An innovative wide FoV gamma-ray detector in the South Hemisphere

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By R Santonico
The purpose of this talk is to extrapolate some 10 years of experience made with data taking and analysis of Argo-YBJ, to an improved detector of the same type.

The main challenge should be the detection of gamma rays in the energy range down to 100 GeV and, at the same time, to study cosmic rays through 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.
The ARGO-YBJ experiment

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

4300 m above sea level  ~ 600 g/cm²

90 km North from Lhasa (Tibet)

Tibet ASγ

The Yangbajing Cosmic Ray Laboratory

ARGO

INFN  IHEP/CAS
Basic concepts for an unconventional air shower detector

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

❖ FULL COVERAGE
(Resistive Plate Chambers, 92% coverage)

❖ HIGH READOUT SEGMENTATION
Space pixels: 146,880 strips (7×62 cm²)
Time pixels: 18,360 pads (56×62 cm²)

→ image the shower front with unprecedented details

→ get an energy threshold of a few hundreds of GeV
Status and performance

- In observation since July 2004 (with increasing 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

\[ N \approx 21 \cdot (E_{\text{TeV}}/Z)^{1.5} \]
10% uncertainty estimated in the energy range 1 – 30 (TeV/Z)
A RPC is just a gas filled plane capacitor with high resistivity electrodes.

External signal pick up electrodes can be easily tailored with any shape.

Chamber size: 1.25x2.80 m²; Time resolution ~ 1.5 ns.

Argo gas mixture: $C_2H_2F_4/Ar/iC_4H_{10} = 75/15/10$; Operated in Streamer Mode.

Two “big pads” of 1.25x1.40 m² allows the analog readout.
Gamma-Ray Astronomy with ARGO-YBJ

- Energy threshold: few hundreds of GeV → Overlaps with Cherenkov detectors
- Large duty cycle: 86%
- Large field of view: ~2 sr
- Declination band from -10° to 70°
- Integrated sensitivity in 5 y at ~1 TeV: 0.25 Crab for dec 15° - 45°

Crab Nebula 5 years data
Gamma-ray Astromomy  ARGO-YBJ 5-years survey of the Northern Sky

- Integrated sensitivity in 5 y at ~1 TeV: 0.25 Crab for dec 15° - 45°

G. Di Sciascio, Frascati Workshop 2015, Mondello May 28, 2015
ARGO-YBJ 5-years Survey of Inner Galactic Plane

\[ E_{50} \approx 0.7 \, \text{TeV} \]

\[ 20^\circ < l < 90^\circ, |b| < 10^\circ \]

\[ E_{50} \approx 1.8 \, \text{TeV} \]

MGRO J2031+41

HESS J1912+101

MGRO J1908+06

HESS J1841-055
CR energy spectrum

• One of the most interesting Argo results concerns the measurement of the CR spectrum up to several PeV energy
• This was possible thanks to the analog readout of the signals which allowed to observe the shower core density with an unprecedented detail
• Working at high altitude (4300 m asl) offered the following advantages
  1. Small fluctuations: near the shower maximum
  2. p and Fe produce showers with similar size
  3. Low energy threshold

Absolute energy scale calibration with the Moon Shadow technique and overposition with direct measurements
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 $\sim 20/m^2$
- Max analog dens $\sim 10^4/m^2$
- Access the LDF in the shower core
- Sensitivity to primary mass
- Info/checks on Hadronic Interactions
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)
- $<N> \approx 1 \times 10^9$ particles/pulse
- 10 ns pulses, 1-49 Hz
- beam spot uniform on 3x5 cm

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

$\Rightarrow$ Linearity up to $\approx 2 \times 10^4$ particle/m$^2$
Light component (3 TeV - 5 PeV) and all particles spectrum
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**

• 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
A Wide FoV Detector for Gamma-Ray Astrophysics in the Range
100 GeV - 10 TeV in the Southern Hemisphere

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Abstract

We present the concept of a new wide-FoV high-altitude detector in the Southern hemisphere dedicated to gamma-ray astronomy in the range 100 GeV - 10 TeV. The new instrument is based on large-area particle detectors (Resistive Plate Chambers, RPCs) already tested and implemented in the ARGO shower array experiment. The new experiment will have a sensitivity better than 10% Crab Nebula flux per year at 100 GeV with a very good angular resolution. It will be unique and complementary to CTA-South...
Upgrades suggested by the Argo experience in view of a future experiment:

The results of Argo in gamma ray astronomy and CR physics were achieved with a *downgraded* detector with respect the proposal, which was based on

- A RPC carpet of 120x120 m\(^2\)
- A 1\(X_0\) Pb converter on top of it

The real detector was a carpet of 5600 m\(^2\) without any photon converter on top.

An obvious upgrade:

- increase the area to 10 000-20 000 m\(^2\)
  - Much higher statistics
  - *photon-hadron discrimination* possible (the small size of Argo did not allow this discrimination)
- A 1\(X_0\) Pb photon converter would substantially *increase the number of detected shower particle*
Primary photons of 100 GeV, 500 GeV and 5 TeV at 5000 m asl

**Photons are the main component of the shower**

- 6 part/m$^2$
- 0.3 part/m$^2$
- 0.02 part/m$^2$
Upgrades:
Operation at higher altitudes

- Operating at higher altitudes, ~5000 m, would be a further important advantage, mainly for low energy photons.
- Extrapolation from 4300 m (YBJ-lab) to 5000 m (about -1.4 $X_0$) gives an increase of almost a factor of 2 for the number of particles produced by a 100 GeV primary photon.
Proton vs Photon showers at different altitudes

Started discussions about different ideas for new experiment at higher altitude. The goal is to lower the energy threshold in the 100 GeV range:

**HAWC-South**

**LATTES**: RPCs + water Cherenkov

**STACEX**: layers of RPCs

**ALPACA**: scintillator array + water pond
Upgrades:
Improving the detector performance (1)

• Fully analog read out
  • The experience with Argo suggests that for a shower detection the analog read out is more effective than the digital one and should be extended from the “big pad” to the full signal read out
  • Pick up electrodes of e.g. 20x20 cm$^2$, equipped with 1 TDC + 1 ADC per pad would substantially improve the amount of information

• Avalanche mode operation (Argo was operated in streamer)
  • Much wider dynamic range of the analog read out
  • Should allow to resolve a very closed e+e- pair produced by a photon annihilation, its signal amplitude being twice the m.i.p.
  • Better timing. Sub-nanosecond resolution possible but should be compared with the intrinsic shower front fluctuations

• A relevant investment of simulation is crucial to test different ideas of optimization
Upgrades:
Improving the detector performance (2)

• Front end electronics
  • A new full custom front end circuit, dedicated to the RPCs, is under development (by R. Cardarelli) and will replace the one used for Argo
  • The full custom circuit will integrate the ADC and TDC functions
  • The output for each fired pad will be a shaped signal, suitable for coincidence logics, equipped with two numbers digitizing the Amplitude and the Time respectively
  • A solution avoiding a huge complexity of interconnected circuits needed to discriminate and to digitize the input signal

• A relevant investment of simulation is crucial to test different upgrade ideas and to optimize the detector, balancing performance and complexity
Upgrades:
the gas system (3)

• The Argo Gas system was operated in open flow. The operation in closed loop, foreseen in the proposal, remained at the prototype level and was never implemented

• A gas recirculation/purification system would make the running cost negligible thus creating the best conditions for a very long term data acquisition
Ideas about a future detector. Summary

- **Lay out**
  - A central carpet $120\times120$ m$^2$ hosted inside a very light and cheap building
  - Surrounded by a sampling array of similar sensitive area but spread on an area some 10 times larger. Some experience has been already achieved on the “outside door” RPC operation

- **Read out**
  - Fully analog read out with pads of area about 20x20 cm$^2$
  - “big pads” of about 1 m$^2$ for very high multiplicities
  - New front end full custom circuit integrating the time and amplitude digitization

- **RPC operation**
  - Avalanche mode with
  - Gas properly chosen for avalanche operation

- **Gas system**
  - Closed loop with a few volumes/day flux inside door
  - Open loop outside door with minimal gas supply (to be checked)

- **Altitude:** > 5000 m
The challenge of 100 GeV threshold and the site choice

• It is a big challenge requiring a careful evaluation of all parameters determining the detector sensitivity

• The laboratory altitude is, to some extent, the most important parameter for to detect low energy gammas. Evaluate:
  • The human limits: → to be included in the project optimization like other technological parameters
  • Strong requirements on the technology to minimize the permanence of the personnel at the experiment site.
  • A support laboratory close to the experiment but located at lower level would be very important for the final testing of the modules before installation. Local manpower might be crucial in the set up of the experiment.
Argo-Stacex comparison

- STACEX site: **5000 m altitude or more.** Argo: 4300 m
- RPC detectors eventually with Pb; no Pb
- Area: **14,000 m\(^2\)** (full coverage); 6000 m\(^2\) full cov +
  surrounded by a comparable sampling array 1000 m\(^2\) guardring

- Energy ranges:
  - Photons: **100 GeV – > 20 TeV**
  - CRs: **300 GeV – 20 PeV**
  - 300 GeV – 10 TeV
  - 600 GeV – 5/10 PeV

- 1-year gamma-ray sensitivity (@ 1 TeV):
  - **50 mCrab**
  - ½ Crab
Recent results from Fermi at Energies $E > 50$ GeV confirm the importance of a low energy threshold.
The VHE sky (IACTs+Fermi 2FHL)

\( F > \sim 10 \text{ mC.U.} \)

\( E > 50 \text{ GeV} \) sources (Fermi-LAT, 2FHL)

(courtesy of P. Giommi)
Conclusions

• The combination of high altitude site, full coverage and high segmentation of the read out, made Argo a unique experiment, which achieved relevant results even beyond the expectations of the proposal. To extend this original approach to a new upgraded experiment will offer a relevant discovery potential

• A RPC wide FoV gamma-ray detector, in the energy range 100 GeV-20 TeV, located in the Southern Hemisphere, would be unique and complementary to other experiments planned to take data in the next decade

• The experience of Argo has clearly identified a list of improvements for a future experiment: higher altitude site, increased area, addition of a photon converter, RPC avalanche mode operation with improved timing and fully analog read out achievable with a new front end electronic

• Two collaborations, Lattes, Stacex, are already considering this possibility. A common proposal can create a very ambitious project with a large international participation

• Several collaboration items can be found even in the short-middle term: computer simulation, site choice and preparation of a pilot test to be performed in the chosen site