The GAMMA-400 Space Experiment: Gammas, Electrons and Nuclei Measurements

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On behalf of the GAMMA-400 collaboration

9th Workshop on Science with the New Generation of High Energy Gamma-ray Experiments

20 – 22 June, 2012
Lecce – Italy

Presentation outline

- Introduction
- GAMMA-400 mission
- Baseline (Russian) project
- Italian proposal
- Summary

GAMMA-400 Mission

GAMMA-400 Collaboration

- Lebedev Physical Institute (leading organization)
- National Research Nuclear University MEPhI
- Ioffe Physical Technical Institute
- Open Joint Stock Company "Research Institute for Electromechanics" (Istra)
- Institute for High Energy Physics (Protvino)
- Space Research Institute
- Istituto Nazionale di Fisica Nucleare, INFN, Italy
- Istituto Nazionale di Astrofisica

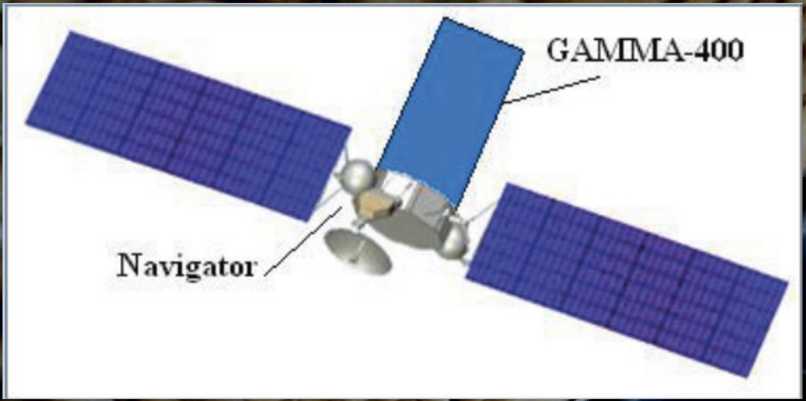
GAMMA-400 project

No gamma-ray space mission planned after Fermi and Agile

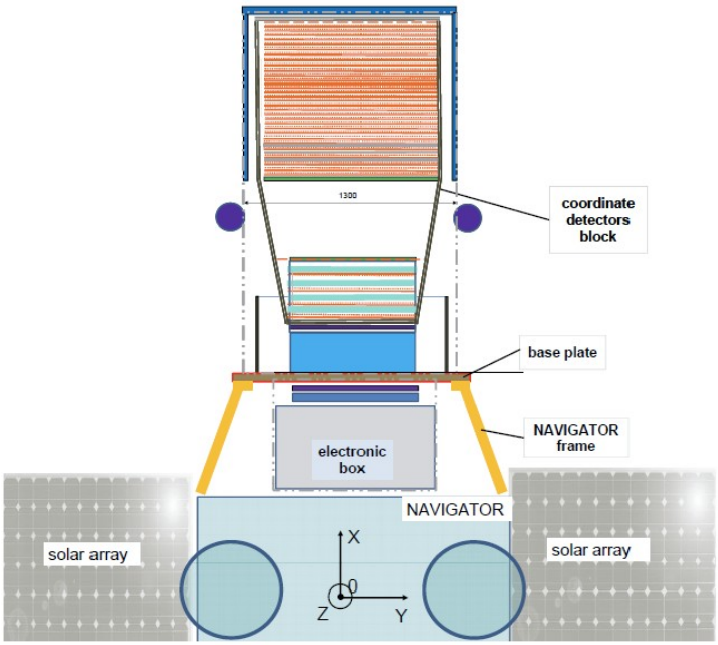
GAMMA-400:

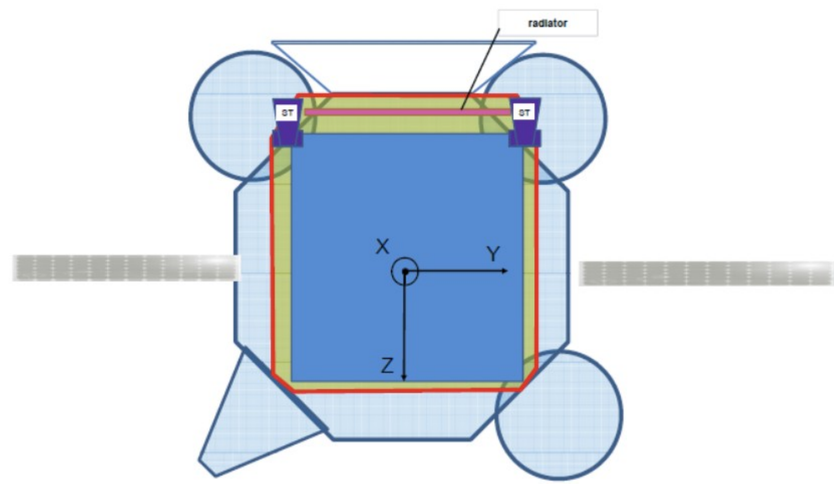
- Total mass budget: 2600 kg
- Maximum power consumption: 2000 W
- Telemetry downlink: 100 GB/day
- Lifetime: > 7 years
- Orbit, initial parameters: apogee 300000 km, perigee 500 km, orbital period 7 days, inclination angle 51.8°.

GAMMA-400 space observatory installed on the Navigator service module.

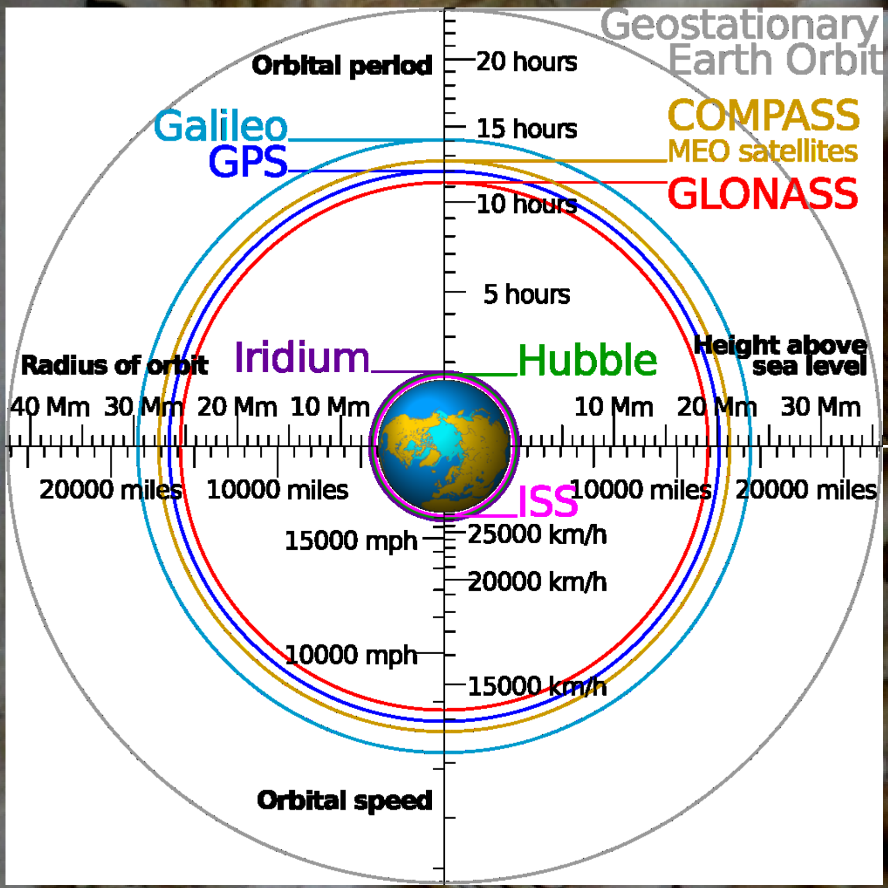


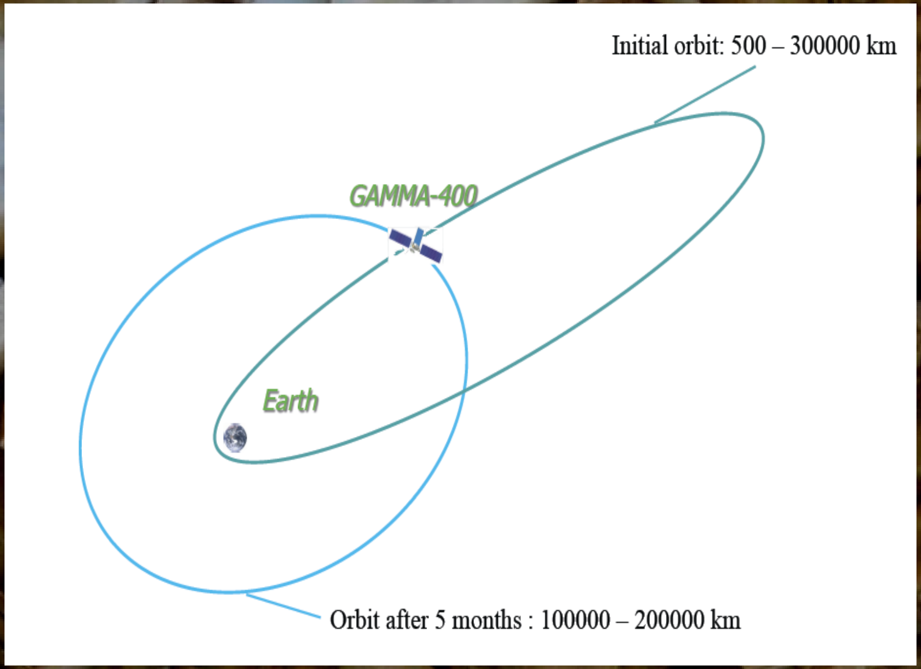
GAMMA-400 project





GAMMA-400 orbit





GAMMA-400

High Earth Orbit (HEO)

GAMMA-400 – baseline

Russian requirements (@2010)

Gamma-ray energy range	0.1-3000 GeV
Multilayer converter	100 x 100 cm^2 0.84 Xo
Calorimeter	80 x 80 cm^2 ~ 30 Xo
Angular resolution (100 GeV)	~ 0.01°
Energy resolution (100 GeV)	1%
Proton rejection	10^6

Russian GAMMA-400 Scientific Goals (@2012)

Main scientific investigations

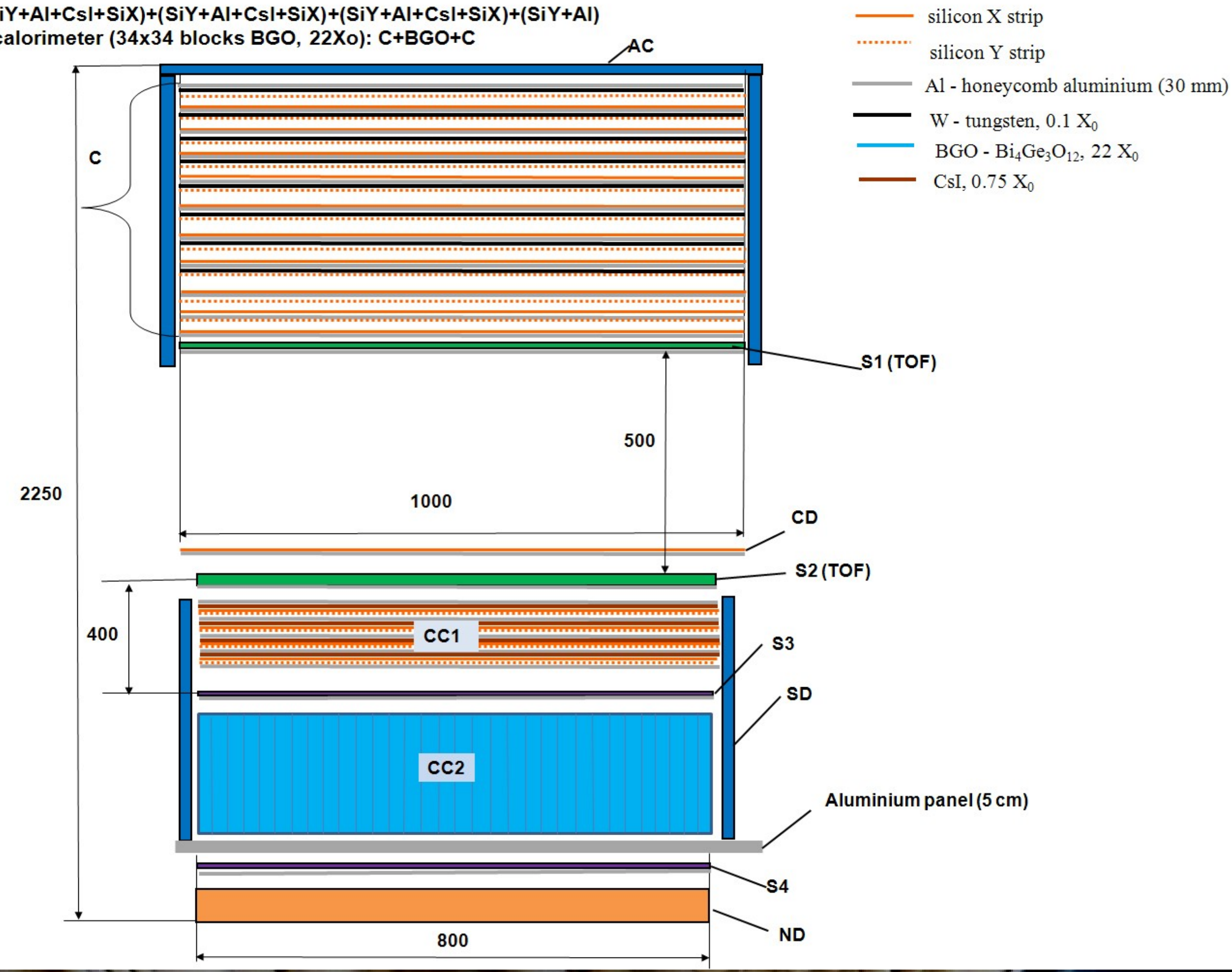
To study the nature and features of weakly interacting massive particles, from which the dark matter consists;

To study the nature and features of variable gamma-ray activity of astrophysical objects from stars to galactic clusters;

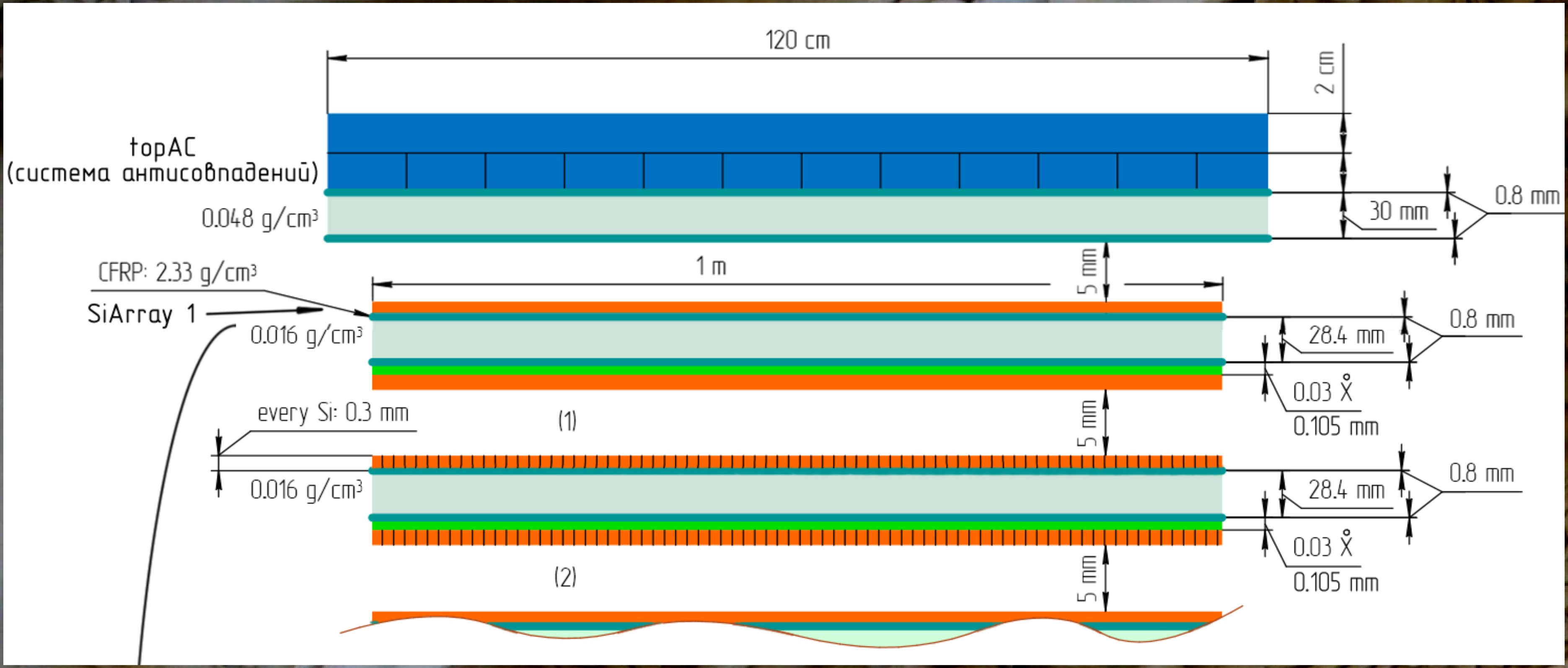
To study the mechanisms of generation, acceleration, propagation, and interaction of cosmic rays in galactic and intergalactic spaces.

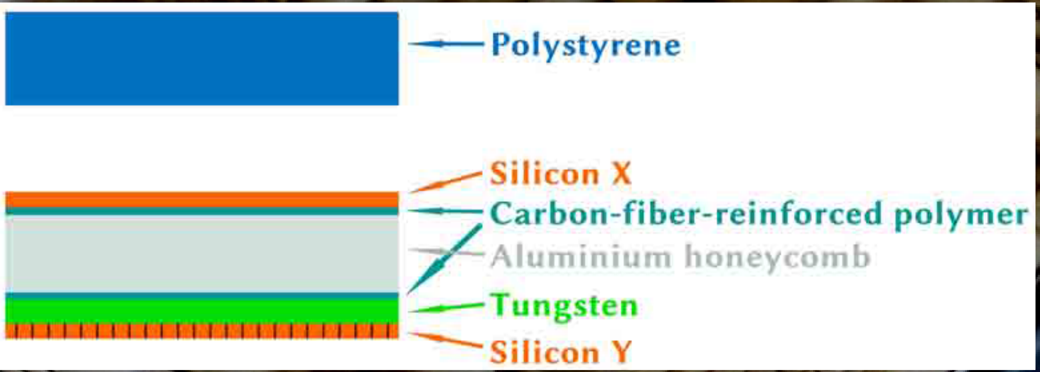
Russian design (@2012)

AC — anticoincidance detector;
C — converter (1 Xo);
11 layers:
(Al+W+SiY)+(SiX+Al+W+SiY)+(SiX+Al+W+SiY)+....+(SiX+Al+SiY)+(SiX+Al+SiX)+(SiX+Al)
CD — coordinate detector — (Si+Al)
S1, S2 — time of light scintillation detector (TOF): S1+Al, S2+Al
S3, S4 — scintillation detectors of electromagnetic calorimeter: S3+Al, S4+Al
CC1 — preshower (3Xo),
5 layers: (Al+CsI+SiX)+(SiY+Al+CsI+SiX)+(SiY+Al+CsI+SiX)+(SiY+Al+CsI+SiX)+(SiY+Al)
CC2 — electromagnetic calorimeter (34x34 blocks BGO, 22Xo): C+BGO+C
SD — side detectors,
ND — neutron detector



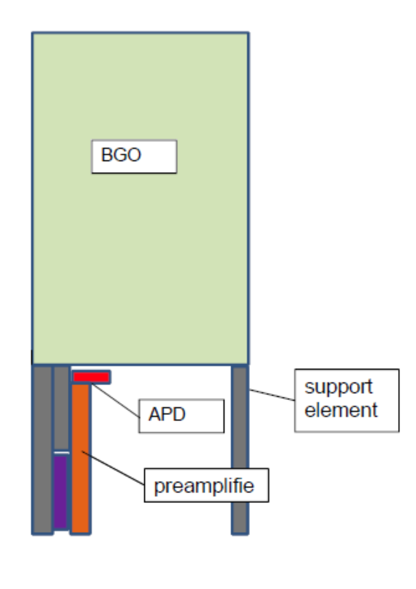
Tracking system

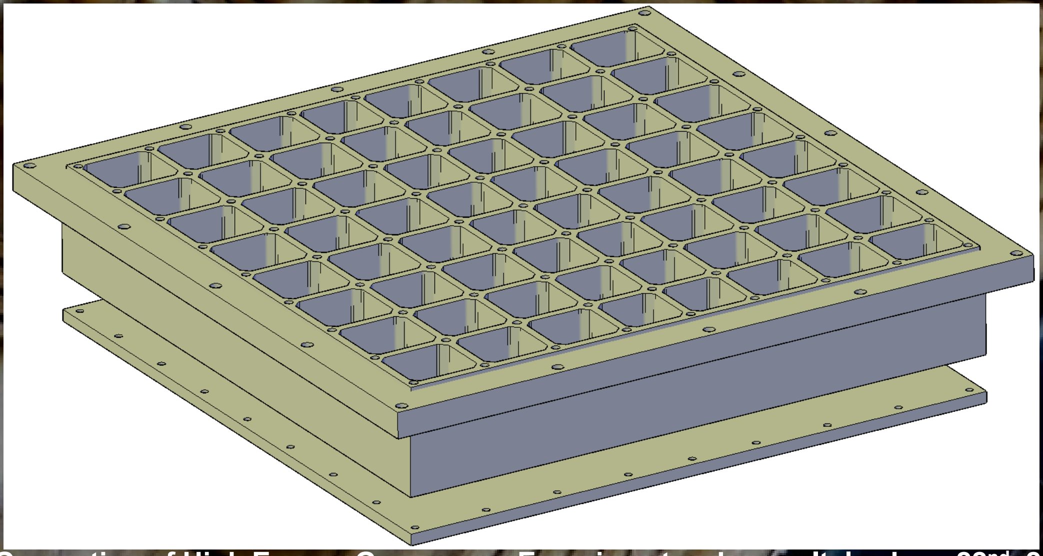




Homogeneous calorimeter

- Sensitive volume 800x800x25 cm^3
- 1024 BGO crystals 25x25x250 mm^3
- 22 r.l. normal particle direction
- 70 r.l. lateral particle direction
- Total mass 1150 kg
- Power consumption 200 W





GAMMA-400 – Italian proposal

GAMMA-400: unique instrument and opportunity

First time double instrument: photon and particle (electrons and nuclei)

- **Excellent Silicon Tracker**
  - **breakthrough angular resolution 4-5 times better than Fermi-LAT at 1 GeV**
  - **improved sensitivity compared with Fermi-LAT by a factor of 5-10 in the energy range 30 MeV – 10 GeV**
- **Heavy Calorimeter with optimal energy resolution and particle discrimination**
  - **Electron/positron detection beyond TeV energies**
  - **Nuclei detection up to 10^{15} eV energies**
- **Trigger with ToF capabilities ("smart" AC)**

GAMMA-400
“the Cosmic Accelerator Hunter”

Three main components of cosmic radiation:

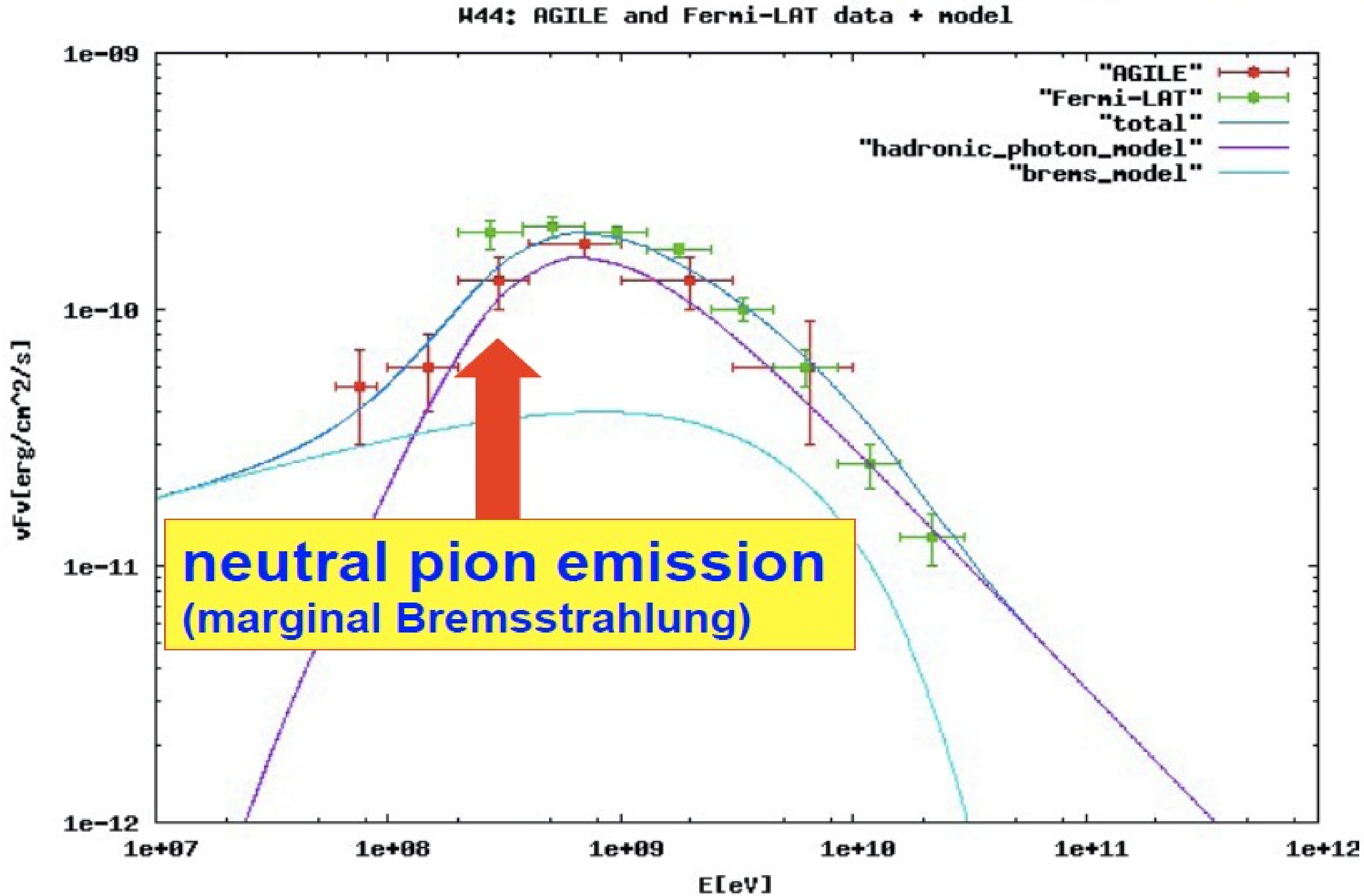
1. **gamma-rays from 30 MeV up to TeV energies, to be studied with substantial improvements concerning the angular resolution, the broad-band sensitivity, and the continuous exposure of sources without Earth occultations**
2. **electrons+positrons in the TeV energy range and beyond, to be measured with much improved sensitivity compared with current space, balloon-borne, and ground measurements**
3. **proton/nuclei cosmic-rays up to the "knee", whose spectrum and composition is to be studied with unprecedent details up to 1 PeV/nucleon**

Scientific goals

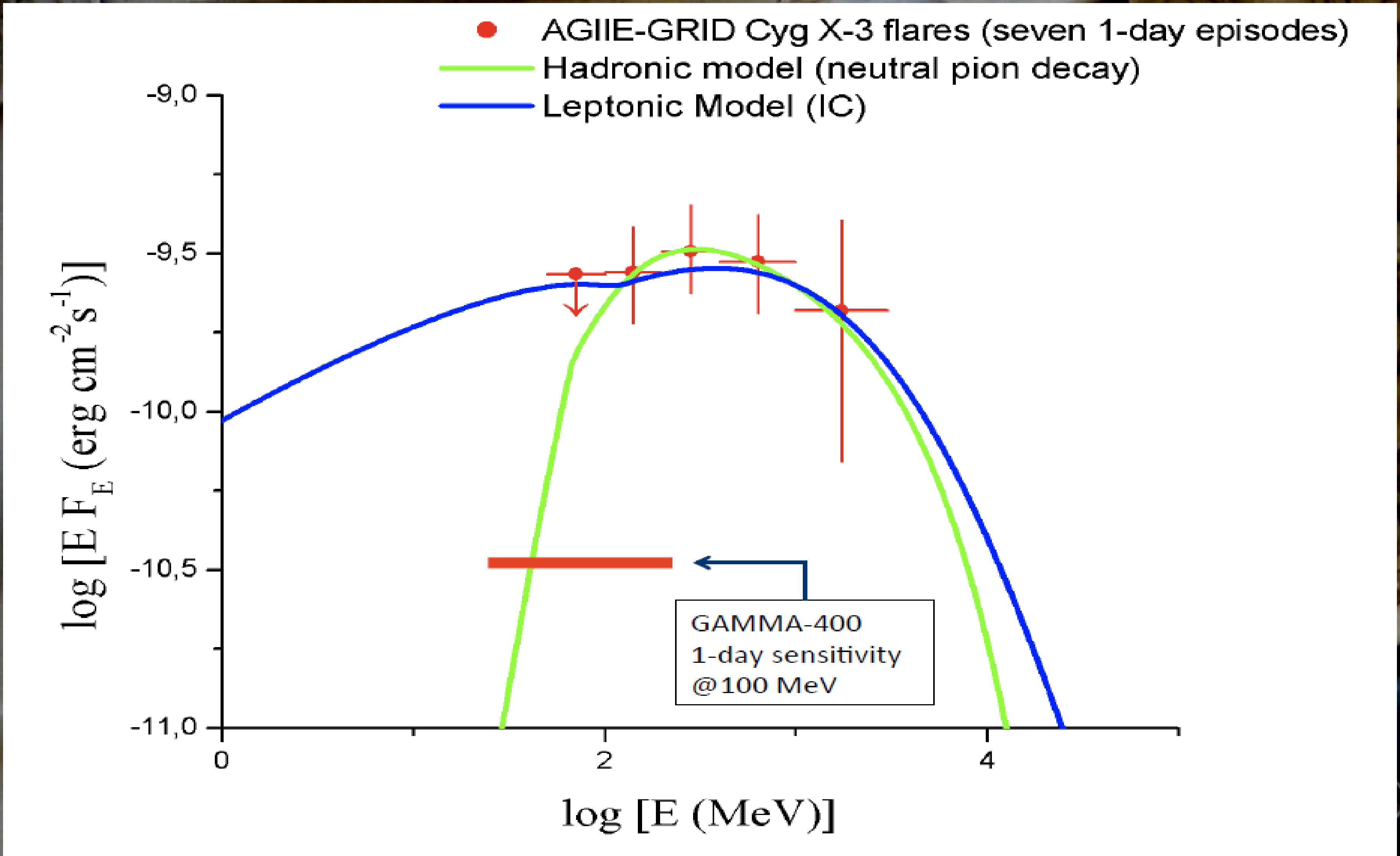
- **Cosmic-Ray acceleration in Supernova Remnants and Galactic diffusion resolved with the greatest detail both in space and spectra.** Large sensitivity to neutral pion emission below 200 MeV.
- **Dark Matter studies at GeV energies, resolving the Galactic Center and excellent sensitivity for searches in spheroidal galaxies (10 times better than Fermi-LAT).**

Scientific goals – low energy γs

(Giuliani, Cardillo et al. 2011)



Scientific goals – low energy γs

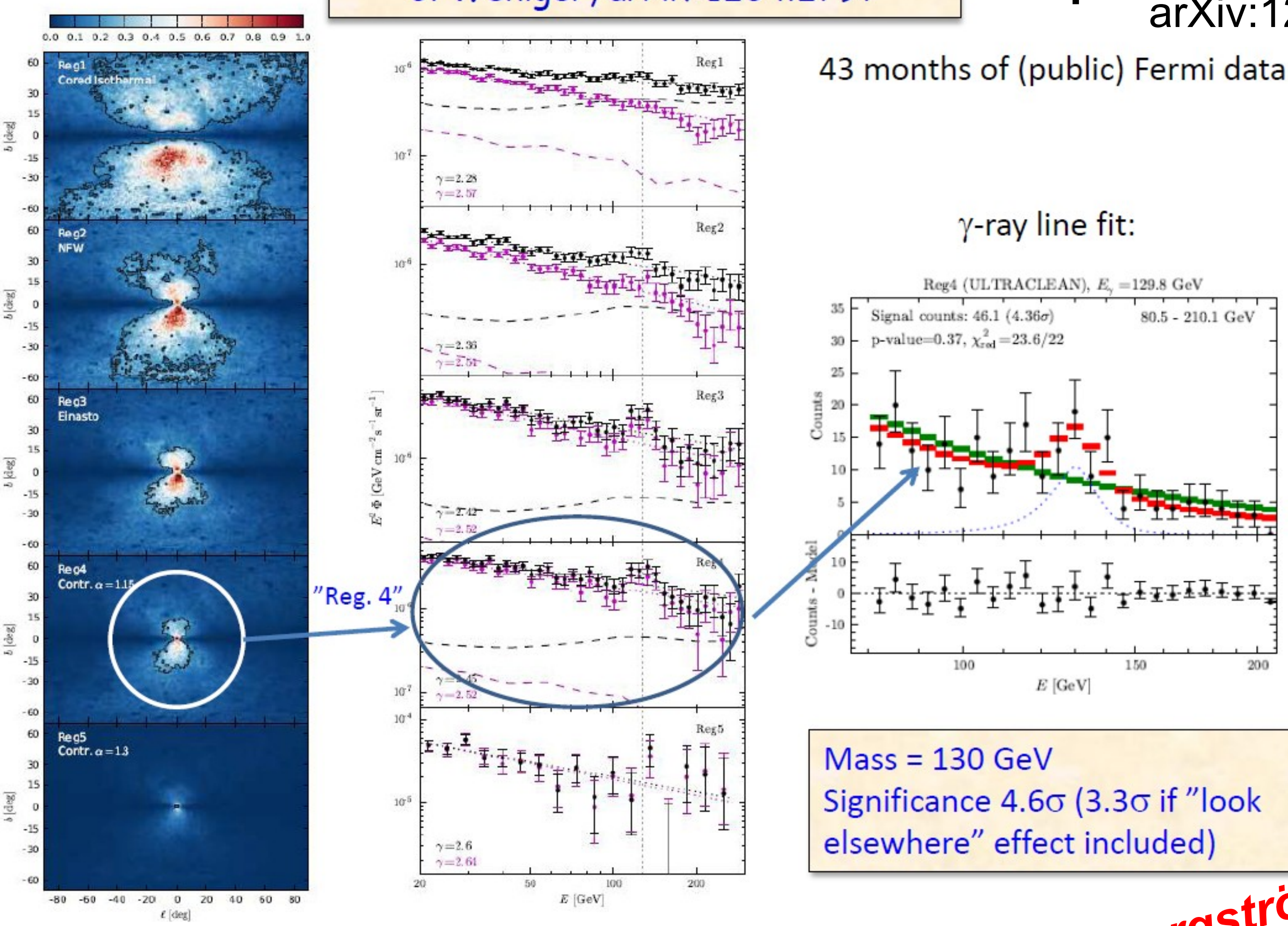


Scientific goals – high energy γs

C. Weniger, arXiv:1204.2797

\+ arXiv:1205.1045
arXiv:1206.1616

43 months of (public) Fermi data



Mass = 130 GeV
Significance 4.6σ (3.3σ if "look elsewhere" effect included)

Lars Bergström

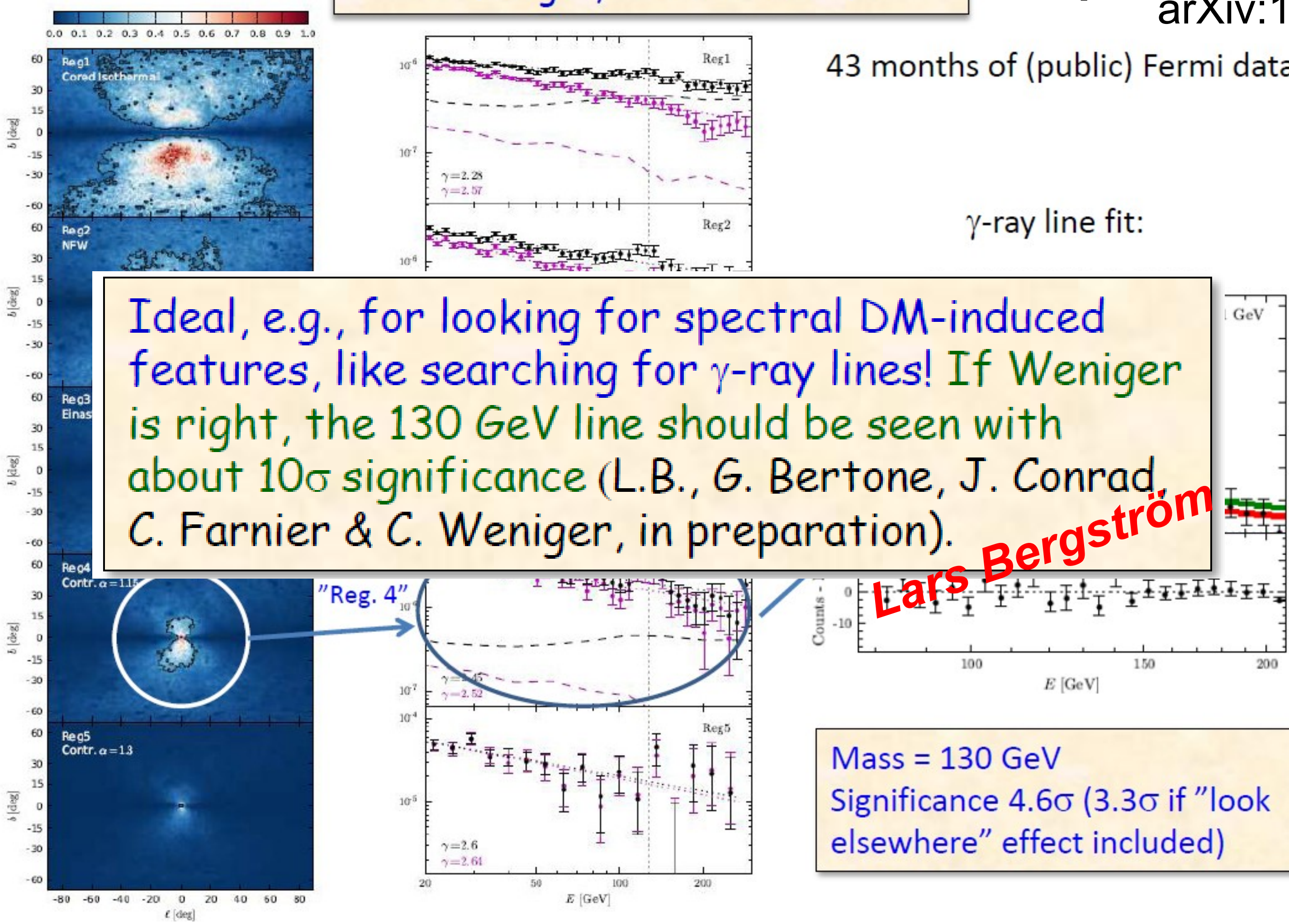
Scientific goals – high energy γs

arXiv:1205.1045
arXiv:1206.1616

C. Weniger, arXiv:1204.2797

43 months of (public) Fermi data

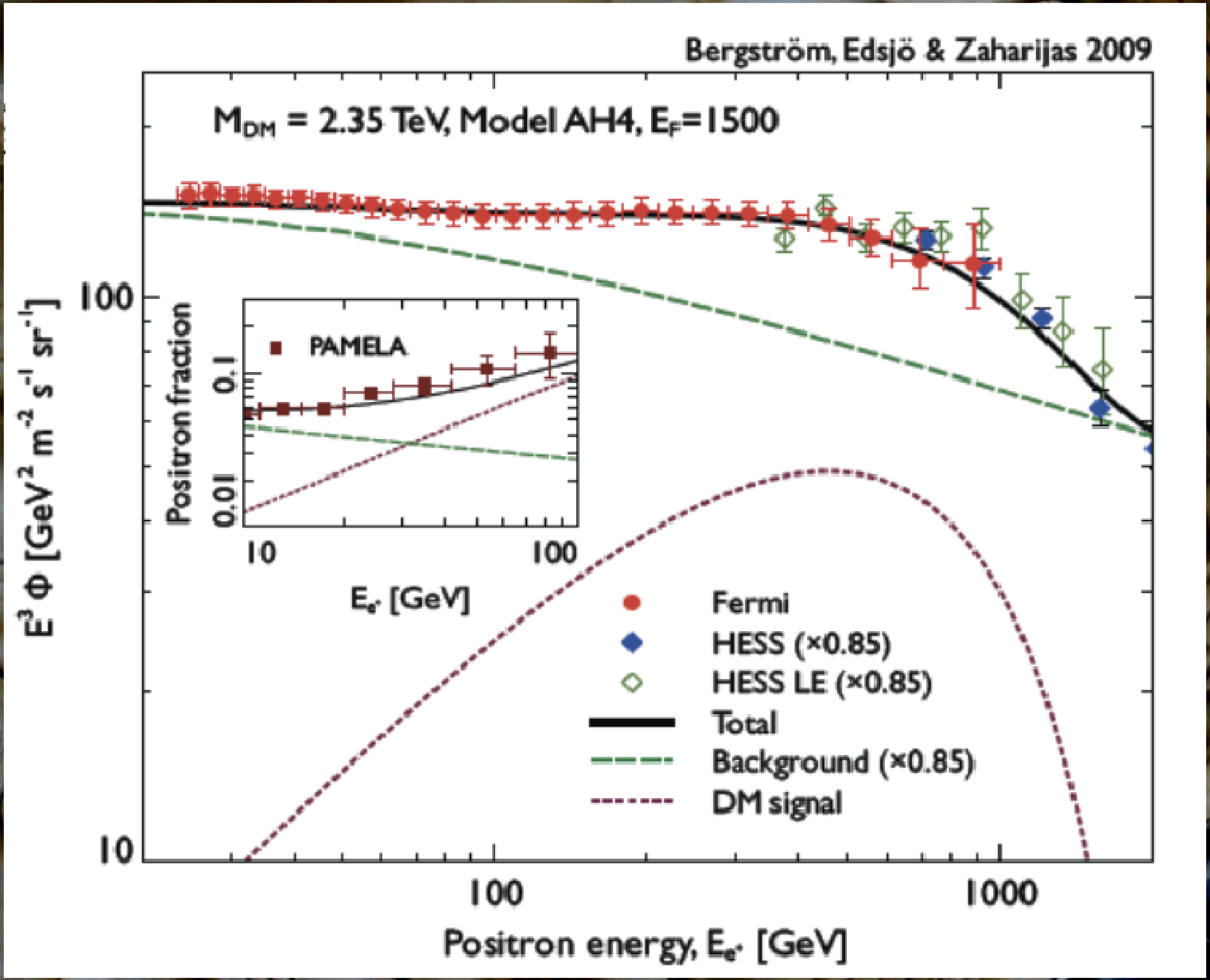
γ-ray line fit:



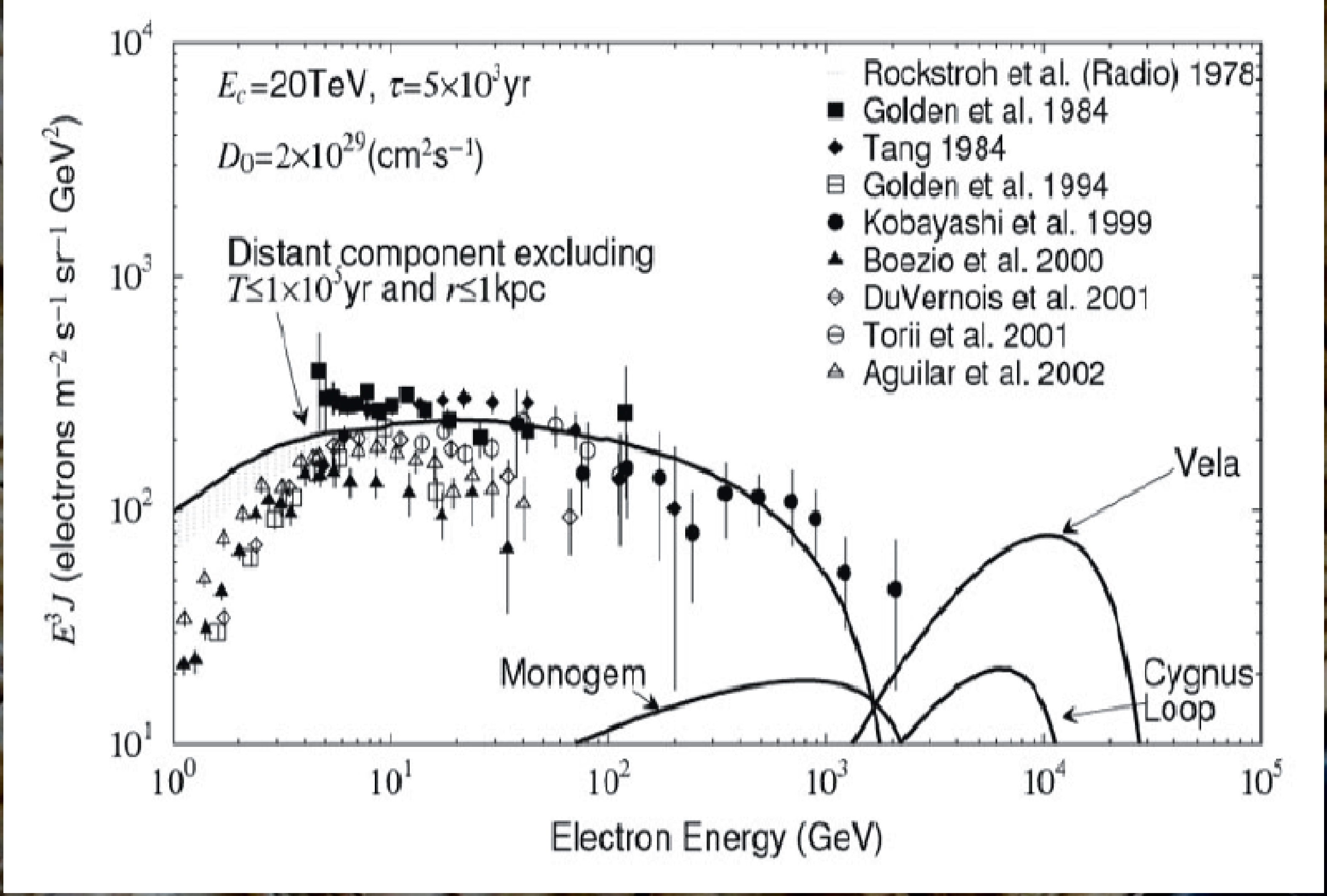
Ideal, e.g., for looking for spectral DM-induced features, like searching for γ-ray lines! If Weniger is right, the 130 GeV line should be seen with about 10σ significance (L.B., G. Bertone, J. Conrad, C. Farnier & C. Weniger, in preparation).

Mass = 130 GeV
Significance 4.6σ (3.3σ if "look elsewhere" effect included)

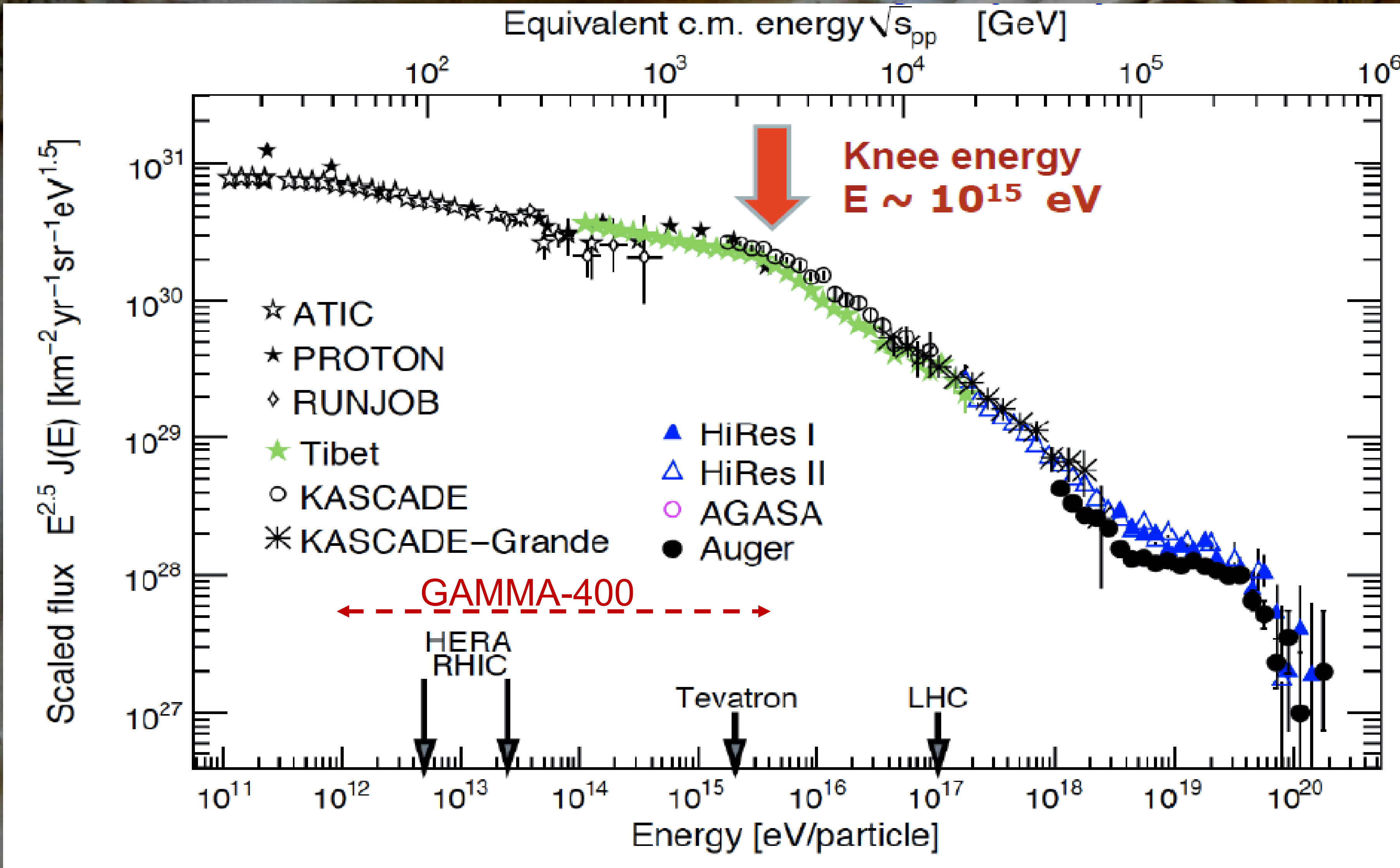
Scientific goals – electrons



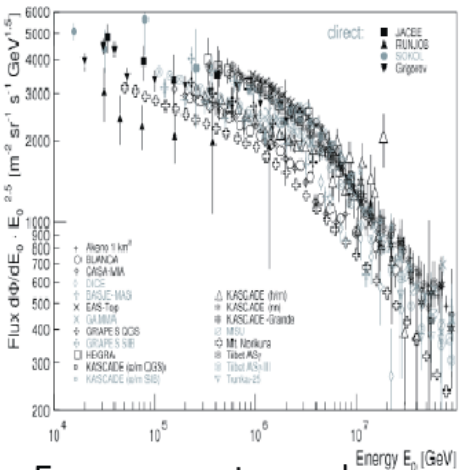
Scientific goals – electrons



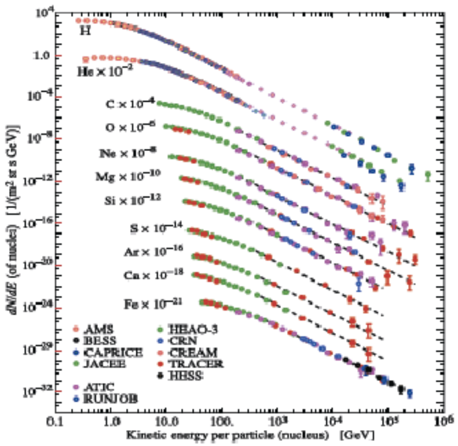
Scientific goals – Nuclei



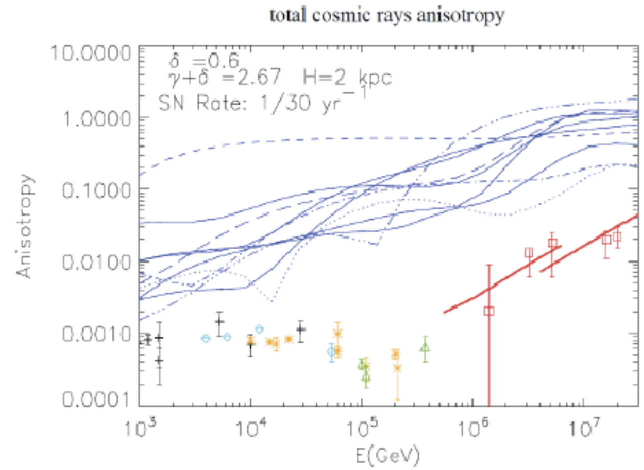
Scientific goals – Nuclei



Energy spectrum shape



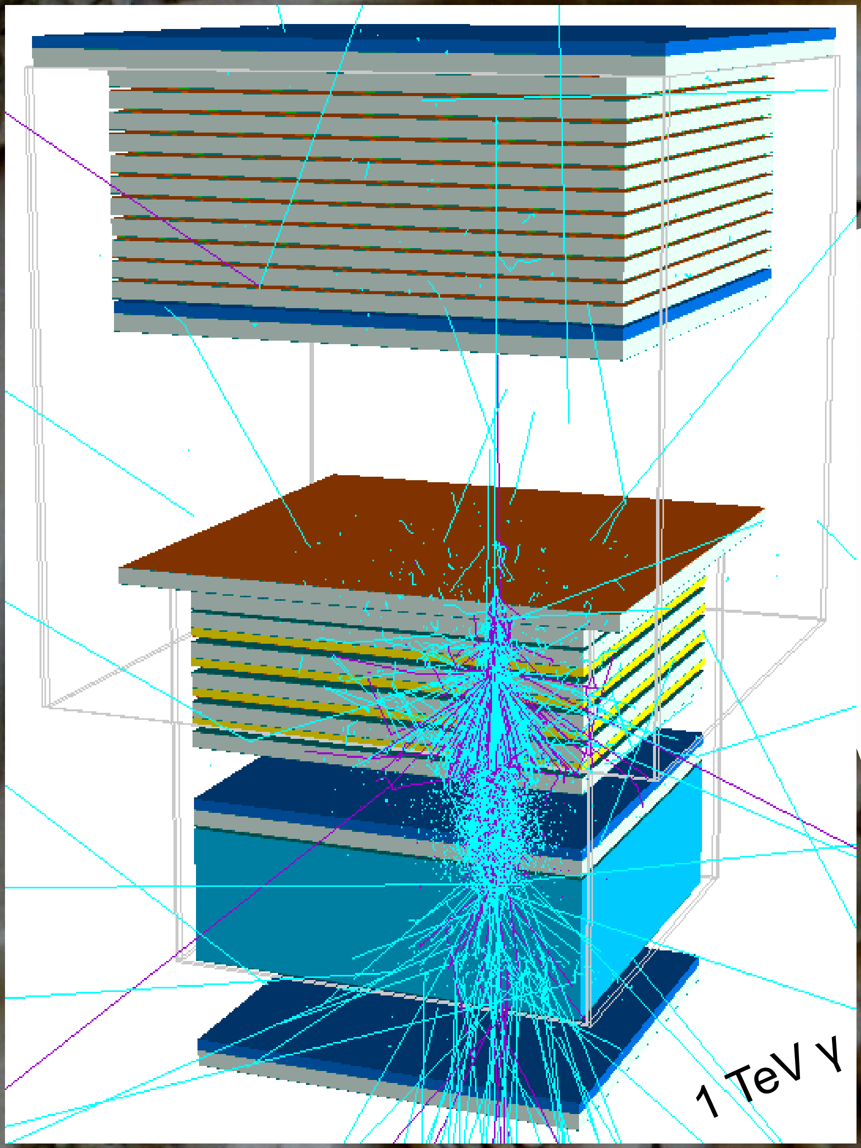
Composition

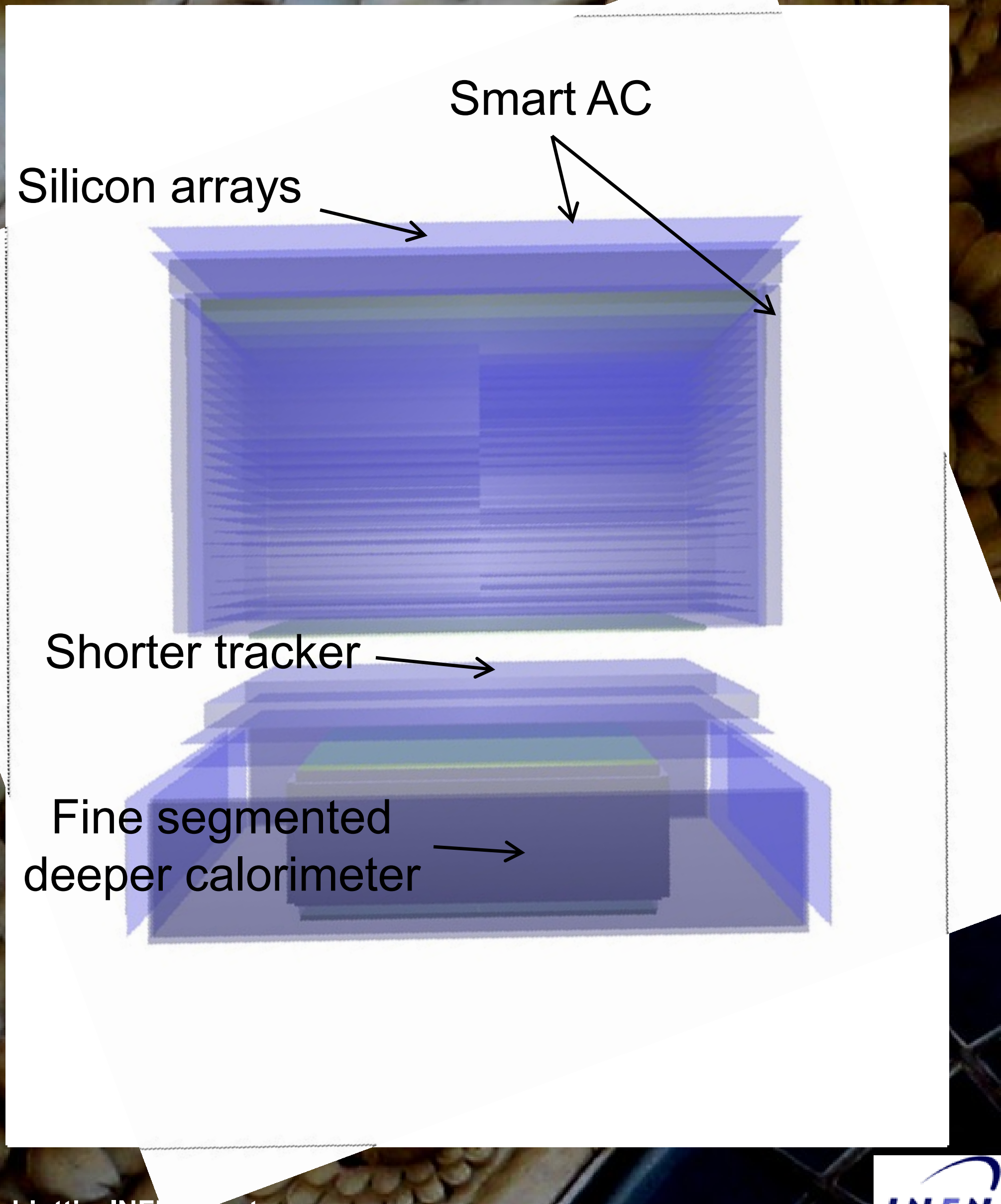


Anisotropy

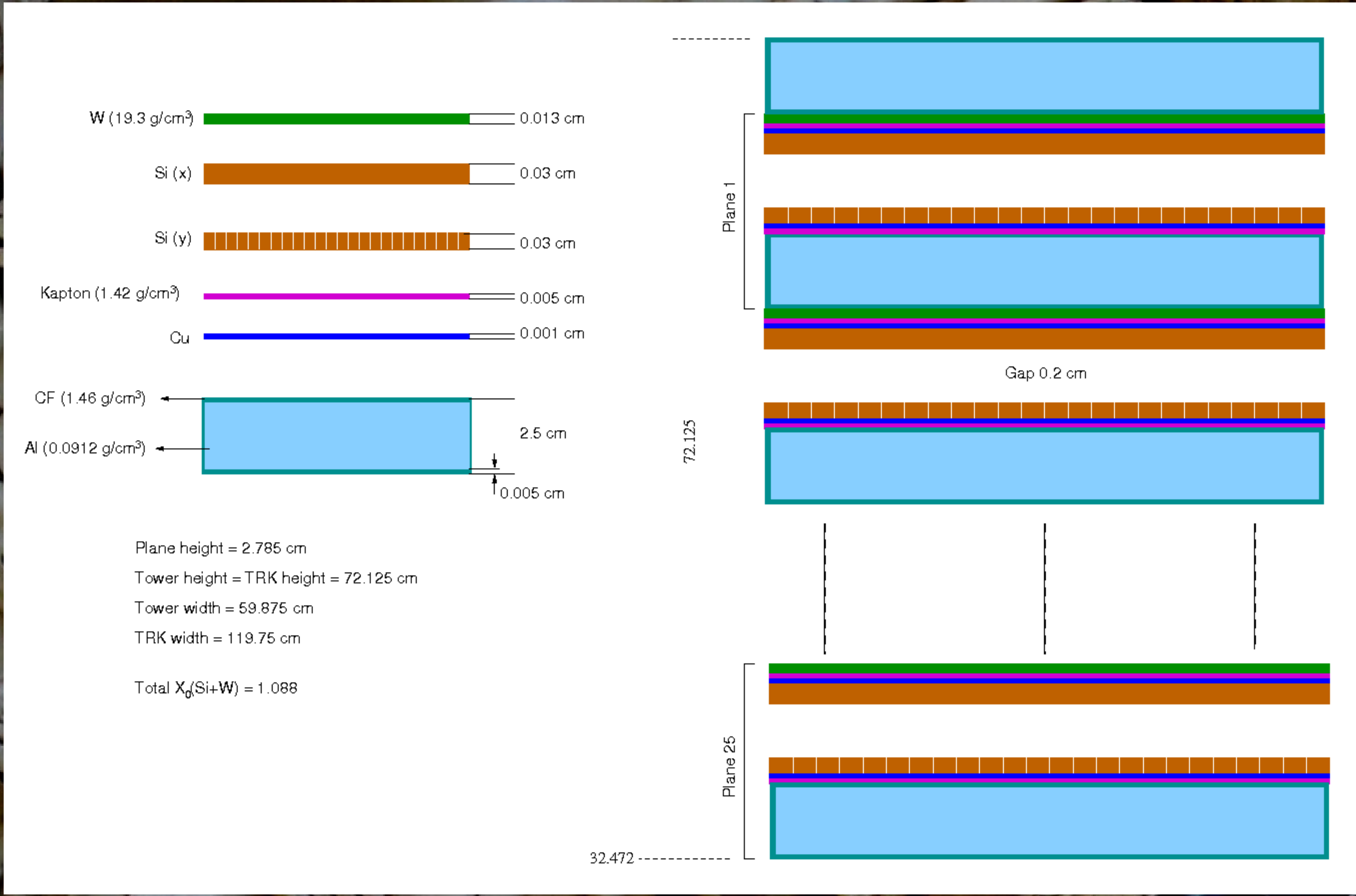
- Study the acceleration mechanism (or mechanisms)
- Study the limit of the acceleration phenomena
- Understand the kind of sources in the Galaxy
- Answer the question: is there the same mechanism (or source) for different nuclei?
- Study the distribution of the sources
- Study the propagation process in the Galaxy

Russian vs. Italian design





Tracker geometry

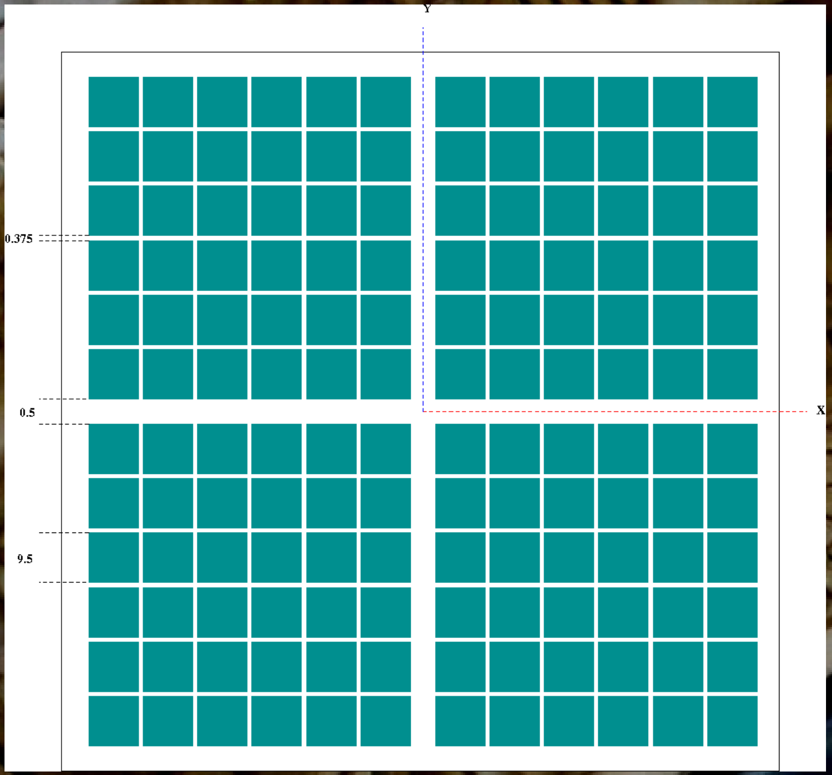


Tracker geometry

4 towers
tower dimension = 59.875 x 59.875 x 72.125 cm^3
tracker dimension = 119.75 x 119.75 x 72.125 cm^3

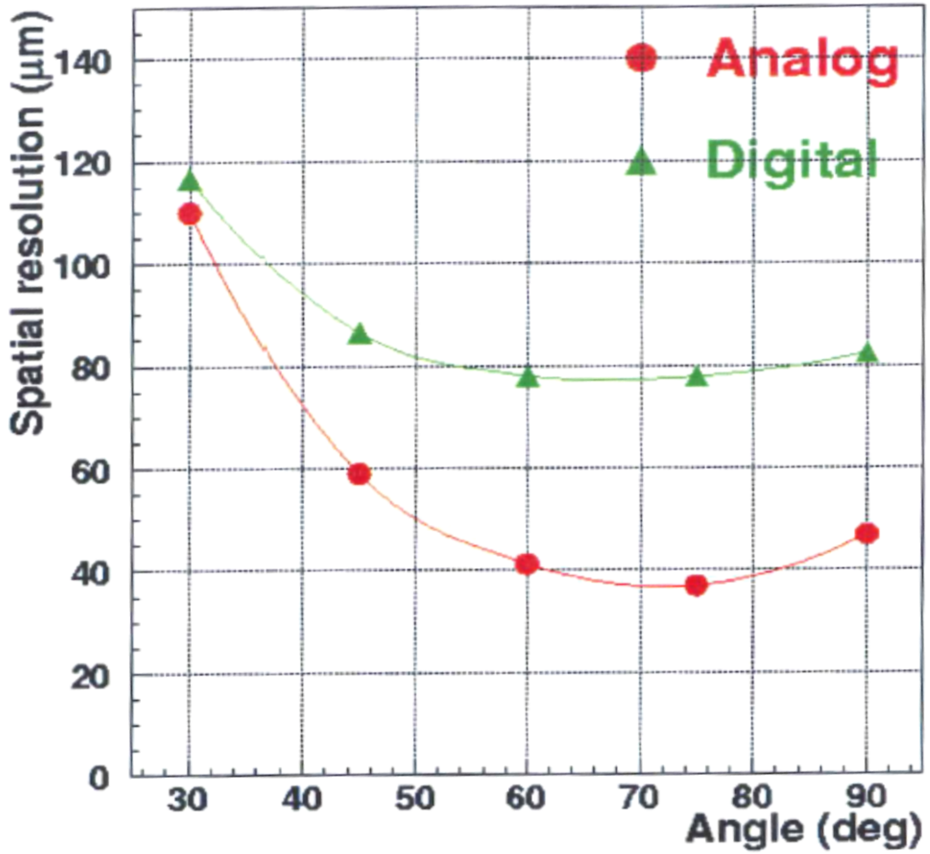
W thickness = 3%
25 planes - each plane 2 array (view) of the silicon tiles

Each array contains **6x6 silicon tiles**
tile dimension = 9.5 x 9.5 x 0.03 cm^3
each tile contain 900 strips of pitch 0.01 cm.



NB: schematic view, dead areas and Si sensors not to scale!

Analog vs. digital read-out



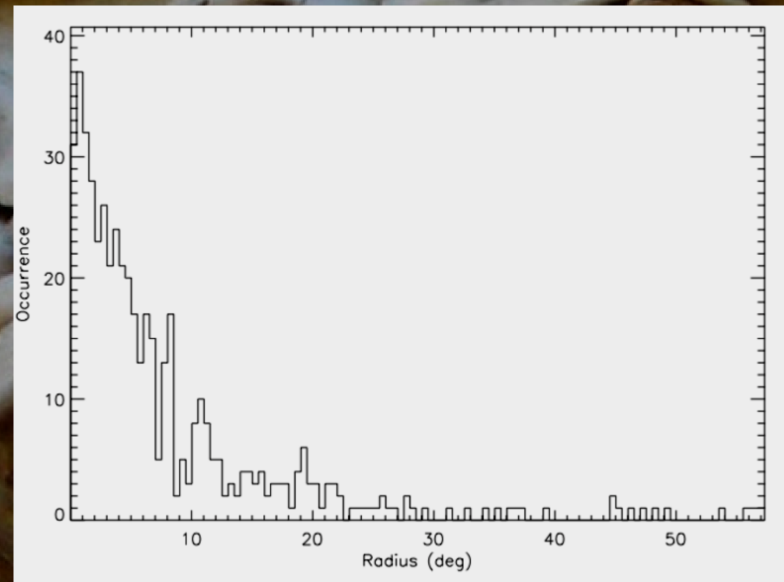
M. Prest (AGILE)

Digitization + Kalman reconstruction take into account analog readout!

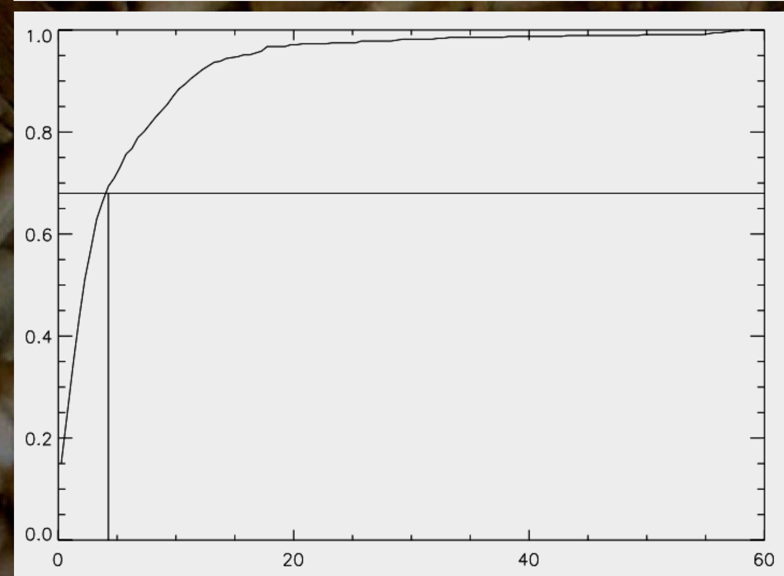
50 MeV – θ reconstruction

theta=30º phi=225º

PARALLEL FRONT

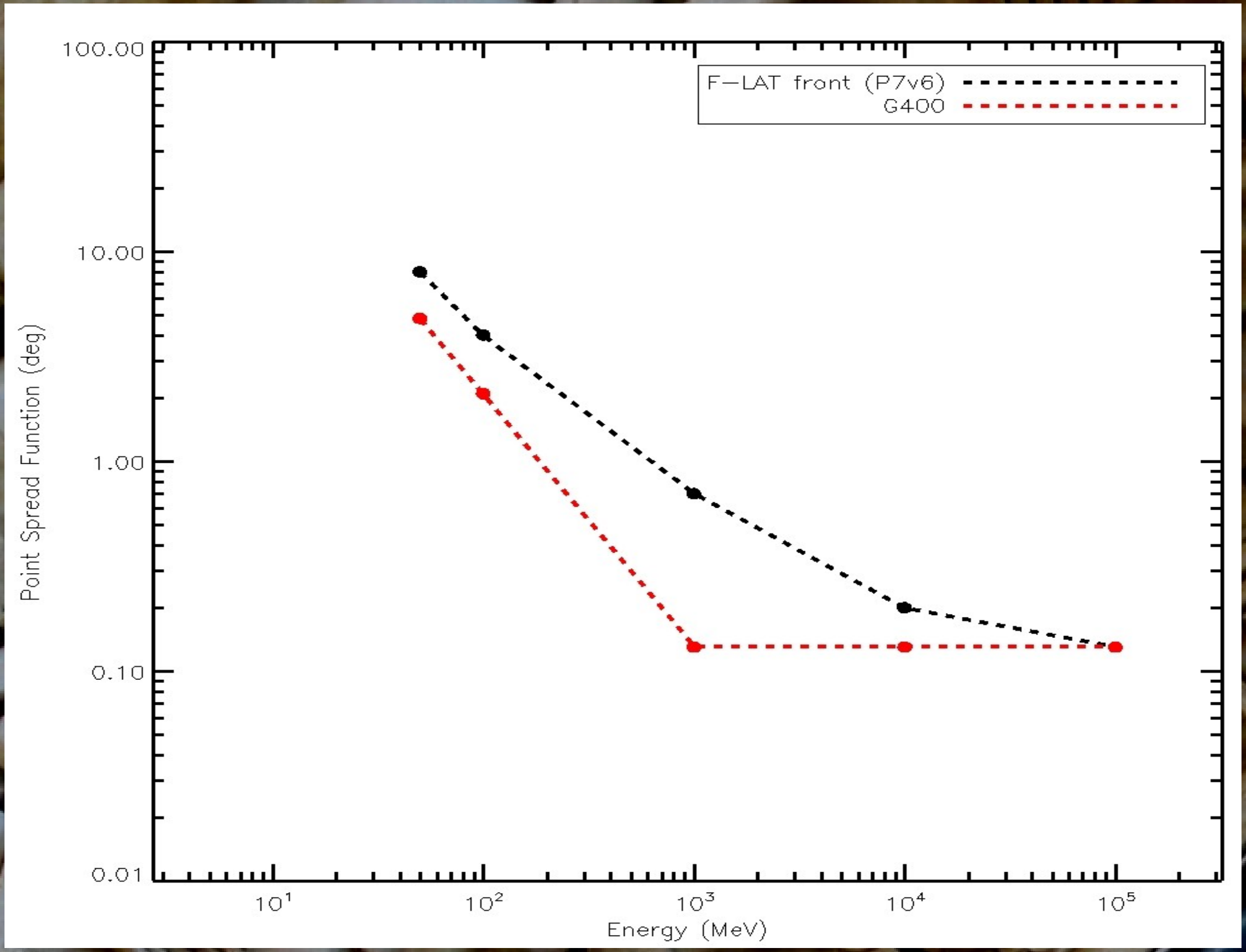


PSF_theta (68%) = 3.9º



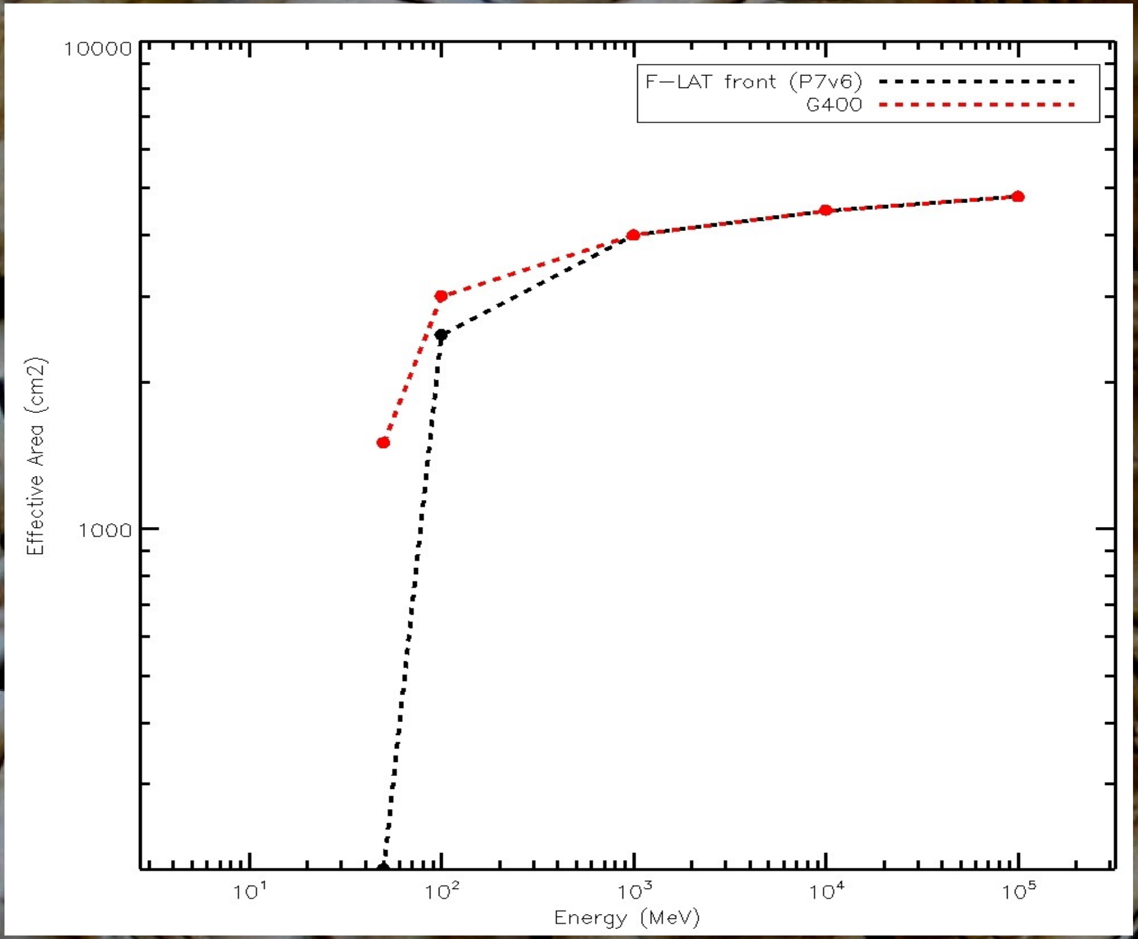
G-400 vs. Fermi PSF (68% containment radius) (Fermi: 0°; G-400: 30°)

G-400 set-up: 25 planes, 0.03 X_0 tungsten, 2.8 cm spacing, Si pitch 120 micron, analog (alternate) readout, Kalman reconstruction, assumed bkg rejection eff. 10^{-4}



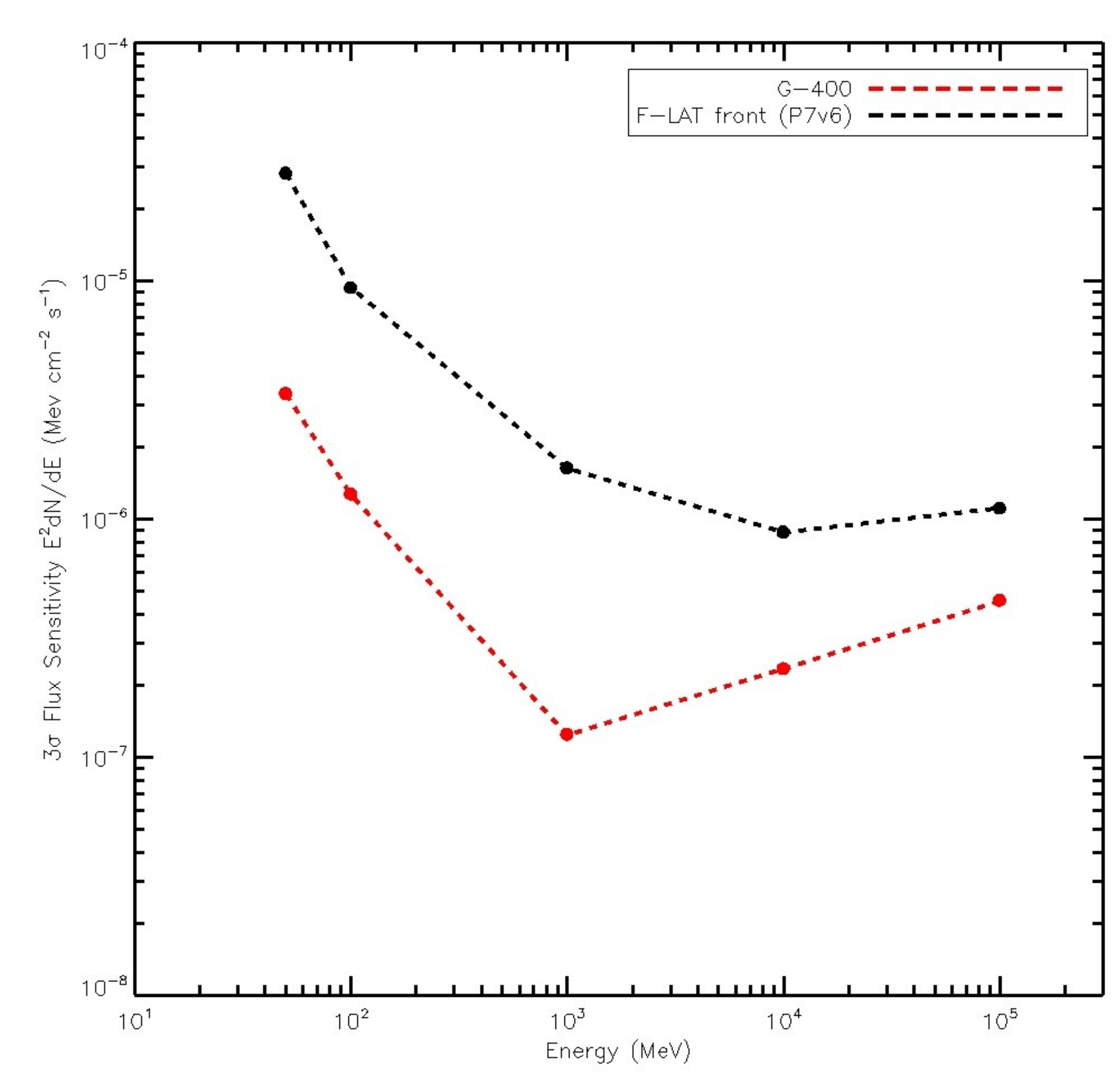
G-400 vs. Fermi effective area (0-30 degrees)

G-400 set-up: 25 planes, 0.03 X_0 tungsten, 2.8 cm spacing, Si pitch 120 micron, analog (alternate) readout, Kalman reconstruction, assumed bkg rejection eff. 10^{-4}



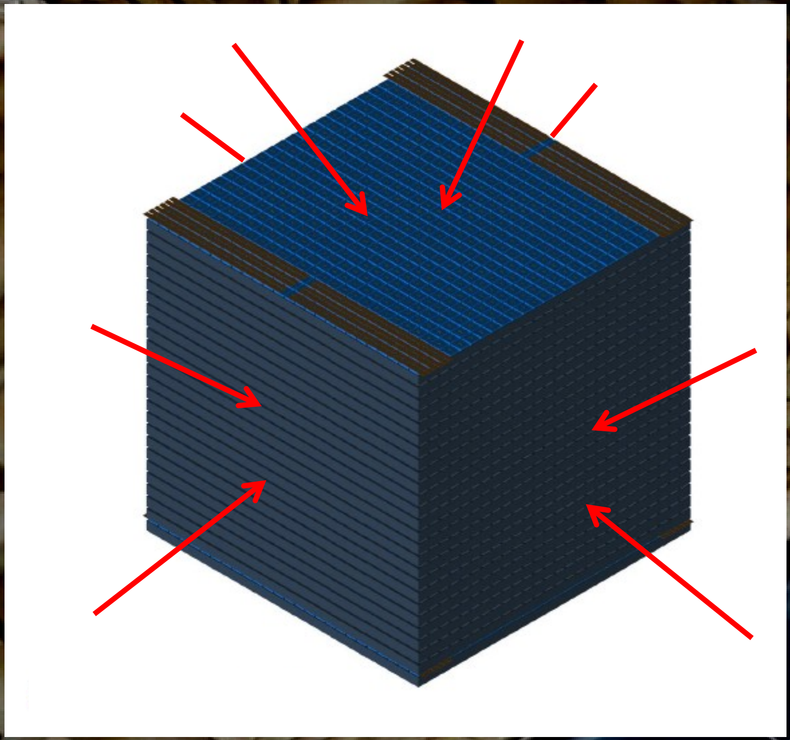
G-400 vs. Fermi 3σ flux sensitivity (2-week observing time)

Fermi-LAT in sky scanning mode, G-400 in pointing mode with no Earth occultation

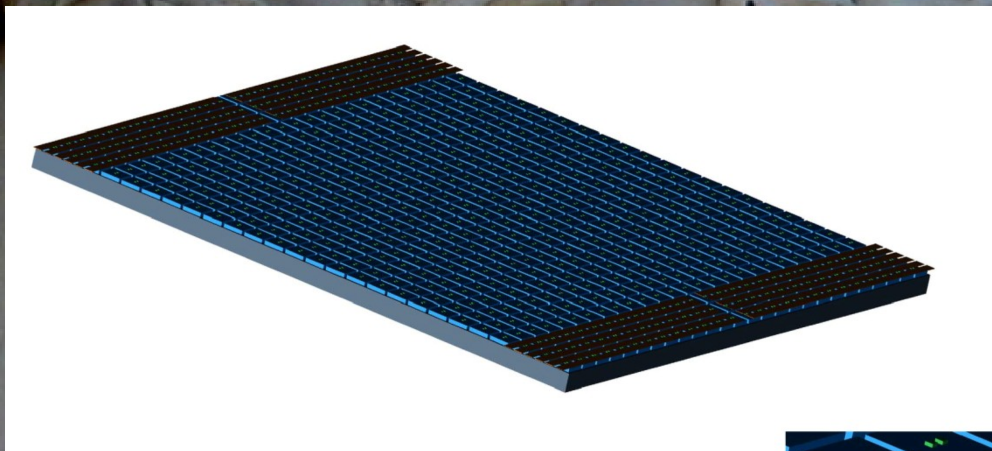


Calorimeter geometry

- Homogeneous calorimeter
- Symmetric, to maximize the Geometric Factor
- Total weight < 1600 kg
- Very high dynamic range
- Finely segmented in every direction
  $1\ R_M \times 1\ R_M \times 1\ R_M$ small BGO or CsI crystals, cubic shape
- Few mm gap between crystals

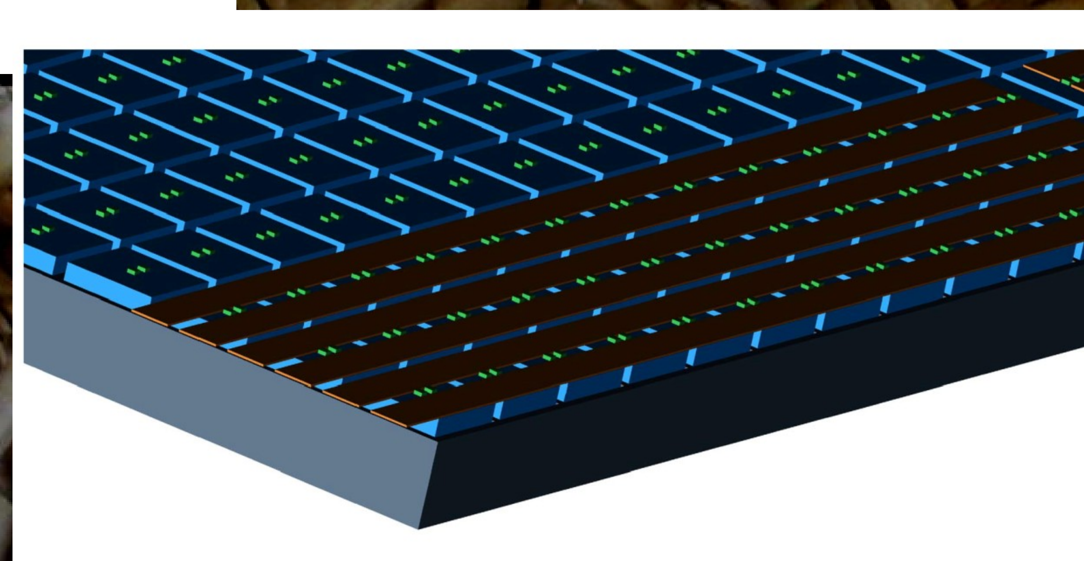


The calorimeter plane



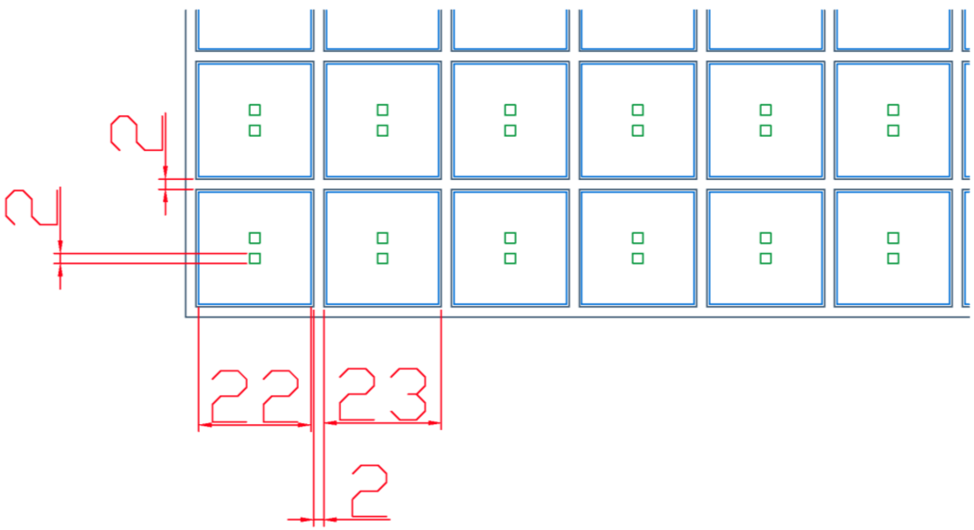
Blue: Crystals
Grey: Aluminium support
Green: Light detectors
Brown: Readout cables

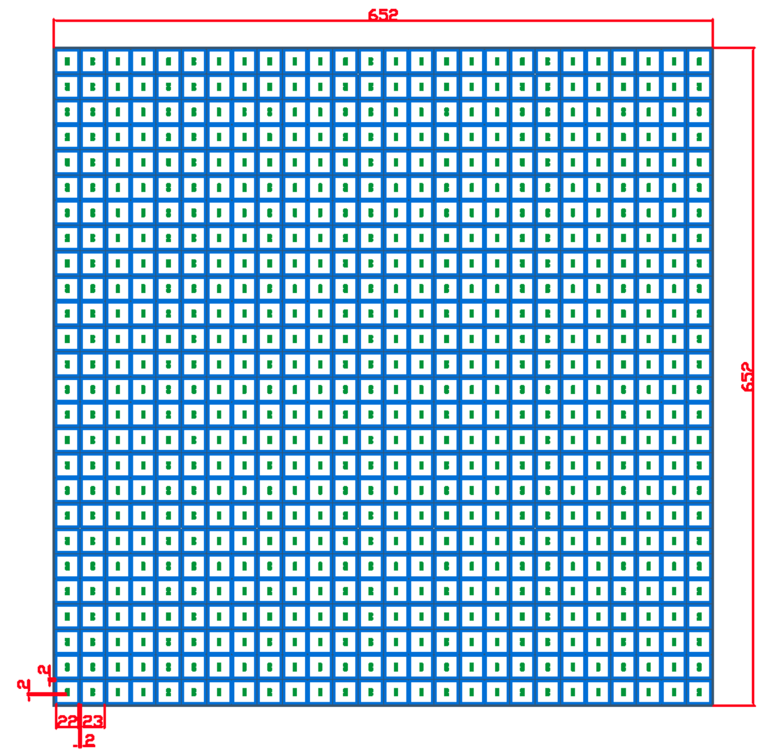
Readout is foreseen on 2 opposite sides



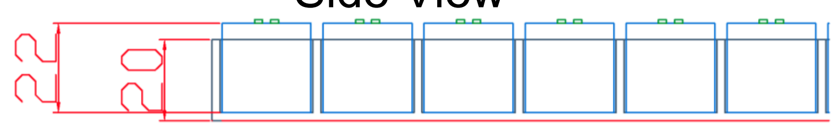
The calorimeter plane

Top View





Side View



BGO ~1600 kg

	Cubes	Cubes	Cubes	Cubes
N×N×N	28×28×28	28×28×27	29×29×25	32×32×20
L (cm)	2.2*	2.2*	2.2*	2.2*
Crystal volume (cm^3)	10.6	10.6	10.6	10.6
Gap (cm)	0.3	0.3	0.5	0.3
Mass (Kg)	1667	1607	1596	1555
N.Crystals	21952	21268	21025	20480
Size (cm^3)	70.0×70.0×70.0	70.0×70.0×67.5	78.3×78.3×67.5	80.0×80.0×50.0
Depth (R.L.) " (I.L.)	55×55×55 2.7×2.7×2.7	55×55×53 2.7×2.7×2.6	57×57×49 2.8×2.8×2.4	63×63×39 3.1×3.1×1.9
Planar GF (m^2sr) (fiducial**)	1.43×1.43×1.43	1.43×1.43×1.38	1.80×1.54×1.54	1.89×1.16×1.16

(* one Moliere radius)
(** within a reduced perimeter of size (N-1)*L)

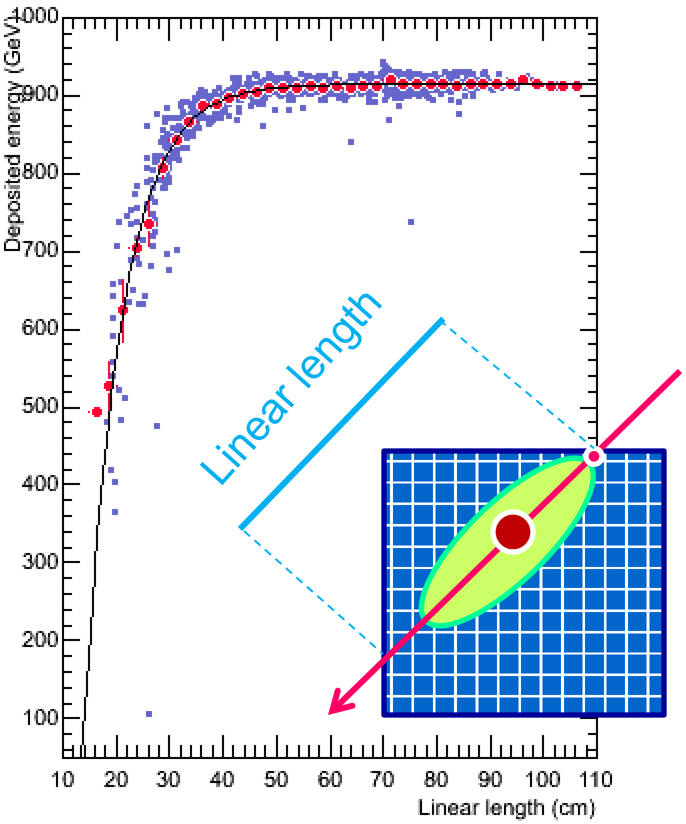
CsI(Tl) ~1600 kg

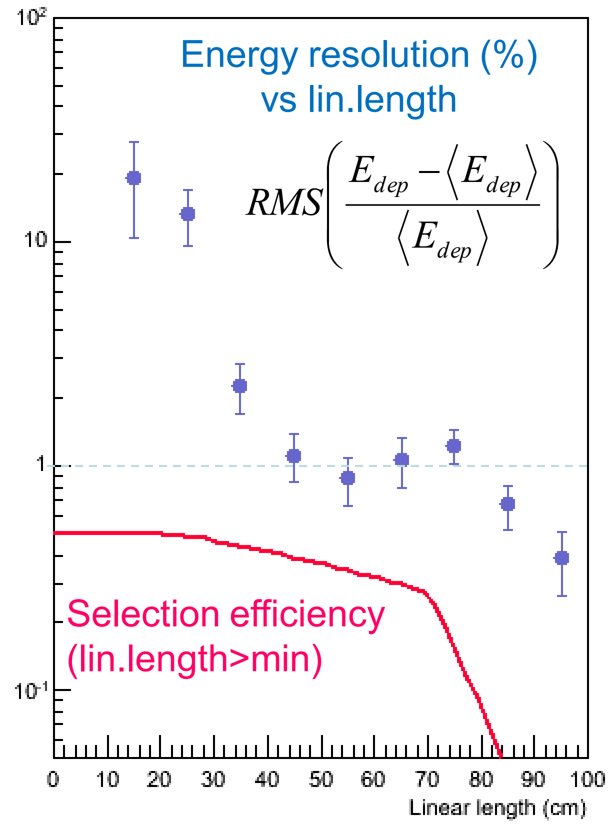
	Cubes	Cubes	Cubes	Cubes
N×N×N	20×20×20	20×20×19	21×21×18	32×32×32
L (cm)	3.6*	3.6*	3.6*	2.2
Crystal volume (cm^3)	46.7	46.7	46.7	10.6
Gap (cm)	0.3	0.4	0.3	0.3
Mass (Kg)	1683	1599	1578	1574
N.Crystals	8000	7600	7497	32768
Size (cm^3)	78.0×78.0×78.0	80.0×80.0×76.0	81.9×81.9×81.9	80.0×80.0×80.0
Depth (R.L.) " (I.L.)	39×39×39 1.8×1.8×1.8	39×39×37 1.8×1.8×1.7	41×41×33 1.9×1.9×1.6	38×38×38 1.8×1.8×1.8
Planar GF (m^2sr) (fiducial**)	1.72×1.72×1.72	1.81×1.72×1.72	1.91×1.53×1.53	1.89×1.89×1.89

(* one Moliere radius)
(** within a reduced perimeter of size (N-1)*L)

Electrons

Geometry:
BGO
28×28×28
L = 22mm
G = 3mm

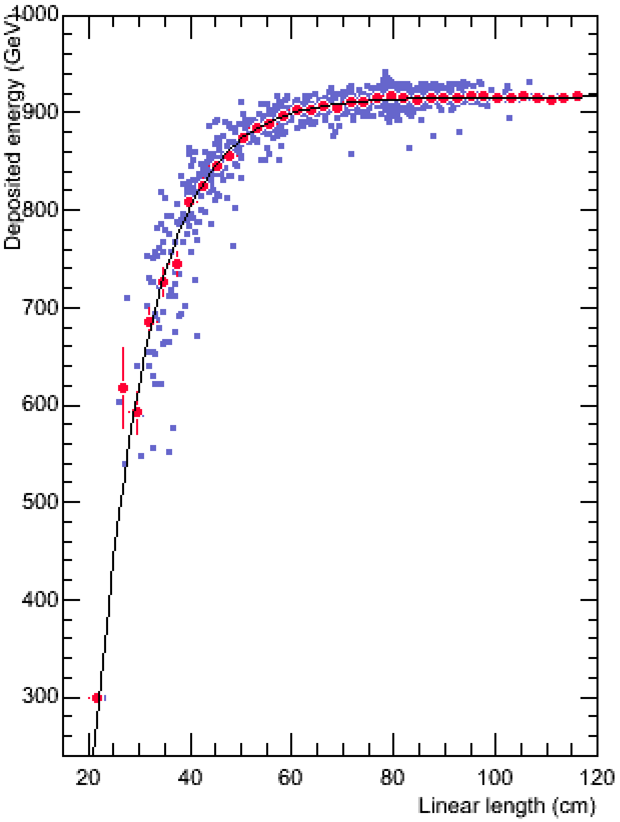


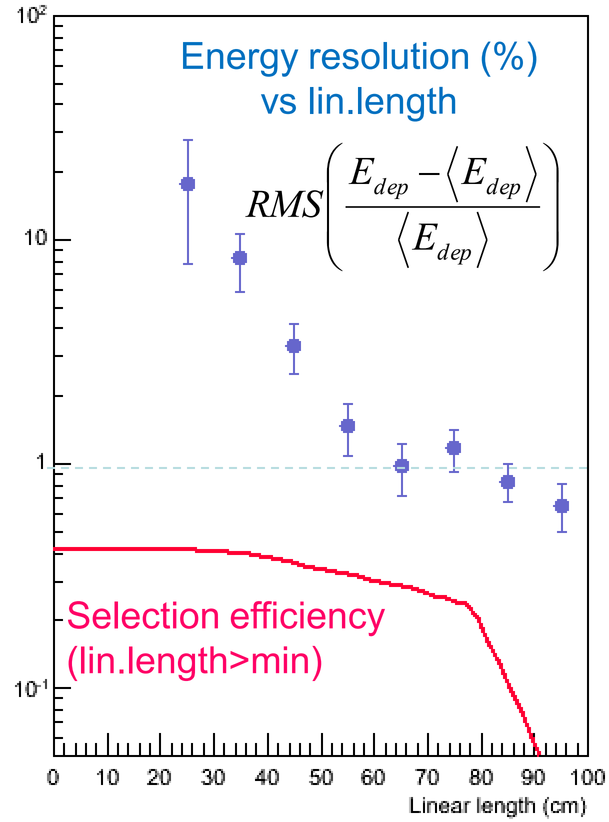


Selection:
- Extrapolated trajectory crossing top surface
- Maximum energy deposit within 2 crystals from lateral borders
- 1σ upper cut on maximum shower depth
- 1σ lower cut on maximum-to-total energy deposit

Electrons

Geometry:
CsI
20×20×20
L = 36mm
G = 3mm





Selection:

- Extrapolated trajectory crossing top surface
- Maximum energy deposit within 2 crystals from lateral borders
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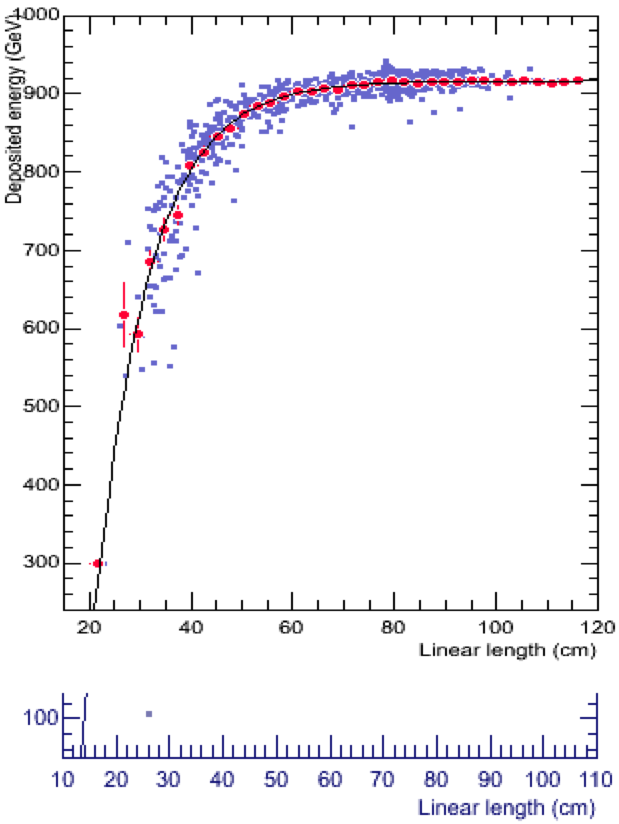
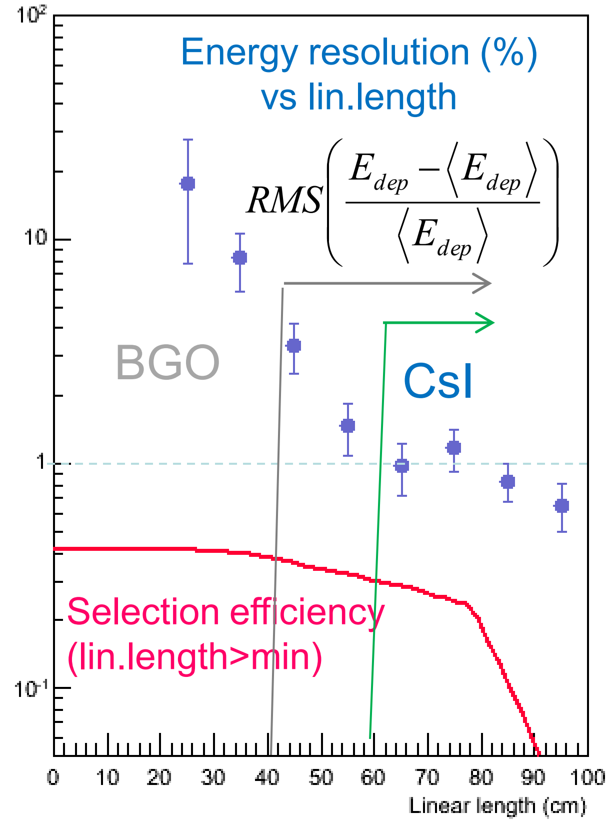
- 1σ lower cut on maximum-to-total energy deposit

1 TeV

Electrons

BGO vs. CsI(Tl)





Selection:
- Extrapolated trajectory crossing top surface
- Maximum energy deposit within 2 crystals from lateral borders
- 1σ upper cut on maximum shower depth
- 1σ lower cut on maximum-to-total energy deposit

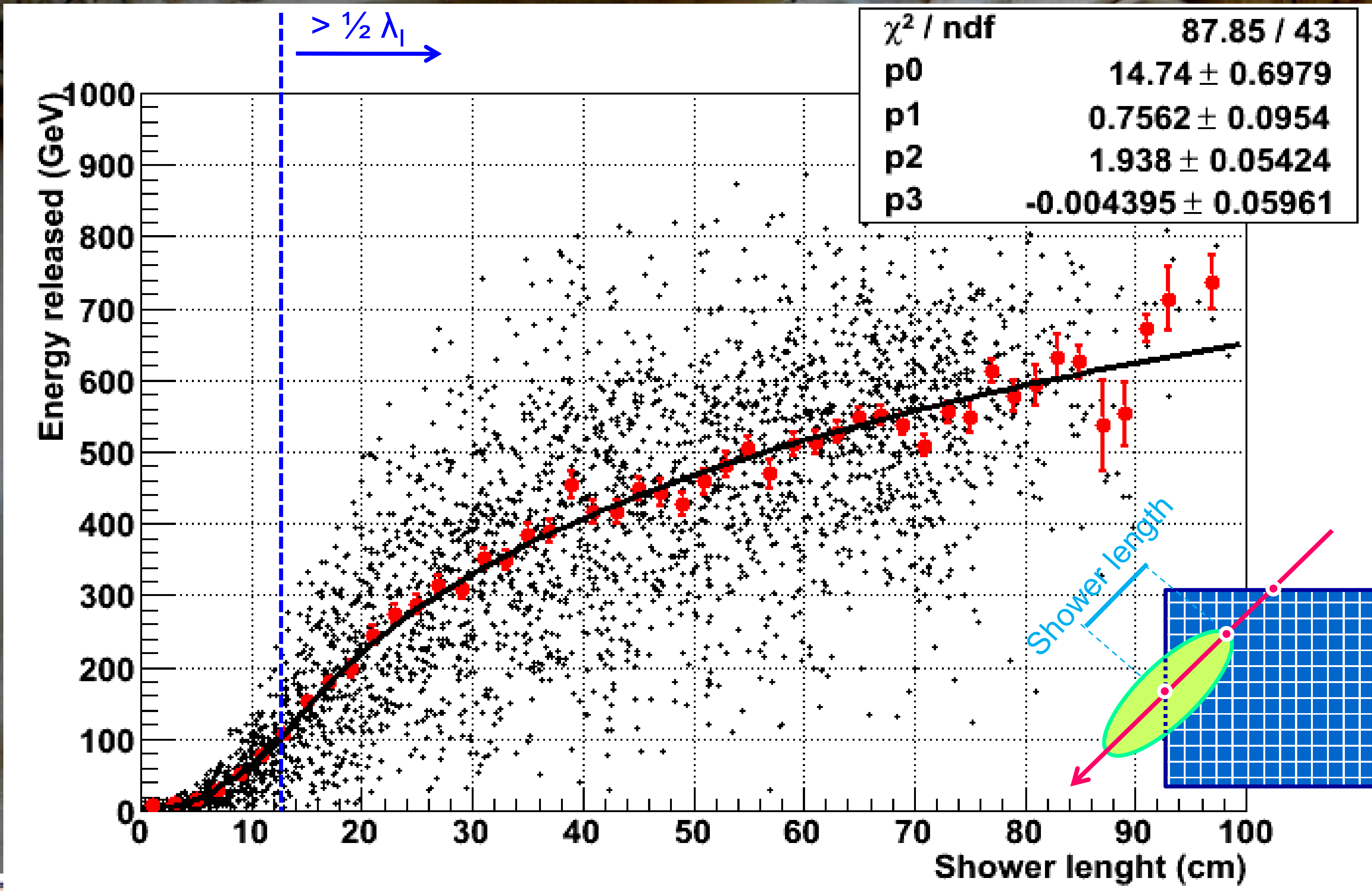
1 TeV

Electrons, summary

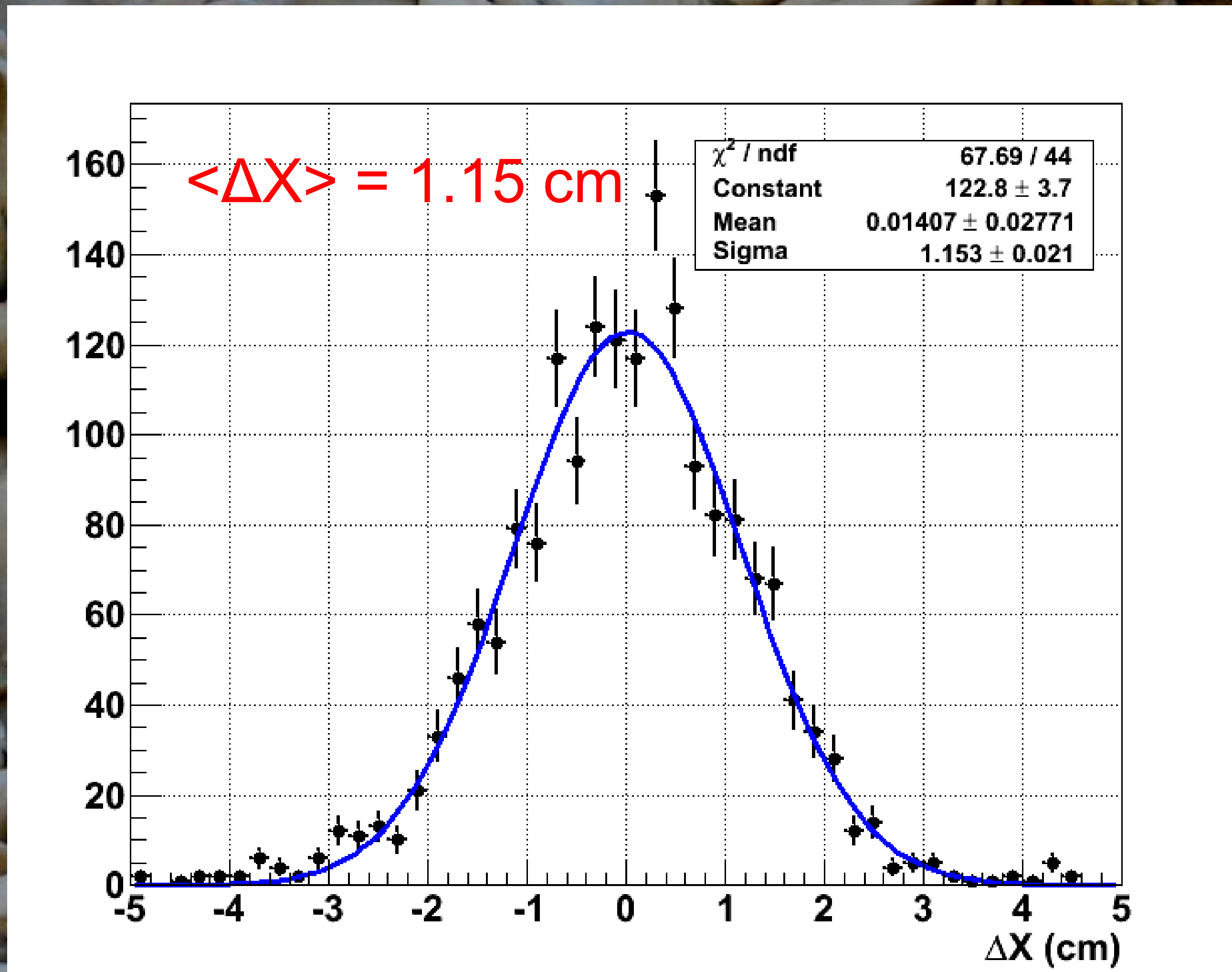
	Geometry	Planar GF (top)	Energy	σ(E)/E * (68.7%)
1	BGO 28×28×28 cube (2.2+0.3)cm	1.53 m^2sr	100GeV	~0.96%
2	BGO 29×29×25 cube (2.2+0.5)cm	1.92 m^2sr	100GeV	~1.39%
4	CsI 20×20×20 cube (3.6+0.5)cm	1.91 m^2sr	100GeV	~0.87%
5	CsI 32×32×32 cube (2.2+0.5)cm	2.01 m^2sr	100GeV	~0.99%

* shower-maximum fiducial containment+shower length > 40cm (BGO) 60cm(CsI)
** top and bottom fiducial containment

Protons (1 TeV)

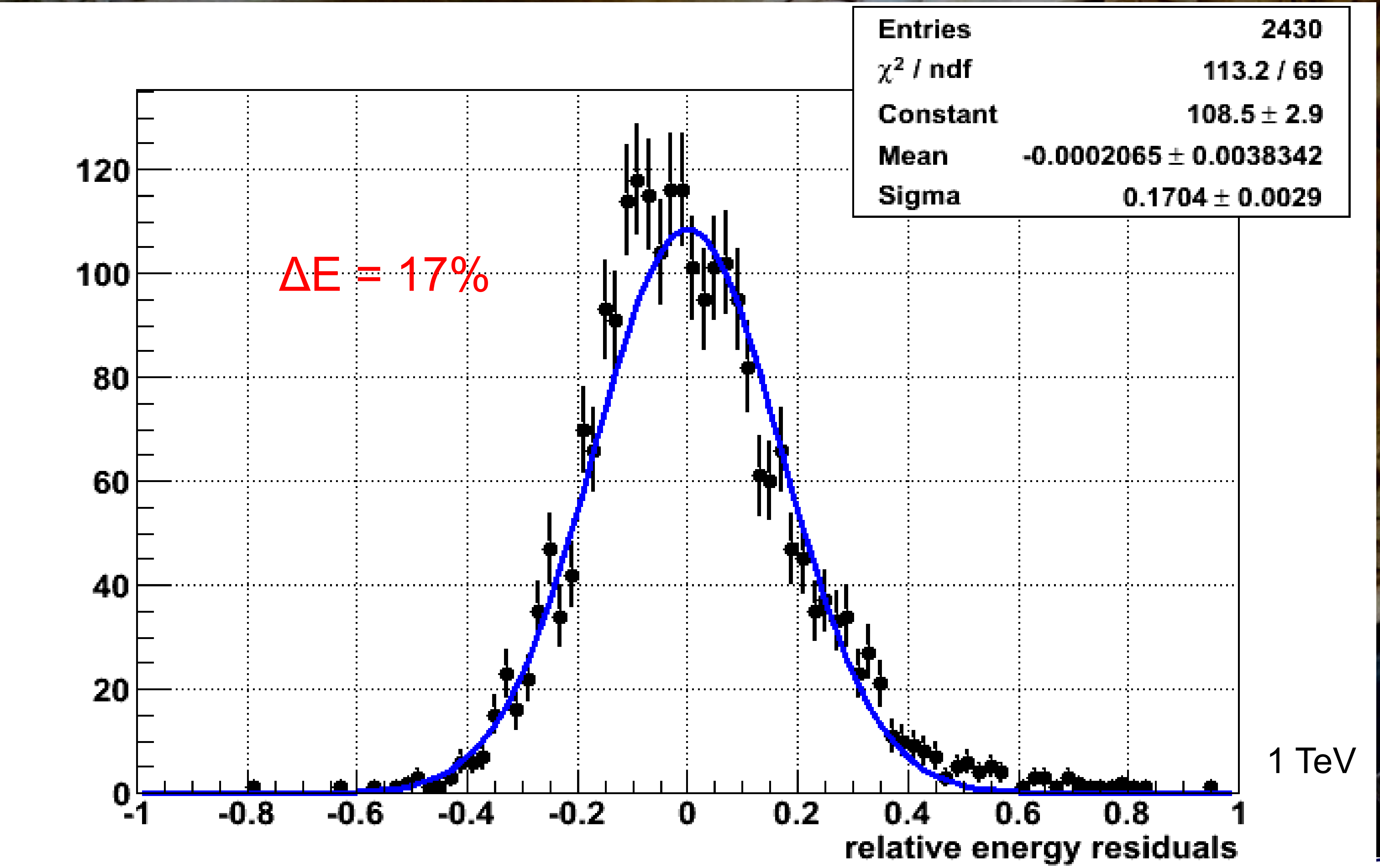


Protons, shower starting point resolution

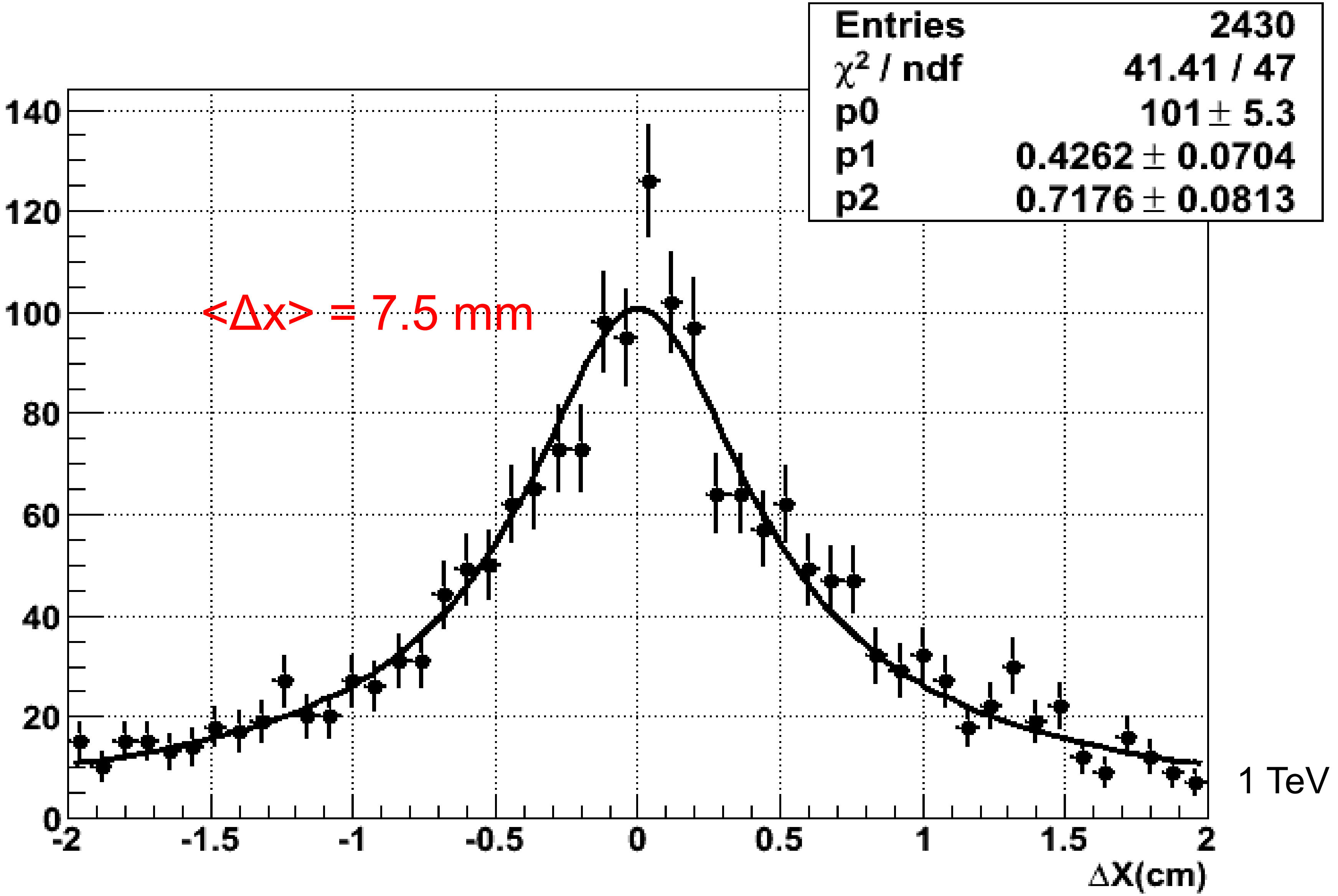


1 TeV

Protons, energy resolution



Protons, pointing resolution at calorimeter top



Protons, summary per geometry model (BGO)

BGO	Cubes	Cubes	Cubes
N×N×N	28×28×28	29×29×25	32×32×20
L (cm)	2.2*	2.2*	2.2*
G (cm)	0.3	0.5	0.3
Mass (Kg)	1667	1596	1555
N.Crystals	21952	21025	20480
Size (cm^3)	70.0×70.0×70.0	78.3×78.3×67.5	80.0×80.0×50.0
Depth (R.L.) " (I.L.)	55×55×55 2.7×2.7×2.7	57×57×49 2.8×2.8×2.4	63×63×39 3.1×3.1×1.9
Planar GF (m^2sr) (fiducial**)	1.43×1.43×1.43	1.80×1.54×1.54	1.89×1.16×1.16
σ(x)	0.75 cm	0.79 cm	0.85 cm
Efficiency	54%	53% (top) 41% (side)	55% (top) 43% (side)
Effective G.F.	5 x 0.77 = **3.86 m^2 sr**	1 x 0.923 + 4 x 0.634 = **3.46 m^2 sr**	1 x 1.04 + 4 x 0.504 = **3.05 m^2 sr**
σ(E)/E	**17%**	**20%**	**23%**

Protons, summary per geometry model (CsI)

CsI(TI)	Cubes	Cubes
N×N×N	20×20×20	32×32×32
L (cm)	3.6*	2.2
G (cm)	0.3	0.3
Mass (Kg)	1683	1574
N.Crystals	8000	32768
Size (cm^3)	78.0×78.0×78.0	80.0×80.0×80.0
Depth (R.L.) " (I.L.)	39×39×39 1.8×1.8×1.8	38×38×38 1.8×1.8×1.8
Planar GF (m^2sr) (fiducial**)	1.72×1.72×1.72	1.89×1.89×1.89
σ(x)	0.91 cm	0.78 cm
Efficiency	44%	41%
Effective G.F.	5 x 0.75 = **3.75 m^2 sr**	5 x 0.77 = **3.86 m^2 sr**
σ(E)/E	**16%**	**16%**

		Electrons			Gamma rays		Protons		
	Geometry	E (TeV)	GF_{eff} (m^2sr) (top)	$\frac{\sigma(E)}{E}$	E (TeV)	$\frac{\sigma(E)}{E}$	**E (TeV)**	**GF_{eff} (m^2sr) (tot)**	**$\frac{\sigma(E)}{E}$ (top)**
1	BGO 28×28×28 (2.2+0.3)cm	0.1 0.5 1	0.627 0.658 0.643	0.81% 0.60% 0.63%	0.1	0.96%	1	3.86	17%
2	BGO 29×29×25 (2.2+0.5)cm	1	0.827	1.09%	0.1	1.39%	1	3.46	20%
3	BGO 32×32×20 (2.2+0.3)cm						1	3.05	23%
4	CsI 20×20×20 (3.6+0.5)cm	1	0.573	0.69%	0.1	0.87%	1	3.75	16%
5	CsI 32×32×32 (2.2+0.5)cm	1	0.683	0.75%	0.1	0.99%	1	3.86	16%

Summary

- GAMMA-400 great opportunity as a new space experiment
- 30 MeV – 1 GeV energy range crucial for gamma rays physics
- unique features to make simultaneous measurements of gammas, electrons and nuclei
- many discoveries to be made by GAMMA-400, dark matter searches, CR origin, production, acceleration to the largest energies, etc.
- target: deliver technical sample in 2017

Thanks!