HAD_01:
Measurements of Jets and Photons in Heavy Ion Collisions at the Highest Beam Energy during the LHC-Run 2 by ALICE

Tatsuya Chujo (Univ. of Tsukuba)
2015 Joint Workshop of TYL/FJPPL and FKPPL (Particle Physics Laboratories) @OIST

May 20, 2015
OIST, Okinawa, Japan
Outline

1. Introduction
3. Project proposal (2015-2016)
4. Summary
I. Introduction
Quark Gluon Plasma (QGP)

- De-confined state of quarks and gluon inside hadrons under the extremely high temperature and energy density
- Lattice QCD calculations:
  - Critical temperature: $T_c = 150\text{-}200\ \text{MeV}$
  - Crossover phase transition from hadronic phase to parton phase.
- A primordial state of universe, after few micro second of Big Bang.
Experimental study on QGP by Relativistic Heavy Ion collisions

CERN-LHC (2009-)
\( \sqrt{s_{NN}} = 2.76 \) (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
Probing QGP by Higher harmonics

Fluctuations of the Universe

Plank (2013)
Determination of cosmological parameters

Power spectrum

Fluctuations of Little bang

ALICE, Sep, 2011

Heavy Ion Collisions
Initial condition, QGP property (e.g. $\eta/s$)

Fig. 1. Left: correlation function for charged hadron pairs from head-on Pb–Pb collisions. Right: corresponding spectrum of Fourier harmonic amplitudes vs. $n$. 8th!
LHC Heavy Ion Physics Highlights (Run-1: 2009-2013)

- Initial temperature: $T_{\text{int}} \approx 304 \pm 51$ MeV
  - $\sim 1.4 \times T_{\text{int}}$ (RHIC).
- Denser ($\sim x2$) and longer lifetime w.r.t RHIC
- Strong collective flow, jet quenching.
- Disappearance of excited $Y$ states, evidence for creation of high temperature matter
- Recombination of $c$-$c\bar{c}$ pairs ($J/\psi$)
- Collectivity in small system p-Pb, p-p (high multip.)
- ...

**Jet quenching**

**Thermal photon radiation**

![Thermal photon radiation graph](https://example.com/thermal.png)

**Y family melting**

![Y family melting graph](https://example.com/yfamily.png)
Energy balance by low $p_T$ particle at large angle

Net-$p_T$ along the sub-leading jet

$$\sum_i p_T^i \cos(\phi_i - \phi_{Leading\ Jet})$$

CMS (2011)

$$\Delta R = \sqrt{\Delta \phi^2 + \Delta \eta^2} = 0.8$$

Leading Jet

$A_J = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}}$
QGP fluid + jet model

Fluid expanding strongly in the longitudinal direction

- (3+1)-D perfect QGP-fluid (PPM)
- Expanding coordinate system $(\tau, x, y, \eta)$
- New scheme at high precision
- Initial condition of the energy density
  $\eta : \text{Flat + Gaussian}$
  $x, y : \text{Glauber model (Pb-Pb, central coll.)}$

Di-jet

- Massless
- Back to back same energy jets
- Traveling straight in the plane $\eta = 0$

$A_J = \frac{p_{T1} - p_{T2}}{p_{T1} + p_{T2}}$
Mach cone; EOS dep.

- Different $c_s$ for Ideal and lattice, different angle.
- Possibility to measure $c_s$ (EOS) by soft hadron angle.

Y. Tachibana, T. Hirano, PRC 90, 021902(R) (2014)
Keys to understand dE/dx in QCD plasma

1. Control path length (parton scattering point)
2. Energy calibration (e.g. γ-jet)
3. Detection of medium response by jet (parton) propagation
Our project goals:

• To perform high precision measurements and to develop original physics data analysis during the LHC Run-2 (2015-2018) for the quantitative determination of QPG properties at the highest temperature.

• Particular emphasis on jets and photons measurements, Japan and France in ALICE, by EMCal/DCal detectors, which has been built within the framework of France-Japan collaboration.

• Participation of Japan in the French lead upgrade project MFT (Muon Forward Tracker)
ALICE jet results (1)

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

- Observed jet suppression in Pb-Pb, un-modified in p-Pb.

Pb-Pb 2.76 TeV

- Charged particles
  - ALICE (0-10%)/(50-80%)
  - CMS (0-5%)/(50-90%)
  - ATLAS Calo Jets R=0.3 (0-10%)/(60-80%)

p-Pb 5.02 TeV

- Charged jets ALICE Preliminary
- anti-\(k_t\) R=0.4, \(|\eta_{\text{lab}}|<0.5\)
- Charged hadrons, NSD, \(|\eta_{\text{ cms}}|<0.3\)

- Normalization
- Uncertainty reference + Glauber (charged jets)

\( p_T^{\text{track}}, p_T^{\text{jet}} \) (GeV/c)
Path length “control” experiment

**π^0-jet correlations**

From TDR ALCE-DCal
(work done by H. Yokoyama, M. Sano)

- Hard scattering point (in x-y plane) of trigger π^0 with associate recoil jet.
- The higher E_T π^0, the stronger surface bias.
- \( \langle q\text{-hat} \rangle = 20 \text{ & } 50 \text{ GeV}^2/\text{fm} \)
  - small difference.
  - can be used as geometry measure of emission point, without knowing the quench parameters.

2015 Joint Workshop of TYL/FJPPL and FKPPL @ OIST, May 20, T. Chujo (U. Tsukuba)
π⁰-jet correlations in pp (7TeV)

- Provide an important baseline data for Pb-Pb.
- Clear back-to-back jet peak is seen, and narrower width with increasing jet $p_T$ and trigger $\pi^0$ $p_T$.
- Now analyzing Pb-Pb data.
DCal (Di-jet Calorimeter) in ALICE

- Jet measurement including neutral particles, Electromagnetic Calorimeter for jet trigger, DCal.
- **Japan-France-US-Italy-China collaboration in ALICE**
- 2009: ALICE approval. supported by FJPPL.
- 2011: Finished all module production in Tsukuba and shipped them to France
- 2013/2014: all SM tested at CERN (D. Watanabe, N. Tanaka, et al.)
- 2013-2015: EMCal/DCal/PHOS L1 jet trigger development (H. Yokoyama, R. Hosokawa, R. Guernane)
  - Tsukuba-Grenoble collaboration for jet trigger.
- **2014 Nov.: Installation completed in ALICE P2**
- EMCal/ DCal detector, deputy project leader: T. Chujo (2013.11-)
DCal detector modules before installation
(Sep. 2013 @ CERN, ALICE assembly area)
DCal detector modules after installation
(Nov. 2014 @ CERN, ALICE)
EMCal/ DCal/ PHOS Jet L1 trigger

Jet trigger efficiency
(w/ BG subtraction from DCal side)

Rejection factor
(w/ BG subtraction from DCal side)

↑ DCal + PHOS trigger patch (H. Yokoyama)

H. Yokoyama, R. Hosokawa, R. Guernane, J. Kral, T. Chujo

• Grenoble LPSC - Tsukuba- Jyvaskyla team for L0/L1 trigger
  • Tsukuba: EMCal/ DCal /PHOS Level-1 jet & photon trigger, FPGA firmware development.
• Reasonable turn-on curve on jet trigger.
• Rejection factor $10^4$ at 30 GeV jet.
Frist workshop in Tsukuba (March 3-7, 2014) within the framework of France-Japan ALICE collaboration. @ Univ. of Tsukuba, ~80 participants [FJPPL supported]
2nd workshop in Sante-Maxime (March 15-16, 2015)
“ALICE physics analysis workshop”
~30 participants [FJPPL supported]
Dual Degree Program (Ph.D) 
Grenoble U. - U. of Tsukuba

• Grenoble University (Joseph Fourier) and University of Tsukuba, agreed to start the joint double degree program (Ph.D) in 2015.

• Supervised by two institutes (Grenoble and Tsukuba) on same thesis topics.

• Ph.D degrees will be obtained from both Grenoble and Tsukuba after successful defense.

  • Hiroki Yokoyama (U. Tsukuba): started April 2015.
    • “π0-jet correlations in p-Pb”, jet trigger
  • Ritsuya Hosokawa (U. Tsukuba): will start Sep. 2015.
    • “Full jet pT spectra in 13 TeV p-p and 5.1 TeV Pb-Pb”, jet trigger

• They are the first students for this program, both worked on ALICE.
MFT: Muon Forward Tracker, proposed in ALICE (-4.0 < \(\eta\) < -2.5)

- Silicon pixel tracker in Muon Spectrometer
- Separation of charm/beauty down to very low \(p_T\)
- Precise \(\psi(2s)\) measurement even in central Pb-Pb
- Prompt and non-prompt \(J/\psi\) separation
- Improve S/B ratio and mass resolution for Low Mass di-muons

The MFT project has been approved by the ALICE Collaboration to be part of the ALICE upgrade planned for the LHC LS 2017/2018. Hiroshima G. joined for this project in 2014.
3. Project Proposal
(2015-2016)
ALICE Run-2 (2015-2018) and DCal, jet physics

• Highest beam energy ever at LHC in Run-2 (2015-2018)
  – pp ( $\sqrt{s} = 13$ TeV)
  – Pb-Pb ( $\sqrt{s_{NN}} = 5.1$ TeV)
  – p-Pb ( $\sqrt{s_{NN}} = 5.1$ TeV?)

• Longest, hottest, and largest QGP creation at LHC

• 2015 plan:

Proton-proton collision at 900 GeV as determined by the inner silicon trackers in the ALICE detector (Image: ALICE/CERN)

http://home.web.cern.ch/about/updates/2015/05/low-energy-collisions-tune-lhc-experiments
Our proposal (2015-2016)

- Run-2 start-up, and first physics data taking by DCal.
- Successful operation of EMCal/DCal operation, jet trigger
- Physics outputs from EMCal/DCal.
- Data analysis in Run-1 and new Run-2, will be presented at Quark Matter 2015 international conference, Kobe, Sep-Oct, 2015, Japan (French collaborators will be invited).
  - H. Hamagaki (chair)
- Double degree PhD program for two students.
- Further involvement of MFT project.

qm2015.riken.jp
# FJPPL (TYL) application 2015-2016

**Fiscal year April 1st 2015 – March 31st 2016**

Please replace the red examples by the appropriate data in black

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<td>LHC_8</td>
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| French Group | | Japanese Group |
|--------------|:|----------------|
| **Leader**  | Yves Schutz | Tatsuya Chujo |
| Deputy leader | Christophe Furger | Yasuo Mianne |
| Members      | Gustavo Conesa Balbastre | ShinIchi Esumi |
|              | Renaud Vernet | Toru Sugitate |
|              | Magali Estienne | Kenta Shigaki |
|              | Marie Germain | Hideki Hamagaki |
|              | Rachid Guernane | Taku Gunji |
|              | Julien Faivre | Motoi Inaba |
|              | Gines Martinez | Hiroshi Masui |
|              |                  | Ken Oyama |
|              |                  | Yosuke Watanabe |
|              |                  | Oliver Busch |

Lab./Organis.:
- SUBATECH
- LPSC
- CCIN2P3
- NiAS

Lab./Organis.:
- U. Tsukuba
- U. Tsukuba Tech.
- U. Hiroshima
- U. Tokyo

Positions:
- Dr
- Pr
- MC
**HAD_01: Funding request (2015-2016)**

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<th>Description</th>
<th>€/unit</th>
<th>Nb of units</th>
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<td>Stay in Japan (local expense)</td>
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<th>Nb of units</th>
<th>Total (¥)</th>
<th>Requested to</th>
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<tr>
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<td>4 travels (Round trip)</td>
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<td>Stay in France (students, for the double degree program)</td>
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<td>600 KEK</td>
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<td><strong>Total</strong></td>
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<td><strong>1,200</strong></td>
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* In addition to a support from France, we would like to ask for a support from KEK to conduct PhD double degree program for 2 students (Grenoble-Tsukuba)
4. Summary

✓ 2014-2015:

- ALICE DCal has been finally installed to ALICE experimental area successfully.
- Jet Level 1 trigger development has been completed within the FJPPL framework.
- Ready for the physics data taking in Run-2.
- Grenoble-Tsukuba PhD double degree program has been newly launched in 2015.
- Newly involved in the MFT project in 2014 (Hiroshima).

✓ 2015-2016:

- **DCal first data, physics outputs on jet from ALICE w/ DCal.**
  (1) Develop double degree program
  (2) QM 2015 international conference in Kobe, Sep-Oct, 2015, French collaborators will be invited.
- Asked TYL-FJPPL support for both (1) and (2).
Backup slides
LHC schedule beyond LS1

Only EYETS (19 weeks) (no Linac4 connection during Run2)

LS2 starting in 2018 (July)  18 months + 3 months BC (Beam Commissioning)

LS3 LHC: starting in 2023 => 30 months + 3 BC

Injectors: in 2024 => 13 months + 3 BC

LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators

Monday 2nd December 2013
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 ~ few GeV/fm
   - Cannot explained by hadron gas.
   - One of the evidences of QGP formation