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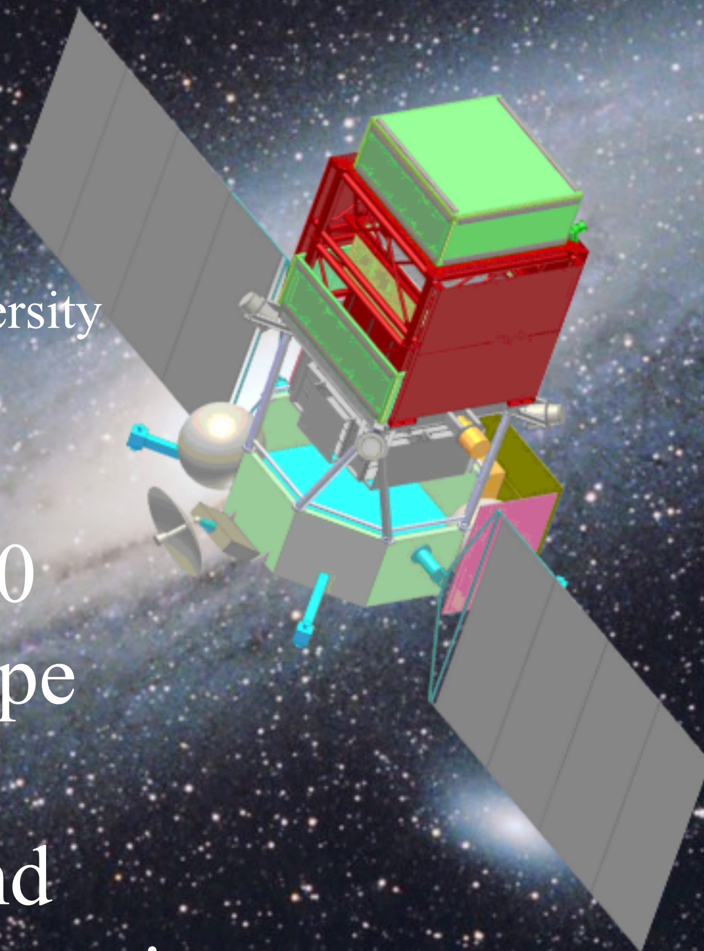

The GAMMA-400 gamma-ray telescope characteristics: angular resolution and electrons/protons separation

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L P I

SciNeGHE 2014, 4-6 June, Lisbon, Portugal

The present time of the development of high-energy gamma-ray astronomy outside the Earth's atmosphere can be characterized as the **Fermi-LAT era.** Indeed, the basic information and basic scientific and methodological results are associated with the Fermi-LAT flight. The total number of gamma-ray sources has reached two thousand. A specific feature in the energy spectrum of the high-energy gamma-ray emission from the Galactic center has revealed.

The next important step in the development of gamma-ray astronomy outside the Earth's atmosphere and in the understanding the nature of the processes occurring in the active variable astrophysical objects (such as the Galactic center, the Cygnus constellation, extended sources, unidentified sources from the Fermi-LAT catalog) will be obtained by **using high-energy gamma-ray telescopes with angular and energy resolutions better than the Fermi-LAT ones**.

Simultaneously, by improving the physical characteristics, the **signal/background ratio will considerably increase**; this is very important to **resolve high-energy gamma-ray lines**, which can arise from the annihilation or from the decay of hypothetical dark matter particles.

GAMMA-400 SCIENTIFIC GOALS

The GAMMA-400 main scientific goals are:

- study of the origin of the dark matter by means of gamma-ray astronomy;
- precise measurements of Galactic and extragalactic discrete astrophysical sources;
- research of high-energy gamma-ray bursts;
- research of high energy electron + positron fluxes;
- research of high-energy nuclei fluxes.

GAMMA-400 PERFORMANCES

For gamma-ray energies more than 100 GeV:

energy resolution ~1%

angular resolution better than 0.02 deg.

This talk will present:

1. The methods to reconstruct the direction of incident gamma photon
2. The capability of the GAMMA-400 gamma-ray telescope to distinguish electrons and positrons from protons.

1. Space topology of high energy gamma photon interaction in the detector.

   Main Problems:

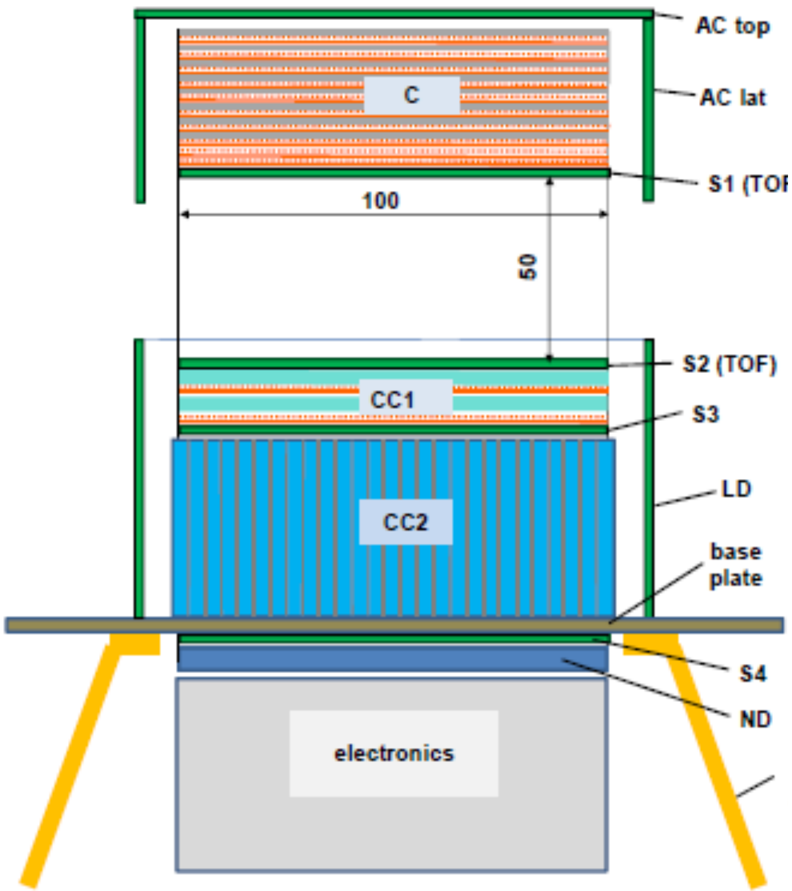
   multiple secondary particles,

   back-splash particles

   They could mask the initial tracks of electron/positron pair from conversion of incident gamma photon. The methods developed allow us to reconstruct the direction of electromagnetic shower axis and extract the electron/positron trace. As a result, the direction of incident gamma photon with the energy of 100 GeV is calculated with an accuracy of better than 0.02 deg.

2. The main components of cosmic rays are protons and helium nuclei, whereas the part of lepton component in the total flux is ~10^{-3} for high energies. Using combined information from all detector systems:
   - rejection factor ~ 4×10^5 for vertical incident particles and ~3×10^5 for particle with initial inclination of 30 deg.

GAMMA-400 PHYSICAL SCHEME



AC - anticoincidence detectors (AC top , AC lat)

C - Converter-Tracker - total 1 Xo

8 layers W 0.1 Xo +Si (x,y) (pitch 0.1mm)

2 Si(x,y) no W

S1, S2 - TOF detectors

S3, S4 calorimeter scintillator detectors

CC1 - imaging calorimeter (2Xo)

2 layers: CsI(Tl) 1Xo + Si(x,y) (pitch 0.1 mm)

CC2 - electromagnetic calorimeter

CsI(Tl) 23 Xo 3.6x3.6x3.6 cm^3 - 28x28x12=9408 crystals

LD - 4 lateral calorimeter detectors

ND - neutron detector

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______ 2009 г.

ПРОЕКТ ГАММА-400

ИССЛЕДОВАНИЕ КОСМИЧЕСКОГО ГАММА-ИЗЛУЧЕНИЯ И ПОТОКОВ ЭЛЕКТРОНОВ И ПОЗИТРОНОВ В ДИАПАЗОНЕ ЭНЕРГИЙ 1-3000 ГэВ

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Москва, 2009 г.

Translation

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THE GAMMA-400 PROJECT

THE RESEARCH OF A COSMIC GAMMA RAYS AND ELECTRON+POSITRON FLUXES IN THE ENERGY RANGE OF 1–3000 GeV

From LPI

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Moscow, 2009

GAMM-400 HAS BEEN APPROVED
by the decret of the Russian Government of December 28, 2012 No. 2594-R

Russian Government program
"Russian Cosmic Activity in 2013–2020"

Three space observatories are foreseen:

1. **"WSO-UV",**
2. **"Spectrum-M" ("Millimetron")**
3. **"GAMMA-400"**

for the purpose of execution of research of astrophysical objects in various electromagnetic ranges and high energy gamma rays.

Gamma 400 simulation

Simulation environment: GEANT4 (4.9.4p02)
GLAST physical list (http://www-glast.slac.stanford.edu/software/PDR/SAS/g4prot.htm)
Crosscheck with QGSP_BIC_HP physics list

Simulation results for high energy gamma particles in GAMMA 400 instrument:

1. Energy resolution.

2. Angular resolution.

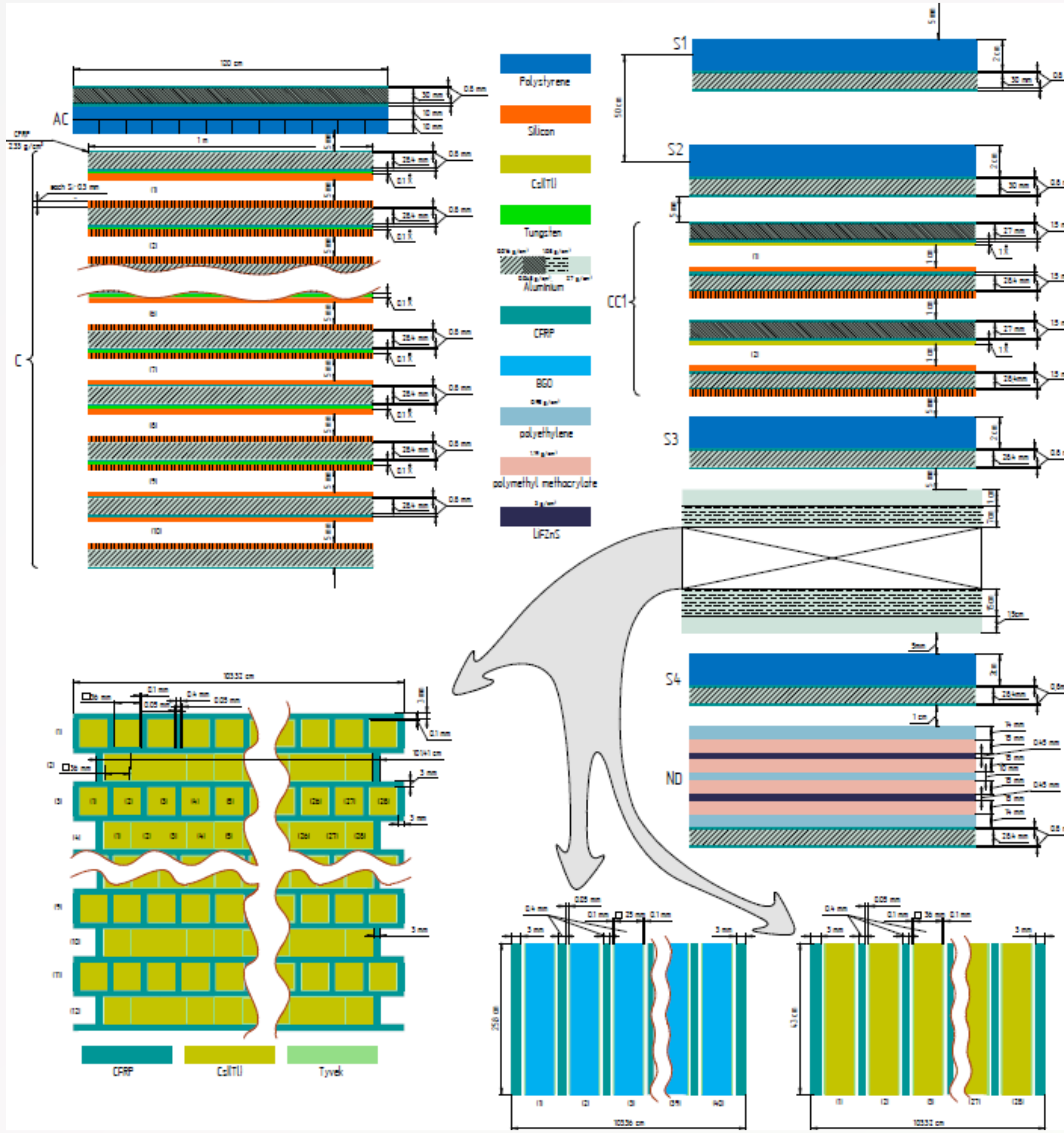
3. Electrons/protons separation.

3. Acceptance.

4. Effective area.

5. Instrument optimization.

Simulation scheme in detail



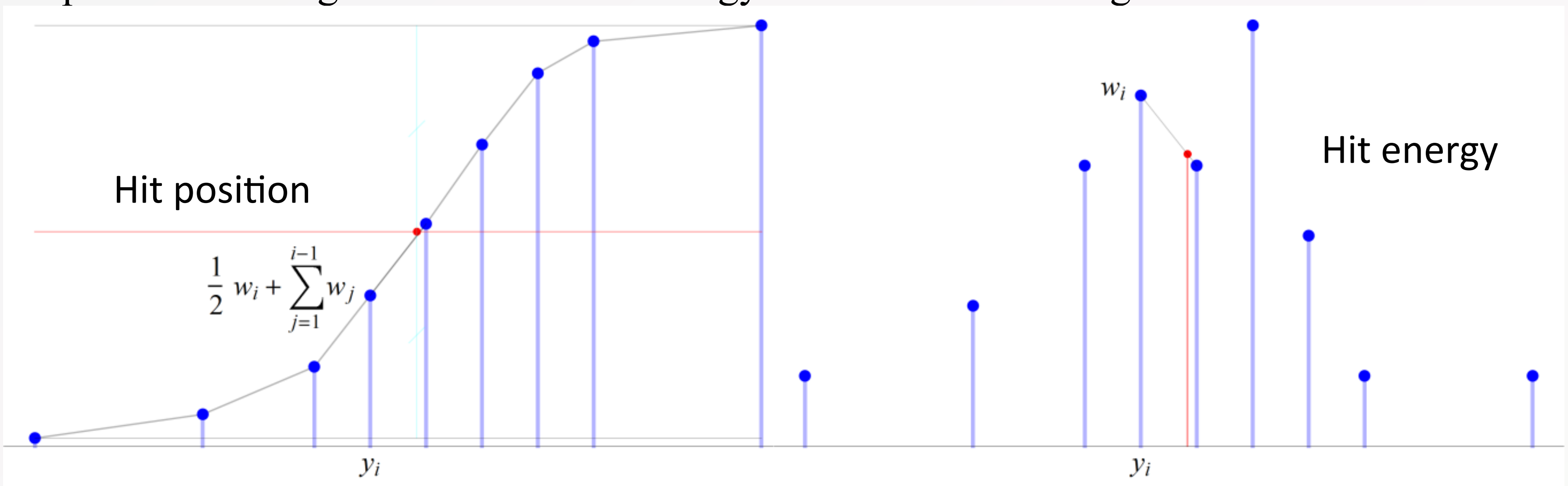
Angular resolution

Algorithm for direction reconstruction

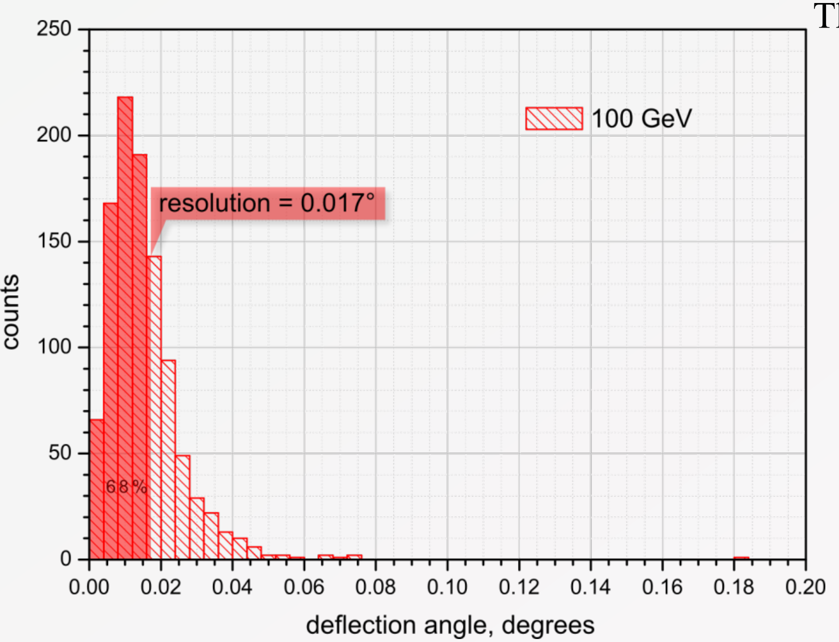
Energy deposits in 12 x-y silicon-strip layers with 100 μm pitch.

10 layers, 8 of which being interleaved with 0.1 X_0 tungsten foils, composes a converter-tracker, whereas other 2 layers are inserted in position-sensitive calorimeter.

- Simulation of gamma-ray detection
- Direction-reconstruction technique based on strip energy release
- Dependence of angular resolution on energy and direction of the gamma



1) Finding median line: a half sum of left and right integral amplitude points (left figure).
2) Abscissa of the red and blue lines intersection gives the position (coordinate) of median (left figure).
3) Energy weight of median is the ordinate of red line intersection with the line linking adjacent (respective median position) points (right figure).
4) Ordinary fitting for all planes with defined median. Construct the estimation of shower axis.
5) Start iteration, narrowing region relative to the shower axis (limit five sizes of strip pitch).



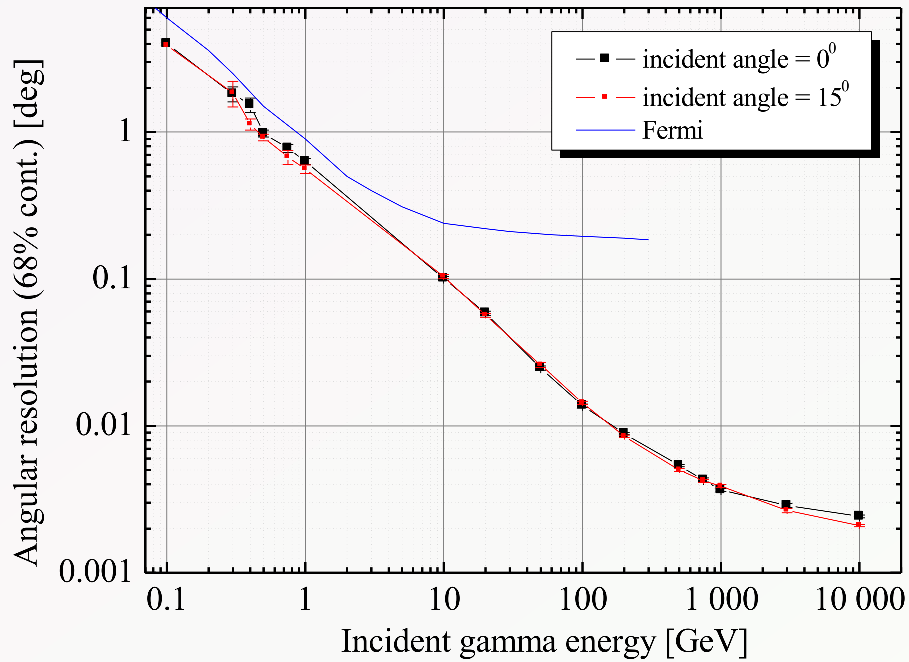
The root-mean-square space angle due to multiple scattering is given by:

$$\theta = \sqrt{2} \times \frac{13.6\ MeV}{\beta pc} \times |z| \times \sqrt{\xi} \times [1 + \ln(\xi)]$$

p – momentum;
βc – *velocity;*
z - charge number of the incident particle;
ξ - the thickness of the scattering medium in units of radiation length.

If considering an electron or positron ($|z|=1$) passing the remaining part of the converter ($\xi \approx 0.5$) from the first pair produced by an incident 100 GeV gamma, and having $\beta = 1$, $pc \approx 50$ GeV, we derive $\Theta \approx 0.015°$. This estimate shows that angular resolution by the technique in question is quite close to the limit imposed by the physics of multiple scattering.

A histogram of the deflection angle distribution



Computed angular resolution vs. energy of incident gamma.

Electron/proton separation

Basic ideas

1. Comparison of longitudinal and transversal shower profiles and the total energy deposition in a calorimeter system on the basis of the fact that electromagnetic and hadronic showers have different spatial and energy topology view.
2. Number of neutrons generated in the electromagnetic cascade is much smaller than that in the hadronic cascade.

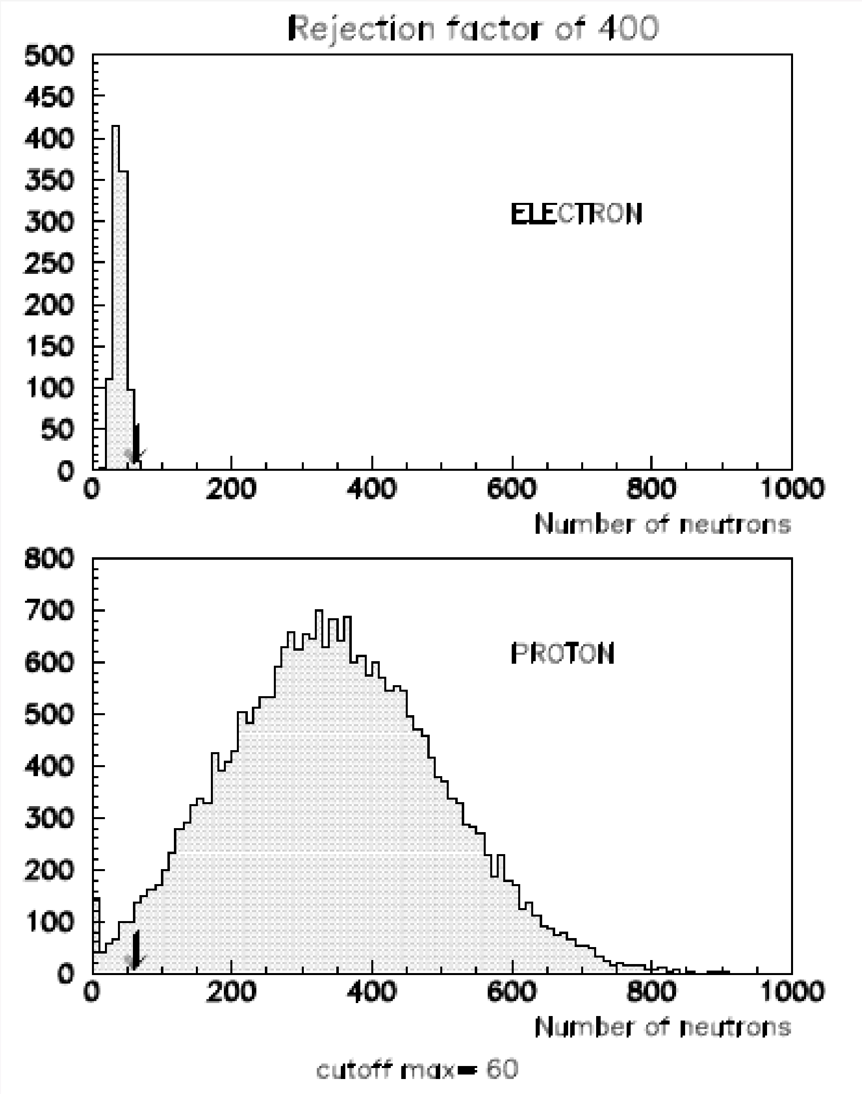
Protons produce the main background, when detecting electrons in cosmic rays. Rejection based on: ND, S4, S3, S2, CC1 and CC2

Rejection Factor: ratio of number of initial protons with energy more than 100 GeV, assuming that the proton energy spectrum power is -2.7, to the number of events identified as electrons with energy 100±2 GeV.

All processed criteria to suppress protons are based on selecting cutoffs to distinguish proton and electron events. **The location of the cutoff for each criterion is selected in order to retain 98% of electrons.**

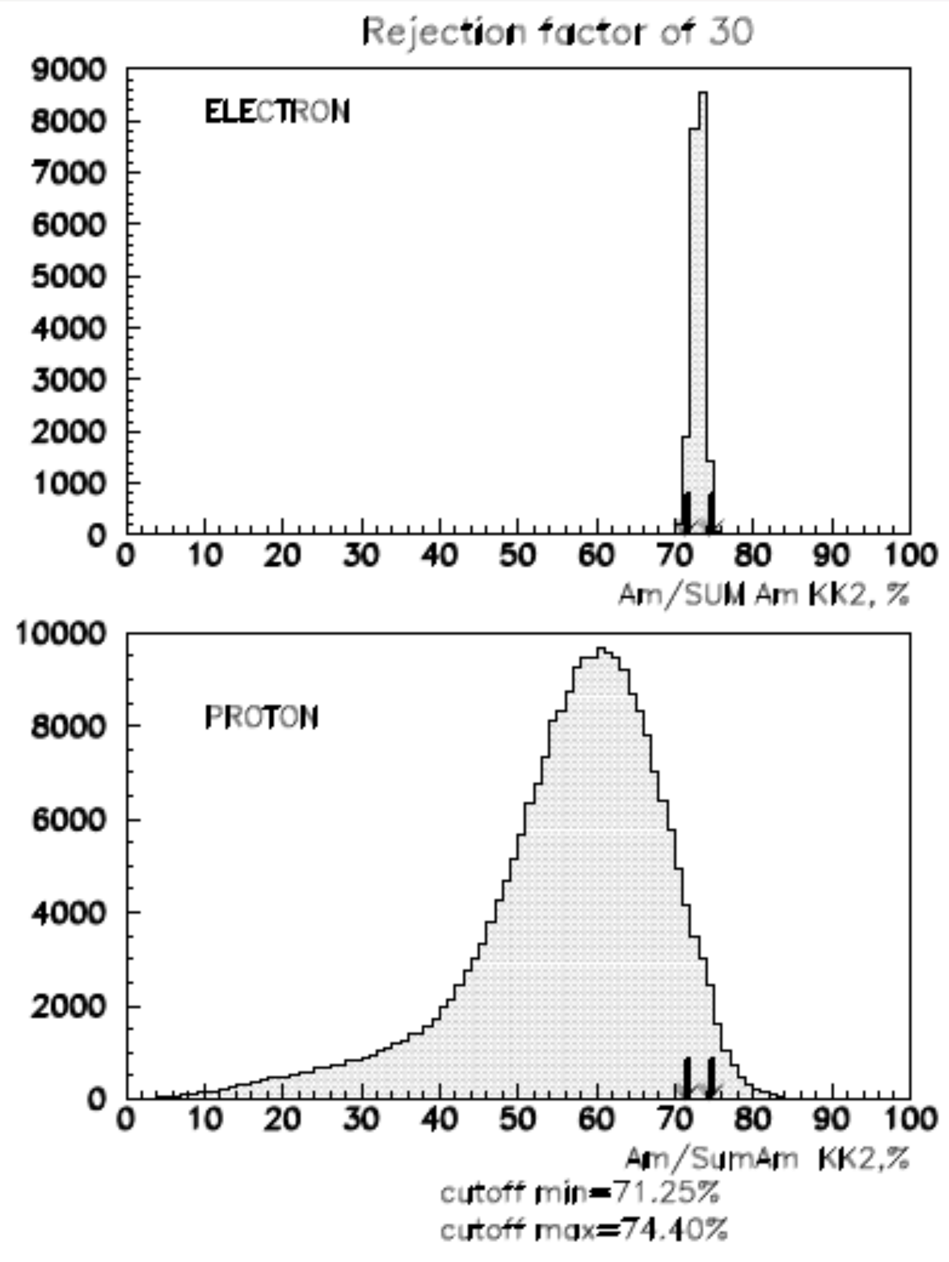
In total 15 cutoffs are used to reject protons.
~30% of electrons are lost due to proton rejection.

Number of neutrons



The main contribution in the total rejection factor for protons in the GAMMA-400 telescope deals with significantly different number of neutrons generated in the electromagnetic and hadron cascades. In cascades induced by protons, the generation of neutrons is larger than in the electromagnetic shower. The source of neutrons in cascades induced by electron concerns with generation of gamma rays with energy about 17 MeV. Those gamma rays, by-turn, could generate neutrons in Giant resonance reaction. By analyzing information from the neutron detector placed just under the CC2 calorimeter, it is possible to suppress protons by a factor of 400. The neutron number cutoff to separate protons is equal 60.

Signal in CC2



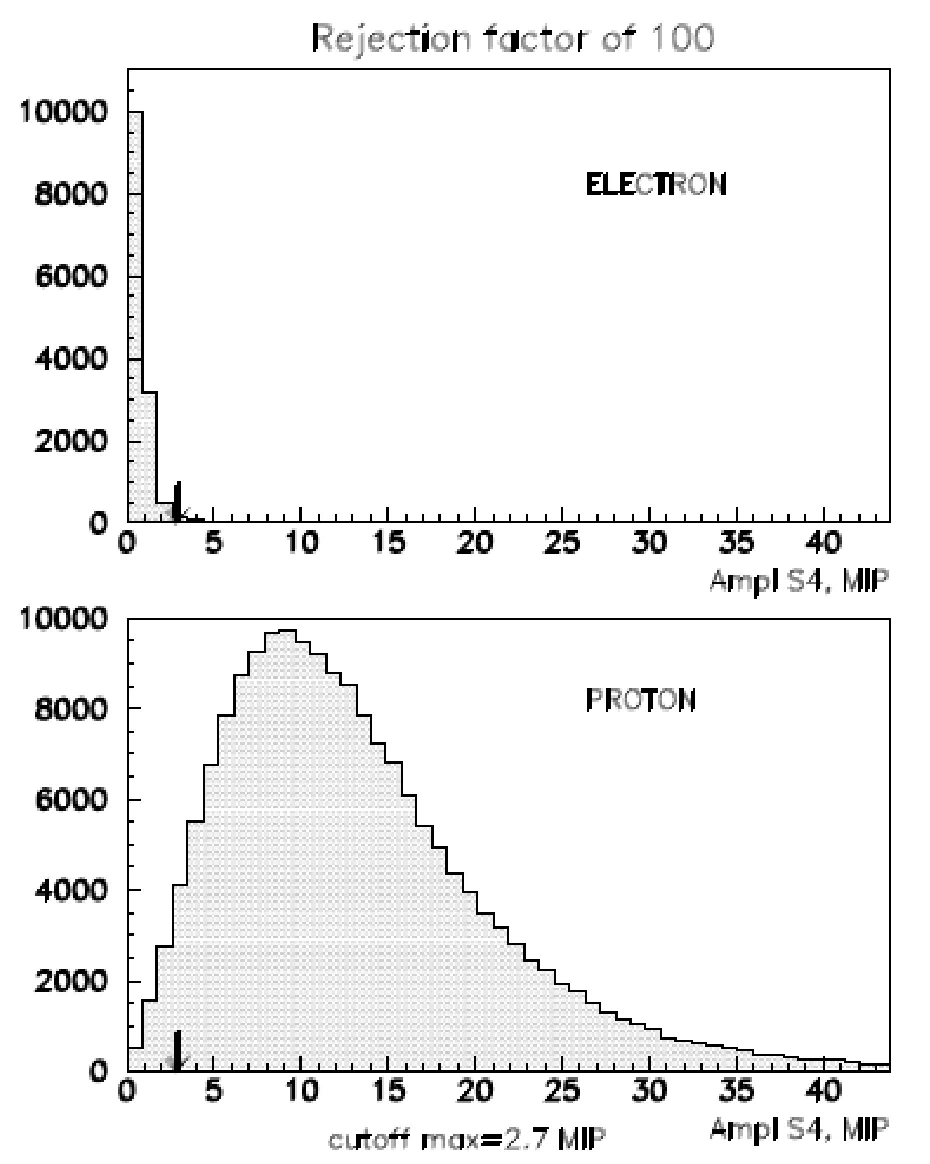
Additional rejection is obtained by analyzing CC2 CsI(Tl) crystals signals.

Basic idea:
Difference of the transverse size for hadron and electromagnetic showers

Variable used:
Ratio of signal in the crystal containing shower axis to the value of total signal in CC2 for initial electrons and protons are compared.

Applying this rejection provides a rejection factor of ~30

Signal in S4



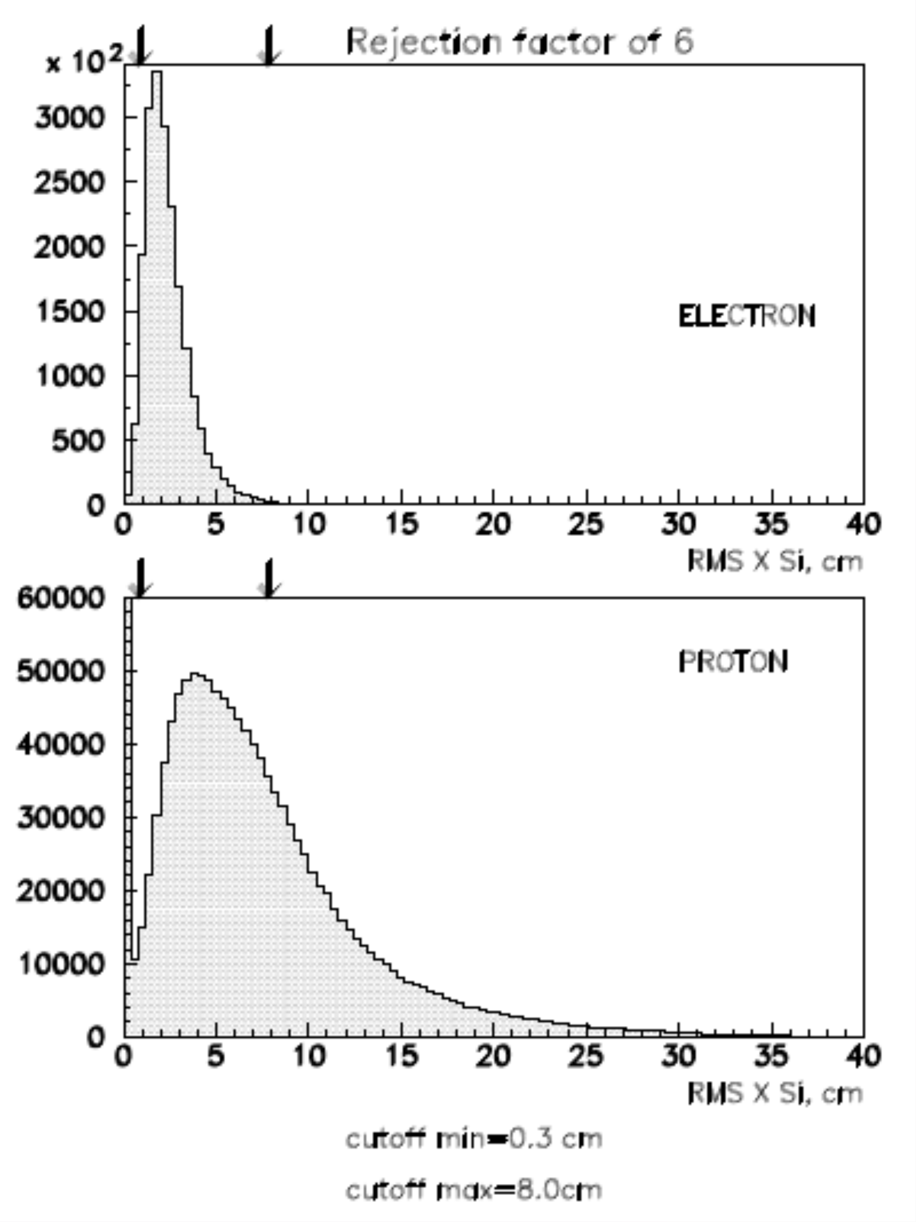
Basic idea:
difference in the attenuation length for hadron and electromagnetic cascades.

Electromagnetic showers initiated by the electron with initial energy ~ 100 GeV are fully contained inside the calorimeter (25 X_0, 1.2 λ_0).

Variable used:
Energy in S4 bottom detector

Selecting events with signals in S4 less than 2.7 MIP, we obtain a rejection factor of 100.

Transverse size in CC1

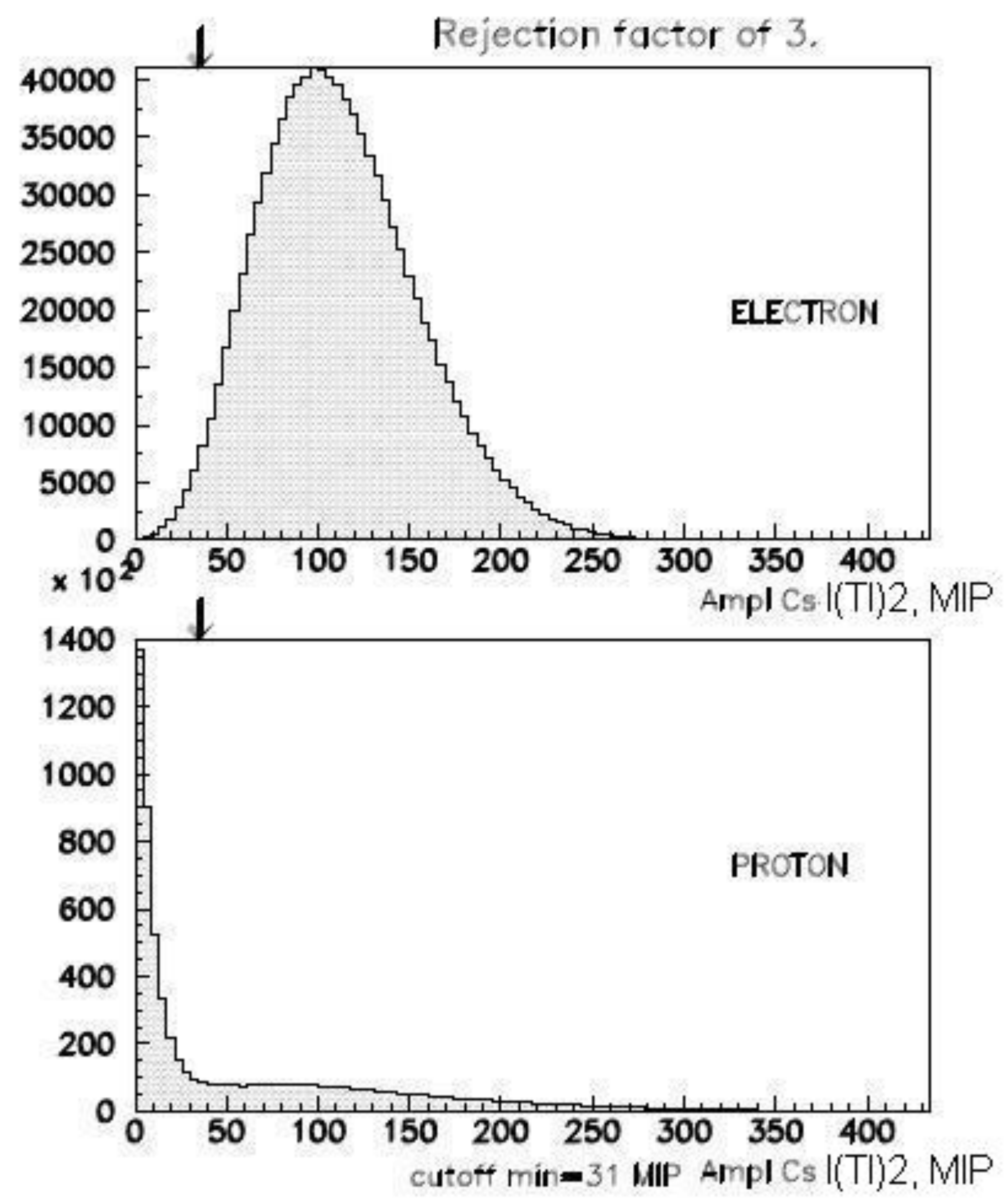


Basic idea:
difference in the proton and electron shower transverse size measured with silicon strips in CC1.

Variable used:
RMS of coordinates of strips with signals

Applying this selection provides a rejection factor of ~6.

Energy deposit in CC1, S2 and S3



Basic idea:
Hadron showers begins to develop deeper inside the instrument

Variables used:
energy release in CC1, S2 and S3, since the thickness of material just above these detectors is less than 4 X_0.

Additional rejection factor ~ 3, 2, 2 are obtained

Summary on Rejection Factor

All above discussed proton rejection criteria were considered separately from each other.

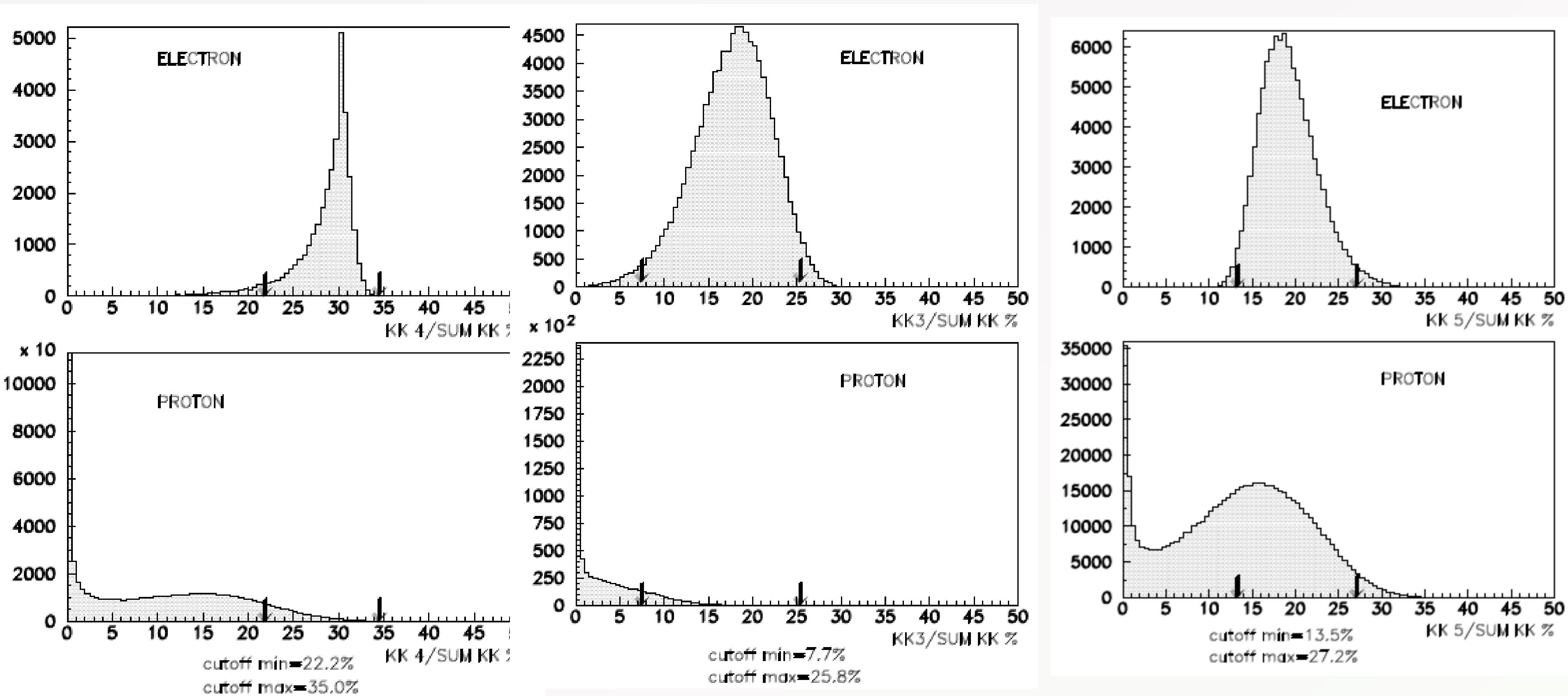
Using all criteria in the combination, it is possible to obtain an overall rejection factor for protons equal to $(4.0 \pm 0.4) \times 10^5$.

Table contains the information about the standalone rejection factor of each criterion (without the other ones) and the reduction factor in the total rejection factor decreasing if this criterion is not used.

Detector system, number of cutoffs	Own rejection factor for each cutoff	Reduction in the total rejection factor if this criterion is not used
ND (1 cutoff)	400	2
CC2 (2 cutoffs)	30	2.6
S4 (2 cutoffs: 1 cutoff for each scintillation layer)	100	1.7
Strips in CC1 (4 cutoffs: 2 cutoffs for each X or Y silicon strip)	6	1.2
CsI(Tl) from CC1 (2 cutoffs: 1 cutoff for each CsI(Tl) crystal)	3	1.3
S2, S3 (4 cutoffs: 2 cutoffs for each detector)	2	1.3

Some comments on inclined tracks

The same proton rejection algorithm can in principle be applied for inclined tracks.
Cutoffs values should clearly be changed.
A Rejection Factor ~ 3.10^5 can be obtained with 30^0 inclined tracks.

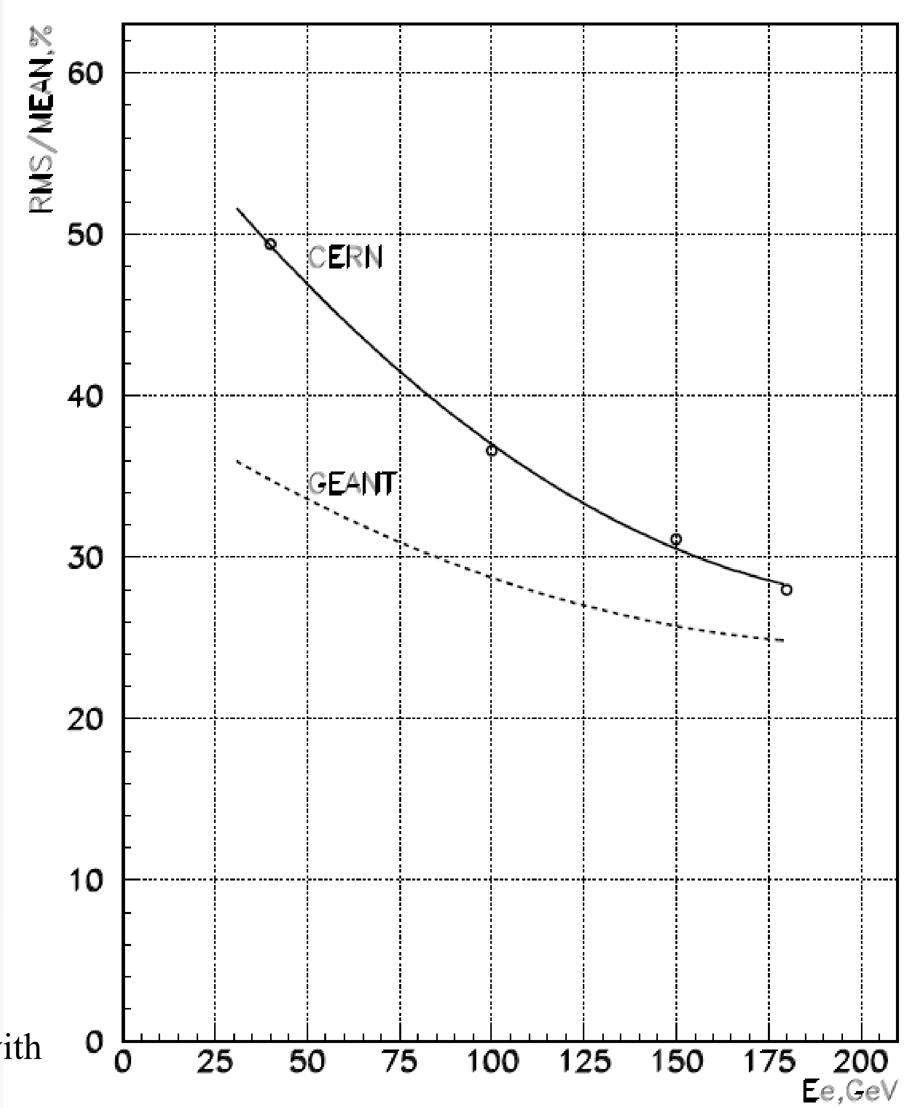


Conclusions

- GAMMA-400 is an optimal instrument to detect gamma and electrons
- Angular resolution better than 0.02 deg can be obtained for photon energy larger than 100 GeV
- Effective rejection of protons from electrons can be achieved exploiting the difference in the development of hadron and electromagnetic showers inside the finely segmented instrument. A rejection factor for vertical and inclined protons several times better than 10^5 for proton energy larger than 50 GeV can be obtained

Thanks for your attention!

Preliminary calculations have shown that the information from scintillation detectors can also significantly increase the proton rejection. In such approach the width of distribution of signals from electrons and protons is the mainly important parameter. In the GEANT 4 simulations the value of scintillation detector response is formed only by ionization losses of the particle inside the detector. To take into account the efficiency of deposited energy transmitting into the light flash, the efficiency of light collection, and the efficiency of the light to electric signal transformation in photomultiplier, the data of beam test calibration were used. The solid line presents the dependence of ratio of RMS to the average signal in scintillation detector from the energy of electrons in the CERN calibration test beam. This calibration was performed within the framework of the PAMELA experiment for scintillation detector similar to the one intended to apply in the GAMMA-400 instrument. The results of simulation from GEANT4 are also shown by dashed line. Comparing the results of calibration and calculation it is possible to deduce additional spreading parameter for simulation data. The value of signal in scintillation detector is the calculated, as: $E = E_0 + E'$



E_0 - energy releasing due to ionization losses, MIP;

E' - the spreading signal calculated from the Gauss distribution with

$$\sigma \approx 0.33 \times E_0 - 4.\times 10^{-4} \times E_0^2$$

COMPARISON OF BASIC PARAMETERS OF OPERATED, EXISTING, AND PLANNED SPACE-BASED AND GROUND-BASED INSTRUMENTS

	SPACE-BASED INSTRUMENTS					GROUND-BASED GAMMA-RAY FACILITIES			
	EGRET	**AGILE**	**Fermi-LAT**	**CALET**	**GAMMA-400**	**H.E.S.S.-II**	**MAGIC**	**VERITAS**	**CTA**
Operation period	1991-2000	2007-	2008-	2014	2019	2012-	2009-	2007-	2018
Energy range, GeV	0.03-30	0.03-50	0.02-300	10-10000	**0.1-10000**	> 30	> 50	> 100	> 20
Angular resolution (E_γ > 100 GeV)	0.2° (E_γ~0.5 GeV)	0.1° (E_γ~1 GeV)	0.1°	0.1°	**~0.01°**	0.07°	0.07° (E_γ = 300 GeV)	0.1°	0.1° (E_γ = 100 GeV) 0.03° (E_γ = 10 TeV)
Energy resolution (E_γ > 100 GeV)	15% (E_γ~0.5 GeV)	50% (E_γ~1 GeV)	10%	2%	**~1%**	15%	20% (E_γ = 100 GeV) 15% (E_γ = 1 TeV)	15%	20% (E_γ = 100 GeV) 5% (E_γ = 10 TeV)

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

	Fermi-LAT	**GAMMA-400**
Orbit	circular, 565 km	high-elliptical, 500-300 000 km
Energy range	20 MeV - 300 GeV	100 MeV – 10 000 GeV
Effective area ($E_\gamma > 1$ GeV)	~8000 cm^2	~5000 cm^2
Coordinate detectors	Si strips (pitch 0.23 mm)	Si strips (pitch 0.1 mm)
Angular resolution ($E_\gamma > 100$ GeV)	~0.1°	~0.01°
Calorimeter - thickness	CsI ~8.5X_0	CsI(Tl)+Si strips ~25X_0
Energy resolution ($E_\gamma > 100$ GeV)	~10%	~1%
Proton rejection coefficient	~10^4	~10^6
Mass	2800 kg	4100 kg
Telemetry downlink capability	15 GB/day	100 GB/day

GAMMA-400 Collaboration

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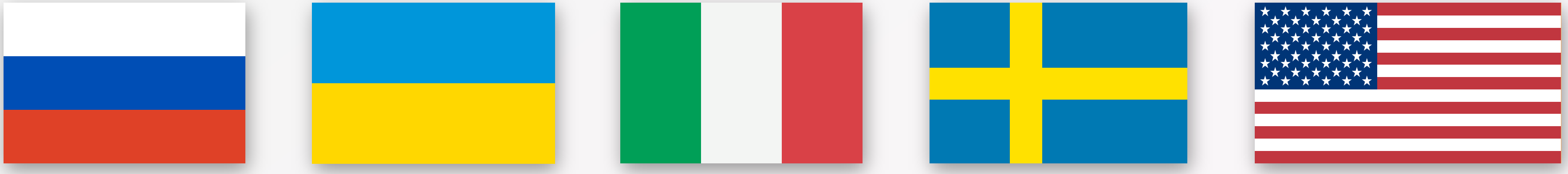
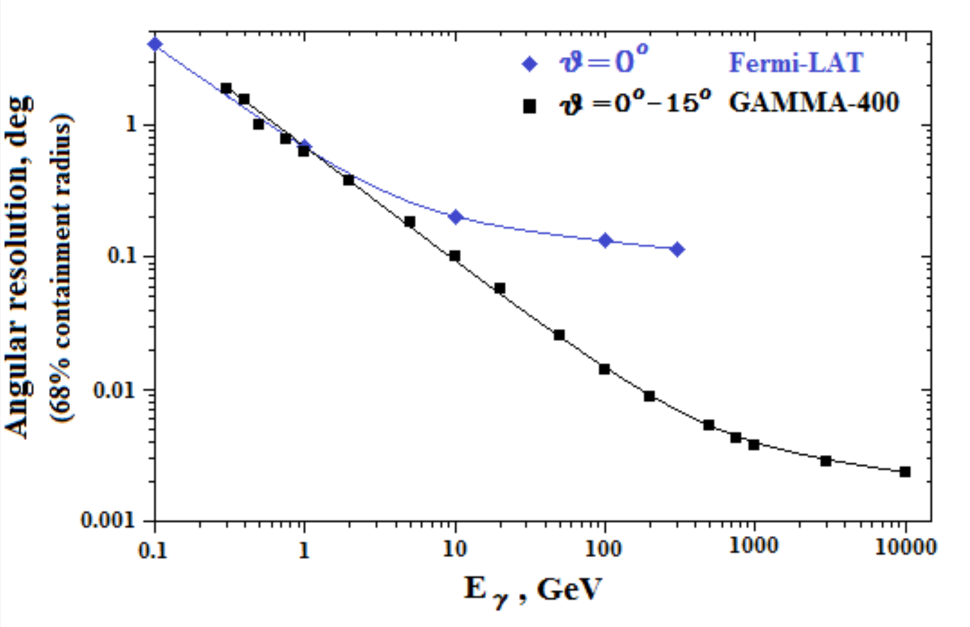
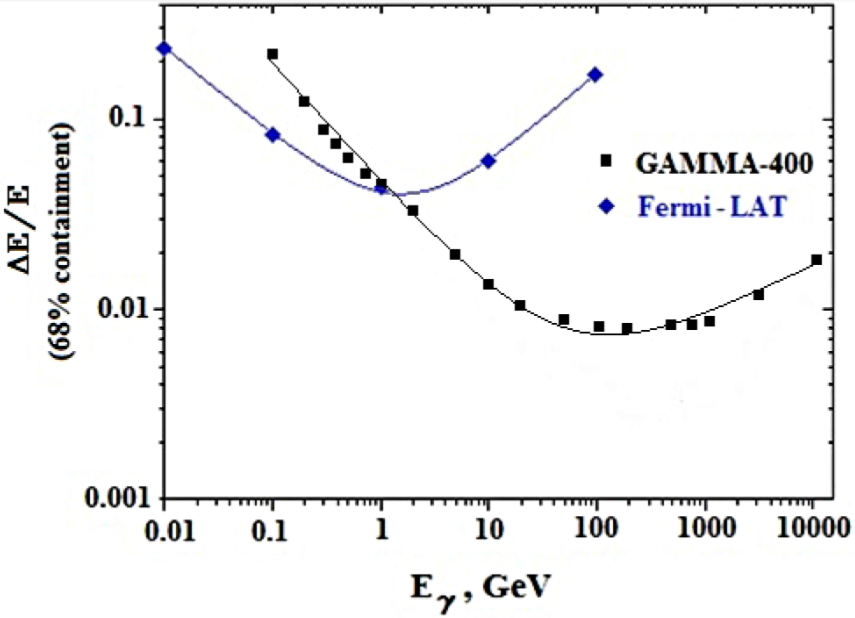
GAMMA-400 Collaboration



Collaboration is open to entrance

Energy resolution vs. energy for normal incidence for Fermi-LAT and GAMMA-400





Angular resolution vs. energy for Fermi-LAT (for normal incidence) and GAMMA-400 (for θ=0°-15°)