14th International Conference on Nucleus-Nucleus Collisions (NN2024)

18.–23. Aug. 2024
Whistler Conference Centre
America/Vancouver Zeitzone

FAIR — Facility for Antiproton and Ion Research in Europe

The CBM Time-of-Flight project

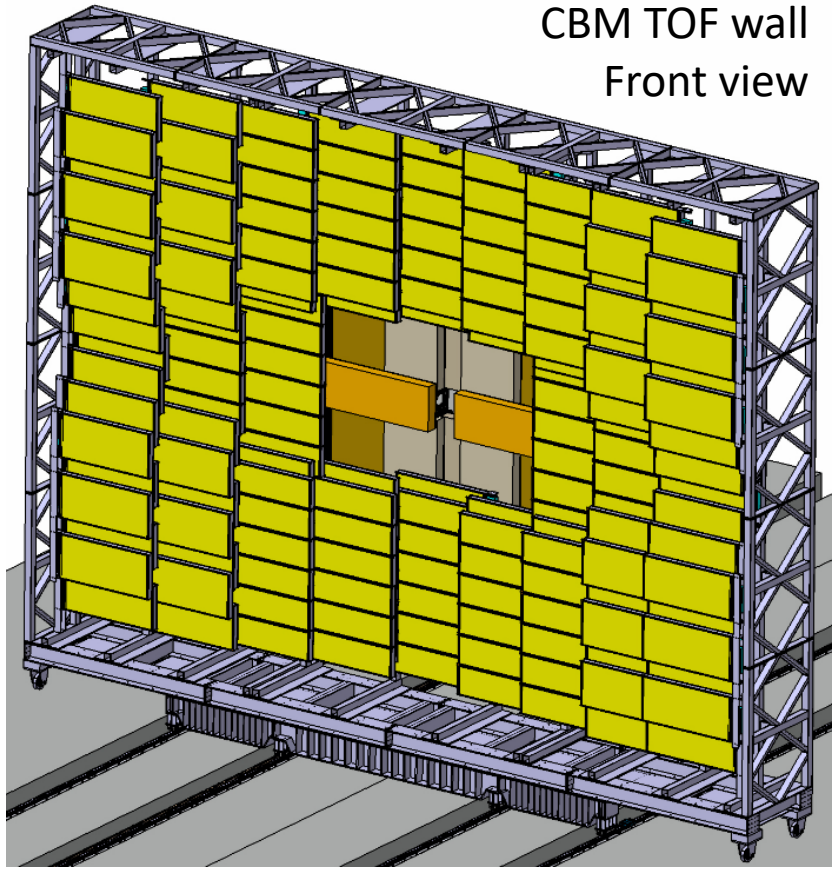
Ingo Deppner

GSI Helmholtzzentrum für Schwerionenforschung GmbH

19.08.2024

Outline

- Introduction to FAIR, CBM and CBM-TOF
- TOF FAIR Phase 0 program
  - eTOF status at STAR/BNL
  - mTOF at mCBM at SIS18/GSI
    - Conditions and counter performance at high rate
    - mCBM performance and Λ-Reconstruction
    - (Gas) Aging of MRPCs and mitigation steps
- Environmental impact of detector gas, possible solutions and implications
- Summary and time line

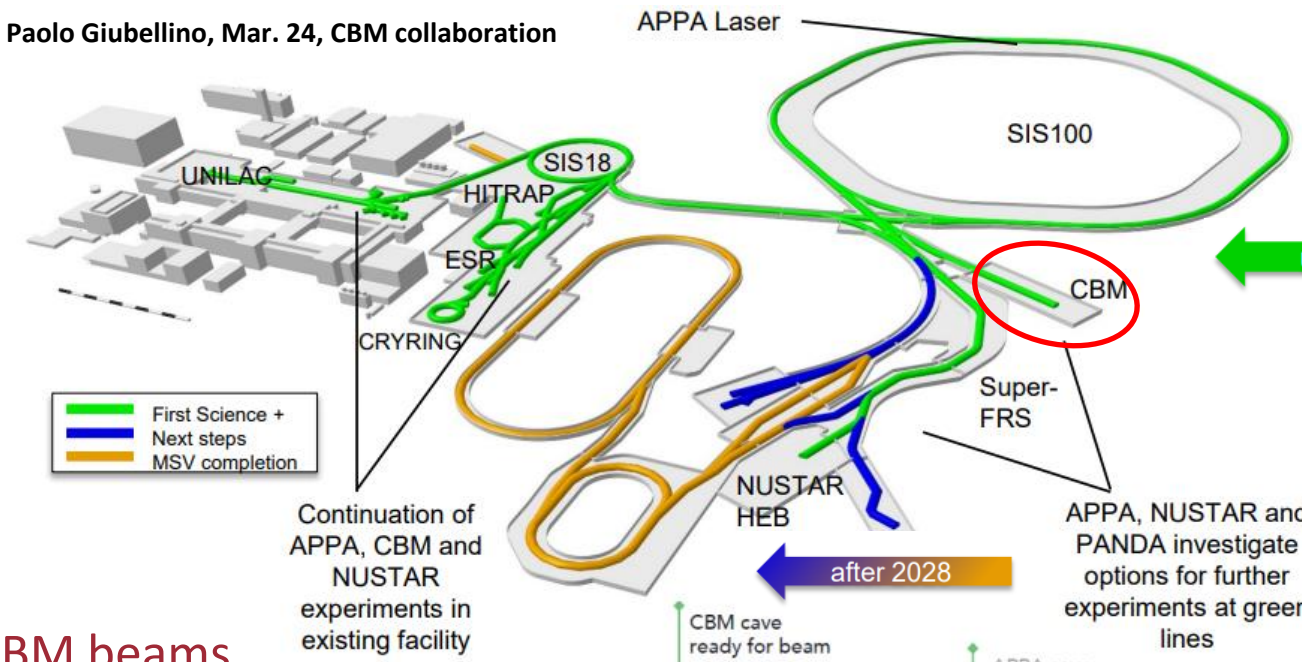


CBM TOF wall
Front view

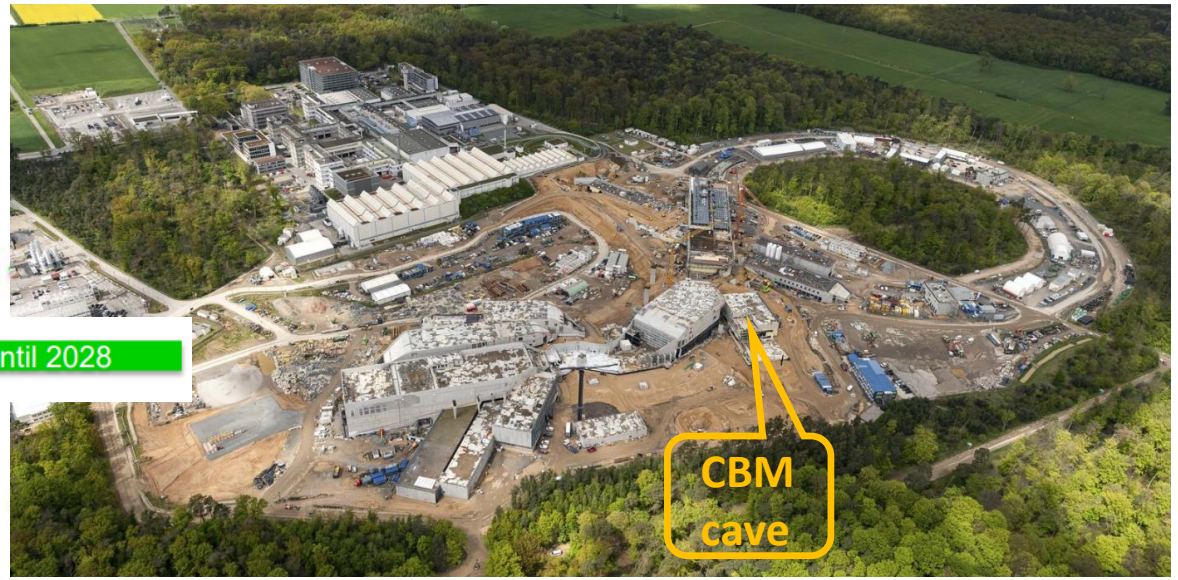
Introduction to FAIR

Facility for Antiproton and Ion Research (FAIR)

Paolo Giubellino, Mar. 24, CBM collaboration

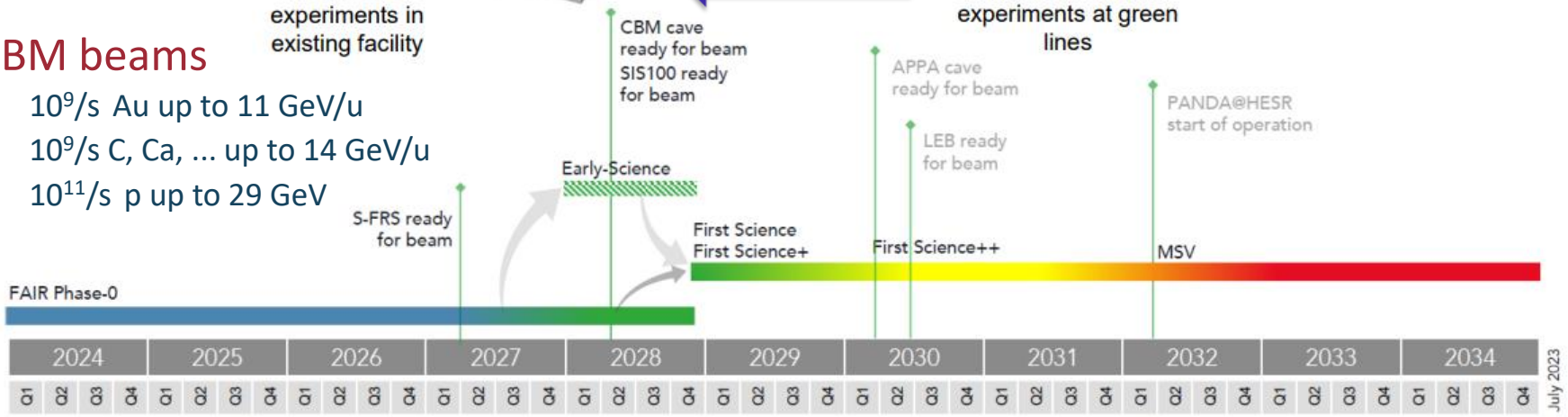


until 2028



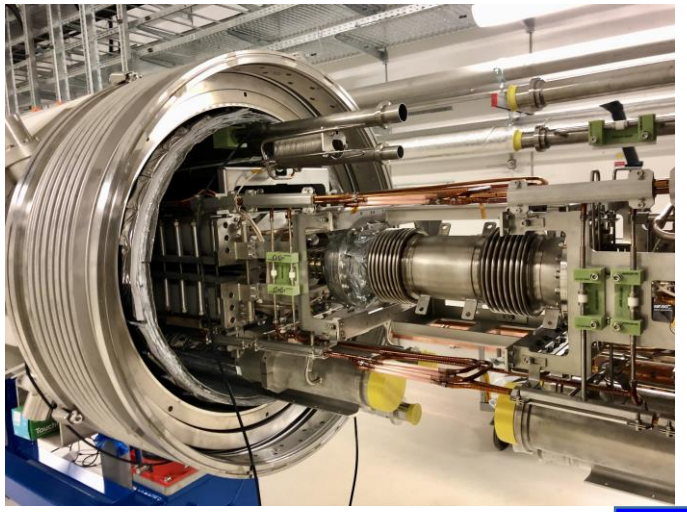
https://edms.cern.ch/ui/file/2893949/LATEST/FAIR*.mp4

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

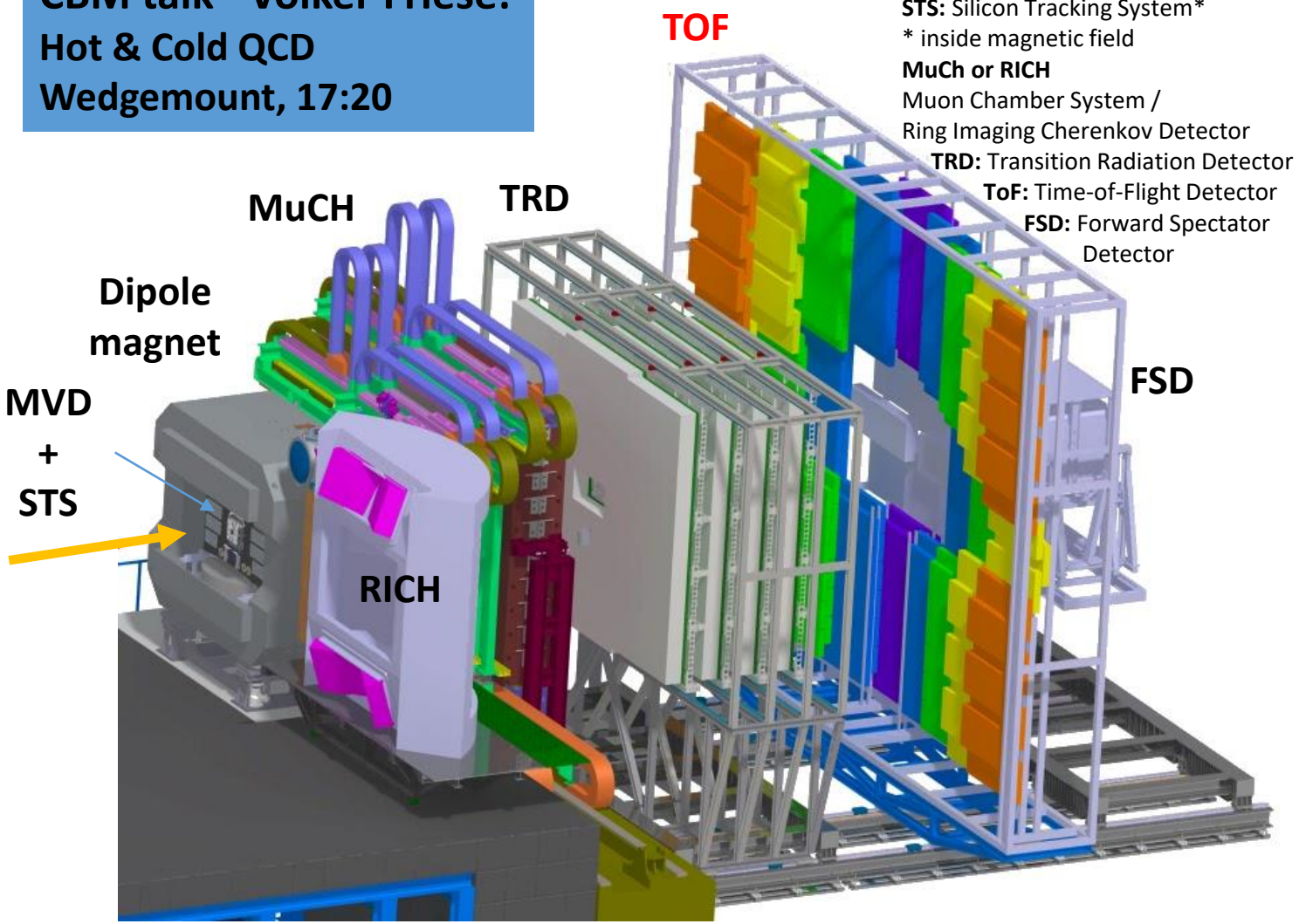


First dipole magnets installed at SIS100

Introduction to CBM

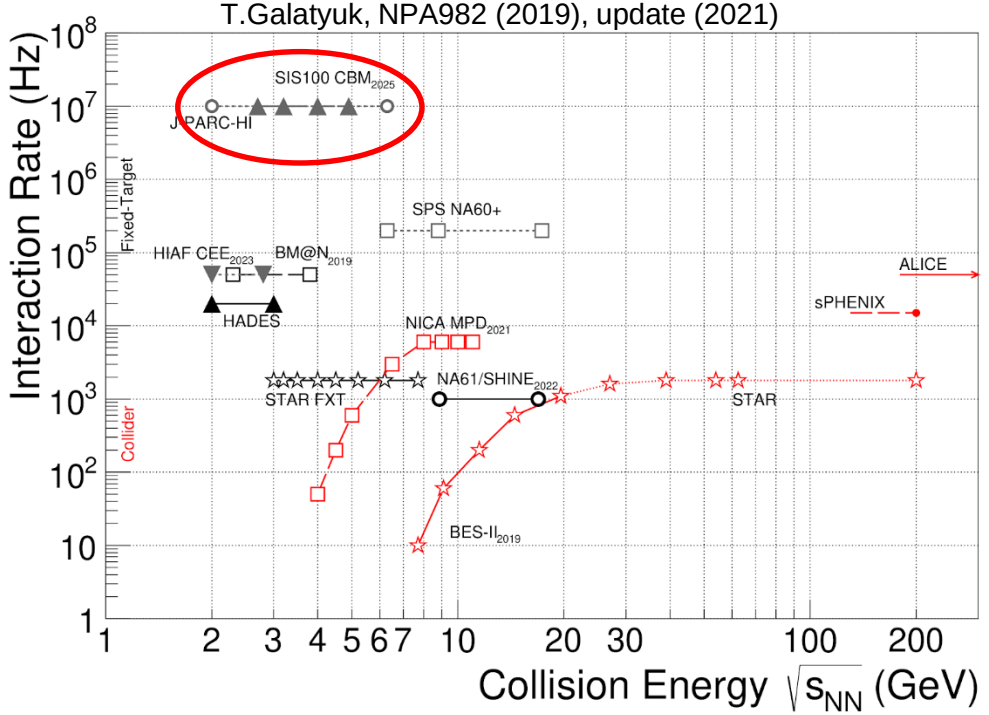
Compressed Baryonic Matter (CBM) Experiment

CBM talk - Volker Friese:
Hot & Cold QCD
Wedgemount, 17:20



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)

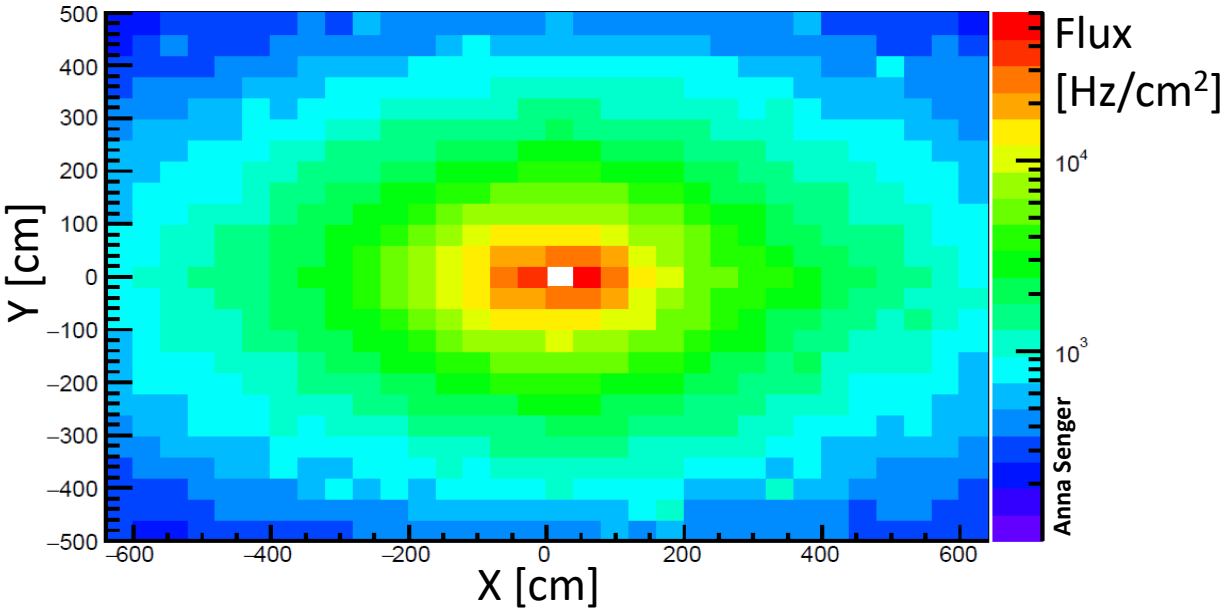


- Tracking acceptance: $2.5^o < \theta_{Lab} < 25^o$
- Peak R_{int} is 10 MHz for Au+Au
- Fast & radiation hard detectors
- Free-streaming DAQ
- 4D tracking (space, time)
- Online event selection and reconstruction
- Data rate: 1 TB/sec

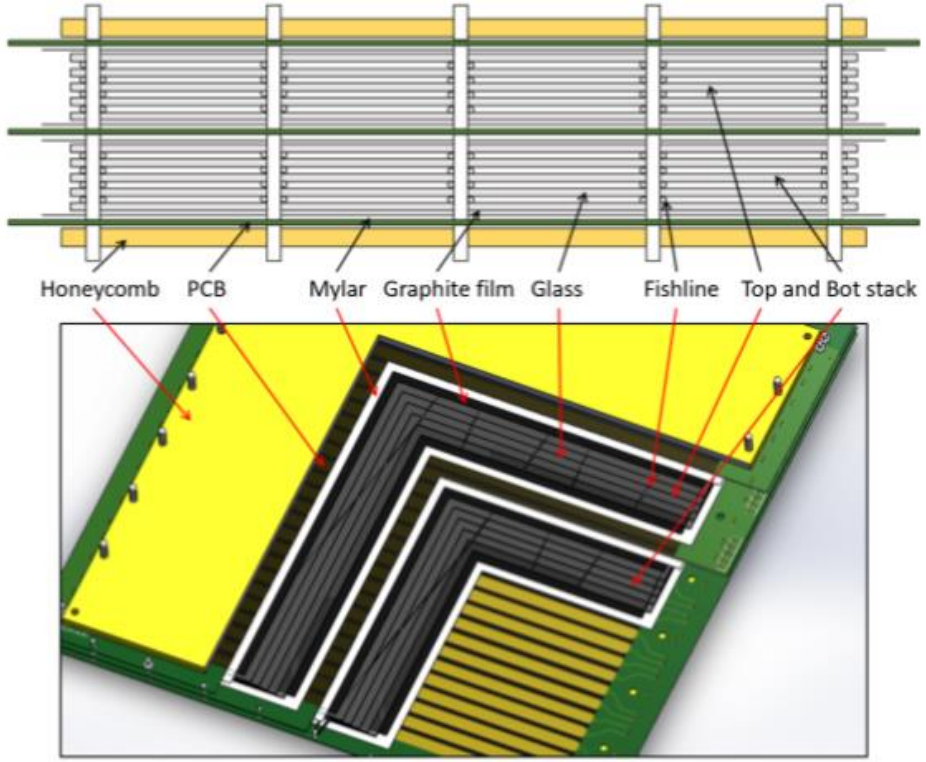
Introduction CBM TOF

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

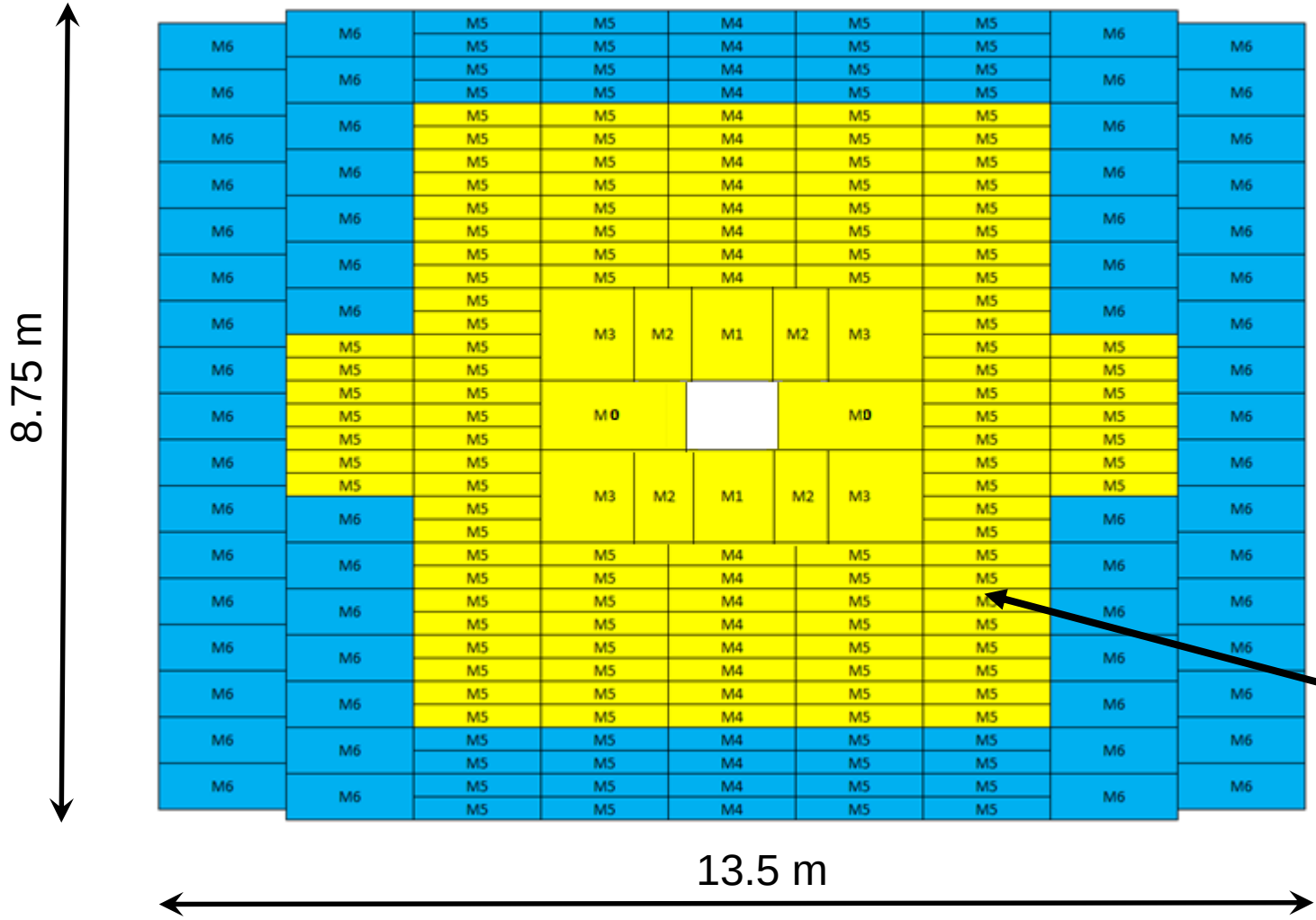
- **Full system time resolution σ_T ~ 80 ps**
- **Efficiency > 95 %**
- **Rate capability ≤ 50 kHz/cm²**
- **Polar angular range 2.5° – 25°**
- **Active area of 120 m²**
- **Occupancy < 5 %**
- **Low power electronics (~100.000 channels)**
- **Free streaming data acquisition**

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%**

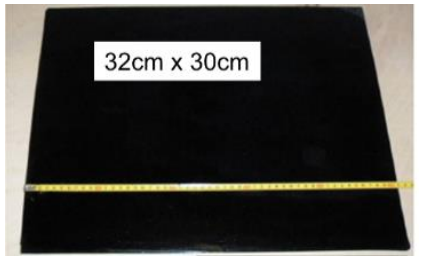
Introduction CBM TOF

Active area

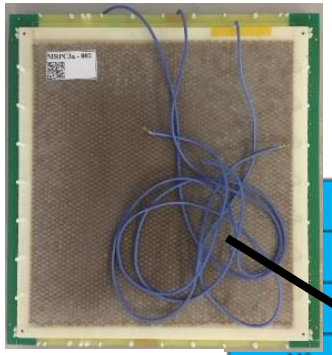


- **A module contains several MRPC counters**
- **Region containing counters equipped with thin float glass, $\rho \approx 10^{12}\ \Omega$ cm**
- **Region containing counters equipped with low resistivity glass, $\rho \approx 10^{10}\ \Omega$ cm**

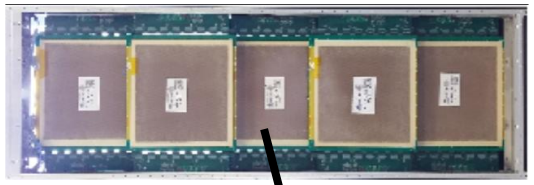
Low resistivity glass (China)



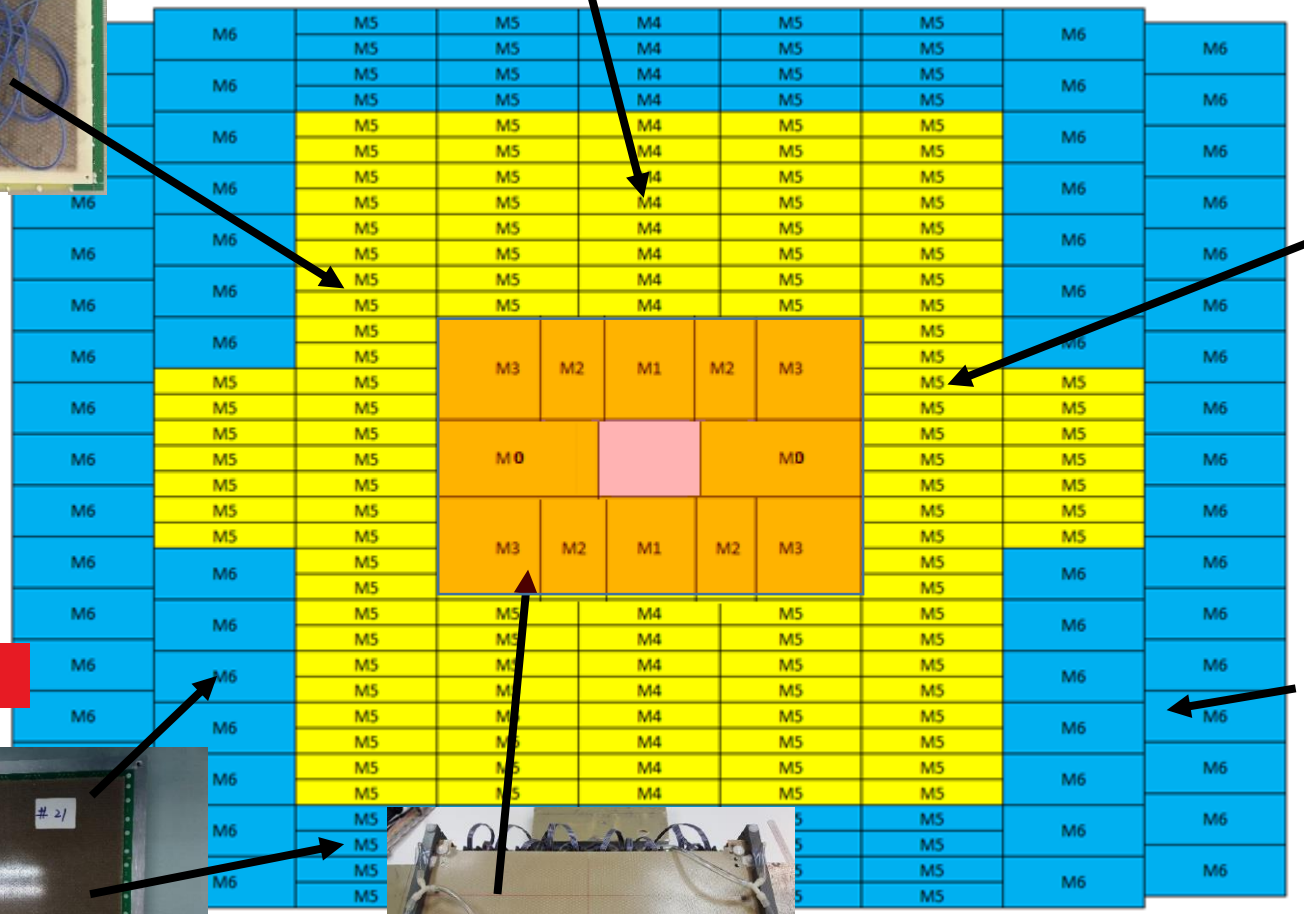
Introduction CBM TOF



MRPC2
(Tsinghua)



M4 Module
(Heidelberg (HD))

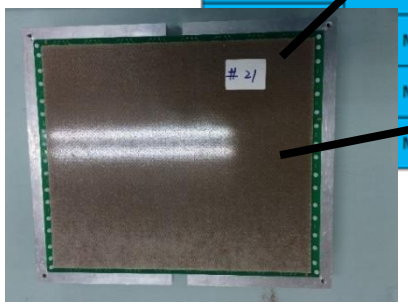


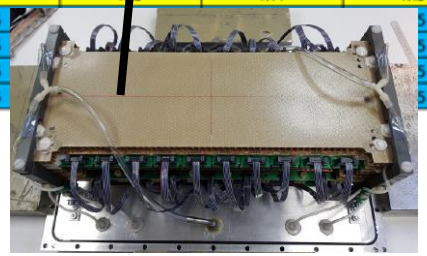
M5 Module (HD)

- **Full size counter with close to 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

FAIR Phase 0

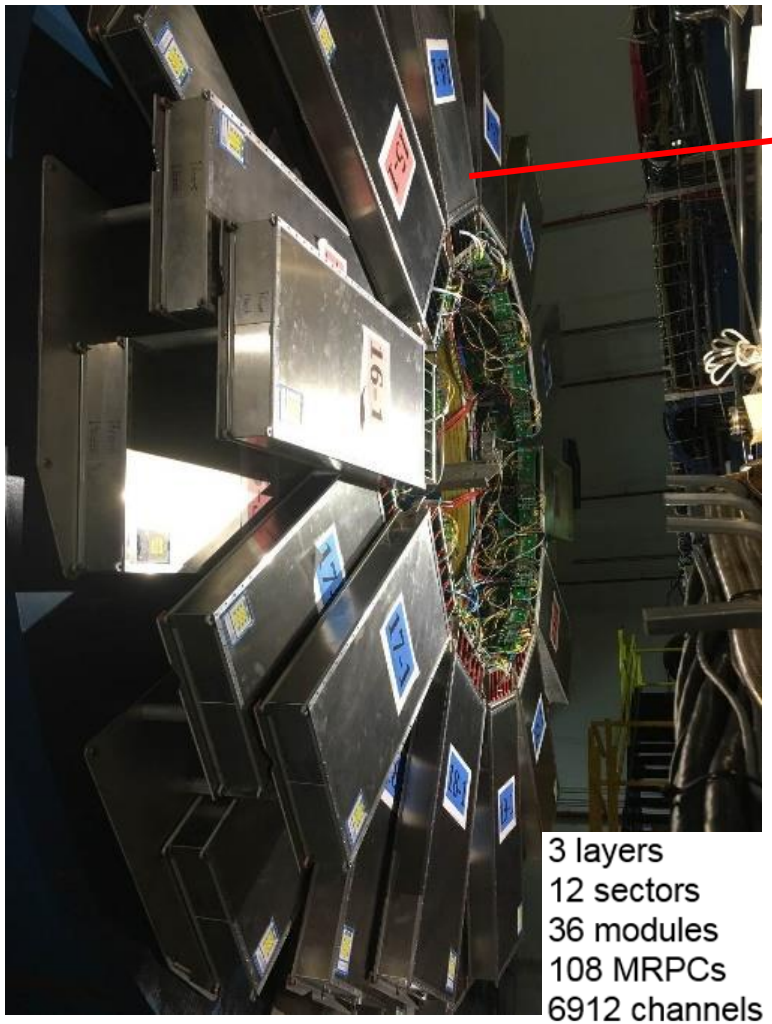
- **FAIR Phase 0 is a bridge program until the start of FAIR**
- **It comprises the installation and testing of developed equipment in running experiments and analysis of obtained data**

<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

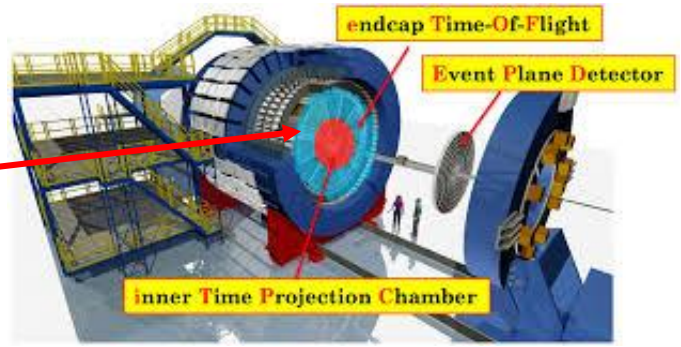
eTOF introduction

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



3 layers
12 sectors
36 modules
108 MRPCs
6912 channels

arXiv: 1609.05102

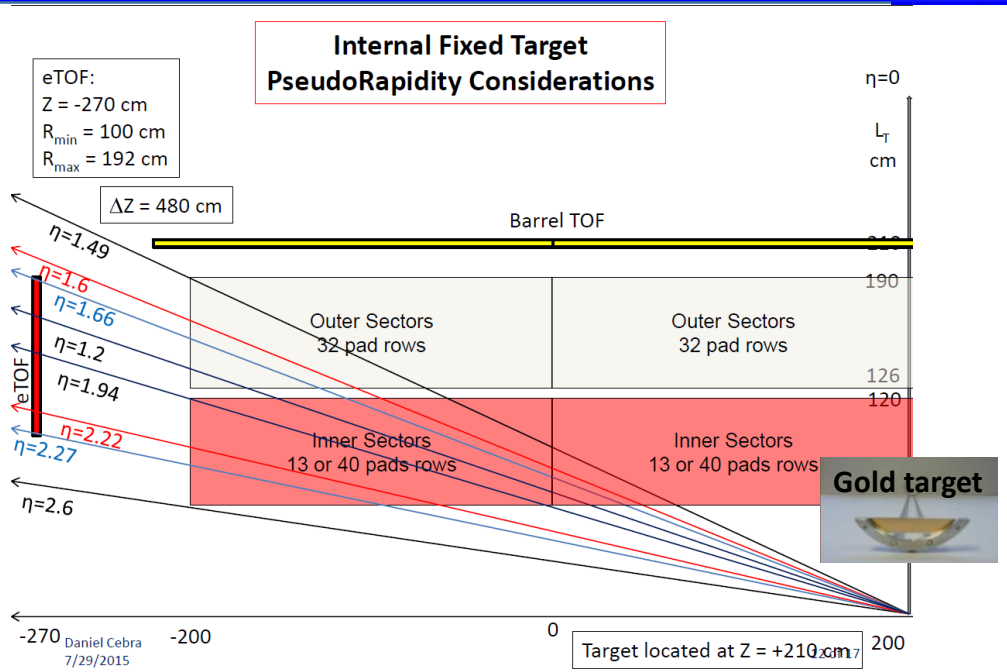


Fixed target mode

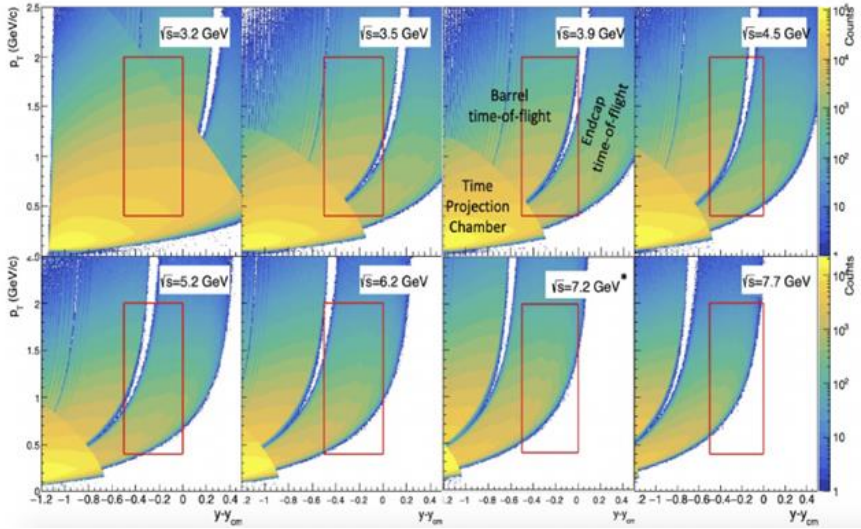
$\sqrt{s_{NN}}$ /GeV	# coll. Events	Year
3.0	2 B	2021
3.5	100 M	2020
3.9	50 M	2020
4.5	100 M	2020
5.2	100 M	2020
6.2	100 M	2020
7.7	50 M	2020
9.2	50 M	2021
11.5	50 M	2021
13.7	50 M	2021

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



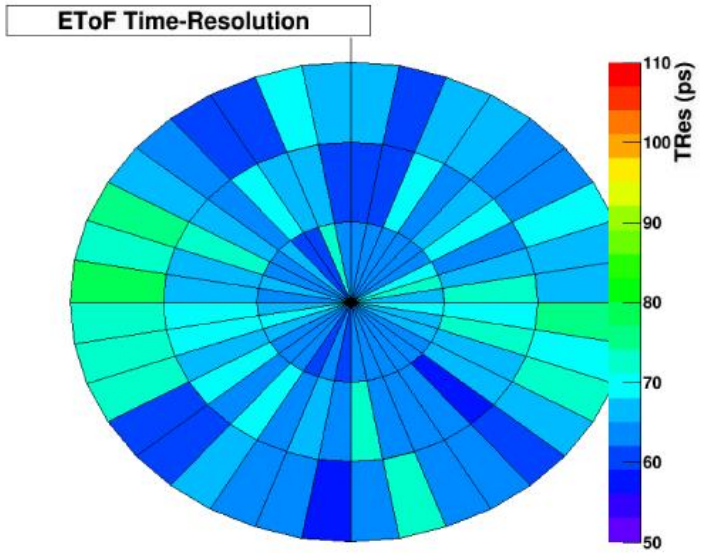
Proton fluctuations acceptance with $-0.5<y-y_{CM}<0$ analysis window in red



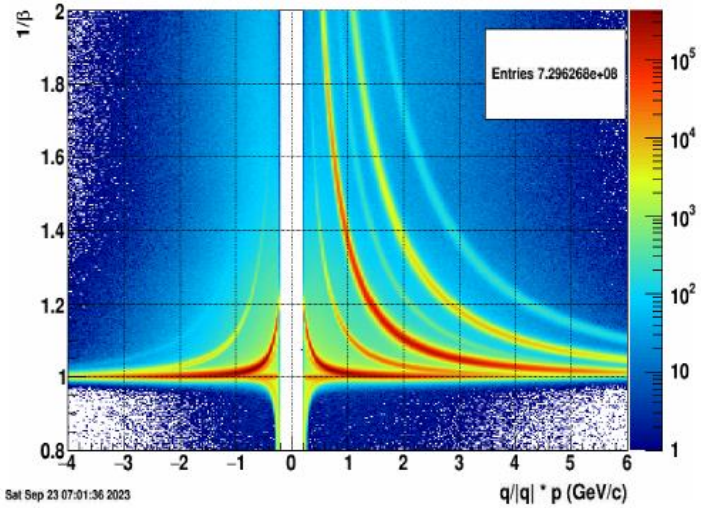
eTOF performance

- 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

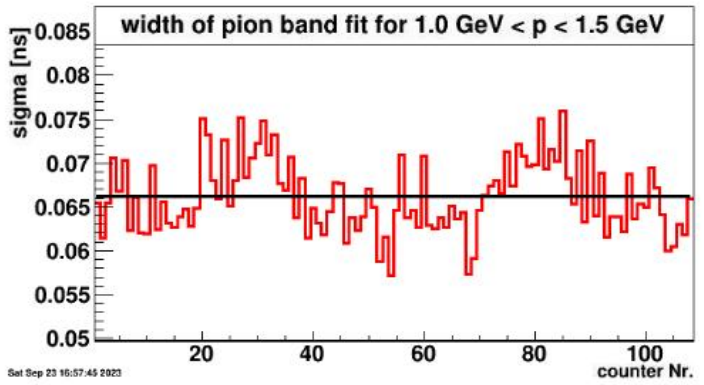
EToF Performance at 4.5 GeV FXT 2020

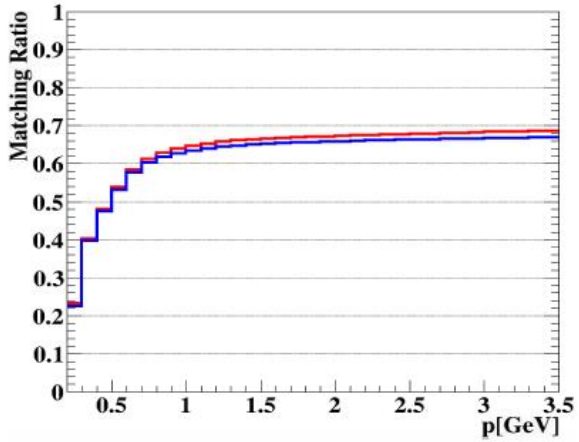


ETof-Time-Resolution at 3.5 GeV FXT 2020



1 / β vs. momentum

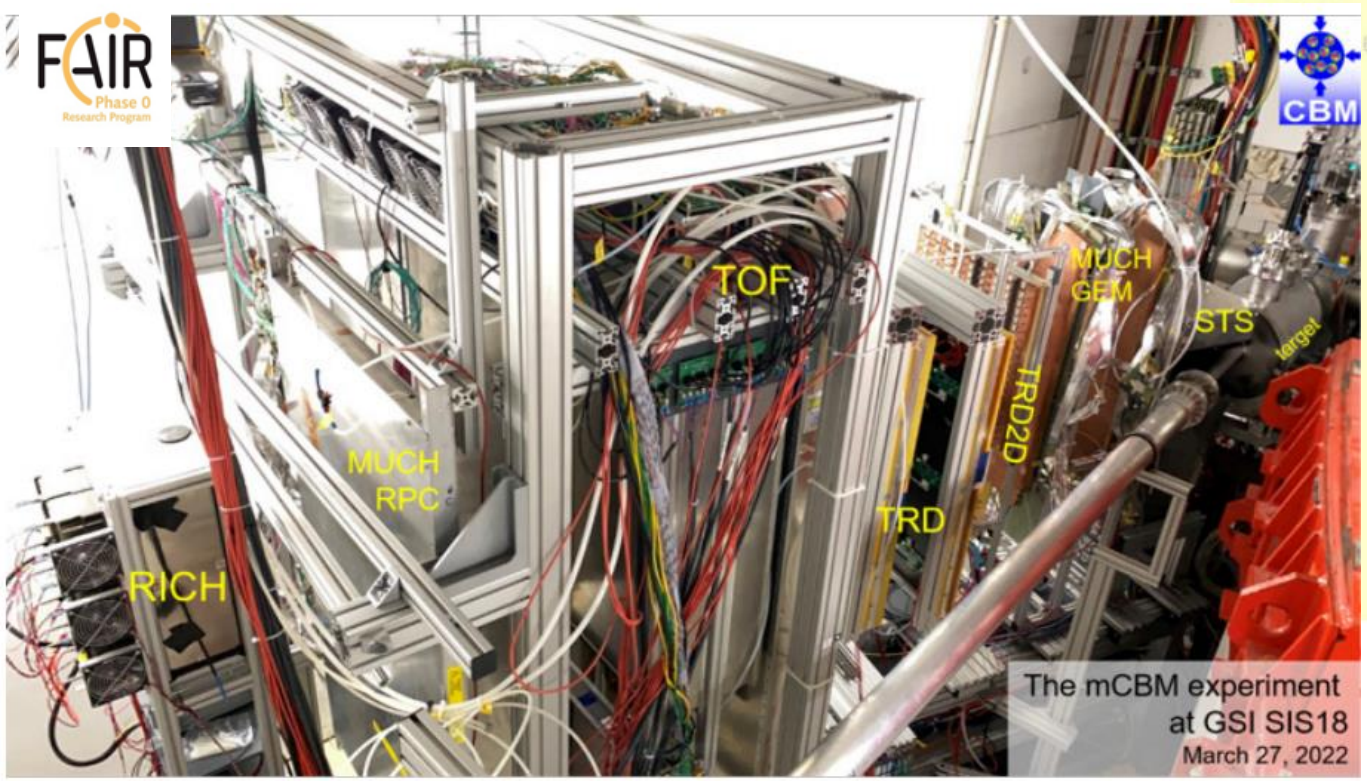




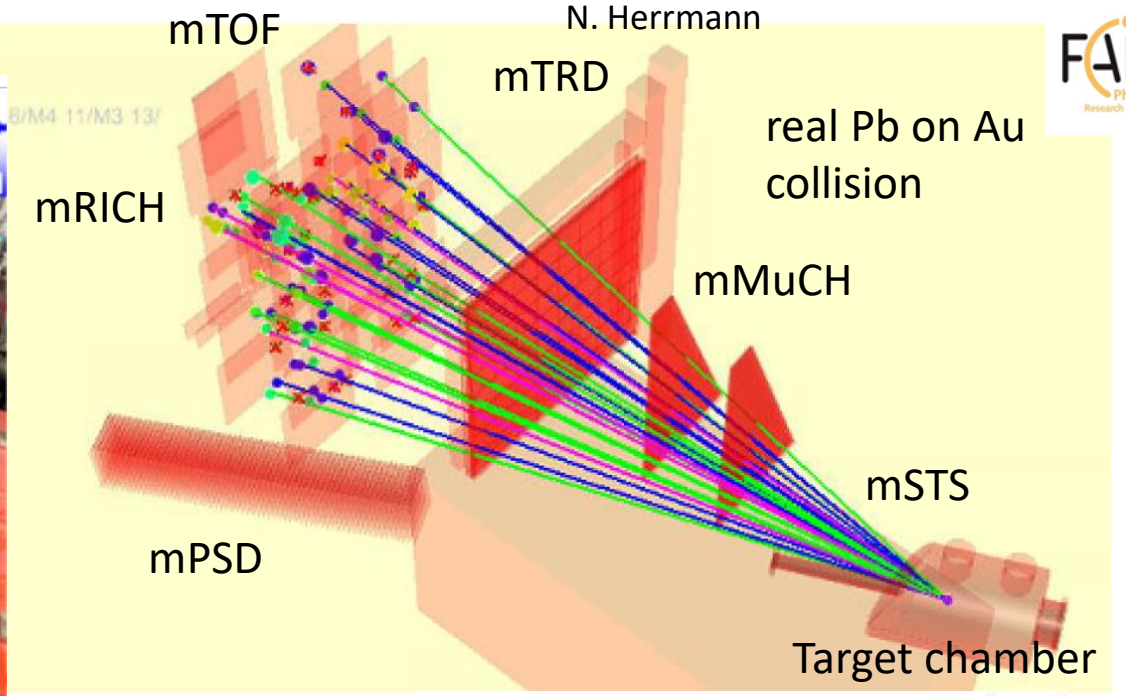
Matching Efficiency at 65% for p > 1GeV

mCBM @ SIS18

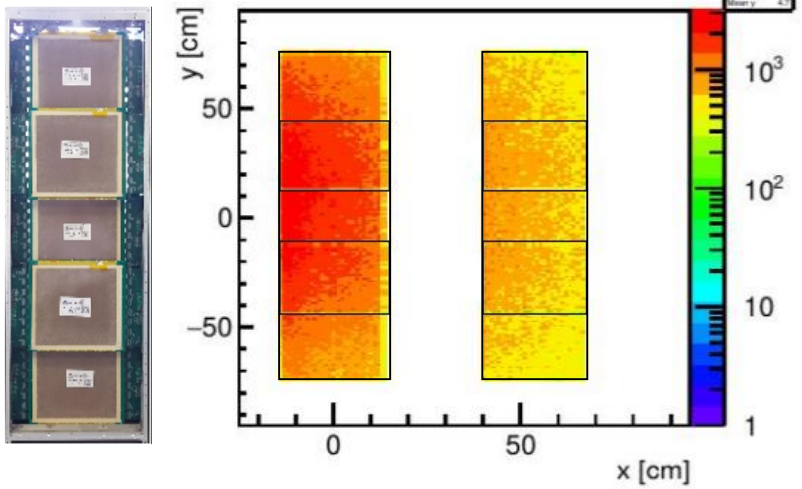
FAIR Phase 0: mCBM setup @ SIS18



N. Herrmann



Simulation: Au+Au @ 1.24 GeV mbias



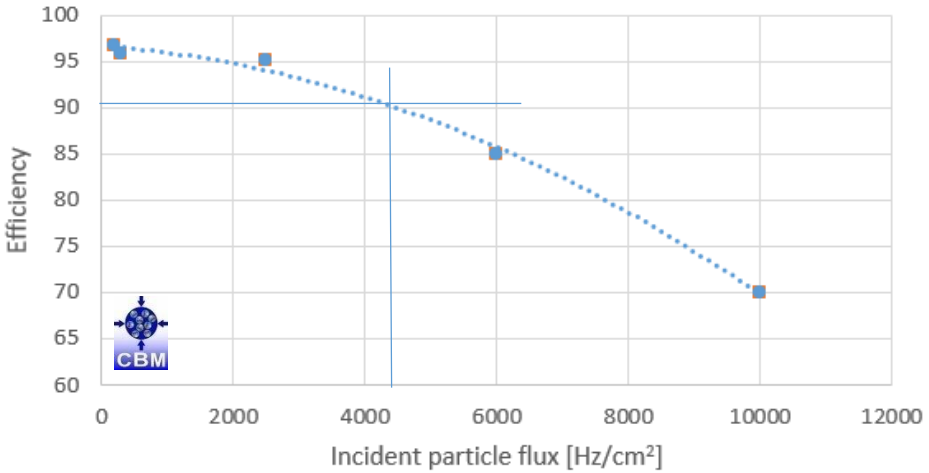
- mCBM is a full system test setup installed at SIS18/GSI dedicated for high rate detector and readout test including free streaming data acquisition and online event selection
- Interaction rates up to 10 MHz, charged particle fluxes of up to 30 kHz/cm^2
- Having a high rate test stand is highly important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

mCBM beam time results

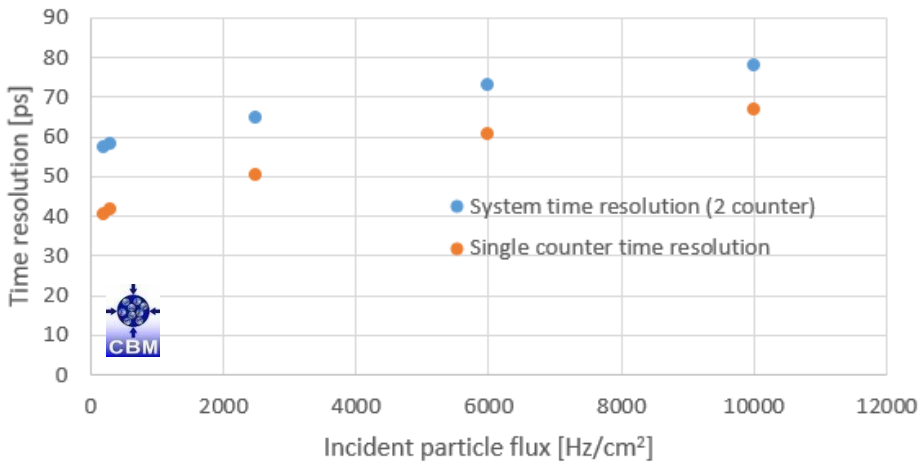
low rate **thin float glass** counter

Performance beyond specs

Efficiency as function of incident ch. particle flux



Time resolution as function of incident ch. particle flux



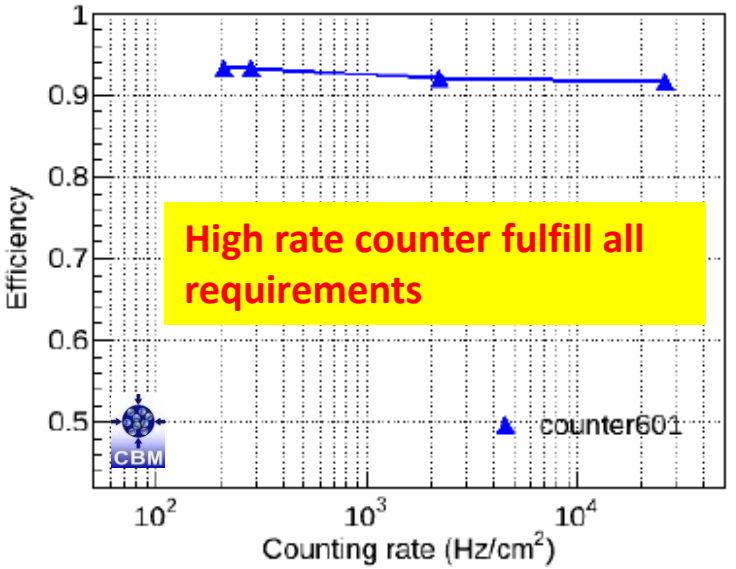
mCBM Beamtime mCBM March 2021

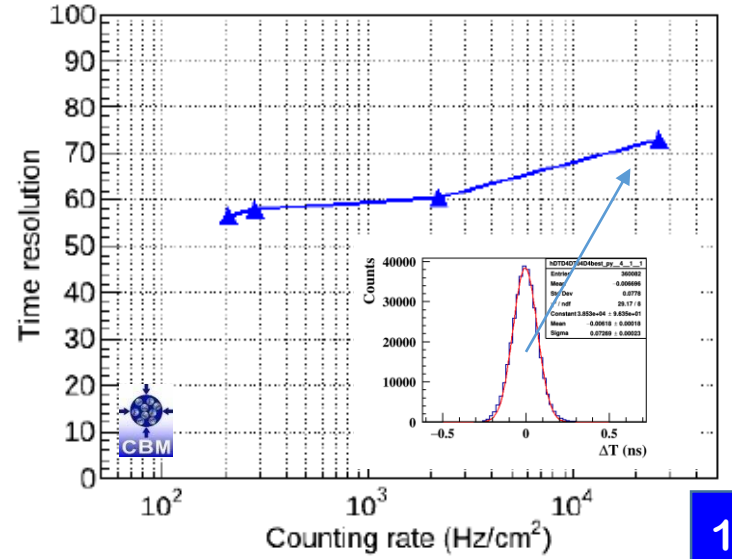
Gas Mixture: R134a/SF_6 - 97.5%/2.5%

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

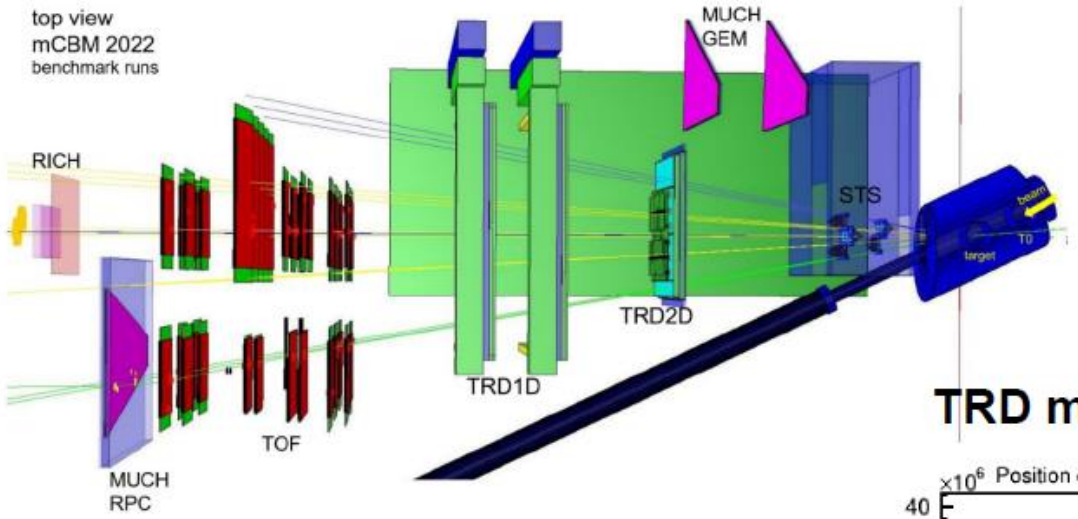
Test setup

low resistivity glass counter





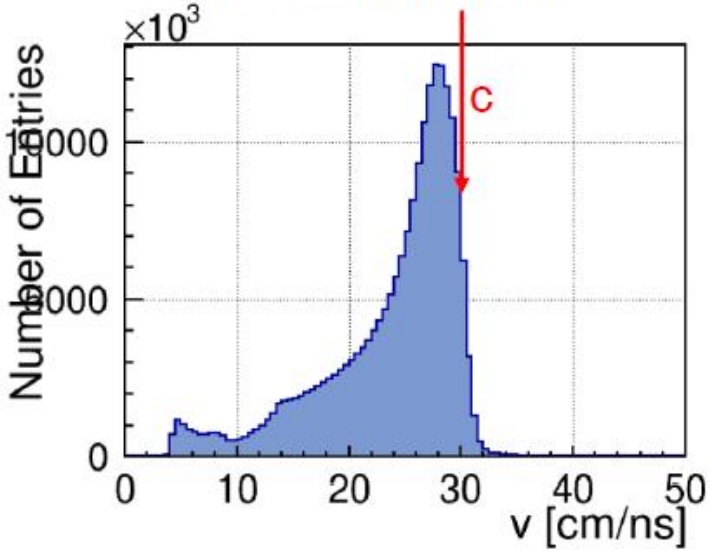
Test setup in 2021/2022



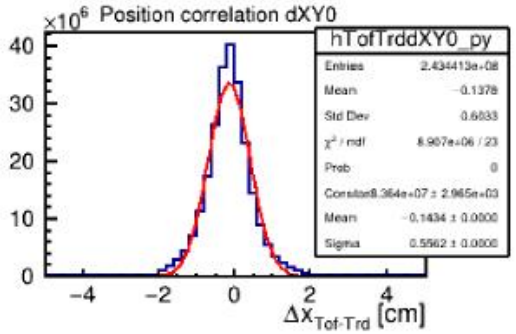
Run 2391

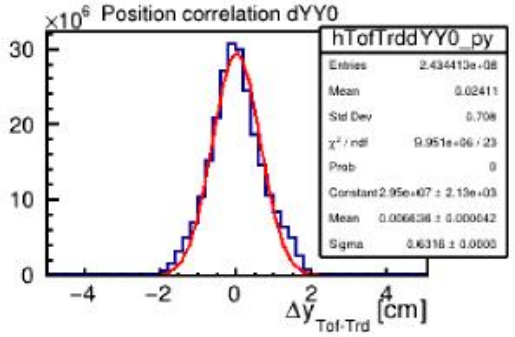
Data taken May 26, 2022
Duration: ~2h
5×10^7 ions per spill, 10s spill,
400 - 500 kHz collision rate

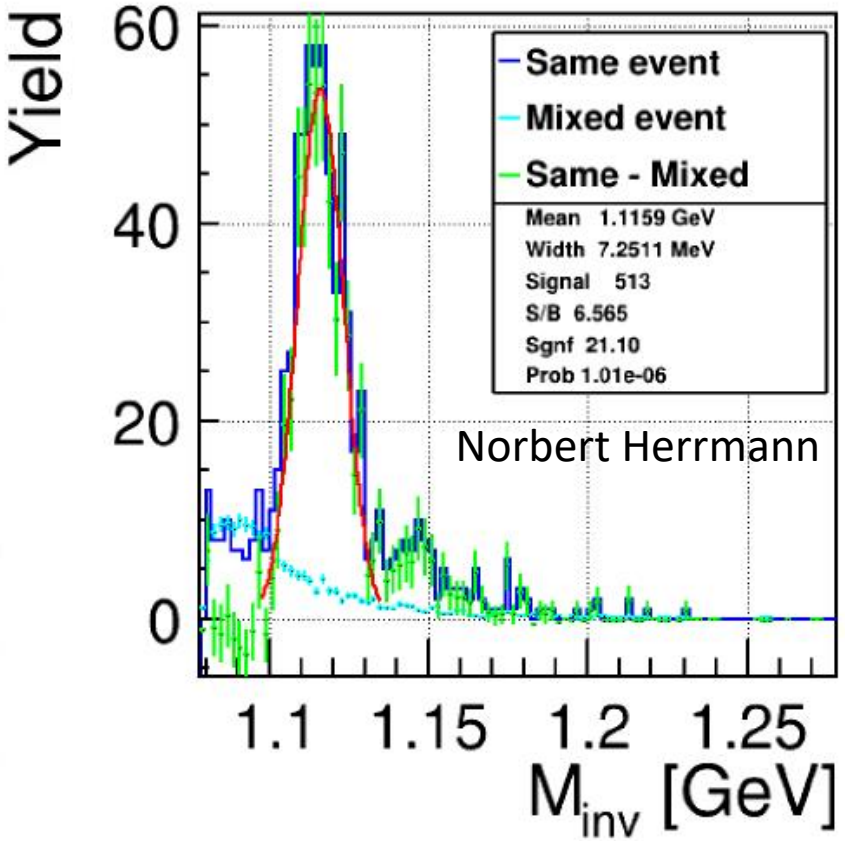
TOF calibration



TRD matches

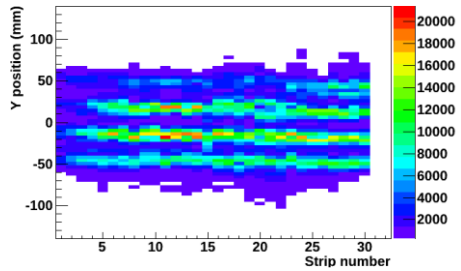




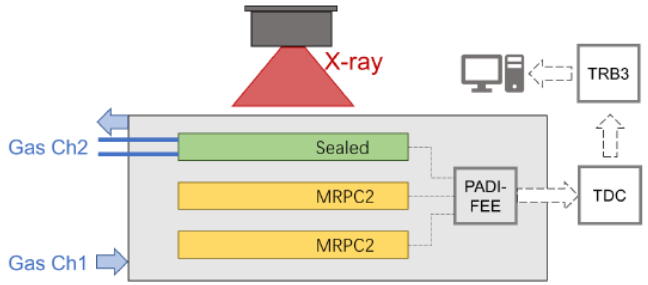


Aging & gas pollution

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

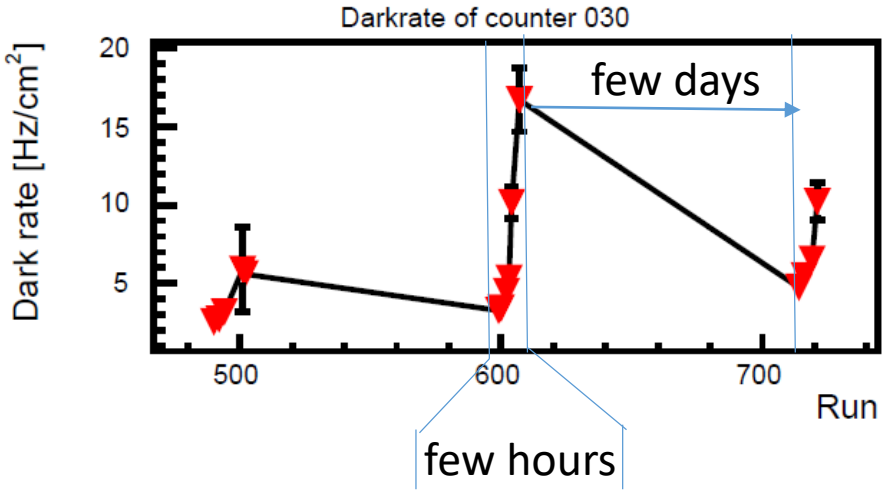


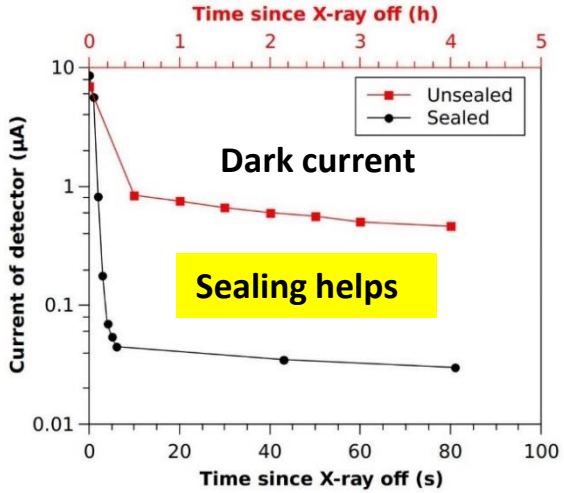
- Gas pollution effect was reproduced at IRASM (Bucharest) with high gamma flux
- X-Ray test at Beijing, Bucharest and USTC confirmed the gas pollution effect

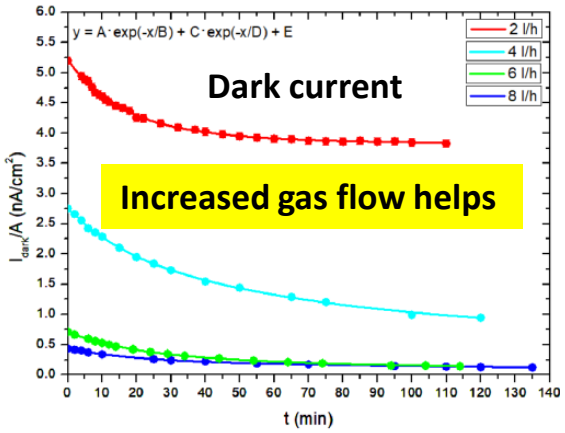


- The effect can be minimized by sealing the MRPC and increasing the gas flow
- Mitigation step might not be enough

Observations @ mCBM 2020
rapid increase of dark rate





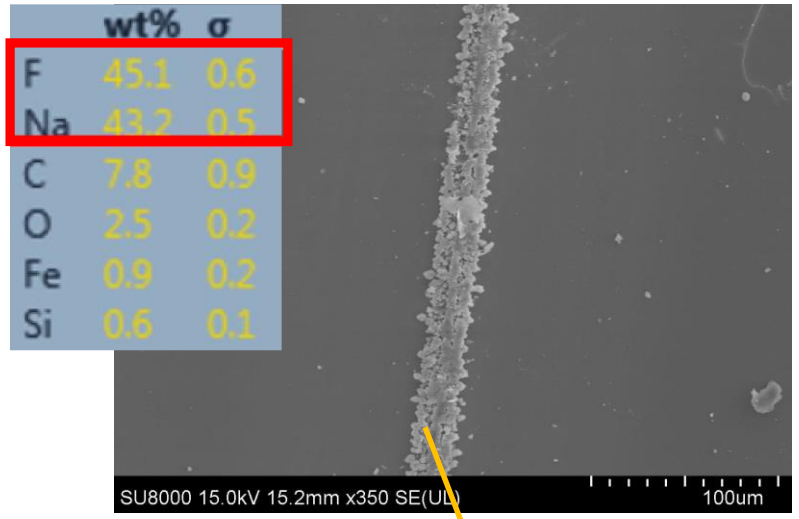


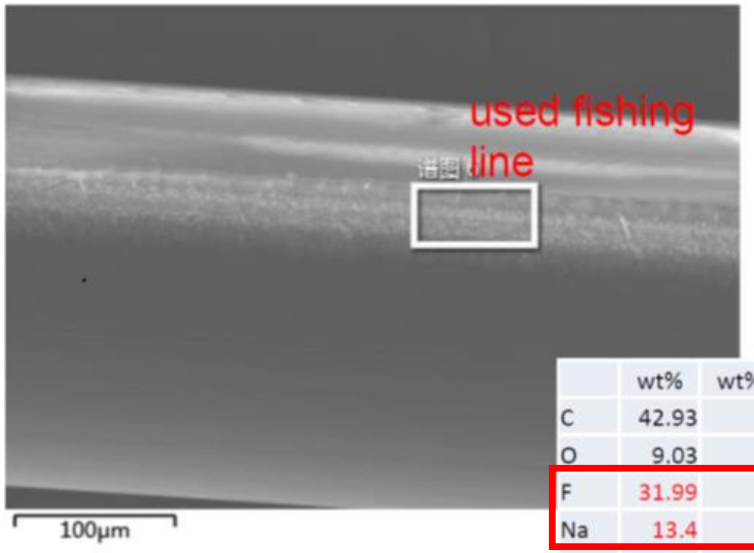
Dark current relaxation after irradiation

Aging & gas pollution

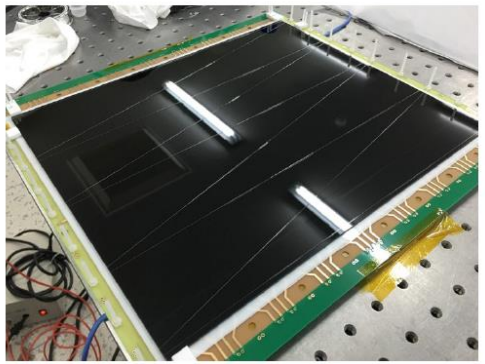
Observations: continuous increase in dark rate (permanent aging)

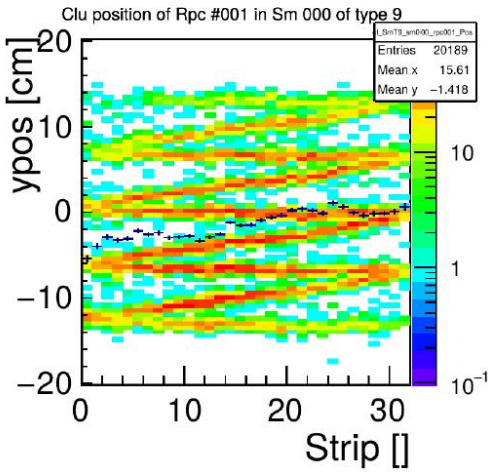
- Traces of NaF was found on the glass surface
- Dark rate (noise) is generated entirely on spacers (fishing lines)
- Electrical field simulations performed: in close vicinity to spacer touching point the E-field is 4 times higher

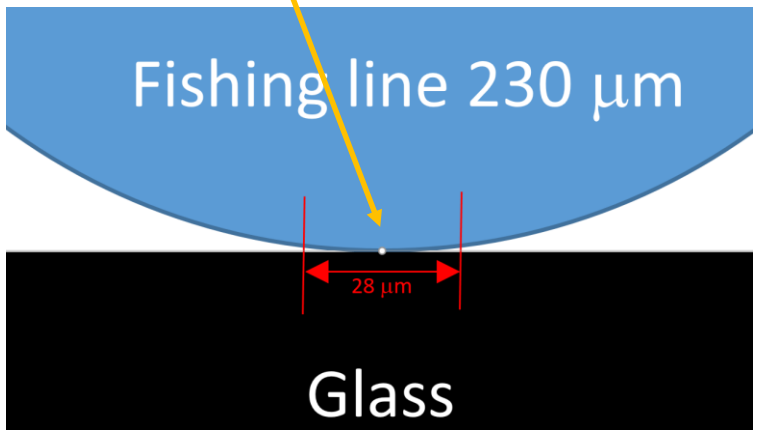




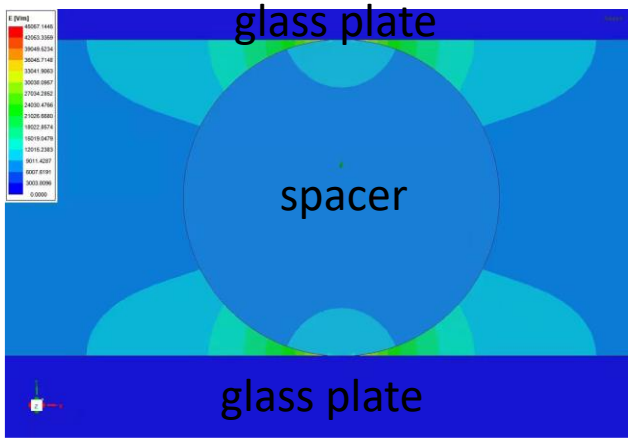
	wt%	wt% Sigma
C	42.93	0.21
O	9.03	0.15
F	31.99	0.18
Na	13.4	0.1
Si	2.36	0.04
Pt	0.28	0.07





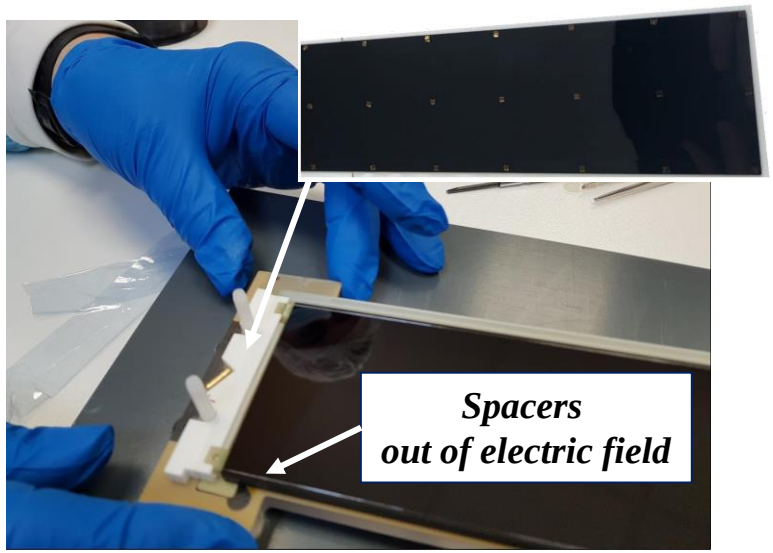


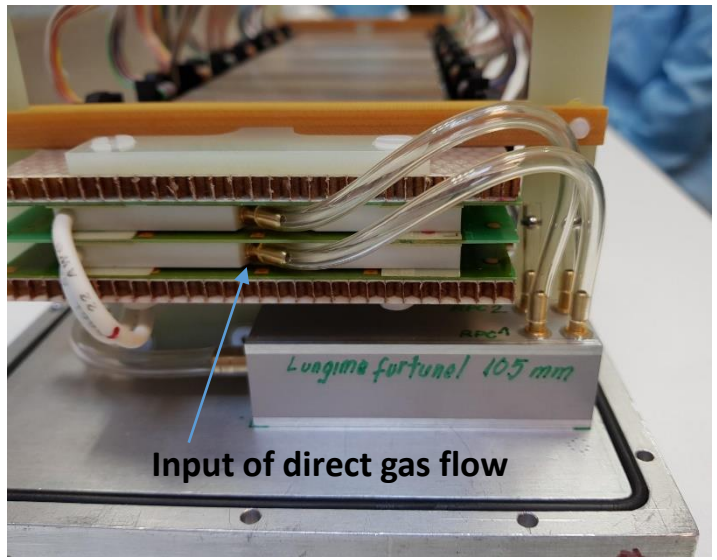
Electrical field simulations

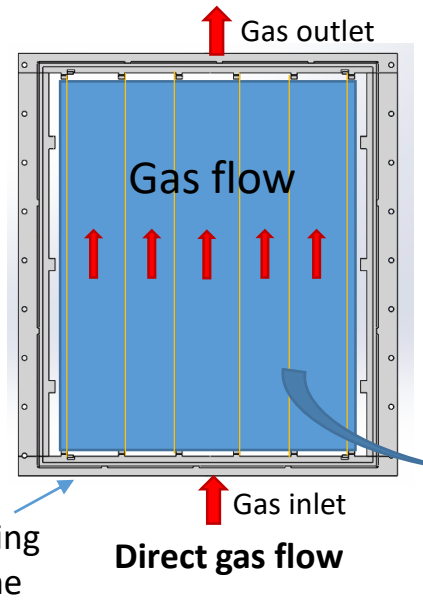


Mitigation of gas pollution and aging

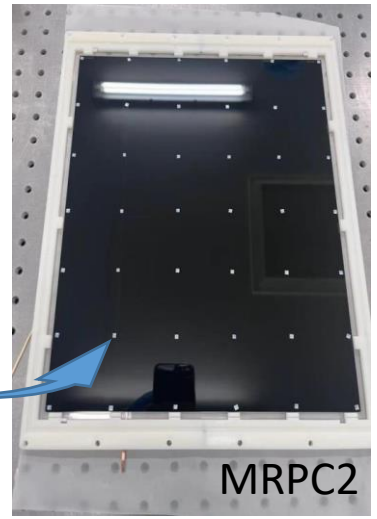
High rate counter (MRPC1)



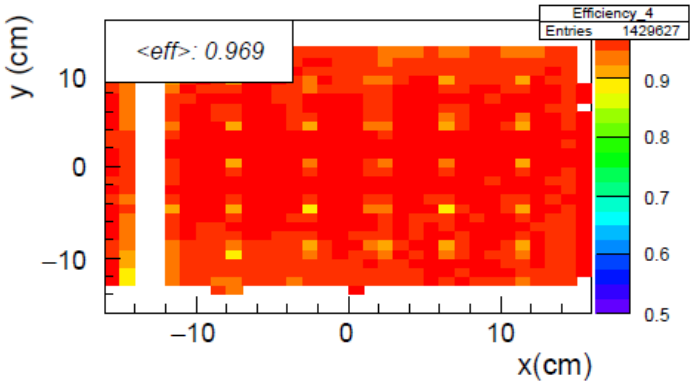




Introduction of pad spacers

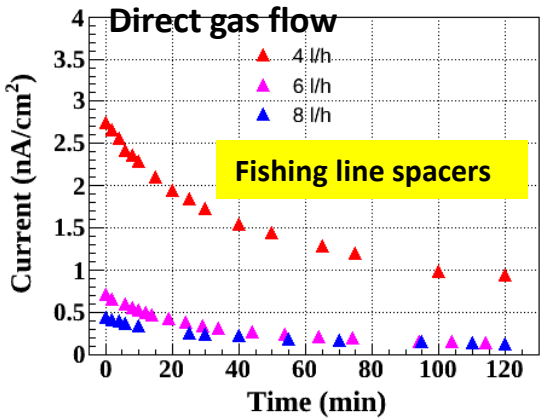


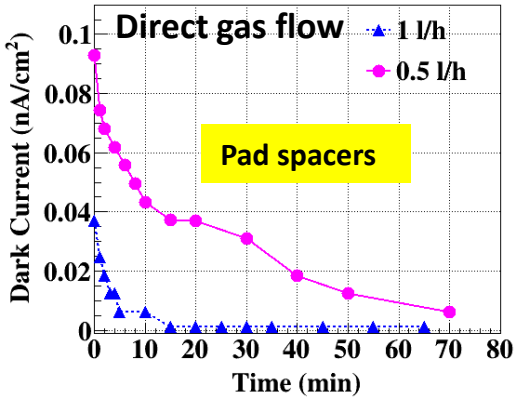
Efficiency of MRPC2

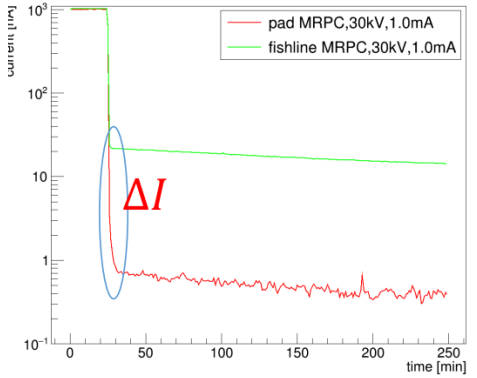


Mitigation strategies of CBM TOF: Direct gas flow + pad spacers

Current behavior after X-ray exposer





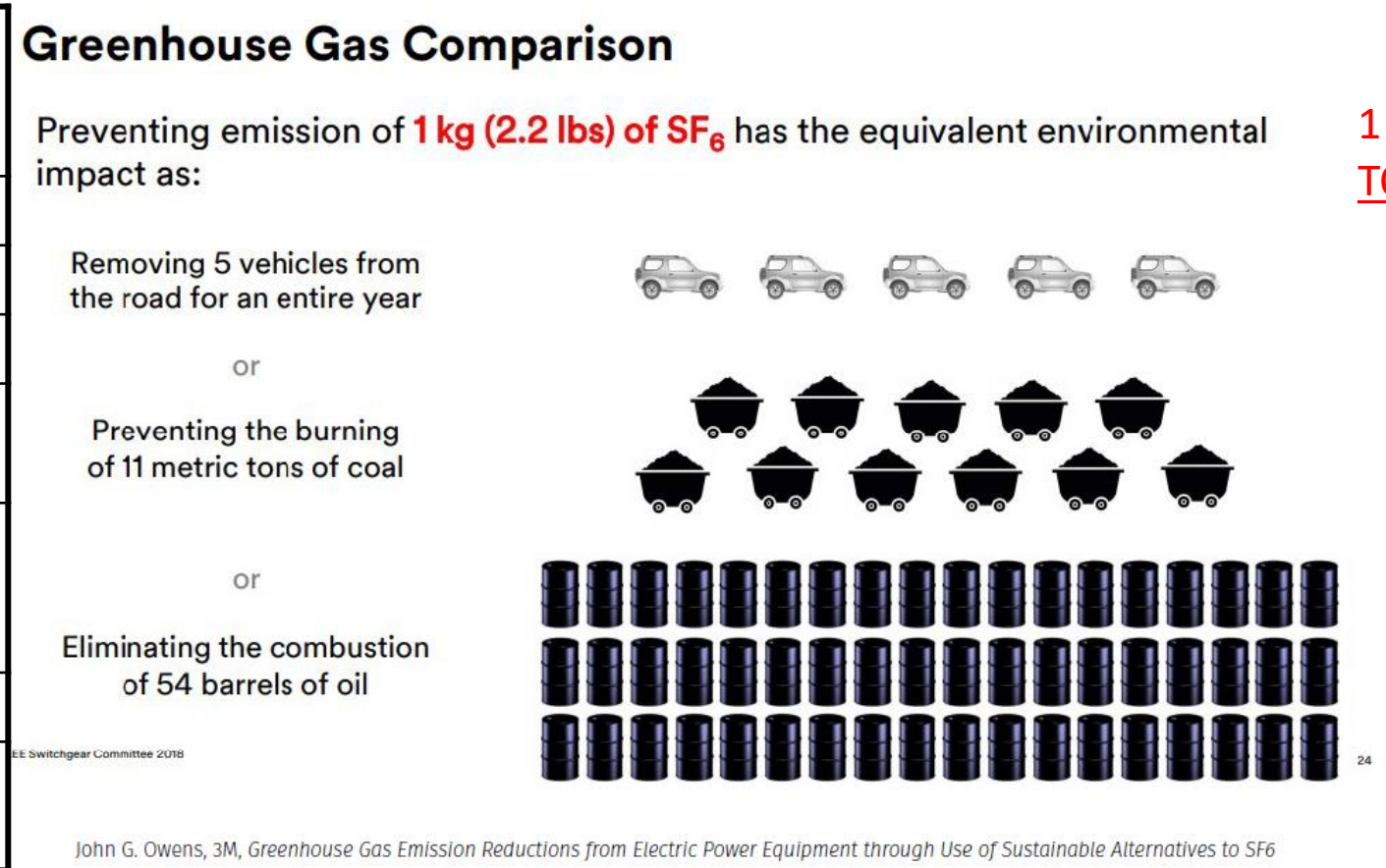


Current decrease after turning off X-ray

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)	

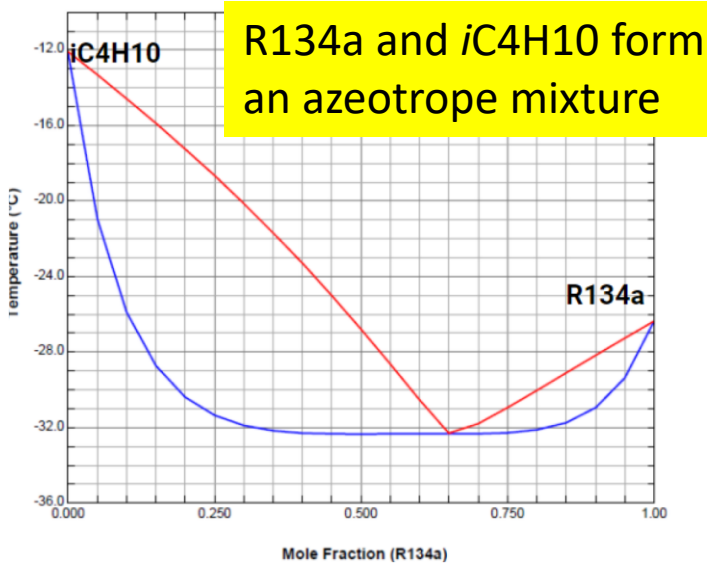


John G. Owens, 3M, *Greenhouse Gas Emission Reductions from Electric Power Equipment through Use of Sustainable Alternatives to SF6*

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

Conclusions for the CBM TOF gas system

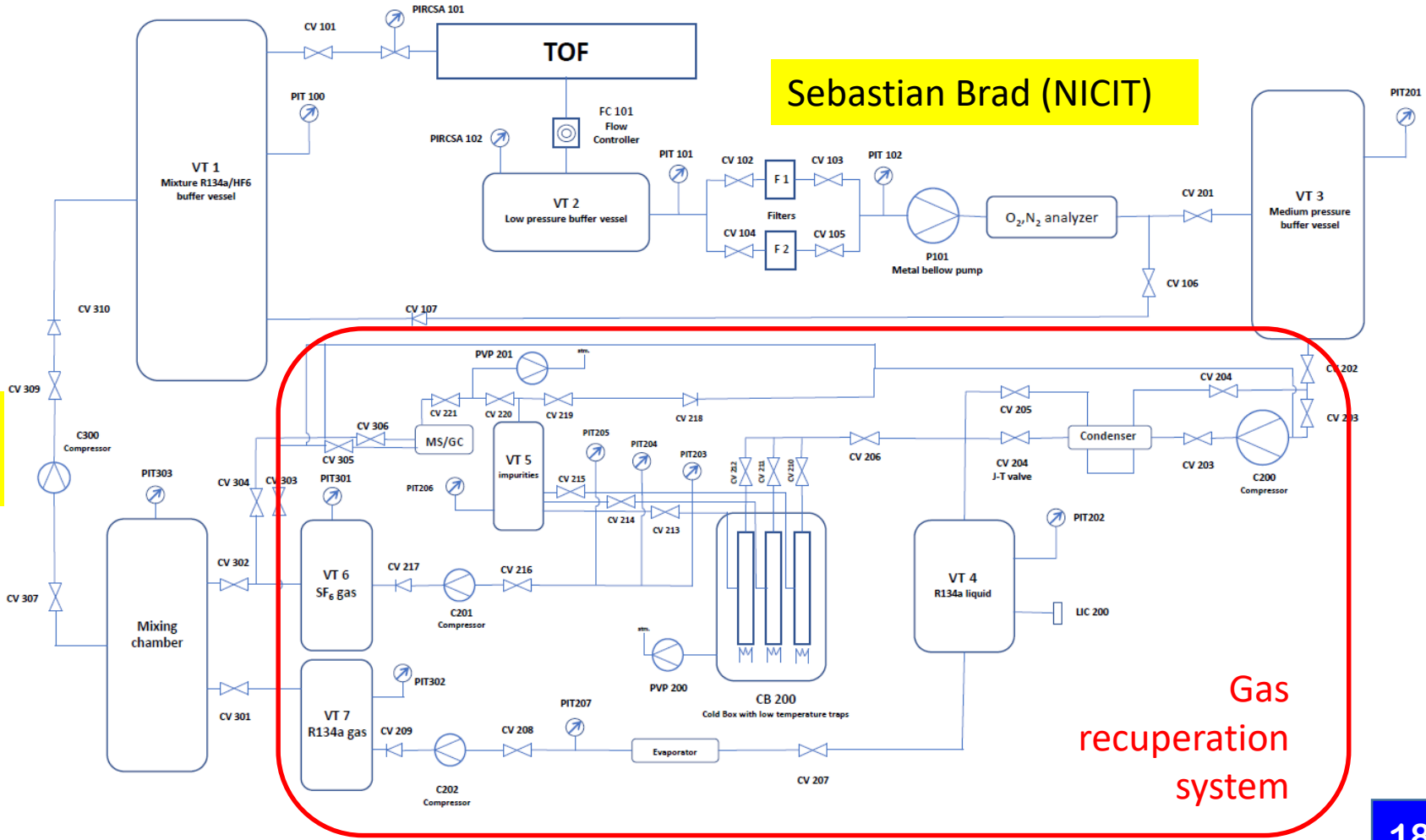
- Stay with Tetrafluorethane (R134a) (enhanced F-ion production for HFO in high rate environment)
- Abandon iso-Butan (aging , safety, difficult to recycle)
- Reduce fraction of SF_6 to 2.5% (reduction of GWP, difficult to recycle)
- Increase the flow rate
- Build a recuperation system (reuse of gas,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



R134a and *i*C4H10 form an azeotrope mixture

230 modules
Total gas volume 25 m³

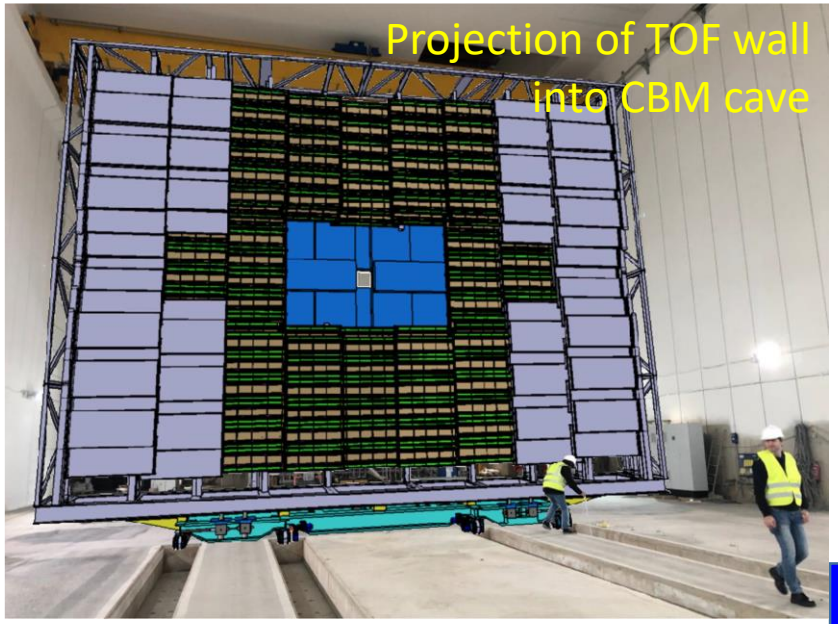
Sebastian Brad (NICIT)



Gas recuperation system

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 perfumed very well during BESII and is a key component in the physics analysis
- MRPC aging and gas pollution effects at high rates observed
  - mitigation strategies established
  - new counter with adopted designs developed, built and tested at mCBM in Dec. 23
  - Counter mass production in China started 07/24
- Standard gas mixture has high environmental impact
- 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 start (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

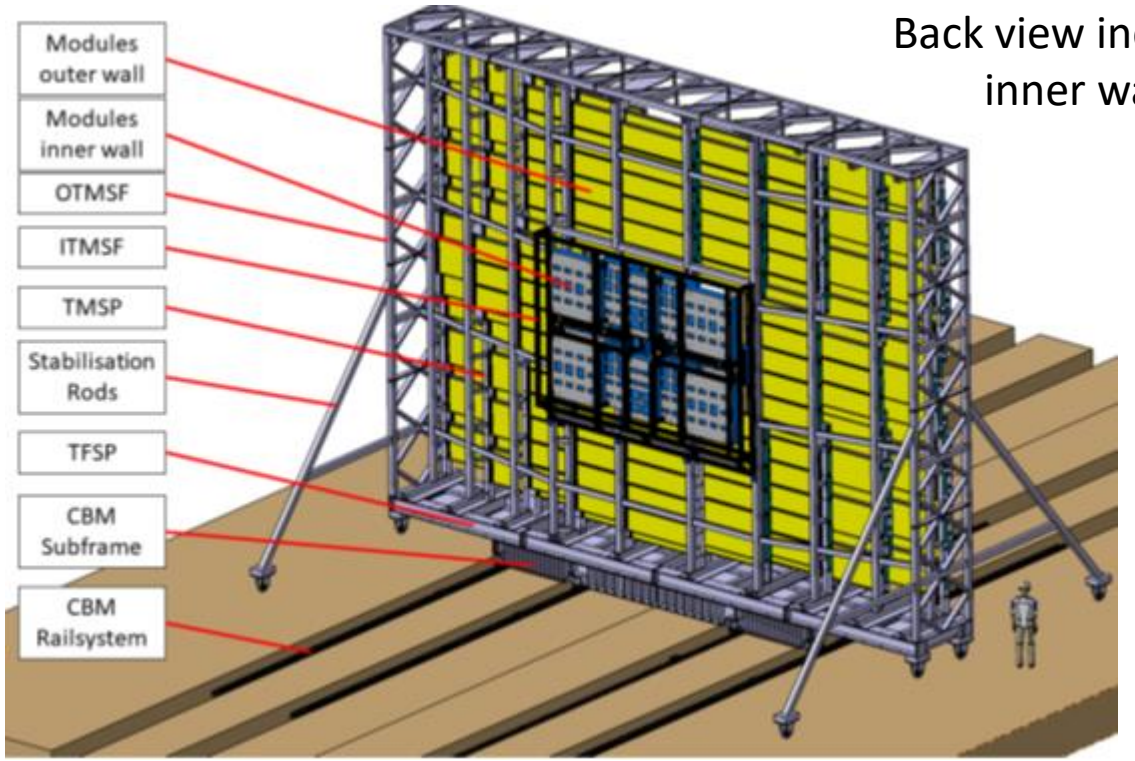
bmb+f
Großgeräte der physikalischen Grundlagenforschung

STRONG 2020

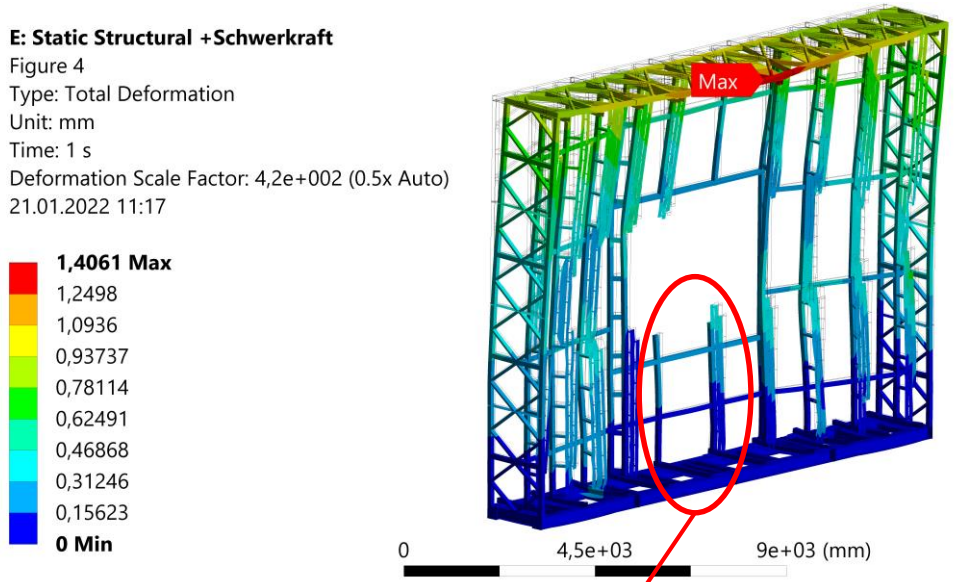
FAIR
FAIR — Facility for Antiproton and Ion Research in Europe

FAIR
Phase 0
Research Program

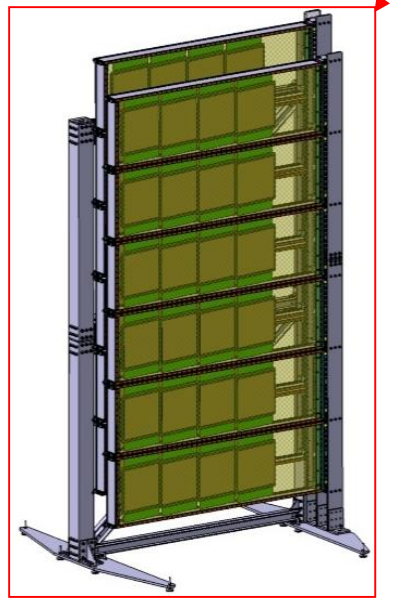
Main frame design



Back view incl. inner wall

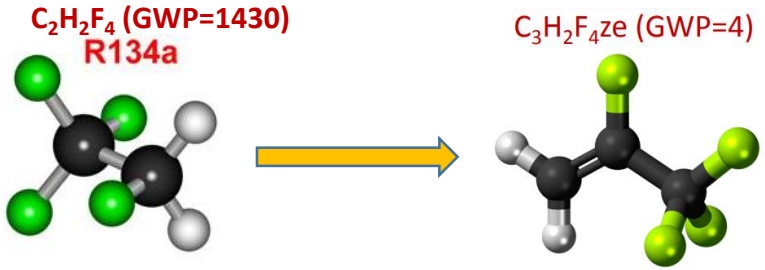


Mockup frame + 12 modules



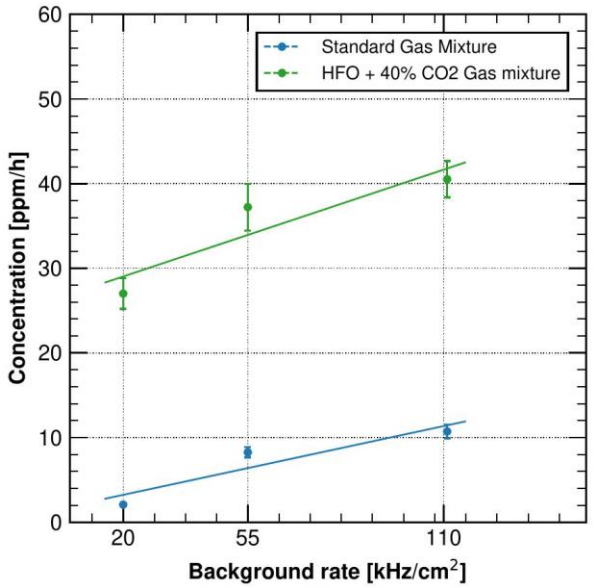
- TOF frame entered engineering design phase
- Outer module design almost complete (and tested in mCBM)
- Suspension for modules for low material budget and fast and easy mounting designed
- Stability calculations of the frame performed (ANSIS)
- Mockup frame for testing of module mounting procedure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

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)