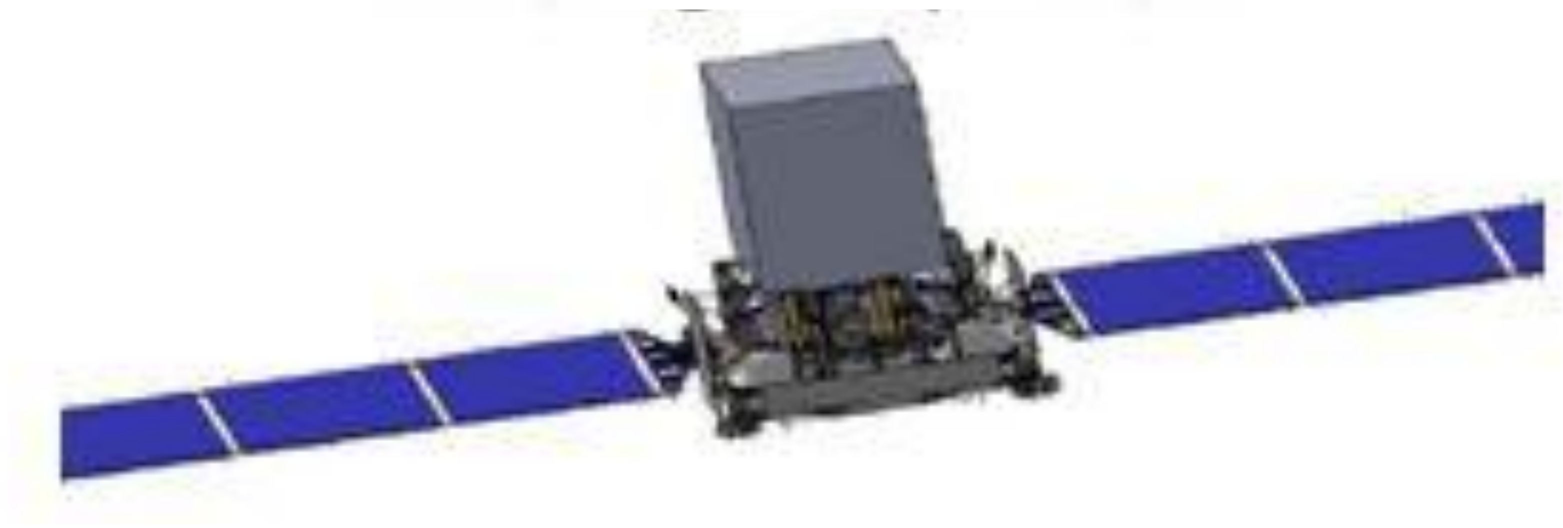
The GAMMA- 400 Project



M.Tavani

(substituting A. Galper)

9° AGILE Workshop, 17 Apr., 2012

Horror vacui…

- several projects/observatories at radio, mm, optical and TeV energies
- no gamma-ray instruments planned after *Fermi*…

High-energy astrophysics challenges

- unique time for high-energy astrophysics
- GAMMA-400 will substantially improve and provide windows of discovery after AGILE and FERMI
- G-400 will be the only space gamma-ray Observatory at the end of the decade, synergic with ground-based and other space detectors (e.g., radio, optical, X-ray, TeV).

Gamma-400 Approved by ROSCOSMOS

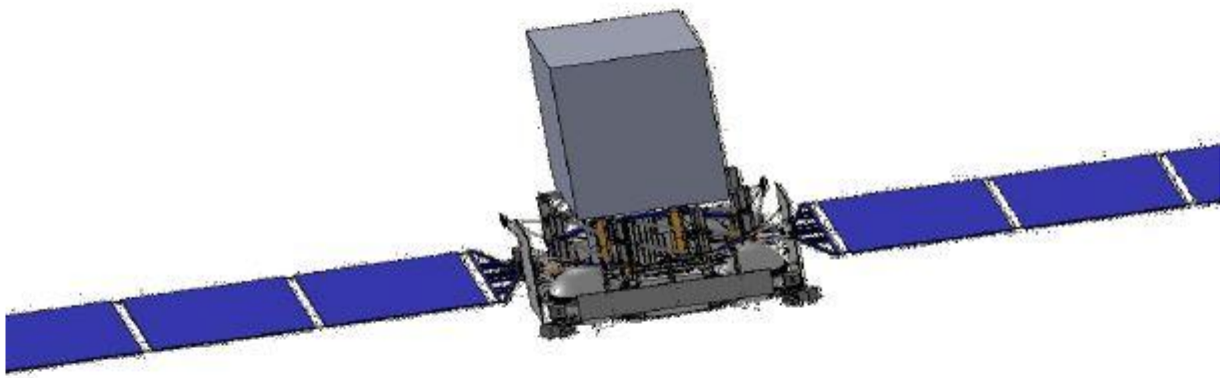
originally devoted to the study of: gamma rays (0.03 – 3 TeV)
& high-energy electrons and positrons.
Availability for a revision of the project that does not alter the original objectives

- The characteristics of the satellite:
  - scientific payload 2600 kg,
  - power budget 2 kW,
  - expected lifetime >5 years

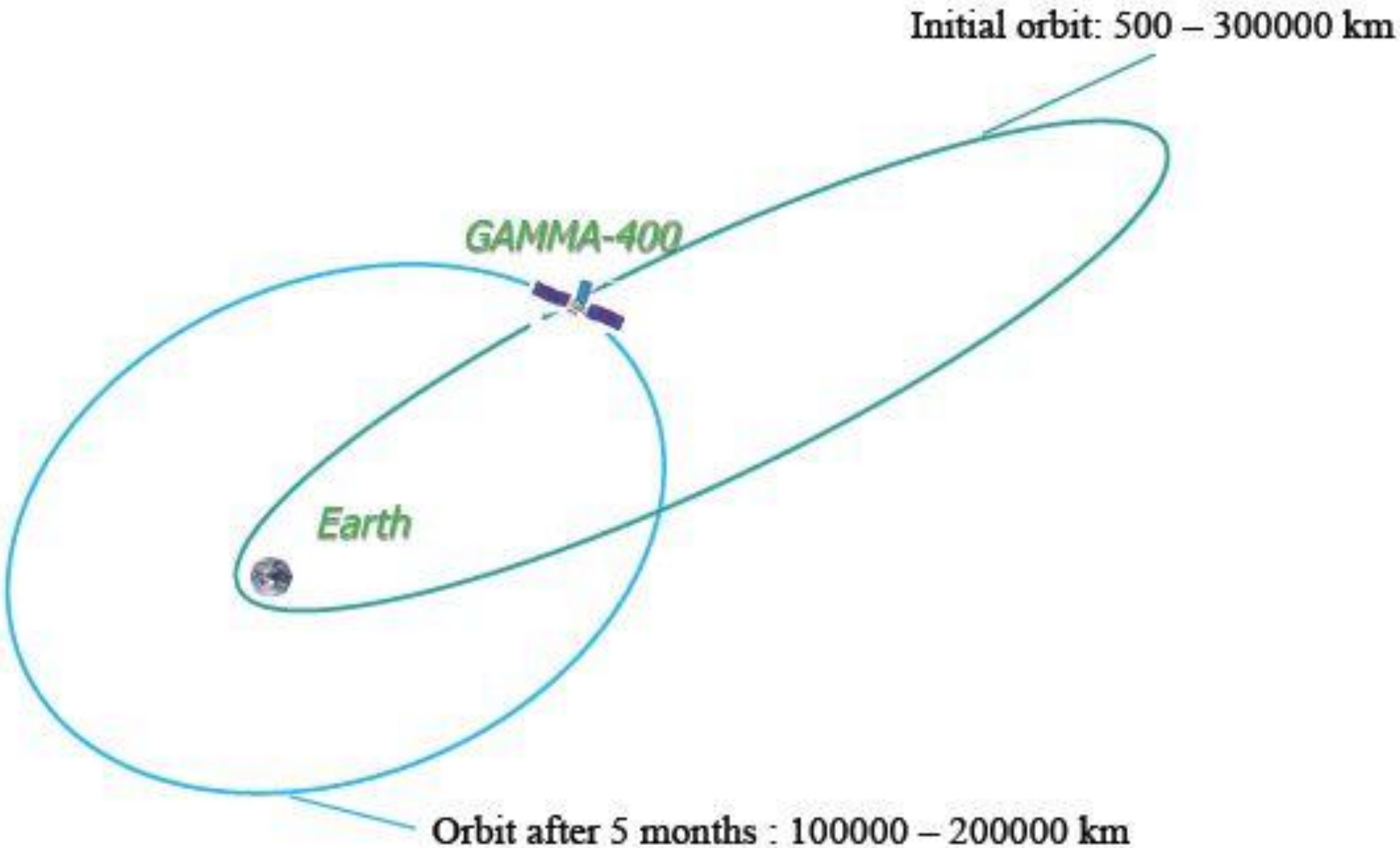
provide excellent opportunities to configure the apparatus for accomplishing extremely important physics tasks beyond the current generation of space missions. The Italian contribution to the project would concentrate on:

- Study of the p and He spectra up to the "knee" region (10^{14} – 10^{15} eV)
- Extension of the gamma capability in the 50 – 300 MeV region

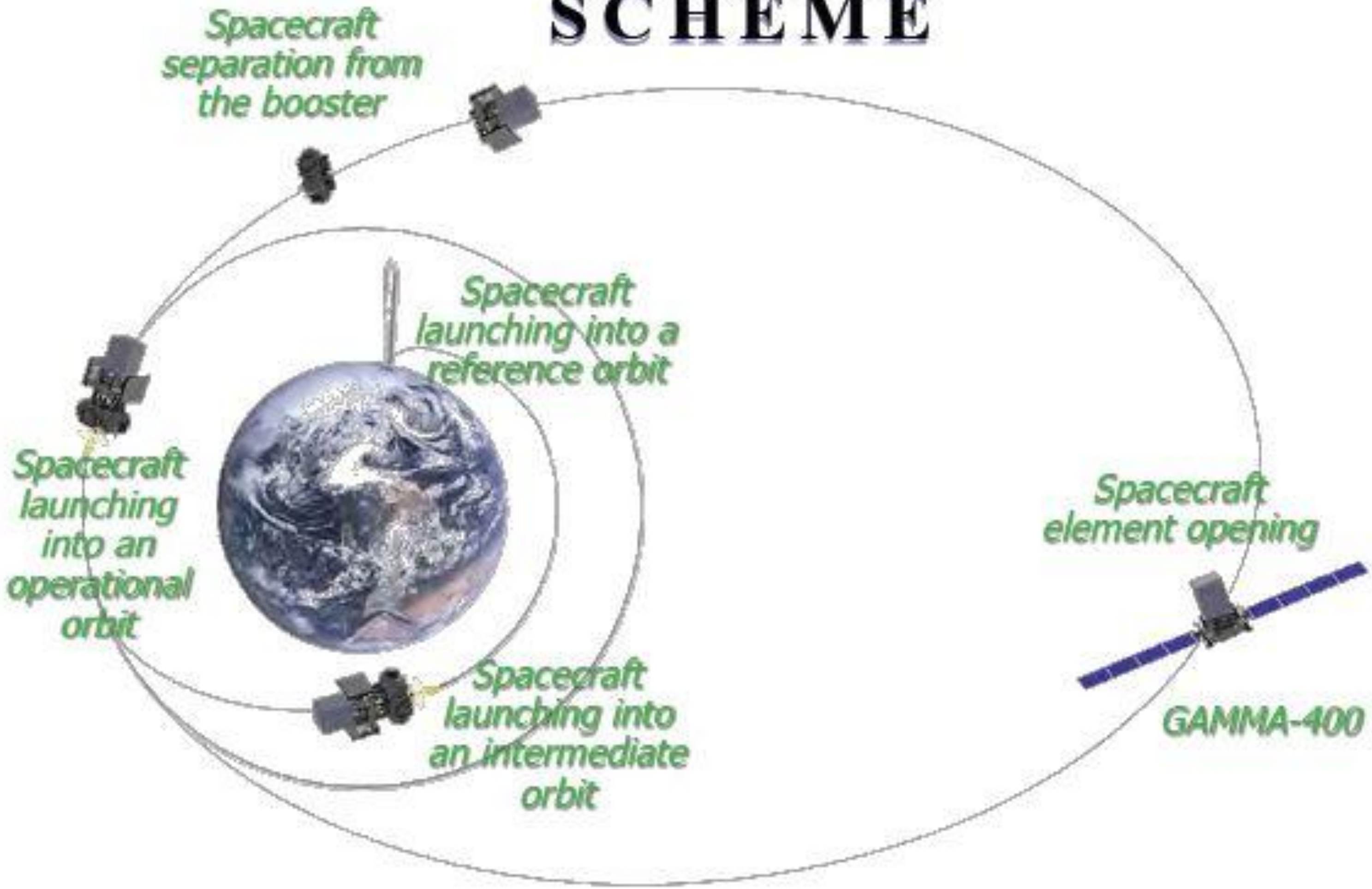
Gamma-400 instrument installed on the 'Navigator' spacecraft



ORBIT EVOLUTION



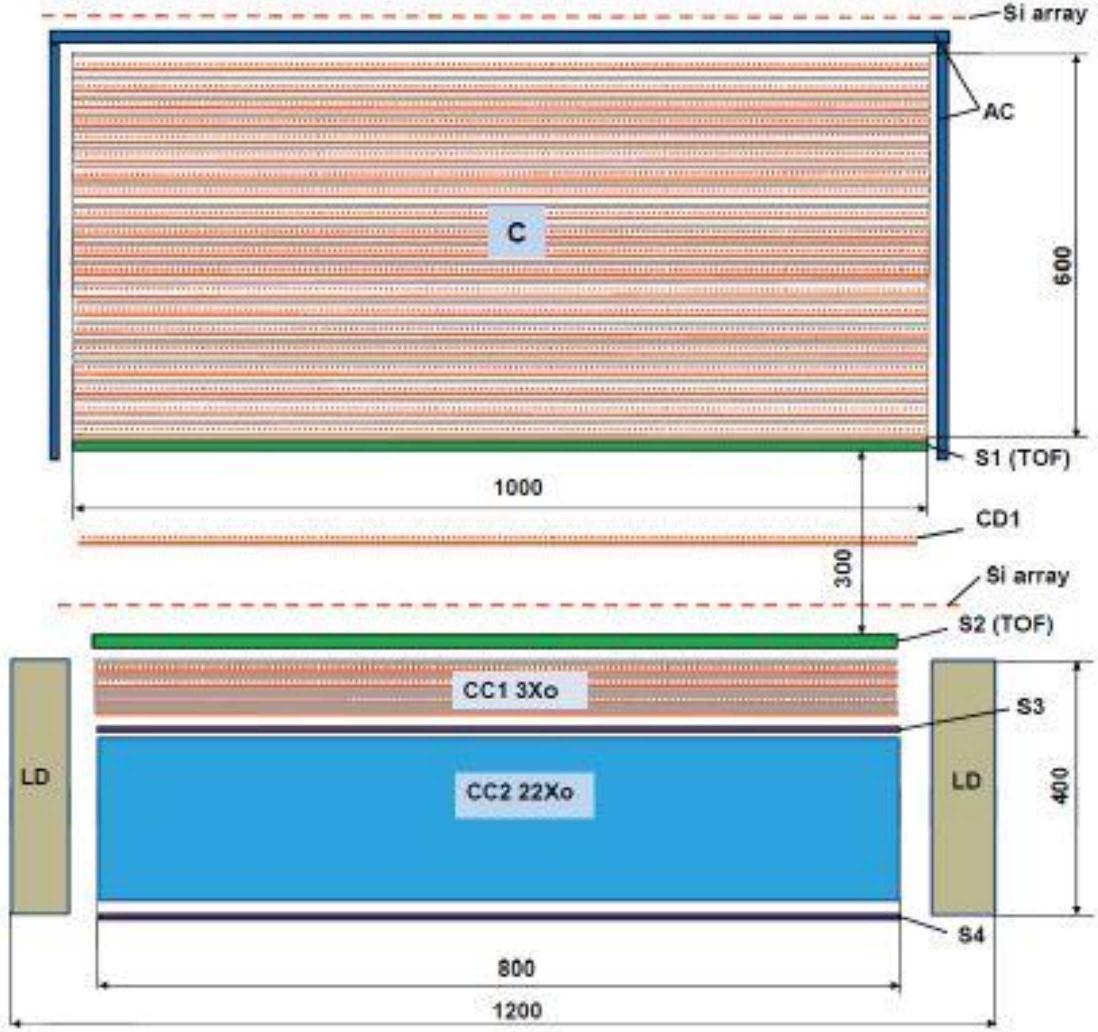
GAMMA-400 LAUNCHING SCHEME



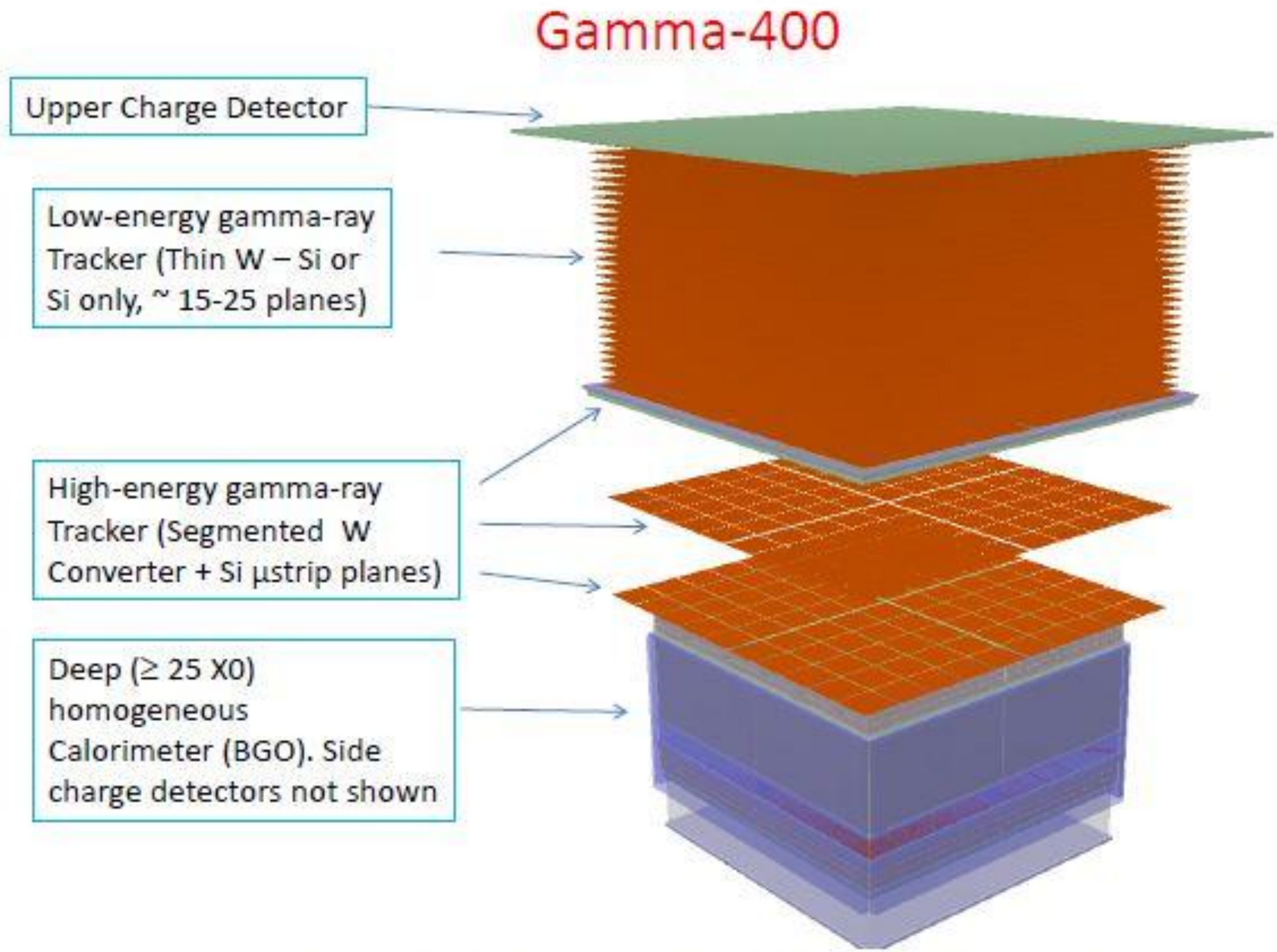
Gamma-400 main parameters

Gamma-ray energy range	**30 MeV – 100 GeV**
Calorimeter	90 x 90 cm^2 ~ 25 X_o
Angular resolution (Eγ ≥ 100 GeV)	~ 0.01°
Energy resolution (Eγ ≥ 10 GeV)	~ 1%
Proton rejection	10^6
Telemetry downlink	100 GB/day
Power consumption	2000 W
Max. dimensions	2x2x3 m^3
Scientific payload mass	2600 kg

Gamma-400



Si array
AC
C
600
S1 (TOF)
1000
CD1
300
Si array
S2 (TOF)
CC1 3Xo
S3
LD
CC2 22Xo
LD
400
S4
800
1200



apparatus versions used in one of the preliminary simulations.

- **G-400 will be the ideal COSMIC ACCELERATOR HUNTER of the next decade**

- **particle acceleration in**
  - Neutron stars and PWNe
  - Black holes
  - Supernova Remnants
  - AGNs (blazars)
  - GRBs

G-400 a new generation instrument

- **It will combine for the first time photon and particle (electrons and nuclei) detection in a unique way**

1. **gamma-rays from 30 MeV up to TeV energies**

2. **electrons/positrons in the TeV energy range and beyond**

3. **proton/ion cosmic-rays up to the "knee"**

- **G-400 is a gamma-ray/cosmic-ray mission with substantial differences with respect to the current generation of gamma-ray astrophysics missions (AGILE and Fermi), cosmic-ray instruments (PAMELA, AMS, CALET) and balloon-borne instruments.**

- **The G-400 design under study has unique properties.**

Gamma-400
"Hunting for Cosmic Accelerators"

The Gamma-400 mission: a brief description

O. Adriani[1], G. Barbiellini[2], M. Boezio[2], V. Bonvicini[2], S. Bottai[1], G. Castellini[3], F. Longo[2], P. Maestro[4], P.S. Marrocchesi[4], E. Mocchiutti[2], A. Morselli[5], P. Papini[1], R. Sparvoli[5], P. Spillantini[1], M. Tavani[6], A. Vacchi[2], E. Vannuccini[1] and N. Zampa[2].

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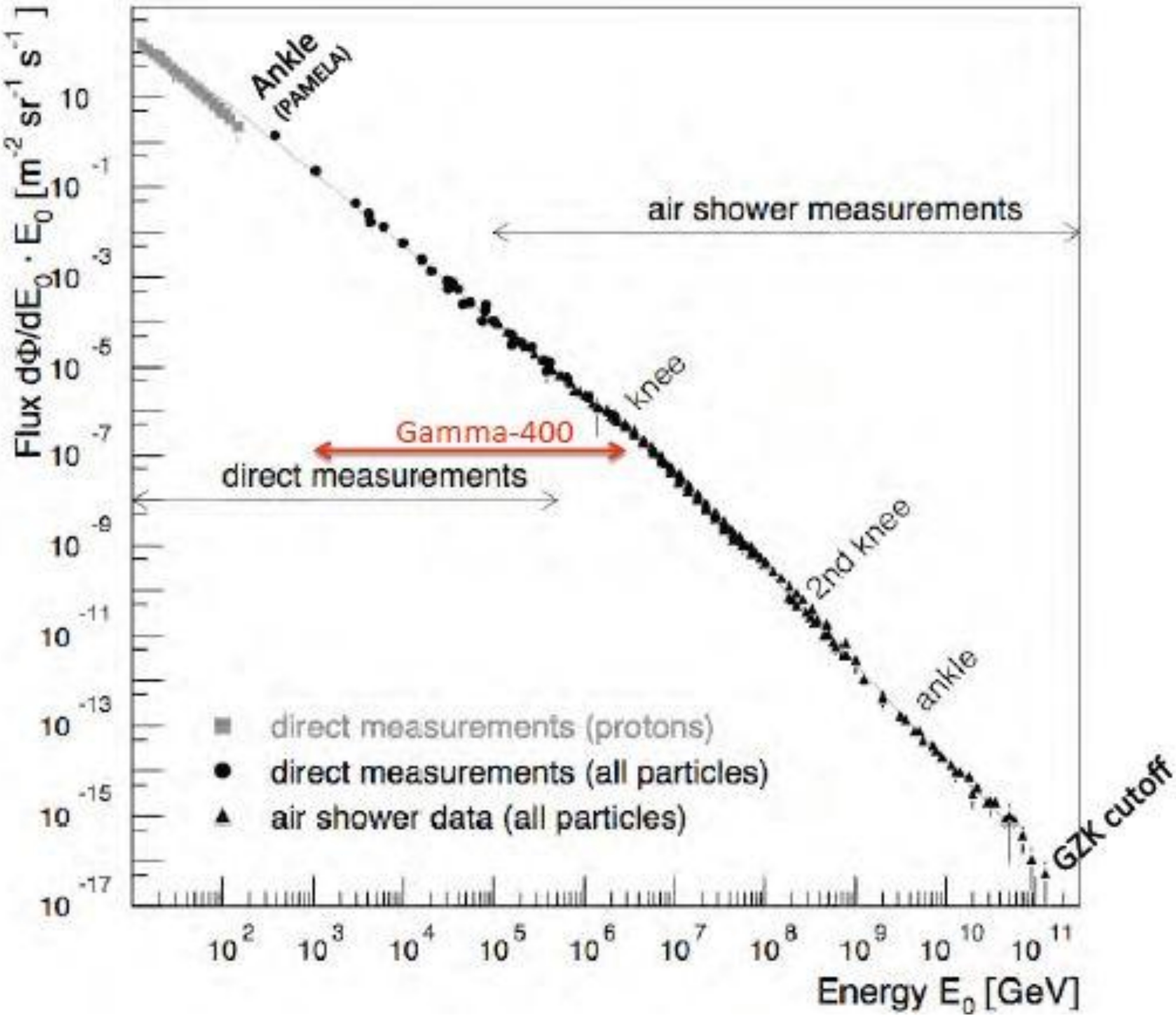
[5] Istituto Nazionale di Fisica Nucleare, Sezione di Roma 2 and Physics Department of University of Rome "Tor Vergata", Via della Ricerca Scientifica 1, I-00133 Rome, Italy.
[6] Istituto Nazionale di Astrofisica – IASF and Physics Department of University of Rome "Tor Vergata", Via della Ricerca Scientifica 1, I-00133 Rome, Italy.

1. Short history of the project

During a meeting between ASI and Roscosmos (Russian Federal Space Agency) held in Rome on October 20th, 2009, and dedicated to science and exploration of the Universe, the Russian delegation illustrated the Federal Space Program, which included the GAMMA-400 mission.

- **G-400 will be a "dual" instrument** capable of measuring both photons and particles based on a state-of-the-art imaging Silicon Tracker and a very deep Calorimeter with 20-25 X_0 and large acceptance;
- **extended gamma-ray sensitivity in the range 30 MeV – 1 TeV**, improving the current sensitivity near 100 MeV by a factor 5-10, and source exposure at 10-100 GeV by a factor of 5-6 for extended pointings;
- **much improved angular resolution at gamma-ray energies** (~2^{o} at 100 MeV, ~0.1^{o} above 10 GeV) for a very large field of view (2.5 sr);

- **pointing strategy with no Earth occultations**, very large exposure per unit time for extended monitoring (months) of individual sources;
- **efficient leptonic (e^- + e^+) detection** with optimal lepton/ion discrimination and spectral determination in the poorly studied range 1-10 TeV;
- **deep calorimetry for proton/ion detection and spectroscopy** up to knee energies near 1 PeV/nucleon.



Flux dΦ/dE0 · E0 [m^-2 sr^-1 s^-1]
Energy E0 [GeV]
Ankle
(PAMELA)
air shower measurements
knee
Gamma-400
direct measurements
2nd knee
ankle
GZK cutoff
direct measurements (protons)
direct measurements (all particles)
air shower data (all particles)

Counts estimation

Collecting parameters
Time = 5 years
G.F. = 1 m^2 sr
efficiency = 1

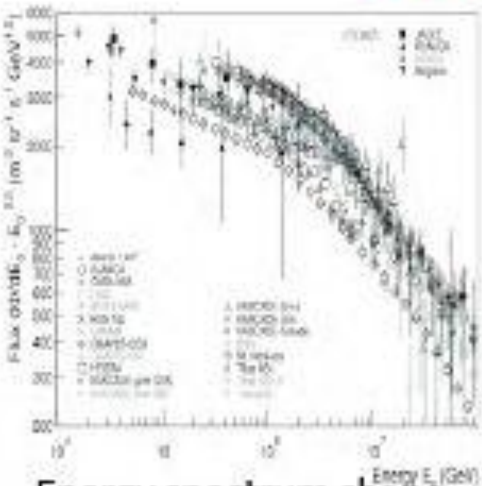
	E > 0.1 PeV	E > 0.5 PeV	E > 1 PeV	E > 2 PeV	E > 4 PeV
H(1)	3037	180	48	11	1.8
He(2)	2872	199	60	17	3.9
Li(3) – F(9)	1415	98	31	9.3	2.7
Ne(10) – Cr(24)	1454	102	33	11	3.2
Mn(25), Fe(26), Co(27)	1514	120	40	14	4.5

Counts with Polygonato model

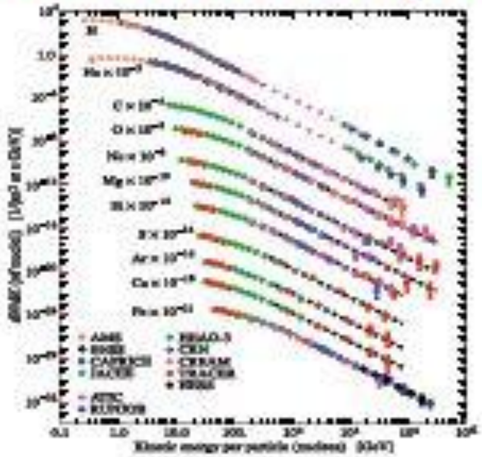
	E > 0.1 PeV	E > 0.5 PeV	E > 1 PeV	E > 2 PeV	E > 4 PeV
H(1)	3060	195	60	19	5.6
He(2)	2882	206	66	22	6.8
Li(3) – F(9)	1415	98	31	9.9	3.1
Ne(10) – Cr(24)	1454	102	33	11	3.4
Mn(25), Fe(26), Co(27)	1514	120	40	14	4.5

Counts without the knee cutoff (power low extrapolation)

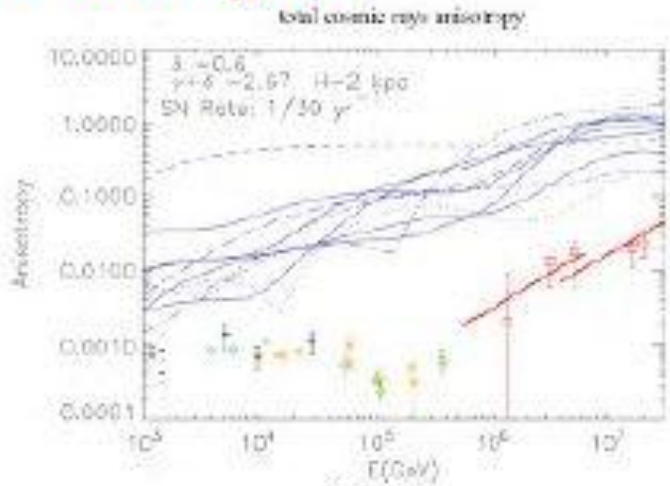
The goal is to measure with the same experiment CR nuclei from the TeV up to the PeV region



Energy spectrum shape



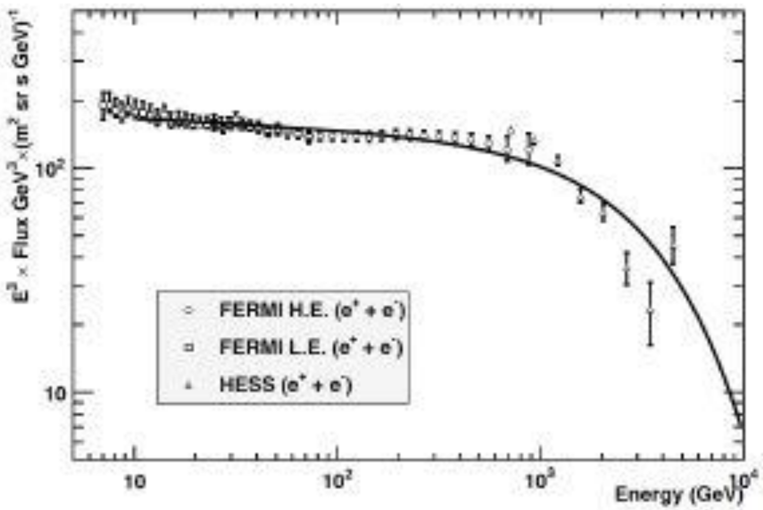
Composition



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

Expected flux of electrons + positrons



Expected counts
(maximum calorimeter capability)

Collecting parameter
Time = 5 years
G.F. = 2.5 m^2 sr
efficiency = 1

	E > 0.5 TeV	E > 1 TeV	E > 2 TeV	E > 4 TeV
electron + positron	83144	15908	2482	264

Expected counts
(present proposed configuration)

Collecting parameter
Time = 5 years
G.F. = 4x0.18 m^2 sr +0.50 m^2 sr = 1.22 m^2 sr
efficiency = 1

	E > 0.5 TeV	E > 1 TeV	E > 2 TeV	E > 4 TeV
electron + positron	40574	7763	1211	129

- 1. **gamma-rays from 30 MeV up to TeV energies**,
  - **angular resolution**
  - **the broad-band sensitivity**
  - **continuous exposure of sources without Earth occultations**

- 2. **electrons/positrons in the TeV energy range and beyond**

- 3. **proton/ion cosmic-rays up to the "knee“**

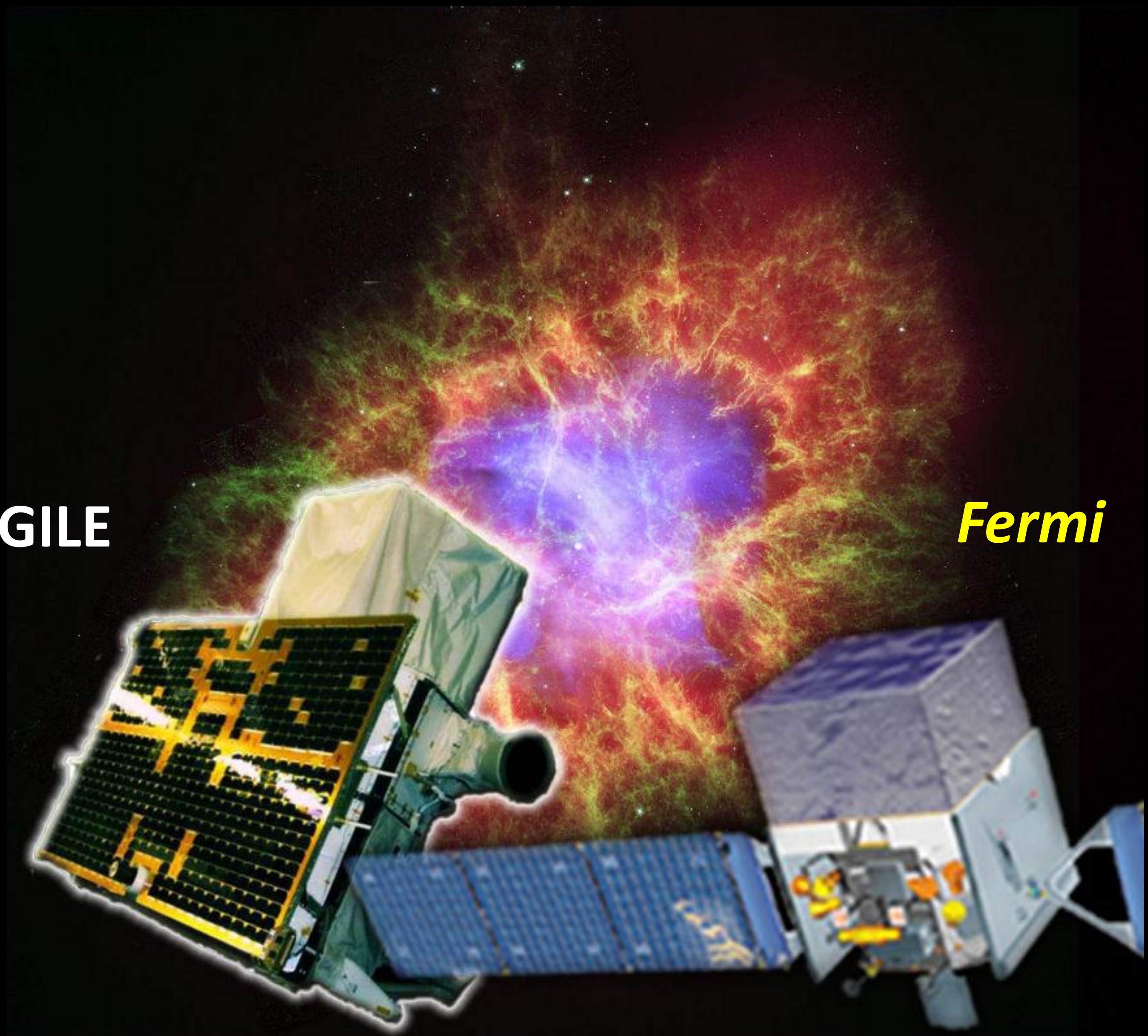
Scientific goals

- **High-resolution mapping and space-resolved spectral studies of all relevant Supernova Remnants.** Large sensitivity to neutral pion emission below 3-400 MeV.

- **Ideal detector for transients:** uninterrupted (no Earth occultations) and large-exposure monitoring of extragalactic and Galactic sources.

Gamma-ray astrophysics missions (above 30 MeV)

SAS-2	NASA	Nov. 1972 – July 1973
COS–B	ESA	Aug. 1975 – Apr. 1982
CGRO	NASA	Apr. 1991 – Jun. 2000
AGILE	ASI	April 23, 2007
Fermi	NASA	June 11, 2008



Picture of the day, Feb. 28, 2011, NASA-HEASARC

A quick comparison

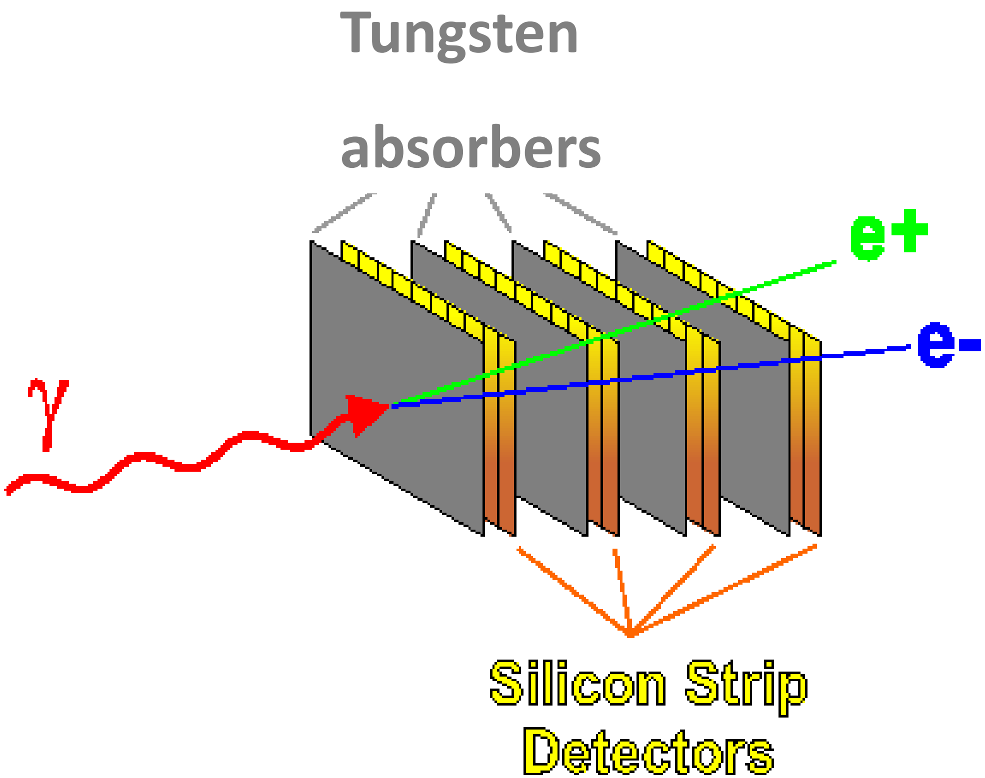
	AGILE	FERMI-LAT
A_{eff} (100 MeV) (cm^2)	~ 400	~ 400-800
A_{eff} (1 GeV) (cm^2)	~ 500	~ 4000 - 8000
FOV (sr)	2.5	2.5
sky coverage	1/5	whole sky
Energy resolution (~ 400 MeV)	50 %	10 %
PSF (68 % cont. radius) 100 MeV 1 GeV	 3^o - 4^o < 1^o	 4^o - 5^o < 1^o

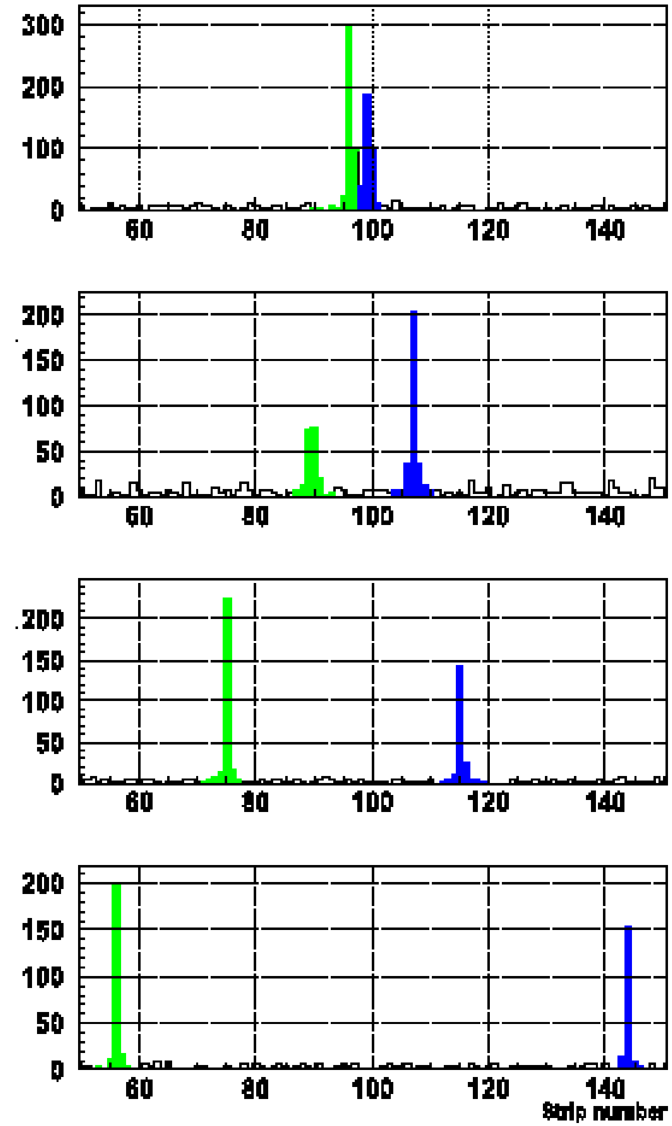
A quick comparison

	AGILE	FERMI-LAT	G-400
A_{eff} (100 MeV) (cm^2)	~ 400	~ 400-800 800-1600	4000
A_{eff} (1 GeV) (cm^2)	~ 500	~ 8000	6000
FOV (sr)	2.5	2.5	2.5
sky coverage	1/5	whole sky	1/5
Energy resol. (~ 400 MeV)	50 %	10 %	10%
PSF(68% cont. radius) 100 MeV 1 GeV	3^o - 4^o < 1^o	4^o - 5^o < 1^o	1.5^o - 2^o 0.2-0.3^o

A quick comparison

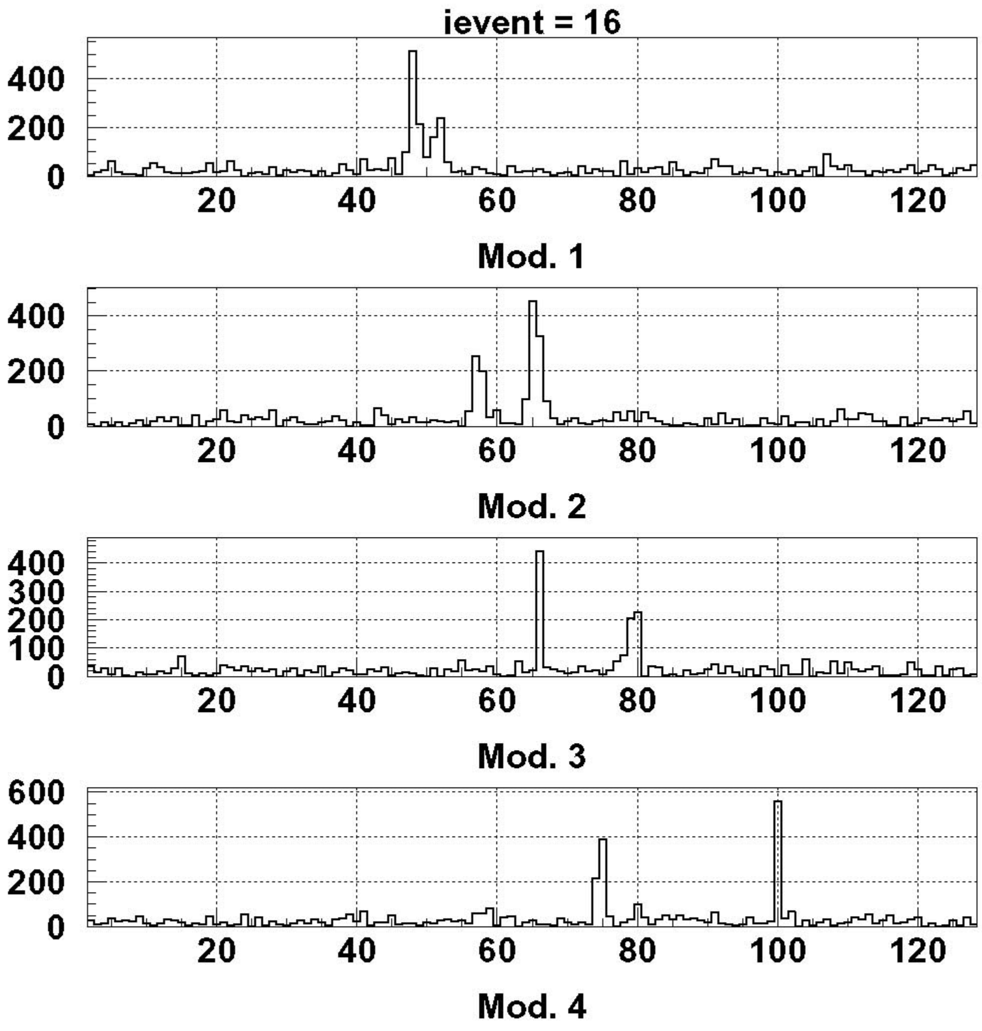
	AGILE	FERMI-LAT	G-400
Tracker active elements	Si	Si	Si
Tracker planes	10+2	12 4 + 2	20+2
plane converter (W) in X_0	0.07	0.025 0.25	0.03-0.035
total Tracker depth in X_0	~ 1	~ 0.4 ~ 0.7	~ 1
Si microstrip pitch	121 μ	240 μ	100-120 μ
readout	analog	digital	analog



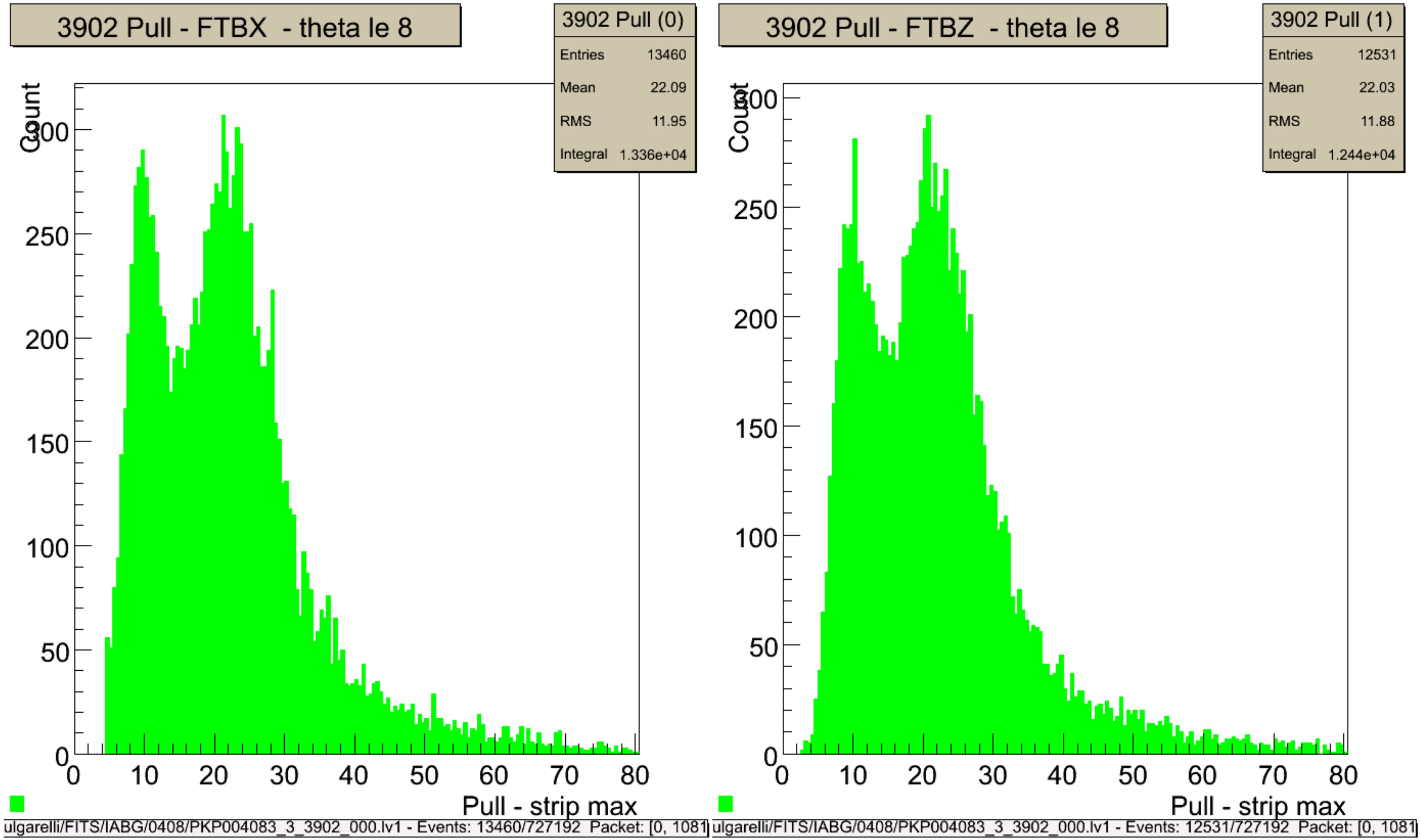


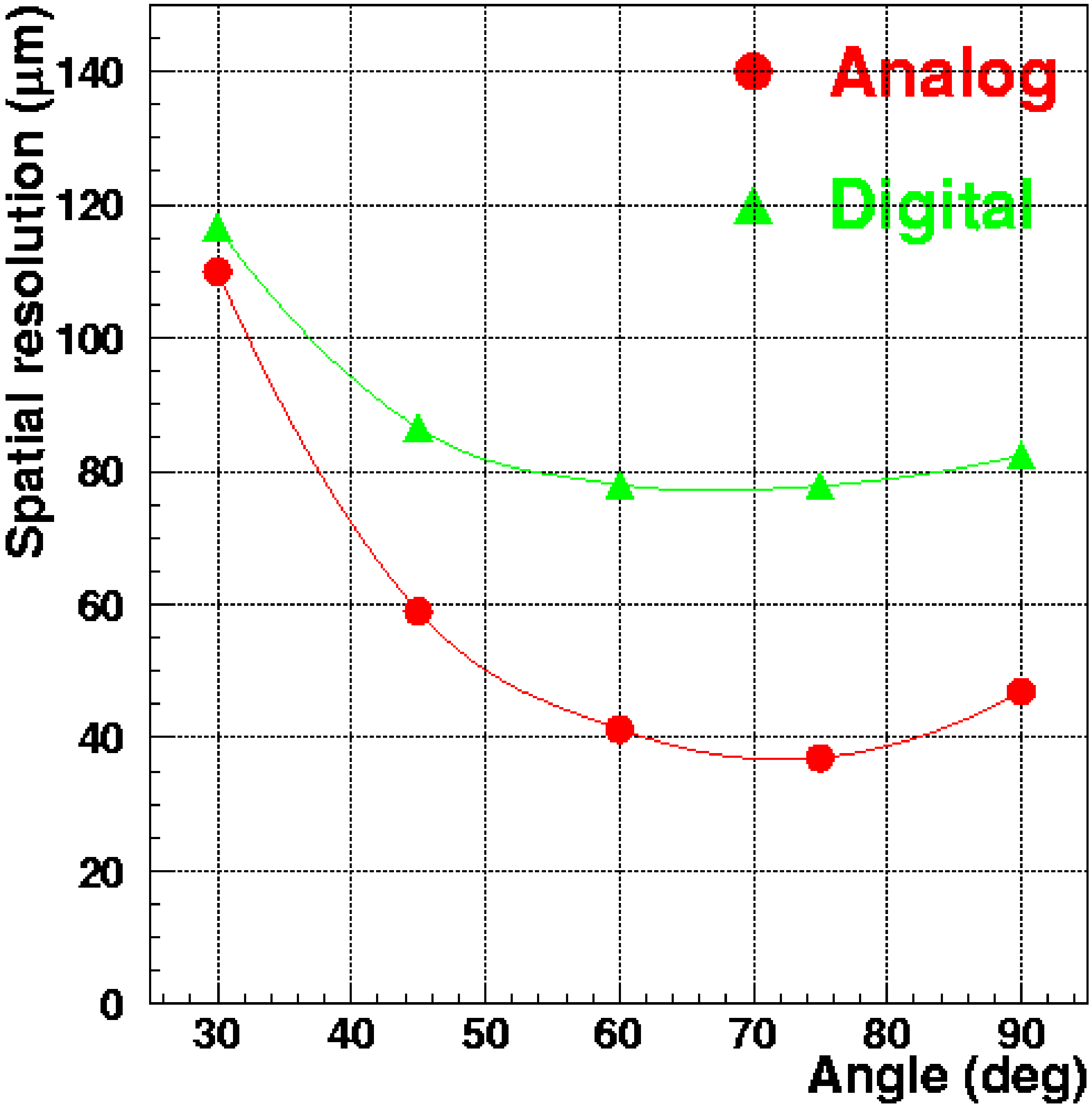
PHOTAG TESTBEAM - INFN TS/IFC MI

gamma-ray detected by the AGILE Tracker



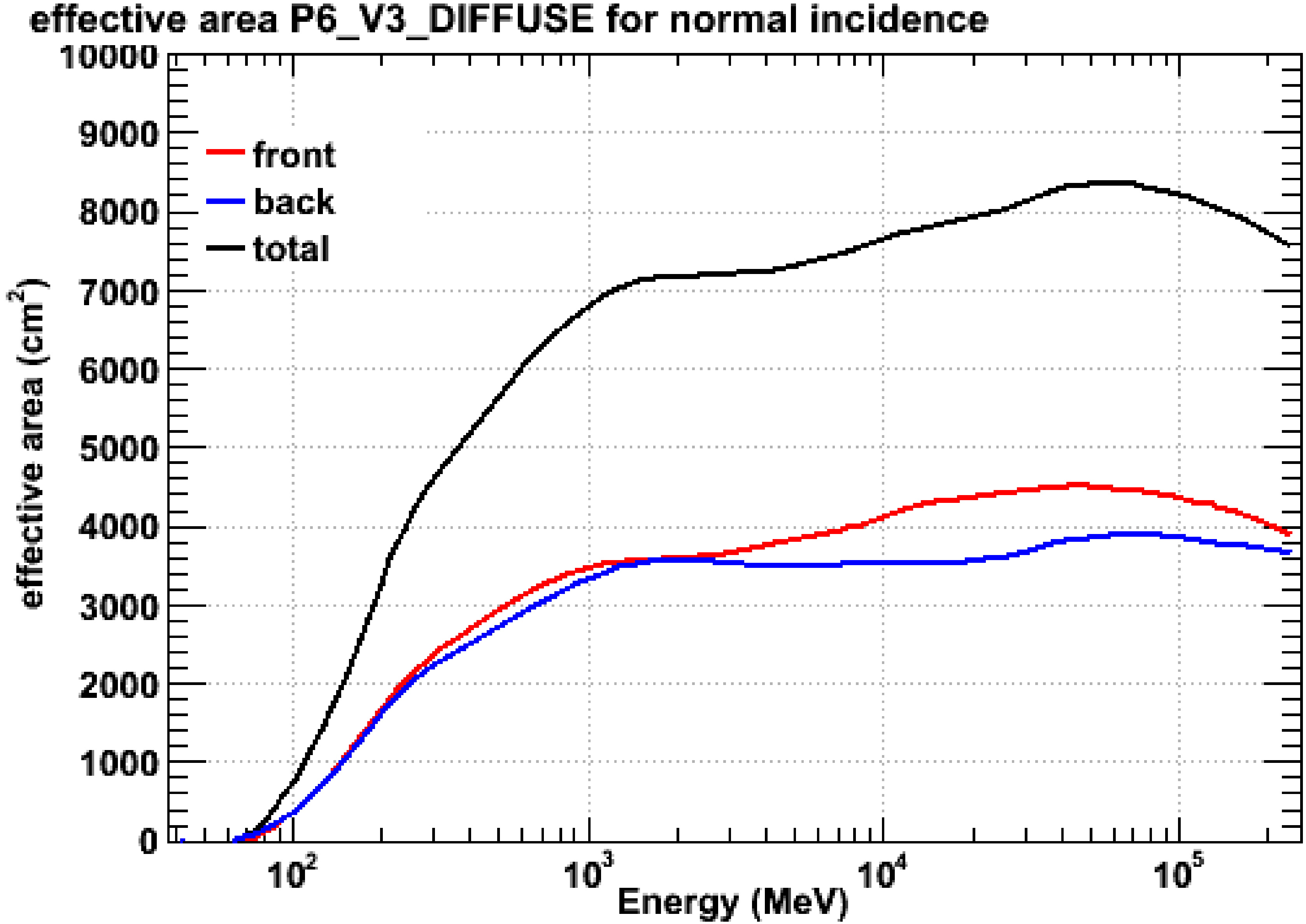
AGILE Tracker data: total (readout and floating) strip distribution: floating strip high efficiency configuration



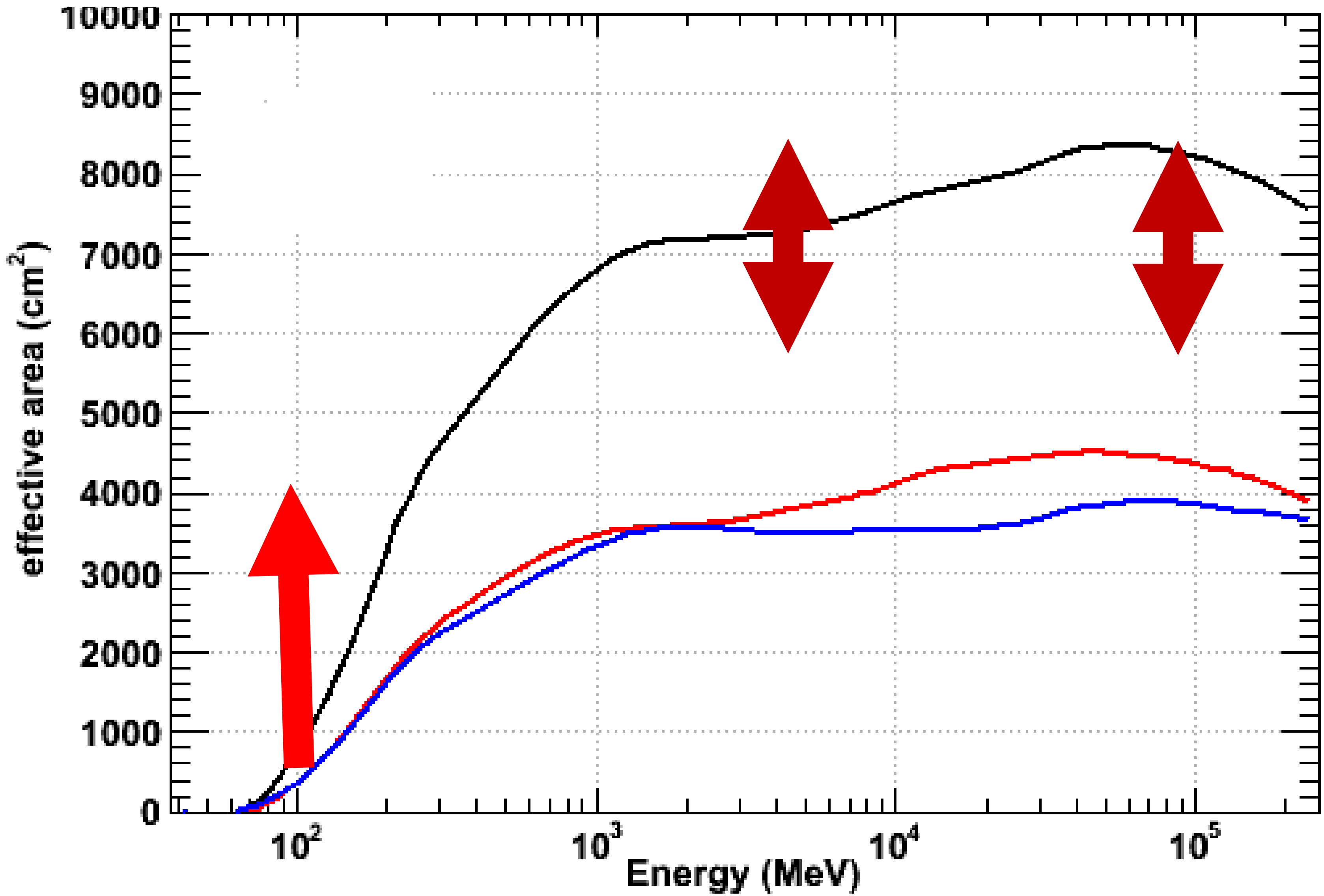


Spatial resolution (μm)
0
20
40
60
80
100
120
140
30
40
50
60
70
80
90
Angle (deg)
Analog
Digital

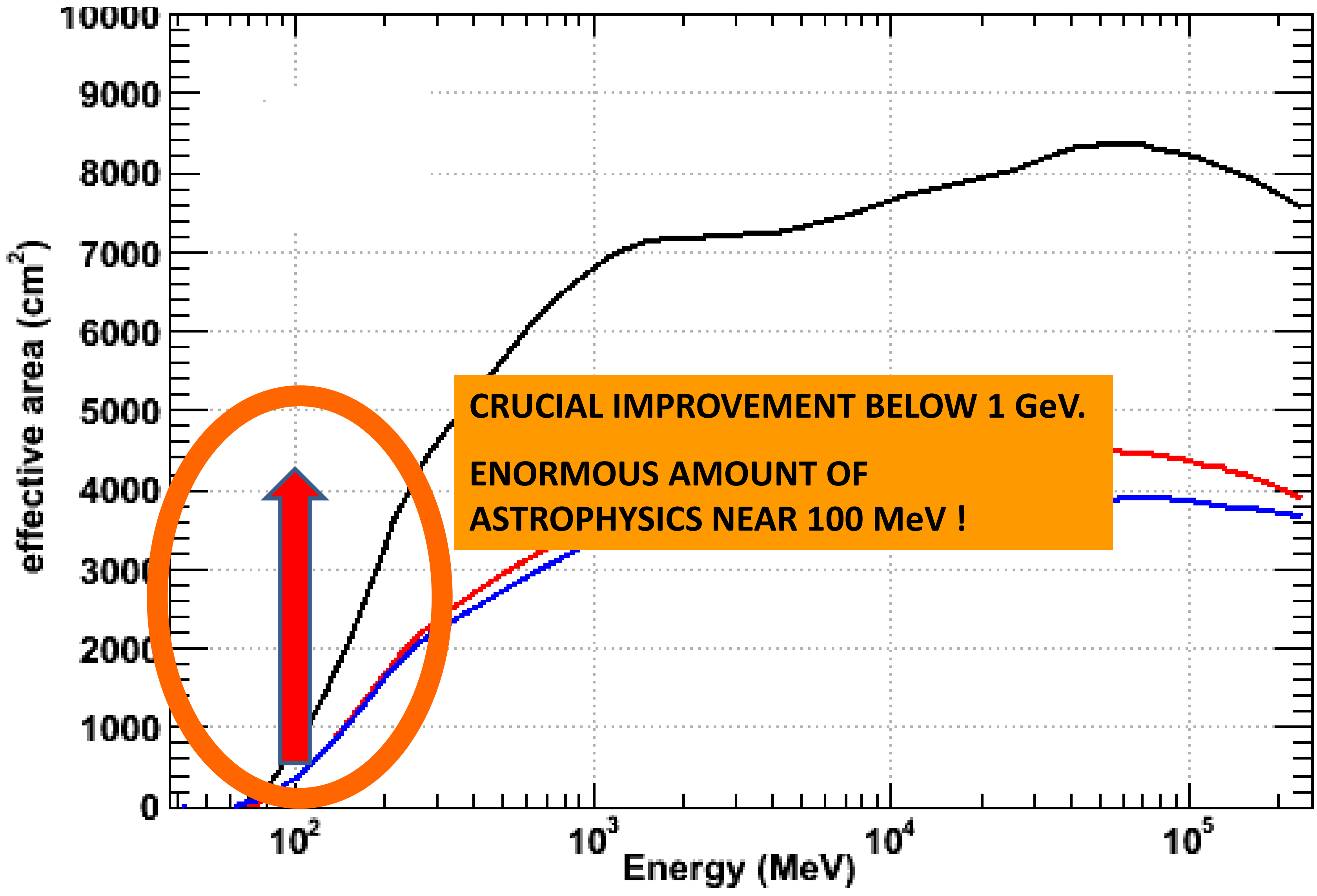
FERMI-LAT A_{eff}



GAMMA-400 IMPROVEMENT IN A_{eff}



GAMMA-400 TRACKER IMPROVEMENT



INSTRUMENT 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**.

READOUT: all strips

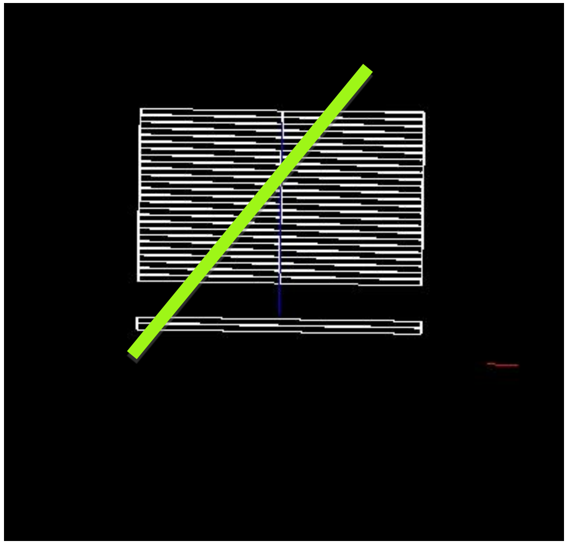
CLUSTER POSITIONING: energy-weighted

2. APPLYING KALMAN RECONSTRUCTION to GEANT4 SIMULATIONS (I.Donnarumma, S. Sabatini, F. Longo, R.Sarkar)

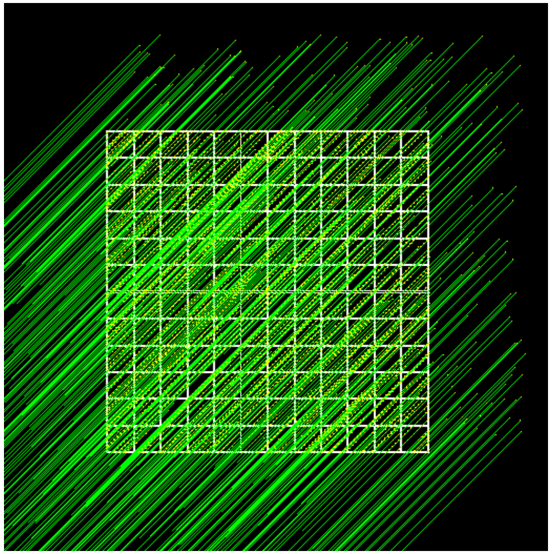
Simulated Energies: 0.05, 0.1, 0.4, 1, 10 GeV
Theta: 30
PHI: 225
N_EVENTS= 1000

2 CASES:

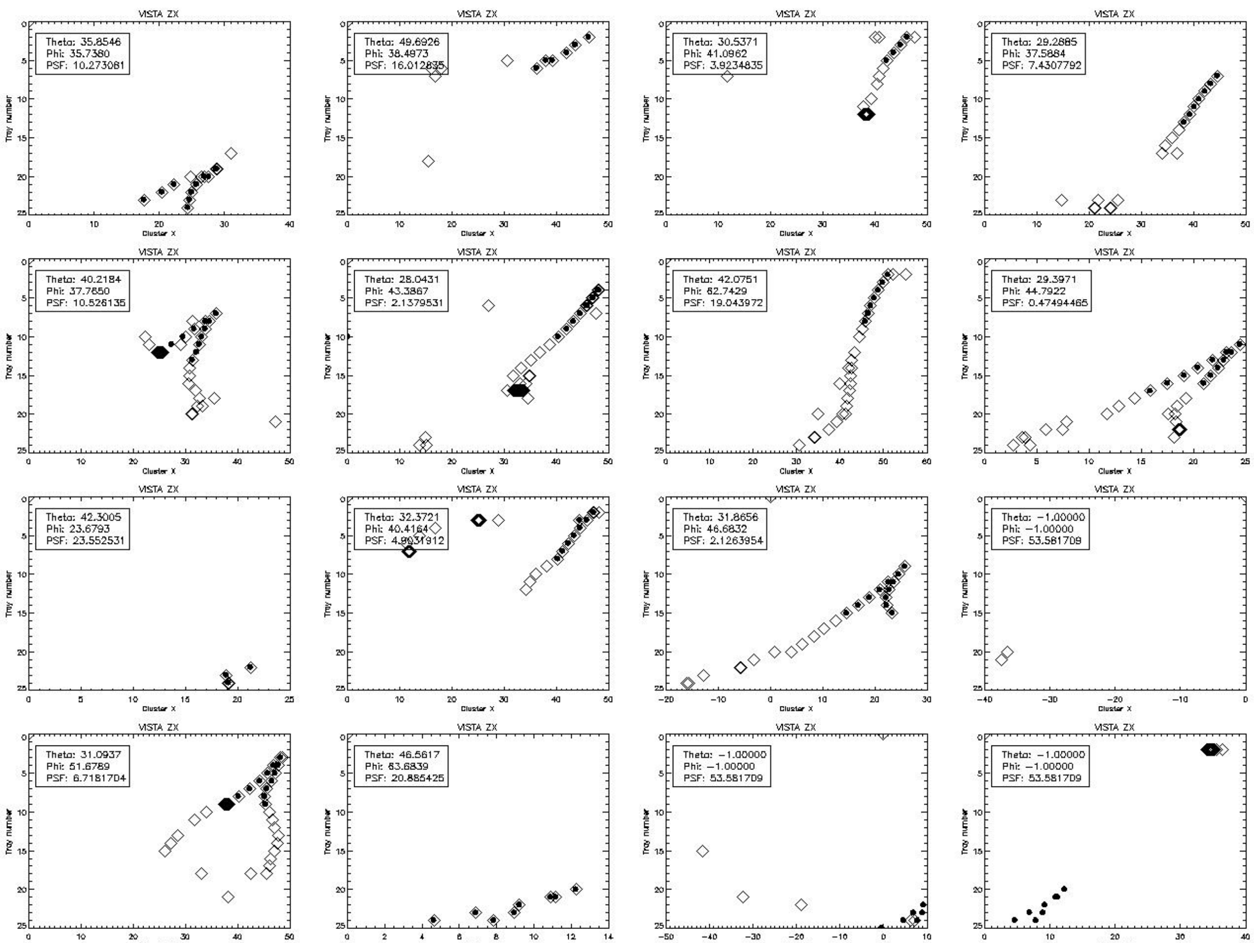
BEAM



PARALLEL FRONT



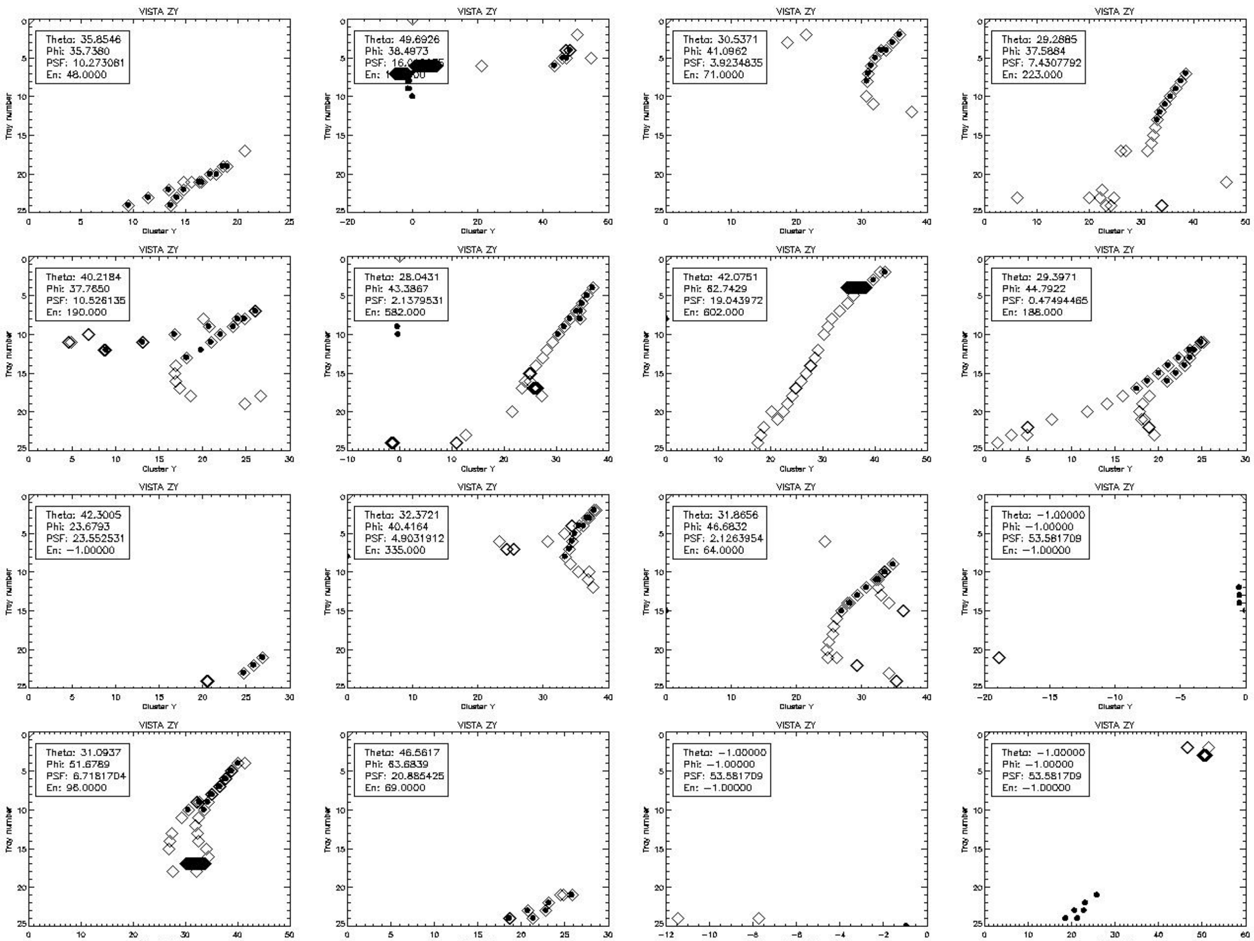
EXAMPLES OF TYPICAL TRACKS – X VIEW



Diamonds: Simulated Tracks

Dots: Reconstructed tracks

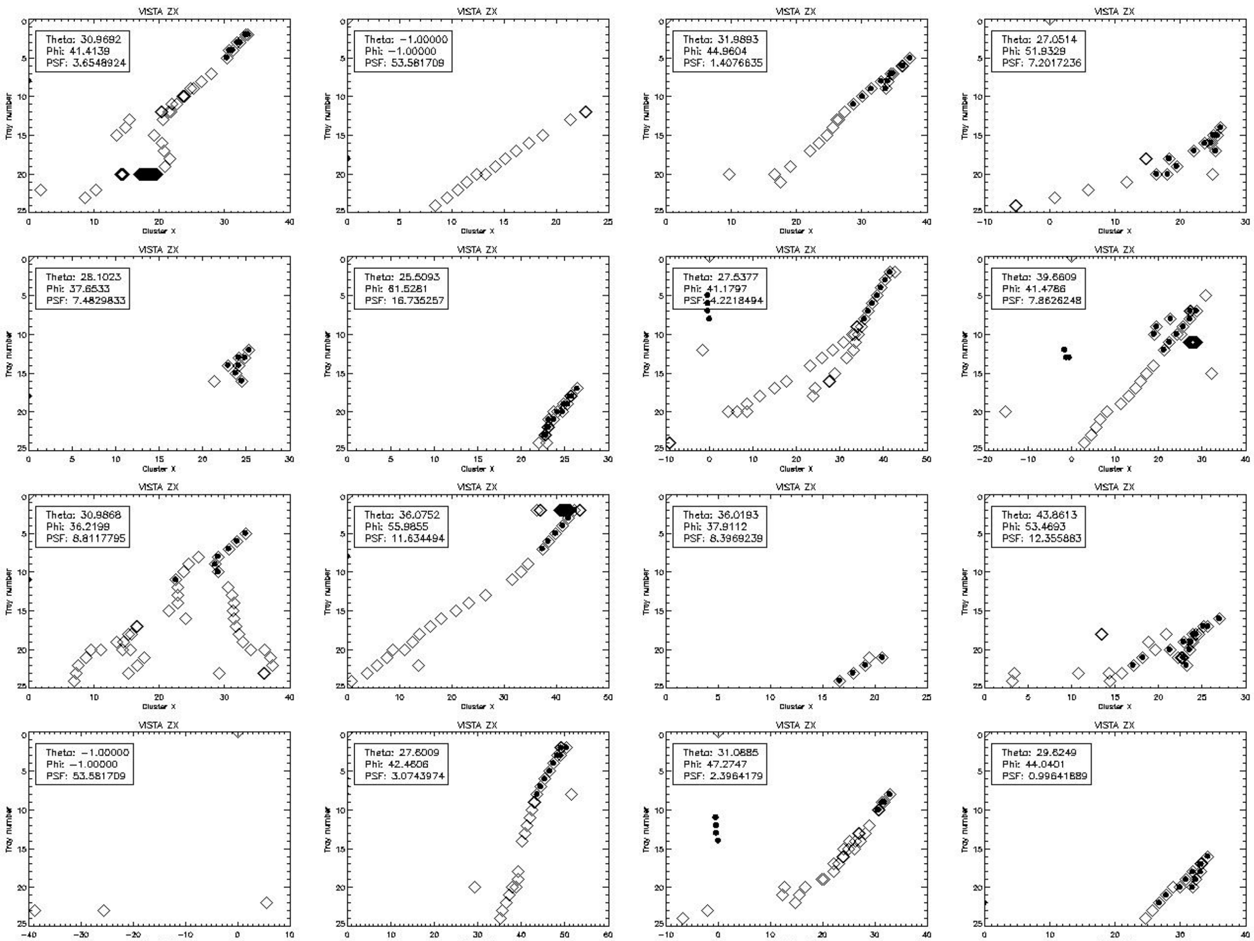
EXAMPLES OF TYPICAL TRACKS – Y VIEW



Diamonds: Simulated Tracks

Dots: Reconstructed tracks

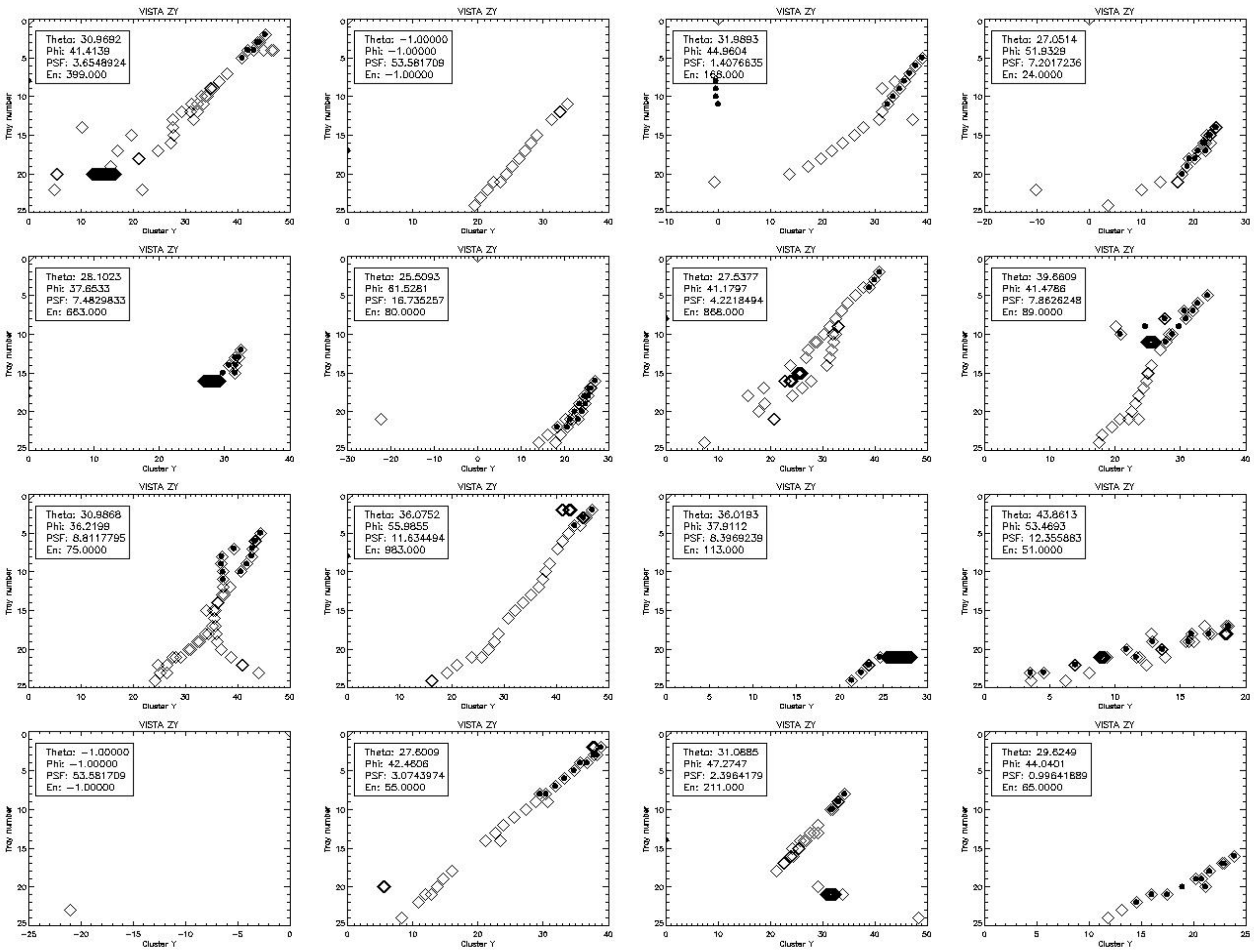
EXAMPLES OF TYPICAL TRACKS – X VIEW



Diamonds: Simulated Tracks

Dots: Reconstructed tracks

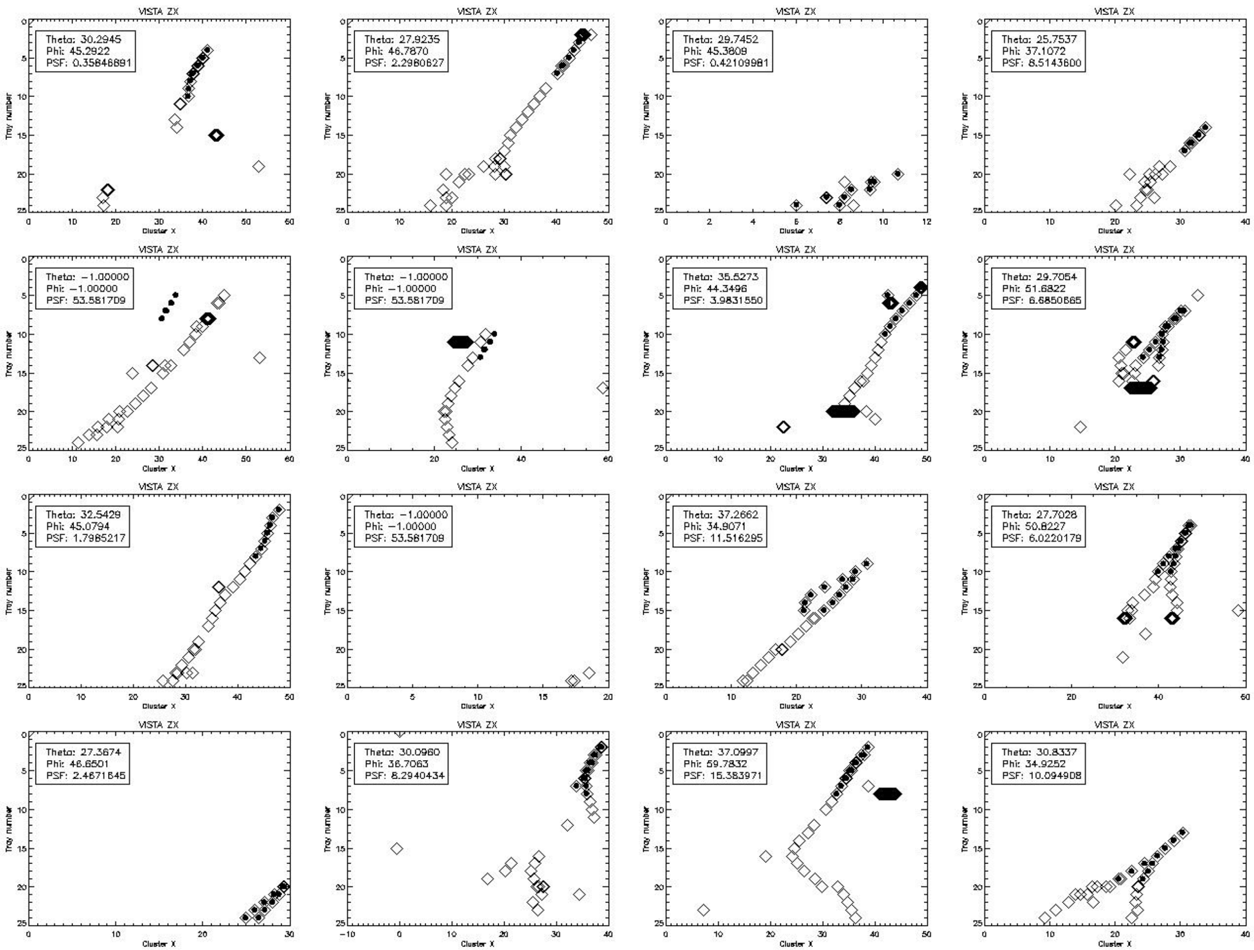
EXAMPLES OF TYPICAL TRACKS – Y VIEW



Diamonds: Simulated Tracks

Dots: Reconstructed tracks

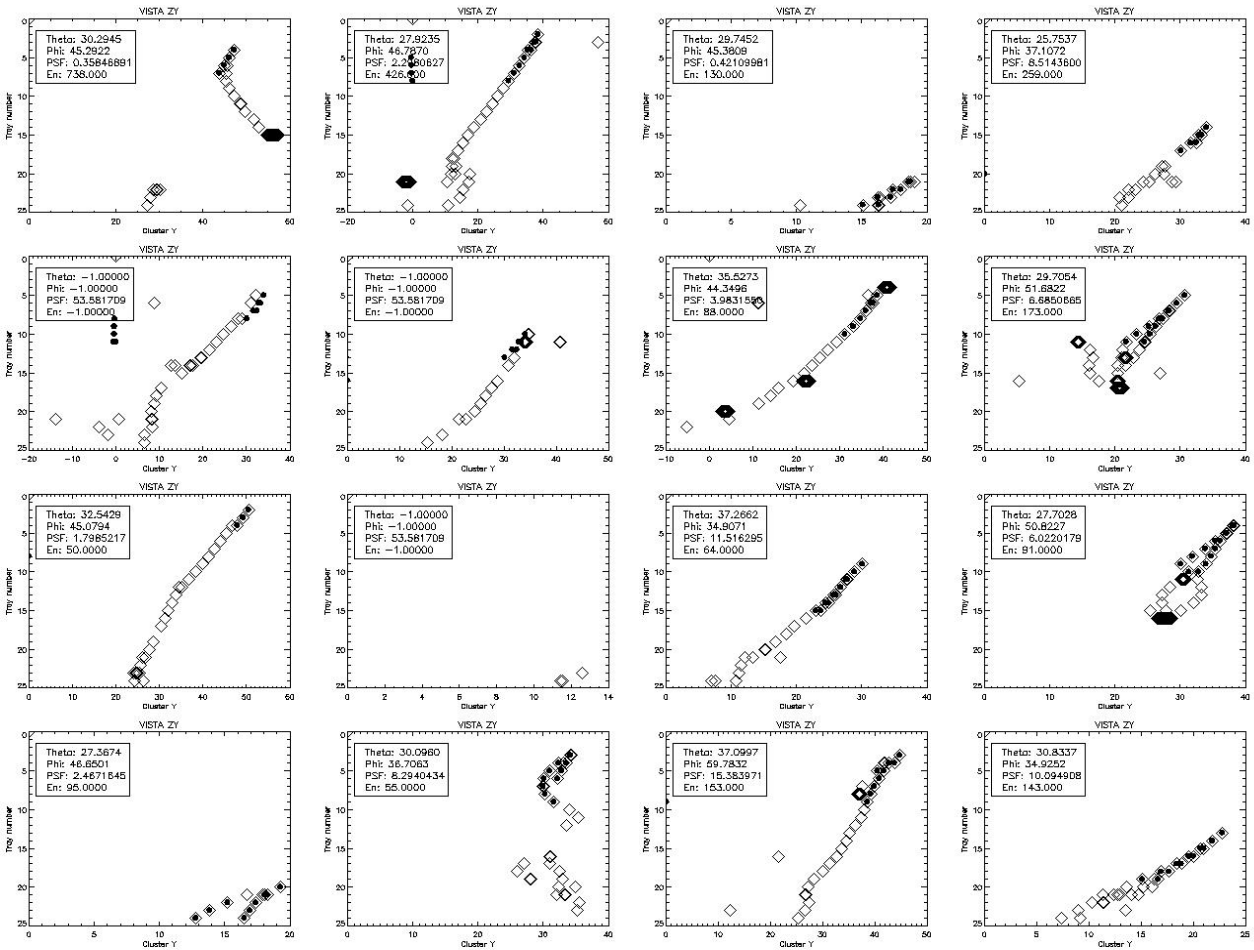
EXAMPLES OF TYPICAL TRACKS – X VIEW



Diamonds: Simulated Tracks

Dots: Reconstructed tracks

EXAMPLES OF TYPICAL TRACKS – Y VIEW



Diamonds: Simulated Tracks
Dots: Reconstructed tracks

- **Gamma-400 will be configured in the next months**
- **unique opportunity to improve current gamma-ray detection from space**
- **huge scientific potential**
- **no more vacuum in gamma-rays from space !**