The Compressed Baryonic Matter Experiment at FAIR

Outline:

* Physics case
* Detector layout
* Feasibility studies and Detector R&D

FAIR community meeting, Daresbury Laboratory, 24-25th January, 2006
Probing strongly interacting matter

Compression + heating = quark-gluon plasma
(pion production)

Neutron stars  Early universe
The phase diagram of strongly interacting matter

RHIC, LHC: high temperature, low baryon density
FAIR: moderate temperature, high baryon density
critical endpoint

liquid

gas

coexistence

P

V

T_c
Critical endpoint:
Z. Fodor, S. Katz, hep-lat/0402006
S. Ejiri et al., hep-lat/0312006
$\mu_B < \approx 400$ MeV: crossover

baryon density:

$$\rho_B \approx 4 \left( \frac{mT}{2\pi} \right)^{3/2} x$$

$$\left[ \exp((\mu_B - m)/T) - \exp((-\mu_B - m)/T) \right]$$

baryons - antibaryons
Diagnostic probes

U+U 23 AGeV

charm

Φ, Ξ, Ω

K, π, Λ, η

prompt γ

thermal γ

ρ → e⁺ e⁻

decay γ

resonance decays
Compressed Baryonic Matter: physics topics and observables

Probing the equation-of-state at high $\rho_B$

- **Observables:** collective flow of hadrons, particle production at threshold energies (open charm)

Search for the deconfinement phase transition at high $\rho_B$
- enhanced strangeness production?
  - **Observables:** $K, \Lambda, \Sigma, \Xi, \Omega$
- anomalous charmonium suppression?
  - **Observables:** charmonium ($J/\psi, \psi'$), open charm ($D^0, D^\pm$)

Search for the critical endpoint

- **Observable:** event-by-event fluctuations ($K/\pi, p_T, ...$)

Search for chiral symmetry restoration at high $\rho_B$
- in-medium modifications of hadrons
  - **Observables:** $\rho, \omega, \phi \rightarrow e^+e^-$, open charm, .....
Experimental program of CBM:

Observables:
Penetrating probes: $\rho$, $\omega$, $\phi$, $J/\psi$ (vector mesons)
Strangeness: $K$, $\Lambda$, $\Sigma$, $\Xi$, $\Omega$
Open charm: $D^0$, $D^\pm$, $D_s$, $\Lambda_c$
Global features: collective flow, fluctuations, ..., exotica

Systematic investigations:
A+A collisions from 8 to 45 (35) AGeV, $Z/A=0.5$ (0.4)
p+A collisions from 8 to 90 GeV
p+p collisions from 8 to 90 GeV
Beam energies up to 8 AGeV: HADES

Detector requirements
Large geometrical acceptance
Good hadron and electron identification
Excellent vertex resolution
High rate capability of detectors, FEE and DAQ

Large integrated luminosity:
High beam intensity and duty cycle,
Available for several month per year
Data at FAIR energies: pion and kaon production in central Au+Au and Pb+Pb collisions

signature of a phase transition around 30 AGeV?
Data at FAIR energies: dynamical fluctuations of particle ratios measured event-by-event

NA49, nucl-ex/0403035

- $K/\pi$: increase towards low energies (20 AGeV), not reproduced by UrQMD transport code
- $p/\pi$: correlation due to resonance decays
Theoretical prediction of meson production in central Au+Au collisions

Hadron String Dynamics transport calculation
D-meson measurements

Some hadronic decay modes

\(D^\pm (c\tau = 317 \mu m):\)
- \(D^+ \rightarrow K^0\pi^+ \ (2.9\pm0.26\%)\)
- \(D^+ \rightarrow K^-\pi^+\pi^+ \ (9 \pm 0.6\%)\)

\(D^0 (c\tau = 124.4 \mu m):\)
- \(D^0 \rightarrow K^-\pi^+ \ (3.9 \pm 0.09\%)\)
- \(D^0 \rightarrow K^-\pi^\pi^- \ (7.6 \pm 0.4\%)\)

D meson production in pN collisions

Measure displaced vertex with resolution of \(\approx 50 \mu m\)!
J/ψ measurements at FAIR energies

<table>
<thead>
<tr>
<th>Central Collisions</th>
<th>25 AGeV Au+Au</th>
<th>158 AGeV Pb+Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>J/ψ Multiplicity</td>
<td>1.5·10⁻⁵</td>
<td>1·10⁻³</td>
</tr>
<tr>
<td>Beam Intensity</td>
<td>1·10⁹/s</td>
<td>2·10⁷/s</td>
</tr>
<tr>
<td>Interactions</td>
<td>1·10⁷/s (1%)</td>
<td>2·10⁶/s (10%)</td>
</tr>
<tr>
<td>Central Collisions</td>
<td>1·10⁶/s</td>
<td>2·10⁵/s</td>
</tr>
<tr>
<td>J/ψ Rate</td>
<td>15/s</td>
<td>200/s</td>
</tr>
<tr>
<td>6% J/ψ → e⁺e⁻ (μ⁺μ⁻)</td>
<td>0.9/s</td>
<td>12/s</td>
</tr>
<tr>
<td>Spill Fraction</td>
<td>0.8</td>
<td>0.25</td>
</tr>
<tr>
<td>Acceptance</td>
<td>0.25</td>
<td>≈ 0.1</td>
</tr>
<tr>
<td>J/ψ Measured</td>
<td>0.17/s</td>
<td>≈ 0.3/s</td>
</tr>
<tr>
<td></td>
<td>≈ 1·10⁵/week</td>
<td>≈ 1.8·10⁵/week</td>
</tr>
</tbody>
</table>
Looking into the fireball ...

... using penetrating probes:

short-lived vector mesons decaying into electron-positron pairs
Dilepton Sources in Heavy-Ion Collisions

no $\rho, \omega, \phi \rightarrow e^+e^-$ measurement between 2 and 40 AGeV
no $J/\psi \rightarrow e^+e^- (\mu^+\mu^-)$ measurement below 160 AGeV
no D-meson measurement below RHIC energies
Experimental challenges

Central Au+Au collision at 25 AGeV: URQMD + GEANT4

- $10^7$ Au+Au reactions/sec
  (beam intensities up to $10^9$ ions/sec, 1% interaction target)

- determination of (displaced) vertices with high resolution ($\approx 50$ μm)

- identification of electrons and hadrons
Radiation hard Silicon (pixel/strip) Tracking System in a magnetic dipole field

Electron detectors: RICH & TRD & ECAL: pion suppression better $10^4$

Hadron identification: TOF-RPC

Measurement of photons, $\pi$, $\eta$, and muons: electromagn. calorimeter (ECAL)

High speed data acquisition and trigger system
Hyperon detection with STS without p, K, π identification

\[ \Lambda (uds) \]

\[ \Xi^- (dss) \]

\[ \Omega^- (sss) \]

efficiency 15.8% 6.7% 7.7%
D^+ mesons from Au+Au collisions at 25 AGeV

Track reconstruction:
realistic magnetic field,
7 pixel detectors (no strips yet),
no particle ID required

D^+ production cross section from HSD
25 AGeV Au+Au from UrQMD

81000 D^+ mesons registered in 10^{12} min. bias Au+Au collisions at 25 AGeV
(→ 1 - 100 days depending on read-out speed of Silicon vertex detector)
Signal/Background ($\pm 1.4 \sigma$):

$s/b = 0.5$ at mass of $\omega$ meson
$s/b = 0.3$ at mass of $\phi$ meson

Electron-positron pairs from Au+Au collisions at 25 AGeV

Simulations without track reconstruction & electron identification

Experimental challenge: branching ratios $\sim 10^{-5}$-10^{-4} for $\rho, \omega, \phi \rightarrow e^+e^-$

major sources of physical background:
- Dalitz decays $\pi^0 \rightarrow e^+e^-\gamma$
- gamma conversion $\gamma \rightarrow e^+e^-$

Signal/Background ($\pm 1.4 \sigma$):

$s/b = 0.5$ at mass of $\omega$ meson
$s/b = 0.3$ at mass of $\phi$ meson
Alternative option: $\mu$ ID system with absorber

C/Fe absorbers + detector layers

Simulations Au+Au 25 AGeV:

- track reconstruction from hits in STS and muon chambers
- muon ID: tracks from STS to muon chamber behind absorber
- vector meson multiplicities from HSD transport code

$J/\psi \rightarrow \mu^+\mu^-$  $s/b \sim 100$
<table>
<thead>
<tr>
<th>Detector Type</th>
<th>Requirements</th>
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<tbody>
<tr>
<td>Silicon Pixel Detector:</td>
<td>- Low material budget: $d &lt; 200 \mu m$</td>
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<td>- Single hit resolution: $&lt; 20 \mu m$</td>
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<td>- Radiation hardness: $10^{15} n_{eq}/cm^2$</td>
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<td></td>
<td>- Fast read out</td>
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<tr>
<td>Transition Radiation Detector:</td>
<td>- $e/\pi$ discrimination of $&gt; 100$ ($p &gt; 1$ GeV/c)</td>
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<td>- High rate capability up to $100$ kHz/cm$^2$</td>
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<td></td>
<td>- Position resolution of about $200 \mu m$</td>
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<td></td>
<td>- Large area ($\approx 450 - 650$ m$^2, 9 - 12$ layers)</td>
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<td>Si-Strip detectors:</td>
<td>- Pitch: $50 \mu m$</td>
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<td>- Thickness: $200 \mu m$</td>
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<td></td>
<td>- Double sided, stereo angle $15^\circ$</td>
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<td>- Area: $2$ m$^2$</td>
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<tr>
<td>Resistive Plate Chamber (ToF-RPC):</td>
<td>- Time resolution $\leq 80$ ps</td>
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<td>- High rate capability up to $25$ kHz/cm$^2$</td>
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<tr>
<td></td>
<td>- Efficiency $&gt; 95%$</td>
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<tr>
<td></td>
<td>- Area: $100$ m$^2$</td>
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<tr>
<td>Ring Imaging Cherenkov Detector:</td>
<td>- $e/\pi$ discrimination $&gt; 100$</td>
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<td></td>
<td>- Hadron blind up to about $6$ GeV/c</td>
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<tr>
<td></td>
<td>- Low mass mirrors</td>
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<td></td>
<td>- Fast UV detector</td>
</tr>
<tr>
<td>Electromagnetic Calorimeter:</td>
<td>- Energy resolution of $5%/\sqrt{E(GeV)}$</td>
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<tr>
<td></td>
<td>- High rate capability up to $15$ kHz</td>
</tr>
<tr>
<td></td>
<td>- $e/\pi$ discrimination of $50-200$</td>
</tr>
<tr>
<td></td>
<td>- Area $100$ m$^2$</td>
</tr>
<tr>
<td>Muon detection system:</td>
<td>- Fast gas chambers (GEM)</td>
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<td></td>
<td>- High granularity</td>
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<tr>
<td>FEE and DAQ:</td>
<td>- Self triggered digitization, dead time free</td>
</tr>
</tbody>
</table>
CBM
8 - 45 AGeV

HADES
2 - 8 AGeV
Next steps:

- CBM Technical Proposal 2007
- CBM Physics Book
  Workshop at ECT* in Trento
  May 29 - June 2, 2006
  "The physics of high baryon density"

http://www.gsi.de/fair/experiments/CBM
<table>
<thead>
<tr>
<th>Country</th>
<th>Institutions</th>
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<tbody>
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<td>Croatia</td>
<td>RBI, Zagreb</td>
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<td>China</td>
<td>Wuhan Univ. Hefei Univ.</td>
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<td>Cyprus</td>
<td>Nikosia Univ.</td>
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<td>Czech Republic</td>
<td>CAS, Rez Techn. Univ. Prague</td>
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<td>France</td>
<td>IReS Strasbourg</td>
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<td>Hungaria</td>
<td>KFKI Budapest Eötvös Univ. Budapest</td>
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<td>Korea Univ. Seoul Pusan National Univ.</td>
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<td>Russia</td>
<td>CKBM, St. Petersburg IHEP Protvino INR Troitzk ITEP Moscow KRI, St. Petersburg</td>
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