Improvement of the GAMMA-400 physical scheme for precision gamma-ray emission investigations

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GAMMA-400: Gamma Astronomical Multifunctional Modular Apparatus

According to
the new approved Russian Federal Space Program 2016-2025
the GAMMA-400 space observatory is scheduled to launch in 2025-2026

GAMMA-400 scientific goals

-Searching for gamma-ray lines for the energy range of 20 MeV - 1 TeV in the discrete source, diffuse, and isotropic gamma-ray emission when annihilating or decaying dark matter particles;
-Searching for new and study of known Galactic and extragalactic discrete high-energy gamma-ray sources: supernova remnants, pulsars, accreting objects, microquasars, active galactic nuclei, blazars, quasars; studying their structure with high angular resolution and measuring their energy spectra and luminosity with high energy resolution;
-Identifying discrete gamma-ray sources with known sources in other energy ranges.

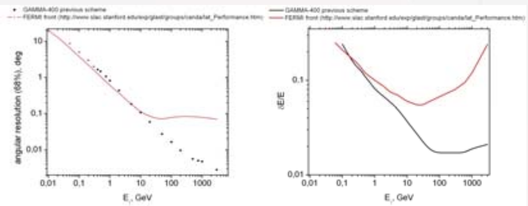
Motivation of this study

Improve physical characteristics of the GAMMA-400 gamma-ray telescope in the energy range of ~10-100 MeV, most unexplored range today. Such observations are crucial today for a number of first-rank problems faced by modern astrophysics and fundamental physics, including the origin of chemical elements and cosmic rays, the nature of dark matter, and the applicability range of the fundamental laws of physics.

Realization

Physical scheme modification while maintaining physical characteristics for high-energy (> 1 GeV) gammas.

GAMMA-400 characteristics of previous physical scheme

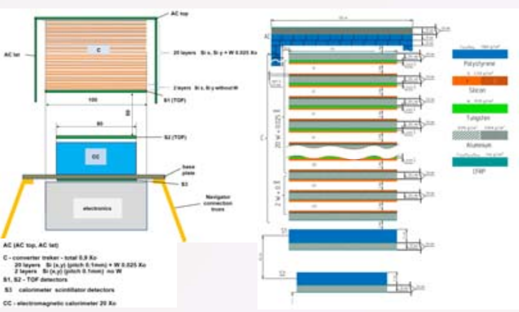


The idea was to involve more thin layers in converter.
Instead of 8 layers of tungsten with thickness 0.1 X_0 in previous physical scheme, use 20 layers of tungsten with thickness 0.025 X_0.

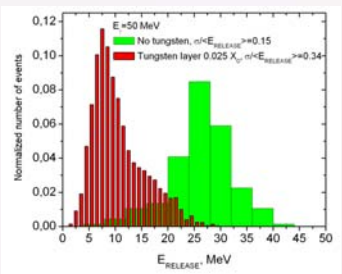
Adopted physical scheme for converter:
20 tungsten layers 0.025 X_0, 2 last layers without tungsten.
Total thickness of matter in converter 0.8 X_0

GAMMA-400 physical scheme for 2016

Total mass ~ 2100 kg
22 layers in converter
20 top layers with tungsten 0.025 X_0



To improve energy resolution it is necessary to minimize "dead" matter in converter layers

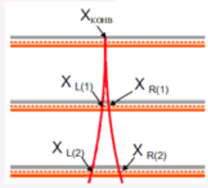


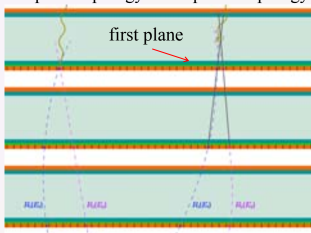
V. Tatischeff, M. Tavani, et al.,
The e-Astrogam gamma-ray space mission,
arXiv:1608.03739v1, 12 Aug 2016

Simulation environment: GEANT4 (4.10.01p02)

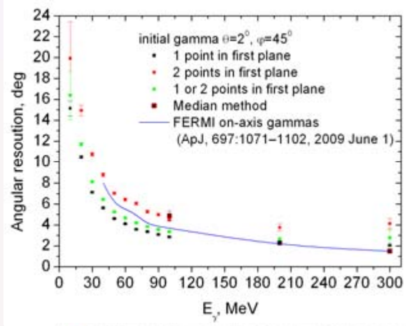
Methods to restore incident angle of low energy (< 300 MeV) gamma.
Imaginary curvature method
M.D. Kheymits, et al., Method of incident low-energy gamma-ray direction reconstruction in the GAMMA-400 gamma-ray space telescope, Journal of Physics: Conference Series 675 , 2016

Low energy trigger: Signal in six (3X, 3Y) successive silicon layers of converter.
Step 1: From the radius of track the pair component energies E_R and E_L are restored.
Step 2: Coordinate of $X_{L(W)}$ on conversion plate is restored from $X_{L(0)}$, $X_{L(1)}$, $X_{L(2)}$ and E_L .
Step 3: Coordinate of $X_{R(W)}$ on conversion plate is restored from $X_{R(0)}$, $X_{R(1)}$, $X_{R(2)}$ and E_R .
Step 4: Calculate middle point coordinate: $X_{conv} = X_{R(W)} \times (E_R/(E_L+E_R)) + X_{L(W)} \times E_L/(E_L+E_R))$.
Step 5: Repeat the steps 2, 3, 4 for (X_{conv}, $X_{R(0)}$, $X_{R(1)}$) and (X_{conv}, $X_{L(0)}$, $X_{L(1)}$).
Step 6: Calculate angles $\alpha_R(X_{conv}, X_{R(0)}, X_{R(1)})$ and $\alpha_L(X_{conv}, X_{L(0)}, X_{L(1)})$.
Step 7: Calculate 'weighted' plane angle $\alpha = \alpha_R \times E_R/(E_L+E_R) + \alpha_L \times E_L/(E_L+E_R)$.



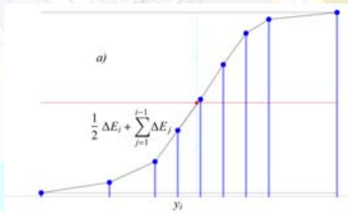


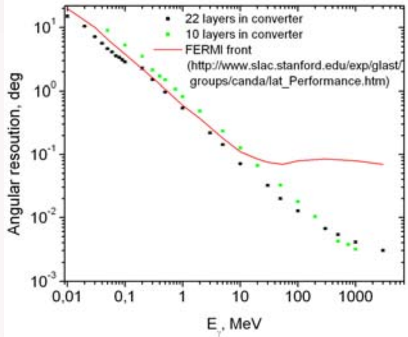
Modified methods for thin layers in converter.
The gamma conversion events topology can be separated into the following two samples. The first one presents the conversion in tungsten layer (0.025 X_0), which is shown in left part of the figure. For such events the pair components release the energy (mainly) in one strip just under the tungsten plane. The second sample corresponds to the conversion in support matter just upper the tungsten plane, which is shown in right part of the figure. For such events the pair components release the energy (mainly) in different strips. The vertical localization of conversion point in this case has significantly less accuracy.



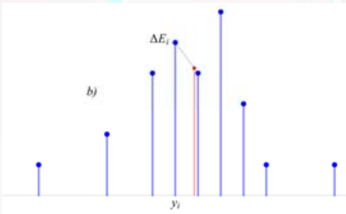
Methods to restore incident angle of high energy (>300 MeV) gamma.
Median method
A.A. Leonov, et al., The GAMMA-400 gamma-ray telescope characteristics. Angular resolution and electrons/protons separation,
Proceedings of Science, http://pos.sissa.it/archive/conferences/218/008/Scineghe2014_008.pdf

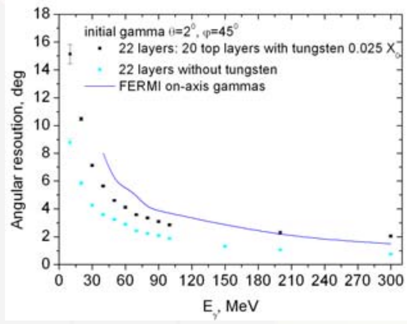
A direction-reconstruction technique based on strip energy release has been developed. The plane flux of gamma has simulated just above top AC plane. At first, for each silicon-strip layer with energy release the following procedure is applied. The distribution of the sum of energy releases in strips along strip positions is constructed (Fig. a). The horizontal line is median, which is calculated as a half sum of the extreme points for constructed distribution. The intersection point of median with piecewise continuous distribution gives the estimation of median energy location in silicon-strip layer (Fig. a).



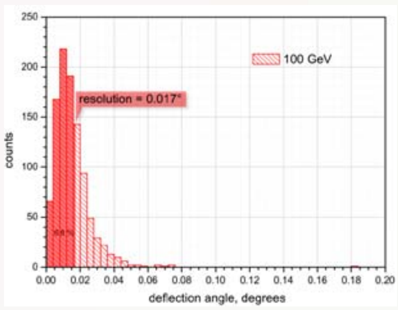


To find the energy weight of the median the ordinary distribution of energy releases in strips along strip positions is built (Fig. b). The median energy weight is defined using the obtained median location for the piece line linking adjacent (respective median location) points of the obtained distribution (Fig. b). Then the estimation of the initial direction is obtained using fitting procedure for the median locations in silicon-strip layers. Around the estimated direction the corridor from strips is constructed. The energy releases in strips outside the corridor are ignored. After that the iteration procedure starts, narrowing the corridor from strips in each silicon-strip layer, but not less, then five strip pitch. For each iteration step the median energy weight from previous iteration is taken into account.

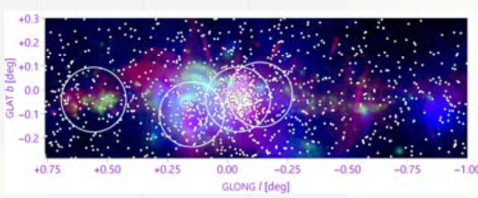




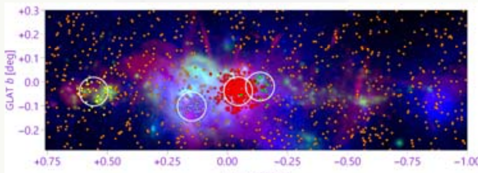
To calculate the angular resolution, the distribution of a space angular deflection between the direction reconstructed for each event and the median value for all events in distribution is analyzed. Such distribution for 100 GeV gamma is shown in Figure. Angular resolution is defined a semiopening of the circular conical surface, containing 68% of events.



GAMMA-400 and Fermi-LAT survey of Galactic center



The Fermi-LAT experimental data obtained in the vicinity of Galactic center for the energy range of 10-100 GeV and selected for maximum zenith angle less than 90^0 (circles for four sources are the Fermi-LAT angular resolution).



The results of simulation obtained by applying maximum likelihood method for average psf_{68} value of GAMMA-400. Four sources (yellow, magenta, red and green points) are identified from the "diffuse" background (orange points), but in significantly more compact region (circles for four sources are the GAMMA-400 angular resolution).