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

Fundamental questions:
Equation of State of QCD matter at neutron star densities
Phase structure of QCD matter
Chiral symmetry restoration at large densities
Bound states with strangeness
Charm in dense baryonic matter
Dense Baryonic Matter

**Neutron stars**
- **Temperature** \( T < 20 \text{ MeV} \)
- **Density** \( \rho < 10 \rho_0 \)
- **Lifetime** \( T \sim \text{infinity} \)

**Neutron star merger**
- **Temperature** \( T < 70 \text{ MeV} \)
- **Density** \( \rho < 3\rho_0 \)
- **Reaction time** \( (\text{GW170817}) \)
  \( T \sim 10 \text{ s} \)

**Heavy ion collisions at SIS100**

Temperature \( T < 120 \text{ MeV} \)

**Reaction time** \( t \sim 10^{-23} \text{ s} \)

**Compressed Baryonic Matter**

N.Herrmann, Dec.1st, 2017

KHUK Annual Meeting 2017, Bad Honnef
EOS is soft ($K=200\text{MeV}$) for densities $\rho/\rho_0 < 2.5$ (SIS18), Soft EOS not repulsive enough to allow for a neutron star with $2M_\odot$, Stiffening of EOS must occur in the SIS100 energy range.
CBM  physics and observables

QCD equation-of-state
• collective flow of identified particles
• particle production at threshold energies

Phase transition
• excitation function of hyperons
• excitation function of LM lepton pairs

Critical point
• event-by-event fluctuations of conserved quantities

Chiral symmetry restoration at large $\rho_B$
• in-medium modifications of hadrons
• dileptons at intermediate invariant masses

Strange matter
• (double-) lambda hypernuclei
• Search for meta-stable objects (e.g. strange dibaryons)

Heavy flavour in cold and dense matter
• excitation function of charm production
Main features:
- radiation tolerant detectors and front-end electronics
- free streaming (triggerless) data,
- all detector hits with time stamps,
- software based event selection

Reaction rate: \( \text{Au + Au, } 10^7 \text{ collisions per second} \)
Data rate: \( \sim 1 \text{ TB/s} \)
CBM – Strategy

Exploration of QCD phase diagram as international effort:

- NA61 @ SPS / CERN
- BM@N @ Nuclotron/JINR
- STAR (F.t.) @ RHIC/BNL
- MPD @ NICA / JINR

CBM’s unique feature
High statistics measurement of rare probes
Final state particle abundance

Particle yields from central Au + Au collisions

Strange and charmed particle production thresholds in pp - collisions

<table>
<thead>
<tr>
<th>reaction</th>
<th>$\sqrt{s}$ (GeV)</th>
<th>$T_{lab}$ (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pp \rightarrow K^+ \Lambda p$</td>
<td>2.548</td>
<td>1.6</td>
</tr>
<tr>
<td>$pp \rightarrow K^+ K^- pp$</td>
<td>2.864</td>
<td>2.5</td>
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<tr>
<td>$pp \rightarrow K^+ K^+ \Xi^- p$</td>
<td>3.247</td>
<td>3.7</td>
</tr>
<tr>
<td>$pp \rightarrow K^+ K^+ K^+ \Omega^- n$</td>
<td>4.092</td>
<td>7.0</td>
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<tr>
<td>$pp \rightarrow \Lambda \bar{\Lambda} pp$</td>
<td>4.108</td>
<td>7.1</td>
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<tr>
<td>$pp \rightarrow \Xi^- \Xi^+ pp$</td>
<td>4.520</td>
<td>9.0</td>
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<tr>
<td>$pp \rightarrow \Omega^- \bar{\Omega}^+ pp$</td>
<td>5.222</td>
<td>12.7</td>
</tr>
<tr>
<td>$pp \rightarrow J/\Psi pp$</td>
<td>4.973</td>
<td>12.2</td>
</tr>
</tbody>
</table>
PHSD interpretation of $\Xi^{-}$ - production


Predicted sensitivities of production yields:

- strong dependence on Chiral Symmetry Restoration (CSR)
- measurable dependence on Equation of State (NL1, NL3)

Strong theoretical support necessary to link observables to matter properties.
CBM experimental setup (day-1)

- Tracking acceptance: $2^\circ < \theta_{lab} < 25^\circ$
- Free streaming DAQ
- $R_{int} = 10 \text{ MHz (Au+Au)}$

$$R_{int} \approx 0.5 \text{ MHz}$$

- Software based event selection

Day-1 setup = MSV setup – Compute Performance - ECAL
Phase-1 = Day1 with full Compute Performance + ECAL

Day-1 funding: ~ 90% secured
German contributions to CBM

CBM day 1 setup percentage secured funding

<table>
<thead>
<tr>
<th>Country</th>
<th>Percentage</th>
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<td>Germany</td>
<td>29.9%</td>
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<tr>
<td>Russia</td>
<td>26.8%</td>
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<tr>
<td>India</td>
<td>10.1%</td>
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<tr>
<td>Poland</td>
<td>5.3%</td>
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<td>Romania</td>
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<tr>
<td>Czech Republic</td>
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<td>France</td>
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<td>Hungary</td>
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<tr>
<td>Korea</td>
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<tr>
<td>Common fund</td>
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CBM collaboration percentage PhD holders

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<tr>
<td>Russia</td>
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<td>France</td>
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<td>Korea</td>
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<tr>
<td>Ukraine</td>
<td>0.4%</td>
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Participating German University Groups

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<tr>
<th>Sub-system</th>
<th>Institution</th>
<th>Group Leader</th>
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<tbody>
<tr>
<td>MVD</td>
<td>Univ. Frankfurt</td>
<td>Prof. J. Stroth *</td>
</tr>
<tr>
<td>STS</td>
<td>Univ. Tübingen</td>
<td>Prof. H.R. Schmidt *</td>
</tr>
<tr>
<td>RICH</td>
<td>Univ. Giessen Univ. Wuppertal</td>
<td>Prof. C. Höhne *</td>
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<td>Univ. Wuppertal</td>
<td>Prof. K.H. Kampert *</td>
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<td>TRD</td>
<td>Univ. Frankfurt</td>
<td>Prof. C. Blume *</td>
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<td></td>
<td>Univ. Heidelberg</td>
<td>Prof. P. Fischer</td>
</tr>
<tr>
<td></td>
<td>Univ. Münster</td>
<td>Nf. Wessels</td>
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<tr>
<td>TOF</td>
<td>Univ. Heidelberg TU</td>
<td>Prof. N. Herrmann *</td>
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<tr>
<td></td>
<td>Darmstadt</td>
<td>Prof. T. Galatyuk *</td>
</tr>
<tr>
<td>DAQ/FLES</td>
<td>KIT Karlsruhe</td>
<td>Prof. J. Becker</td>
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<td></td>
<td>Univ. Frankfurt</td>
<td>Prof. U. Kebschull</td>
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<td>Prof. I. Kisel</td>
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<td>Univ. Frankfurt</td>
<td>Prof. V. Lindenstruth *</td>
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<tr>
<td></td>
<td>Zuse Inst. Berlin</td>
<td>Prof. A. Reinefeld</td>
</tr>
<tr>
<td></td>
<td>Univ. Frankfurt</td>
<td>Prof. A. Toia</td>
</tr>
</tbody>
</table>

* Project leadership within the group
### Timeline and activities

**Target date for Day-1:** Jun 2024

**Commissioning beam from SIS100**

<table>
<thead>
<tr>
<th>#</th>
<th>Project</th>
<th>TDR Status</th>
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<tbody>
<tr>
<td>1</td>
<td>Magnet</td>
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<tr>
<td>4</td>
<td>TOF</td>
<td>approved 2015</td>
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<tr>
<td>5</td>
<td>MuCh</td>
<td>approved 2015</td>
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<tr>
<td>6</td>
<td>PSD</td>
<td>approved 2015</td>
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<tr>
<td>7</td>
<td>TRD</td>
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<tr>
<td>8</td>
<td>MVD</td>
<td>submission 2018</td>
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<tr>
<td>9a</td>
<td>Online Systems: DAQ</td>
<td>submission 2018</td>
</tr>
<tr>
<td>9b</td>
<td>Online Systems: FLES</td>
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</tr>
<tr>
<td>10</td>
<td>ECAL</td>
<td>submission 2018</td>
</tr>
</tbody>
</table>
CBM day-1 – program

Observables: Strangeness and Dileptons

Excitation function of yields and phase-space distributions of multi-strange hyperons and lepton pairs in AA (C+C, Au+Au) collisions from 2-11 A GeV. Search for hypernuclei (no data available in this energy range).

multi-strange hyperons  hypernuclei  dilepton invariant mass
Di-electron measurement
Full performance, uses MVD, limited to 100 kHz

Hyperon measurements, e.g. Au+Au at 10A GeV:

Hypernuclei measurement, e.g. Au + Au at 10A GeV

Di-Muon
LM measurement at 8A GeV
CBM – FAIR Phase 0 projects (2018 – 2022)

1. Install, commission and use 430 out of 1100 CBM RICH multi-anode photo-multipliers (MAPMT) including FEE in HADES RICH photon detector

2. Install, commission and use 10% of the CBM TOF modules including read-out chain at STAR/RHIC (BES II 2019/2020)

3. Upgrade BM@N experiment with 4 Silicon stations of CBM/STS design in the BM@N experiment at the Nuclotron JINR/Dubna (Au-beams in late 2020)

4. Install, commission and use the Project Spectator Detector at the BM@N experiment

5. mini CBM (mCBM@SIS18) demonstrator for full CBM data taking and analysis chain
CBM FAIR Phase 0 project at SIS18: mCBM

Demonstrator for full CBM data taking and analysis chain

The mCBM test-setup (“mini-CBM”) will focus on

- test of final detector prototypes
- free streaming data transport to a computer farm
- online reconstruction and event selection
- offline data analysis

under full load conditions \((Au + Au, 10^7\text{ interactions/s})\)


N.Herrmann, Dec.1st, 2017

KHUK Annual Meeting 2017, Bad Honnef
mCBM performance benchmark

(Sub)threshold $\Lambda$ – baryon reconstruction.

Event based MC simulation of $10^8$ events
(measurement time: 10 s)

$\Lambda \rightarrow p + \pi^-$

Acceptance & Efficiency

Ni+Ni 1.93 AGeV

Au+Au 1.24 AGeV

N.Herrmann, Dec.1st, 2017

KHUK Annual Meeting 2017, Bad Honnef
### Schedule of mCBM construction

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/2017</td>
<td>cave &amp; beam line: reconstruction started, procurement started</td>
</tr>
<tr>
<td>11/2017</td>
<td>$\mu$DAQ test stand @ Heidelberg operational</td>
</tr>
<tr>
<td>12/2017</td>
<td>beam dump mounted</td>
</tr>
<tr>
<td>03/2018</td>
<td>cave reconstruction completed</td>
</tr>
<tr>
<td>04/2018</td>
<td>mFLES cluster @ Green IT Cube installed</td>
</tr>
<tr>
<td>05/2018</td>
<td>beam line installed and commissioned</td>
</tr>
<tr>
<td>05/2018</td>
<td>installation of detector stations</td>
</tr>
<tr>
<td>06/2018</td>
<td>start commissioning w/o beam</td>
</tr>
<tr>
<td>08/2018</td>
<td>start commissioning with beam</td>
</tr>
</tbody>
</table>

N.Herrmann, Dec.1st, 2017

KHUK Annual Meeting 2017, Bad Honnef
Participating CBM groups:

- Tsinghua Univ. Beijing
- GSI Darmstadt
- TU Darmstadt
- Univ. Frankfurt
- Univ. Heidelberg
- USTC Hefei
- CCNU Wuhan

Participation of German groups in BES II secured by additional funds (Germany VF).

Test module installed (Oct. 2016),
Module is operational (Oct. 2016),
STAR DAQ interface (Jan. 2017),
Full sector test (Spring 2018),
Wheel installation (Summer 2018),
BES II data taking (2019/2020),
Transfer of modules to FAIR (2021/22).

N.Herrmann, Dec.1st, 2017

KHUK Annual Meeting 2017, Bad Honnef
STS & PSD in BM@N (JINR)

Silicon Tracking Stations

Au beams up to 4.5 GeV/u

Silicon Tracking Stations

dipole magnet

GEM tracker

PSD calorimeter

BM@N timeline: NICA white paper

2018 Installation of PSD detector (MoU signed)
2020 Installation of 4 Si tracking stations (MoU signed)
2020 Au beams from Nuclotron

Improvement in efficiency & signal / background

Invariant mass: $\Lambda \rightarrow p + \pi^-$

S/(S+B) = 121.2
S/B = 10.4
Eff. = 14.5%
Peak 6176.4
Mean 1.1155
Sigma 0.0022

N.Herrmann, Dec.1st, 2017

KHUK Annual Meeting 2017, Bad Honnef
CBM – Collaboration: 55 institutions, 470 members

**China:**
CCNU Wuhan
Tsinghua Univ.
USTC Hefei
CTGU Yichang
Chongqing Univ.

**Czech Republic:**
CAS, Rez
Techn. Univ. Prague

**France:**
IPHC Strasbourg

**Germany:**
Darmstadt TU
FAIR
Frankfurt Univ. IKF
Frankfurt Univ. FIAS
Frankfurt Univ. ICS
GSI Darmstadt
Giessen Univ.
Heidelberg Univ. P.I.
Heidelberg Univ. ZITI
HZ Dresden-Rossendorf
KIT Karlsruhe
Münster Univ.
Tübingen Univ.
Wuppertal Univ.
ZIB Berlin

**India:**
Aligarh Muslim Univ.
Bose Inst. Kolkata
Panjab Univ.
Univ. of Jammu
Univ. of Kashmir
Univ. of Calcutta
B.H. Univ. Varanasi
VECC Kolkata
IOP Bhubaneswar
IIT Kharagpur
IIT Indore
Gauhati Univ.

**Korea:**
Pusan Nat. Univ.

**Poland:**
AGH Krakow
Jag. Univ. Krakow
Warsaw Univ.
Warsaw TU

**Romania:**
NIPNE Bucharest
Univ. Bucharest

**Russia:**
IHEP Protvino
INR Troitzk
ITEP Moscow
Kurchatov Inst., Moscow
VBLHEP, JINR Dubna
LIT, JINR Dubna
MPEH Moscow
PNPI Gatchina
SINP MSU, Moscow

**Ukraine:**
T. Shevchenko Univ. Kiev
Kiev Inst. Nucl. Research

**Hungary:**
KFKI Budapest
Eötvös Univ.

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30th CBM Collaboration meeting in Wuhan
24-28 September 2017

CBM Scientists

N. Herrmann, Dec. 1st, 2017

KHUK Annual Meeting 2017, Bad Honnef
CBM scientific program at SIS100 is unique

- explore QCD matter at neutron star core densities
- employ high statistics capability
  - to achieve high-precision of multi-differential observables
  - to enable rare processes as sensitive probes

CBM day-1 setup allows start of program with significant discovery potential

- excitation function of hyperons production
- excitation function of di-lepton production
- study of hypernuclei

CBM Phase 0 activities targeted towards usage and understanding of major components & production of visible physics results with CBM devices

- CBM – RICH sensors & readout in HADES at SIS18
- CBM – TOF and HPC software in STAR at RHIC/BNL
- CBM – PSD and CBM - STS in BM@N at Nuclotron/JINR
- Integration of all subsystems & FLES in mCBM at SIS18