



Compressed Baryonic Matter  
experiment at FAIR

CBM



# CBM: status, plans, challenges, hopes, help needed

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FAIR, Sweden@FAIR, 02 February 2023

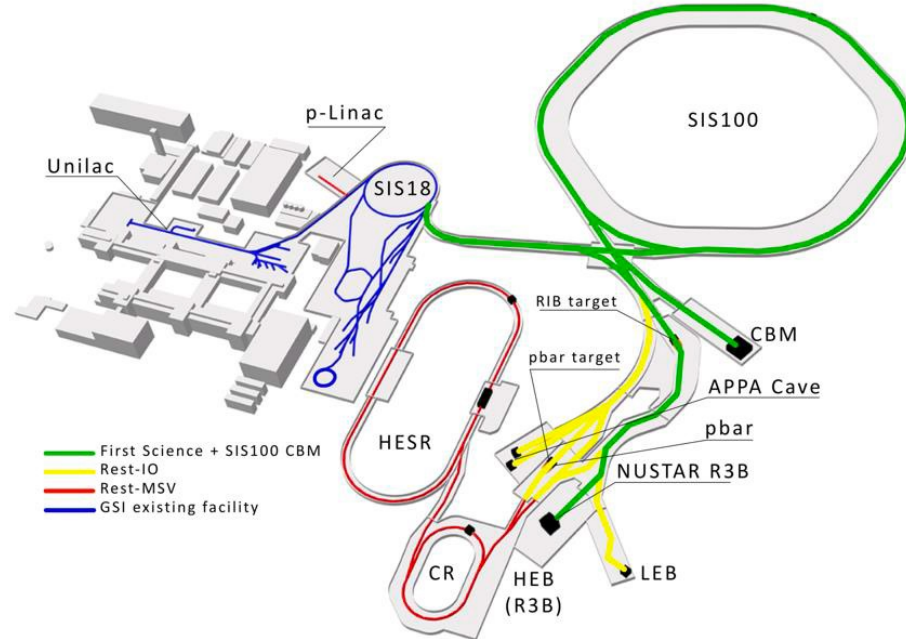




# C.B.M. pillar at FAIR

- C.B.M. at FAIR: dedicated high-rate heavy-ion experimental program
- Accelerator chain: injector (UNILAC+SIS18), SIS100, high-energy beam transfer lines
- Beams parameters: up to  $10^9$  ( $10^{11}$ ) Hz beam intensity for Au ions (protons), at full SIS100 energy range

SIS-100 Capabilities			
Beam	Z	A	$E_{\max}$ [AGeV]
p	1	1	29
d	1	2	14
Ca	20	40	14
...			
Au	79	197	11
U	92	238	10.7

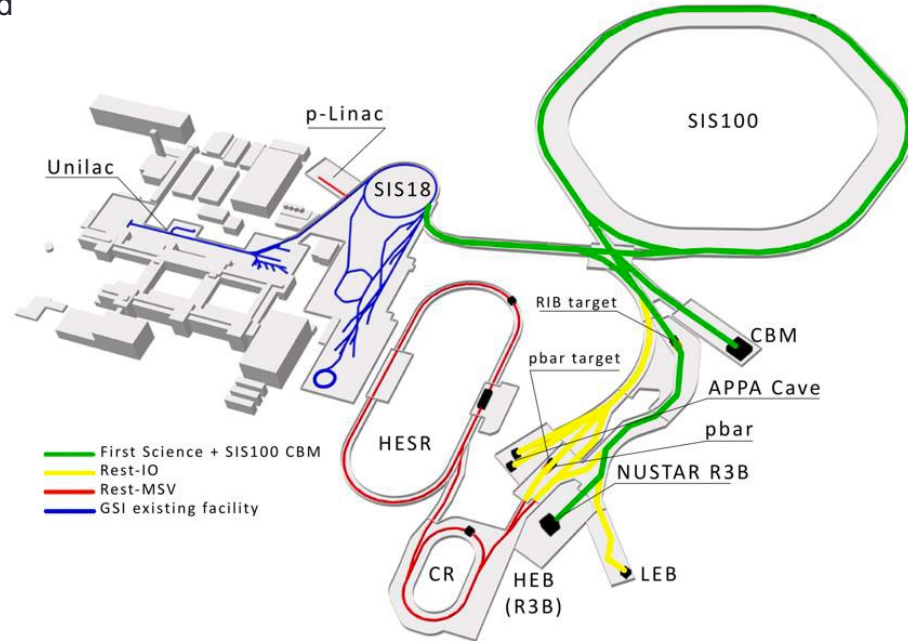




# Scientific review

*It should be emphasized that timely completion of SIS100 is critical because it will provide a truly unique opportunity in the world for CBM to carry out its heavy-ion science program.*

- Given the financial constraints, a start configuration including SIS100, SFRS with the High Energy cave, and CBM is recommended
  - Early Science (SIS18 to SFRS)
  - First Science (SIS100 to SFRS)
  - First Science+ (**SIS100 to CBM**)
- The realization of the steps will be started in full
- Decision by the next FAIR Council







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CBM



# CBM STATUS AND PLANS



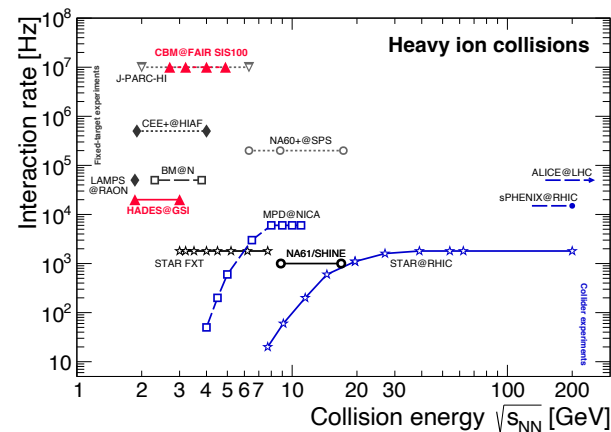
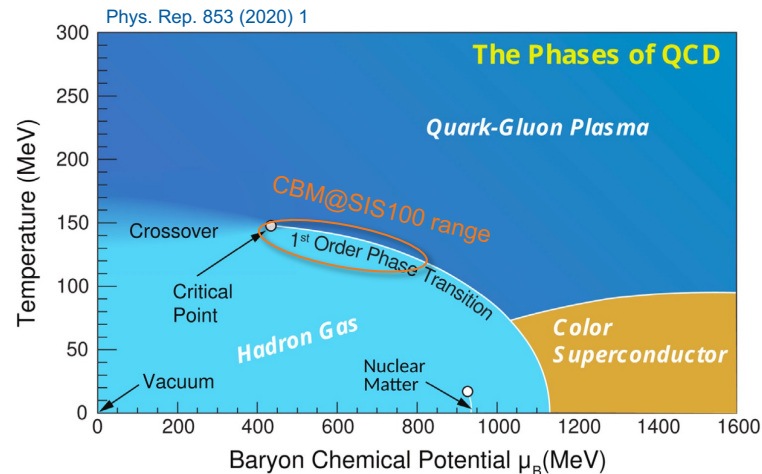
# CBM experiment

## CBM Mission Statement:

- Systematically explore QCD matter at large baryon densities with high accuracy and rare probes at the highest interaction rates

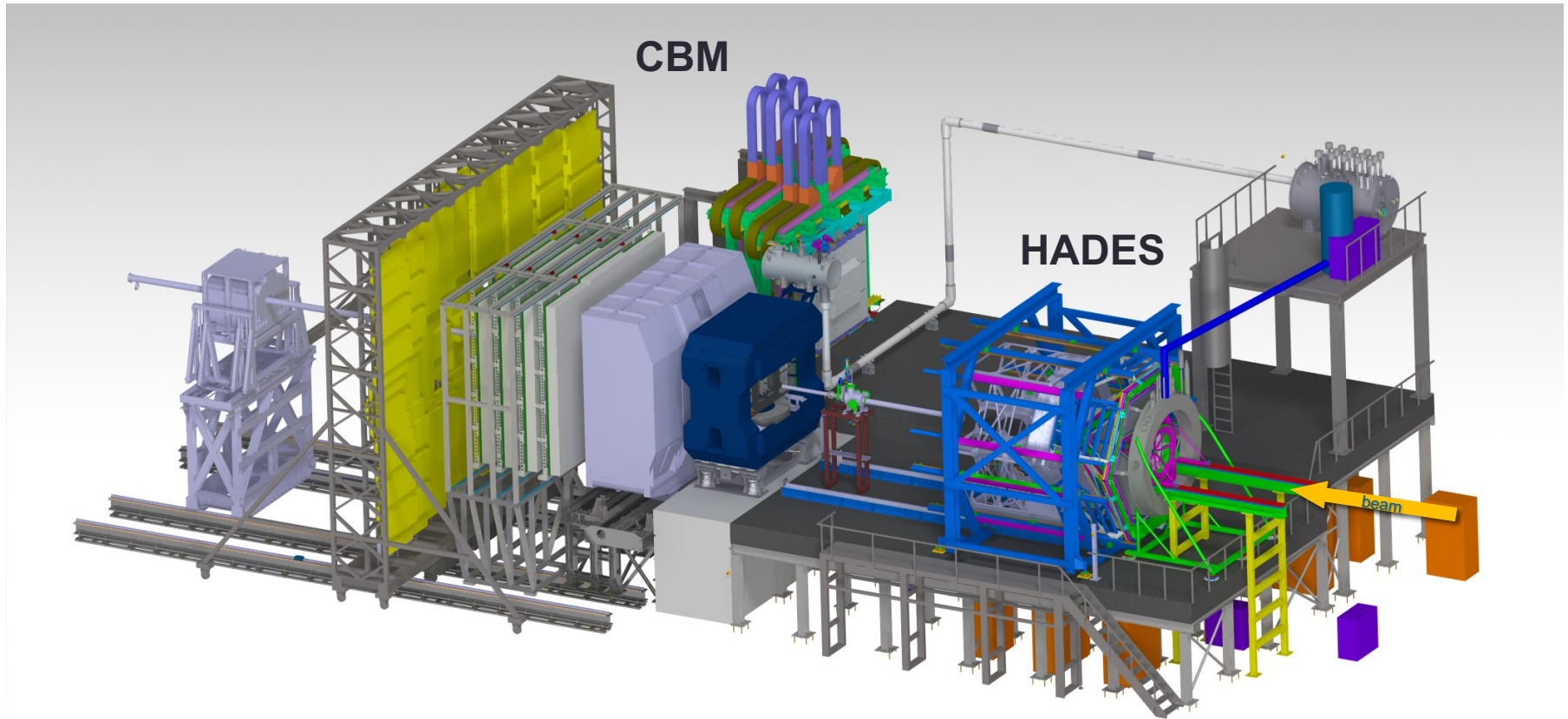
## Experimental challenge:

- Locate the onset of new phases of QCD
- Detect the conjectured QCD critical point
- Probe microscopic matter properties





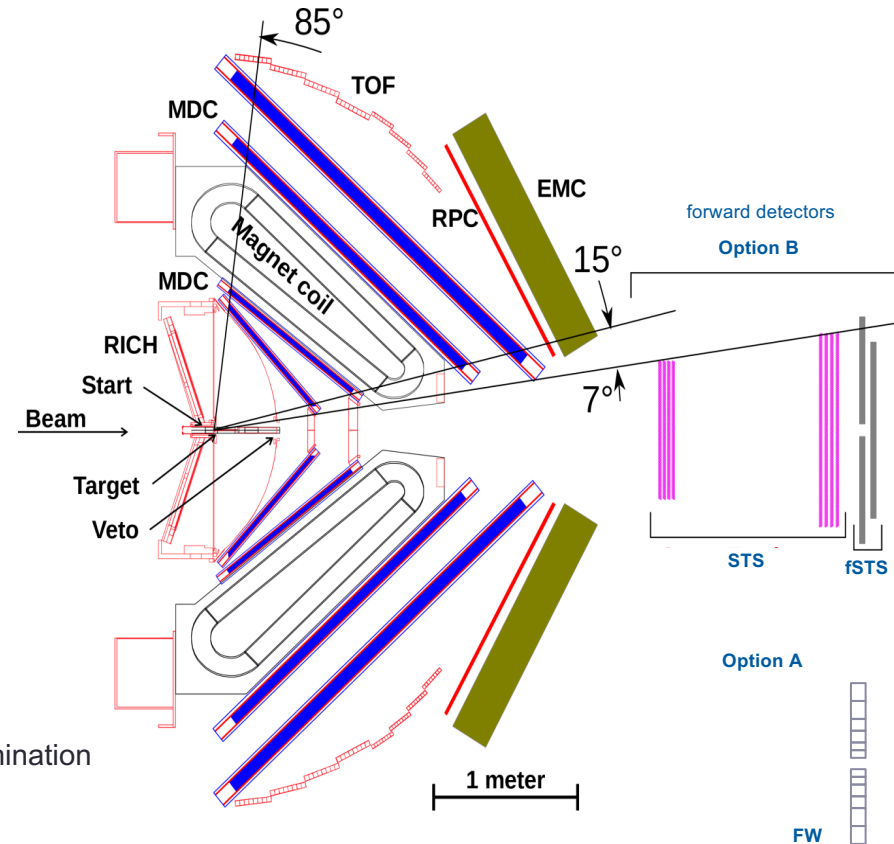
# C.B.M. experiments





# The HADES detector at SIS18

- **Collaboration:** 135 members from 22 institutes, 9 countries
- **Detector design**
  - toroidal spectrometer with six-sector superconducting magnet (momentum kick: 0.3-0.15 Tm)
  - low-mass tracking with drift chambers (MDC)
  - RICH surrounding the target in field free region
  - RPC and scintillator-based time-of-flight systems
  - electromagnetic calorimeter (EMC)
  - LGAD as T0 detectors in beam
- **Two options for forward measurements**
  - $A + A$  at 15-20 kHz (option A)  
granular scintillator array for event plane and centrality determination
  - $p + p, \pi + p$  at 50 kHz (option B)  
tracking with four planes of straw tubes and forward RPC (fRPC) for momentum measurement w/o field



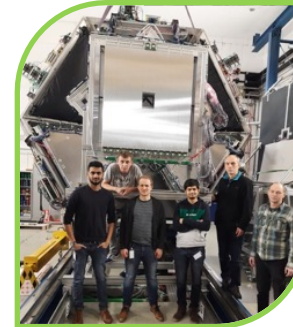


# HADES upgrades with FAIR technology

- Improved physics performance through instrumentation of the very forward hemisphere using FAIR technology
  - Forward RPC (Based on R&D for neuLAND), RICH (with CBM MAPMTs), eCAL, iTOF, T0 (with LGADs), Straw Tracker (based on PANDA straw technology and PANDA PASTTREC FEE chip)
- In particular important for the Hyperon Program

## Sweden @ HADES

- Contribution to the PANDA@HADES programme
- Institutionen för fysik och astronomi - Uppsala universitet
- Stockholms universitet, Fysikum, Instrumenteringsfysik och kärnfysik
- Very fruitful collaboration, 9+ researchers involved!
- Main focus on the hyperon physics with the proton beam experiments
- Tracking code for the Straw Tracker and a package for kinematical refits



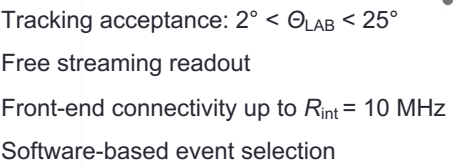
STS

Jagiellonian Univ.

TransFAIR, Jülich

- PANDA straw technology
- PANDA PASTTREC FEE chip



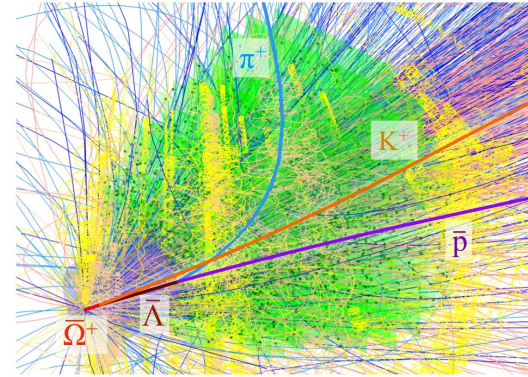




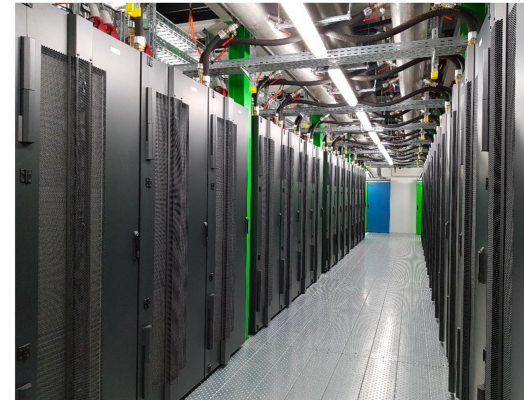
# Physics goals realization (rate challenge)

- High intensity proton and ion beam (pp, pA, AA collisions)
- High event rates, up to  $10^7$  Hz Au+Au collisions
- High multiplicity collisions,  $\mathcal{O}(1000)$  particles/coll
- Data rates:  $\sim 1$  TB/s; Data volume: 10 – 20 PB/year
- Fast, radiation hard detectors & front-end electronics
- Free-streaming readout and 4D (space + time) event reconstruction
- PID: hadrons and leptons, displaced ( $\sim 50$   $\mu\text{m}$ ) vertex reconstruction for charm measurements
- High speed data acquisition and performance computing farm for online event selection

CBM simulation, central Au+Au @ 10A GeV/c



Green IT Cube @ GSI





# CBM timeline

## CBM Cave

- Dedicated cave with a massive beam dump for high-intensity, high-energy beams
- **CBM Cave shell completed**
- Building shell construction completed in Q1.2023
- **Technical Building Infrastructure in 2024**

## CBM Installation

- CBM installation activities (platform) start in Q1.2023!
- **CBM ready for beam in Q3.2027**, ~12 months contingency for CBM global commissioning
- **SIS100 ready for beam in Q3.2028**





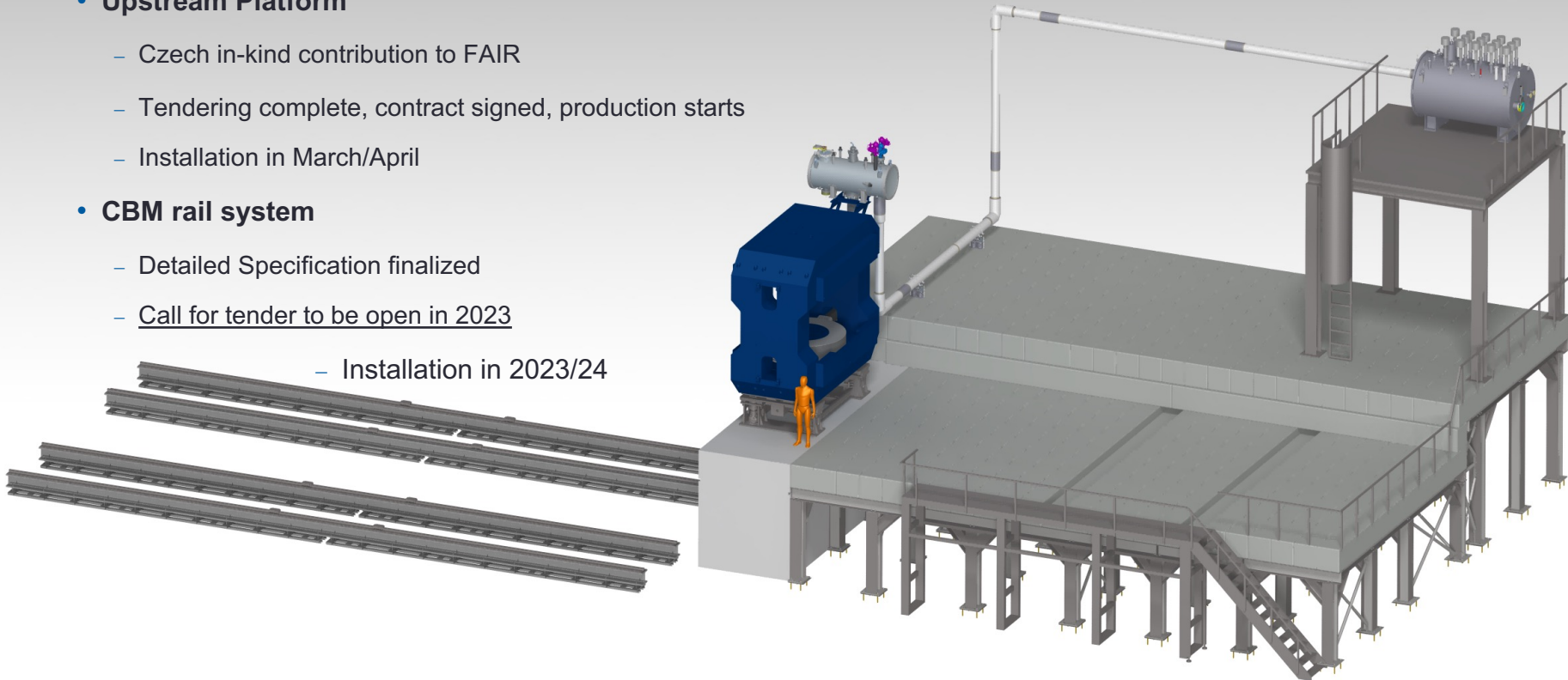
# Infrastructure → ongoing and upcoming procurements

- **Upstream Platform**

- Czech in-kind contribution to FAIR
- Tendering complete, contract signed, production starts
- Installation in March/April

- **CBM rail system**

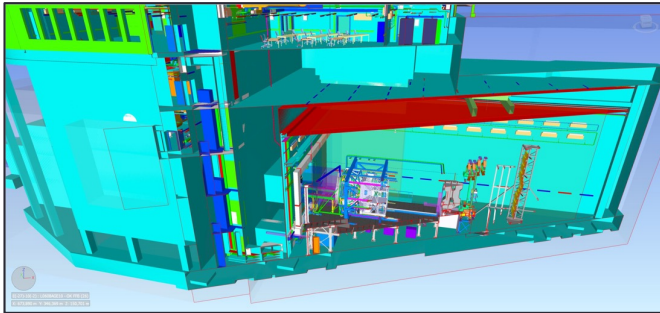
- Detailed Specification finalized
- Call for tender to be open in 2023
- Installation in 2023/24



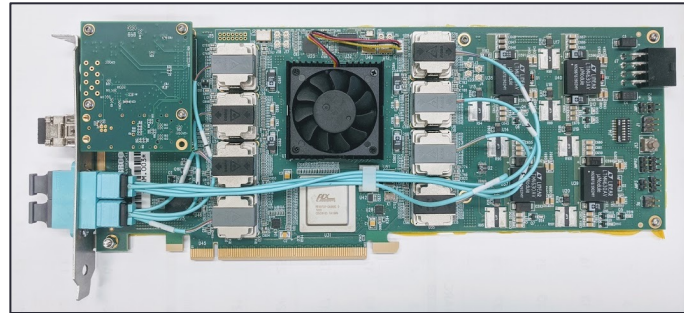


# Required CBM infrastructure and systems

- Remaining common infrastructure
  - Racks, detector cables, optical fibers, vacuum systems, target mechanism, ...
- Data Acquisition hardware
  - Common Readout Interface boards (FPGA-based, PCIe board)
  - First Level Event Selector → entry nodes
  - TDR submitted to the Expert Committee for Experiments
  - ...




CBM service planning



Common Readout Interface PCIe board (Gen 1)

- *Kintex UltraScale FPGA*
- *Avago MiniPod transceivers,*
- *MTP-48 connectors*
- *Voltage converters*




Compressed Baryonic Matter Experiment

**Technical Design Report  
for the CBM**

**Online Systems – Part I**  
DAQ and FLES Entry Stage

The CBM Collaboration



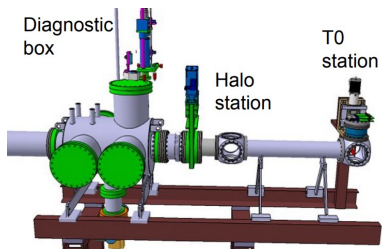
November 2022

commit date 2022-11-16  
commit hash 2786034 (dhan)

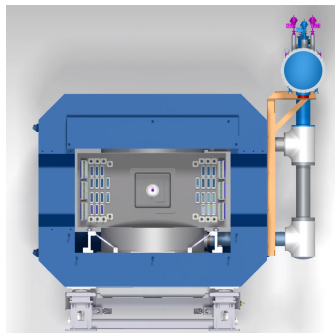
Online TDR



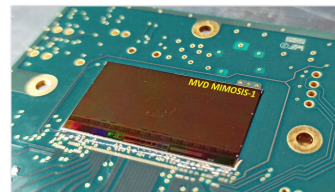
**Beam Monitoring**



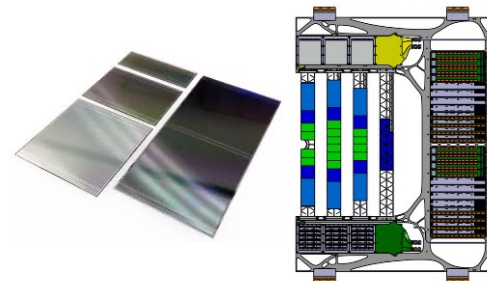
**SC Dipole Magnet**



**Micro-Vertex Detector**



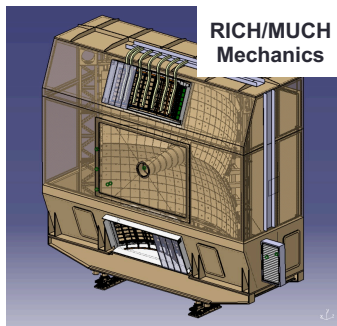
**Silicon Tracking System**



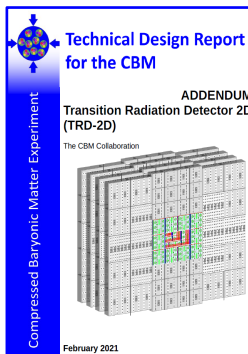
**Muon Chambers**



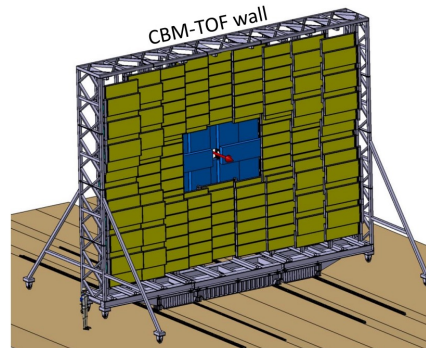
**Ring Imaging Cherenkov Detector**



**Transition Radiation Detector**



**Time-of-Flight**



**Projectile Spectator Detector**



- Main detector components on the verge of mass production
- Challenge: re-procurement of **missing** Russian components





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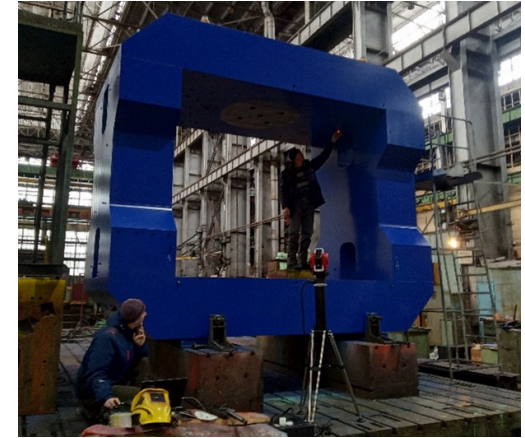


# CBM CHALLENGES



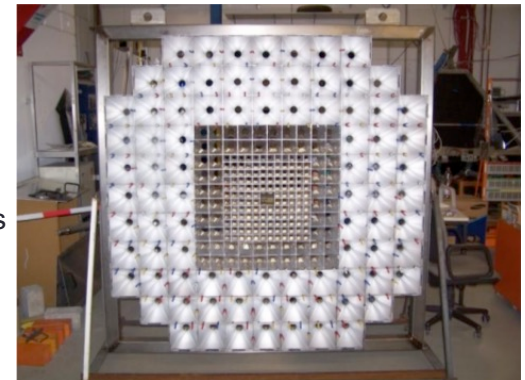
## Superconducting magnet

- **CBM Dipole defined as an item for urgent re-procurement**
  - Budget allocated
  - Call for tender open since Friday 20.01.2023  
<https://ted.europa.eu/udl?uri=TED:NOTICE:51017-2023:TEXT:EN:HTML>
  - On the critical path for CBM installation and commissioning:  
~4 years for tendering, production, installation and commissioning
  - **Tender for the power supply and quench protection to be open in 2024!**



## Projectile Spectator Detector → New Forward Wall

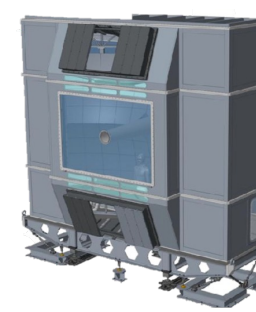
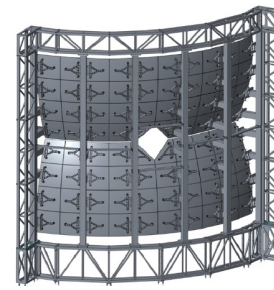
- Original concept based on hadronic calorimeter (Pb/Scintillator)
- New Forward Wall based on **on plastic scintillator** detectors
- Provides an **opportunity to improve performance** at low energies and high interaction rates
- New subproject defined (CTU, Czechia)
- New collaborators welcome (FEE, Readout)!



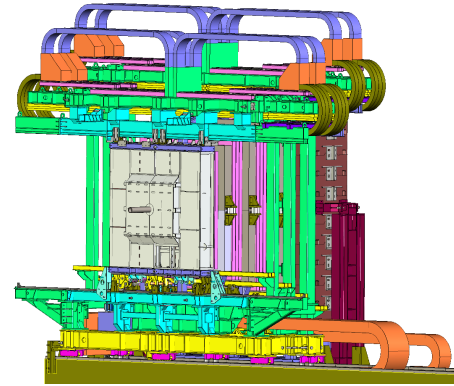
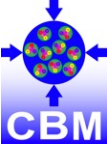


## RICH mechanics and gas system

- Gas box, support stand, mirror system
- Engineering work must start asap
- Gas system



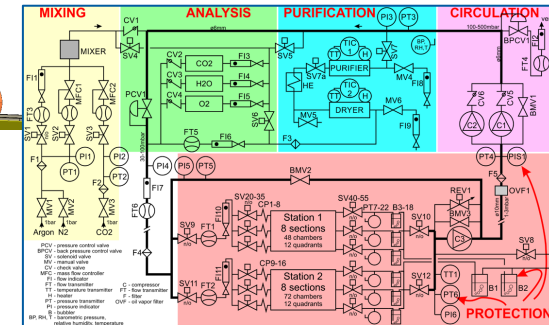
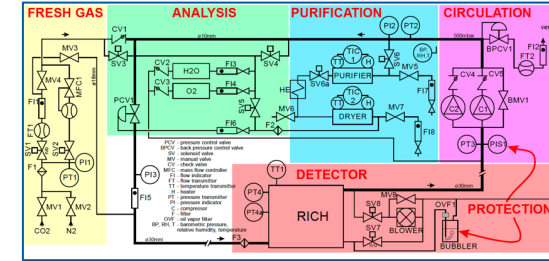
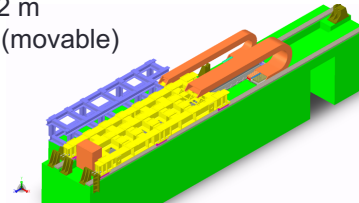
- 6×6×2 m
- 16 t



## MUCH mechanics and gas system

- Absorbers, superstructure, rails
- Engineering work must start asap
- Gas system

- 7×7×2 m
- 110 t (movable)







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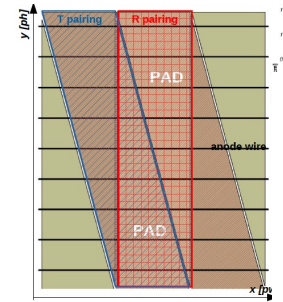


# CBM HOPES

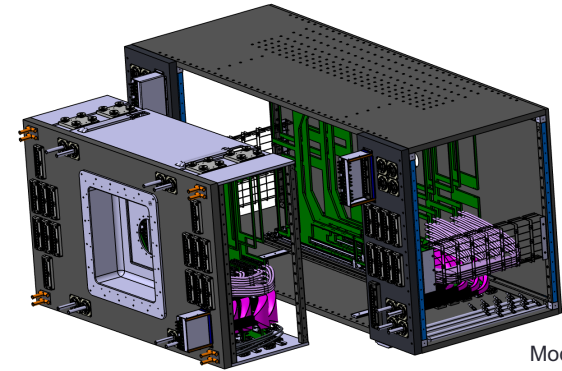


# Possible improvements for Day-1

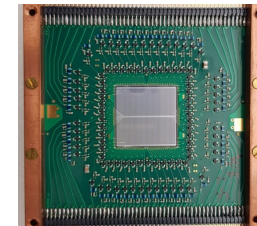
- **High-rate MWPCs with 2D readout for ultra-low  $p_t$  tracking for the inner-most TRD region**
  - TDR Addendum under review by the ECE
- **Prepare an upgrade path for STS with radiation hard pixel sensors**
  - Gain from the ongoing developments at CERN for the LS3 upgrades
  - Feasibility of the upgrade with the STS “3+5” modular setup
- **Start and HALO detectors based on LGAD sensors**
  - Currently employed by HADES START detector
  - Sensor development: Bruno Kessler Foundation; readout: ATLAS
  - Performance with high-intensity heavy ion beams to be shown



TRD 2D readout scheme



Modular STS setup

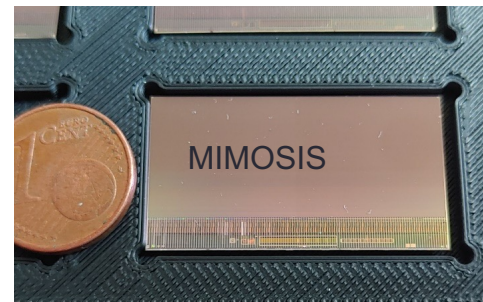


HADES START

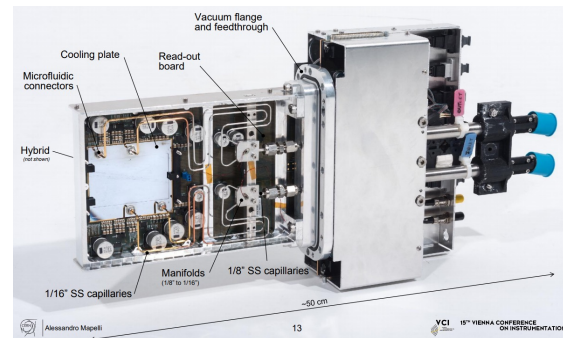


# Strategy for detector upgrades

- **After first 3 years of operation (~2032) major upgrades are considered**
  - upgrade MVD with next generation MAPS (IPHC, CERN developments)
  - possible addition of timing silicon layers (LGADs, SPADs)
  - forward silicon tracker (fragments ID inside the beampipe)
- **Timeline fits well the upgrade/production plans of the HL-LHC, eIC, ...**
  - aim for state-of-art rate capability, improved time measurement, reduced material budget and improved radiation hardness
  - improved cooling (microchannel) → readout rates
- **Long-term upgrades (see e.g. ECFA detector R&D roadmap)**
  - muon systems, PID detectors, timing, calorimetry, ...



State-of-art MAPS: MIMOSIS-1 prototype for MVD



Microchannel cooling concept (© A. Mapelli)





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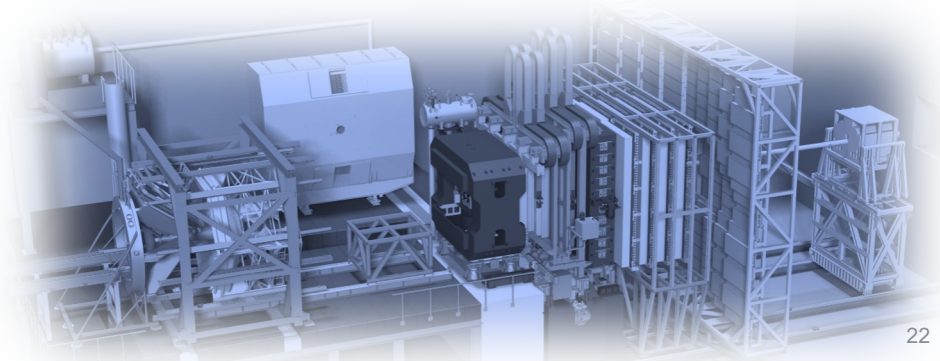


# SUMMARY



# Summary

- **Timely completion of SIS100:** unique physics program with C.B.M.
- Highly competitive due to high interaction rate capability
- CBM is progressing well toward science program with SIS100 beams
- All subsystems on the verge of the series production, installation of CBM infrastructure in the cave starts early 2023
- **CBM “ready for beam” in 2027!**
- Many opportunities for new collaborators and contractors to join CBM!
  - Common infrastructure items
  - Missing in-kind contributions
  - Detector upgrades
  - Rich physics program
- Looking forward to your positive consideration!







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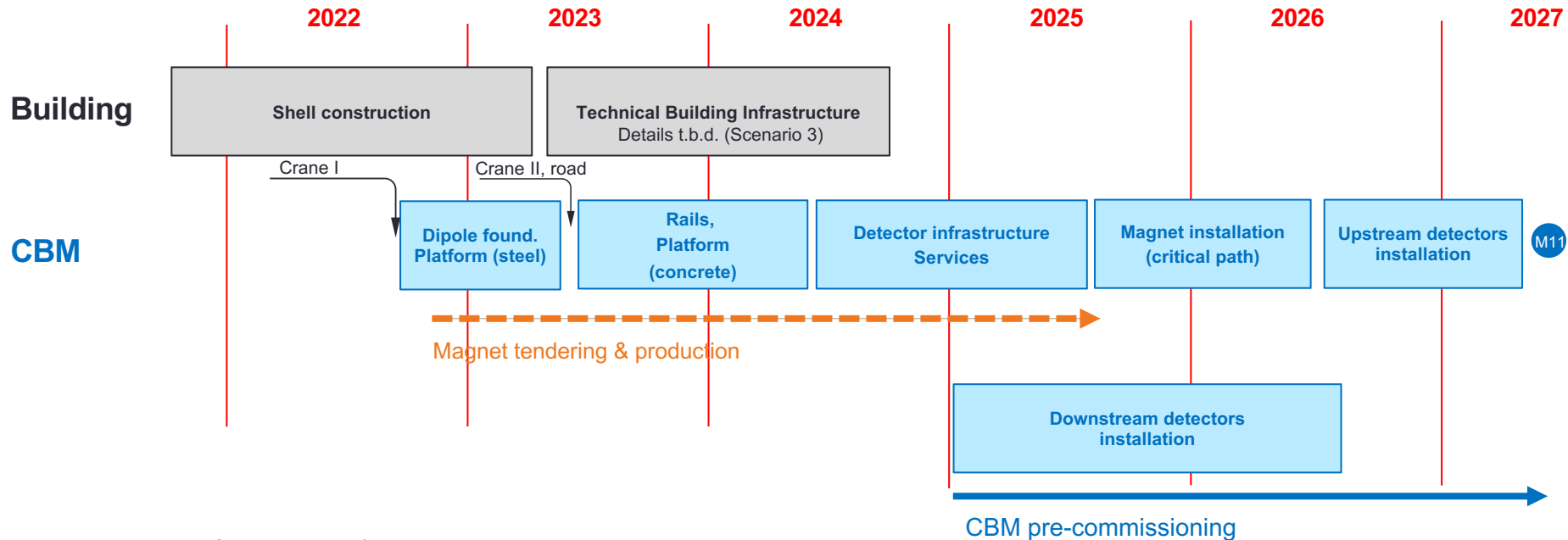
CBM



BACKUP



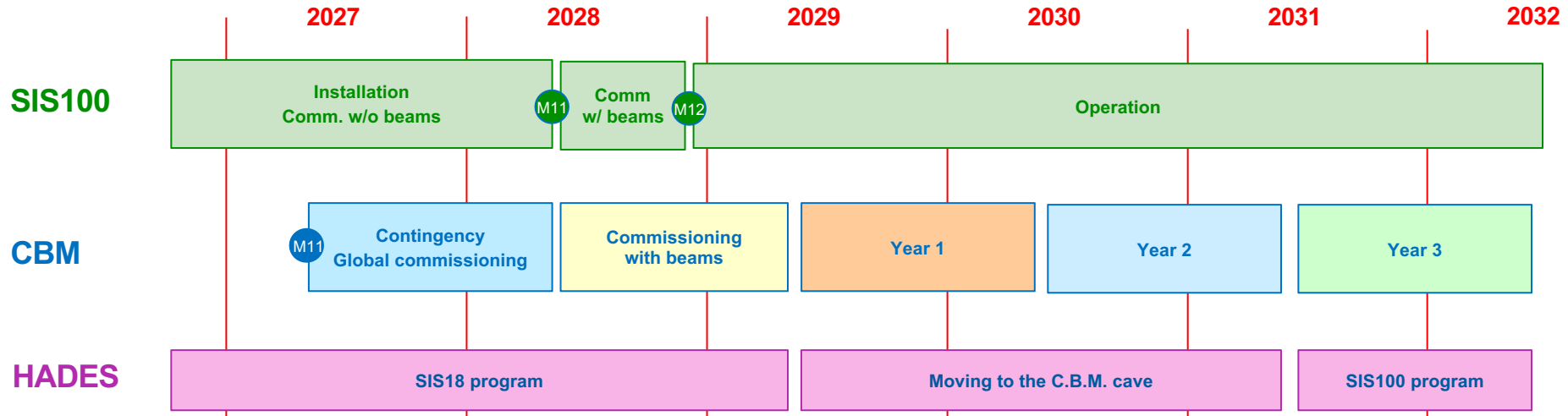
# Installation plan



- We plan CBM ready for beam in mid 2027
- ~ 1y contingency until SIS100 commissioning with beams (used for CBM global commissioning)
- Magnet on the critical path → plans will clarify after tendering.



# Outlook



- **Preparing for a competitive program in 2028**
- CBM input submitted to NuPECC LRP: <https://indico.ph.tum.de/event/7050/contributions/6344/>



# Highlights from the detector projects

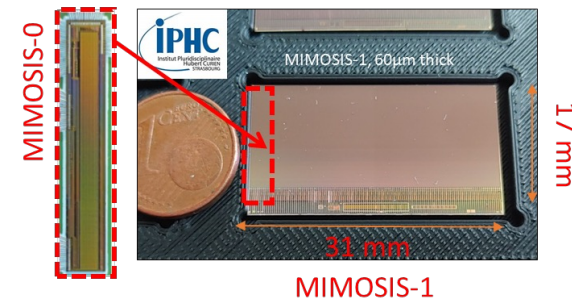
## BMON (TU Darmstadt)

- Start detector Concept for Day-1 based on pcCVD high-purity diamond sensors
- Successful implementation in mCBM
- A concept of the beam abort system being worked out (estimate manpower, invest)
- R&D on novel technologies (LGAD) ongoing



## MVD (U Frankfurt, GSI, IKF Frankfurt, IPHC Strasbourg, Pusan Nat'l Univ, Czech TU)

- TDR submitted and accepted by ECE in 2021
- MIMOSIS-1: extensive testing (9) and irradiation (3) campaigns
- MIMOSIS-2 submitted for production (first beam at DESY in Jul 2023)
- RO chain development, integration and services



## STS (GSI, KIT Karlsruhe, JU Crakow, AGH Crakov, KINR Kiev, Univ. Tübingen, Warsaw UT)

- Preproduction of the STS modules ongoing.
- 10 STS modules to be integrated into the J-PARC E16 experiment
- PRR in Spring 2023 for the full scale production
- 75 wafers of SMX\_V2.2 ASICs delivered
- 7.5 kW NOVEC cooling plant prototype and realistic thermal demonstrator





# Highlights from the detector projects

**MUCH** (U Aligarh Muslim, Bose Inst., U Panjab, U Jammu, U Kashmir, U Calcutta, B.H. U Varanasi, VECC, IOP Bhubaneswar, NISER Bhubaneswar, IIT Kharagpur, IIT Indore, U Gauhati)

- MUCH GEMs and RPCs installed in mCBM setup
- Production of Station 1 GEM chambers to be launched soon (GEMs available).
- Successful GIF++ and mCBM high-rate campaign for GEMs and RPCs

**RICH** (U Giessen, U Wuppertal, GSI Darmstadt)

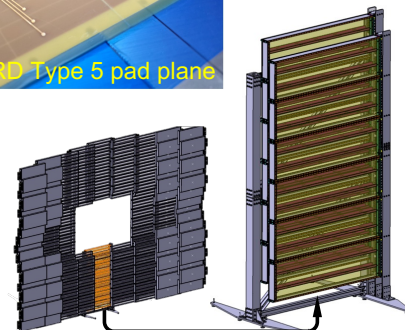
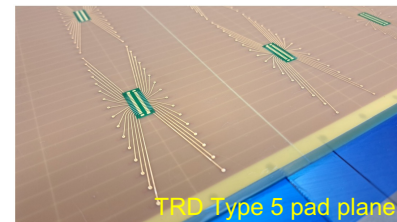
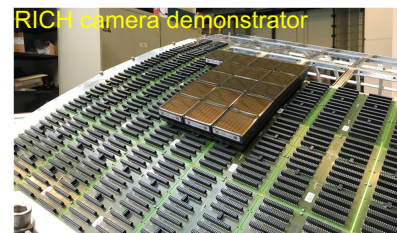
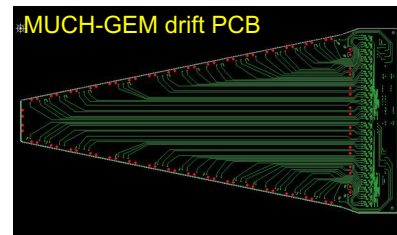
- Photocamera prototype → cooling concept verification ongoing
- Mirror production to be launched soon (2023)
- FEE production/assembly started.

**TRD** (NIPNE Bucharest, U Frankfurt, U Heidelberg, U Münster, IRI Frankfurt)

- Pre-production (modules type “5”) ongoing. Raw material for full production procured.
- SPADIC 2.3 ASIC tests ongoing → submission of successor ASIC early 2023
- Mechanical structure (frame) development. Prototype of gas supply.

**TOF** (THU Beijing, NIPNE Bucharest, GSI, USTC Hefei, U Heidelberg, CCNU Wuhan)

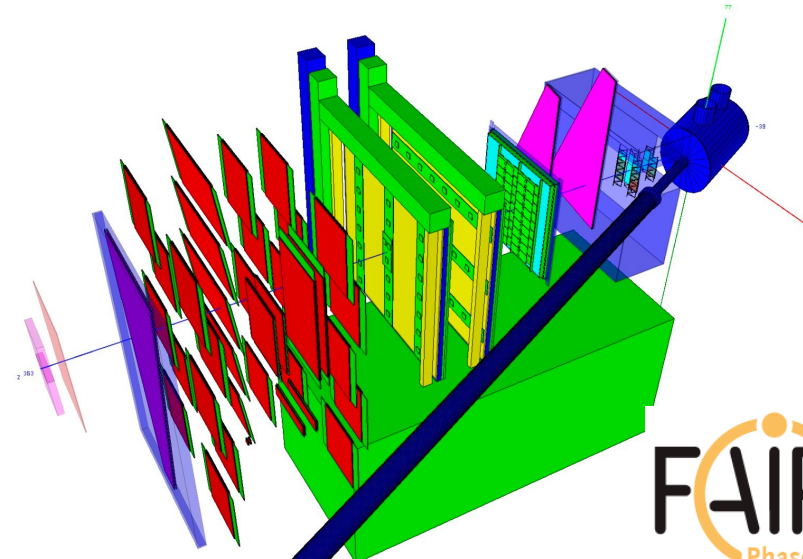
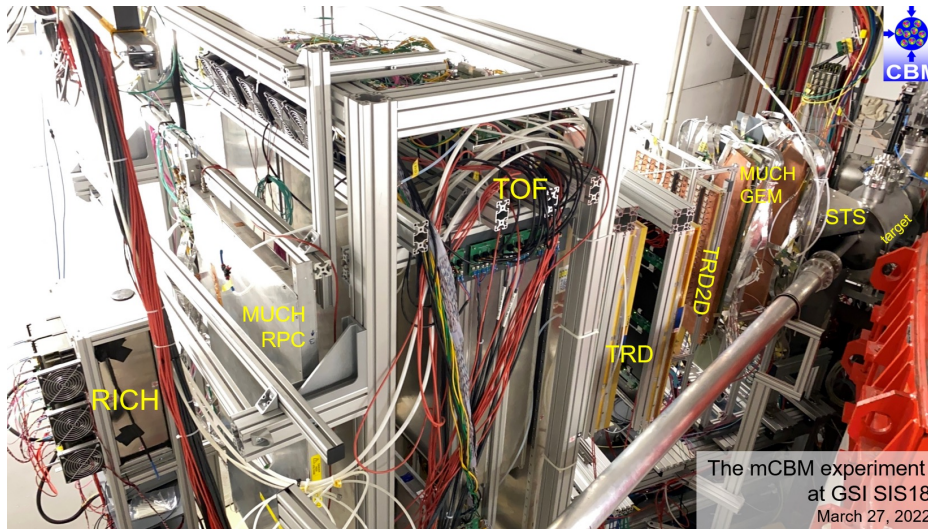
- Pre-production of MRPC launched in China. Pre-production module assembly in HD starts now.
- High-rate capabilities demonstrated in mCBM
- Mainframe CDR accepted – prototype frame being produced
- FEE PRR in Q1.2023!



TOF prototype wall



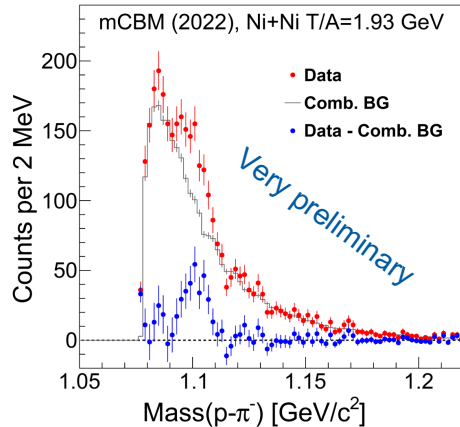
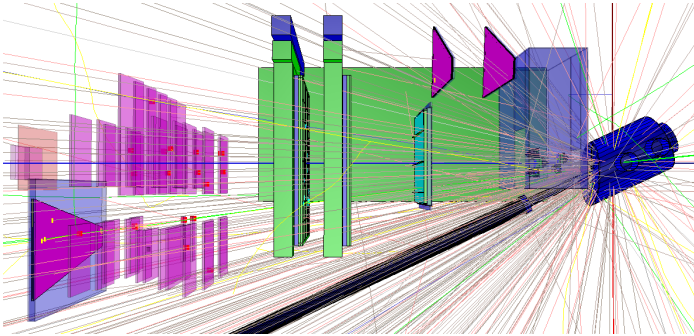
# FAIR Phase-0: mCBM at SIS18



- Full system test, verification of the triggerless-streaming read-out and data transport of CBM
- High-rate detector tests with up to 10 MHz collision rates
- Physics program:  $\Lambda$  excitation function in SIS18 energy range



# mCBM @ SIS18 – CBM full system setup



## $\Lambda$ production benchmark runs 2022

### Ni + Ni, T = 1.93 AGeV

- May 26, 2022, total run duration: 5h 55m
- av. collision rate: 400 kHz
- av. data rate 1.5 GB/s to disc, 32 TB data collected

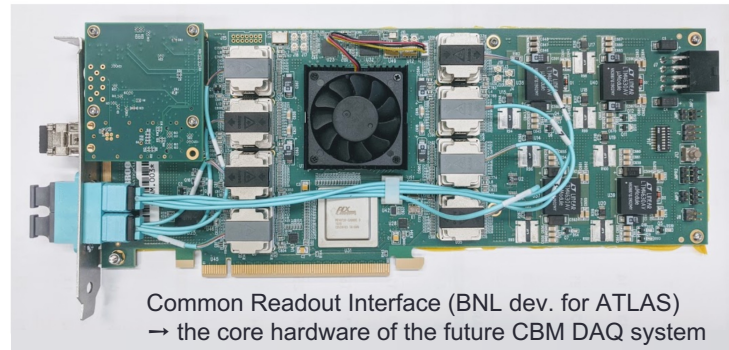
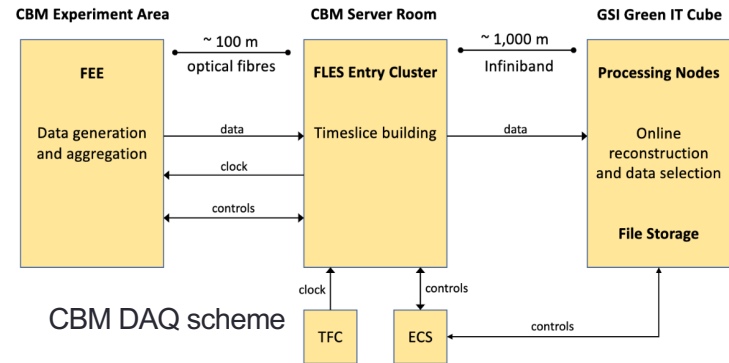
### Au + Au, T = 1.23 AGeV

- June 17-18, 2022, total run duration: 34h 33m
- av. collision rate: 200 – 300 kHz
- av. data rate 1.4 – 2.2 GB/s to disc, 180 TB data collected
- First results promising - work on calibration and alignment ongoing
- Further development of the readout chain and online analysis tools
- High-rate detector tests and  $\Lambda$  production runs in 2024-2025 approved by G-PAC (36/18 shifts as a primary/secondary user)



# R&D highlights: DAQ

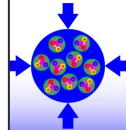
- Free-streaming readout implemented and commissioned in mCBM
- Connection scheme, hardware, achieved occupancies close to the final CBM DAQ → can be scaled towards full CBM
- High-rate capabilities demonstrated up to 10 MHz
- Benchmark run
  - Au+Au at 1.23 AGeV, 35h run duration
  - $\sim 2 \times 10^{10}$  collisions recorded (180 TB of raw data)
  - average interaction rate: 200 kHz
- DAQ TDR Part I (DAQ and FLES) submitted to ECE





# CBM Online Systems

- Free-streaming readout implemented and commissioned in mCBM
- Connection scheme, hardware, achieved occupancies  
close to the final CBM DAQ → can be scaled towards full CBM
- High-rate capabilities demonstrated
- TDR Online Systems – Part I (DAQ and FLES) **submitted** to ECE
- TDR Online Systems – Part II (Online analysis, event selection and controls)
  - last CBM TDR to be submitted



## Technical Design Report for the CBM

### Online Systems – Part I

DAQ and FLES Entry Stage

The CBM Collaboration



November 2022

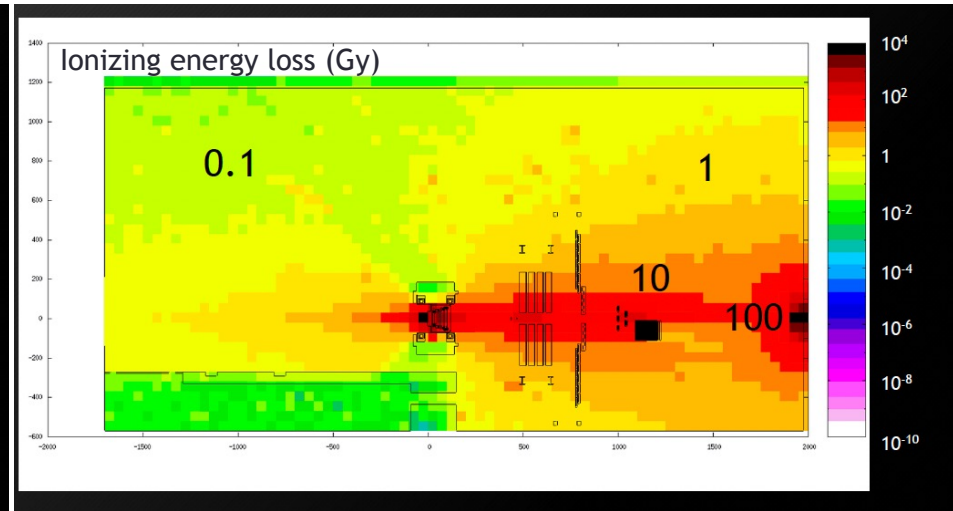
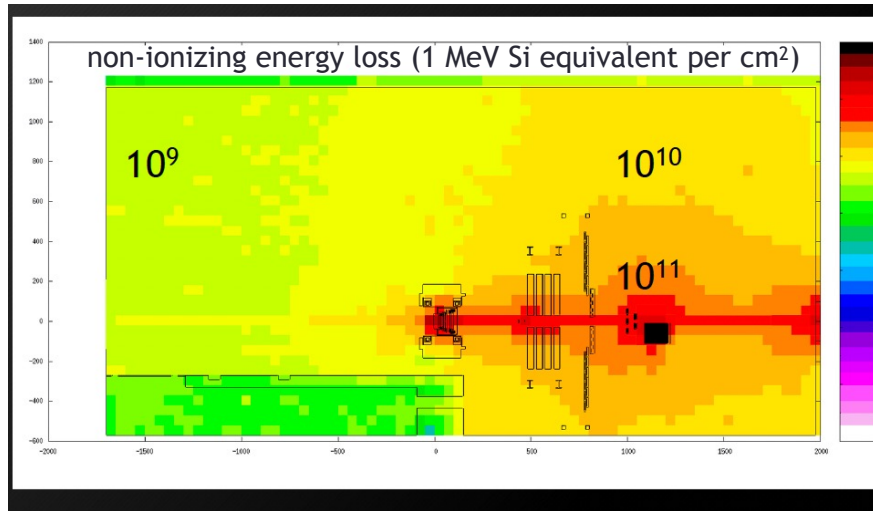
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commit hash 278fd34 (clean)

Compressed Baryonic Matter Experiment



# Radiation levels in CBM

Au beam @ 11A GeV, after 1 month with  $10^9$  Au/s







Compressed Baryonic Matter  
experiment at FAIR

CBM



# MISSING COMPONENTS DETAILS





Compressed Baryonic Matter  
experiment at FAIR

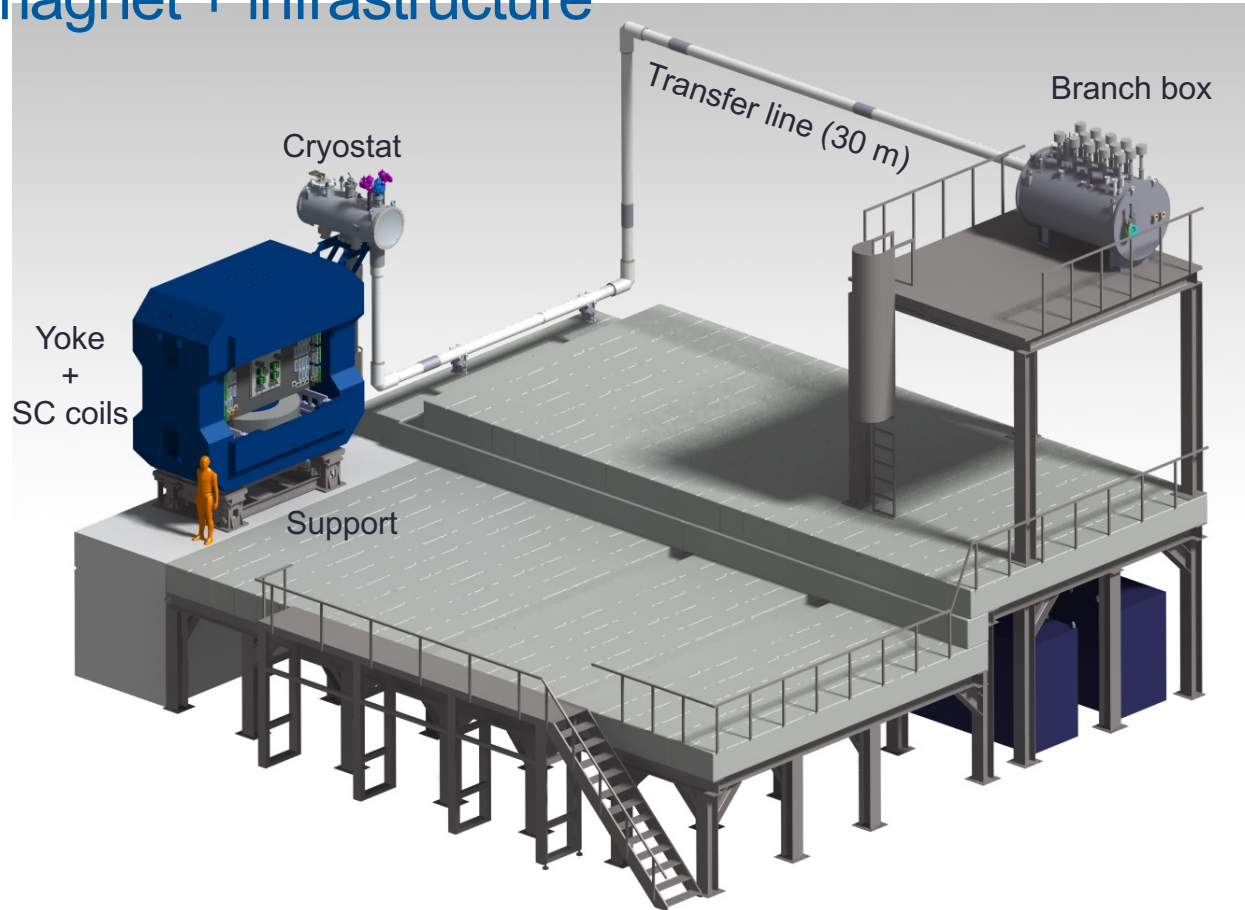
CBM



MAGNET

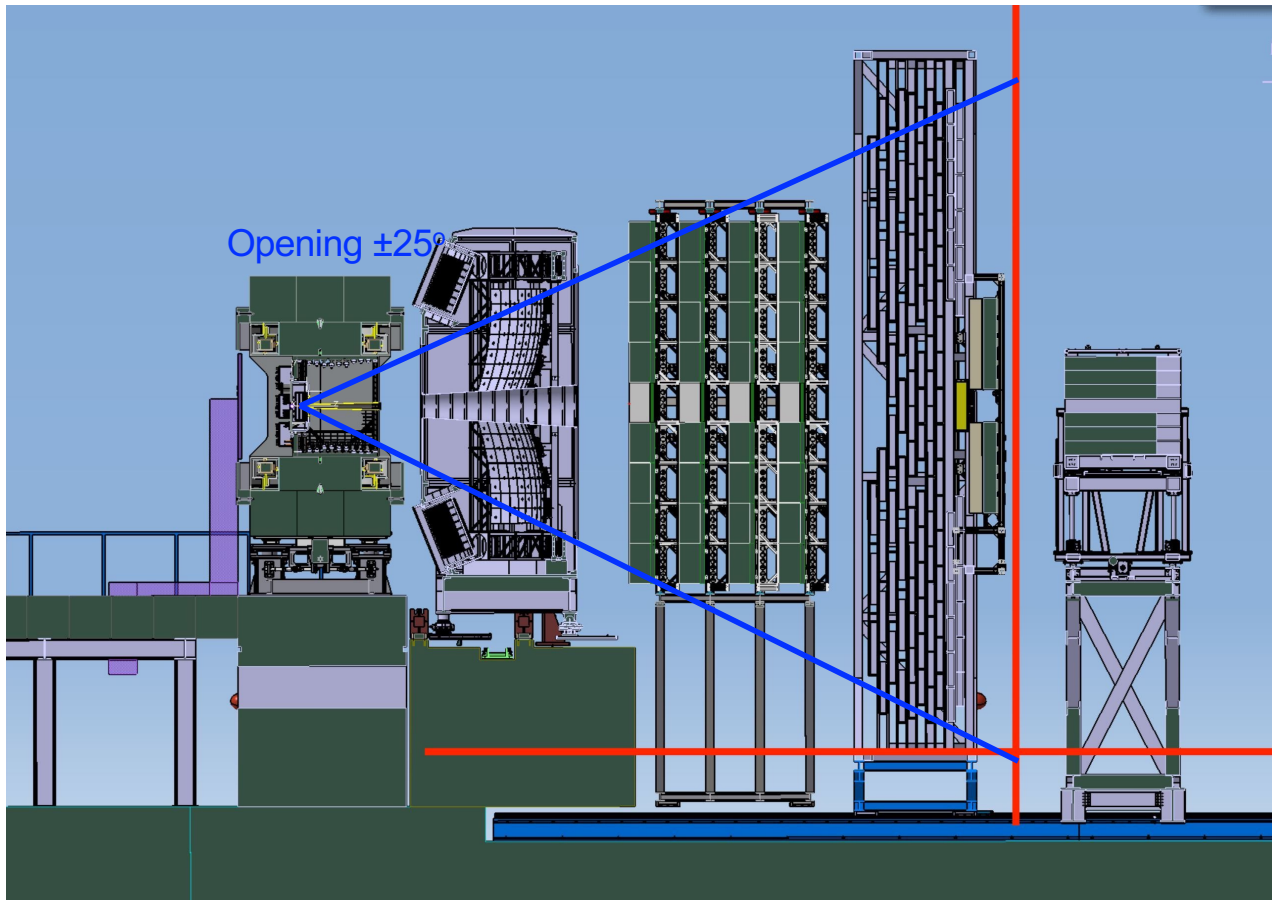


# CBM magnet + infrastructure





## CBM – side view





**1470 (H) x 3300 (W)**





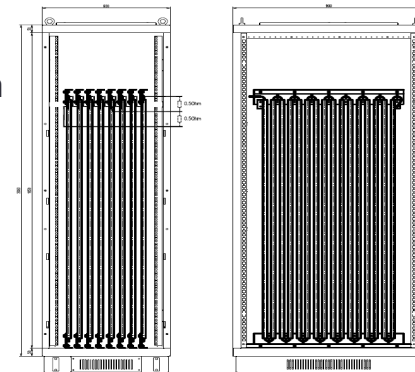
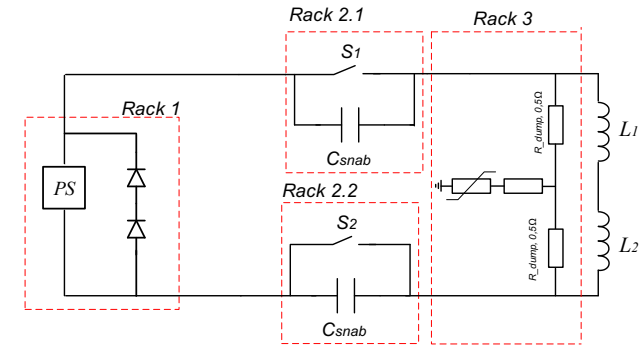
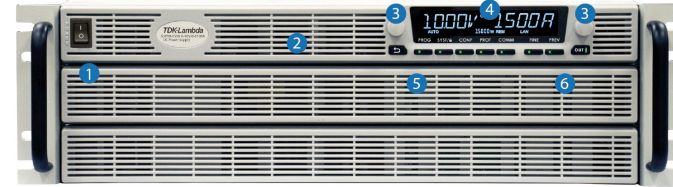
# Parameters/requirements

Main parameters of the CBM magnet	
Magnetic field integral along 1 m about the center, T*m	1.02
Maximal magnetic field on the coils, T	3.6
Inner diameter of the SC winding, m	1.396
Vertical distance between the poles, m	1.44
Operating current, A	666
Total current, MA	1.143
Number of turns per coil	1716
Number of layers	52
Stored energy, MJ	5.0
Coils cold mass, kg	3600
Operating temperature, K	4.5
Inductance at operating current, H	21
Vertical force acting on the coils toward the iron yoke, MN*	3.0



# Power supply + energy extraction system

- Current in a circuit 667 A.
- The amount of the stored energy to be extracted is 5,1 MJ.  
Stored energy should be extracted to the external dump resistor with the value of 1 Ohm.
- The active elements of the dump resistor should not be hotter than 80C. Middle point should be introduced and grounded in order to minimize the voltage between the coil and ground.
- Dump resistor should have as minimal as possible stray inductance and must be installed in parallel with the extraction switch or magnet.
- Two symmetrical energy extraction systems.
- Two free-wheeling diodes for the slow energy extraction.







Compressed Baryonic Matter  
experiment at FAIR

CBM



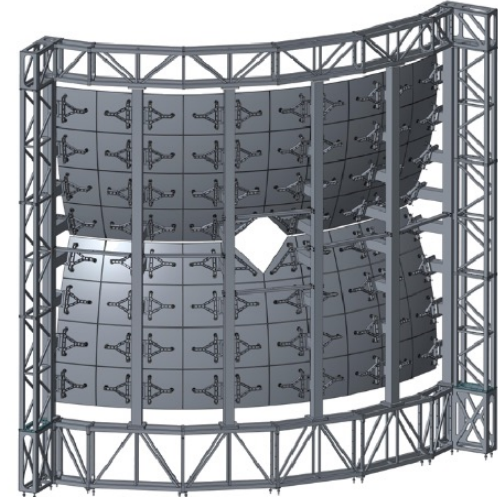
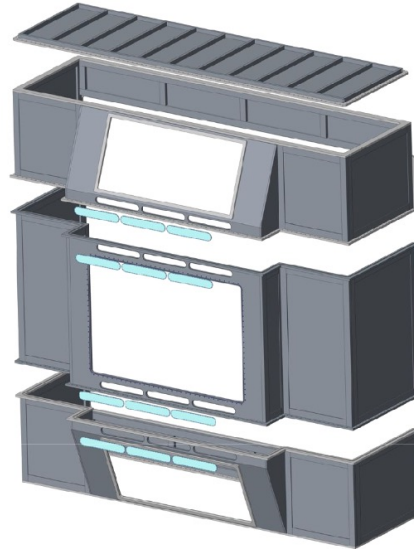
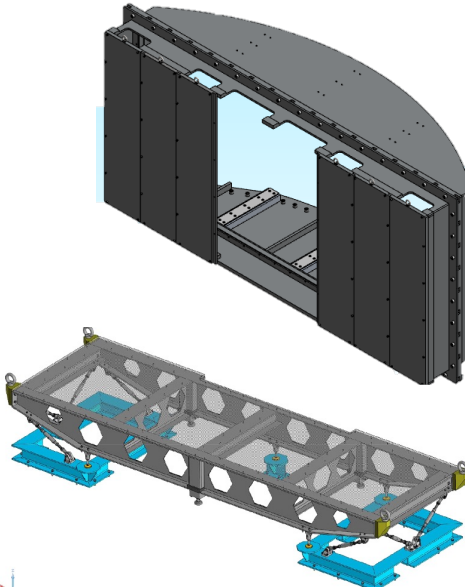
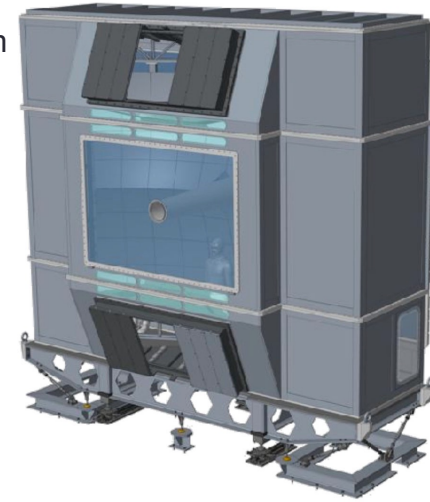
RICH



✓  $6 \times 6 \times 2$  m  
✓ 16 t

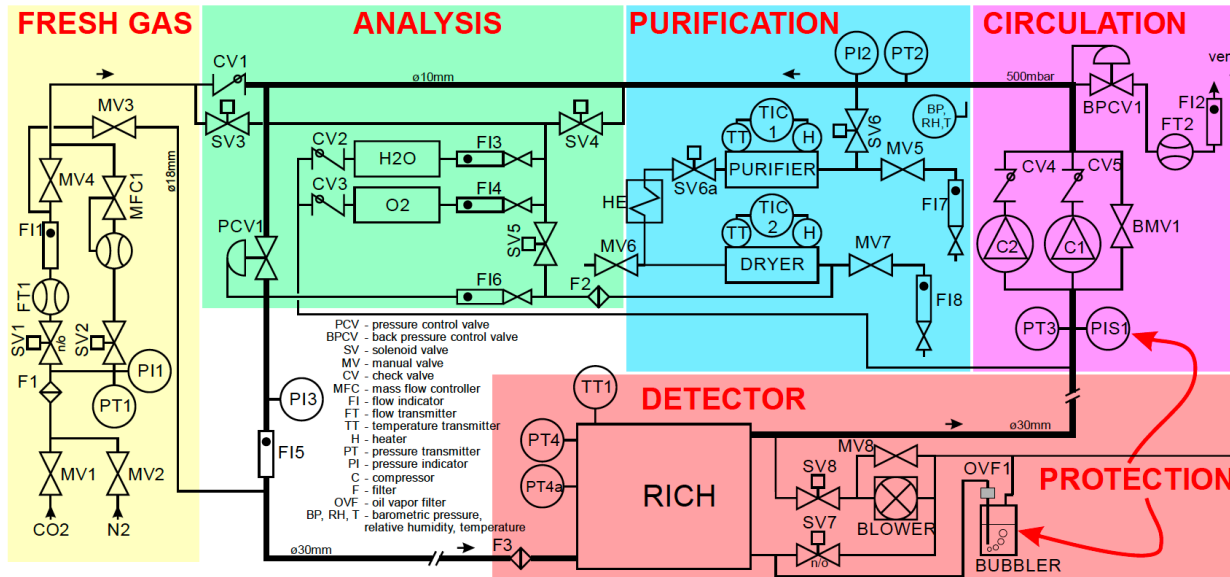
## PNPI contributions to RICH

- RICH mechanics: Gas box, support stand, mirror system
- Mechanical design of shielding box (complete, depends on the magnet design)
- Gas system





# RICH GAS SYSTEM



## Requirements:

- Gas: pure CO<sub>2</sub>
- Differential pressure =  $2.0 \pm 0.1$  mbar
- Detector volume =  $\sim 60$  m<sup>3</sup>
- Purging flow rate = 100 slpm
- Recirculation flow rate = 40 slpm
- Oxygen content < 9000ppm
- Moisture content < 2000ppm





Compressed Baryonic Matter  
experiment at FAIR

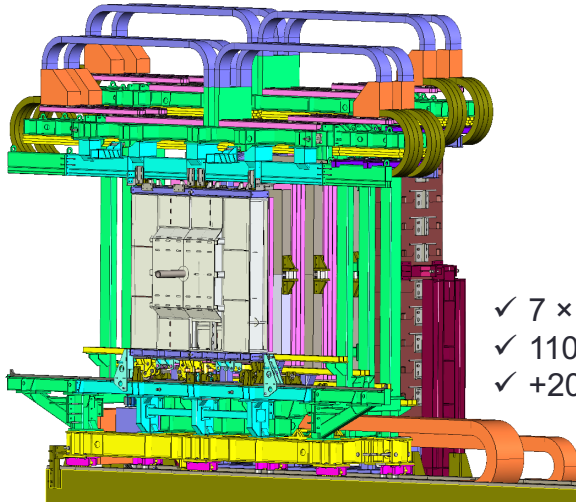
CBM



MUCH



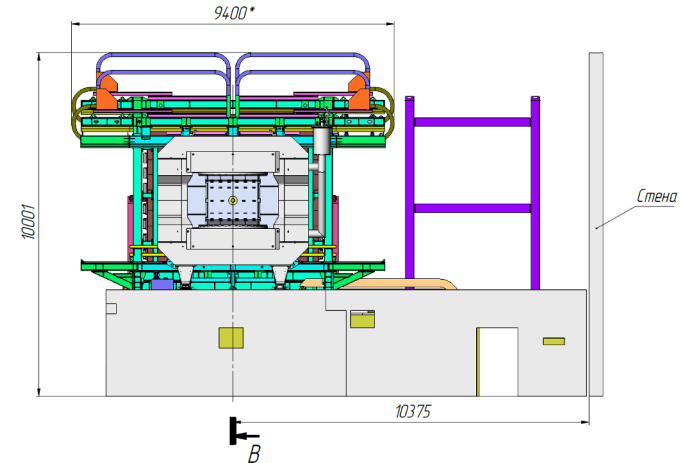
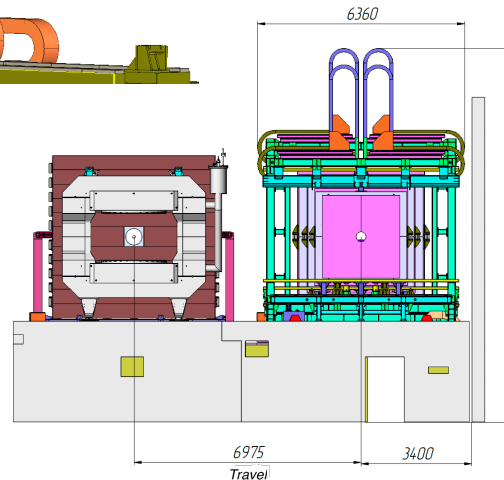
# MUCH MECHANICS



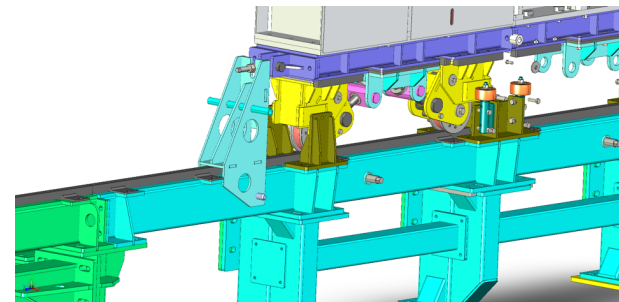
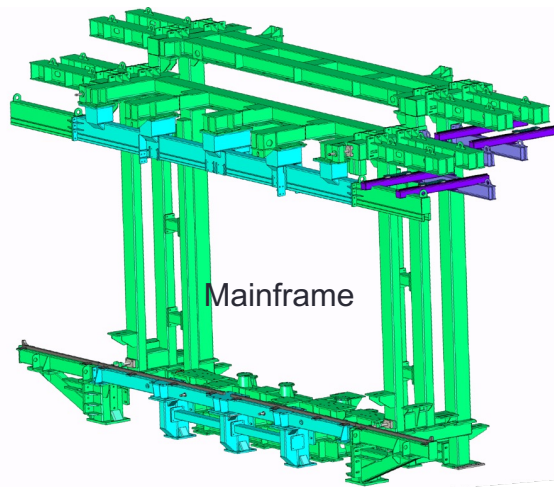
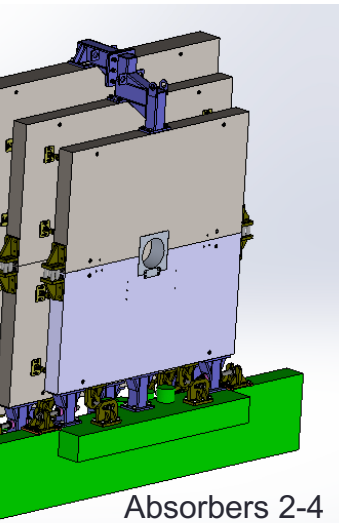
PNPI contribution to CBM MUCH detector

- MUCH mechanics: absorbers, superstructure, rails
- Mechanical design of the 5<sup>th</sup> absorber
- Gas systems

- ✓  $7 \times 7 \times 2$  m
- ✓ 110 t (movable)
- ✓ +200 t (Absorber 5, 1.5 m)

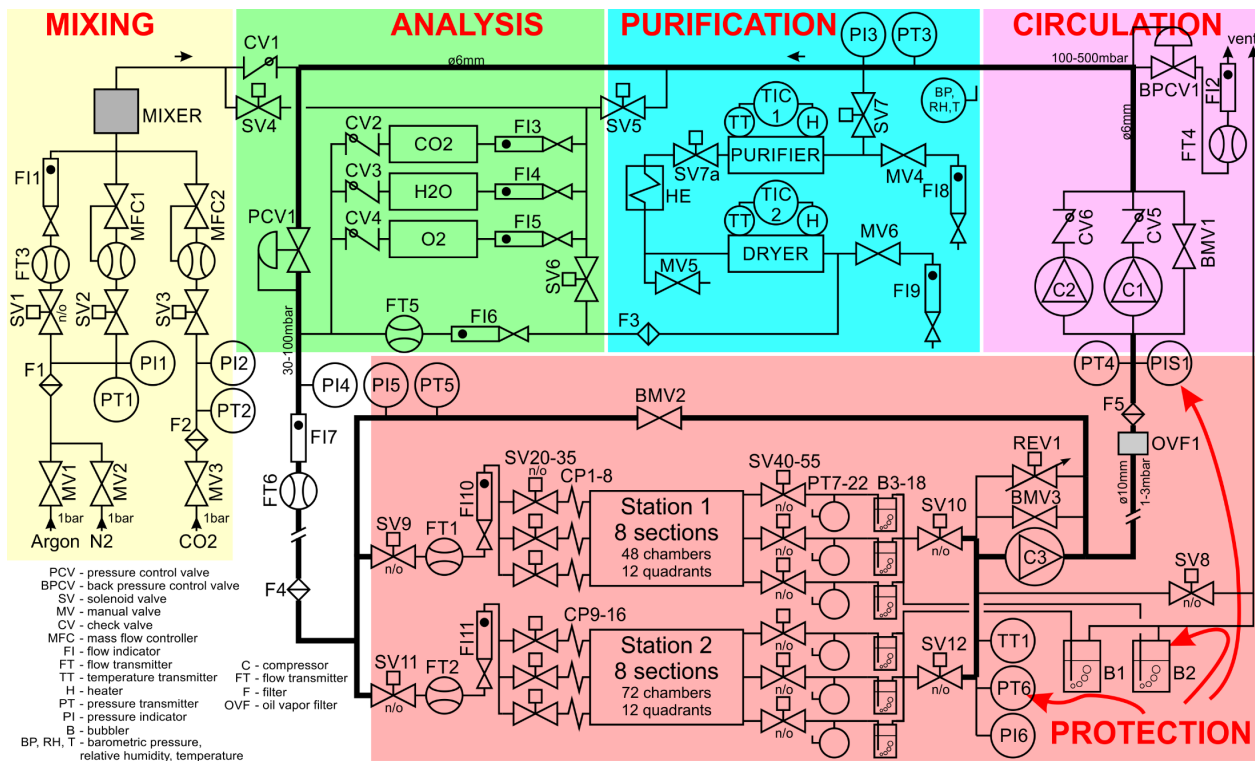








# MUCH GAS SYSTEM



## Requirements:

- Gas mixture – Ar + 30% CO<sub>2</sub>
- Differential pressure = 1.0-2.0±0.1 m
- Detector volume = 200 liters
- Detector structure – 8 sections
- Leak detection in each section
- Purging flow rate = 4 slpm
- Recirculation flow rate = 2 slpm
- Oxygen content <10ppm
- Moisture content <10ppm





Compressed Baryonic Matter  
experiment at FAIR

CBM



PSD



# New CBM Forward Detector

- Discussion on a new CBM Forward Detector as a possible Czech contribution
- Based on plastic scintillator, similar to HADES forward hodoscope wall or STAR Event Plane Detector
- Experience of NPI Rez and CTU Prague groups in HADES FW and ALICE FIT FDD projects

