XVII Conference on Resistive Plate Chambers and Related Detectors

FAIR — Facility for Antiproton and Ion Research in Europe

GSI

9.–13. Sept. 2024
Europe/Madrid Zeitzone

Status of the CBM Time-of-Flight project

Ingo Deppner

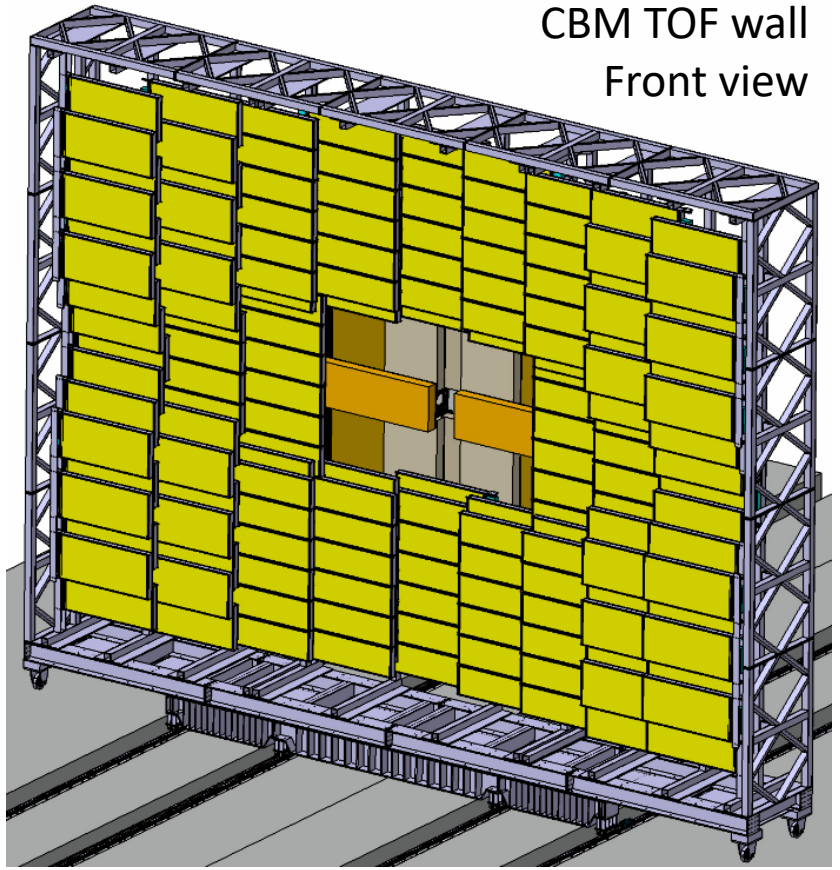
GSI Helmholtzzentrum für Schwerionenforschung GmbH

10.09.2024

Outline

- Introduction to FAIR, CBM and CBM-TOF
- CBM – TOF read out electronics
- TOF FAIR Phase 0 program
  - eTOF status at STAR/BNL
  - mTOF at mCBM at SIS18/GSI
    - (Gas) Aging of MRPCs and mitigation steps
    - Conditions and counter performance
- Counter and module mass production
- Summary and time line

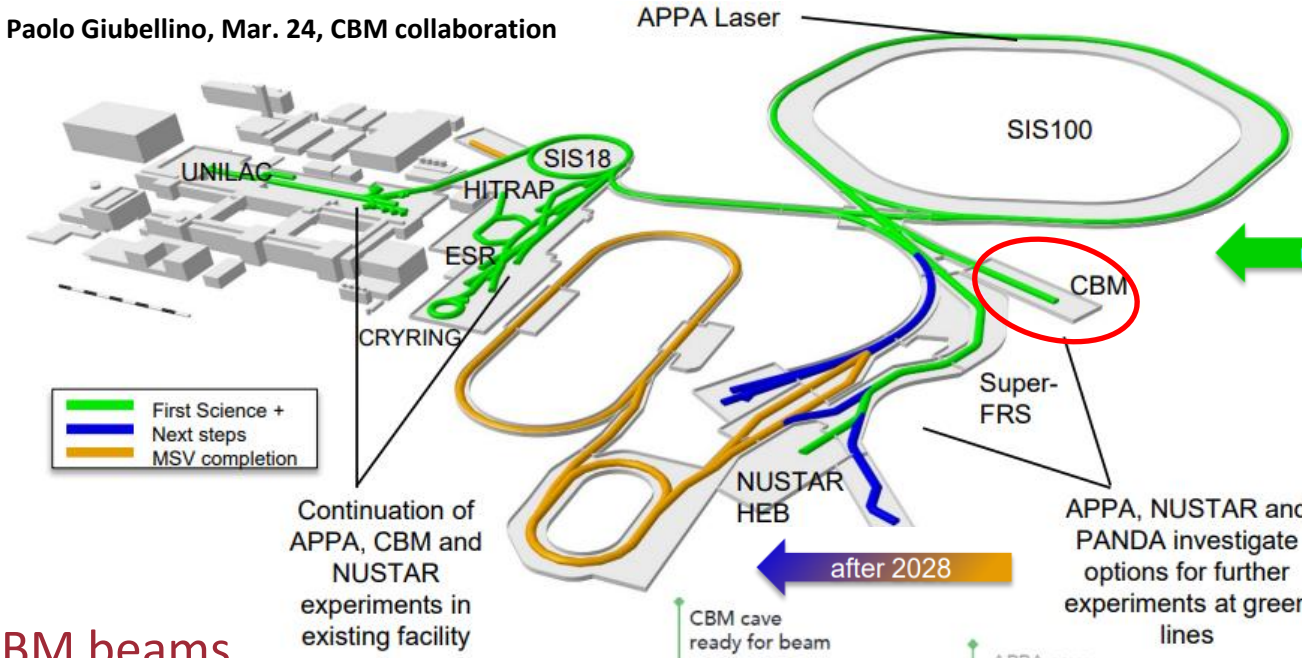
CBM TOF wall
Front view



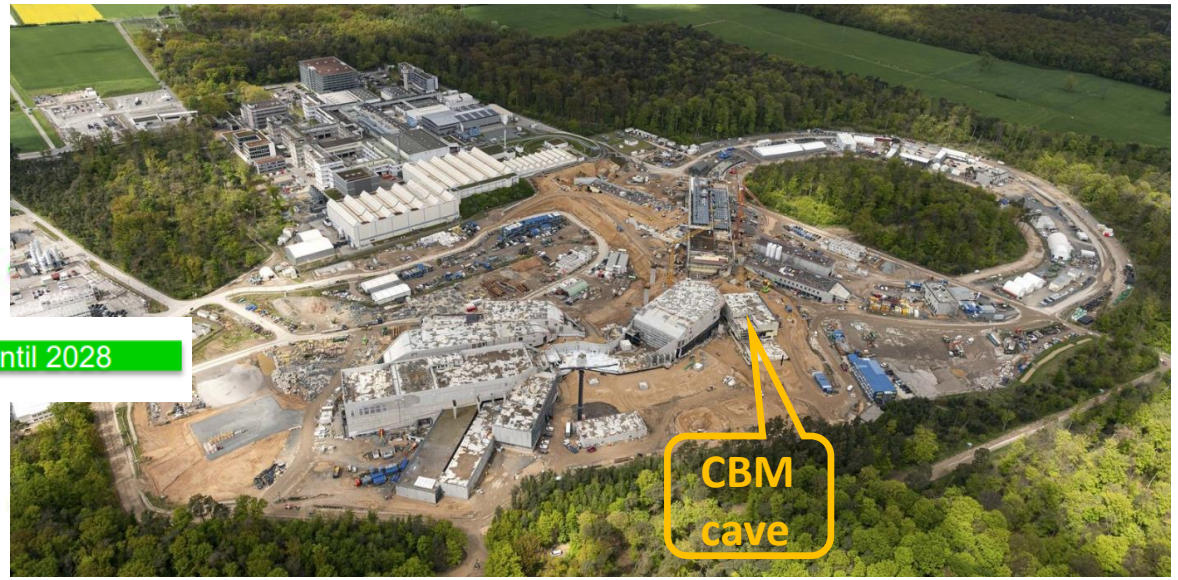
Introduction to FAIR

Facility for Antiproton and Ion Research (FAIR)

Paolo Giubellino, Mar. 24, CBM collaboration



until 2028

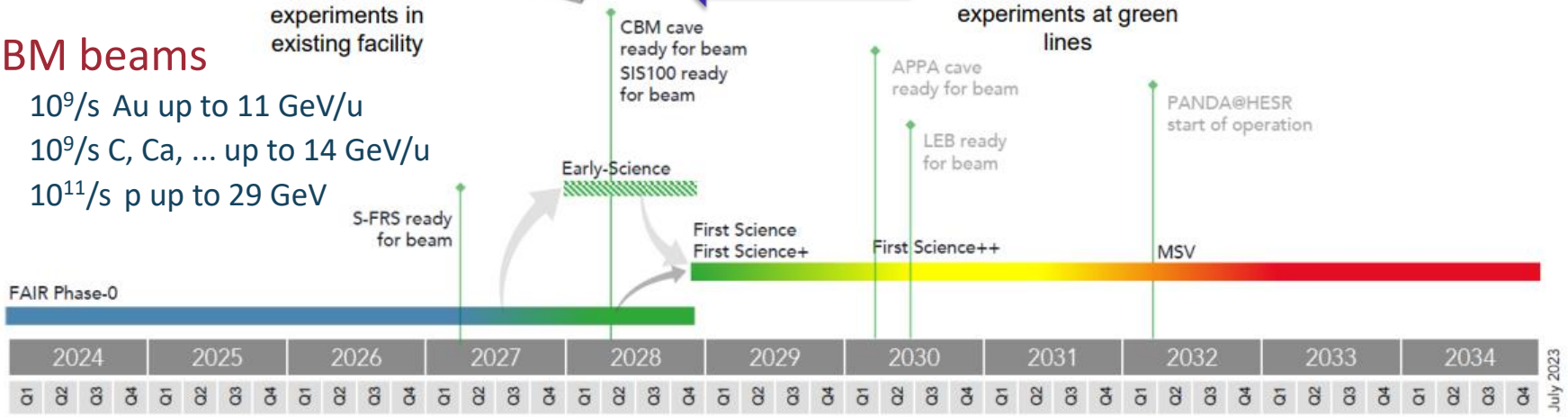


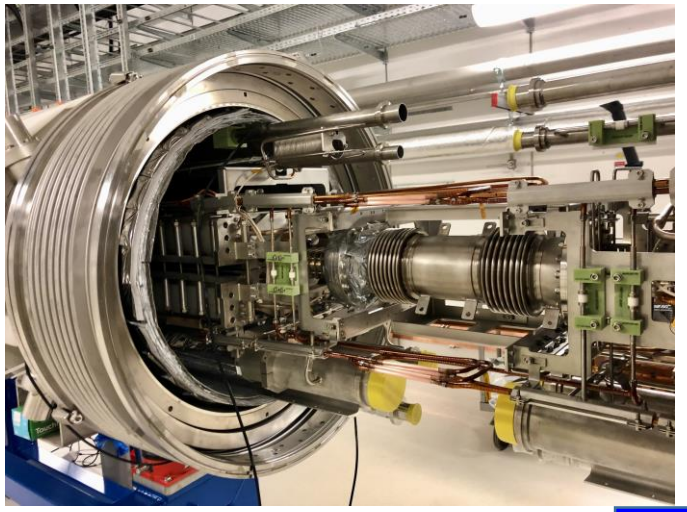
https://edms.cern.ch/ui/file/2893949/LATEST/FAIR*.mp4

after 2028

CBM 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

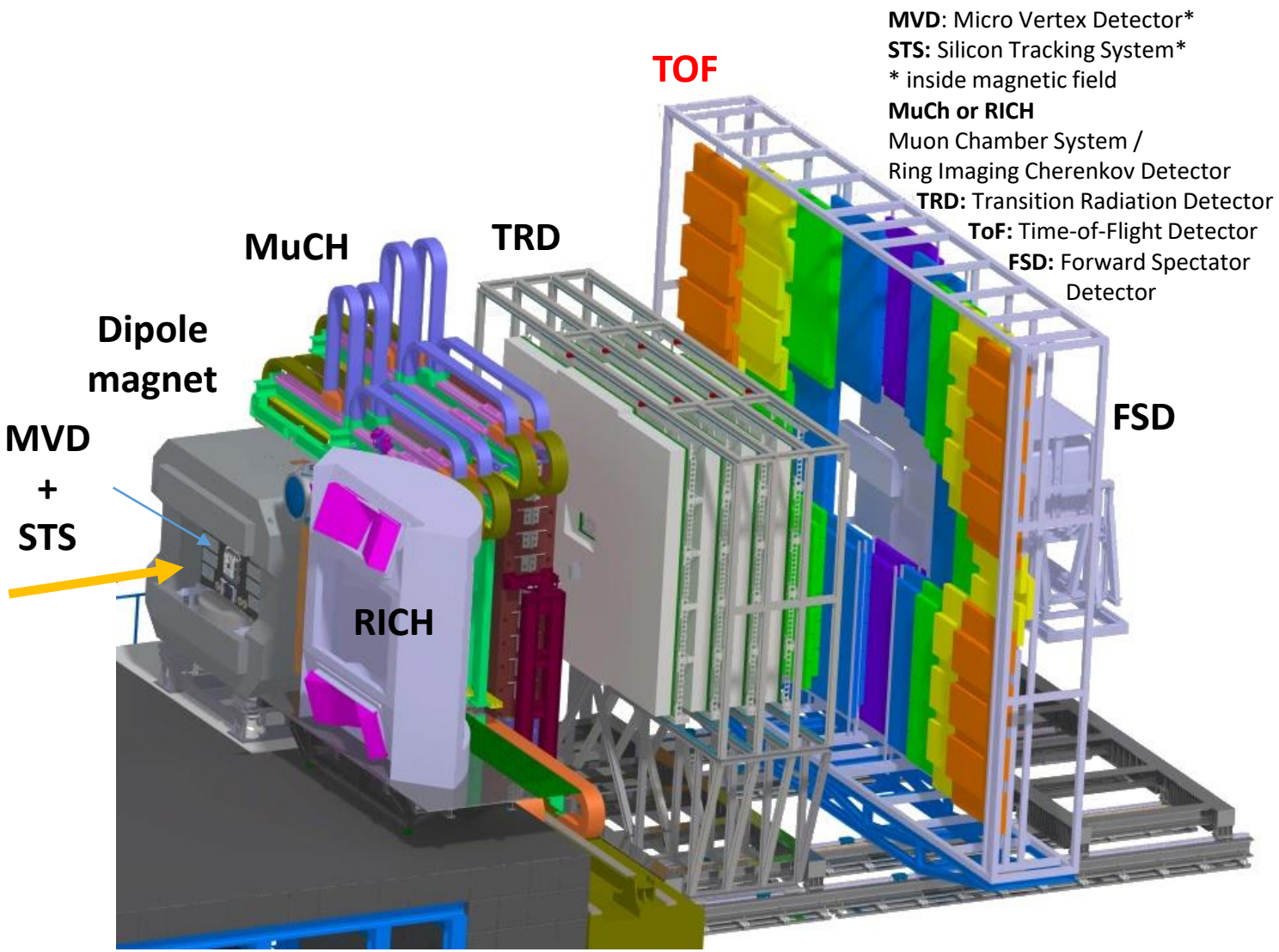




First dipole magnets installed at SIS100

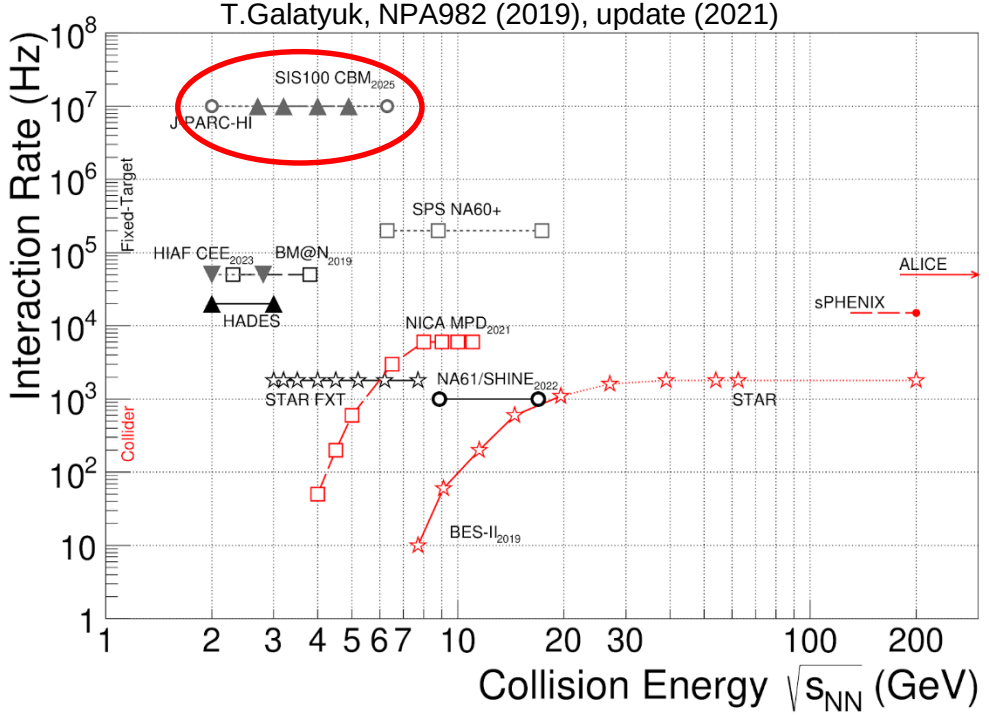
Introduction to CBM

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
FSD: Forward Spectator Detector

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

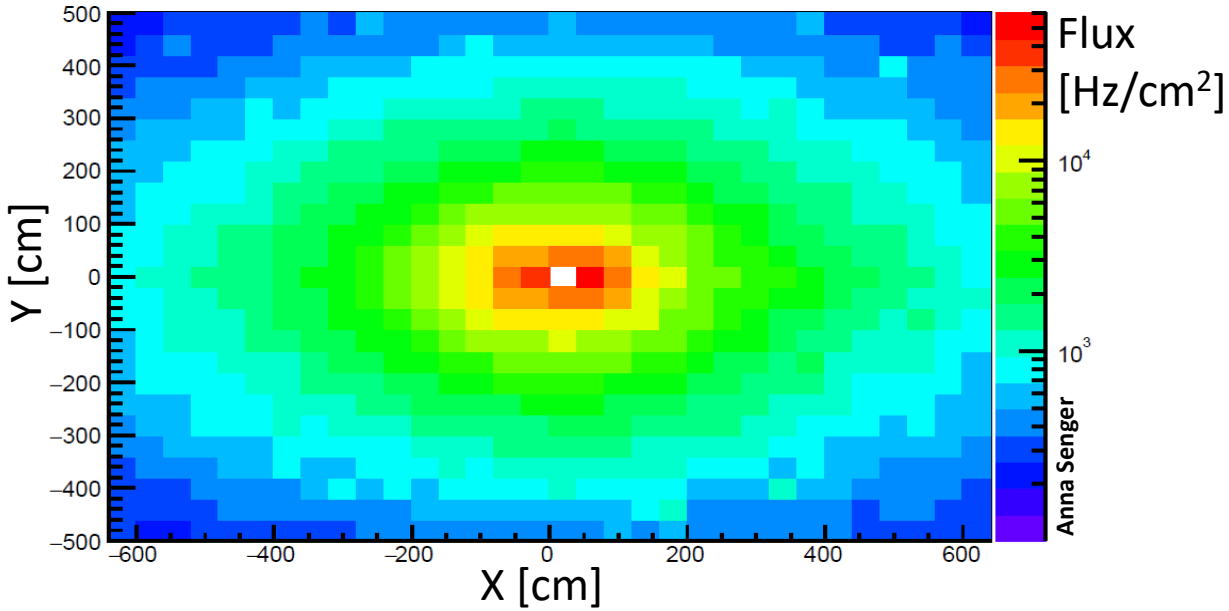


- Tracking acceptance: $2.5^o < \theta_{Lab} < 25^o$
- Peak R_{int} is 10 MHz for Au+Au
- Fast & radiation hard detectors
- Free-streaming DAQ
- 4D tracking (space, time)
- Online event selection and reconstruction
- Data rate: 1 TB/sec

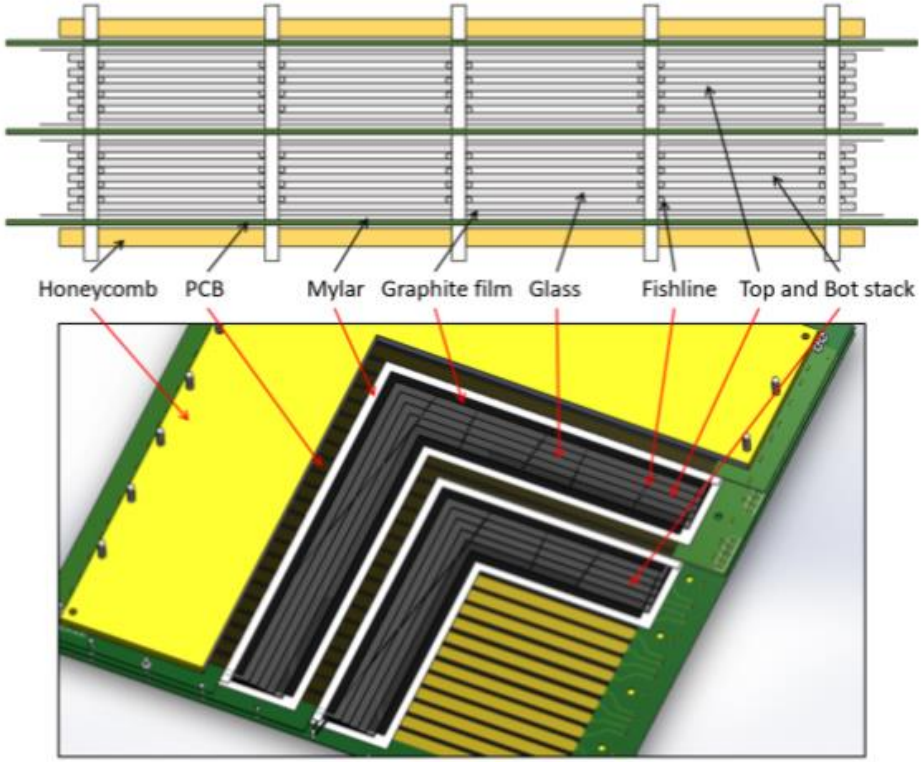
Introduction CBM TOF

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

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



Example: Structure of MRPC with low resistive glass



CBM-TOF Requirements

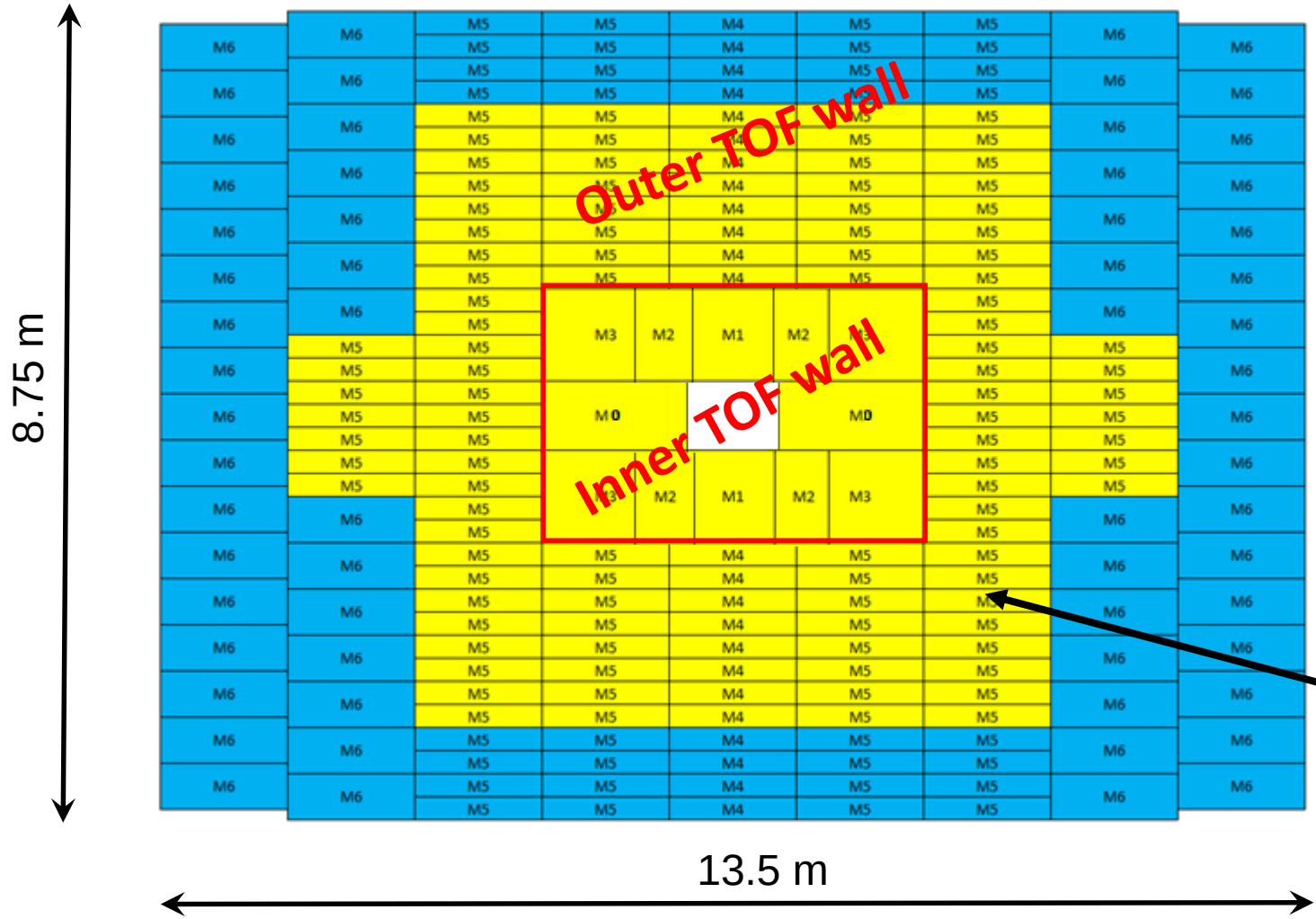
- **Full system time resolution σ_T ~ 80 ps**
- **Efficiency > 95 %**
- **Rate capability ≤ 50 kHz/cm²**
- **Polar angular range 2.5° – 25°**
- **Active area of 120 m²**
- **Occupancy < 5 %**
- **Low power electronics (~100.000 channels)**
- **Free streaming data acquisition**

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%**

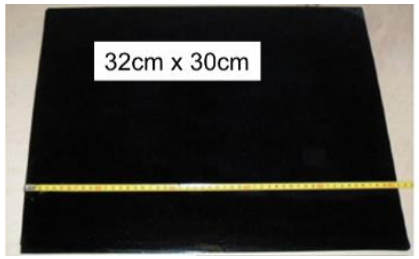
Introduction CBM TOF

Active area

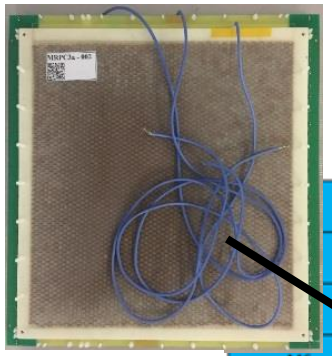


- **A module contains several MRPC counters**
- **Region containing counters equipped with thin float glass, $\rho \approx 10^{12}\ \Omega$ cm**
- **Region containing counters equipped with low resistivity glass, $\rho \approx 10^{10}\ \Omega$ cm**

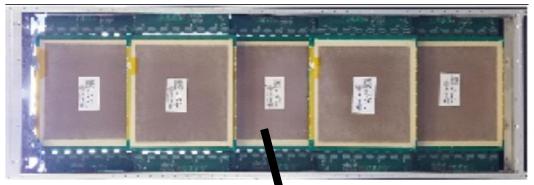
Low resistivity glass (China)



Introduction CBM TOF



MRPC2
(Tsinghua)



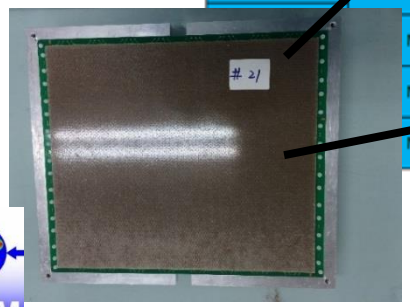
M4 Module
(Heidelberg (HD))

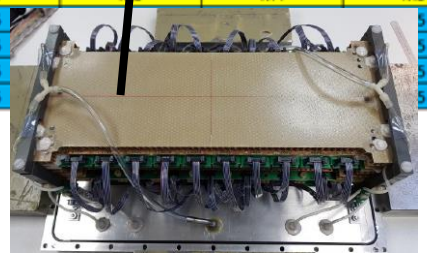
M5 Module (HD)

- **Full size counter with final design for all regions build and tested**
- **M4, M5 and M6 full size modules constructed and installed at mCBM**

M6 Module (HD)

MRPC3/4
(USTC)



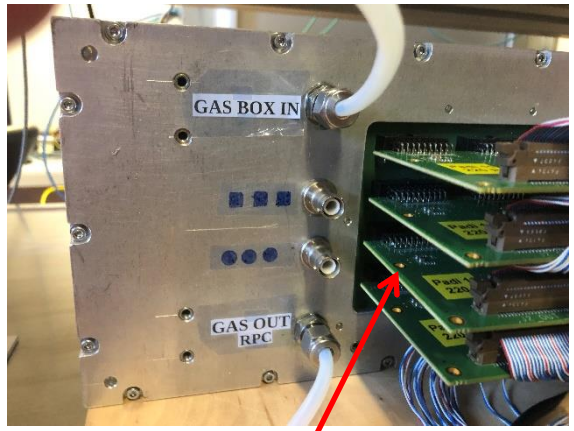


MRPC1a - 1c
(NIPNE Bucharest)

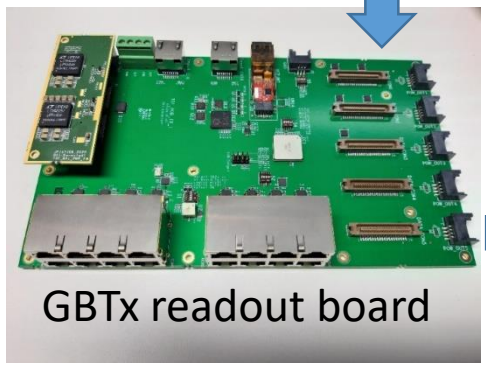
≈ 230 modules
≈ 1500 MRPCs
≈ 95000 channels

CBM TOF readout

Readout chain of inner wall



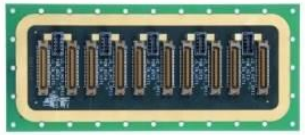
PADI XI +
GET4 board
32 ch.



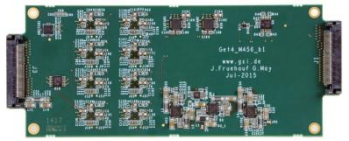
GBTx readout board

PADI XI board (preamp. disc.)
32 ch.

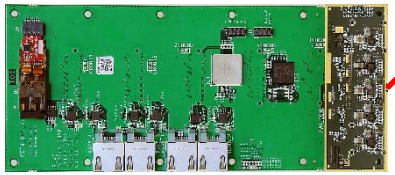
Module
feed-
through



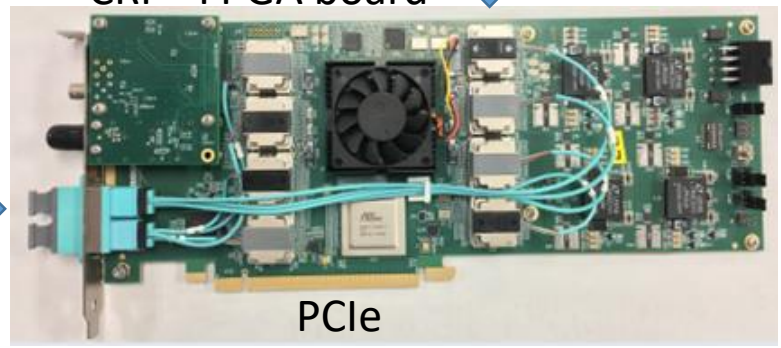
GET4 TDC
32 ch.



GBTx readout
board

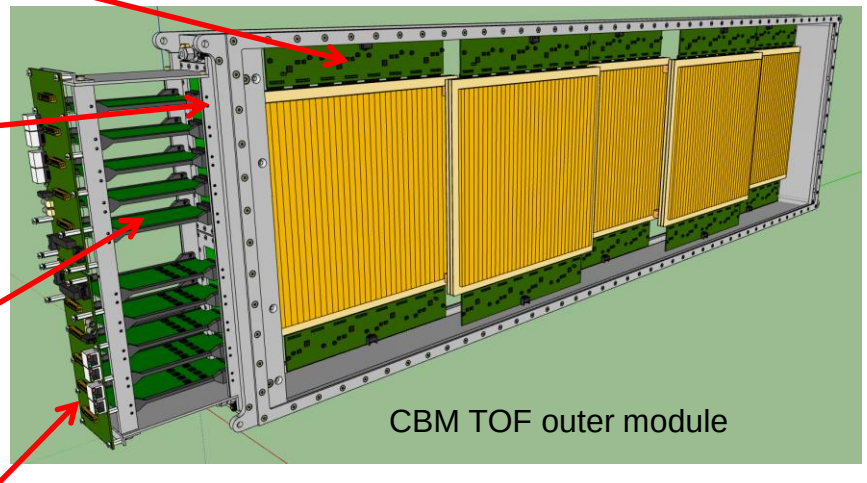


CRI – FPGA board



PCIe

Readout chain of outer wall



FAIR Phase 0

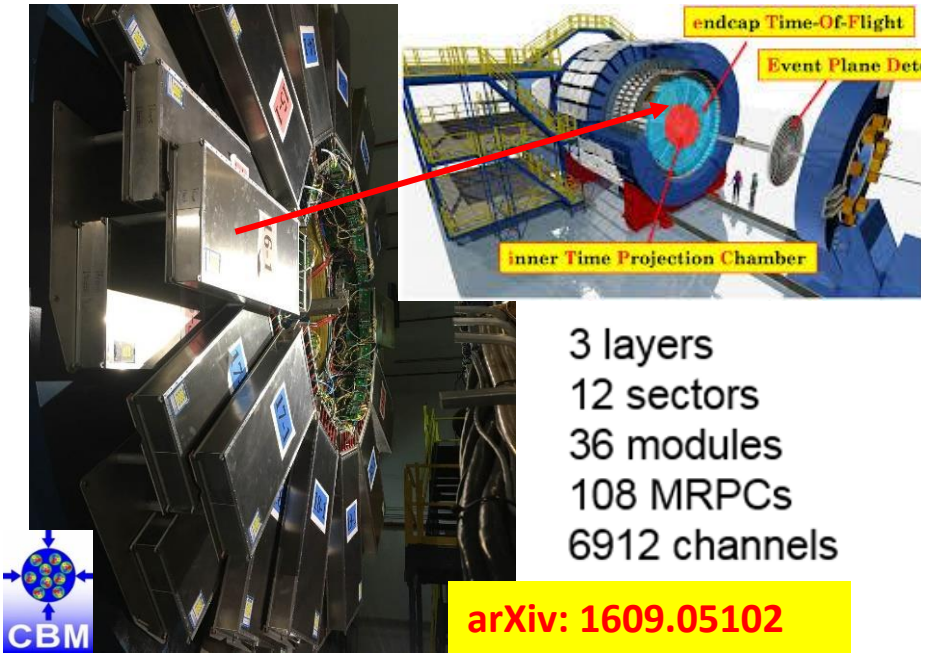
- **FAIR Phase 0 is a bridge program until the start of FAIR**
- **It comprises the installation and testing of developed equipment in running experiments and analysis of obtained data**

<u>FAIR Phase 0 programs of CBM-TOF</u>

1. **eTOF project at STAR@BNL (6912 channels)**
   for long term stability test and physics results purpose
2. **mTOF project at mCBM@SIS18 (1600 channels)**
   for high rate and system integration test purpose

eTOF@STAR/BNL

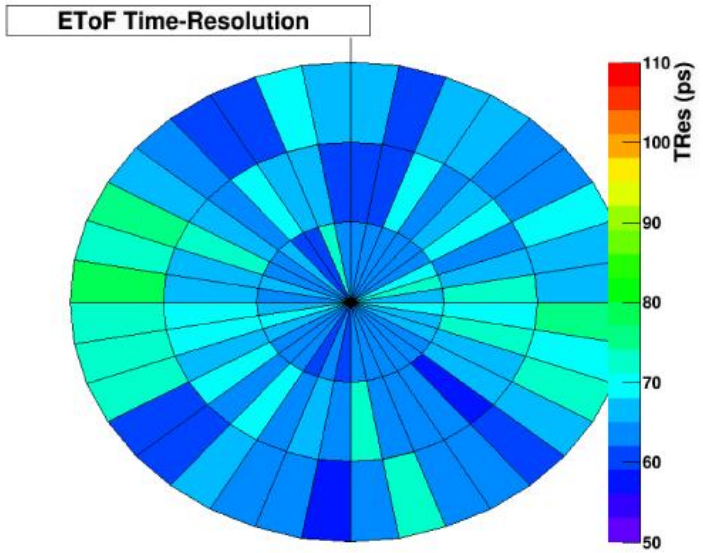
- Average system time resolution below 70 ps
- Matching efficiency with TPC > 65% for particle momenta above 1 GeV/c
- Calibration almost completed
- PID capability demonstrated - mission accomplished
- data analysis is work in progress



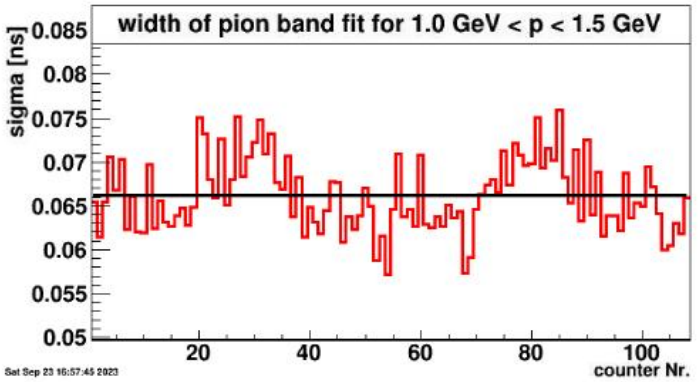
3 layers
12 sectors
36 modules
108 MRPCs
6912 channels

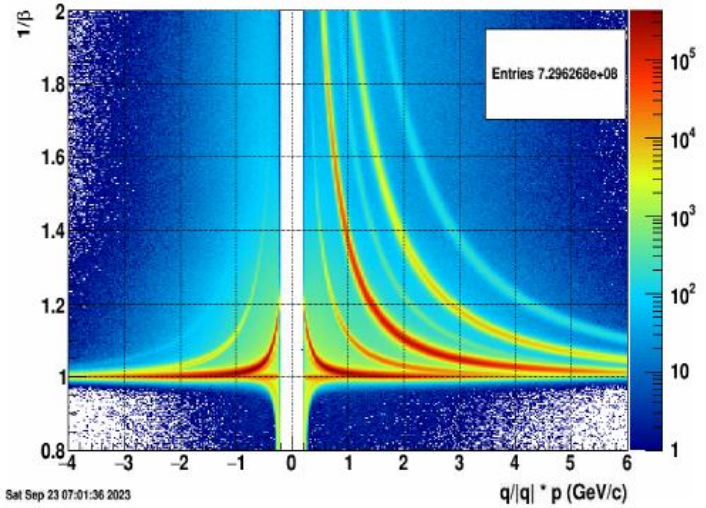
arXiv: 1609.05102

EToF Performance at 4.5 GeV FXT 2020

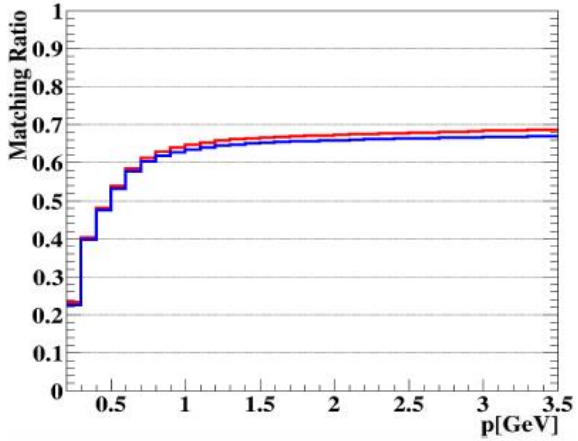


ETof-Time-Resolution at 3.5 GeV FXT 2020





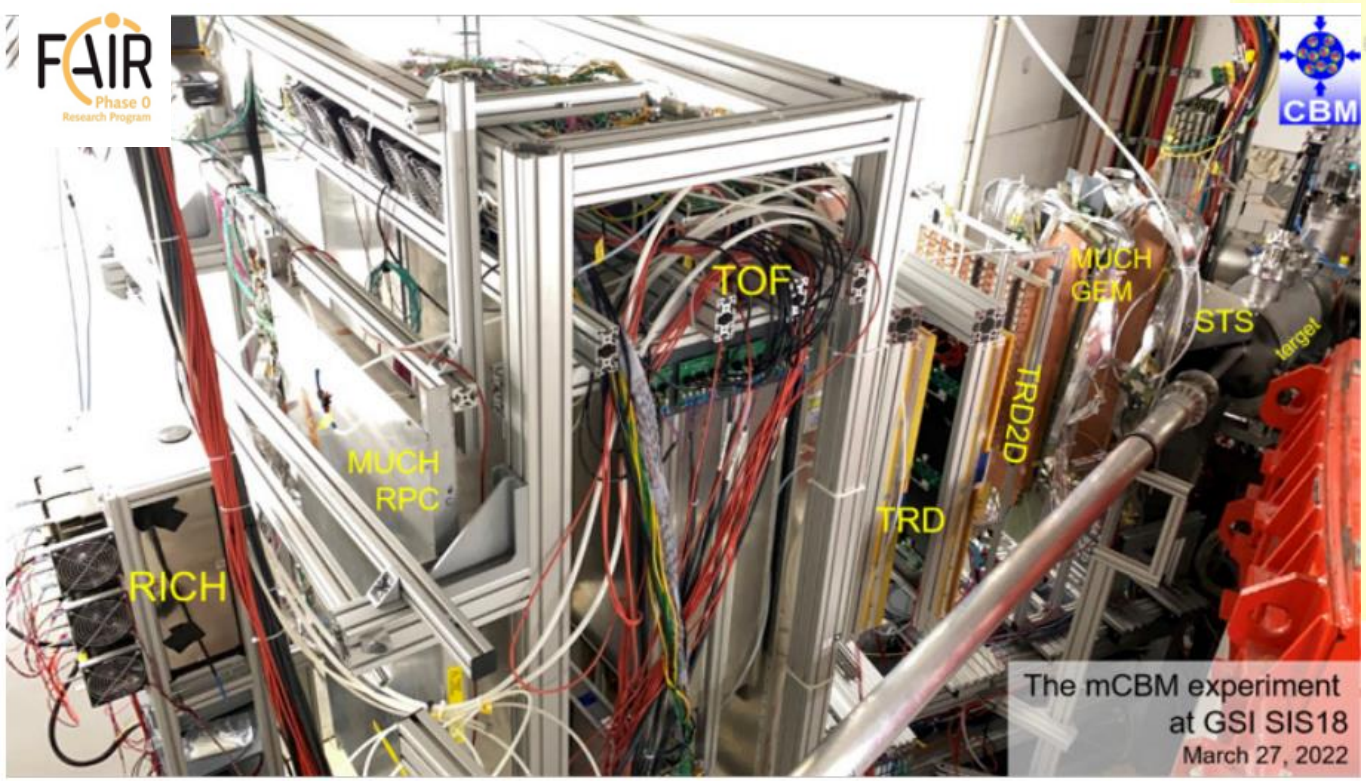
1 / β vs. momentum



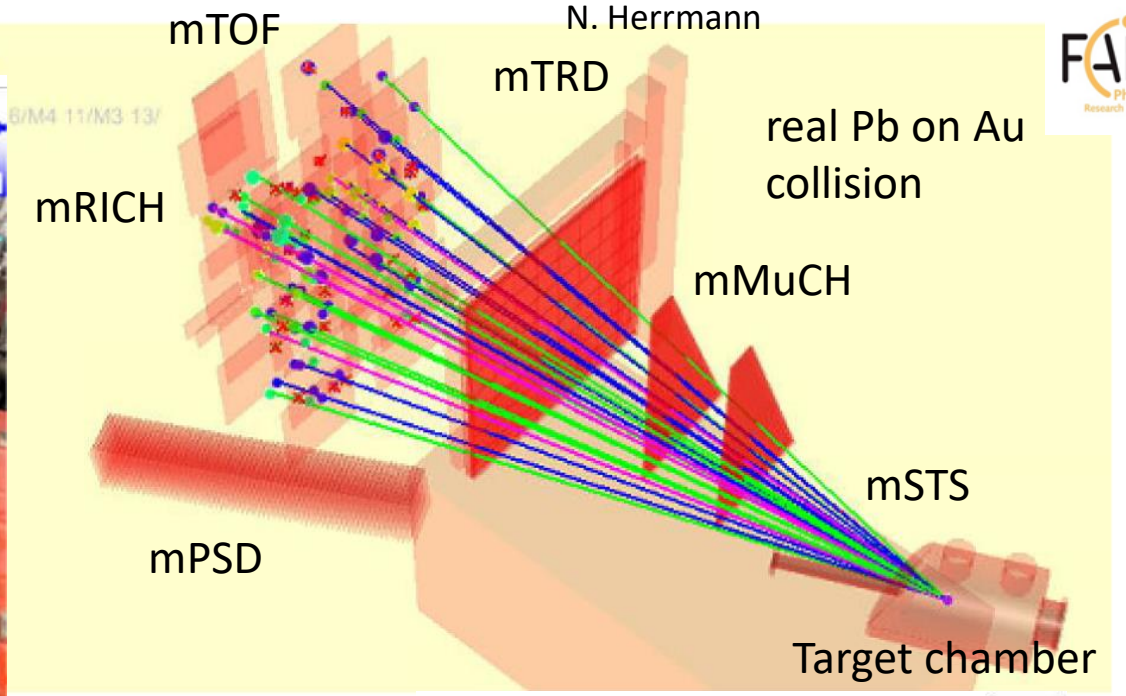
Matching Efficiency at 65% for p > 1GeV

mCBM @ SIS18

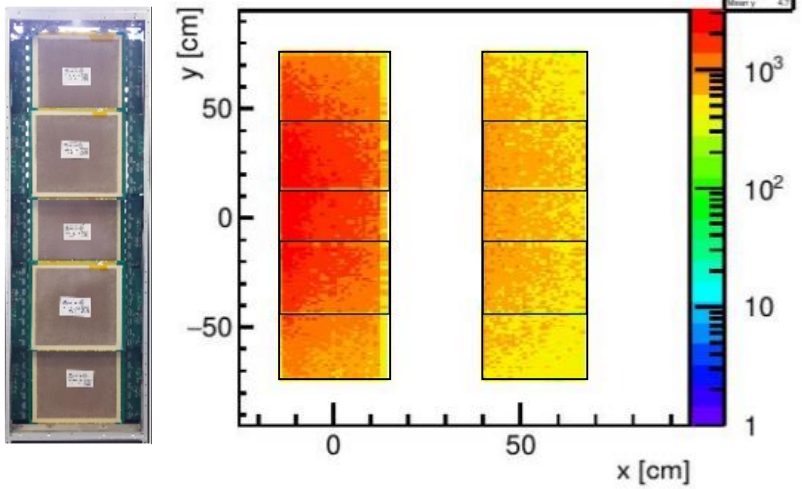
FAIR Phase 0: mCBM setup @ SIS18



N. Herrmann



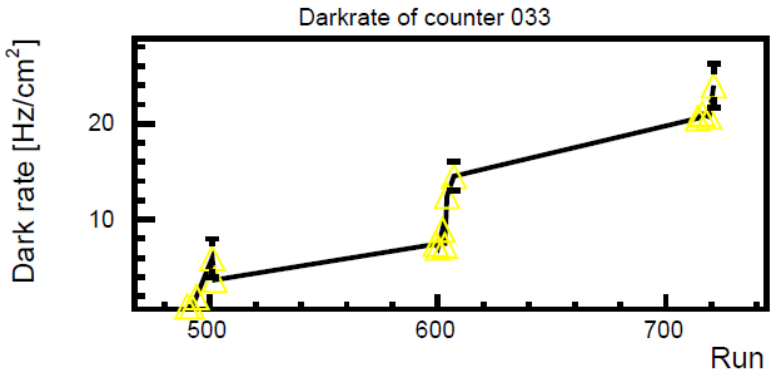
Simulation: Au+Au @ 1.24 GeV mbias

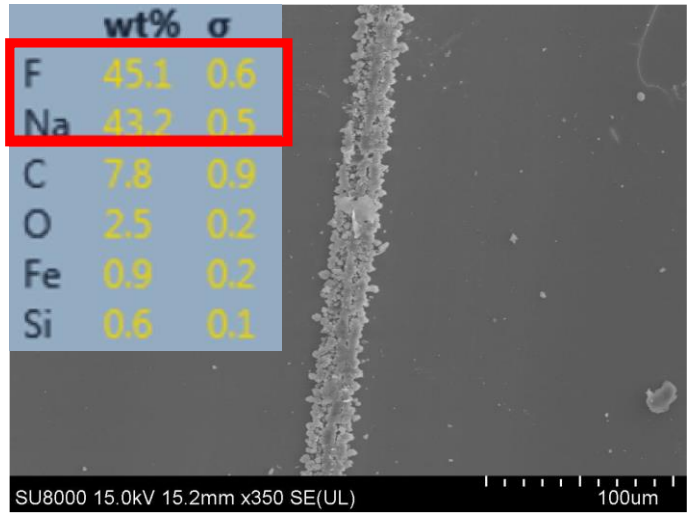


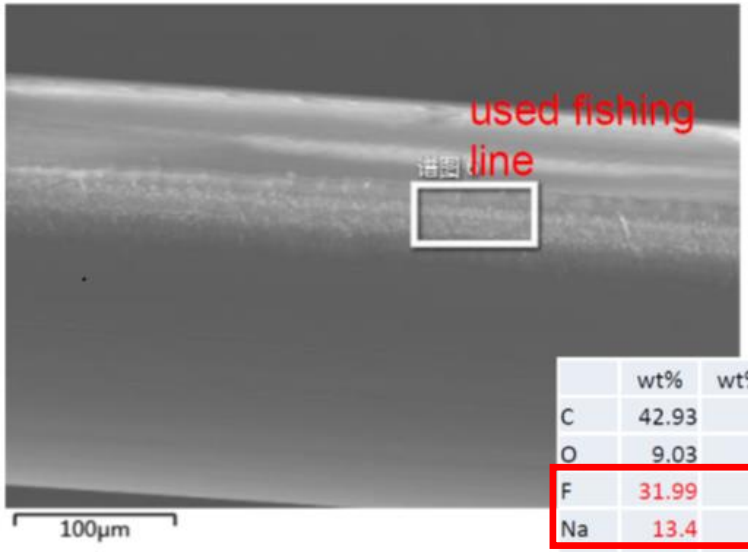
- mCBM is a full system test setup installed at SIS18/GSI dedicated for high rate detector and readout test including free streaming data acquisition and online event selection
- Interaction rates up to 10 MHz, charged particle fluxes of up to 30 kHz/cm^2
- Having a high rate test stand is highly important for detector development

Aging & gas pollution (?)

Observations: continuous increase in dark rate (permanent aging)

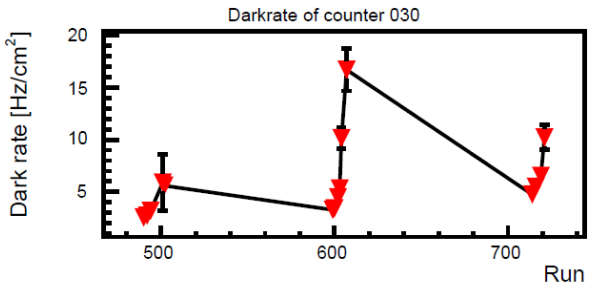


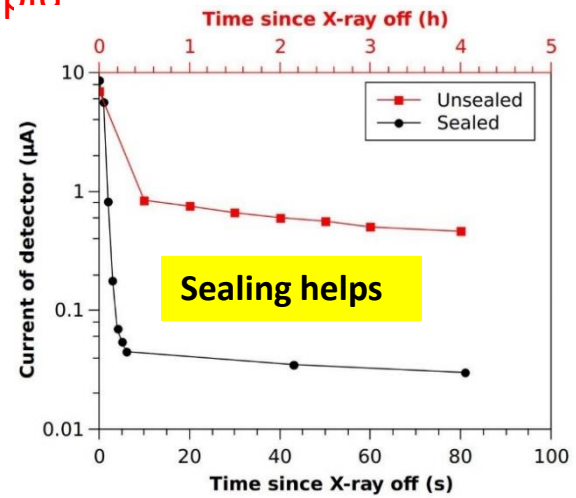


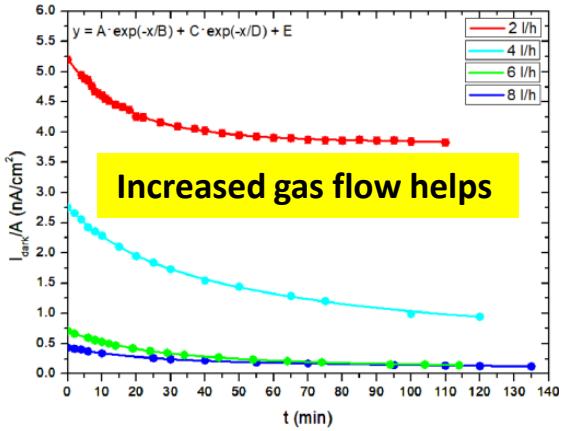


	wt%	wt% Sigma
C	42.93	0.21
O	9.03	0.15
F	31.99	0.18
Na	13.4	0.1
Si	2.36	0.04
Pt	0.28	0.07

Observations @ mCBM 2020 rapid increase of dark rate





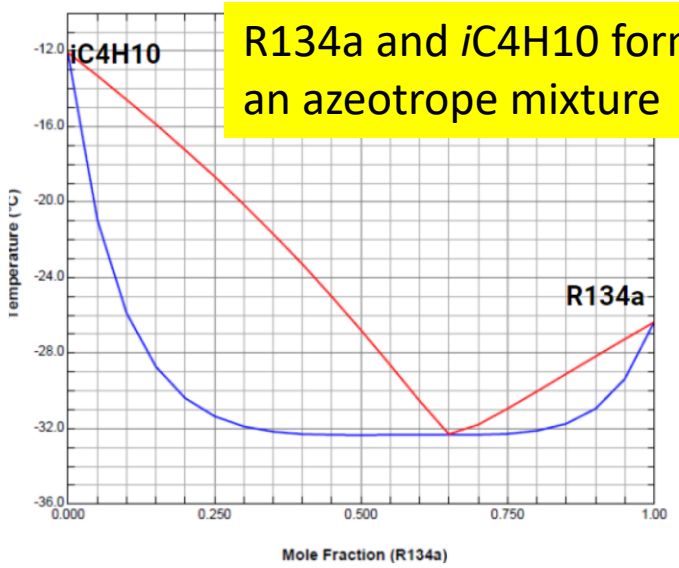


Possible reasons for increase during exposure and (exponential) decrease after

- Activation
- Temperature
- Gas pollution

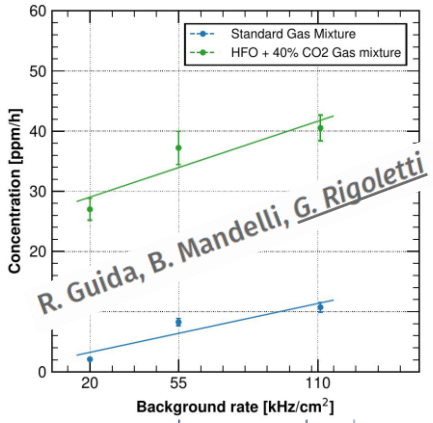
Conclusions for the CBM TOF gas system

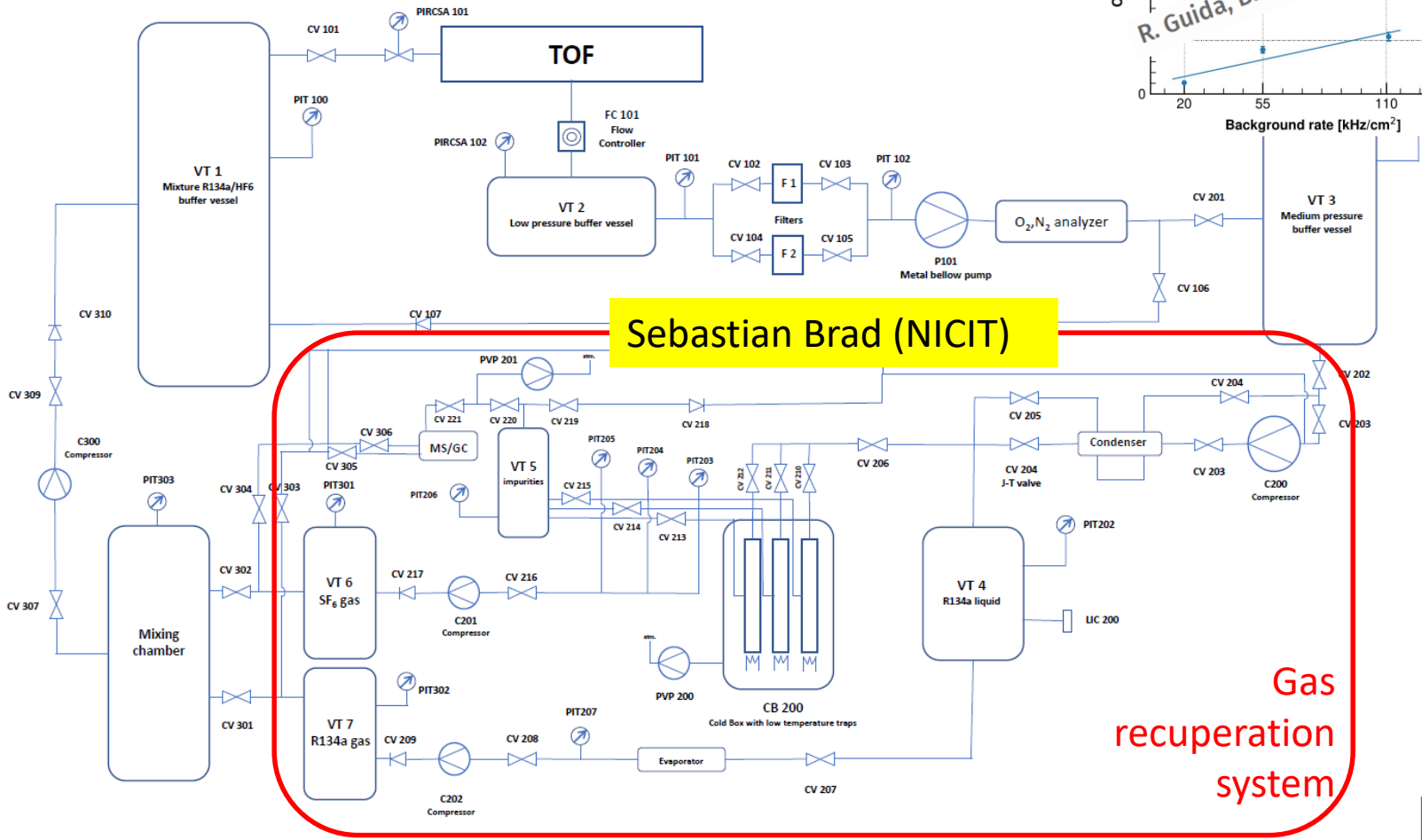
- Stay with Tetrafluorethane (R134a) (enhanced F-ion production for HFO in high rate environment)
- Abandon iso-Butan (aging , safety, difficult to recycle)
- Reduce fraction of SF_6 to 2.5% (reduction of GWP, difficult to recycle)
- Increase the flow rate
- Build a recuperation system (reuse of gas,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



R134a and *i*C4H10 form an azeotrope mixture

230 modules
Total gas volume 25 m³



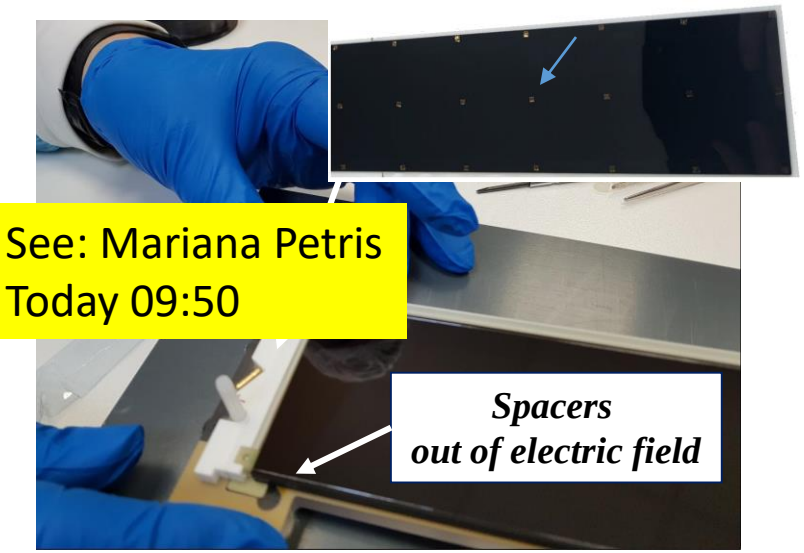


Sebastian Brad (NICIT)

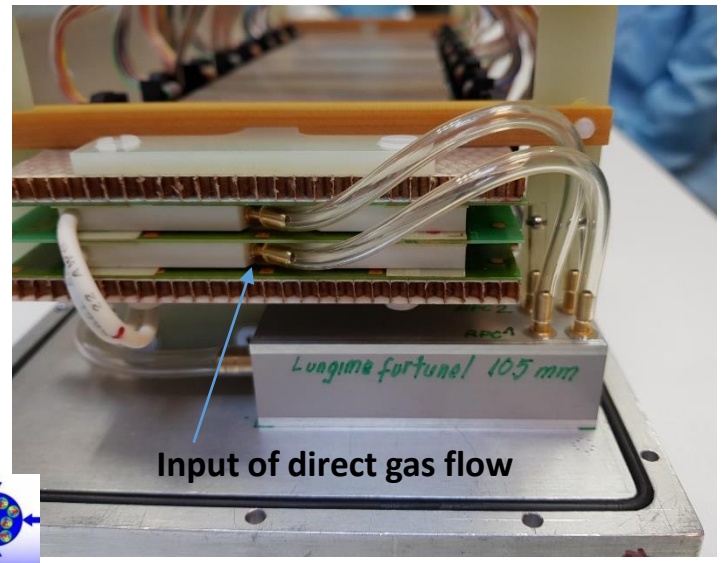
Gas recuperation system

Mitigation of gas pollution and aging

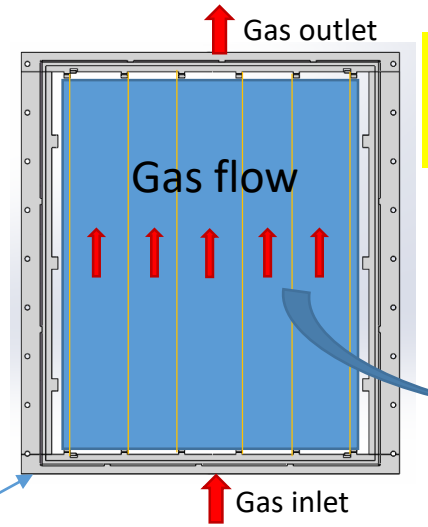
High rate counter (MRPC1)



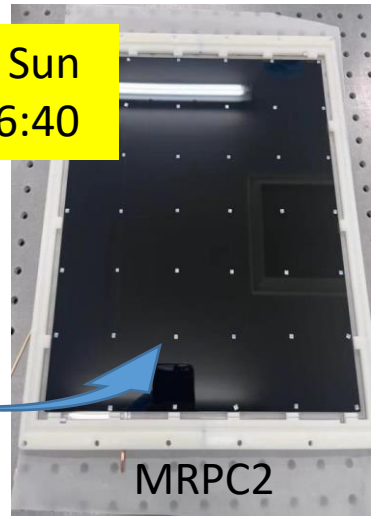
See: Mariana Petris
Today 09:50



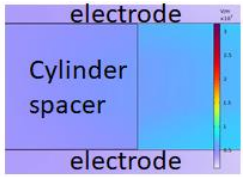
Intermediate rate counter (MRPC2)



See: Kai Sun
Today 16:40



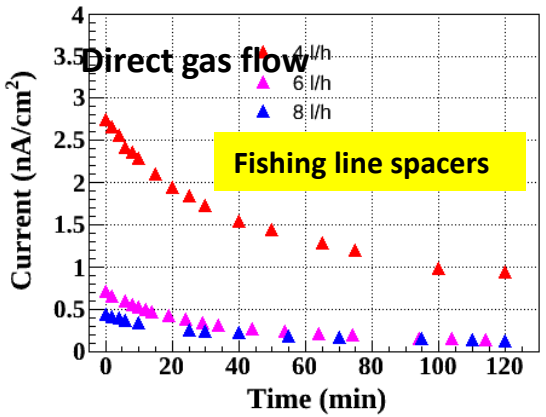
Introduction of pad spacers

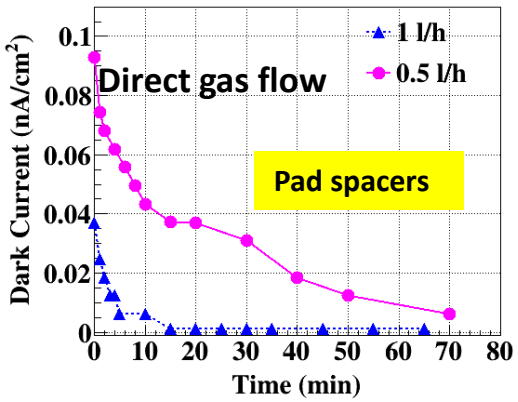


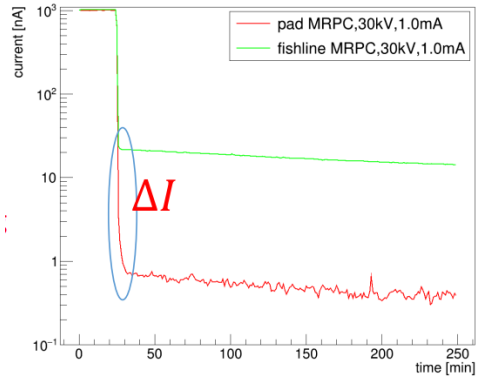
MRPC3

See: Ming Yao
Tomorrow 13:10

Current behavior after X-ray exposer



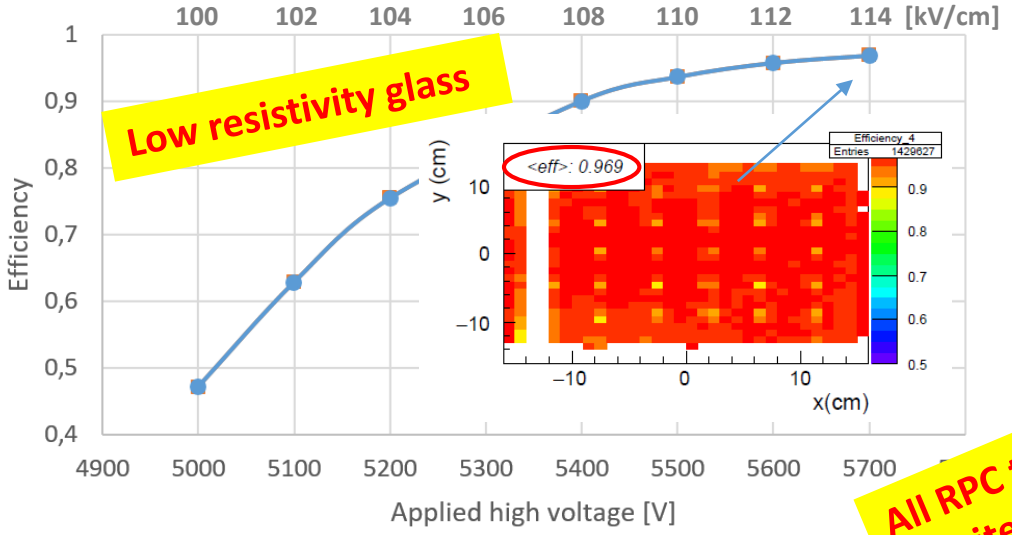




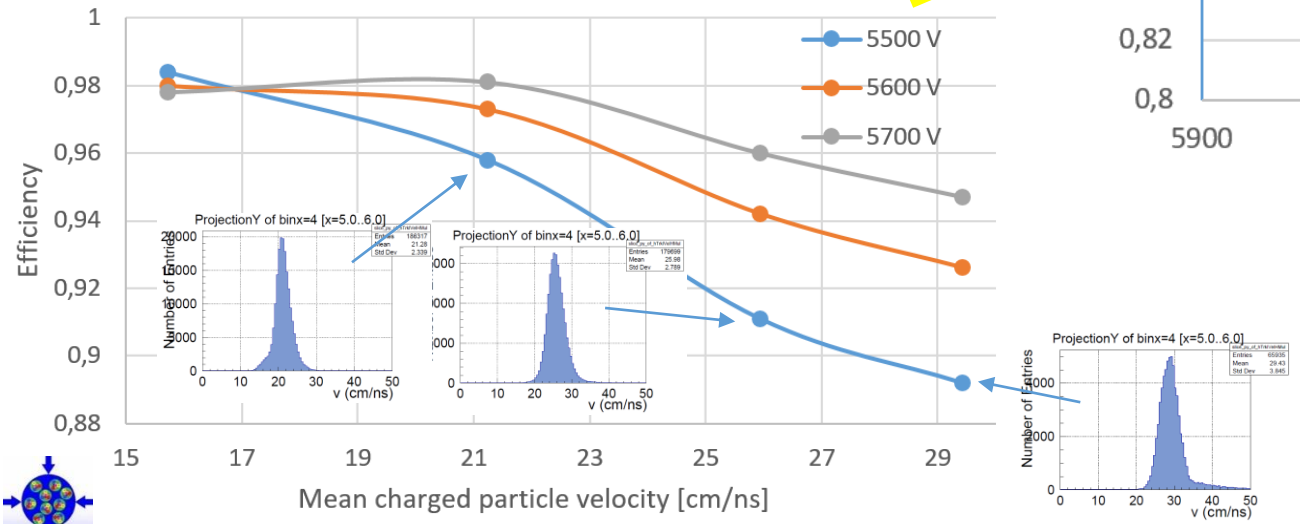
Current decrease after turning off X-ray

Beam test with final MRPC design

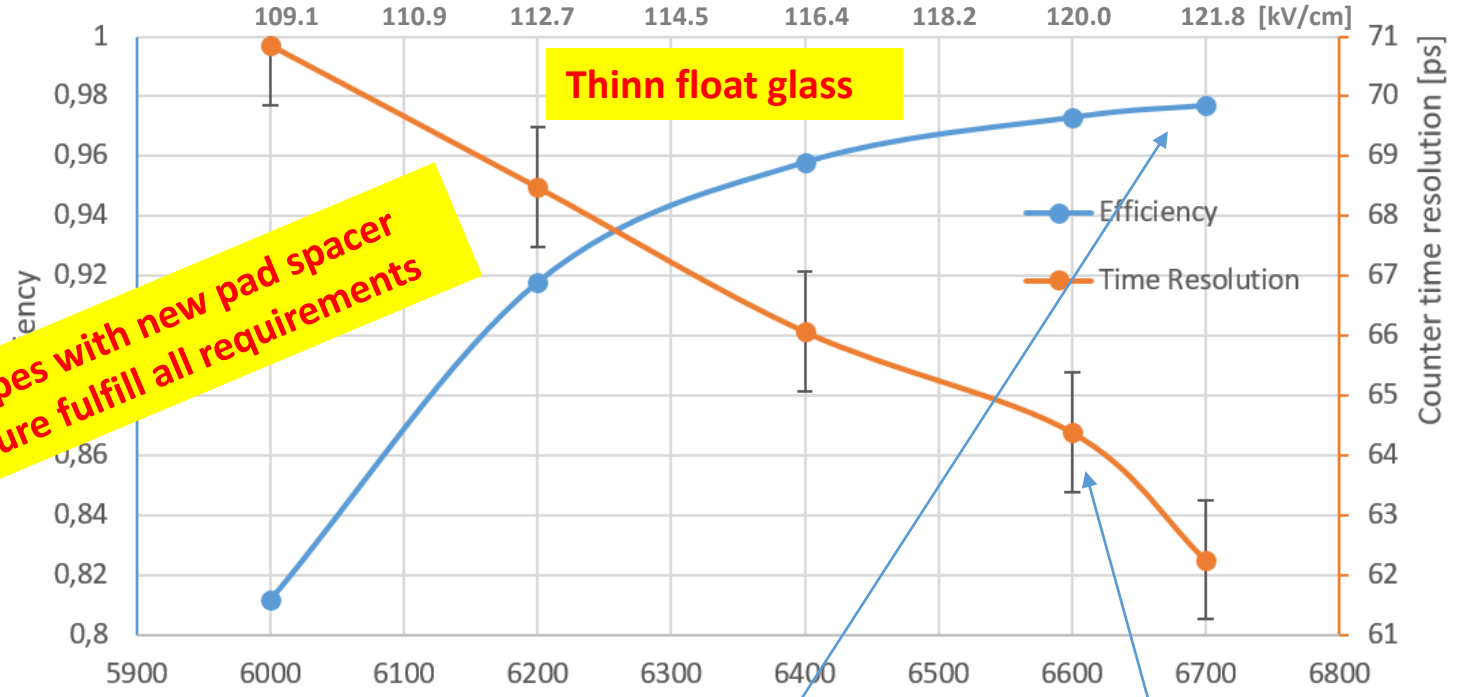
Efficiency of MRPC2 vs. applied high voltage



MRPC2 efficiency vs charged particle velocity

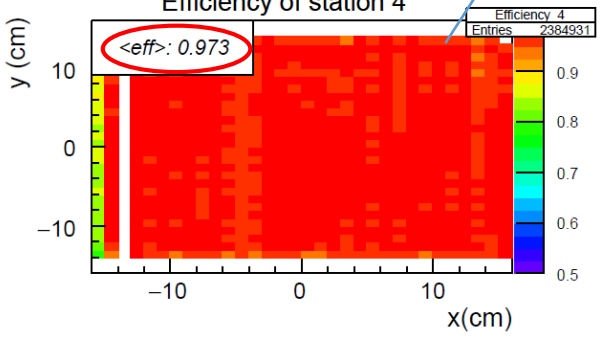


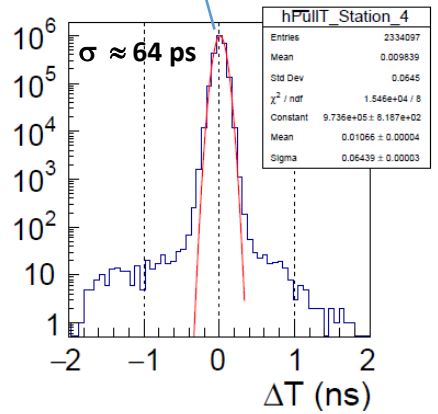
Efficiency and time resolution of MRPC3 vs. applied high voltage



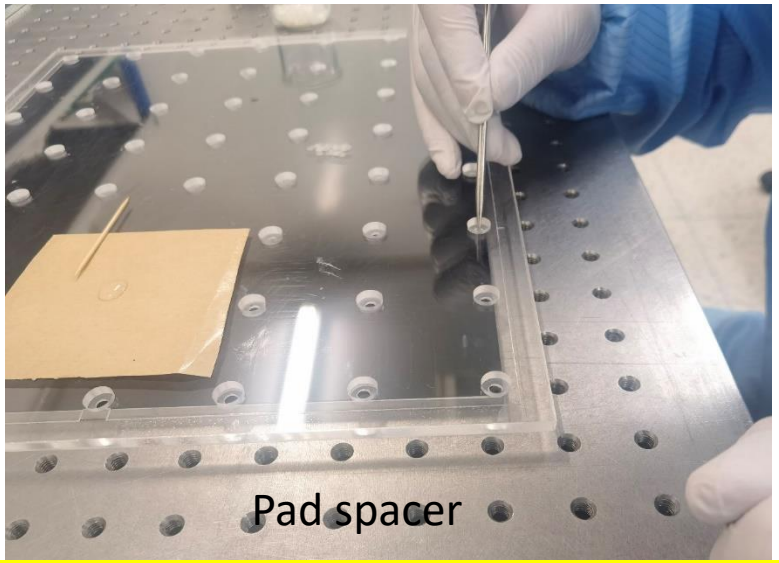
All RPC types with new pad spacer architecture fulfill all requirements

Efficiency of station 4

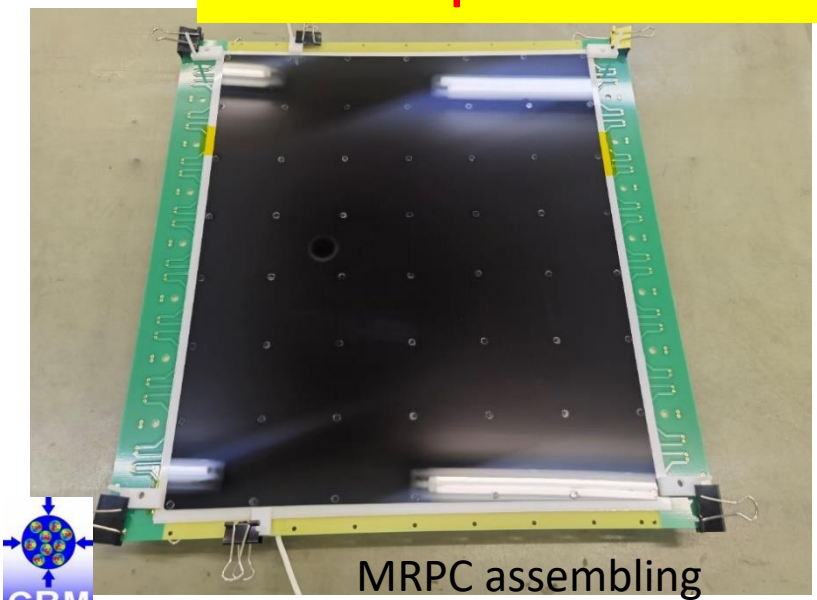


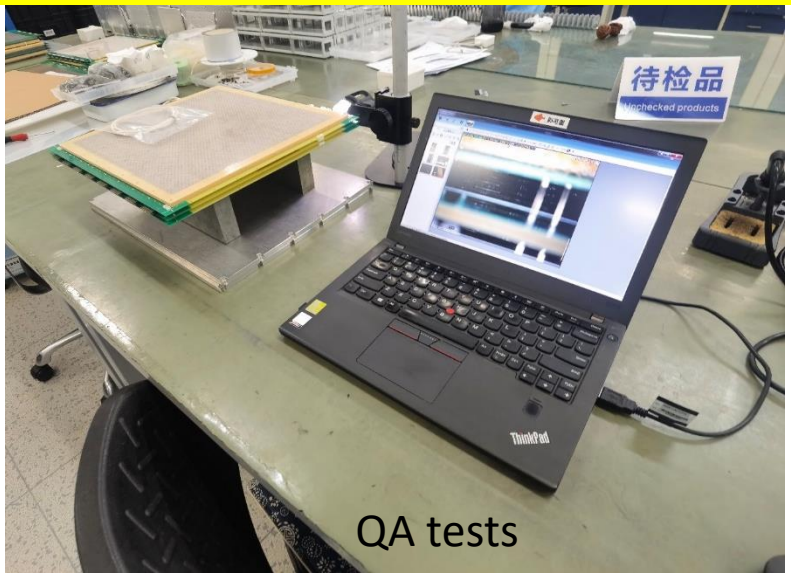


MRPC2 series production



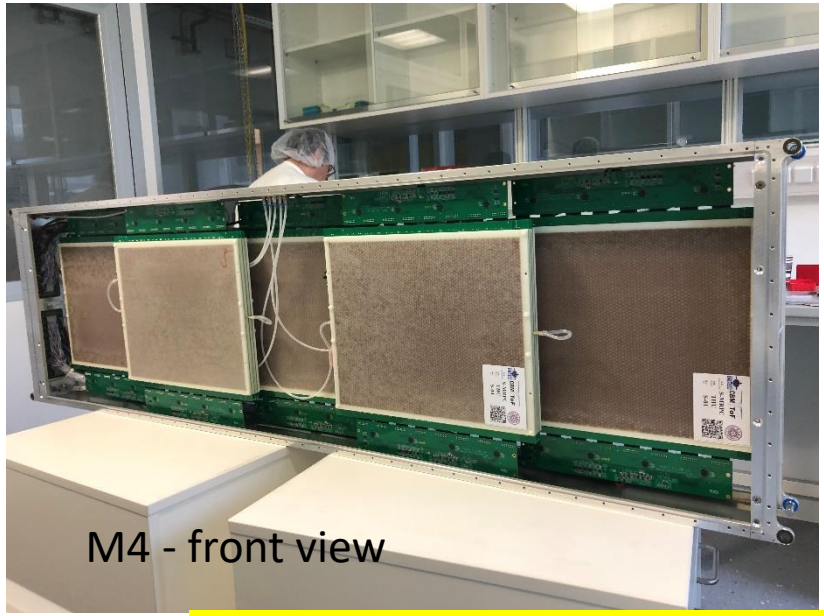
A series production of 245 MRPCs (120 MRPC2 and 125 MRPC4) started at Tsinghua and USTC





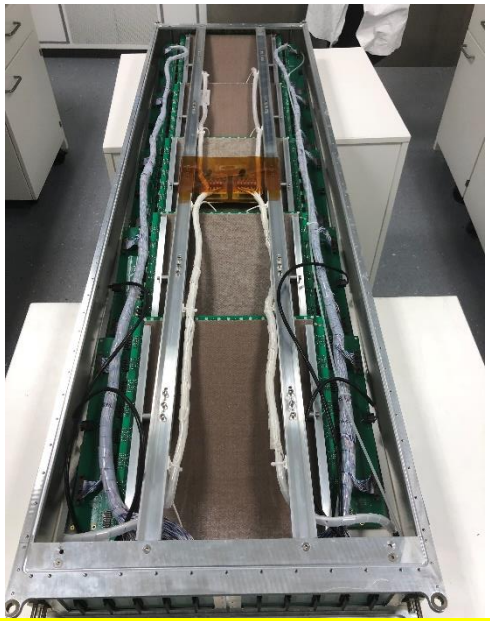
Pre-series module production

M4 Type module



M4 - front view

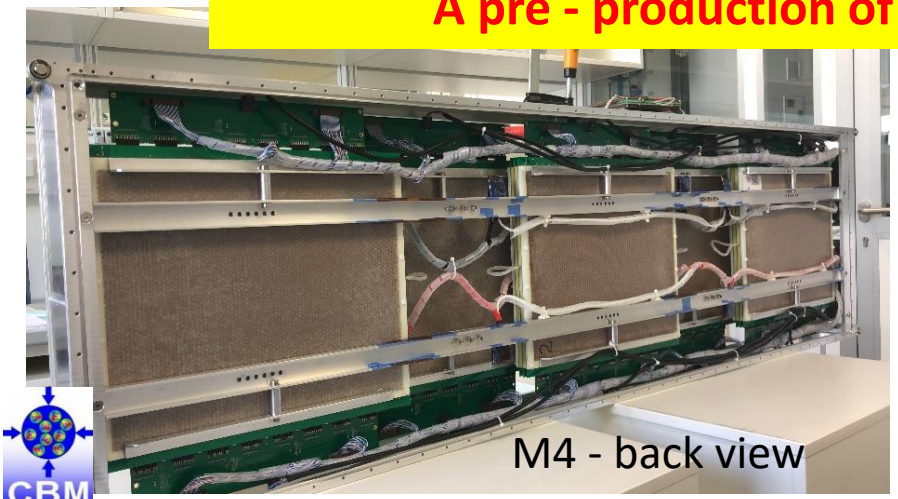
M5 Type module



M6 Type module

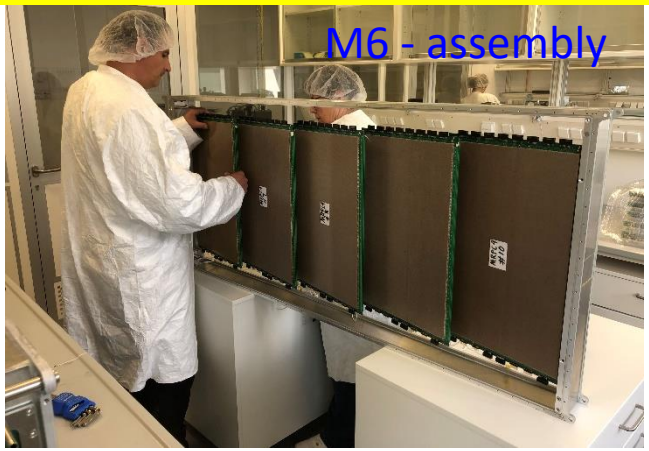
Installation and test mCBM

A pre - production of 10 Modules of type M4, M5 and M6 started at Heidelberg



M4 - back view

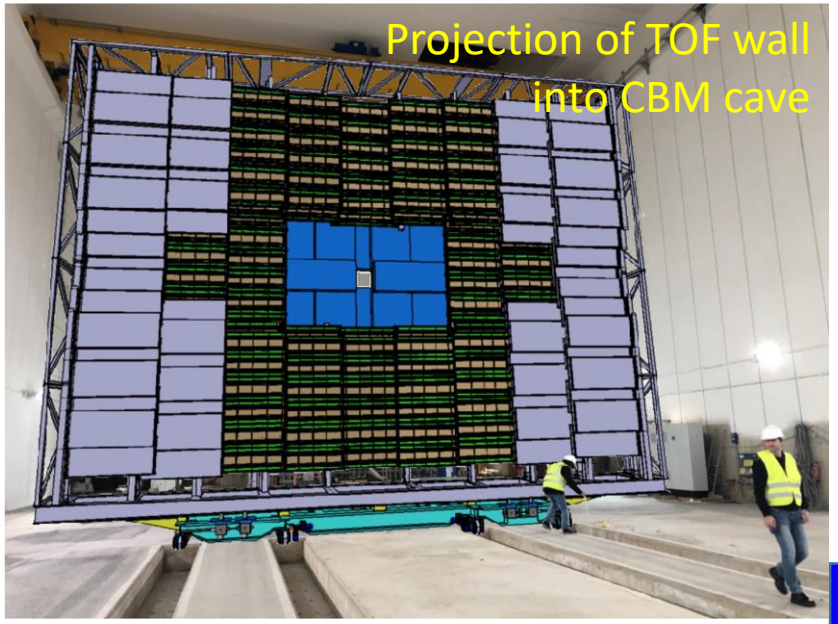
M4 - assembly



M6 - assembly

Summary, outlook and time line

- Long term and high rate test performed (eTOF@STAR & mCBM@SIS18)
  - Time resolution, rate capability demonstrated, float glass counter beyond specs
  - eTOF performed very well during BESII and is a key component in the physics analysis
- MRPC aging effects at high rates observed:
  - mitigation strategies established
  - new counter with adopted designs developed, built and tested at mCBM
- Closed loop gas system with recuperation system under development



Time line and major milestones

- ✓ 2nd counter pre-production finished Q3/2023
- ✓ Module pre-production started: Q4/2023
- ✓ Counter production started (China): 07/2024
- ➢ TOF ready installed: end of 2027 (in line with FAIR schedule)

Thank you for your attention

Contributing institutions:

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

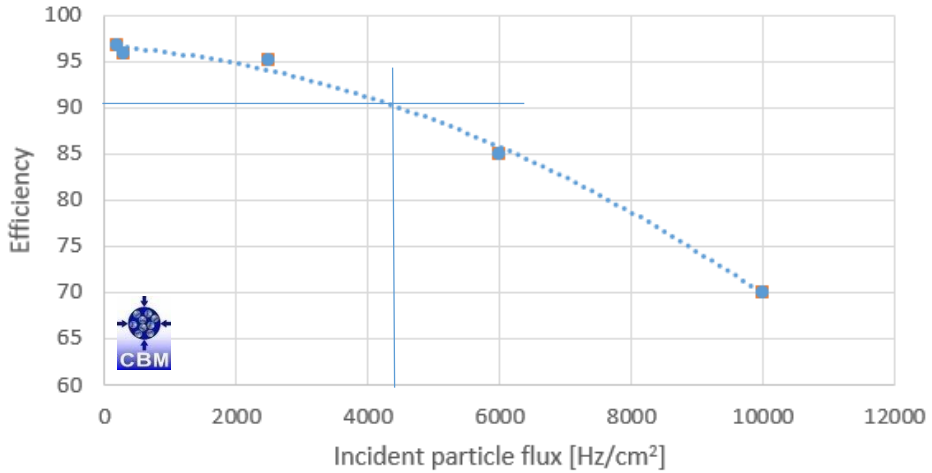
*Cooperation suspended

mCBM beam time results

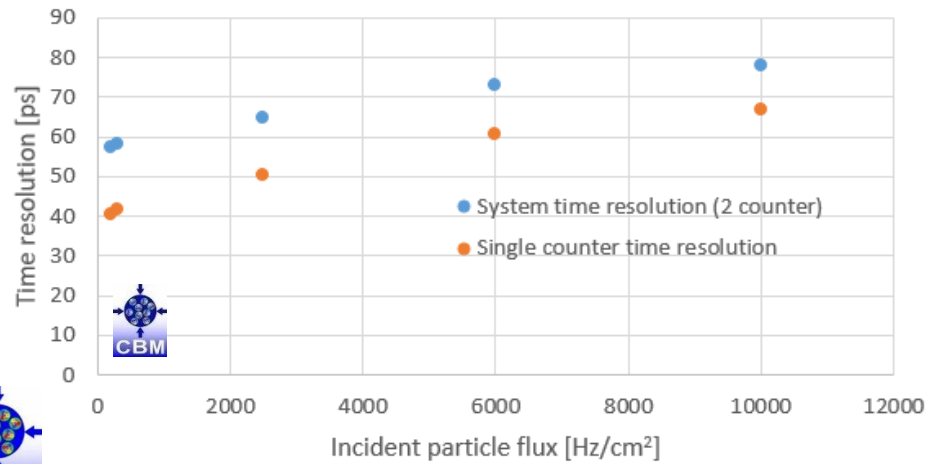
low rate **thin float glass** counter

Performance beyond specs

Efficiency as function of incident ch. particle flux



Time resolution as function of incident ch. particle flux



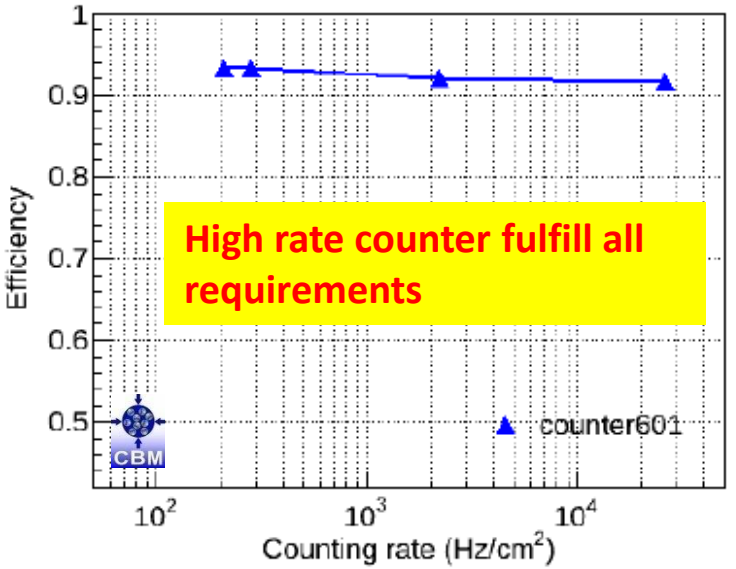
mCBM Beamtime mCBM March 2021

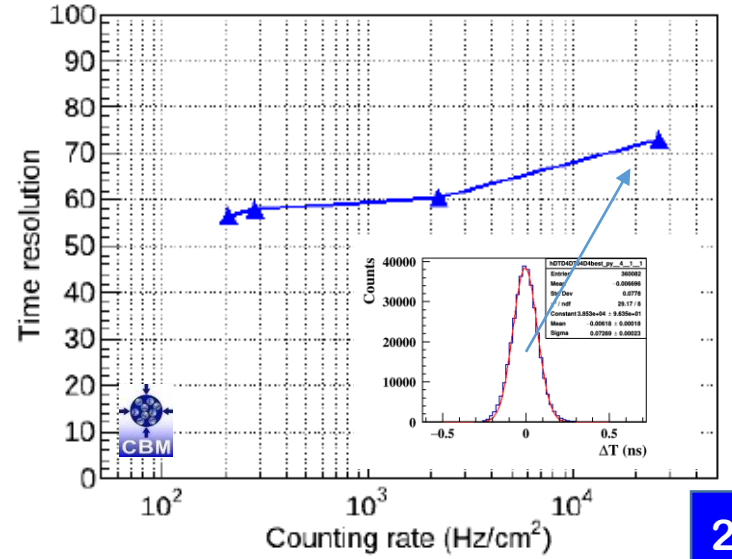
Gas Mixture: R134a/SF_6 - 97.5%/2.5%

MRPCs	left	right
# gaps	2 x 5	2 x 5
Gap size	230 μm	200 μm
Glass	Thin fl.	Low rs.
Glass res.	10^{12} Ωcm	10^{10} Ωcm
Glass th.	280 μm	700 μm
Strip pitch	1 cm	0.9 cm

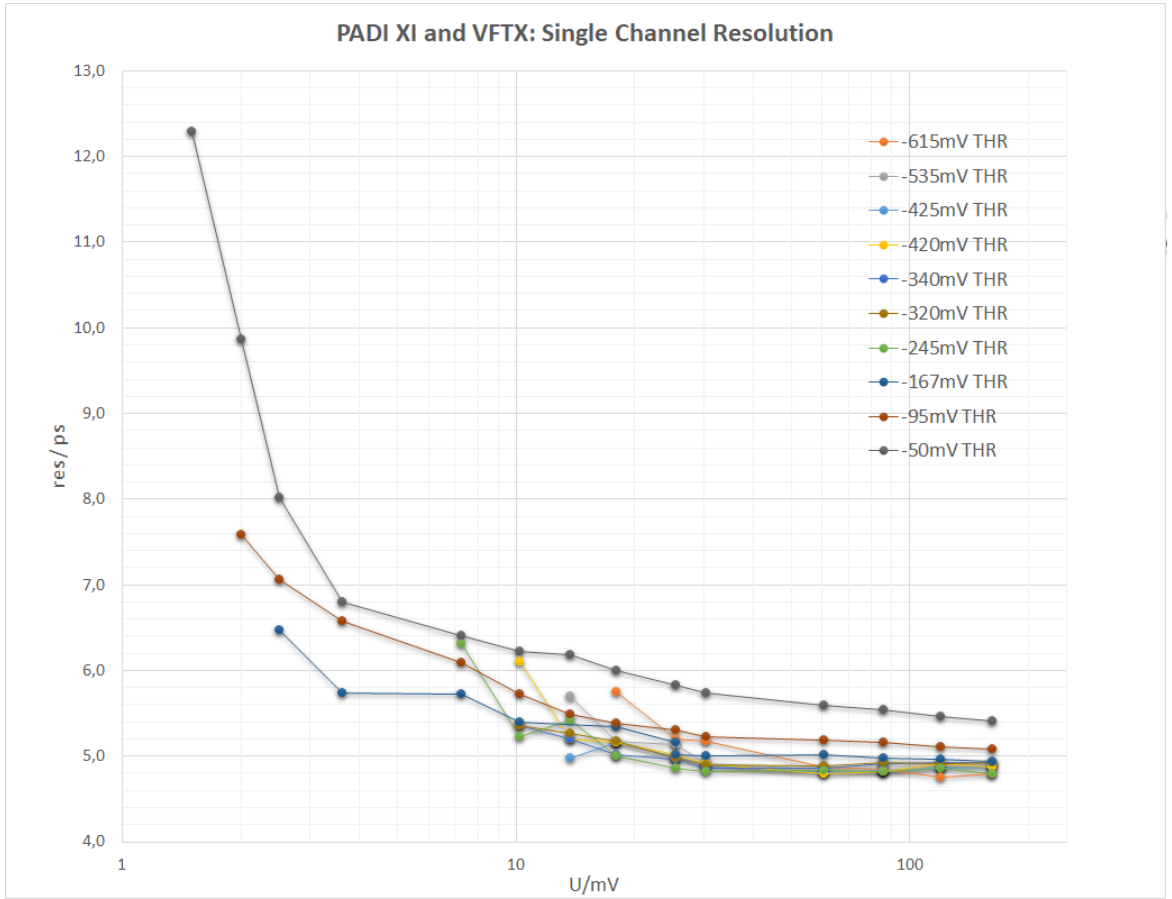
Test setup

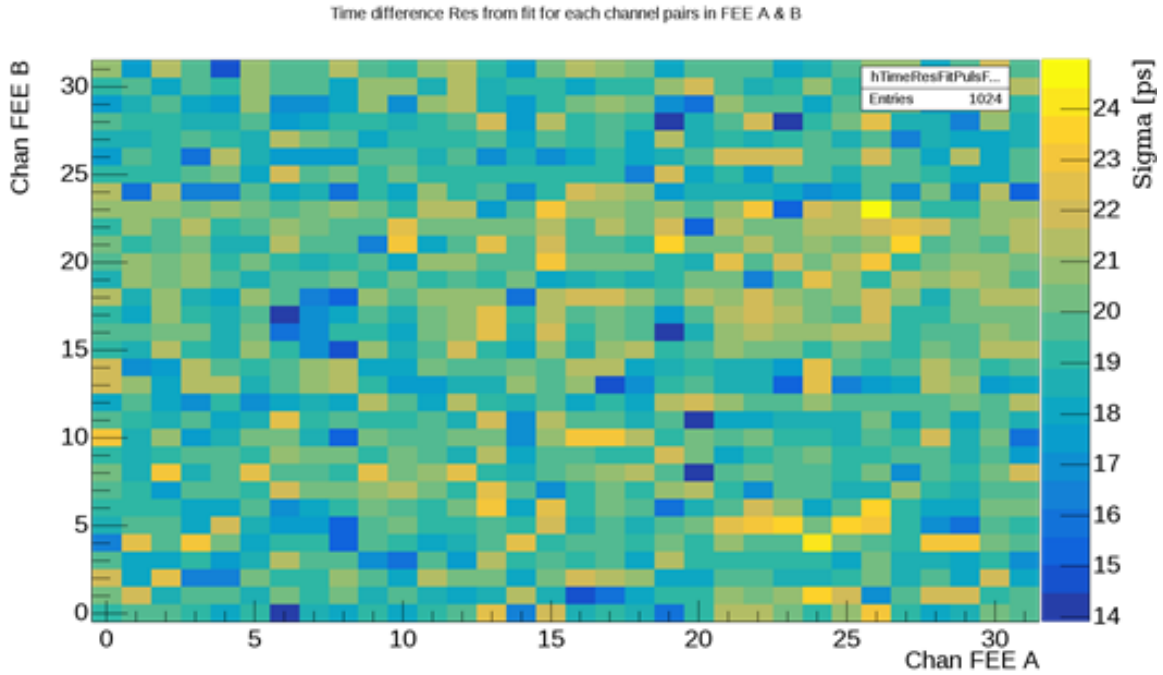
low resistivity glass counter





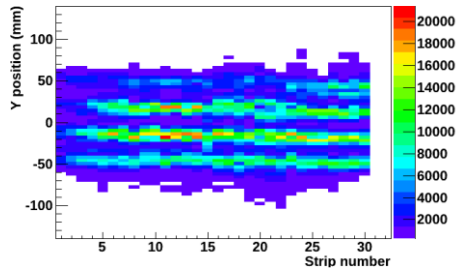
TOF electronics resolution



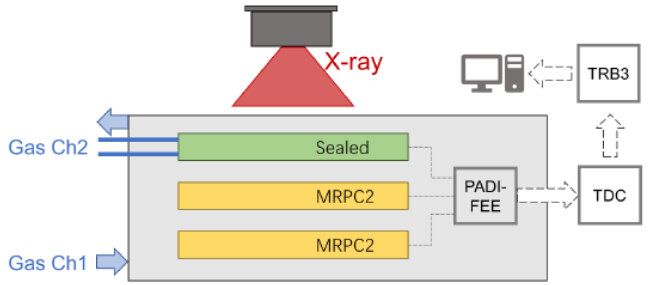


Aging & gas pollution

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

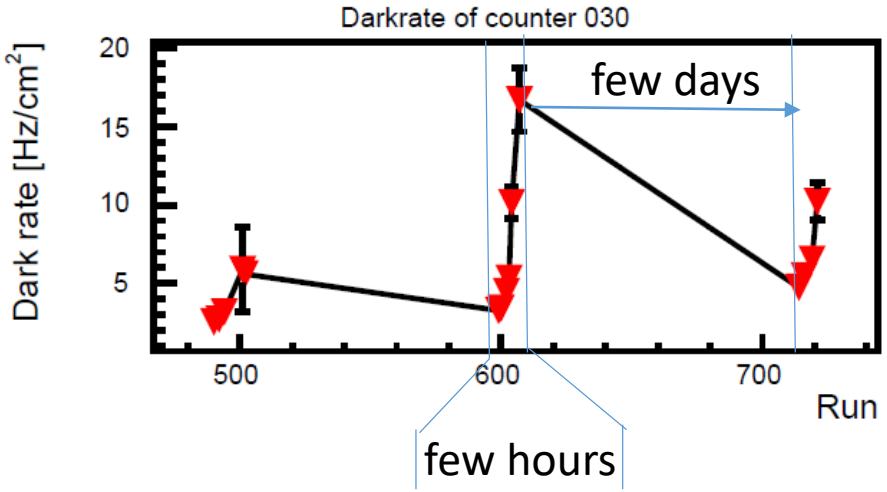


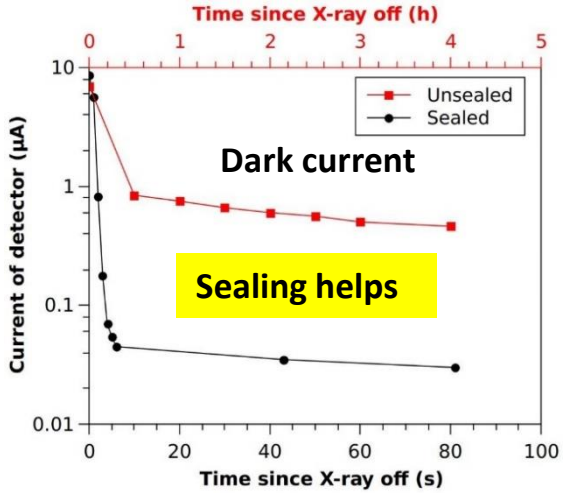
- Gas pollution effect was reproduced at IRASM (Bucharest) with high gamma flux
- X-Ray test at Beijing, Bucharest and USTC confirmed the gas pollution effect

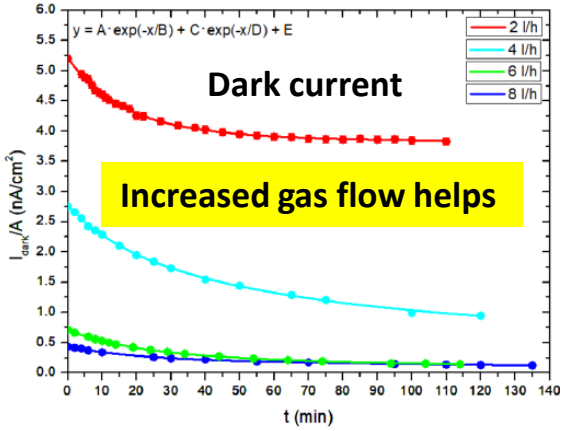


- The effect can be minimized by sealing the MRPC and increasing the gas flow
- Mitigation step might not be enough

Observations @ mCBM 2020
rapid increase of dark rate





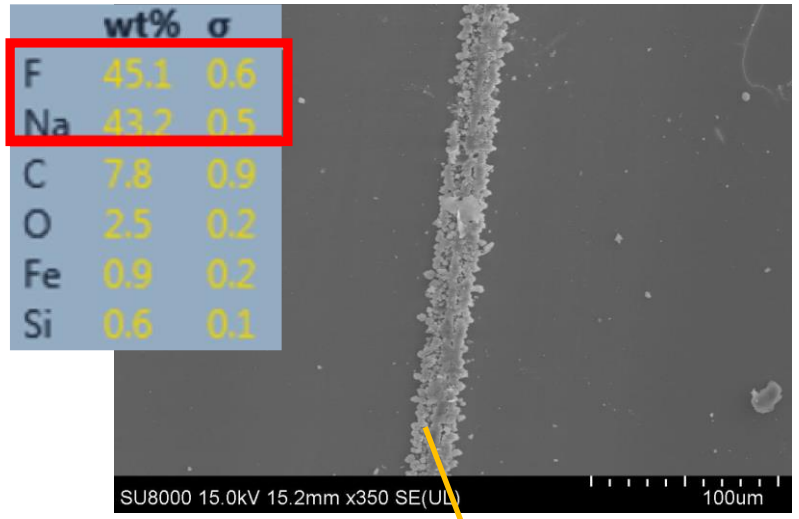


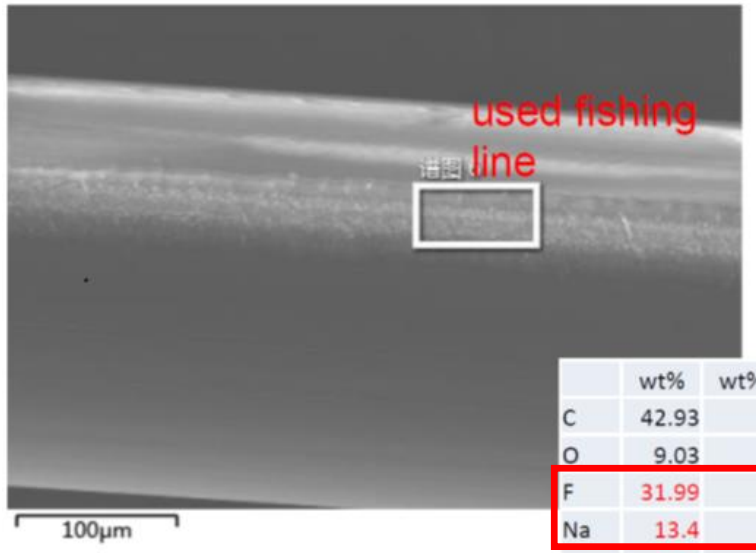
Dark current relaxation after irradiation

Aging & gas pollution

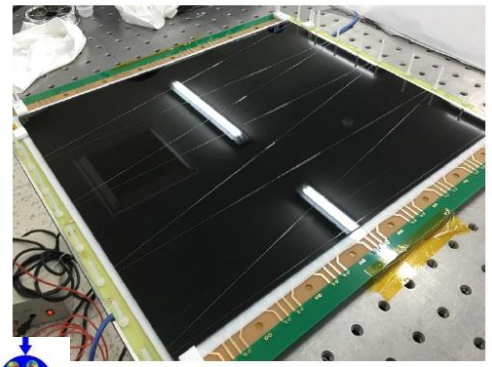
Observations: continuous increase in dark rate (permanent aging)

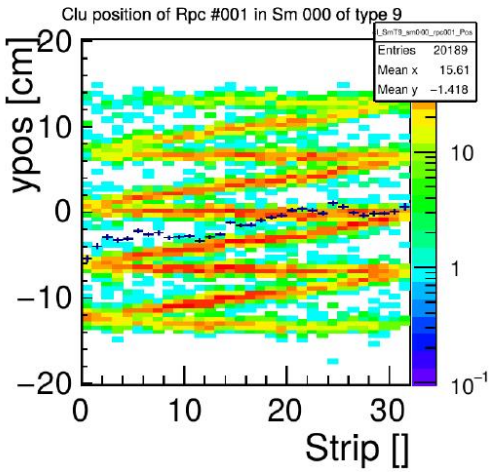
- Traces of NaF was found on the glass surface
- Dark rate (noise) is generated entirely on spacers (fishing lines)
- Electrical field simulations performed: in close vicinity to spacer touching point the E-field is 4 times higher

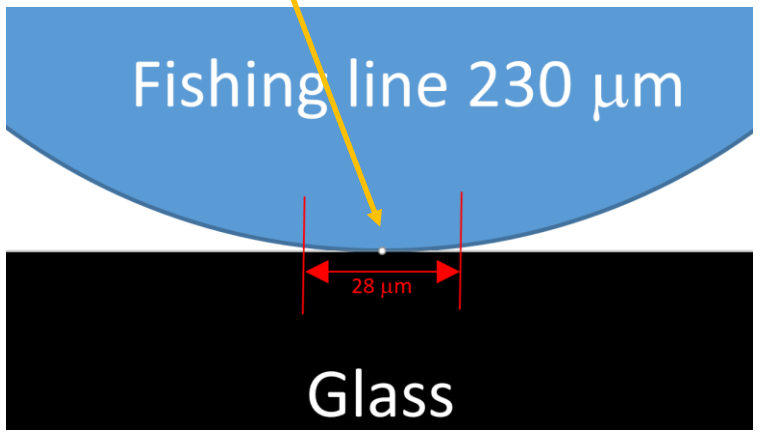




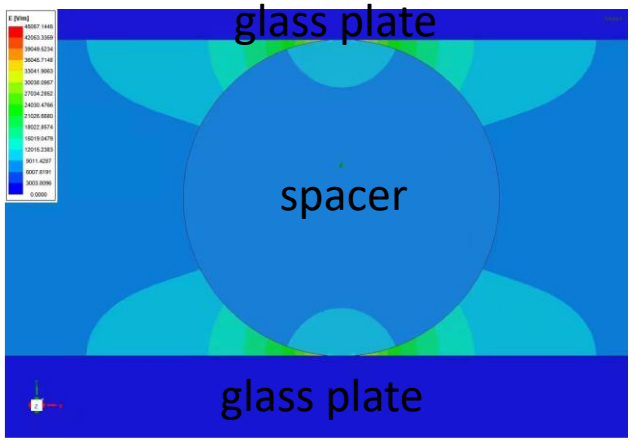
	wt%	wt% Sigma
C	42.93	0.21
O	9.03	0.15
F	31.99	0.18
Na	13.4	0.1
Si	2.36	0.04
Pt	0.28	0.07



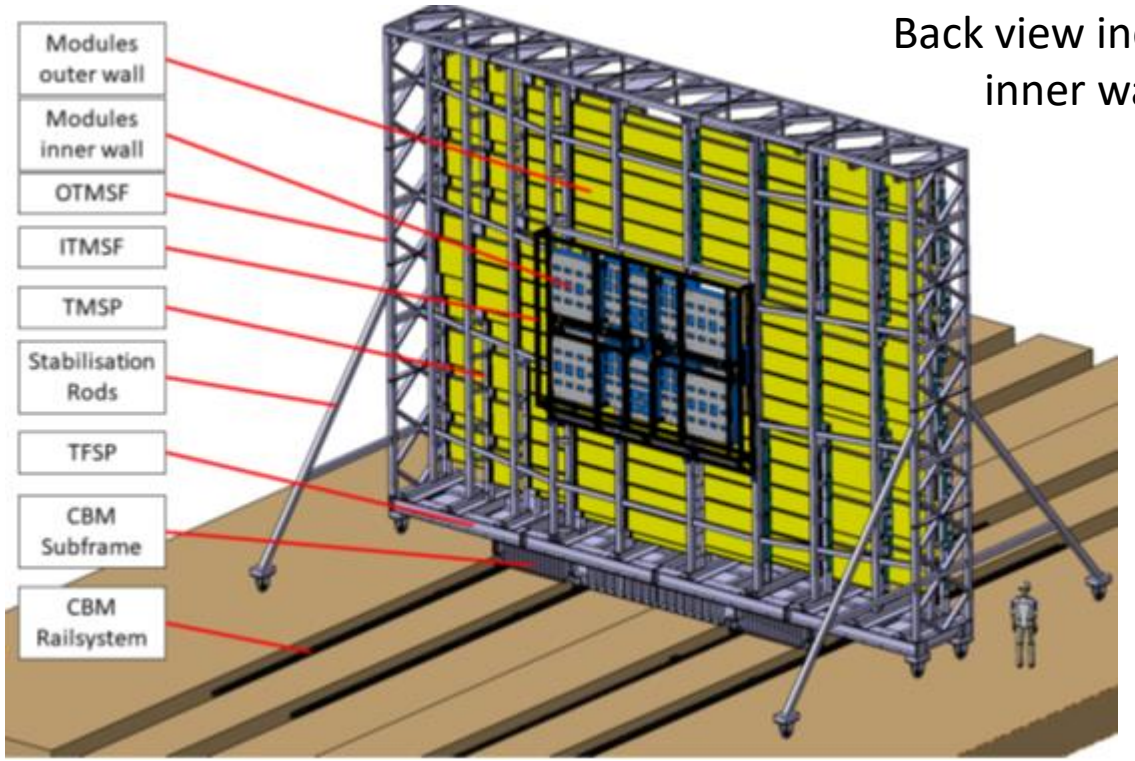




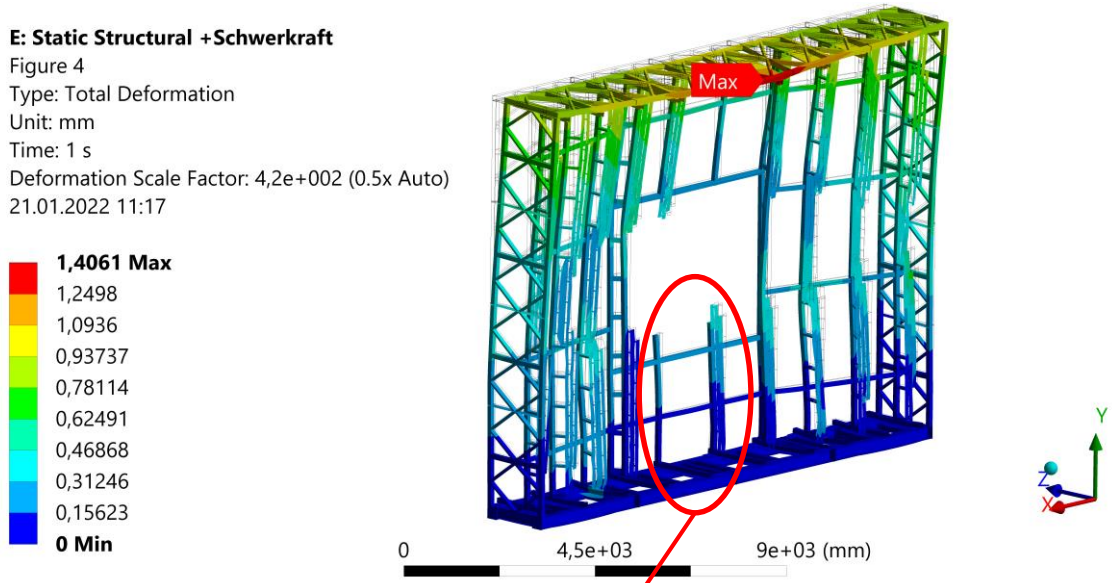
Electrical field simulations



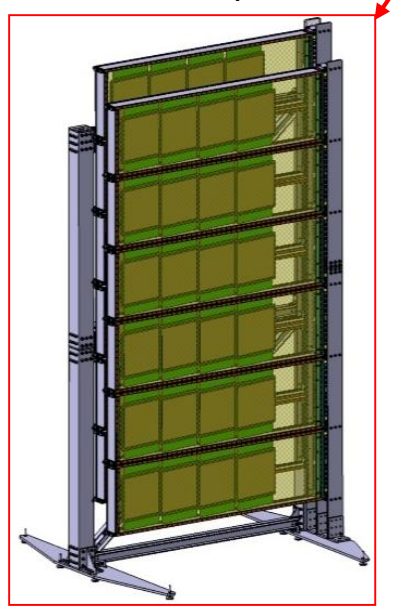
Main frame design



Back view incl. inner wall



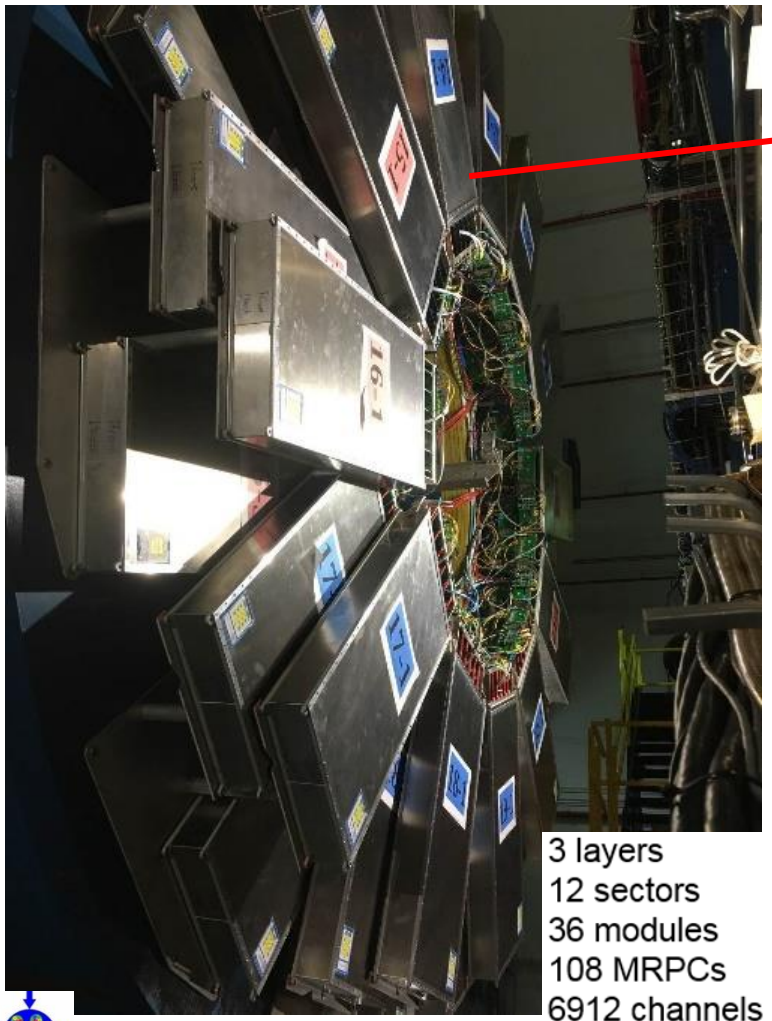
Mockup frame + 12 modules



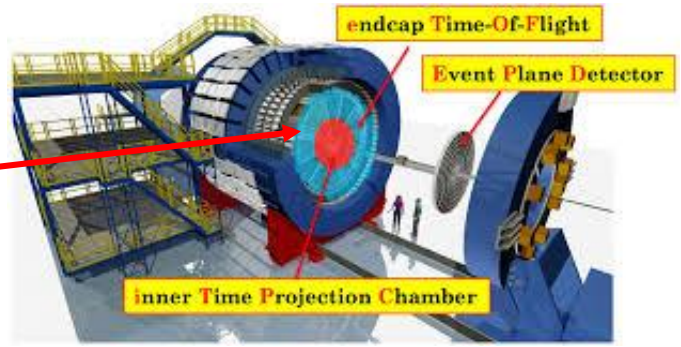
- TOF frame entered engineering design phase
- Outer module design complete (and tested in mCBM)
- Suspension for modules for low material budget and fast and easy mounting designed
- Stability calculations of the frame performed (ANSIS)
- Mockup frame for testing of module mounting procedure and infrastructure

eTOF introduction

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



3 layers
12 sectors
36 modules
108 MRPCs
6912 channels

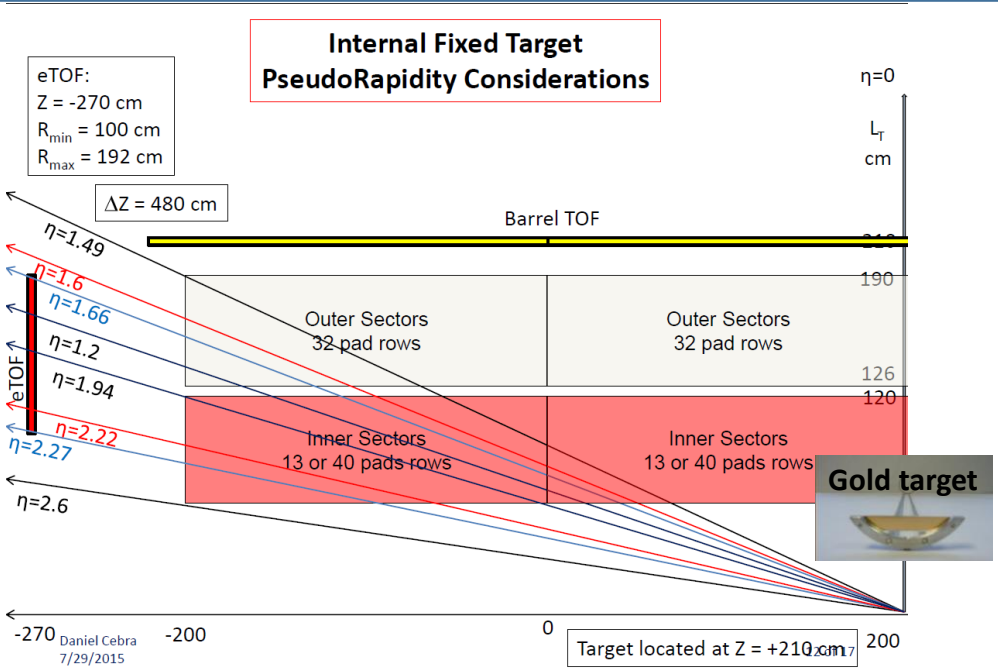


Fixed target mode

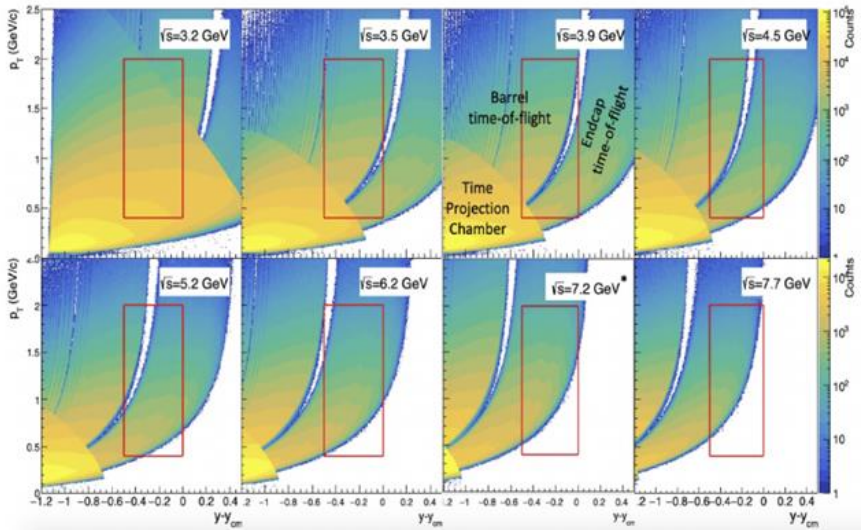
$\sqrt{s_{NN}}$ /GeV	# coll. Events	Year
3.0	2 B	2021
3.5	100 M	2020
3.9	50 M	2020
4.5	100 M	2020
5.2	100 M	2020
6.2	100 M	2020
7.7	50 M	2020
9.2	50 M	2021
11.5	50 M	2021
13.7	50 M	2021

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

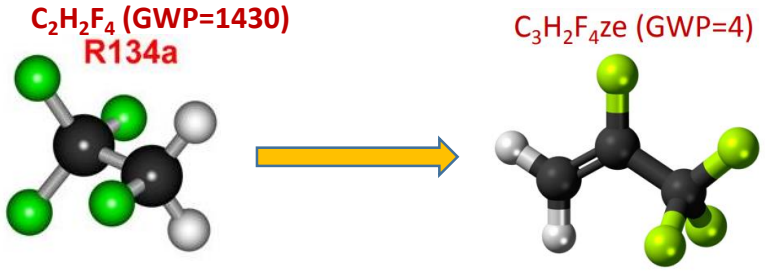


Proton fluctuations acceptance with $-0.5<y-y_{CM}<0$ analysis window in red



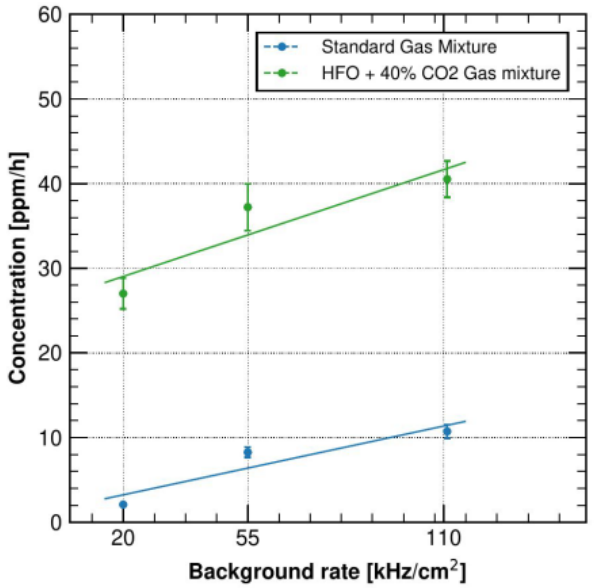
arXiv: 1609.05102

Alternative gas search for MRPCs

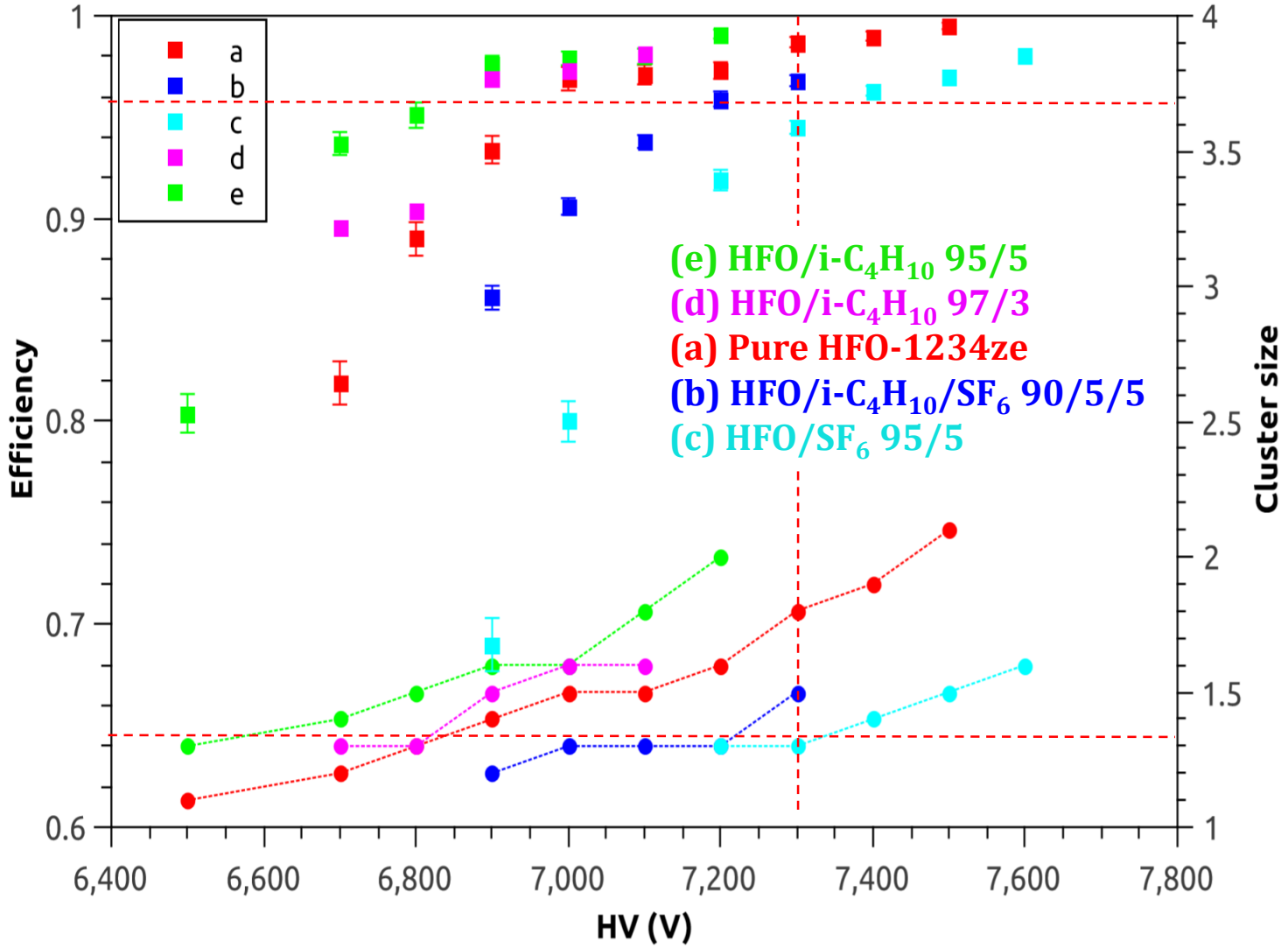


- Working point is shifted by about 2 kV in respect to traditional gas mixture
- Time resolution worse compared to std. gas mixture

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



I. Deppner *et al.* Toward an environmental friendly operation of the CBM-TOF system. *Eur. Phys. J. Plus* 138, 1080 (2023)



Environmental impact of TOF gas

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

gas	Isobu-tane	Reclin® R134a	Sulfur-hexafluo ride
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)	

Greenhouse Gas Comparison

Preventing emission of **1 kg (2.2 lbs) of SF_6** has the equivalent environmental impact as:

1 CBM-TOF refill

Removing 5 vehicles from the road for an entire year

500

or

Preventing the burning of 11 metric tons of coal

110

or

Eliminating the combustion of 54 barrels of oil

540

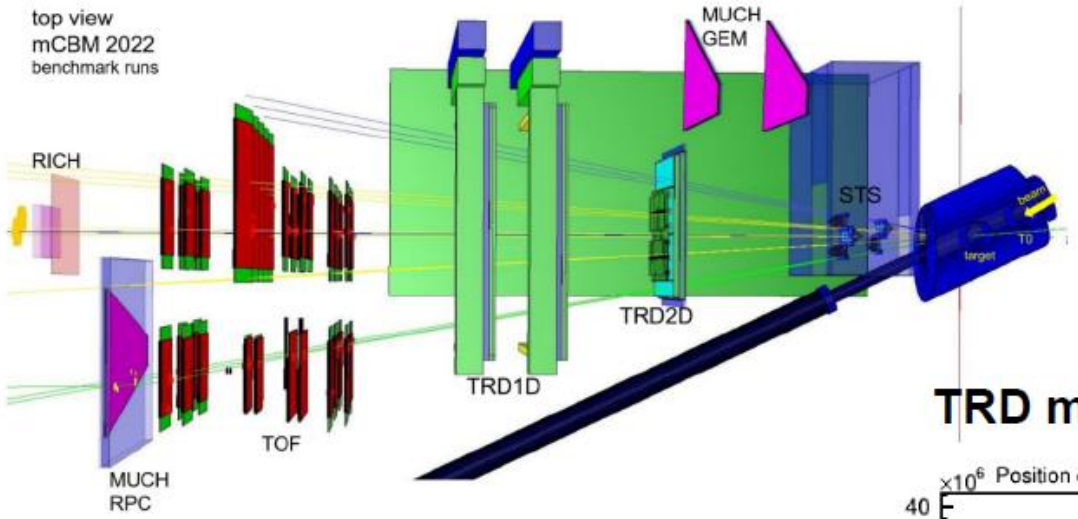
EE Switchgear Committee 2018

24

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

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

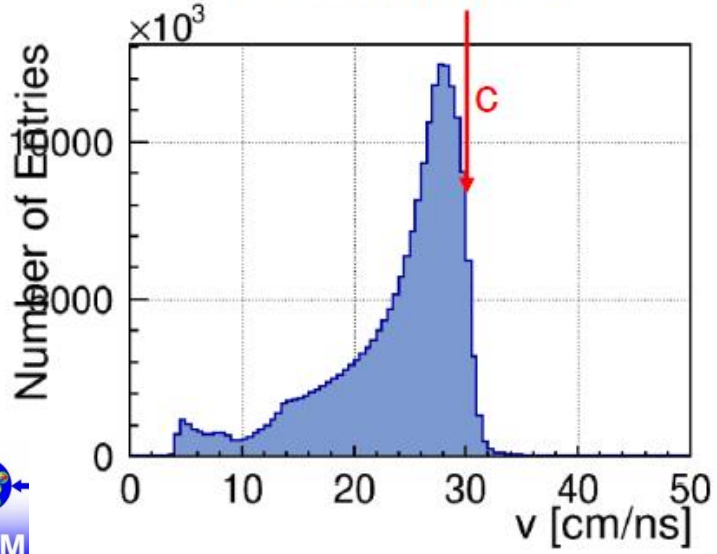
Test setup in 2021/2022



Run 2391

Data taken May 26, 2022
Duration: ~2h
5×10^7 ions per spill, 10s spill,
400 - 500 kHz collision rate

TOF calibration



TRD matches