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HARPO: 1.7–74 MeV gamma-ray beam validation of a high angular resolution, high linear polarisation dilution, gas time projection chamber telescope and polarimeter

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Summary. — A presentation at the SciNeGHE conference of the past achievements, of the present activities and of the perspectives for the future of the HARPO project, the development of a time projection chamber as a high-performance gamma-ray telescope and linear polarimeter in the e^+e^- pair creation regime has been given.

A number of groups are developing pair-conversion detector technologies alternative to the tungsten-converter/thin-sensitive-layer stacks of the COS-B/EGRET/*Fermi* LAT series, to improve the single-photon angular resolution. Presently observers are almost blind in the 1–100 MeV energy range, mainly due to the degradation of the angular resolution of e^+e^- pair telescopes at low energies: to a large extent, the sensitivity-gap problem is an angular-resolution issue. Also no γ-ray polarimeter in the pair creation regime, that is above 1 MeV, had ever been flown to space.

Gas detectors such as TPCs (time projection chambers) can enable an improvement of up to one order of magnitude in the single-photon angular resolution (0.5° @ 100 MeV) with respect to the *Fermi* LAT (5° @ 100 MeV), a factor of three better than what can be expected for Silicon detectors (1.0–1.5° @ 100 MeV) [1]. With such a good angular resolution, and despite a lower sensitive mass, a TPC can contribute to close the sensitivity gap at the level of 10^{-6} MeV/(cm^2 s) [1]. In addition, the single-track angular resolution is so good that the linear polarisation fraction and angle of the incoming radiation can be measured [2]. In constrast with dense telescopes (Si, emulsions), gas detectors can detect the conversion of very low energy photons (fig. 1), which is crucial as the signal of conversion to pairs peaks at 5–7 MeV for most cosmic sources.

The HARPO prototype is a 30 cm cubic TPC. It uses an argon-isobutane gas mixture as its active target, that is a fast-gas with a full-length drift time of 9 μs that ensures a low

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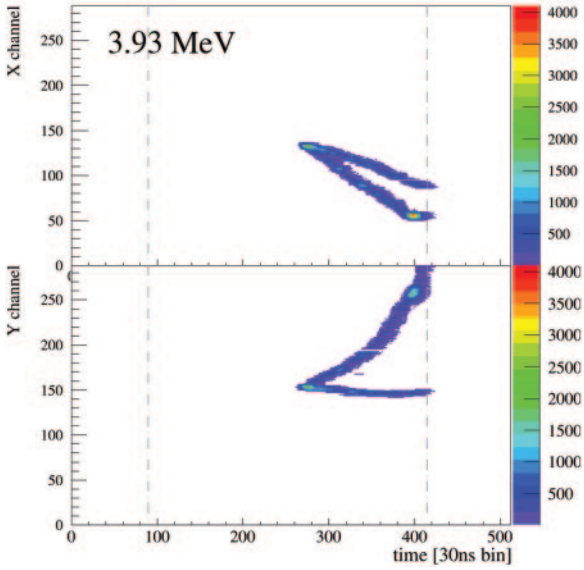

Fig. 1. – The two projections (x, t) and (y, t) of the signal recorded upon the conversion of a 4 MeV photon provided by the BL01 polarized γ-ray beam line at NewSUBARU, in the 2.1 bar argon-isobutane 95-5%gas mixture of the HARPO TPC. The left and right dashed vertical lines correspond to the time of the trigger and to the arrival time of the "ionisation" electrons who enjoyed the full drift length from the cathode to the anode, respectively.

background pile-up probability in flight operation, and is also a cool-gas that provides diffusion coefficients almost as low as the thermal limit [3].

We have characterized the detector performance in the pressure range 1–4 bar in the 1.7–74 MeV fully-polarised or non-polarised gamma-ray beam provided by the BL01 line at NewSUBARU [4]. A trigger adapted to the large flux of single-track background noise coming from the beam line was instrumental to enabling a high-efficiency data taking [5]. The excellent value of the polarisation asymmetry dilution factor that we measured paves the way to the opening of the polarimetry window in the MeV-GeV energy range [6].

In telescopes in which γ-ray conversions take place in high-Z converter plates, such as in the *Fermi* LAT, the angular resolution is coarse enough that the accuracy of the $\gamma \rightarrow e^+e^-$ event generator used in the simulation is not an issue. But for the high angular resolution telescope that is considered here, the kinematic contribution of the unmeasured ion recoil dominates the single-photon angular resolution and the use of an exact generator, such as the one that we developed [2], is mandatory [7, 9]. Also we have discovered that none of the otherwise existing generators simulate the conversion of linear polarization accurately [7]. We are presently editing our generator to make it available to the community.

With this tool, we found that the definition of "the" azimuthal angle of the gamma conversion that was used since the end of the last century in linear polarimetry studies, provides a measure of the polarisation asymmetry that underestimates significantly its value, which implies that the precision of the measurement of the polarisation fraction of a source is then degraded (increased). The maximal value of the asymmetry, that is found to be compatible with the low-energy and high-energy asymptotes, was

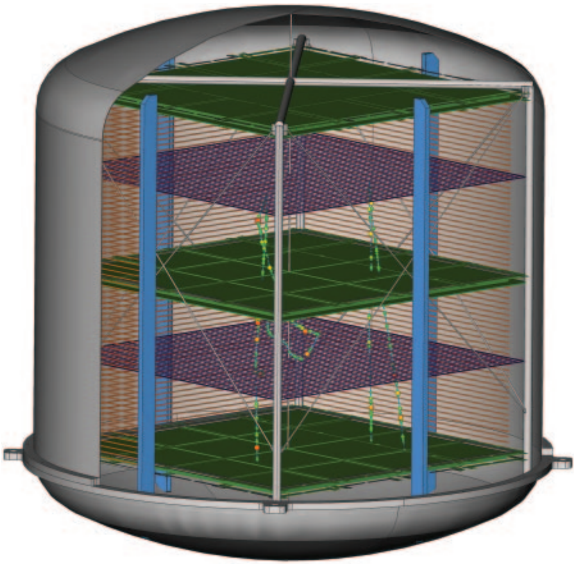

Fig. 2. – Artist view of the flight prototype with 2 simultaneous 11.8 MeV geant4 photon conversions overlaid.

obtained with the azimuthal angle of the bisectrix of the electron and of the positron directions [8, 9].

The electrical power budget is strictly limited onboard space missions and therefore it was not possible to equip the TPC endplate with a collection anode with a 2D segmentation (pads). Instead we use a pair of orthogonal series of strips (x and y), at the cost an ambiguity in the pairing of the two x tracks and of the two y tracks. The violent fluctuation of the ionisation energy deposition along the tracks makes the signal time spectrum a marker of each track, that is collected almost in the same way by the x strips and by the y strips, enabling a powerful track matching [6, 10]. In the special situation of two tracks almost overlapping in a given view (say, x), obviously no matching is needed. These events make peaks at azimutal angles 0 and $\pi/2$ which may be frightening at first glance, but the azimutal information carried by the pair is barely degraded as the dilution of the polarisation asymmetry only decreases as $e^{-2\sigma_\phi^2}$, where σ_ϕ is the experimental resolution of the measurement of the azimuthal angle ϕ [2]: a moments method enables the optimal extraction of the available azimuthal information [2, 8].

The HARPO project has also implied several hardware developments; as the gas quality of the EGRET tracker/converter degraded rapidly to the extent that they had to change gas every year —which is not surprising for a spark chamber, most likely among the most efficient way to perform chemistry under ionizing radiation— we have monitored the evolution of the gas quality of the HARPO detector when kept in a sealed mode over several months: after a small oxygen component is filtered out, the detector is functioning nominally [11].

The "ground", HARPO, phase of the project is not far from completion. We are now designing a "flight" prototype named ST3G (stègue) "Self-Triggered TPC for γ-ray telescope" (fig. 2) for which the trigger will be built using the real-time information provided by the readout chips. We have designed ASTRE "Asic with SCA and Trigger for detector Readout Electronics" [12] a modified version of the AGET readout chip [13], that is also resistant to ionizing radiation: a first batch of chips has been produced and their tests are ongoing. We aim at characterizing the behaviour of that flight trigger system with a stratospheric balloon flight. The HARPO data taking on beam was performed by using NewSUBARU-GACKO (Gamma Collaboration Hutch of Konan University).

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