

EXPLORING QCD MATTER WITH CBM

PROGRESS TOWARDS FIRST BEAMS

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(GSI/FAIR and TU Darmstadt)

September 7-9, 2026

"Unlocking the QCD phase diagram"

Celebrating the 80th birthday of Prof. Peter Braun-Munzinger



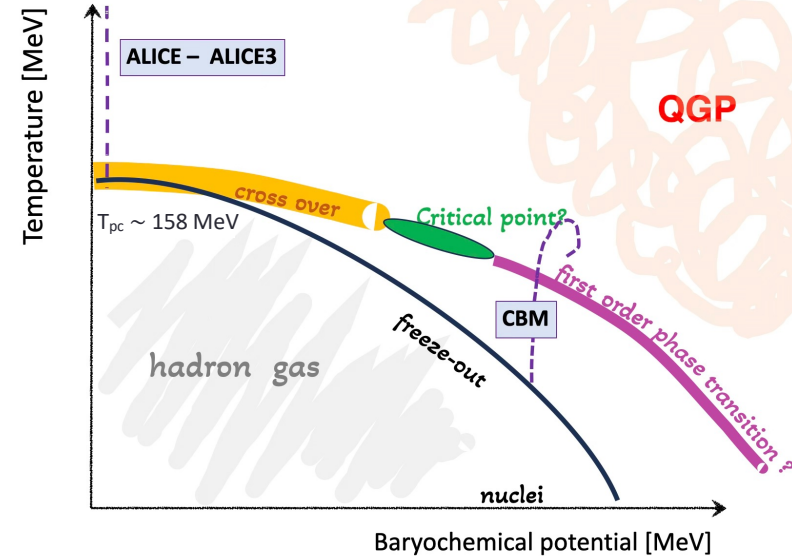
Exploring the QCD phase diagram at high net baryon densities

Vanishing μ_B , high T (lattice QCD)

- Smooth crossover from hadronic to partonic medium
 - $T_{pc} = 156.5 \pm 1.5$ MeV (physical quark masses)
 - $T_{pc} = 158.0 \pm 0.6$ MeV (physical quark masses)
 - $T_c = 132^{+3}_{-6}$ MeV (chiral limit)
- No critical point indicated by lattice QCD at $\mu_B/T < 3$

Large μ_B , moderate T

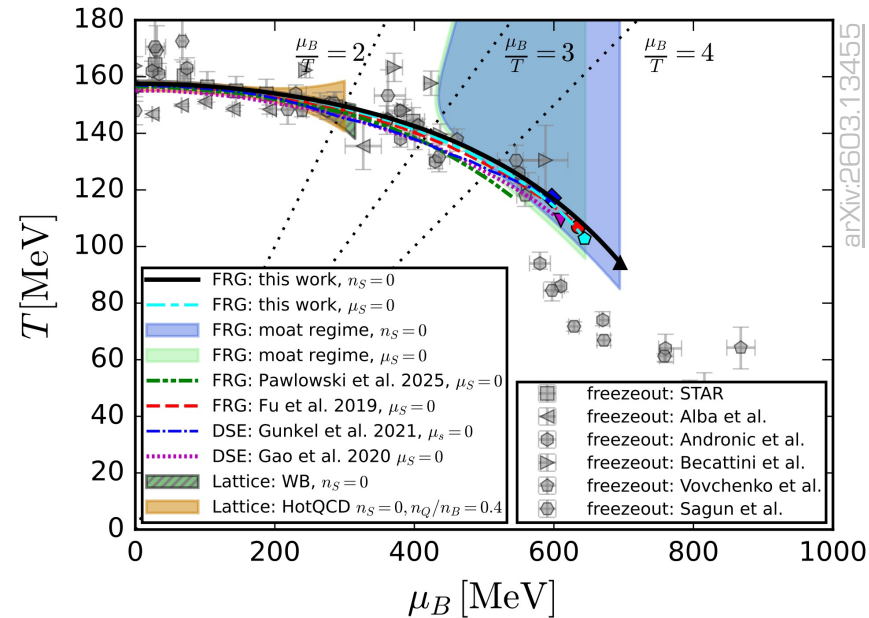
- Limits of hadronic existence?
- 1st order phase transition?
- QCD Critical point?
- Equation-of-state of dense matter?



Compressed Baryonic Matter experiment mission

Search for landmarks of the QCD matter phase diagram:

- Isolate unambiguous signals of new phases of QCD matter, order of phase transitions, QCD critical point
- Probe the microscopic matter properties



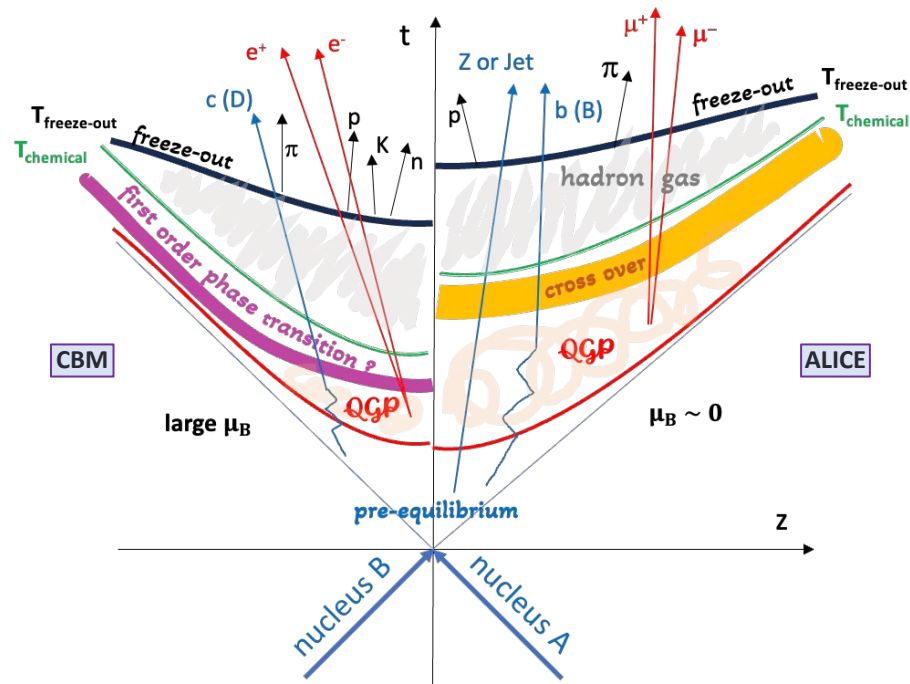
CEP location well constrained by now.

And it's in the FAIR energy range!

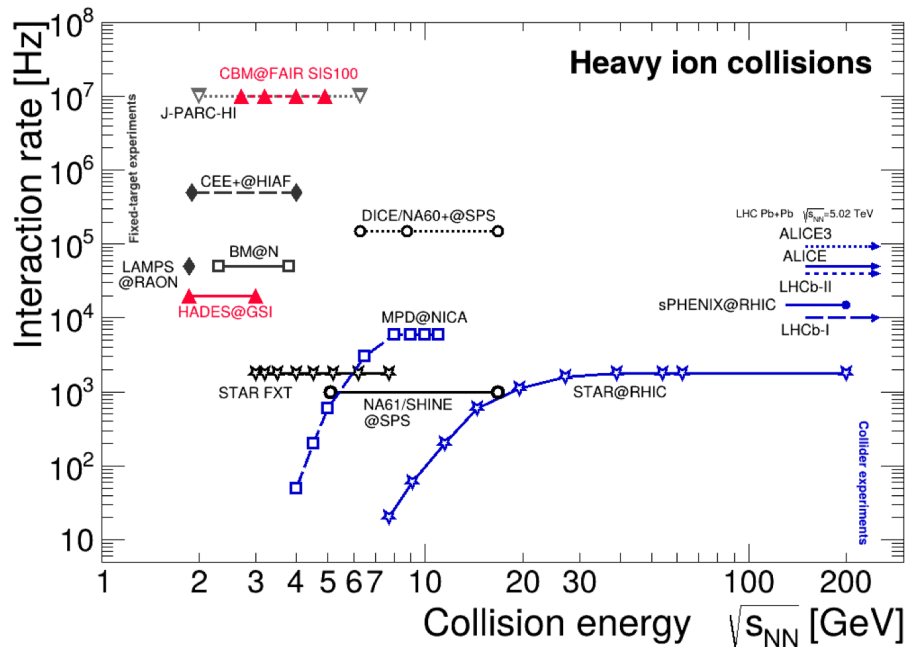
Cutting-edge science with cutting-edge detectors

Tools for discovery:

- Heavy Ion Collisions
 - rare probes at high interaction rates
- Cutting-edge detector technology:
 - excellent tracking and vertexing
 - great PID capabilities
 - high-rate capabilities
 - radiation hardness



Strategy



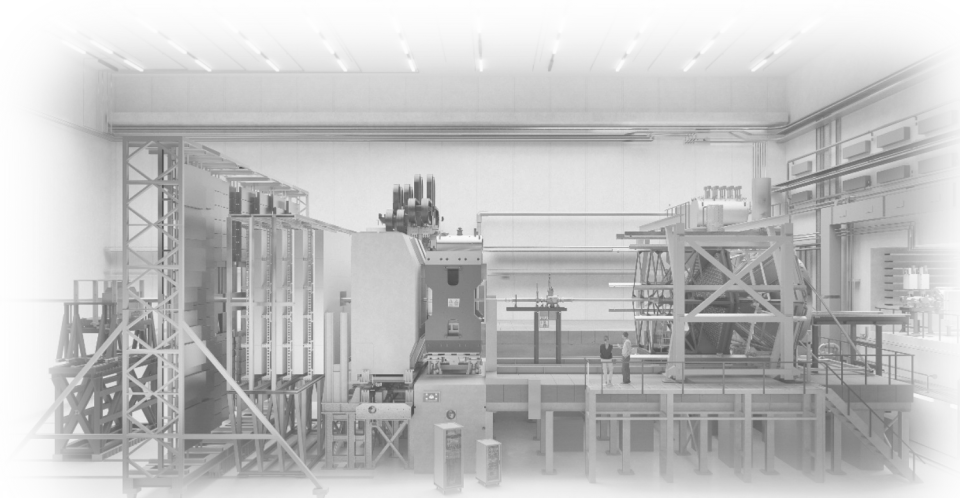
Measure with utmost precision:

- Light flavour hadrons, incl. (multi-)strangeness (chemical freeze-out T , μ_B)
- Flow, vorticity (equation-of-state)
- Event-by-event fluctuations (criticality)
- Dileptons (emissivity)
- Hypernuclei (interaction)
- Charm (transport properties)

Focus on rare/penetrating probes and precision measurements.

Requires high statistics/rates and excellent understanding of detector response.

FAIR

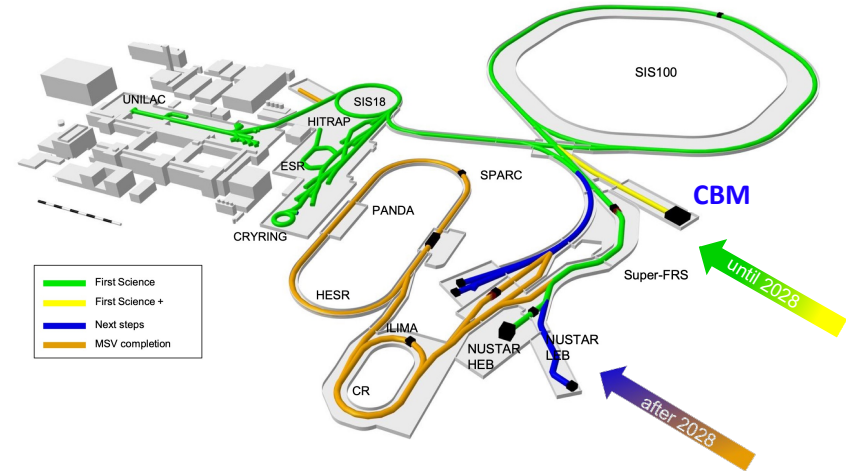


Facility for Antiproton and Ion Research in Europe

- APPA - Atomic, Plasma Physics and Applications
- CBM - Compressed Baryonic Matter
- NUSTAR - Nuclear Structure, Astrophysics and Reactions
- PANDA - Physics with High Energy Antiprotons

SIS-100 beams		
Beam	$p_{lab, max}$	$\sqrt{s}_{NN, max}$
Heavy ions (Au)	12 AGeV/c	4.9 GeV
Lght ions (Z/A=0.5)	14 AGeV/c	5.5 GeV
Protons	29 GeV/c	7.6 GeV

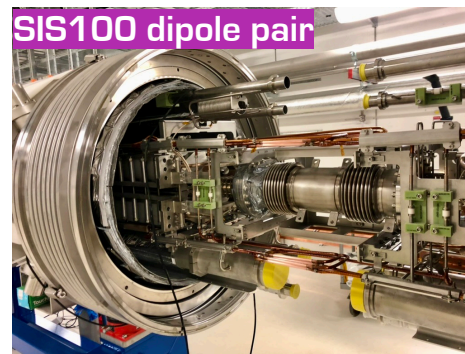
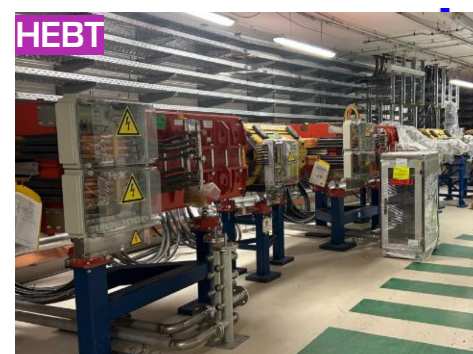
- Intensity: $\sim 10^{13}/s$ for p; $\sim 10^{11}/s$ for U
- Antimatter: antiproton beams
- Precision: system of storage and cooler rings



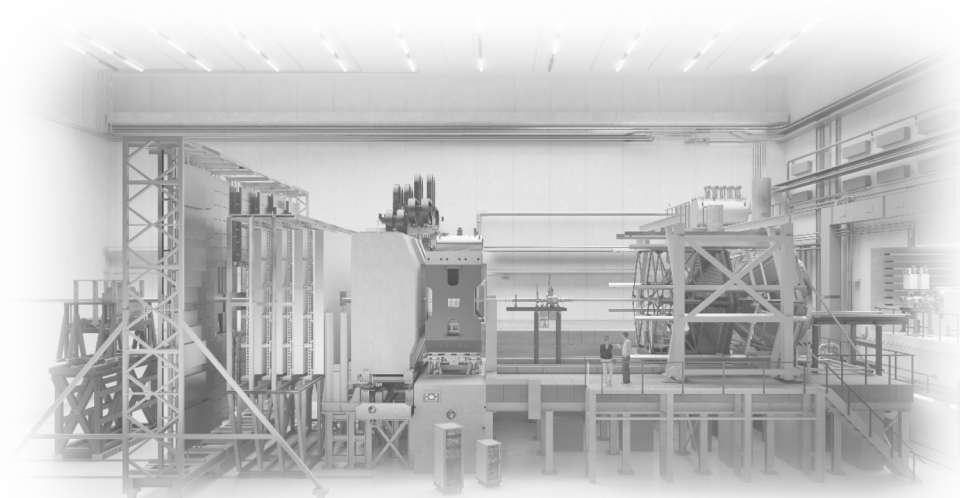
- July 2017: Start of excavation and trench sheeting
- July 2018: Start of shell construction
- [June 2022: staging review](#)
- 2023: Buildings completed (First Science+ and Next steps)
- 2024: Start of installation
- 2025: Start of commissioning
- **2028: Start Operation**

FAIR status

- Civil Construction for the approved scope is completed.
- Installation and commissioning of the Technical Building Infrastructure (TBI) is close to finalisation.
- Installation of the Cryoplant is completed.
- Commissioning of Cryoplant and Cooling water is ongoing
- Installation of SIS-100 synchrotron and Super-Fragment Separator is ongoing.
- New Fair Control Center (FCC) operational

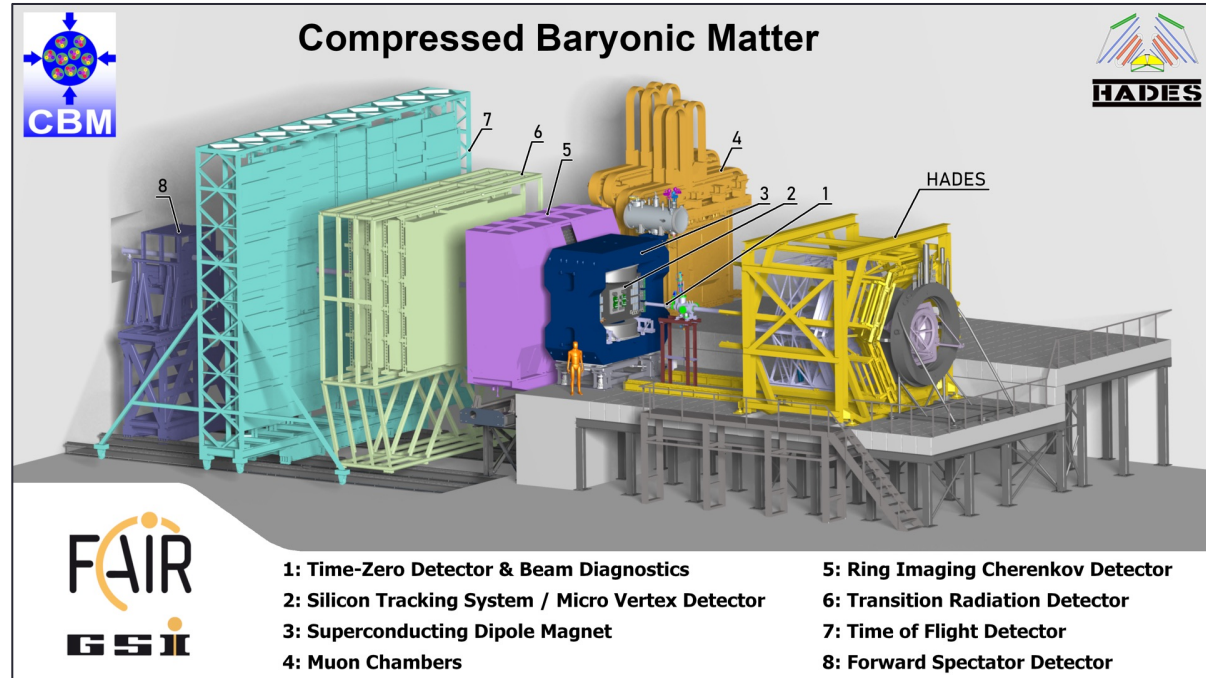


CBM@FAIR



Compressed Baryonic Matter experiment

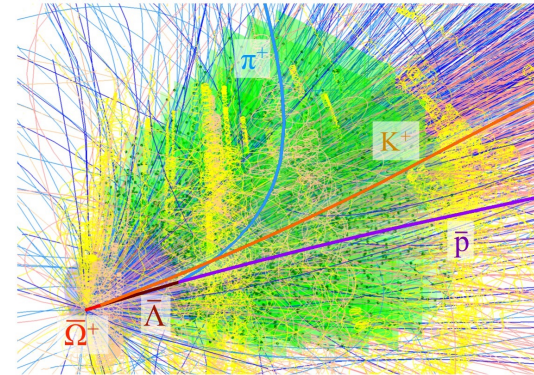
- Fixed target experiment for high collision rates
- Large physics acceptance to cover mid-rapidity for all energies, down to low p_t
- Versatile detector systems optimized setup for various observables
- Light weight tracker based on silicon detectors for fast and precise track reconstruction
- Powerful Particle Identification for hadrons and leptons



339 members from 10 countries
 49 full member institutions
 12 associated member institutions

CBM experiment: rate challenge

- High event rates, up to 10^7 Hz Au+Au collisions
- High multiplicity collisions, $O(750)$ particles/collision
- Data rates: $O(\text{TB/s})$
- Data volume: 10-20 PB/year



CBM simulation, central Au+Au @ 10 AGeV/c

- Fast, radiation-hard detectors & front-end electronics
- Free-streaming front-end connectivity up to 10 MHz
- High-speed DAQ and high-performance computing farm for online event selection $\rightarrow$ highly selective data reduction



GSI Green IT Cube

CBM Target Hall

CBM Cave

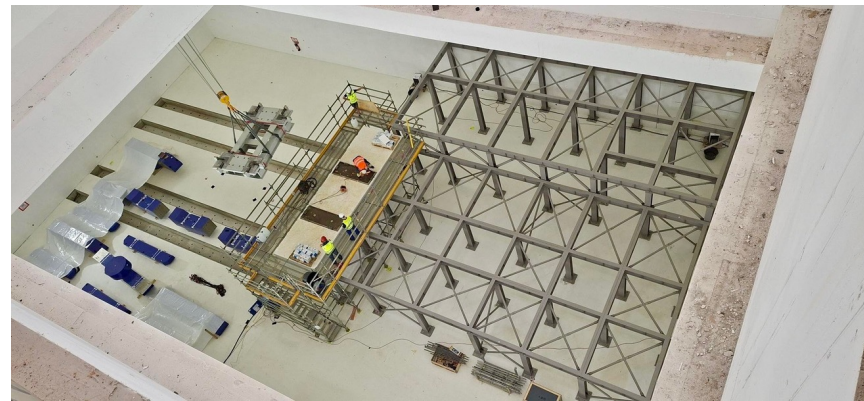
- A dedicated cave with a massive beam dump for high-intensity, high-energy beams
- CBM Cave/Building shell completed

FAIR Council decision on 31.08:

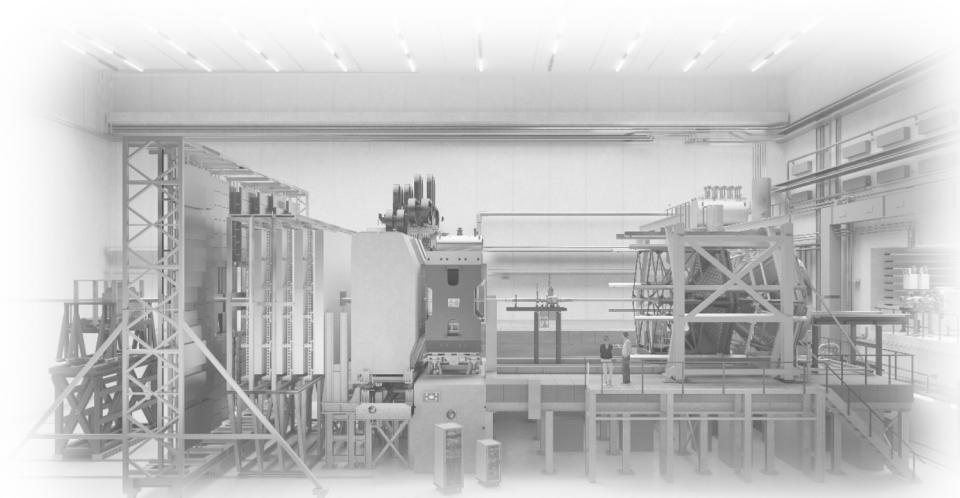
- Approval of Technical Building Infrastructure for FS+

CBM installation activities have started:

- Heavy infrastructure: since 2025
- Building/CBM infrastructure: 2026-2028
- Detectors: 2028-2029
- Ready for beam: 2029



CBM CONSTRUCTION

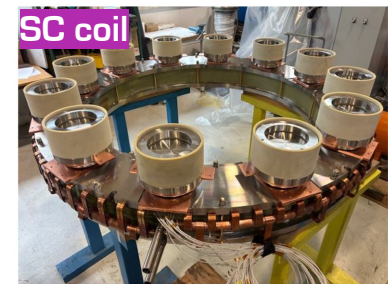
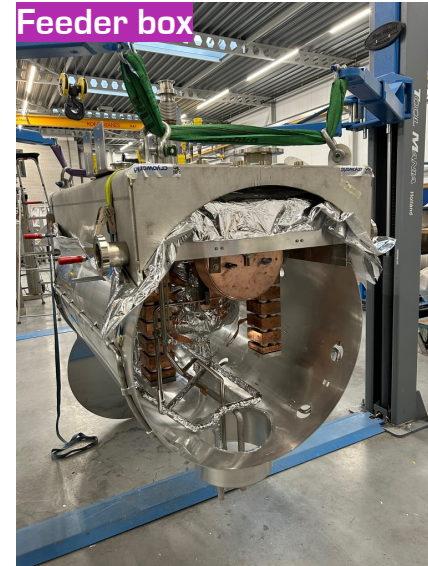
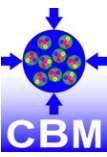
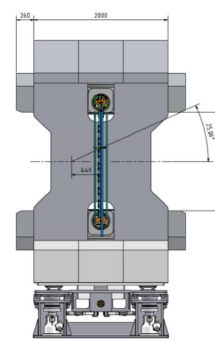
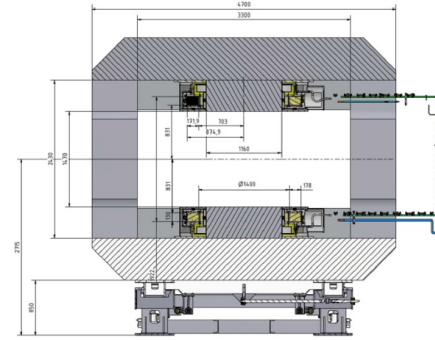


The CBM superconducting dipole

- Magnetic field: 1 T ($\Delta p/p < 2\%$)
- Aperture: $1.47 \times 3.3 \text{ m}^2$
- Acceptance: $\pm 25^\circ$ (vertical), $\pm 30^\circ$ (horizontal)
- Total weight of the yoke: $\sim 150 \text{ t}$
- Conductor: NbTi in copper; $\text{Cu}/\text{SC} \geq 5$
- Operating temperature: 4.5 K

STATUS:

- Magnet yoke delivered to FAIR, PSU produced
- Ongoing manufacturing of the coil system and cryogenics
- Installation of the Yoke and Feeder Box in the CBM cave in Fall 2026



Beam Monitoring: T0 and HALO

TU Darmstadt, GSI

T0: provides a precise start-time reference for the ToF system

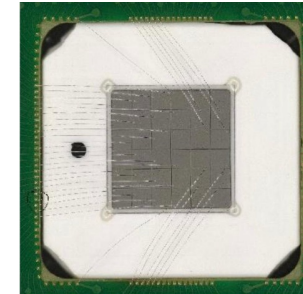
HALO: continuously monitors beam quality and stability

Day-1 concept based on pcCVD high-purity diamond sensors

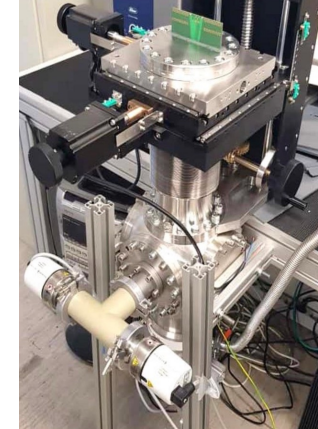
- 1 cm × 1 cm, 80 μm thickness (low X/X_0),
- Time resolution: 50 ps, rate capability 10^7 particles/s
- Front-End Electronics ready and operational DAQ system
- Feedthrough installation and vacuum test completed

R&D on novel sensor technologies → LGAD

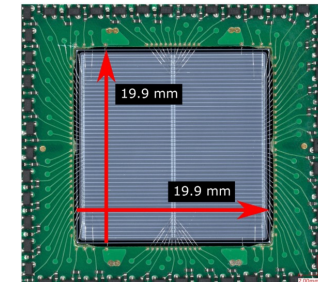
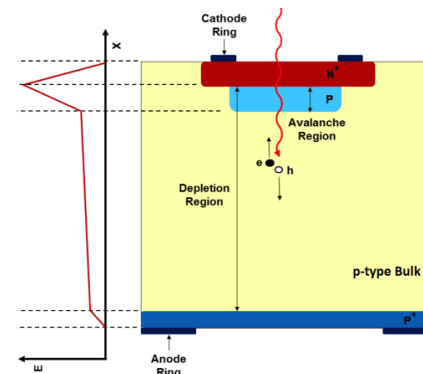
- Currently employed by HADES START detector ([NIM 1039 \(2022\) 167046](#))
- Sensor development: Bruno Kessler Foundation;
- Performance with high-intensity heavy ion beams to be shown



36CH pcCVD detector

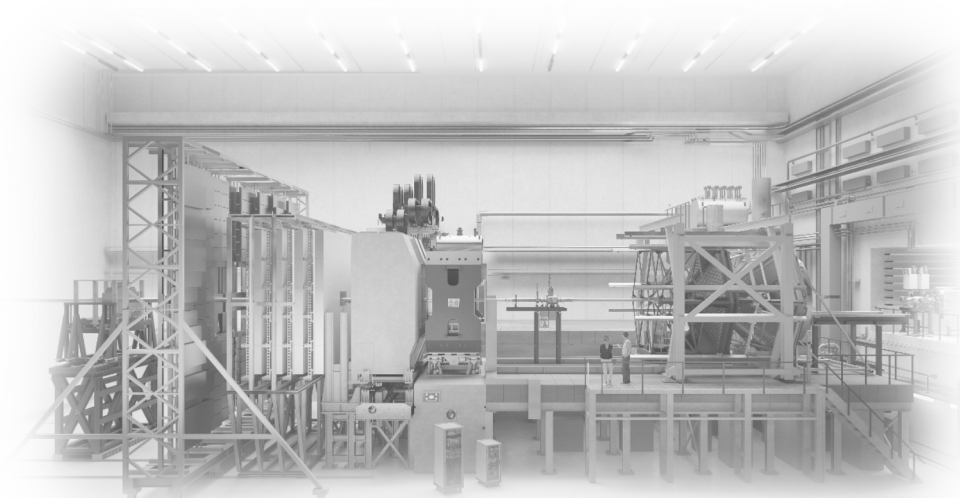


Motorized 3-Axis Vacuum Manipulator



HADES LGAD-TO

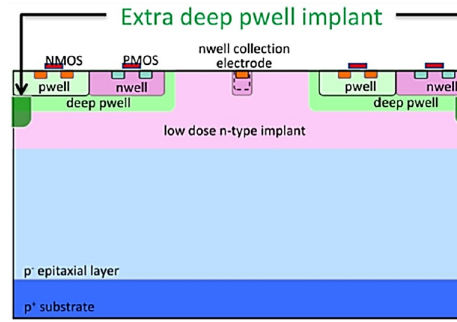
CBM TRACKING



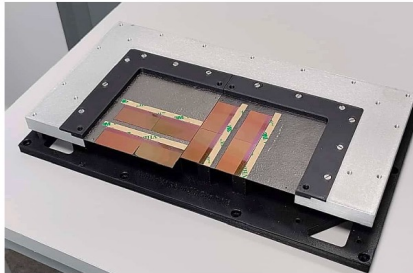
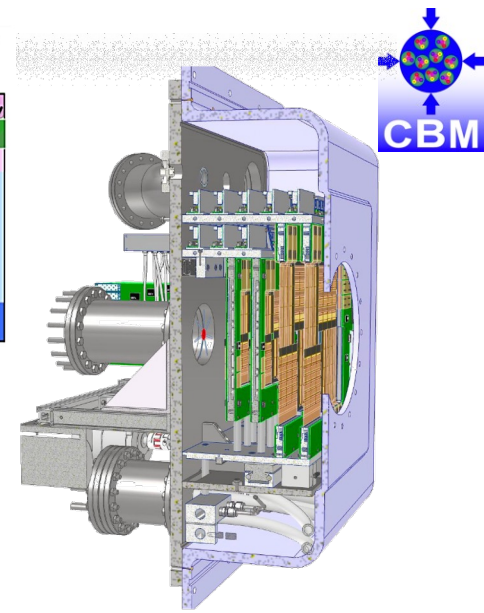
Micro Vertex Detector

Goethe University Frankfurt, GSI, IPHC Strasbourg

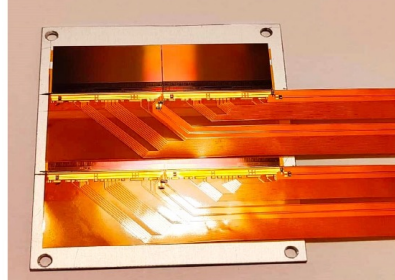
- Pointing precision at the target region
- Reconstruction of low-momentum tracks
- 4 detector stations, based on **MAPS** technology ($\sim 1200 \text{ cm}^2$)
 - 100 kHz Au+Au @ 11 AGeV
 - Non-uniform hit density in time and space
 - High radiation environment, operating in a vacuum
 - Material budget of $\mathcal{O}(0.5\% X_0)$ with Thermal Pyrolytic Graphite (TPG) carriers
- MIMOSIS-0 (2018), M-1 (2020), M-2/M-2.1 (2024), **M-3 (2026)**



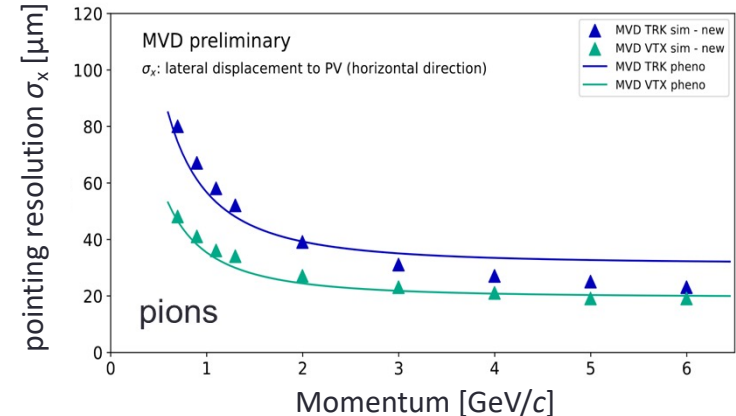
MIMOSIS Sensor



MAPS sensors on TPG carriers



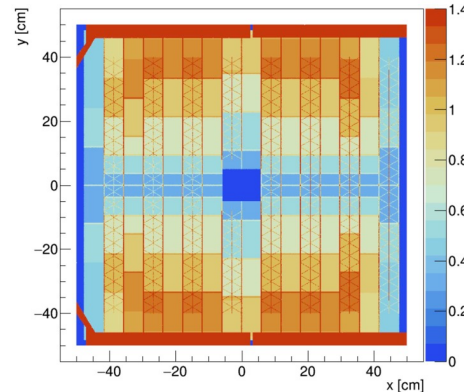
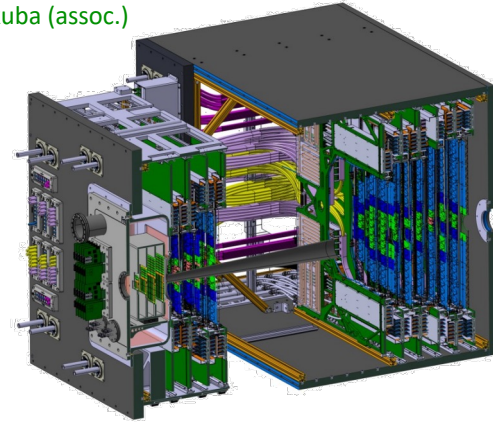
Sensors with FPC cables



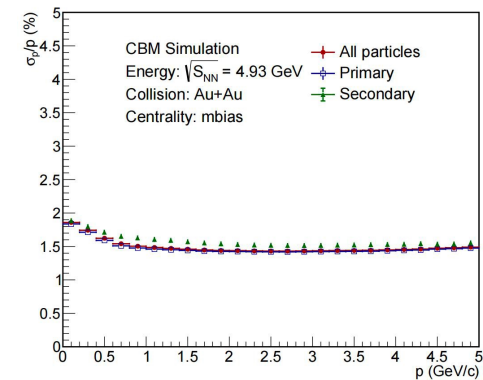
Silicon Tracking System

GSI Darmstadt, KIT Karlsruhe, JU Cracow, AGH Cracow, KINR Kiev, Univ. Tübingen, Warsaw UT, Uni. Frankfurt, KEK Tsukuba (assoc.)

- Main CBM detector for charged particle tracking and momentum determination at $10^5 - 10^7/s$ (A+A), up to $10^9/s$ (p+A) collision rates
- 8 tracking stations (4 m²)
 - Double-sided silicon microstrip sensors
 - Hit spatial resolution $\approx 15 \mu\text{m}$ (x), $110 \mu\text{m}$ (y)
- Low-power, self-triggering front-end electronics
 - SMX v2.2 ASIC ([NIM A 908 \(2018\) 225](#))
 - 128 channels: 5-bit ADC, time resolution ≤ 5 ns
- Material budget: 0.4% – 1.4% X_0 per station
 - $\Delta p/p < 2\%$ ($p > 1$ GeV/c, 1 Tm field)
- Rad. tolerance: $\sim 10^{14}$ 1 MeV n_{eq} over lifetime



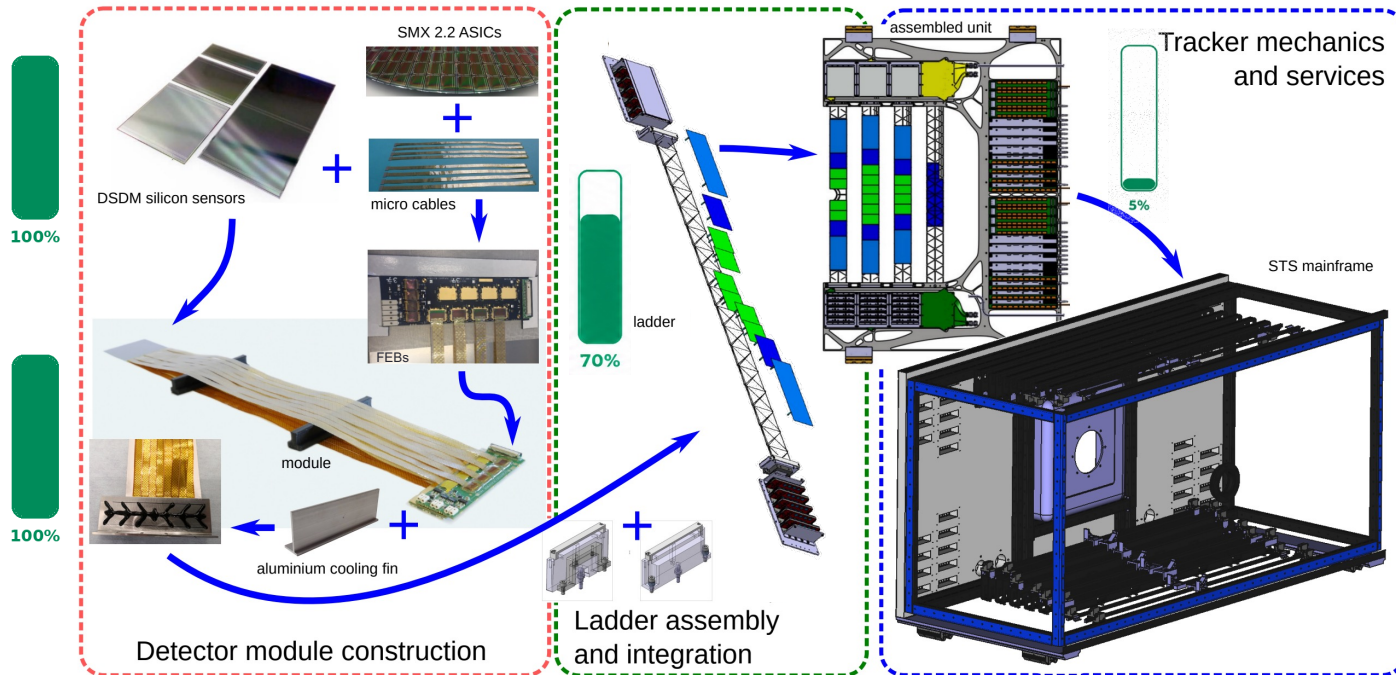
Material budget (x/X_0) Station 8



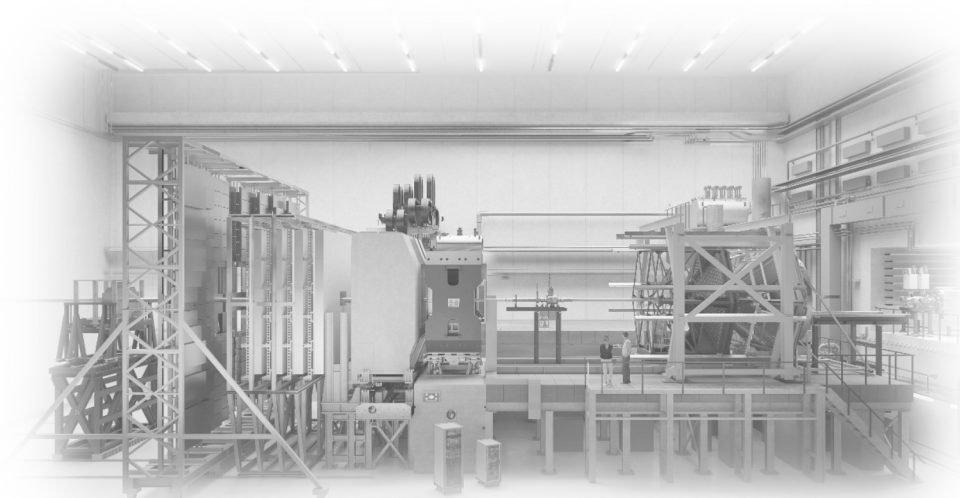
STS momentum resolution

Silicon Tracking System

- Very complex lightweight system, integration effort
- Series production ongoing: 876 modules, 106 ladders, 8 tracking layers



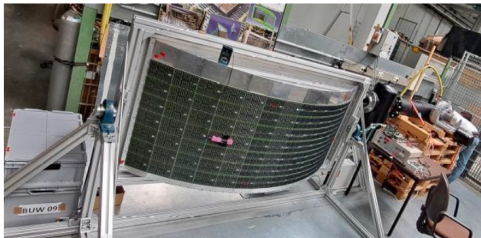
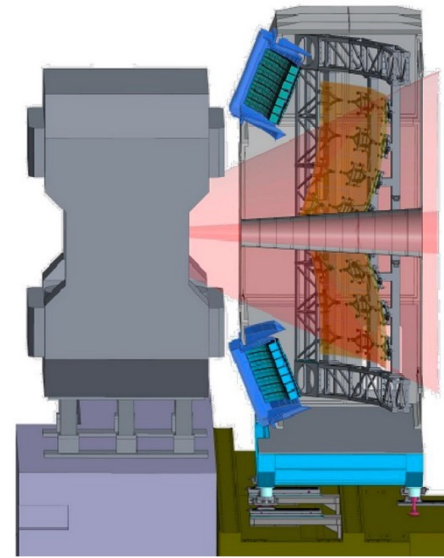
PARTICLE ID



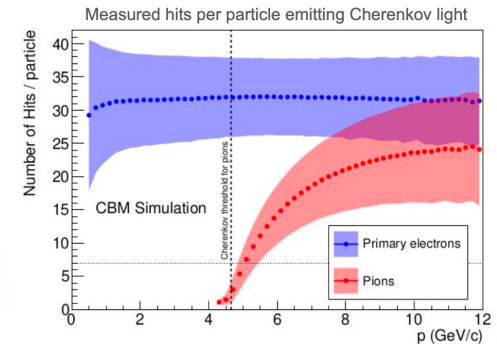
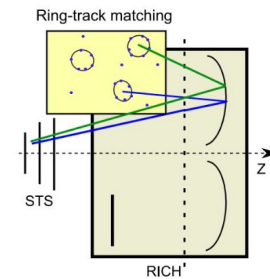
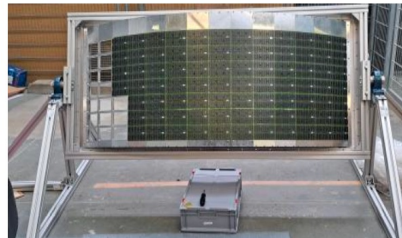
Ring Imaging Cherenkov Detector

Univ. Giessen, Univ. Wuppertal, GSI Darmstadt

- Gaseous RICH detector for electron ID ($p < 8 \text{ GeV}/c$)
- Radiator: CO_2 ($p_{\pi, \text{th}} = 4.65 \text{ GeV}/c$), $\sim 80 \text{ m}^3$ volume
- Photodetector: 2 photodetector planes (MAPMTs, Hamamatsu H12700) with approx. 55 000 channels
- Mirror: 2 large spherical mirrors ($R = 3 \text{ m}$) as focussing optics, $\text{Al}+\text{MgF}_2$ reflective coating
- 2 cameras equipped with PMTs ready, FEE production is ongoing
- Mirror wall PRR passed, production started



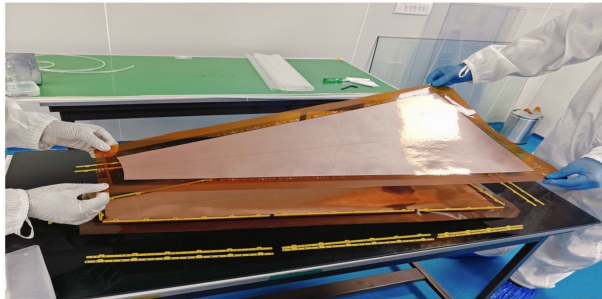
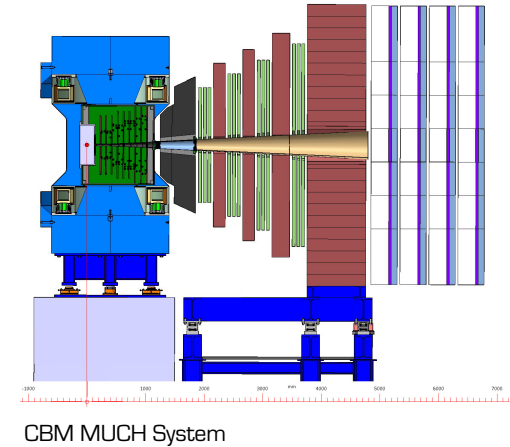
RICH photo-cameras



Muon Chambers

CBM-India collaboration: AMU, BI, PU, JU, KU, CU, BHU, VECC, IOP, NISER, IIT KGP, IIT Indore, GU

- 5 absorbers (Graphite, Fe, Fe, Fe, Fe)
- 4 detector stations, 3 detector layers each,
 - Station 1 and 2: GEM chambers
 - Station 3 and 4: Straw technology under evaluation
- Different configurations for different collision energies and physics
- GEM detectors readout based on the SMX readout ASIC
- Up to 10 MHz interaction rate capability, di-muon trigger!



MuCh GEM1 PRR – assembly in the VECC cleanroom



Series production of Station 1
GEM chambers: 25% complete

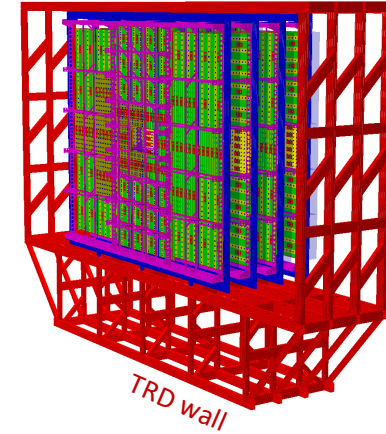
Transition Radiation Detector

NIPNE Bucharest, Univ. Frankfurt, Univ. Heidelberg, Univ. Münster, IRI Frankfurt, GSI and FFN (U. Bochum)

- Electron-ID at high momenta
 $\Rightarrow \pi$ -suppression 10–20 (90% e-eff.)
- ID of light nuclei (e.g. d – ^4He)
 $\Rightarrow dE/dx$ -resolution $\sim 25\%$
- Tracking between STS and TOF
 $\Rightarrow$ space-point resolution $\sim 300\ \mu\text{m}$ (across the pads)
- High rates $\Rightarrow$ fast detector (max. signal coll. $0.3\ \mu\text{s}$)

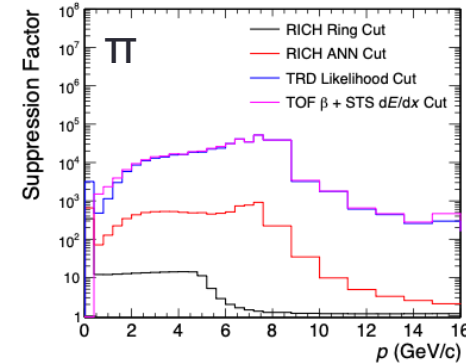
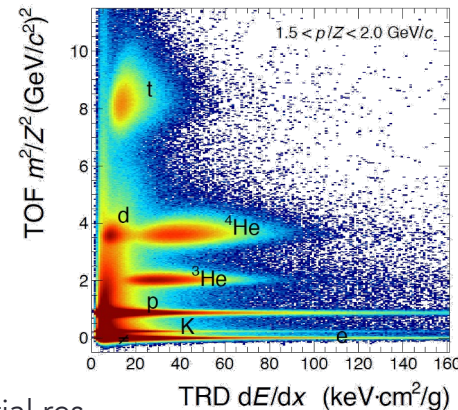


Gas line prototype with a TRD module



Preproduction ongoing, next - production readiness!

- Four detector layers: radiator with PE foam foils + MWPC
- $\sim 250\ 000$ channels, SPADIC ASIC FEE
- Inner Wall (TRD2D) for the highest rates with enhanced spatial res.

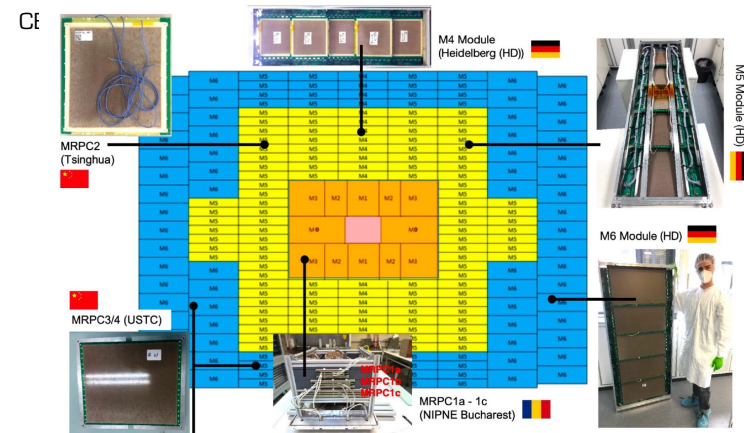
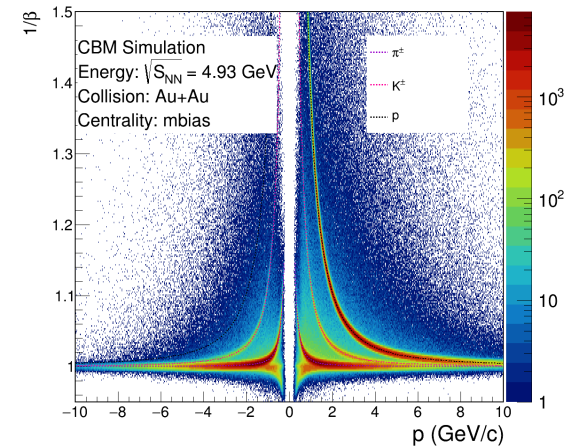
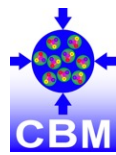


Time of Flight

U. Heidelberg, THU Beijing, NIPNE Bucharest, GSI, TU Darmstadt, USTC Hefei, CCNU Wuhan

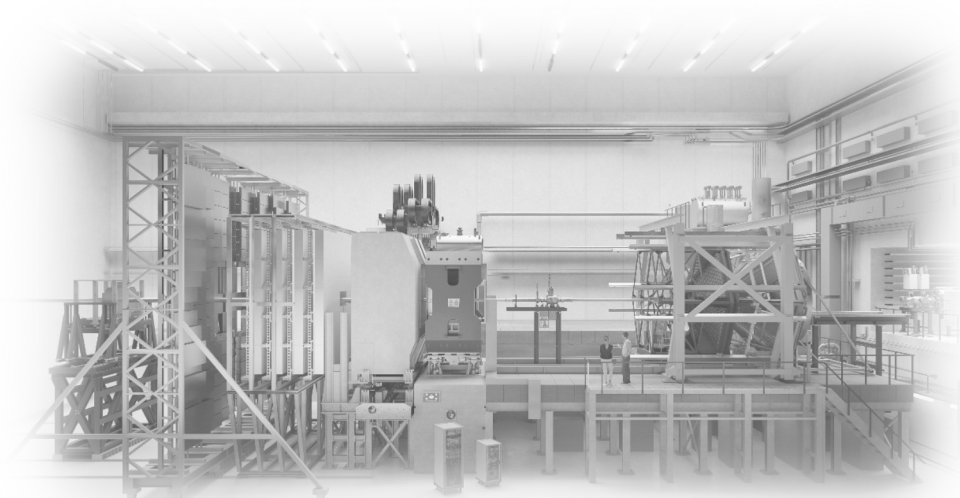
Double-stack multi-gap resistive plate chambers for ultra-high rates

- All CBM TOF wall requirements met!
 - system time resolution: $\sigma_{\text{sys}} \approx 80$ ps
 - efficiency: $\varepsilon \gtrsim 95$ %
 - rate capability up to 50 kHz/cm²
 - Low power FEE (100 000 ch) → PADI XI + GET4 ASICs
- ~ 120 m² = 230 modules, 1400 MRPCs
 - Counters mass production ongoing in China: $\sim 40\%$ produced
 - Modules assembly started in Bucharest and Heidelberg
 - 20% of FEE produced (TDC QA ongoing)
 - Development of gas recuperation and purification system



ToF wall of CBM experiment: 120 m² of high rate MRPC
 Various MRPC modules based on low resistivity glass and float glass

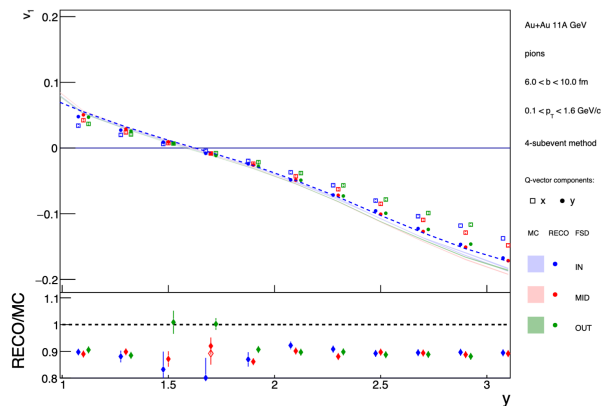
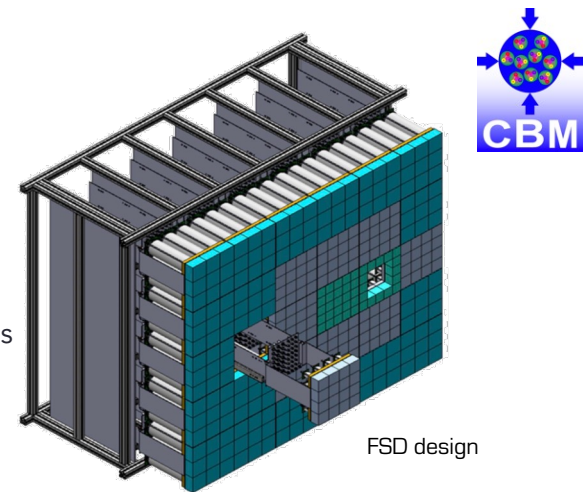
REACTION PLANE CENTRALITY



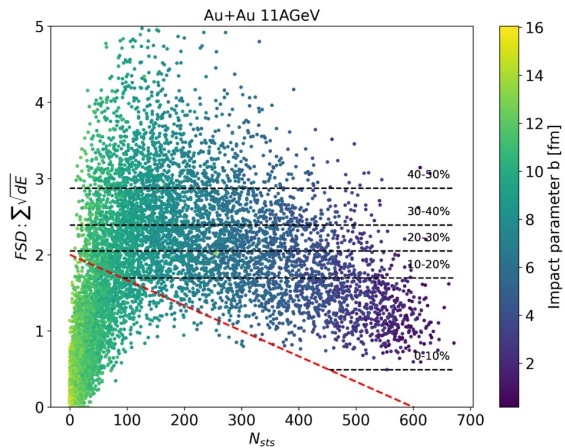
Forward Spectator Detector

CTU Prague, GSI and FFN (U. Bochum)

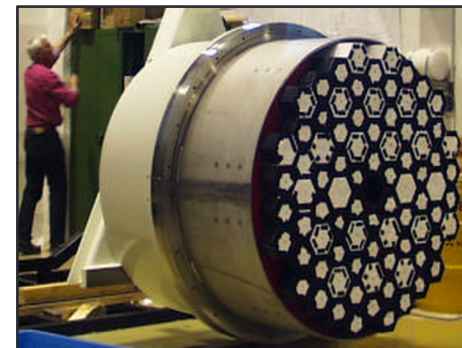
- Centrality and event plane determination, based on a plastic scintillator with PMT readout
- Measures multiplicity, spatial distribution and E -deposition of protons and nuclear fragments
- No correlation to mid-rapidity observables
- Possibility of adding COSY-TOF neutron detector
- TDR in September 2026



v_1 of pions: reconstruction vs. model

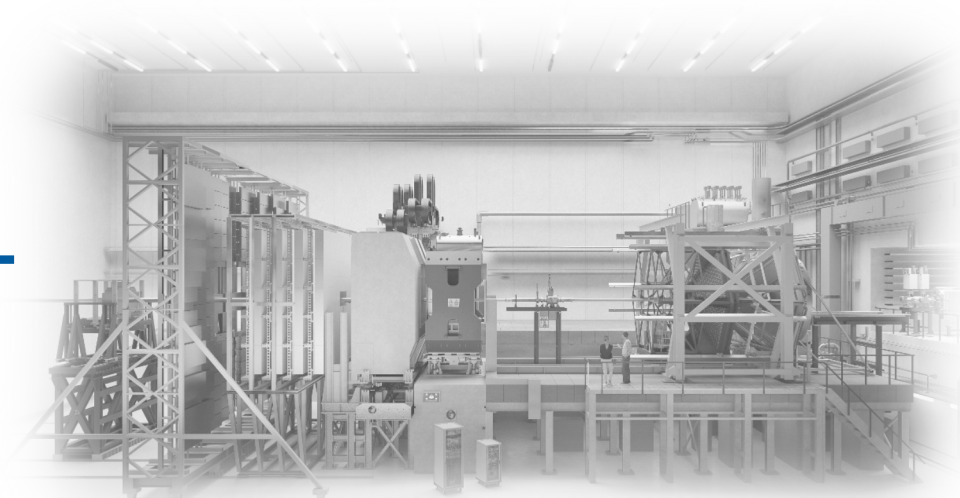


FSD energy deposit vs. track multiplicity



plastic scintillator
 $\varnothing$ 126 cm , 84 modules, l = 45 cm
 n-detection efficiency $\approx$ 30 %

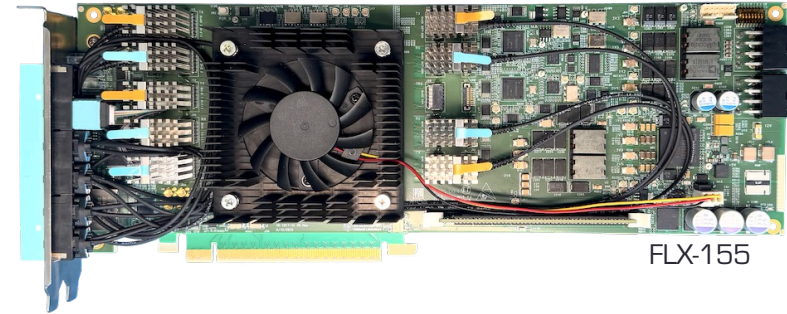
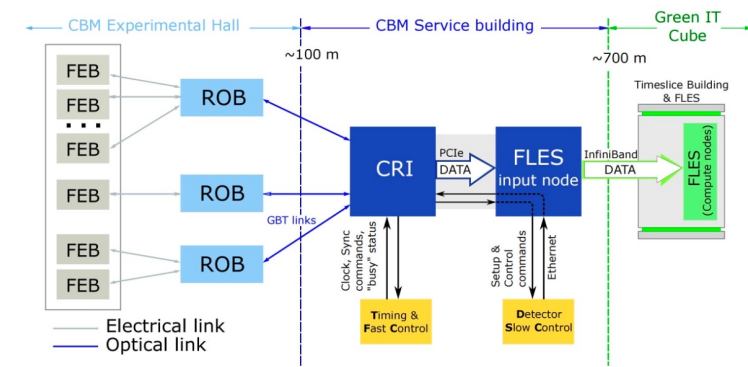
DAQ FULL SYSTEM TEST



CBM data acquisition

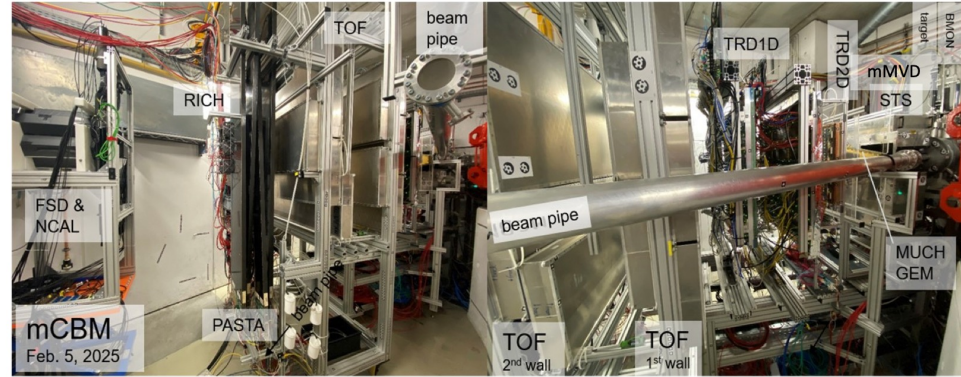
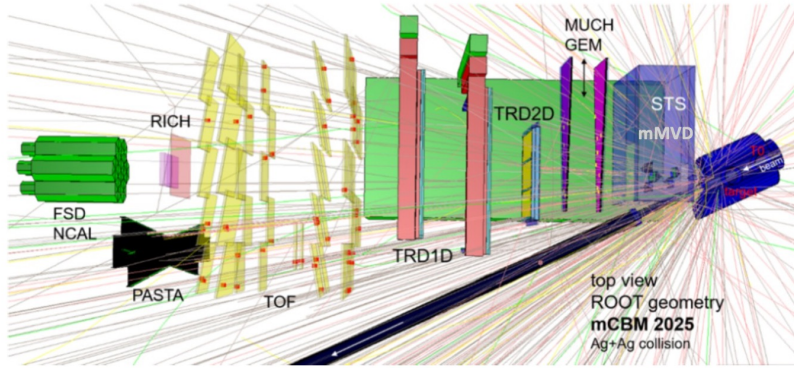
FIAS, GSI, UJ, KIT, ZIB

- Free-streaming readout up to 10 MHz interaction rates (peak)
- Raw data rate about 0.5-1.0 TB/s
- Online reduction of the raw data by ~ 2 orders of magnitude
- FEE of all CBM detectors autonomous and self-triggered, delivers time-stamped hit messages
- FEE synchronized by a central timing system (TFC)
- Online systems: collect, aggregate and deliver data to the online compute farm
- First Level Event Selector: full event reconstruction and identification of selected decays online
- Upcoming purchase of the CBM data aggregators:
FELIX-155 PCIe card (see also ATLAS Phase II, ALICE3 DAQ)

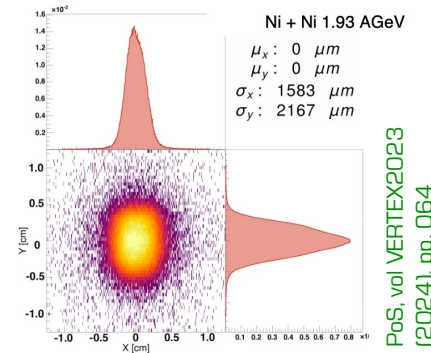


GSI Green-IT Cube

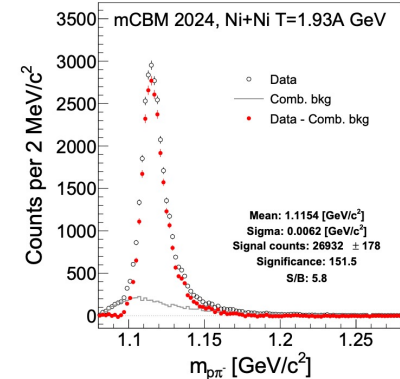
FAIR Phase-0: mCBM at SIS18



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



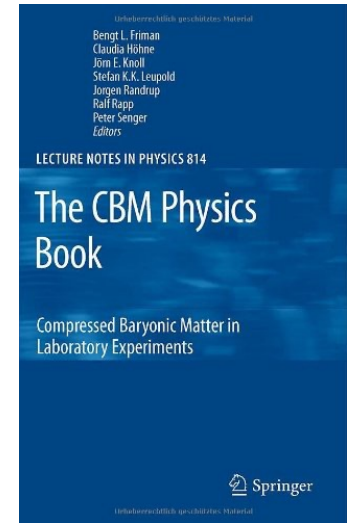
mCBM vertex reconstruction



Prepared for submission

To-Do List

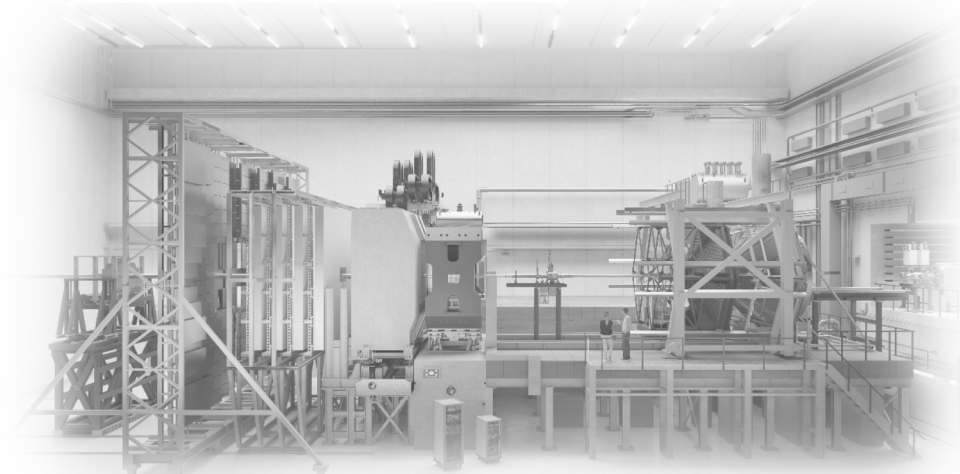
- ☐ QCD matter properties at large μ_B
 - ☐ • Critical point, deconfinement phase transition, equation-of-state
 - ☐ • Hadron yields, collective flow, dileptons, correlations, fluctuations
 - ☐ • (Multi-)strange (anti-)hyperons (Λ , Σ , Ξ , Ω)
- ☐ Chiral symmetry at large μ_B
 - ☐ • In-medium modifications of light vector mesons
 - ☐ • Chiral ρ - ω mixing via intermediate mass dileptons
- ☐ Hypernuclei
- ☐ Charm production and propagation at threshold energies
 - ☐ • Excitation function in $p+A$ collisions (J/ψ , D^0 , $D^{+/-}$)
 - ☐ • Charmonium suppression in cold nuclear matter



Lect. Notes Phys. 814 [2011] pp.1-980

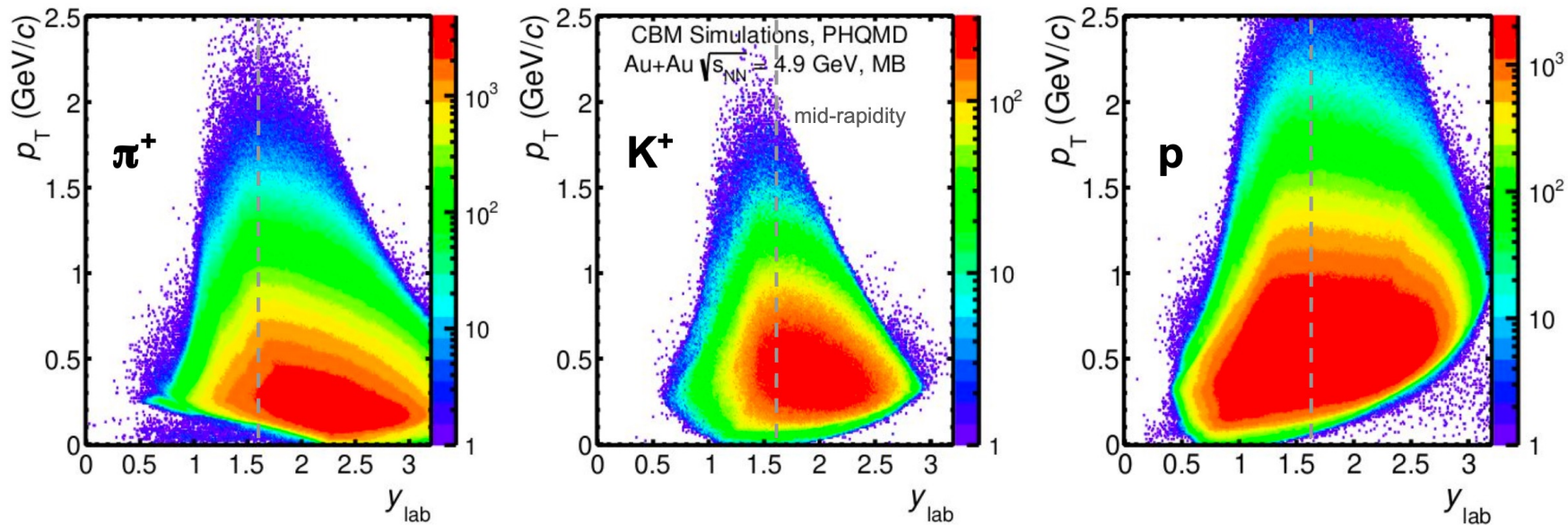
HIGHLIGHTED FUTURE DIRECTIONS

See: [arXiv:2606.16395 \[nucl-ex\]](https://arxiv.org/abs/2606.16395)



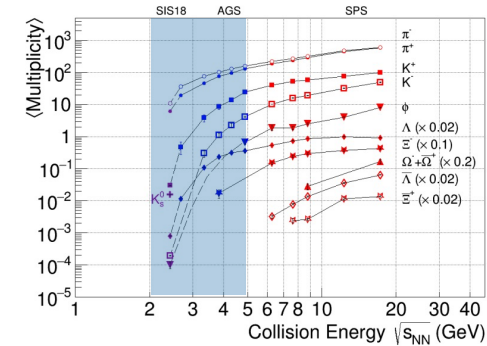
Physics performance studies

- PHQMD / UrQMD simulations at the top energy of $\sqrt{s_{NN}} = 4.9$ GeV
- Large phase space coverage of CBM allows the study of various observables (differentially)

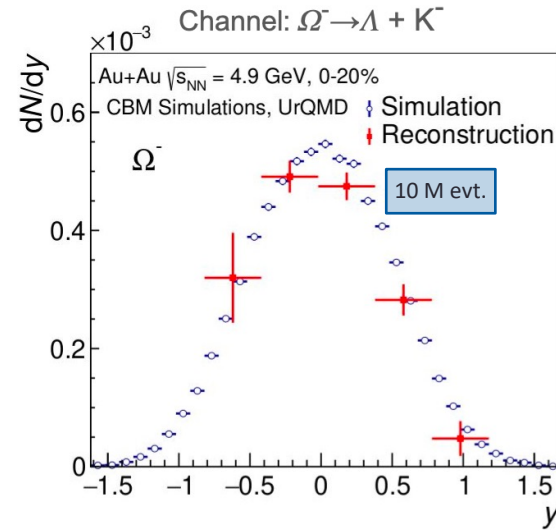
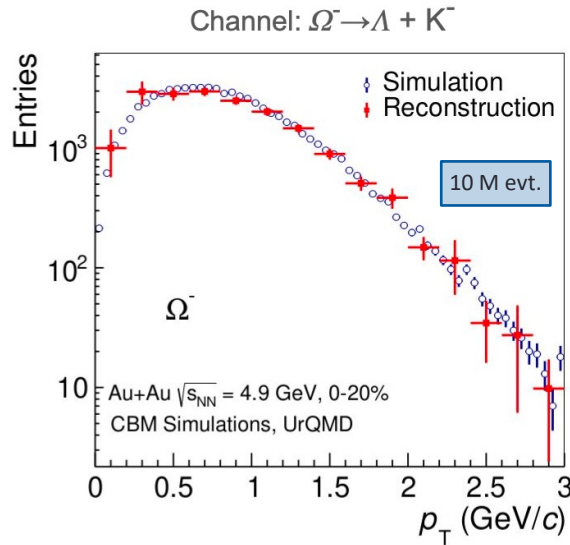


Hadron production

- High-statistics data will allow for multi-differential measurements
- **Multi-strange hyperons:** yield, collective flow, global polarization, etc.
- Very important to keep systematic effects under control



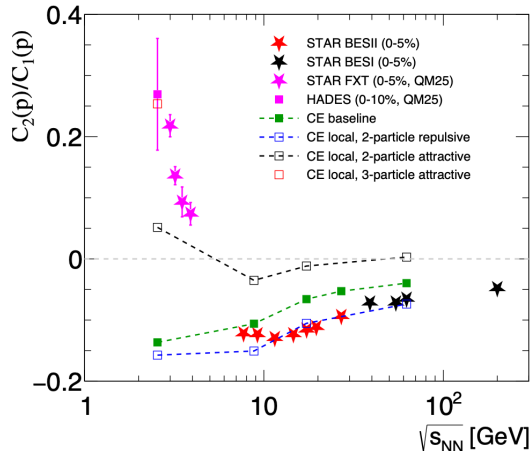
Blume, Markert, PPNP 66 (2011)



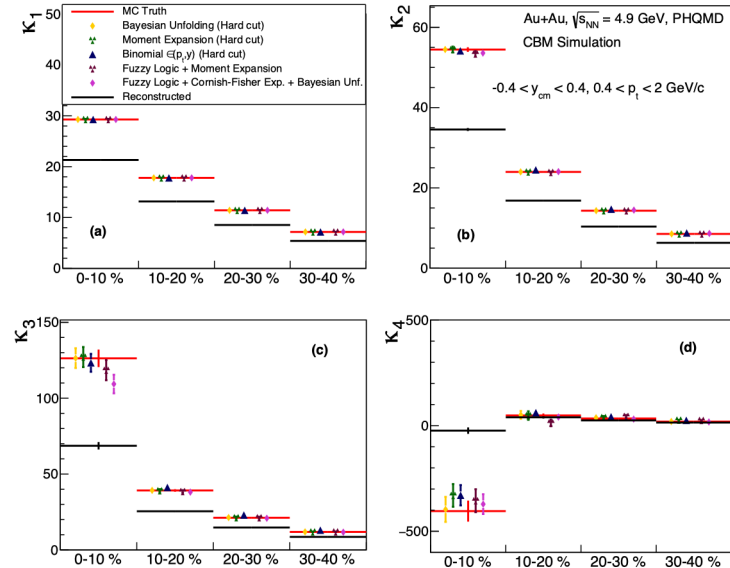
Criticality

- Discontinuities of the higher moments of particle number distributions, and ratios of conserved quantities

(B, Q, S) are sensitive to QCD CEP $\rightarrow$ beam energy scan



HADES, M. Nisiroth, QM 25 Proc. ePrint: 2510.15353
 STAR BESII, PRL 135 (2025) 14, 142301
 STAR FXT, PRC 107 (2023) 2, 024908 and Quark Matter 2025
 B. Friman, A. R. K. Redlich, ePrint: 2508.18879 [nucl-th]
 D. DeMartini and E. Shuryak, Phys. Rev. C 104, 024903 (2021)



- Higher-order moments probe the tails - statistics!
- CBM can systematically study the higher-order cumulants and ratios to contribute significantly to the search of QCD-CEP
- Well capable of reproducing the simulated input for $\kappa_1, \dots, \kappa_4$

Higher order moments of measured multiplicity distributions

$$\sigma^2 / \langle N \rangle = \frac{\kappa_2}{\kappa_1}$$

2nd order

$$S\sigma = \frac{\kappa_3}{\kappa_2}$$

3rd order

$$k\sigma^2 = \frac{\kappa_4}{\kappa_2}$$

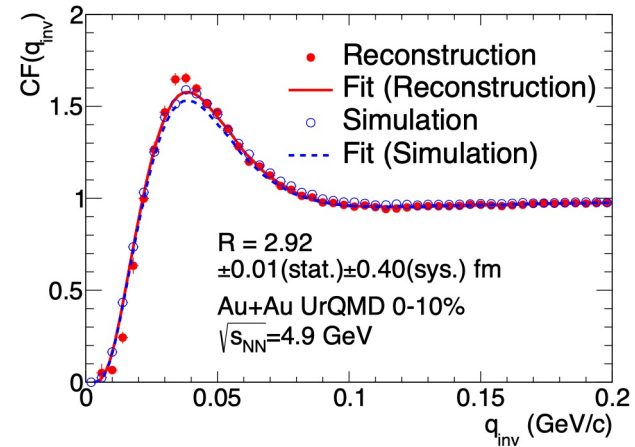
4th order

σ – variance
 S – skewness
 k – kurtosis
 $\kappa_2, \kappa_3, \kappa_4$ cumulants

Interactions

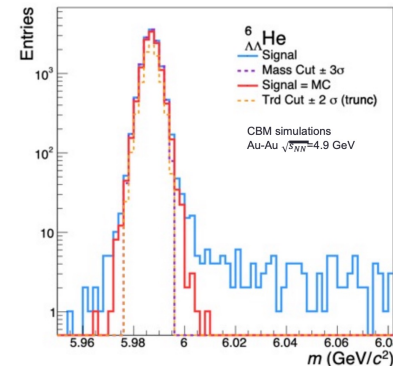
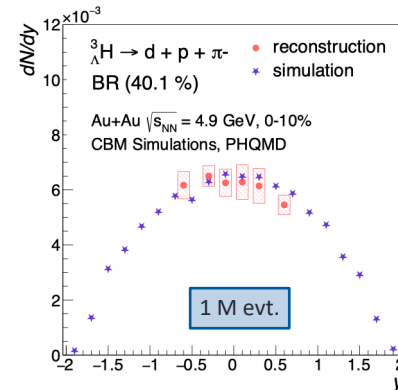
Femtoscopy: probing the space-time structure of the fireball

- Analysis of two-particle correlations close in momentum space
- Extraction of source sizes & emission durations (accuracy of fm)
- Comparison of reconstructed correlations with model output allow to quantify momentum resolution, finite acceptance & reconstruction efficiency effects on final observables

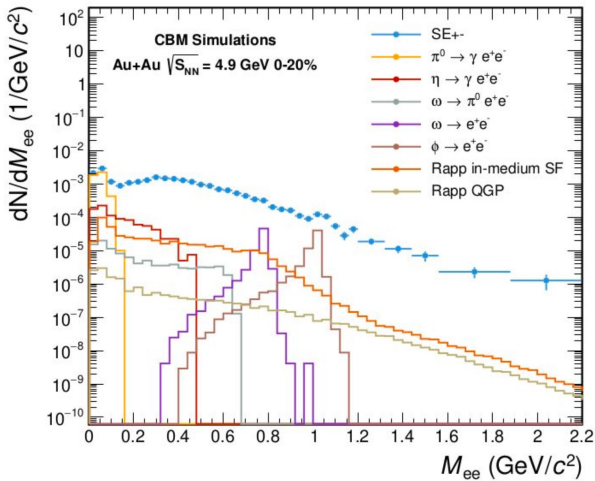


Hypernuclei: YN & YY interactions to constrain nuclear EoS, discovery of double-strange hypernuclei?

- CBM collision energies optimal for hypernuclei production
- High interaction rates and clean identification allow precision measurements

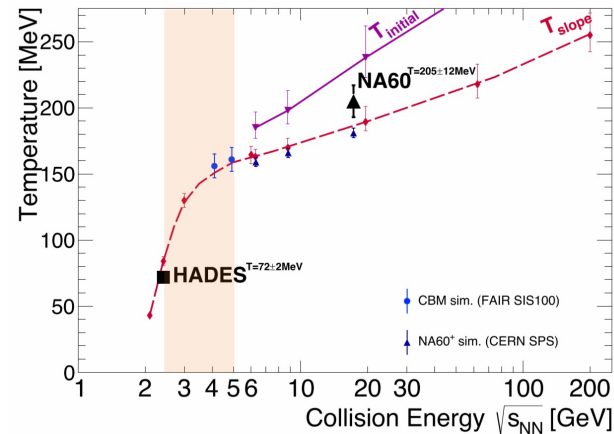


Emissivity

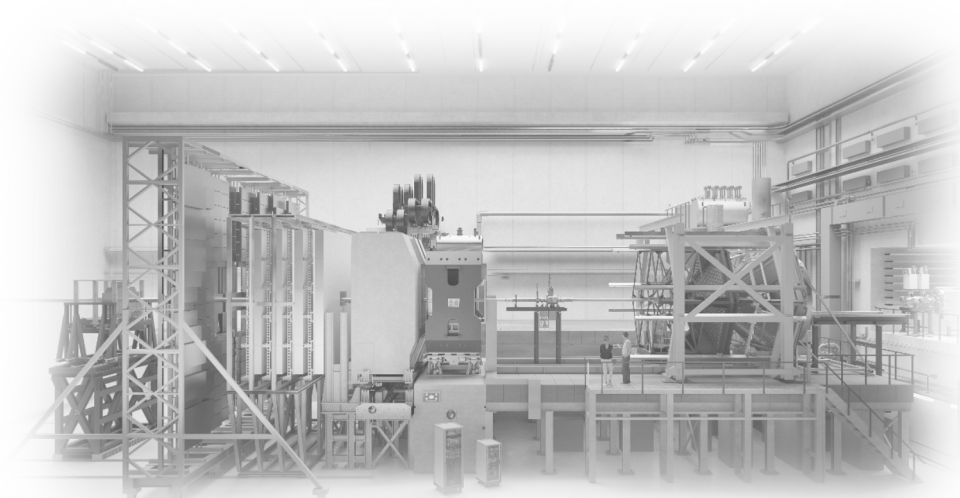


- Electromagnetic Probes: sensitive to all stages of the collision
- Mean fireball temperature from $m_{inv} > 1.2 \text{ GeV}/c^2$
- Access also to the lifetime of the fireball, in-medium modifications of vector mesons, chiral symmetry restoration, etc.
- Importance of background reduction to access rare dilepton probes with $S/B \sim 10^{-2}$

- Non-monotonic behaviour of the caloric curve (flattening) would provide evidence of a phase transition.
- CBM will use di-leptons for systematic measurements in both production channels (e^+e^- and $\mu^+\mu^-$) in the same coverage.

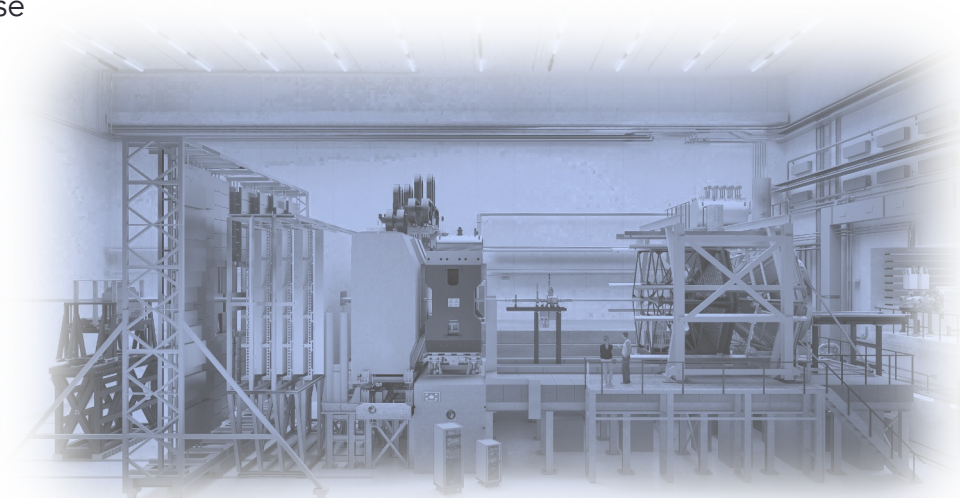


SUMMARY & OUTLOOK



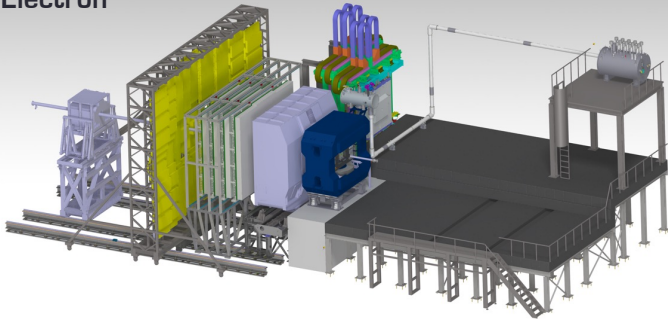
Summary

- Timely completion of SIS100: unique physics program with CBM
- Long-term prospects: highly competitive due to high interaction-rate capability
- CBM is progressing well towards the science program with SIS100 beams
- High-rate capabilities achieved in the extensive R&D phase
- All subsystems are in series production
- Ultimate goal: **CBM ready for beam in 2029!**

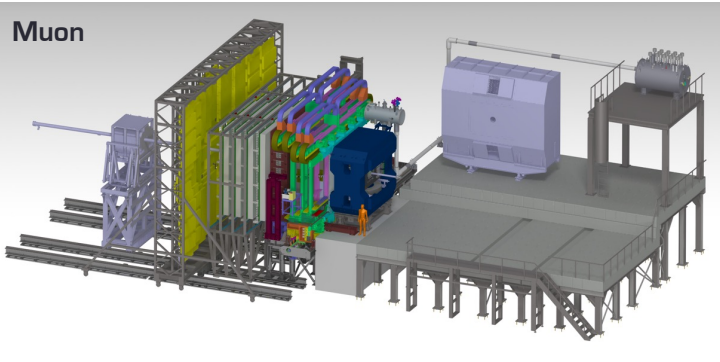


First CBM campaigns

Electron



Muon

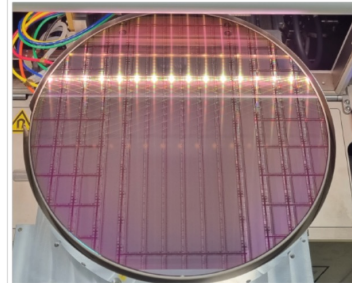
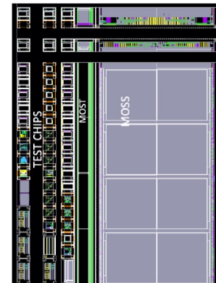
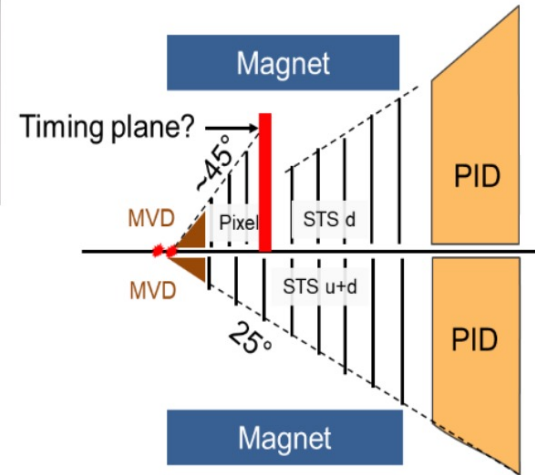


Setup	Included detector systems	Average “Day-1” interaction rate
Electron precision	MVD, STS, RICH, TRD, TOF, FSD	0.1 MHz
Electron high-rate	STS, RICH, TRD, TOF, FSD	0.5 MHz
Muon	STS, MUCH, TRD, TOF, FSD	1 MHz

- **Commissioning** with light ions (Ar), Electron setup
- **Campaigns with** light ions from InterLAC:
 $5 \cdot 10^8$ ions/spill, 100 kHz, Ru-Zr ($E_{\text{max}} = 5$ AGeV), C ($E_{\text{max}} = 12$ AGeV)
 Electron precision setup
- **Proton reactions** upon availability of p/d beams ($E_{\text{max}} = 29$ GeV):
 $p + \text{CH}_2/\text{C}, \text{LH}_2, \text{In}, \text{Au}$, same detector configuration
- **Full UNILAC** restoration: AuAu high-rate, Beam Energy Scan
 Electron setup, Muon setup

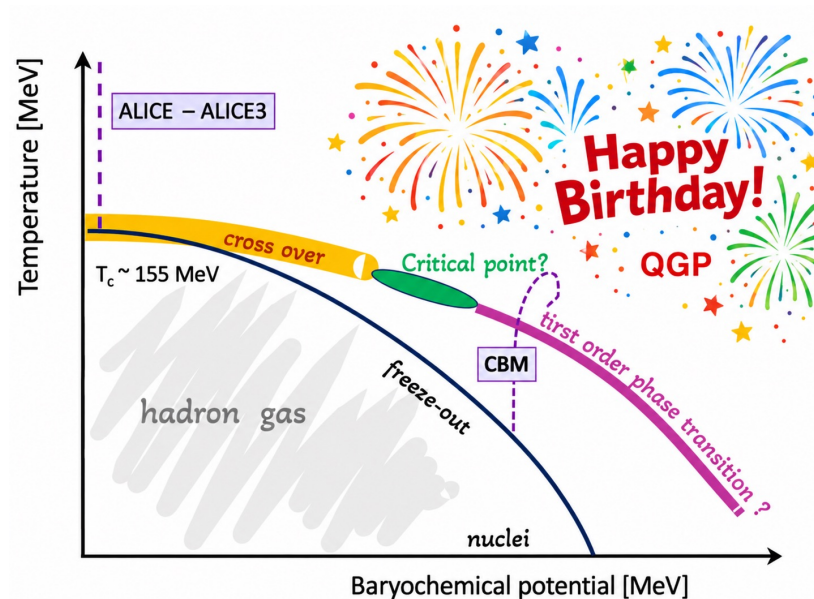
Outlook: strategy for detector upgrades

- After the first years of operation, major upgrades are considered
 - Upgrade MVD and upstream STS stations with radiation-hard pixel sensors
 - Possible addition of timing silicon layers within or behind the tracker (LGADs)
 - RICH readout with SiPMs
 - forward silicon tracker (fragment ID inside the beam pipe)
- 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 → readout rates
- Long-term upgrades (see e.g. ECFA detector R&D roadmap)
 - tracking, muon systems, PID detectors, timing, calorimetry, ...

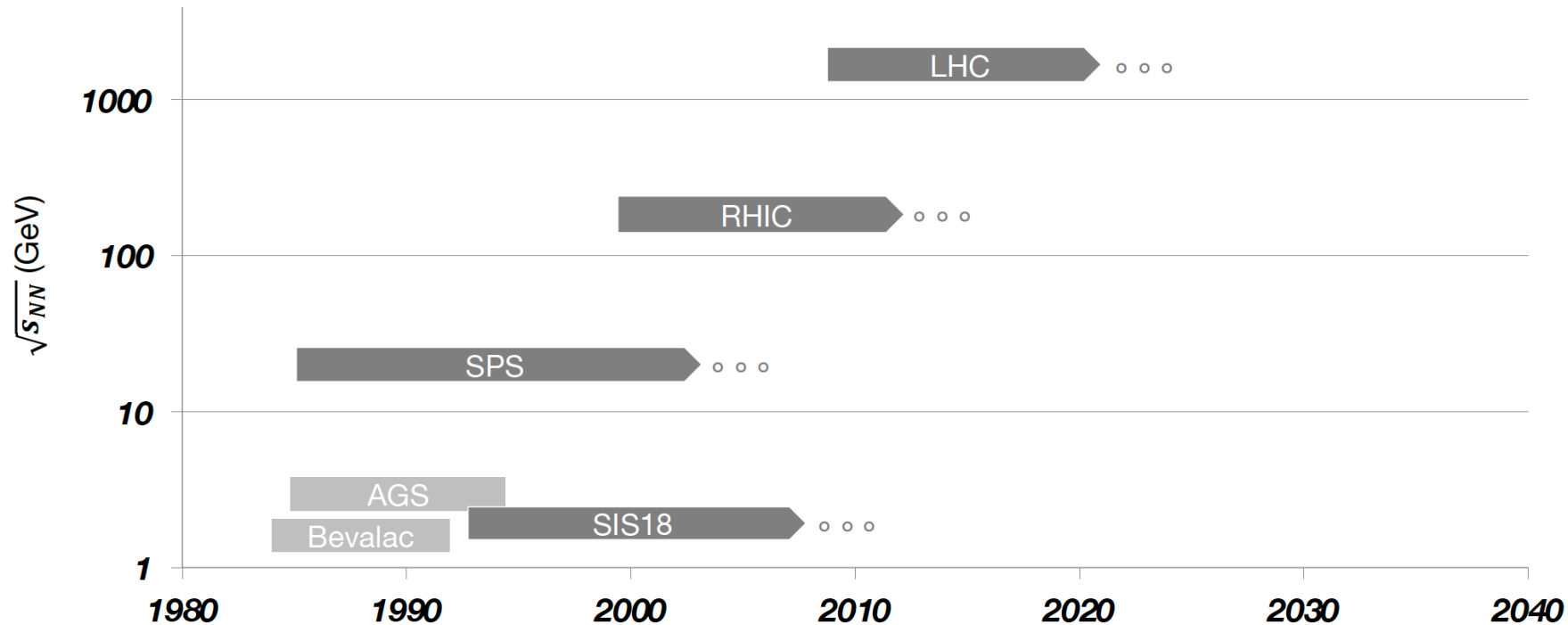


MAPS developments for ALICE ITS3, ALICE3, ...

Thank you!
 &
 Happy Birthday, Peter
 on behalf of the CBM Collaboration



The quest for the highest energy

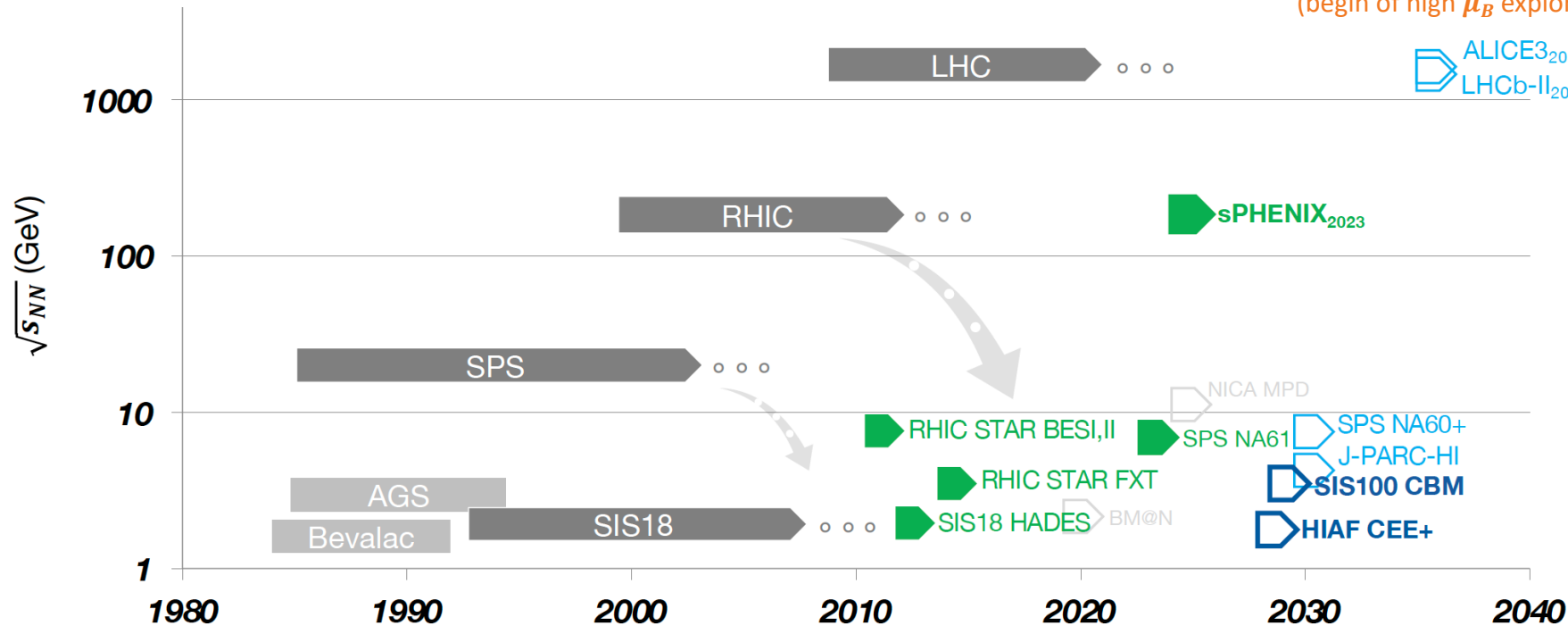


Cartoon by T. Galatyuk

Time $\equiv$ advances in accelerator and detector technologies

The quest for the utmost precision and rare probes

~25 years progress
in technology since AGS
(begin of high μ_B explorations)

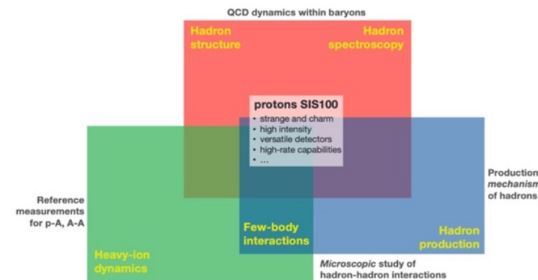


Cartoon by T. Galatyuk

Time $\equiv$ advances in accelerator and detector technologies

Hadron physics at FAIR

- Initiative (2022) from FAIR-motivated group from within CBM, HADES, PANDA
→ strengthen CBM science in hadron physics by involving exclusive channels
- High potential for hadron physics with **pion, proton & deuteron beams from SIS18 and SIS100**
- **Substantial extension of QCD program at FAIR** and its impact on increased attractivity/visibility for international community



Messchendorp, Nerling *et al.*, [arXiv:2512.15986 [hep-ex]]

- Importance of physics with GSI pion beams + HADES strongly emphasized by the community
- **Hadron Physics at CBM** offers additional unique scientific opportunity at FAIR and make realization of First Science+ just mandatory (also in view to keep alive MSV)

Hadron Physics Opportunities at FAIR

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 V. Barz^k, M. Boshkanov^l, A. Bratovnic^m, A. Belyaevⁿ, J. Bernhard^o, P. P. Bhasud^o, L. Biberzky^o, D. Blaschke^{o,p,q},
 M. Bleicher^{r,s}, C. Blumhake^t, X. Brauker^{u,v,w}, E. Bratkovskaya^{x,y}, S. Collins^z, V. Cudde^z, R. Daa^z, S. Diehl^{aa},
 S. Dobbs^{ab}, B. Doenicke^{ab}, M. Doering^{ab,ac}, A. Dubla^{ad}, G. Eichmann^{ad}, E. Epelbaum^{ae}, C. Fernández Ramírez^{af},
 C. S. Fischer^{ag}, A. Fodor^{ah}, T. Galatyuk^{ai,aj}, P. Gaus^{ak}, F. Giacosa^{al}, K. Götzes^{al}, B. Gruber^{al}, F.-K. Guo^{al,aj},
 A. Gusakov^{am}, J. Haidenbauer^{am}, H. W. Hammer^{an}, C. Hanhart^{ao}, C. Heide^{ap}, P. Huick^{aq}, N. Hüsken^{ar},
 K. Itahashi^{as,ap}, R. Kaminski^{at}, K. Kaupert^{au}, R. Kliment^{av}, C. M. Ko^{aw}, B. Kubis^{ax}, A. Kupce^{ay,az}, S. Leupold^{ba},
 M. Lorenz^{ab}, R. Maciula^{ac}, V. Mathieu^{ad}, M. Majumbar^{ae}, D. Mikhaylov^{ah,aj}, M. Mikhaenko^{ak}, C. Morningstar^{al},
 D. Mohler^{al,ac}, Y. Morino^{am}, E. Nandy^{an}, H. Nouri^{ao}, J. R. Pelaez^{ap}, M. T. Peña^{aq}, A. Pilloni^{ah,bh}, C. Rappold^{ba},
 B. Ramstein^{ba}, T. Reichert^{bc,d}, D. Roosen^{be,cf}, C. D. Roberts^{bf,gg}, J. Rittman^{bh}, S. Roy^{bi}, P. Salazar^{bj}, F. Sakuma^{bp},
 T. Saito^{ba,ca}, S. Schandmaier^{ca}, L. Schmitt^{cd,ce}, C. Scheidenberger^{ca,cf}, T. Song^{ci}, J. Struth^{ba,cf}, C. Sturm^{ca},
 A. Szczepaniak^{bp,bq,bz,ba}, A. Szczurek^{ca}, H. Takedashi^{ci}, L. Tolos^{ba,bz}, J. M. Torres-Rincon^{ay,bw}, I. Vidaña^{bi}, J. Taylor^{ca},
 R. Tyson^{ca}, D. Wieduck^{ba}, D. Winney^{ca}, G. Wolf^{ca}, H. Zorawsky^{ba}

