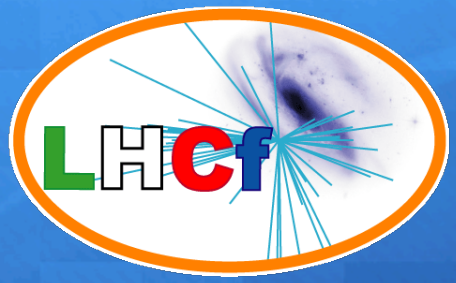


LHCf, connecting collider with astroparticle physics

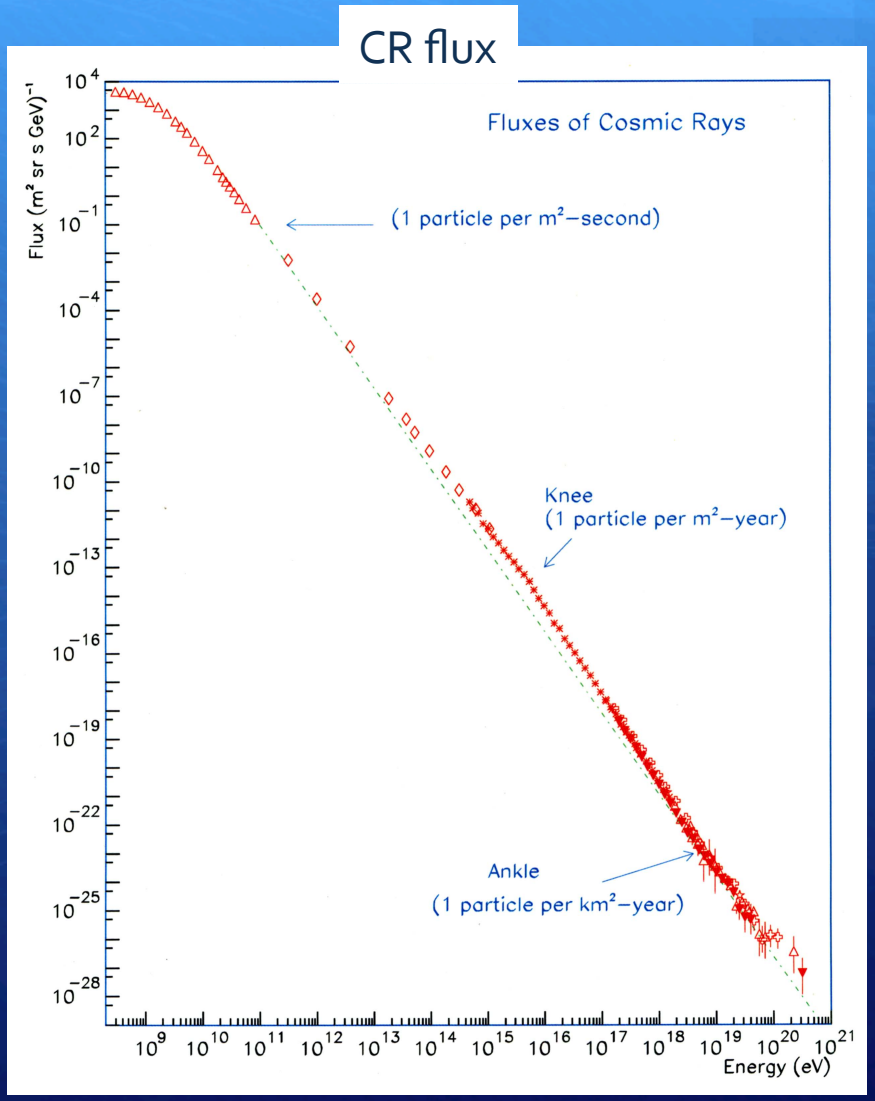
Talashi Sako, KMI/STEL, Nagoya University

KMIIN, 24-26 Oct 2011, Nagoya University

Cosmic-Rays, 100 years from discovery

Victor Hess revealed in 1912 that radiation comes from the sky and named it ‘hohen-strahlung.’

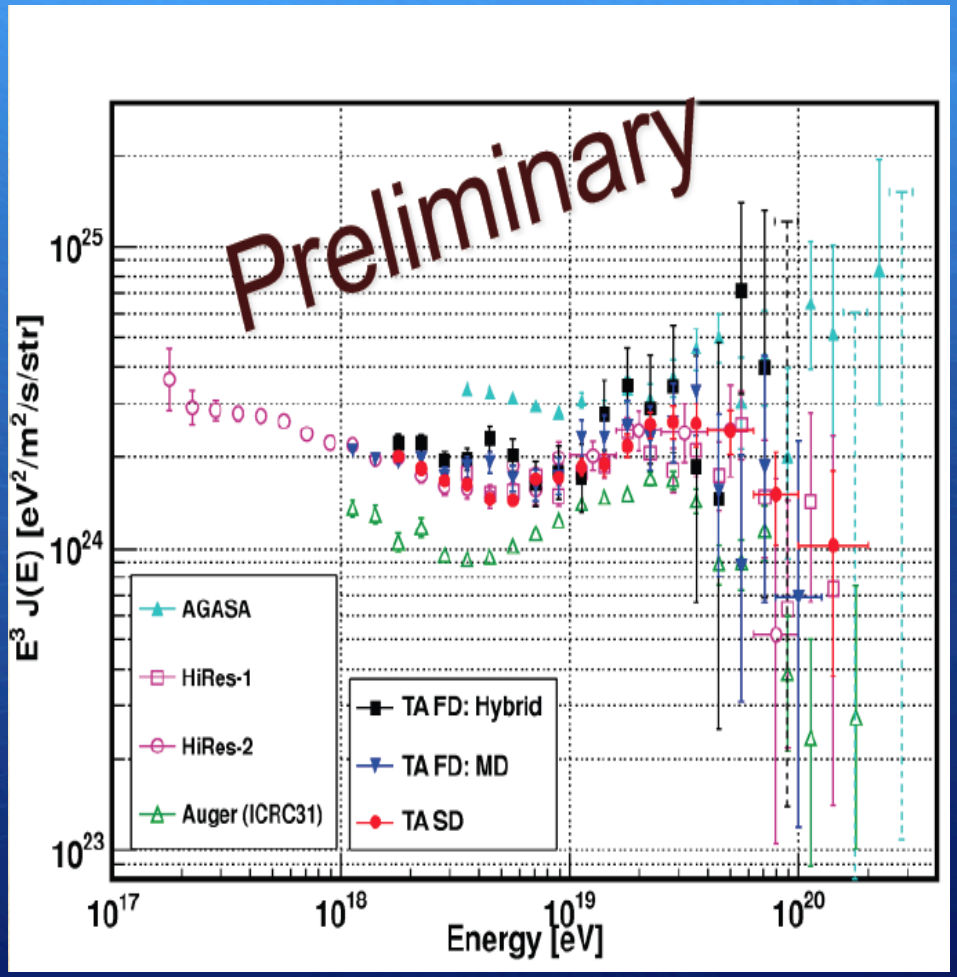
Cosmic-Rays, 100 years from discovery



Victor Hess revealed in 1912 that radiation comes from the sky and named it 'hohen-strahlung.'

Now we observe CRs up to 10^{20}eV (~10J !!)
at a rate of O(1/km² century)

Cosmic-Rays, 100 years from discovery



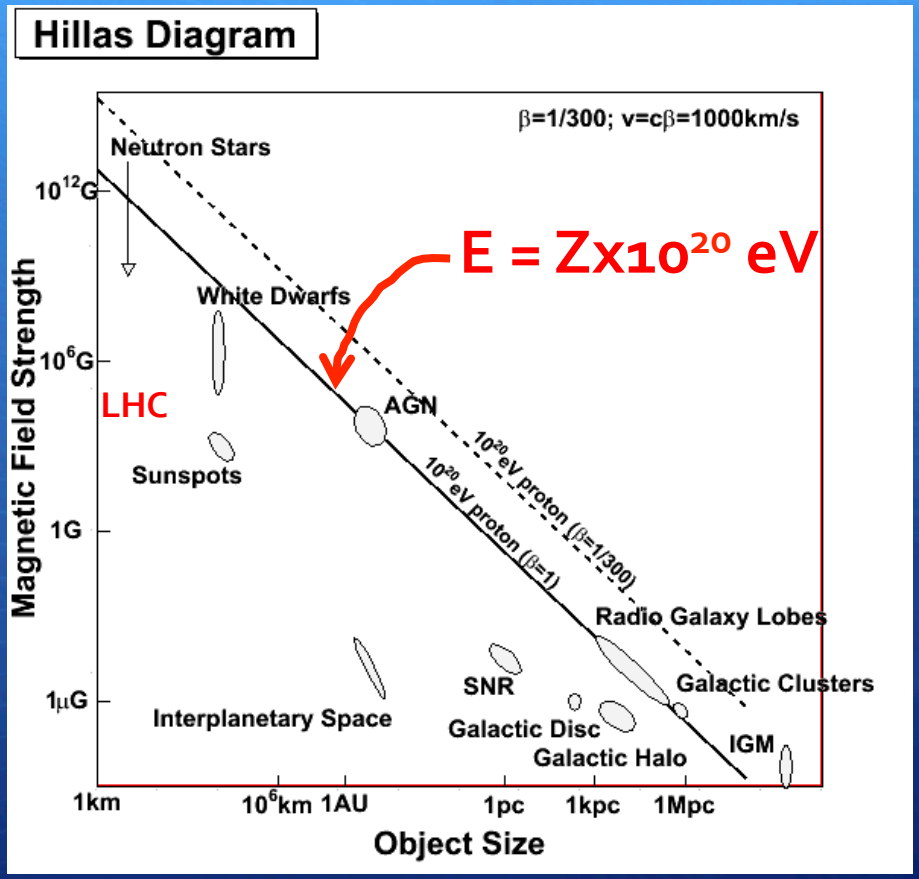
E^3 x(Flux) from AGASA, HiRes, PAO, TA summarized by the TA group

Victor Hess revealed in 1912 that radiation comes from the sky and named it 'hohen-strahlung.'

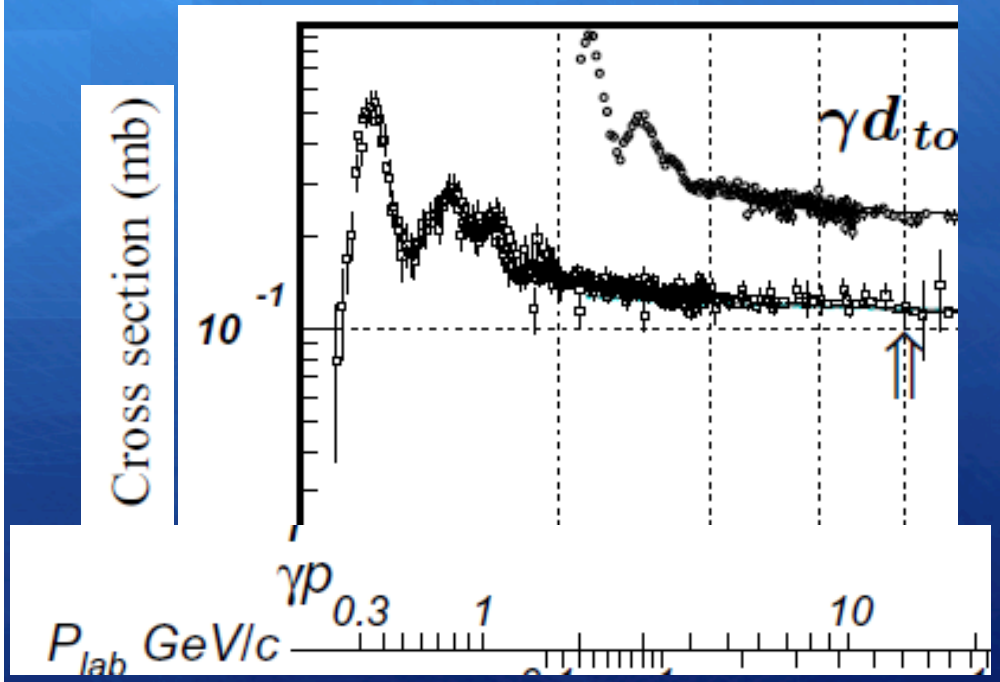
Now we observe CR up to 10^{20}eV (~10J !!)
at the rate of O(1/km^2 century)

Spectral cutoff is confirmed by 3 last experiments at 10^{20}eV
What is indicated?

What is the origin of cut off and UHECR?
-- Standard Models --



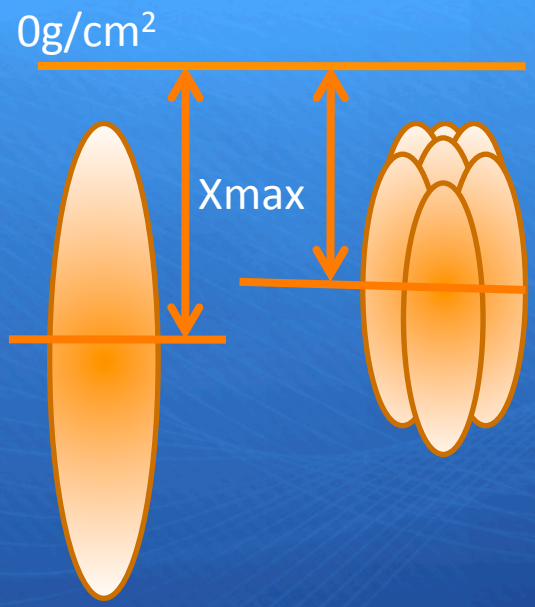
1) Hilas diagram; maximum rigidity E/z determined by LxB



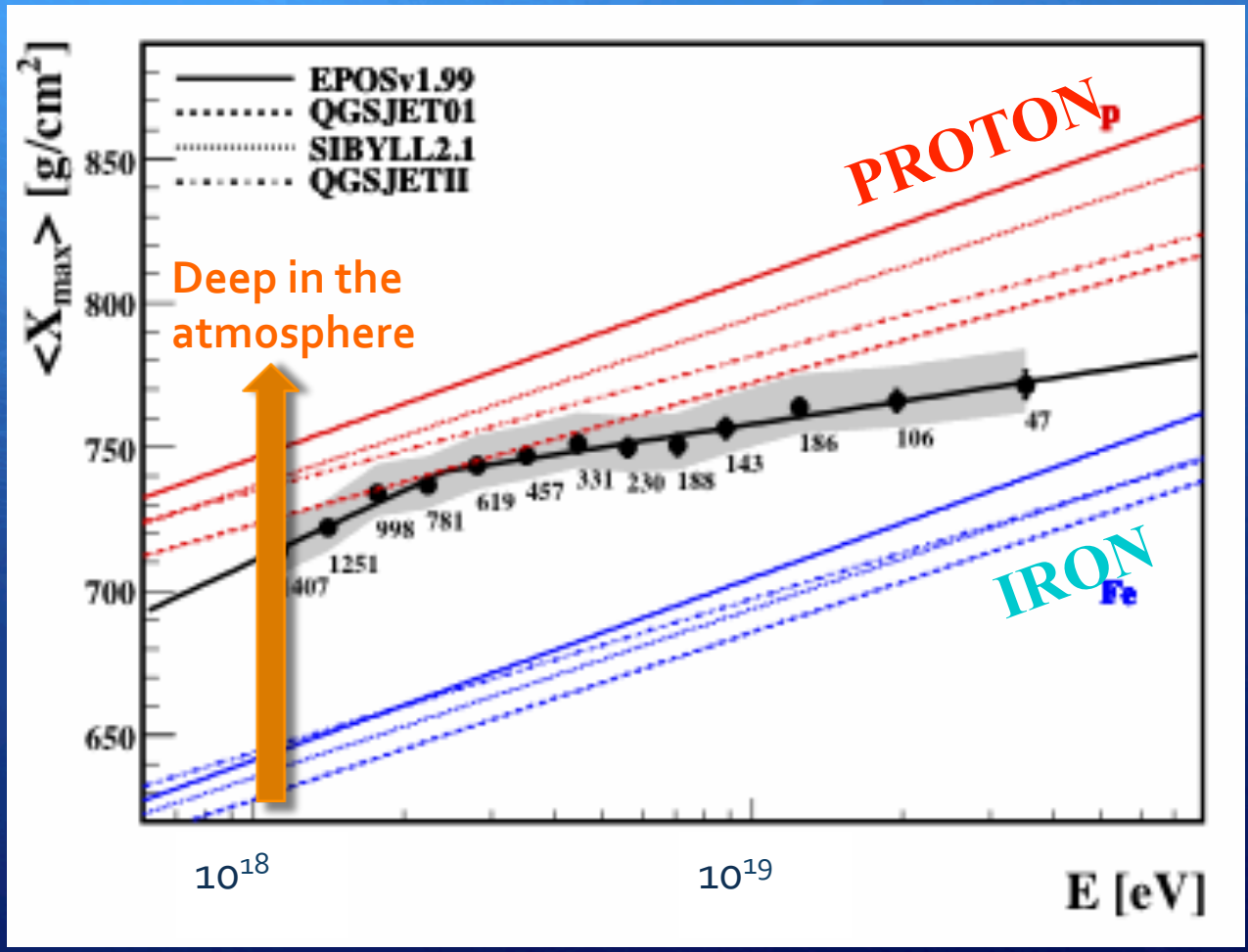
2) GZK mechanism; interaction between CR and CMB (Δ-resonance in case of proton) opens channel at E_{CR}~ 10^{20}eV

Both scenarios are sensitive to the particle type (proton, light/heavy nuclei)

Key observation in UHECR

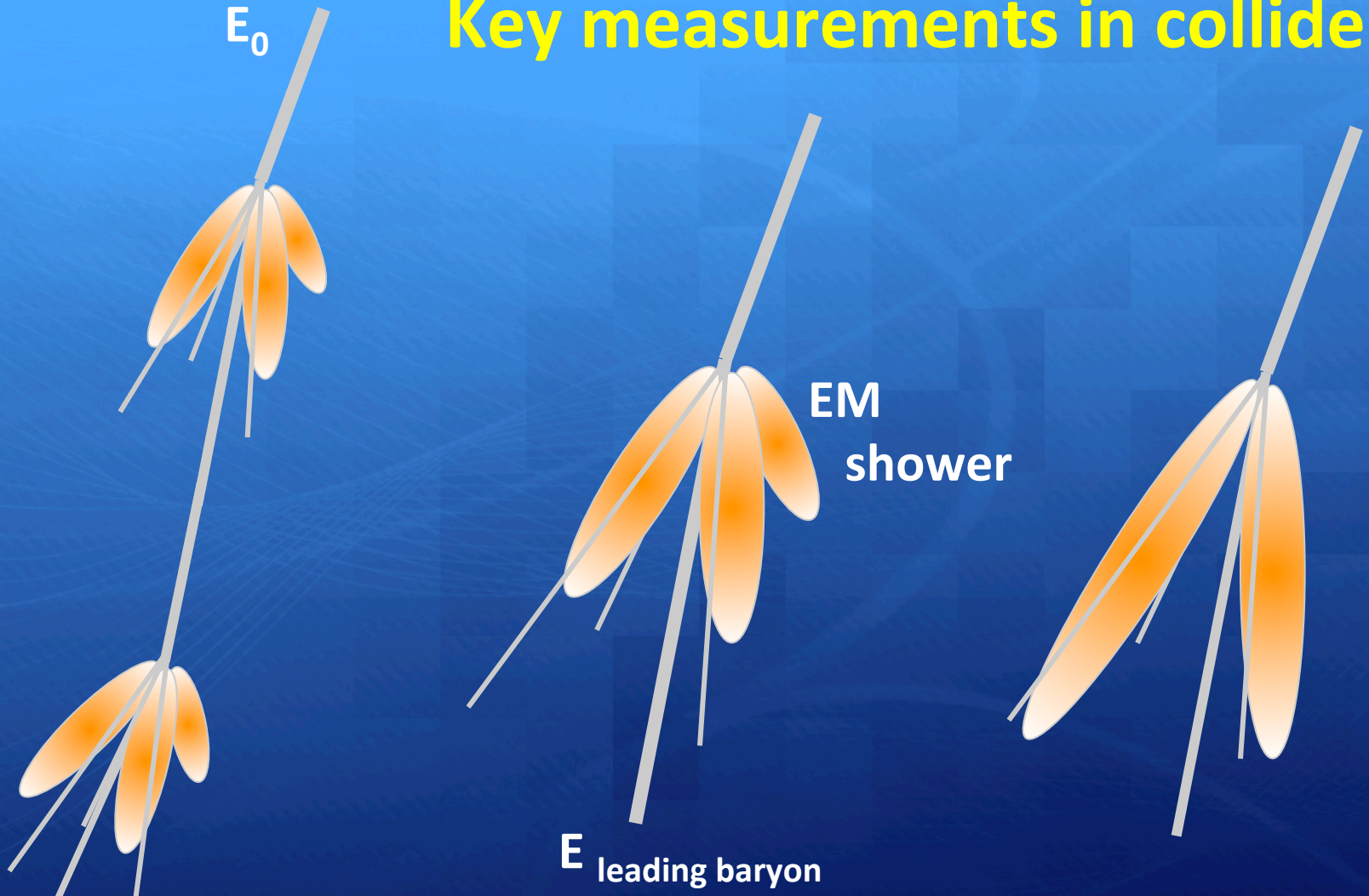


Proton shower and nuclear shower of same total energy



Pierre Auger Observatory (PAO)

Key measurements in colliders



Total cross section

Elasticity / inelasticity

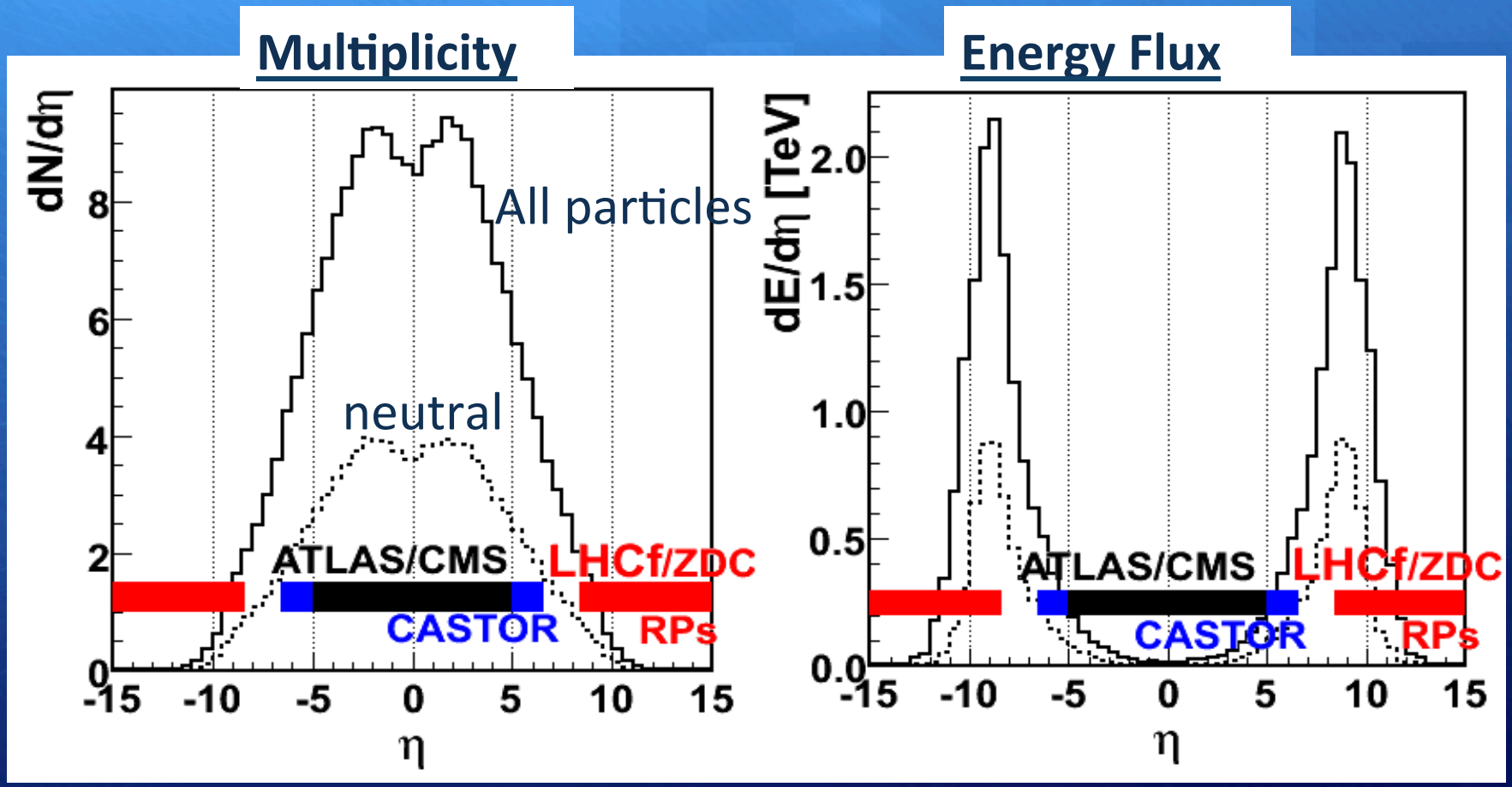
Meson Multiplicity

Forward spectra

What should be measured at colliders

multiplicity and energy flux at LHC 14TeV collisions

pseudo-rapidity; $\eta = -\ln(\tan(\theta/2))$



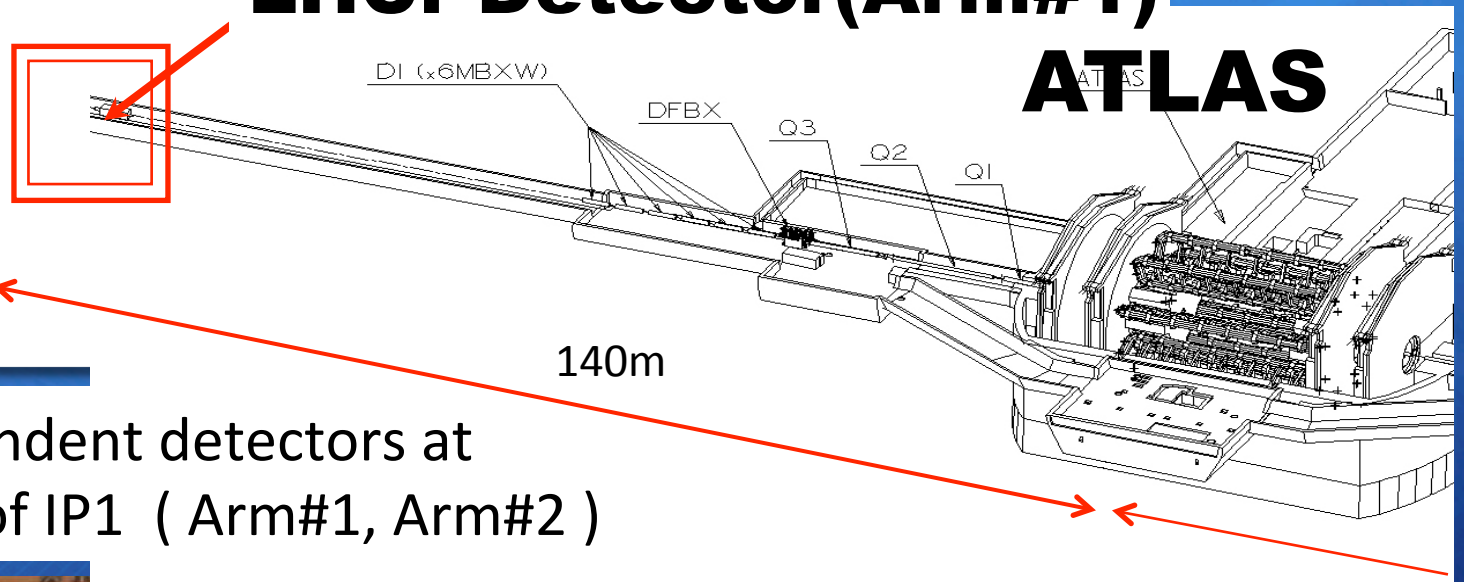
Most of the energy flows into very forward

The LHC forward experiment

$\sqrt{s}$=14TeV

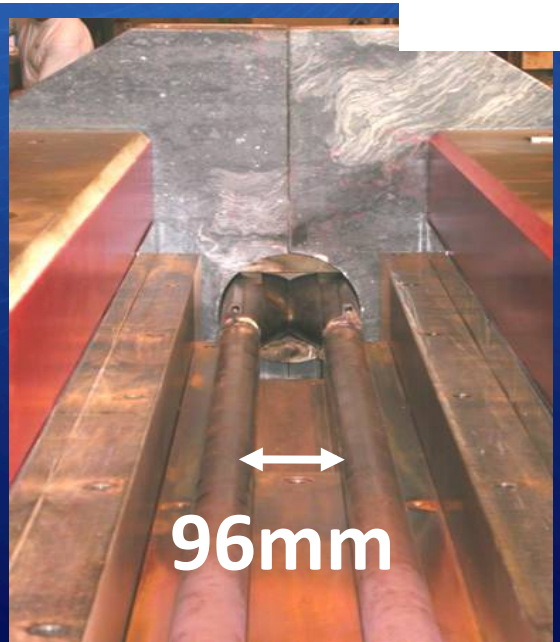
$E_{lab}=10^{17}$eV

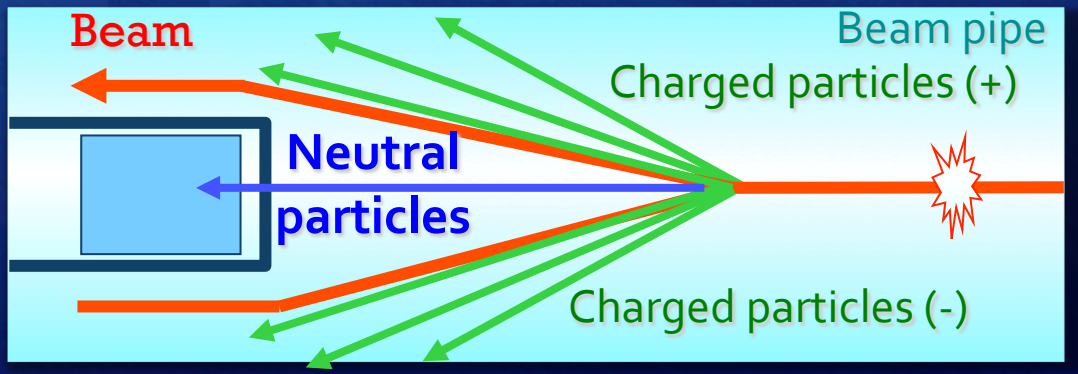
LHCf Detector(Arm#1)



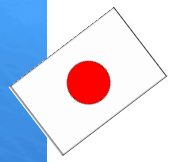
Two independent detectors at either side of IP1 (Arm#1, Arm#2)

LHCf Detector(Arm#2)





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

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

Waseda University, Japan

T.Tamura *Kanagawa University, Japan*

M.Haguenauer *Ecole Polytechnique, France*

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INFN, Univ. di Firenze, Italy

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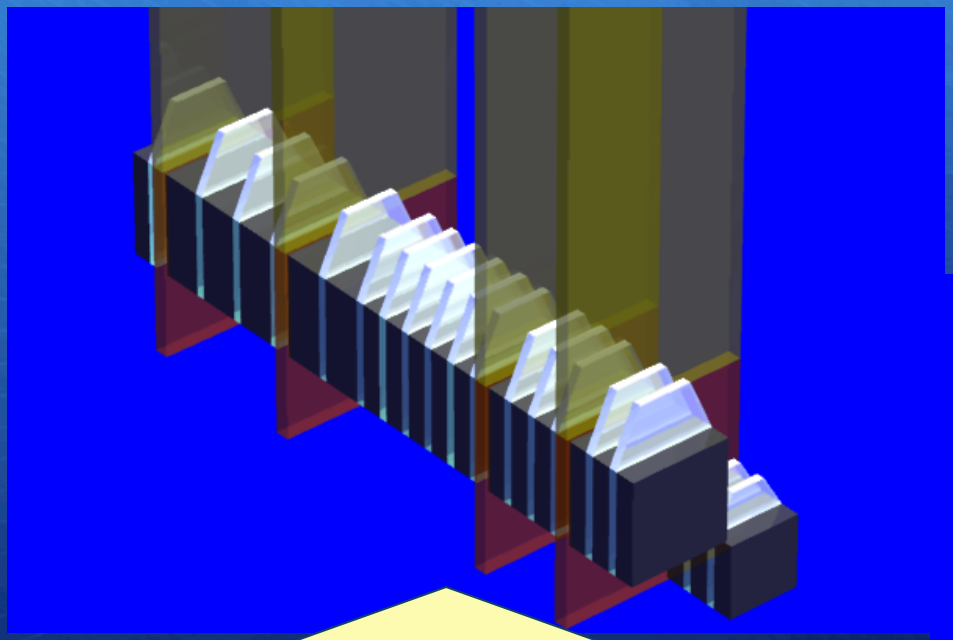
J.Velasco, A.Faus *IFIC, Centro Mixto CSIC-UVEG, Spain*

A-L.Perrot *CERN, Switzerland*

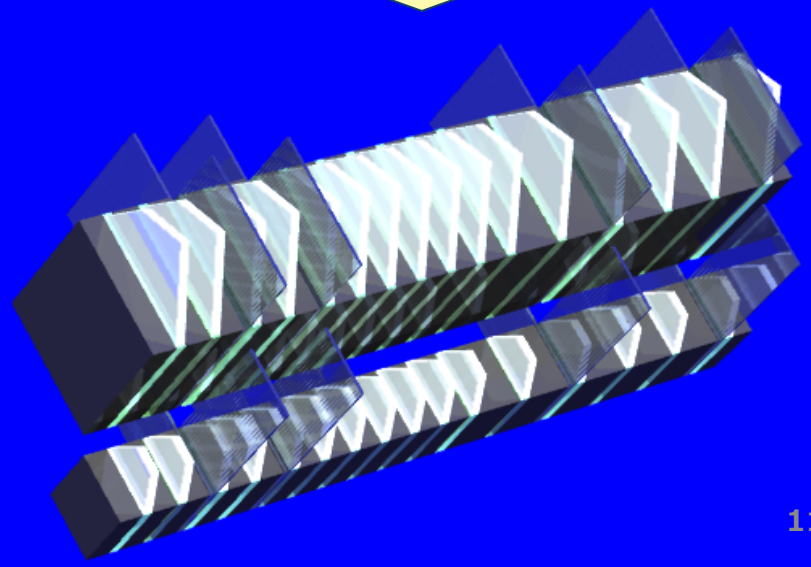
LHCf Detectors

- ✓ Imaging sampling shower calorimeters
- ✓ Two independent calorimeters in each detector (Tungsten 44r.l., 1.6λ, sample with plastic scintillators)

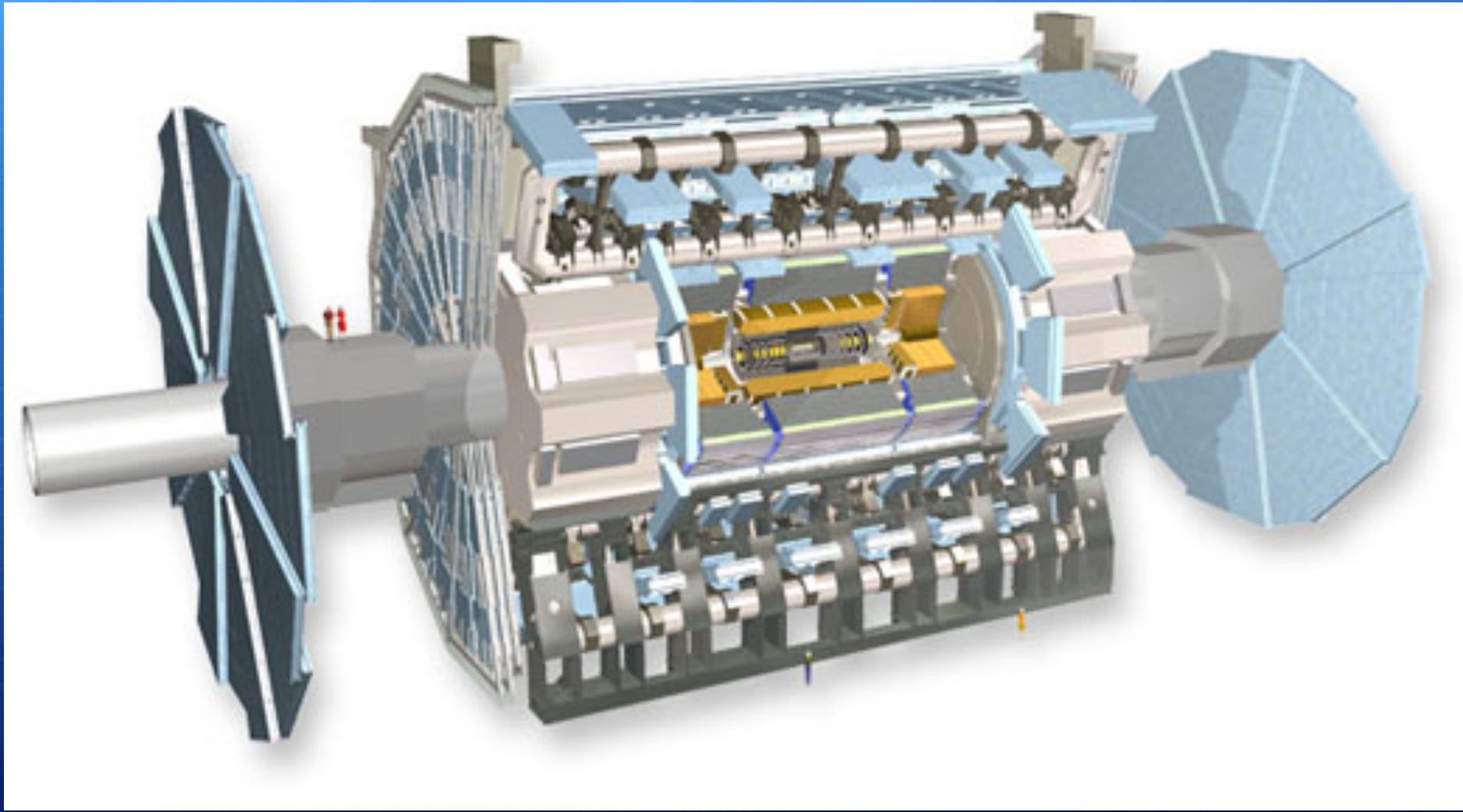


Arm#2 Detector
25mmx25mm+32mmx32mm
4 XY Silicon strip detectors

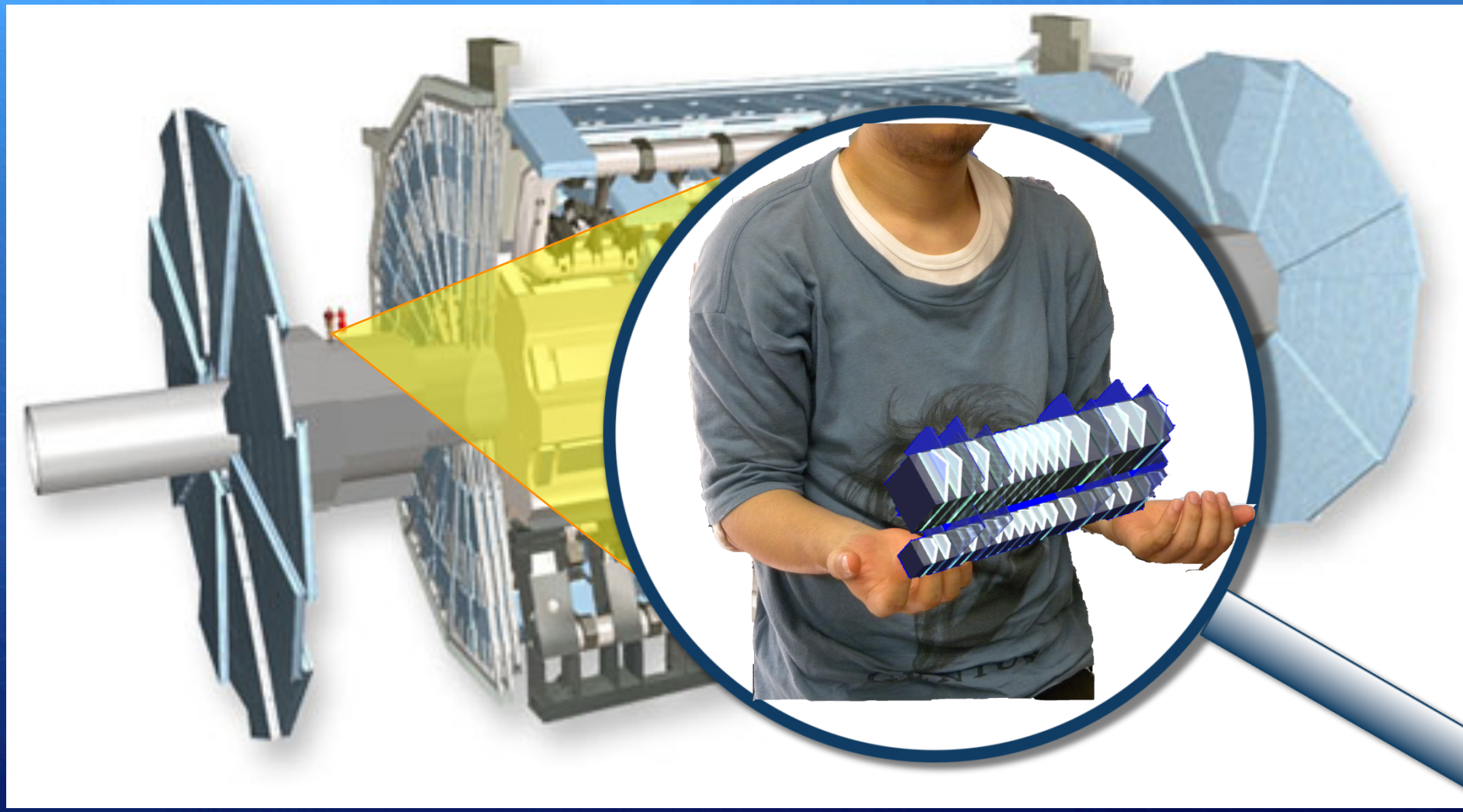
Arm#1 Detector
20mmx20mm+40mmx40mm
4 XY SciFi+MAPMT



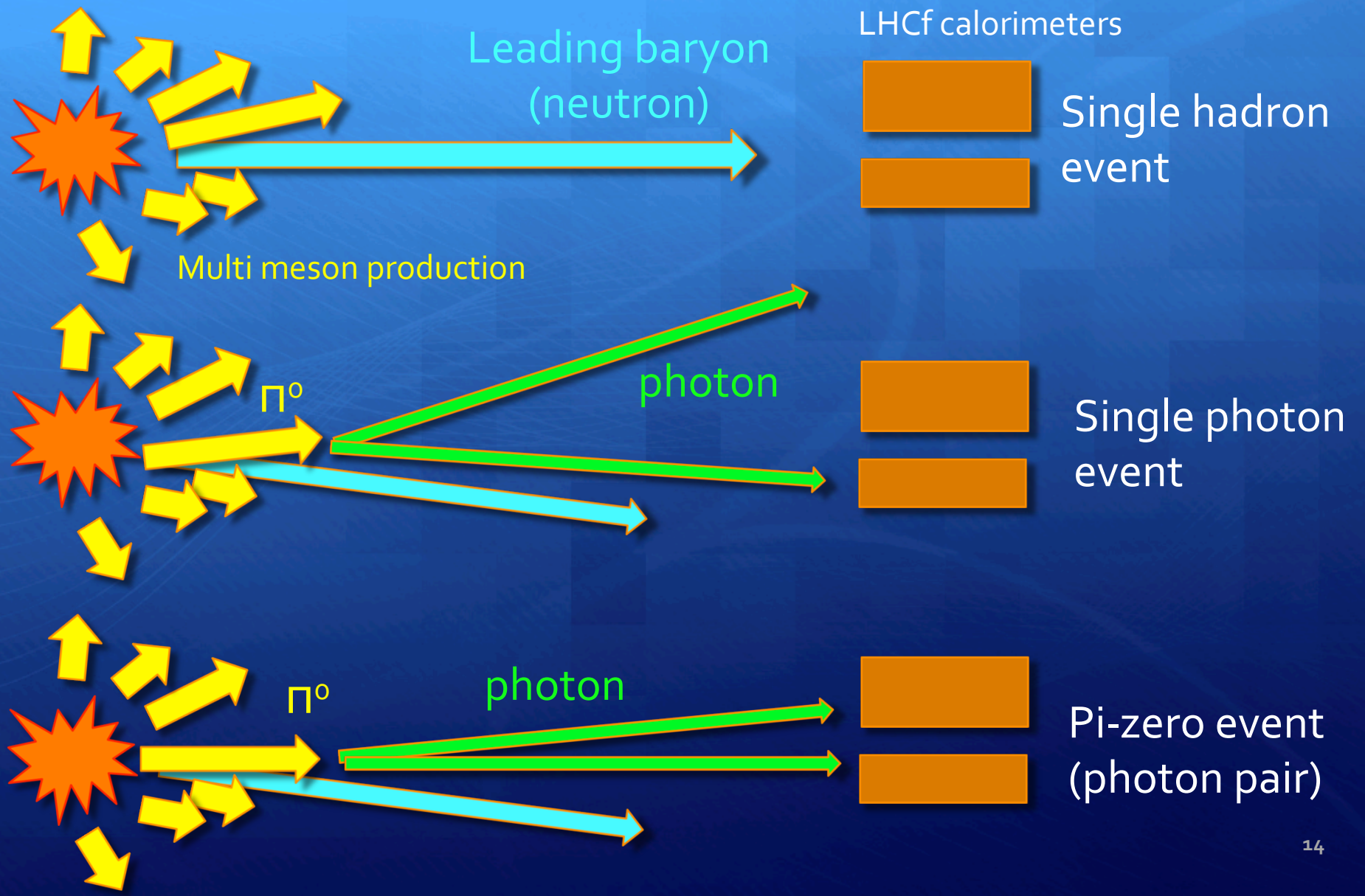
ATLAS & LHCf



ATLAS & LHCf

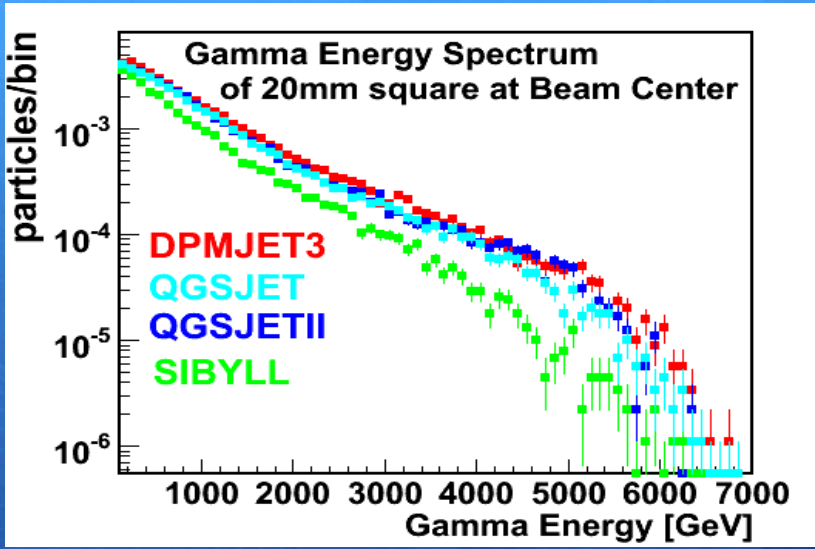


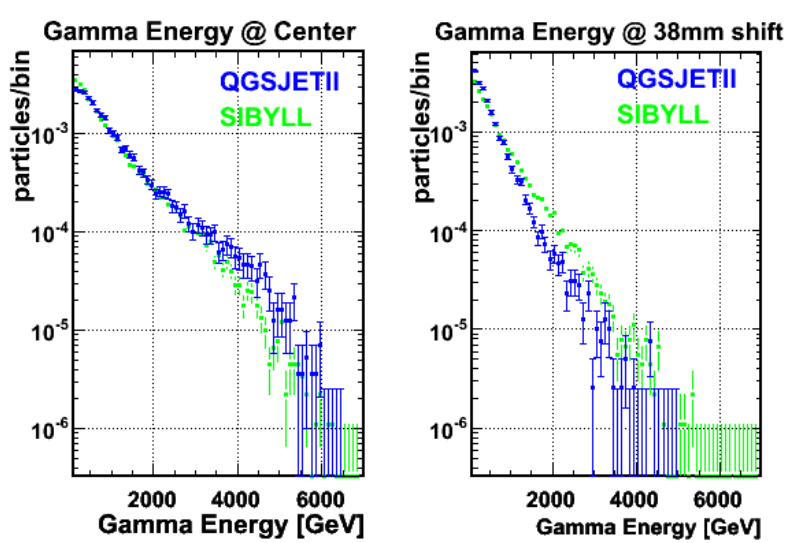
Event category of LHCf

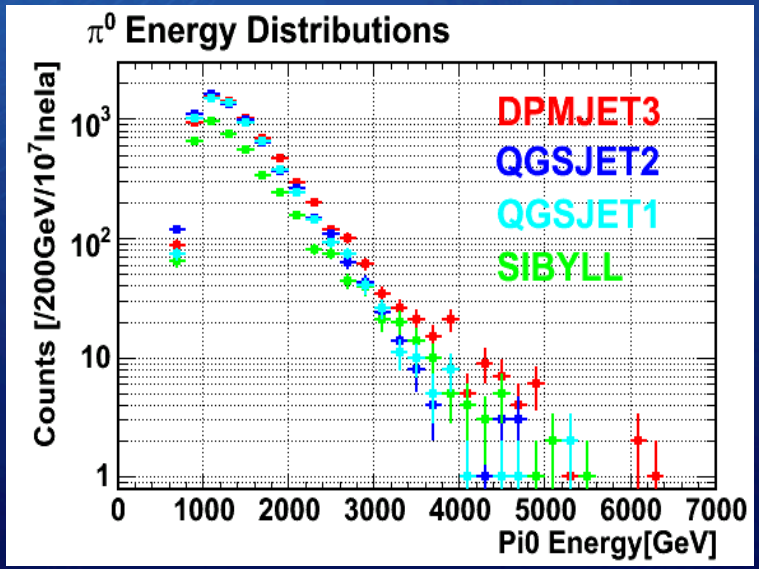


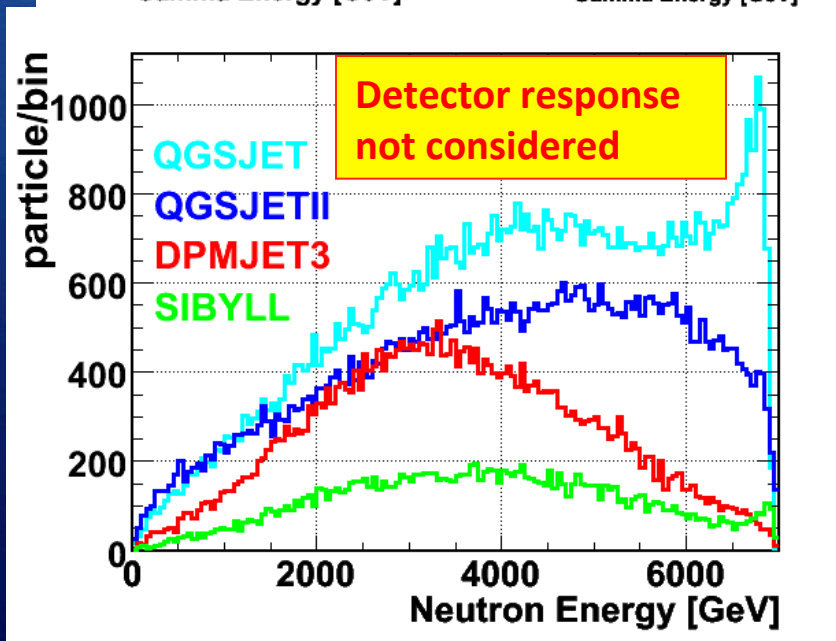
Expected Results at 14 TeV Collisions

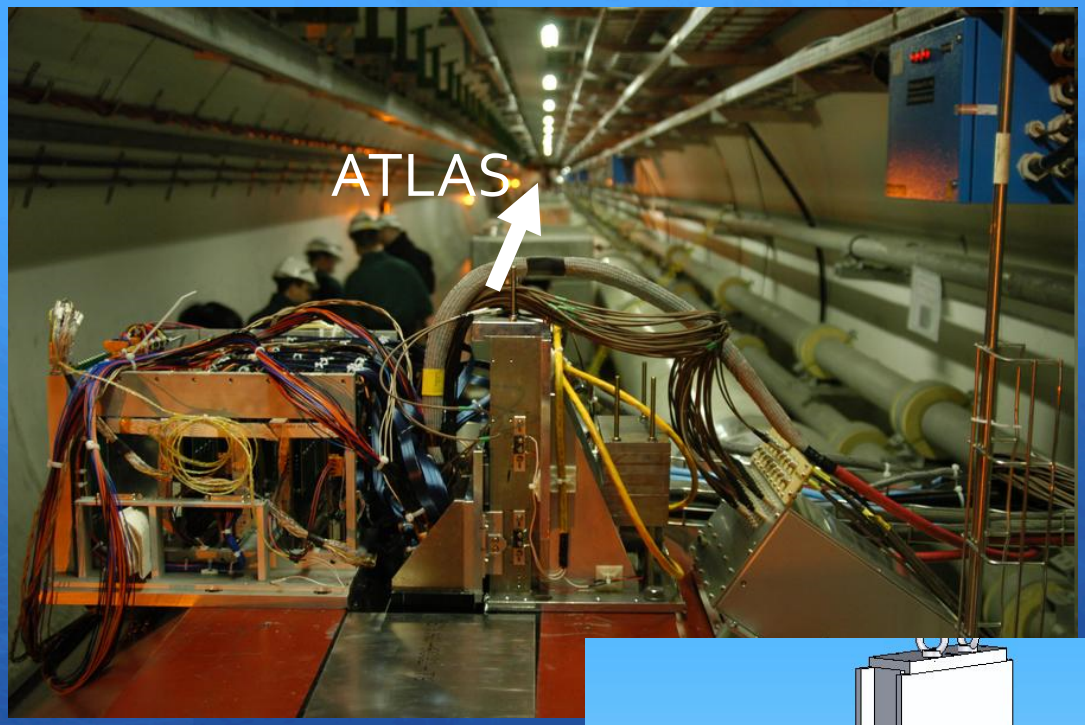
(MC assuming 0.1nb^{-1} statistics)

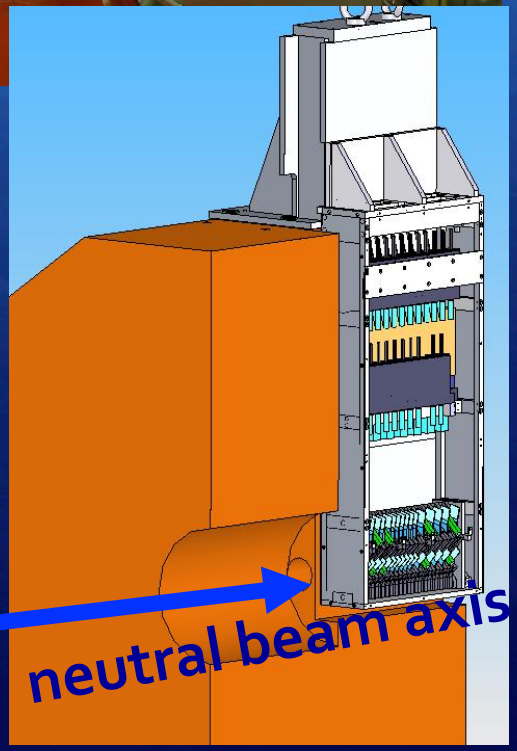












Pseudo-rapidity range.
η > 8.7 @ zero crossing angle
η > 8.4 @ 140urad

Operation 2009-2010

With Stable Beam at $\sqrt{s}$ = 900 GeV

Total of 42 hours for physics

About 10^5 shower events in Arm1+Arm2

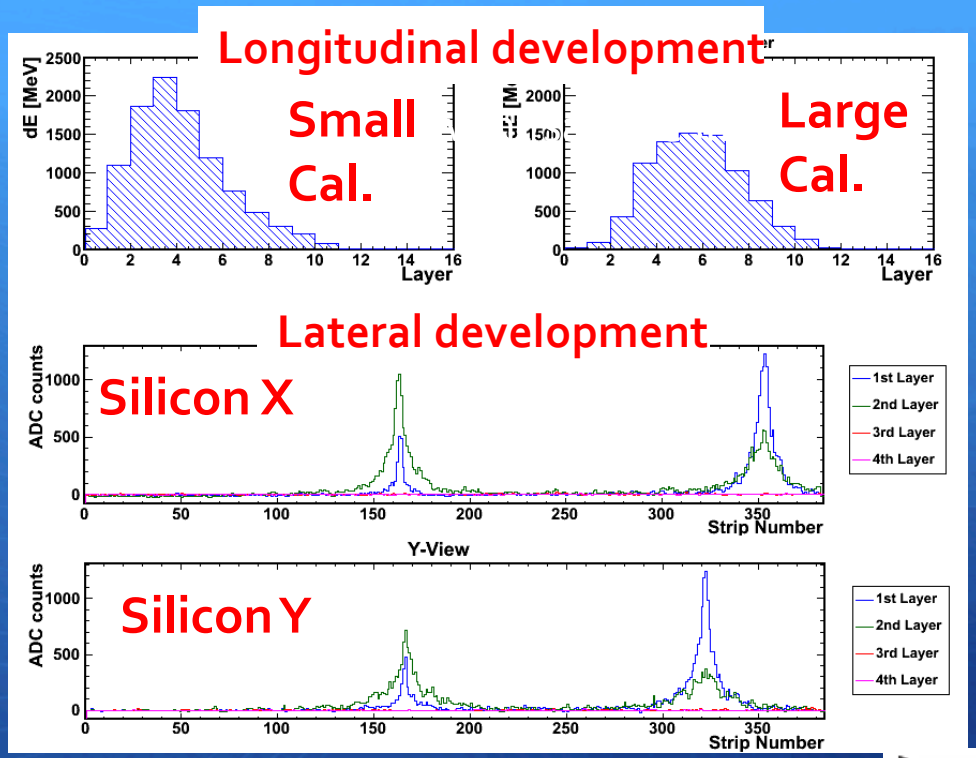
With Stable Beam at $\sqrt{s}$ = 7 TeV

- 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 and Arm2

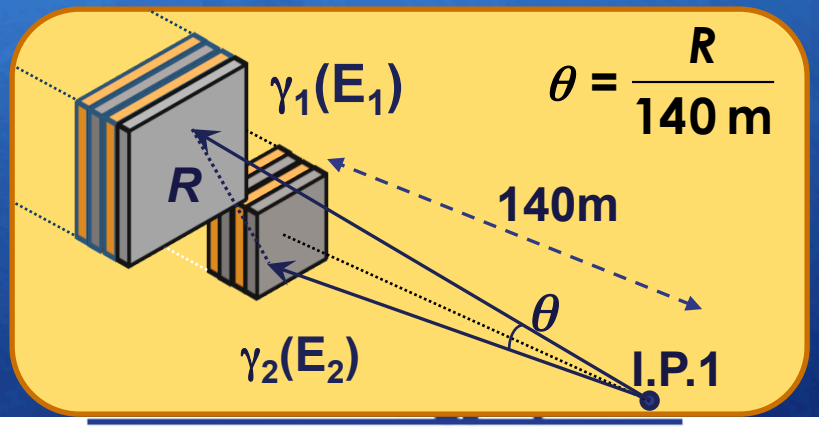
Status

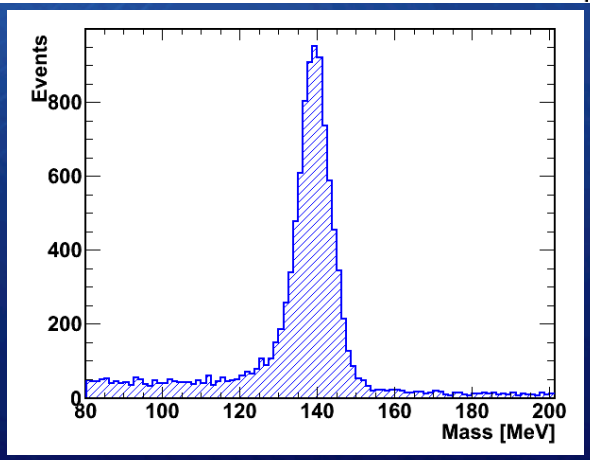
- Completed program for 900 GeV and 7 TeV
  - Removed detectors from tunnel in July 2010
  - Post-calibration beam test in October 2010
- Upgrade to more rad-hard detectors for 14TeV in 2014

EM shower and π⁰ identification

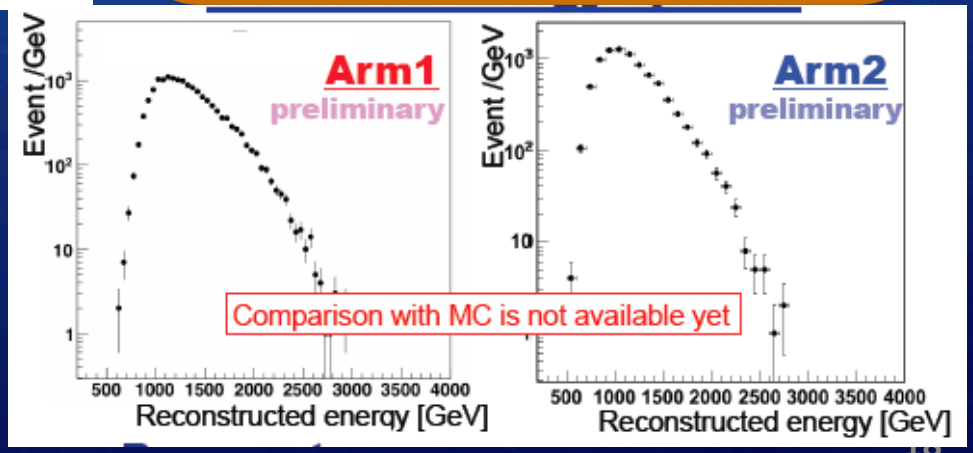


- A Pi0 candidate event
- 599GeV & 419GeV photons in 25mm and 32mm tower, respectively
- $M = \theta\sqrt{(E_1 \times E_2)}$





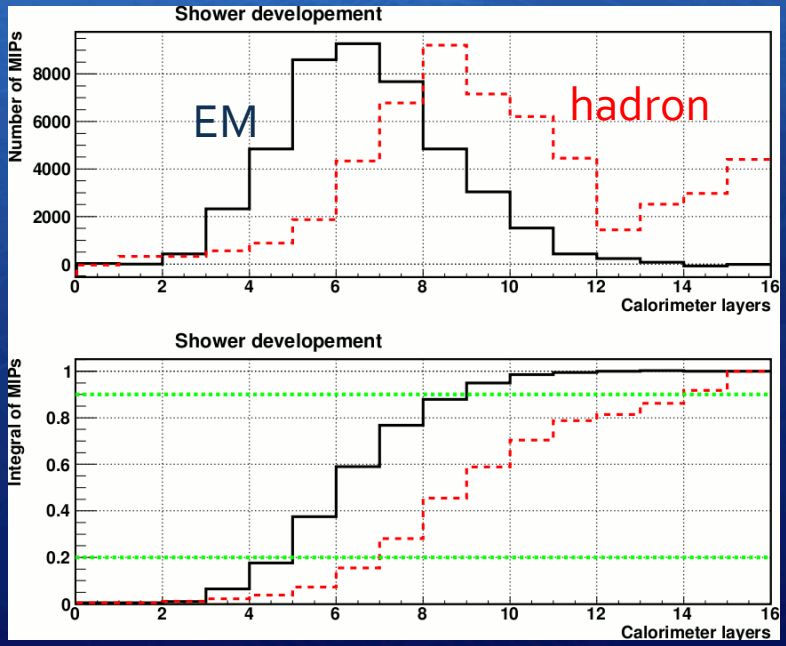
Invariant mass of photon pairs

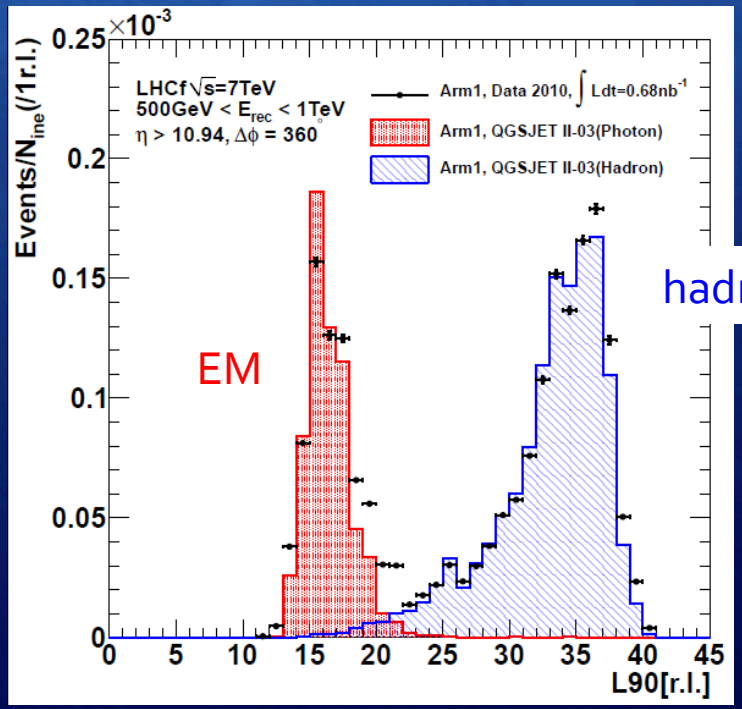


Comparison with models, in progress

Particle Identification

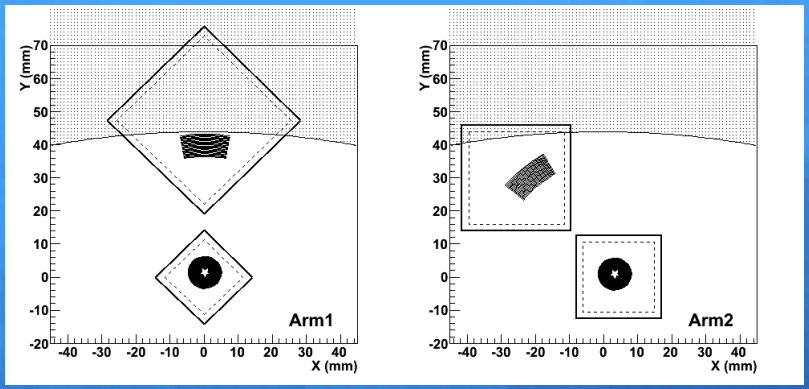
- ✓ PID (EM shower selection)
  - Select events $<L_{90\%}$ threshold and multiply P/ε
    ε (photon detection efficiency) and P (photon purity)
  - By normalizing MC template $L_{90\%}$ to data, ε and P for certain $L_{90\%}$ threshold are determined.





Photon spectra at √s=7TeV collisions

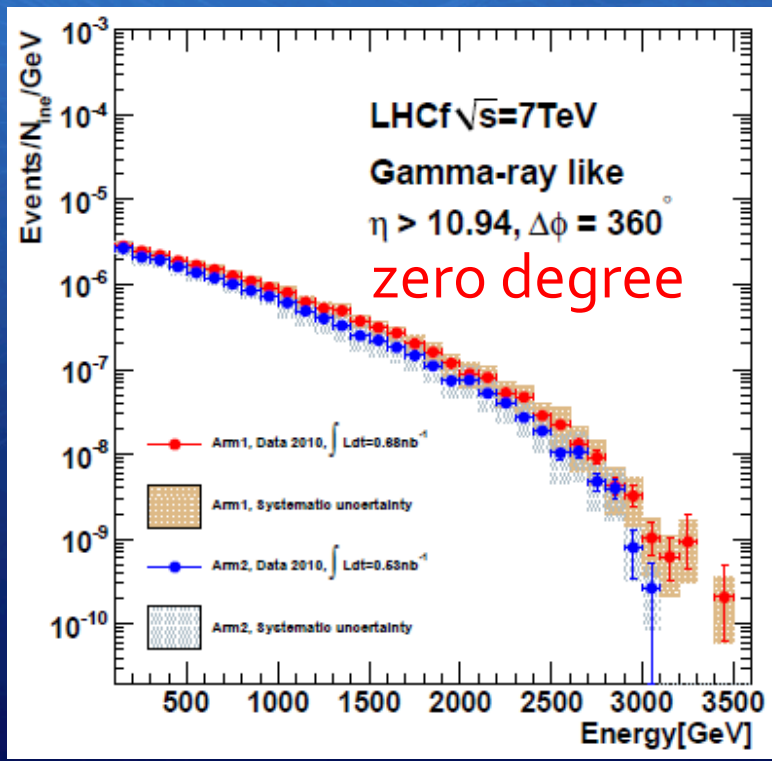
(Adriani et al., PLB, 2011)

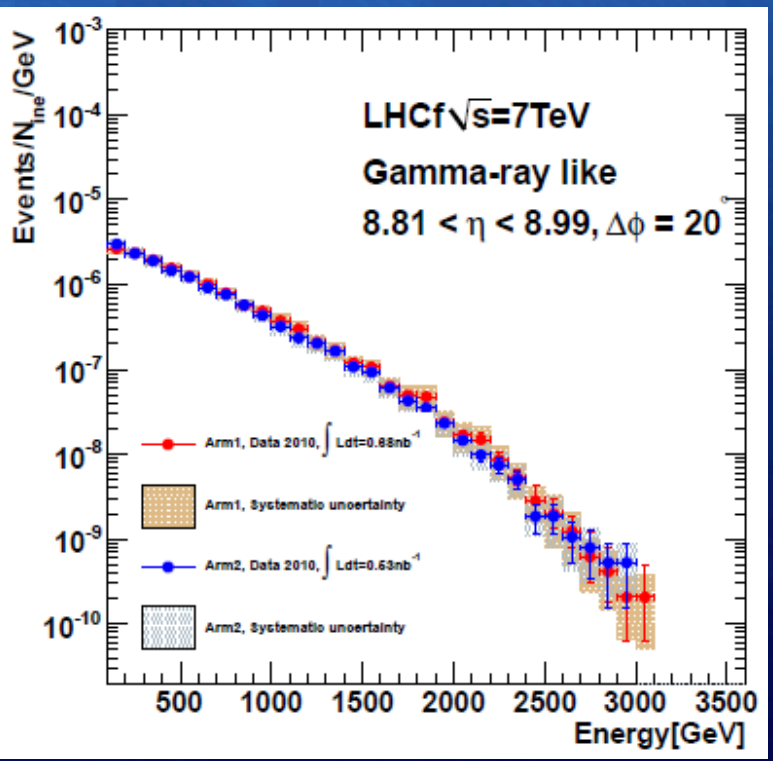


+ Spectra of Arm1&2 at common η

Detail in the poster by H.Menjo

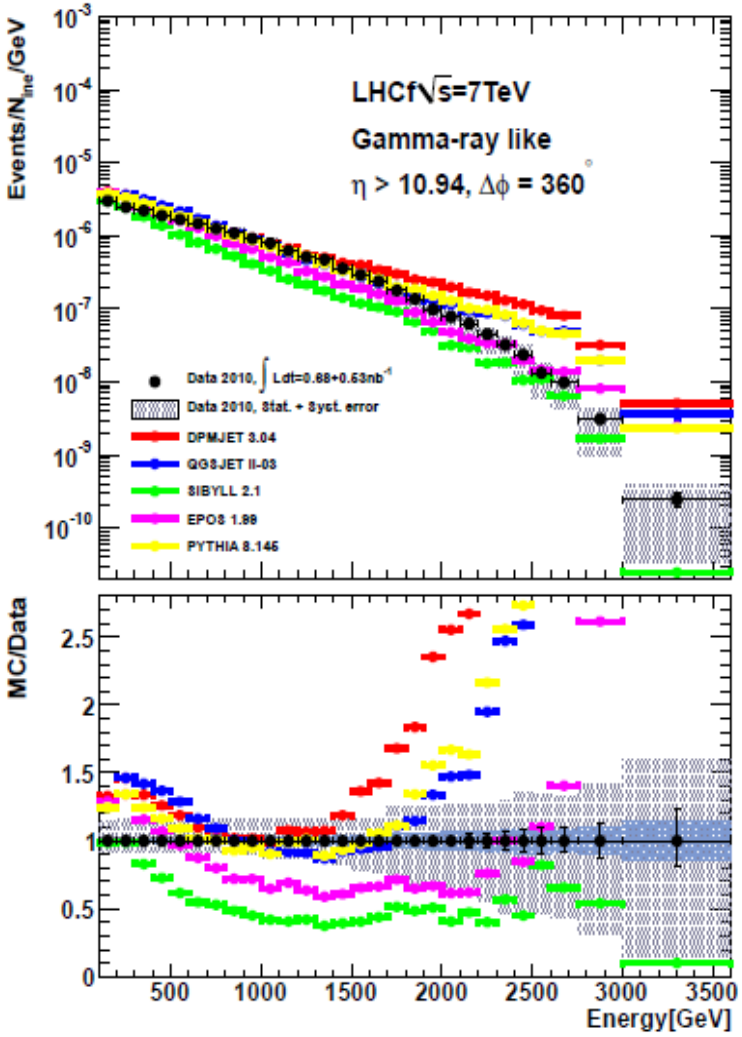
+ σ_{ine} = 71.5mb assumed; consistent with the other LHC experiments

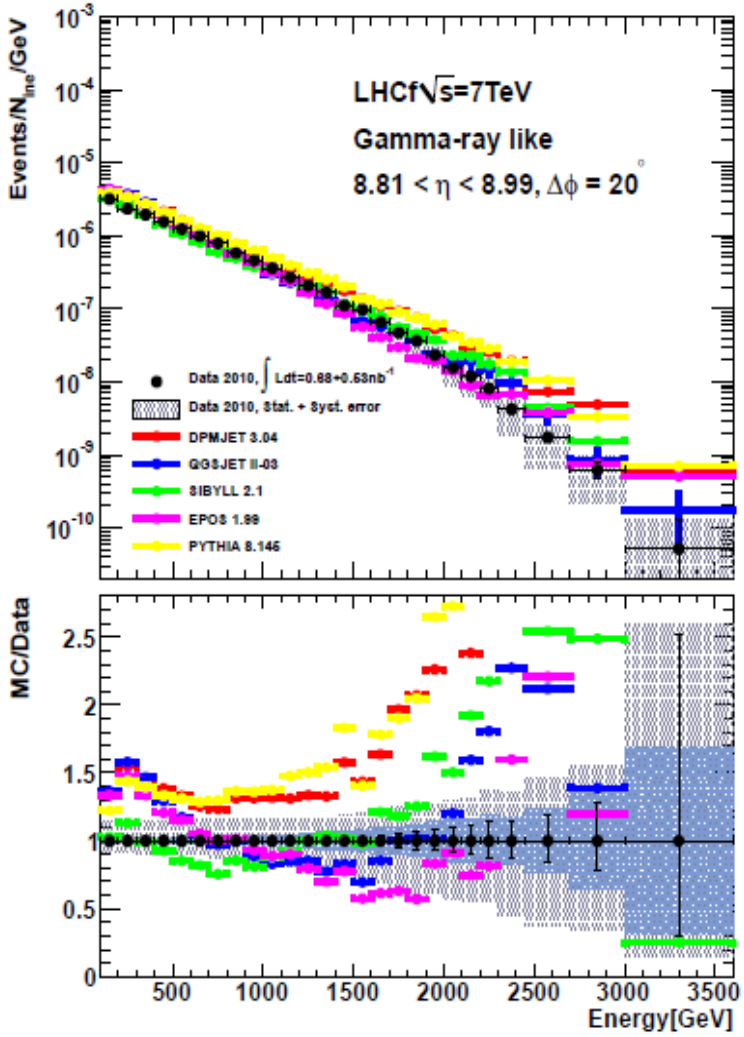




Comparison with Models

Adriani et al., PLB, 2011





DPMJET 3.04 QGSJET II-03 SIBYLL 2.1 EPOS 1.99 PYTHIA 8.145

Comment from a modelist…

… To some extent, I was even surprised that models behave not so bad overall, taking the fact that forward photon spectra are terra-incognita even at fixed target energies…

*terra incognita: Land that has never been explored or mapped; uncharted territory. (by Wiktionary)

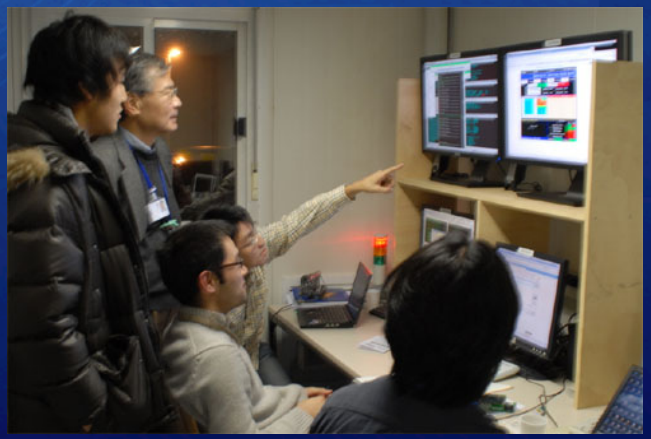
Next Step of LHCf

- **Analysis**
  - Impact on air shower calculation / CR physics
  - Photon spectra at $\sqrt{s}$ = 0.9 TeV in analysis
  - π^0 spectra in analysis
  - P_T spectra
  - Hadron spectra (photon/hadron ratio)
  - Test for LPM effect
  - Correlation with central production (joint analysis with ATLAS)
- Measurements
  - LHC $\sqrt{s}$ = 14 TeV pp
  - LHC p-Pb in study
  - Possibility in the other colliders
  - Dream : N-p, N-N, N-Fe (N; Nitrogen) in future

In progress/assured
In consideration

Summary

- Cosmic-ray observation has driven particle physics in 100-50 years ago
- Now, collider physics drive astroparticle physics
- Combining the knowledge from modern UHECR observations and collider physics, particle astronomy will open new window in astronomy



Thank you