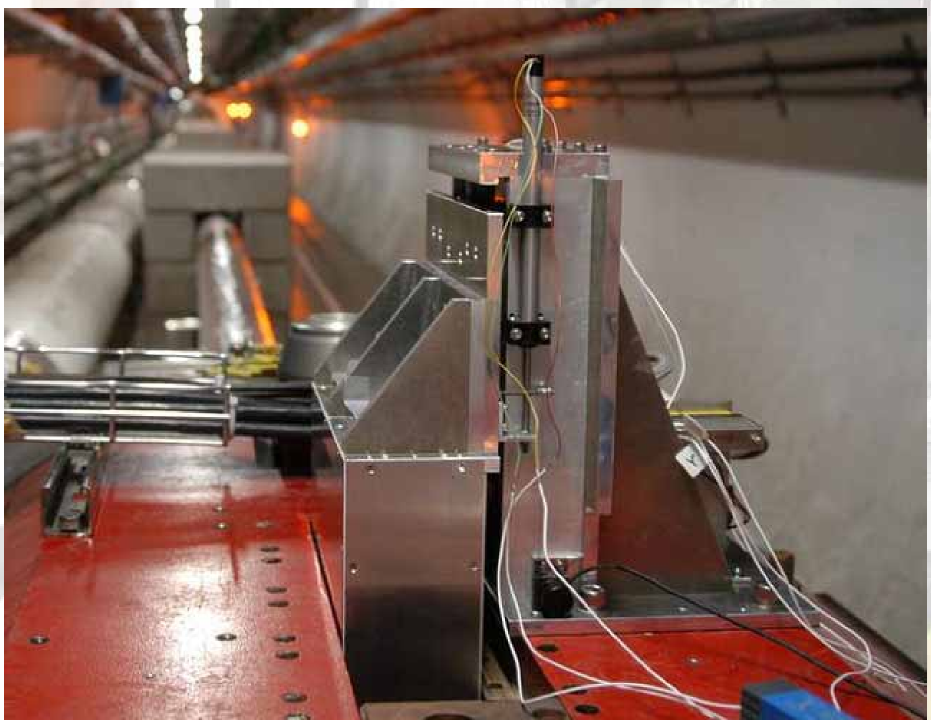
The LHCf experiment

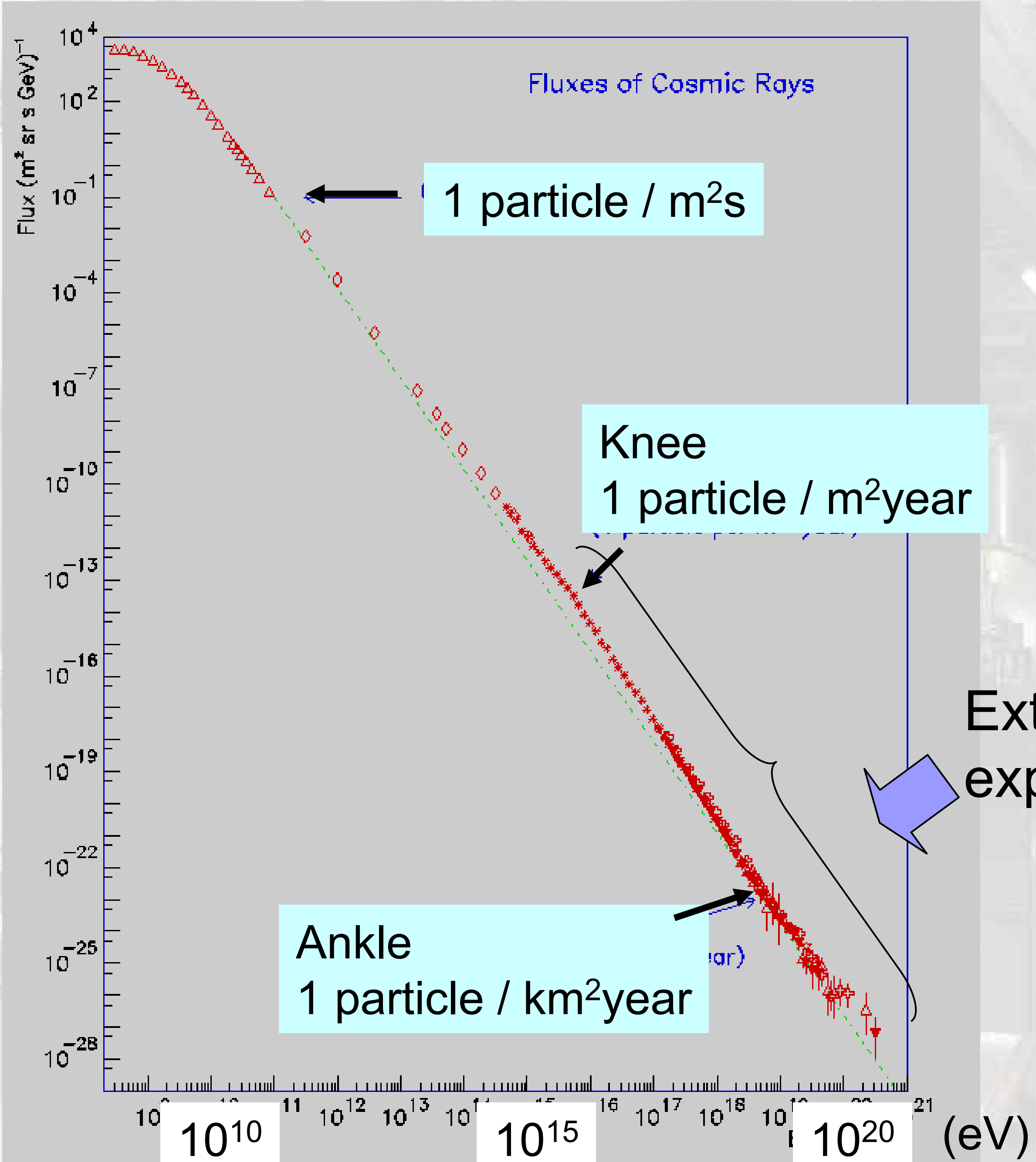
~ Verify hadron interaction models for cosmic rays at 10^{17}eV ~



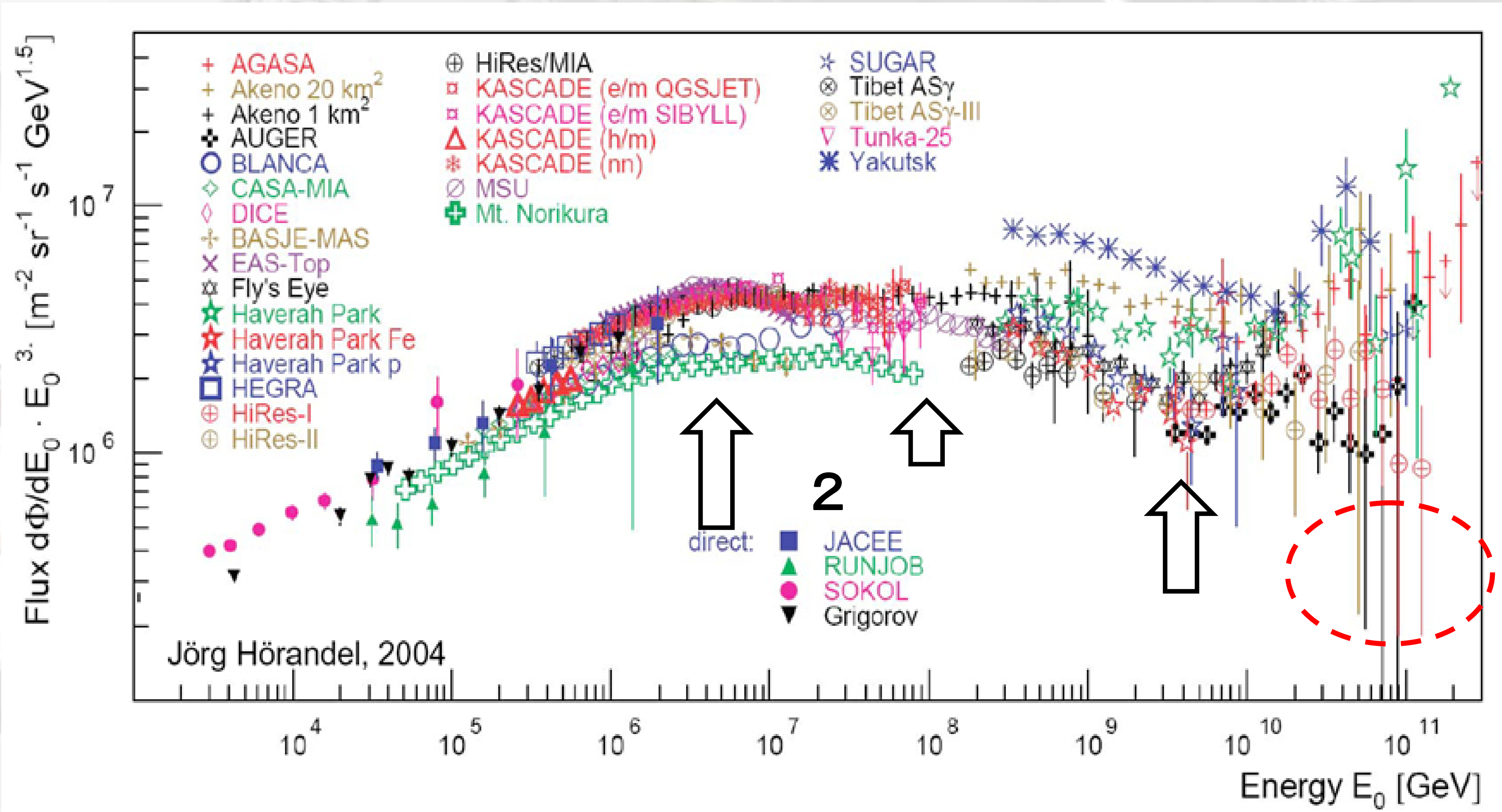
LHCf

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

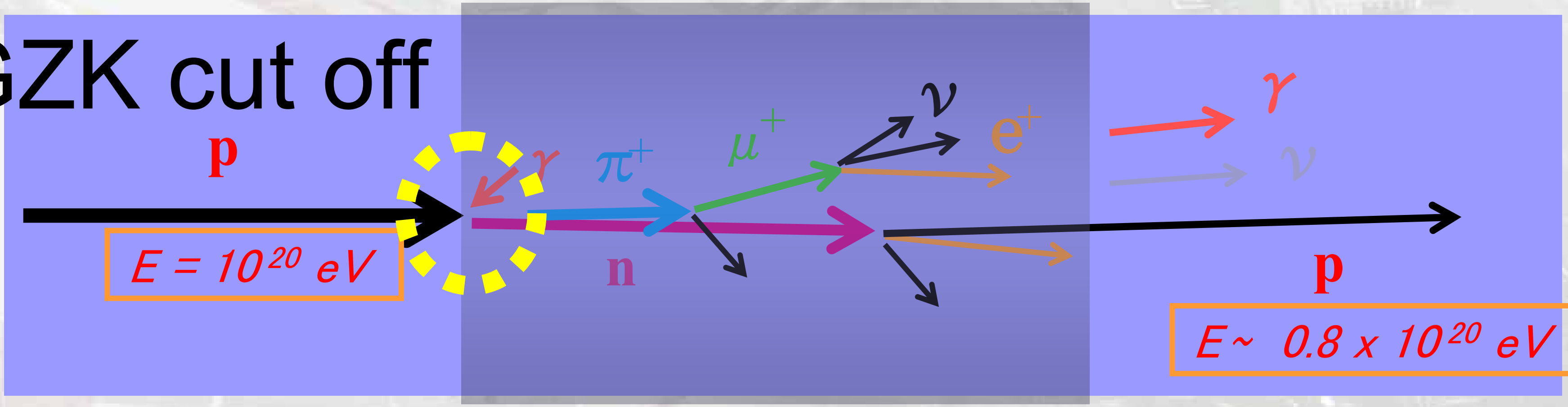
High Energy Cosmic Ray Observations

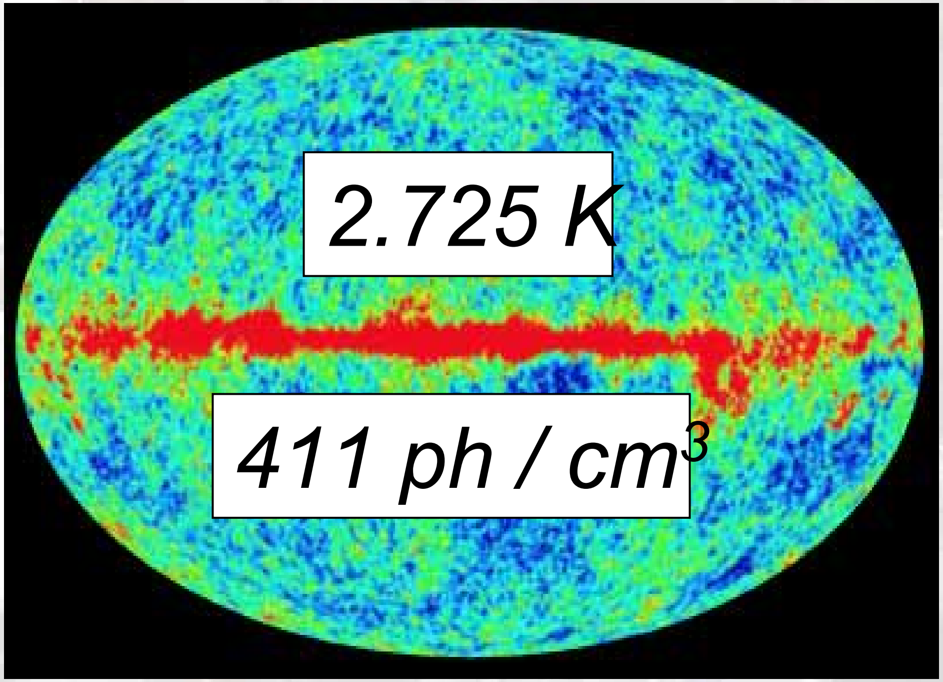


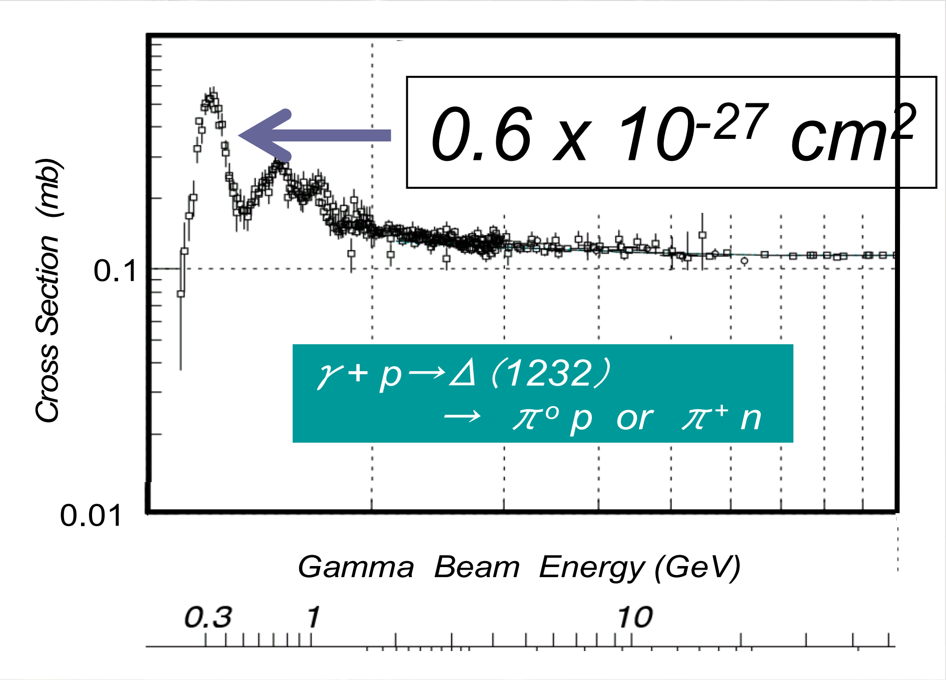
Energy spectrum measurements



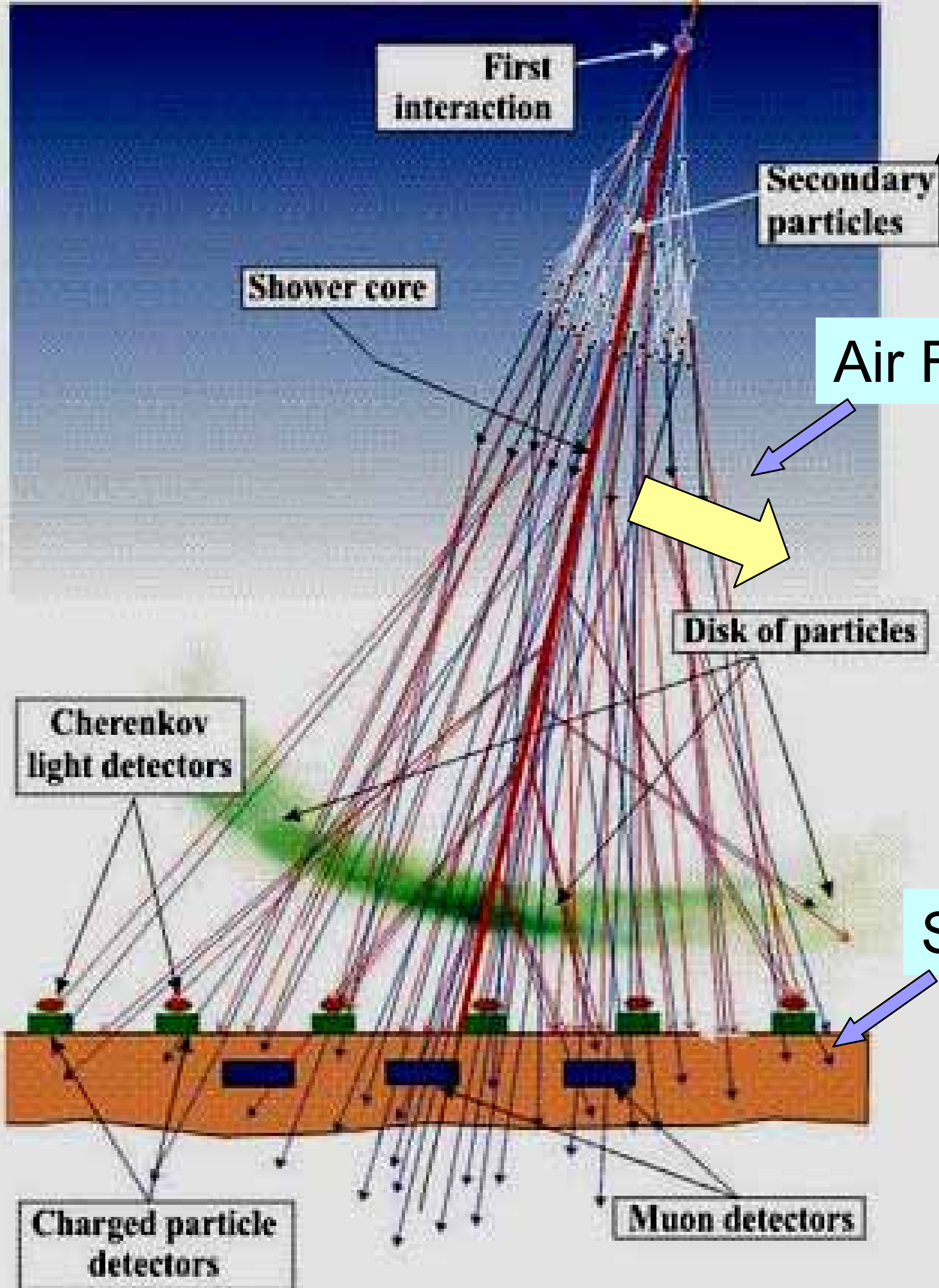
GZK cut off


p
E = 10^20 eV
γ
π+
μ+
ν
e+
n
γ
ν
p
E~ 0.8 x 10^20 eV


2.725 K
411 ph / cm3


0.6 x 10-27 cm2
Cross Section (mb)
0.1
0.01
γ+ p→Δ (1232)
→ π° p or π+ n
Gamma Beam Energy (GeV)
0.3
1
10

Air shower observation



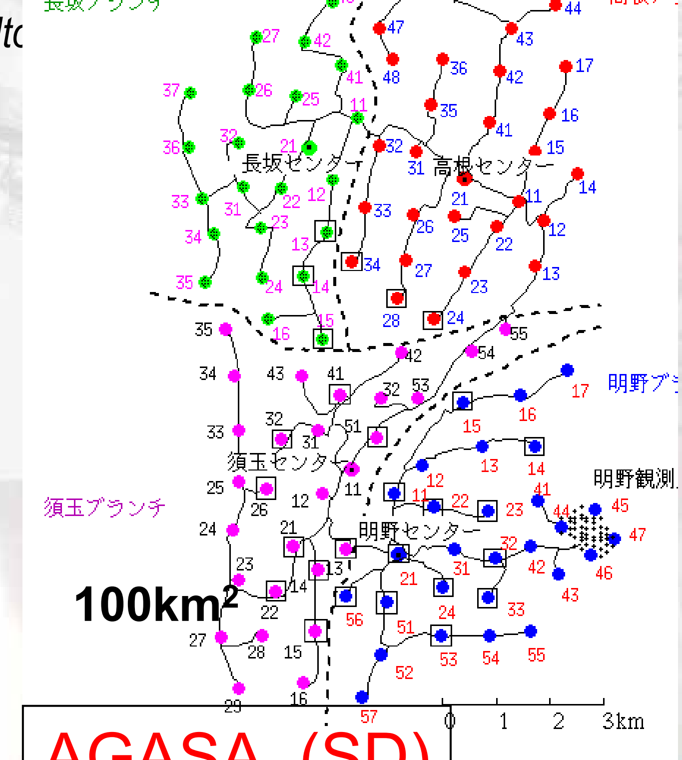
Air Florescence telescope (FD)

EM component
(most of energy)

- Scintillation lights
- Shower directions
- Shower max alititude

Surface Detectors (SD)

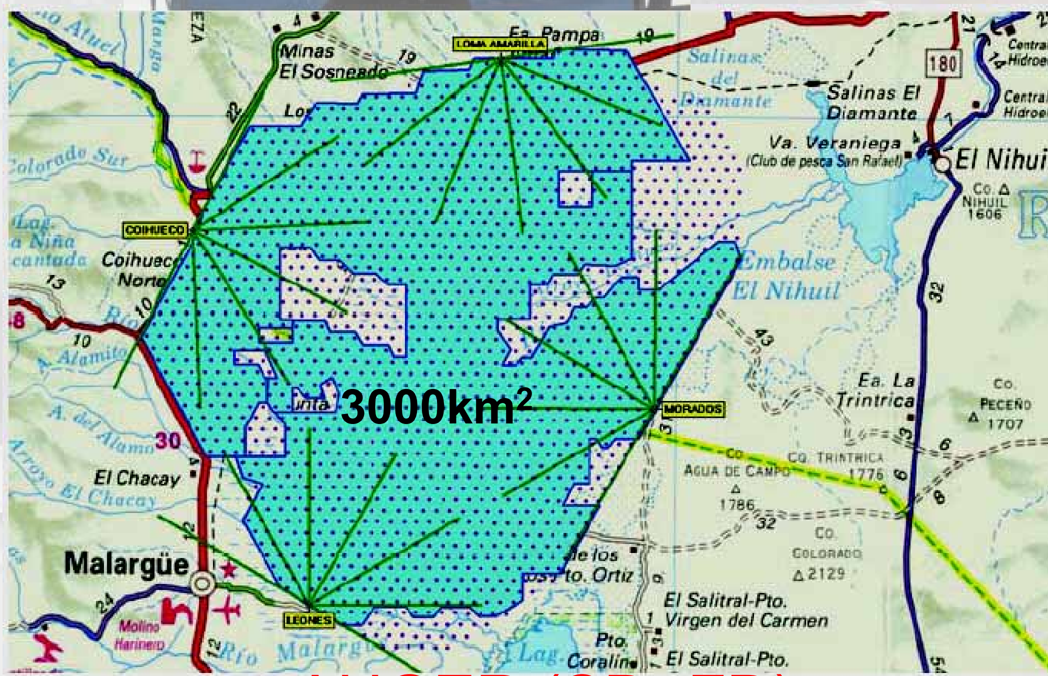
Number of partciles
Arrival timing
Muon or EM component
(at given altitude)



AGASA (SD)

HiRes (FD)

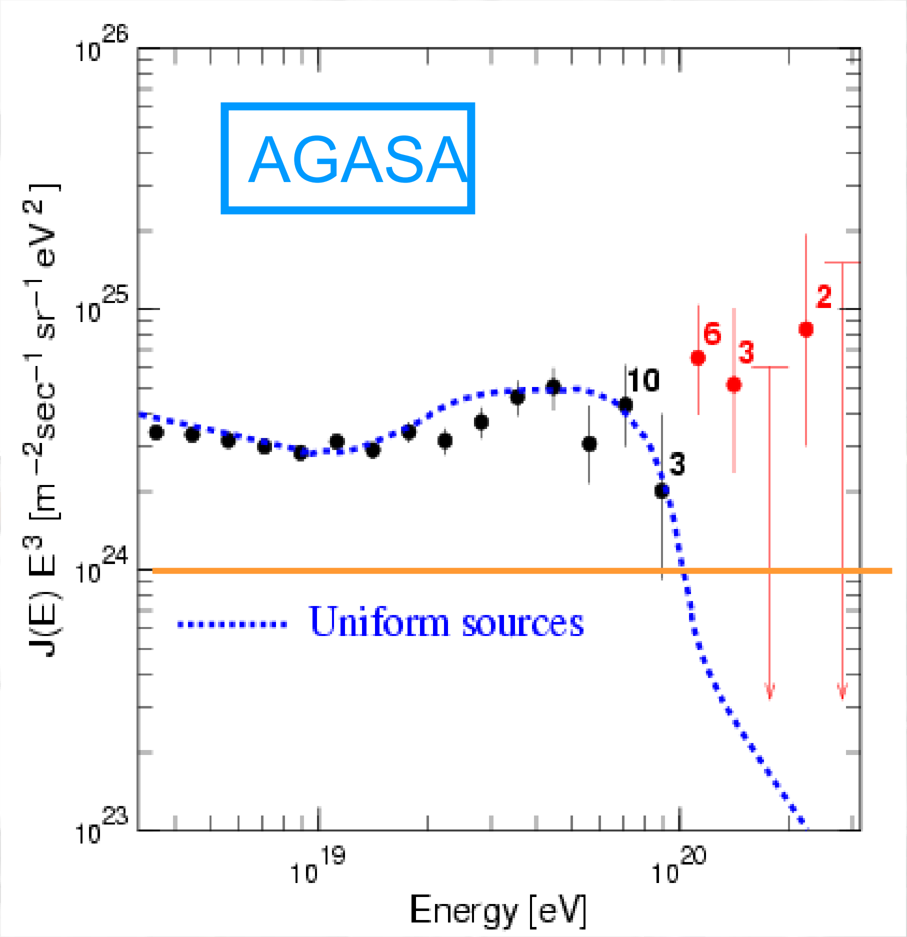
TA (SD+FD)



AUGER (SD+FD)

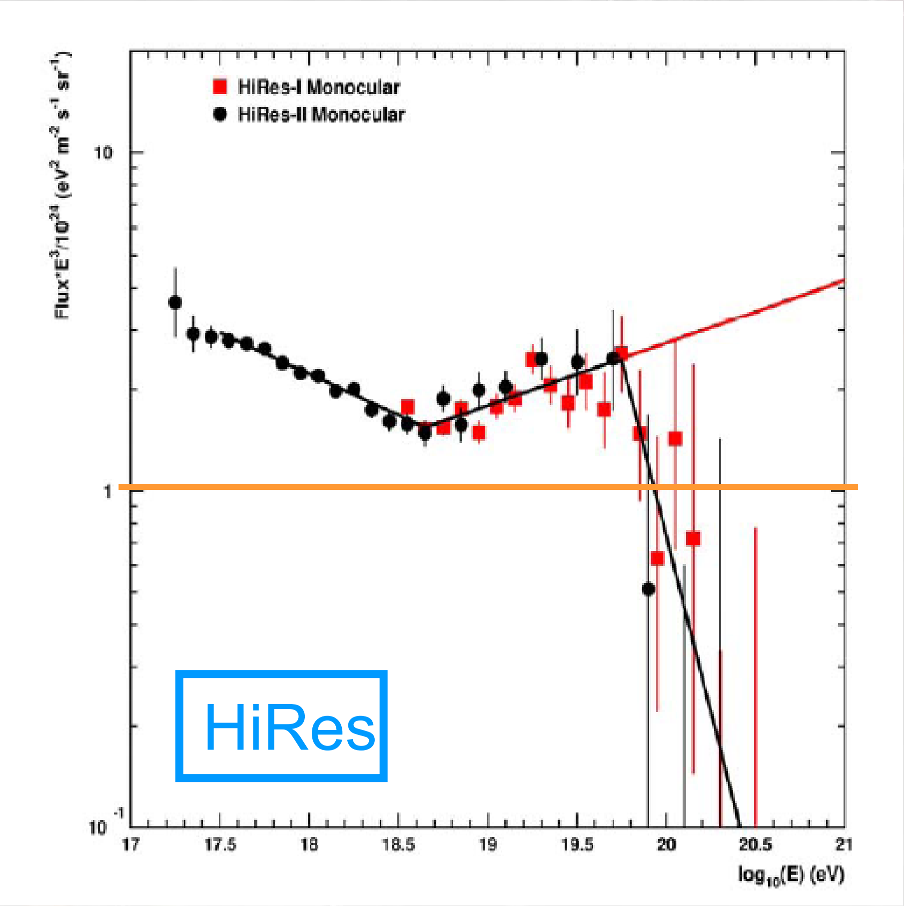
Energy Spectra by AGASA and HiRes (mono)

Ground Array (plastic scintillator)



Astropart.Phys.19(2003)447-462

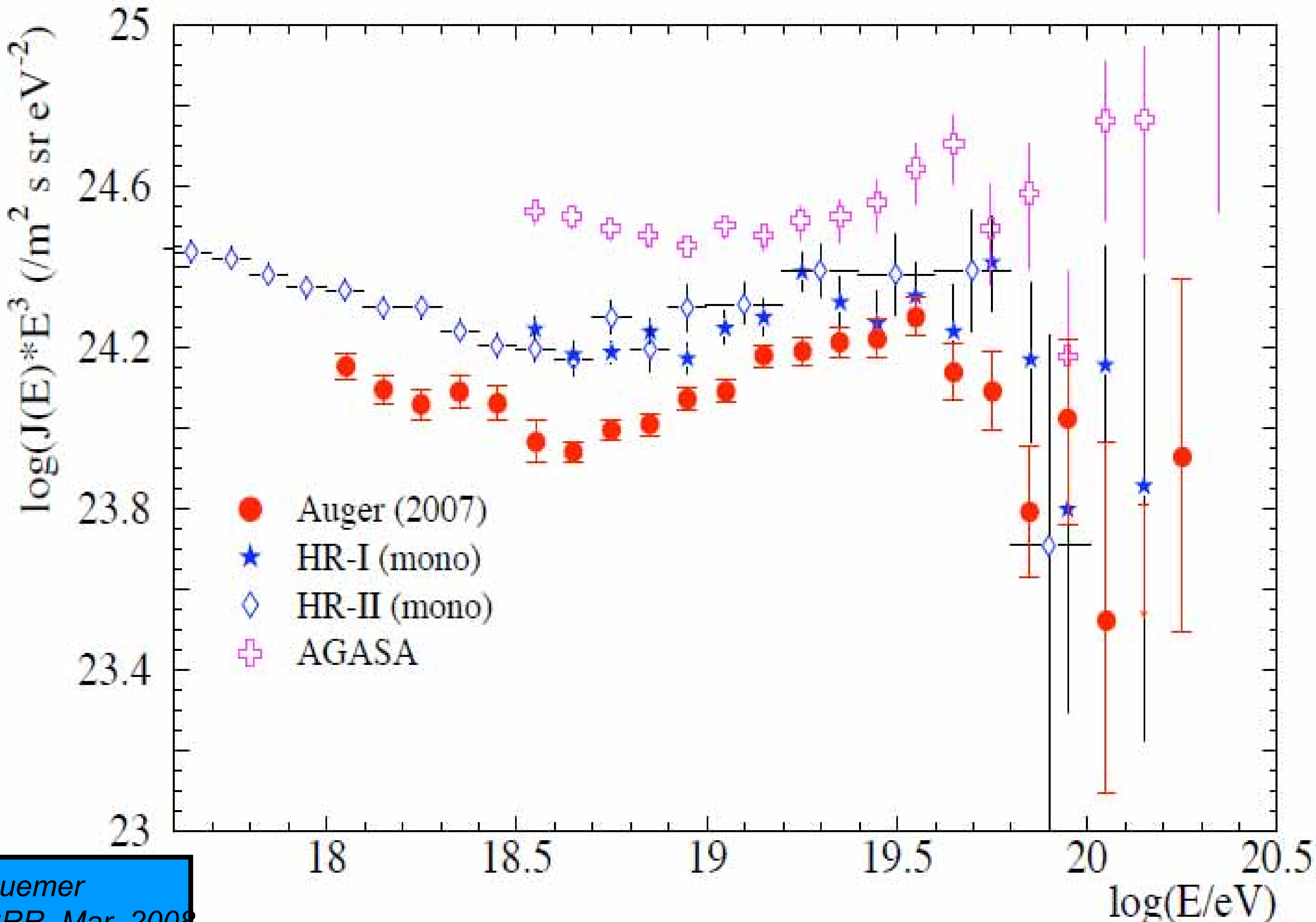
Fluorescence Telescope



Phys.Rev.Lett.100:101101,2008

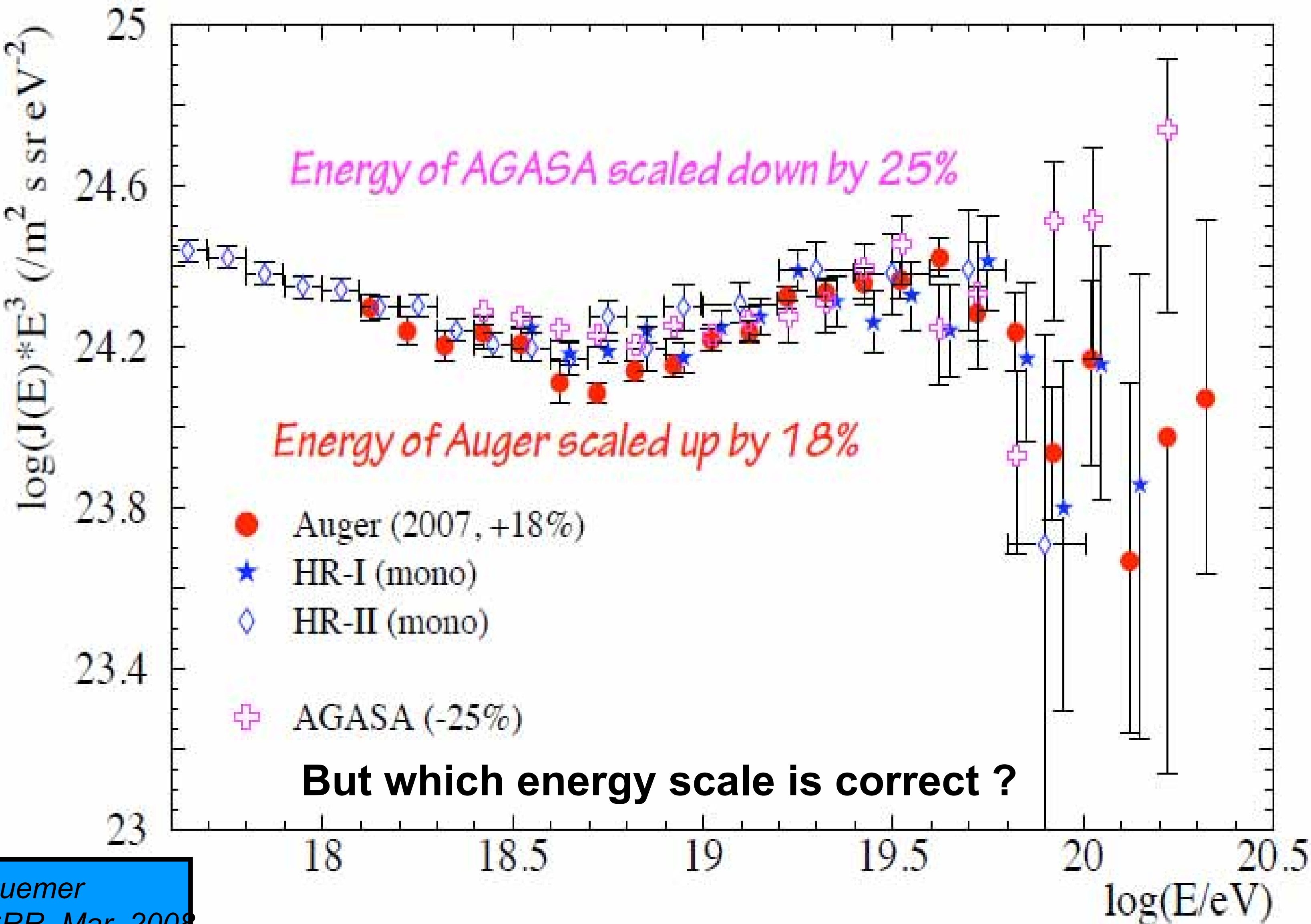
AUGER new results（2007 summer）

c.f. Energy scale was determined by fluorescence detector



J. Bluemer
@ICRR, Mar. 2008

Maybe due to ±25% level of E-scale uncertainty ?

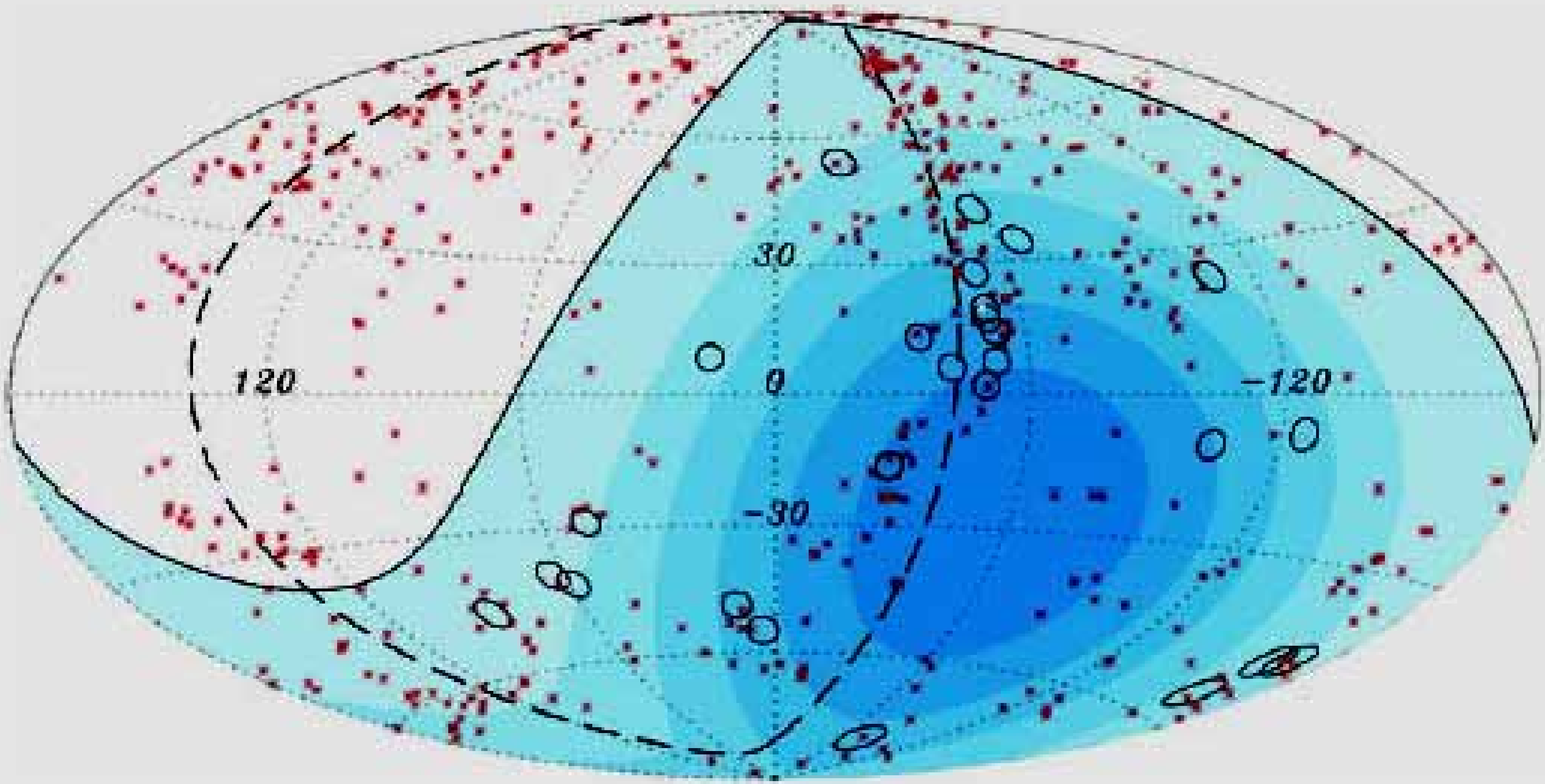


J. Bluemer
@ICRR, Mar. 2008

Arrival directions of UHECRs (AUGER)

Science **318** 938 (2007)

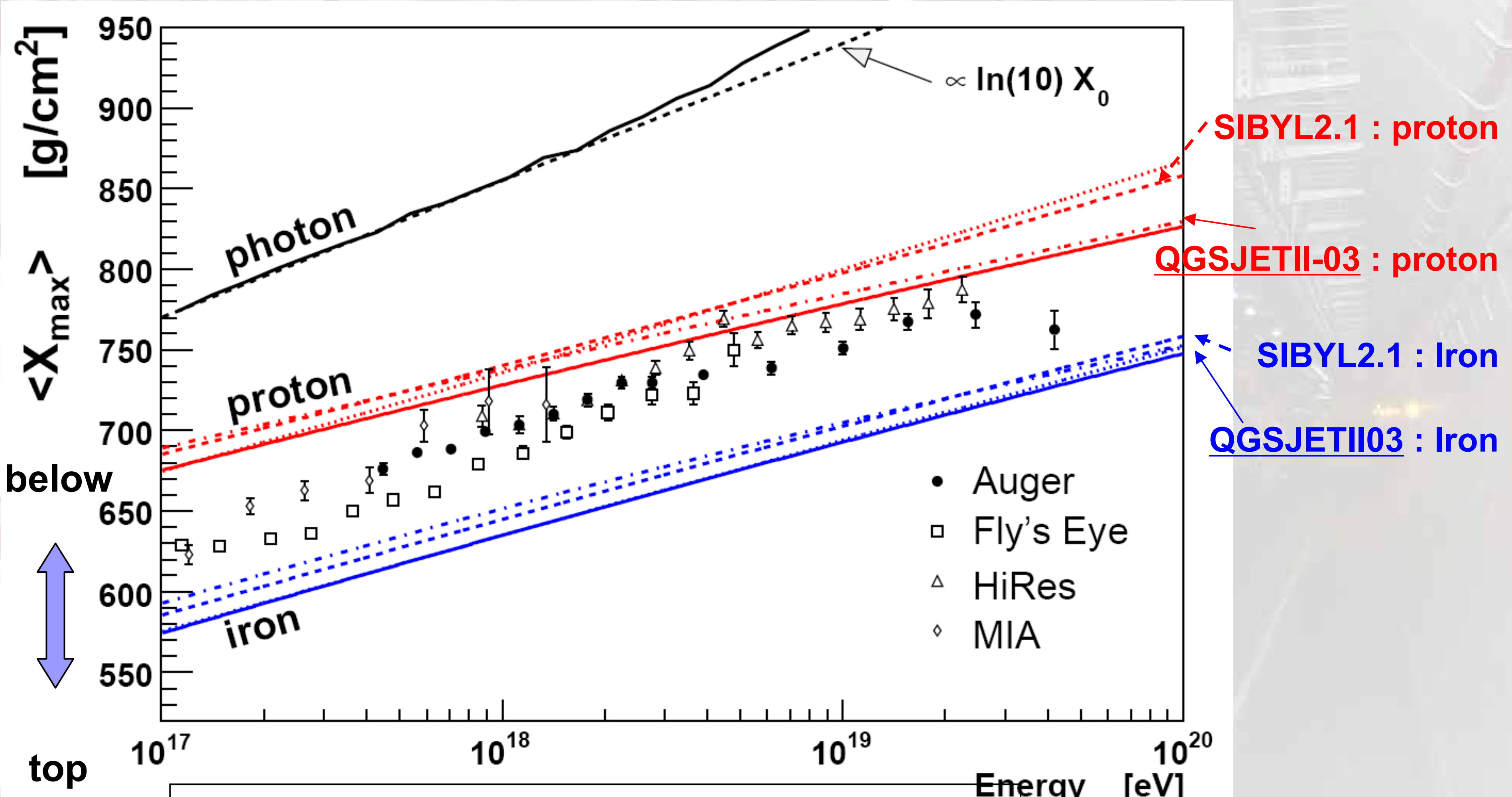
27 UHECRs w/ E>5.7 × 10^{19}eV have correlation to AGNs with 3.1 deg error circles.



UHECR = proton ?

Galactic magnetic field ~ 10^{-6} G → Larmor radius ~ 10kpc @ 10^{20}eV

Composition measurement at GZK region



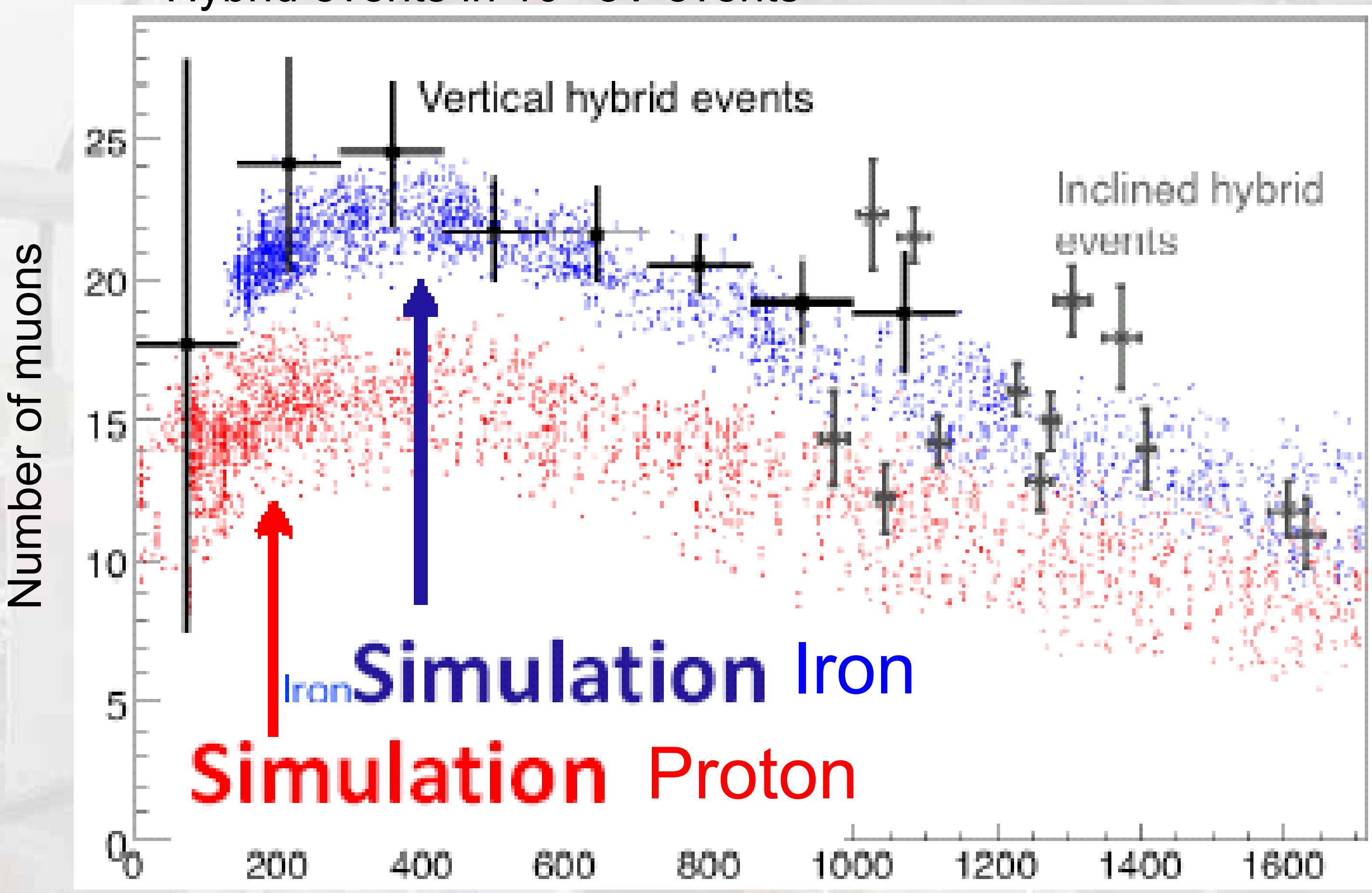
15	16	17	18	19	(log(eV))

light ----> heavy ---> light -------→ heavy??

Galactic extra-galactic

AUGER muon yield favors heavy primary

Hybrid events in 10^{19}eV events



Xmax (g/cm2 from the top)

Hadron Interaction models used in air shower simulations

- QGSJET Ⅰ、Ⅱ
- DPMJET
- SIBYLL
- EPOS

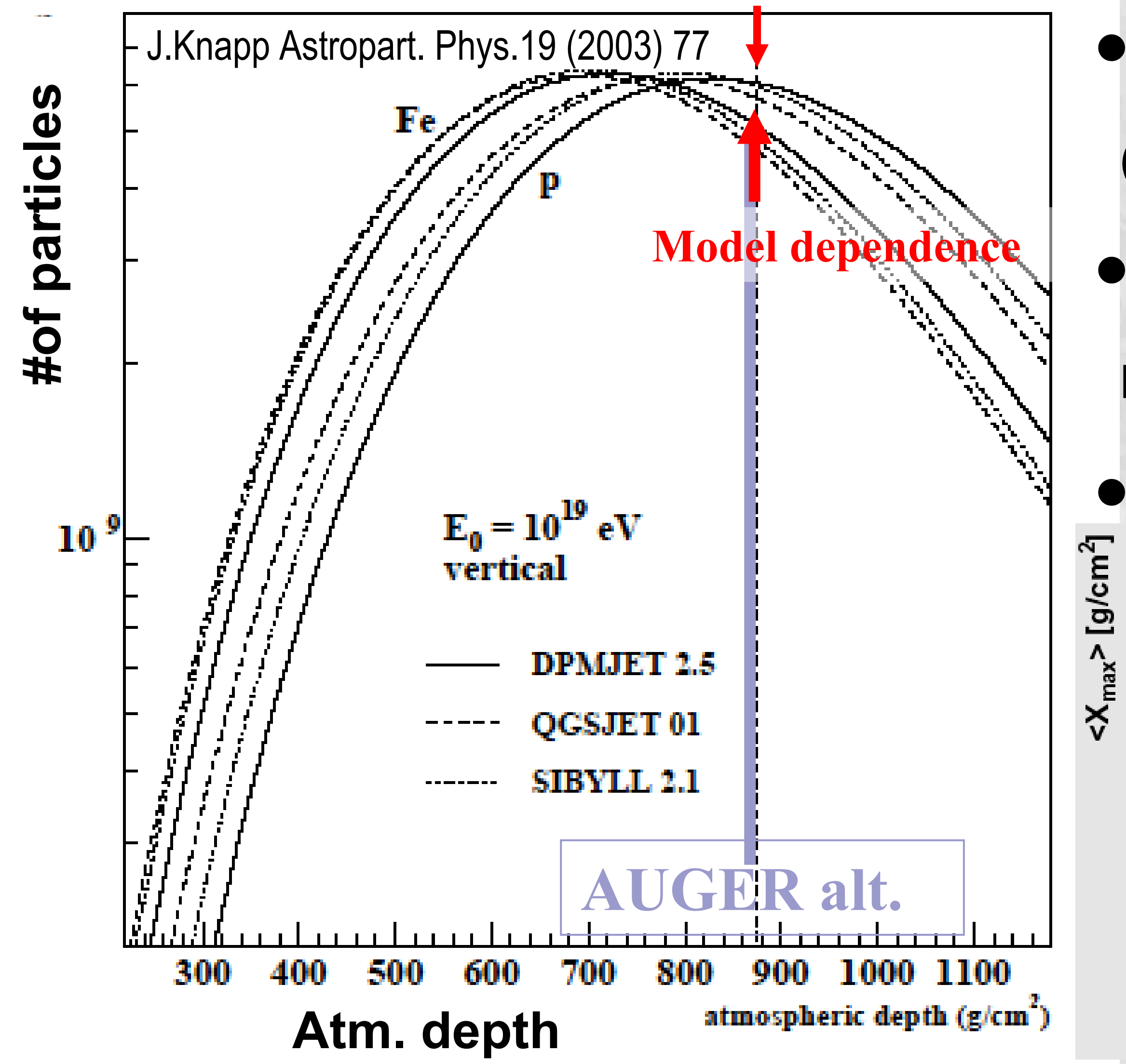
……..

Affect air-shower observables

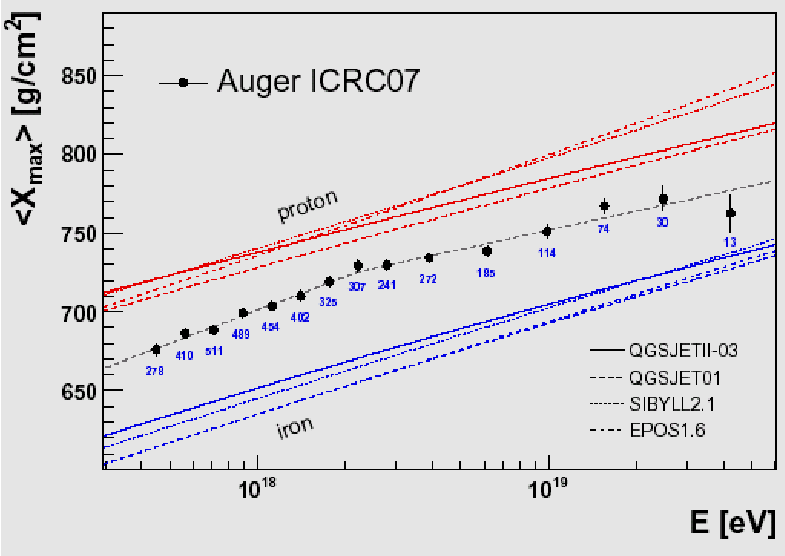
⟺

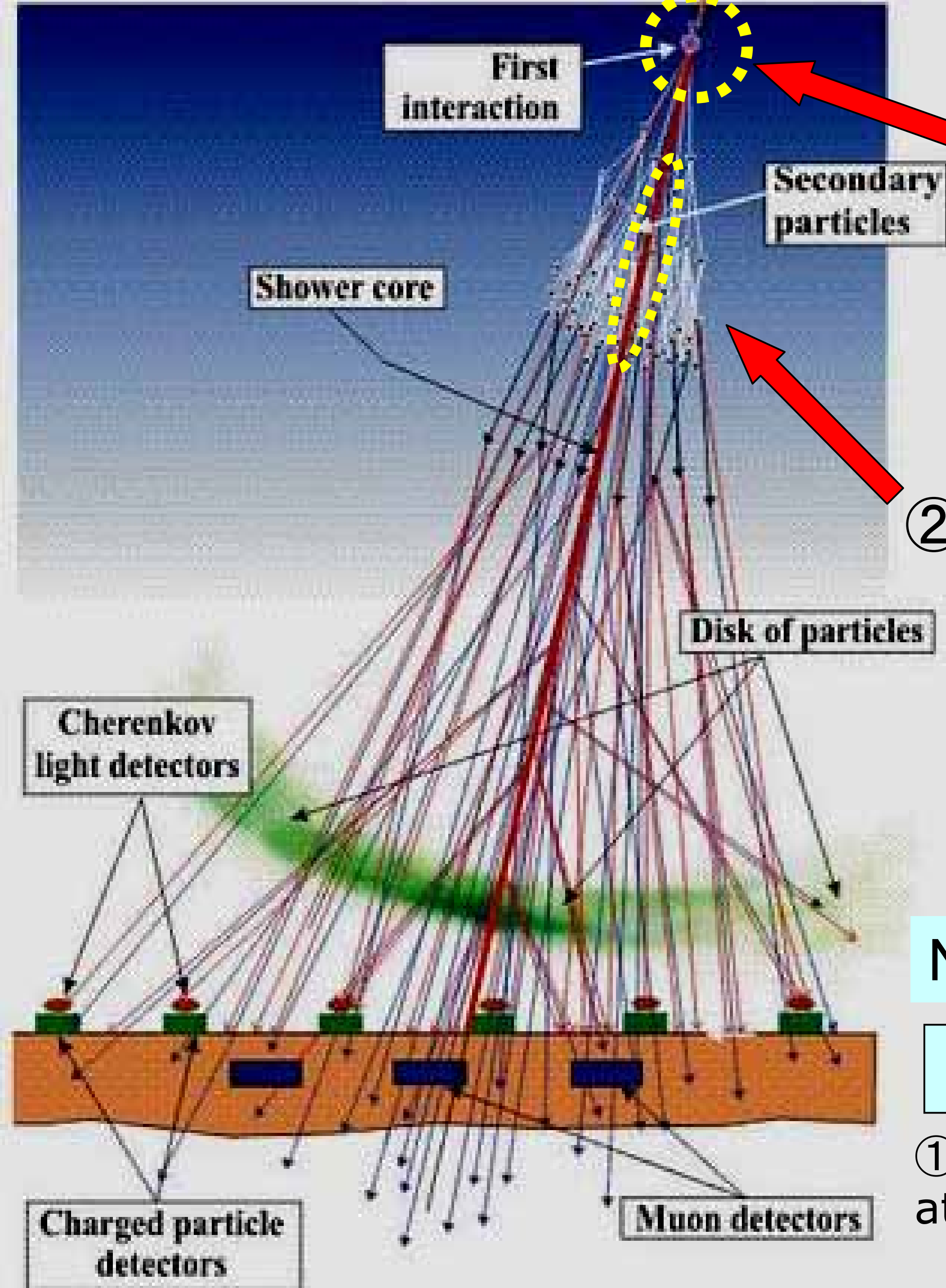
E-scale
Composition

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)

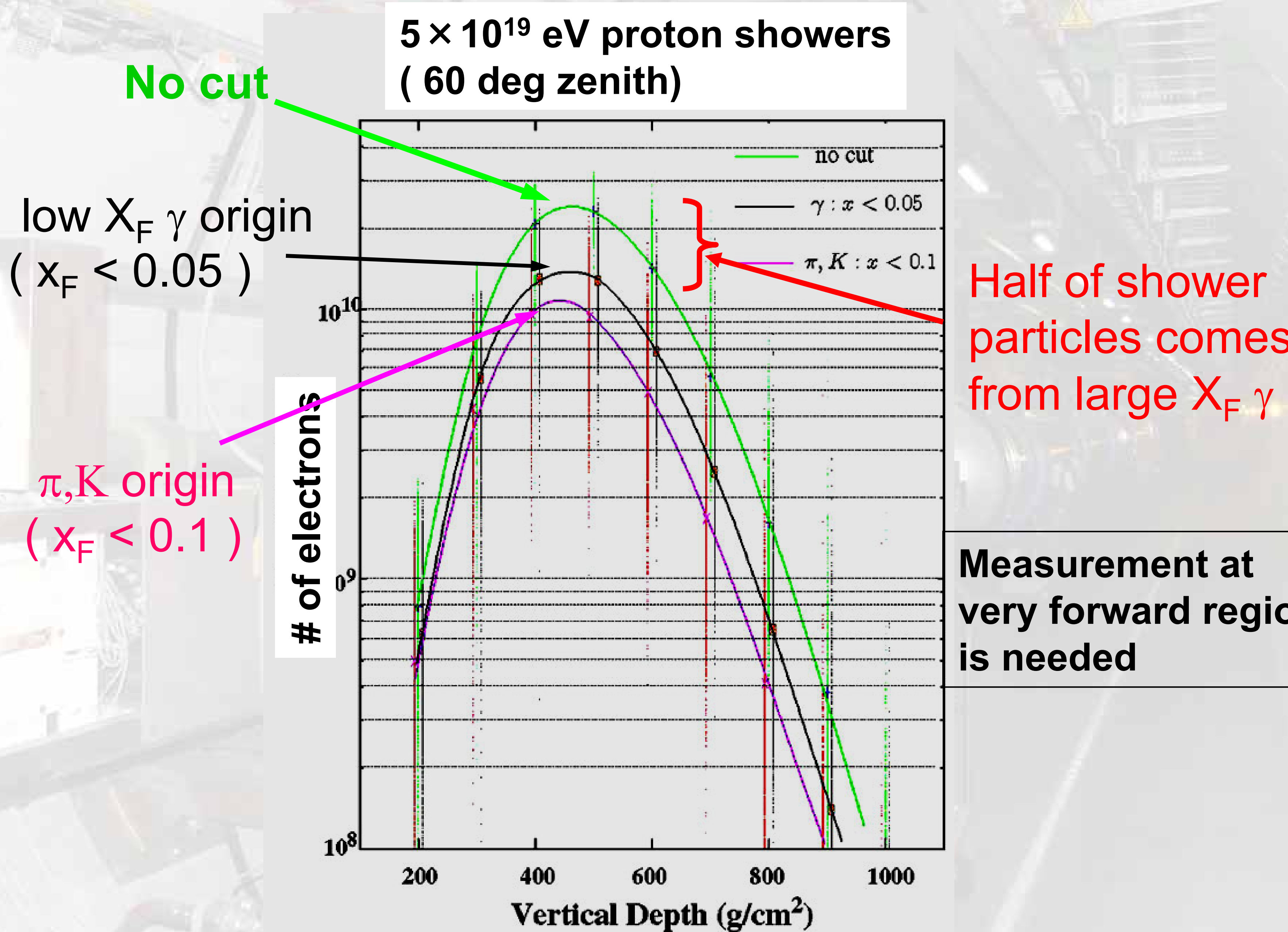
If large k
rapid development
If small k
deep penetrating

Need both ① and ②

LHCf is dedicated to ②

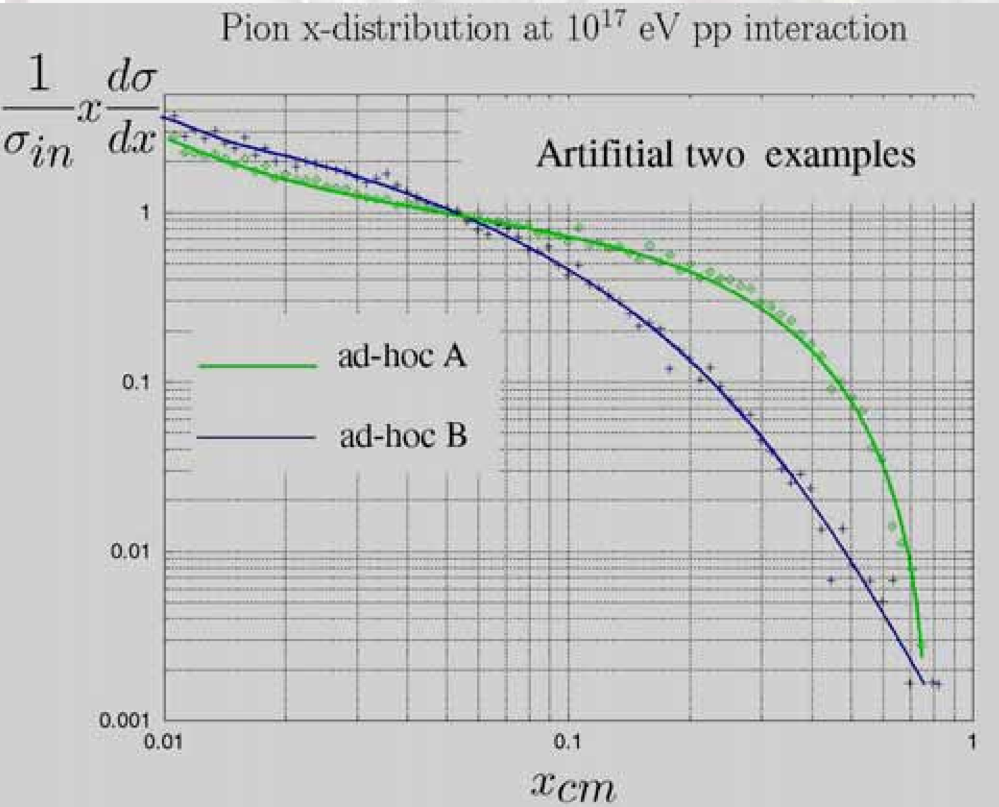
① will be give by Roman Pod at LHC

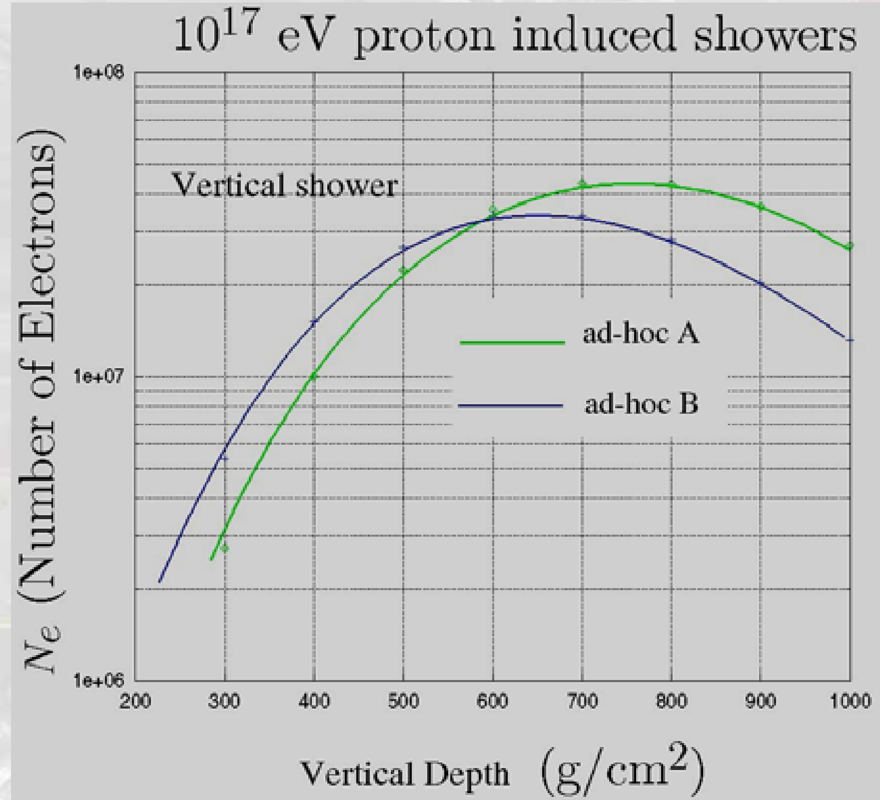
Contribution from very forward production



Measurement at very forward region is needed

Forward production spectra vs Shower curve

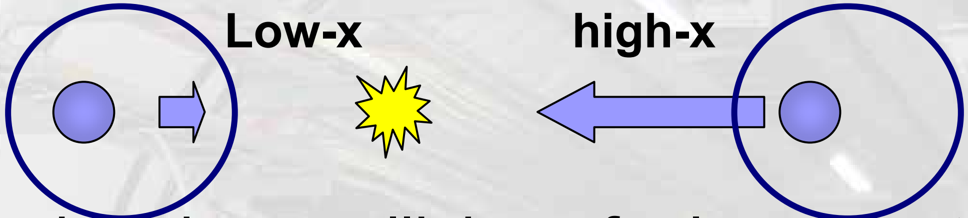




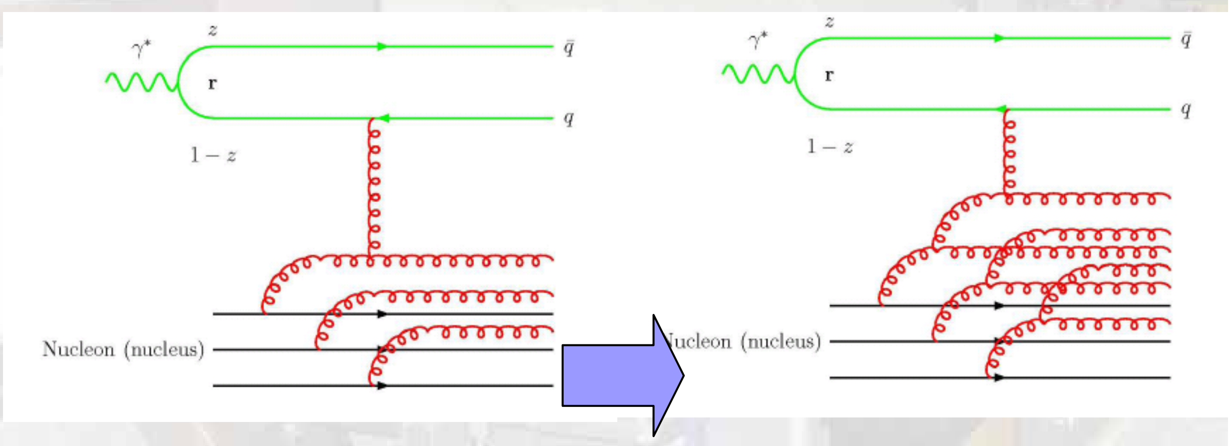
Half of shower particles comes from large X_F γ

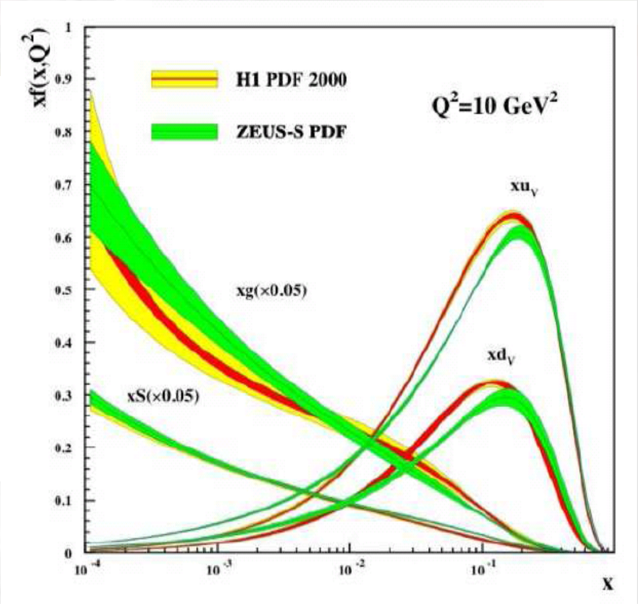
Measurement at very forward region is needed

Very forward – connection to low-x physics



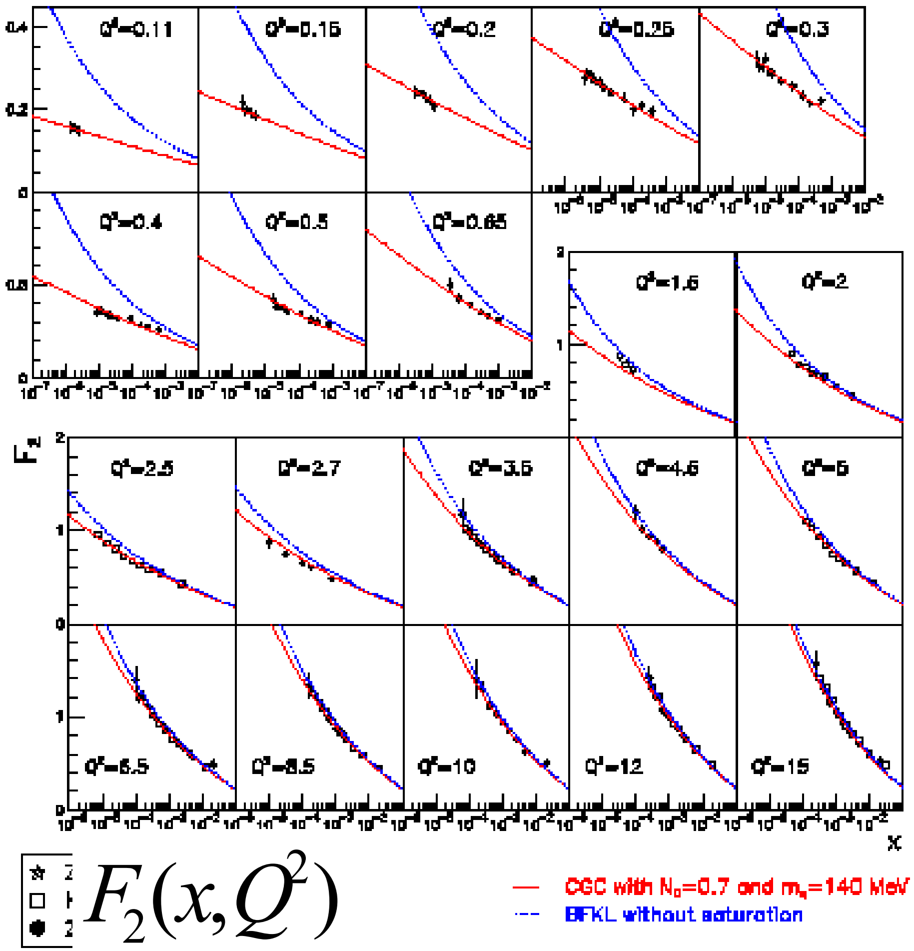
- Very forward region : collision of a low-x parton with a large-x parton
- Gluon become dominating in higher energy collision by self interaction.
- But they may be saturated (gluon satruration)

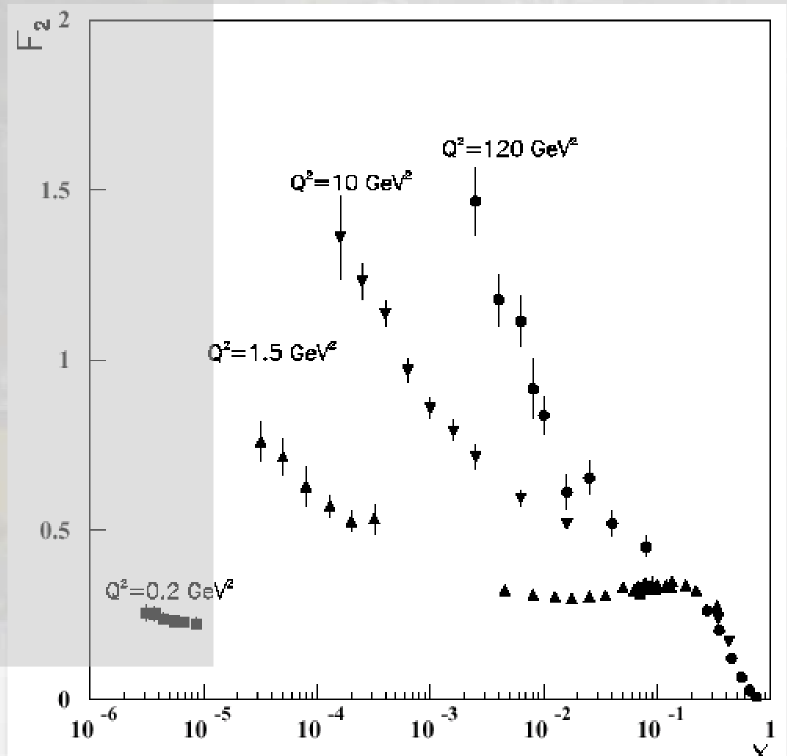




DIS at HERA; Gluon saturation ?

- Recent HERA data suggests gluon saturation at low-x i.e. Color Glass Condensation
- This phenomena may modify very forward interaction at high E.





Red line : the CGC fit

Blue line : BFKL w/o saturation

[Iancu,KI,Munier '04]

Very forward EM measurement at LHC

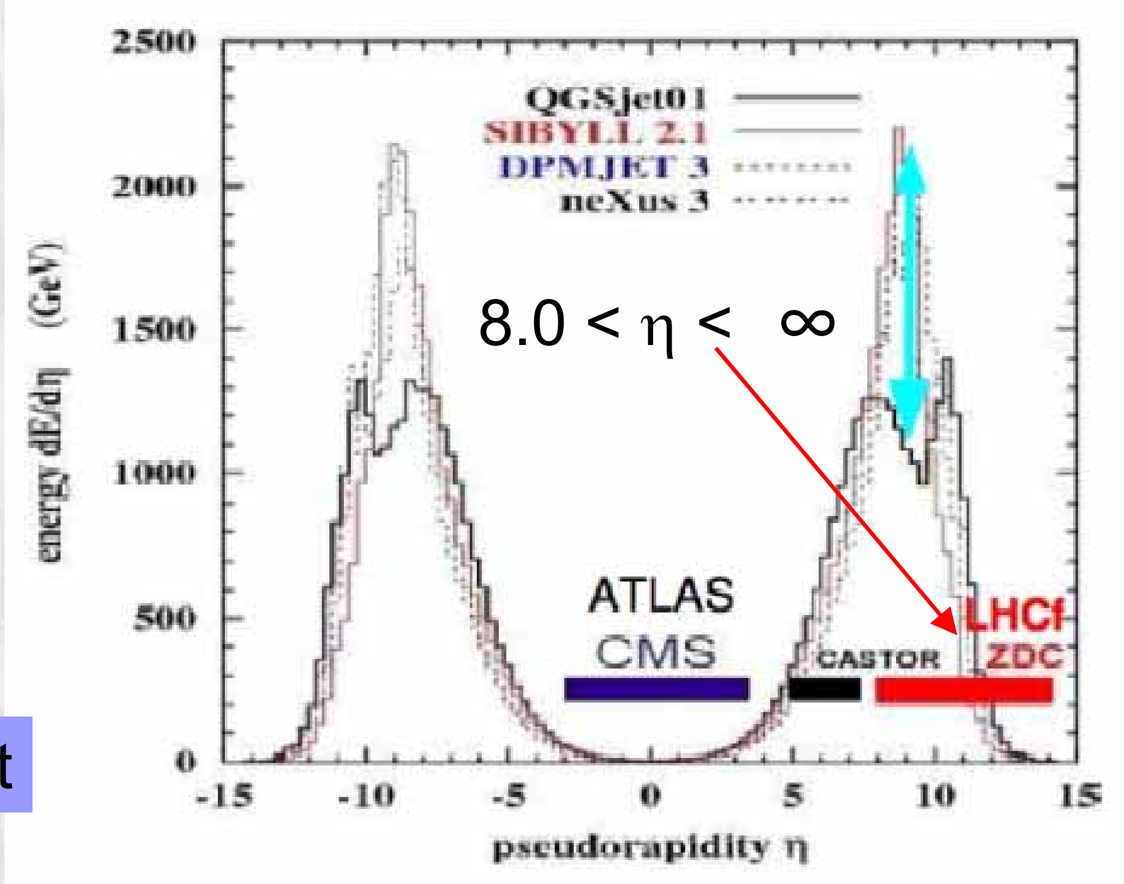
- Energy flow of collisions dominates in very forward region
- Soft and semi-hard processes dominate → need experiments
- ZDC is available at LHC, but not dedicated for EM

Energy flow dominates in very forward

Measure EM component at 0 degree of LHC

↓

The LHCf experiment



The LHCf experiment

The LHCf Collaboration

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Solar-Terrestrial Environment Laboratory, Nagoya University, Japan

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Waseda University, Japan

T.Tamura *Kanagawa University, Japan*

Y.Muraki *Konan University*

M.Haguenauer *Ecole Polytechnique, France*

W.C.Turner *LBNL, Berkeley, USA*

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

INFN, Univ. di Firenze, Italy

A.Tricomi *INFN, Univ. di Catania, Italy*

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

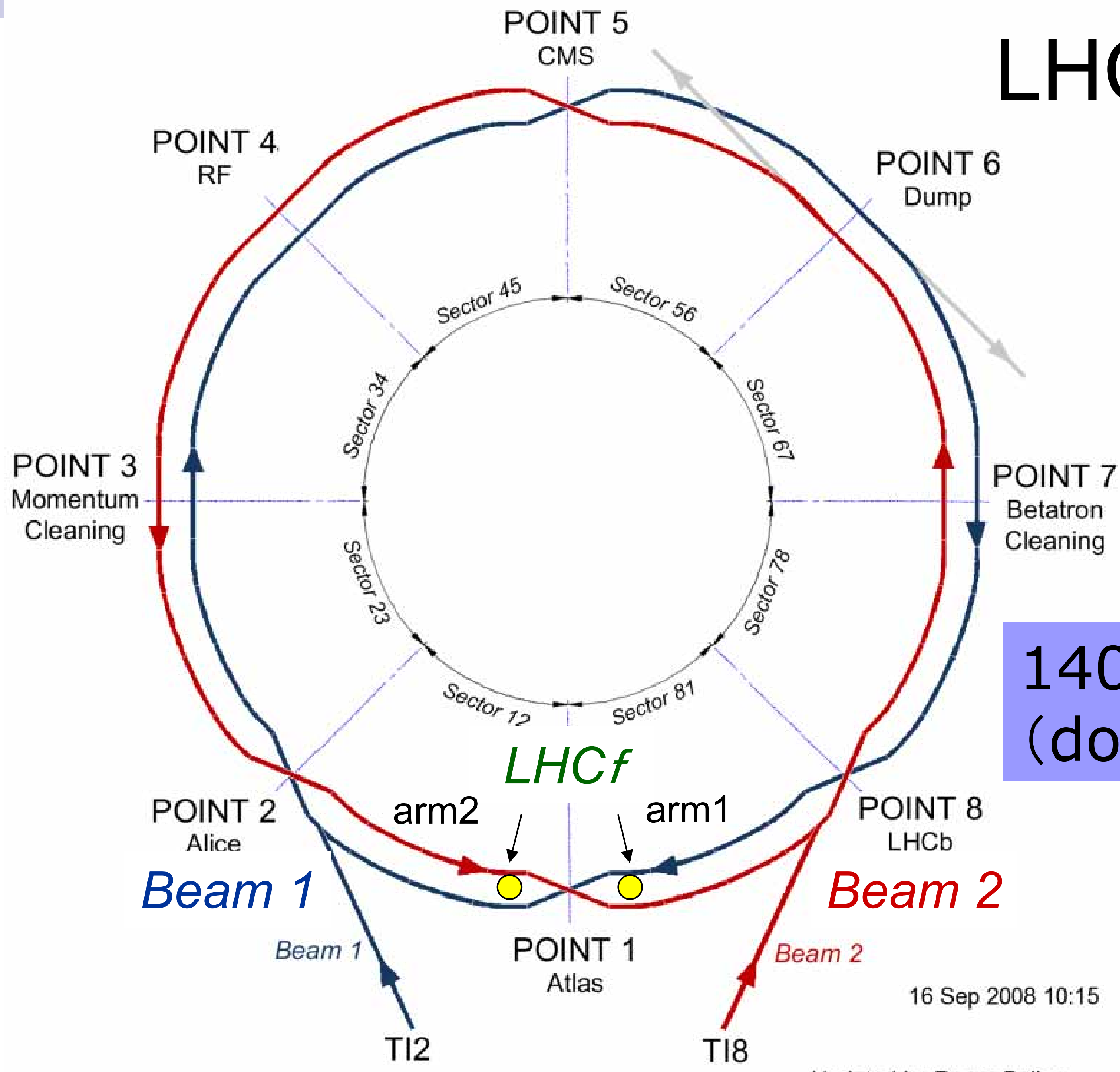
D.Macina, A-L.Perrot *CERN, Switzerland*

The LHCf experiment

See www.stelab.nagoya-u.ac.jp/LHCf

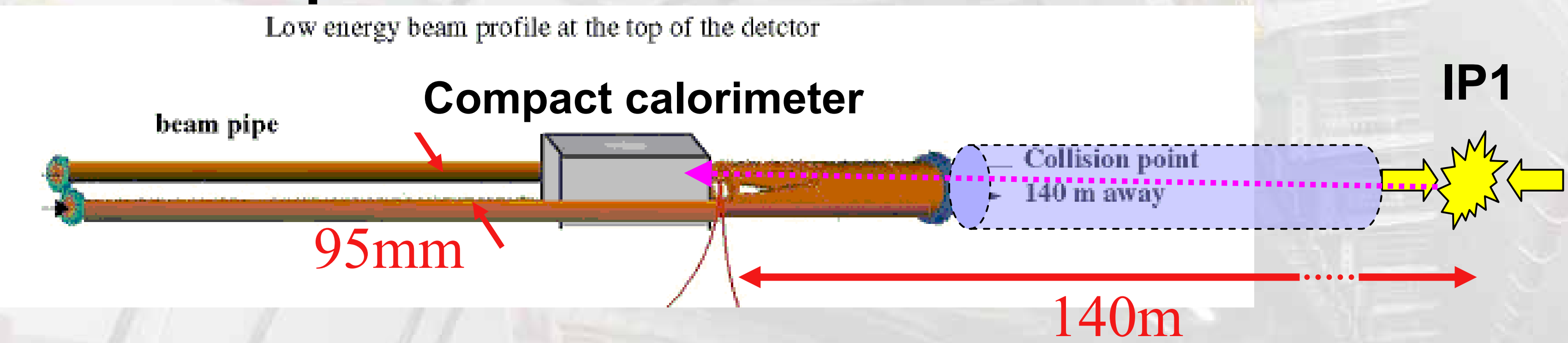
- **Letter Of Intent: May 2004**
- **Technical report: September 2005**
- **Technical Design Report: February 2006**
- **LHCC approval: June 7th, 2006**
- **Detector assembly,beam test: 2007**
- **Installation in the LHC tunnel: Feb 2008**

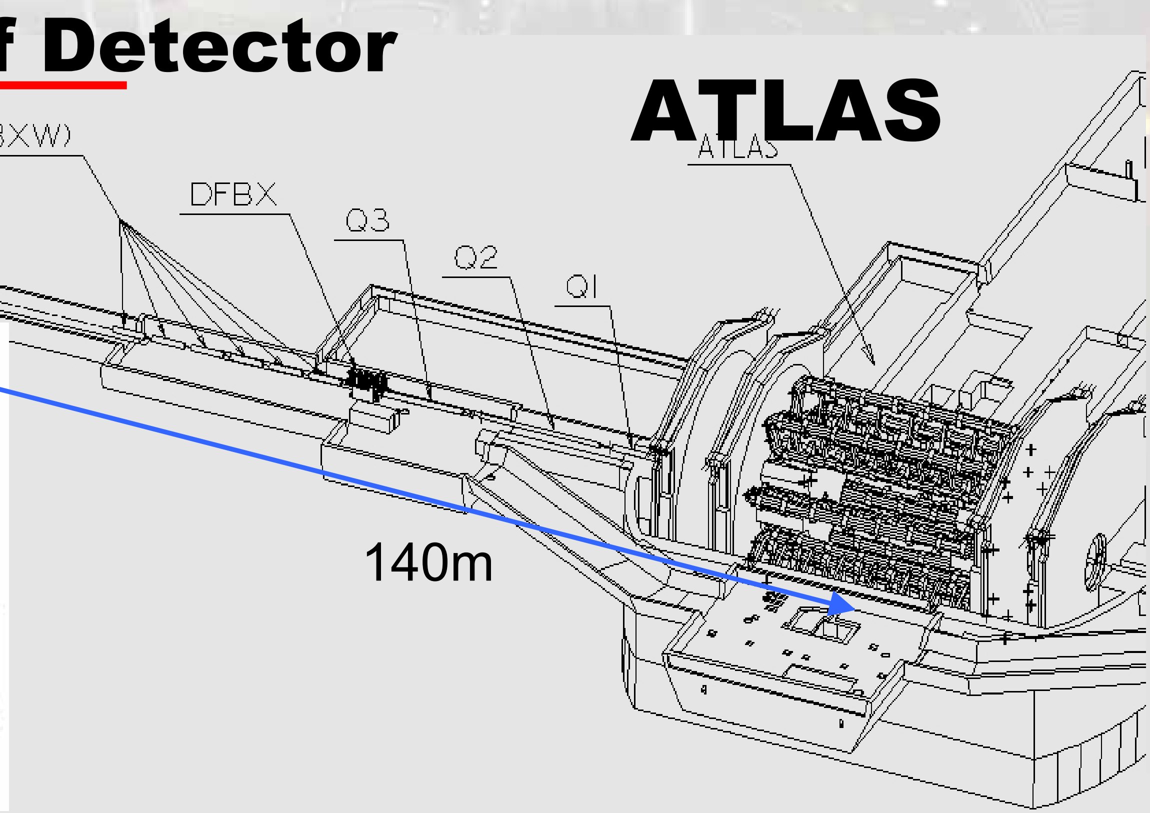
LHCf site

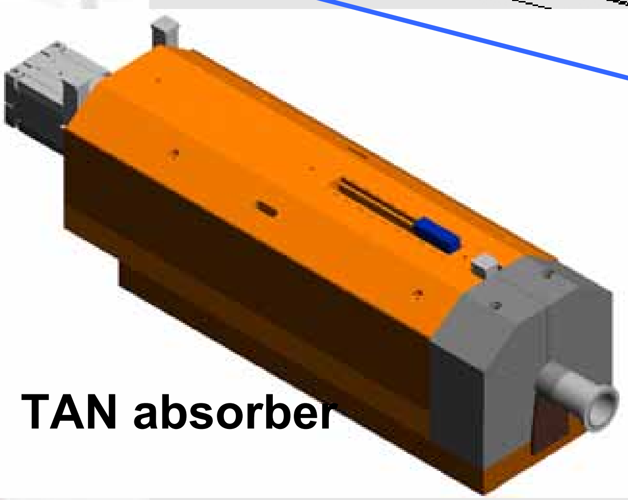


140m from IP1
(double arm)

LHCf experimental site

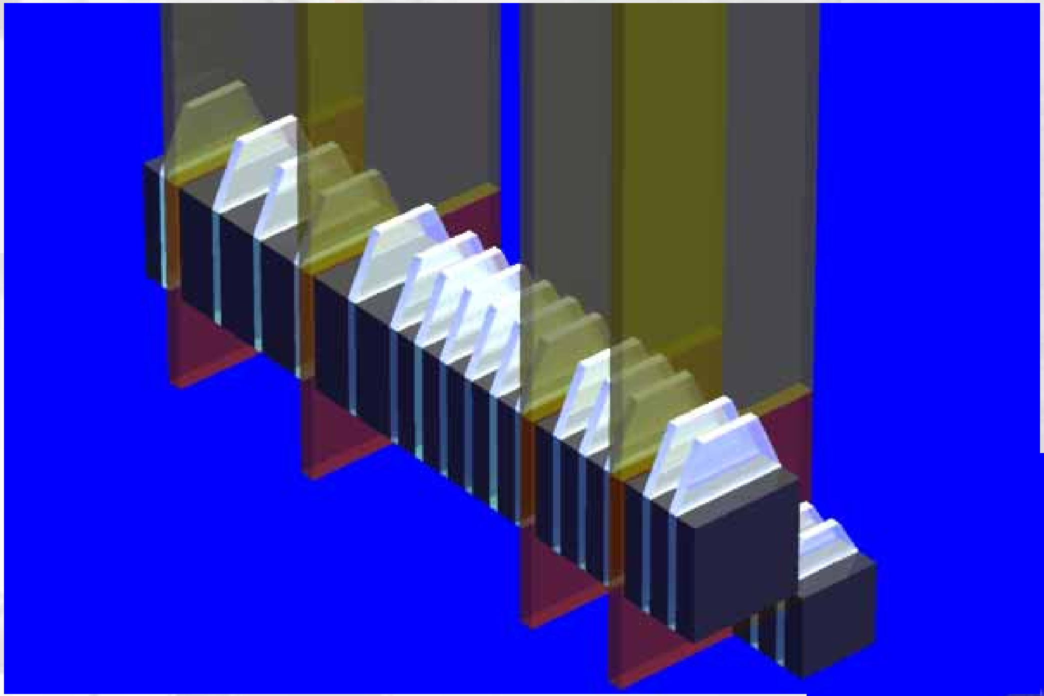




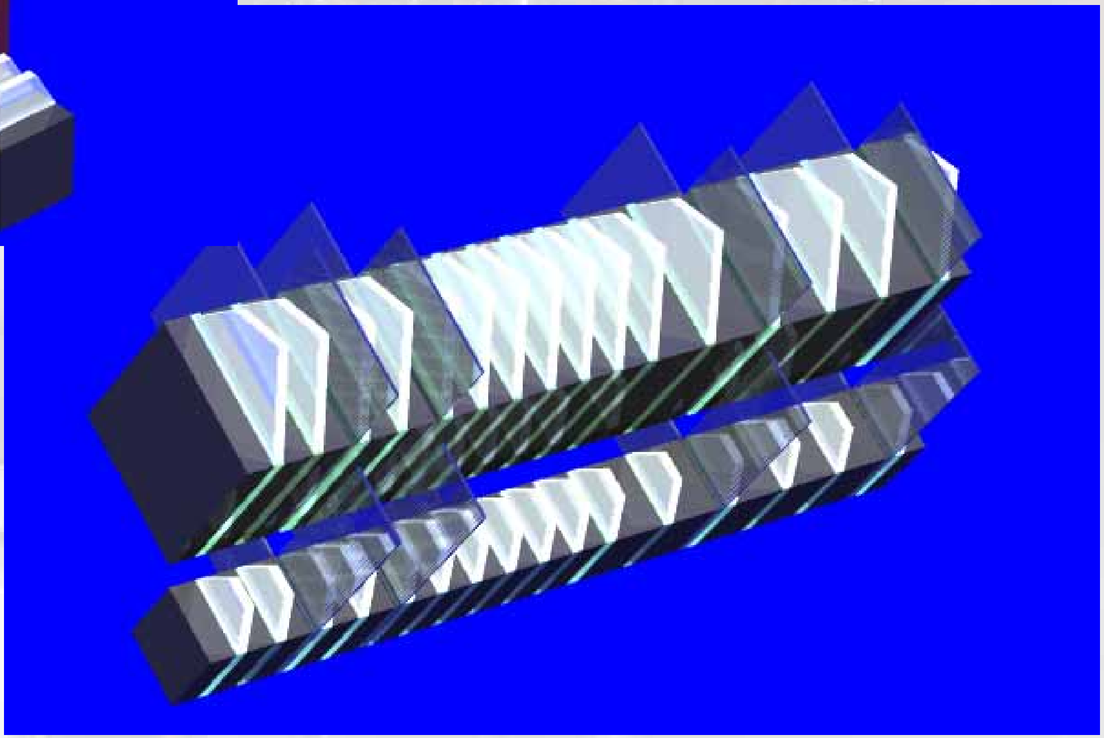


TAN absorber

Double Arm Detectors



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



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

Detector #1

2 towers ~24 cm long stacked vertically with 5 mm gap

Lower: 2 cm x 2 cm area

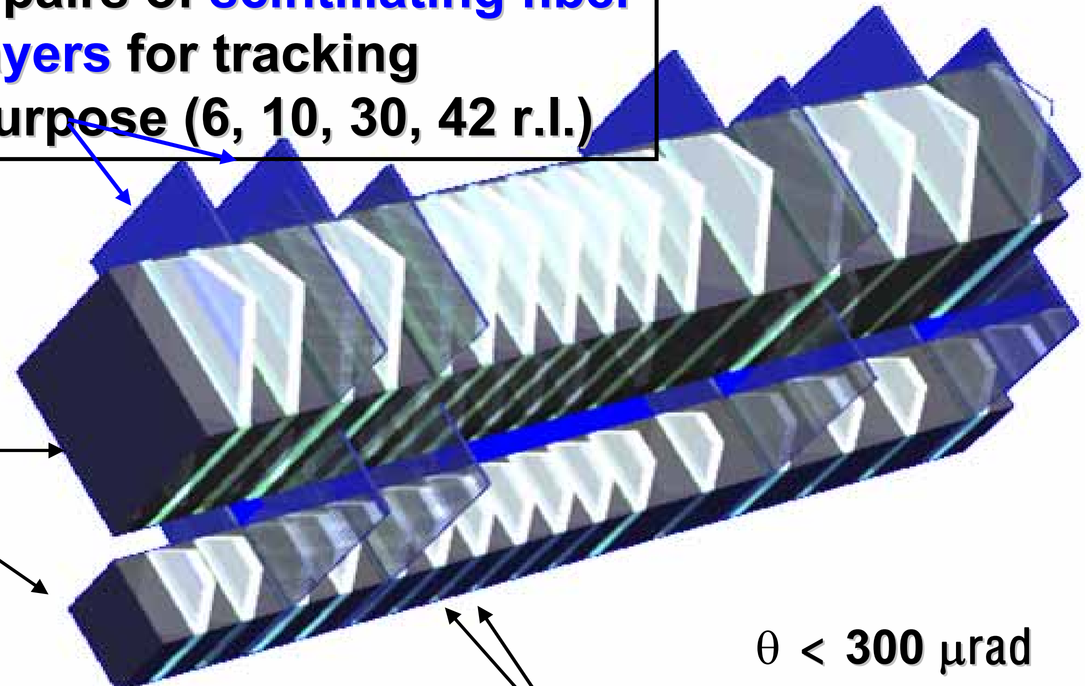
Upper: 4 cm x 4 cm area

Absorber

22 tungsten layers 7mm thick →
44 X_0 (1.6 λ_I) in total

(W: X_0 = 3.5mm, R_M = 9mm)

Very compact EM shower



16 scintillator layers (3 mm thick)

Trigger and energy profile measurements

Compact to prevent multi particle hits
Double stacks to tag $\pi0 \rightarrow 2\gamma$

$$\Delta E/E = \begin{array}{l} \sim 4\% \text{ for EM} \\ \sim 30\% \text{ for Hadrons} \end{array}$$

Detector # 2

We use LHC style electronics and readout

Placed opposite side of detector#1

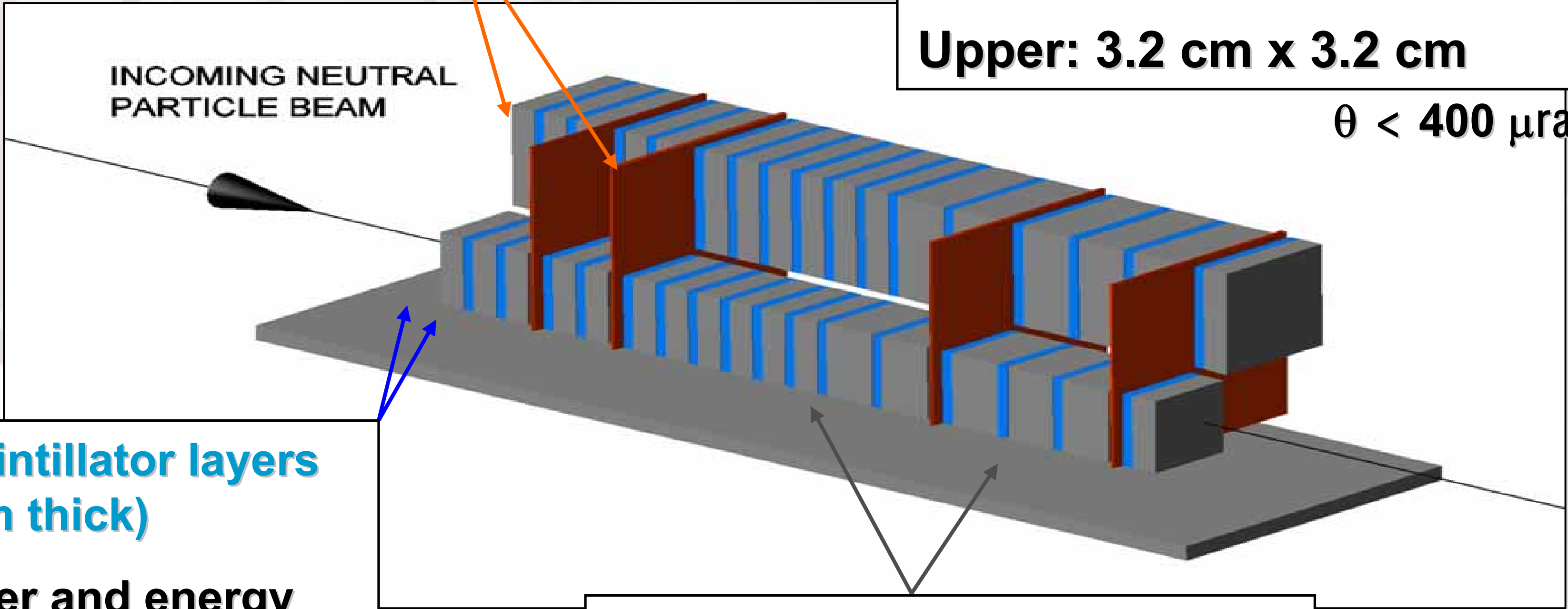
4 pairs of silicon microstrip layers (6, 12, 30, 42 r.l.) for tracking purpose (X and Y) → impact point

2 towers 24 cm long stacked on their edges and offset from one another

Lower:2.5 cm x 2.5 cm

Upper: 3.2 cm x 3.2 cm

$\theta < 400\ \mu rad$



16 scintillator layers (3 mm thick)

Trigger and energy profile measurements

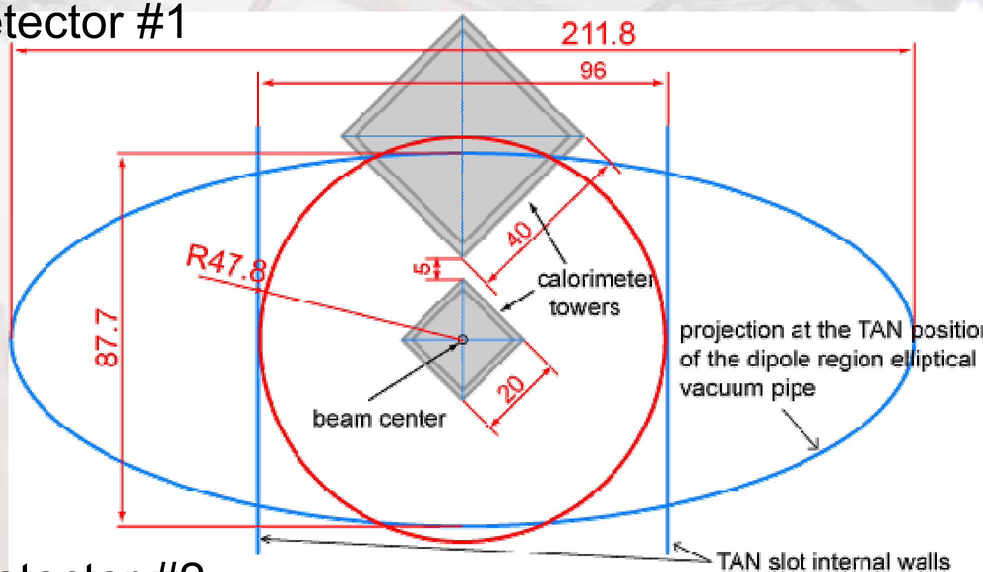
Absorber

22 tungsten layers 7mm thick
→ 44 X_0 (1.6 I_I) in total
(W: X_0 = 3.5mm, R_M = 9mm)

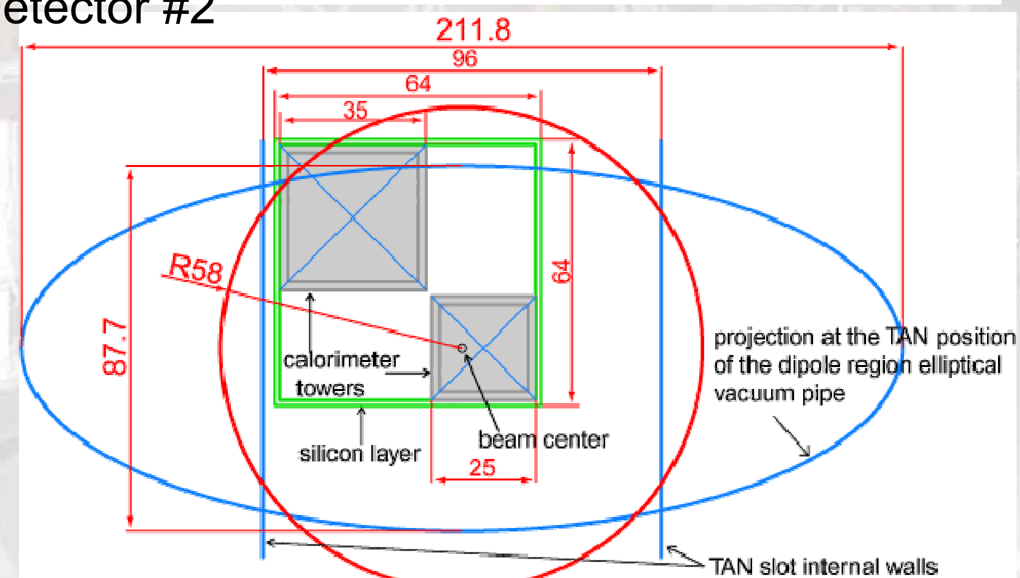
LHCf calorimeters

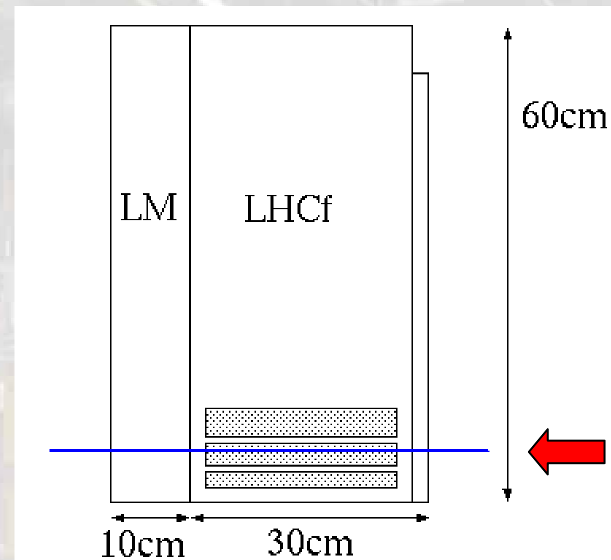
Geometry

The Detector #1



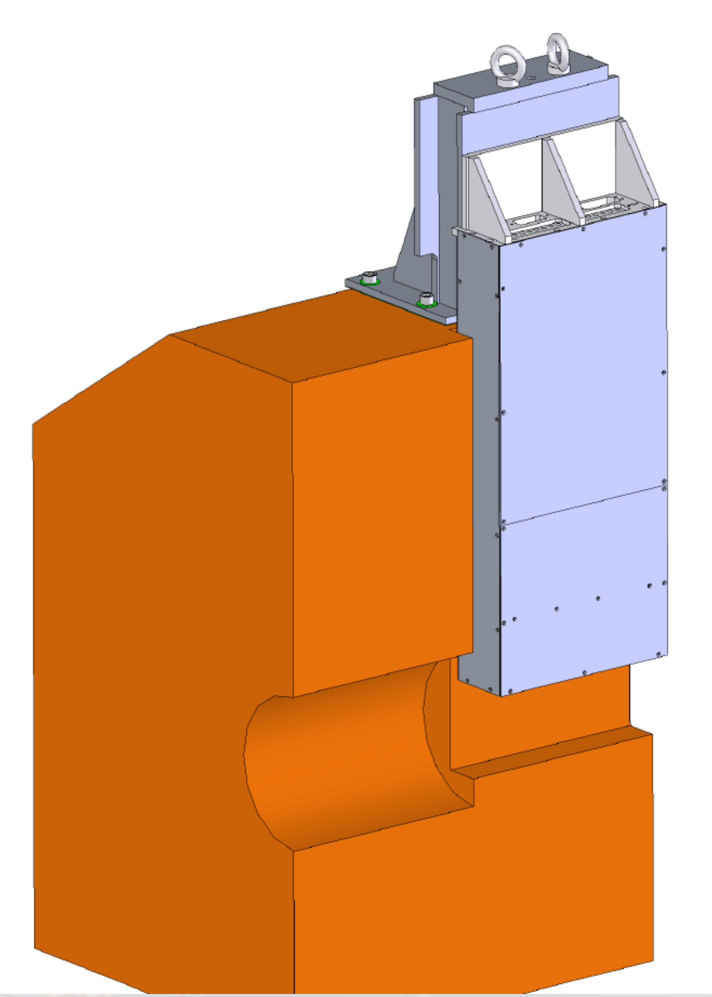
The Detector #2





Side view

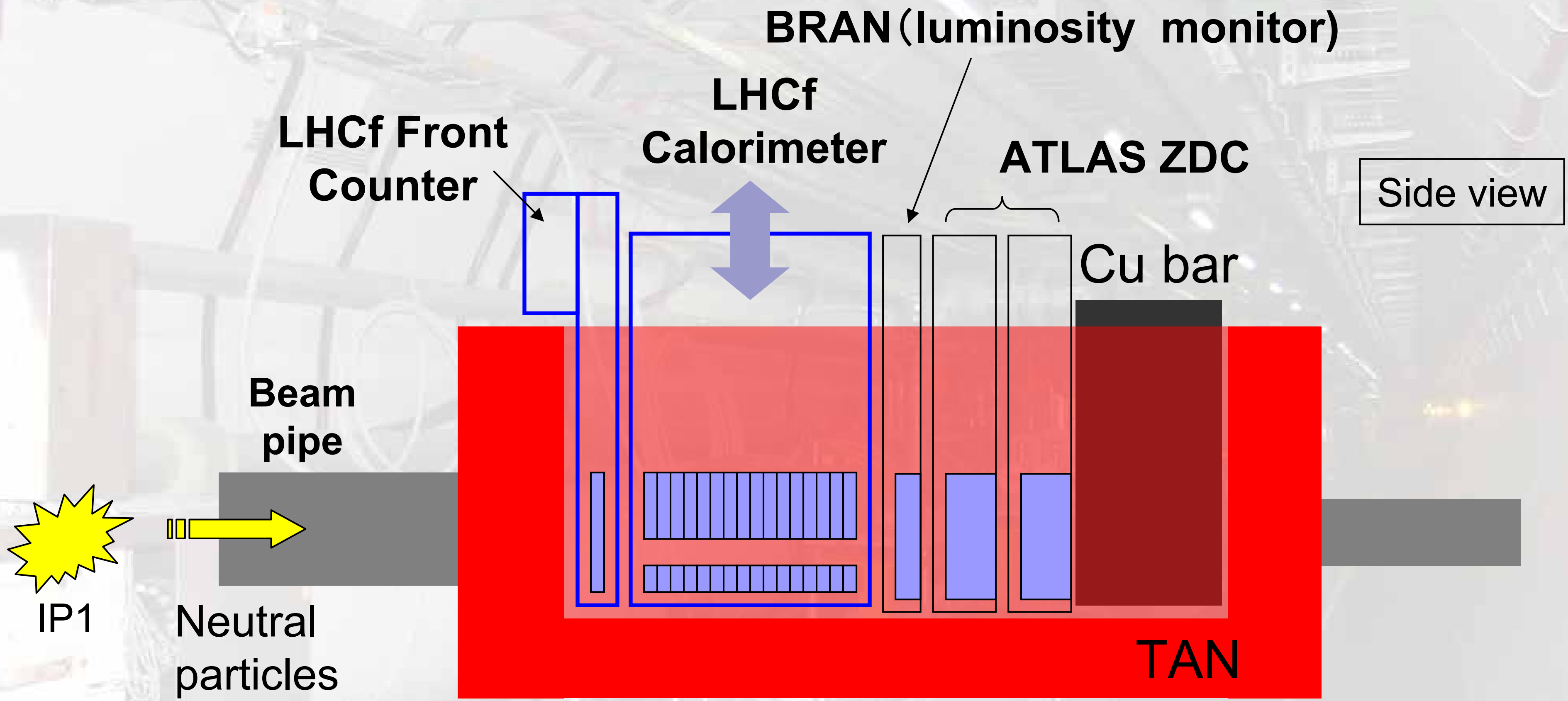
Manipulator



- Retract upward when beam tune to prevent radiation
- Change vertical position to scan covered-p_T region

Remote control from USA15
(200m apart)

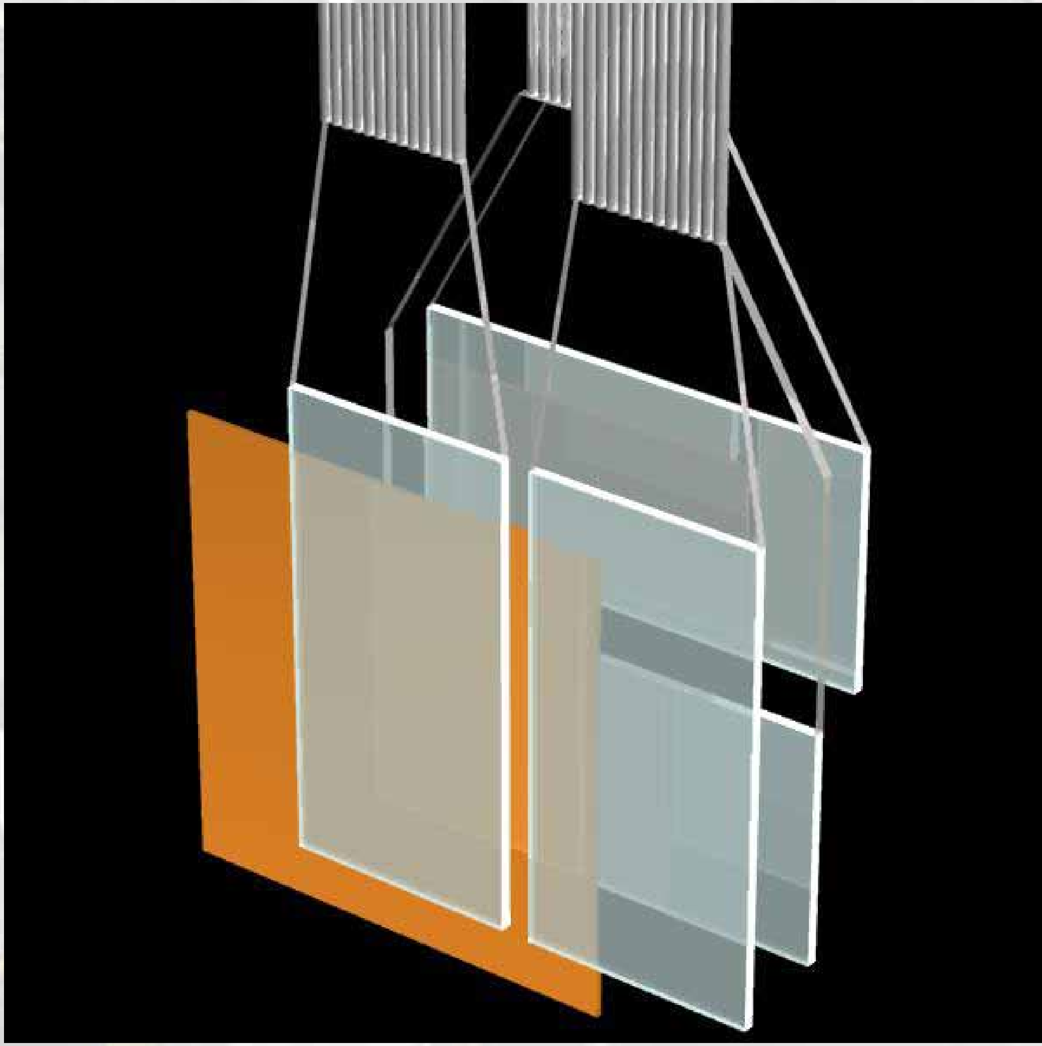
Setup in TAN (side view)



Trigger and event ID exchange btw ATLAS and LHCf

Front Counter

- 2 fixed Front Counters were installed in front of Arm1 and Arm2
- They will not move with Arm1 and Arm2
- They are segmented in 2 x and 2 y slices
- Very useful to check the beam quality and hence decide to move Arm1 and Arm2 in the operating position from the 'garage' position

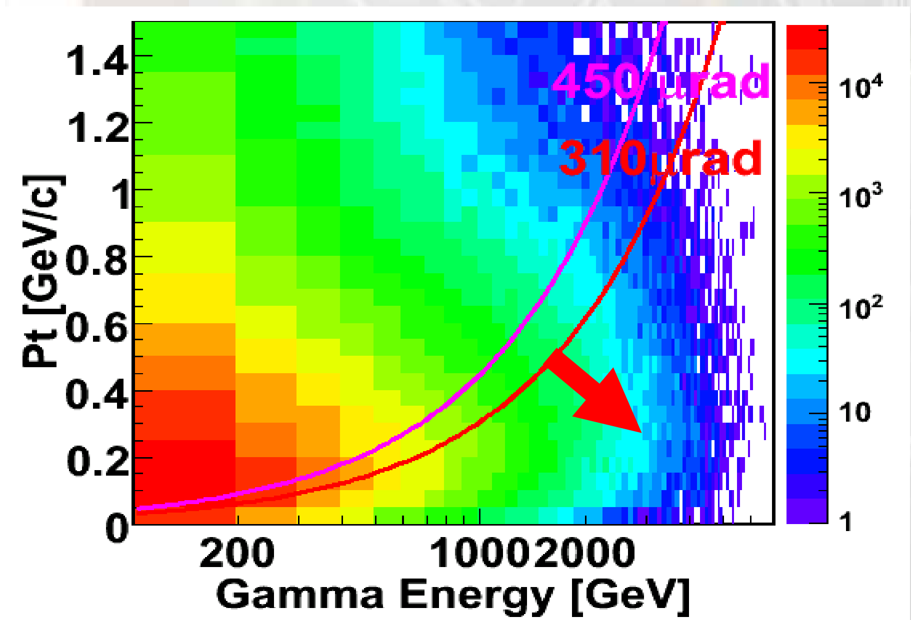


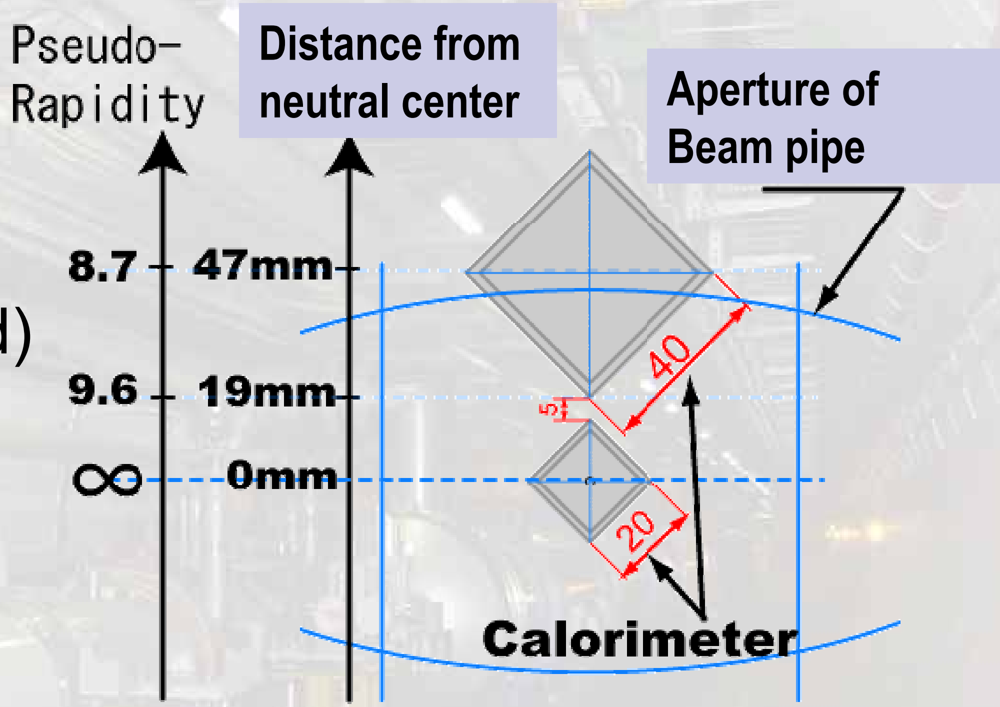
Acceptance

< 310 μ rad
(crossing angle = 0 μ rad)

< 450 μ rad
(crossing angle = 140 μ rad)

All γ from IP





Most of high energy secondary particles covered by LHCf aperture

80% @ E_{gamma} = 1TeV

SPS Beam Test

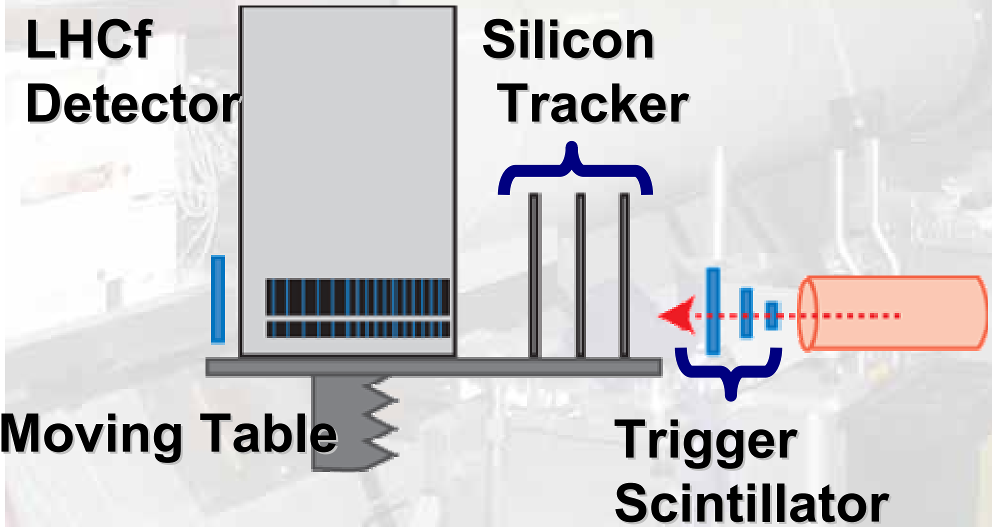
- ✓ CERN : SPS T2 H4
- ✓ Summers 2004, 2006, 2007
- ✓ Incident Particles
  - ✓Proton 150,350 GeV/c
  - ✓Electron 100,200 GeV/c
  - ✓Muon 150 GeV/c

Test was successful

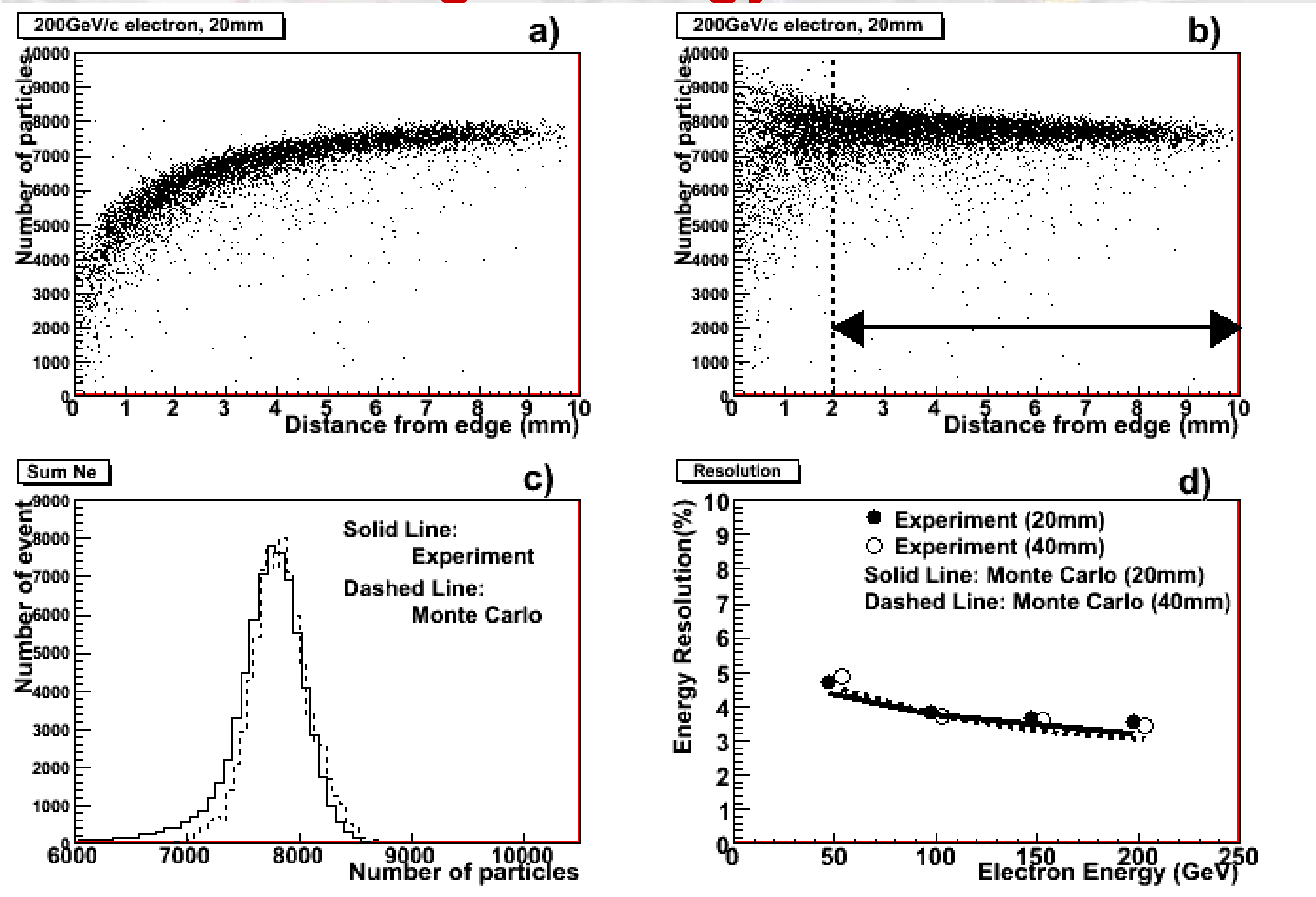
Analysis is under way for

- Energy calibration of the calorimeters
- Spatial resolution of the tracking systems
- PID capability , etc…

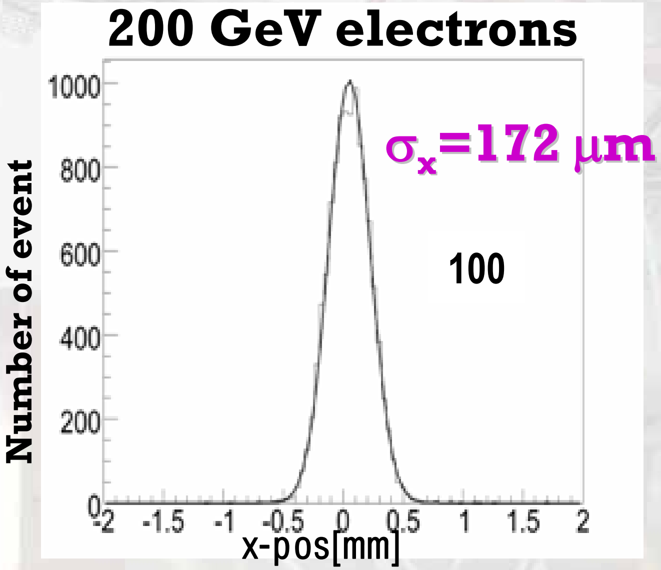
Setup

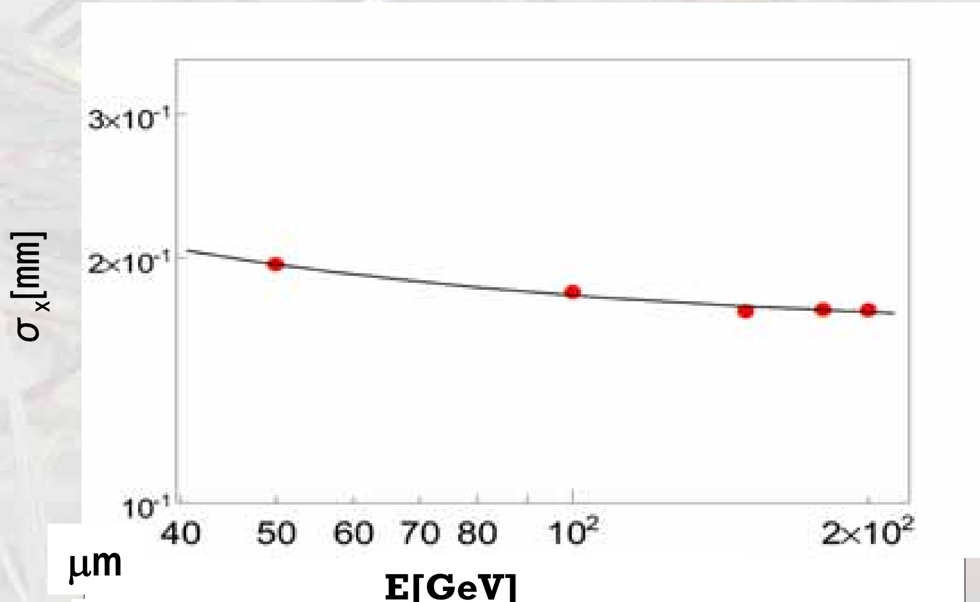


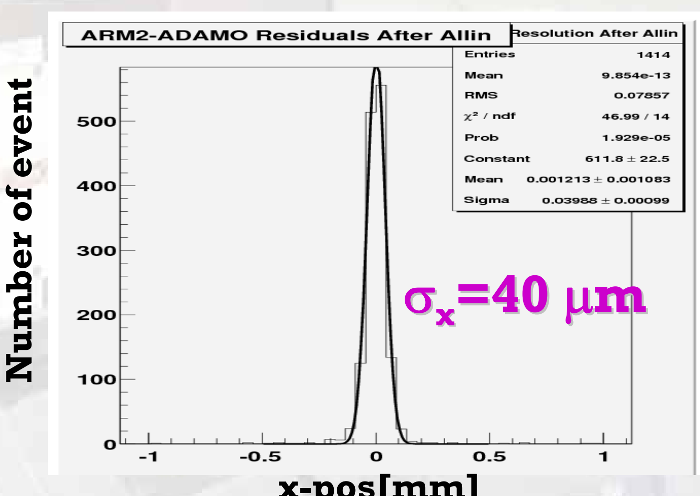
Shower leakage, energy resolution

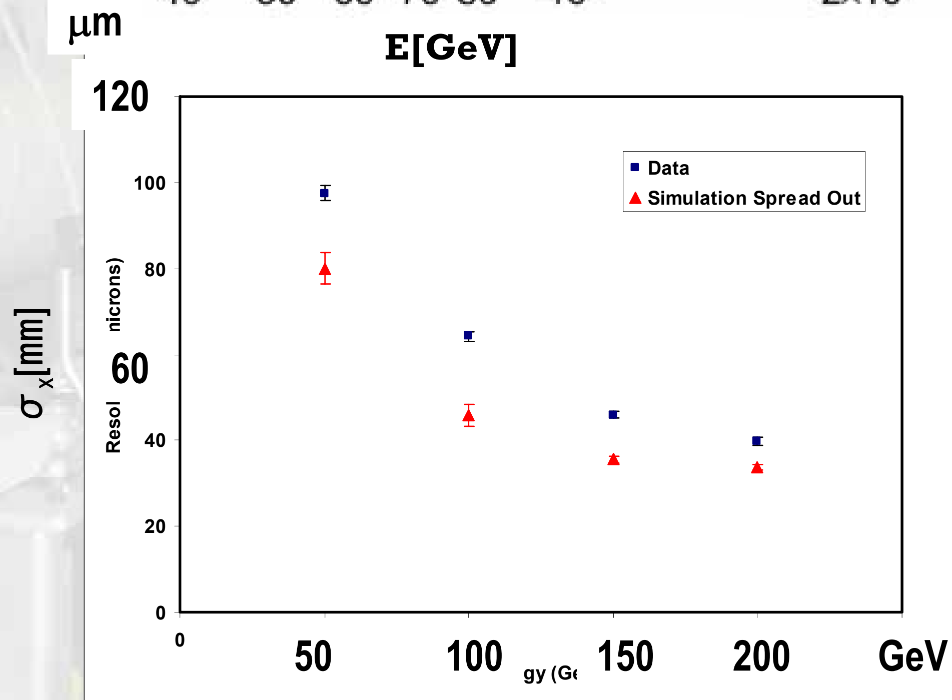


Position resolution for Scfi and Si



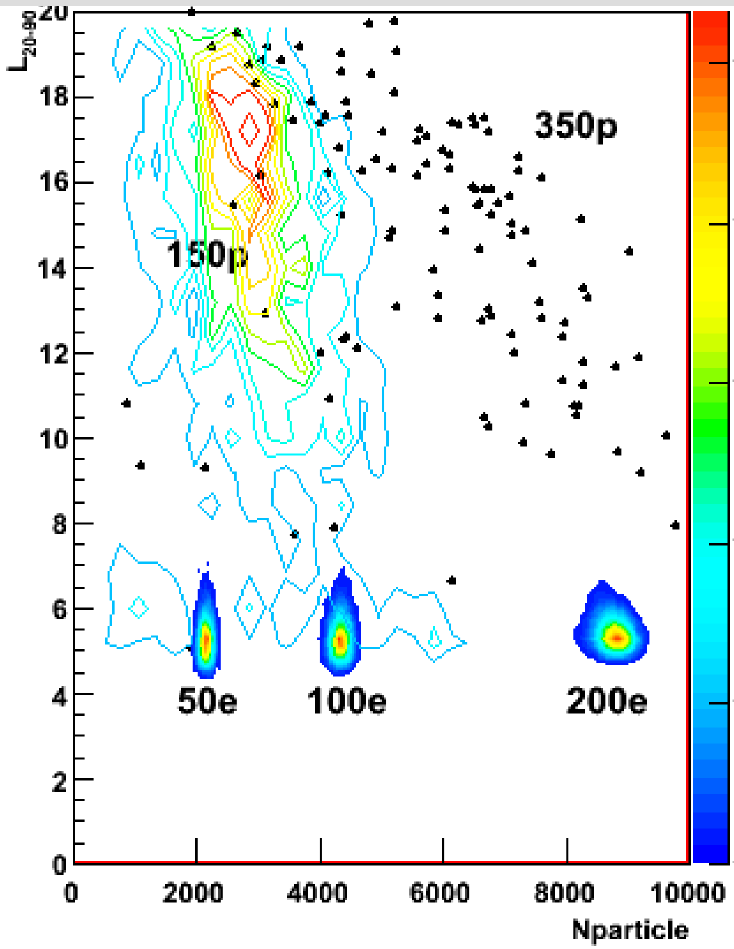


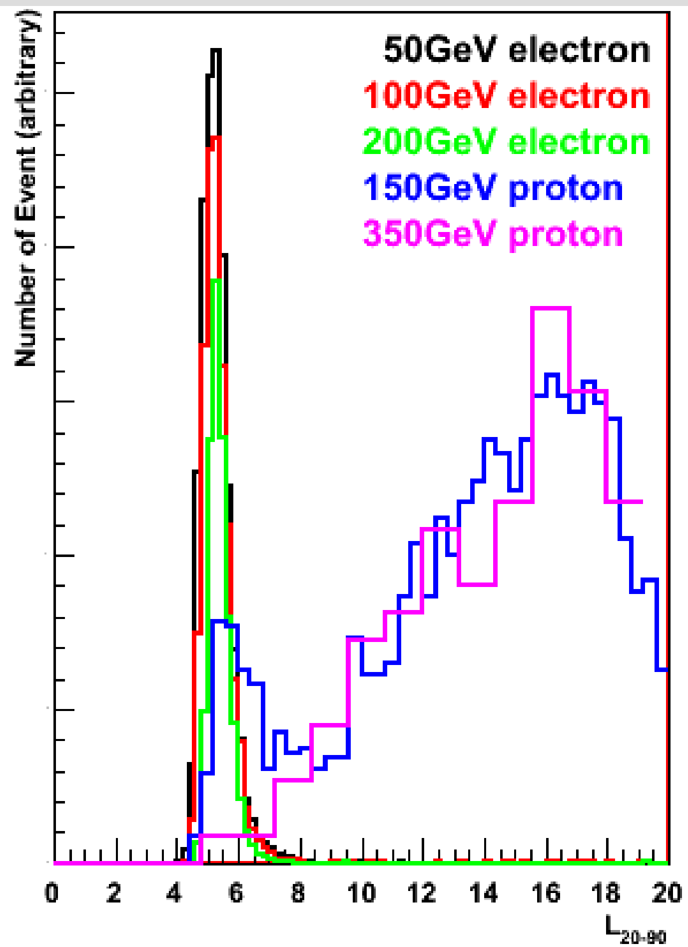




e-p/γ-n separation

- LHCf = 44rad lengths, 1.6 hadron interaction lengths
- L20-90 = Estimator for longitudinal shower length (containing 20% to 90% of total visible E)





Typical event rate of LHCf @L=10^{29}cm^{-2}s^{-1}

For L= 10^{29} cm^{-2}s^{-1}, ~ 10kHz inelastic collisions

	γ	π^0	hadrons
Rate	670 Hz (at 2cm tower)	7 Hz	150 Hz (at 2cm tower)
Time for 10k events	0.34 min.	29.5 min.	28.7 min

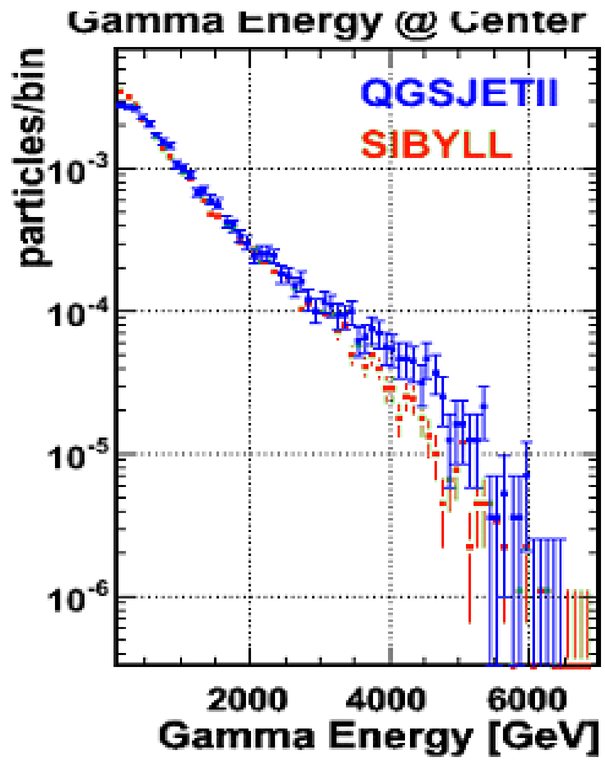
30% analysis efficiency
Is assumed for hadrons

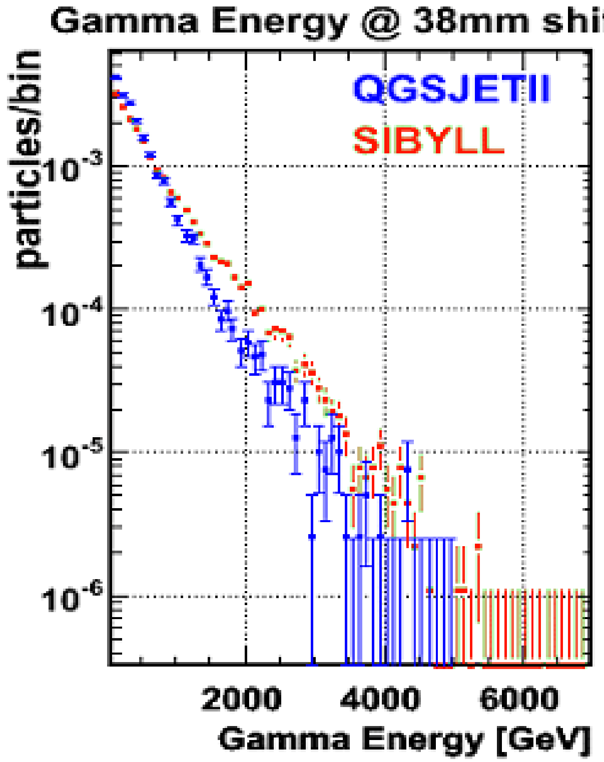
Just one day exposure is enough !

Model discremination in Eγ spectrum

QGSJETII⇔SIBYLL

1000 sec @ $10^{29}cm^{-2}s^{-1}$





QGAJETII(400,000events)

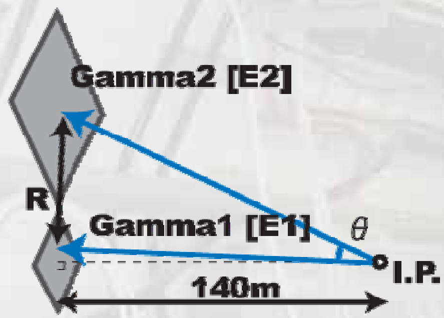
⇔ QGSJET χ^2= 107/125dof (C.L. 88%)

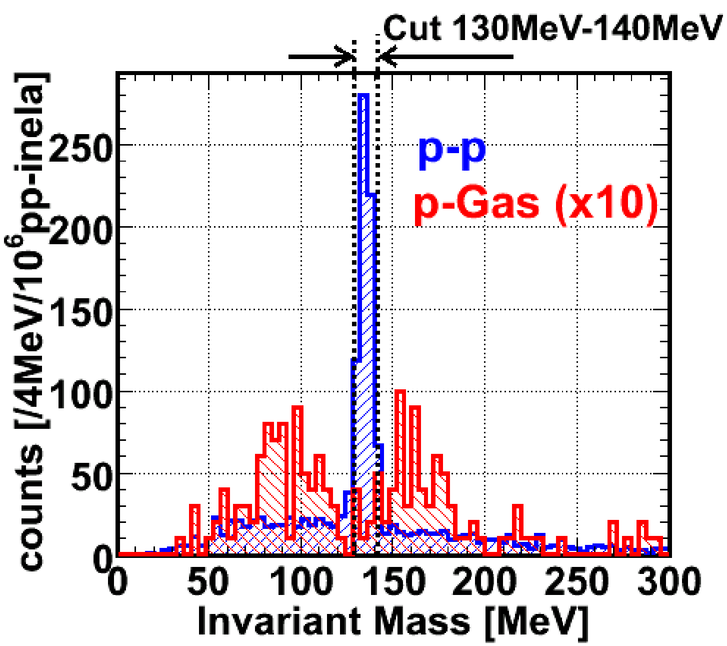
⇔ DPMJET3 χ^2= 224/125dof (C.L. 10^{-8})

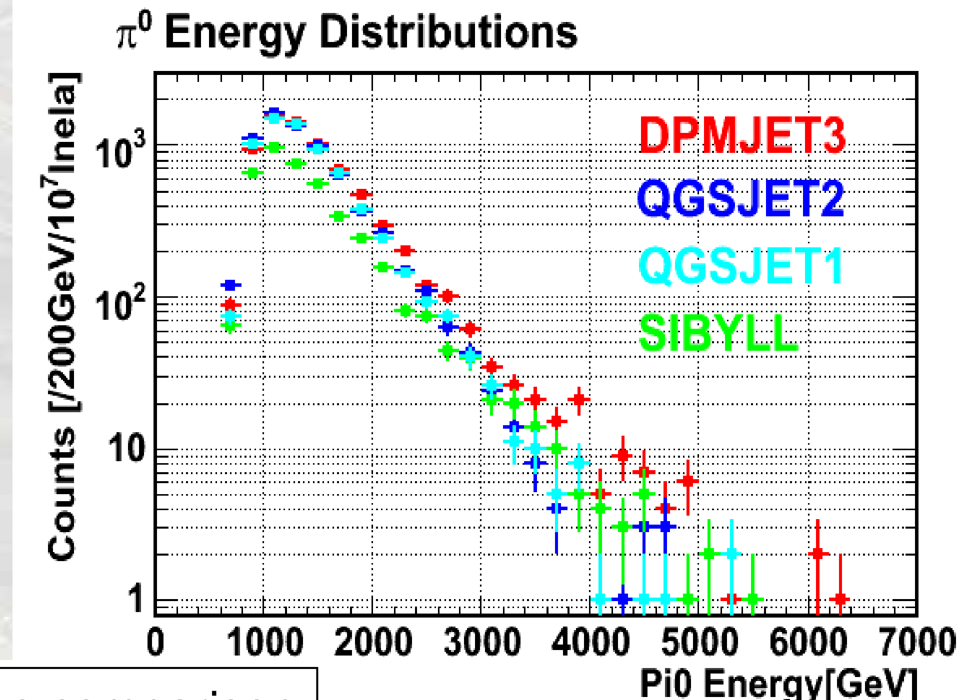
⇔ SIBYLL χ^2= 816/125dof (C.L. $<10^{-15}$)

Model discrimination by π^0 energy spectrum

Powerful BG rejection for beam-gas collision events







Shape comparison

QGSJETII

⇔ DPMJET3 $\chi^2 = 106$ (C.L. $<10^{-6}$)

⇔ SIBYLL $\chi^2 = 83$ (C.L. $<10^{-6}$)

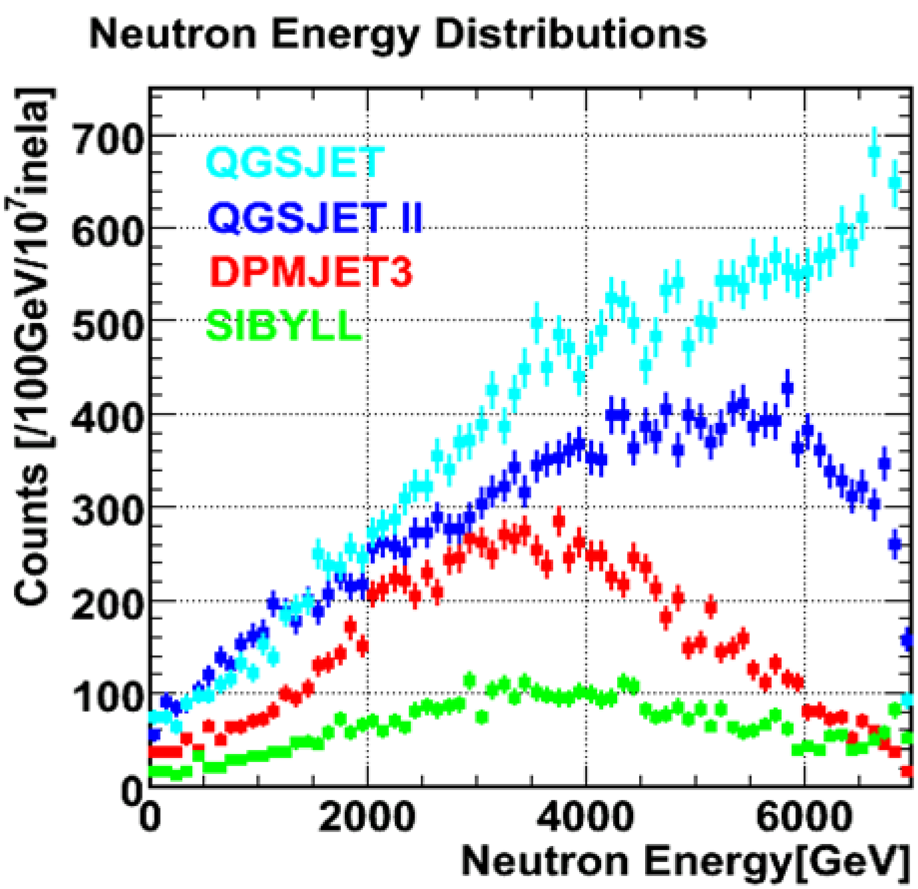
DPMJET3

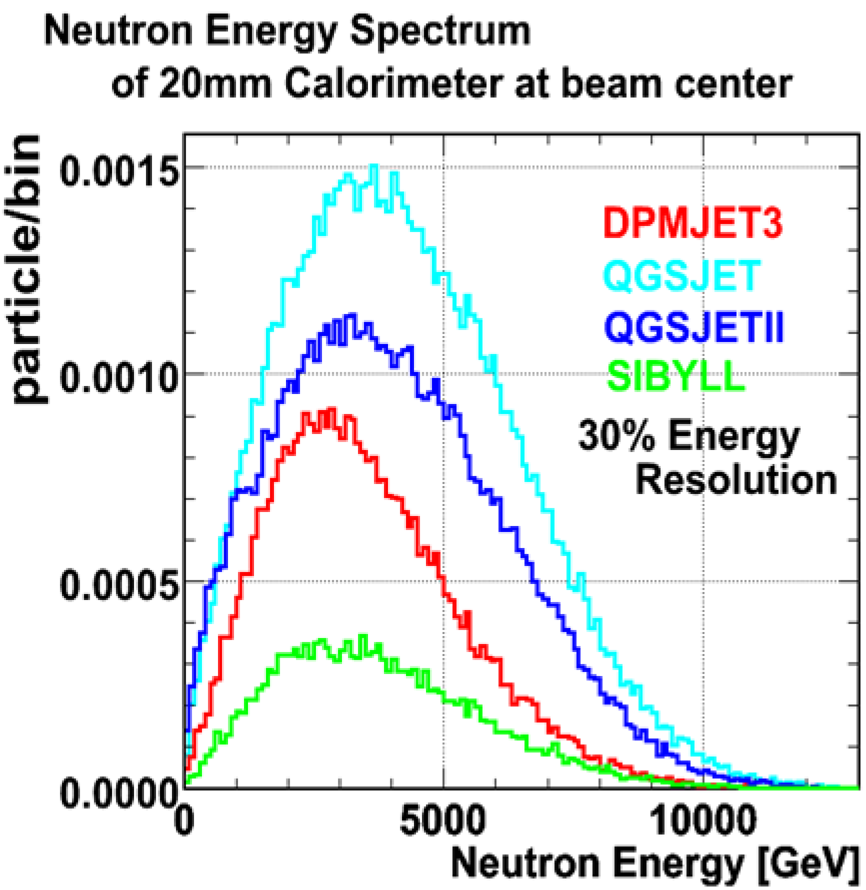
⇔ SIBYLL $\chi^2 = 28$ (C.L.$= 0.024$)

10^7events DOF = 17-2=15

Model dependence of neutron energy distribution

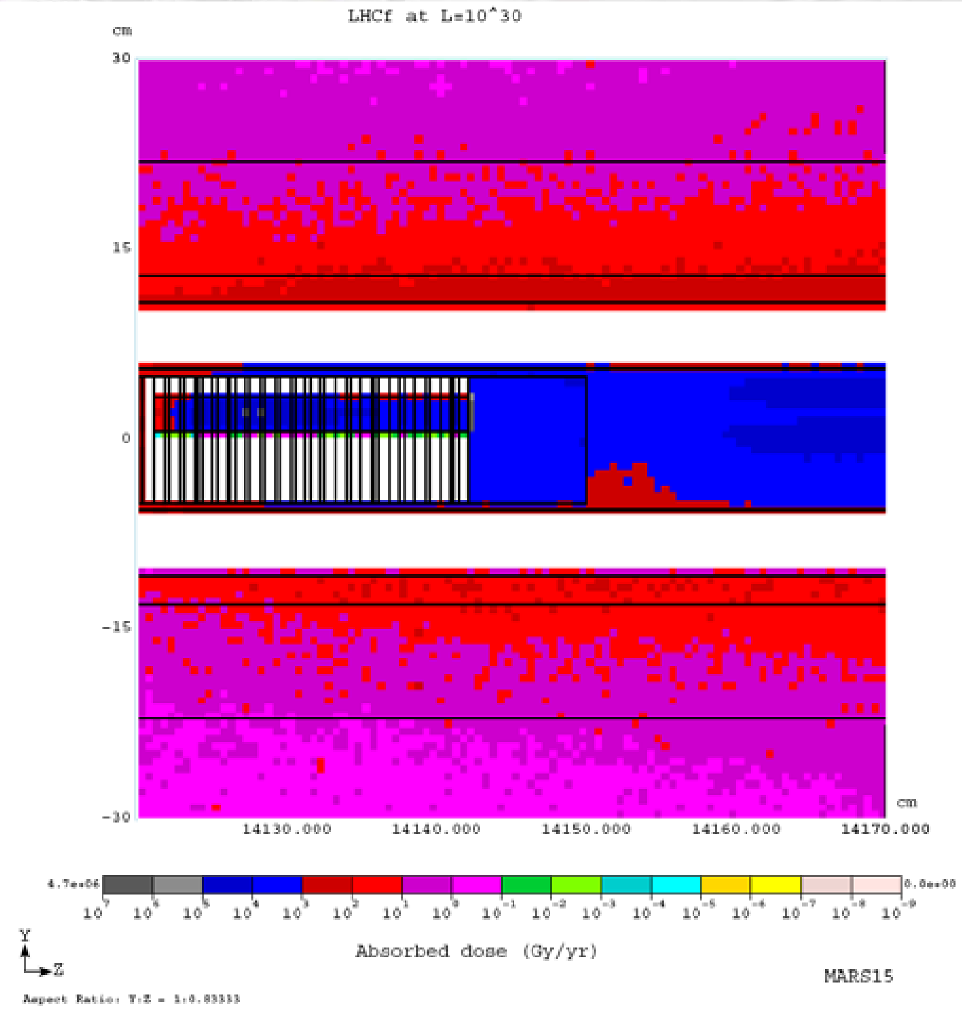
Original n energy **30% energy resolution**

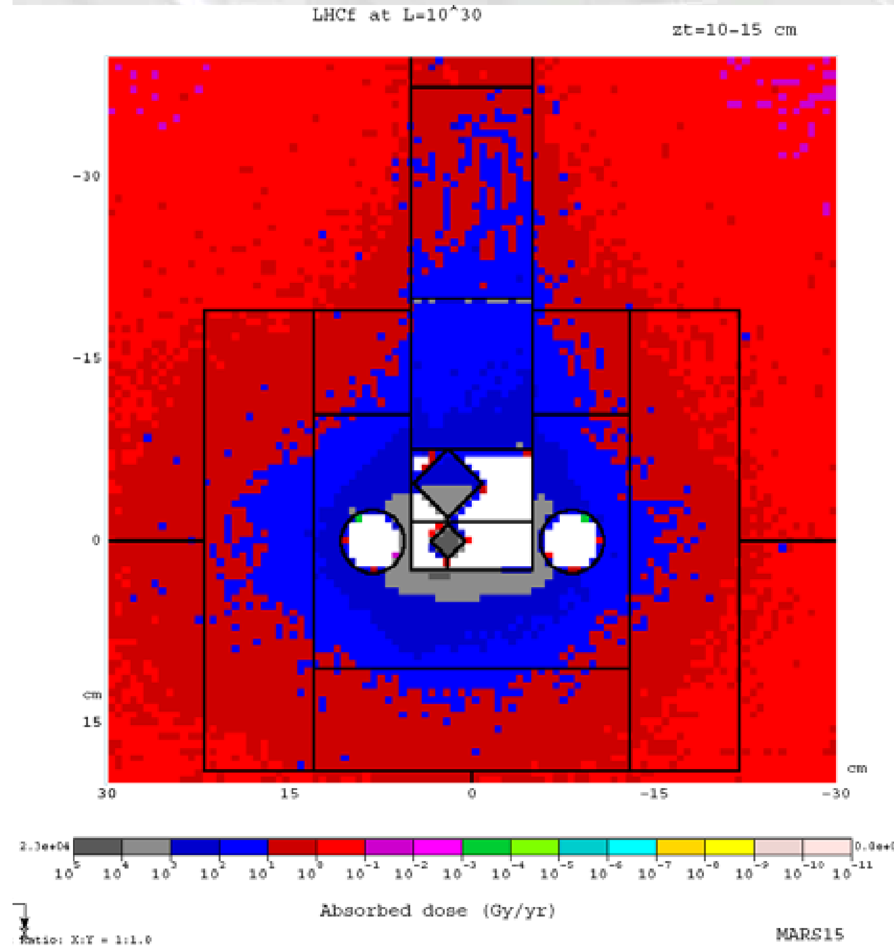




ABSORBED DOSE IN LHCf AT L=10^{30}

MARS simulation (by N.Mokhov)





D_{max}~ 1 0kGy@L=10^{30}/yr(6month run)

OK for a few day run (< 100Gy)

Optimal LHCf run conditions

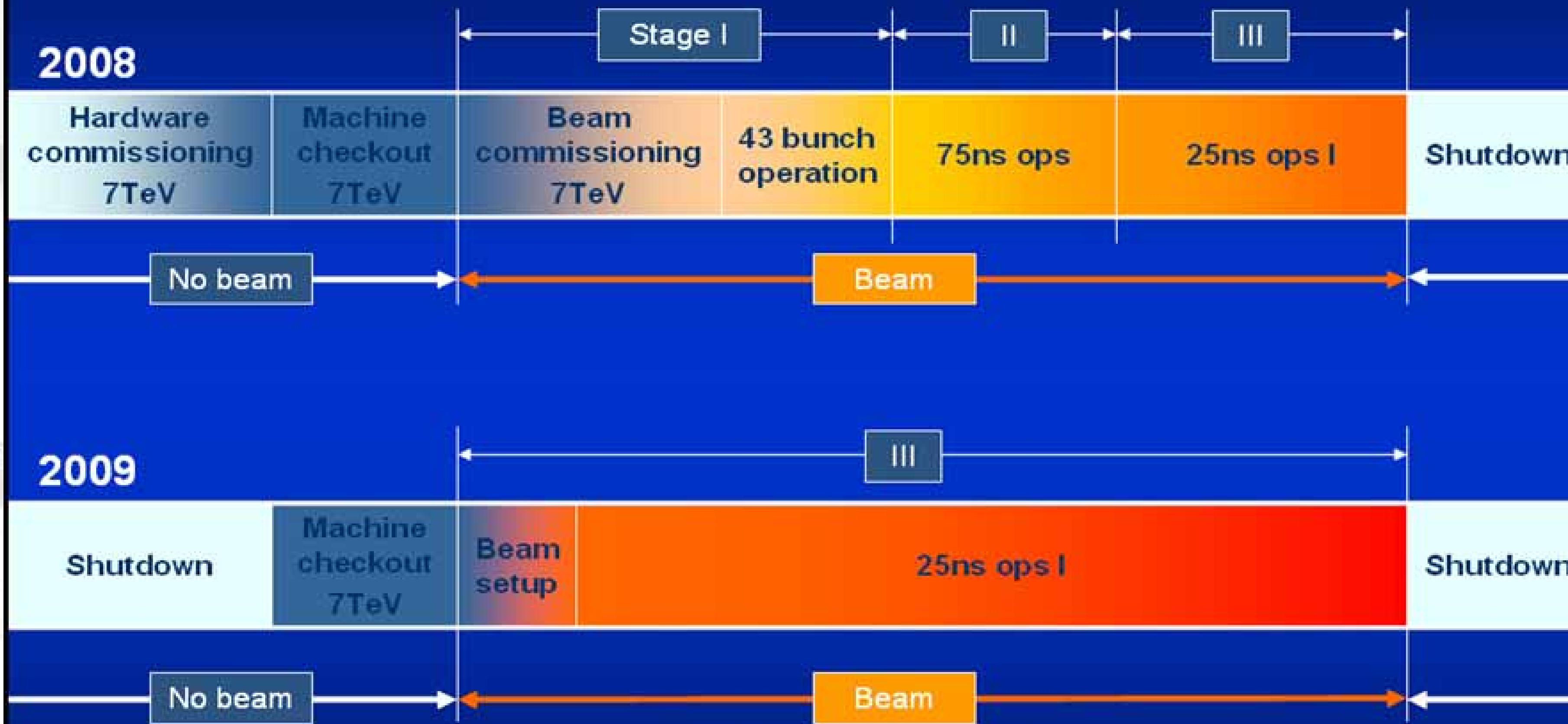
Beam parameter	Value
# of bunches	$\leq$ 43
Bunch separation	> 2 μsec
Crossing angle	0 rad or 140 μrad downward
Luminosity per bunch	< 2 x 10^{28} $cm^{-2}s^{-1}$
Luminosity	$\leq$ ~10^{30} $cm^{-2}s^{-1}$
Bunch intensity	4×10^{10} ppb (β*=18 m) 1×10^{10} ppb (β*= 1 m)

Beam parameters used for commissioning are good for LHCf!!!

Fulfill our DAQ requirement of 2μs interval

No radiation problem for 10kGy by a "year" operation with this luminosity

Beyond 2007



From R. Bailey presentation at January 2007 TAN workshop

R.Bailey, January 2007

Detector installation (Jan08)

Just 40 min. work

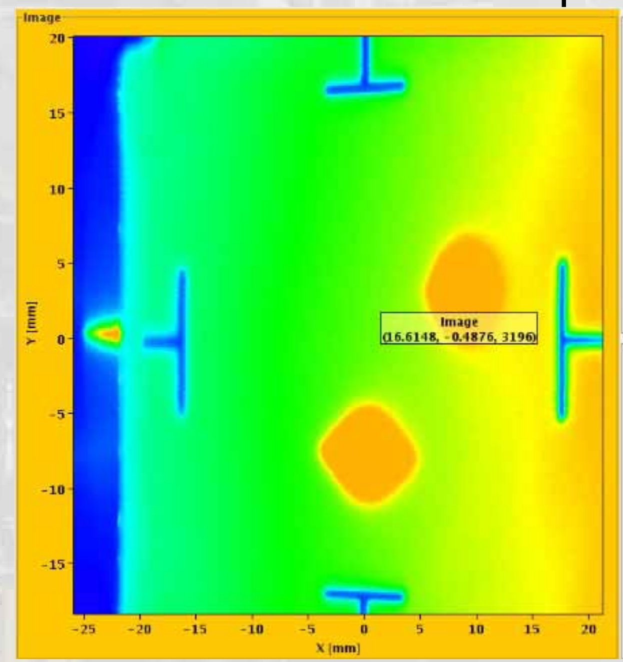
Installed detector in TAN

DAQ preparation @ USA15 (08 Spring)

LHC First Beam Circlulation（Sep 10th）

ATLAS Control Room

Cross Section of Beam Pipe



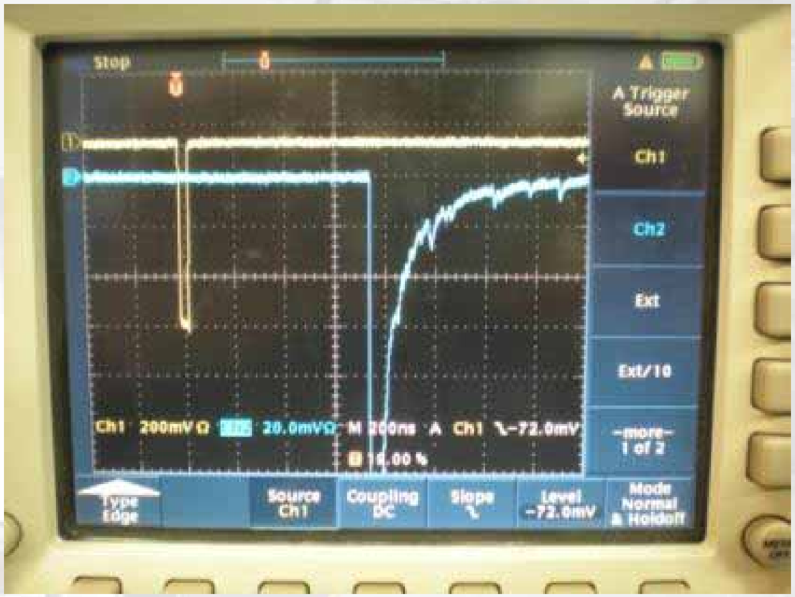
Sep10, 2008 10:25

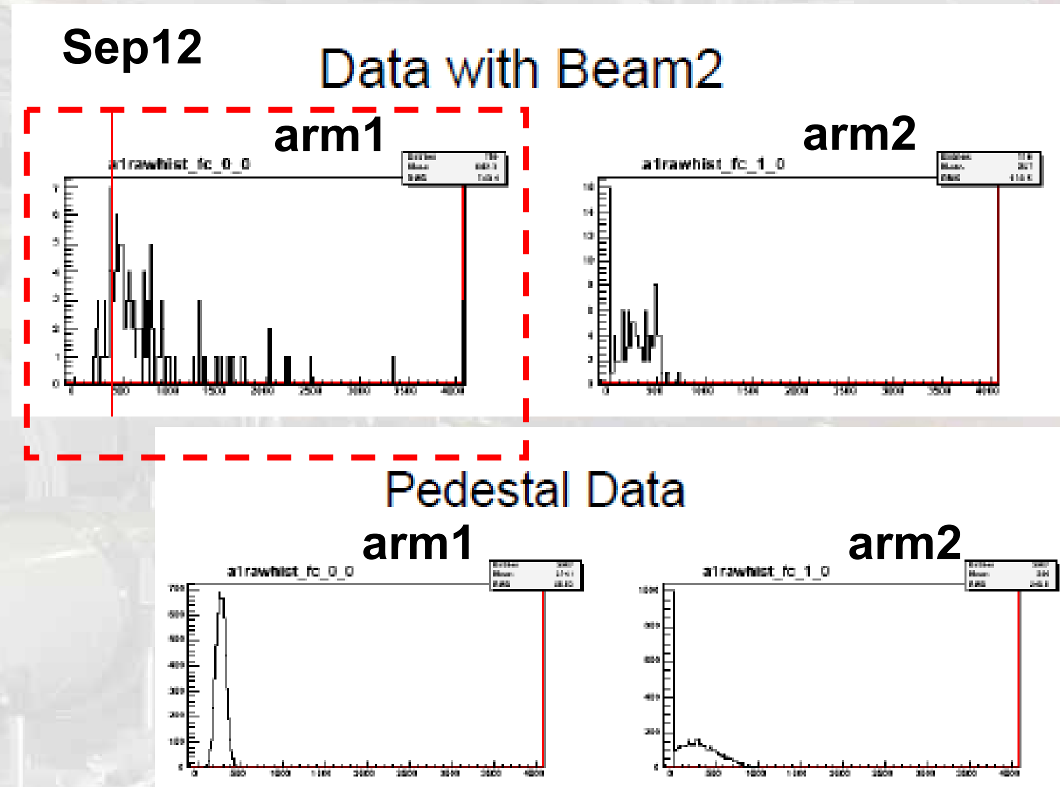
The 1st 450GeV pilot bunch injected and turned around !

（Just 1 hour after beam tuning !）

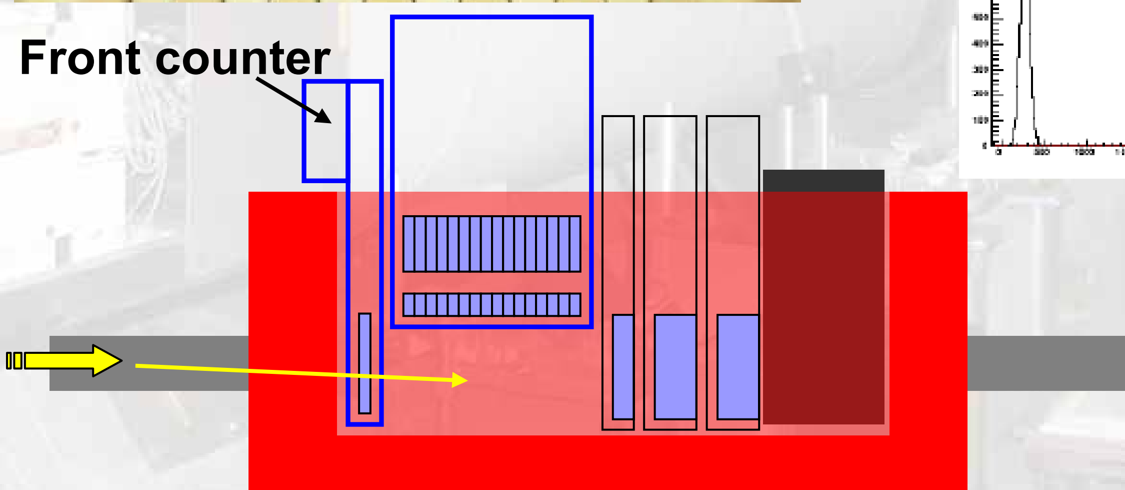
LHCf First signal @ Front Counter

Sep10





Front counter



LHCf proposed running scenario

- 2009 : Phase-I (During LHC commissioning)
  - Run since the very beginning of LHC operations ($L<10^{31}cm^{-2}s^{-1}$, 43 bunches)
  - First 5TeV collision is expected in summer? 2009
  - The LHCf detector is not radiation-hard. But still 10Gy/days@$L=10^{29}/cm^2s$ for a week operation will not be a problem.
  - First 7TeV collision is foreseen at ?

  So far approved

  Re-install detector.
- 200? : Phase-II (Dedicated run)
  - Re-install the detector at the next opportunity of low luminosity run (Possibly with TOTEM run)
  - Enlarge covered P_T region, more detail study
- 200? : Phase-III (possible heavy ion run)
  - Nuclear effect plays an essential role in "muons"
  - Future extension for p-A, A-A run with upgraded detectors?

Summary

- Analyses of UHECR air showers rely on production models at very forward, which should be experimentally verified at energy as high as possible. Even all current models may be wrong.
- LHCf : Dedicated measurements of neutral particles at 0 deg by LHC, providing calibration of interaction models at 10^{17}eV.
- Approved parasite measurements by two small sampling calorimeters at +-140m from IP1 during LHC commissioning in ~~2008~~ →2009
- Just “one day” measurement provides good discrimination of various models in the market.

We are waiting for the LHC 1st collision !