The 27th European Cosmic Ray Symposium

Capabilities of the GAMMA-400 gamma-ray telescope to detect high energy electron flux up to ~10 TeV from lateral directions.

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ECRS, Nijmegen, the Netherlands, 25-29 July 2022

Outline

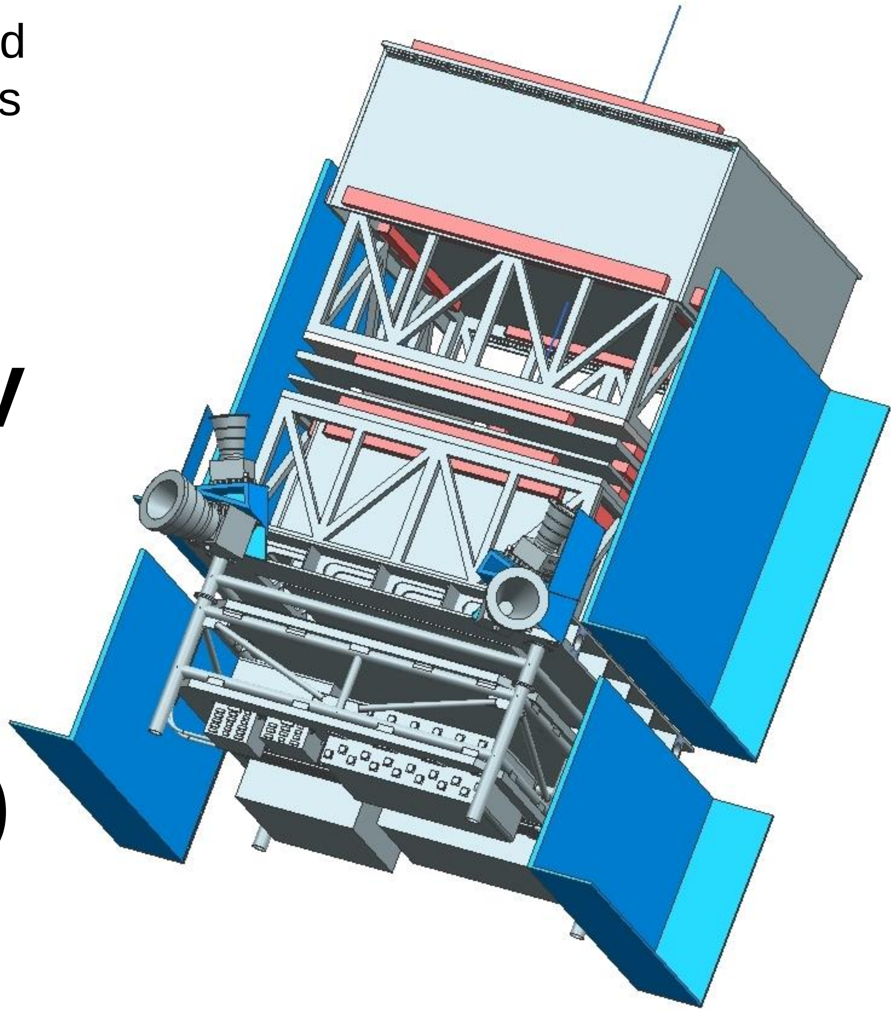
1. Introduction
   Gamma spectrometer GAMMA-400
2. Status of the project
3. Lateral aperture: Additional possibilities
4. TMVA analysis results
5. Conclusion

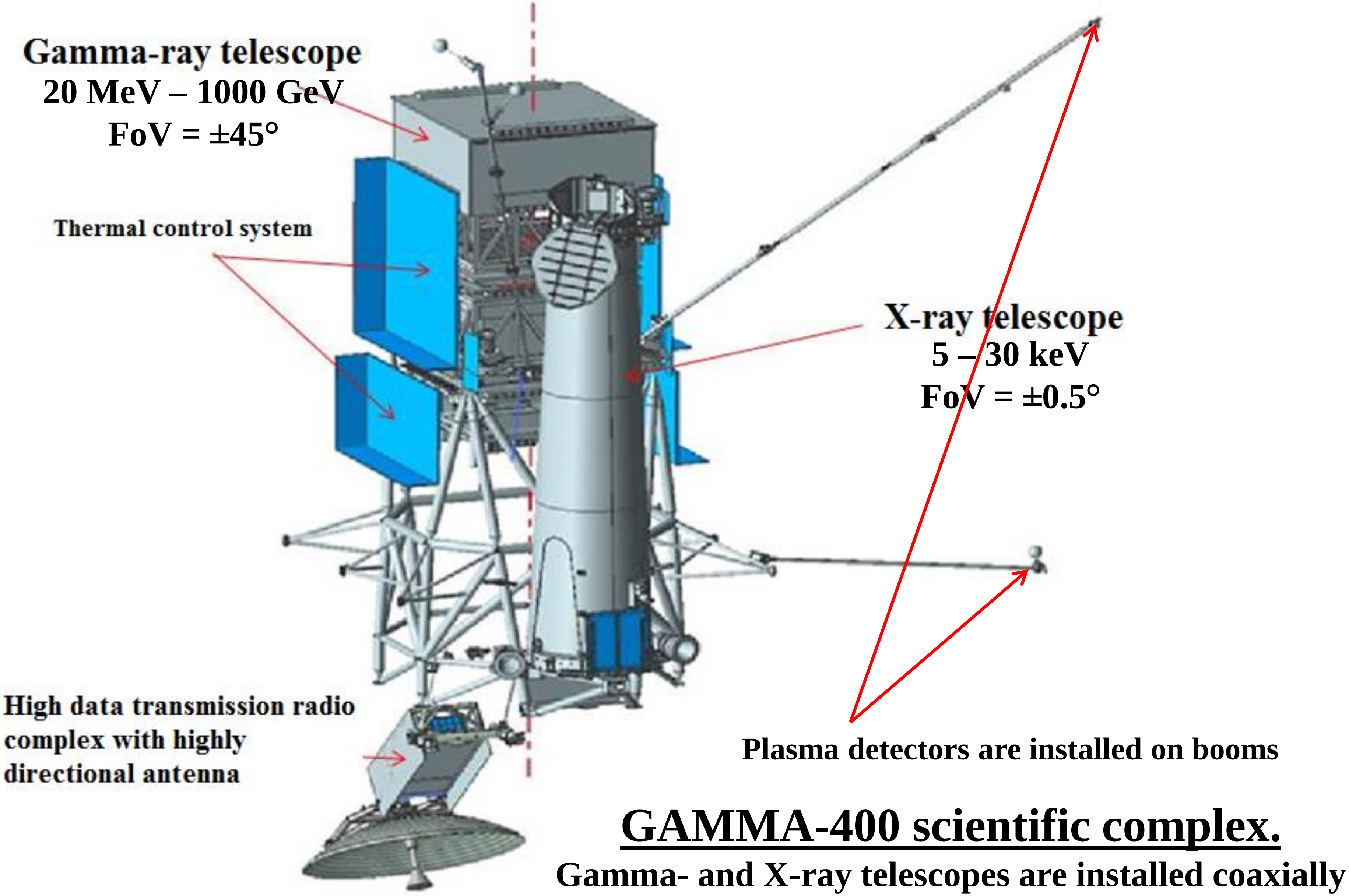
GAMMA-400 gamma-ray telescope

The Federal Space Program of the Russian Federation for 2016-2025:
Space Complex GAMMA-400 is being created to study gamma-ray emission and cosmic rays (LPI, MEPhI).

Energy range $\mathbf{E_\gamma}$
~20 MeV - up to ~10TeV
Energy resolution
(~2% at $\mathbf{E_\gamma}$ = 100 GeV)
Angular resolution
(~0.01° at $\mathbf{E_\gamma}$ = 100 GeV)

(Topchiev+,ASR 2022)





GAMMA-400 scientific complex.

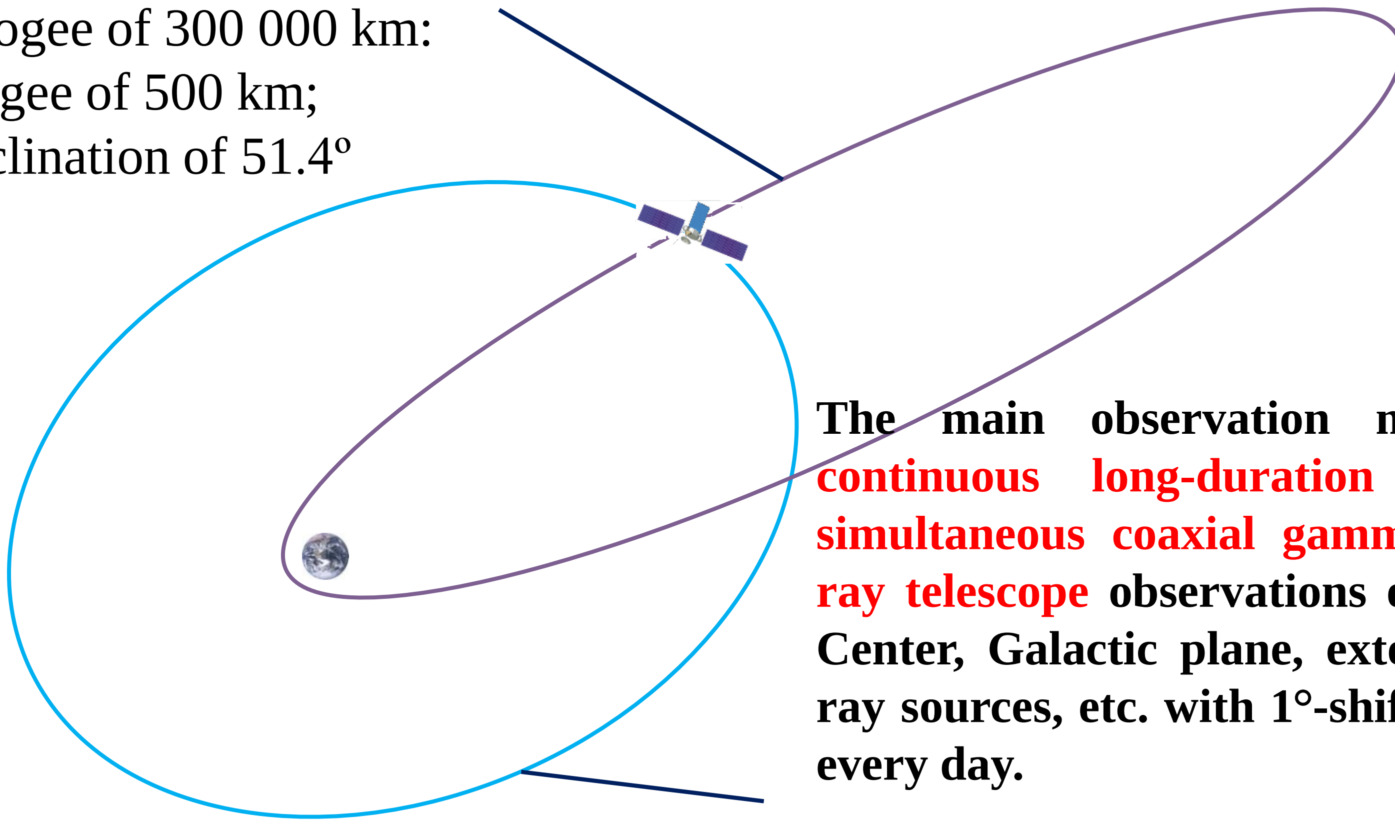
Gamma- and X-ray telescopes are installed coaxially without overlapping fields of view

the Navigator spacecraft platform

The GAMMA-400 orbit evolution and observation modes

The orbit of the **GAMMA-400 astrophysical 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 years



The main observation mode will be continuous long-duration (~100 days) simultaneous coaxial gamma-ray and X-ray telescope observations of the Galactic Center, Galactic plane, extended gamma-ray sources, etc. with 1°-shift of spacecraft every day.

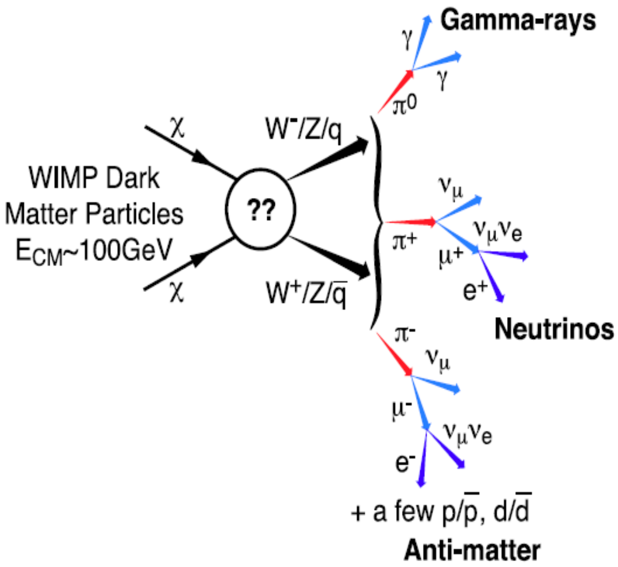
Under the action of gravitational disturbances of the Sun, Moon, and the Earth after ~6 months the orbit will transform to about circular with a radius of ~200 000 km and will be without the Earth's occultation and out of radiation belts.

As a ground receiving station, it is proposed to use the radio-astronomy complex based on the RT-22 radio-telescope in Pushchino (Lebedev Physical Institute), the same station as for Radioastron mission (Spectr-R).

GAMMA-400 main scientific goals

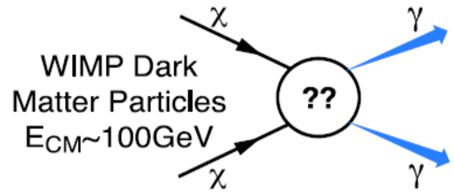
- the nature of "dark matter" in the Universe
- processes in active astrophysical objects
- the origin of high-energy cosmic rays and the physics of elementary particles.

1. Dark matter searching by means of gamma-ray astronomy (~20-1000 GeV)

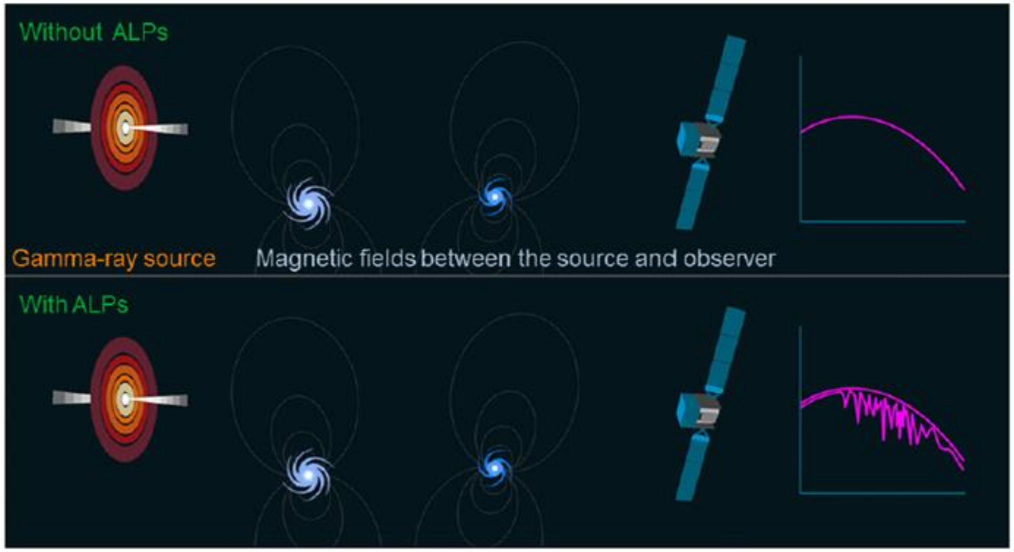


secondary gamma rays

primary monoenergetic gamma rays



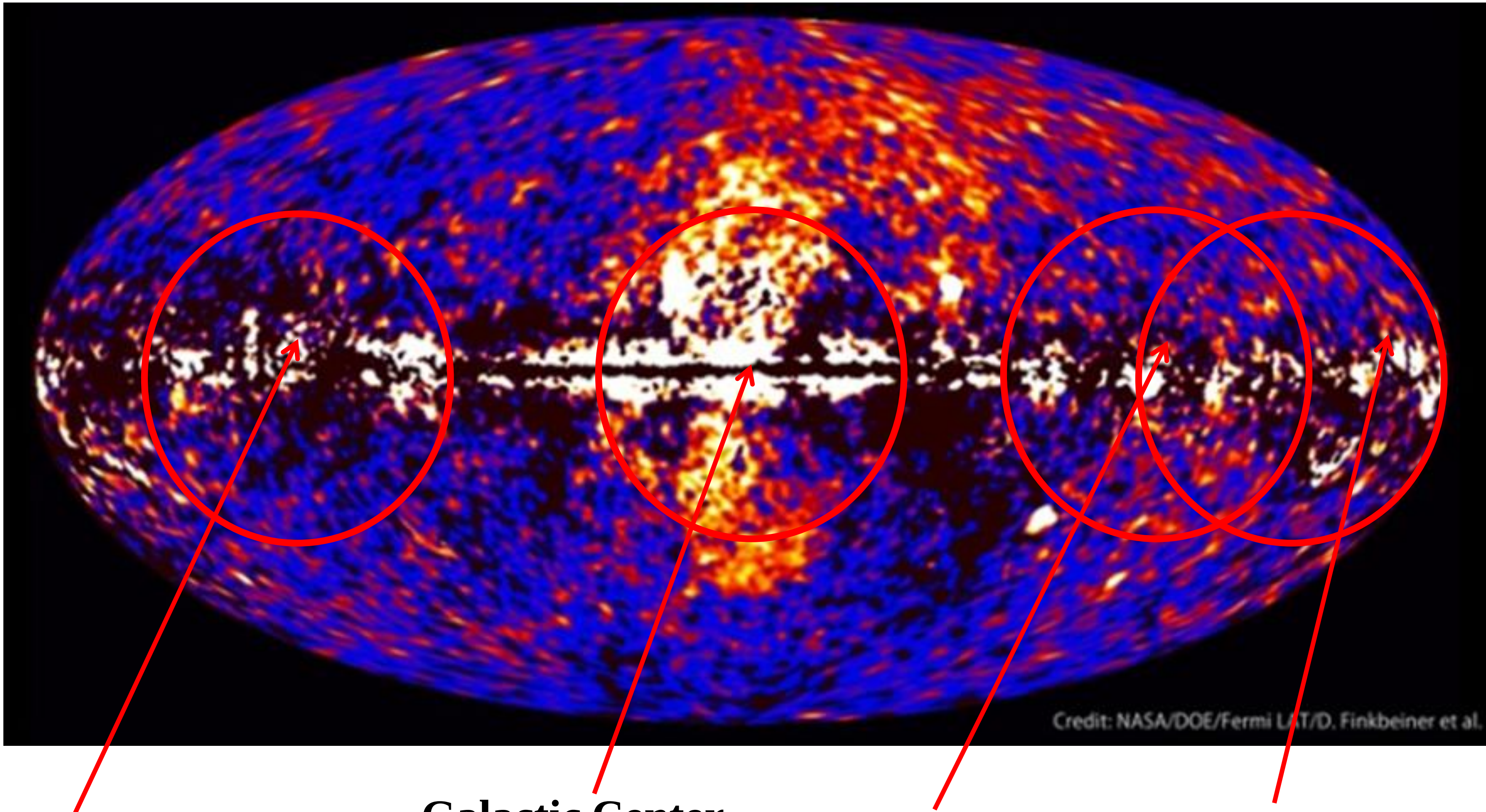
ALP signature searches in pulsar and blazar spectra



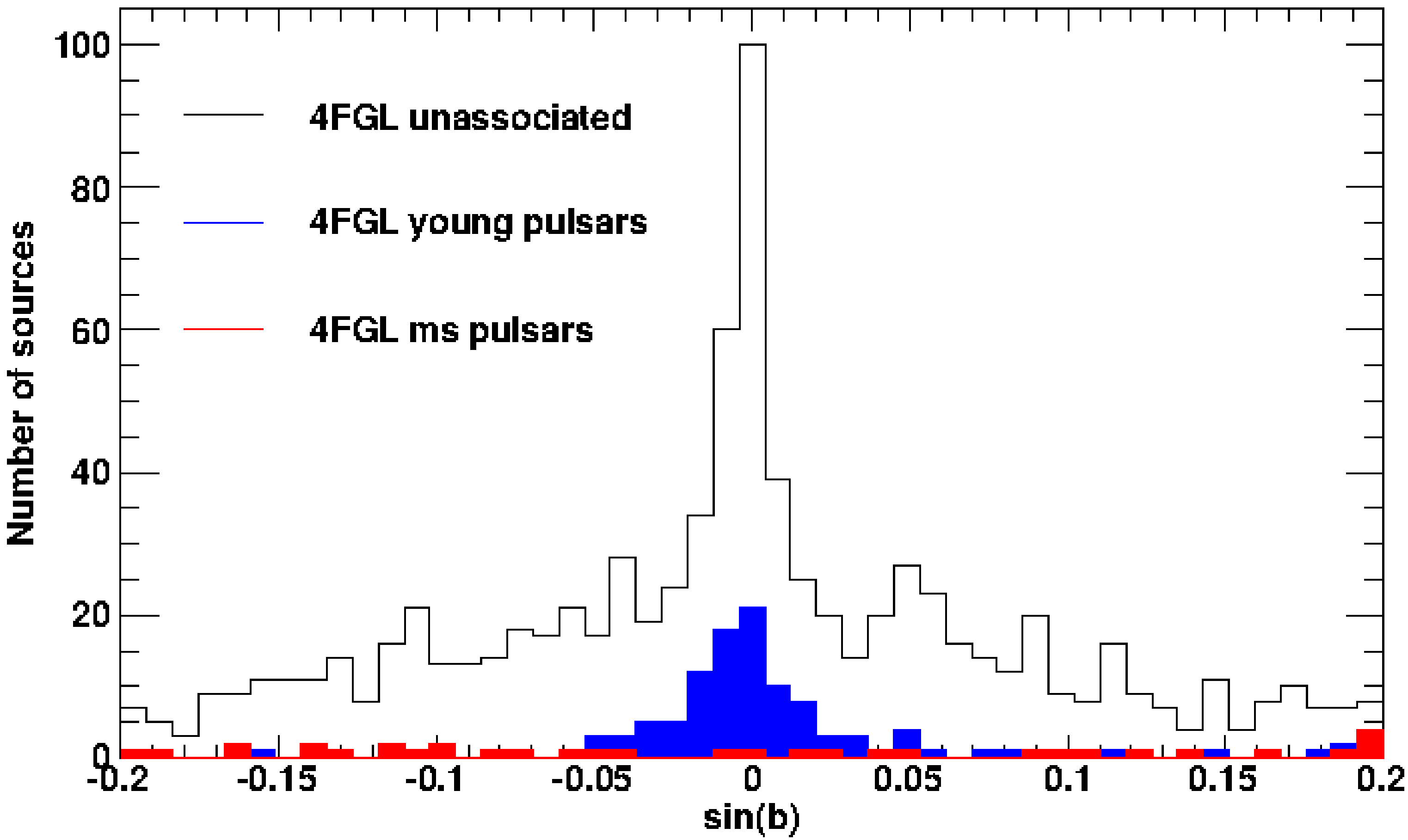
$\gamma + \boldsymbol{B} \leftrightarrow \gamma + ALP$ — conversion

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.

2. Precise and detailed observations of Galactic plane, especially, Galactic Center, Fermi Bubbles, Crab, Vela, Cygnus, Geminga, and other regions with aperture of ±45°



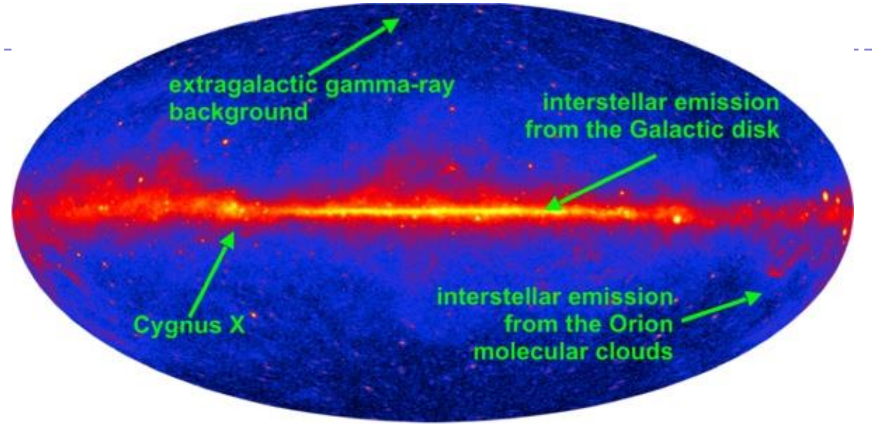
3. Identification of ~2000 (especially in Galactic plane) from 6658 discrete sources (according to 4th Fermi-LAT catalog), precise studying extended sources, studying detail structure and HE processes in active sources, studying gamma-rays from the Sun

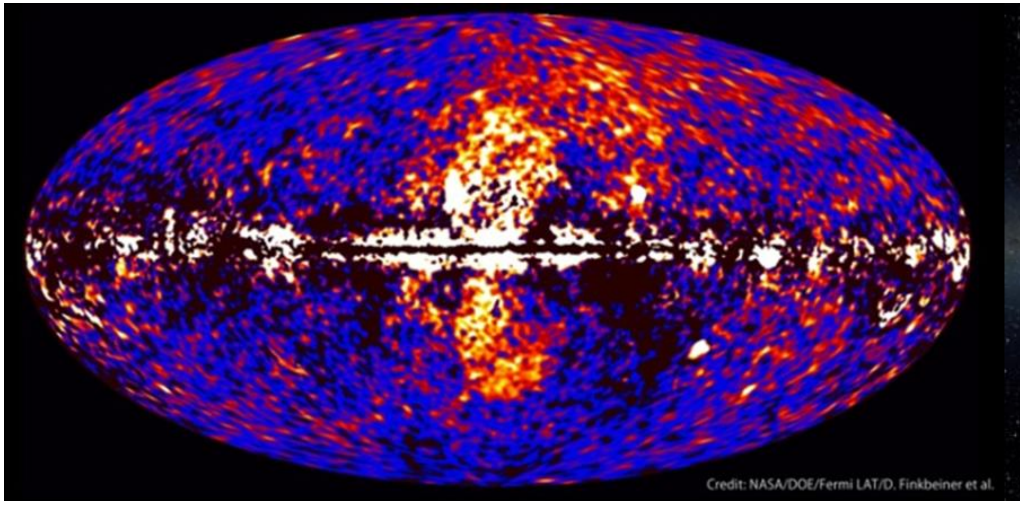


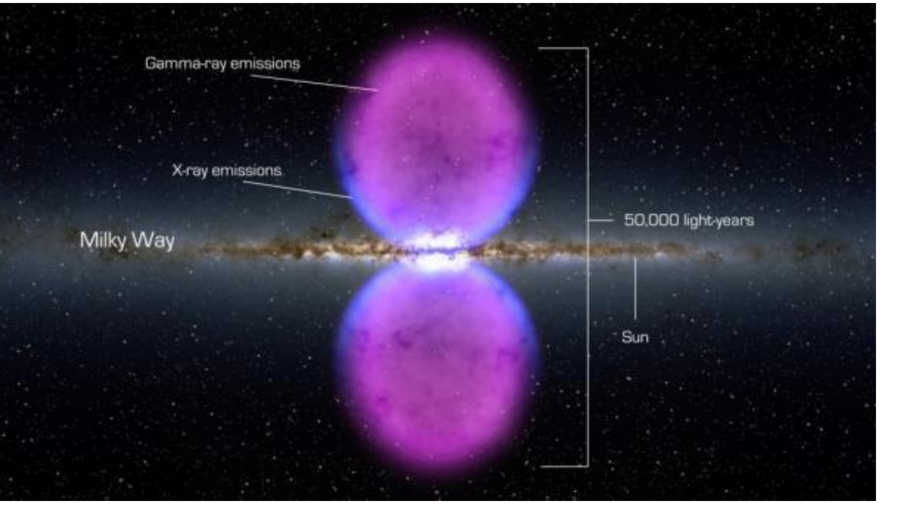
4. Searching for and studying gamma-ray bursts

A.A. Leonov +, Advances in Space Res., 2022

5. Studying diffuse gamma rays



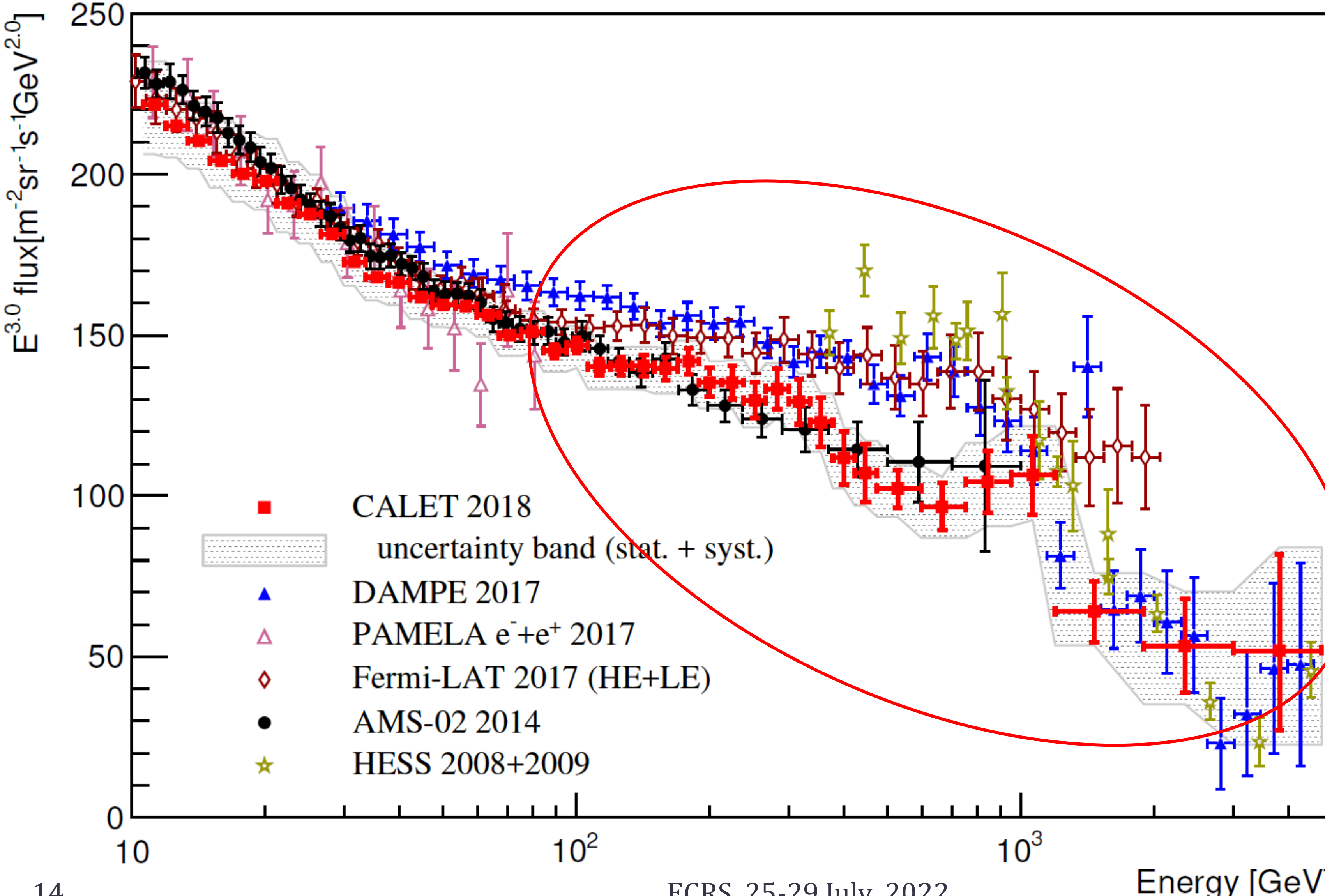




	Space-based gamma-ray telescope						Ground-based facilities
	Medium energy			High-energy			
	ASTROGAM	**AMEGO**	**Fermi-LAT**	**GAMMA-400**	**HERD**	**AMS-100**	**CTA**
Country	Europe	USA	USA	**Russia**	China	Europe +USA	
Energy range, γ rays	0.3 MeV – 3 GeV	0.2 MeV - 10 GeV	50 MeV – 1000 GeV	**20 MeV – 1 TeV**	0.5 GeV – 10 TeV	1 GeV – 10 TeV	> 50 GeV
Observation mode	Scanning	Scanning	Scanning	**Point-source**	Scanning	Scanning	Scanning
Orbit	Circular, ~550 km	Circular, ~550 km	Circular, ~550 km	**Highly elliptical, 500-300 000 km**	Circular, ~400 km	L2	
Angular resolution	0.1°	1°	0.1°	**~0.01°**	0.1°	~0.01°	0.1°
Energy resolution	20%	10%	10%	**~2%**	1-2%	1-2%	15%

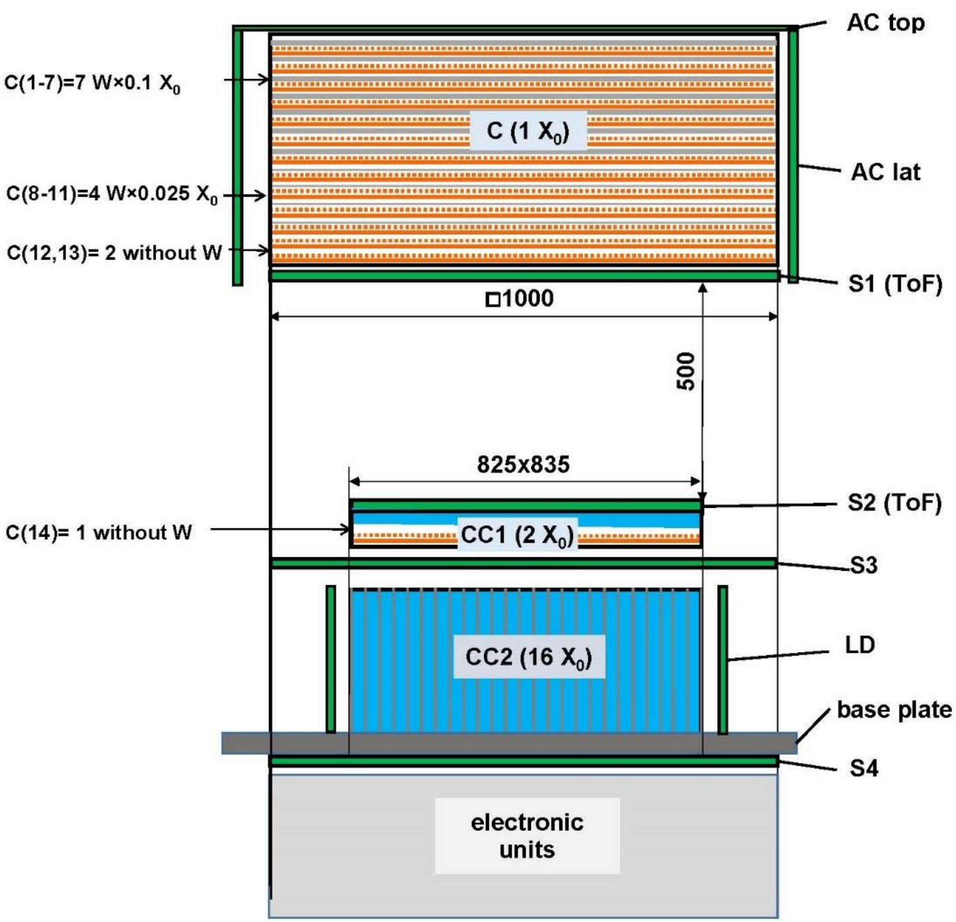
Performance of future gamma-ray telescopes in comparison with Fermi-LAT
(Topchiev+, ASR 2022)

6. Clarification of electron + positron spectrum due to best energy resolution and thicker (18-43 X_0) calorimeter in the energy range 20 MeV -10 TeV from top-down and lateral directions



arXiv:1806.09728

Gamma spectrometer GAMMA-400



AC top – the anticoincidence system
C - converter-tracker
AC lat – the anticoincidence system

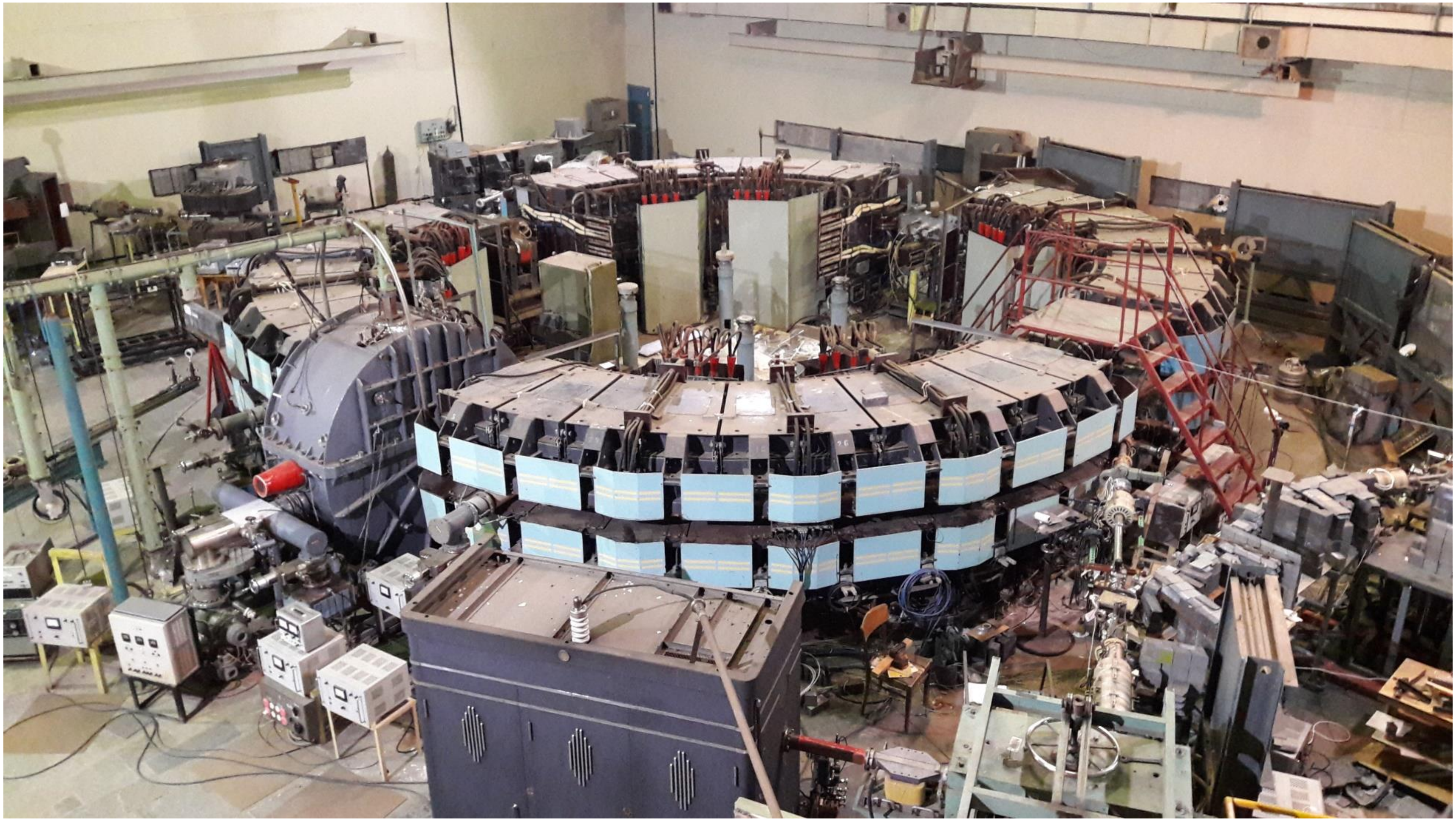
S1, S2, S3, S4 - scintillation detectors

CC1 - position-sensitive calorimeter $2X_0$
CC2 - electromagnetic calorimeter $16X_0$

NEW!
lateral anticoincidence detectors of the calorimeter LD.
CC2 – lateral thickness ~43 X_0

GAMMA-400 will detect gamma rays and electrons + positrons from top-down and lateral directions

S-25R electron synchrotron
(Lebedev Physical Institute, Troitsk)

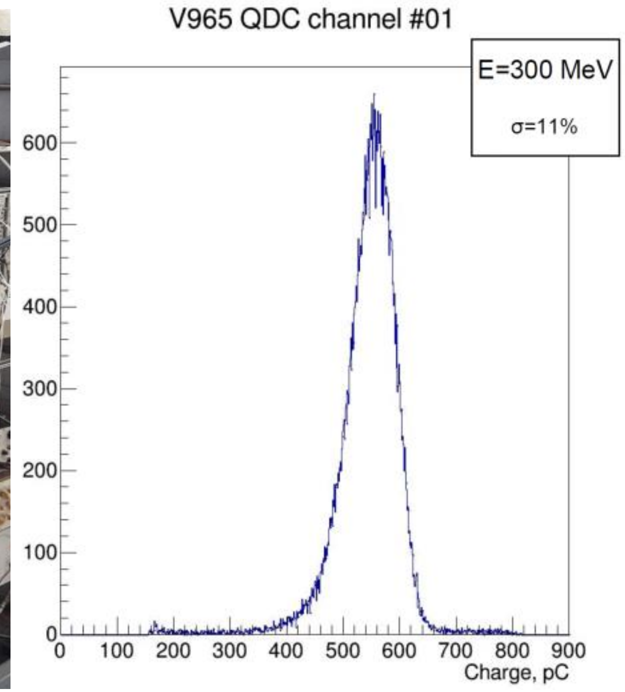


Prototypes of some detector systems were tested and calibrated on positron beams in the energy range of 100-300 MeV in 2019-2022.

Prototype of AC detector. L = 1300 mm, time resolution is ~200 ps, efficiency is 0.999
(A.I. Arkhangelskiy+ ,2020. 2022 in press)


CC2

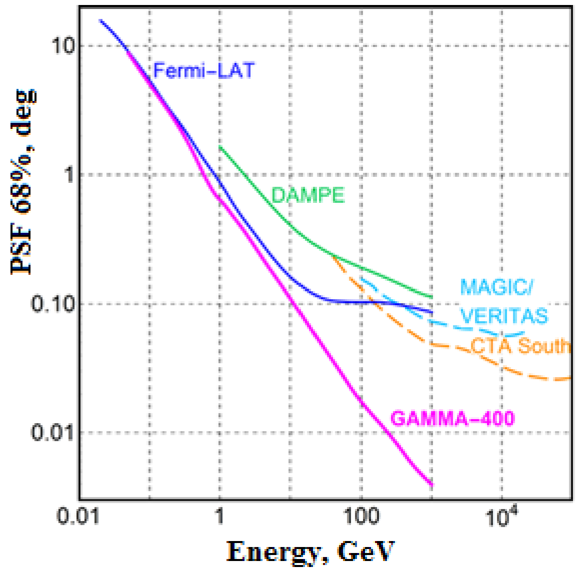

Калориметр КК2


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

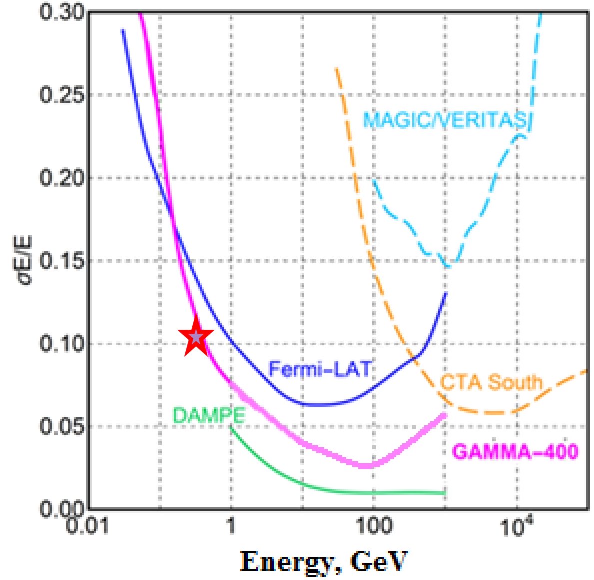

CC2
Co
Co

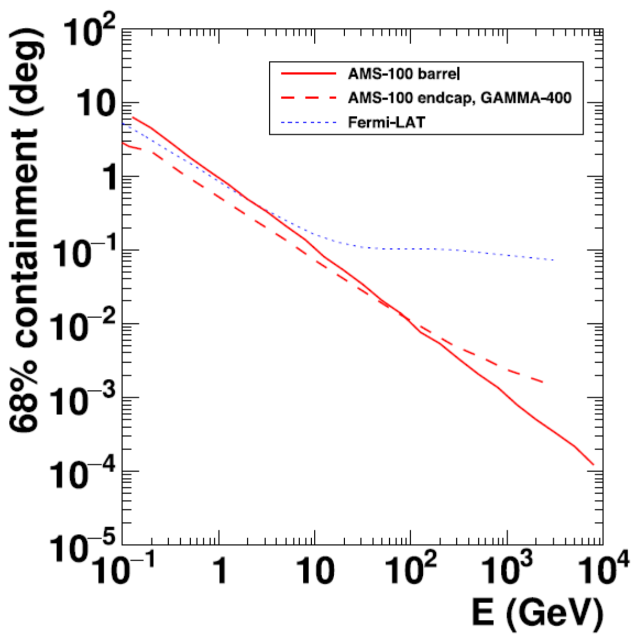

CC2

Angular resolution



Energy resolution





Nuclear Inst. and Methods in Physics Research, A 944 (2019) 162561

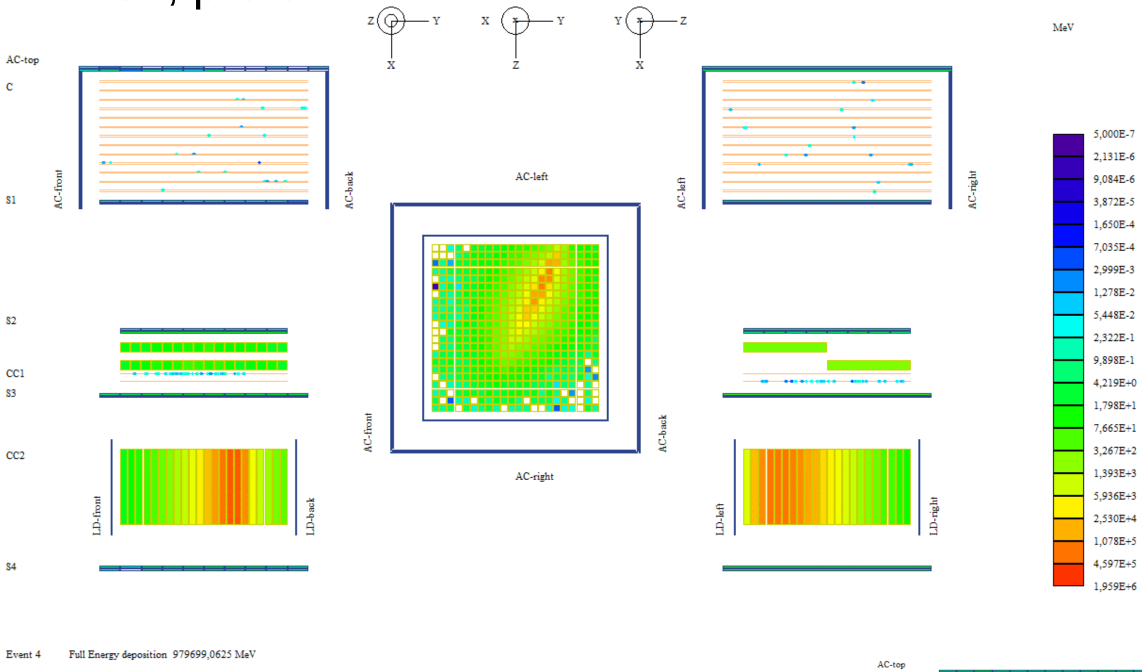
GAMMA-400 calculated angular and energy resolutions vs energy.

★ GAMMA-400 experimental energy resolution for the energy of 300 MeV at LPI electron synchrotron in Troitsk.

(Topchiev+,ASR 2022)

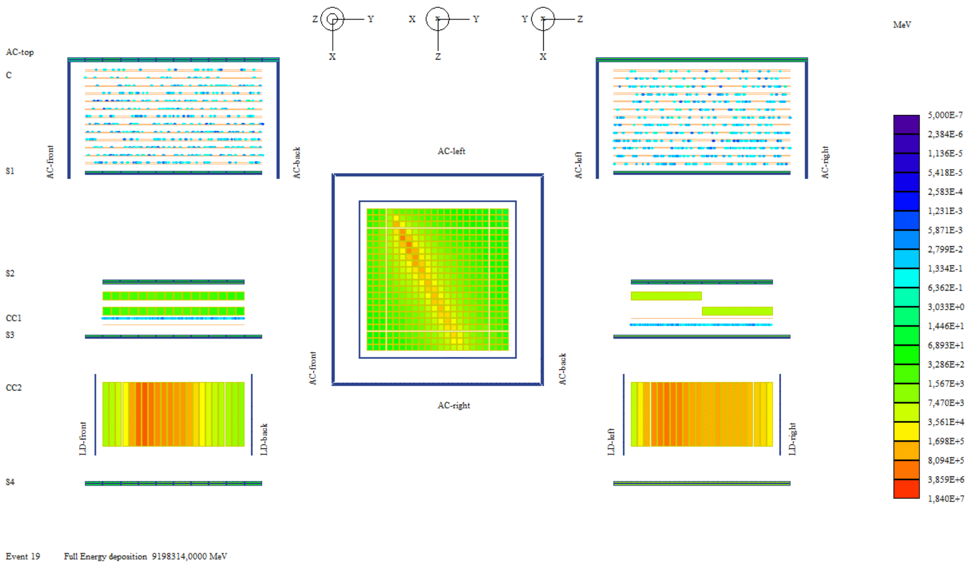
Monte-Carlo simulation of electron and proton events

1 TeV, proton

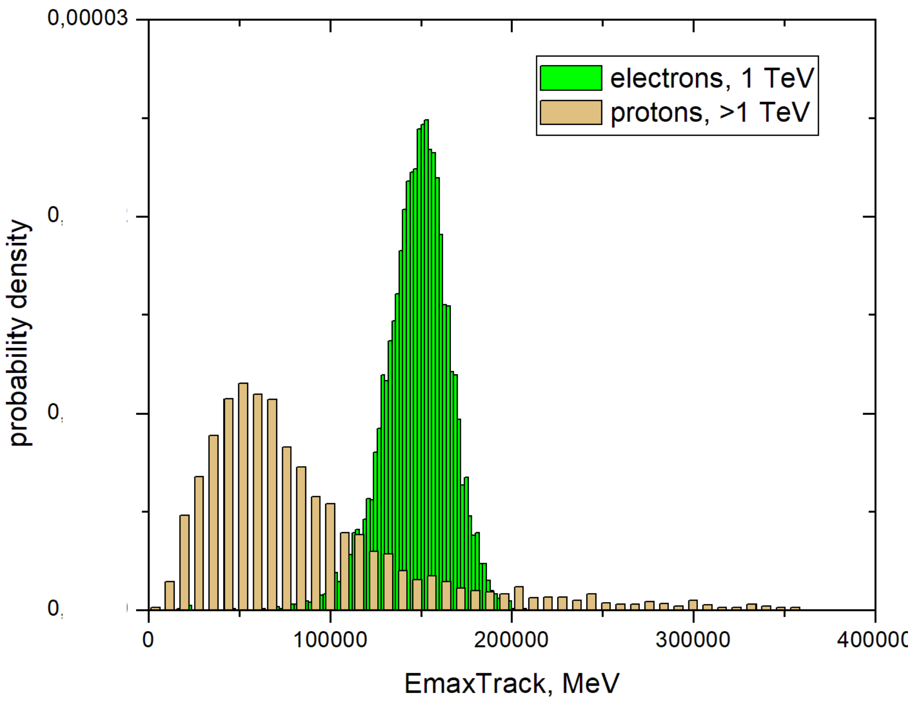


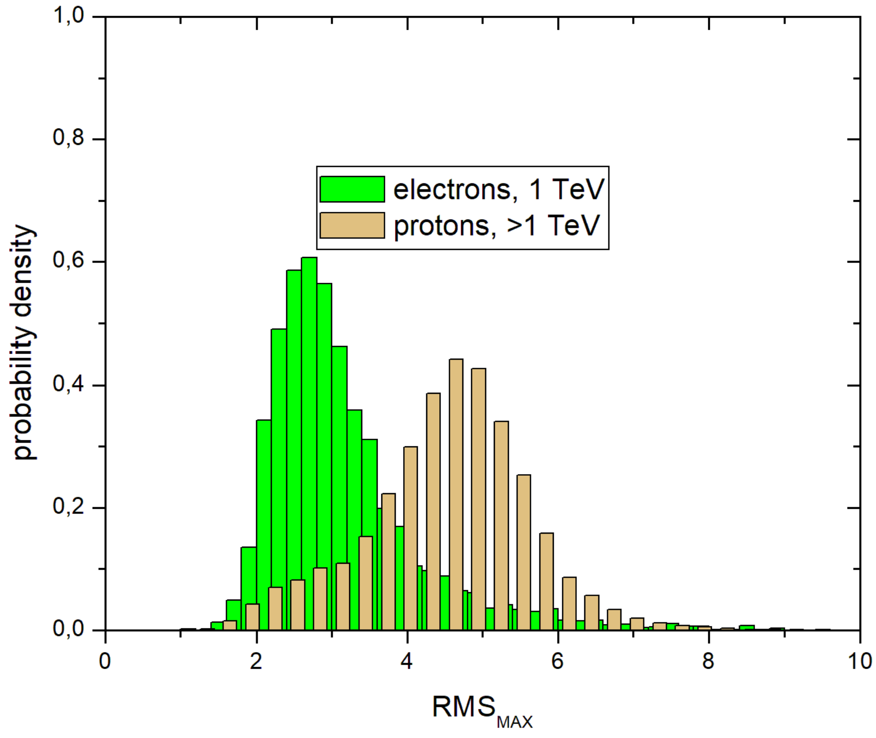
1 TeV, electron
GEANT 4.10 MC simulation

The separation of particles is based on the differences between electromagnetic and hadron showers



Comparison of electron and proton showers

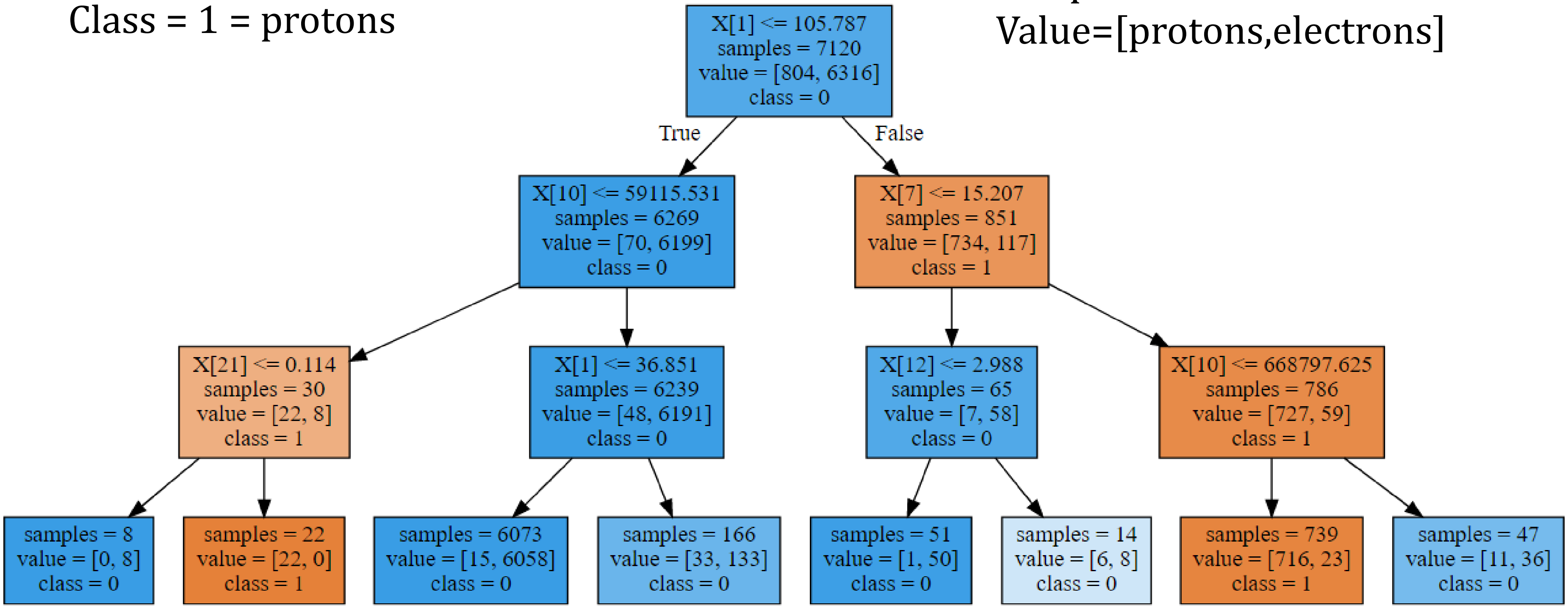




Example of one tree for sampling protons and electrons

Class = 0 = electrons
Class = 1 = protons

x[Number]=feature
Samples =all events in this node
Value=[protons,electrons]

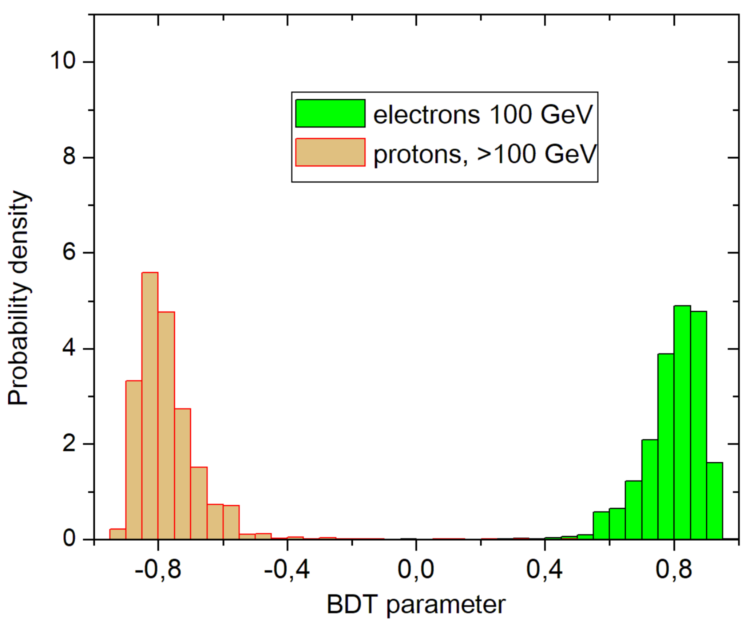


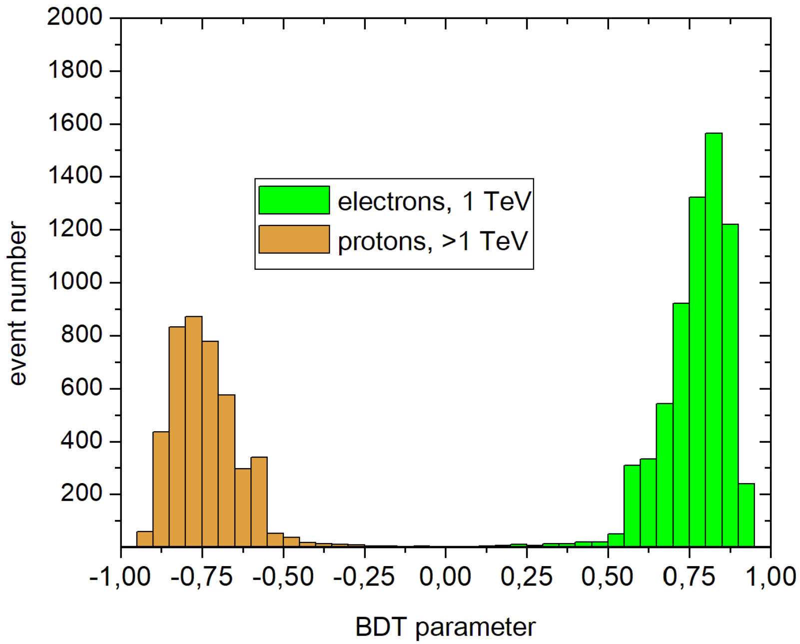
One tree as an electron and proton classifier in the forest ensemble.
Adaptive BDT method was used from TMVA package of ROOT (root.cern.ch) and python tools (https://scikit-learn.org).

Application of machine learning methods

31 parameters for each event;

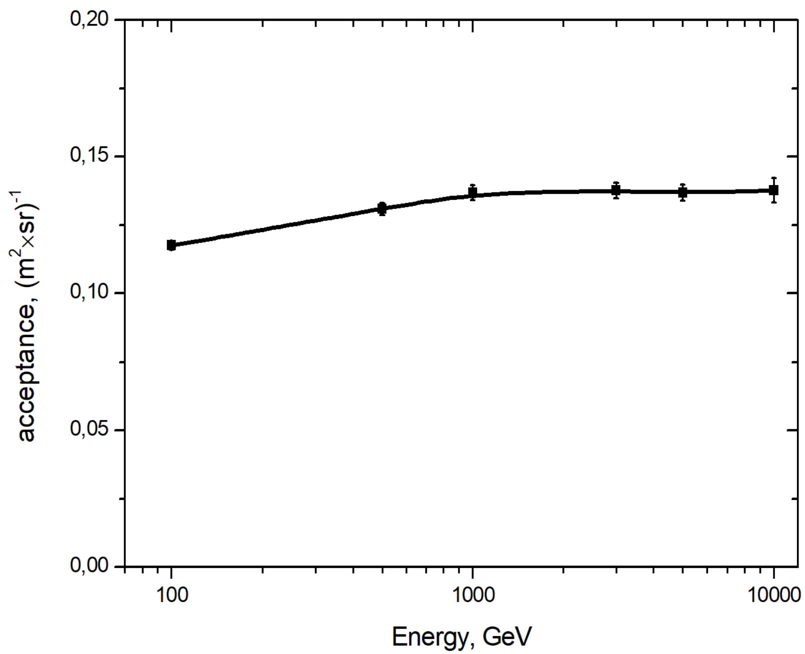
Cross-validation + Adaboosting

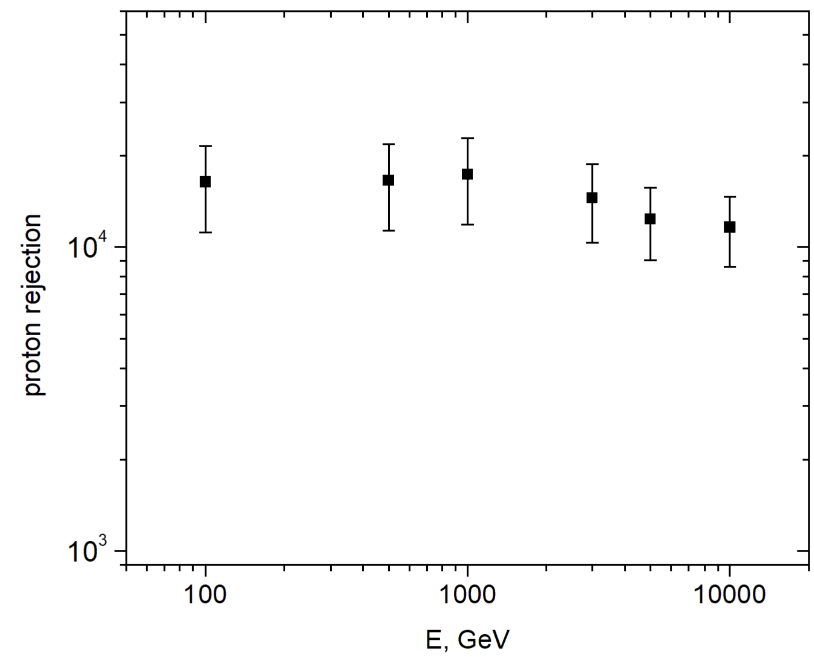




Electron acceptance and proton rejection

For one lateral side





Strong selection by S3 and S4.
Energy resolution δE/E ~2% at 1 TeV

Conclusion

1. The machine learning methods were applied for GAMMA-400 telescope to separate electrons and protons in lateral aperture .
2. A proton rejection coefficient of ~10^4 was obtained in the entire energy range from 100 GeV to 10 TeV

	GAMMA-400		Fermi-LAT	PAMELA	AMS-2	CALET	DAMPE	HERD
Aperture	top-down	Lateral 4 sides	top-down	top-down	top-down	top-down	top-down	5 sides
Acceptance, m^2 sr	~0.3 E_e = 100 GeV	~0.5 E_e = 100 GeV	2.5	0.02	0.4	0.1	0.3	3
Proton rejection factor	~10^4	~10^4	~10^4	~10^4	~10^4	10^5	10^5	>10^5
Calorimeter area, m^2	0.7	4×0.24	0.85	0.06	0.42	0.1	0.36	5x0.4
Calorimeter thickness, X_0	18	43	8.6	16	16	30	32	55

Thank you for your kind attention!

Funding

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