

RPC 2022

XVI Workshop on Resistive Plate Chambers and Related Detectors

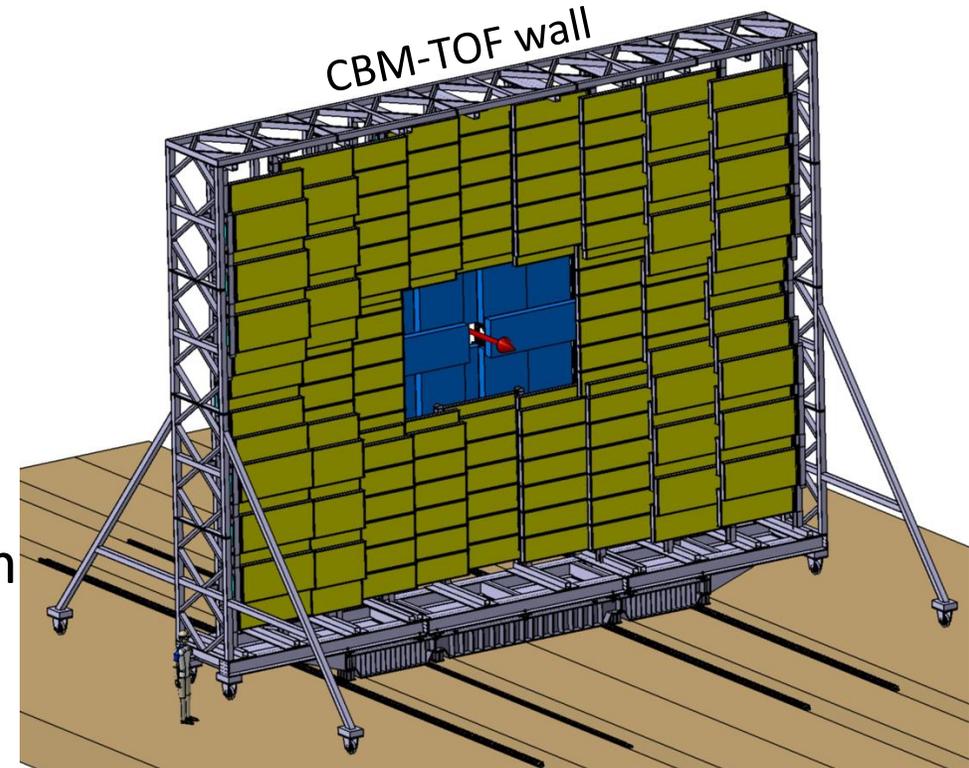
Status of the CBM Time-of-Flight project

Ingo Deppner

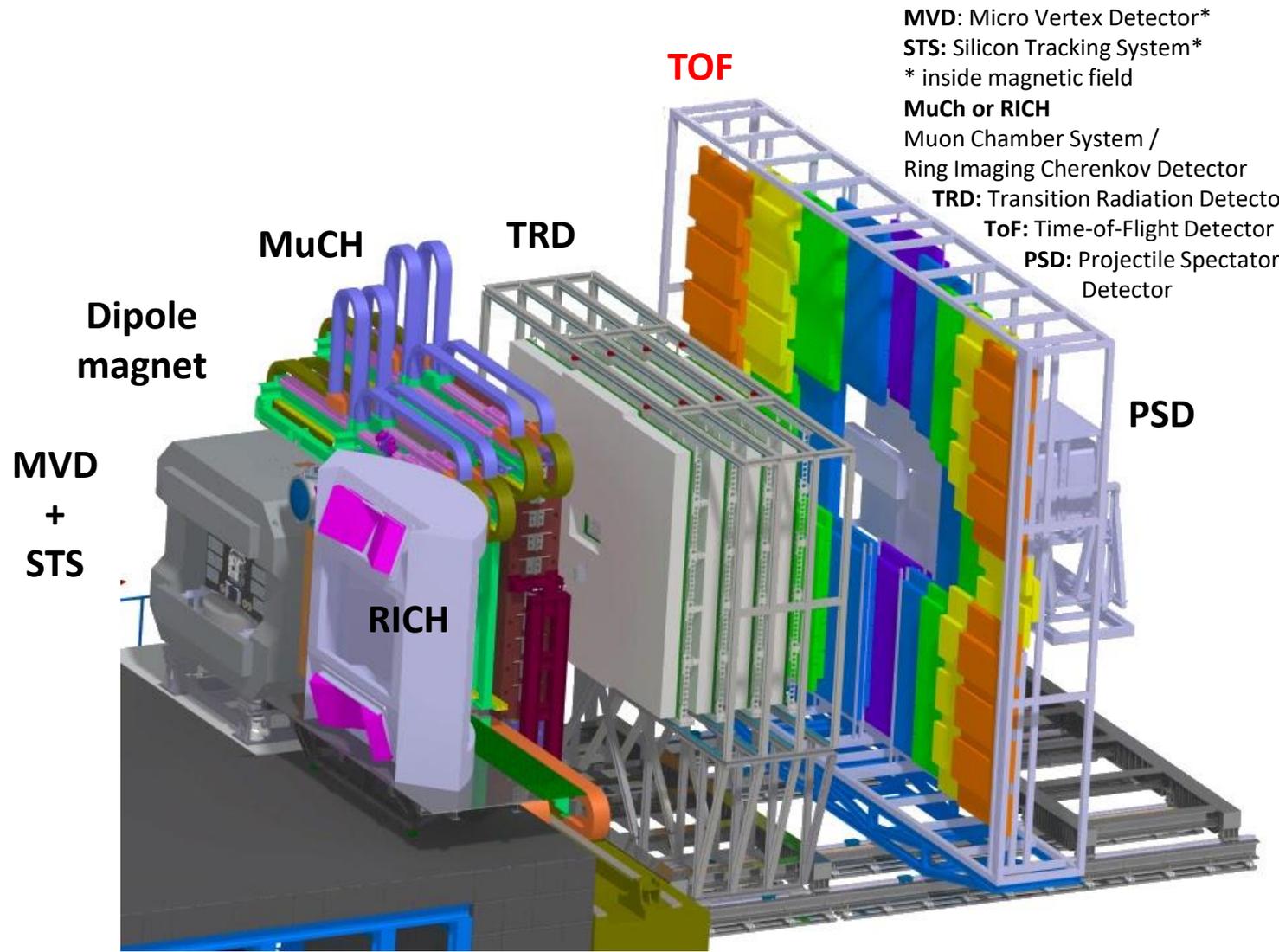
Physikalisches Institut, Heidelberg University

26.09.2022

- ❖ Introduction to CBM-TOF
- ❖ TOF FAIR Phase 0 program
 - eTOF status at STAR/BNL
 - mTOF at mCBM at SIS18/GSI
 - Conditions and counter performance with beam
 - (Gas)Aging of MRPCs and mitigation steps
- ❖ Conclusions for the CBM TOF gas system
- ❖ Summary, outlook and time line

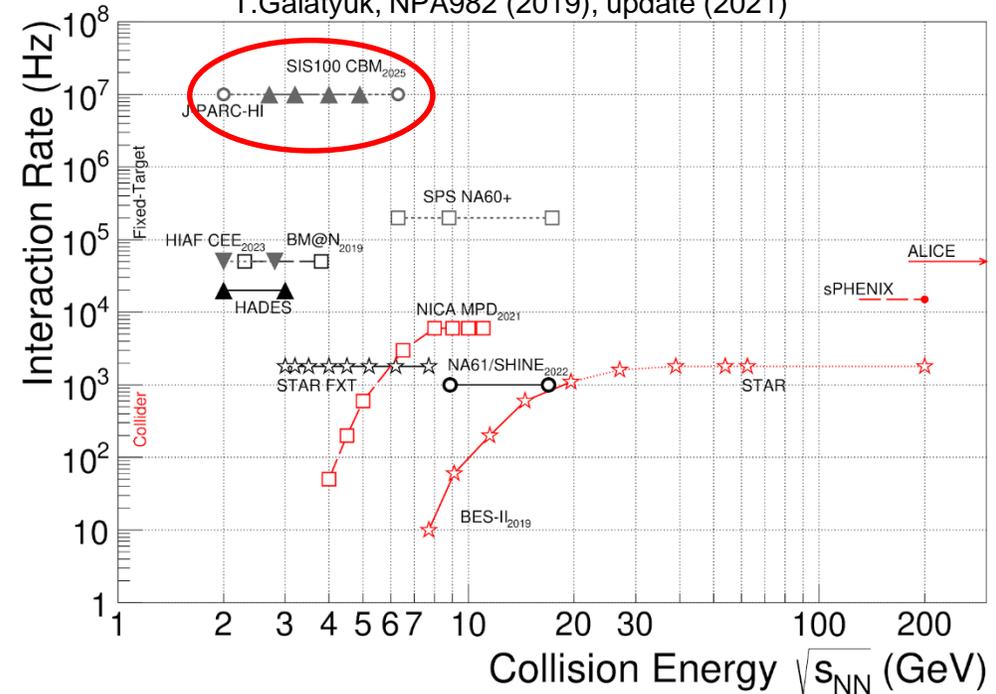


Compressed Baryonic Matter (CBM) Experiment



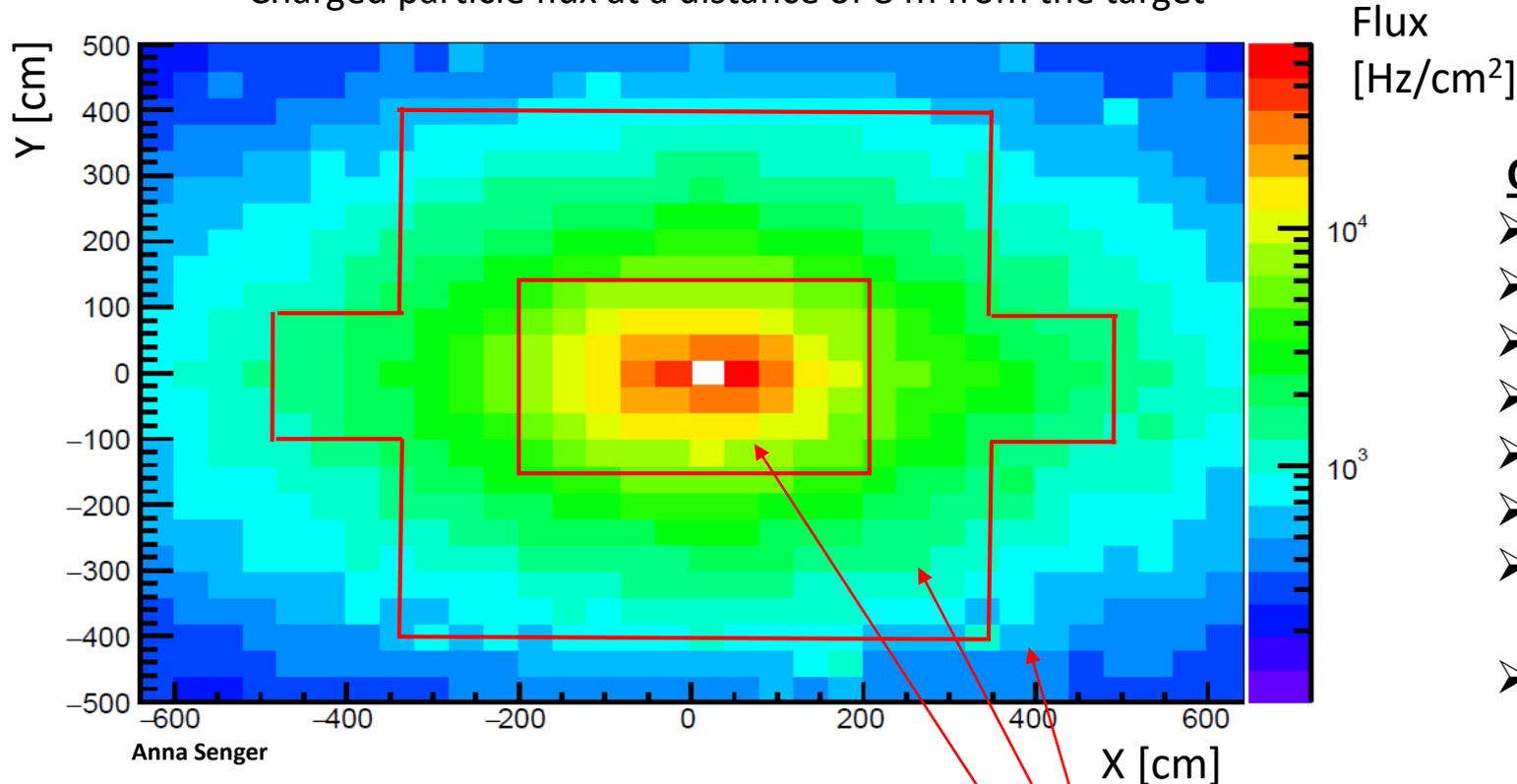
MVD: Micro Vertex Detector*
STS: Silicon Tracking System*
 * inside magnetic field
MuCh or RICH
 Muon Chamber System /
 Ring Imaging Cherenkov Detector
TRD: Transition Radiation Detector
ToF: Time-of-Flight Detector
PSD: Projectile Spectator
 Detector

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



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

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



Anna Senger

- Low rate region
- Intermediate rate region
- High rate region

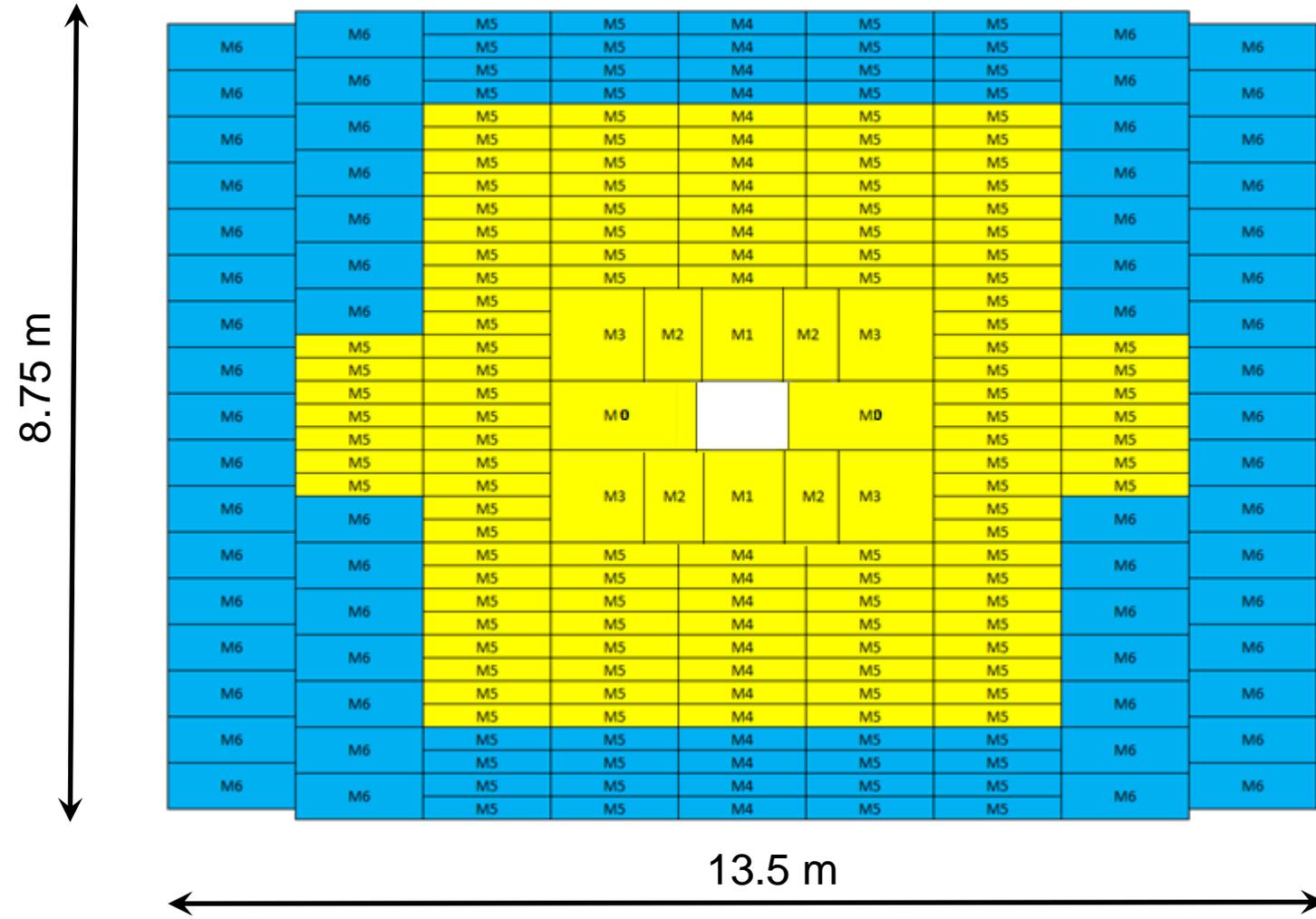
Multi-gap Resistive Plate Chambers (MRPC) are the most suitable TOF detectors fulfilling our requirements

CBM-TOF Requirements

- Full system time resolution $\sigma_T \sim 80$ 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

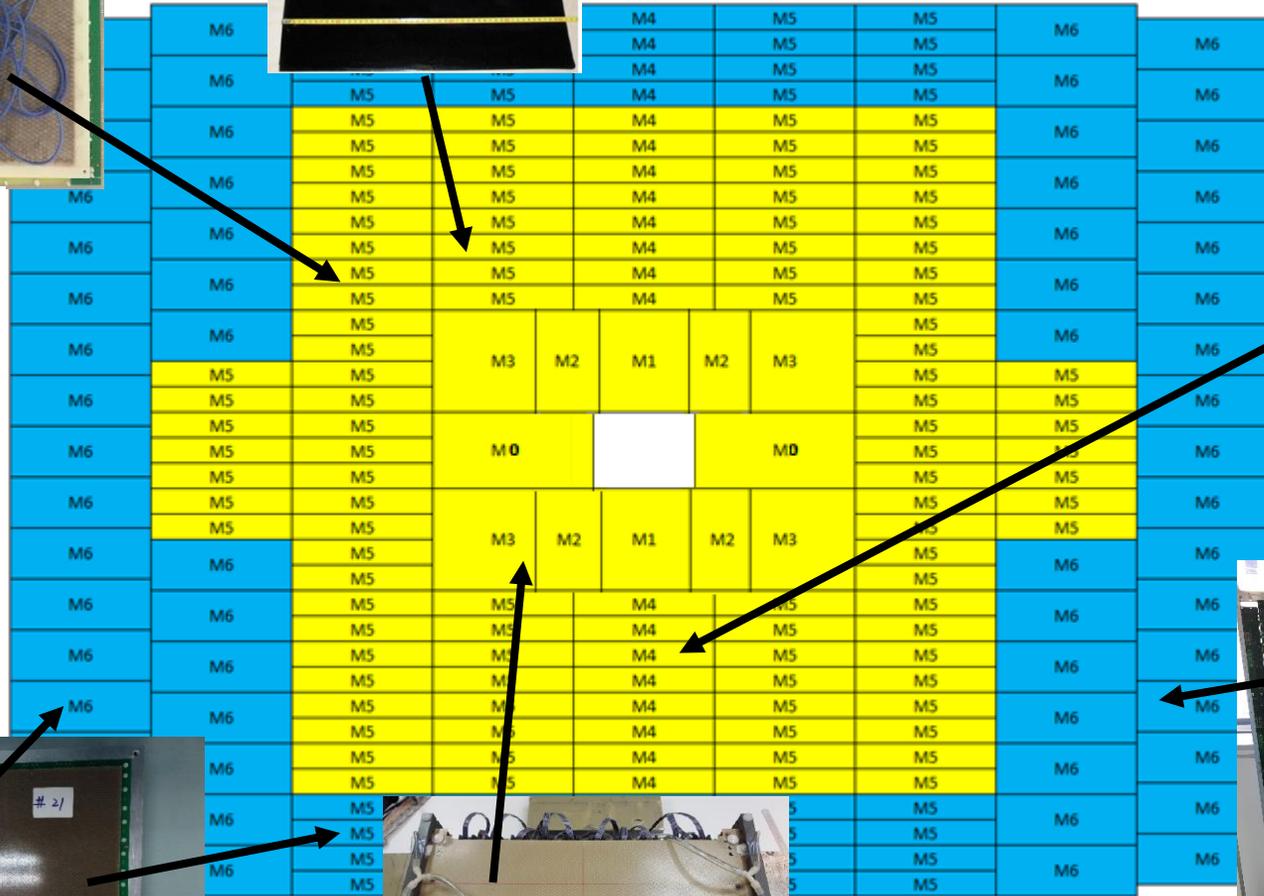
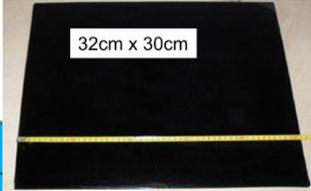
Charged hadron identification is provided by Time-of-Flight (TOF) measurement

Active area



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

Low resistivity glass



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

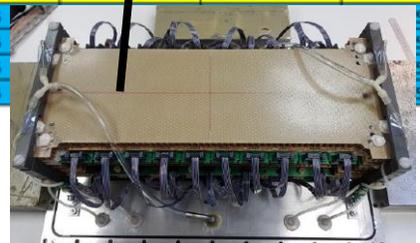
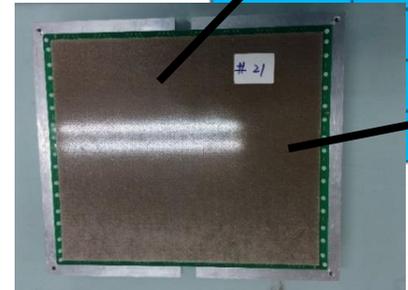
M6 Module (HD)



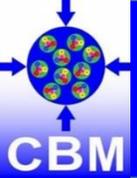
230 modules
≈ 1500 MRPCs
≈ 100000 channels

MRPC2
(Tsinghua)

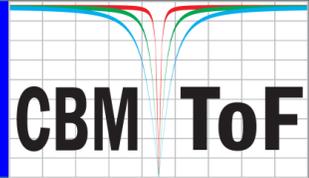
MRPC3/4
(USTC)



MRPC1a - 1c
(NIPNE Bucharest)



CBM TOF MRPC family



	MRPC1a	MRPC1b	MRPC1c	MRPC2	MRPC3	MRPC4
# Gaps	2 x 5	2 x 5	2 x 5	2 x 4	2 x 5	2 x 5
Gap size	200 μm	200 μm	200 μm	250 μm	230 μm	230 μm
Glass type	Low res.	Low res.	Low res.	Low res.	Float	Float
Glass thickness	700 μm	700 μm	700 μm	700 μm	230 μm	230 μm
MRPC size	30 cm x 6 cm	30 cm x 10 cm	30 cm x 20 cm	32 cm x 27 cm	32 cm x 27 cm	32 cm x 53 cm
# Strips	32	32	32	32	32	32
Strip length	6 cm	10 cm	20 cm	27 cm	27 cm	53
Pitch	0.90 cm	0.90 cm	0.90 cm	1.0 cm	1.0 cm	1.0 cm
Impedance	100 Ω	100 Ω	100 Ω	50 Ω	50 Ω	50 Ω
Developed at	IFIN-HH (RO)	IFIN-HH (RO)	IFIN-HH (RO)	Tsinghua (CH)	USTC (CH)	USTC (CH)
Needed for CBM	0	132	168	580	200	310

- FAIR Phase 0 is a bridge program until the start of FAIR in 2025/2026
- It comprises the installation and testing of developed equipment in running experiments and analysis of obtained data

FAIR Phase 0 programs of CBM-TOF

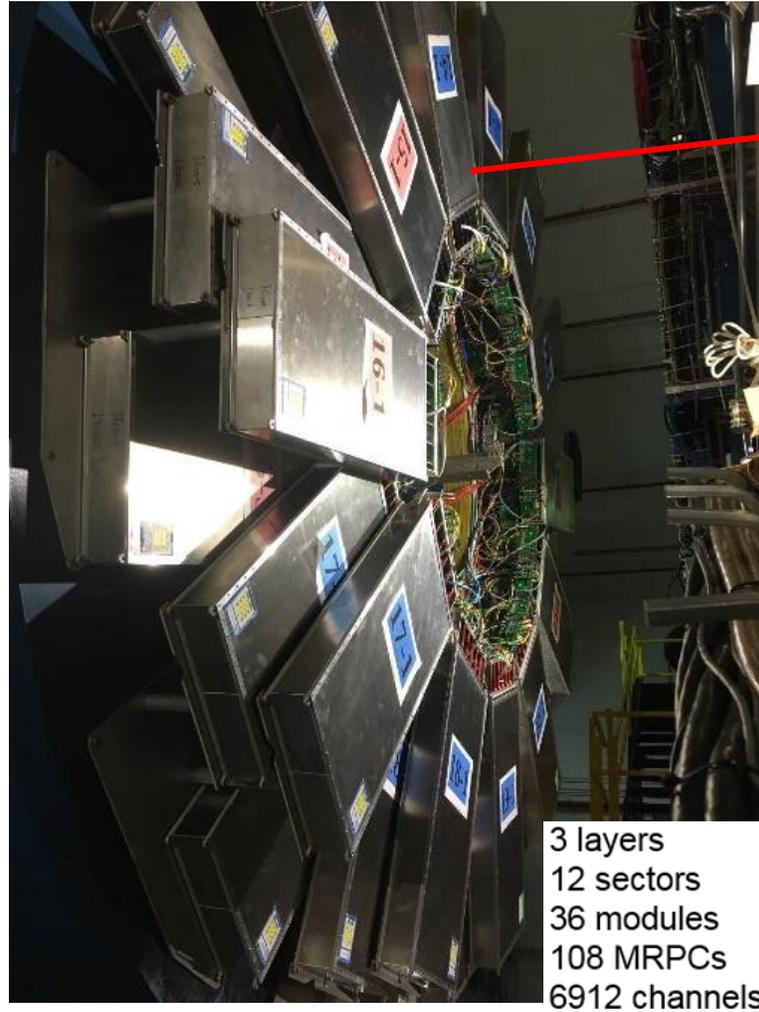
1. **eTOF project at STAR@BNL (6912 channels)**
for long term stability test and physics results purpose

Discussed during
RPC2020 conference

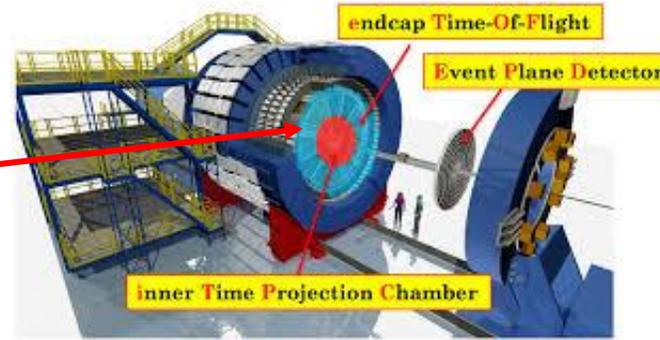
2. **mTOF project at mCBM@SIS18 (1600 channels)**
for high rate and system integration test purpose

Focus on this RPC
conference (RPC2022)

- eTOF successfully operated in RUN 19/20/21 (BES II)



3 layers
12 sectors
36 modules
108 MRPCs
6912 channels

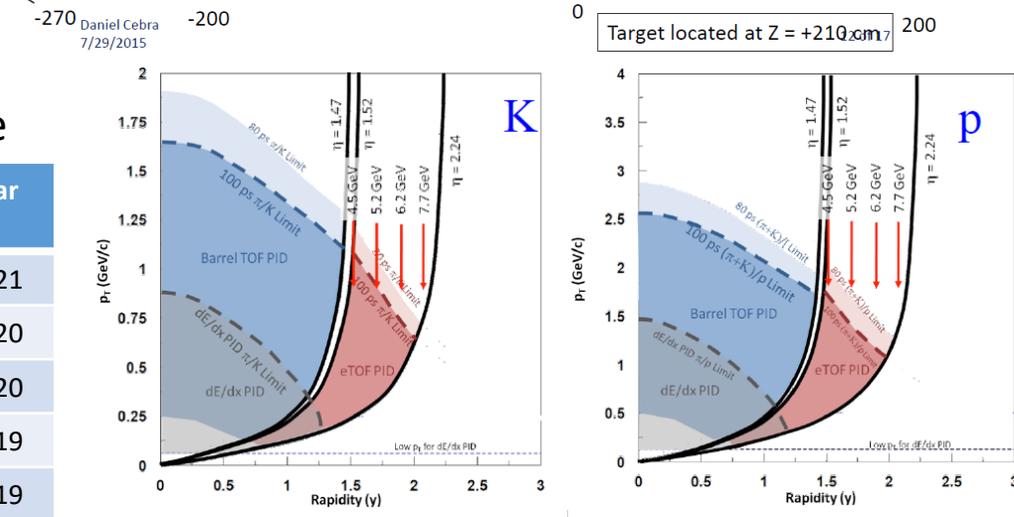
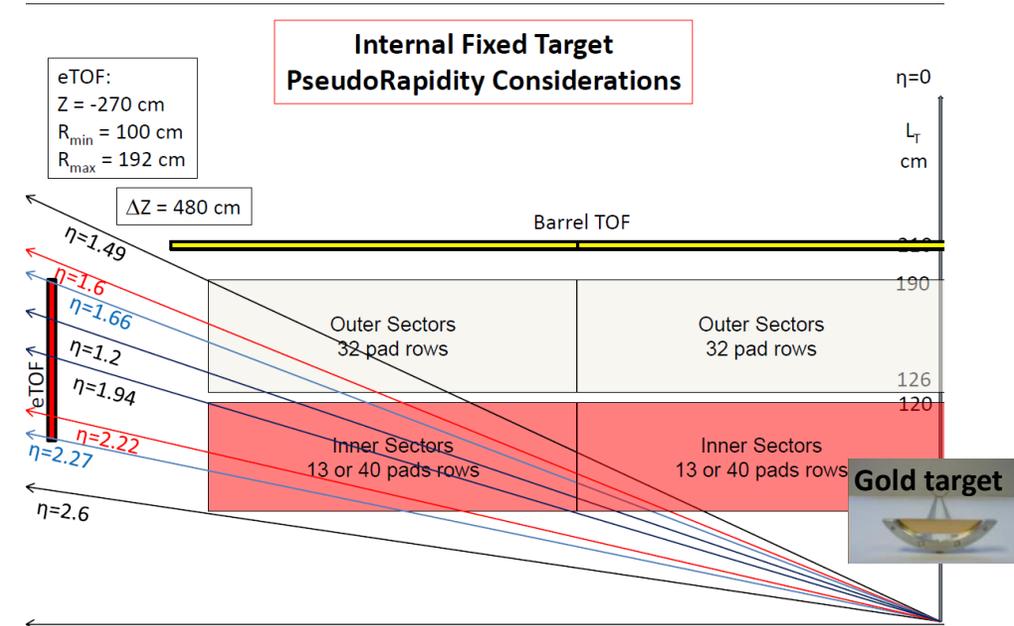


Fixed target mode

$\sqrt{s_{NN}}$ /GeV	# coll. Events	Year
3.0	2 B	2021
3.5	100 M	2020
3.9	50 M	2020
4.5	100 M	2020
5.2	100 M	2020
6.2	100 M	2020
7.7	50 M	2020
9.2	50 M	2021
11.5	50 M	2021
13.7	50 M	2021

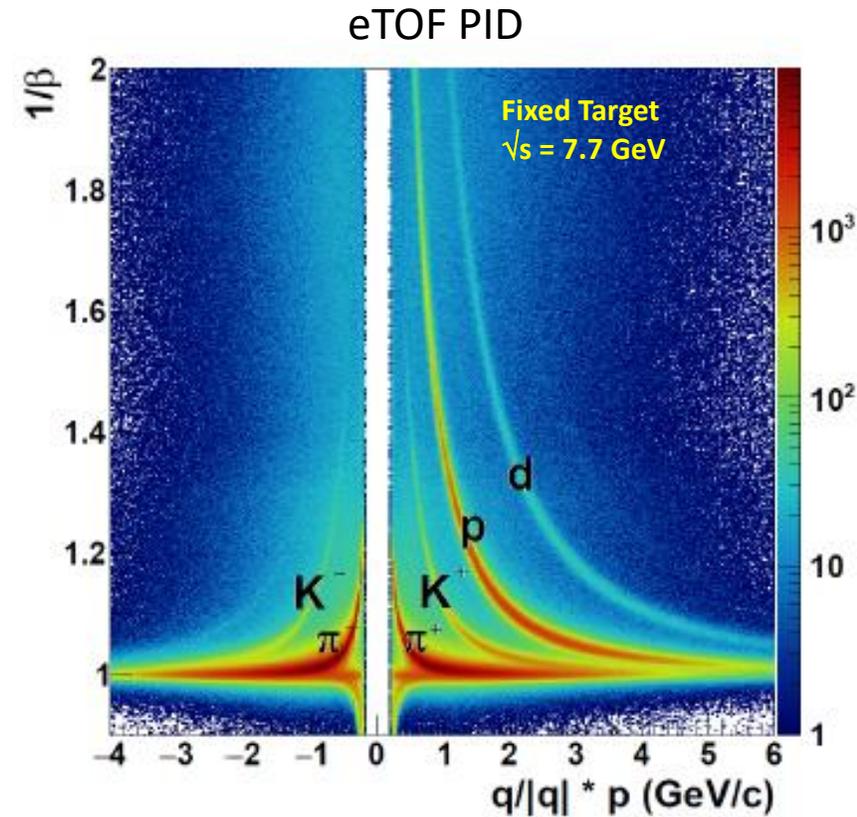
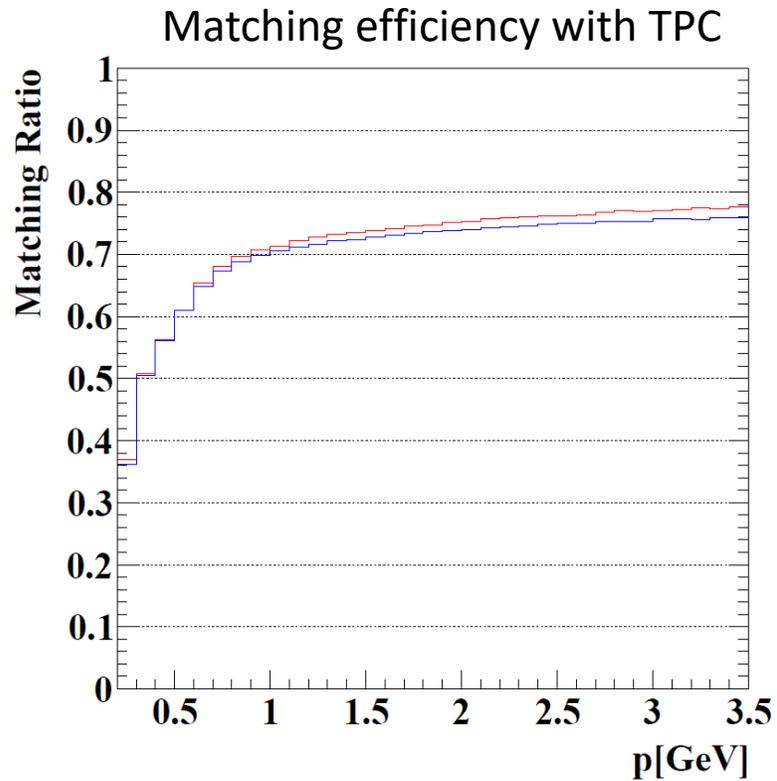
Collider mode

$\sqrt{s_{NN}}$ /GeV	# coll. Events	Year
7.7	100 M	2021
9.1	150 M	2020
11.5	230 M	2020
14.6	320 M	2019
19.6	580 M	2019

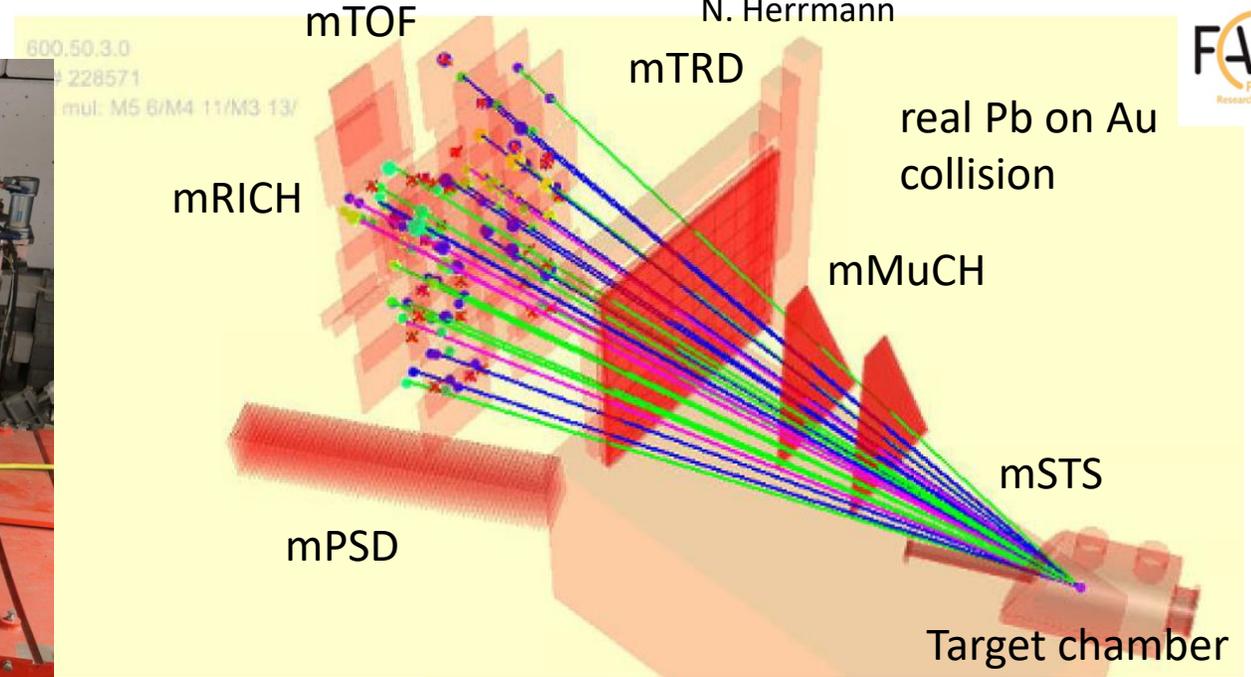
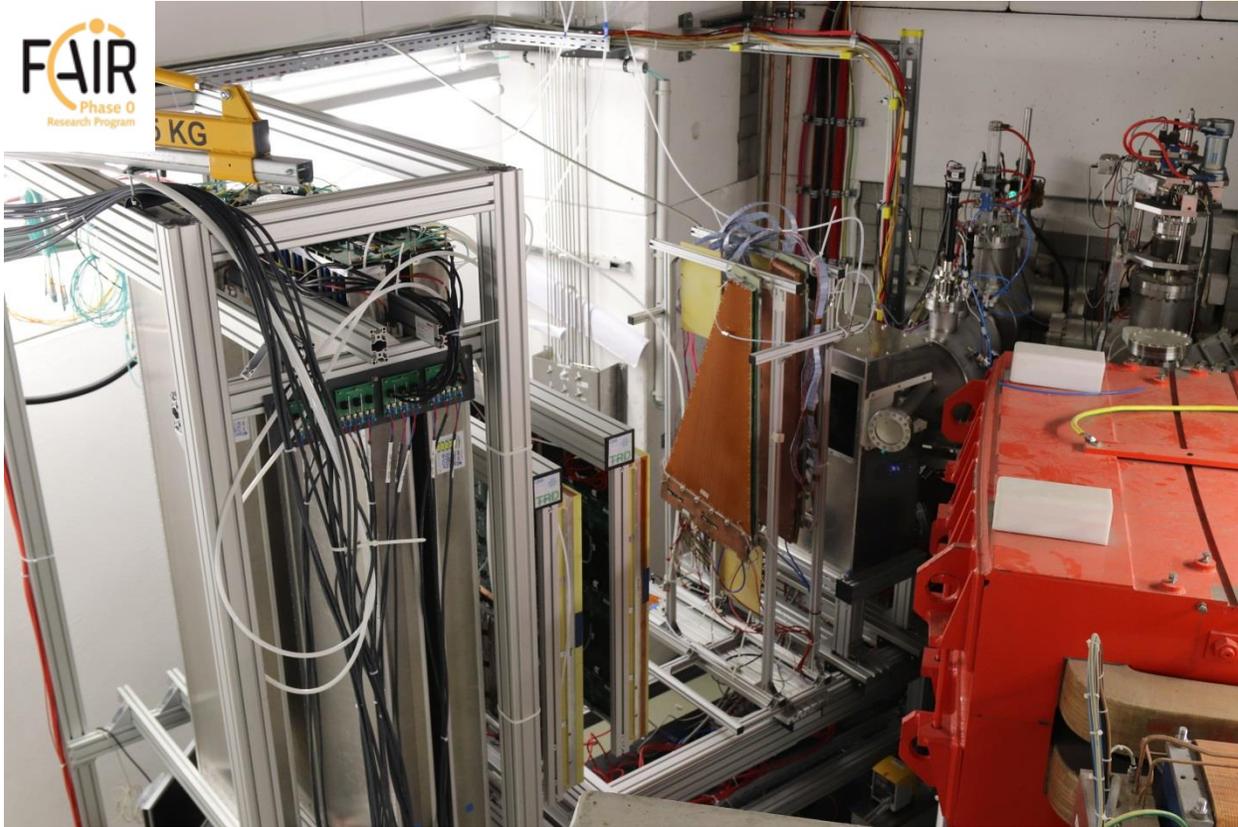


Fixed target mode

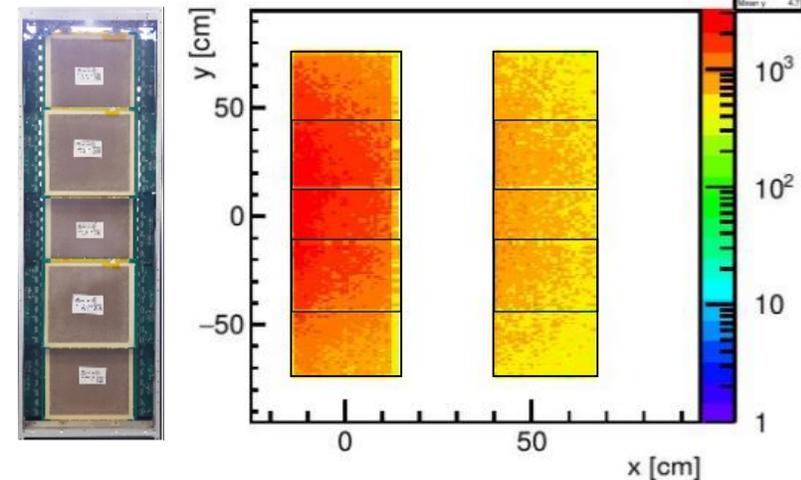
- System synchronization on the level of 35 ps
- System time resolution better than 85 ps
- PID capability demonstrated
- Physics analysis started



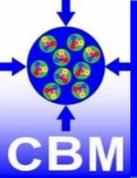
FAIR Phase 0: mCBM setup @ SIS18



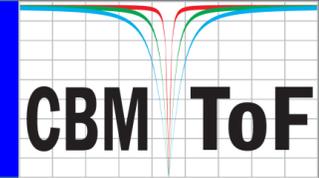
Simulation: Au+Au @ 1.24 GeV mbias



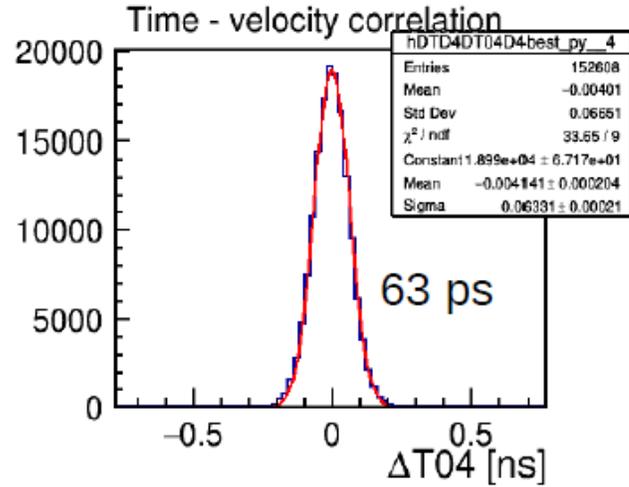
- mCBM is a full system test setup installed at SIS18/GSI dedicated for high rate detector and readout test including free streaming data acquisition and online event selection
- Charged particle fluxes of up to 30 kHz/cm²



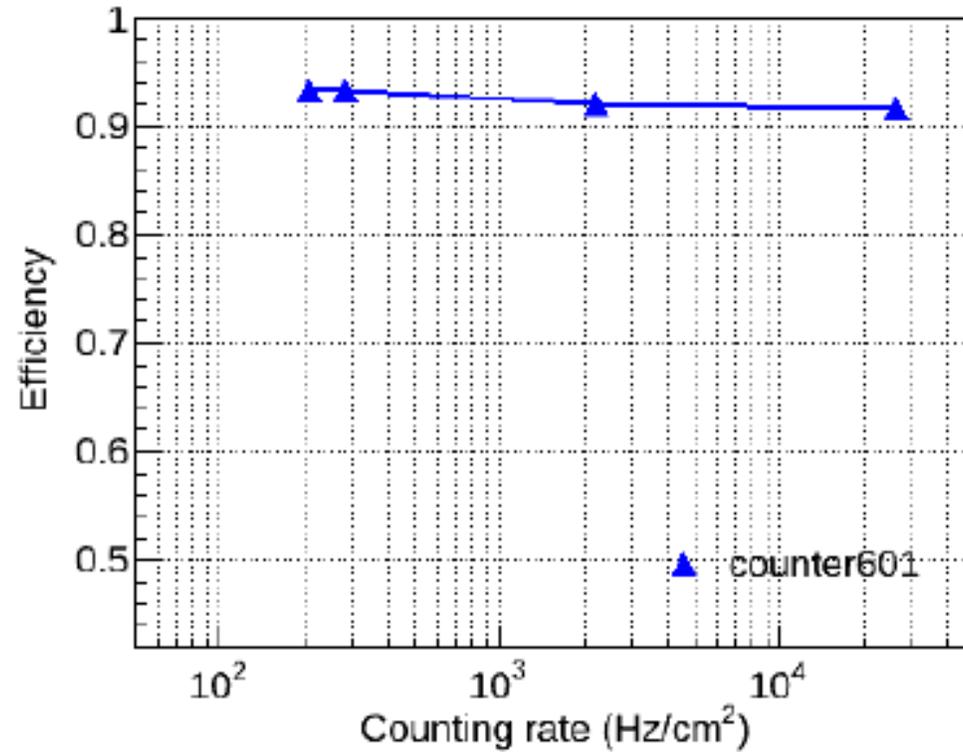
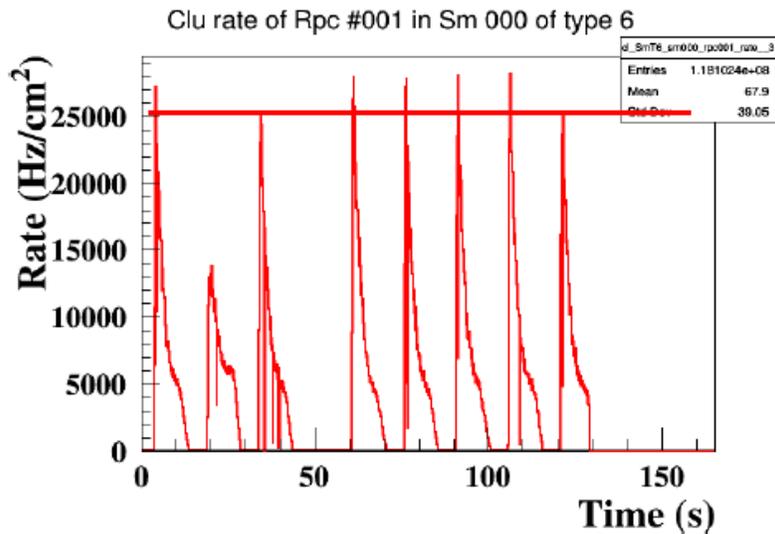
mCBM beam time results 2021



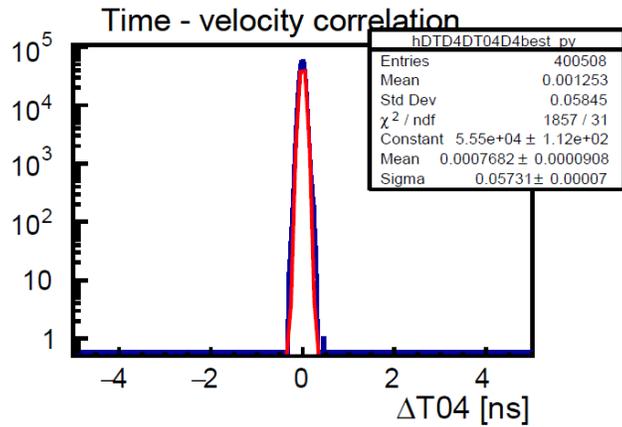
MRPC1a (low resistivity glass counter)



see talk by:
Mariana Petris
Fr. 10:00

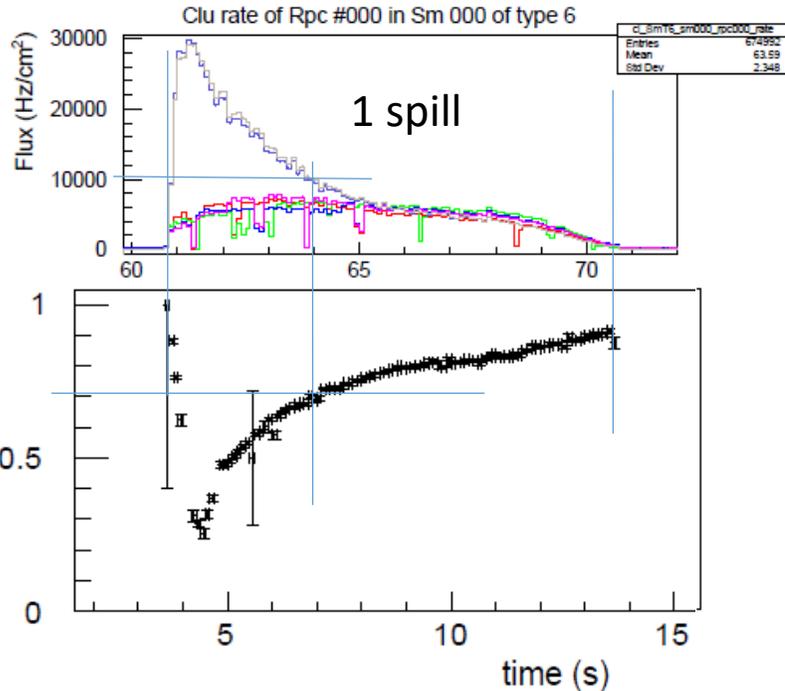
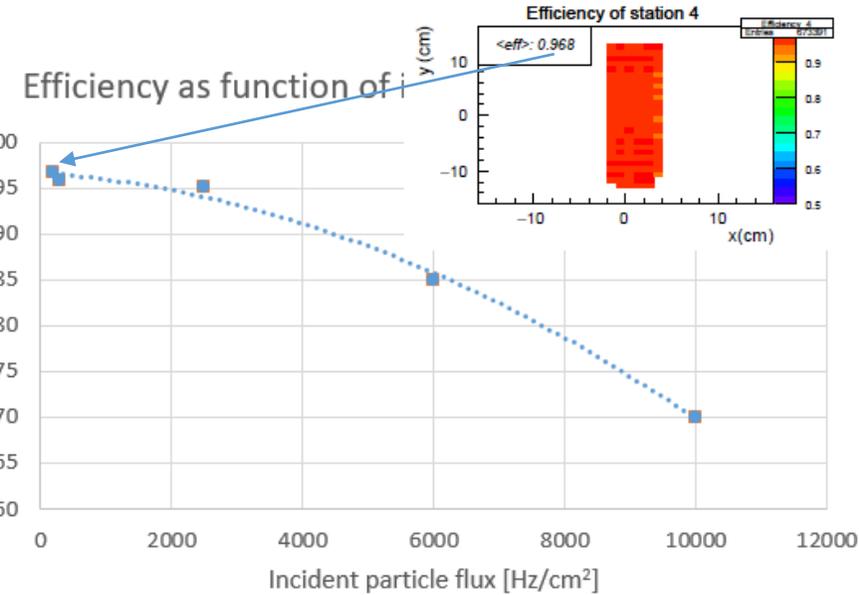


MRPC3 (low rate thin float glass counter)



Results at fluxes below 1 kHz/cm²

- Efficiency for rates above < 95 % on full counter surface
- System time resolution < 62 ps
- Counter time resolution < 45 ps

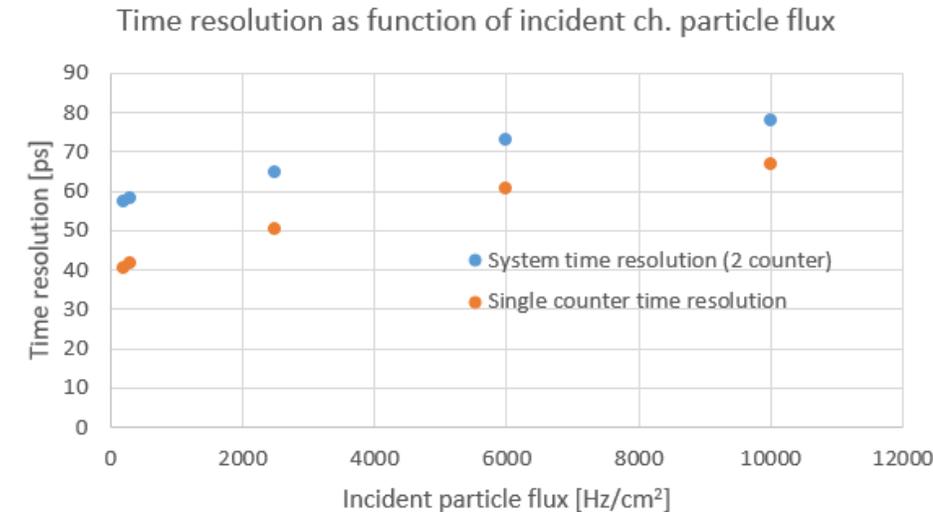


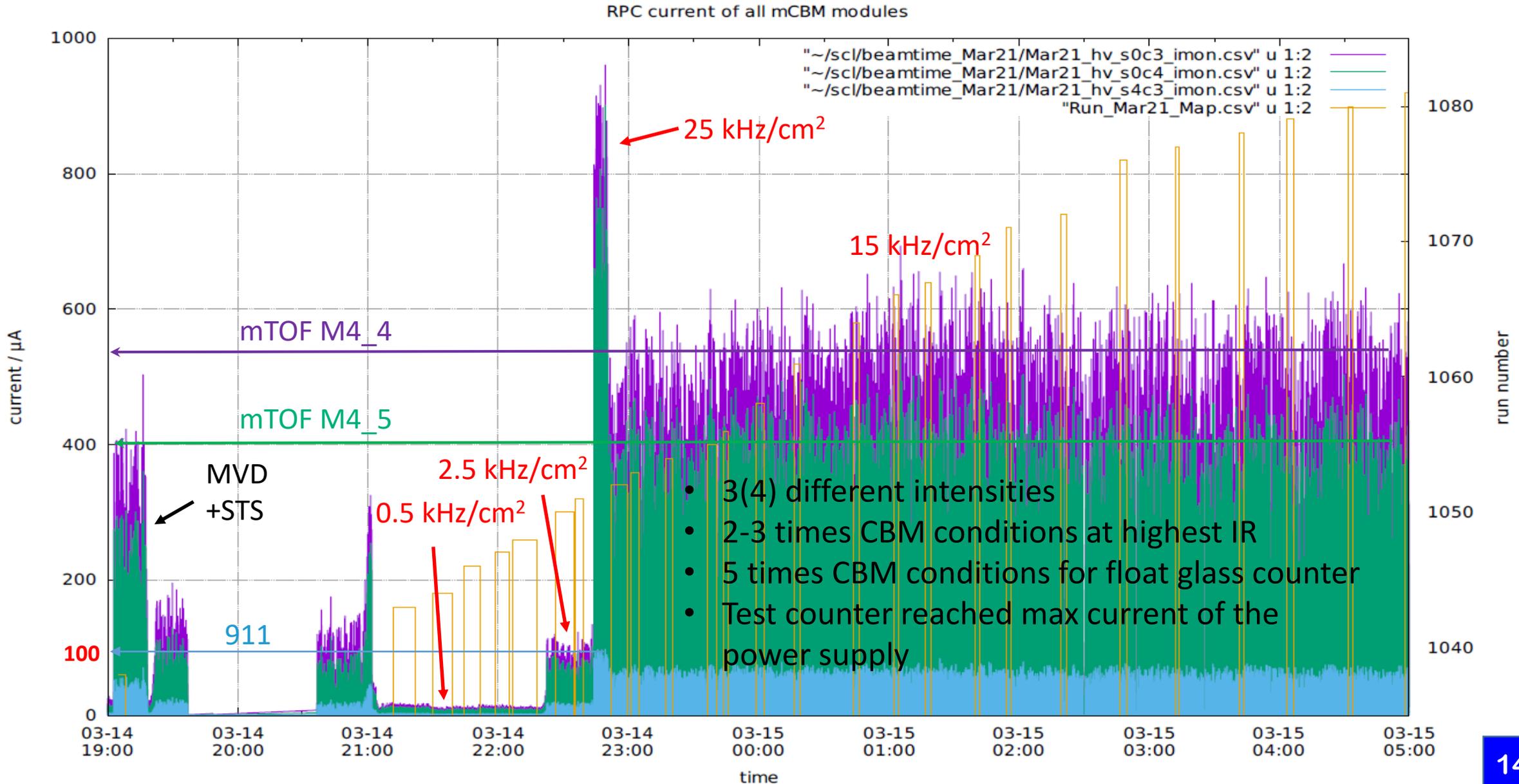
Data loss issues (during beam time)

- Bandwidth limitations
- Get4 dropouts
- Time slice losses
- Readout changed in 2022

Next steps

- Data analysis ongoing (much more to come)
- More detector test at mCBM required



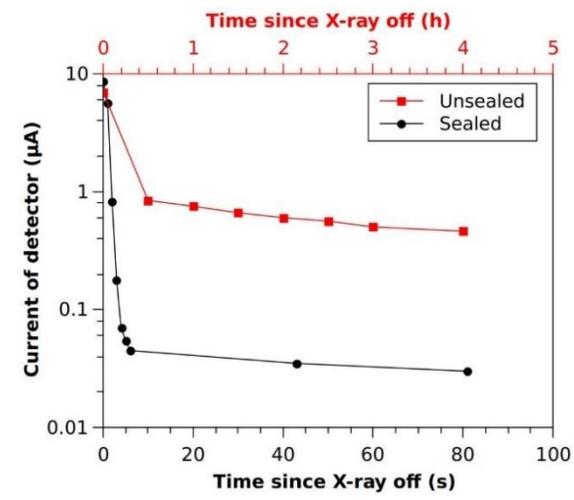
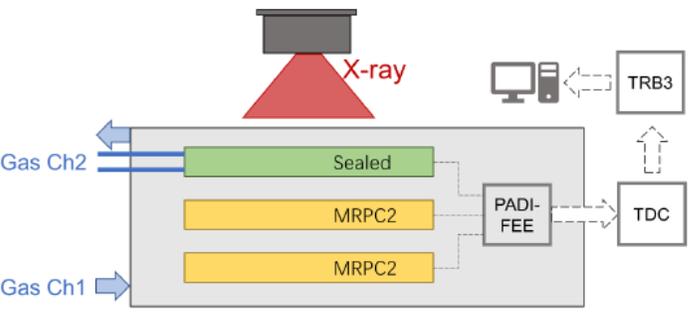
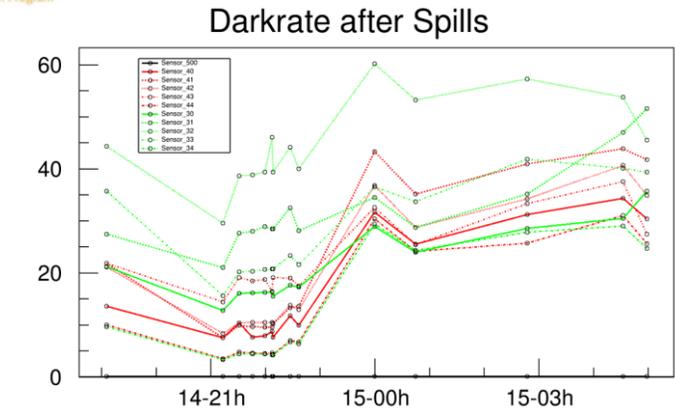
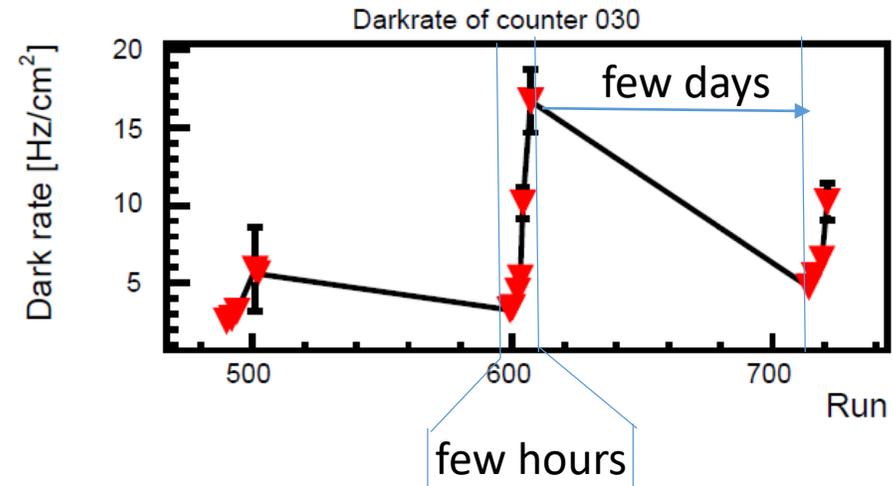


- Gas pollution effect observed at mCBM at high rate (about 10 – 20 kHz/cm²)
- Gas pollution effect was reproduced at IRASM (Bucharest) with high gamma flux (see talk by **Mariana Petris - Fr. 10:00**)
- X-Ray test at Beijing confirmed the gas pollution effect
- The effect was minimized by sealing the MRPC and increasing the gas flow

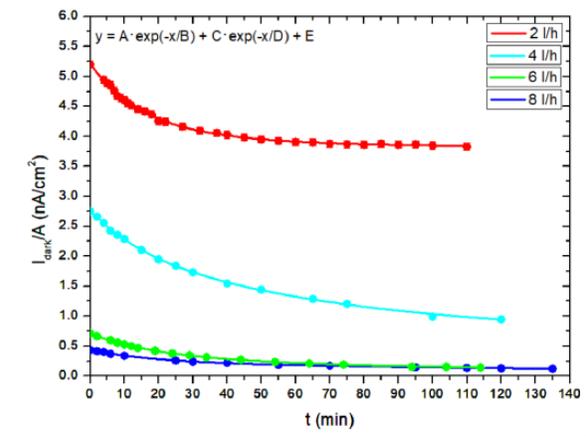
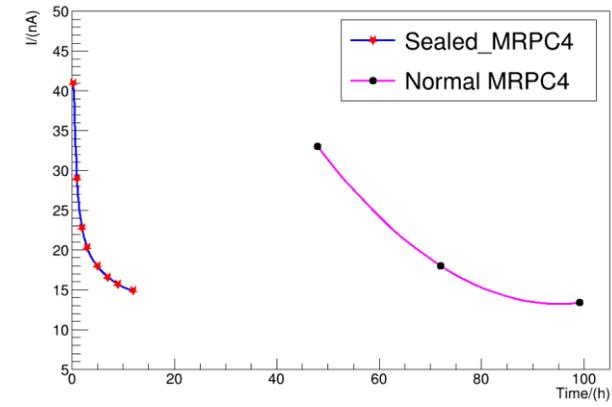
Observations @ mCBM 2020
rapid increase of dark rate



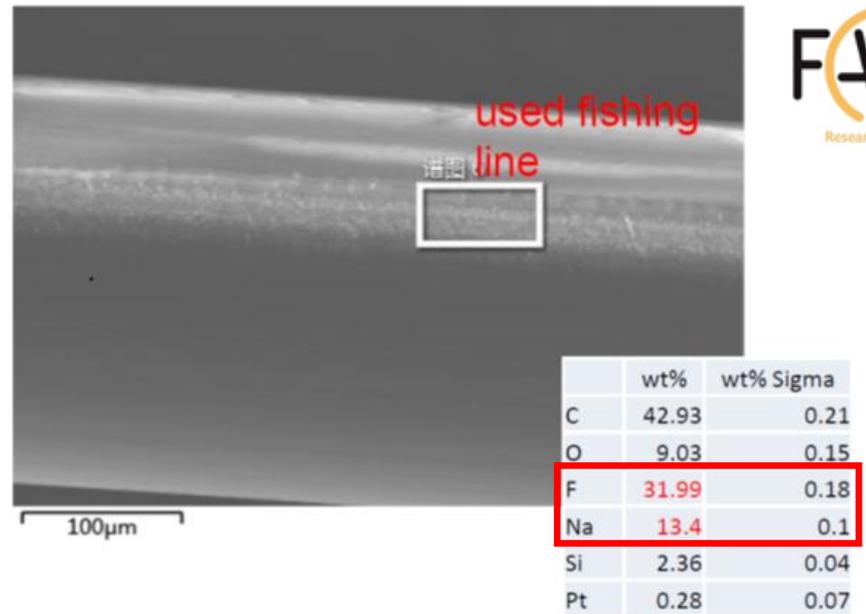
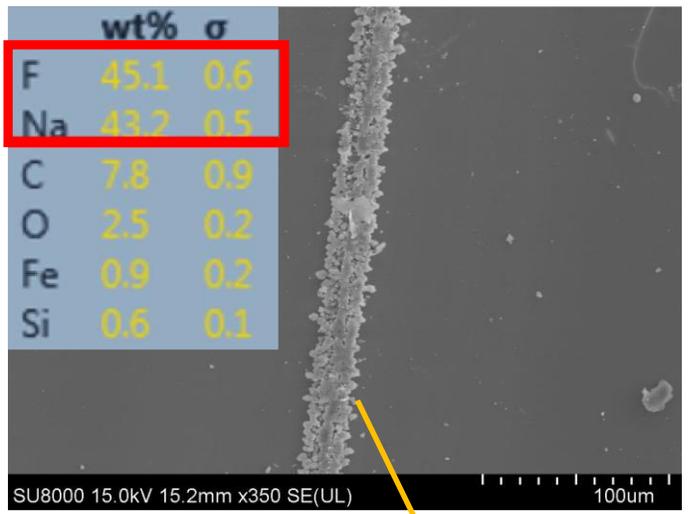
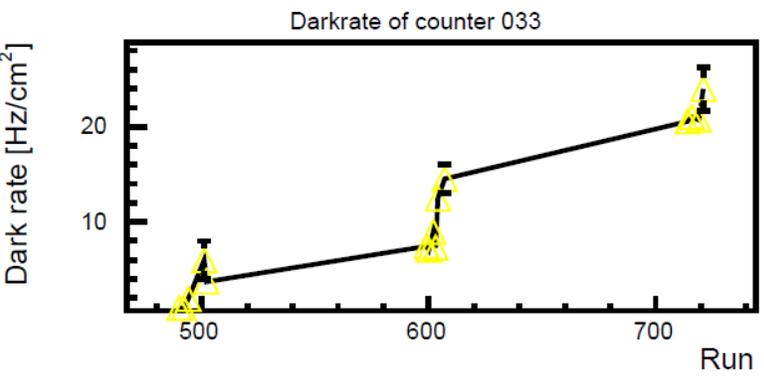
Observations confirmed
@ mCBM 2021



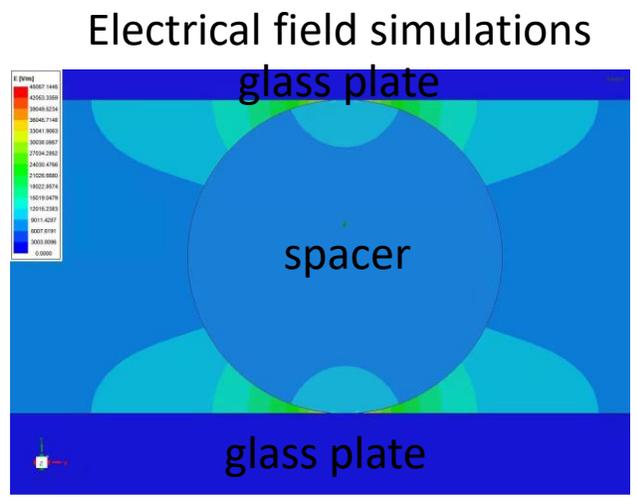
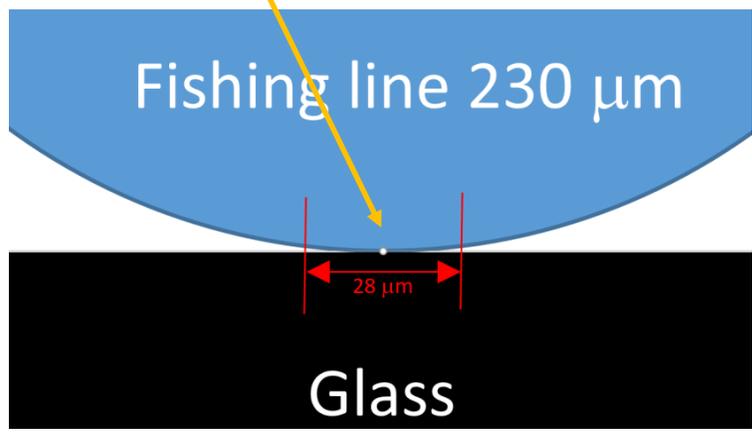
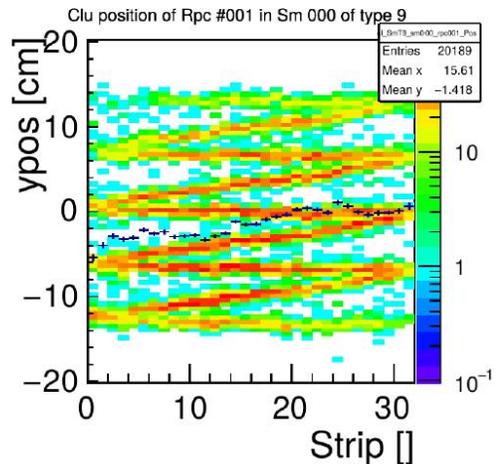
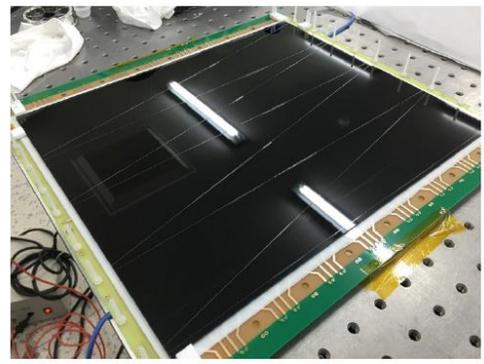
Dark current relaxation after irradiation



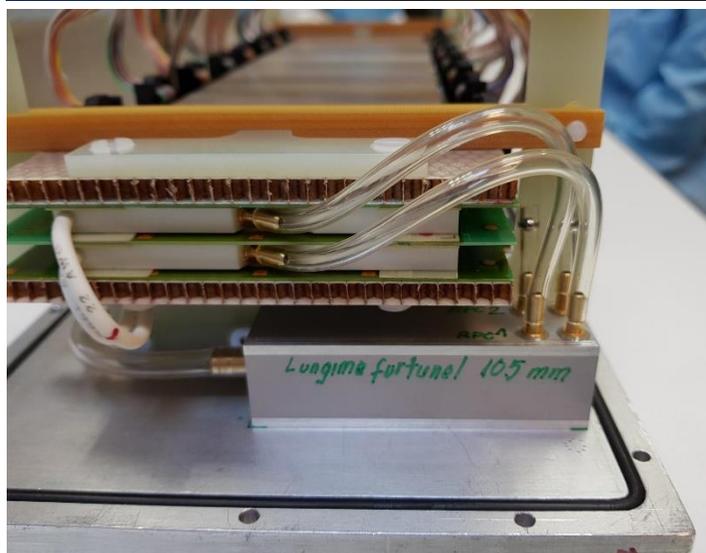
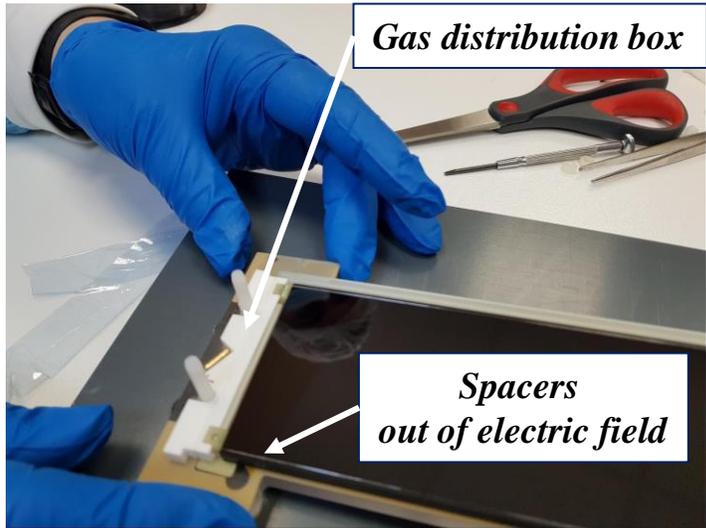
Observations: continuous increase in dark rate (permanent aging)



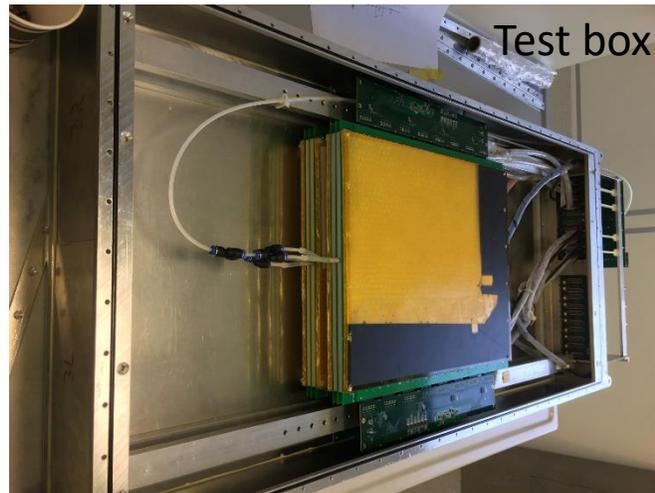
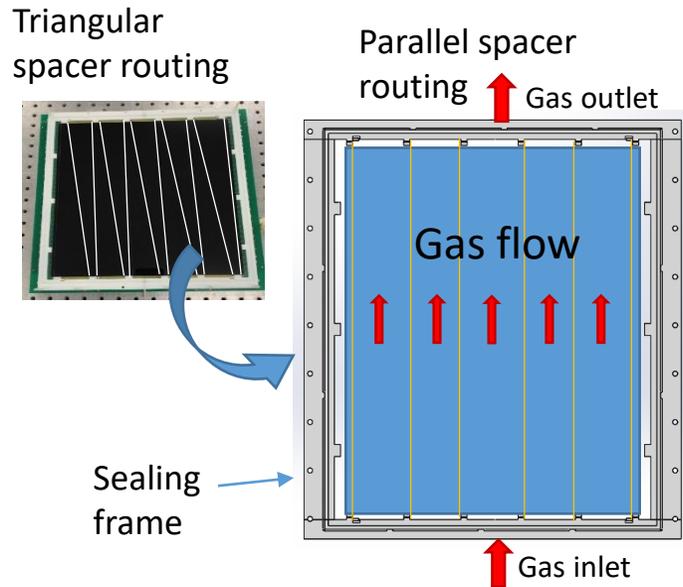
- Traces of NaF was found on the glass surface
- Dark rate (noise) is generated entirely on spacers
- Electrical field simulations performed



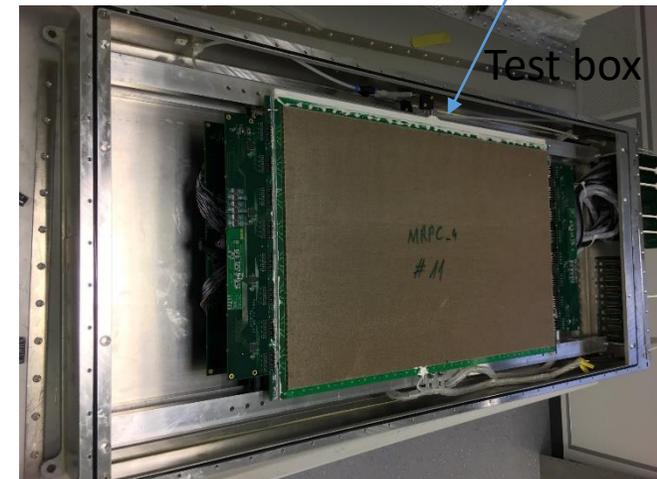
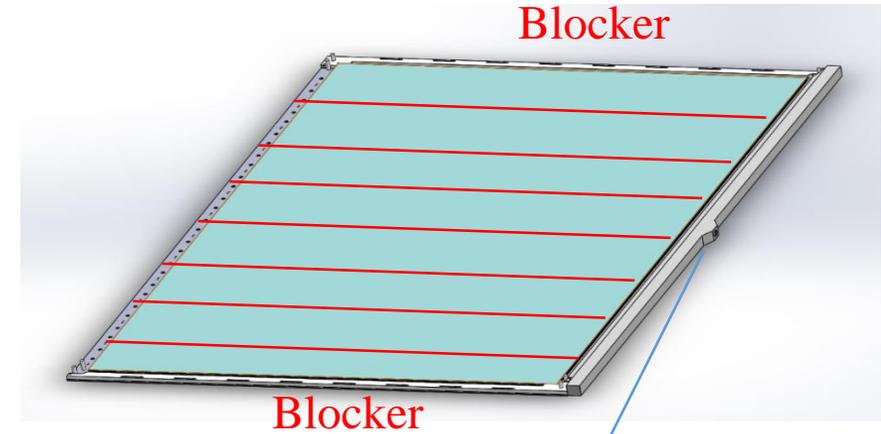
High rate counter (MRPC1)

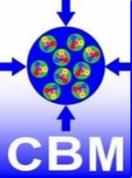


Intermediate rate counter (MRPC2)

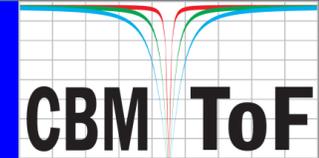


Low rate counter (MRPC3/4)





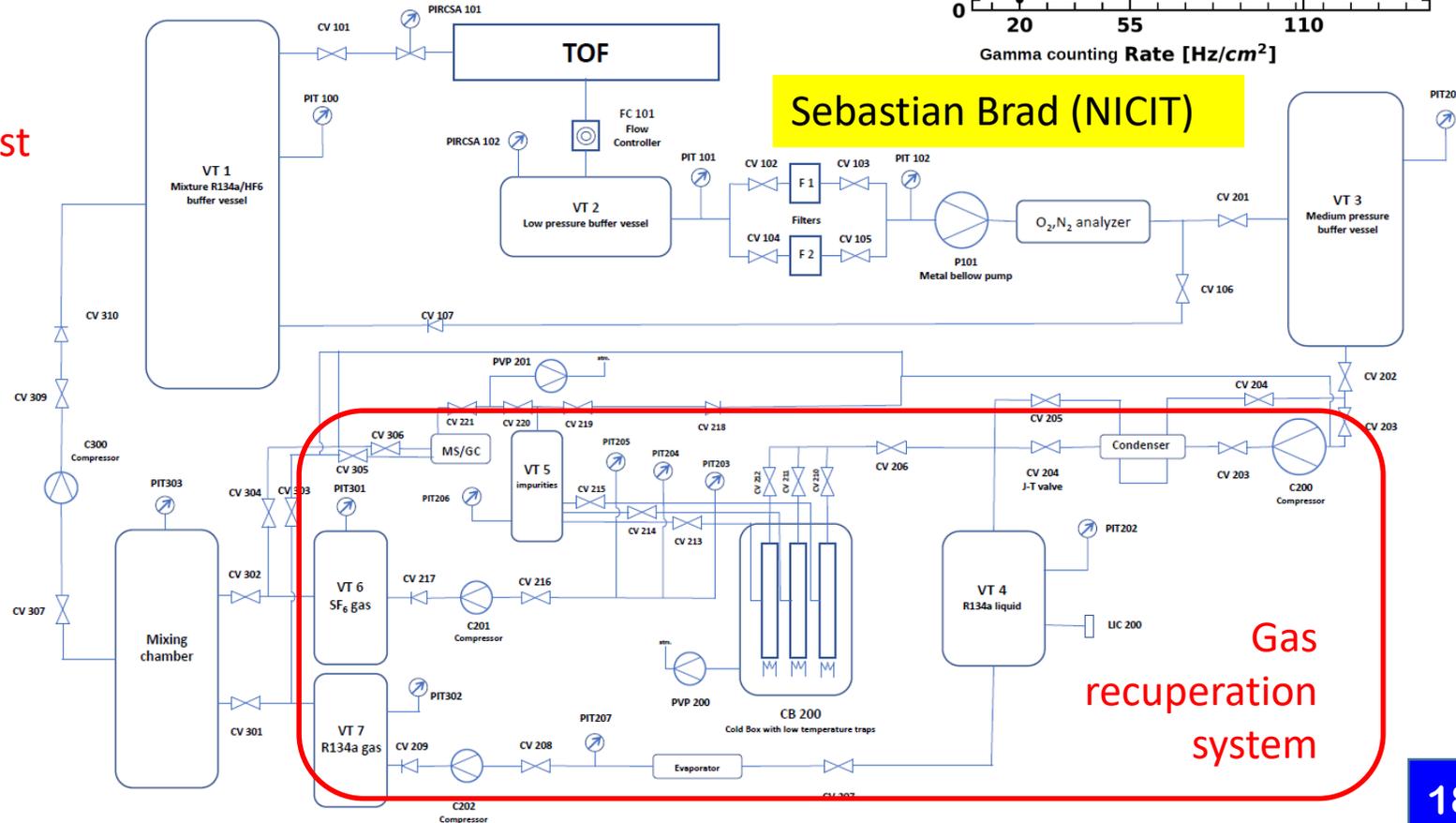
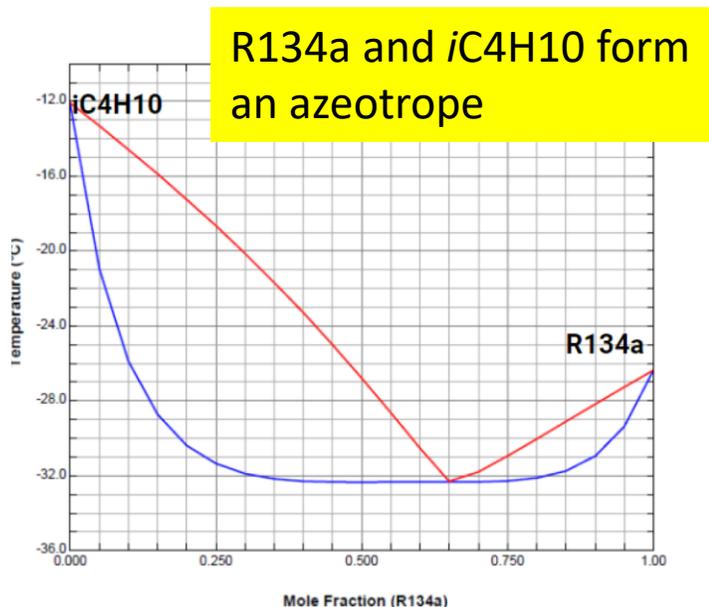
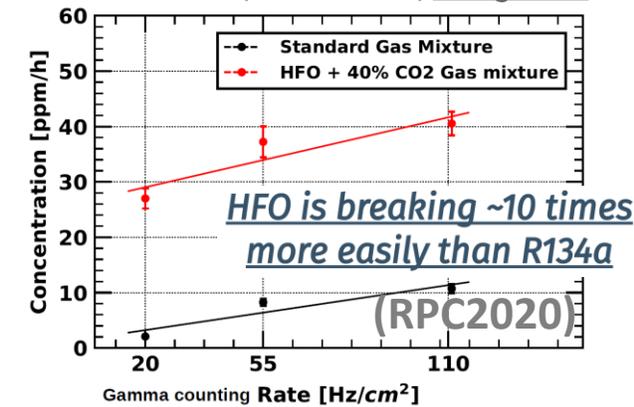
Conclusions for the CBM TOF gas system



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 SF₆ to 2.5% (reduction of GWP, difficult to recycle)
- Increase the flow rate
- Build a recuperation system (reuse of gas, cost reduction, GWP reduction)

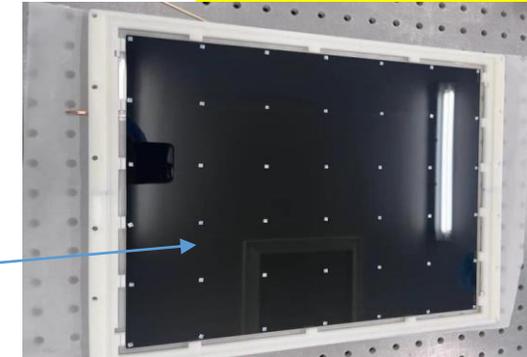
230 modules
Total gas volume 25 m³



see talk by: **Botan Wang**

Th. 9:40

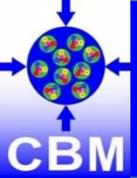
- High rate (mCBM) and long term stability (eTOF) test performed
 - float glass counter beyond specs
- MRPC aging and gas pollution effects at high rates observed
 - mitigation strategies established
 - R&D on rectangular spacers ongoing
 - new counter with adopted designs developed, built and currently tested at mCBM
- Layout of final gas system (with recuperation) in preparation



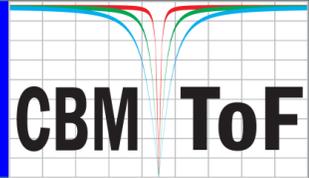
Time line and major milestones

- Counter electronics PRRs: Q4/2022
- 2nd counter pre-production Q4/2022
- Counter production start: Q2/2023
- Module (pre) production start: Q1/2023
- TOF ready for beam: end of 2025





Thank you for your attention

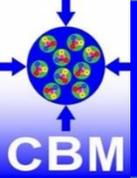


Contributing institutions:

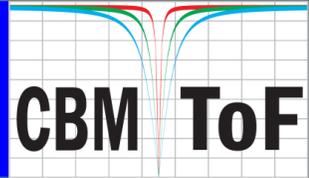
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NIPNE	Bucharest,
GSI	Darmstadt,
TU	Darmstadt,
USTC	Hefei,
PI	Heidelberg,
ITEP*	Moscow,
CCNU	Wuhan,

*Cooperation suspended

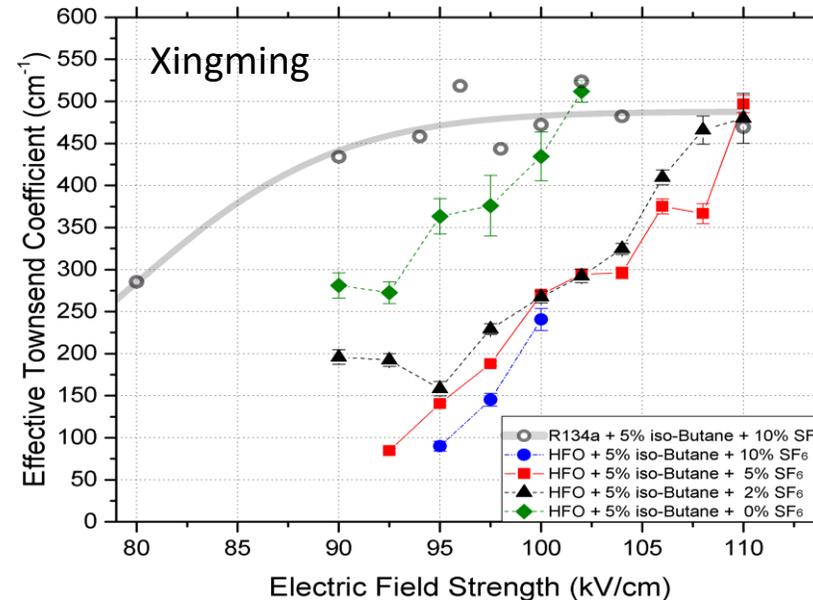
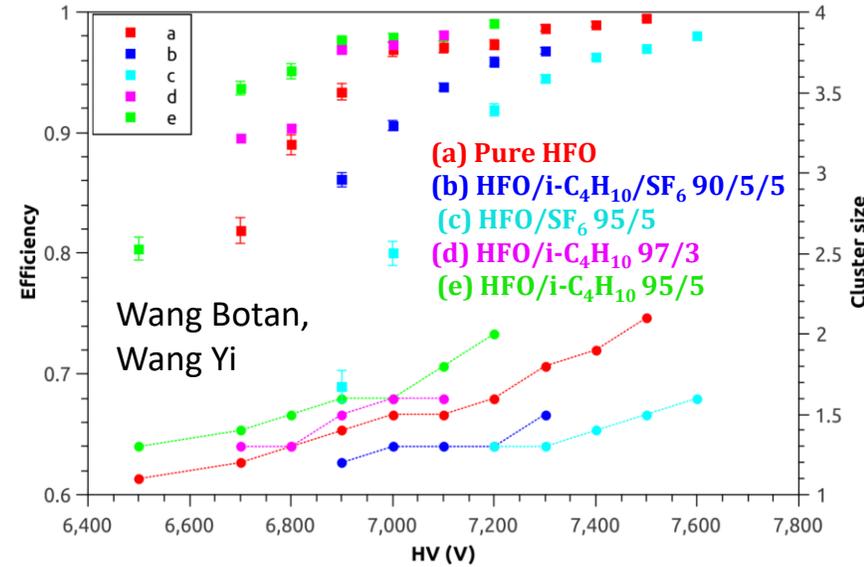




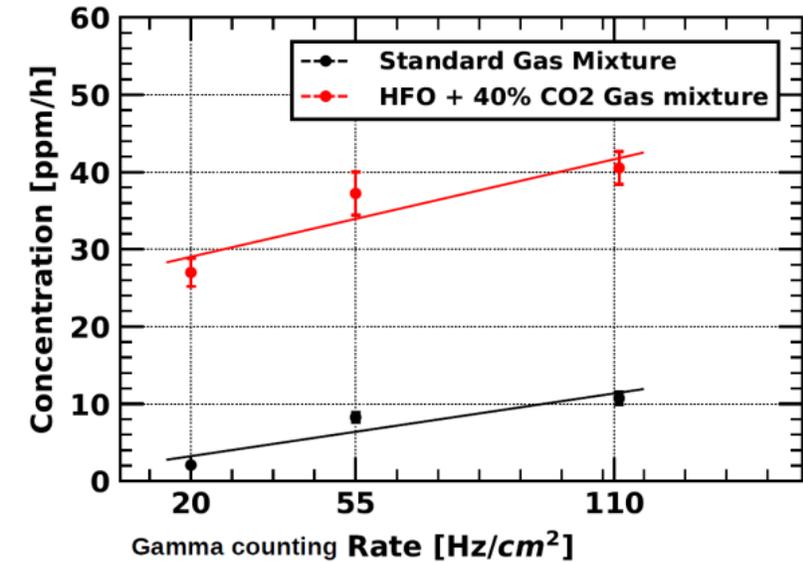
Alternative gas search in CBM TOF



- Alternative gas mixtures were investigated
- Time resolutions in the order of 80 ps to 100 ps were obtained
- Gas mixtures with HFO fulfil our TOF requirements
- Working point is shifted by about 2000 V
- Measurements of the eff. Townsend coefficient show no major difference for gas mixtures with more than 2 % SF₆
- The instability of HFO in comparison to R134a is counterproductive in a high rate environment



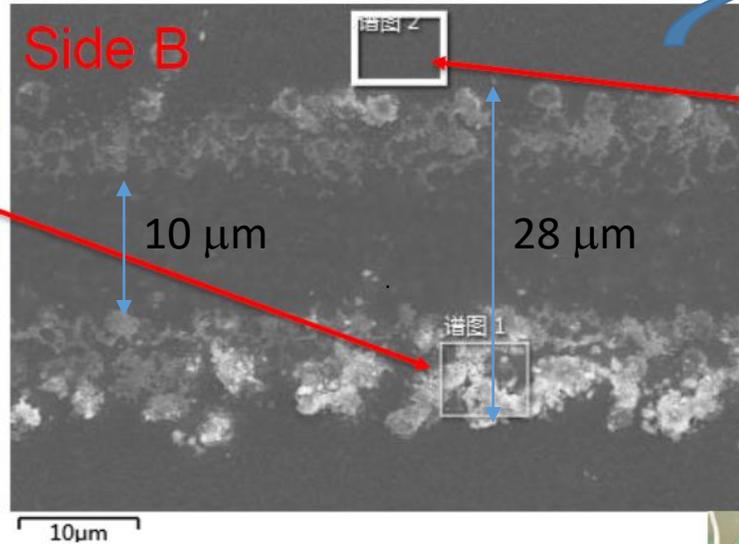
R. Guida, B. Mandelli, G. Rigoletti (RPC2020)



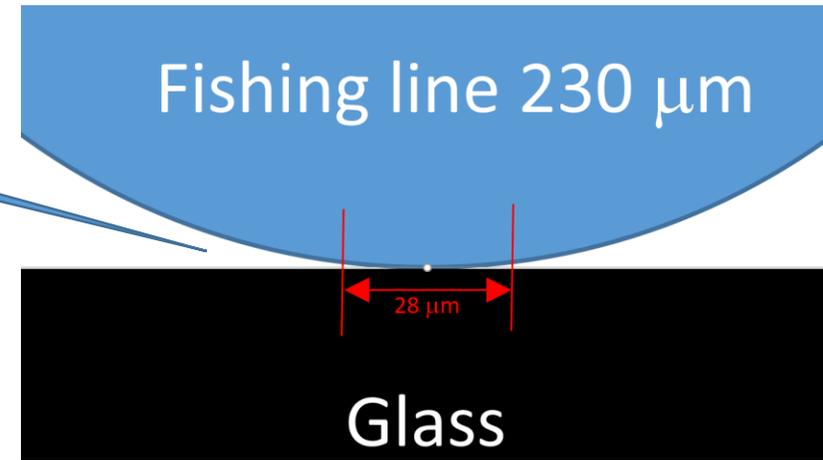
HFO is breaking ~10 times more easily than R134a

◆ fishing line tracks area of MRPC #95

	wt%	wt% Sigma
C	1.77	0.27
O	27.14	0.22
F	21.28	0.23
Na	12.48	0.13
Mg	1.66	0.06
Al	1.99	0.06
Si	26.92	0.18
Ca	3.84	0.09
Sn	1.24	.15
Pt	1.7	0.16



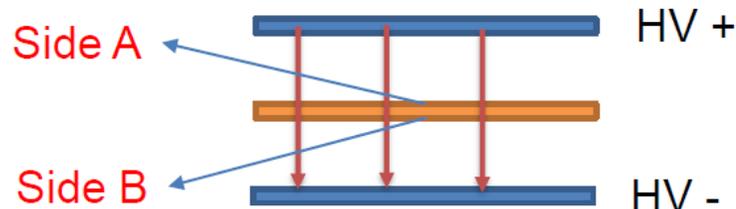
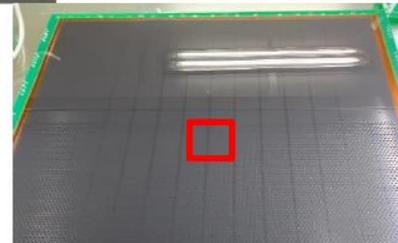
	wt%	wt% Sigma
C	1.79	0.43
O	42.16	0.31
Na	9.62	0.12
Mg	2.34	0.07
Al	2.62	0.07
Si	32.87	0.24
K	0.22	0.07
Ca	5.01	0.11
Sn	1.66	0.22
Pt	1.72	0.18



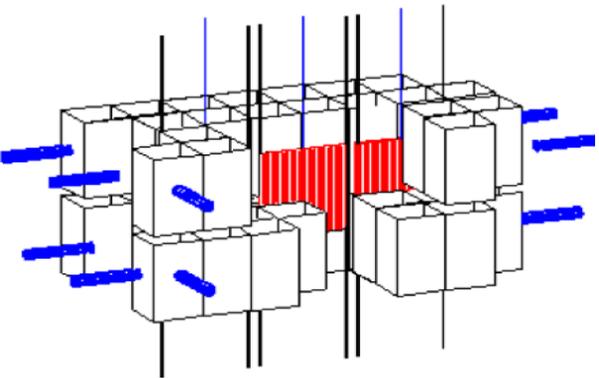
Unused float glass

	wt%	wt% Sigma
O	42.43	0.23
Na	9.62	0.11
Mg	2.46	0.06
Al	2.68	0.06
Si	33.86	0.18
K	0.21	0.06
Ca	5.14	0.1
Sn	1.94	0.21
Pt	1.65	0.18

- ✓ Very little C is found on Side B, lower than side A
- ✓ Na fraction (~12%) increases in stain area
- ✓ F is found in stain area



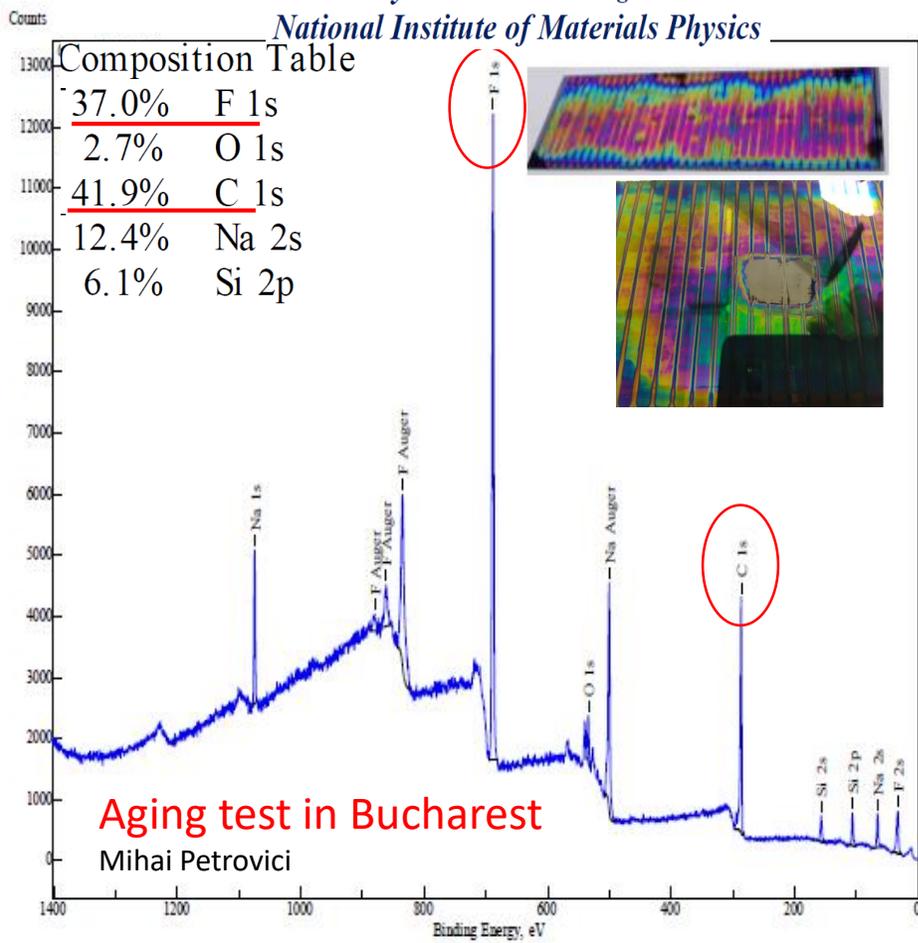
- IRASM/IFIN-HH industrial irradiator,
- present ⁶⁰Co source activity: 360 kCi



- Aging test performed at IRASM (360 kCi)
- Glass inspections performed with various methods (SEM, XPS, AFM RBS, non-RBS, THz-TDS)
- **Glass resistivity remains unchanged**

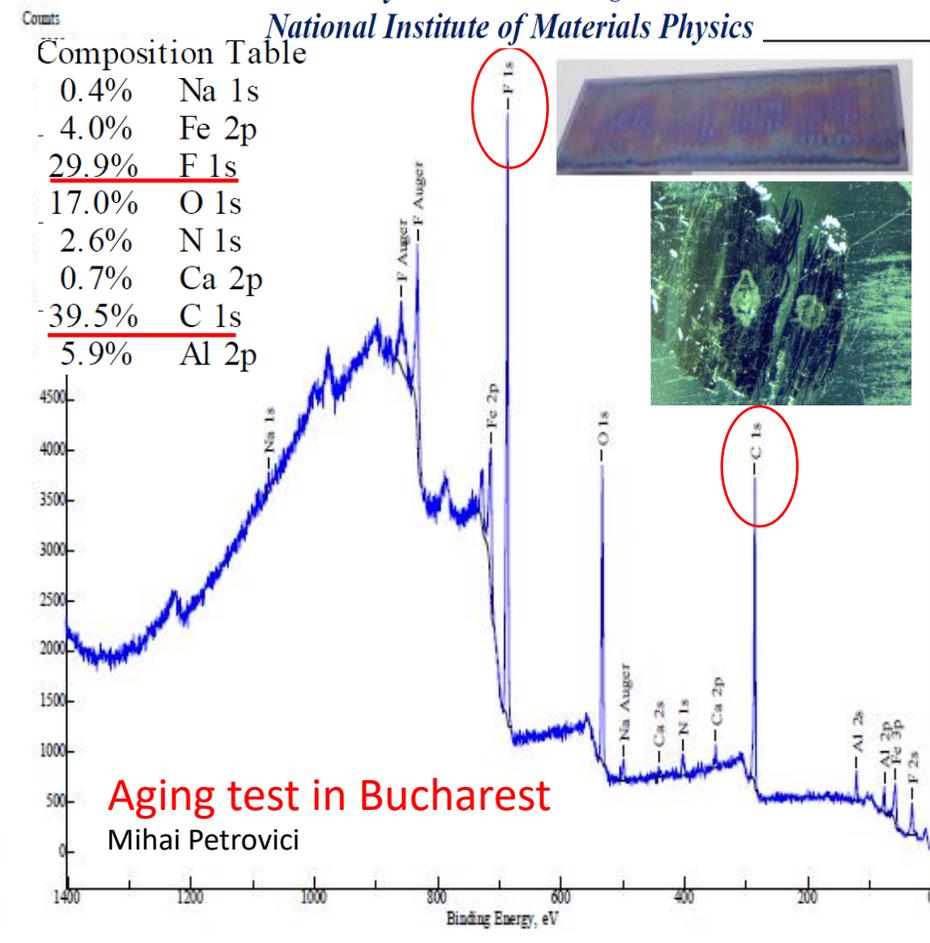
Surface facing the cathode

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

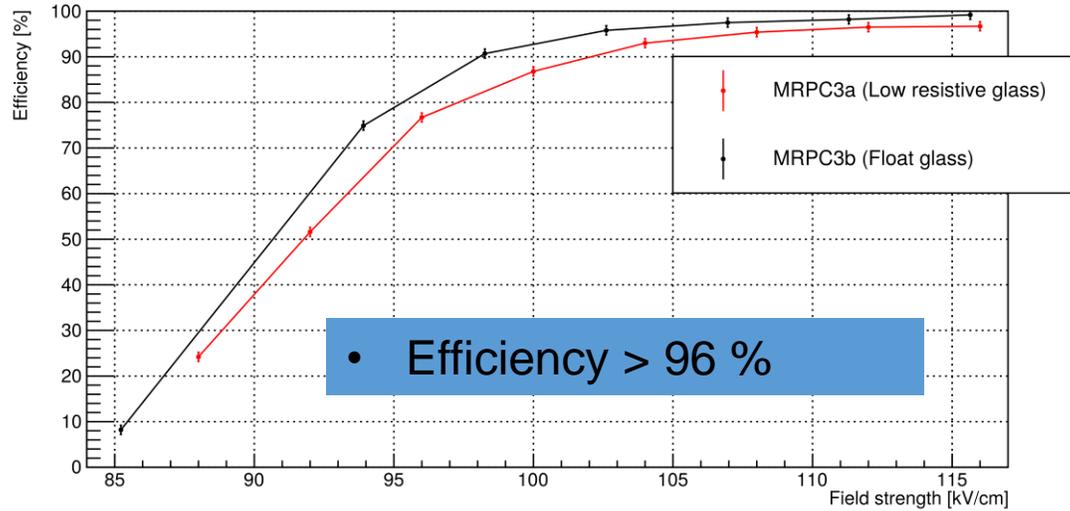


surface facing the anode

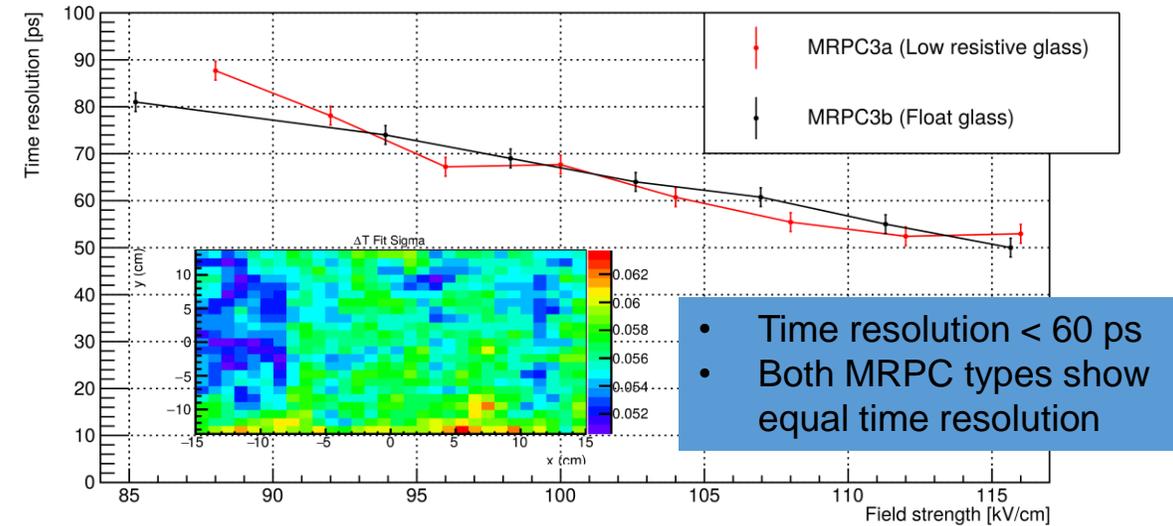
XPS analysis - thanks to C. Negrila
National Institute of Materials Physics



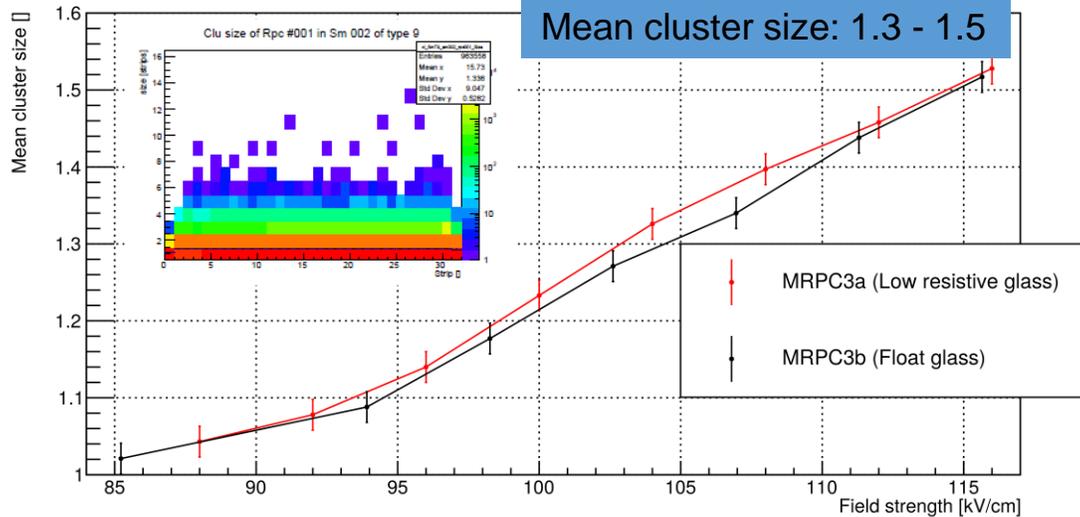
Efficiency vs. Field strength



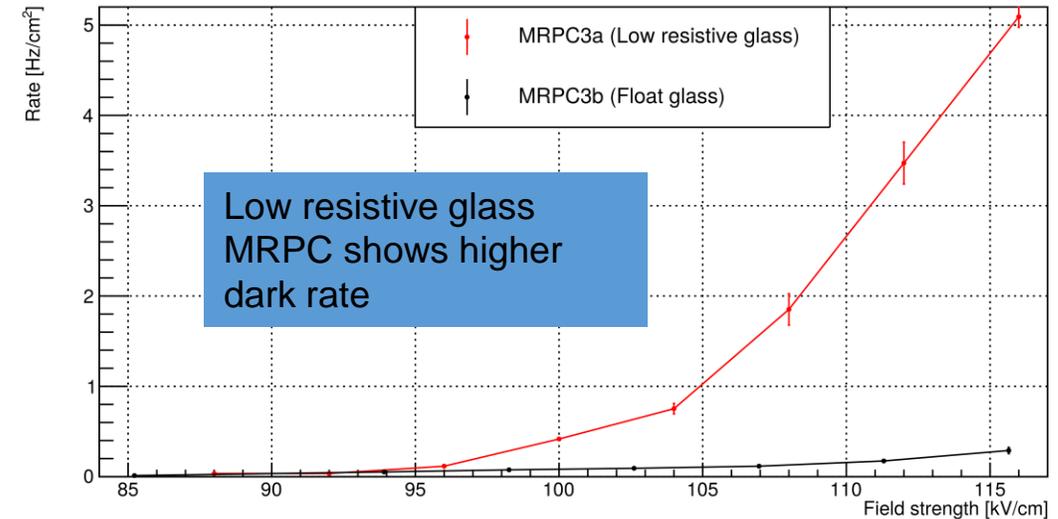
Time resolution vs. Field strength



Mean cluster size vs. Field strength

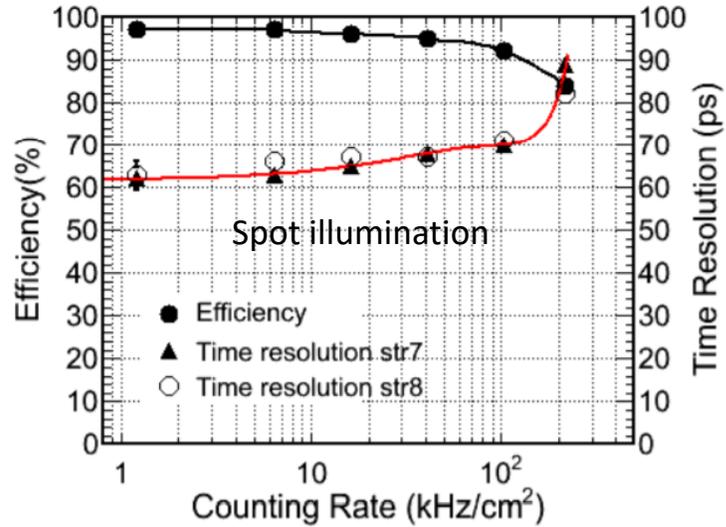


Rate vs. Field strength



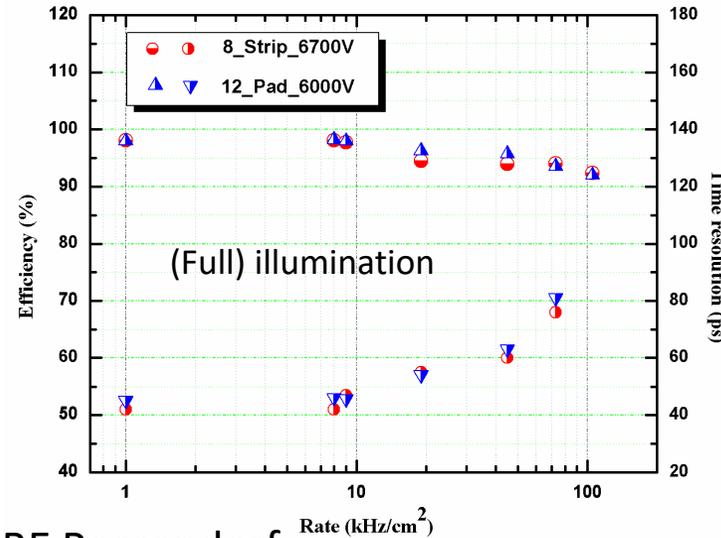
Inner region COSY beam time

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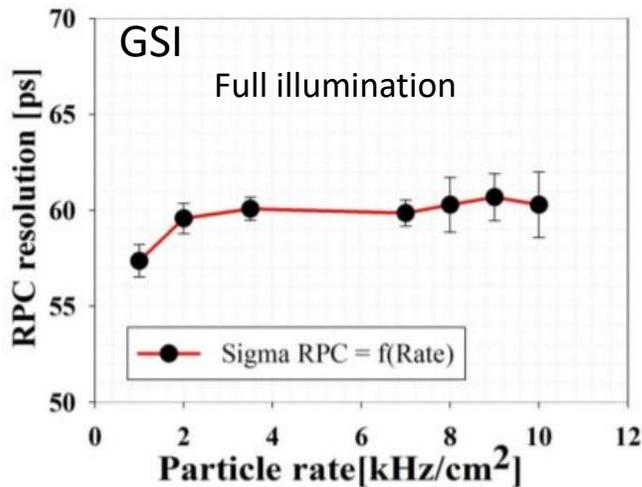
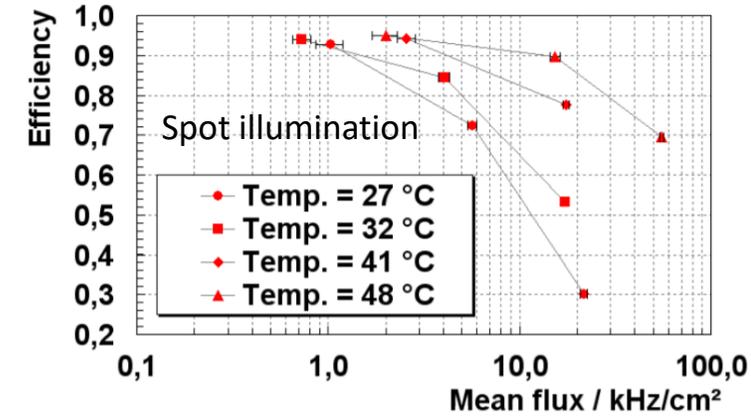
Intermediate region

Nuclotron DUBNA

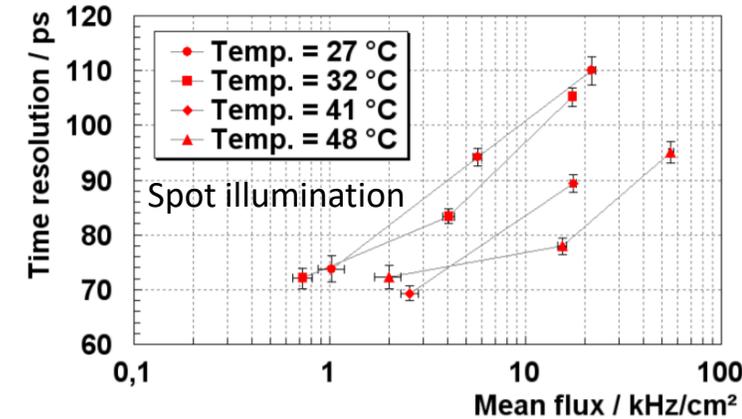
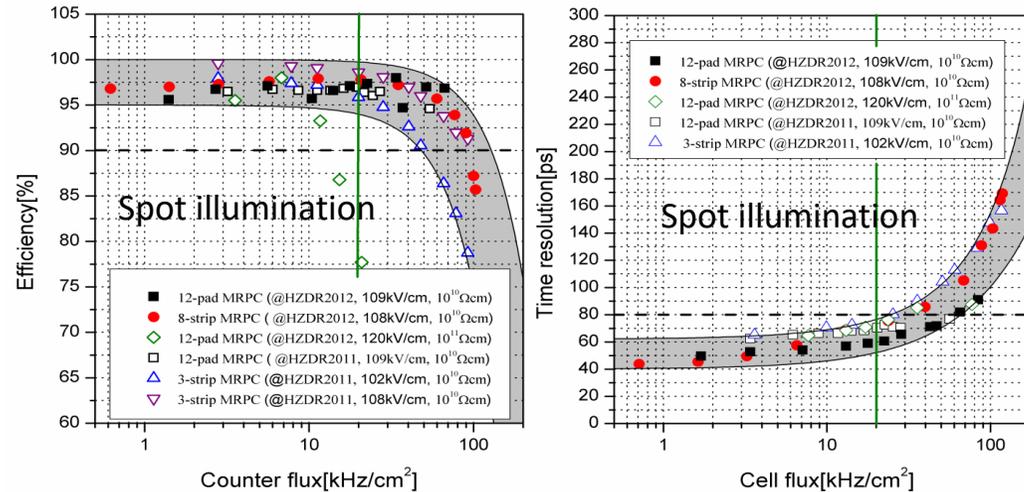


Outer region

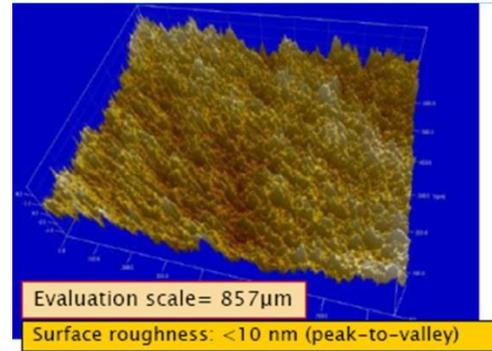
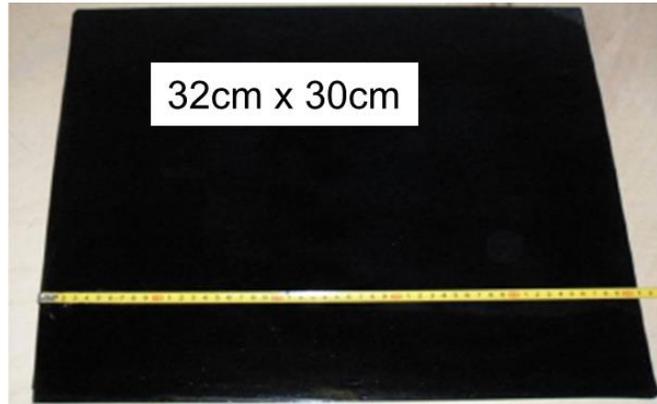
COSY beam time



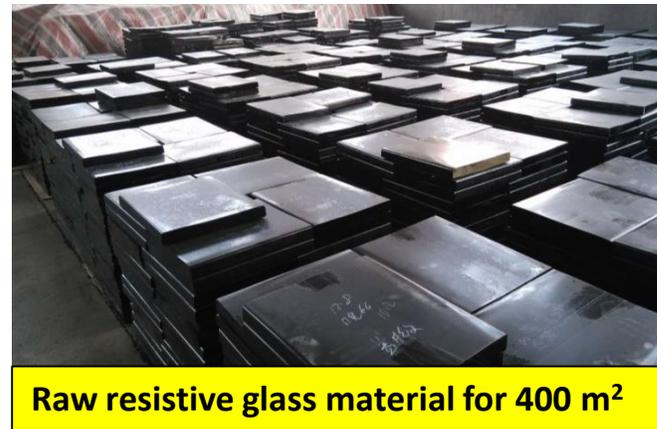
ELBE Rossendorf



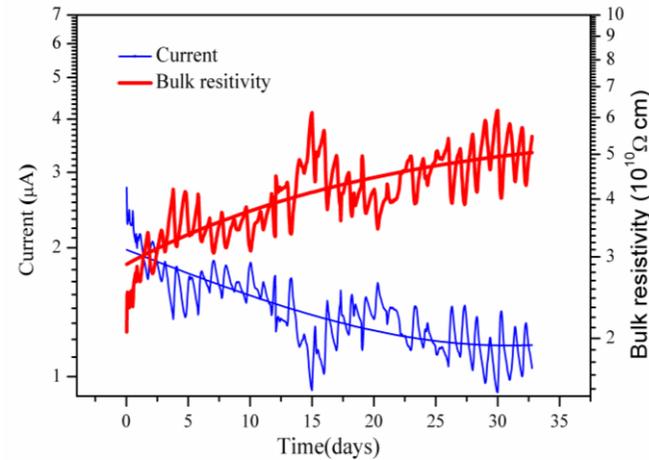
Resistive glass for high-rate MRPCs is developed in Beijing, China



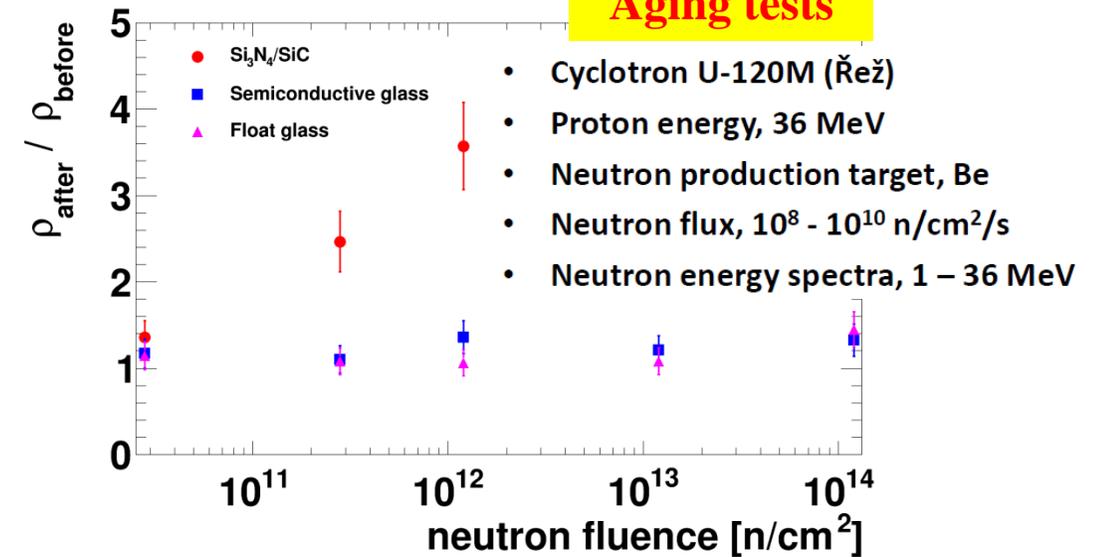
Maximal dimension	32cm × 30cm
Bulk resistivity	$10^{10} \Omega\text{cm}$
Standard thickness	0.7, 1.1mm
Thickness uniformity	20 μm
Surface roughness	< 10nm
Dielectric constant	7.5 - 9.5
DC measurement	Ohmic behavior stable up to 1 C/cm ²



Raw resistive glass material for 400 m²



Aging tests



Main parameters comparison	PADI-1	PADI-2	PADI-6	PADI-8
Channels per chip	3	4	4	8
PA Bandwidth (MHz)	280	293	416	411
PA Voltage Gain	74	87	244	251
Conversion Gain (mV/fC)	6.3	7.8	35	30
Baseline DC offset σ (mV)	6.7	21.9	5.9	1
PA Noise (mV _{RMS})	3.37	2.19	5.82	5.5
Equivalent Noise Charge (e_{RMS})	3512	1753	1039	1145
Threshold type	Extern	Extern	Ext. & DAC	DAC
Threshold dynamics (\pm mV)	Non.lin. 280	Non.lin. 300	Lin. 500	Lin. 750
Input Impedance Range (Ω)	30-450	37 - 370	38 - 165	30 - 160
Power consumption (mW/channel)	21.6	17.4	17.7	17

