Recent results from LHCf

G. Mitsuka (Nagoya University)  
on behalf of the LHCf Collaboration

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Outline

- Introduction and Physics motivation
- Status of LHCf
- Photon event analyses
  - 900GeV photon analysis
  - 7TeV $\pi^0$ analysis
- Conclusions and Future prospects
Introduction and Physics motivation

- Zero degree instrumentation slot at 140m away from IP1(ATLAS).
- p–p collision at $\sqrt{s}=14\text{TeV}$ corresponds to $E_{\text{lab}}=10^{17}\text{eV}$.
- Detectors are located at the best position to measure the large energy flow that strongly contributes the air-shower development.
**Status of LHCf**

### Physics program at CERN

**2004, 2006, and 2007**
- Calibration at SPS
  
  \( \text{(NIM A 671 (2012) 129–136)} \)

**2008**
- First data taking at 900GeV (only FC)

**2009**
- First data taking at 900GeV

**2010**
- Physics program at 900GeV/7TeV was completed
  
  \( \text{(Luminosity : JINST 7 T01003 (2012)} \)

  \( 7\text{TeV photon : Phys. Lett. B 703 128-134 (2011))} \)

- Post-calibration at SPS

**2012**
- Possibly pA run?
  
  \( \text{(CERN-LHCC-2011-015 ; LHCC-I-021)} \)

### R&D for 14TeV run

**2009, 2010**
- Beam test of GSO scintillator at HIMAC (JAPAN, Chiba)
  
  \( \text{(JINST 6 T0900 (2011))} \)

**2011**
- Beam test of the LHCf Arm1 detector with GSO scintillator at HIMAC (JAPAN, Chiba)

### Poster contributions
- The current status of LHCf experiment and Future plan (K. Kawade)
- LHCf plan for p-Pb forward particle measurement (T. Sako)
Photon event analysis

- Gain correction
- Peak search (as 1-hit)
- 1st energy reconstruction
- Peak search (multi-hit)
- Shower leakage & 2nd energy rec.
- Particle identification

- E<80(10)GeV → Single-hit
- E>80(10)GeV → Multi-hit

- Multi-hit
  - Large tower
  - 40mm

- Single-hit
  - Small tower
  - 20mm

- 1st energy reconstruction is needed to remove low-energy events where multi-hit selection efficiency is quite low.
- Only single-hit events are used in the following physics analysis, since the performance of energy reconstruction of multi-hit events is still worse.
Photon event analysis

- Gain correction
- Peak search (as 1-hit)
- 1st energy reconstruction
  - E ≤ 80(10)GeV
  - Peak search (multi-hit)
  - E > 80(10)GeV
- Single-hit
- Multi-hit
- Shower leakage & 2nd energy rec.
- Particle identification

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Photon event analysis

- **Gain correction**
- **Peak search (as 1-hit)**
- **1st energy reconstruction**
  - E > 80(10)GeV
  - E < 80(10)GeV
- **Peak search (multi-hit)**
  - Single-hit
  - Multi-hit
  - Shower leakage & 2nd energy rec.
  - Particle identification

- **Large tower**
- **Multi-hit**
- **Small tower**
- **Single-hit**

- 1st energy reconstruction is needed to remove low-energy events where multi-hit selection efficiency is quite low.
- Only single-hit events are used in the following physics analysis, since the performance of energy reconstruction of multi-hit events is still worse.
900GeV photon analysis

Photon like events are categorized into two rapidity ranges:
- $\eta > 10.15$
- $8.77 < \eta < 9.46$

Unavoidable PID inefficiency and impurity are corrected in each bin.
Integral luminosity $\sim 0.3\,\text{nb}^{-1}$, and uncertainty is 21%.
Independent data analysis using the Arm1 and Arm2 data show an overall good agreement within their systematic uncertainties.
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900GeV photon analysis

Combined data vs MC simulations

Preliminary
900GeV photon analysis

Suppose a Pt of \( \sqrt{s} = 900\text{GeV} \) events can be scaled to the Pt at \( \sqrt{s} = 7\text{TeV} \) as

\[
P_T(\sqrt{s} = 7\text{TeV}) = P_T(\sqrt{s} = 900\text{GeV}) \frac{7\text{TeV}}{900\text{GeV}}.
\]

Then the spectrum inside \( R = 5\text{mm} \) at \( \sqrt{s} = 7\text{TeV} \) would be equivalent to that \( R < 38.9\text{mm} \) at \( \sqrt{s} = 900\text{GeV} \).

No systematic error is considered in both collision energies, although this treatment may not change an impression of the comparison.

Good agreement of each \( X_F \) scaling spectrum indicates a weak Pt dependence of the energy spectrum.
7TeV π⁰ analysis

- Standard LHCf photon reconstruction
- Two-photon selection
- Invariant mass reconstruction
- Signal window
- Sideband
- BG subtraction
- Unfolding (det. response correction)
- Acceptance correction
- Combining Arm1 and Arm2

Event example of π⁰ candidate

- Imperfect detector response to π⁰ events should cause a large distortion of spectra, thus spectra must be corrected for the detector response.
- The LHCf detector cannot cover 2π azimuthally. Acceptance inefficiency is corrected as a function of $E_\pi$ and $P_T$. 
7TeV $\pi^0$ analysis

**Type-I**
- Large tower
  - $\pi^0$
  - Large angle
  - Simple
  - Clean
  - High-stat.

**Type-II**
- Large tower
  - $\pi^0$
  - Small angle
  - Large BG
  - Low-stat.
  - but can cover
    - High-E
    - Large-\(P_T\)

**Type-I sample**
- LHCf-Arm1

**Type-II sample**
- LHCf-Arm1
  - Type-II at large tower
  - Type-II at small tower

**LHCf-Arm1 Data 2010**
- Preliminary
  - BG
  - Signal
7TeV $\pi^0$ analysis

**Type-I**
- Large tower
- $\pi^0$
- Large angle
- Simple
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**Type-II**
- Large tower
- $\pi^0$
- Small angle
- Large BG
- Low-stat.
- but can cover
  - High-E
  - Large-$P_T$

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**Type-I sample**

- **Type-I** LHCf-Arm1
- Preliminary

**Type-II sample**

- **Type-II** at large tower
- LHCf-Arm1
- Data 2010

**LHCf-Arm1 π0 sample**

- **Type-II** at small tower
- BG
- Signal
- Preliminary
7TeV π⁰ analysis

- Remaining background spectrum is estimated using the sideband information, then the BG spectrum is subtracted from the spectrum made in the signal window.

\[ \text{Signal} = f(E, P_T)^{\text{signal}} - \]

\[ f(E, P_T)^{\text{BG}} \frac{\int_{\hat{M} - 3\sigma_u}^{\hat{M} + 3\sigma_u} \mathcal{L}_{BG} dM}{\int_{\hat{M} - 6\sigma_l}^{\hat{M} - 3\sigma_l} \mathcal{L}_{BG} dM + \int_{\hat{M} + 3\sigma_u}^{\hat{M} + 6\sigma_u} \mathcal{L}_{BG} dM} \]

- Detector responses are corrected by an unfolding process that is based on the iterative Bayesian method.

(G. D’Agostini NIM A 362 (1995) 487)

- Detector response corrected spectrum is proceeded to the acceptance correction.
7TeV $\pi^0$ analysis

- No energy-scale systematic uncertainty quoted.
- Consistent spectra are obtained between Arm1 and Arm2.
7TeV π⁰ analysis

7TeV photon spectra by LHCf

Photon analysis and π⁰ analysis compensate each missing information.
- High energy photon originates from large $P_T$ π⁰ events.
- Photon spectrum includes a contribution from other hadrons/baryons.

Conclusions and Future prospects

- LHCf has measured the energy and transverse momentum spectrum of the forward emitted particles at the 900GeV and 7TeV proton–proton collisions.

- Feynman scaling spectrum of the 900GeV and 7TeV photon events agree well each other. This may indicate a weak dependence of energy spectrum on its $P_T$.

- Consistent $\pi^0$ spectra are obtained between the Arm1 and Arm2 detector. Combined spectra and a comparison with various hadronic interaction models will be available soon.

- Many analyses are ongoing:
  - Photon $P_T$ analysis
  - Hadron event analysis
  - p–Pb capability
Backup
7TeV photon analysis

LHCf $\sqrt{s}=7$TeV
Gamma-ray like
$\eta > 10.94$, $\Delta \phi = 360^\circ$

LHCf $\sqrt{s}=7$TeV
Gamma-ray like
$8.81 < \eta < 8.99$, $\Delta \phi = 20^\circ$
7TeV $\pi^0$ analysis

- **LHCf $\sqrt{s}=7$TeV $\pi^0$**
  - $9.0 < y < 9.2$
  - $9.2 < y < 9.4$
  - $9.4 < y < 9.6$
  - $9.6 < y < 10.0$

**MC/Data**

- $p_T$ [GeV/c]
- $p_T$ [GeV/c]
7TeV $\pi^0$ analysis
900GeV photon analysis
900GeV photon analysis

• Suppose a $P_T$ of $\sqrt{s}=900\text{GeV}$ events can be scaled to the $P_T$ at $\sqrt{s}=7\text{TeV}$ as

$$P_T(\sqrt{s} = 7\text{TeV}) = \frac{7\text{TeV}}{900\text{GeV}} \cdot P_T(\sqrt{s} = 900\text{GeV}).$$

• Then the spectrum inside $R=5\text{mm}$ at $\sqrt{s}=7\text{TeV}$ would be equivalent to that $R<38.9\text{mm}$ at $\sqrt{s}=900\text{GeV}$.

• No systematic error is considered in both collision energies, although this treatment may not change an impression of the comparison.

• Good agreement of each $X_F$ scaling spectrum indicates a weak $P_T$ dependence of the energy spectrum.
900GeV photon analysis

**EPOS**

LHCf Arm1 Photon Like

![EPOS Graph](image)

- $\sqrt{s}=7\text{TeV} (\eta > 10.94)$
- $\sqrt{s}=900\text{GeV Scaled to } \sqrt{s}=7\text{TeV} (\eta > 8.88)$

**QGSJET II-03**

LHCf Arm1 Photon Like

![QGSJET Graph](image)

- $\sqrt{s}=7\text{TeV} (\eta > 10.94)$
- $\sqrt{s}=900\text{GeV Scaled to } \sqrt{s}=7\text{TeV} (\eta > 8.88)$