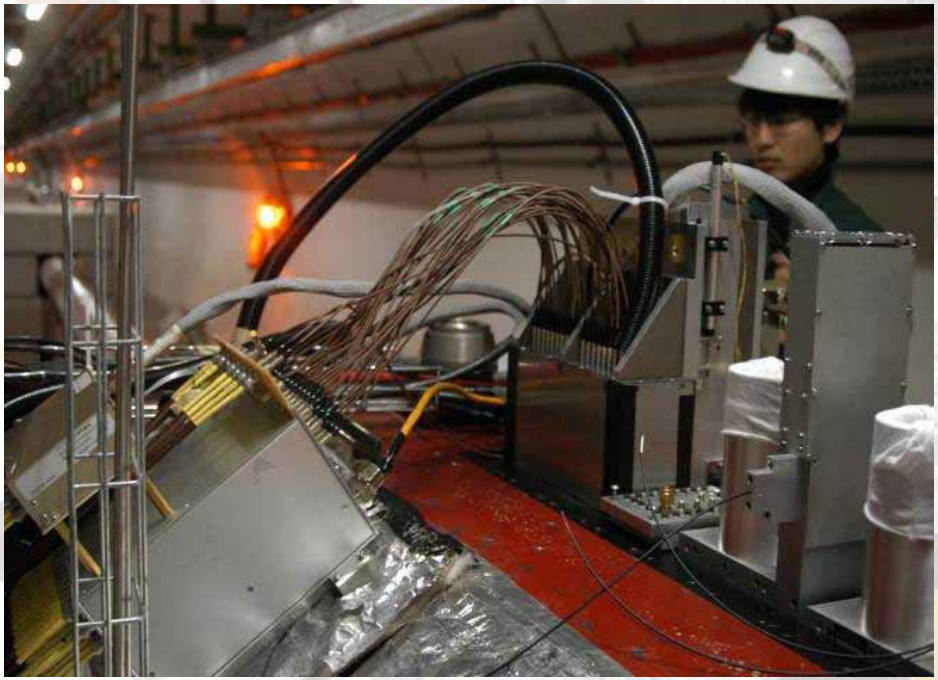
The LHCf experiment

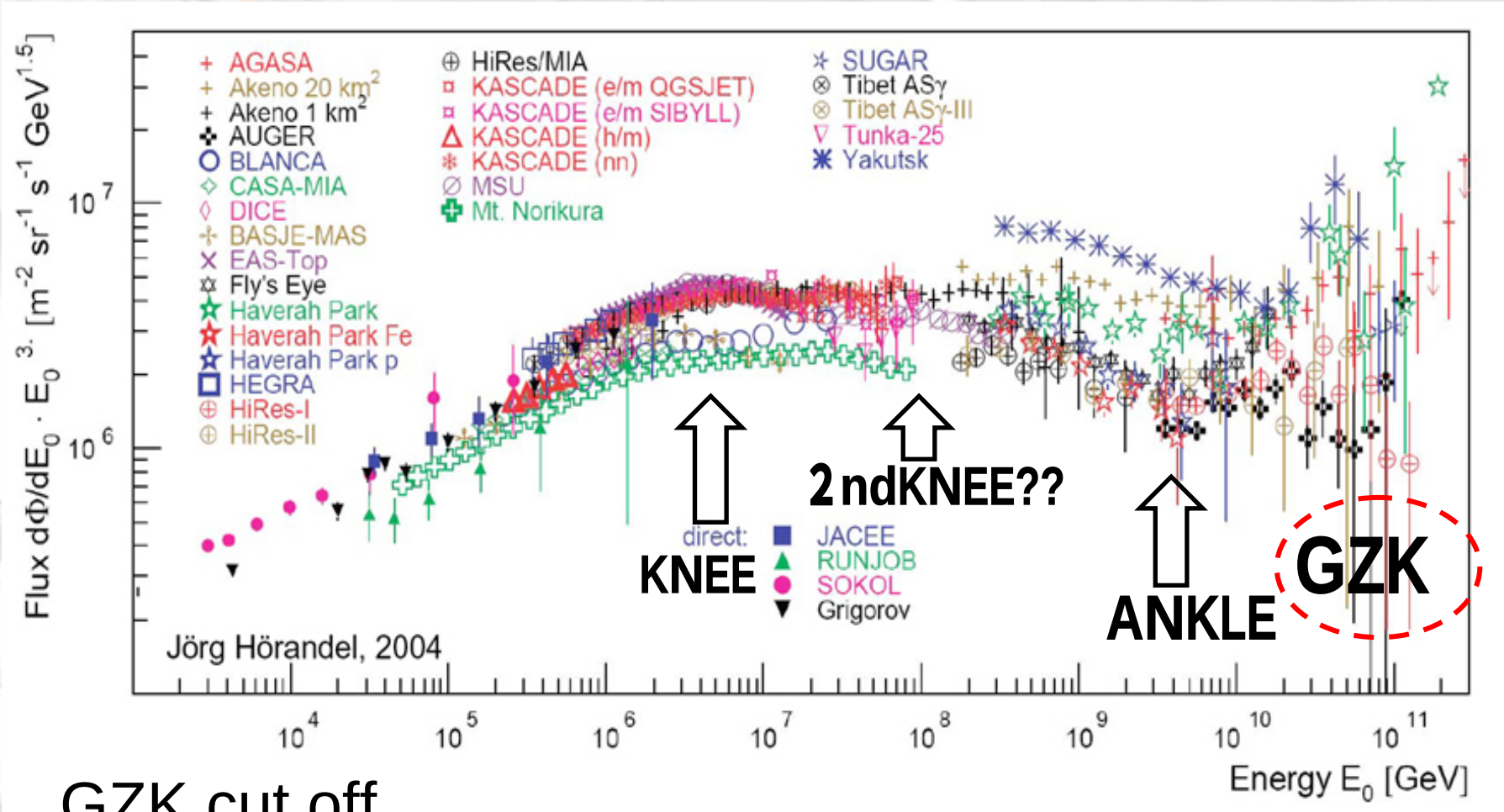
~ from cosmic rays to hadron physics



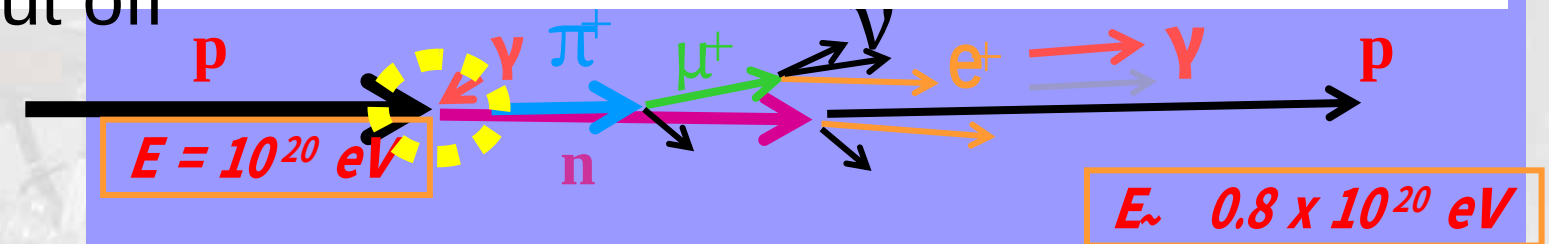
Yoshitaka Itow
Solar-Terrestrial Environment Laboratory
Nagoya University
for the LHCf collaboration

High Energy Astrophysics 2009
Nov 10-13, 2009, KEK

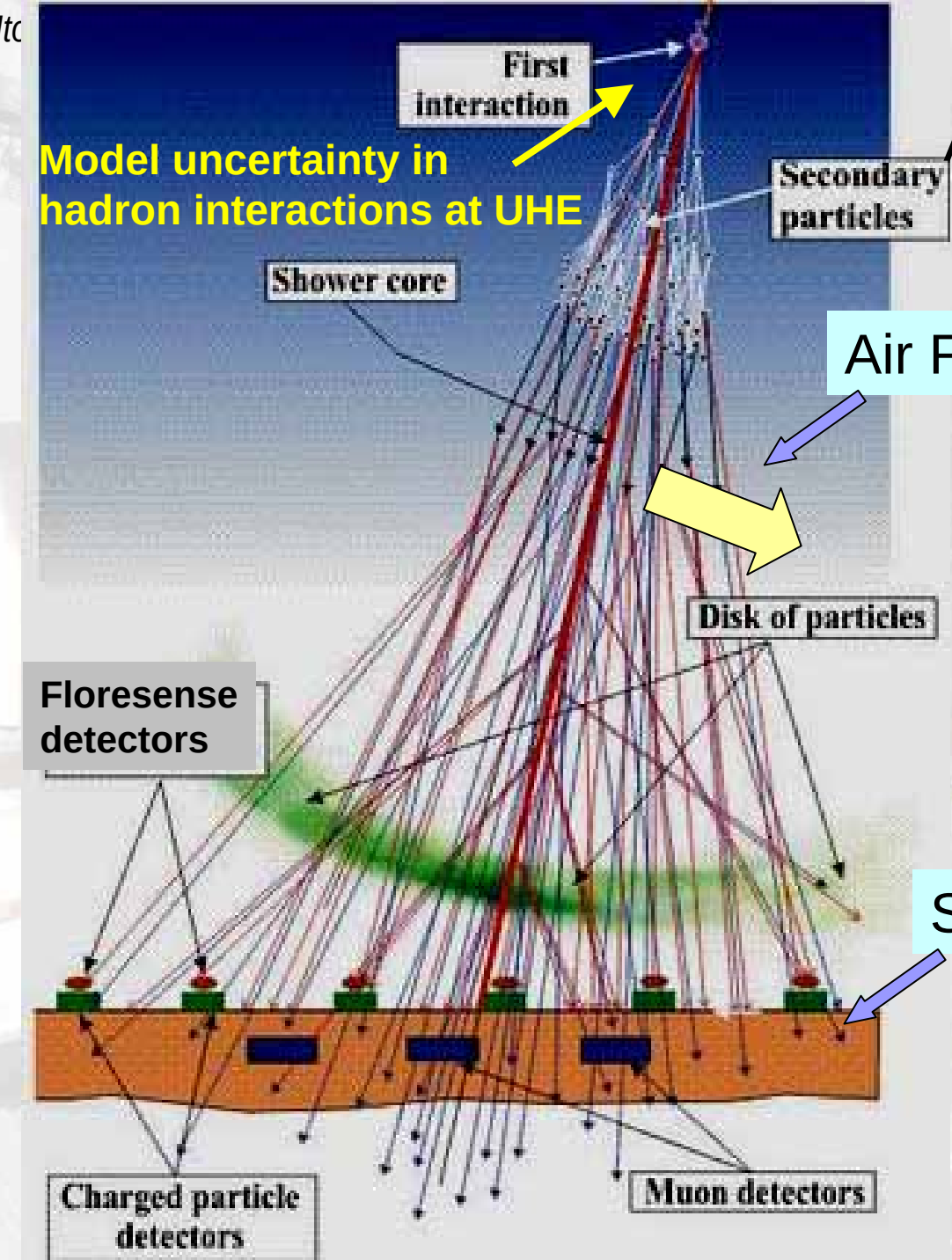
Energy spectrum of UHE cosmic rays



GZK cut off



Air shower observation



Air Florescence telescope (FD)

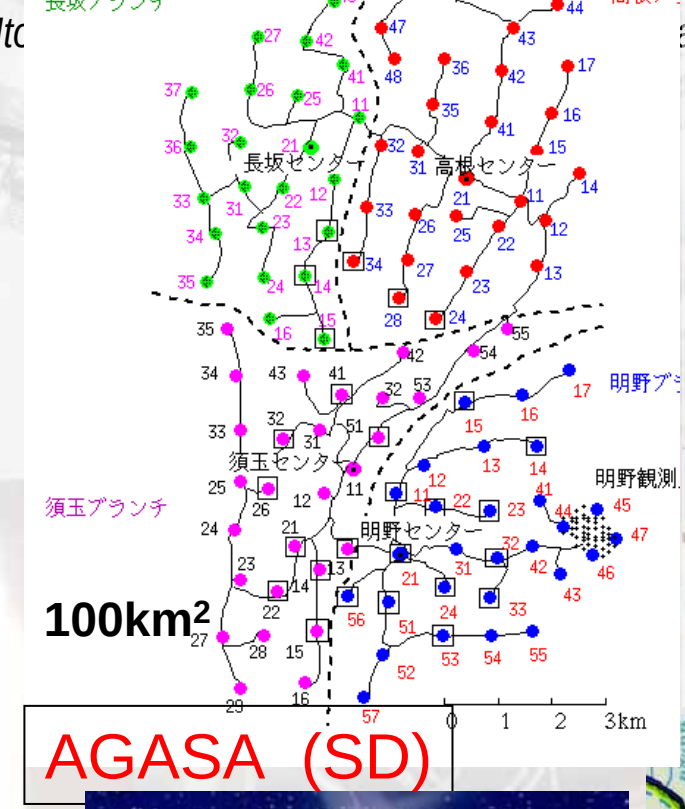
EM component
(most of energy)

- Scintillation lights
- Shower directions
- Shower max alititude

Surface Detectors (SD)

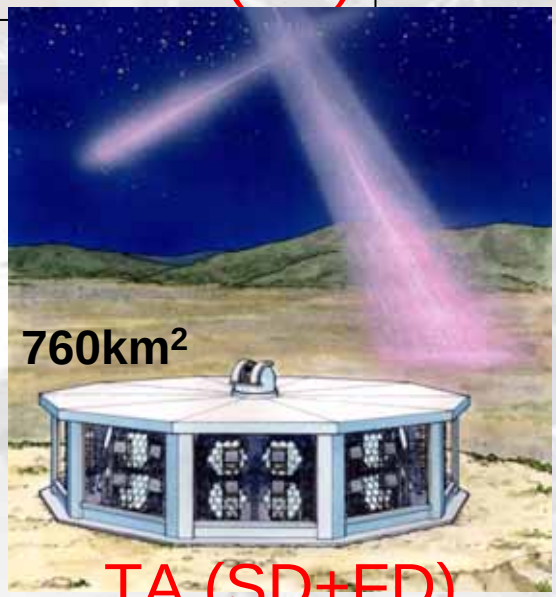
Number of partciles
Arrival timing
Muon or EM component
(at given altitude)

Airs shower experiments for UHECRs

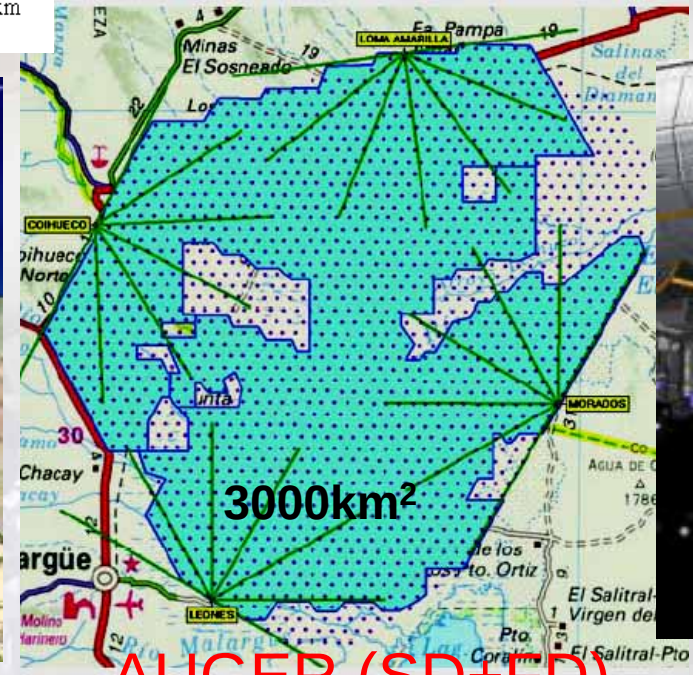


AGASA (SD)

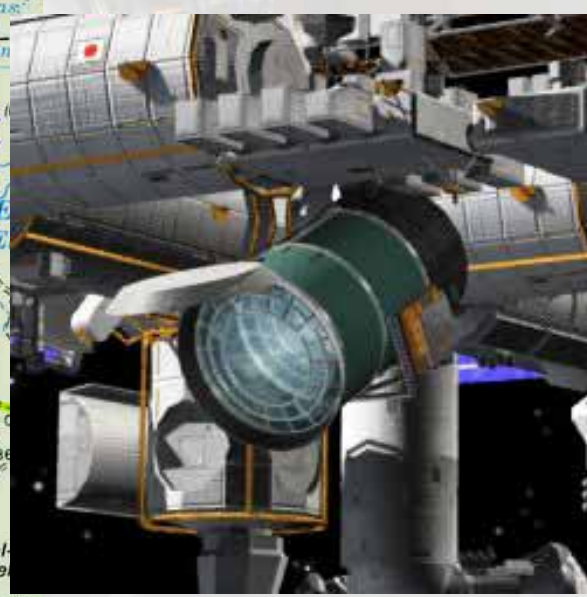
HiRes (FD)



TA (SD+FD)

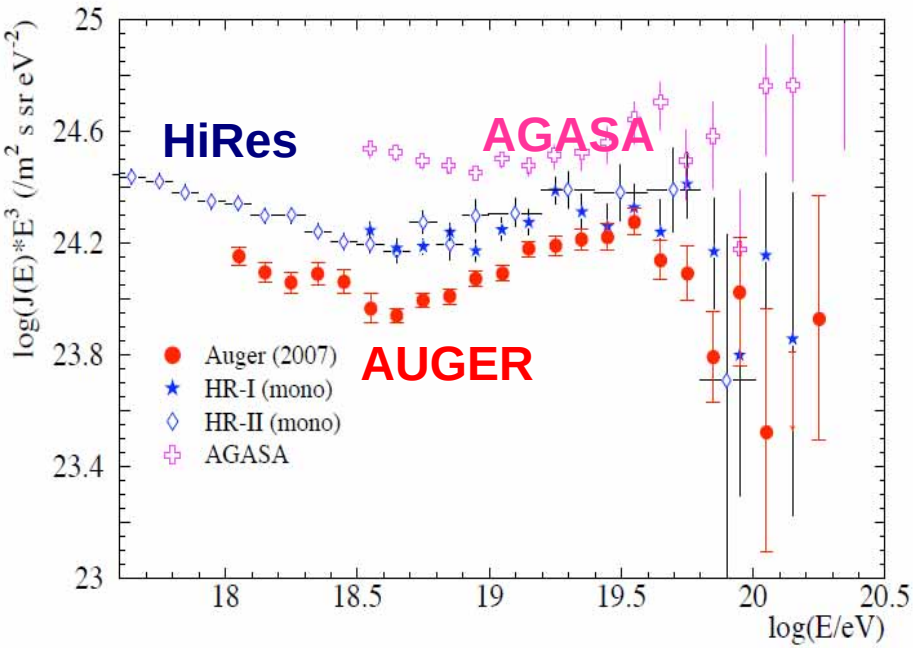


AUGER (SD+FD)

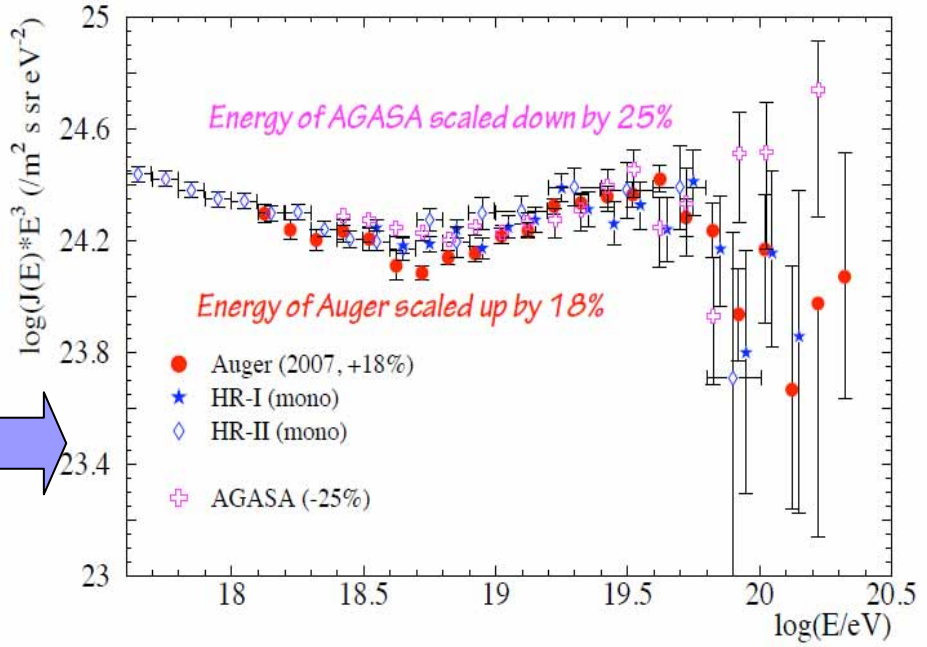


JEM-EUSO (FD)

Energy scale issue; GZK cut off feature in AGASA, HiRes and AUGER (2007 summer)



Energy scaling by +-25%



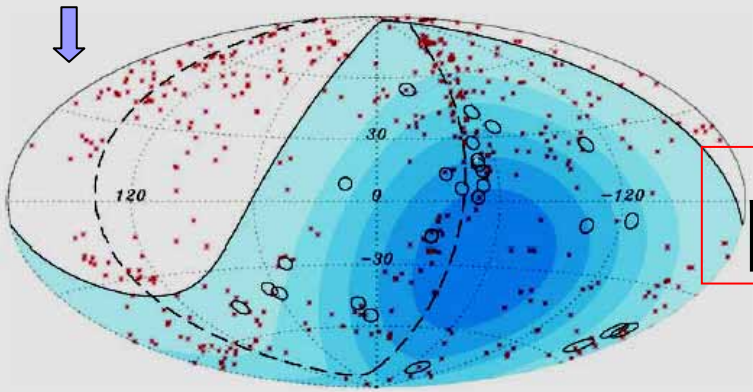
c.f. Energy scale was determined by fluorescence detector

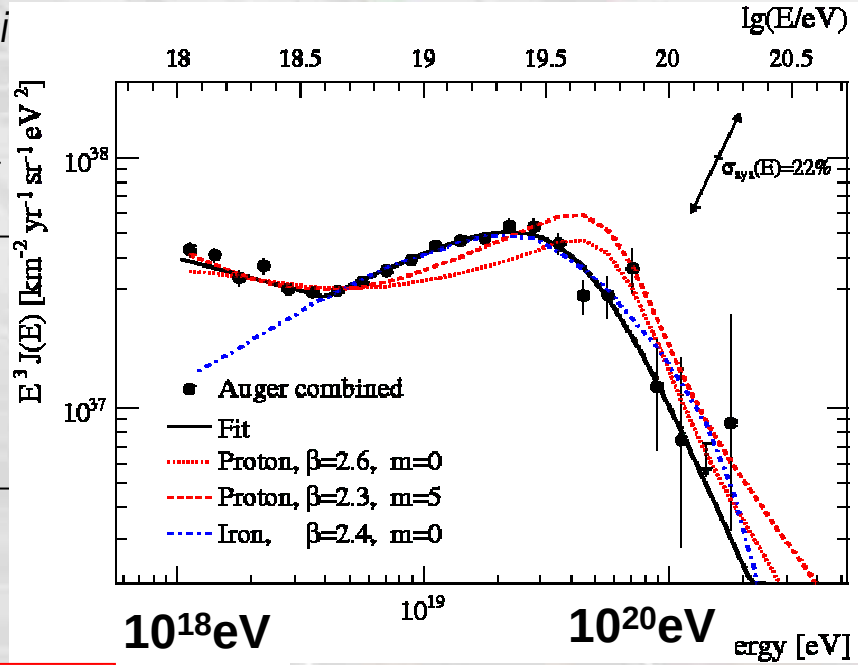
J. Bluemer
@ICRR, Mar. 2008

UHECR GZK Problem

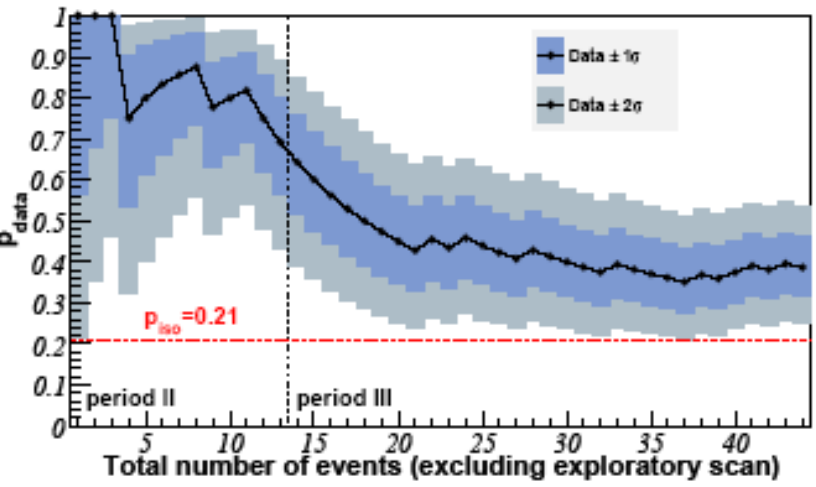
~ recent situation ~

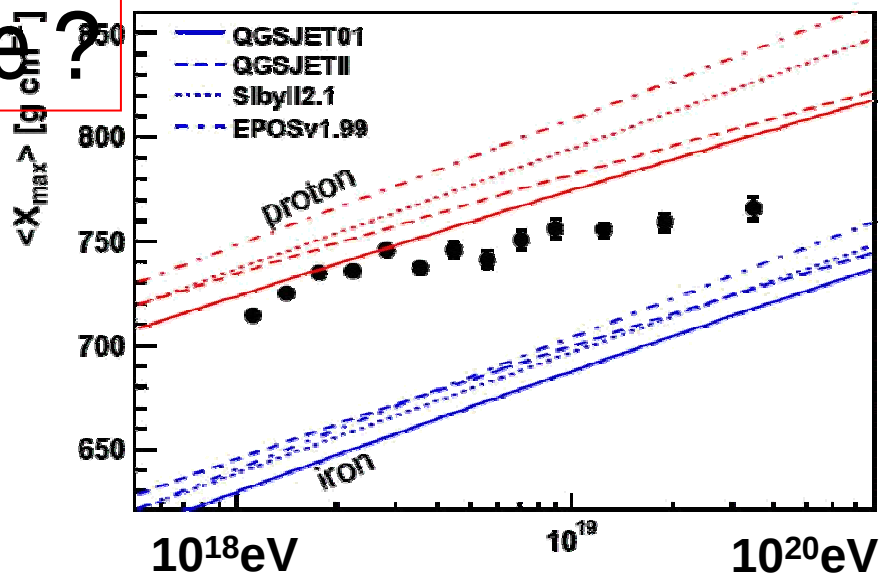
AUGER reported clear "cut off" feature and directional correlation to AGN ,suggesting UHECR is proton, while it got weaker for newer data (ICRC09)





p or Fe ?





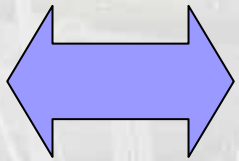
AUGER shower max position data suggests composition gets heavier, not proton.

Hadron Interaction models used in air shower simulations

- QGSJET Ⅰ、Ⅱ
- DPMJET
- SIBYLL
- EPOS

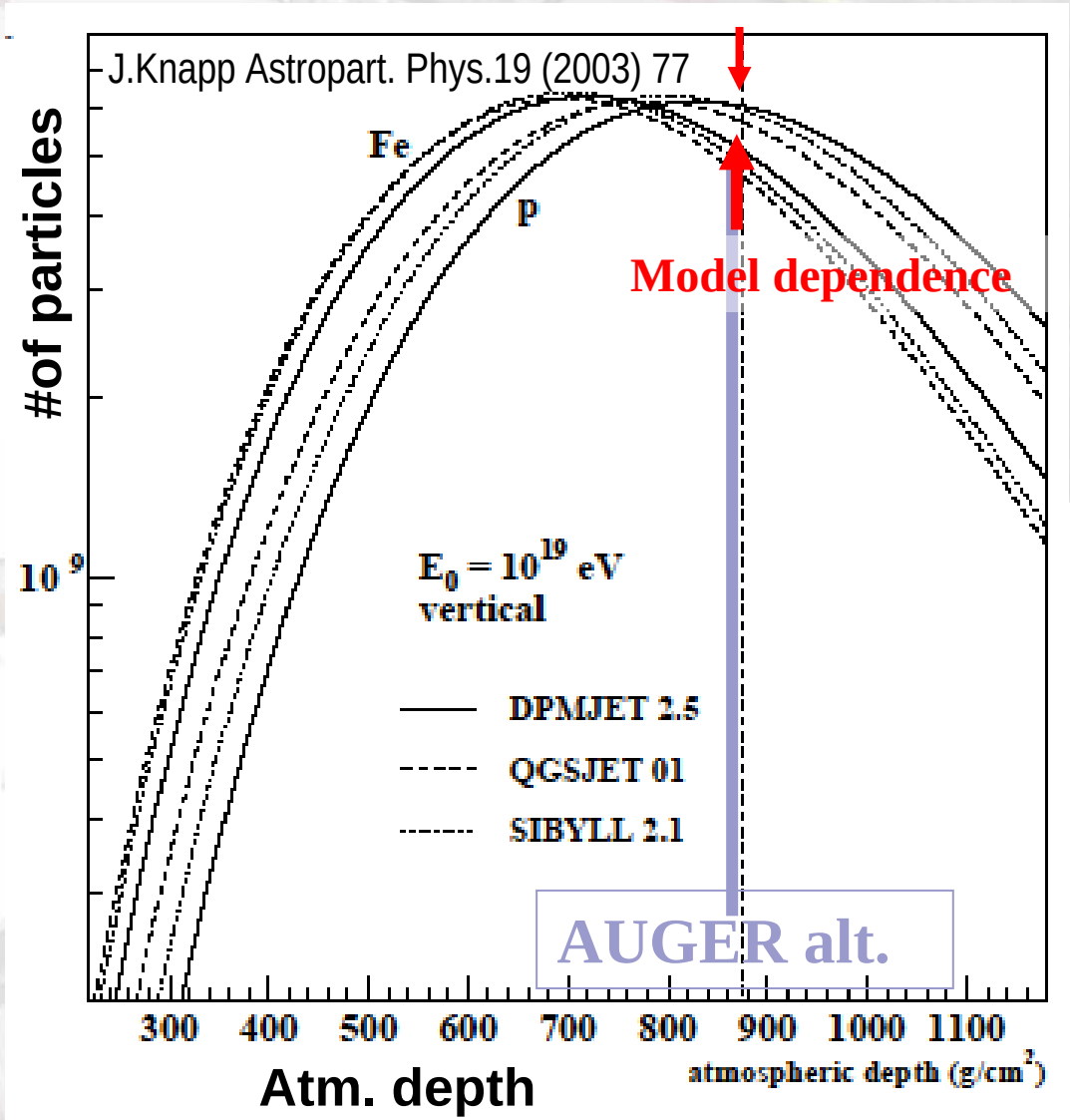
……..

Affect air-shower observables

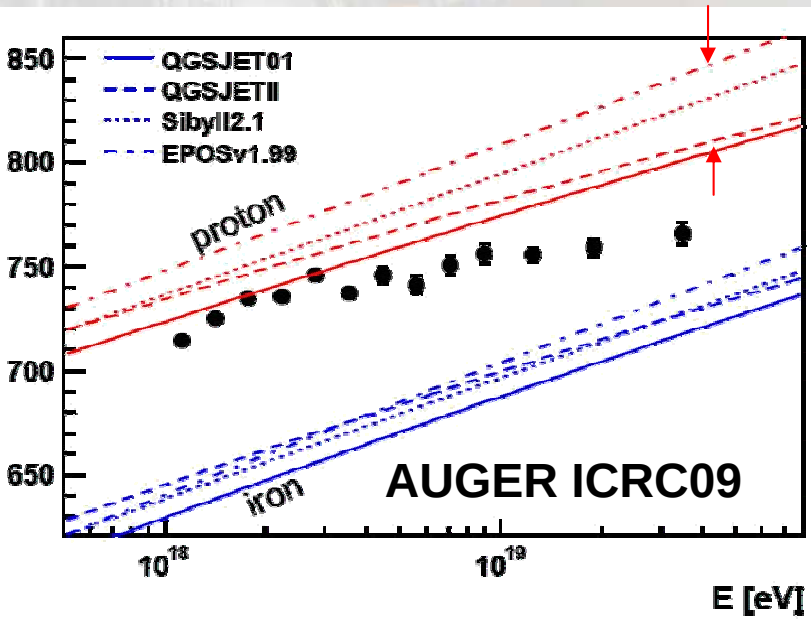


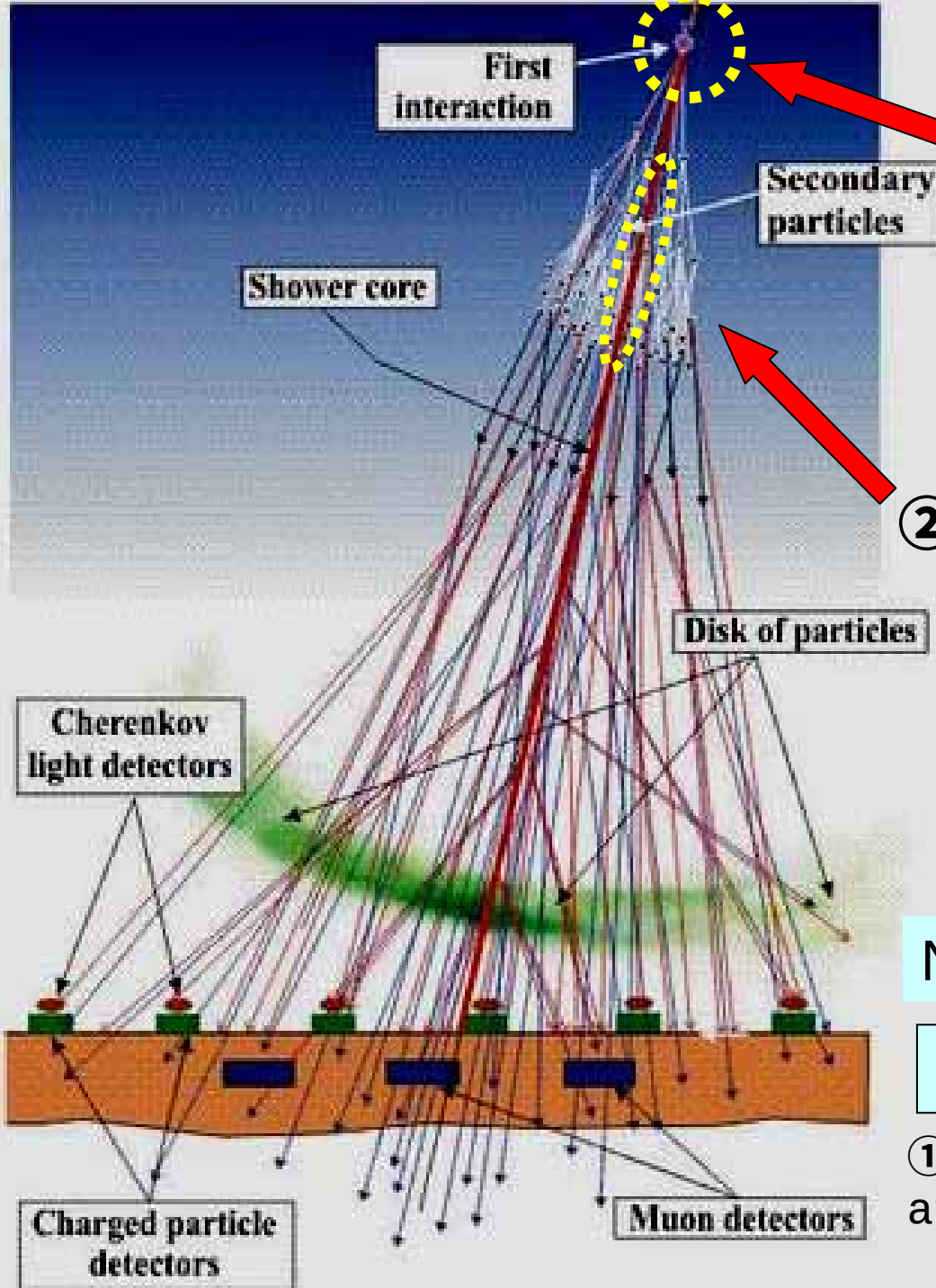
E-scale
Composition

Degeneracy in composition and hadron interaction models



- 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





① Inelastic cross section

If large σ
rapid development
If small σ
deep penetrating

② Forward energy spectrum (or Inelasticity k)

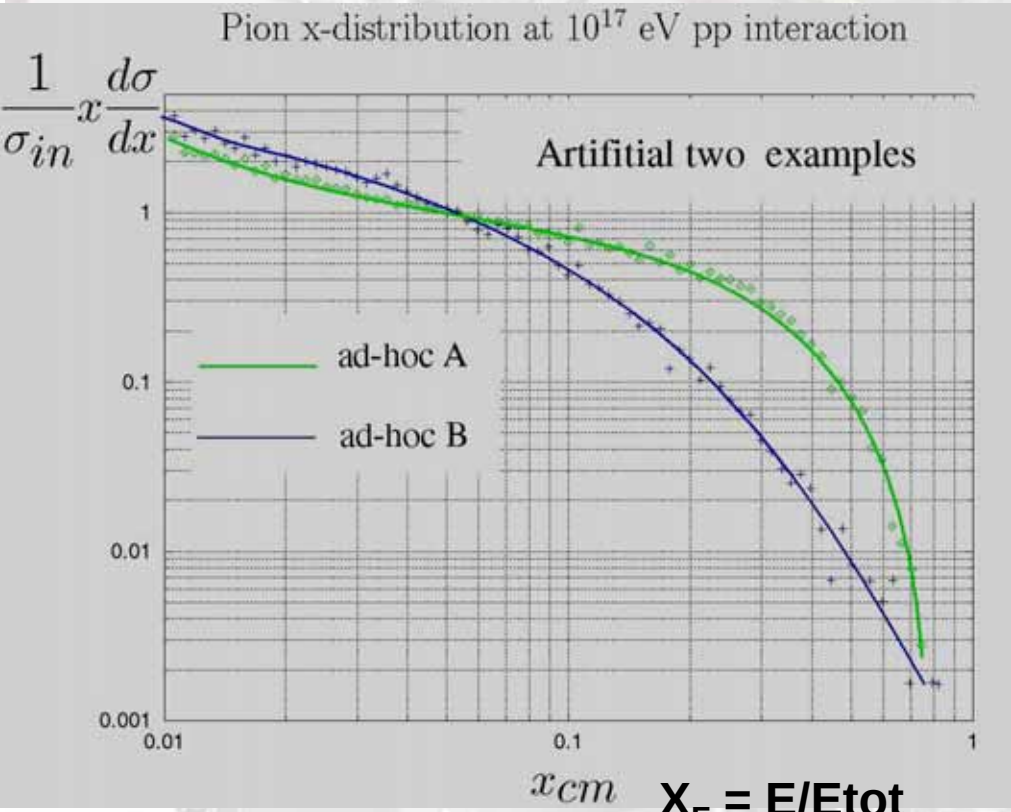
If large k
rapid development
If small k
deep penetrating

Need both ① and ②

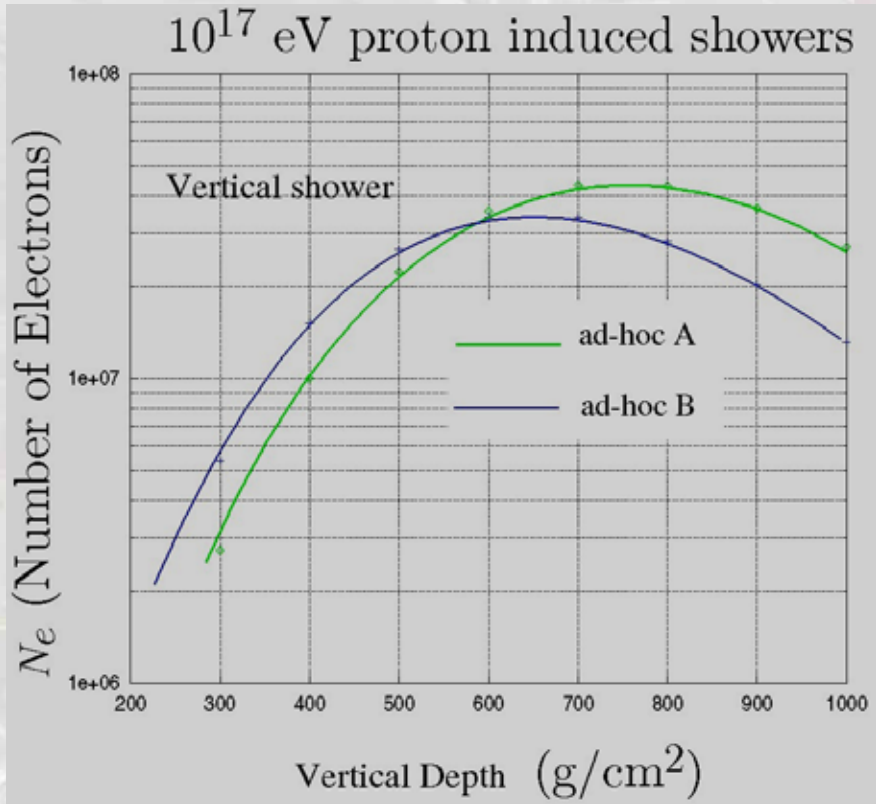
LHCf is dedicated to ②

① will be give by Roman Pod at LHC

Forward production spectra vs Shower curve

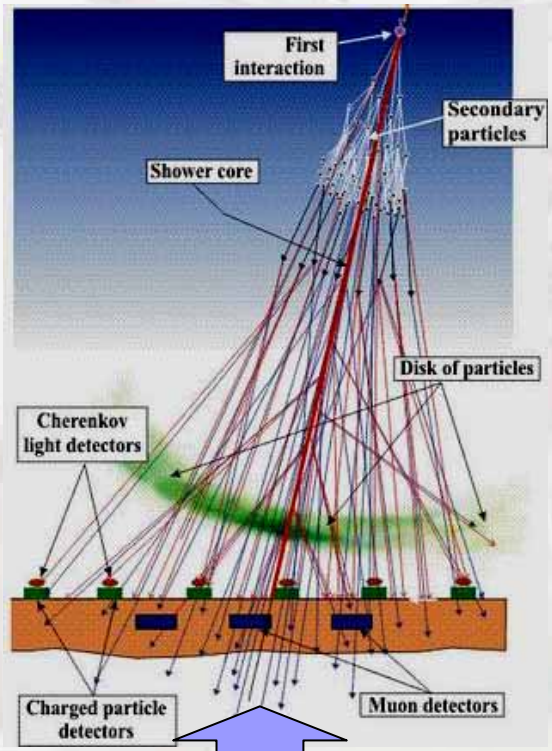


X_F = E/Etot



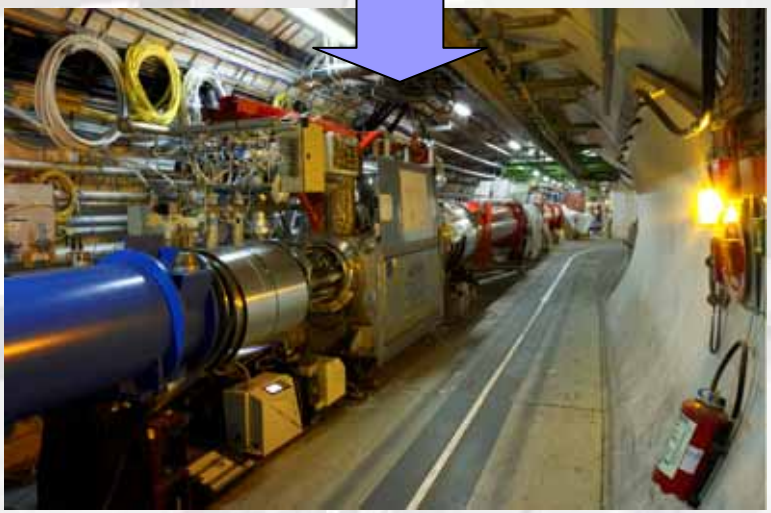
Half of shower particles comes from large X_F γ

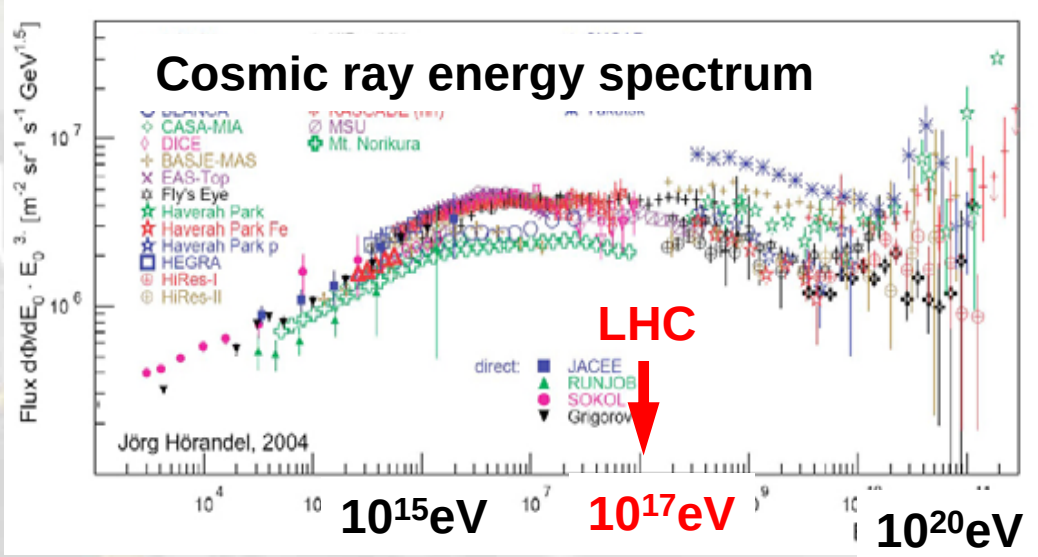
Measurement at very forward region is needed



LHCf physics motivation

- Verify cosmic ray interaction models at LHC energy ($E_{CR}=10^{17}$eV)
- Precise measurement of π^0,γ ,n at very forward, which is relevant to air shower development of UHECR
- Because of radiation, data taking is foreseen only at low luminosity ($L<10^{31}cm^{-2}s^{-1}$, 43 bunch) mode in LHC commissioning phase.





The LHCf Collaboration

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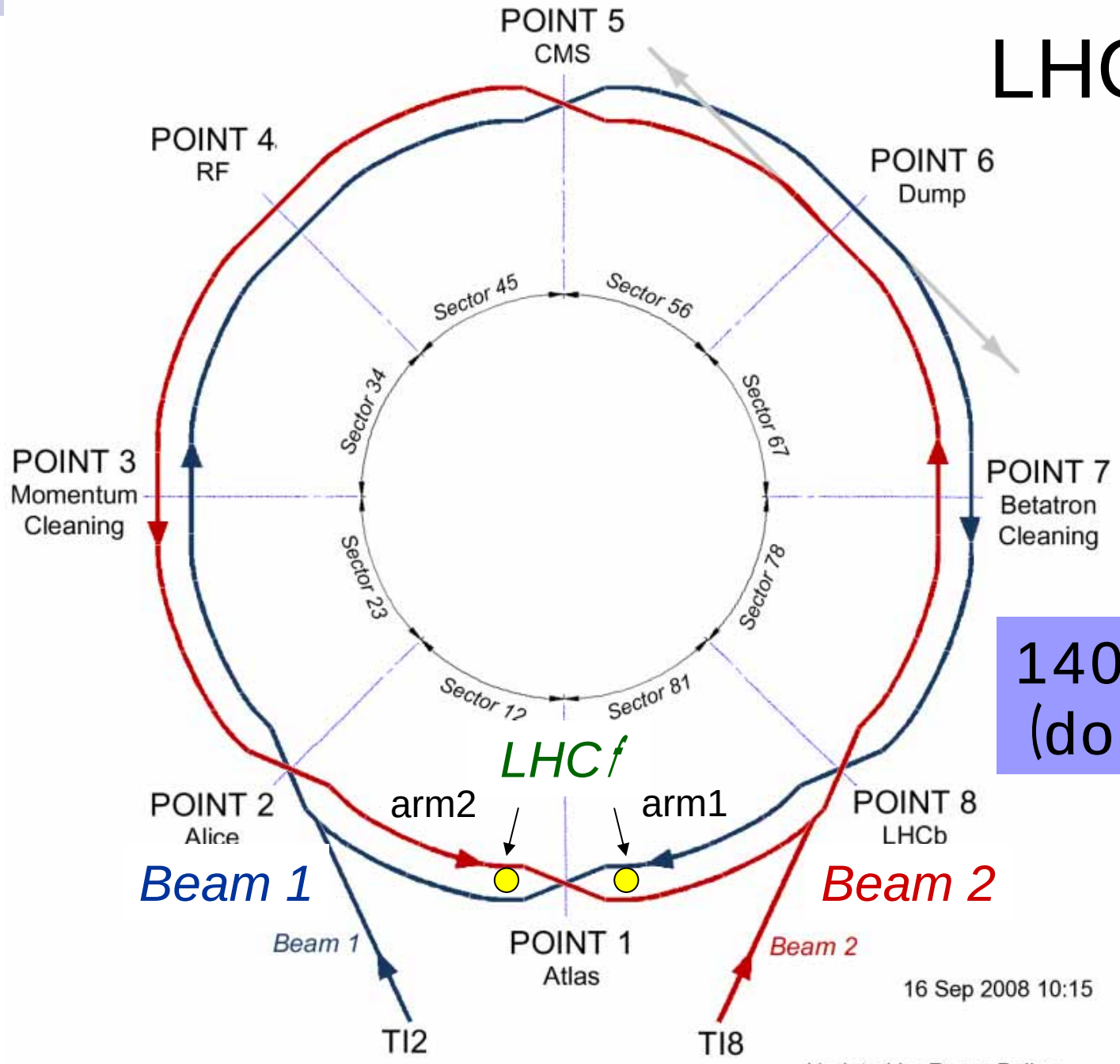
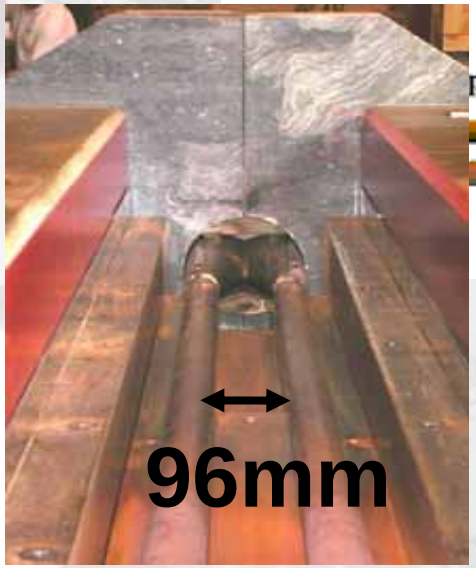
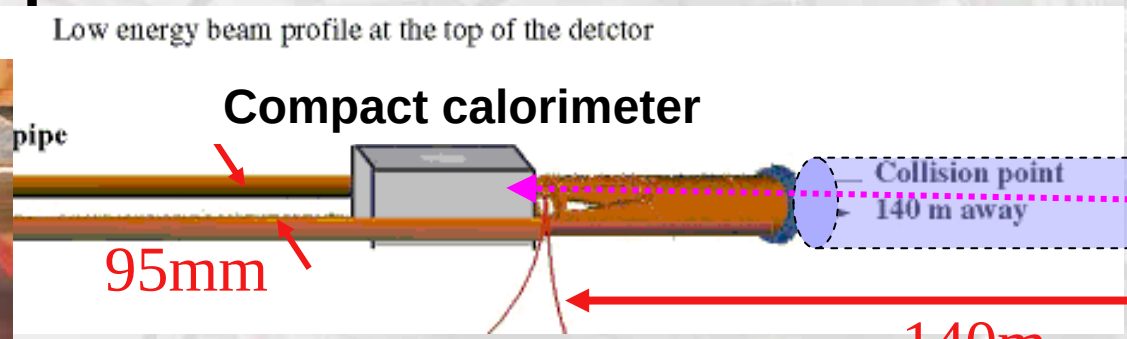
LHCf site

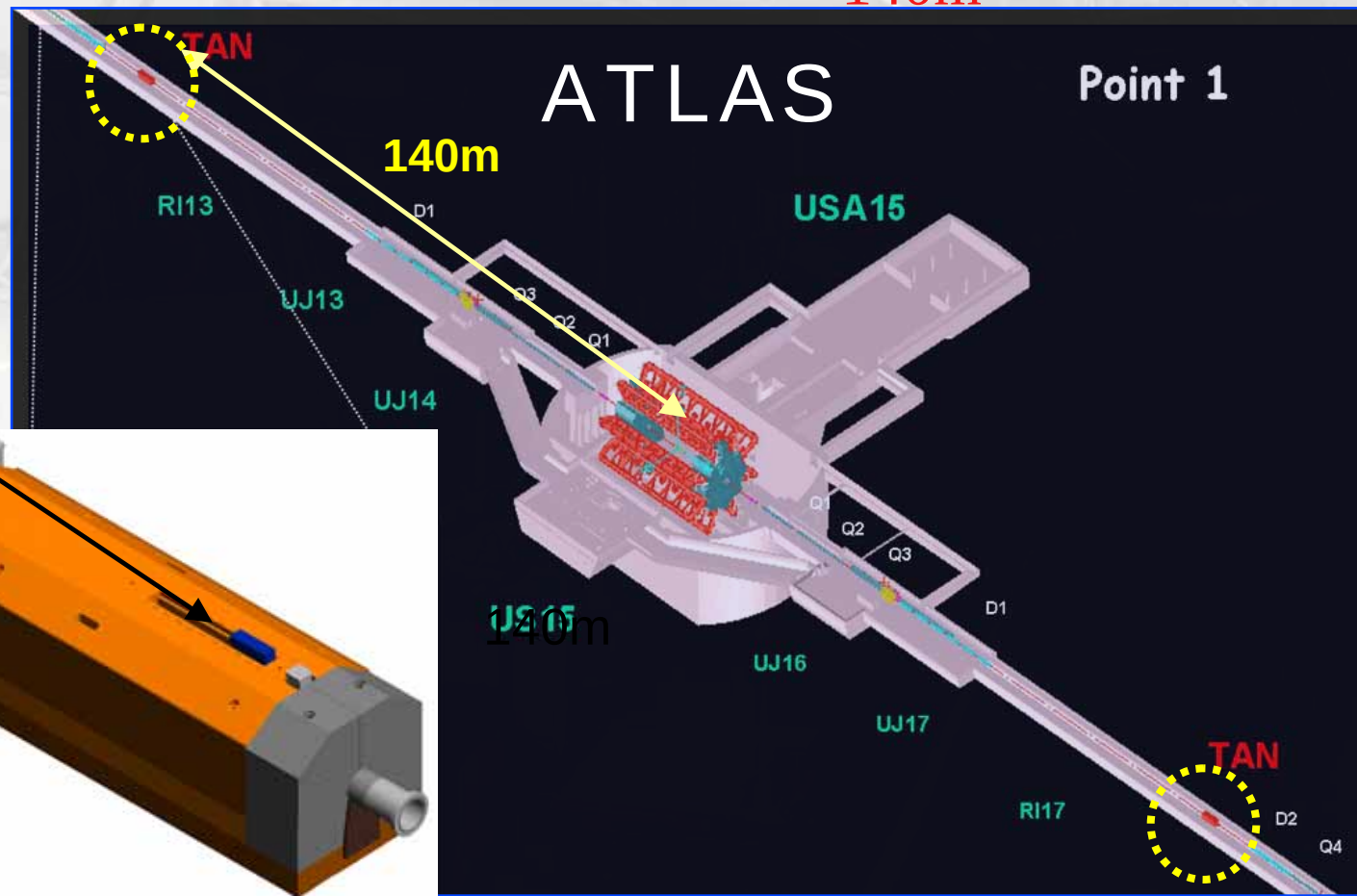


140m from IP1
(double arm)

LHCf experimental site







LHCf

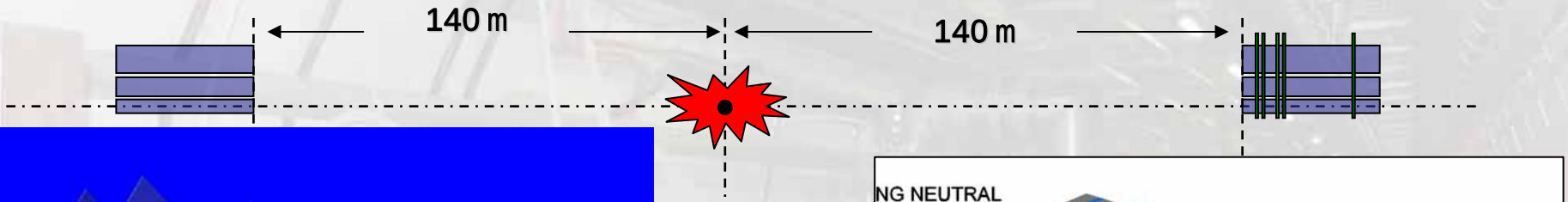
TAN absorber

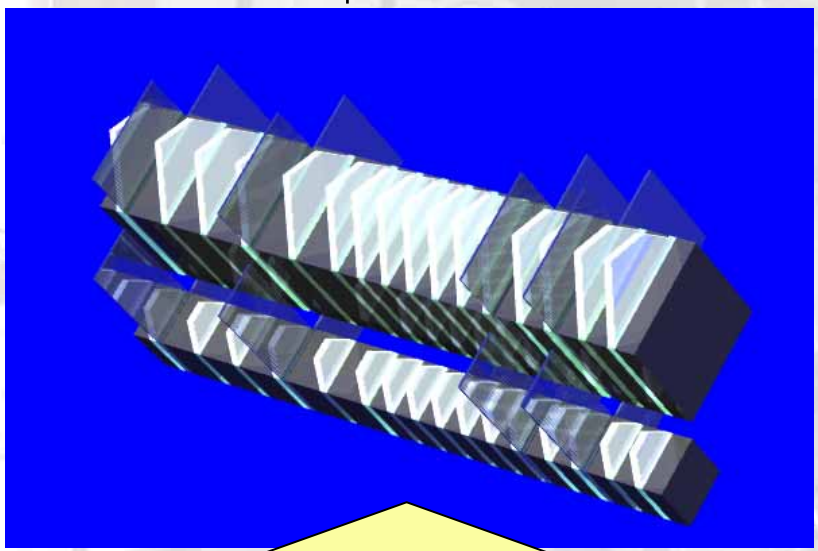
LHCf: location and detector layout

Detector I
Tungsten
Scintillator
Scintillating fibers

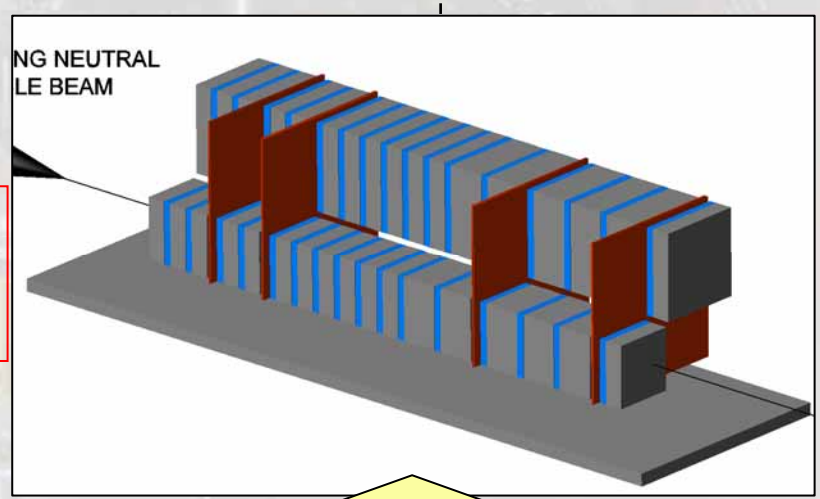
INTERACTION POINT
IP1 (ATLAS)

Detector II
Tungsten
Scintillator
Silicon μstrips





$44X_0$,
$1.6\ \lambda_{int}$



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

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

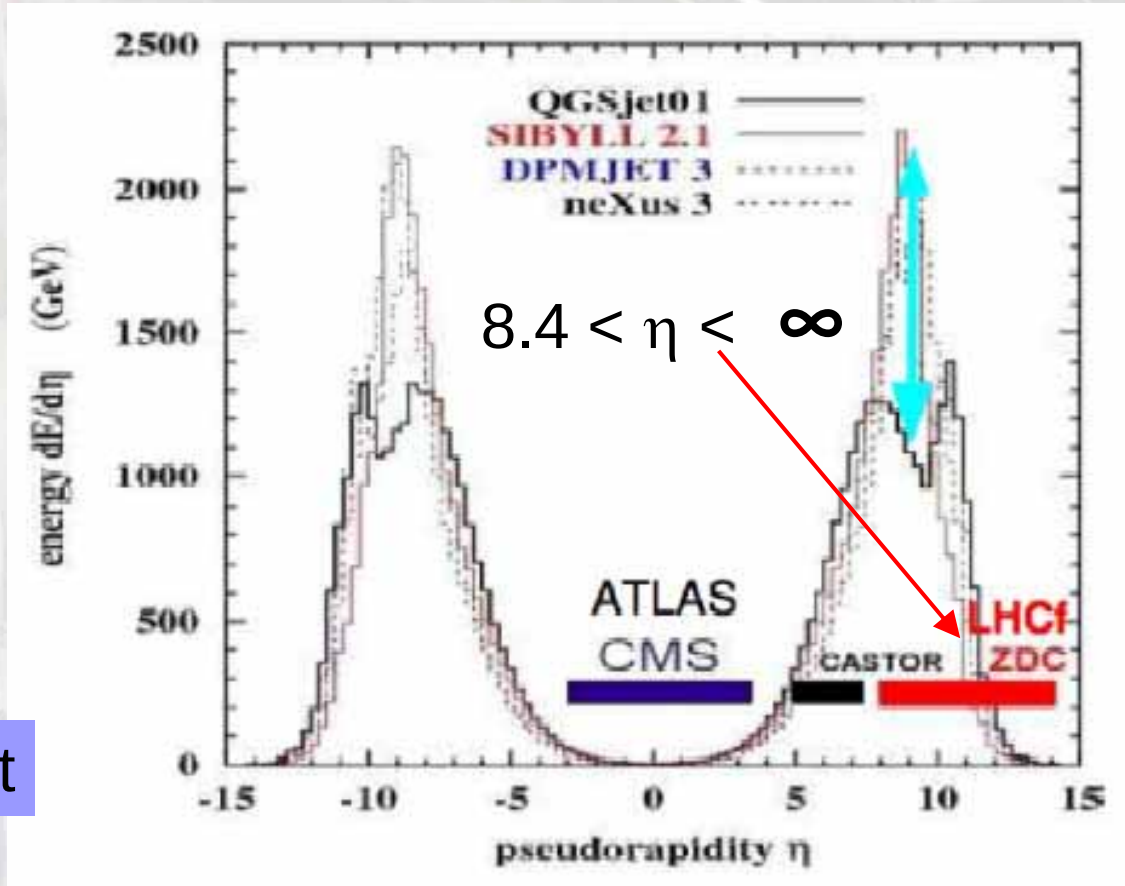
Very forward EM measurement at LHC

- Energy flow of collisions dominates in very forward region
- Soft and semi-hard processes dominate → need experiments
- ZDC's available at other LHC exp's., but not dedicated for EM

Energy flow dominates in very forward

Measure EM component at 0 degree of LHC

The LHCf experiment

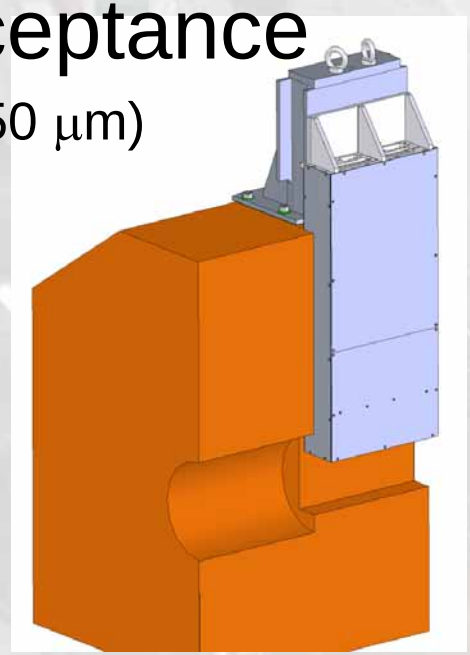


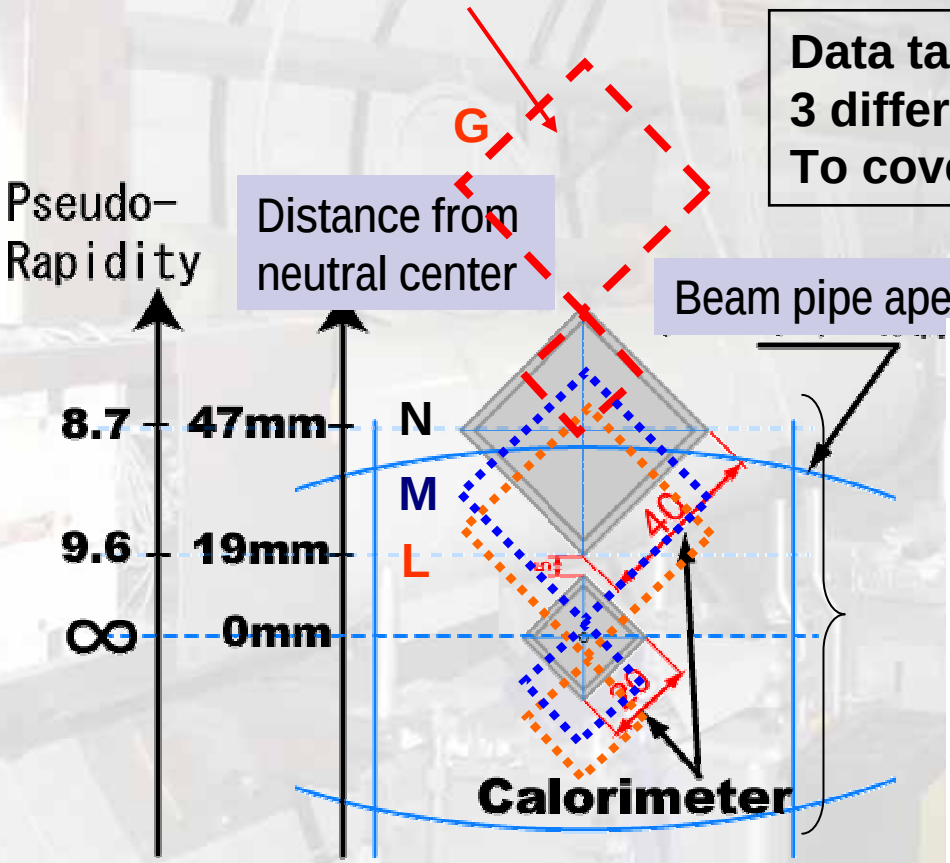
Detector vertical position and acceptance

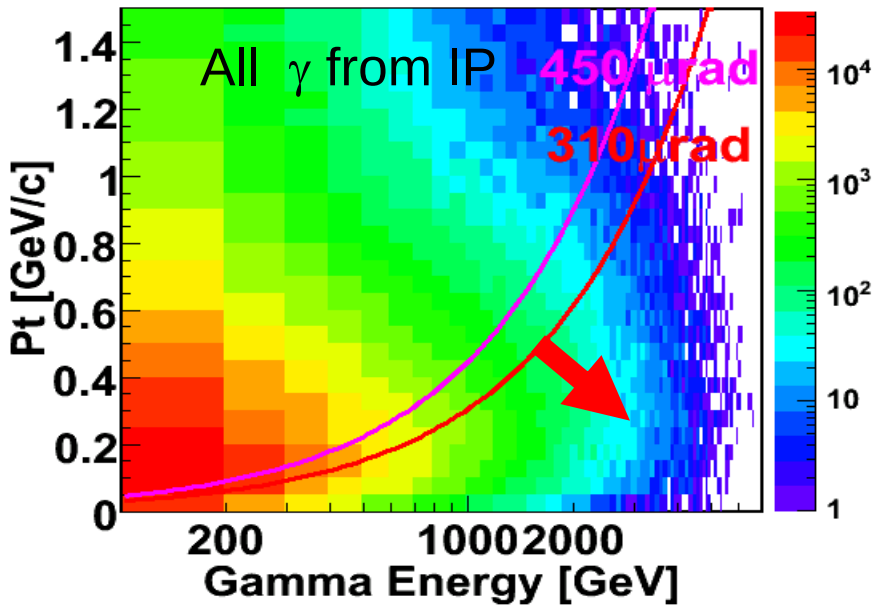
- Remotely changed by a manipulator(w/ accuracy 50 μm)

Garage position when beam tune
To prevent unnecessary dose
(10^{-3} of data taking mode)

Data taking mode
3 different position
To cover P_T gap

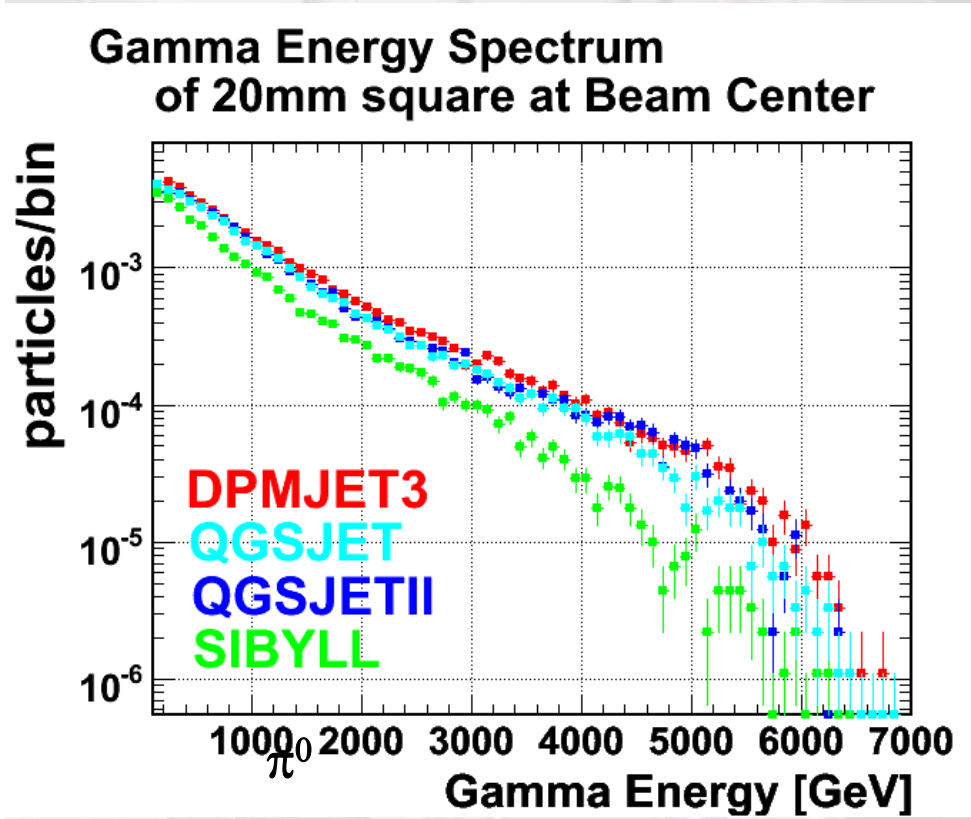


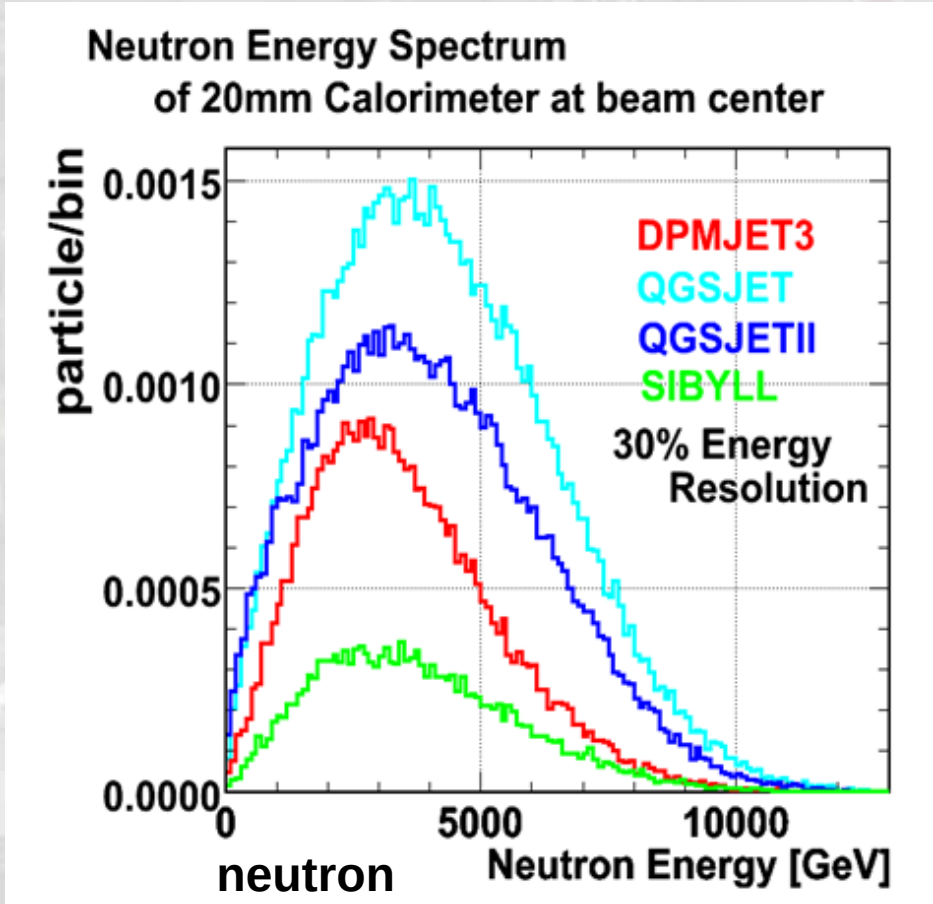




Model dependence of forward energy spectra

- Single γ / neutron samples

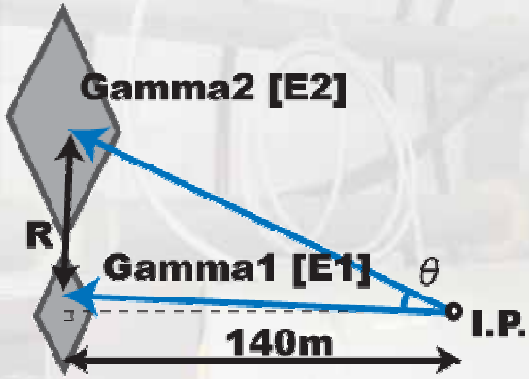


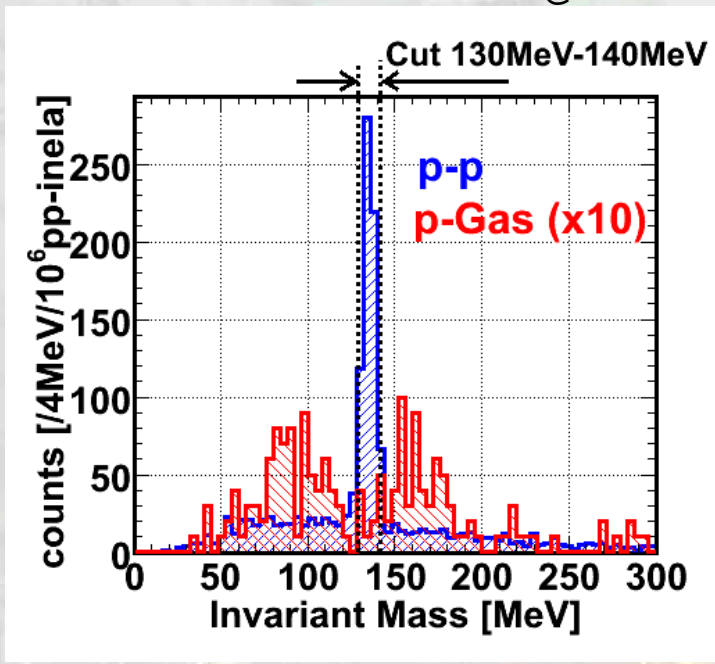


Various distributions at 7+7 TeV

The basic sample ; π^0

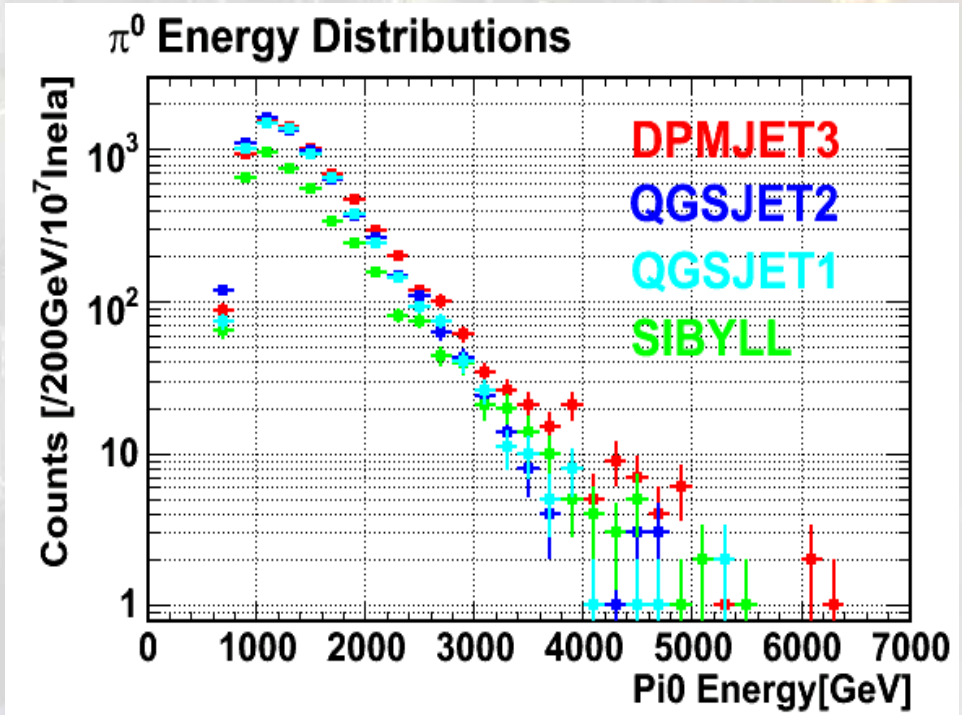
- A clean sample against beam-gas background.
- Energy scale can be checked by data itself





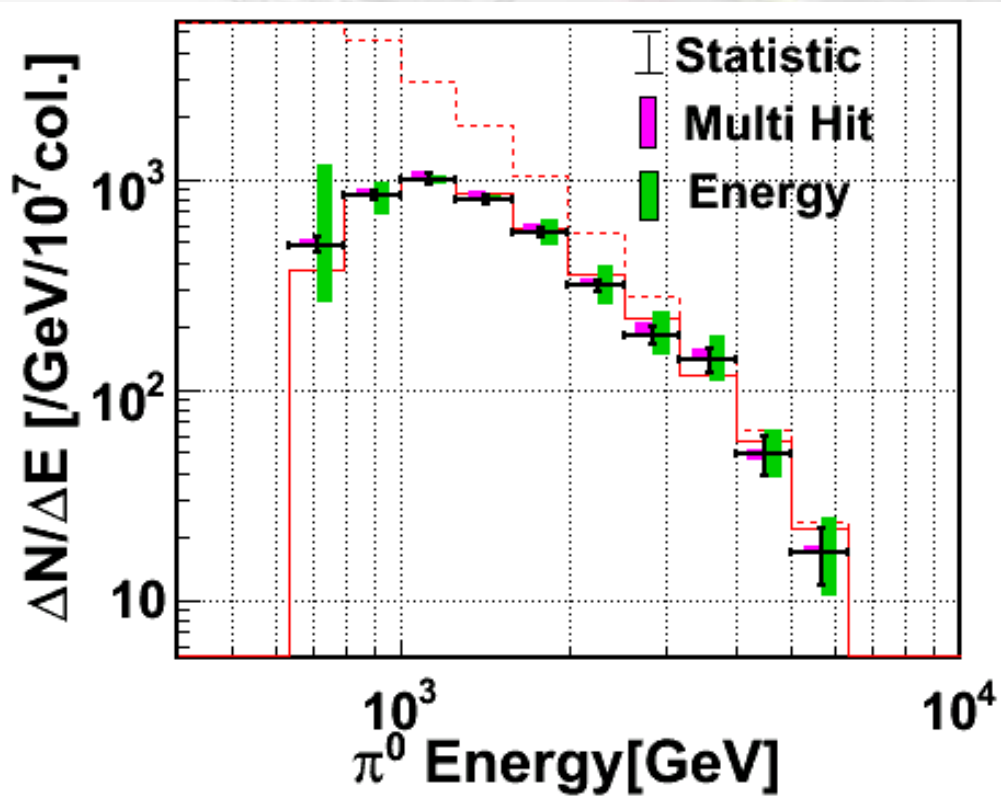
Shape comparison

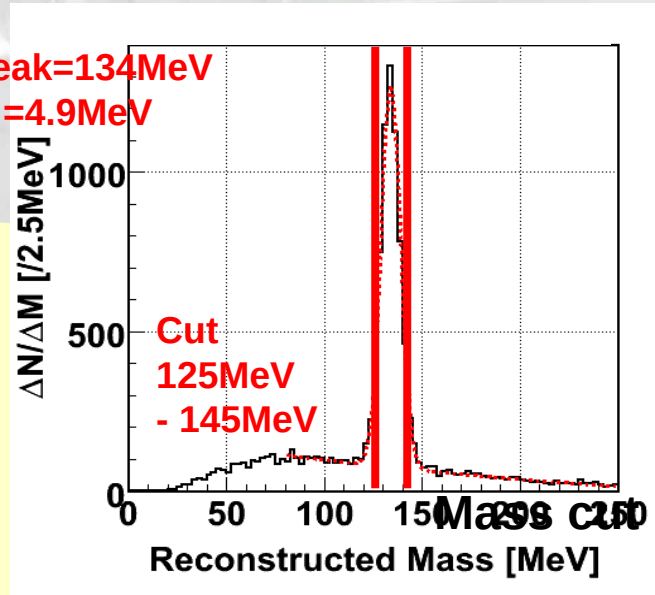
QGSJETII
⇔ DPMJET3 χ^2= 106 (C.L. <10^{-6})
⇔ SIBYLL χ^2= 83 (C.L. <10^{-6})
DPMJET3
⇔ SIBYLL χ^2= 28 (C.L.= 0.024)
10^7events DOF = 17-2=15

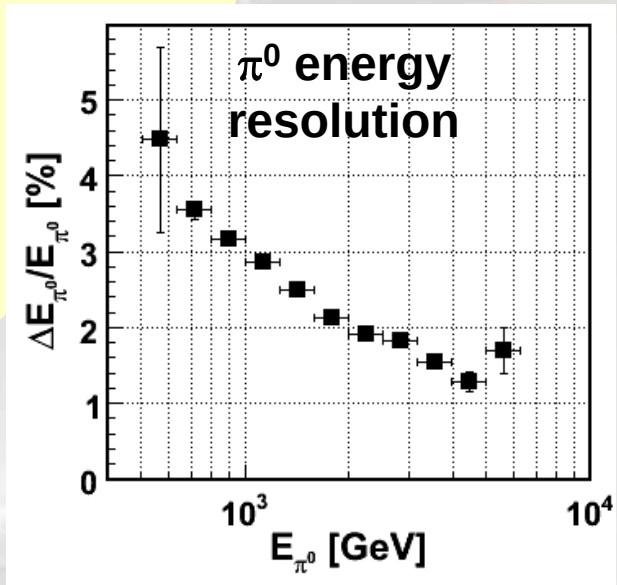


Reconstructed energy spectrum of π^0 (@7+7TeV)

Based on ~10^4 π^0 samples at 2 positions



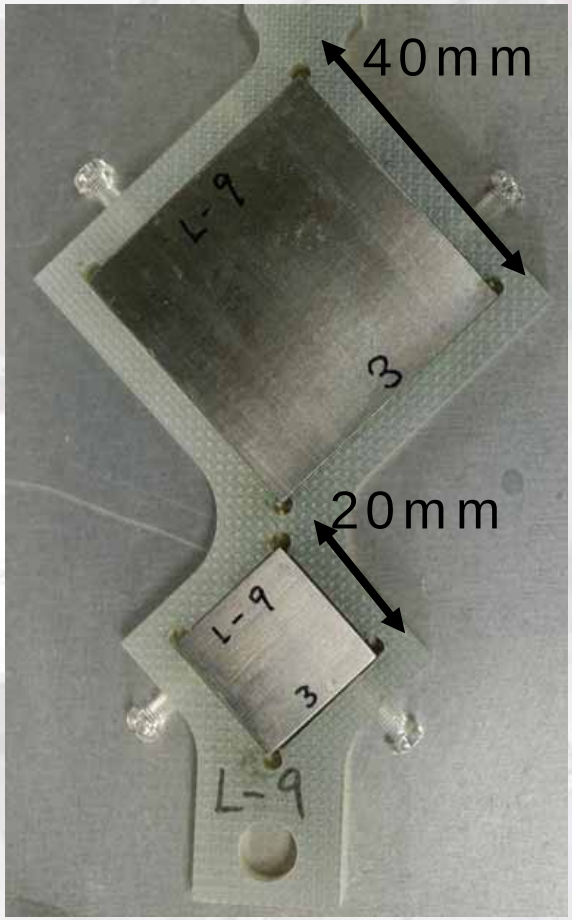




- Uncertainty of Multi Hit contamination
- Uncertainty of energy scale： assumed as ±5%
- Uncertainty of relative normalization btw 2 pos. <0.1%
- Uncertainty of neutral beam center <0.1%

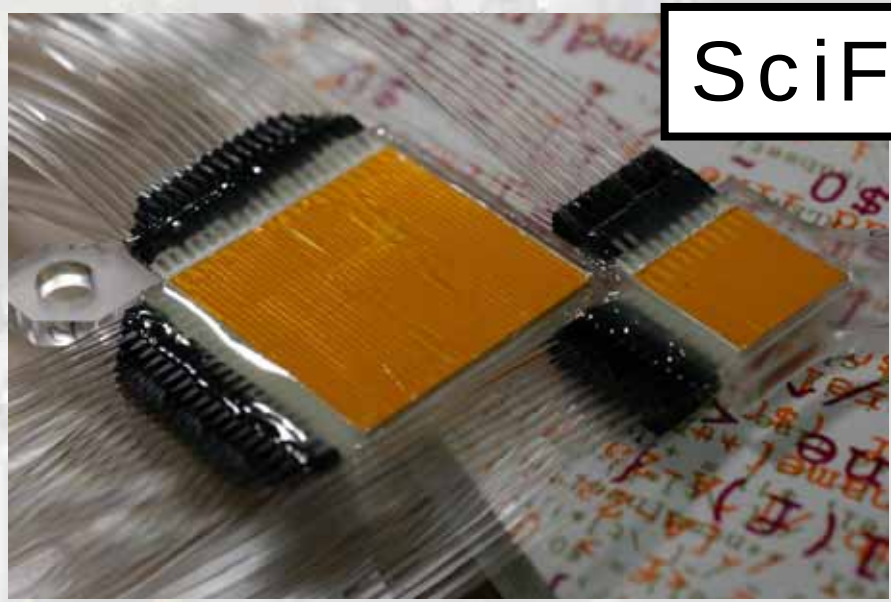
Arm1 detector

Tungsten
7mm(2r.l.)



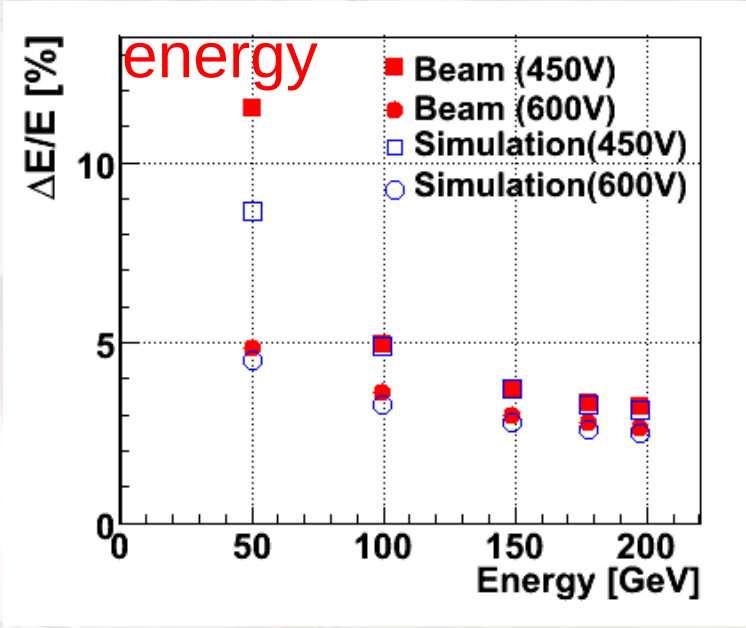
Scintillator

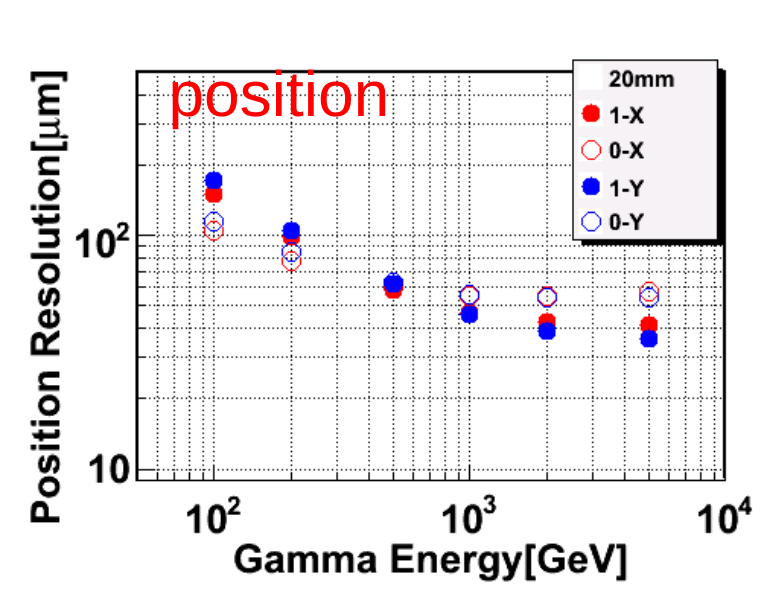
SciFi



LHCf calorimeters

Calibration at SPS H4 Beam Test(04,06 and 07)





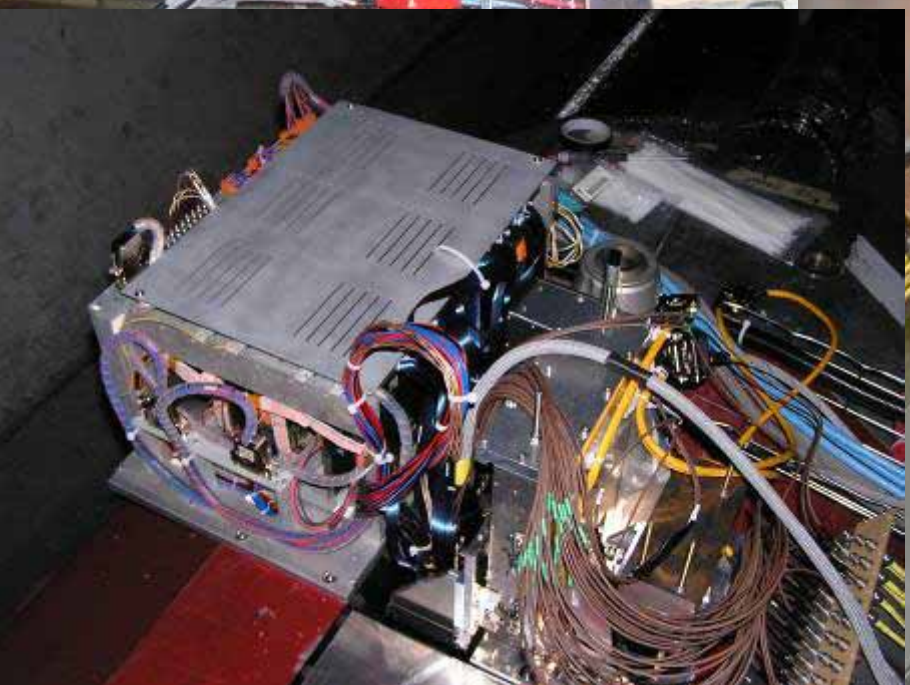
- ✓ **p 150,350 GeV/c**
- ✓ **e 100,200 GeV/c**
- ✓ **μ 150 GeV/c**

- **Energy calibration**
- **Spatial resolution**
- **PID capability , etc…**

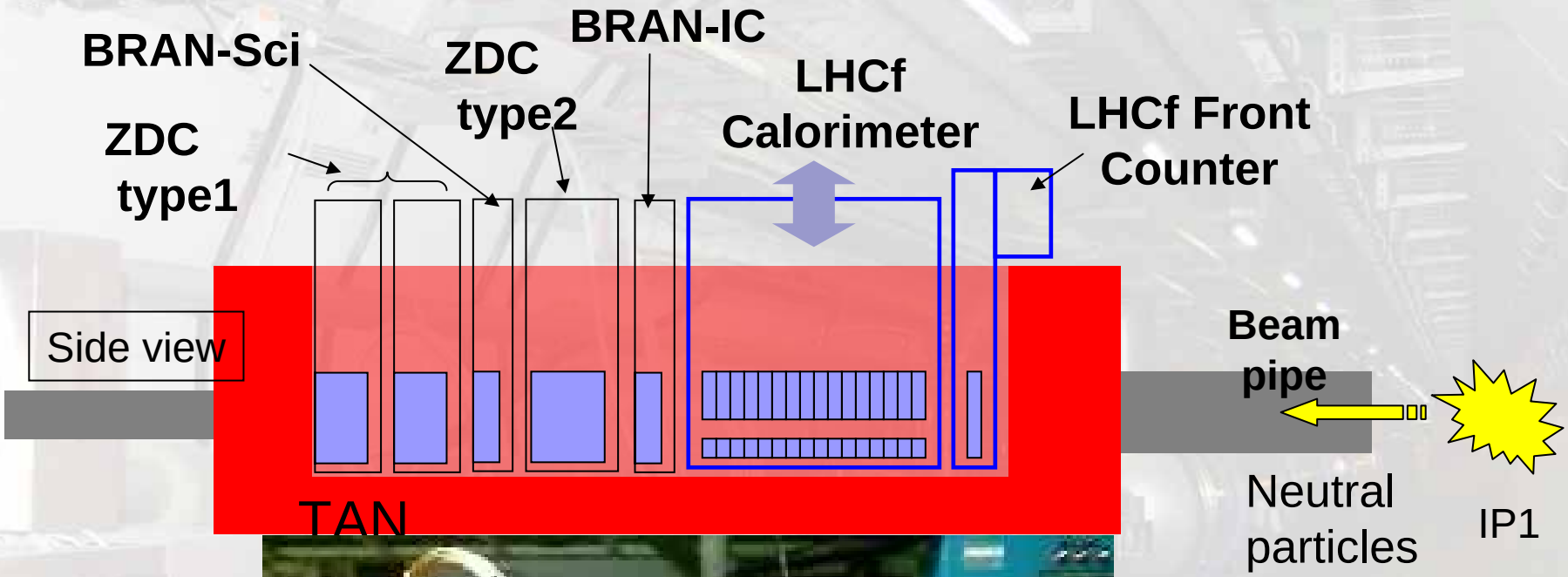
Detectors in place

Installation performed in two phases:

1. **Pre-Installation (2007)**
   Baking out of the beam pipe (200 ° C)
2. **Final Installation (Jan 2008)**

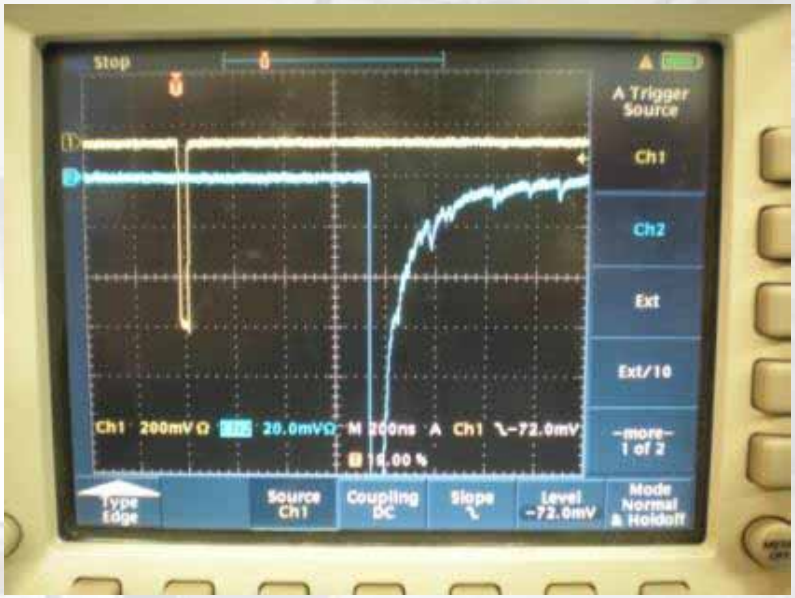


Current setup in IP1-TAN (side view)



LHCf First signal @ Front Counter

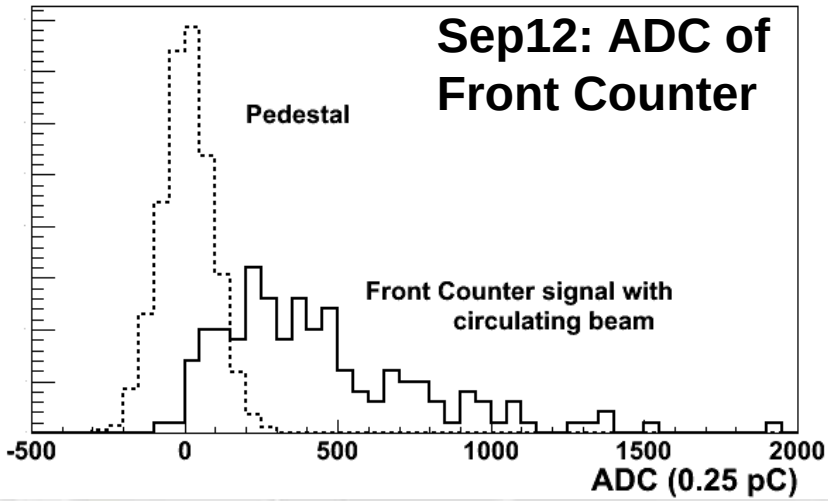
Sep10, 2008,the first signal at scope

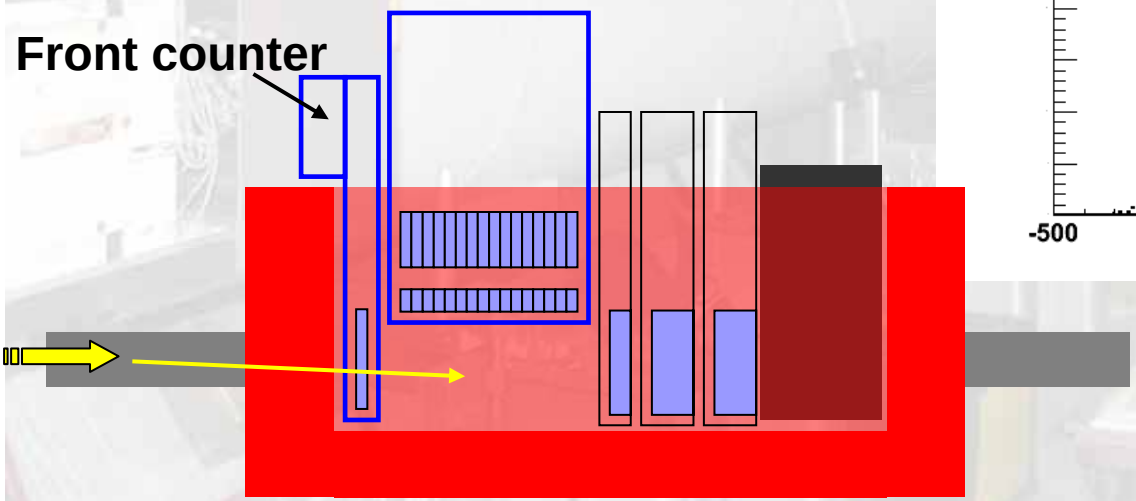


Sep10, 2008 10:25

The 1st 450GeV pilot bunch injected and turned around !

(Just 1 hour after beam tuning !)



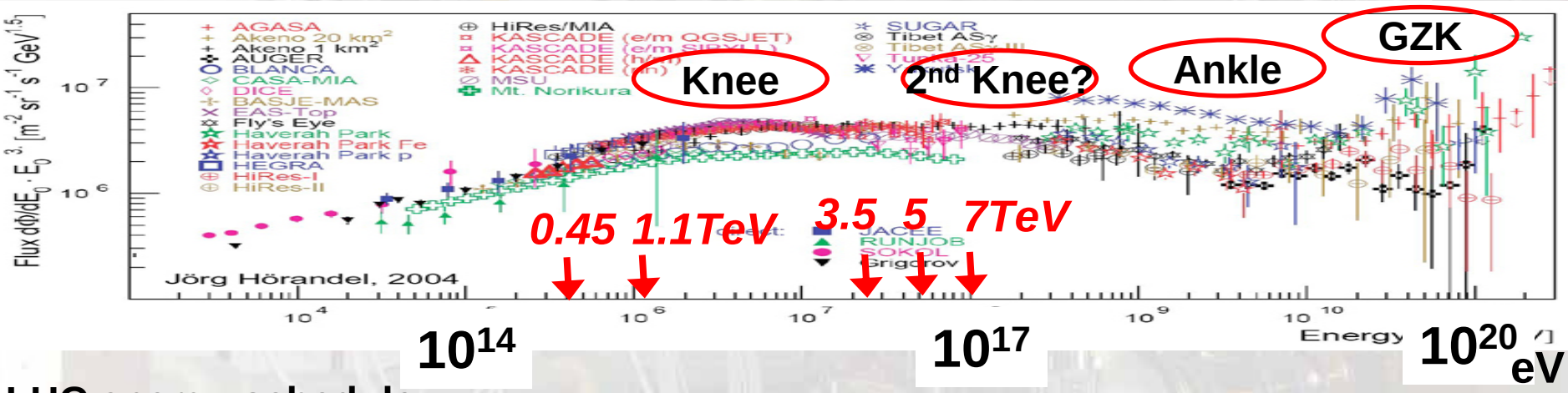


LHCf takes data every when LHC increases energy

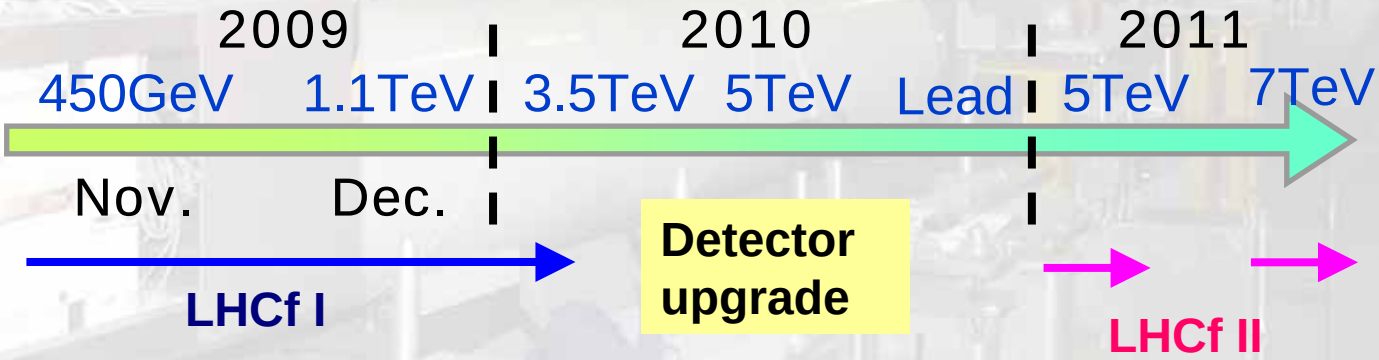
HEAT

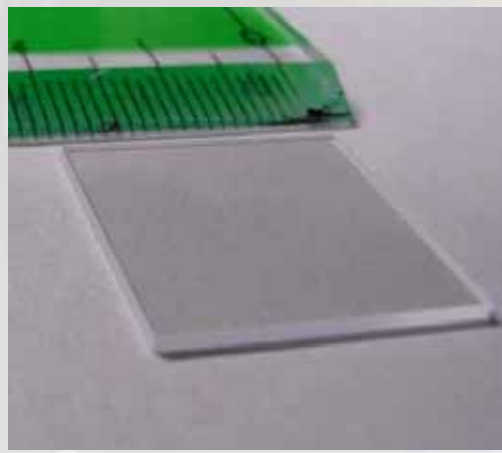
TALE

AUGER, TA



LHC energy schedule

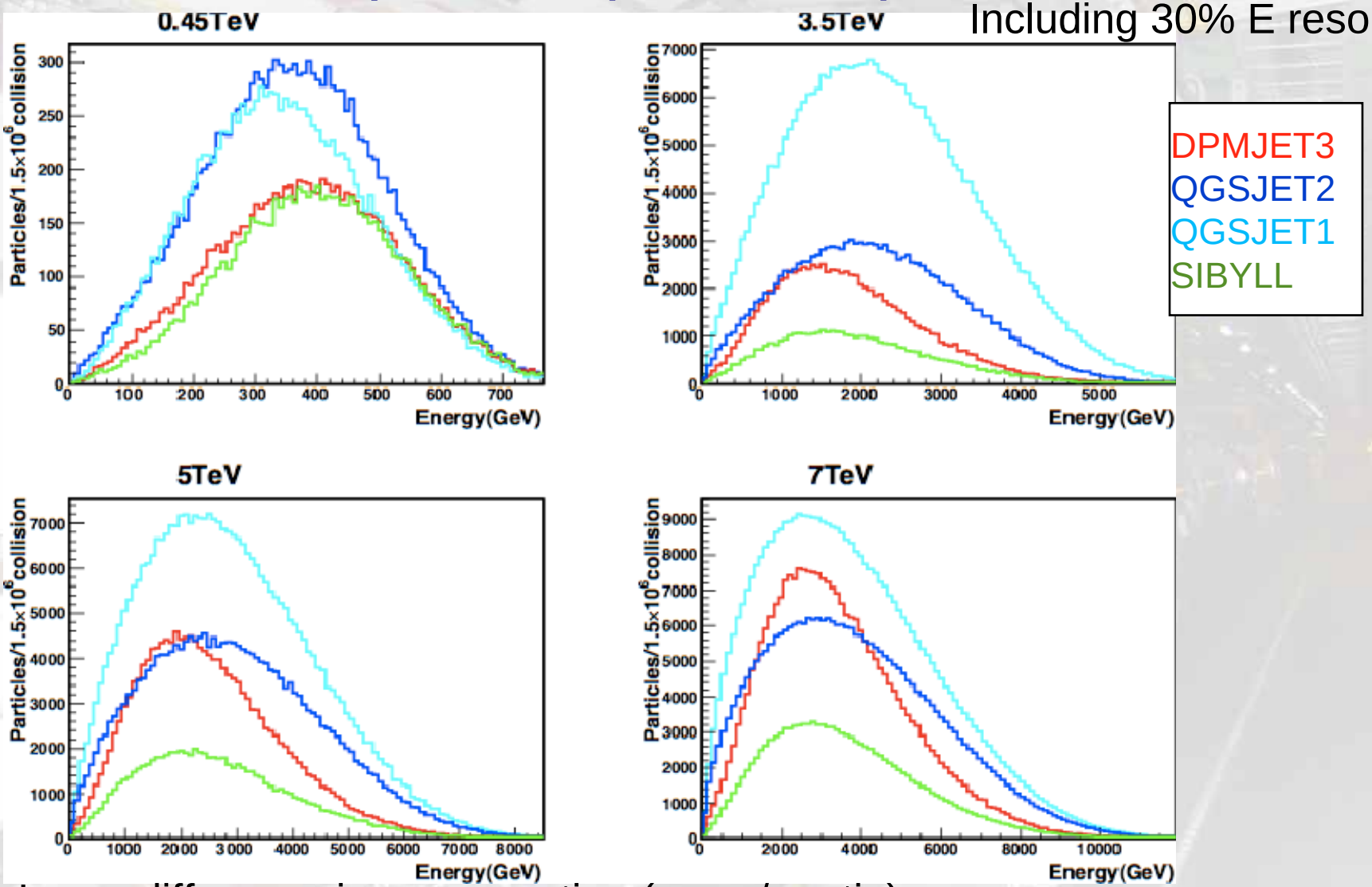




- **Current detector will be "burned" until 3.5TeV run**
- **New detector w/ rad-hard GSO scinitillator will be ready for 5 and 7 TeV runs**

Hadron component (neutrons) for different energy

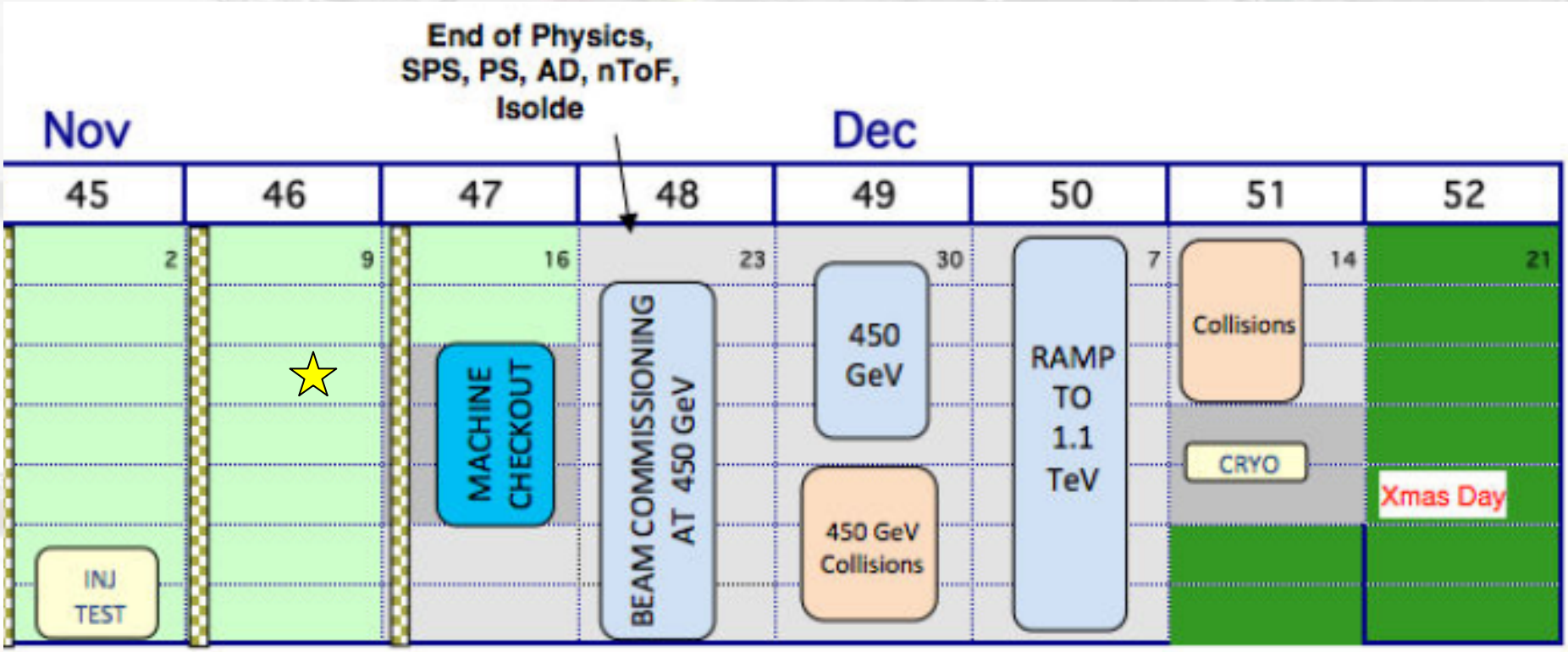
Including 30% E resolution



Large difference in cross section (or a γ/n ratio) .

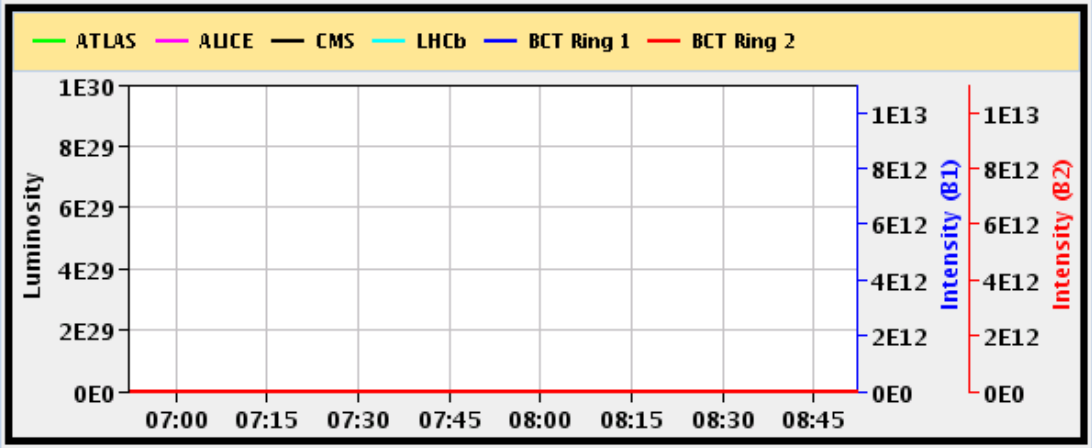
Initial accuracy of luminosity 15% by “luminosity scan” would be even enough to discriminate.

LHC ; schedule in this year

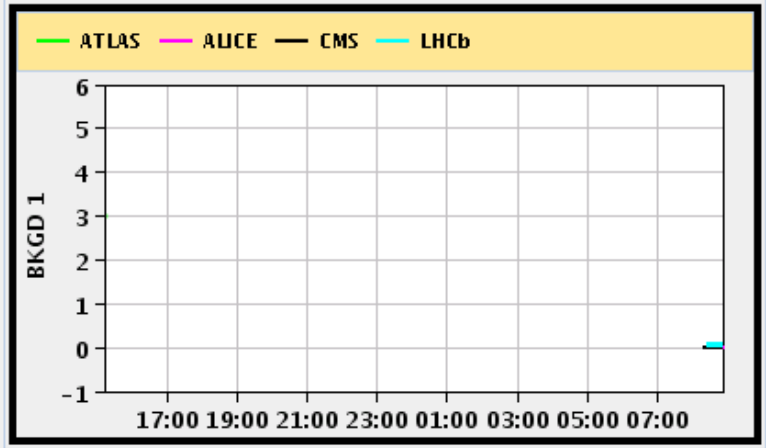


	ATLAS	ALICE	CMS	LHCb
Experiment Status	CALIBRATION	STANDBY	date from DIP so	OFF
Instantaneous Luminosity	pdate from DIP sour	1.000e+27	9.752e-03	-1.000e+00
Integrated Luminosity	pdate from DIP sour	1.000e+27	0.000e+00	0.000e+00
BKGD 1	3.000	0.005	0.001	0.044
BKGD 2	2.900	0.000	0.000	0.150
BKGD 3	60.000	0.000	0.001	0.005

Performance over the last 24Hrs



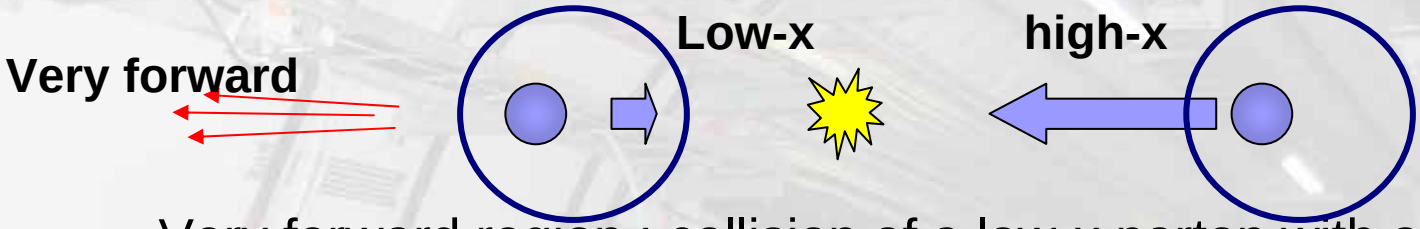
Background 1



LHCf	OFF	LHCb VELO Position	OUT	TOTEM

	Beam 1	Beam 2
Global Beam Permit	false	false
Setup Beam Flag	true	true
Beam Presence	false	false
Moveable Devices Allowed In	false	false
Stable Beams Flag	false	false

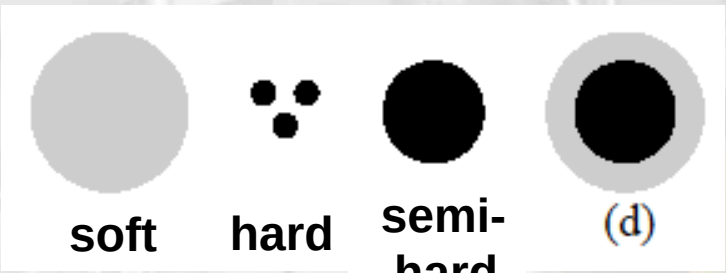
Very forward – connection to low-x physics

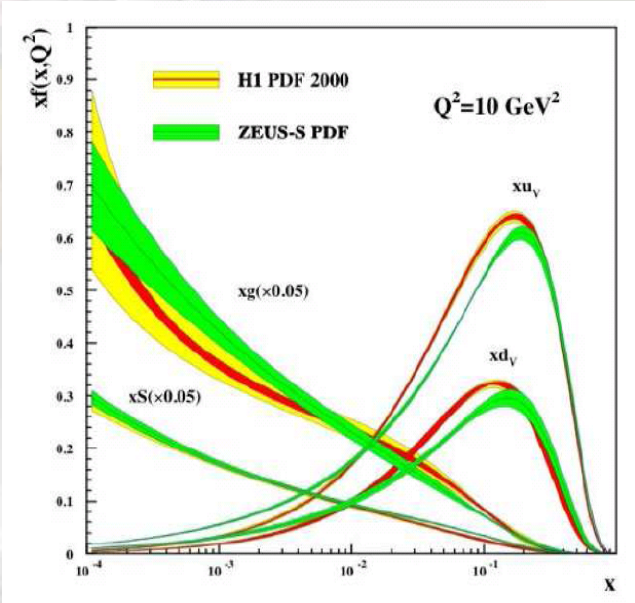


- Very forward region : collision of a low-x parton with a large-x parton
- Small-x gluon become dominating in higher energy collision by self interaction.
- But they may be saturated (Color Glass Condenstation)

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)

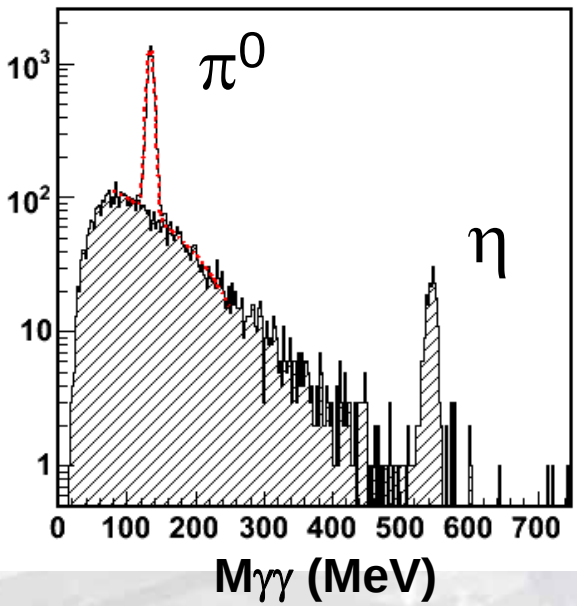


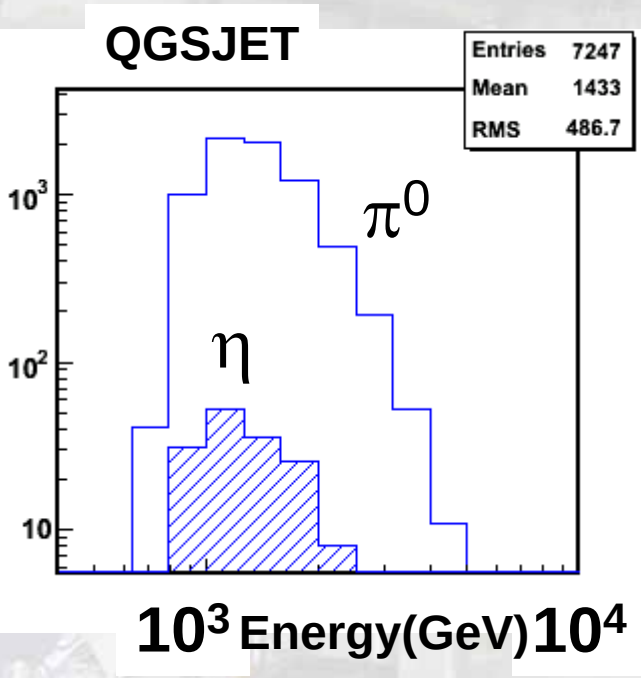


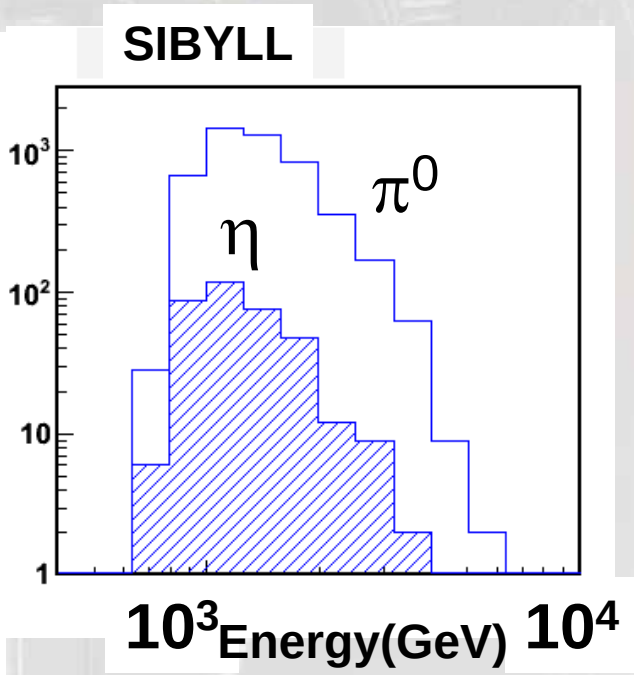
High static sample for very forward hadron productions

- ~10^7 π^0 can be corrected for a few 100 nb^{-1} each at 3,5 and 7TeV
- higher mass hadrons ($\eta \rightarrow \gamma\gamma$, $\Lambda \rightarrow n\pi^0$, etc) can be reconstructed.

7+7 TeV MC





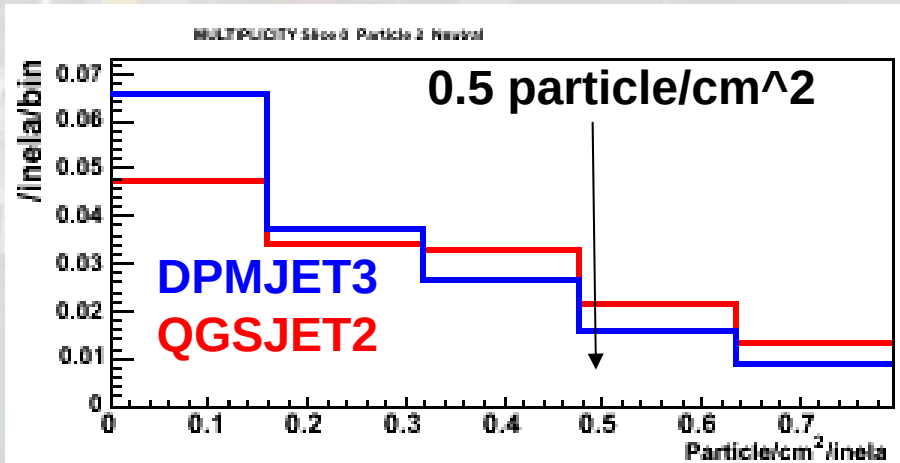


Future Heavy Ion run

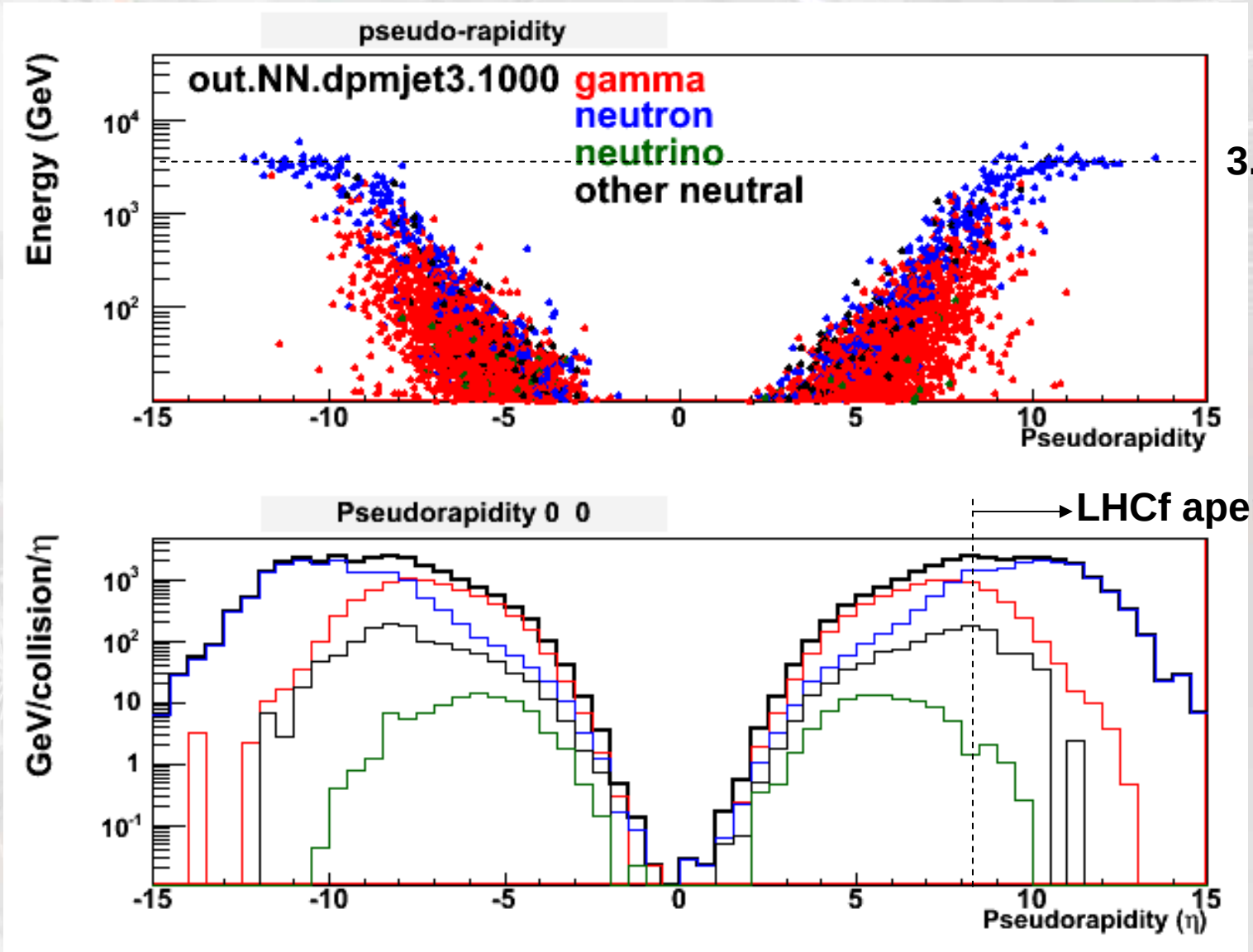
- It is essential to take A-A or p-A collision data to understand nuclear effect in the model.
- So far only heavy ions (Pb-Pb) collisions are forseen (earliest in late 2010) at LHC, in which LHCf will not be in.
- Too much multiplicity in the forward for such heavy ions for inclusive measurements. Lighter nuclei (N-N or C-C etc) collisions , which are not forseen in LHC so far, gives reasonable multiplicity.
- Presumably to cope with higher multiplicity, need detector upgrade using such as 2-D imaging with silicon pixels.

Rad-hard (>1M Gy) Silicon Pixel detector ?

3.5TeV/n N- N collisions
Mulitiplicity in 0-1cm cone at 140m



Neutral from 3.5TeV/n N+N collisions(DPMJET3)



Summary

- LHCf : Dedicated measurements of neutral particles at 0 deg at LHC energy for the verfication of cosmic rays interaction models.
- Detectors are installed at IP1 in 2008, ready for collisions.
- As increasing energy of LHC, providing several calibration points at 10^{14}~10^{17}eV of cosmic rays.
- For 0.45, 1.1 3.5 TeV in 2009~2010 with LHCf-1.
- For 5 and ~7 TeV in > 2010 with upgraded LHCf-2 with rad-hard GSO scintillators.
- Connection to forward hadron physics. High stat. neutral hadron production data in LHCf.
- Future HI runs. R&D in progress.

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.