LHCf: Luminosity monitoring and measurement

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for the LHCf Collaboration
CONTENTS

Brief introduction to the LHCf (physics & detector)

Relative Luminosity measurement (single event, double arm, pi0)

Background (beam-gas)
Problems in the high-energy CR

- **Existence of the GZK cutoff (extra Galactic)**
  Cosmic microwave background prevents CRs of $>10^{20}\text{eV}$ from traveling over 20Mpc
  Cutoff in the energy spectrum is expected.

- **Chemical composition (Galactic $<10^{18}\text{eV}$)**
  Acceleration limit will be determined by rigidity ($\propto p/z$).
  Maximum energy depends on $z$
  CR composition must change at around acceleration limit.
Existence of cutoff is not clear.

If no cutoff, exotic solutions will come out.

AGASA reports 18% systematic uncertainty in energy determination.

10% of systematic is due to interaction model.

Huge experiment (Auger, TA) will solve the statistics, but not for interaction model.

Accelerator calibration is necessary.
Composition

<table>
<thead>
<tr>
<th>Energy (eV)</th>
<th>Xmax (g/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td></td>
</tr>
</tbody>
</table>

Number of particles vs. Atmospheric depth

- Iron
- Proton

Xmax vs. Energy (eV)

- LHC 450GeV
- LHC 7TeV

- DPMJET 2.5
- QGSJET 01
- SIBYLL 2.1

- Fly's Eye
- HiRes-MIA
- Yakutsk 1993
- Yakutsk 2001
- CASA-BLANCA
- HEGRA-AIROBICC
- SPASE-VULCAN
- DICE

Proton

Iron
Forward (zero degree) measurement

Beam pipes are separated into two in the TAN by 96mm.

Most of the HE secondary neutral particles enter in this gap.
Model discrimination at 7 TeV

QGSJETII ↔ SIBYLL

\[ \theta \sim 0 \text{ radian} \quad \theta \sim 270 \mu \text{ radian} \]

In the 1st phase, we need relative luminosity
We want to rescale the vertical axis into the cross section in future
Simultaneous measurement with TOTEM

Gamma-ray spectrum at the neutral center and off-center expected from two models. \(10^7\) inelastic scat. is supposed.
LHCf Detector

Position sensitive shower calorimeters in the TAN

Arm#1

Two shower calorimeters (44 rl)
Tungsten & 16 plastic scintillators
SciFi hodoscope

4cmx4cm, 2cmx2cm

Scintillation light read by 32 PMTs
SciFi light read by 8 MAPMTs

Scintillators and PMTs are connected by optical fibers (not drawn)
LHCf Arm#1 & Arm#2

Detectors at either side of the IP1

Arm#1

Silicon $\mu$ strip instead of SciFi
Final assembly finishes in April

Arm#2
Just to understand scaling...
LHCf “Event”

- BC identification by two BPTX signals (level1)
- $>100\text{GeV}$ shower identification in any 1 of the calorimeters ($>10\text{GeV}$ at 450GeV) (level2)
  \[\Rightarrow\text{ single event}\]
- Two gamma-ray showers in a single detector
  \[\Rightarrow \pi^0\text{ decay gammas}\]
  (available only at 7TeV run)
- Coincident showers in the two detectors
- Front counter (in preparation)
LHCf operation plan

- LHCf detector & electronics require >2 μ sec event separation
  ⇒ operation at 43 bunch.
- <1kHz DAQ rate
  ⇒ moderate upto $L=10^{29}$ cm$^{-2}$sec$^{-1}$
  radiation weak; ~0.5y lifetime @ $L=10^{30}$
  several hours operation for science

LHCf measures the relative luminosity in the commissioning phase.
Absolute normalization in future with RP
Single event rate

• \( @L=10^{29} \) with \( \sigma_{\text{inela}} = 100\text{mb}, \)
  \[ \text{collision rate} = 10^4 /\text{sec} \]

I use these numbers in this talk. Event rates are scalable in L except for offline information.

• Aperture of the LHCf;
  \(~0.1\) single event / collision @ 7 TeV
  (event rate \(~1\text{kHz} = \text{DAQ limit})
  \(~0.002\) single event / collision @ 450 GeV
  (event rate \(~20\text{Hz}) \Rightarrow \text{discuss later} \)
Particle in front of the TAN

**7TeV**

- Particle Map (> 100GeV)
- Flux Map

**450GeV**

- Particle Map (> 5GeV)
- Flux Map

**Number flux**

**Energy flux**
Resolution of the neutral center determination (7TeV run, offline)

10^6 inelastic interactions \sim 100 \text{ sec at } L=10^{29} \text{ cm}^{-2} \text{ s}^{-1}

Using a simple peak finding analysis
0.1 \text{ mm resolution is obtained}
Event rate summary for 7 TeV run
(relative luminosity monitoring)

- Single event rate; \( \sim 1 \text{kHz @} L=10^{29}\text{cm}^{-2}\text{s}^{-1} \)
- Double arm coincidence \((10\% \times 10\%=1\% \text{ aperture} \sim 100\text{Hz})\) is powerful to reduce beam-gas, beam halo background.
- Pi0 mass reconstruction also reduces the background with 1% aperture \((100\text{Hz}; \text{offline})\)
- Position resolution for the neutral center \((\text{offline})\)
Front Counter (in preparation)

To overcome the small aperture in the 450GeV run

Double layer thin plastic scintillator
80mm $\times$ 80mm

$\Rightarrow$ 0.02 events/collision @ 450GeV run

1 r.l. of the beam pipe converts neutral particles (mainly gammas) into charged particles.
Event rate summary for 450GeV run
(relative luminosity monitoring)

- Single event rate; 20Hz@L=10^{29}
- Single event of the front counter; 200Hz
- Position dependence … unable
- Double arm coincidence of front counter
  \((\sim 2\% \times 2\% = 0.04\%)\) 4Hz
- Pi0 reconstruction … unable
- Model dependence (science goal)
Model discrimination at 450 GeV

Expected gamma, neutron spectrum at $10^6$ inelastic interactions
Incident on detector
It corresponds to $\sim 100$ sec at $L=10^{29}$ cm$^{-2}$s$^{-1}$.
Detector response, analysis not included.
BG for relative lumi measure

• Beam-gas collision
  \[ \frac{R_{\text{collision}}}{R_{\text{gas}}} \text{ depends on the vacuum condition and the beam optics.} \]

  with \( N_{\text{H}_2 \text{ equiv}} = 4 \times 10^{12} \text{ m}^{-3} \) (*), ratio is <0.01 at the worst estimate in the LHCf operation

### Performance at 450GeV

<table>
<thead>
<tr>
<th></th>
<th>43</th>
<th>43</th>
<th>156</th>
<th>156</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_b$</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>$i_b \times 10^{10}$</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>intensity per beam</td>
<td>$8.6 \times 10^{11}$</td>
<td>$1.7 \times 10^{12}$</td>
<td>$6.2 \times 10^{12}$</td>
<td>$1.6 \times 10^{13}$</td>
</tr>
<tr>
<td>beam energy (MJ)</td>
<td>.06</td>
<td>.12</td>
<td>.45</td>
<td>1.1</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$2.10^{28}$</td>
<td>$7.10^{28}$</td>
<td>$2.610^{29}$</td>
<td>$1.610^{30}$</td>
</tr>
<tr>
<td>event rate</td>
<td>0.7</td>
<td>2.8</td>
<td>10</td>
<td>65</td>
</tr>
<tr>
<td>$W$ rate</td>
<td>0.8</td>
<td>3</td>
<td>11</td>
<td>70</td>
</tr>
<tr>
<td>$Z$ rate</td>
<td>0.08</td>
<td>0.3</td>
<td>1.1</td>
<td>7</td>
</tr>
</tbody>
</table>

1. Assuming 450GeV inelastic cross section 40mb
2. Assuming 450GeV cross section $W \rightarrow l^\nu$ 1nb
3. Assuming 450GeV cross section $Z \rightarrow ll$ 100pb
Beam-gas event at 450 GeV

• Gas pressure is estimated to be $10^{-8}$ Torr (R. Bailry, 2006)
• $10^{-8}$ Torr corresponds to $2 \times 10^{15} \text{H}_2/\text{m}^3$
• Beam-gas event rate, comparable to the collision event rate.
• Gas distribution is necessary for detailed estimation
• Double arm (front counter) coincidence
• Estimation before collision
Conclusion

- LHCf can measure relative luminosity at the commissioning phases.
- 1kHz(@7TeV) and 20Hz(@450GeV) single event rates are expected.
- Double arm event and Pi0 reconstruction (offline, 7TeV only) are useful to eliminate beam-gas BG.
- Front counters raise the event rates.
- Position resolution helps neutral center monitoring (offline, 7TeV only).
Backup
Event classification

a, b, c are proportional to luminosity, but not d. Double arm coincidence is necessary to eliminate d.
Pi0 mass reconstruction

![Graph showing counts versus invariant mass and pi0 energy]

- Counts [4MeV/10^6 pp-inela]
- Invariant Mass [MeV]
- 10^7 inelastic interaction
- Pi0 Energy [GeV]

- Data points for p-p and p-Gas (x10)
- Cuts at 130 MeV-140 MeV
- Contributions from DPMJET3, QGSJETII, and SIBYLL
Effect on BRAN

Same interaction length for copper bars and LHCf towers
Particle distribution in BRAN as a function of beam center

Out of LHCf; Gamma-ray showers developed in the beam pipe and BRAN itself

Full MC with beam-pipe, LHCf, BRAN
The ratio of particles detected by the 4 parts of the BRAN detector
The threshold of BRAN is set at > 500 particles
Position identification by the LHCf