Exploitation of hard EM probes and Jets to study the QGP with LHC-ALICE

Yasuo MIAKE
Univ. of Tsukuba
Outline

✓ QGP
  • what we learned at RHIC
    and homework for LHC
✓ Jet quench
  • Jets/hard EM
  • property of QGP
✓ DiJet Calorimeter
  • design, rates, schedule
  • Japan-French collaboration
✓ Analysis Mechanism
✓ Summary

New proposal in FJPPL2010
in this talk,
focus on Jet Quench
Quark-Gluon Plasma

hadron gas
T, \rho \text{ low}

phase transition
T, \rho \text{ critical}

quark-gluon-plasma
T, \rho \text{ high}

RHIC(200\text{GeV})
since 2000

LHC(5.6\text{TeV})
soon

\checkmark \text{Physics of QCD in extreme}
T, \rho \text{ and small } x

\checkmark \text{Nucleus-Nucleus collisions}
What we learned at RHIC

\[ \epsilon_{\text{QGP}} \sim 2 \text{ [GeV/fm}^3\text{]} \]
\[ < n_q, \bar{n}_q > \sim \frac{\epsilon_{\text{QGP}}}{< m_T >} \sim \frac{2 \text{GeV}}{0.4 \text{GeV}} \sim 5 \]
\[ \lambda_q = \frac{1}{n \sigma_{qq}} \]
\[ \sim \frac{1}{5 \times 0.4} = 0.5 \text{ [fm]} \]
\[ \lambda_q \ll R_{\text{system}} \]

- Strongly interacting QGP
- Statistical nature & space/time evolution of collisions well established
  - Hadro-chemical equilibrium (T, \( \mu \))
  - Kinematical equilibrium (T, \( \beta \))
  - Universal pt&azimuthal distributions of quarks (Quark coalescence model)

Soft physics well understood (I think)
Good textbook on QGP!
RHIC vs LHC

<table>
<thead>
<tr>
<th></th>
<th>RHIC</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sqrt{s_{NN}}$ (GeV)</td>
<td>200</td>
<td>5500</td>
</tr>
<tr>
<td>$T/T_c$</td>
<td>1.9</td>
<td>3.0-4.2</td>
</tr>
<tr>
<td>$\varepsilon$ (GeV/fm$^3$)</td>
<td>5</td>
<td>15-60</td>
</tr>
<tr>
<td>$\tau_{QGP}$ (fm/c)</td>
<td>2-4</td>
<td>$&gt;10$</td>
</tr>
</tbody>
</table>

✓ Home work to the LHC, physics of jet quench

⇒ LHC has superior advantage in hard probes

Yasuo MIAKE, June 15, 2010, LAPP, France
“Jet Quenching” in nucleus-nucleus collision.

- Two quarks suffer a hard scattering in AA collision
  - One goes out to vacuum creating jet,
  - but the other goes through the QGP suffering energy loss due to gluon energy

**Manifestation:**
- attenuation/disappearance of jet
- suppression of high pt hadrons
- modification of jet fragmentation
Modification of back-to-back corr.

Direct evidence of loss of ‘jet’

Azimuthal correlation w.r.t. high pt leading particle (trigger).

- \( p_T^{\text{trig}} = 4 \sim 6 \text{ GeV/c} \times p_T^{\text{assoc}} > 2 \text{ GeV/c} \)

- \( \Delta \phi \) (radians)

- pedestal and flow subtracted

- \( d+Au \) FTPC-Au 0-20%

- \( p+p \) min. bias

- \( Au+Au \) Central

- pp ; clean di-jet

- \( dAu \); similar to pp

- \( Au+Au \); Similar on the same side (suggesting jet-like mechanism), but b-to-b disappeared

- Effect is not in initial but in final stage

- Energy loss of partons in dense matter created in \( Au+Au \)
Suppression of high $p_t$ particles

Nuclear Modification Factor

\[
R_{AA} = \frac{\text{"hot/dense QCD medium"}}{\text{"QCD vacuum"}} = \frac{dn_{AA}/dp_Tdy}{\langle N_{\text{binary}} \rangle \cdot dn_{pp}/dp_Tdy}
\]

PHENIX Au+Au (central collisions):
- Direct $\gamma$
- $\pi^0$ Preliminary
- $\eta$
- GLV parton energy loss ($dN/dy = 1100$)

$\checkmark$ Pions are suppressed, direct photons are not
Change of shape in the away-side

$p_{T}^{\text{trig}} = 3\sim4$ GeV/c $\times p_{T}^{\text{assoc}}$

(a) $3-4 \otimes 0.4-1$ GeV/c
- Au + Au 0-20%
- $p + p$

(b) $3-4 \otimes 1-2$ GeV/c $\times 1.5$

(c) $3-4 \otimes 2-3$ GeV/c

(d) $3-4 \otimes 3-4$ GeV/c $\times 3.5$

$\Delta \Phi = \pi \pm 1$ with decreasing momentum

Discussed in terms of Mach Cone, Cherenkov Em.

PHENIX, arXiv:0705.3238 [nucl-ex]
Why the jet quench is important?

Characteristic Energy Loss in dense matter

↓

the property of the matter
Energy loss of charged particle in a matter

Collisional
✓ Bethe-Bloch

Radiative
✓ Bethe-Heitler (thin; \( L \ll \lambda \))
✓ Landau-
Pomeranchuk-Migdal (thick; \( L \gg \lambda \))

✓ Measurements of \( dE/dx \) gives prop. of matter

• Energy loss in QED plasma gives \( T \) & \( m_D \) info.

Yasuo MIAKE, June 15, 2010, LAPP, France
Energy Loss in QCD

- Collisional loss
- Radiative loss
  ➔ Bethe-Heitler regime
  ➔ LPM regime
  ➔ “dead-cone” effect

Many theories on

\[ \Delta E \propto \alpha_S C_R \langle \hat{q} \rangle L^2 \]

(Executive) Summary

Radiative loss is dominant

Effects are:
- suppression of high pt hadron
- unbalanced back-to back
- modification of jet fragmentation
  softer, larger multiplicity, angular broadening

\[ \Delta E_{\text{gluon}} > \Delta E_{\text{quark}} > \Delta E_{\text{charm}} > \Delta E_{\text{bottom}} \]
How we study
Jet quench
at LHC

Meas. of high pt suppression/
Hadron corr.

↓

Full back-to back jet analysis of higher energy jets
DCal as an extension of EM-Cal

✓ For better performance of back-to-back capability
  ➔ Define back-to-back jets
  ➔ Trigger back-to-back jets

✓ Progress
  ● Proposed in Feb., 09
  ● Discussed w. IN2P3 in May, 09
  ● Discussed in March, 09
  ● Proposal in May, 09
  ● Partial approval in July, 09
  ● Full approval by ALICE in Oct. 09

✓ Construction started!
Beam View

✓ 5 contiguous modules possible, while exact back-to-back is 3
Probes for the study

\section*{γ-Jet}

- Quark Jet
- Small Xsection
- Experimentally challenging

\section*{Di-jet}

- Mostly Gluon Jet
- Larger Xsection
- Interpretation is complicated

\section*{π^0-Jet}

- Clean \(\pi^0\) trig
- Large Xsection
- Important for DCal

Systematic meas. of these processes for model comparison provides at high precision level.
What we expect; Reach of Jet Energy

**Inclusive-Jet Annual Yield**
- Using FastJet Anti-kt
- Pb+Pb minbias √s=5.5TeV
- binary scaling from p+p
  - L=0.5/mb/s; 10^6 sec
  - R=0.2
  - R=0.4

**Di-Jet Annual Yield**
- Using FastJet Anti-kt
- Pb+Pb minbias √s=5.5TeV
- binary scaling from p+p
  - L=0.5/mb/s; 10^6 sec
  - BtoB requirement: |Δη|<0.5

**γ-Jet Annual Yield**
- Using FastJet Anti-kt
- Pb+Pb minbias E=5.5TeV
- binary scaling from p+p
  - L=0.5/mb/s; 10^6 sec
  - BtoB requirement: |Δη|<0.5

✓ For 10^4 events/year in Pb+Pb@5.5TeV,
- Inclusive jet up to 200 GeV
- Di-Jet to 100 GeV

Yasuo MIAKE, June 15, 2010, LAPP, France
vides fundamental information on its properties. In a generated in the reaction (Fig. 2). The energy lost by a particle in the fragmentation of a parton having suffered energy loss in "jet quenching" [6] i.e. the attenuation or disappearance of the spray of lepton and hadron pairs or quark-antiquark pairs produced in the medium, is called a "jet". One of the first proposed "smoking guns" of QGP formation was "Jet quenching" in a head-on nucleus-nucleus collision. Two partons (q̂) from the projectile and target, respectively, traverse the dense plasma created (characterised by transport coefficient ˆD and thickness ˆL), go through the average transverse momentum squared transferred in a single collision: one goes out directly to the vacuum, radiates a few gluons and hadronises, the other undergoes multiple Coulomb scatterings are named medium, and also gives the thermal masses of the plasma constituents, the typical momentum exchanges with the medium and also gives the screening length of the (chromo)electric fields in the plasma.

The QED and QCD coupling "constants" are extremely useful to characterise the interactions of a parton inside a medium: 1/2(1/g^2 + 1/g^2) encodes the "scattering power" of the medium. The following (closely related) variable are the "thermal masses" of the plasma constituents, i.e. 2m = m(q̂, particle inside a medium). Here g is the coupling parameter) is the inverse of 2m.

\[
\text{Balance} = \frac{E_{\text{JET}}^1 - E_{\text{JET}}^2}{1/2(E_{\text{JET}}^1 + E_{\text{JET}}^2)}
\]

\[\text{DCAL}(R=0.4) - \text{EMCAL}(R=0.4)\]

\[\begin{align*}
Pb+Pb, \sqrt{s_{\text{NN}}} = 5.5 \text{TeV}, & 0-10\% \text{central} \\
L = 0.5 \text{nb}/s, 10^8 \text{ sec} &
\end{align*}\]

\[\text{qPythia}(\langle q^2 \rangle = 0 \text{GeV}^2/\text{fm})\]

\[\text{qPythia}(\langle q^2 \rangle = 50 \text{GeV}^2/\text{fm})\]

\[\sigma(\text{Balance}) \]

\[\text{Threshold of } E_T^{\text{DCAL}} \text{ [GeV]} \]

\[\text{Threshold of } E_T^{\text{EMCAL}} \text{ [GeV]} \]

\[\text{Balance} = \frac{E_T^{\text{DCAL}} - E_T^{\text{EMCAL}}}{1/2(E_T^{\text{DCAL}} + E_T^{\text{EMCAL}})}\]

\[\text{Mean} = 0.161\]

\[\text{σ}(\text{Balance})\]

\[\text{Threshold of } E_T^{\text{DCAL}} \text{ [GeV]} \]

\[\text{Threshold of } E_T^{\text{EMCAL}} \text{ [GeV]} \]

✓ Sensitivity in data of 1 year

Yasuo MIAKE, June 15, 2010, LAPP, France
IV.2 Perspective view of the DCal and PHOS integrated on a common support. As discussed in the text, the support structure is a component of the full international project scope. Five PHOS modules are shown although only three, those contiguous with the proposed DCal, are installed in ALICE at the moment and considered part of DCal.

Yasuo MIAKE, June 15, 2010, LAPP, France
France-Japan collaboration for ALICE-DCal

Institute & People

LPSC Grenoble
• Christophe Furget
• Jean-François Muraz

Subatech Nantes
• Manoel Dialinas

IPHC Strasbourg
• Christelle Roy

Contributions to DCal

LPSC Grenoble:
- DCal module straps
- DCal supper module (SM) cables
- DCal platform, shipping boxes
- DCal SM assembly

Subatech Nantes:
• DCal SM installation tool, support structure, integration
• DCal strip module production, DCal strong back
LPSC Grenoble (July, 2009)

Jean-François Muraz

Christophe Furger
Assembly, cabling, calibration, storage and shipping of all DCal SModules.
### Table V.1 Proposed individual group responsibilities for the major national groups participating in DCAL.

<table>
<thead>
<tr>
<th>Group</th>
<th>Group Leader</th>
<th>Proposed Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>T.J. Symons, LBNL</td>
<td>3 super modules&lt;br&gt;Dectector design&lt;br&gt;Overall project management&lt;br&gt;Project technical coordination&lt;br&gt;DCal LED system</td>
</tr>
<tr>
<td>Japan</td>
<td>Y. Miake, Tsukuba</td>
<td>1.5 super module</td>
</tr>
<tr>
<td>France</td>
<td>C. Roy, IPHC Strasbourg</td>
<td>0.5 super modules&lt;br&gt;Support structure design, fabrication&lt;br&gt;Oversight and payment of up to 2/3 the cost&lt;br&gt;Installation tooling design&lt;br&gt;Installation oversight&lt;br&gt;Jet trigger Design, hardware and integration&lt;br&gt;SM integration and cosmic calibration</td>
</tr>
<tr>
<td>China</td>
<td>D. Zhou</td>
<td>1 super module</td>
</tr>
<tr>
<td>Italy</td>
<td>N. Bianchi</td>
<td>Module assembly&lt;br&gt;Fiber production facilities</td>
</tr>
</tbody>
</table>

Table V.2 gives the full definition of the scope associated with each super module as used in Table V.1.

The Japanese and Chinese groups are new to the module production activities that have become routine in the US, France and Italy during the EMCal project. Because time is short to the start-up of DCal production, both Japanese and Chinese technicians and engineers will undergo extensive training at existing EMCal assembly facilities. Specialized assembly tooling required by the Chinese and Japanese in order to participate in module assembly will be provided on-site at the Italian laboratories Frascati and Catania. This is a significant contributed resource and is included in Table V.1.

The DOE technical scope and deliverables associated with the ALICE DCal project are presented in Table V.3 in terms of the scope associated with a single functional super module described in Table V.2. As stated above, the US DOE is contributing 3 super modules to the DCal of which one is already funded under the EMCal project by conversion of the two so-called 1/3 size super modules included in the EMCal scope into a single DCal super module. This effectively corresponds to spatial rearrangement of the EMCal acceptance to improve its physics potential while reducing new costs to the DOE. Given this, table V.3 represents the new scope of two DCal super modules to be funded under this project.
Japanese Analysis Facility discussed with French experts within Asian communities at Hiroshima in Jan. 2010

Remarks from the workshop;
◆ Active discussion started.
◆ FJPPL project members involved.
◆ Successful PROOF demo. carried out.
◆ Asian communities quite interested in.
◆ Task-force group formed.
◆ All activities are in scope of this project.

ALICE Analysis Workshop for Asian Communities
January 21-23, 2010, Graduate School of Science, Hiroshima University, Higashi-Hiroshima, Japan

The aim of our workshop is to share information on the current status of ALICE physics analyses for Asian communities and to work out our strategy in the near future.

In particular, the workshop will focus on the following topics:
- ALICE Analysis Framework and Practices
- ALICE Computing Strategy and Status
- ALICE Analysis Facilities for Asian Communities

Organizing Committee
Sugitate, Toru Hiroshima University (Chair)
Shigaki, Kenta Hiroshima University
Miyoshi, Takahiro Hiroshima University
Nakamiya, Yoshhide Hiroshima University
Ouchida, Misaki Hiroshima University

Takahashi, Emi (Secretary)

Sponsorship
JSPS
ALICE Tier-2 at Hiroshima

- The ALICE WLCG site “JP-HIROSHIMA-WLCG” with EGEE/gLite3.2 on SLC5;
- A full WLCG service up and running; VOBOX, LCG-CE, CREAM-CE, BDII, WMS/LB, XROOTD-SE, APEL, UI, etc..
- CPU and storage resources; 752 Xeon-cores and 276 TB disk servers
  Currently ~2/3 of resources in local use
- Network B/W: MPLS 1Gbps to KEK on SINET3
- ALICE associated Tier-1 in CCIN2P3/Lyon
  37/50Mbps to CCIN2P3/Subatech
- Responsible by Prof. T. Sugitate/Deputy Leader

- Some more resources at Tsukuba and Tokyo.
Summary of Japanese Analysis Facility

- Infrastructure (CPU, storage, network) exists in Asian institutes, e.g., at Hiroshima and KISTI
- Software framework exists or under development in French institutes
- Closer collaboration between France/Japan turns out to
  - challenge fast data analyses and strengthen Asian communities
  - establish and spread new technologies, e.g., PROOF on GRID
  - innovate a global computing model at large distances
- Primary people involved and request
  - France: YS/SUBATECH, RV/CCIN2P3, ??
  - Japan: TS/Hiroshima, HH/Tokyo, ??/Tsukuba
Our requirements

EXPLOITATION OF HARD EM PROBES AND JETS TO STUDY THE QGP WITH LHC-Alice

<table>
<thead>
<tr>
<th>French Group</th>
<th>Japanese Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Title</td>
</tr>
<tr>
<td>Leader</td>
<td>Yves Schmutz</td>
</tr>
<tr>
<td>Deputy leader</td>
<td>Christelle Roy</td>
</tr>
<tr>
<td></td>
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</table>

Visits to Japan

<table>
<thead>
<tr>
<th>Description</th>
<th>€/unit</th>
<th>Nb of units</th>
<th>Total (€)</th>
<th>Requested to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travels</td>
<td>150</td>
<td>20 days</td>
<td>3000</td>
<td>IN2P3</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>4 travels</td>
<td>4000</td>
<td>IN2P3</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>7000</td>
<td></td>
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</table>

Funding from Japan

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<tr>
<th>Description</th>
<th>k¥/Unit</th>
<th>Nb of units</th>
<th>Total (k¥)</th>
<th>Requested to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel</td>
<td>150</td>
<td>10</td>
<td>1500</td>
<td>KFK</td>
</tr>
<tr>
<td>Visit to France</td>
<td>20/day</td>
<td>150</td>
<td>3000</td>
<td>KFK</td>
</tr>
<tr>
<td>Travel + per diem</td>
<td>300</td>
<td>10</td>
<td>3000</td>
<td>KFK</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>7500</td>
<td></td>
</tr>
</tbody>
</table>

✓ French; 10 people asking 7000€ for travel
✓ Japanese; 9 people asking 7500k¥ for support
✓ New application to FJPPL
✓ Asking support for DCal/EMCal projects,
  ● which has emerge as rapid growing projects at ALICE
  ● Tighten Japan-France-USA-Italy-China collaboration
  ● Daily collaboration between Japan-France
    ➡ Two students/PD will stay Nates, Grenoble,„,„