

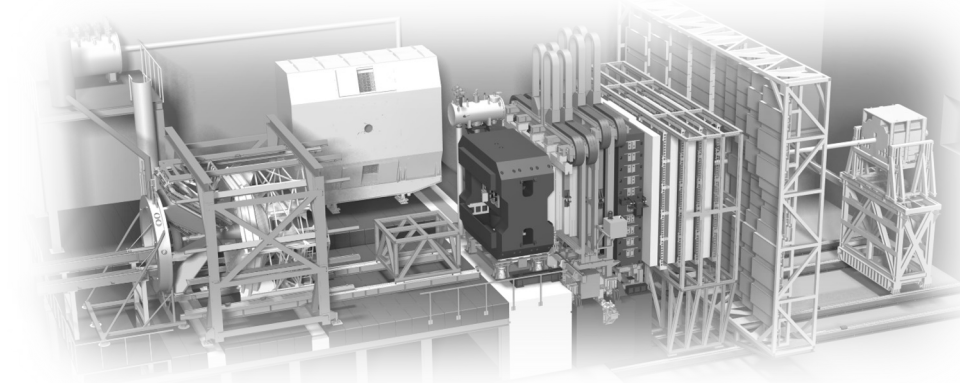
## Status of experiments (CBM and HADES)

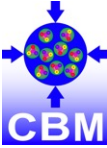
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Tetyana Galatyuk, GSI / TU Darmstadt

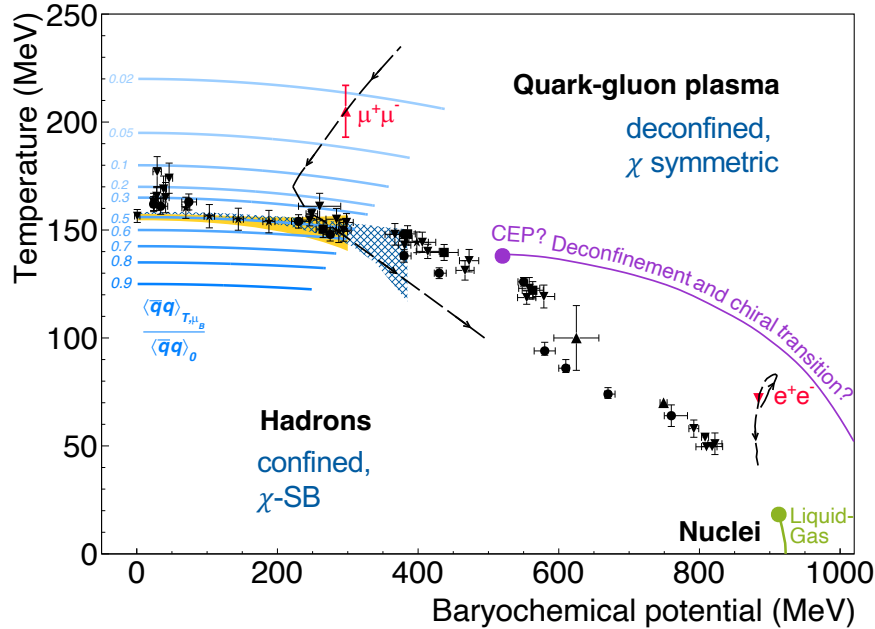
13<sup>th</sup> meeting of the FAIR RRBs

May 16-17, 2024





# Compressed baryonic matter objectives



## Search for landmarks of the QCD matter phase diagram:

- isolate unambiguous signals of new phases of QCD matter, order of phase transitions, conjectured QCD critical point
- probe microscopic matter properties
- heavy-ion beams

## Study various aspects of meson/baryon physics:

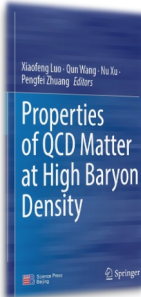
- (*u, d, s, c*) production mechanism, spectra, correlations
- em transition form-factors
- secondary pion, *p, d* beams

Worldwide experimental and theoretical efforts

Relevance for astrophysics

HADES, Nature Phys. 15 (2019) 10, 1040-1045  
 NA60, Specht *et al.*, AIP Conf.Proc. (2010) 1322  
 Andronic *et al.*, Nature 561 (2018) no.7723

[HotQCD], PLB 795 (2019) 15-21  
 [Wuppertal-Budapest], PRL 125 (2020)  
 Fu, Pawłowski, Rennecke, PRD 101, 053032 (2020)  
 Bernhardt, Fischer and Isserstedt, PLB 841 (2023)  
 Hippert *et al.*, arXiv:2309.00579  
 Basar, arXiv:2312.06952



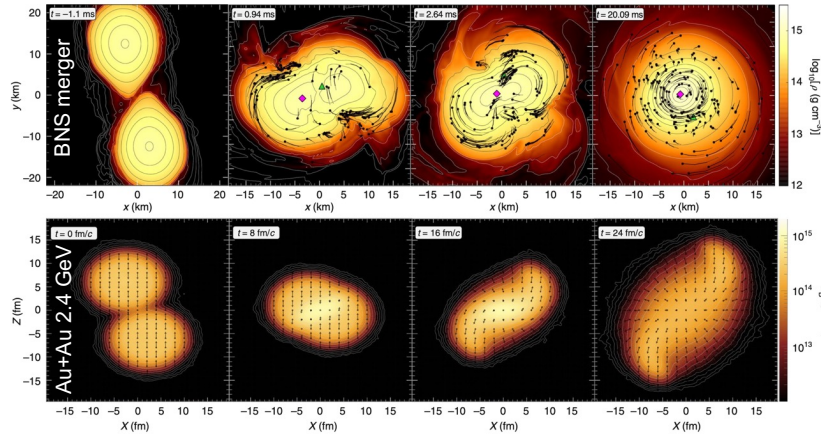
Chen, Dong, Fukushima, Galatyuk, *et al.*,  
 doi:10.1007/978-981-19-4441-3\_4 (2022)

# Laboratory studies of the matter properties in compact stellar objects

ARTICLES  
<https://doi.org/10.1038/s41567-019-0583-8>  
 nature physics

Probing dense baryon-rich matter with virtual photons  
 The HADES Collaboration\*

18 orders of magnitude in scales  
 still similar  $T < 70$  MeV,  $\rho < 3\rho_0$  for both

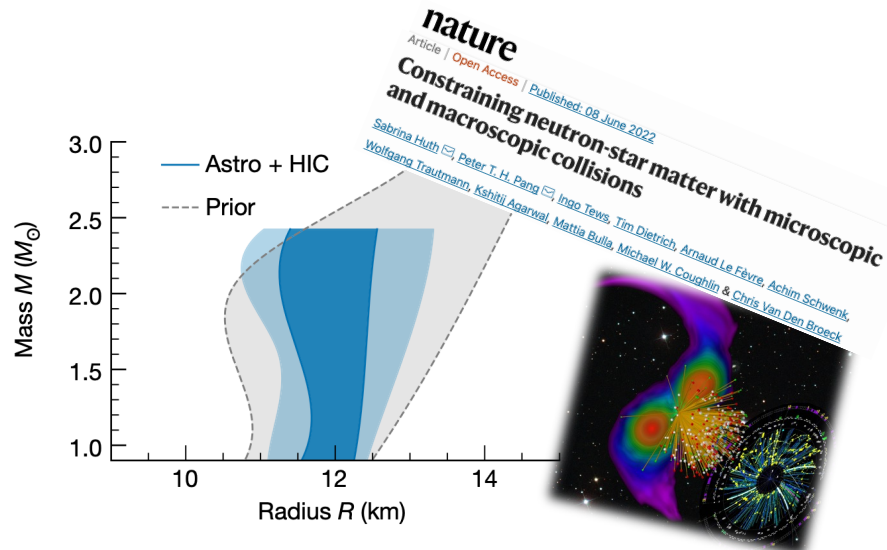
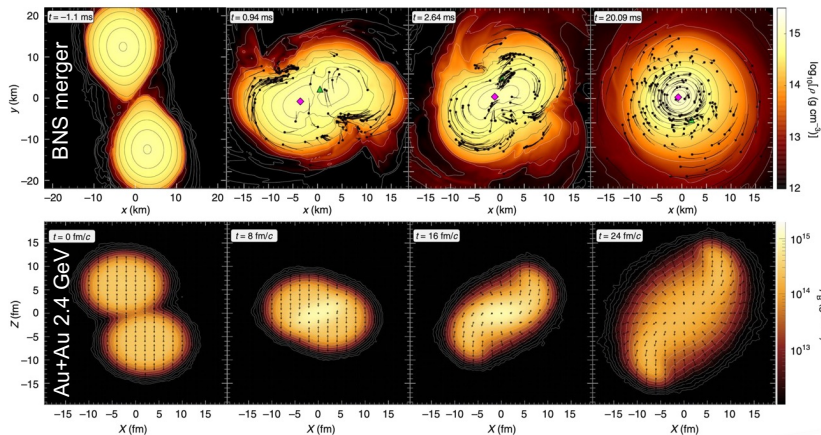


# Laboratory studies of the matter properties in compact stellar objects

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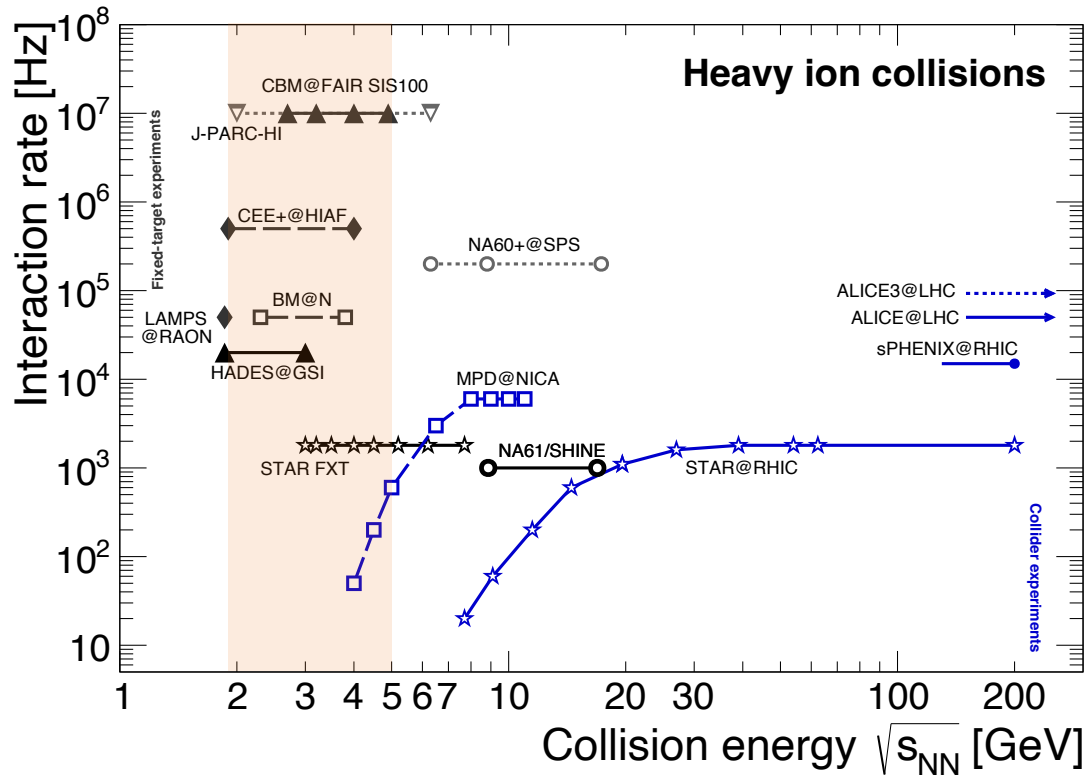
Remarkable consistency between multi-messenger observations and constraints from heavy-ion data

Going forward,  
 it is important that both statistic and systematic sources of uncertainty  
 for HIC experiments are further improved.

advancing HIC experiments to probe higher densities,  
 above  $2-3n_{\text{sat}}$ , will be key



# Some basic facts on high $\mu_B$ facilities

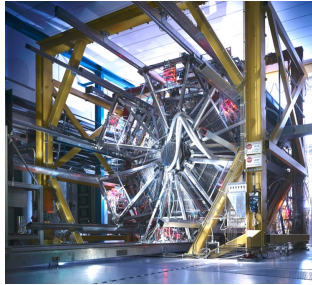


## Program needs ever more precise data and sensitivity for rarest signals

- **CBM** will play a unique role in the exploration of the QCD phase diagram in the region of high  $\mu_B$  with rare and electromagnetic probes: high rate capability
- **HADES**: established thermal radiation at high  $\mu_B$ , limited to 20kHz and  $\sqrt{s_{NN}}=2.4$  GeV
- STAR FXT@RHIC: BES program completed; limited capabilities for rare probes
- CEE+@HIAF construction: multipurpose detector based on TPC, anticipated rate capability 500 kHz
- J-PARC-HI proposal
- BM@N: limited capabilities for rare probes
- $\mu_B \cong 0$ : ALICE / ALICE 3: exploit the forefront detector technologies and high luminosity potential of the LHC for ions

# Facility for Antiproton and Ion Research

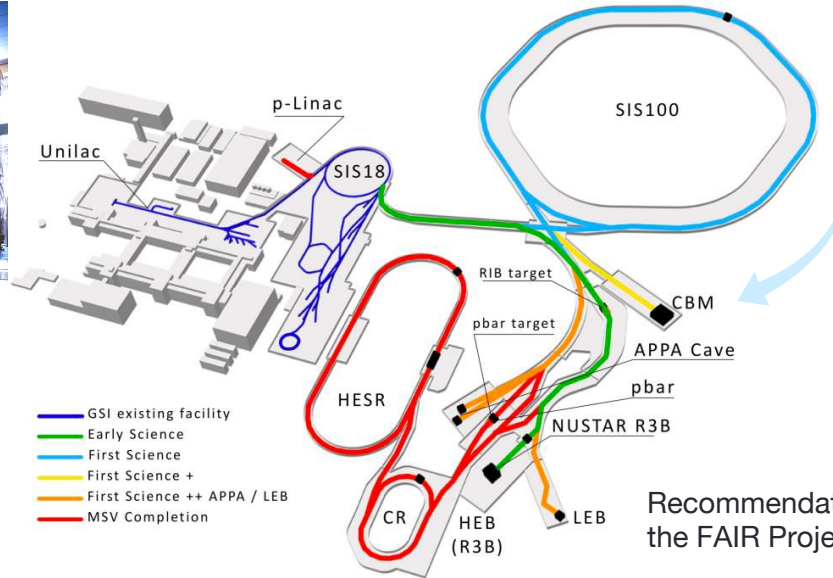
HADES at SIS18



**FAIR Phase-0 at GSI**  
~3 month beamtime/year

**CBM Phase-0**  
@HADES, mCBM

**PANDA Phase-0**  
@HADES



CBM at SIS100



© GSI/FAIR, Zeitrausch

Recommendation of the "First Science and Staging Review of the FAIR Project" (endorsed by the FAIR Council in Oct. 2022):

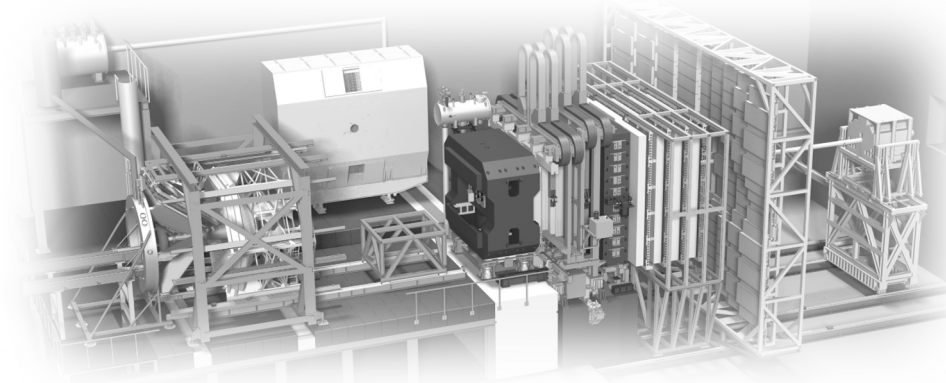
Prioritize implementation of Scenario #3: SIS100, Super-FRS-HEB, CBM - the most appropriate start scenario to achieve world-leading science

**FS+ currently not fully funded**

# Compressed Baryonic Matter experiment

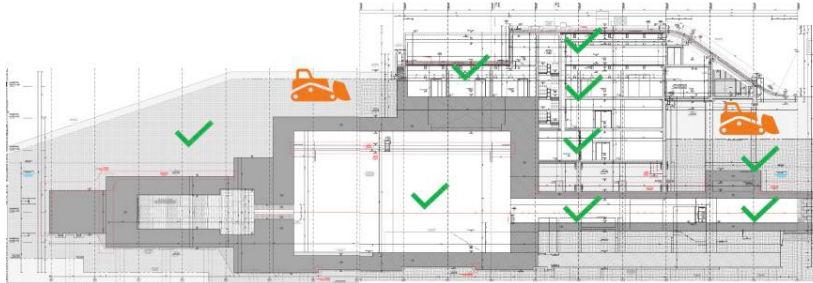
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**CBM**



# CBM building status

- Shell construction and finishing works are completed
- Waiting for the **road** and **crane** to allow timely installation of magnet foundation, upstream platform – concrete, rail system, cryo platform (>2024)
- CBM cave will serve CBM/HADES, hadron physics, BIOMAT (TDRs BIOMAT at S-FRS and CBM under evaluation)
- **TBI of CBM building: council decision in June 2024** ~ TBI installation in 2025

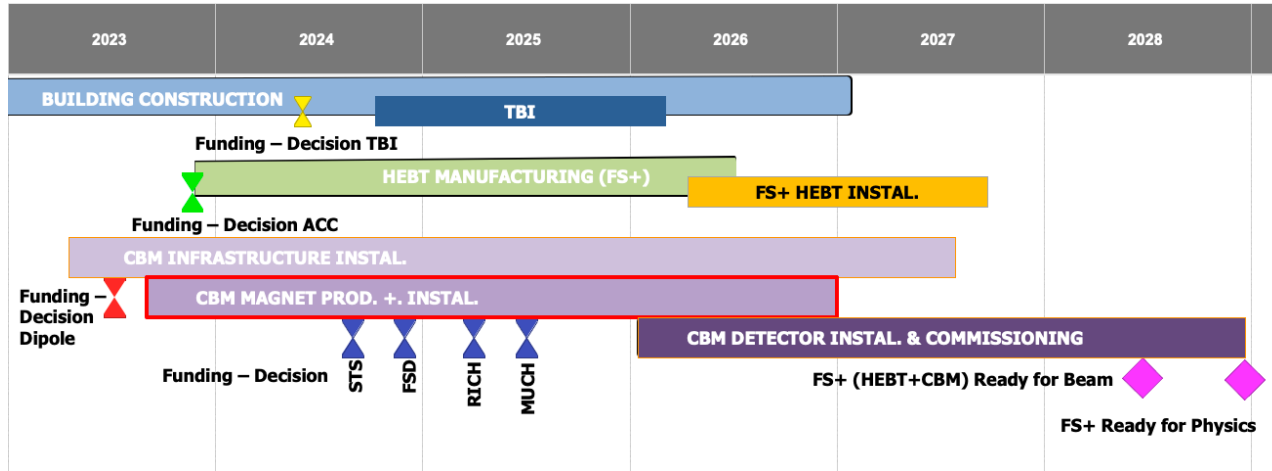


## CBM Technical Building Infrastructure - Status





# Key milestones for timely CBM realization



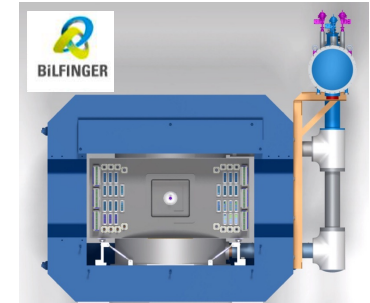
- Strategy: get subprojects approved step-by-step

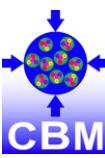
**magnet contract signed by FAIR management, award of contract to Bilfinger Noell GmbH 20.12.2023, re-procurement accomplished!**

next step: HEFT to CBM cave (Jul. 2024)

**critical next step:** TBI of CBM building (Jul. 2024)  
commissioning of buildings and detector installation requires timely completion of TBI

Designation	Estimated Date
Award of contract	20.12.23
Preliminary Design Review (PDR)	20.03.24
Conceptual Design Review (CDR)	20.06/24
Final Design Review (FDR)	23.12.24
Final Acceptance Test FAT	24.04.26
Shipment incl. documentation	25.05.26
Site Acceptance Test (SAT)	09.09.26
Final Acceptance	20.01.27
Magnetic field mapping	20.04.27





# Funding situation for Day-1 setup

## Project funds

- critical for success: Council release of available project funds for experiments for the following re-procurement
- re-procurement (X) of Russian IKCs required for timely installation of CBM experiment

## 3rd party funds

- 84,3% secured funding
- secured funding will increase after Council decisions

## Common Fund (CF)

- ~22% Russian contribution to CF (M€ ~0,7+0,3) are not covered at present
- amendment of the Construction MoU (endorsed at CBM Collaboration Board, presented to ECE in Apr. 2024) → next RRB approval

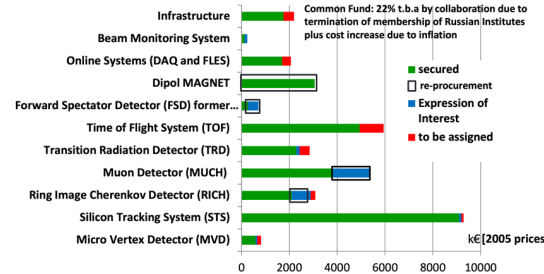
## German university funds (BMBF):

- all groups are **largely funded** in period 2024 – 2027
- RICH, TRD and TOF – funds for coverage of reduced solid angle
- participation to Generic R&D consortia and DRDs

Table 1: Components/services to be procured for the completion of the CBM science programme, their estimated costs (current price level) and their latest date for procurement/expense to keep the timeline.

1	EXP	CBM SC Dipole magnet	4-5 Mio. €	July 2023
2	EXP	CBM Silicon Tracker System	0,9 Mio. €	Q3 2024
3	EXP	CBM PSD	0,5 Mio. €	Q4 2024
4	EXP	CBM RICH	1,0 Mio. €	Q2 2025
5	EXP	CBM MUCH	2,0 Mio. €	Q3 2025
6	ACC	CBM beamline magnets	4,2 Mio. €	Q4 2024
7	ACC	CBM beamline vacuum comp.	2,3 Mio. €	Q4 2024
8	S&B	TGA CBM cave	14,3 Mio. €	Q2 2024
9	S&B	TGA CBM cave risks	7 Mio. €	2024/2025
		<b>Sum</b>	<b>ca. 37 Mio. €</b>	

for details talks J. Eschke



total cost: M€ 35,27 (2005 Euro)  
 secured: M€ 29,73  
 Eol: M€ 3,22  
 t.b.a.: M€ 2,21

84,3% secured funding

Amendment CBM C-MoU

22.04.2024

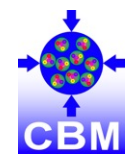
Amendment to the CBM Construction Memorandum of Understanding (C-MoU)

The CBM Construction Memorandum of Understanding dated 15.04.2020 is modified in the provisions addressed by this Amendment.  
 All other provisions of the CBM Construction MoU and its Annexes remain unchanged.

All subsystems are on the verge of series production

Pre-production is ongoing in (almost) all systems





# CBM system mass production

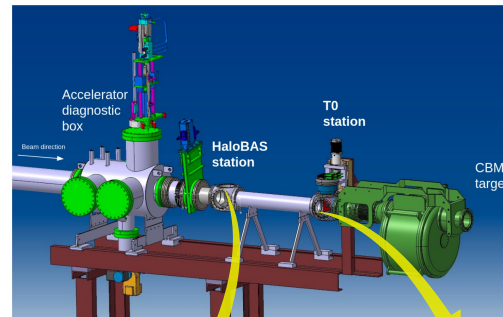
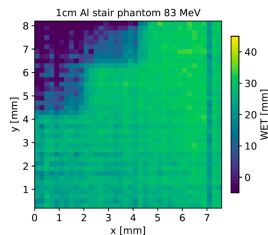
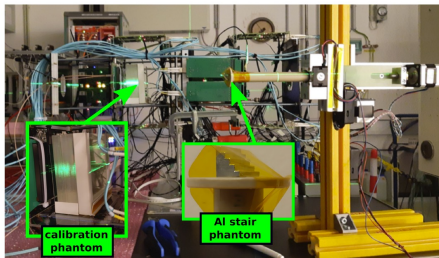
## Beam monitoring system (BMON)

- T0 determination & beam focusing/monitoring (fast beam abort system)
- T0 high purity pcCVD diamond demonstrator successfully tested in mCBM runs
- novel sensor technologies (LGAD, SiC) under investigation

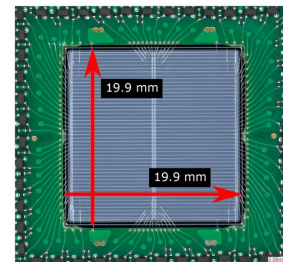
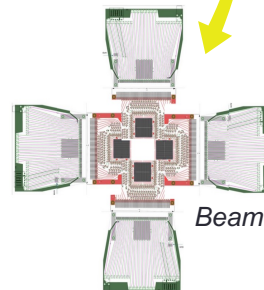


## LGAD-based ion imaging system

MedAustron testbeam in April 2023



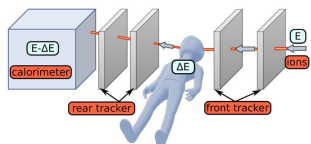
T0 at mCBM



LGAD sensor



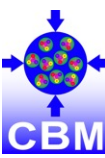
1cm x 1cm x 80 μm pcCVD diamond sensor



$$\int_L RSP(\vec{x}(s)) ds = WEPL(E, \Delta E)$$

## First TOF-based pRad

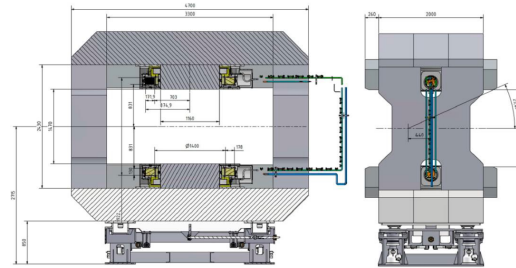
Ulrich-Pur et al., Phys.Med.Biol. 69 (2024) 7, 075031



# CBM tracking system

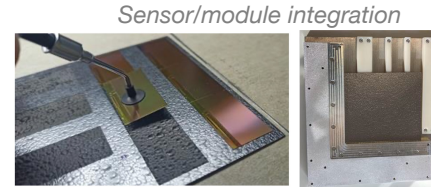
## Superconducting dipole magnet

- award of contract to Bilfinger Noell GmbH 20.12.2023
- preliminary Design Review took place on April 17, 2024



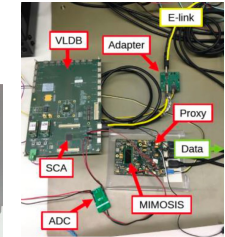
## Micro Vertex Detector (MVD)

- intensive test campaigns of full-size MAPS prototype MIMOSIS-2.1
- start of MIMOSIS-3 design towards PRR
- preparation of MS EDR/PRR on sensor integration and modules/half station (carrier, cold plates)



Sensor/module integration

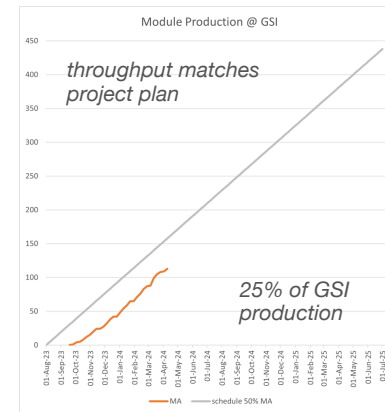
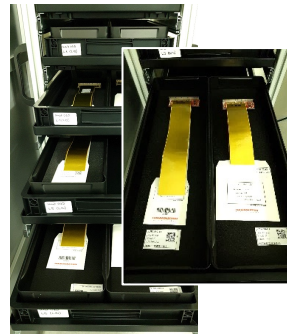
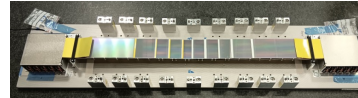
Test setup CBM read-out



## Silicon Tracking System (STS)

- new Project Leader Christian Schmidt (GSI)
- module and ladder series assembly started, > 100 modules assembled
- mechanical survey matches specifications
- full tests under preparation → PRR
- excellent performance in mCBM runs 2022/2024 proven

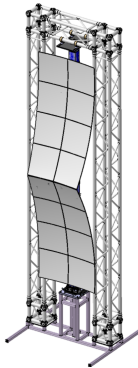
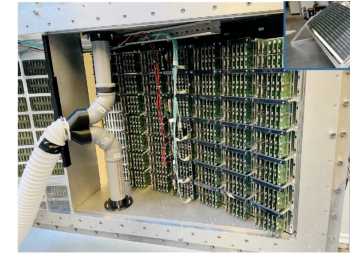
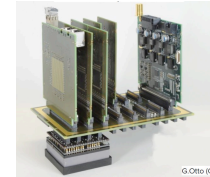
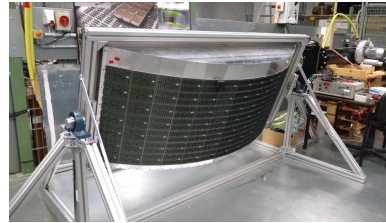
first CBM-STs series ladder



# CBM particle identification detectors

## Ring Imaging Cherenkov detector (RICH)

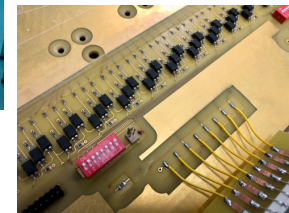
- 1 of 2 photo cameras ready
- 50% FEE produced
- cooling air distribution installed, being tested now
- first complete technical design of mirror wall, first prototype ready



## MUon CHamber system (MUCH)

- new Project Leader: Arup Bandyopadhyay (VECC)
- intensive test campaigns of full-size GEM and RPC prototypes at GIF++ and mCBM, readout stability
- MUCH GEM chamber production protocol. Steps towards the PRR
- high-voltage scheme simulations and optimisation
- high-rate tests preparation of the hadron test beam at mCBM

CBM TC visit in VECC Kolkata (06-10.05.2024)

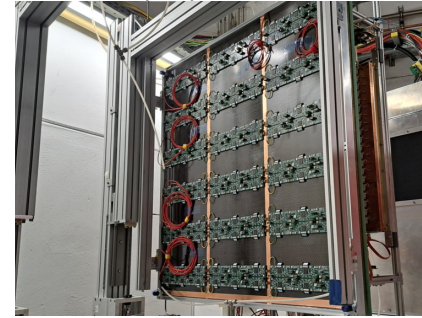


# CBM particle identification detectors

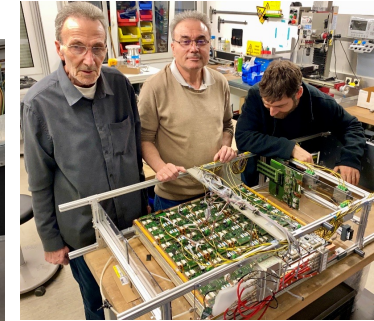
## Transition Radiation Detector (TRD)

- first pre-production modules of 1D and 2D options ready
- TRD-2D module fully equipped with new FASP read-out electronic, important test within mCBM

*TRD pre-production module*



*TRD-2D module*



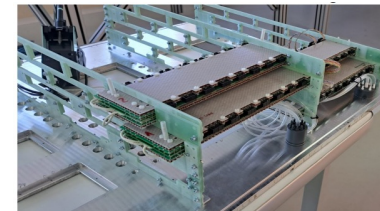
## Time of flight detector (TOF)

- counter pre-production concluded, PRR in May/June
- TOF module M0 production

*TOF in mCBM*



*TOF module pre-production*



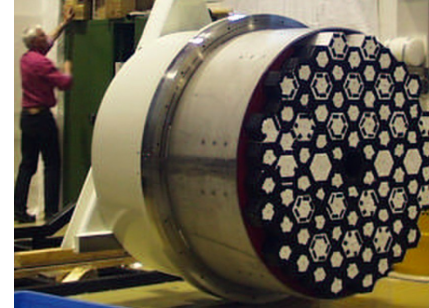


# CBM centrality, event plane & neutron detector

## Forward Spectator Detector (FSD)

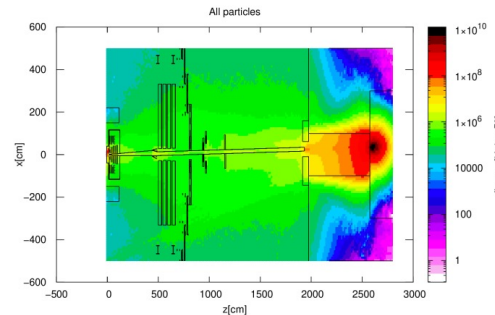
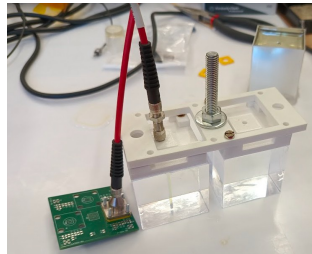
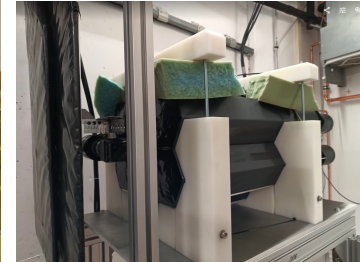
- FSD group developments:
  - secured finance of ~120K EUR for hardware from Czech government
  - funding from Czech Technical University for FSD full postdoc position
  - joining of Bochum University in Sep. 2023:
    - extension of physics program towards pp/dp collisions
    - in-king contributions to hardware: photomultipliers and forward neutron detector
  
- new design: ZnS scintillators and LYSO crystals for central part
- read-out via SiPM or/and PMT
- readout electronics based on existing solution: TRB+DiRICH
- extensive FLUKA studies of doses and neutron flux for radiation damage assessment
- GEANT simulation for physics performance, fix of detector geometry

COSY-TOF neutron detector



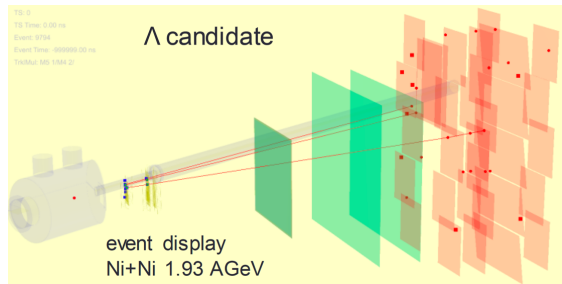
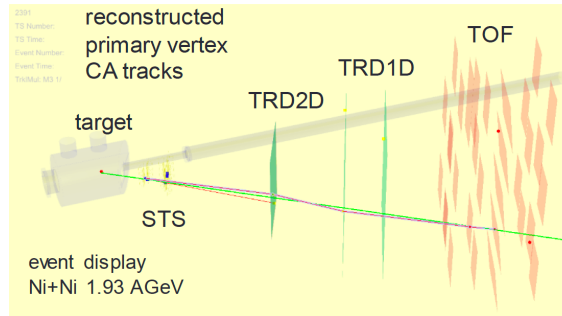
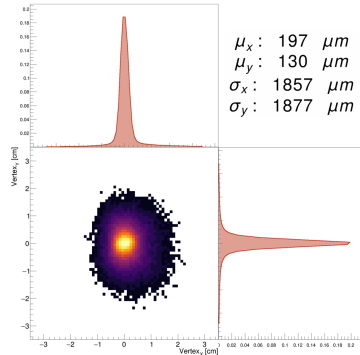
$\varnothing$  126 cm  
 84 modules,  $l = 45$  cm  
 plastic scintillator  
 neutron efficiency ~30%

test setup in mCBM

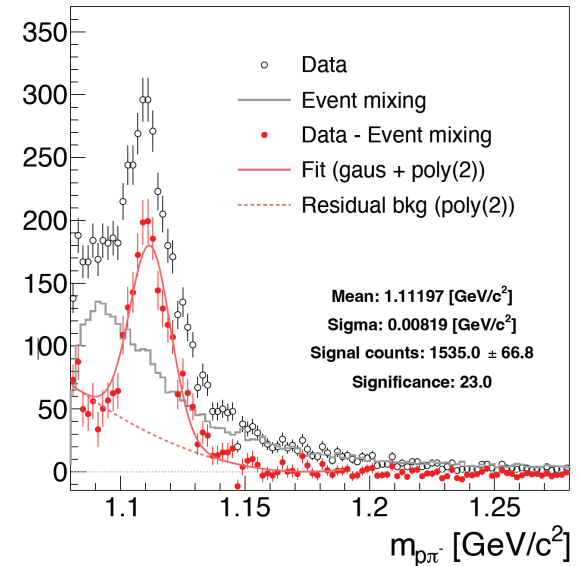


# CBM software development

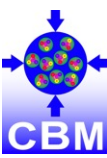
- Application to experiment data taken with mCBM in 2022
- $\Lambda$  candidates have been reconstructed using *CA+KFP* package



CBM CA track reconstruction  
 → input for CBM *KFP* package



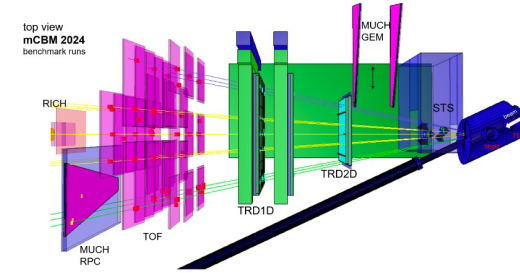




# mCBM campaign 2024 (G-22-00110)

## Updates to the setup:

- STS 3 stations, 6×6cm<sup>2</sup> module upstream (station 0) added
- TRD2D complete read-out
- TRD1D type-8 (768 ch) substituted by type-5 stations (3456 ch)
- TOF 2 complete RPC walls + test modules
- test system(s) FSD&NCAL, at 25° (and 0°), RICH read-out under test



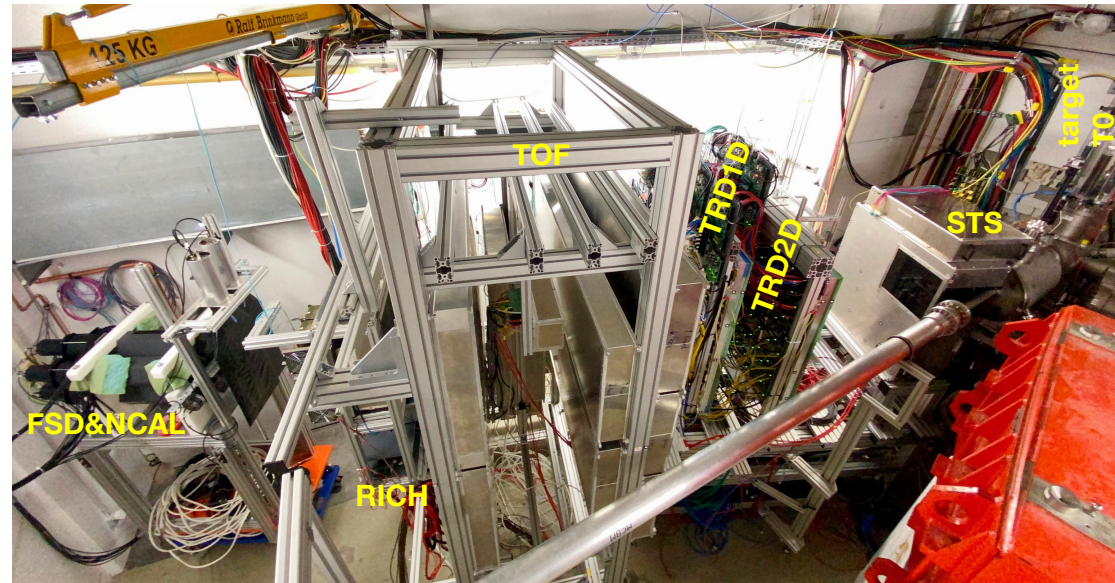
photograph: April 24th , 2024

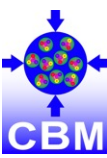
## Online system prototype:

- STS, TRD, TOF, RICH unpacker optimized
- DigiEvent building & filter on M<sub>digi</sub>
- STS & TRD & TOF hit reconstruction
- CA track reconstruction
- Select ion of events with  $\Lambda$  candidate

## Important role of mCBM >2025

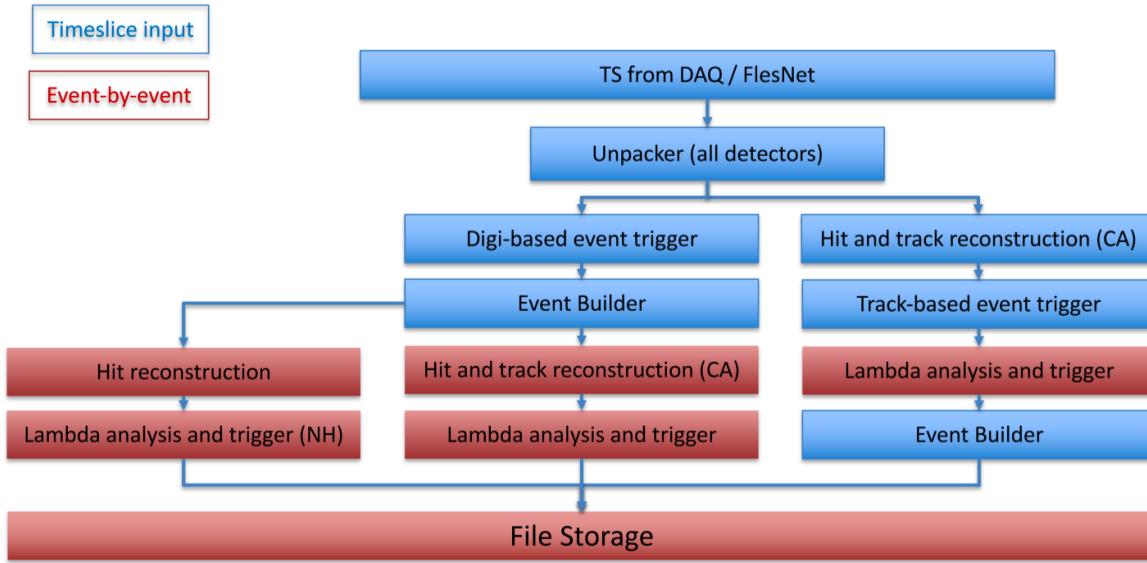
- tests of the (final) prototypes and (pre)production modules
- online data processing





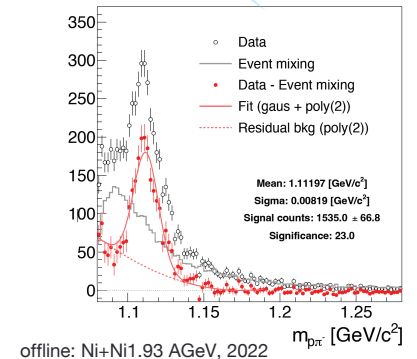
# Online Data Processing

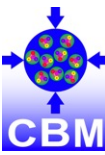
- Prototype of CBM online reconstruction and selection under development
- Archiving of all raw data is not possible, data reduction by online feature detection and selection
- Test with mCBM May 6-14, 2024 (completed)



## Objective Run 2024:

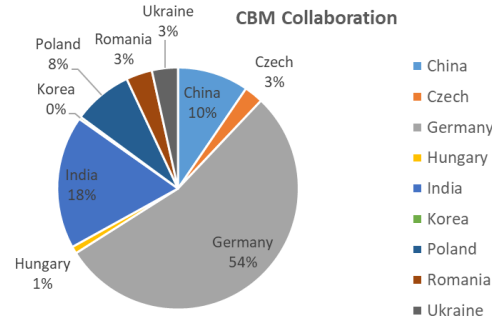
Ni+Ni at T = 1.93, 1.58, 1.23, 1.0 AGeV  
 Online reconstruction and selection  
 (events with  $\Lambda$  candidate)





# Collaboration status

- 47 full member institutions
- 10 associated member institutions
- from 10 countries, 315 full members
  
- Full membership: Jim Ritman, GSI and FFN (Univ. Bochum)
- Enhancement of CBM-Japan cooperation:
  - associated: KEK, Univ. Tsukuba, Hiroshima University
  - Eol: Nagasaki Institute of Applied Science, RIKEN
- Attracting new teams USA, Denmark, Taiwan



## Advertisements:

**FAIR**  
Facility for Antiproton and Ion Research

**GSI**  
Helmholtzzentrum für Schwerionenforschung GmbH

GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt operates one of the leading particle accelerators for science. Currently, the new FAIR Facility for Antiproton and Ion Research's one of the world's largest research projects, will be built in international cooperation. GSI and FAIR offer the opportunity to work together in this international environment with a team of employees committed to ensure each day to conduct world-class science.

For the department **FFN** we are looking for an

**Postdoc in Hadron Physics (all genders)**  
Posting ID: 24.55-4403

**RUB**  
Rheinisch-Westfälische  
Universität  
Bochum

Fakultät ▾ Studium ▾

**JOINT PROFESSORSHIP  
(m/f/div; W2) AT THE RUHR-  
UNIVERSITÄT BOCHUM AND AT  
GSI DARMSTADT IN  
EXPERIMENTAL PHYSICS IN  
THE FIELD OF EXPERIMENTAL  
EXPLORATION OF HADRONS**

10.04.24 | Stellenangebote

Ready for advertisement:  
W2, Goethe University in Frankfurt  
W2, Bergische University Wuppertal  
Senior Scientist, GSI, department HADES

# Early career researches (ECR) support

C.B.M. advocates for visibility of ECRs:

- in collaboration  $\leadsto$  CBM honors the outstanding doctoral theses, April 2024
  - *Dr Vikas Singhal, PhD from Homi Bhabha National Institute, Mumbai now at the Variable Energy Cyclotron Centre (VECC), Kolkata, India,*
  - *Dr Marcel Bajdel, PhD from Goethe University in Frankfurt employed at the GSI*
- nationally and internationally  $\leadsto$  visible contributions at conferences/workshops, participation in the international schools
- supporting with travel grants  
*(May 2024 - Abhishek Kumar Sharma, Aligarh Muslim University, India. Participation to "European AI for Fundamental Physics Conference 2024", Amsterdam, Netherlands, and a follow-up stay at GSI)*







# Special state funding (Landessonderförderungen)



## Helmholtz Forschungsakademie Hessen für FAIR (HFHF)

<https://hfhf-hessen.de>

Academy founded together with Helmholtz, funding from HMWK and GSI as a permanent successor institution to the Hessian LOEWE center HIC for FAIR

- funding period: since 2020 (permanent)
- funded by: TU Darmstadt, U Frankfurt, FIAS, U Giessen
- total funding volume: approx. **M€ 3 per year**



## ELEMENTS

<https://elements.science>

Research Cluster ELEMENTS: Exploring the universe from microscopic to macroscopic scales, M€ 16, of which **M€ 8** provided by the state of Hesse in the period **2021 - 2025**

- funded: 23 PIs from TU Darmstadt, U Frankfurt, U Giessen, GSI
- new appointments: 17 doctoral students, 11 PD, 2 junior research groups, 2 W2-TT professorships

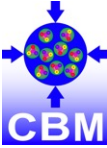


## NRW-FAIR Exzellenz-Netzwerk

<https://nrw-fair.ep1.rub.de/index.php/de/>

M€ 81 (personnel funds only) state funding 2022 - 2026 for five excellent research networks in North Rhine-Westphalia → **M€ 16 for NRW-FAIR**

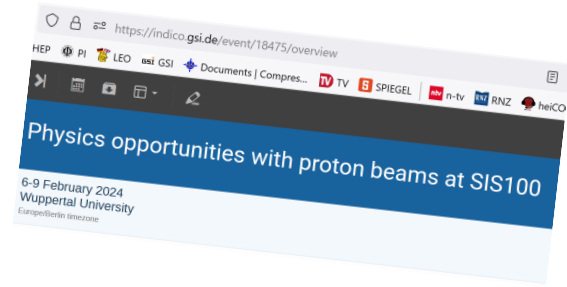
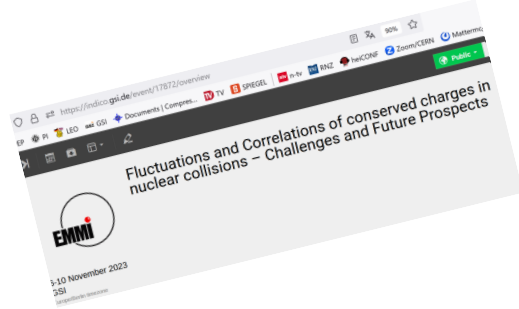
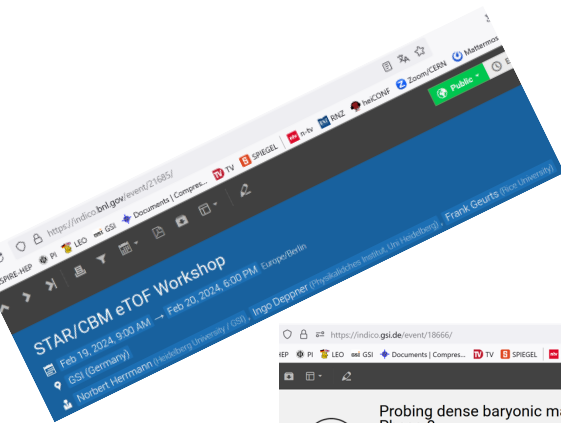
- funded: U. Bochum, U. Bonn, FZ-Jülich, U. Münster, U. Wuppertal; GSI (partner without funding)
- in NRW-FAIR there are a total of 27 professors (15 experiment professorships (10 PANDA, 5 CBM) and 12 theory professorships (8 PANDA, 4 CBM), 28 PD, 20 doctoral students and two newly created professorships (both for hadron physics) are financed by the network



# C.B.M. strategy

- Steadily push and develop physics cases to maximally utilize CBM's new and unique capabilities
- Produce visible progress/results to convince FAIR council that CBM is a viable option for first use of SIS100 beams, and that the collaboration is active and strong to achieve the goals
- Establish even stronger theory support and connection to complementary research fields

coveners and members of the TWGs



organizers, chairs, members of LOCs and IACs of major international conferences





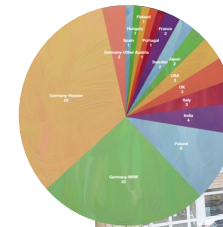
# Physics perspectives with hadron beams at GSI/FAIR

- Initiative (2022) from FAIR-motivated group from within CBM, HADES, PANDA (building up on success of PANDA Phase-0 at HADES)
- Promote the realisation of FS+ at FAIR
- Identify a QCD-inspired physics program with SIS100 proton beams
- Evaluate its complementarity with programs at other facilities
- Strengthen collaborations among hadron-, nuclear- and heavy-ion communities
- Reach out for new collaborators from both experiment and theory!



- ↘
- Kick-off satellite event at MESON2023 in June 2023
  - Feasibility studies using Monte Carlo simulations
  - Workshop “physics opportunities with proton beams at SIS100” in Wuppertal, February 2024

<https://indico.gsi.de/event/18475/overview>



87 participants





# High Acceptance DiElectron Spectrometer

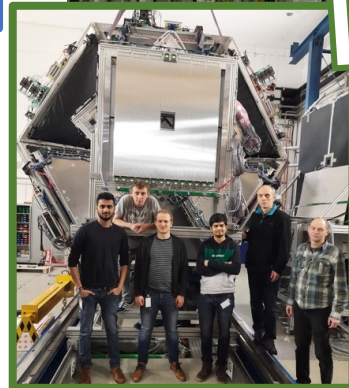
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## HADES



# The upgraded HADES detector 2022

- Improved physics performance through instrumentation of the very forward hemisphere using FAIR technology
- In particular important for the Hyperon Program



## Forward RPC

LIP Coimbra

- Based on R&D for neuLAND
- TRB3 read-out

## STS2

Jagiellonian Univ.

- PANDA straw technology
- PANDA PASTTREC FEE chip

## STS1

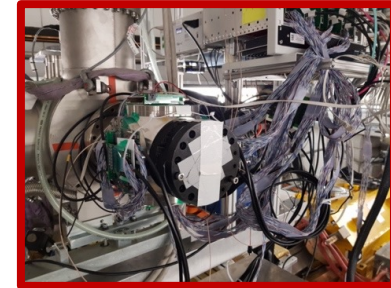
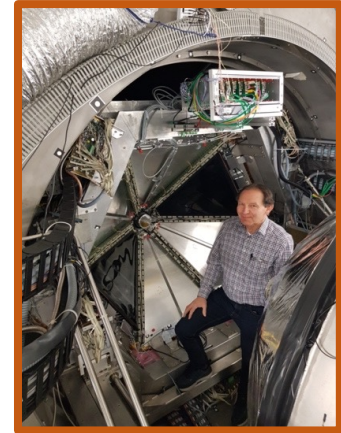
TransFAIR, Jülich

- PANDA straw technology
- PANDA PASTTREC FEE chip

## iTOF

TransFAIR, Jülich

- APD read-out
- Enhances trigger purity



## T0

GSI, TU Darmstadt

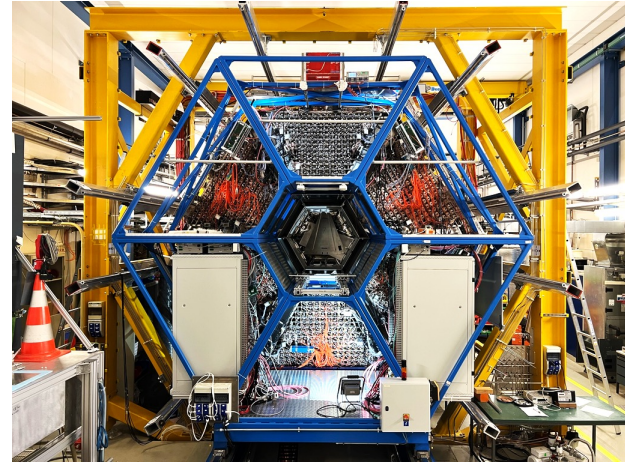
- LGAD technology
- In-beam detector



# Status detector 2024

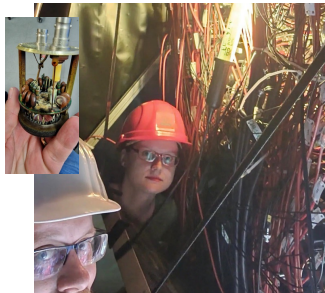
## Electromagnetic calorimeter (ECAL)

- proven technology: lead glass modules read out with Hamamatsu PMTs
- performance:  $\Delta E/E = 5.5\%$  at 1.0 GeV (photons)
- completion of ECAL, all 6 sectors in operation

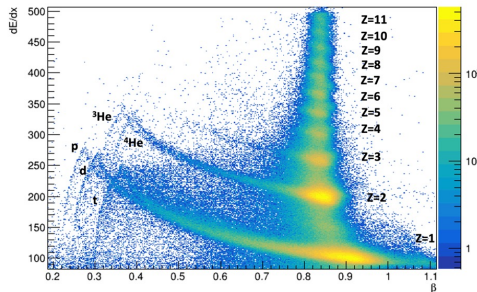


## Forward Wall rework

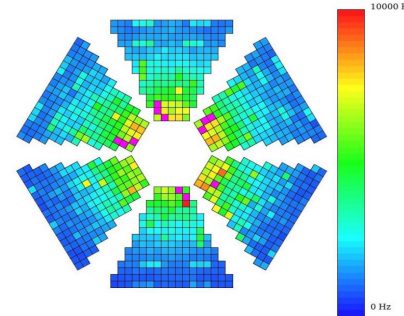
- replacement of voltage dividers



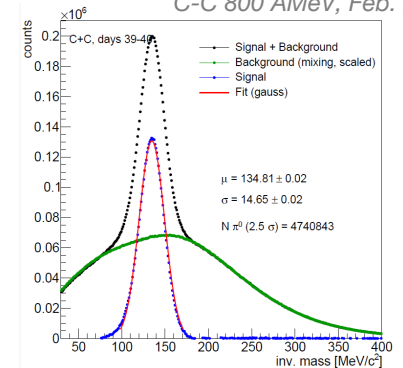
charge separation up to Z=11  
Au-Au 800 AMeV, Feb. 2024



ECAL FE rate during the Au-Au at 800 AMeV run, March 2024



online spectrum  $\pi^0 \rightarrow \gamma\gamma$   
C-C 800 AMeV, Feb. 2024

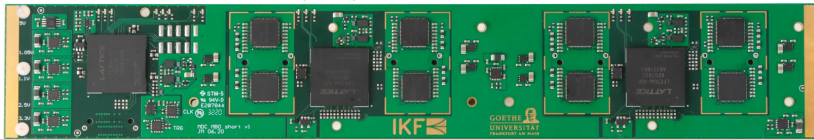


# Status detector >2024

## Mini-drift chambers (MDC)

- Production of MDC FEE mostly completed
  - readout system tested with a full-size drift chamber, 1.92 GeV p, COSY
  - time precision of the detector and read-out system  $\sigma_t = 3.6$  ns
  - efficiency > 96% (MIPs)
- ~ **step-wise installation, commissioning in 2024/2025**

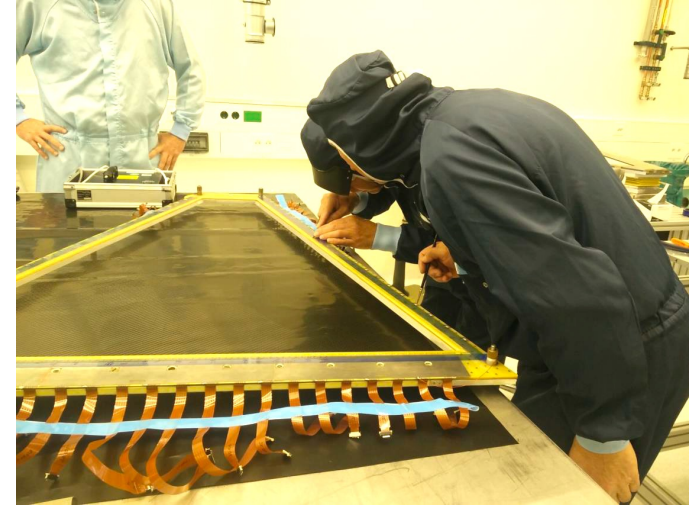
Michel *et al.*, HADES, INST 19 (2024) 02, C02056



*main board of the new MDC electronics*

*highly configurable 8-channel PASTTREC2 ASIC chip (CMOS),  
designed for the straw tube detectors of the PANDA experiment  
digitization with FPGAs*

*chamber exchange, spare chambers available*

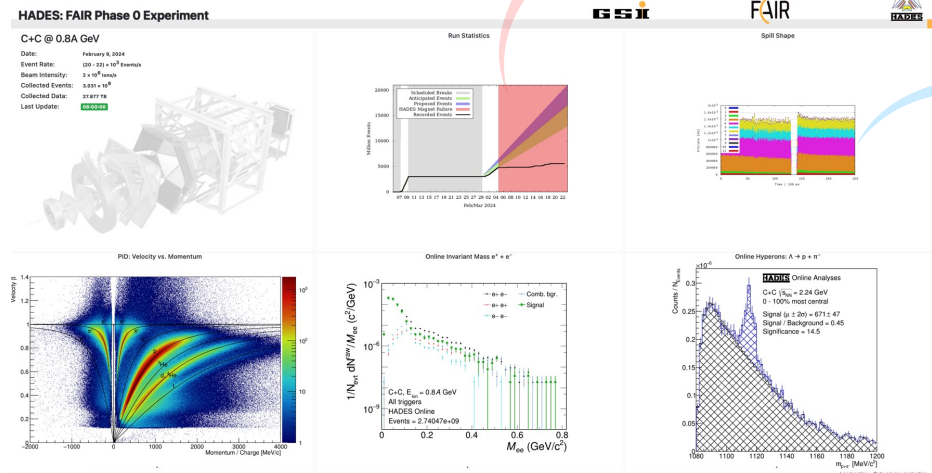




# HADES G22-0022

## Online monitor [link](#)

Magnet failure



Ph. Niedermayer *et al.*

**Breakthrough in slow extraction at SIS18**

- for the first time, the new regulated knock-out extraction and the  $\mu$ -spill cavity were turned on at SIS18
- KO extraction: electrostatic septum is regulated using the actual interaction rate at HADES
- $\mu$ -spill cavity was turned on an tested

**~ for HADES: duty factor 56% → 85%, DAQ life-time 66% → 90%**

In the first four days before the failure system was running with excellent performance, about 2 Billion events could be collected (C-C, Au-Au, 800 AMeV)

# Status of HADES-Magnet Cryogenic Plant

- A failed transformer in the compressor of the cryogenic plant caused a longer shutdown of the HADES magnet.
- After the recommissioning of the compressor a leak in the first heat exchanger inside the cold-box of the cryogenic plant was detected.
- Operating the magnet with magnetic field needs more cooling power than the cryogenic plant without this heat exchanger can deliver, so unfortunately the ongoing HADES beam time had to be cancelled.
- Several options to mitigate the problem are currently being evaluated, offers from companies are expected soon and intensive consultations with experts are ongoing.



*picture of the interior of a very similar cold-box of a cryogenic plant*

# HADES towards FAIR

## Conclusion of Phase-0 (now – 2026)

- progress made on finalizing and publishing data from Ag-Ag 2019 and pp 2022 Runs
- options for HADES beam in 2025 (HADES can count on ~15 days):
- proposed run needs to have an A or A- grade from last G-PAC recommendation:

**G22-0022 75 shifts (A):** 9 days (27 shifts) to complete the proposal

**G22-0141  $\pi$ +CH<sub>2,C</sub> 95 shifts (A-):** 6 days (18 shifts) for energy scan of baryon excitation functions and decay modes

**Strong interest from high- $\mu_B$  HIC community, relevance for astrophysics**

**Strong interest from hadron structure community, crucial input to PWA**

## Intermediate program during commissioning of ES, FS, FS+ (2027 – ~2030)

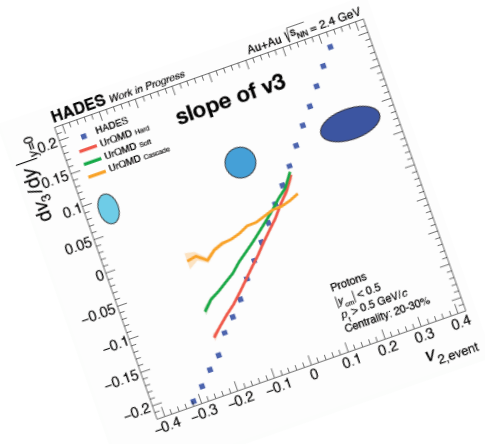
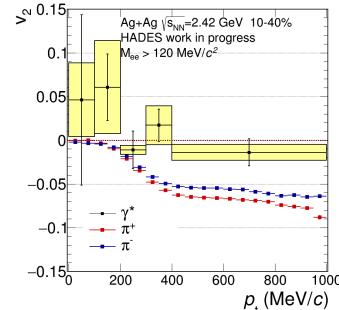
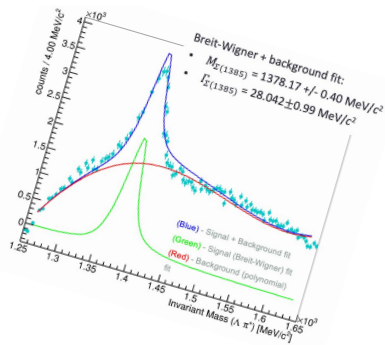
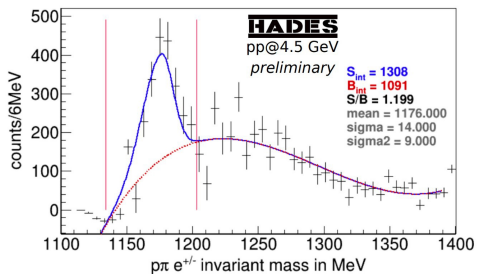
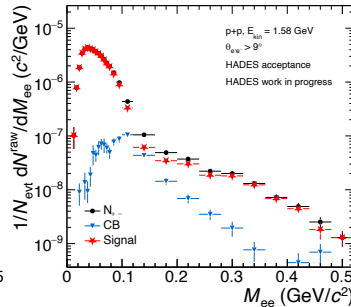
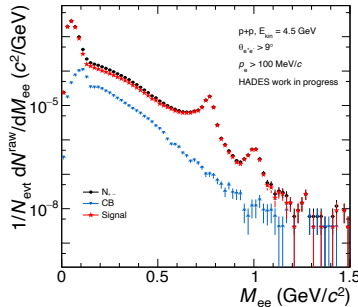
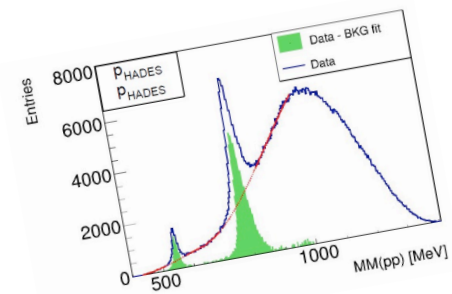
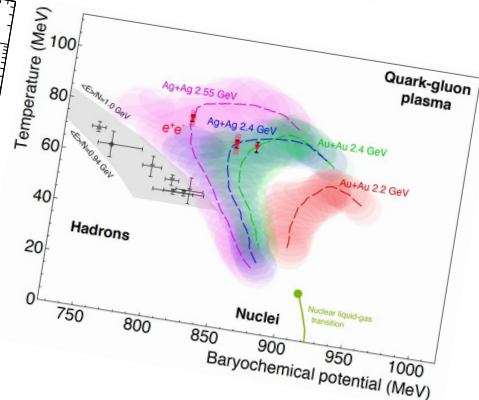
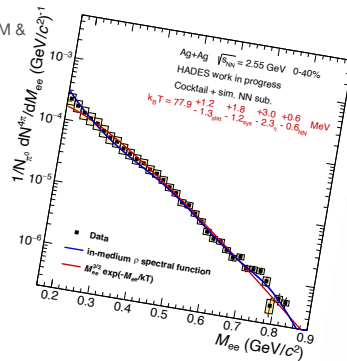
- imperative to follow-up and solidify the discussions regarding the operation of and the physics perspectives of HADES during these phases

## Operation with SIS100 beam (beyond ~2030)

- will go inline with preparation of a new MoU (FAIR M&O MoU). Participating institutes need to be identified

# HADES highlights

Results from Ag-Ag and pp runs are being consolidated and prepared for publications



# Summary

## From NuPECC LRP2024 Executive Summary (draft as of April 2024)

- To investigate nuclear matter at high baryonic density, the timely completion of **SIS-100** at **FAIR** and the realization of the **CBM** experiment are of utmost importance. Efforts should continue to support R&D activities related to advanced **CBM** silicon vertexing and tracking devices.
- The full exploitation of the existing detectors and facilities, in particular **HADES** and **R3B** at **SIS-18/SIS-100**, should receive full support.
- Full exploitation of the novel research opportunities as provided by the FAIR facility for the **APPA**, **CBM**, **NUSTAR** and **PANDA** collaborations.
- Realization of First Science+ until 2028 followed by the expedited completion of the **APPA** cave and the **Super-FRS** low-energy branch.

Thank you  
for your attention!

