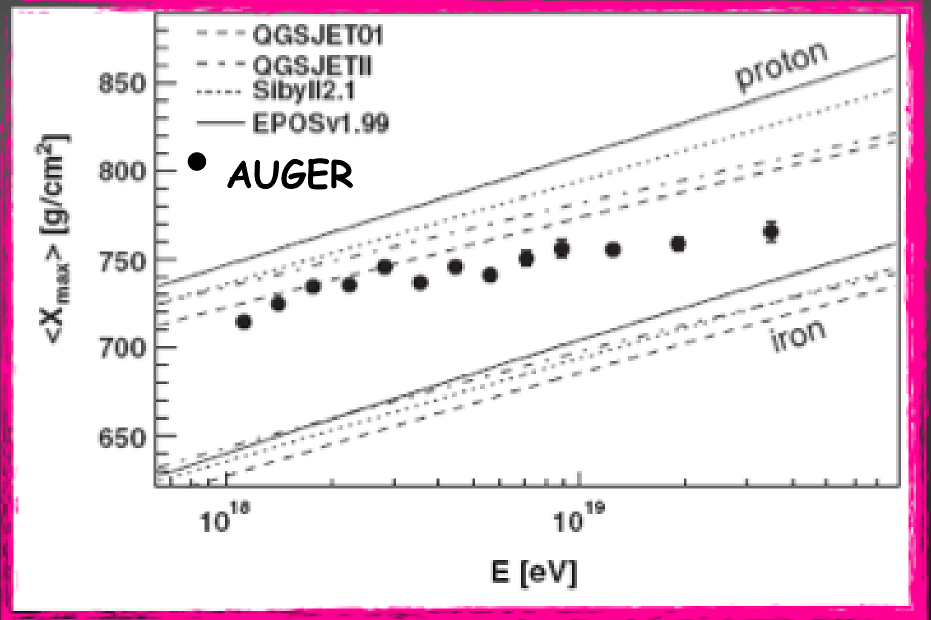
Workshop on Hadron-Hadron & Cosmic-Ray Interactions at multi-TeV Energies
ECT* - Trento, Nov 29th - Dec 3rd, 2010

Preliminary results on neutral particles in the forward region at LHC with the LHCf experiment

Massimo Bongi - INFN (Florence, Italy)
LHCf Collaboration

Hadron-Hadron & Cosmic-Ray Interactions at multi-TeV Energies

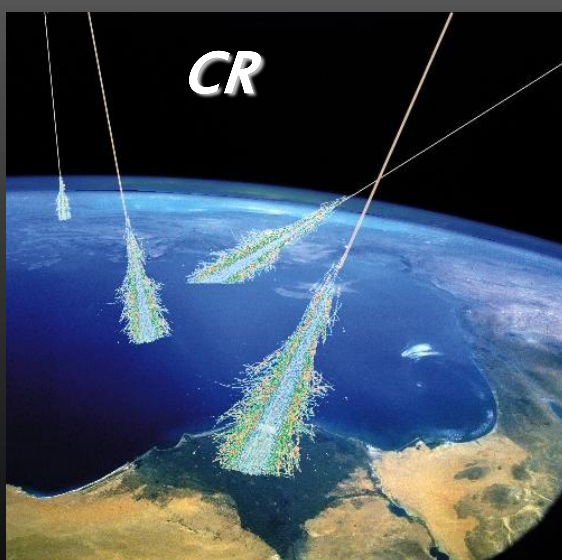
- Recent excellent observations (e.g. PAO, HiRes, TA) but the origin and composition of UHECR is still unclear
- Uncertainty in hadron-hadron interactions affects:
  - the prediction of X_{max}
  - SD observations
- Study of very forward particle emission at as high as possible energy is indispensable

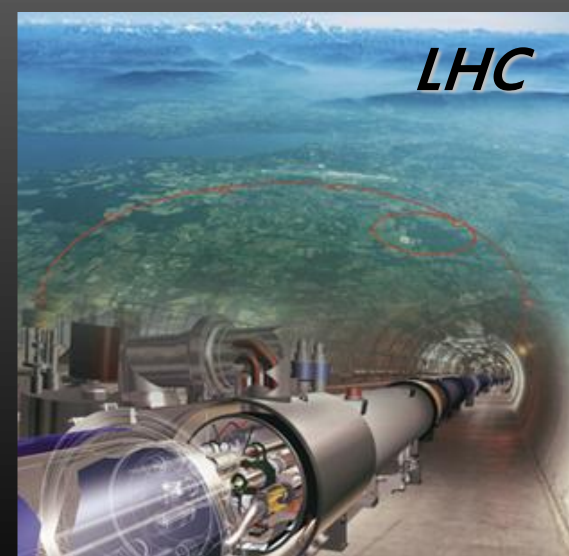


→ ***LHC forward (LHCf) experiment***

CR <=> LHC connection

- The dominant contribution to the energy flux in the atmospheric shower development comes from the very forward produced particles
- Precise measurement of γ, π^0 and n spectra in the very forward region at LHC
- 7 TeV + 7 TeV in the CM frame → $\sim 10^{17}$ eV in "fixed target" frame





The LHCf Collaboration

K.Fukatsu, Y.Itow, K.Kawade, T.Mase, K.Masuda, Y.Matsubara, G.Mitsuka, K.Noda, T.Sako, K.Suzuki, K.Taki

Solar-Terrestrial Environment Laboratory, Nagoya University, Japan

K.Yoshida — *Shibaura Institute of Technology, Japan*

K.Kasahara, M.Nakai, Y.Shimizu, T.Suzuki, S.Torii

Waseda University, Japan

T.Tamura — *Kanagawa University, Japan*

Y.Muraki — *Konan University, Japan*

M.Haguenauer — *Ecole Polytechnique, France*

W.C.Turner — *LBNL, Berkeley, USA*

O.Adriani, L.Bonechi, M.Bongi, R.D'Alessandro, M.Grandi, H.Menjo, P.Papini, S.Ricciarini, G.Castellini

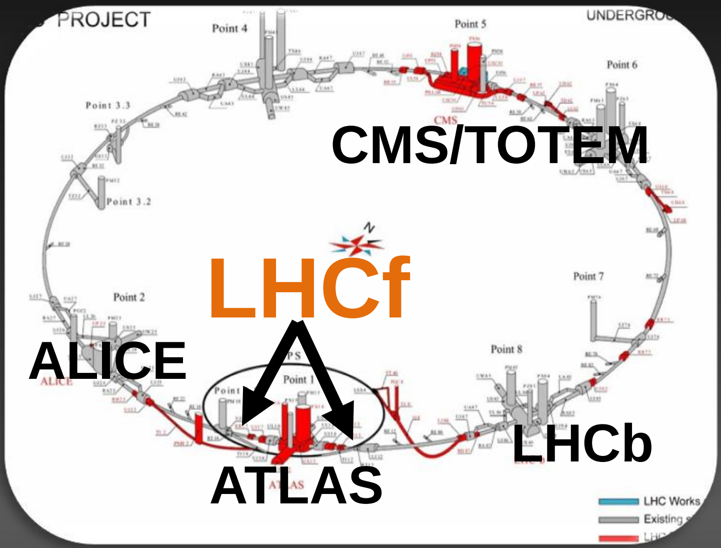
INFN and Universita' di Firenze, Italy

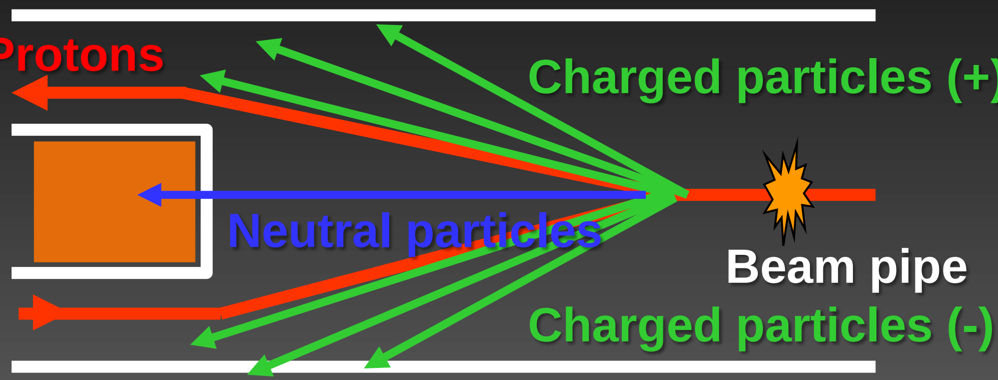
A.Tricomi — *INFN and Universita' di Catania, Italy*

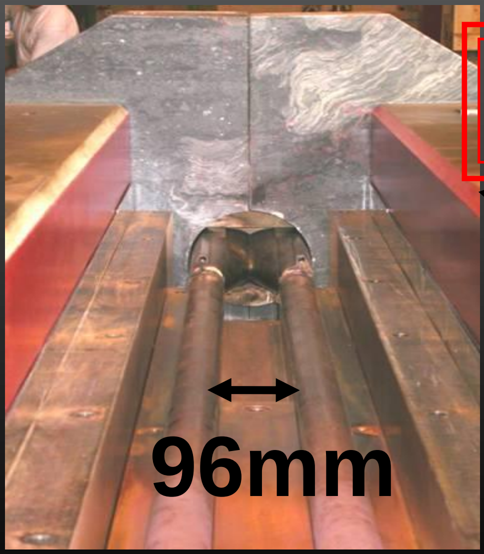
J.Velasco, A.Faus — *IFIC, Centro Mixto CSIC-UVEG, Spain*

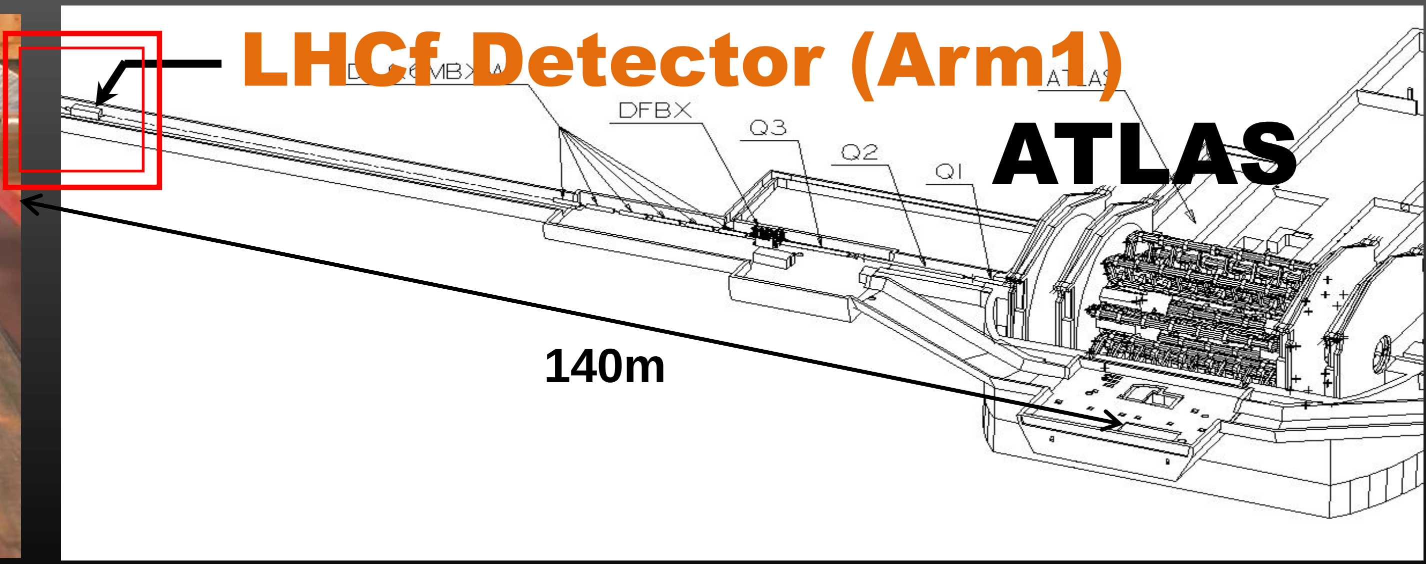
D.Macina, A-L.Perrot — *CERN, Switzerland*

Experimental set-up

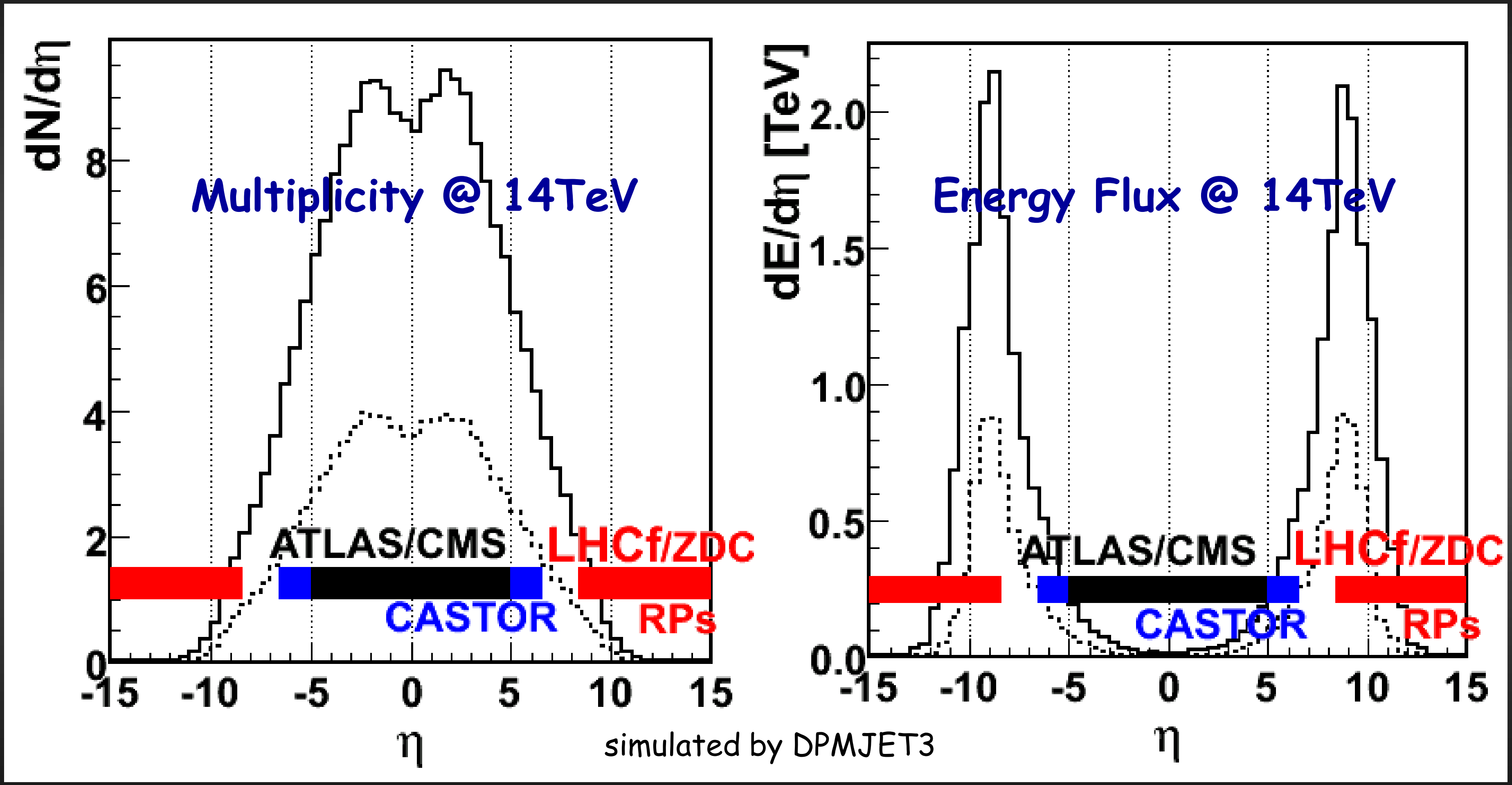








Particle and energy flow vs pseudorapidity



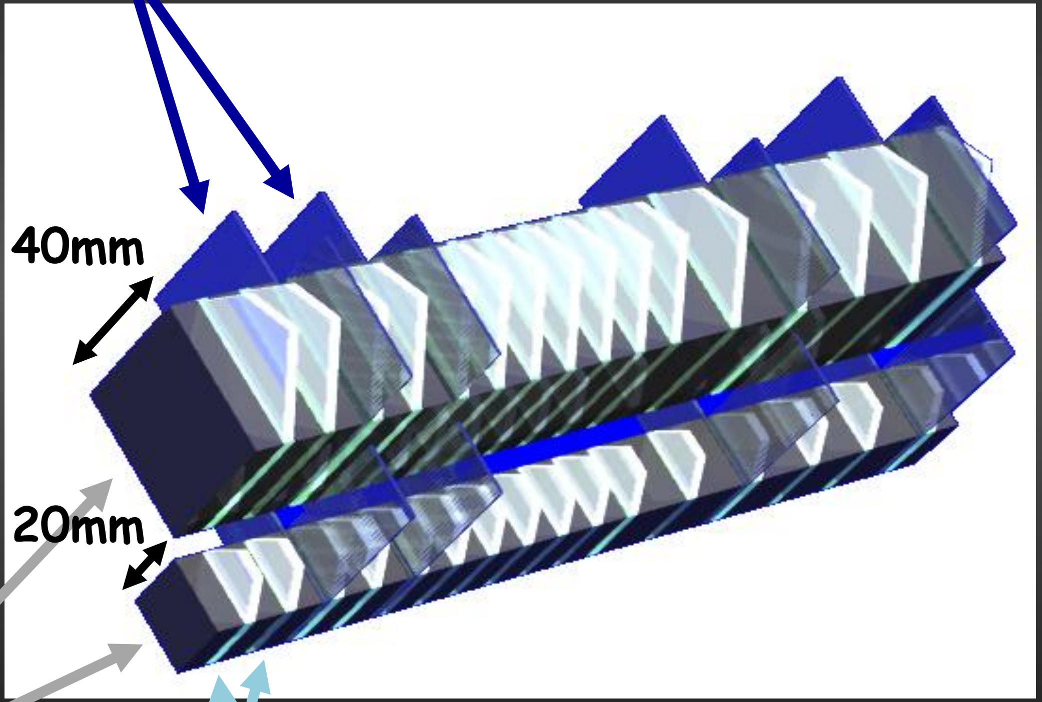
Low multiplicity **High energy flux**

Arm1 detector

- **Sampling E.M. calorimeters:**
  each detector has two calorimeter towers, which allow to reconstruct π^0

- ***Front counters:***
  thin plastic scintillators, 80x80 mm^2
  - monitor beam condition
  - rejection of background due to beam - residual gas collisions by coincidence analysis

Scintillating Fibers + MAPMT:
4 pairs of layers (at 6, 10, 30, 42 X_0), tracking measurements (resolution < 200 μm)



Absorber: 22 tungsten layers, 44 X_0, 1.7 λ

Plastic Scintillator: 16 layers, 3 mm thick, trigger and energy profile measurement

Arm2 detector

Silicon Microstrip: 4 pairs of layers (at 6, 12, 30, 42 X_0), tracking measurements (resolution ~ 40 μm)

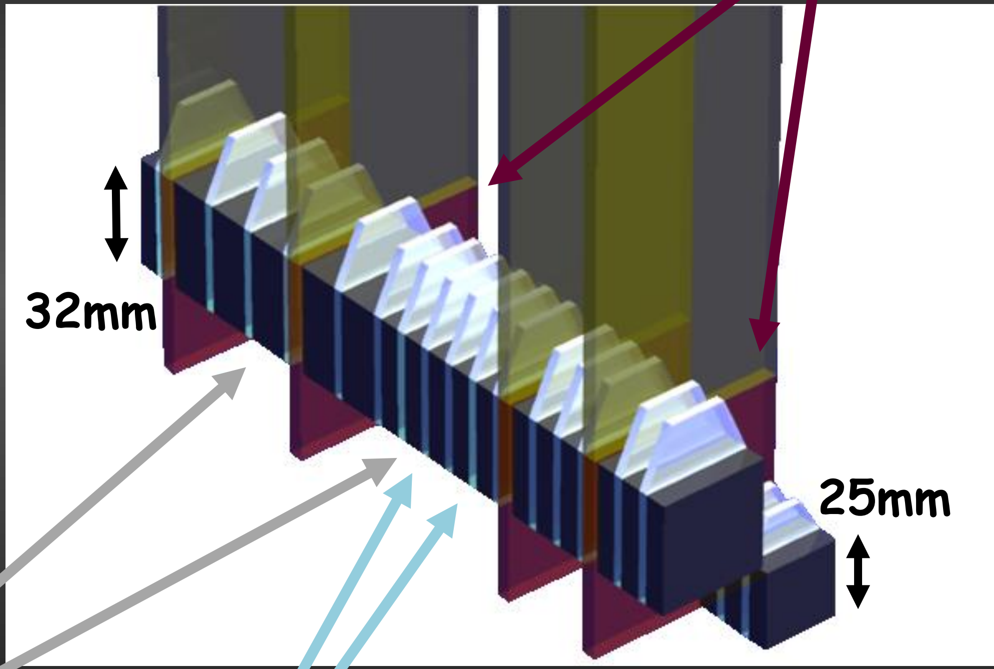
- **Sampling E.M. calorimeters:**

  each detector has two calorimeter towers, which allow to reconstruct π^0

- *Front counters:*

  thin plastic scintillators, 80x80 mm^2

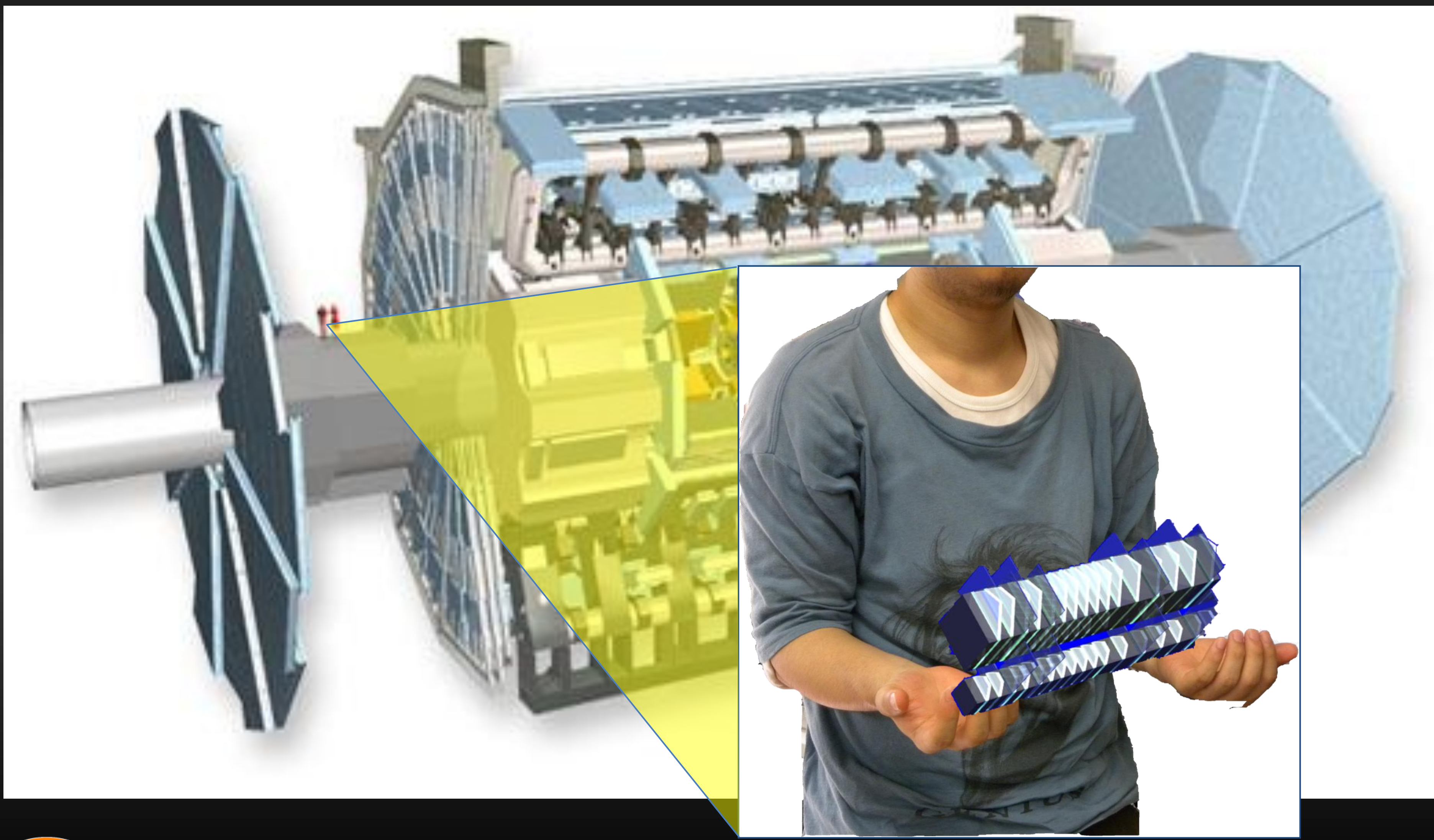
  - monitor beam condition
  - rejection of background due to beam - residual gas collisions by coincidence analysis



Absorber: 22 tungsten layers, 44 X_0, 1.7 λ

Plastic Scintillator: 16 layers, 3 mm thick, trigger and energy profile measurement

ATLAS & LHCf




290mm
90mm
Arm1 detector


Arm2 detector

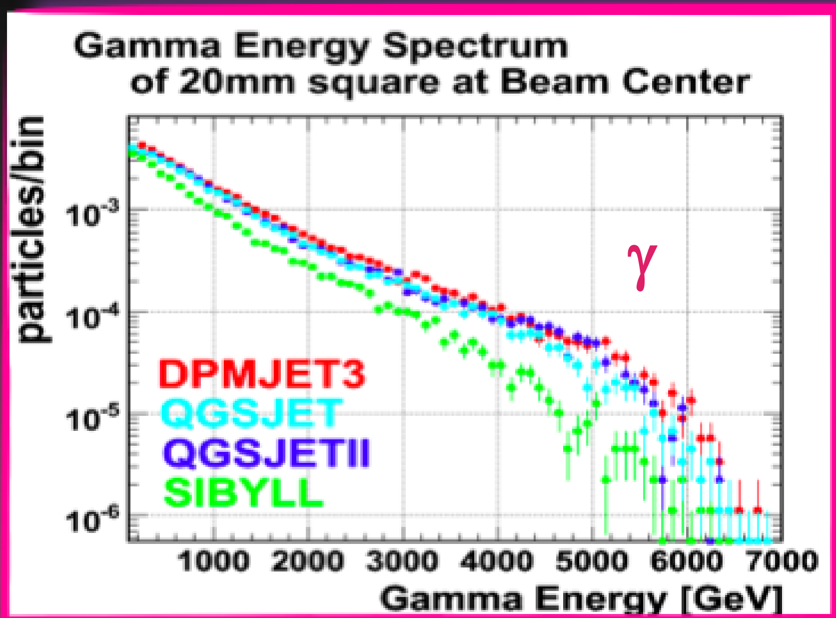
Expected results @ 14 TeV collisions

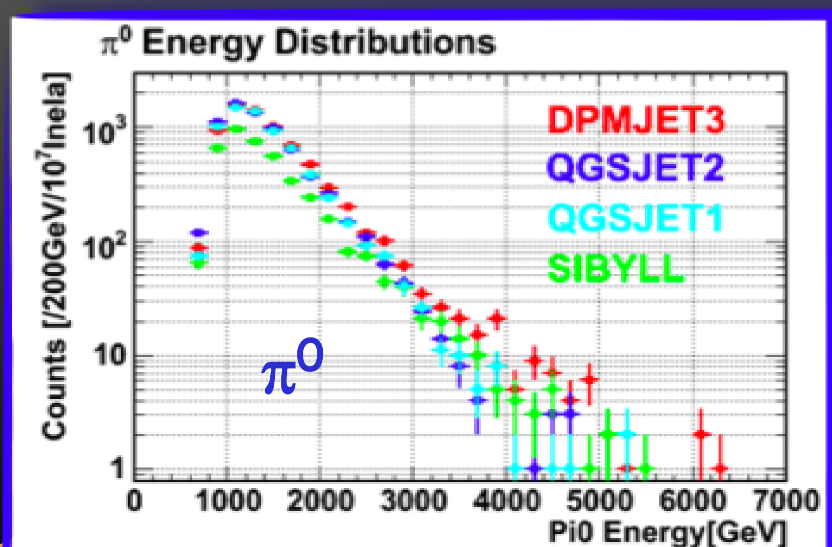
Energy spectra and transverse momentum distribution of:

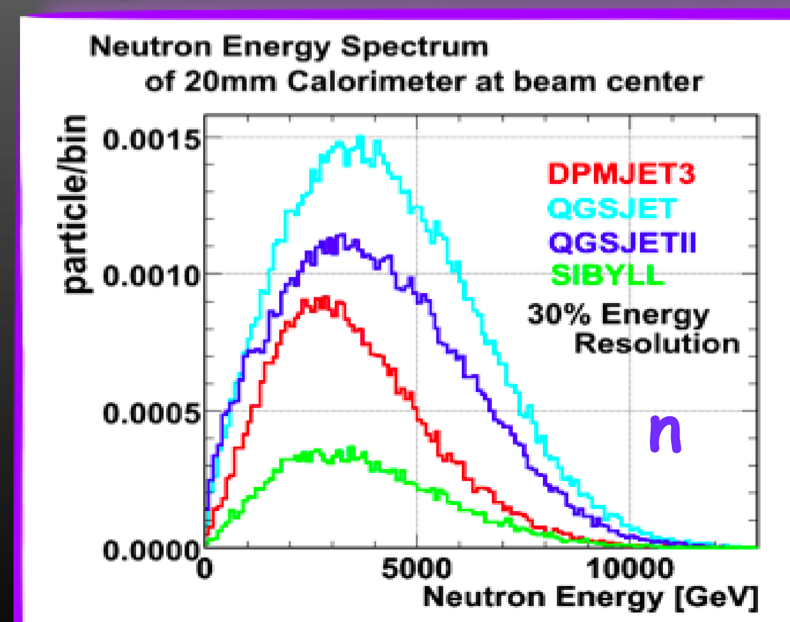
- photons (E > 100 GeV): $\Delta E/E <$ 5%
- neutral pions (E > 500 GeV): $\Delta E/E <$ 3%
- neutrons (E > few 100 GeV): $\Delta E/E \sim$ 30%

in the pseudo-rapidity range $\eta > 8.4$

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







Summary of operations in 2009 and 2010

With Stable Beam at 900 GeV

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

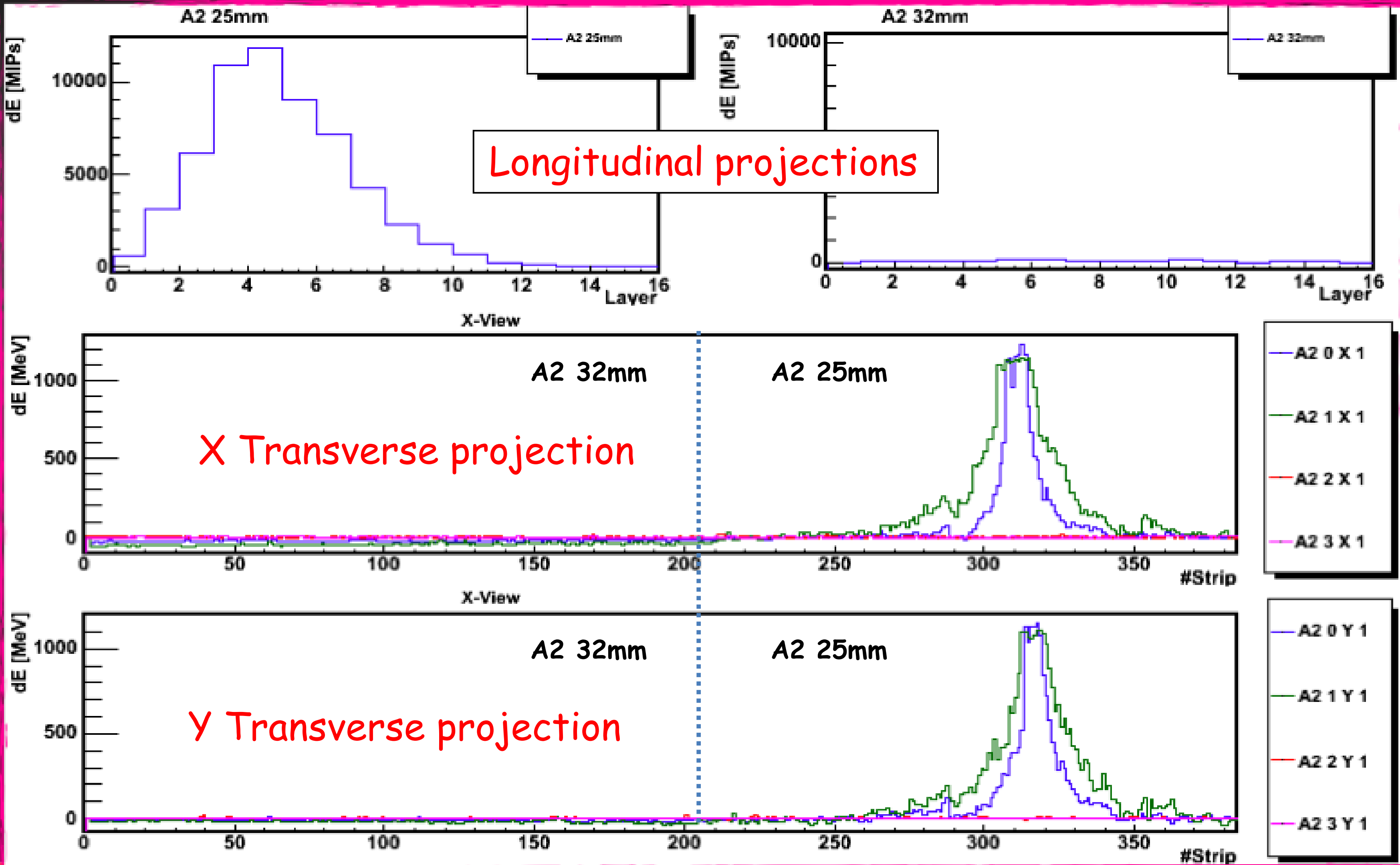
With Stable Beam at 7 TeV

- 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
- ~ $4 \cdot 10^8$ shower events in Arm1+Arm2
- ~ 10^6 π^0 events in Arm1+Arm2

Status

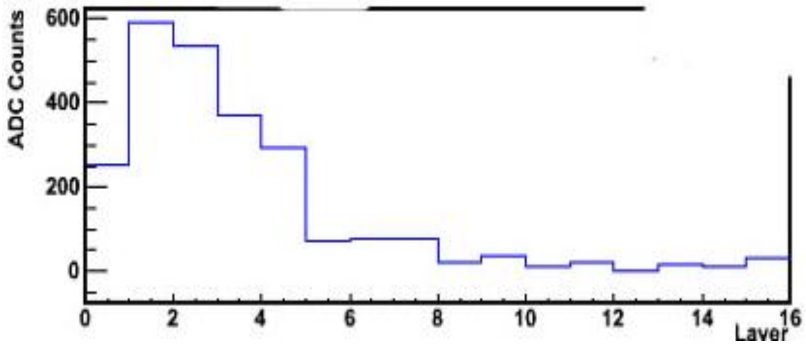
- Completed program for 900 GeV and 7 TeV
  - Removed detectors from tunnel in July 2010
  - Post-calibration beam test in October 2010
- Upgrade to more rad-hard detectors to operate at 14 TeV in 2013

TeV γ rays not from Crab but… …underground!



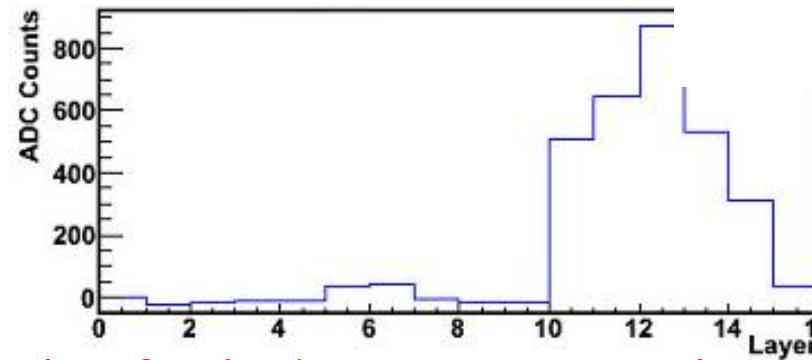
Particle identification

Typical transition curve for γ rays

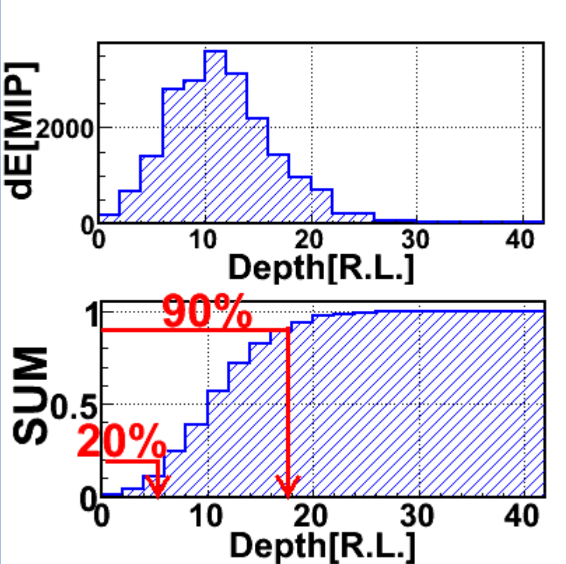


Thick for E.M. interaction ($44X_0$)

Typical transition curve for hadrons

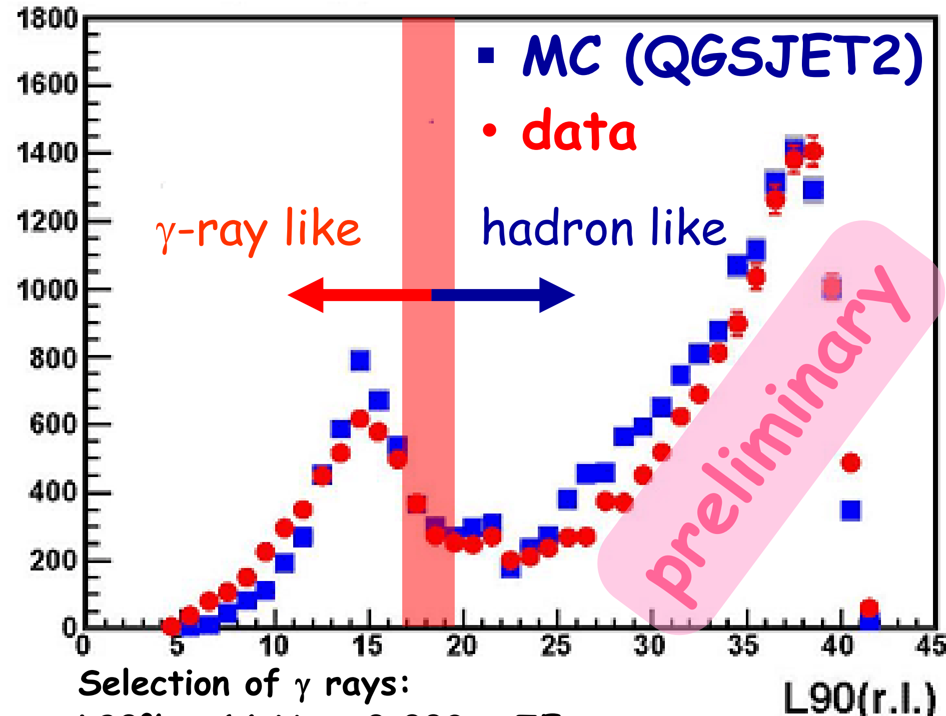


Thin for hadronic interaction(1.7λ)



L90% @ 40 mm cal. of Arm1

Definition of L90%

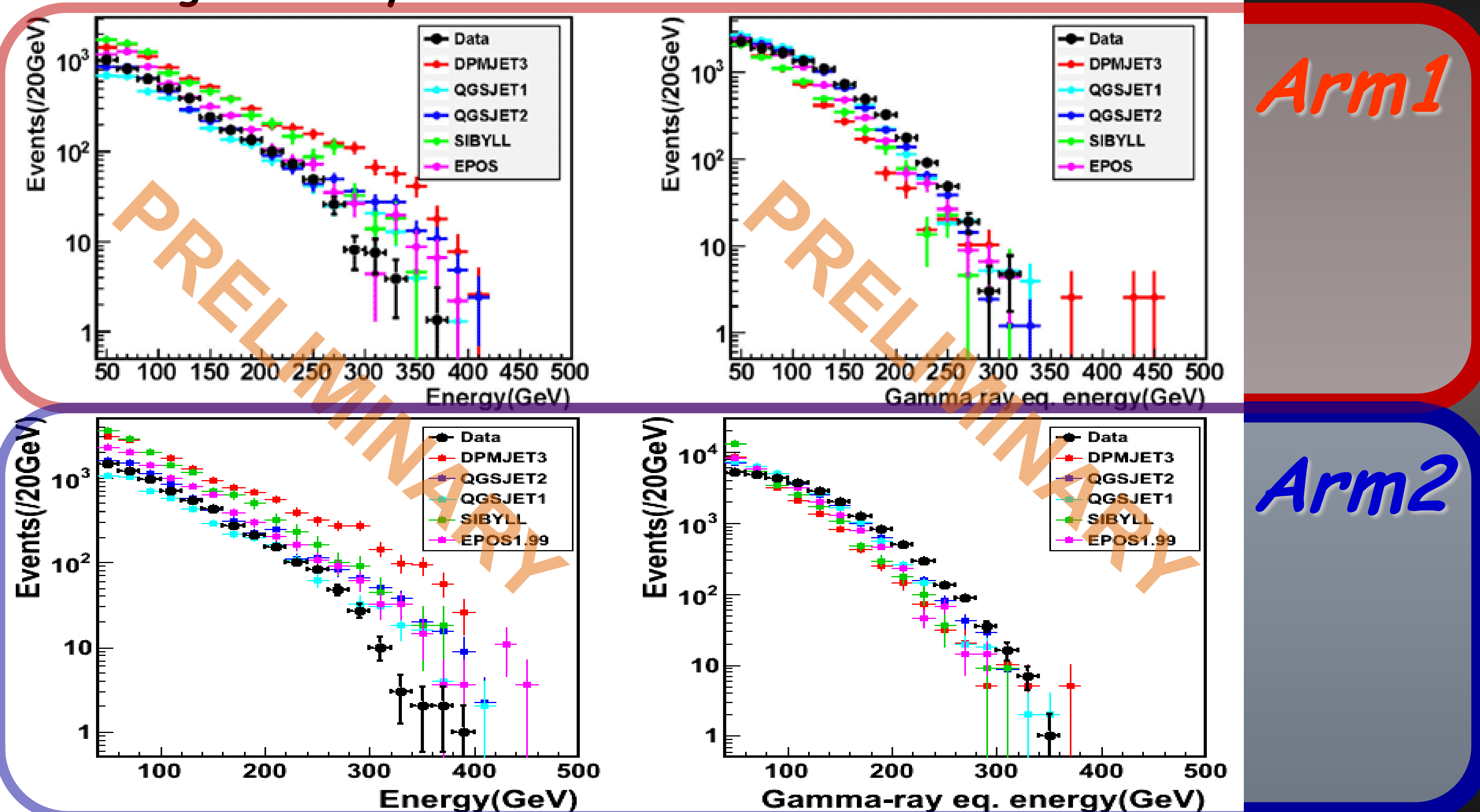


Selection of γ rays:
L90% < $16\ X_0 + 0.002 \times \Sigma E_r$

- L90% is the longitudinal position containing 90% of the shower energy
- PID study is still ongoing (use of neural networks is under investigation)

Energy spectra at 900 GeV

gamma-ray like | hadron like

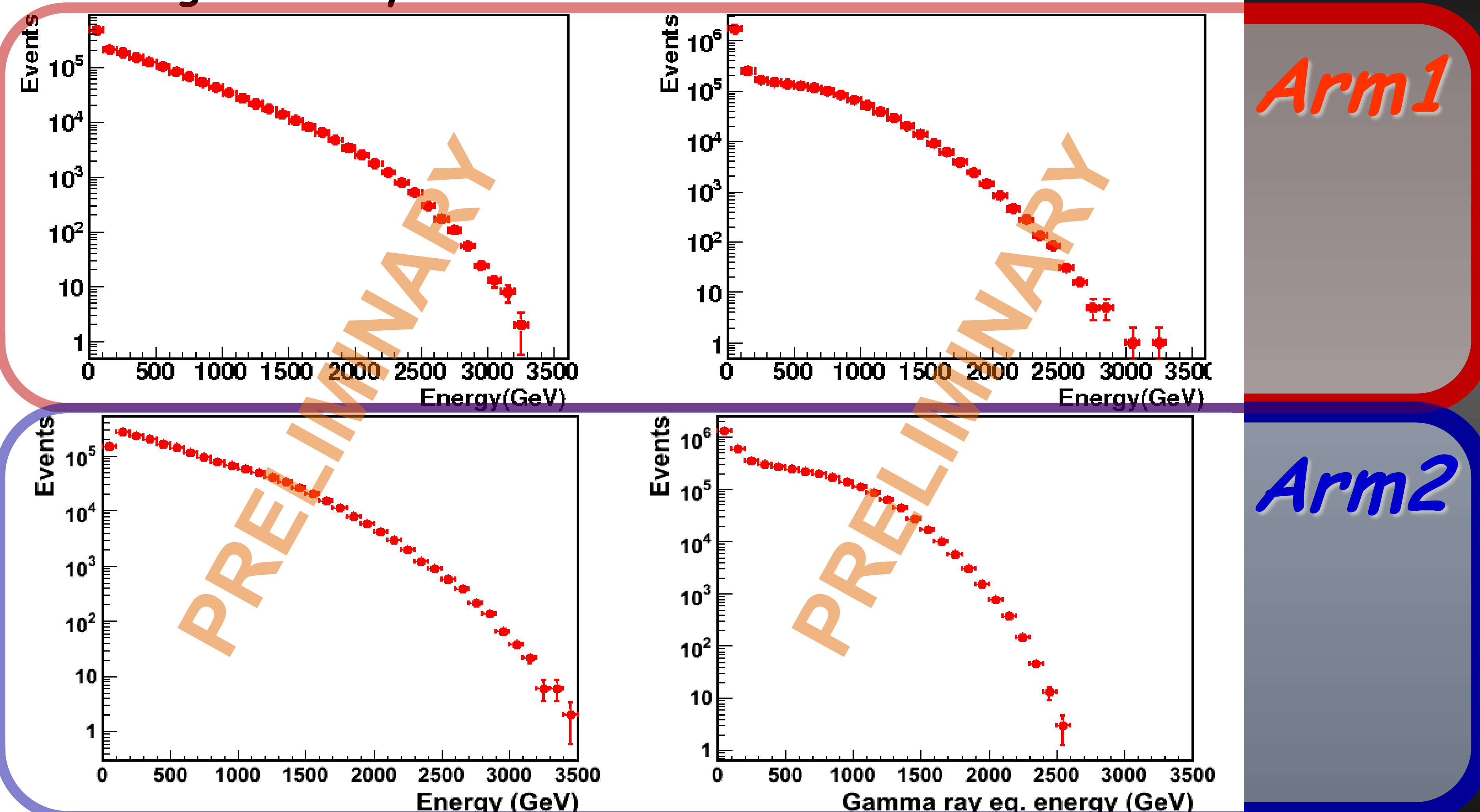


Acceptance is different for the two arms.
Spectra are normalized by # of γ-ray and hadron like events.
Response for hadrons and systematic errors are under study.

Only statistical errors are shown

Energy spectra at 7 TeV

gamma-ray like **hadron like**

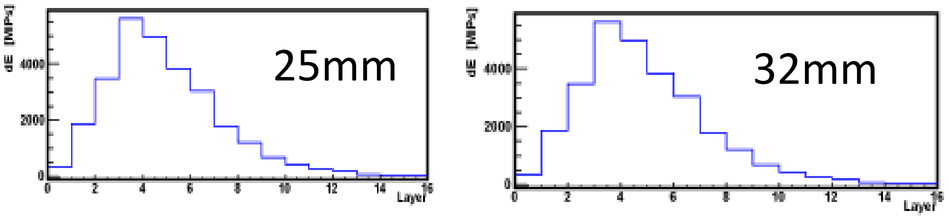


Very high statistics: only 2% of data is shown here.
Comparison with MC is under development

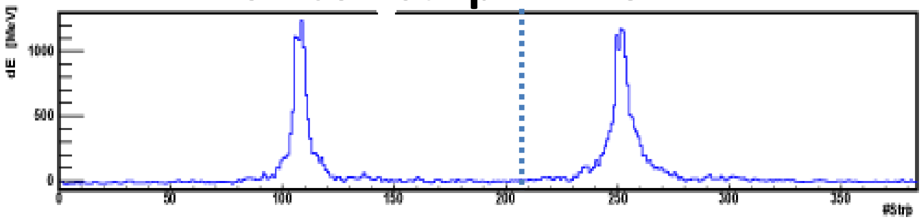
Only statistical errors are shown

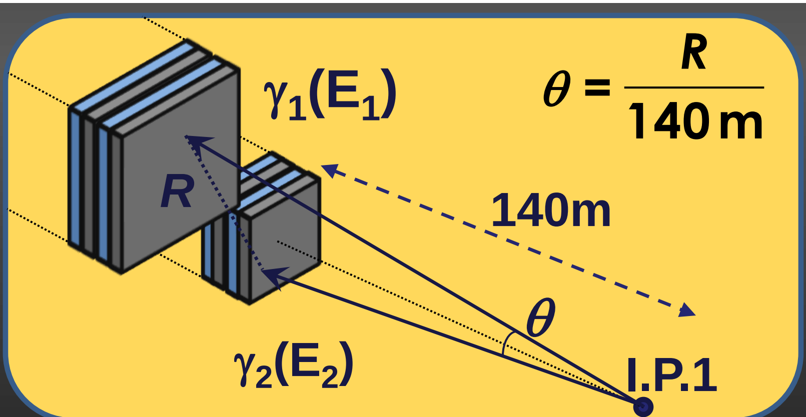
Neutral pions

An example of event (Arm2)



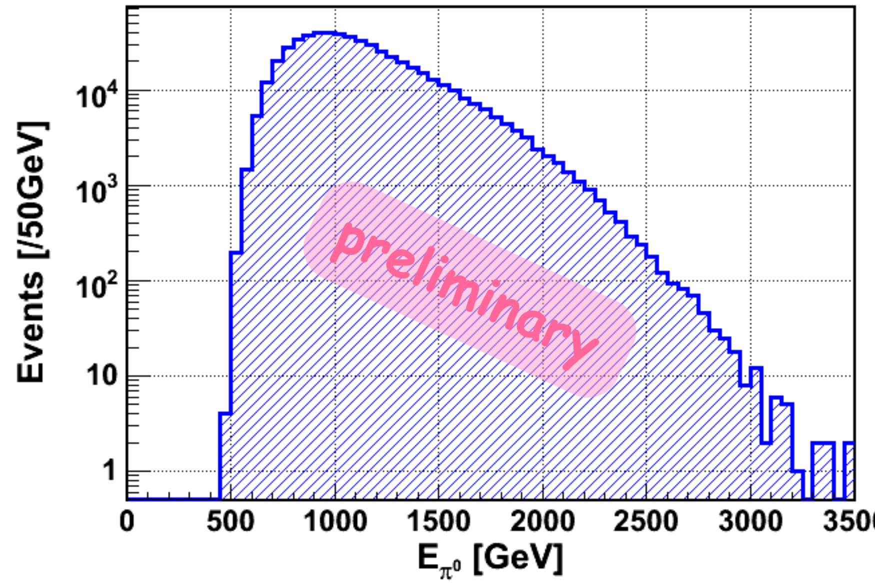
Silicon strip - X view



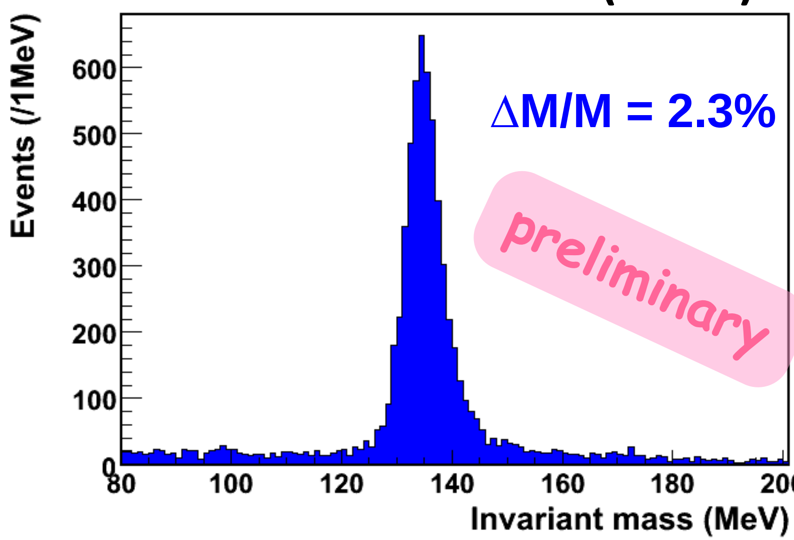


- π^0s are a main source of electromagnetic secondaries in high energy collisions
- the mass peak is very useful to confirm the detector performances and to estimate the systematic error of energy scale calibration

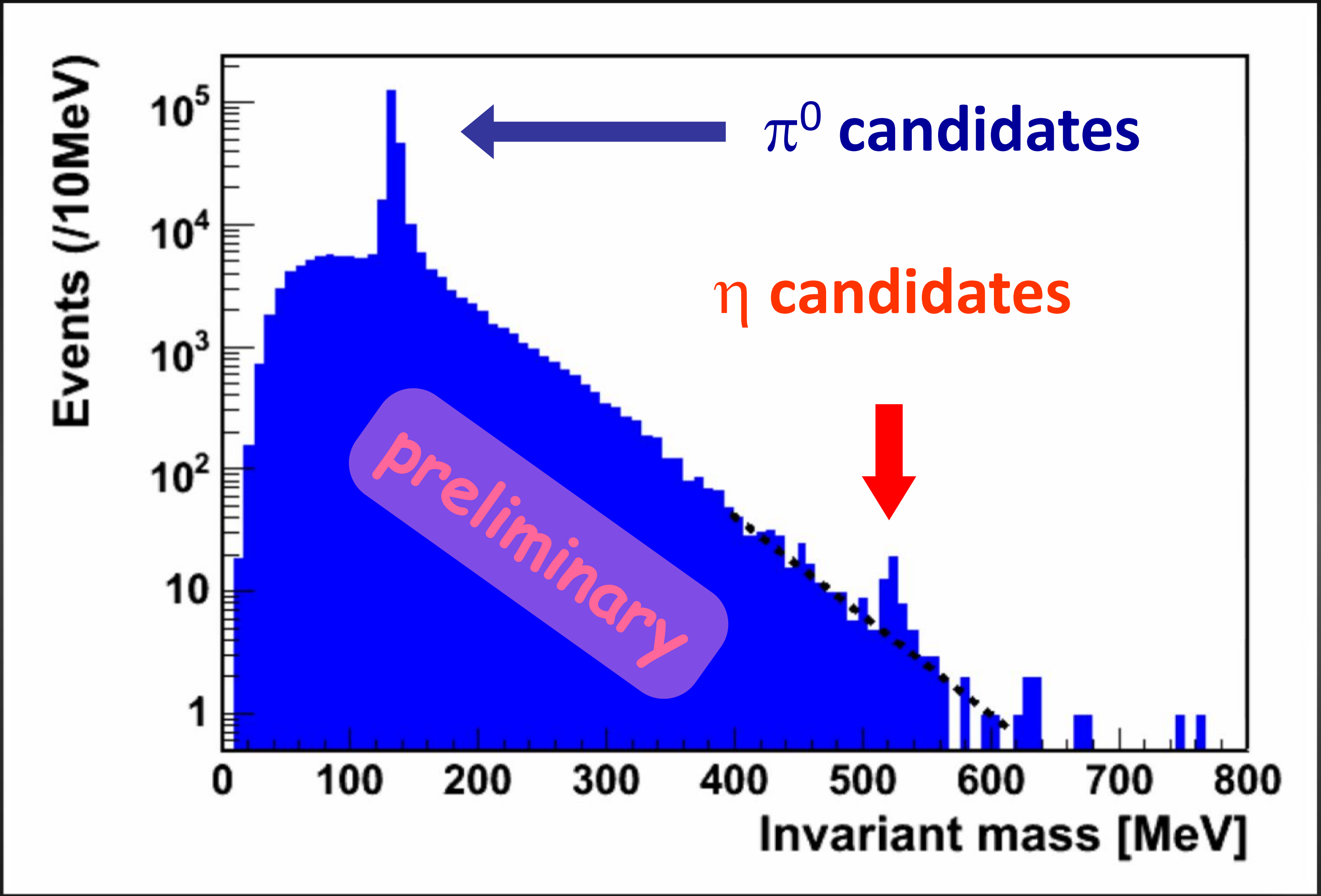
Energy spectrum (Arm2)



Reconstructed mass (Arm2)

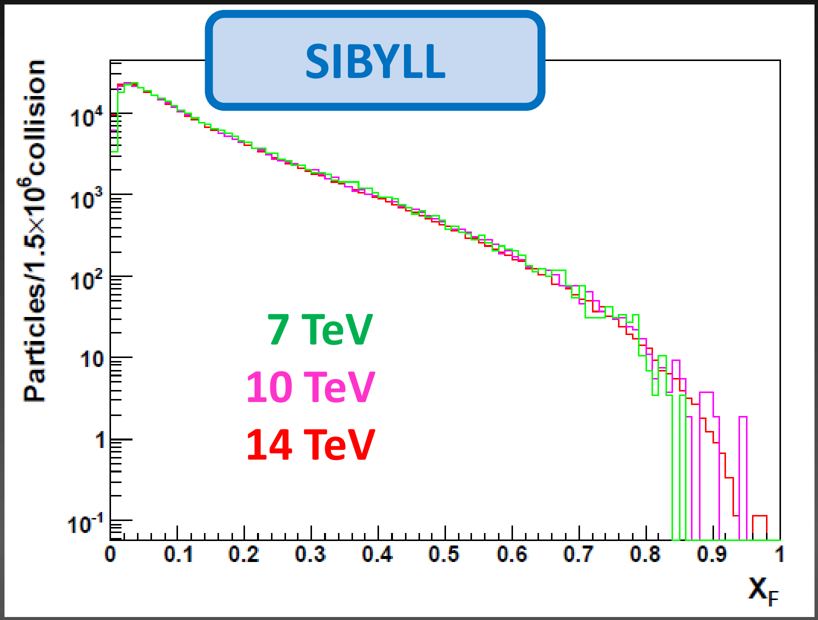


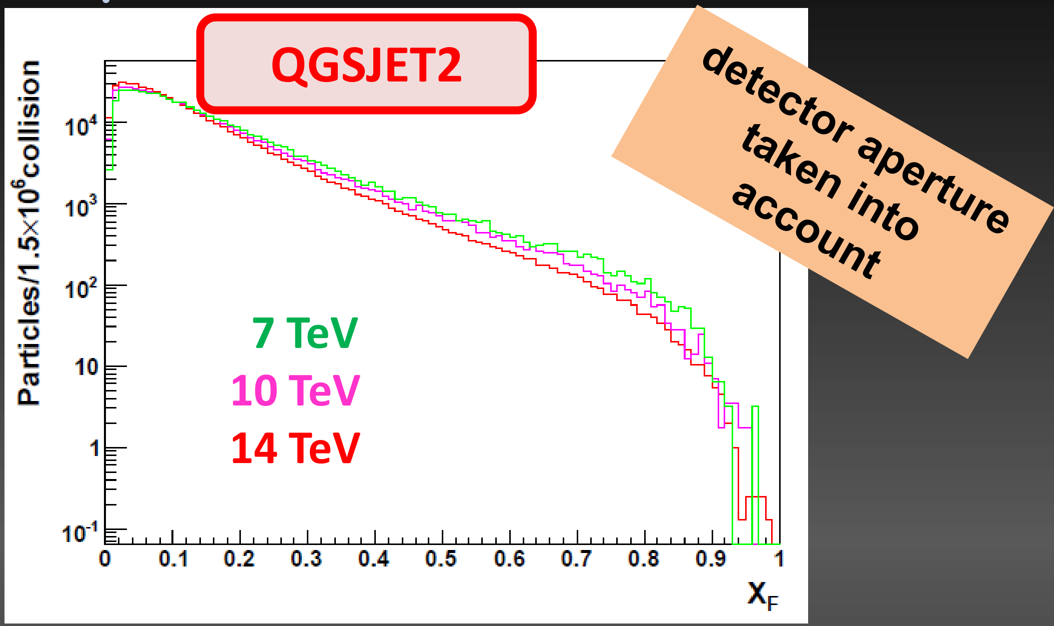
2γ invariant mass spectrum @ 7 TeV

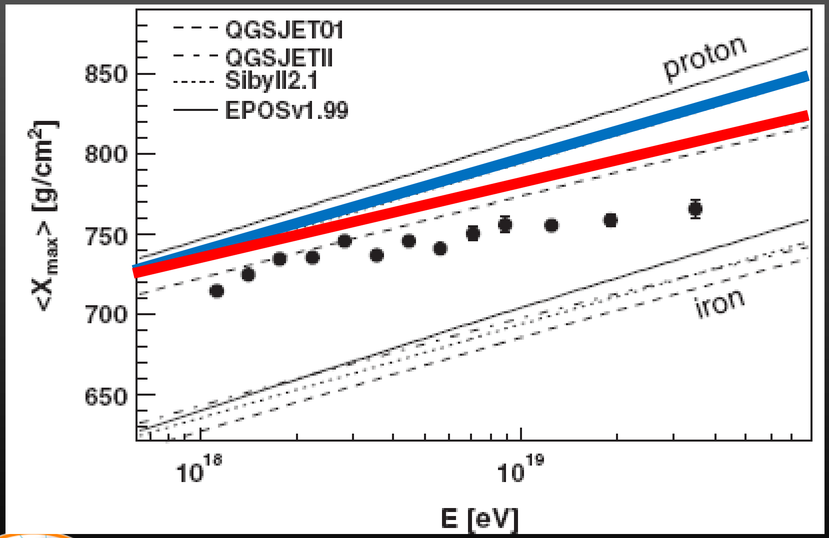


- The search for η particles is an important tool for discriminating hadronic interaction models, because their spectra differ from model to model
- Important tool also for energy scale calibration

14 TeV in 2013: not only the highest energy, but energy dependence too!







- Secondary gamma-ray spectra in p-p collisions at different collision energies (normalized to the maximum energy)
- SIBYLL predicts perfect scaling while QGSJET2 predicts softening at higher energy

Schedule and future plan

2010, Oct	**Beam test** at SPS to confirm the radiation damage and the performance
end of 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 for **operation at 14 TeV**

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 p-p interactions in the very forward region of IP1 (at $\eta > 8.4$)

- 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

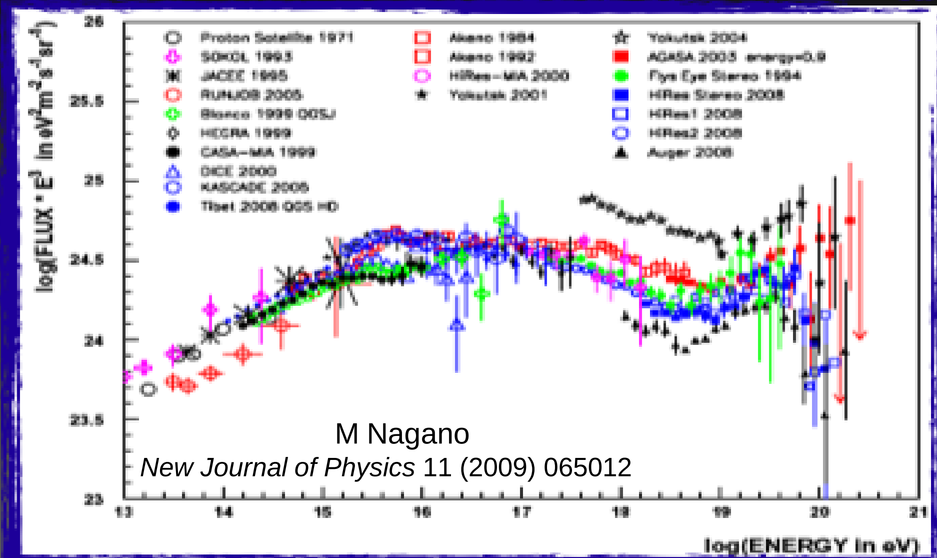
- LHCf successfully completed operations at 900 GeV and at 7 TeV; the detectors have been removed from the LHC tunnel on 21st July 2010

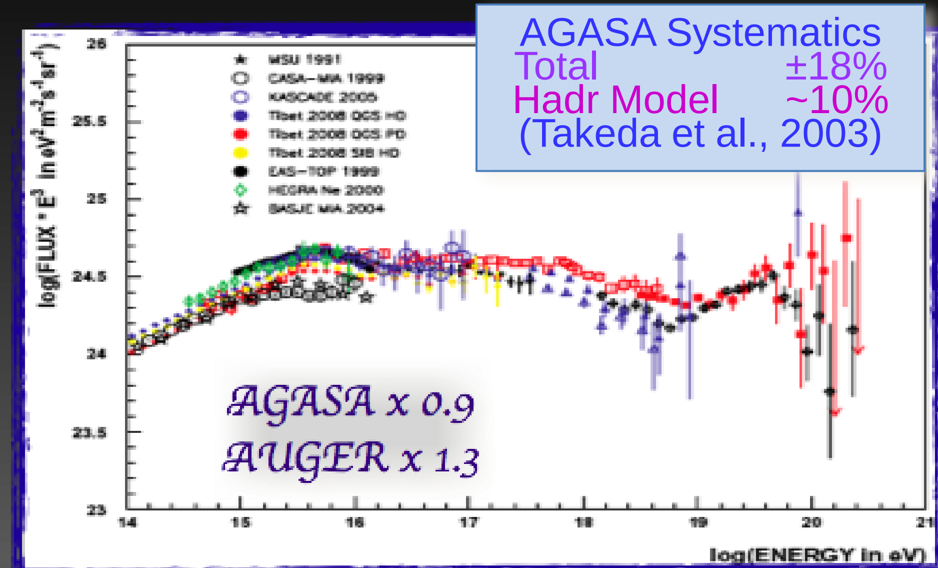
- Analysis of data at 900 GeV is almost completed; we will finalize analysis at 7 TeV before the end of this year

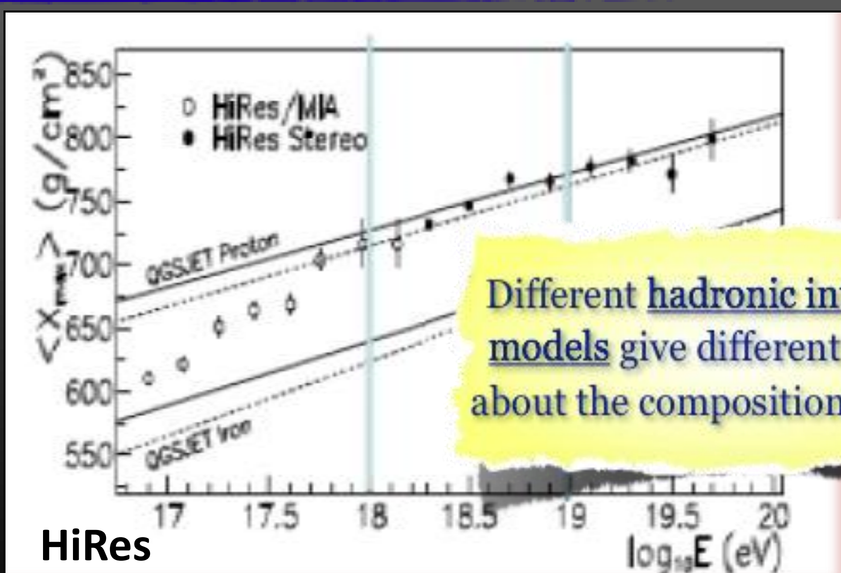
- Detectors will be upgraded in 2011-2012 for radiation hardness and will be re-installed for data taking at 7 TeV + 7 TeV in 2013

Backup

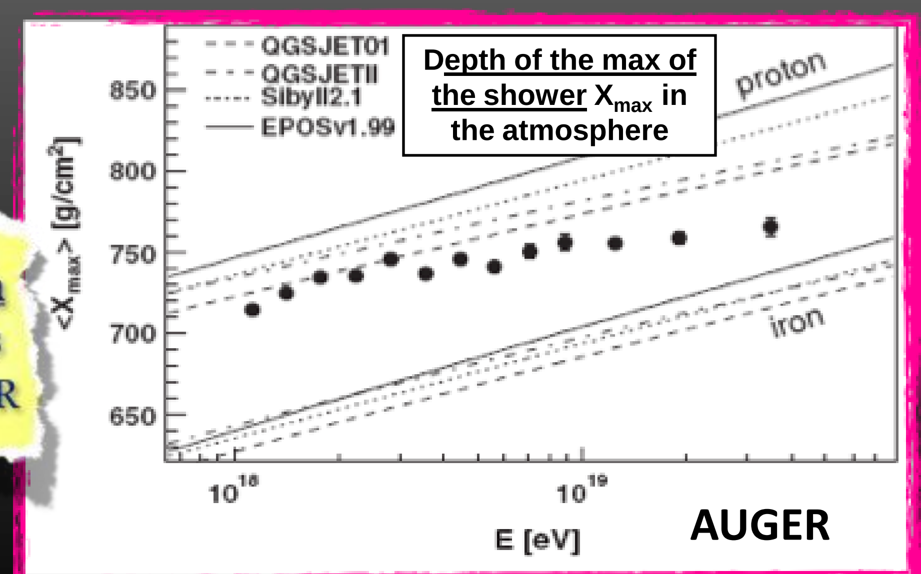
Open Issues on UHECR spectrum

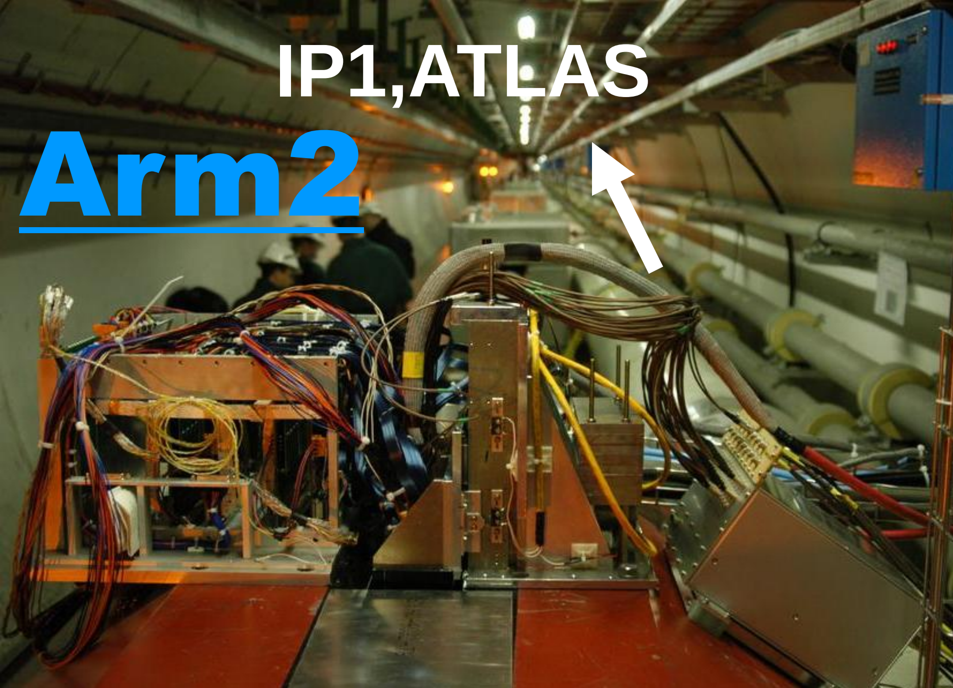


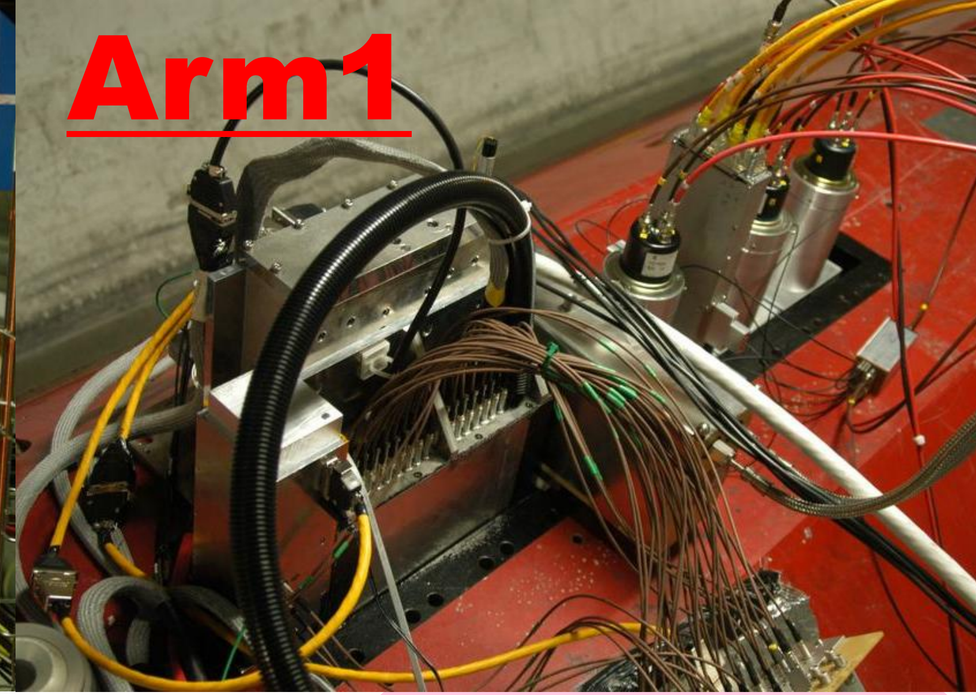


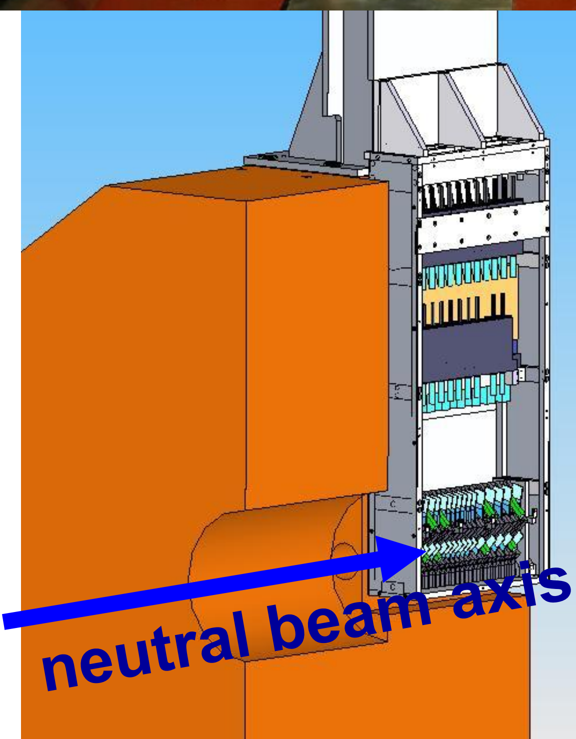


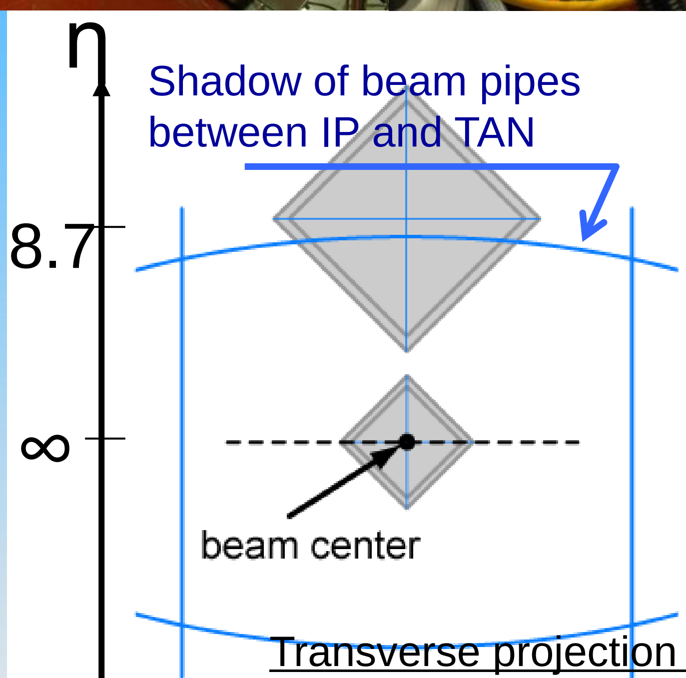
Different hadronic interaction models give different answers about the composition of HECR





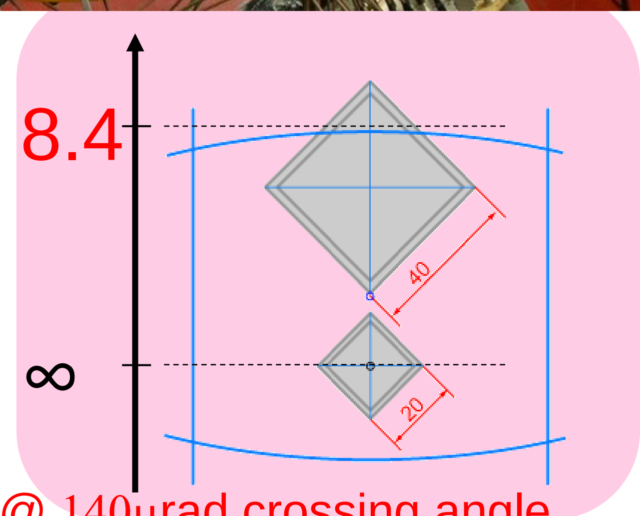






Transverse projection of Arm#1

@ zero crossing angle



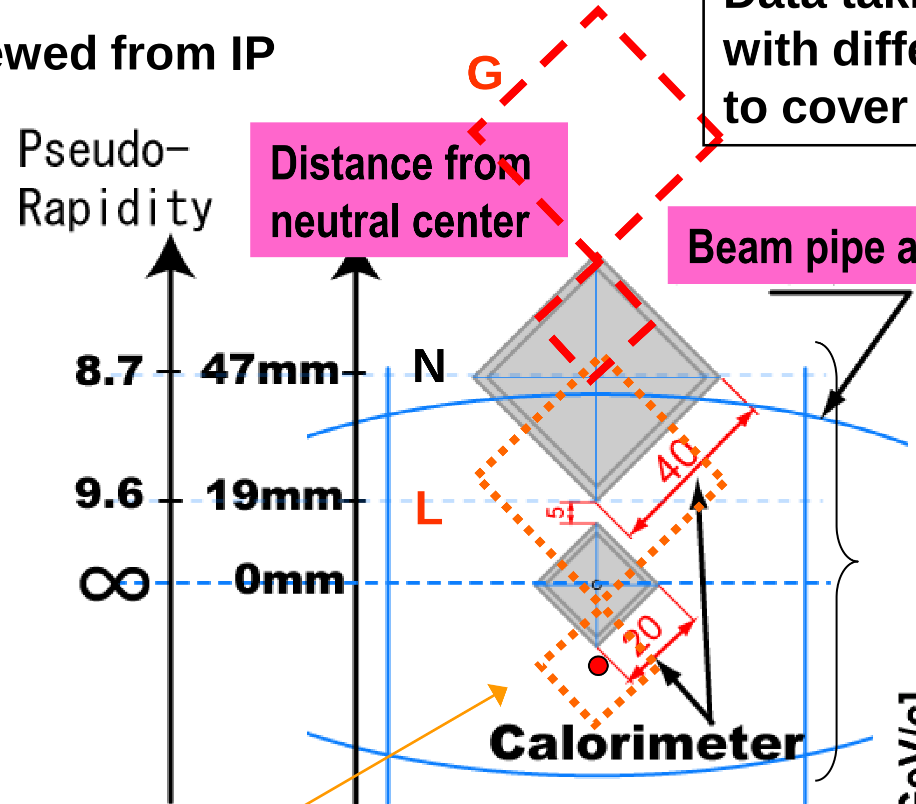
@ 140μrad crossing angle

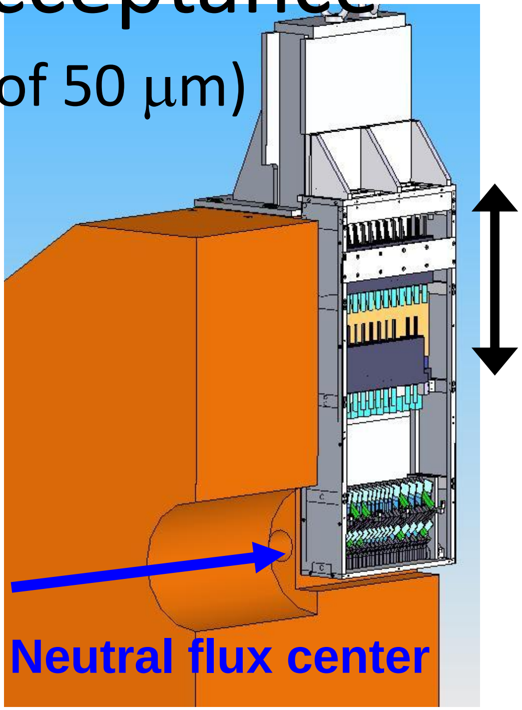
Detector vertical position and acceptance

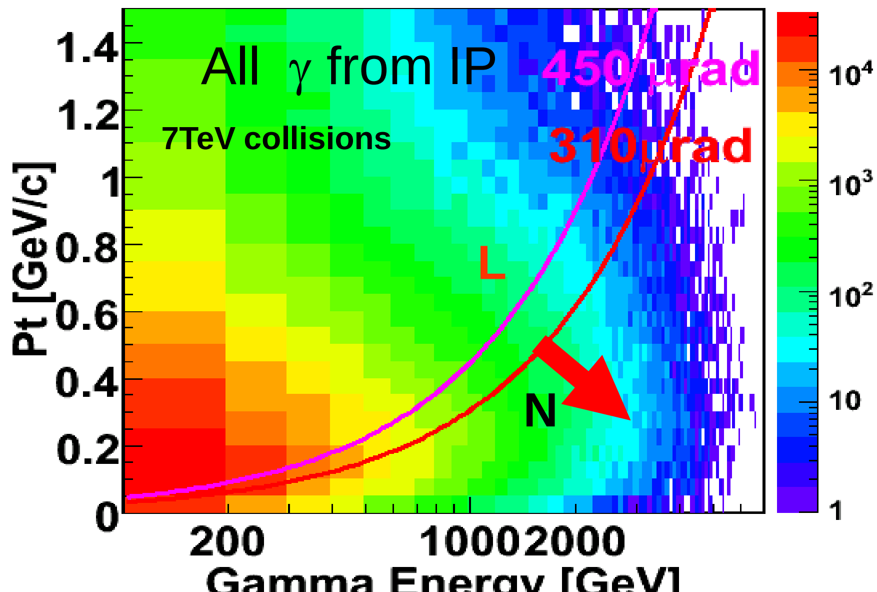
Remotely changed by a manipulator(with accuracy of 50 μm)

Viewed from IP

Data taking mode with different position to cover P_T gap

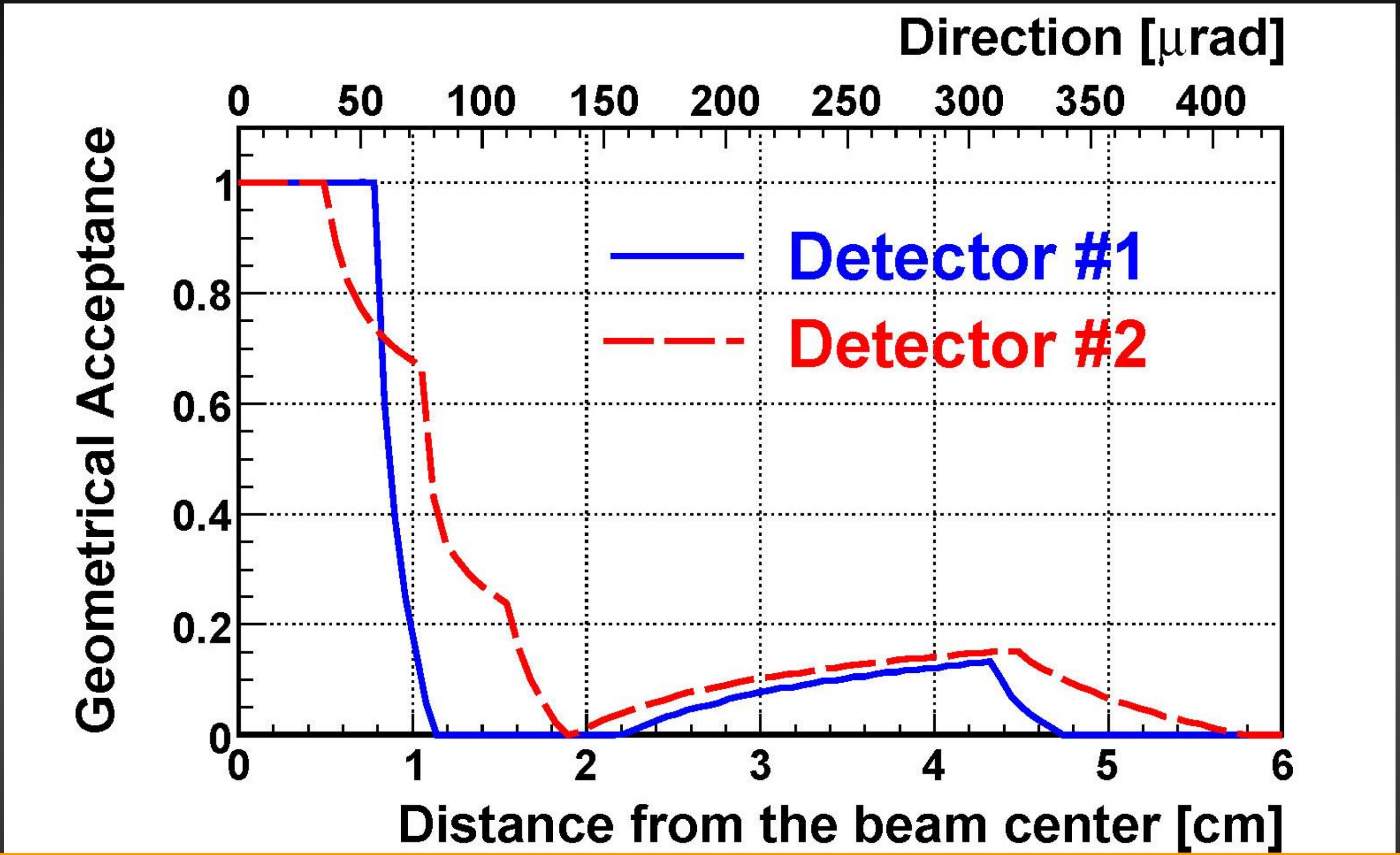






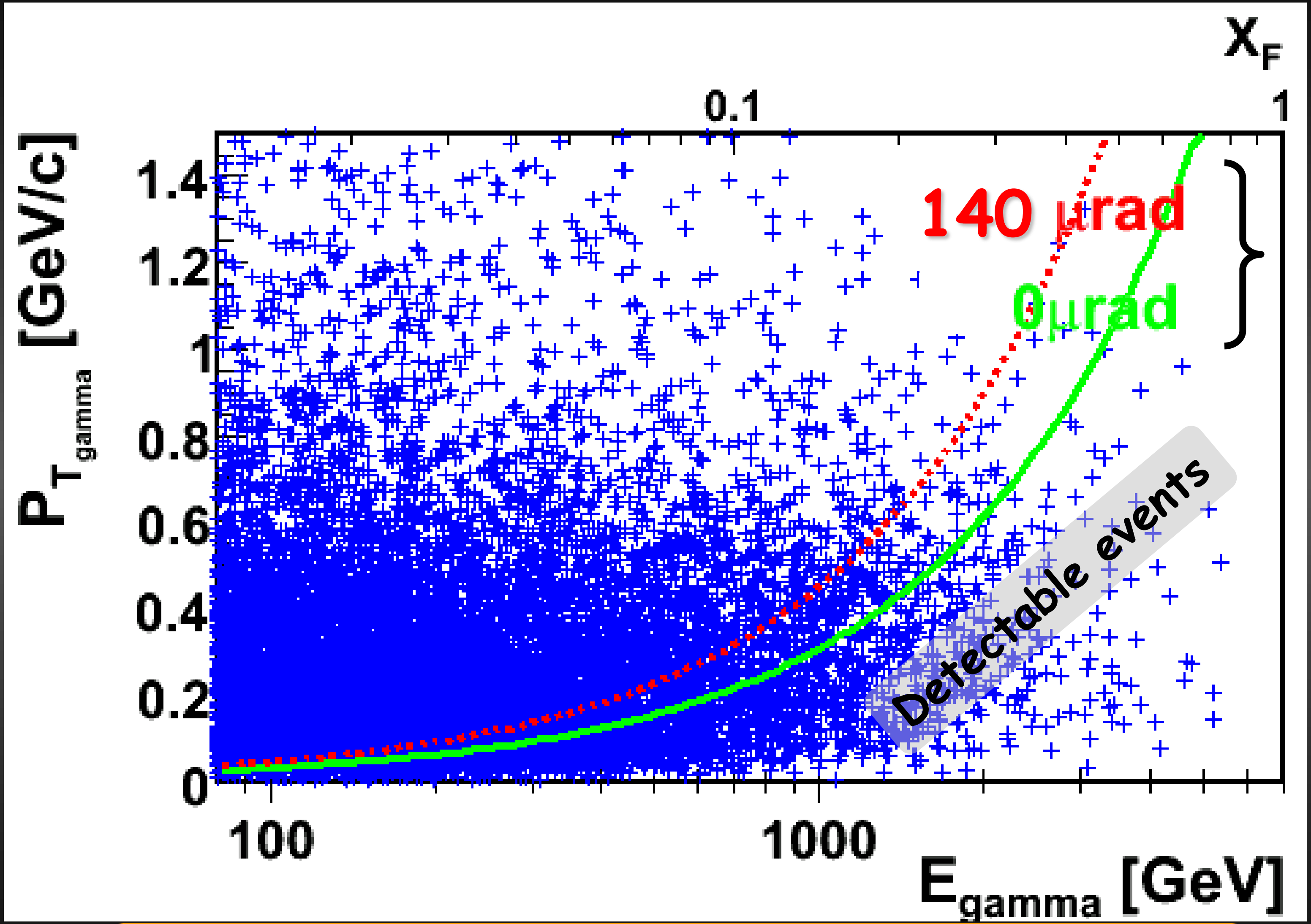
Collisions with a crossing angle lower the neutral flux center thus enlarging P_t acceptance

LHCf single γ geometrical acceptance



Mechanical manipulators allows to remotely move LHCf: some runs with the detectors vertically shifted few cm allow to cover the whole kinematical range

LHCf acceptance on $P_{T\gamma}$-E_γ plane



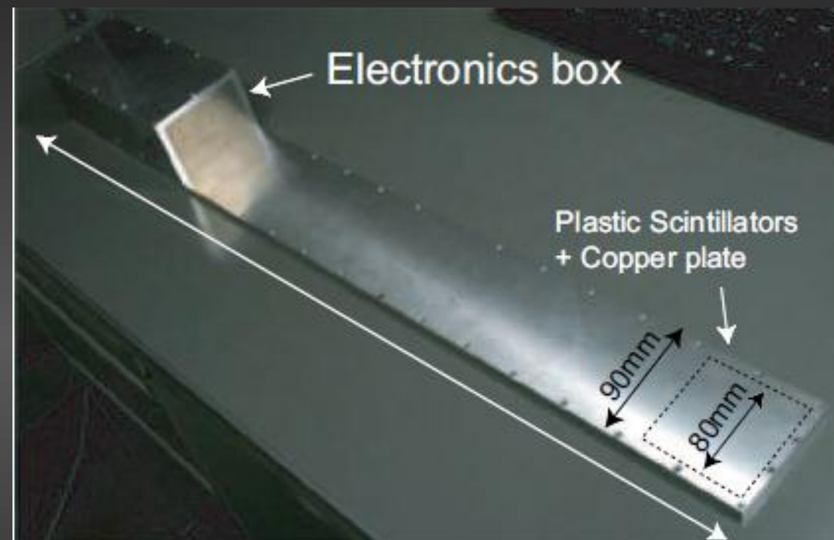
Beam crossing angle

A vertical beam crossing angle > 0
increases the acceptance of LHCf

Front counters

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

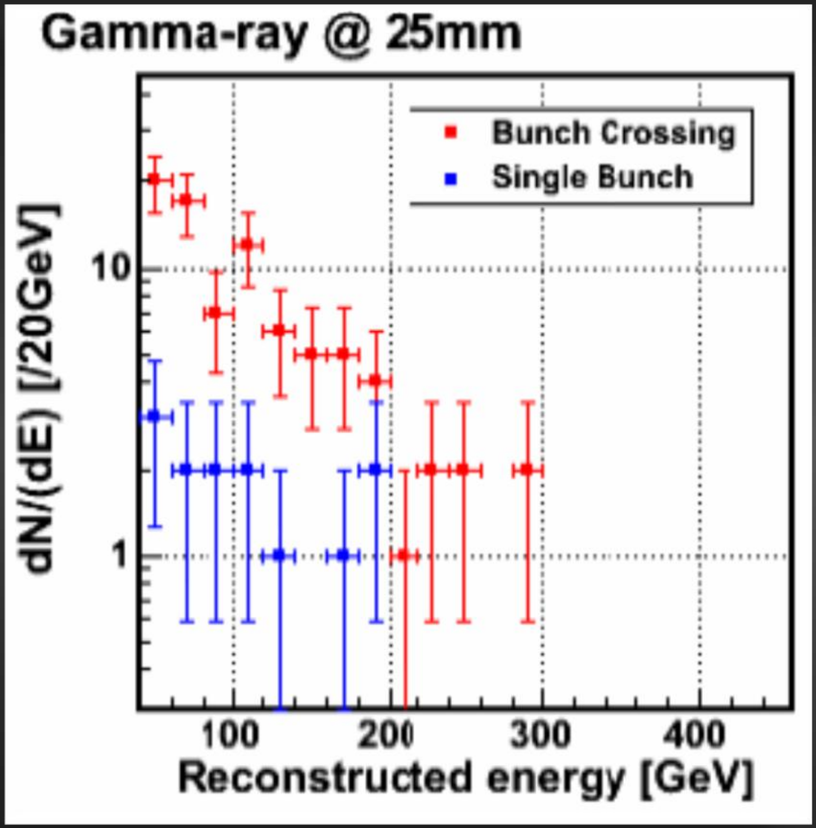
<u>Schematic view of Front counter</u>



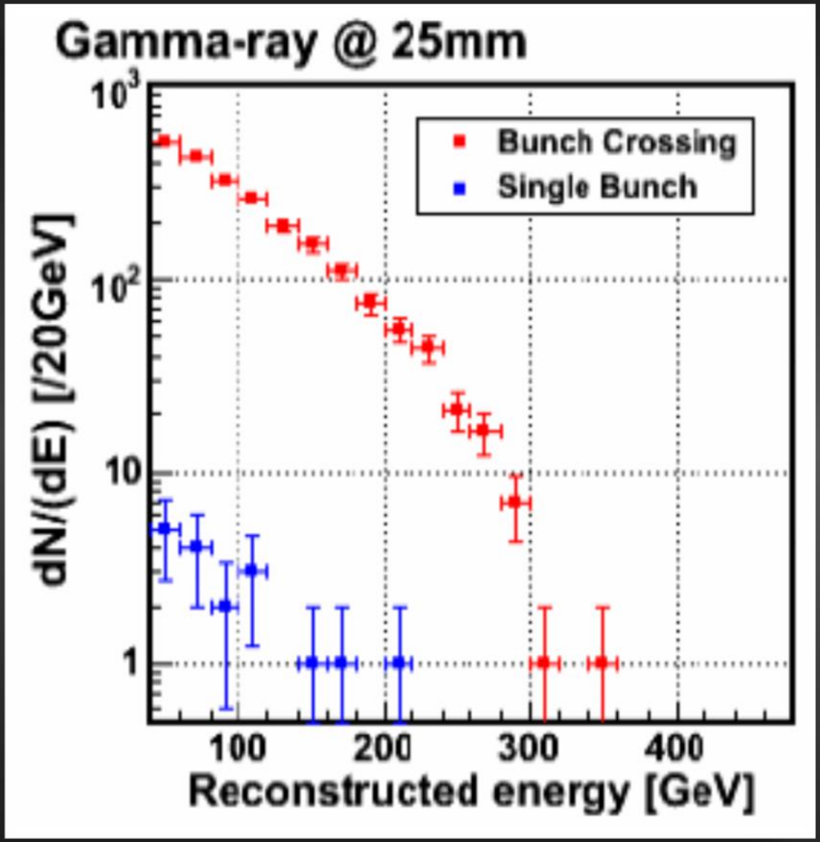
- **To monitor beam condition.**
- **For background rejection of beam-residual gas collisions by coincidence analysis**

Beam-gas backgroud @ 900 GeV

2009

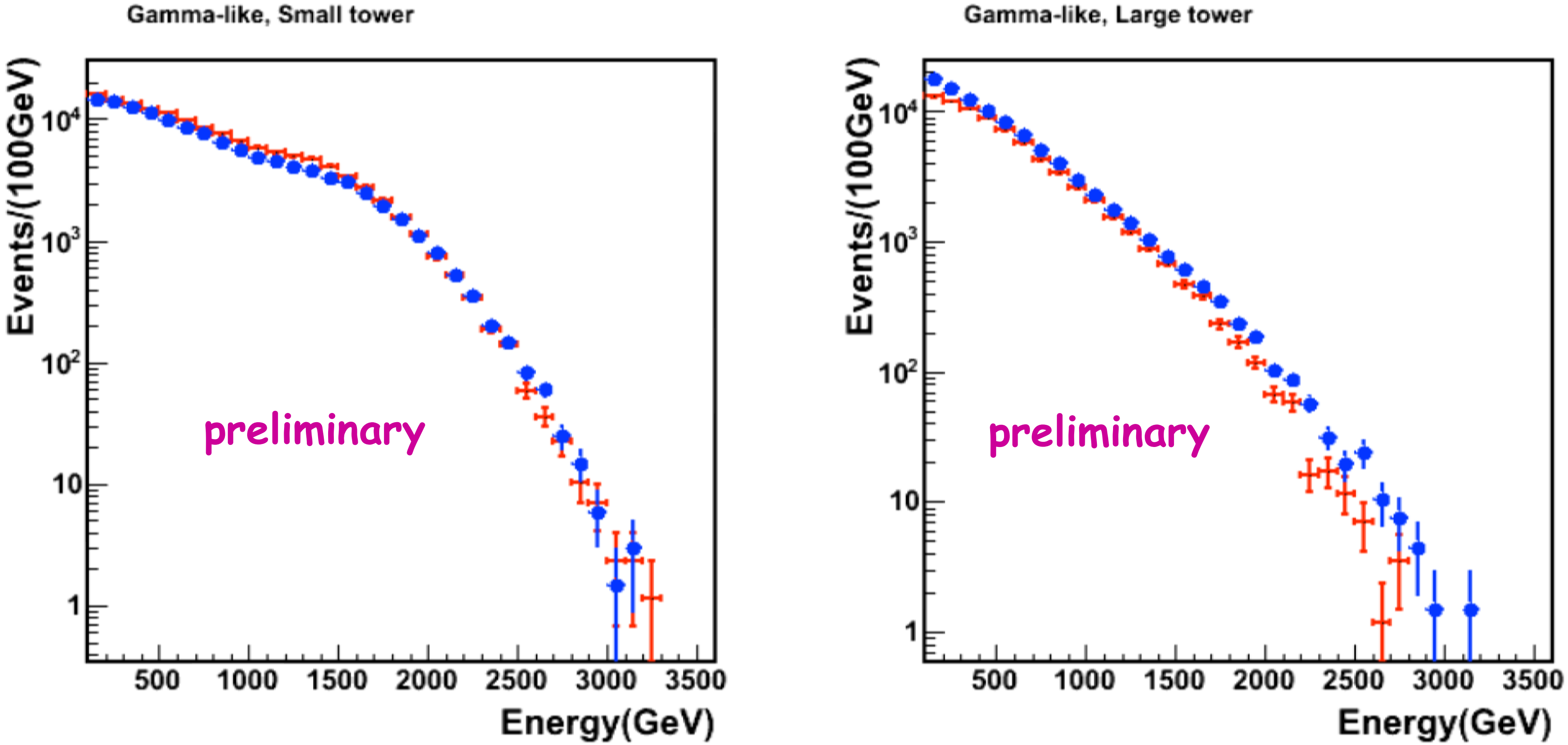


2010



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

Comparison of Arm1 and Arm2 @ 7 TeV



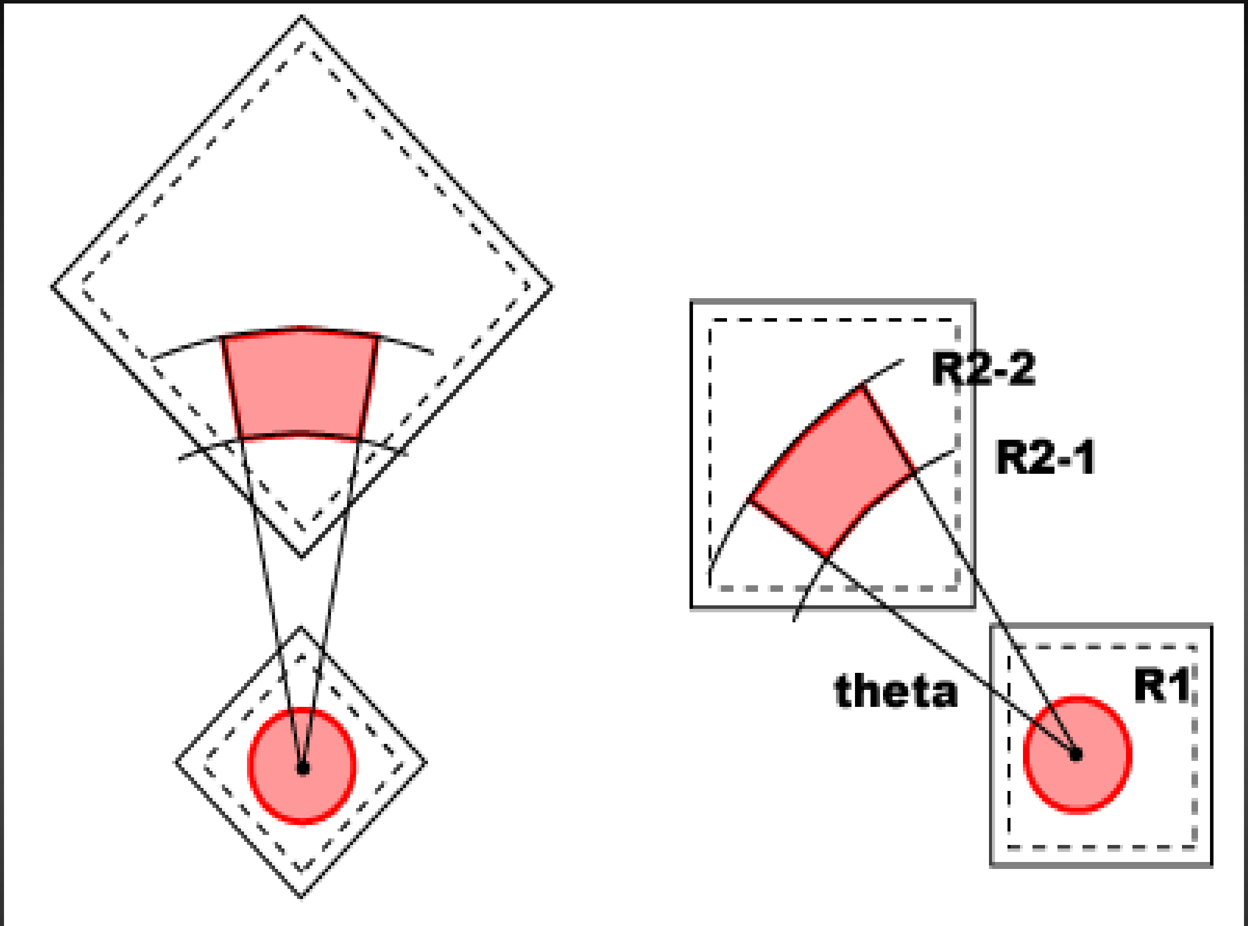
Red : Arm1 **Blue** : Arm2

Same runs, same conditions, common rapidity region selected.

Spectra corrected for the live time of detectors.

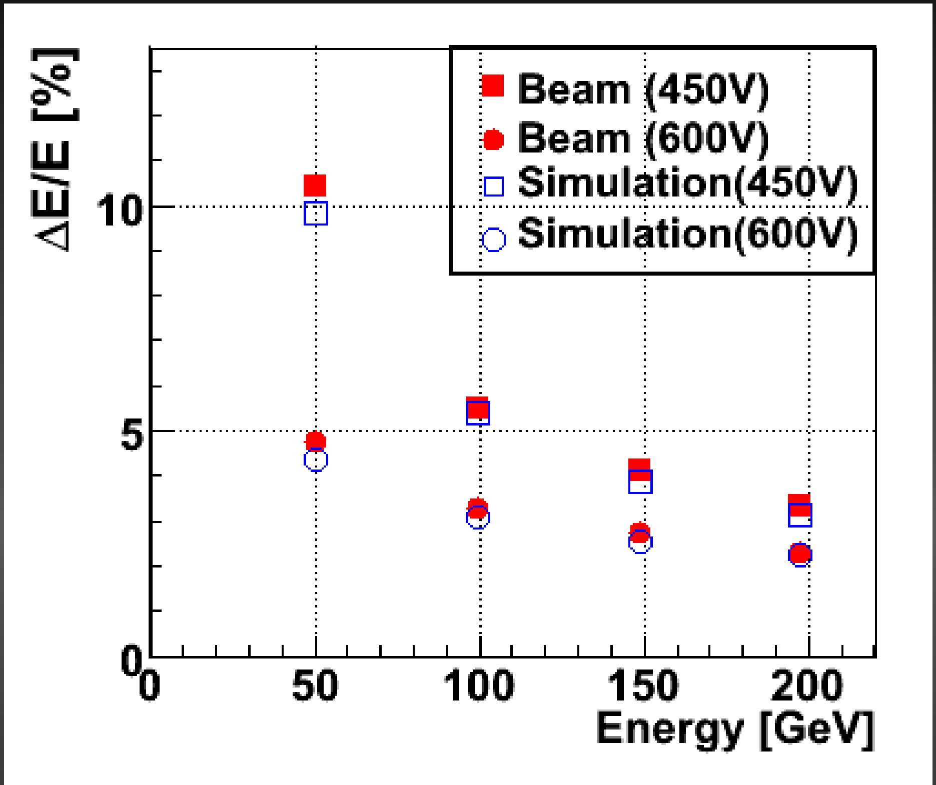
Selection of rapidity region (comparison Arm1/2)

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

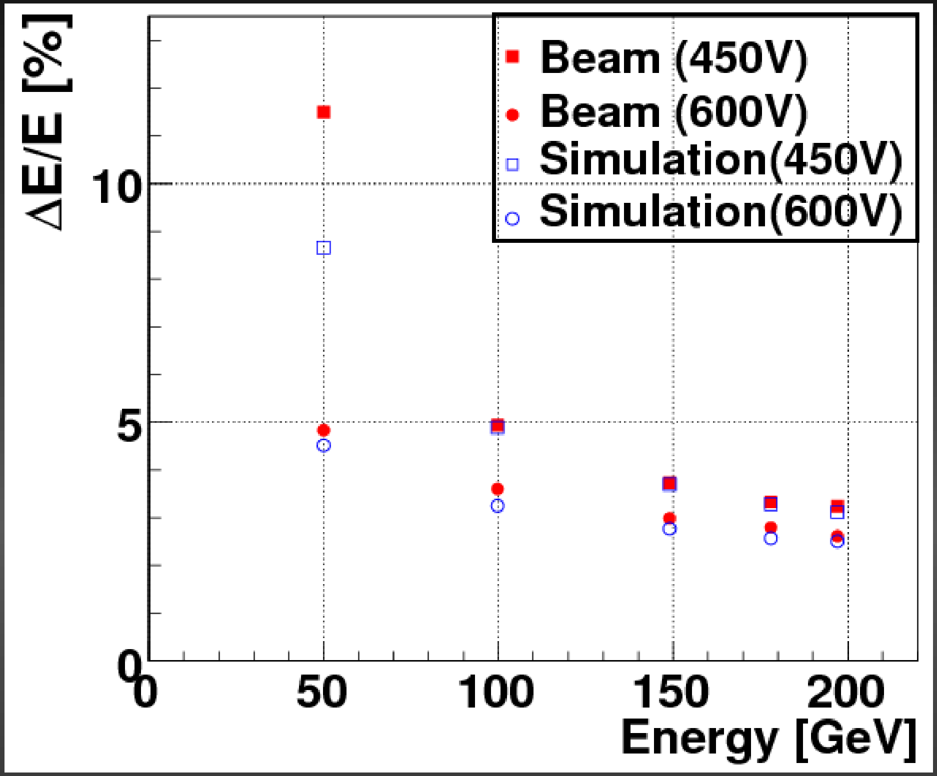


Both Arm1 and Arm2 cover the same rapidity area in small and large tower. Here the beam center is determined by our measurements.

LHCf energy resolution



2.5 x 2.5 cm² tower

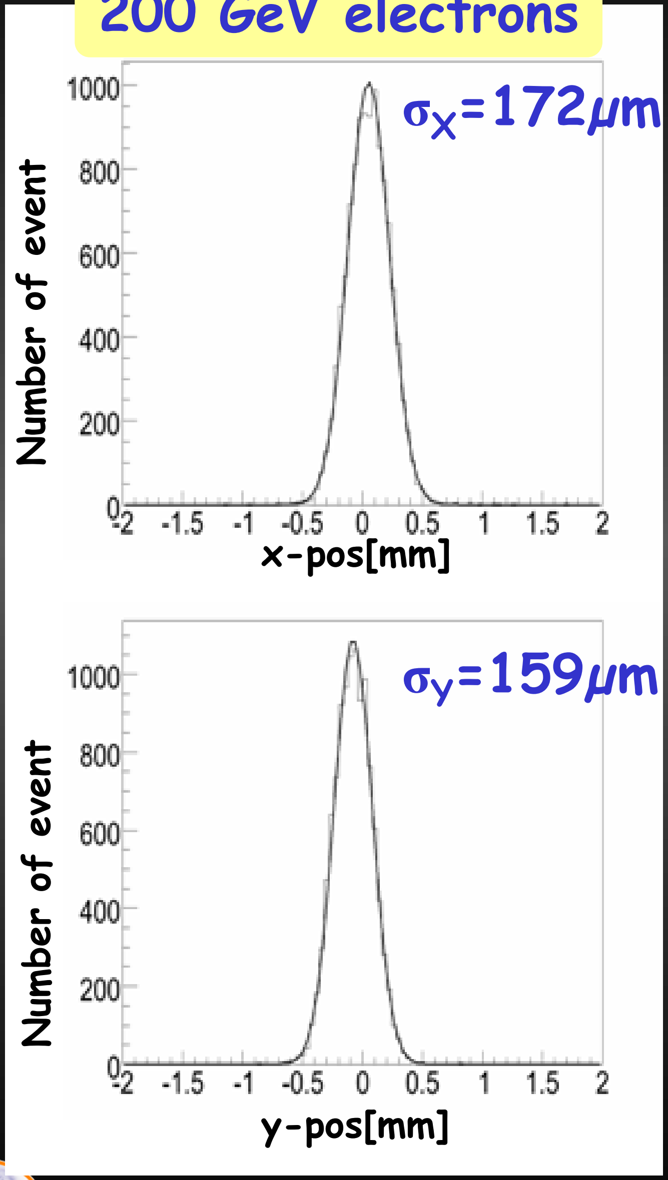


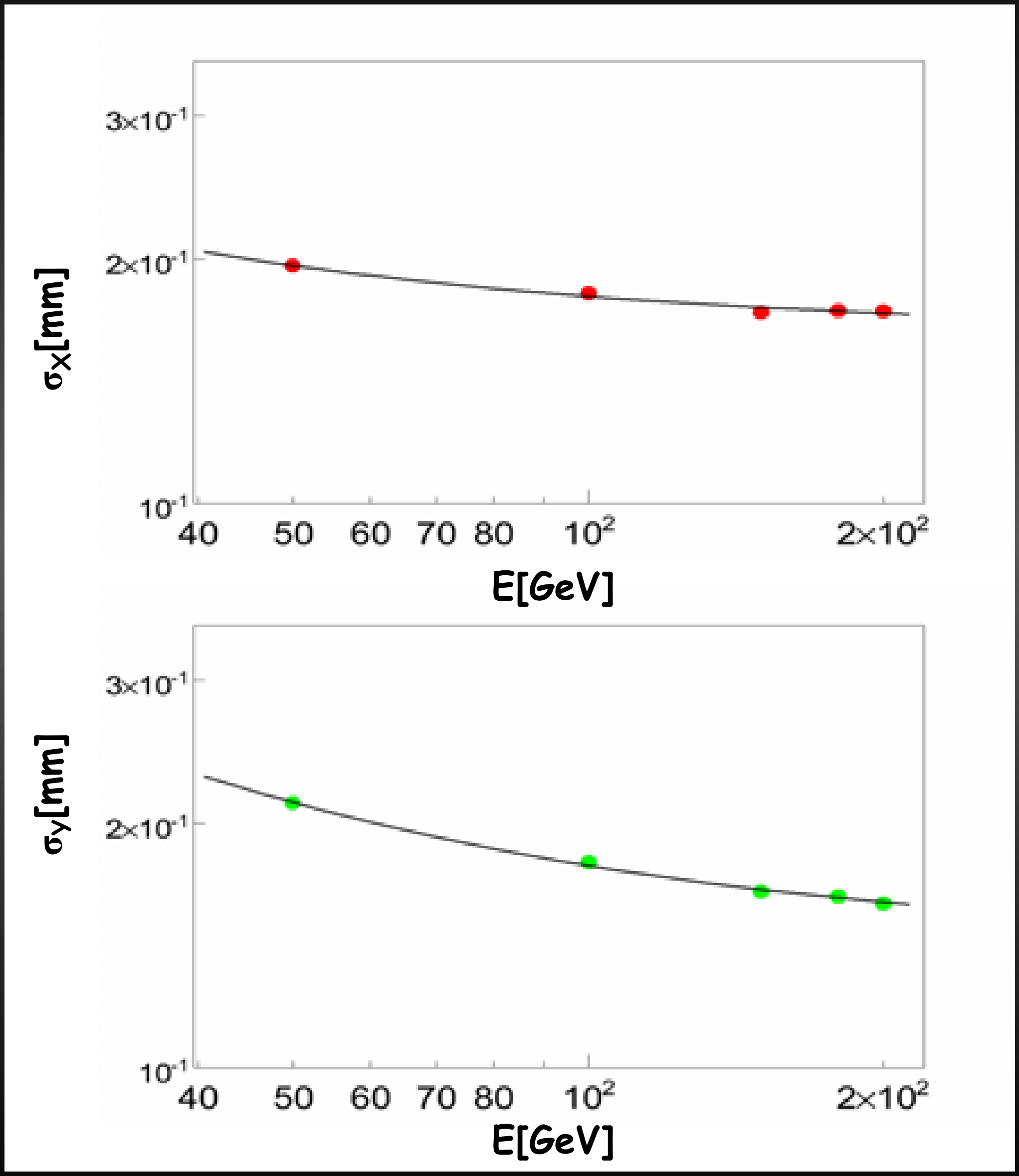
2.0 x 2.0 cm² tower

Energy resolution < 5% at high energy, even for the smallest tower

Arm1 position resolution

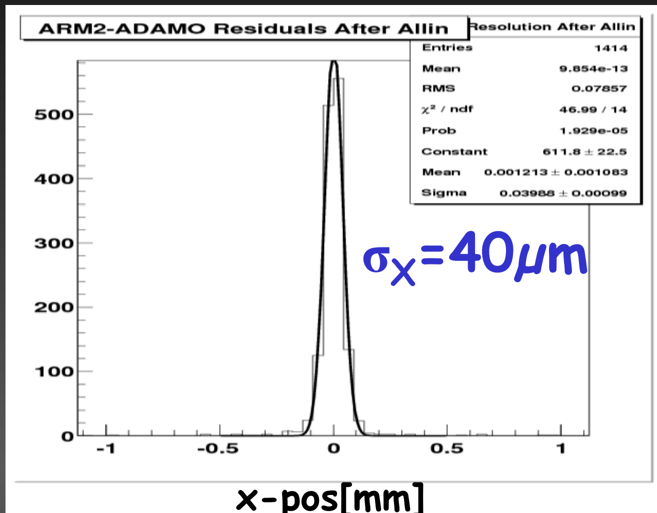
200 GeV electrons

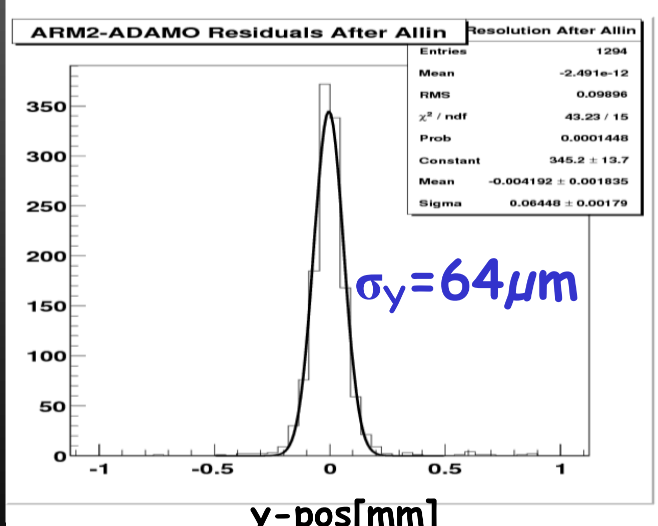


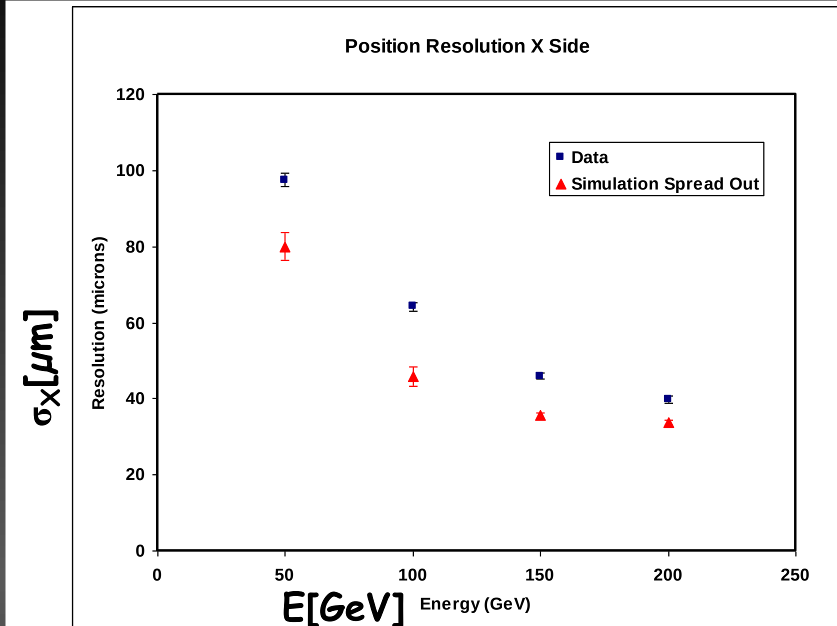


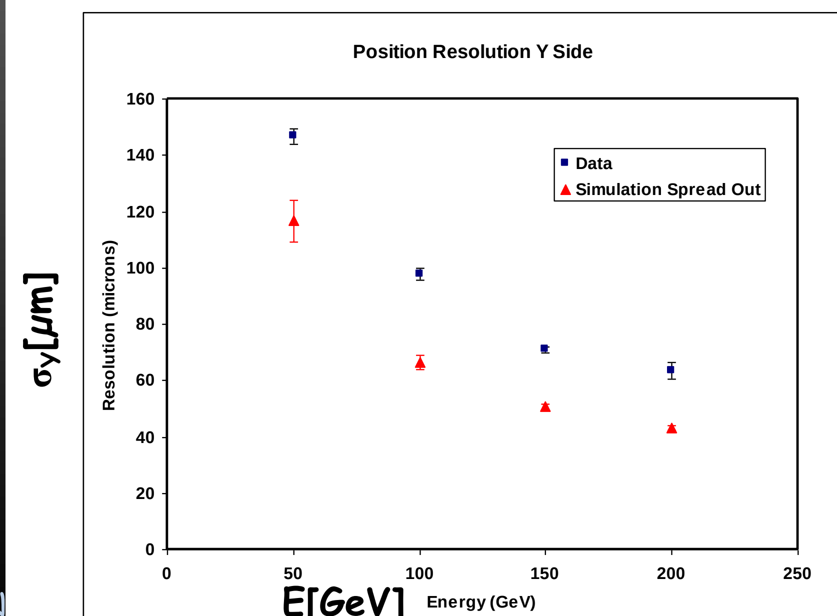
Arm2 position resolution

200 GeV electrons



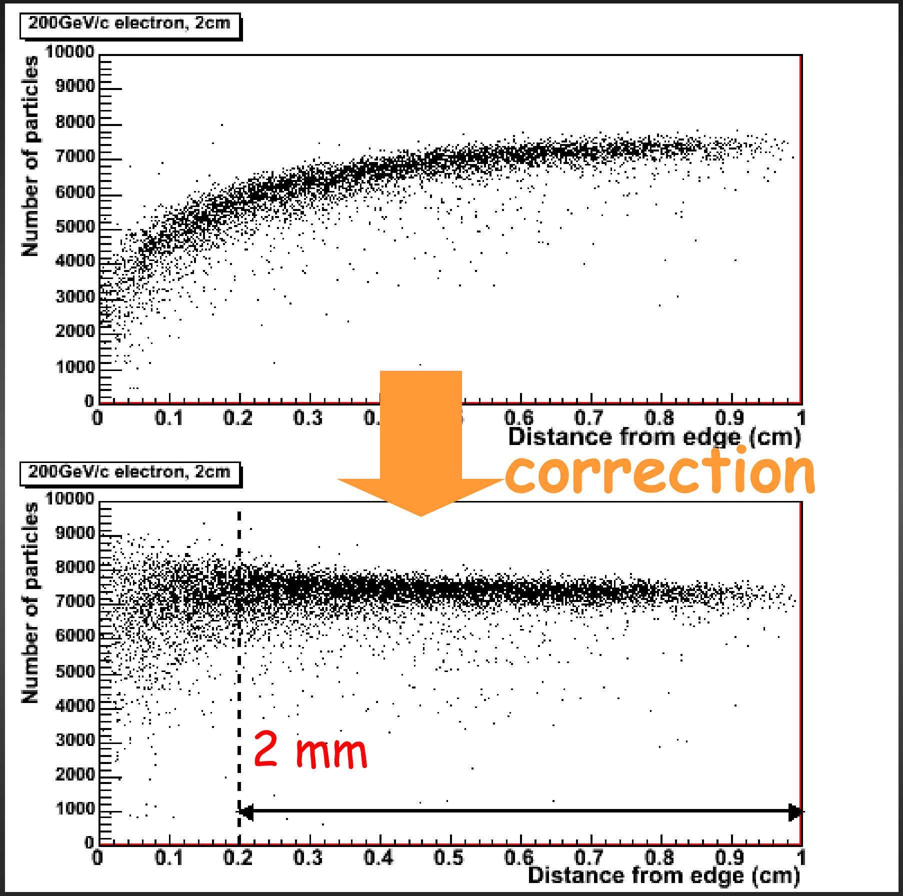






Alignment has been taken into account

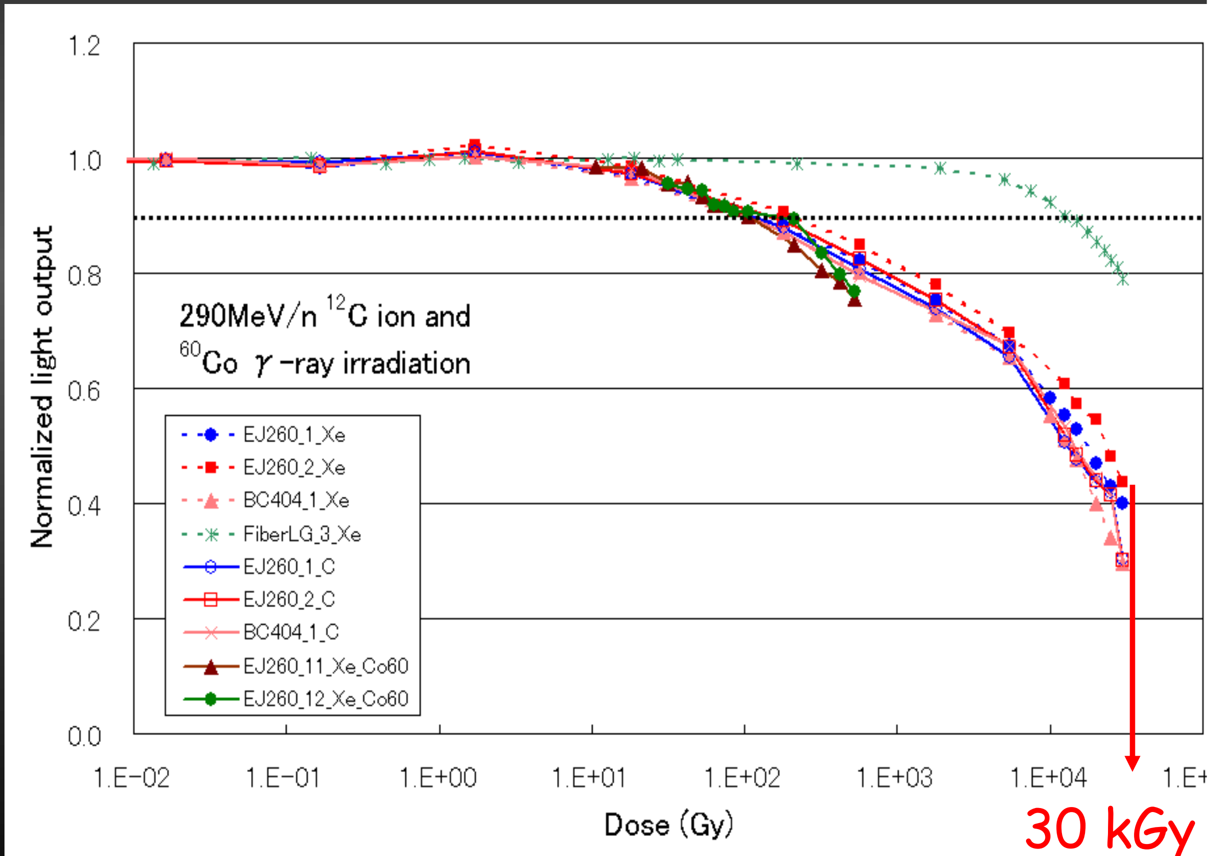
Leakage Correction



(Arm1 prototype)

Radiation damage studies

- **test of Scintillating fibers and scintillators**

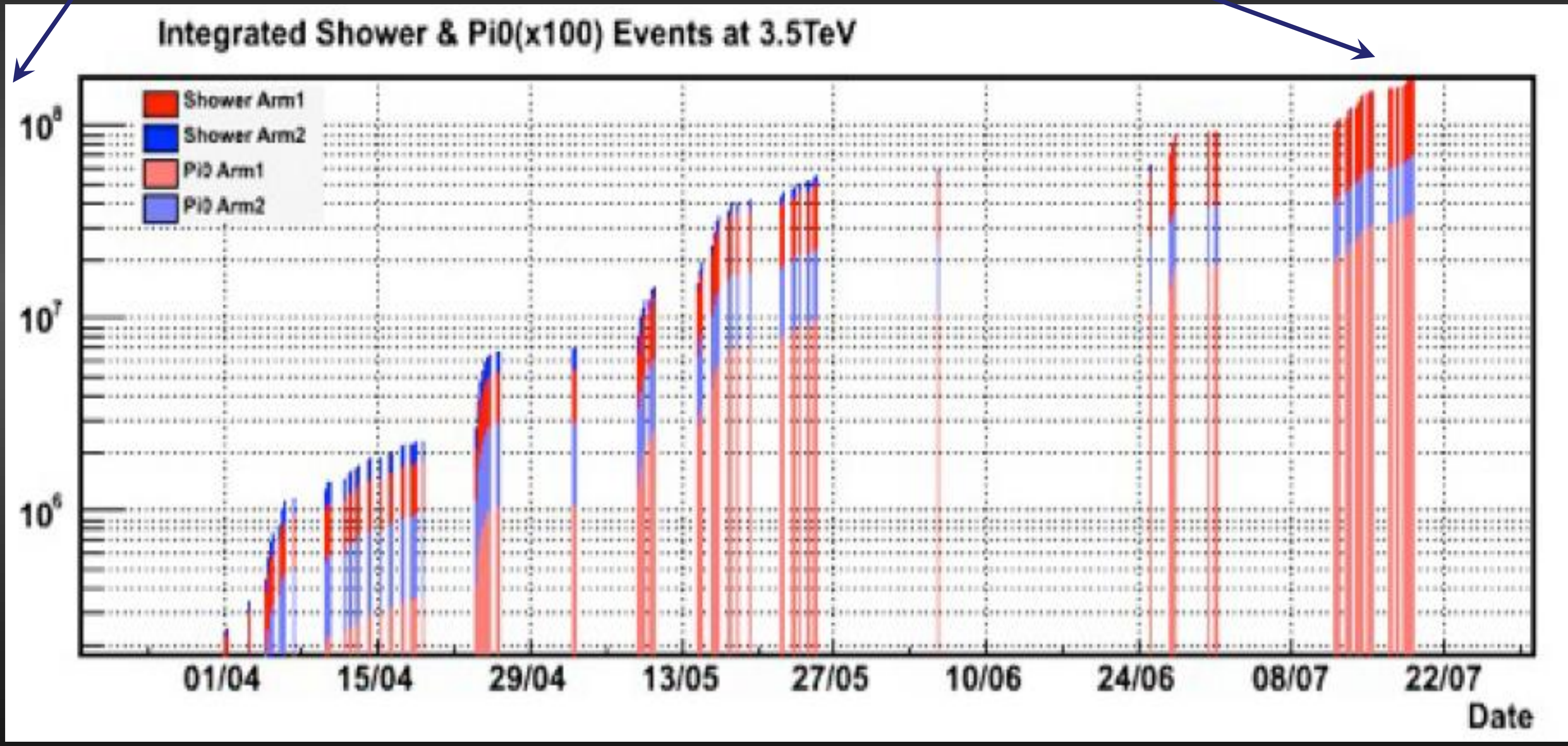


- Dose evaluation on the basis of LHC reports on radiation environment at IP1
- ~ 100 Gy/day @ 10^{30} $cm^{-2}s^{-1}$ luminosity are expected
- ~ 10 kGy during few months operation lead to ~ 50% light output decrease
- continuous laser calibration to monitor scintillators and correct for the decrease of light output

Accumulated Events in 2010

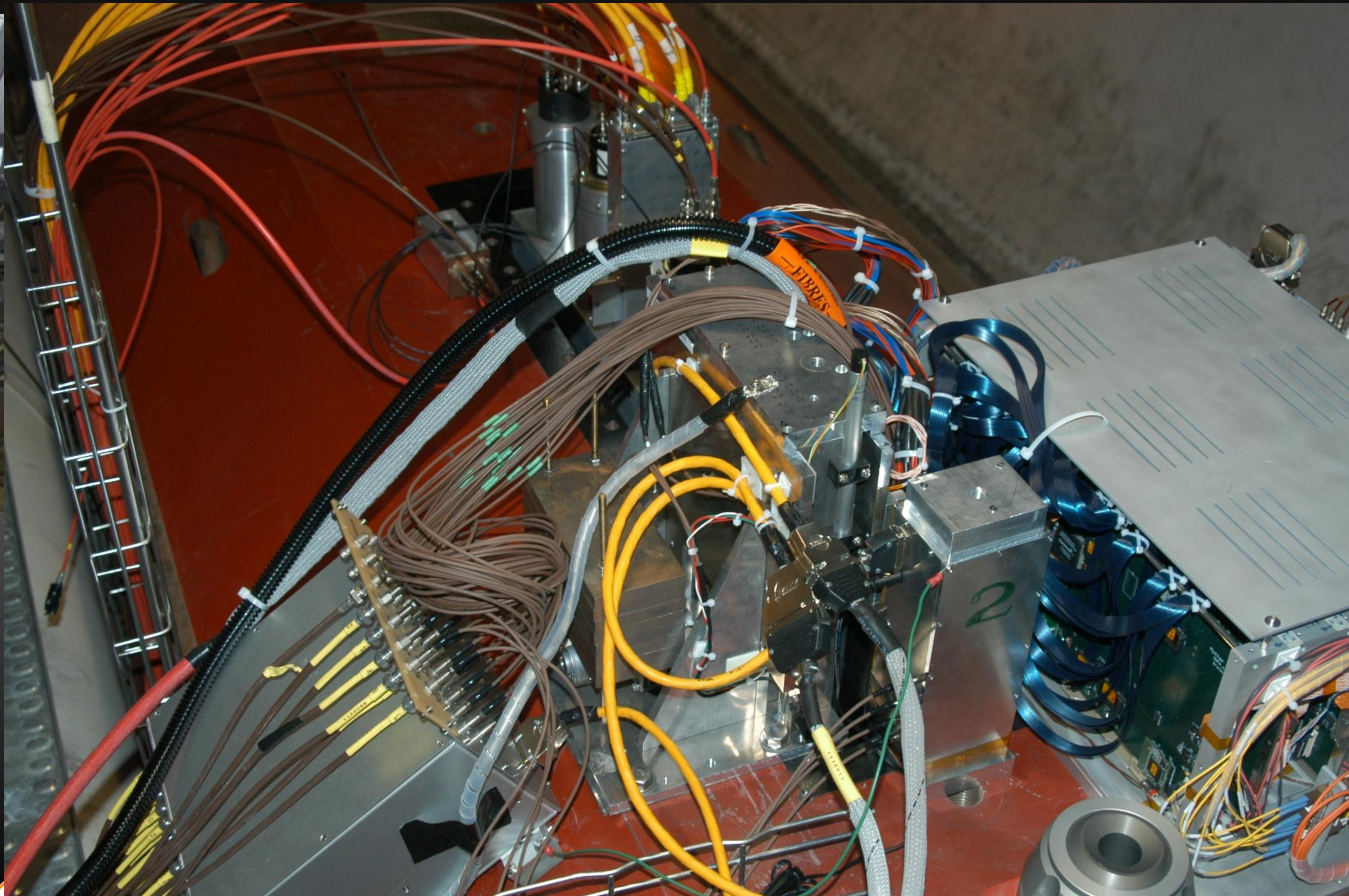
10^8 events!

LHCf removal



LHCf Arm1 – installation

LHCf Arm2 - installation



LHCf data taking

The LHCf control room in the ATLAS area