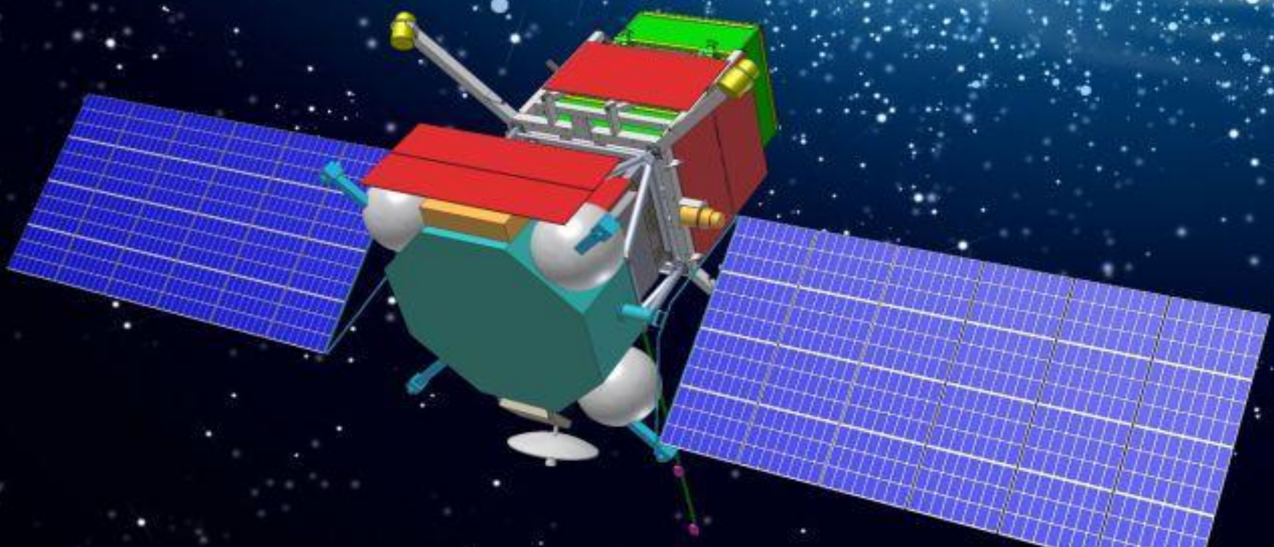
Russian Academy of Sciences
P.N.Lebedev Physical Institute
LPI

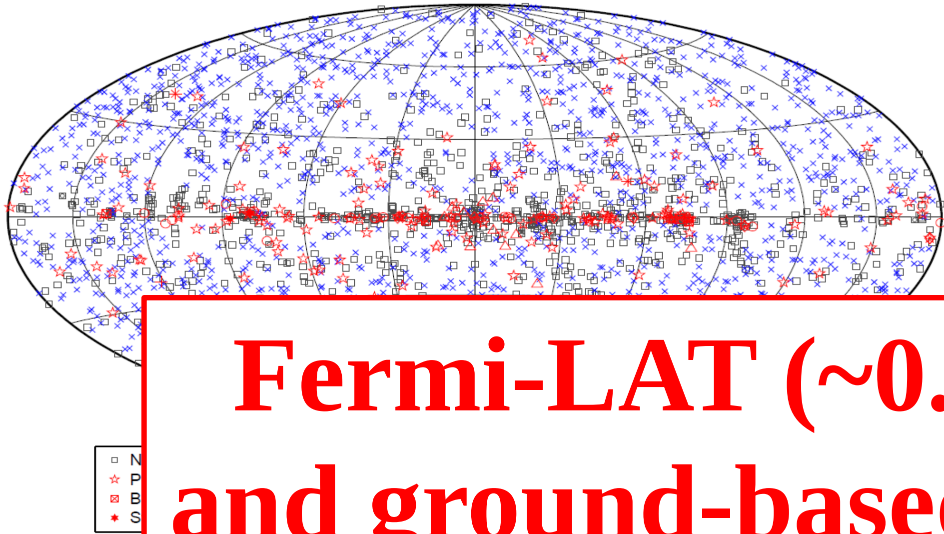
Nikolay Topchiev
for the GAMMA-400 Collaboration

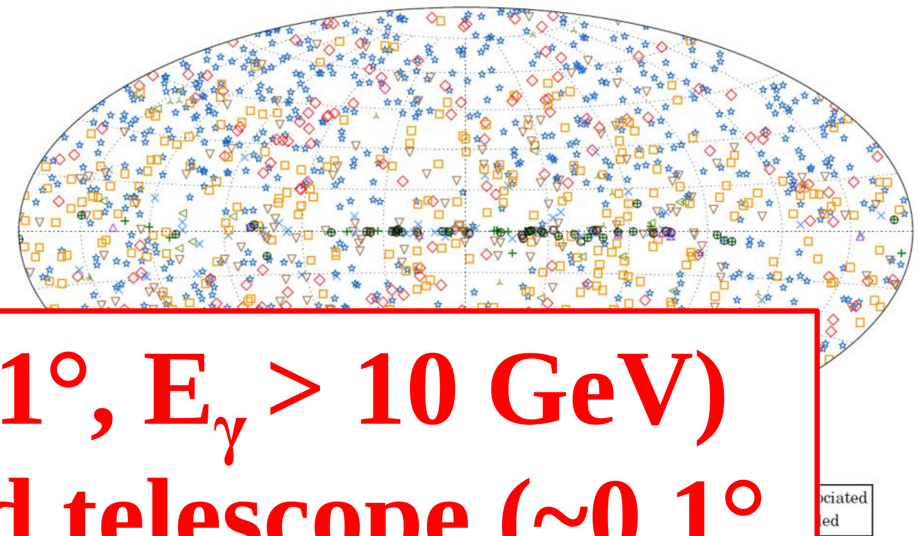
Future space-based GAMMA-400 gamma-ray telescope for the gamma- and cosmic-ray studies



July 6-10, 2018, ECRS2018, Altai State University, Barnaul, Russia

High-energy gamma-ray studying

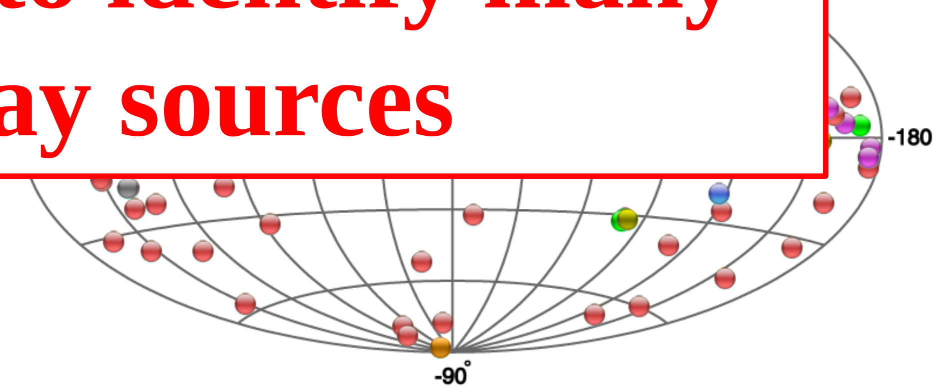




Fermi-LAT (~0.1°, E_γ > 10 GeV) and ground-based telescope (~0.1°, E_γ ~ 100 GeV) angular resolutions are insufficient to identify many gamma-ray sources

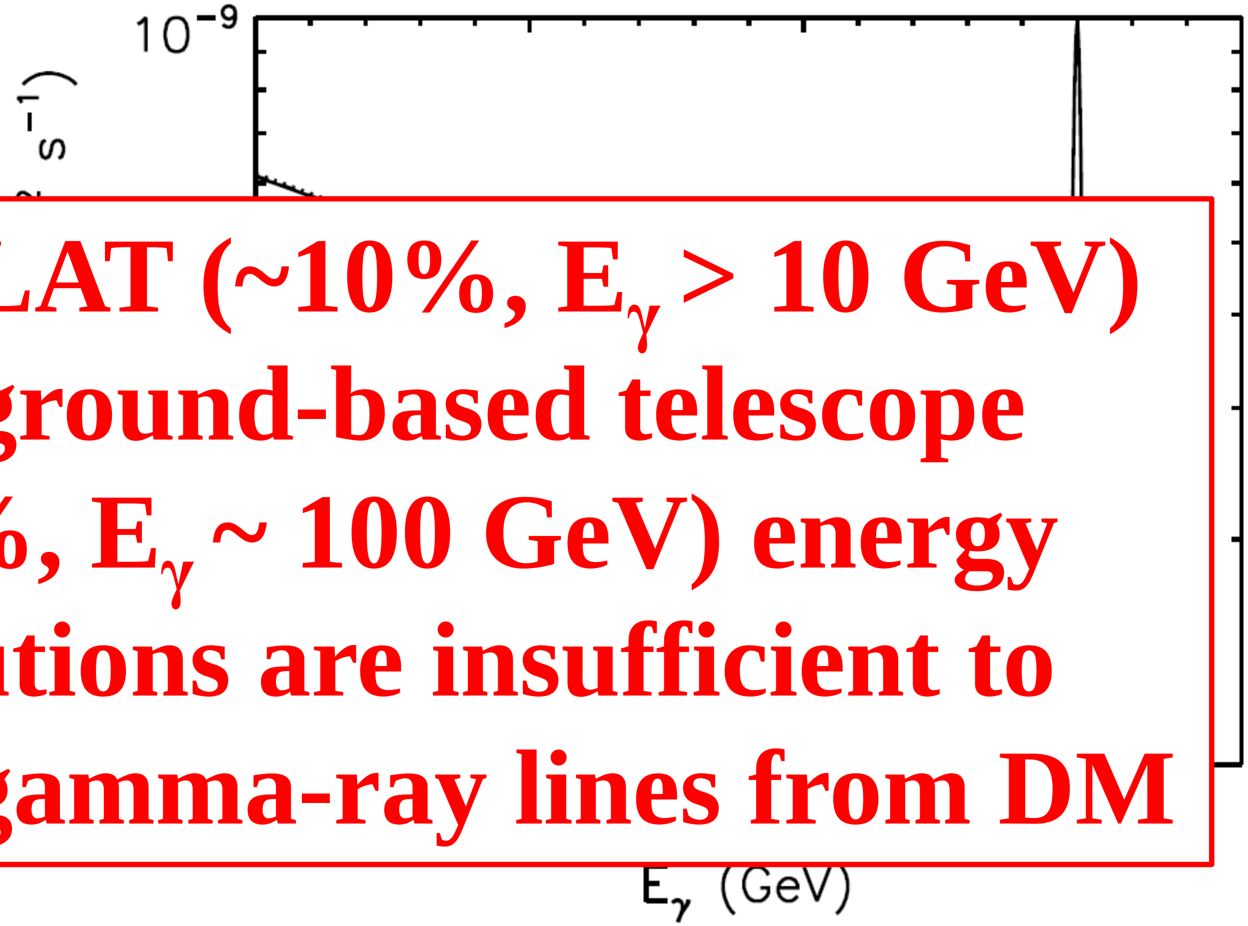
Ferm
resol
~0.1°

Ground-based telescope angular resolution is ~0.1° (E_γ ~ 100 GeV)



Distribution of 210 discrete sources (**TeVCat**, E_γ > 100 GeV)

Capabilities of different gamma-ray telescopes to resolve DM lines



Fermi-LAT (~10%, E_γ > 10 GeV) and ground-based telescope (~15%, E_γ ~ 100 GeV) energy resolutions are insufficient to resolve gamma-ray lines from DM

The gamma ray flux as a function of the photon's energy for a WIMP of mass 300 GeV. Shown are three different experimental energy resolutions.

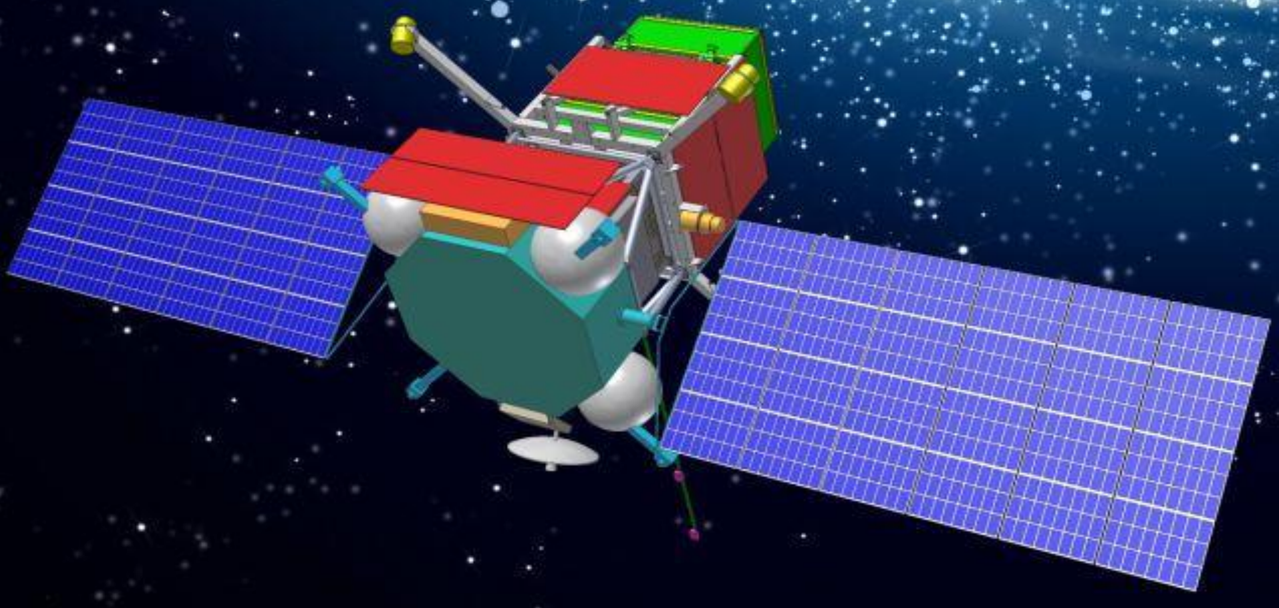
Energy resolution for Fermi-LAT is ~10% (E_γ > 10 GeV) and ground-based gamma-ray telescopes is ~15% (E_γ ~ 100 GeV)

arXiv:1009.5107

Future gamma-ray telescopes should have the significantly improved angular and energy resolutions

Such a new generation telescope will be

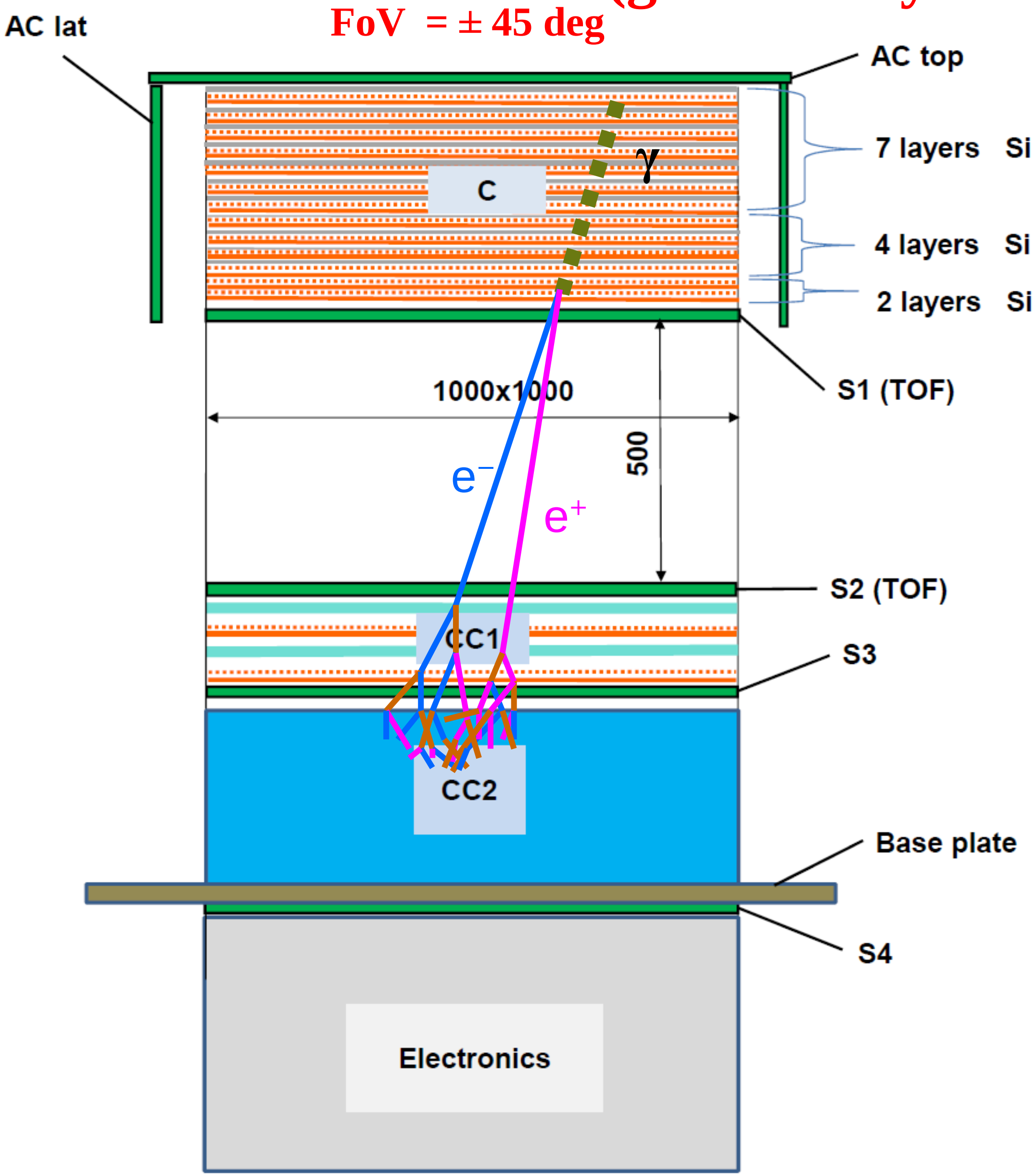
GAMMA-400



GAMMA-400
MAIN SCIENTIFIC GOALS

The GAMMA-400 main scientific goals are: dark matter searching by means of gamma-ray astronomy; precise and detailed observations of Galactic plane, especially, Galactic Center, Fermi Bubbles, Crab, Vela, Cygnus, Geminga, Sun, and other regions, extended and point gamma-ray sources, diffuse gamma rays with unprecedented angular **(~0.01° at E_γ = 100 GeV)** and energy resolutions **(~1% at E_γ = 100 GeV)**, as well as detecting electron + positron fluxes with energies up to 10 TeV.

The GAMMA-400 physical scheme (gamma-ray detection)

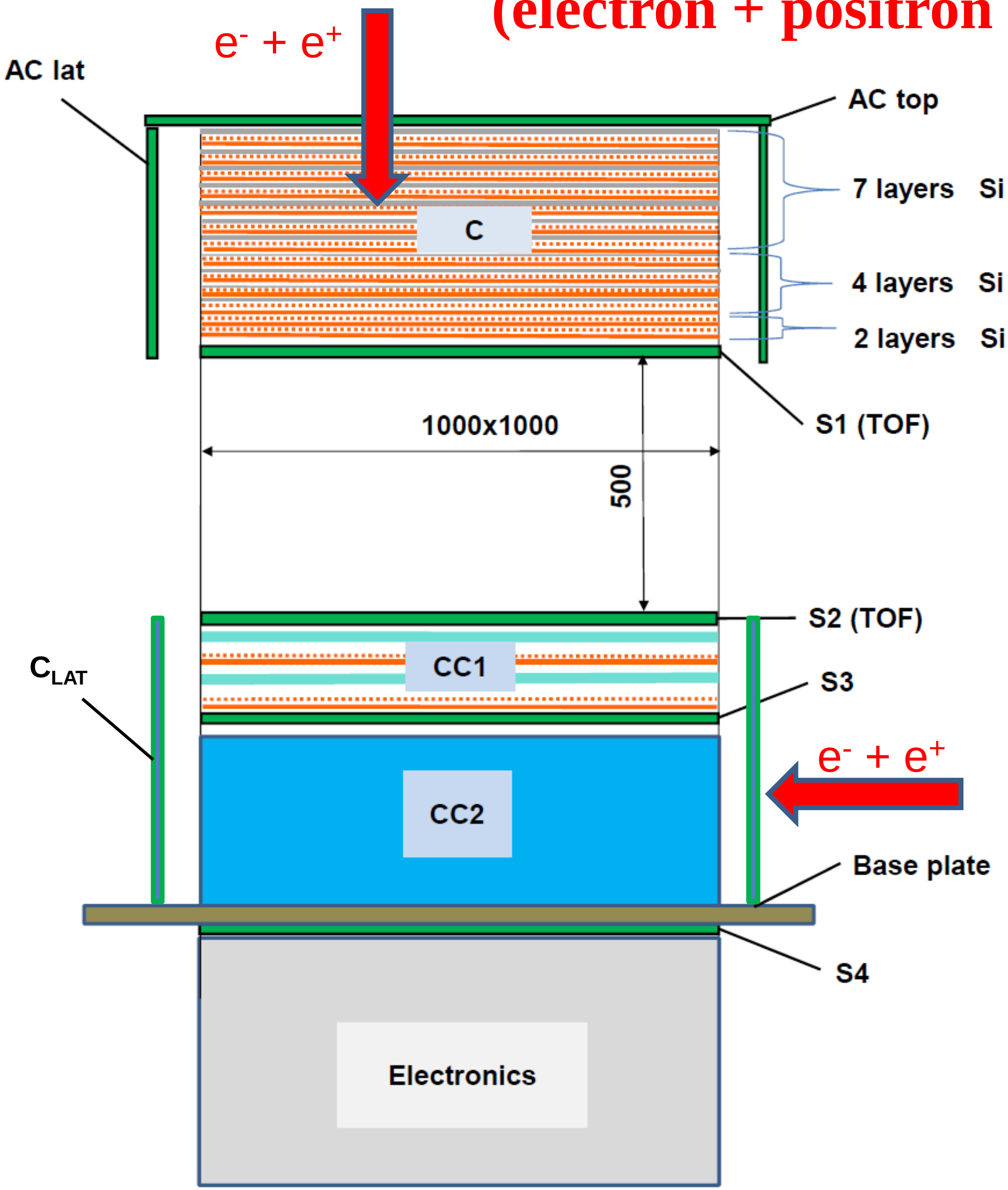


AC – anticoincedence system
C - converter-tracker ~1 X_0
S1, S2 – TOF detectors
CC1, CC2 – calorimeter vertical thickness ~22 X_0
S3, S4 – scintillator detectors

$$M = \overline{AC} \times S1 \times S2$$

ΔE = ~20 MeV – ~10 TeV
$\Delta\theta$ = ~2° (E_γ = 100 MeV)
$\Delta\theta$ = ~0.01° (E_γ = 100 GeV)
$\Delta E/E$ = ~10% (E_γ = 100 MeV)
$\Delta E/E$ = ~1% (E_γ = 100 GeV)

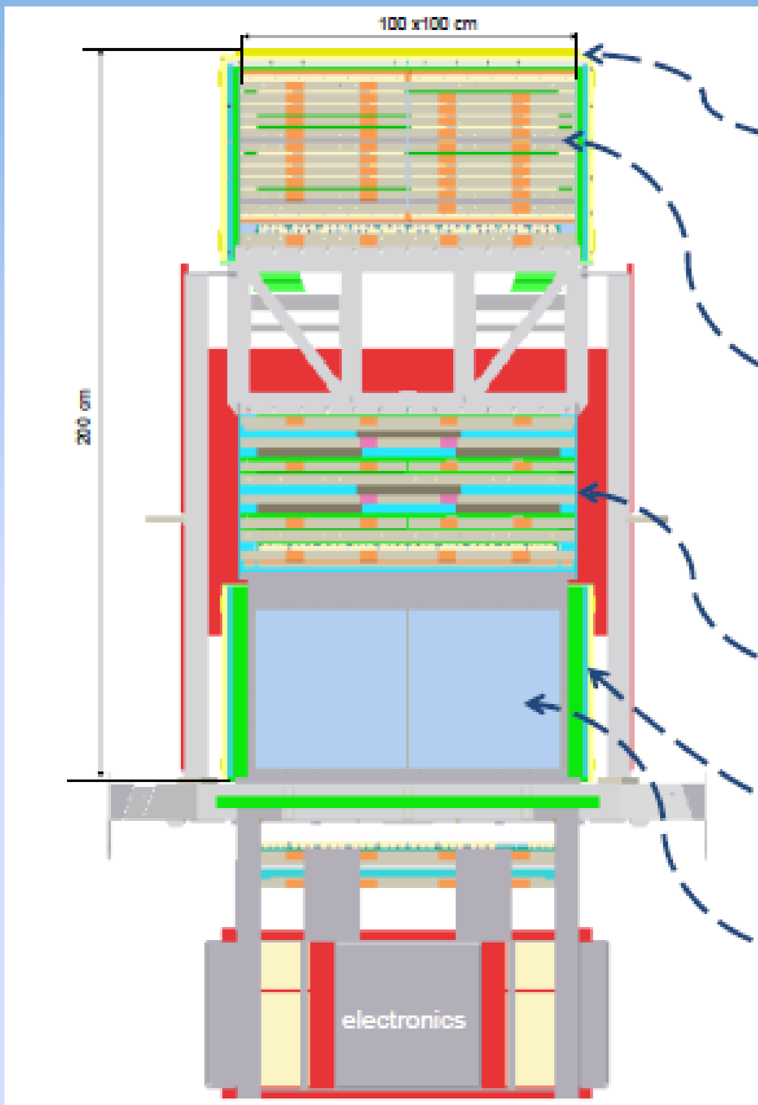
The GAMMA-400 physical scheme (electron + positron detection)



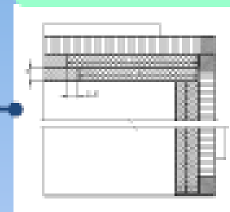
AC – anticoincedence system
C - converter-tracker ~1 X_0
S1, S2 – TOF detectors
CC1, CC2 – calorimeter
vertical thickness ~22 X_0
lateral thickness ~54 X_0
S3, S4 – scintillator detectors
C_{LAT} – lateral calorimeter detectors

GF_{CR} > 3 m^2sr (all sides)
ΔE = ~1 GeV – ~10 TeV
$\Delta\theta$ = ~0.01° (E = 100 GeV)
$\Delta E/E$ = ~1% (E = 100 GeV)

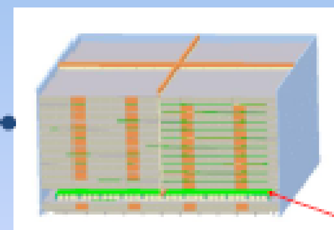
The GAMMA-400 physical scheme



Main systems

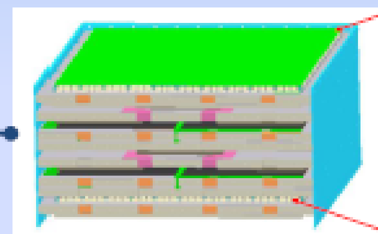


AC anticoincidence
double layer thickness 10×2 mm, overlay 5 –10 mm
Efficiency is 0.999995



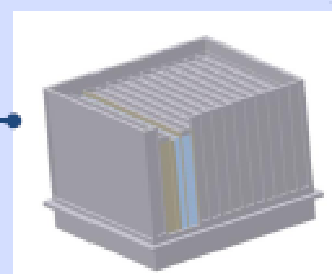
CONVERTER-TRACKER 100X100 cm
- The single-sided SSDs strips with 80 μm pitch,
- 13 pair SSD (X, Y)
- 7 paired layers (W 0.1 radiation lengths)
- 4 paired layers (W 0.02 radiation lengths)
- Last 2 paired layers no W.
- **Analog readout**

TOF time of light
- C1 top counter - two layers of fast plastic scintillators
- C2 bottom counter - two layers of fast plastic scintillators
- distance C1 – C2 500 mm



CC1 imaging calorimeter
- Two super layers
- CsI(Tl) 20 mm + Si strip detectors (X,Y SSD, pitch 80 μm)
- 2 radiation lengths

C3 calorimeter trigger counter
two layers of fast plastic scintillators



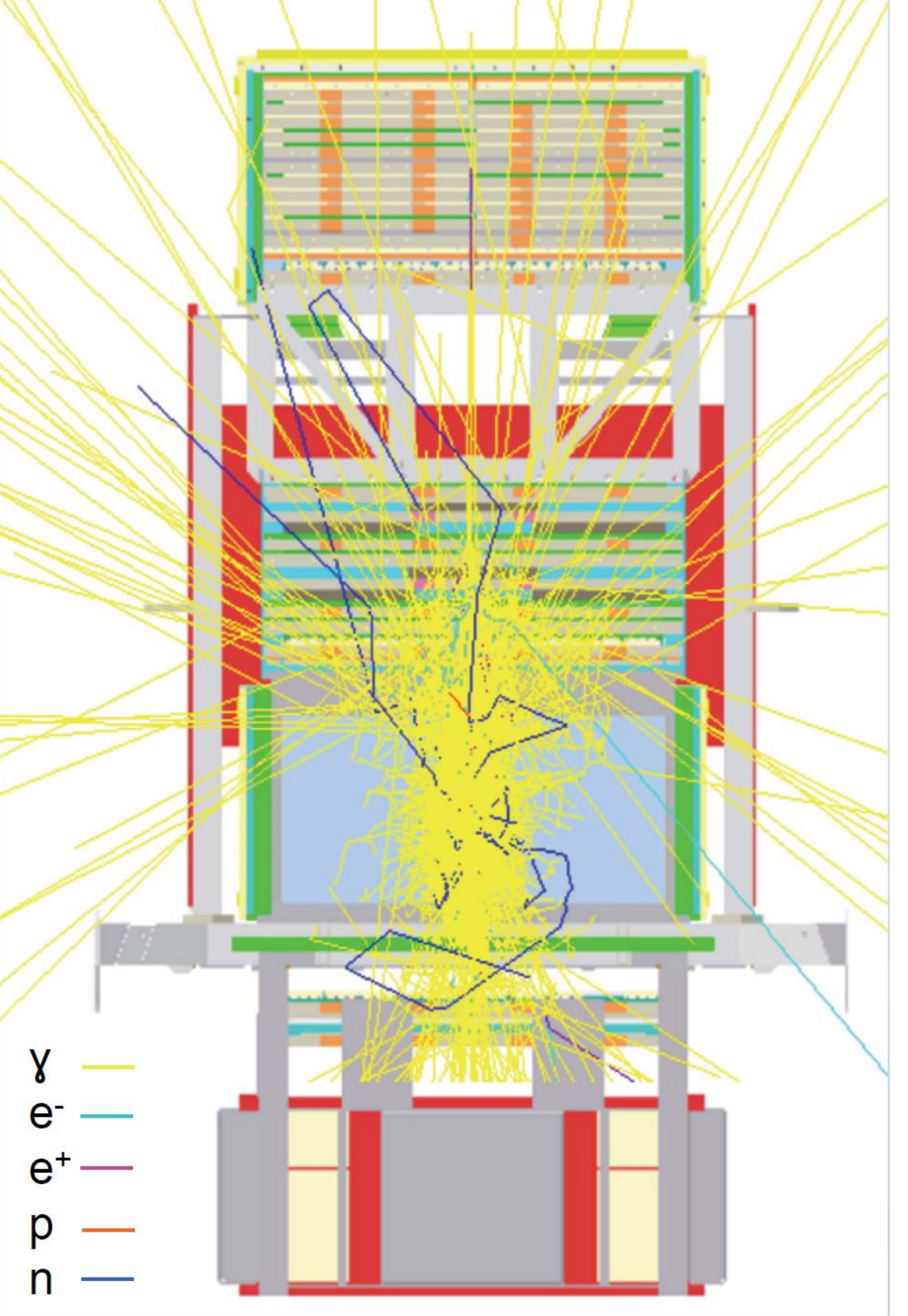
CC2 electromagnetic calorimeter 100x100 cm
- CsI(Tl) crystals 20 radiation lengths
- The total vertical thickness of the calorimeter CC1+CC2 is **22 radiation lengths**
- e/p rejection is ~5x10^5

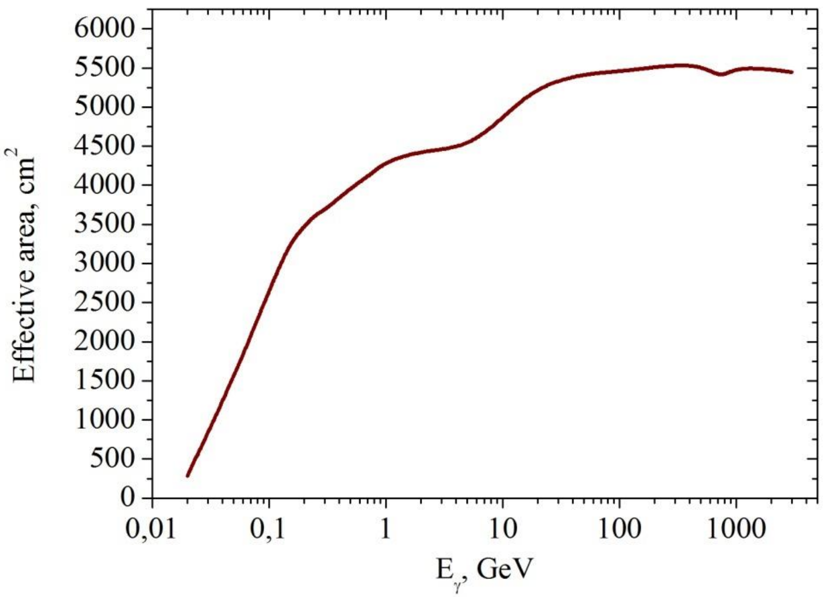
C_{lat} calorimeter lateral detectors
two layers of fast plastic scintillators

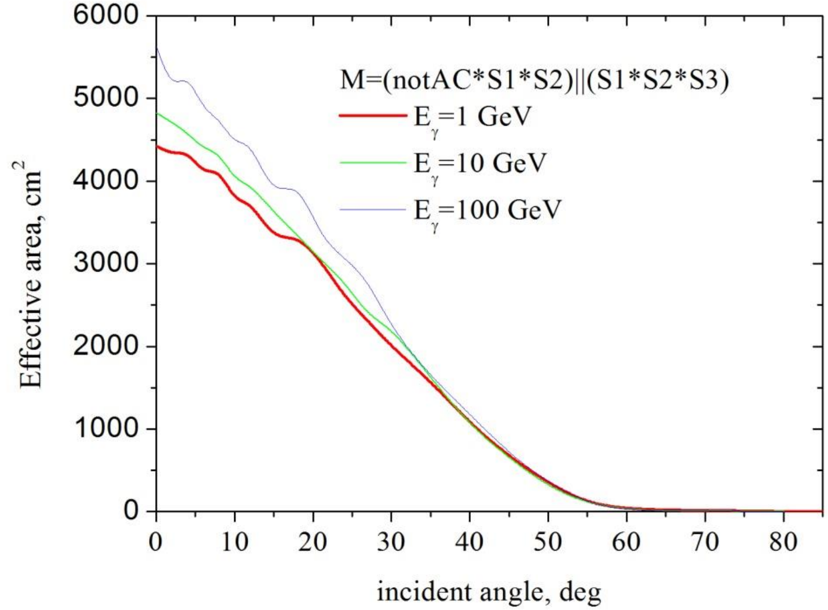
Backsplash at $E_\gamma = 30$ GeV

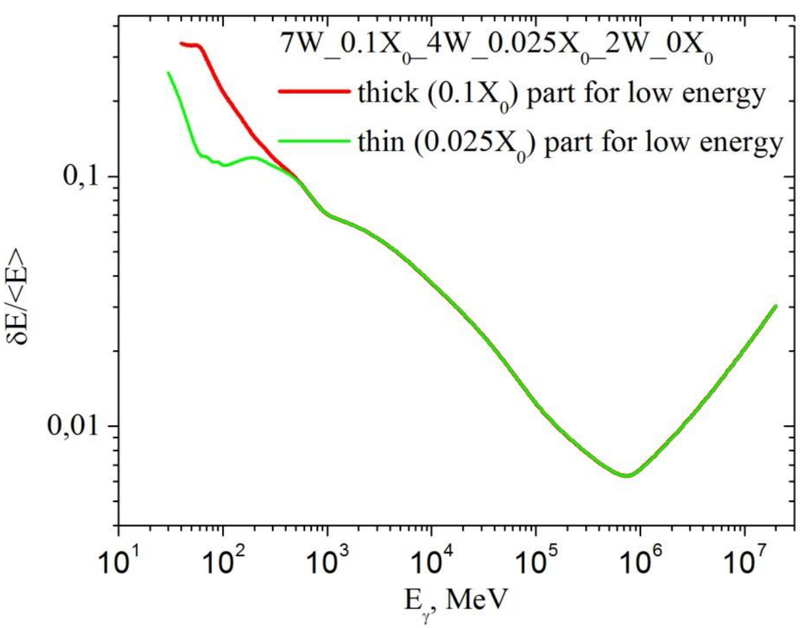
When recording gamma rays with the energy more than a few tens of GeV, the backscattering (BS) particle flux occurs, the flux of particles (mainly, gamma rays with the energy of ~1 MeV) formed during the development of the electromagnetic shower in the calorimeter and moving in the opposite direction to the anticoincidence detector.

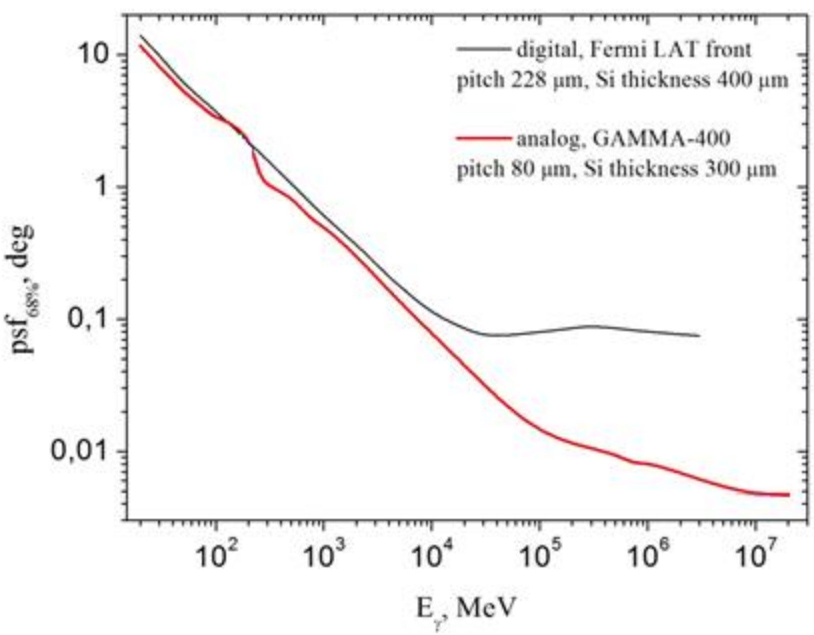
Methods to reduce BS:
-the segmentation (including the two-layer structure) of AC detectors;
-time of flight from AC to CC2 and back is ~6 ns due to the increased distance from CC2 to the converter-tracker equal to 100 cm.




Effective area, cm^2
E_γ, GeV
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0,01
0,1
1
10
100
1000


M=(notAC*S1*S2)||(S1*S2*S3)
E_γ=1 GeV
E_γ=10 GeV
E_γ=100 GeV
Effective area, cm^2
incident angle, deg
6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80


7W_0.1X_0_4W_0.025X_0_2W_0X_0
thick (0.1X_0) part for low energy
thin (0.025X_0) part for low energy
δE/<E>
E_γ, MeV
0,1
0,01
10^1
10^2
10^3
10^4
10^5
10^6
10^7

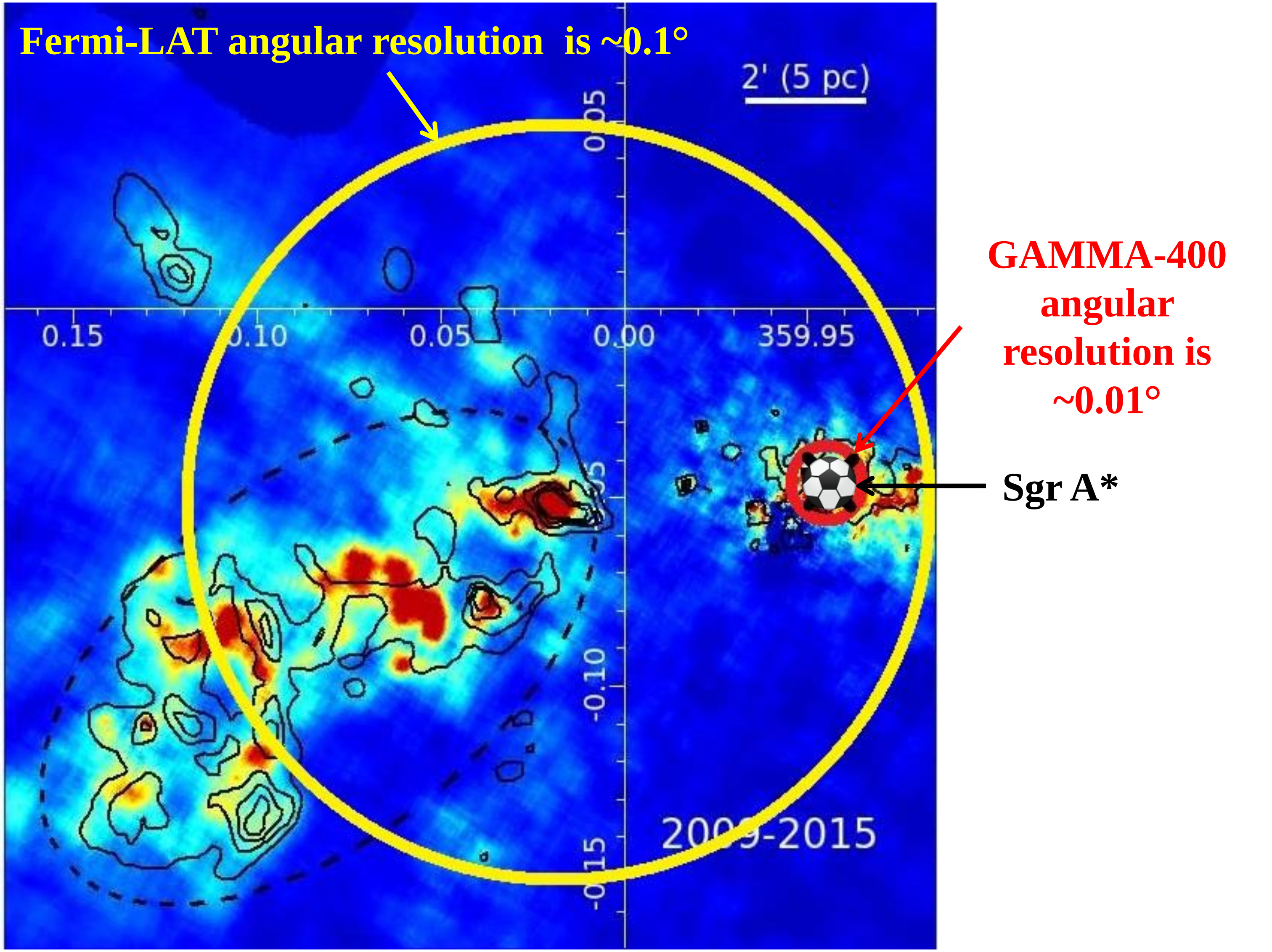

digital, Fermi LAT front
pitch 228 μm, Si thickness 400 μm
analog, GAMMA-400
pitch 80 μm, Si thickness 300 μm
$psf_{68\%}$, deg
E_γ, MeV
10
1
0,1
0,01
10^2
10^3
10^4
10^5
10^6
10^7

Comparison of the main parameters for GAMMA-400 and Fermi-LAT

	Fermi-LAT	GAMMA-400
Orbit	Circular, 565 km	Highly elliptical, 500-300000 km **(without the Earth's occultation)**
Operation mode	Sky-survey (3 hours)	**Point observation (up to 100 days)**
Source exposition	1/8	**1**
Energy range	~100 MeV - ~300 GeV	**~20 MeV – ~10 TeV**
Effective area ($E_\gamma > 1$ GeV)	~5000 cm^2 (front)	~4000 cm^2
Coordinate detectors - readout	Si strips (pitch 0.23 mm) digital	Si strips (**pitch 0.08 mm**) **analog**
Angular resolution	~3° (E_γ = 100 MeV) ~0.2° (E_γ = 10 GeV) ~0.1° (E_γ > 100 GeV)	**~2° (E_γ = 100 MeV)** **~0.1° (E_γ = 10 GeV)** **~0.01° (E_γ = 100 GeV)**
Calorimeter - thickness	CsI(Tl) ~8.5X_0	CsI(Tl)+Si **~22X_0**
Energy resolution	~18% (E_γ = 100 MeV) ~10% (E_γ = 10 GeV) ~10% (E_γ > 100 GeV)	**~10% (E_γ = 100 MeV)** **~3% (E_γ = 10 GeV)** **~1% (E_γ = 100 GeV)**
Proton rejection factor	~10^3	**~5x10^5**
Mass	2800 kg	~4000 kg
Telemetry downlink volume, Gbytes/day	15 Gbytes/day	**100 Gbytes/day**

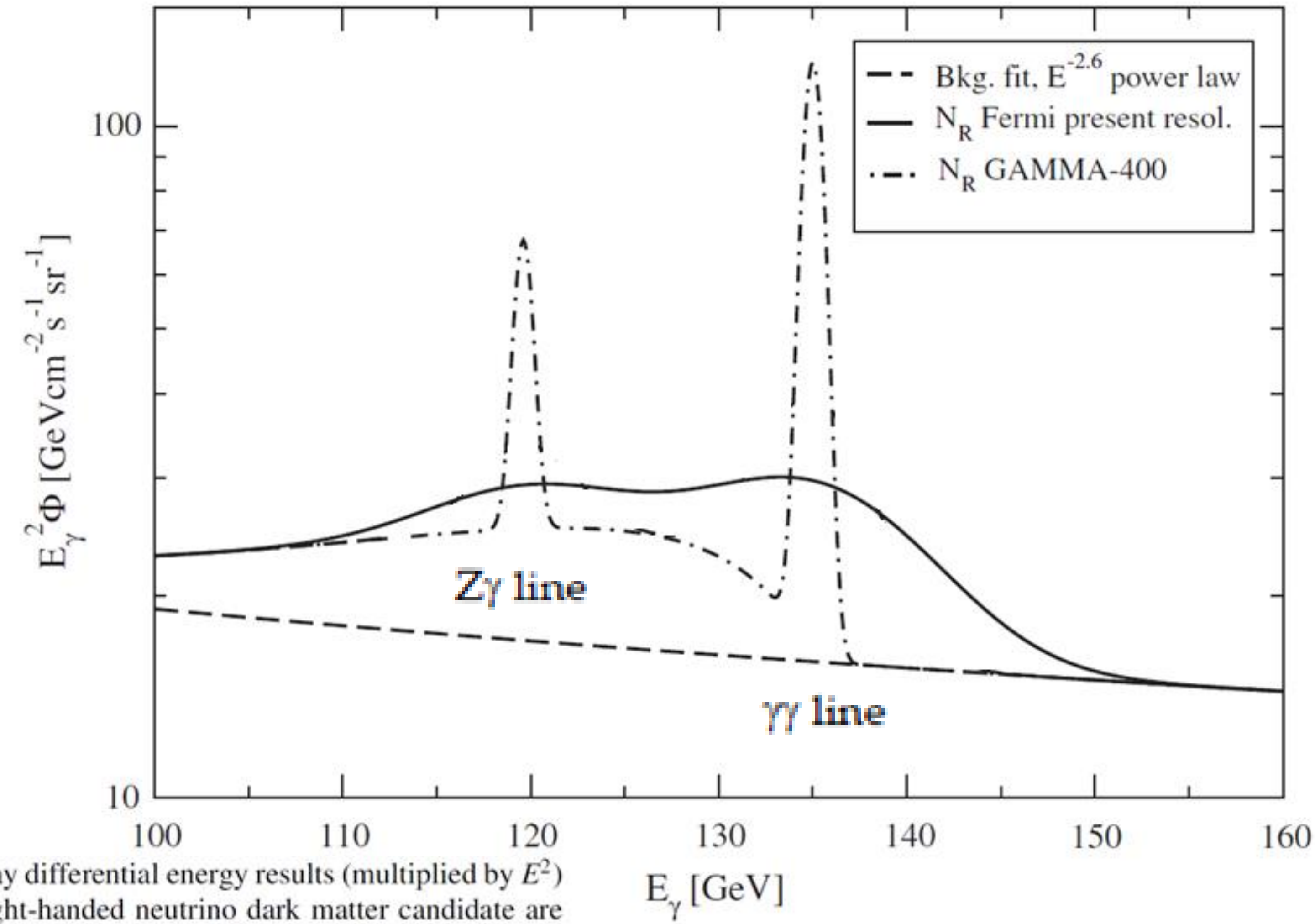
Comparison of main parameters of operated, current, and planned space-based and ground-based instruments

	SPACE-BASED INSTRUMENTS					GROUND-BASED GAMMA-RAY FACILITIES			
	AGILE	**Fermi-LAT**	**DAMPE**	**CALET**	**GAMMA-400**	**H.E.S.S.-II**	**MAGIC**	**VERITAS**	**CTA**
Particles	γ	γ	e, nuclei, γ	e, nuclei, γ	γ, e	γ	γ	γ	γ
Operation period	2007-	2008-	2015	2015	~2025	2012-	2009-	2007-	~2020
Energy range, GeV	0.03-50	0.02-300	5-10000	10-10000	**0.02-~10000**	> 30	> 50	> 100	> 20
Angular resolution (E_γ = 100 GeV)	0.1° (E_γ~1 GeV)	0.1°	0.1°	0.1°	**~0.01°**	0.07°	0.07° (E_γ = 300 GeV)	0.1°	0.1° (E_γ = 100 GeV) 0.05° (E_γ > 1 TeV)
Energy resolution (E_γ = 100 GeV)	50% (E_γ~1 GeV)	10%	1.5%	2%	**~1%**	15%	20% (E_γ = 100 GeV) 15% (E_γ = 1 TeV)	15%	20% (E_γ = 100 GeV) 5% (E_γ = 10 TeV)
Sensitive area, m^2	0,36	1,8	0,36	0,1	**1**				



Comparison of the capabilities to study Galactic Center by Fermi-LAT with the angular resolution of ~0.1° for E_γ = 100 GeV (yellow circle) and GAMMA-400 with the angular resolution of ~0.01° for E_γ = 100 GeV (red circle), using Chandra X-ray observation. The Sgr A* position is marked by cross.

Comparison of the Fermi-LAT and GAMMA-400 capabilities to resolve gamma-ray lines from dark matter particles



ΔE/E
10%
1%

FIG. 3. The γ-ray differential energy results (multiplied by E^2) for a 135 GeV right-handed neutrino dark matter candidate are shown, with the present Fermi-LAT energy resolution $\Delta E/E =$ 10% FWHM (solid line)

and with a future γ-ray instrument, such as GAMMA-400 [38] (dash-dotted line) with resolution at the one percent level. The extrapolated power-law $\sim E^{-2.6}$ of the presently measured continuous γ-ray background is also shown.

PHYSICAL REVIEW D **86,** 103514 (2012)

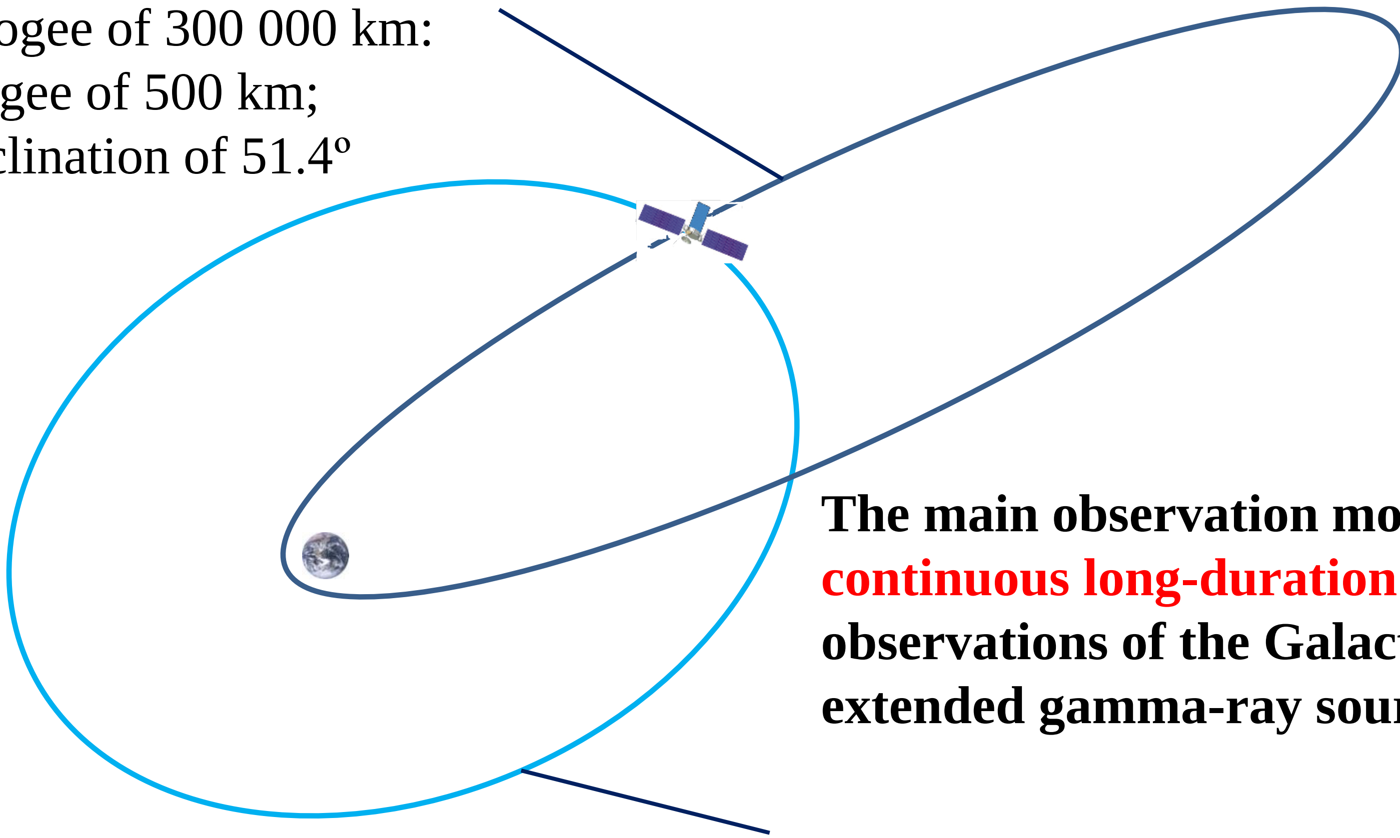
130 GeV fingerprint of right-handed neutrino dark matter

Lars Bergström*

The GAMMA-400 orbit evolution and observation modes

The orbit of the GAMMA-400 space observatory will have the following initial parameters:
-an apogee of 300 000 km:
-a perigee of 500 km;
-an inclination of 51.4º

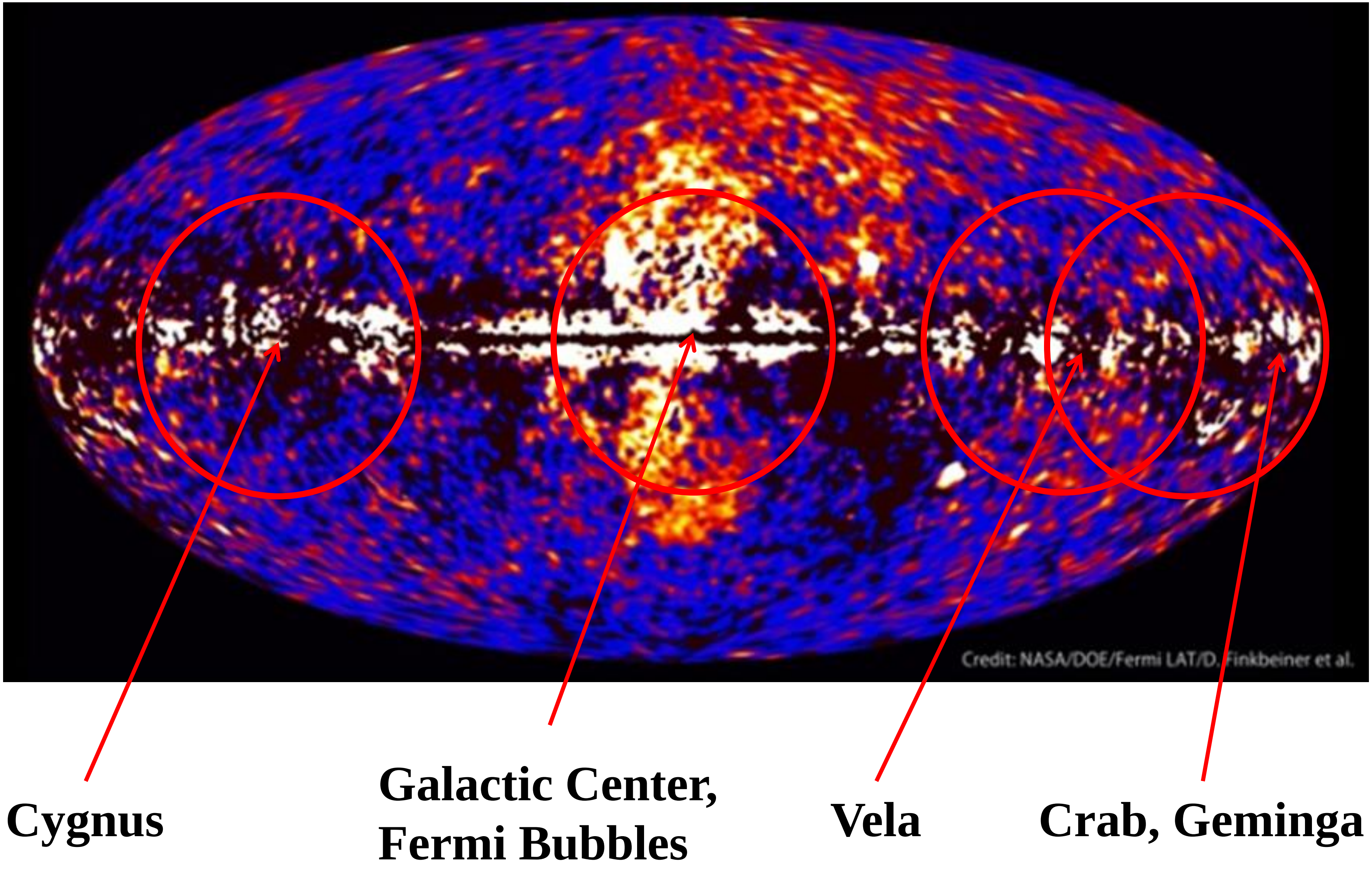
Time of operation will be 7-10 years



The main observation mode will be continuous long-duration (~100 days) observations of the Galactic Center, extended gamma-ray sources, etc.

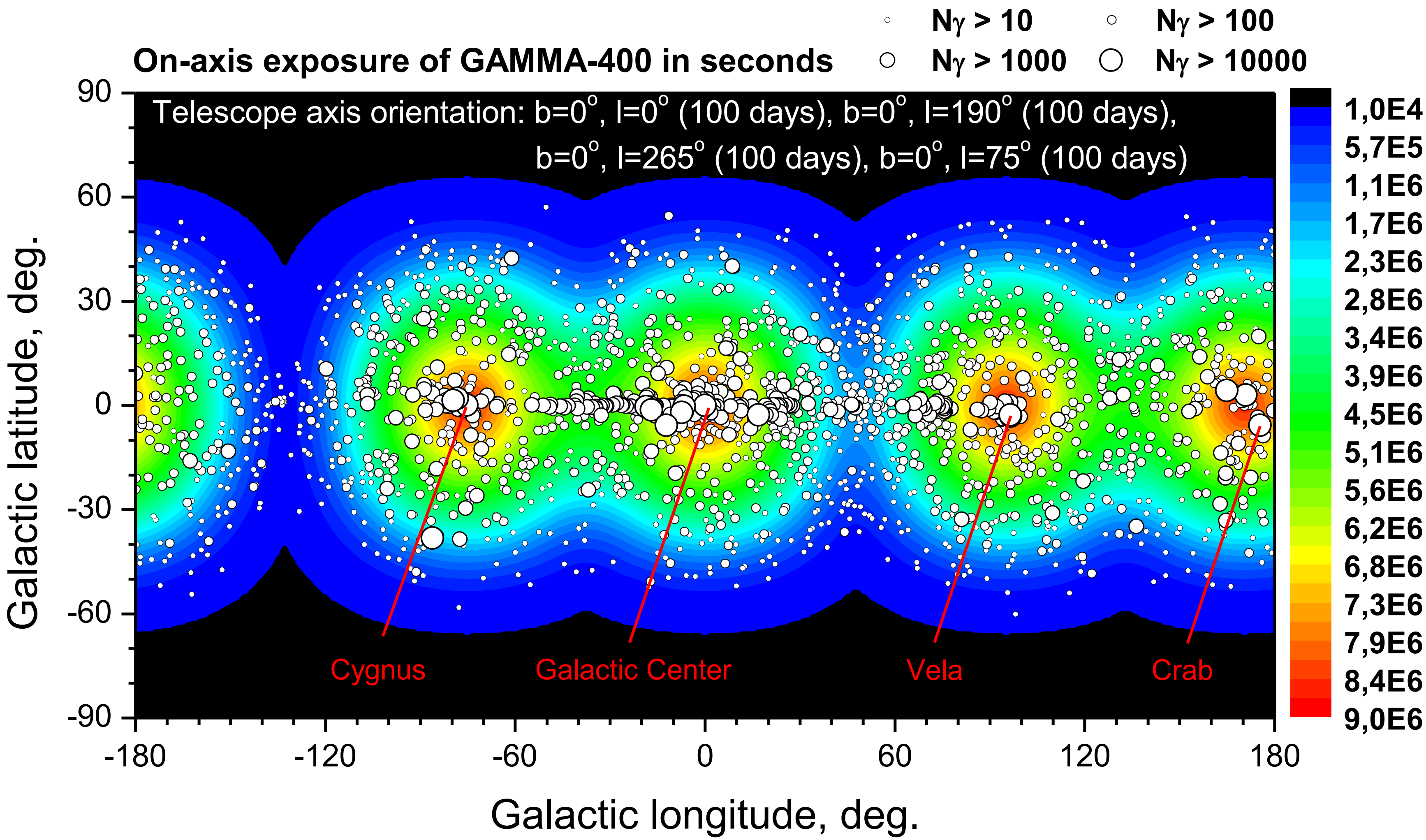
Under the action of gravitational disturbances of the Sun, Moon, and the Earth after ~6 months the orbit will transform to about circular with a radius of ~200 000 km and will be without the Earth's occultation and out of radiation belts.

Galactic Center, Fermi Bubbles, Crab, Cygnus, Vela, Geminga, and other regions will be observed with the GAMMA-400 aperture of ±45°



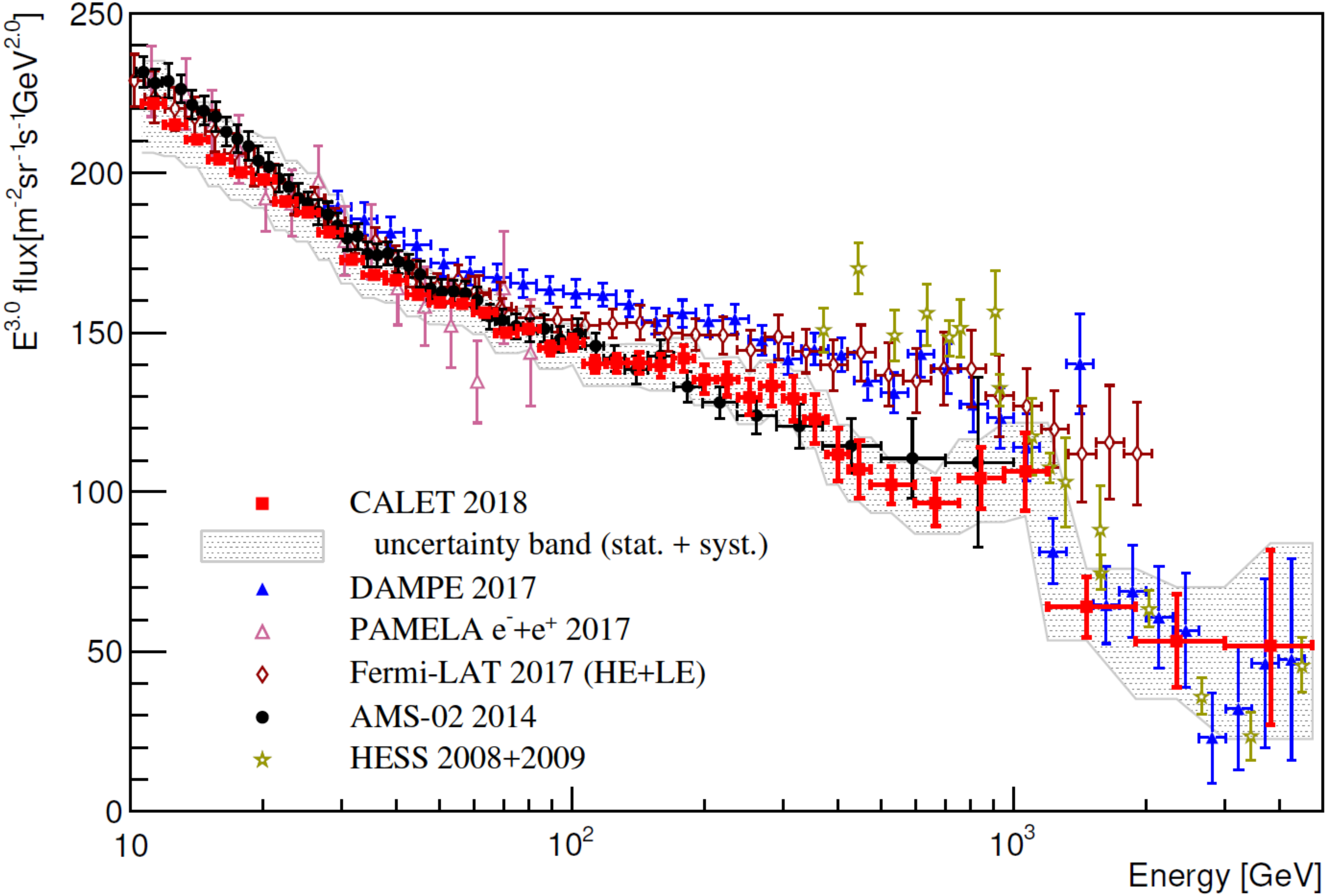
Number of simultaneously and uninterruptedly observed sources (at $N_\gamma > 10$ for each source) and number of gammas, when observing Galactic center, Crab + Geminga, Vela, and Cygnus regions by GAMMA-400 (effective area = 4000 cm^2, T_{obs} = 100 days, aperture ±45°), using the data from 3FGL for different energy ranges

Energy range / Direction	100 MeV-100 GeV		1 GeV-100 GeV		10 GeV-100 GeV	
	$N_{sources}$	N_γ	$N_{sources}$	N_γ	$N_{sources}$	N_γ
Galactic center b=0°, l=0°	723	523146	422	47505	21	1364
Crab + Geminga b=0°, l=190°	495	310384	175	39163	11	1020
Vela b=0°, l=265°	649	523077	280	63253	9	1163
Cygnus b=0°, l=75°	604	318788	269	30941	12	1007



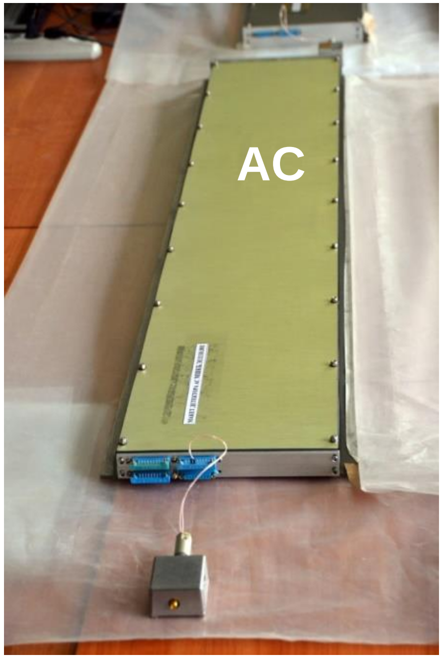
On-axis exposure of GAMMA-400 in seconds
Nγ > 10
Nγ > 100
Nγ > 1000
Nγ > 10000
Telescope axis orientation: b=0°, l=0° (100 days), b=0°, l=190° (100 days),
b=0°, l=265° (100 days), b=0°, l=75° (100 days)
Galactic latitude, deg.
Galactic longitude, deg.
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180
Cygnus
Galactic Center
Vela
Crab
1,0E4
5,7E5
1,1E6
1,7E6
2,3E6
2,8E6
3,4E6
3,9E6
4,5E6
5,1E6
5,6E6
6,2E6
6,8E6
7,3E6
7,9E6
8,4E6
9,0E6

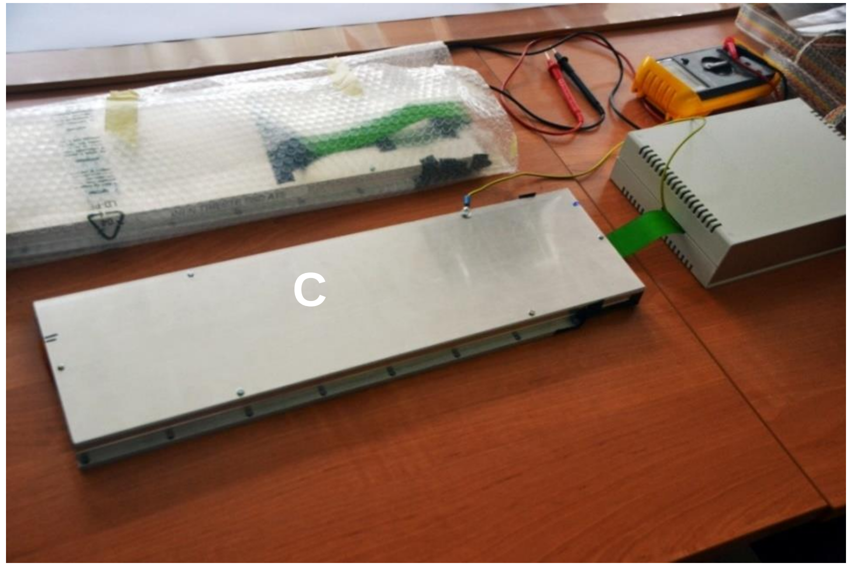
Electron + positron spectrum

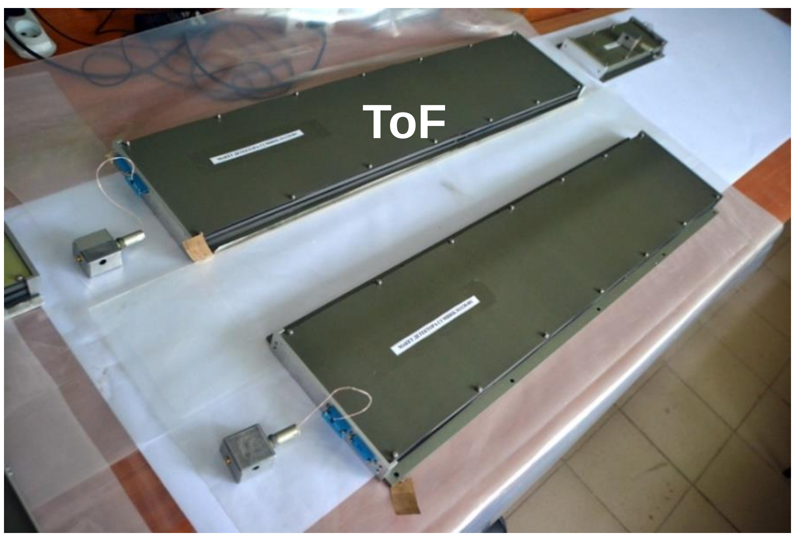


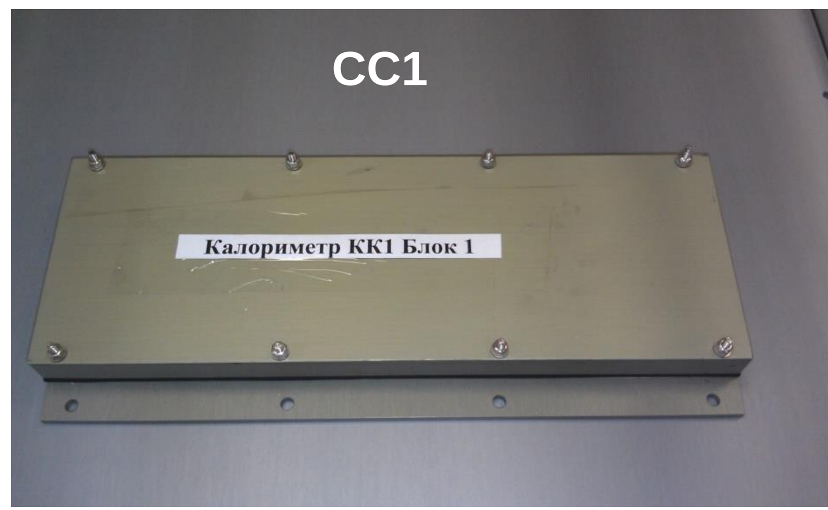
arXiv:1806.09728

GAMMA-400 laboratory prototypes of detector systems

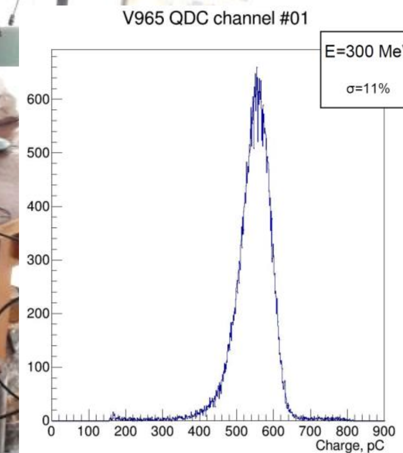








Calibration of prototypes on electron beam (100-300 MeV) at LPI accelerator



Conclusions

- **After Fermi-LAT the GAMMA-400 mission represents a unique opportunity to significantly improve the direct data of LE+HE gamma rays and electron + positron fluxes due to unprecedented angular and energy resolutions, large area, and continuous long-term observations.**
- GAMMA-400 is funded by the Russian Space Agency and according to the Russian Federal Space Program 2016-2025 the GAMMA-400 space observatory is scheduled to launch in ~2025.
- We are open to the participation of foreign scientists in the manufacture of some detector systems.

GAMMA-400 site - http://gamma400.lebedev.ru/