Di-muon Measurements with the CBM Experiment at FAIR

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VECC, Kolkata

“Advanced Detectors for Nuclear, High Energy and Astroparticle Physics”
Outline

CBM Experiment @ FAIR

- Overview of CBM experiment
- CBM Experimental set-up
- Experimental challenges

Simulation study on Dimuon measurement at CBM

- Design of Dimuon detection system
- Dimuon measurement technique
- Feasibility of detection of low mass vector mesons which decay into dimuon channel \([\rho, \omega, \phi \rightarrow (\mu^+\mu^-)]\).
Exploring QCD-phase diagram

Two regions in phase diagram hadronic phase and Quark gluon plasma phase & they are separated by a phase boundary. Lot of efforts are being made to locate this phase boundary of nuclear matter both theoretically and experimentally.

There are two extremes in QCD phase diagram: High temperature / low net baryon density and low temperature / high net baryon density region.
At very high temperature:
- \( \text{N of baryons} \approx \text{N of antibaryons} \)
  - Situation similar to early universe
- L-QCD finds crossover transition between hadronic matter and Quark-Gluon Plasma

Experiments:
- LHC, RHIC top energy (\( \sqrt{s} = 200 \text{ GeV} \))
At very high temperature:
- \( N \) of baryons \( \approx \) \( N \) of antibaryons
- Situation similar to early universe
- L-QCD predicts crossover transition between hadronic matter and Quark-Gluon Plasma

Experiments:
- LHC, RHIC top energy (\( \sqrt{s} = 200 \text{ GeV} \))

At high baryon density:
- \( N \) of baryons \( \gg \) \( N \) of anti-baryons
- Densities like in neutron star cores
- Models predict first order phase transition with possible existence of mixed phase.

Experiments:
- BES at RHIC, NA61 CERN SPS, CBM at FAIR, NICA at JINR
CBM is an upcoming experiment at Facility for Anti-Proton and Ion Research (FAIR) in Darmstadt, Germany.

It is a fixed target experiment using heavy-ion beams from 4-(35)45 A GeV.

Designed and dedicated to explore the QCD phase diagram in the regime of moderate temperatures and high net-baryon densities.
So we can expect a baryon rich QGP at CBM energy.

Model calculation predicts that Matter density may reach 5-10 times normal nuclear density ($\rho^0 \sim 0.14 \text{ fm}^3$) depending on collision energy.


So we can expect a baryon rich QGP at CBM energy.
The equation-of-state of high baryon density matter
collective flow of hadrons

Indication of Deconfinement phase transition at high $\rho_B$
- Yield, spectra, collective flow of strange ($K, \Lambda, \Sigma, \Xi, \Omega$), Charmed particles ($J/\psi, \psi', D_0, D_s, D^\pm, \Lambda_c$) and dileptons
- Charmonium suppression, $J/\psi$.
- Strangeness enhancement

QCD Critical End Point (CEP)
Event by Event fluctuations of conserved quantities and particle ratios ($K/\pi, ... \Xi/\pi, \Omega/\pi$)

Onset of chiral symmetry restoration at high $\rho_B$
In-medium properties of hadrons will be changed. (Mass shift and broadening in the medium).
$(\rho, \omega, \phi \rightarrow e^+e^- (\mu^+\mu^-)$
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$(\rho, \omega, \phi \rightarrow \mu^+\mu^-)$

$\rho, \omega, \phi \rightarrow (\mu^+\mu^-)$ Dimuon
(Low Mass Vector Mesons)
CBM Experimental Set-up

Muon Chambers (MUCH) Detects $\mu+\mu-$

Transition Radiation Detector (TRD)

Time Of Flight (TOF)

Electromagnetic Calorimeter (ECAL)

Ring Imaging Cherenkov Detector (RICH)

Target

Magnet

Silicon Tracking Station (STS)

Projectile Spectator Detector (PSD)
Experimental Challenges

$10^5 - 10^7$ Au+Au interactions/sec

Determination of (displaced) vertices ($\sigma \sim 50 \mu m$)

Identification of leptons and hadrons

Fast and radiation hard detectors

High speed data acquisition and high performance computer farm for online event selection

4-D ($x,y,z,t$) event reconstruction
Di-muon Studies
Muon Chamber is a conical shaped set-up with detector coverage is 5.7° to 25° (1.5<\(\eta<3.0\)).

Unique feature of CBM muon chamber is that hadron absorbers are sliced and detectors are placed in between them.

Other HEP experiment use a single thick absorber for detection of muons. If a single thick absorber will be used here, then will loose information of low momentum muons which comes from low mass vector mesons.

Absorbers will be used for hadron absorption.

1st absorber is made of Carbon of thickness 60 cm and rest are made of Iron of 20+20+30 cm thickness.

Gap between the consecutive absorbers is 30 cm and 3 detector chambers (Station) are placed in between the absorbers.

Gas Electron Multiplier (GEMs) will be used in the first two stations. For the last two stations, we are planning to use Resistive Plate Chambers (RPCs).

R & D is going on the feasibility study of using RPCs.
Muon Detection at CBM

Selection of muon tracks for low mass vector mesons (8 AGeV energy Au+Au)---Tracks should have, MUCH hits>=11, STS hits>=7, $\chi^2$ much <1.3, $\chi^2$ vertex <2.0

Muons from $J/\psi$

Muons from $\rho,\omega,\phi$

High momentum particle

Reject this track
Muon Detection at CBM

Selection of muon tracks for low mass vector mesons---
Tracks should have, MUCH hits>=11, STS hits>=7, χ² much <1.3, χ² vertex <2.0
Uniqueness and Challenges in Dimuon measurement at CBM

Uniqueness---
- No di-lepton measurement between 2-40 A GeV.
- For the First time CBM aims to measure precisely rarely produced dimuons in the FAIR energy range.

Challenges---
Previous experiments at AGS and SPS has overlap with CBM energy but due to low luminosity and detector limitations they could not measure rare particles.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Energy range</th>
<th>Reaction rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAR-BES @ RHIC BNL</td>
<td>$\sqrt{s} = 7 - 200$ GeV</td>
<td>1 - 800</td>
</tr>
<tr>
<td>NA61 @ SPS CERN</td>
<td>$E_k = 20 - 160$ A GeV</td>
<td>80</td>
</tr>
<tr>
<td>MPD @ NICA Dubna</td>
<td>$\sqrt{s} = 4 - 11$ GeV</td>
<td>1000</td>
</tr>
<tr>
<td>CBM @ FAIR Darmstadt</td>
<td>$E_k = 2 - 35$ A GeV</td>
<td>$10^5 - 10^7$</td>
</tr>
</tbody>
</table>

- CBM will be operated at very high interaction rate (~10 MHz).
- This is a prerequisite for collecting high statistics data of rarely produced particles (eg. $J/\psi$, $\rho$, $\phi$)
Simulation for Dimuon measurement at CBM

Tools Used

- **CBM Frame -Work**
  CBMROOT (environment)

- **Event Generators**
  PLUTO -- To generate signal particles \((\rho, \omega, \phi)\) & decay them into **dimuons**.
  URQMD – To generate other **background** events.

- **GEANT3** - Transport the particles through the CBM set-up
Simulation chain

- Event Generator (Pluto, UrQMD, Box ...)
- Transport (Geant, Fluka)
- Detector segmentation
- Digitization
- Clustering and hit production
- Tracking
- Particles \( (\text{pid, px, py, pz}) \)
- MC points, MC tracks
- Pads \( (x, y, z) \)
- Digi objects \( (\text{Fired pads}) \)
- Hits
- Tracks

Select tracks as muon candidate

Apply selection cuts
- MUCH hits\( \geq 11 \)
- STS hits\( \geq 7 \)
- \( \chi^2 \text{ much} < 1.3 \)
- \( \chi^2 \text{ vertex} < 2.0 \)

Finally identified muon candidate tracks are used for Dimuon analysis
Simulation Results
[ 8 AGeV central Au+Au ]

Point Density Distribution

Occupancy : Fraction of total no of pads fired per event

Particle rate (Scaled by 10 MHz interaction rate)
Simulation Results
[ 8 AGeV central Au+Au ]

Raw input cocktail
(From pluto)

Invariant mass--

$$P^2_{\rho, \omega, \phi} = (P_{\mu^+} + P_{\mu^+})^2$$

P- Four momentum

Reconstructed cocktail
(After passing through detector)
Simulation Results
[ 8 AGeV central Au+Au ]

S/B plot

Particle | Eff (%) | S/B
---|---|---
ρ | 1.03 | 0.005
ω | 1.01 | 0.287
φ | 1.53 | 0.005
η | 0.56 | 0.004
ηD | 0.23 | 0.092
ωD | 0.37 | 0.004

Background comes mainly from decays of pions and kaons, and punched through hadrons.

Y-pT acceptance (ρ)

Input Pluto

Reconstructed

pT (GeV/c)

Counts

pT (GeV/c)
Dilepton measurements is an integral part of the physics program at CBM. They are believed to be penetrating probes carrying undistorted information of the dense collision zone.

Till now there is no dilepton data in 2-40 AGeV, so CBM will make pioneering measurements in this energy region.

A muon detector set up using novel concept of segmented hadron absorber has been designed & realistic simulations via dimuon channel will establish the feasibility of such measurements.
Acknowledgement

Prof. Subhasis Chattopadhyay
Dr. Partha Pratim Bhaduri
All CBM collaborators

Thank You
Back up
## Combinatorial Background/Signal in Dilepton Experiments

Reference: hadron cocktail at masses of 0.5-0.6 GeV  

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Centrality</th>
<th>Lepton flavor</th>
<th>B/S as meas. or simul.</th>
<th>B/S rescaled to dN_{ch}/dy=300</th>
</tr>
</thead>
<tbody>
<tr>
<td>HADES-SIS100</td>
<td>semicentr</td>
<td>e^{+}e^{-}</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>CERES DR</td>
<td>semicentr</td>
<td>e^{+}e^{-}</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>CERES SR/TPC</td>
<td>central</td>
<td>e^{+}e^{-}</td>
<td>110</td>
<td>100</td>
</tr>
<tr>
<td>PHENIX with HBD</td>
<td>central</td>
<td>e^{+}e^{-}</td>
<td>250</td>
<td>100</td>
</tr>
<tr>
<td>PHENIX w/o HBD</td>
<td>central</td>
<td>e^{+}e^{-}</td>
<td>1300</td>
<td>600</td>
</tr>
<tr>
<td>STAR</td>
<td>central</td>
<td>e^{+}e^{-}</td>
<td>400</td>
<td>200</td>
</tr>
<tr>
<td>ALICE Upg ITS</td>
<td>central</td>
<td>e^{+}e^{-}</td>
<td>1200</td>
<td>200</td>
</tr>
<tr>
<td>CBM-SIS100</td>
<td>central</td>
<td>e^{+}e^{-}</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>CBM-SIS300</td>
<td>central</td>
<td>e^{+}e^{-}</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>NA60 (inn)</td>
<td>semicentr</td>
<td>μ^{+}μ^{-}</td>
<td>35</td>
<td>80</td>
</tr>
<tr>
<td>NA60-like (20AGeV)</td>
<td>central</td>
<td>μ^{+}μ^{-}</td>
<td>90</td>
<td>110</td>
</tr>
<tr>
<td>CBM</td>
<td></td>
<td></td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>central Au+Au @ 25 A GeV : 5 stations</td>
<td></td>
<td></td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>6 stations (NA60-like acceptance)</td>
<td></td>
<td></td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>central Au+Au @ 8 A GeV: 4 stations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

H.J.Specht
Much setup (SIS100/300)

60 (C+Pb) + 20 Fe + 20 Fe + 30 Fe + 35 Fe + 100 Fe (cm)
30 cm gap between 2 absorbers
TOF information

TOF is used to reduce background \((m^2 \geq 0.05 \text{ GeV}^2/\text{C}^4)\)
Challenges in Dimuon measurement at CBM

Particle multiplicities times branching ratio for central Au+Au collisions at 25 AGeV as calculated with the HSD transport code

<table>
<thead>
<tr>
<th>particles</th>
<th>$\rho^0$ (775 MeV)</th>
<th>$\omega$ (783 MeV)</th>
<th>$\phi$ (1020 MeV)</th>
<th>$\eta$ (550 MeV)</th>
<th>$\eta_D$ (550 MeV)</th>
<th>$\omega$ (783 MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiplicity (HSD)</td>
<td>9</td>
<td>19</td>
<td>0.12</td>
<td>16</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>BR(\mu\mu channel)</td>
<td>4.55*10^{-5}</td>
<td>9*10^{-5}</td>
<td>2.87*10^{-5}</td>
<td>5.6*10^{-6}</td>
<td>3.1*10^{-4}</td>
<td>1.3*10^{-4}</td>
</tr>
<tr>
<td>Per event yield</td>
<td>4.09*10^{-4}</td>
<td>1.71*10^{-3}</td>
<td>3.44*10^{-6}</td>
<td>8.96*10^{-5}</td>
<td>4.96*10^{-3}</td>
<td>2.47*10^{-3}</td>
</tr>
</tbody>
</table>