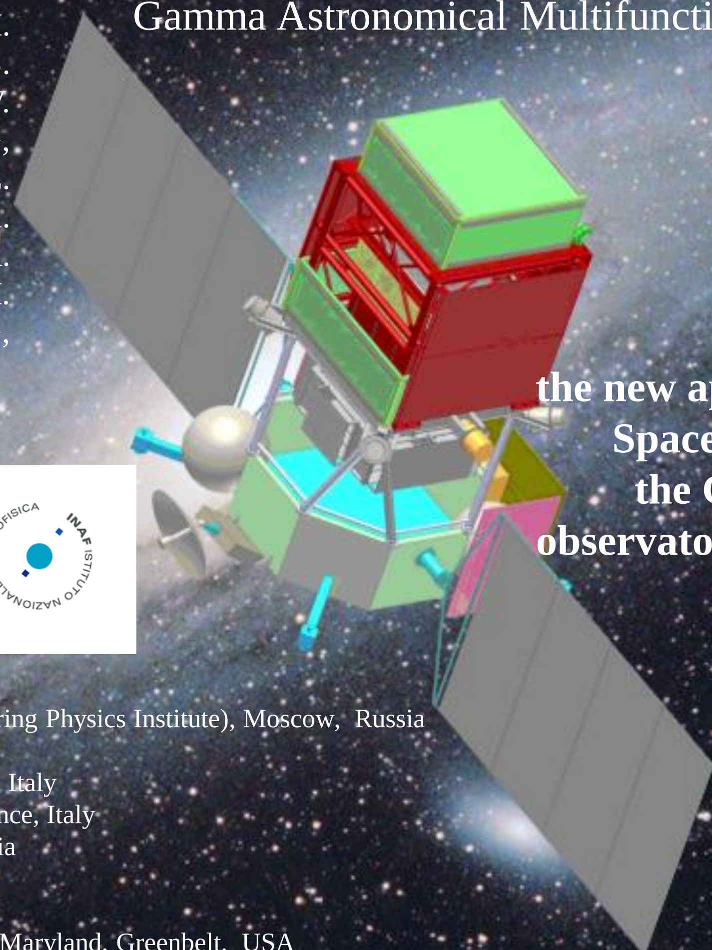
Modifications of method for low energy gamma incident angle reconstruction in GAMMA-400 gamma-ray telescope

A.A. Leonov[1,2], A.M. Galper[1,2], N.P. Topchiev[2], V. Bonvicini[3], O. Adriani[4], I.V. Arkhangelskaja[1], A.I. Arkhangelskiy[1], A.V. Bakaldin[5], S.G. Bobkov[5], M. Boezio[3], O.D. Dalkarov[2], A.E. Egorov[2], M.S. Gorbunov[5], Yu.V. Gusakov[2], B.I. Hnatyk[6], V.V. Kadilin[1], V.A. Kaplin[1], A.A. Kaplun[1], M.D. Kheymits[1], V.E. Korepanov[7], F. Longo[3], V.V. Mikhailov[1], E. Mocchiutti[3], A.A. Moiseev[8], I.V. Moskalenko[9], P.Yu. Naumov[1], P. Picozza[10], M.F. Runtso[1], O.V. Serdin[5], R. Sparvoli[10], P. Spillantini[4], Yu.I. Stozhkov[2], S.I. Suchkov[2], A.A. Taraskin[1], M. Tavani[11], E.M. Tyurin[1], Yu.T. Yurkin[1], and V.G. Zverev[2]

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

[1]National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia
[2]Lebedev Physical Institute, Moscow, Russia
[3]Istituto Nazionale di Fisica Nucleare, Sezione di Trieste, Trieste, Italy
[4]Istituto Nazionale di Fisica Nucleare, Sezione di Florence, Florence, Italy
[5]Scientific Research Institute for System Analysis, Moscow, Russia
[6]Taras Shevchenko National University, Kyiv, Ukraine
[7]Lviv Center of Institute of Space Research, Lviv, Ukraine
[8]NASA Goddard Space Flight Center and CRESST/University of Maryland, Greenbelt, USA
[9]Hansen Experimental Physics Laboratory and Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, USA
[10]Istituto Nazionale di Fisica Nucleare, Sezione di Rome “Tor Vergata”, Rome, Italy
[11]Istituto Nazionale di Astrofisica IASF and Physics Department of University of Rome Tor Vergata, Rome, Italy

2nd International Conference on Particle Physics and Astrophysics, Moscow, October 10-14, 2016

GAMMA-400 scientific goals

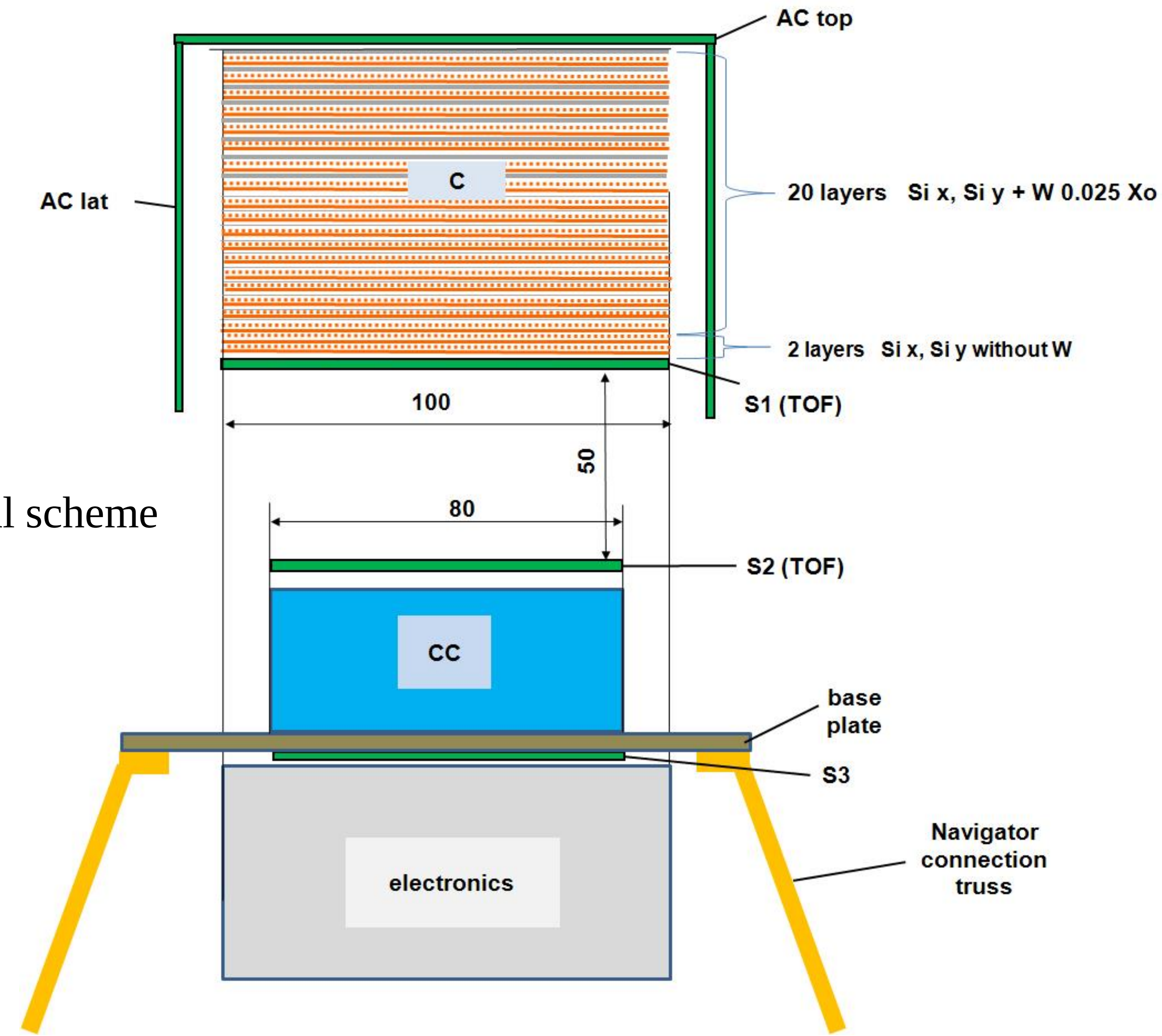
-Searching for gamma-ray lines for the energy range of 20 MeV - 1 TeV in the discrete source, diffuse, and isotropic gamma-ray emission when annihilating or decaying dark matter particles;

-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.

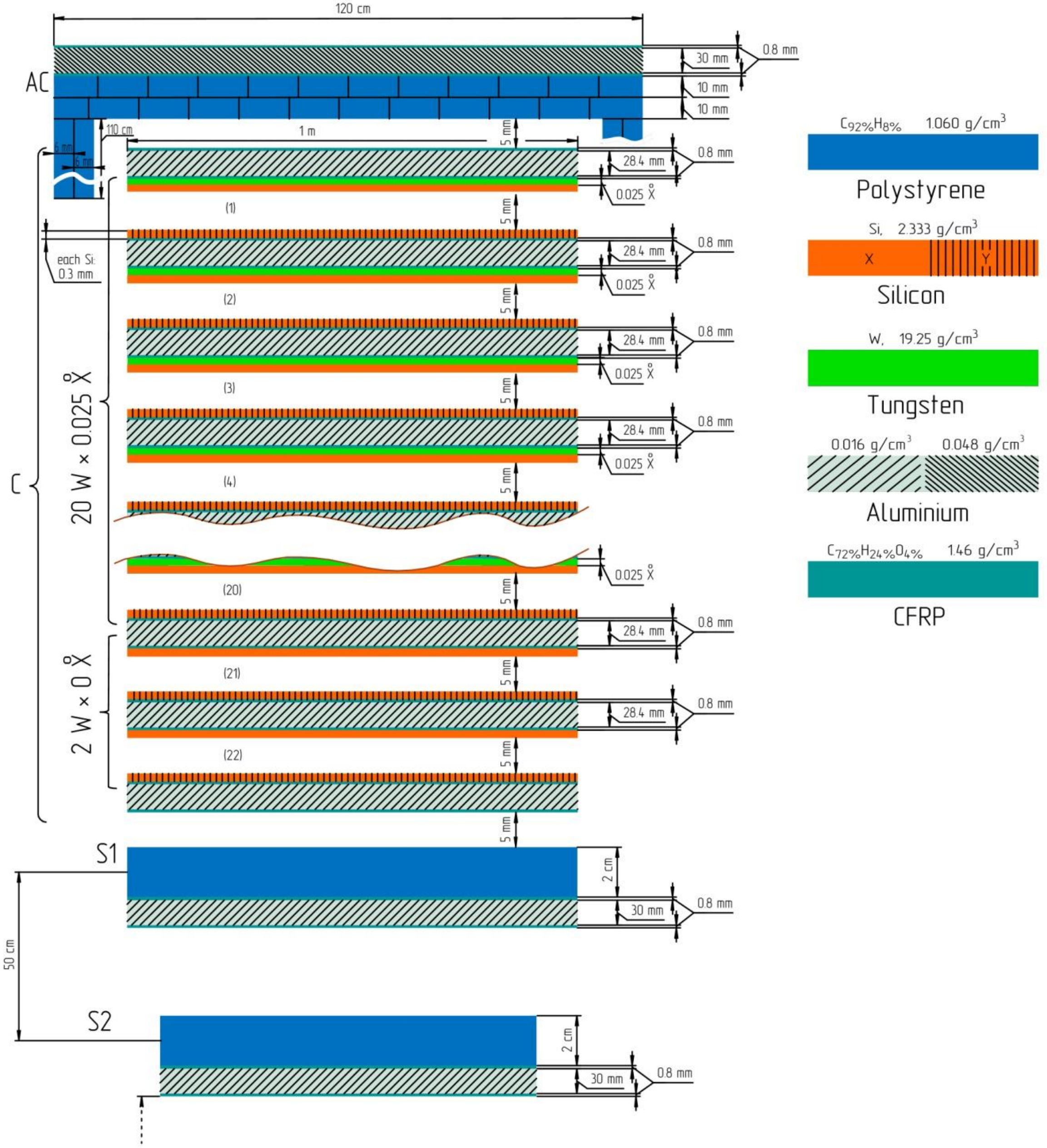
Motivation of this study

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.



GAMMA-400 physical scheme

Magnified view of converter



Imaginary curvature method (ICM)

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 .

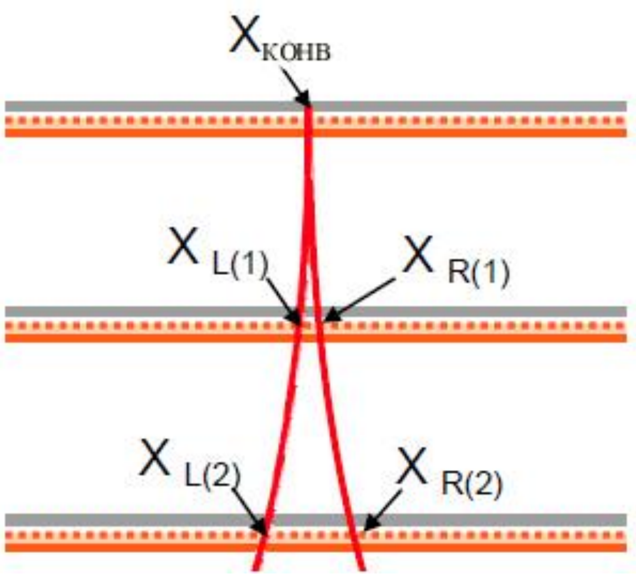
Step 4: Calculate middle point coordinate:

$$X_{conv} = X_{R(W)} \times (E_R /(E_L+E_R) + X_{L(W)} \times E_L /(E_L+E_R)).$$

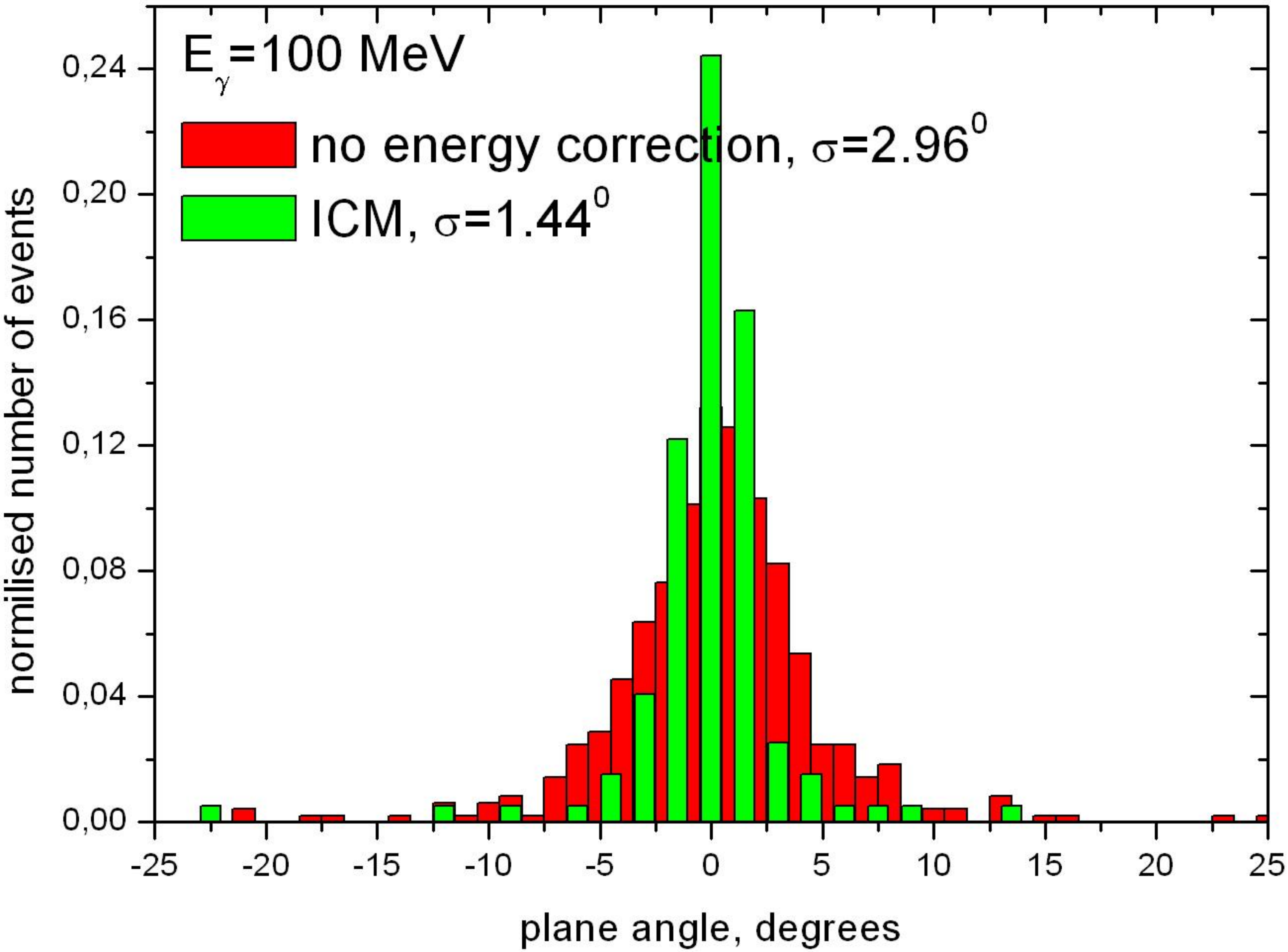
Step 5: Repeat the steps 2, 3, 4 for (X_{conv}, $X_{R(0)}$, $X_{R(1)}$) and (X_{conv}, $X_{L(0)}$, $X_{L(1)}$).

Step 6: Calculate angles α_R(X_{conv}, $X_{R(0)}$, $X_{R(1)}$) and α_L(X_{conv}, $X_{L(0)}$, $X_{L(1)}$).

Step 7: Calculate 'weighted' plane angle $\alpha = \alpha_R \times E_R /(E_L+E_R) + \alpha_L \times E_L /(E_L+E_R)$.



M.D. Kheymits, A.A. Leonov 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 032012, 2016

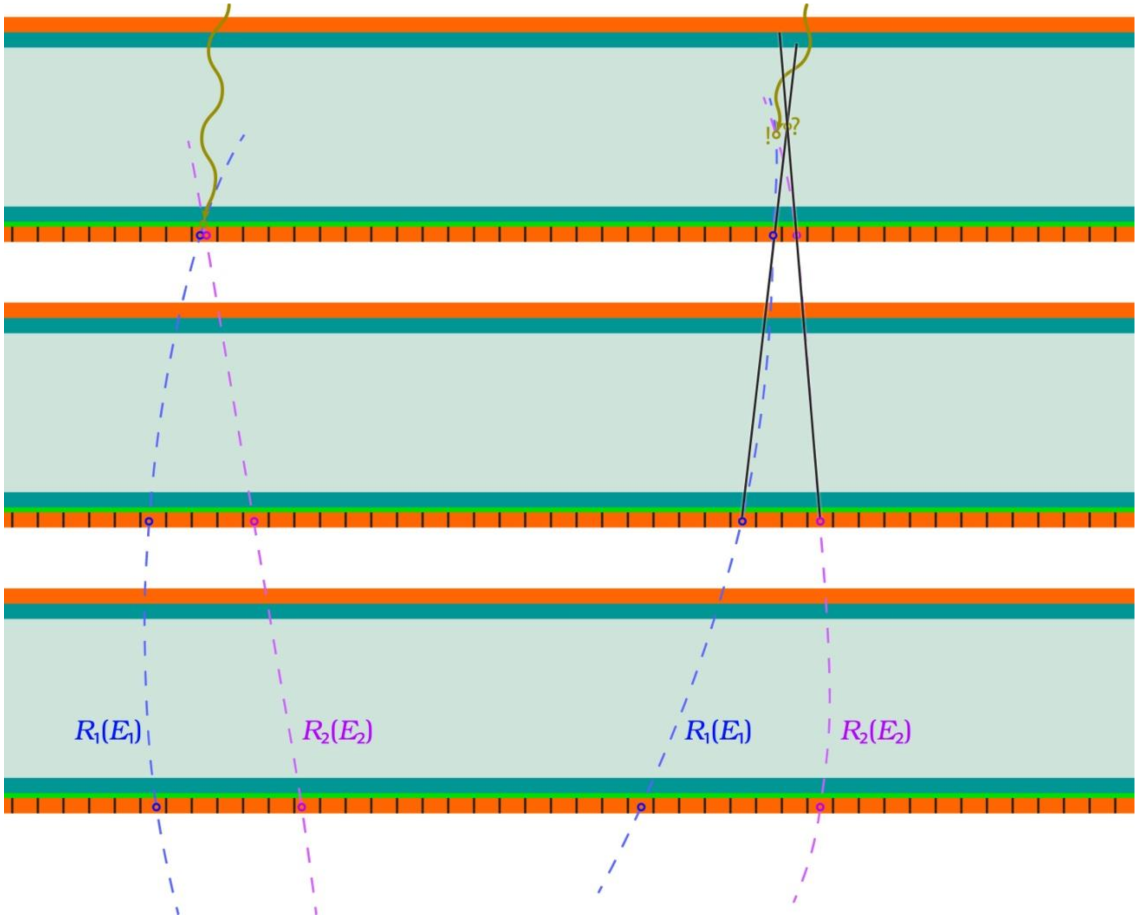


E_γ =100 MeV
no energy correction, σ=2.96^0
ICM, σ=1.44^0
0,24
0,20
0,16
0,12
0,08
0,04
0,00
normilised number of events
-25
-20
-15
-10
-5
0
5
10
15
20
25
plane angle, degrees

Modified method ICM for thin layers in converter.

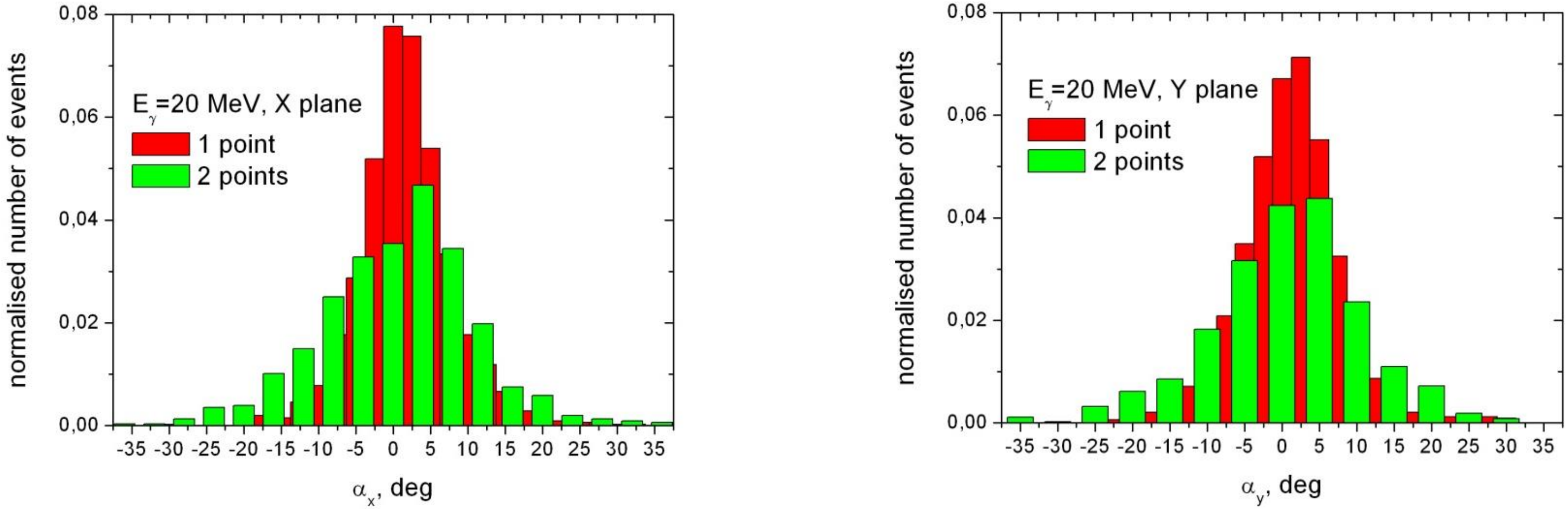
The gamma conversion events topology can be separated into the following two samples. The first one presents the conversion in tungsten layer (0.025 X_0), which is shown in left part of the figure. For such events the pair components release the energy (mainly) in one strip just under the tungsten plane. 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.

1 point

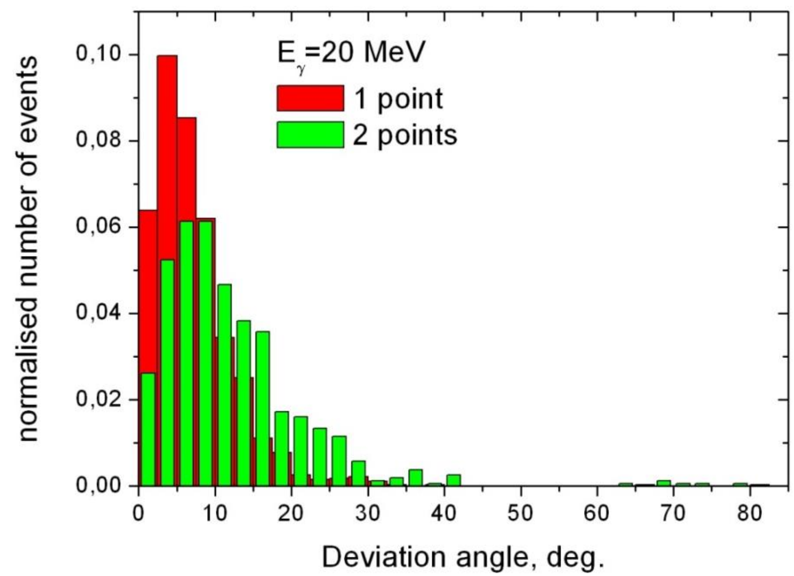


2 points

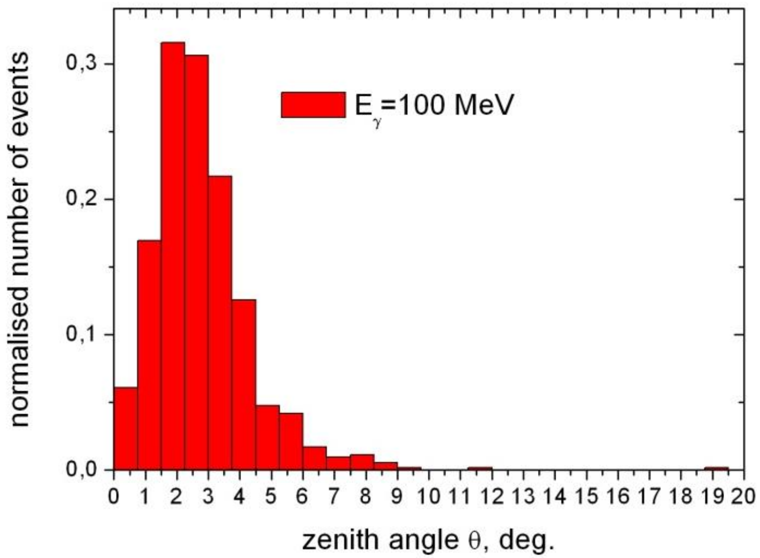
The distributions for plane angles of initial 20 MeV gamma (zenith=2^0, polar=45^0) in X and Y projections

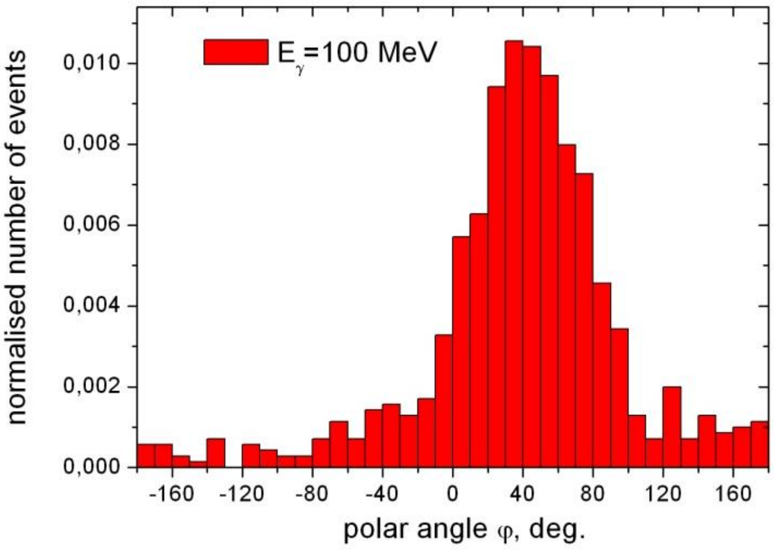


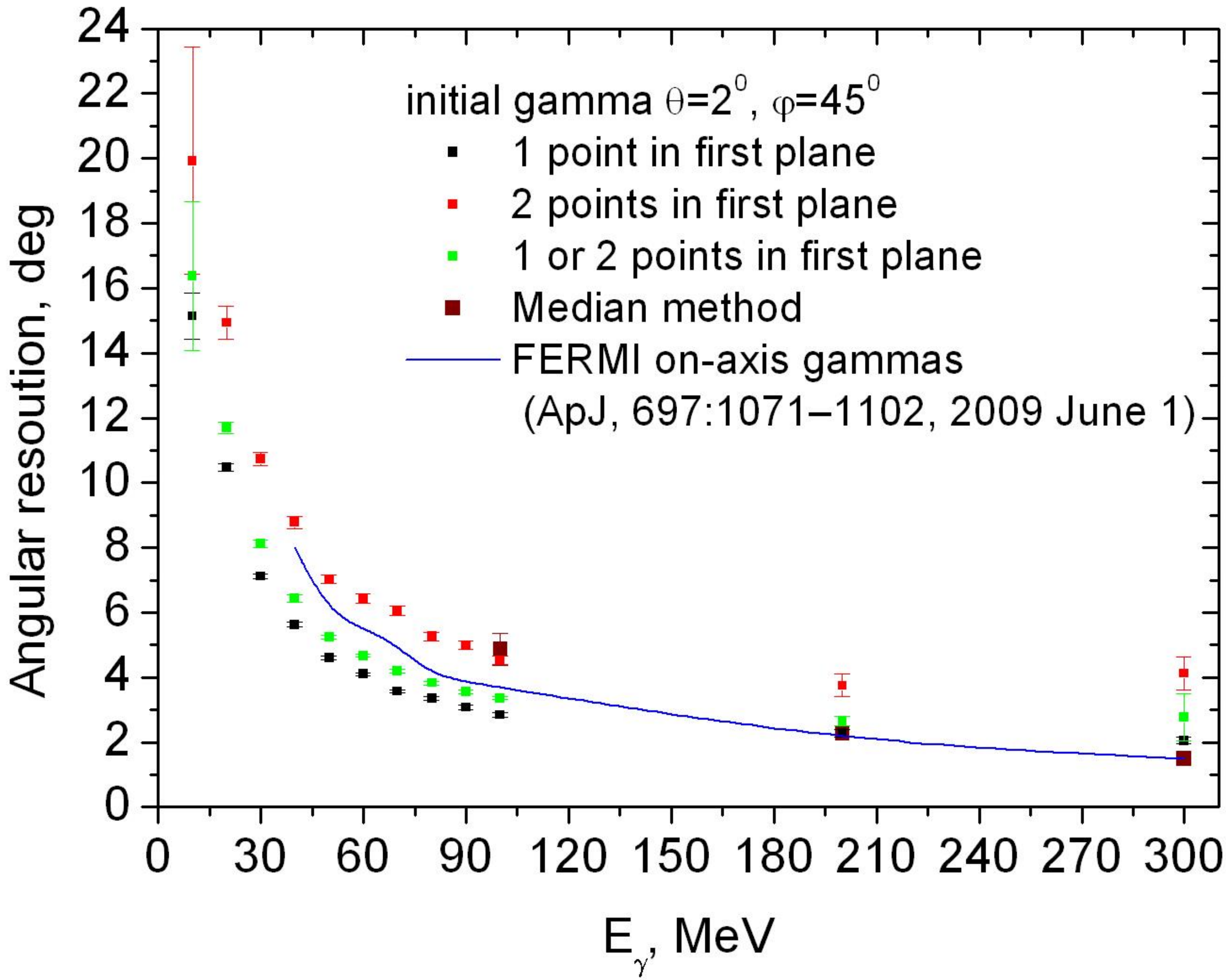
The distributions for the space deviation angle between restored and initial directions

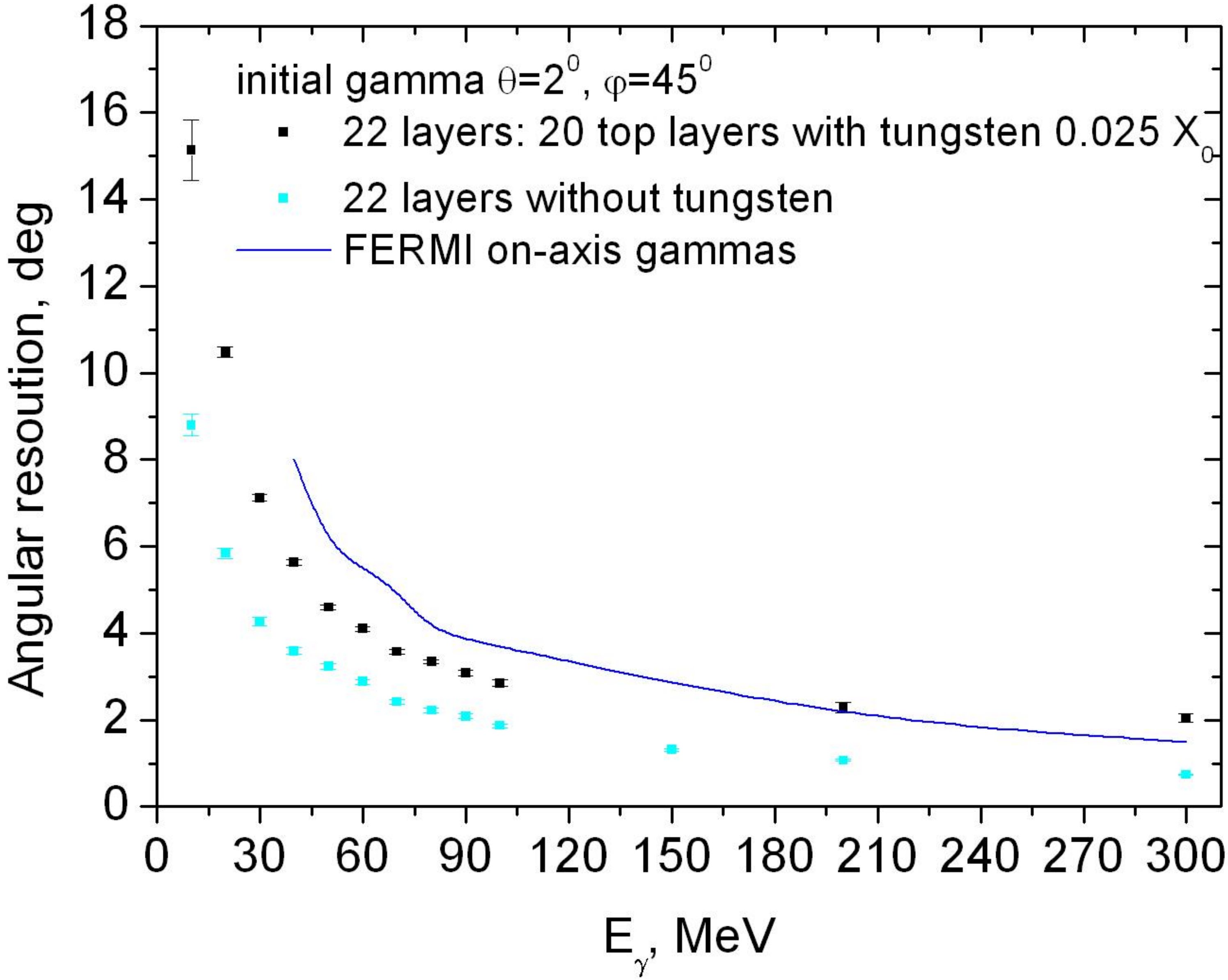


To demonstrate qualitatively that zenith and polar angle of initial gamma are restored appropriately, the distributions for these angles are shown for 100 MeV gamma.



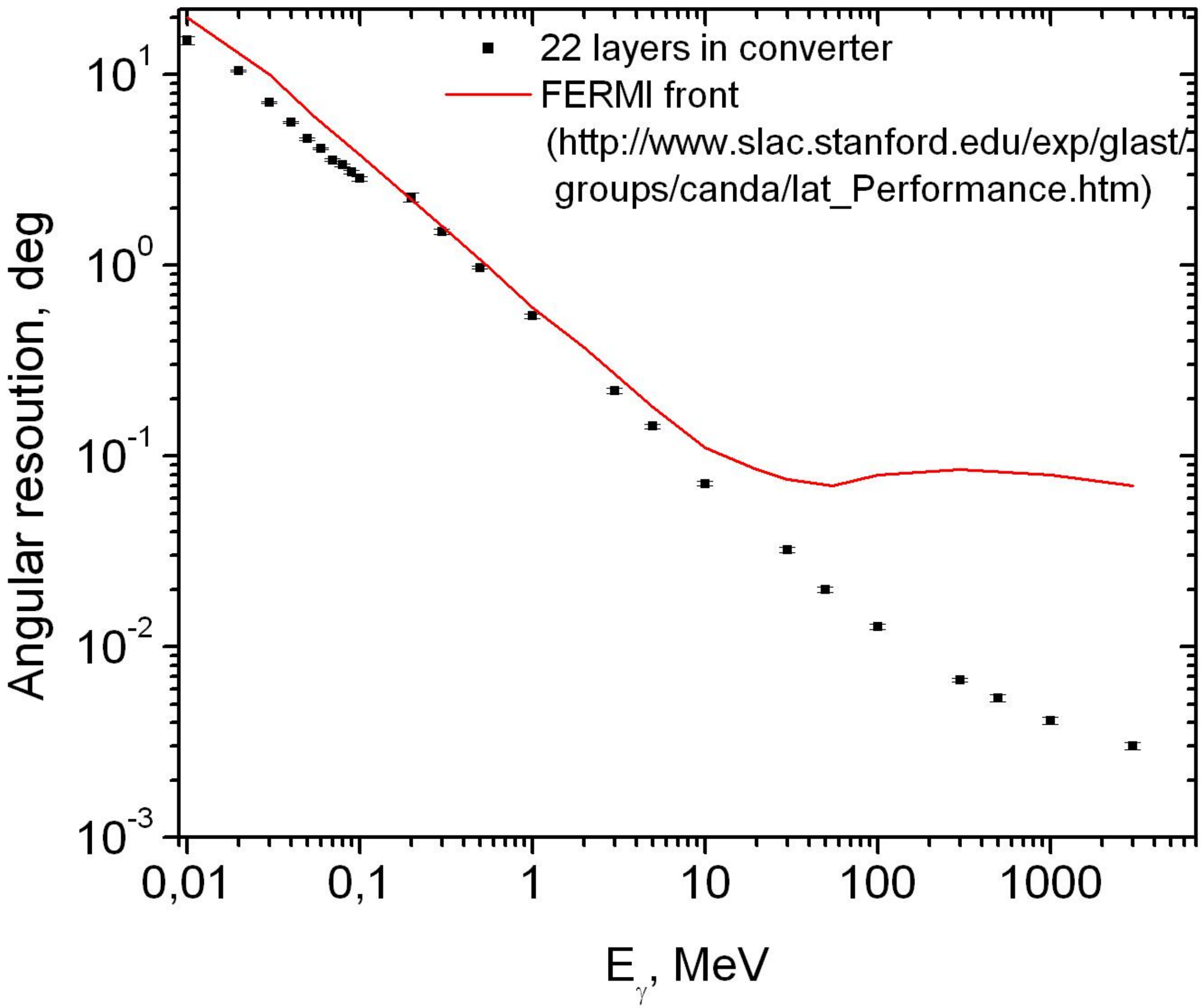



initial gamma θ=2⁰, φ=45⁰
1 point in first plane
2 points in first plane
1 or 2 points in first plane
Median method
FERMI on-axis gammas
(ApJ, 697:1071–1102, 2009 June 1)
Angular resoution, deg
E$_\gamma$, MeV
0
2
4
6
8
10
12
14
16
18
20
22
24
0
30
60
90
120
150
180
210
240
270
300

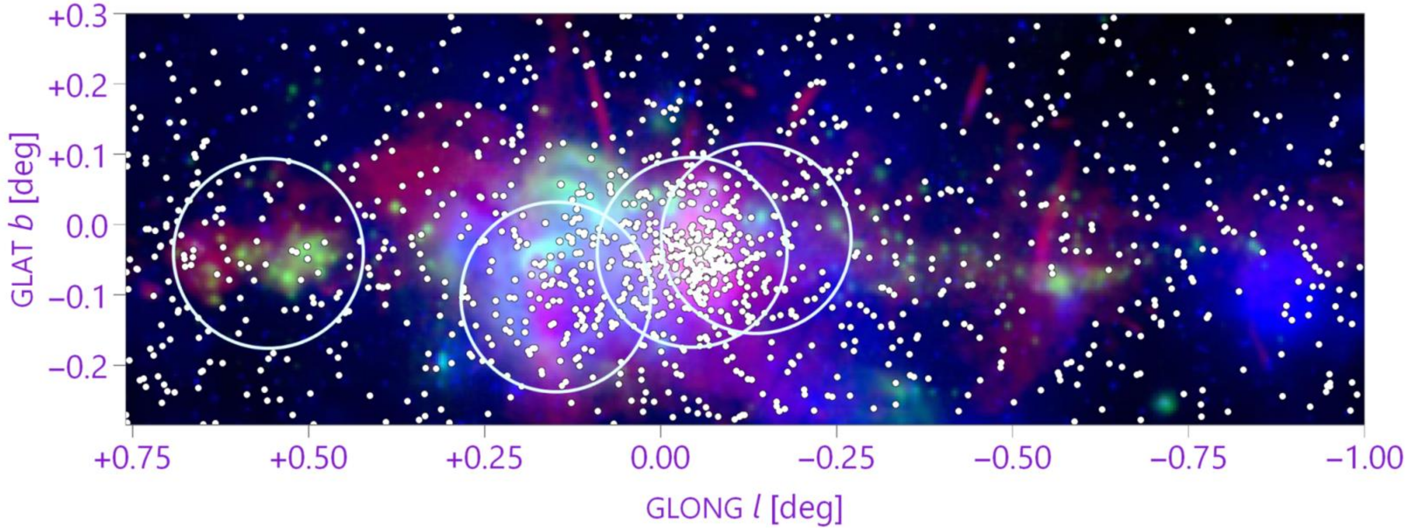


initial gamma θ=2⁰, φ=45⁰
22 layers: 20 top layers with tungsten 0.025 X0
22 layers without tungsten
FERMI on-axis gammas
Angular resoution, deg
Eγ, MeV
0
2
4
6
8
10
12
14
16
18
0
30
60
90
120
150
180
210
240
270
300

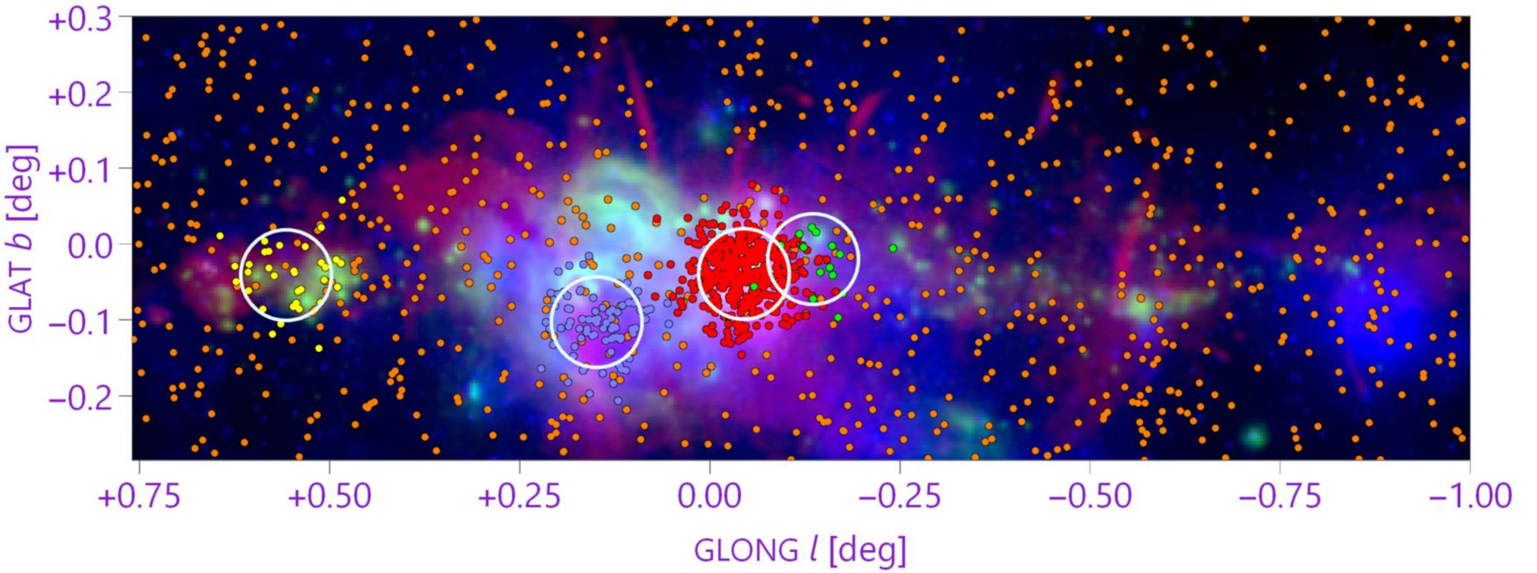
Total angular resolution



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).

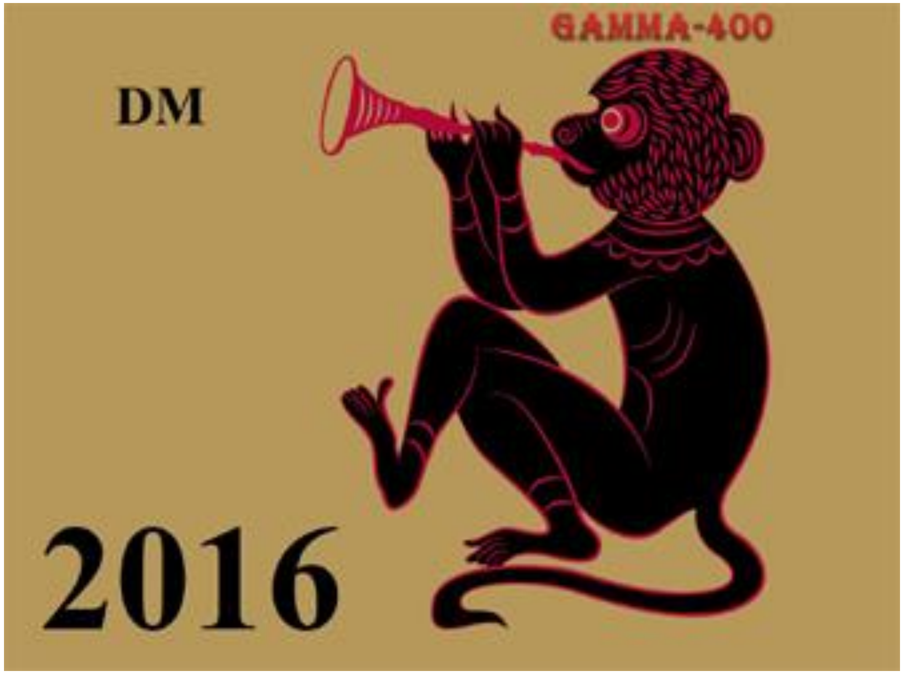


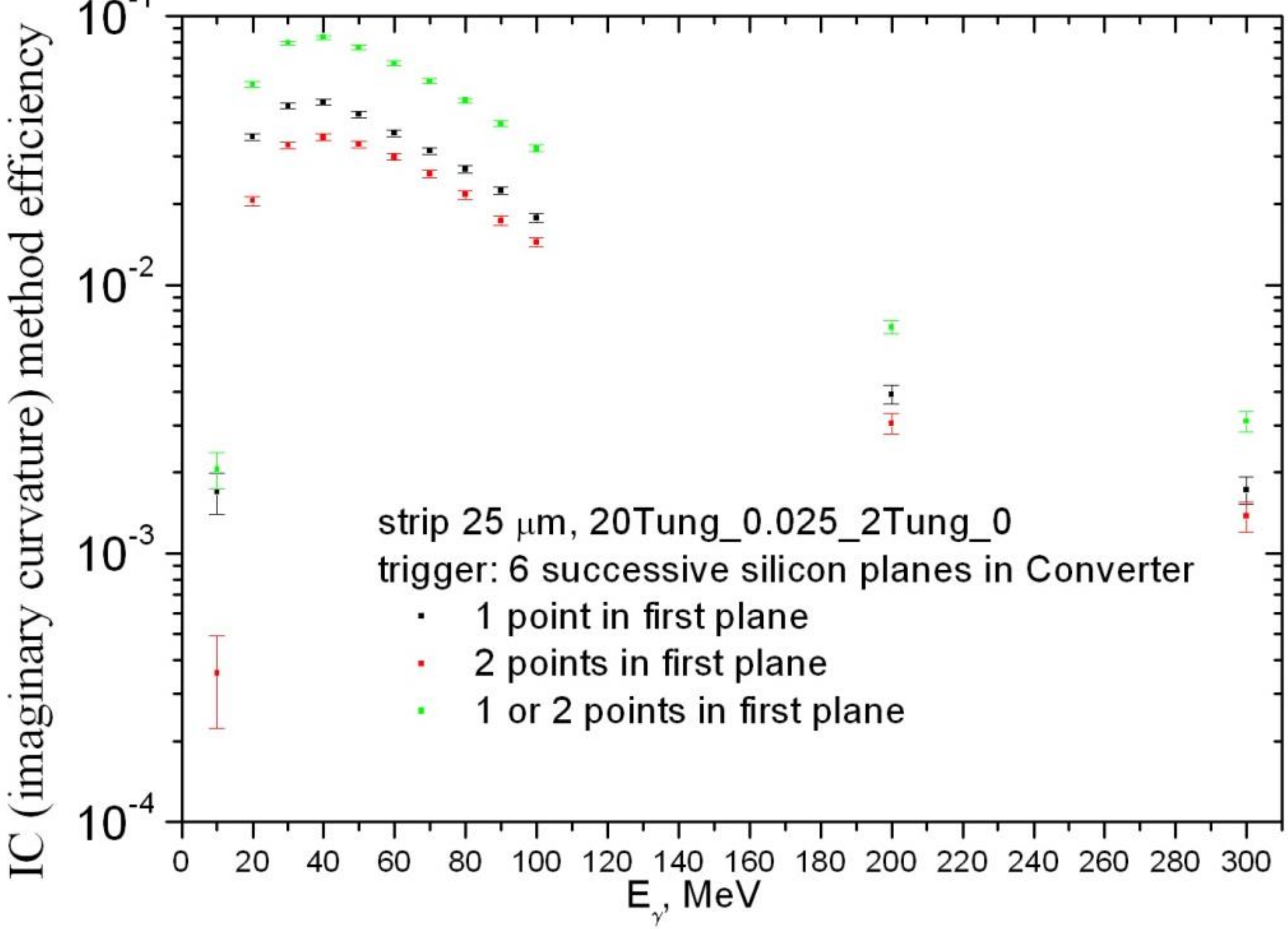
The results of simulation obtained by applying maximum likelihood method for average psf_{68} value of GAMMA-400. Four sources (yellow, magenta, red and green points) are identified from the “diffuse” background (orange points), but in significantly more compact region (circles for four sources are the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



Thanks for attention!

GAMMA-400: Good luck for Dark Matter (DM) search




IC (imaginary curvature) method efficiency
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
E_γ, MeV
strip 25 μm, 20Tung_0.025_2Tung_0
trigger: 6 successive silicon planes in Converter
1 point in first plane
2 points in first plane
1 or 2 points in first plane