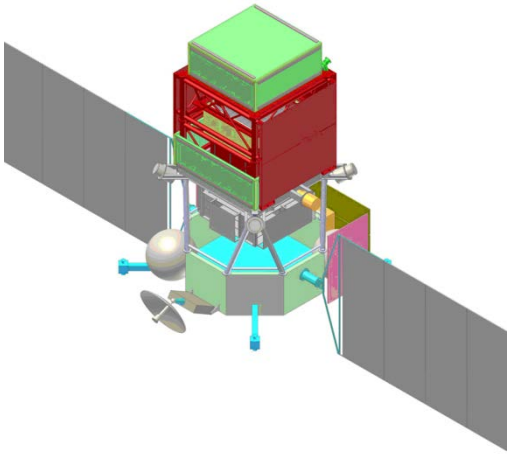


The GAMMA-400 mission

Valter Bonvicini
INFN Trieste, Italy
On behalf of the GAMMA-400 Collaboration

VULCANO Workshop, 18-24 May 2014

Outline

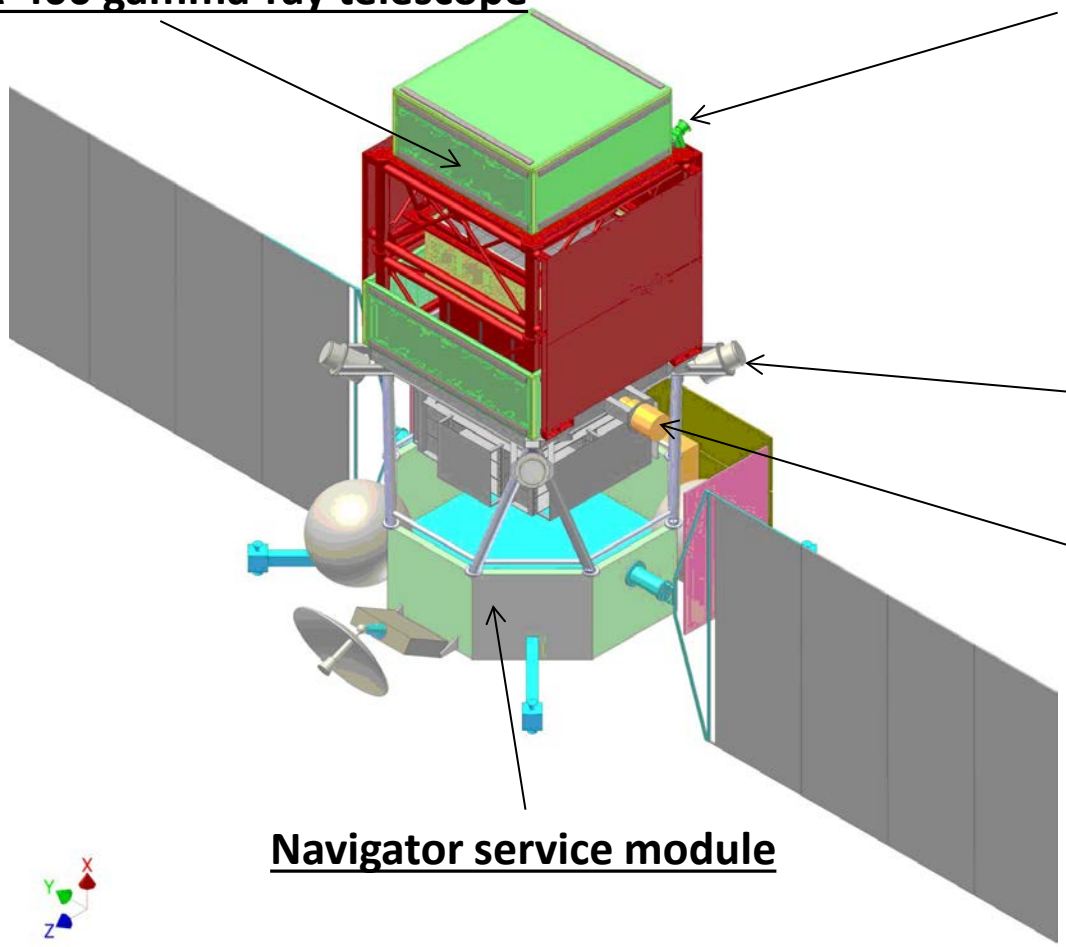
- Origin and evolution of the project
- The apparatus
  - The converter/tracker
  - The calorimeter
- Physics with GAMMA-400
  - Photons
  - Electrons
  - Nuclei
- Conclusions

The GAMMA-400 project

- Mission is approved by ROSCOSMOS (launch currently scheduled by 2020)
- GAMMA-400:
  - Scientific payload mass: 4100 kg
  - Power budget: 2000 W
  - Telemetry downlink capability: 100 GB/day
  - Lifetime: > 7 years
  - Orbit (initial parameters): apogee 300000 km, perigee 500 km, orb. period 7 days, inclination 51.8 °
  - GAMMA-400 will be installed onboard the platform “Navigator” manufactured by Lavochkin

GAMMA-400 SCIENTIFIC COMPLEX ON THE NAVIGATOR SERVICE MODULE

GAMMA-400 gamma-ray telescope



Navigator service module

Star sensors (2) with accuracy of ≈5" **(Space Research Institute)**

Gamma-ray burst monitor "Konus-FG" (6) (Ioffe Physical Technical Institute, St. Petersburg)

4 direction detectors on telescopic booms

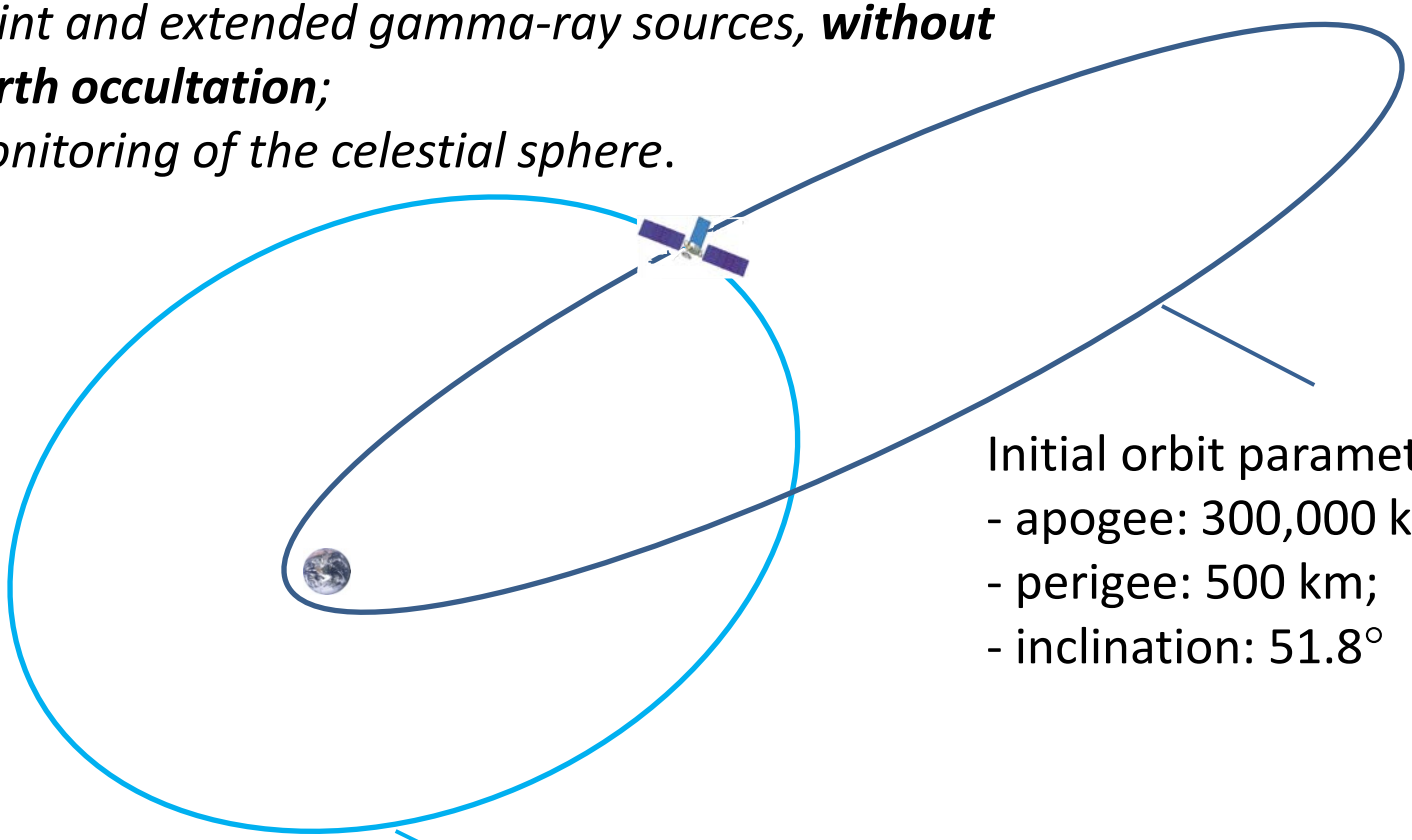
2 spectrometric detectors

Magnetometer (2) (Ukraine, Lviv) on telescopic boom

ORBIT EVOLUTION AND OBSERVATION MODES

Observation modes:

- *continuous long-duration (~100 days) observation of specific regions of celestial sphere, including point and extended gamma-ray sources,* ***without Earth occultation****;*
- *monitoring of the celestial sphere*.



Initial orbit parameters:
- apogee: 300,000 km:
- perigee: 500 km;
- inclination: 51.8°

After ~ 5 months the orbit will become more circular with a radius of ~200,000 km.

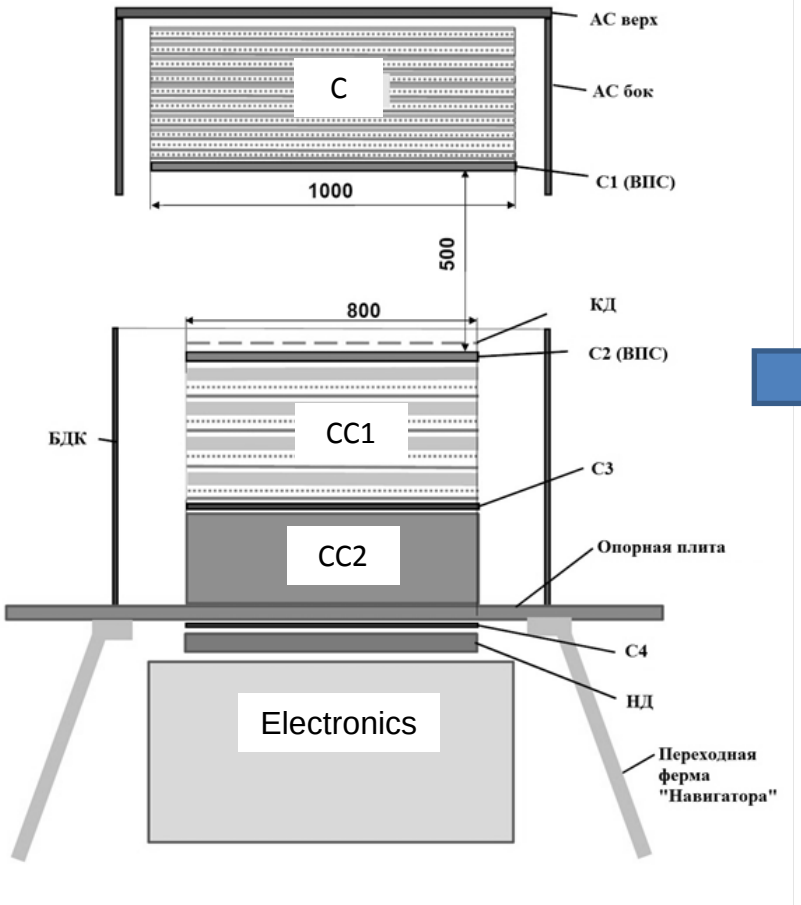
GAMMA-400

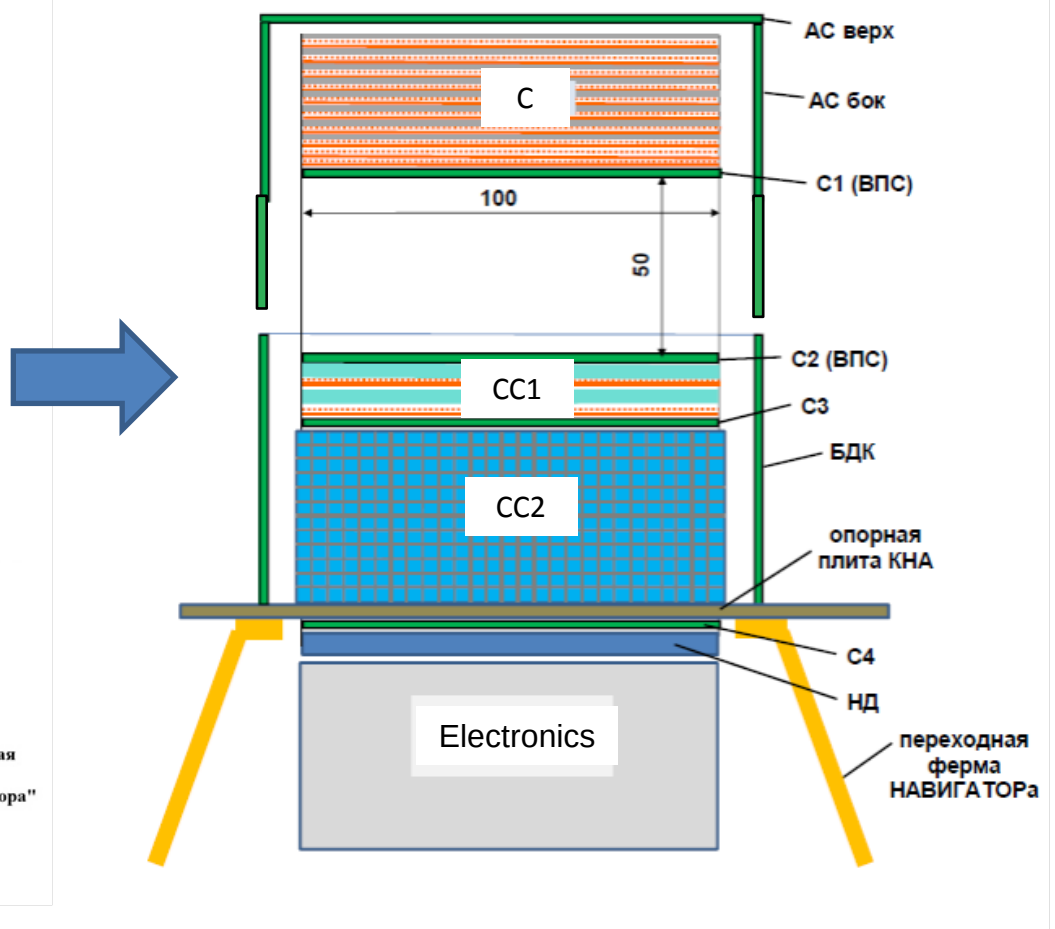
- Original Russian design focused on:
  - High Energy Gamma-rays (~ 10 GeV – 3 TeV)
  - High energy electrons (e^+ and e^-) up to TeV
- Scientific objectives (from Russian proposal):
  - "To study the nature and features of weakly interacting massive particles, from which the Dark Matter consists"
  - "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"

Improvements in the GAMMA-400 design and performance

- During the last years, the collaboration between Italian and Russian groups has resulted in a new version of the apparatus. Guideline:
  - to develop a jointly defined **dual instrument** that, taking into account the currently available financial resources, optimizes the scientific performance and improves them with respect to the original version: this new version **has been agreed upon by both (Russian and Italian) sides during a collaboration meeting held in Moscow in February 2013.**

GAMMA-400 evolution

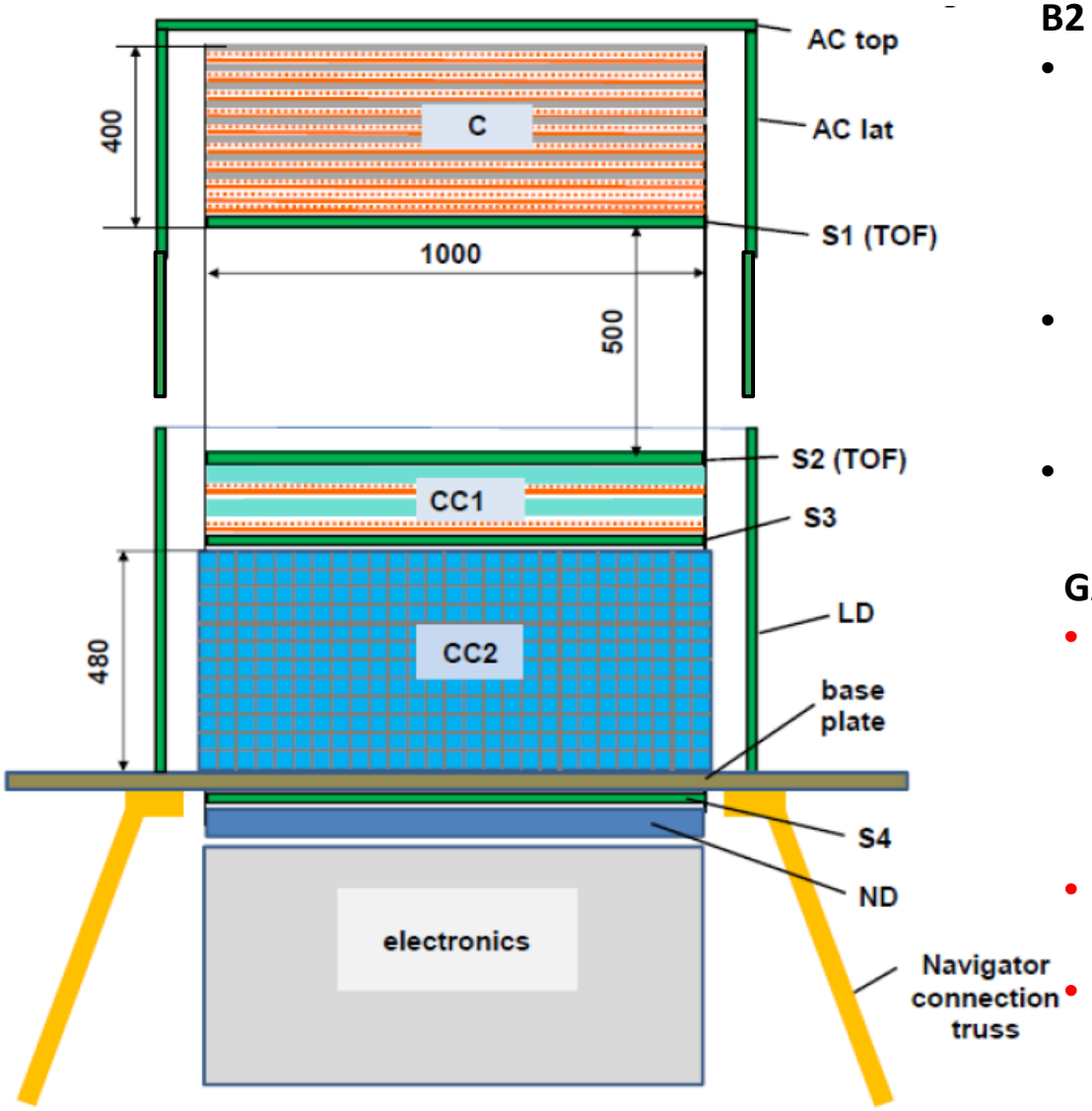




Original Russian proposal (2011)

Jointly agreed Russian-Italian proposal (2013)

The GAMMA-400 apparatus



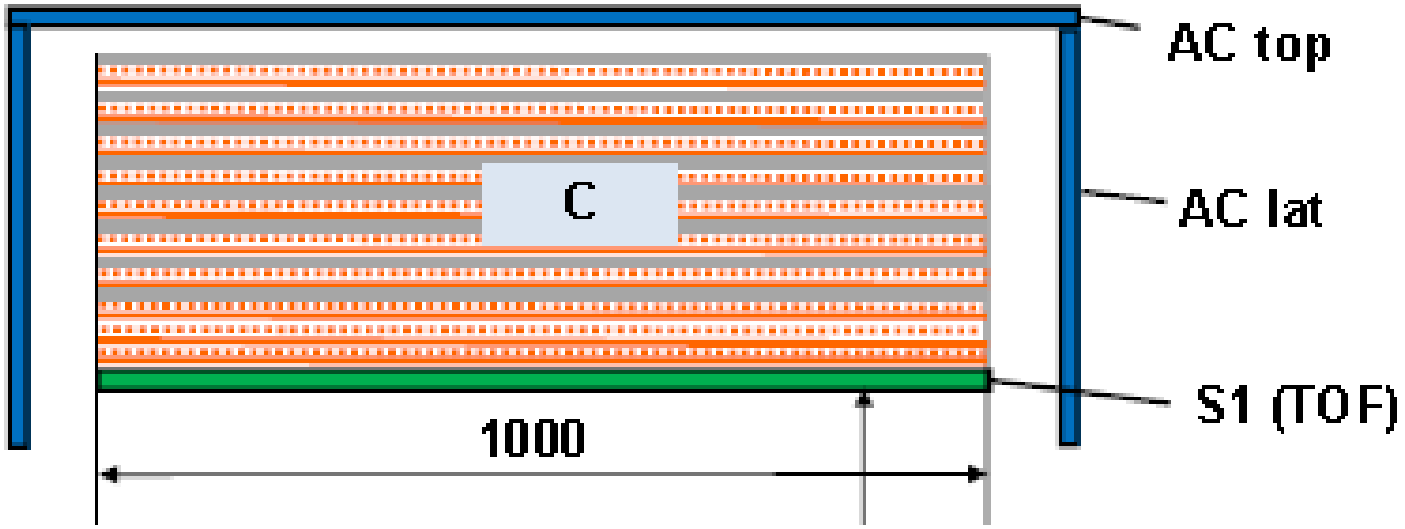
B2 over B1 improvements:

- Introduction of a highly segmented homogeneous calorimeter with CsI cubes ⇒ improved energy resolution, extended GF with lateral particle impingement, nuclei capability
- Increase of the planar dimensions of the calorimeter (from 80 cm x 80 cm to 100 cm x 100 cm) ⇒ larger A_{eff}
- Si strip detector pitch of the 2 CC1 layers decreased from 0.5 mm to 0.08 mm

GAMMA-400 characteristics:

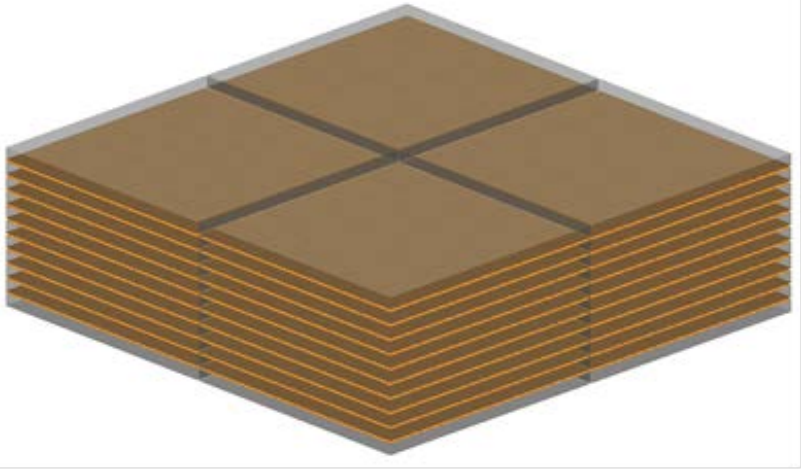
- **a dual instrument** for **photons** (100 MeV ÷ 1 TeV) and **cosmic rays** (electrons ~ 10 TeV and high energy cosmic-ray nuclei, p and He spectra at the "knee" (10^{14} – 10^{15} eV);
- **State of the art Si-W converter/tracker with analogue read-out;**
- **3-D, deep, homogeneous calorimeter with excellent resolution and large acceptance.**

Converter/Tracker



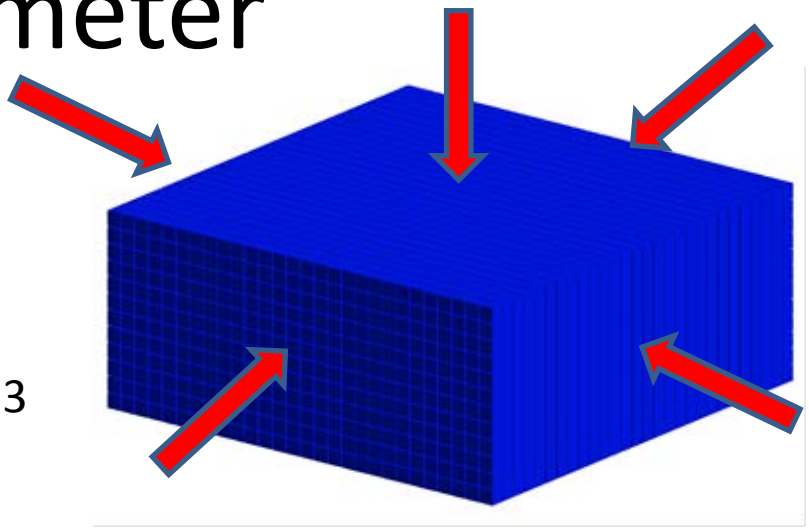
- 10 x-y layers (20 views):
  - 8 layers W $0.08X_0$ + 8 planes Si (x,y)
  - 2 layers of Si (x,y), no W

Converter/Tracker

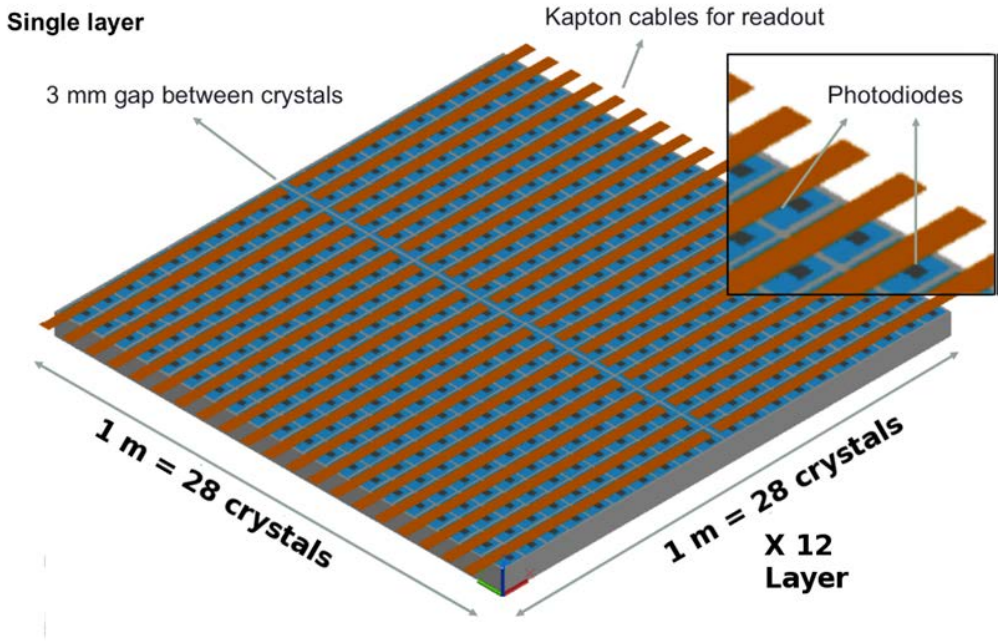


- Homogeneous Si-W Tracker
- 4 towers (~ 50 cm x 50 cm each);
- 8 W/Si-x/Si-y planes + 2 Si-x/Si-y planes (no W)
- Thickness of each plane 0.1 X_0
- Each sensor ~ 9.7 cm x 9.7 cm from 6” wafers;
- Sensors arranged in ladders (5 detectors/ladder), 1 ladder ~ 50 cm;
- Implant pitch 80 µm (fine segmentation)
- Read-out pitch 240 µm (capacitive charge division, one strip every 3 is read-out), 384 read-out strips/ladder;
- 2000 silicon detectors;
- 153600 readout channels, 2400 front-end ASICs (64 channels/ASIC)
- Power consumption (FE only): ~ 80 W

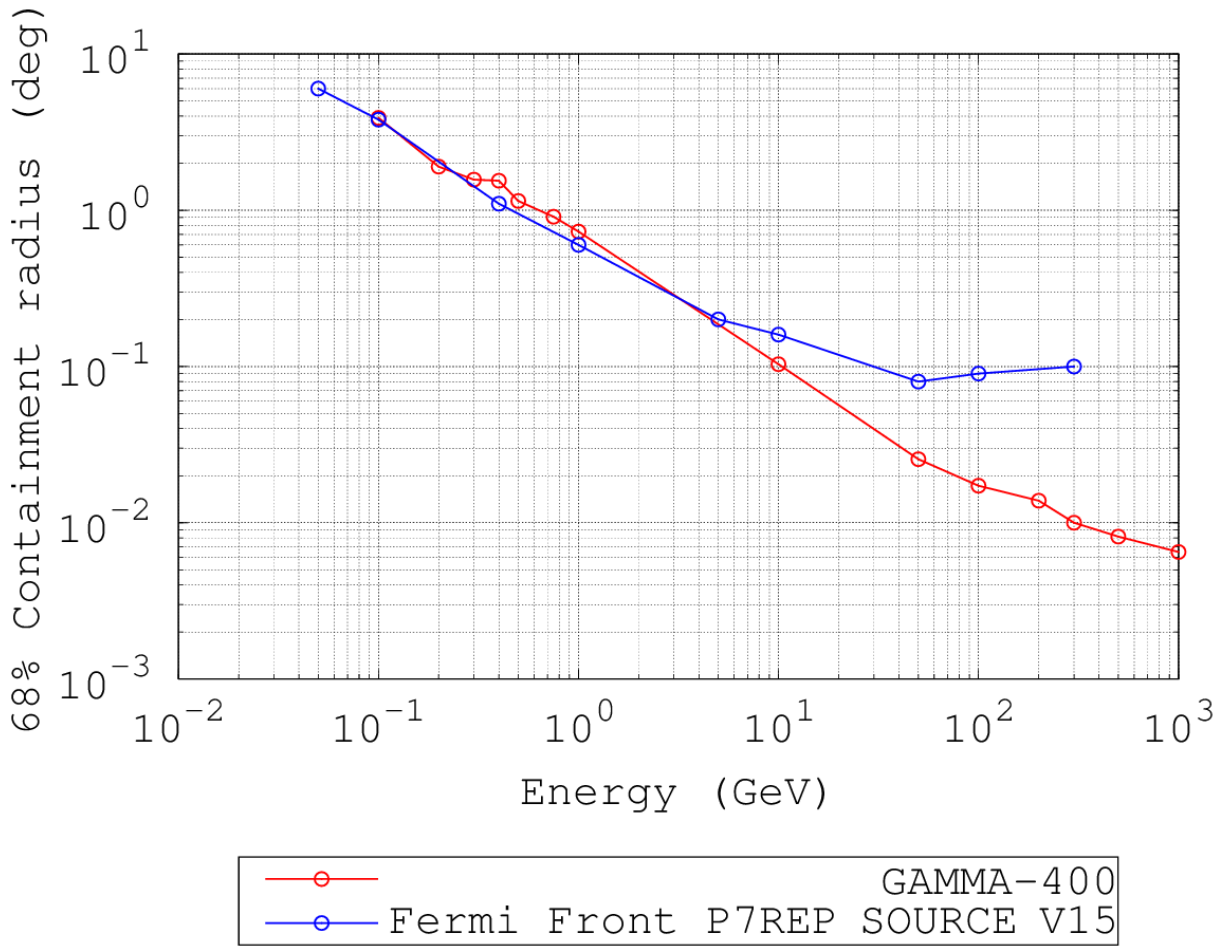
CC2 Calorimeter



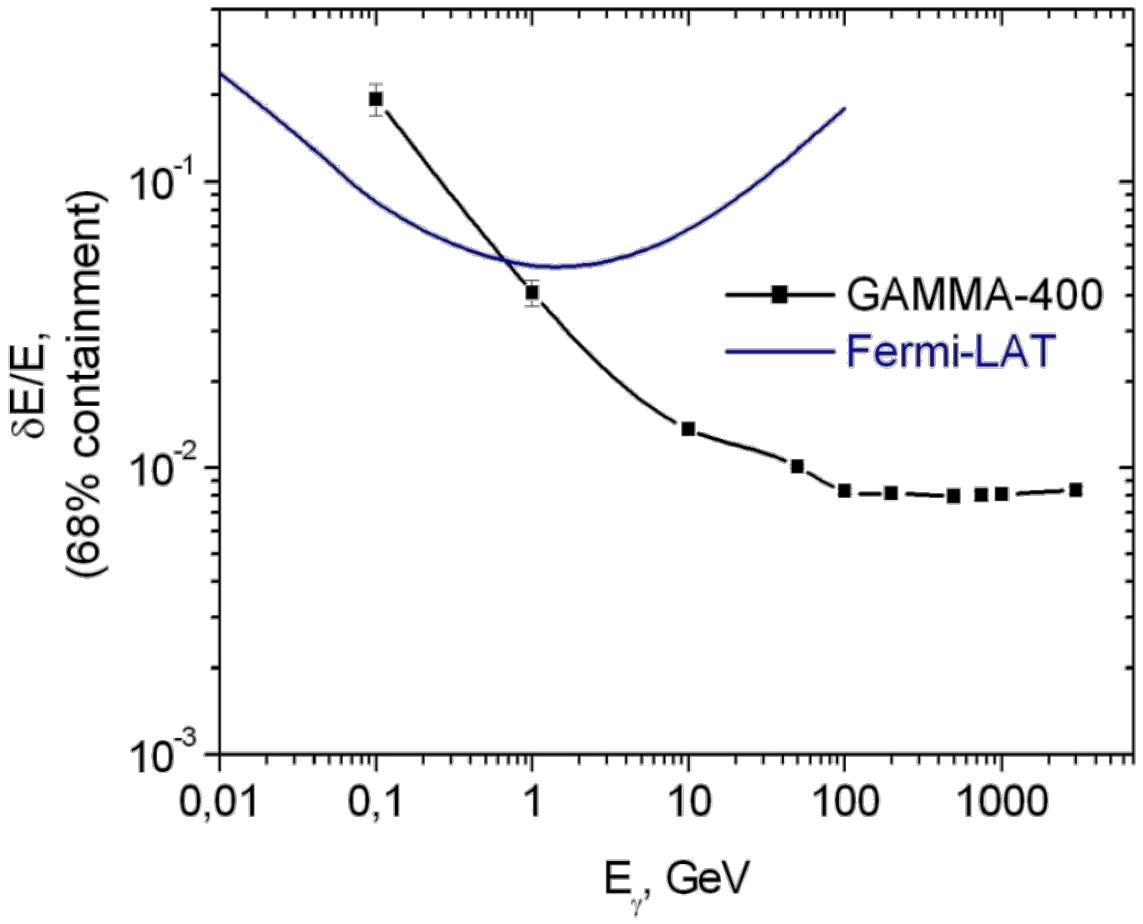
- 28 x 28 x 12 CsI(Tl) cubes
- L_{cubes} = 3.6 cm
- CC2 dimensions: 1 x 1 x 0.47 m^3
- X_0: 54.6 x 54.6 x 23.4
- λ_I: 2.5 x 2.5 x 1.1
- Mass = 1980 kg
- Planar GF: 9.5 m^2sr
- $GF_{eff,\ el.}$ $^{0.1\text{-}1\ TeV}\sim$ 3.4 m^2sr
- $GF_{eff,\ prot.}$ $^{1\ TeV}\sim$ 3.9 m^2sr



Angular resolution

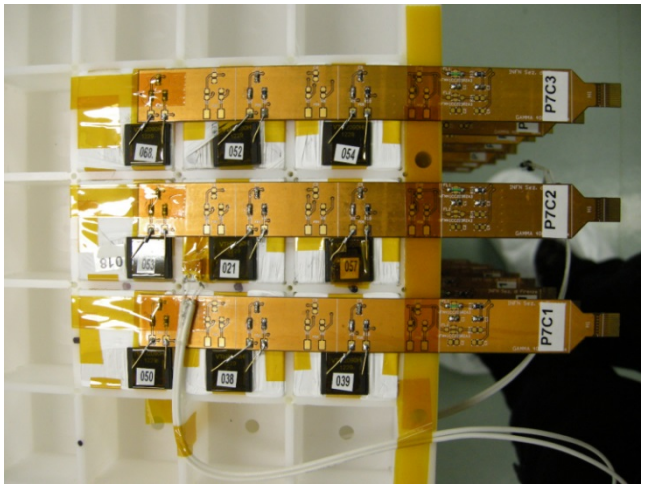


Energy resolution for γ



Calorimeter prototype

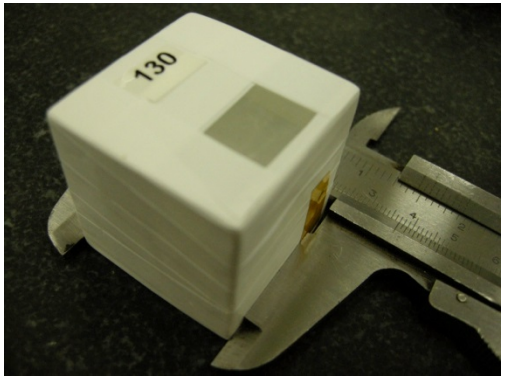
- 14 Layers
- 9 crystals in each layer (crystals 3.6 x 3.6 x 3.6 cm^3)
- 126 Crystals in total
- 126 Photodiodes
- 50.4 cm of CsI(Tl)
- 27 X_0, 1.44 λ_I
- Photodiodes read-out by 9 CASIS1.2A 16-channel ASICs)

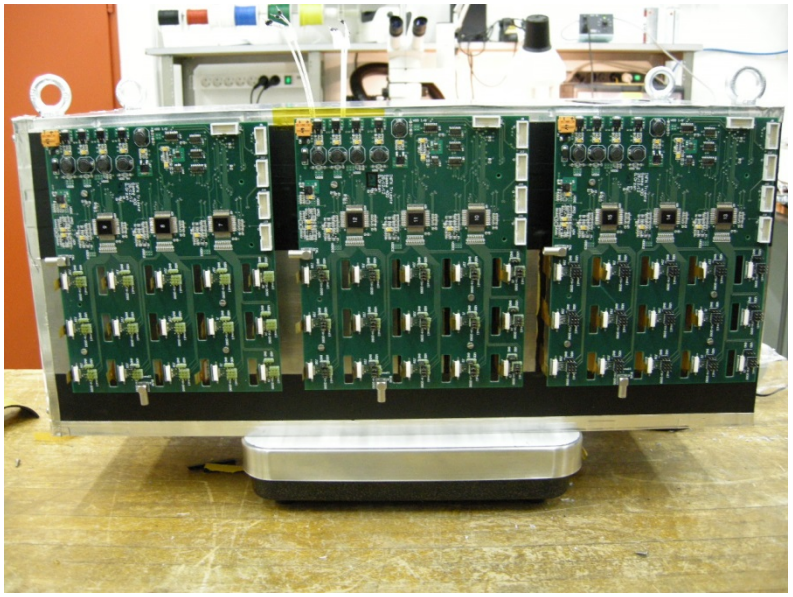


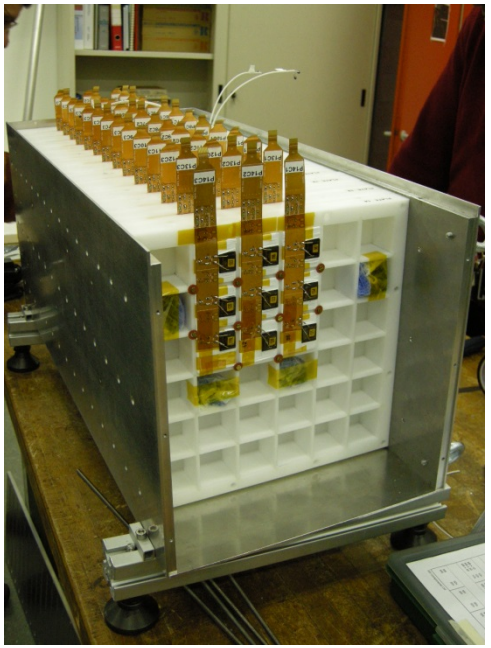
Mechanics:
INFN Pisa

Front-end electronics:
INFN Trieste

Crystals, photodiodes, DAQ, assembly:
INFN Florence



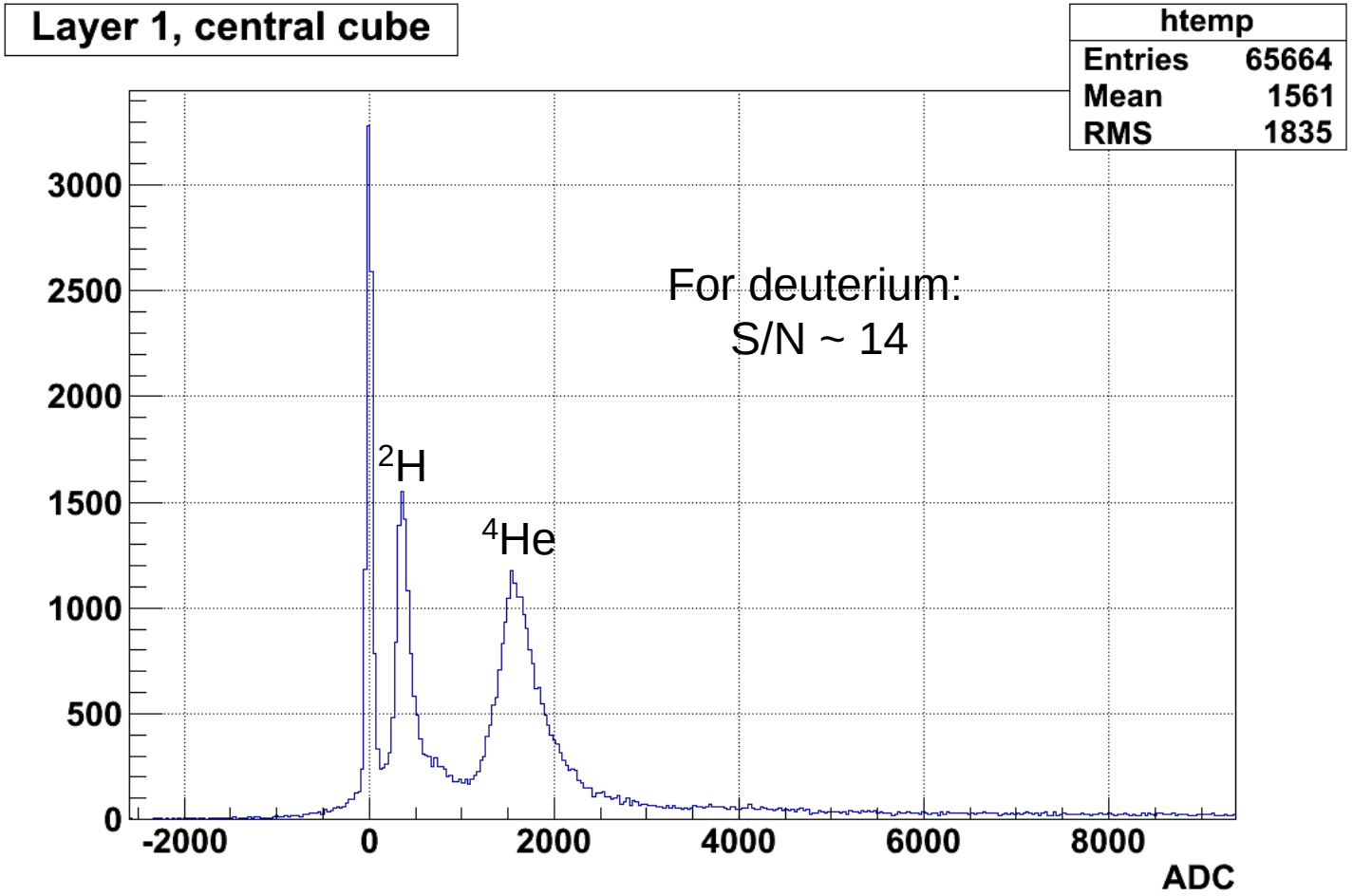




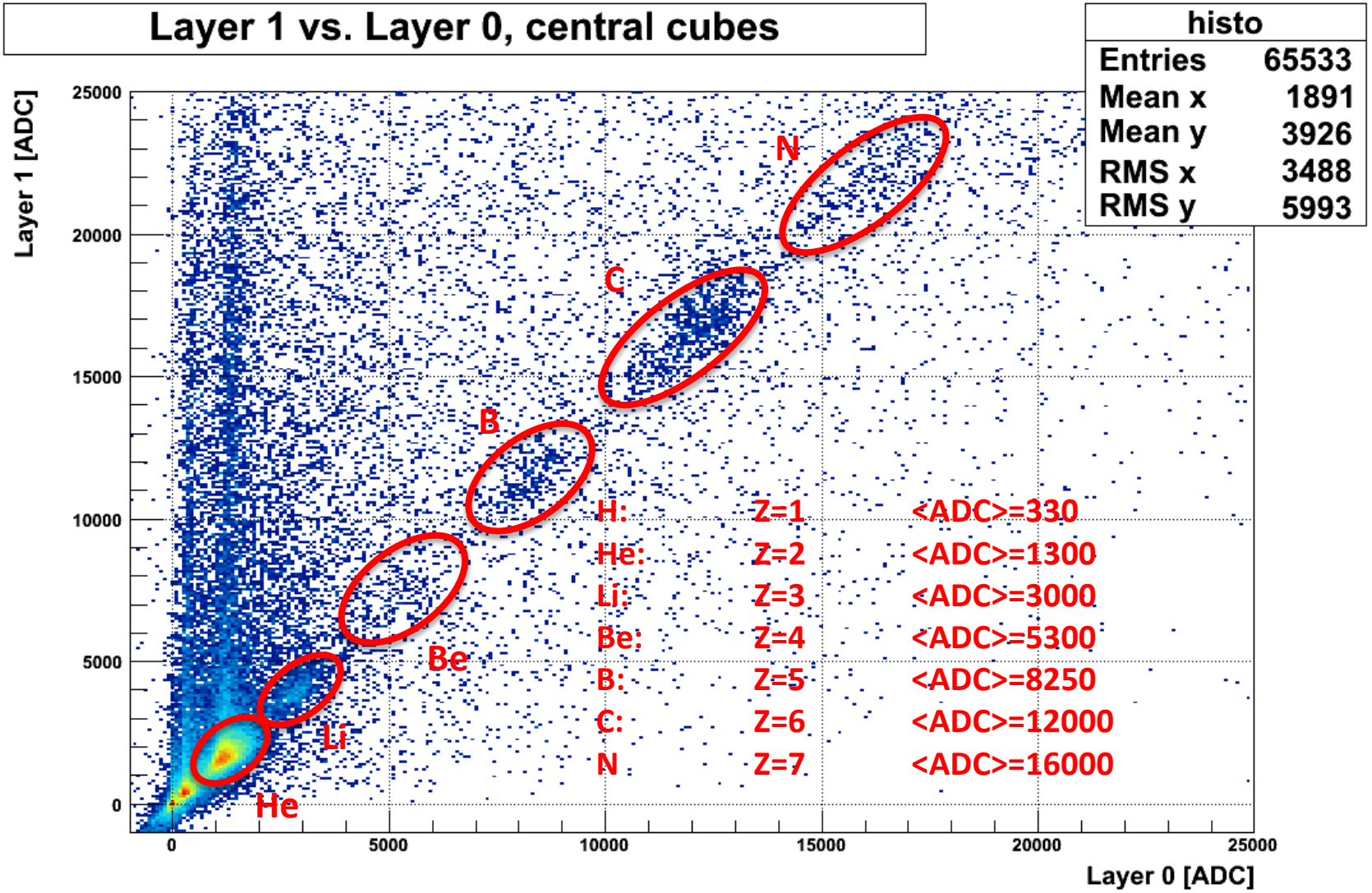
Prototype test beam results - 1

CERN SPS H8 Ion Beam: Z/A = 1/2, 12.8 GV/c and 30 GV/c (February 2013)

Notice: charge information from a precise silicon Z-measuring system located in front of the prototype

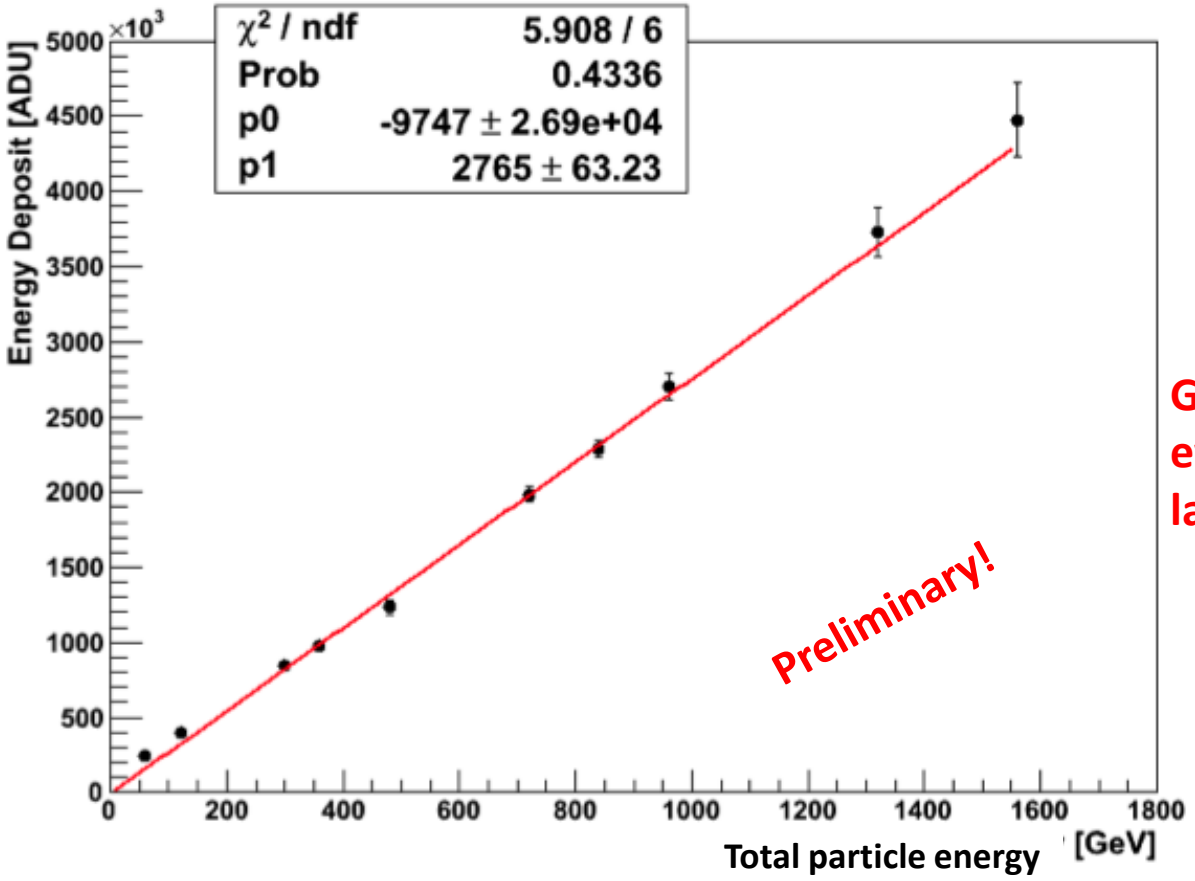


Prototype test beam results - 2



Prototype test beam results - 3

Energy Deposit Vs Beam Energy (D,He,B,C,O,Mg,Si,S,Ti,Fe)



Good linearity even with the large area PD!

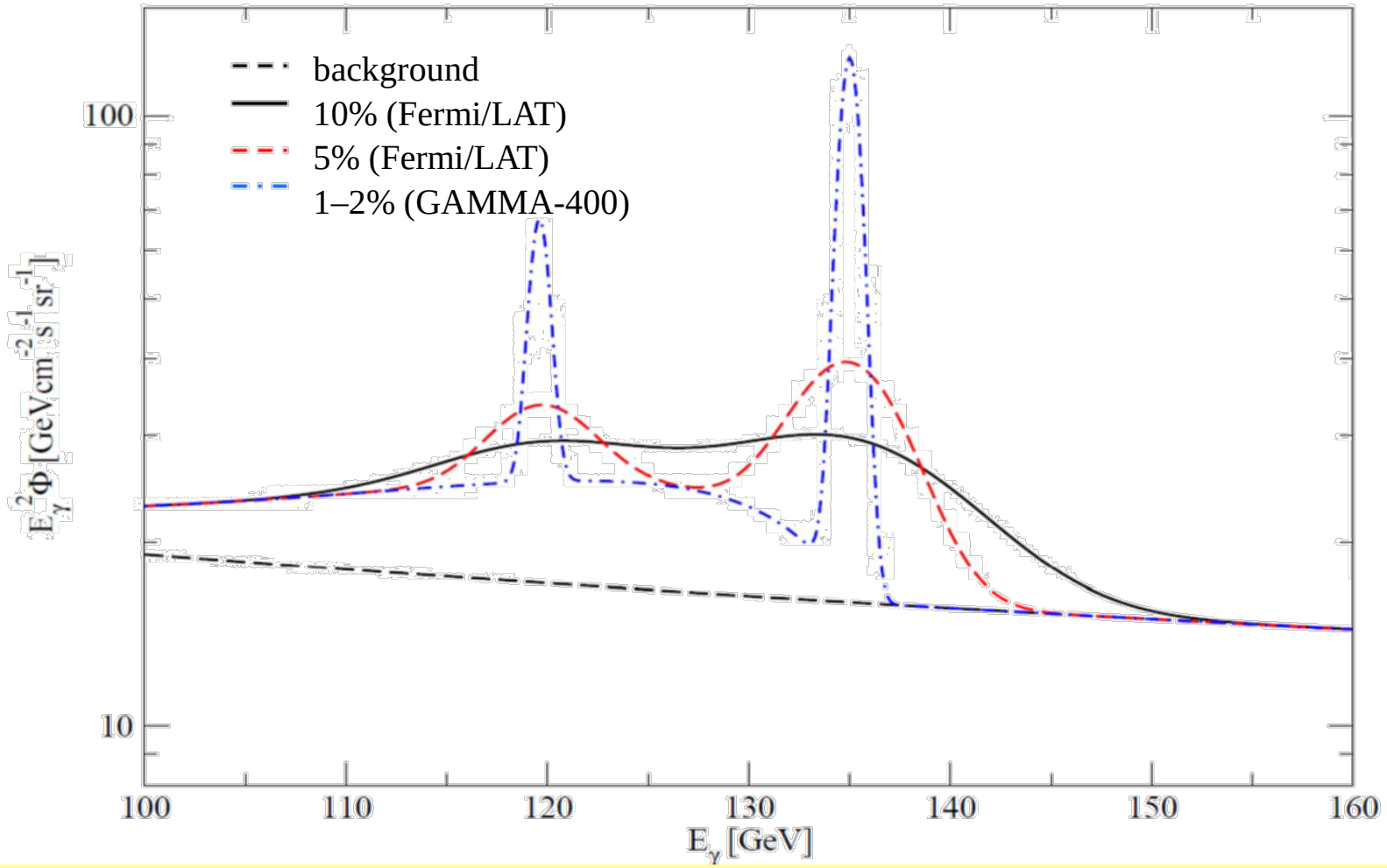
Physics with GAMMA-400

- GAMMA-400 is focused on the detection of the three main component of cosmic radiation:
  - **γ-rays from 100 MeV up to TeV energies**, to be studied with substantial improvements concerning the angular resolution at high energies and the continuous exposure to sources without Earth occultation
  - **electrons/positrons up to ~ 10 TeV**, to be measured with much improved sensitivity compared with current space, balloon-borne, and ground measurements
  - **cosmic-ray nuclei up to the "knee",** whose spectrum and composition is to be studied with unprecedented detail up to ~ few PeV/nucleon

Photons

- Detection of possible Dark Matter signal
  - Gamma-ray lines
  - Satellites
  - Dwarf Spheroidal Galaxies
  - Galactic Center
- Measurement of the high-energy γ-ray spectrum
  - SNR
  - Pulsars and PWN
  - Massive star clusters
  - AGN
  - GRB

Increasing the energy resolution



The γ-ray differential energy results for a 135 GeV right-handed neutrino dark matter candidate.

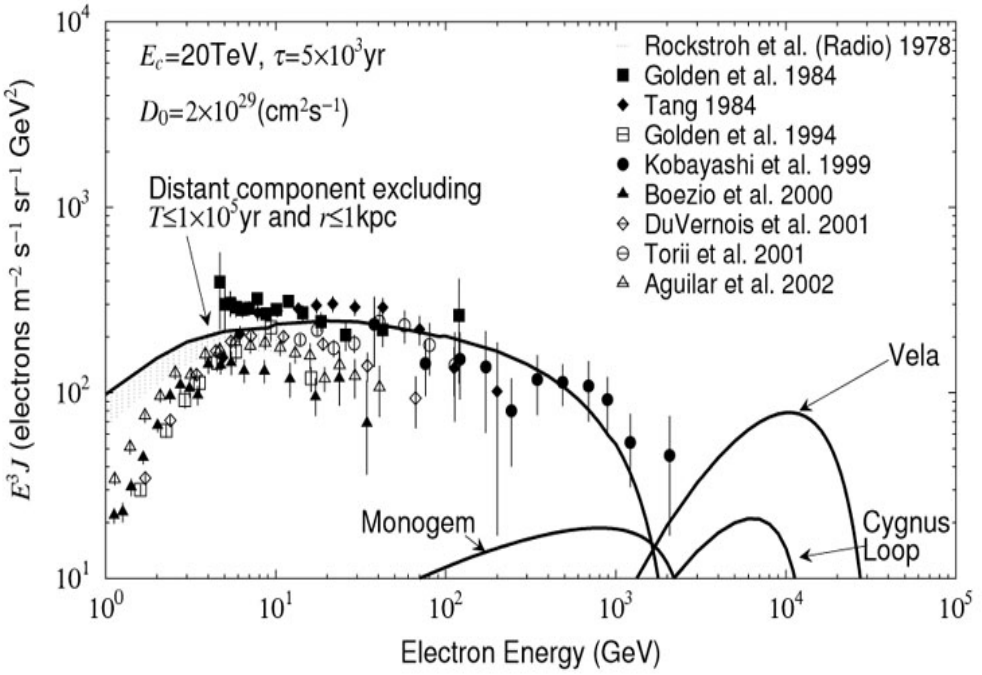
L. Bergström, Phys. Rev. D 86 (2012) 103514, arXiv:1208.6082

Electrons can tell us about local GCR sources

- High energy electrons have a high energy loss rate $\propto E^2$
  - Lifetime of ~10^5 years for > 1 TeV electrons
- Transport of GCR through interstellar space is a diffusive process
  - Implies that source of high energy electrons are < 1 kpc away

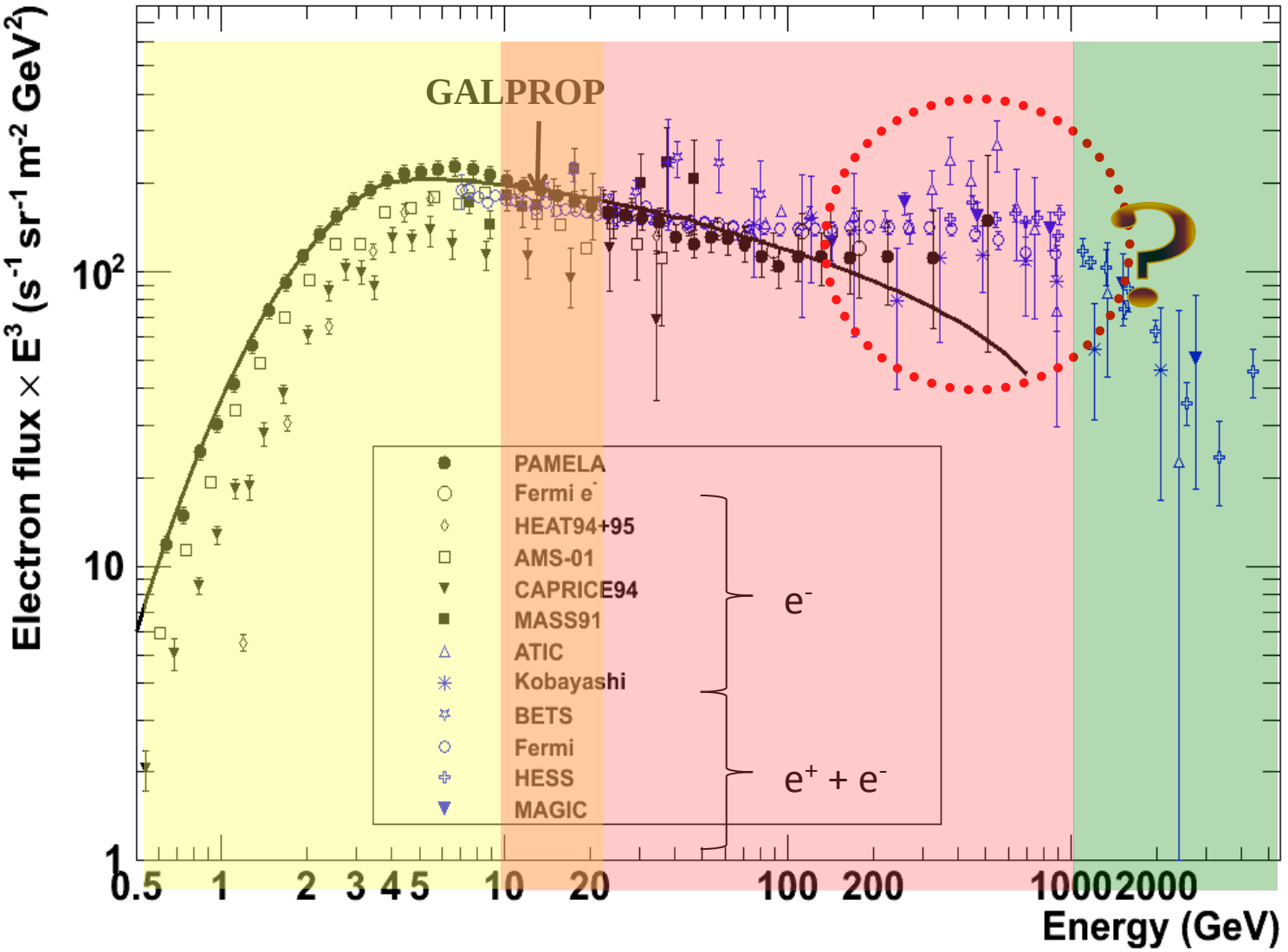
Only a handful of SNR meet the lifetime & distance criteria

Kobayashi et al., ApJ 601 (2004) 340-351: calculations show structure in electron spectrum at high energy

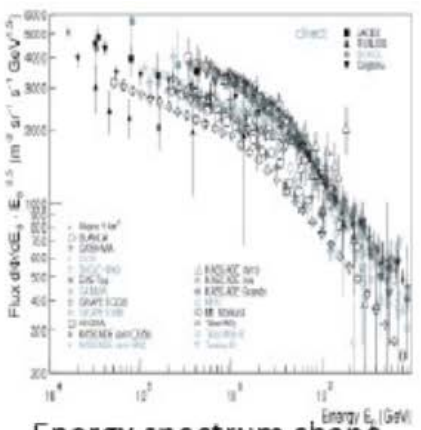


J. P. Wefel, TevPA 2011, Stockholm (2011)

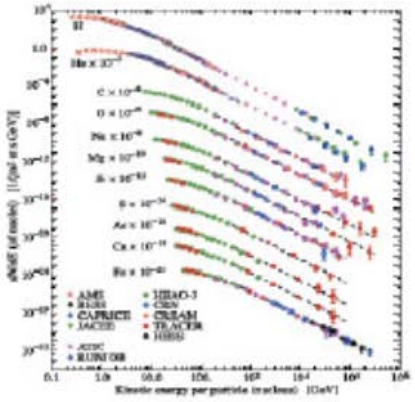
Electron Spectrum



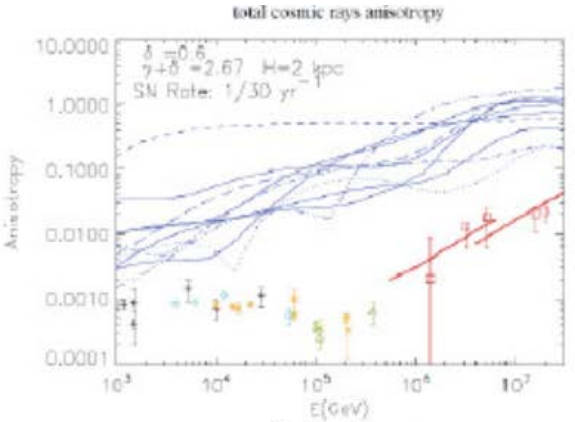
Nuclei



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

Conclusions

- The GAMMA-400 mission represents a unique opportunity to perform simultaneous measurements of photons, electrons and nuclei with unprecedented accuracy.
- GAMMA-400 will provide in-depth investigations on some of the most challenging physics items, such as:
  - DM search in γ and high-energy electron spectra
  - CR origin, production and acceleration to the highest energies
  - Flux and elemental composition of nuclei at the knee
- Synergy with ground-based Cerenkov arrays (CTA) and other wavelength instruments.