

The Compressed Baryonic Matter (CBM) Experiment at FAIR

Philipp Kähler for the CBM Collaboration



WWU Münster

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Overview

- The Compressed Baryonic Matter Experiment
- CBM Subdetectors STS, MVD, MuCh, RICH, TRD, TOF, ECAL, PSD
- Free-Streaming Readout and Computing
- FAIR Phase 0: System Performance Tests at Beam Facilities



The CBM Experiment at FAIR

- FAIR Phase 1 / SIS100 currently in construction
- Compressed Baryonic Matter (CBM) is one of the pillars of FAIR

SIS100 beam energies:

beam	Z	Α	E (AGeV)
р	1	1	29
d	1	2	14
Ca	20	40	14
Ni	28	58	13.6
In	49	115	11.9
Au	79	197	11
U	92	238	10.7



Collision energies:
$$\sqrt{s_{\rm NN}} = 2.5...5$$
 GeV



FAIR Construction Status



FAIR construction site, excavation of the SIS100 tunnel, April 2018. Detector installation and commissioning: 2021–2024, commissioning with beam: 2024, beam operation: 2025.



CBM Baryon Densities



Phys. Review C 75 (2007) 034902

Exploration of the QCD phase diagram at high baryonic densities:

- Fixed-target experiment
- Investigation of the properties of dense QCD matter
- ► Transport calculations at SIS100 energies: $\epsilon \leq 2.5 \text{ GeV fm}^{-3} \text{ and } 5 \dots 8\rho_0,$ expecting to reach neutron-star densities
- Long time (\geq 5 fm/c) in dense QCD regime



CBM Baryon Densities



Becattini et al., Phys. Lett. B **764** (2017) 241 STAR, Phys. Review C **96** (2017) 044904 Andronic et al., arXiv:1710.09425 and refs. therein

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High Rates with the CBM Experiment

Heavy-ion interaction rates (heavy systems) up to 10 MHz. Access to rare observables, probing the medium in an unprecedented level of precision:

- Low-mass vector mesons by di-lepton pair reconstruction
- Excitation functions of multi-strange hyperons near expected phase boundary (e.g. $\overline{\Omega}^+$ /week: ~ 10⁵ @ $\sqrt{s_{\rm NN}} = 3.5$ GeV)
- Access to collective flow of multi-strange hyperons
- Single and double hyper-nuclei programme, including discovery potential
- Critical point search using event-by-event fluctuations of conserved quantities

Challenges in QCD matter physics – The scientific programme of the Compressed Baryonic Matter experiment at FAIR, Eur. Phys. J. A **53** (2017) 60 and arXiv:1607.01487



Poster: E. Bechtel, ELW-03

Philipp Kähler, CBM Collaboration



CBM Subdetectors

STS

Silicon Tracking System*

MVD

Micro Vertex Detector*

* magnetic field

MuCh or RICH

MuonChamber System/ Ring Imaging Cherenkov Detector

TRD

Transition Radiation Detector

ToF

Time-of-Flight Detector

ECAL

Electromagnetic Calorimeter

PSD

Projectile Spectator Detector







CBM Silicon Tracking System



- Charged particle tracking, momentum measurement in 1 Tm dipole field
- Double-sided silicon strip sensors, 8 stations, total 4 m²
- Position resolution about 25 microns, time resolution about 5 ns

Poster: J. Heuser, INS-14



- Final sensors and module assembly developed
- Detector construction: 2019 to 2022
- Installation into CBM: 2023

Detector testing at COSY, February 2018:

- Signal to noise 15 ± 3
- Hit efficiency > 95 % in 1.7 GeV proton beam

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CBM Muon Chambers

- 4 stations and 4 + 1 absorbers
- GEM detector technology (3 mm Ar/CO₂)
- Graphite absorber (magnet), followed by Fe
- Geometrical acceptance: 5.7 25 degree



Real-size (80 x 40 cm²) GEM detector module

Detector testing at CERN-SPS, November 2016:

 Large-size chambers succesfully operated in fixed-target testbeam (Pb+Pb)

Poster: A. Kumar, A. Dubey, INS-17

- Reconstruction of di-muon cocktail: 8 AGeV Au+Au
- Track selection: associated hits in STS and MuCh, track \(\chi_2\) at STS/MuCh/prim. vertex, TOF mass cut





Multi-wire proportional chambers (12 mm Xe/CO₂).

CBM Transition Badiation Detector

- fast design. PE foam foil radiator
- Read-out: mirror charge on cathode-pads
- Electron detection due to absorption of TR photons additional to particle energy loss
- Pion suppression by four TRD layers
- Separation of light nuclei, e.g. $d \leftrightarrow^4 He$ (reconstruct: ${}^{5}_{A}He \rightarrow {}^{4}He + p + \pi^{-} // {}^{6}_{AA}He)$

Poster: C. Blume, INS-05



dns 105

105

10⁹

 10^{2}

10

TRD

- BICH

- BICH+TRD

- BICH+TRD+TOF

n (GeV/c)







- DESY electron beam (1 4 GeV), directly through detectors
- Full set of four MWPCs and radiators
- MWPC tracking station and scintillator coincidence reference
- Xe-CO₂ 80:20 as detector gas
- Slow data recorded for correlation with detector characteristics: HV, gas oxygen content, temperature, pressure



Measurement programme:

- Detector response to electrons, TR spectrum
- Electron detection efficiency
- Track reconstruction



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CBM Readout and Computing

- CBM-DAQ is free-streaming and self-triggered based on innovative frontend electronics
- Interaction rates resulting in high computing requirements
- FPGA-based readout chain (feature extraction) complemented by high-performance computing in the Green Cube
- Early reconstruction of self-contained units, data processing: in FPGA, FLES, online software
- Event definition: online in 4D-tracking from overlapping time-slices (First-Level Event Selector)

CBM detector cave __100 m_ CBM service building __-700 m

CBM: a fixed target.

heavy ion physics

experimen

high interaction rate.



DAO room

data pre-processing

on FLES input cluster

Green Cube: online

timeslice building

and event selection

Computer center

Poster: D. Emschermann, INS-10

Philipp Kähler, CBM Collaboration



FAIR Phase 0 Projects



- Detectors and read-out well-tested and confirmed separately
- Integration at beam facilities: eTOF at STAR/RHIC, RICH at HADES, STS and PSD at BM@N/JINR and operation of CBM detectors at mCBM/SIS18 starting in 2018, full free-streaming CBM-DAQ
- ▶ mCBM: full event reconstruction, online tracking and selection, ∧ reconstruction as performance



Summary and Outlook

Physics Programme:

- Probing QCD matter at high net-baryon densities
- Rich physics programme, measurements with unprecedented statistical precision
- Comprehensive performance studies in progress

Development and Construction:

- High rates challenging to detectors and DAQ, preparation measurements
- FAIR civil construction for SIS100 in progress

Detector and System:

- Subdetectors and electronics tested at beam facilities
- Full system test-setup FAIR phase 0 started



More CBM on QM2018

- Perspectives on strangeness physics with the CBM experiment at FAIR, Iouri Vassiliev
- > Test and developm. of the front-end electronics for the Silicon Tracking System of the CBM experiment, Adrian R. Rodriguez
- Large area triple GEM chambers for muon tracking at CBM experiment at FAIR, Anand Kumar Dubey
- Performance and Design of the Transition Radiation Detector for the CBM Experiment, Christoph Blume
- The free-streaming data acquisition system for the Compressed Baryonic Matter experiment at FAIR, David Emschermann
- Emissivity of baryon-rich matter dilepton spectroscopy in CBM, Etienne Bechtel
- The Projectile Spectator Detectors for the CBM at FAIR and NA61/SHINE at CERN, Fedor Guber
- The CBM Time-of-Flight system, Ingo Deppner
- ▶ The Silicon Tracking System of the CBM experiment at FAIR, Johann Heuser
- ▶ The RICH detector for the CBM experiment at FAIR, Jordan Bendarouach
- Multi-differential analysis with KF Particle Finder in the CBM experiment, Maksym Zyzak
- News from the Micro Vertex Detector of CBM, Philipp Sitzmann
- Time-based particle reconstruction and event selection in the CBM experiment, Valentina Akishina
- Performance for anisotropic flow measurements of the future CBM experiment at FAIR, Viktor Klochkov
- Performance of the new DiRICH based readout chain for MAPMTs in test beam data, Vivek Patel

Thank you for your attention!







CBM Baryon Densities



Clockwise evolution, 1 step is 1 fm/c. Excitation energy density means energy density minus mass density. Dashed line: possible area of phase coexistence.

Exploration of the QCD phase diagram at high baryonic densities:

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CBM Rapidity Coverage





CBM Transition Radiation Detector



TRD station with four layers of radiator/MWPC. $6.25 \times 5.15 \text{ m}^2$, four types of detector modules suiting the hit density distribution. Each 2^{nd} layer rotated by 90 degree.

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CBM Transition Radiation Detector



Veenhof, NIMPR A A419 (1998) 726-730

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Radiator prototypes:

- Full-size radiator boxes, 30 cm depth
- PE foam foils of 2 mm each
- Rohacell housing (8 mm)
- Stabilised by polymer filament grid
- Contacting directly to entrance window, additional 15 mm

Electrical scheme:

 Detector chambers electrically isolated against support structure





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Installed read-out:

- Four SPADIC 2.0 on beam positions of each TRD, one SPADIC 2.0 for gas gain monitoring
- ▶ Two SPADIC 2.0 on reference MWPCs, one LEMO-SPADIC 2.0 on Scint/PMTs
- New shaping time of 240 ns, 16 MHz sampling, up to 32 samples read
- Four AFCK boards, IPbus controls, FLES data recording



TRD High-Rate Test at CERN-GIF





Simulated gamma spectrum in empty GIF bunker, three attenuator levels, *GIF*

- ▶ ¹³⁷Cs source, 13 TBq
- Three-level attenuator system to control photon rate over large scale
- γ emission of 662 keV, interactions with material
- TRD prototype: 1 cm² cathode-pad size
- Xe-CO₂ 80:20 as detector gas, controlled in pressure and oxygen contamination



TRD High-Rate Test at CERN-GIF



Measured anode currents with respect to photon flux

Measurement programme:

- Detector load in the CBM domain and above: exclusion of space-charge effects
- DAQ chain at highest loads
- Homogeneity of detector

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TRD Read-Out and Electronic Status

- SPADIC front-end: 16 MHz/8 B sampling, self-triggered and free-streaming
- Forced-Neighbour Read-Out for efficient charge reconstruction
- Tail cancellation and multi-hit flagging
- e-link via GBTx (on module) to FPGA layer in entry nodes, feature extraction on-site



Quad-FEB, four SPADIC 2.0, 4 x 32 channel, inter-chip and inter-FEB neighbour-trigger (rendering)

Current integration branches:

- Quad-FEB based on SPADIC 2.0 with inter-chip neighbour-trigger
- Commissioning of SPADIC 2.1-based read-out: optimisation of protocol usage
- C-ROB ("Read-Out Board", GBTx) integration



TRD Lab and In-Beam Tests

Lab measurements

- Electronic integration
- Front-end setting optimisation
- Oxygen/humidity levels in detector gas
- Gas gain confirmation

In-beam tests

- Earlier tests at SIS18, CERN-PS, CERN-SPS
- Electron testbeam at DESY II, 2017
- High-rate test at Gamma Irradiation Facility CERN-GIF⁺⁺, 2017
- High-rate test at CERN-GIF⁺⁺ including muon beam, 2018
- miniCBM at SIS18, in installation



TRD prototypes at DESY, MWPCs + Radiators