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Forward energy and particle flow with the LHCf experiment

Lorenzo Bonechi
University and INFN – Florence (Italy)
on behalf of the LHCf collaboration

The LHCf international collaboration

O.Adriani[1,2], L.Bonechi[1,2], M.Bongi[2], G.Castellini[2,3], A.Faus[4], K.Fukatsu[5], M.Grandi[2], M.Haguenauer[6], Y.Itow[5], K. Kawade[5], K.Kasahara[7], D.Macina[8], T.Mase[5], K.Masuda[5], Y. Matsubara[5], H.Menjo[2], G.Mitsuka[5], Y.Muraki[9], M.Nakai[7], K.Noda[5], P.Papini[2], A.-L.Perrot[8], S.Ricciarini[2], T.Sako[6], Y.Shimitsu[7], K.Suzuki[5], Y.Suzuki[7], K.Taki[5], T.Tamura[10], S.Torii[7], A.Tricomi[11], W.C.Turner[12], K.Yoshida[13], J.Velasco[4]

1) *University of Florence, Italy*
2) *INFN Section of Florence, Italy*
3) *IFAC – CNR, Florence, Italy*
4) *IFIC, Centro Mixto CSIC-UVEG, Spain*
5) *Solar-Terrestrial Environment Laboratory, Nagoya University, Japan*
6) *Ecole Polytechnique, France*
7) *Waseda University, Japan*
8) *CERN, Switzerland*
9) *Konan University, Japan*
10) *Kanagawa University, Japan*
11) *INFN and University of Catania, Italy*
12) *LBNL, Berkeley, USA*
13) *Shibaura Institute of Technology, Japan*

Outline of this presentation

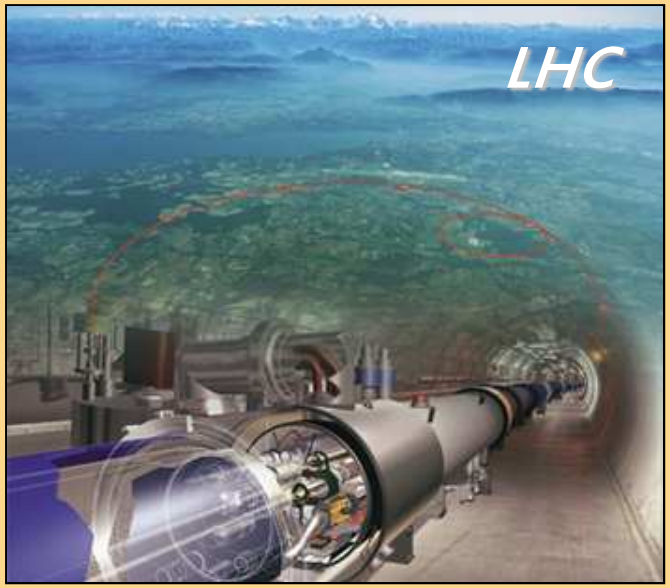
- **The Physics of LHCf**
  - Cosmic rays in the atmosphere and hadronic interaction models
  - Open issues on the HE Cosmic Ray spectrum
- **Overview of the experiment**
  - Detection of neutral particles at low angle at LHC
  - Description of detectors
- **Preliminary results** (2009/2010 runs)
  - 900 GeV
  - 7 TeV
- **Future plan**

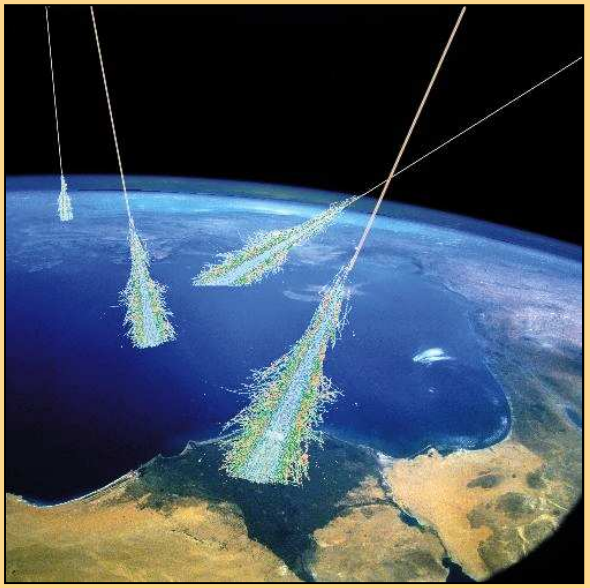
PART 1

The Physics of LHCf

Main topics

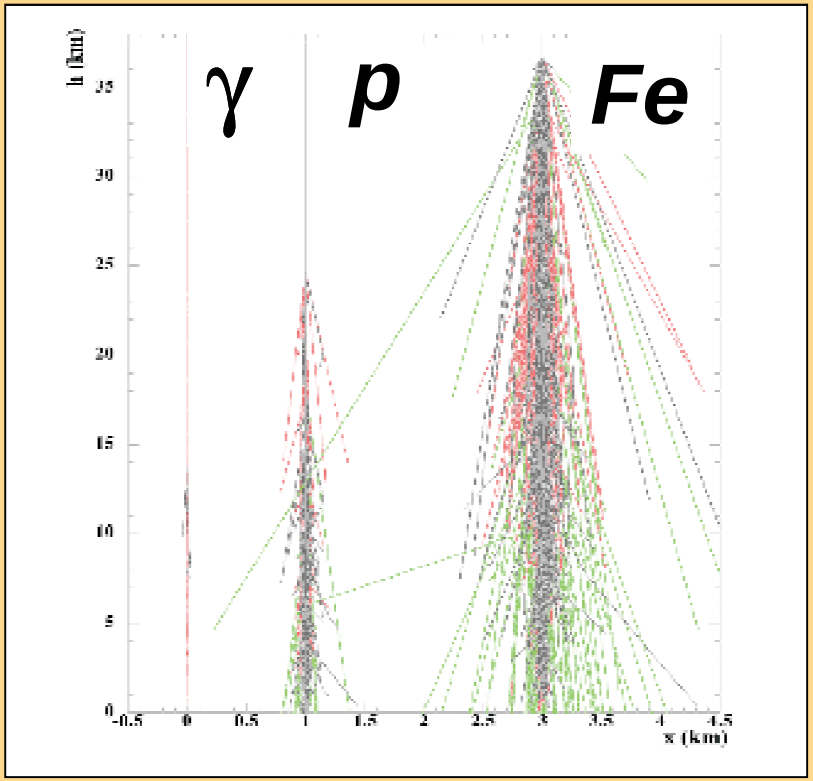
- **Experimental measurement:**
  - Precise measurement of γ, π^0 and n spectra in the very forward region at LHC
- **7 TeV + 7 TeV in the c.m. frame → 10^{17} eV in the laboratory frame:**
  - We can better simulate in the biggest's world laboratory what happens in nature when a Very High Energy Cosmic Ray interacts in the atmosphere
- **Why in the very forward region?**
  - Because the dominant contribution to the energy flux in the atmospheric shower development is carried on by the very forward produced particles





Cosmic ray showers

Air shower developments



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

Extensive air shower observation

- longitudinal distribution
- lateral distribution
- Timing

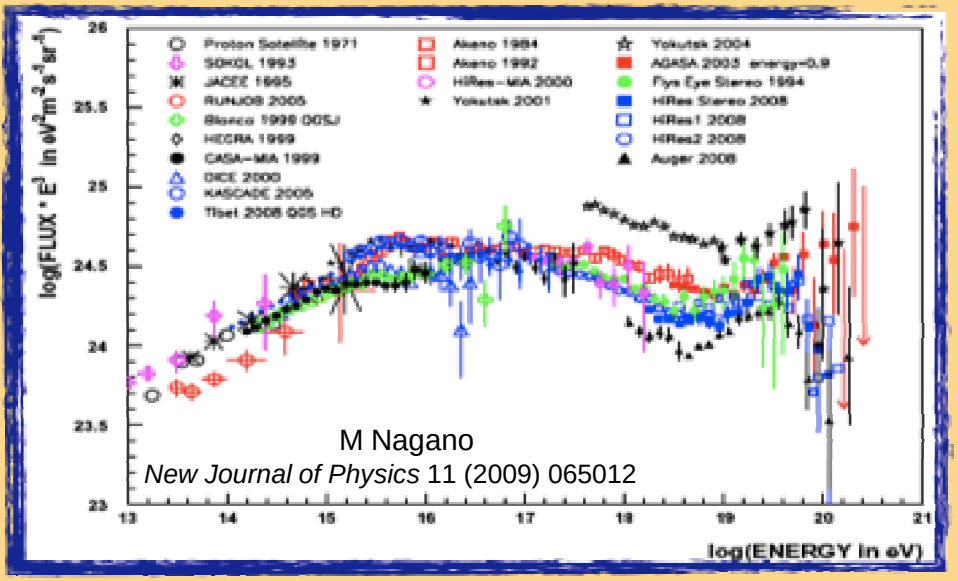
Air shower development

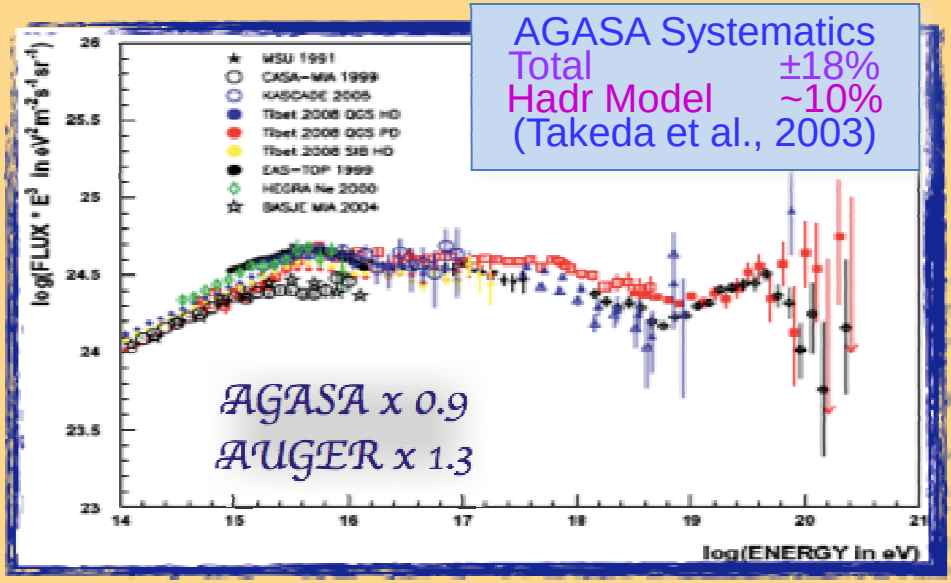
- Type of primary
- Energy
- Arrival direction

Astrophysical parameters

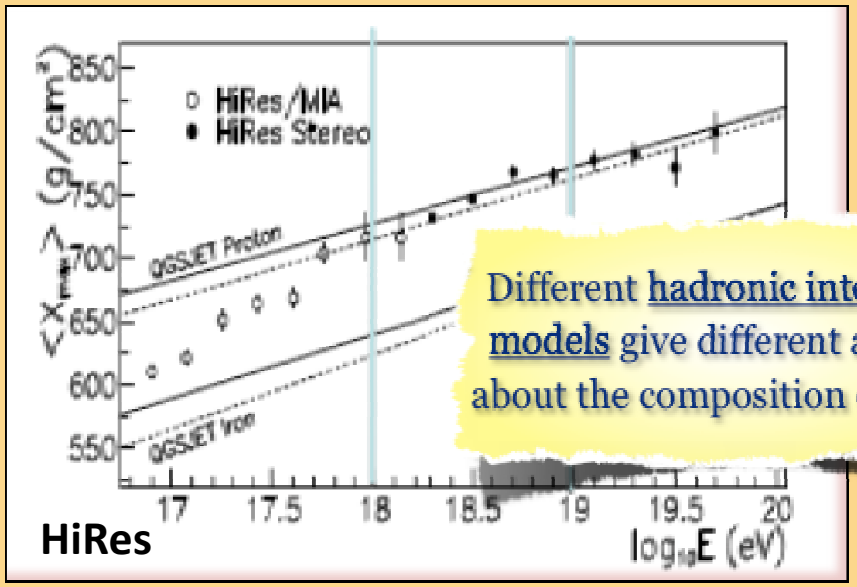
- Spectrum
- Composition
- Source distribution

Open Issues on HECR spectrum

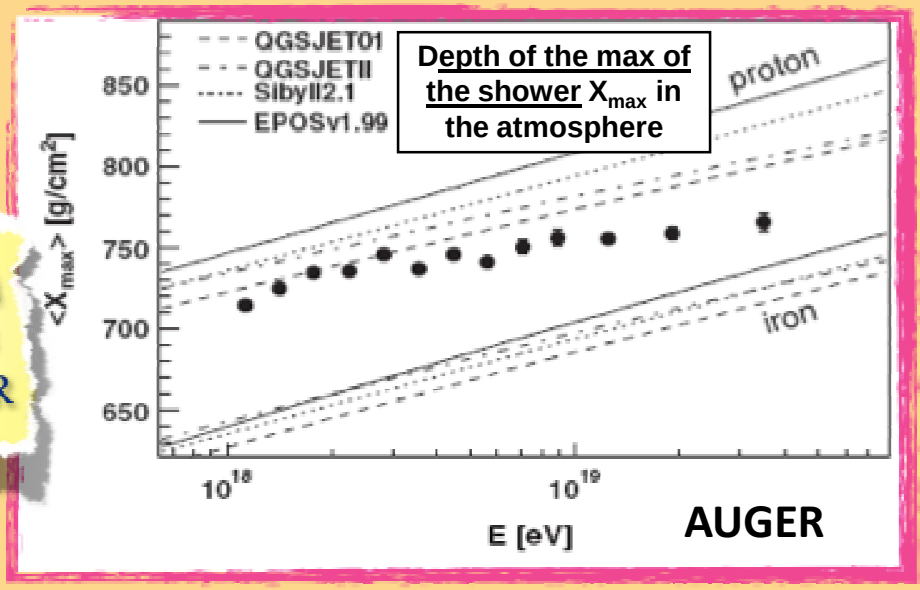




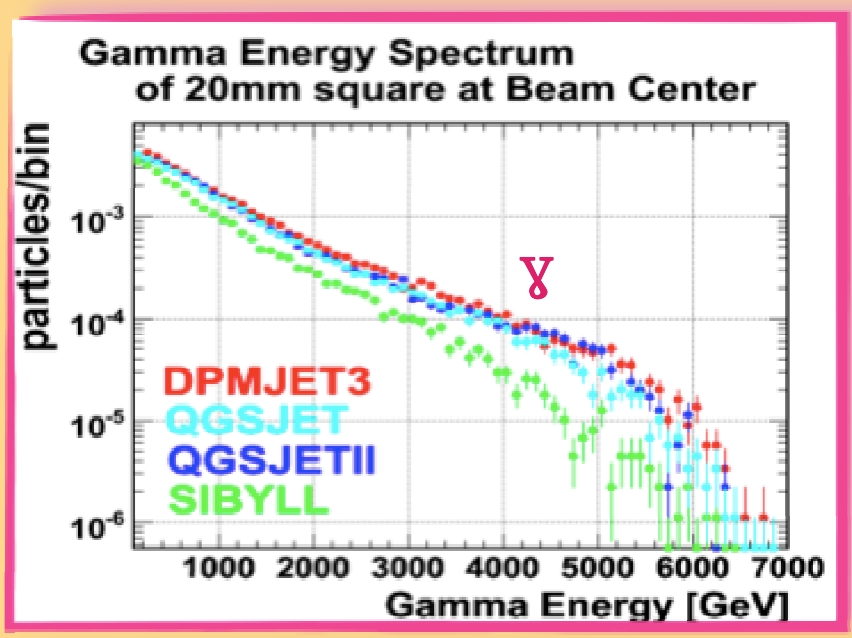
AGASA Systematics
Total ±18%
Hadr Model ~10%
(Takeda et al., 2003)



Different hadronic interaction models give different answers about the composition of HECR



What do we expect from LHCf?

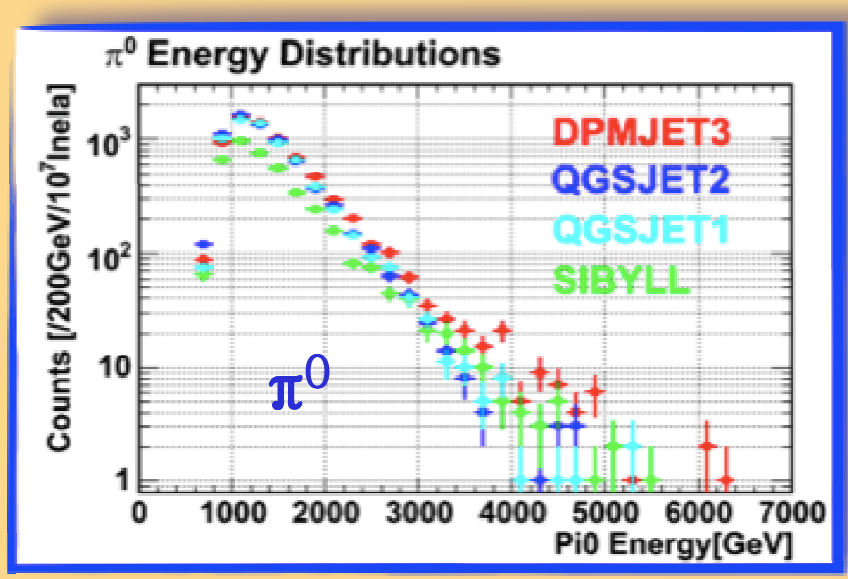


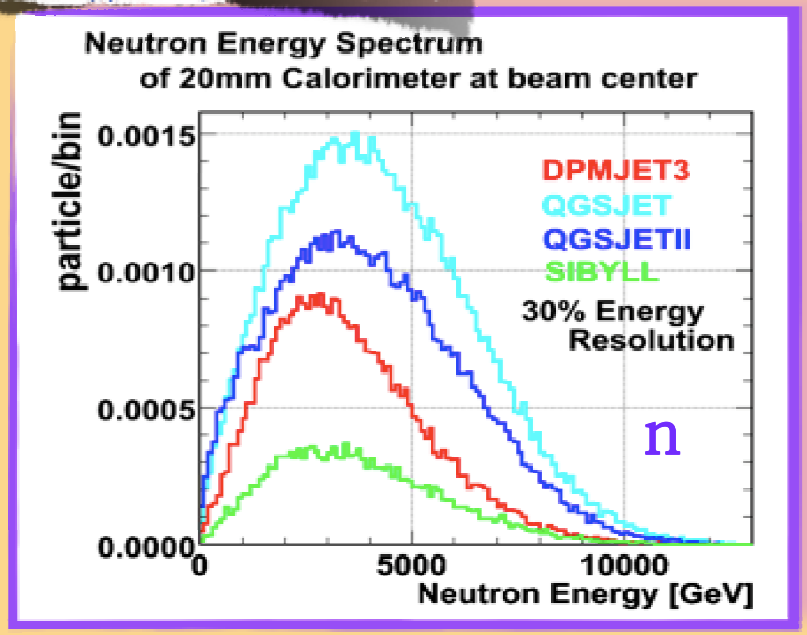
Energy spectra and transverse momentum distribution of

- γ (E>100GeV, ΔE/E<5%)
- Neutrons (E> few 100 GeV, ΔE/E~30%)
- π^0 (E>500GeV, ΔE/E<3%)

in the pseudo-rapidity range η>8.4

10^6 collisions
↔ 2min. exposure @ $10^{29}cm^{-2}s^{-1}$

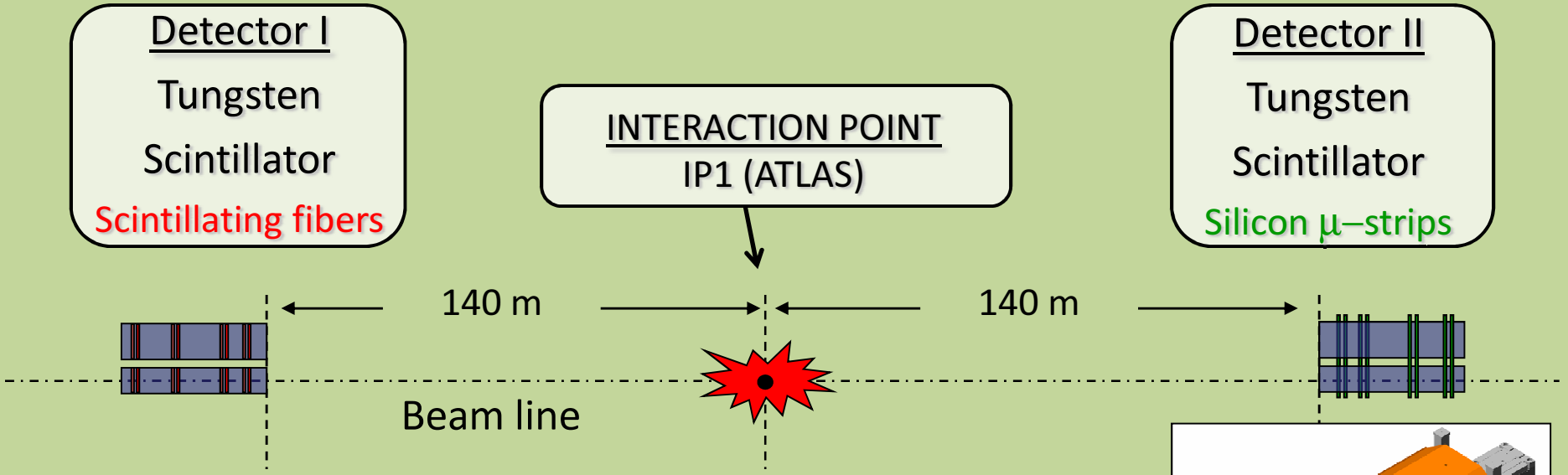




PART 2

Overview of method and detectors

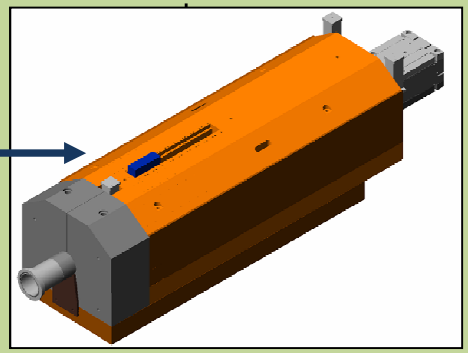
LHCf location inside the LHC



Detectors should measure energy and impact point of γ from π^0 decays

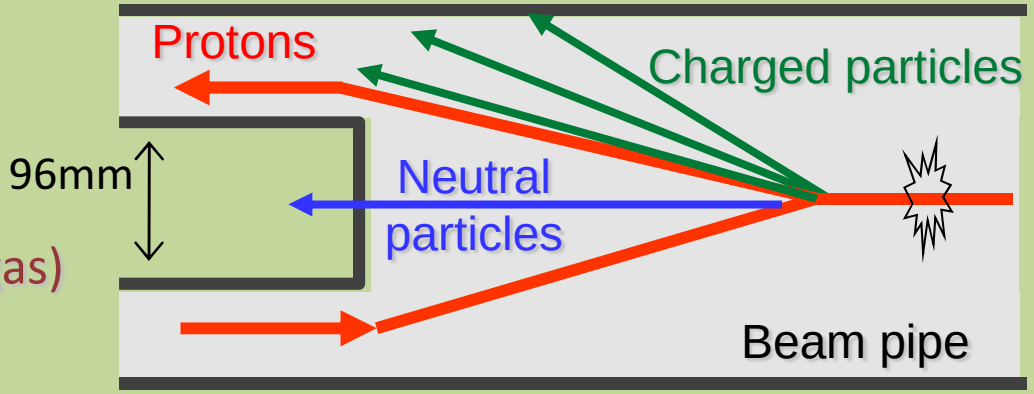
→ **e.m. calo tracking layers**

Located Inside the TAN, absorber for neutral particles



Two independent detectors on both sides of IP1

- ✓ Redundancy
- ✓ Background rejection (esp. beam-gas)



The LHCf detectors

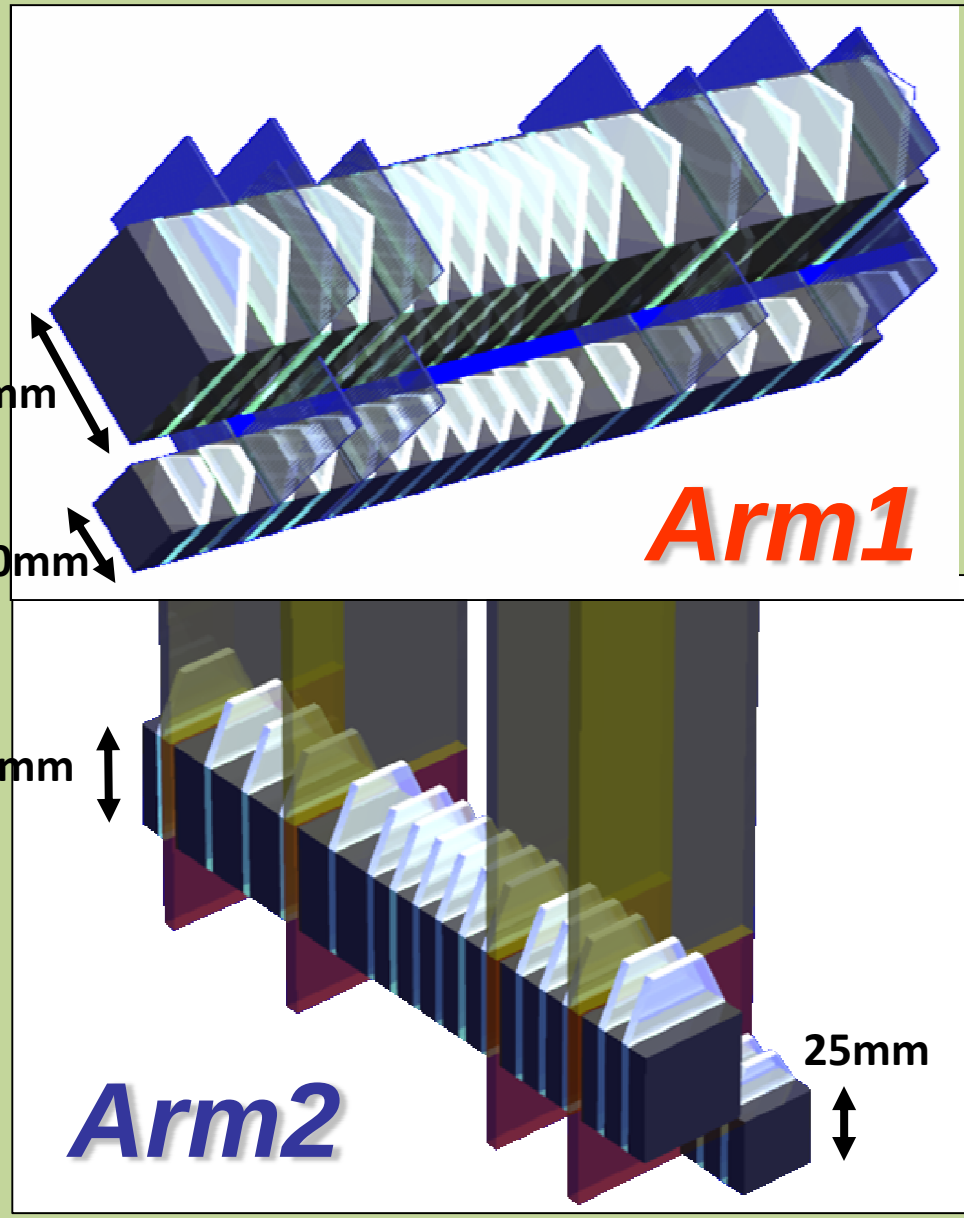
Sampling E.M. calorimeters

- W (44 r.l , 1.7λ_I) and Scintillator x 16 Layers
- 4 tracking layers:
  XY-SciFi(Arm#1) 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 Counters

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


290mm
90mm
Arm#1 Detector


Arm#2 Detector

PART 3

Preliminary results (2009 and 2010 runs)

Summary of operations in 2009 and 2010

With Stable Beam at 450 + 450 GeV

- **Total of 42 hours for physics**
- **About 10^5 showers events in Arm1+Arm2**

With Stable Beam at 3.5 + 3.5 TeV

- **Total of 150 hours for physics with different setups**
  - **Different vertical position to increase the accessible kinematical range**
  - **Runs with or without beam crossing angle**
- **$\sim 4 \cdot 10^8$ shower events in Arm1+Arm2**
- **$\sim 10^6$ π^0 events in Arm1+Arm2**

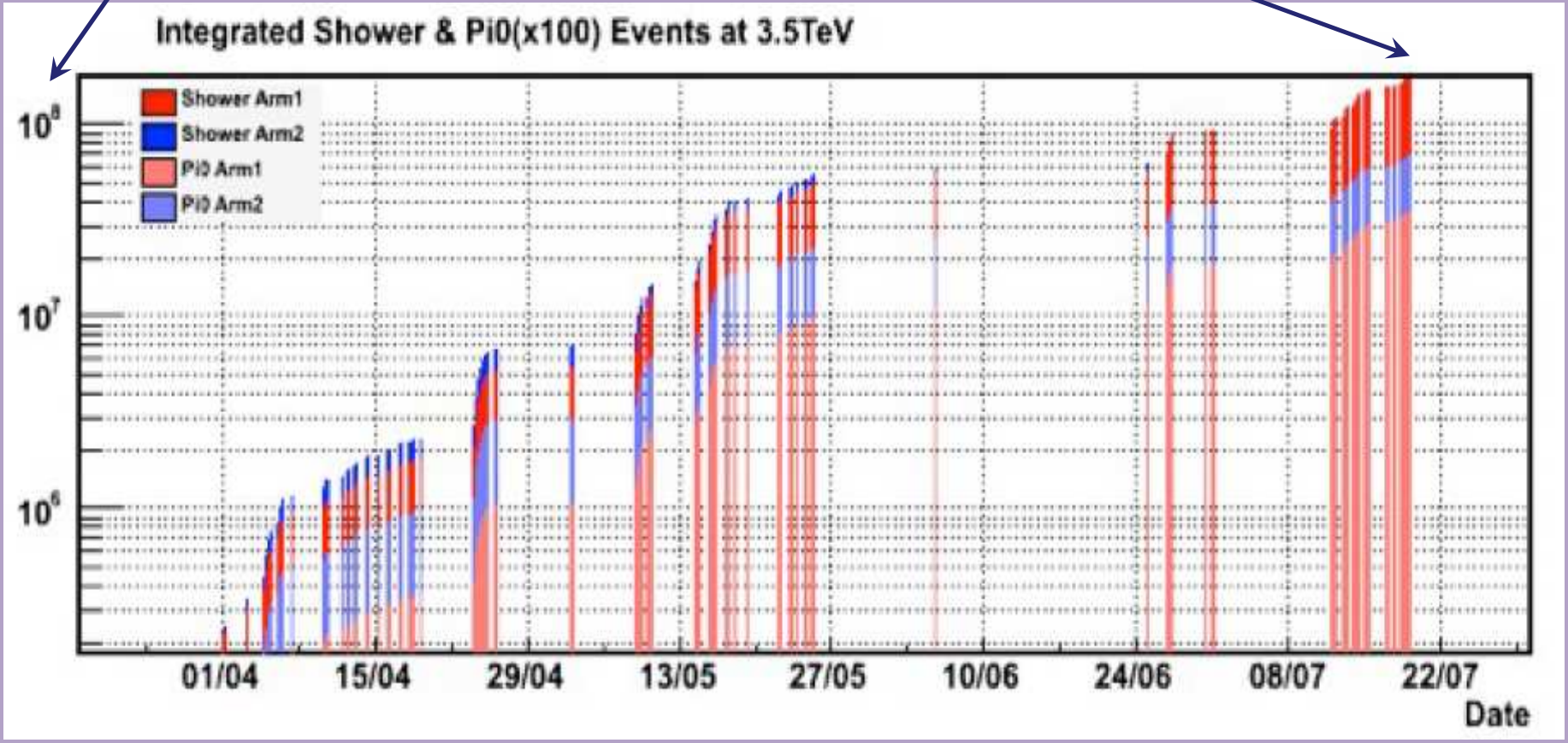
Status

- **Completed program for 900 GeV and 7 TeV**
  - **Removed detectors from tunnel in July 2010**
  - **Post-calibration beam test in October 2010**
- **Upgrade to more rad-hard detectors**

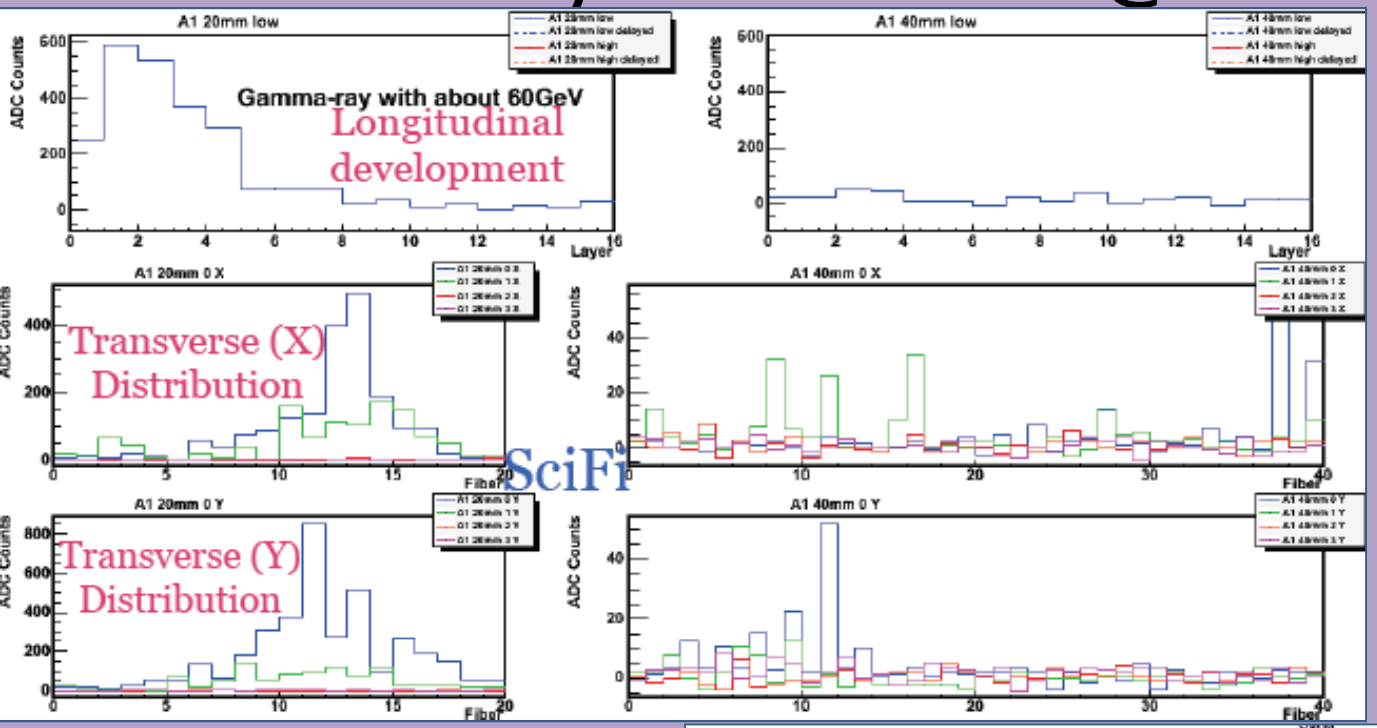
Accumulated events in 2010

10^8 events!

LHCf removal

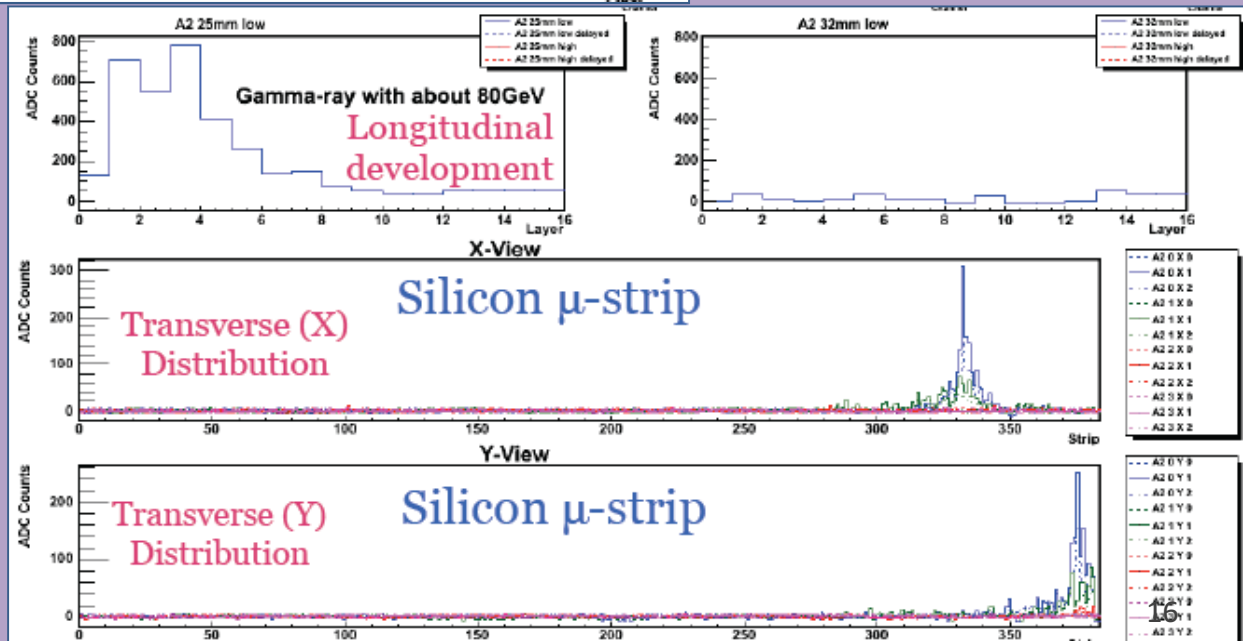


Analysis of events @ 900 GeV



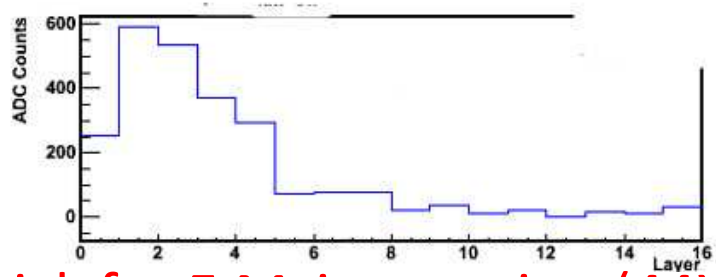
Event sample @ Arm1

Event sample @ Arm2



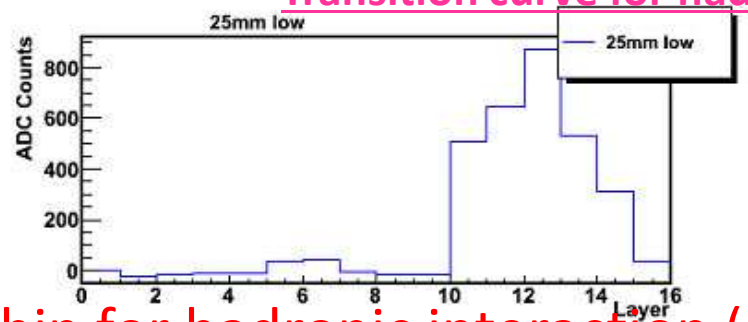
Particle identification

Transition curve for γ-ray



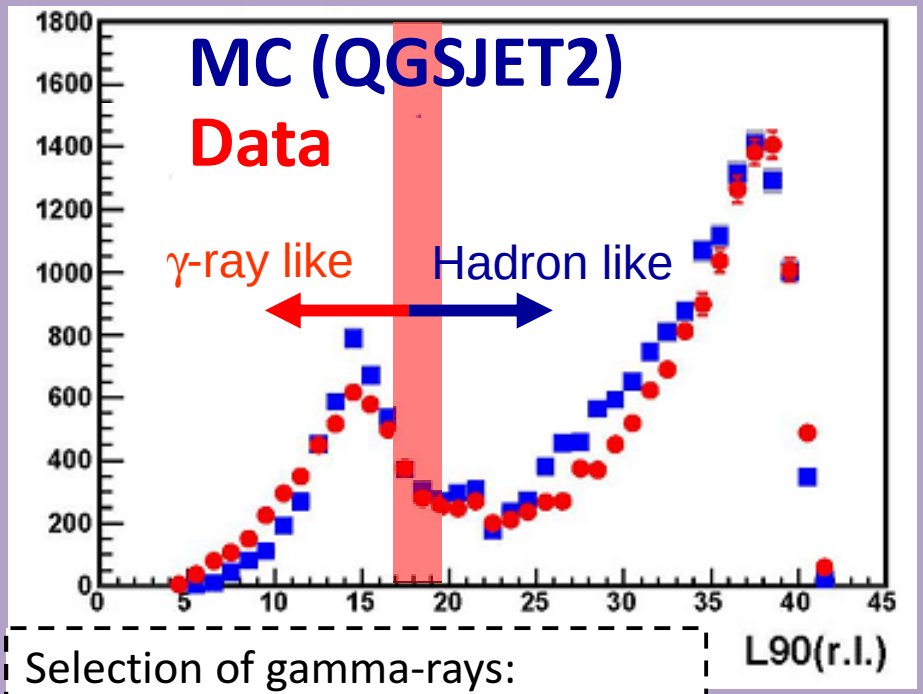
Thick for E.M. interaction ($44X_0$)

Transition curve for hadron



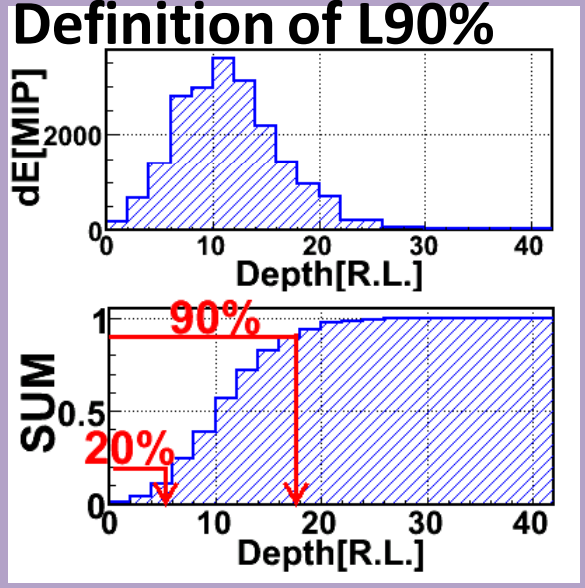
Thin for hadronic interaction (1.7λ)

L90% @ 40mm cal. of Arm1



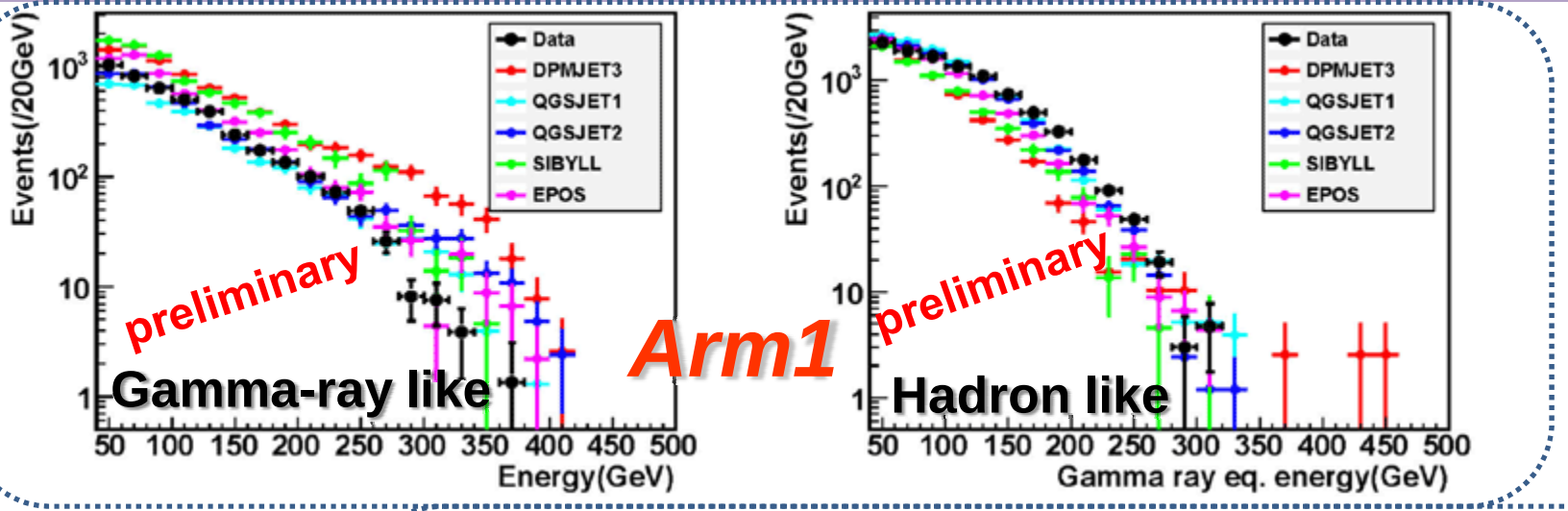
Selection of gamma-rays:
L90% < 16 r.l. + 0.002 x ΔE_r(GeV)

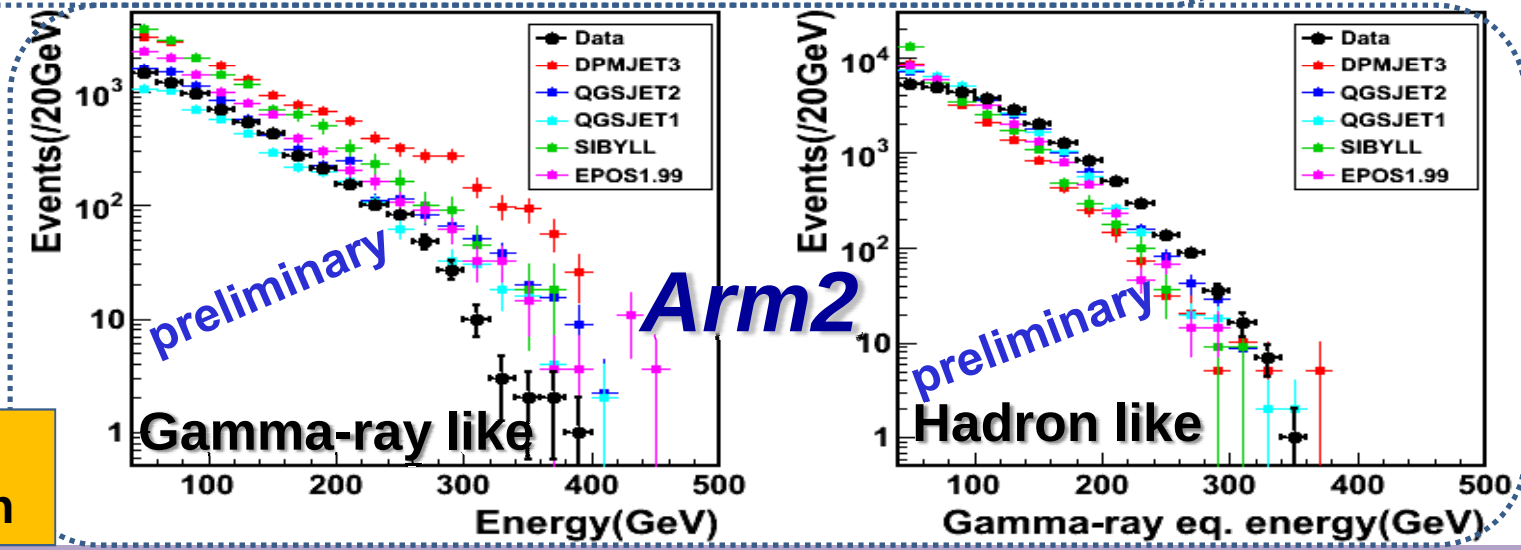
Definition of L90%



- L90% is defined as the longitudinal position containing 90% of energy
- PID study is still ongoing

Spectra @ 900GeV

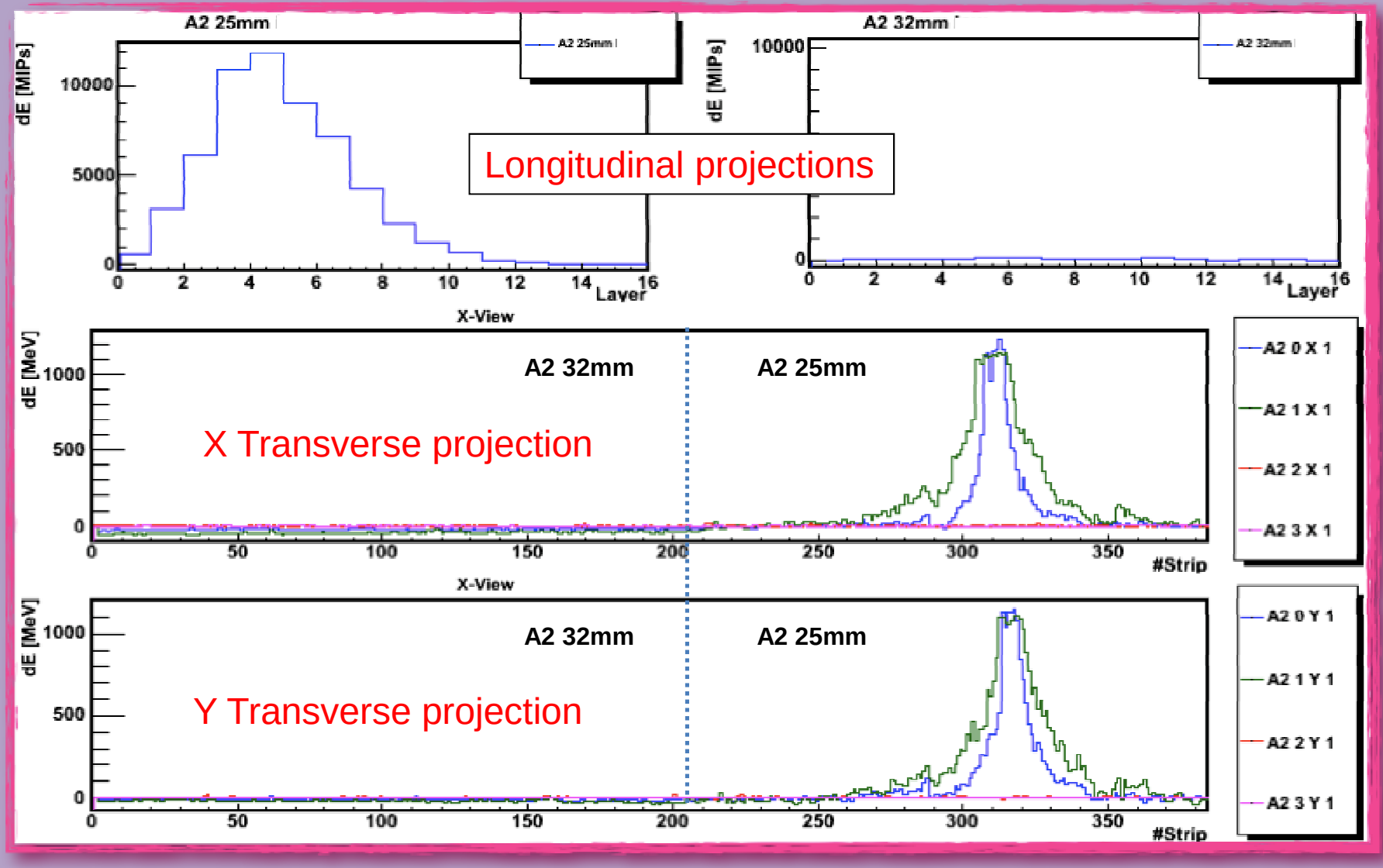




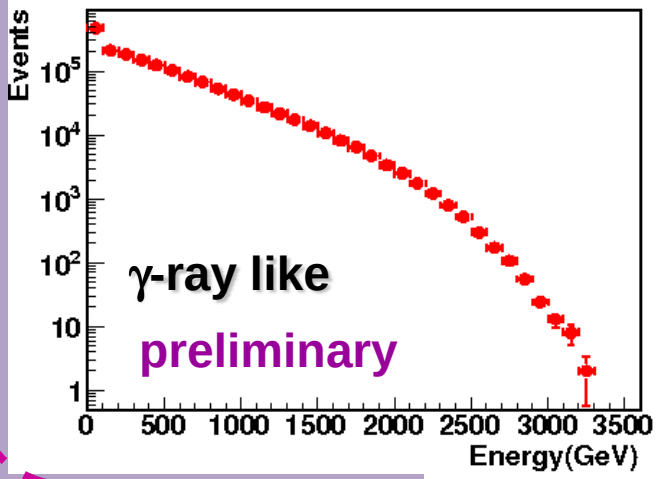
Only statistical errors are shown

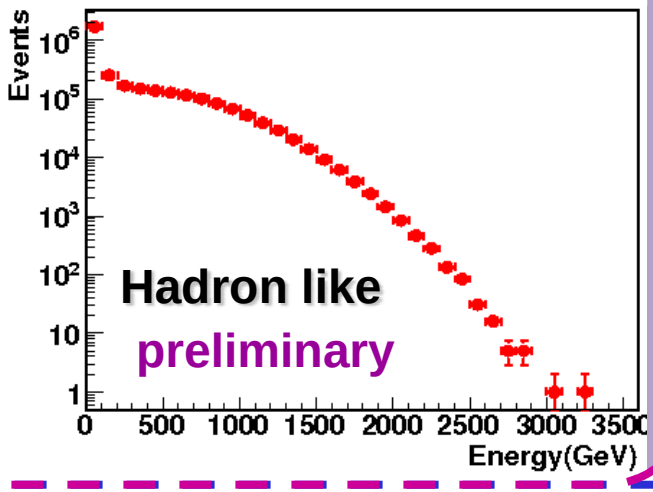
Spectra are normalized by # of gamma-ray and hadron like events. Response for hadrons and systematic errors (mainly absolute energy scale) are under study.

Beautiful e.m. events @ 7 TeV !!!



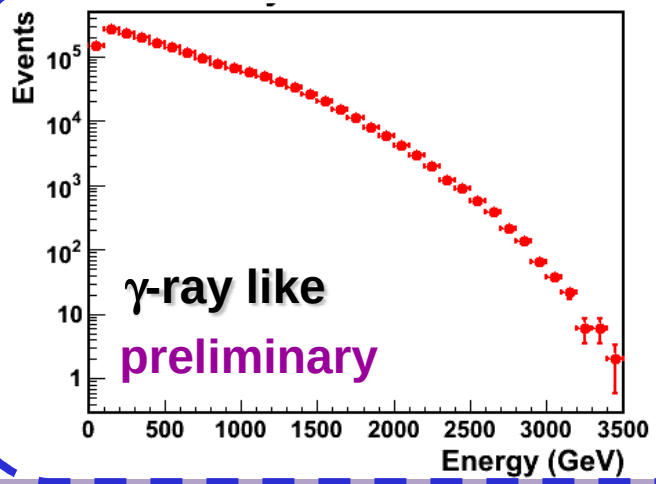
Neutral particle spectra @ 7 TeV

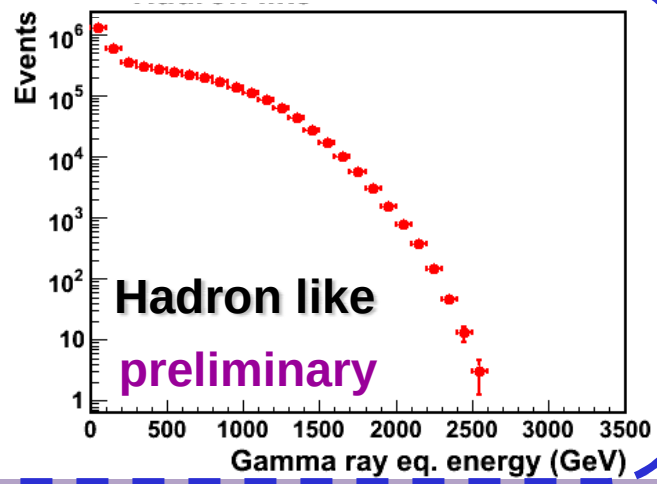




Arm1

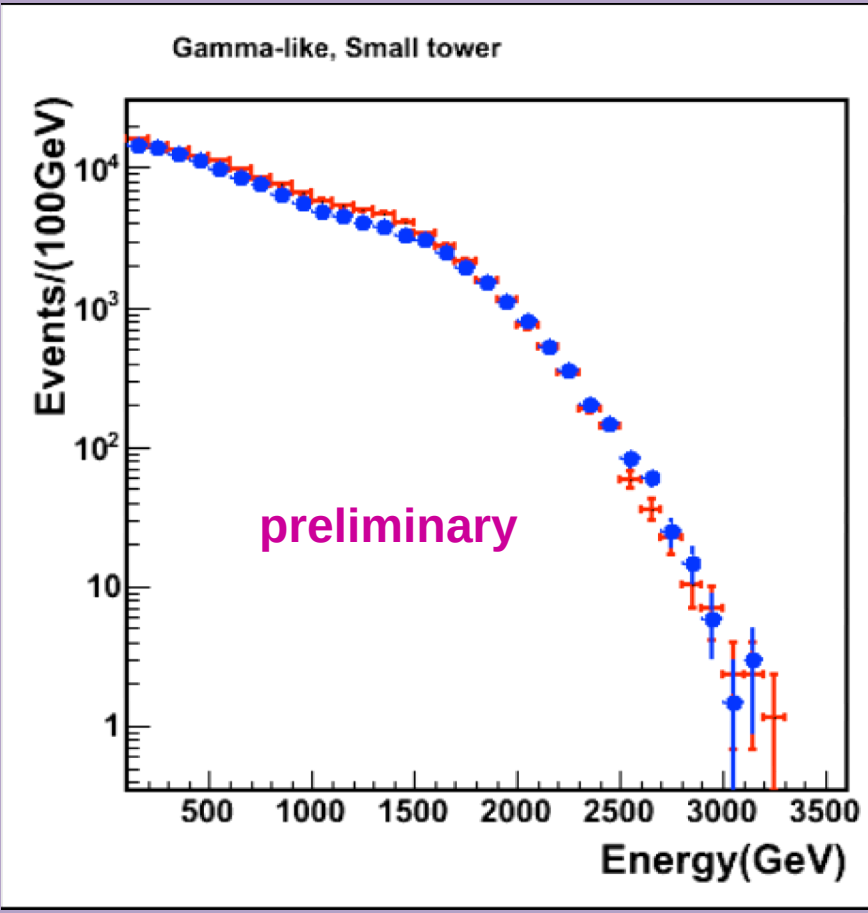
Arm2

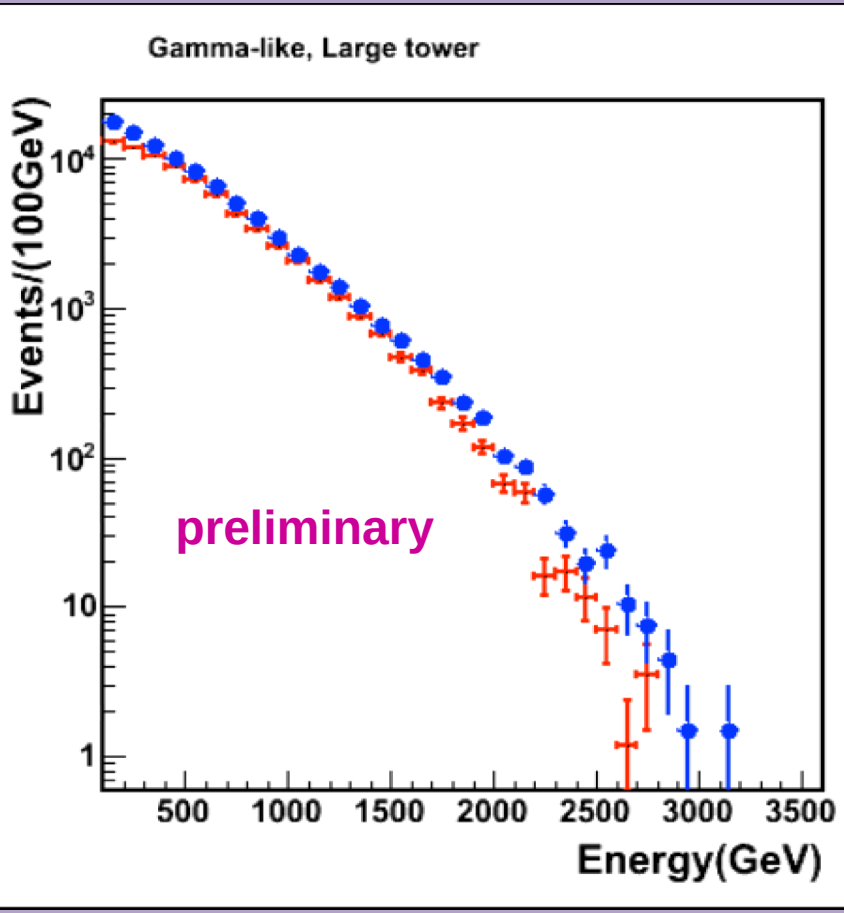




- Very high statistics: only 2% of data is used
- Comparison with M.C. is under development

Comparison of Arm1 and Arm2 @ 7 TeV





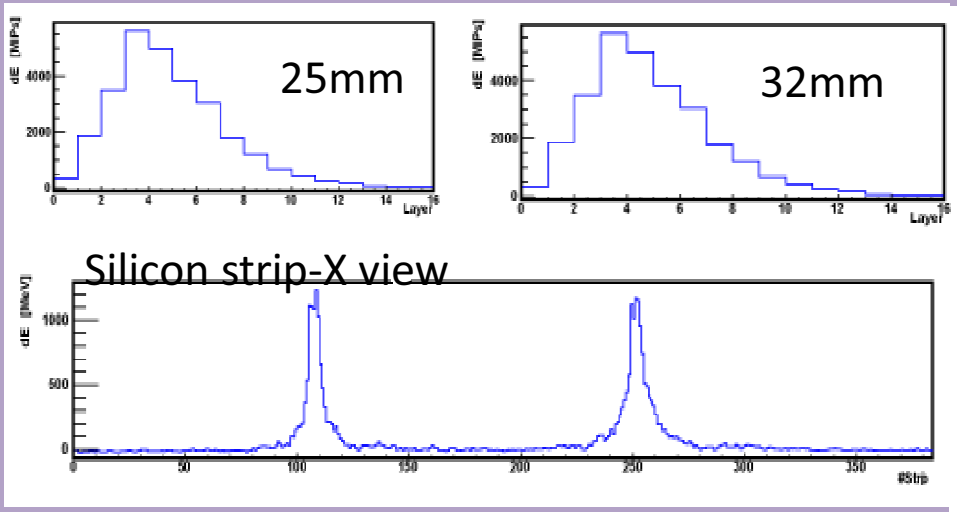
Red : Arm1 **Blue** : Arm2

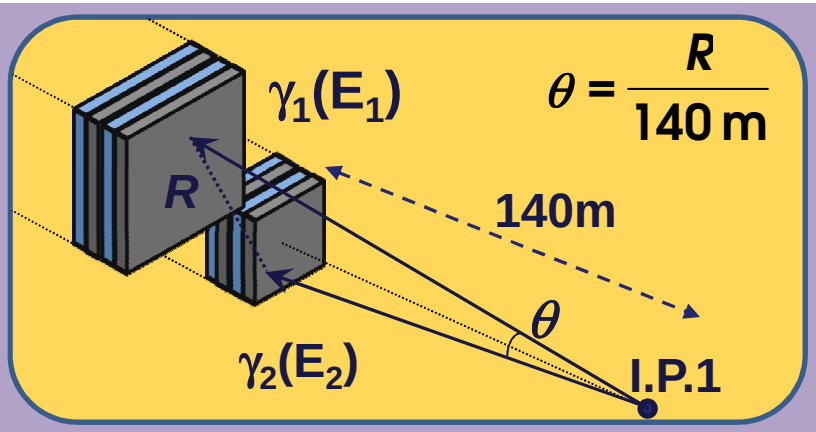
Same runs, same conditions, common rapidity region selected.

Spectra corrected for the live time of detectors.

Neutral pions

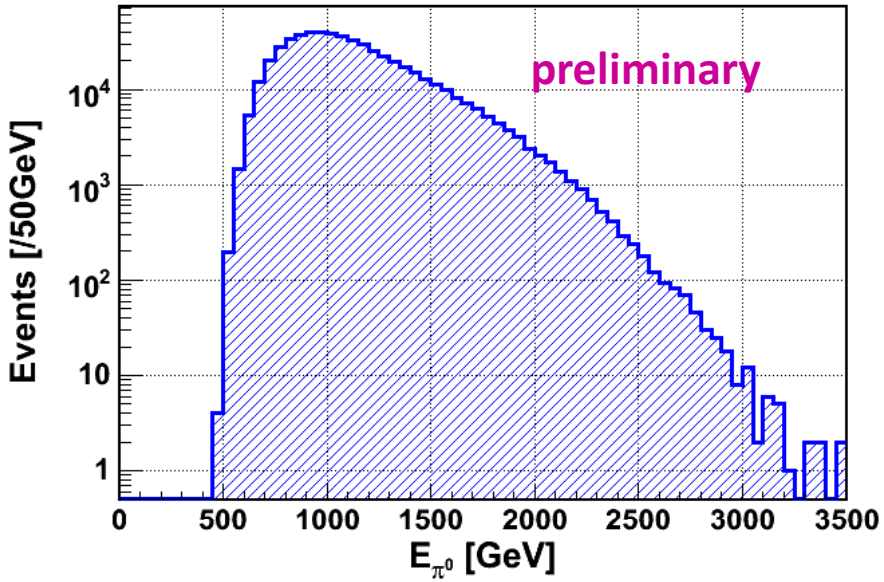
An example of event (Arm2)



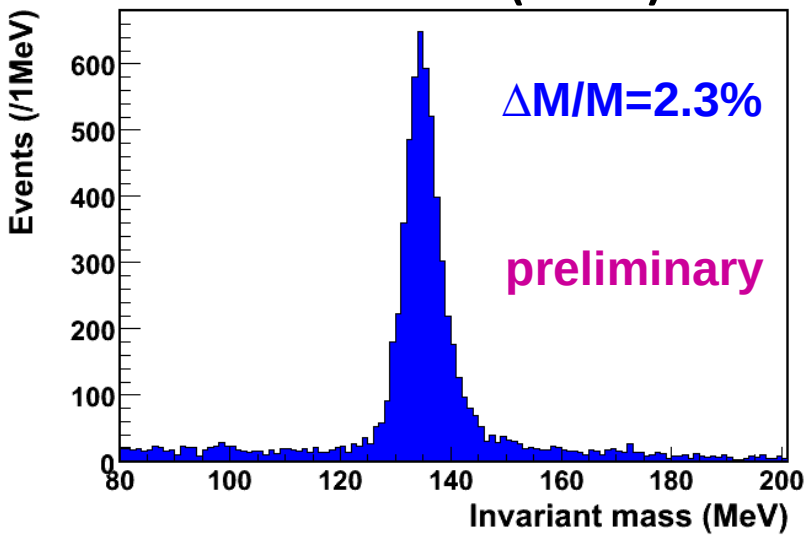


- Pi0's are a main source of electromagnetic secondaries in high energy collisions.
- The mass peak is very useful to confirm the detector performances and to estimate the systematic error of energy scale.

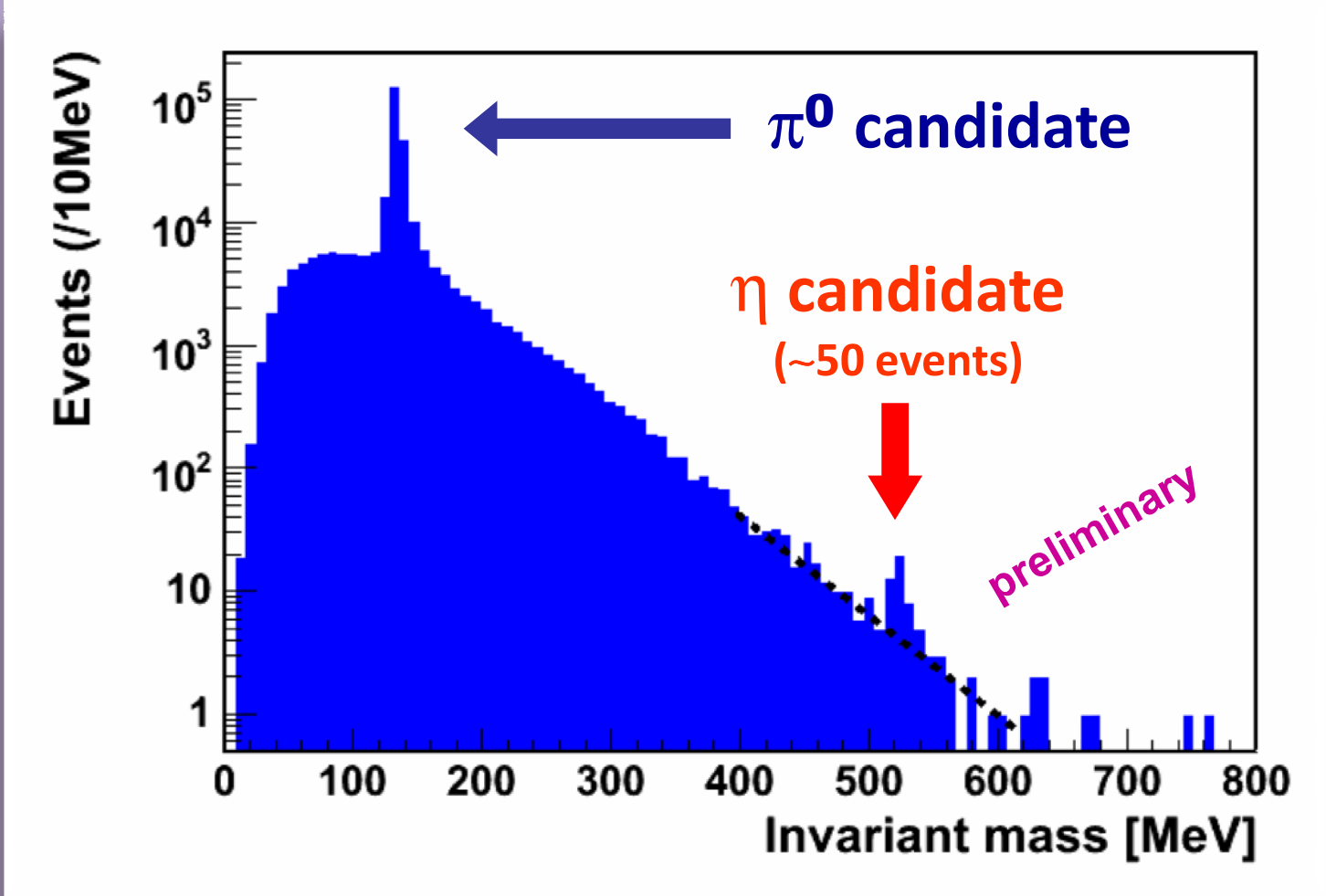
Energy spectrum (Arm2)



Reconstructed mass (Arm2)



2γ invariant mass spectrum @ 7 TeV



- The search for η particles is an important tool for discriminating hadronic interaction models, because their spectra differ a lot from model to model
- Important tool also for energy scale calibration

Schedule and future plan

2010, Oct	Beam test at SPS to confirm the radiation damage and the performance
END 2010	Finalize analysis at 900 GeV (almost completed) and at 7 TeV
2011/2012	Upgrade the detector for radiation hardness: replacement of scintillators and SciFi with GSO
2013	Re-installation of detectors in the tunnel again for the operation at 14TeV

Then we are thinking about

- Operation at LHC light ion collisions (not Pb-Pb).

Conclusions

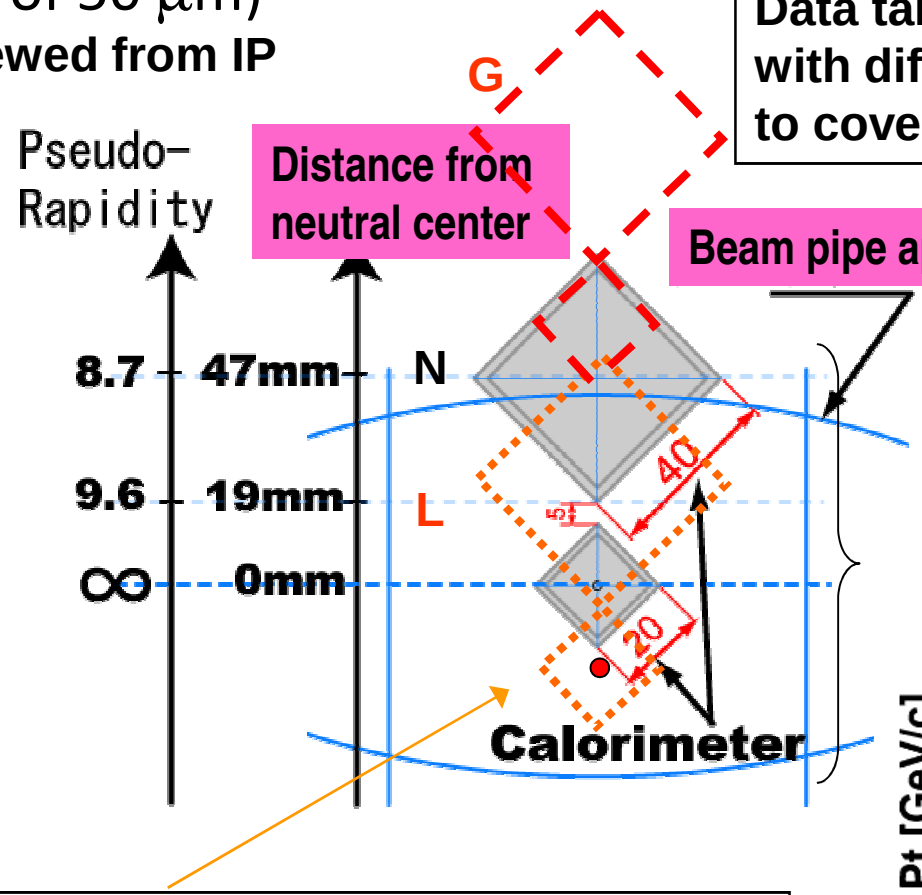
- LHCf is a forward experiment at LHC; its aim is to measure **energy spectra and transverse momentum distributions of very energetic neutral secondaries from pp interactions in the very forward region** of IP1 (at pseudo-rapidity greater than 8.4)
- Results will help **calibrating the hadronic interaction models**; one important field where this measurements are mostly important is the study of atmospheric showers induced by HECR particles
- LHCf **successfully completed operations at 900 GeV and 7 TeV**. The LHCf detectors has been removed from the LHC tunnel on July 21st 2010.
- Analysis of data at 900 GeV is almost completed; we will finalize analysis at 7 TeV before the end of the year.
- Detectors will be **upgrade**d in 2011/2012 for radiation hardness and will be re-installed for data taking at 7 TeV+7 TeV in 2013.

Backup slides

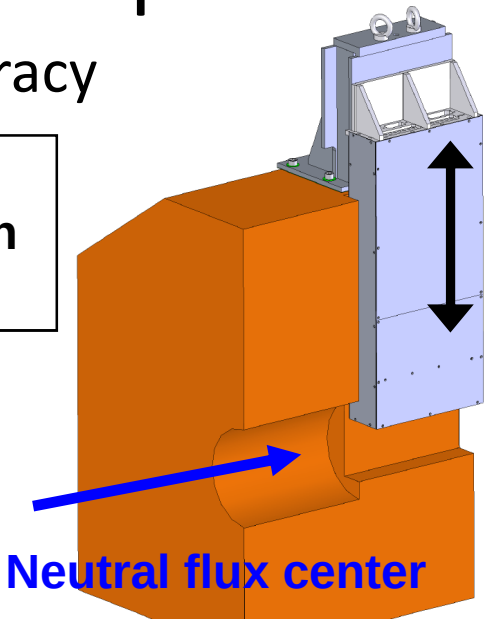
Detector vertical position and acceptance

- Remotely changed by a manipulator(with accuracy of 50 μm)

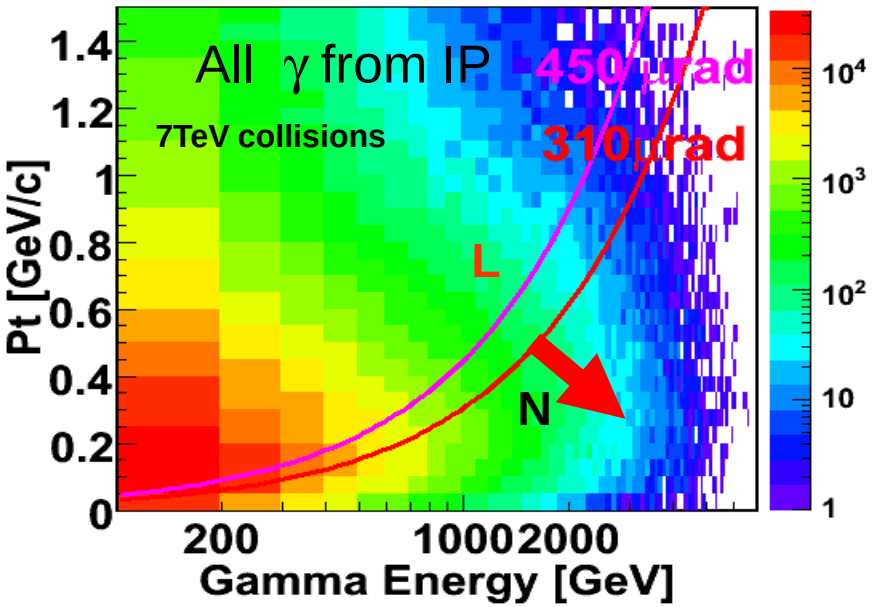
Viewed from IP



Data taking mode with different position to cover P_T gap



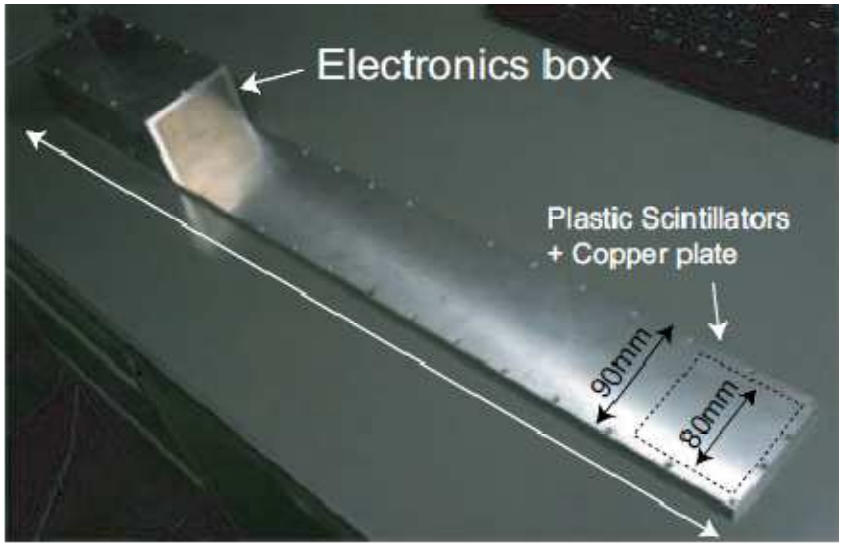
Collisions with a crossing angle lower the neutral flux center thus enlarging P_T acceptance



Front counters

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

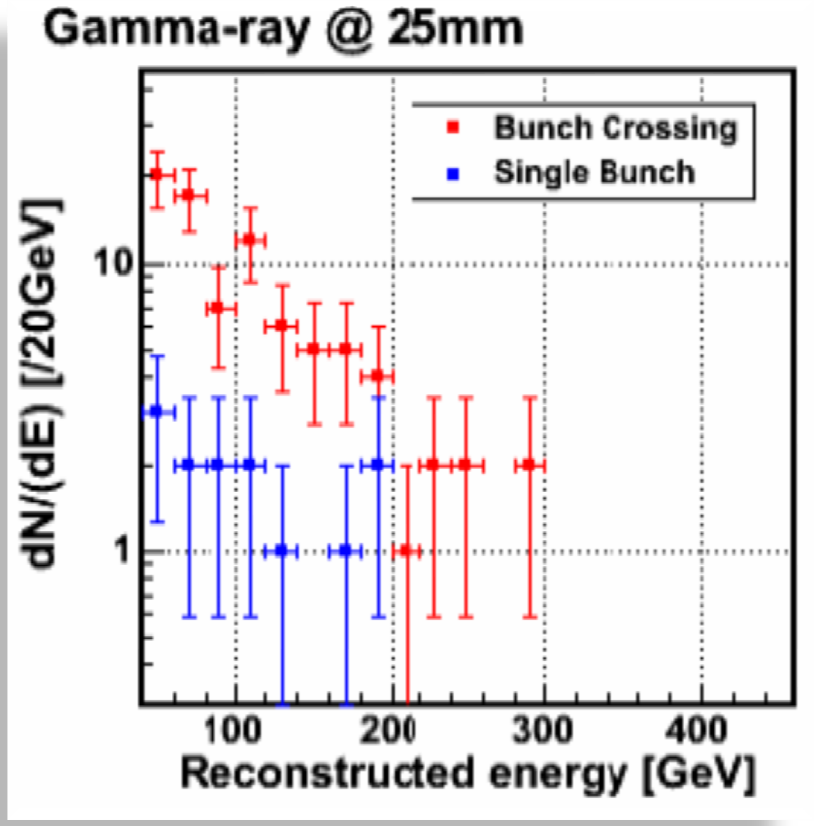
Schematic view of
Front counter



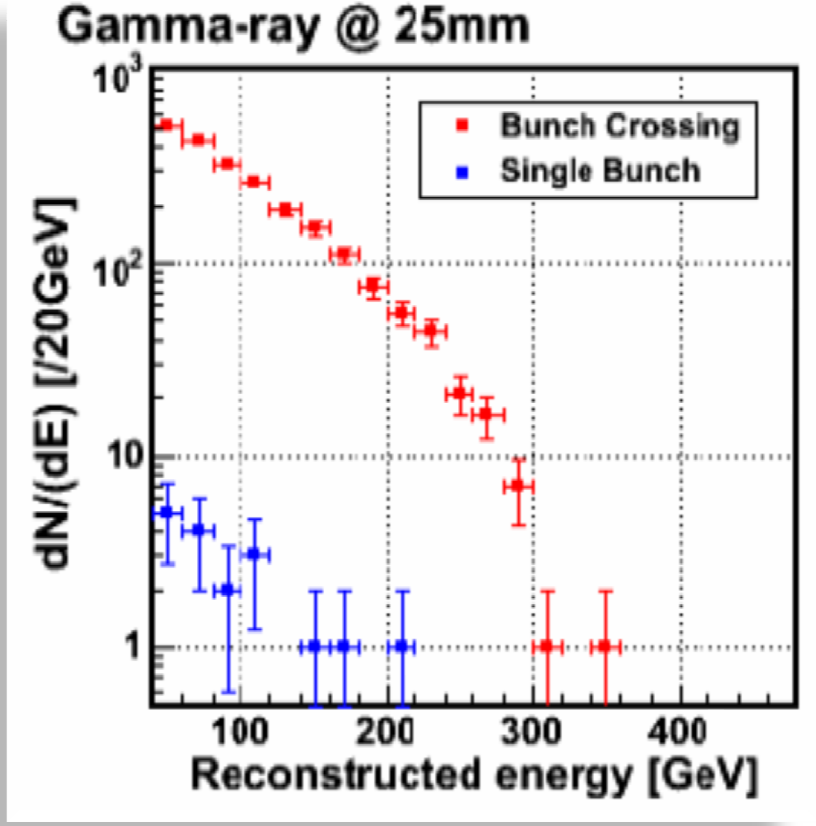
- **To monitor beam condition.**
- **For background rejection of beam-residual gas collisions by coincidence analysis**

Beam-gas backgroud @ 900 GeV

2009

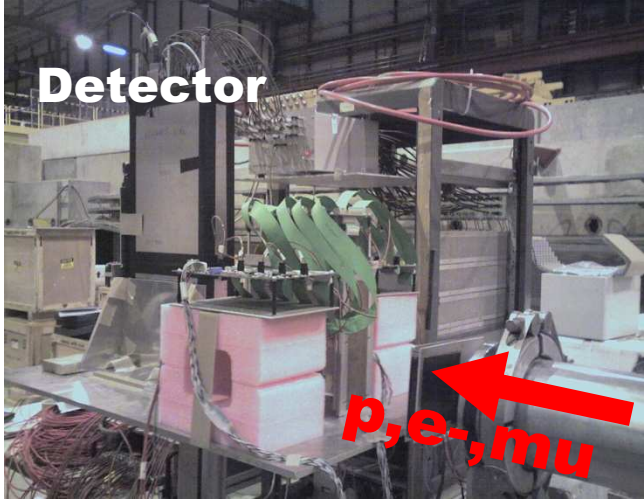


2010

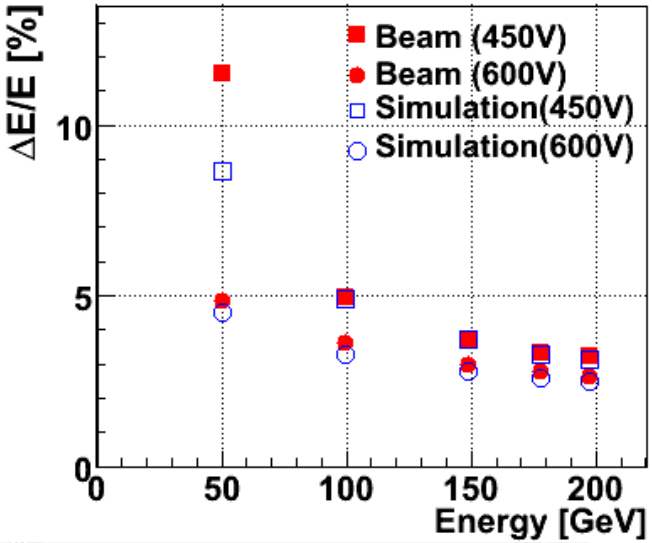


Very big reduction in the Beam Gas contribution!!!!
Beam gas ~ I, while interactions ~ I^2

Beam test @ SPS

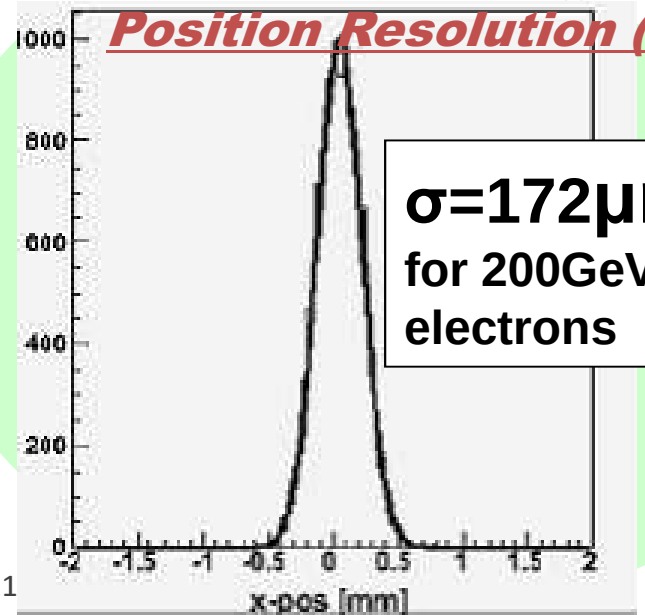


Energy Resolution for electrons with 20mm cal.



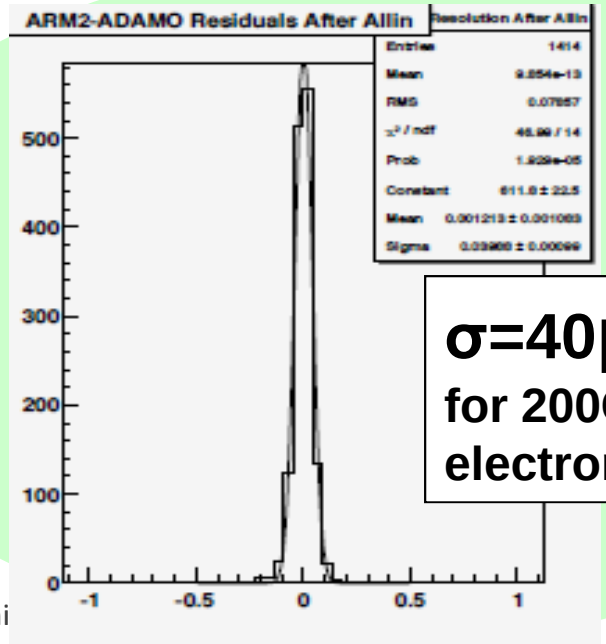
- Electrons 50GeV/c – 200GeV/c
- Muons 150GeV/c
- Protons 150GeV/c, 350GeV/c

Position Resolution (Scifi)



σ=172μm
for 200GeV electrons

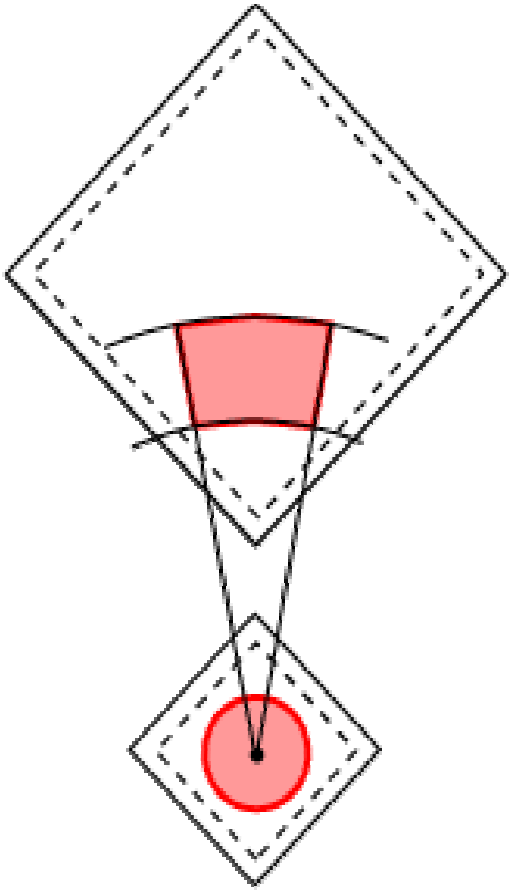
Position Resolution (Silicon)

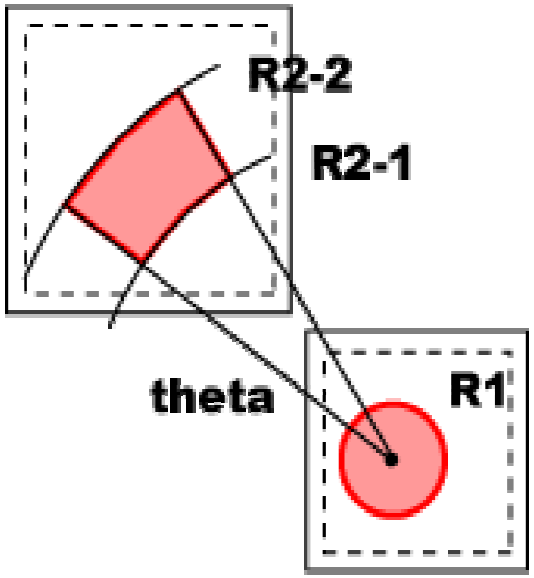


σ=40μm
for 200GeV electrons

Selection of rapidity region (comparison Arm1/2)

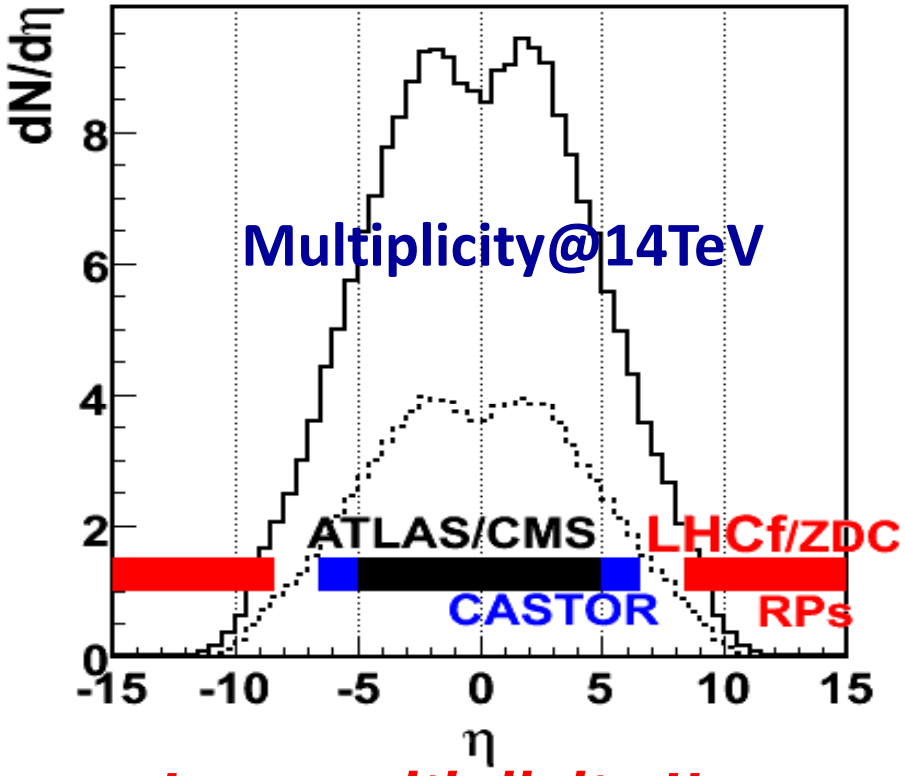
R1=5mm
R2-1 = 35mm
R2-2 = 42mm
theta = 20°



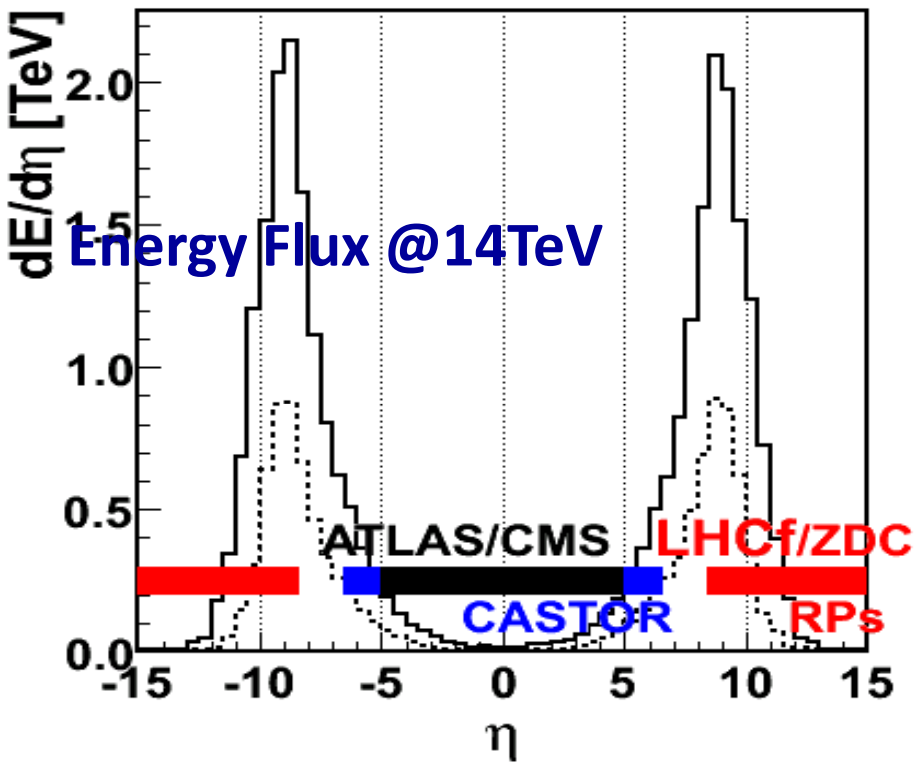


Both Arm1 and Arm2 cover the same rapidity area in small and large tower. Here the beam center is determined by our measurements.

Particle and energy flow vs rapidity



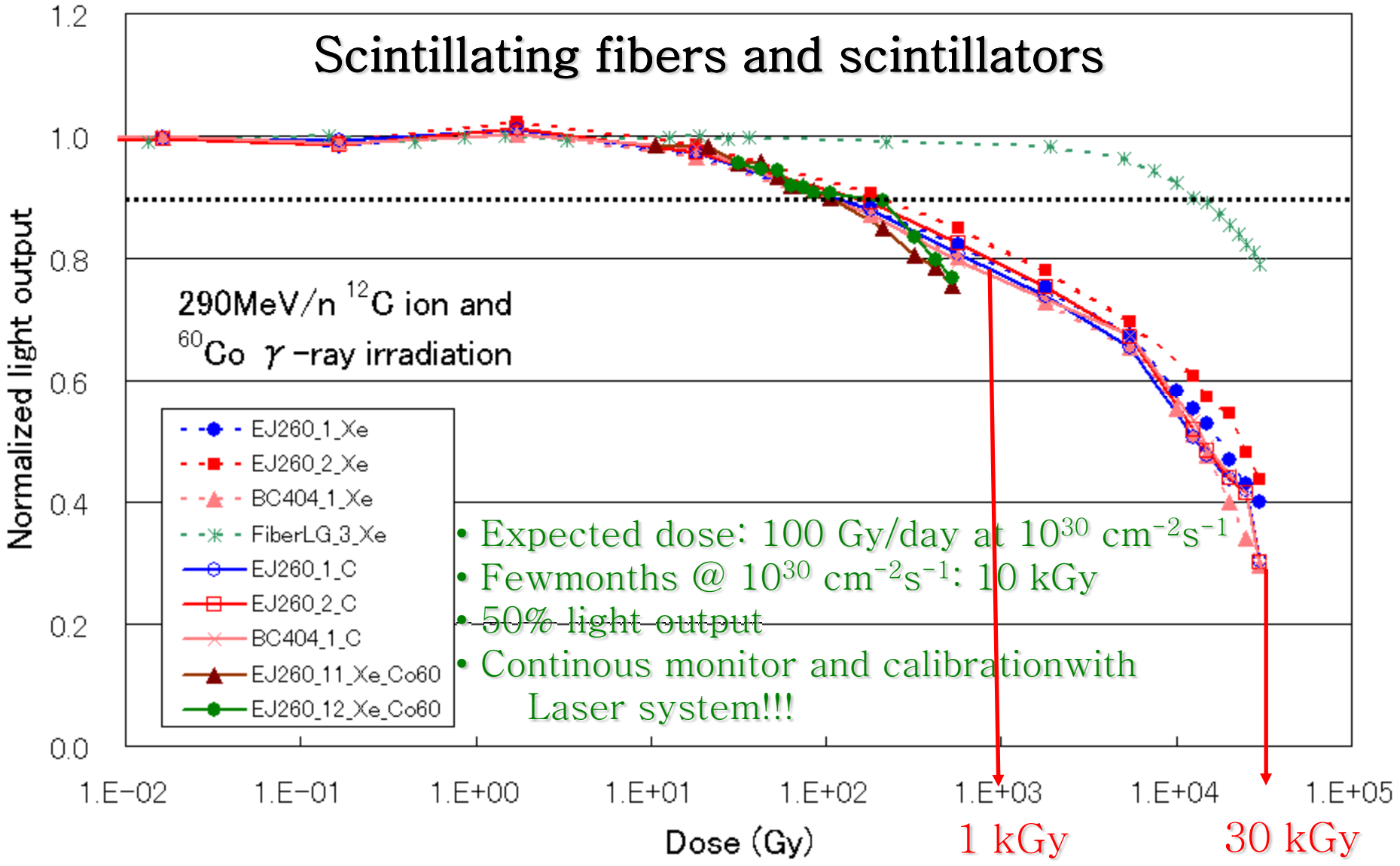
Low multiplicity !!



High energy flux !!

simulated by DPMJET3

Radiation damage



Status of detectors and upgrade

- LHCf detectors removed from the TAN on 20th July 2010

  -Plastic scinitillator degradation of a few % due to > 5 Gy dose

- "Post"-calibration by a SPS test beam are planned on 15th to 28th October

- Re-installation at LHC at the next energy upgrade. R&D and fabrication of radiation-hard GSO scinitillators and fibres are on-going for the "phase-2" of the LHCf detector.