Cosmic ray physics with the GAMMA-400 experiment

P. Cumani (University of Trieste - INFN Sez. di Trieste)

on the behalf of the GAMMA-400 collaboration




Cooperation in the design and production of scientific equipment

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

- Mission approved by ROSCOSMOS (launch currently schedule by November 2018)
- GAMMA-400 will be installed onboard the platform "Navigator" manufactured by Lavochkin
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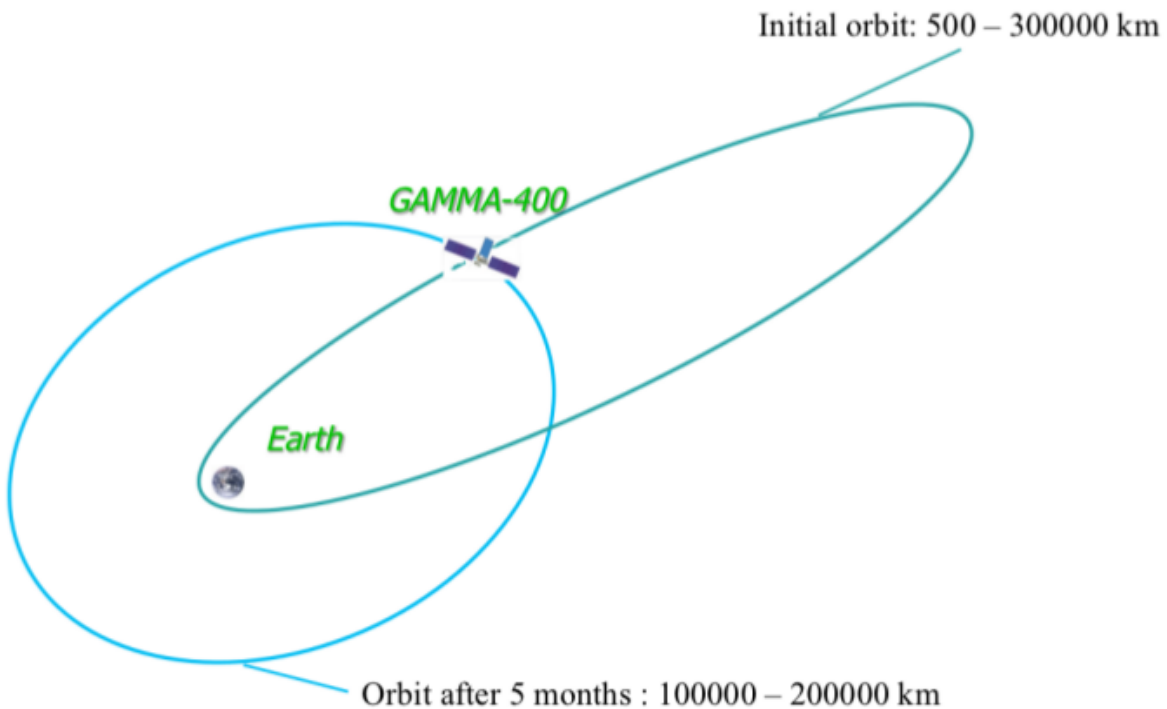
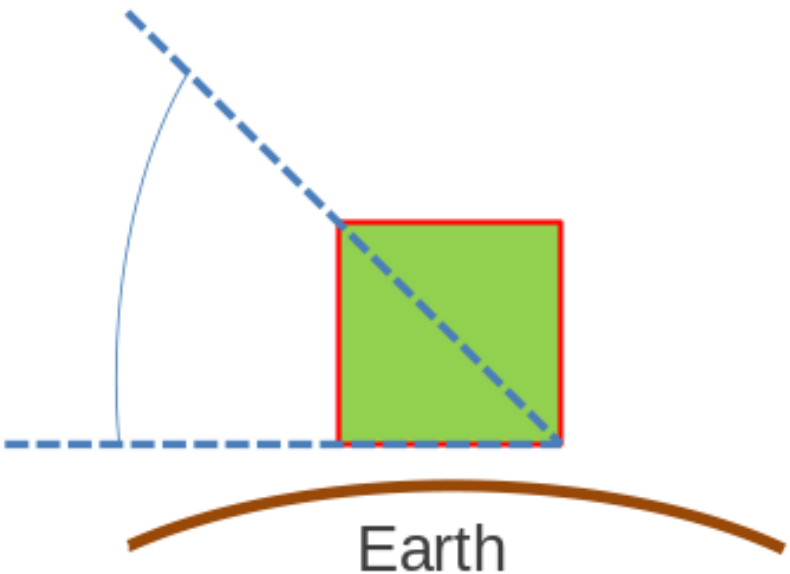
  - Scientific payload mass: 2600 kg
  - Power budget: 2000 W
  - Telemetry downlink capability: 100 GB/day
  - Lifetime: 10 years

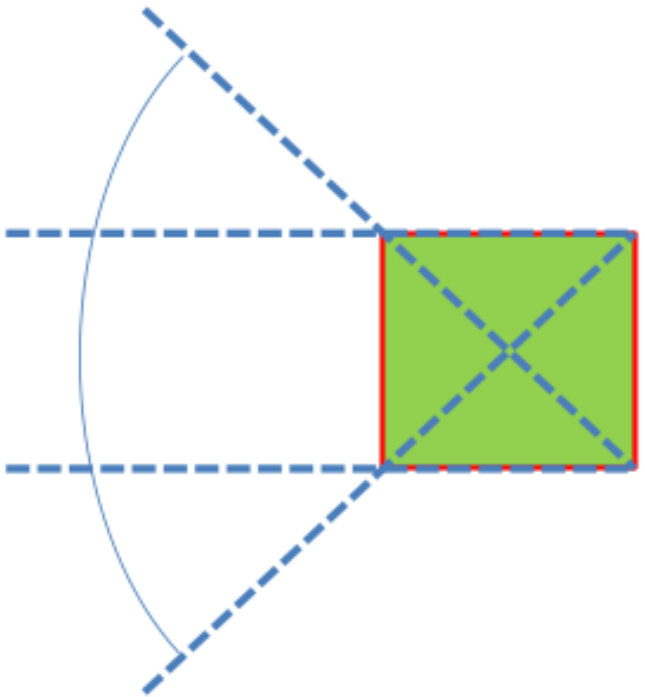
Space mission GAMMA-400



Acceptance of the Calorimeter (Side view)

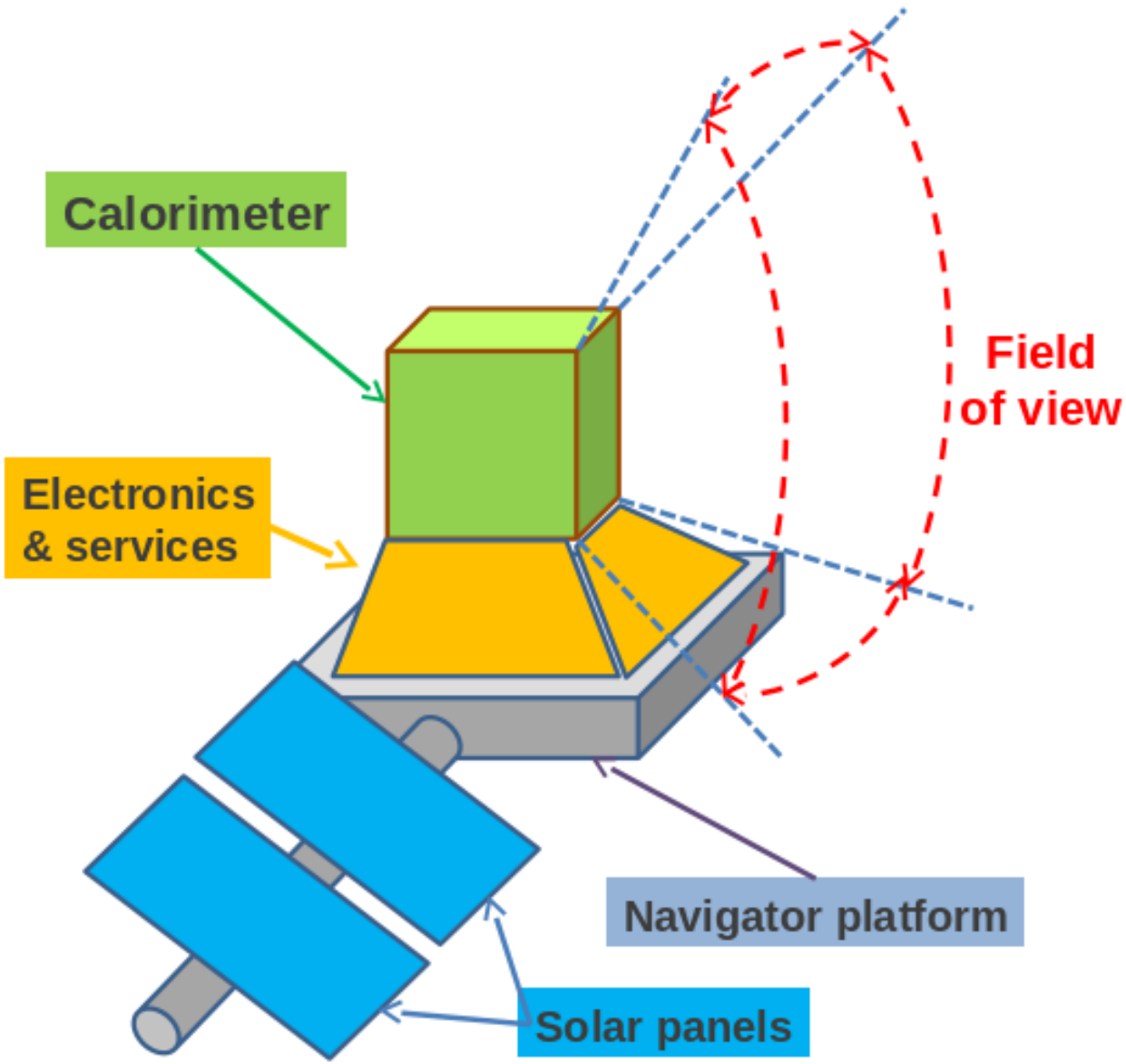


in LEO



in High Altitude Orbit

Acceptance of the Calorimeter



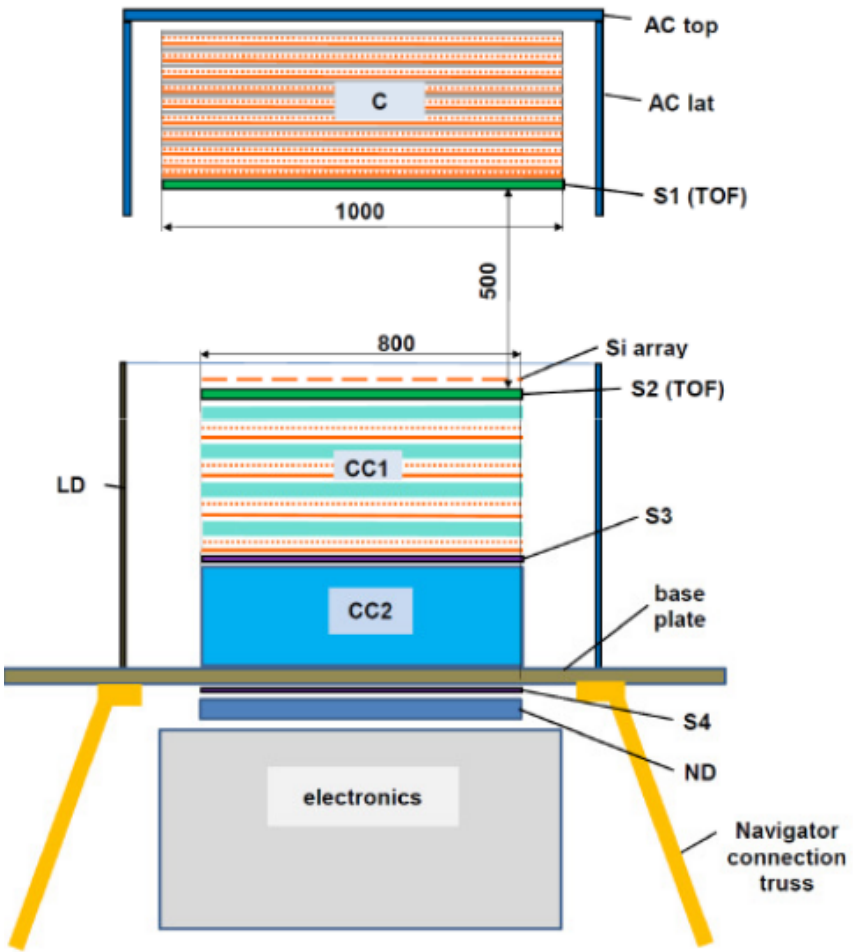
Original Russian design focused on:

- High energy gamma-rays (10 GeV - 3 TeV)
- High energy electrons (e^- and e^+) up to TeV energies

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"

GAMMA-400 baseline



AC - anticoincidence detectors (AC_{top} + AC_{lat})

C - Converter-Tracker - 1 Xo

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

S1, S2 - TOF detectors

Si array - Si pad (1x1 cm^2) detector

S3, S4 - calorimeter scintillator detectors

CC1 - imaging calorimeter 3Xo

4 layers: CsI 0.75 Xo + Si(x,y) (pitch 0.5 mm)

CC2 - electromagnetic calorimeter 22Xo

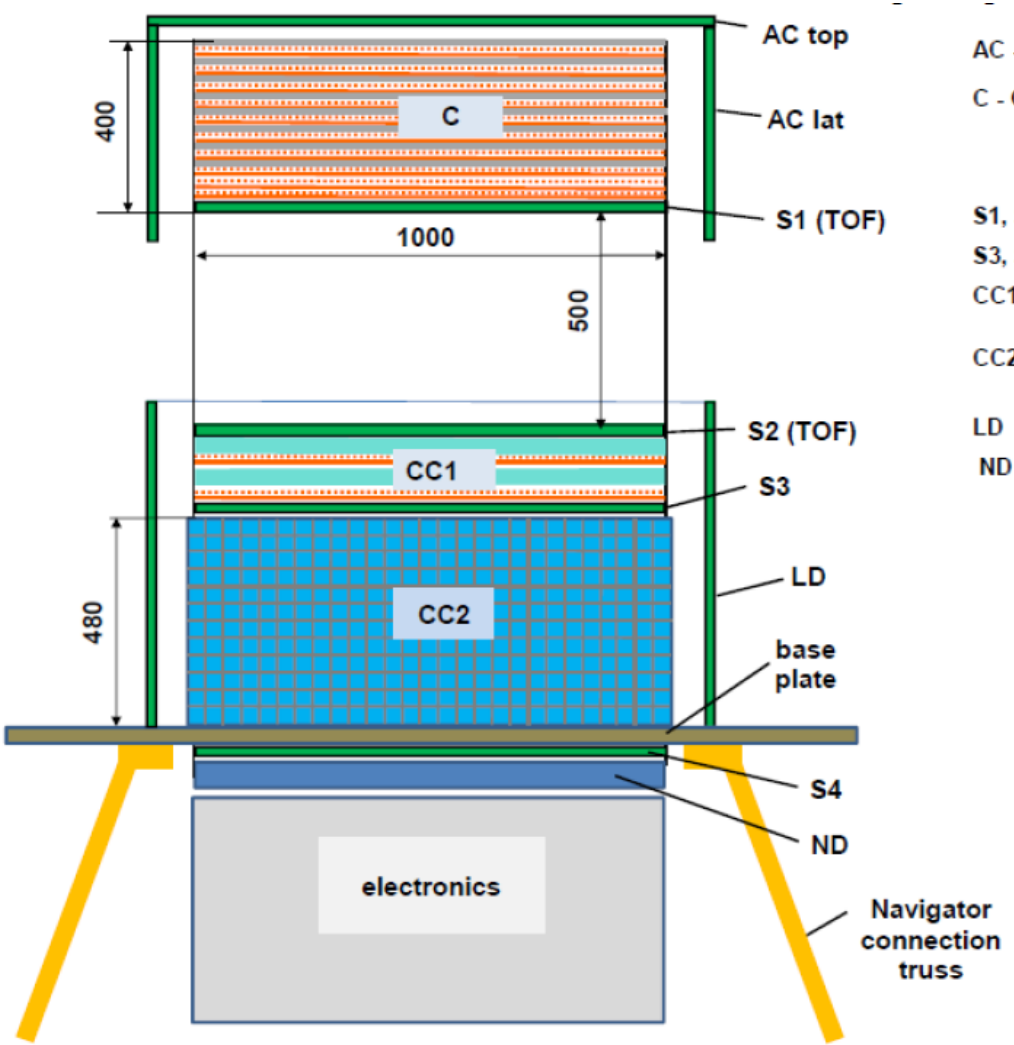
BGO (1024 crystals 2.5x2.5x25 cm^3)

LD - 4 lateral calorimeter detectors 50x120 cm^2

ND - neutron detector

* To be changed to "25 Si(x,y) (pitch 0.1 mm) + 4 W (0.2 Xo)" for enhanced LE instrument option

GAMMA-400 present configuration



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

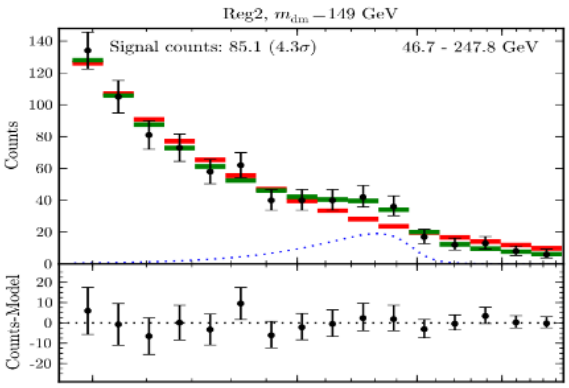
CC1 - imaging calorimeter (2Xo)
2 layers: CsI(Tl) 1Xo + Si(x,y) (pitch 0.5 mm)

CC2 - electromagnetic calorimeter
CsI(Tl) 23 Xo 3.6x3.6x3.6 cm^3 - 28x28x12=9408 crystals

LD - 4 lateral calorimeter detectors

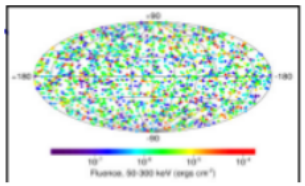
ND - neutron detector

Galactic/ Extragalactic gamma-ray sources

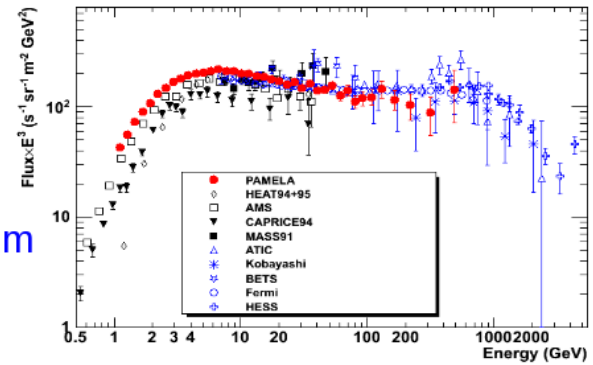


Dark Matter

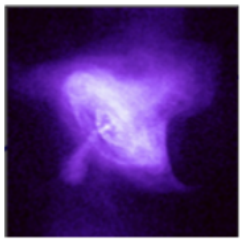
CR propagation



GRBs

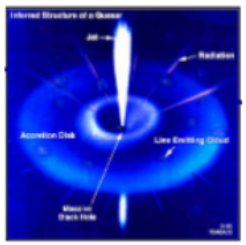


Electron spectrum

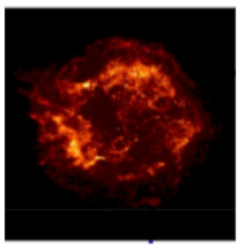


Pulsars

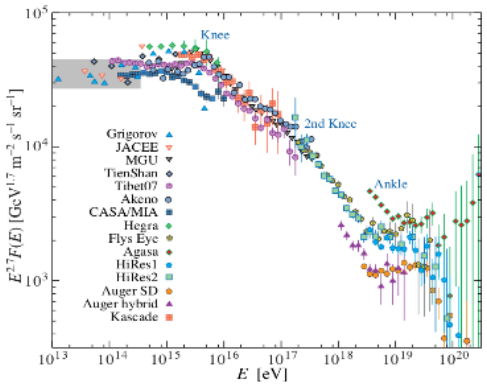
Knee origin



AGNs

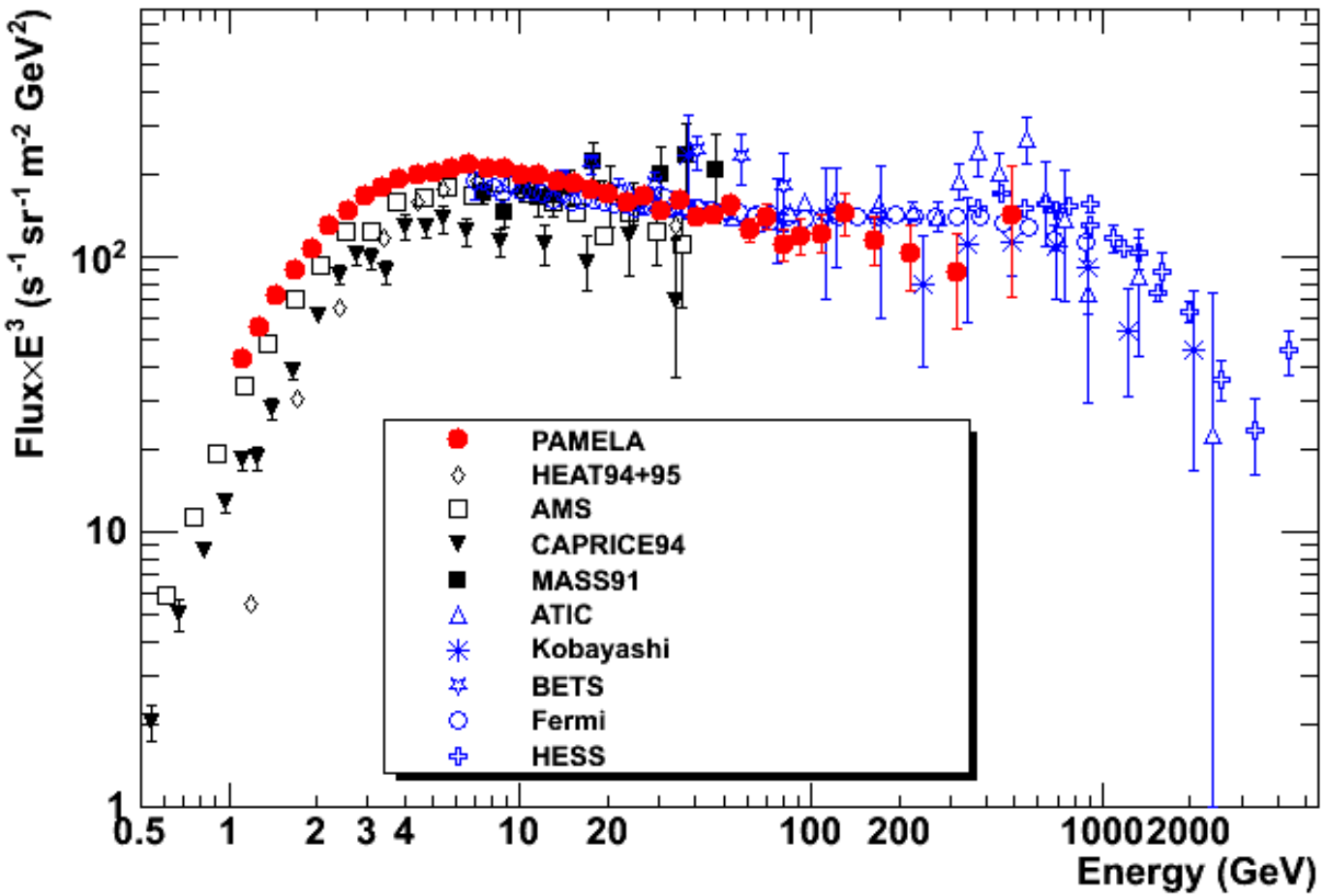


SNRs

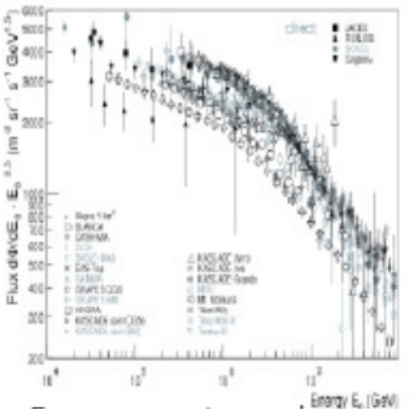


CR origin and acceleration mechanisms

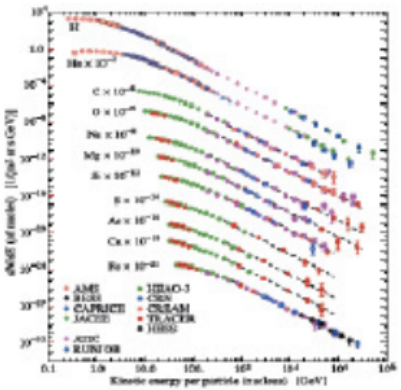
Electrons spectrum



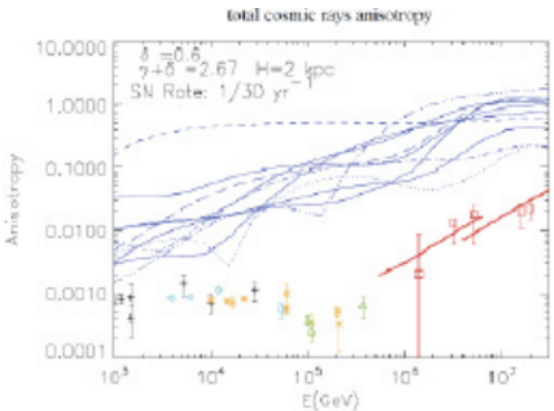
Cosmic ray acceleration and propagation



Energy spectrum shape



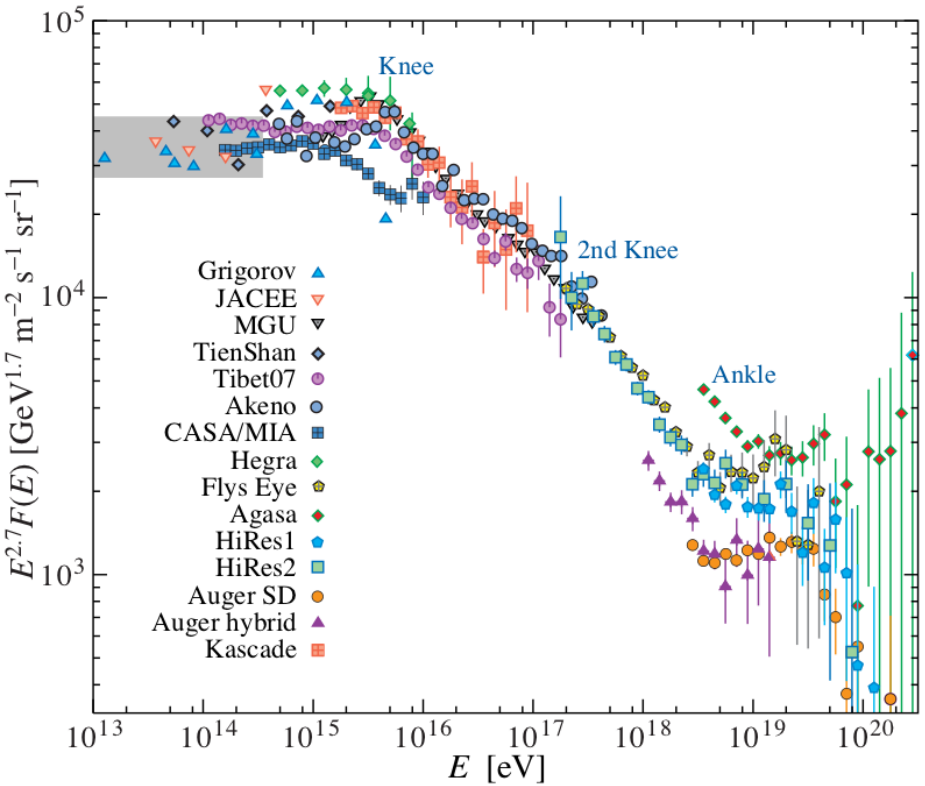
Composition



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

Nuclei



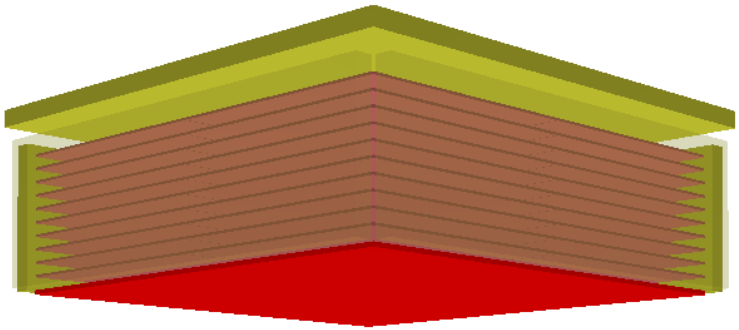
- Knee structure
- Structures in the GeV-TeV region recently discovered for p and He
- Spectral measurements in the knee region up to now are only indirect

Physics Goal

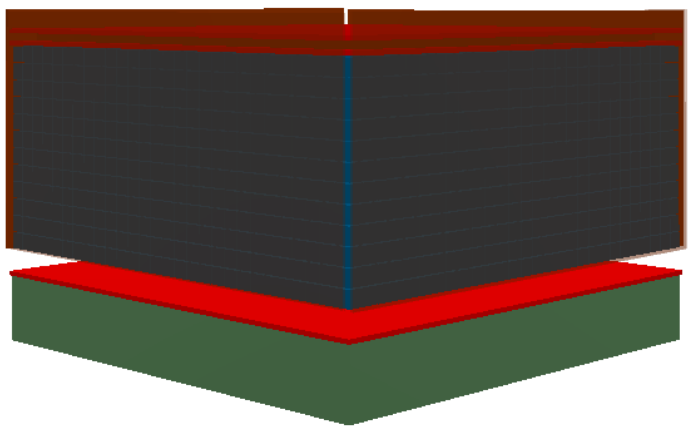
- e^- up to the TeV region to search for structures in the spectrum and to study close-by sources
- High energy proton and nuclei to study the knee region

Requirements

- Very large geometrical factor
- Good electron and hadron energy resolution
- Excellent electron/hadron separation

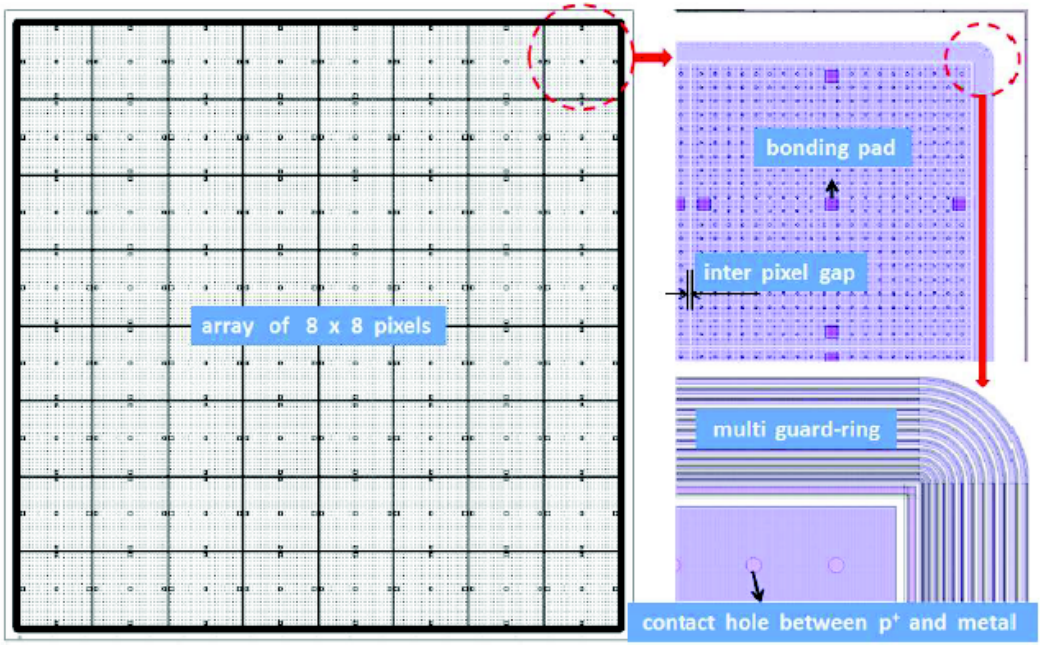


GAMMA-400 detectors



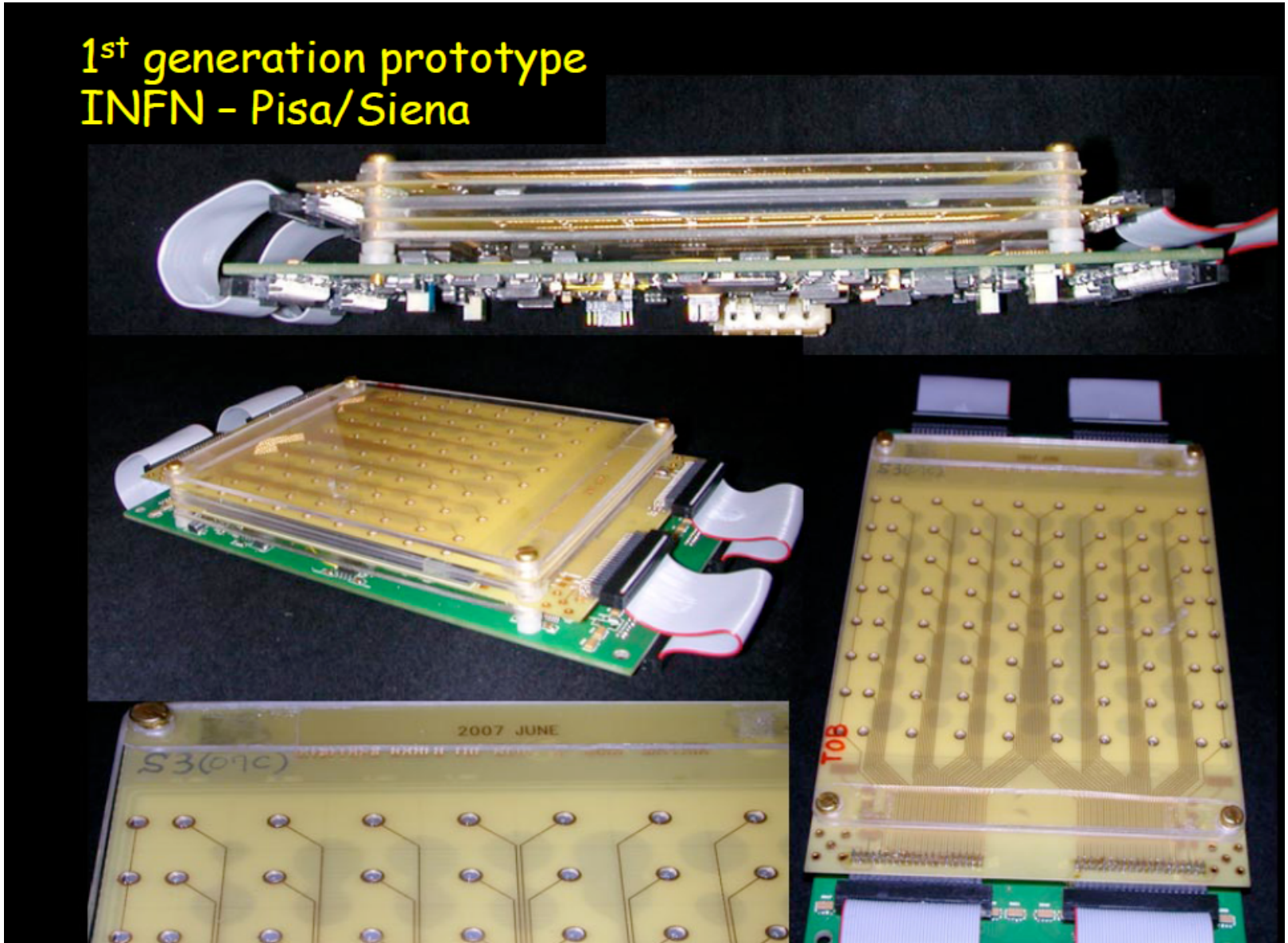
GAMMA-400: Silicon Array

Pisa/Siena Silicon Array: 64 pixels sensor

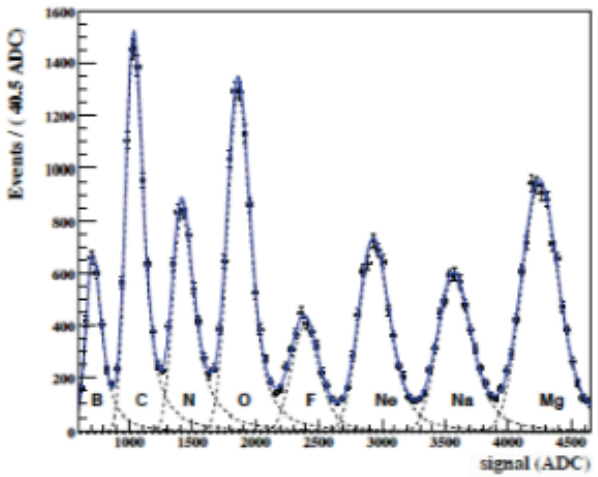


number of pixels	64
sensor size	95 mm × 95 mm
number of guard-rings	13
active area	90.64 mm × 90.64 mm
pixel pitch	11.33 mm

GAMMA-400: Silicon Array



GAMMA-400: Silicon Array

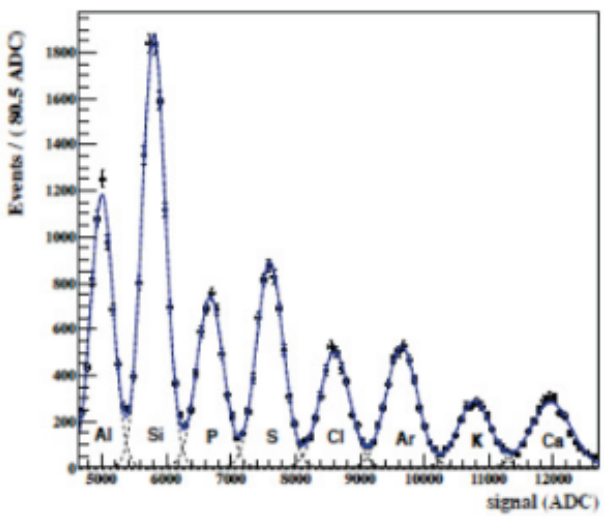


(a)

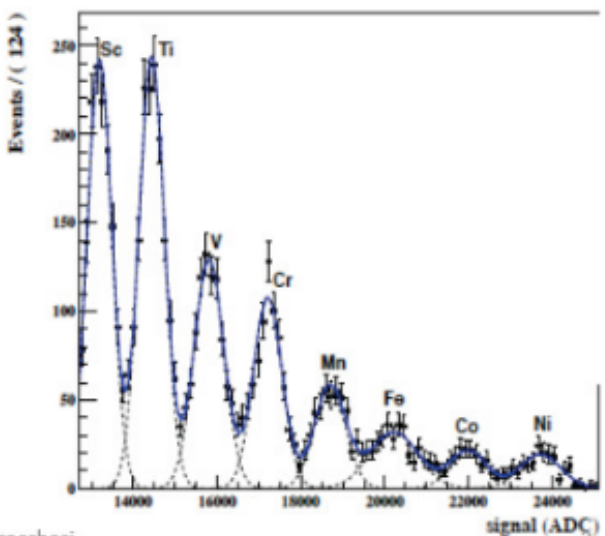
Oct. 2010 GSI beam test

Charge Resolution:

0.2 to 0.25 charge unit from B to Ni (Z=28)

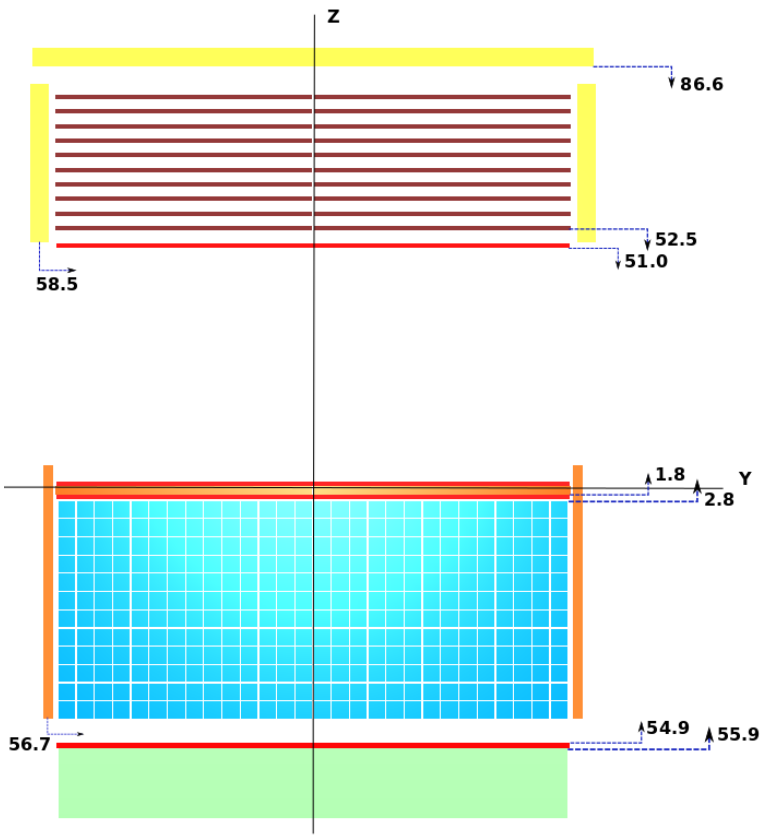


(b)



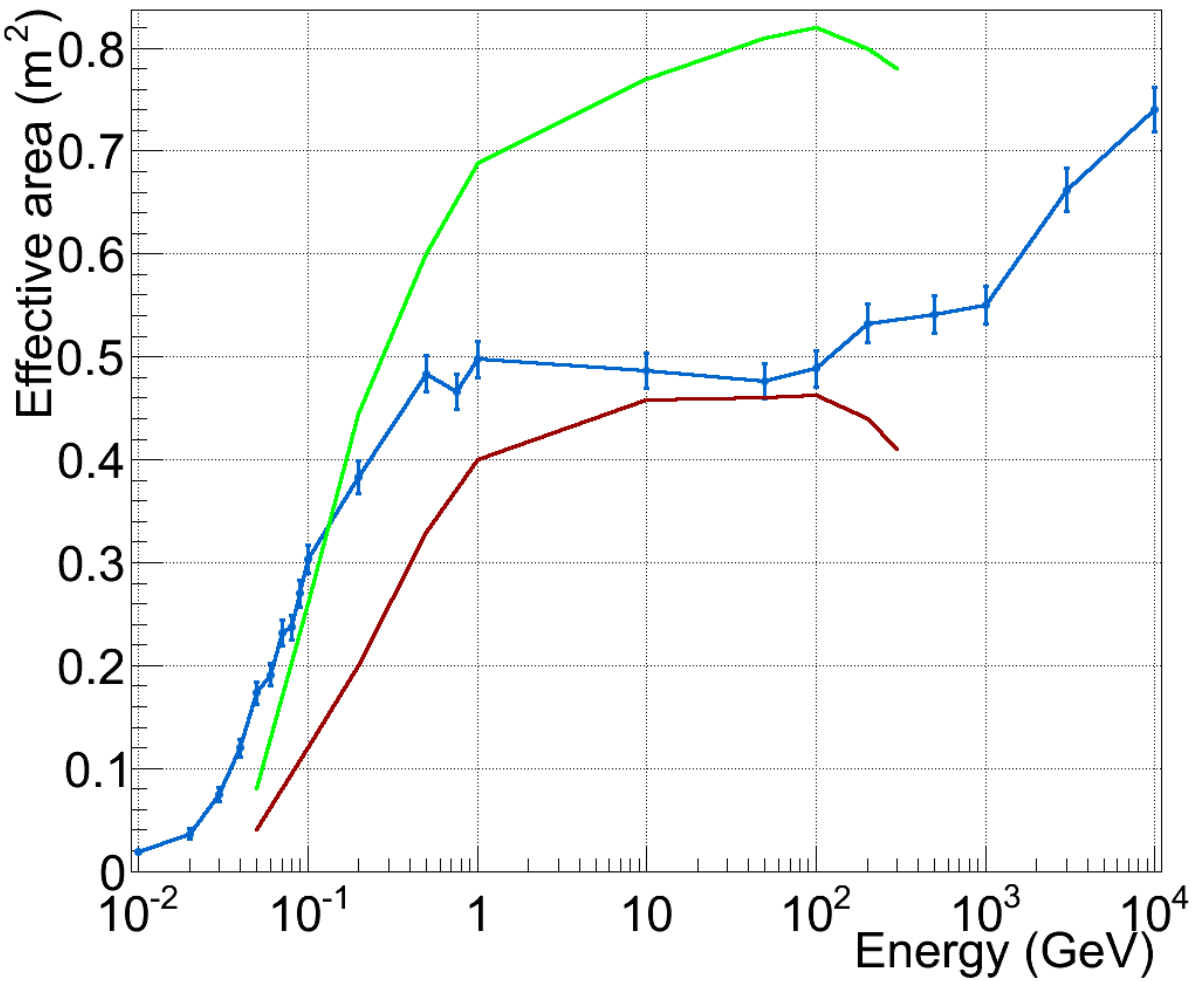
(c)

GAMMA-400: Tracker

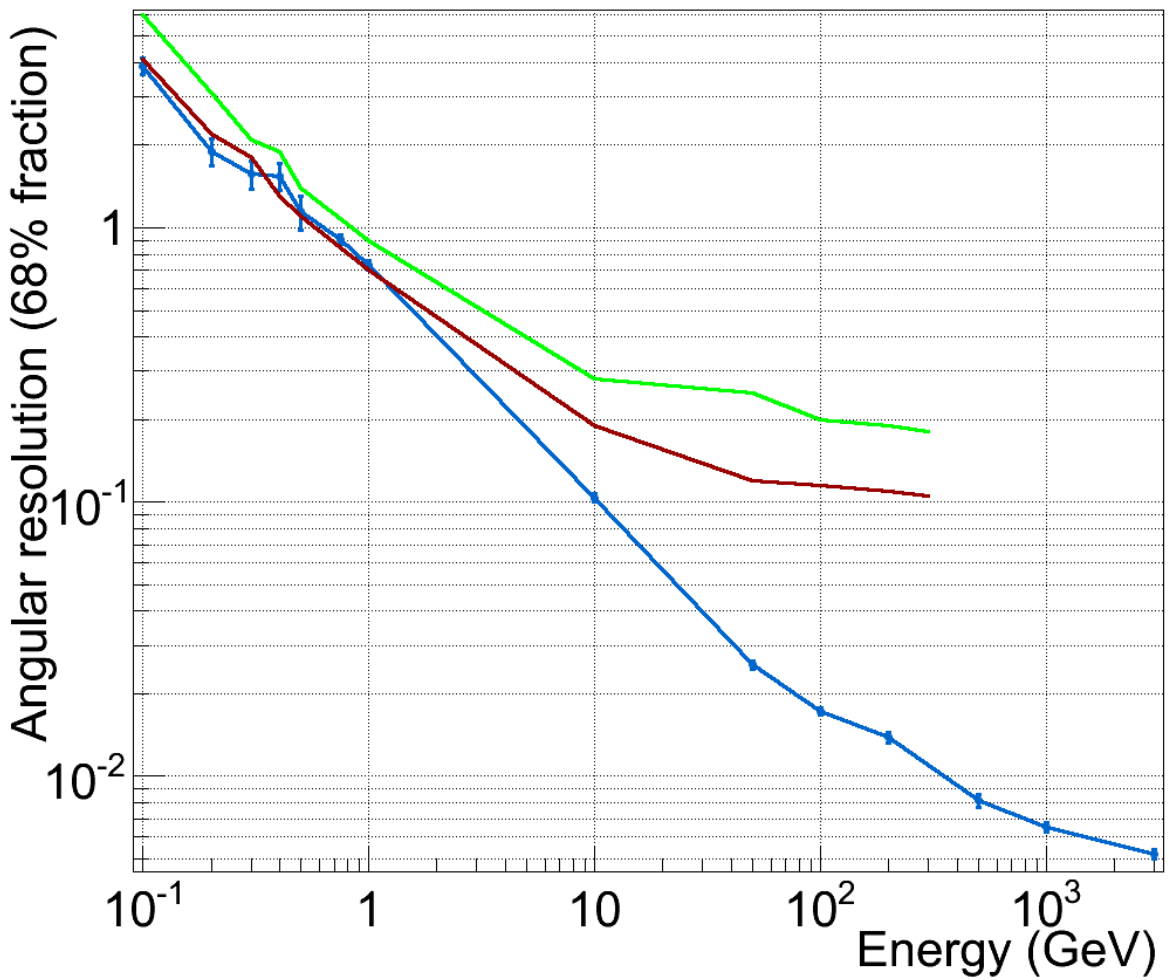


- 4 towers
- 10 planes (each plane 2 array of the Si tiles)
  - Si: microstrip along x-axis
  - Honeycomb Al support
  - First 8 planes: W (0.1 X_0)
  - Si: microstrip along y-axis

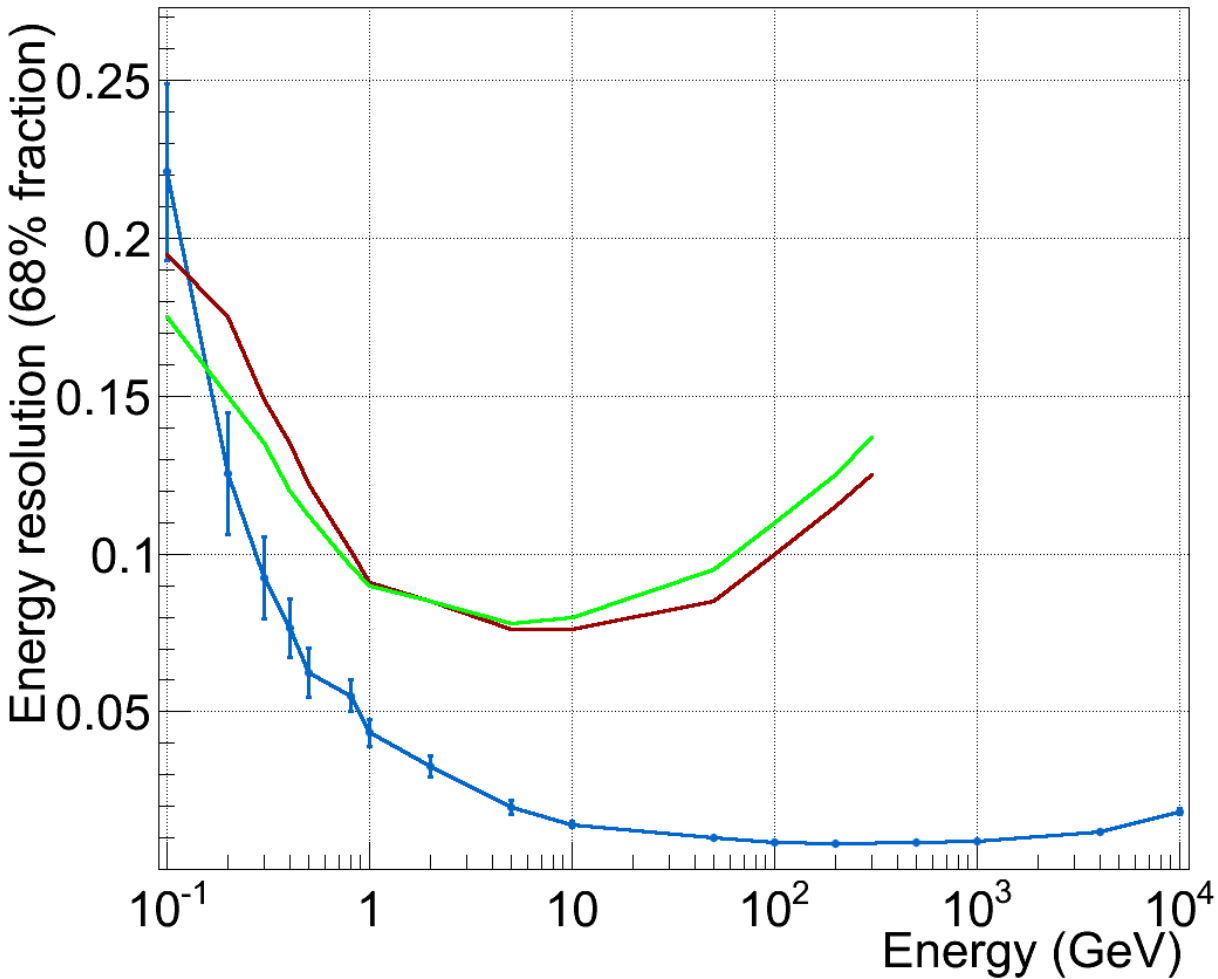
Simulated performance: effective area (Preliminary)



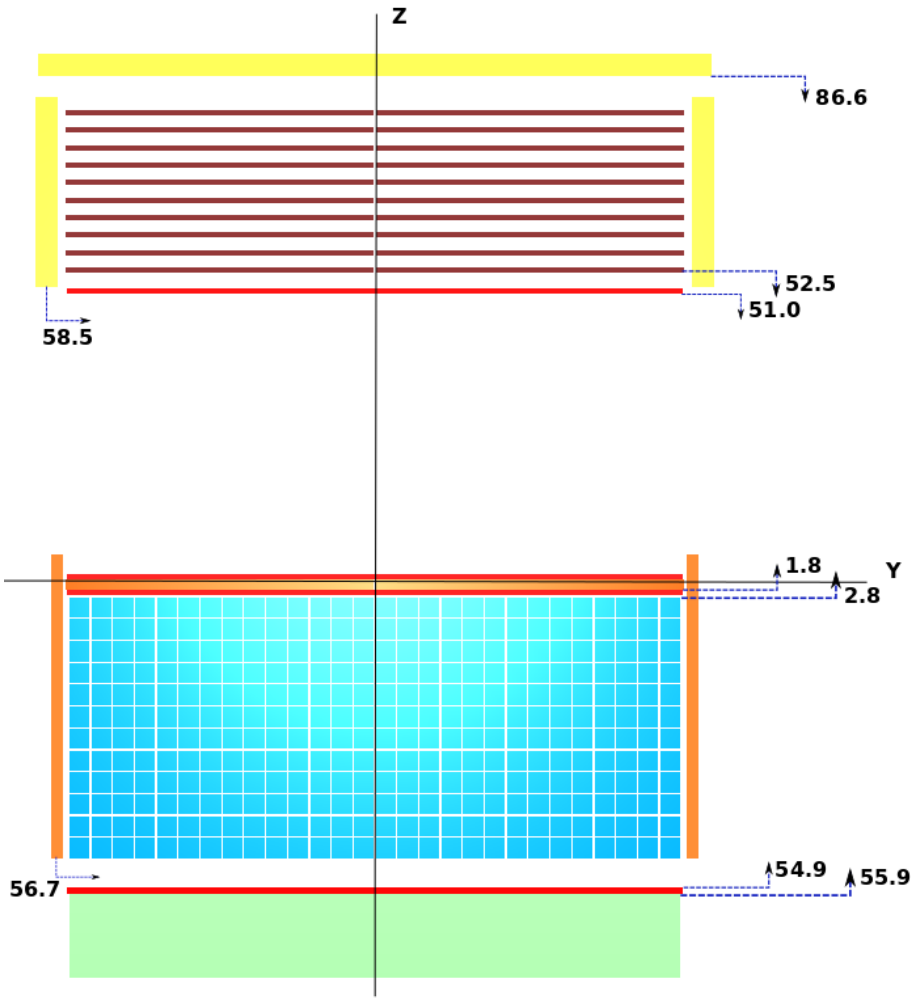
Simulated performance: angular resolution (Preliminary)



Simulated performance: energy resolution for γ (Preliminary)



GAMMA-400: Calorimeter



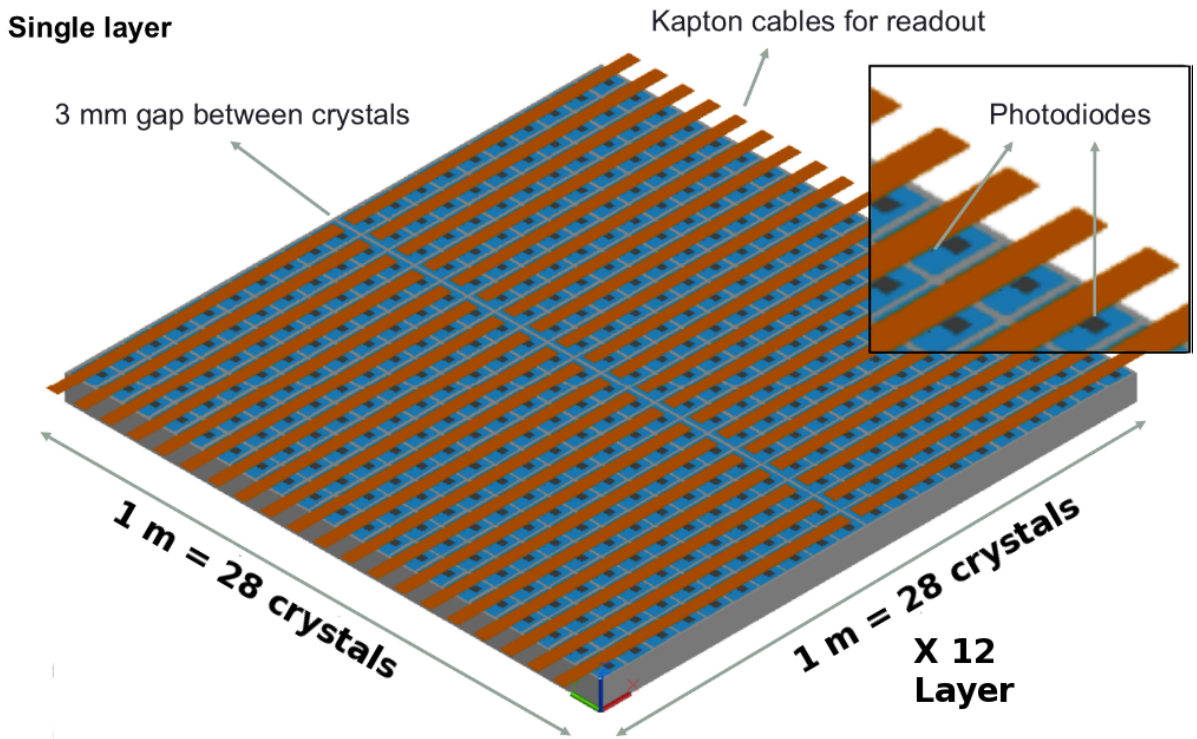
Calorimeter CC1 (Si-CsI(Tl))

N layers	2
Si pitch	0.5 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

Calorimeter CC2: readout



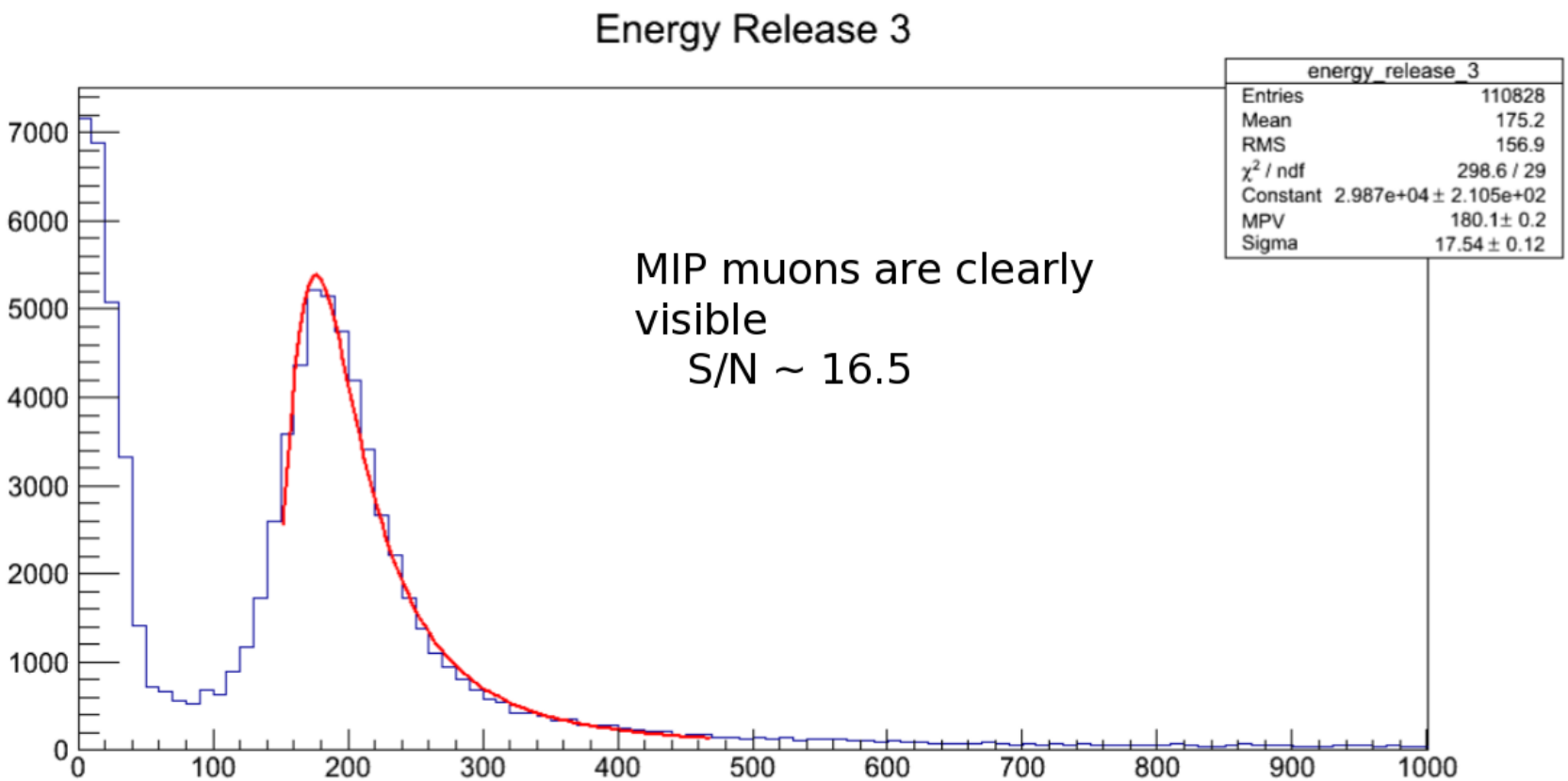
At least 2 photo diodes per crystals to cover the huge dynamical range (1-10^7 MIP)

Calorimeter CC2: test beam

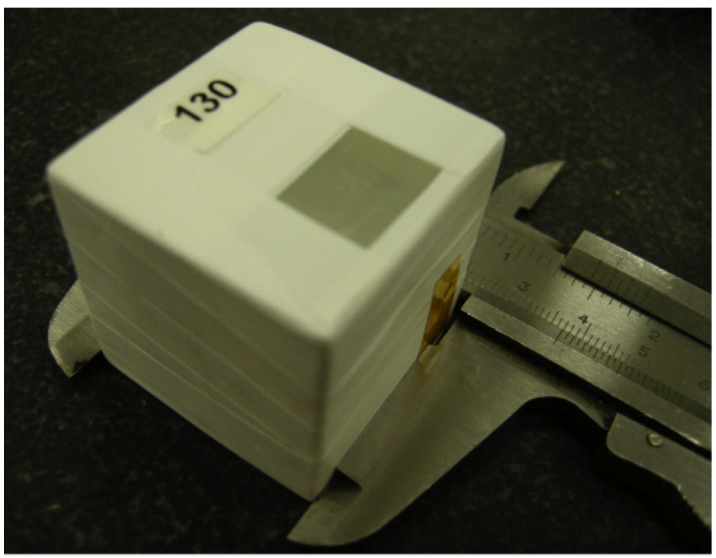
- October 2012 @ CERN SPS (e^-, p, muons): small, so called "pre-prototype" (4 layers, 3 crystals each)
- February 2013 @ CERN SPS (Ions): bigger, properly called "prototype" (14 layers, 9 crystals each)
- October 2013 @ INFN Frascati: 700 MeV e^-

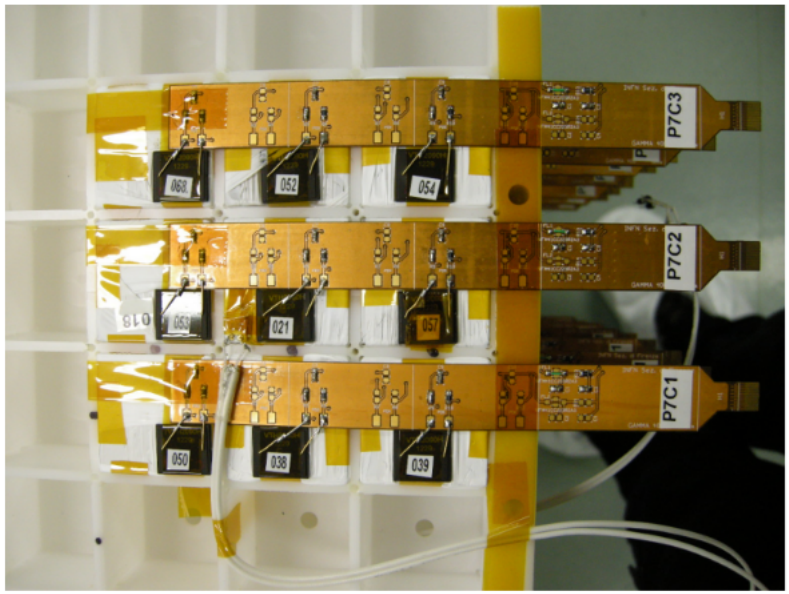
"Pre-prototype" results

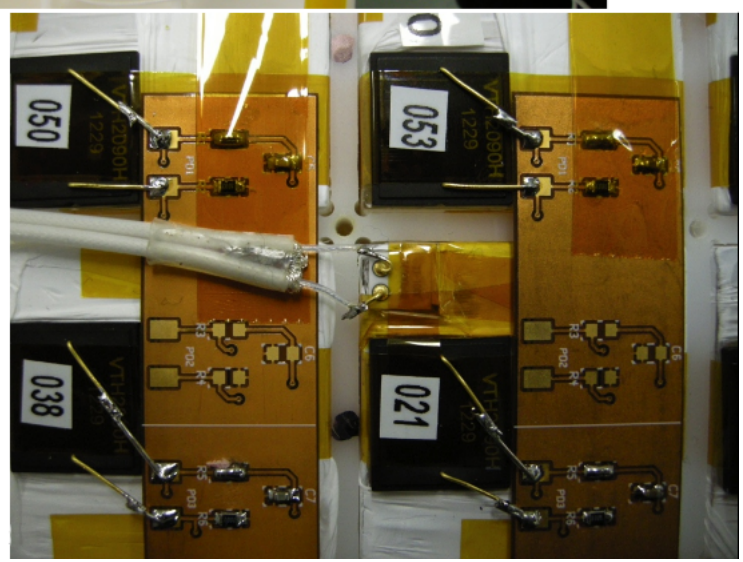
Muon beam



The prototype

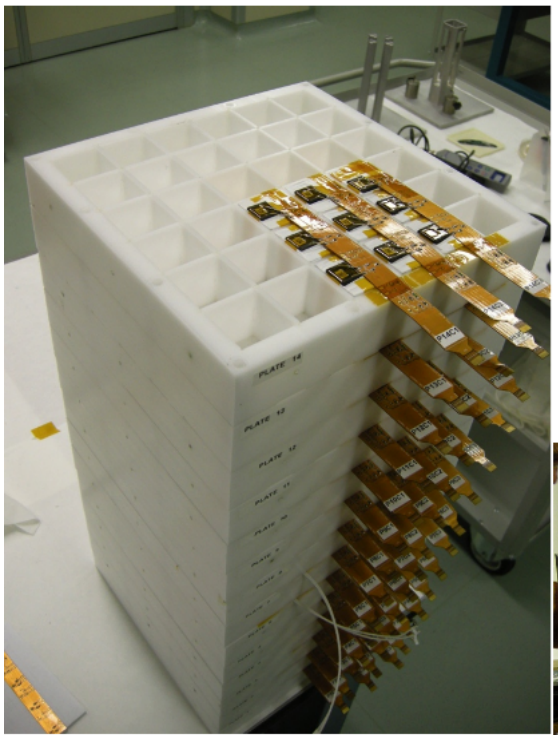


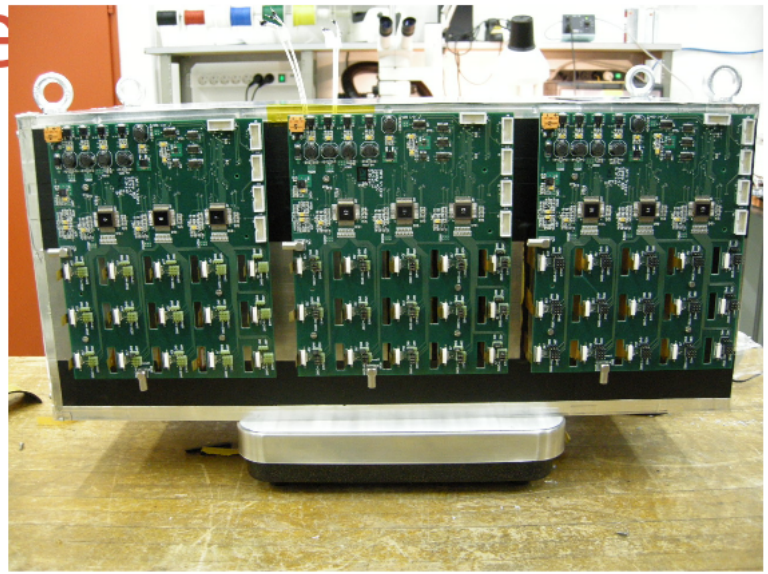


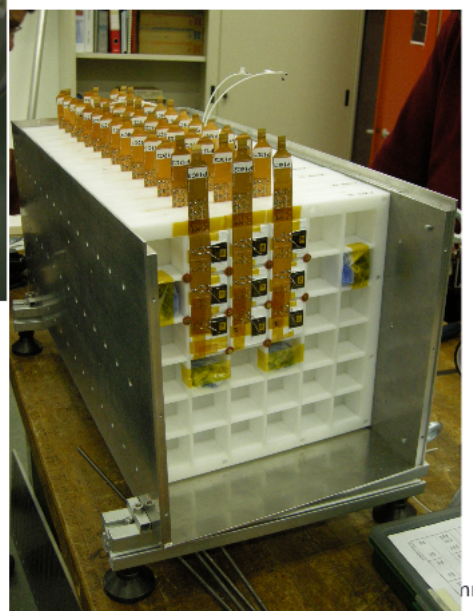


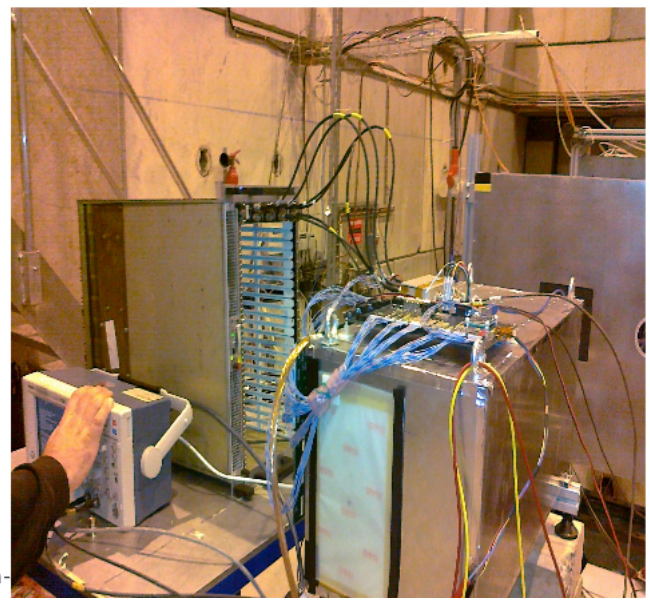
O. Adriani

The prototype





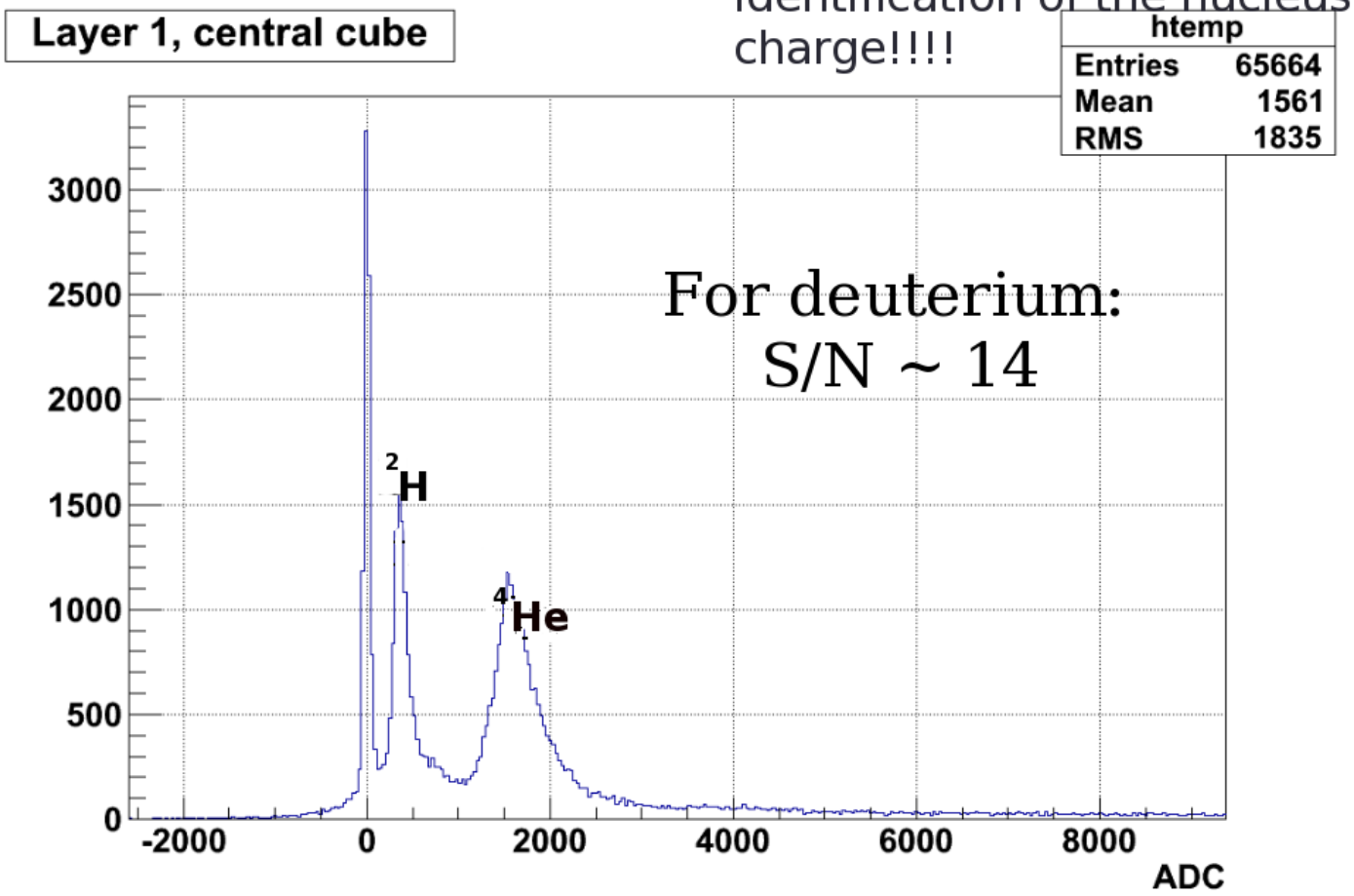




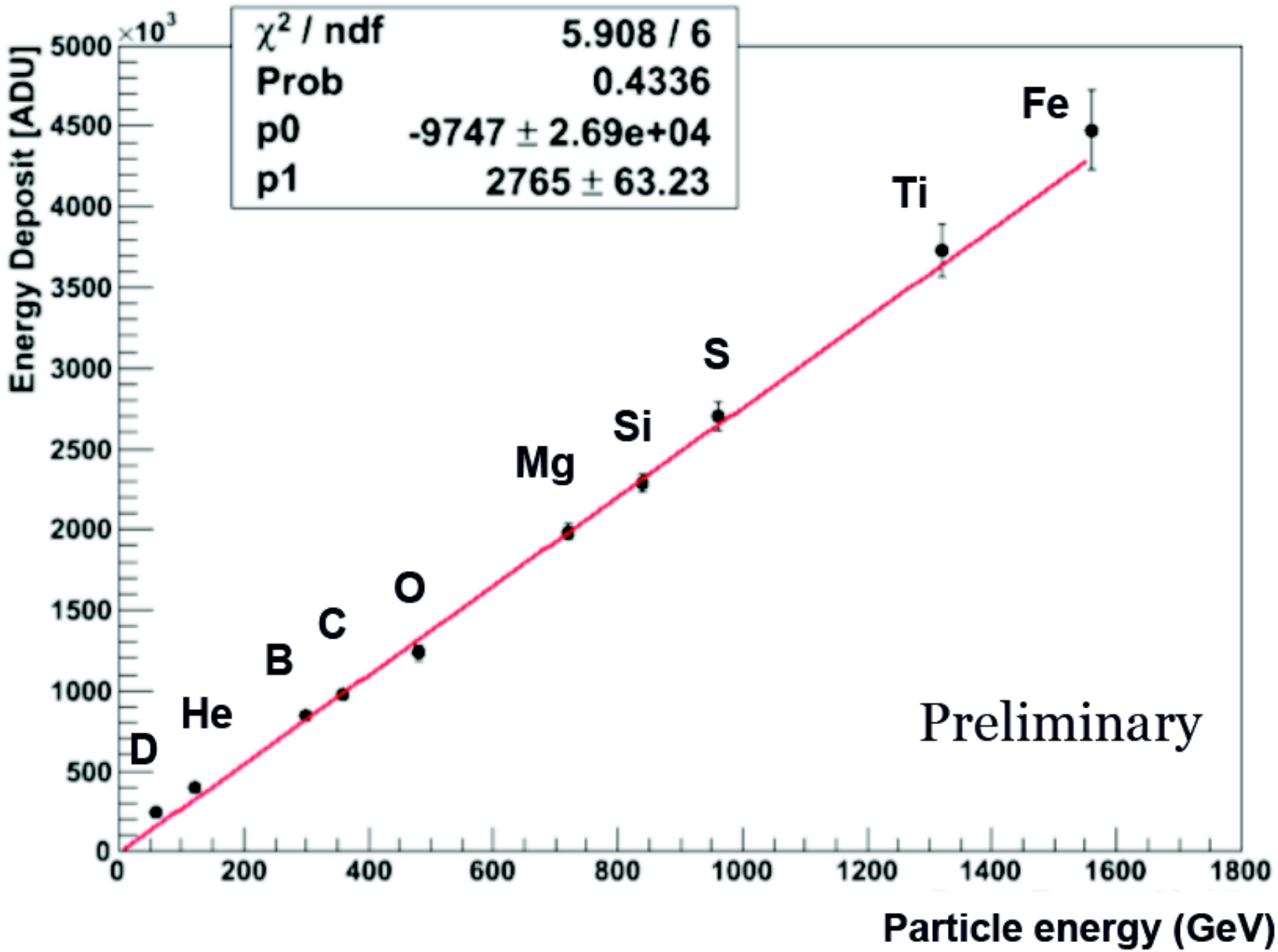
Pulse height spectrum in a crystal

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

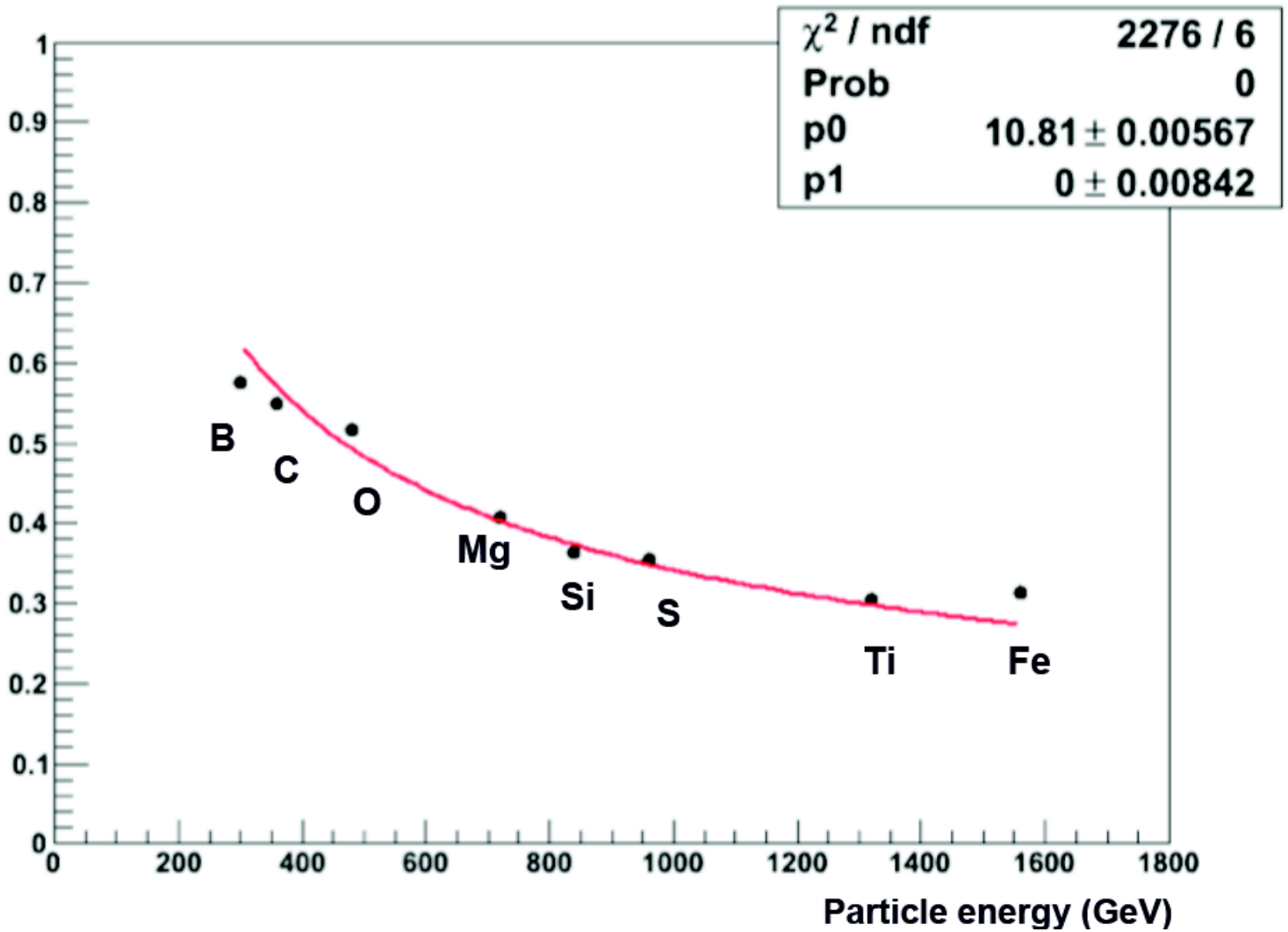
Please note: we can use the data from a precise silicon Z measuring system located in front of the prototype to have an exact identification of the nucleus charge!!!!



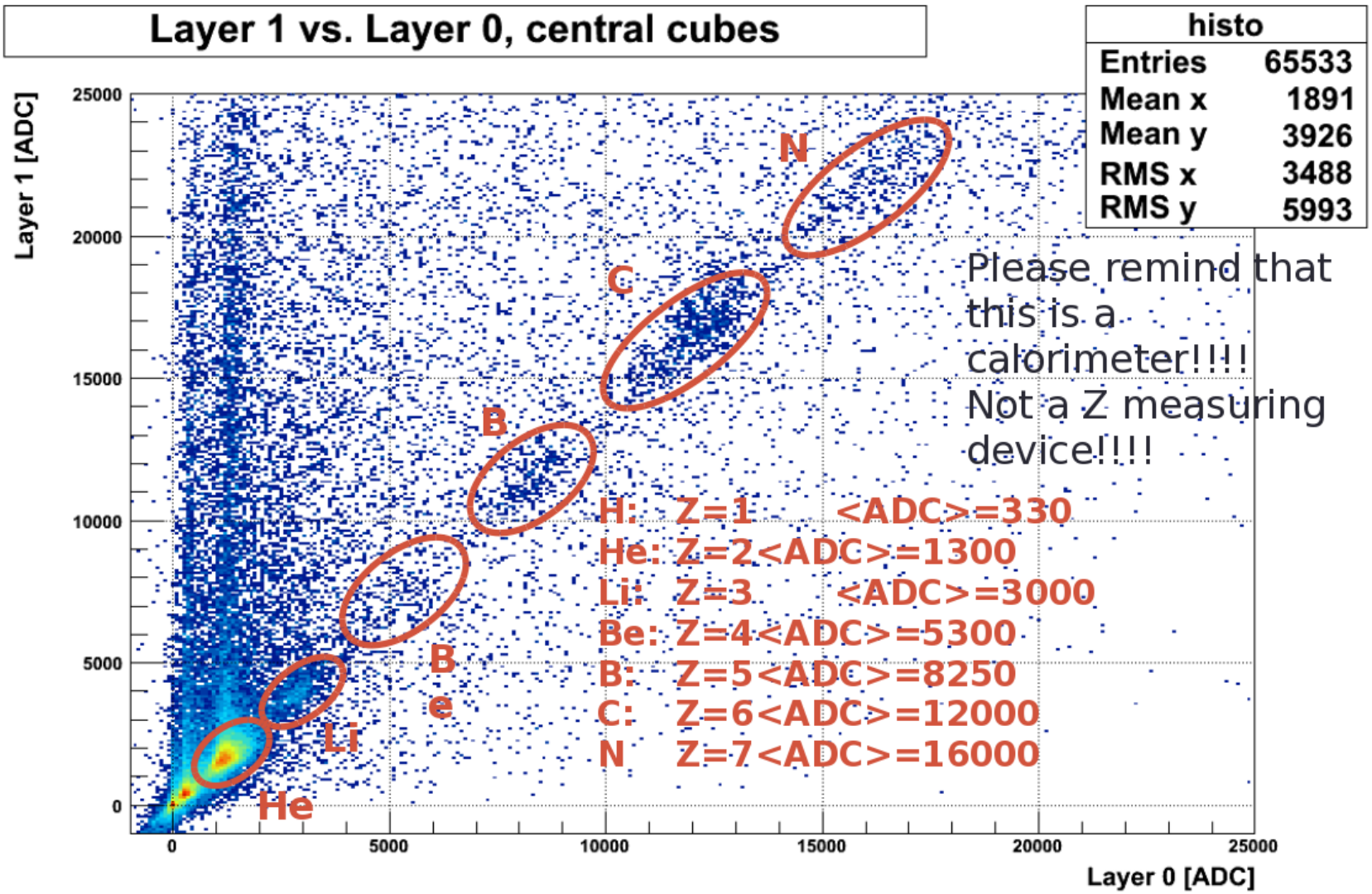
Energy deposit



Energy resolution



Test beam results



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	~2%	25.4 X_0	10^5	518819	99266	15488	1647

p and He count estimation

~knee

Experiment	Duration	GF (m^2 sr)	Calo σ(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	~40%	25.4 X_0 1.2 λ_0	0.8	18951	17921	1123	1242	300	374	69	106	11	24

Nuclei count estimation

~knee

Experiment	Duration	GF (m^2 sr)	Calo σ(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

Conclusions

- Important for the multiwavelength/multimessenger approach
- Pointing strategy without Earth occultation / Big FOV
- The GAMMA-400 Tracker is an evolution of AGILE and Fermi-LAT
- The GAMMA-400 calorimeter design of novel concept gives unique energy resolution and depth for electrons and nuclei

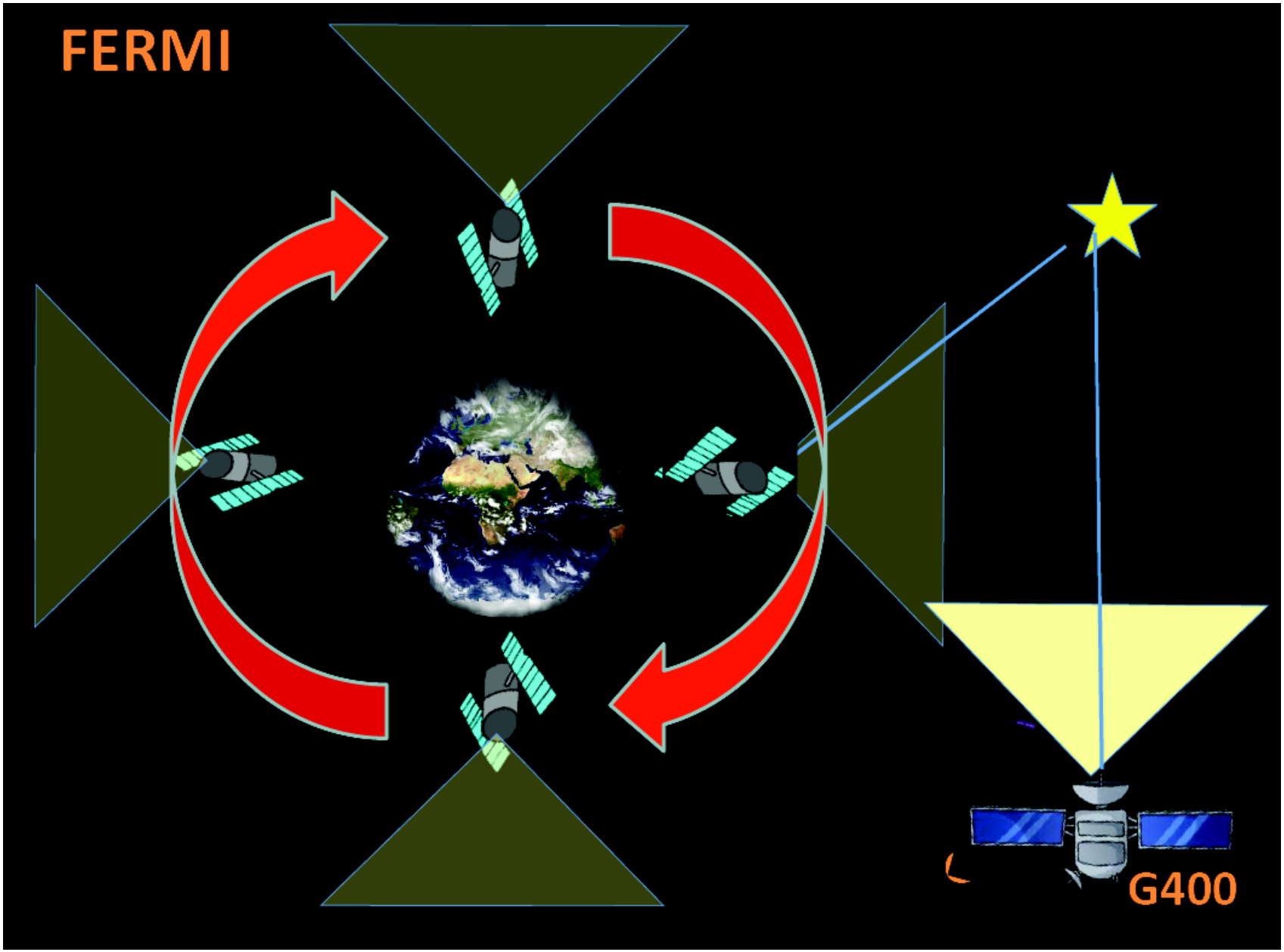
Conclusions

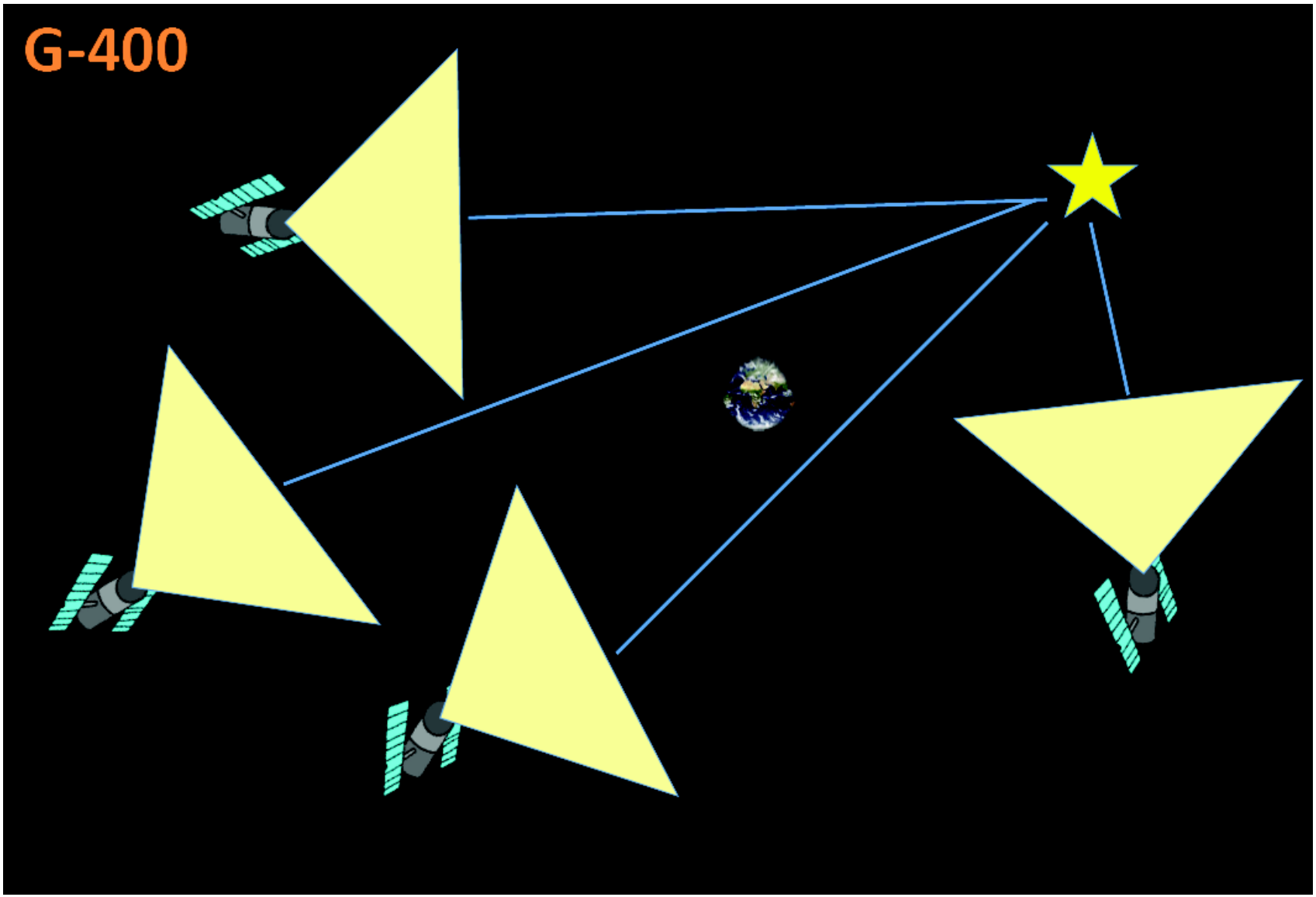
- The GAMMA-400 mission represents a unique opportunity to perform simultaneous measurements of photons, electrons and nuclei with unprecedented accuracy.
- GAMMA-400 can provide in-depth investigations on some of the most challenging physics items, such as DM searches, CR origin, production and acceleration to the highest energies...

GAMMA-400 website

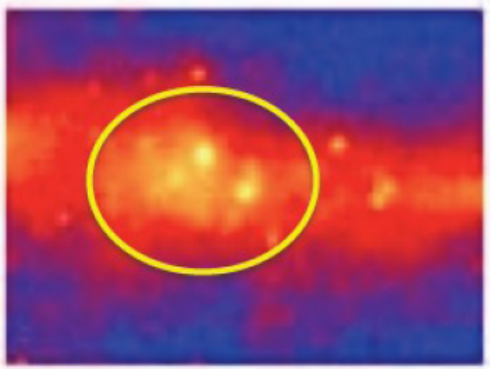
http://gamma400.lebedev.ru/indexeng.html

SPARE SLIDES

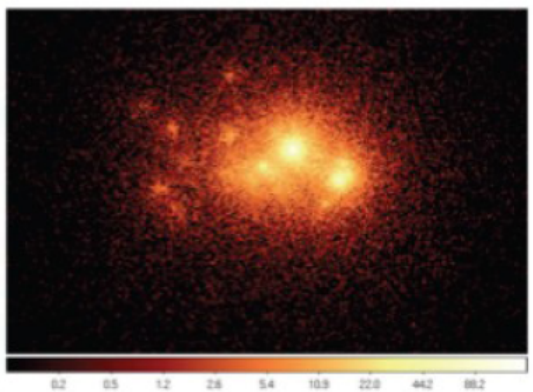

FERMI
G400


G-400

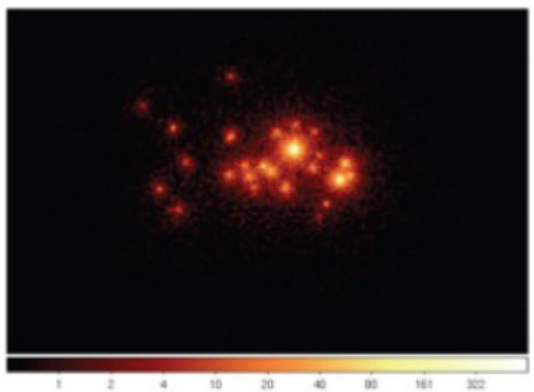
Cygnus region above 30 MeV



Fermi LAT 2-year flight data



Fermi LAT 2-year simulated data

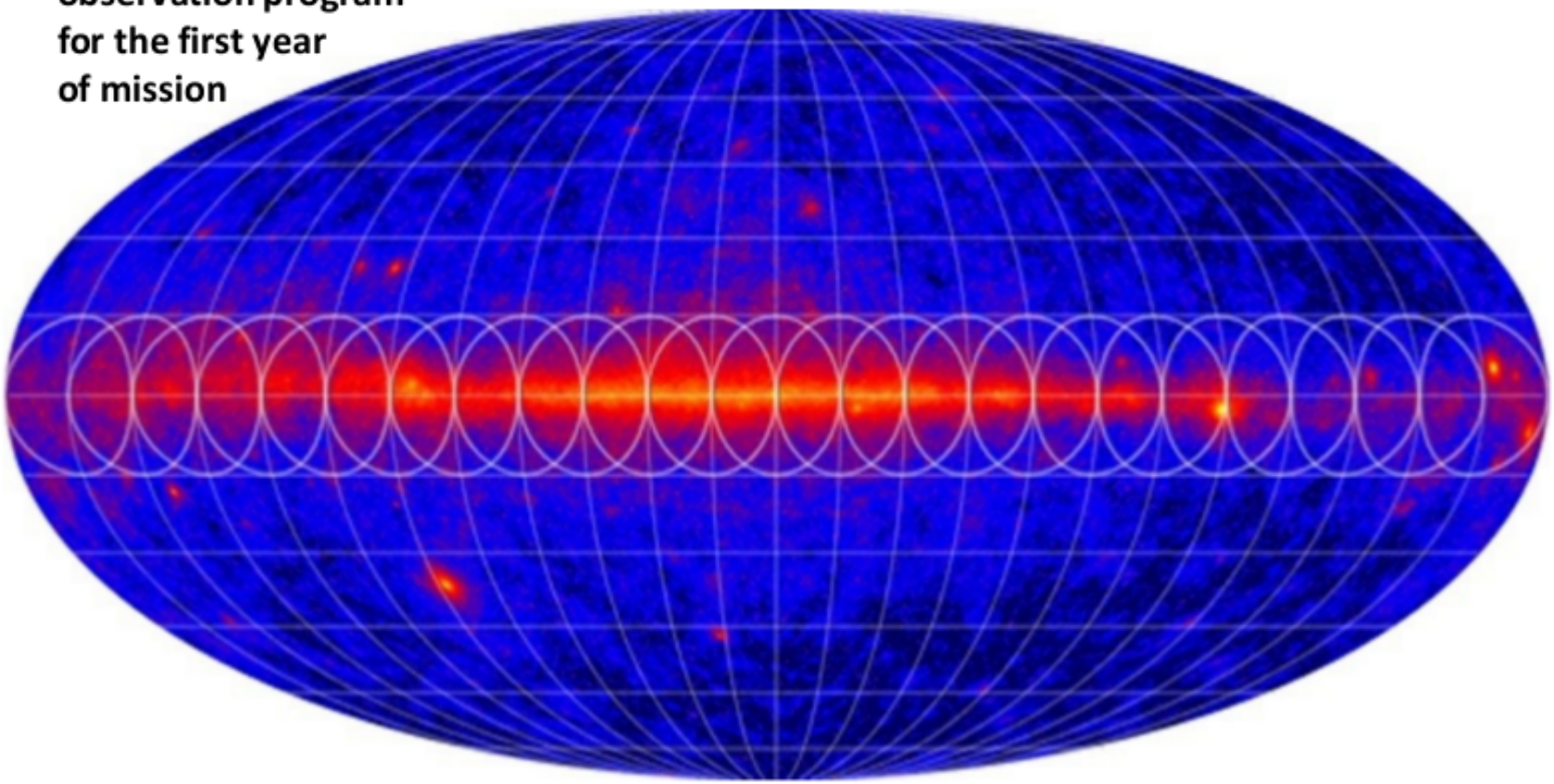


Gamma-400 2-year simulated data

Alexander Moiseev Aspen 2013 Closing in on Dark Matter

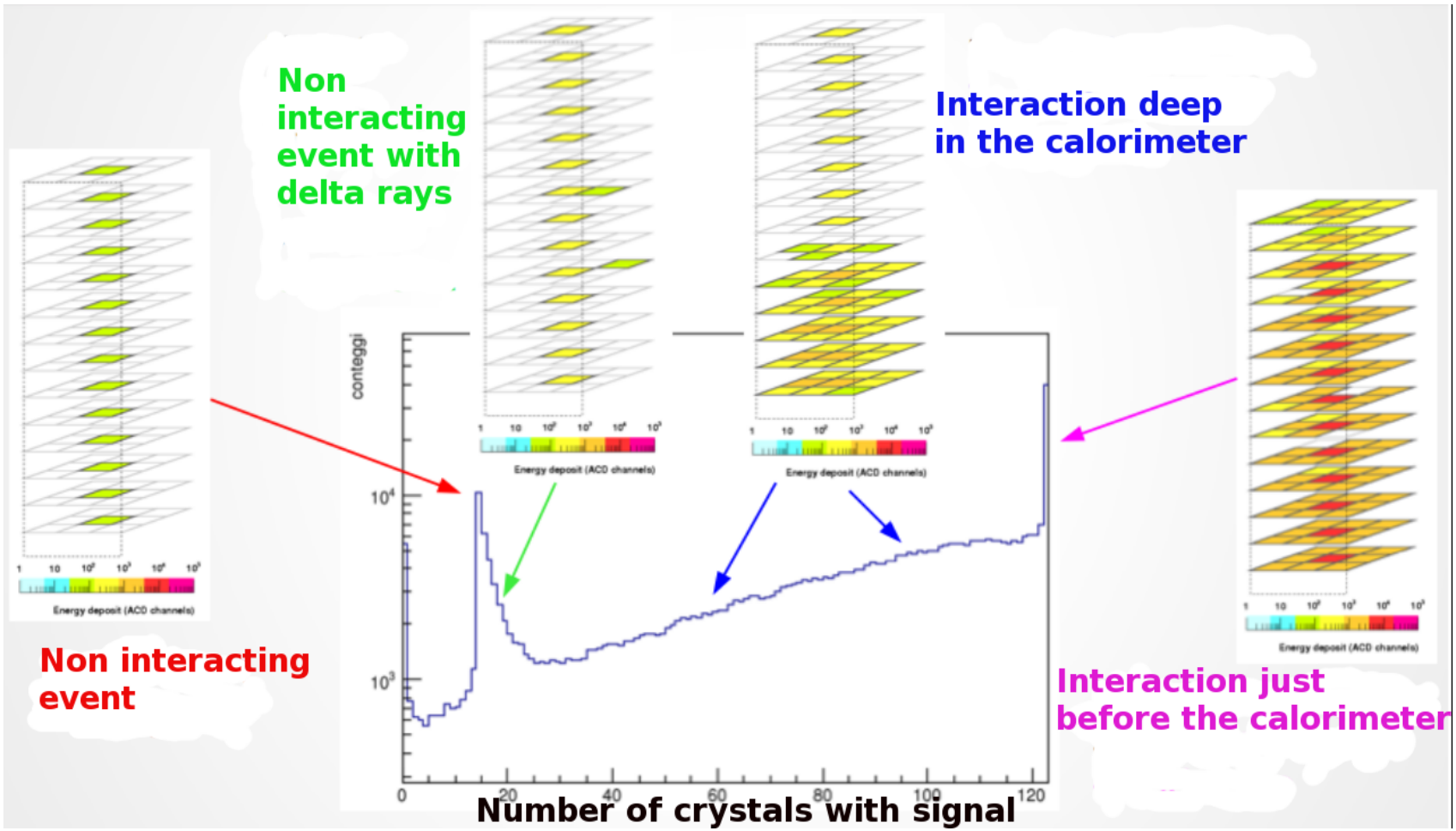
Fermi Gamma-Ray Sky

GAMMA-400 observation program for the first year of mission



Scanning of the Galaxy

Topology


Non interacting event with delta rays
Interaction deep in the calorimeter
Non interacting event
Interaction just before the calorimeter
conteggi
Number of crystals with signal
Energy deposit (ACD channels)