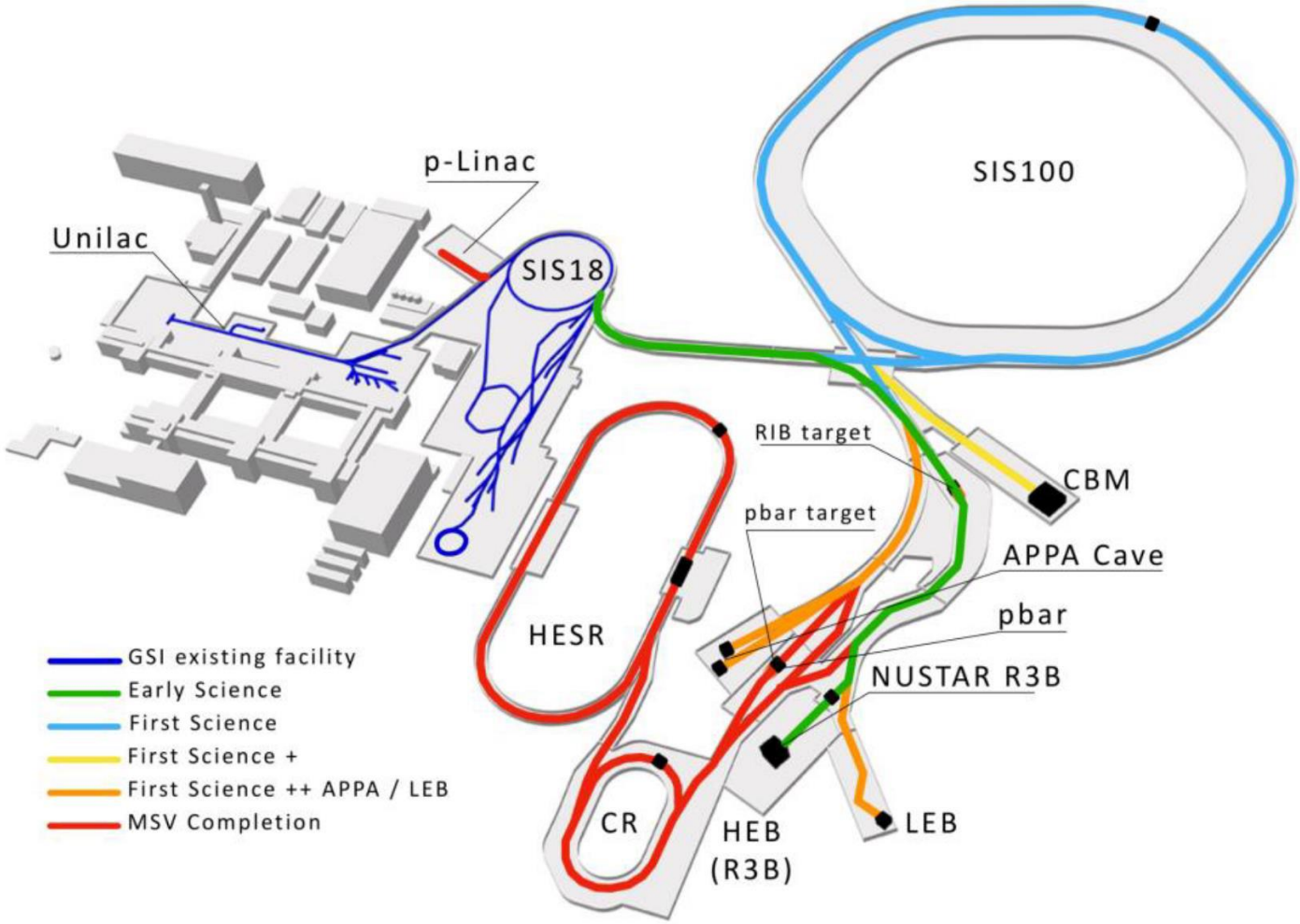
# CBM: status and planning

N. Herrmann, Heidelberg University

# Recent developments of FAIR and CBM




Substantial cost increase surfaced in 2021,
Russian attack on Ukraine

Science evaluation in 2022
(chairs: R. Heuer, R. Tribble)

Recommendation:
downscope FAIR project with cost cap

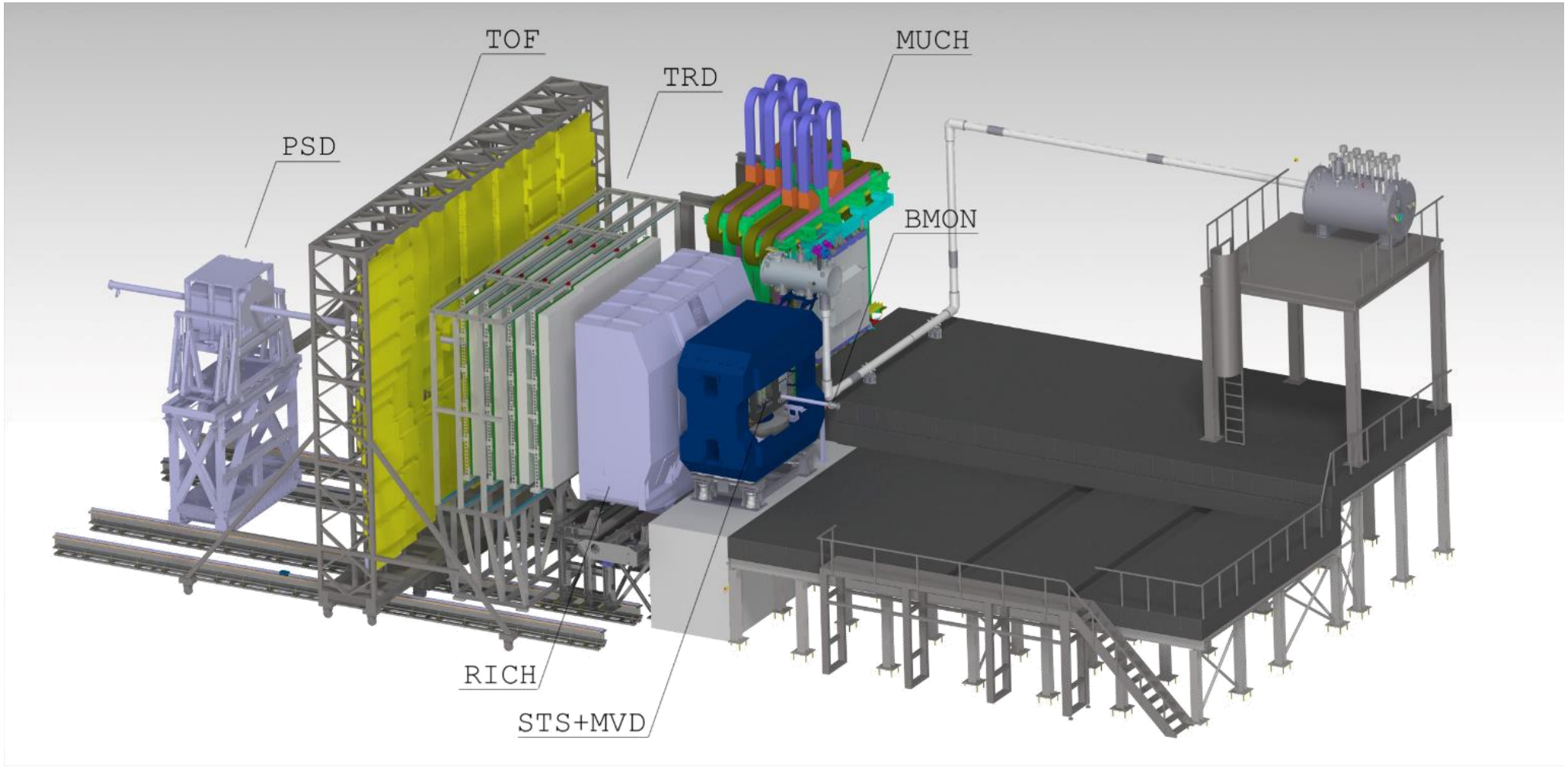
Suggested scenario:
FS+: SIS100 & SFRS/R3B & CBM

Additional funds provided by BMBF
Planned scenario: FS

Start of FS operation: 2028/29

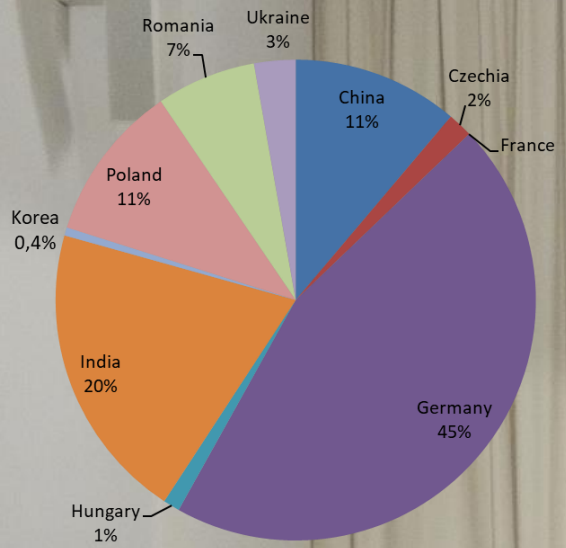
https://www.gsi.de/fileadmin/oeffentlichkeitsarbeit/fair/FAIR-report_221025.pdf

# CBM experiment




CBM Day-1 configuration (2028) : rate capability 100 kHz Au+Au reactions with streaming (triggerless) readout of MVD, STS, RICH, MUCH, TRD, TOF and FSD

# CBM collaboration




47 (+10) institutes

310 full members

**41st CBM collaboration meeting, Mar. 2023, TUD, Darmstadt**

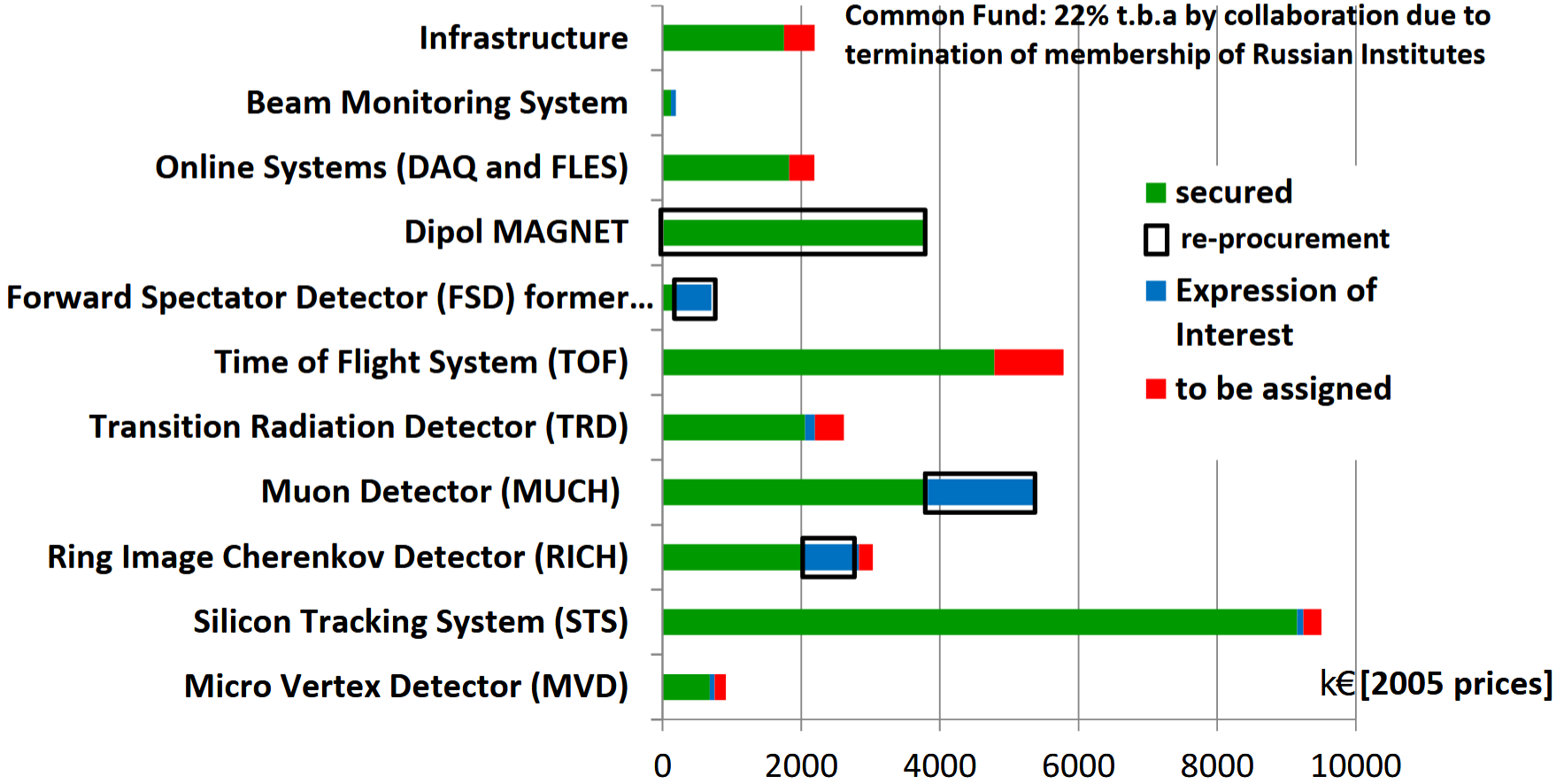
# Revised CBM day-1 funding (Jun. 2023)

**Estimated re-procurement costs [2023 EUROS]**

- Magnet: 6,14 M€
- Forward Detector (former PSD): 0,72 M€
- RICH mechanics, gassystem: 1,28 M€
- MUCH absorbers, mechanics: 2,56 M€

**total cost: 35,97 M€ (2005 EURO)**
**secured: 30,17 M€**
**EoI: 3,32 M€**
**t.b.a. 2,48 M€**

**83,9 % secured funding**



# Consequences FS / FS+

- Council decision:

**(6) The additional non-German commitments will in principle be used to secure First Science. Exceptions from this principle with regard to a possibility to go beyond First Science require a Council decision, in particular the CBM magnets, expected for Summer 2023.**

- FAIR management plan:

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 |
| | | **Sum** | **ca. 37 Mio. €** | |

The collaboration is actively seeking alternative funding sources for detector components (items 2-5), thus, possibly mitigating the financial needs. In case of several years of delay, a significant increase of costs of at least 20% would be expected.

**CBM is part of FAIR2028. Thanks to all involved committees and management!**

- Note: Project core invest is necessary but not sufficient to keep the CBM collaboration active.
  BMBF – funds through German „Verbundforschung“ are indispensable and needed for funding of personnel (PhD students and postdocs)

# FAIR Council decisions July 5-6, 23

- Procurement of the CBM dipole magnet approved with a budget frame of 5,6 Mio€@today.
- Additional commitments of shareholders expected until the Council in Dec. 2023.
- Positive decision on FS+ in the Council Dec. 2023 possible provided after review of Cost to Completion FS / FS+ including the risk situation by Cost Scrutiny Group

# CBM experimental hall

# CBM installation in experimental hall

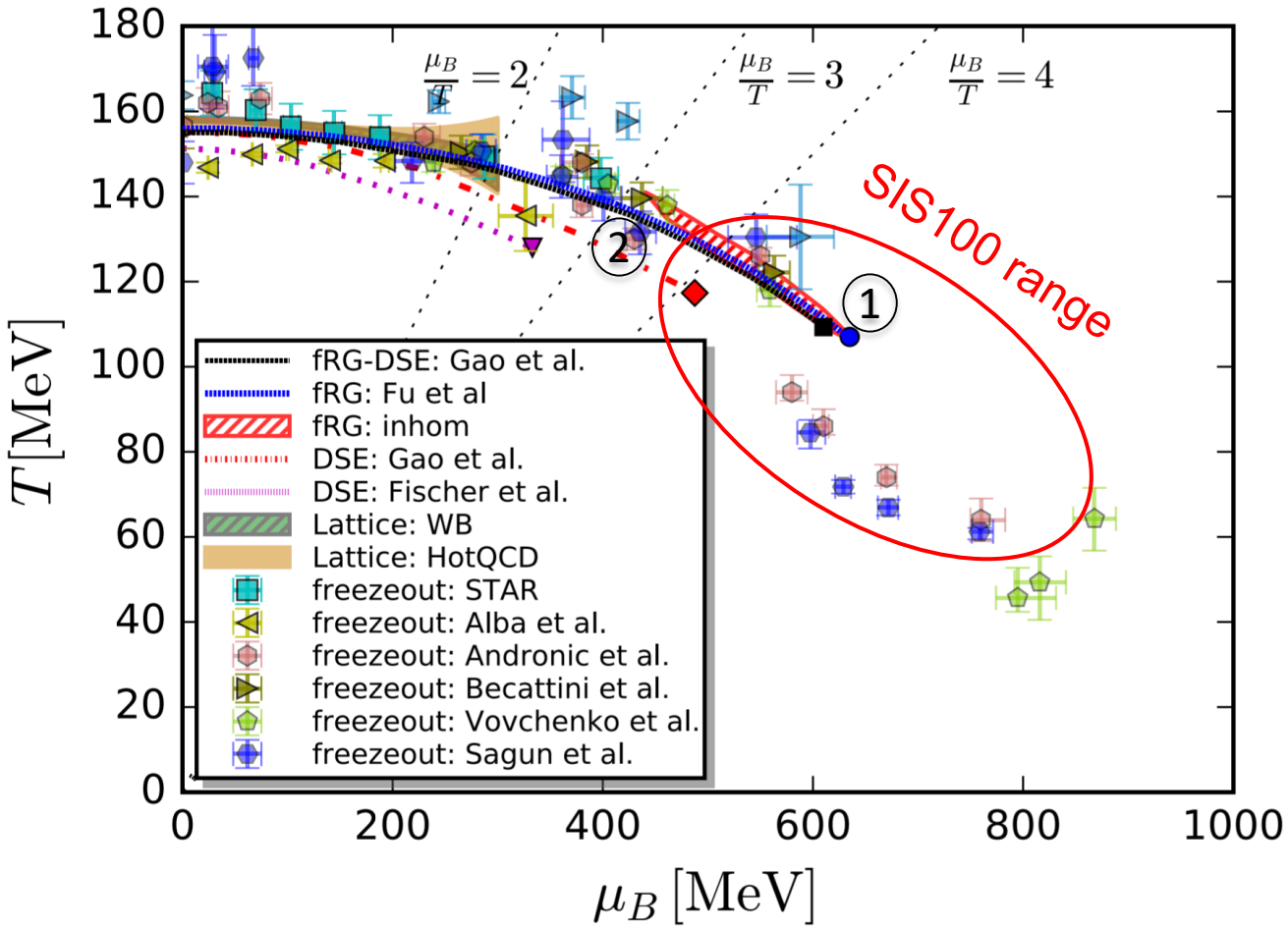
Upstream platform

Czech contribution to CBM

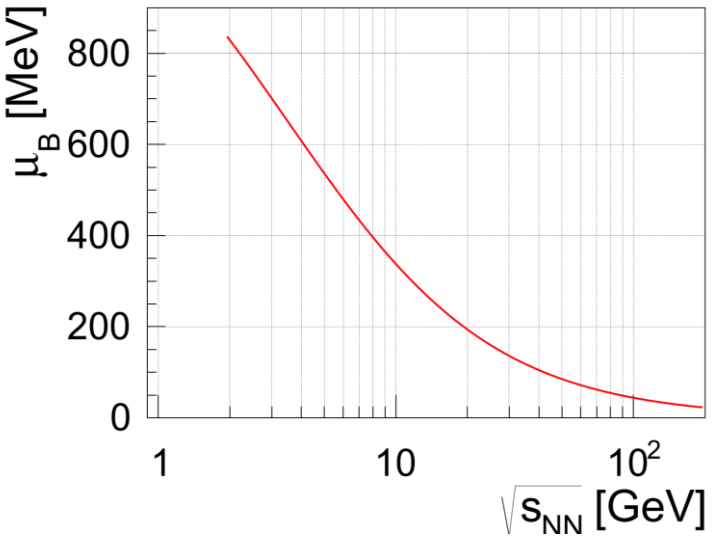
# Phase structure of QCD

Location of chiral cross over

W. Fu, J. Pawlowski, F. Rennecke, *Phys.Rev.D* 101 (2020) 5, 054032, arXiv:1909.02991




A. Andronic et al., Nucl.Phys.A772:167 (2006)



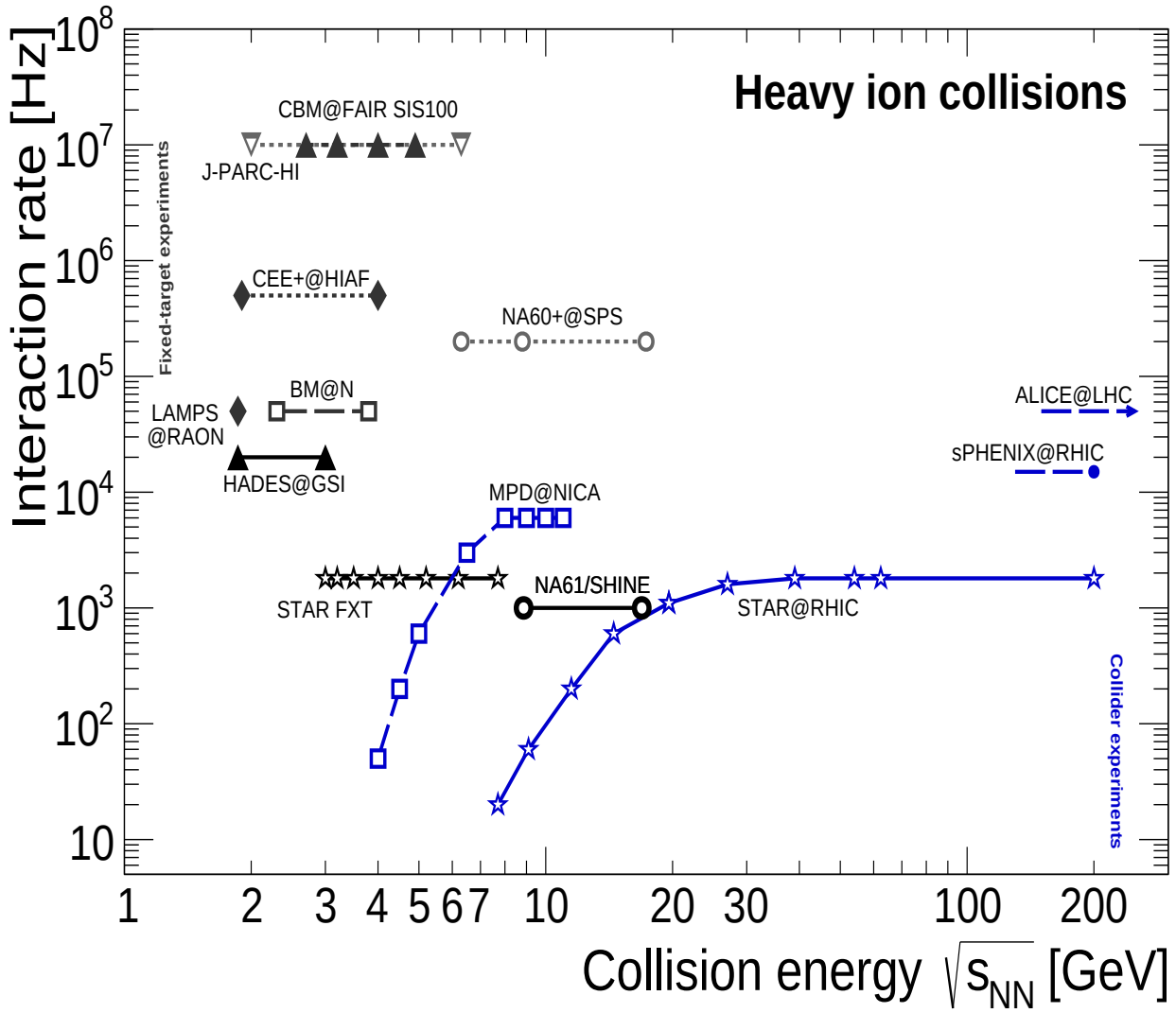

| | $\mu_B$ (MeV) | $\sqrt{s_{NN}}$ (GeV) | $T_{lab}$ (A GeV) |
|---|---|---|---|
| 1 | 622 | 3.8 | 6.0 |
| | 500 | 5.2 | 15.0 |
| 2 | 400 | 7.8 | 31.5 |

Challenges:

Phase transition not at freeze-out line, need probes with memory,
reaction dynamics needs to be controlled.

# CBM – Technological Goal

T. Galatyuk, https://github.com/tgalatyuk/interaction_rate_facilities, 2022

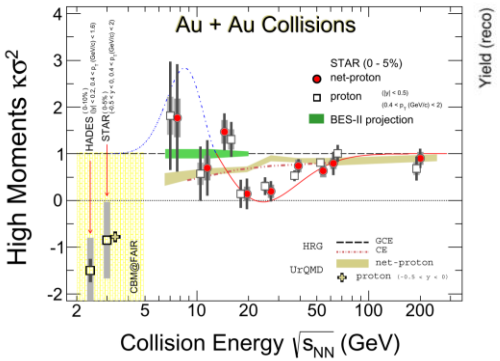


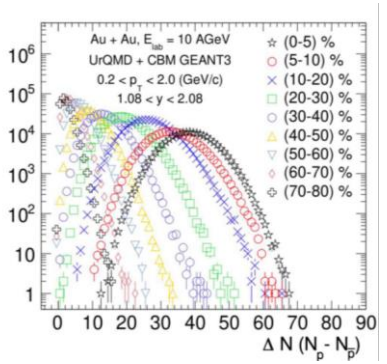

**Mission:**
Systematically explore QCD matter
at large baryon densities
with high accuracy and rare probes.

**Disclaimer:**
not all measurements benefit from the highest possible rates.

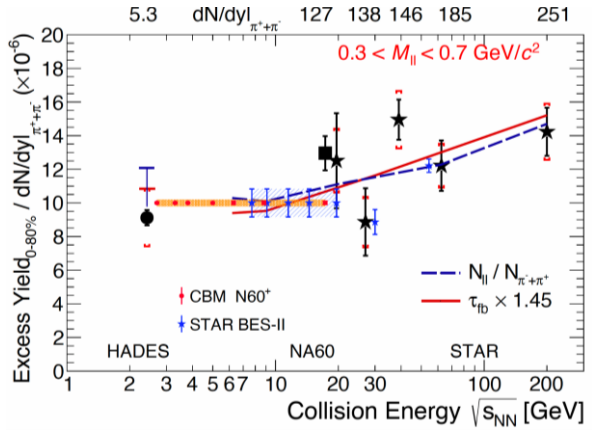
# CBM observables

## Criticality

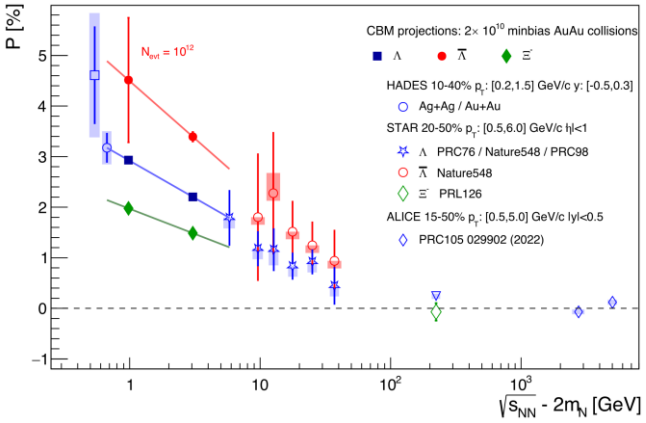


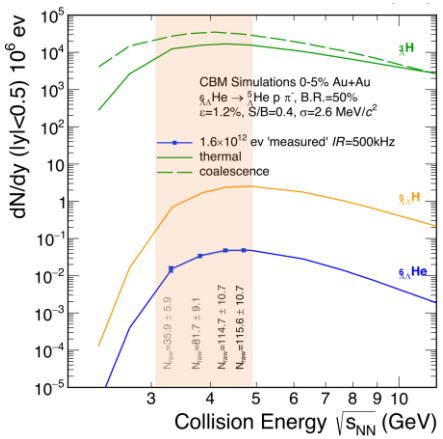

## Emissivity



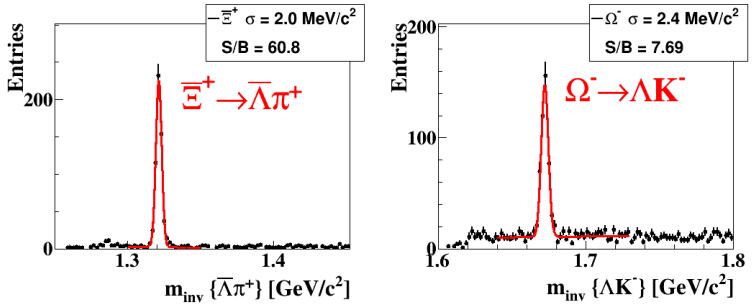

## Vorticity

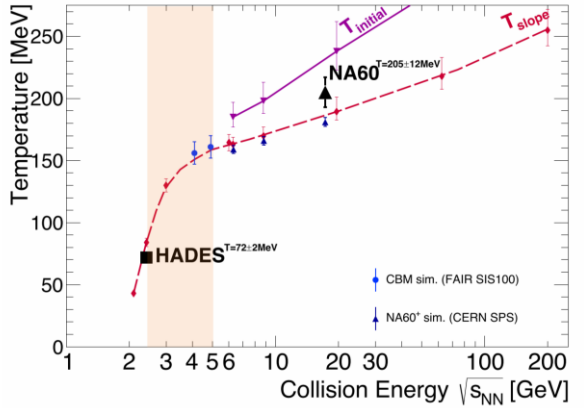



## Hypernuclei



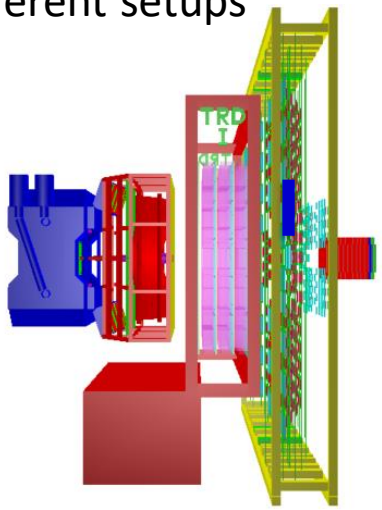

## Equation-of-State



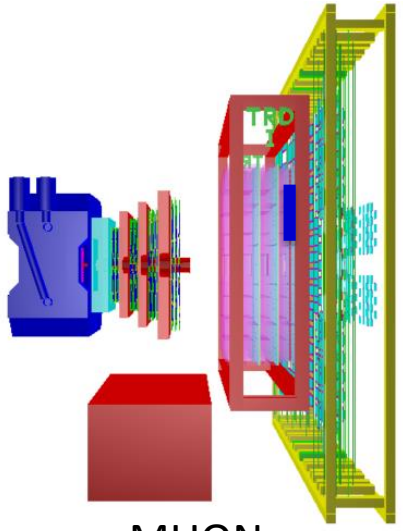



# CBM setups

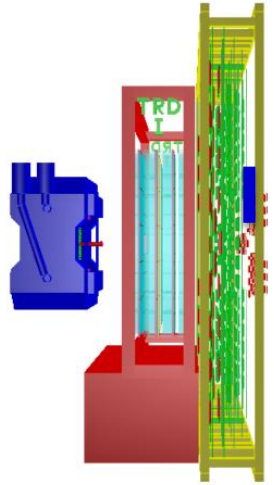
Sideview of different setups




ELEHAD




MUON




HADR

| Setup | Included subsystems | Average day-1 interaction rate | Average MSV - interaction rate | Average event size in Au+Au collisions |
|---|---|---|---|---|
| ELEHAD | MVD,STS,RICH,TRD,TOF,FSD | 0.1 MHz | 0.1 MHz | 75 kB |
| MUON | STS,MUCH,TRD,TOF,FSD | 1 MHz | 5 MHz | 30 kB |
| HADR | STS,TRD,TOF,FSD | 0.5 MHz | 5 MHz | 50 kB |

# Preliminary run plan for first 3 years

| Year | Setup | Reaction | Beam Energies $T_{lab}$ [AGeV] | Days on Target | Number of events | Remarks |
|---|---|---|---|---|---|---|
| 0 | ELEHAD | C+C, Ag+Ag, Au+Au | 2,4,6,8,10,max | 60 | | Commissioning |
| 1 | ELEHAD | Au+Au | 2,4,6,8,10,max | 30 (5 each) | $2 \cdot 10^{10}$ each | EB minBias |
| 1 | ELEHAD | C+C | 2,4,6,8,10,max | 18 (3 each) | $4 \cdot 10^{10}$ each | minBias |
| 1 | ELEHAD | p+Be | 3,4,8,29 | 12 (3 each) | $2 \cdot 10^{11}$ each | minBias |
| 2 | MUON | Au+Au | max | 30 (5 each) | $2 \cdot 10^{12}$ each | minBias |
| 2 | MUON | C+C | max | 18 (3 each) | $4 \cdot 10^{12}$ each | minBias |
| 2 | MUON | p+Be | 11,29 | 12 (3 each) | $2 \cdot 10^{13}$ each | minBias |
| 3 | HADR | Au+Au | 2,4,6,8,10,max | 12 (2 each) | $4 \cdot 10^{11}$ each | EB + Selector(s) |
| 3 | HADR | C+C | 2,4,6,8,10,max | 6 (1 each) | $8 \cdot 10^{11}$ each | |
| 3 | HADES | Ag+Ag | 2,4 | 28 (14 each) | $10^{10}$ each | |
| 3 | ELEHAD | Ag+Ag | 2,4 | 8 (4 each) | $2 \cdot 10^{10}$ each | minBias |

**Assumptions:**

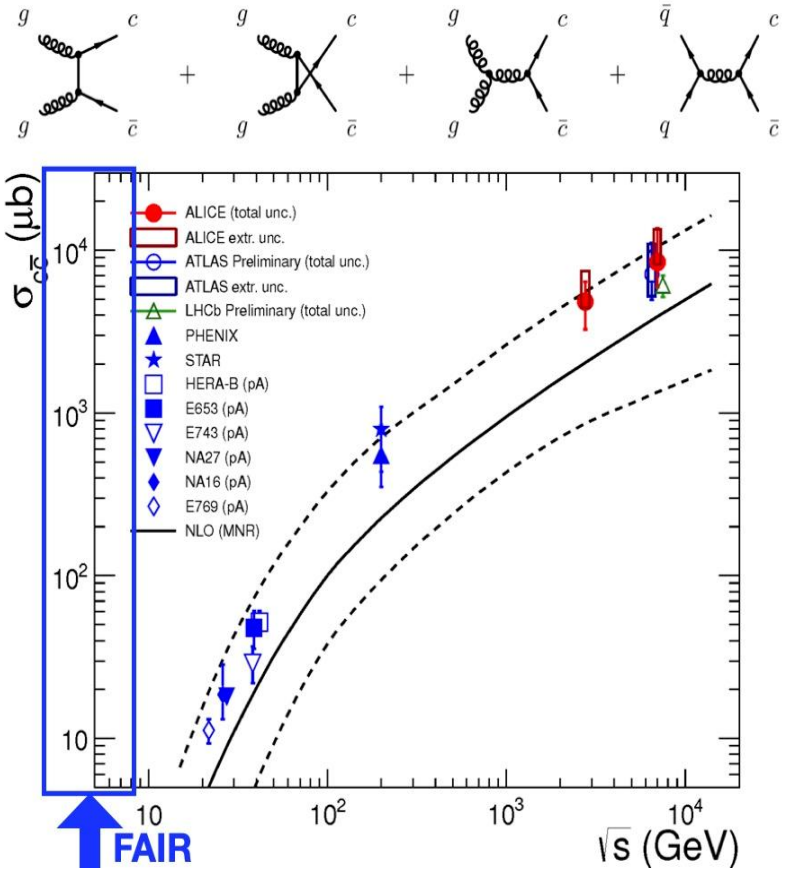
60 days / year beam on target

**Note:**
additional run time
required for pp - program

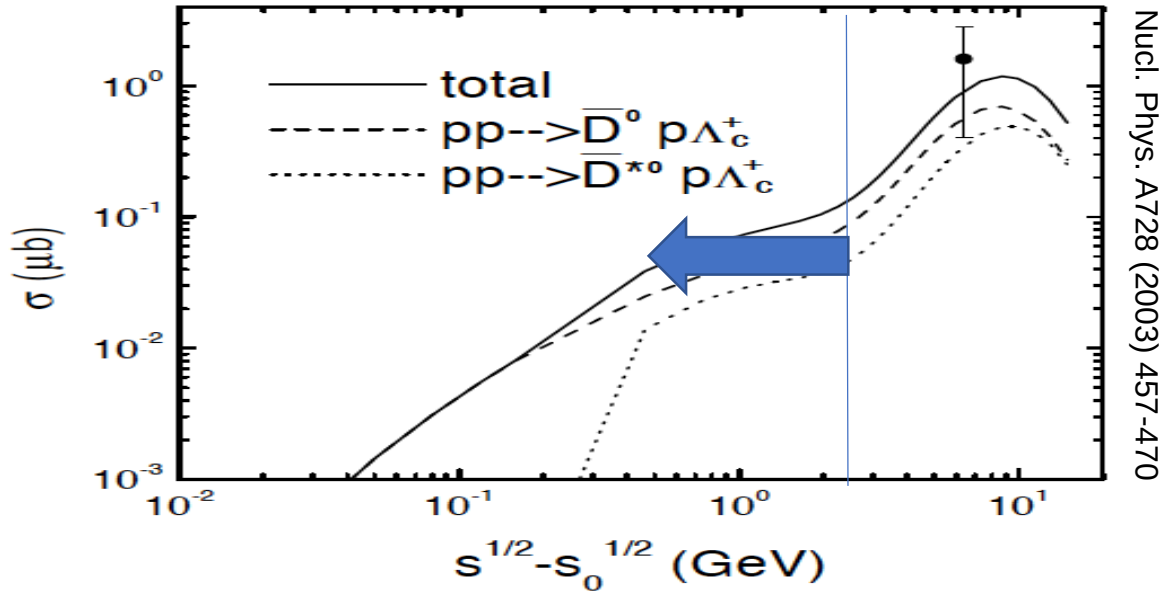
# Extension of the CBM Physics Program

Physics potential of 29 GeV proton beams is being explored together with PANDA (J. Messchendorp, J. Ritman, P. Salabura)

Example for Day-1 CBM hadron setup: charm production, charm-N interaction




- Validity of pQCD at SIS100 energies?
- SU(4) estimates for (exclusive) charm hyperon production: 100 nb@SIS100
- Perspectives to study for the first time near-threshold charm production

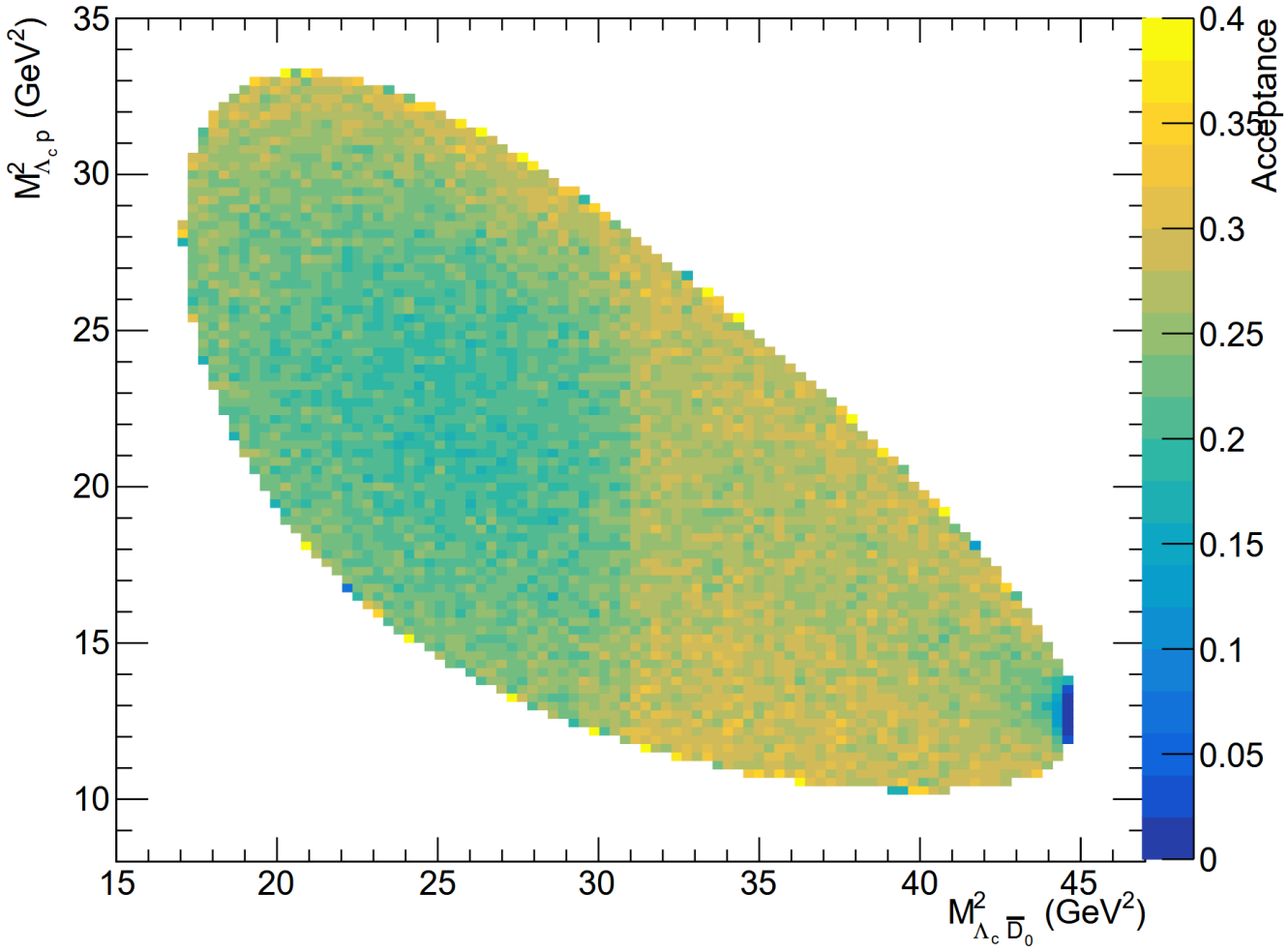



Can intrinsic charm of nucleon enhance production cross section?
(Analogy of ss bar content in nucleon and ϕ production)

# CBM projection for studying exclusive reactions

$$pp \rightarrow p\Lambda_c(\rightarrow pK^-\pi^+)\,\bar{D}_0(\rightarrow K^+\pi-)$$

**Dalitz plot** for uniform population of phase space




**Rate estimate:**

Cross section: 100 nb

Beam intensity: $10^{12}$ 1/s

Target: LH2

Target thickness: 5 cm

Duty cycle: 50%

$\Rightarrow$ Detected reaction rate (including BRs): 1 Hz = 8.6 $10^4$ / d

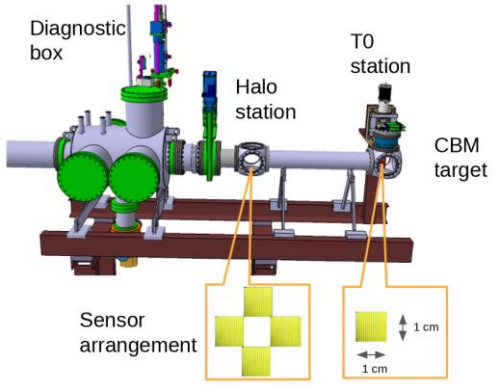
Detailed studies of pD and p$\Lambda_c$ interactions become possible (femtoscopy).

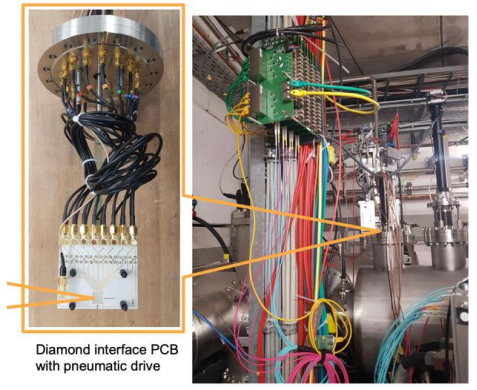
more details => Jim‘s talk

# Status of CBM detector systems

## Beam Monitor (BMON)

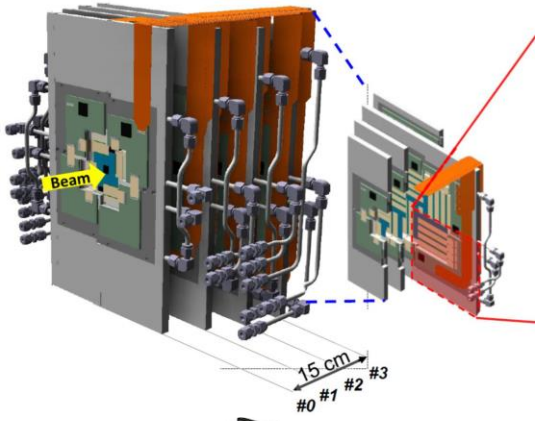
- T0 high purity pcCVD diamond demonstrator successfully tested in mCBM 2022 runs
- novel sensor technologies (LGAD, SiC) under investigation

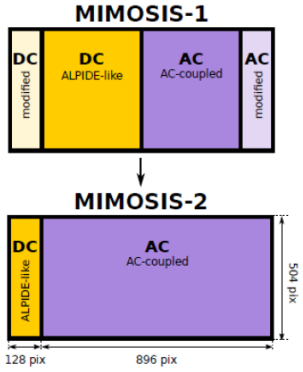


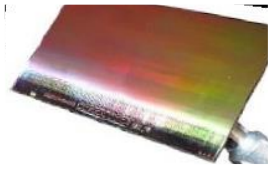




## Micro Vertex Detector (MVD)

- Intensive test campaigns of full-size MAPS prototype MIMOSIS-1 → MIMOSIS-2 expected for mid of 2023
- Preproduction quadrant in preparation

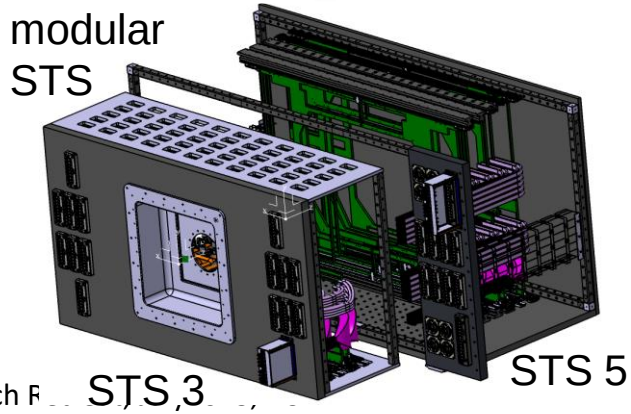


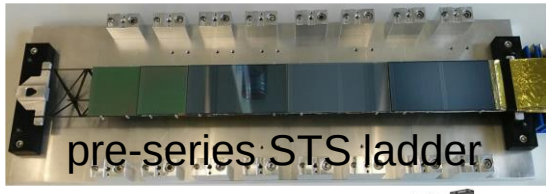



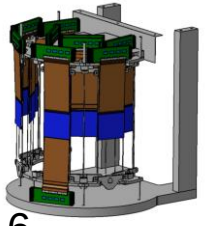
## Silicon Tracking System (STS)

- Revised modular design with 3+5 stations
- Ladder preproduction will be deployed in J-PARC E16
- Re-design of FEB8-2 and FEB8-5



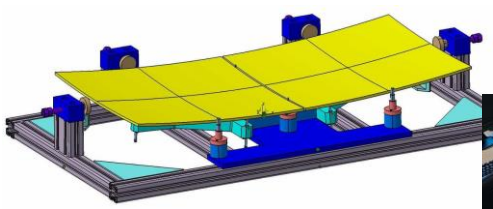

STS ladder pre-series production deployed in J-PARC E16

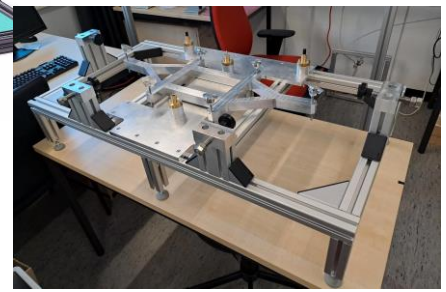


# Status of CBM detector systems

**Ring Imaging CHerenkov detector (RICH)**

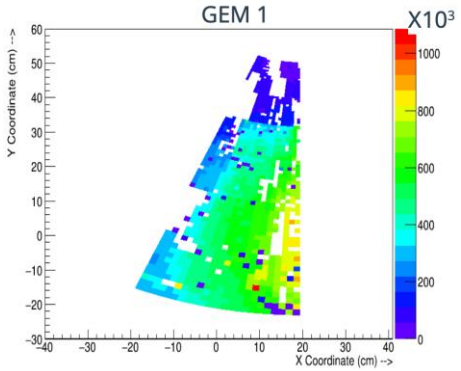
- Towards mechanics engineering design and production readiness
- Photocamera - series production of readout electronics
- Successful runs at HADES and mCBM





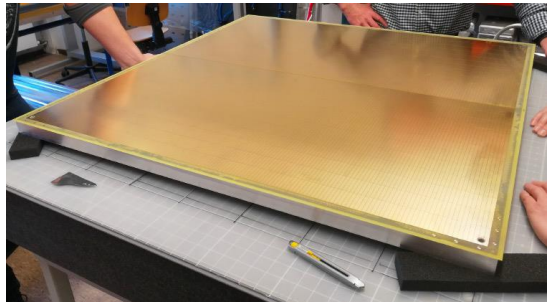
**MUon CHamber system (MUCH)**

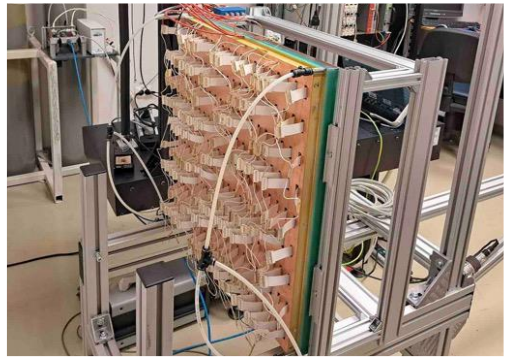
- Intensive test campaigns of full-size GEM and RPC prototypes at GIF++ and mCBM, readout stability significantly improved, data analysis ongoing.




**Transition Radiation Detector (TRD)**

- Preproduction of 4 standard modules
- Construction of full-size TRD-2D prototype (inner part)
- New SPADIC 2.4 design, test submission planned for April 2023
- TRD as intermediate tracker, successful runs at mCBM

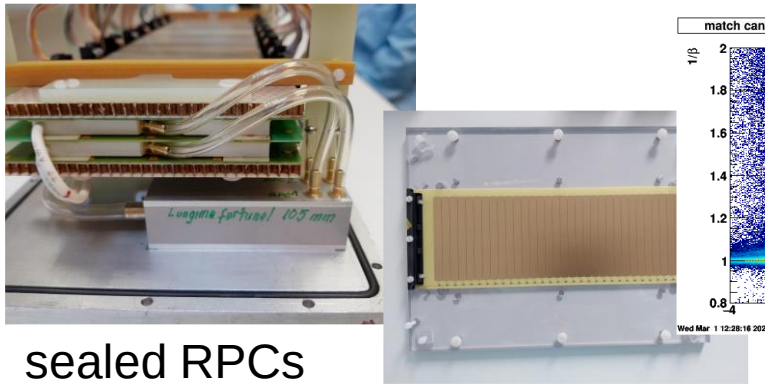




# Status of CBM detector systems

**Time of Flight system (TOF)**

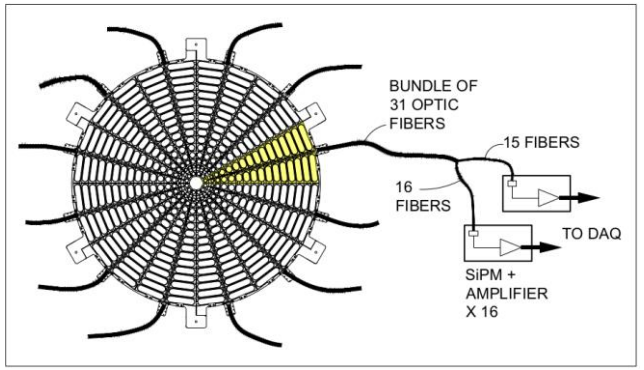
- Successful data taking at STAR and mCBM, data analysis ongoing
- Sealed RPCs to enhance rate capability
- Engineering design of main frame
- RPC preproduction

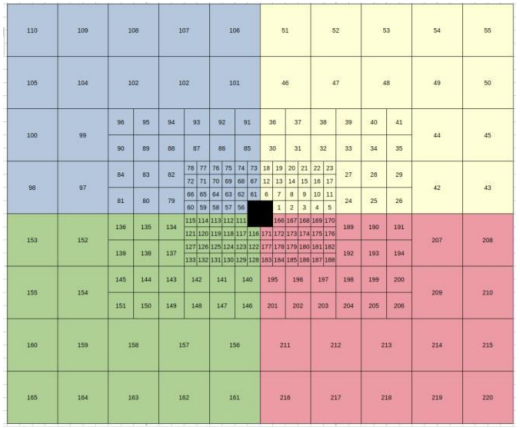



sealed RPCs

**Forward Spectator Detector (FSD)**

- New design, likely based on ZnS scintillators and LYSO crystals for central part
- Read-out via SiPM
- Readout electronics based on existing solutions

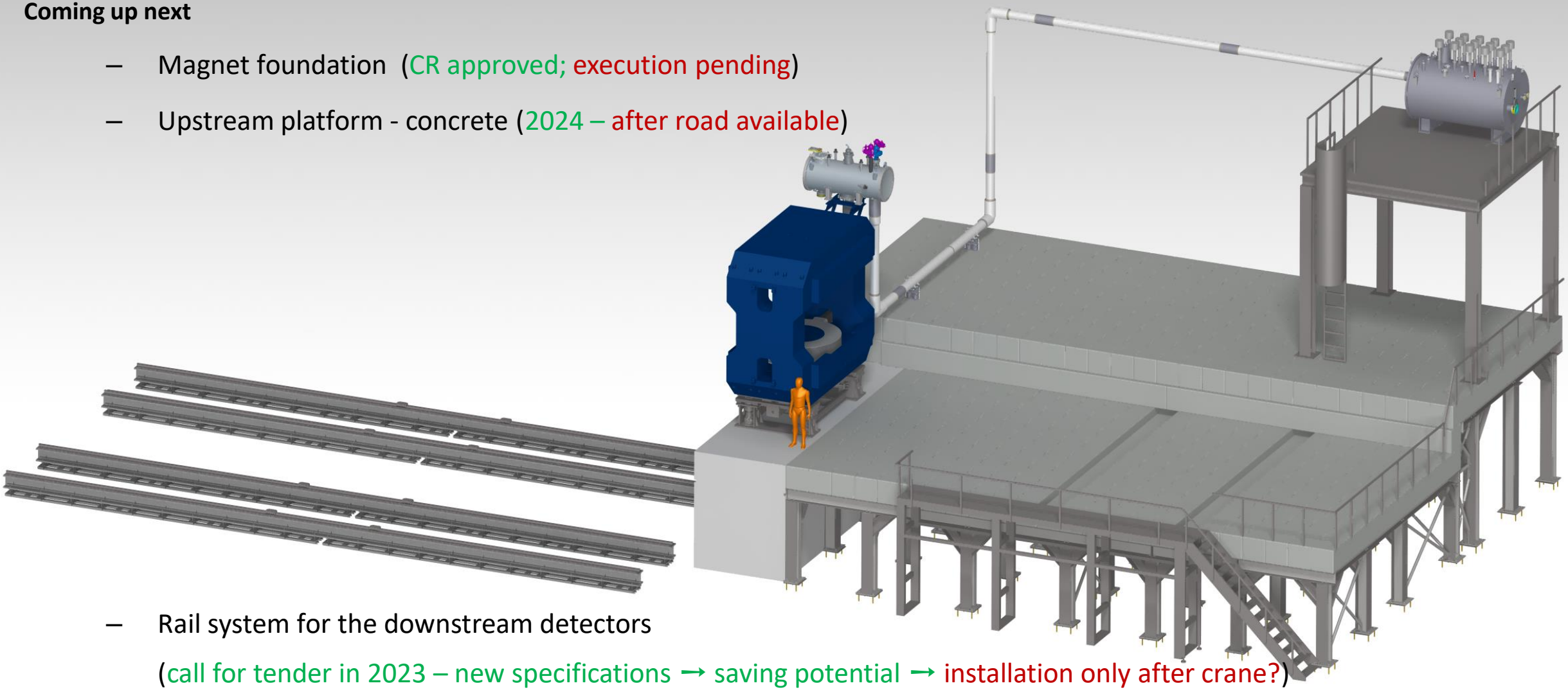


# Cave: common infrastructure, installation

**Coming up next**

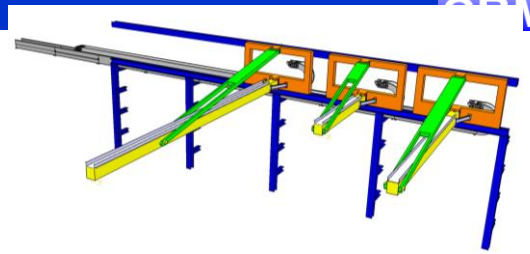
- Magnet foundation (CR approved; execution pending)
- Upstream platform - concrete (2024 – after road available)



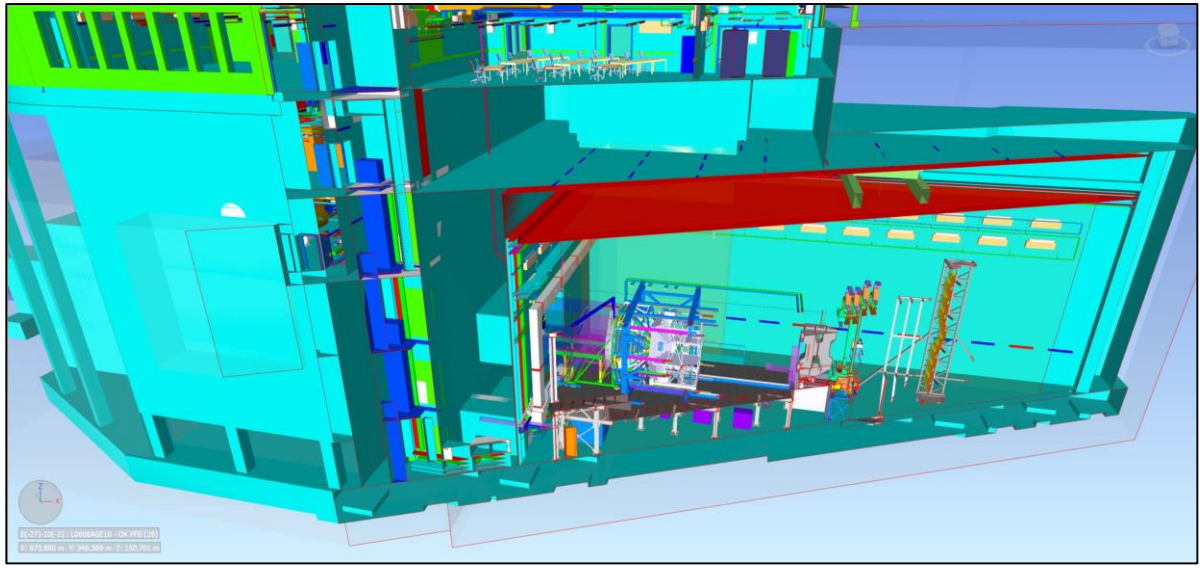
- Rail system for the downstream detectors

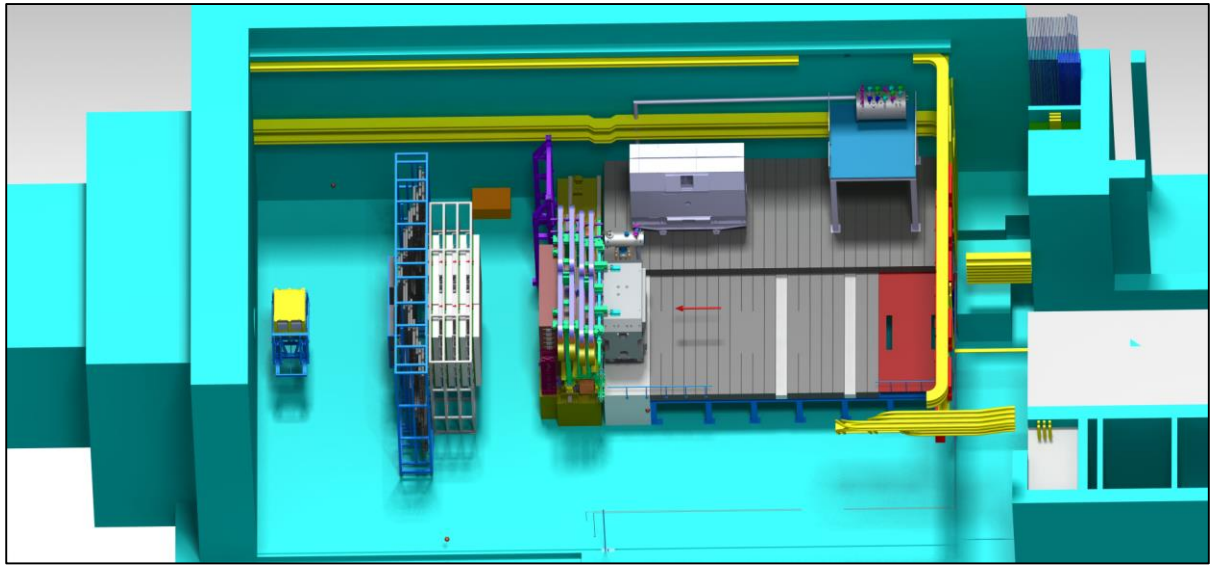
  (call for tender in 2023 – new specifications → saving potential → installation only after crane?)

# Services and integration

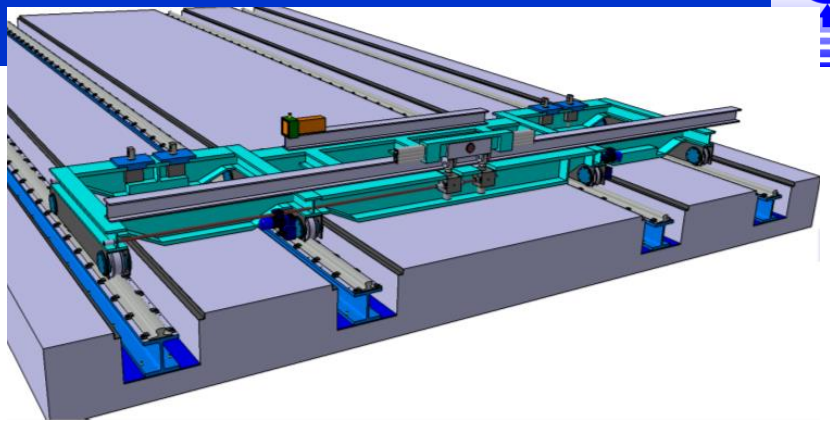


- TGA planning started with electrical network. Emergency shutdown defined.
- Feedback from the sub-systems crucial for proper detector services planning (HV, LV CDRs!)
- Discussion on service installation with expert team ongoing (**IKC with Poland, CBM as an “option” – FS+**)
- Integration, installation logistics worked out within the TC team, in contact of all the subsystems
- **Service installation during/after TGA, in 2025/2026?**

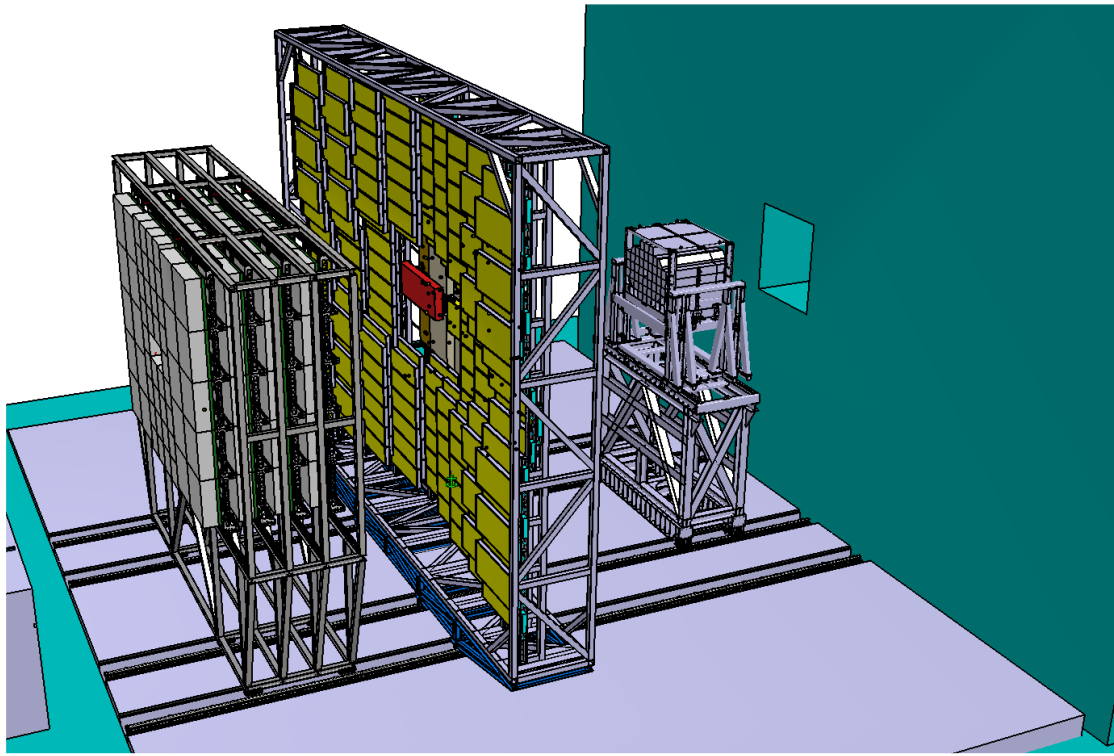




# Detector structures

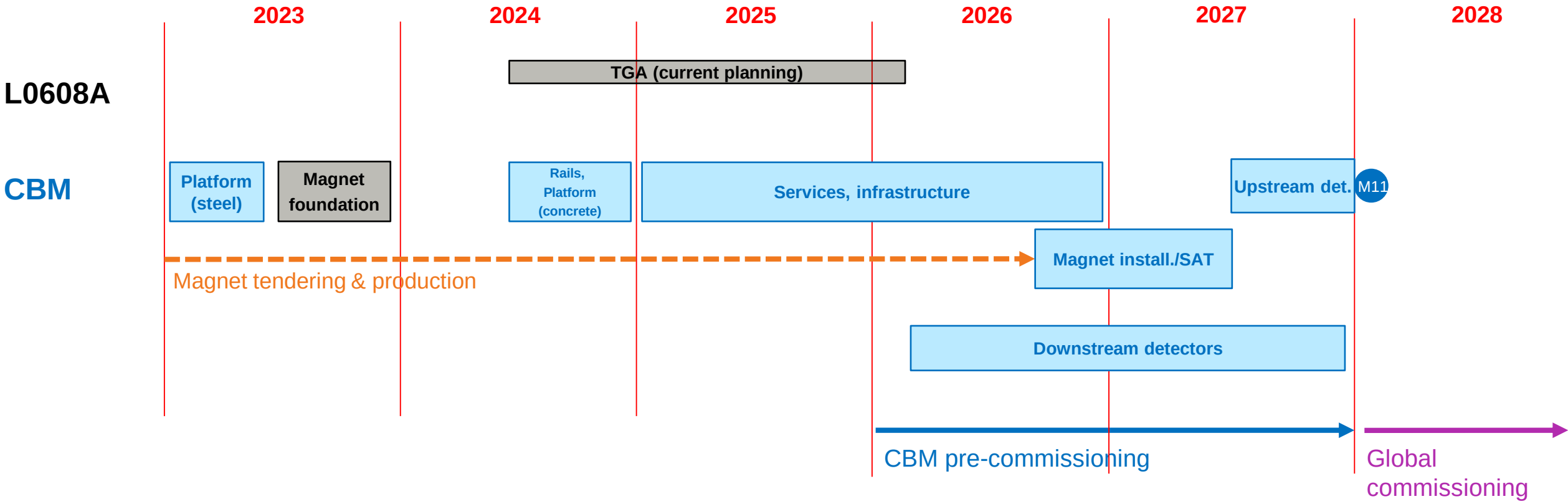


- In 2026, we could start with the large mainframes od the downstream detectors (TRD, TOF, FSD)
- Prerequisite: rail system ready!



- Detector modules (e.g. >200 for TOF) will be installed following their availability in the assembly site (frequent transports, short installation activities in the cave), starting in 26/27
- Module installation not on the critical path. Commissioning can start with any condiguration.
- Connectivity to servies needed to start commissioning (TGA + CBM services)

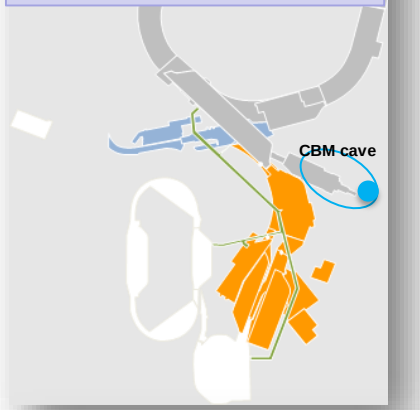
# Installation/commissioning

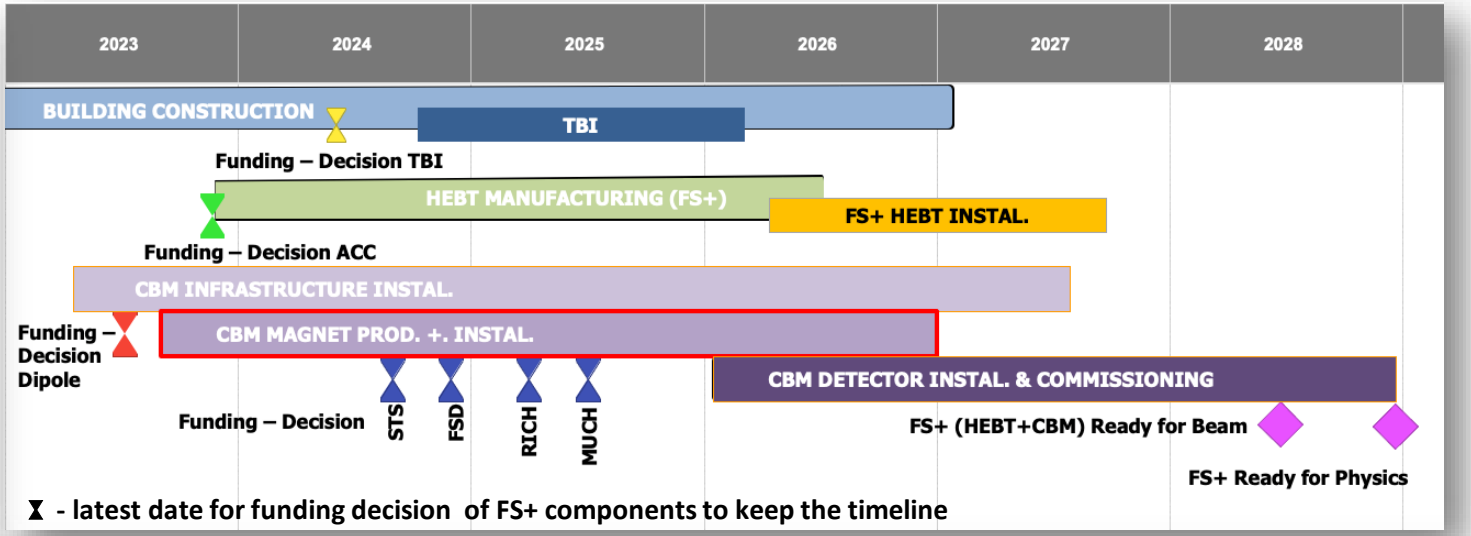



- **We plan CBM to be ready for beam by the end of 2027**
- ~1y contingency until SIS100 “ready for physics” (used for CBM global commissioning)
- Critical path: magnet, to be clarified after tendering

# First Science + in 2028, CBM

**Action 2: Release for procurement CBM Magnets**




- **First science + in 2028 is realistic for CBM (◆)**
- Commissioning of buildings and detector installation requires timely completion of **TBI (⧗)**
- **Commissioning w/ beam follows the commissioning of SIS100 and HEBT (⧗)**
- **critical path of the CBM: CBM dipole magnet (⧗) re-procurement (FAIR) and installation**
- Re-procurement (⧗) of Russian IKCs required for timely installation of CBM experiment
- **Support of national Funding Agencies is absolutely crucial for the completion of CBM!**

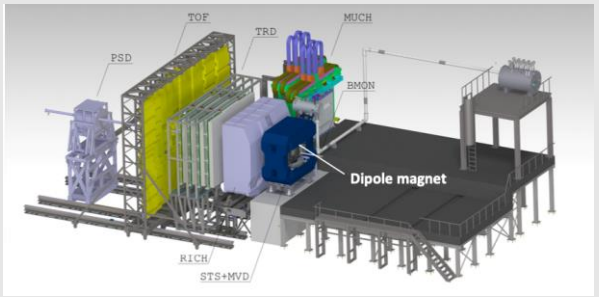


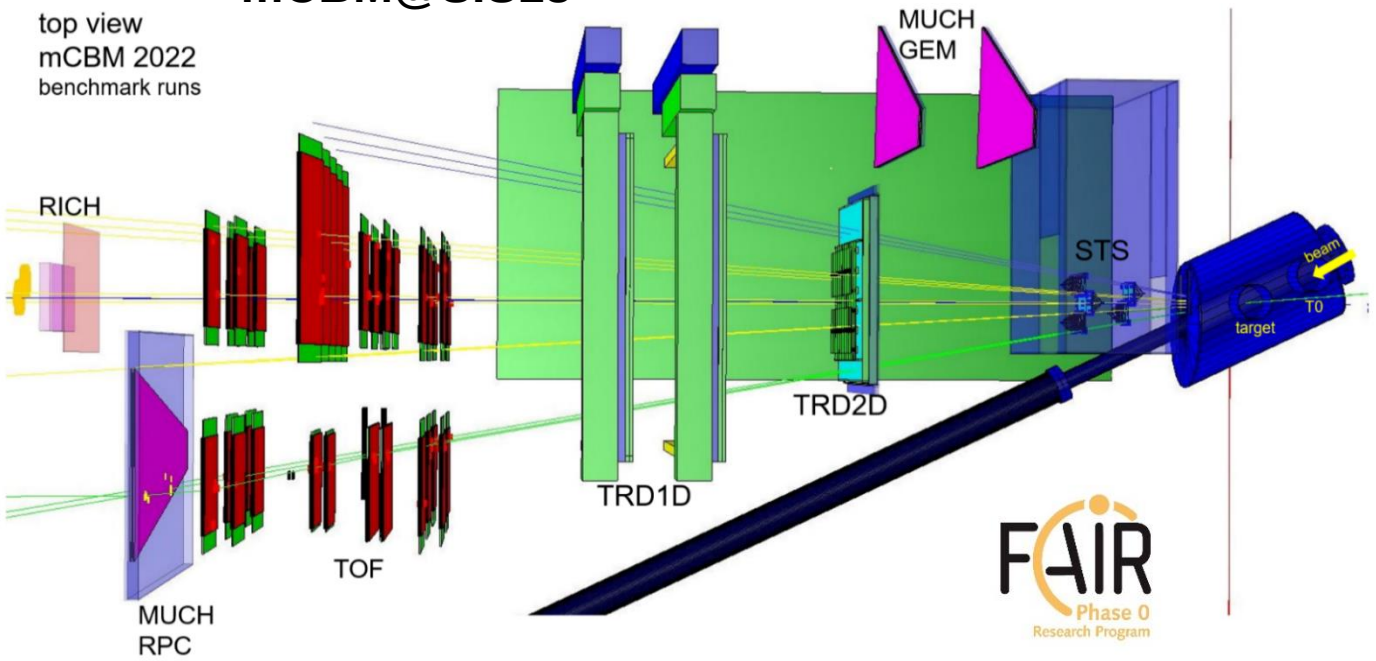

Table 1: Components/services to be procured for the completion of the CBM science programme, their estimated costs (current price level) and their latest date for procurement/expense to keep the timeline.

| | | | | |
|---|---|---|---|---|
| 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 |
| | | **Sum** | **37 Mio. €** | |

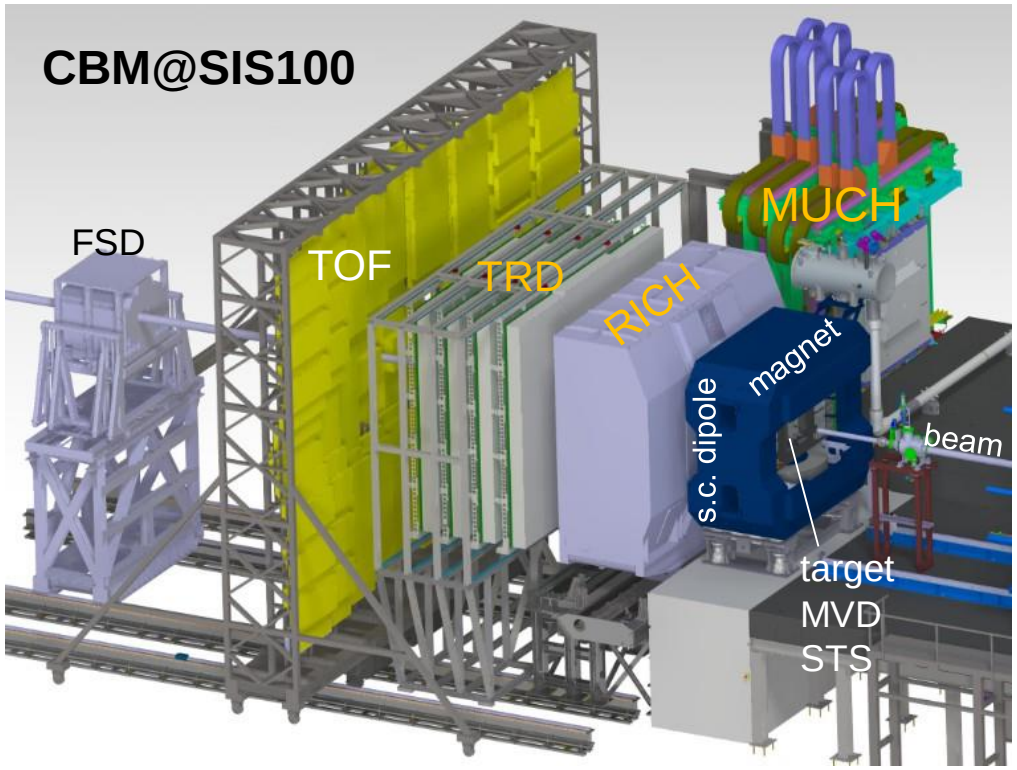
See: 6d_CBM-Milestones-CBS2.3.4.1.pdf

# With mCBM towards CBM

**mCBM@SIS18**




**CBM@SIS100**

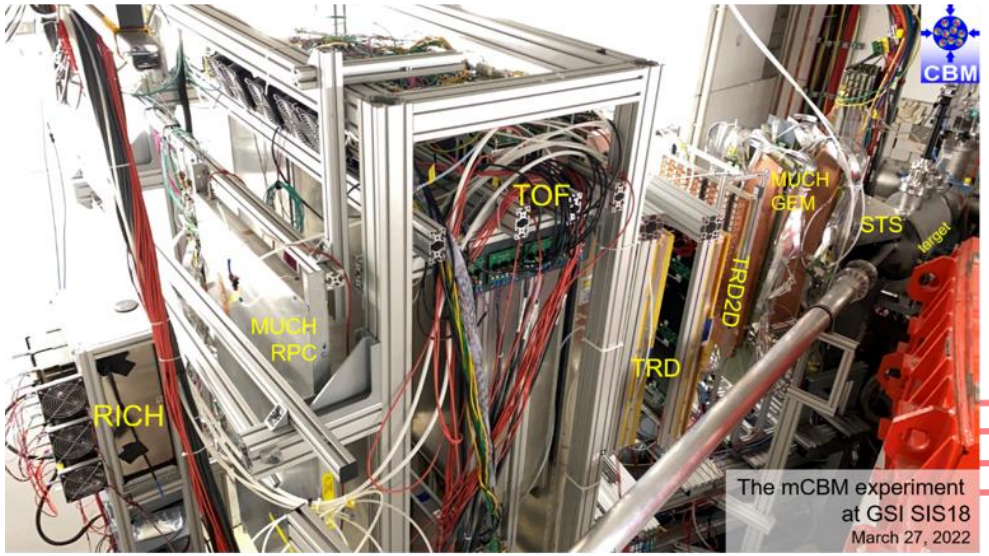



CBM full-system test setup at SIS18/GSI comprising pre-series productions of all CBM detector systems:

| | |
|---|---|
| T0 | 16+16ch pcCVD diamond, 1x1cm$^2$, 80 µm, part of BMON |
| STS | 11 modules, 6x6cm$^2$ and 6x12cm$^2$ double-sided silicon-strip sensors, 5 ladders on 2 stations |
| MUCH | 2 GEMs M2 modules (MUCH 1+2), 1 RPC (MUCH 3+4) |
| TRD | 2 MWPCs with rect. pad (TRD1D, outer region), 1 MWPC with triang. pads (TRD2D, inner part) |
| TOF | 8 MRPCs modules in 2 stacks |
| RICH | 2 aerogel radiators (2 20x20cm$^2$), 36 MAPMTs |

FSD and MVD test systems in preparation

# The free-streaming CBM DAQ and data processing




optical fibers 50m

DAQ container

CRI (PCIe) @ FLES entry nodes

optical fibers 300 m


FLES processing nodes

FAIR Phase 0 Research Program

triggerless-streaming FEE **assigning time stamps to hits**

1 m Copper

GBTx

50 m optical

TFC (CRI based)

CRI FPGA **µSlice building**

FLES entry nodes

300 m optical InfiniBand

Green IT Cube

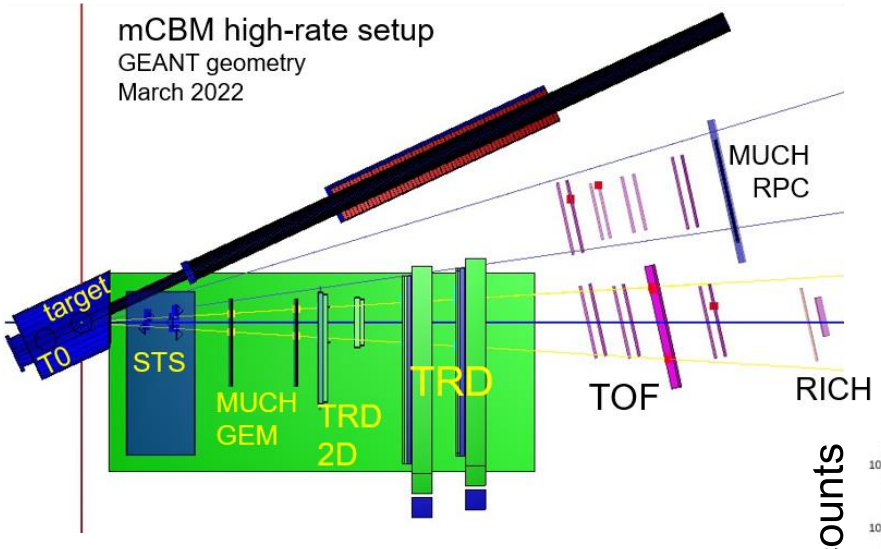
Timeslice Building

Event Reconstruction

Event Selection

Archiving

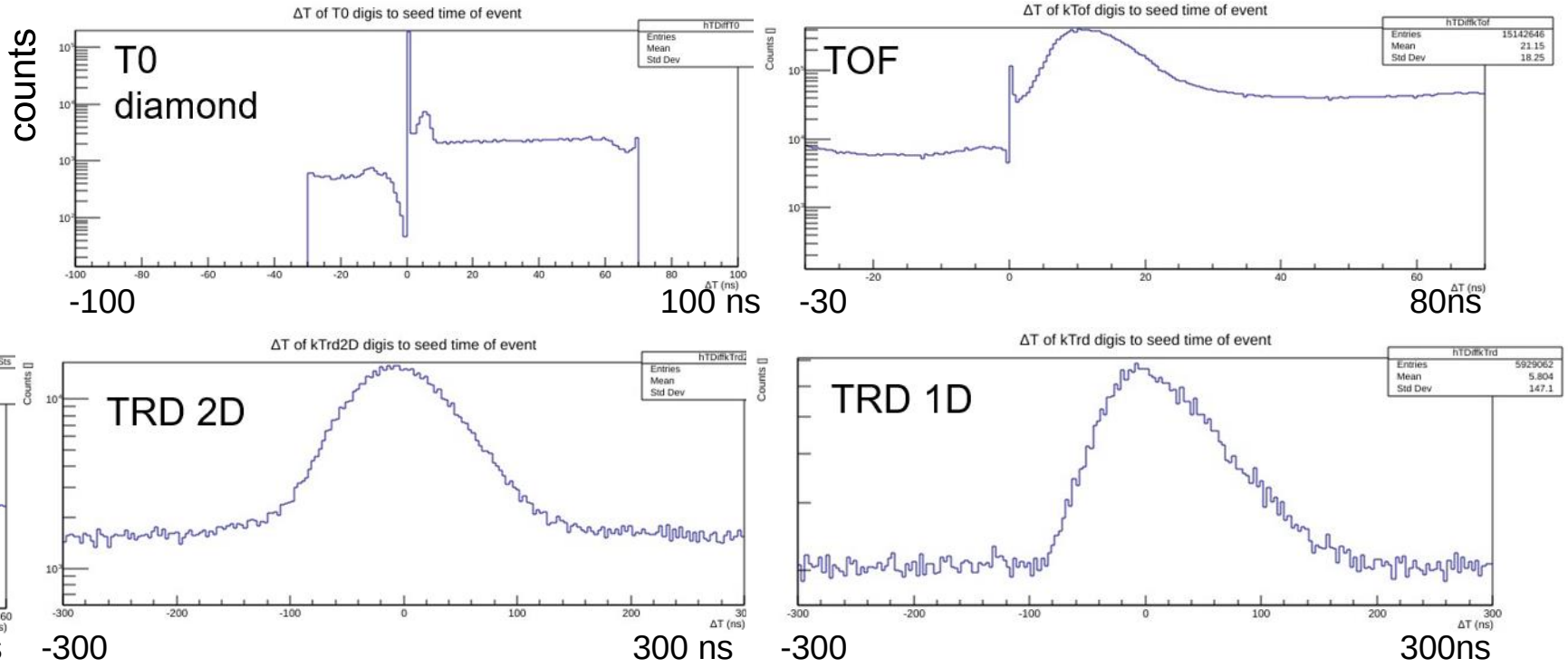
# 1st test version of an (FAIR MQ based) online selection



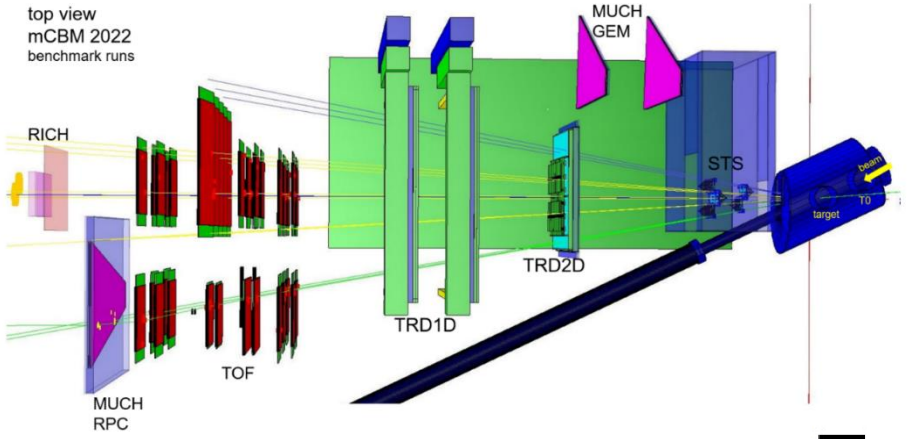

run 2188, March 31, 03:15 CET,
$10^7$ U ions per spill, approx. 100 kHz averaged collision rate

Applied
filter condition: 1 T0 hit, 2 STS hits, 5 TOF hits ("Λ trigger")

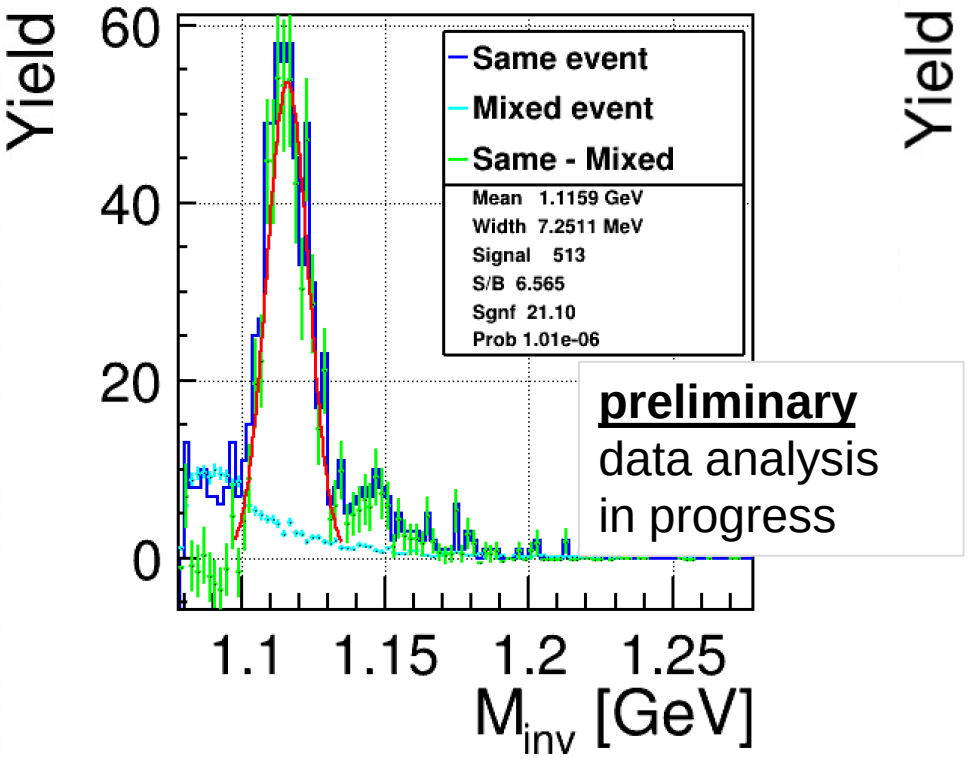
coincidence with T0



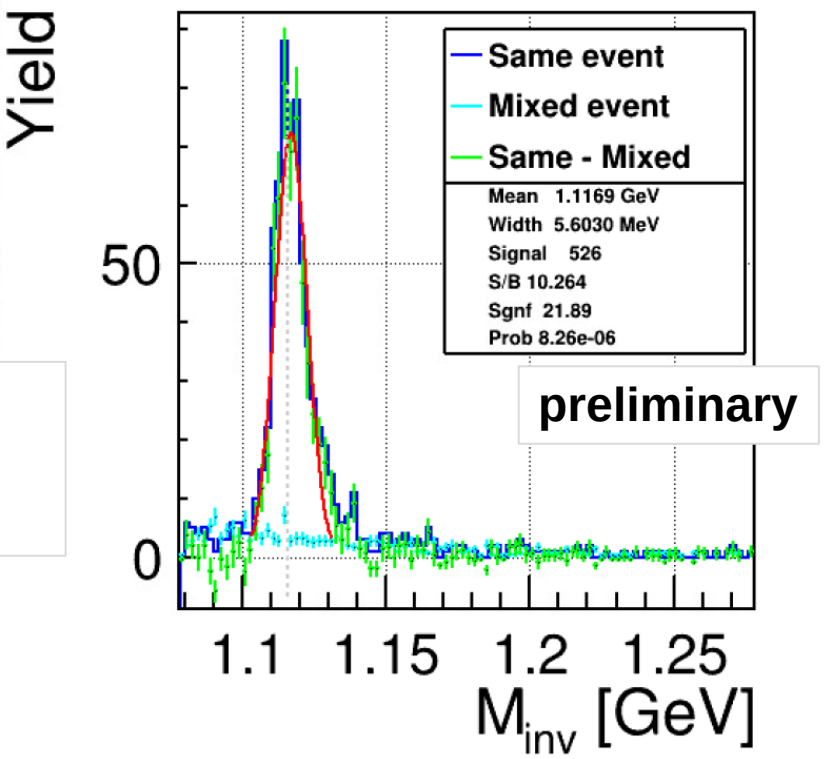
# mCBM: Λ reconstruction in Ni+Ni collisions at 1.93 AGeV




**Data**, run 2391, total run duration **1:57h**
4x to 5x$10^7$ ions per spill, 10s spill
400 - 500 kHz average collision rate



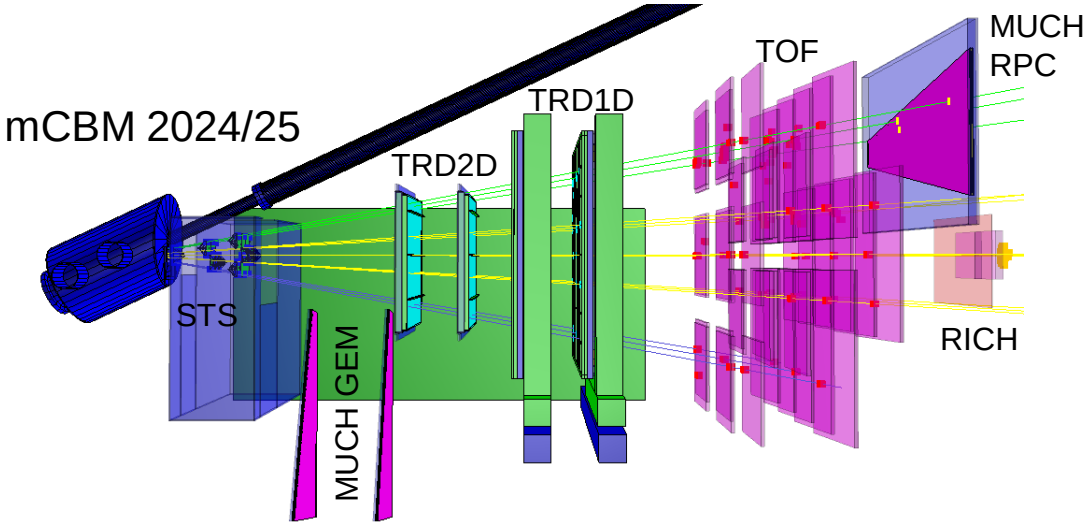

**MC** , identical reconstruction chain
100 M generated events
$10^5$ events / s
63.7 M triggered events

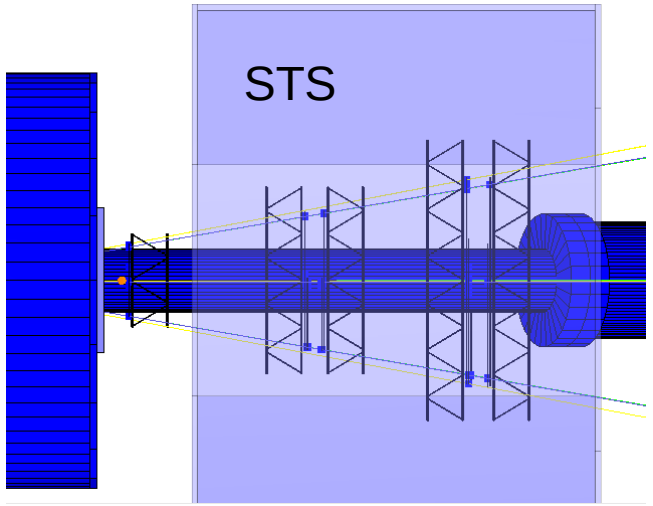



rare signal reconstructed,
- milestone reached !

# mCBM 2023/24 campaign (preliminary schedule)

| | |
|---|---|
| 2023, Jul. 12 | 1st synthetic run for online systems (replay of Ni+Ni & Au+Au runs at cluster) |
| 2023, Oct. | synthetic, dry and cosmics runs, test of online systems (write digi-events) |
| 2023, Nov. 6 - Dec. 19 | first tests with beam during machine engineering runs |
| 2024 Jan. - Feb. 2 | installation & maintenance slot |
| 2024, Mar. 2 - 24 | final commissioning for benchmark run with Au beam, secondary user at HADES block |
| 2024, Mar. 25 - Apr. 26 | data scan and final preparation for online reconstruction and selection |
| 2024, Apr. 29 - May 3 | cosmics run with online systems |
| 2024, May 6 - 13 | Ni+Ni benchmark run, Λ production excitation function at 1.93, 1.58, 1.23 and 1.0 AGeV, online reconstruction and selection (Λ filter), fallback: digi-events |
| 2024, May 15 - Jun 5 | preparation for rate scans |
| 2024, June 12 - 15, 20 | rate scans with U beam |
| 2025, Mar. 18 - 23 | Ag+Ag benchmark run, Λ production excitation function at 1.58, 1.23 and 1.0 AGeV |




mCBM program for 2026/2027 under discussion

# Conclusion

- Uniqueness of CBM physics program is confirmed by all evaluation committees (Heuer/Tribble, ECE and JSC).
- CBM pushes to be part of the official FAIR2028 program by FAIR Council decision.
- CBM planning goes for first SIS100 beams in 2028.
- Substantial funds still need to be acquired for completion of day-1 setup ( => VF-BMBF ).
- Sustained personnel funding (PhD students, postdocs) is essential for all CBM groups.
- CBM is supporting efficient use of the CBM-Cave within FAIR 2028 scope

  - extending physics program with proton beams and proton target to exclusive channels
    => joined program with PANDA

  - APPA (ESA) measurement options are being investigated.