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

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Outline

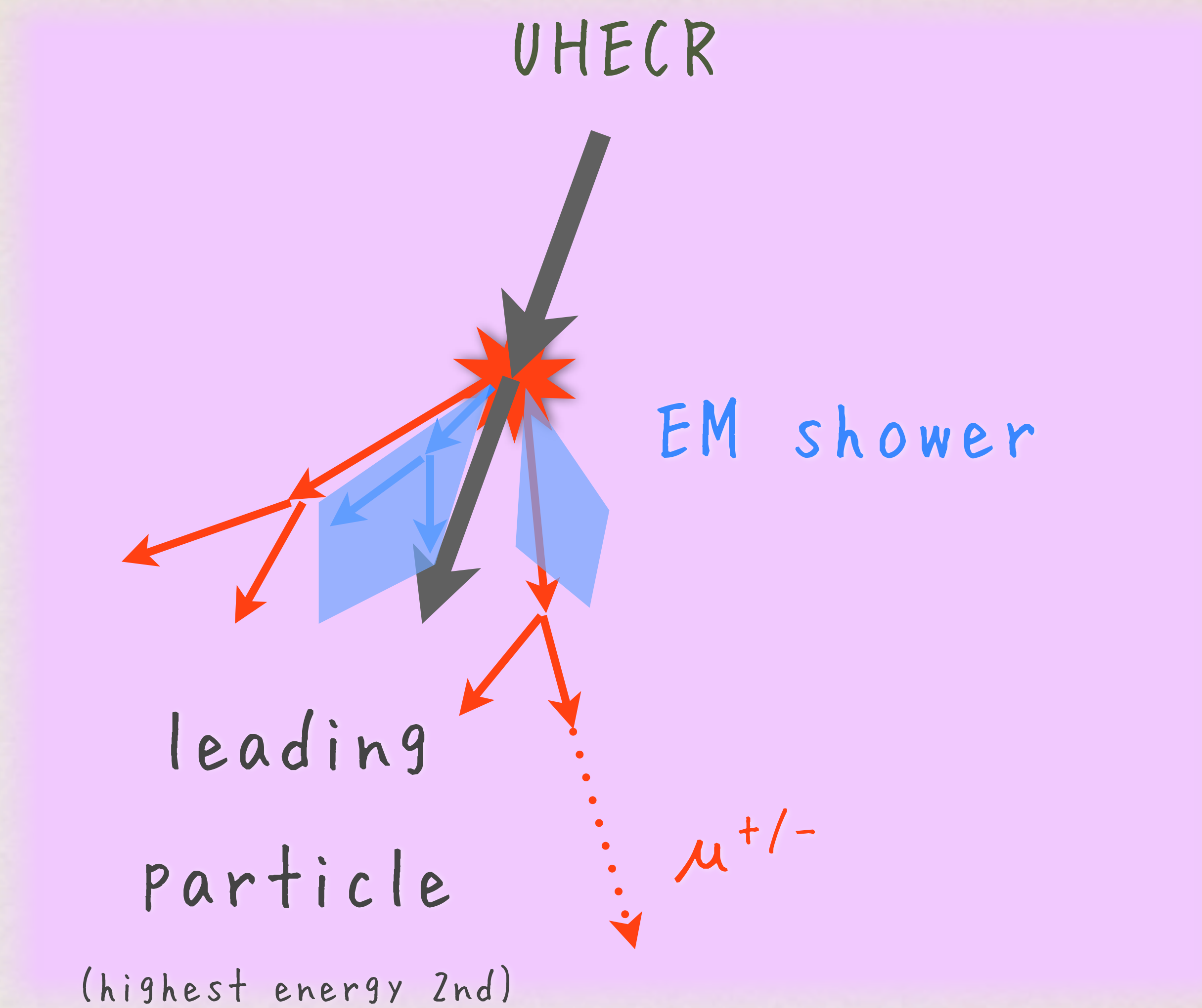
Keywords:
High energy hadronic interaction
LHC forward
Neutron productions

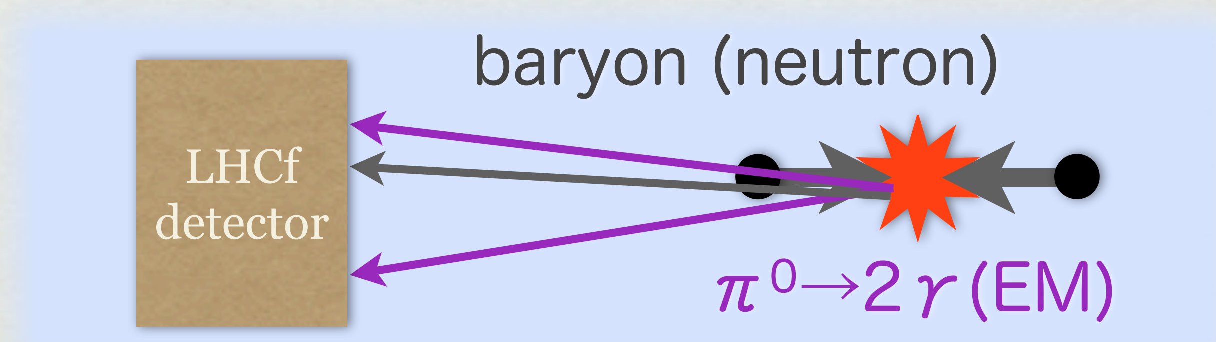
- Physics Motivation
- The LHCf experiment
- Hadronic interaction model spectra
- Performance study of the LHCf detector for neutron by MC
- Summary

Hadronic interactions

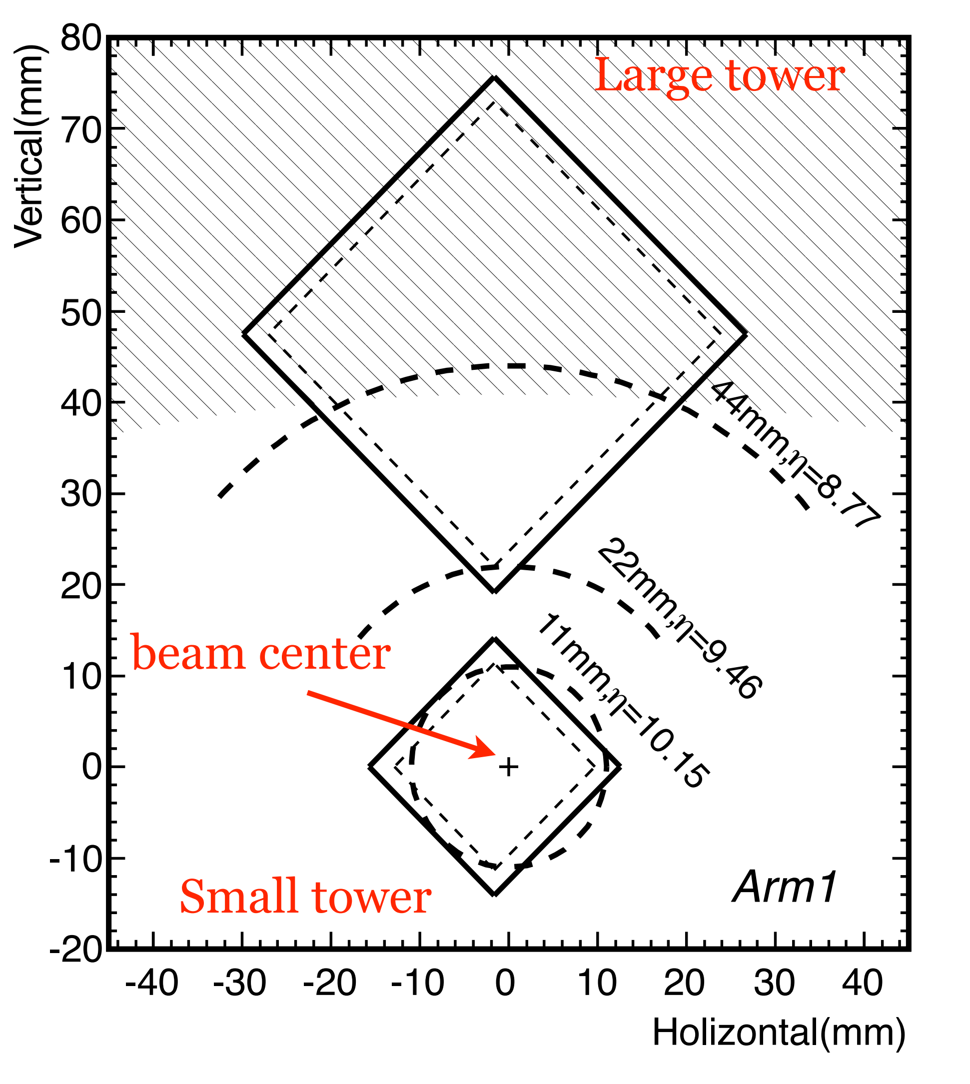
- The development of CR shower is characterized by
  •Total hadronic cross section
  •Multiplicity(N)
  •Inelasticity(k)
  •Secondary particle spectra
  → Interaction models
  = QGSJET, EPOS, SYBILL etc.

- To verify the existing models
  → measurement of forward particle produced at forward region produced by “accelerator”
  → **LHCf**





The LHCf experiment

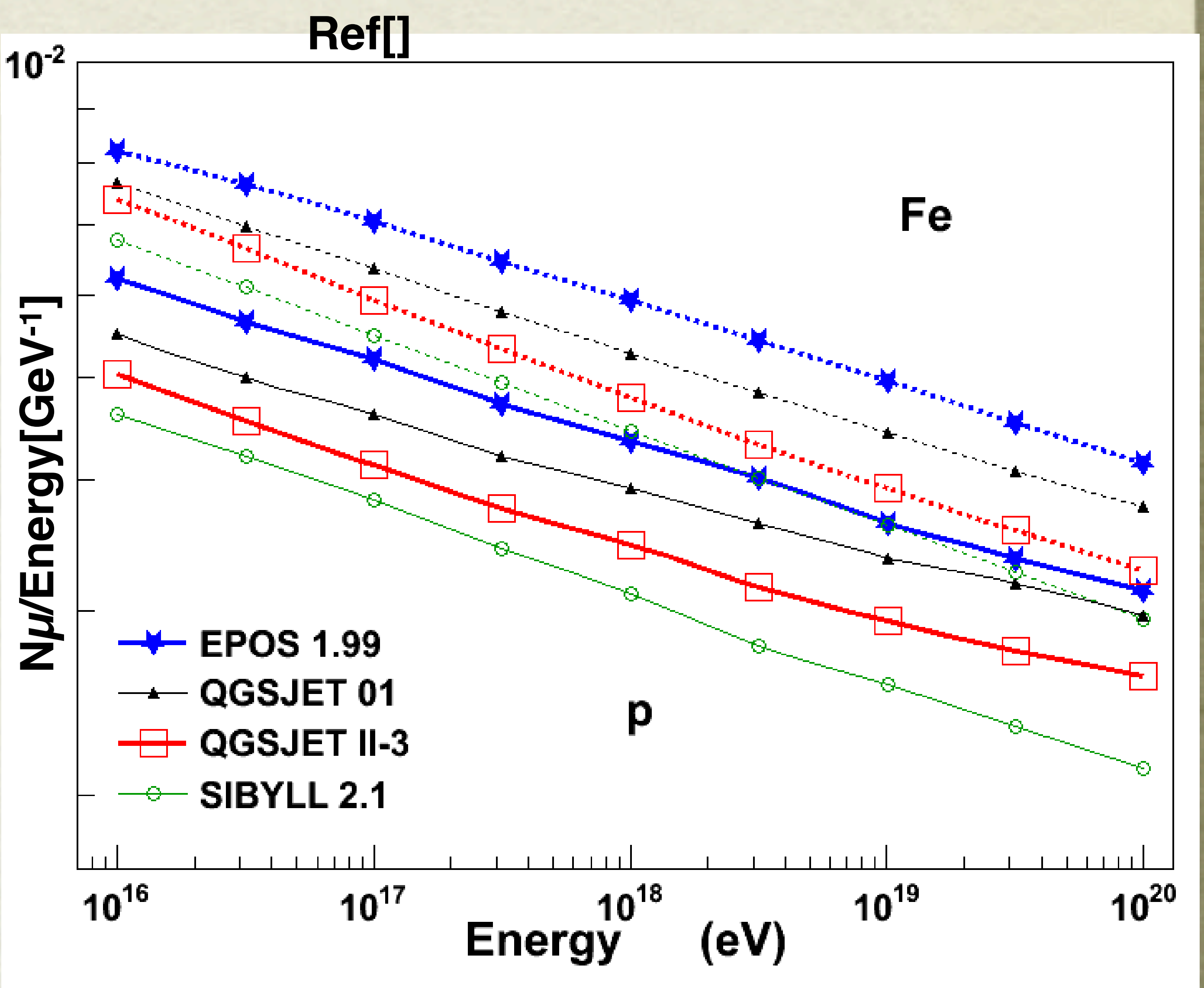


LHCf can only observe neutral particles at forward region

- 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)

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 : $N_\mu \propto N_{baryon}$ (correlated)
- Importance of direct baryon measurement → Inelasticity (primary - leading baryon)



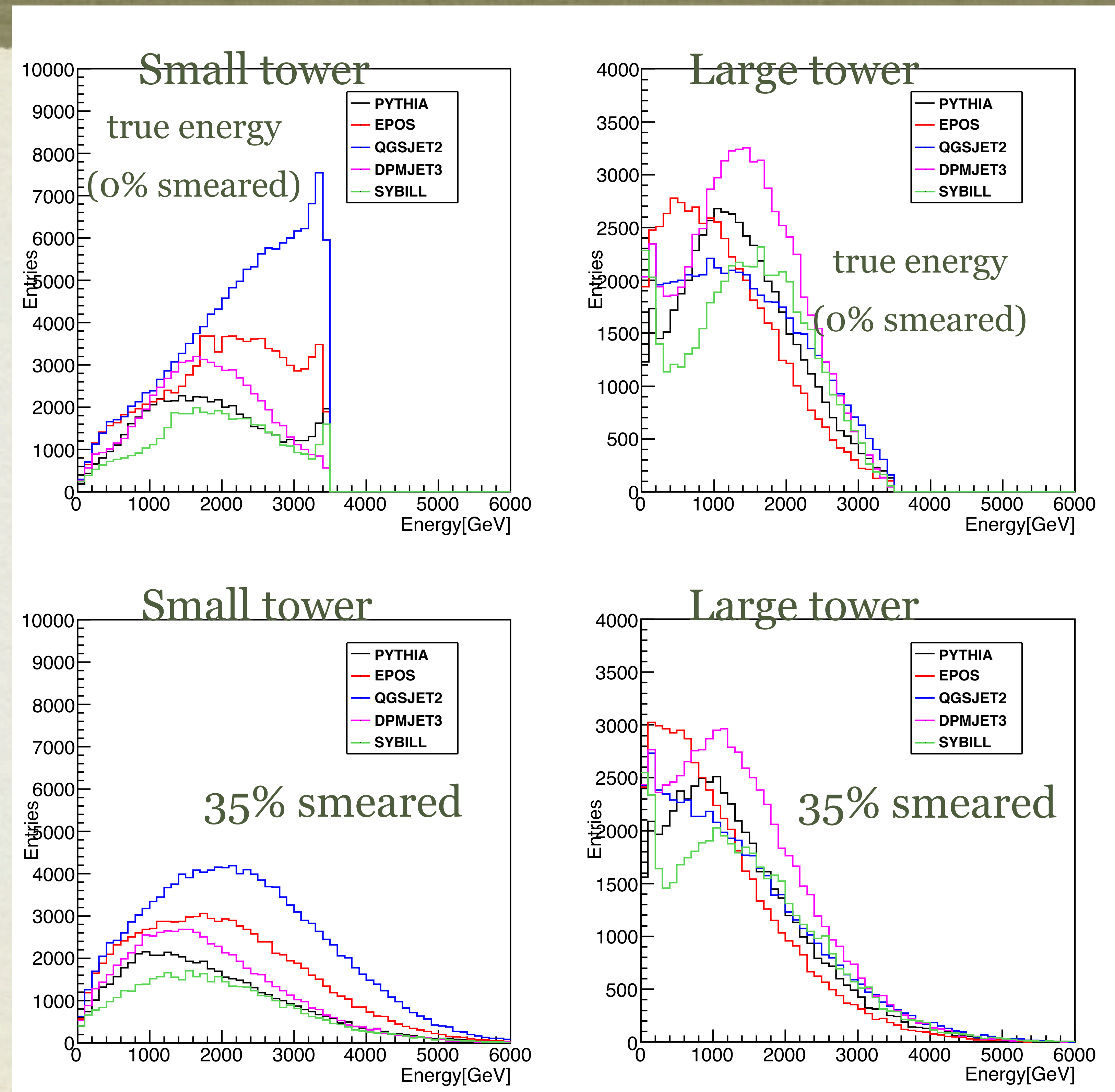
Expected muon number:

large discrepancy between models

Model spectra(LHCf neutron)

- 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%

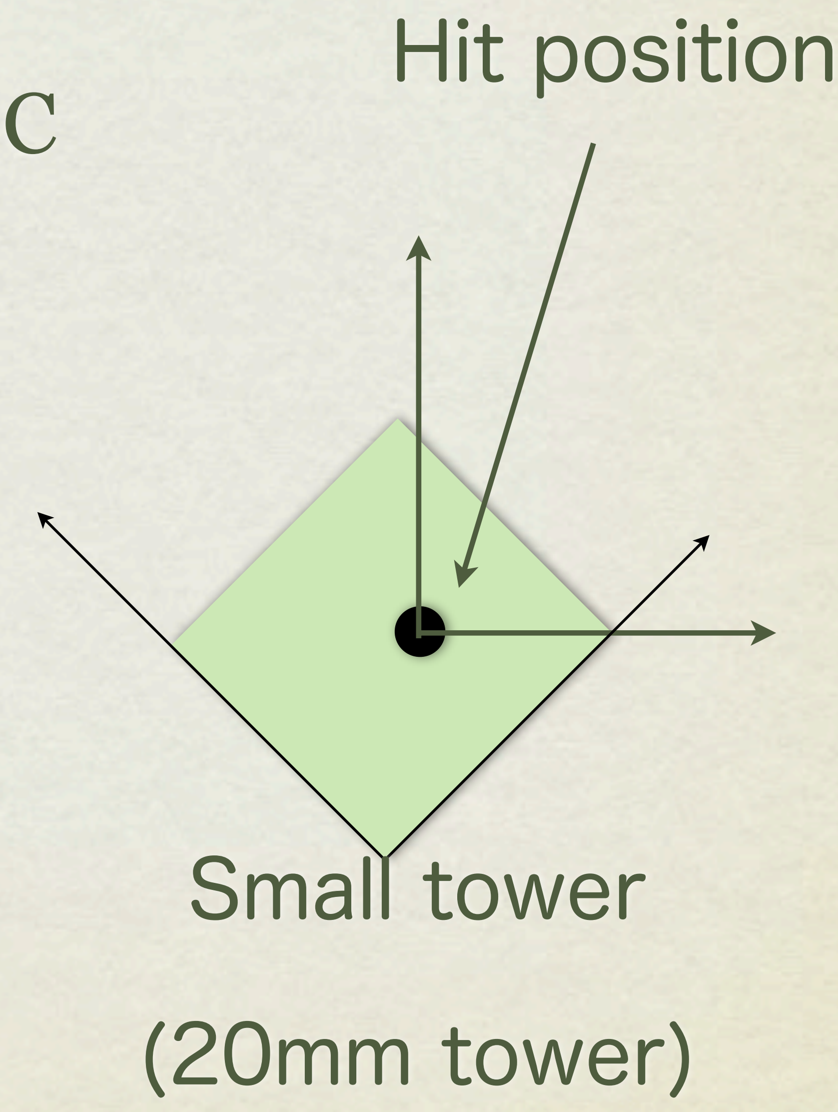
Energy spectra↓



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, 3500GeV)
- direction：0°



Event Reconstruction algorithm

- Offline (analysis) trigger was applied:
  any successive three layers coincidence : threshold level is set to be 200 particles (1 particle ≡ 0.453MeV energy deposit)

- Summation of energy deposit in 2nd to 15th layer (sumdE)

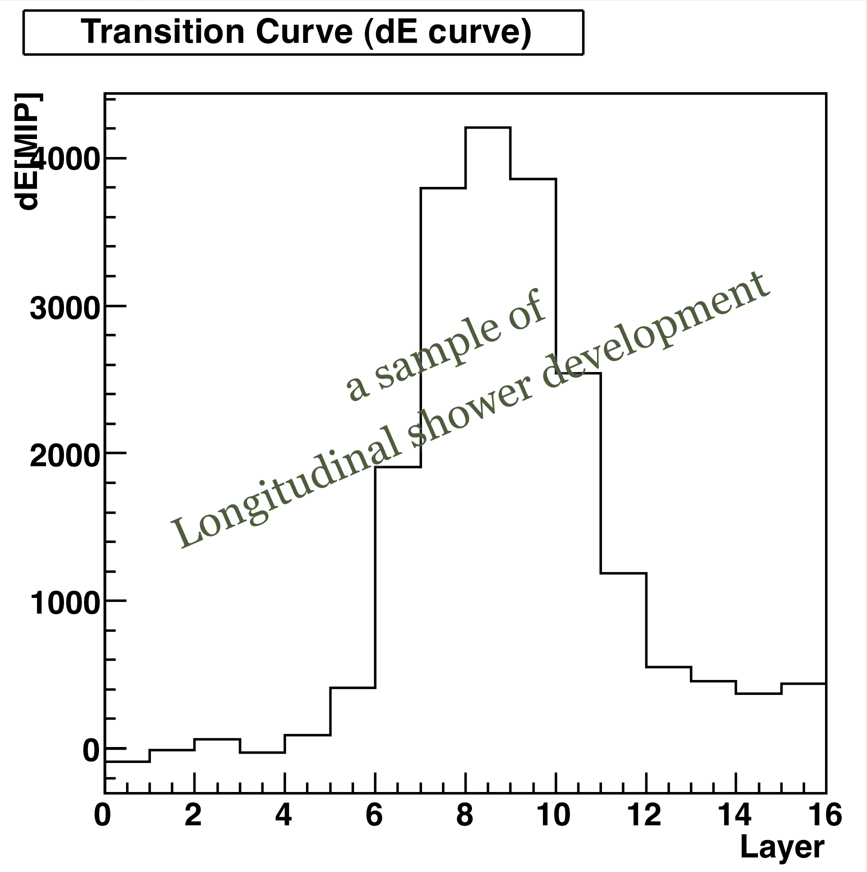
$$SumdE = \sum_{i=2}^{15} dE_i \times N_i$$

(N=1 or 2 depend on the absorber thickness)

-> Energy reconstruction

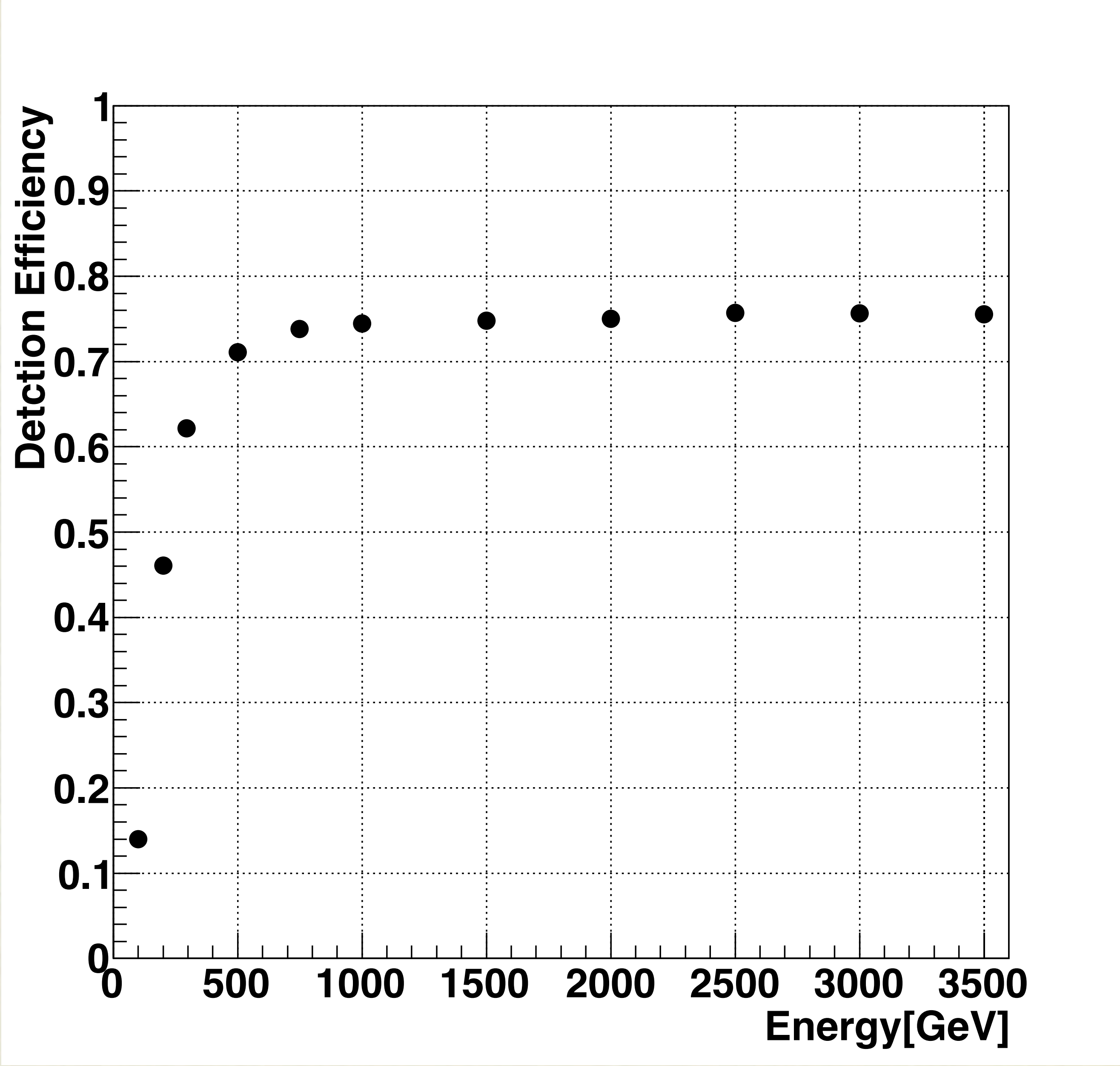
- Position sensitive layer
  -> Lateral hit position reconstruction

- Longitudinal shower development
  -> For particle identification

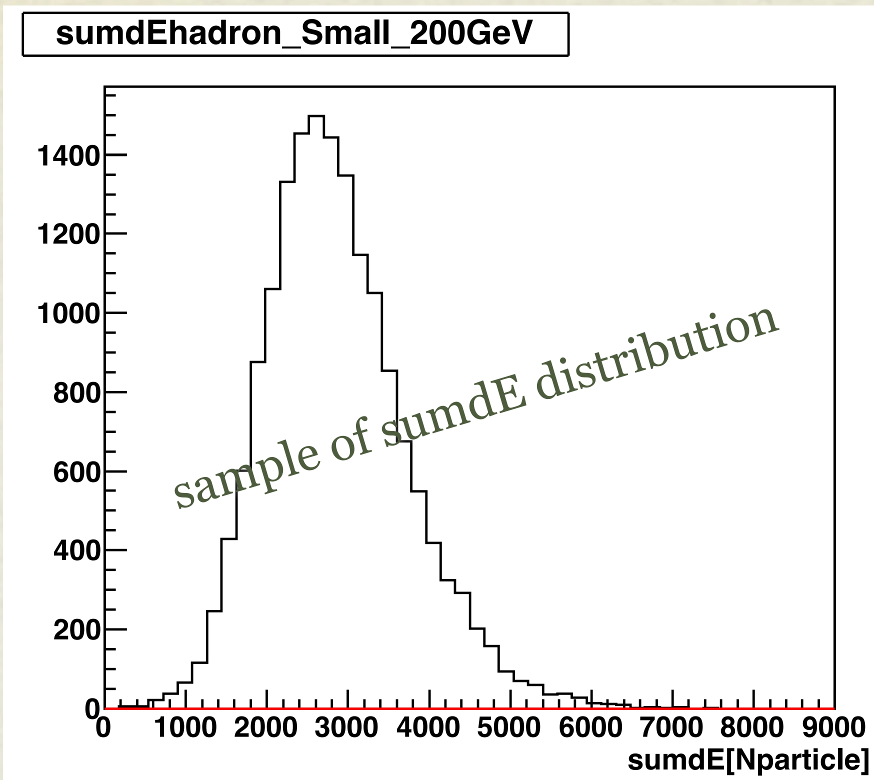


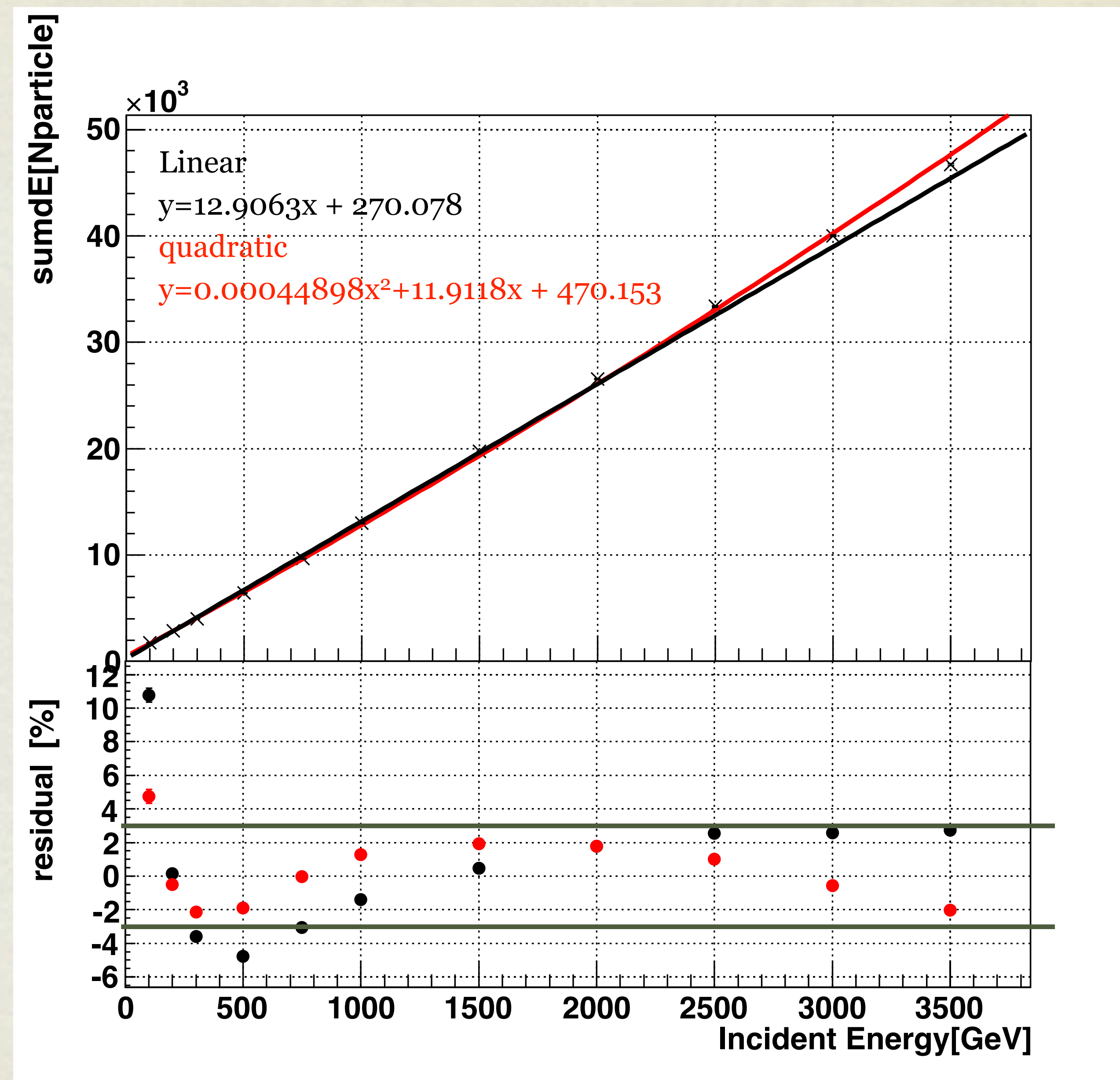
Detection Efficiency of neutron

- Neutron incidents at small tower
- Detection = above trigger level
- Flat efficiency (~70%) at E > 500 GeV



sumdE to Energy conversion and its linearity



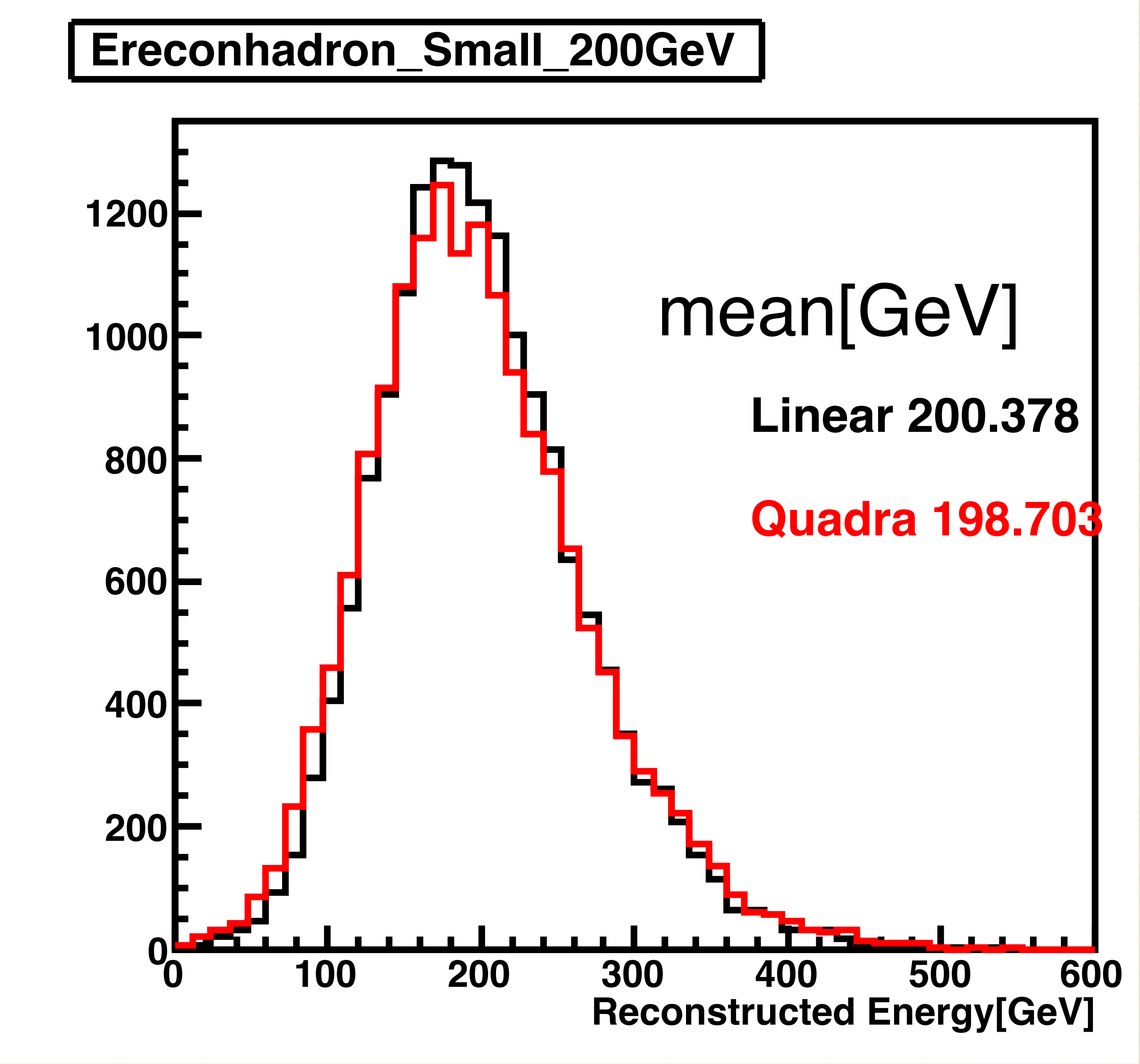


- To reconstruct neutron energy from sumdE (≒ total number of shower particle)
- Linear and quadratic Fit
  → 3% energy linearity (>500GeV)

Performance of neutron energy reconstruction

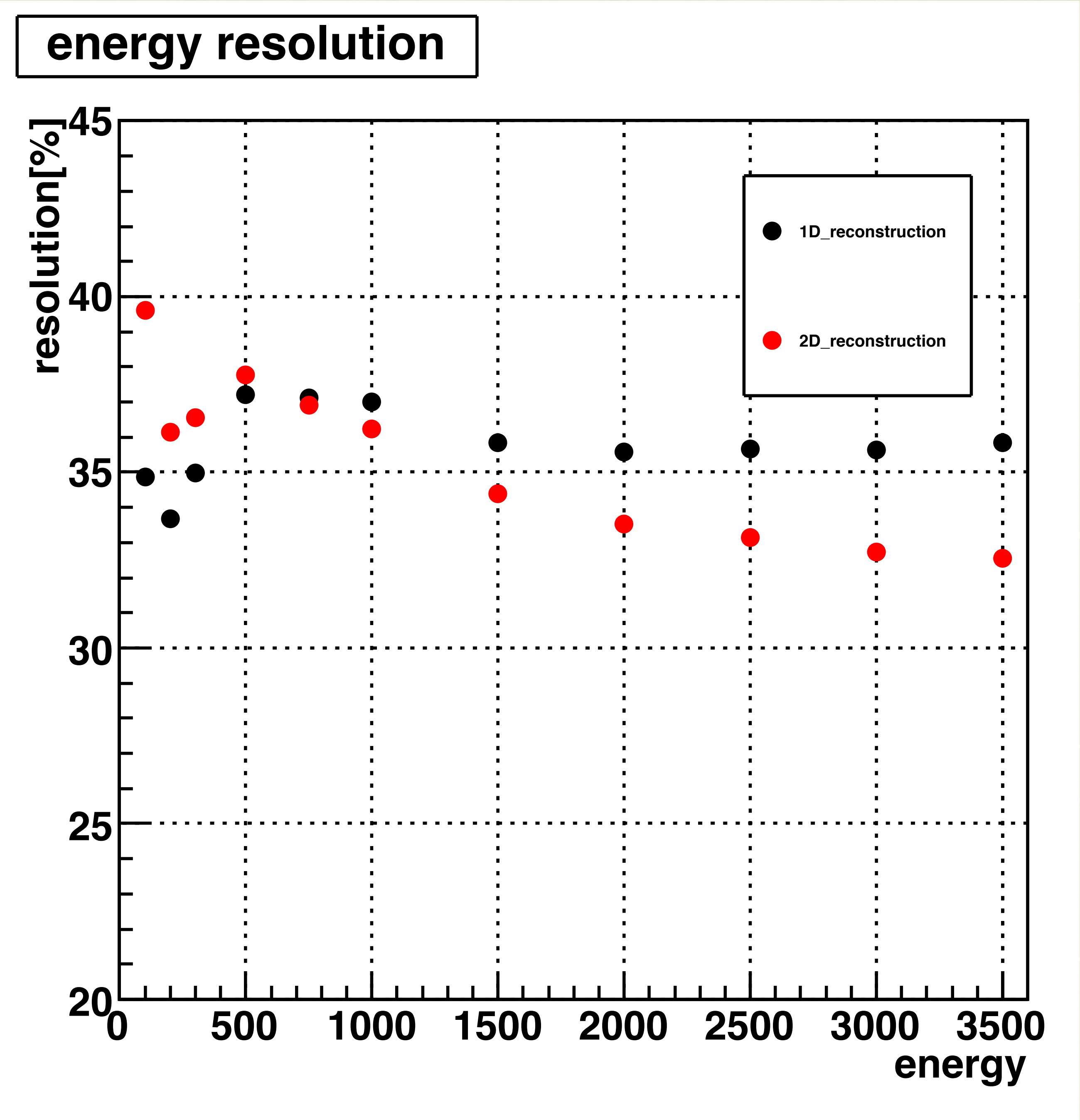
Incident: 200GeV neutron

- 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



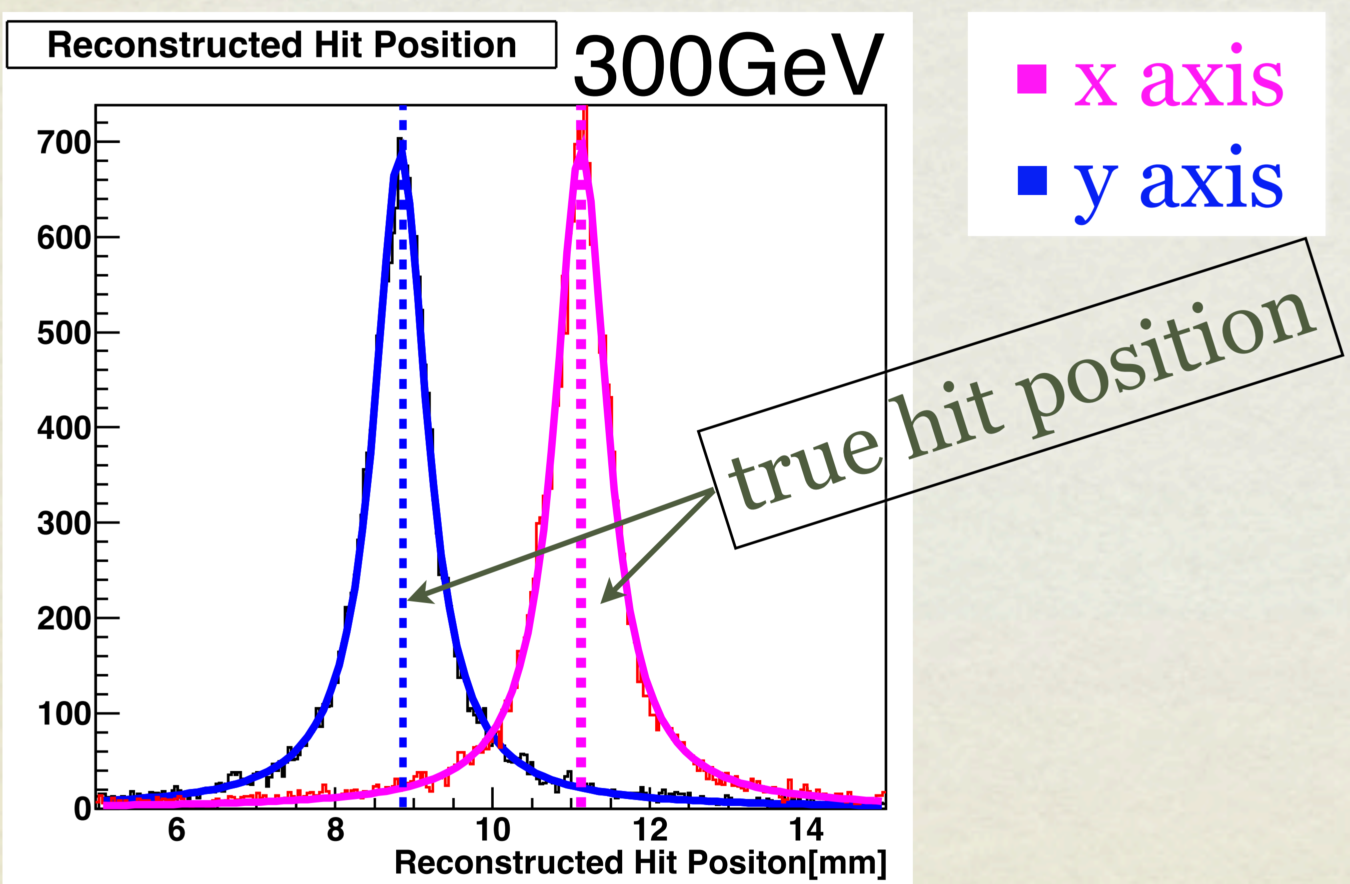
Energy resolution

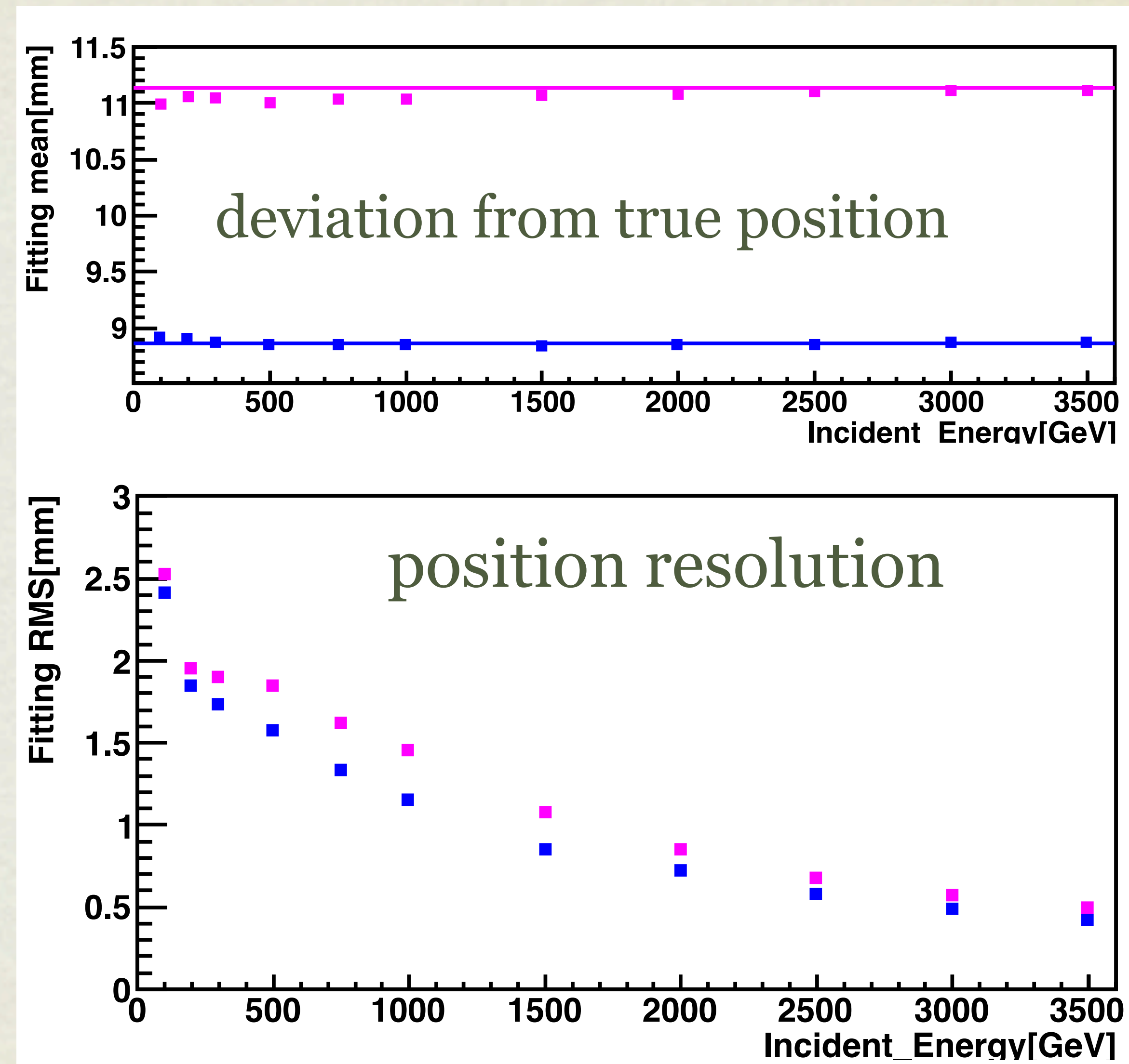
- Energy resolution for each energy
- 33% ~40% resolution without any correction
- Study of the method to improve energy resolution is ongoing
    - By using shower longitudinal information, improve to ~25% (-10%)
    - Other possibility



Lateral hit position reconstruction

- Lateral hit position resolution is 0.5 ~ 2.5mm

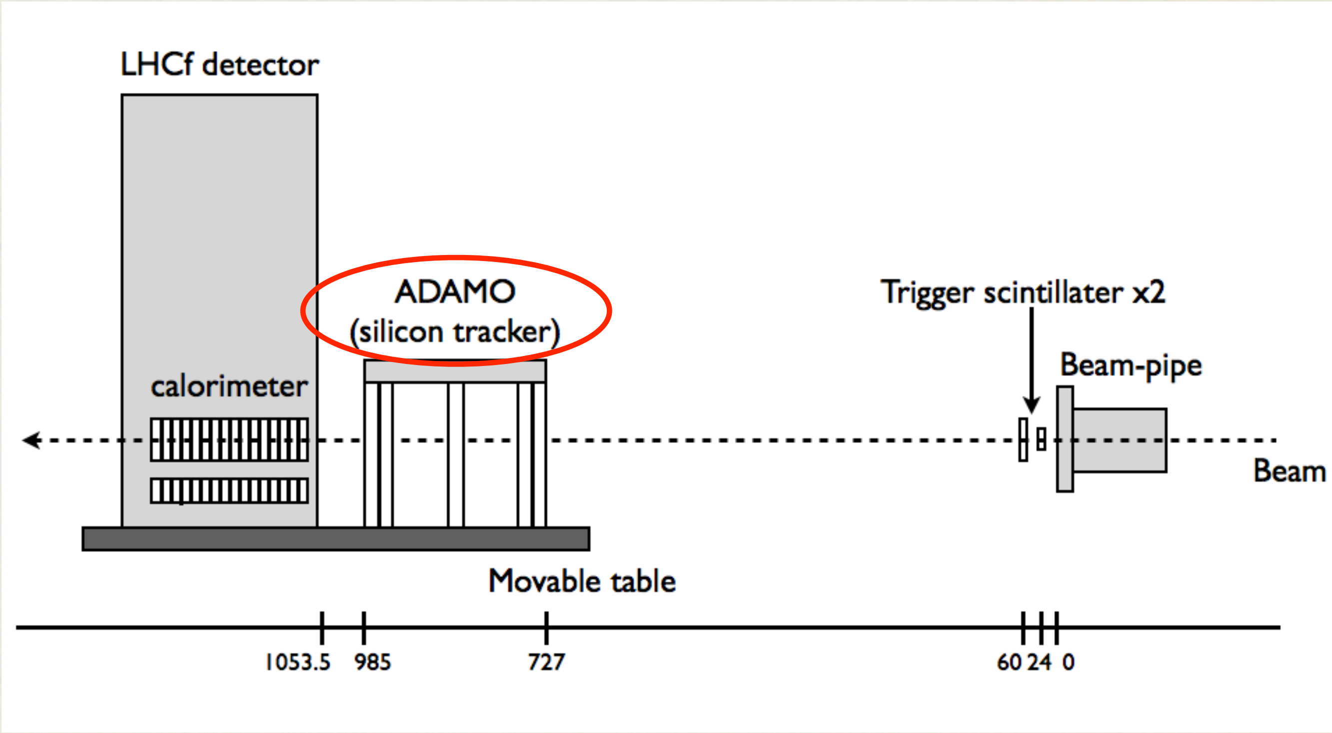


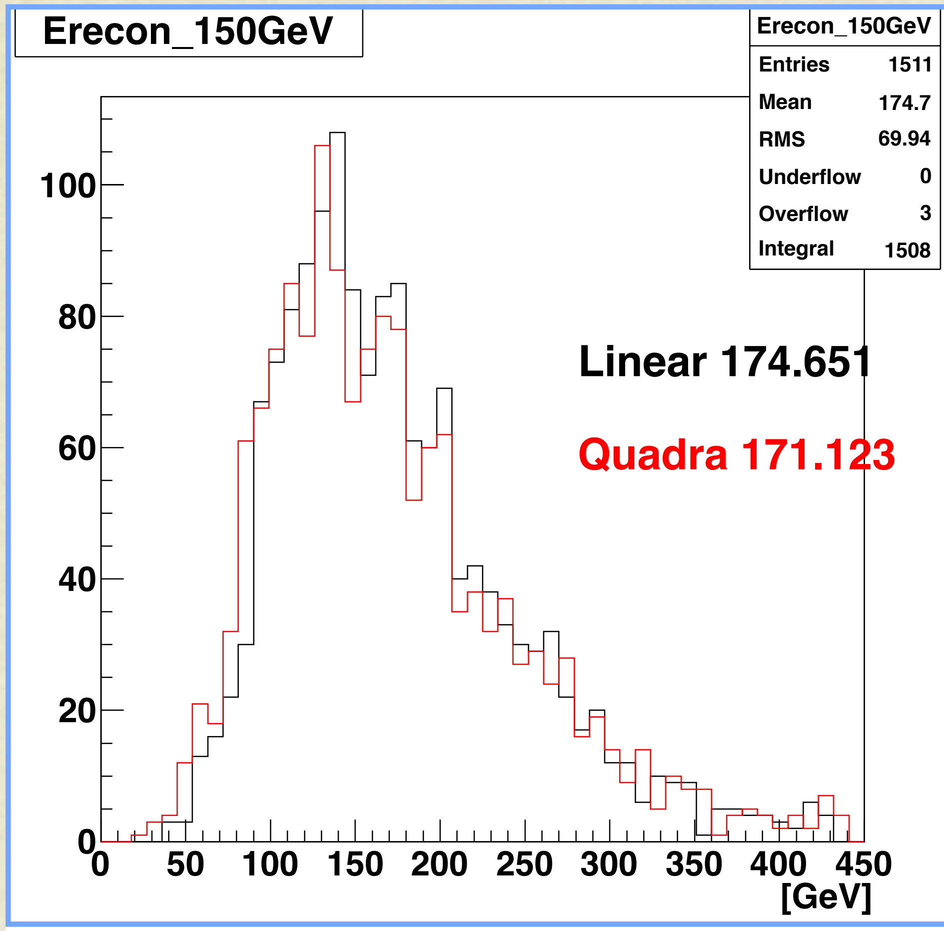


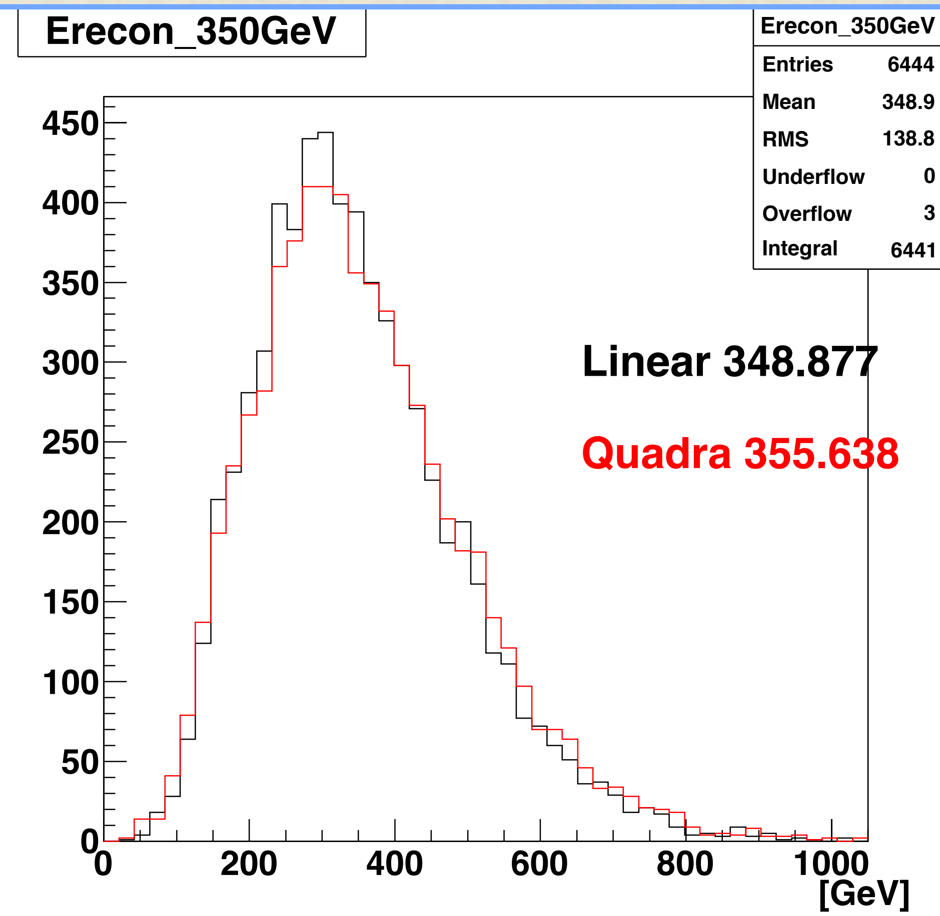
Detector calibration at CERN-SPS

- 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

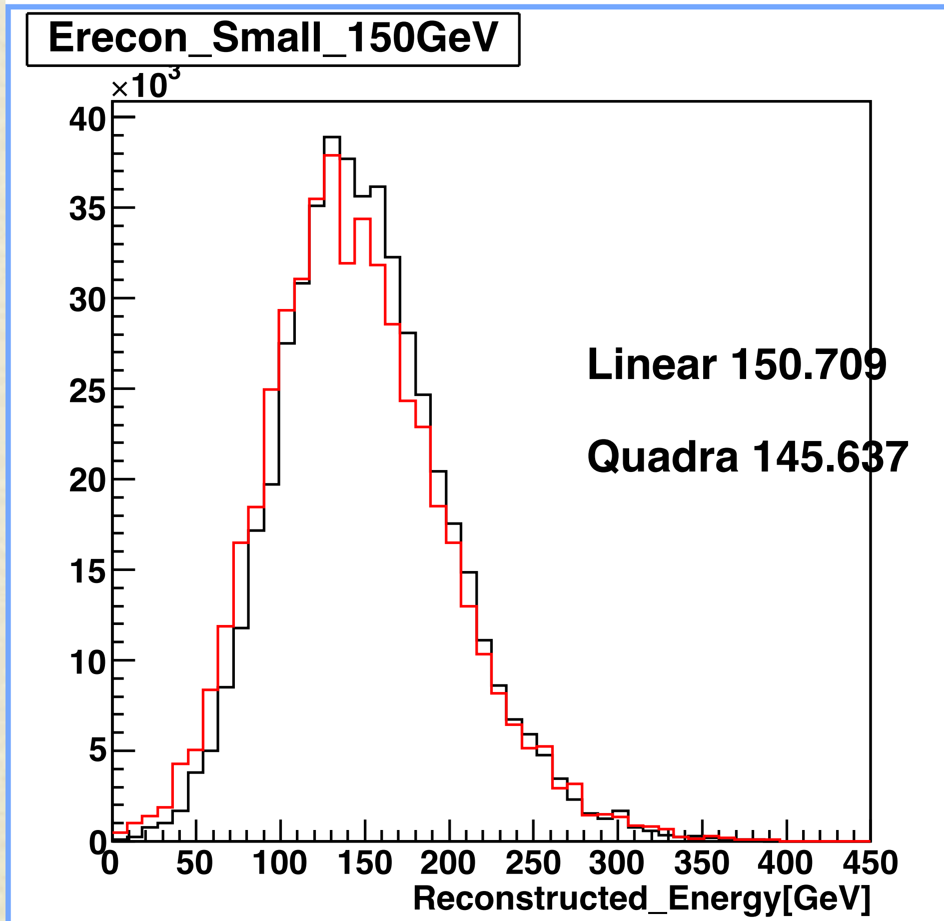


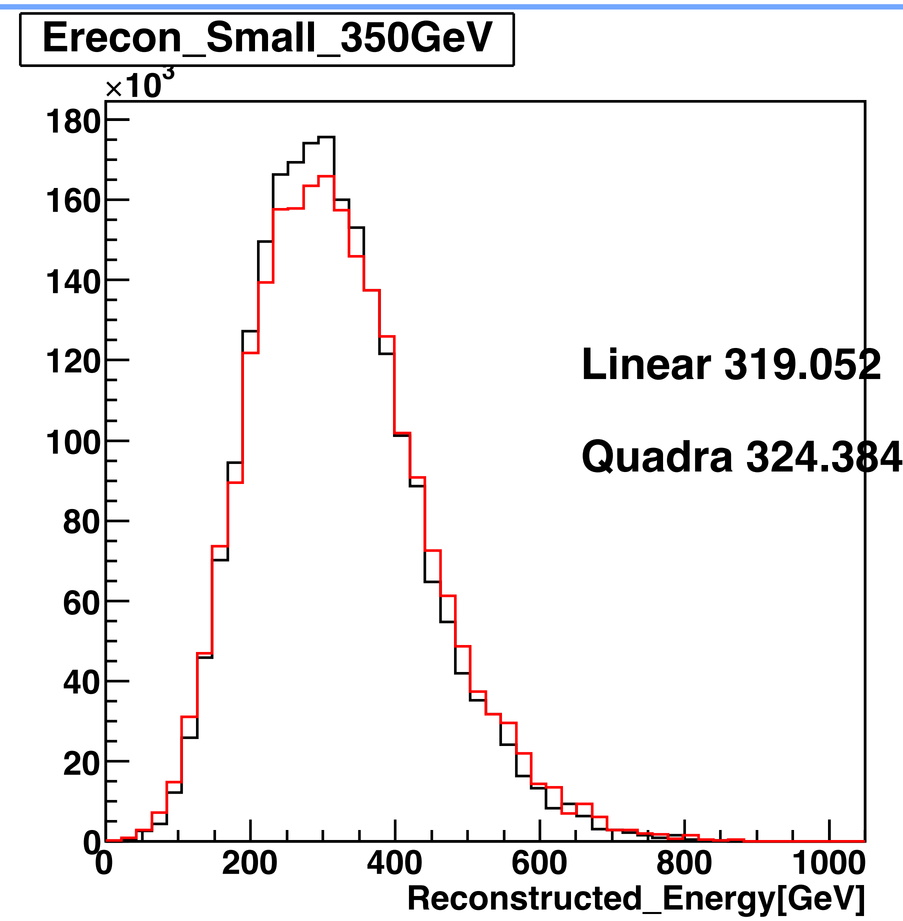




beam test

- 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**

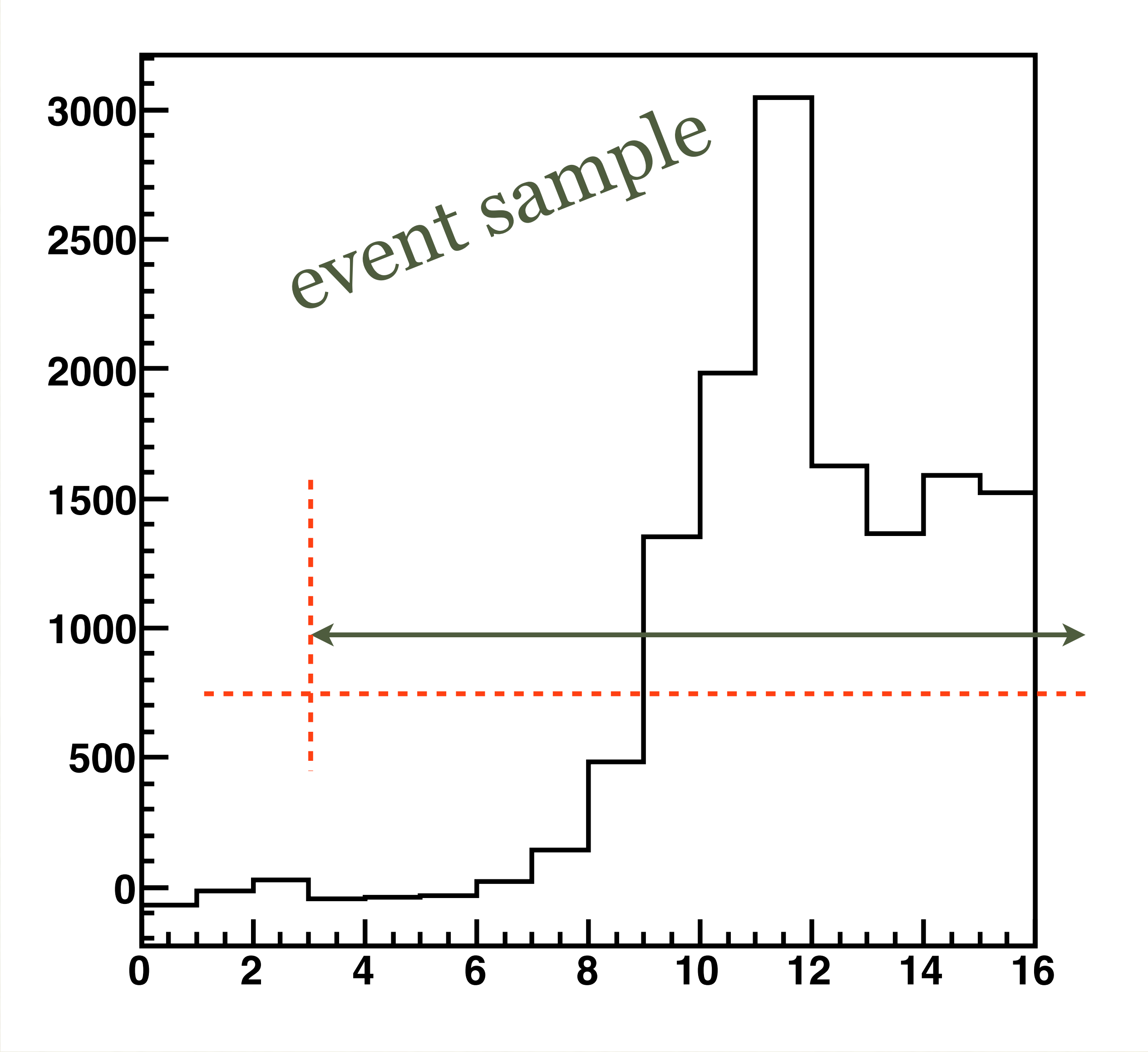
Spare Slide

Transition Curve

- Trigger
  - any successive three layers coincidence
- The response function of SumdE is below

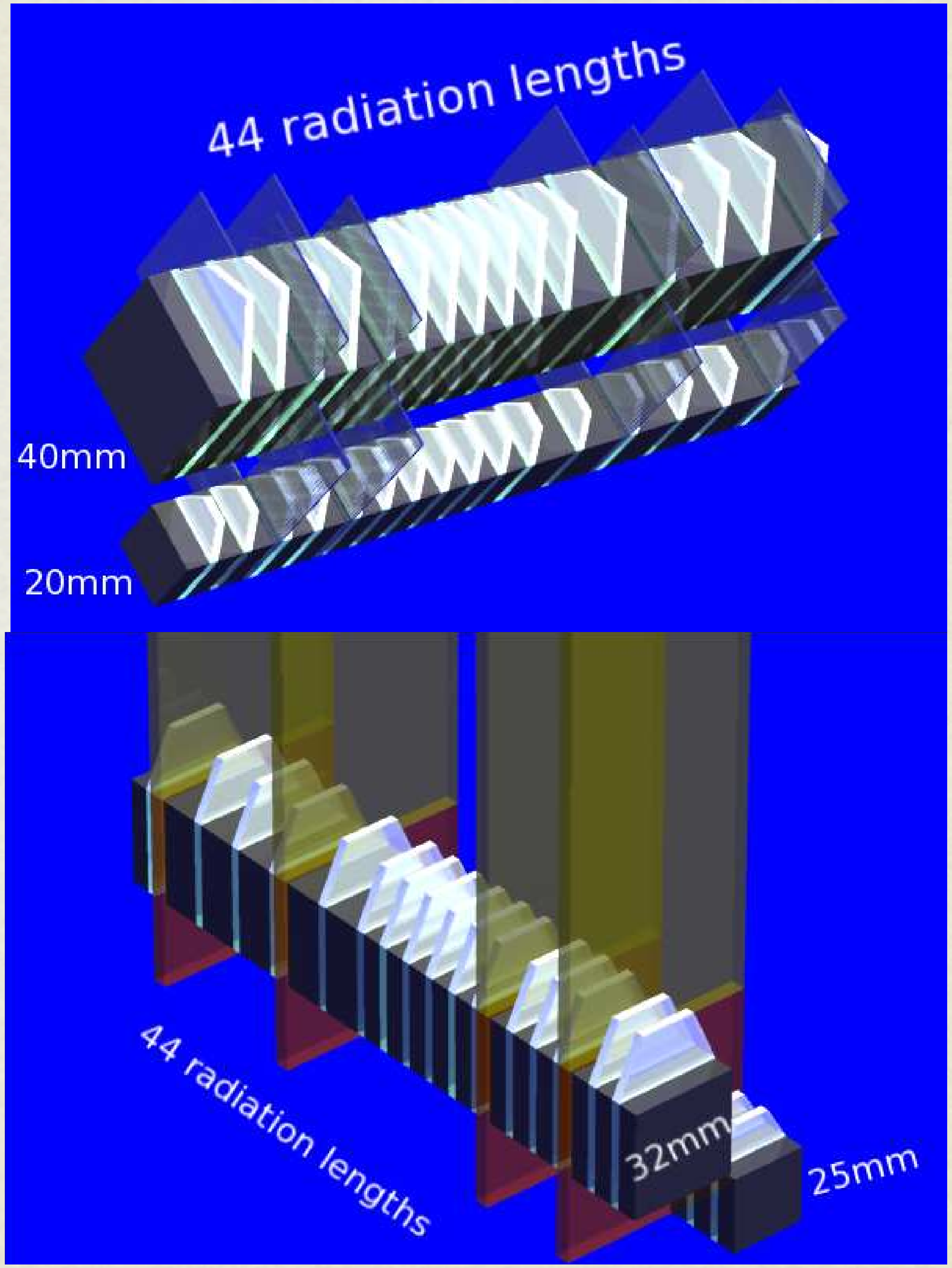
$$SumdE = \sum_{i=1}^{11} dE_i \times N_{stepi}$$

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

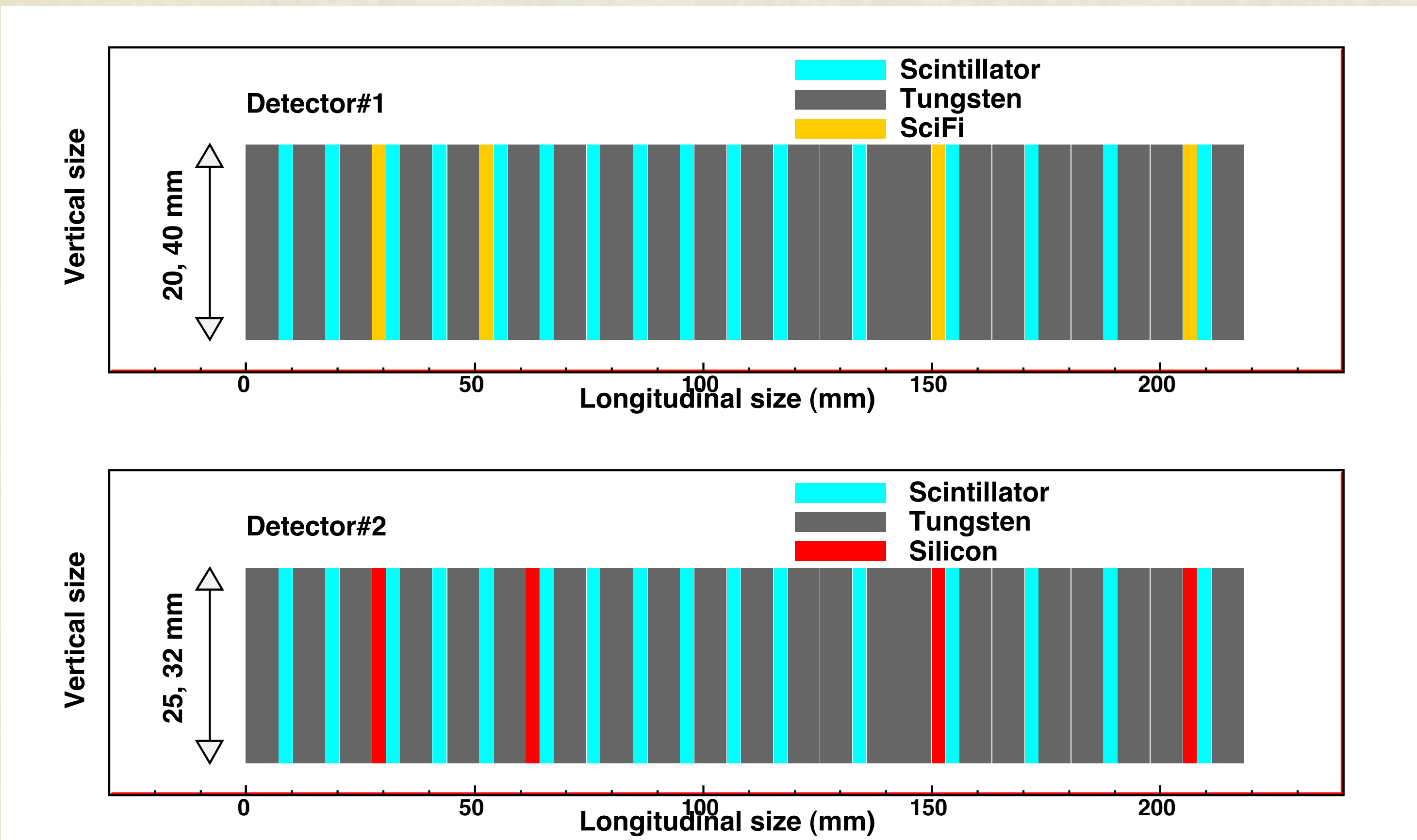


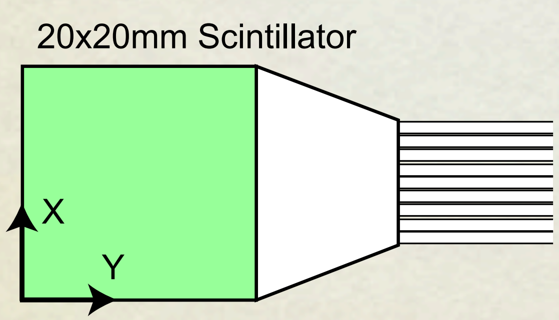
LHCf Detector

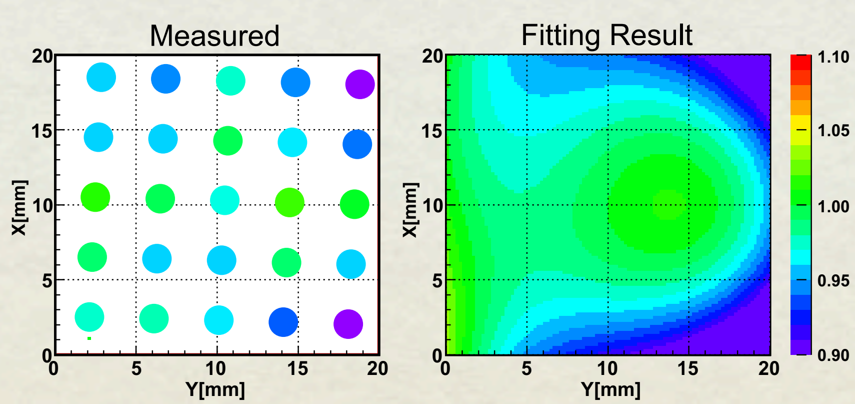
- Composed from 16 layers of scintillator and Tungsten and 4 layers of lateral position sensor (SciFi)
- Total 44r.l. and 1.7λ
- performance for EM shower was well studied,
- but, for hadronic is not studied well



Sampling Layer



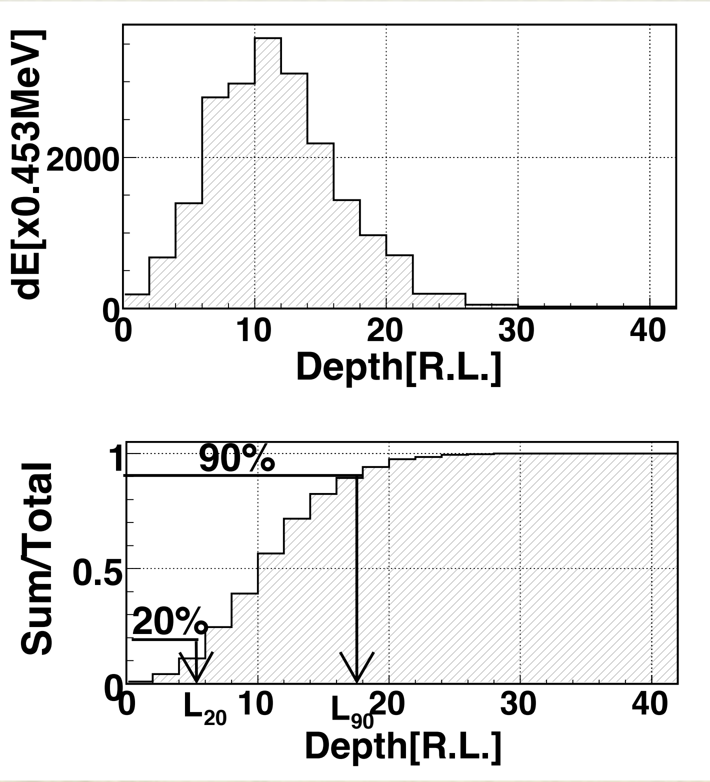


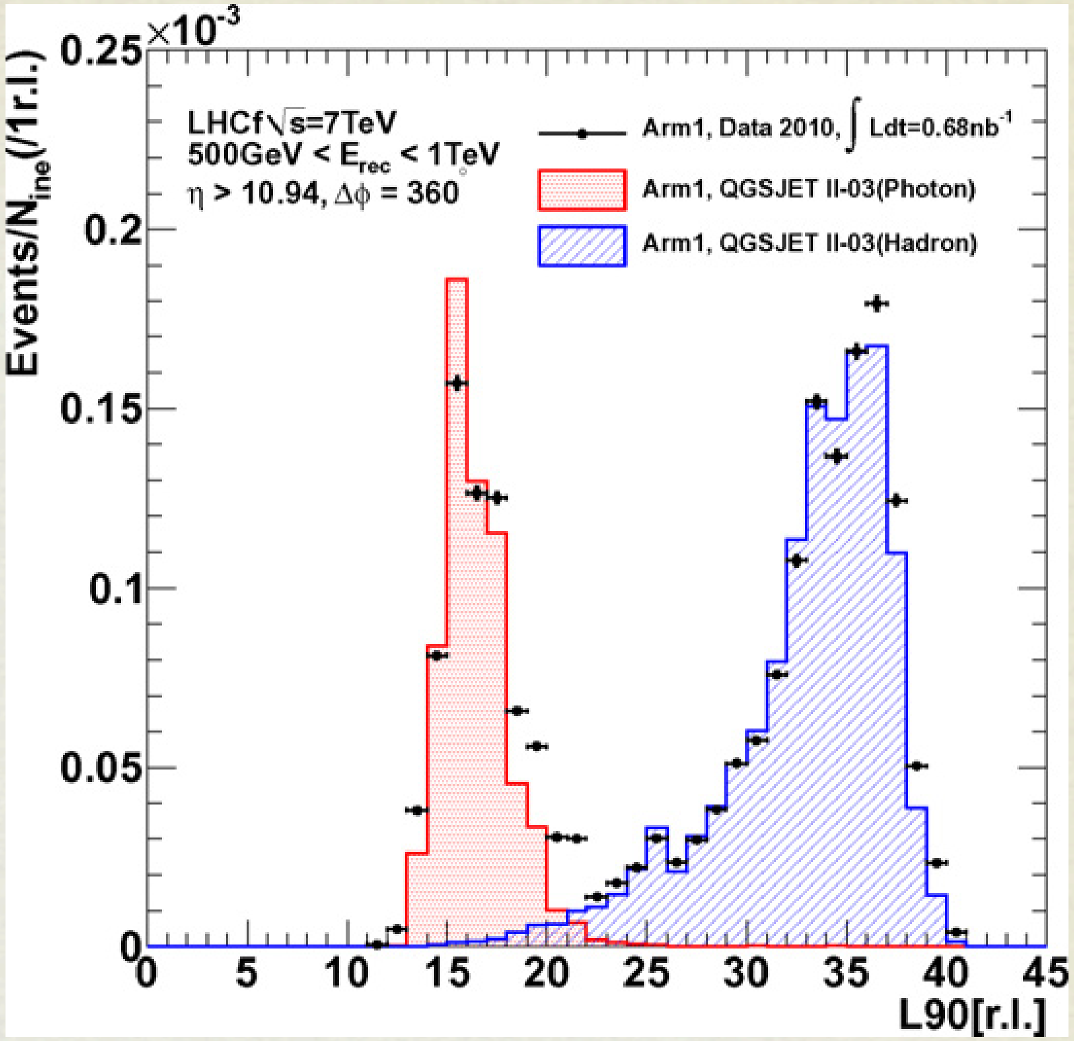


- 7mm or 14mm thickness of Tungsten Absorbers
- 16 layer of sampling layers (Plastic scintillator EJ260)
- 4 position (Transverse) sensitive layers

PID selection with L90

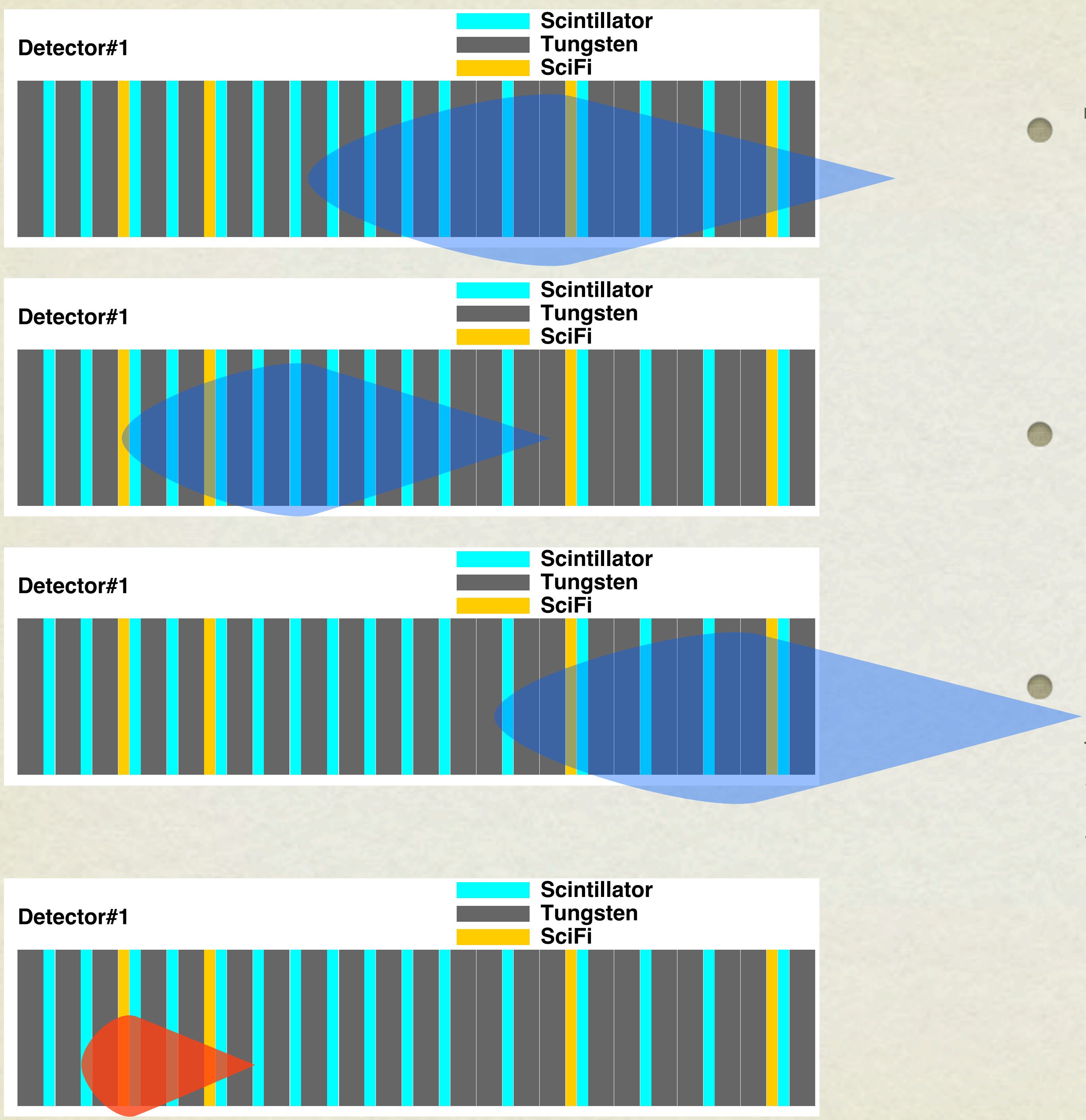
- L90 is the longitudinal depth containing 90% of the total sum of the shower particles.
- Gamma like -> Shallower
- Hadron like -> Deeper





- 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