Dimuon Measurement in CBM Experiment at FAIR

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VECC, Kolkata
Outline

• Dilepton measurements
• CBM experiment at FAIR
• Schematic of dimuon measurements in different expt.
• Muon Chamber (MUCH) system of CBM
  -- Simulation results
  -- Detailed R&D
• Summary
The Compressed Baryonic Matter Experiment (CBM)@FAIR

- Fixed target heavy ion expt.
- Energy range 2-45 GeV/u
- Expected to begin 2021

**CBM physics program:**
- Equation-of-state at high \( \rho_B \)
- Deconfinement phase transition
- QCD critical endpoint
- Chiral symmetry restoration

**Diagnostic probes of the high-density phase:**
- open charm, charmonia
- low-mass vector mesons
- multistrange hyperons
- flow, fluctuations, correlations

**Exploring the QCD Phase Diagram**

- Early universe
- Critical point?
- Deconfinement and chiral transition
- FAIR SIS 300
- Neutron stars
- Color Superconductor?

**Rare Probes**
- high interaction rates
- selective triggers
The Dileptons

- Dilepton pairs emitted in energetic heavy-ion collisions provide valuable information on the evolution and on the properties of the hot and dense fireball.

- Comparison of charmonium yields measured in proton-nucleus and nucleus-nucleus collisions has led to the observation of an anomalous dissociation of charmonium in central collisions of heavy nuclei which was explained by color screening in the quark-gluon phase.

- Till today, this observation still has remained one of the most convincing experimental facts hinting towards the existence of partonic degrees of freedom in the fireball at top SPS energies.

- The dilepton measurements at the CERN-SPS have been performed mainly at 158 A GeV, except for one spectrum taken in Pb+ Au at 40 A GeV by the CERES collaboration where even an increased excess yield has been observed.
Anomalous suppression

Using the previously defined reference:

Central Pb-Pb: → still anomalously suppressed

In-In: almost no anomalous suppression

B. Alessandro et al., EPJC39 (2005) 335
• A systematic beam energy scan in order to search for the onset of in-medium mass modifications of vector mesons or for partonic contributions to the dilepton yield has not been performed yet.

• With the dilepton measurements in heavy-ion collisions at FAIR energies the CBM collaboration will open a new era of dilepton experiments in the energy range between 2 and 40 A GeV where the highest net- baryon densities can be created in the laboratory,

• no dileptons have been measured in heavy ion collisions at these energies.

• The CBM collaboration will systematically measure both dielectrons and dimuons in p+p, p+A and A+A collisions as function of beam energy and size of the collision system.

• The dielectron and dimuon high-precision data will complement each other, and will provide a complete picture on dilepton radiation off dense baryonic matter. Also gamma conversion contamination is largely suppressed in case of dimuons.
The CBM experiment

- Tracking, momentum, $V^0$: MVD+STS+dipole magnet
- Event characterization: PSD
- Hadron id: TOF
- Lepton id: RICH+TRD or MUCH
- $\gamma$, $\pi^0$: EMC
- High speed DAQ & trigger

HADES

MVD + STS

RICH

TRD

TOF

EMC (park. pos.)

Muon detector

(parking position)

PSD

SIS 100 setup
Aim: to detect dimuon signals from low mass vector mesons and $J/\psi$.

Novel subsystem of segmented absorbers -- design goal being to simultaneously identify low and high momentum muons over full phase space.

SIS100: 2-4 GeV/u $\rightarrow$ 4 chambers + 4 absorbers
SIS300: up to 45 GeV/u $\rightarrow$ 5 det. stations + 6 absorbers
What is the typical configuration for dimuon detection in particle physics?
The NA60 experiment

Muon trigger and tracking
NA10/38/50 spectrometer

Matching in coordinate
and momentum space
Semi-leptonic decays of HF hadrons:

Muons: $1.2 < |y| < 2.2$

~10$\lambda$ hadron absorbers

- Tracked with wire chambers

- Further muon ID with layers of steel and streamer tubes
ALICE Detector

(Muon Arm)
The ALICE forward muon spectrometer will study the complete spectrum of heavy quarkonia (J/Ψ, Ψ′, Ψ″, γ, γ′, γ″) via their decay in the μ+μ− channel.

The optimized design provides
--- a good shielding capability and
--- a limited multiple scattering (mass resolution).

→ Using low-Z material in the absorber layers close to the vertex, and a high-Z shielding materials at the other end. => Pb + Boronated polyethylene & Pb + tungsten
Muon detection system: MUCH

- ID after hadron absorber with intermediate tracking layers
- **major combinatorical background from** $\pi,K$ decays into $\mu,\nu$, punch through of hadrons and track mismatches
  → use excellent tracking to reject $\pi,K$ decays in the STS

60 C + 20 Fe + 20 Fe + 30 Fe + 35 Fe + 100 Fe (cm)
30 cm gap between 2 absorbers
Optimizing Absorber thicknesses

Inputs for Detector Optimization

URQMD background:
- central Au+Au @8, 10 and 25 AGeV
- p+Au @ 30 GeV

Pluto: signal distributions
- LMVM @ 8 and 25 AGeV
- J/ψ @10 AGeV and 30 GeV

Total number of particles as a function of the traversed length in iron. The particle momenta have been taken from the simulation of central Au+Au collisions at 25 A GeV, their numbers have been normalized.
Track reconstruction efficiency for primary muon tracks from J/psi as a function of momentum for two tracking algorithms: nearest neighbor (red) and branching (blue). Left plot shows MUCH tracking efficiency, right plot shows STS-MUCH tracking efficiency. Horizontal lines represent numbers integrated over momentum.
3 layout options for SIS100 and SIS300

- **Basic SIS100**
- **Extended SIS100**
- **SIS300**

**Lengths:**
- 6.4m (SIS100)
- 7.3m (SIS300)
Detector options

One or two slides to show the options and status

Occupancy (25 AGeV central collisions)

Occupancy vs radius: station 1

Occupancy vs radius: station 2

Occupancy vs radius: station 3

Occupancy vs radius: station 4

Occupancy vs radius: station 5

Occupancy vs radius: station 6

Geant3 + segmentation + GEM profile implemented
Hit density on 1\textsuperscript{st} station (Carbon as first absorber)

\begin{itemize}
  \item FLUKA calculations (min-bias collisions)
  \item 25 AGeV
  \item 10 AGeV
  \item 400 KHz/cm\textsuperscript{2}
\end{itemize}
FLUKA calculations
A. Senger, GSI
Neutron-equivalent dose

- 35 AGeV
- 10 AGeV
TID: Total Ionizing Dose at the outer edge of the detector is around 10 krad

Ref: http://cbm-wiki.gsi.de/cgi-bin/viewauth/Radiationstudies/WebHome?CGISESSID=2bce338388a71f099de8d3ca43e0f2b7
Acceptance plots for J/psi mesons simulated for Au + Au collisions at 10 A GeV for the PLUTO input (left) and after reconstruction (right).
Invariant mass spectra – muons

- Shown: central (b=0fm) Au+Au collisions at 25 AGeV
- Mass resolution: 12 MeV (ω) and 29 MeV (J/ψ) only due to momentum determination in STS
- LMVM spectra for SIS100 show similar quality
- J/ψ in central pAu at 30GeV with superb S/B ratio

![Graph showing invariant mass spectra with peaks for various particles including ρ, φ, and J/ψ.](image)
Challenges in Muon detection

Main issues:

- High collision rates ~ 10 MHz
- The first plane(s) have a high density of tracks
  High granularity ~ average hit rate is about 0.4 hit/cm²
- Should be radiation resistant –
  high neutron dose → ~10^{13} n.eq./sq.cm/year
- Large area detector – with modular arrangement
- Data to be readout in a self triggered mode
  -- a must for all CBM detectors.
  -- and event reconstructed offline by grouping
    the timestamps of the detector hits.
Particle Density at Different MUCH stations

Different detector technologies for different stations
-- For the first two stations, which demand a high rate capability, Gas Electron Multiplier technology (GEM) would be used.
-- Straw tube and TRD for the other layers.
Straw Tube R&D by Dubna Group

The straws with inner diameters of 4 and 9.53 mm have been tested in the SPS test beam at CERN, with the same gas mixture of Ar/CO2 (80/20) and the gas gain 7 104 in both cases. The efficiency was about 98% and 99% for the 4 mm and 9.53 mm straws, respectively.
<table>
<thead>
<tr>
<th>Gas mixture</th>
<th>Percentage</th>
<th>( t_{\text{max}} ), ns</th>
<th>( \text{dE/E}, % )</th>
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<tr>
<td>Ar/CO(_2)</td>
<td>70/30</td>
<td>68.4</td>
<td>180.8</td>
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<tr>
<td>Ar/CO(_2)/CF(_4)</td>
<td>63/32/5</td>
<td>66.7</td>
<td>22.5</td>
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<tr>
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<td>63/27/10</td>
<td>60</td>
<td>26.4</td>
</tr>
<tr>
<td>Ar/CO(_2)/CF(_4)</td>
<td>63/17/20</td>
<td>45</td>
<td>33.5</td>
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<tr>
<td>Ar/CO(_2)O(_2)</td>
<td>(70/30)/0.8</td>
<td>64.1</td>
<td>18.8</td>
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<td>19</td>
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<tr>
<td>Ar/CO(_2)/O(_2)</td>
<td>(70/30)/1.5</td>
<td>59.5</td>
<td>28</td>
</tr>
<tr>
<td>Ar/CO(_2)/O(_2)</td>
<td>(70/30)/3</td>
<td>56.2</td>
<td>-</td>
</tr>
</tbody>
</table>
Spatial resolution as a function of the scaled distance to the anode for the straws with 4 mm (circles) and 9.53 mm (diamonds) inner diameter. gas mixture Ar/CO2 (80/20), and the gas gain was about 70K in both cases.

The signal processing requirements of the straw tube have led to the design of a full-custom, analogue, bipolar ASIC. It provides eight channels of amplifier, shaper, discriminator and base line restorer.
Triple GEM module for the first Two stations
Gas Electron Multiplier (GEM) and its working principle

- Active medium is a gas mixture.
- Electron multiplication takes place in holes of two copper foils separated by kapton.
- Amplification may use 2 or 3 stages.

Cascaded GEMs can give higher gains and have lesser spark probability.

- Maximum size ~100 cm x ~50 cm

Basic elements of a GEM chamber:
1. Drift plane
2. Amplifying element – GEM
3. Readout Plane

A 50 micron polyimide foil with a 5 micron Cu layer deposited on both sides of polyimide.
Prototype fabrication at VECC

CERN made framed GEMs 10 cm x 10 cm
Gas - Ar/CO2 – 70/30

Thermal stretching and framing of 31 cm x 31 cm large size GEMs at VECC
Beam test of GEM prototype chambers

**Aim:**
-- to test the response of the detector to charged particles, mainly in terms of efficiency, cluster size, gain uniformity, rate handling capability
-- testing with actual electronics for CBM: nXYTER
  nXYTER is a 32 MHz, 128 channel self triggered ASIC first developed by DETNEE collaboration for neutron measurements.
  – coupled to ROC(ReadOut Controller)
  and then fed to the DAQ.
-- testing with the actual CBM DAQ

The nXYTER ADC spectra is inverted as compared to conventional picture, this has to be subtracted from a baseline value channel by channel
Test setup at Jessica beamline at COSY (Julich)
Beam spot (for high intensity runs), 2.3 GeV/c protons

Beam profiles as seen by 10 cm x 10 cm prototype and 31 cm x 31 cm prototype (right)
Test Results

self triggered mode

Pulse height spectra

Cluster size vs. voltage

Published in NIMA
Rate test
using high intensity Cu X-ray
source in RD51 lab at CERN, with conventional electronics

Gain remains almost stable with rate
Highest Rate in this picture ~ 1.4 MHz/cm²

Published in JINST-2014

2/29/2016
Heavy Flavour meet, SINP, Kolkata, 03-05
Feb 2016
Test with absorbers – MiniMUCH at CERN SPS, H4 beamline. Pion beams of GeV/c (with some muons and electrons)
Residuals for GEM2

Reconstructing the track using GEM1 and GEM3 and Projecting the hits at plane_GEM2 and finding the distribution of residuals

2/29/2016
Heavy Flavour meet, SINP, Kolkata, 03-05
Feb 2016
Building a Real size MUCH sector prototype
Layout -- one layer of MUCH on a Drive
# of sectors, FEB, area, etc.

<table>
<thead>
<tr>
<th>Station # for SIS100</th>
<th>Layer #</th>
<th>Total no of pads</th>
<th>R1 (cm)</th>
<th>Pad size (min)</th>
<th>R2 (cm)</th>
<th>Pad size (max)</th>
<th>Area (sq.mt)</th>
<th>No of 128 channel FEB/layer (round off)</th>
<th>No of Sector per layer</th>
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<td>1</td>
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<td>28800</td>
<td>25</td>
<td>4.36mm</td>
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<td>240</td>
<td>16</td>
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<tr>
<td>2</td>
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<td>28800</td>
<td>25</td>
<td>4.36mm</td>
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<td>17.48mm</td>
<td>2.95</td>
<td>240</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>30600</td>
<td>34.5</td>
<td>5.9mm</td>
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<td>30600</td>
<td>34.5</td>
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<table>
<thead>
<tr>
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<th>Total no of pads</th>
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<th>Pad size (min)</th>
<th>R2 (cm)</th>
<th>Pad size (max)</th>
<th>Area (sq.mt)</th>
<th>No of 128 channel FEB/layer (round off)</th>
<th>No of Sector per layer</th>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>28800</td>
<td>25</td>
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<td>123.5</td>
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<td>2</td>
<td>2</td>
<td>30240</td>
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<td>5mm</td>
<td>123.5</td>
<td>21.3mm</td>
<td>4.5</td>
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<td>123.5</td>
<td>21.3mm</td>
<td>4.5</td>
<td>240</td>
<td>20</td>
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</tbody>
</table>
Sector Chamber elements – (old design)

Top Honeycomb plate
Pad plane PCB with clamping frame
Enclosure frame with 'O' ring seal
Drift plane PCB

GEM1
GEM2
GEM3
GEM spacer frame -1
GEM spacer frame -2
GEM spacer frame -3

HV divider

Murthy S. Ganti, VECC
Real size readout PCB designed at VECC
Readout PCB
inner side

Readout PCB
outer side
with FEB connectors
Real size GEM foil

For CBM MUCH -- GEM foils having 24 HV Segmentation.
Stretching of GEM foils – glue-less approach – “ns2”

- Now all the three layers of each clamp segment are fastened together with screws at select places. While designing the layout of the GEM foil some circular copper patterns are generated at the edges to enhance the grip of the edge clamp segments.
- The clamp segments are provided with an internal groove to accommodate a stainless steel nut. Thus after assembly of the segment a screw can be inserted sideways through the segment which mates with the embedded nut Fig.xx
- The outer chamber frame has provision to insert screws from side walls through a small gas tight O-ring seal and the screw can be coupled to the embedded nut in the corresponding clamp segment.
- After clamping all the foils the screws on the sides of the chamber frame can be tightened to stretch the foils in-situ. The screws are tightened until optimum tension is reached in all the three GEM foils.
- HV contacts are brought out of the foils through spring contacts. This needs further improvement.
- For large scale production it may be possible to mould the clamp segments with some engineering plastic like PEEK.

This method completely eliminates the slow gluing procedure and suitable for large volume production of chambers. Also since the grid-spacers are absent in the active zone, sparking probability due to glass filaments on the grid edges is eliminated. The chamber is opened for GEM replacement.
Drift Plane

GEM Foil segmentation and HV connection

12-14 segments on either side

Total 24-28 HV segments per foil
Figure 8: Position of power connectors for GEM foils.
Module Assembly schematic

Drift Plane

HV chain

Spacers

GEM foils

Readout Plane

6 mm slotted Al or grid for cooling

Readout board

39 mm

Drift board

8 mm Aluminum Base – support structures

6 mm Aluminum frame or grid with water cooling

FEBs
GEM foils for Real-size prototype
Response of the real size prototype to Fe55 X-rays
Beamtest of real size prototype at JESSICA@COSY, Juelich
Beam spots at different positions of the prototype

Real Size 2D Mapping

**Run133**
X,Y=(16,10)
Pad size=5.46mm

**Run100**
X,Y=(21,18)
Pad size=5.97mm

**Run91**
X,Y=(19,16)
Pad size=5.76mm

**RUN169**
X,Y=(32,7)
Pad size = 7.26 mm

2/29/2016
Heavy Flavour meet, SINP, Kolkata, 03-05 Feb 2016
Test Results of Real Size Prototype

-- a gain uniformity of < 15% observed
Technical Design Report for the CBM

Muon Chamber (MUCH)

The CBM Collaboration

December 2013

Technical Design Report
Submission for internal review: 21/10/13
Review: 7-8 Nov 2013

Submitted to FAIR: December 2013

Approved – December 2014

( VECC + 12 Indian Institutes, GSI Darmstadt, PNPI Gatchina, JINR Dubna )
Summary

• Dimuon measurement is at the core of the CBM physics program

• Feasibility studies performed for a layout with segmented absorber and detector triplets

• Different detector technologies will be implemented at different stations

• SIS100 layout R&D completed, can be extended to SIS300 chambers

• First Real size Prototype using “ns2” stretching assembled and tested successfully with proton beams and using self triggered nXYTER electronics. New radiation hard chip for actual experiment would be available soon.

• Mechanical design underway for superstructure and detector chambers.

• GEM module production may start early next year.
Thank You
BACKUPS
# Experiments exploring dense nuclear matter

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Energy $\sqrt{s_{NN}}$ (Au/Pb beams)</th>
<th>Observables</th>
<th>Reaction rates Hz</th>
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<tbody>
<tr>
<td>STAR@RHIC BNL</td>
<td>7 – 200 GeV</td>
<td>hadrons, electrons, muons</td>
<td>1 – 800</td>
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<td>(limitation by luminosity)</td>
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<tr>
<td>NA61@SPS CERN</td>
<td>6.4 – 17.4 GeV</td>
<td>hadrons</td>
<td>80</td>
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<tr>
<td>HADES@SIS18 GSI</td>
<td>&lt; 2.4 GeV</td>
<td>electrons, hadrons</td>
<td>$2 \cdot 10^4$</td>
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<td>(limitation by detector)</td>
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<td>Future/planned Experiments:</td>
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<tr>
<td>CBM@SIS FAIR</td>
<td>2.7 – 4.9 GeV 2.7 – 8.3 GeV</td>
<td>hadrons, electrons, muons</td>
<td>$10^5 – 10^7$</td>
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<td>MPD@NICA Dubna</td>
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<td>hadrons</td>
<td>100 - 1000</td>
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<td></td>
<td></td>
<td></td>
<td>(limitation by luminosity)</td>
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Cooled plate for FEB cooling

8mm thick Aluminum plate with internal channel for water flow

Chilled water In/Out connections
Background - muons

Particles identified as muons = reconstructed after MUCH (25 AGeV central Au+Au)

• Total number allows for a trigger also for LMVM

LMVM setup (no TOF)

reconstructed background (tracks per event):
- all 0.1063
- μ 0.075 (70%)
- π 0.0052
- K 0.0224
- p 0.0018
- other 0.0003
- ghost 0.0015

min. 14 MuCh hits

J/ψ setup (no TOF)

reconstructed background (tracks per event):
- all 2.1e-02
- μ 2.0e-02
- π 1.3e-04
- K 7.7e-04
- p 4.1e-05
- other 4.7e-05
- ghost 3.7e-04

min. 17 MuCh hits
Picture of the triple GEM prototype chambers

built at VECC

built by GSI Colleagues

(GEMS stretched and framed at GSI)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GEM chamber (VECC)</th>
<th>GEM chamber (GSI)</th>
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<tbody>
<tr>
<td>Drift gap</td>
<td>3 mm</td>
<td>3 mm</td>
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<tr>
<td>Transfer gap-1</td>
<td>1 mm</td>
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<td>Transfer gap-2</td>
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<tr>
<td>Induction gap</td>
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<tr>
<td>Segmentation</td>
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<tr>
<td>Number of pads</td>
<td>512</td>
<td>256</td>
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### CBM @ SIS-100 & SIS-300

The first years of CBM operation will be at SIS-100 with a start setup

<table>
<thead>
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<th>Beam</th>
<th>$p_{\text{lab, max}}$</th>
<th>$\sqrt{s_{\text{NN, max}}}$</th>
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</thead>
<tbody>
<tr>
<td>heavy ions (Au)</td>
<td>11A GeV</td>
<td>4.7 GeV</td>
</tr>
<tr>
<td>light ions (Z/A = 0.5)</td>
<td>14A GeV</td>
<td>5.3 GeV</td>
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<tr>
<td>protons</td>
<td>29 GeV</td>
<td>7.5 GeV</td>
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### CBM at SIS-300

<table>
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<th>$p_{\text{lab, max}}$</th>
<th>$\sqrt{s_{\text{NN, max}}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>heavy ions (Au)</td>
<td>35A GeV</td>
<td>8.2 GeV</td>
</tr>
<tr>
<td>medium ions (In) (Cu)</td>
<td>38A GeV 41A GeV</td>
<td>8.5 GeV 8.9 GeV</td>
</tr>
<tr>
<td>light ions (Z/A = 0.5)</td>
<td>45A GeV</td>
<td>9.3 GeV</td>
</tr>
<tr>
<td>protons</td>
<td>90 GeV</td>
<td>13 GeV</td>
</tr>
</tbody>
</table>

.... at interaction rates up to 10 MHz ($J/\psi$)