LHC students poster session, 13 March 2013

LHCf measurements of neutron production at large rapidity

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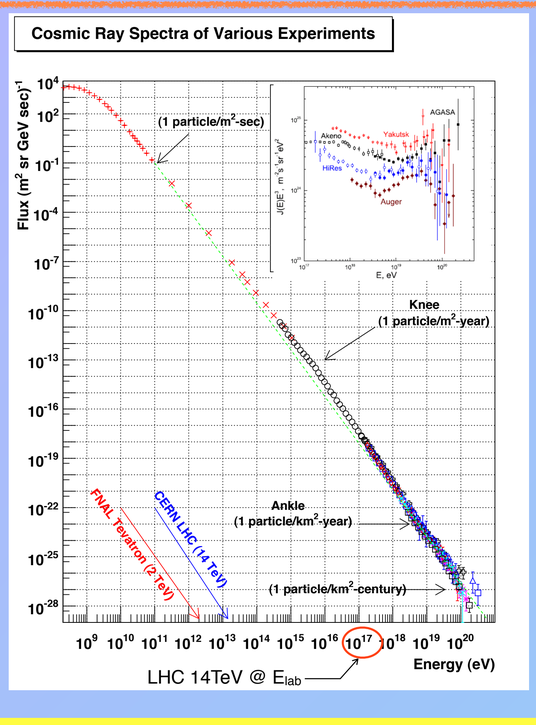
Abstract

The Large Hadron Collider forward (LHCf) experiment has successfully finished the first phase of data taking at $\sqrt{s}$ = 0.9 and 7 TeV proton-proton collisions in 2010. In this poster, the performance of LHCf detector for hadronic shower and the current status of neutron analysis are presented. The energy resolution, energy linearity, and position resolution were estimated by using test beam experiment at SPS and MC simulation. The energy spectra of the arm1 detector calculated from interaction models are compared.

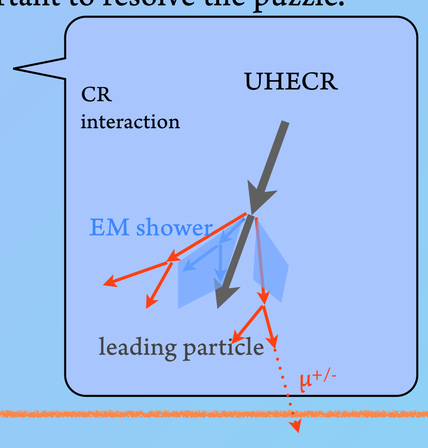
Introduction

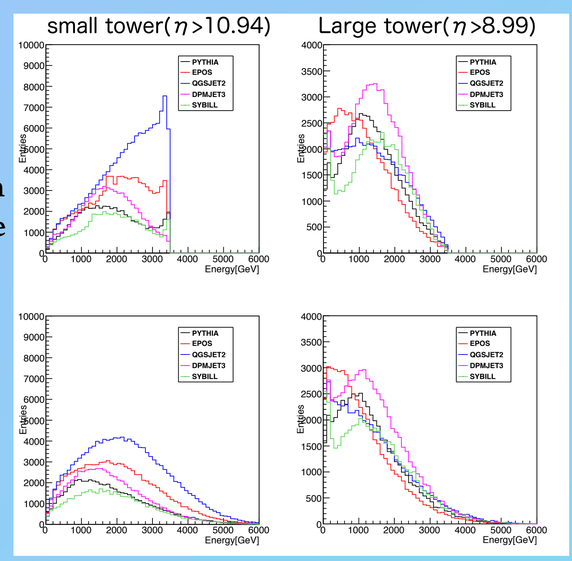


For the recent observations of high energy cosmic ray by the Pierre-Auger observatory and the TA experiment, the uncertainty in hadron interaction models becomes more crucial to understand their spectra. To constrain the uncertainty in the hadron interaction models in ultra-high energy region, observation of very forward particles at the LHC is essentially important to resolve the puzzle.

Key parameters can be observed in accelerator experiments

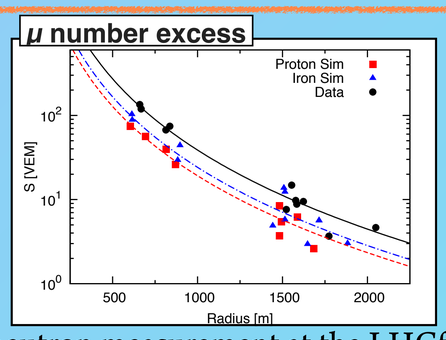
1. σ_{inel}
   → TOTEM
2. inelasticity
   → neutron at LHCf
3. secondary spectra
   → photon at LHCf





The figures show energy spectra for each interaction model. The upper two figures are MC true spectra and the bottom two are energy spectra smeared by 35% with gaussian. The left (right) correspond to small (large) tower.

The right upper figure shows a measured number of muons compared with MC prediction.



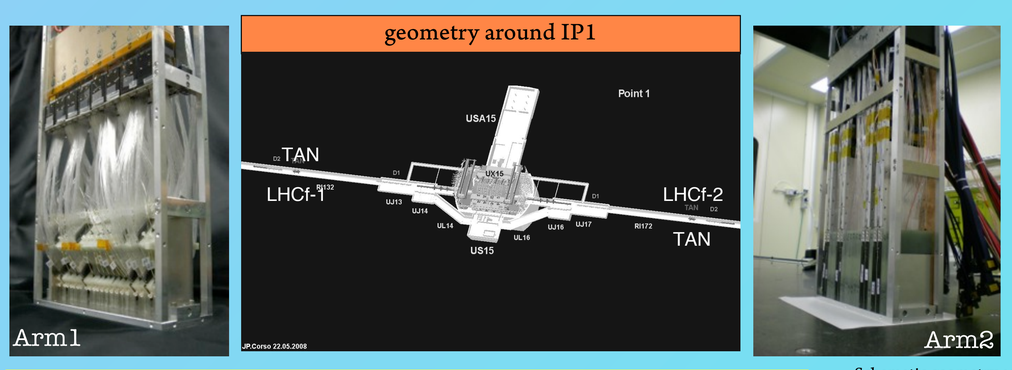
The neutron measurement at the LHCf experiment is helpful to understand leading particle spectra in cosmic ray interaction. Elasticity defined as the fraction of energy taken by the leading particle can be measure by the LHCf neutron events.

The neutron spectra are keys to solve the muon number excess issues in cosmic ray observations[1].

LHCf experiment and Detectors

The LHCf experiment is one of the LHC experiments dedicated to measure the energy and transverse momentum of particles emitted at the very forward region. Two independent detectors named Arm1 and Arm2 were installed ±140m away from the LHC IP1 (ATLAS interaction point). Each detector has two calorimeter towers composed of 44 r.l. of the tungsten plates and 16 sampling layers of the plastic scintillators. The detectors involves four X-Y pairs of the position sensitive detectors (SciFi in Arm1 and silicon strip detector in Arm2, respectively).

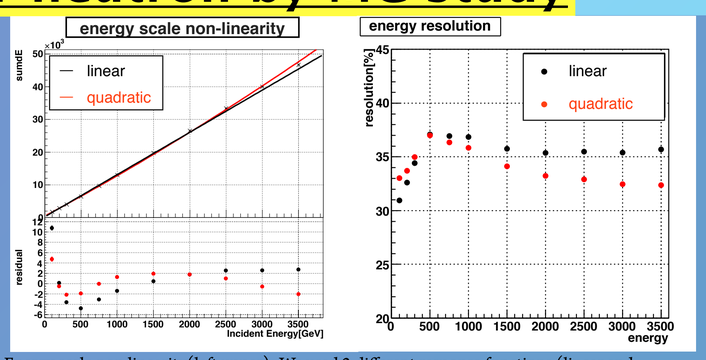
We successfully completed the phase1 operation for $\sqrt{s}$=7TeV p-p collisions in 2010. The next target is planed to take the data at $\sqrt{s}$=14TeV (=10^{17}eV at E_{lab}) p-p collisions after 2014.



Schematic geometry around IP1 and the pictures of the LHCf detector

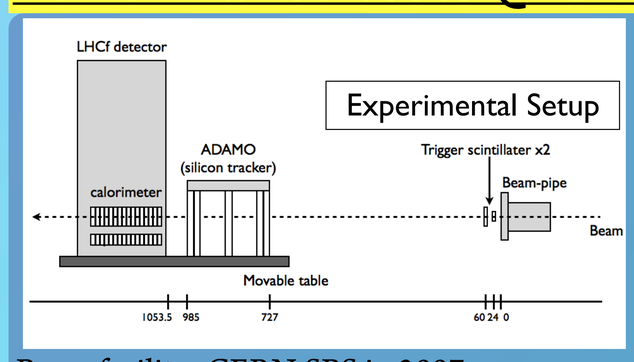
Detector performance for neutron by MC study

- Detection efficiency
  more than 70% for > 500GeV neutron
- Energy scale non-linearity
  < ±3%
- Energy resolution
  30-37% irrespective to neutron energy
- Lateral hit position resolution
  0.5 ~ 2.0 mm for small tower, 1.0 ~ 4.0 mm for large tower



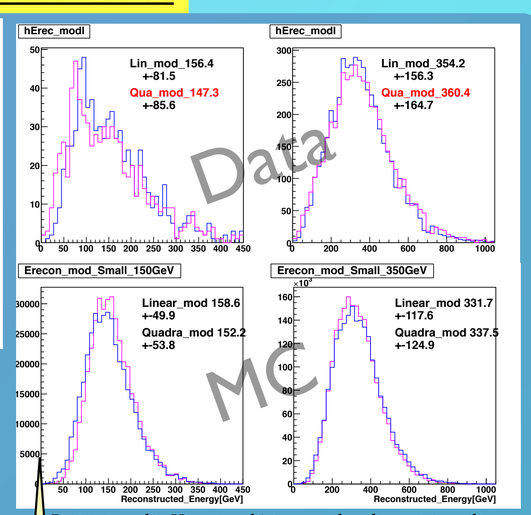
Energy scale non linearity(left upper): We used 2 different response functions (linear and quadratic). Both of them show less than ±3% non-linearity (left bottom).
Energy resolution(right): Energy resolution as a function of incident energy.

Performance tests @ CERN SPS



Beam facility: CERN SPS in 2007
Beam : proton(150GeV and 350GeV)

Result: The beam test results are compared with MC simulation as shown in right figure. They are well agreed but the data have broader distribution. This indicates MC simulation still needs to be tuned.



Beat test results: Upper two histograms show beam test results, and bottom two show MC result. Blue (Magenta) line is the energy reconstructed with linear (quadratic) response function. The left(right) correspond to the result of 150GeV(350GeV).

some difference between the both, especially in the σ
→ We have to understand the MC more well.

Data and reconstruction algorithm

- Data
  Fill# 1104 (same as published photon paper[2])
  Integrated luminosity 0.68nb^{-1} = 4.8 x 10^7 collisions
- MC statistics
  QGSJET2 : 0.99*10^7 collisions
  EPOS : 0.99*10^7 collisions
  PYTHIA : 0.99*10^7 collisions
  DPMJET3: 0.99*10^7 collisions
  SYBILL : 0.49*10^7 collisions
- Event Selection
  trigger (offline) ; coincidence of any successive three layers
  Fiducial cut ; 2mm from the calorimeter edge events are rejected
  Multi hit cut ; only single hit events are selected
- Energy reconstruction
  Linear function of SumdE (summation of energy deposit)

$$SumdE = \sum_{i=2}^{15} dE_i \times N_{stepi}$$

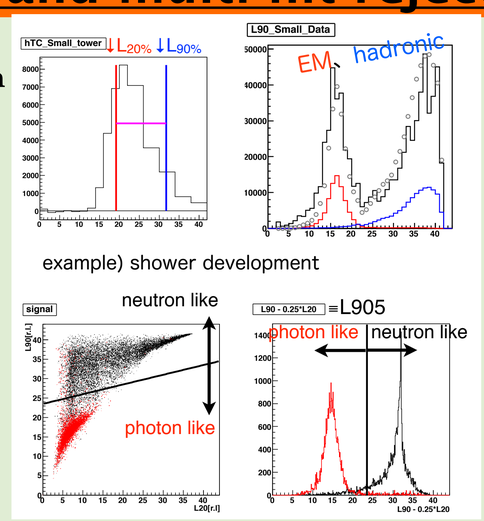
- Lateral hit position
  SciFi X and Y hit position reconstruction
- Particle identification (PID)
  From difference in longitudinal shower development

Particle identification and multi hit rejection

The PID method uses difference in longitudinal shower development between photon incident and hadron incident. They are described by $L_{20\%}$ and $L_{90\%}$ parameter as shown in figureA1. $L_{20\%}$ ($L_{90\%}$) is the longitudinal distance in radiation lengths measured from the entrance to a calorimeter to the position where 20%(90%) of the total shower energy has been deposited.

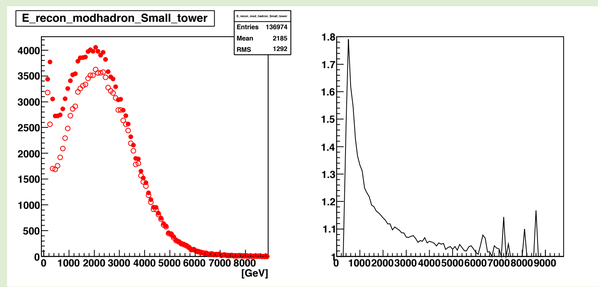
In this analysis, the two dimensional PID cut shown in figureA2 was applied.

By using this method, we obtained more than 96% of efficiency with less than 2% of photon contamination for small tower.



FigureA1(upper): An example of transition curve and the definition of $L_{20\%}$ and $L_{90\%}$. The right shows $L_{90\%}$ distribution of photon(Red) and hadron(Blue) and $\sqrt{s}$=7TeV data (Black).
FigureA2(bottom): 2D scattering of $L_{20\%}$ and $L_{90\%}$ parameter, and its projection to $L_{90\%}$-0.25*$L_{20\%}$.

More than two particles hit in one calorimeter simultaneously, these events were treated as "multi hit" event. Reconstruction of multi hit event is difficult, so they are rejected from the analysis. The ratio of multi hit event in MC simulation was obtained (figureB).



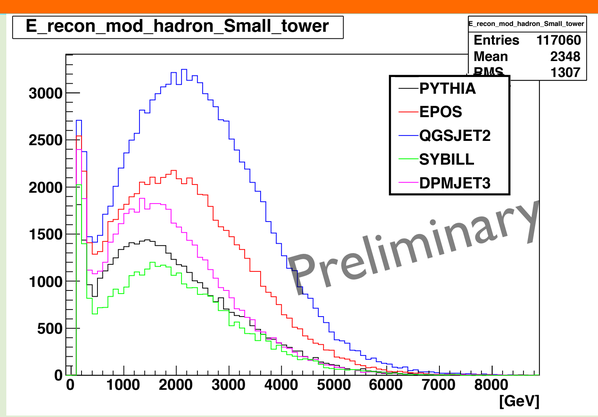
FigureB: The energy spectra with and without multi-hit cut(MHC). The right figures show ratio(with MHC / without MHC).

Preliminary result

Here we show very preliminary results for various MC generators. Full detector MC and analysis procedure same as experimental data are applied. The vertical axises are normalized to a number of event per 10^7 inelastic collisions.

NEXT plans;

- comparison with $\sqrt{s}$ = 7TeV data.
- Estimation of systematic uncertainty
- More detailed understand of detector simulation
- Comparison with arm2 detector
- Spectra deconvolution (Unfolding technique)
- etc...



The energy spectra obtained from hadronic interaction models(see legend).
The same analysis procedure were performed for each model.
There is large difference between models.
We will compare these spectra with the spectra of $\sqrt{s}$ = 7TeV data.

Summary and prospects

LHCf has successfully completed the data taking for $\sqrt{s}$ = 7 TeV p-p collisions in 2010. Currently, we are intensively working for neutron analysis. The performance of the LHCf detectors for neutron measurement was confirmed by the MC calculation and the SPS beam test. The LHCf calorimeters have a detection efficiency of more than 70 % for > 500GeV neutrons, with ±3% non-linearity of energy scale and 30-37% of energy resolution. The calorimeters have the position resolution of 0.5 to 4.0mm for lateral direction.

We are analyzing the neutron events at $\sqrt{s}$ = 7 TeV p-p collisions and the results are presented in this poster.

Future plans:

We will compare the data with the spectra simulated with interaction models, and more detailed study to understand detector simulation is needed. Finally we will compare with arm2 results.

Reference
[1] J. ALLEN et al., ICRC proceedings (2011)
[2] O.Adriani et al., Physics Letters B 703 (2011) 128-134