Exploring the Phase Diagram of Strongly interacting Matter

News from SPS and RHIC

Tim Schuster

30th International School of Nuclear Physics, Erice, 16 - 24 September 2008
Critical point and crossover:
Fodor et. al.: JHEP 0404 (2004) 050
CERN press release 2000:

"... evidence of a new state of matter where quarks and gluons are not confined..." (L. Maiani)

Outline

CERN press release 2000:

"...evidence of a new state of matter where quarks and gluons are not confined..."  (L. Maiani)

Onset of Deconfinement at lower SPS energies

Critical point and crossover:
Fodor et. al.: JHEP 0404 (2004) 050
CERN press release 2000:

"... evidence of a new state of matter where quarks and gluons are not confined..." (L. Maiani)

Onset of Deconfinement at lower SPS energies

Properties of deconfined matter studied at RHIC

Critical point and crossover:
Fodor et. al.: JHEP 0404 (2004) 050
CERN press release 2000:
"... evidence of a new state of matter where quarks and gluons are not confined..." (L. Maiani)

Onset of Deconfinement at lower SPS energies

Properties of deconfined matter studied at RHIC

Study properties of the Onset of Deconfinement and search for the Critical Point at energies $5 < \sqrt{s_{NN}} < 20$ GeV
Outline

• Indications for a phase transition
  – Onset of deconfinement at SPS energies
  – Signatures of deconfined matter at RHIC energies

• Experimental programs to probe the phase diagram
  – NA61/SHINE, fixed-target experiment at CERN-SPS
  – STAR, collider detector at RHIC-BNL

• Physics program and capabilities to
  – Study the onset of deconfinement
  – Search for the QCD critical point
• Maximum seen in strangeness to pion ratio at low SPS energies:
  
  Difficult to model in hadronic scenarios
  (e.g. HGM: Cleymans et al., PRC 60 (1999) 054908)

  Predicted as signal for the onset of deconfinement
  (SMES, APP B30 (1999) 2705)
• Observations in RHIC data indicating the formation of a hot partonic medium:
  - Jet energy loss
  - Strong collective flow
  - Quark number scaling

• Can we turn off these signatures when going down in energy?
Experiment

NA61/SHINE at CERN-SPS

NA49 Pb+Pb, $\sqrt{s_{NN}} = 17$ GeV

LHC

SPS

SHINE

NA61
Experiment

STAR at BNL-RHIC

STAR Au+Au, $\sqrt{s_{NN}} = 200$ GeV
**Large acceptance hadron spectrometers**

- TPC: $Q, x, p, dE/dx$
- Particle identification in the TPCs:
  - pions, kaons, protons via $dE/dx$
  - $K^0_s, \Lambda, \Xi, \Omega$: decay topology + inv. mass. + $dE/dx$
  - $\varphi, K^*, \Lambda^*$: inv. mass. + $dE/dx$
- plus further detectors: TOF, EMC, ...
Advantages of a collider detector in an energy scan:

- Acceptance stays constant with energy, full azimuth

- Spatial track density rises slower
Advantages of a fixed-target experiment in an energy scan:

- Large acceptance for all spectator nucleons and fragments: Precise centrality determination

- Beam/target nucleus species can be changed quickly
  - NA61/SHINE will run in parallel with LHC-ion
  - Fragmentation beam from the primary Pb beam
How do “horn” position and amplitude vary with system size?

→ NA61/SHINE will extend the NA49 energy and system size scan

NA49 energy and system size scan

NA61/SHINE plan

= 2M events
Physics Plans

Onset of Deconfinement

- **Elliptic flow $v_2$**
  - Probes the early stage of the collision
  - Test for initial pressure and degrees of freedom
  - Measured over a wide range of energy for pions

![Graph showing elliptic flow $v_2$ vs. $E_{beam}/A$ (GeV)]
Physics Plans

Onset of Deconfinement

- To test the scaling, identified hadron $v_2$ must be measured up to large $p_T$

\[ \sqrt{s_{\text{NN}}} = 200 \text{ GeV} \]

\[ \frac{v_2}{n} \]

\[ \frac{\text{Data/Fit}}{p_T/n (\text{GeV/c})} \]
Physics Plans

Onset of Deconfinement

- Proton $v_2$ collapse predicted as signal for deconfinement
  (H. Stöcker: NPA 750 (2005) 121)
  - NA49: Difference between methods: Depends on $v_2$ fluctuations and non-flow contributions
  - Azimuthally symmetric detector STAR can measure event-by-event flow vector
  - STAR event plane resolution makes measurement with smaller error possible
  - Event plane detector as upgrade under discussion
• Lattice calculations show change in quark number susceptibilities
  - For light and strange quarks
  - Smooth transition at $\mu_B = 0$
  - Divergence at the critical point

F. Karsch, PoS (CPOD07) 026

• Look for structures in the excitation function of fluctuations!
  - net-proton Kurtosis as a function of beam energy
  - two proton correlation functions
  - deuteron over proton
• Dynamical fluctuations of the $K/\pi$ ratio rise steeply towards low SPS energies
  
  – Cannot be reproduced in hadronic model (UrQMD)

  – However, no quantitative prediction for critical point

• STAR TOF will improve unambiguous kaon identification at low energies
  
  – Systematic measurement over wide energy range possible with smaller error

Submitted to Phys. Rev. C  
STAR data: S. Das, J. Phys. G32 S541
Other fluctuation measures (\(N, <p_T>\)) show no significant energy dependence for central Pb+Pb collisions at SPS energies

- Are critical point signatures washed out in the hadronic phase?
- Small systems freeze out at higher temperatures: A 2-D scan (\(T,\mu_B\)) is possible by varying (\(A,\sqrt{s}\))

Becattini et al., Phys. Rev. C 73, 044905
### Status and Schedule

<table>
<thead>
<tr>
<th>Year</th>
<th>Reaction</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>p+Pb</td>
<td>Test run</td>
</tr>
<tr>
<td>2007</td>
<td>p+C</td>
<td>Neutrino physics detector R&amp;D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 month p beam successfully completed, positive evaluation of results</td>
</tr>
<tr>
<td>2008</td>
<td>p+C, p+p</td>
<td>high $p_T$, cosmic ray &amp; neutrino physics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Currently successfully running!</td>
</tr>
</tbody>
</table>

**proposed future runs:**

<table>
<thead>
<tr>
<th>Year</th>
<th>Reaction</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>p+Pb at 158A GeV</td>
<td>high $p_T$</td>
</tr>
<tr>
<td></td>
<td>p+p at 6 energies</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>p+Pb at 6 energies</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>S+S at 6 energies</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>C+C at 6 energies</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>In+In at 6 energies</td>
<td></td>
</tr>
</tbody>
</table>
• 2008: Successful test run at $\sqrt{s_{NN}} = 9.2$ GeV:

• 2010: 8-10 weeks exploratory run proposed

• 2012: Focussed run in region of interest exposed in exploratory run
Summary

- Explore the phase diagram of strongly interacting matter in A+A collisions at $5 < \sqrt{s_{NN}} < 20$ GeV:
  - Study the properties of the onset of deconfinement
  - Search for the critical point

- Worldwide efforts to scan the phase diagram:
  - RHIC energy scan: Au+Au at $5 < \sqrt{s_{NN}} < 200$ GeV
    Systematic study with energy independent acceptance over a wide energy range
  - NA61 at SPS: Various A+A species at $5 < \sqrt{s_{NN}} < 17$ GeV
    Adds a complementary system size scan and larger rapidity coverage
  - CBM at FAIR, MPD at NICA: $\sqrt{s_{NN}} < 9$ GeV
    High rate: Measurement of rare probes at lower energies