The Compressed Baryonic Matter Experiment at FAIR

Physics Program, Challenges and Status
Landscape of Discovery in Super-Dense Matter Physics
Landscape of Discovery in Super-Dense Matter Physics

energy

luminosity

terra incognita
Landscape of Discovery in Super-Dense Matter Physics

energy

luminosity

Shine@SPS

Shine
BES

terra incognita

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luminosity

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STAR@RHIC

Shine@SPS

RHIC BES

Shine BES

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ALICE@LHC

ALICE upgrade

STAR@RHIC

terra incognita

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Landscape of Discovery in Super-Dense Matter Physics

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ALICE@LHC

ALICE upgrade

STAR@RHIC

Shine@SPS

RHIC BES

MPD@NICA

CBM@SIS300

CBM@SIS100

**terra incognita**

$R_{int} = 10^5 - 10^7 \text{ Hz}$

(limitation by present detector technology)

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Maximal net-baryon density (from hadron gas model): $E_{\text{beam}} \approx 30A$ GeV ($\sqrt{s_{NN}} \approx 8$ GeV)
**Experiments on Superdense Nuclear Matter**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Observables for beam energies below $\sqrt{s_{NN}} = 12$ GeV (high baryon density region)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>hadrons</td>
</tr>
<tr>
<td>STAR@RHIC</td>
<td>yes</td>
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<tr>
<td>BNL</td>
<td></td>
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<tr>
<td>NA61@SPS</td>
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<td>CERN</td>
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<tr>
<td>MPD@NICA</td>
<td>yes</td>
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<td>Dubna</td>
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<td>CBM@FAIR</td>
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<td>Darmstadt</td>
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</table>

rare probes
Outline

• Focus of this talk
  – Exploration of Dense Matter with new, rare probes
    • (sub)threshold production of multi-strange hyperons
    • hyper-nuclei
  – Experimental Challenges & Status of CBM

• No covered (because of time constraints)
  – bulk observables
    • flow, fluctuations, correlations, ....
  – Hadrons in Dense Matter
    • low mass vector mesons
    • charm & open charm
recent observation of a $\frac{M}{M_{\odot}} \approx 2$ Neutron Star

- no stable against gravitational collapse with soft EOS (e.g. quark matter EOS)
- stable Neutron Star with quark-hadron mixed phase incl. hyperons
  - important: knowledge hyperon-hyperon interaction
- **experimental prerequisites:**
  - probes of high density phase (are traditional flow measurements sufficient?)
Exploring the EOS at $3\rho_0 < \rho < 7\rho_0$ with (Sub)-Threshold Production of Multi-Strange Hyperons

Direct production:

\[ pp \to \Xi^- K^+ K^+ p \ (E_{\text{thresh}} = 3.7 \text{ GeV}) \]
\[ pp \to \Omega^- K^+ K^+ K^0 p \ (E_{\text{thresh}} = 7.0 \text{ GeV}) \]

Production via multiple collisions*):

\[ pp \to K^+ \Lambda p \quad (E_{\text{thresh}} = 1.6 \text{ GeV}) \]
\[ pp \to K^+ K^- pp \quad (E_{\text{thresh}} = 2.5 \text{ GeV}) \]

\[ \Lambda \Lambda \to \Xi^- p \quad \Lambda \Xi^- \to \Omega^- n, \]
\[ \Lambda K^- \to \Xi^- \pi^0 \quad \Xi^- K^- \to \Omega^- \pi^- \]

sub-threshold production cross section of $\Xi^-$, $\Omega^-$ probes dense, baryonic matter….

- AGS physics revisited with new probes
- measure excitation functions for multi-strange hyperons in light and heavy collision system

Exploring the EOS at $3\rho_0 < \rho < 7\rho_0$ with (Sub)-Threshold Production of Multi-Strange Hyperons

<table>
<thead>
<tr>
<th>Beam energy</th>
<th>$\Xi^-$</th>
<th>$\Omega^-$</th>
<th>$\bar{\Lambda}$</th>
<th>$\Xi^+$</th>
<th>$\Omega^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0A GeV</td>
<td>$9.0 \cdot 10^6$</td>
<td>$1.8 \cdot 10^5$</td>
<td>$3.6 \cdot 10^3$</td>
<td>$5.3 \cdot 10^3$</td>
<td>$9.0 \cdot 10^2$</td>
</tr>
<tr>
<td>6.0A GeV</td>
<td>$2.6 \cdot 10^7$</td>
<td>$5.0 \cdot 10^5$</td>
<td>$2.4 \cdot 10^5$</td>
<td>$1.4 \cdot 10^4$</td>
<td>$2.8 \cdot 10^3$</td>
</tr>
<tr>
<td>8.0A GeV</td>
<td>$4.0 \cdot 10^7$</td>
<td>$1.4 \cdot 10^6$</td>
<td>$3.6 \cdot 10^6$</td>
<td>$2.0 \cdot 10^5$</td>
<td>$6.0 \cdot 10^4$</td>
</tr>
<tr>
<td>10.7A GeV</td>
<td>$5.4 \cdot 10^8$</td>
<td>$2.2 \cdot 10^6$</td>
<td>$6.8 \cdot 10^6$</td>
<td>$3.8 \cdot 10^5$</td>
<td>$1.2 \cdot 10^4$</td>
</tr>
</tbody>
</table>

\[ \Lambda \Lambda \to \Xi^- p \quad \Lambda \Xi^- \to \Omega^- n, \]
\[ \Lambda K^- \to \Xi^- \pi^0 \quad \Xi^- K^- \to \Omega^- \pi^- \]

sub-threshold production cross section of $\Xi^-, \Omega^-$ probes dense, baryonic matter…. 
- AGS physics revisited with new probes 
- measure excitation functions for multi-strange hyperons in light and heavy collision system

Multi-Strangeness

search for
• double hyper-nuclei
  \( ^5\Lambda \Lambda \text{He}, ^6\Lambda \Lambda \text{He} \)
• MEMOS\(^\dagger\)
  \( (\Xi^0\Xi^-)_b, (\Xi^0\Lambda)_b, \ldots \)

\(^\dagger\) Metastable Exotic Multihypernuclear Objects
Double-strange hypernuclei

Observed ΛΛ hypernuclei:

1963: ΛΛ⁴⁰Be (Danysz et al.)
1966: ΛΛ⁶He (Prowse et al.)
1991: ΛΛ⁴⁰Be or ΛΛ⁴⁰Be (KEK-E176)
2001: ΛΛ⁴He (BNL-E906)
2001: ΛΛ⁶He (KEK-E373)
2001: ΛΛ¹⁰Be (KEK-E373)
Search for Double Hypernuclei

conventional production mechanism\(^\ast\):

\[
\begin{align*}
\bar{K}^- & \rightarrow u \bar{s} s u \bar{s} \\
N & \rightarrow u u d s s d \\
K^+ & \rightarrow \Xi^- + ^{12}C \\
& \rightarrow \Lambda\Lambda^6He + ^4He + t
\end{align*}
\]

heavy collisions:
production via coalescence of $\Lambda$ with light fragments

40 AGeV: 50 $\Lambda'$s/central Au+Au collision
10 AGeV: 15 $\Lambda'$s/central Au+Au collision

yield: $10^{-4} \Lambda\Lambda^4He, 10^{-6} \Lambda\Lambda^5H, 3 \cdot 10^{-8} \Lambda\Lambda^6He$ /central collision

>10^4/week 120/week 3.6/week

\(^\ast\) Takahashi et al, PRL 87 (2001)
Search for Double Hypernuclei

conventional production mechanism\(^\ast\):

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\begin{align*}
K^- & \quad s\bar{u} & \quad K^+ & \quad u\bar{s} \\
N & \quad u\bar{d} & \quad \Xi^- & \quad + \quad ^{12}C \\
& \quad s\bar{s} & \quad \Lambda\Lambda & \quad He + ^4He + t
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>10\(^4\)/week 120/week 3.6/week

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Signal: strange dibaryon 
\((\Xi^0 \Lambda)_b \rightarrow \Lambda \Lambda\) \((ct=3\text{cm})\)

M = 10\(^{-6}\), BR = 5%

Background:
Au+Au @ 25 AGeV
32 \(\Lambda\) per central event
11 \(\Lambda\) reconstructable
FAIR Modules 0-3 (SIS100):

- protons up to 29 GeV
- Au+Au 11 AGeV,
- Ca+Ca 14 AGeV

→ HADES + CBM Start Version

FAIR Module 6 (SIS300):

- protons up to 89 GeV
- Au+Au 35 AGeV,
- Ca+Ca 44 AGeV

→ CBM
CBM @ FAIR

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→ CBM

CBM Full Version

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Rare Probes, High Rates

- Requirement for a high rate experiment:
  - fast and rate-capable detectors
  - fast read-out electronics
  - radiation-hard detectors and electronics
  - high-throughput data acquisition and efficient online data selection

⇒ new territory from a detector, electronics, trigger/computing point of view!
Detector systems

- **Main tracking device: STS**
  - low-mass silicon strip detectors in magnetic dipole field
  - tracking efficiency > 90 %
  - momentum resolution ≈ 1%

- **Micro-vertex detector for open charm: MVD**
  - low-mass silicon pixel detector close to the target
  - high precision (resolution ≈ 3 μm)

- **Electron identification: RICH and TRD**
  - RICH with C0₂ radiator, two focal planes and MAPMT photo detection
  - several layers of thin TRDs with MWPC readout

- **Hadron identification: TOF**
  - RPC wall at 10 m flight distance, resolution <= 80 ps

- **Muon identification: active absorber system**
  - several absorber / GEM detector layers

- **ECAL for photon and electron identification**
  - lead/scintillator sandwich

- **Event characterisation: PSD**
  - compensated forward calorimeter

- **low mass, radiation hard!**
- **new technology: high rate & resolution MAPS!**
- **new technology: fast TRD!**
- **new technology: high rate & resolution RPC!**
- **new technology: GEM instrumented absorber!**
The key to open charm is a high-precision, ultra low-mass vertex detector

- MAPS: integrated electronics, very low material budget, very precise (3 μm)
- Not intrisically fast and radiation hard, but tremendous progress: 40 μs r/o frame, stands up to $10^{13}$ n$_{eq}$/cm$^2$
- now almost „state of the art“ (STAR, ALICE, NA61 upgrades)
double sided silicon microstrip detector
15° stereo angle, 60 µm pitch, 300 µm thick, bonded to ultra-thin micro-cables, radiation hardness
CBM Start-Version: Silicon Tracking System

Technical Design Report for the CBM

Superconducting Dipole Magnet

The CBM Collaboration

Compressed Baryonic Matter Experiment

December 2012

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CBM Start-Version: Silicon Tracking System

Superconducting Dipole Magnet
The CBM Collaboration

Silicon Tracking System (STS)
The CBM Collaboration
The Big Challenge: Data Reduction

At 10 MHz, online data reduction by $\approx 1000$ is mandatory.

Trigger signatures are complex (open charm) and require partial event reconstruction.

- No a-priori association of signals to physical events!
- „Event building“ becomes non-trivial at high rates
- Need extremely fast reconstruction algorithms!

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<th>Anfang</th>
<th>Ende</th>
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<td>1</td>
<td>1. FAIR Civil Construction</td>
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<td>2. Flattening, Tending, Construction of Site and Buildings</td>
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<td>3. Ready to move in HEDT Connection SIS18 – SIS100</td>
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<td>6. Ready to move to HEDT - T1X1</td>
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<td>7. Ready to move in Multifunction Cavities (CBM-HADES)</td>
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<td>8. Ready to move in HEDT – T1F1</td>
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<td>9. Ready to move in Super FRS</td>
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<td>11. Ready to move in p-bar Target</td>
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<td>13. Ready to move in CR</td>
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<td>14. Ready to move in HESR</td>
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<td>15. FAIR Accelerator for Set-Up Phase</td>
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<td>16</td>
<td>16. Module 0 - 3</td>
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<td>17. System Block 1 of Mod 0 - 3</td>
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<td>18. HEDT Connection SIS10 – SIS100 (T1S1, T1S2, T1S3, T1S4)</td>
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<td>19. Super FRS</td>
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<td>20. System Block 2 of Mod 0 - 3</td>
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<td>21. HEDT-SIS100 (TBD)</td>
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<td>22. SIS100</td>
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<td>23</td>
<td>23. HEDT - T1X1, T1C1, T1D1, T1C2, T1C3 - T1X2, T1X3, T1X4</td>
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<td>24. Multifunction Cases (CBM-HADES)</td>
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<td>25. System Block 3 of Mod 0 - 3</td>
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<td>26</td>
<td>26. HEDT-T1F1, T1F2, T1F3, T1S1, T1S2, T1F4, T1F5</td>
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<td>27. HEDT - TAP, TAP2, TCR, THS</td>
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### CBM Time Line

<table>
<thead>
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<tr>
<td>1</td>
<td>CBM Civil Construction</td>
<td>Fr 06.11.09</td>
<td>Mi 09.05.18</td>
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<tr>
<td>2</td>
<td>R&amp;D detectors &amp; read-out systems</td>
<td>Fr 06.11.09</td>
<td>Mi 09.05.18</td>
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<tr>
<td>3</td>
<td>Construction Detectors &amp; read-out Systems</td>
<td>Fr 29.04.16</td>
<td>Fr 29.04.16</td>
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<tr>
<td>4</td>
<td>Installation, commissioning</td>
<td>Fr 29.04.16</td>
<td>Fr 29.04.16</td>
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<td>5</td>
<td>First data taking</td>
<td>Fr 29.04.16</td>
<td>Fr 29.04.16</td>
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<td>6</td>
<td>CBM cave ready: May 1, 2017</td>
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<td>7</td>
<td>SIS100 ready: Oct. 13, 2017</td>
<td></td>
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</tbody>
</table>

**CBM cave ready: May 1, 2017**

**SIS100 ready: Oct. 13, 2017**
CBM Collaboration (55 Labs, 400 People)

Croatia:
RBI, Zagreb
Split Univ.

China:
CCNU Wuhan
Tsinghua Univ.
USTC Hefei

Czech Republic:
CAS, Rez
Techn. Univ. Prague

France:
IPHC Strasbourg

Hungary:
KFKI Budapest
Budapest Univ.

Norway:
Univ. Bergen

Germany:
Frankfurt Univ. IKF
Frankfurt Univ. FIAS
GSI Darmstadt
Giessen Univ.
Heidelberg Univ. P.I.
Heidelberg Univ. KIP
Heidelberg Univ. ZITI
HZ Dresden-Rossendorf
Münster Univ.
Tübingen Univ.
Wuppertal Univ.

Korea:
Korea Univ. Seoul
Pusan Nat. Univ.

Romania:
NIPNE Bucharest
Univ. Bucharest

India:
Aligarh Muslim Univ.
Panjab Univ.
Rajasthan Univ.
Univ. of Jammu
Univ. of Kashmir
Univ. of Calcutta
B.H. Univ. Varanasi
VECC Kolkata
SAHA Kolkata
IOP Bhubaneswar
IIT Kharagpur
Gauhati Univ.

Poland:
AGH Krakow
Jag. Univ. Krakow
Silesia Univ. Katowice
Warsaw Univ.

Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
KRI, St. Petersburg
Kurchatov Inst., Moscow
LHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP MSU, Moscow
St. Petersburg P. Univ.

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