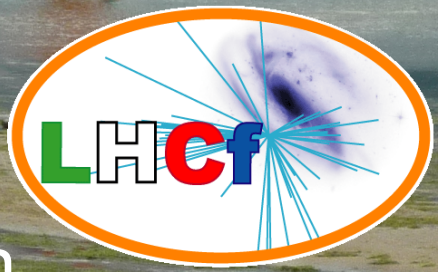
Forward photon energy spectrum at 7TeV p-p collisions measured by the LHCf experiment

Hiroaki MENJO
(KMI, Nagoya University, Japan)
On behalf of the LHCf collaboration



ISMD 2011, Hiroshima, Japan, 26-30 Sep. 2011

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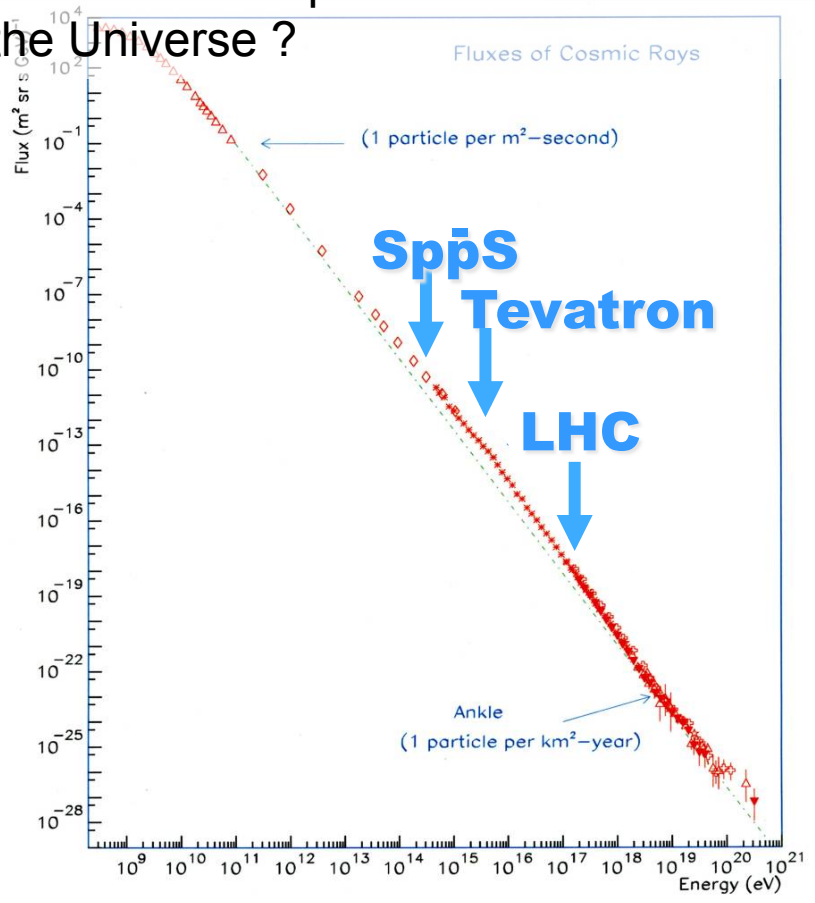
- Introduction
- The LHCf experiment
  -An LHC forward experiment-
- Forward photon energy spectrum at $\sqrt{s}$ = 7eV p-p collisions
- Future plans
- Summary

Large Hadron Collider

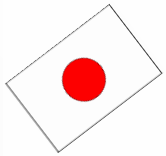
-The most powerful accelerator on the earth-

Ultra High Energy Cosmic Rays

What is the most powerful accelerator in the Universe ?



The LHCf collaboration



K.Fukatsu, T.Iso, Y.Itow, K.Kawade, T.Mase, K.Masuda, Y.Matsubara, G.Mitsuka, Y.Muraki, T.Sako, K.Suzuki, K.Taki *Solar-Terrestrial Environment Laboratory, Nagoya Univ.*

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Y.Shimizu *JAXA*

T.Tamura *Kanagawa University*

M.Haguenauer *Ecole Polytechnique, France*

W.C.Turner *LBNL, Berkeley, USA*

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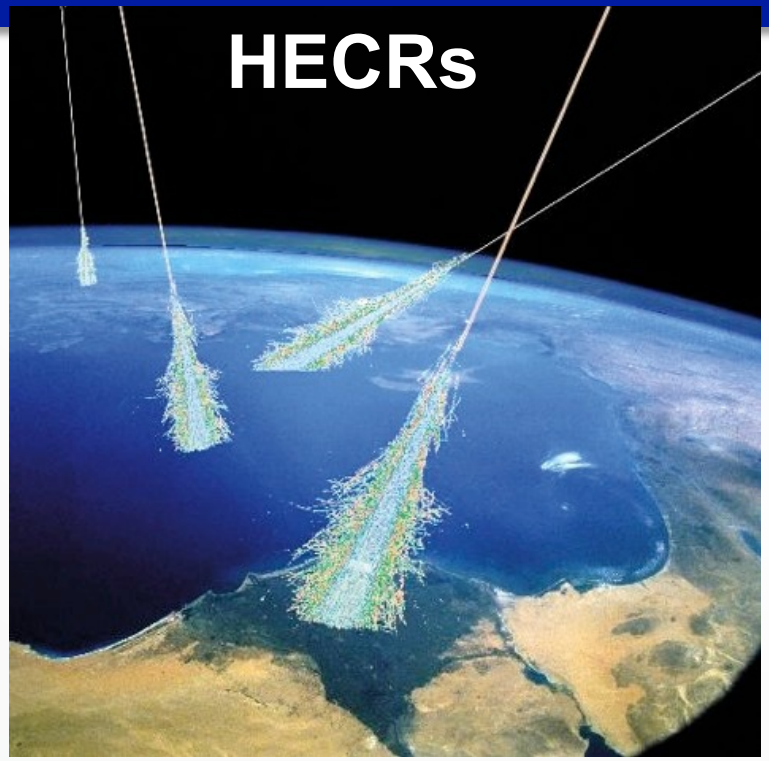
K.Noda, A.Tricomi *INFN, Univ. di Catania, Italy*

J.Velasco, A.Faus *IFIC, Centro Mixto CSIC-UVEG, Spain*

A-L.Perrot *CERN, Switzerland*

Introduction



Extensive air shower observation

- longitudinal distribution
- lateral distribution
- Arrival direction

Air shower development

Astrophysical parameters

- Spectrum
- Composition
- Source distribution

X_{max}

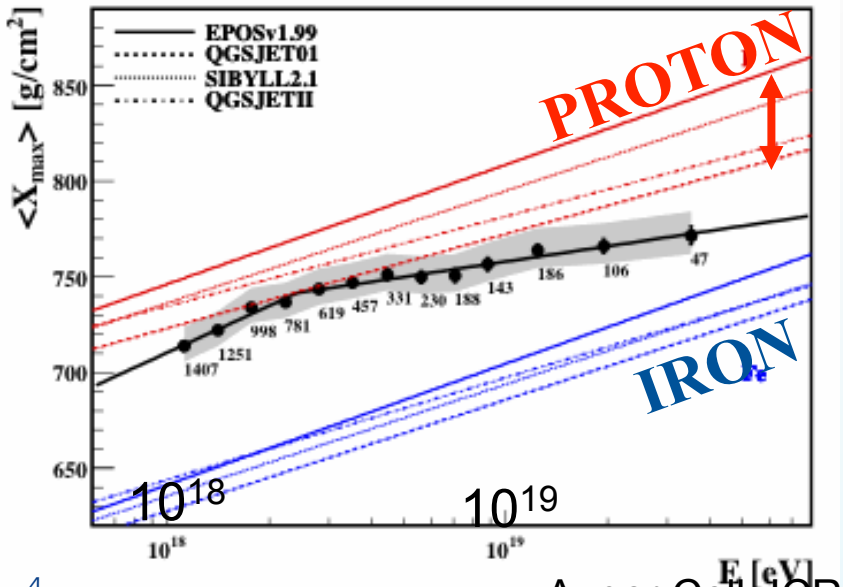
the depth of air shower maximum.
An indicator of CR composition

Uncertainty of hadron interaction models

V

Error of $<X_{max}>$ measurement

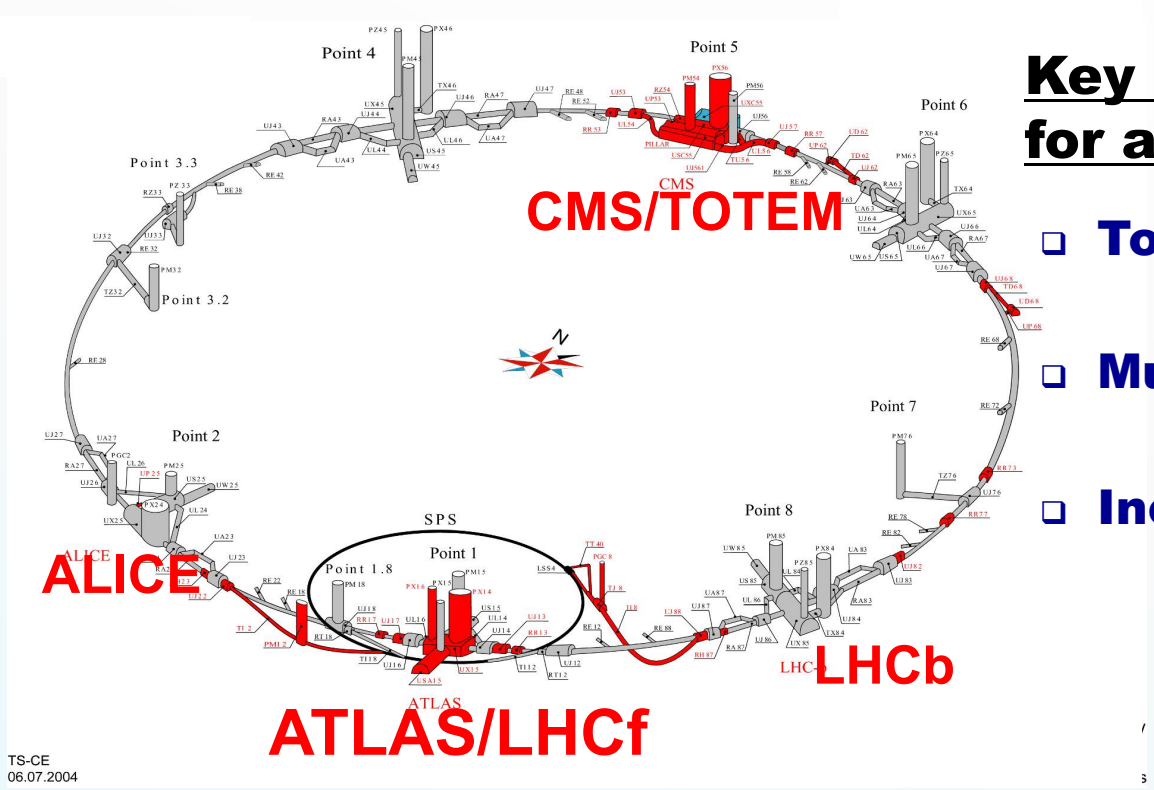
X_{max} distribution measured by AUGER



Auger Coll. ICRC2011

The Large Hadron Collider (LHC)

pp 7TeV+7TeV → $E_{lab} = 10^{17}$eV 2014-
pp 3.5TeV+3.5TeV → $E_{lab} = 2.6 \times 10^{16}$eV
pp 450GeV+450GeV → $E_{lab} = 2 \times 10^{14}$eV

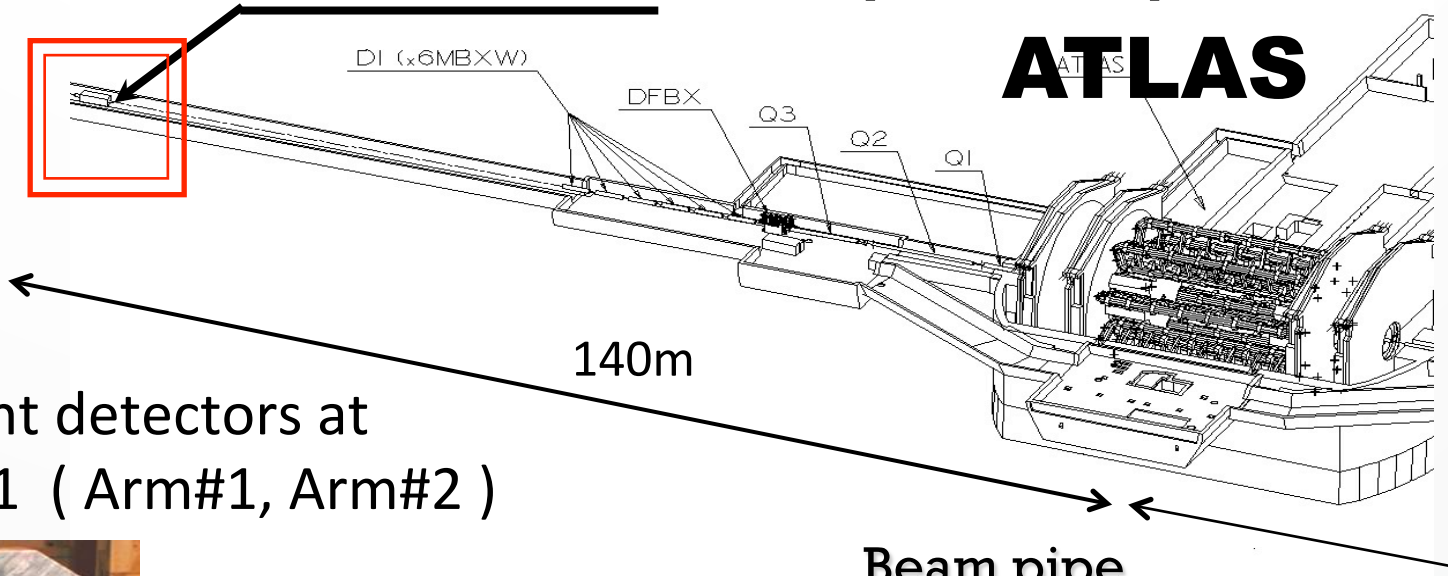


Key parameters for air shower developments

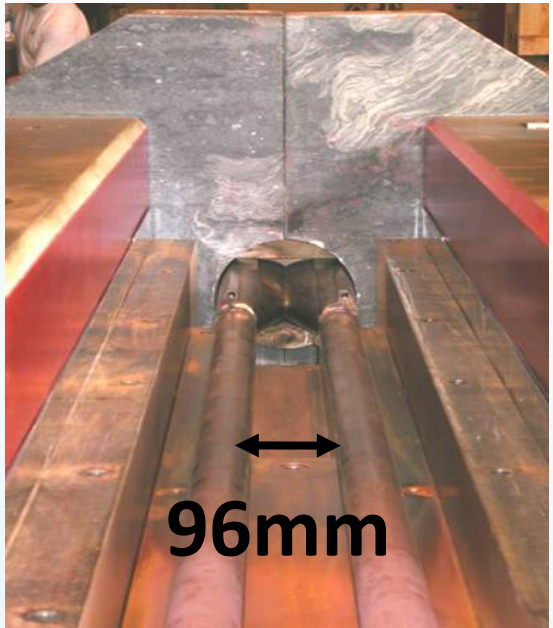
- Total cross section
  ↔ TOTEM, ATLAS, CMS
- Multiplicity
  ↔ Central detectors
- Inelasticity/Secondary spectra
  ↔ Forward calorimeters
  LHCf, ZDCs

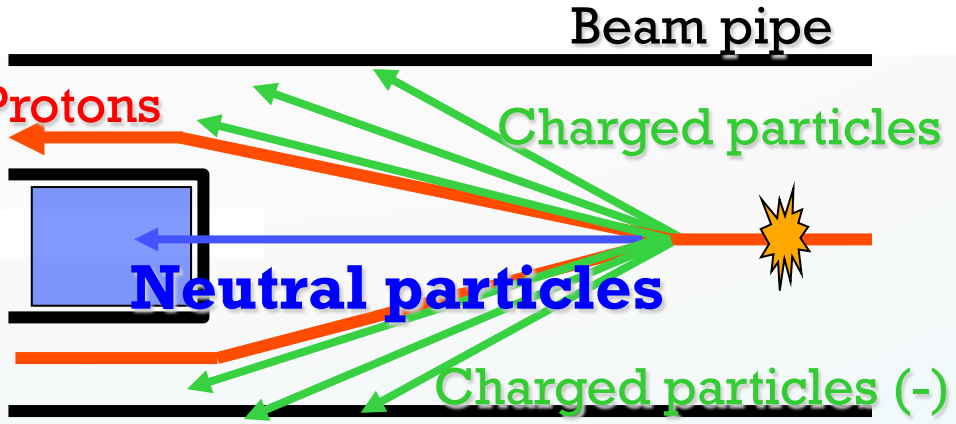
The LHCf experiment

LHCf Detector(Arm#1)



Two independent detectors at
either side of IP1 (Arm#1, Arm#2)





TAN -Neutral Particle Absorber-

transition from one common beam pipe to two pipes

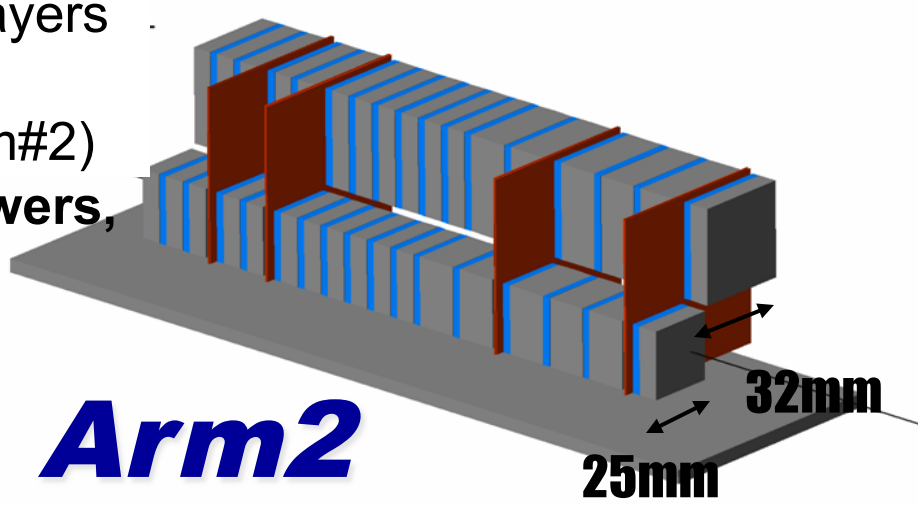
Slot : 100mm(w) x 607mm(H) x 1000mm(T)

The LHCf Detectors

Sampling and Positioning Calorimeters

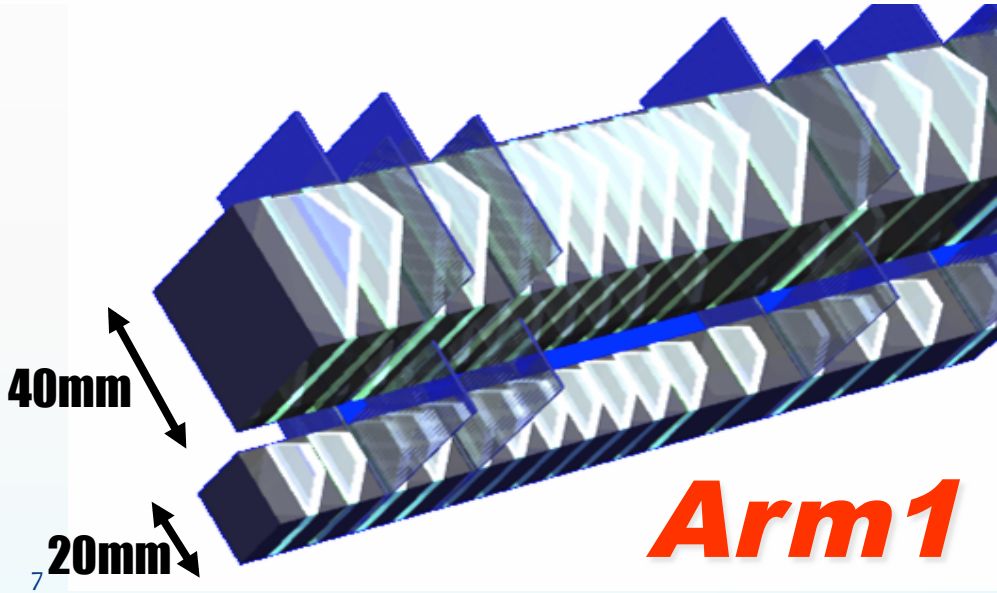
- W (44 r.l , 1.7λ_I) and Scintillator x 16 Layers
- 4 positioning layers
  XY-SciFi(Arm1) and XY-Silicon strip(Arm#2)
- **Each detector has two calorimeter towers, which allow to reconstruct π^0**

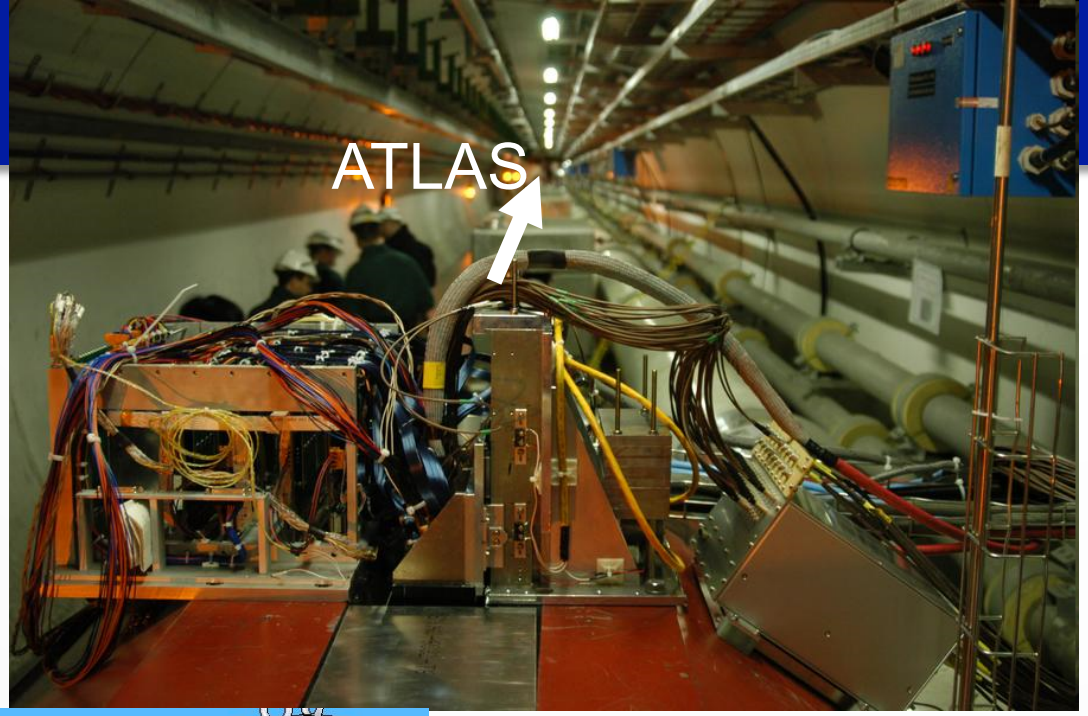
Expected Performance
Energy resolution (> 100GeV)
< 5% for photons
30% for neutrons
Position resolution
< 200μm (Arm#1)
40μm (Arm#2)

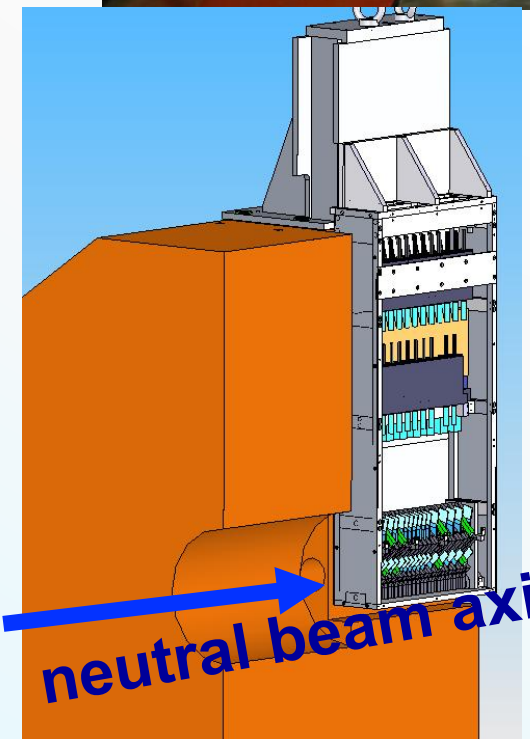


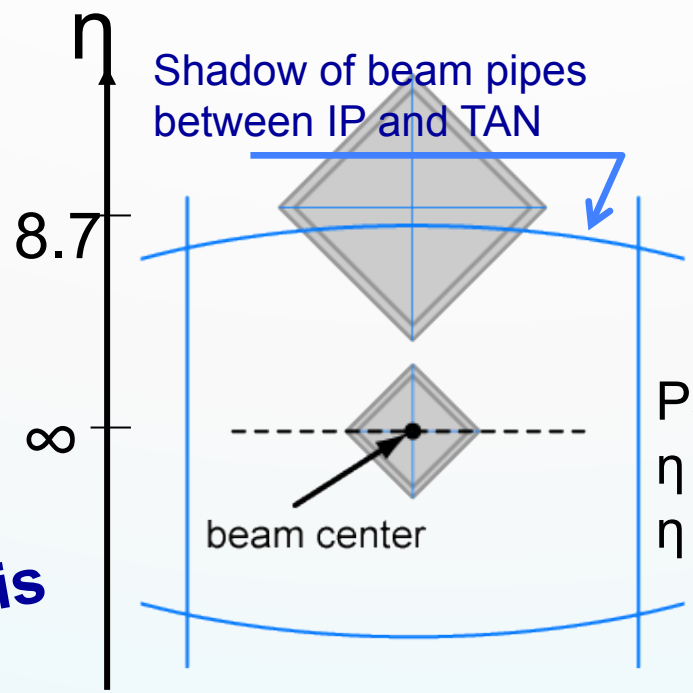
Front Counter

- thin scintillators with 80x80mm^2
- **To monitor beam condition.**
- **For background rejection of beam-residual gas collisions by coincidence analysis**





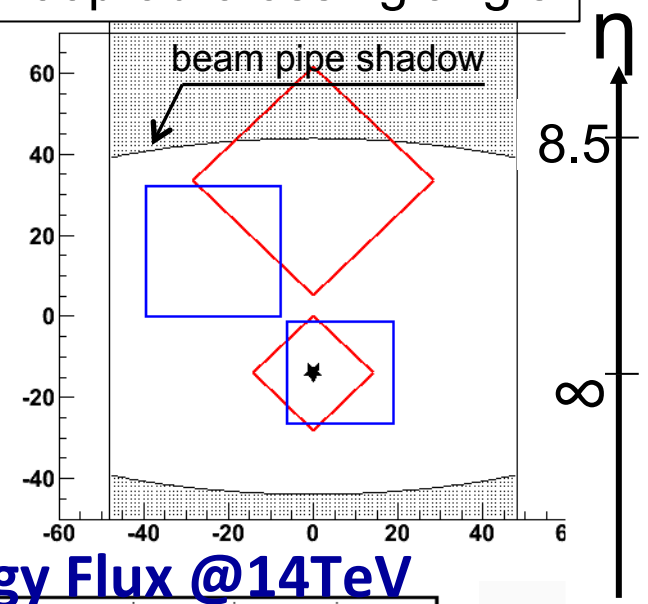




Pseudo-rapidity range.
η > 8.7 @ zero crossing angle
η > 8.4 @ 140urad

LHCf can measure

Front view of calorimeters
@ 100μrad crossing angle

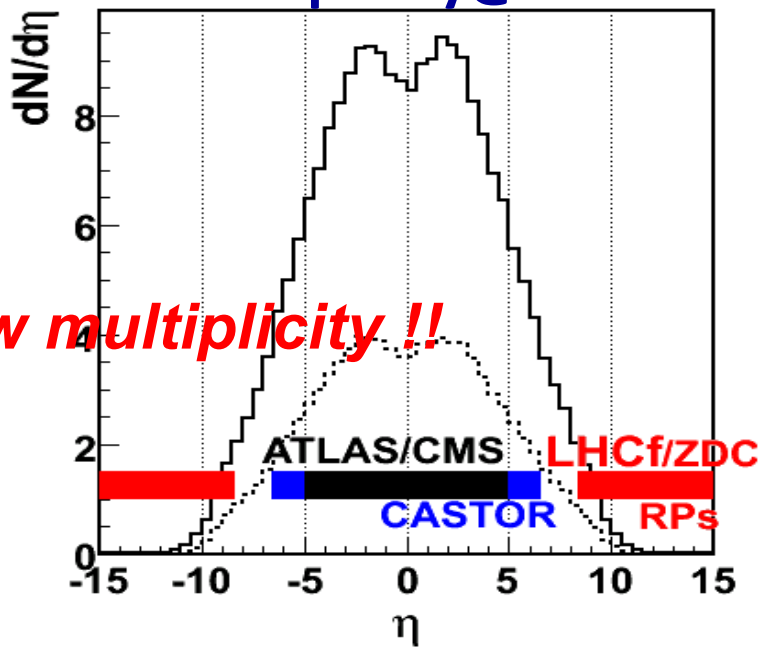


Energy spectra and
Transverse momentum distbution of

- **Gamma-rays (E>100GeV,dE/E<5%)**
- **Neutral Hadrons (E>a few 100 GeV, dE/E~30%)**
- **π^0 (E>600GeV, dE/E<3%)**

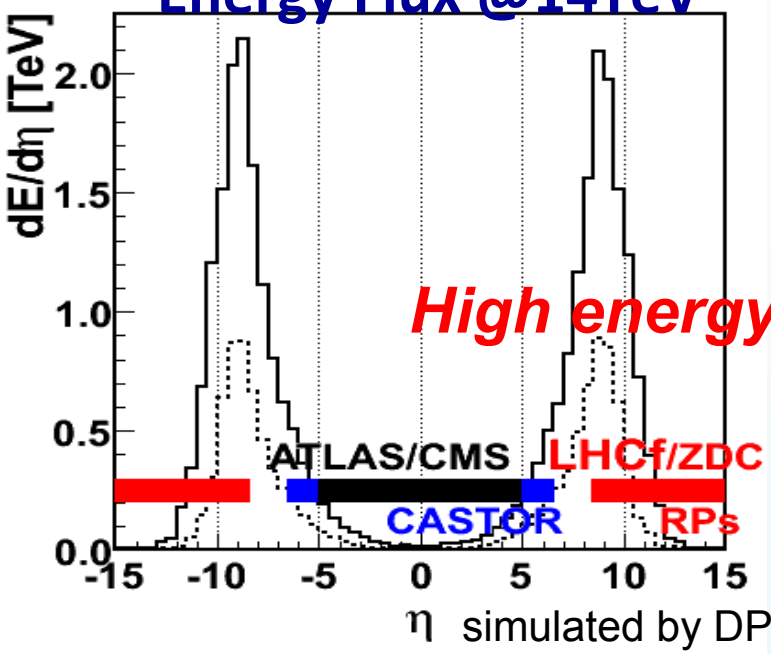
at pseudo-rapidity range >8.4

Multiplicity@14TeV



Low multiplicity !!

Energy Flux @14TeV



High energy flux !!

η simulated by DPMJET3

Operation in 2009-2010

At 450GeV+450GeV

- 06 Dec. –15 Dec. in 2009
  27.7 hours for physics, 2.6 hours for commissioning
  ~2,800 and ~3,700 shower events in Arm1 and Arm2
- 02 May – 27 May in 2010
  ~15 hours for physics
  ~44,000 and ~63,000 shower events in Arm1 and Arm2

At 3.5TeV+3.5TeV

- 30 Mar. – 19 July in 2010
  ~ 150 hours for physics with several setup
  With zero crossing angle and with 100μrad crossing angle.
  ~$2x10^8$ and ~$2x10^8$ shower events in Arm1 and Arm2

Operation at √s = 900GeV and 7TeV has been completed successfully.
The detectors has been removed from the LHC tunnels at July 2010,
and will be upgraded for the future operations.

Forward photon spectrum at $\sqrt{s}$ = 7eV p-p collisions

" Measurement of zero degree single photon energy spectra for $\sqrt{s}$ = 7 TeV proton-proton collisions at LHC "

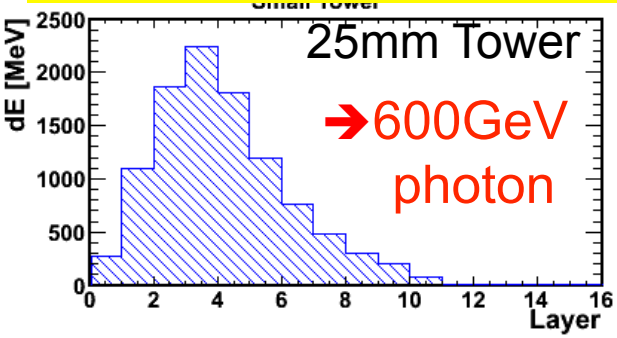
O. Adriani, et al., PLB, Vol.703-2, p.128-134 (09/2011)

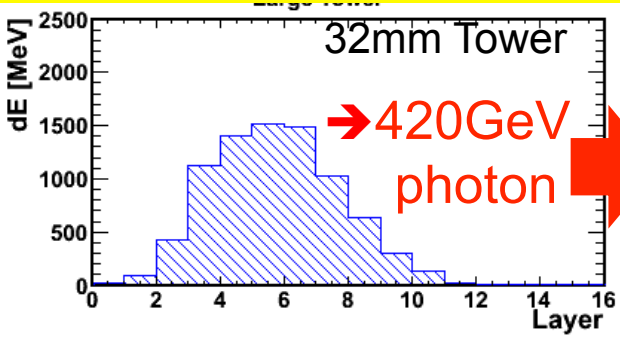
Analysis for the photon spectra

- DATA
  - 15 May 2010 17:45-21:23, at Low Luminosity $6 \times 10^{28} cm^{-2} s^{-1}$
  - 0.68 nb-1 for Arm1, 0.53nb-1 for Arm2
- MC
  - DPMJET3.04, QGSJETII03, SYBILL2.1, EPOS1.99
    PYTHIA 8.145 with the default parameters.
  - 10^7 inelastic p-p collisions by each model.
- Analysis Procedure
  - Energy Reconstruction from total energy deposition
    in a tower with some corrections, shower leakage out etc.
  - Particle Identification
    by shape of longitudinal shower development.
  - Cut multi-particle events.
  - Two Pseudo-rapidity selections, $\eta > 10.94$ and $8.81 < \eta < 8.9$.
  - Combine spectra between the two detectors.

Event sample

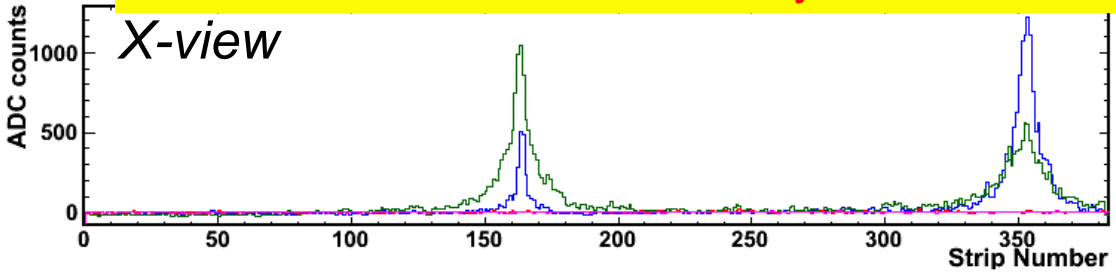
Longitudinal development measured by scintillator layers

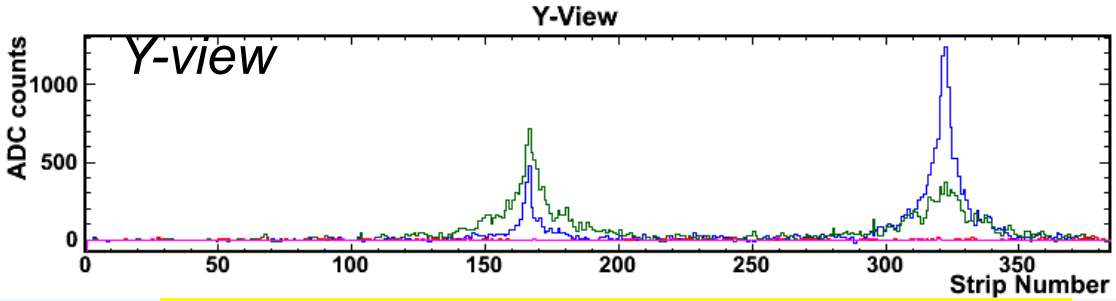




Total Energy deposit
➔Energy
Shape
➔PID

Lateral distribution measured by silicon detectors





Hit position,
Multi-hit search.

π^0 mass reconstruction from two photon.

$$M_{\pi 0} = \sqrt{E_{\gamma 1} E_{\gamma 2}} \cdot \theta$$

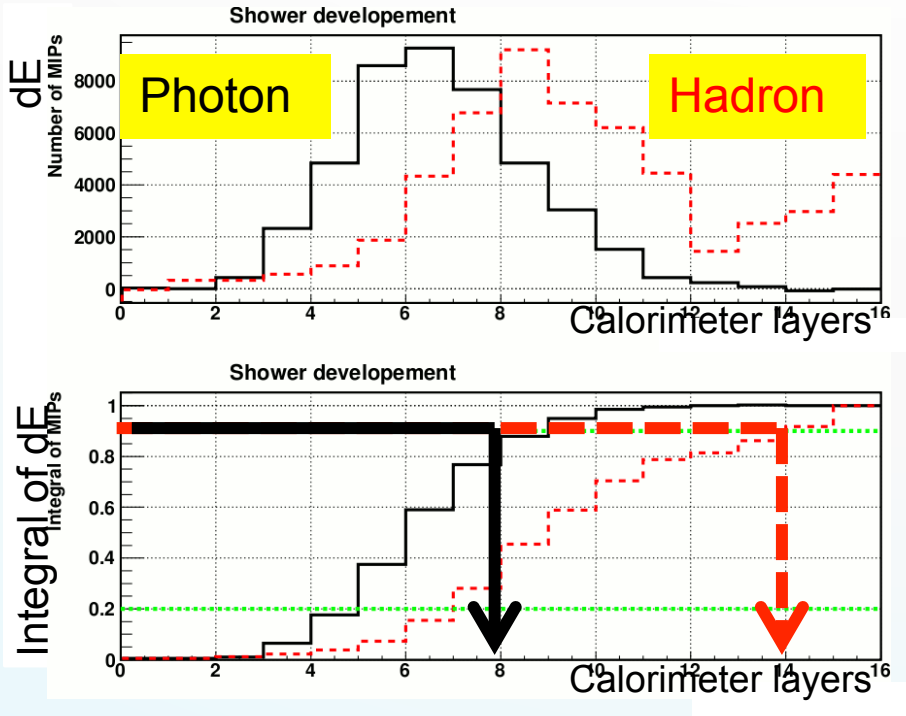
Systematic studies

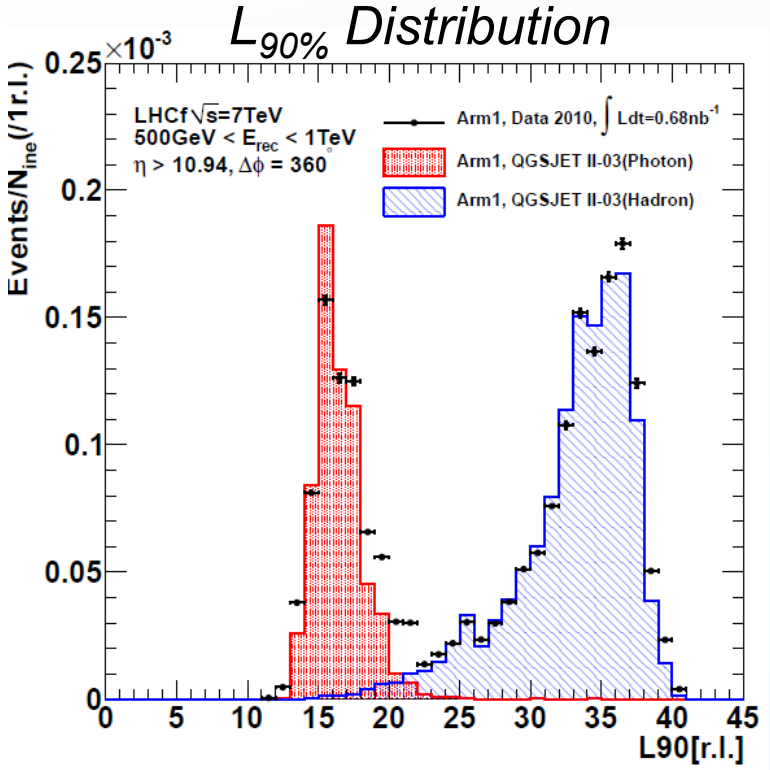
Particle Identification

- Event selection and correction
  - Select events $<L_{90\%}$ threshold and multiply P/ε
    ε (photon detection efficiency) and P (photon purity)
  - By normalizing MC template $L_{90\%}$ to data, ε and P for certain $L_{90\%}$ threshold are determined.

Calorimeter Depth

Elemag: 44r.l.
Hadronic: 1.7λ

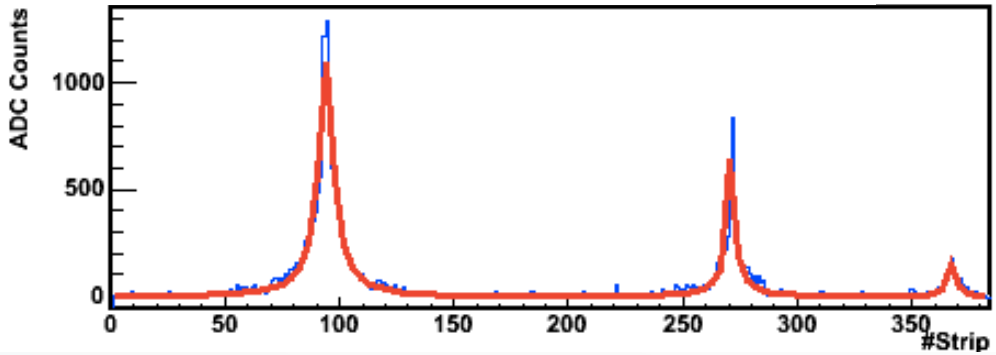




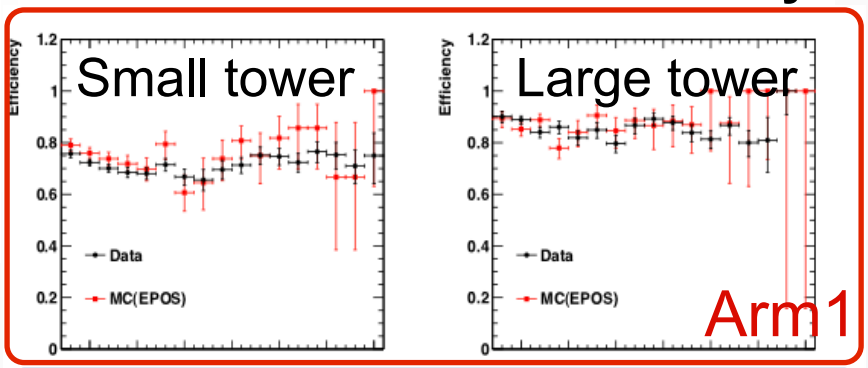
Multi-hit identification

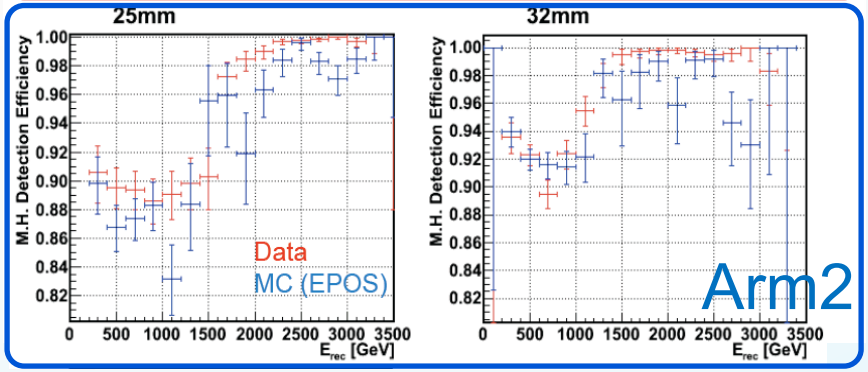
- Event cut of multi-peak events,
  - Identify multi-peaks in one tower by position sensitive layers.
  - Select only the single peak events for spectra.

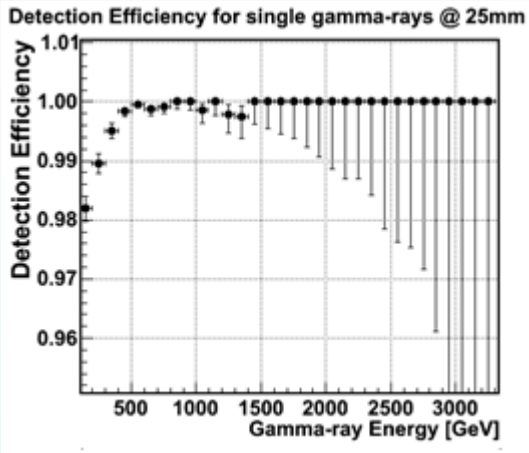
An example of multi peak event



Double hit detection efficiency





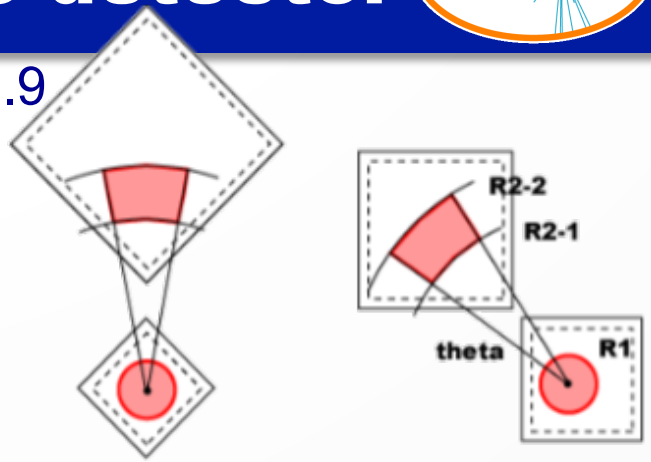


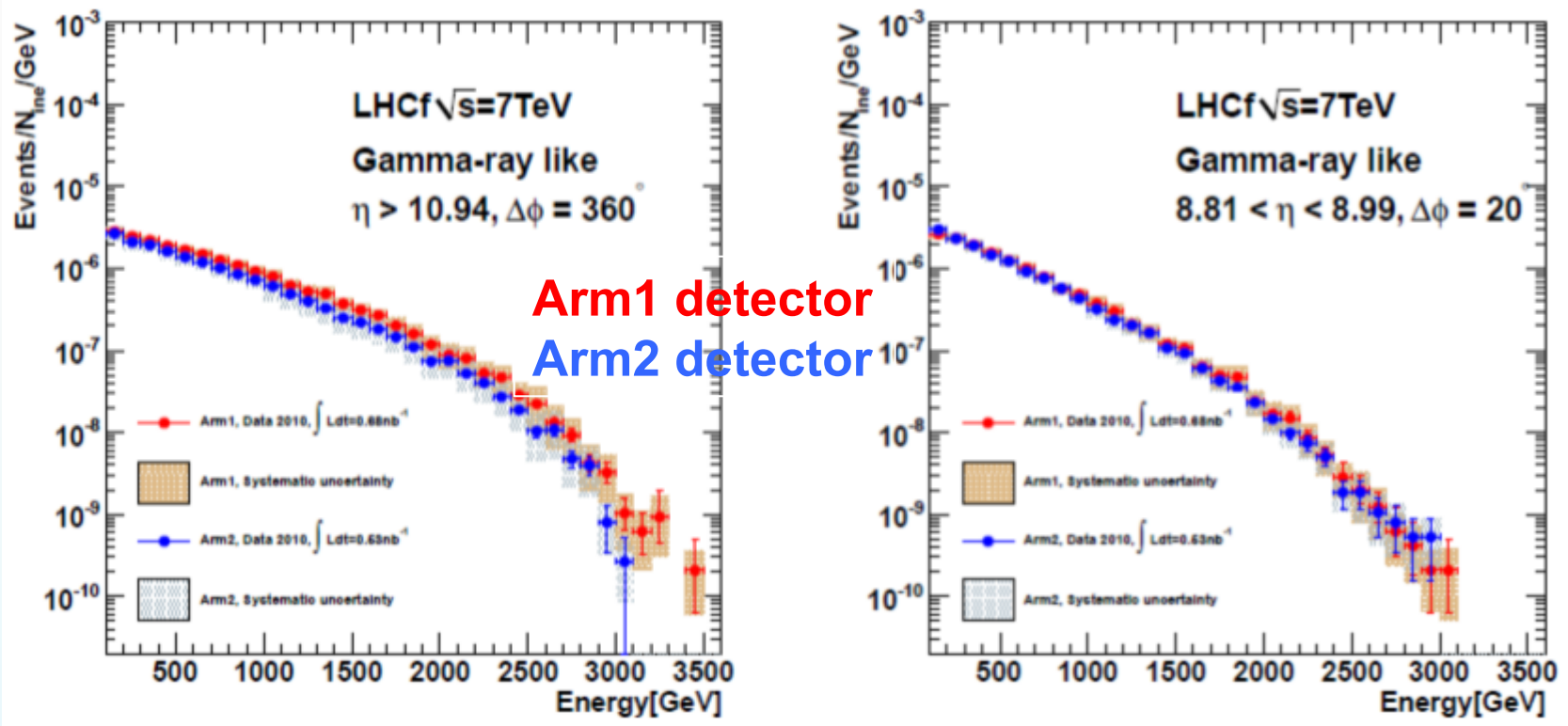
Single hit detection efficiency

Comparison between the two detector

- Pseudo-rapidity selection, $\eta>10.94$ and $8.81<\eta<8.9$
- Normalized by number of inelastic collisions with assumption as inelastic cross section of 71.5mb
- Spectra in the two detectors are consistent within errors.

➔ Combined between spectra of Arm1 and Arm2 by weighted average according to errors



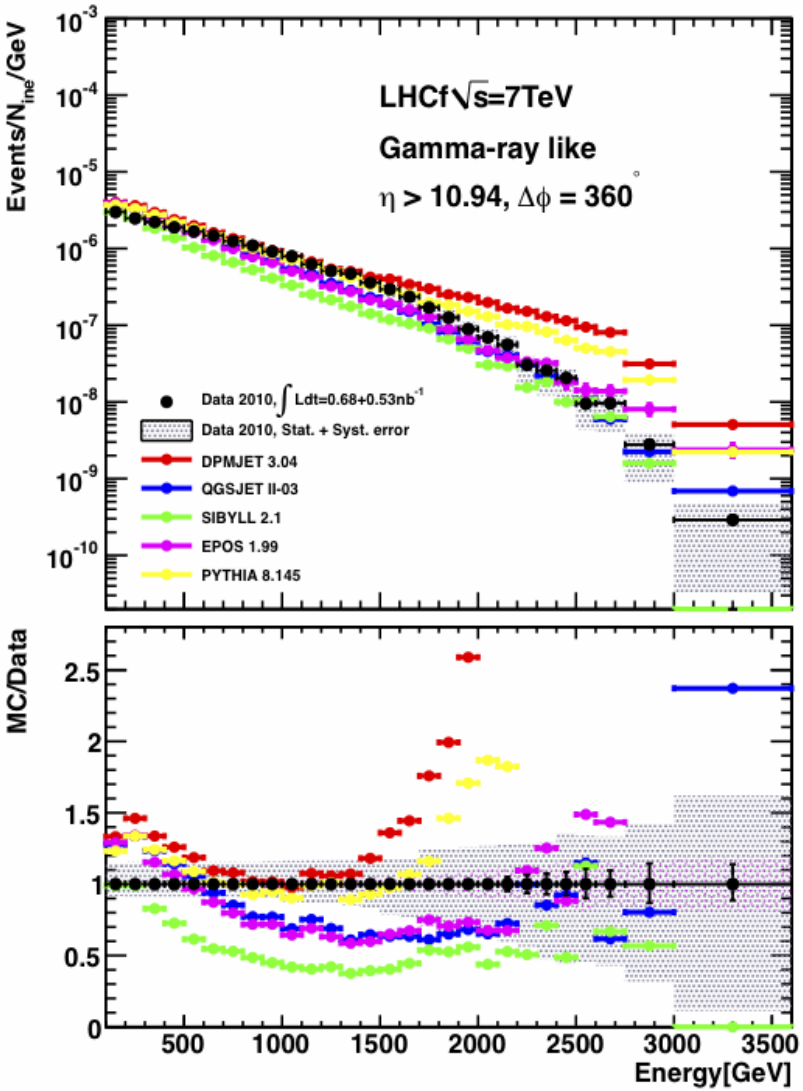


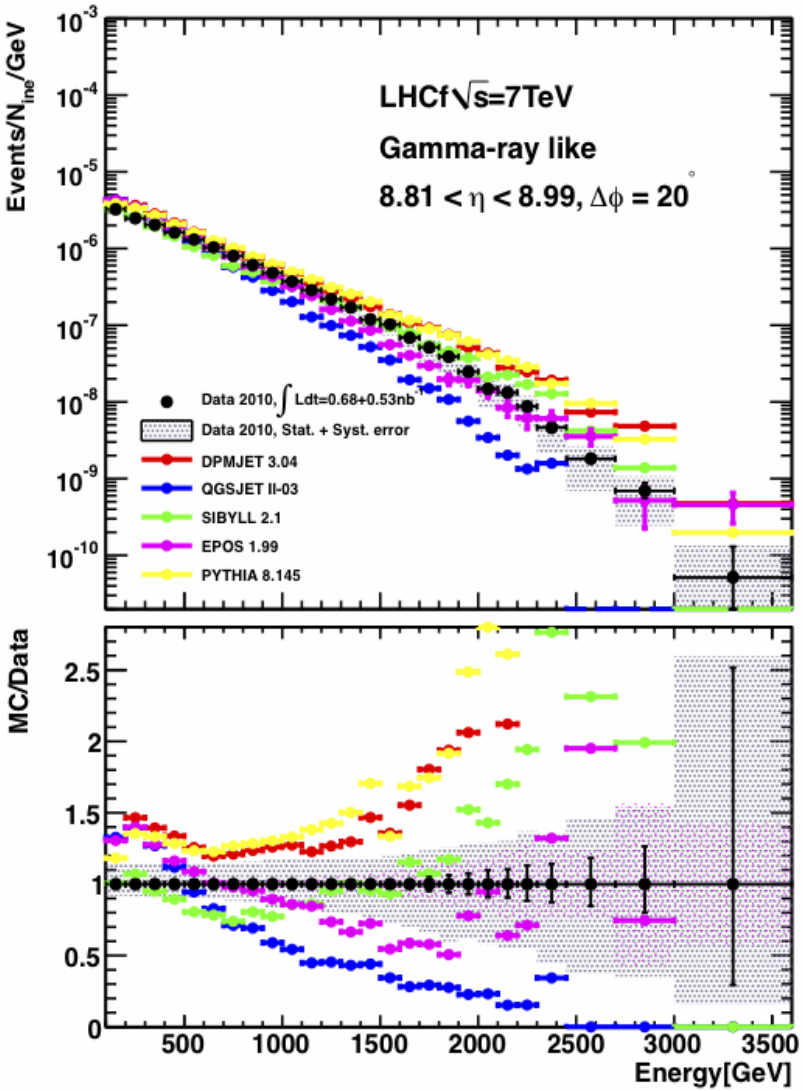
Comparison between MC's

DPMJET 3.04 QGSJETII-03 SIBYLL 2.1 EPOS 1.99 PYTHIA 8.145

Gray hatch : Systematic Errors

Blue hatch: Statistics errors of MC





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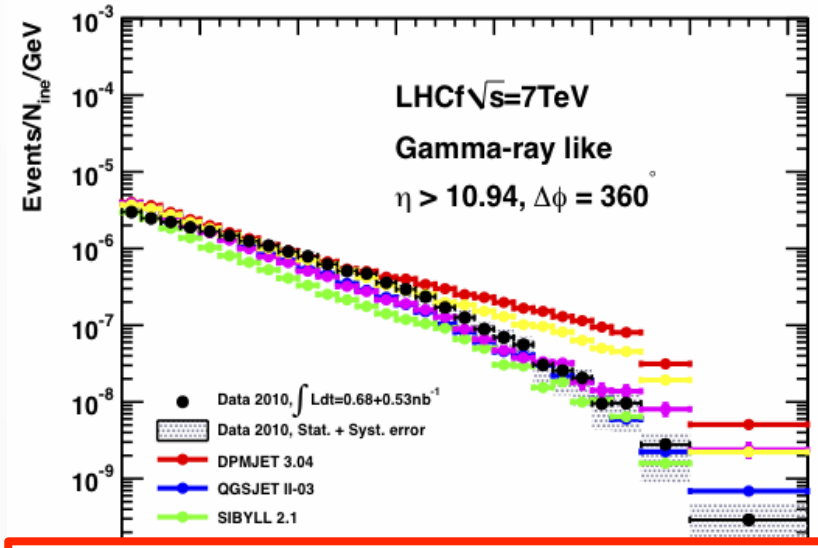
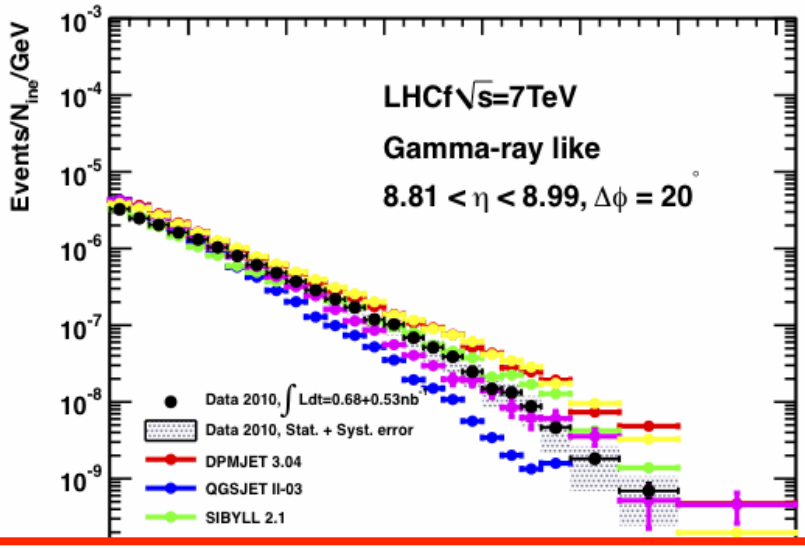
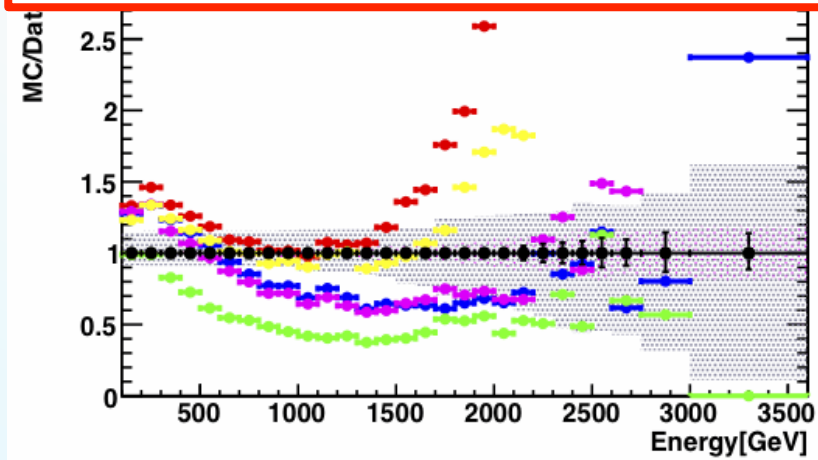
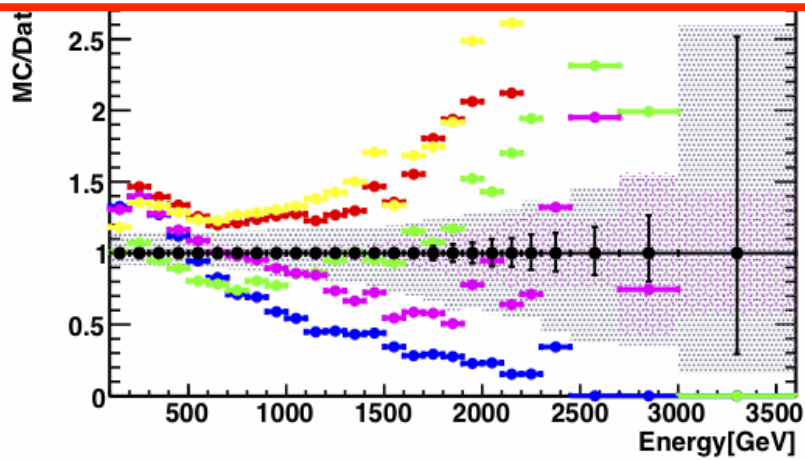




No model are not able to reproduce the LHCf results perfectly





Next Plans

- Ongoing analysis
  - Energy spectrum of photons in the wider pseudo-rapidity range.
  - P_T distribution
  - Hadron spectra
  - π^0 spectra
  - Photon and Hadron energy spectra at 900GeV.
- Future operations
  - p-p collisions at the LHC designed energy, $\sqrt{s}$ = 14TeV in 2014.
  - Planning operations in 2012 and 2013.
    - p-Pb collisions at LHC
    - Operations at RHIC

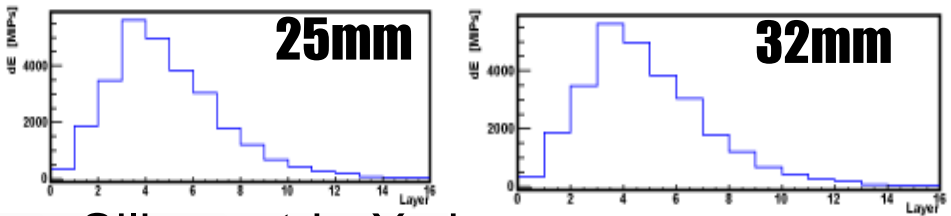
Summary

- LHCf is one LHC experiment dedicated for cosmic ray physics. The aim is to calibrate the hadron interaction models which are used in air shower simulations.
- LHCf measured photon forward energy spectra in the pseudo-rapidity ranges, $\eta>10.94$ and $8.81<\eta<8.9$ at $\sqrt{s}$ = 7TeV proton-proton collisions.
- We compared the spectra with several interaction models
  - None of the models perfectly agree with data
  - Large discrepancy especially in the high energy with all models.
- Analysis is ongoing. Results at $\sqrt{s}$ = 7TeV p-p collisions, energy spectra of photon, hadron, PT distributions and etc., will be provided soon and many results from future operations, p-p at 14TeV, p-A also.

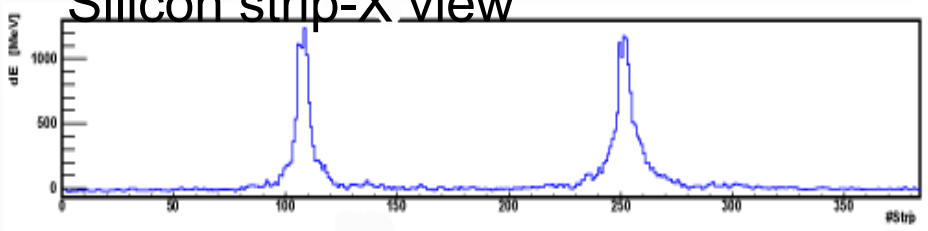
Backup slides

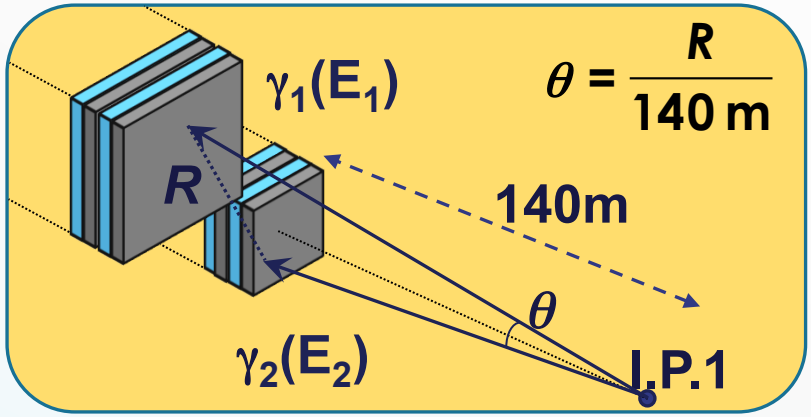
π^0 reconstruction

An example of π^0 events



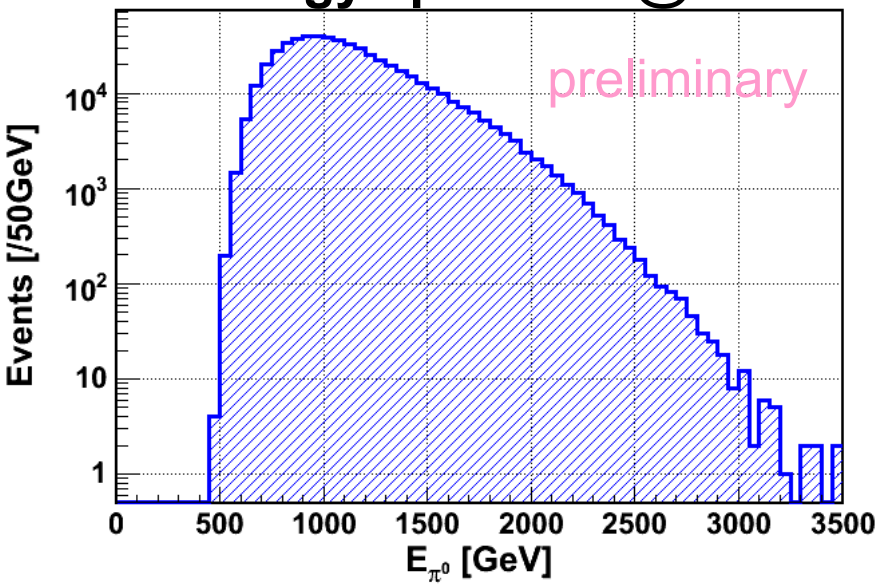
Silicon strip-X view



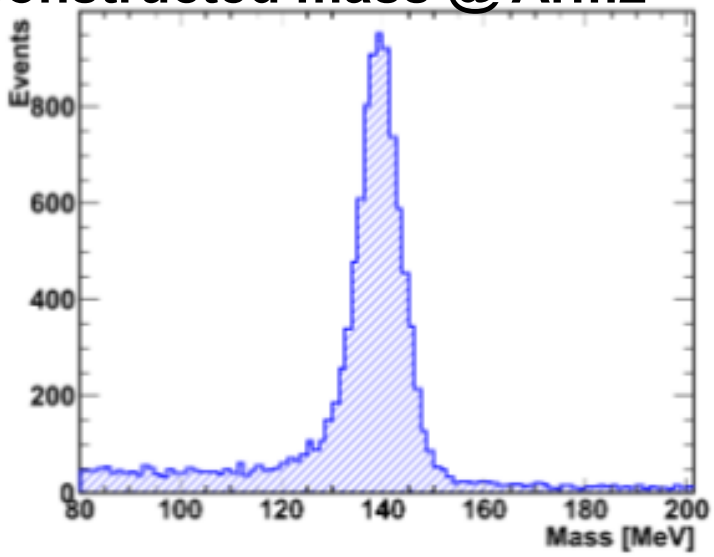


- Pi0's are a main source of electromagnetic secondaries in high energy collisions.
- The mass peak is very useful to confirm the detector performances and to estimate the systematic error of energy scale.

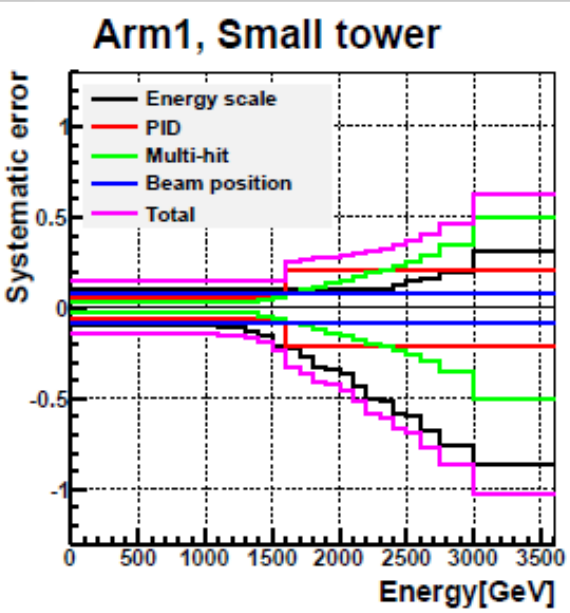
measured energy spectrum @ Arm2

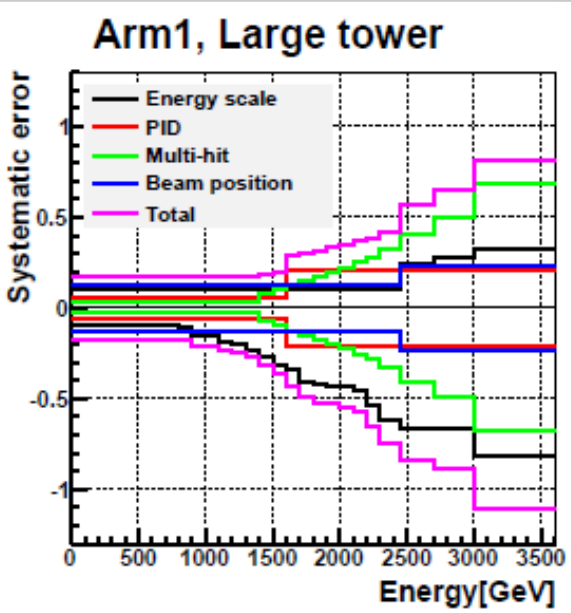


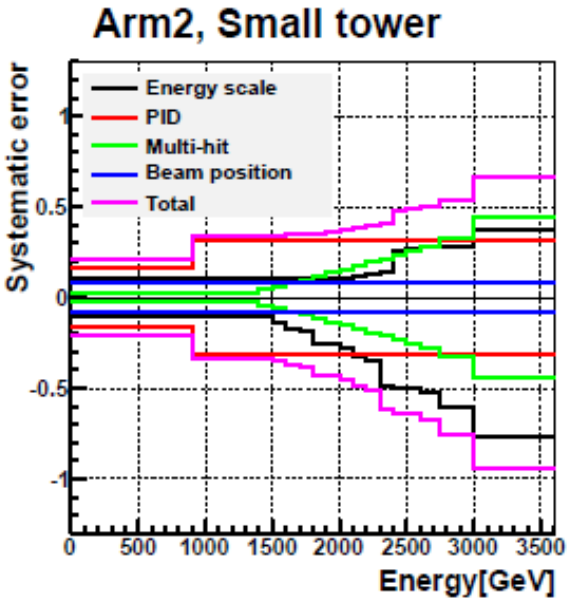
Reconstructed mass @ Arm2

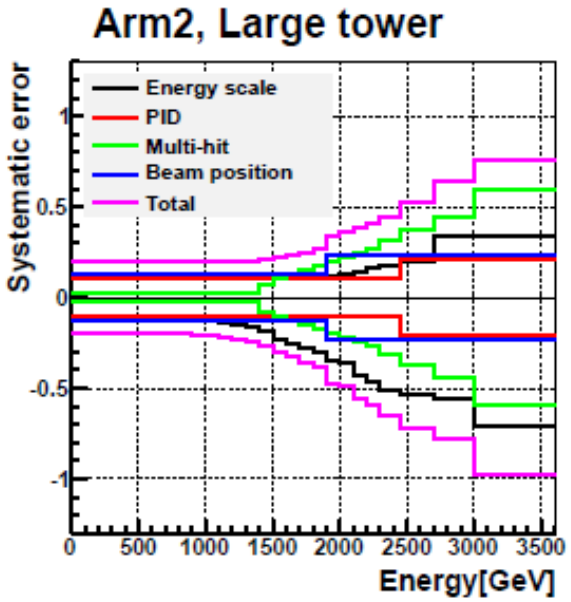


Summary of systematic errors



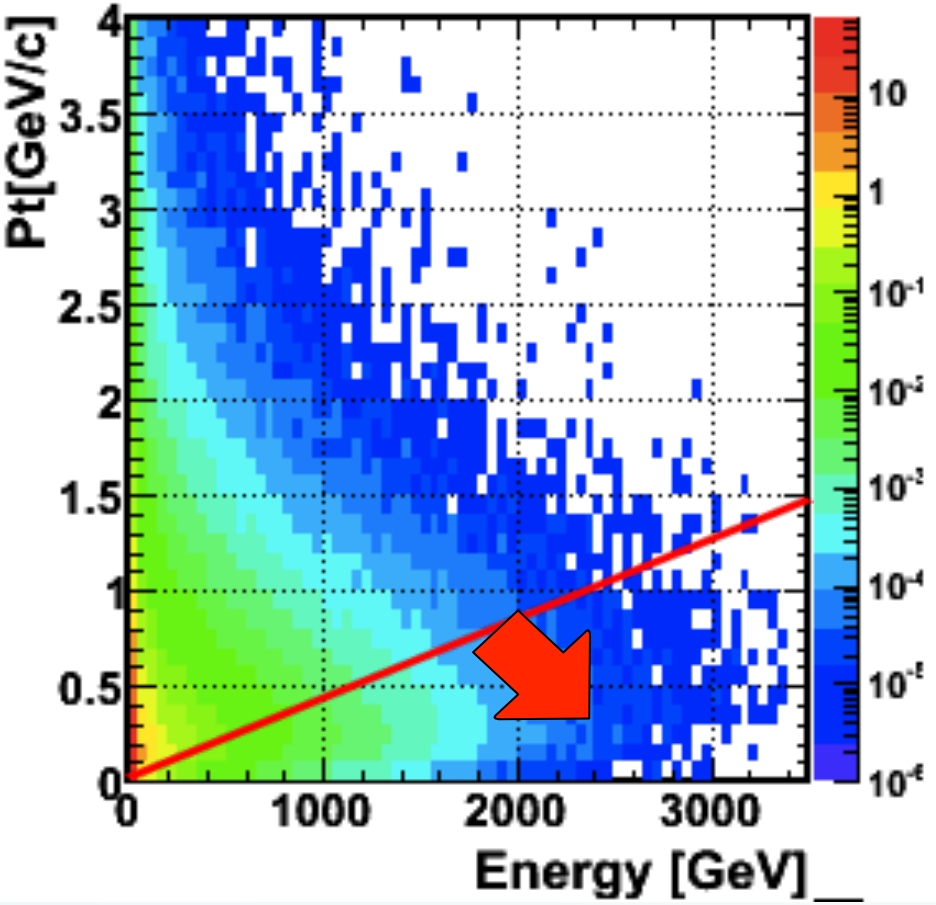






P_T distribution for photons

pp 7TeV, EPOS



Front Counter

- ✓ Fixed scintillation counter
- ✓ $L=CxR_{FC}$; conversion coefficient calibrated during VdM scans