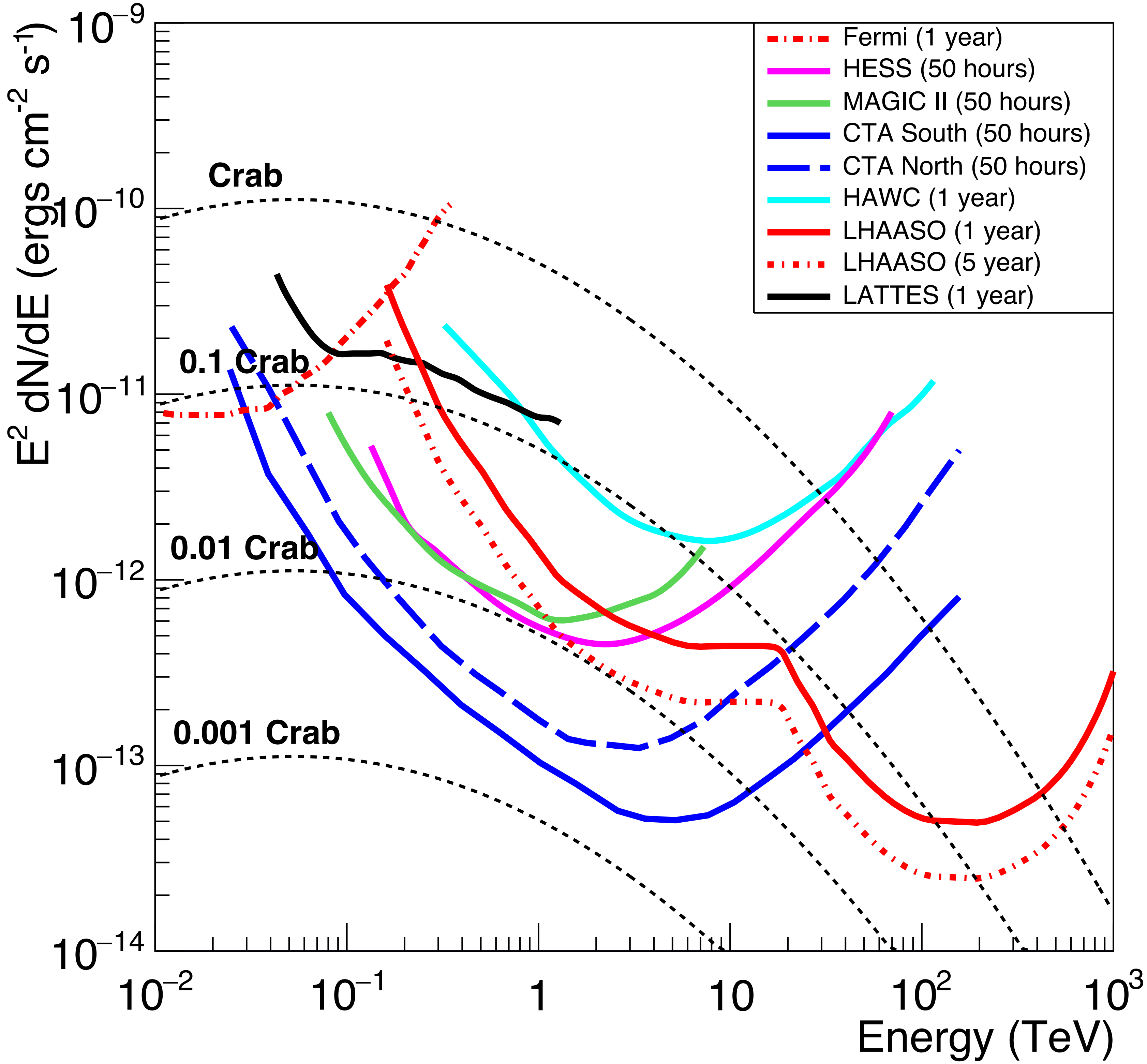
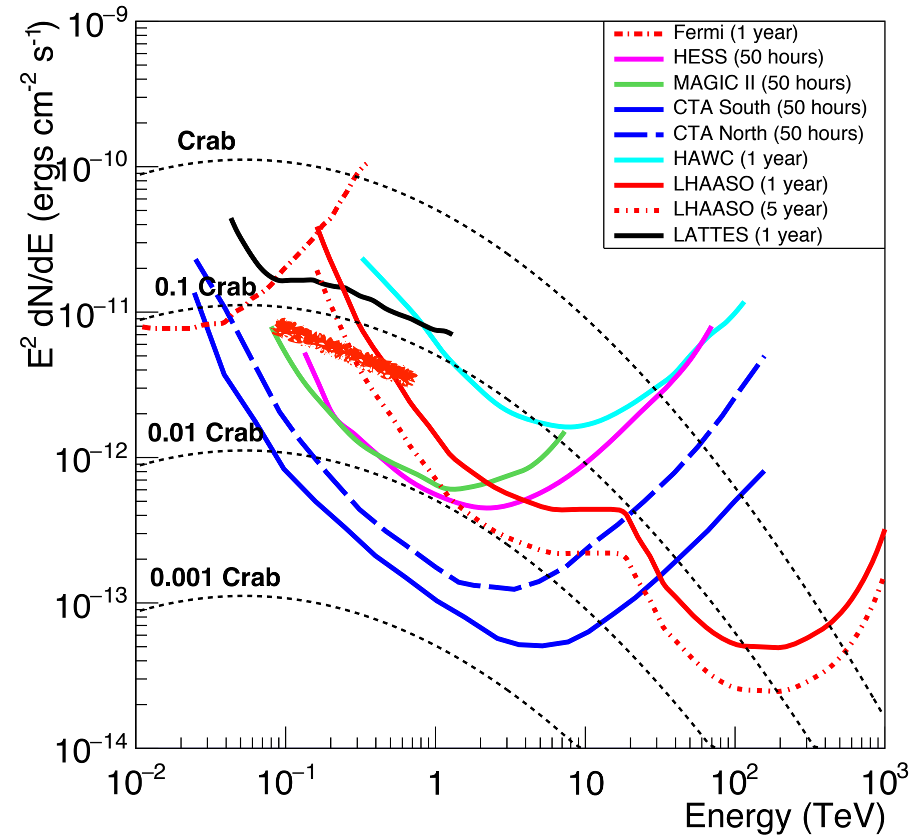
Point sources sensitivity



CTA and a new Wide FoV observatory

A future Wide FoV Observatory to be useful to CTA needs:

- <10% Crab sensitivity below TeV
- *Low energy threshold* (≈ 100 GeV)
- Ability to detect extragalactic transient (AGN, GRBs)
- *Southern hemisphere site*



★ Is this possible ?

Φ_B = background flux

ψ_{70} = opening angle

$A_{eff}^{\gamma,p}(E)$ = effective area

Minimum Detectable Gamma-Ray Flux (1 year):

$$\Phi_\gamma^{MDF} \propto \sqrt{\Phi_B} \cdot \frac{1}{R \cdot \sqrt{A_{eff}^\gamma}} \cdot \psi_{70} \cdot \frac{1}{Q_f}$$

$$R = \sqrt{\frac{A_{eff}^\gamma(E)}{A_{eff}^B(E)}}$$

$$Q_f = \frac{\text{fraction of surviving photons}}{\sqrt{\text{fraction of surviving hadrons}}}$$

The key parameters

$$S \propto \frac{\Phi_\gamma}{\sqrt{\Phi_{bkg}}} \cdot R \cdot \sqrt{A^\gamma_{eff}} \cdot \frac{1}{\sigma_\theta} \cdot Q$$

$$\Phi_\gamma \sim E_{thr}^{-\gamma}$$

$$\Phi_{bkg} \sim E_{thr}^{-\gamma_{bkg}}$$

Because for the integral fluxes we can write

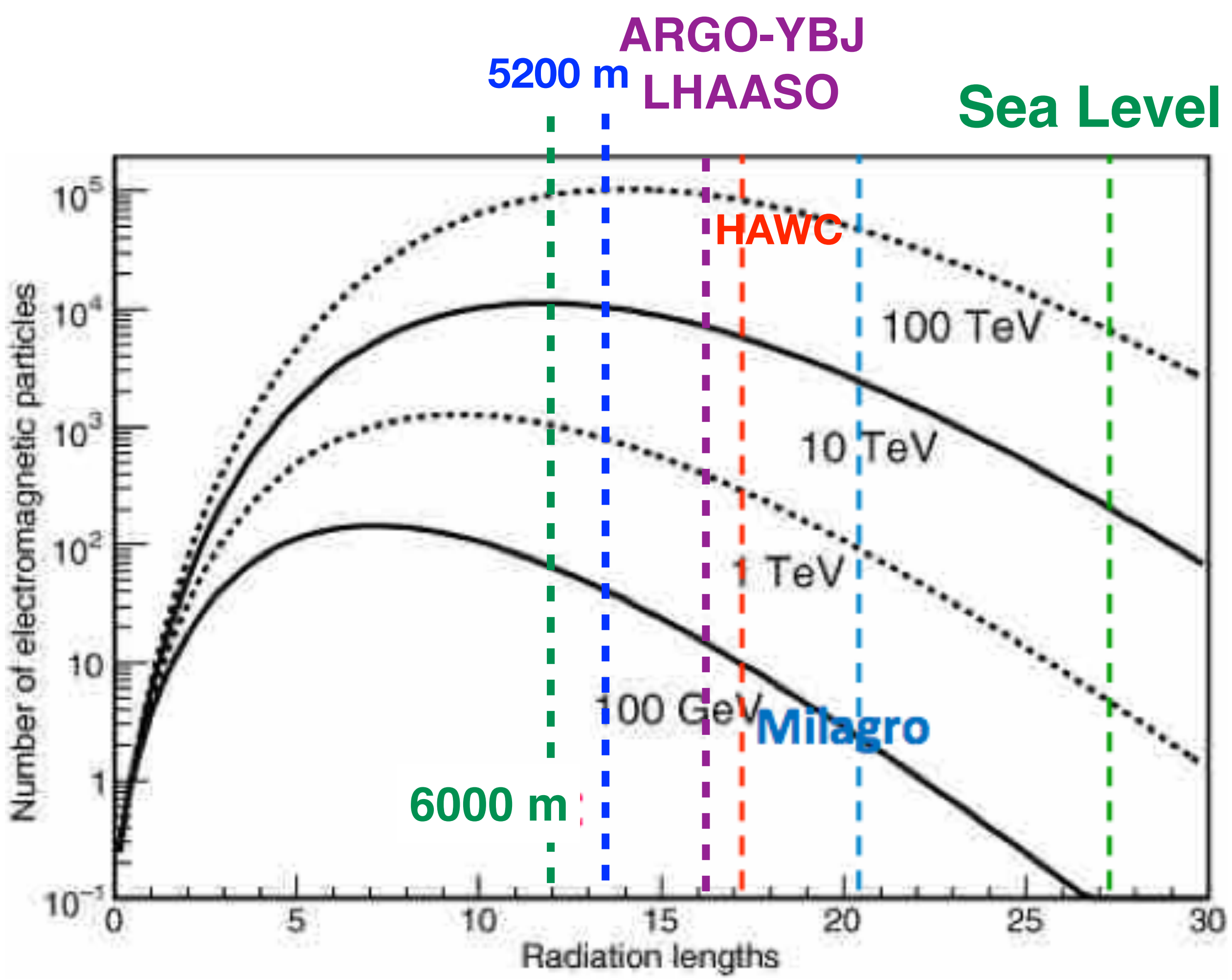
we obtain
$$\frac{\Phi_\gamma}{\sqrt{\Phi_{bkg}}} \sim E_{thr}^{-(\gamma-\gamma_{bkg}/2)} \sim E_{thr}^{-2/3}$$

being $\gamma \sim 1.5$ and $\gamma_{bkg} \sim 1.7$.

The *key parameters* to improve the sensitivity are

- The energy threshold
- R, the signal/background relative trigger efficiency
- The angular resolution
- Q-factor, the background rejection capability

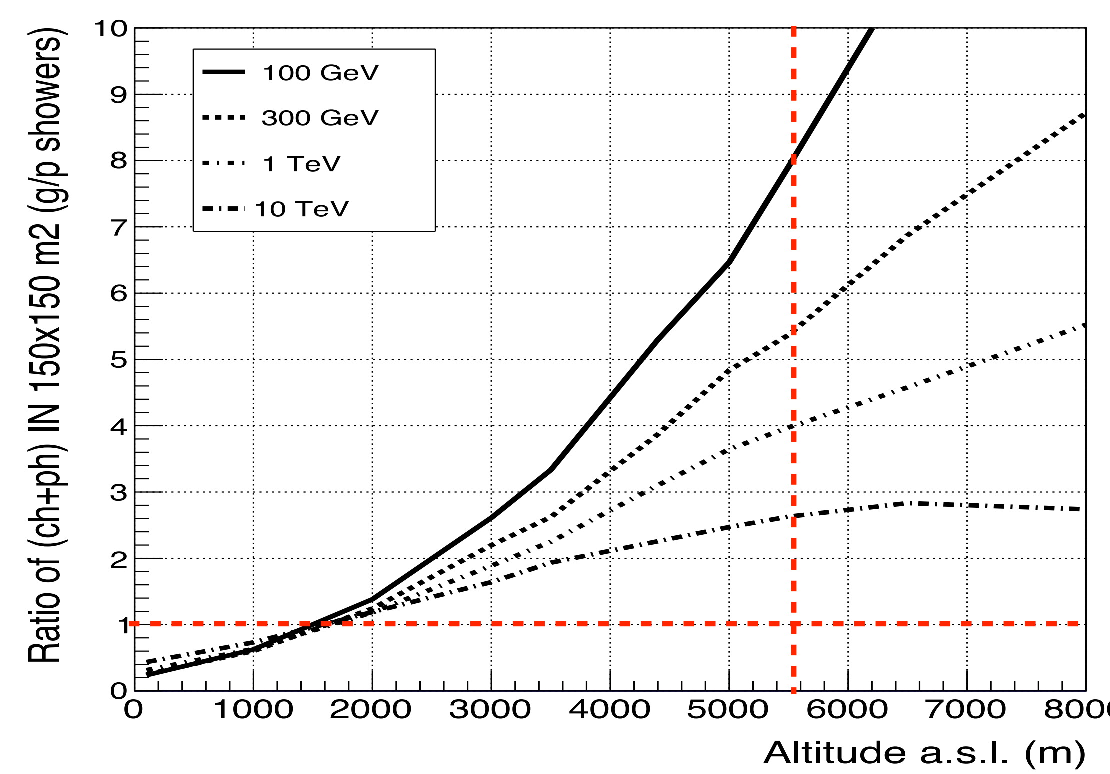
Lowering the energy threshold: extreme altitude



Lowering the energy threshold:

- *Extreme altitude (≈5000 m asl)*
- *Detector and layout*
- *Coverage and granularity of the read-out*
- *Trigger logic*
- *Detection of secondary photons*

Trigger probability of a detector larger for γ-showers than for p-showers at extreme altitude.



ARGO-YBJ energy distributions

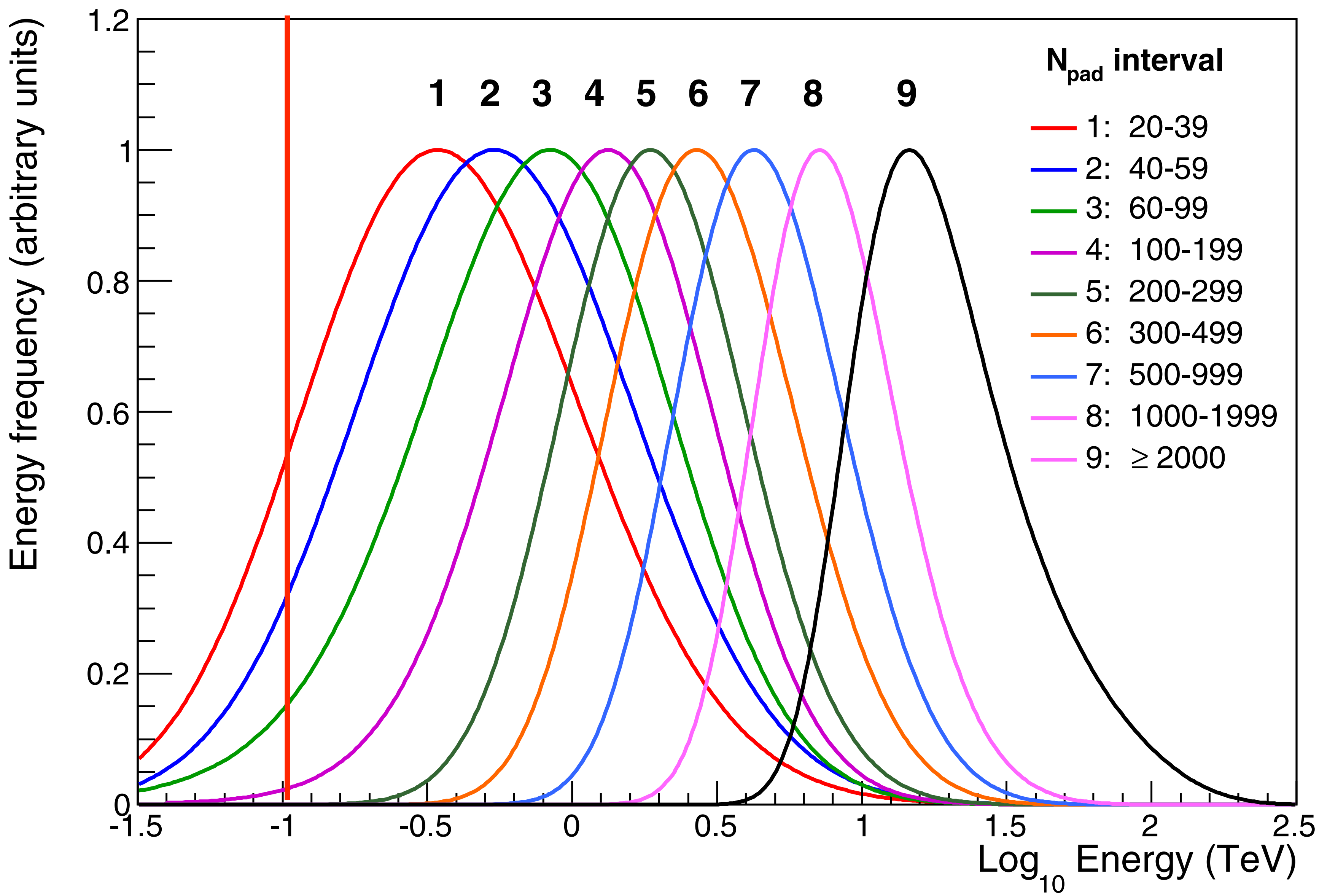


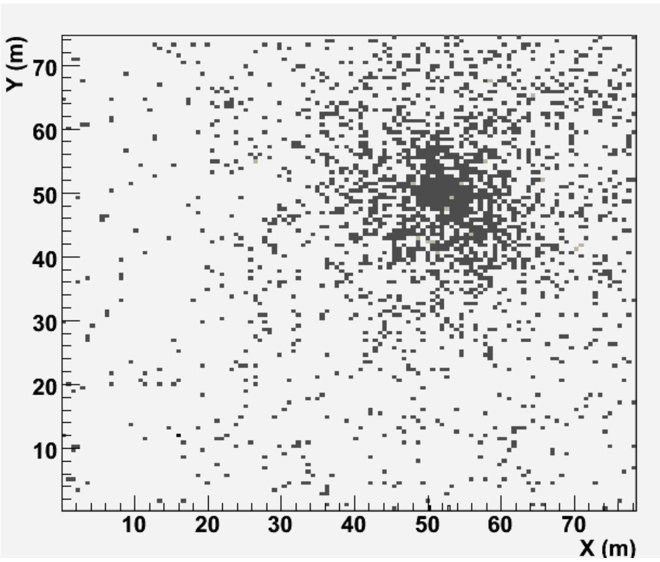
Figure 3. Normalized distribution of the primary gamma-ray energy for different $N_{\rm pad}$ intervals, for a Crab-like source.

Median energy first bin = 360 GeV

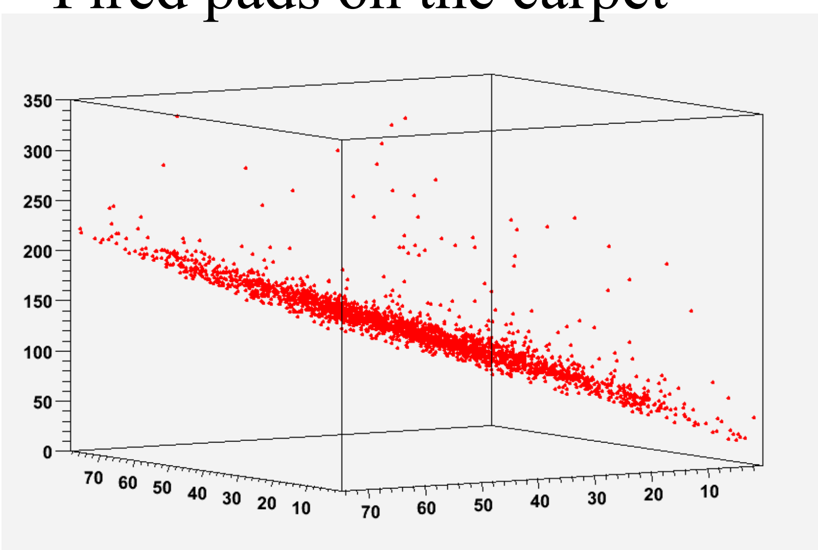
Topology-based Trigger logic:
>20 pads out of 15,000 bkg free !

Shower detection

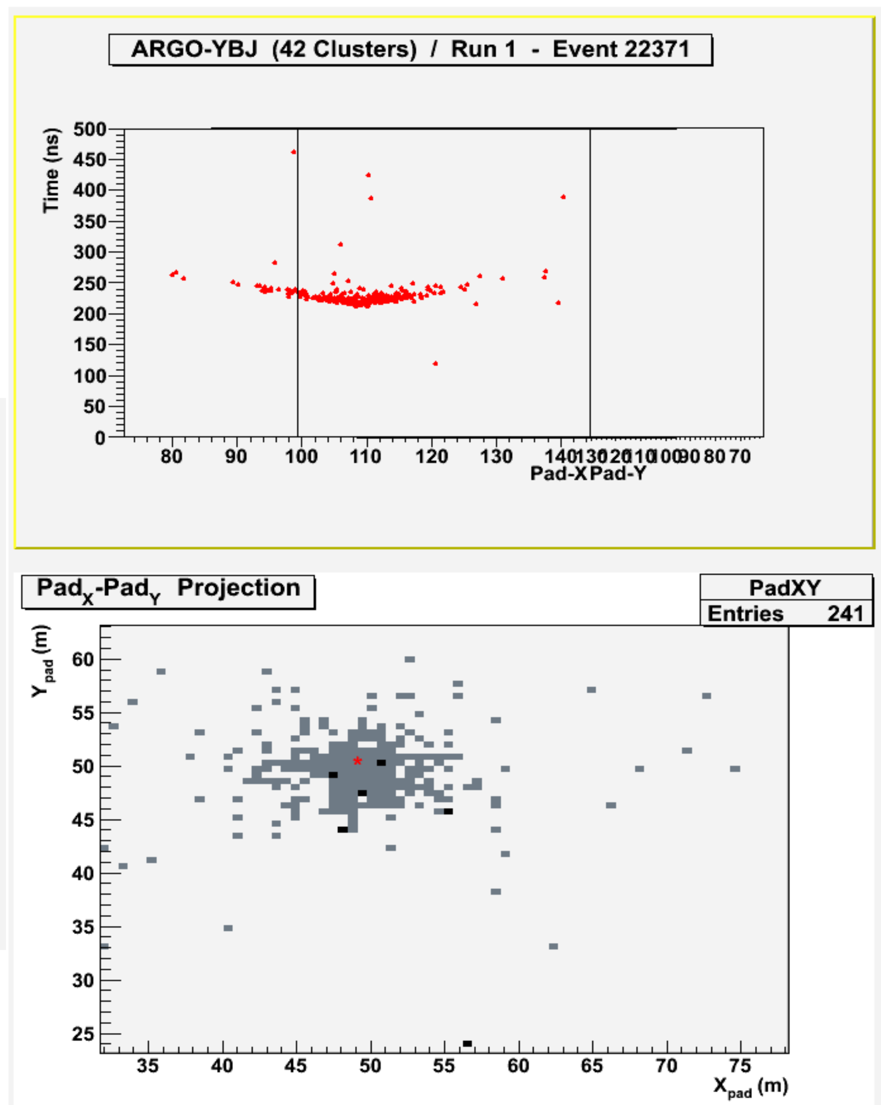
Small and compact events

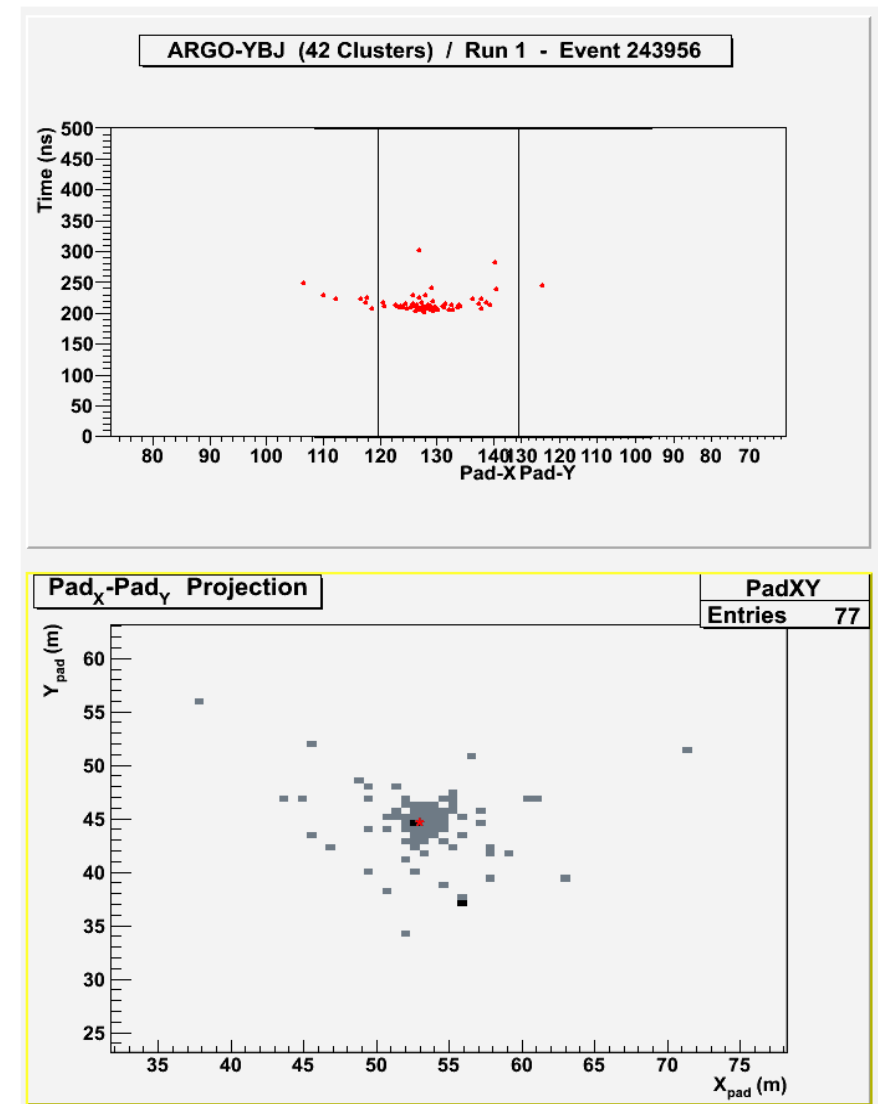


Fired pads on the carpet



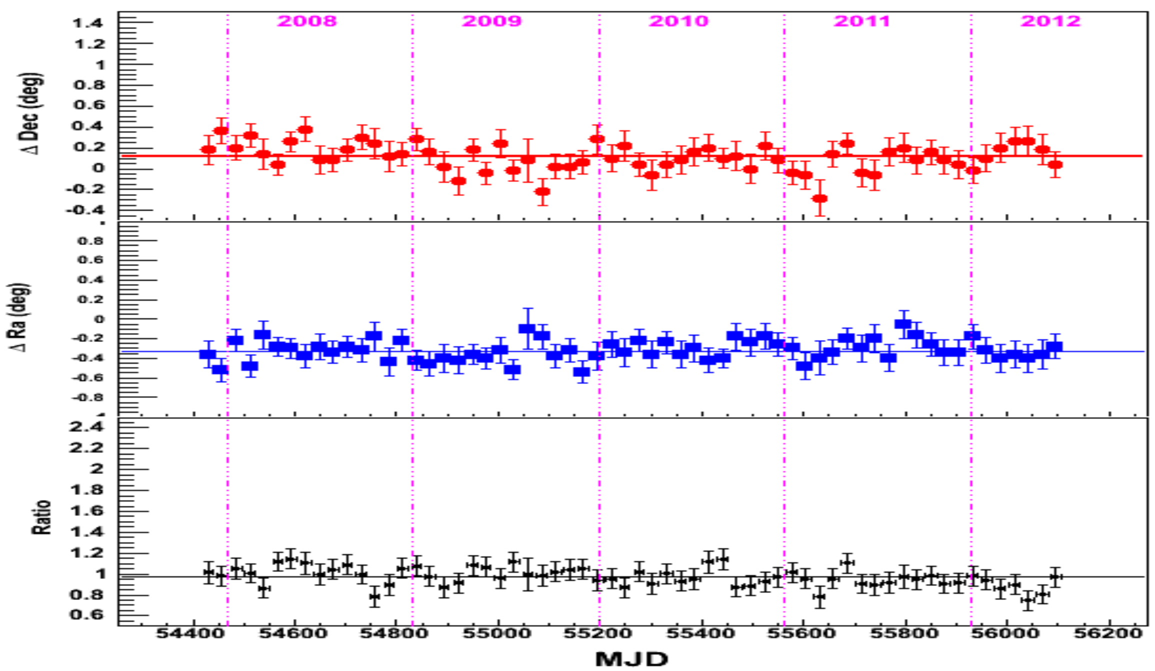
Arrival time vs position



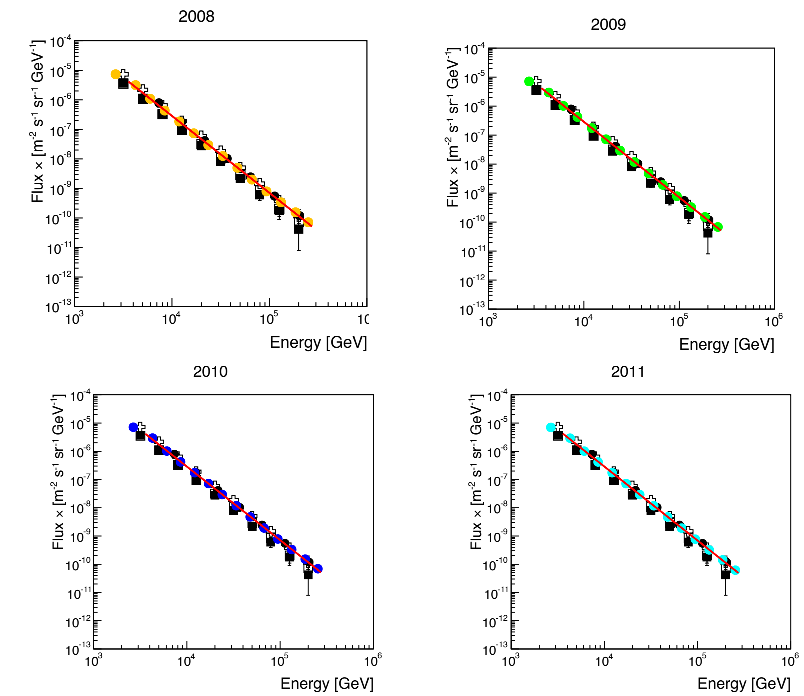


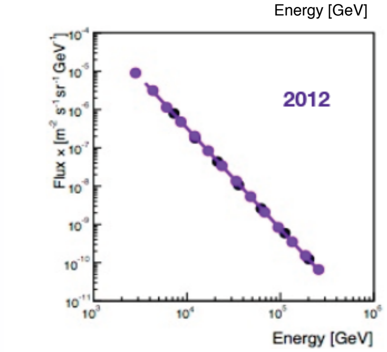
Detector stability at different energies

Stability of angular resolution and pointing accuracy (TeV)



Stability of CR flux measurement
p+He spectrum (3 - 300 TeV)

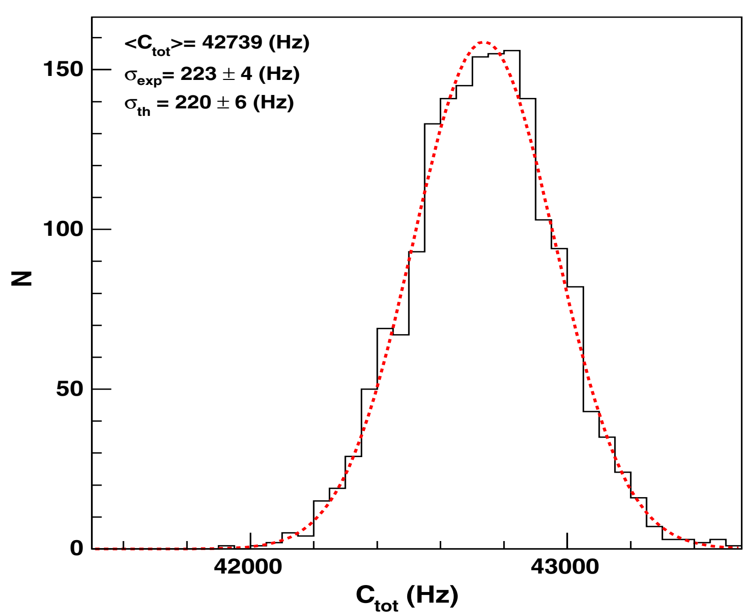


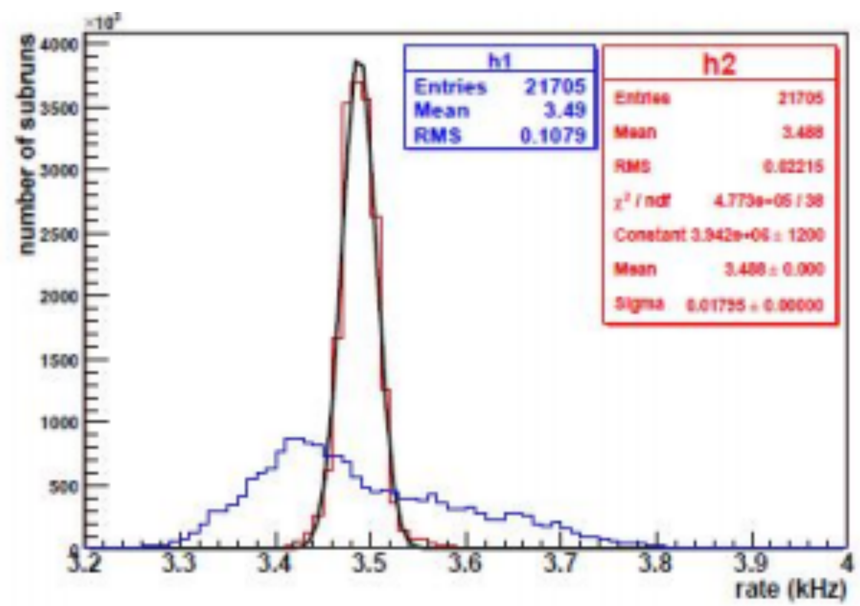


year	Gamma
2008	2.61±0.02
2009	2.61±0.02
2010	2.61±0.02
2011	2.62±0.02
2012	2.63±0.02

flux difference at 5% level

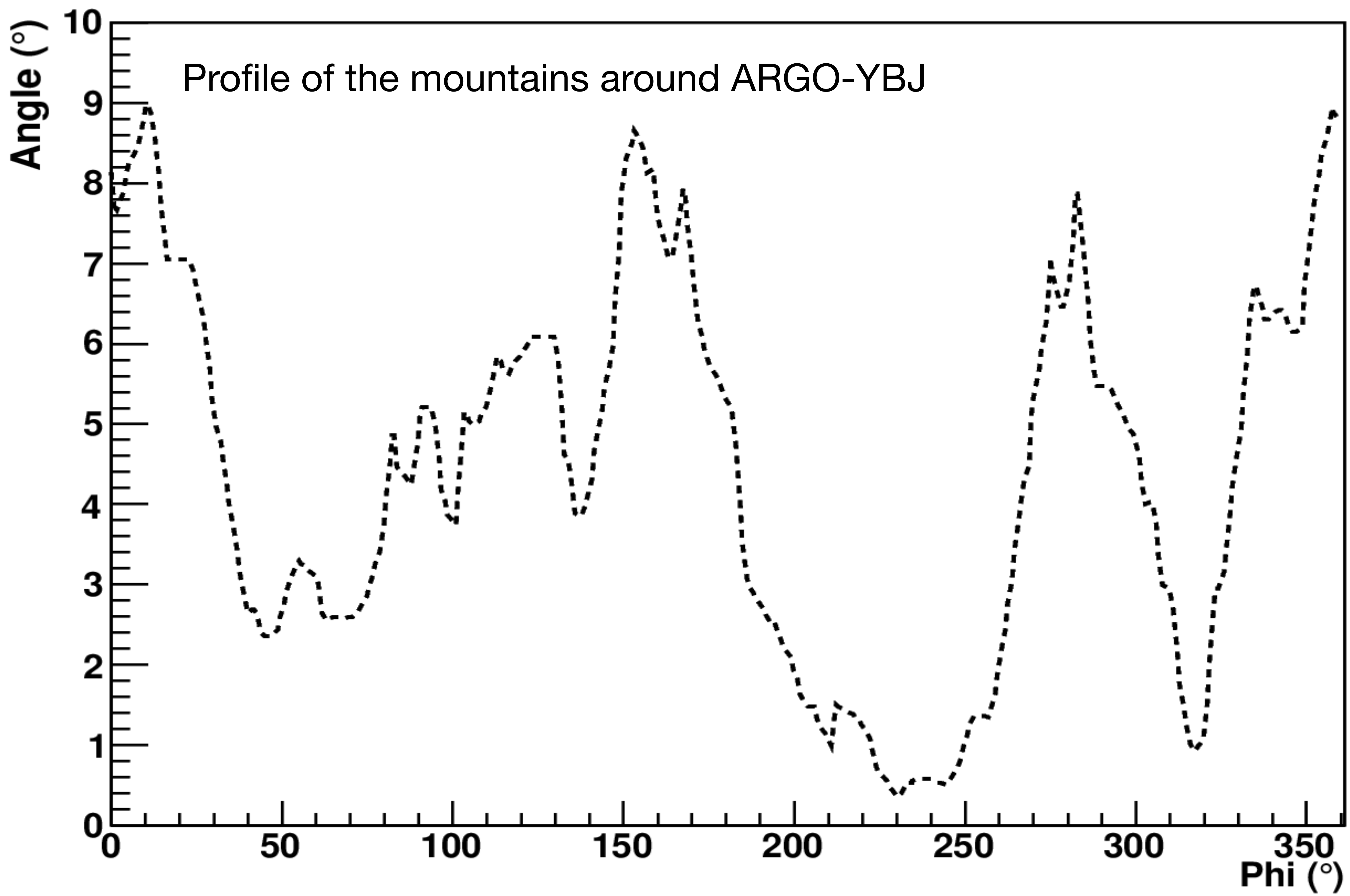
Distribution of particles
hitting a cluster (GeV)



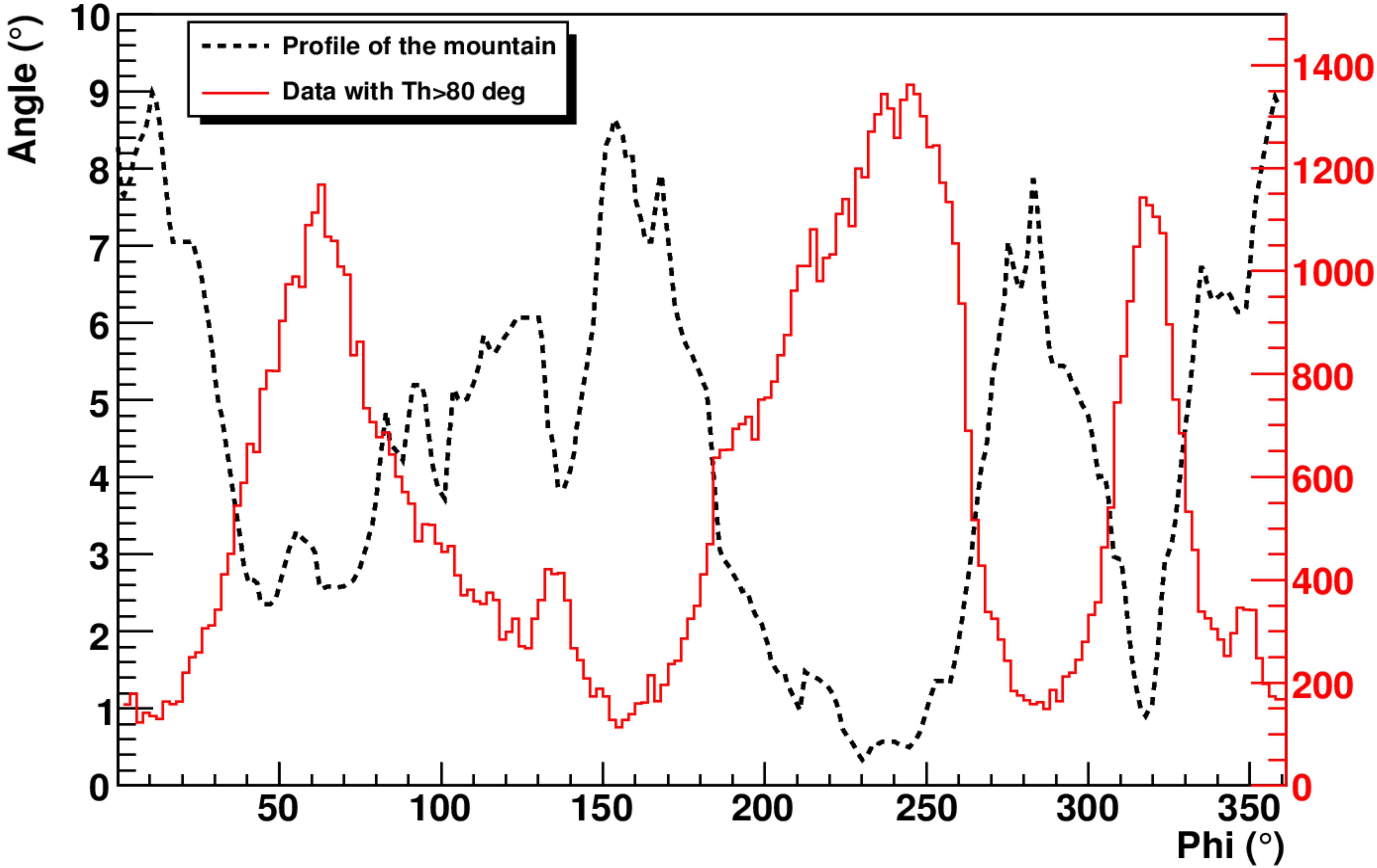


Intrinsic Trigger Rate stability 0.5%
(after corrections for T/p effects)

Azimuthal distribution EAS > 80 deg



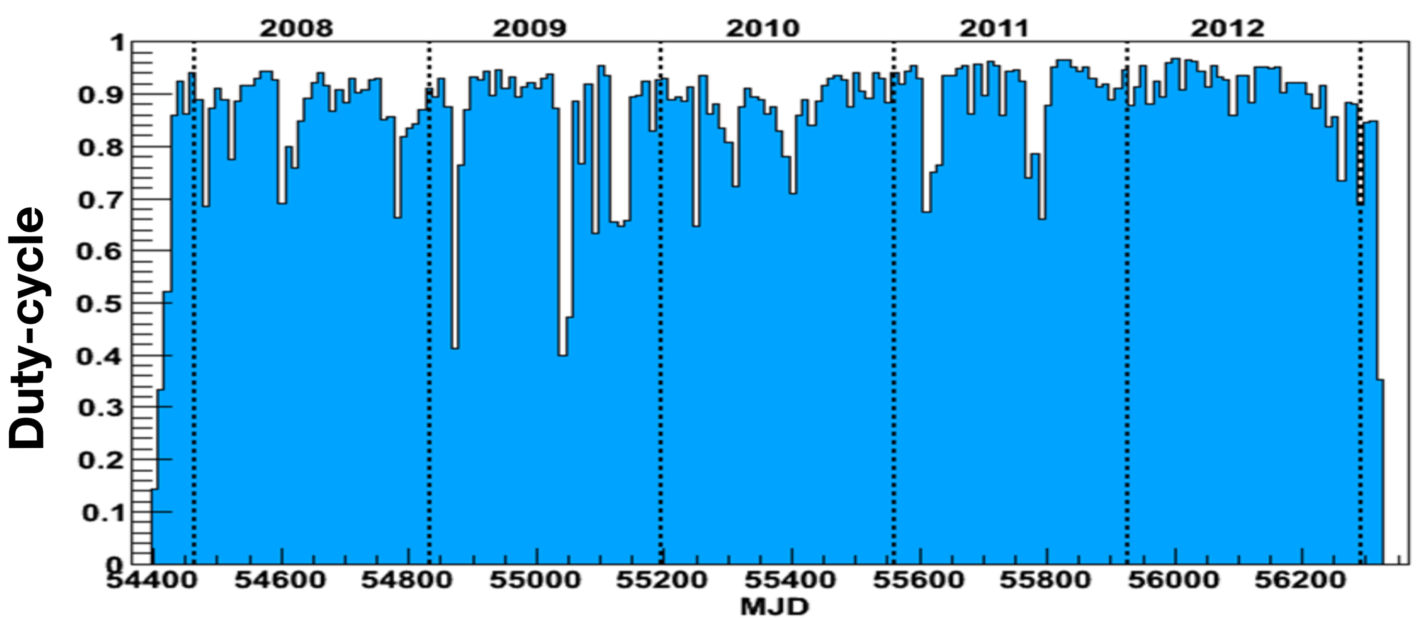
Azimuthal distribution EAS > 80 deg

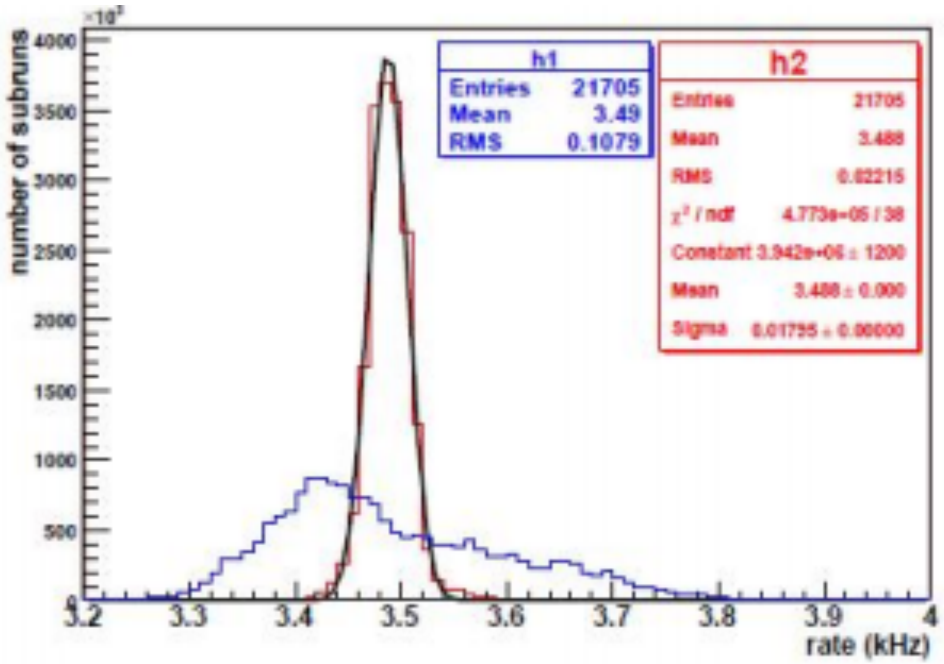


ARGO-YBJ milestones

- In data taking since July 2004 (with increasing portions of the detector)
- Commissioning of the central carpet in June 2006
- Stable data taking full apparatus since November 2007
- End/Stop data taking: February 2013

- Average duty cycle ~87%
- Trigger rate ~3.5 kHz @ 20 pad threshold
- N. recorded events: ≈ $5 \cdot 10^{11}$ from 100 GeV to 10 PeV
- 100 TB/year data

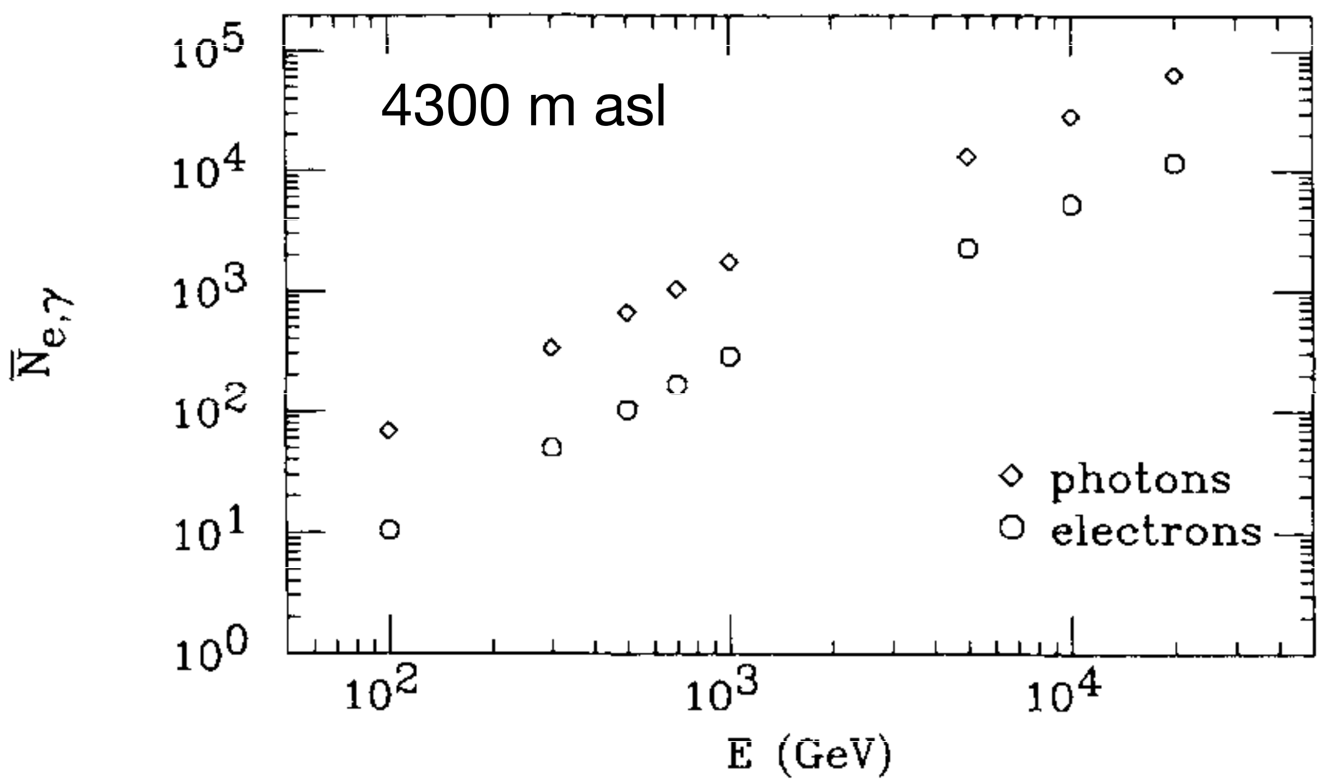


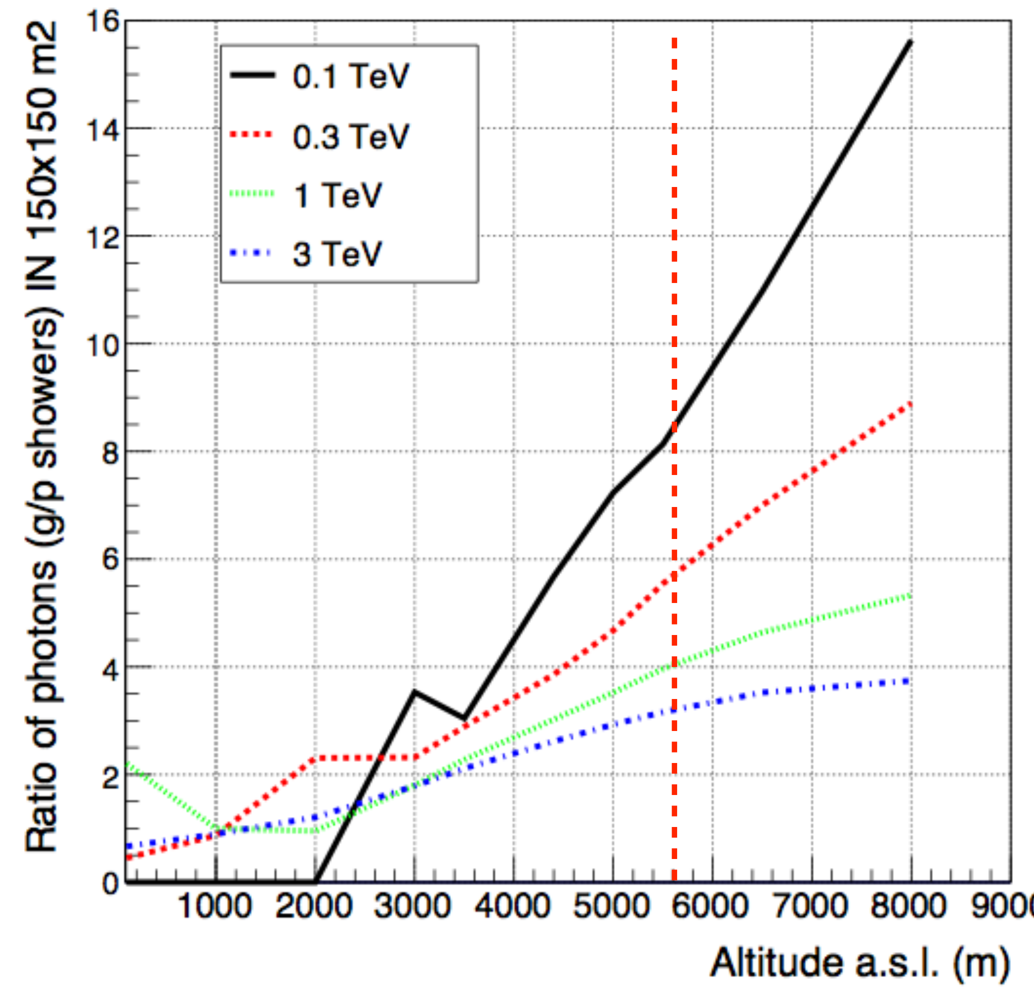


Intrinsic Trigger Rate stability 0.5%
(after corrections for T/p effects)

Secondary photons

gamma rays dominate the particles on ground (≈7:1 for 100 GeV γ-showers at 4300 m asl)





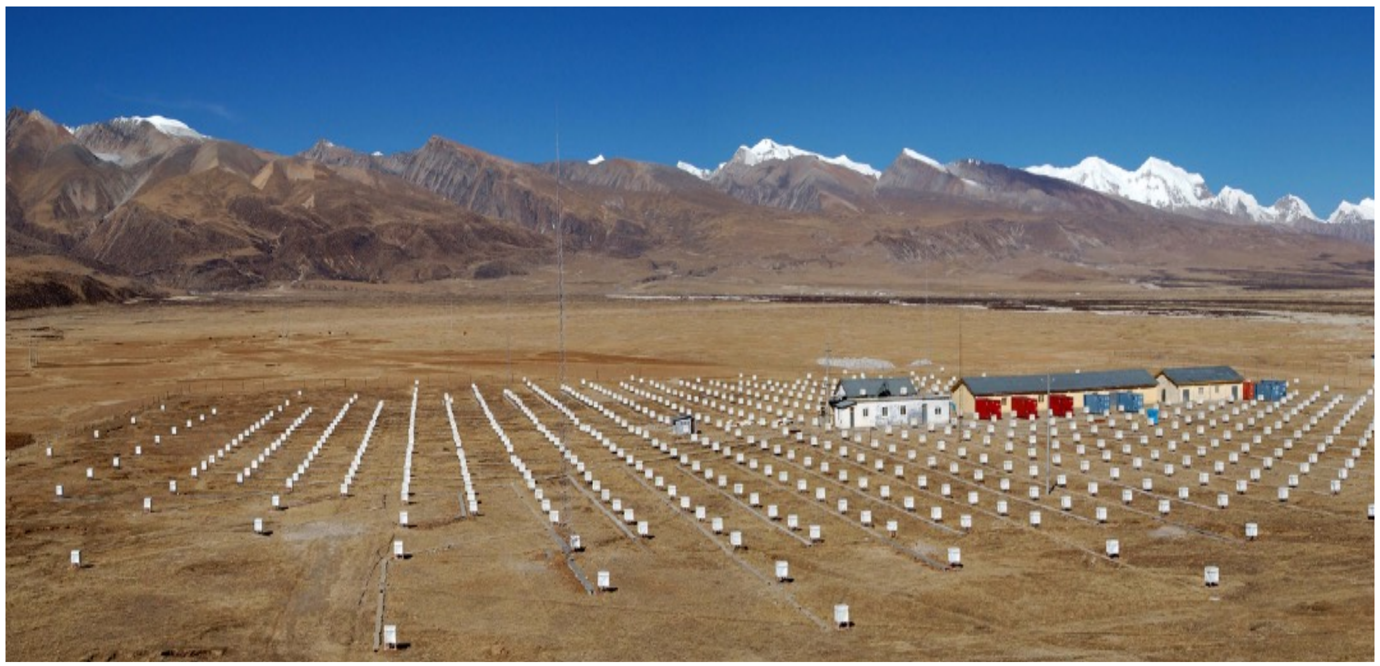
In γ-showers the ratio $N\gamma/Nch$ decreases if the comparison is restricted to a small area around the shower core.
For instance, we get $N\gamma/Nch \approx 3.5$ at a distance $r < 50$ m from the core for 100 GeV showers.

The number of secondary photons in γ-showers exceeds the number of gammas in p-showers with increasing altitude.

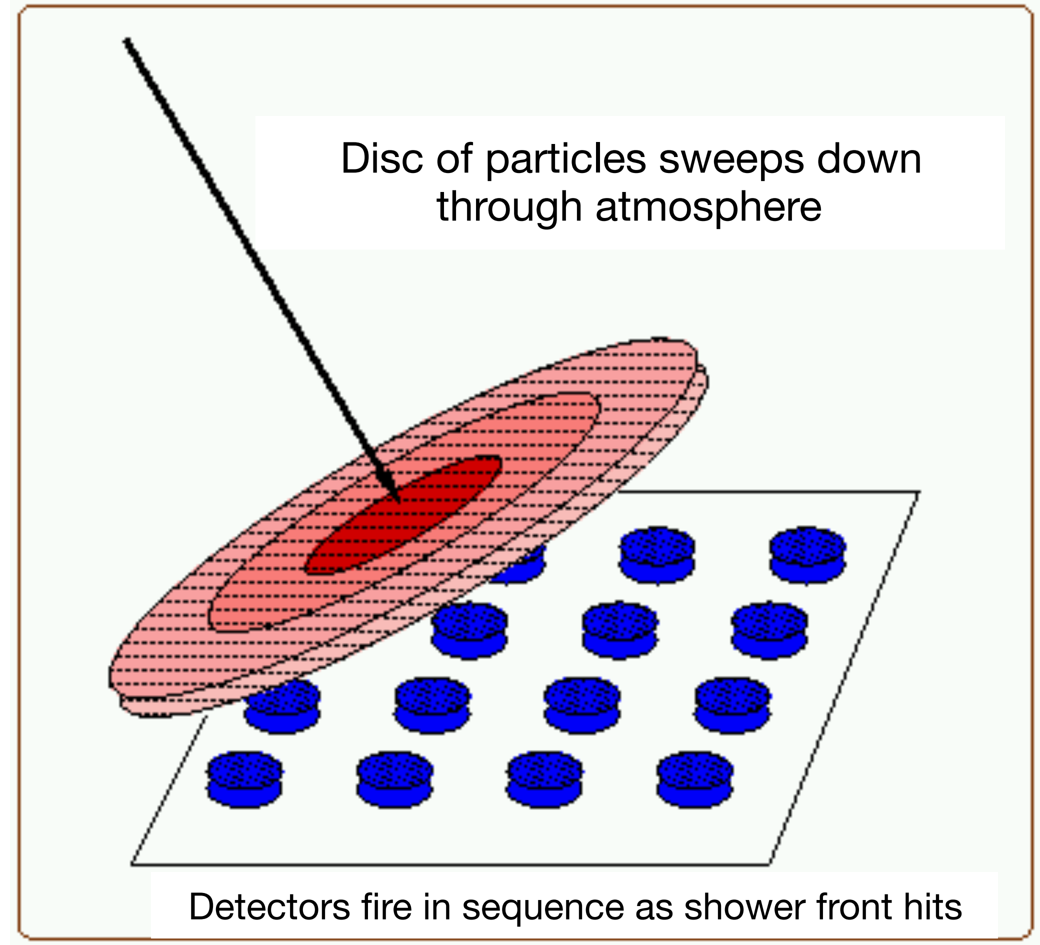
Detection of secondary photons very important to lower the energy threshold
and to improve the angular resolution

Extensive Air Shower Array

Large number of detectors spread over an area of order 10^5 m^2

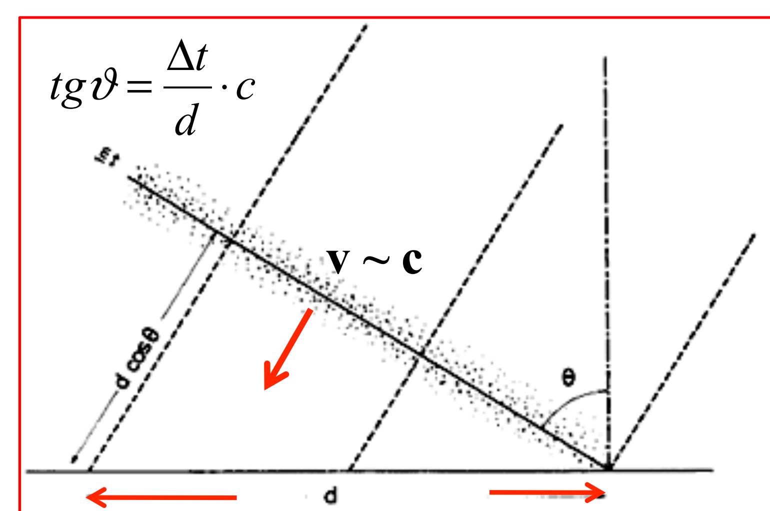


scintillators, water tanks (Cherenkov light in water), hadron calorimeters, Cherenkov telescopes, emulsions, etc.



coverage factor (sensitive area/instrumented area) ≈ 10^{-3} - 10^{-2}

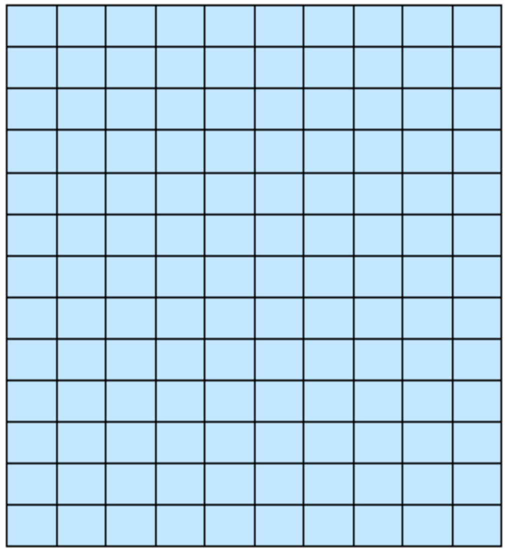
"density sampling" + "fast timing"



ARGO-YBJ: a full coverage detector

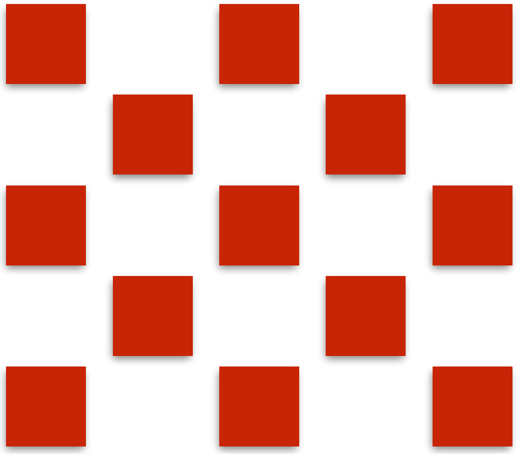
ARGO-YBJ is a high altitude full coverage EAS-array
optimized for the detection of small size air showers.

ARGO-YBJ central carpet



a continuous carpet of detectors
coverage factor ≈ 0.92

sparse array



coverage factor ≈ 10^{-3} - 10^{-2}

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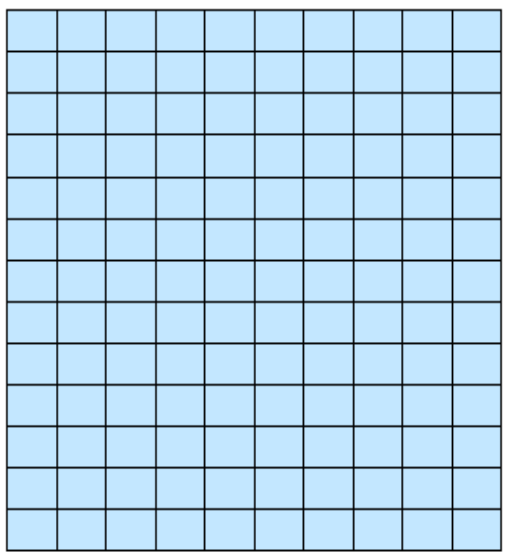

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coverage factor ≈ 0.92

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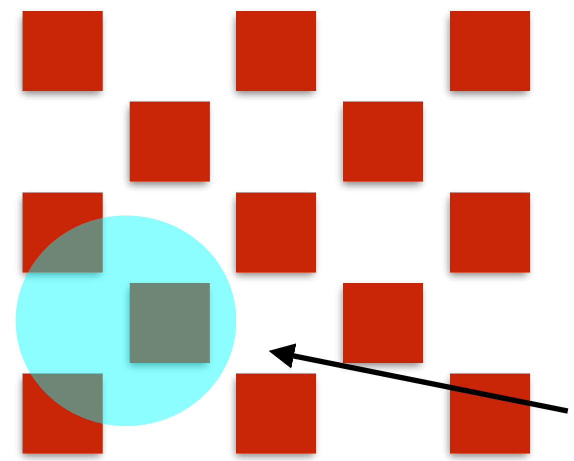

high energy shower = big shower
➔ trigger

coverage factor ≈ 10^{-3} - 10^{-2}

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ARGO-YBJ is a high altitude full coverage EAS-array
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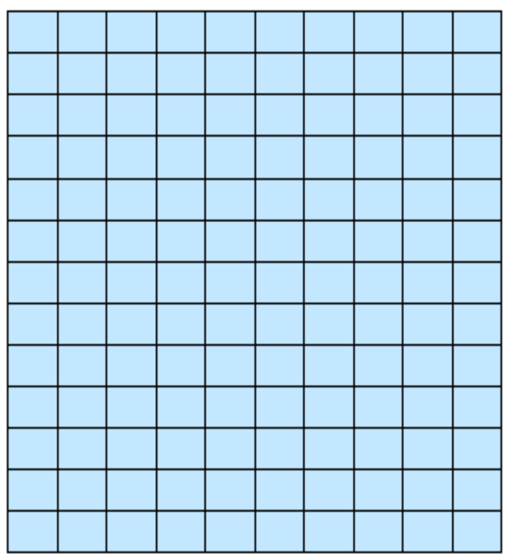
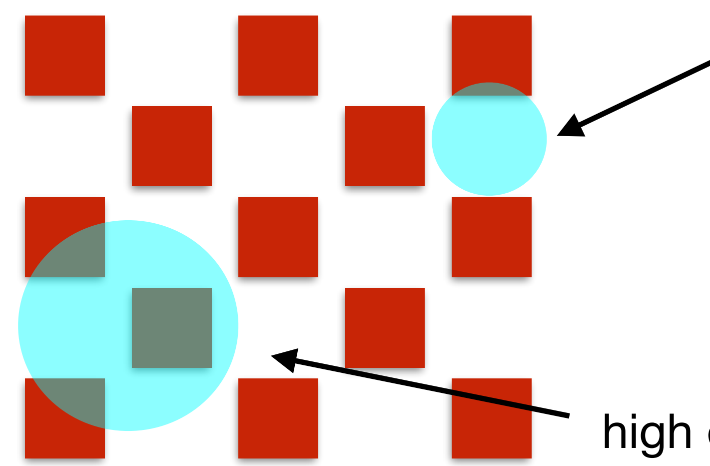
ARGO-YBJ central carpet



a continuous carpet of detectors
coverage factor ≈ 0.92

sparse array



low energy shower = small shower
➔ NO trigger

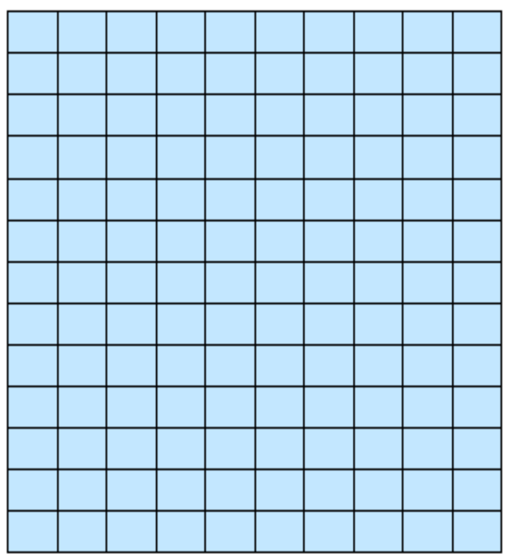
high energy shower = big shower
➔ trigger

coverage factor ≈ 10^{-3} - 10^{-2}

ARGO-YBJ: a full coverage detector

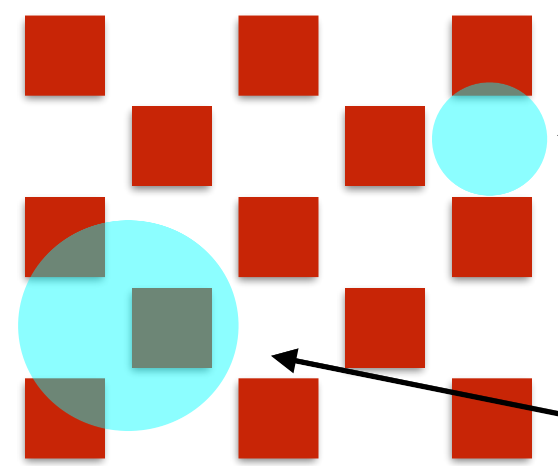
ARGO-YBJ is a high altitude full coverage EAS-array
optimized for the detection of small size air showers.

ARGO-YBJ central carpet



a continuous carpet of detectors
coverage factor ≈ 0.92

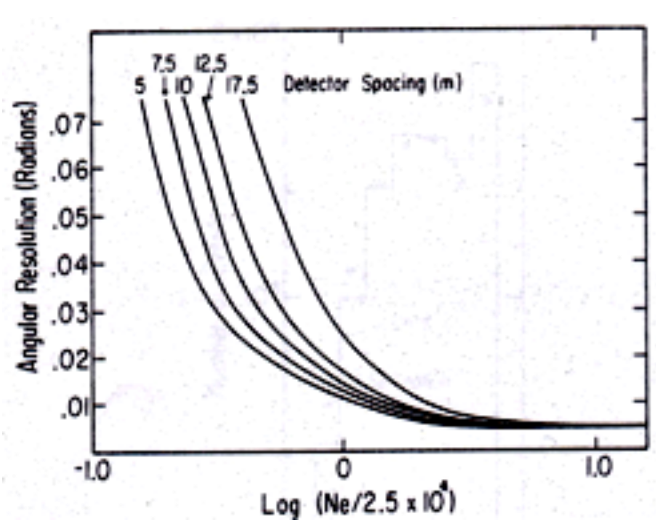
sparse array

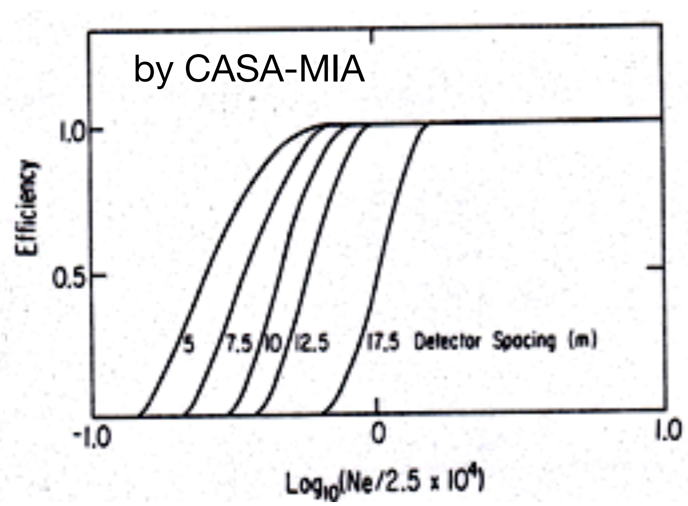


low energy shower = small shower
➔ NO trigger

high energy shower = big shower
➔ trigger

coverage factor ≈ 10^{-3} - 10^{-2}





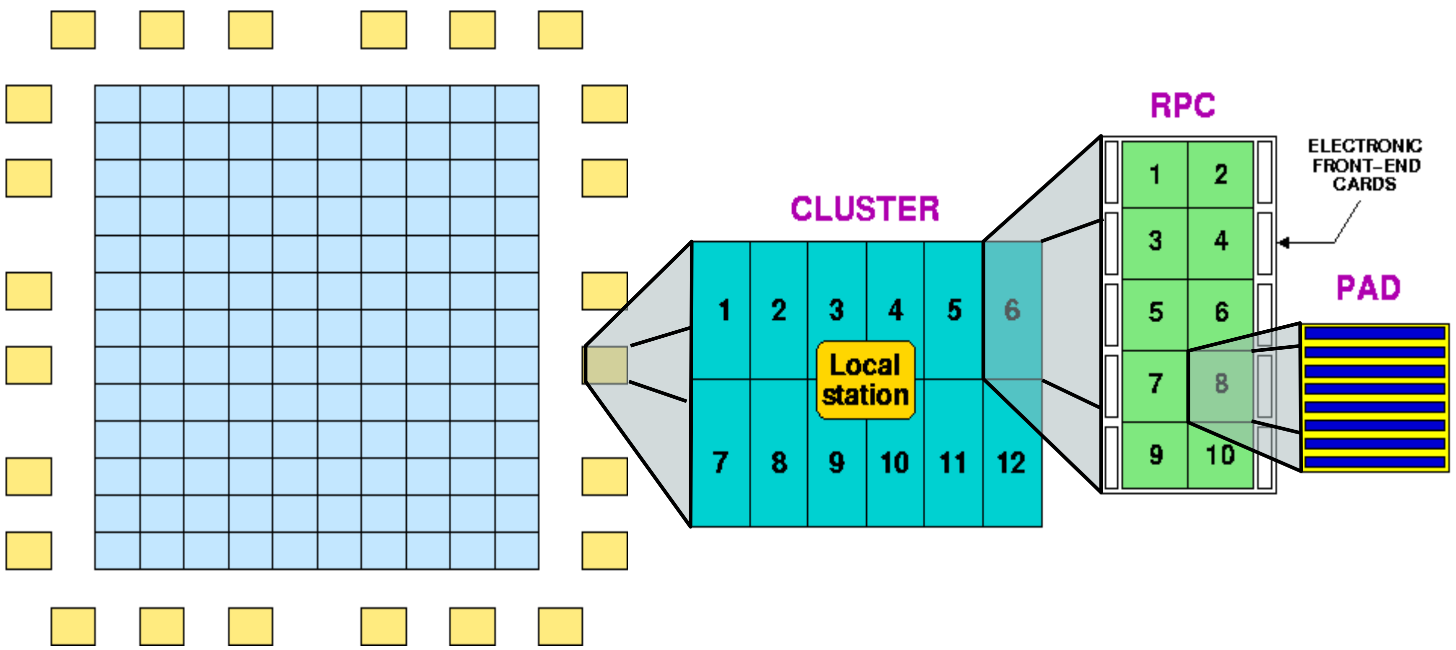
Increasing the sampling (~1% ➜100%)

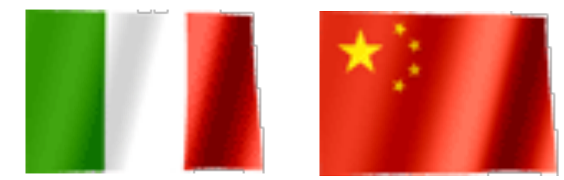
⬇

- Improves angular resolution
- Lowers energy threshold

The ARGO-YBJ experiment

ARGO-YBJ is a telescope optimized for the detection of small size air showers



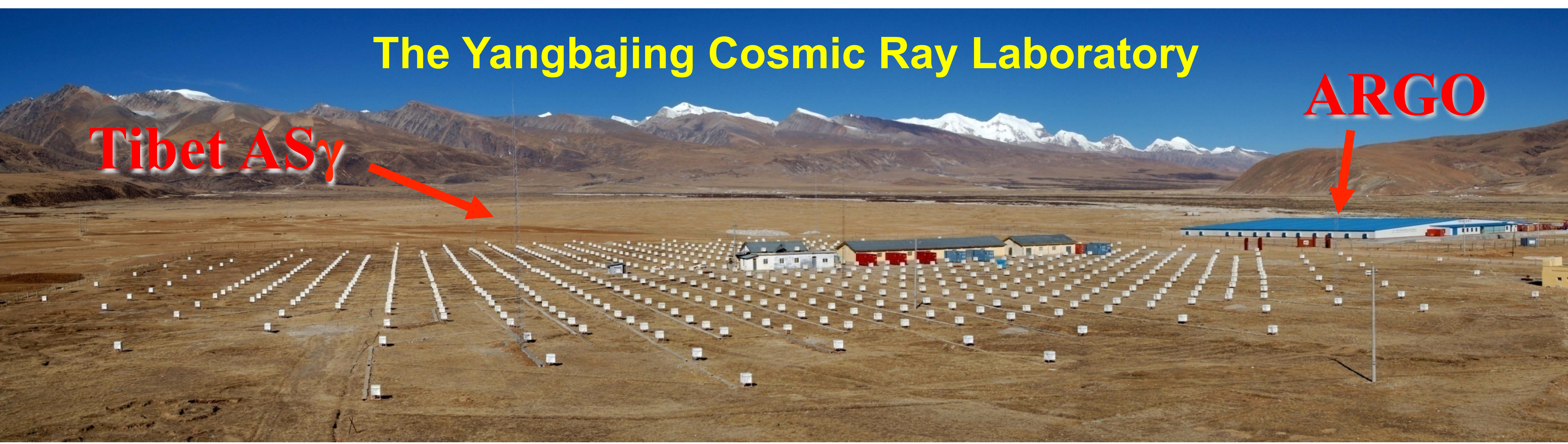


INFN IHEP/CAS

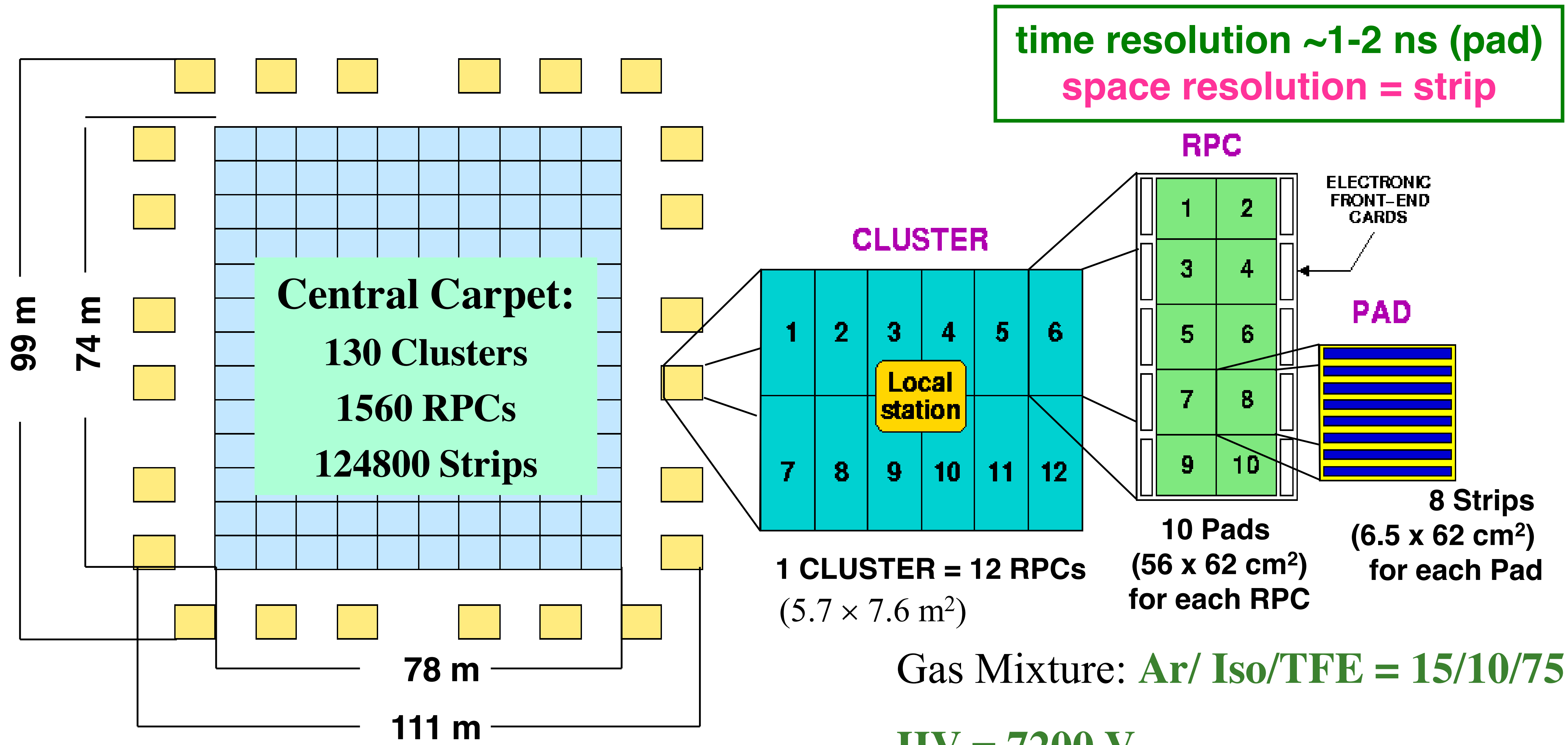
Longitude: 90° 31’ 50” East
Latitude: 30° 06’ 38” North

90 km North from Lhasa (Tibet)

4300 m above sea level
$\sim$ 600 g/cm^2



The ARGO-YBJ layout

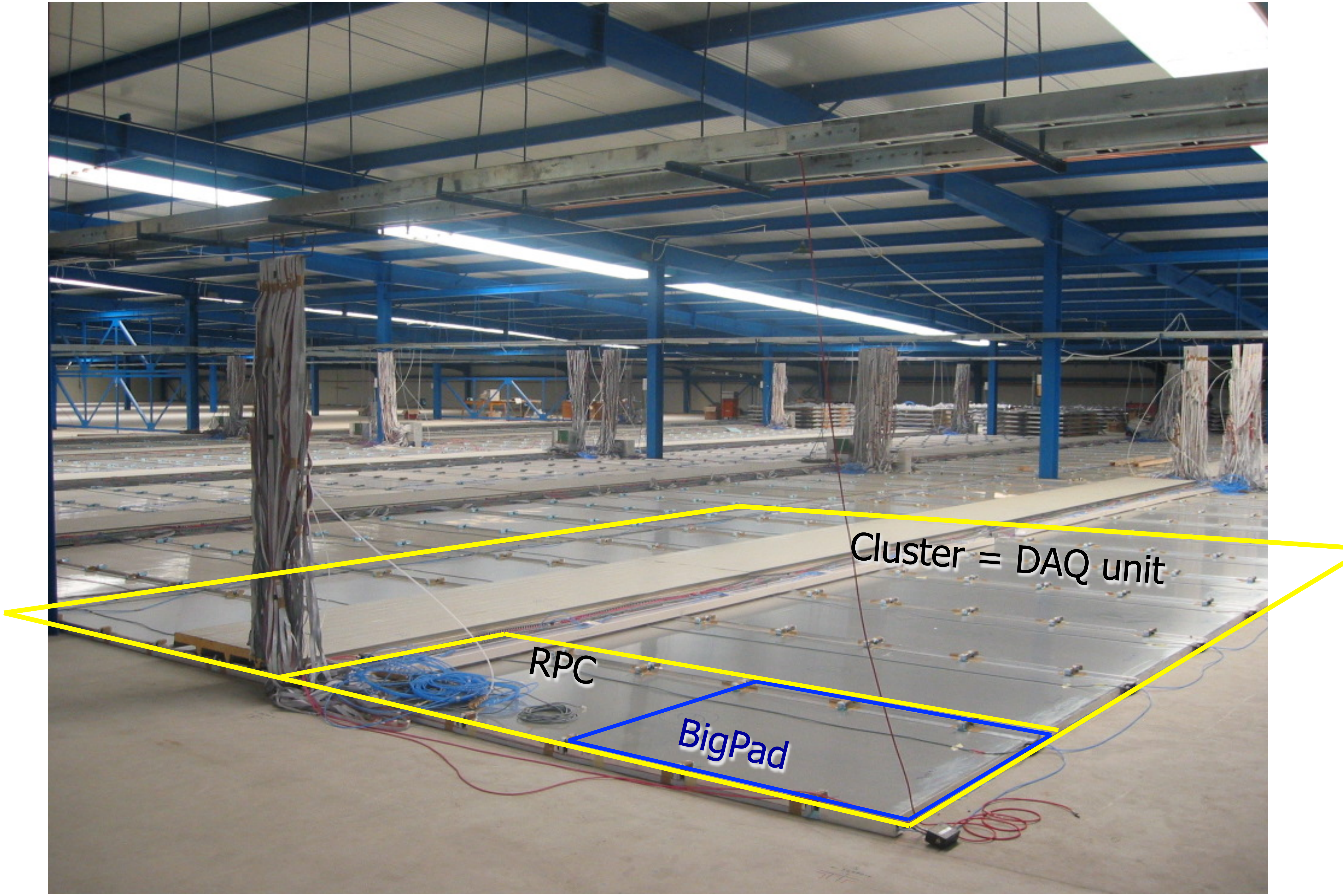


Gas Mixture: **Ar/ Iso/TFE = 15/10/75**

HV = 7200 V

Single layer of Resistive Plate Chambers (RPCs)
with a full coverage (92% active surface) of a large area (5600 m²)
+ sampling guard ring (6700 m² in total)

The experimental hall



The basic concepts

…for an unconventional air shower detector

❖ HIGH ALTITUDE SITE
(YBJ - Tibet 4300 m asl - 600 g/cm2)

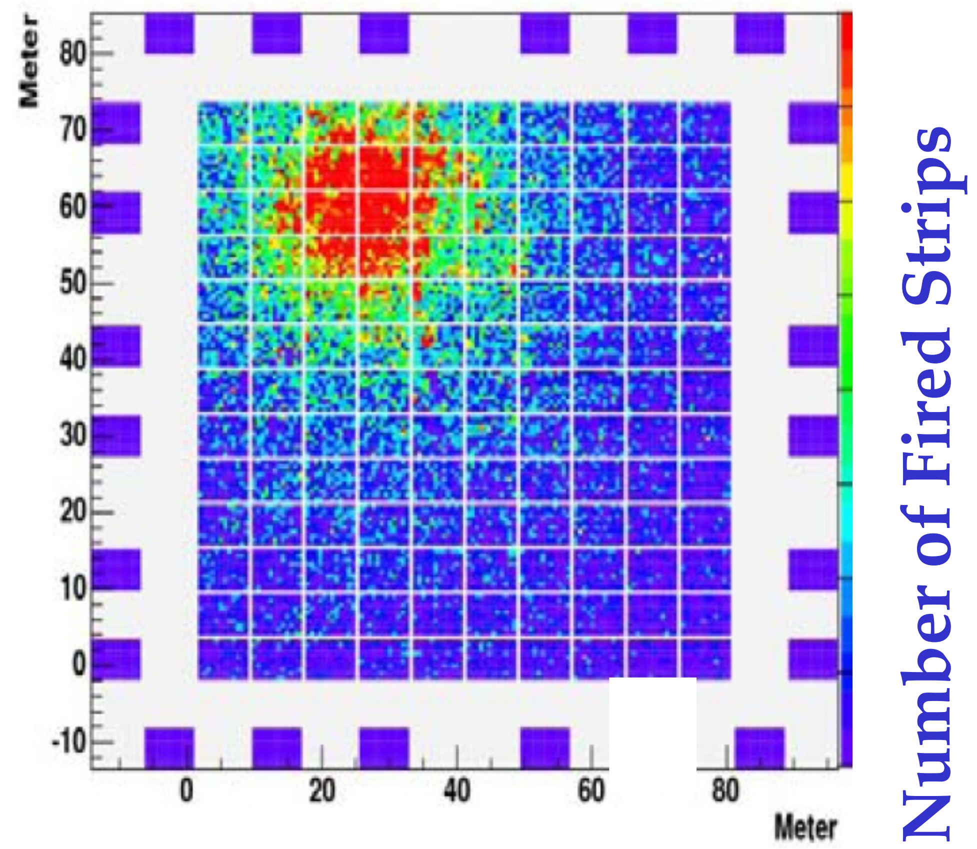
❖ FULL COVERAGE
(RPC technology, 92% covering factor)

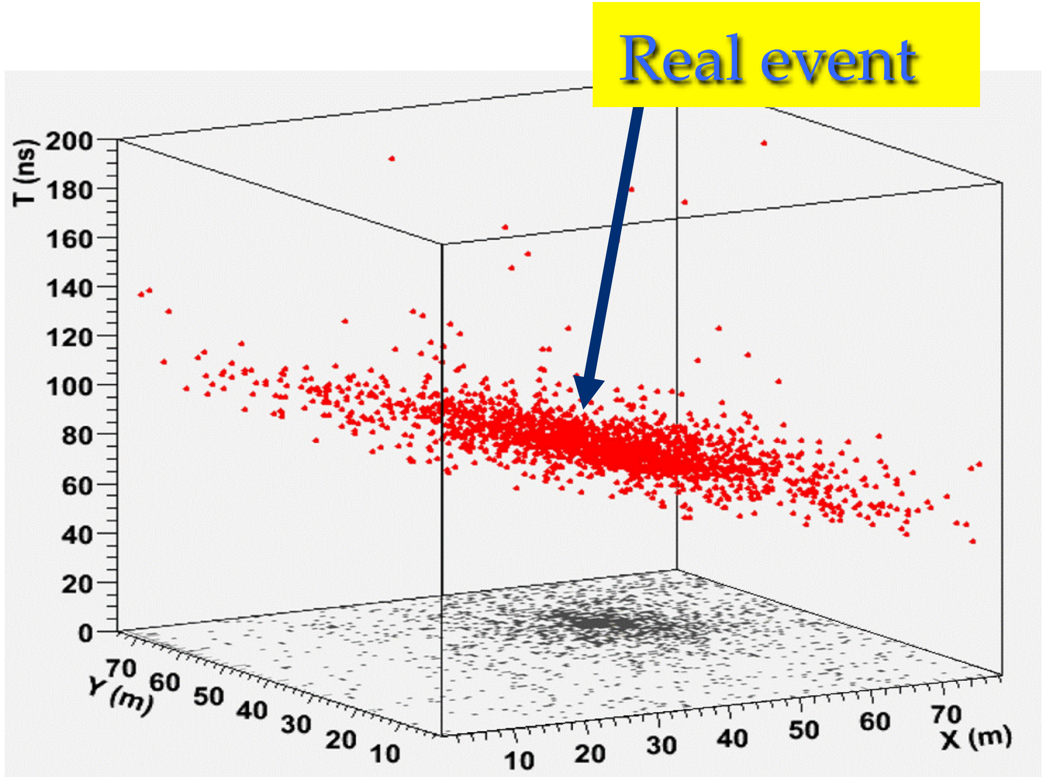
❖ HIGH SEGMENTATION OF THE READOUT
(small space-time pixels)

Space pixels: 146,880 strips (7×62 cm^2)
Time pixels: 18,360 pads (56×62 cm^2)

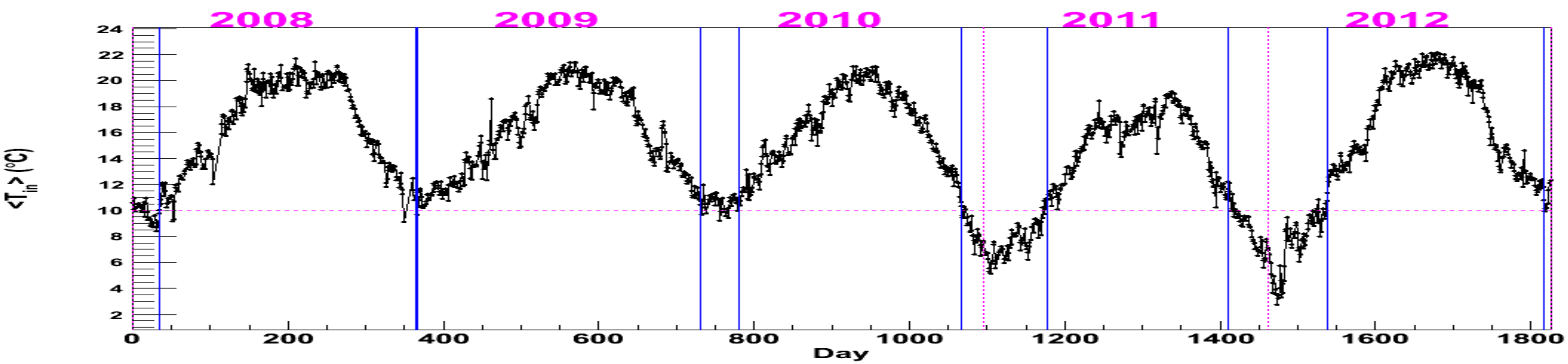
… in order to

- image the shower front with unprecedented details
- get an energy threshold of a few hundreds of GeV





The daily temperature in the ARGO hall



- The data sample for each year

Year	T>10℃	days	T<10℃	days
2008	36-366	331	1~35	35
2009	1-365	365	0	0
2010	50-336	287	1~49, 337~365	78
2011	82-316	235	1~81, 317~365	130
2012	78-356	279	1~77, 356~366	87

Energy threshold

HAWC (2017)

ARGO-YBJ (final)

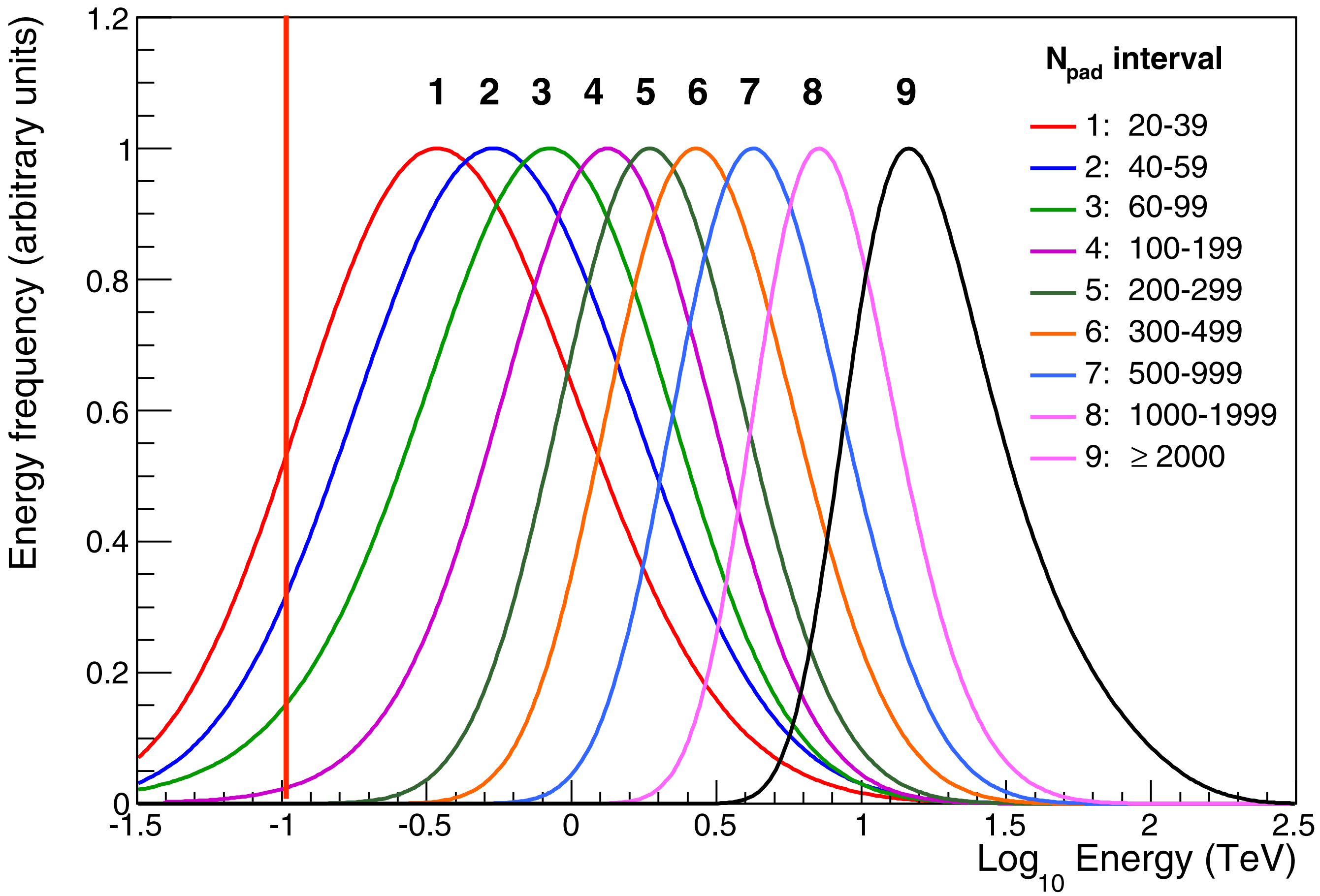


Figure 3. Normalized distribution of the primary gamma-ray energy for different N_{pad} intervals, for a Crab-like source.

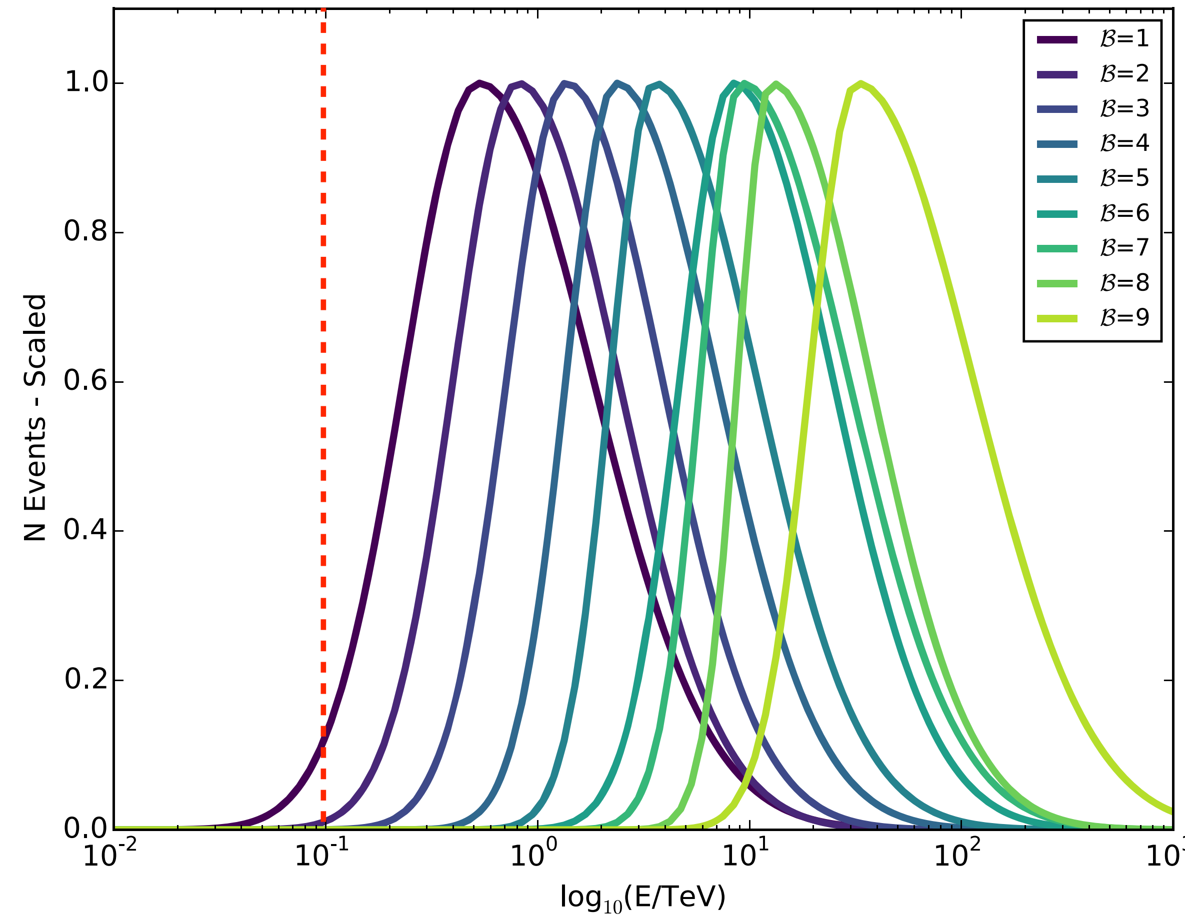


Figure 2. Fits to the true energy distribution of photons from a source with a spectrum of the form $E^{-2.63}$ at a declination of +20°N for $\mathcal{B}$ between 1 and 9, summed across a transit of the source. Better energy resolution and dynamic range can be achieved with a more sophisticated variable that takes into account the zenith angle of events and the total light level on the ground. The curves have been scaled to the same vertical height for display.

full coverage RPC carpet operated at 4300 m asl

coverage ≈ 92%

high granularity

E_{50} ≈ 360 GeV

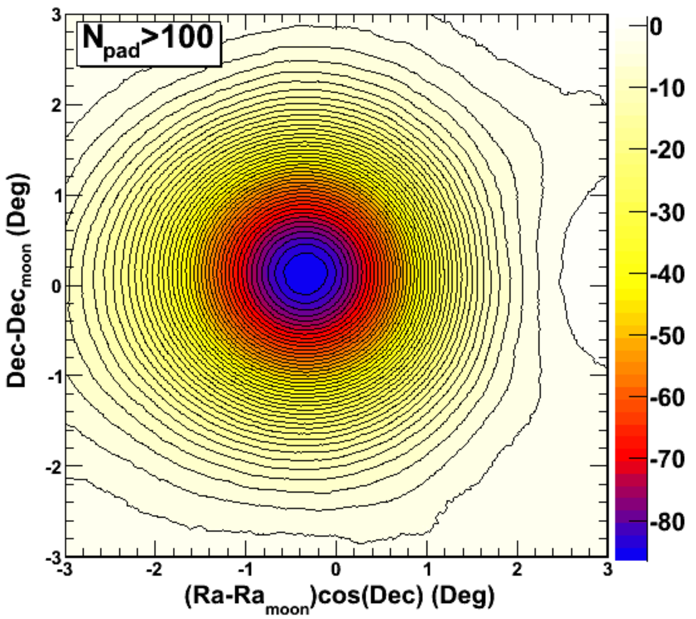
array of water tanks operated at 4100 m asl

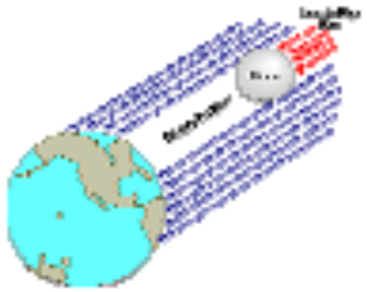
coverage ≈ 60%

E_{50} ≈ 700 GeV

Calibration of the energy scale

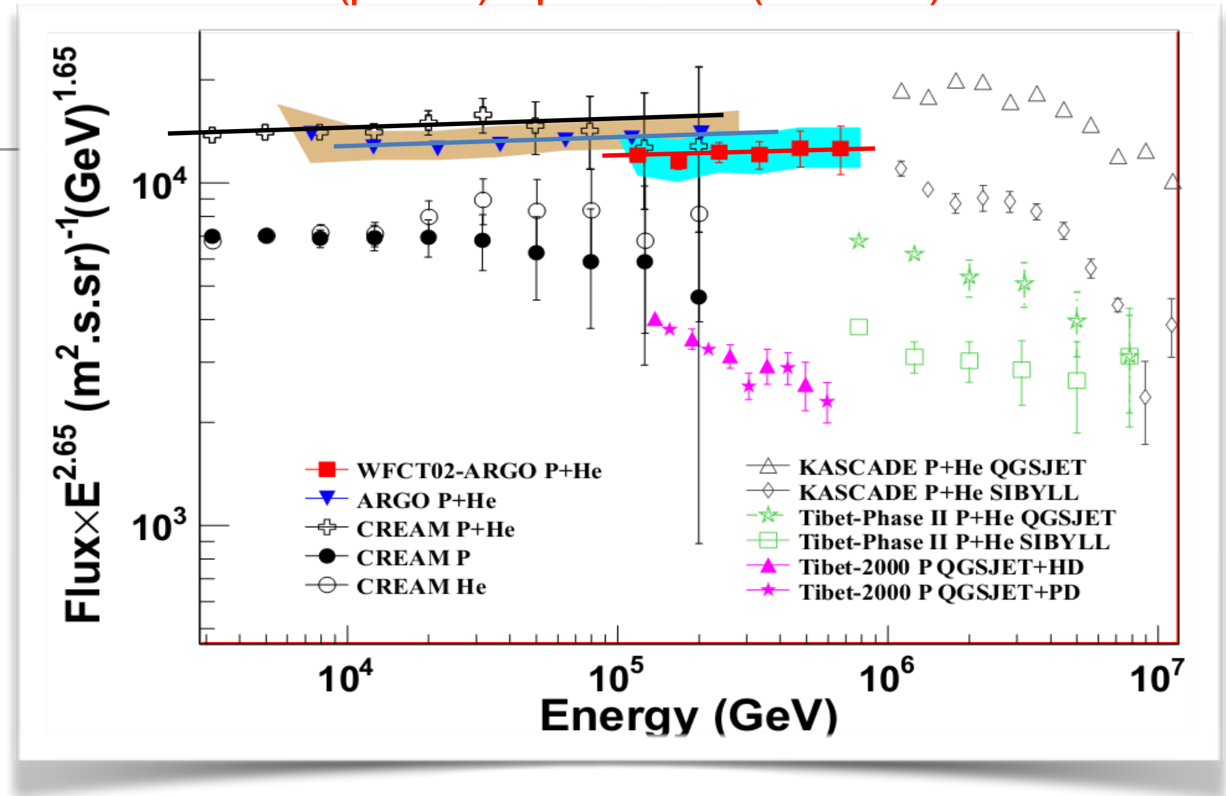
ARGO-YBJ: *Moon shadow tool*





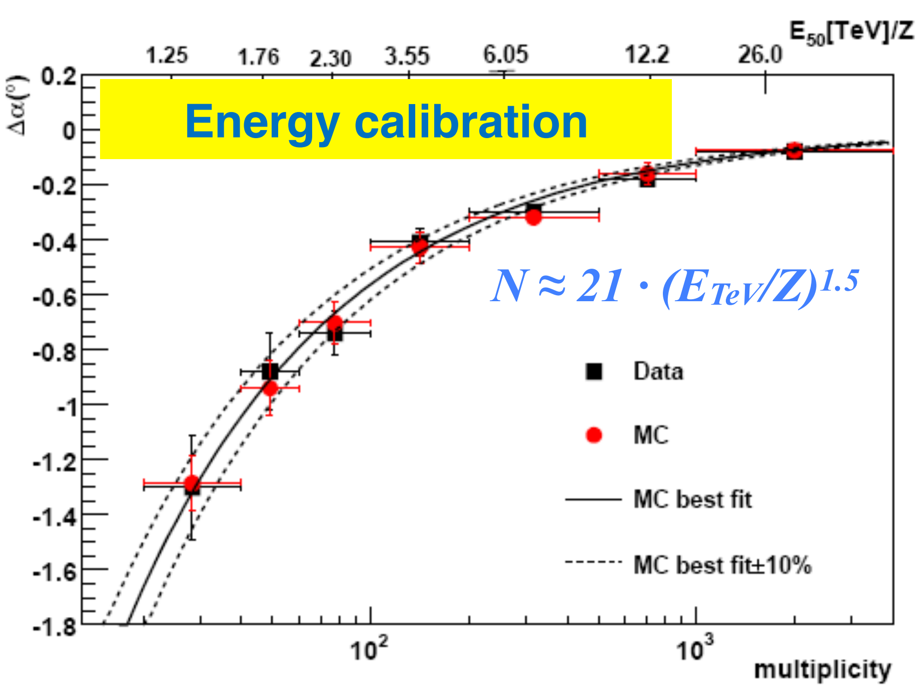
PRD 84 (2011) 022003

(p+He) spectrum (2 - 700) TeV



Chin. Phys. C 38, 045001 (2014)

The energy scale uncertainty is estimated at 10% level in the energy range 1 – 30 (TeV/Z).



- CREAM: 1.09 × 1.95 × 10^{-11} (E/400 TeV)$^{-2.62}$
- ARGO-YBJ: 1.95 × 10^{-11} (E/400 TeV)$^{-2.61}$
- Hybrid: 0.92 × 1.95 × 10^{-11} (E/400 TeV)$^{-2.63}$

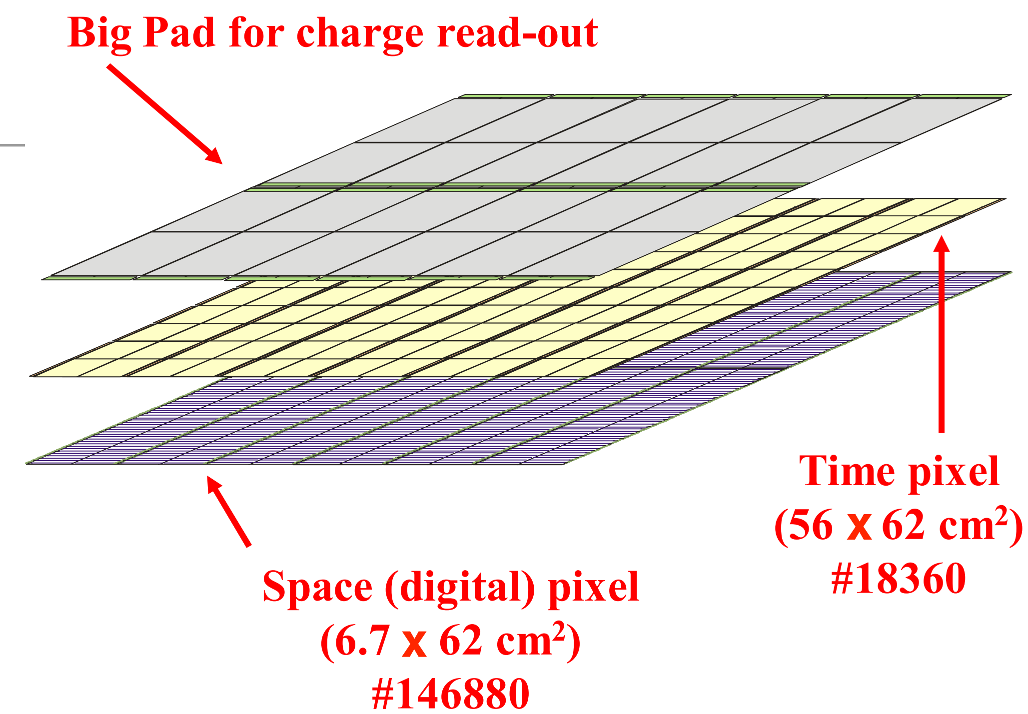
Single power-law: 2.62 ± 0.01

Flux at 400 TeV:

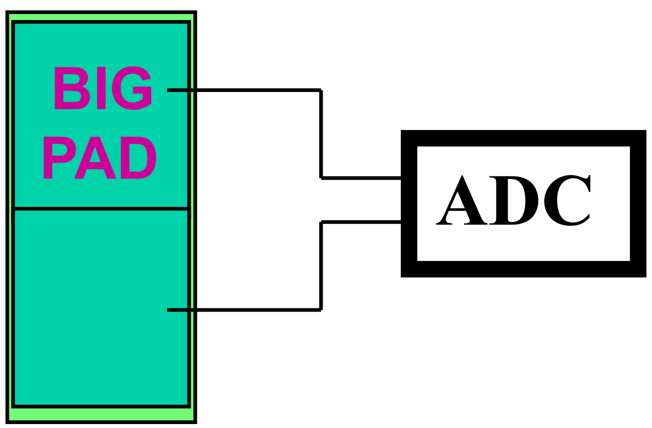
1.95 × 10^{-11}± 9% (GeV^{-1} m^{-2} sr^{-1} s^{-1})

The 9% difference in flux corresponds to a difference of ± 4% in energy scale between different experiments.

The RPC charge readout



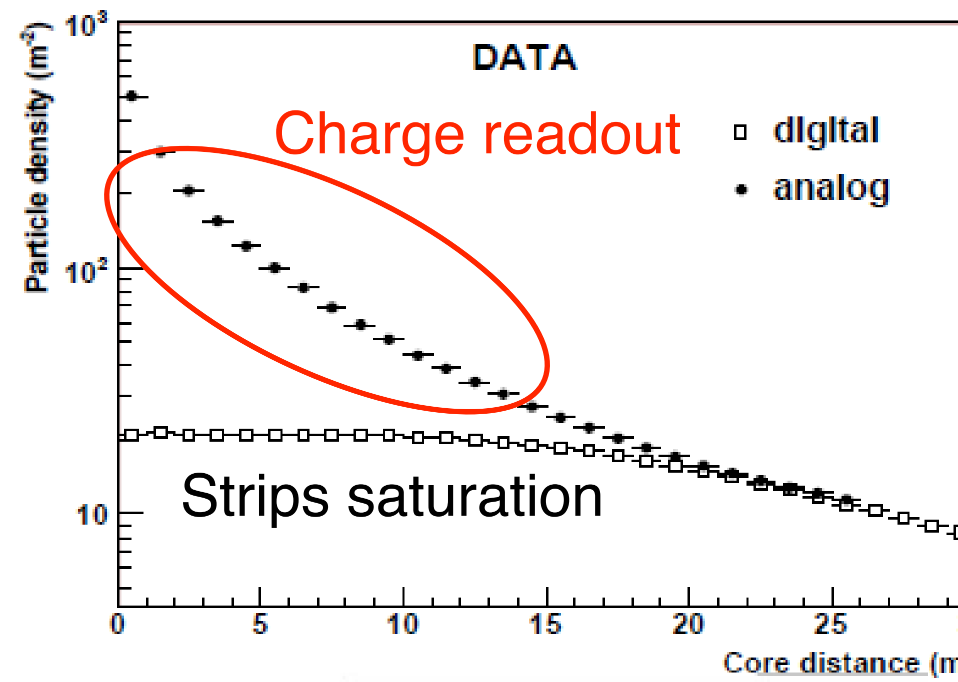
…extending the dynamical range up to 10 PeV

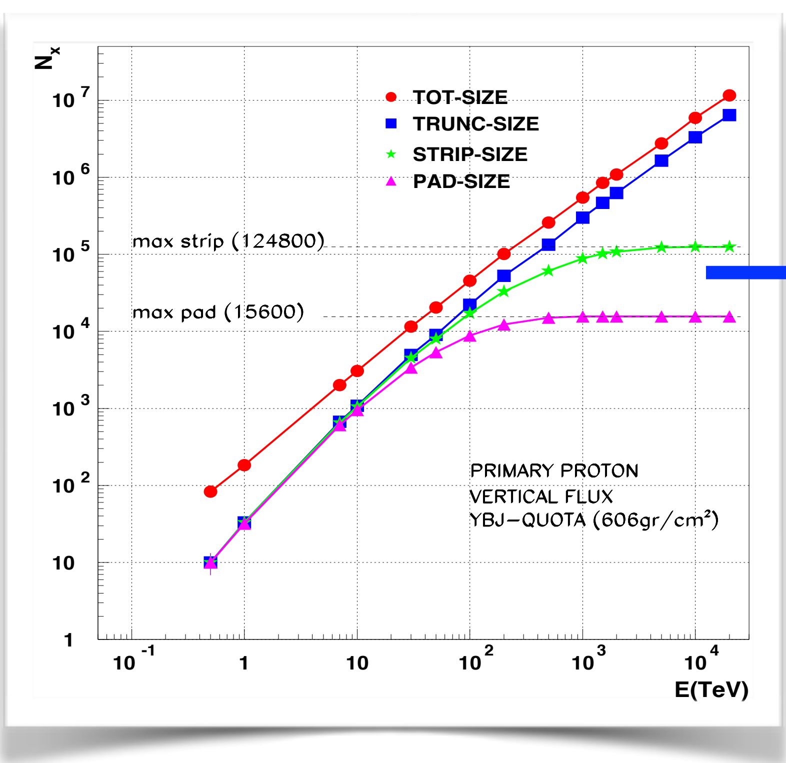


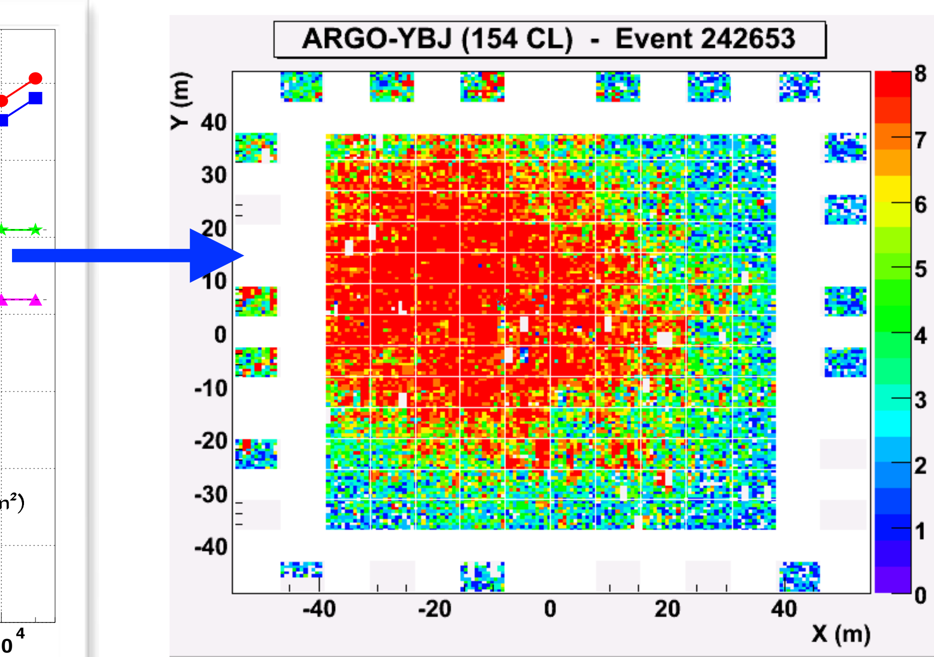
4 different gain scales used to cover a wide range in particle density:

$$\rho_{max-strip} \approx 20 \text{ particles/m}^2$$

$$\rho_{max-analog} \approx 10^4 \text{ particles/m}^2$$



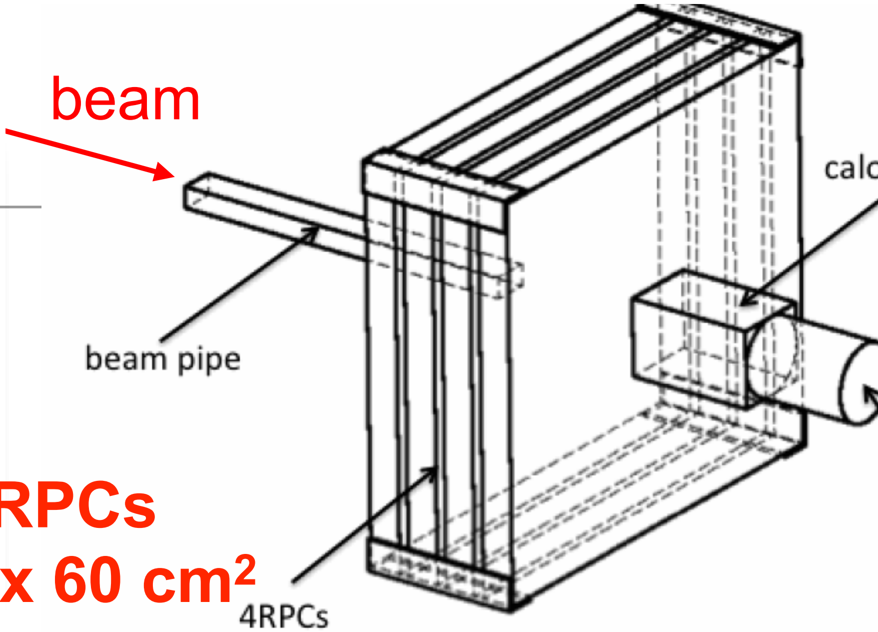




Intrinsic linearity: test at the BTF facility

Linearity of the RPC @ BTF in INFN Frascati Lab:

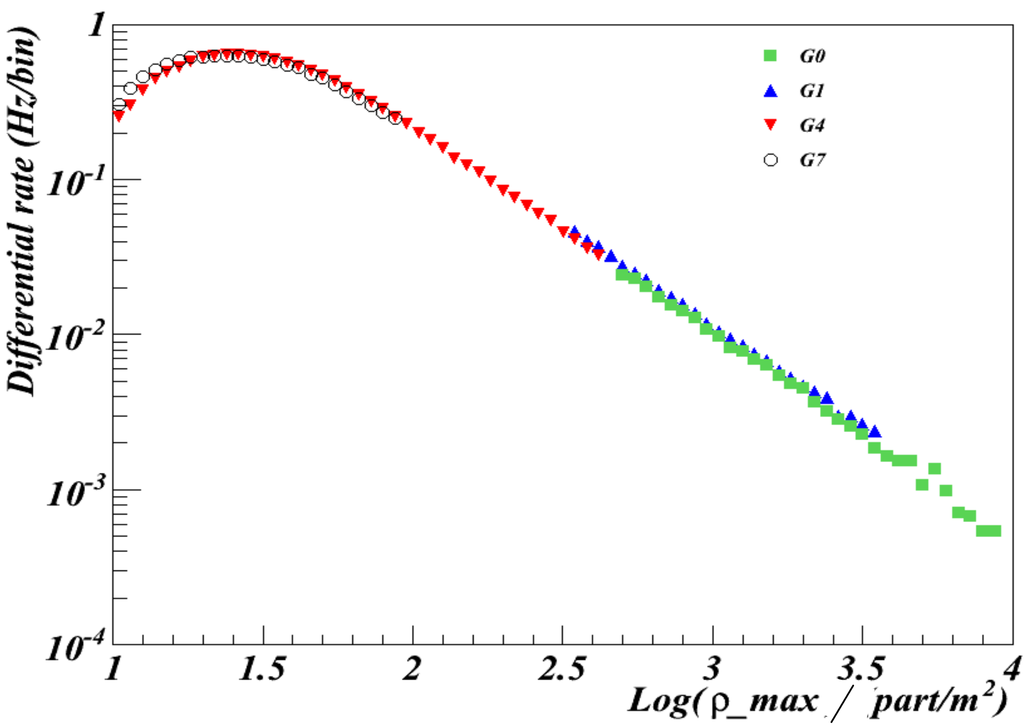
- *electrons (or positrons)*
- *E = 25-750 MeV (0.5% resolution)*
- *<N>=1÷10⁸particles/pulse*
- *10 ns pulses, 1-49 Hz*
- *beam spot uniform on 3×5 cm*



4 RPCs
60 x 60 cm²

Calorimeter: lead glass block from OPAL, PMT a Hamamatsu R2238.

Good overlap between 4 scales with the maximum density of the showers spanning over three decades



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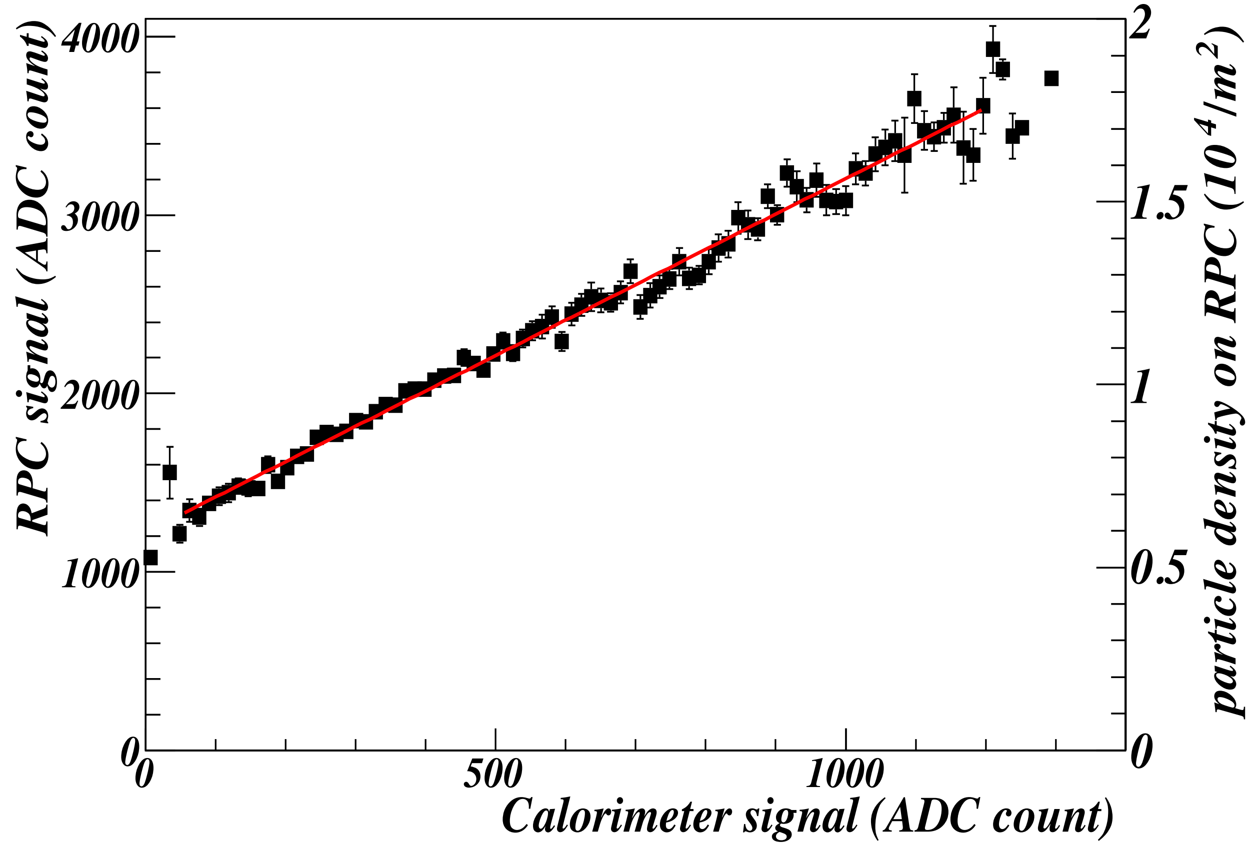
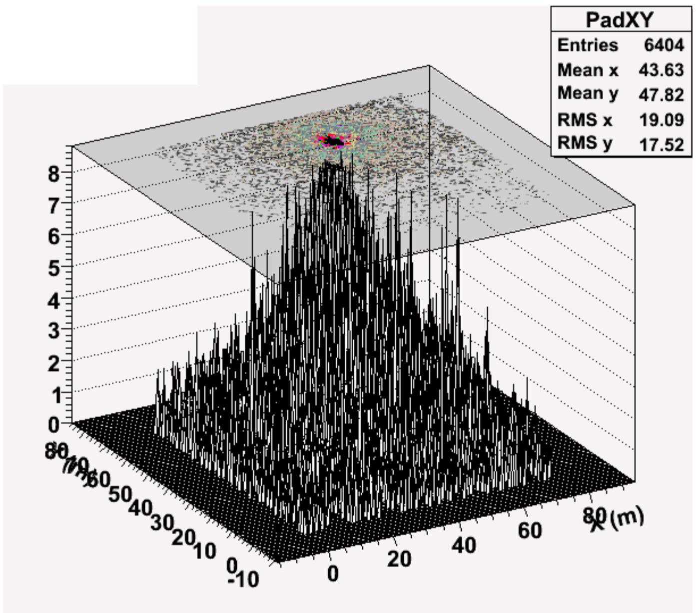
The RPC signal vs the calorimeter signal



➔ Linearity up to ≈ 2 · 10^4 particle/m²

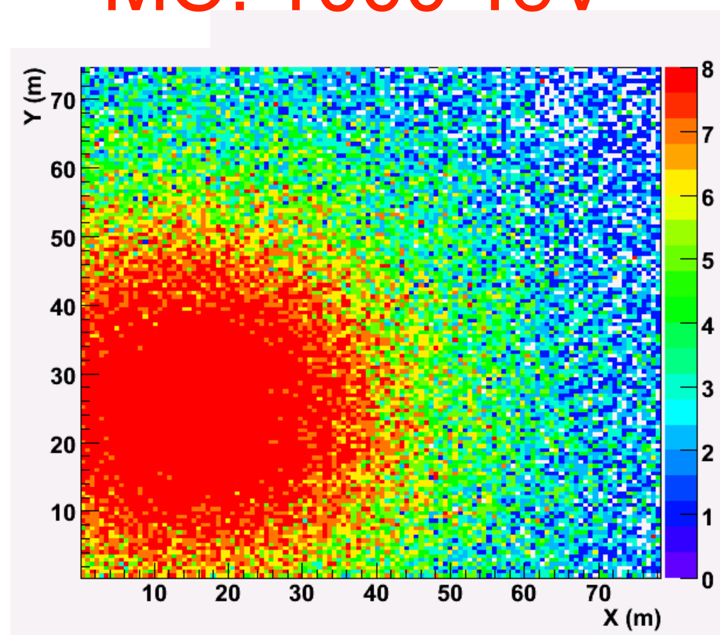
The RPC charge readout: the core region

MC: 100 TeV



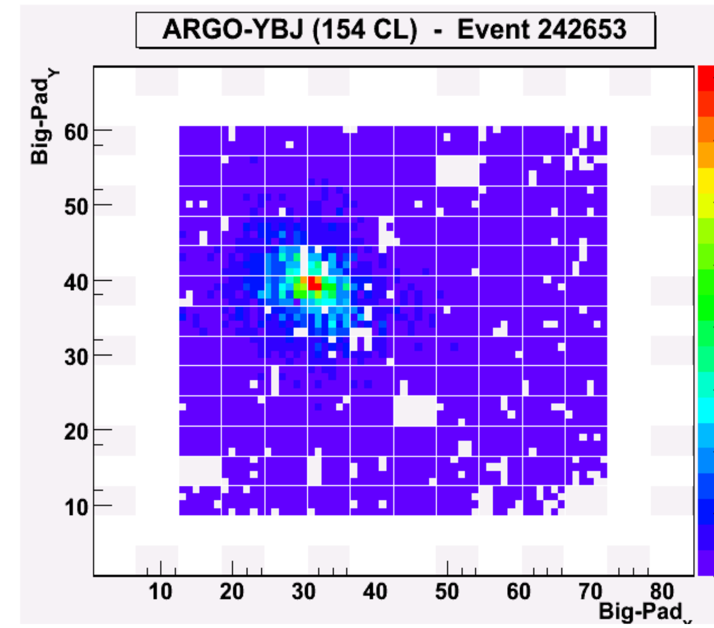
Strip read-out

MC: 1000 TeV

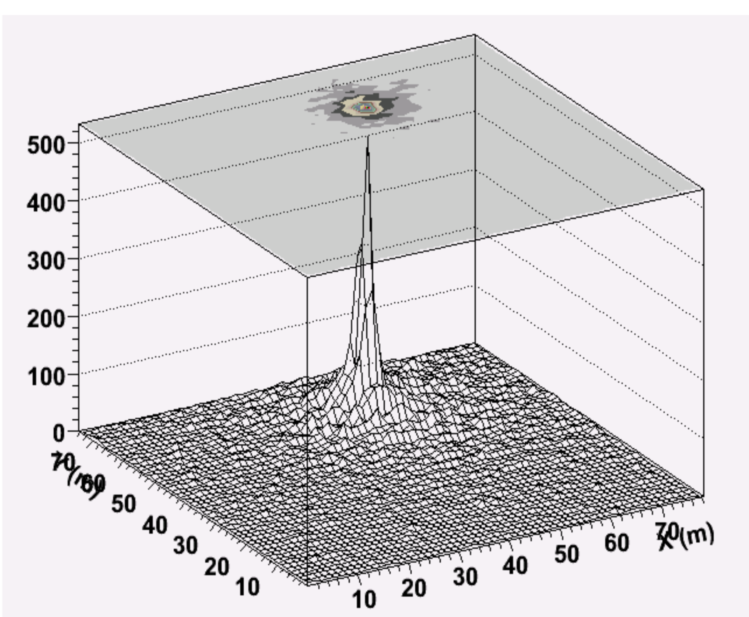


Strip read-out

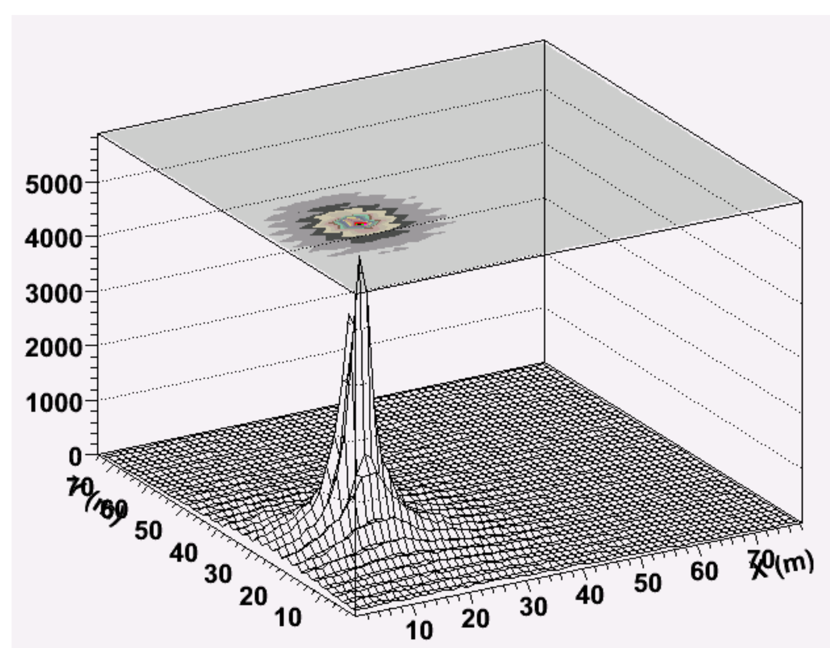
Data



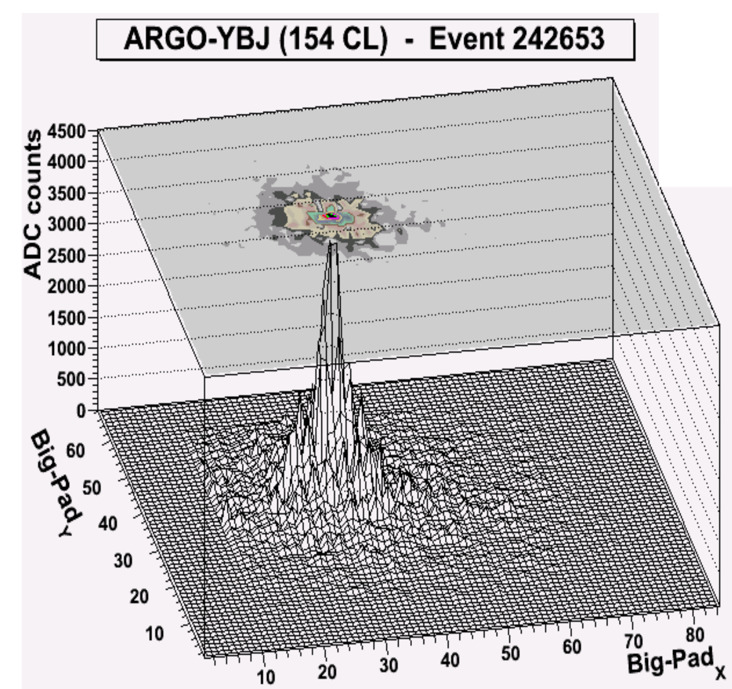
Strip read-out



Charge read-out



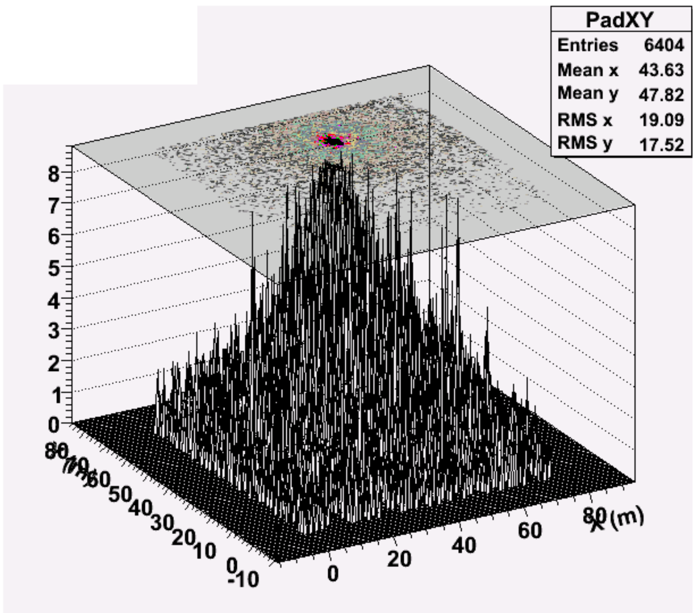
Charge read-out



Charge read-out

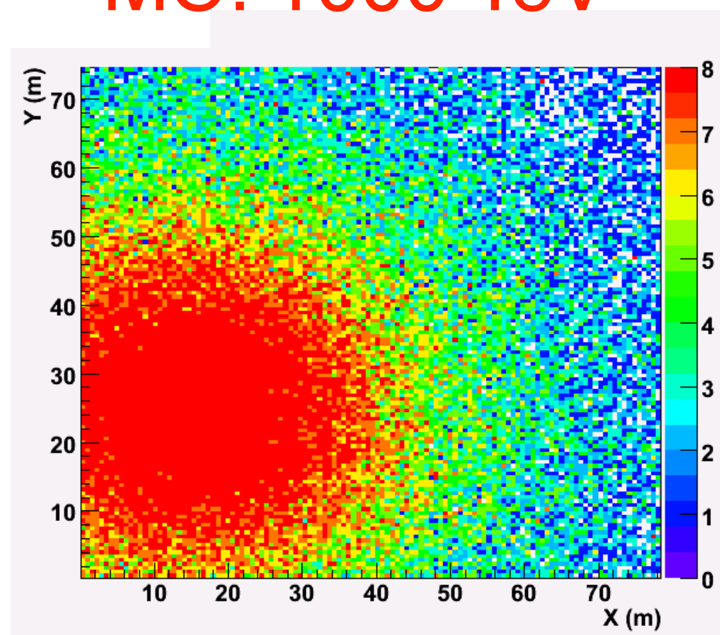
The RPC charge readout: the core region

MC: 100 TeV



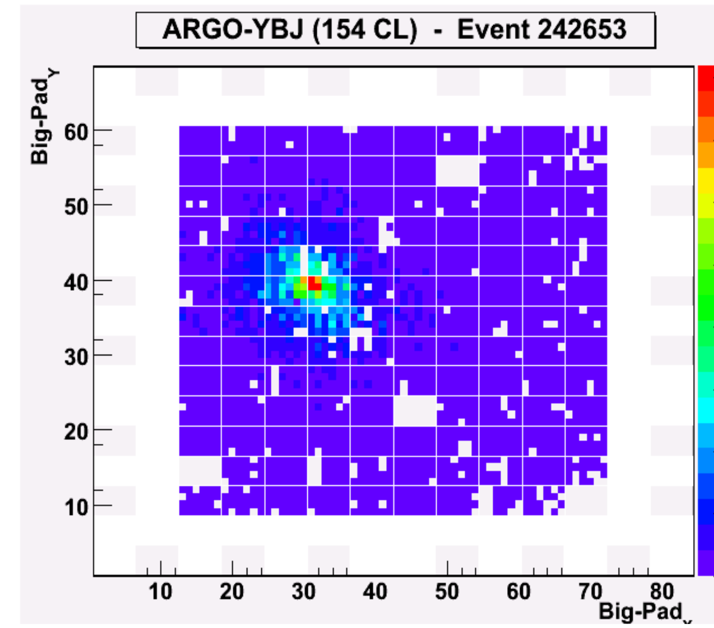
Strip read-out

MC: 1000 TeV



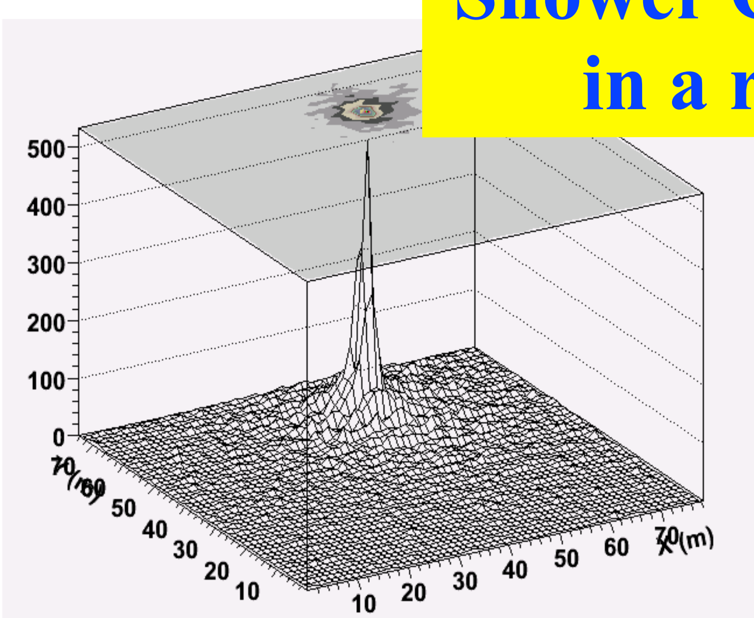
Strip read-out

Data

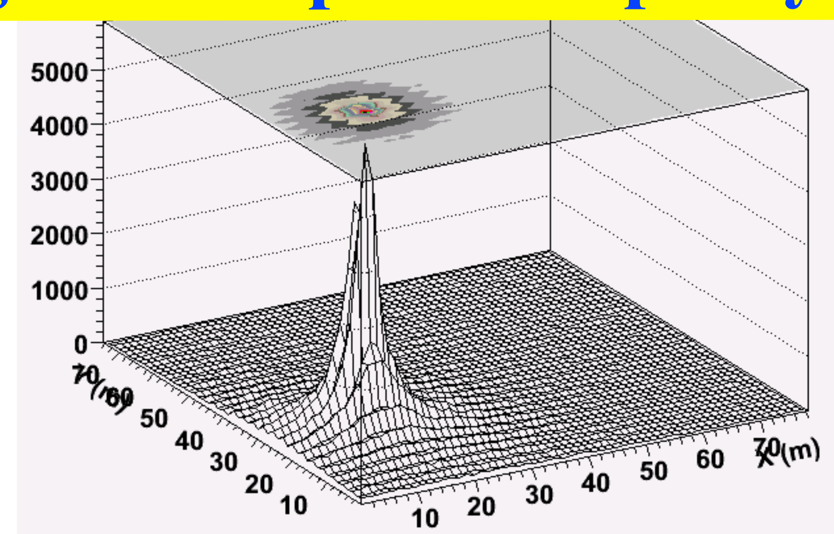


Strip read-out

Shower Core = study of hadronic interactions in a region with pseudorapidity > 8 !!!



Charge read-out



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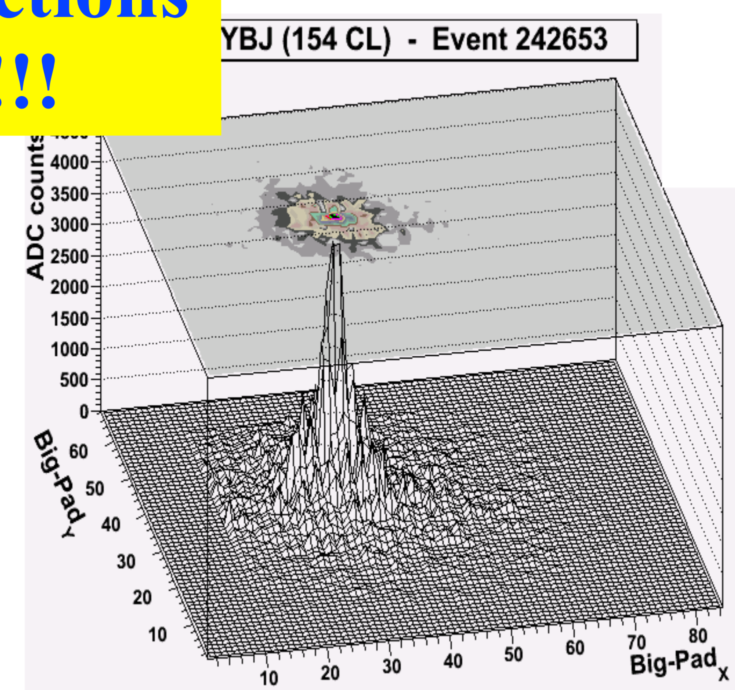


Charge read-out

Southern Hemisphere: LATTES

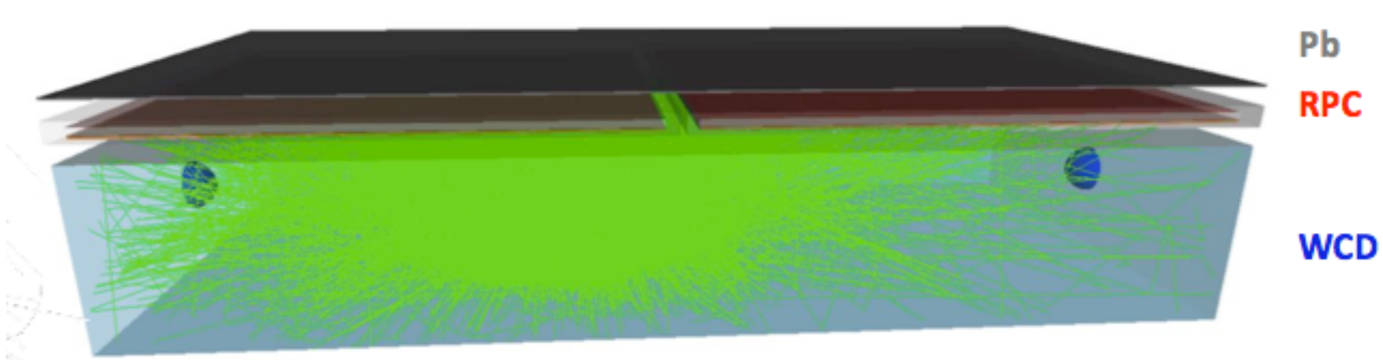
arXiv:1607.03051

P. Assis, U. Barres de Almeida, A. Blanco, R. Conceicao, B. D'Ettorre Piazzoli, A. De Angelis, M. Doro, P. Fonte, L. Lopes, G. Matthiae, M. Pimenta, R. Shellard, B. Tome'

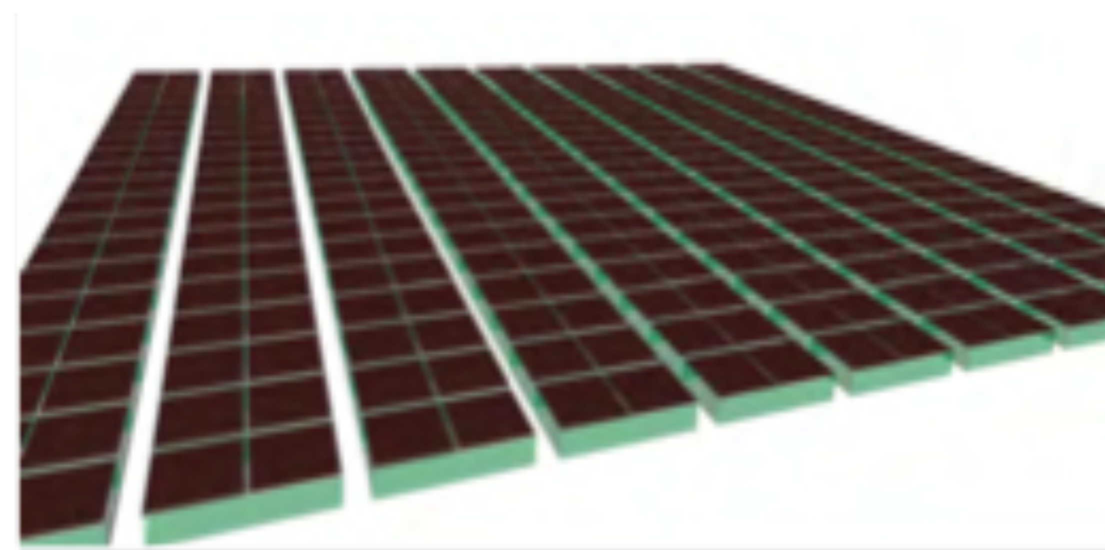
An array of hybrid detectors constituted by

1. one Water Cherenkov Detector (WCD) with a rectangular horizontal surface of 3 m × 1.5 m and a depth of 0.5 m, with signals read by PMTs at both ends of the smallest vertical face of the block.

2. On top of the WCD there are two MARTA RPCs, each with a surface of (1.5 × 1.5) m^2 and with 16 charge collecting pads. Each RPC is covered with a thin (5.6 mm) layer of lead.



- Thin lead plate (Pb)
  - 5.6 mm (one radiation lenght)
- Resistive Plate Chambers (RPC)
  - 2 RPCs per station
  - Each RPC with 4x4 readout pads
- Water Cherenkov Detector (WCD)
  - 2 PMTs (diameter: 15 cm)
  - Dimensions: 1.5 m x 3 m x 0.5 m



Depth of water tank too small ?
Outdoor operation ?
Glass vs bakelite
Granularity of the read-out ?
Analog read-out ?