The comparison of neutral baryon production between a data and models at the LHC forward region

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Outline

- Physics Motivation
- The LHCf experiment
- Hadronic interaction model spectra
- Performance study of the LHCf detector for neutron by MC
- Summary

Keywords:
High energy hadronic interaction
LHC forward
Neutron productions
The development of CR shower is characterized by:
- Total hadronic cross section
- Multiplicity (N)
- Inelasticity (k)
- Secondary particle spectra
  → Interaction models
  = QGSJET, EPOS, SYBILL etc.

To verify the existing models:
→ Measurement of forward particle produced at forward region produced by “accelerator”
→ LHCf
The LHCf experiment

- The LHCf experiment can provide the data to calibrate the hadronic interaction models
- Two calorimeters at ±140m away from the LHC IP1 (=ATLAS).
- 16 layers of sampling calorimeter with 4 lateral position sensitive layers
- 1.7 λ and 44 r.l (thin for hadron)

LHCf can only observe neutral particles at forward region
Importance of neutral baryon (≒ neutron) in CR physics

- Muon excess in CR observation is found relative to the MC predictions (~30% than MC)
- The MC predictions have large difference between models ->
  - The number of muons increases with the number of baryons: \( N_\mu \propto N_{\text{baryon}} \) (correlated)
- Importance of direct baryon measurement
  → Inelasticity (primary - leading baryon)

![Graph showing expected muon number with energy, comparing different models: EPOS 1.99, QGSJET 01, QGSJET II-3, SIBYLL 2.1.](image)

Expected muon number: large discrepancy between models
- Hadron events at $10^7$ p-p collisions
- Large difference among the models (PYTHIA, EPOS, QGS2, DPM3, SYBILL)
- Clear difference even with energy resolution by 35%
Sensitivity study of LHCf detectors for neutron
Set up of MC simulations

- EPICS v8.81 (MC simulation package)
- Neutrons are injected to the center of LHC beam (no crossing angle).
- Energy: (100, 200, 300, 500, 750, 1000, 1500, 2000, 2500, 3000, 3500 GeV)
- Direction: 0°
Offline (analysis) trigger was applied: any successive three layers coincidence: threshold level is set to be 200 particles (1 particle $\equiv 0.453$ MeV energy deposit)

- Summation of energy deposit in 2nd to 15th layer ($\text{sumdE}$)
  \[
  \text{sumdE} = \sum_{i=2}^{15} dE_i \times N_i \quad (N=1 \text{ or } 2 \text{ depend on the absorber thickness})
  \]
  $\rightarrow$ Energy reconstruction

- Position sensitive layer
  $\rightarrow$ Lateral hit position reconstruction

- Longitudinal shower development
  $\rightarrow$ For particle identification
Neutron incidents at small tower

Detection = above trigger level

Flat efficiency (~70%) at E > 500 GeV
sumdE to Energy conversion and its linearity

- To reconstruct neutron energy from sumdE (≒ total number of shower particle)
- Linear and quadratic Fit → 3% energy linearity (>500GeV)
Performance of neutron energy reconstruction

- Reconstruct energy by using inverse function of linear and polynomial
- Large fluctuation because of short hadronic interaction length
- Energy resolution is defined as the RMS of the distribution

Incident: 200GeV neutron

![Graph showing reconstructed energy distribution with mean values for Linear and Quadra approximations.](image)
- Energy resolution for each energy
- 33% ~40% resolution without any correction
- Study of the method to improve energy resolution is ongoing
  - By using shower longitudinal information, improve to ~25% (-10%)
- Other possibility
Lateral hit position reconstruction

- Lateral hit position resolution is 0.5 ~ 2.5mm
Detector calibration at CERN-SPS

- Beam test to confirm the performance studied by MC

- “MC” Energy Scale was tested by using proton (150GeV & 350GeV) beam at CERN-SPS
  - (Gain of each channel is calibrated with 50-200GeV electron beam)

- Lateral position resolution was also studied

- Same event reconstruction algorithm is used

**Experimental Setup for the beam test**
**beam test**

- Proton incident aimed to tower center
- should consider some corrections

**MC**

- same beam profile as beam test was used
- neutron incident
Summary

- **Motivation for the analysis of forward neutron**
  - MC prediction: Large discrepancy among the models
  - Direct measurement of inelasticity

- **The performance of the LHCf detector for forward neutron** (only for the incident at calorimeter center)
  - ~70% detection efficiency (>500GeV)
  - ±3% energy linearity
  - ~35% energy resolution
  - 1mm to 2mm of lateral position resolution (weak energy dependence)
  - Energy scale has been tested by SPS beam test (preliminary)

- **The data analysis for the 7TeV pp collisions is ongoing**
Spare Slide
Transition Curve

- Trigger
  - any successive three layers coincidence

- The response function of SumdE is below

\[
SumdE = \sum_{i=1}^{11} dE_i \times N_{stepi}
\]

\[
SumdE = \sum_{i=2}^{15} dE_i \times N_{stepi}
\]
- Composed from 16 layers of scintillator and Tungsten and 4 layers of lateral position sensor (SciFi)
- Total 44 r.l. and 1.7λ
- Performance for EM shower was well studied,
- but, for hadronic is not studied well
Sampling Layer

- 7mm or 14mm thickness of Tungsten Absorbers
- 16 layer of sampling layers (Plastic scintillator EJ260)
- 4 position (Transverse) sensitive layers
**PID selection with L90**

- L90 is the longitudinal depth containing 90\% of the total sum of the shower particles.
- Gamma like -> Shallower
- Hadron like -> Deeper

- PID selection with L90 was well studied in gamma analysis
Fluctuation of visible energy

- The LHCf detector CANNOT contain overall of shower especially for hadronic showers
- Fluctuate due to the amount of contain of shower
- Because the LHCf detectors have only 1.7 hadronic interaction length, over 20% of neutrons do not interact with detector