Probing the Quark Gluon Plasma

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The ALICE Collaboration

- ~1000 Members
  - 63% from CERN member states
- ~30 Countries
- ~100 Institutes
- ~150 MCHF capital cost (+magnet)

US ALICE

11 Institutions 53 members (inc. 12 grad. Students)

Cal. St. U. –San Luis Obispo, Creighton University, University of Houston, Lawrence Berkeley Nat. Lab, Lawrence Livermore Nat. Lab, Oak Ridge Nat. Lab, Ohio State University, Purdue University, University of Tennessee, Wayne State University, Yale University
QCD at high temperatures

\[ T_c \sim 175 \pm 8 \text{ MeV} \rightarrow \varepsilon_c \sim 0.3 - 1 \text{ GeV/fm}^3 \]

Few degrees of freedom - confined

Many degrees of freedom - deconfined

\[ \varepsilon_c \sim 0.3 - 1 \text{ GeV/fm}^3 \]
At RHIC we learned...

...the medium is hot, dense, and behaves like a fluid
# Simple Expectations for Heavy Ion Physics at LHC

<table>
<thead>
<tr>
<th></th>
<th>SPS</th>
<th>RHIC</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sqrt{s_{NN}}$ (GeV)</td>
<td>17</td>
<td>200</td>
<td>5500</td>
</tr>
<tr>
<td>$dN_d/d\eta$</td>
<td>~700</td>
<td>~1200</td>
<td>~2000-8000</td>
</tr>
<tr>
<td>$T/T_c$</td>
<td>1.1</td>
<td>1.9</td>
<td>3.0-4.2</td>
</tr>
<tr>
<td>$\varepsilon$ (GeV/fm$^3$)</td>
<td>3</td>
<td>5</td>
<td>15-60</td>
</tr>
<tr>
<td>$\tau_{qp}$ (fm/c)</td>
<td>$\leq$2</td>
<td>2-4</td>
<td>$&gt;$10</td>
</tr>
</tbody>
</table>

**RHIC and LHC:**
Cover 2 – 3 decades of energy ($\sqrt{s_{NN}}$ ~ 20 GeV – 5.5 TeV)

To discover the properties of hot QCD at $T \sim$ 150 – 600 MeV
Probes of a Quark Gluon Plasma

Soft Probes
- Determine expansion dynamics: will be different from RHIC
- Soft physics measurements: RHIC with extended PID
- $T, \mu_B, \varepsilon, $ spectra, collective effects (flow),…

Hard Probes – Jet Quenching
- Jets, $\gamma, \pi^0, $ leading particles to large $p_T$

Hard Probes – Heavy Quarks
- Displaced vertices ($D^0 \rightarrow K^- \pi^+$) from TPC/ITS
- Electrons in Transition Radiation Detector (TRD)

Hard Probes – Quarkonia
- $J/\psi, \Upsilon, \Upsilon' $ (excellent),$ \Upsilon'' $(2-3 yrs),$ \psi' $ ???
Experimental Challenges & ALICE Solutions

- **Extreme particle densities** \( (dN_{ch}/d\eta \sim 2000 \rightarrow \text{several thousand}) \)
  
  500 times p+p at LHC, 2 –4 times Au+Au at RHIC
  
  → ALICE solution for particle densities: high granularity 3D tracking, long path-lengths from interaction vertex [e.g. EMCal at 4.5 m]

- **Large dynamic range in \( p_T \)**
  
  from very soft (0.1 GeV/c) to fairly hard (100 GeV/c)
  
  → ALICE solution to extend \( p_T \) range: thin detectors, modest field (low \( p_T \)), large lever arm for tracking & resolution at large \( p_T \)
  
  ALICE: \( \sim 10\% \ X_0 \) inside \( r < 2.5 \text{ m}, B = 0.5T \)

- **Measure & ID many particles**
  
  requires: secondary vertices, lepton ID, hadron ID
  
  → ALICE solution for extended particle ID: employ many technologies \( dE/dx \), Cherenkov & transition rad., TOF, calorimeters, muon filter, topological.

- **Modest luminosity and interaction rates** 10 kHz (Pb + Pb)
  
  - Every Pb+Pb event is interesting
  
  - ALICE rates → allow slow detectors (TPC, SDD), moderate radiation hardness
Size: 16 x 26 meters
Weight: 10,000 tons
Detectors: 18
Size: 16 x 26 meters
Weight: 10,000 tons
Detectors: 18

Fully installed and commissioned
Size: 16 x 26 meters
Weight: 10,000 tons
Detectors: 18

Partially installed
Status in LHC Run 1, Run 2
**ALICE detectors and acceptance**

**Central barrel** $-0.9 < \eta < 0.9$
- $\Delta\phi = 2\pi$ tracking, PID (TPC/ITS/TRD/ToF)
- single arm RICH (HMPID)
- single arm e.m. cal (PHOS)
- jet calorimeter (EMCal)

**Forward muon arm** $-2.4 < \eta < -4$
- absorber, 3 T-m dipole magnet
- 5 tracking + 2 trigger planes

**Multiplicity detectors** $-3.4 < \eta < 5$
- including photon counting in PMD

**Trigger & timing detectors**
- 6 Zero Degree Calorimeters
- T0: ring of quartz window PMT's
- V0: ring of scintillator Paddles

\[ \eta = -\ln(\tan(\theta/2)) \]

Christine Nattrass (UTK), SES APS, November 13, 2009
The Time Projection Chamber

Specifications
- Designed for $dN_{ch}/d\eta=8000$
- $|\eta|<0.9$, radius 0.9-2.5m
- In a 0.5 T Solenoidal Field
- 570k channels, 80MB/event
- 3% radiation length
- Outer diameter 5 m, Length 5 m
- Largest ever
TRD, TOF, HMPID

Transition Radiation Detector
- $p_T > 1$ GeV electron id, $p_T > 3$ GeV trigger
- 540 modules, 4.8 cm radiator with 1.2M channels
- MWPC readout

Time Of Flight
- Multi-gap Resistive Plate Chambers (MRPC)
- 50 ps resolution at ~5m
- $|\eta| < 0.85$, $\Delta \varphi = 2\pi$

High Momentum PID
- Proximity focused, Ring Imaging Cherenkov RICH
- $|\eta| < 0.6$, $\Delta \varphi = \pi/3$
- PID $1 < p < 6$ GeV
PHOS

PHOton Spectrometer
- PbO$_4$W crystal calorimeter
- $\gamma, \pi^0, \eta$ for $1<p<100$ GeV
- $|\eta|<0.12$, $\Delta \phi=100^\circ$
- $\sigma(E)/E = 3\%$, $\sigma(x,y)=4\text{mm}$
EMCal

- Lead-scintillator sampling calorimeter
- 13 k towers
- Each tower $\Delta\eta \times \Delta\phi = 0.014 \times 0.014$
- Shashlik geometry
- Avalanche phototodiodes
  - $\Delta\eta = 1.4, \Delta\phi = 107^\circ$
  - $\sigma(E)/E = 0.12/\sqrt{E} + 0.02$

Funding approval: Feb. 2008
(\sim ALICE Upgrade: US, Italy, France, CERN, Finland)
- 7+2/3 US Super-Modules (SM)
- 3 EU SMs (Italy and France)
- Construct and Install 2008-2011
Simulated event
ALICE Performance

TPC acceptance = 90%

Low material budget → low $p_t$ cut off

No vertex, $B = 0.5$ T

Momentum resolution ~ 5% @ 100 GeV
TPC Performance

dE/dx resolution
initial calibration:
measured 5.7%
(design 5.5%)

ALICE
Preliminary

Cosmic event

Separation power

Christine Nattrass (UTK), SES APS, November 13, 2009
Day 1 p+p physics

- Global event properties
- Constrain/tune PYTHIA

\[ \frac{dN_{ch}}{d\eta} |\eta = 0| \]

Multiplicity distributions

\[ \langle p_T \rangle \text{ vs } N_{ch} \]
Hard Probes (from initial parton scattering):
- Heavy quark production
- High-$p_T$ hadrons
- Jets

Parton energy loss → modification of jets and leading particles & jet-correlations
ALICE hard physics capabilities:
- Electron/hadron discrimination (TRD, EMCal)
- $\mu$ measurements (forward muon arm)
- Good $\gamma/\pi^0$ discrimination (EMCal, PHOS)
- Fast trigger on jets (EMCal)

Hard Probes statistics in ALICE:

10^7/year in minbias Pb+Pb

- Inclusive jets: $E_T \sim 200$ GeV
- Dijets: $E_T \sim 170$ GeV
- $\pi^0$: $p_T \sim 75$ GeV/c
- Inclusive $\gamma$: $p_T \sim 45$ GeV/c
- Inclusive e: $p_T \sim 30$ GeV/c

*One year of running = one month of Pb+Pb collisions
Medium modification of fragmentation

Fragmentation along jet axis: $z = \frac{p_{\text{hadron}}}{p_{\text{parton}}}$

$$\xi = \ln\left(\frac{E_{\text{jet}}}{p_{\text{hadron}}}\right) \sim \ln \left(\frac{1}{z}\right)$$

N. Borghini, U. Wiedemann
hep-ph/0506218

- OPAL, $\sqrt{s} = 192–209$ GeV
- in vacuum, $E_{\text{jet}} = 100$ GeV
- in medium, $E_{\text{jet}} = 100$ GeV
- TASSO, $\sqrt{s} = 14$ GeV
- in vacuum, $E_{\text{jet}} = 7$ GeV
- in medium, $E_{\text{jet}} = 7$ GeV

Pb+Pb 0–10%: $<\phi> = 50 \text{ GeV}^2/\text{fm}$

Annual ALICE run statistics

Pb+Pb 0–10%: $<\phi> = 50 \text{ GeV}^2/\text{fm}$

Large background corrections, 5% sys. uncertainty assumed
Quarkonia

Heavy Quarks

mass/color dependence of parton E-loss

- Displaced vertices ($D^0 \rightarrow K^- \pi^+$) from TPC/ITS
- Electrons in Transition Radiation Detector (TRD)

Quarkonia

Initial T, Debye screening, recombination,...

- $J/\psi$, $\Upsilon$, $\Upsilon'$ (excellent), $\Upsilon''$ (2-3 yrs), $\psi'$ (very difficult)
Conclusions

- ALICE is able to
  - Measure thousands of particles per event
  - Measure particles over a wide kinematic range (0.1-100 GeV/c)
  - Identify many particles over a wide kinematic range
    - $\pi$, k, p, e, $\mu$, $\Lambda$, $K^0_S$, $\Xi$, $\Omega$, $D^0$
- Expect exciting results from p+p soon

Thank you!
Take a stack of fliers home and post them in your department!

January 15-17, 2010

Goal: To help undergraduate women continue in physics by
- Providing the opportunity to experience a professional conference
- Providing information about graduate school and professions in physics
- Introducing them to other women in physics

- Research talks
- Panel discussions about graduate school and careers in physics
- Presentations and discussions about women in physics
- Laboratory tours
- Student research talks
- Student poster session

Application deadline: Dec. 15, 2010

Applications received by Nov. 15, 2009 will receive full consideration for travel awards. Notification of travel awards and room reservation instructions will begin Nov. 15th and continue until funds are exhausted. For more information and for application forms, see http://www.southeastcuwp.org/
EMCal Assembly

- 3072 identical modules, 2x2 towers
- 1.5° taper in $\eta$
- Tower granularity $\delta \eta = \delta \phi = 0.014$
- 20.1 $X_0$
- 77 layers Pb:Sc = 1.44 : 1.76 mm

24 Strip Modules per Super Module
1 APD per tower
12 Modules per strip module