Energy spectra measured by a LHC forward experiment :

LHCf

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on behalf for the LHCf collaboration

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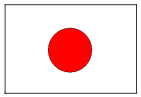
Outline

LHCf is a LHC forward experiment, which is dedicated for UHECR physics.

- Introduction and physics motivation
- Overview of the LHCf experiment
- Operation in 2009 and 2010
- First results at 900GeV and 7TeV
- Summary

The LHCf collaboration



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T.Tamura *Kanagawa University, Japan*

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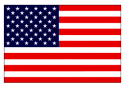

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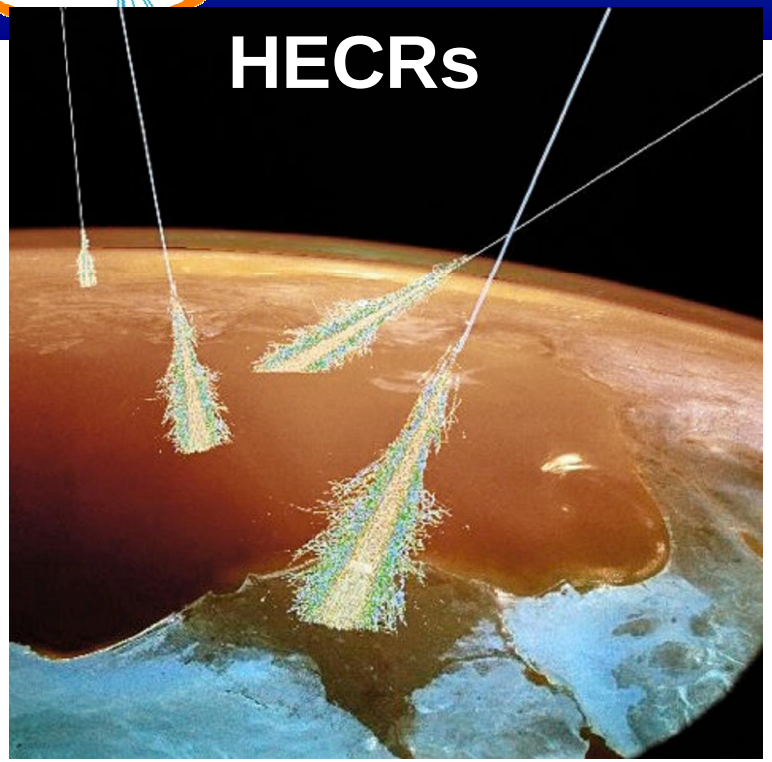
Introduction



Extensive air shower observation

- longitudinal distribution
- lateral distribution
- Arrival direction

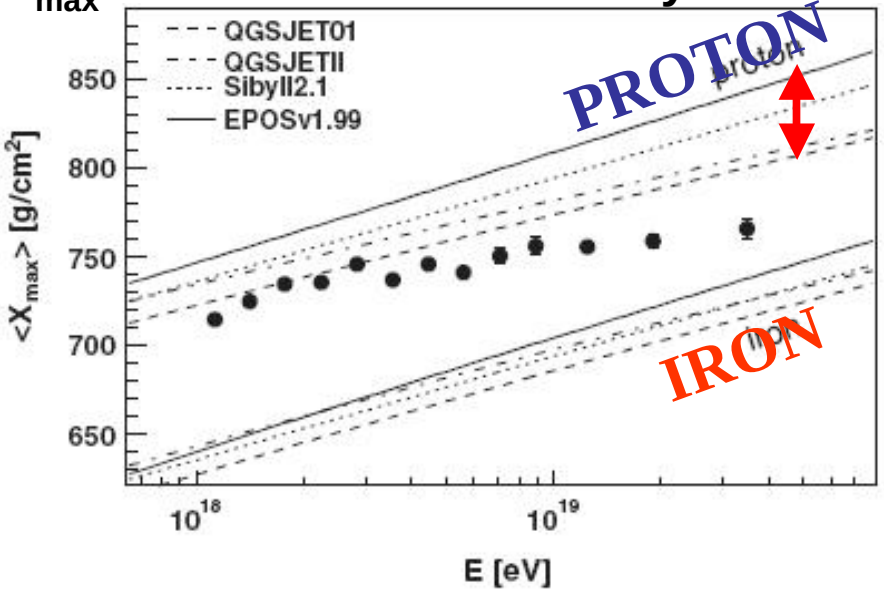
Air shower development

Astrophysical parameters

- Spectrum
- Composition
- Source distribution

The hadron interaction models are used in air shower simulations have an uncertainty due to the lack of experimental data
in the energy range over 10^{15}eV

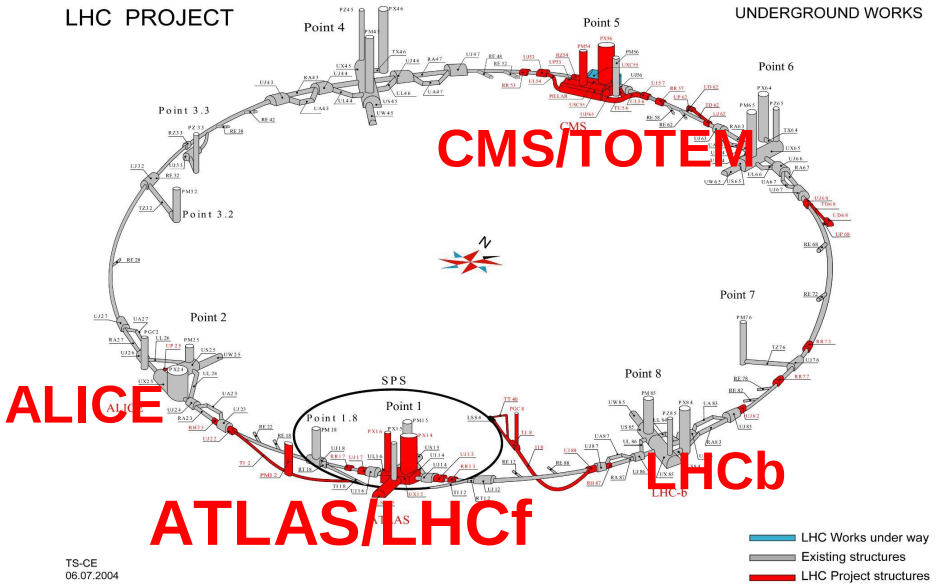
X_{max} distribution measured by AUGER

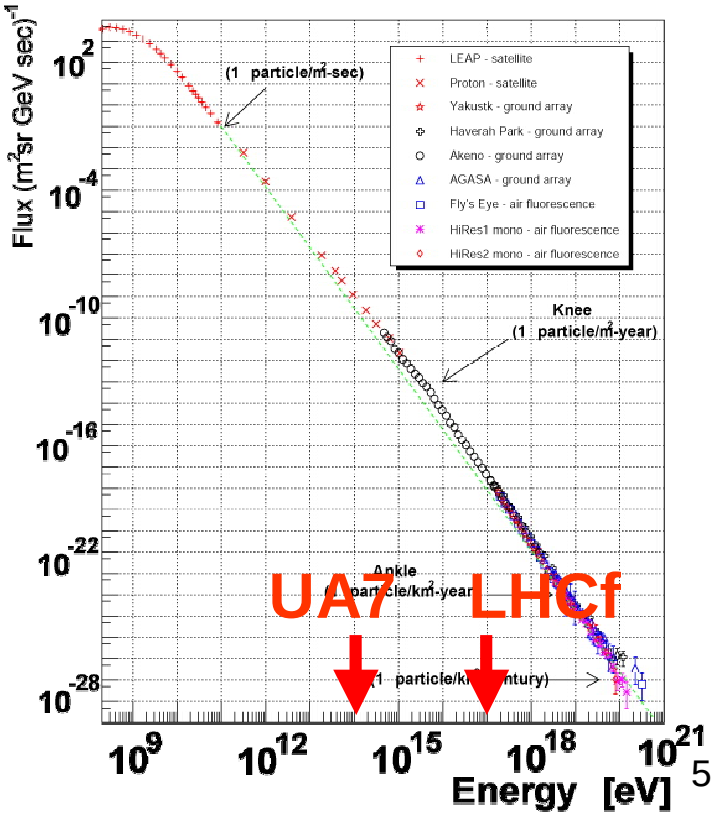


The Large Hadron Collider (LHC)

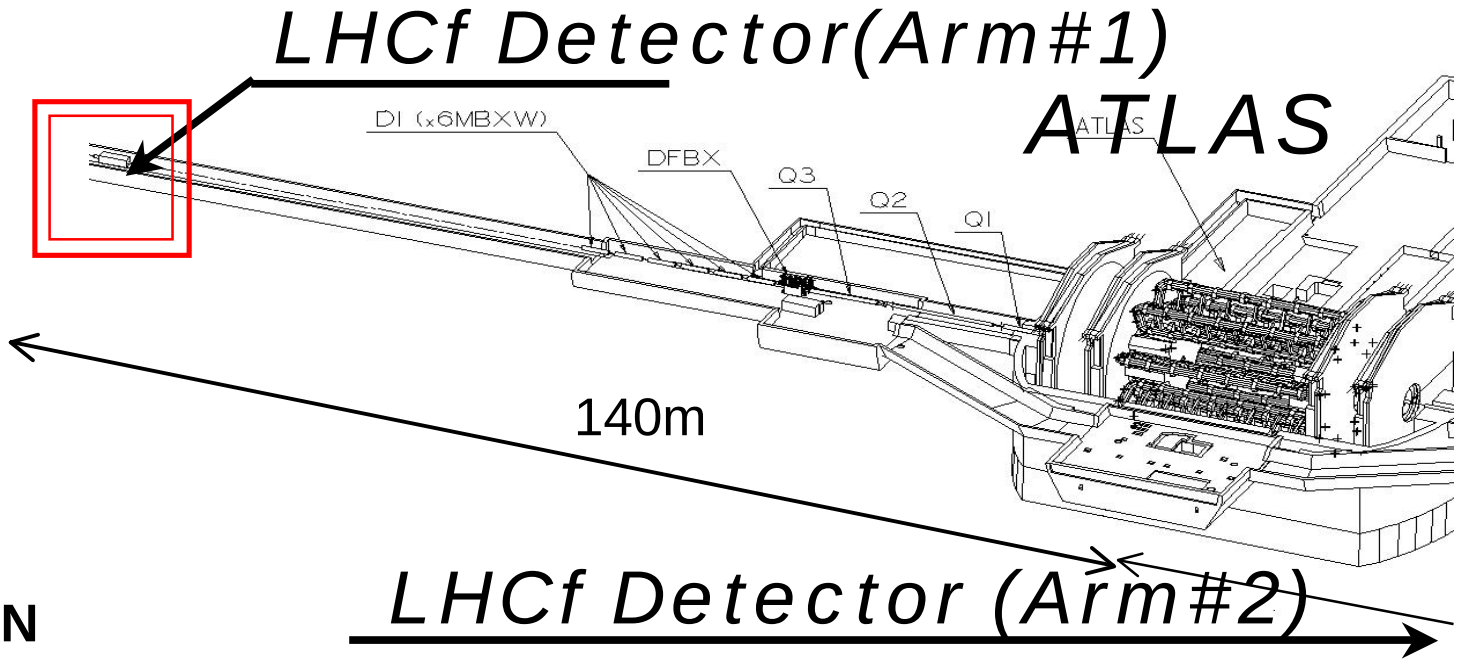
7TeV+7TeV	$\rightarrow E_{lab} = 10^{17}$eV	2013
3.5TeV+3.5TeV	$\rightarrow E_{lab} = 2.6\times10^{16}$eV	2010-2011
450GeV+450GeV	$\rightarrow E_{lab} = 2\times10^{14}$eV	2009-2010

LHCf is one of the forward experiments at LHC
The aim is to calibrate hadron interaction models at the highest energy region of 10^{17}eV.

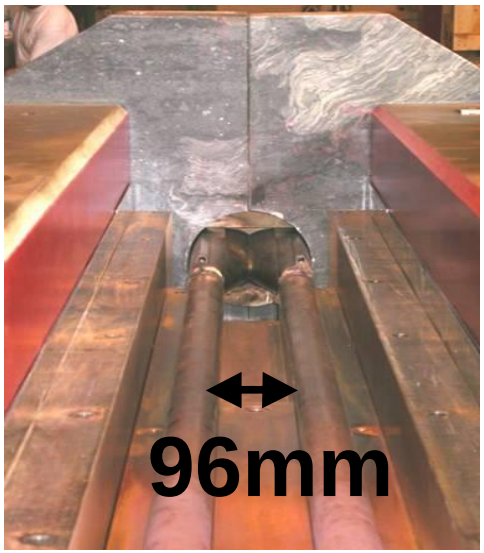




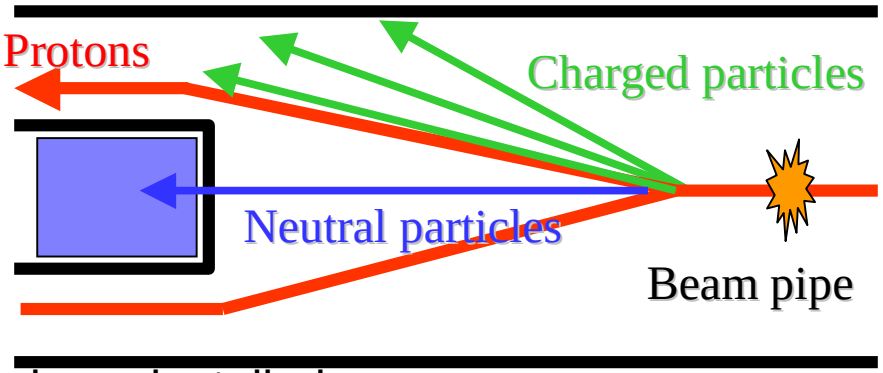
Experimental set-up



Inside of TAN
-Neutral particle absorber-



!! Detectors at zero degree of collisions !!

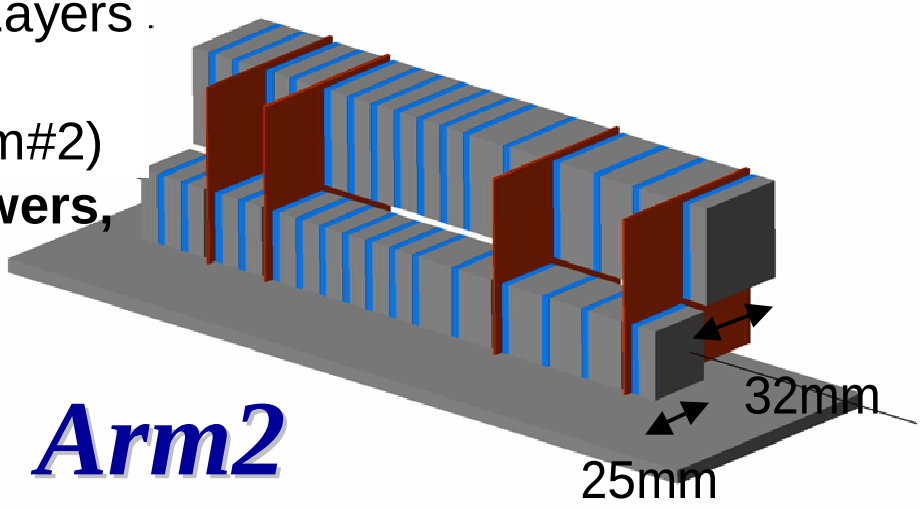


The detector has been installed in 96mm gap of the beam pipes.

The LHCf detectors

Sampling and Positioning Calorimeters

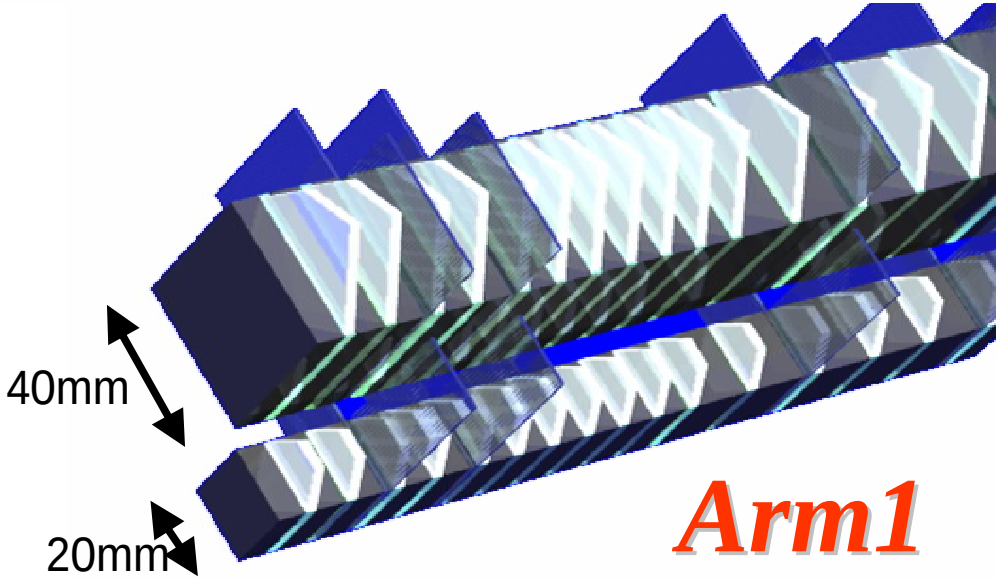
- W (44 r.l , 1.7 λ_I) and Scintillator x 16 Layers
- 4 positioning layers
  XY-SciFi(Arm1) and XY-Silicon strip(Arm#2)
- **Each detector has two calorimeter towers, which allow to reconstruct π^0**

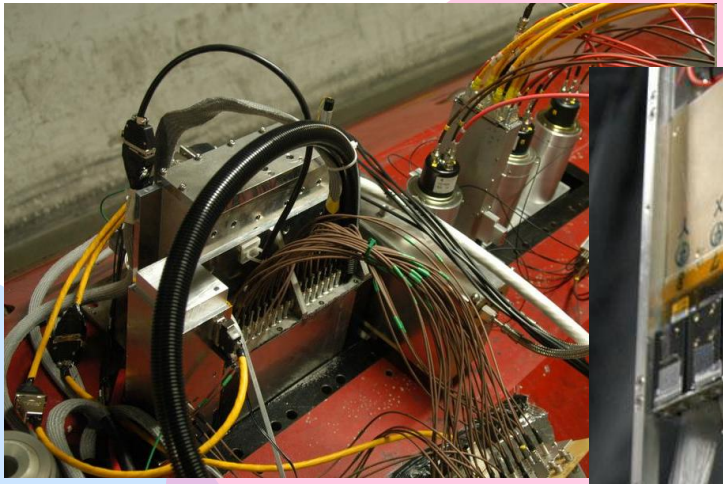


Expected Performance
Energy resolution (> 100GeV)
< 5% for photons
30% for neutrons
Position resolution
< 200μm (Arm#1)
40μm (Arm#2)

Front Counter

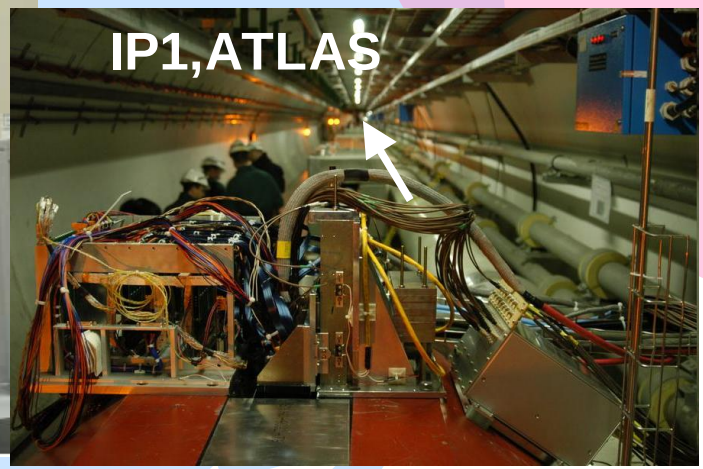
- thin scintillators with 80x80mm^2
- **To monitor beam condition.**
- **For background rejection of beam-residual gas collisions by coincidence analysis**





Arm1

Arm2



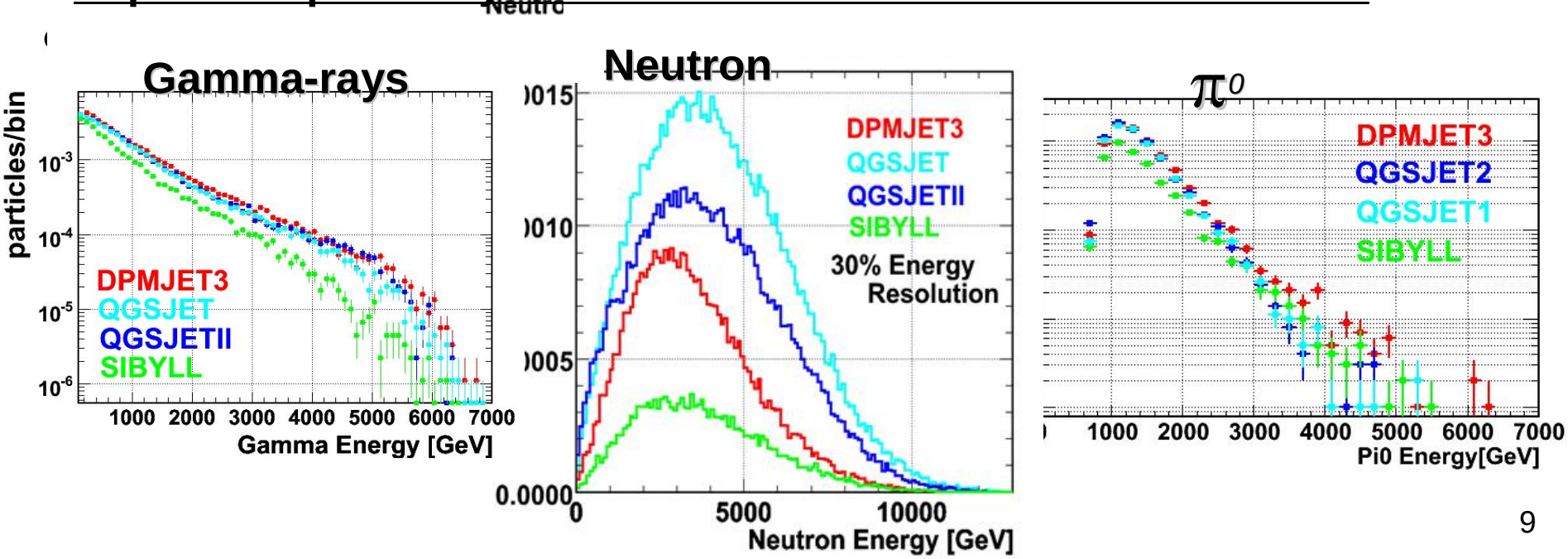
LHCf can measure

Energy spectra and
Transverse momentum distribution of

- **Gamma-rays (E>100GeV,dE/E<5%)**
- **Neutral Hadrons (E>a few 100 GeV, dE/E~30%)**
- **Neutral Pions (E>700GeV, dE/E<3%)**

at psudo-rapidity range >8.4

Expected spectra by hadron interaction models at 7TeV+7TeV



Operation in 2009-2010

At 450GeV+450GeV

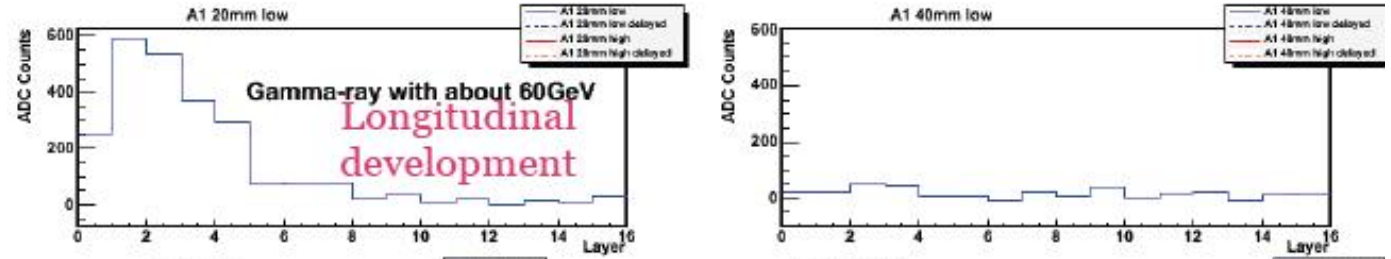
- 06 Dec. –15 Dec. in 2009
  27.7 hours for physics, 2.6 hours for commissioning
  ~2,800 and ~3,700 shower events in Arm1 and Arm2
- 02 May – 27 May in 2010
  ~15 hours for physics
  ~44,000 and ~63,000 shower events in Arm1 and Arm2

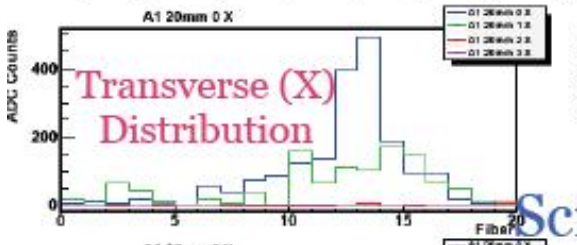
At 3.5TeV+3.5TeV

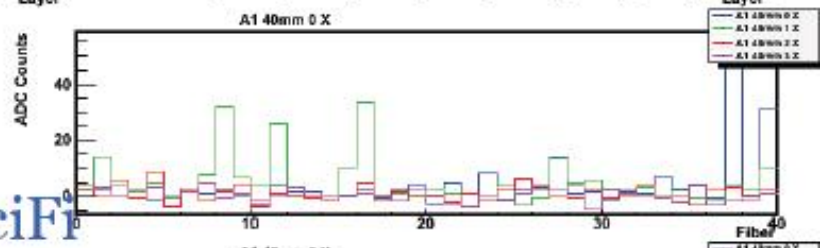
- 30 Mar. – 19 July in 2010
  ~ 150 hours for physics with several setup
  ~2×10^8 and ~2×10^8 shower events in Arm1 and Arm2

We completed operation at 900GeV and 7TeV successfully !!

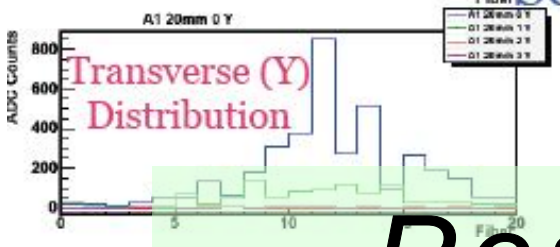
The detectors were removed from the LHC tunnel on 20 July 2010.
The detectors will be re-installed for operation at 7TeV+7TeV in 2013
after the upgrade of the detector.

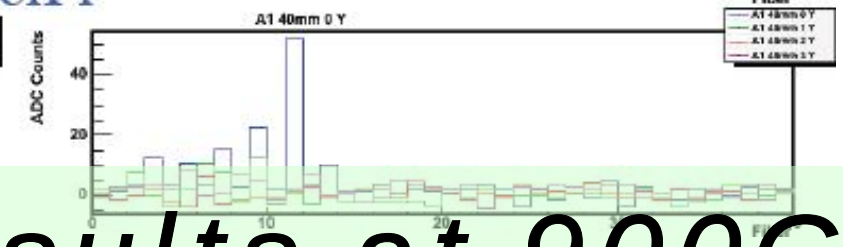






SciFi

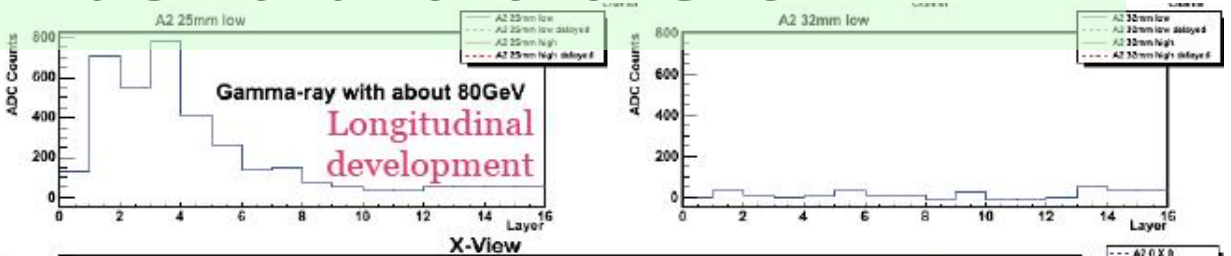


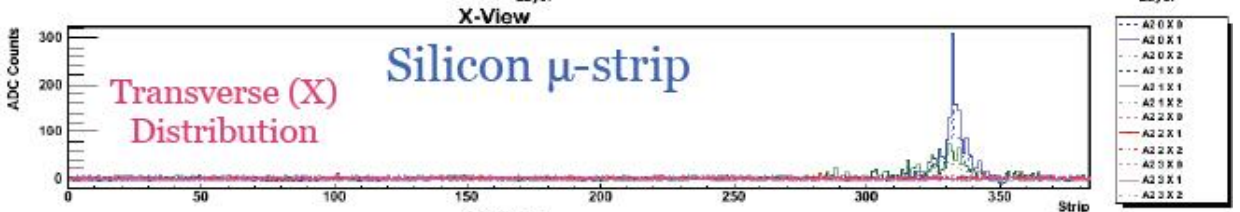


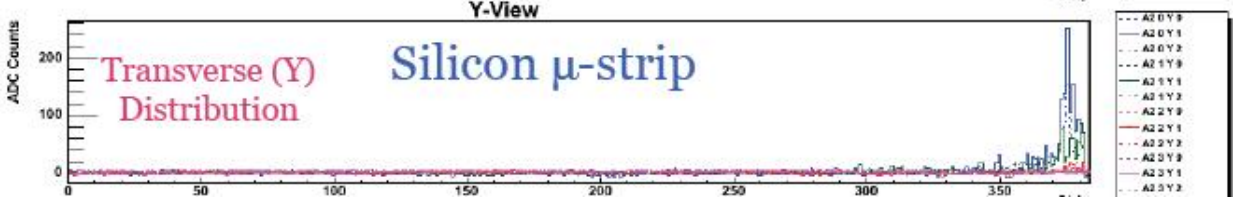
Event sample @ Arm1

Results at 900GeV

Event sample @ Arm2

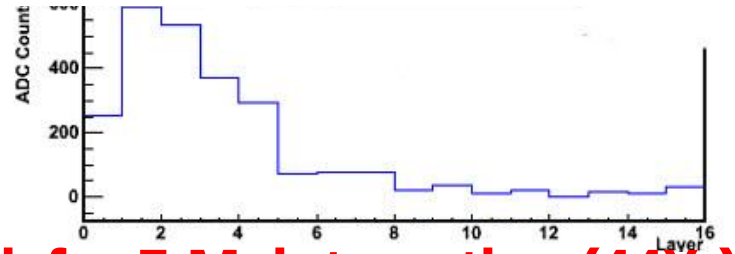






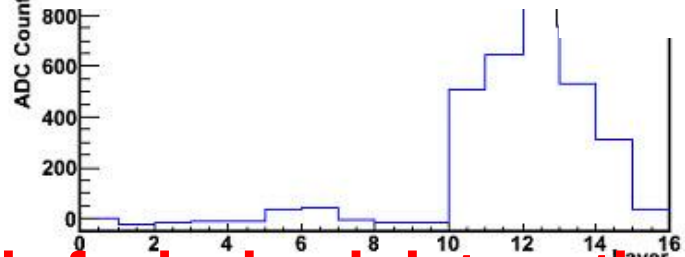
Particle Identification

A transition curve for Gamma-ray



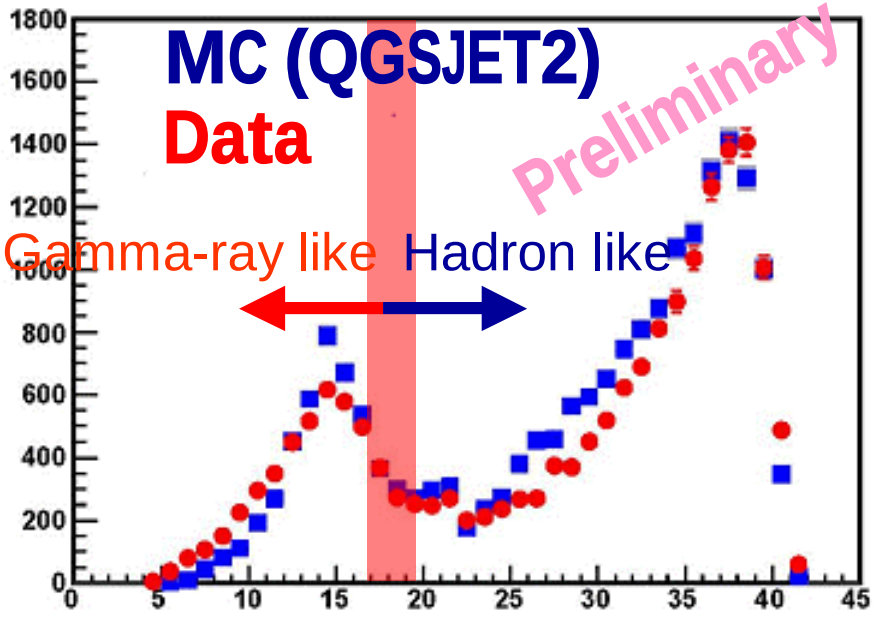
Thick for E.M. interaction ($44X_0$)

A transition curve for Hadron



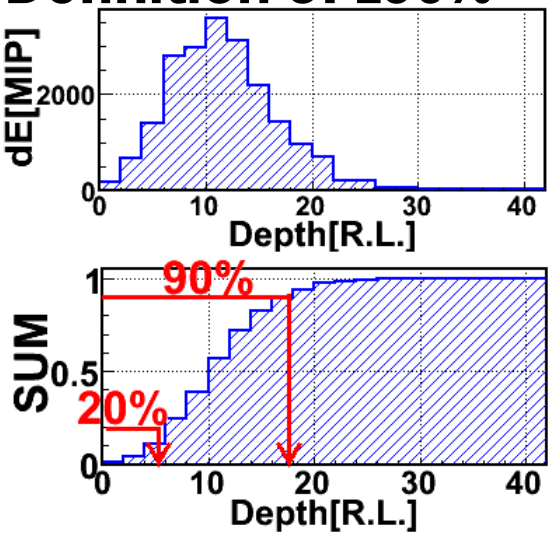
Thin for hadronic interaction(1.7λ)

L90% @ 40mm cal. of Arm1



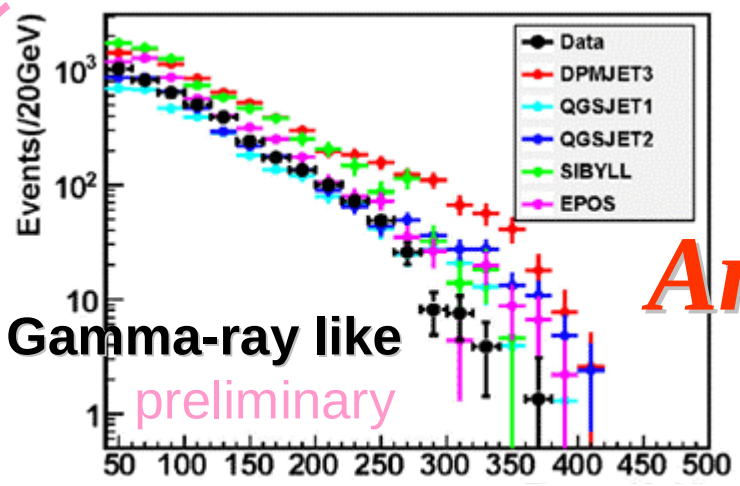
Criteria for gamma-rays
16 r.l. + 0.002 x ΣdE

Definition of L90%

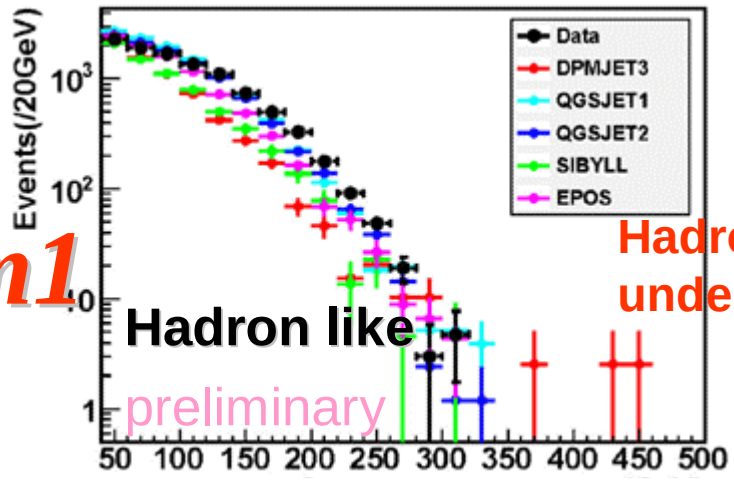


- L90% is defined as the longitudinal position containing 90% of the sum of the shower particles.
- PID study is still ongoing

Spectra at 900GeV

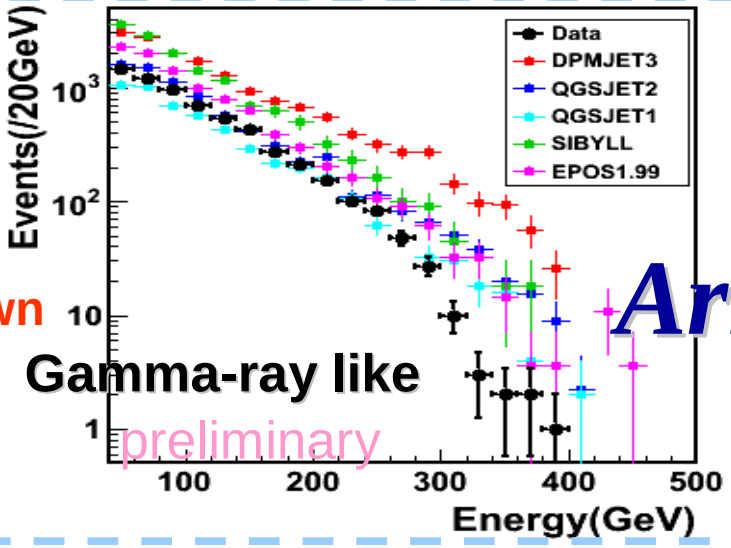


Arm1

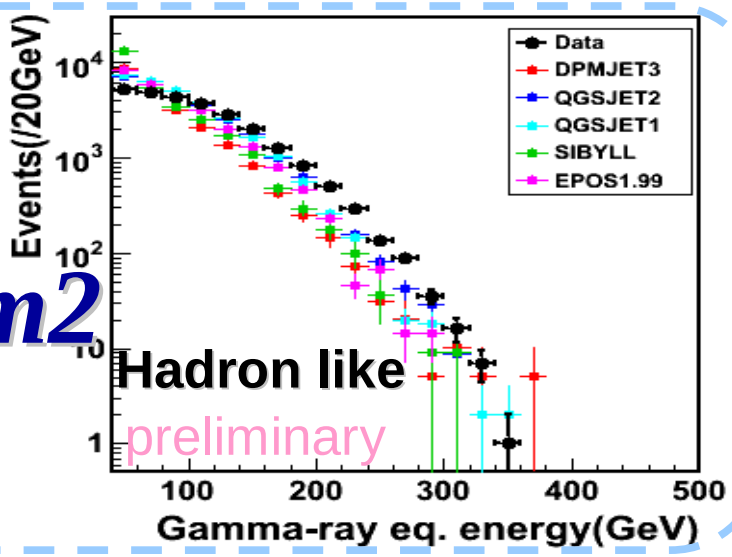


Hadron response under study

Only statistical errors are shown



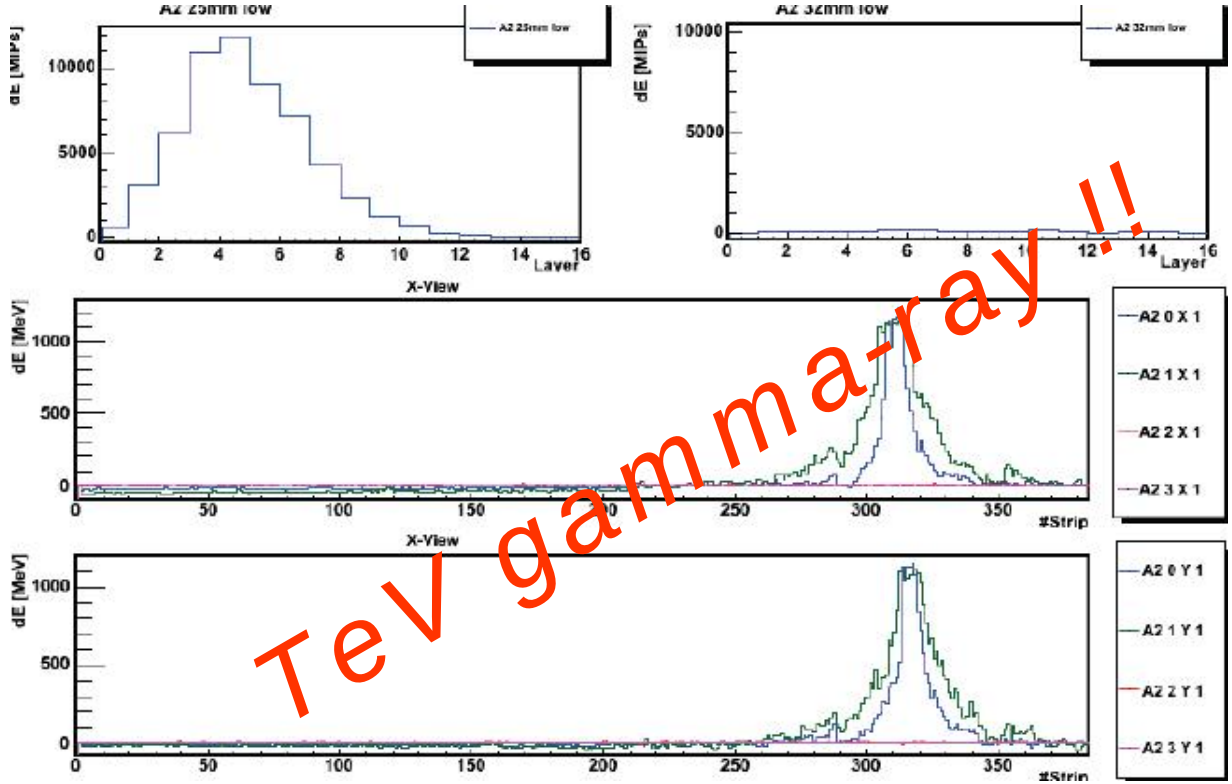
Arm2



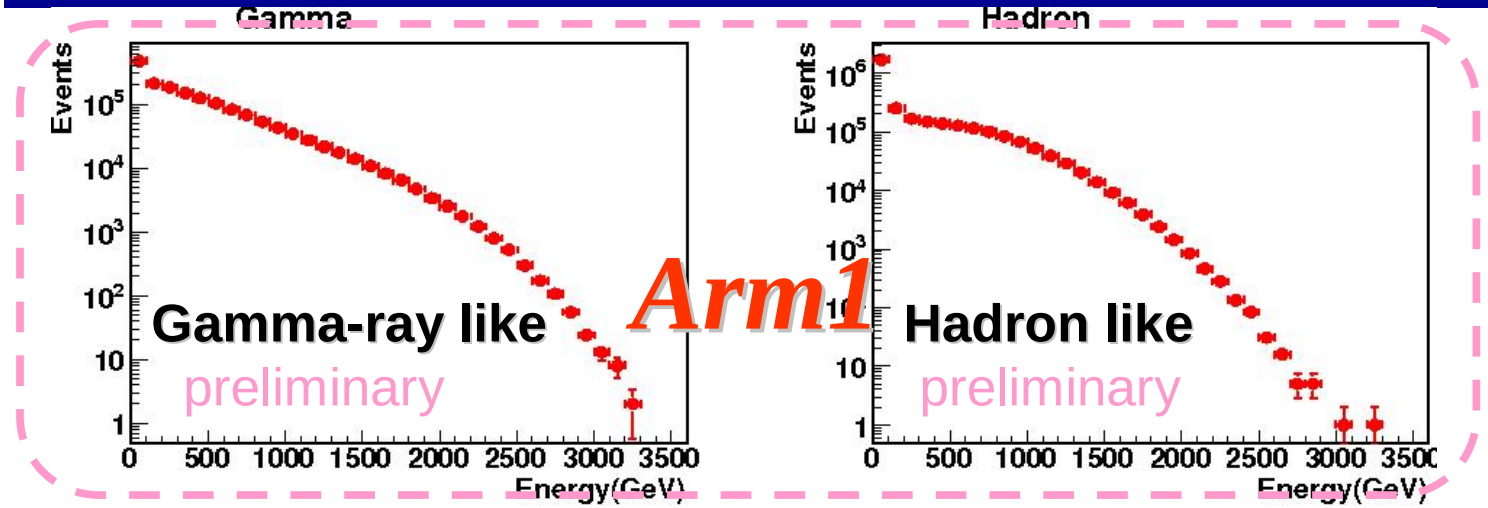
The spectra are normalized by number of gamma-ray and hadron like events
The detector response for hadrons and the systematic error are under study.

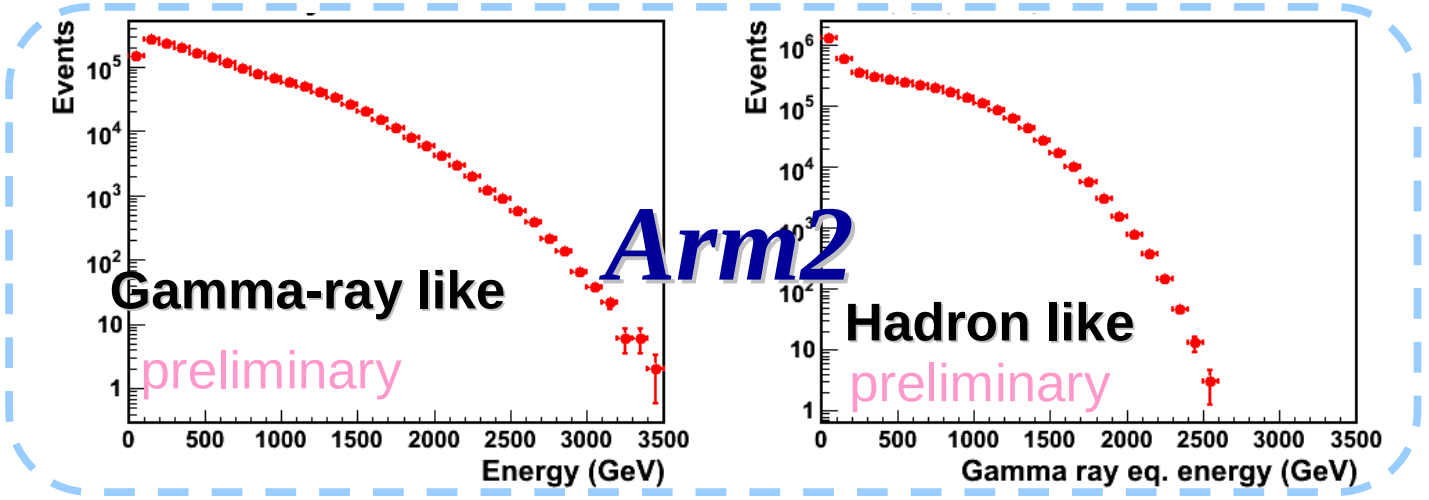
Results at 7TeV

Event sample measured by Arm2 at 30 March 2010



Measured Spectra at 7TeV

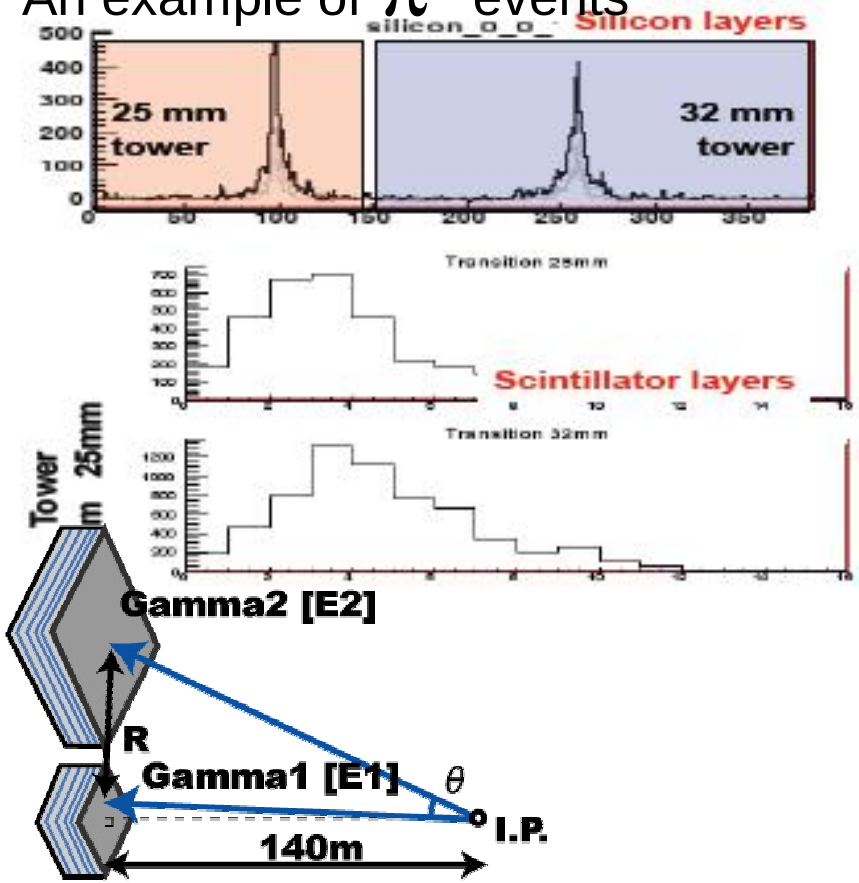




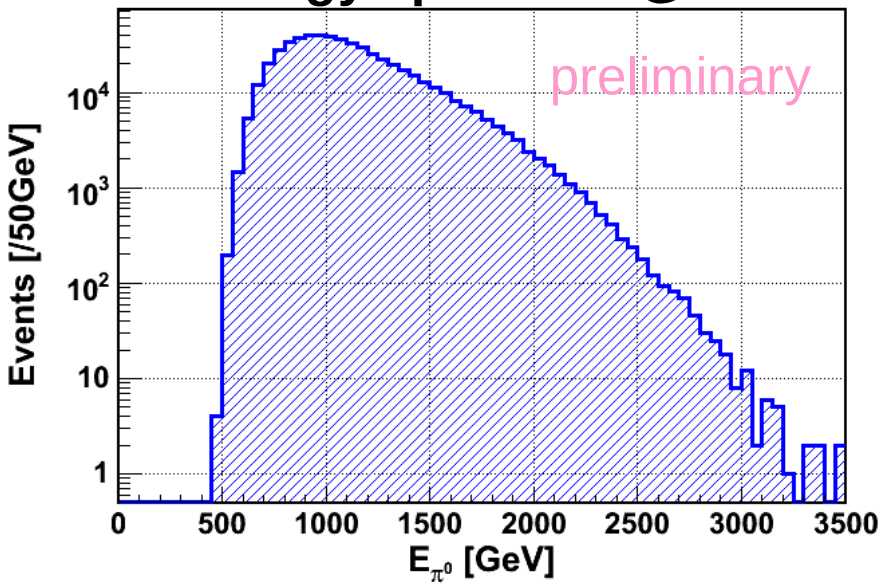
Very high statistics !! only 2% of all data
Comparisons with MC are under way.

π^0 reconstruction

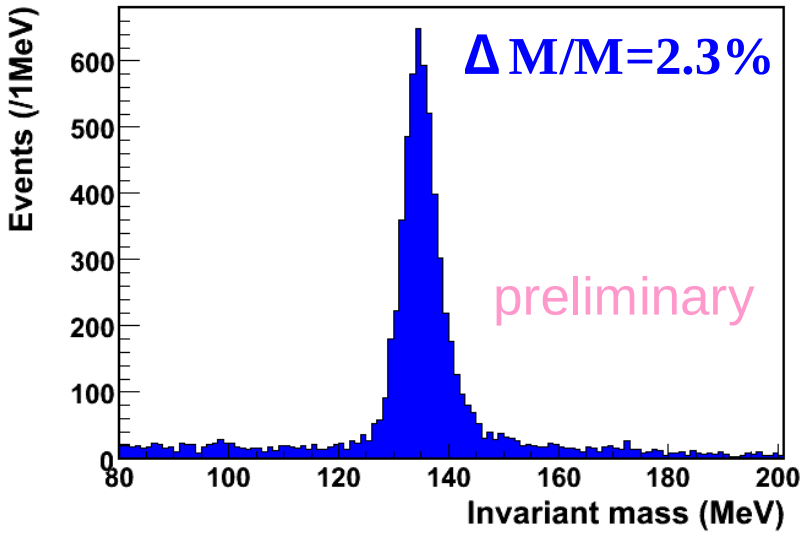
An example of π^0 events



measured energy spectrum @ Arm2

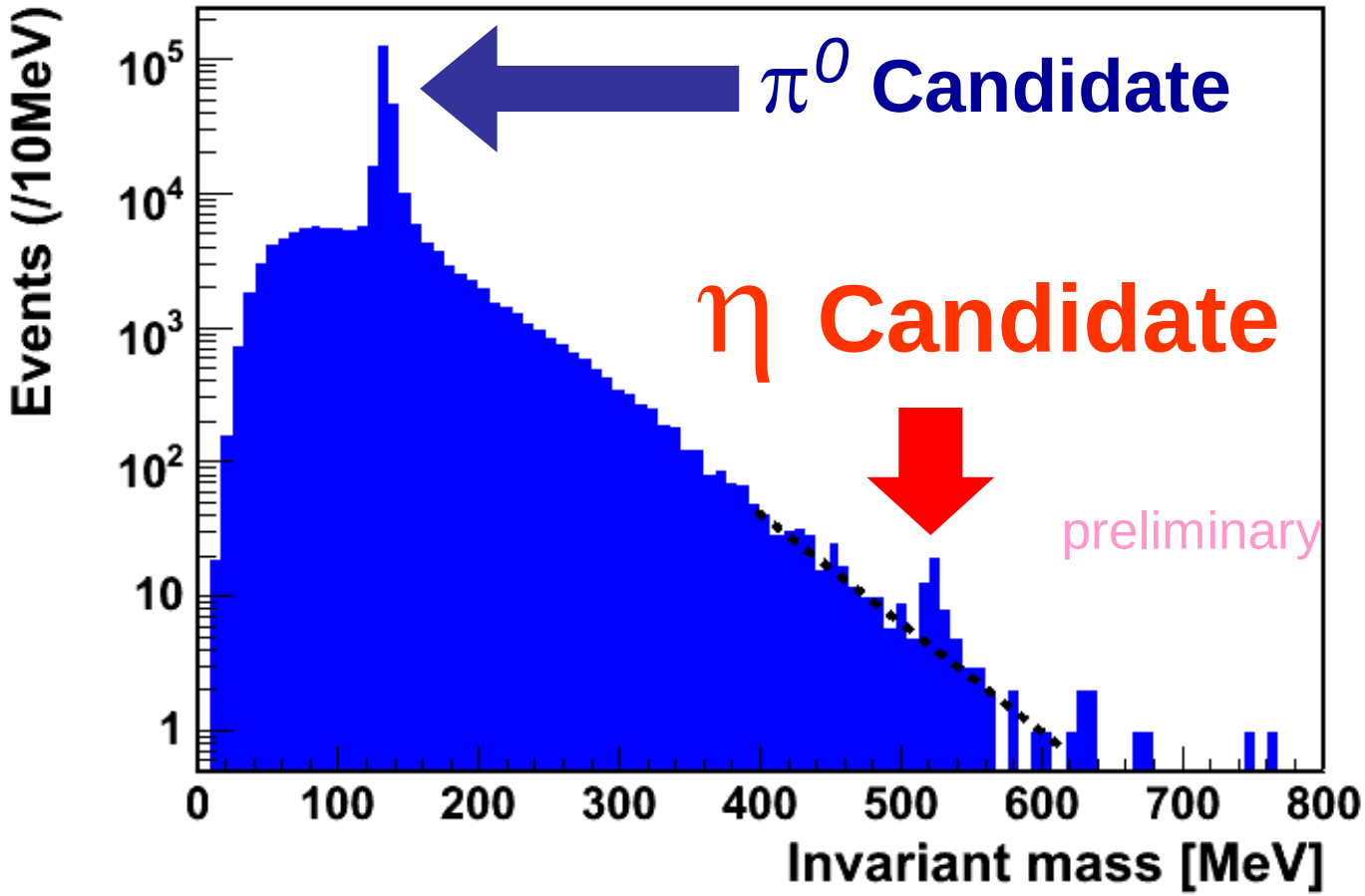


Reconstructed mass @ Arm2



- 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.

η search



- η/π^0 ratio vary a lot among different interaction models.
  A good handle to probe the hadron interaction models
- Another calibration point for more robust energy scale

Summary

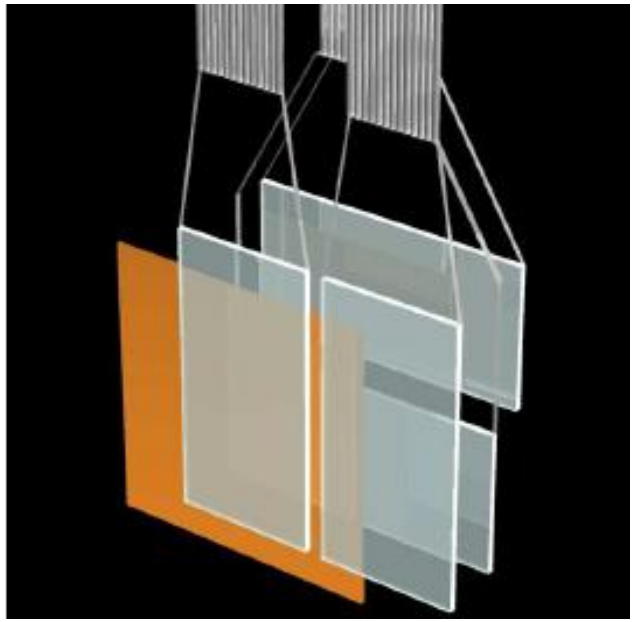
- The LHCf experiment is a dedicated experiment for UHECR to measure energy and transverse momentum spectra of neutral particles in a LHC forward region.
- LHCf successfully completed data taking at 900GeV and 7TeV. The LHCf detectors has been removed from LHC the tunnel and will be re-installed for data taking at 7TeV+7TeV in 2013.
- 900 GeV analysis is almost final and ready to be submitted for publication while 7 TeV analysis is progressing quickly

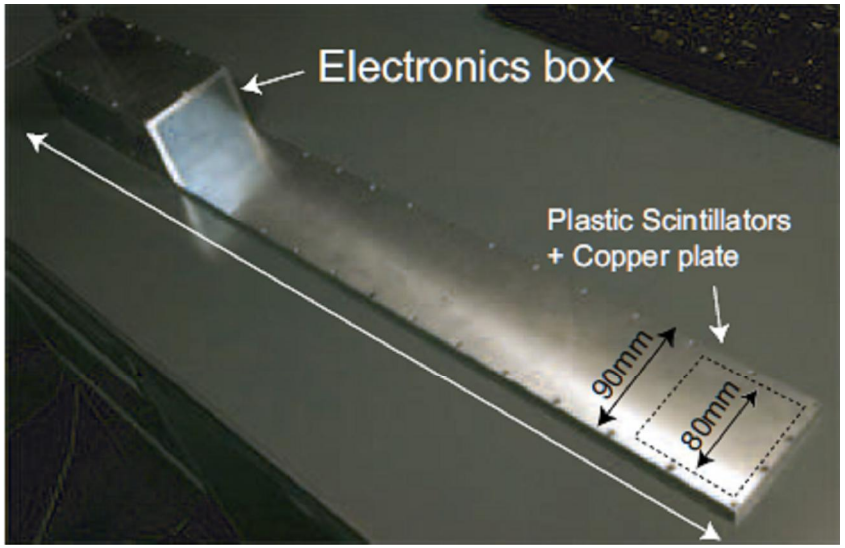
Buck up

Sub detectors -Front Counter-

- Thin scintillators with 8x8cm^2 acceptance, which have been installed in front of each main detector.

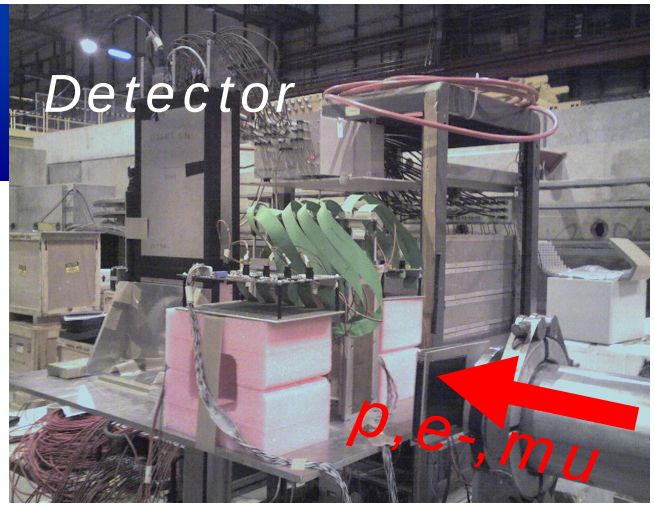
Schematic view of Front counter



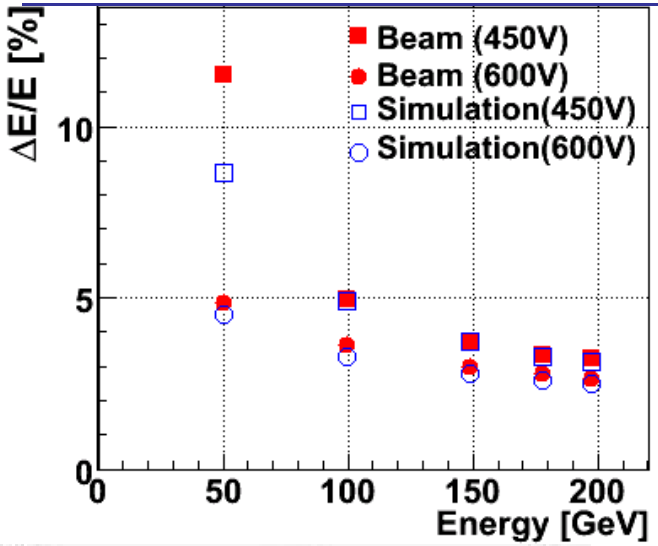


- **To monitor beam condition.**
- **For background rejection of beam-residual gas collisions by coincidence analysis**

Beam test at SPS

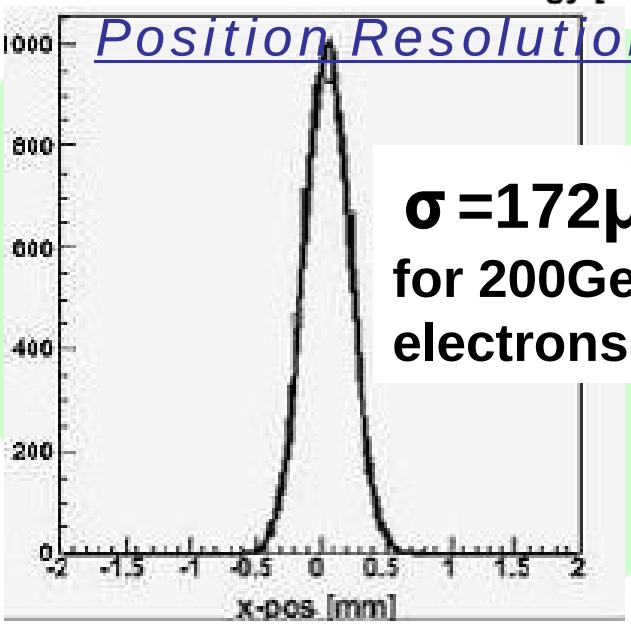


Energy Resolution for electrons with 20mm cal.



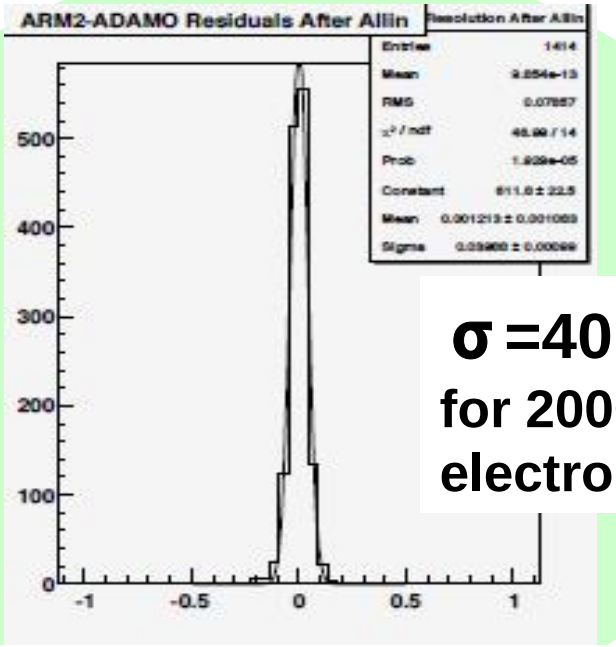
- Electrons 50GeV/c – 200GeV/c
- Muons 150GeV/c
- Protons 150GeV/c, 350GeV/c

Position Resolution (Scifi)



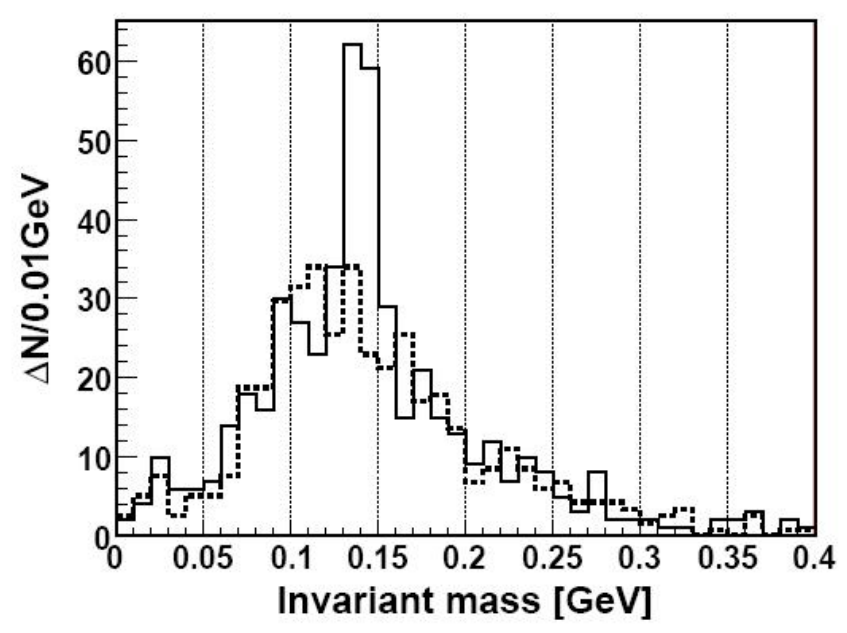
σ =172μm
for 200GeV electrons

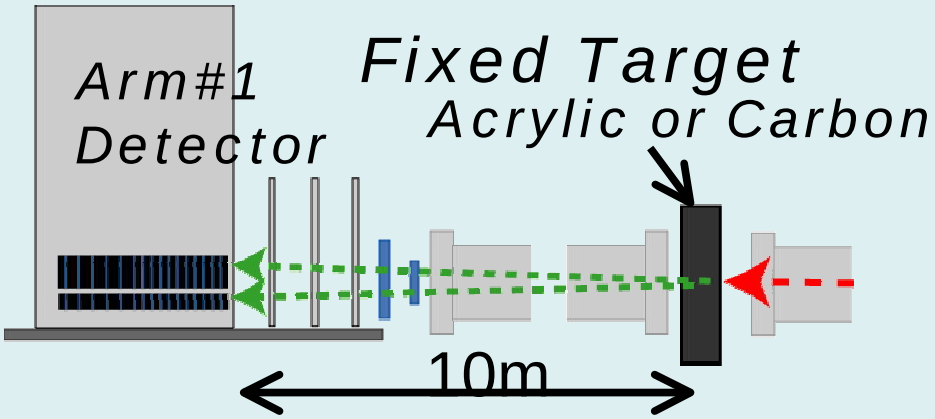
Position Resolution (Silicon)



σ =40μm
for 200GeV electrons

π^0 reconstruction at the beam test

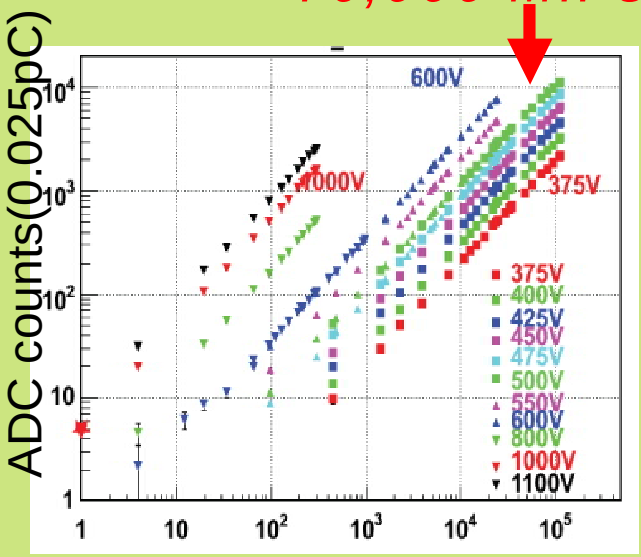




π^0 mass was reconstructed from gamma-ray pair measured by the both two calorimeters

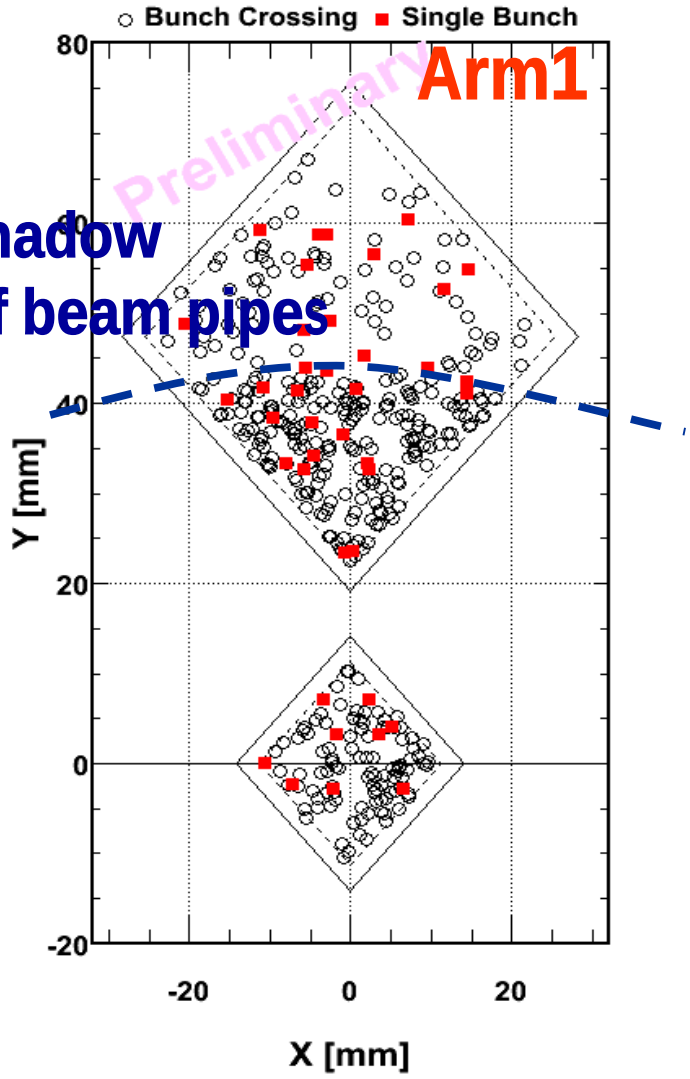
Calibration over SPS energy

Response of all PMTs
for large amount of light over SPS energy
upto 70,000 MIPs eq. (7TeV elemag shower)
has been calibrated by a fast N_2 laser.

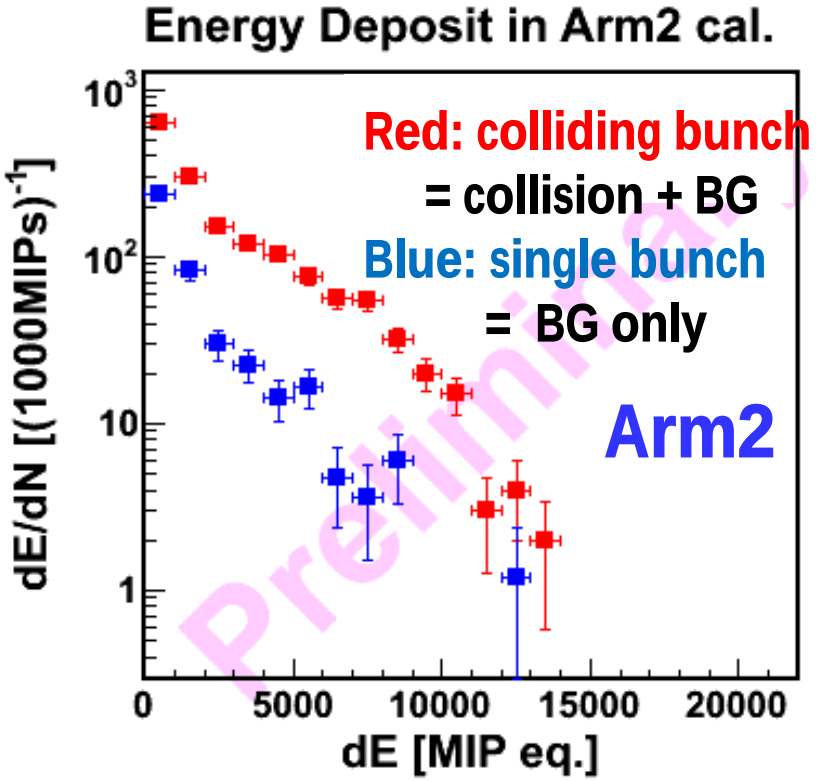


lts at 900GeV

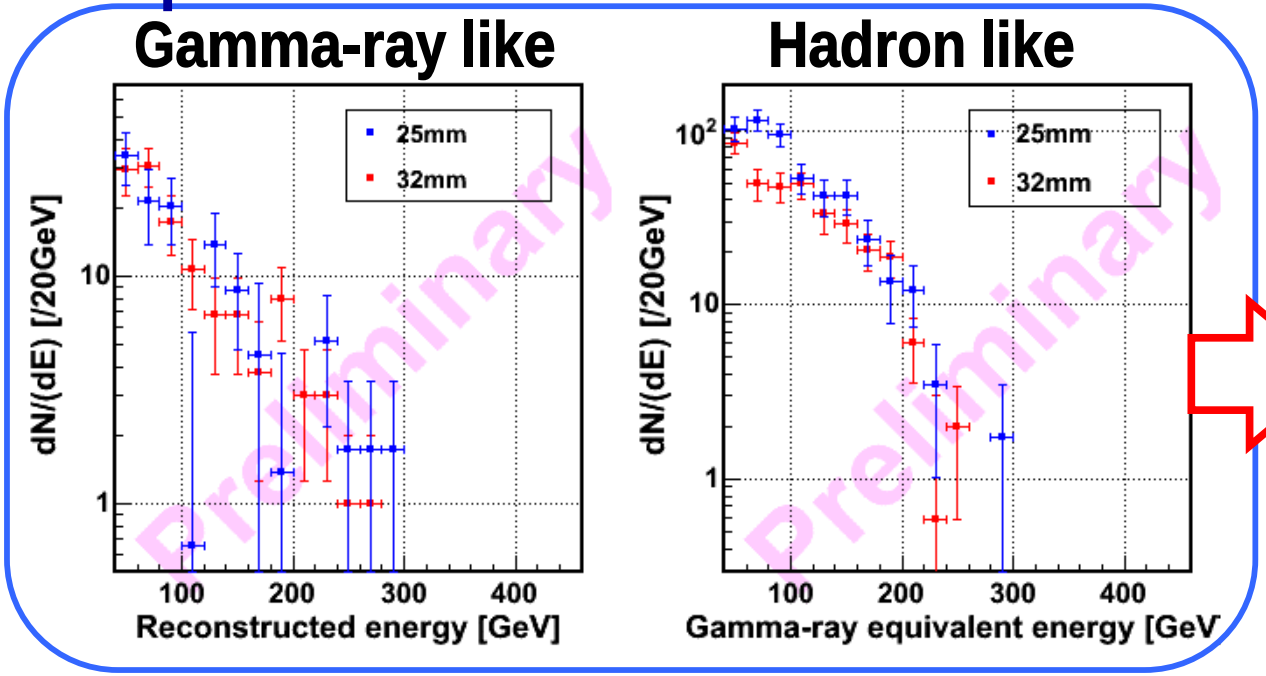
Hit map of Gamma-rays



Background due to beam-residual gas collision is about 10%

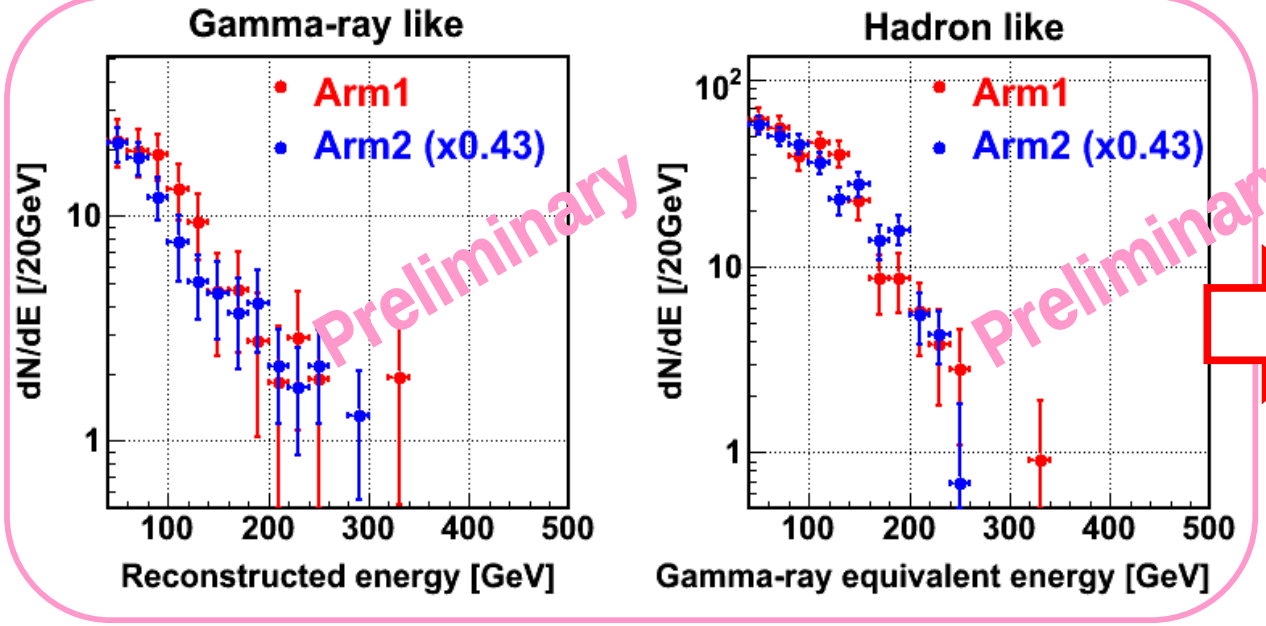


Comparison between calorimeter towers of Arm2



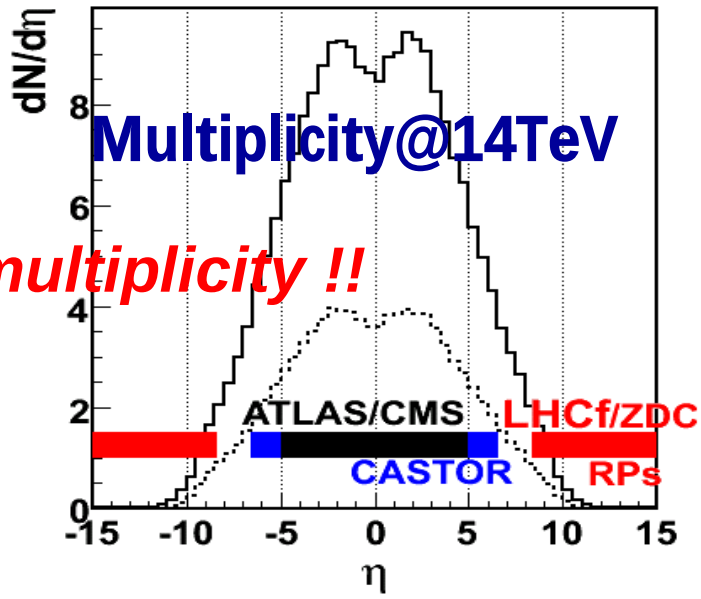
Spatially flat profile in η>8.7 at 900GeV

Comparison between two Arms

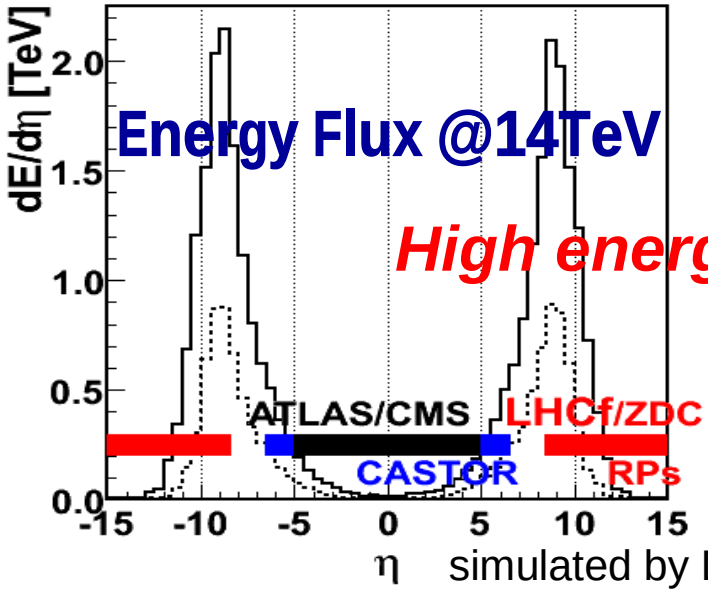


Both detectors give consistent spectra

Rapidity distribution at 14TeV

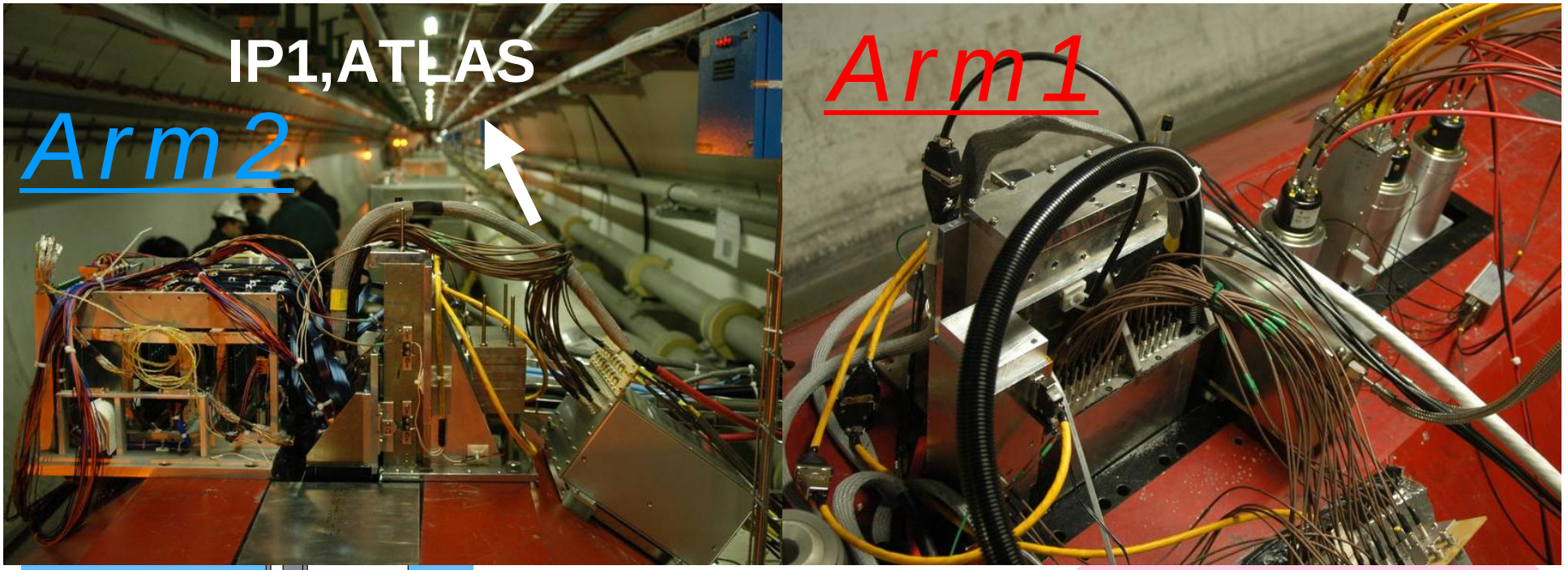


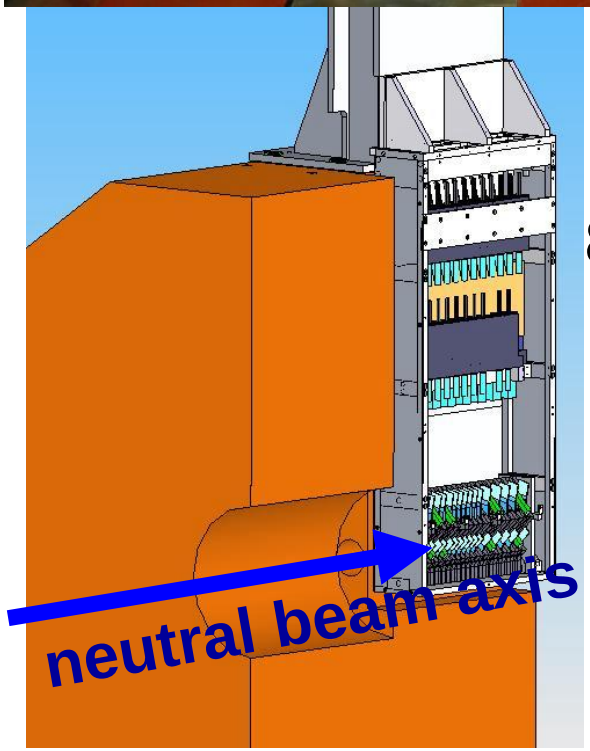
Low multiplicity !!

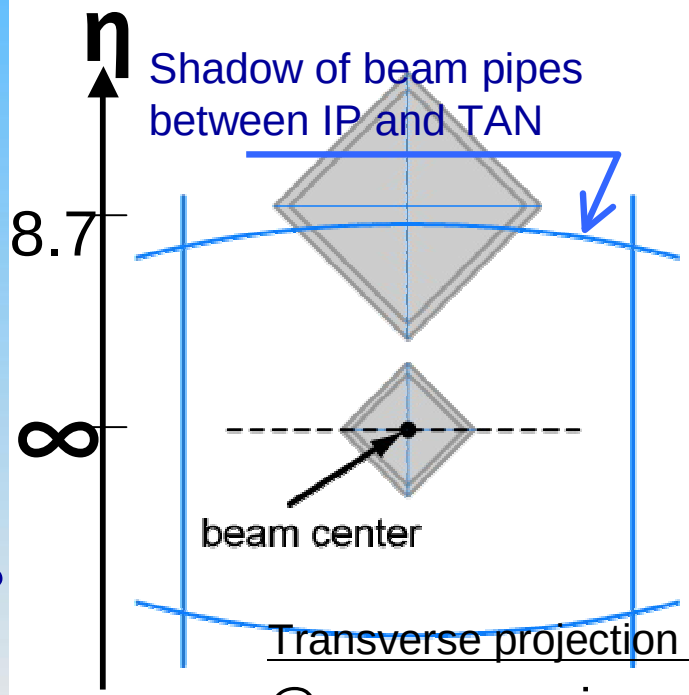


High energy flux !!

simulated by DPMJET3

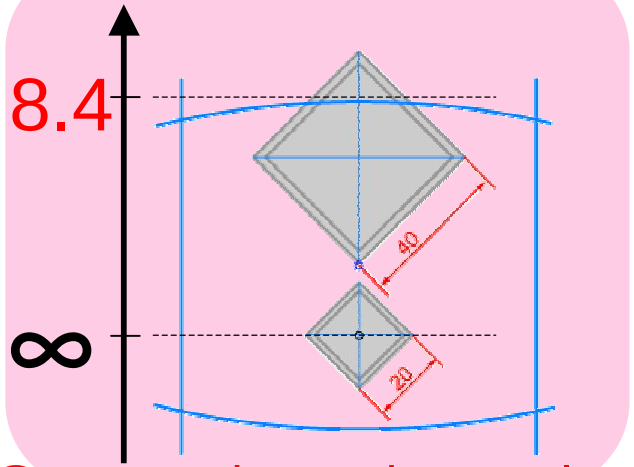






Transverse projection of Arm#1

@ zero crossing angle



@ 140μrad crossing angle