Preliminary results of the 2003 GLAST campaign at CERN SPS

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This note gives a brief overview of the motivation of the experiment, the experimental method employed and presents the first results. The analysis is currently in progress at Bordeaux (France) and at Kalmar (Sweden).

1 Introduction

1.1 Brief presentation of GLAST

The Gamma-Ray Large-Area Space Telescope (GLAST) [1] is the next generation high-energy gamma-ray satellite, to be launched by NASA in 2007. The GLAST collaboration includes institutes from USA, Japan, Italy, France and Sweden. GLAST received the status of "recognized experiment" from CERN in June 2000.

GLAST's main instrument, the large area telescope (LAT), will cover the energy range between 20 MeV and 300 GeV, wider than that of its predecessor EGRET[2] (E $<$ 30 GeV) with enhanced sensitivity (a factor of 25) and better angular resolution. The satellite will mainly be devoted to studying the cosmic accelerators of relativistic particles, electrons or hadrons, and the environment in which these particles interact with matter or radiation to produce gamma-rays. A large variety of sources, either galactic (solar flares, pulsars, supernovae remnants...) or extragalactic (active galaxy nuclei, sources of gamma-ray bursts...) have already been identified with the data from EGRET. Thanks to its improved performance, GLAST may discover new gamma-ray emitters (microquasars or binary systems are among possible candidates). After one year of operation, the GLAST catalog should include over thirty times more sources than EGRET's. The good source localization provided by the LAT will make it relatively easy to find counterparts in other wavelength bands, at least for the brightest sources (note that 60% of the sources detected by EGRET have no known counterparts.)

1.2 Importance of the 30-300 GeV energy band

Among the new features offered by the LAT, the coverage of the energy band 30-300 GeV is of prime scientific importance and constitutes one of the major breakthroughs with respect to the previous instrument, EGRET, limited to 30 GeV. Long unexplored, this band has just recently been scratched by the new generation of ground-based experiments like CELESTE[3]and STACEE[4].

While 270 sources have been detected by EGRET below 30 GeV, only 8 confirmed sources have been seen above 300 GeV by ground-based telescopes. The extinction of most sources thus takes place within this energy band, the precise high-energy cutoffs remaining unknown so far. These cutoff energies will provide extremely valuable information. For example, for gamma-ray pulsars, the two most favored models, the so-called outer-gap and polar cap models predict different cutoff energies; measuring the cutoff energies will thus enable one to establish which model prevails. Studying the spectral cutoffs of the "blue" blazars as a function of their distances could shed light on the attenuation of the gamma-rays via e^+e^-pair production on the Extragalactic Background Light. This study will allow the determination of the EBL in a little-explored wavelength band, where direct measurements are difficult because of large foreground contributions. As a last example, if the neutralino annihilation line can be observed by GLAST, the neutralino mass must be pinned down as accurately as possible, as it represents a fundamental parameter of the SUSY theories. Some theoretical predictions indicate that this energy would lie between 50 and 200 GeV. For GLAST to have a significant sensitivity in this search, its energy resolution must be below 5%.

The few above examples demonstrate that the potential scientific success of GLAST is intimately linked to the accuracy of the gamma-ray energy assessment beyond 30 GeV.

1.3 Description of the LAT

The LAT comprises three sub-systems:

- a tracker allowing the gamma-ray direction to be reconstructed; this tracker is made of 18 layers of crossed silicon strips interlaced with W foils where the incident gamma-ray converts into a e^+e^-pair, amounting to a total thickness of 1.3 X_0;
- a CsI calorimeter (CAL, 8.5 X_0 in thickness), enabling the gamma-ray energy to be determined;
- an anticoincidence shield made of scintillator tiles for vetoing charged cosmic rays.

The calorimeter module of each of the 16 towers is made of 8 layers of 12 CsI crystals, 32.6 cm x 2.67 cm x 1.99 cm each, arranged in individual cells made of carbonfibers. The calorimeter thickness is only 8.5 radiation lengths due to the limited weight budget. Each crystal is read out at each end by two photodiodes, a large one (1 cm^2 in area) and a small one (0.15 cm^2 in area). Each photodiode is associated with two electronic chains with high and low gain respectively, leading to a total of 4 different dynamic ranges. The CsI crystals are tapered so that the shower position along the crystal can be inferred from the relative amount of light measured at each end. A position resolution of 1 mm is expected for sufficiently high-energy showers ($E > 500$ MeV).

1.4 Calibration strategy

In flight, the calorimeter will be calibrated by using the well-defined energies deposited via ionization by high-energy cosmic-ray ions (C, O, Si, Fe). Before the flight, on the ground, four towers of the LAT will be exposed to gamma-rays and positrons at SLAC, for energies below 30 GeV. The corresponding data will be employed for benchmarking the simulations that will generate the response functions for the whole detector: effective area, "point spread function", and energy resolution function. Complementary data are needed in the energy range beyond that available at SLAC.

2 Purpose of the SPS experiment

The experiment carried out at the CERN SPS concerned the determination of the calorimeter response up to 300 GeV.

The main goal was to measure precisely the shower longitudinal profile and benchmark the energy-reconstruction methods at high energy, especially for crack-crossing showers. Two different reconstruction methods, established through Monte-Carlo simulations, are currently envisioned above 1 GeV. At low energy or large off-axis angle, the energy reconstruction is primarily based on the sum of the energies measured in the calorimeter, the leakage being estimated from the energy deposited in the last crystal layer (" last-layer correlation method "). This method is only applicable for showers having their maximum contained within the calorimeter. For higher energies (E>50 GeV at normal incidence) and smaller off-axis angles, the energy must be deduced from a fit of the shower profile. It is of course crucial to check the reliability of the simulations in this case. Curiously enough, there have been relatively few comparisons between measured and calculated profiles: the reason lies in the fact that high-energy physics calorimeters are usually thick enough (24 X_0 for ATLAS) to provide for a direct measurement of the total electromagnetic energy without resorting to profile fitting. The data most-often referred to in the literature [5] were obtained more than 30 years ago, and dealt with 1 GeV electrons impinging on water and Aluminum.

The second goal was to estimate the resolution of the shower localization using the calorimeter only. The localization capability of the calorimeter allows for a crude determination of the trajectory, complementary to that provided by the tracker.This information is used in the background filtering algorithm, mostly to reject upward-going albedo events. The impact of the direct energy deposition within the photodiodes should be studied as well.

The third objective was to establish the energy-deposition patterns for hadrons (pions), especially for nuclear-reaction events. In contrast to electromagnetic showers, hadronic showers are much more difficult to model accurately. Benchmarking the hadronic simulations against real data is thus even more essential than for the electromagnetic ones.

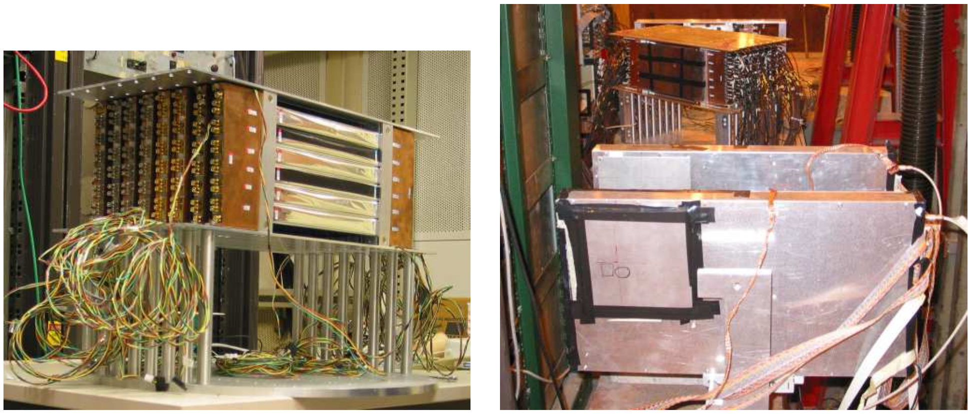

Figure 1: Left:View of the arrangement of 48 crystals. Right:View of the experimental setup. From the foreground back: the two silicon chambers, the set of 48 detectors (rotated with respect to the beam axis) , the set of 15 crystals (partly hidden).

3 Experimental method

The experiment took place in August 2003 on the H6A beam line in the SPS West Area, over 6 days of beam time. Runs were performed at:

- 10-20-50-80-120-150 GeV for electrons;
- 20 GeV for muons;
- 20 GeV and 100 GeV for pions.

A total of 63 crystals were used, arranged as follows:

- 48 CDEs (crystal detector element), similar to the flight ones (same manufacturer, same specifications, same bonding and wrapping, same PIN diodes for the readout) were assembled into 8 independent groups of 6 and held together by a 4mm-thick Aluminum frame (Fig. 1 left). The frames were placed horizontally and screwed to a rotating plate, sitting on a X-Y moving table. The ensemble was rotated by angles varying between 0 and 30 degrees during the experiment. This arrangement emulated a GLAST tower fairly accurately.
- 15 prototype crystals of two different makes, with dimensions 250 mm x 30 mm x 30 mm, arranged into 3 layers of 5 and placed behind the arrangement described above.

Since the flight electronics was not yet available at the time of the experiment, the photodiode readout electronics was composed of low-noise charge preamplifiers and linear amplifiers developed in Bordeaux. Two sets of amplifiers with different gains were used depending on the impinging particles: high-gain amplifiers were used with muons while low-gain amplifiers were used for pions and electrons (the gain ratios were about 120). Cross-calibration between the different amplifiers was performed using a pulser whose signal was injected into the preamplifiers. The ADCs were commercial ones (VME CAEN V785). The electronic saturation occurred around 3 GeV and 20 GeV for the big and small diodes respectively.

The trigger was provided by two 2 mm-thick plastic scintillator detectors in coincidence located a few meters upstream of the CDEs: all channels were read out for each event. The beam intensity on the T2-H6 beam line was limited to a few hundred Hz.

Two silicon chambers developed at Trieste provided X-Y information allowing for the reconstruction of the trajectories of the incident particles with a resolution of 40 microns. Passive material, necessary for the cascade to develop, was used in conjunction with the crystals. This passive material were made of superposed Pb and Al sheets, whose thicknesses (0.50 cm and 1.49 cm, respectively) were chosen so that the resulting associated radiation length matched that of CsI. The Moliere radius associated with this assembly was very close to that of CsI (3.8 cm). In the study of crack-crossing showers, since too few CDEs were available to build two full towers this passive material replaced some CDEs at places where the deposited energy was expected to be low.

Figure 1 right shows a view of the setup (the plastic detectors are missing for clarity).

4 Preliminary results

4.1 Absolute energy calibration

The energy calibration, i.e. determination of the conversion factor (MeV/ADC unit) was established by fitting the measured deposited-energy distributions for 20 GeV muons with the corresponding distributions predicted by GEANT4 (Fig.2). The vertical position of the detector was changed so that the beam hit two neighboring bars simultaneously, enabling the whole calibration to be carried out in only three different runs. Although the deposited energy for such minimum-ionizing particles crossing a crystal perpendicularly is only 12 MeV on the average, it was possible to extend the calibration range up to 20 GeV by using the pulser technique mentioned above.

4.2 Deposited-energy distributions

The consistency of both the data and the calibration can be checked by comparing the four energy distributions measured by the two photodiodes (big and small) on each end of the crystals, in the overlapping energy regions. Fig. 3 displays such a comparison for the six crystals of a given layer (for distributions extending beyond 3 GeV, only those associated with the small diodes are given). The distributions are found consistent within 3% for most of the crystals.

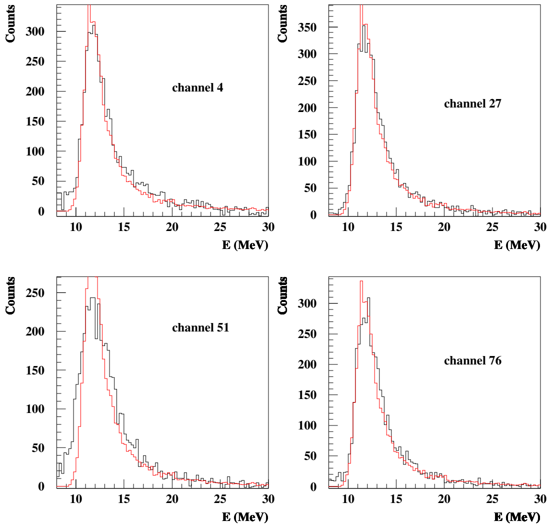

Figure 2: Comparison of the measured deposited-energy distributions (black histograms) with those predicted by GEANT4 (red histograms). The beam was 20 GeV muons.

4.3 Longitudinal shower profiles

The longitudinal shower profile was studied first. As mentioned above, very few data have been published concerning these profiles. Some experimental profiles obtained under different conditions are presented in Fig. 4(dots), together with the results of preliminary GEANT4 simulations (bars). The open (solid) dots correspond to the data from the left (right)-hand ends of the crystals: there is good agreement between these two independent pieces of information. Overall, GEANT4 provides a good reproduction of the measured profiles. The slight observed discrepancies may essentially stem from the neglect of the material located upstream of the detector, allowing the cascade to be initiated earlier. Work is in progress to improve the simulations accordingly.

4.4 Localization studies

Thanks to the light tapering in the CsI crystals, the position of the shower impact can be measured through the light asymmetry, defined as: (L-R)/(L+R), where L and R stand for the light amount (i.e. energy) collected on the left-hand and right-hand sides respectively. Several crystals were scanned using 120 GeV electron and 20 GeV muon beams. Fig. 5 shows the results of such a scan for 6 different positions located 5 cm apart. The comparison between muons and electrons is useful since the light-tapering coefficients for the whole instrument will be determined prior to the launch with “cosmic” muons and applied to electromagnetic showers in orbit. For high-energy electrons, the

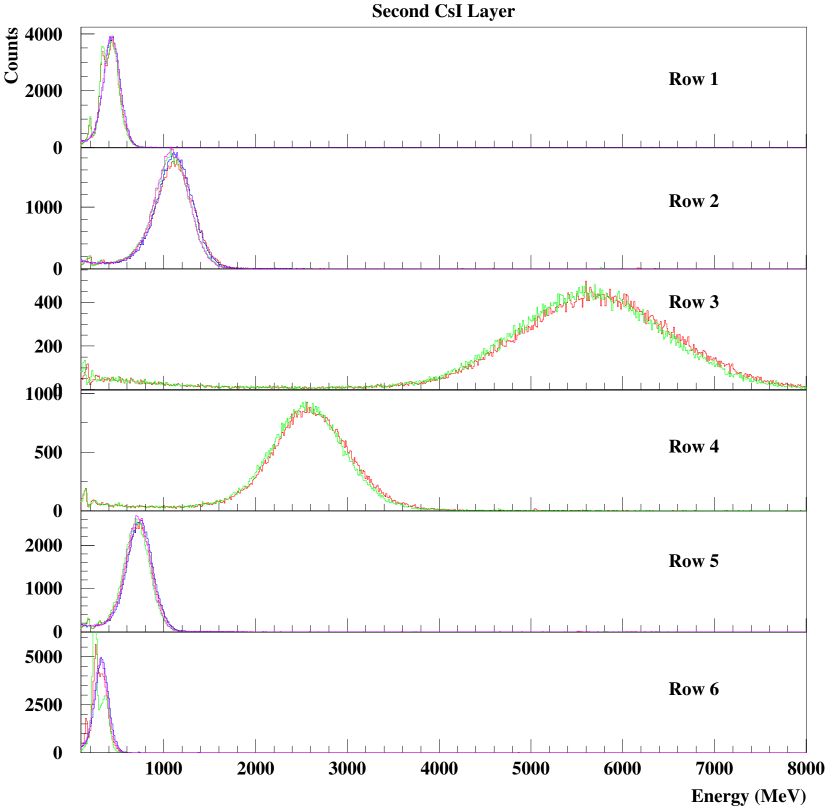

Figure 3: Comparison between the energy distributions measured in the different electronic channels (red: small left, green: small right, cyan: big left, purple: big right) for six crystals of a given layer. The beam is 120 GeV positrons. An 8 X_0-thick Pb block was placed in front of the detector.

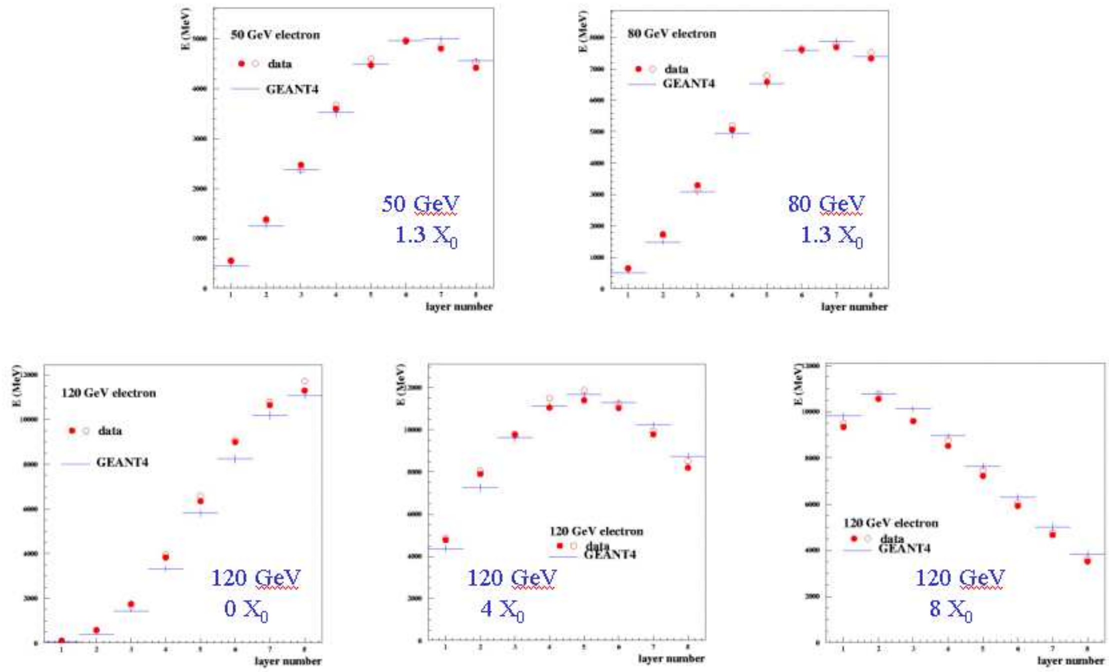

Figure 4: Measured longitudinal profile (dots) compared to the GEANT4 predictions (bars), for different electrons energies and thicknesses of the upstream Pb block.

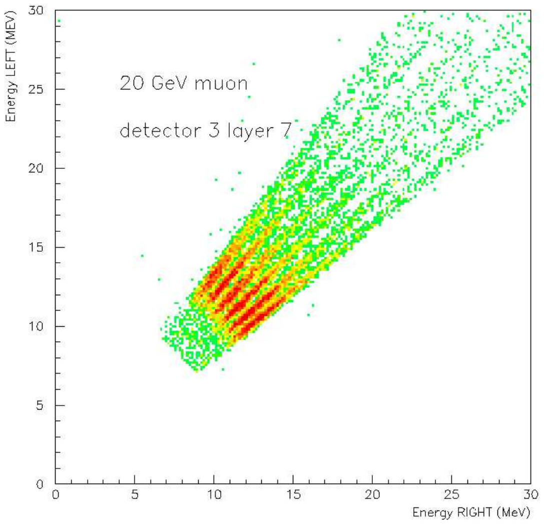

Figure 5: Energy measured on the left-hand end plotted versus the energy on the right-hand end, for 6 different beam positions.

observed resolution is about 1.2 mm (Fig. 6) while it is about 5 mm for muons, matching well the expectations. The dependence on the deposited energy will be studied.

5 Conclusion

In this note, a few results aiming at demonstrating the good quality of the data collected during the 2003 SPS run have been presented. Although the analysis is not complete, it is already clear that the main objectives will be met. Further analysis will include the study of the transverse shower distribution, the effect of direct energy deposition within the photodiodes, the bias in the trajectory localization for off-axis showers, the determination of the patterns of the nuclear reactions induced by pions...

The analysis is the object of a Swedish diploma work and part of a PhD work.

References

[1] http://glast.stanford.edu

[2] http://lheawww.gsfc.nasa.gov/docs/gamcosray/EGRET

[3] http://doc.in2p3.fr/themis/CELESTE

[4] http://www.astro.ucla.edu/~stacee

[5] C.J. Crannel et al., Phys. Rev. 184, 1969, 426.

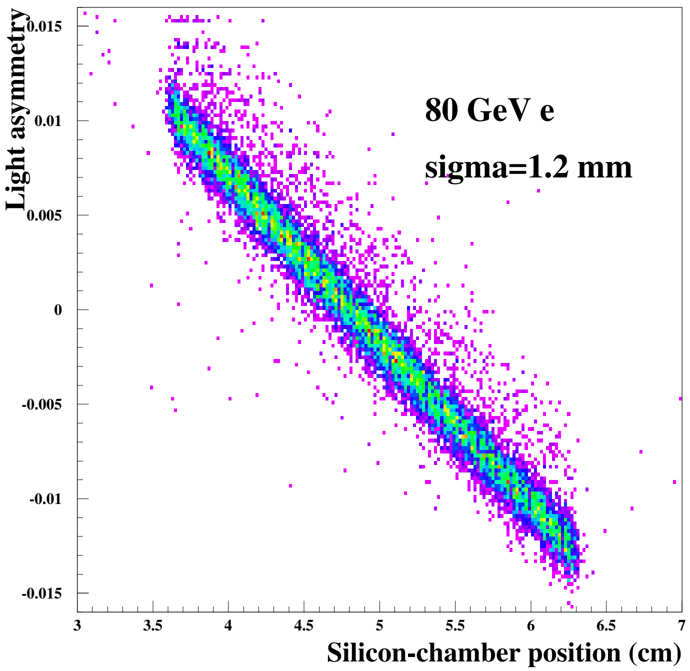

Figure 6: Light asymmetry in a crystal plotted as a function of the position measured in one of the two silicon chambers, for 80 GeV electrons.