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PHYSICS WITH THE ARGO DETECTOR

ARGO Collaboration

Abstract

The ARGO telescope consists of a layer ($\sim$ 95% active area) of RPC's (resistive plate counters) covering an area $\geq 5000\,m^2$ and operating at an altitude greater than 4000 m a.s.l. . A small size test-carpet will be operating in the Yangbajing Laboratory (Tibet, China). ARGO will provide a detailed space-time picture of the shower front allowing to face a wide range of fundamental issues including gamma-ray from point sources, diffuse gamma-rays from the galactic plane, GBR's physics and the measurement of the $\overline{p}/p$ ratio at TeV energies. Additional objectives come from using ARGO as a traditional EAS array covering the full energy range from 10^{12} to $10^{16}\,eV$. The physics merits of this detector are presented.

INTRODUCTION

ARGO is a telescope optimized for the detection of small size air showers. The design of the detector is very simple: it consists of a single layer ($\sim$ 95% of active area) of RPC's (Resistive Plate Counters) covering an area $> 5000\,m^2$ and providing a detailed space-time picture of the shower front. RPC's have been employed successfully both in cosmic ray and accelerator experiments and their extensive use is envisaged for future experiments at SLAC and LHC. Performances, low cost and the opportunity of assembling in a close structure make this device a very attractive alternative to the traditional scintillation counters.

Once operated at high elevation ($> 4000\,m\ a.s.l.$) ARGO could image with high efficiency and sensitivity atmospheric showers initiated by primaries of energies in the range $10GeV \div 500TeV$. This performance makes ARGO a powerful detector to study cosmic γ-radiation at an energy threshold not far from the present experimental limits of the satellite technology and covering the unexplored range of energies between 50 and 300 GeV. Data gathered with ARGO will allow to face a wide range of fundamental issues. These include:

1) Gamma–astronomy, at a $\sim 100\,GeV$ threshold energy. More than 300 galactic and extragalactic point candidate sources can be monitored, with a sensitivity to unidentified sources better than 10% of the Crab flux.

2) Diffuse Gamma–Rays from the Galactic plane, molecular clouds and SuperNova Remnants (SNR) at energies $\geq 100\,GeV$ never observed so far.

3) Gamma Ray Burst (GRB) physics, by allowing the extension of the satellite measurements over the full GeV/TeV energy range.

4) $\overline{p}/p$ ratio at energies $300\,GeV \div \sim TeV$ not accessible to satellites, with a sensitivity adequate to distinguish between models of local (galactic) $\overline{p}$ production and models accounting for an extragalactic origin.

5) The primary proton spectrum in the $10 \div 200\,TeV$ region, with sensitivity sufficient to detect a possible change of the slope of the energy spectrum.

6) Sun and Heliosphere physics, including cosmic ray modulations at $10\,GeV$ threshold energy, the continuous monitoring of the large scale structure of the interplanetary magnetic field and high energy gamma and neutron flares from the Sun.

Additional objectives come from using ARGO as a traditional EAS array covering the full energy range from 10^{11} to $10^{16}\,eV$. At an altitude $> 4000\,m\,a.s.l.$ the electron size of the shower produced by primaries energies $10^{15} \div 10^{16}\,eV$ around the 'knee' of cosmic ray spectrum is practically independent of their mass.

The detector performances have been studied by means of a MonteCarlo simulation. Three different shower propagation codes have been used: the EPAS code (B. D'Ettorre Piazzoli and G. Di Sciascio, 1994) to develop the electromagnetic cascade in atmosphere, the HADRAS code (G. Di Sciascio, 1993) to describe the cascade induced by primary hadrons and the GEANT code (R.Brun et al., 1993) to propagate electrons and photons at the sampling level through the detector. Calculations have been carried out for the Yangbajing Cosmic Ray Laboratory (Lhasa, Tibet), 4300 m a.s.l., $30^0\,N$ latitude.

The detailed structure of the RPCs carpet has been taken into account. An RPC's carpet of $120 \times 120\,m^2$ has been considered with a 95% active area. Moreover a 95% efficiency has been take into account. A lead converter 0.5 cm thick covers uniformly the RPC plane to increase the number of charged particles and to reduce the time spread of the shower front by means of the shower photon conversion. Each RPC ($112 \times 280\,cm^2$) is equipped with a read-out system of 3 cm wide, 56 cm long strips. Signals from the strips are OR-ed in order to get the time of the first particle and the number of particles hitting each $50 \times 50\,cm^2$ "pad". The information from these "logic pads" can be easily managed for triggering purposes. The arrival times have been smeared out by taking into account the transit time in the strip (delay $= 4\,ns/m$), the time resolution of the detector ($\sigma_\tau = 1\,ns$) and the time resolution of the digitizing electronics ($\sigma_{el} = 1\,ns$). Results concerning the shower core reconstruction, the angular resolution, the effective area and the γ/h discrimination are described in Abbrescia et al. (1996).

PHYSICS PERFORMANCES

We present here only a few results, selected from Abbrescia el al. (1996), concerning the ARGO capability to observe gamma ray point sources and GRB's, and to measure the $\overline{p}/p$ ratio at TeV energies. In evaluating the ARGO sensitivity to face physics items requiring good angular resolution, as gamma astronomy and the measurement of the Moon or Sun shadow, only events with more than 20 hits (pads) have been considered. The physics items for which even a poor angular resolution is sufficient (GRBs) have been studied by using all the recorded events with ≥ 6 fired pads.

Gamma ray point sources. The ARGO sensitivity for a 5σ detection in 1 year of data taking corresponds to a differential flux at $100\,GeV$ of $6 \cdot 10^{-13} \div 1.5 \cdot 10^{-12}$ $ph/cm^2 \cdot s \cdot GeV$ depending on the spectral shape. By using the most recent Whipple spectrum, the time of observation needed to measure the unpulsed flux from the Crab is about ten days at a threshold energy of 350 GeV. Thus, ARGO should provide an accurate survey of the Crab spectrum from a few GeV to a few TeV.

To have information about the ARGO sensitivity to observe a photon spectrum whose shape is essentially determined by the absorption with the IR background, the spectra of Mrk 421 (measured by EGRET and Whipple) and 3C454 (extrapolated by the EGRET data), both with the same spectral index have been considered. The spectrum of 3C454, at $z = 0.86$, is assumed to be dominated above $100\,GeV$ by absorption effects as determined by a minimal evolution of the IR background (Biller, 1995). The ratio of integral fluxes $\phi_\gamma^{3C454}(> E)/\phi_\gamma^{Mrk421}(> E)$ is about 4.4 at 10 GeV but only 0.2 at $400\ GeV$, so that this represents a typical case of a source (3C454) very bright at EGRET energies but very faint at 400 GeV threshold energy. The source 3C454 is detected at a level of $5\,\sigma$ in about 40 days of observation. On the contrary, the detection of Mrk421 requires 3 months. This results shows that the ARGO sensitivity largely depends on the spectral shape in the energy range $100 \div 500\,GeV$.

Gamma ray Bursts. The suitable trigger for the detection of photons in the GeV range is obtained by requiring more than 6 fired pads. The angular resolution is about 2.6 degrees. In Fig. 1 is shown the minimum detectable energy fluence in the $10 \div 100$ GeV energy range for a Gamma Ray Burst of duration $\Delta t = 10\,s$ and spectrum exponent $\alpha = 3$ and $E_{max} = 1\,TeV$. As a comparison the upper limits obtained by EAS-TOP in the same energy range using the same spectral parameters in a GRB search in coincidence with 45 BATSE bursts are shown in the same figure, together with the fluences measured at lower energy by BATSE and EGRET during the powerful event GRB940217.

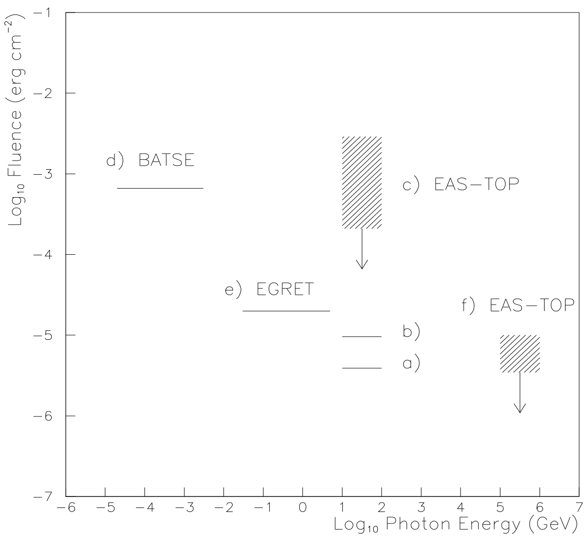

Figure 1: *The minimum energy fluence detectable by ARGO in the energy range 10 GeV $< E <$ 100 GeV for a gamma ray burst of duration Δt = 10 s and spectrum slope $\alpha = 3$ and E_{max} = 1 TeV for ARGO (line a) and ARGO–3600 (line b); upper limits obtained by EAS-TOP in the same energy range using the same spectral parameters in a GRB search in coincidence with 45 BATSE bursts (box c); fluences measured at lower energy by BATSE (line d) and EGRET (line e) during the powerful event GRB 940217.*

Measurement of the $\overline{p}/p$ ratio at TeV energies. By selecting events with a pad number $30 \div 350$, a proton beam with an energy of 800 GeV can be defined. The Fig. 2 shows the distribution of the arrival direction of air showers which should be produced by the protons intercepted by the Moon (a total of about $1.5 \cdot 10^5$ protons in 1 year of data taking). The shadow departs strongly from a circular shape and is elongated as compared with the 9 $mrad$ angular dimension of the Moon. The overlap of the proton shadow over the negative angles (eastward) is quite small. An acceptance cut $\pm 0.5^0$ around the Moon center reduces the proton contamination to the antiproton shadow below 10^{-3} with a loss of the signal of about 10%. In an angular box $\Delta\Theta_x = 0.5^0 \div 4.5^0$, $\Delta\Theta_y = -0.3^0 \div 0.3^0$ about 70% of the signal is contained, corresponding to a number of missing events of about 10^5 events. Thus, the proton shadow is measured with high statistical significance (70σ) and its profile could be used to evaluate the profile of the antiproton shadow. We find that an antiproton flux as predicted by Stecker and Wolfendale would be detected by ARGO with 4σ significance in 1 year of data taking. In case of no signal detection, the upper limits at 90% C.L. set by ARGO (2 yrs of data taking) and ARGO-3600 (60×60 m^2, 3 yrs of data taking) are 6.5×10^{-3} and 1.6×10^{-2} (see Fig. 3). Since the theoretical evaluation of the antiproton/proton ratio for baryon-symmetric Universe models is far above such limits while this ratio for antiprotons originating in the Galaxy is expected to be much below, the operation of ARGO could support or refuse the hypothesis of an extragalactic origin of the antiprotons.

CONCLUSIONS

Physics potentials make ARGO an unique detector to bridge the GeV and TeV energy regions, in this way providing full complementarity to several satellite programs. The ARGO-TEST, a small area RPC's carpet, will be operating in the Yangbajing site as a preliminary test of several practical and technical aspects. Detector assembling should start late in 1997 and data taking in 1998.

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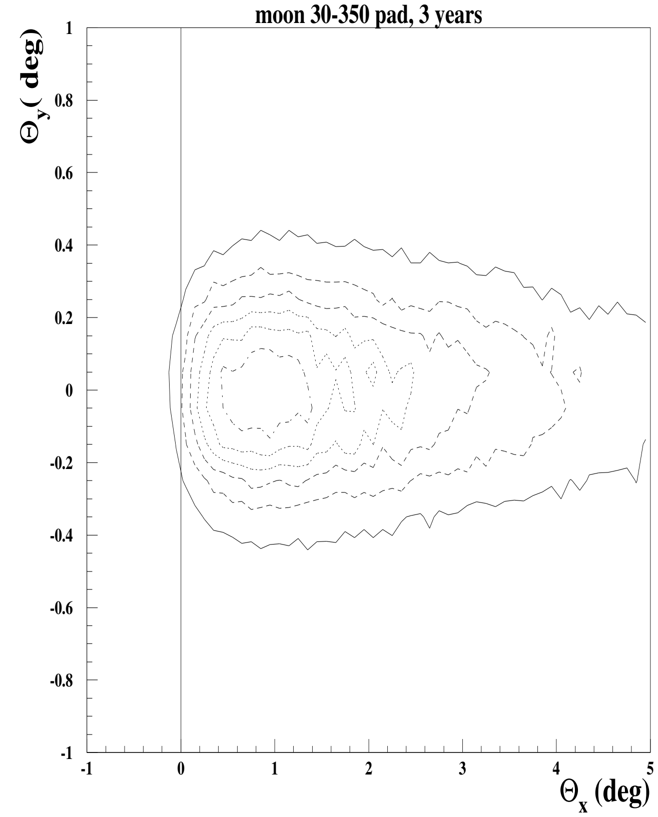

Figure 2: *Distribution of the arrival direction of air showers produced by the protons intercepted by the Moon. Θ_x and Θ_y measure the angular distance from the Moon center along the right ascension (E–W direction) and the the declination (S–N direction), respectively.*

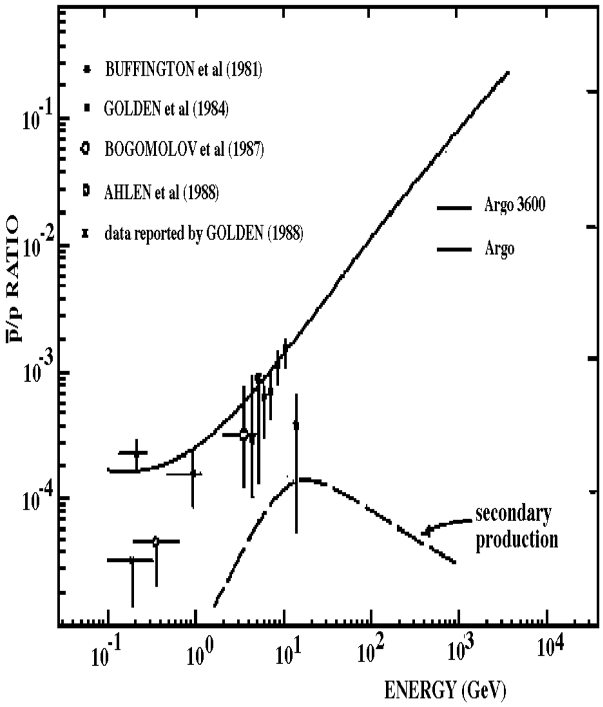

Figure 3: *Upper limits at 90% c.l. on the $\bar{p}/p$ ratio set by ARGO and ARGO–3600 in case of no signal detection (see text).*

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