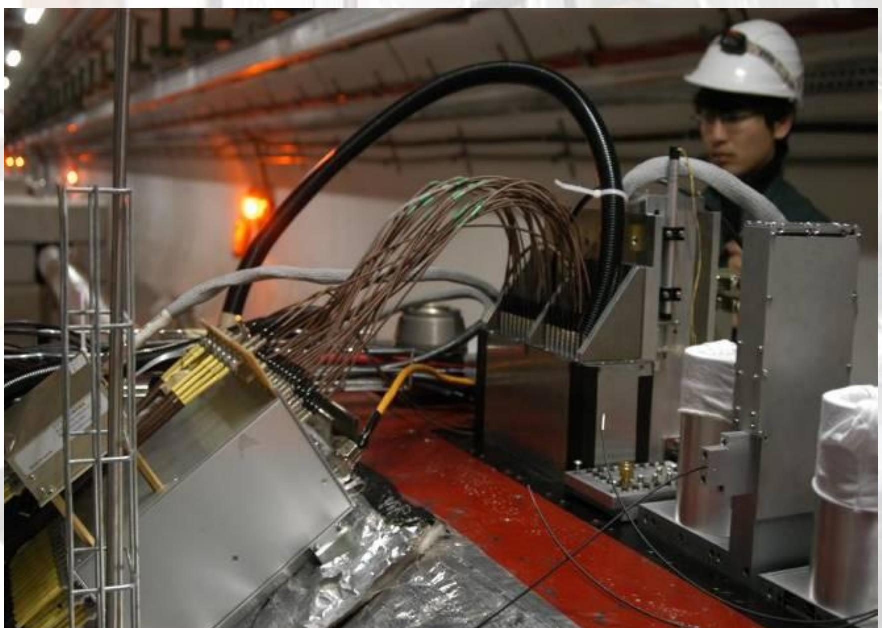
The LHCf experiment

~ cosmic rays and forward hadron physics ~



Yoshitaka Itow
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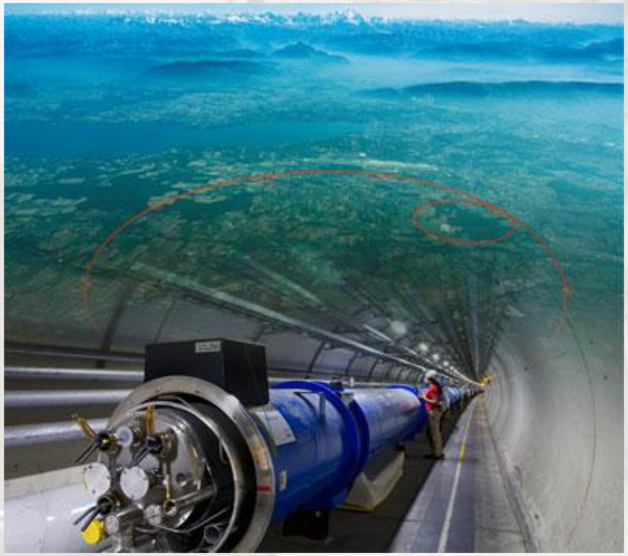
for the LHCf collaboration

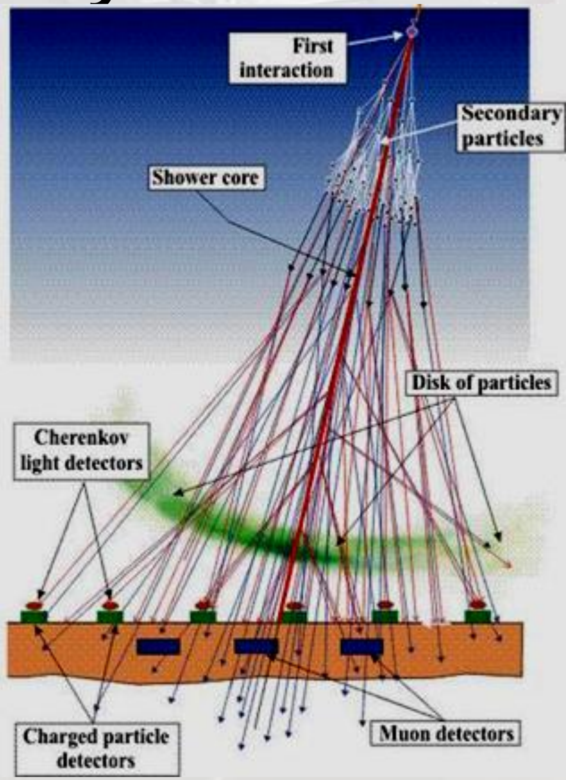
"Future directions in high energy QCD"
Oct 20-22, 2011, RIKEN

Hadron interactions at ultra high energy
Accelerator ⇔ Cosmic rays



Precision improvement

Hint for interaction at ultra-ultra high energy

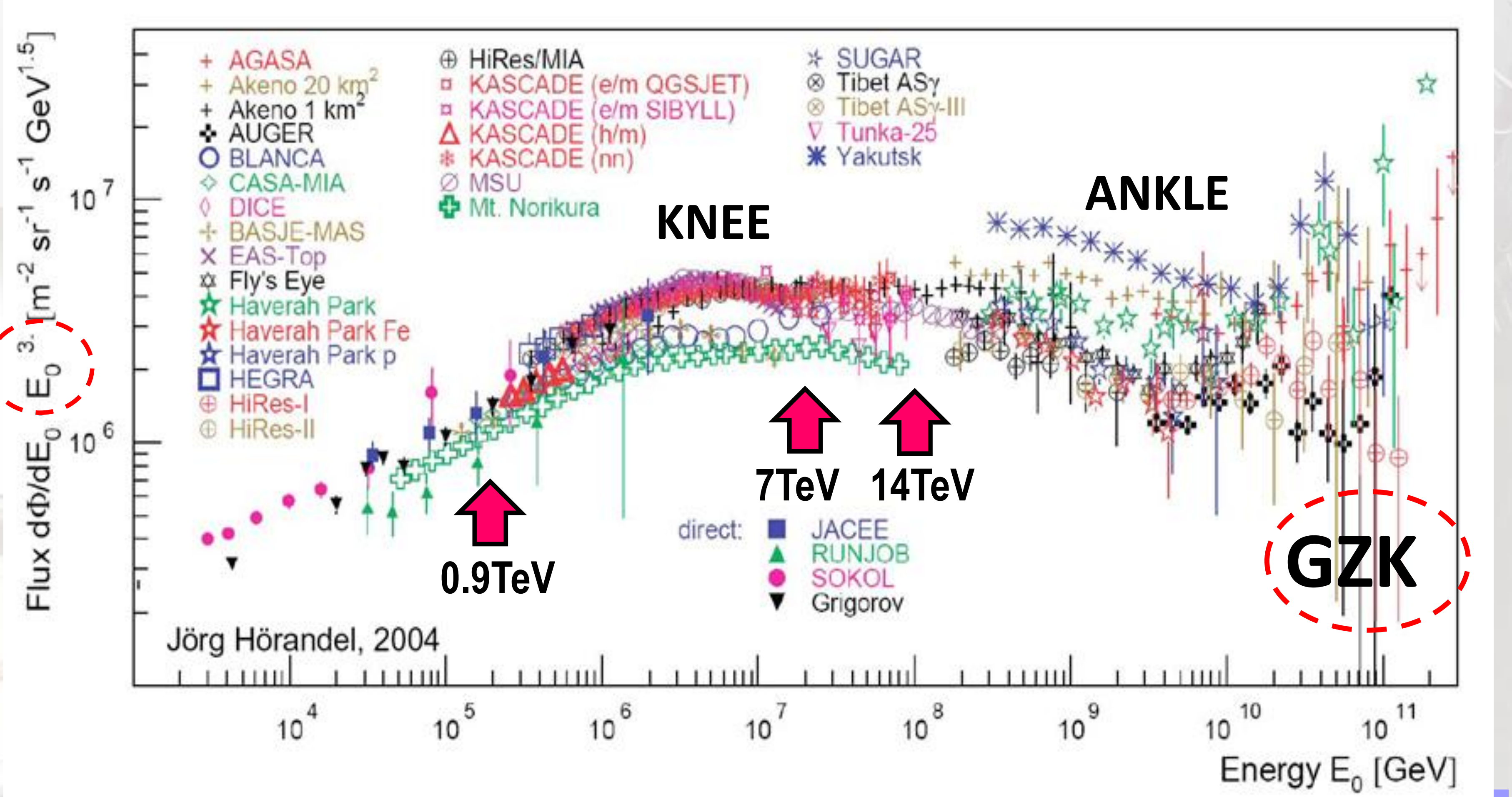


$$E_{CM} \sim (2 \times E_{lab} \times M_p)^{1/2}$$

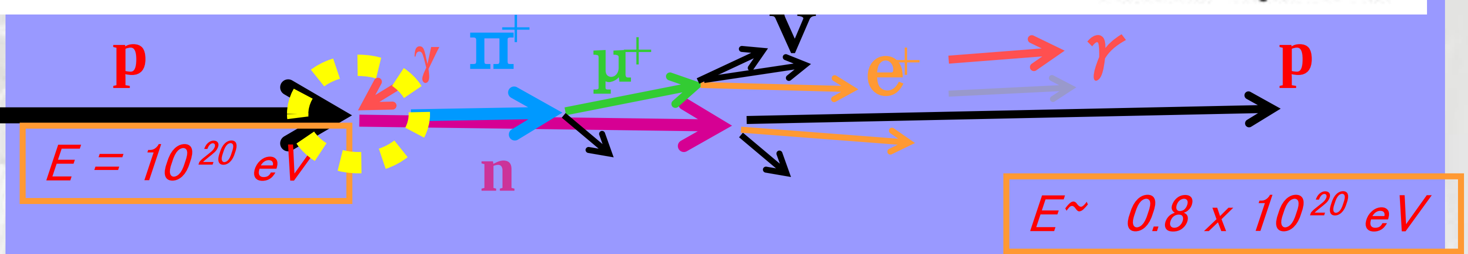
$\sqrt{s}$=14TeV collision at LHC

→10^{17}eV cosmic rays

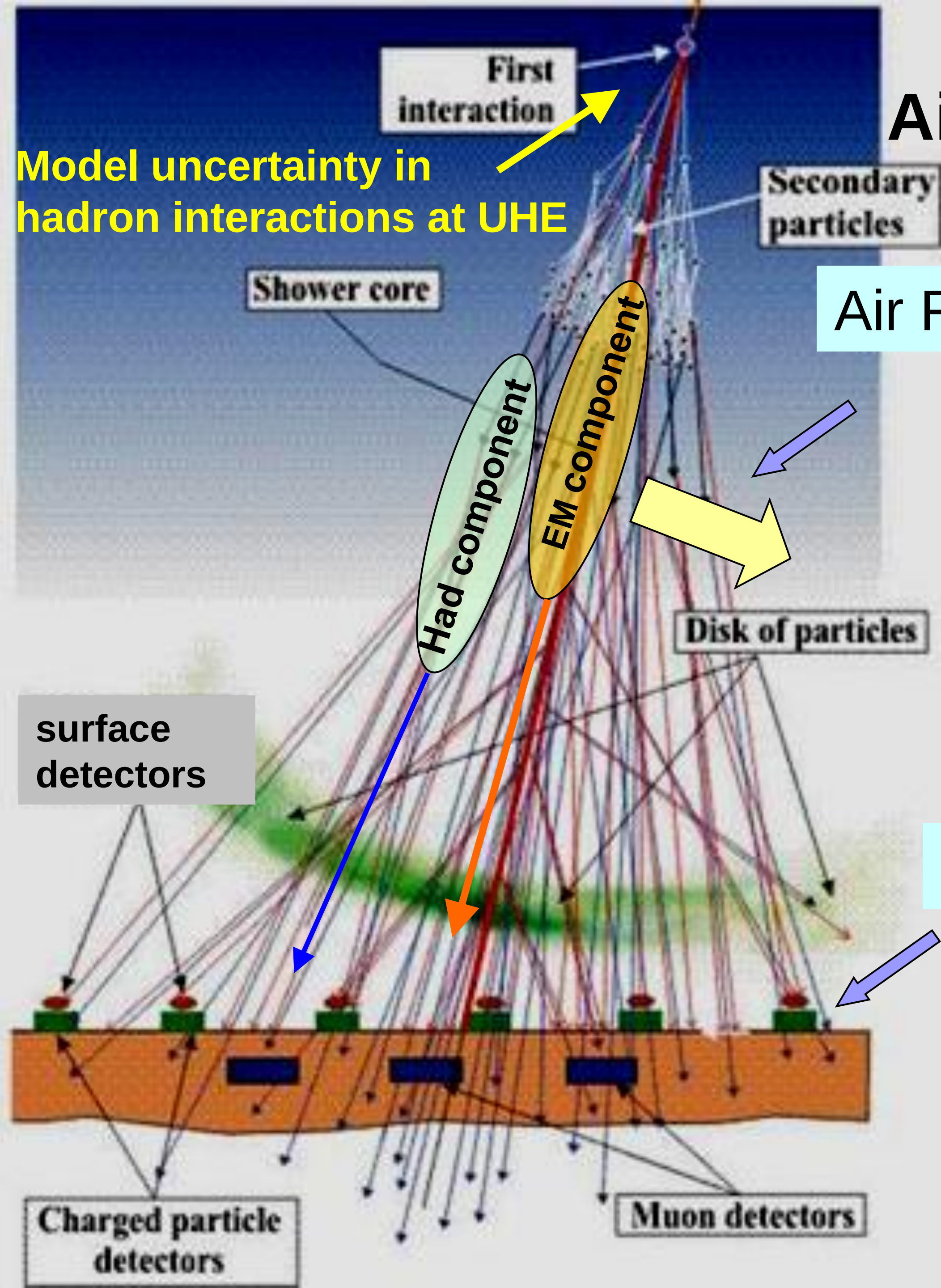
Energy spectrum of UHE cosmic rays



GZK cut off



Air shower observation



Air Florescence telescope (FD)

EM component
(most of energy)

Scintillation lights
Shower directions
Shower max altitude

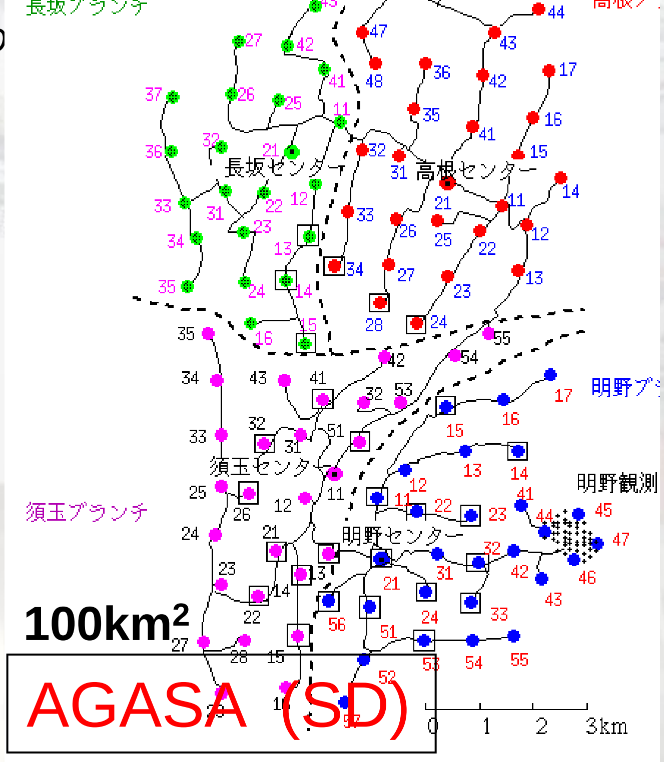
✓ Robust against interaction model.
✓ Detector systematics

Surface Detectors (SD)

Number of particles
Arrival timing
Muon or EM component
(at given altitude)

✓ interaction model dependence.

Airs shower experiments for UHECRs



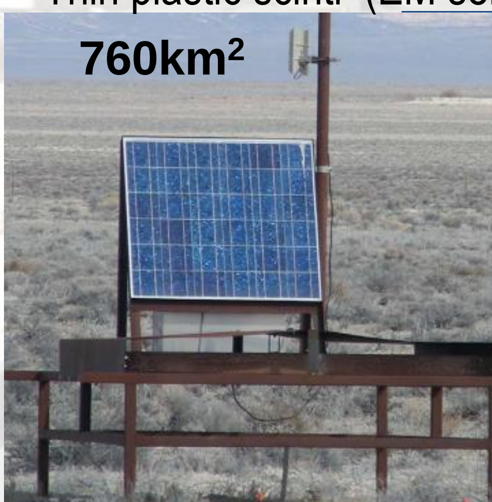
100km^2

AGASA (SD)

HiRes (FD)

Thin plastic scinti (EM sensitive)

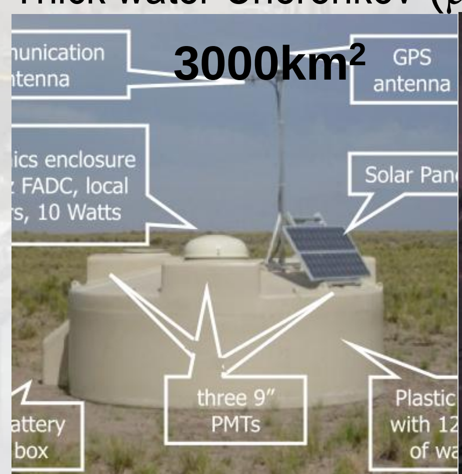
760km^2

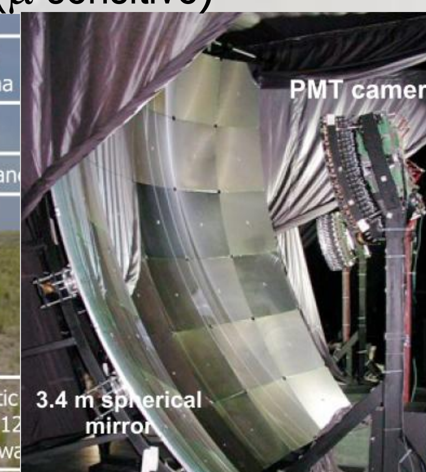


TA (SD+FD)

Thick water Cherenkov (μ sensitive)

3000km^2

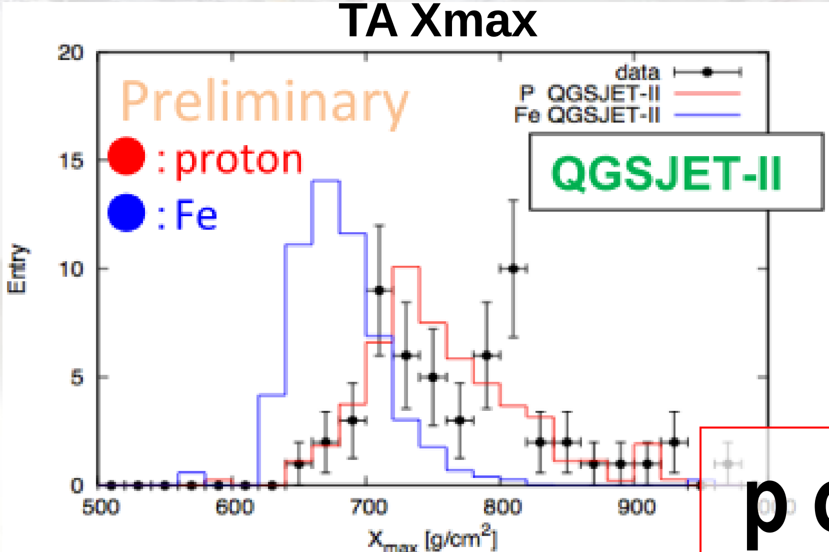


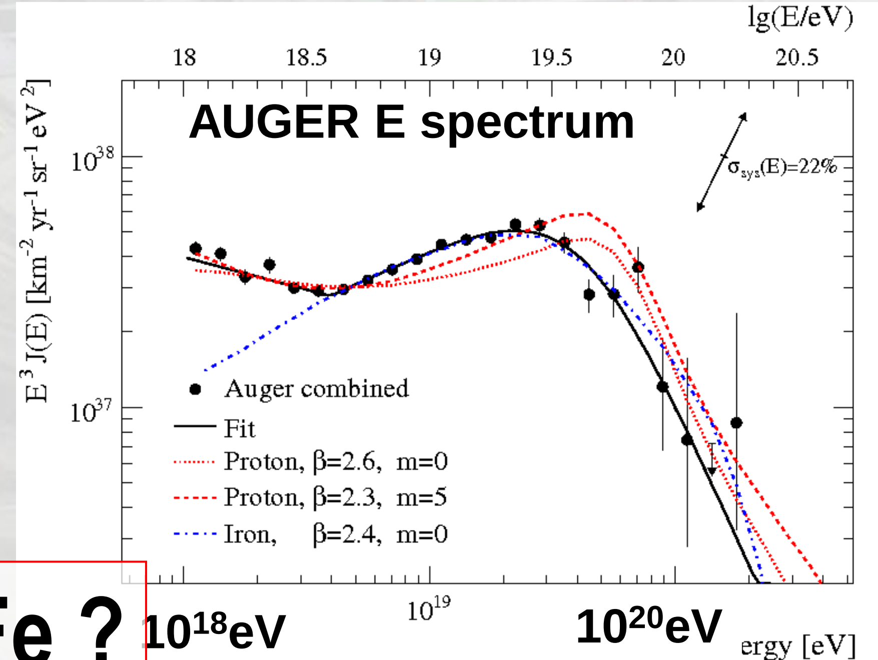


AUGER (SD+FD)

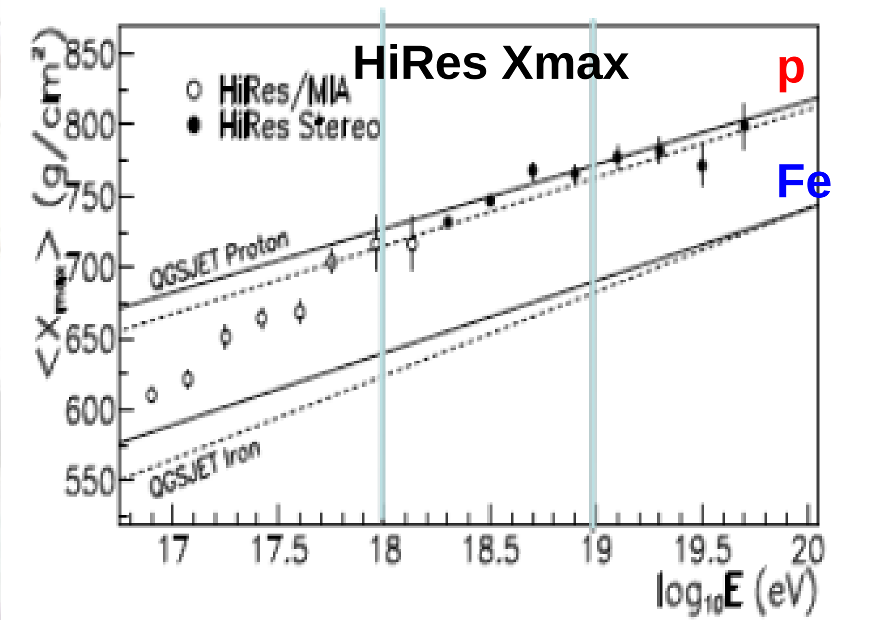
UHECR GZK Problem

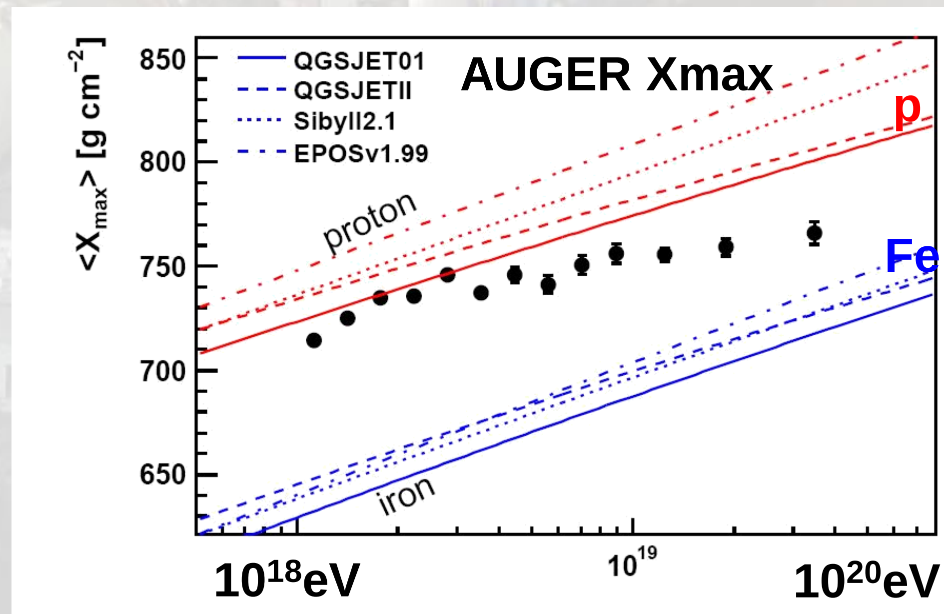
~ recent situation ~



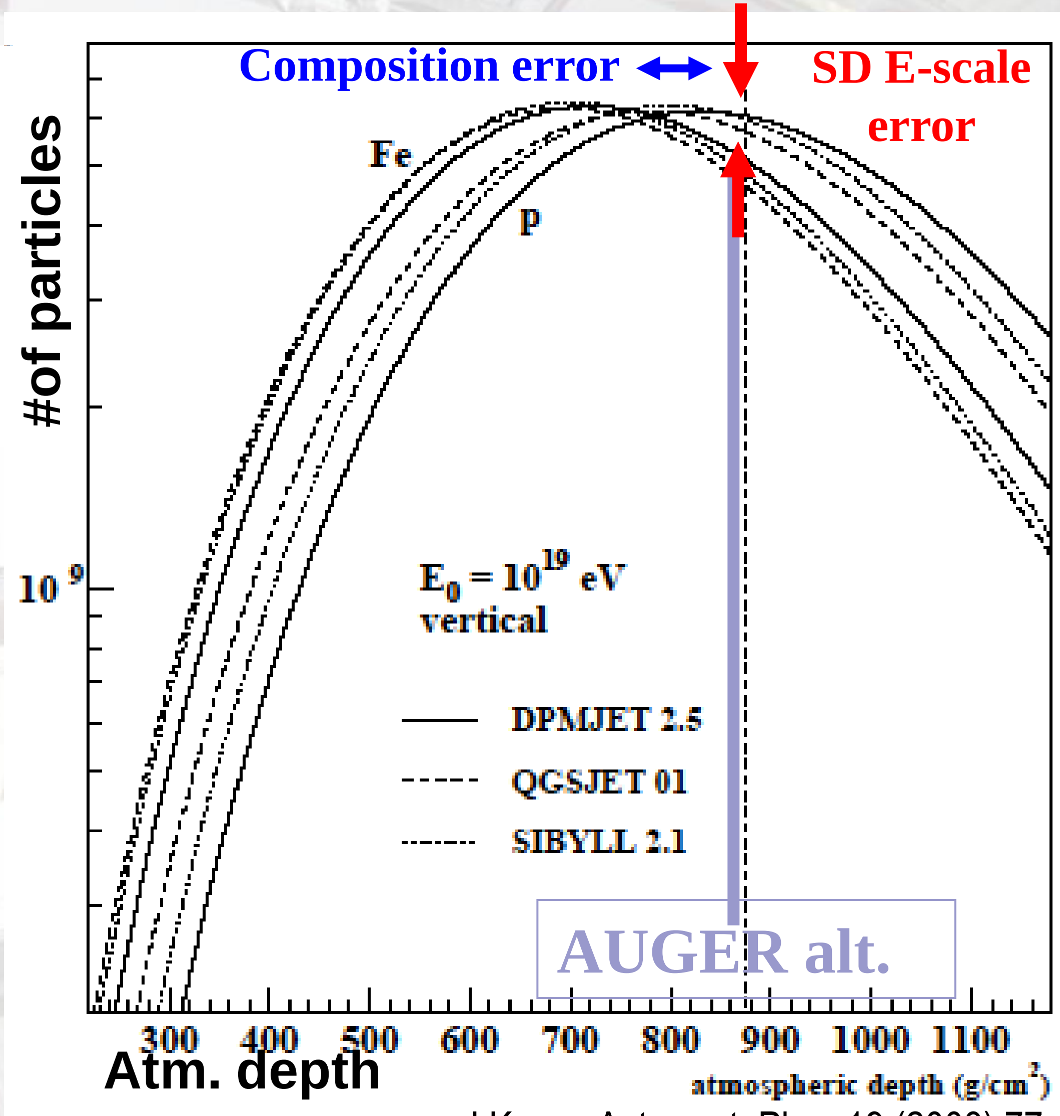


p or Fe ?



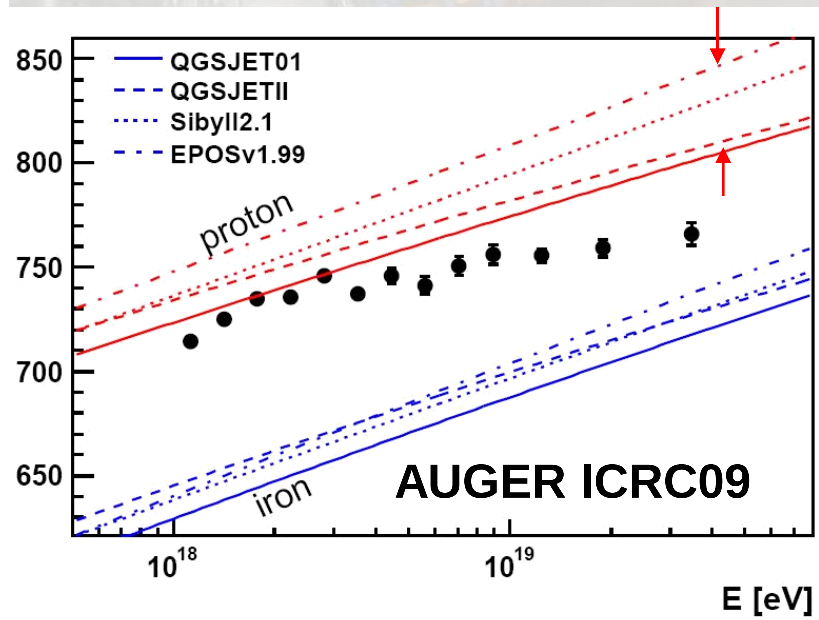


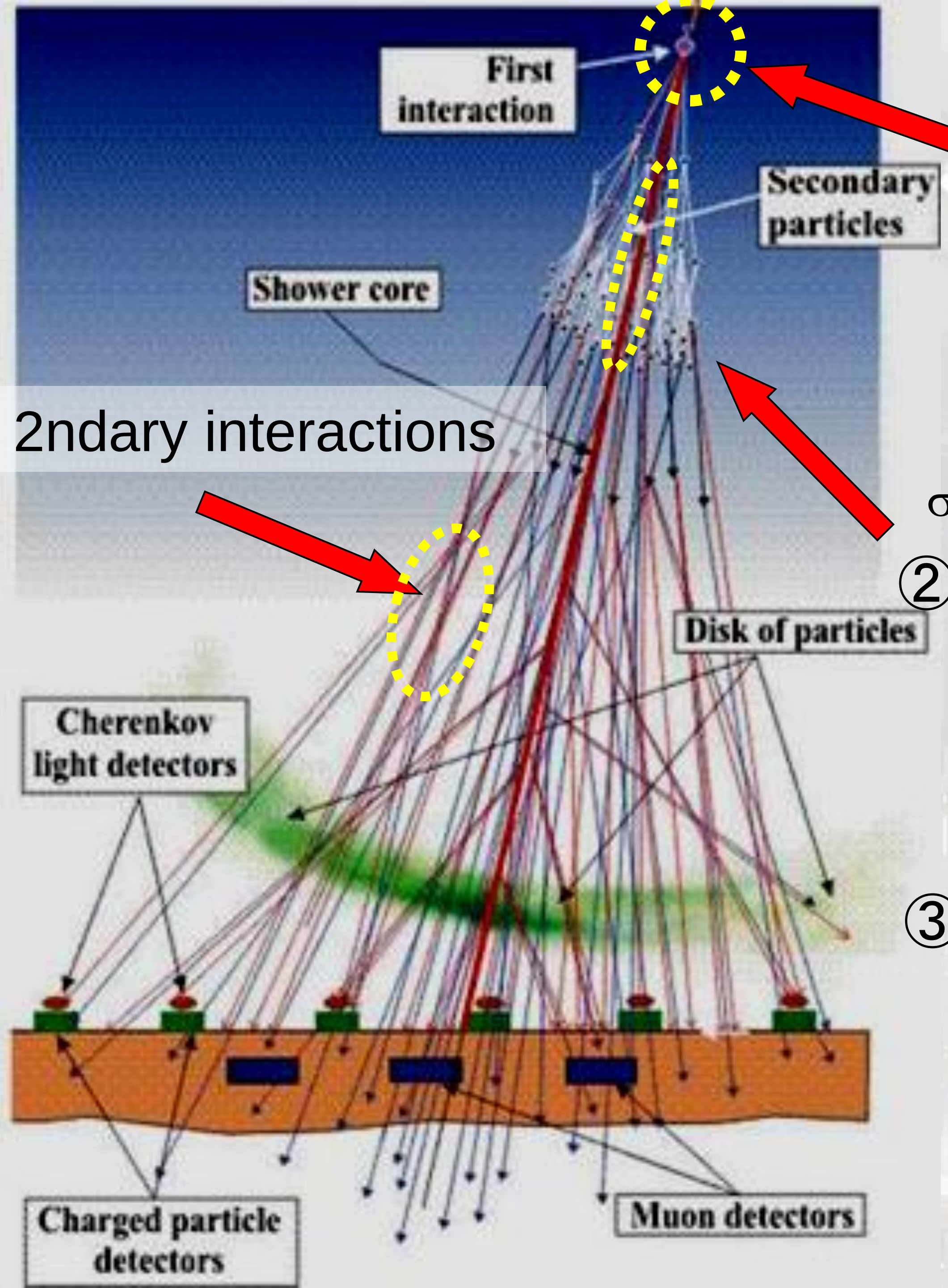
Impact of shower development uncertainty on E-scale/composition



J.Knapp Astropart. Phys.19 (2003) 77

- Surface detector would get uncertainty of E-scale (AGASA claims 20%)
- Florescence should be OK (a few %) for E-scale But FD ←→ SD problem
- Composition uncertainty





④ 2ndary interactions

① Inelastic cross section

If large σ
rapid development
If small σ
deep penetrating

$\sigma_{inela} = 73.5 \pm 0.6^{+1.8}_{-1.3}$ mb(TOTEM)

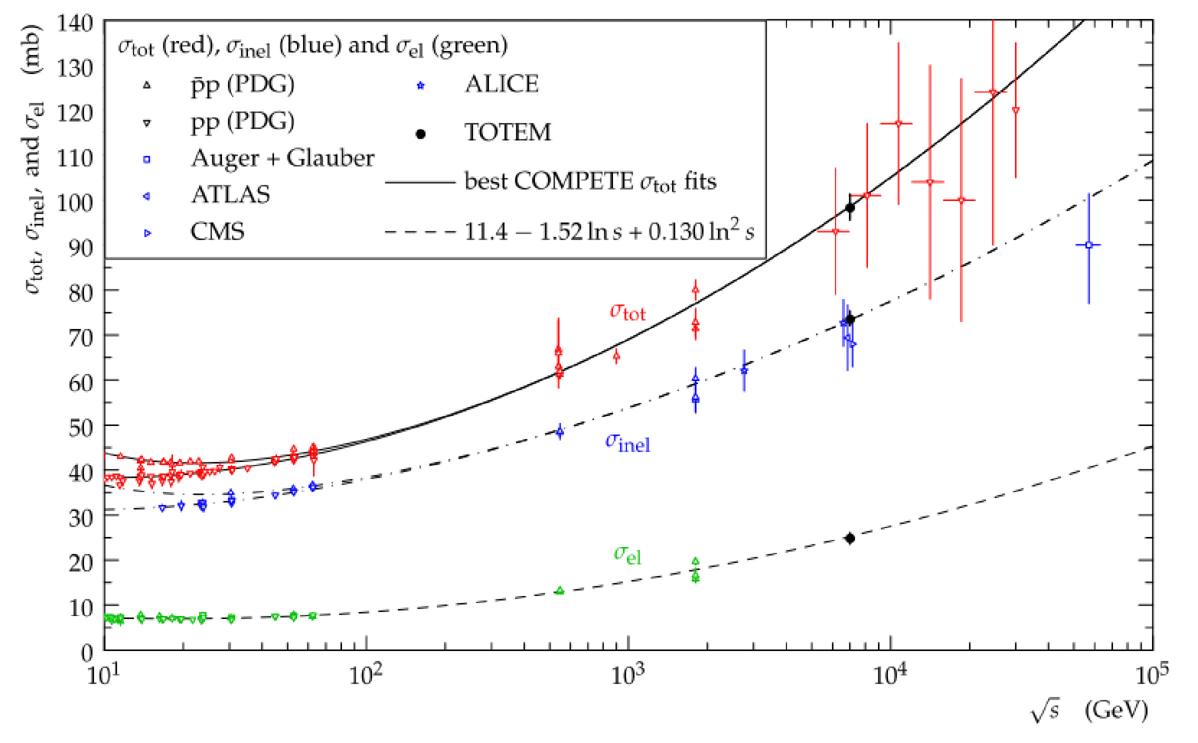
② Forward energy spectrum

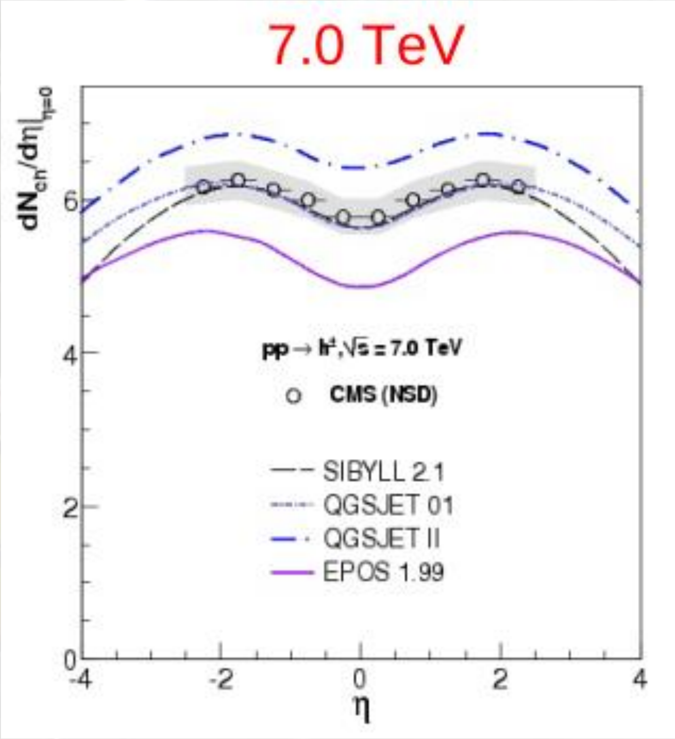
If softer
shallow development
If harder
deep penetrating

③ Inelasticity k

If large k
rapid development
If small k
deep penetrating

Recent input from LHC data

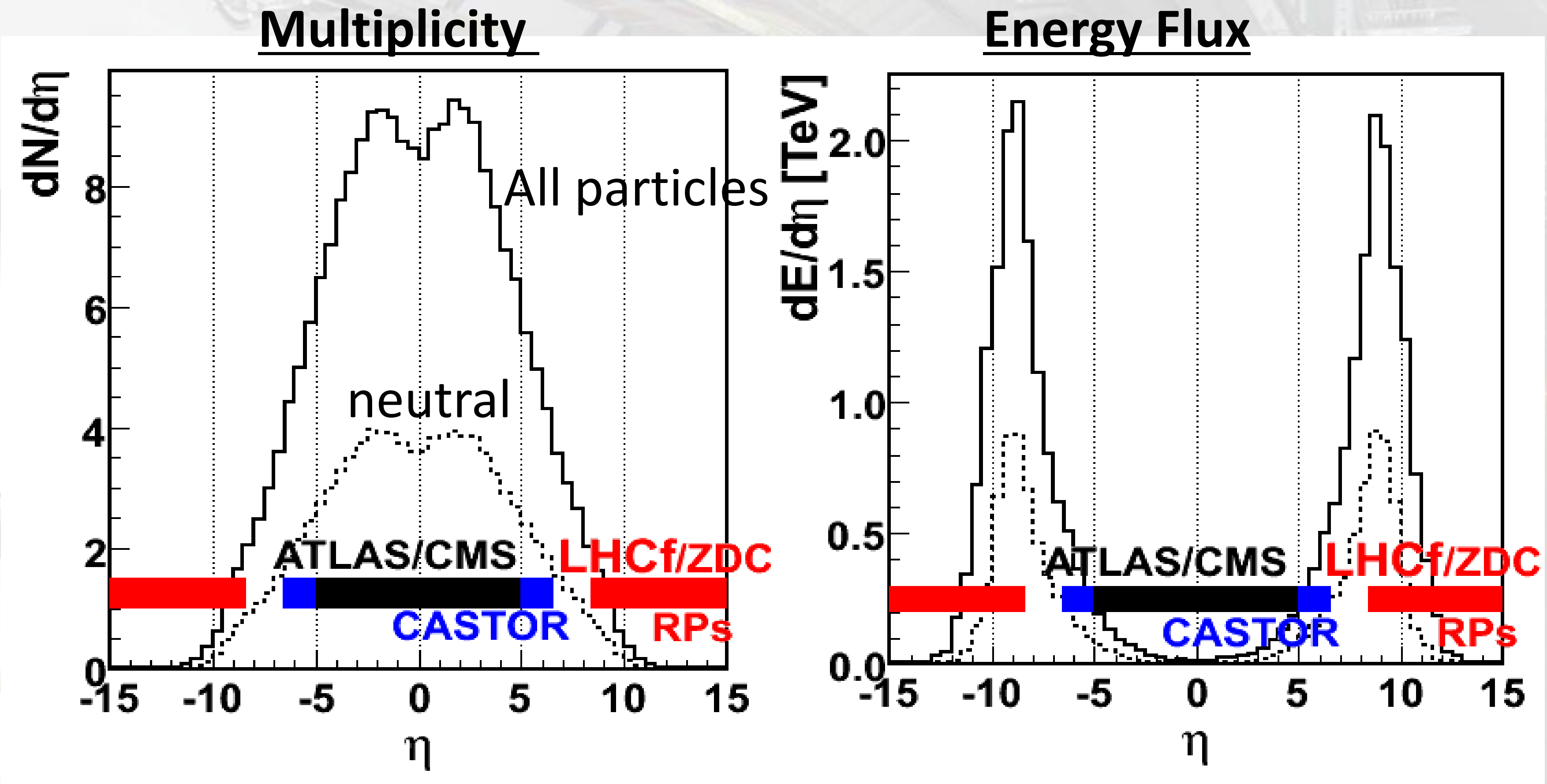




Inelastic cross section

Charged hadron multiplicity

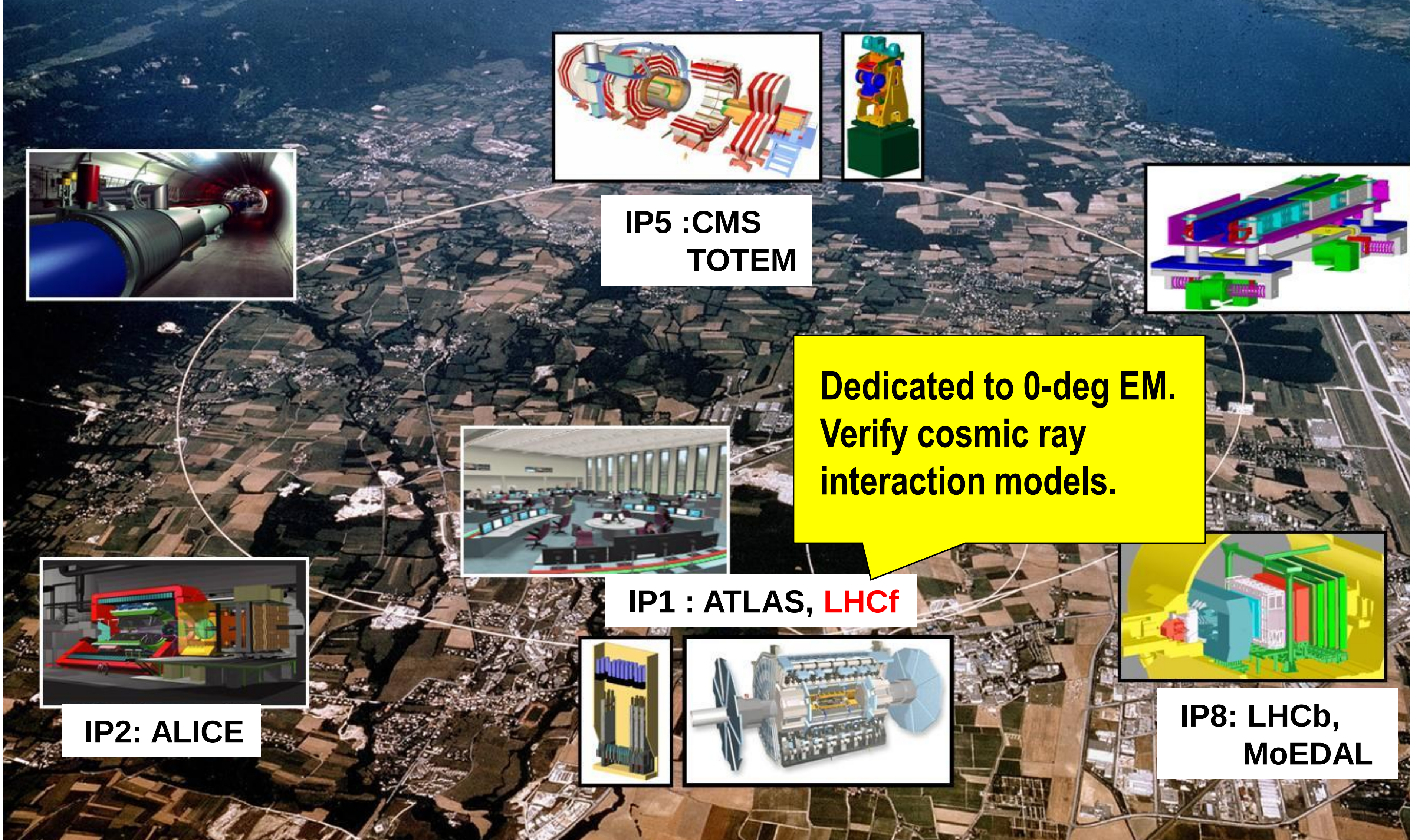
Very forward : Majority of energy flow



Most of the energy flows into very forward

(Particles X_F > 0.1 gives 50% of shower particles)

The seven LHC experiments



The LHCf collaboration

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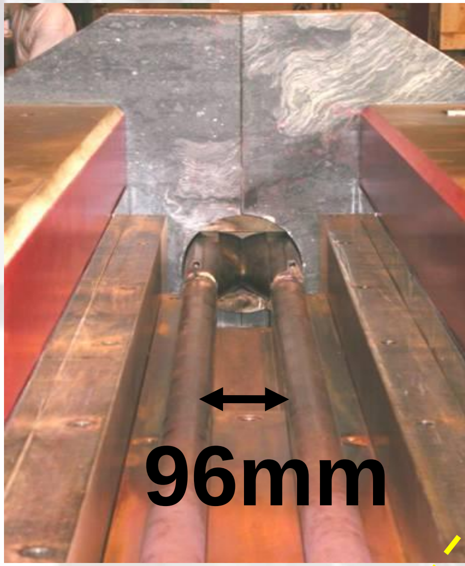
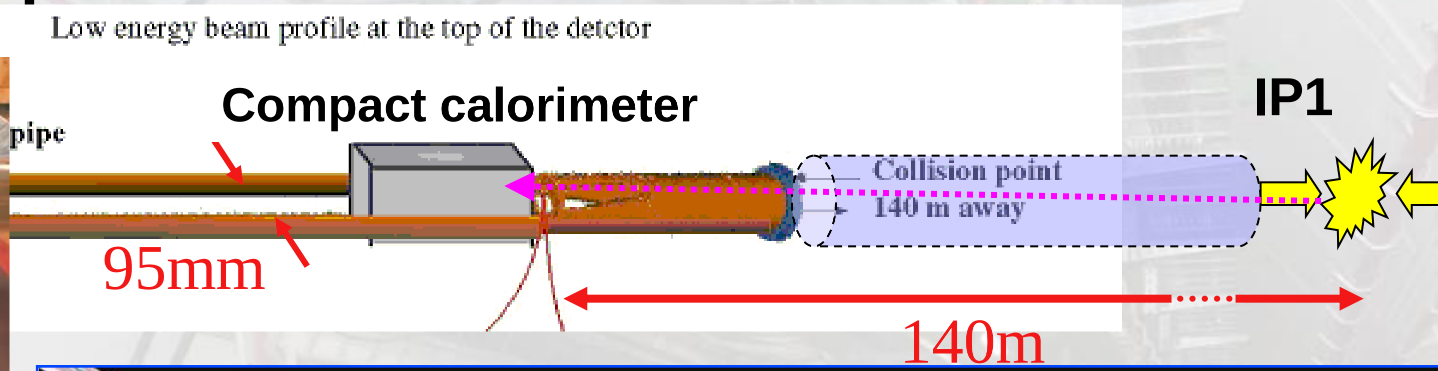
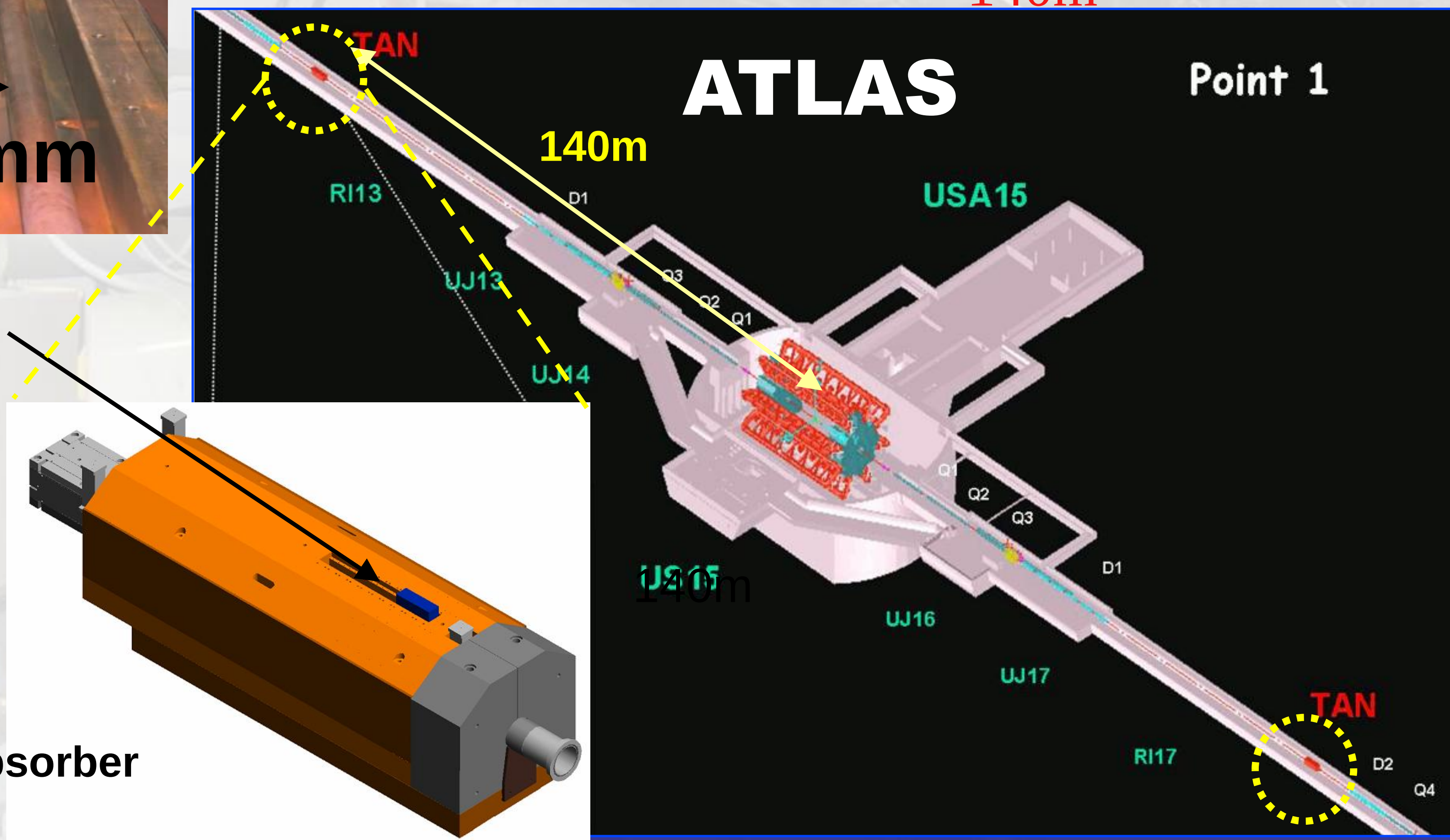
J.Velasco, A.Faus *IFIC, Centro Mixto CSIC-UVEG, Spain*

A-L.Perrot *CERN, Switzerland*

LHCf experimental site



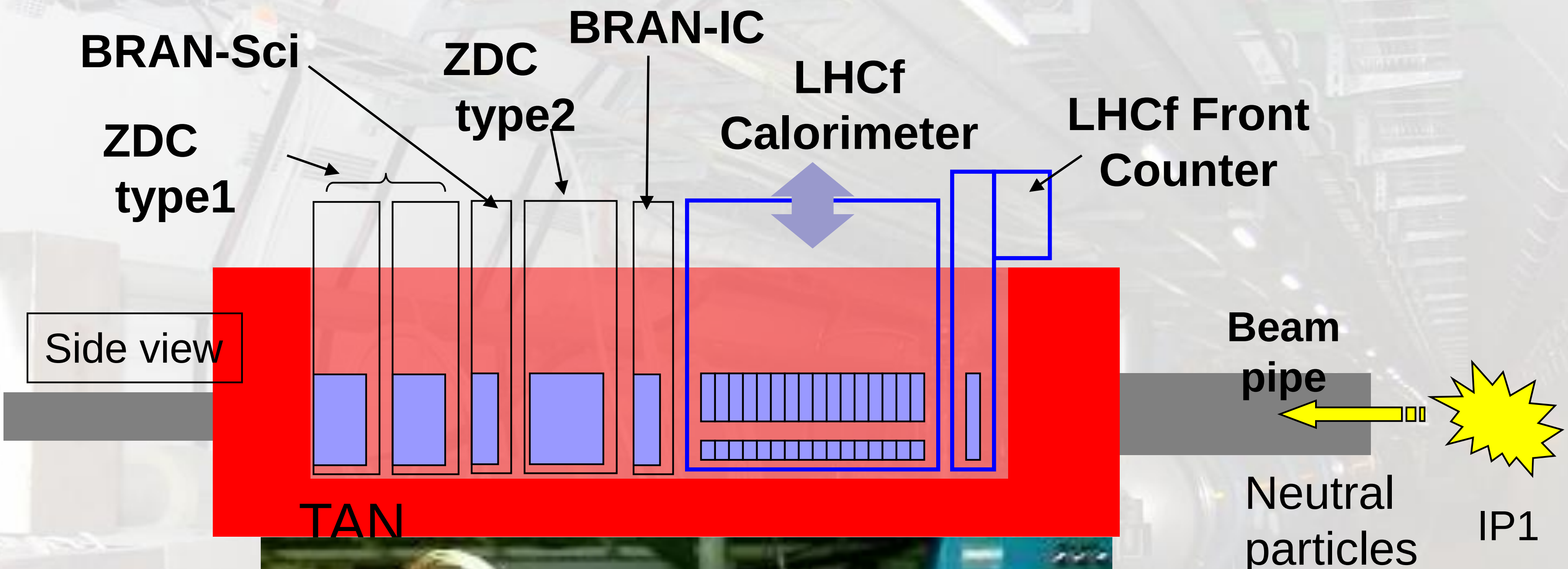




LHCf

TAN absorber

Setup in IP1-TAN (side view)

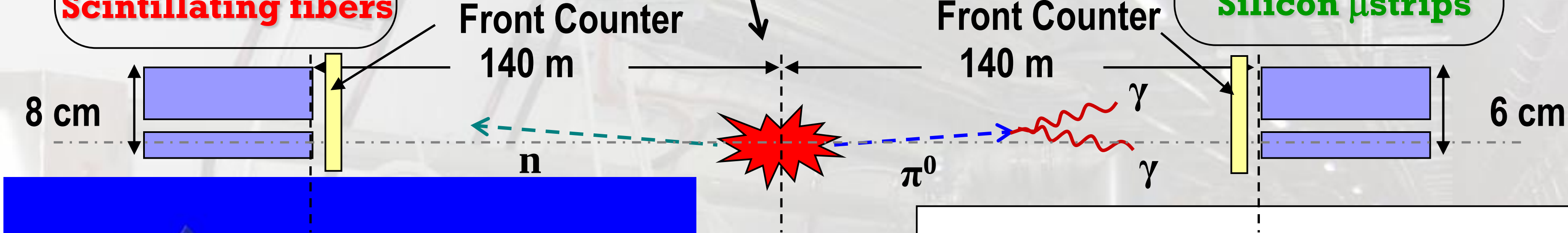


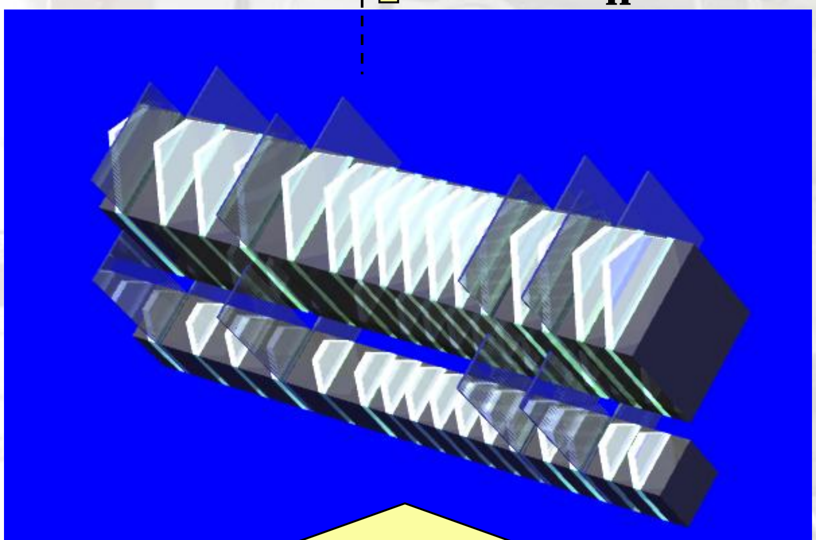
LHCf: location and detector layout

Detector I
Tungsten
Scintillator
Scintillating fibers

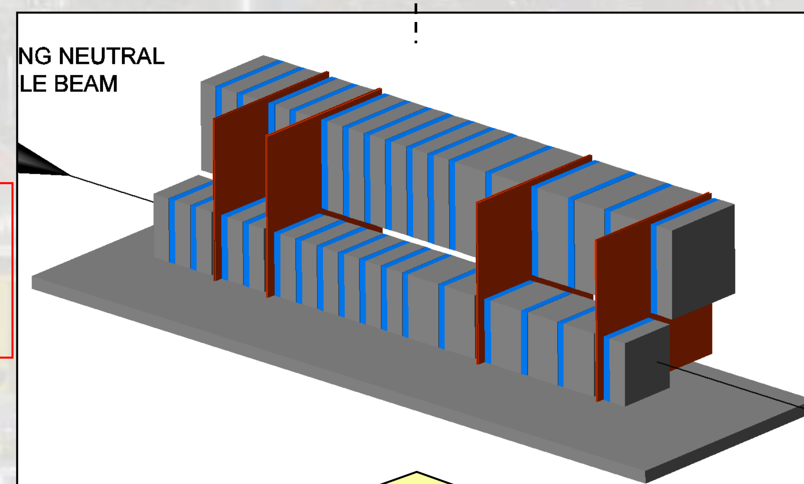
INTERACTION POINT
IP1 (ATLAS)

Detector II
Tungsten
Scintillator
Silicon μstrips





44X_0,
1.6 λ_{int}

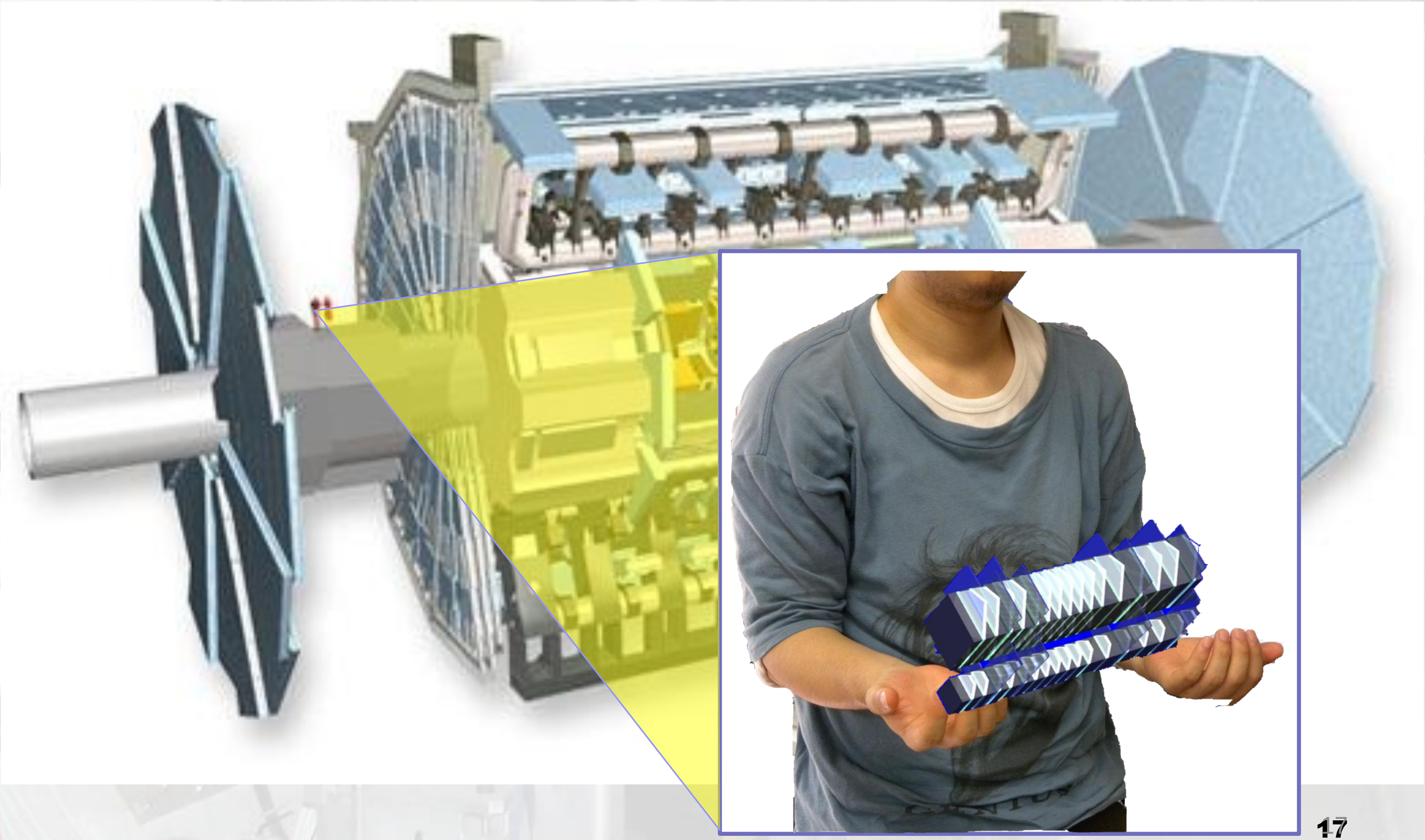


Arm#1 Detector
20mmx20mm+40mmx40mm
4 SciFi tracking layers

Arm#2 Detector
25mmx25mm+32mmx32mm
4 Silicon strip tracking layers

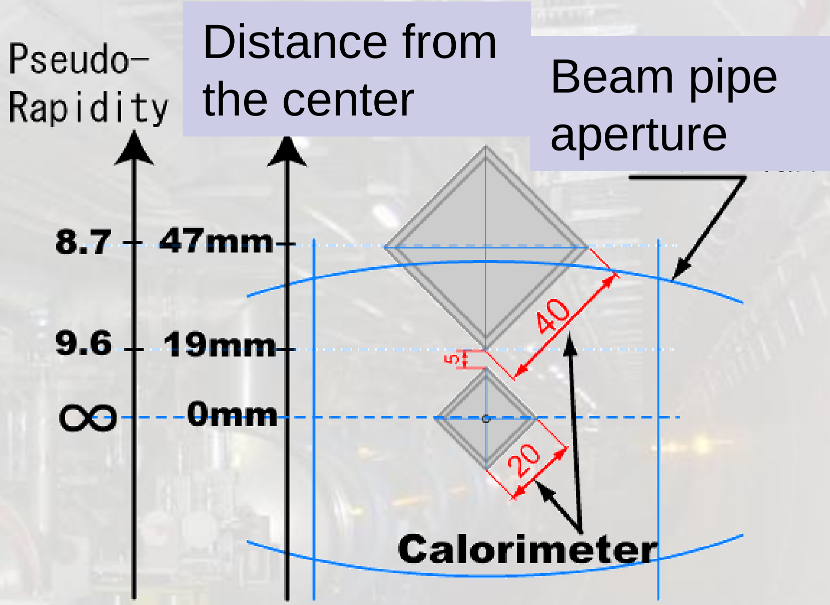
LHCf calorimeters

ATLAS & LHCf



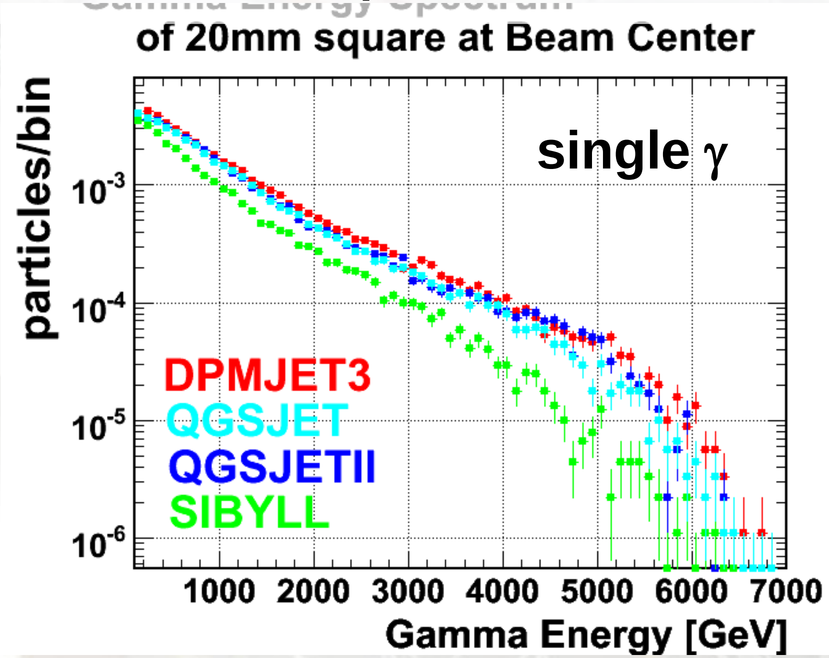
LHCf detector characteristics

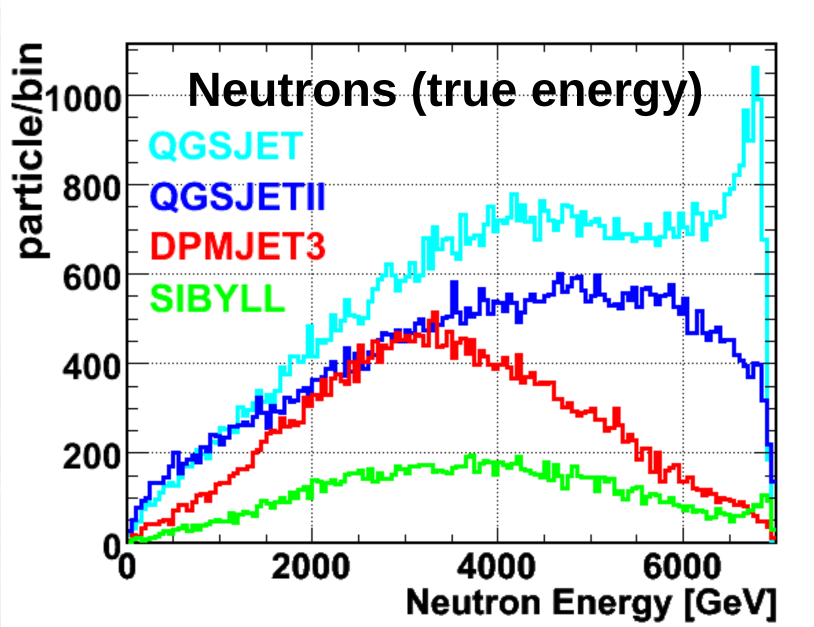
- Single incident per tower with the small aperture as possible (comparable to tungsten Moliere radius)
- Shower leakage can be corrected by shower incident position.
- A pair of tower for π^0 reconstruction
- Movable to cover P_T gap
- Covered $|\eta| > 8.4$

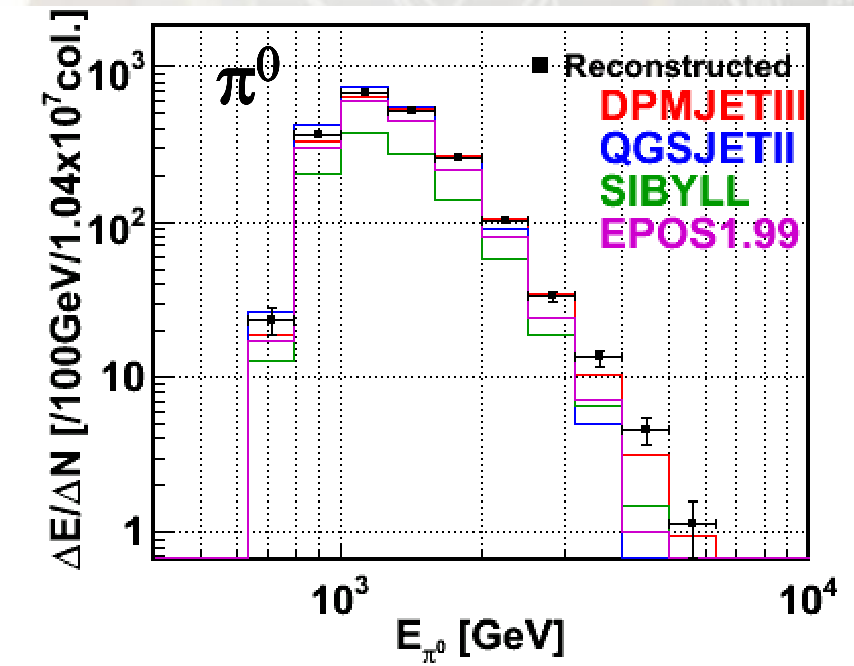


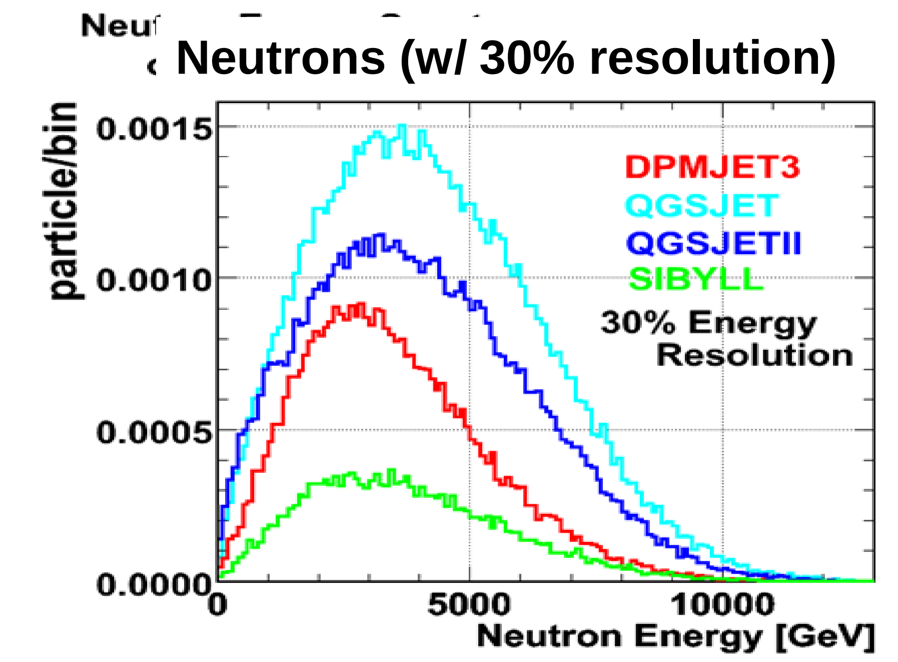
- **Gamma-rays (E>100GeV,dE/E<5%)**
- **Neutral Hadrons (E>a few 100 GeV, dE/E~30%)**
- **Neutral Pions (E>700GeV, dE/E<3%)**
- **Shower incident position (170μm / 40μm for Arm1/Arm2**

Forward E spectra forseen at 14TeV (MC for ~0.1nb^{-1})









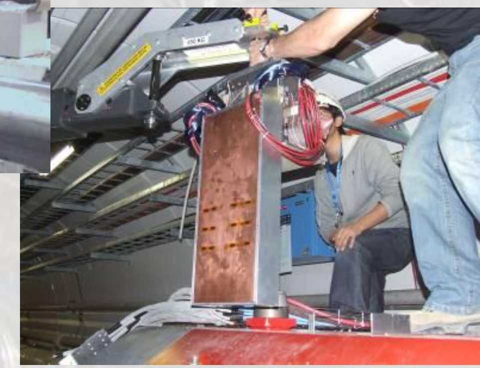
Brief history of LHCf

- May 2004 LOI
- Feb 2006 TDR
- June 2006 LHCC approved

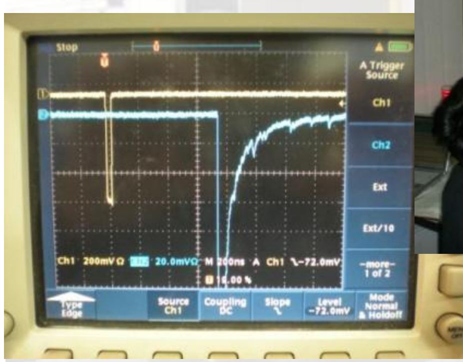
Jul 2006 construction

Aug 2007 SPS beam test

Jan 2008 Installation

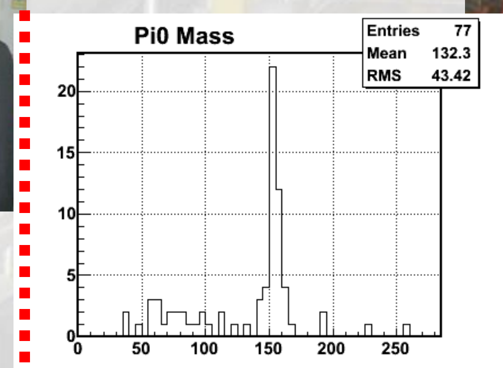


Sep 2008 1st LHC beam



Dec 2009 1st 900GeV run

Mar 2010 1st 7TeV run

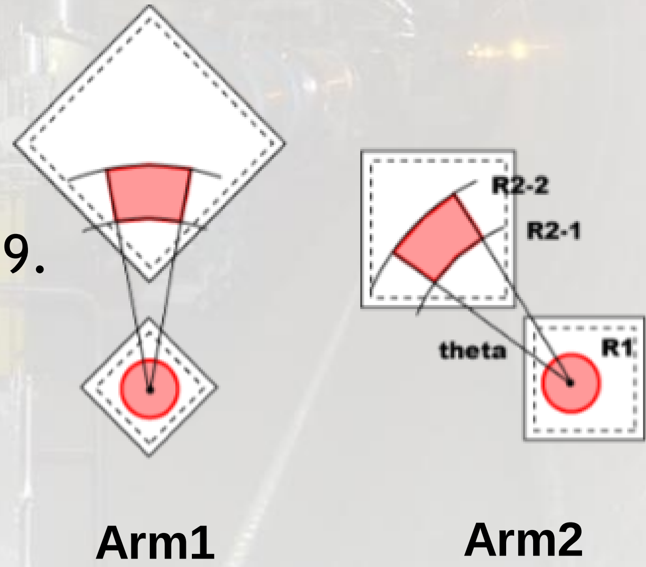


Jul 2010 Detector removal

The single photon energy spectra at 0 degree

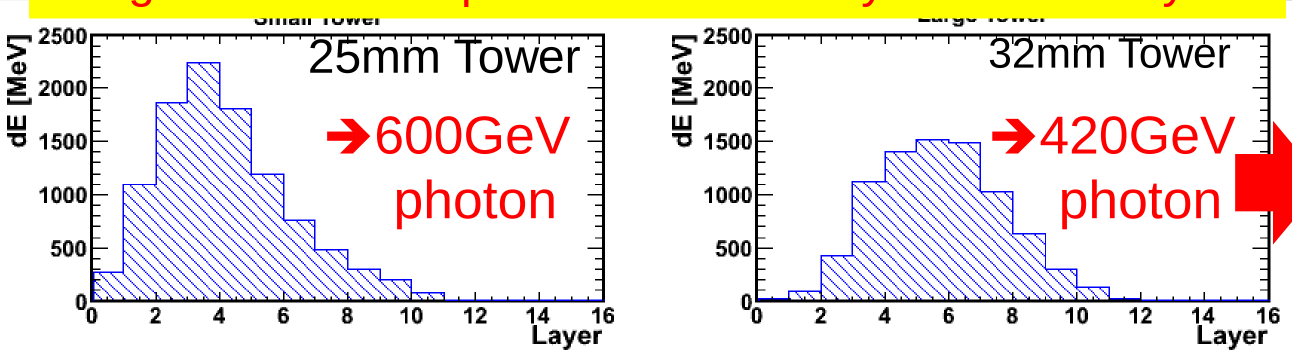
(O.Adriani et al., PLB**703 (2011) 128-134**

- DATA
  - 15 May 2010 17:45-21:23, at Low Luminosity $6x10^{28}cm^{-2}s^{-1}$, no beam crossing angle
  - 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
  - Two pseudo-rapidity, η>10.94 and 8.81<η<8.9.
  - No correction for geometrical acceptance.
  - Combine spectra between Arm1 and Arm2.
  - **Normalized by number of inelastic collisions** with assumption as σ_{inela} = 71.5mb. (c.f. $73.5\pm0.6^{+1.8}_{-1.3}$ mb by TOTEM)



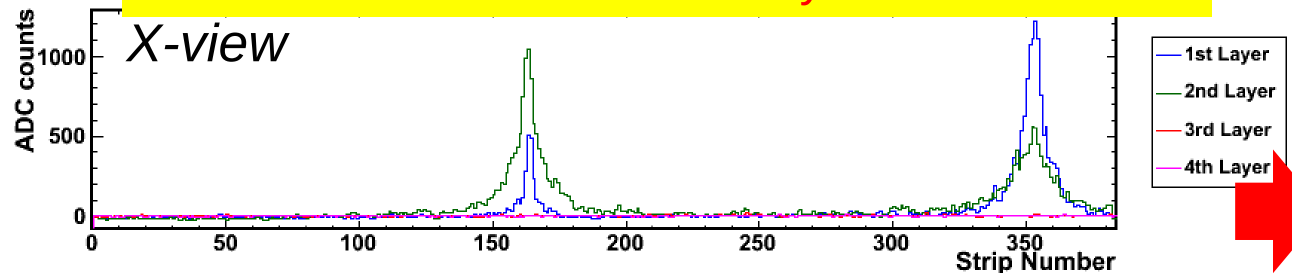
Event sample

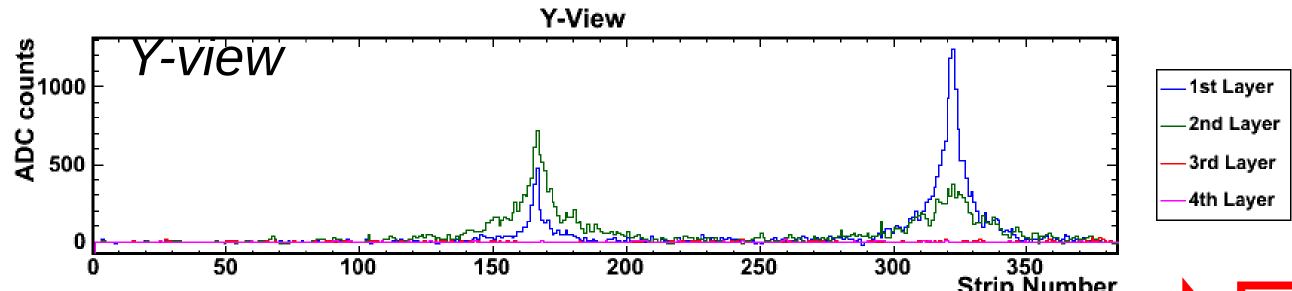
Longitudinal development measured by scintillator layers



Total Energy deposit
➔Energy
Shape
➔PID

Lateral distribution measured by silicon detectors





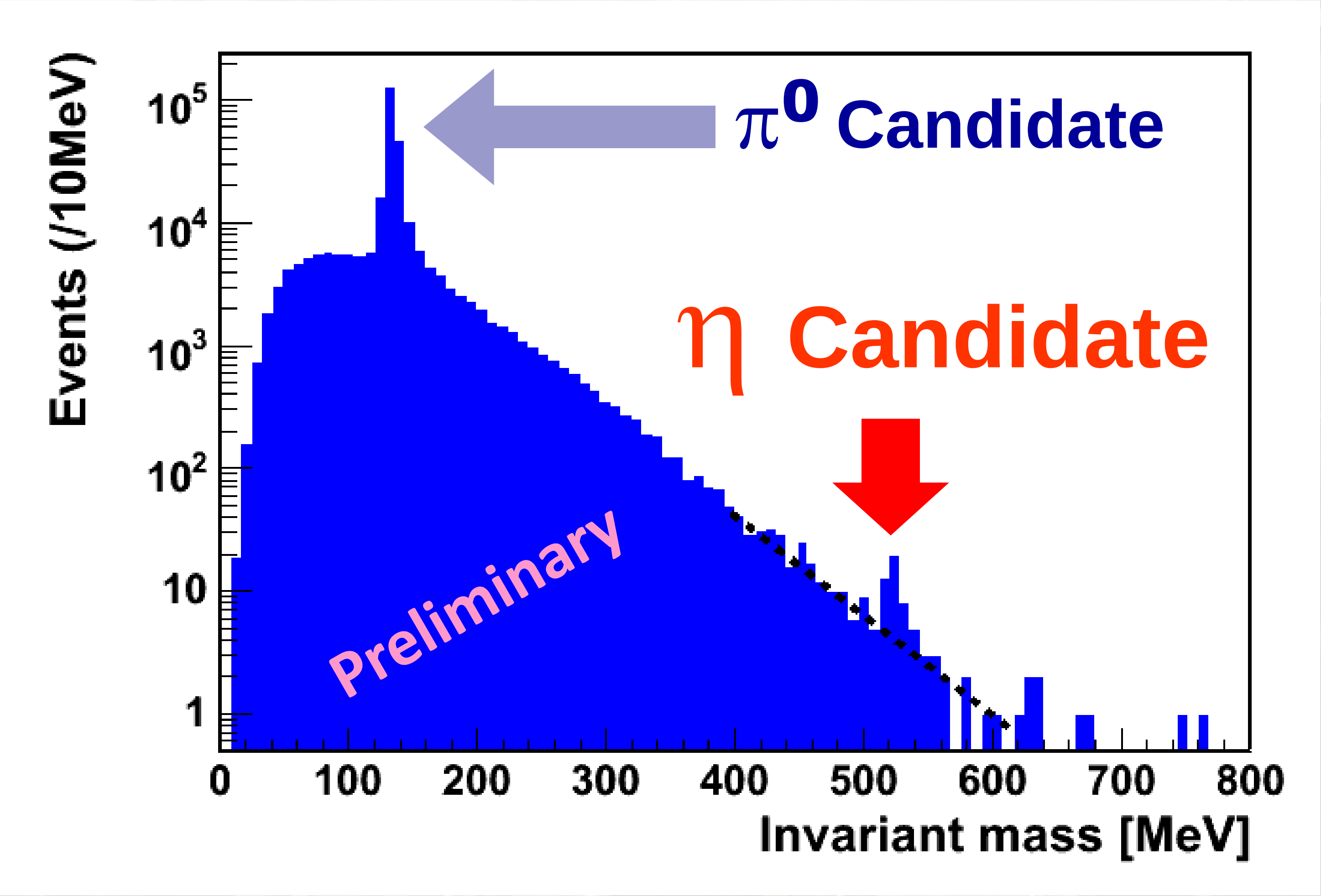
Hit position,
Multi-hit search.

π^0 mass reconstruction from two photon.

$$M_{p0} = \sqrt{E_{g1}E_{g2}} \times q$$

Systematic studies

Reconstruction of π^0, η



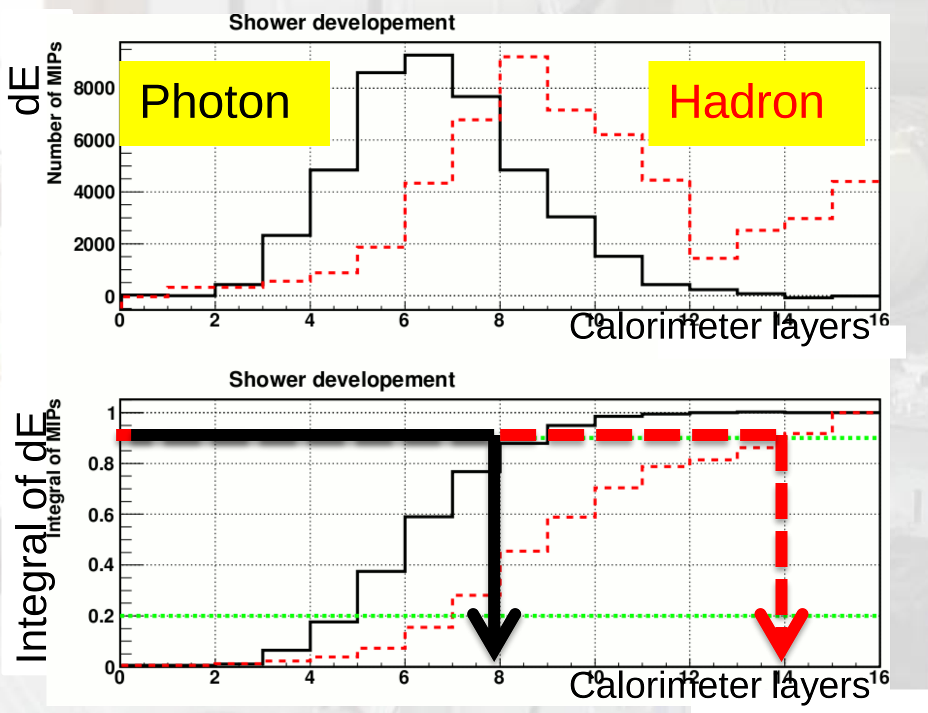
Another good energy calibration point.
Production yield of η much differs among the models.

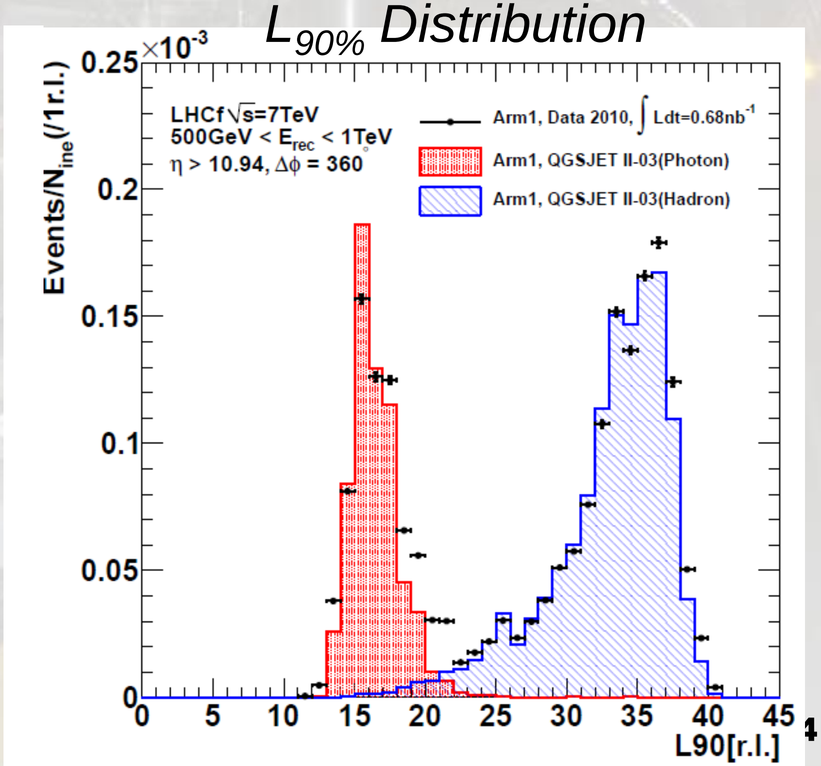
Particle Identification

Calorimeter Depth

Elemag: 44r.l.
Hadronic: 1.7λ

- 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.

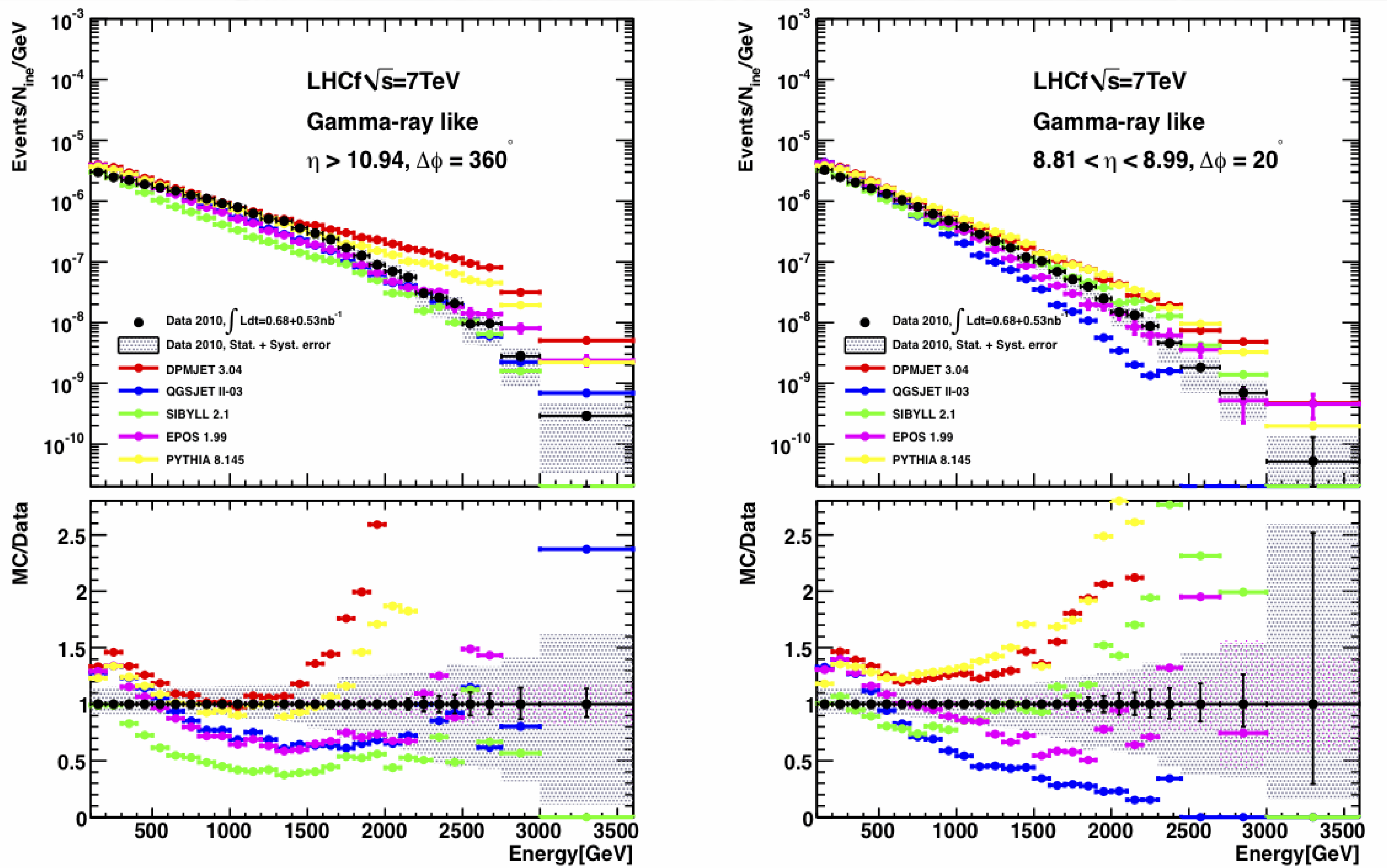




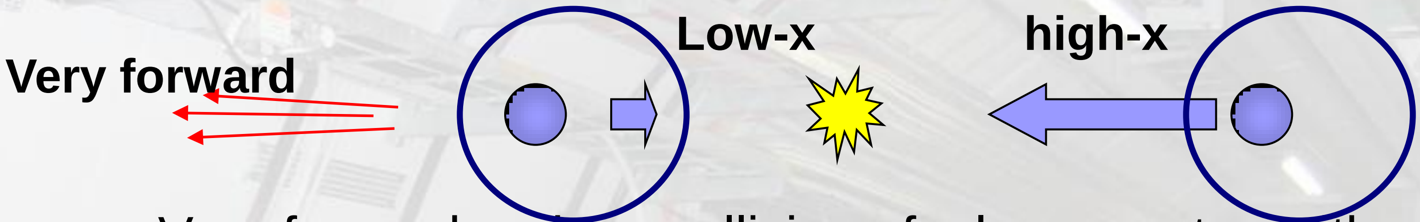
Comparison between MC's

DPMJET 3.04 QGSJETII-03 SIBYLL 2.1 EPOS 1.99 PYTHIA 8.145

Gray hatch : Systematic Errors **Blue hatch: Statistics errors of MC**



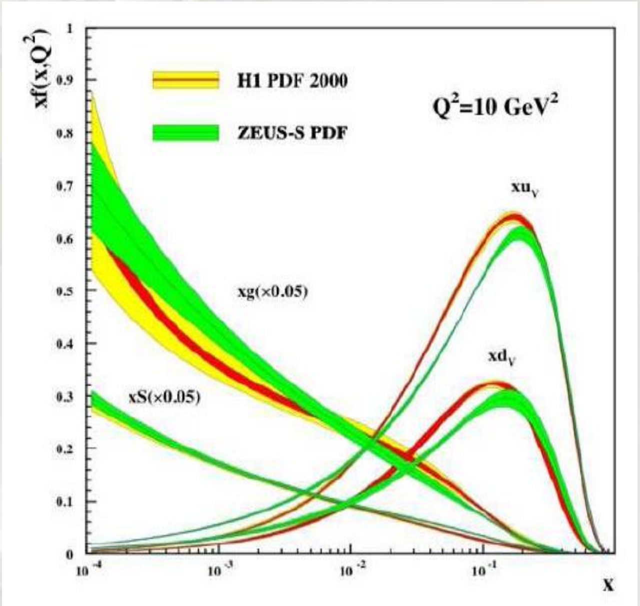
Very forward – connection to low-x physics



- Very forward region : collision of a low-x parton with a large-x parton
- Small-x gluon become dominating in higher energy collision by self interaction.
- But they may be saturated (Color Glass Condenstation)

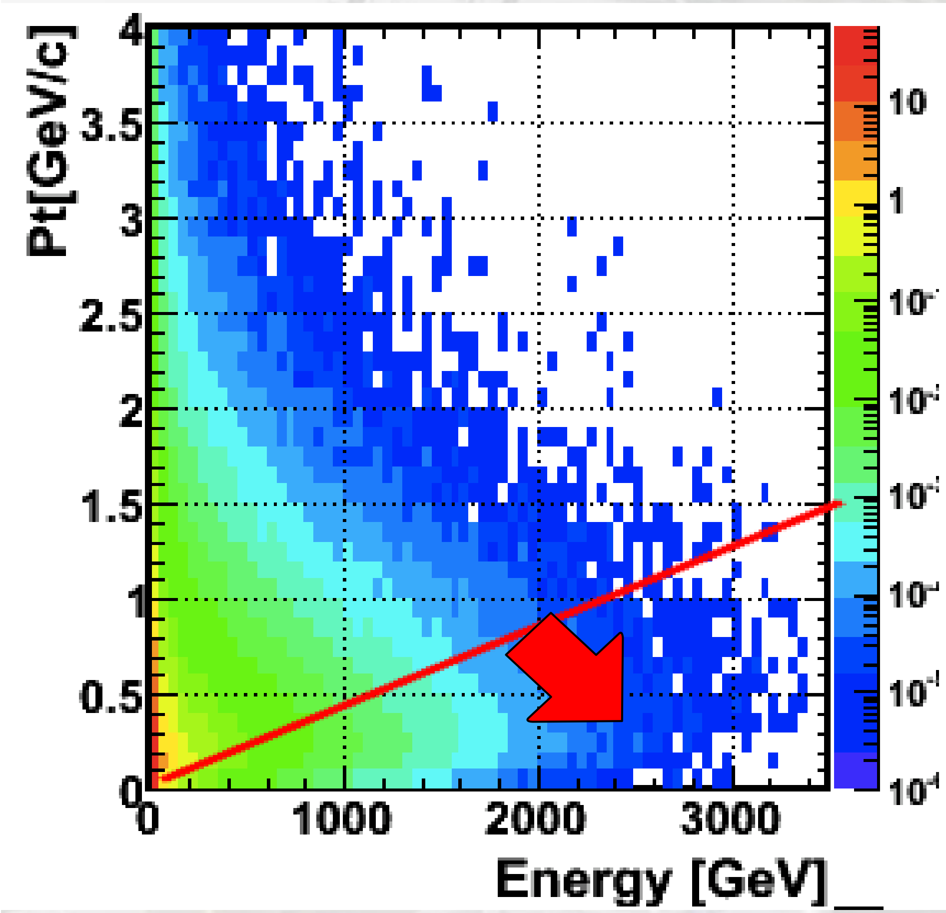
Naively CGC-like suppression may occur in very forward at high energy

→ **However situation is more complex**
(not simple hard parton collsions,
but including soft + semi-hard)

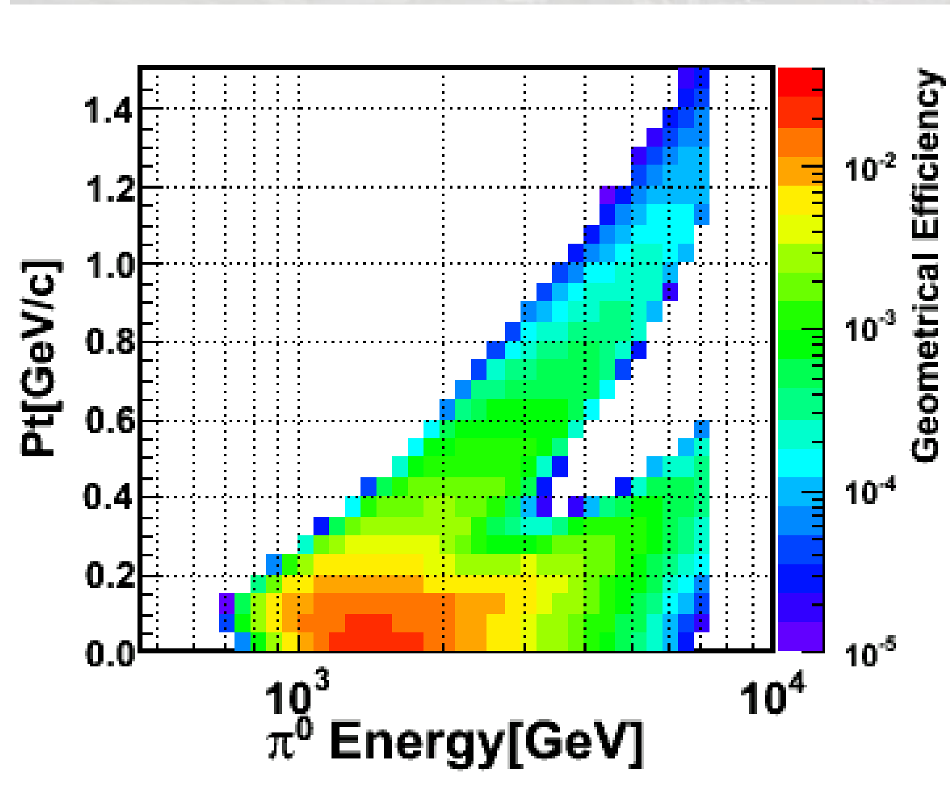


What P_T range LHCf sees ?

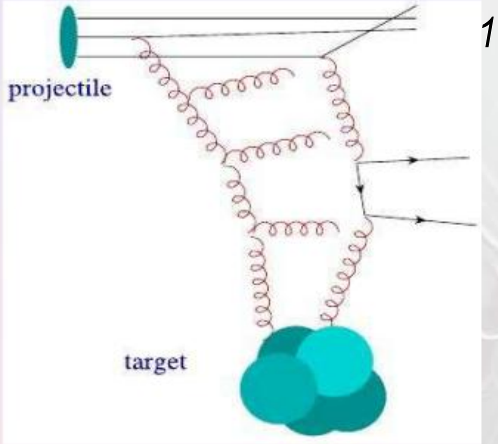
γ



π^0

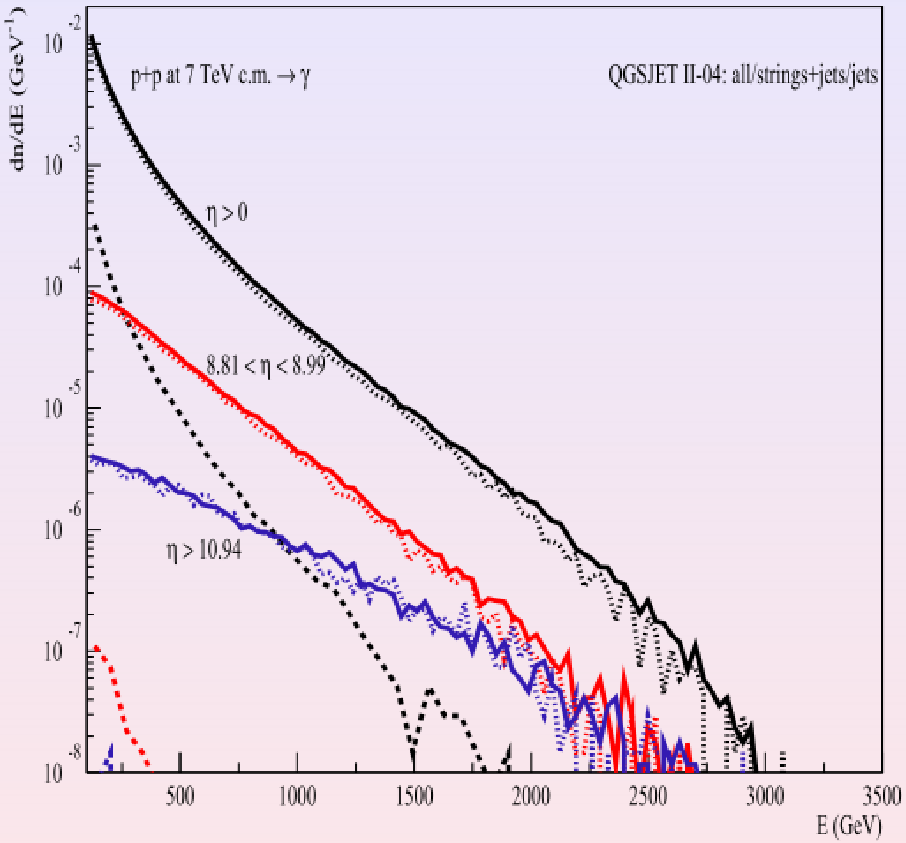


pp 7TeV, EPOS



[picture from R. Engel]

Forward spectra of γs: partial contributions



- forward γ-spectra – mainly hadronization of 'soft' partons ('soft' strings)
- small contribution of proton 'remnants' (both diffractive & ND interactions)
- hadronization of high p_t partons – unobservable by LHCf

By S.Ostapchenko

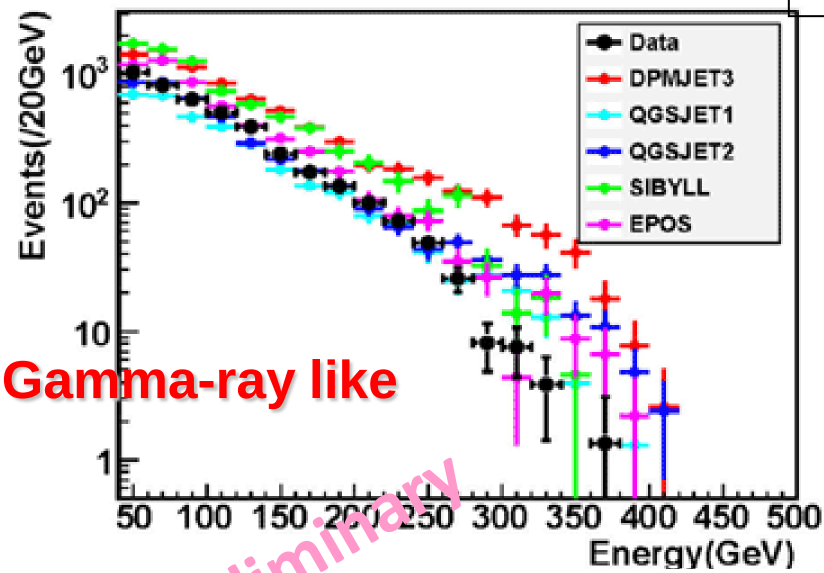
Future direction of LHCf

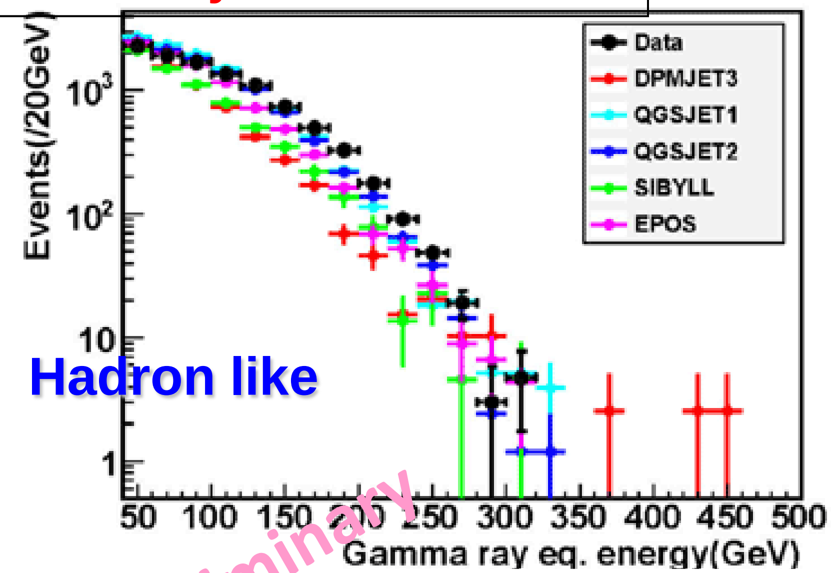
- Different collision energy
- Nuclear effect (p-A, A-A runs)
- RHIC 0degree ?

900GeV spectra

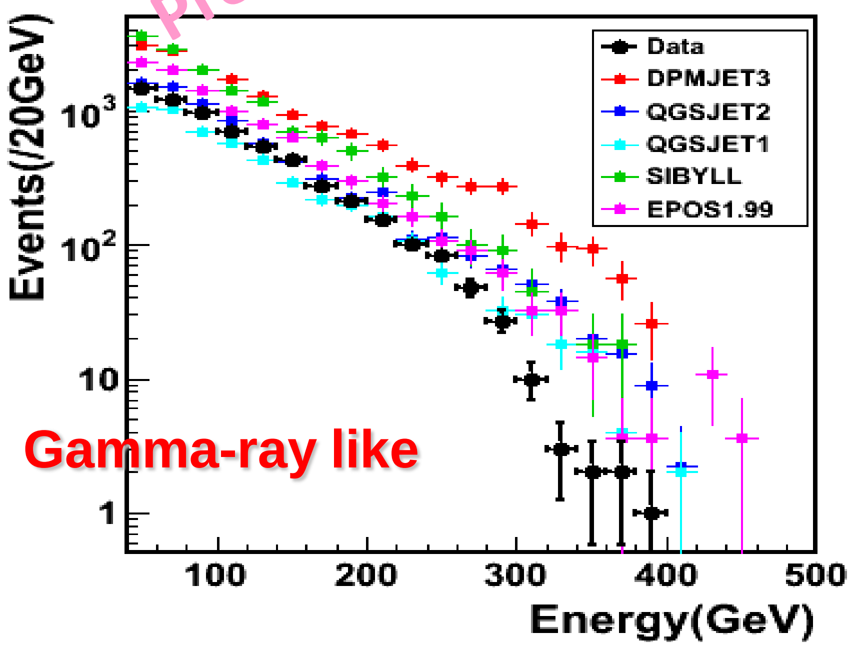
Eff. uncorrected, stat.error only
Normalized by total # of events.

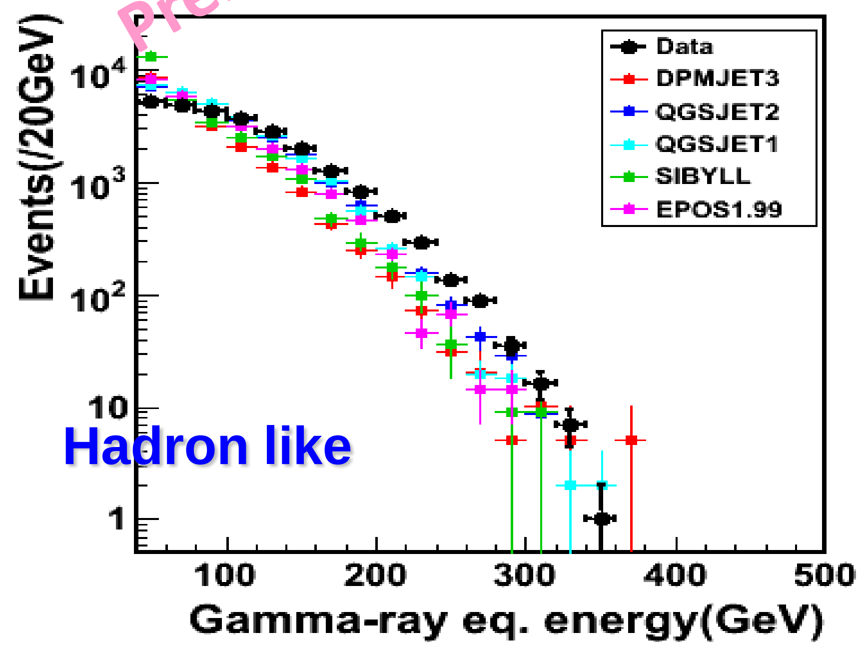
Arm1



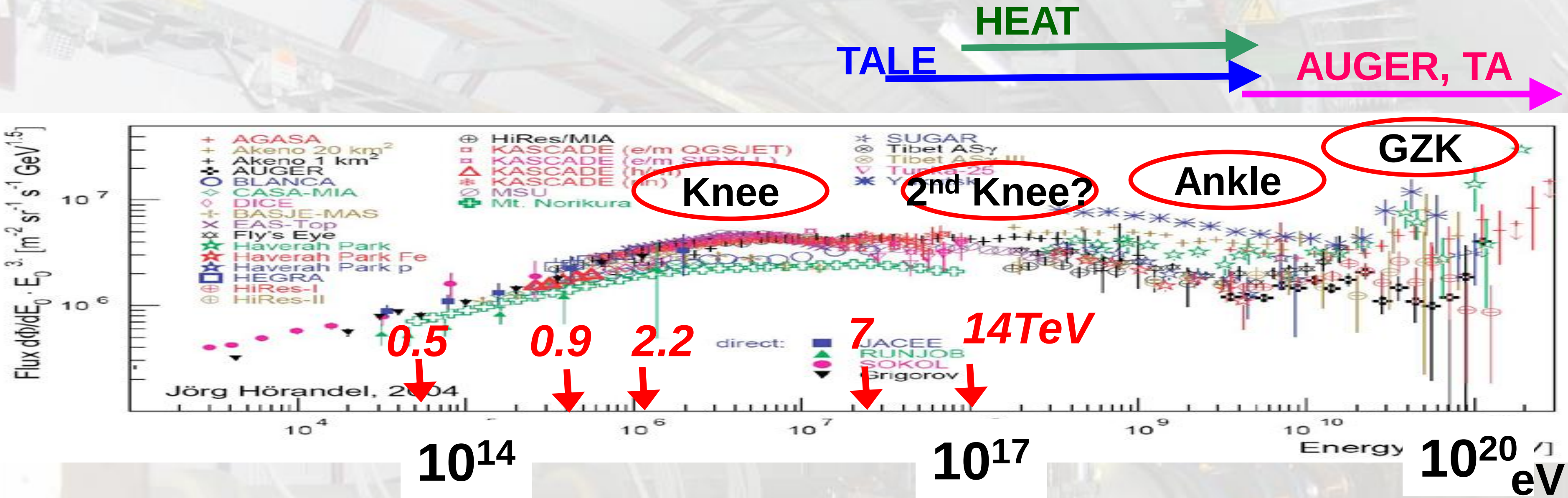


Arm2



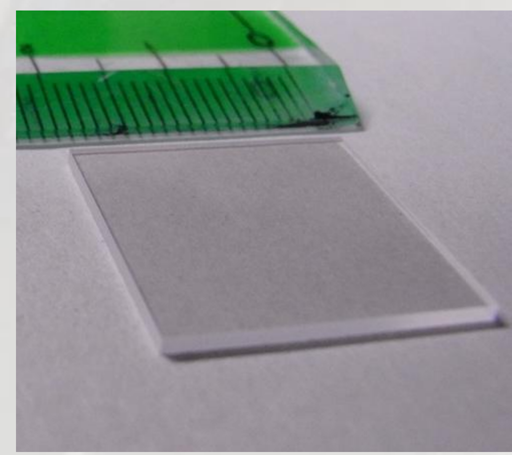


LHCf takes data every when LHC increases energy



LHC energy schedule

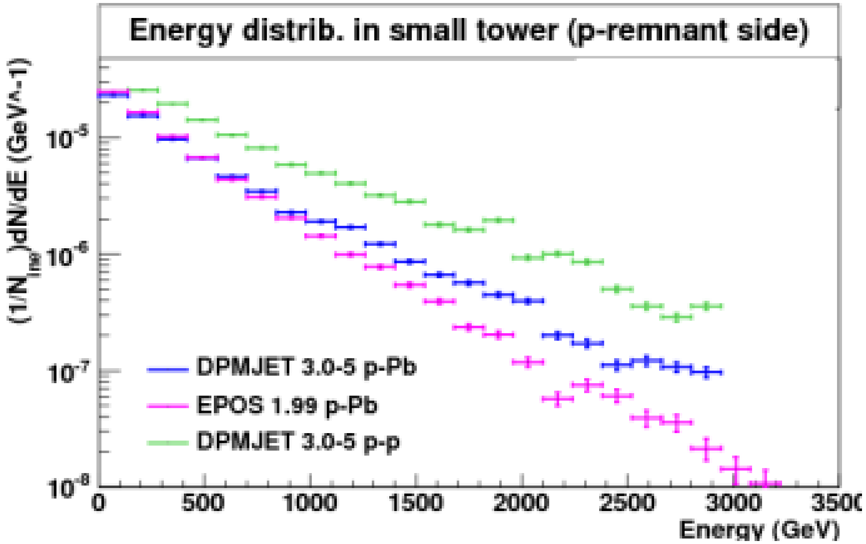
2010	2011~2012	2013~2014?	2015?
0.9, 7 TeV	p-Pb ?	LHC shutdown	2, 14TeV
LHCf I	Detector upgrade		LHCf II



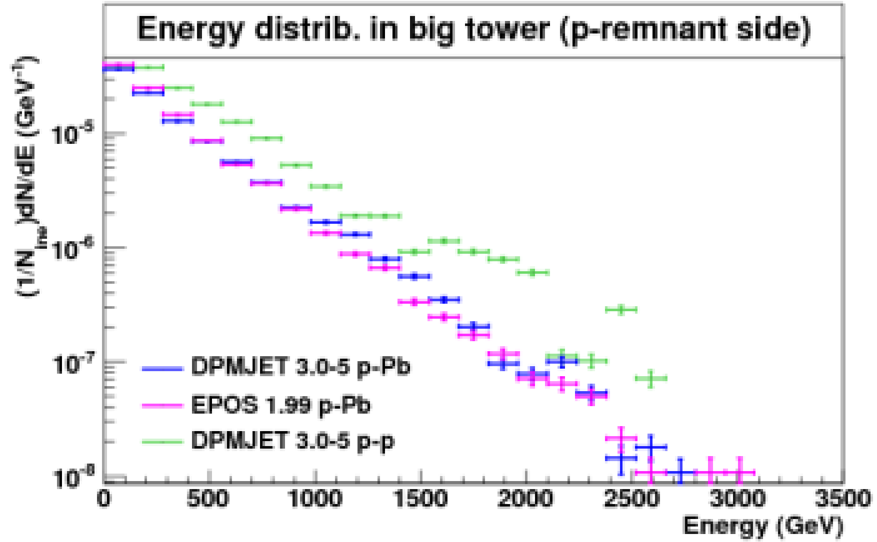
- **New detector w/ rad-hard GSO scinitillator will be ready.**

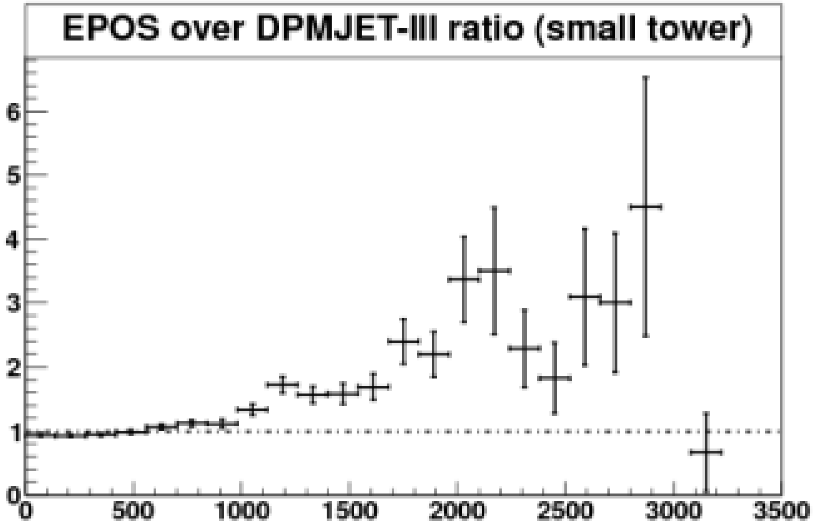
Proton-remnant side – photon spectrum

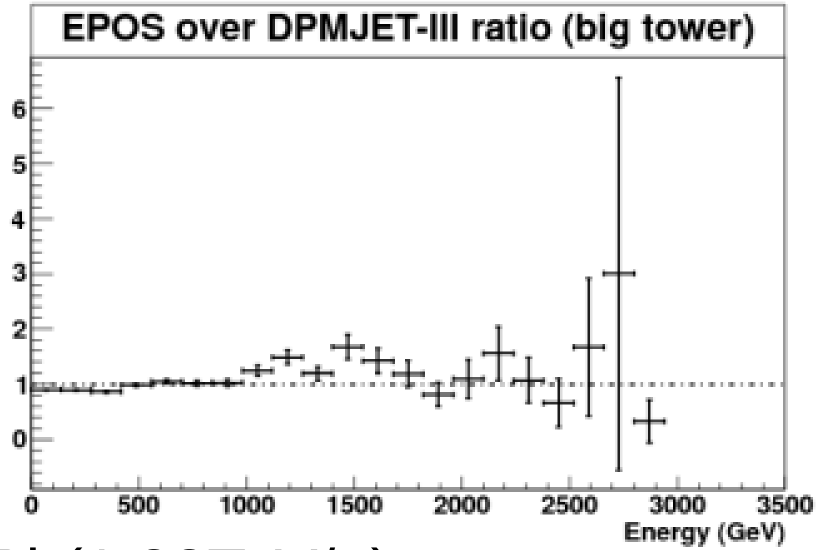
Small tower



Big tower

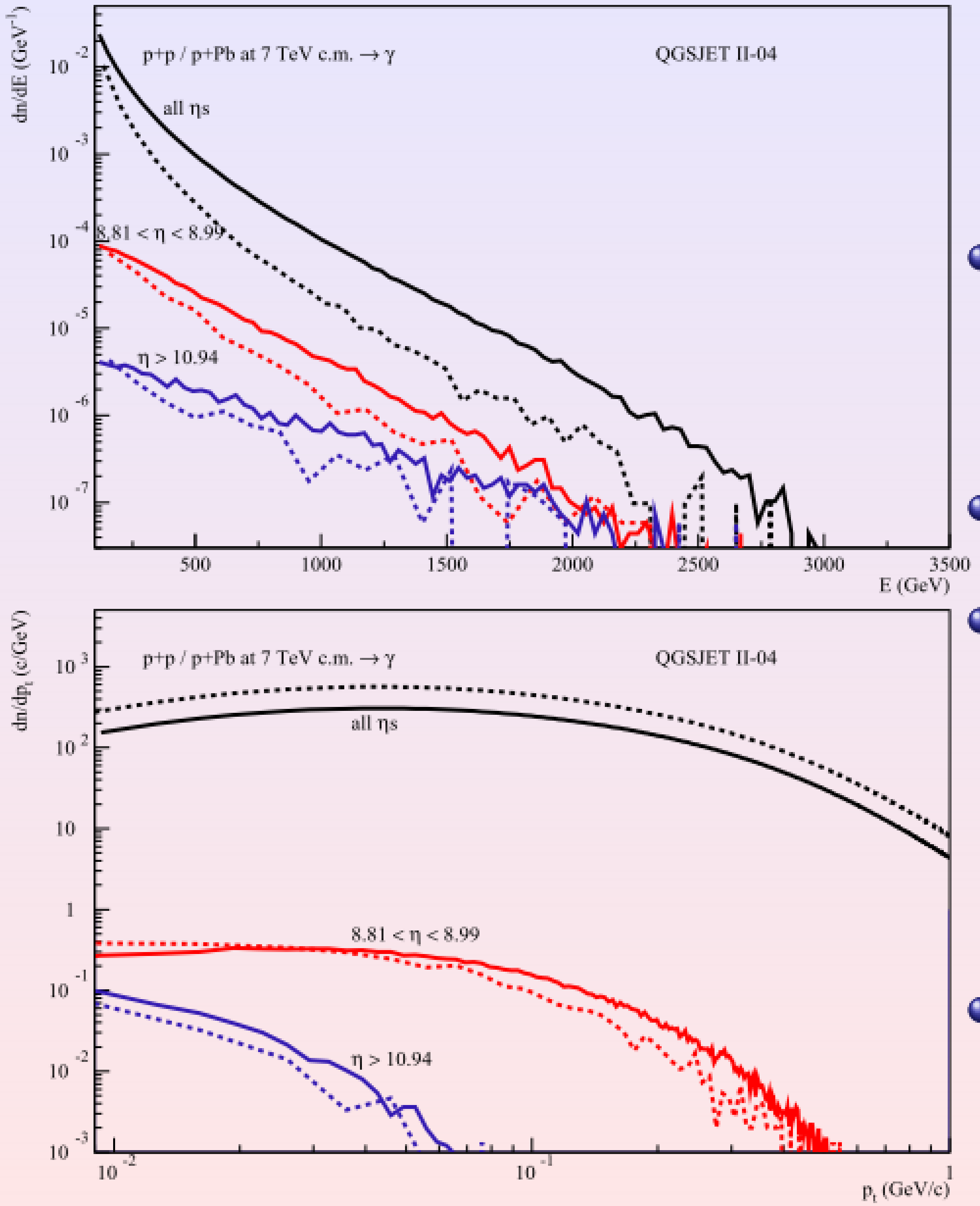






p (3.5TeV) + Pb(1.38TeV/n)

From proton-proton to proton-lead

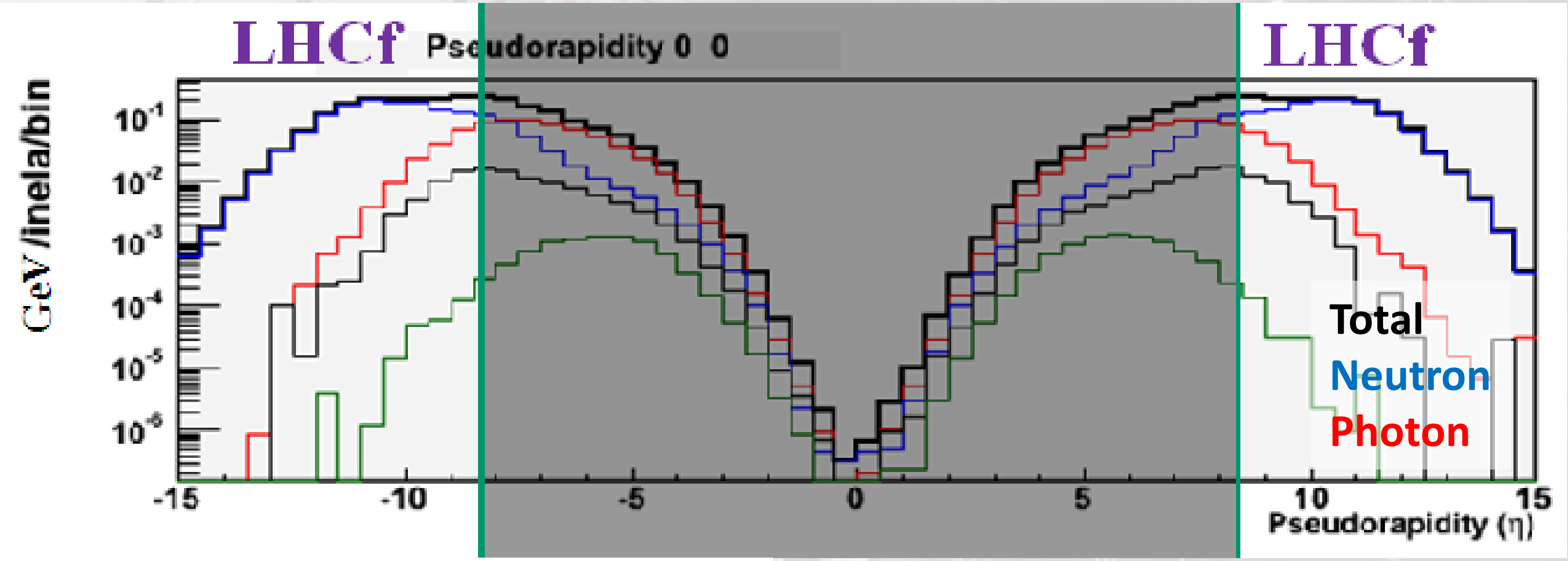


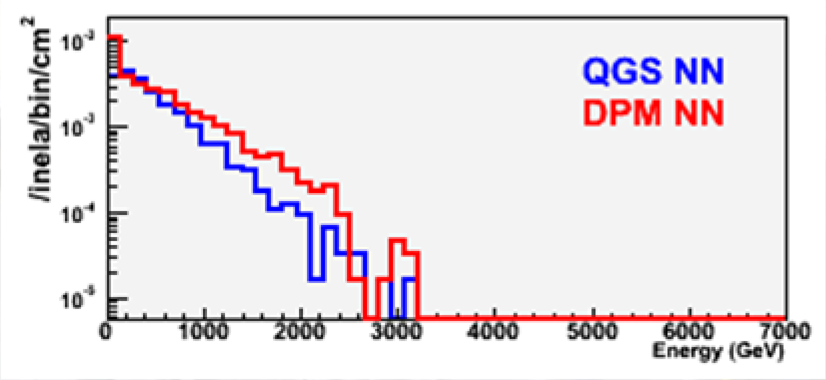
By Ostapchenko

- from pp to $p - Pb$: strong scaling violations for γ-spectra
- very model-dependent!
- e.g., stronger effect expected in CGC: scattering on a dense parton cloud ⇒ softer γ-spectra
- also: higher $\langle p_t \rangle$ due to saturation ⇒ γs move away from LHCf

LHC N-N run ?

- ✓ p-Pb relevant to CR physics?
- ✓ CR-Air interaction is not p-p, but A_1-A_2 (A1:p, He,…,Fe, A2:N,O)



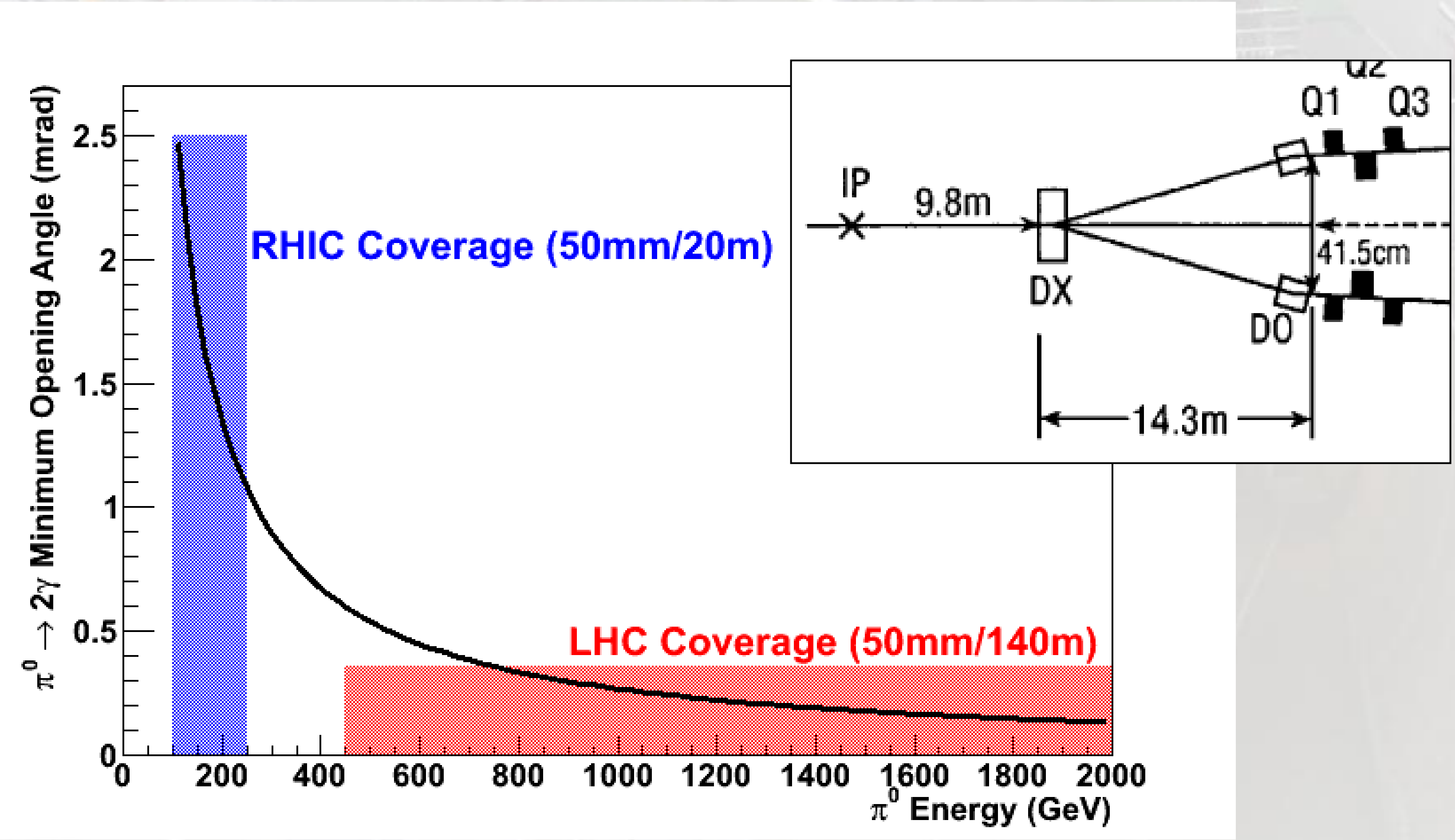


LHC Nitrogen-Nitrogen collisions

Top: energy flow at 140m from IP

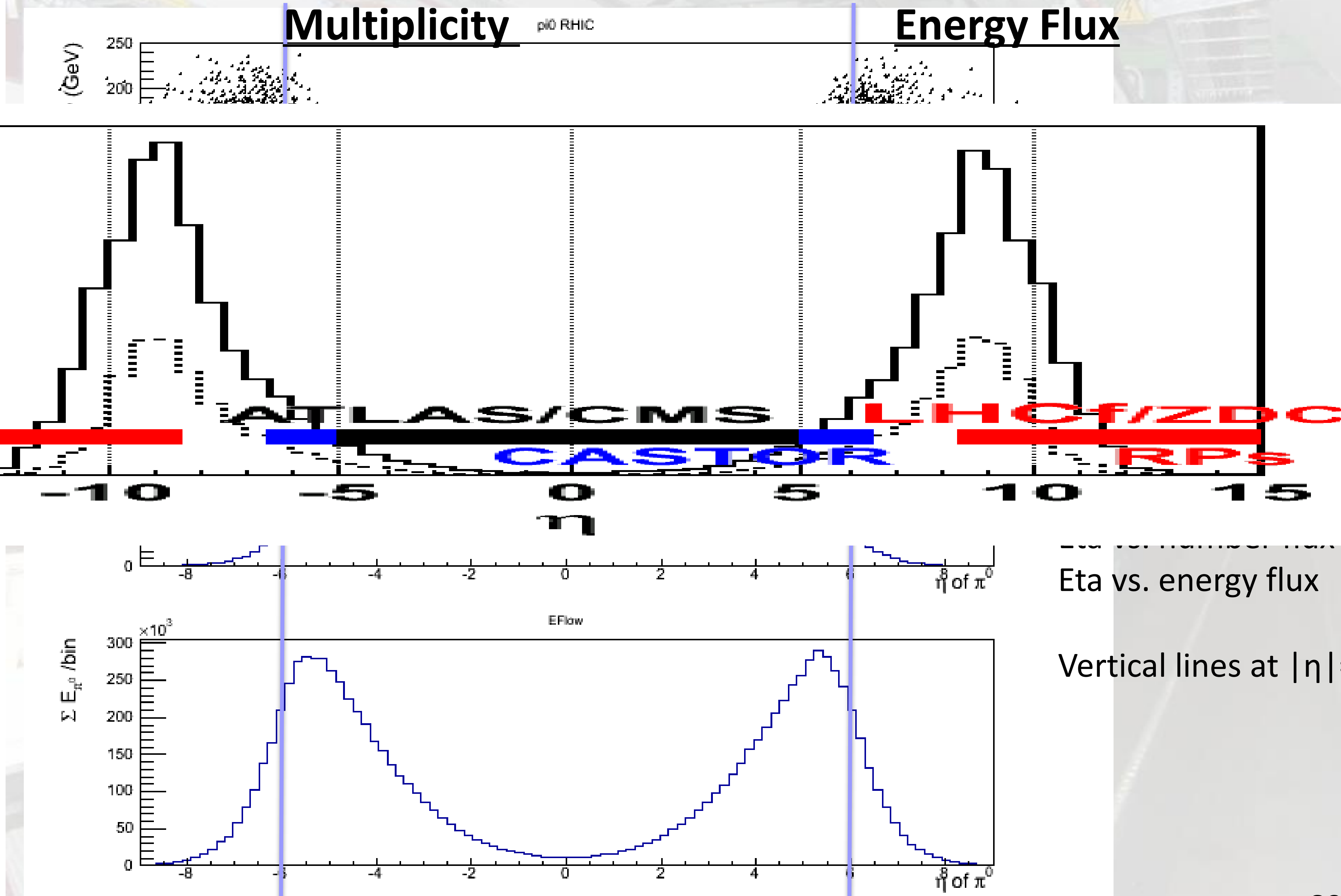
Left : photon energy spectra at 0 degree

RHIC: π^0 at $\sqrt{s}$ =500GeV



- ✓ **ZDC space at PHENIX (by Goto-san):**
  10cm radius beam pipe aperture at 18m => η>5.9

Pi0 in 500GeV p-p collisions by PYTHIA8



Eta vs. number flux

Eta vs. energy flux

Vertical lines at |η|=6

Summary

- LHCf : Dedicated measurements of neutral particles at 0 deg at LHC energy for the verification of cosmic rays interaction models at 10^{17}eV.
- Phase-I run successfully completed. Analysis on-going.
  - E spectra for 7Tev single gamma
  - Agreement with models is “so-so”, but none of models really agrees.
  - Analysis is going on for 7TeV pi0, 900GeV gamma, and so on.
- Future plan
  - Revisit LHC for next energy upgrade at ~2015 with a rad-hard detector. Also p-A run at 2012 ?
  - Possible future LHC A-A runs? R&D in progress.
  - <500GeV runs at RHIC are also very interesting.

UHECR data may hint ultra high energy interactions at beyond-LHC energy. To approach, LHCf will give firm base of understanding at 10^{17}eV.