Perspectives on strangeness physics with the CBM experiment at FAIR

• Physics case
• MSH reconstructions
• BES-I MSH measurements, models and predictions
• Tests with experimental data
• Summary

13 June 2019 Bari
Physics case: Exploring the QCD phase diagram

The equation-of-state at high $\rho_B$
collective flow of hadrons,particle production at threshold energies:
**multi-strange hyperons, hypernuclei**

Deconfinement phase transition at high $\rho_B$
excitation function and flow ofstrangeness ($K, \Lambda, \Sigma, \Xi, \Omega$ and $\phi$)

Chiral symmetry restoration at high $\rho_B$
in-medium modifications of hadrons ($\rho$)excitation function of **multi-strange (anti)hyperons**

QCD critical endpoint
excitation function of event-by-event fluctuations($\pi, K, p, \Lambda, \Xi, \Omega...$)

Projects to explore the QCD phase diagram at large $\mu_B$:
RHIC (STAR) beam energy-scan, HADES, NA61@SPS,MPD@NICA: bulk observablesCBM: bulk and **rare observables, high statistic**!
Experiments exploring dense QCD matter

CBM: unprecedented (high) rate capability

- determination of (displaced) vertices with high resolution ($\approx 50 \, \mu\text{m}$)
- identification of leptons and hadrons
- fast and radiation hard detectors
- self-triggered readout electronics
- high speed data acquisition and online event selection
- powerful computing farm and $4D$ tracking
- software triggers
No data available at FAIR energy

In the AGS (SIS100) energy range, only about 300 Ξ- hyperons have been measured in Au+Au collisions at 6AGeV.

High-precision measurements of excitation functions of multi-strange hyperons in A+A collision with different mass numbers A at SIS100 energies have a discovery potential to find a signal for the onset of deconfinement in QCD matter at high net-baryon densities.

What about models?

Non-trivial $\sqrt{s}$ dependence of strange baryons

Strangeness results submitted for publication soon

Ω± (!)
MSH measurements and models

- STAR BES data by Helen Caines
  EMMI Workshop
  GSI February 2019
- Thermal model by A. Andronic
  32 CBM week
- PHSD by P. Moreau
  SQM 2015

- Very reasonable agreement by both models
- More strangeness needed (PHSD)
QGP and Chiral symmetry restoration

“Chiral symmetry restoration versus deconfinement in heavy-ion collisions at high baryon density”
W. Cassing, A. Palmese, P. Moreau, and E. L. Bratkovskaya

Chiral symmetry restoration (CSR) change the flavor decomposition – more s-sbar pairs produced.

Droplets of QGP allow to interact s-sbar quarks and create more multi-strange (anti)-baryons.

- Presence of QGP significantly increase yield of $\Omega^+$ at FAIR energy
- CSR effect increase yield of $\Omega^-$ and $\Omega^+$ at FAIR energy
Performance of the CBM track finder

• For studies several theoretical models like UrQMD and PHSD are used.
• Track finder is based on the Cellular Automaton method.
• High efficiency for track reconstruction of more then 92%, including fast (more then 90%) and slow (more then 65%) secondary tracks.
• Time-based track finder is developed, efficiency is stable with respect to the interaction rate.
• Low level of split and wrongly reconstructed (ghost) tracks.

minimum bias : 6ms/core track finder, 1 ms/core particle finder

Simulation

Reconstruction

Hyperons selection

AuAu 10AGeV/c
165 π
170 p
26 K
15 Λ
20 K°
0.3 Ξ-

2 models
High rate scenario: event reconstruction with 4D tracking

100 kHz

1 MHz

10 μs window

10 MHz

<table>
<thead>
<tr>
<th>Detectors</th>
<th>Events</th>
<th>Integral</th>
</tr>
</thead>
<tbody>
<tr>
<td>HitTime_0.1MHz</td>
<td>260232</td>
<td>3471</td>
</tr>
<tr>
<td>HitTime_1MHz</td>
<td>260064</td>
<td>1.167e+04</td>
</tr>
<tr>
<td>HitTime_10MHz</td>
<td>259823</td>
<td>1.145e+05</td>
</tr>
</tbody>
</table>
# 4D Track Finder in CBMROOT

100 AuAu 10 AGeV mbias events

<table>
<thead>
<tr>
<th>Efficiency, %</th>
<th>3D</th>
<th>0.1 MHz</th>
<th>1 MHz</th>
<th>10 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>All tracks</td>
<td>92.5 %</td>
<td>93.8 %</td>
<td>93.5 %</td>
<td>91.7 %</td>
</tr>
<tr>
<td>Primary high-p</td>
<td>98.3 %</td>
<td>98.1 %</td>
<td>97.9 %</td>
<td>96.2 %</td>
</tr>
<tr>
<td>Primary low-p</td>
<td>93.9 %</td>
<td>95.4 %</td>
<td>95.5 %</td>
<td>94.3 %</td>
</tr>
<tr>
<td>Secondary high-p</td>
<td><strong>90.8 %</strong></td>
<td><strong>94.6 %</strong></td>
<td><strong>93.5 %</strong></td>
<td><strong>90.2 %</strong></td>
</tr>
<tr>
<td>Secondary low-p</td>
<td>62.2 %</td>
<td>68.5 %</td>
<td>67.6 %</td>
<td>64.3 %</td>
</tr>
<tr>
<td>Clone level</td>
<td>0.6 %</td>
<td>0.6 %</td>
<td>0.6 %</td>
<td>0.6 %</td>
</tr>
<tr>
<td>Ghost level</td>
<td>1.8 %</td>
<td>0.6 %</td>
<td>0.6 %</td>
<td>0.6 %</td>
</tr>
<tr>
<td>True hits per track</td>
<td>92%</td>
<td>93 %</td>
<td>93 %</td>
<td>93 %</td>
</tr>
<tr>
<td>Hits per MC track</td>
<td>7.0</td>
<td>7.0</td>
<td>6.97</td>
<td>6.70</td>
</tr>
</tbody>
</table>
Particle identification with PID detectors

PID detectors:
- ToF (Time of Flight) — hadron identification;
- RICH (Ring Imaging CHerenkov detector) — electron identification;
- TRD (Transition Radiation detector) — electron and heavy fragments identification.

PID detectors of CBM will allow a clear identification of charged tracks.
• More than 150 decays. All decays are reconstructed in one go.

• Based on the Kalman filter method - mathematically correct parameters and their errors.

• KF Particle Finder is successfully tested in STAR and allows to reconstruct up to 2 times more signal.

• STAR developments are fully merged with the KF Particle Finder repository.
Multi Strange particle reconstruction performance

5M central AuAu collisions 10AGeV/c

- CBM will allow clean reconstruction of rare strange probes with high efficiency and high statistics.
- Tools for the multi-differential physics analysis are prepared.
Multi strange hyperons reconstruction with missing mass method

- Comparable efficiencies, better control over the systematic errors
- $\Sigma^+$ and $\Sigma^-$ physics: completes the picture of strangeness production

$\Sigma^-$ reconstruction with missing mass method

$\Sigma^+ \rightarrow n\pi^+$

$\Sigma^-$ reconstruction with missing mass method

$\Sigma^+ \rightarrow n\pi^+$

$\Sigma^-$ reconstruction with missing mass method

$\Sigma^+ \rightarrow n\pi^+$

Entries

$m_{\text{inv}} \Lambda \pi^-[\text{GeV/c}^2]$

$M=1321.4\ \text{MeV/c}^2$, $\varepsilon_d=8.3\%$

$\sigma=2.0\ \text{MeV/c}^2$, $S/B=7.35$

$m_{\text{inv}} \Lambda \pi^-[\text{GeV/c}^2]$

$M=1321.2\ \text{MeV/c}^2$, $\varepsilon_d=6.5\%$

$\sigma=3.2\ \text{MeV/c}^2$, $S/B=2.22$

$\Sigma^- \rightarrow n\pi^-$

$S/B = 16.5$

$\Sigma^+ \rightarrow n\pi^+$

$S/B = 3.06$

5M central AuAu collisions 10AGeV/c
CBM KF Particle Finder test @ STAR 4.4M Au+Au events $\sqrt{s} = 7.7$

- CBM KF Particle Finder is successfully applied to the STAR data in a wide energy range.
- STAR data are excellent platform to test and improve our reconstruction software.

all centralities, no cuts on rapidity
Testing CBM algorithms online: STAR express analysis

- The standard calibration, production and analysis remain unchanged.
- Start the calibration procedure as soon as data become available.
- Make possible physics analysis of the data as soon as the calibration is reasonable.
- Unify approaches in extended (x)HLT and online (o)RCF to speed up the express workflow.
- Combine high competence of xHLT and oRCF experts involved in online operation.
- Provide PWGs with instant and uncomplicated access to the data, like picoDST etc.

2020, 2021

- $t_{\text{HLT}} = t_{\text{DAQ}} + 1s$
- $t_{\text{Cal}} = t_{\text{DAQ}} + 1W$
- $t_{\text{Prod}} = t_{\text{Cal}} + 1W$
- $t_{\text{Phys}} = t_{\text{Prod}}$
- $t_{\text{Cal}} = t_{\text{Run}} + 1m$
- $t_{\text{Prod}} = t_{\text{Cal}} + 6m$
- $t_{\text{Phys}} = t_{\text{Prod}} + 6m$

$T_{\text{BES-II}} = 2021 + 6m + 1m + 6m + 6m + 6m = 1+2y = 2021+2022$

$T_{\text{BES-II}} = 2021 + 6m + 2m + 1y + 1y = 2+3y = 2023+2024$

Maksym Zyzak, 33rd CBM Collaboration Meeting, Darmstadt
Hypernuclei production in A+A collisions

5M mBias events Au+Au at 10AGeV/c
50 sec at 0.1MHz IR (1.8 k/sec)

Expected collection rate: ~60 $^6\Lambda\Lambda$He in 1 week at 10MHz IR (not day-1)

- According to the current theoretical predictions CBM will be able to perform comprehensive study of hypernuclei, including:
  - precise measurements of lifetime;
  - excitation functions;
  - flow.
- It has a huge potential to register and investigate double $\Lambda$ hypernuclei.
# Day-1: Expected particle yields

**Au+Au @ 6, 10 AGeV**

<table>
<thead>
<tr>
<th>Particle (mass MeV/c^2)</th>
<th>Multiplicity central ev. 6 AGeV</th>
<th>Multiplicity central ev. 10 AGeV</th>
<th>decay mode</th>
<th>BR</th>
<th>ε (%)</th>
<th>yield in 90 days 6AGeV</th>
<th>yield in 90 days 10 AGeV</th>
<th>IR MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{\Lambda} ) (1115)</td>
<td>5.1 \cdot 10^{-3}</td>
<td>0.041</td>
<td>( \bar{\rho}\pi^+ )</td>
<td>0.64</td>
<td>19.7</td>
<td>1.2 \cdot 10^8</td>
<td>1.0 \cdot 10^9</td>
<td>0.1</td>
</tr>
<tr>
<td>( \Xi^- ) (1321)</td>
<td>0.11</td>
<td>0.36</td>
<td>( \Lambda\pi^- )</td>
<td>1</td>
<td>9.9</td>
<td>2.0 \cdot 10^9</td>
<td>7.0 \cdot 10^9</td>
<td>0.1</td>
</tr>
<tr>
<td>( \Xi^+ ) (1321)</td>
<td>1.8 \cdot 10^{-3}</td>
<td>1.5 \cdot 10^{-2}</td>
<td>( \bar{\Lambda}\pi^+ )</td>
<td>1</td>
<td>8.7</td>
<td>3.0 \cdot 10^7</td>
<td>2.5 \cdot 10^8</td>
<td>0.1</td>
</tr>
<tr>
<td>( \Omega^- ) (1672)</td>
<td>6.8 \cdot 10^{-4}</td>
<td>4.4 \cdot 10^{-3}</td>
<td>( \Lambda K^- )</td>
<td>0.68</td>
<td>4.4</td>
<td>4.0 \cdot 10^6</td>
<td>2.6 \cdot 10^7</td>
<td>0.1</td>
</tr>
<tr>
<td>( \Omega^+ ) (1672)</td>
<td>1.4 \cdot 10^{-5}</td>
<td>2.6 \cdot 10^{-3}</td>
<td>( \Lambda K^+ )</td>
<td>0.68</td>
<td>3.9</td>
<td>7.0 \cdot 10^4 (0 w/o QGP?)</td>
<td>1.4 \cdot 10^7</td>
<td>0.1</td>
</tr>
<tr>
<td>( ^3_\Lambda H ) (2993)</td>
<td>4.2 \cdot 10^{-2}</td>
<td>3.8 \cdot 10^{-2}</td>
<td>( ^3 H\pi )</td>
<td>0.25</td>
<td>12.7</td>
<td>2.7 \cdot 10^8</td>
<td>2.5 \cdot 10^8</td>
<td>0.1</td>
</tr>
<tr>
<td>( ^4_\Lambda He ) (3930)</td>
<td>2.4 \cdot 10^{-3}</td>
<td>1.9 \cdot 10^{-3}</td>
<td>( ^3 He\pi )</td>
<td>0.32</td>
<td>11.4</td>
<td>1.7 \cdot 10^7</td>
<td>1.4 \cdot 10^7</td>
<td>0.1</td>
</tr>
<tr>
<td>( ^5_\Lambda\Lambda He ) (5047)</td>
<td>5.0 \cdot 10^{-6}</td>
<td>( ^3 He2p2\pi )</td>
<td>0.01</td>
<td>3</td>
<td>15</td>
<td>250</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>( ^6_\Lambda\Lambda He ) (5986)</td>
<td>1.0 \cdot 10^{-7}</td>
<td>( ^4 He2p2\pi )</td>
<td>0.01</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td>0.1</td>
</tr>
</tbody>
</table>
Summary

• CBM detector is an excellent device to measure not only bulk observables, but strangeness, hypernuclei and other rare probes with high statistic.

• The CBM experiment will provide multidifferential high precision measurements of strange hadrons including multi-strange (anti)-hyperons.

• High precision measurements of excitation functions of multi-strange hyperons in A+A collision with different mass numbers A at SIS100 energies have a discovery potential to find a signal for the onset of deconfinement in QCD matter at high net-baryon densities.

• The discovery of (double-) Λ hypernuclei and the determination of their lifetimes will provide information on the hyperon-nucleon and hyperon-hyperon interactions, which are essential ingredients for the understanding of the nuclear matter EoS at high densities, and, hence, of the structure of neutron stars.