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THE GAMMA-400 MISSION

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Abstract

GAMMA-400 is a new space mission scheduled to be launched at the end of the current decade on-board the Russian space platform Navigator. The

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experimental apparatus is designed for simultaneous detection of gamma and cosmic rays in a broad energy range: 100 MeV $-$ 3 TeV for photons, 1 GeV - 20 TeV for electrons and positrons, and up to $10^{15} - 10^{16}$ eV for p and He. The characteristics of the instrument are optimized to address some of the most impelling science topics, such as search for signatures of dark matter, studies of Galactic and extragalactic gamma-ray sources, Galactic and extragalactic diffuse emission, gamma-ray bursts, as well as high-precision measurements of the spectra of cosmic-ray electrons + positrons and nuclei.

1 Origin and evolution of the project

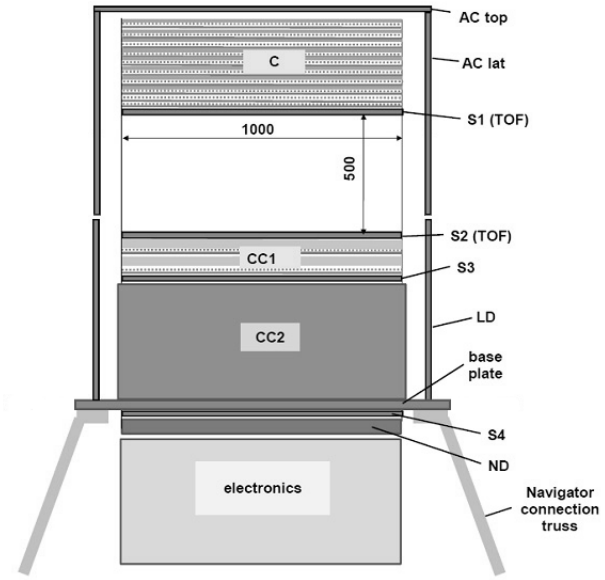

Figure 1: *Schematic view of the baseline. From top to bottom: the tracker (C), anticoincidence system (AC top and lat), time-of-flight system (S 1 to 4), calorimeter (CC1 and CC2), charge identification system on the side of the calorimeter (LD) and neutron detector (ND). The values are in mm.*

GAMMA-400 [1)] is a Russian space mission, approved by the Russian Space Agency RKA-ROSCOSMOS, with an international contribution. The

apparatus will be installed on the platform Navigator and, apart from the detectors shown in fig. 1 and described in the next section, will comprise also six gamma-ray burst monitor Konus-FG and two magnetometers.
The launch is currently scheduled by 2020 and the mission is expected to have a lifetime of at least 7 years. The orbit will initially be highly eccentric (apogee 300000 km, perigee 500 km) with an inclination of 51°. After 5 months the orbit will become more circular with an average radius of about 200000 km. This high altitude orbit will allow GAMMA-400 to make long, continuous observation of specific regions of the celestial sphere, without Earth occultation.
During the past years, the collaboration between the Russian and Italian group focused on the development of a dual instrument, capable of studying not only gamma-rays and electrons, as originally intended, but also cosmic-rays protons and nuclei.

2 The apparatus

The apparatus [2)] is composed by a converter/tracker and a calorimeter, described in the following. Plus, in order to discriminate the high charged particles background from the gamma-rays, a neutron detector as well as an anticoincidence and a time-of-flight system are foreseen. A charge identification system will be placed on the sides of the calorimeter to discriminate between the different nuclear species.
The tracker and the calorimeter are widely spaced ($\sim$ 50 cm). This substantial distance helps to improve the angular resolution at high energy. The top 2 X_0 of the calorimeter are composed by interleaved planes of CsI slabs and Silicon strip planes. At high energy, where the multiple scattering is negligible, the long lever arm between the hits on these Silicon planes and the hits in the tracker facilitate the reconstruction of the incoming direction of the gamma-ray.

2.1 Converter/Tracker

The main purposes of the tracker are to convert the incoming gamma-ray inside the inert material and detect the created pair inside the Si.
The GAMMA-400 tracker, whose schematic view is shown in fig. 2, is designed as a four tower detector. Each tower is composed by ten planes, each of which has two layers of single-sided Si microstrip, for the x/y view respectively. The read-out of strips is analogue. The Si sensors make use of the capacitive charge

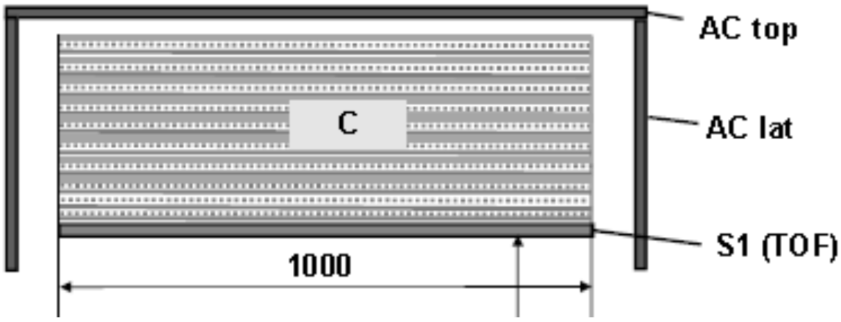

Figure 2: *Schematic view of the tracker.*

division, helping to reduce the number of read-out channels while maintaining an excellent position resolution. The strip pitch is 80 μm with one every three strips read-out. The read-out pitch is thus 240 μm. Five sensors, square tiles of $\sim$9.7$\times$9.7 cm^2, are arranged in a ladder. Each plane is composed by five of these ladders.

The first eight planes of the tracker comprise a Tungsten layer, absent in the last two planes, to ensure the conversion of the gamma-ray. The thickness of each of the first eight planes is $\sim$ 0.1 X_0.

The performance of GAMMA-400, compared those of Fermi-LAT, are presented in fig. 3. The results for the angular resolution at low energy are improved by the use of the analogue read-out, which ensures a lower error on the position with respect to the digital read-out. At high energy, the use of the long lever arm between the tracker and the Si planes in the calorimeter permits to reach an angular resolution better than 0.1° from 10 GeV and better than 0.02° starting from 100 GeV.

2.2 Calorimeter

The calorimeter is composed by an array of 28$\times$28$\times$12 cubes of CsI(Tl), each of side 3.6 cm. This novel concept for the detector permits to reconstruct the shower created from particles coming not only from the top, but also from the sides of the calorimeter. The planar geometrical factor is therefore very high

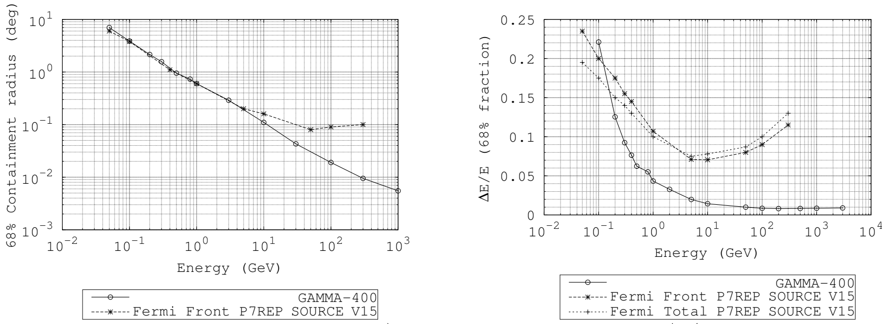

Figure 3: *Angular resolution a) and energy resolution b) (circle and continuous line) compared to the performance of Fermi-LAT (front in dashed line and stars, total in dotted line and cross hair).*

($\sim$10 m^{2}sr). The effective geometrical factor, result of the implementation of the necessary cuts, in the 100 GeV - 1 TeV energy range is equal to $\sim$3.4 m^{2}sr for electrons and $\sim$3.3 m^{2}sr for protons. The total radiation length is $54.6\times54.6\times23.4$ X_0 while the interaction length is $2.5\times2.5\times1.1$ λ_I.

The possibility to reconstruct the shower of particles coming also from the sides of the detector can be exploited to improve significantly the total effective area of the instrument. The large geometrical factor of the calorimeter alone can also be exploited for gamma-ray physics. In this case the angular resolution, while not sufficient for a precision study the sources, can nonetheless be useful to provide a trigger to other instruments to perform multiwavelength studies of the same source. In the case of a transient phenomenon (e.g. AGN flare), the position of the flaring source could be used to repoint on-ground telescopes, which have a limited field-of-view.

The energy resolution for gamma-rays, thanks also to the depth and performance of the calorimeter, reaches 1% at 100 GeV. The expected energy resolution for electrons will be of 1% at TeV energies, while the hadronic energy resolution for protons will be $\sim$ 35%.

A prototype of the calorimeter has already been built. It consists of 14 layers, nine crystals each. The prototype has been tested at CERN SPS with protons and deuterium.

3 Physics with GAMMA-400

GAMMA-400 has been optimized to detect the three main component of the cosmic radiation: gamma-rays from 50 MeV up to TeV, electrons up to ∼20 TeV and protons and nuclei up to the "knee" (few PeV/nucleon).

3.1 Photons

For what concerns the gamma-rays, the main scientific objective of GAMMA-400 will be the search of a possible signal related to Dark Matter annihilation or decay. This search, to be performed looking to the Galactic Center, Dwarf Spheroidal Galaxies and satellites such as galaxy clusters, will rely on the excellent angular and energy resolutions of GAMMA-400. The improvement in energy resolution will not only permit the detection of the lines resulting from by the $\gamma\gamma$ annihilation channel of the Dark Matter candidate, but also the detection of features in the spectrum. Some of this features, if present, could help to discriminate between different candidates [3].
Apart from the search for Dark Matter signal, GAMMA-400 will study also astrophysical sources such as supernova remnants, Active Galactic Nuclei, pulsars and pulsar wind nebulae and gamma-ray bursts, thanks also to the very wide field-of-view of the Konus-FG. GAMMA-400 will help in the detection of new candidates of these sources, in the discrimination against the background and the study of their high energy spectrum.
GAMMA-400 will also be used as a trigger for transients to be used for observation from the ground, thanks to the large field-of-view guaranteed by the calorimeter.

3.2 Electrons

High energy electrons have a high energy loss rate, proportional to E^2, thus a limited lifetime. TeV electrons must be accelerated at less than 1 kpc away from Earth. Therefore, by studying the spectrum of TeV electrons, one can have insight on the acceleration mechanism inside nearby sources. Thanks to its high energy resolution, GAMMA-400 will be able to detect spectral features [4] in the all-electron spectrum.

3.3 Nuclei

The knee origin is still an open question in cosmic-rays physics. Up to now, measurements could only be performed with balloons or detectors on the ground. GAMMA-400, thanks to its very deep and wide calorimeter, will be able to detect protons and nuclei up to the knee. Being a space-borne experiment, it will be able to study directly the knee, without any previous interaction of the particles with the atmosphere. Thanks to its Geometrical Factor and energy resolution, GAMMA-400 will shed light on the cosmic-rays acceleration mechanism, propagation and composition.

4 Conclusions

The GAMMA-400 mission represents a unique opportunity to perform simultaneous measurements of photons, electrons and nuclei with unprecedented accuracy, thanks to its highly performing tracker and calorimeter. It will provide in-depth investigations on some of the most challenging physics items, such as: Dark Matter search using gamma-ray and high-energy electron spectra, the cosmic-ray origin, production and acceleration to the highest energies and the flux and elemental composition of nuclei in the knee region. The synergy with ground-based Cerenkov-arrays (such as CTA) and other wavelength instruments, will ensure a continuation of the effort of the Fermi mission, after its ending, in the multiwavelength study of gamma-ray sources.

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