Recent Results from LHCf

Gaku Mitsuka (Nagoya University, Japan) for the LHCf collaboration
Outline

- Introduction and Physics motivation
- The LHCf detectors
- Status of the LHCf experiment
  - First results at $\sqrt{s}=900\text{GeV}$ and 7TeV
    - All data at $\sqrt{s}=900\text{GeV}$
    - Focusing on March-May at $\sqrt{s}=7\text{TeV}$
- Conclusions and Future prospects
Totally ~40 collaborators

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Introduction

The LHCf experiment...

- aims to reduce the uncertainty of hadron interaction models around the TeV energy region using LHC, which are mainly used in cosmic ray experiments.
- observes neutral particles produced by the p-p collisions emitted in the very forward (including zero degree, $\eta>8.4$), equivalent to air-shower of cosmic ray.
- can discriminate the existing interaction models (e.g. DPMJET3, QGSJET, etc...) by comparison and provide crucial data for building future models.
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Forward measurements

- Zero degree instrumentation slot at 140m away from IP1 (ATLAS).
- p-p collision at $\sqrt{s}=14\text{TeV}$ corresponds to $E_{\text{lab}}=10^{17}\text{eV}$. 
Forward measurements

Fluxes of Cosmic Rays

Interests of UHE-CR obs.

$p$-p collision at $\sqrt{s}=14\text{TeV}$ corresponds to $E_{\text{lab}}=10^{17}\text{eV}$.

Documentation slot at 140m away from IP1 (ATLAS).
The LHCf detector

- Sampling & imaging calorimeters either side of IP1.
- Two compact towers in both detectors.
  - Tungsten absorbers: 44r.l., 1.7λ
  - 16 plastic scintillator sampling layers
  - 4 position sensitive layers

**Arm1 detector**
- 20mmx20mm + 40mmx40mm
- Consists of scintillation fibers
- Located at 6, 10, 30, 42 r.l.

**Arm2 detector**
- 25mmx25mm + 32mmx32mm
- Consists of silicon strip detector
- Located at 6, 12, 30, 42 r.l.
Single $\gamma\pi^0$ Expected phenomena

DPMJET3 | QGSJET1 | QGSJET2 | SIBYLL

30% Energy Resolution

Spectrum in the forward region at 140m away from IP (=LHCf site).

Energy resolution is taken into account by smearing the true energy instead of detector simulation.

Neutron/Gamma ratio is also applicable to the discrimination.

All figures assume $10^7$ collisions@14TeV

Vertical bar indicates stat.err

Particles/collision

Particles/(200GeV)
Operation in 2009-10

**Run in 2009**

- From End of October 2009 LHC restarted operation
  - 450 GeV + 450 GeV → 1.2 TeV + 1.2 TeV
- Few weeks of ‘smooth’ running allowed LHCf to collect some statistics at 450+450 GeV in the stable beam conditions.
- Extremely useful period to debug all the system
  - No particular problem came out from the run
  - Detectors are working very well and in a stable way

**Run in 2010**

- Successful data taking at 7TeV ongoing
  - Integrated luminosity ~ 14nb⁻¹ until the technical stop on May.
  - 35M showers and 330K π⁰s obtained (arm1+arm2).
  - Energy scale calibration with a π⁰ peak.
- Statistics improved at 900 GeV >10times larger than 2009.
- Detector shows good performance with stable quality.
  - Good stability < ±2% level. No radiation problem until May.
Analysis@900GeV
(Run2009+2010)
Gamma and hadron showers can be discriminated by the difference of the longitudinal shower development.

Longitudinal development is parametrized with L20% and L90%.

PID performance is checked with SPS calibration data taken in 2007.
- 50-200GeV for electrons
- 150, 350 GeV for protons

~90% purity both for gamma and hadron.

PID study is still ongoing.
Spectra of 900GeV data

- QGSJET2 seems to agree with data, *but conclusion is too early.*
- Note that the detector response for hadron showers is under study with SPS 350,150GeV proton data and very conservative systematic error for energy scale +10%-4% must be taken into account.

More precise analysis is ongoing.
Analysis@7TeV
Data taking has been carried out quite stably.

<table>
<thead>
<tr>
<th></th>
<th>Gamma-like</th>
<th>Hadron-like</th>
<th>$\pi^0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm1</td>
<td>1.7E7</td>
<td>3.3E7</td>
<td>1.0E5</td>
</tr>
<tr>
<td>Arm2</td>
<td>1.8E7</td>
<td>3.5E7</td>
<td>2.3E5</td>
</tr>
</tbody>
</table>
Event display of π⁰(2-gamma)

Lateral view

Longitudinal view

π⁰ mass

Arm I
σ = 6.3MeV

π⁰ energy

Extremely high energy π⁰

Energy (GeV)

Invariant mass (MeV)

R

θ = \frac{R}{140m}
Spectra of 7TeV data

- **High statistics**
  - Only 1% of total data are used
- **Very clean sample**
  - Beam-gas BG is ~ 1%

**Ongoing studies:**
- Model discrimination
- \( \eta \), strange meson
- LPM effects
$\eta$ search

$\pi^0$

$\eta \sim 50$ events
LHCf will go out from the TAN(LHCf site) day after tomorrow.
- Plastic scintillator degrades a few % by ~6Gy on July 15th (~200nb⁻¹).

“Post”-calibration by a SPS test beam are planned on October.

Revisit LHC at the next energy upgrade. R&D and fabrication of radiation-hard GSO scintillator are on-going for the “phase-2” of the LHCf detector.

GSO bar

GSO scintillator
Conclusions

- LHCf has started physics program quite successfully.
  - 100K showers at 900GeV (Run2009 + 2010)
  - 35M showers and 330K $\pi^0$ at 7TeV (Run2010 until May technical stop)

- Detectors work fine and stably.
  - Almost negligible beam-gas background $\sim$1%
  - The $\pi^0$ peak demonstrates good performance as expected.

- Detectors will leave LHC tunnel on Tuesday.

- Rapid progress in analysis.
  - 900GeV results and 7TeV results, need more precise studies
  - Finalizing SPS beam test data (energy scale, PID and hadron shower)
Supplements
Measurements of very forward particles using the highest energy accelerator have a key to constrain the uncertainties unavoidable in the high-energy cosmic ray experiments.
Detector box...
- is hanged by the manipulator.
- is movable vertically about 120mm.
- stands by during non-“stable beam” to avoid an accumulated dose.
Front Counter

Front counter...
- consists of 4 scintillation counters, 2 for X and 2 for Y.
- has large aperture (80mm x 80mm).
- can work prior to the stable beam declaration.
- acts as the luminosity monitor and beam-gas BG monitor.

Movable depending on the beam status

Neutral particles

Beam pipe

TAN

Lumi-scan

Gaussian fit

Arm1

Arm2

Coincidence

LHCf Experiment page

Front Counter Count Rate

OP Vistars
Detector Stabilities

Calorimeter

**Pedestal fluctuation**

**ADC counts**

- 450GeV collision
- (+/-2%)

**Light yield by N² laser**

**ADC counts**

- 450GeV collision
- (+/-2%)

Pedestal (Scifi)

- 10 counts

Pedestal (Silicon)

- 10 counts

450GeV collision
Analysis of 900GeV run

  - \( \sim 5 \times 10^5 \) collisions at IP1.
  - 2,800 and 3,700 showers in Arm1 and Arm2.
- Absolute energy calibration by \( \pi^0 \) taken at 7TeV run.

Expected spectra with \( 10^7 \) collisions.

Large model dependence can be seen even in 900GeV.
Detector stability

Gain calibration with $N^2$ laser for scintillator layers

Stable within 2% for all period

$\pi^0$ mass time variation

$\pm 2\%$
Particle Hit-maps

Particles originated in the p-p collision should be enclosed inside the pipe projection.

Gamma-like, $E_{\text{rec}} = 1$ TeV

Longitudinal shower development

X-view of silicon strip

Y-view of silicon strip
Air shower development
QGSJET2, Arm1-Normal

Generation Distribution of QGSJET2

Geometrical Efficiency for $\eta$

Expected measurement distribution

$\eta$

Generation Distribution of $\pi^0$ QGSJET2

Geometrical Efficiency for $\pi^0$

Expected measurement distribution

$\pi^0$
## Summary of Expected number of events

<table>
<thead>
<tr>
<th></th>
<th>QGSJET2</th>
<th>SIBYLL</th>
<th>Pythia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\eta$</td>
<td>$\pi^0$</td>
<td>$\eta/\pi^0$</td>
</tr>
<tr>
<td><strong>Arm1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Normal)</td>
<td>0.08</td>
<td>46.9</td>
<td>0.002</td>
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<tr>
<td><strong>Arm1</strong></td>
<td>7.35</td>
<td>238.4</td>
<td>0.031</td>
</tr>
<tr>
<td>(-20mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Arm2</strong></td>
<td>1.6</td>
<td>123.7</td>
<td>0.012</td>
</tr>
<tr>
<td>(Normal)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Arm2</strong></td>
<td>3.36</td>
<td>191.3</td>
<td>0.018</td>
</tr>
<tr>
<td>(-10mm)</td>
<td></td>
<td></td>
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Acceptance gain due to Crossing Angle

No crossing angle

100 $\mu$rad crossing angle

A very significant gain in acceptance is clearly visible!