RPC applied to cosmic ray physics: the case of the ARGO-YBJ experiment

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AIDA
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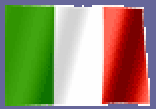
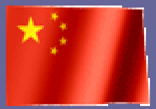
Outline

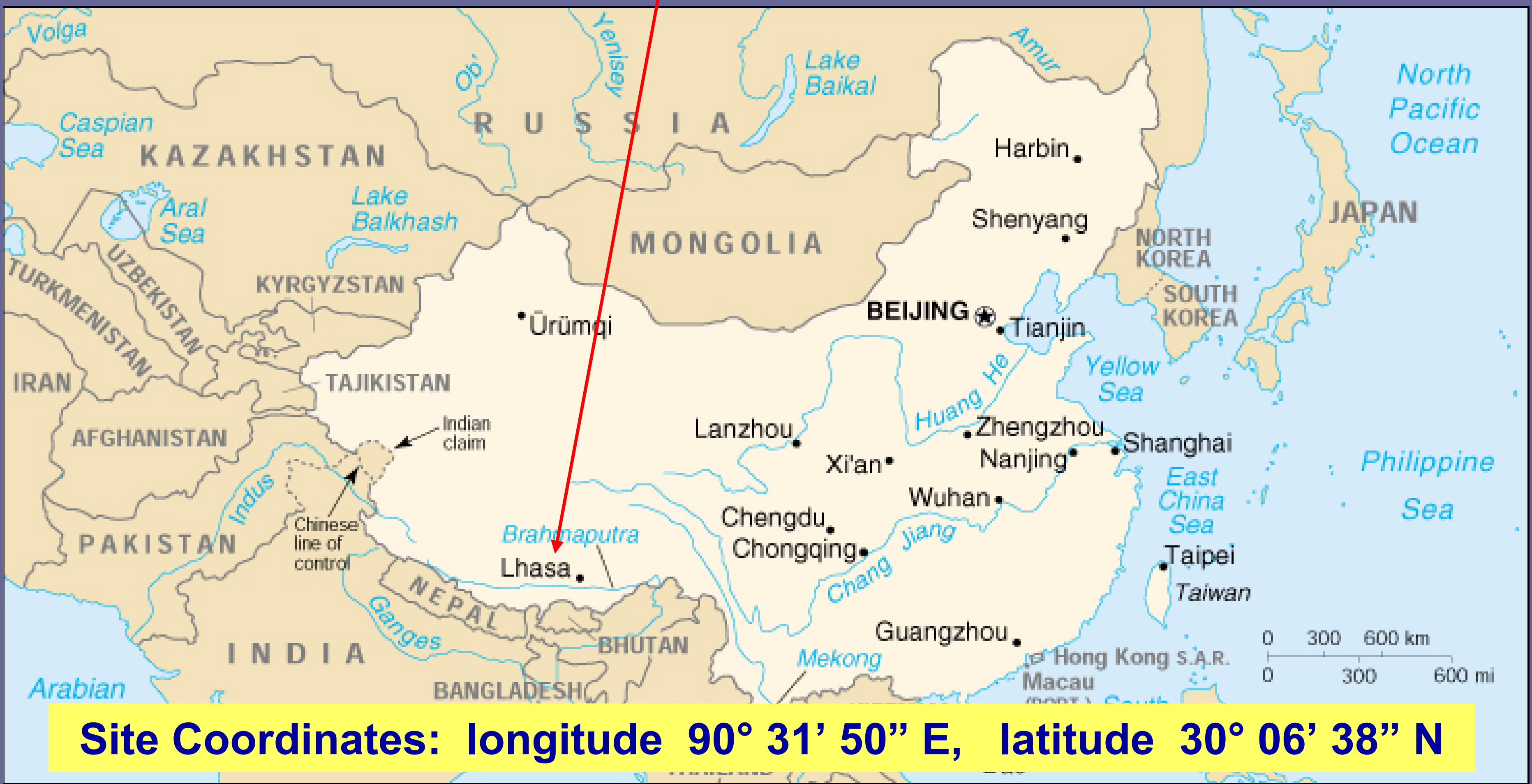
- Cosmic Rays and Motivations
- The Detector : Double Readout
- The Digital Detector Performance
- The Motivation for RPC Analog Readout
- The Analog Readout System
- Calibration and stability of the detector
- Checks and performance evaluation
- Conclusions

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

ARGO-YBJ

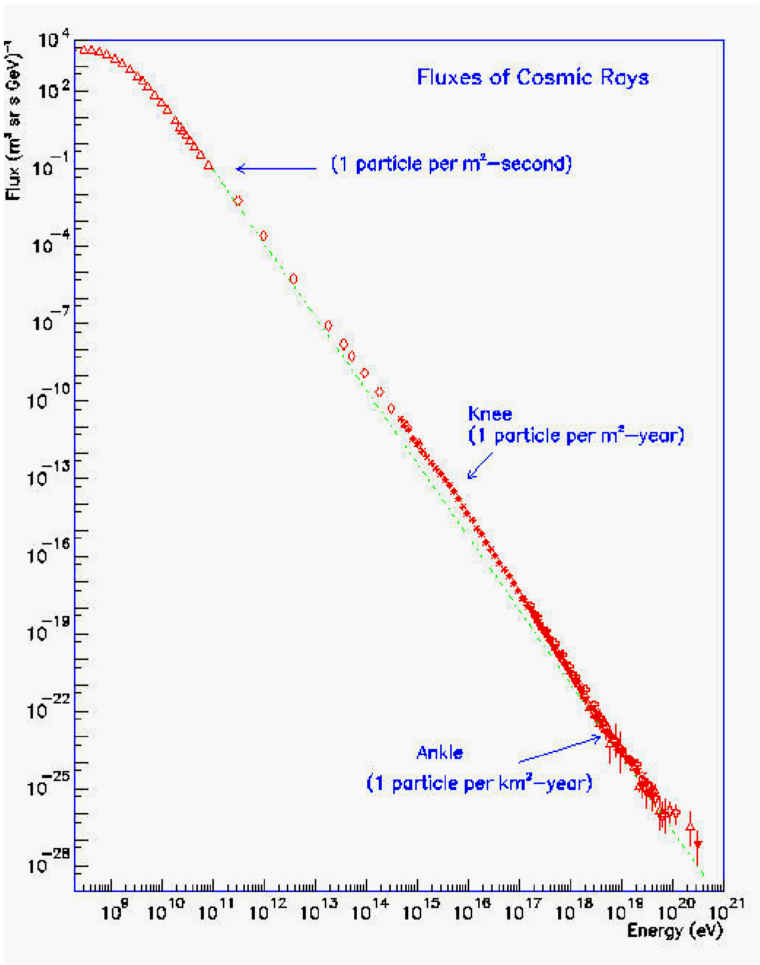



- **Collaboration between:**
  - **Istituto Nazionale di Fisica Nucleare (INFN) – Italy**
  - **Chinese Academy of Science (CAS) -China**
- **Site: YangBaJing Cosmic Ray Laboratory (Tibet, P.R. of China), 4300 m a.s.l.**



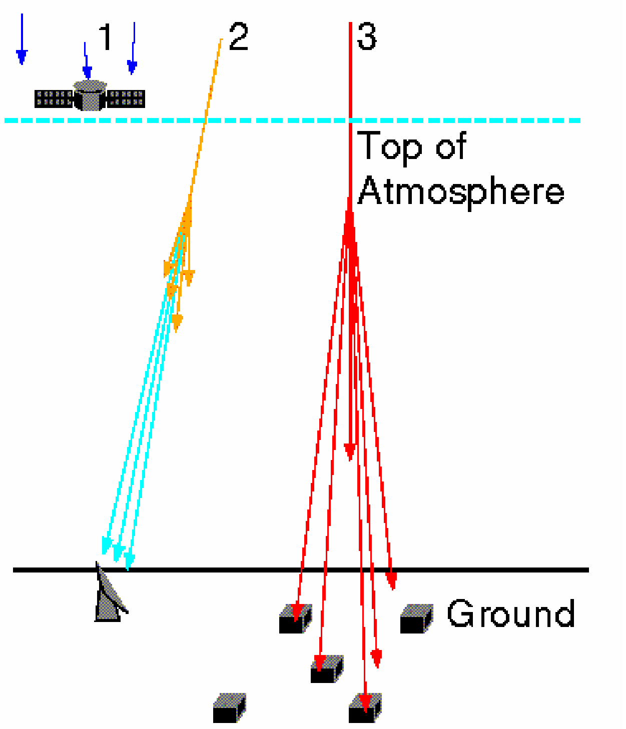
Site Coordinates: longitude 90° 31’ 50” E, latitude 30° 06’ 38” N

Cosmic Rays : Spectrum and Detection



Cosmic rays have an energy distribution extending over more than 12 decades, but frequencies are quite different.

At low energies, direct measurements can be performed at the top of the atmosphere by balloon experiments or satellite experiments



At higher energies, only indirect measurements are possible by ground based experiments

The basic concepts to lower the energy threshold

…an unconventional air shower detector

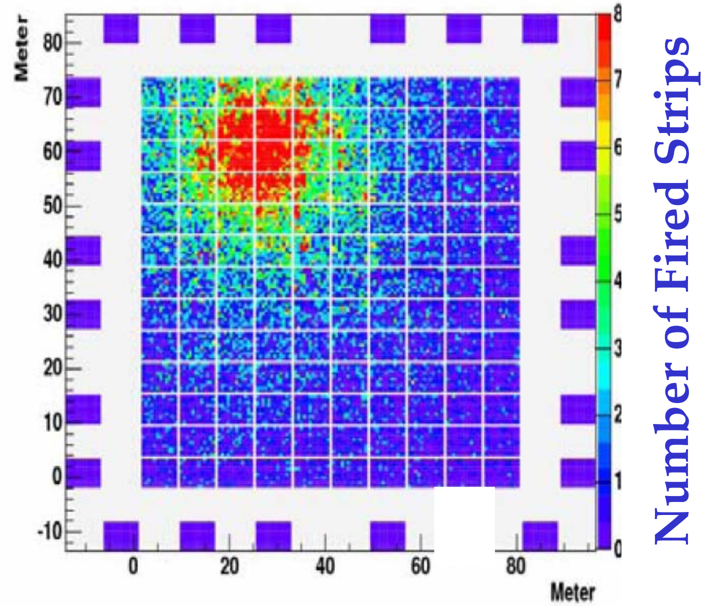
- ***HIGH ALTITUDE SITE***
  (YBJ - Tibet, 4300 m a.s.l, ~ 600 g/cm^2)

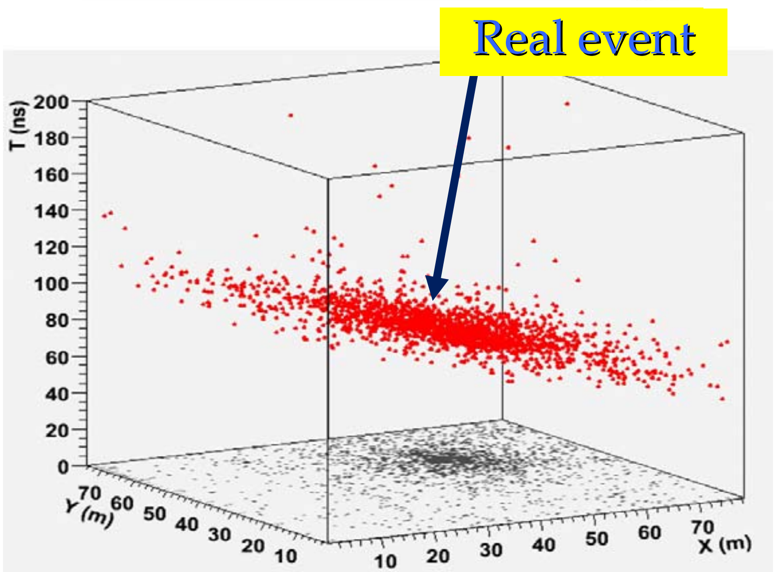
- ***FULL COVERAGE***
  (RPC technology, 92% covering factor)

- ***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)

Good linearity up to 200 TeV
Proton induced showers





ARGO-YBJ Physics goals

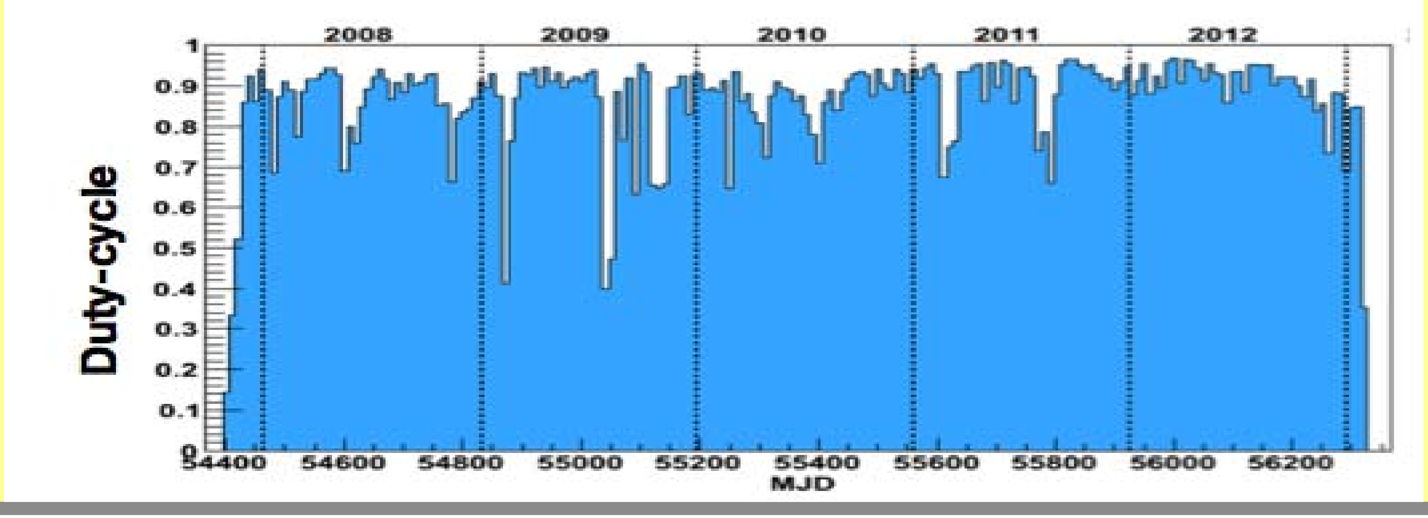
- **VHE γ Ray Astronomy:**
  - (search for)/(study of) point-like (and diffuse) galactic and extra-galactic sources with a few hundreds GeV energy threshold
- **Cosmic Ray physics:**
  - energy spectrum and composition
  - Study of the shower space-time structures
  - Flux anisotropies
  - P-Air cross section measurements and hadronic interaction studies
  - Antip-p ratio at TeV energies
  - Geomagnetic effects
- **Search for GRB's** (full GeV/TeV energy range)

through the …

Observation of Extensive Air Shower produced in the atmosphere by primary γ's and nuclei


Strip =SPACE PIXEL, 62 x 7 cm², 124800
Pad =TIME PIXEL, 62 x 56 cm², 15600
BigPad =CHARGE readout PIXEL, 123 x 139 cm², 3120 (central carpet)
Gas Mixture: Ar/ Iso/TFE = 15/10/75
Streamer mode. HV = 7200 V
Cluster = DAQ unit = 12 RPCs
σt≈1.8 ns, ε > 95 %
RPC
BigPad
Pad
Strip
BP Amplitude : mV to many Volts
110 x 100 m²
78 x 74 m²
ARGO DETECTOR

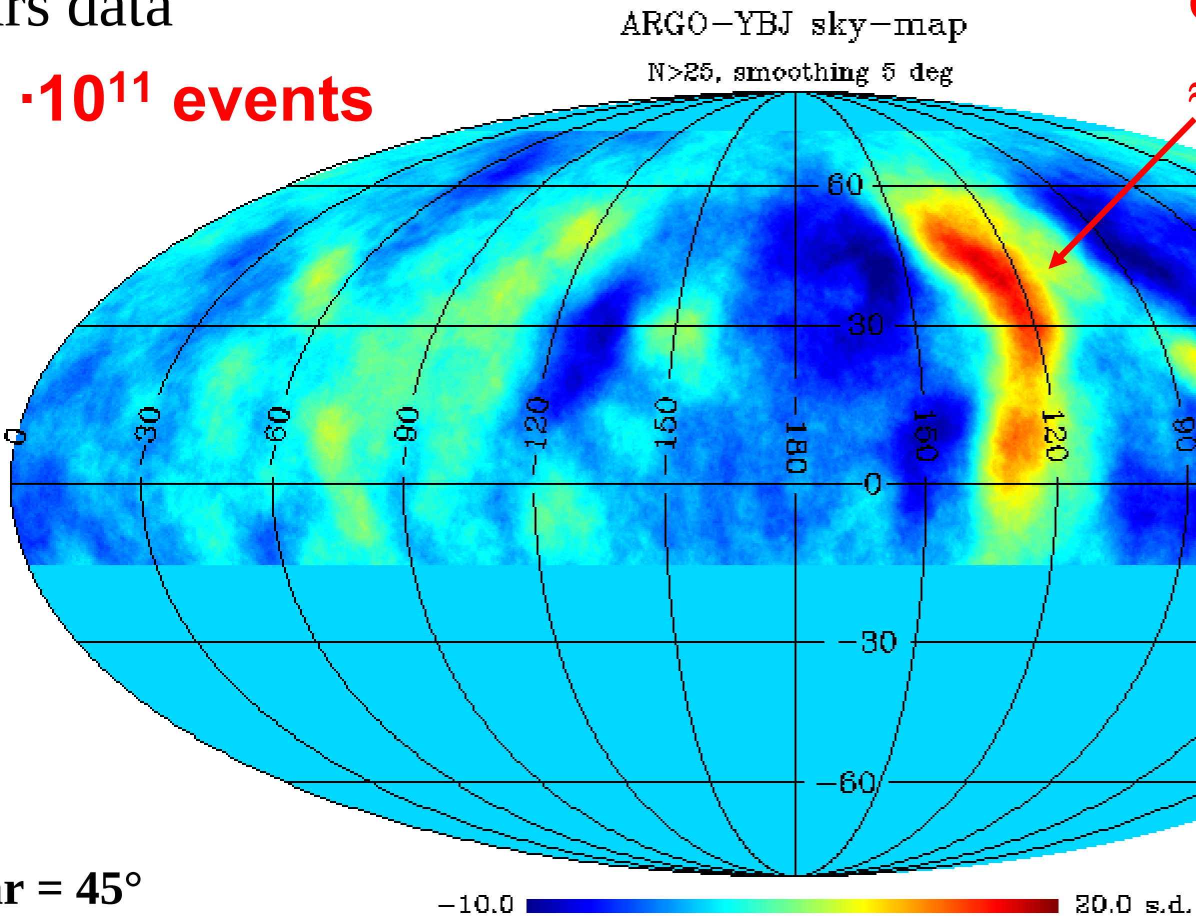
Status and performance

- In operation since July 2006 (commissioning phase)
- Stable data taking since November 2007 with final configuration
- End/Stop data taking: January 2013
- The average duty cycle ~ 85%
- Trigger rate ~3.5 kHz @ 20 pad threshold
- N. of recorded events ~ 5 10^{11} from 100 GeV to PeV
- Dead time 4%
- 

Stability (digital): Medium scale anisotropy

3 years data

~2.0 ·10¹¹ events



Cosmic rays excess

≈ 0.06%

≈ 0.1%

Δt =3 hr = 45°

$N_{PAD} > 25$

Proton median energy ≈ 2 TeV

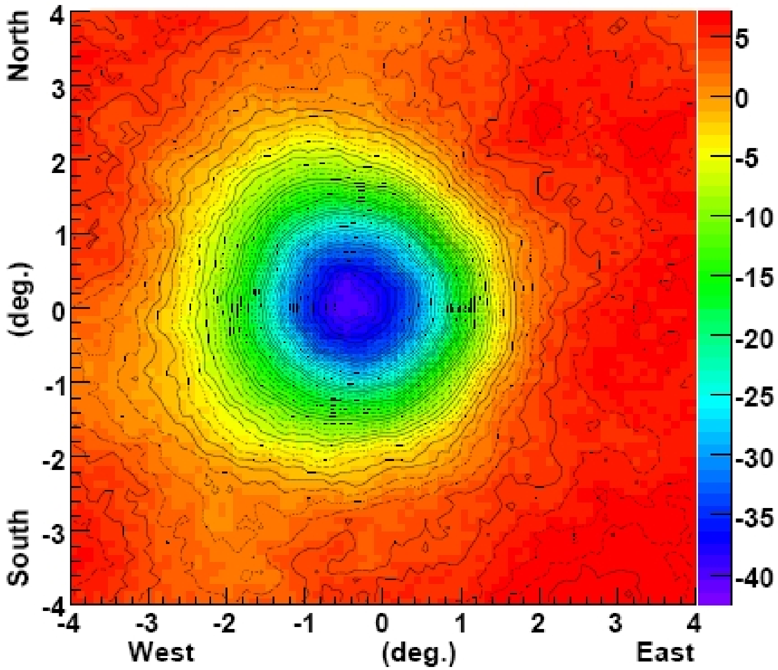
PRD 88 (2013) 082001

Smoothing radius = 5°

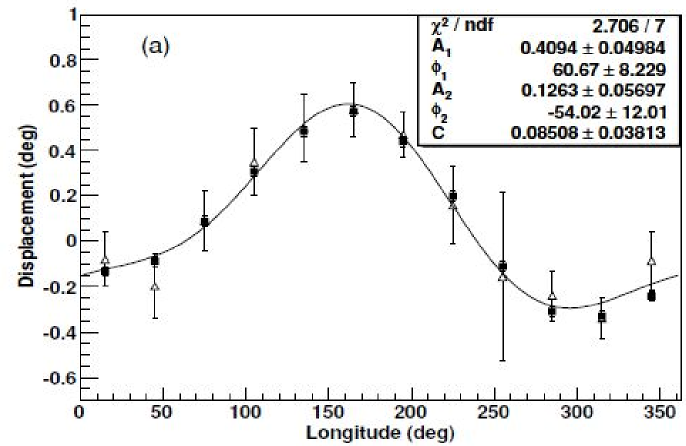
Stability (digital): The Sun shadow

Deficit: 45 standard deviations (903 days)

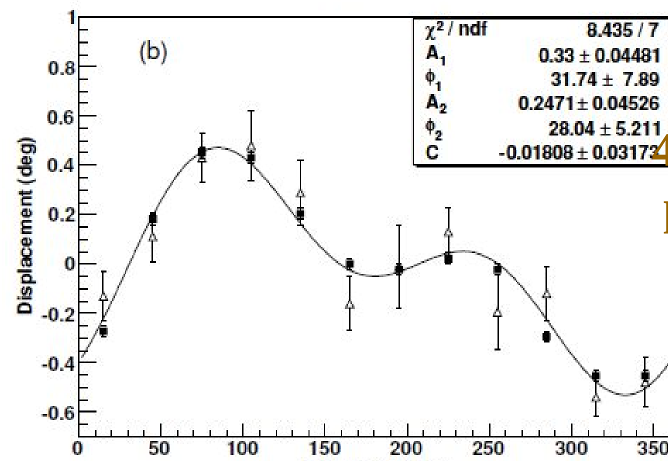
The position of the Sun shadow moves according to the IMF pattern



ApJ 729 (2011) 113)



Bisector pattern



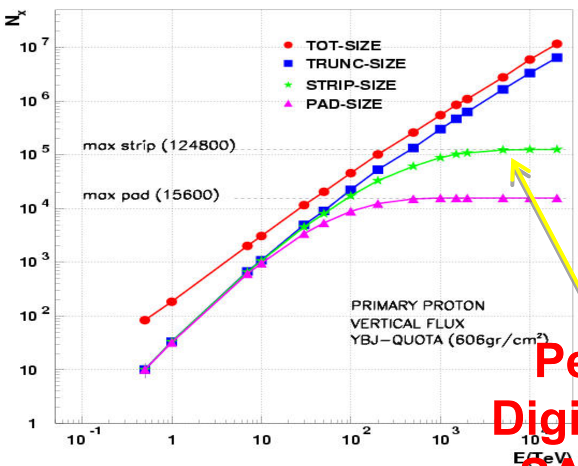
4-sector pattern

△ *data in 12 groups according to the Earth position (Carrington longitude)*

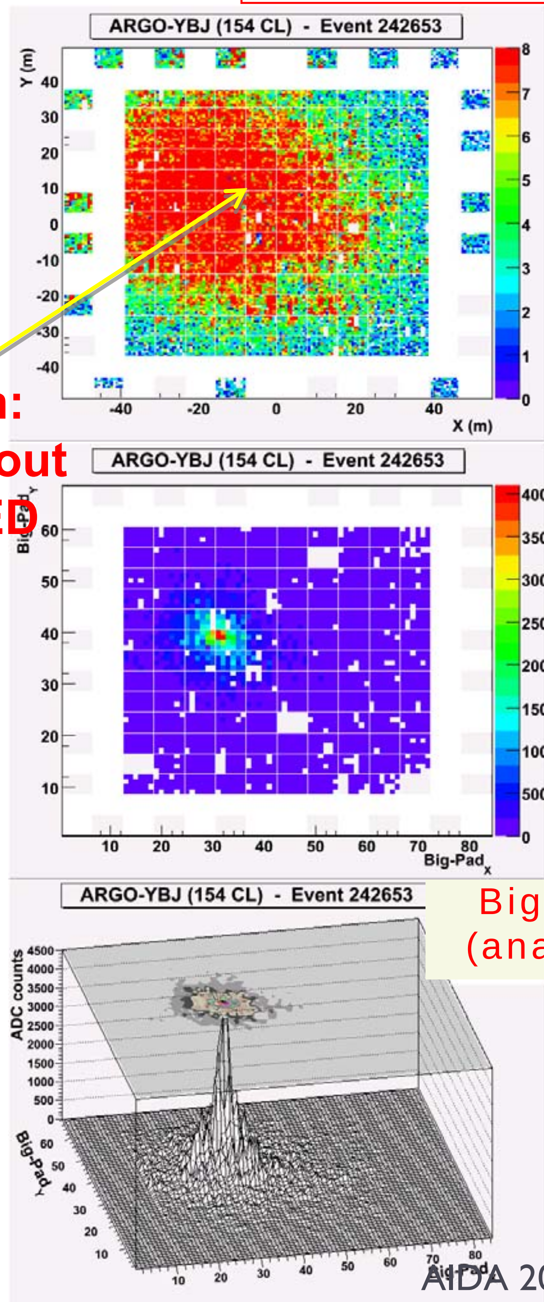
■ *expected displacement (IMF model, Amenomori 2000)*

The RPC Analog ReadOut

Real Event



PeV region:
Digital Readout
SATURATED



Strip (digital)

BigPad (analog)

To investigate the PeV region → ability to detect air showers with a secondary charged particles density of
~ 10^4 particles/m²

Different gain scales (G0,…, G7) used to cover a wide range in particle density:

$\rho_{max\_strip} \approx 20$ **part/m²**

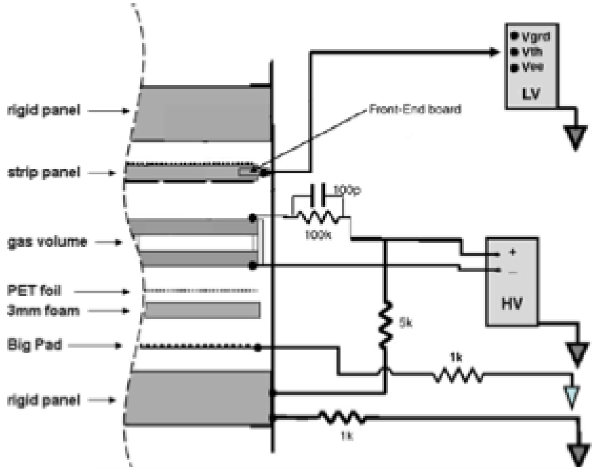
$\rho_{max\_analog} \approx 10^4$ **part/m²**

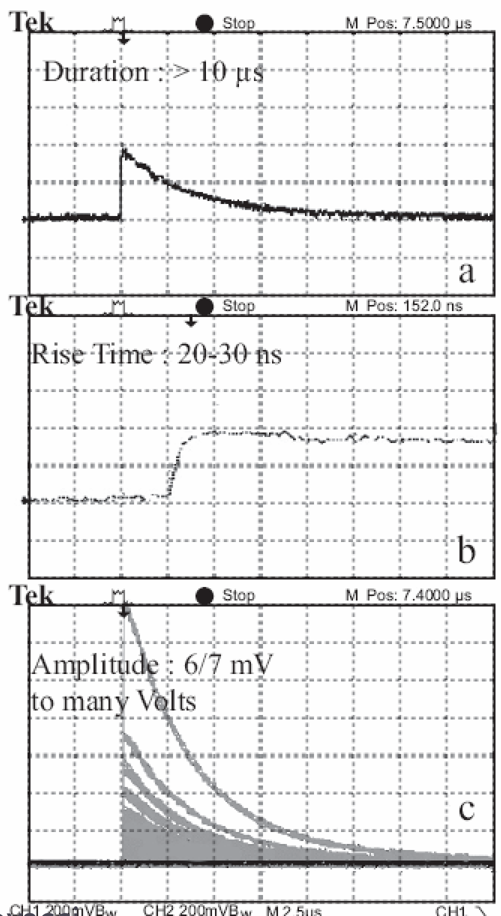
.. imaging of showers core with unprecedented resolution and detail:

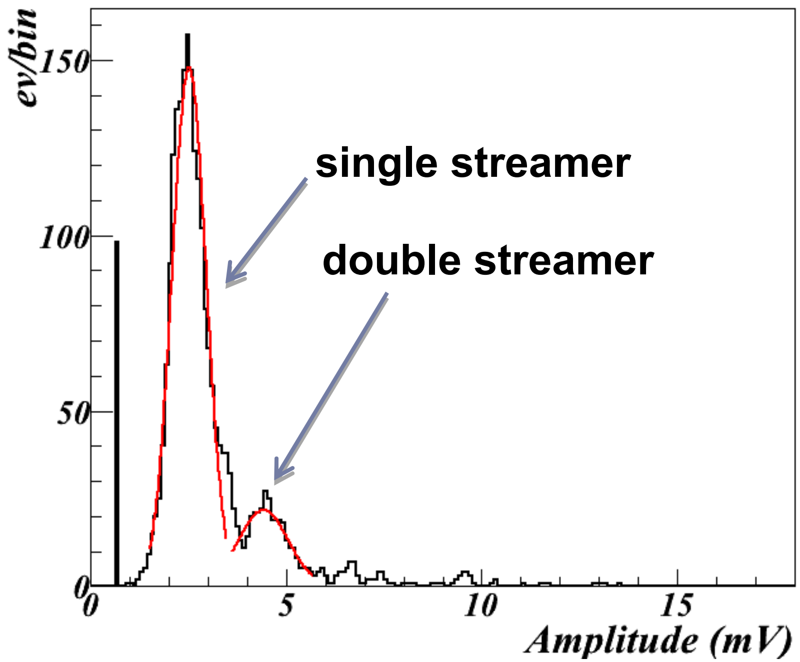
- ⌘Access to the **Lateral Distribution Function** (LDF)
- ⌘Sensitivity to **primary mass**
- ⌘Info/checks on **Hadronic Interactions**

The BigPad Signal

Signal characteristics







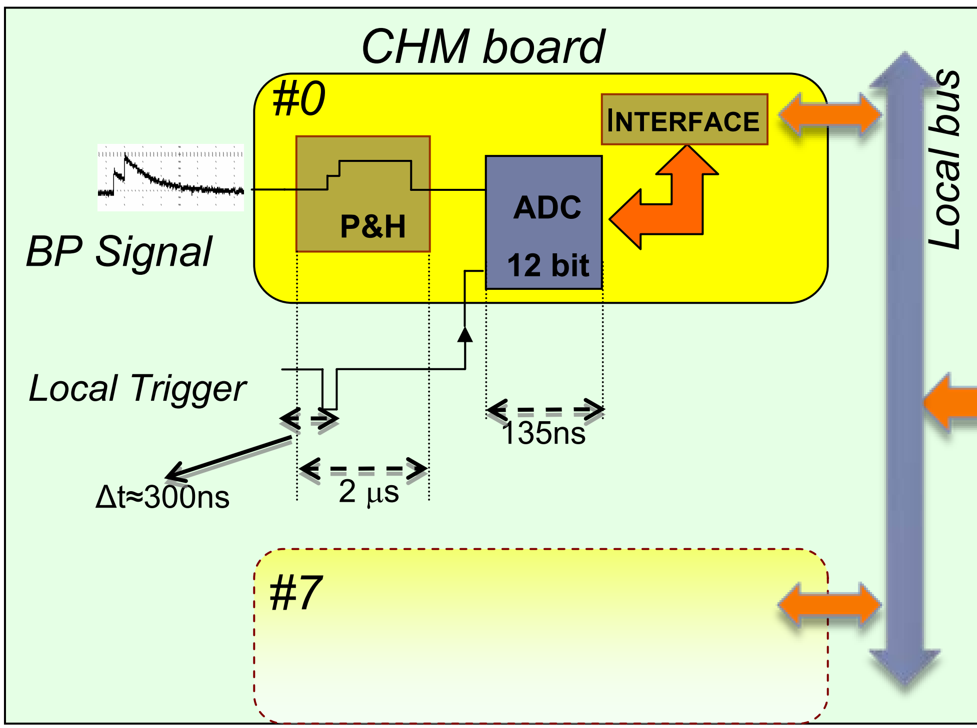
Amplitude distribution of the Big Pad signals induced by m.i.p., at 7.2 kV, as measured at the experimental site of YangBaJing . The pedestal (the BP electronic noise) as well as the single and double streamer peaks are clearly visible. The two curves represent the best gaussian fits to the first and second peak of the distribution.

→ $\sigma_{Amplitude}$(1 m.i.p) ≈ 20%

The analog ReadOut System

- ≈ 3200 ch. on a large area suffering a big variations of the environmental parameters (P and T)
- wide range: ρ 10 ÷ 2 * 10^4 particles/m^2 => mV to many Volts
- signal timing

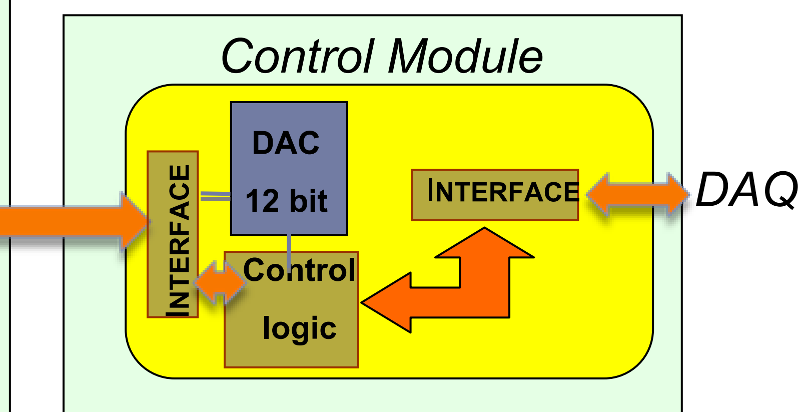
The *Local Trigger on each Cluster* is based on an high multiplicity (≥73 part.)



The basic ReadOut System (MINICRATE) has 2 identical sections; each one is independent and manages 1 Cluster:

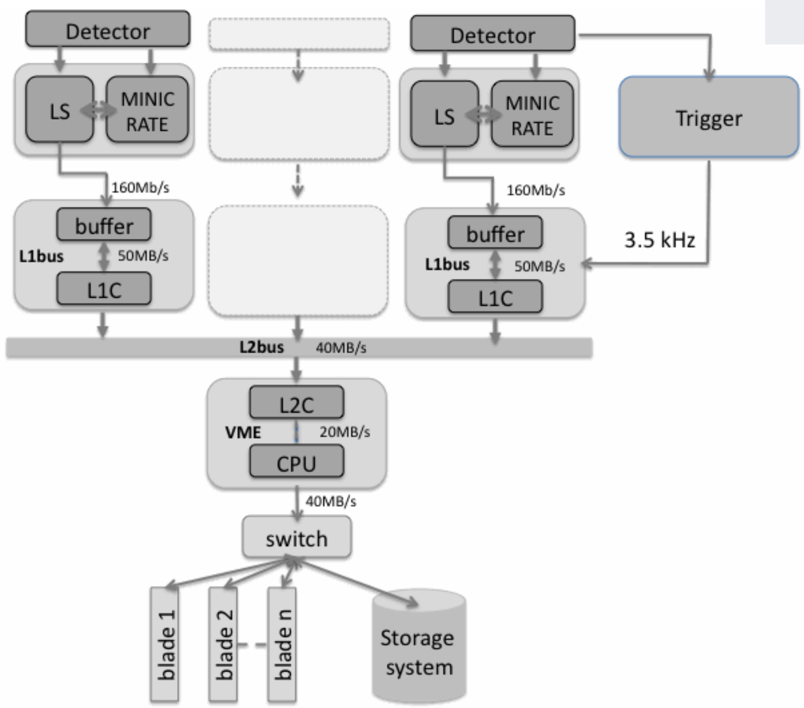
◆ 3 ***CHargeMeter*** (CHM) boards for the processing of 8 BP channels:
- -Shaping
- -Linear amplifier
- -Peak & Hold
- -12bit ADC (AD7472, 1.9 LSB DNL) by Analog Devices

◆ 1 ***Control Module*** to manage the interface with the DAQ, Configuration and Calibration:
- -12bit DAC (DAC902 with a 0.5 DNL)
- -FPGA

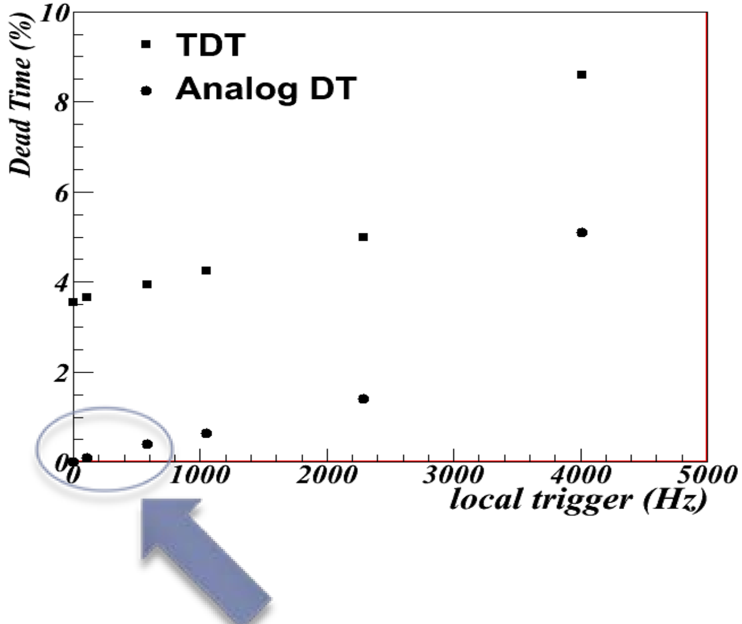


The data flow

trigger	condition	action	issued	rate
Local trigger	>73 pads/Cluster	ADC conversion	LS	20 Hz
Global trigger	>20 pads/Carpet	Analog data readout	Trigger System	3.5 kHz



A test to study the contribution of the analog data readout to the Dead Time (DT) has been done.

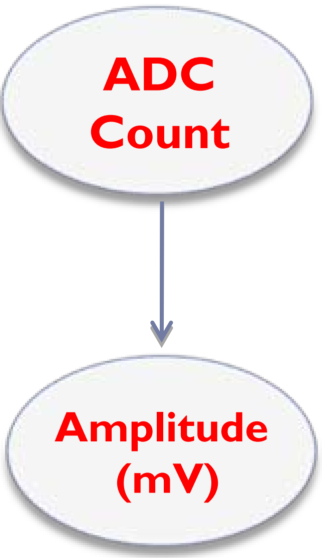


- DAQ based on a two-layer read-out architecture implementing an **event-driven** data collection by using two custom bus protocols, based on VME-bus.
- It sustains a data transfer rate peak of 40 MB/s. The average rate is ≈ 7 MB/s.
- The **Analog data frame**:

  1 MINICRATE section → Local Station (LS) synchronized by the global trigger

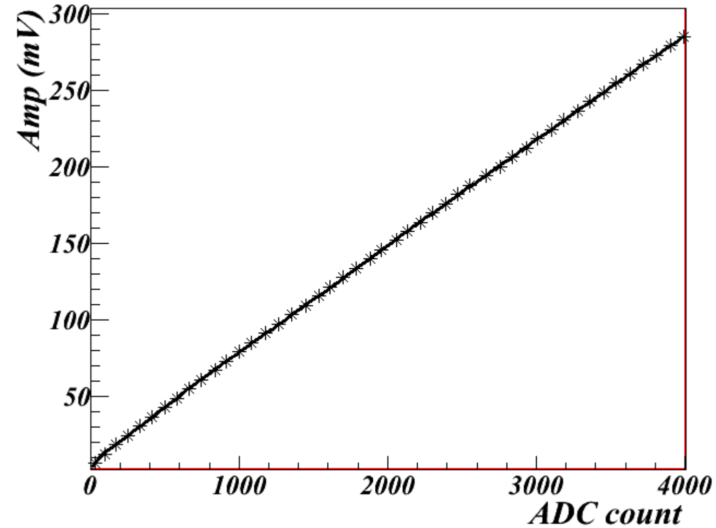
Analog Dead Time <2% of Total DT (local trigger < 20 Hz)

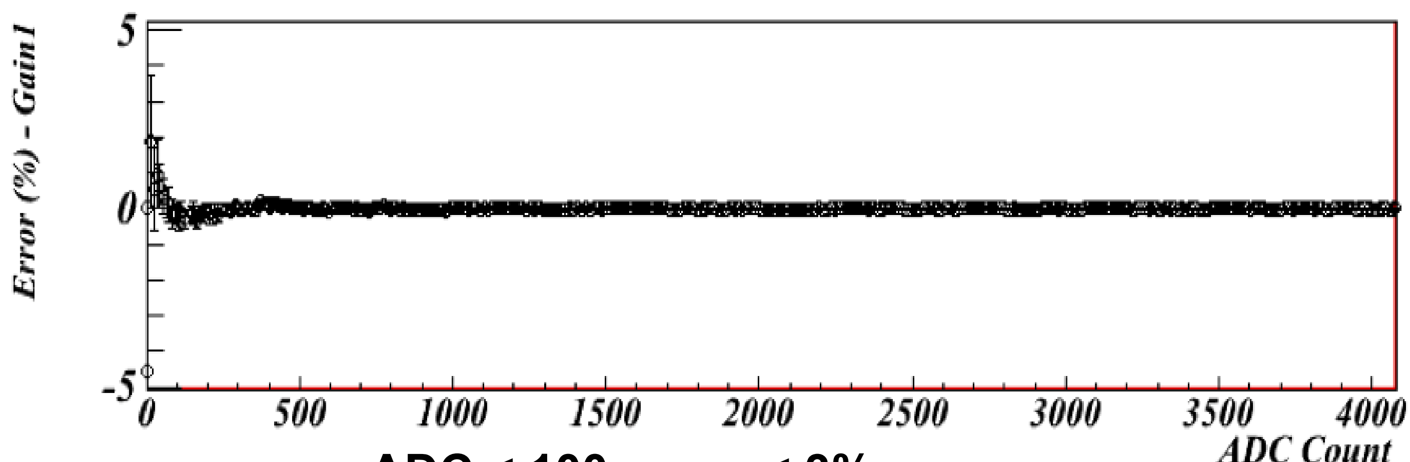
The Calibration Procedure : electronics



Electronic Calibration

- Calibration Runs are managed by RunControl
- Issued periodically → time stability < 1%
- Functional Fit Amp_DAC vs ADC_cnt





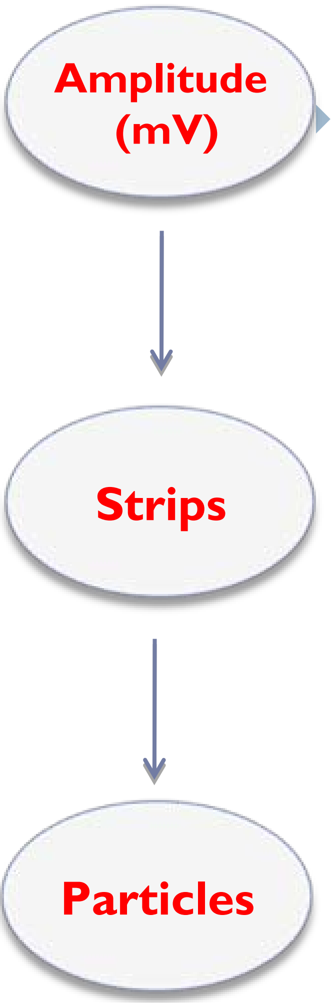
ADC < 100: error < 3%

ADC >100: error < 1%

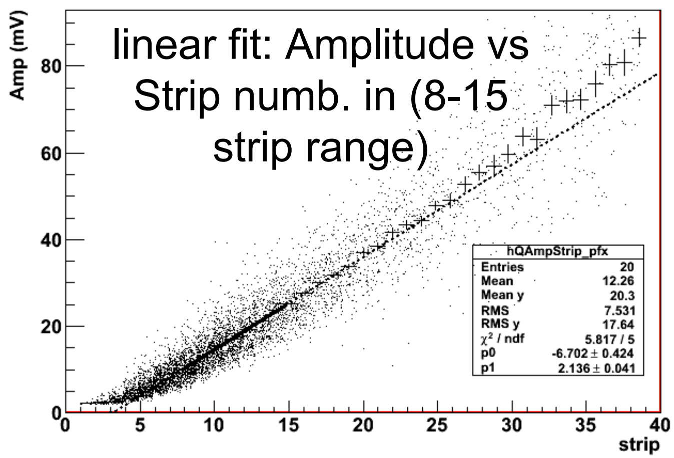
The Calibration Procedure : Gain

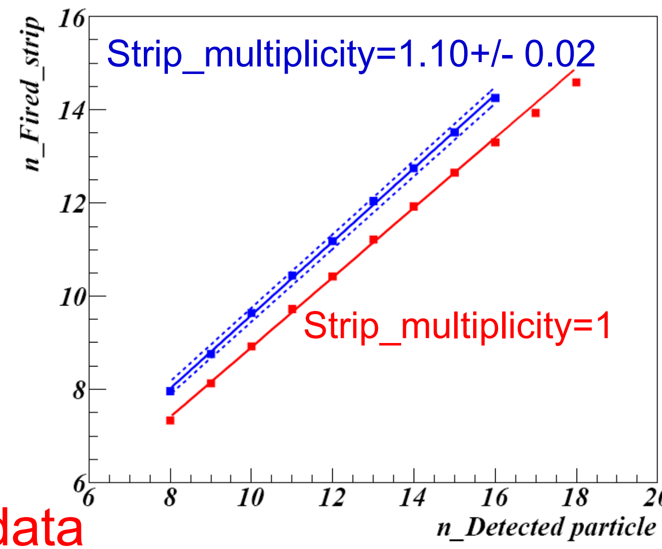
Gain Calibration: from the amplitude to the number of particles on the BP

$$G(mV/particle) = \frac{\Delta Amp(mV)}{\Delta n_{fired-strip}} \times \frac{\Delta n_{fired-strip}}{\Delta n_{detected-particle}}$$



- For each BP:direct comparison between Amplitude of the analog signal and number of fired strips (digital information). With the most sensitive scale (at most ≈ 150 particles on the BP)





G: stat. error ≈ 2% in 1 hour data

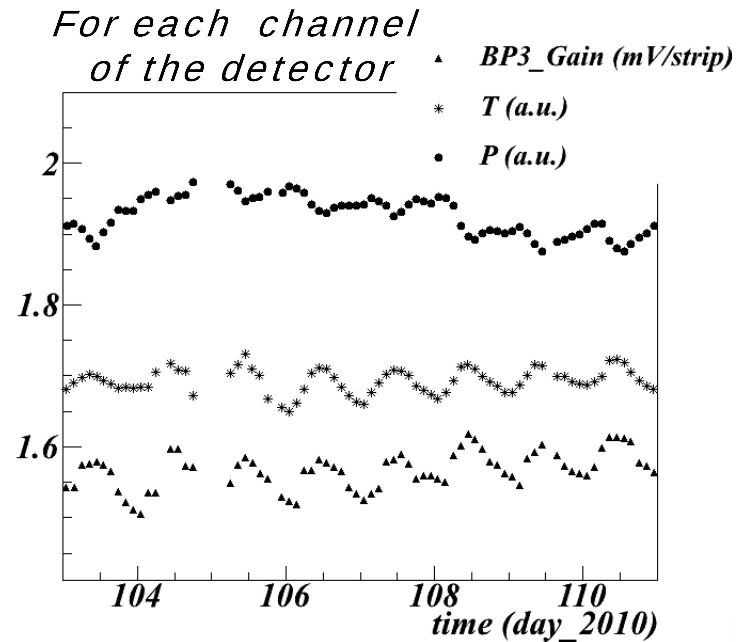
- from MC simulation & data the relation between strip fired and particles can be obtained

→ $\varepsilon_G = (2.3\%)_{stat} + (3.8\%)_{sys}$

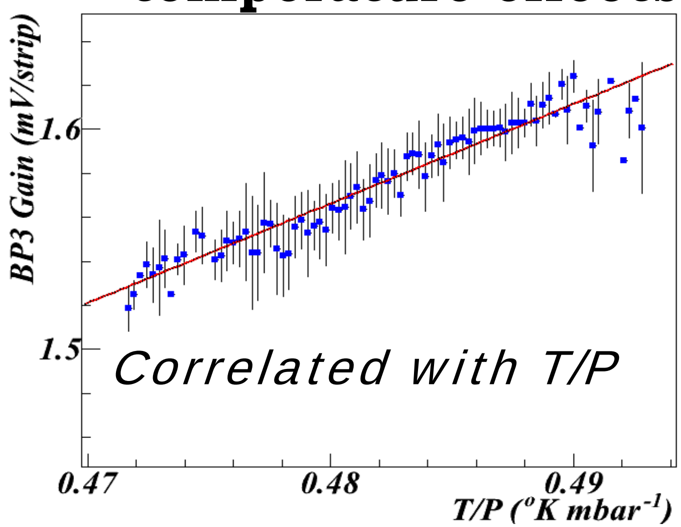
Gain Monitoring

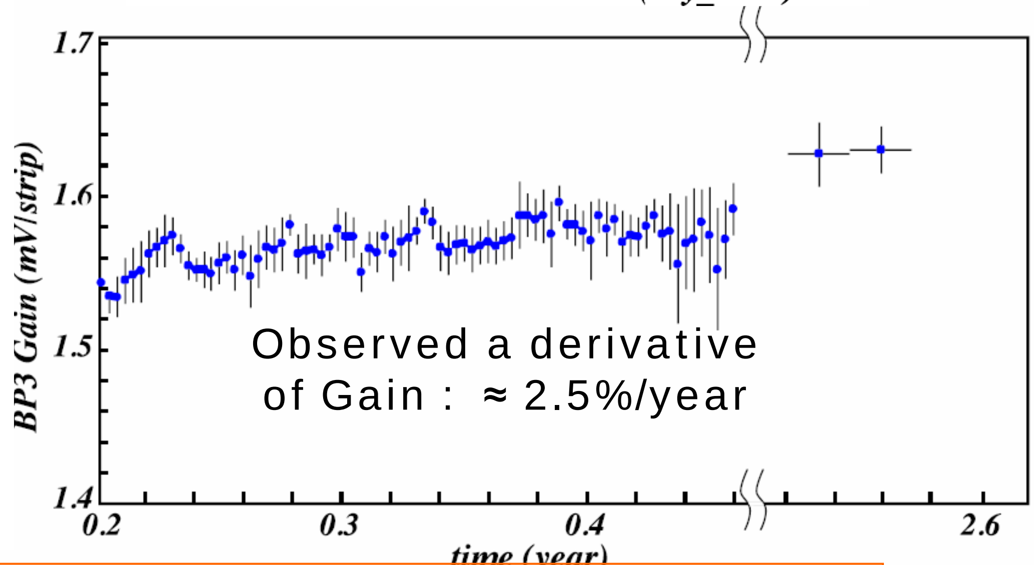
The Gain values have been monitored to study the environmental dependence:

- environmental parameters: T (±0.25°C) and P (±0.5 mbar) by DCS



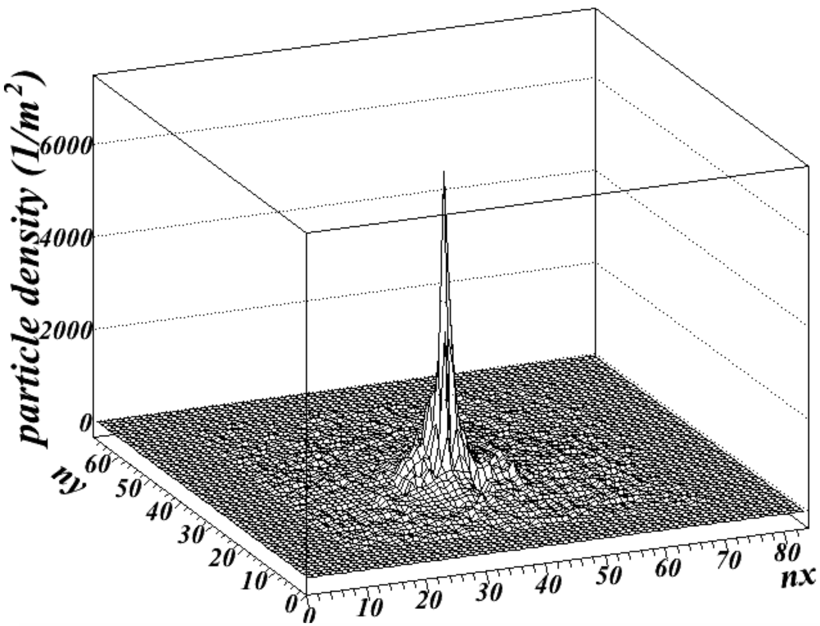
Correction for pressure and temperature effects



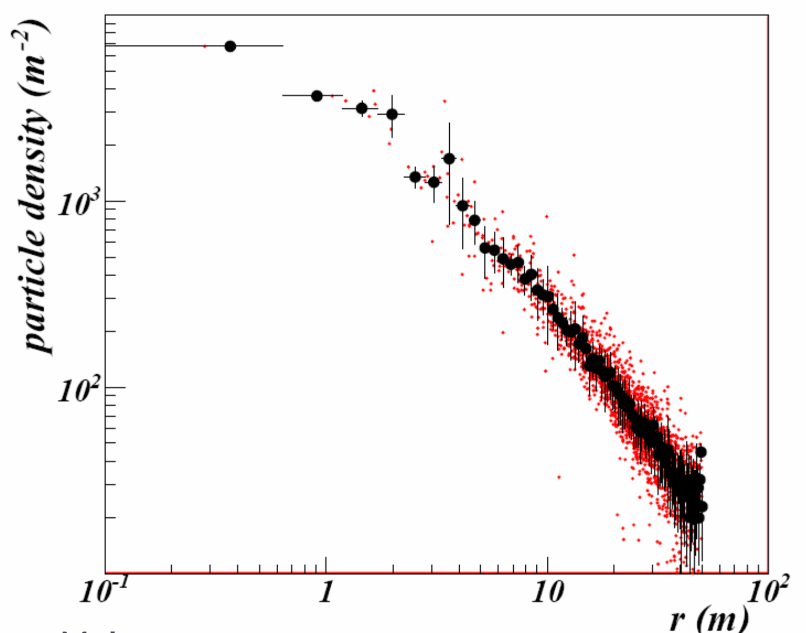


The other scales can be calibrated using the Gain7 values applying then the PT correction on a run by run base.

A Shower Event



Shower as recorded by ARGO-YBJ through the analog readout system. According to Montecarlo simulations, the shower would correspond to a primary proton of about 2 PeV. In the vertical scale is reported the particle density measured in the BigPad, whose area is about 1.7 m^2. nx and ny are the coordinate of the BigPad. The area with low particle counts corresponds to the central carpet (78x74 m^2)}.

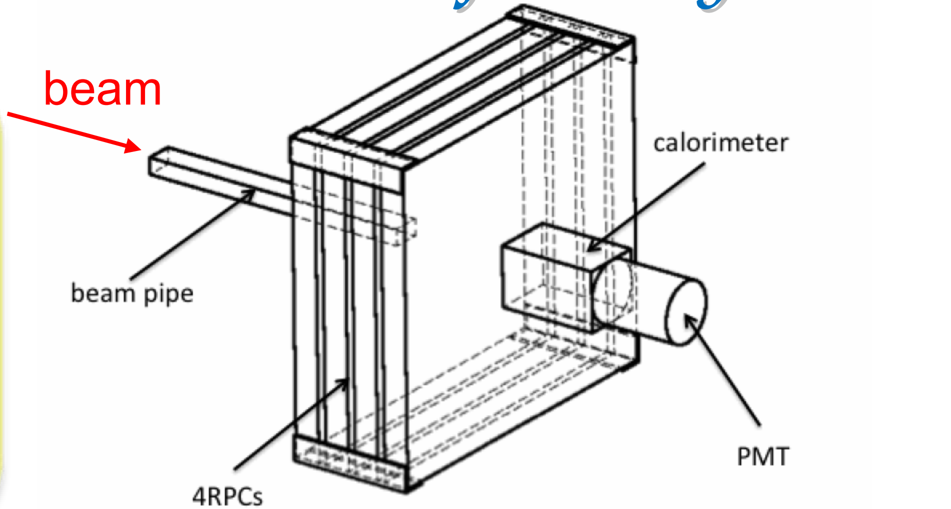


Lateral distribution of the particle density for the event shown in the above figure .The red point are the measured density of particles on the BPs, while the black points are the mean values (+/- r.m.s.) of the particle density measured in bins of distance, 0.5 m wide, from the shower core.

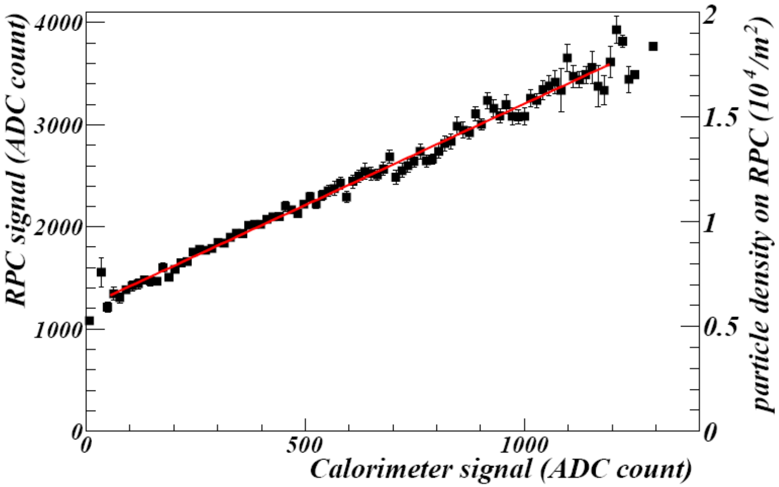
Intrisic linearity: test at the BTF facility

Linearity of the RPC @ BTF in Frascati:

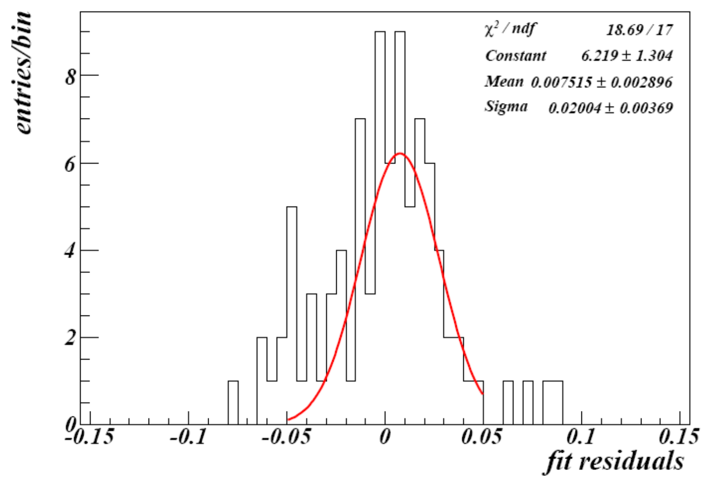
- *electrons (or positrons)*
- *E = 25-750 MeV (0.5% resolution)*
- *$\langle N \rangle = 1 \div 10^8$ particles/pulse*
- *10 ns pulses, 1-49 Hz*
- beam spot uniform on 3*5 cm^2



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



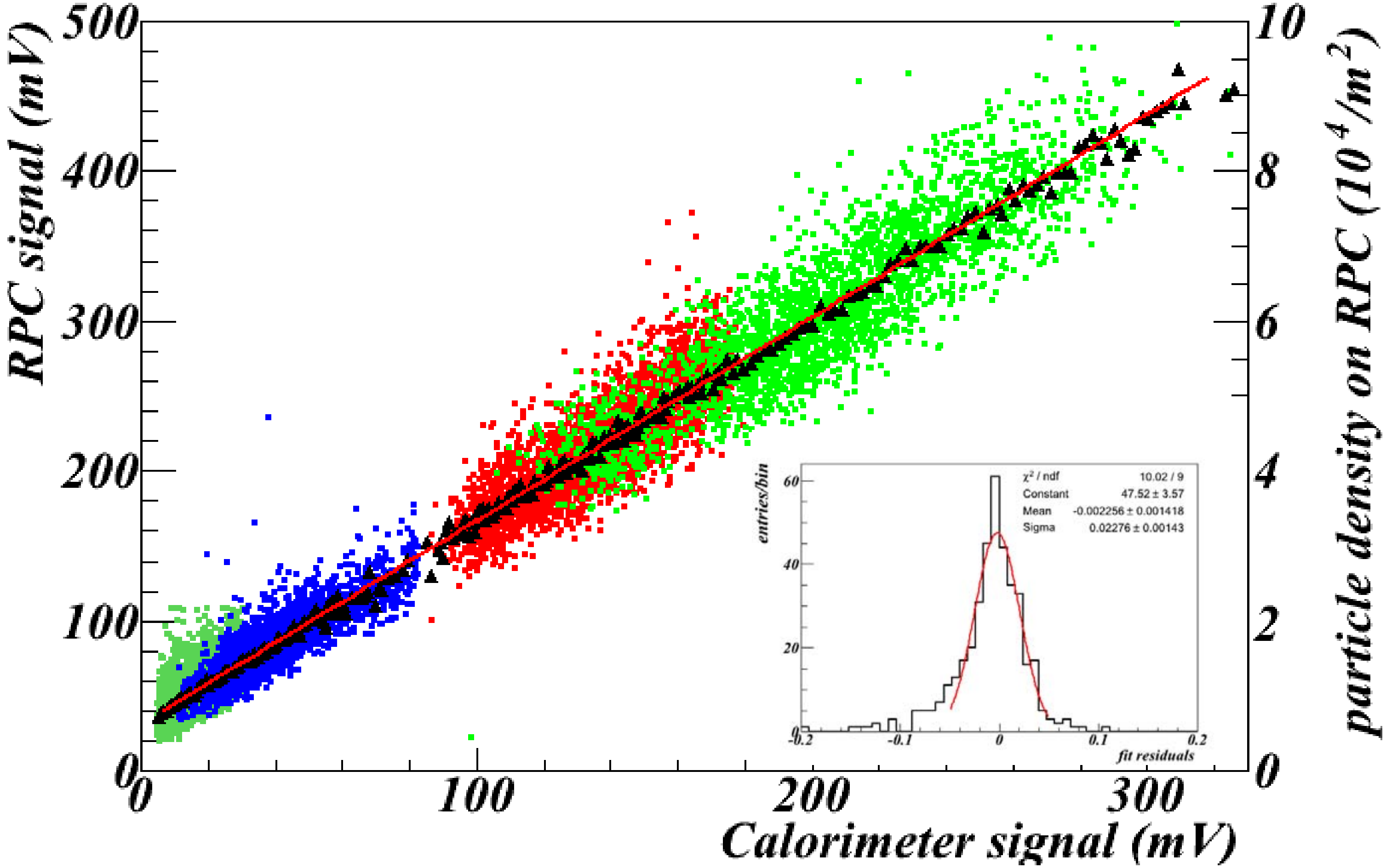
The RPC signal vs the calorimeter signal



Normalized residuals: the gaussian fit to the distribution → no deviations from linearity

→ Linearity up to ≈ 2 10^4 particle/m^2

Intrisic linearity: test at the BTF facility (2)



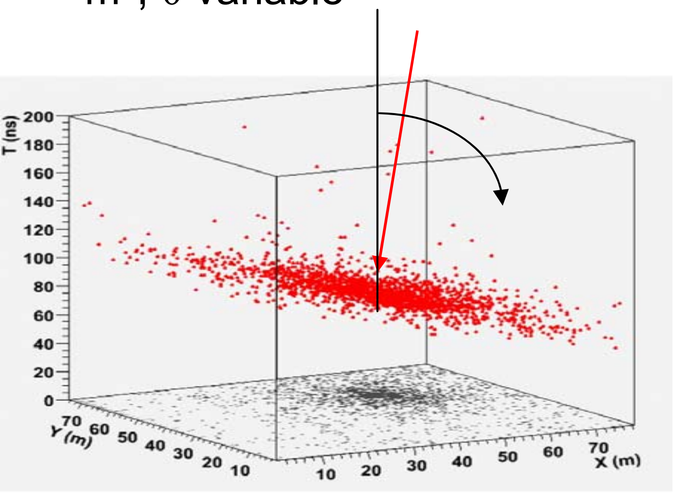
The RPC signal vs the calorimeter signal

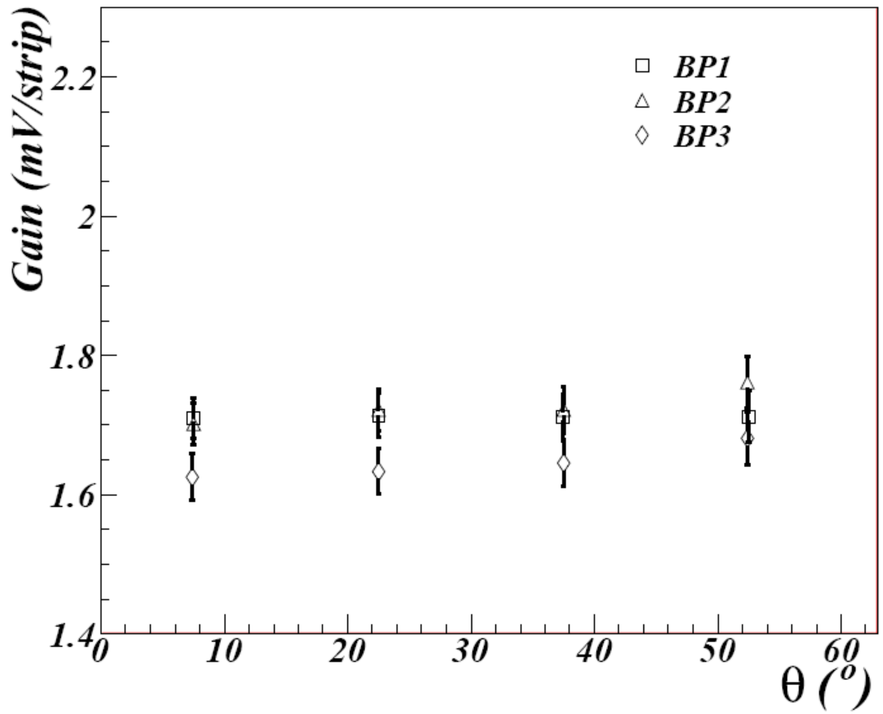
Normalized residuals: the gaussian fit to the distribution → no deviations from linearity

→ *Linearity up to ≈ 8 10^4 particle/m^2*

Gain: θ dependence

Events selected with core in a fiducial area of 2400 m^2, θ variable





Gain (mV/strip) versus incidence angle θ of the shower, with respect to the zenith, for a few BPs.

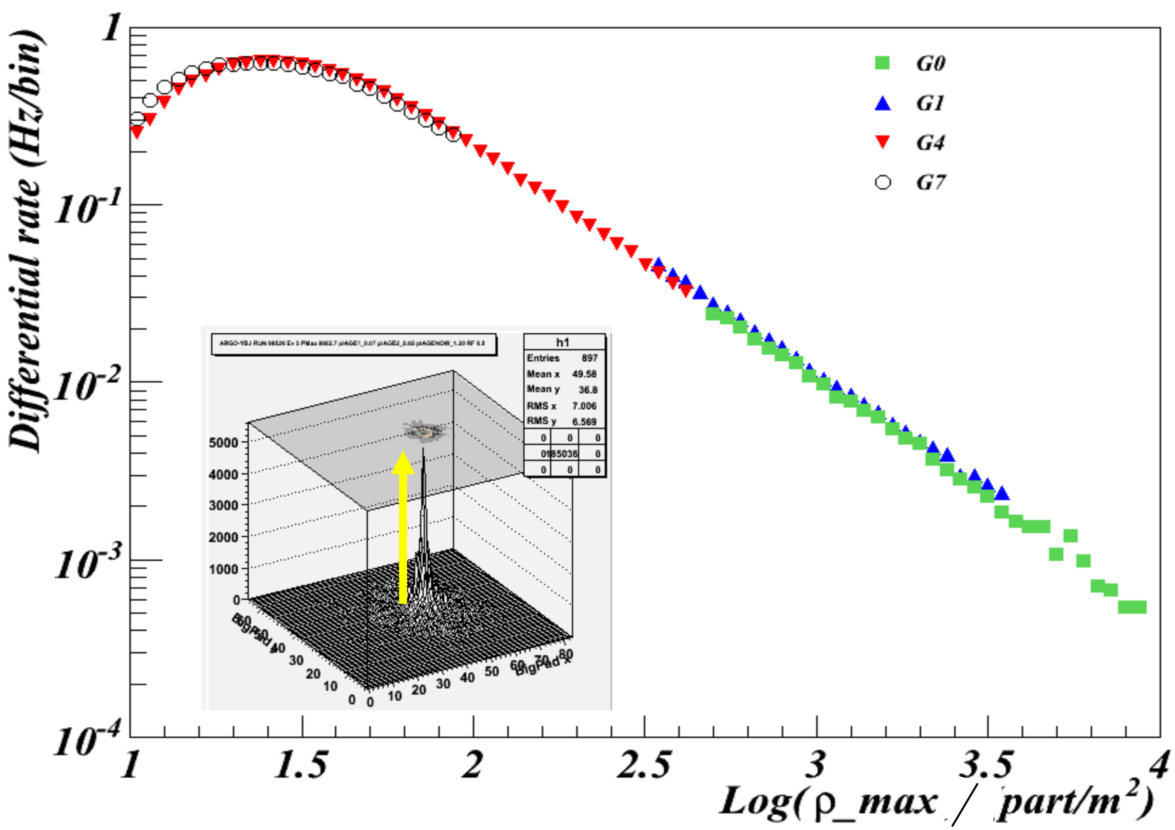
Checks and performance evaluation

<u>**4 data sample:**</u>

ρ : 10 → 10^4 part/m^2

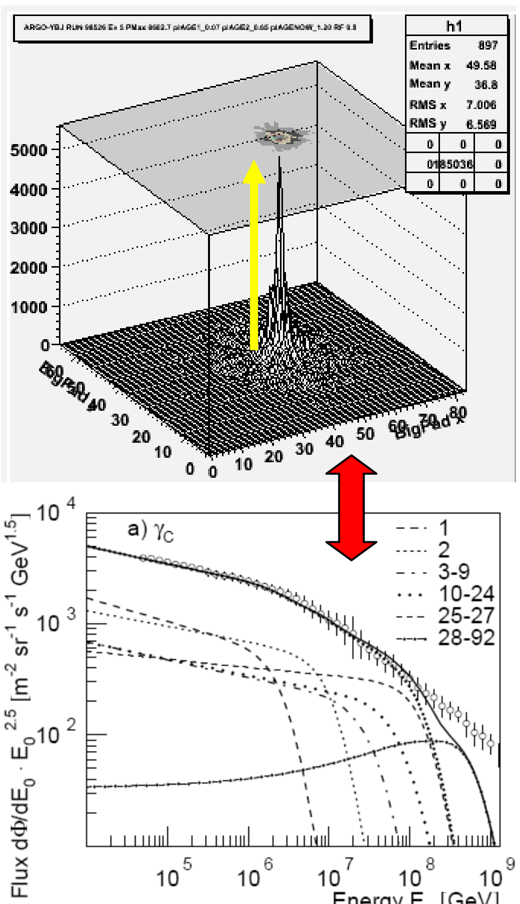
Event selection:

- **Core reconstructed in a fiducial area of 2400 m^2 ;**
- **Zenith angle < 15°**

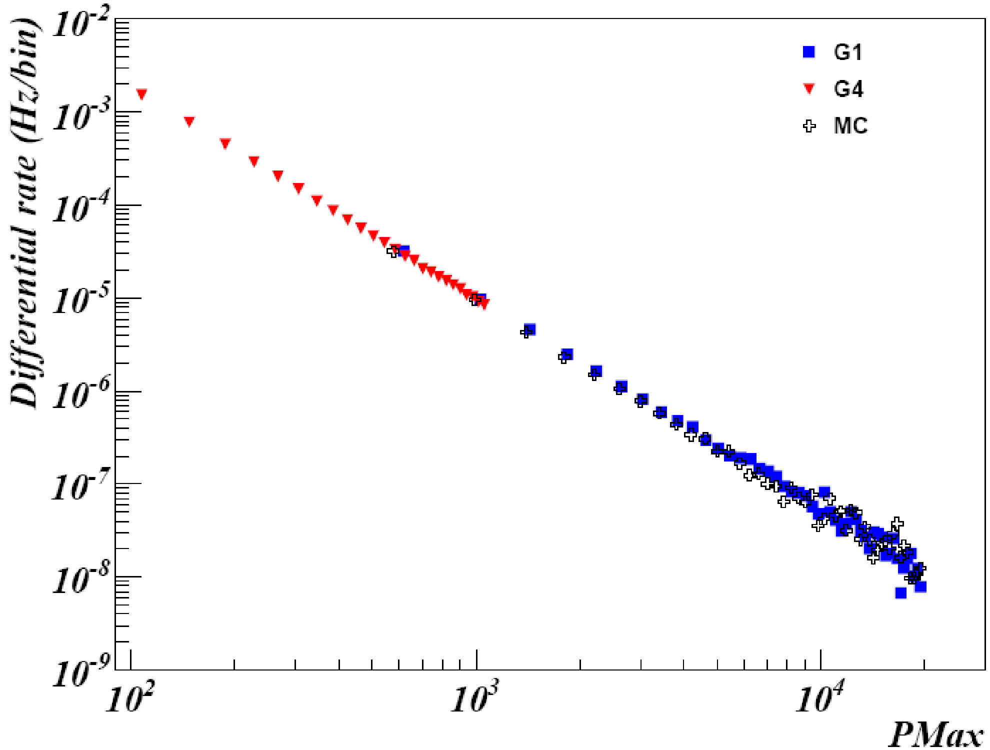


Good overlap between 4 scales with the maximum density of the showers spanning over three decades

Absolute comparison Data-MC



J.R. Horandel , Astroparticle Physics 19 (2003) 193-220



Differential rate of the shower density at core, PMax, for events with core in a fiducial area of the carpet (2400 m^2) and θ<15° showing a very good matching between different scales The results from a Montecarlo simulation are shown for comparison.

Conclusions

Very good stability and performance of the digital detector (low energies).

The analog RPC detector of ARGO-YBJ (3200 pixels):

- each pixel is instrumented to count the number n of charged particles with a resolution $20\%/\sqrt{(n)} + 4.4\%$ where the first term is related to the fluctuation of the streamer formation in the gas gap of the RPC, while the second term accounts for the uncertainty in the absolute calibration functions and control of the environmental parameters. As far the long-term stability of the detector, the m.i.p. signal shows a mean variation of of +4.3%/year;
- the dynamic range of each pixel extends as far as particle densities of $8 \times 10^4/m^2$ and more, allowing to measure the number of charged particles around the core of air shower from PeV primaries with an accuracy $< 5\%$;
- the performance of this device does not depends on the air shower incidence angle at least up to 50 degrees.

For future applications:
Some more attention has to be payed to the gas supply system;
Need for HV stabilization with respect to the environmental parameters
Some decrease of performance observerd at level of 1-2%/year

Given the site characteristics and the very low assistance during data taking, the detector has operated very smoothly and with great success.