ARGO-YBJ: physics results and detector stabilization

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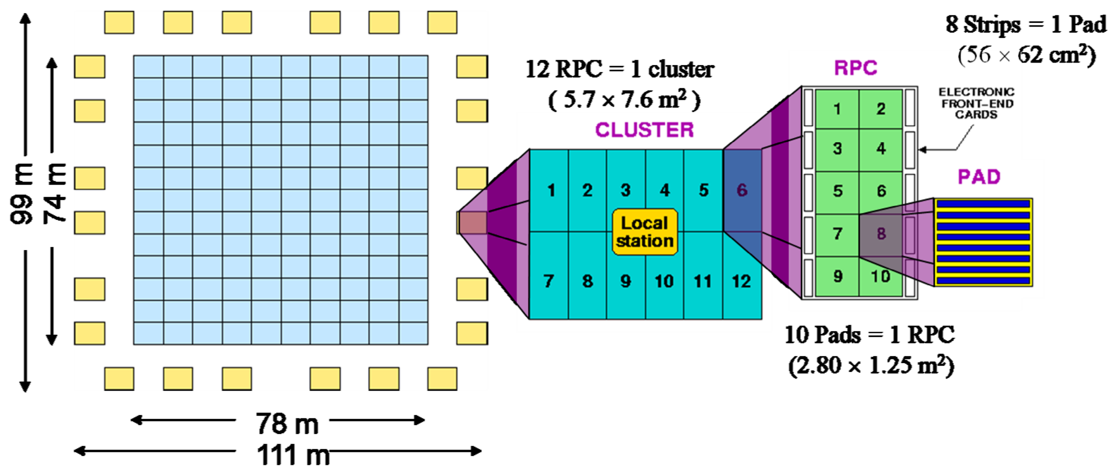
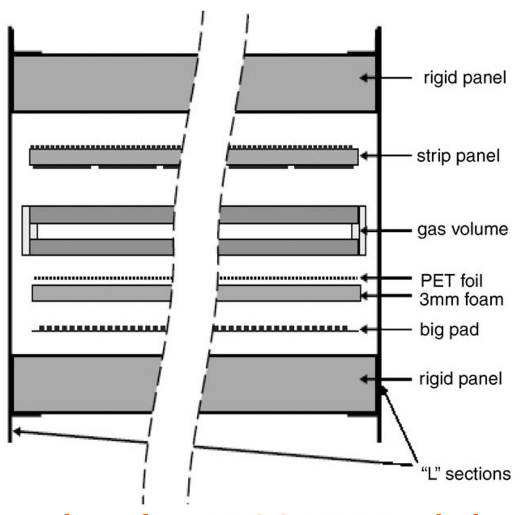
The ARGO-YBJ experiment



Layout of the ARGO-YBJ detector



Expanded cross section of an ARGO-YBJ Resistive Plate Chamber

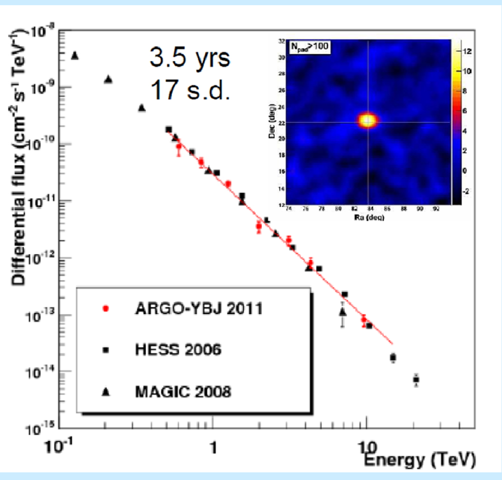
ARGO-YBJ is a collaboration between the INFN (Italy) and the IHEP/CAS (China).
ARGO-YBJ is a ground-based detector of air-shower particles.
It is a wide field-of-view γ-ray and cosmic-ray telescope, optimized to detect air showers induced by primaries with energy greater than a few hundred GeV.
This low-energy threshold is achieved by operating at very high altitude and by using a "full-coverage" detection surface of Resistive Plate Chambers (RPCs).

ARGO-YBJ is located at YangBaJing (Tibet, China), 90 km North of Lhasa, at an altitude of 4300 m a.s.l.
Longitude 90° 31' 50" East
Latitude 30° 06' 38" North
ARGO-YBJ has a full-coverage detection area (5600 m^2) surrounded by a guard ring, covering a total area of 10^4 m^2. The detection unit is a "pad", namely the logical OR of 8 adjacent read-out strips. Each ARGO-YBJ RPC contains 10 pads.
The whole detector was built with 1836 RPCs (18360 pads and 146880 read-out strips overall).
ARGO-YBJ started taking data in July 2006 for the commissioning phase, and in November 2007 with the completed layout. Since then the experiment has been running smoothly and uninterruptedly.

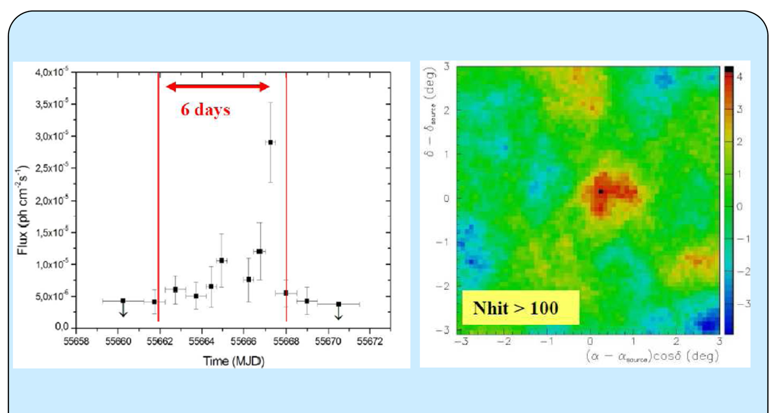
The ARGO-YBJ RPCs are operated in streamer mode at 7200 V with a gas mixture $Ar/iC_4H_{10}/C_2H_2F_4$ = 15/10/75.
The gap width is 2 mm.
The single-hit time resolution is about 1.5 ns.
Average duty cycle: 85%
Average trigger rate: 3.4 kHz at a 20-pad lower threshold on the central carpet within a 400 ns time window.
Over 4×10^{11} events have been recorded so far.
220 GBytes/day are transferred to the data centers of IHEP (Beijing) and CNAF (Bologna).

Physics results

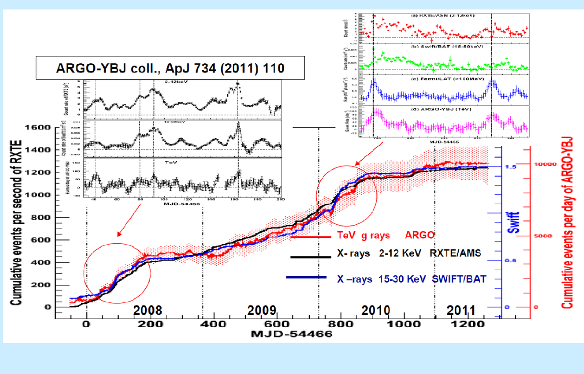
The main goals of ARGO-YBJ are γ-ray astronomy at energy greater than a few hundred GeV and cosmic-ray physics at energy greater than 1 TeV.
A conical fit of the shower fronts allows the reconstruction of the arrival direction of the primaries.
No γ-hadron discrimination has been applied so far. Background estimation is made by using the "time-swapping" and the "equi-zenith" methods.
ARGO-YBJ performed an all-sky survey in the declination range from –10° to 70°. In 3.5 years, five sources with significance greater than 5 standard deviations have been detected: Crab (17 s.d.), MRK 421 (12 s.d.), MGRO J1908+06 (6 s.d.), MGRO J2031+41 (6.3 s.d.). Interesting results were obtained on long-term variability, correlation between TeV and X-ray emission, and spectra [1, 2, 3].



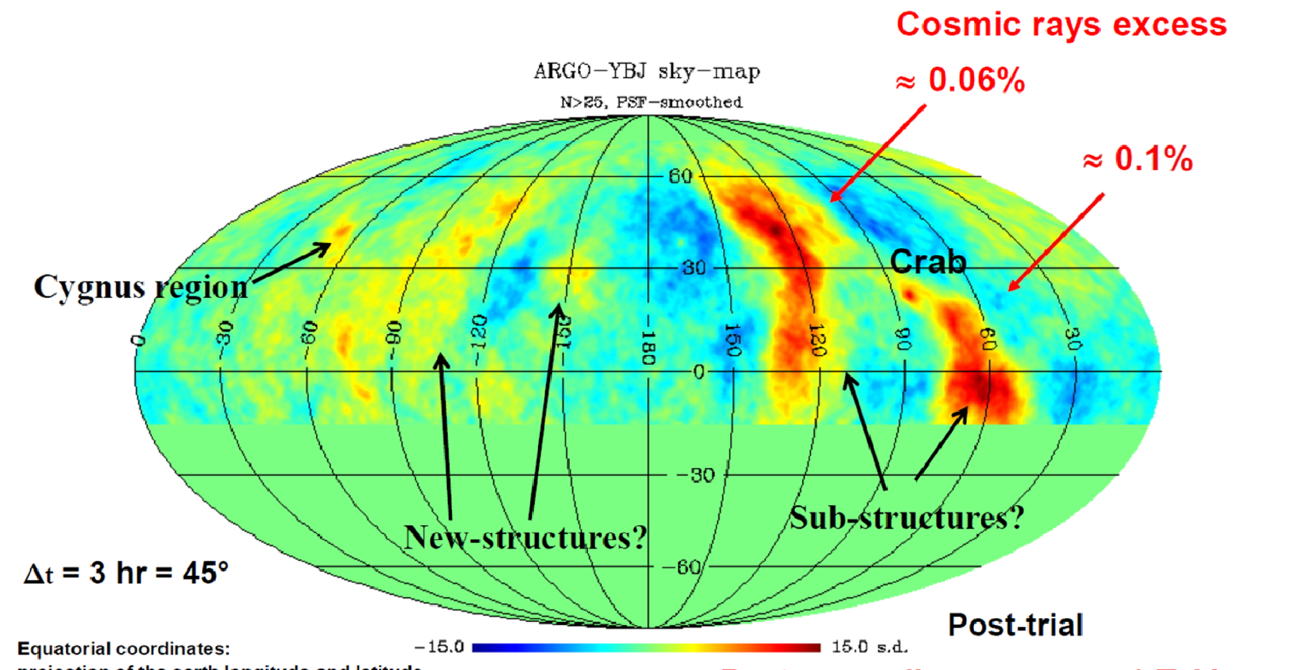
Comparison of the differential flux of TeV γ-rays from the Crab measured by ARGO-YBJ (red circles), HESS (black squares) and MAGIC (black triangles). The ARGO-YBJ significance map of the Crab sky region is also shown (top right).



LEFT: light curve measured by AGILE in the time interval April 14th-20th, 2011 (6 days).
RIGHT: ARGO-YBJ significance map of the Crab sky region in the same time period. The maximum measured significance was 3.5 s.d. To be compared with the expected value of about 0.6 s.d.
This sky map was obtained by selecting events with a median energy of about 3 TeV.



Cumulative light curves for the AGN MRK 421 measured by ARGO-YBJ in the TeV range (red), RXTE/AMS in the 2-12 keV range (black) and SWIFT/BAT in the 15-30 keV range (blue). The curves are shown on the same plot after being rescaled suitably. Good correlation between X–ray and γ-ray emission was found. ARGO-YBJ was the first experiment (and the only one so far) to carry on a long-term monitoring of an extragalactic source in the TeV energy range.



The study of the arrival directions of cosmic rays at energy greater than 1 TeV shows significant evidence for a puzzling anisotropy, as Milagro and Tibet AS-γ had noticed. Currently no explanation for this effect has been given yet. ARGO-YBJ is studying this effect in great detail by selecting events with median energy of about 1 TeV. Two extended excess regions in the sky map are evident, with maximum significance of about 15 s.d. so far. The possibility that these excesses may be due to peculiar fluxes of photons or electrons had been ruled out already. Neutron fluxes from nearby stars can be excluded as well. So this is peculiar of the hadron arrival directions in the heliosphere in the TeV energy range. The rightmost excess region is aligned with the direction of the heliotail, and the direction of both regions is nearly perpendicular to the expected direction of the interstellar magnetic field. Several authors proposed a possible connection between this anisotropy and a nearby supernova [4].

Detector stabilization

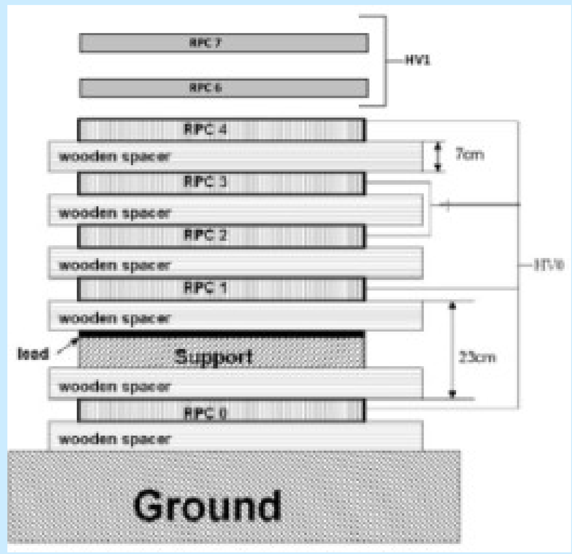
The gas gain in RPCs depends on the environmental conditions, namely on the local temperature and barometric pressure [4]. If V_{app} is the fixed applied voltage when the measured absolute temperature is T and the measured barometric pressure is p, then the effective voltage, if the reference absolute temperature and barometric pressure are chosen to be T_0 and p_0 respectively, is

$$V_{eff} = V_{app} \frac{T}{T_0} \frac{p_0}{p} \qquad (1)$$

Standard operating conditions for the ARGO-YBJ RPCs correspond to applied voltage V_0 at absolute temperature T_0 and barometric pressure p_0. Accounting for the fact that the effect of temperature changes affects the ARGO-YBJ RPCs with a delay of about one hour [5], the "operating-point" follow-up can be obtained according to the following rule:

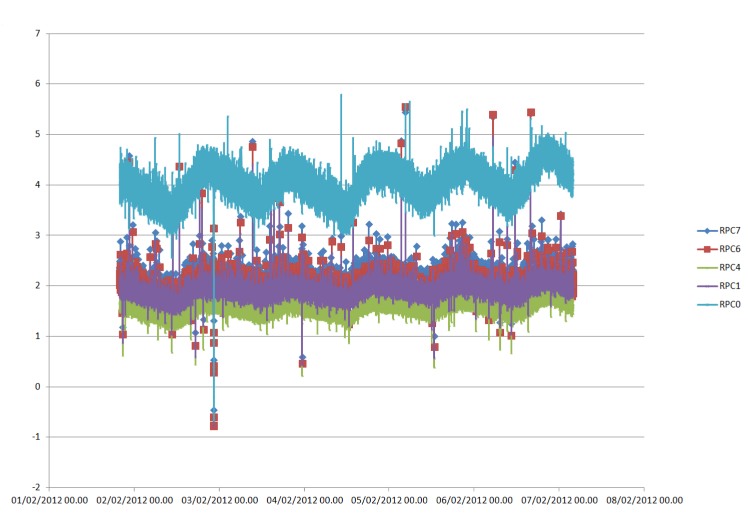
$$V_{app}(t) = V_0 \frac{T_0}{p_0} \frac{p(t)}{T(t - 1\,hour)} \qquad (2)$$

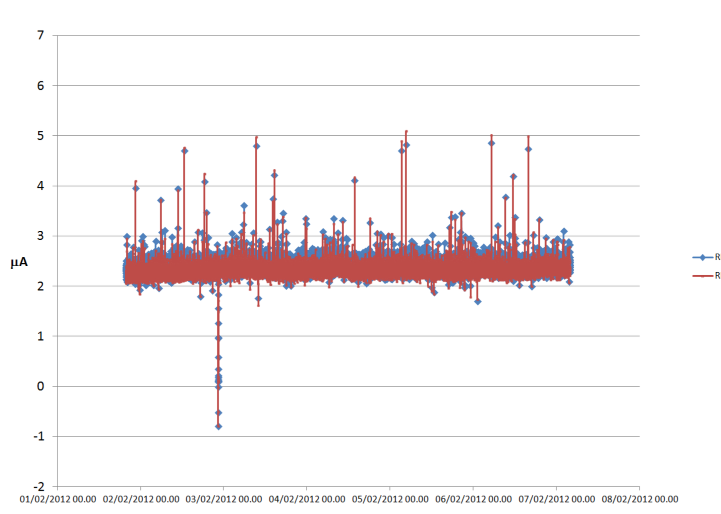
This algorithm is meant to stabilize the gas gain inside the RPCs, so that the detector can always work at constant operating conditions. However, it must always be kept in mind that this procedure only concerns the gas gain in the RPCs, and does not account for possible further effects connected to temperature changes in the whole acquisition chain.



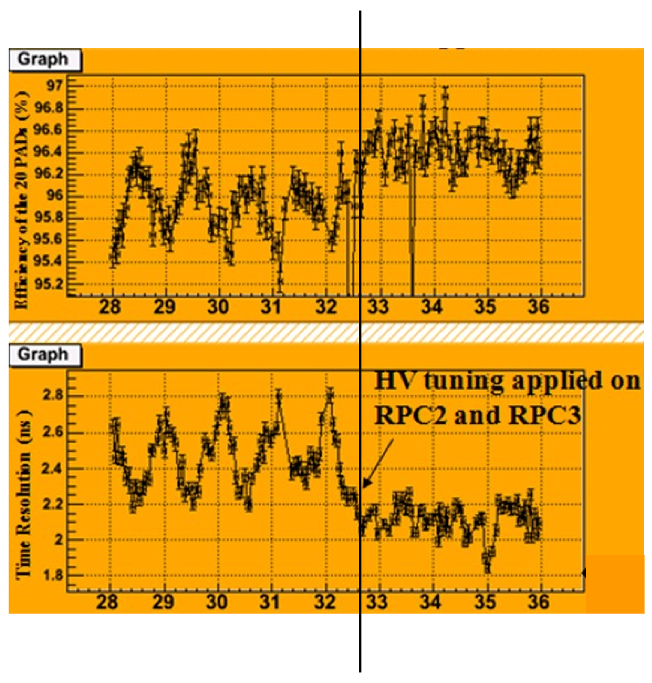
A small-size cosmic-ray telescope was installed close to the South side of the ARGO-YBJ carpet as a monitoring and testing facility for the RPCs. This telescope is connected to the general ARGO-YBJ acquisition system, so its data are recorded according to the standard trigger condition on the ARGO-YBJ carpet. Therefore, the analysis on the telescope must be performed with an off-line procedure. Cosmic-ray tracks are tagged by a coincidence of chambers 0, 1 and 4. These three chambers, together with chambers 2 and 3, are powered at 7200 V which is the standard voltage applied to the RPCs in the ARGO-YBJ carpet. The telescope has been running since 2008, using chambers 2 and 3 as the test chambers. The effect of the varying environmental conditions could be studied in detail.

The chambers 2 and 3 were powered according to the algorithm described previously in Eq. (2). This way, a continuous comparison could be made between a "standard" behaviour of the other chambers in which the applied voltage is left unchanged and a "corrected" behaviour in which the applied voltage is suitably regulated to compensate the gas-gain changes. The reference values for the absolute temperature and the barometric pressure are chosen to be close to the yearly average values provided by the monitoring system (DCS), namely T_0 = 288.65 K and p_0 = 600 mbar. The DCS, which includes all the monitoring and control procedures of the ARGO-YBJ experiment, must act on RPCs 2 and 3 at regular time intervals so that the voltage change to be applied each time is not greater than a few Volts. In this test the time interval was chosen to be 15 minutes. The complete high-voltage control algorithm also includes safety checks: for instance, the "new" voltage to be applied is used only if it is close enough to the previous applied voltage, to avoid critical mistakes induced by possible failures in the read-out of the environmental sensors. In addition, limits on the current absorbed by the power supply are set, so that the detectors are protected against any possible dangerous increase of current.





The voltage-control procedure was applied on the chambers 2, 3 in the cosmic-ray telescope from February 1st till February 6th, 2012. The current absorbed by all the chambers in the telescope was monitored, and the results are shown above for the chambers kept at fixed voltage (LEFT) and for the chambers 2, 3 (RIGHT). The effectiveness of the regulation algorithm is definitely apparent from the extreme stability of the current absorbed by the chambers 2 and 3 throughout the test, compared to the daily trend shown by the other chambers.



The detection efficiency and the time resolution of the chambers 2, 3 were monitored as well, and their behaviours before and after the start of the voltage-regulation test were compared. The result is shown in the charts to the left. The vertical line marks the time when the test was started. Before that time the voltage applied to the RPCs 2 and 3 was constant (7.2 kV). These plots show unambiguously that both the efficiency and the time resolution became more stable after applying the voltage-regulation procedure.

The devised feedback on the RPC applied voltage turned out to be reliable and stable. It is ready to be applied to the ARGO-YBJ full detector, and to any other detector with a response depending on the environmental parameters.

References

[1] The Astrophysical Journal Letters 714 (2010) L208
[2] The Astrophysical Journal 734 (2011) 110
[3] The Astrophysical Journal Letters 745 (2012) L22
[4] Salvati and Sacco. Astronomy & Astrophysics 485, 527-529 (2008)
[5] P. Camarri on behalf of the ARGO-YBJ collaboration; *Proceedings of the 29th ICRC*, Pune (India), Aug 3-10, 2005.
P. Camarri on behalf of the ARGO-YBJ collaboration; *Proceedings of the 30th ICRC*, Merida (Mexico), Jul 3-11, 2007
[6] P. Camarri, C.Y. Wu on behalf of the ARGO-YBJ collaboration; *Proceedings of the 31st ICRC*, Łódź (Poland), Jul 7-15, 2009