Exploitation of hard electromagnetic probes and jets to study the QGP with LHC-ALICE

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2013 Joint Workshop of the France-Japan (TYL) and France-Korea (FKPPL) Particle Physics Laboratories

June 4, 2013
Yonsei University, Seoul, Republic of South Korea
Outline

1. Introduction
2. What have we learned on QGP so far, and where we go?
3. ALICE experiment and Di-jet Calorimeter project
4. Proposal (LHC_05) in FY2013
5. Summary
I. Introduction
What is Quark Gluon Plasma (QGP)?

- De-confined state of quarks and gluon inside hadrons under the extremely high temperature and energy density
  - New and still unknown state of matter.
- Lattice QCD calculations:
  - Critical temperature: $T_c = 150-200$ MeV
  - Crossover phase transition from hadronic phase to parton phase.

![Diagram of Quark Gluon Plasma](image)

$L = -\frac{1}{4} G_{\mu \nu}^a G^{\mu \nu}_a + \bar{q} \gamma^\mu (i \partial_\mu - g t^a A^a_\mu) q - m\bar{q}q$
Quark-Gluon Plasma (QGP)

Time: few μ sec after the big bang.
Temperature: 2 Trillion K
Energy density: > 1 GeV/fm³
Experimental study on QGP by Relativistic Heavy Ion collisions

CERN-LHC (2009-), ring length ~27 km
$\sqrt{s_{NN}} = 2.76$ (5.5 design) TeV Pb-Pb
2.76, 7.0, 8.0 TeV p-p
5.02 TeV p-Pb

LHC-ALICE experiment:
36 countries, 129 institutions,
~1,000 collaborators.
The dedicated experiment to HI program and QGP study at LHC
2. What have we learned on QGP so far, and where we go?
First three years of Heavy Ion Programs at LHC (Run-1: 2009-2013)

- Initial temperature: $T_{\text{int}} \sim 304 \pm 51$ MeV $\sim 1.4 \times T_{\text{int}}$ (RHIC).
- Large radial and elliptic flow (ALICE, ATLAS, CMS)
- **Large jet quenching effect (ALICE, ATLAS, CMS)**
- Disappearance of excited $\Upsilon$ states (evidence for creation of high temperature matter, CMS)
Jet quenching (energy loss of parton in QGP)

1) Decrease of high momentum particle yields
   - No observation at lower colliding beam energy (e.g. SPS)
2) Disappearance of back-to-back jets
3) Energy loss \( \sim \) few GeV/fm
   - Cannot explained by hadron gas.
   - \( \rightarrow \) One of the evidences of QGP formation
Jet quenching is one scattering (with cross section $d^* / dt$, where $t = Q^2$ is the momentum transfer squared) in a medium of temperature $T$, is:

$$\langle E_1^{\text{scat}} \rangle \approx Z E / dI_{\text{rad}} / dt,$$

(4)

Radiative energy loss through inelastic scatterings within the medium (Fig. 3, right), dominates at higher momenta. This loss can be determined from the corresponding single- or double-differential photon or gluon Bremsstrahlung spectrum ($/dI_{\text{rad}}/dk^2$, where $/dI_{\text{rad}}/dk^2$ are respectively the energy and transverse momentum of the radiated photon or gluon):

$$E_1^{\text{scat}}_{\text{rad}} = Z E / dI_{\text{rad}} / dt,$$

or

$$E_1^{\text{scat}}_{\text{rad}} = Z E / d^2I_{\text{rad}} / d(k^2 d\gamma^2).$$

(5)

For incoherent scatterings one has simply:

$$E_{\text{tot}} = N \cdot E_1^{\text{scat}},$$

where $N = L / (\text{is the medium opacity. The energy loss per unit length or stopping power}^7$ is:

$$-dE / dl = \langle E_{\text{tot}} \rangle / L,$$

(6)

which for incoherent scatterings reduces to:

$$-dE / dl = \langle E_1^{\text{scat}} \rangle / (\text{.}

Energy losses in QED

As an illustrative example, we show in Fig. 4 the stopping power of muons in copper. At low and high energies, the collisional (aka "Bethe-Bloch") and the radiative energy losses dominate respectively.

- In case of QED...

Energy loss of charged particle in a matter

Collisional
- Bethe-Bloch

Radiative
- Bethe-Heitler (thin; $L << \lambda$)
- Landau-Pomeranchuk-Migdal (thick; $L >> \lambda$)

✓ $dE/dx$ measurement $\rightarrow$ determination of matter properties

- $dE/dx$ in QED plasma $\rightarrow$ gives $T$ & $m_0$
In case of QCD:
Energy loss in QGP

Collisional
\( \Delta E \propto \ell^1 \)

Radiative
\( \Delta E \propto \ell^2 \)

- Dominant energy loss is gluon radiation

✓ dE/dx meas. → Matter properties, jet tomography

- Jets and EM probes (photons):
  - Powerful tools for the study of QGP’s properties
Revealing of new QGP properties by jet

At LHC energy:

• Hard processes dominant compared to that at RHIC.
• New measurements based on jets

1) QGP medium response by jet propagation.

2) Heavy quark jet, di-jet, gamma-jet. → jet tomography.

3) Redistribution of lost energy, EOS, velocity of sound.

4) Interaction of heavy quark and strongly coupled QGP → (thermalization, interaction strength)

ALICE Di-jet calorimeter (2015-)
with soft particles

Unique measurements by LHC-ALICE

T. Chujo, 2013 Joint Workshop of FJPPL (TYL) and FKPL, Yonsei Univ. Seoul, Korea, June 1, 2013
3. ALICE experiment and Di-jet calorimeter upgrade
ALICE experiment (Run-1, 2009-2013)

**EMCal**
Lead-Scintillator Sampling Calorimeter
Δη = 1.4, Δφ = 100°
APD Photosensors

**PHOS**
PWO crystal EMC.
220° < φ < 320°, Δη = 0.24
high energy resolution ~3%/√E
γ trigger.

**TPC**
Charged particles Δη = 1.8.
Excellent momentum resolution.
Excellent PID and heavy flavor tagging.

FJPPL (TYL) and FKPPL, Yonsei Univ. Seoul, Korea, June 4, 2013
ALICE Dijet Calorimeter (DCal)

- Extension of the acceptance of EMCal.
- Lead-scintillator sampling type EMC with APD readout.
  - EMCal: $\Delta \phi = 113^\circ$
  - DCal: $\Delta \phi = 66^\circ$ (on opposite side of EMCal → good uniformity, less sys. uncertainty)
  - $\Delta \eta = 0.7$ for both EMCal and DCal + PHOS
  - Energy resolution: $\sim 10%/\sqrt{E}$
- Allow back-to-back hadron-jet, di-jet measurements in ALICE, with $R = 0.4$ jet cone radius, up to $p_T \sim 150$ GeV/c.
- Enhance jet, $\gamma$ trigger capability.
- Full energy scale for $\gamma$: 250 GeV.
ALICE-DCal Collaboration

China
Huazhong Normal University (CCNU), Wuhan

Finland
University of Jyvaskyla

France
LPSC Grenoble, Subatech Nantes, IPHC Strasbourg

Italy
INFN Catania (Armando Palmeri, Angela Badala), LNF Frascati (Alessandra Fantoni)

Japan
Hiroshima University, University of Tokyo, University of Tsukuba

Switzerland
CERN

USA
Lawrence Berkeley National Laboratory, Wayne State University, University of Houston, University of Tennessee, Lawrence Livermore National Laboratory, Yale University, Oak Ridge National Laboratory, Creighton University, Cal Poly San Luis Obispo, Purdue University
France-Japan collaboration for ALICE-DCal (2008-)

Institute & People

LPSC Grenoble (FR)
- Christophe Furget
- Jean-François Muraz

Subatech Nantes (FR)
- Manoel Dialinas
- Magali Estienne

IPHC Strasbourg (FR)
- Christelle Roy

Tsukuba (JP)
- Y. Miake, S. Esumi, M. Inaba, T. Chujo

Contributions to DCal

LPSC Grenoble:
- module straps, SM cables, platform,
- shipping boxes, SM assembly, Calibration

Subatech Nantes:
- DCal SM installation tool, support structure, integration
- DCal strip module production, DCal strong back

Tsukuba:
- DCal module production (1 1/3 SM out of 6 + 2/3 SM)
All modules are stored in Grenoble & CERN.

← 2012.12 (done by LPSC, Grenoble)

APD gain calibration (dispersion <1.2%)

← 2011.07 (@ Univ. of Tsukuba, final shipping prep.)

DCal Super modules
2013.03 (LPSC, Grenoble)
DCal SM insertion test

2013.05 (CERN, P2)
Load test of DCal support frame
2012.10 (CERN, P2)
1.35 * nominal load (6 DCal supermodules + .4 PHOS modules + 2 DCal minisupermodules).
DCal support frame
2013.05 (CERN, P2)
SM insertion test is underway.
Space for DCal (and PHOS)

**DCal installation schedule:**

- **Physics data taking will start from LHC Run-2 (2015-).**
Perspective of physics with DCal: Medium response with jets

- Excellent hadron PID (0.15 – 20 GeV/c) and photon ID, suitable detector to measure the medium response with jet ID triggered by EMCal.

- Bulk properties (PID spectra, $v_n$, HBT, etc.) with a large jet energy imbalance.

- Key to access $c_s$, EOS?
4. Proposal (LHC_05) in FY2013
# LHC_05 Members

**FJPPL (TYL) application 2013-2014**

*Fiscal year april 1st 2013 – March 31st 2014*

*In red are example to be replaced by the appropriate data in black*

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<tr>
<td><strong>Leader</strong></td>
<td><strong>French Group</strong></td>
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<tr>
<td>Yves Schutz</td>
<td>Leader: DR1</td>
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<tr>
<td>Christelle Roy</td>
<td>Deputy leader: DR2</td>
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<td>Christophe Furger</td>
<td>Dr</td>
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<td>Renaud Vernet</td>
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<td>Rachid Guernane</td>
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<td>Julien Faivre</td>
<td>MC</td>
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T. Chujo, 2013 Joint Workshop of FJPPL (TYL) and FKPPPL, Yonsei Univ. Seoul, Korea, June 4, 2013
Activities in FY2012 (+FY2013)

- **DCal:**
  - EMCal (DCal) new readout electronics, SRU (Scalable Readout Unit, SRU), tested at CERN and Tsukuba.

- **Data analysis:**
  - $\pi^0$-jet, hadron-jet correlations in p-p, Pb-Pb.
  - Developed analysis with Grenoble group.
  - One M2 student (Tsukuba) and a staff (TC) stayed at LPSC Grenoble (2 weeks, Mar. 2013)

**FJPPL support in 2012**

$\pi^0$-jet correlations in p-p (D. Watanabe)

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Our proposal in FY2013

1) DCal installation and commissioning (including SRU readout) at CERN.

2) Collaboration with French Groups for jet/ direct photon analysis.
   ➡ FJPPL + JSPS-CRS bilateral research program (2013-2015, rep.TC)
   ➡ Plan to have a France-Japan mini-workshop on ALICE data analysis in Japan in this fall or winter.

✓ Request for funding for travels (Japan ⇌ France) and staying cost (both Japan, France)

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Summary

✓ ALICE Di-jet calorimeter (DCal) project is well proceeded, France-Japan collaboration keeps playing an important role in this project.

✓ DCal will be installed during LS1 (2013-2014), and start physics data taking from LHC Run-2 (2015-).
✓ Expected unique physics programs using di-jet and photons with soft particles.
  - QGP medium response by jets, jet tomography, EOS etc..
✓ Requested travel support in FY2013 to keep this strong and excellent collaboration between France and Japan for both detector and data analysis in ALICE.
Back up slides
DCal Activities at Tsukuba (History, 2008-)

- Dec. 2008: Visited Wayne State Univ., and leaned how to build EMCal.
- Feb. 2009: DCal presentation to the ALICE Upgrade management.
- Mar. 2009: DCal presentation to the ALICE MB (also at ALICE upgrade forum).
- Oct. 2009: ALICE MB/CB approved 6B configuration. The orders of the major components have been completed.
- Aug. 2010: All components delivered (delayed due to Scint. production).
- Oct. 2010: Started mass production at Tsukuba.
- Nov. 2010: Send materials to Catania, and assemble (2 people from Tsukuba)
- Nov. 2010: Catania team visited Tsukuba
- (Mar. 2011): Earthquake
- May 2011: Restarted module assembly
- Feb. 2012: First Japanese DCal super module has been fully calibrated at Grenoble.
DCal components

- Lead
- Paper
- Scint.
- Module (77 layers)
- 4 APD/module
- Strip (12 modules)
- DCal (6 S.M.)
- S.M. (192 modules)