The Compressed Baryonic Matter experiment at FAIR
Experimental program and status

Christian Pauly, BU Wuppertal
for the CBM collaboration
Research communities from more than 50 countries covering many different aspects of physics:

- Hadron spectroscopy with anti-protons (PANDA)
- Rare Isotope beams
- Plasma Physics
- **Heavy-Ion Physics with the CBM experiment and HADES**

Using beams from two parallel synchrotrons:

**SIS100: (starting 2018)**
- 2-29 GeV (protons)
- 2-11 A GeV (Au)

**SIS300: (few years later)**
- 2-89 GeV (protons)
- 2-35 A GeV (Au)
Exploring the QCD phase diagram in region of high net baryon density

Probing the QCD diagram at very high $T$ and $\rho_B \approx 0$ (early universe):
- ALICE, ATLAS, CMS at LHC
- STAR, PHENIX at top RHIC energies,

Probing the QCD phase diagram at moderate $T$ and (very) high $\rho_B$:
- Beam energy scan at RHIC, NA61 at CERN SPS (but limited statistics, observables)
- CBM at FAIR, MPD at NICA

Density $\rho \geq 6\rho_0$
$\rho_0$ nucl. matter density

Courtesy of K. Fukushima & T. Hatsuda
How to produce dense matter in the lab?

At FAIR / CBM: **Au+Au** collisions at medium energies, fixed target
- SIS 100: Ekin 2.0 – 11 AGeV, $\sqrt{s_{NN}} = 2.7 – 4.7$ GeV
- SIS 300: Ekin 2.0 – 35 AGeV, $\sqrt{s_{NN}} = 2.7 – 8.3$ GeV

contrary to “high T” physics at LHC: Pb+Pb collisions at highest energy

**density** as function of time according to transport calculations

**density** and **temperature at freezeout** for different beam conditions

Maximum freezeout density reached at 30 AGeV, well within SIS300 range

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**Hadron String dynamics**
W. Ehehalt, W. Cassing
How to probe dense matter?

- need penetrating probes sensitive to the early, high-density phase of fire ball evolution!
- CBM: di-lepton decays of light vector mesons and charm
  - **light vector mesons**
    \[ \rho, \omega, \Phi \rightarrow e^+ e^- / \mu^+ \mu^- \]
  - **Charmonium**
    \[ J/\Psi, \Psi' \rightarrow e^+ e^- / \mu^+ \mu^- \]
  - **open charm**
    \[ D^+, D^0 \rightarrow K + \pi \]
    \[ K + \pi \pi \]
    \[ K + \pi \pi \pi \]
- measure both **di-electron and di-muon** channels
  - same physics, but different detection methods
  - good control over systematic errors
- **Rare probes!**
  - high luminosity
  - reaction rate up to 10MHz (J/Psi)
  - good particle ID (pion suppression better $10^{-4}$)
Dileptons as probe of high density phase

- CERES data at 40 AGeV and 158 AGeV: excess higher at lower energy → connection to baryon density
- HADES: excess in C+C can be understood from elementary processes (pn-> pny, Bremsstrahlung, Δ decay, ...)
  **but:** additional excess in more dense system Ar+KCl (1.76 AGeV) in-medium effects ???

No data between 2 and 40 AGeV beam energy!
**charmonium (J/Ψ, c̅c) production**

- J/Ψ produced in hard collisions at initial stage of collision → probing dense medium on higher energy scale
- If the medium is partonic (and not hadronic):
  - formation suppressed due to Debye screening
  - increased formation of open charm (D mesons)
  - ratio: charmonium / open charm
- But: J/Ψ can also be absorbed in cold nuclear matter!

Need for **precise multi-differential data**, both p-N and N-N to disentangle absorption in nuclear matter from dissociation in partonic matter (QGP)

Predictions for J/Ψ over D,D ratio, two different models: quark like or (pre) hadron like medium

- **HSD:** O. Linnyk et al., Int. J. Mod. Phys. E17, 1367 (2008)

Debye color screening

Measured cc cross section overview no data at FAIR energy range
Multi strange hyperon production

- **direct production:**
  \[ pp \rightarrow \Xi^- K^+ K^0 p \quad E_{\text{thr}} = 3.7 \text{ GeV} \]
  \[ pp \rightarrow \Omega^- K^+ K^0 p \quad E_{\text{thr}} = 7.0 \text{ GeV} \]

- **Multistep, sub-threshold production**
  in nuclear collisions via strangeness exchange:
  \[ pp \rightarrow \pi^- K^+ \Lambda \quad E_{\text{thr}} = 1.6 \text{ GeV} \]
  \[ pp \rightarrow p p K^+ K^- \quad E_{\text{thr}} = 2.5 \text{ GeV} \]

  followed by:
  \[ \Lambda \Lambda \rightarrow \Xi^- \pi \quad \Lambda \Xi^- \rightarrow \Omega^- n \quad \text{or} \]
  \[ \Lambda K^- \rightarrow \Xi^- \pi^0 \quad \Xi^- K^- \rightarrow \Omega^- \pi \]
  
  or even **three-body collisions involving \( \Lambda \) and \( K \)**

- Production cross section depends on density
  \( \rightarrow \) enhanced production in dense medium

- systematic study of \( \Xi^- \) and \( \Omega^- \) production
  as function of beam energy and size of nuclei:
  \( \rightarrow \) study the nuclear matter equation of state, EoS

Available data in SIS100 range very scarce,
no data on \( \Omega^- \) production below 40 AGeV
• Particle yields as measured with HADES
  • Ar+KCl, 1.76 A GeV, $\sqrt{s_{NN}} = 2.61$ GeV

• Comparison with thermal fit: THERMUS

• $\Xi^-$ yield off by factor 25 !!!

• Can not be described by Statistical Hadronization Model, SHM
Summary: Observables to be studied with CBM

- **Particles containing charm quarks** (D mesons, charmonium: J/Psi)
  - Access to early, dense phase of collisions

- **Low-mass vector mesons** decaying into dilepton pairs ($\rho, \omega, \phi$)
  - Hadron properties within dense phase of fireball evolution

- **Collective flow of identified hadrons**
  - Obtain information on the equation-of-state, EoS of dense matter

- **Kaons, hyperons and hadronic resonances**
  - Strangeness is sensitive probe for fireball evolution

- **Hyper-Nuclei, exotic particles**
  - Strange dimension of chart of nuclei,
  - hyperon-nucleon and hyperon-hyperon interaction

- **Dynamical fluctuations of particle multiplicities, momenta**
  - Indication for first order phase transition, search for critical point

- **Photons**
  - Direct radiation from the early fireball

- **Two-particle correlations, hadronic femtoscopy**
  - Determine source size, space-time characteristics of source

these (and more) observables can be studied with CBM providing unprecedented statistics
Experimental challenge (i)

Particle multiplicity x Branching ratio
for min bias Au+Au collisions at 25 A GeV (from HSD and thermal model)

SPS, Pb+Pb @ 30 A GeV
RHIC, Au+Au \( \sqrt{S_{NN}} = 7.7 \) GeV

Not yet measured
At maximum density in heavy ion collisions

Driving CBM experimental requirements
The CBM detector setup

Electron setup
RICH and TRD for electron-ID
pion suppression >10^4

Muon setup
instrumented iron absorber

- Exceptional high rate capability (up to 10 MHz for J/Ψ)
- Hadron- and lepton reconstruction/ID with large acceptance
- Displaced vertex reconstruction (open charm, strangeness)
- Fully self-triggered readout, no hardware triggering
- Online event reconstruction and selection
- Excellent fast tracking inside 1Tm superconducting magnet
**STS+MVD – the heart of CBM**

**STS: Silicon Tracking Station**
- Double-sided silicon strip sensors
- Track reconstruction for momenta >0.1 GeV
- Momentum resolution: $\Delta p/p \sim 1\%$ (p=1 GeV)
- ~100 individual “ladders”, ~1200 indiv. detectors
- > 2mio channels (!)

**MVD: Micro Vertex Detector**
- Monolithic Active Pixel Sensors, MAPS
- 5 / 60 μm primary/secondary vertex resolution
  (→ open charm, hyperon reconstruction)

STT thermal enclosure (-5°C) inside CBM magnet

Detector layers:
Low-weight carbon structures

Sensor development:
Double-sided microstrips
60 μm pitch, 300 μm thick

QGHXM13, St Goar, 21.03´13
### Experiments studying dense baryonic matter

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Energy range (Au/Pb beams)</th>
<th>Reaction rates Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAR, PHENIX@RHIC BNL</td>
<td>$\sqrt{s_{\text{NN}}} = 7 - 200 \text{ GeV}$</td>
<td>$1 - 800$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(limitation by luminosity)</td>
</tr>
<tr>
<td>NA61@SPS CERN</td>
<td>$E_{\text{kin}} = 20 - 160 \text{ A GeV}$</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s_{\text{NN}}} = 6.4 - 17.4 \text{ GeV}$</td>
<td>(limitation by detector)</td>
</tr>
<tr>
<td>MPD@NICA Dubna</td>
<td>$\sqrt{s_{\text{NN}}} = 4.0 - 11.0 \text{ GeV}$</td>
<td>$\sim 1000$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(design luminosity of $10^{27} \text{ cm}^{-2}\text{s}^{-1}$ for heavy ions)</td>
</tr>
<tr>
<td>HADES@SIS100 Darmstadt</td>
<td>$E_{\text{kin}} = 1.5 \text{ AGeV Au+Au}$</td>
<td>$5 \times 10^4$</td>
</tr>
<tr>
<td></td>
<td>$E_{\text{kin}} = 8 \text{ AGeV Ni + Ni}$</td>
<td>(limitation by detector and DAQ)</td>
</tr>
<tr>
<td>CBM@FAIR Darmstadt</td>
<td>$E_{\text{kin}} = 2.0 - 35 \text{ A GeV}$</td>
<td>$10^5 - 10^7$</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{s_{\text{NN}}} = 2.7 - 8.3 \text{ GeV}$</td>
<td>(limitation by detector)</td>
</tr>
</tbody>
</table>
CBM online event reconstruction, running scenarios

- Key to achieve interaction rates up to 10 MHz:
  very effective event selection (up to factor 1000)
  using **fast online full event reconstruction**
  no hardware triggers

- All data transferred to computer cluster (up to 1TB/sec)
  - fast reconstruction algorithms
  - parallel processing on ~60k cores, GPU processing

- Different running scenarios depending on physics measurements
  - maximum rates / data reduction not possible for all channels
  - rate limit of vertex pixel detector (→ displaced vertices, hyperons)

<table>
<thead>
<tr>
<th>Untriggered</th>
<th>Medium rate</th>
<th>Maximum rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^4$ ev/sec</td>
<td>$10^5$-$10^6$ ev/sec</td>
<td>$10^7$ ev/sec</td>
</tr>
<tr>
<td>1 GB/sec raw data</td>
<td>&lt;100 GB/sec raw data</td>
<td>1 TB/sec raw data,</td>
</tr>
<tr>
<td>1GB/sec to disk</td>
<td>1GB/sec to disk</td>
<td>1GB/sec to disk</td>
</tr>
<tr>
<td>No online event selection possible</td>
<td>online data reduction: 10-100</td>
<td>online data reduction: <strong>1000</strong></td>
</tr>
<tr>
<td>- Pions, kaon, proton, hyperon yields spectra and flow</td>
<td>- low-mass di-muons</td>
<td>- charmonium $(e^+ e^-, \mu^+ \mu^-)$</td>
</tr>
<tr>
<td>- low-mass dileptons</td>
<td>- open charm (limited by vertex det)</td>
<td></td>
</tr>
</tbody>
</table>
CBM performance (i): Charm / charmonium

- All performance simulations:
  - realistic detector geometry
  - event generator: UrQMD (+PLUTO)
  - GEANT3

- J/Ψ will be running at maximum event rate:
  - 10 MHz minimum bias event rate

- Open charm at reduced rate:
  - 100 kHz – 1MHz
  - limited by Micro Vertex Detector MVD
  - reconstruction of displaced vertices

Au+Au 25 AGeV (SIS300)

\( J/\psi \rightarrow e^+e^- \quad 4 \cdot 10^{10} \) events

\( D^0 \rightarrow K \pi \pi \pi \)

\( D^0 \quad S/B = 0.5(0.16) \quad \text{eff} = 3.95\% \)

\( 10^{10} \text{ centr} \)

\( D^0 \)

\( 1500 \)

\( 1000 \)

\( 500 \)

\( 1.5 \)

\( 2 \)

\( m_{\text{inv}} \text{ (GeV/c}^2) \)

\( D^\pm \rightarrow K \pi \pi \pi \)

\( 125D^+ \quad S/B = 2.5(1.24) \quad \text{eff} = 4.75\% \)

\( 63D^+ \)

\( 60 \)

\( 40 \)

\( 20 \)

\( 1.5 \)

\( 2 \)

\( 2.5 \)

\( m_{\text{inv}} \text{ (GeV/c}^2) \)
CBM performance (ii): di-electron decays of vector mesons

@SIS100: 8 AGeV
Using STS, RICH and TOF

@SIS300: 25 AGeV
Using STS, RICH, TRD and TOF

<table>
<thead>
<tr>
<th></th>
<th>(\rho)</th>
<th>(\omega)</th>
<th>(\phi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>eff. [%]</td>
<td>3.12</td>
<td>4.11</td>
<td>4.89</td>
</tr>
<tr>
<td>S/BG</td>
<td>-</td>
<td>0.64</td>
<td>0.04</td>
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<tr>
<th></th>
<th>(\rho)</th>
<th>(\omega)</th>
<th>(\phi)</th>
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<tbody>
<tr>
<td>eff. [%]</td>
<td>4.39</td>
<td>5.53</td>
<td>7.08</td>
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<tr>
<td>S/BG</td>
<td>-</td>
<td>0.31</td>
<td>0.11</td>
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</table>
CBM performance (iii): (multi strange) hyperon production

Hyperon yields in 10s CBM run at maximum interaction rate 10 MHz

1M central events

Au+Au 25 A GeV (SIS300)
Detector development and design

- CBM detector design in advanced stage
- Technical design reports for several detector systems submitted
- Real size prototype systems of all major components
- Tested in test beams at CERN PS, CERN SPS, COSY and GSI

**Silicon Pixel sensors MAPS**

for Micro Vertex detector beamtest at CERN SPS, 2012

**Combined RICH, TRD and RPC beam test**

CERN PS, 2011 and 2012

**Silicon strip sensor stations for STS beam test at COSY, FZ-Jülich**

2011 and 2012
some results from RICH beam tests

- typical single event rings
- event-integrated ring image and hit multiplicity
- ring radius as function of momentum
- ring radii for momentum $p=8$ GeV/c

- very clean single event rings
- in average $\sim 20$ photons/ring (electrons)
  in agreement with Monte Carlo
- nearly no uncorrelated background noise $\sim 10$ Hz / channel

- ring radii for electrons and pions
  corresponding to Monte Carlo expectation

- $\mu^-$ separation at $p=8$ GeV/c

QGHXM13, St Goar, 21.03.13
The CBM collaboration

56 institutions, 450 members
**summary and outlook**

- **CBM@FAIR:**
  - explore the QCD phase diagram of nuclear matter
  - at high net baryon density
  - using in particular rare, penetrating probes (dileptons, charm, …)
  - starting at SIS100, later continued at SIS300

- **CBM detector design in very advanced stage**
  - Detailed simulations proof feasibility of physics program
  - prototype detector performances fulfill CBM requirements
  - first TDRs submitted for external review

- **Substantial part of CBM startversion for SIS100 in financed**

- **ordering of first components (eg PMTs for RICH) will start 2014**

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<td>Construction</td>
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<td>Installation</td>
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<td>Commissioning</td>
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<tr>
<td>Expts. at SIS100</td>
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<td>Expts. at SIS300</td>
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The diagram shows the timeline of construction, installation, and commissioning for different phases. The timeline includes:
- **Cave ready**
- **SIS100 ready**
Backup slides
**Expected particle yields:**

*hyperons and hypernuclei*

Strange baryon yields measured per week for $2\cdot10^4$ s min. bias Au+Au collisions. $M\text{(min. bias)} \approx 0.25 \ M\text{(central)}$

Efficiency is 15% for anti-$\Lambda$ and 3% for the multi-strange hyperons.

<table>
<thead>
<tr>
<th>Beam energy A GeV</th>
<th>$\Xi^-$</th>
<th>$\Omega^-$</th>
<th>anti-$\Lambda$</th>
<th>$\Xi^+$</th>
<th>$\Omega^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>$9.10^6$</td>
<td>$1.8.10^5$</td>
<td>$3.6.10^3$</td>
<td>$5.2.10^3$</td>
<td>$9.0.10^2$</td>
</tr>
<tr>
<td>6.0</td>
<td>$2.6.10^7$</td>
<td>$5.0.10^5$</td>
<td>$2.4.10^5$</td>
<td>$1.4.10^4$</td>
<td>$2.8.10^3$</td>
</tr>
<tr>
<td>8.0</td>
<td>$4.0.10^7$</td>
<td>$1.4.10^6$</td>
<td>$3.6.10^6$</td>
<td>$2.10^5$</td>
<td>$6.0.10^4$</td>
</tr>
<tr>
<td>10.7</td>
<td>$5.4.10^8$</td>
<td>$2.2.10^6$</td>
<td>$6.8.10^6$</td>
<td>$3.8.10^5$</td>
<td>$1.2.10^5$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hyper nuclei</th>
<th>$M$ central</th>
<th>BR</th>
<th>$\varepsilon$ %</th>
<th>Yield/s central</th>
<th>Yield/week central</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda^3\text{H}$</td>
<td>$2.10^{-2}$</td>
<td>0.6</td>
<td>7</td>
<td>7.6</td>
<td>$4.6.10^6$</td>
</tr>
<tr>
<td>$\Lambda^5\text{H}$</td>
<td>$6.10^{-6}$</td>
<td>0.36</td>
<td>1</td>
<td>$2.2.10^{-4}$</td>
<td>130</td>
</tr>
<tr>
<td>$\Lambda^6\text{He}$</td>
<td>$1.10^{-7}$</td>
<td>0.36</td>
<td>1</td>
<td>$1.10^{-6}$</td>
<td>2</td>
</tr>
</tbody>
</table>

Central collision rate 10 kHz

BR = 36% for double lambda hypernuclei is a guess
### Expected particle yields:

*open charm, charmonium*$→*$μ^+μ^−$

<table>
<thead>
<tr>
<th>Particle</th>
<th>Multiplicity central</th>
<th>Multiplicity Min. bias</th>
<th>BR [%]</th>
<th>ε [%]</th>
<th>Yield/week Min bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^+$</td>
<td>$2.7 \cdot 10^{-8}$</td>
<td>$9.0 \cdot 10^{-9}$</td>
<td>9.5</td>
<td>13</td>
<td>97</td>
</tr>
<tr>
<td>$D^−$</td>
<td>$5.5 \cdot 10^{-8}$</td>
<td>$1.8 \cdot 10^{-8}$</td>
<td>9.5</td>
<td>13</td>
<td>206</td>
</tr>
<tr>
<td>$D^0$</td>
<td>$2.9 \cdot 10^{-8}$</td>
<td>$9.7 \cdot 10^{-9}$</td>
<td>8.1</td>
<td>1.7</td>
<td>12</td>
</tr>
<tr>
<td>Anti-$D^0$</td>
<td>$8.8 \cdot 10^{-8}$</td>
<td>$3.10^{-8}$</td>
<td>8.1</td>
<td>1.7</td>
<td>37</td>
</tr>
</tbody>
</table>

$M($min. bias$) \approx 1/3 \ M($central$)$

Min. bias reaction rate 1.5 MHz, pile up of 50 central events in the MVD.

<table>
<thead>
<tr>
<th>Collision system</th>
<th>Energy</th>
<th>Multiplicity Central*</th>
<th>Multiplicity Min. bias</th>
<th>ε [%]</th>
<th>Yield/week Min bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>p+C</td>
<td>30 GeV</td>
<td>$5.0 \cdot 10^{-8}$</td>
<td>$1.7 \cdot 10^{-8}$</td>
<td>13</td>
<td>700</td>
</tr>
<tr>
<td>p+Au</td>
<td>30 GeV</td>
<td>$1.2 \cdot 10^{-7}$</td>
<td>$4.0 \cdot 10^{-8}$</td>
<td>13</td>
<td>1800</td>
</tr>
<tr>
<td>Au+Au</td>
<td>10 A</td>
<td>$1.7 \cdot 10^{-7}$</td>
<td>$3.4 \cdot 10^{-8}$</td>
<td>3.3</td>
<td>400</td>
</tr>
</tbody>
</table>

* GeV

* taken from HSD. Min.bias $\approx 1/3$ central for p+A, and 0.2 for A+A
relevance: dense nuclear matter in neutron stars

- How is the inner core of a neutron star composed? Strange matter? Hyperons? Quark matter? → many different models

- What is the Equation-of-State (EOS) of such dense matter?

- Recent mass determination of massive neutron star challenging models
  PSR J1614-2230 with mass \( \sim 1.97 \pm 0.04 \, M_{\odot} \)

Non-local SU(3) NJL with vector coupling
Experimental challenge (ii)

Simulated central Au+Au collision, 25 A GeV, UrQMD+GEANT4
160 p, 400 π⁺, 400 π⁺, 44 K⁺, 13 K⁻
search for double hyper nuclei

- **Hypernuclei**: Nuclei containing one or more hyperons in addition to nucleons
  example: $^5\Lambda\Lambda H$, $^6\Lambda\Lambda He$

- explore third, strange dimension of the chart of nuclei
- information on hyperon-nucleon and hyperon-hyperon interaction, → important role for neutron star models

- So far:
  produced using K- beams bombarding light nuclei:
  strangeness-exchange: s-quark transferred to nucleon forming a $\Lambda$ trapped in nucleus
  Kaon+Nucleus → Pion+Hypernucleus

- only few double hyper-nuclei found so far
- mostly in emulsions
  (displaced decay vertices on 10mu scale ! )

(double) hyper-nuclei production with CBM:

- alternative approach CBM:

  production of (double) hyper-nuclei in heavy ion collisions via coalescence of $\Lambda$ with nucleons or light nuclei

- $\Lambda$ produced abundantly, 
  ~50 per (Pb+Pb) collision above 40 AGeV, 
  still 4 $\Lambda$ per (Au+Au) collision at 4 AGeV

- yield of light nuclei increases rapidly with decreasing beam energy!

- coalescence probability should have maximum at 7 – 11 AGeV: SIS100 energy! (according to statistical model)

- reconstruction and tagging via decay chain:
  $^5_{\Lambda\Lambda}$H $\rightarrow$ $^5_{\Lambda}$He + $\pi^-$
  $^5_{\Lambda}$He $\rightarrow$ $^4$He + p + $\pi^-$

Strangeness production

- Excitation function of yields, spectra and collective flow of strange particles as indication for phase transition
- Non-monotonic behaviour of $K^+ / \pi^+$ ratio
- Strangeness production changes at $\sim 30$ AGeV
**Dileptons with CBM: performance**

@SIS100: 8 AgeV

@SIS300: 25 AgeV

<table>
<thead>
<tr>
<th></th>
<th>ρ</th>
<th>ω</th>
<th>φ</th>
</tr>
</thead>
<tbody>
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<td>eff. [%]</td>
<td>3.12</td>
<td>4.11</td>
<td>4.89</td>
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<tr>
<td>S/BG</td>
<td>-</td>
<td>0.64</td>
<td>0.04</td>
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<th>ρ</th>
<th>ω</th>
<th>φ</th>
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<td>eff. [%]</td>
<td>4.39</td>
<td>5.53</td>
<td>7.08</td>
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<tr>
<td>S/BG</td>
<td>-</td>
<td>0.31</td>
<td>0.11</td>
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</table>
Current status of measurements

- RHIC Brookhaven
  $\sqrt{s} = 130 - 200$ GeV/Nukleon
  additional data from LHC

- SPS CERN
  20-160 GeV/Nukleon

- AGS Brookhaven
  2-10 GeV/Nukleon

- SIS18 GSI
  <2 GeV/Nukleon

“freezeout points” determined for different conditions

Possible critical point
Different steps of a heavy ion collision

Before the collision
two Lorenz-contracted nuclei approaching

Moment of collision:
compression and heating, $T \gg T_{\text{chem}} \sim 160 \text{ MeV}$

Thermalization of the “fireball”
(high $T$ and $\rho$ reached for $\sim 10 \text{ fm/c} = 3.3 \times 10^{-23} \text{ s}$)

Expansion of fireball, cool-down

Chemical freezeout (number and type of particles frozen)
kinematical freezeout (particle spectra frozen)

$T_{\text{chem}} \sim 160 \text{ MeV, } \sim 2 \times 10^{12} \text{ K}$
The Muon Detection System

Requirements:
- Muon reconstruction and identification
- High particle- and dose rates
- 

Realisation
- “instrumented” iron absorber
- Front 3 gaps, small area: “Gas electron Multiplier”, GEM-detectors
- Backward 2 gaps: Strawtube layers

Extensive prototype testing at COSY/Jülich