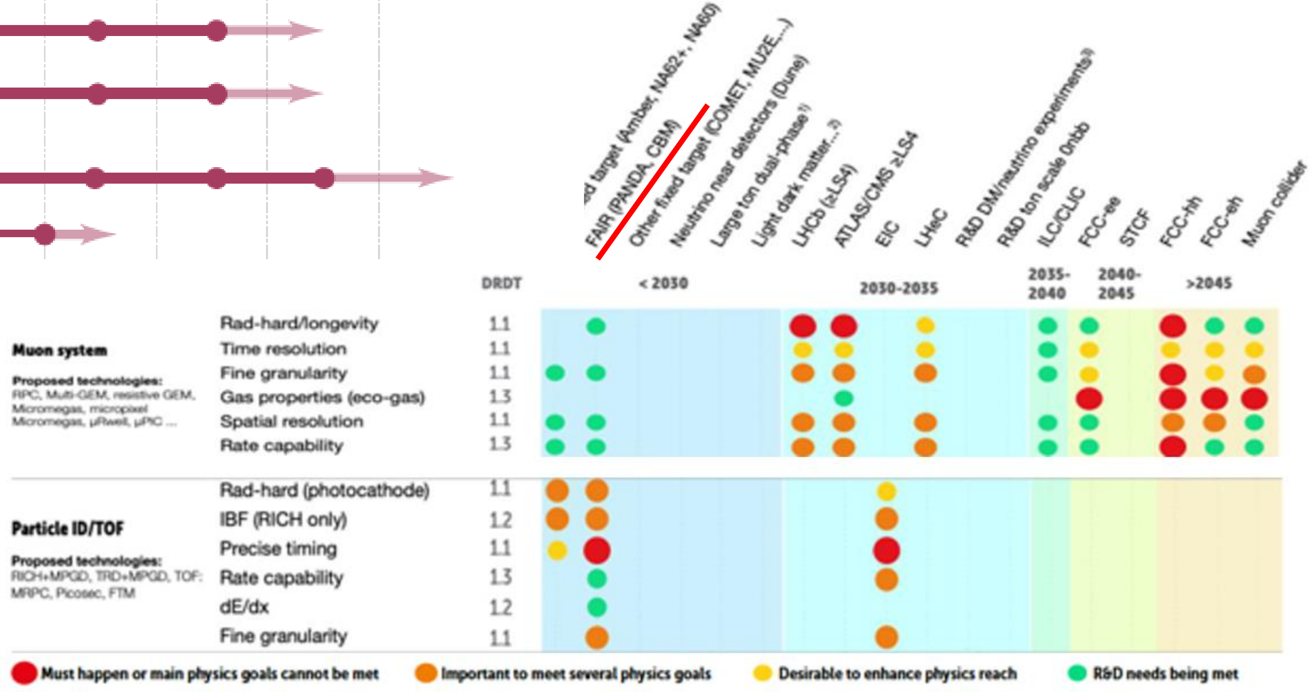

R134a and *i*C4H10 form an azeotrope




Gas recuperation system

# ECFA roadmap and the DRD1 Col.




| # | Task | Performance Goal | DRD1 WGs | ECFA DRDT |
|---|---|---|---|---|
| T1 | Optimize the amplification technology towards large-area detectors | - Uniformity over $m^2$ (time resolution, rate capability, efficiency) | WG1, WG2, WG3, WG4, WG5, WG6, WG7 | 1.1, 1.3 |
| T2 | Enhance timing performance | - Time resolution < 50 ps up to 30 kHz/$cm^2$ | | |
| T3 | Enhance rate capability | - Time resolution < 200 ps up to 100-150 kHz/$cm^2$ | | |
| T4 | Spatial resolution and read-out granularity | - Spatial resolution of mm with low number of readout channels | | |
| T5 | Stability, robustness and longevity | - IBF <1% with <100 ps time resolution for single photoelectrons<br>- Stable, high-gain operation | | |
| T6 | Material studies | - Radiation-hardness<br>- Longevity | | |
| T7 | Gas studies for precise timing applications | - Eco-friendly mixtures<br>- Recuperation<br>- Ageing mitigation<br>- $CO_2$-based mixture with geometrical quenching | | |
| T8 | Modelling and simulation of timing detectors | - Accurate modelling of charge transport and signal induction processes in precise timing detector geometries | | |
| T9 | Readout electronics for precise timing | - Low-noise FEE<br>– High input capacitance<br>– Large dynamic range<br>– Fast rise time<br>– Sensitivity to small charges<br>- Multi-channel readout solution for timing detectors | | |
| T10 | Precision mechanics and construction techniques | - Precise mechanics (μm) over relatively large active areas (hundreds of $cm^2$) | | |
| T11 | Common framework and test facilities for precise timing R&D | - Test bench for precise timing studies | | |

Challenges

Eco-friendly gases: decreasing availability, increasing cost of GH gases

Detector ageing: operational instabilities/ageing in harsh environments,

Front end electronics: timing performance, low power, robustness

Goals

Development of scalable precise timing detector with operational stability and long term robustness

High-rate capability and spatial resolution with suitable FE electronics for the required readout granularity

# Ultra high rate MRPCs

Beam Fragmentation T0 Counter (BFTC) @ CBM

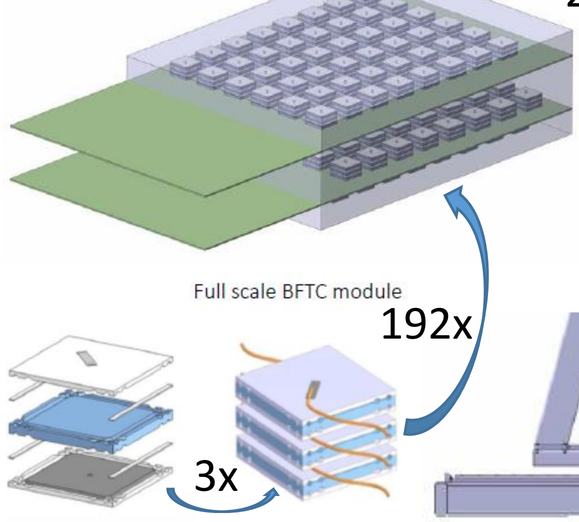
- Single cells ceramic MRPC with high rate capability
- BFTC delivers start time at CBM at high interaction rates
- In-kind contribution from Russia to CBM-TOF
- Collaboration with Russia suspended

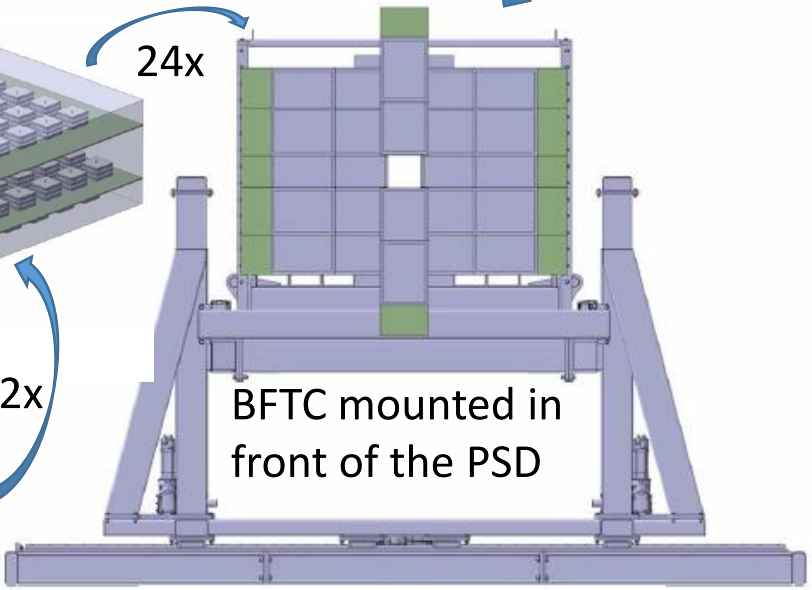
DRD1 - WP7

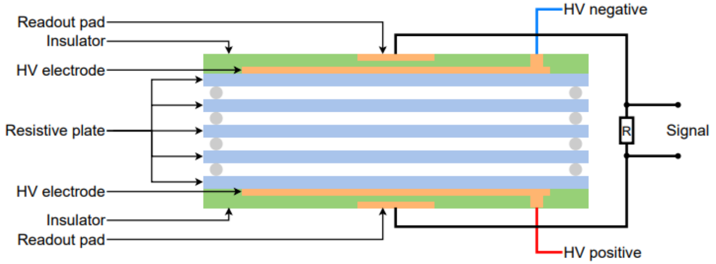
| # | Task | Performance Goal |
|---|---|---|
| T3 | Enhance rate capability | - Time resolution < 200 ps up to 100-150 kHz/cm$^2$ |

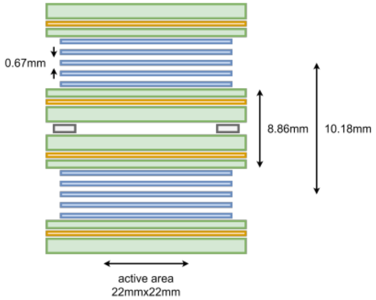
- Idea: replace ceramic counter by low resistive glass
- First steps done in Heidelberg
- DL could collaborate with UHD with this project
- Pushing the rate capability to new frontiers
- Perfect to educate students

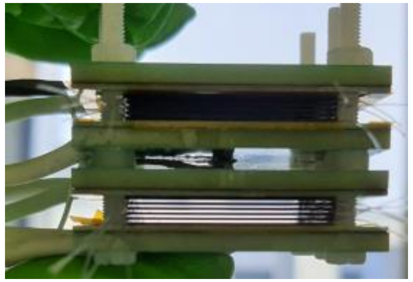
BFTC module

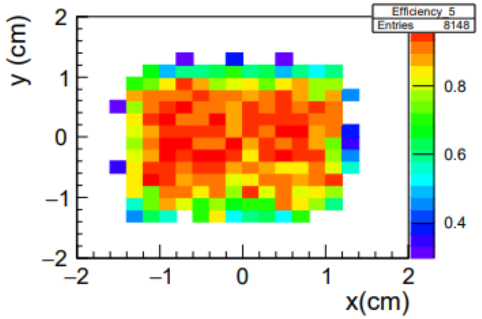




# Future perspective of (M)RPCs

**Application of RPCs and MRPCs world wide**

RPC - are widely used as muon detection systems at CERN, but also cosmic ray experiments and dark matter search

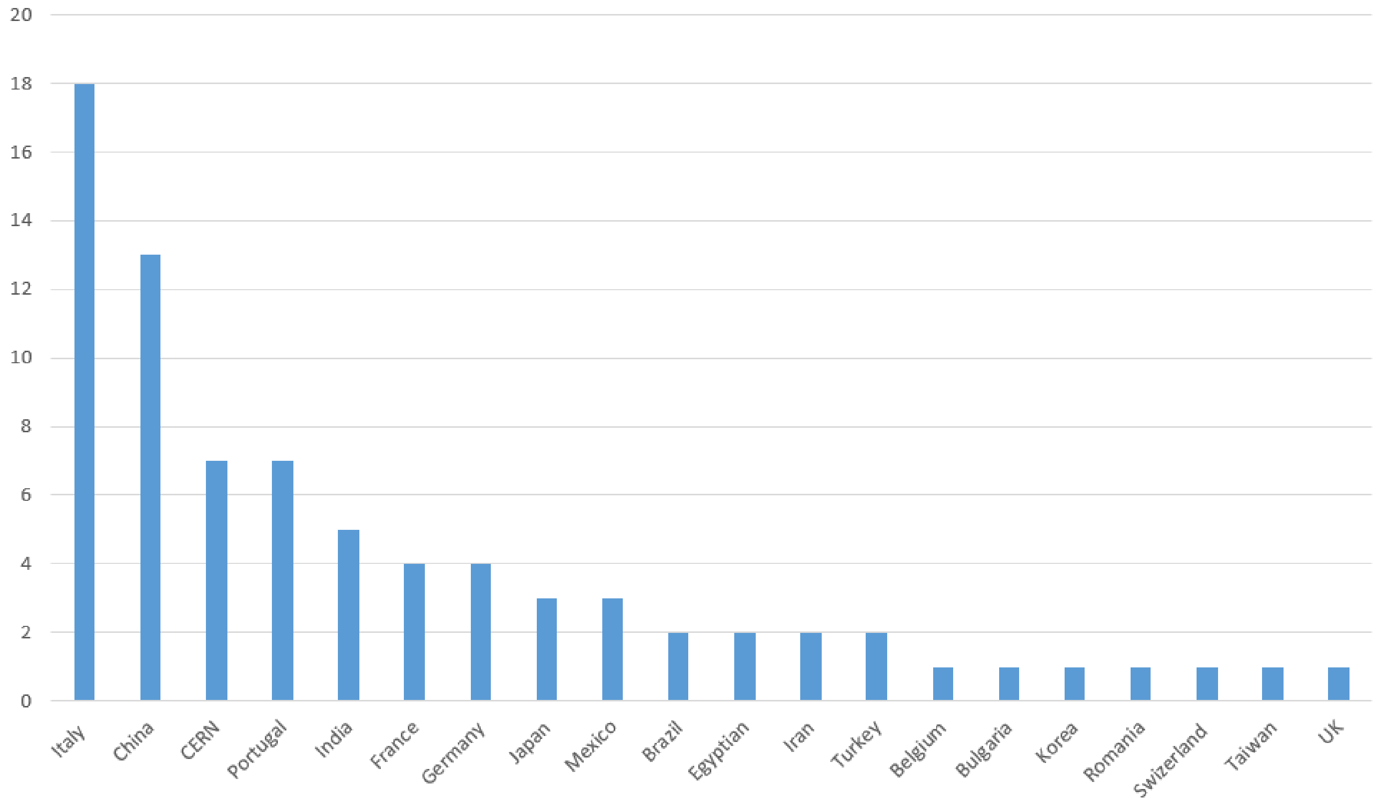
MRPC - are typically used as timing detector, but also in calorimetry, cosmic ray experiments, muon tomography, PET

RPC2022 – Conference

56 Talks (4 days)

26 Poster (3 h)

from 20 different countries



# Future perspective of (M)RPCs

CBM ToF

**Application of RPCs and MRPCs world wide**

RPC - are widely used as muon detection systems at CERN, but also cosmic ray experiments and dark matter search

MRPC - are typically used as timing detector, but also in calorimetry, cosmic ray experiments, muon tomography, PET

| Detector type | Experiment at GSI/FAIR |
|---|---|
| RPCs | CBM (MuCH) |
| MRPCs | CBM (TOF)<br>HADES (TOF) |

**Key parameters of RPCs and MRPCs for FAIR**

RPC - efficiency, rate capability, channel density

MRPC - time resolution, efficiency, rate capability, spatial resolution multi hit capability, channel density

**Used front end electronics for RPCs and MRPCs to be used at CBM**

RPC - Much-XYTER (128 channels)

MRPC - PADI-XI (8 channels), GET4-V2.1 (4 channels, 17 ps t-res.)

**New frontiers for RPCs and MRPCs**

RPC - rate capability -> up to 10 kHz/cm$^2$ (that's a real challenge)

MRPC - time resolution -> down to 30 ps (FEE has to improve either)

- rate capability -> up to 150 kHz/cm$^2$ (new low resistive materials)

**Challenges**

- Eco-friendly gases: decreasing availability, increasing cost of GH gases
- Detector ageing: operational instabilities/ageing in harsh environments,
- Front end electronics: timing performance, channel density, low power, robustness

**For large experiments PID based on TOF using MRPCs is also in future the best choice**

# 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
- EGFA roadmap and DRD1 presented
- At FAIR rate capability and detector aging are the key issues

# Thank you for your attention

**Contributing institutions:**

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

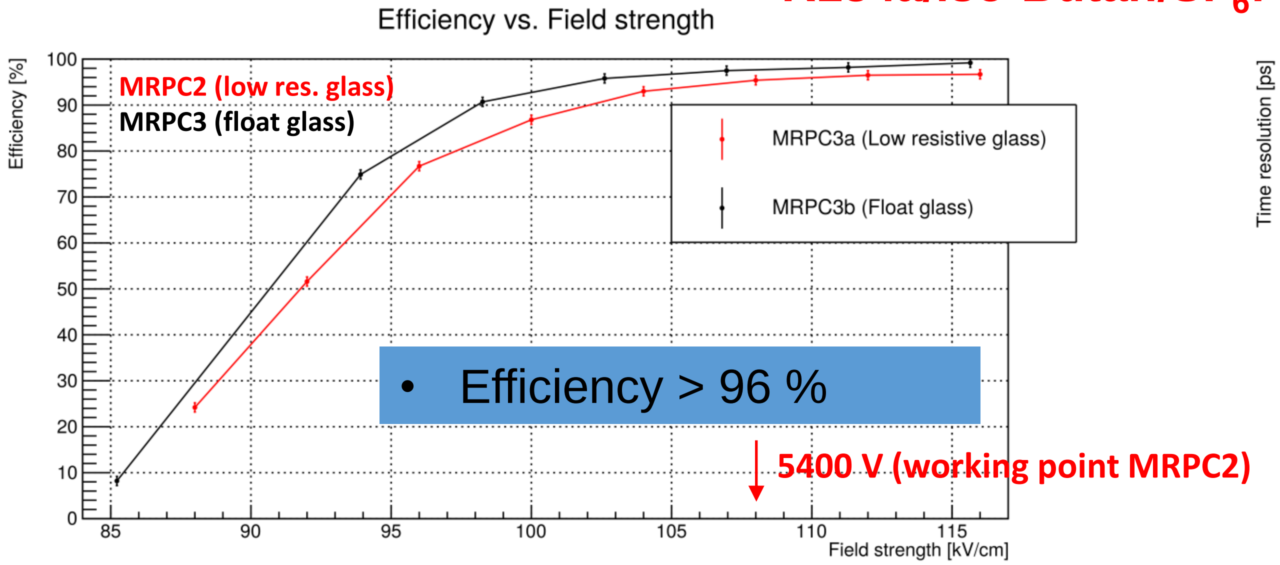
*Cooperation suspended

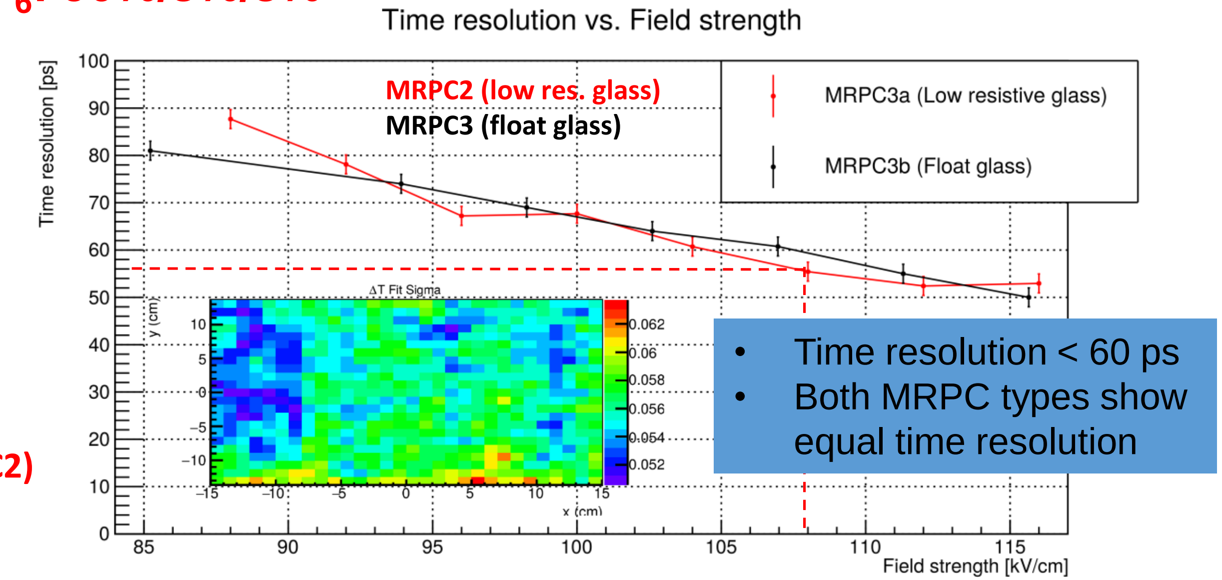
# Backup slides

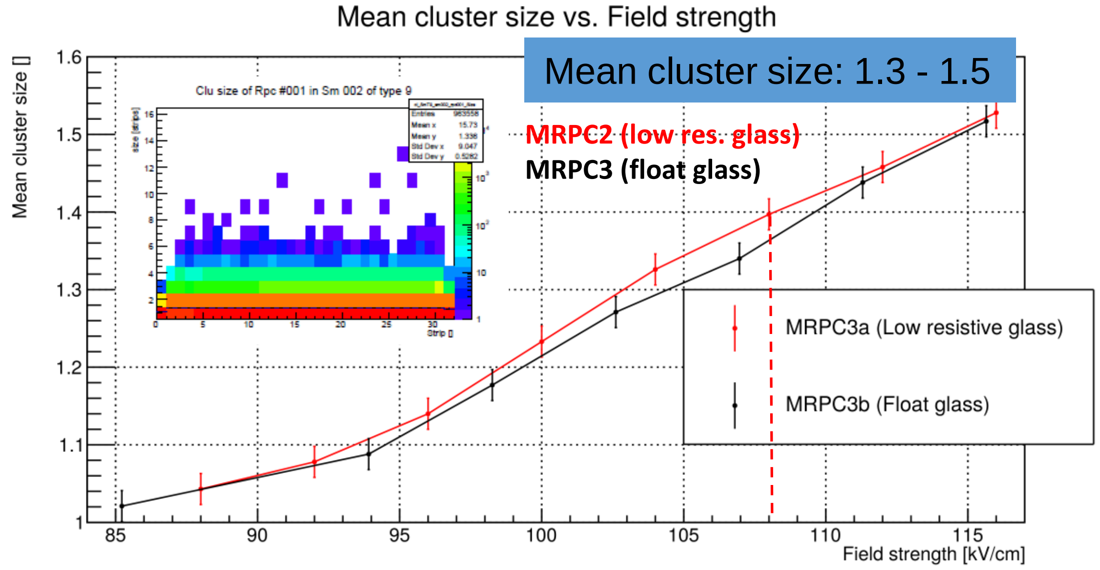
# Cosmic test results (low rate)

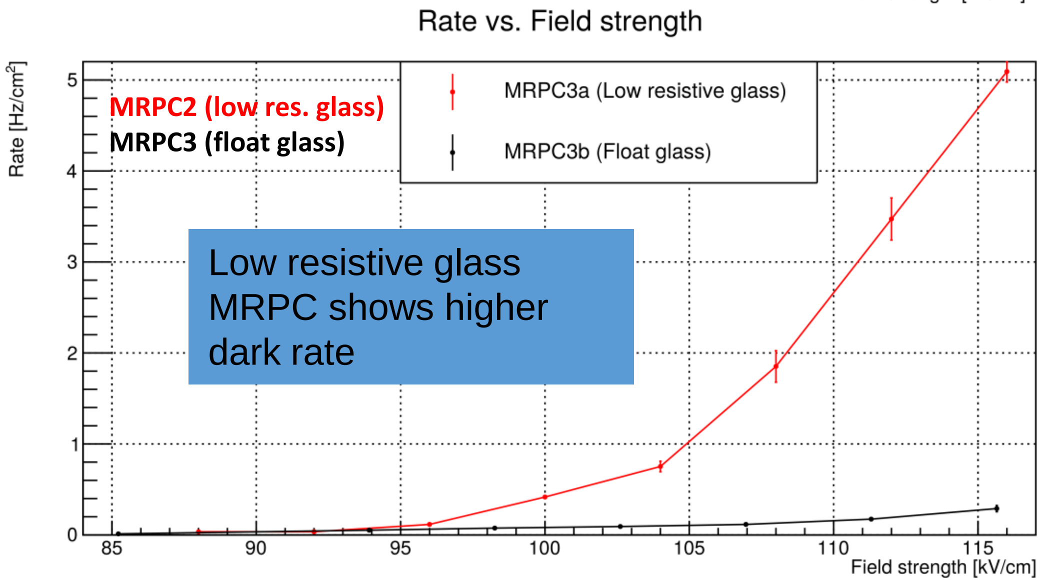
CBM ToF

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



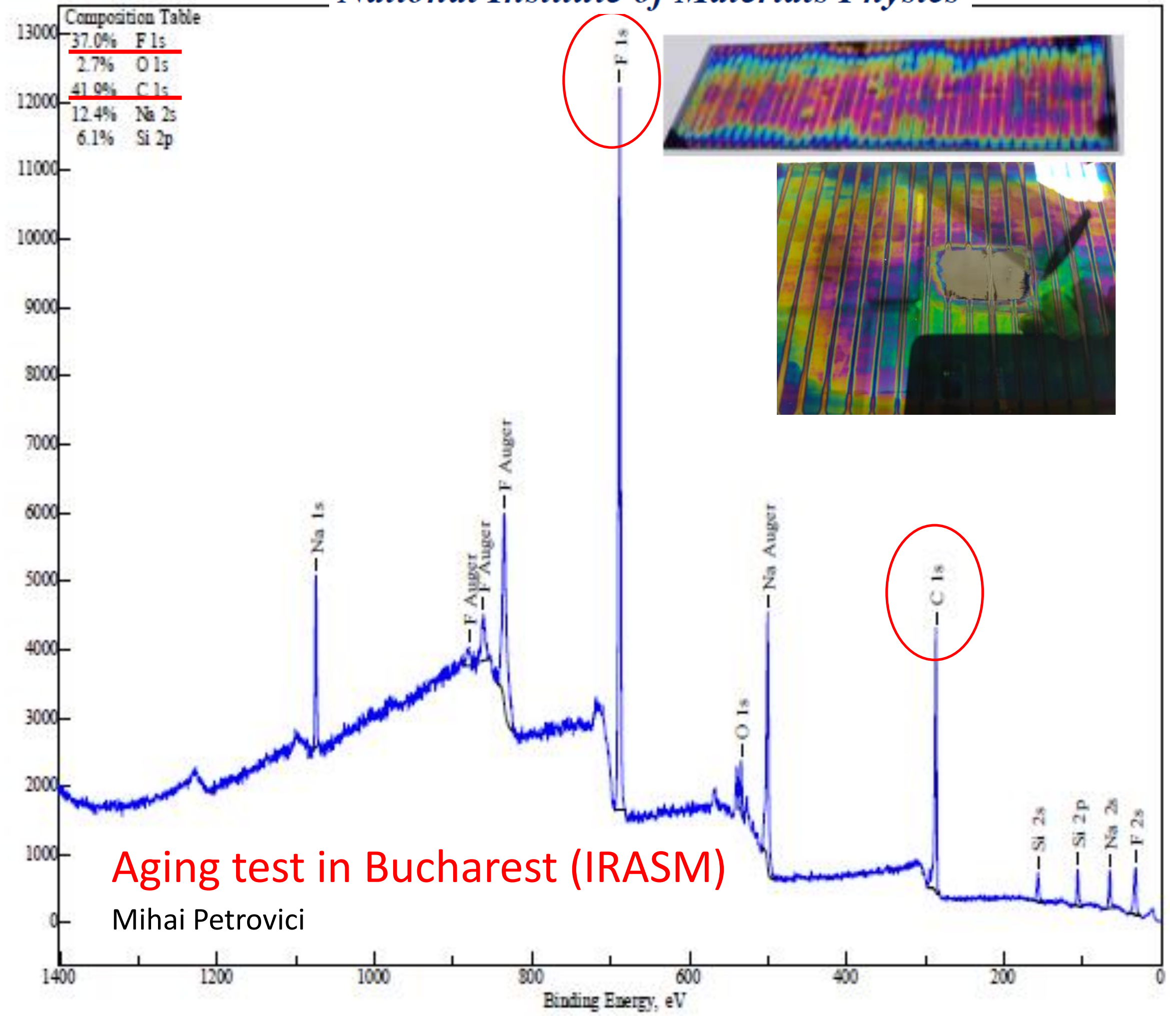
# Gas aging & pollution

High intensity irradiation with gammas at IRASM

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

## *Surface facing the cathode*

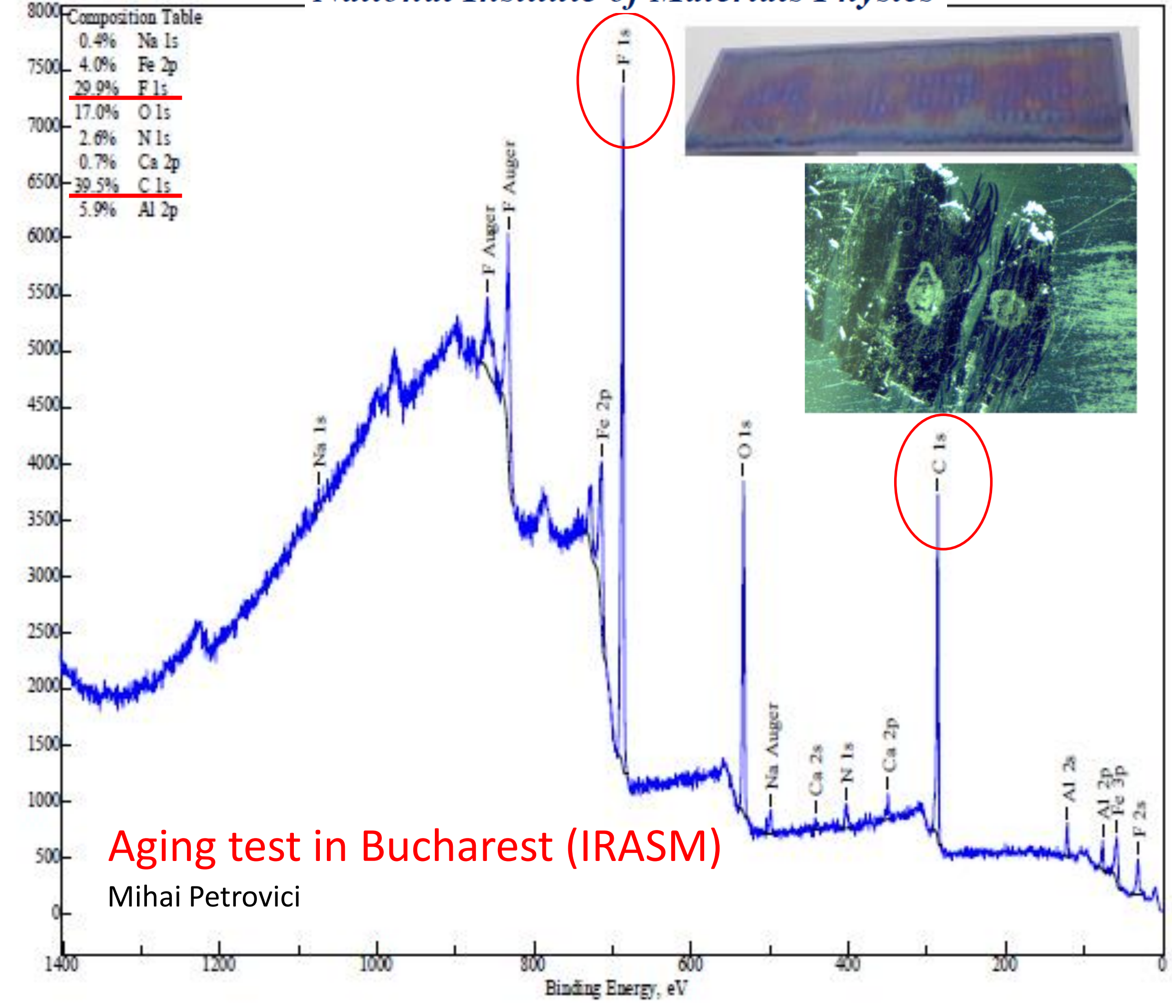
***XPS analysis** - thanks to C. Negrila*
***National Institute of Materials Physics***




Aging test in Bucharest (IRASM)
Mihai Petrovici

## *surface facing the anode*

***XPS analysis** - thanks to C. Negrila*
***National Institute of Materials Physics***




Aging test in Bucharest (IRASM)
Mihai Petrovici