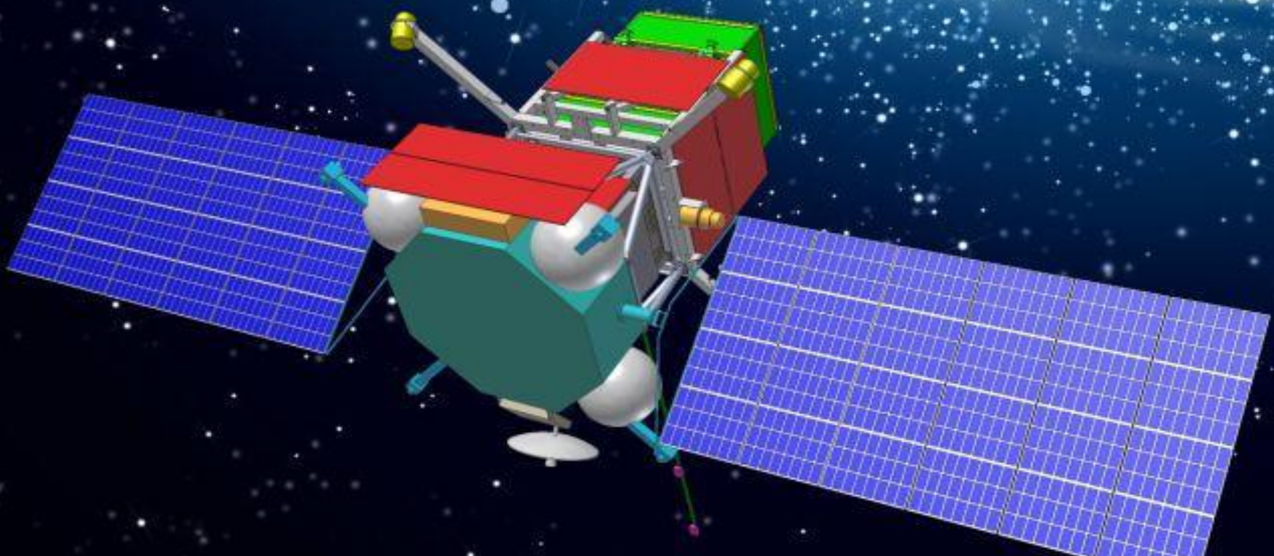
Russian Academy of Sciences
P.N.Lebedev Physical Institute
LPI

Nikolay Topchiev
for the GAMMA-400 Collaboration

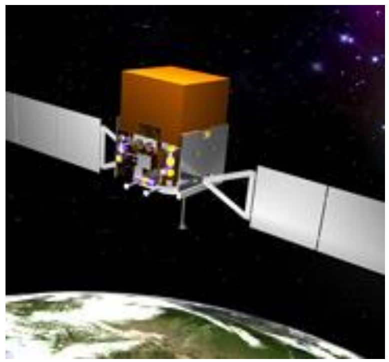
GAMMA-400 gamma-ray telescope for direct gamma- and cosmic-ray observations



June 21-22, 2019, NextGAPES, MSU, Moscow

High-energy gamma-ray studying with space-based instruments

AGILE
Italy
from 2007
100 MeV – 50 GeV
0.36 m^2



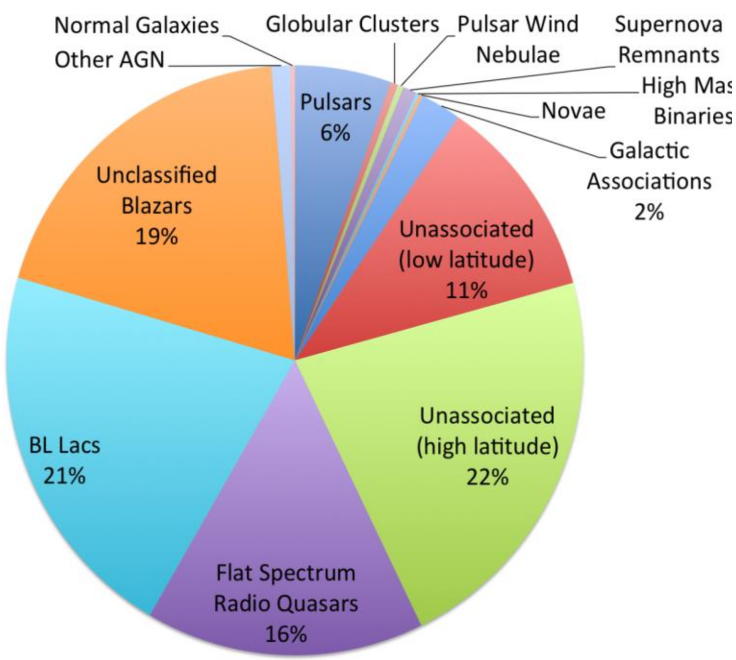
Fermi-LAT
USA
from 2008
100 MeV – 300 GeV
1.8 m^2

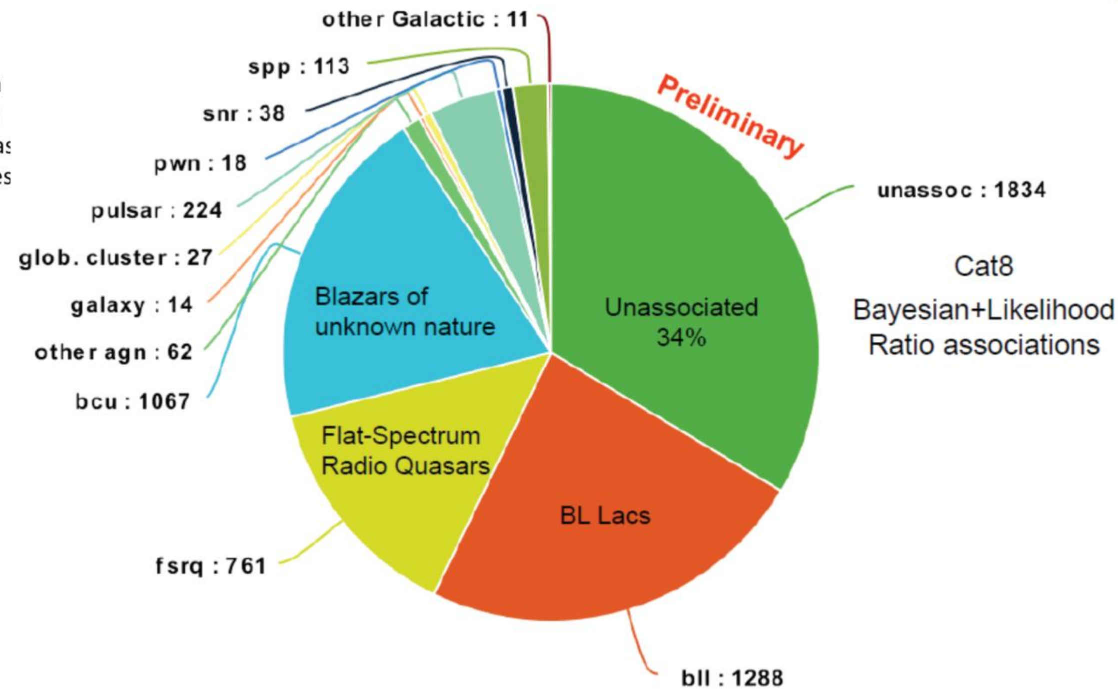
CALET
Japan
from 2015
1 GeV – 10 TeV
0.1 m^2

DAMPE
China
from 2015
5 GeV – 10 TeV
0.36 m^2

High-energy gamma-ray studying

Fermi-LAT





33% sources are unassociated

3033 sources
(**3FGL**, E_γ = 100 MeV – 100 GeV)

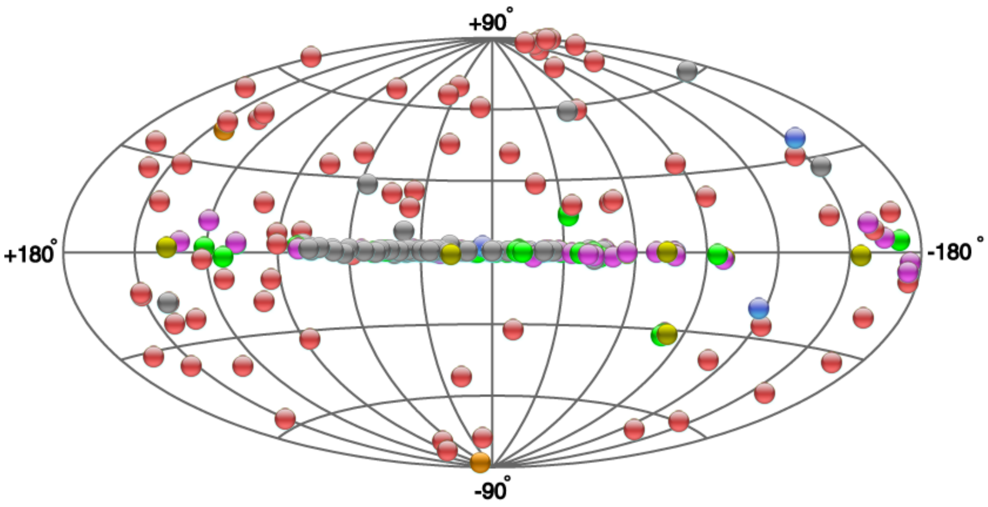
34% sources are unassociated

5523 sources
(**4FGL**, E_γ = 100 MeV – 1000 GeV)

Fermi-LAT angular resolution is ~0.1° (E_γ > 10 GeV)

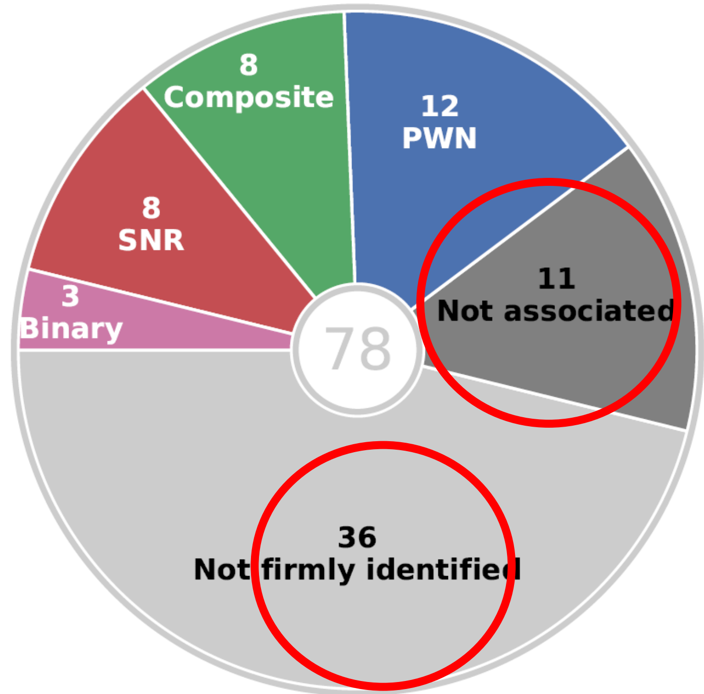
High-energy gamma-ray studying

Ground-based data



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

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

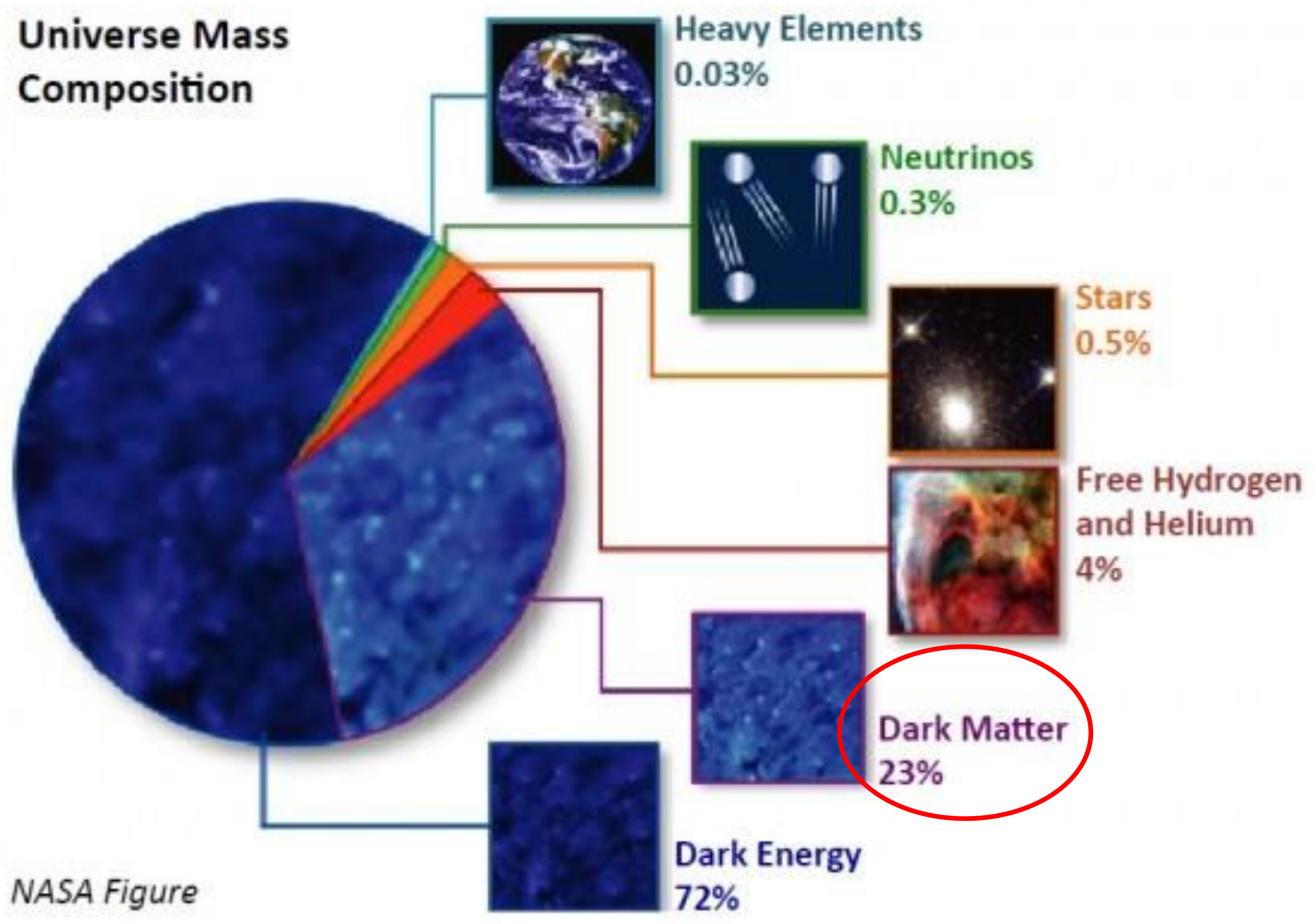


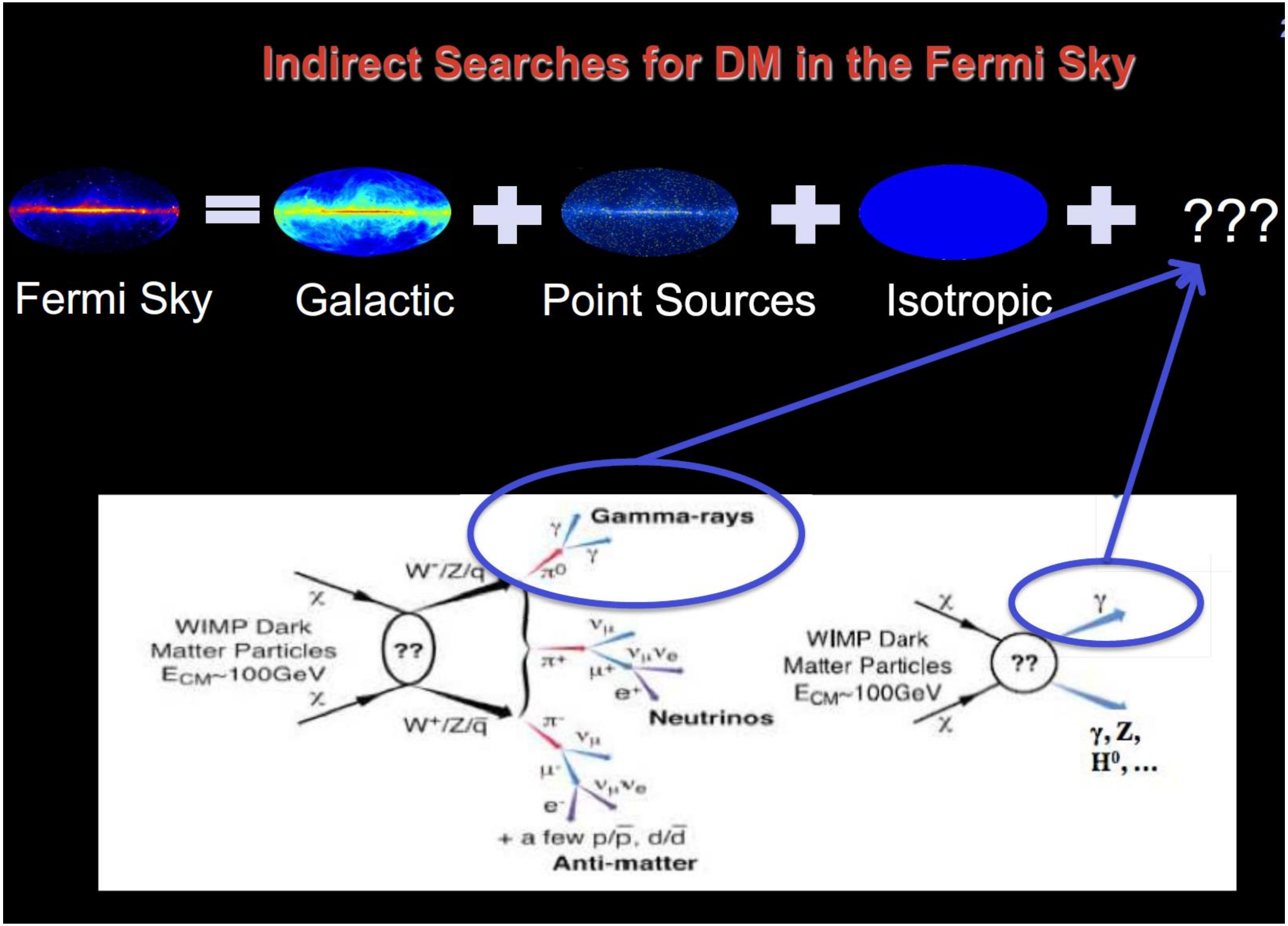
Composition of discrete sources recorded by H.E.S.S.

arXiv :1804.02432

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

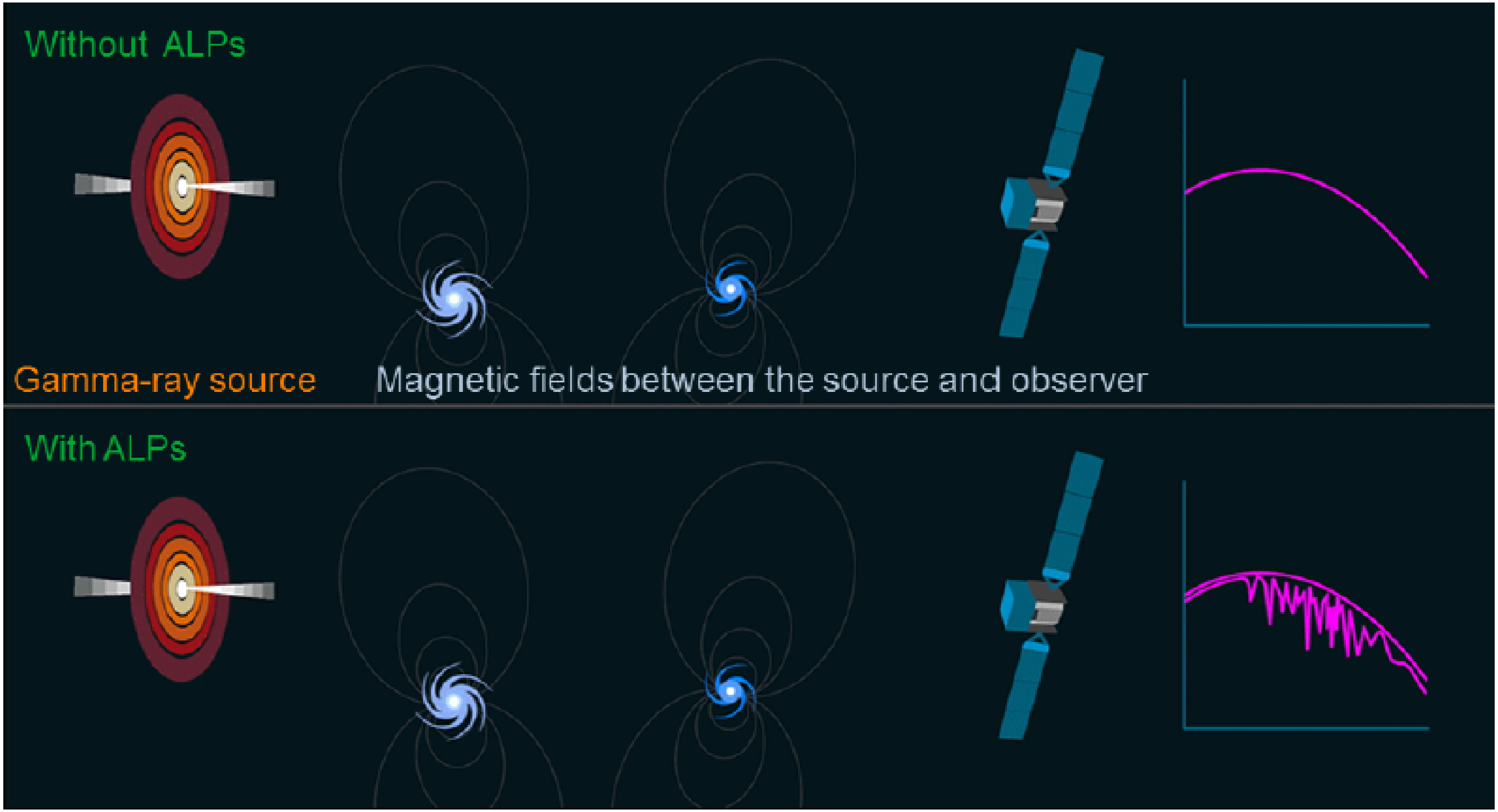
Studying the nature of dark matter with high-energy gamma-ray astronomy





One of the leading candidates for the DM particle are weakly interacting massive particles (WIMPs) producing gamma rays after annihilation or decay

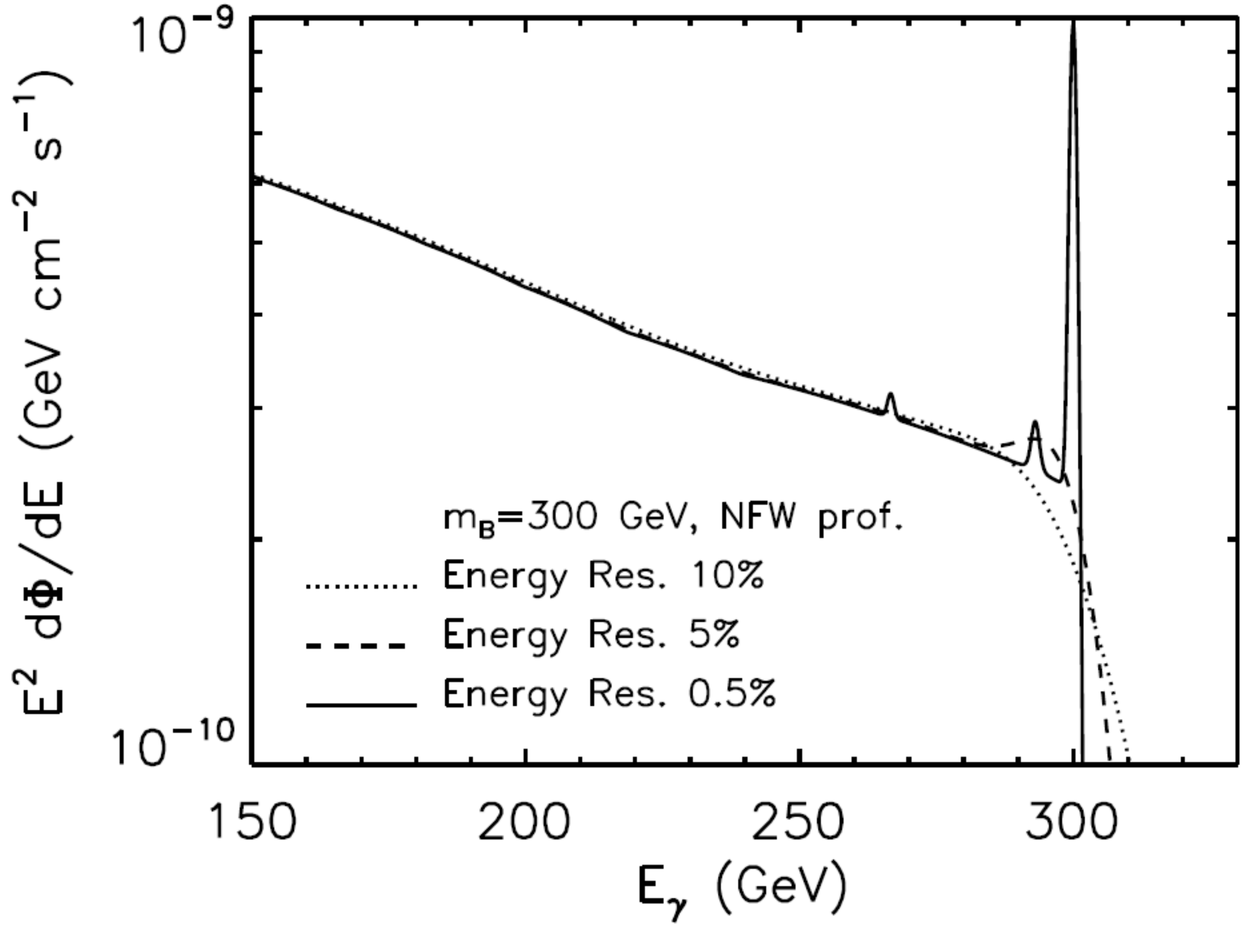
ALP signature searches in pulsar and blazar spectra



$\gamma + \boldsymbol{B} \leftrightarrow \gamma + ALP$ — conversion

The key relevant parameters of ALP are its mass m_a and electromagnetic coupling constant $g_{a\gamma}$. These parameters define the character of spectral features due to conversion.

Capabilities of different gamma-ray telescopes to resolve DM lines



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)

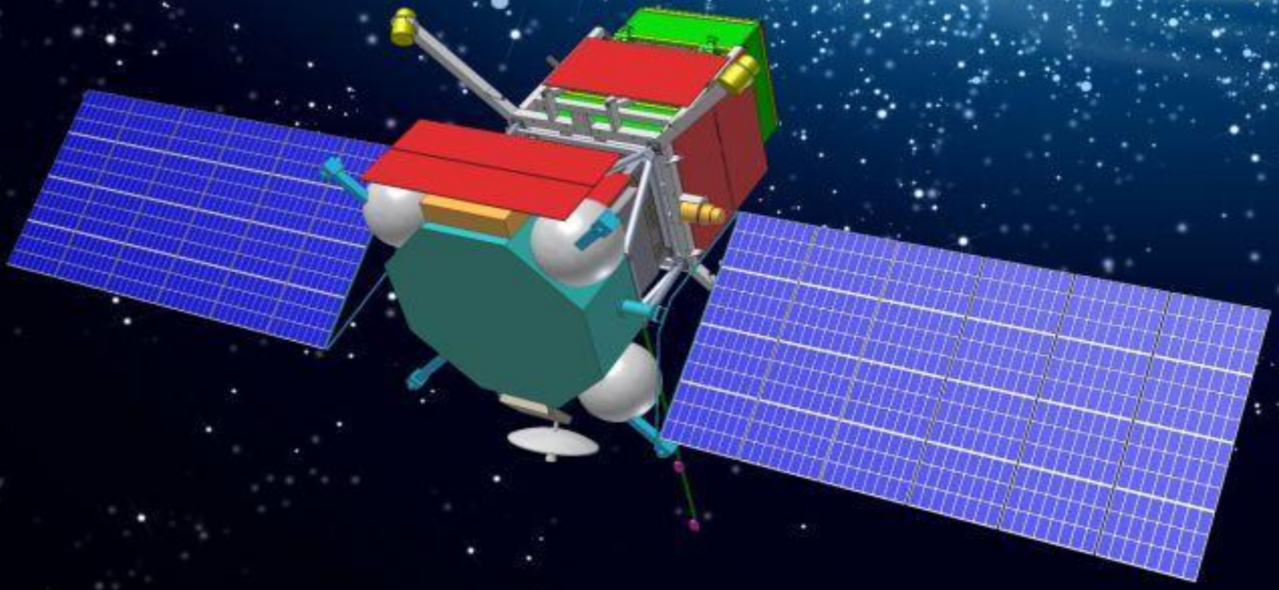
arXiv:1009.5107

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

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

Such a new generation telescope will be

GAMMA-400

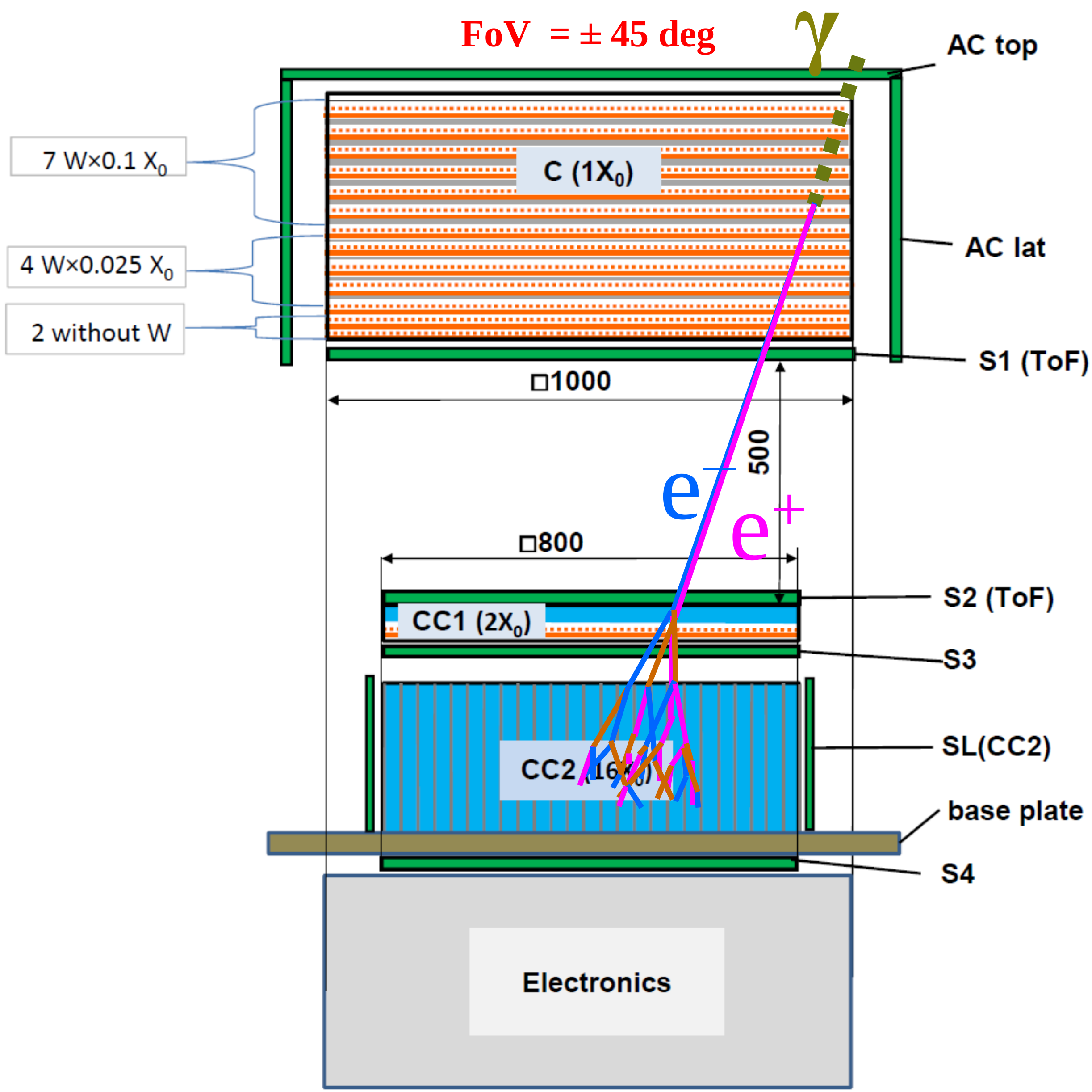


GAMMA-400
MAIN SCIENTIFIC GOALS

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,
- gamma-ray bursts and other transients,
- diffuse gamma rays

with unprecedented angular **(~0.01° at E_γ = 100 GeV)** and energy resolutions **(~2% at E_γ = 100 GeV)**, as well as detecting electron + positron fluxes with energies up to 10 TeV.

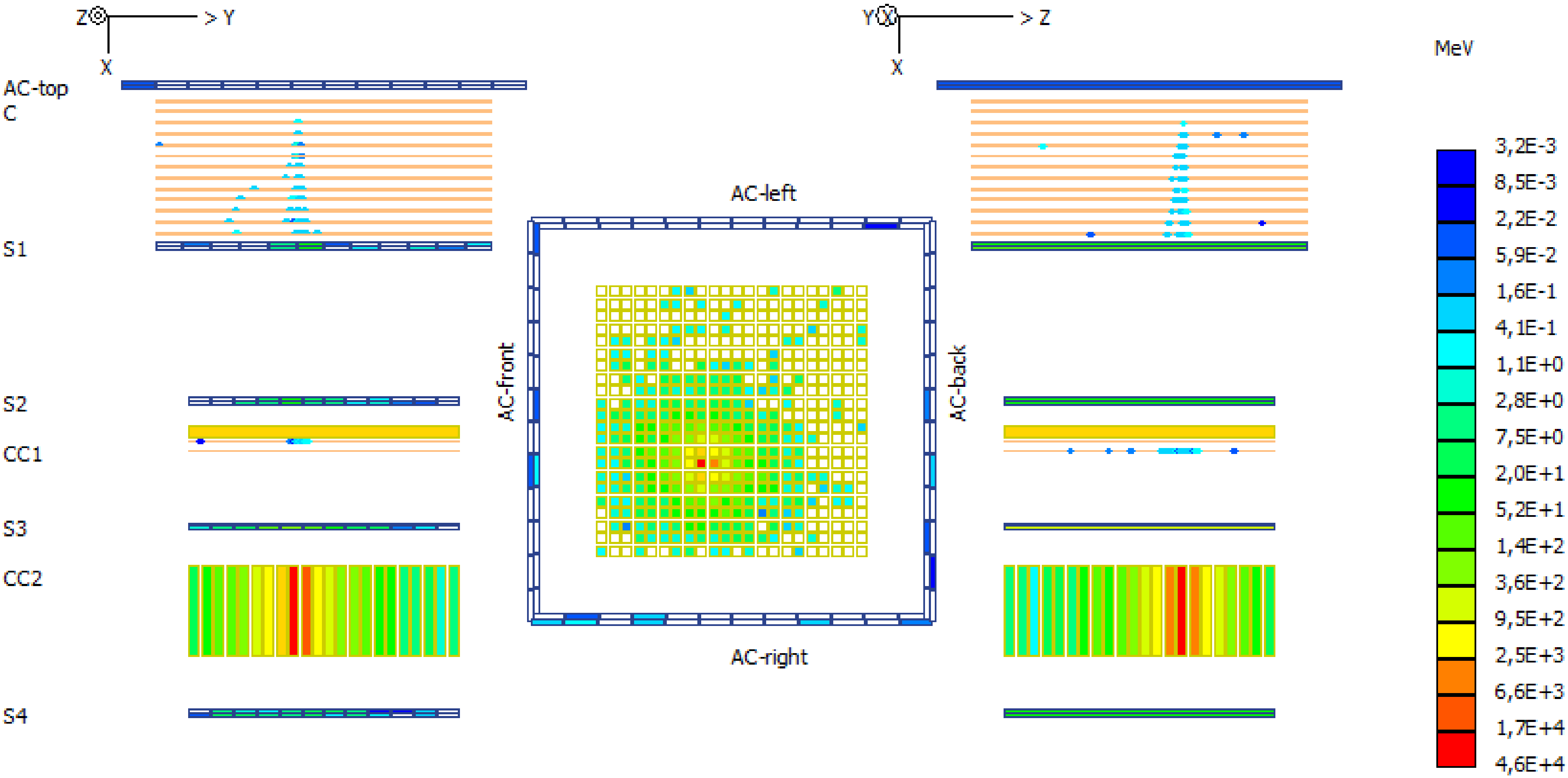
The GAMMA-400 physical scheme - HE



AC – anticoincedence system
C - converter-tracker ~1 X_0
S1, S2 – TOF detectors
CC1, CC2 – calorimeter vertical thickness ~2+16=18 X_0
S3, S4 – scintillator detectors

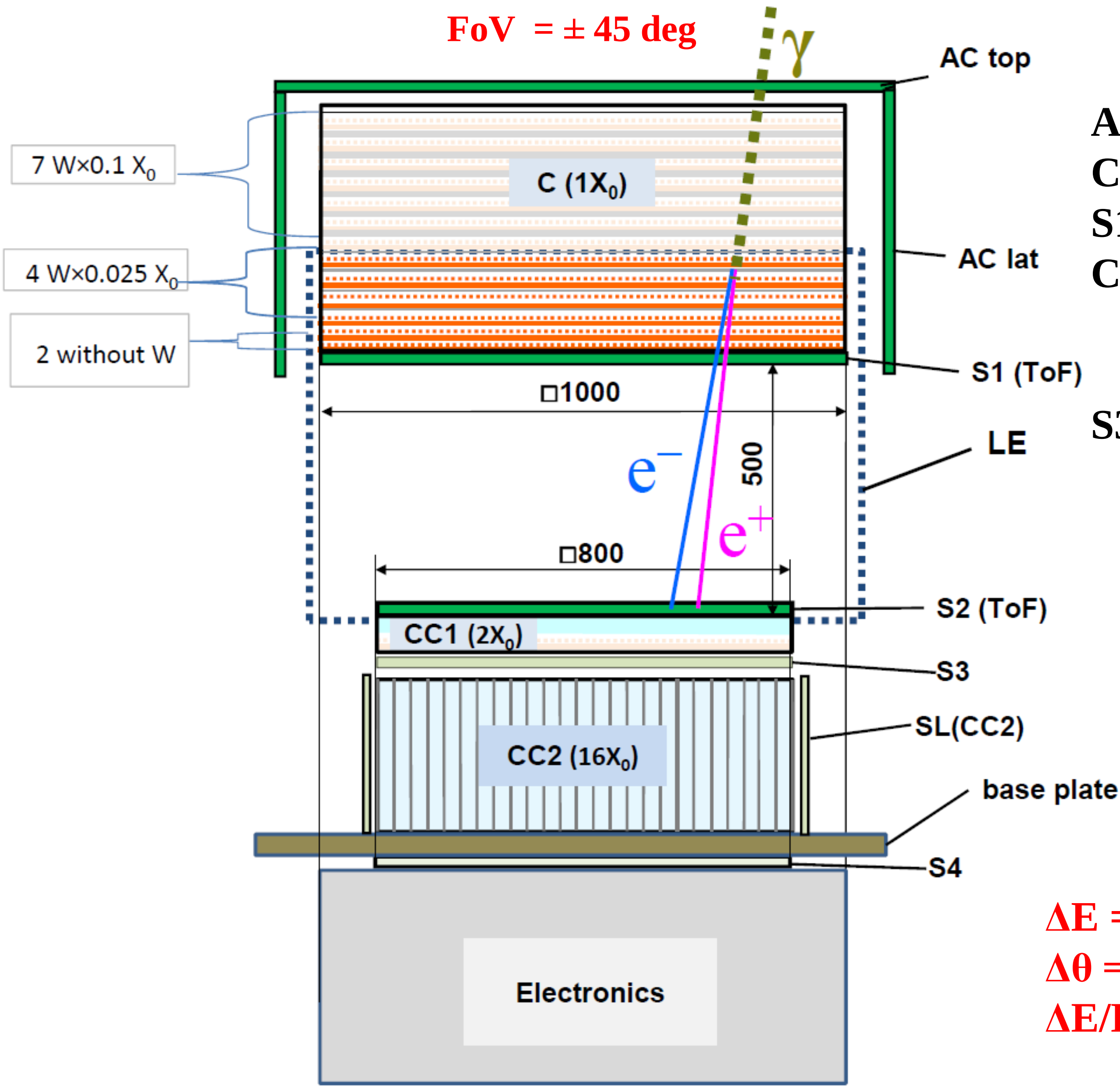
ΔE = ~20 MeV – ~10 TeV
$\Delta\theta$ = ~0.01° (E_γ = 100 GeV)
$\Delta E/E$ = ~2% (E_γ = 100 GeV)

Simulation of recording 50-GeV gamma-quantum



Event 20 Full Energy deposition 45570,0977 MeV

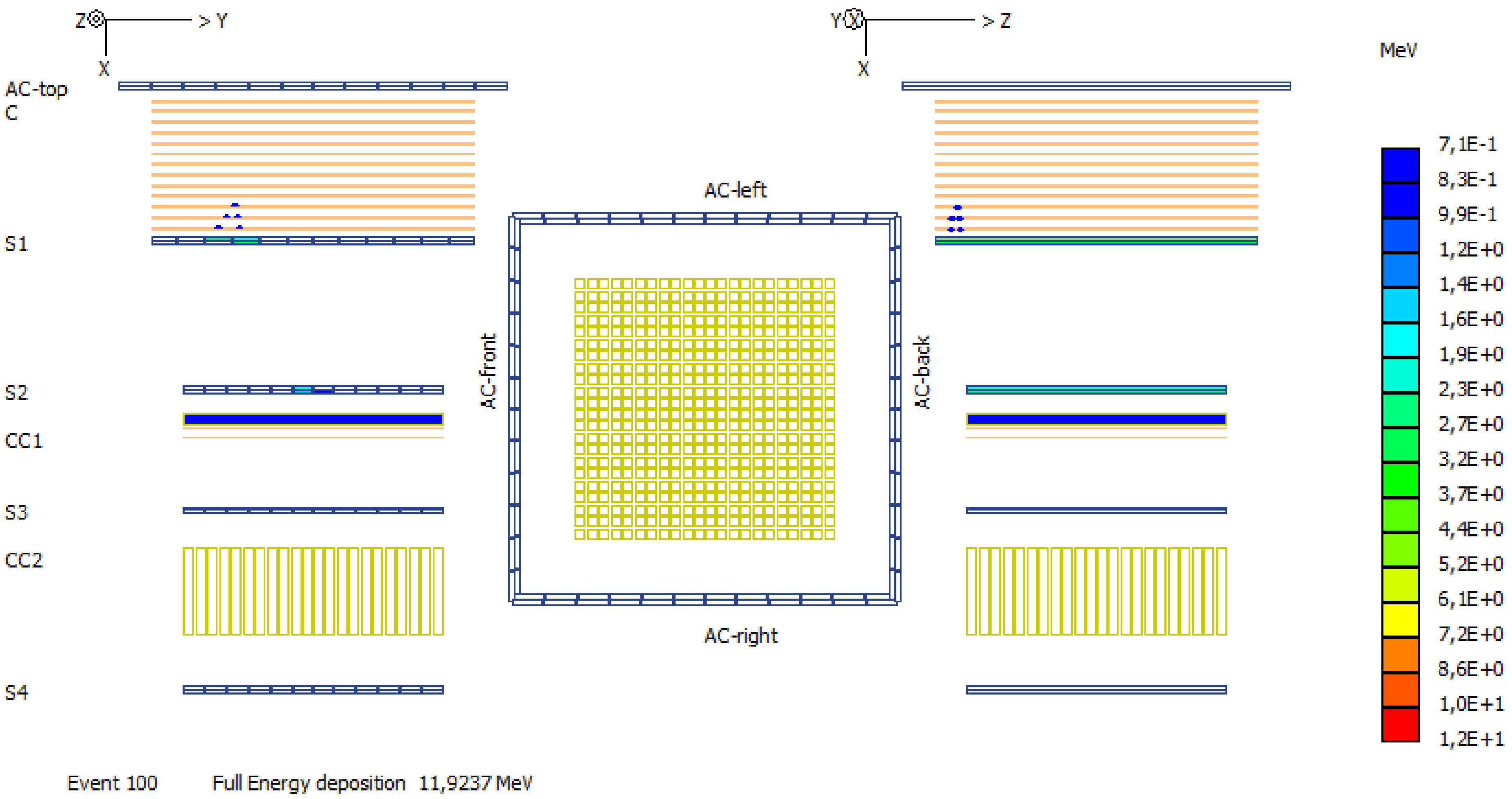
The GAMMA-400 physical scheme - LE



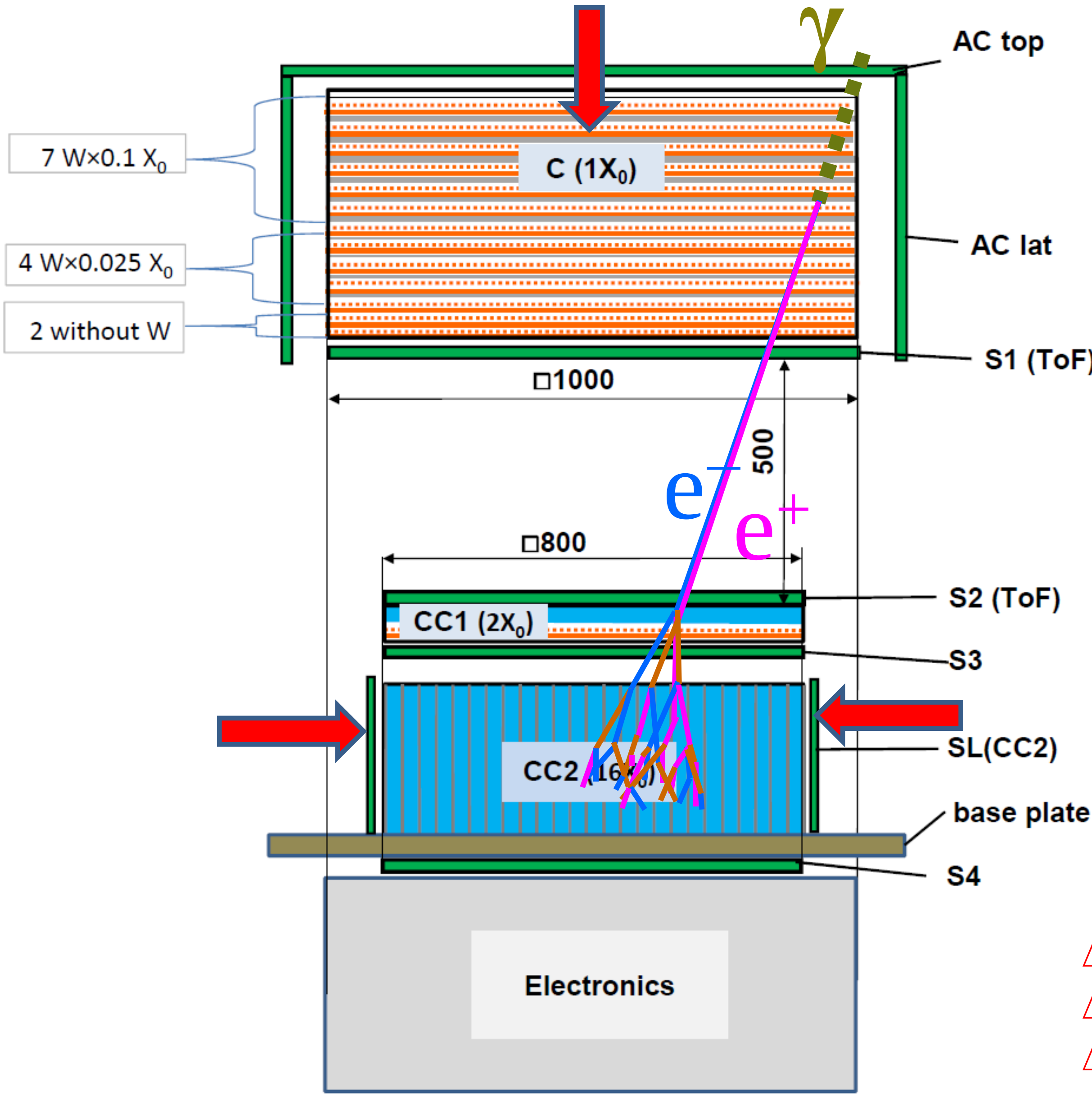
AC – anticoincedence system
C - converter-tracker ~1 X_0
S1, S2 – TOF detectors
CC1, CC2 – calorimeter vertical thickness ~2+16=18 X_0
S3, S4 – scintillator detectors

ΔE = ~20 MeV – ~100 MeV
$\Delta\theta$ = ~3° (E_γ = 100 MeV)
$\Delta E/E$ = ~10% (E_γ = 100 MeV)

Simulation of recording 20-MeV gamma-quantum



The GAMMA-400 physical scheme
(gamma-ray bursts, electrons + positrons)



AC – anticoincedence system

C - converter-tracker ~$1\ X_0$

S1, S2 – TOF detectors

CC1, CC2 – calorimeter vertical thickness ~$2+16=18\ X_0$

CC2 – lateral thickness ~$43\ X_0$

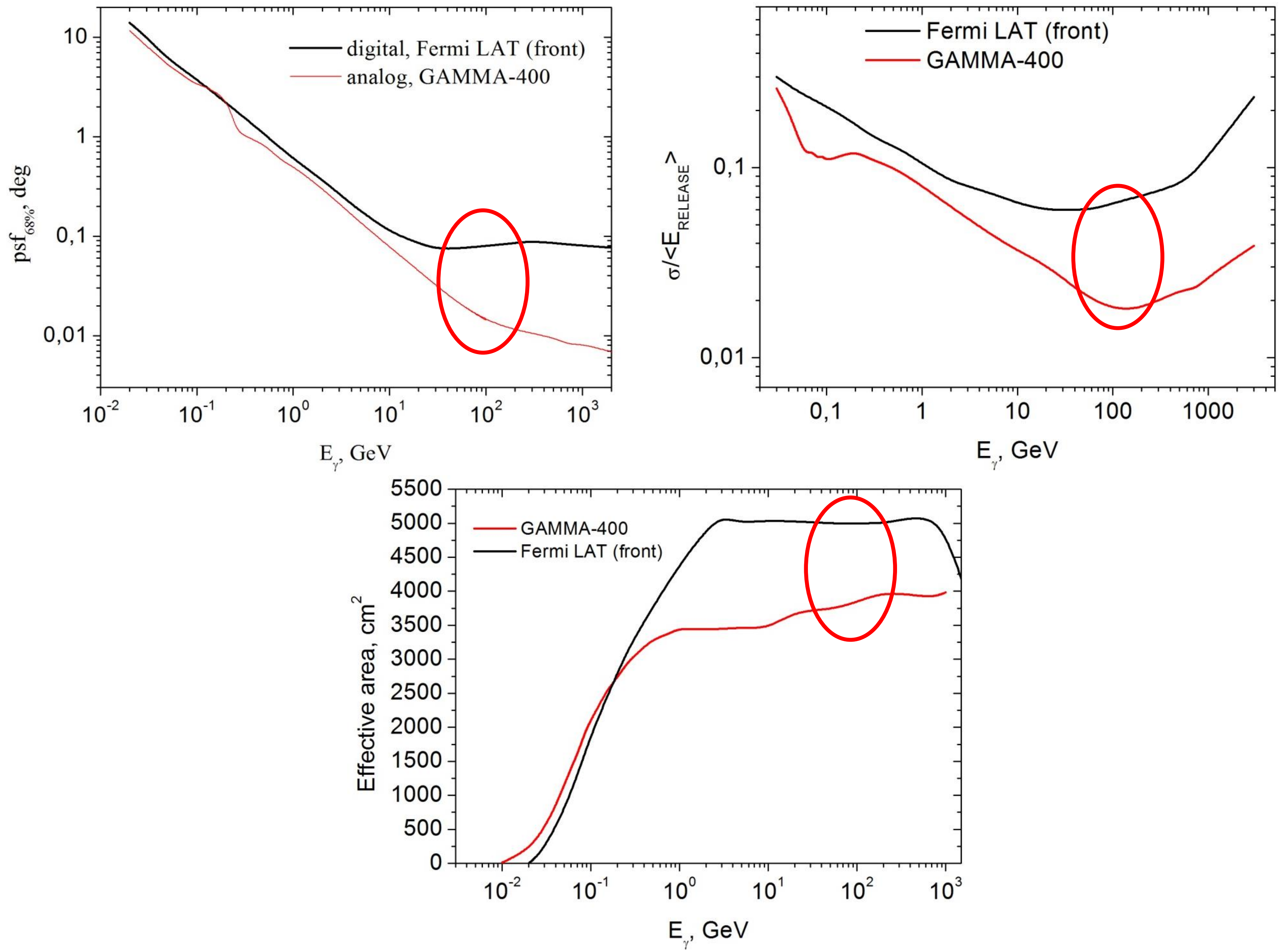
S3, S4 – scintillator detectors

ΔE = ~20 MeV – ~10 TeV

$\Delta\theta$ = ~0.01° (E_γ = 100 GeV)

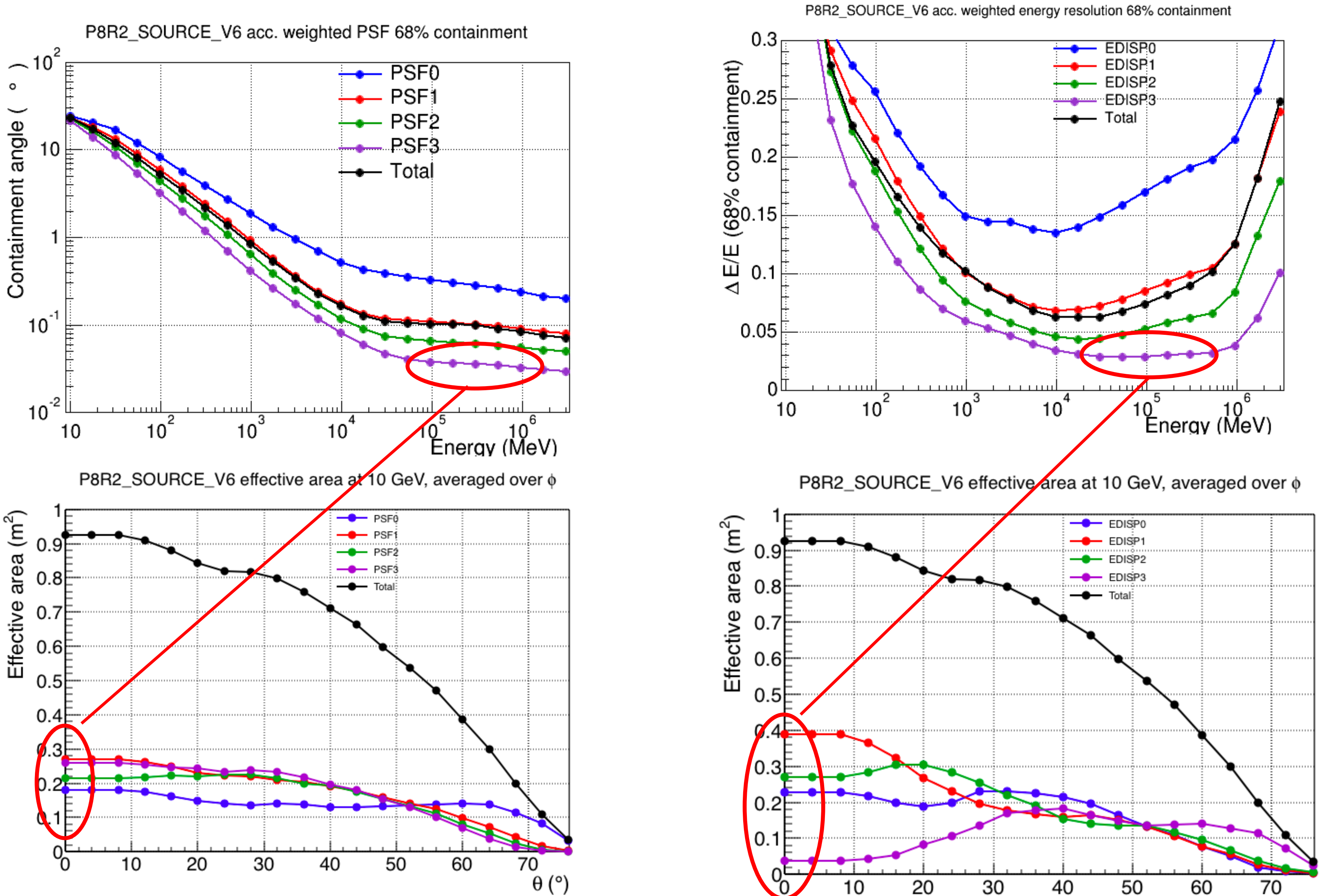
$\Delta E/E$ = ~2% (E_γ = 100 GeV)

GAMMA-400 performance



Fermi-LAT performance

Improvement in the energy and angular resolutions at the expense of decreasing the effective area

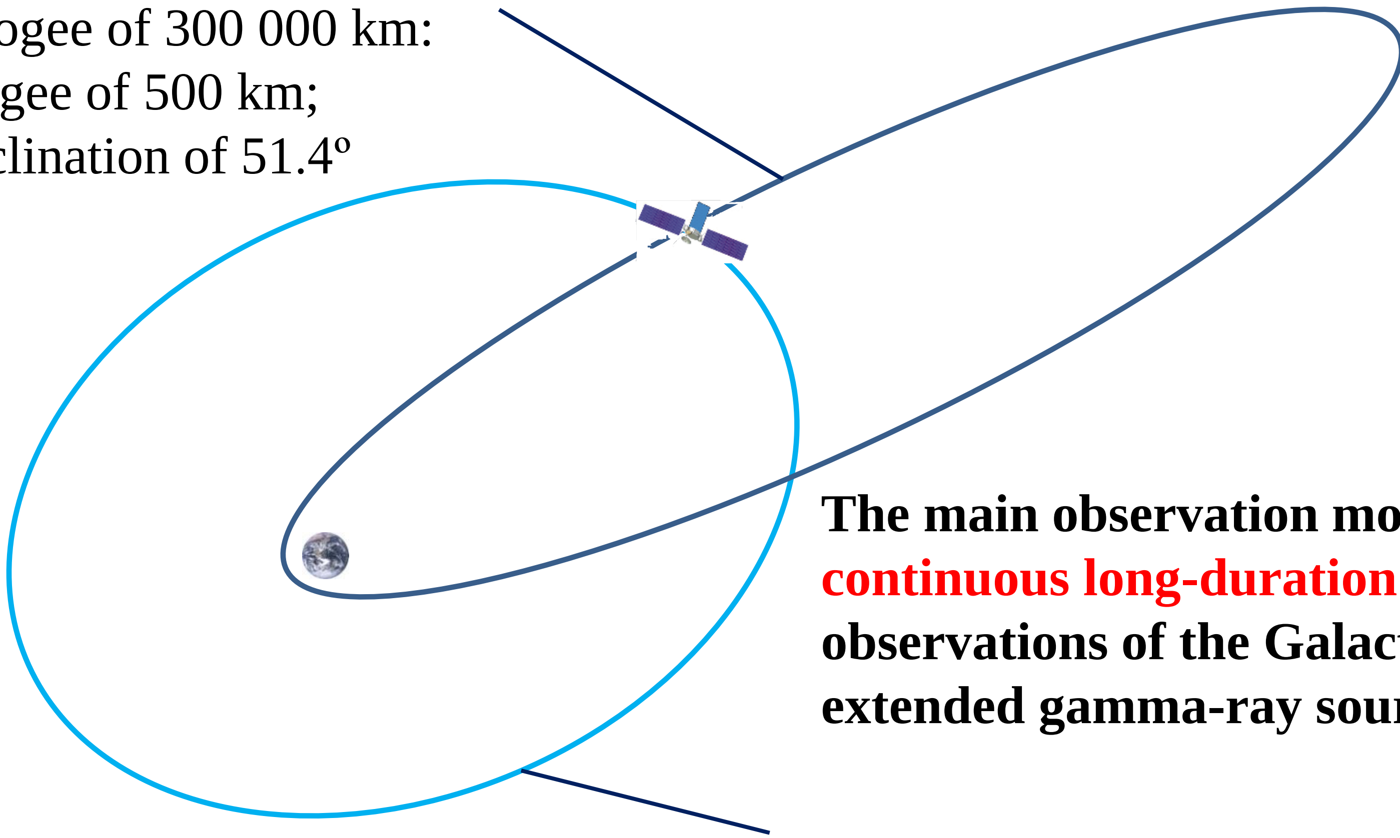


While for GAMMA-400 at 100 GeV: S = ~4000 cm^2; Δθ = ~0.01°; ΔE/E = ~2%

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.

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_γ > 1 GeV)	~5000 cm^2 (front)	~4000 cm^2
Coordinate detectors - readout	Si strips (pitch 0.23 mm) digital	Scintillation fibers **analog**
Angular resolution	~3° (E_γ = 100 MeV) ~0.2° (E_γ = 10 GeV) ~0.1° (E_γ > 100 GeV)	**~3° (E_γ = 100 MeV)** **~0.01° (E_γ = 100 GeV)**
Calorimeter - thickness	CsI(Tl) ~8.5X_0	CsI(Tl)+fibers **~18X_0**
Energy resolution	~18% (E_γ = 100 MeV) ~10% (E_γ = 10 GeV) ~10% (E_γ > 100 GeV)	**~10% (E_γ = 100 MeV)** **~2% (E_γ = 100 GeV)**
Proton rejection factor	~10^3	**~3x10^5**
Mass	2800 kg	~2100 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%	1-2%	1-2%	**~2%**	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	**0.64**				

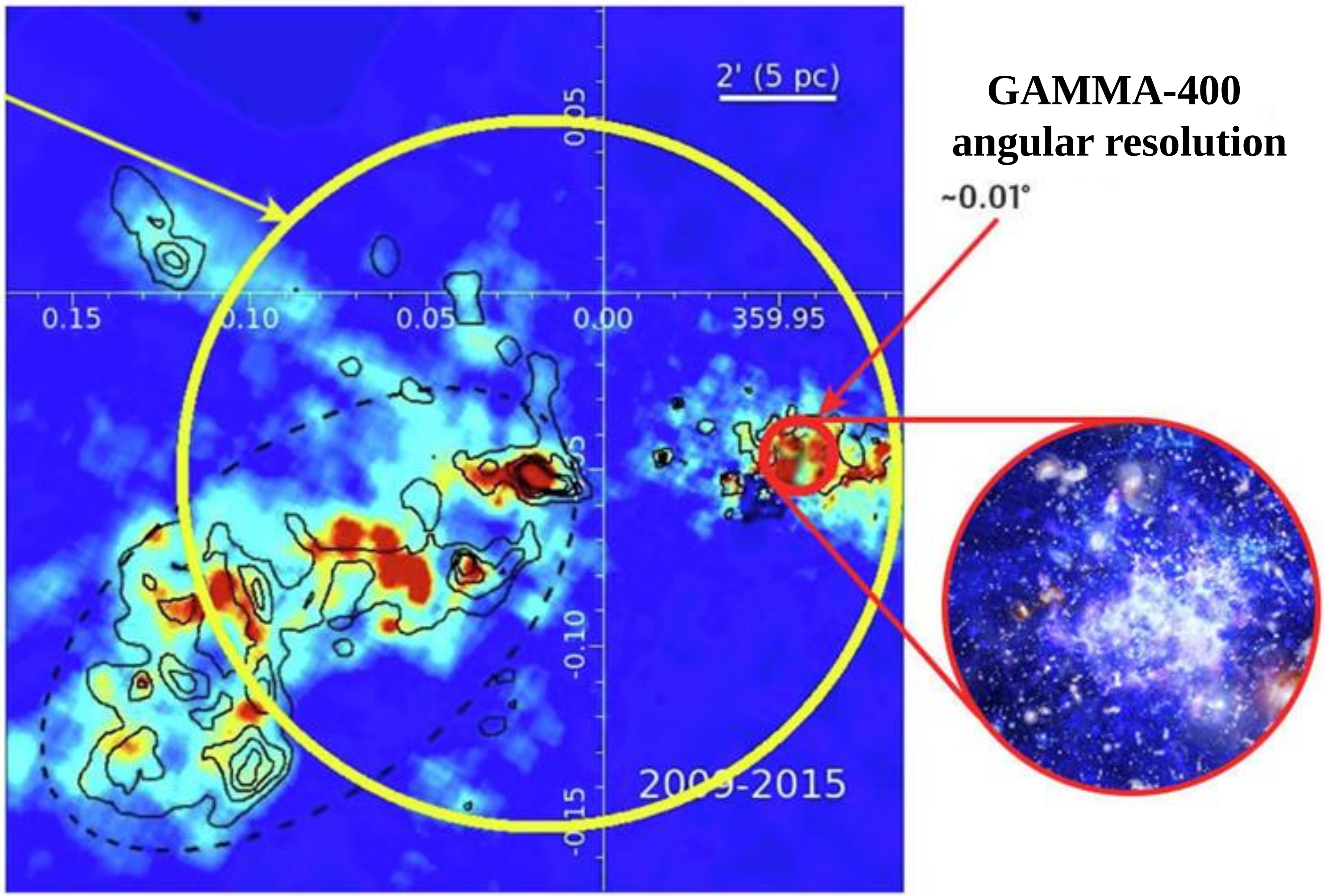
Identification of unidentified Fermi-LAT sources, studying extended sources due to better angular resolution, continuous long-duration (~100 days) observations

~0.1°

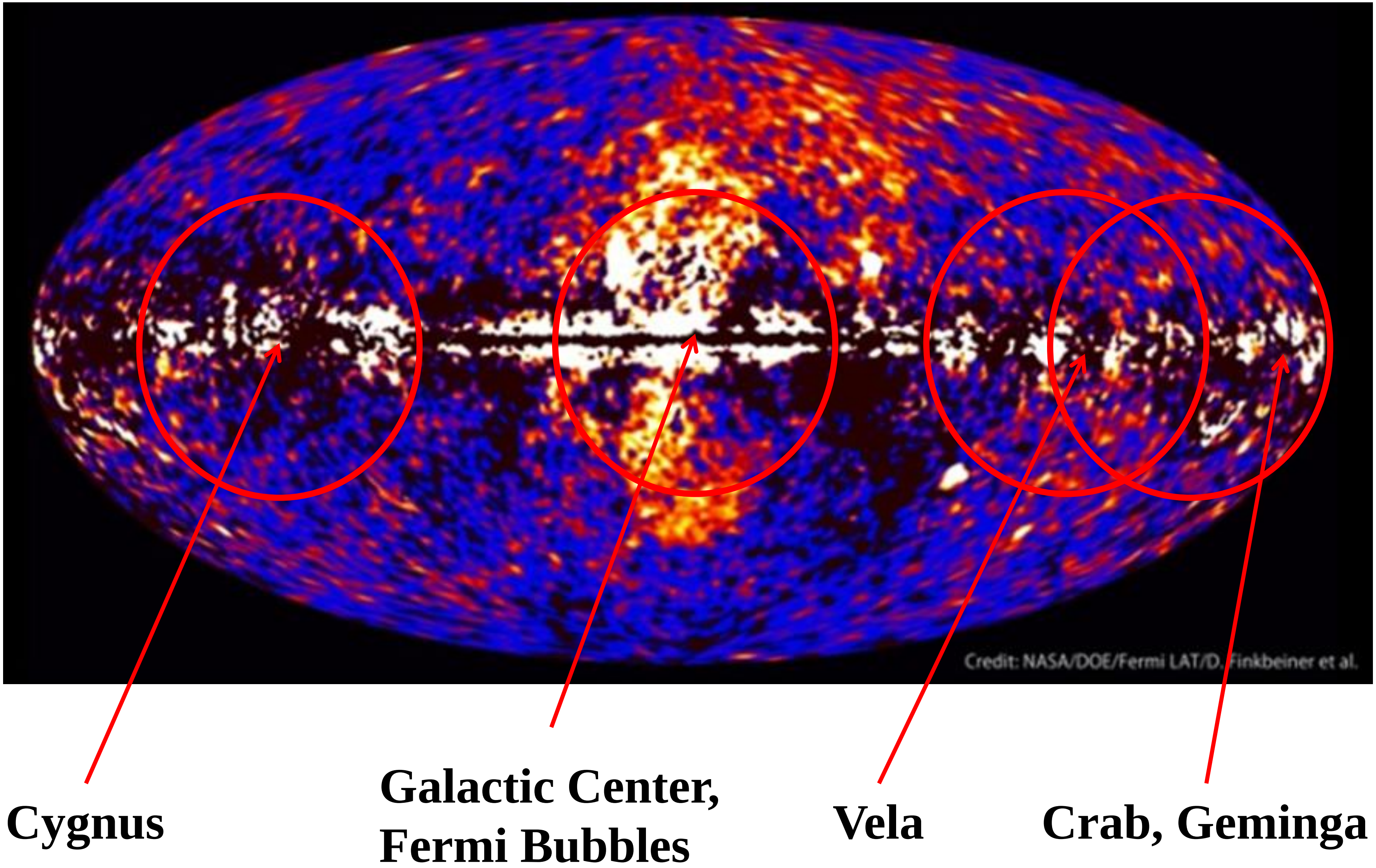
Fermi-LAT angular resolution

GAMMA-400 angular resolution

~0.01°



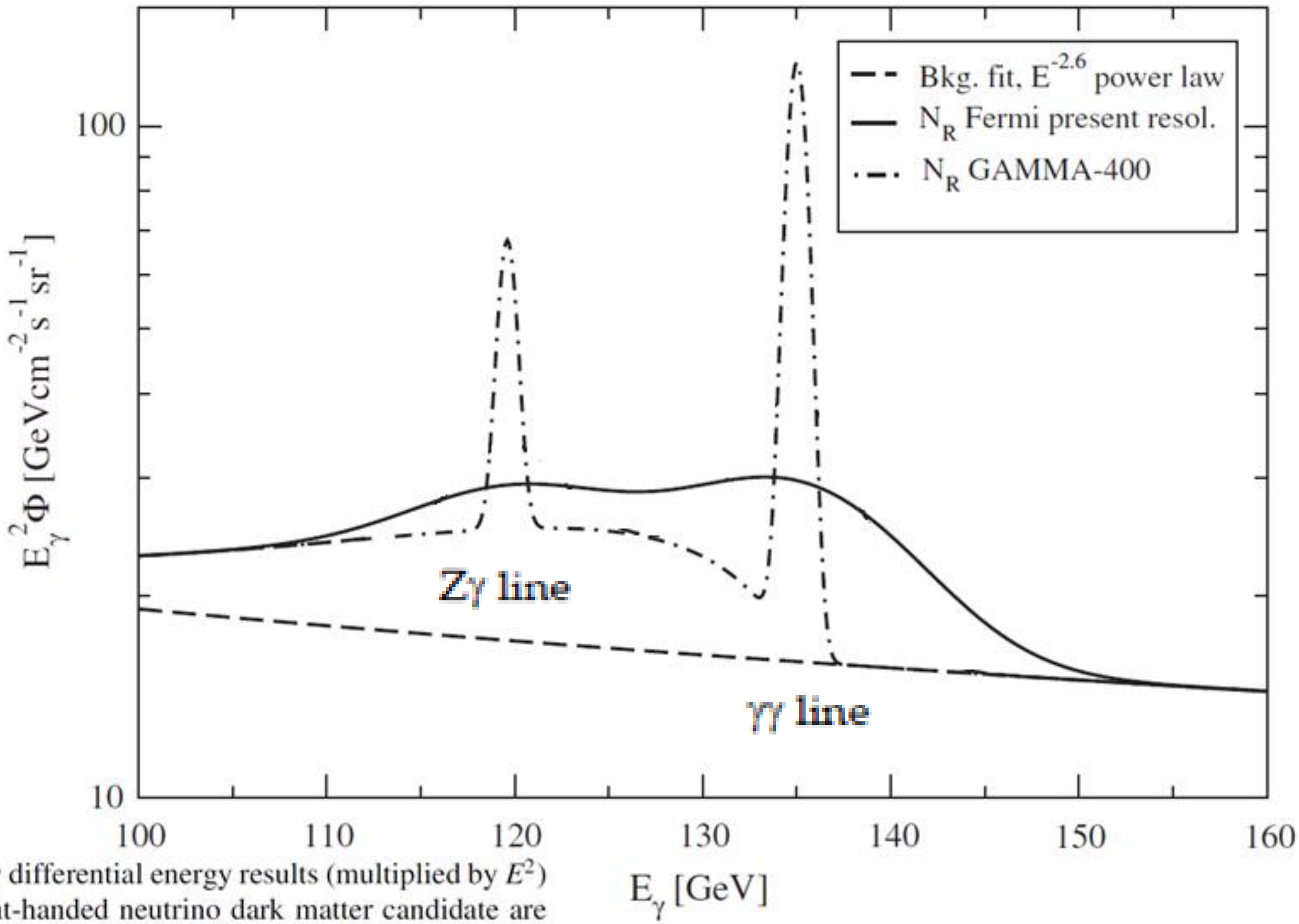
Galactic Center, Fermi Bubbles, Crab, Cygnus, Vela, Geminga, and other regions will be observed with the GAMMA-400 aperture of ±45°



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

Searching for dark matter particles due to better energy resolution



ΔE/E
~10%
~2%

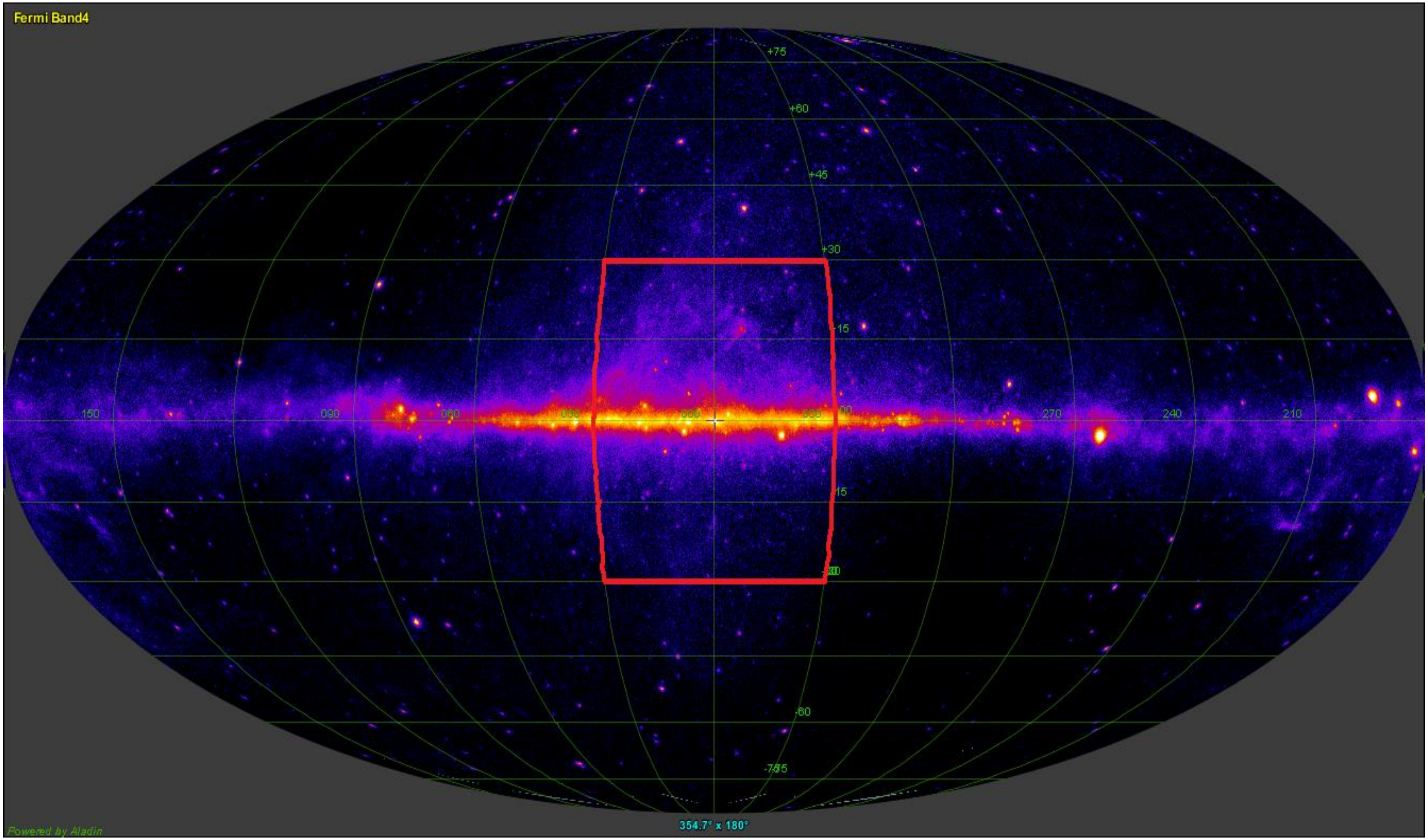
FIG. 3. The γ-ray differential energy results (multiplied by E^2) for a 135 GeV right-handed neutrino dark matter candidate are shown, with the present Fermi-LAT energy resolution $\Delta E/E = 10\%$ FWHM (solid line) and with a future γ-ray instrument, such as GAMMA-400 [38] (dash-dotted line) with 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

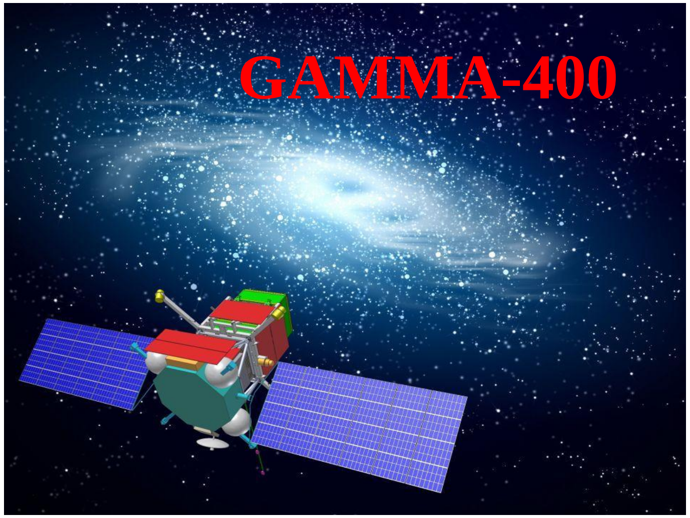
Lars Bergström*

Searching for WIMP and ALP gamma-ray lines in the region of Galactic center

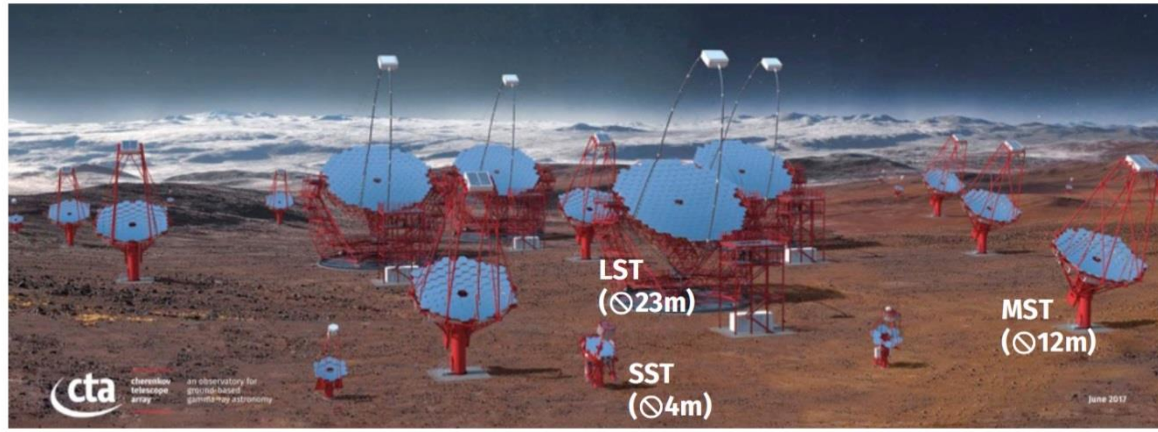


GAMMA-400 FoV

Simultaneous operation of GAMMA-400 and CTA



Cherenkov Telescope Array

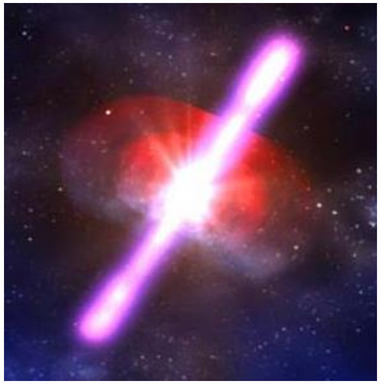


One of our worries in terms of maximising the science output of **CTA** is the coverage of the GeV domain - that is crucial for interpretation of sources - after the termination of Fermi. Obviously, **Gamma-400** is very well suited to fill that gap, and **joint observations or joint projects seem very natural**.

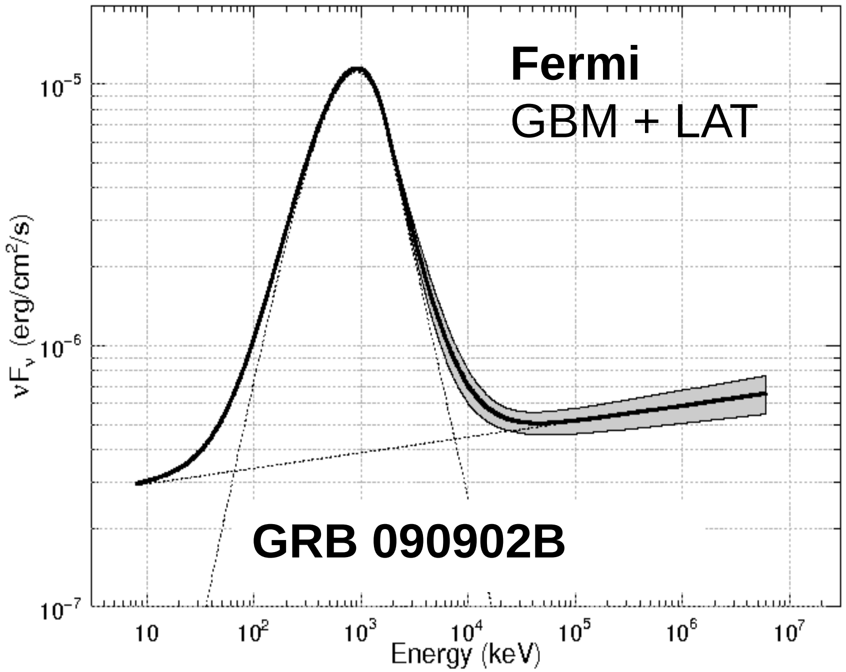
We are currently slightly reorganising our science groups, and one essential element of CTA science planning in the next years will be to set up relations with other instruments aiming to coordinate multiwavelength observations, ultimately with the goal to aim for MoUs where appropriate. **We are certainly be very happy to interact with your team on this** (our yet-to-be appointed new science coordinator would be the prime contact).

With best regards,
Werner Hofmann

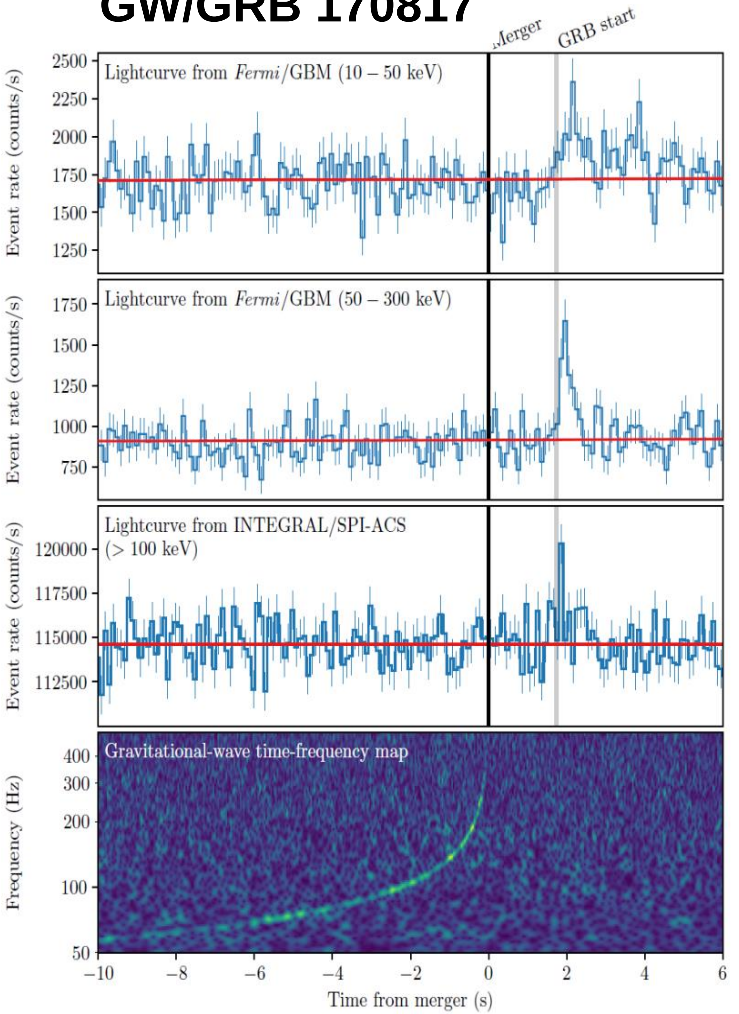
Searching for space gamma-ray bursts (GRB) due to simultaneous observations from on-axis and 4 lateral directions



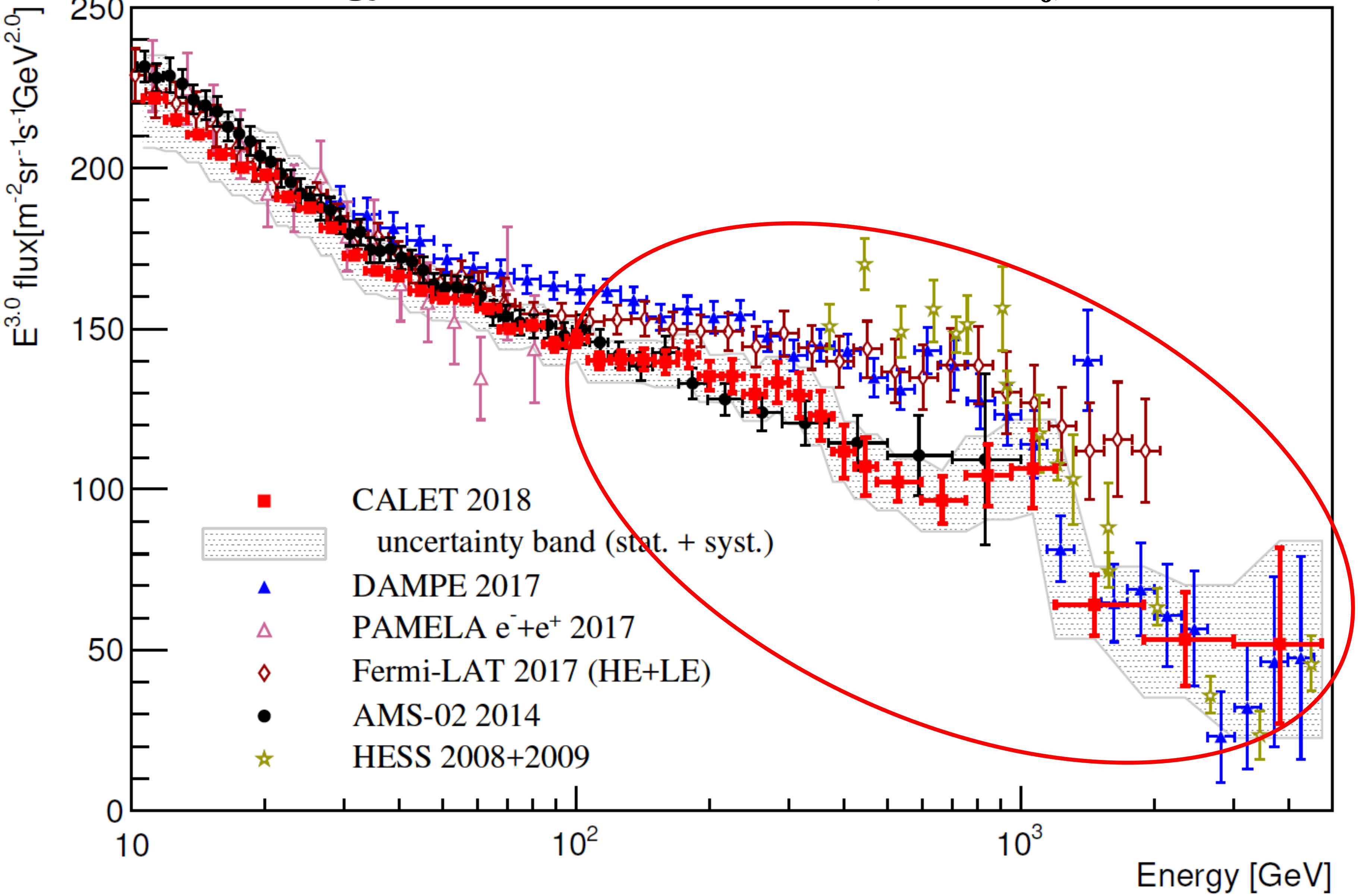
- ~ **5** short GRB/year together with gravitational detectors (**LIGO-Virgo**)
- ~ **5** GRB/year in the energy range up to 400 GeV



GW/GRB 170817

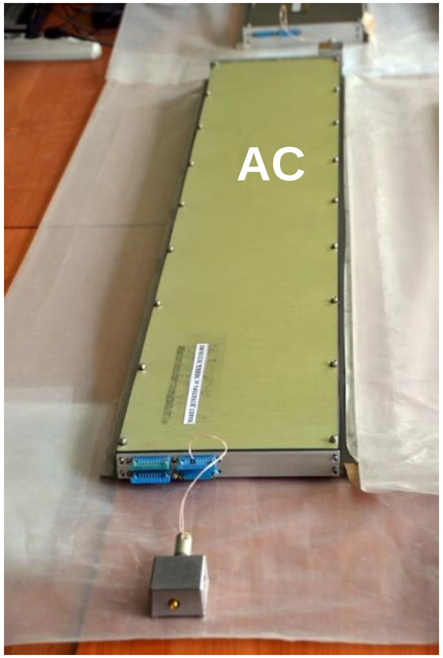


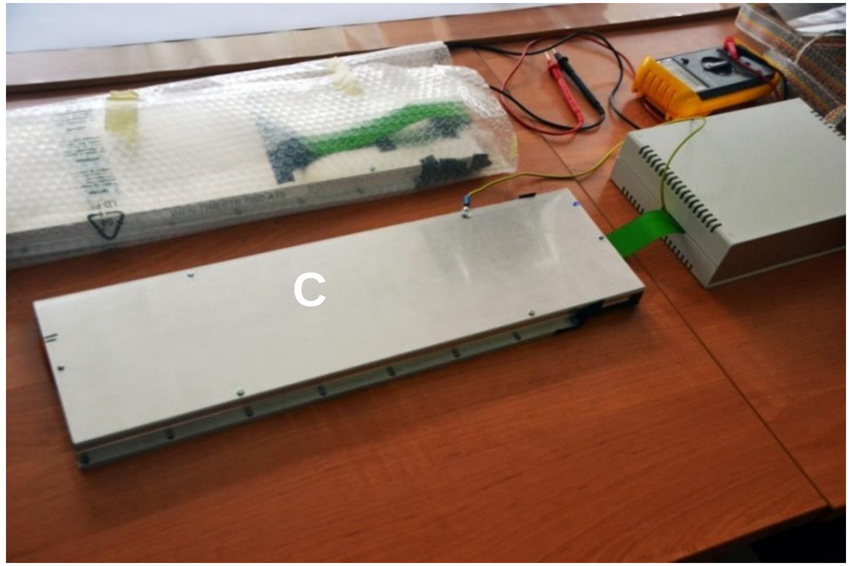
Clarification of electron + positron spectrum due to best energy resolution and thicker (22-43 X_0) calorimeter

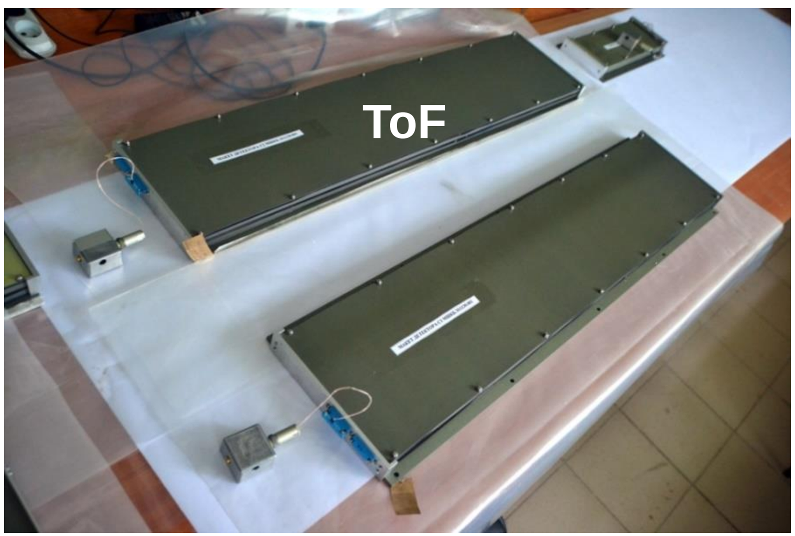


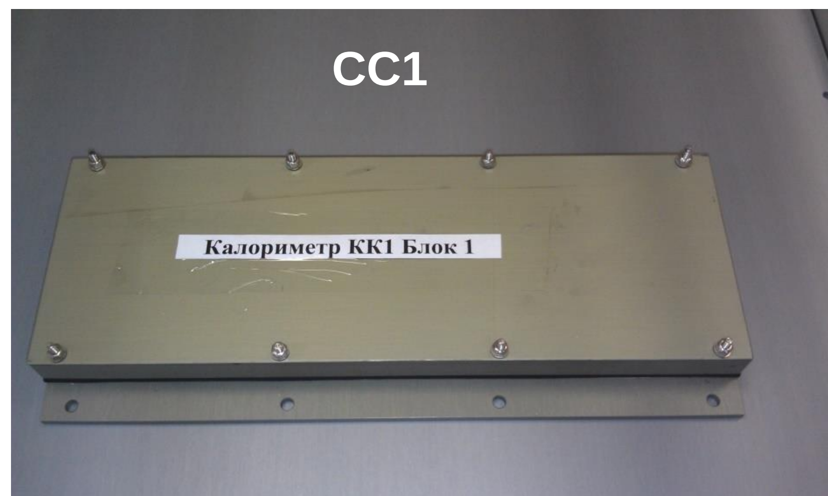
arXiv:1806.09728

GAMMA-400 laboratory prototypes of detector systems

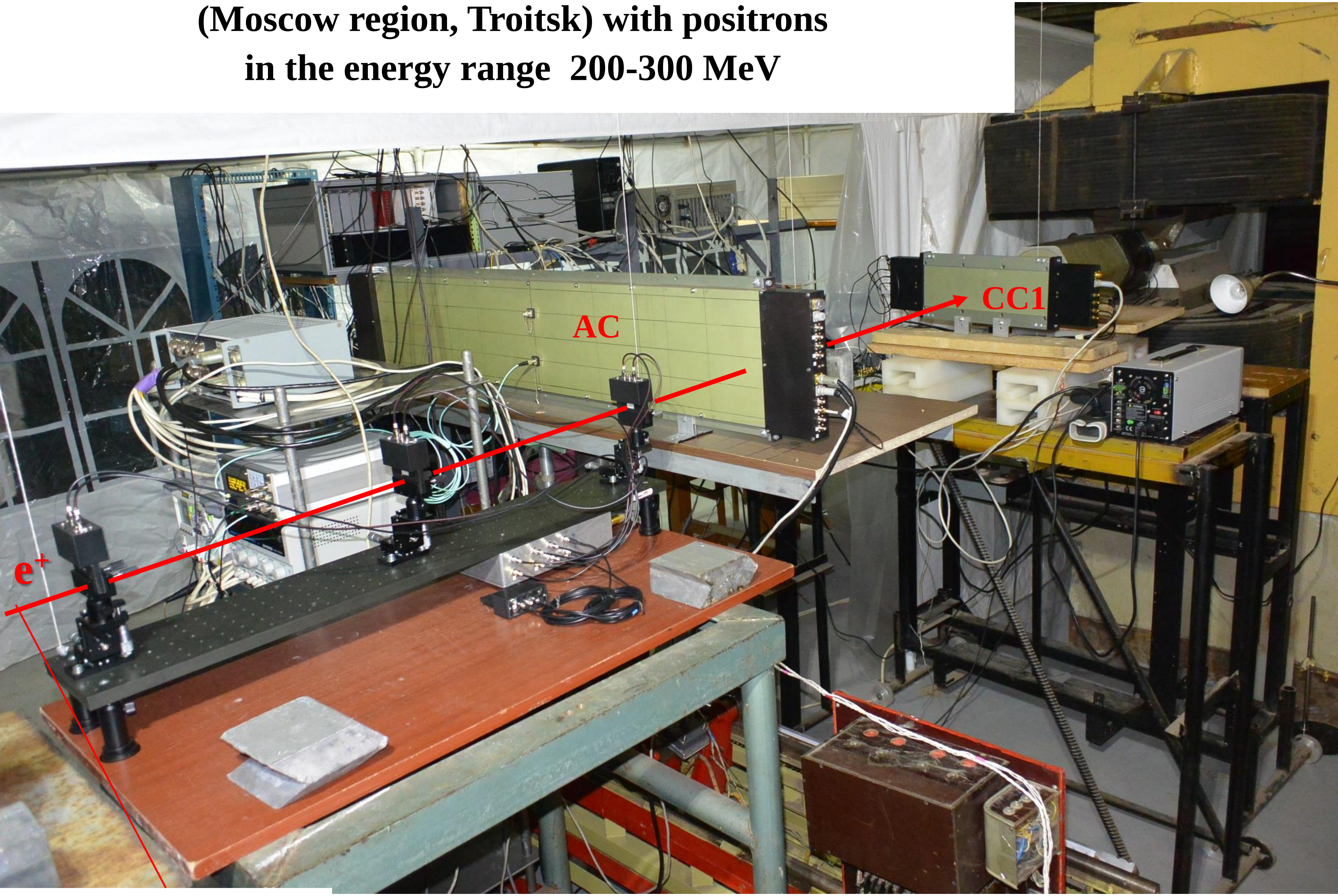


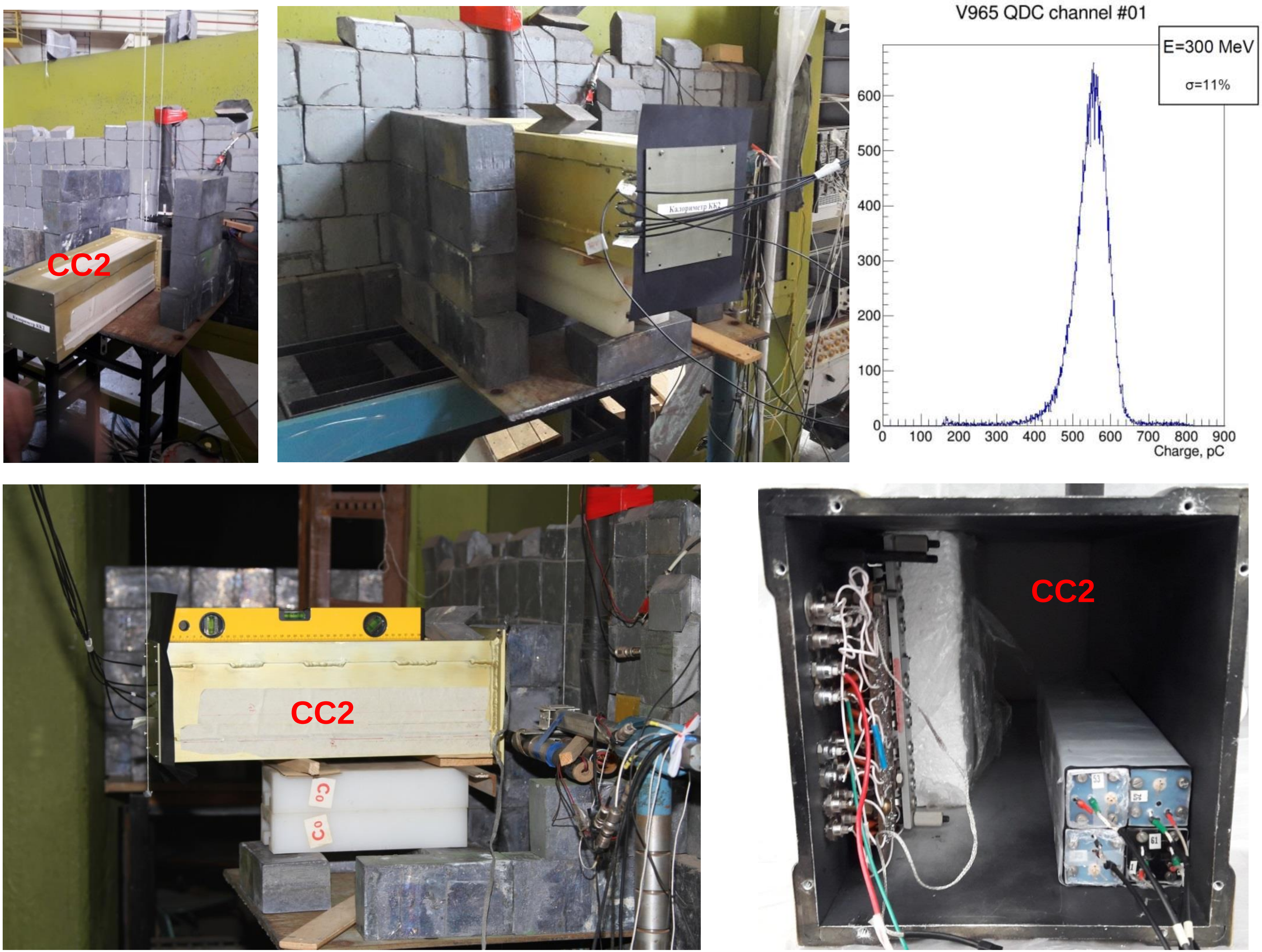






Calibration of GAMMA-400 detectors at LPI synchrotron (Moscow region, Troitsk) with positrons in the energy range 200-300 MeV




CC2
Калориметр КК2
V965 QDC channel #01
E=300 MeV
σ=11%
0
100
200
300
400
500
600
0
100
200
300
400
500
600
700
800
900
Charge, pC
CC2
Co
Co
CC2

Measuring equipment at LPI synchrotron (Moscow region, Troitsk) for calibrating with positrons in the energy range 200-300 MeV

Activities continue
at Troitsk (200-300 MeV) and Protvino (5-25 GeV) accelerators

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/