The RPC in the astroparticle physics of the next future

RPC 2022 workshop

CERN 26-30 Sep 2022

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Collider vs cosmic ray physics

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- Why to talk of Cosmic Rays in the most important accelerator laboratory in the world?
- A personal idea: is it conceivable that strong, electroweek and gravitational forces are experimentally studied on the same floor?
- Cern has illustrious precedents/programs in combining collider and CR physics inside the same detector: LEP is one and in the next future Mathusla plans to combine the search for long living weekly interacting neutral particles with the search of CR in the range of energy 10^13 – 10^17 eV.
- This experiment will require a RPC plane of 10^4 m^2, dedicated to the CR physics, that will integrate 7 planes of scintillator trackers. It will be extensivery illustrated by the J. C. Arteaga in this workshop

The most relevant astrophysical points where our community can contribute

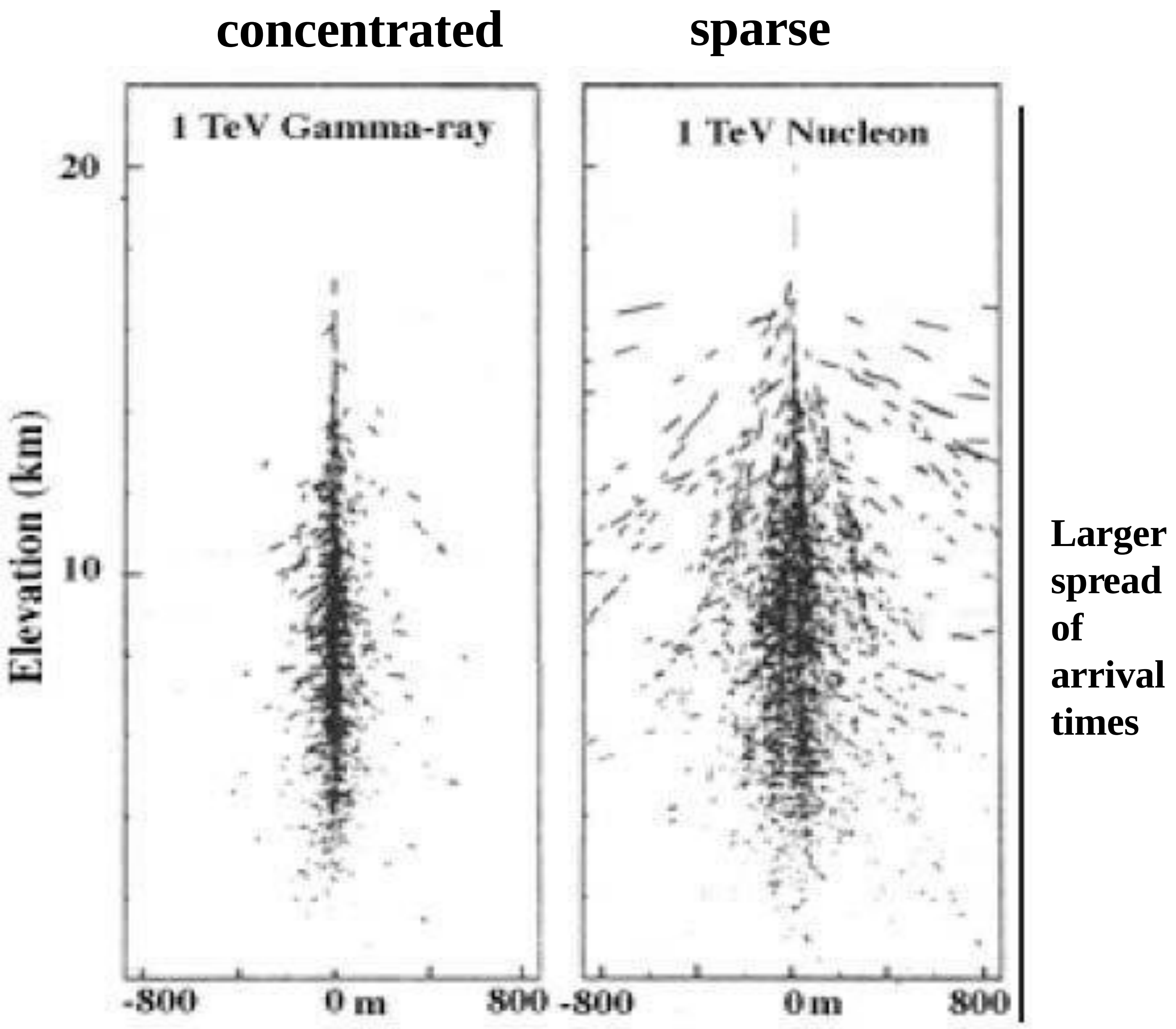
- Recent discovery by Lhaaso of 1 PeV !!! photons emitted by well known sources Crab….→ requires a substantial revision of our ideas about cosmological PeVatrons
- Even more interesting: the emission of Gamma Ray Bursts (GRB) by gravitational collapses, where an energy equivalent to the Sun mass can be irradiated in a very short time
  - Concidence witha possible gravitational wave arrival!
  - GRB time profile: very high at flux and low energy (MeV) at the beginning; very high energy (TeV) and low flux at later times (1-2days)
- Can we give a relevant contribution in this physics?

Detectors for collider and cosmic ray physics

- The RPCs are widely employed in accelerator particle physics. Conversely, concerning cosmic ray physics, Argo was the only ground-based experiment which used this detector in a very extensive way. The brilliant results published by this experiment encourage to propose RPCs for further experiments
- This talk will show examples of RPC based detectors conceived for gamma ray astronomy and cosmic ray physics
- It will also show how to optimize RPCs for this purpose

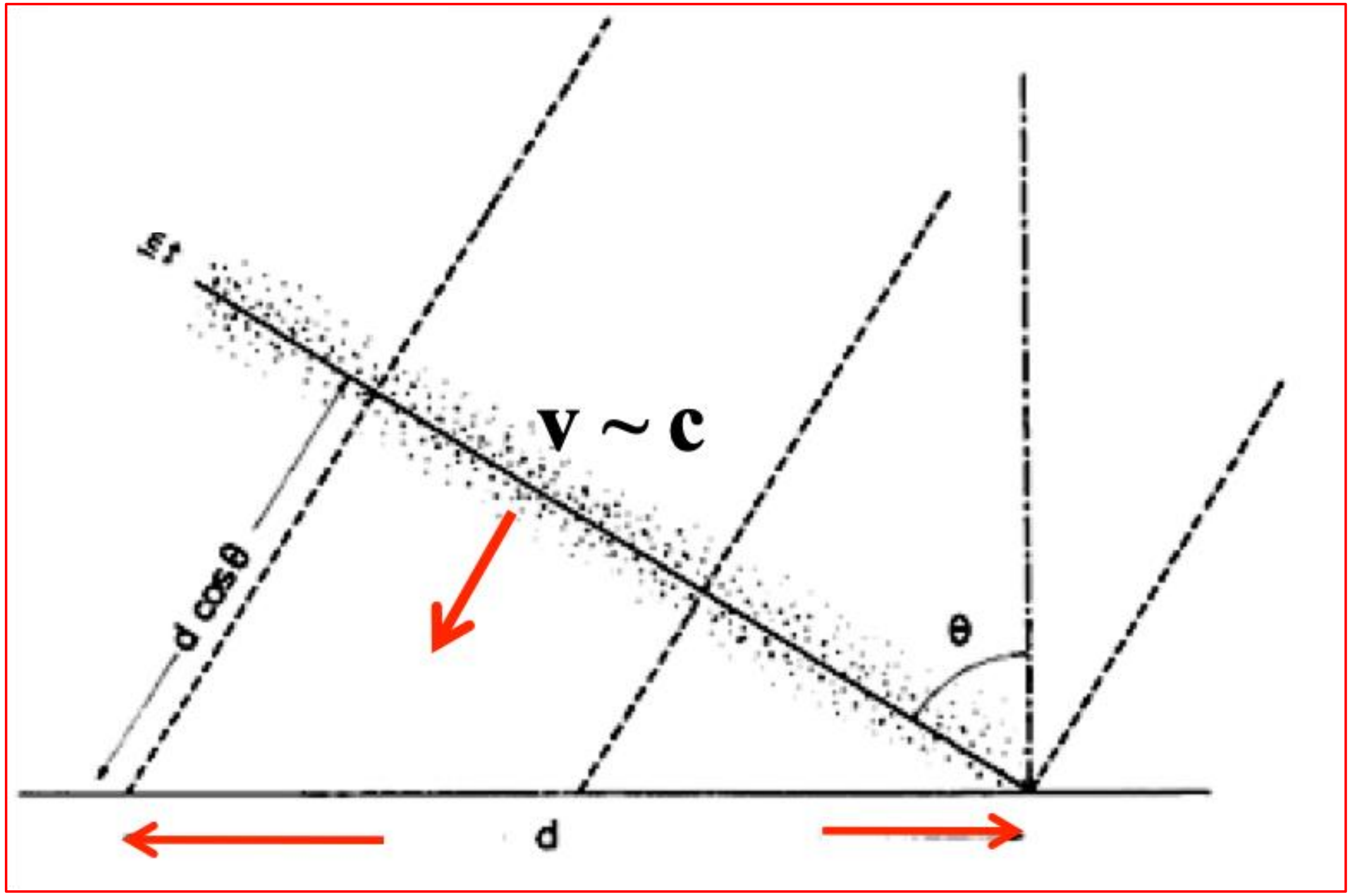
How can be seen a primary cosmic ray by a ground based detector?

- A series of interactions with the atmosphere transforms the single primaty particle in a large electromagnetic/hadronic shower
- The direction of the primary particle can be measured through the inclination of the "shower front"



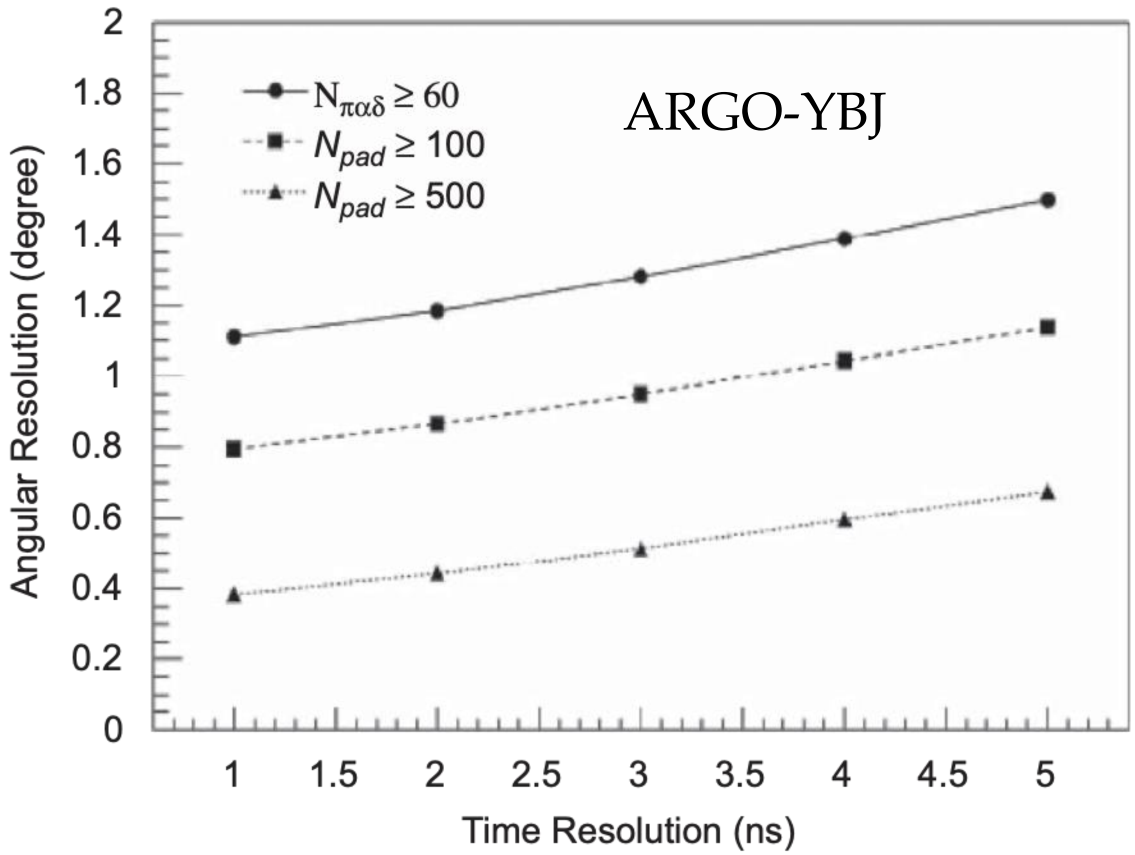
Primary CR direction measurement

- Simultaneous position-time measurements of the particles reaching the floor allow to measure the primary direction
- The shower front thickness, about 1 m, is the limit for the measurement accuracy



Accuracy in the direction measurement

- operated from 2007 to 2012 (final configuration)
- *4300 m* above sea level
- *angular resolution ≈0.5° at 1 TeV*
- 3500 Hz trigger rate
- high granularity of the readout
- *Median Energy at the threshold: ≈340 GeV*
- *Energy Range: 340 GeV - 10 PeV*
- NO background rejection (no outrigger)
- NO conversion of secondary photons (no lead)
- → Sub-nanosecond time resolutions NOT needed



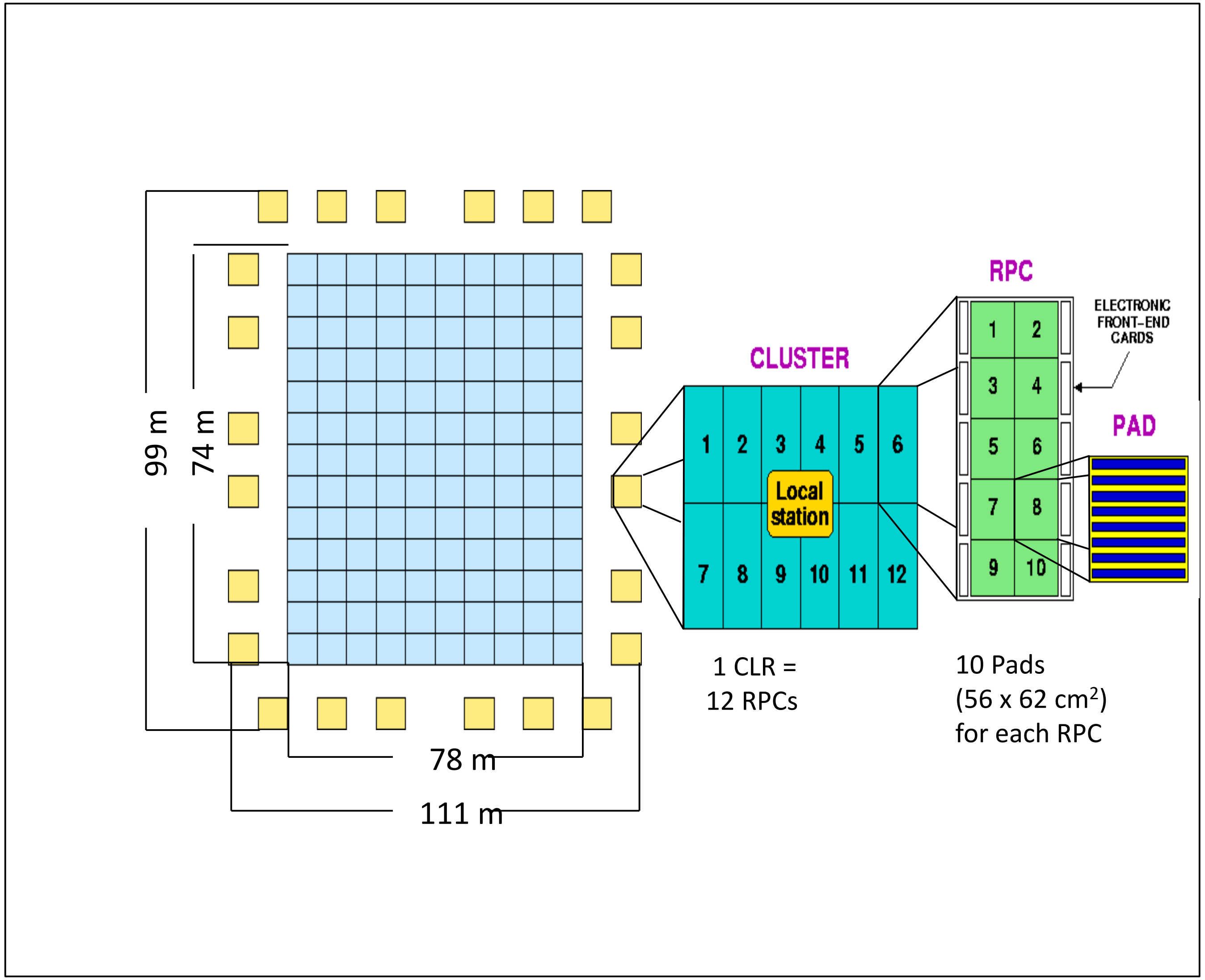
Crucial working parameters of the detector for each application

- A ground based CR detector is based on the imaging of the shower produced by the primary particle inside the atmosphere. The following shower characteristics are relevant for the detector optimization
  - The shower covers a large area, depending on the primary energy
  - The core contains a very large fraction of the shower particles concentrated in a small solid angle. The corresponding hit density can exceed 10^5 m^{-2}
  - The intrinsic time fluctuations of the secondary particles (with respect to the shower front) ranges in the nanosec region
- The required parameters for an excellent CR detection are therefore
  - construction simplicity and low cost
  - the working reliability in hostile environment low maintenance needs
  - moderate space-time resolutions: tens of centimeters x 1-1.5 ns
  - modest rate capability.
  - good capability to measure high hit density in the shower core

The example of Argo

- Argo was a ground based CR detector with unprecedented features:
  - Full coverage core surrounded by a sampling guard ring ocated in a very high mountain laboratory (YBJ 4300 m asl)
  - Exclusive use of Resistive Plate Chambers as a particle detector
  - Aimed to reach a very low energy threshold to overlap the maximum energies achievable with satellite detectors

ARGO-YBJ *RPC technology*

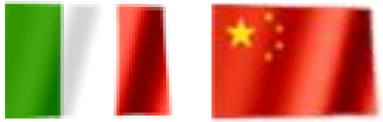


- Space pixels 146,880 (7x62 cm^2)
- Time pixels 18,360 (56x62 cm^2 → 8 OR of 8 strips)
- Streamer mode operation with 2 mm gap → Time resolution 1-2 ns
- Gas TFE/iButane/Ar=75/10/15 → Operating Voltage=7200 V
- Single RPC layer of 5600 m^2 active area - 92% coverage
- + 1100 m^2 guard ring

The ARGO-YBJ experiment

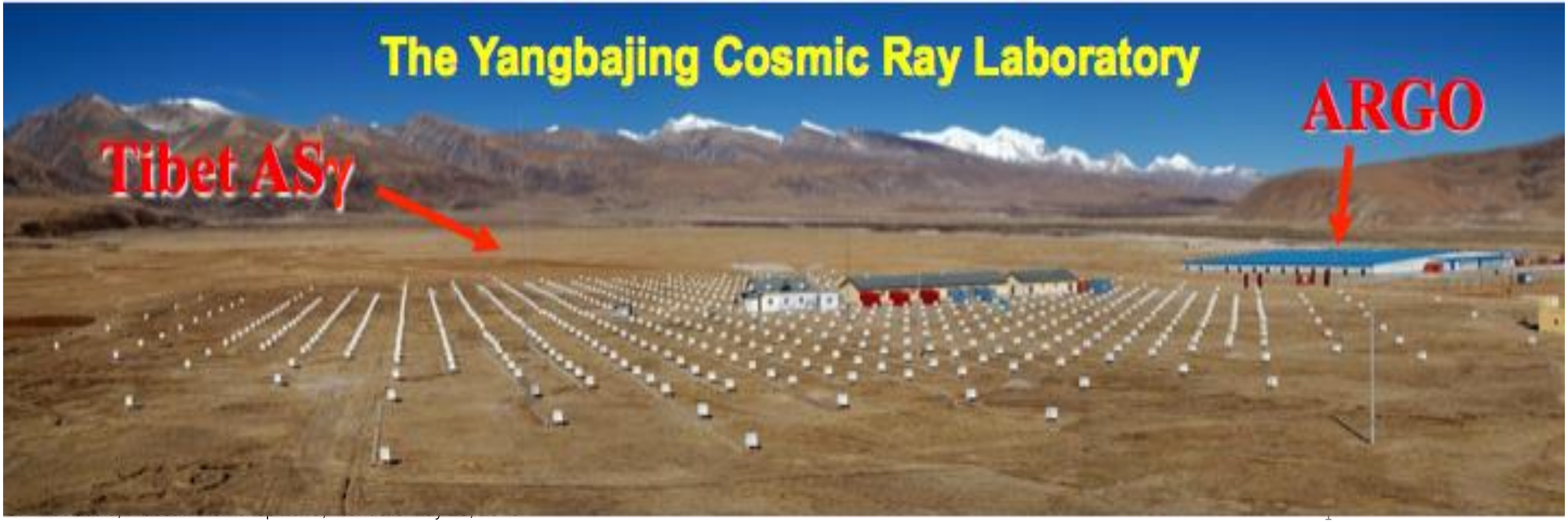
Longitude: 90º 31’ 50’’ East
Latitude: 30º 06’ 38’’ North

4300 m above sea level ∾ 600 g/cm²



INFN IHEP/CAS

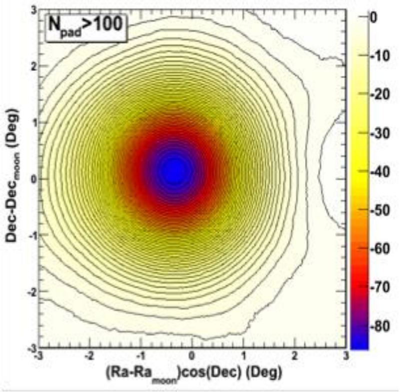
90 km North from Lhasa (Tibet)

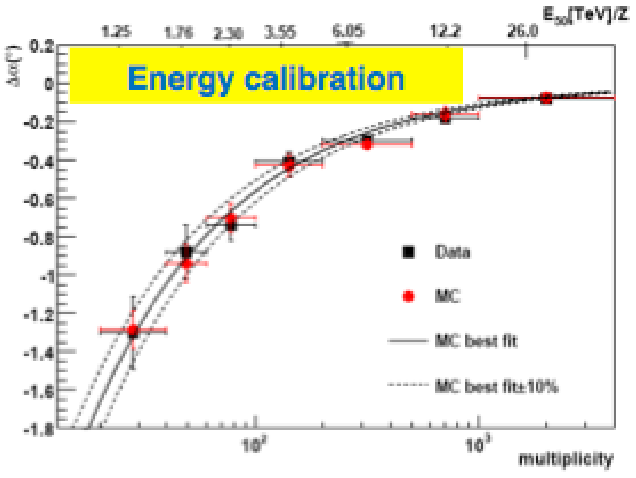


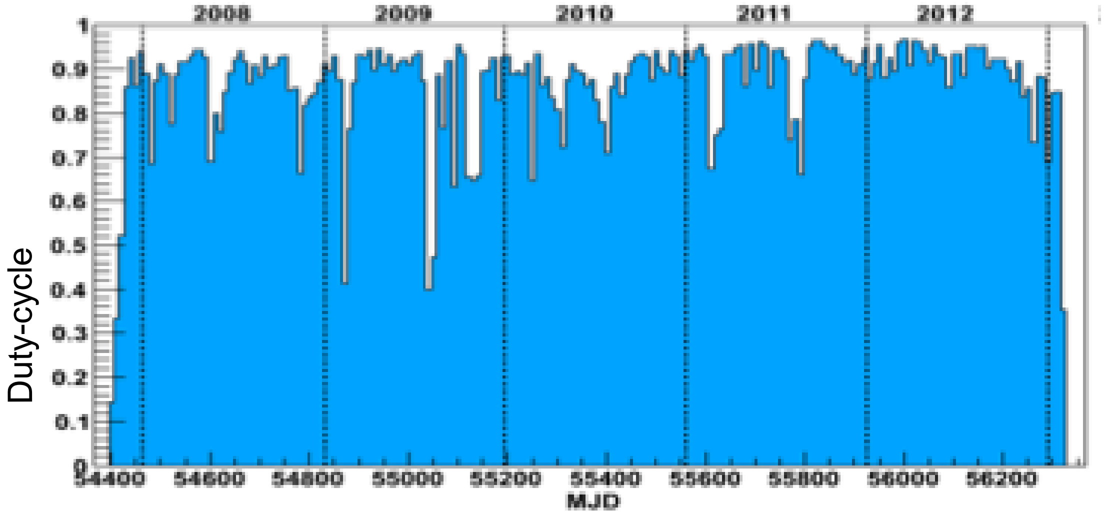
Status and performance

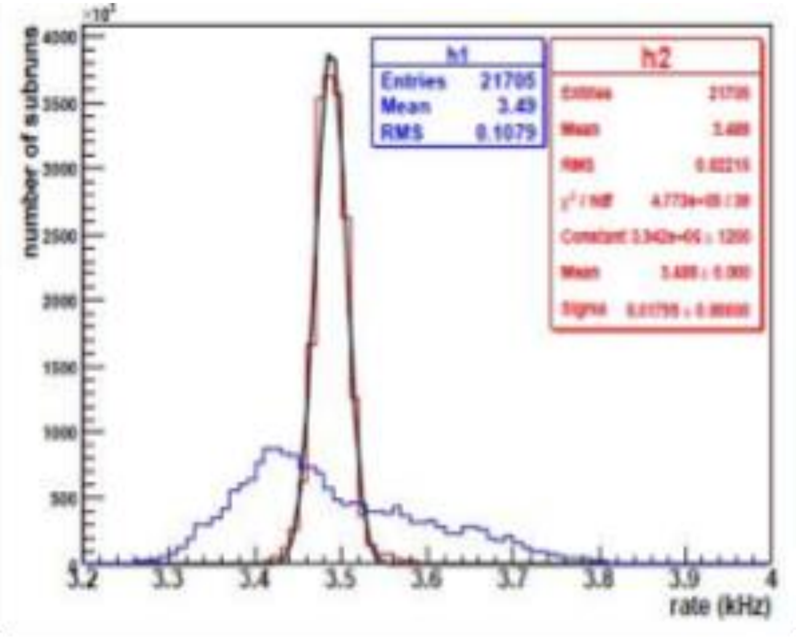
- In observation since July 2004 (with incresing portions of the detector)
- Stable data taking since November 2007
- End/Stop data taking: January 2013
- Very modest maintenance in a hostile environment

- Average duty cycle ~87% Dead time mostly due to frequent cuts of electric power
- 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









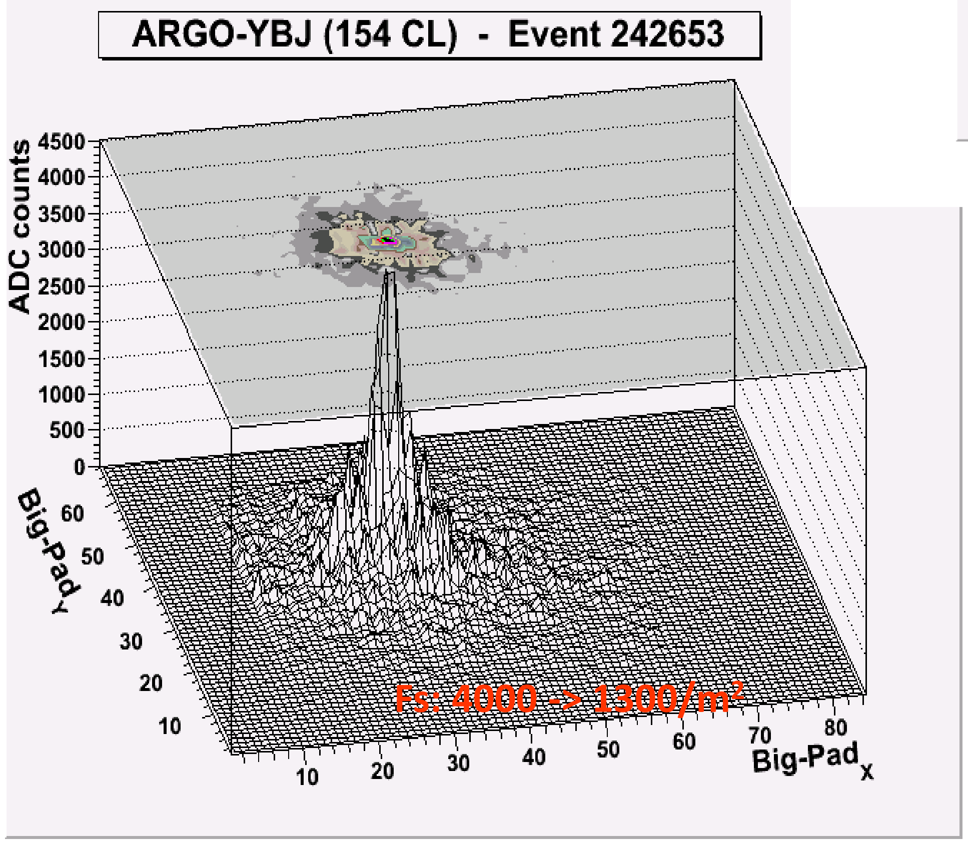
Intrinsic Trigger Rate stability 0.5% (after corrections for T/p effects)

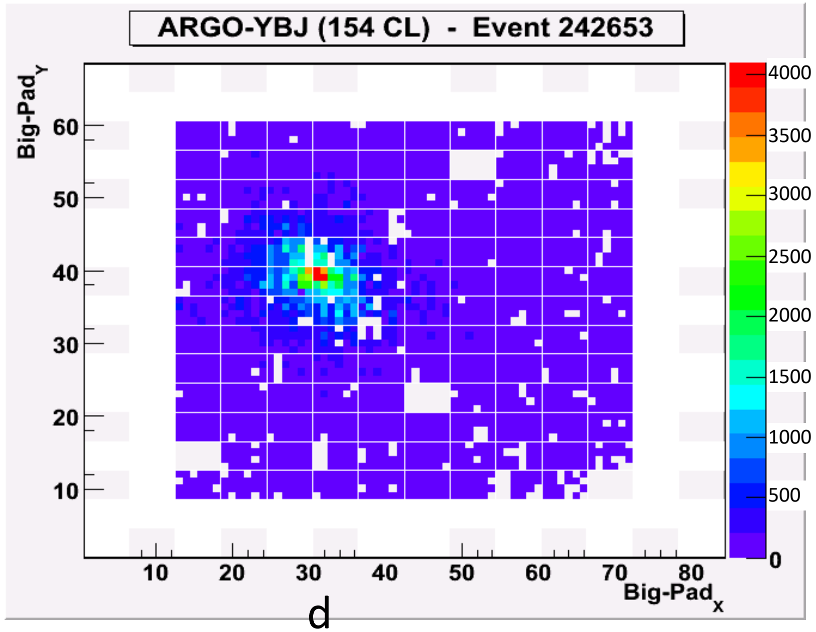
The RPC analog readout

Extending the dynamical range up to PeV

- Is crucial to extend the covered energy range above 100 TeV, where the strip read-out saturates
- Max digital density ~20/m^2
  Max analog dens ~10^4/m^2
- Access the LDF in the shower core
- Sensitivity to primary mass
- Info/checks on Hadronic Interactions

ARGO event





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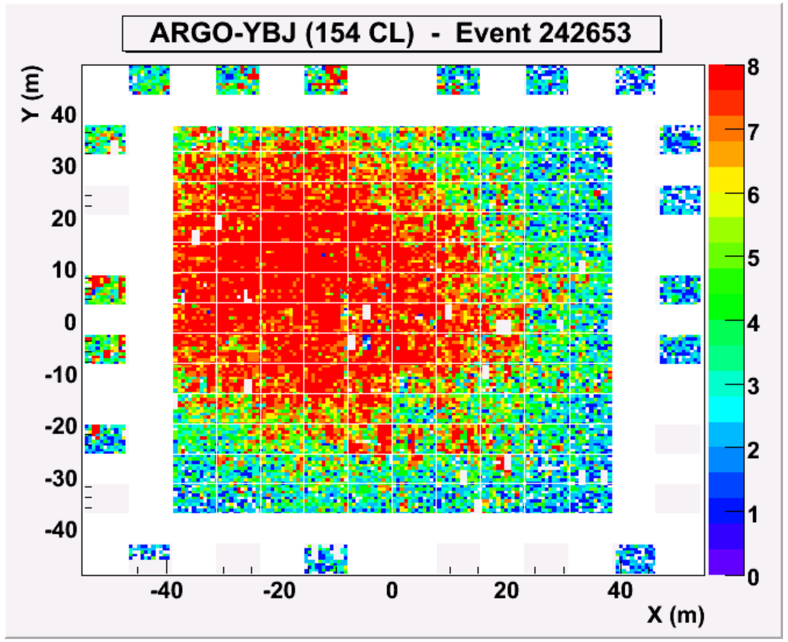
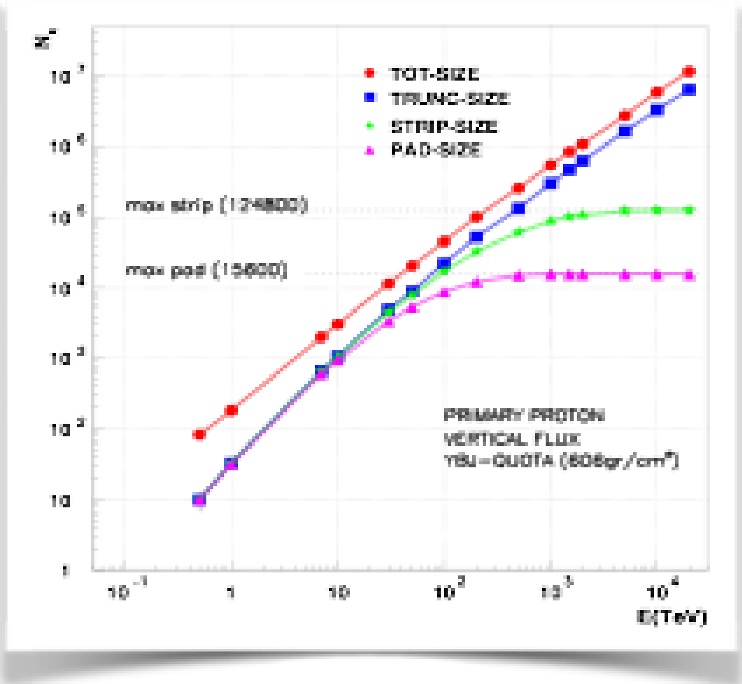
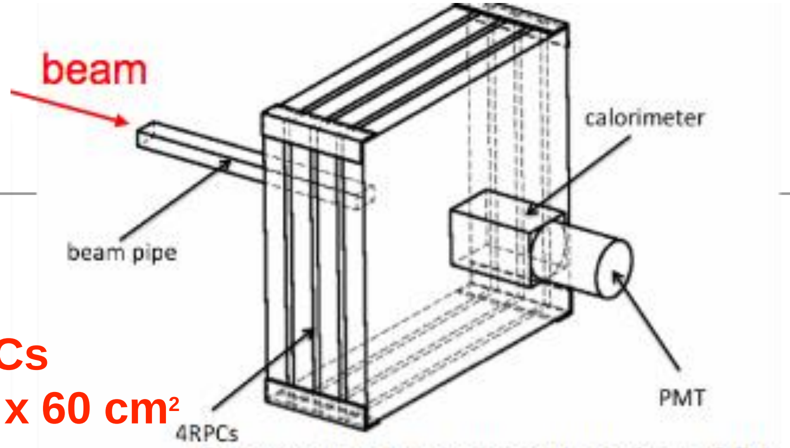




Intrinsic linearity: test at the BTF facility

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*



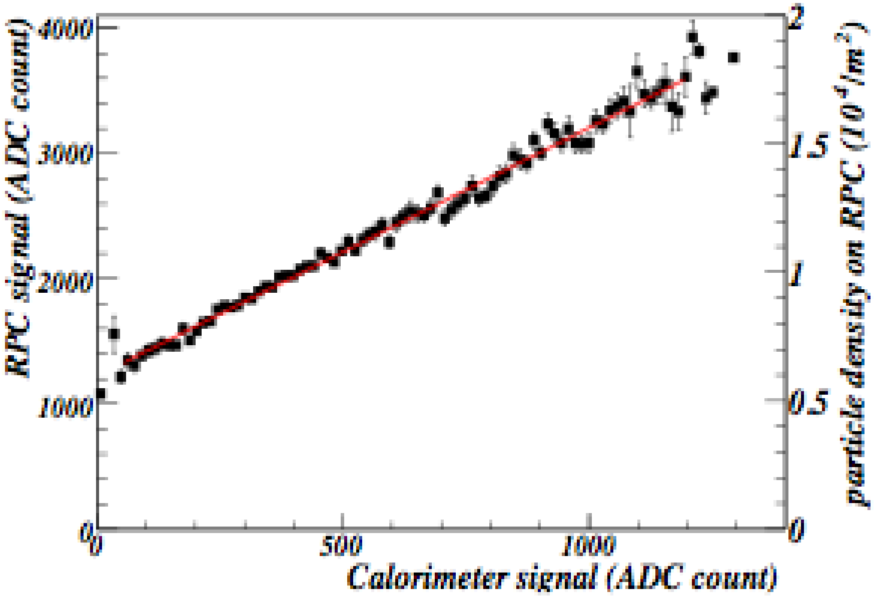
4 RPCs
60 x 60 cm²

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

➔ **Linearity up to ≈ 2 · 10^4 particle/m²**
In *streamer* mode

➔ **Much higher linear range in *avalanche* mode**

The RPC signal vs the calorimeter signal



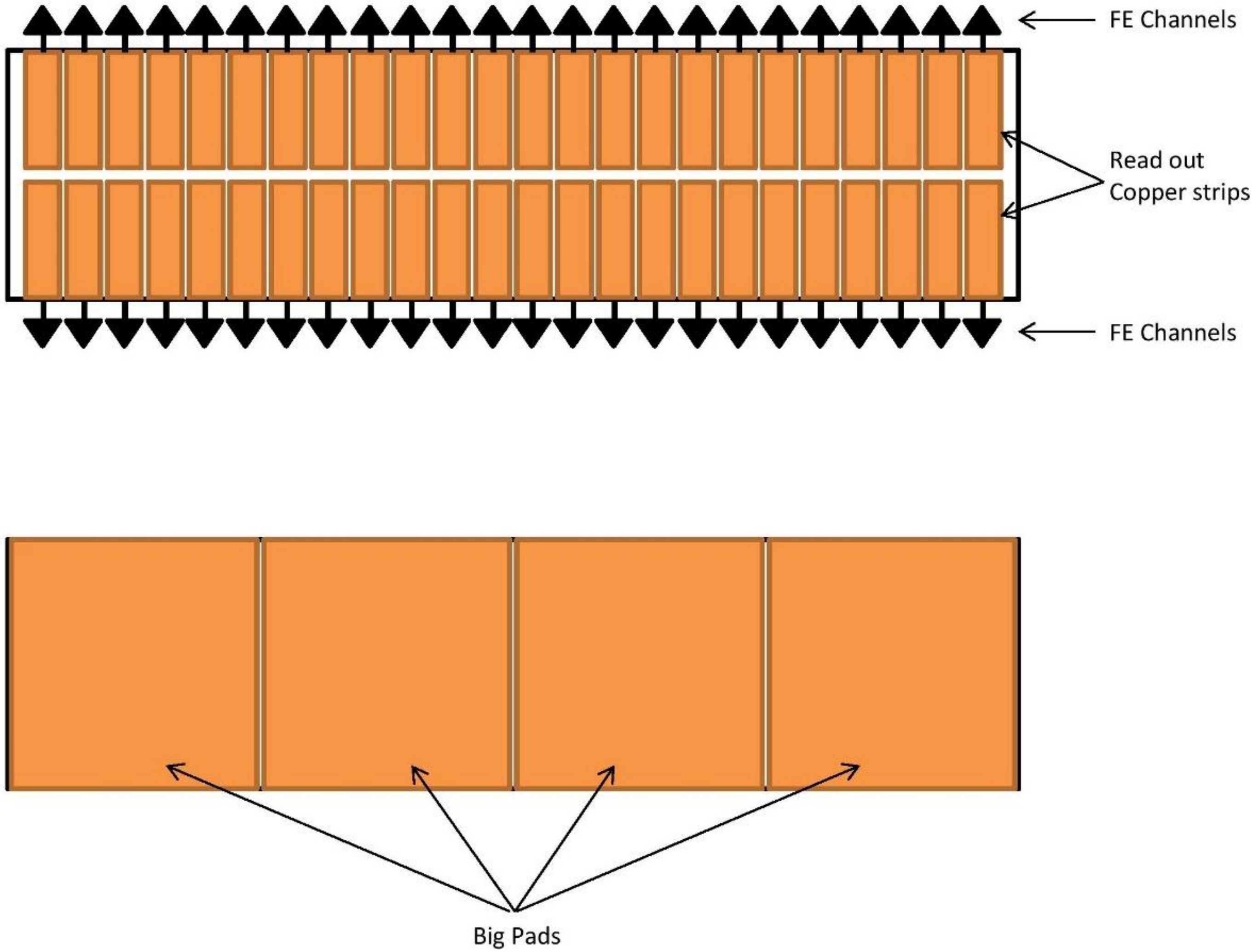
Astrop. Phys. 67 (2015) 47

A look to the future: motivation for a Southern experiment

- The results of 5 years running with Argo suggest that this approach to the ground based CR detection is very promising and should continue with a second generation experiment (STACEX)
- ➢ The main challenge should be the detection of gamma rays in the energy range down to 100 GeV or below and, at the same time, to study cosmic rays trough the shower core, up to about 10-20 PeV.
- ➢ A wide FoV gamma-ray detector, with the above characteristics, located in the Southern Hemisphere, would have a great discovery potential
- Moreover, based on the Argo experience, a number of relevant upgrades can be conceived to improve the sensitivity of a similar detector, in particular for low energy gamma rays
- There are strong reasons for a Southern Experiment
    - **Southern sky is extremely rich and important for astrophysics**
    - No large-FOV TeV experiments in the South
    - Good opportunity today for an ambitious project in the South based on the convergence of different groups.
- The collaboration LATTES (Brasil, Portugal…) is already proposing an RPC Cosmic Ray detector to be located in a high altitude site in the South hemisphere

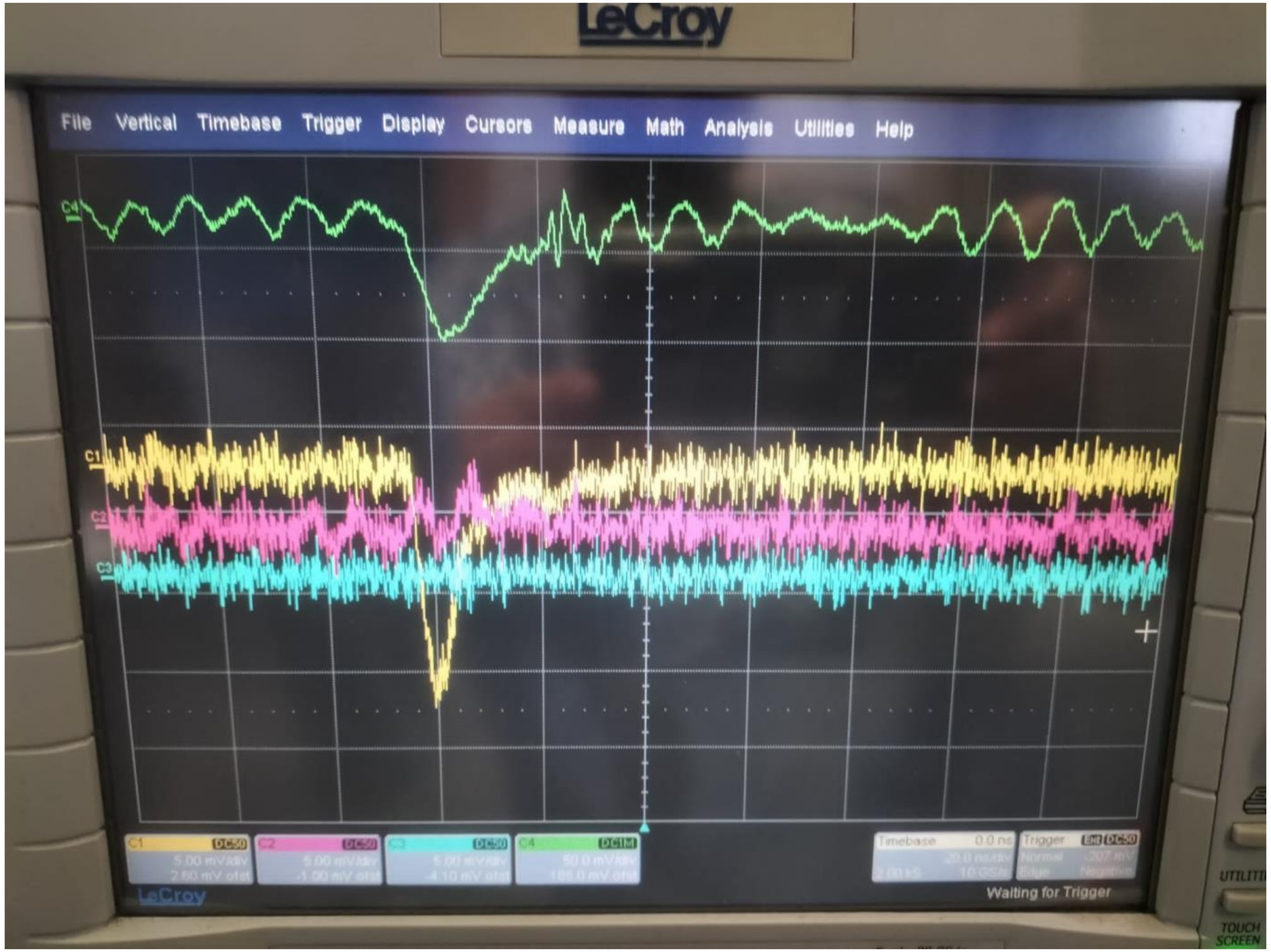
Optimal read out

- Digital read out can be used either for mapping the shower front or for tracking single shower particles (not usual in cosmic shower detection)
  - short strips allmost pads, without impedance matching are the most natural read out to map the shower front. Typical length of 40-50 cm is consistent with the intrinsic timing of the shower front
  - long (usually narrower) read out strips are suitable for tracking. Front end circuit at both ends to measure the longitudinal coordinate may be required.
  - This obliges to increase the TDC resolution beyond the requirements of the shower front timing
- Analog readout
  - This is simply a large area capacitor covering e.g, half of the gas volume area,. It integrates all hits in his area giving a signal of amplitude proportional to the number of hits. Excellent for high hit densities, unsuitable for single hits



FE Channels
Read out
Copper strips
FE Channels
Big Pads

Experimentally detected signals from *pads*



- Avalanche working mode with standard mixture
- Strip length 38 cm
- Small size test with two 5 cm wide strips strips and 1 7 cm strip
- Big (not so big in this case!) pad also visible
- No impedance adaptation

Design of a RPC large area detector of Extensive Air Showers (1)

- Full coverage

  This very succesful approach is particularly suitable for the central part of a very large area detector. The corresponding area should be increase from 5600 m2 of Argo to 20,000 m2 or mare, depending on the available money!!!

- Medium coverage
  - For photon of energy exceeding about 100 TeV, however this area is too small if compared to the very low flux available. A substantial increase in the detector size is needed and the full coverage concept has to be somewhat revised
  - BUT…the gas distribution needed for a sparse detector is more complex.
  - This problem can be avoided if the sensitive area is increased with a number of concentric guard rings. The detector continuity inside each ring makes the gas distribution as easy as in the full coverage case

Medium coverage by means of concentric rings

- Here $\boldsymbol{w}$ is the width of each detector **"ring"**
- $\boldsymbol{r_k}$ is its average radius of the **k-th ring**
- For getting a coverage **moderately decreasing** with **k**

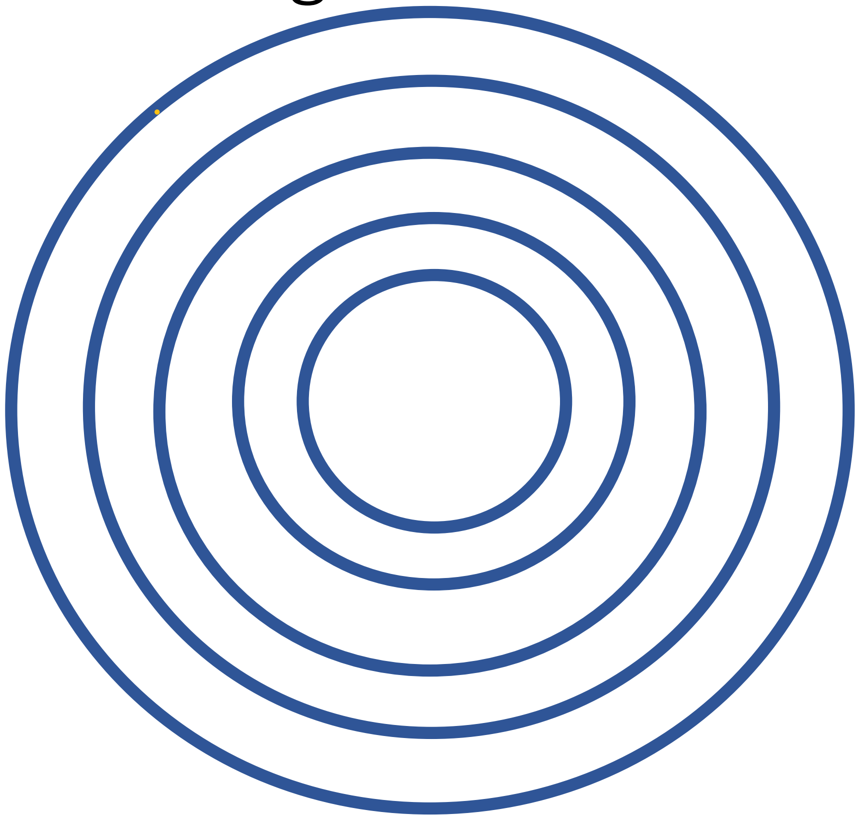
fractional exponents seem to be needed. Examples →

- $\boldsymbol{r_k = a\, k^{1+1/4}}$

$$Coverage = \frac{2w}{a}\frac{k^{1+1/4}}{\{k^{2+1/2}-(k-1)^{2+1/2}\}}$$

- $\boldsymbol{r_k = a\, k^{1+1/n}}$

$$Coverage = \frac{2w}{a}\frac{k^{1+1/n}}{\{k^{2+2/n}-(k-1)^{2+1/n}\}}$$



Full coverage detector at the center

Design of RPC large area detector of Extensive Air Showers (2)

- Sampling array
  - Finally, for photon energies around 1 PeV or more, about 1 km^2 is needed.
  - This can be achieved with a sparse sampling array.
  - In this case it is difficult to imagine a gas distribution system. The solution can be that of sealed RPCs with possibly a very small local gas reservoir.
  - Important progress from our Portugal colleagues. Interesting tests in course also in Rome

A fascinating challenge: the detection of Gamma Ray Bursts with ground-based RPC detectors

- The GRB are intense «rains» of gamma photons produced by gravitational callapses
- Correlating them to gravitational wave signals emitted by the same events is a fascinating problem
- It has been observed that a GRB has a long time evolution (even a few days) from very high intensity and low energy (1 MeV) to very low intensity and high energy (TeV)
- Following this evolution without inerruption from a 10 GeV threshold to the extintion of the burst can be a major achievement for the RPCs

A project for the next future

- In the PNRR framework, an european funding project, INFN will support the construction and test of an hybrid RPC + Water-Cerenkof of about 200 m^2
- This test is part of a R&D activity of a very large collaboration, SWGO, interested to realize a very large cosmic ray detector, with special enphasis to the gamma rays, to be installed in the South Hemisphere at an altitude of 4500-5000 m