Measurement of Photons and Neutral Pions in the Very Forward Region of LHC

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(The LHCf collaboration)
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1. Review of experimental purpose
2. The results of the test experiment
3. Trigger, Beam condition, Schedule, Concluding remarks

Measurement of Photons and Neutral Pions in the Very Forward Region of LHC

1. Scientific purpose

The main purpose is to establish proton-proton interactions at the highest energy region with use of the highest energy accelerator in the world. It has been a long dream for cosmic ray physicists.

2. Experimental proposal

The proposal describes that a small calorimeter will be installed in front of the collision point at 140m away. It would be the smallest experiment using the largest accelerator in the world.
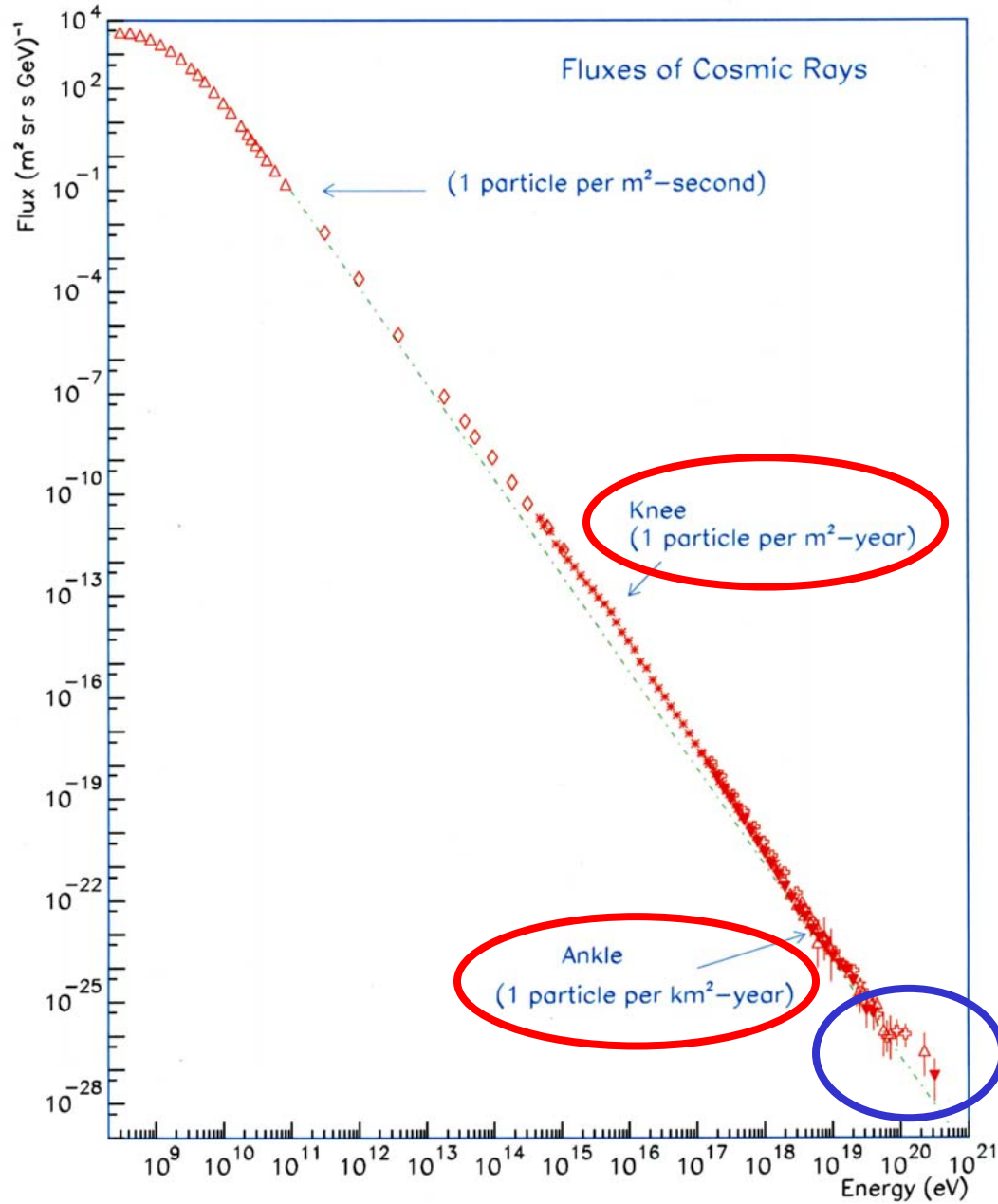
3. The beam condition

We require rather low luminosity operation, say 10 bunches(43) in the ring with 1×10^{10} protons in a bunch. The machine people will enjoy a very special run of the accelerator for only a few hours.

4. Summary

We will be able to establish very important data point by this experiment, which will be very useful for not only cosmic ray people but also the GEANT 4 people.
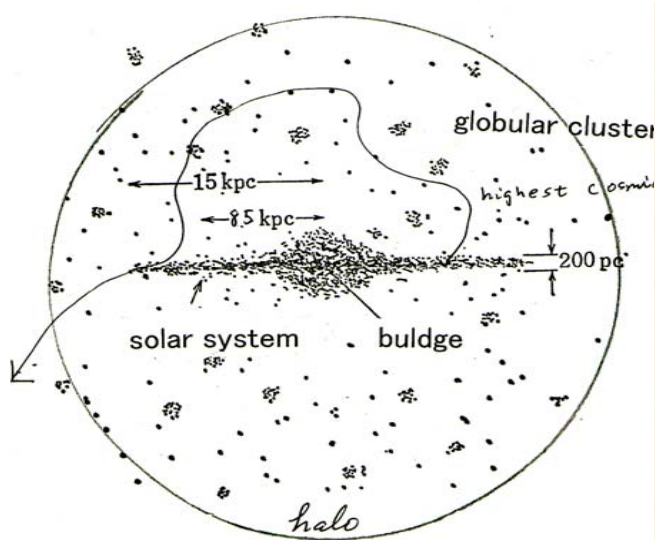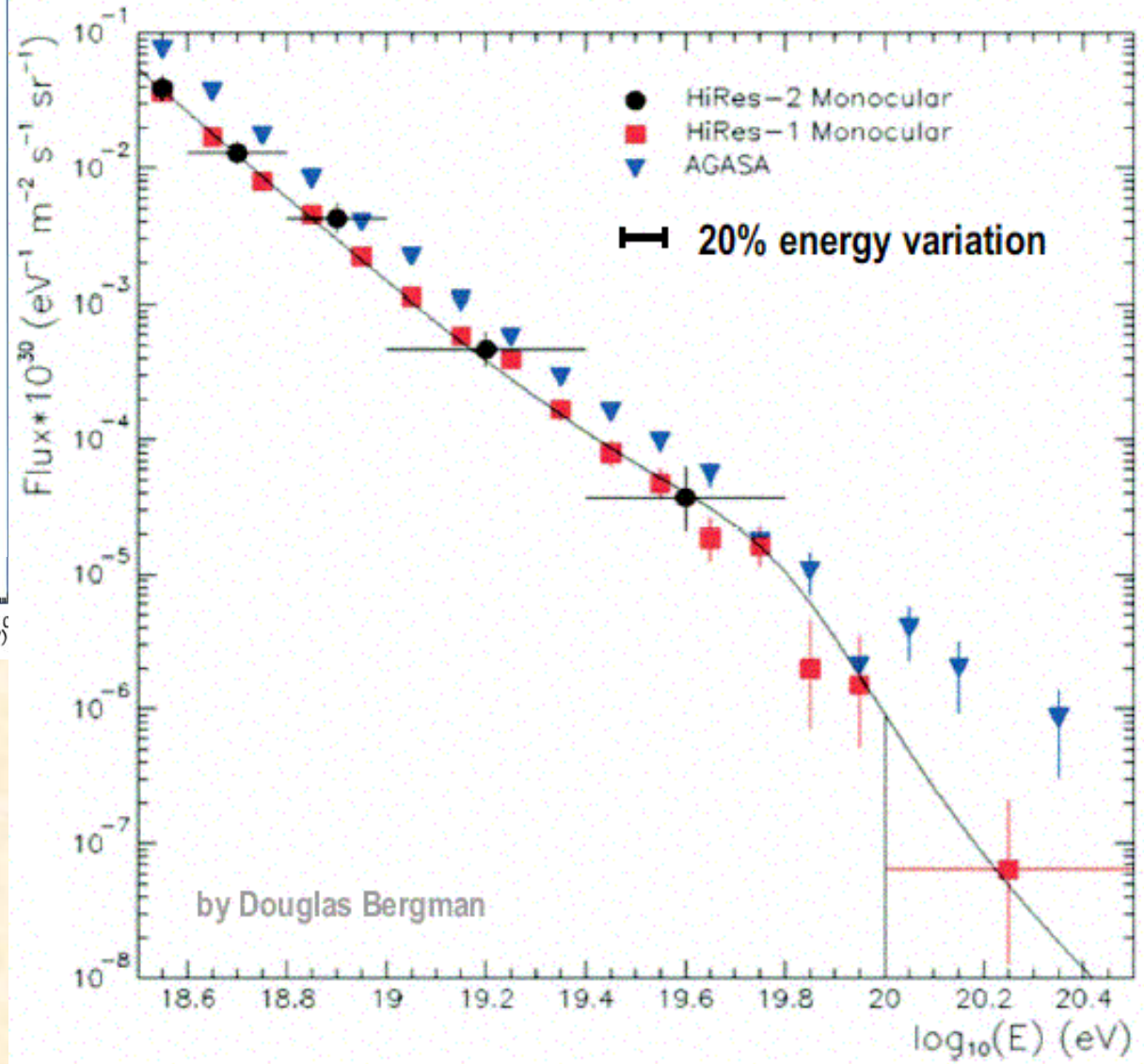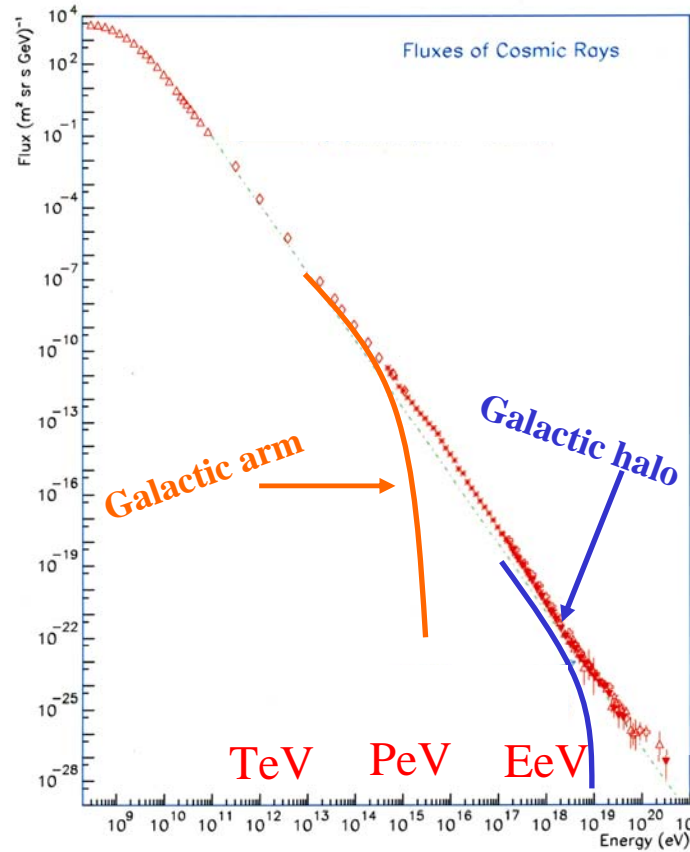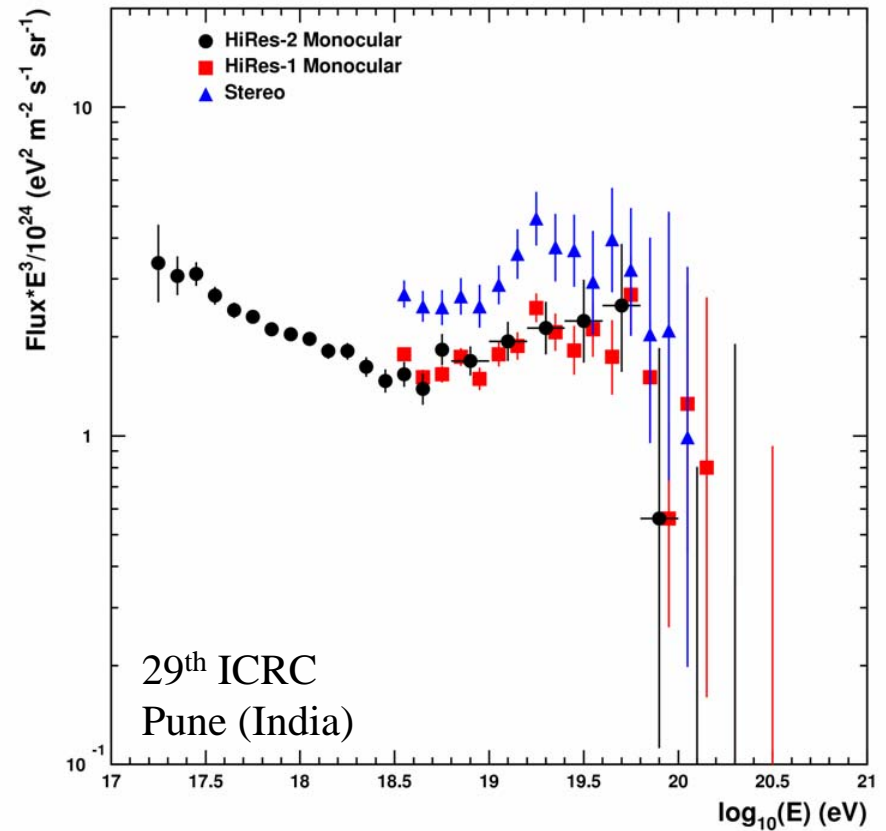
Cosmic Ray Flux

10^9 eV   **10^20 eV**

Energy spectrum of Cosmic Rays

Fluxes of Cosmic Rays

Galactic arm

Galactic halo

TeV   PeV   EeV

15 kpc
8.5 kpc
globular cluster
highest cosmic
200 pc
solar system   buldge
halo

- HiRes-2 Monocular
- HiRes-1 Monocular
- AGASA

⊢––⊣ 20% energy variation

by Douglas Bergman

New AUGER and Stereo Hi Res data (preliminary)

29th ICRC
Pune (India)

29th ICRC
Pune (India)
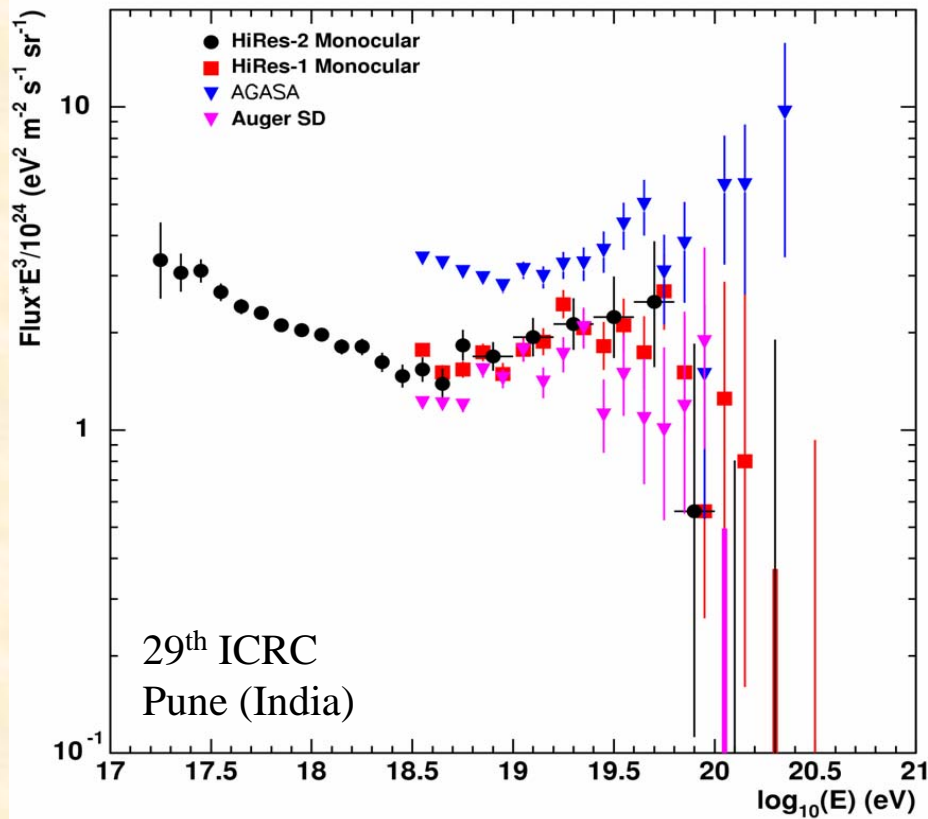
inclusive cross-section

Pion x-distribution at 10^{17} eV pp interaction

production cross-section

$$\frac{1}{\sigma_{in}} x \frac{d\sigma}{dx}$$

Artifitial two examples

ad-hoc A

ad-hoc B

A ~ DPMJET/QGSJET

x_{cm}

0.01

0.1

region to be examined

X_{cm}

10^{17} eV proton induced showers

N_e (Number of Electrons)

Vertical shower

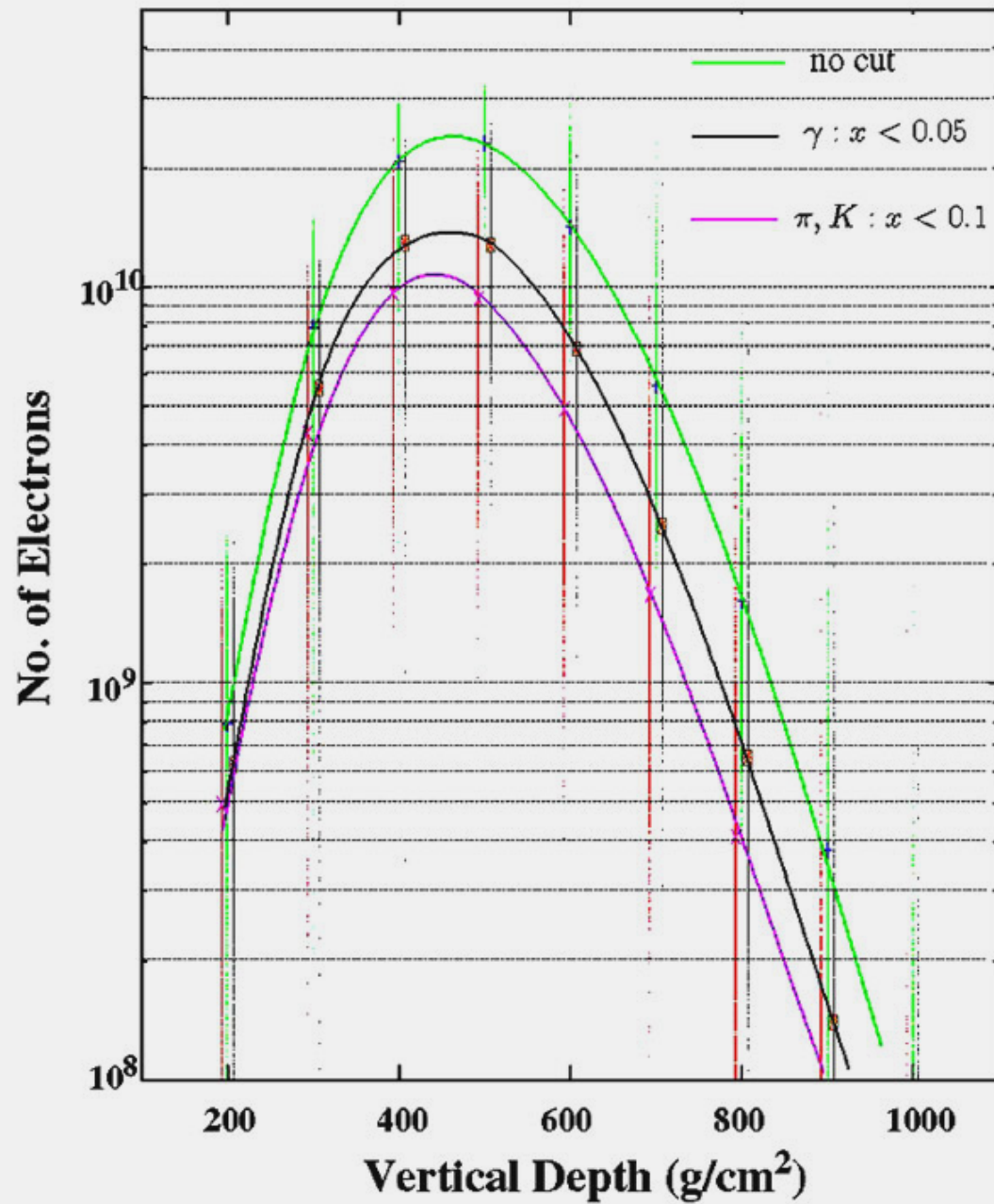shower development

ad-hoc A

ad-hoc B

Vertical Depth (g/cm^2) 900 g/cm²
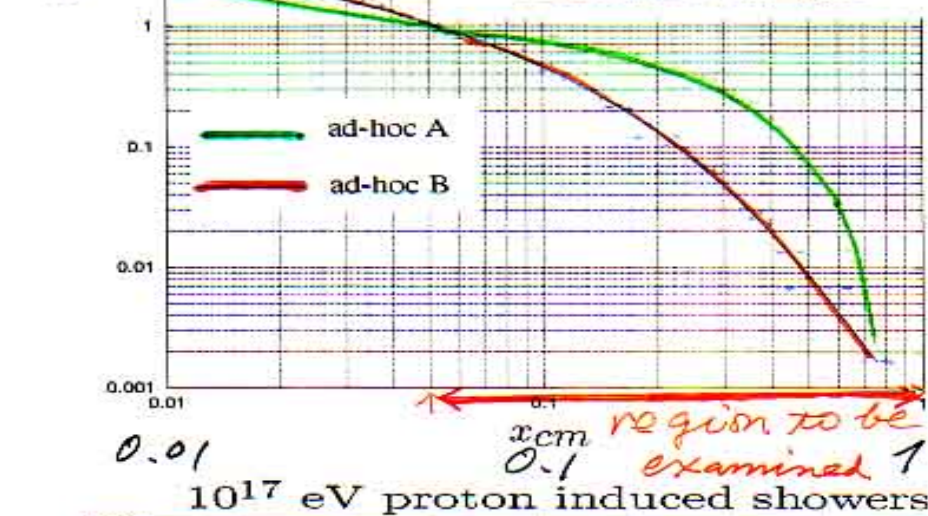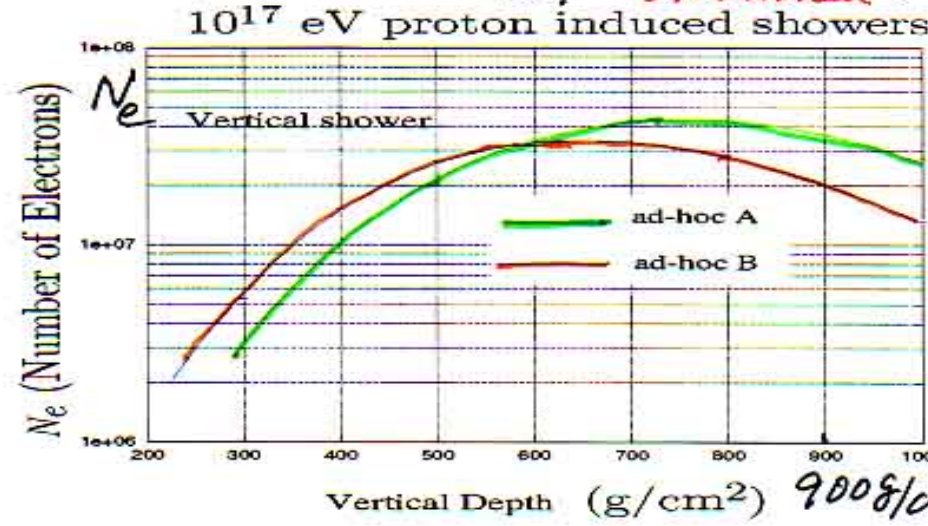
Fig. 9 Two different type production models of secondary particles are presented
as a function of the Feynman variable X at the center of mass(top) and shower
curves expected from the production type A and B for $E_0=1 \times 10^{17}$ eV.
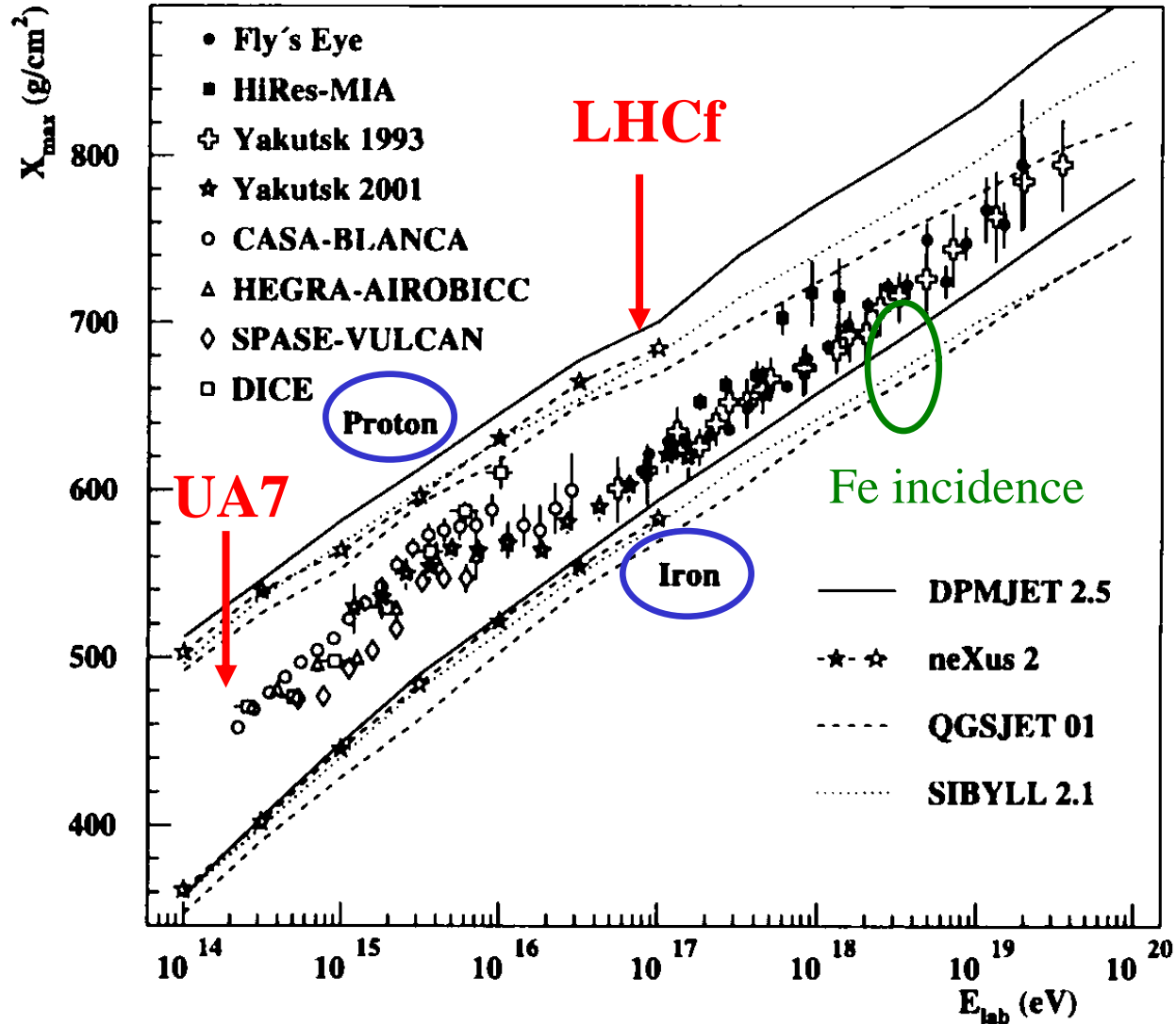At 900 g/cm2, the number of partciles differs about 1.75 times.

5x10^{19} eV proton initiated showers

Zenith angle 60 deg.

Legend:
- no cut (green)
- $\gamma : x < 0.05$ (black)
- $\pi, K : x < 0.1$ (magenta)

$x_F < 0.05$

$x_F < 0.1$

No. of Electrons

Vertical Depth (g/cm^2)

The position of shower maximum
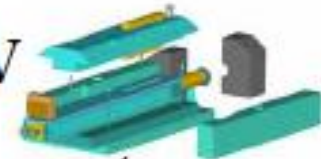## Knapp et al, Astroparticle Physics, 19(2003) 77

Additional statement on the L.O.I.

Within a year (2004-2005), two new data have been presented in the 29th ICRC by the AUGER and Hi-Res groups, but the riddle on the highest energy cosmic rays has been left.   It has been cleared that the forthcoming results by the LHCf experiment will become more and more important.
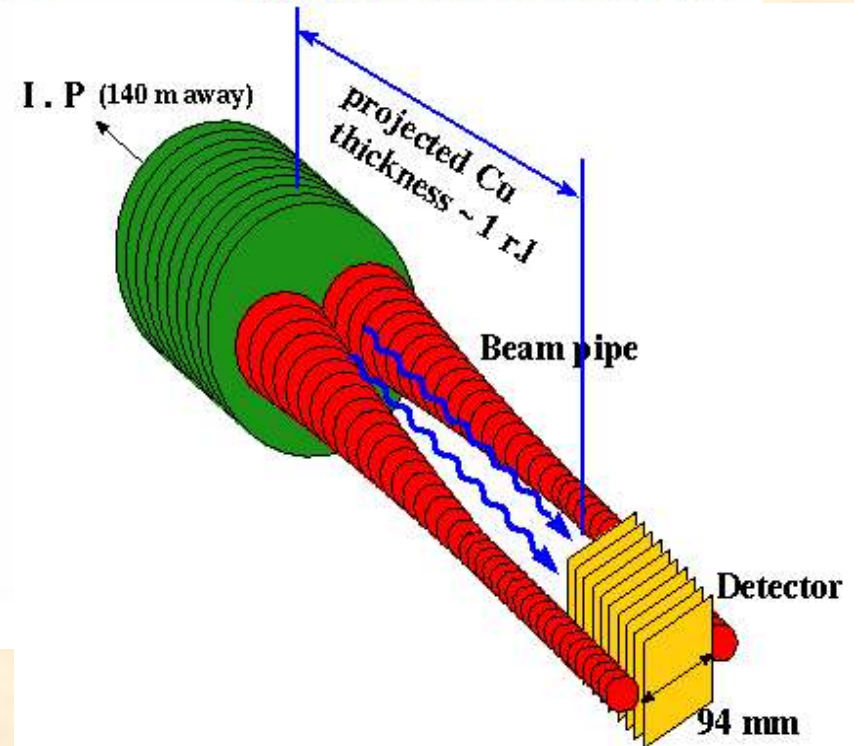
TAN VACUUM DESIGN -3D OVERVIEW

Y Chamber

THE VACUUM TUBE CONTAINS TWO COUNTER-ROTATING BEAMS. THE BEAMS TRANSITION FROM ONE BEAM IN EACH TUBE TO TWO BEAM IN THE SAME TUBE.
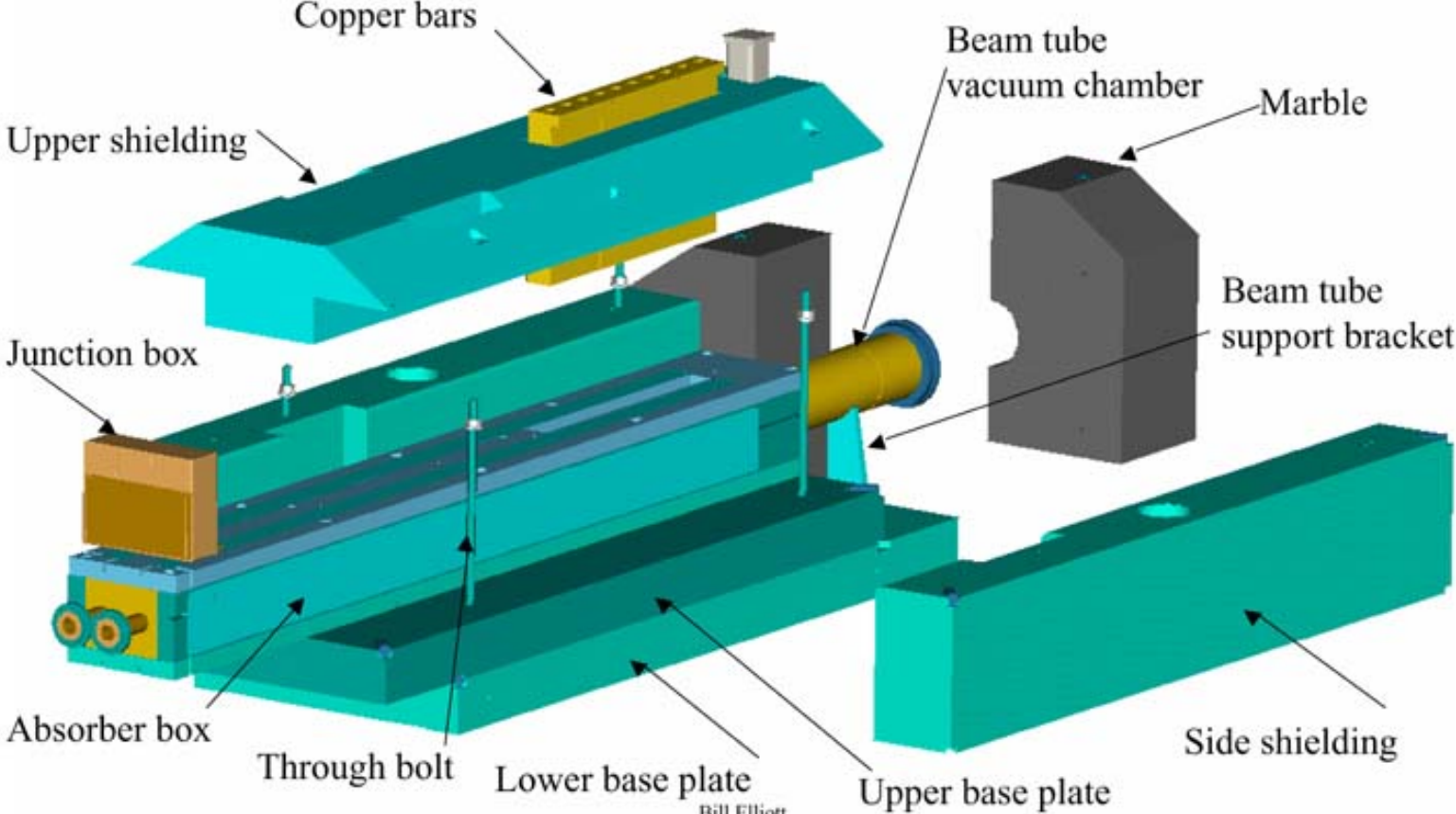
Detector location

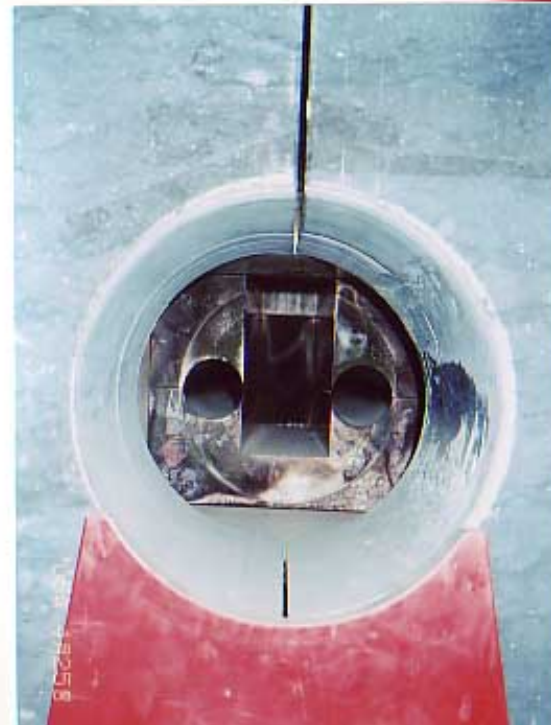THE TWO COUNTER-ROTATING BEAMS INTERSECT 140 METERS

I . P (140 m away)

projected Cu thickness ~ 1 rl

Beam pipe

Detector

94 mm

TAN Nomenclature

Copper bars

Beam tube vacuum chamber

Marble

Upper shielding

Junction box

Beam tube support bracket

Absorber box

Through bolt
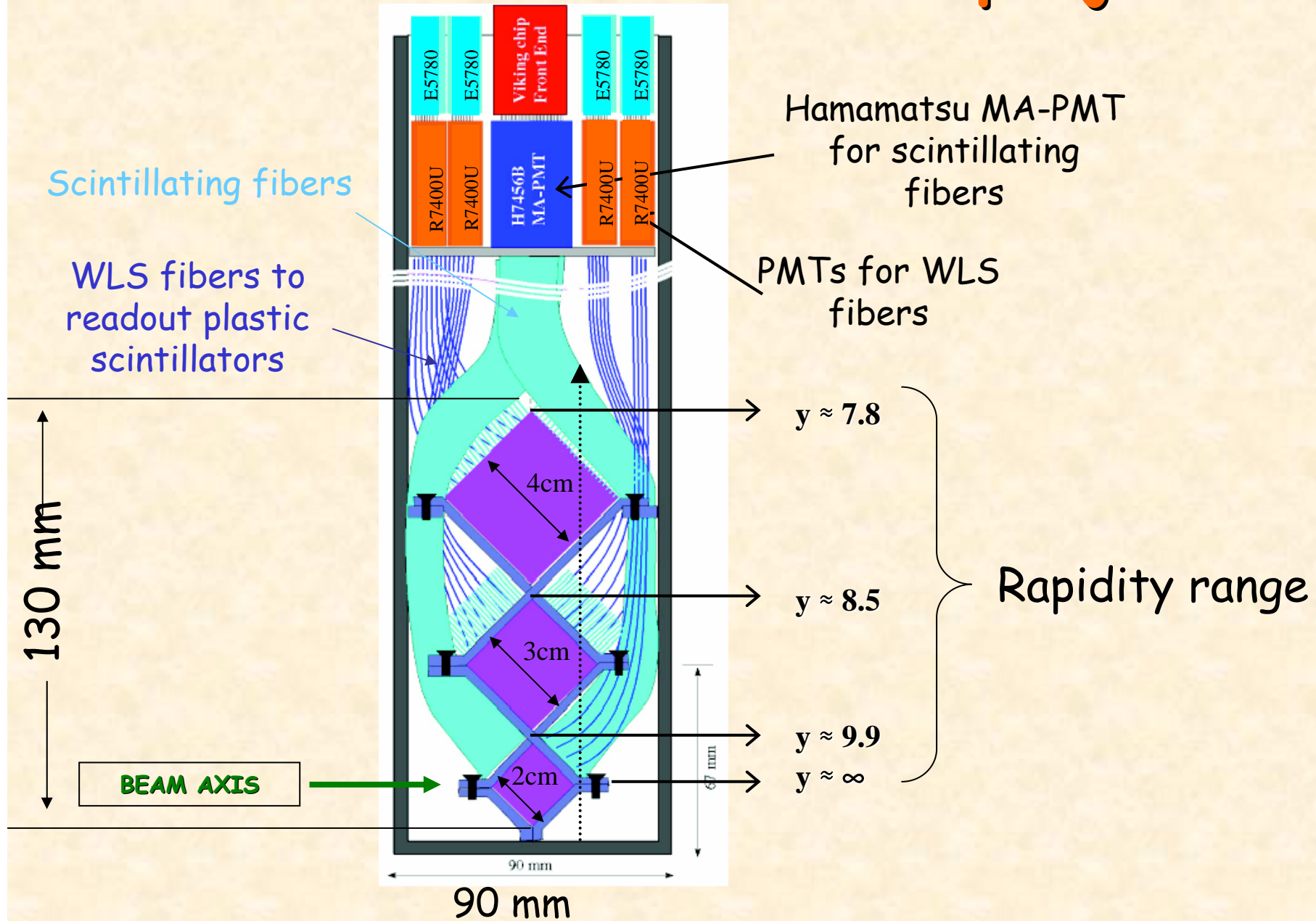
Lower base plate

Upper base plate

Side shielding

Bill Elliott
TAN/TAS ASSEMBLY

3

The TAN for the luminosity monitor

Photos taken
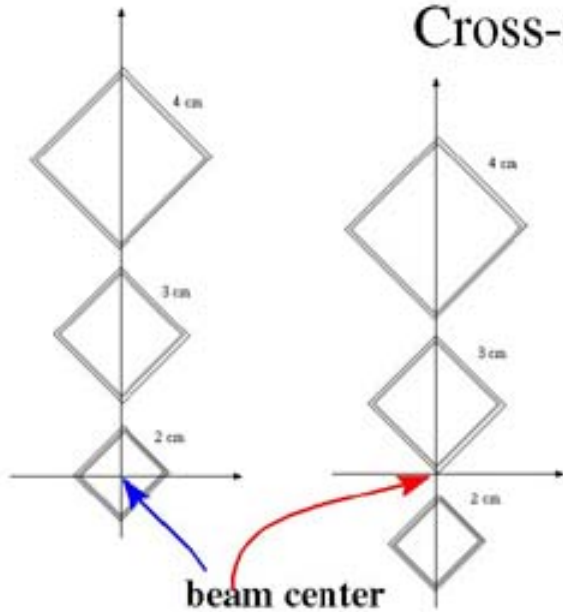On April 25th, 2005
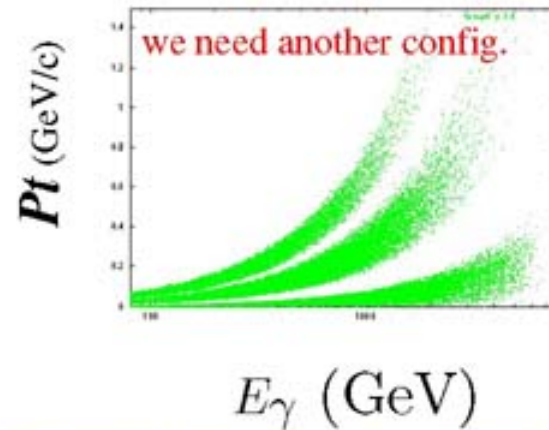At CERN

Detector #1: transverse projection

Scintillating fibers

WLS fibers to readout plastic scintillators

BEAM AXIS

130 mm

90 mm

E5780
E5780
Viking chip Front End
E5780
E5780

R7400U
R7400U
H7456B MA-PMT
R7400U
R7400U

Hamamatsu MA-PMT for scintillating fibers

PMTs for WLS fibers

$y \approx 7.8$

$y \approx 8.5$

$y \approx 9.9$

$y \approx \infty$

Rapidity range

4cm

3cm

2cm

90 mm

67 mm

Energy resolution

$< \Sigma_c(> 6) >$ (ptcl's)

2cm x 2cm tower

No scifi saturation
and fit to it

With scifi saturation at
1000 ptcls

$4.2 \times 10^3 \dfrac{E_\gamma}{100}$

Root mean square energy resolution (%)

$\Sigma_c(> 6)$

$\dfrac{5}{\sqrt{\left(\dfrac{E_\gamma}{100}\right)}} + 1.2$

No scifi saturation
and fit to it

With scifi saturation at
1000 ptcls

6 %

2 %

E_γ (GeV)

100 GeV

1 TeV

Cross-section derivation

By standard config.

Acceptance corrected

Pt (GeV/c)

we need another config.

E_γ (GeV)

beam center

With two config., we can reconstruct cross-section of standard model (lines : dpmjet3) by observing 10^6 events (dots)

Geometircal acceptance

Geometrical acceptance α

Distance from the beam center (cm)

$\dfrac{1}{\sigma_{in}} x \dfrac{d\sigma}{dx}$

Pt-all
< 1GeV
< 0.5
< 0.25
< 0.125
< 0.071

E_γ (GeV)
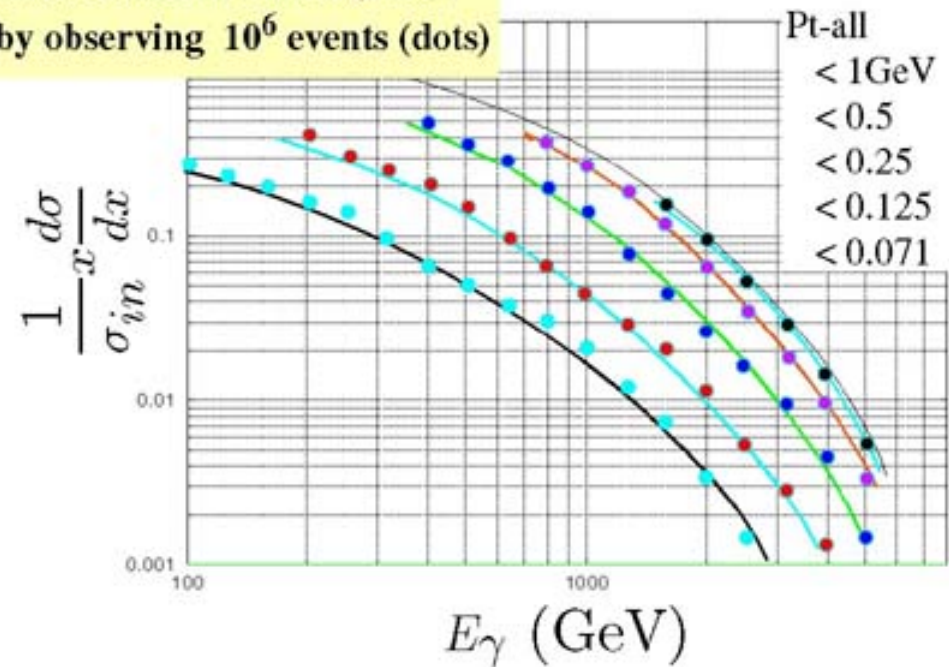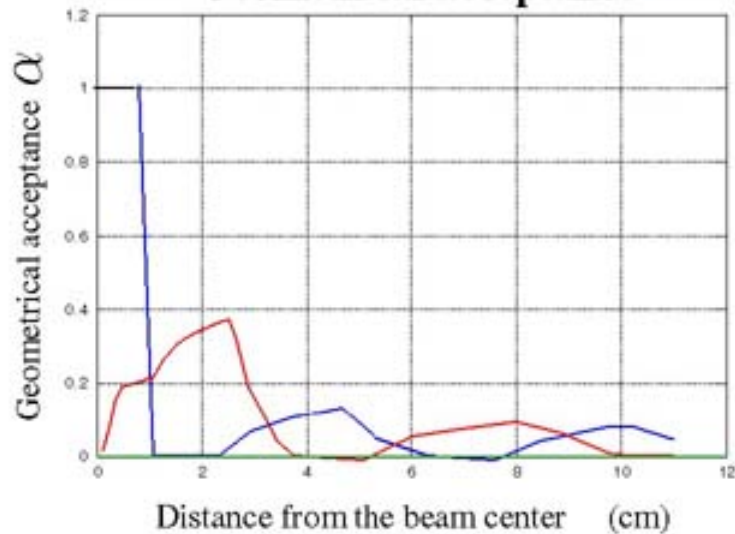
What we have done in a year

1. Monte Carlo calculations using **DPMJET3, QGSJET and SYBILL** models (popular in cosmic rays).

2. We have made the same detector that we have proposed and made an exposure at the CERN   NA H4 beam line.
   $\rightarrow$ e , μ , p   to measure Δ **E/E** and **edge effect**

3. We have investigated the calibration of the absolute value of shower particles in a range from **1000 – 100,000** by using a nitrogen laser system.

   We would like to report mainly those results today.

Monte Carlo γ ray energy spectrum

10^6 generated LHC interactions → 1 minute exposure

Gamma Energy Spectrum of 20mm square at Beam Center
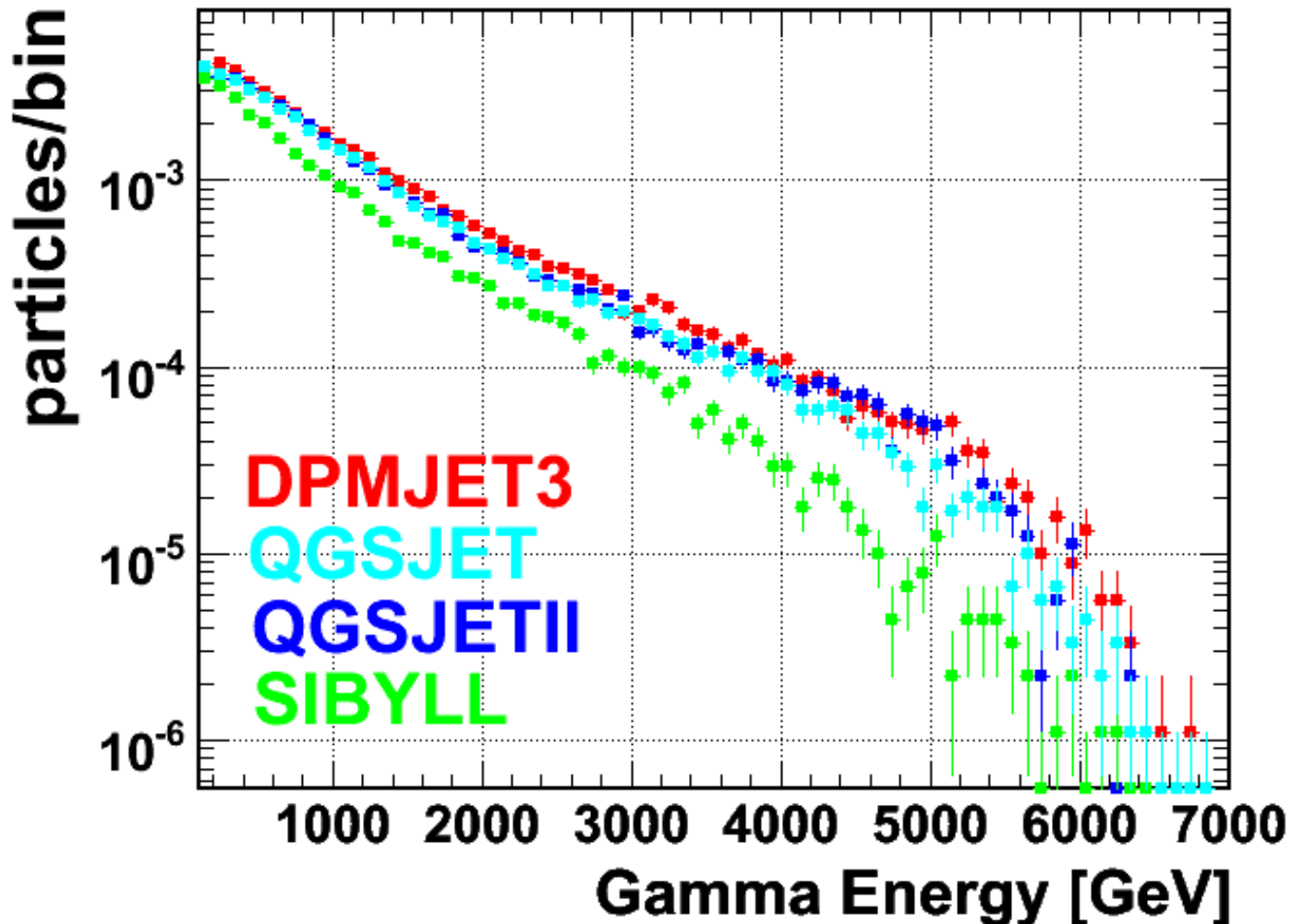
γ ray energy spectrum for different positions

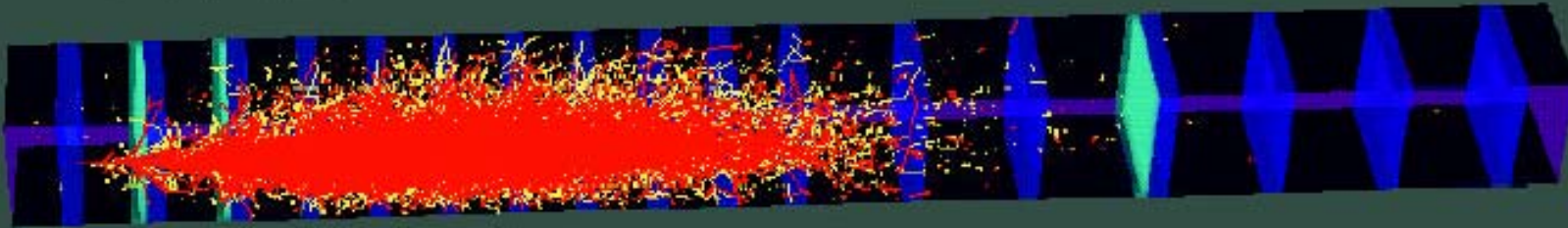Gamma Energy Spectrum of 20mm calorimeter at Center
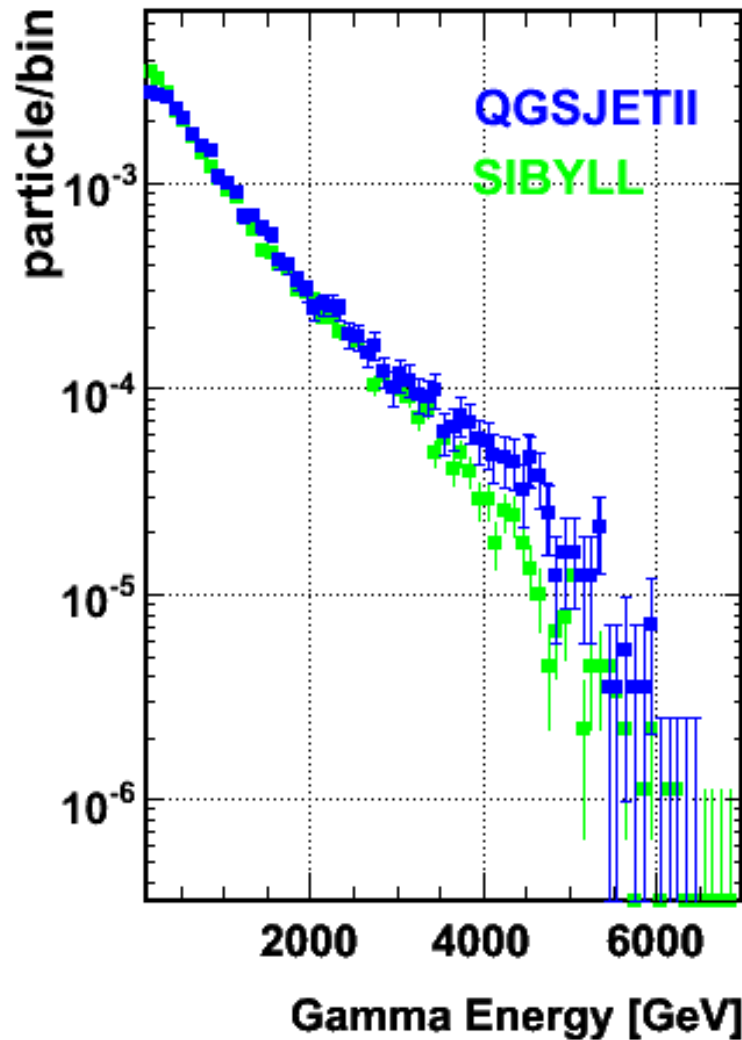
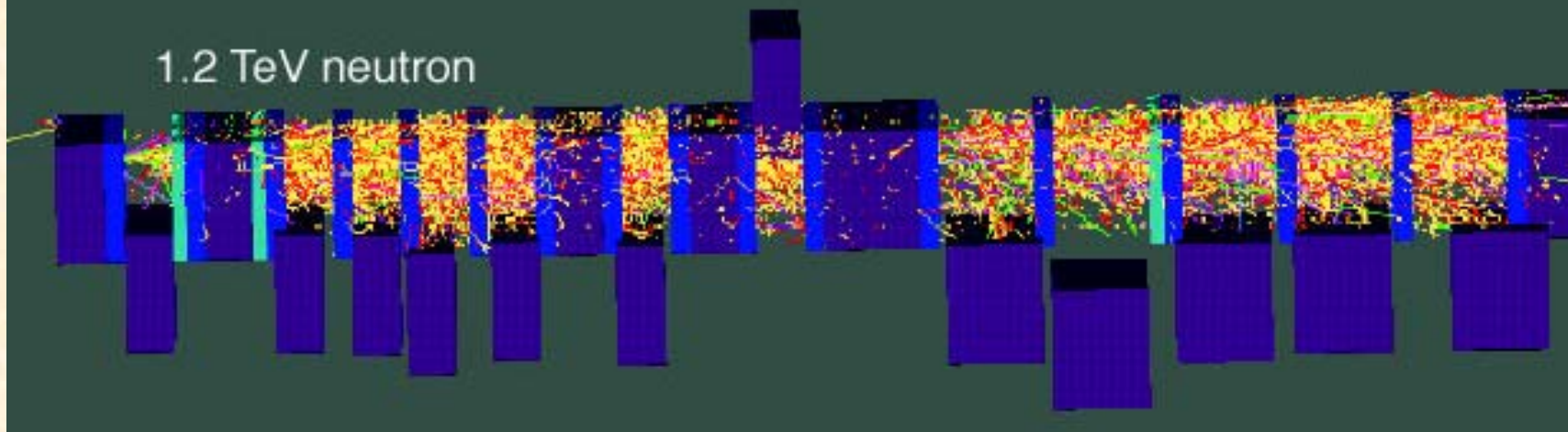Gamma Energy Spectrum of 20mm calorimeter at 30mm shift
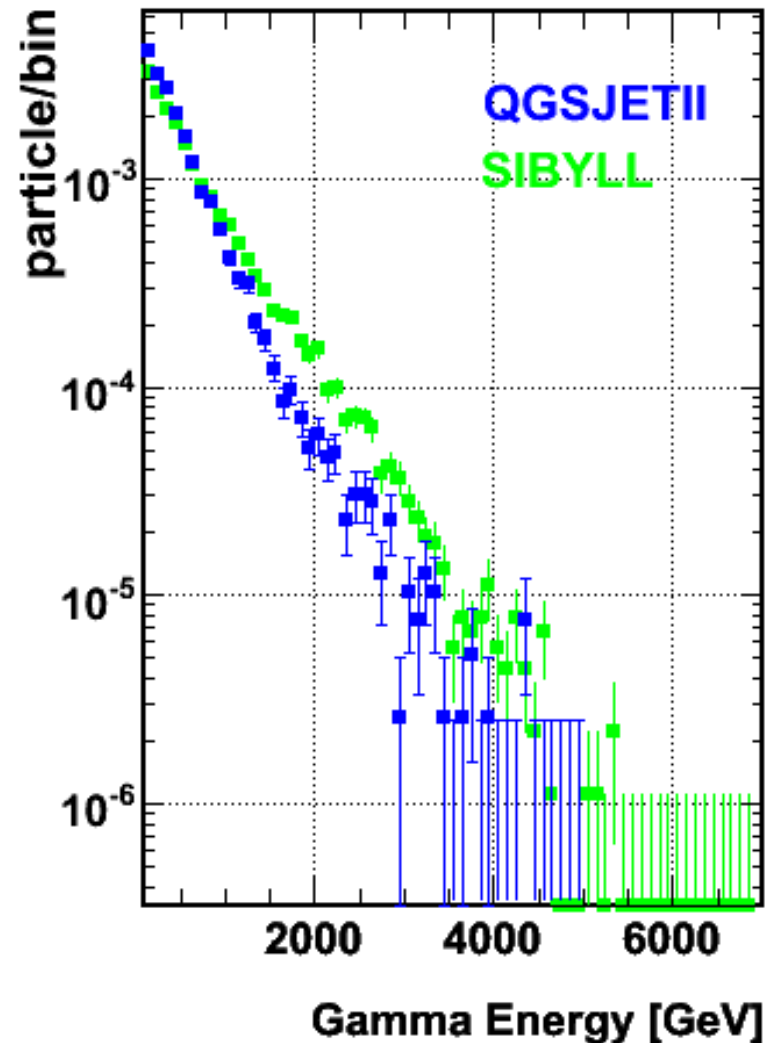
Examples of simulated events for γ and n

400 GeV photon

1.2 TeV neutron

Additional statement on the L.O.I.

Within a year, two new data have been presented at
the 29th ICRC by the AUGER and Hi - Res groups, but still the riddle
on the highest energy cosmic rays has been left and furthermore
the forthcoming results from the LHCf experiment has been important.
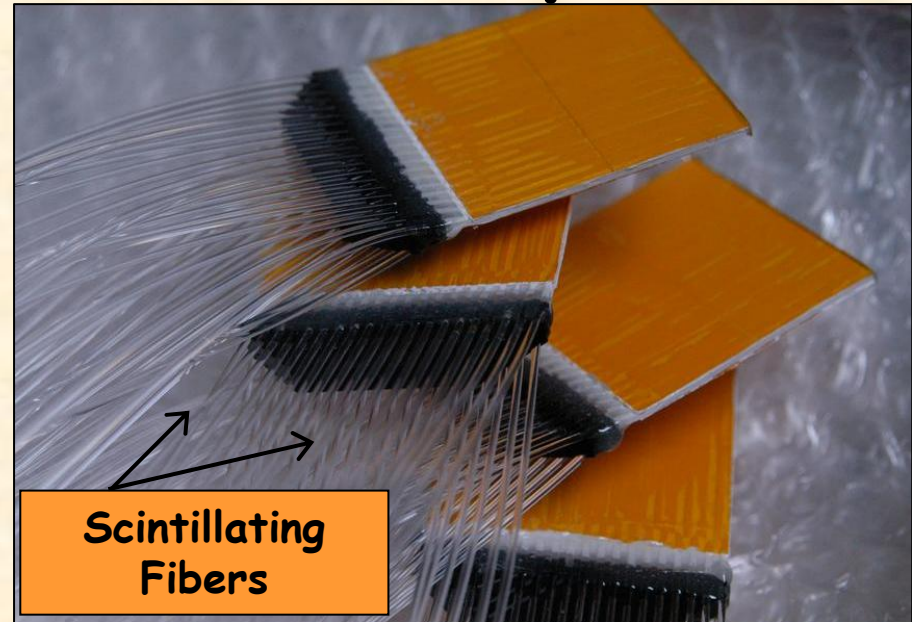
Summary 1 (on physics)

The particle production cross-section in the very forward
region that will be obtained by the LHCf experiment will
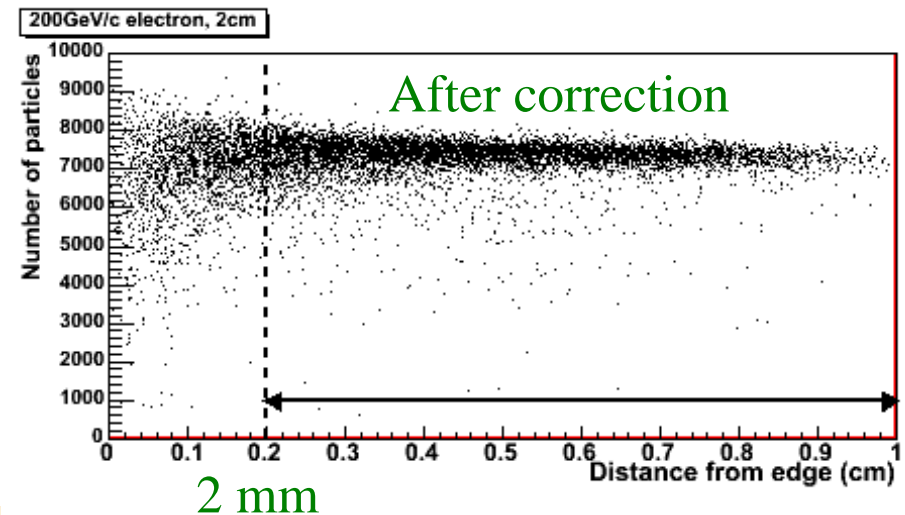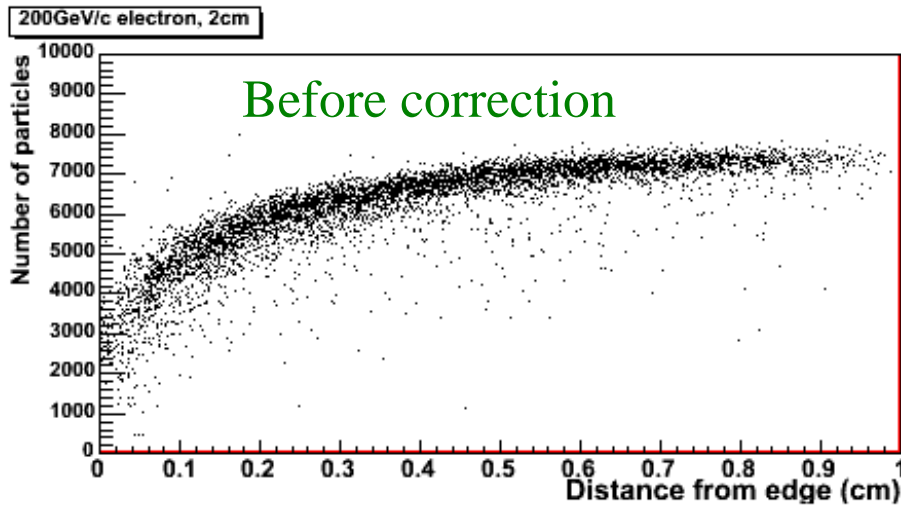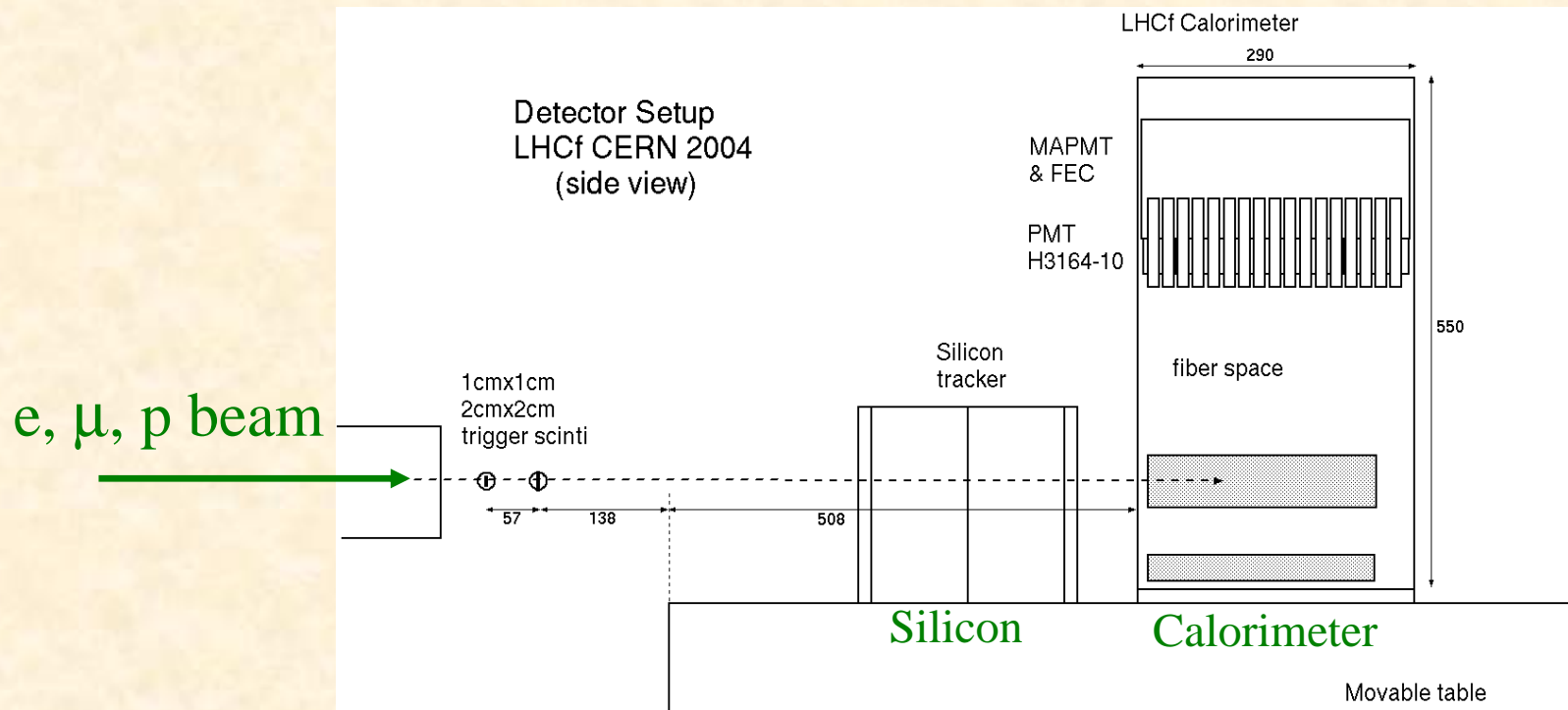be very useful for various Monte Carlo generators.
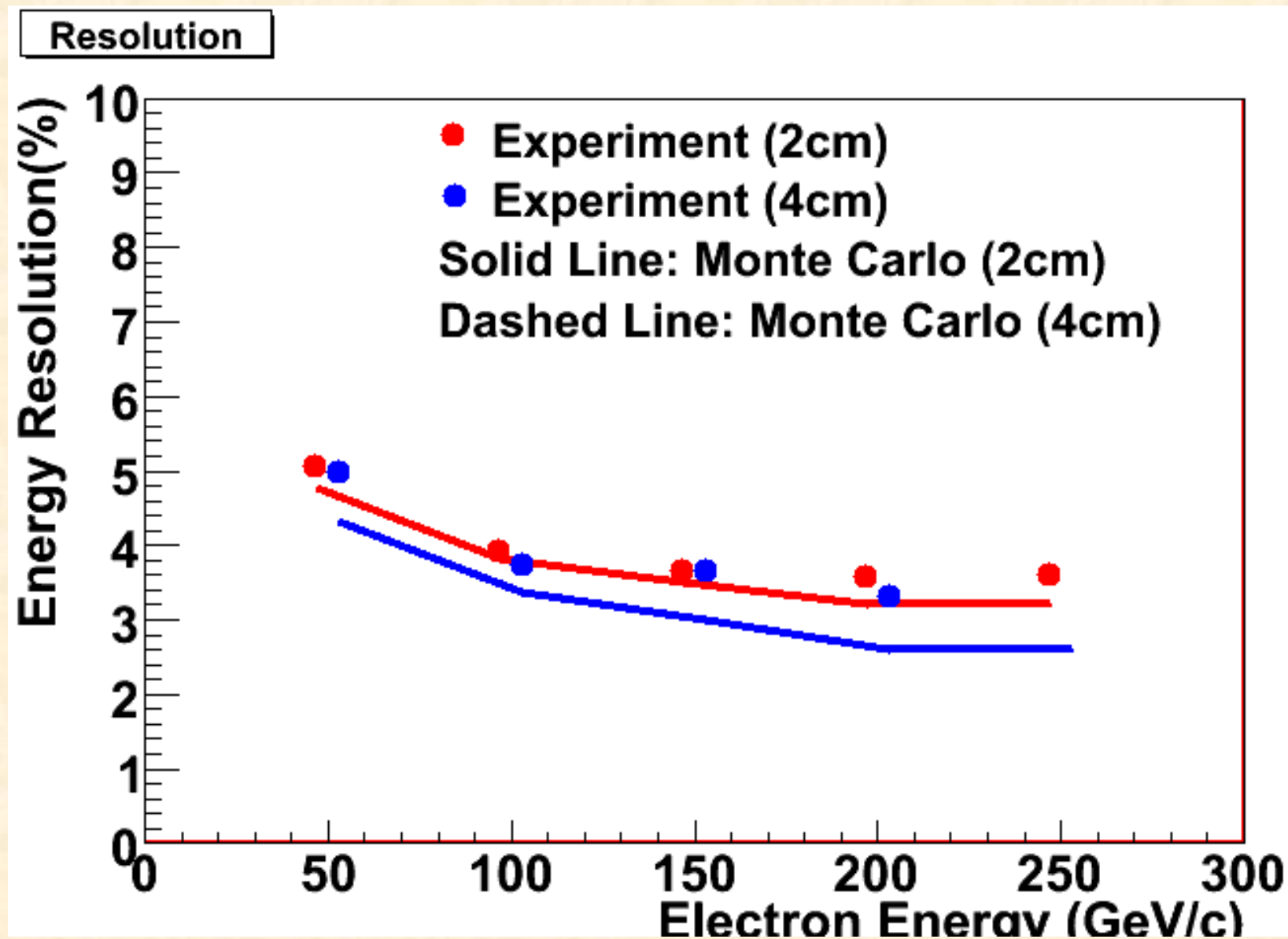
The calorimeter in the test experiment

Scintillating Fibers

Scintillators plane

Size: 9.6 cm x 29 cm x 55 cm
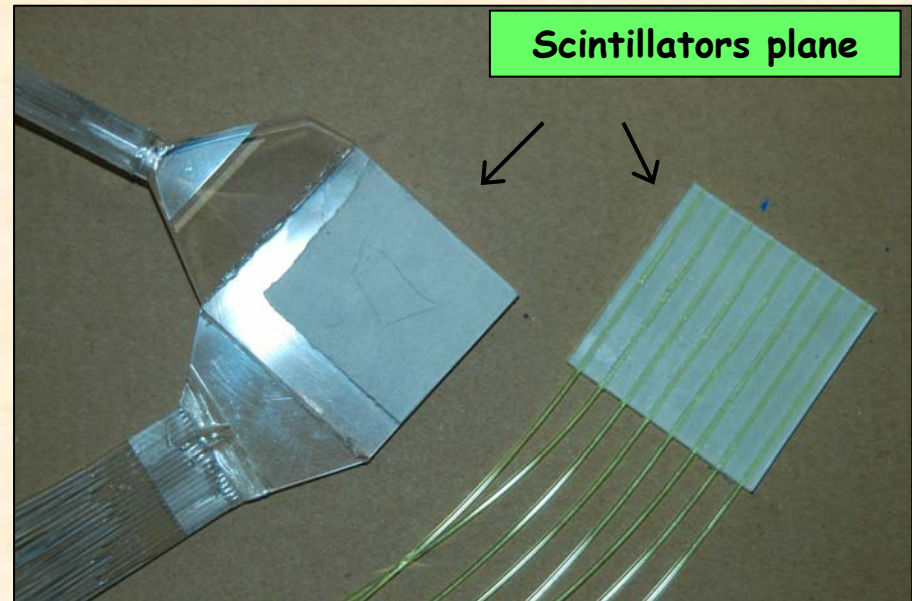
The CERN test experiment on August 2004 (H4 Beam Line)

Detector Setup
LHCf CERN 2004
(side view)

LHCf Calorimeter

290

MAPMT
& FEC

PMT
H3164-10

550

fiber space

Silicon
tracker

e, μ, p beam

1cmx1cm
2cmx2cm
trigger scinti

57   138   508

Silicon   Calorimeter

Movable table

200GeV/c electron, 2cm

Before correction

200GeV/c electron, 2cm

After correction

2 mm

Energy resolution

We successfully developed high dynamic range photomultiplier system (R7400U modified)
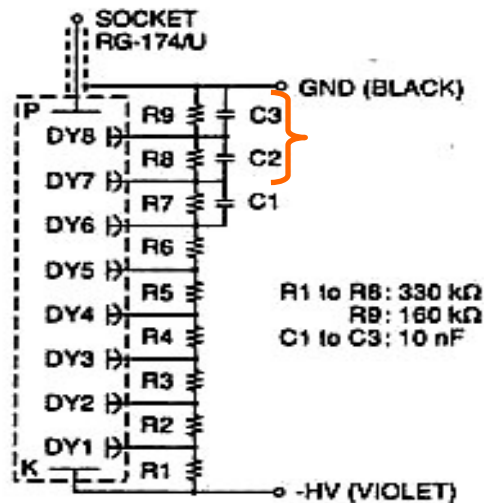
Before Modification
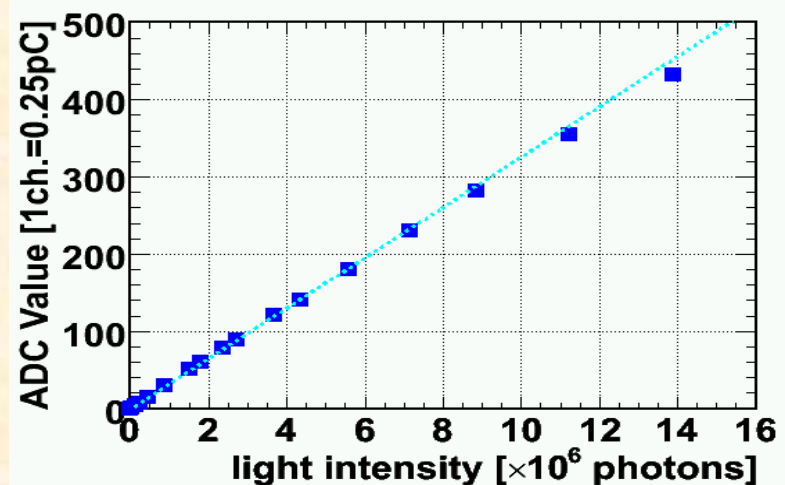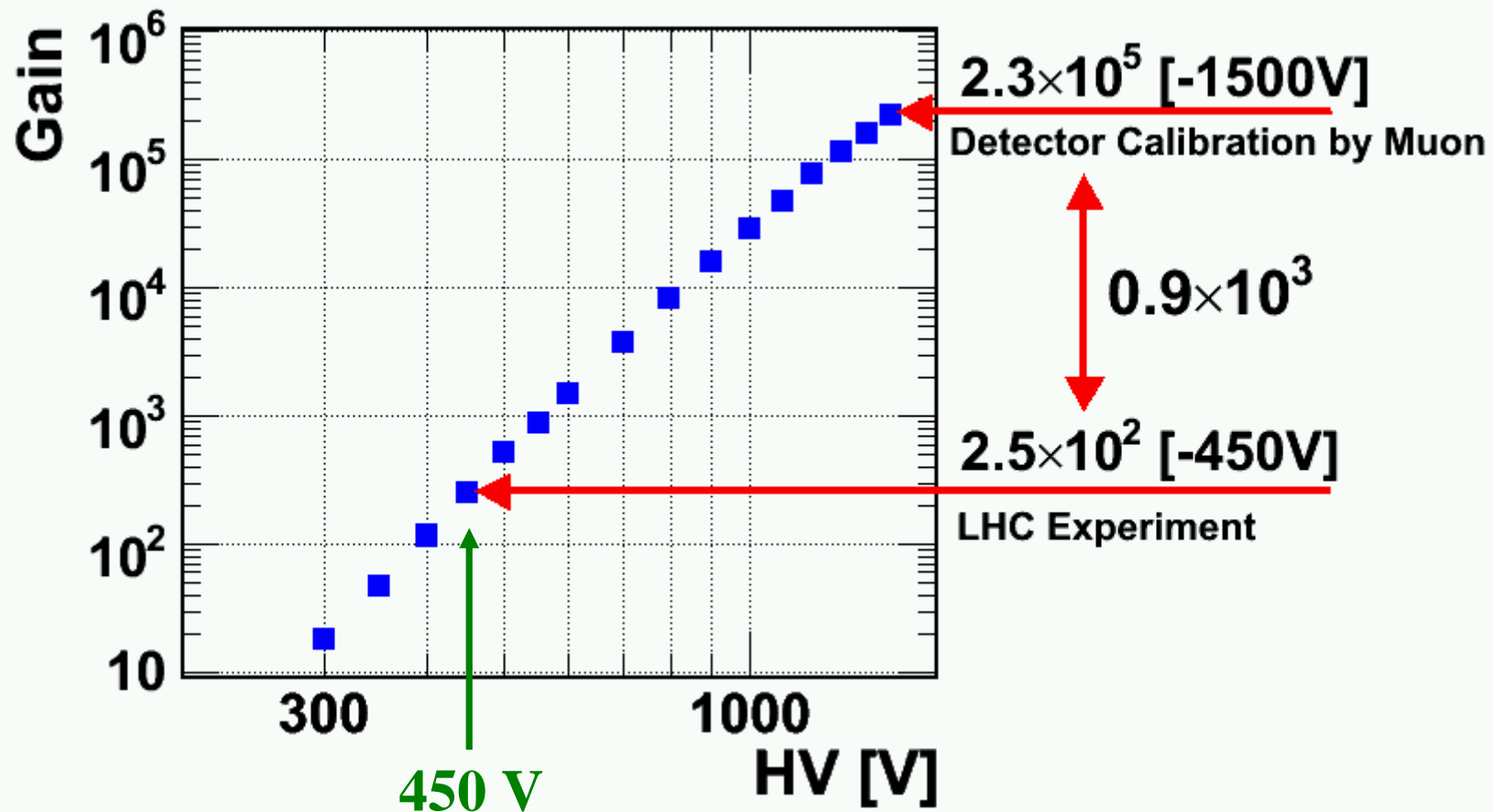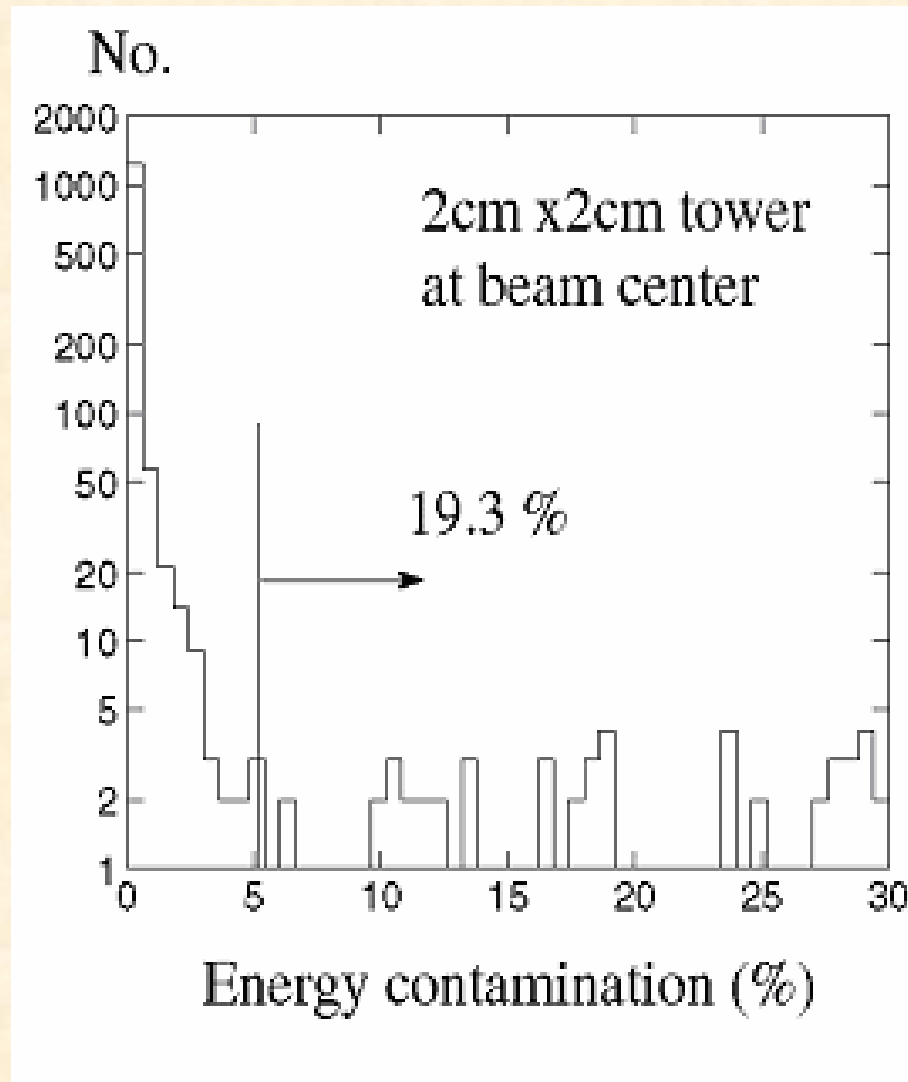GAIN: 5000 HV: -400 V
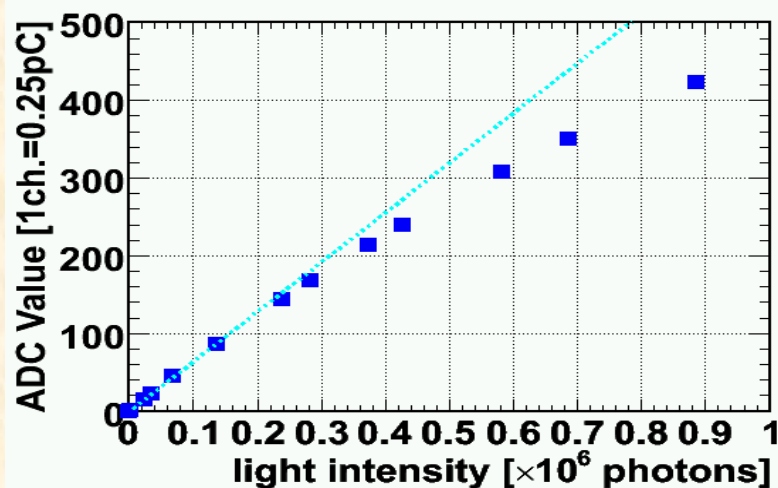
After Modification
GAIN: 260 HV: -450V

HV – GAIN at R7400U Modified

Multiple events/energy contamination

Tower 3 x3 + 2x2 + 4x4

π^0 Invariant mass distribution

# of events

— without error

— with errors

— < 5% Energy contamination removed

$\Delta m/m \sim 4\%$

Invariant Mass M (GeV)
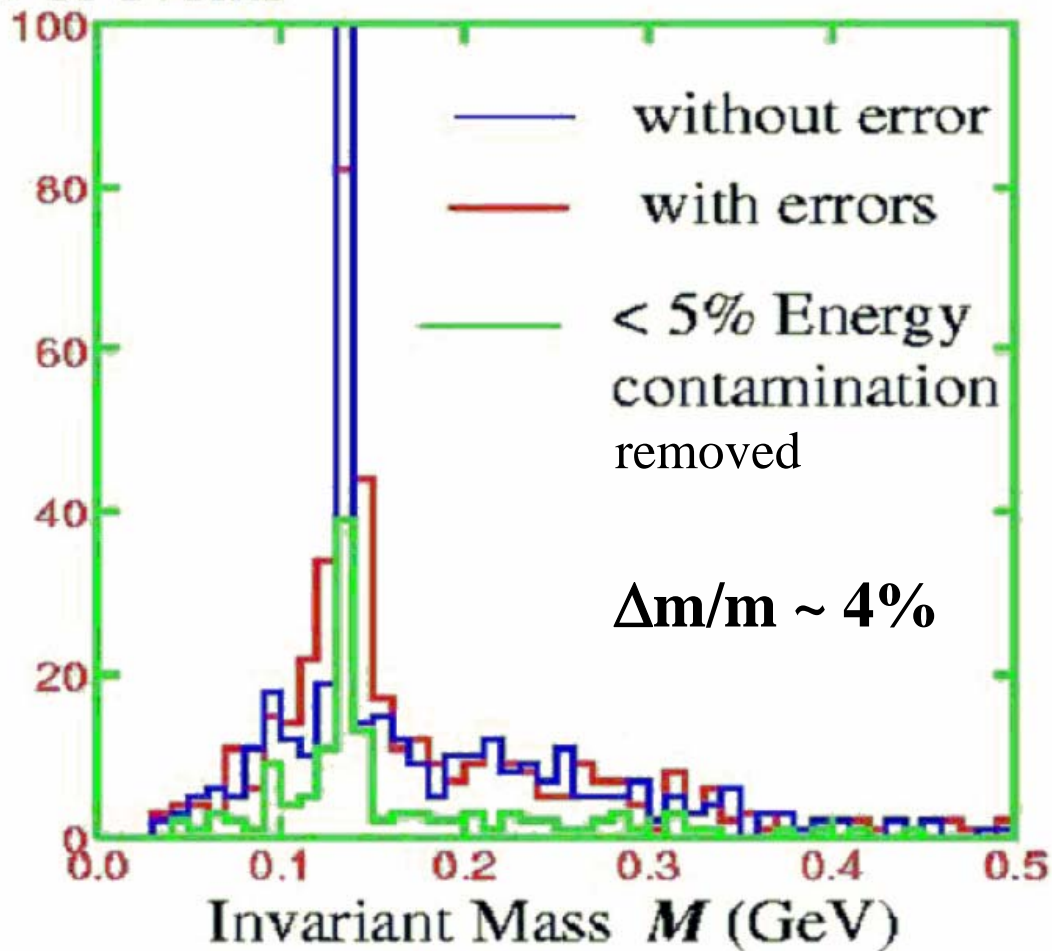
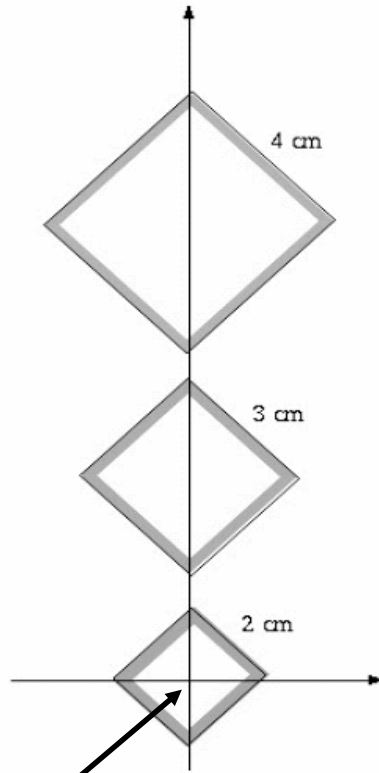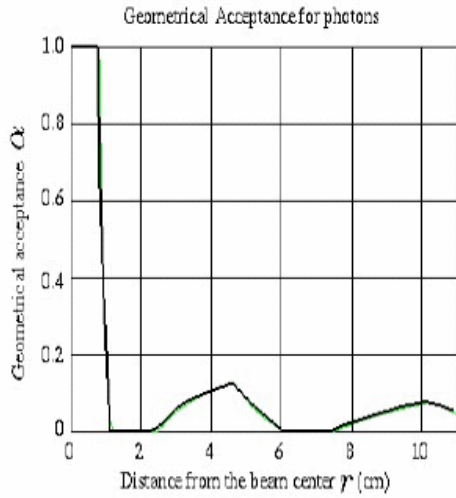10^6 LHC interactions
~ 1 minute exposure

Summary 2

By the actual experiments, we have demonstrated that the experiment proposed in the L.O.I. and Technical Report of the LHCf experiment **CAN** measure the production cross-section of photons with $X_F \geq 0.1$ with an accuracy of $\Delta E/E \sim 4\%$. The mass of neutral pions will be obtained with an accuracy about $\Delta m/m \sim 4\%$.

Hopefully we will be able to get the absolute value of the mass of neutral pions without any systematic adjustment of the energy scale of shower particles.
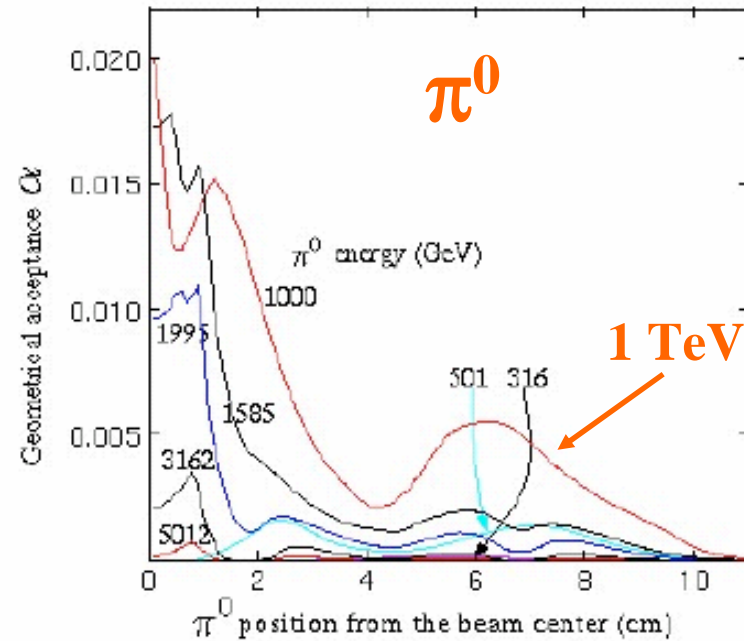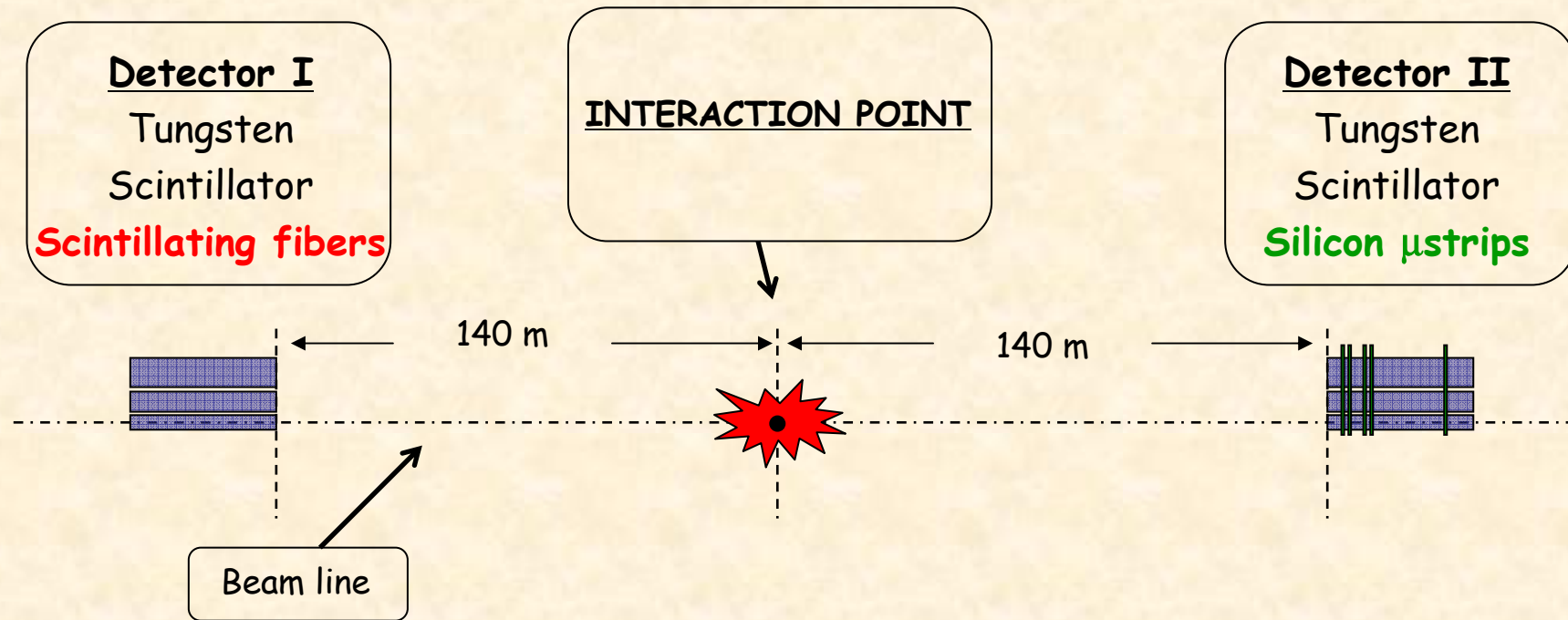
Geometrical acceptance

γ

Geometrical Acceptance for photons

4 cm

3 cm

2 cm

The axis of the beam pipe

2 γ from π⁰: 1%

π⁰

π⁰ energy (GeV)

1000

1995

1585

3162

5012

301 316

1 TeV

2 independent detectors on both sides of IPX

Detector I
Tungsten
Scintillator
Scintillating fibers

INTERACTION POINT

Detector II
Tungsten
Scintillator
Silicon μstrips

← 140 m →   ← 140 m →

Beam line
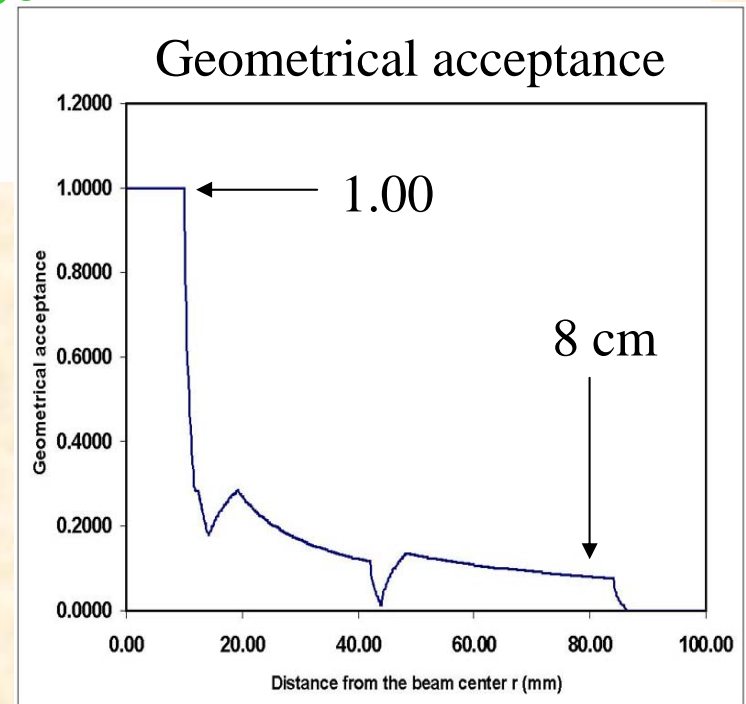
1. Redundancy
2. Background rejection (especially beam-gas)
3. Physics single diffractive/double diffractive

Detector #2

7 cm

7 cm

Silicon

W + Sci

4 cm

3 cm

2 cm

Si   Si Si   Sci+W   Si

Geometrical acceptance

1.00

8 cm
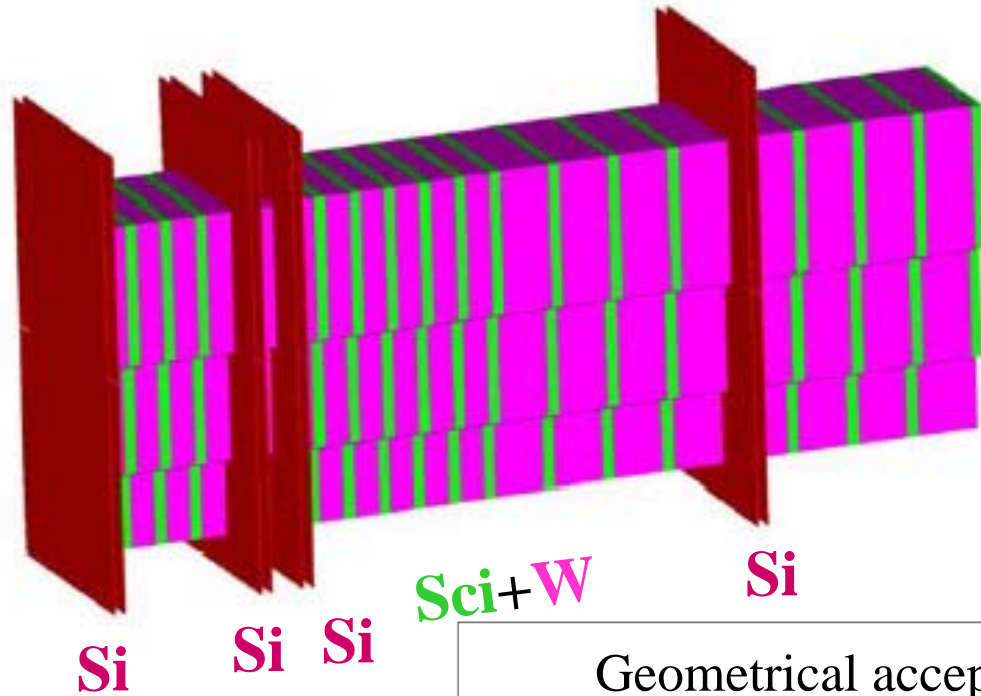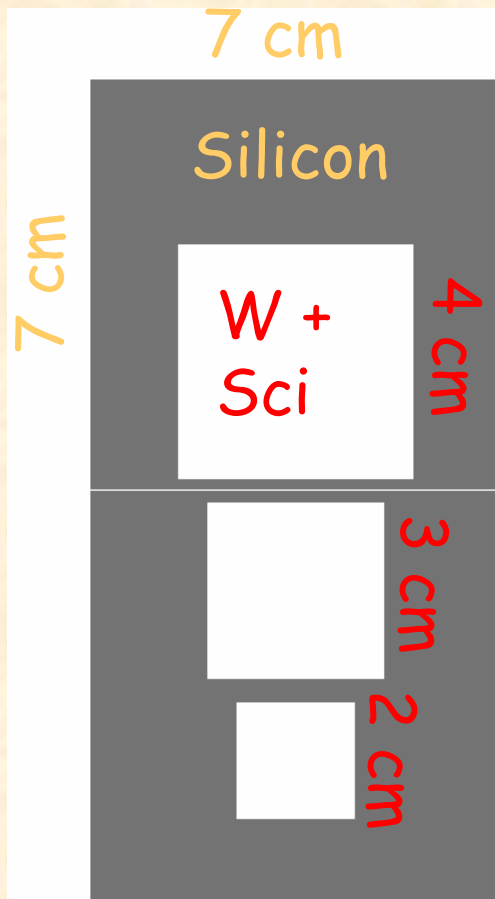
SciFi are replaced by silicon μstrips
70x70 mm²
Pitch 80 μm
3 double layers (x-y)
1 double layer in front of the calorimeter

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project

LHC Project Report 674

RESIDUAL GAS DENSITY ESTIMATIONS
IN THE LHC EXPERIMENTAL INTERACTION REGIONS

A. Rossi and N. Hilleret

Abstract

The residual gas density for proton-proton runs in the LHC interaction regions IR1, IR2, IR5 and IR8 has been estimated using the VAcuum Stability COde (VASCO) [1] for the two scenarios of machine start-up and after electron scrubbing [2]. The results can be used for estimation of background noise to the LHC experiments for those operation phases.
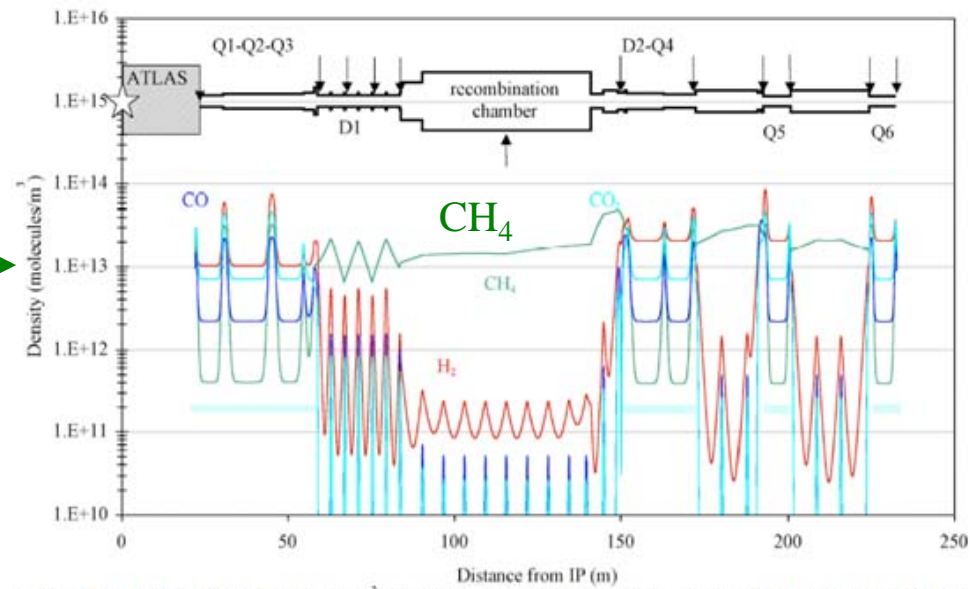
Accelerator Technology Division

Figure 3: Residual gas density (molecules·m⁻³) profile in the interaction region IR1, for the "machine start-up" period, at 1/3 of nominal beam current and top energy. The sections of the beam pipe at CT are underlined with a light blue marker. The interaction point is indicated with a star. The arrows represent the lumped pumps. The data are presented for on side of the experimental region, since the geometry is symmetrical with respect to the interaction point.
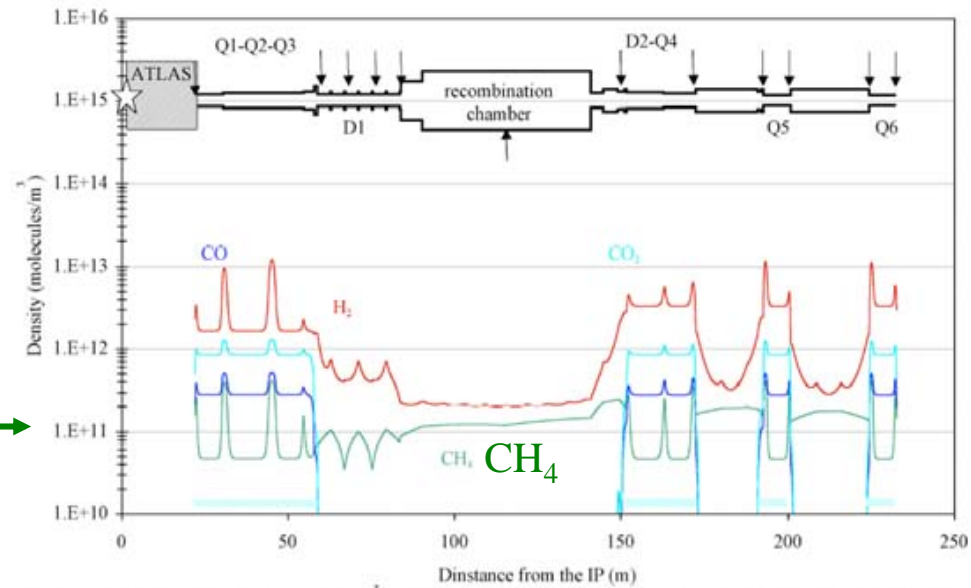

Figure 4: Residual gas density (molecules·m⁻³) profile in the interaction regionIR1, for the "after machine conditioning" period, at nominal beam current and top energy.

Summary 3 (on trigger)

The trigger pulse will be made by

1) arm #1 * arm#2 * machine signal
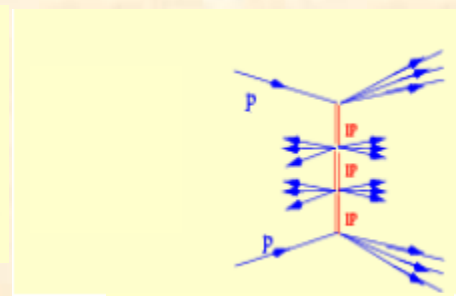
2) (arm#1 * machine signal) OR (arm#2 * machine signal)

_____

3) arm#1* machine signale * ATLAS trigger signal
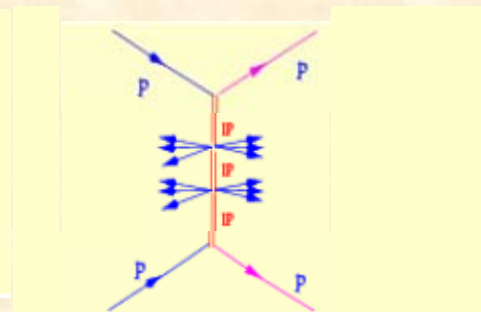   (to be discussed with the ATLAS people)
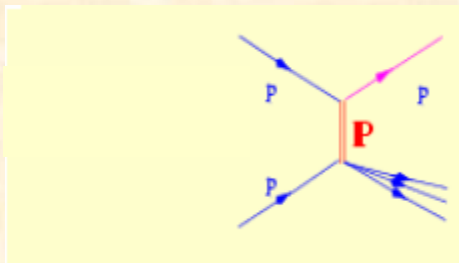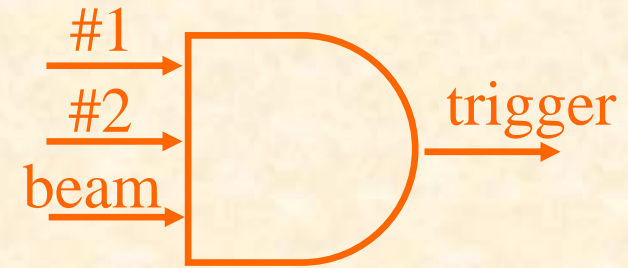
Single diffraction
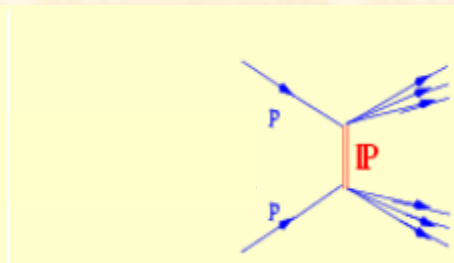
Double diffraction

Diffractive + many
pions production

Many pions production

The beam gas contamination

We estimate beam-beam: beam-gas = 2 : 1   @ L= 10^{29} and early stage
but   at the later stage   = 1: 0.01 @ L= 10^{29} and later stage

At the beginning, taking account of the acceptance for the beam-gas event by the
M.C. calculation, we found that the ratio between
beam-beam : beam-gas = 10 : 1   (contamination is ~10%)

However if we will take arm#1*arm#2 trigger, it will be reduced to 1000:1.

Unfortunately a that time we may loose pure single diffractive event.

Therefore we must repeat the data-taking after machine conditioning.

However the above value is estimated for the high luminosity case and in fact
in the early low luminosity case, the gas in the beam pipe would be not so
much.   We must ask a calculation to the CERN vacuum group.

Concluding Remarks

★**A very important data will be obtained without change of present LHC projects.**

★**The data will become extremely useful not only for cosmic ray physics, but also for**

  high energy physics.

★**The data will be used for a long time.**

• **Other remarks**

∗**We also want to measure N-N or p-N or**

  or N-Fe collisions. (N= N_2 and O_2)

∗**We also get another important data on neutrons and K^0s and the inelasticity.**

Schedule

- We will write the Technical Design Report as soon as possible and come to present it in the early 2006.
- We will start the construction of the detector to make the beam test in the summer of 2006.

- During that time, we will discuss with the vacuum group of the LHC and the operation group of the LHC.
- Our detector will be also useful to know the collision rate between the beam-beam and beam-gas collisions at the beginning.
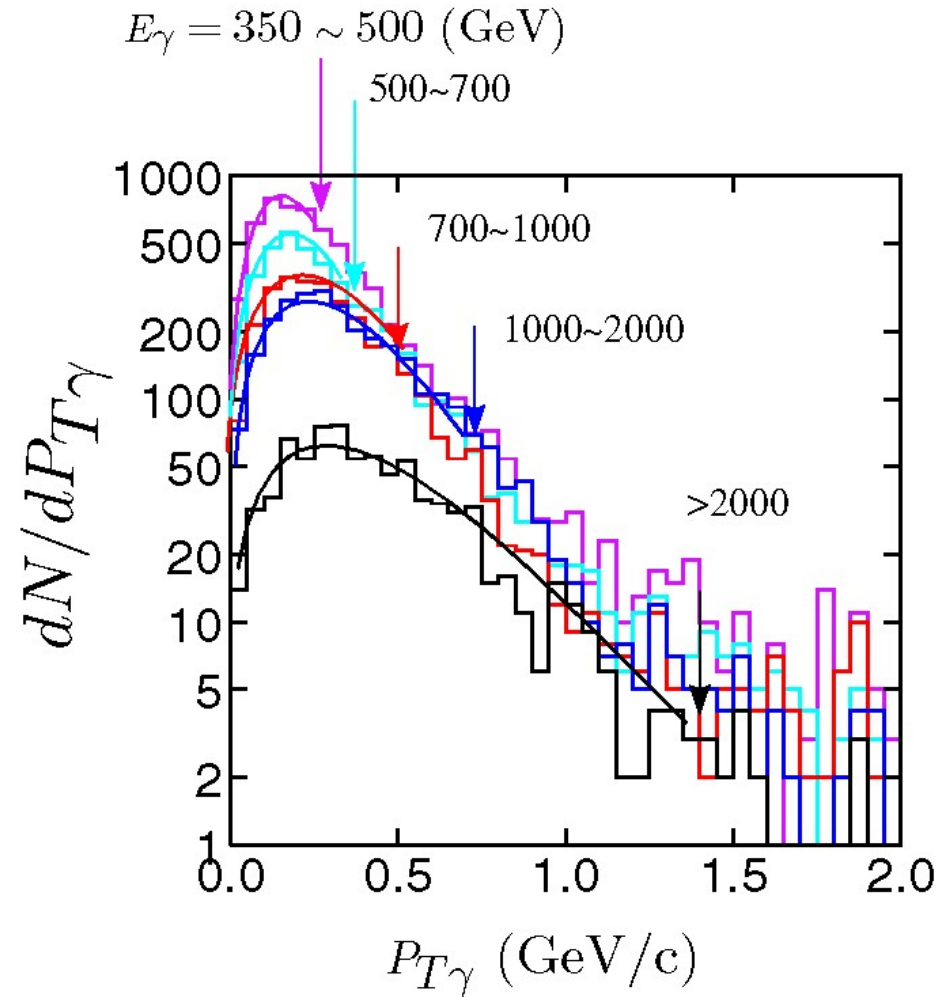
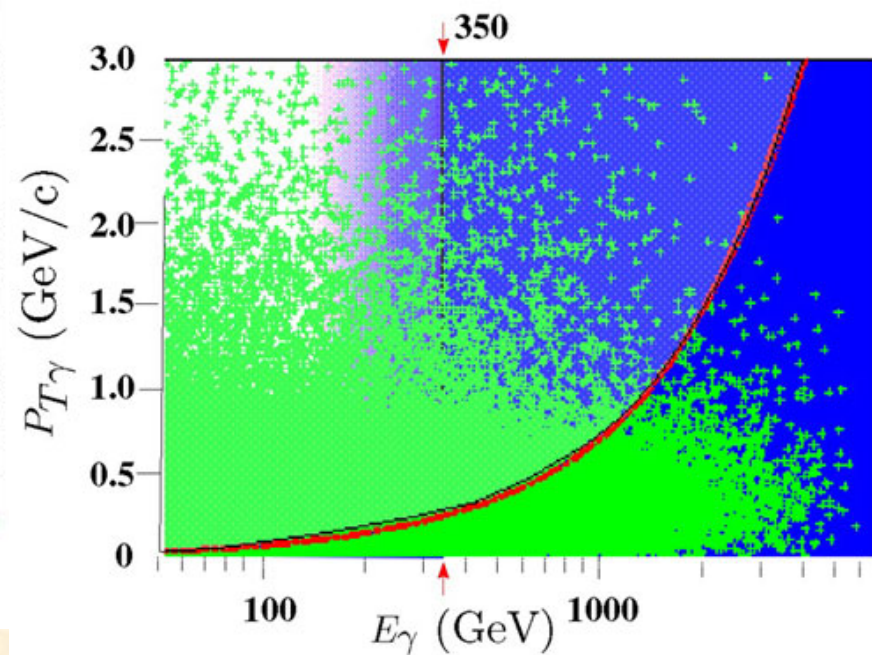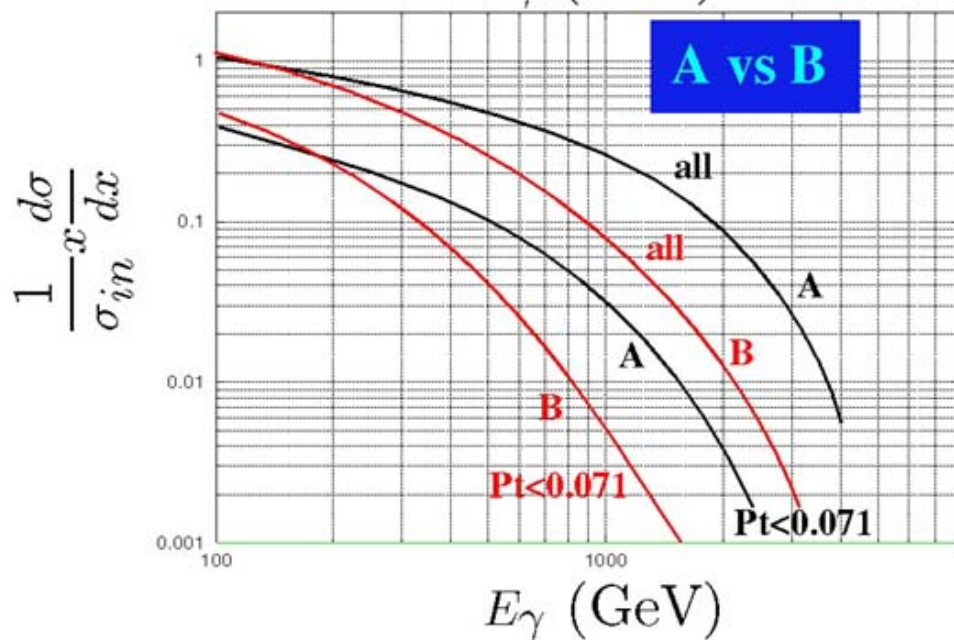# Coverage of $P_{T\gamma}$ and E_γ range
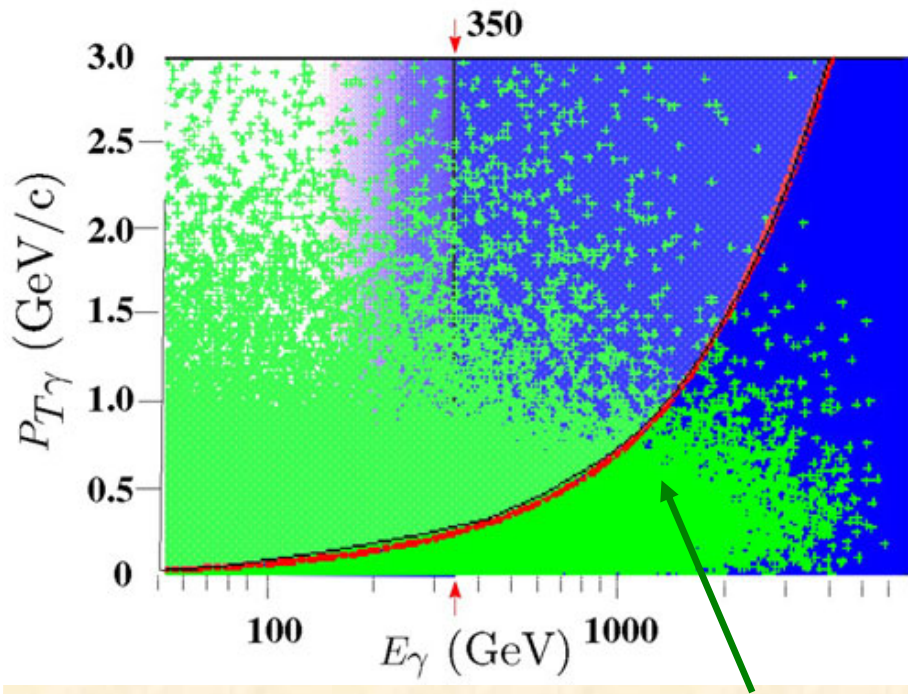
Accessible region

Photons in the $P_{T\gamma}$-E_γ plot
Red line corresponds to the beam pipe

The number of γ detected depends on the geometrical acceptance

Difference in Artifitial Two Models

A

$$\frac{1}{\sigma_{in}}\frac{x}{x}\frac{d\sigma}{dx}$$

all

Pt
<1
<0.5
<0.25
<0.125
<0.071

E_γ (GeV)

B

all

Pt
<1
<0.5
<0.25
<0.125
<0.071

E_γ (GeV)

$$\frac{1}{\sigma_{in}}\frac{x}{x}\frac{d\sigma}{dx}$$

A vs B

all

all

A

A   B

B

Pt<0.071

Pt<0.071

E_γ (GeV)

350

$P_{T\gamma}$ (GeV/c)

3.0
2.5
2.0
1.5
1.0
0.5
0

100   E_γ (GeV)   1000
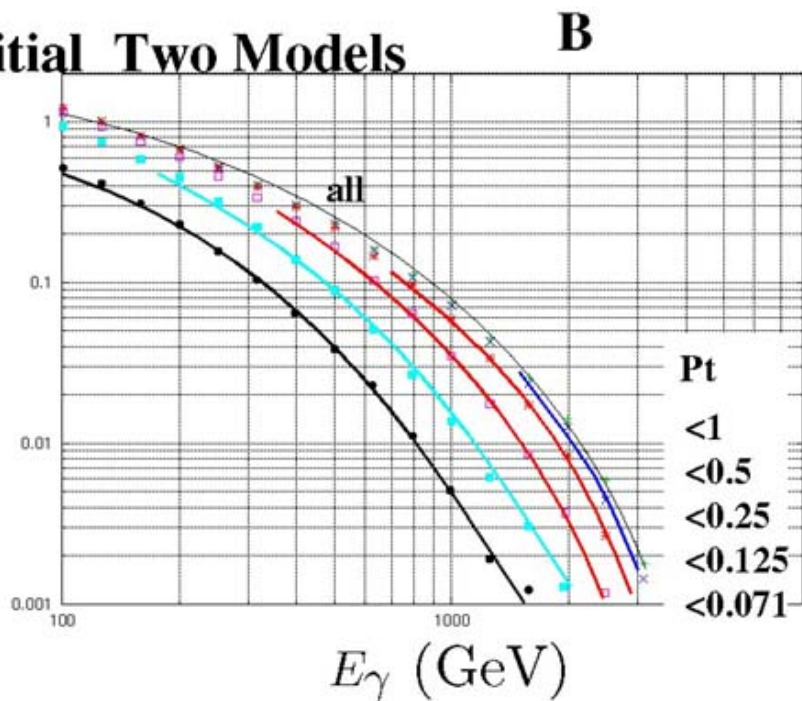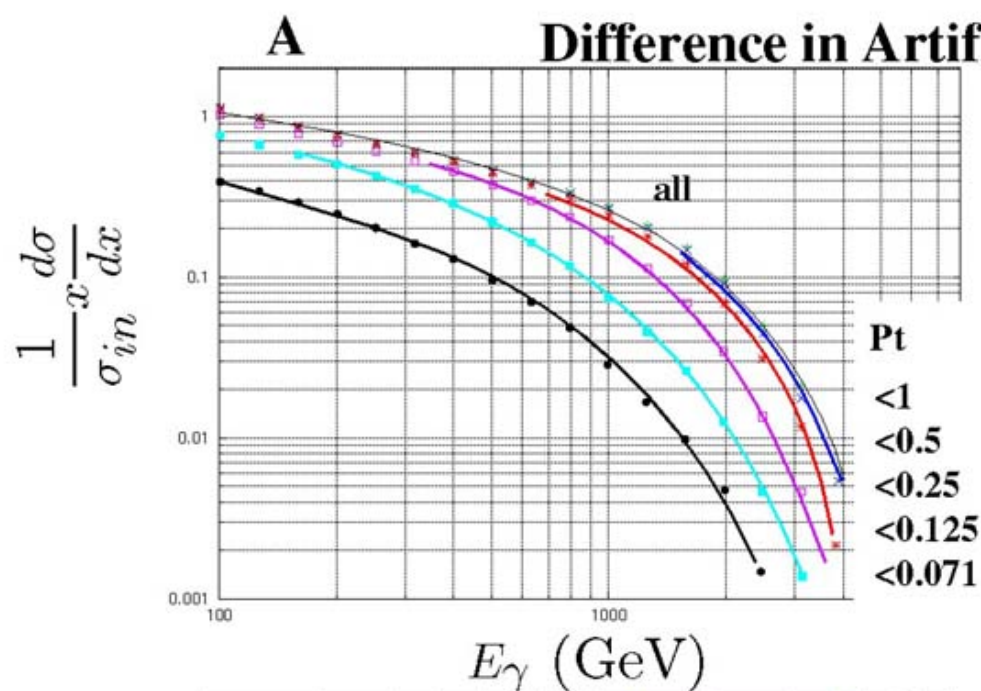
How to calibrate the absolute number of particles like 10^5

1) The maximum current 100pC is determined from the ADC. The maximum countable value of the ADC is 100pC.

2) For the shower particles 10^5, 25 photo-electrons x 10^5 particles x 1.6 x10^{-19} Coulomb x **250**(gain) = 100 pC. So the gain of the photomultipliers must be set at 250. We searched corresponding voltage to the gain 250 from the catalogue and found that it should be around 450V.

3) Then we have searched the Minimum Ionizing Particle (MIP) peak by using β-rays. For the HV -1500 Volts, we have seen the peak. At that voltage, the gain of the photomultiplier is 2.3×10^5. The peak of the 1 MIP corresponds to 25 photo-electrons and 0.9 pc.

4) So in actual experiment, we expose our calorimeter at the muon beam at first, under HV=-1500V. Then reduce it to -450V. Then the muon single peak corresponds to 900 particles @-450V.

5) The minimum resolution of the number of particles is estimated as to be 25 particles. But this value depends on the electric noise and pedestal. Thus we can say by using the modified photomultiplier, the number of particles in a range of ~100 – 100,000 MIPs can be measured, using almost linear range of the gain of the photomultiplier.

Peak of Beta Ray @ -1500V

pedestal   peak of beta ray

**HV-1500V
for R7400U Modified**
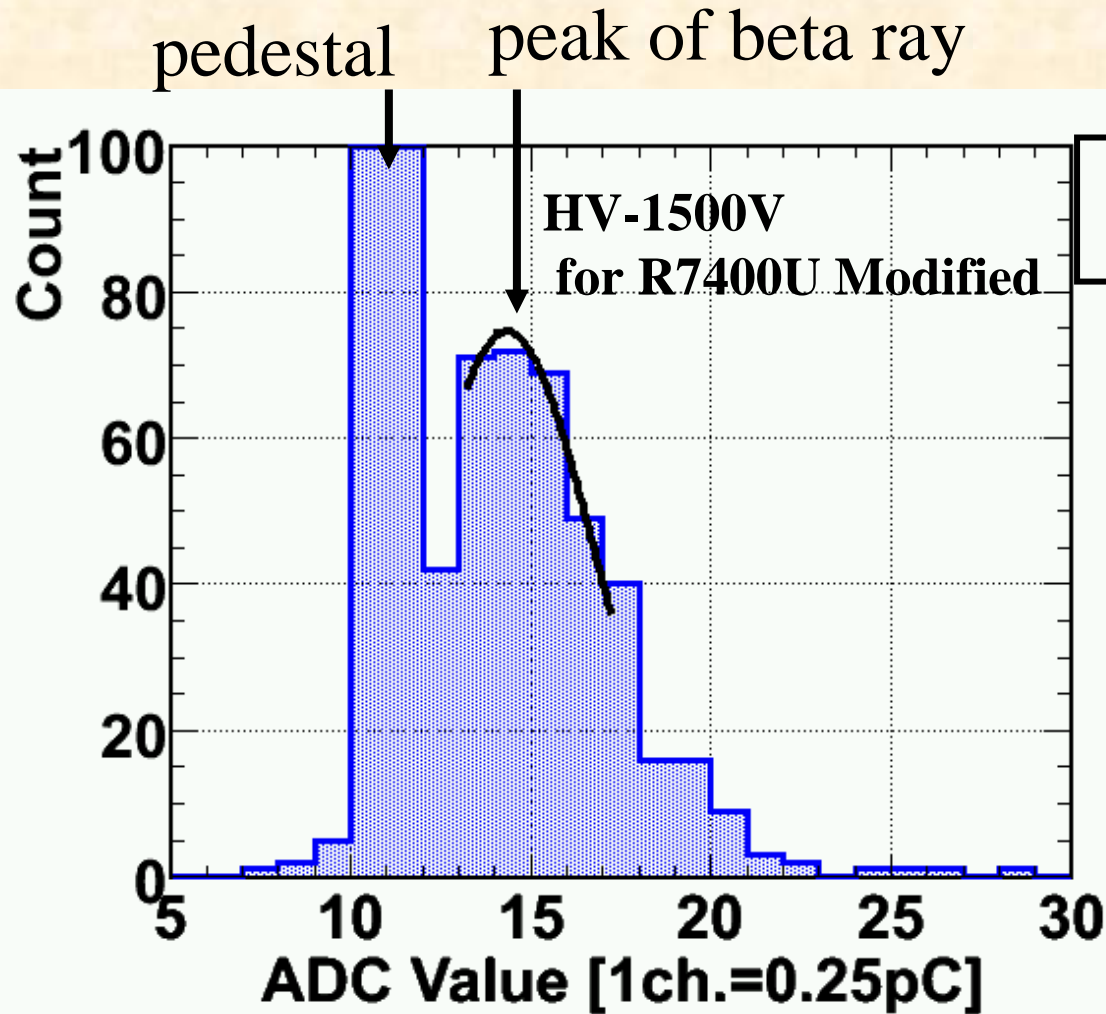
Beta Ray Source

$^{90}Y :: Emax = 2.282 MeV$

peak of beta – pedestal
= 3.7 ADC counts

⬍

MC simulation

$dE_{\text{peak of beta}}$
= 0.52 ~ 0.57 MeV

$dE_{\text{peak of 150GeV/c Muon}}$
= 0.45 MeV

Count (y-axis), *ADC Value [1ch.=0.25pC]* (x-axis)

Neutron Energy Spectrum of 20mm Calorimeter at beam center

DPMJET3
QGSJET
QGSJETII
SIBYLL

30% Energy Resolution
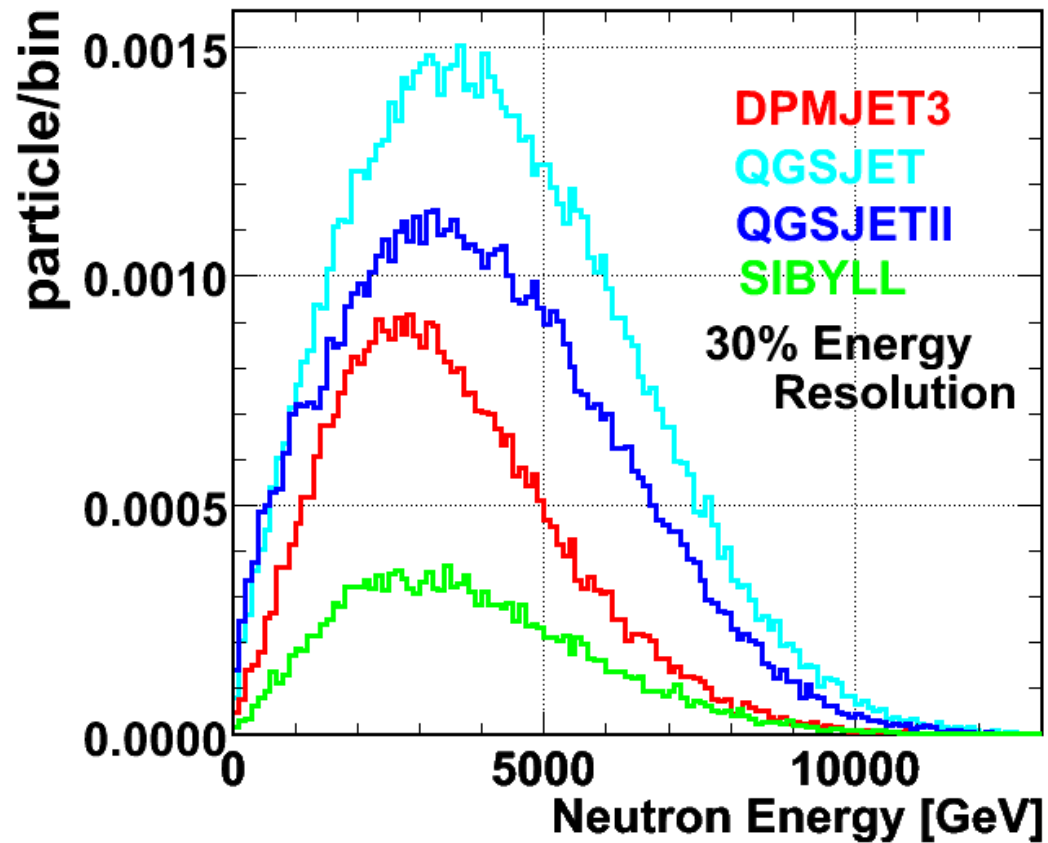
Neutron spectrum by different model

Neutron energy resolution

Energy resolution: 6TeV neutron 2cm x 2cm 47 r.l tower

4.1% events
S1>20 ptcls
d > 2 mm

$\sigma = 30\ \%$
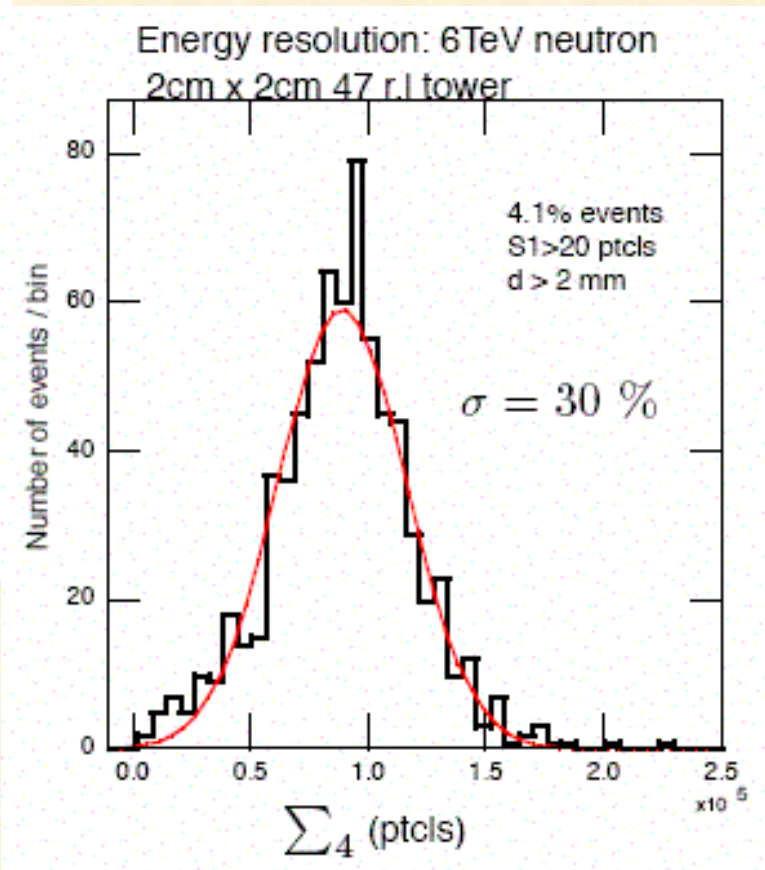
Beam pipe effect

+ particles from the collision point
■ particles from the beam pipe

3000 interactions: all particles

neutrons