Performance of LHCf in Run II

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on behalf of the LHCf collaboration

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The LHCf collaboration


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LHCf is one of the LHCf forward experiments, motivated for testing the hadronic interaction models used in the air shower simulations for Ultra-High Energy Cosmic Rays UHECRs (~ $10^{20}$eV) at LHC

**Key Parameters**

- Inelastic Cross Section → TOTEM, ATLAS, CMS, ALICE
- Forward Energy Spectrum → LHCf, ZDC and etc.
- Inelasticity $k = 1 - p_{\text{lead}} / p_{\text{beam}}$ → LHCf, ZDC and etc.
- Multiplicity → Central detectors
- + Nuclear Effect @ CR-Air
Two LHCf detectors (Arm1 & Arm2) are installed into the very forward region of the LHC interaction point (IP1). LHCf can measure neutral particles ($\gamma$, $n$) at the rapidity range $\eta > 8.4$. 
The LHCf detectors

**Sampling and Positioning Calorimeters**
- \( W \) (44 r.l, 1.7\( \lambda_1 \)) and Scintillator x 16 Layers
- Four positioning sensitive layers
  - XY-Scintillator bars (Arm1) and XY-Silicon strip (Arm#2)
- **Each detector has two calorimeter towers, which allow to reconstruct \( \pi^0 \)**

**Expected Performance**
- Energy resolution (> 100GeV)
  - < 5% for Photons
  - 40% for Neutrons
- Position resolution
  - < 200\( \mu \)m for Photons
  - a few mm for Neutrons

**Front Counter**
- thin scintillators with 80x80mm\(^2\)
- To monitor beam condition.
- For background rejection of beam-residual gas collisions by coincidence analysis
The LHCf detectors

- Arm1 Detector
- GSO Scintillator
- Silicon strip detector
- Detector in the LHC tunnel
Results in Run I

**pp, 7TeV Photon**
- PLB 703 (2011) 128-134
- PLB 715 (2012) 298-303

**pp, 7TeV Neutron**
- Submitted to PLB (arXiv:1503.03505)

**pPb, 5TeV**
- PRD 86 (2012) 092001
- Submitted to PLB (arXiv:1507.08764)

**LHCf √s=7TeV π^0**
- 8.9 < y < 9.0
  - PRC 89 (2014) 065209

**LHCf √s=7TeV γ**
- 10.94 < η < 10.96
Operation in 2015

- LHCf physics operation with pp $\sqrt{s}=13\text{TeV}$ has been completed!!
  - LHCf detectors were installed in Nov. 2014
  - Special physics operation with low pile-up in 9 - 13 June 2015.
  - After the operation, LHCf detectors were removed on 15 June during TS1.

Photo @ CERN
Most of collaborators were in the front of the LHCf control room.
LHCf in Run II

- **Physics Motivation**
  - Test the hadronic interaction models at the highest collision energy. $E_{\text{Lab}}=0.9 \times 10^{17}\text{eV}$
  - Energy Scaling
  - Enlarge the $p_T$ acceptance.

- **Detector/DAQ upgrades for Run II**
  - Improved the radiation hardness with replacing Plastic scintillators → GSO scintillators
  - Modified the silicon strip detectors to improve the dynamic range.
  - Optimized the layer depths of silicon strip detector in Arm2.
  - Upgraded the trigger system with new logic board.
  - Installed a new layer system as a calibration source for PMTs
Special run in June 2015

- The LHCf dedicated run.
  - 6 physics fills
  - Low Pileup: $\mu = 0.01-0.03$
    - $\mu=0.01$ for photon, neutron analysis
    - $\mu=0.03$ for $\pi^0$ analysis

Coincidence-signal rate of Front Counters ($\propto$ Luminosity)

$\beta^*=19m, I_b=2 \times 10^{10}$  $\beta^*=19m, I_b=10^{11}$, separation collisions
Operation in Run II

- 26.6 hours of operation with DAQ rate of 200 - 500 Hz
- 39 M shower events and 0.53 M \( \pi^0 \) events were obtained.
- The final triggers of LHCf were sent to ATLAS for common operation.

<table>
<thead>
<tr>
<th></th>
<th>Arm1</th>
<th>Arm2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shower Events</td>
<td>18 M</td>
<td>21 M</td>
</tr>
<tr>
<td>( \pi ) Events</td>
<td>0.22 M</td>
<td>0.31 M</td>
</tr>
</tbody>
</table>
Arm1 Event Display

LHCf Arm1 Detector
π⁰ Candidate Event
LHC p-p, \( \sqrt{s} = 13 \text{ TeV} \) Collisions

\( E_{\gamma} = 323 \text{ GeV} \)

\( E_{\gamma} = 407 \text{ GeV} \)
Arm1 Event Display

LHCf Arm1 Detector

Arm2 Event Display

LHCf Arm2 Detector

\[ \pi^0 \text{ Candidate Event} \]

LHC p-p, \( \sqrt{s} = 13 \text{ TeV} \) Collisions

\[ E_\gamma = 323 \text{ GeV} \]
\[ E_\gamma = 407 \text{ GeV} \]

\[ E_\gamma = 1.01 \text{ TeV} \]
\[ E_\gamma = 1.02 \text{ TeV} \]
Peaks corresponding to $\pi^0$, $\eta$

- Event sample for measurement of $\pi^0, \eta$ inclusive spectra
- Evaluate the energy scale of calorimeters.

Energy thresholds for $\pi^0$ and $\eta$ detections

- For $\pi^0$: $E_{\pi^0} > 600\text{GeV}$
- For $\eta$: $E_{\eta} > 2.2\text{ TeV}$
Stability of Energy Scale

- The energy scales of detectors could be monitored by peak mass position of $\pi^0$.
- They were stable within a few %.

![Graph showing stability of energy scale over time with LHCf data at p-p $\sqrt{s} = 13$ TeV.](image)
The energy scales of detectors could be monitored by peak mass position of $\pi^0$.

They were stable within a few %.

- Gain of each PMT were also monitored by using a laser calibration system.
Signals of LHCf final trigger were sent to the ATLAS DAQ system to trigger the ATLAS.

**Physics Items of the common operation**

- **Diffractive Physics**
  Study of forward particle production with event category of diffractive/non-diffractive

- **Measurement of $p-\pi$ interaction**
  A MC study by PYTHIA

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**Diagram**

- **L1**
  - **L1_LHCF**
  - **L1_ID**
  - **Raw**
  - **Rec.**

- **Final Trigger**
  - **Raw**
  - **Rec.**

- **Merge**
LHCf had an operation in 9-13 June, 2015 with low-pileup collisions. In 26.6 hours operation, 39 M showers and 0.5 M $\pi^0$ events were obtained.

During the operation, the detectors and the DAQ worked without any problems. The energy scale of calorimeters were stable within a few %.

Common operation with ATLAS has been performed with sending the LHCf trigger to ATLAS.

Analysis for physics are on-going now.