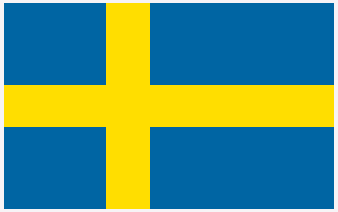
Status of the Gamma-400 space experiment

Roberta Sparvoli – Univ. Roma Tor Vergata for the G-400 collaboration



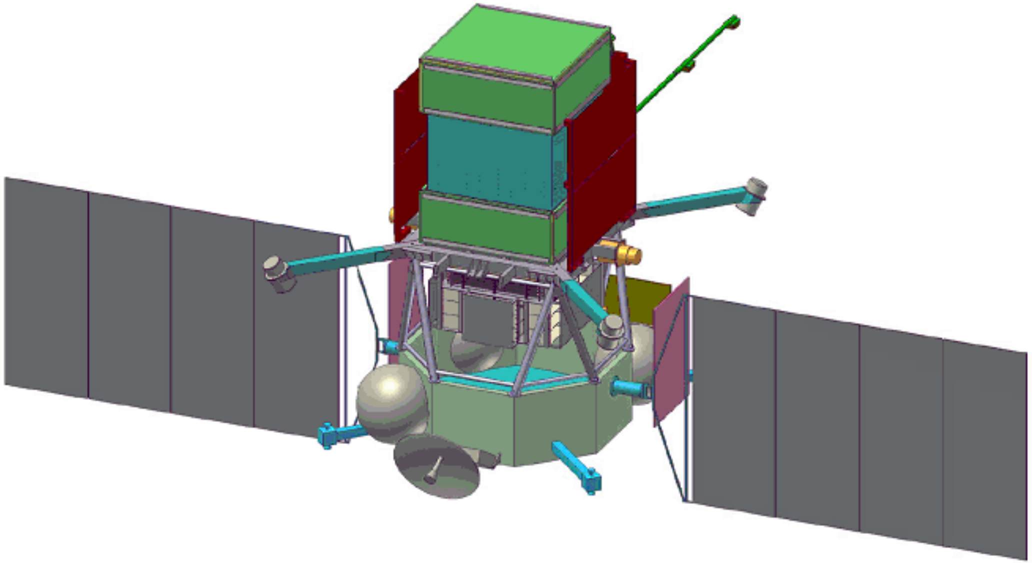



Cooperation in the design and production of scientific equipment

Russian scientific organizations	Foreign scientific organizations
LPI RAS – Leading Institute	INFN (Italy) – Converter/Tracker and Calorimeter
NRNU MEPhI – TOF and A/C detectors	INAF (Italy) – Converter/Tracker
NIIEM — design, temperature control system	Taras Schevchenko National University (Ukraine) — Ukrainian main collaborator
NIISI RAS — electronics	CrAO (Ukraine) — ground-based observatio
Ioffe Institute — Konus-FG burst monitor	IKI (Ukraine) — magnetometer
IKI — star sensor	ISM (Ukraine) — scintillators
IHEP — calorimeters, scintillators	KTH (Sweden) — anticoincidence
TsNIIMASH — space qualification	

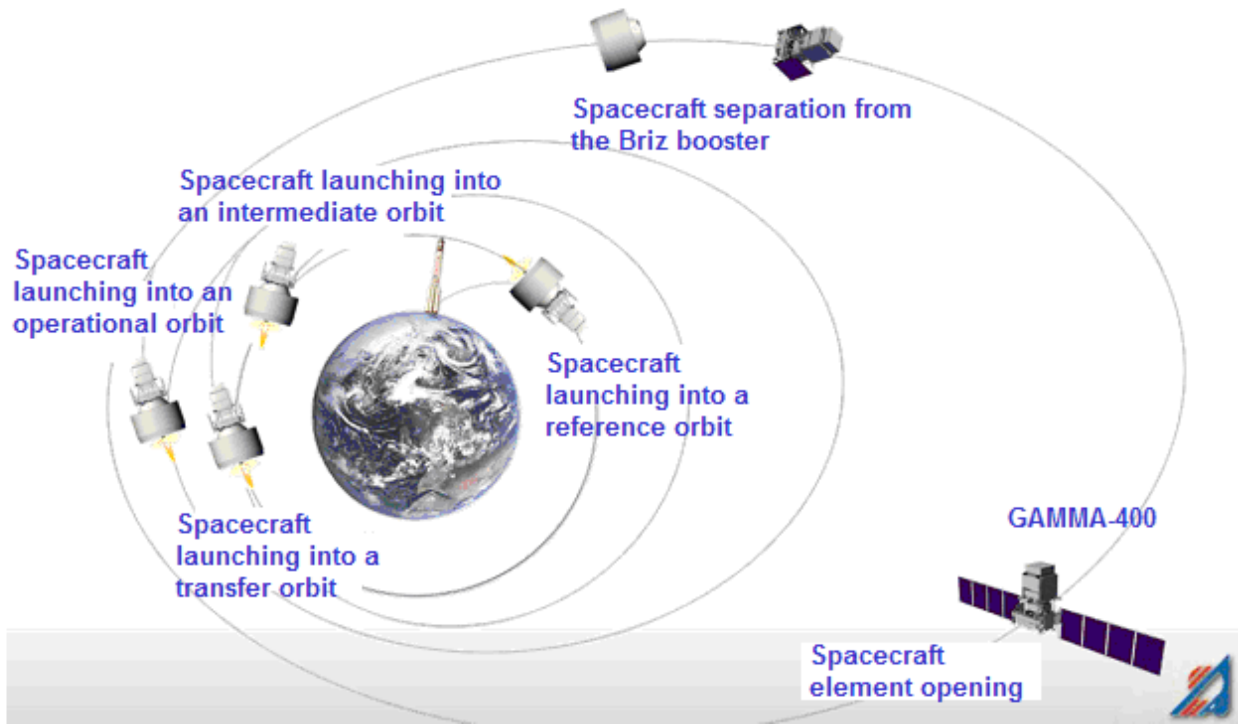
GAMMA-400

- Mission approved by ROSCOSMOS (launch currently scheduled by November 2018)
- GAMMA-400 will be installed onboard the platform "Navigator" manufactured by Lavochkin
  - Scientific payload mass 4100 kg (rocket changed from Zenith to Proton-M)
  - Power budget 2000 W (like previously)
  - Telemetry downlink capability 100 GB/day
  - Lifetime ~ 10 yrs

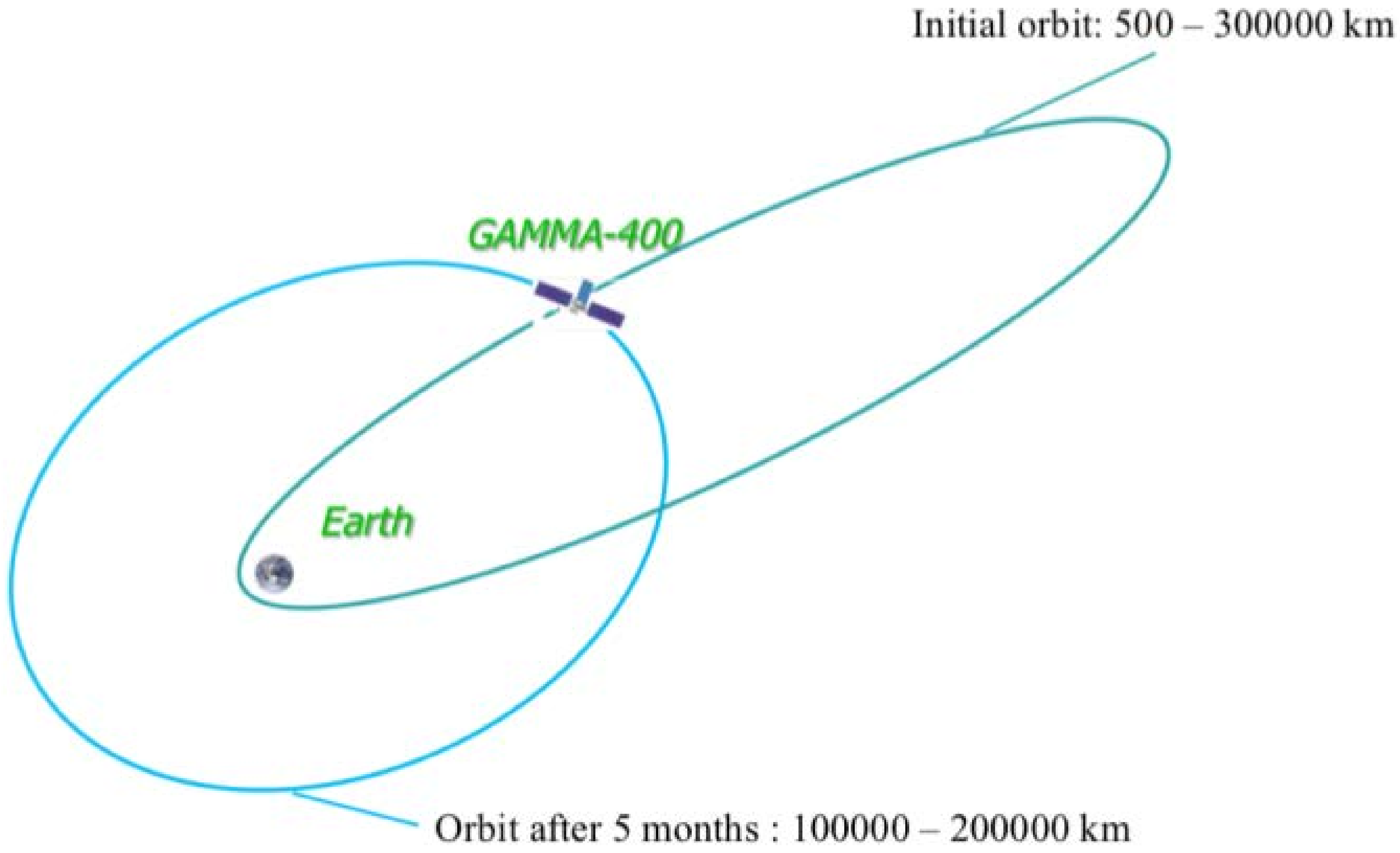


GAMMA-400 on the Navigator service module

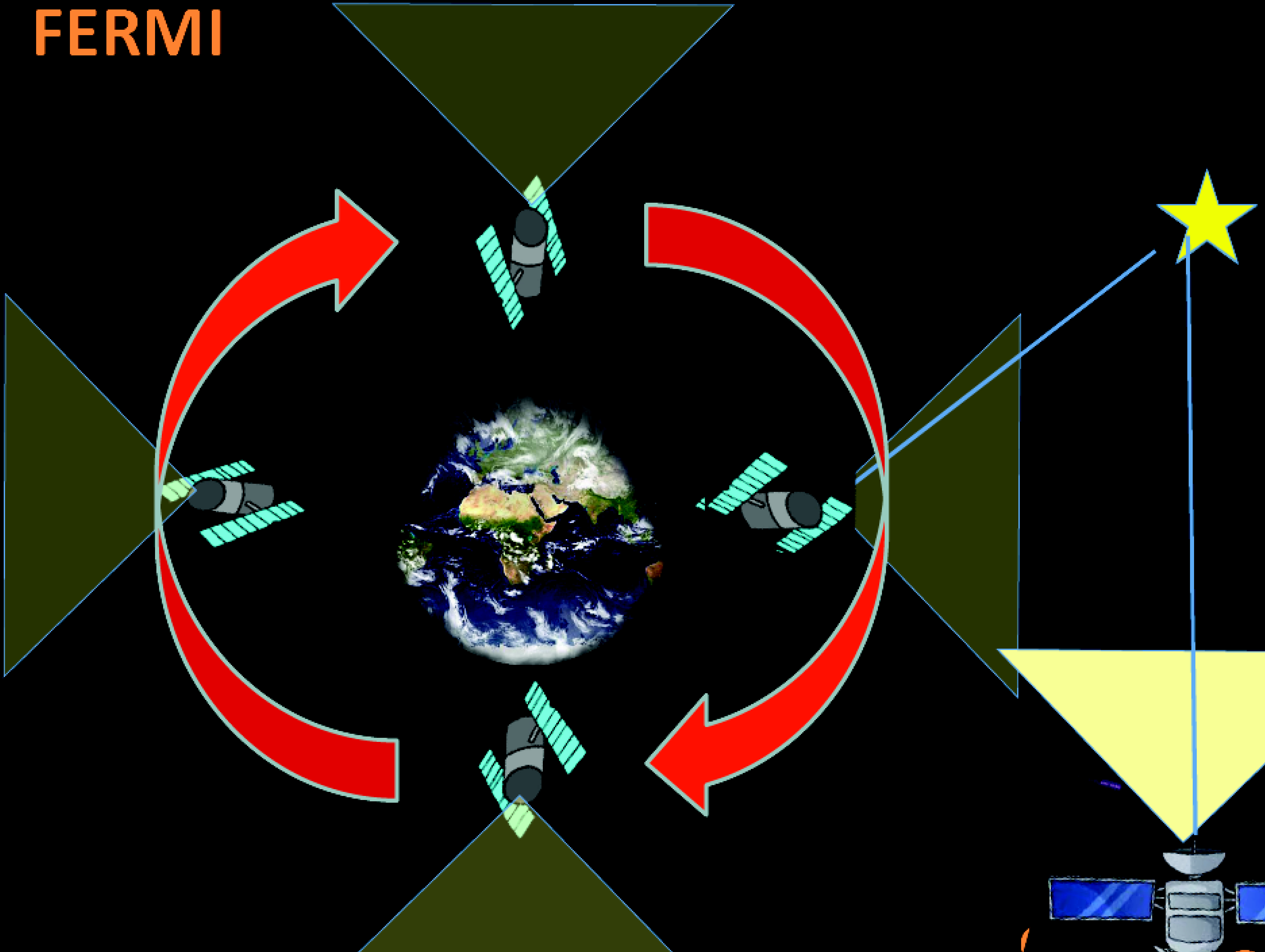
GAMMA-400 spacecraft launching scheme

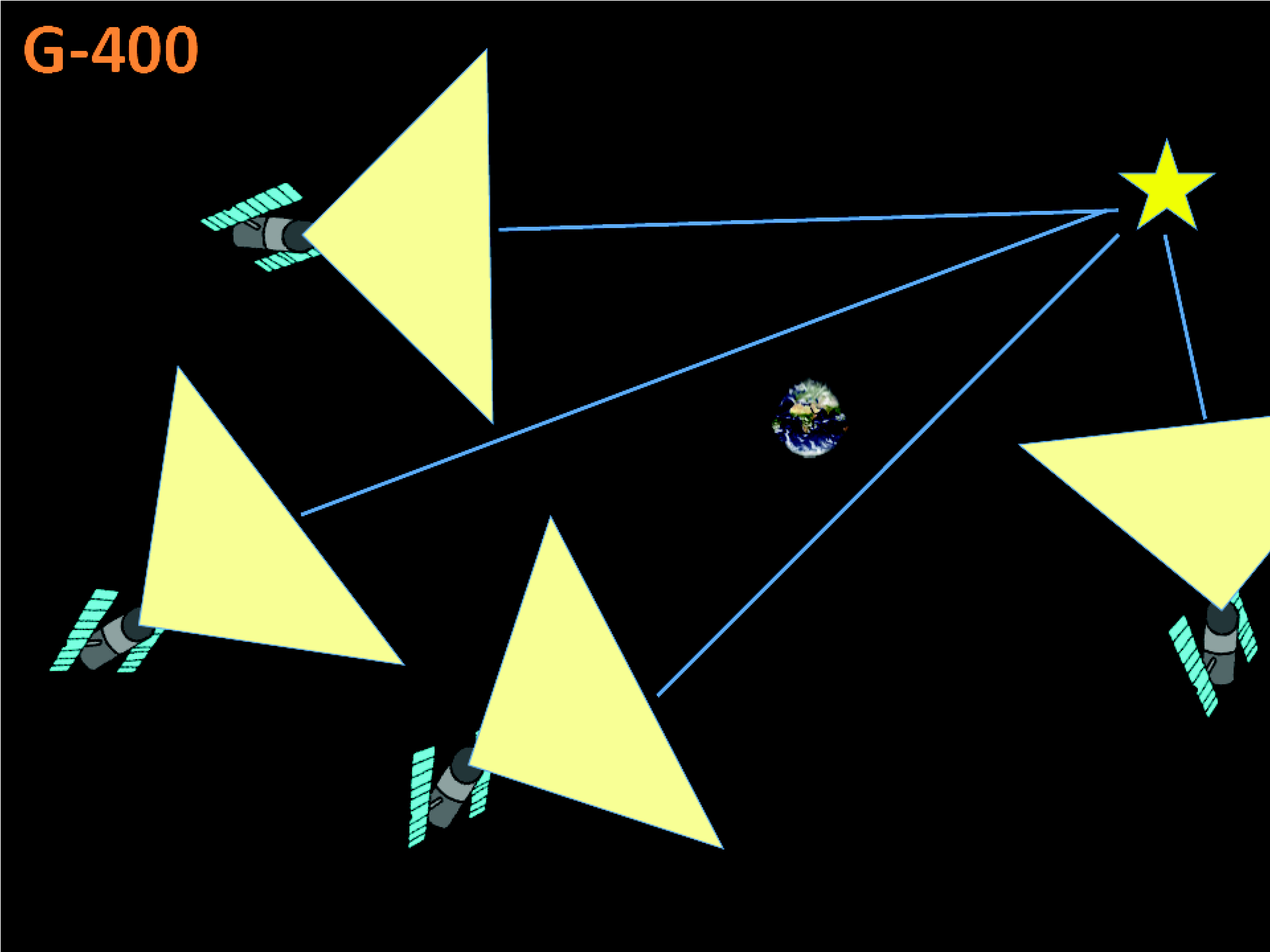


GAMMA-400


Initial orbit: 500 – 300000 km
GAMMA-400
Earth
Orbit after 5 months : 100000 – 200000 km

FERMI




G-400

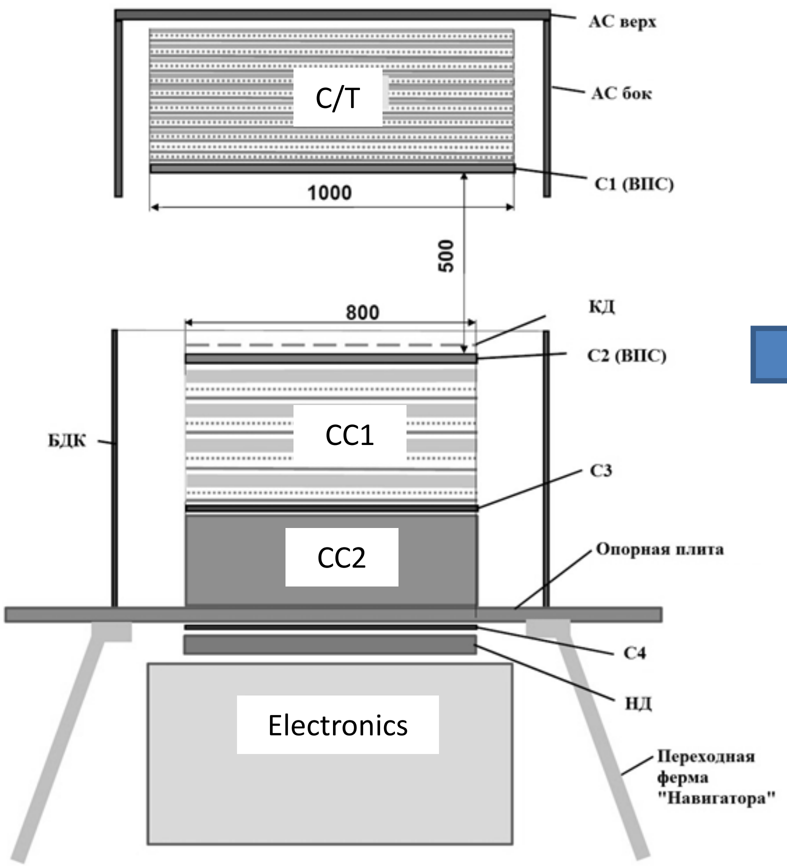
GAMMA-400

- 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"

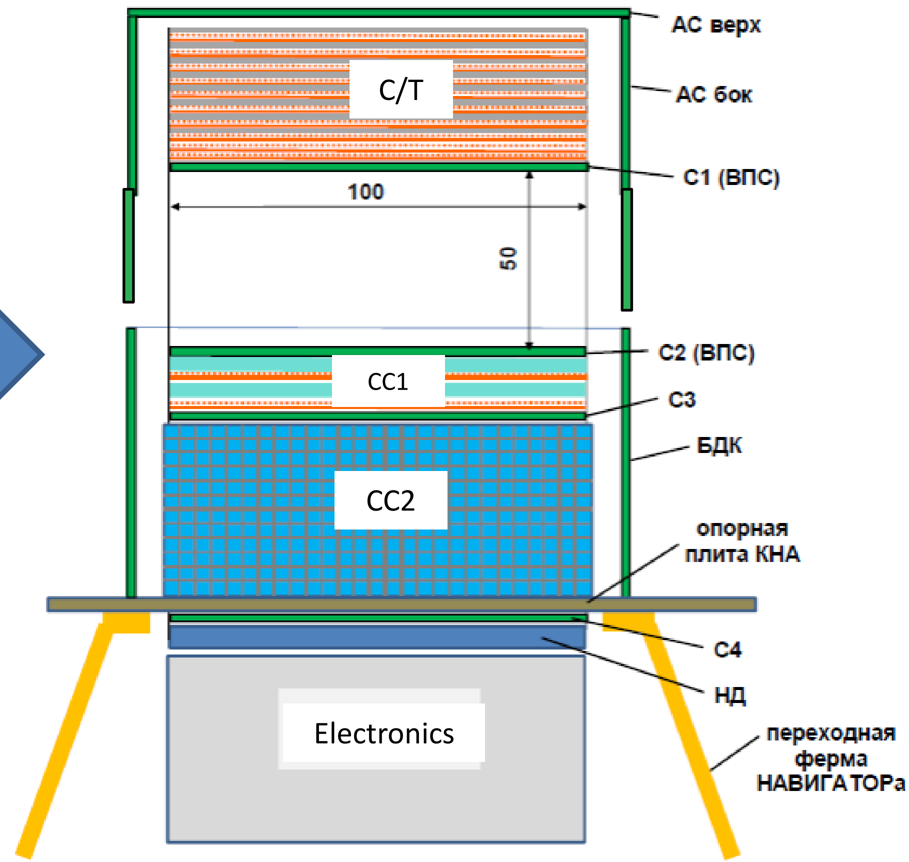
Improvements in the GAMMA-400 design and performance

- During the last two years, a great deal of effort has been deployed by the Italian collaboration in order to significantly improve the scientific characteristics of the G-400 mission. The guidelines of this work have been:
  A. to agree upon 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 B1 version: this new "baseline" version, called B2, **has been agreed upon by both (Russian and Italian) sides during a collaboration meeting held in Moscow in February 2013. Current window: 100 MeV - > 3000 GeV**
  B. to define the best configuration for **a dual instrument for photons (30 MeV - > 3000 GeV) and cosmic rays (electrons > 1 TeV and high-energy cosmic-ray nuclei, p and He spectra close to the "knee" region (10^{14} – 10^{15} eV)):** E2 version.

GAMMA-400

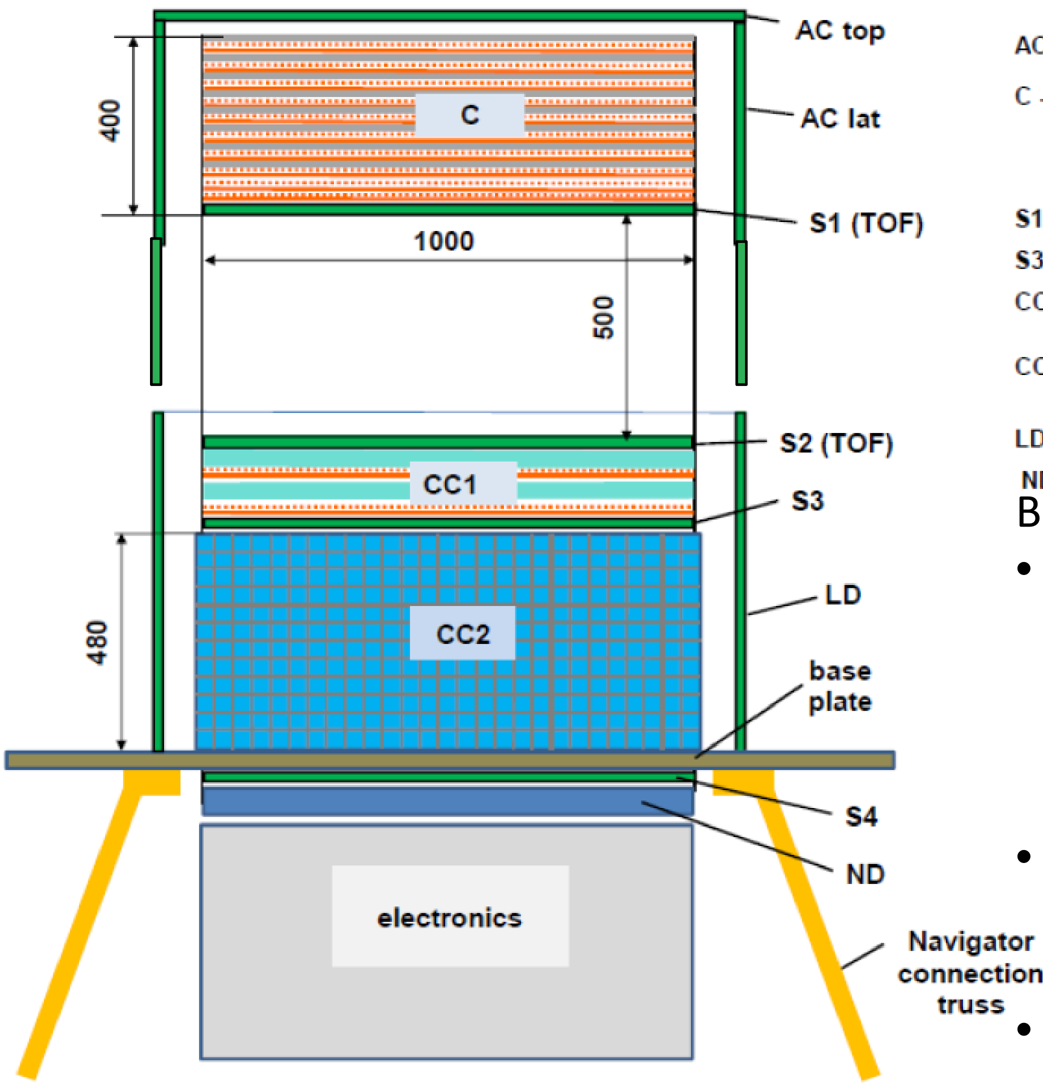


Original Russian proposal (2011)



Jointly agreed Russian-Italian proposal (2013)

The new B2 baseline



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

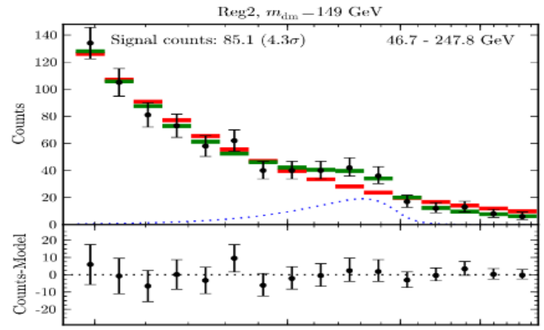
ND - neutron detector

B2 over B1 improvements:

- Introduction of the 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 0.1 mm

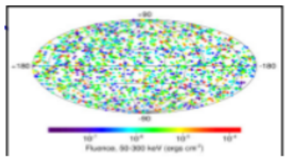
Physics with GAMMA-400

Galactic/ Extragalactic gamma-ray sources



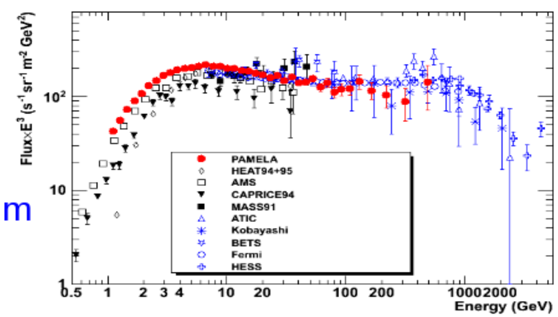
Dark Matter

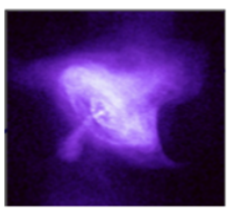
CR propagation



GRBs

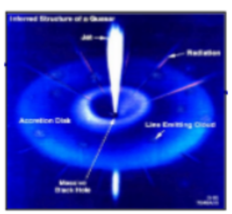
Electron spectrum



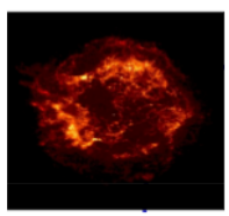


Pulsars

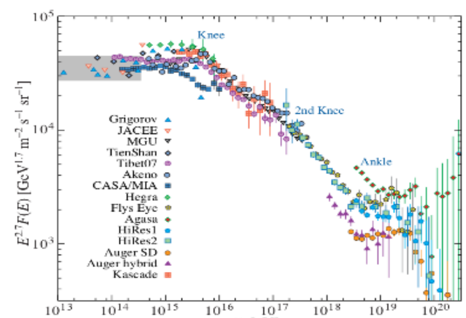
Knee origin



AGNs

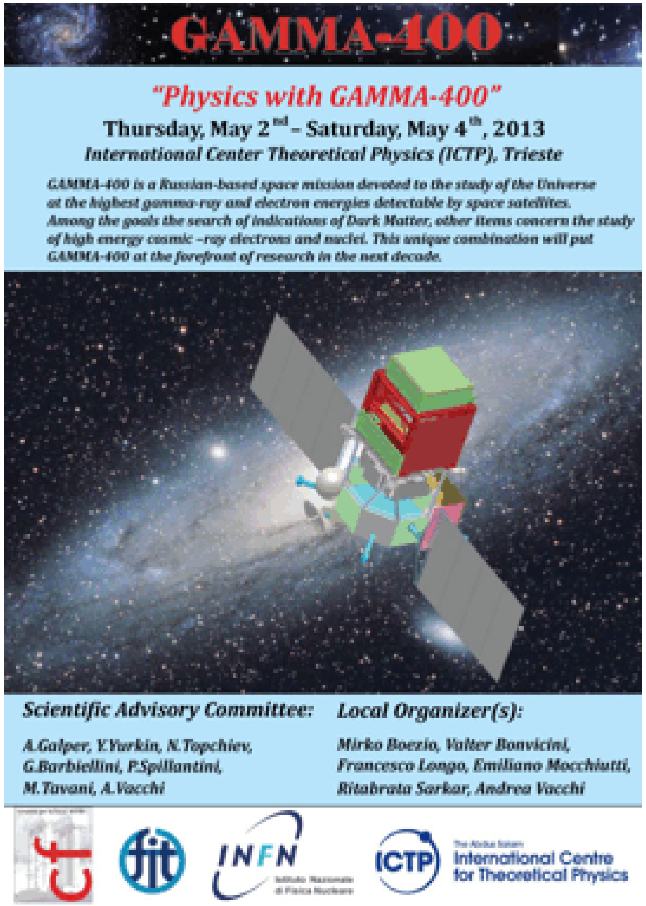


SNRs

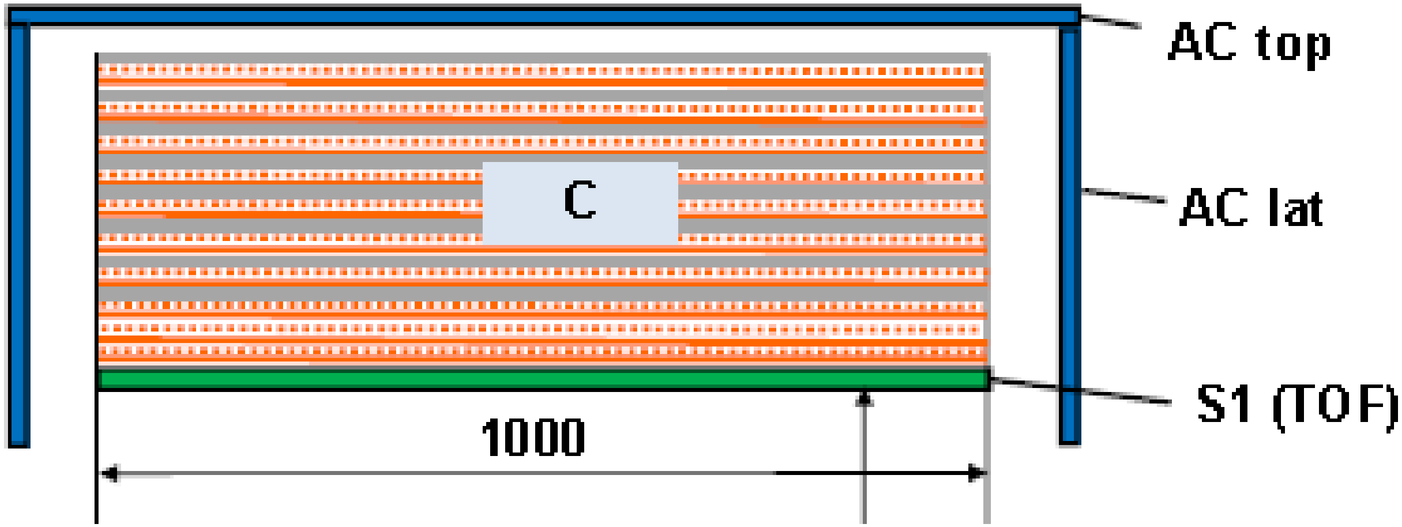


CR origin and acceleration mechanisms

- Workshop “Science with GAMMA-400” held in Trieste (ICTP), 2-4 May 2013
- Presentations at http://www.fondazioneinternazionale.org/attiConvegni.php

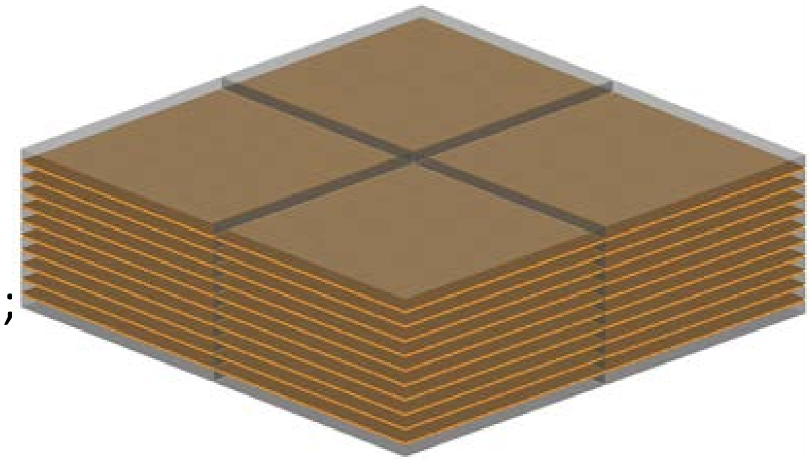


B2 detectors: Converter/Tracker



- 8 layers W $0.8X_0$ + 8 planes Si (x,y)
- 2 layers of Si (x,y), no W

B2 detectors: Converter/Tracker



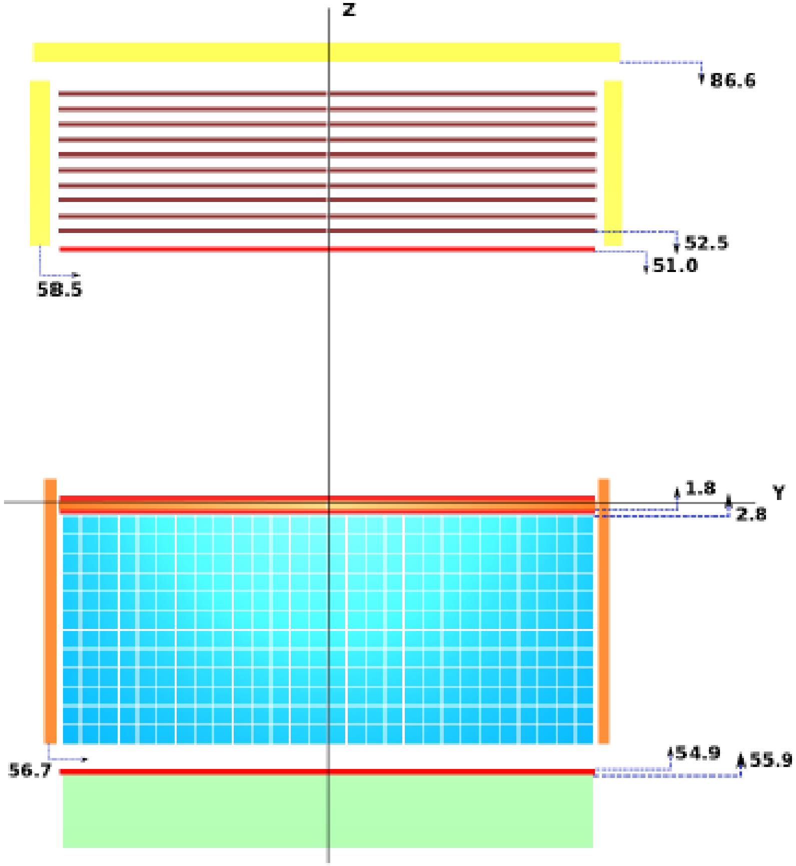
- Homogeneous Si-W Tracker
- 4 towers (~ 50 cm x 50 cm each);
- 8 W/Si-x/Si-y planes + 2 Si-x/Si-y planes (no W);
- Thickness of each plane 0.1 X_0
- Each sensor ~ 9.7 cm x 9.7 cm from 6” wafers;
- Sensors arranged in ladders (5 detectors/ladder), 1 ladder ~ 50 cm;
- Read-out pitch 240 μm (capacitive charge division), 384 strips/ladder
- Implant pitch:
  - Either 120 μm (one strip every 2 is read-out)
  - Or 80 μm (one strip every 3 is read-out)
- 2000 silicon detectors;
- 153600 readout channels, 2400 front-end ASICs (64 channels/ASIC)
- Power consumption (FE only): ~ 80 W

Converter/Tracker: FE electronics

- Front-end ASIC: architecture similar to TAA1 used in AGILE, with sparse read-out (only triggered ASICs are read-out).
- Configuration: CSA, shaping amplifier, S/H and MUX. Each channel has a comparator with adjustable (via a DAC) threshold for trigger.
- The ASIC should be designed in a “modern” technology: AMS 0.35 μm CMOS is well known (reliability) and offers excellent noise performance!

B2: Calorimeter

GAMMA-400: Calorimeter



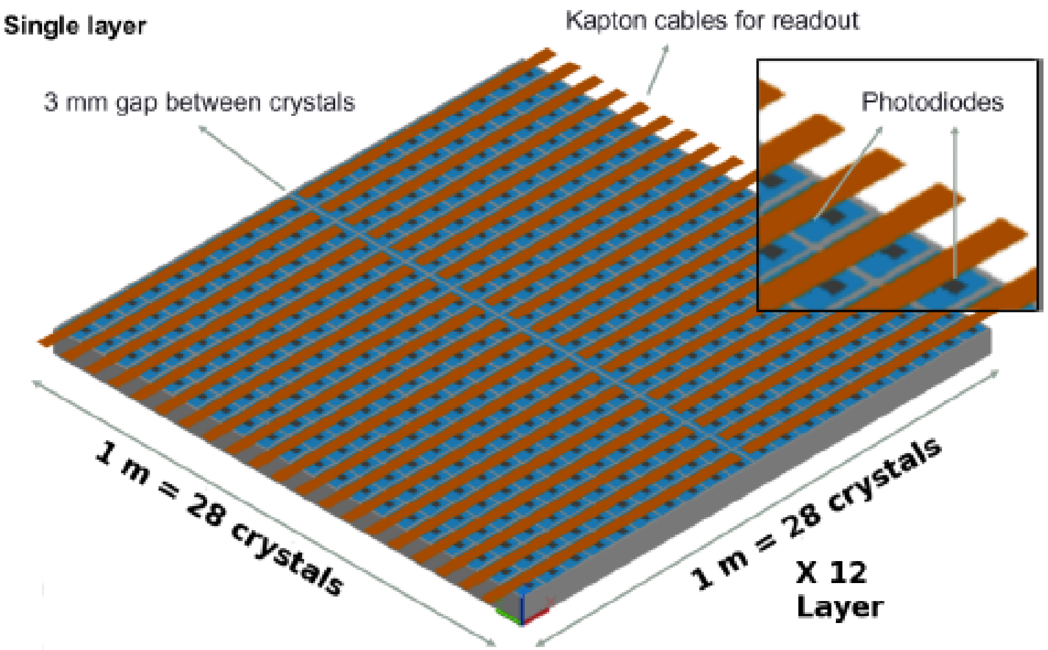
Calorimeter CC1 (Si-CsI(Tl))

N layers	2
Si pitch	0.1 mm
Size	1x1x0.04 m^3
X_0	2
λ_I	0.1

Calorimeter CC2 (CsI(Tl))

NxNxN	28x28x12
L	3.6 cm
Size	1x1x0.47 m^3
X_0	54.6x54.6x23.4
λ_I	2.5x2.5x1.1
Mass	1683 kg

B2: Calorimeter



At least 2 photo diodes per crystals to cover the huge dynamical range (1-10^7 MIP)

B2: Calorimeter

- Minimum 2 photodiodes are needed on each CsI crystal to cover the HUGE (1 MIP $\div$ 10^7 MIP) dynamic range, hence
- A front-end electronics with large dynamic range and sensitivity down to 1-MIP signals is needed:
- CASIS 1.2 ASIC (INFN Gr. 5 experiments CASIS and CASIS-2)

B2: Calorimeter

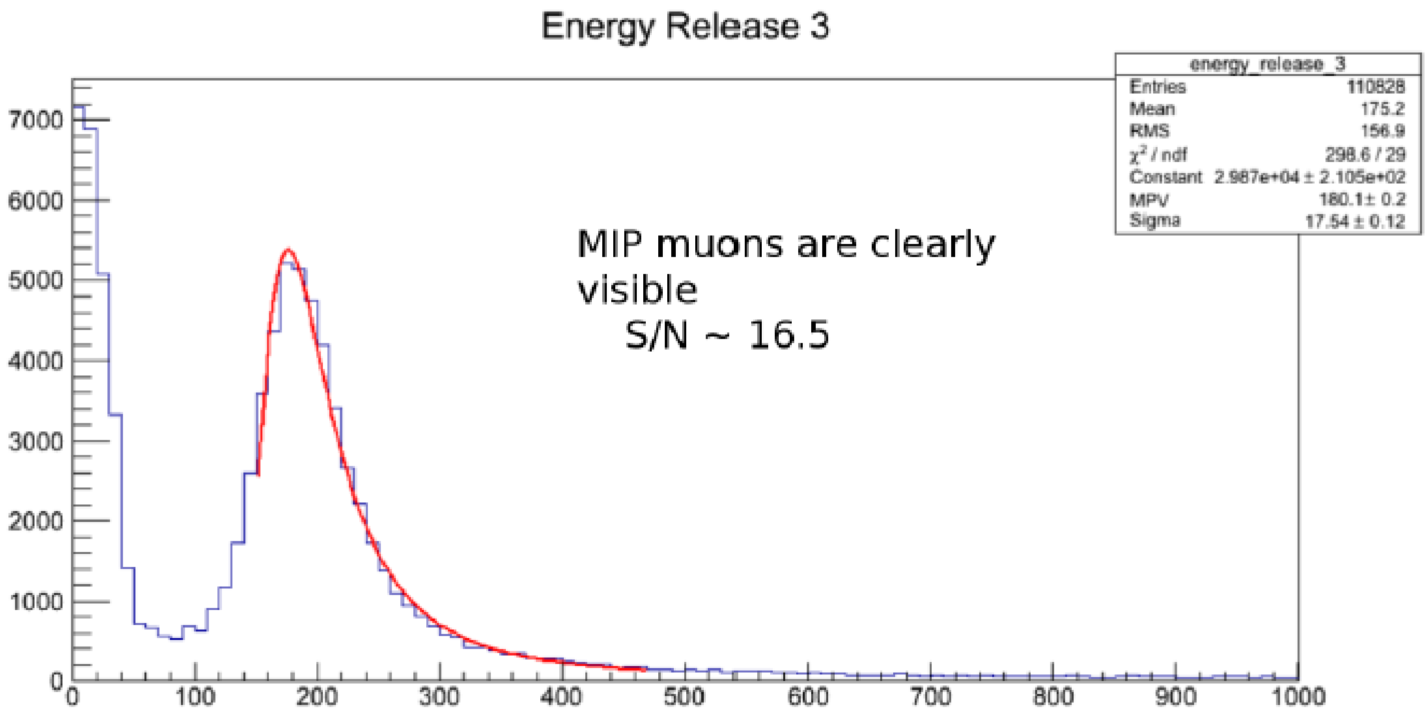
Calorimeter CC2: test beam

- October 2012 @ CERN SPS (e^-, p, muons): small, so called "pre-prototype" (4 layers, 3 crystals each)
- February 2013 @ CERN SPS (Ions): bigger, properly called "prototype" (14 layers, 9 crystals each)
- October 2013 @ INFN Frascati: 700 MeV e^-

B2: Calorimeter

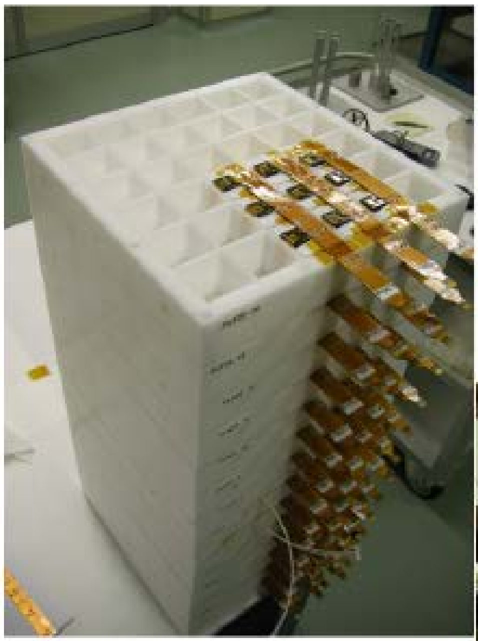
"Pre-prototype" results

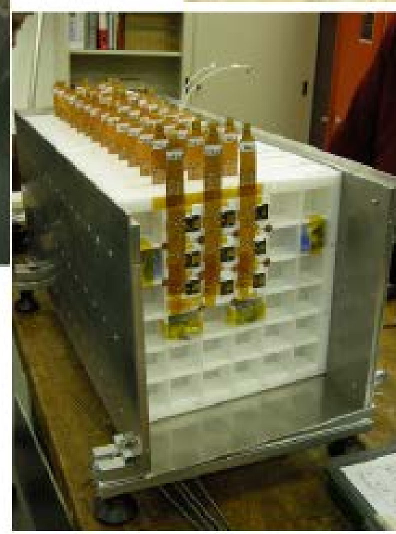
Muon beam



B2: Calorimeter

The prototype



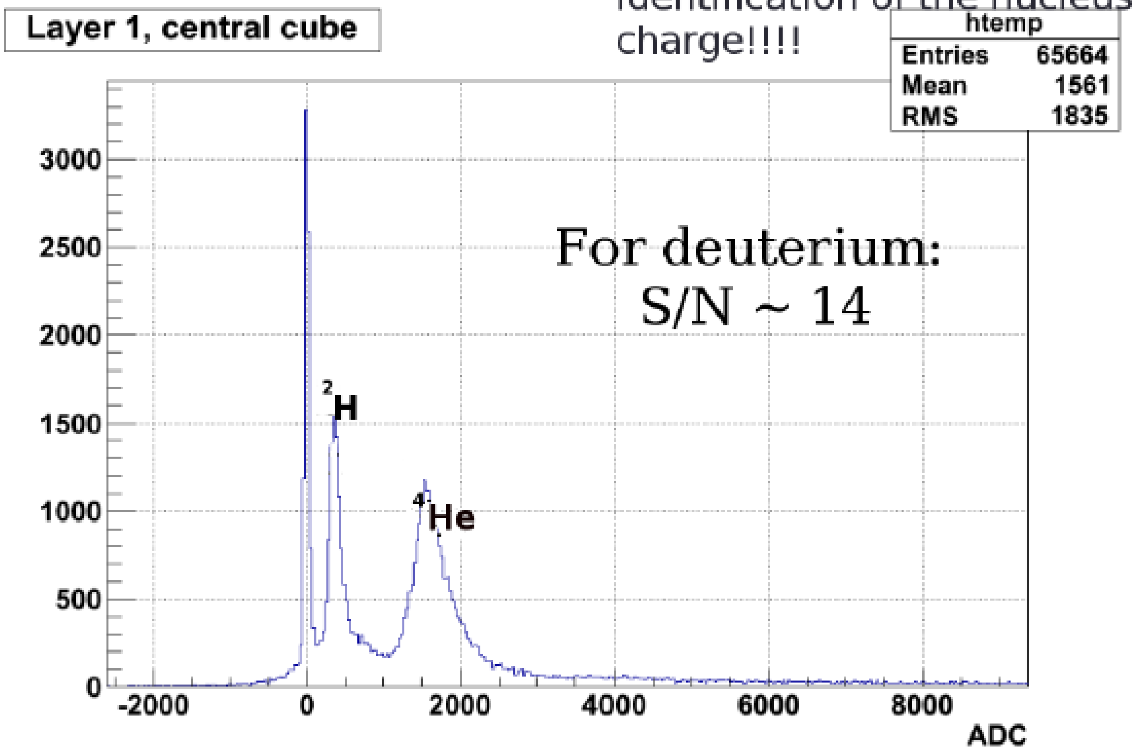


B2: Calorimeter

Pulse height spectrum in a crystal

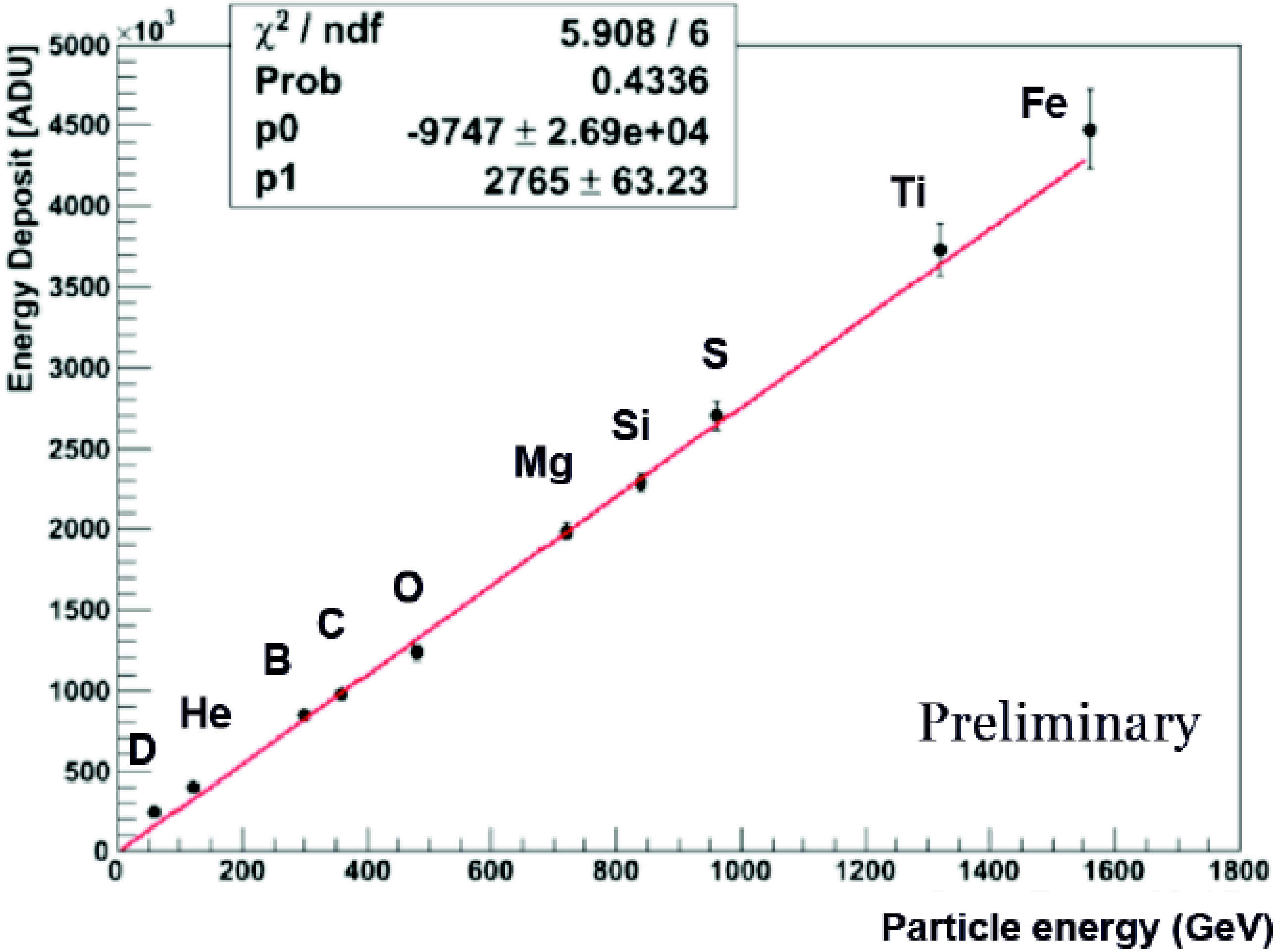
SPS H8 Ion Beam: Z/A = 1/2, 12.8 GV/c and 30 GV/c

Please note: we can use the data from a precise silicon Z measuring system located in front of the prototype to have an exact identification of the nucleus charge!!!!



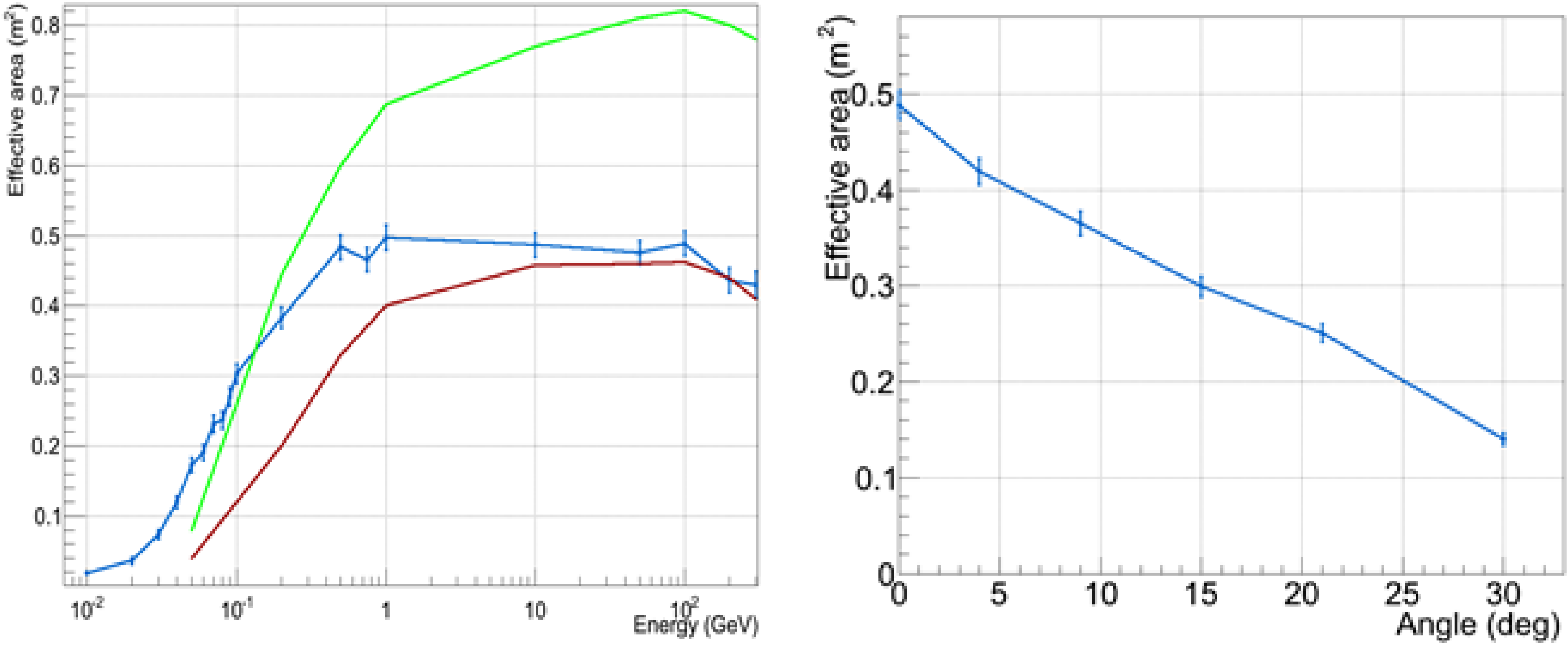
B2: Calorimeter

Energy deposit



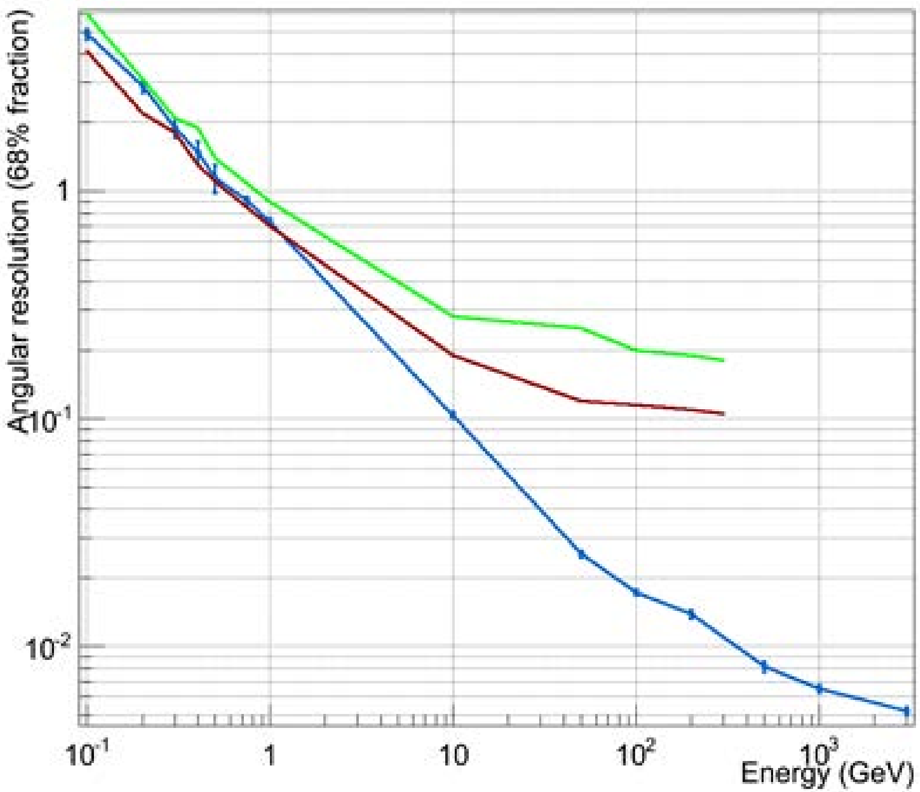
Performance of the B2 configuration

Preliminary!



Effective area (m²) of the G-400 instrument with B2 configuration. Left panel: variation of the effective area with energy for normal incidence and flat area distribution (Blue: G-400, Green: Fermi-LAT total, Red: Fermi-LAT front). Right panel: variation of effective area of G-400 at 100 GeV with polar angle for flat area distribution.

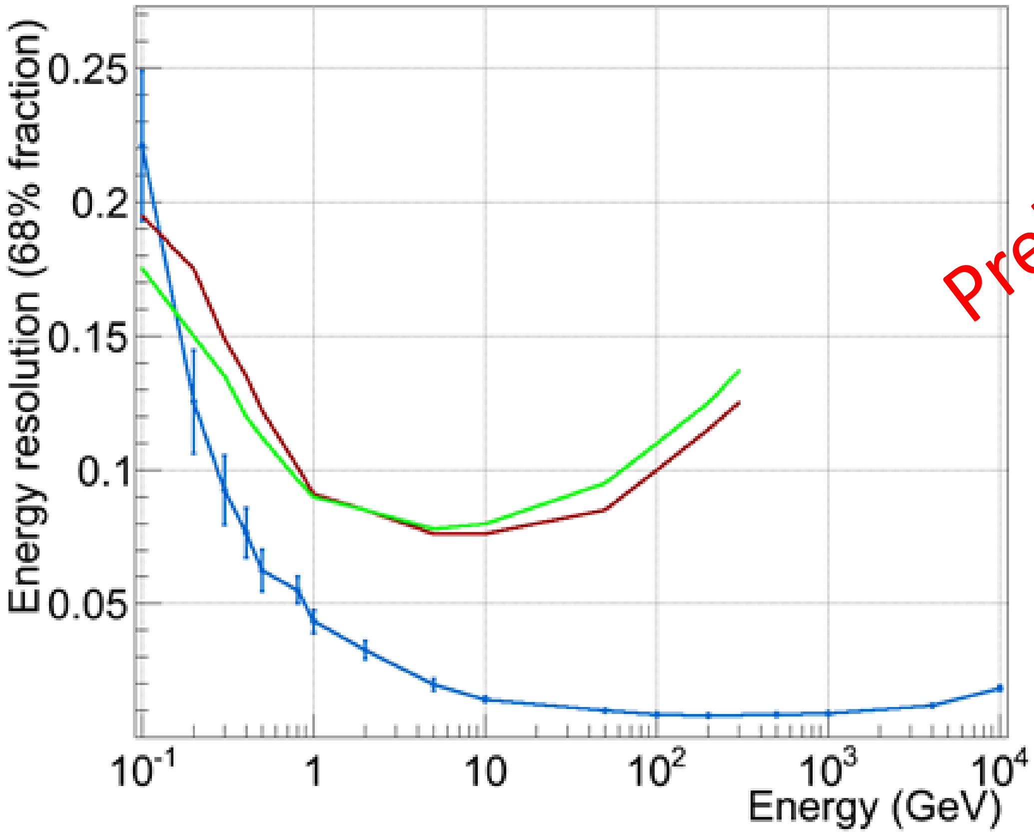
Performance of the B2 configuration



Preliminary

Variation of angular *resolution (68% fraction) of the G-400 instrument with B2 configuration with energy for normal incidence and flat area distribution, and comparison with Fermi-LAT. (Blue: G-400, Green: Fermi-LAT total, Red: Fermi-LAT front)*

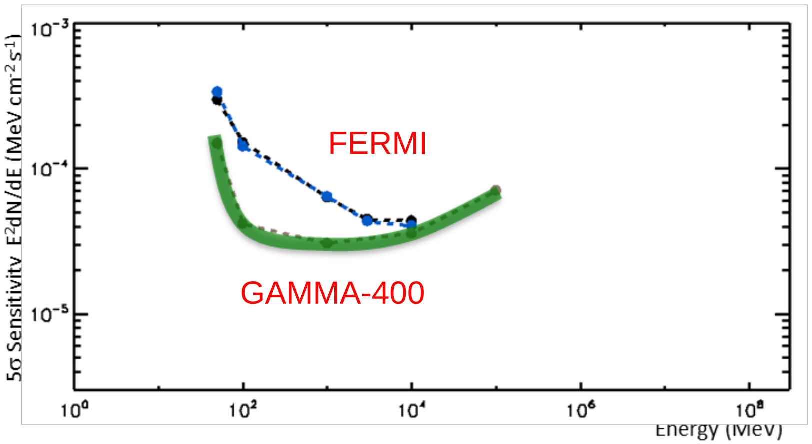
Performance of the B2 configuration



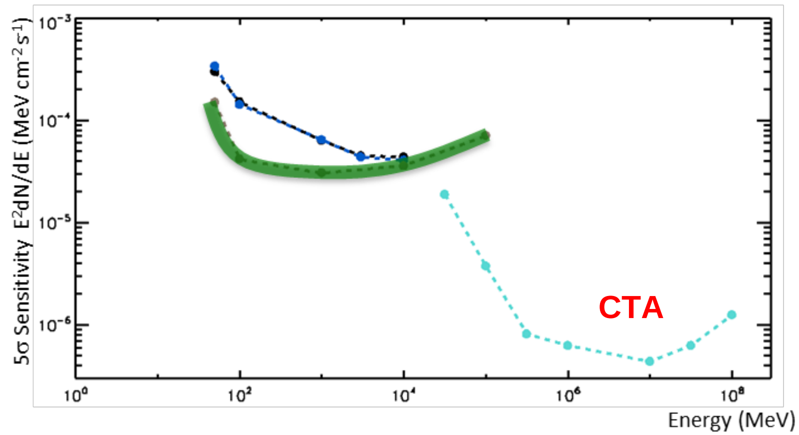
Variation of *energy resolution (68% fraction) of the G-400 instrument with B2 configuration with energy for normal incidence and flat area distribution, and comparison with Fermi-LAT. (Blue: G-400, Green: Fermi-LAT total, Red: Fermi-LAT front)*

Performance of the B2 configuration

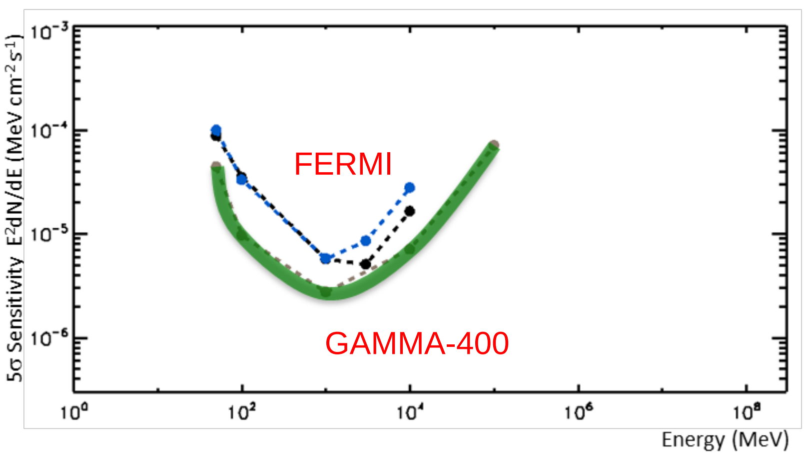
30 days – (Eff$_G$=1, Eff$_F$=1/6) _ Gal Centre Sensitivity



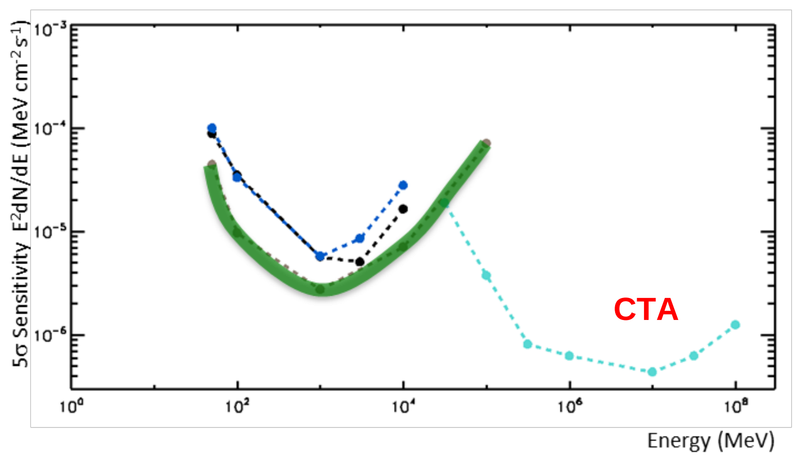
30 days – (Eff$_G$=1, Eff$_F$=1/6) _ Gal Centre Sensitivity



30 days – (Eff$_G$=1, Eff$_F$=1/6) _ Extra-Gal Sensitivity



30 days – (Eff$_G$=1, Eff$_F$=1/6) _ Extra-Gal Sensitivity



B2: Electron count estimation

Experiment	Duration	GF (m^2 sr)	Calo σ(E)/E	Calo depth	e/p rejection factor	E>0.5 TeV	E>1 TeV	E>2 TeV	E>4 TeV
CALET	5 y	0.12	~2%	30 X_0	10^5	7982	1527	238	25
AMS02	10 y	0.5	~2%	16 X_0	10^3	66515	12726	1986	211
ATIC	30 d	0.25	~2%	18 X_0	10^4	273	52	8	1
FERMI	10 y	1.6 @ 300 GeV 0.6@ 800 GeV	~15%	8.6 X_0	10^4	59864	6362	NA	NA
G400	10 y	3.9	~ 1%	25.4 X_0	10^5	518819	99266	15488	1647

B2: p and He count estimation

~knee ↓

Experiment	Duration	GF (m^2 sr)	Calo $\sigma(E)/E$	Calo depth	ε sel	E>0.1 PeV		E>0.5 PeV		E>1 PeV		E>2 PeV		E>4 PeV	
						p	He	p	He	p	He	p	He	p	He
CALET	5 y	0.12	~40%	30 X_0 1.3 λ_0	0.8	292	276	17	19	5	6	1	2	0	0
CREAM	180 d	0.43	~45%	20 X_0 1.2 λ_0	0.8	103	97	6	7	2	2	0	1	0	0
ATIC	30 d	0.25	~37%	18 X_0 1.6 λ_0	0.8	10	9	1	1	0	0	0	0	0	0
G400	10 y	3.9	~ 35%	25.4 X_0 1.2 λ_0	0.8	18951	17921	1123	1242	300	374	69	106	11	24

B2: Nuclei count estimation

~knee

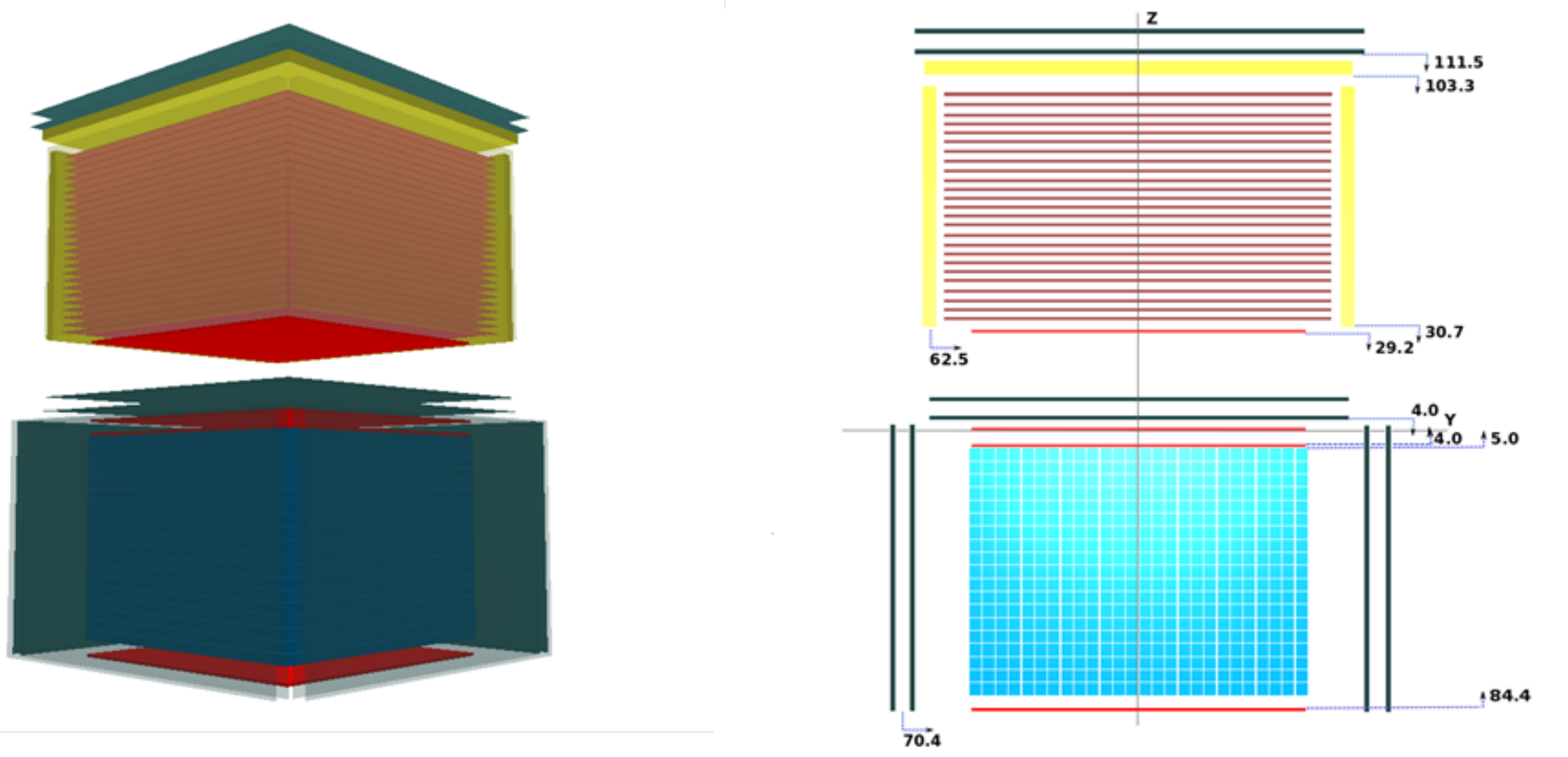
Experiment	Duration	GF (m^2 sr)	Calo $\sigma(E)/E$	Calo depth	ε sel	E>0.1 PeV		E>0.5 PeV		E>1 PeV		E>2 PeV		E> 4 PeV	
						^{3}Li to ^{9}F	^{10}Ne to ^{24}Cr	^{3}Li to ^{9}F	^{10}Ne to ^{24}Cr	^{3}Li to ^{9}F	^{10}Ne to ^{24}Cr	^{3}Li to ^{9}F	^{10}Ne to ^{24}Cr	^{3}Li to ^{9}F	^{10}Ne to ^{24}Cr
CALET	5 y	0.12	~30%	30 X_0 1.3 λ_0	0.8	136	140	9	10	3	3	1	1	0	0
CREAM	10 y	0.46	~45%	20 X_0 1.2 λ_0	0.8	51	53	4	4	1	1	0	0	0	0
ATIC	30 d	0.25	~37%	18 X_0 1.6 λ_0	0.8	5	5	0	0	0	0	0	0	0	0
TRACER	30 d	5	-	TRD	0.8	93	96	6	7	2	2	1	1	0	0
G400	10 y	3.9	~40%	25.4 X_0 1.2 λ_0	0.8	8830	9073	612	636	193	206	58	69	17	20

GAMMA-400: milestones for 2014

Description	Scheduled date
Finalisation of the tracker project and time schedule for the construction of the engineering and flight models	31-05-2014
MoU signature between RSA and INFN for the construction of the Gamma-400 tracker/converter by the Italian collaboration upon Russian financing	31-12-2014
Pubblication and presentation at conferences of results from tests of the calorimeter prototype and the final simulations of the detector.	31-12-2014

GAMMA-400 E2

- Gamma-400: a multi-purpose mission (photons@ high- and low-energies, electrons, nuclei)
- Revised design of the converter/tracker
  - Breakthrough angular resolution (4-5 times better than Fermi-LAT @ 1 GeV)
  - Improved sensitivity down to 30 MeV !
- Homogeneous and isotropic calorimeter (~ 50 X_0 and 2 λ_I) with optimal energy resolution and particle discrimination
  - Electron/positron detection beyond TeV energies
  - Nuclei detection up to 10^{15} eV ("knee")
- Nuclei identification capability (dE/dx measurement) with Silicon pad detectors
- Trigger with TOF capabilities ("smart" AC)

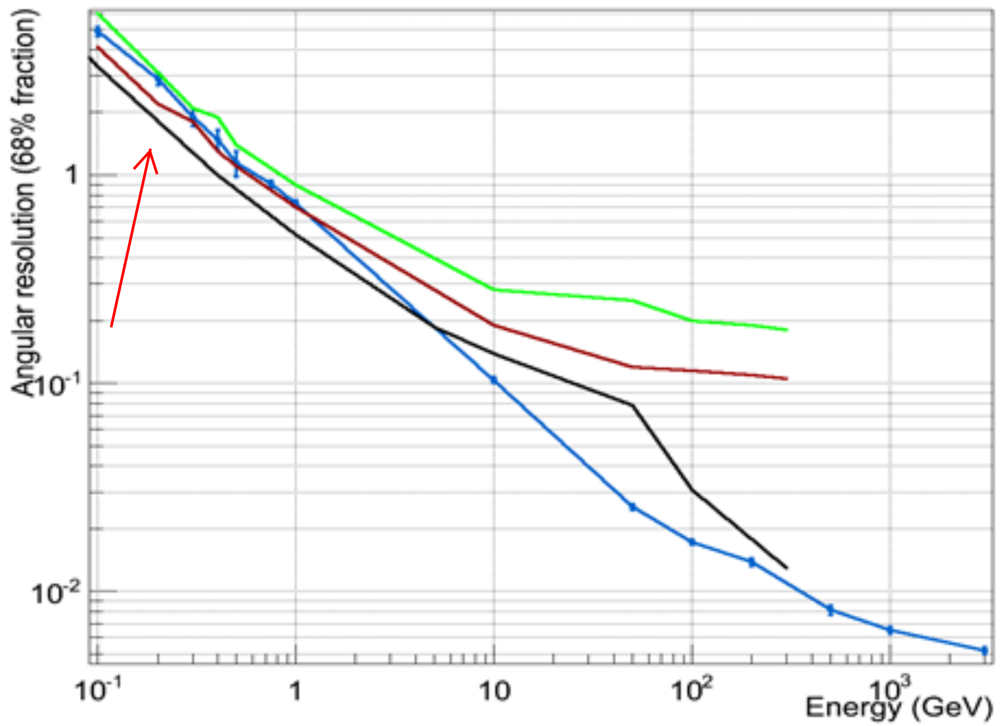


A 3D view (left) and schematic configuration (right) of the E2 G-400 configuration.

E2 vs. B2 Trackers

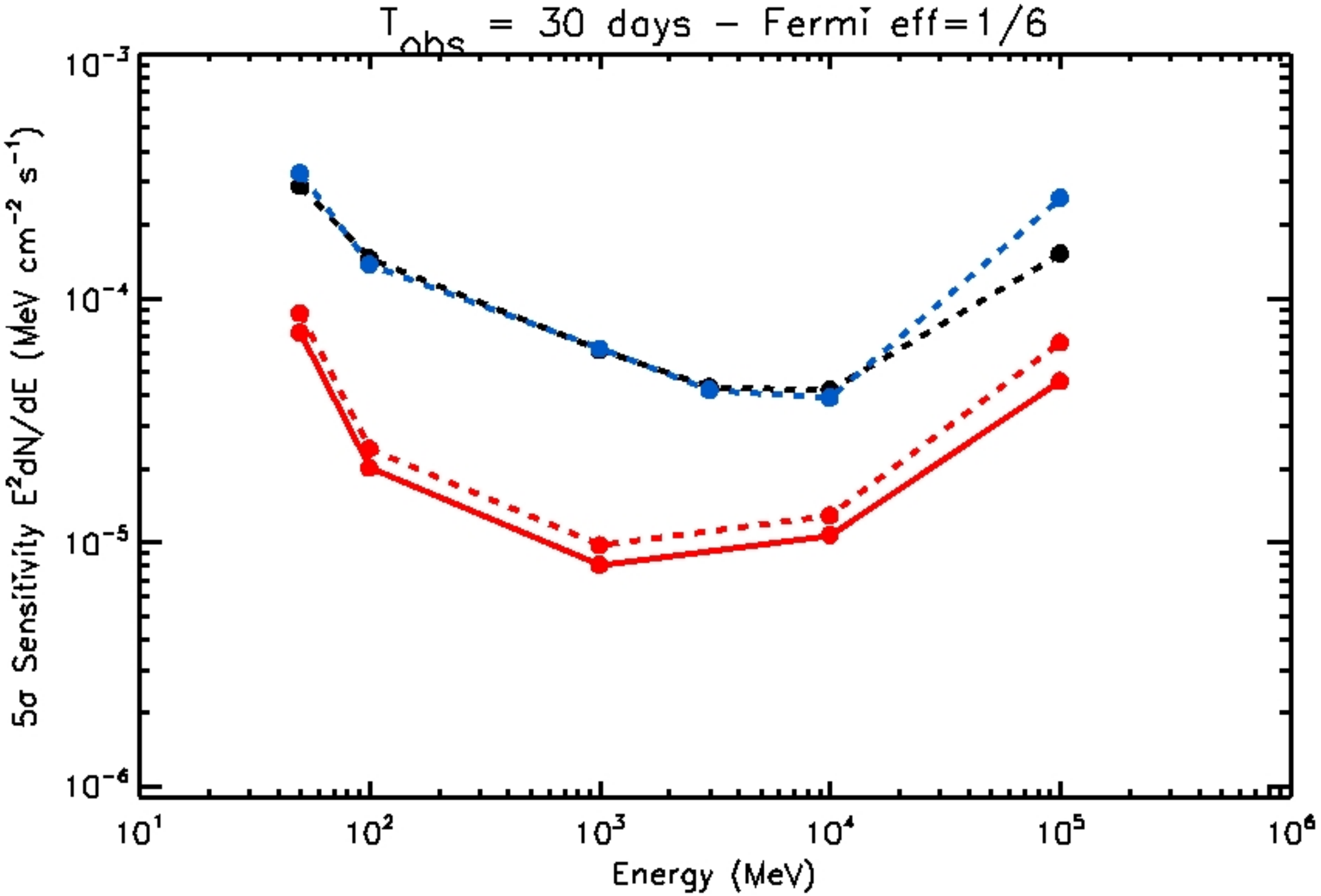
Parameter	B2	E1
N. towers	4	4
N. Planes	10	25
Converter (W) thickness (X_0)	0.1	0.03
Plane spacing (cm)	3.5	2.8-3.0 (TBD)
Si sensor dim. (cm)	9.7x9.7	9.7x9.7
Implant strip pitch (μm)	80 or 120	80 or 120
Readout strip pitch (μm)	240	240
Readout channels/plane	15360	15360
Total readout channels	153600	384000
Total Silicon detector number	2000	5000

E2 expected performance (Tracker + Calorimeter)



Point Spread Function results obtained at normal incidence with a more conservative cut on the reconstructed events. Fermi-LAT total Pass7_V6 (Green), Fermi-LAT front Pass7_V6 (Red), GAMMA-400 E2 (Black) and GAMMA-400 B2 (Blue).

G-400 goal sensitivity
30-day observation – Fermi exp. eff=1/6 (sky-scanning)
Galactic Centre



G-400: 60x60 cm^2(red solid line) ; G-400: 50x50 cm^2 (red dotted line) .

Fermi (black dotted: total LAT, PASS7); Fermi (blue dotted: upper LAT, PASS7)

GAMMA-400

- a breakthrough, unique opportunity for Italy
- improving gamma-ray angular and E resolution with respect to Fermi-LAT (both at 0.1-1 GeV and 100 GeV) is crucial !
  - Dark Matter from galactic Center and galaxies
  - cosmic-ray acceleration sites (SNRs, ISM)
  - Black hole physics
  - Compact objects

The only high-performance space instrument of the next decade synergic with CTA !!

- excellent possibility to detect nuclei up to the knee