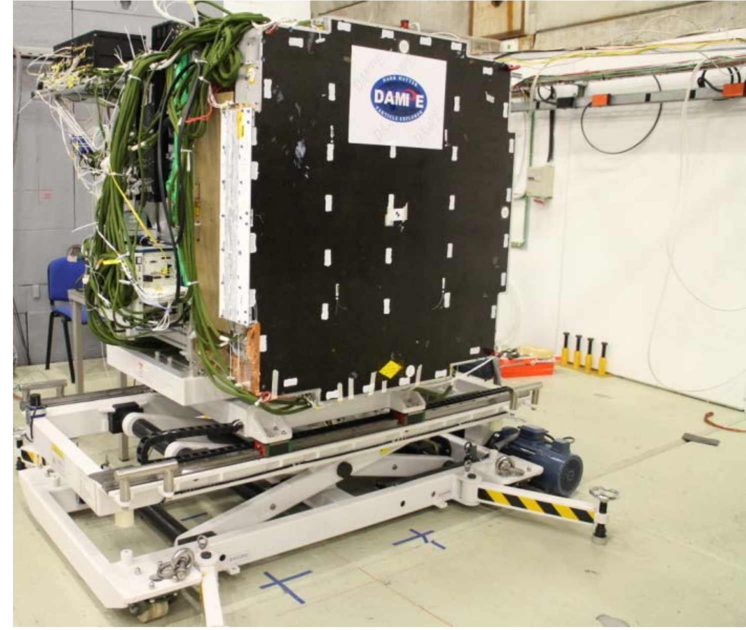


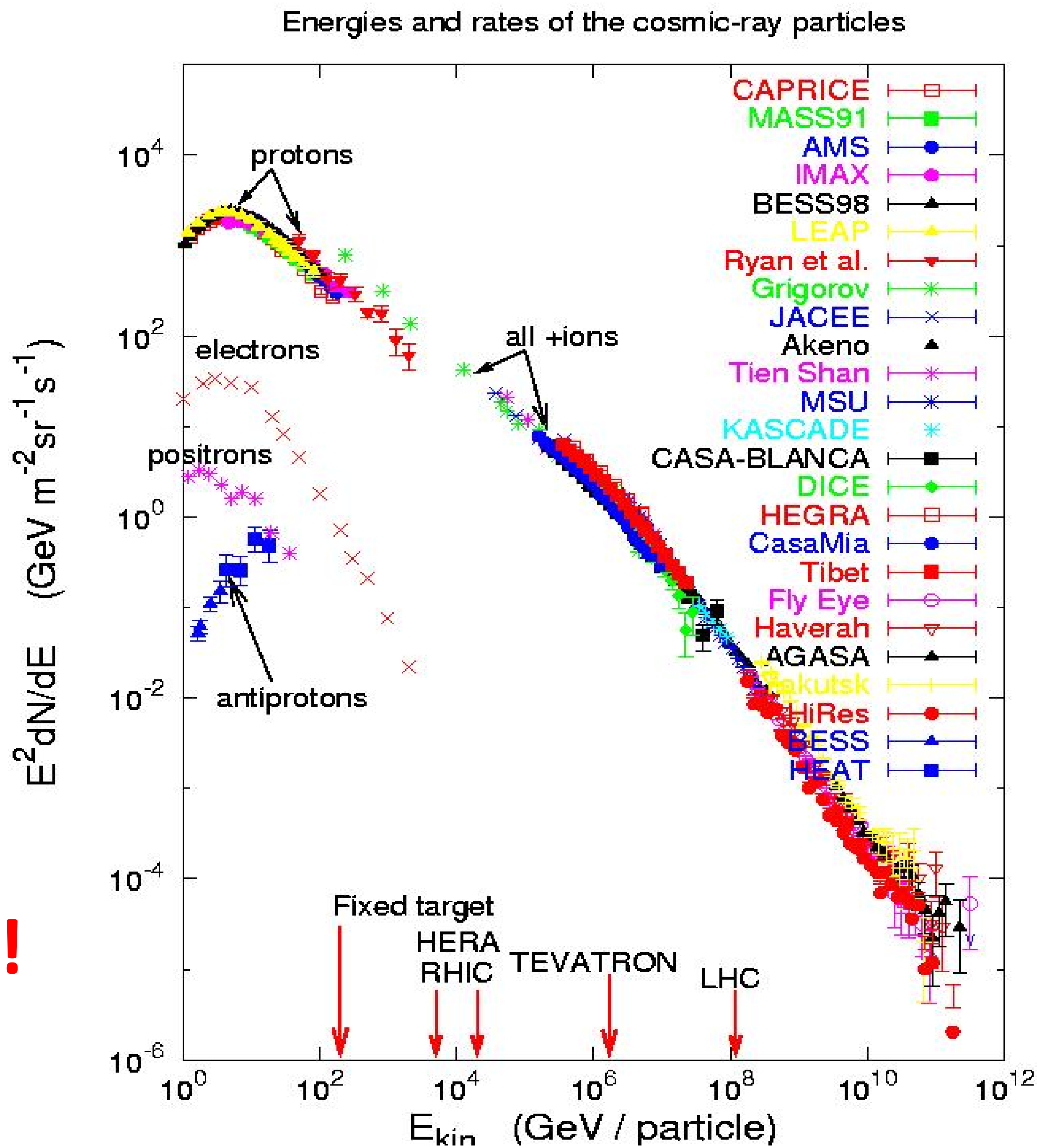
DAMPE
(Dark Matter Particle Explorer)

Paolo Bernardini, Ivan De Mitri,

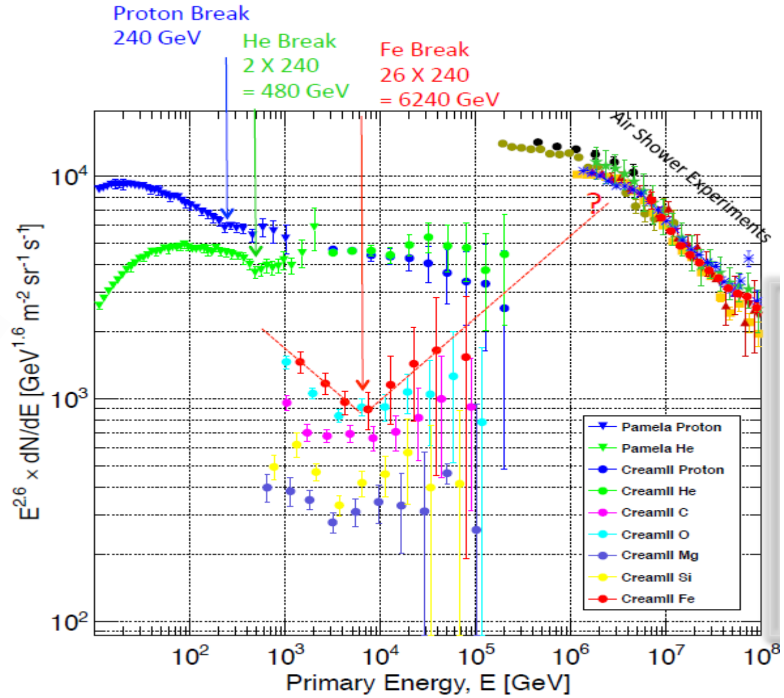
Giovanni Marsella, Antonio Surdo, John Hefele (*)

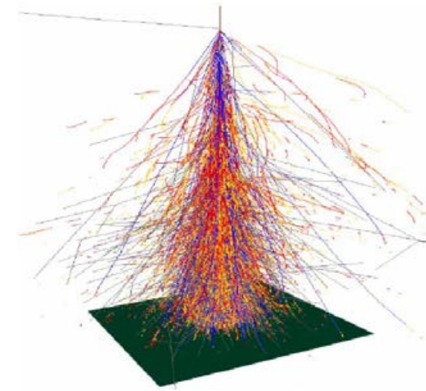
Consiglio di Sezione INFN,
8-10 luglio 2015

(*) Texas Tech University, DoE/INFN student exchange program


Energies and rates of the cosmic-ray particles
protons
electrons
positrons
antiprotons
all +ions
CAPRICE
MASS91
AMS
IMAX
BESS98
LEAP
Ryan et al.
Grigorov
JACEE
Akeno
Tien Shan
MSU
KASCADE
CASA-BLANCA
DICE
HEGRA
CasaMia
Tibet
Fly Eye
Haverah
AGASA
Yakutsk
HiRes
BESS
HEAT
Fixed target
HERA
RHIC
TEVATRON
LHC
$E^2 dN/dE$ (GeV $m^{-2} sr^{-1} s^{-1}$)
E_{kin} (GeV / particle)

The beam !





Direct measurements

Requirements:

Calorimetry vs Spectrometry

Large acceptances

<30% resolutions

Output:

Fully explore the sub-PeV region

Limitations:

Surface/weight limited

Hard to reach the all-particle knee

Need high technology

Indirect measurements

Requirements:

Multi-Hybrid approach

Operate at (not too) high altitude

Large surfaces / samplings

Output:

Reach the highest energies

Limitations:

Very poor mass resolution

Intrinsically limited by systematics

Give many hints but few answers

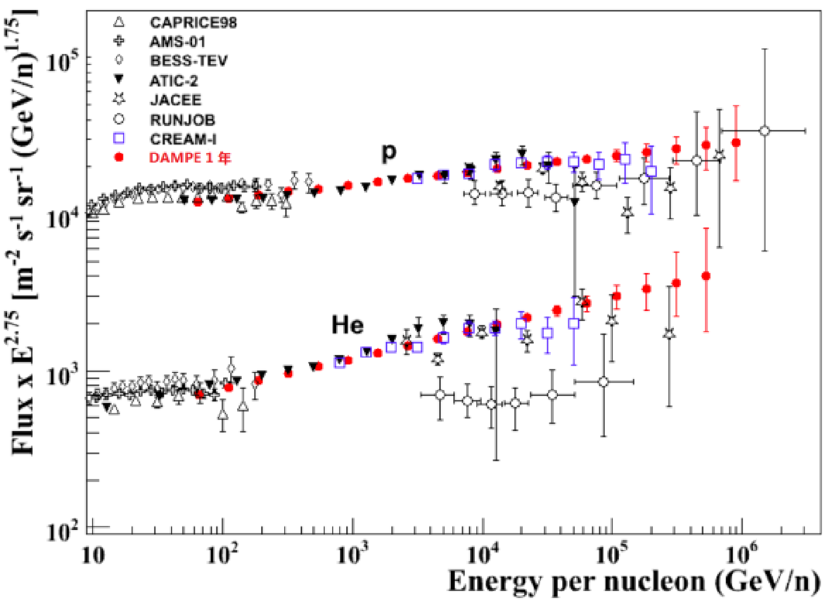
Scientific Objectives of DAMPE

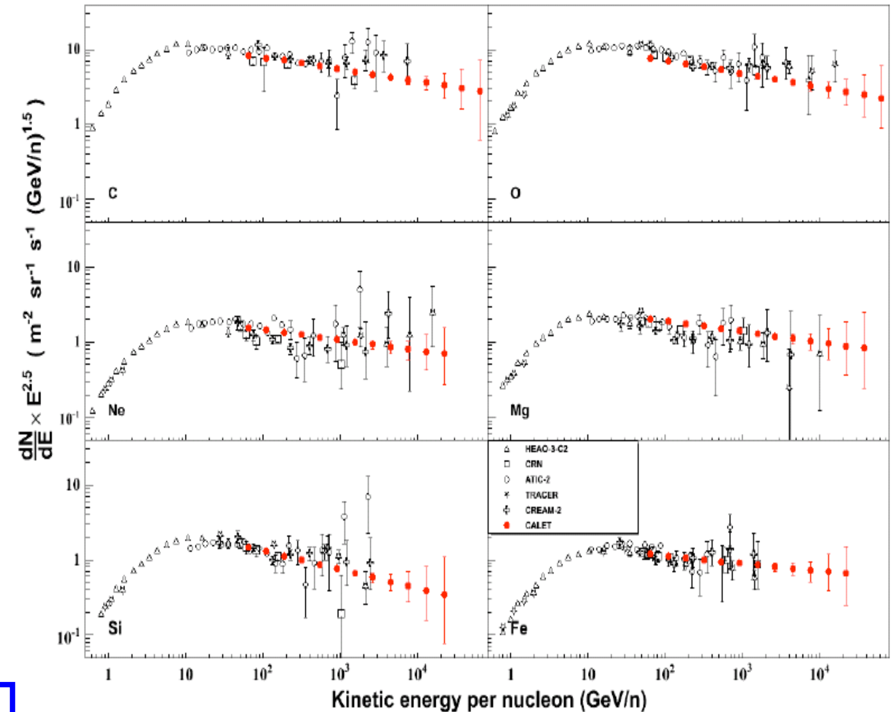
- **High energy particle detection in space**
  - **Study of the cosmic e, γ spectra and Search for DM signatures**
  - **Study of cosmic ray (nuclei) spectrum and composition**
  - **High energy gamma ray astronomy**

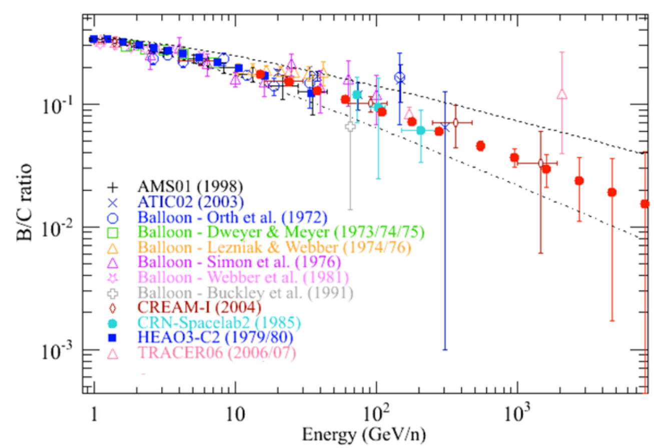
Detection of 10 GeV - 10 TeV e/γ, 100 GeV - 500 TeV CR
Excellent energy resolution and tracking precision
Complementary to Fermi, AMS-02, CALET, ISS-CREAM, …

- **Follow-up mission to both Fermi/LAT and AMS-02**
  - **Extend the energy reach to the TeV region, providing better resolution**
  - **Overlap with Fermi on gamma ray astronomy**
  - **Run in parallel for some time**

CR Spectra & Composition with DAMPE

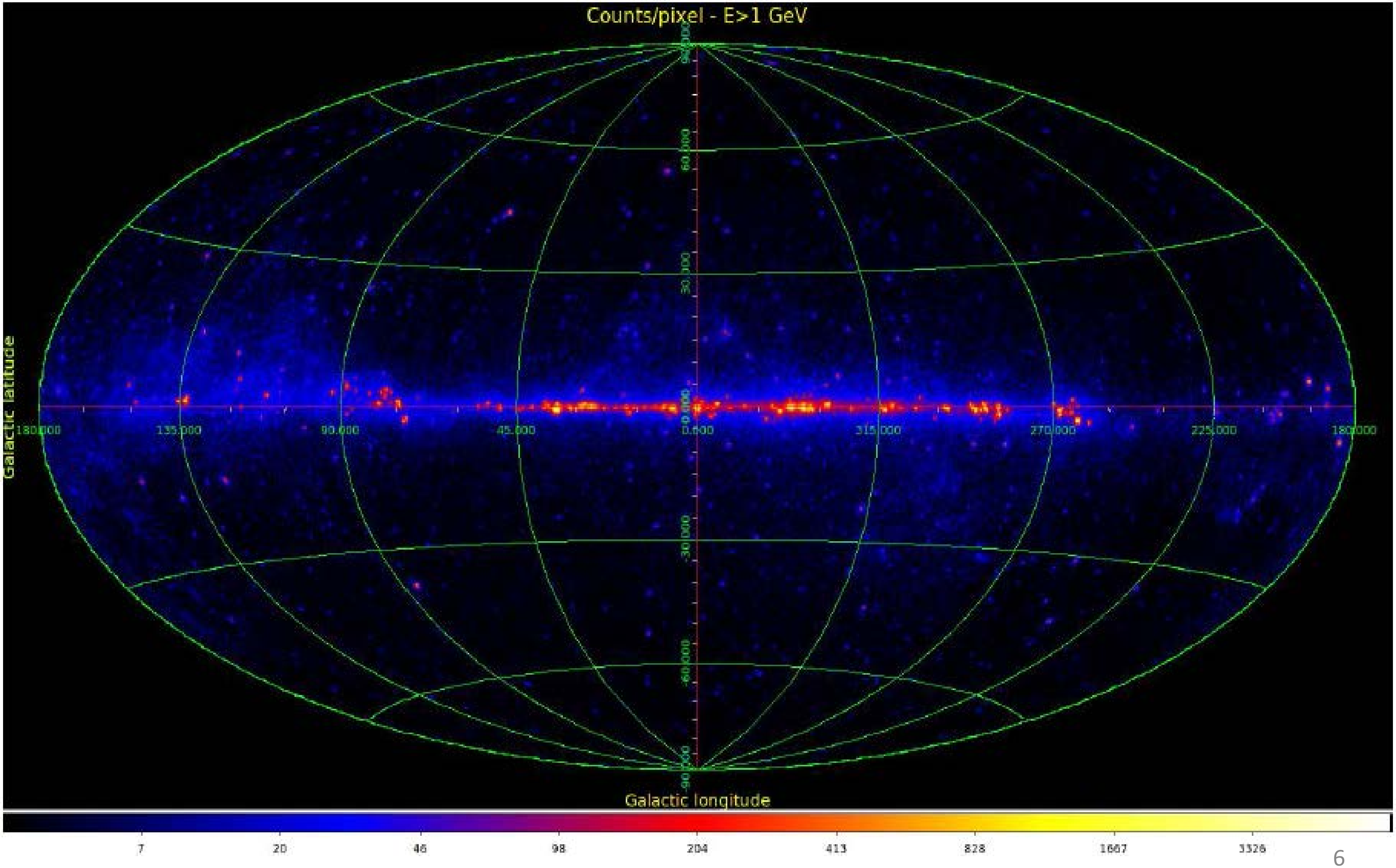






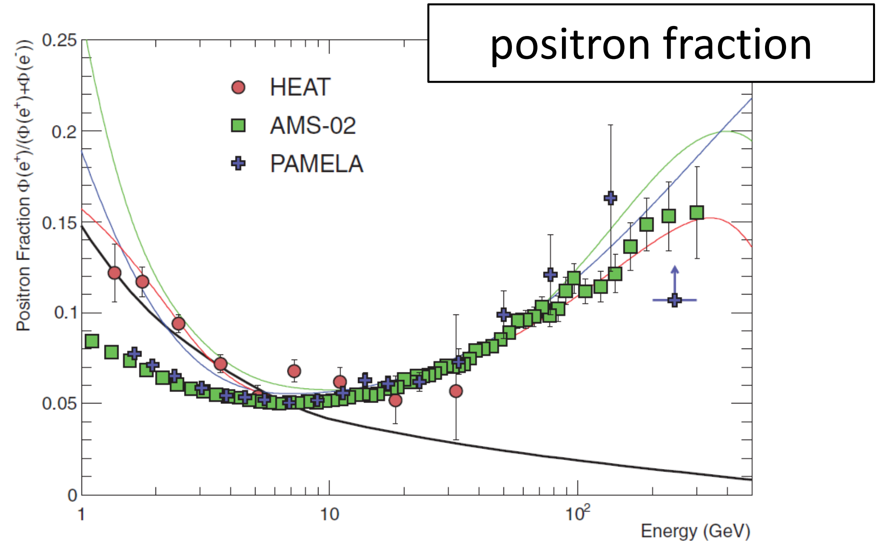
Proton spectrum to ≈ 900 TeV
He spectrum to ≈ 400 TeV/n
Spectra of C, O, Ne, Mg, Si to ≈ 20 TeV/n
B/C ratio to ≈ 4-6 TeV/n
Fe spectrum to ≈ 10 TeV/n

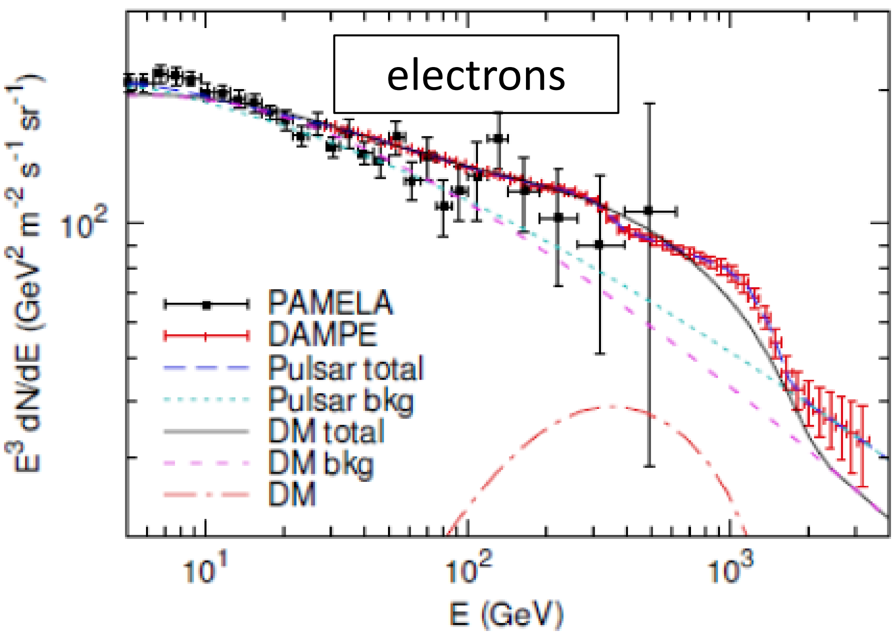
DAMPE 1 year all sky above 1 GeV

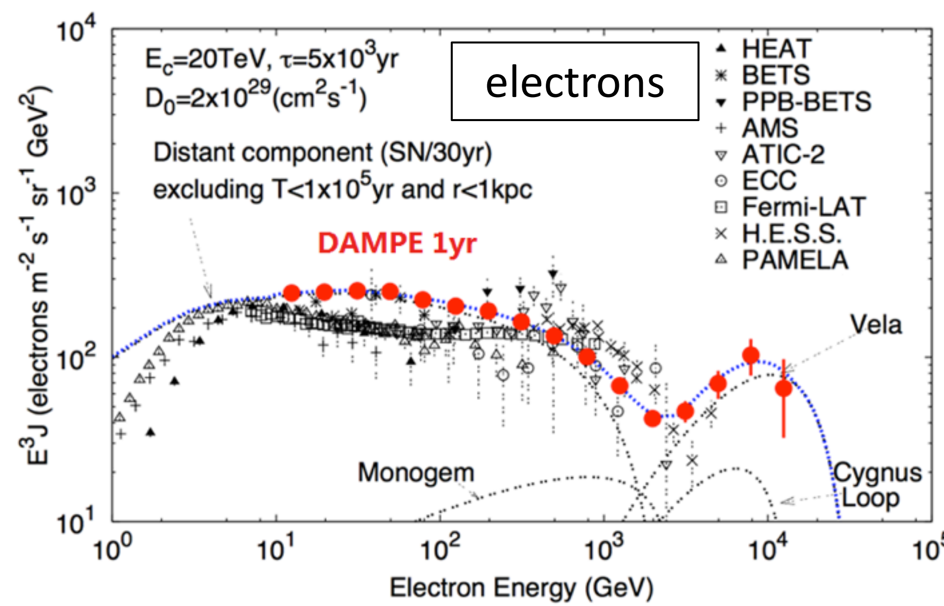


DM or Pulsar ?

Need a detector in space that can detect electrons around 1 TeV with very good energy resolution







The DAMPE Collaboration

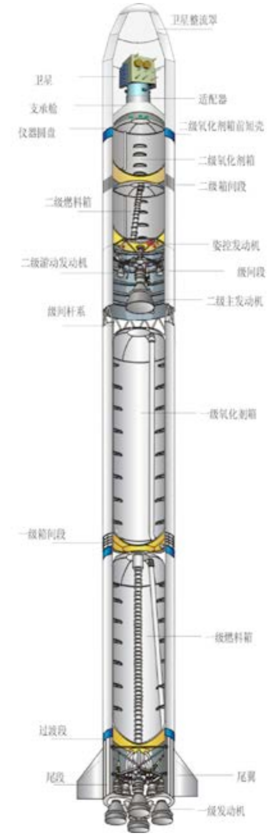
- China
  - Purple Mountain Observatory, CAS, Nanjing
    - Chief Scientist: Prof. Jin Chang
  - Institute of High Energy Physics, CAS, Beijing
  - National Space Science Center, CAS, Beijing
  - University of Science and Technology of China, Hefei
  - Institute of Modern Physics, CAS, Lanzhou

- Switzerland
  - University of Geneva

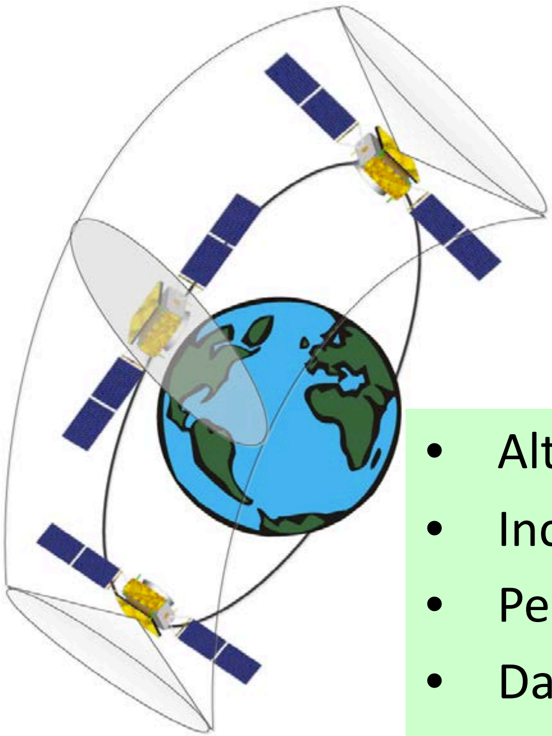
- Italy
  - INFN and University of Perugia
  - INFN and University of Bari
  - INFN and University of Lecce

Dark Matter Particle Explorer Satellite

- One of the 5 satellite missions of the Strategic Priority Research Program in Space Science of CAS
  - Approved for construction (phase C/D) in Dec. 2011
  - Scheduled launch date **December 17, 2015** from Jiuquan Satellite Launch Center in the Gobi desert

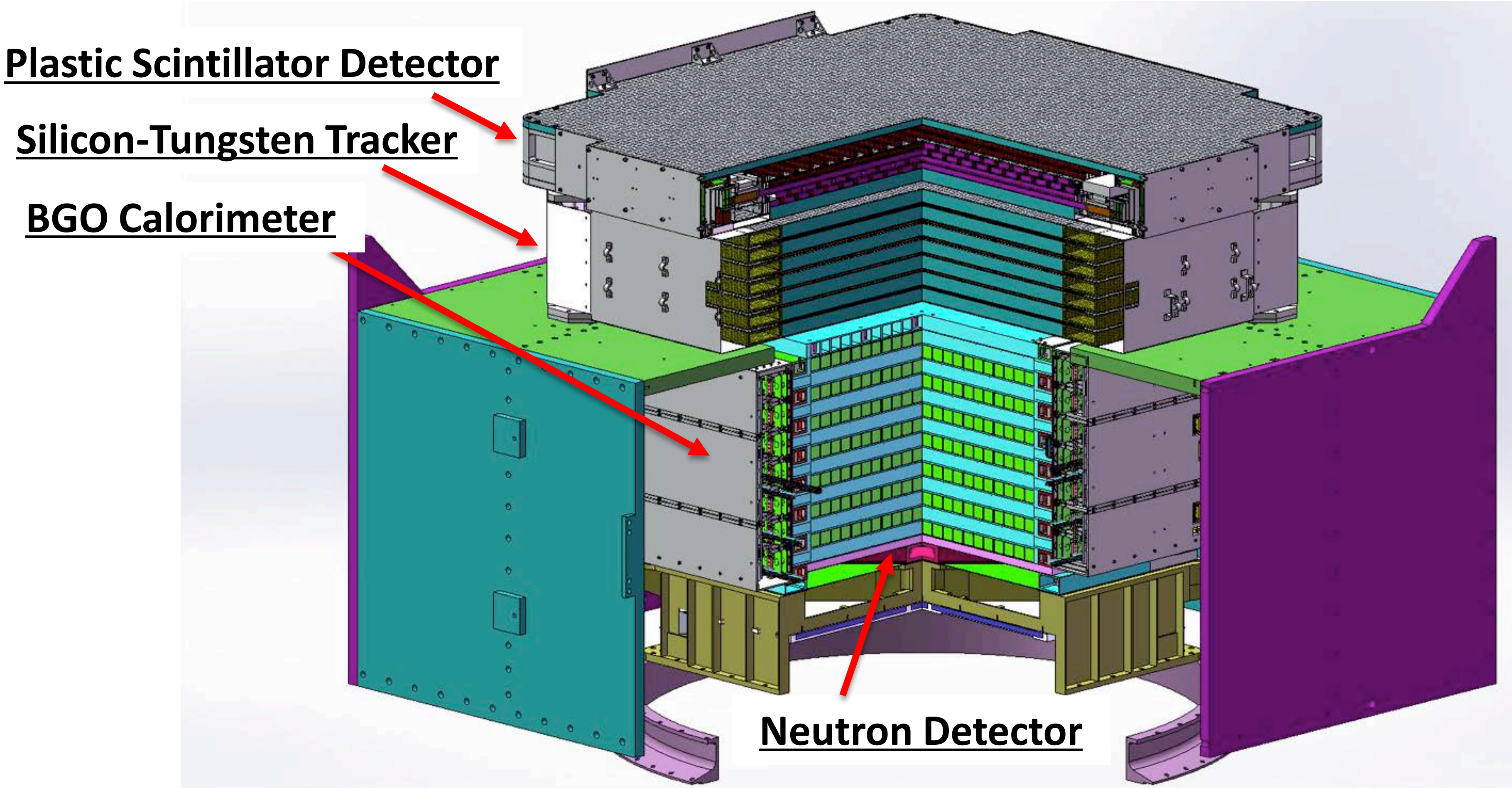


- Satellite < 1900 kg, payload ~1340kg
- Power consumption 640W (400 W)
- Lifetime > 3 years
- Launched by CZ-2D rockets



- Altitude 500 km
- Inclination 87.4065°
- Period 90 minutes
- Dawn/dusk (6:30 AM) sun-synchronous orbit

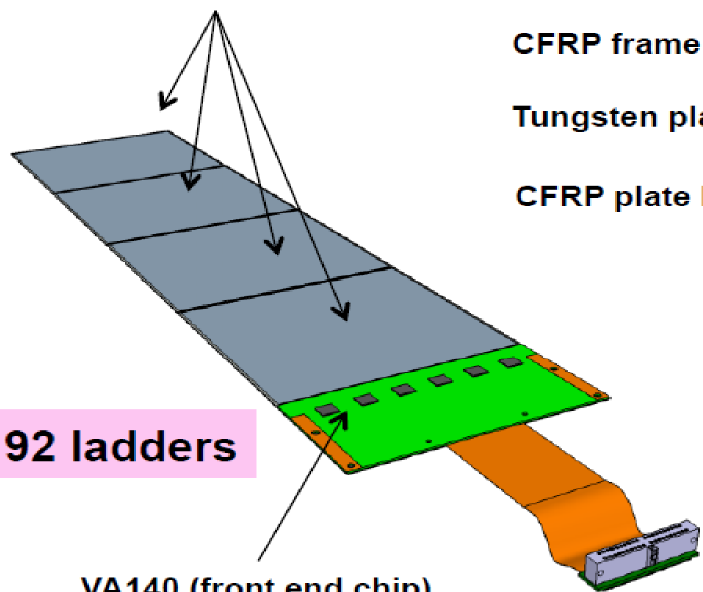
The DAMPE Detector

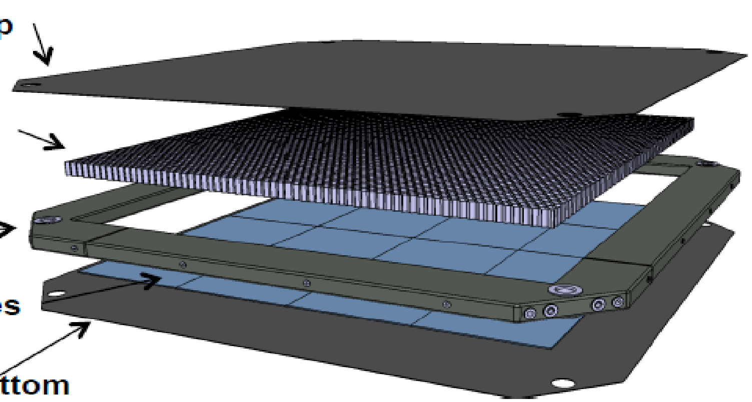


W converter + thick calorimeter (total 33 X_0) + precise tracking + charge measurement ➡ high energy γ-ray, electron and CR telescope

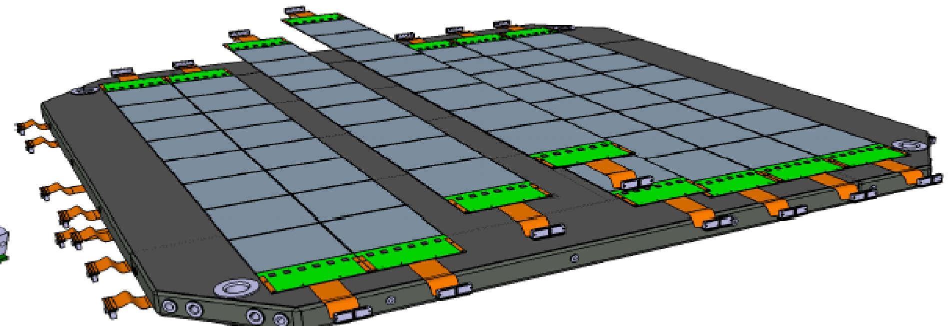
Si Layer and Ladders (INFN)

768 silicon sensors





12 layers, 6-x and 6-y



192 ladders

1152 ASICs

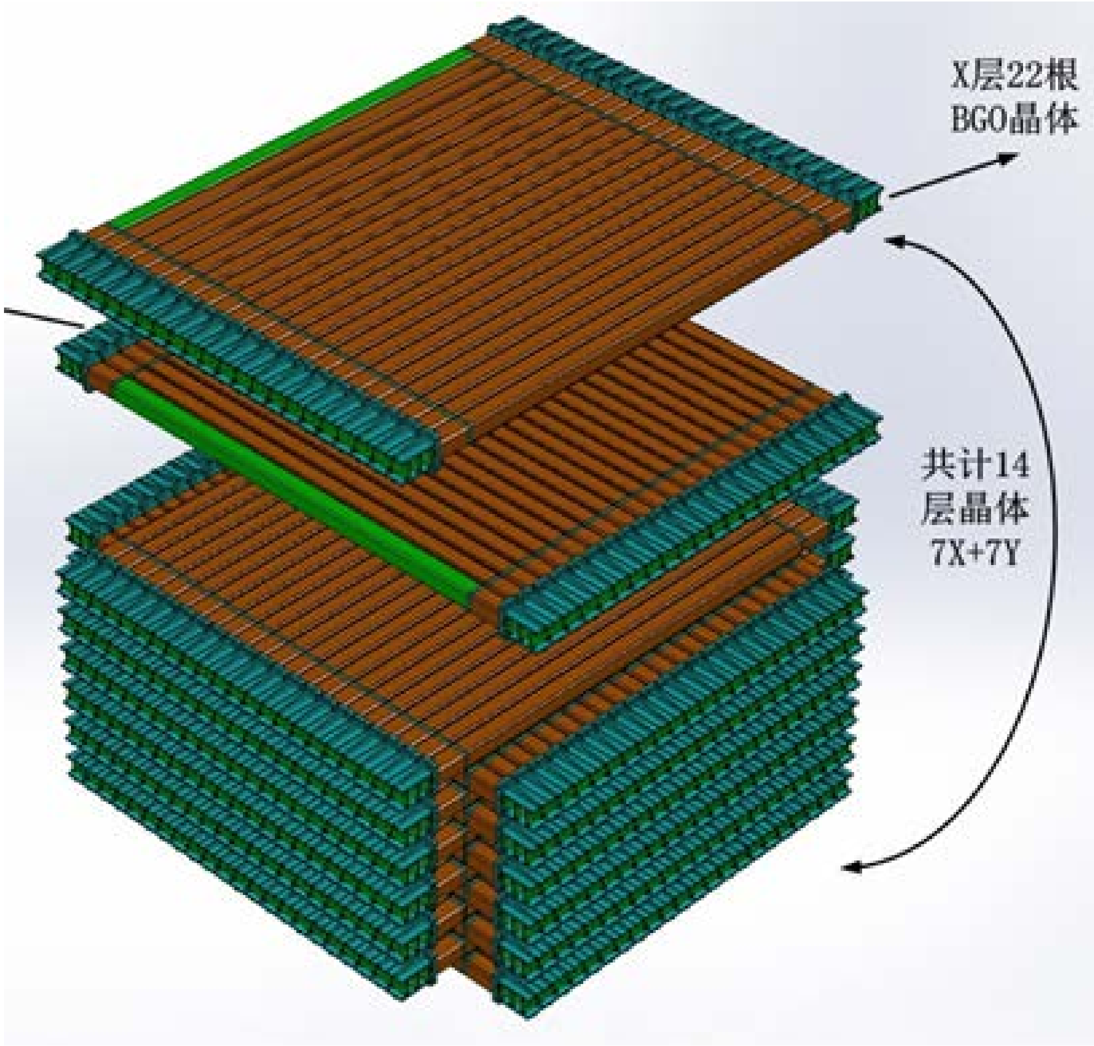
73728 channels

Each ladder is composed by 4 $95 \times 95 \times 0.320$ mm^3 *Silicon Strips Detectors* (SSD).

- Each SSD has 768 *strips* (width 48 μm);
- distance between two strips 121 μm;
- 1 over 2 strips is readout (384 channels):a correction on the signal collected must be applied ⇒ charge sharing

3D Imaging BGO Calorimeter

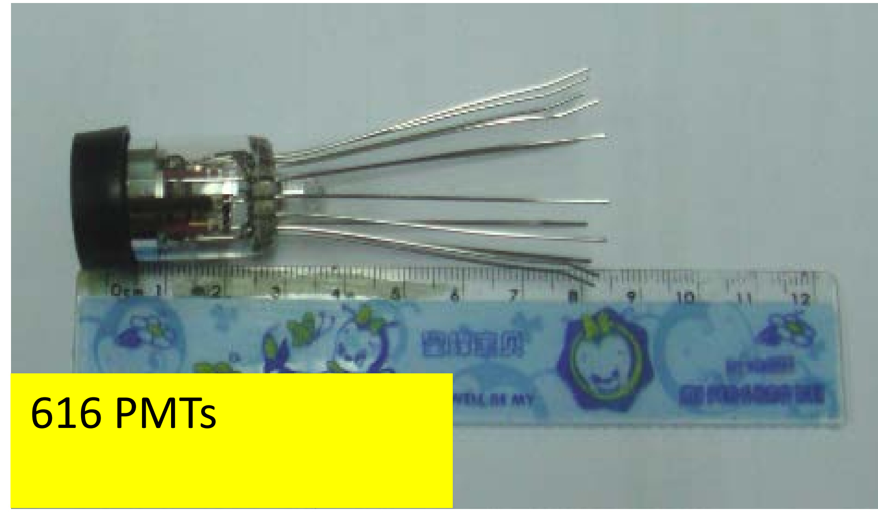
- 14 layers of 22 BGO crystals
  - Dimension of BGO bar: 2.5×2.5×60cm^3
  - Hodoscopic stacking alternating orthogonal layers
  - depth ~32X_0
- Two PMTs coupled with each BGO crystal bar in two ends
- Electronics boards attached to each side of module

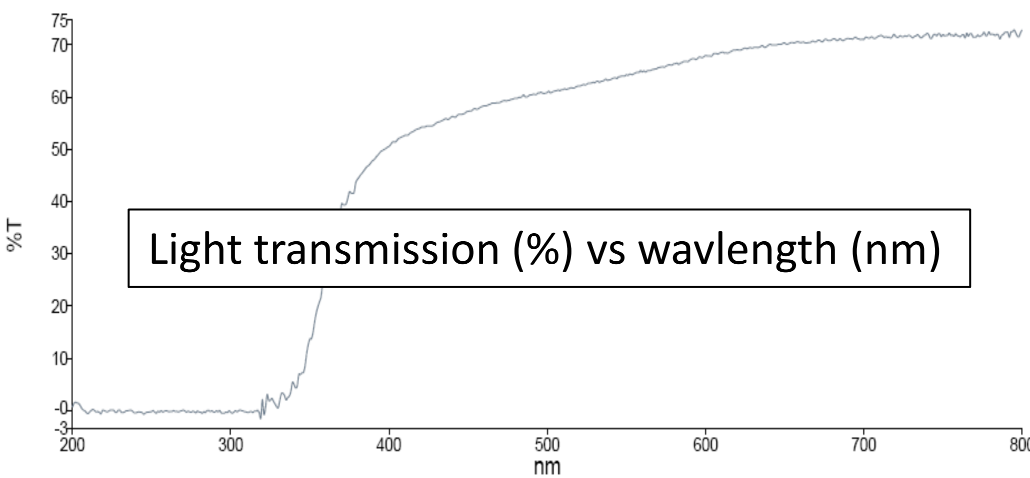


3D Imaging BGO Calorimeter

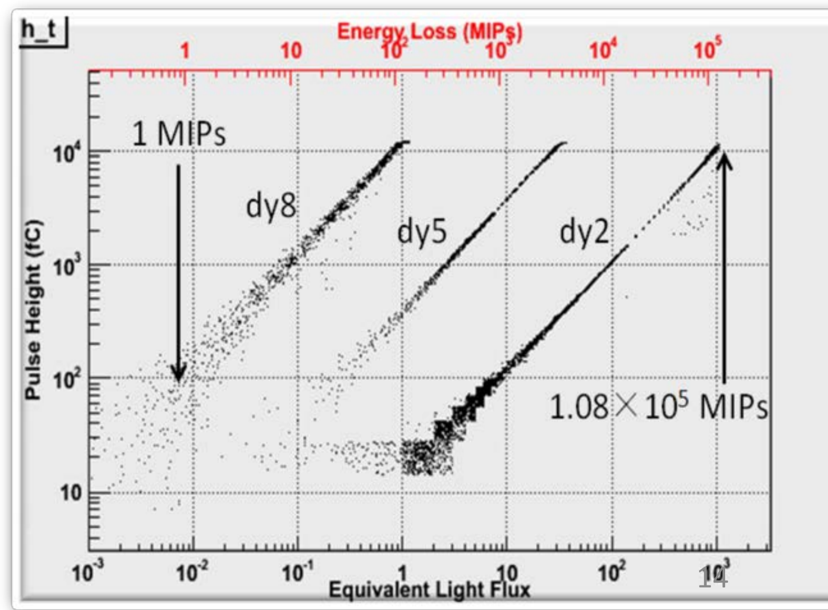
308 BGO bars

616 PMTs



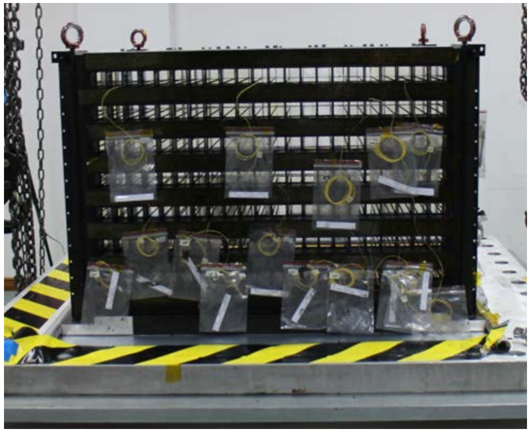


Light transmission (%) vs wavlength (nm)



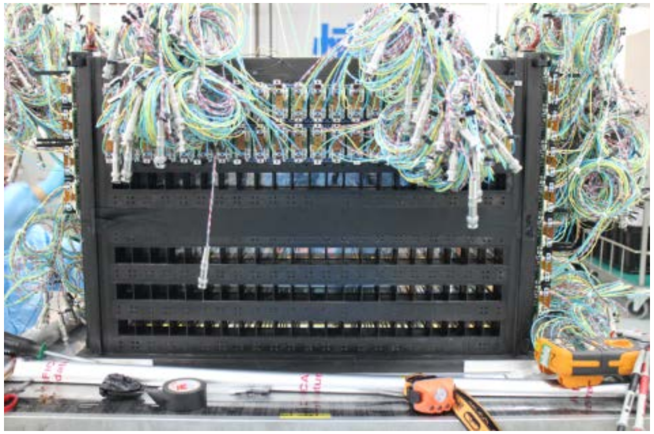
3D Imaging BGO Calorimeter

Assembly

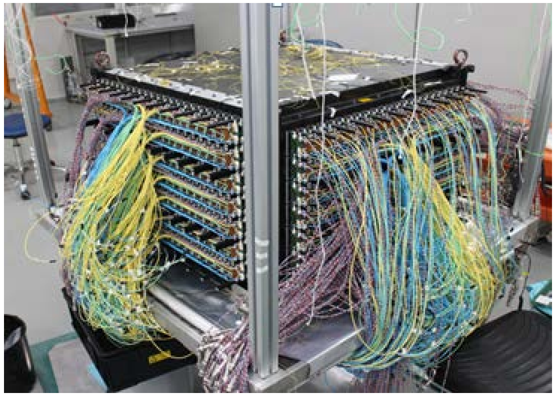


Carbon Fiber Structure

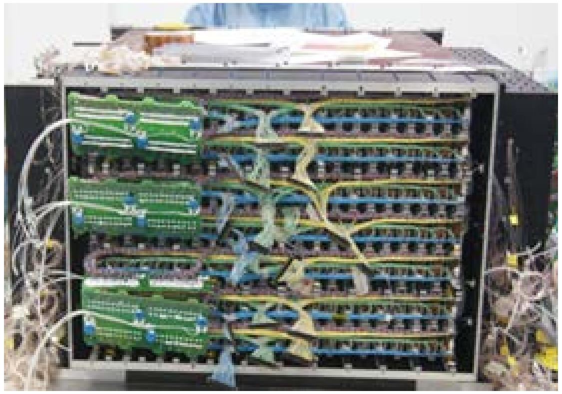
BGO crystal install



PMT install



Cable arrange



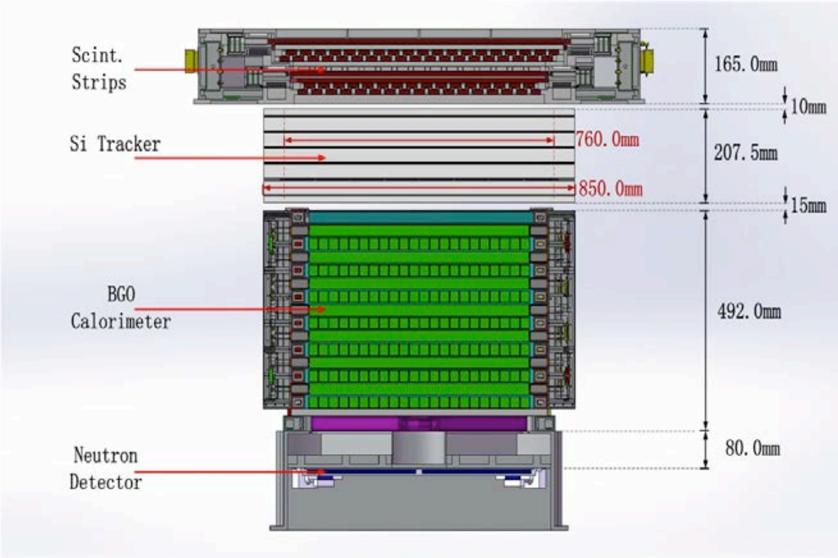
Cable connector

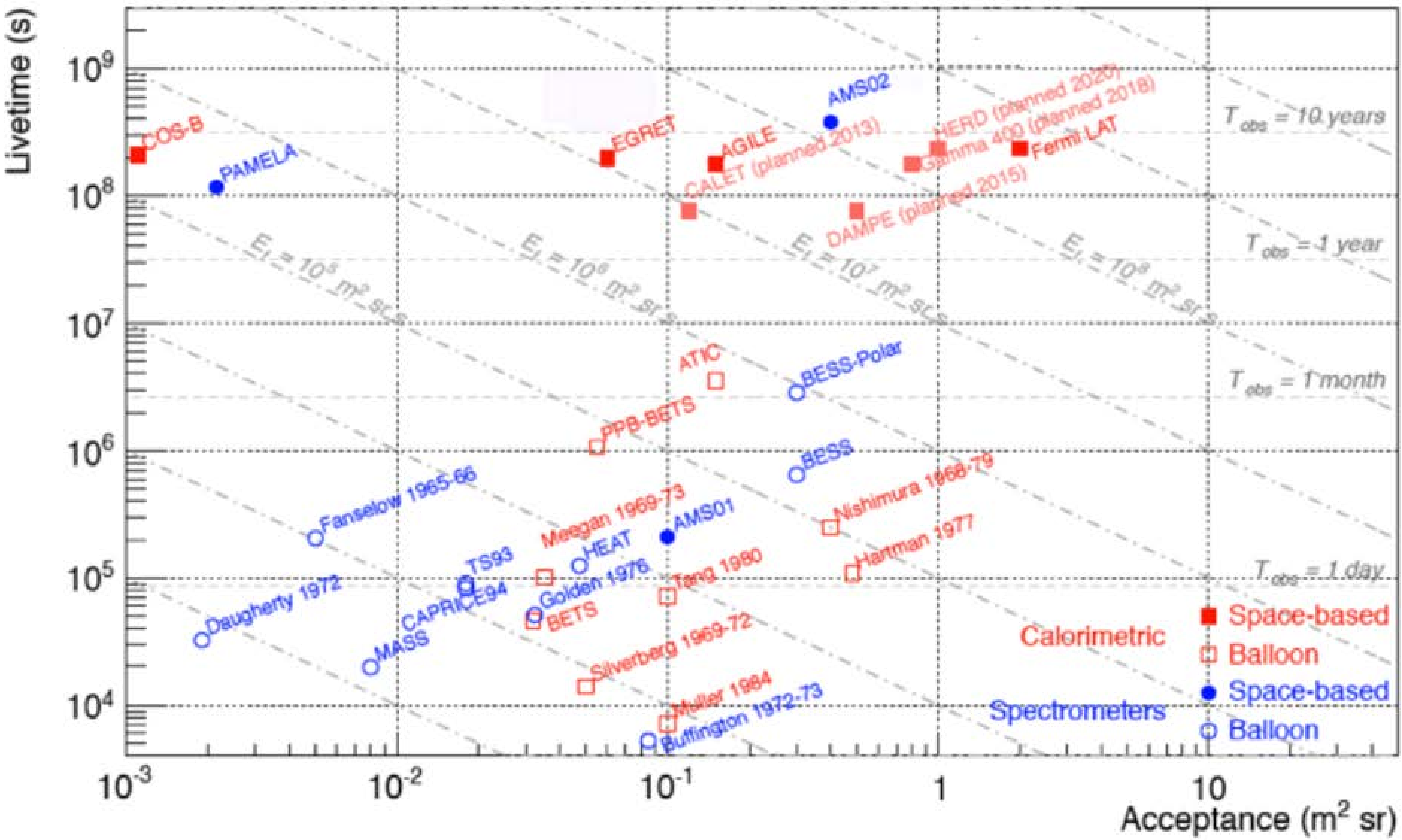
BGO Cal

Comparison with AMS-02 and Fermi

	DAMPE	AMS-02	Fermi LAT
e/γ Energy res.@100 GeV (%)	1.5	3	10
e/γ Angular res.@100 GeV (°)	0.1	0.3	0.1
e/p discrimination	10^5	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	31	17	8.6
Geometrical accep. (m^2sr)	0.29	0.09	1

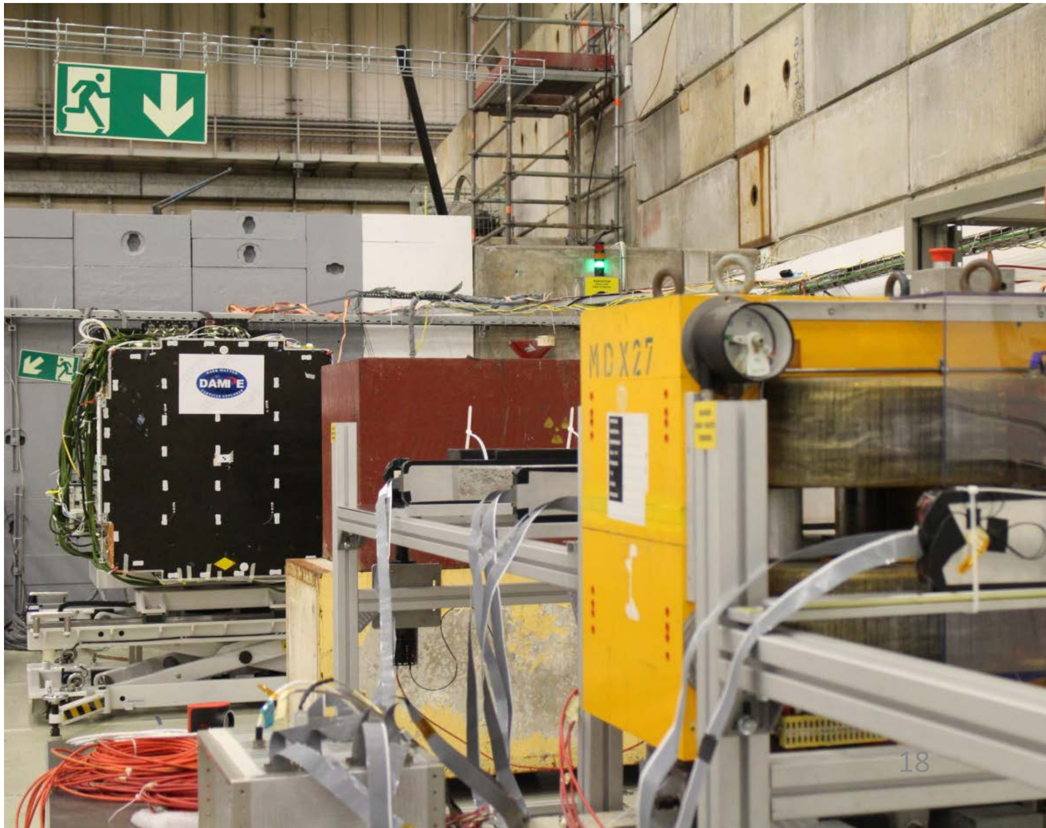
- **Geometrical acceptance with BGO alone: 0.36 m^2sr**
  - **BGO+STK+PSD: 0.29 m^2sr**
  - **First 10 layers of BGO (22 X_0) +STK+PSD: 0.36 m^2sr**




Livetime (s)
Acceptance (m² sr)
COS-B
PAMELA
EGRET
AGILE
AMS02
CALET (planned 2013)
HERD (planned 2020)
Gamma 400 (planned 2018)
Fermi LAT
DAMPE (planned 2015)
T obs = 10 years
T obs = 1 year
T obs = 1 month
T obs = 1 day
ATIC
BESS-Polar
PPB-BETS
BESS
Nishimura 1968-79
Fanselow 1965-66
Meegan 1969-73
AMS01
HEAT
TS93
Golden 1976
Tang 1980
Hartman 1977
Daugherty 1972
CAPRICE94
BETS
MASS
Silverberg 1969-72
Muller 1984
Buffington 1972-73
Calorimetric
Spectrometers
Space-based
Balloon
Space-based
Balloon

Test beam activity at CERN (nov '14 - nov'15)

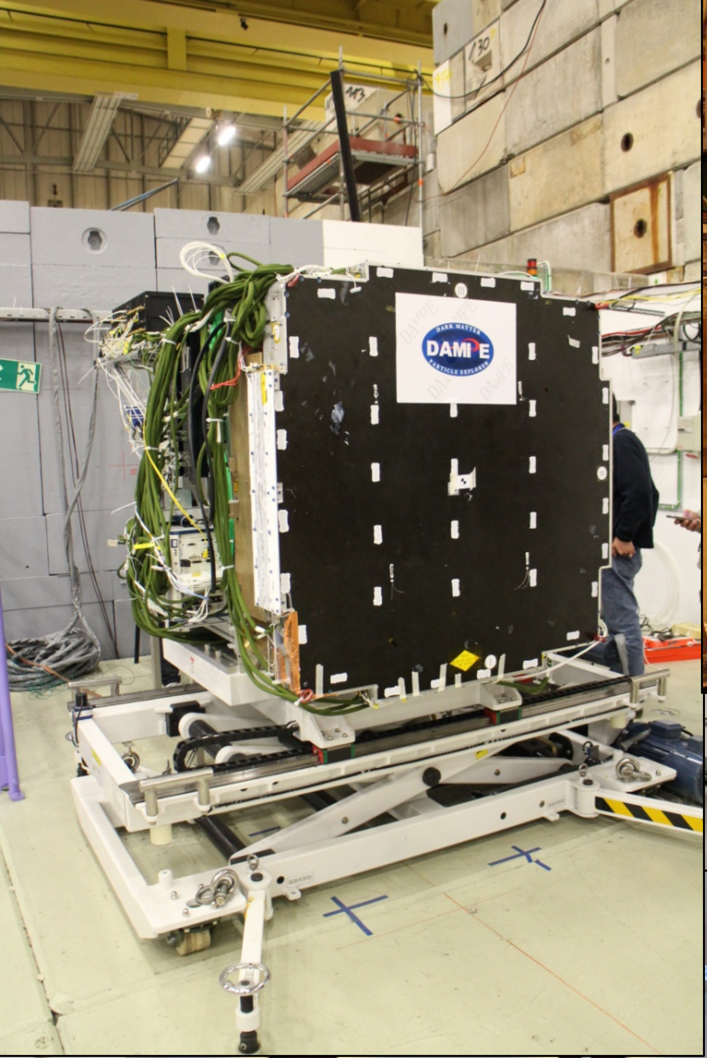
- **14days@PS，29/10-11/11 2014**
  - **e @ 0.5GeV/c, 1GeV/c, 2GeV/c, 3GeV/c, 4GeV/c, 5GeV/c**
  - **p @ 3.5GeV/c, 4GeV/c, 5GeV/c, 6GeV/c, 8GeV/c, 10GeV/c**
  - **π-@ 3GeV/c, 10GeV/c**
  - **γ @ 0.5-3GeV/c**
- **8days@SPS，12/11-19/11 2014**
  - **e @ 5GeV/c, 10GeV/c, 20GeV/c, 50GeV/c, 100GeV/c, 150GeV/c, 200GeV/c, 250GeV/c**
  - **p @ 400GeV/c (SPS primary beam)**
  - **γ @ 3-20GeV/c**
  - **μ @ 150GeV/c,**
- **17days@SPS，16/3-1/4 2015**
  - **Fragments：66.67-88.89-166.67GeV/c**
  - **Argon：30A- 40A- 75AGeV/c**
  - **Proton：30GeV/c，40GeV/c**
- **21days@SPS，10/6-1/7 2015**
  - **Primary Proton: 400GeV/c**
  - **Electrons @ 20, 100, 150 GeV/c**
  - **γ @ 50, 75 , 150 GeV/c**
  - **μ @ 150 GeV /c**
  - **π+ @10, 20, 50, 100 GeV/c**
- **10days@SPS, 11/11-20/11 2015**
  - **-- Pb 30AGeV/c (and fragments) (HERD)**
- **6days@SPS, 20/11-25/11 2015**
  - **-- Pb 030 AGeV/c (and fragments)**

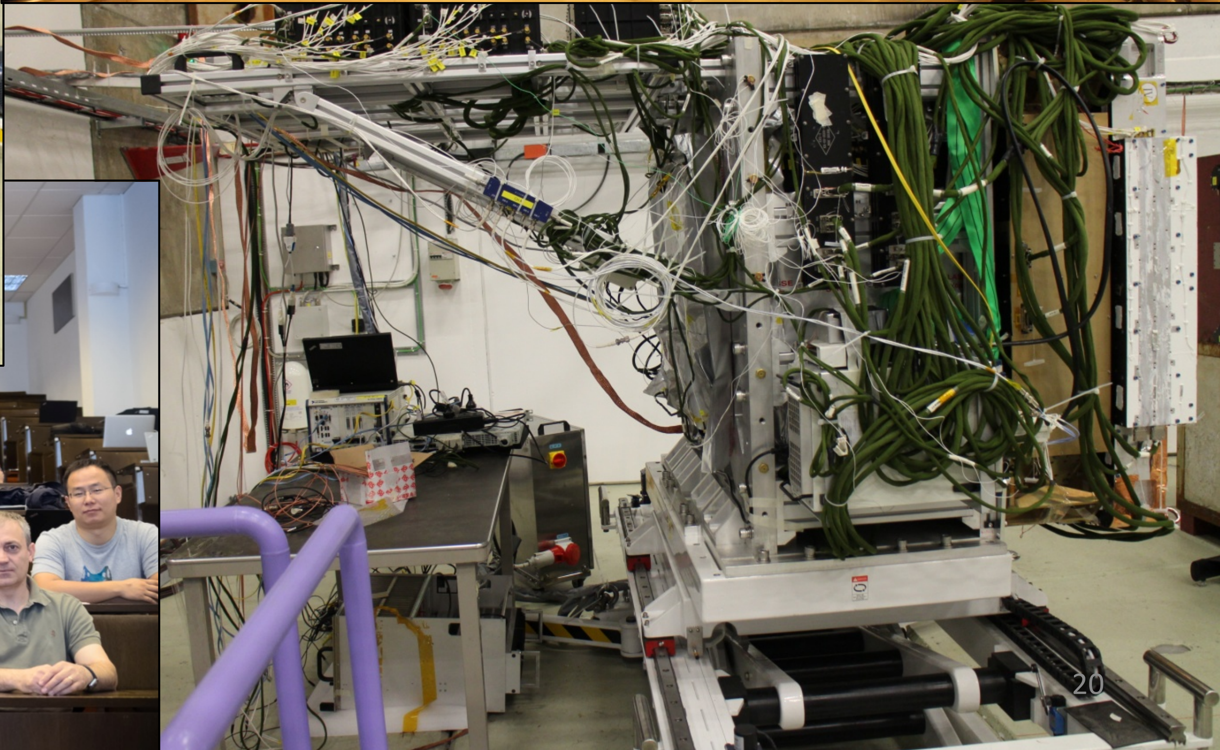


CERN recognized experiment

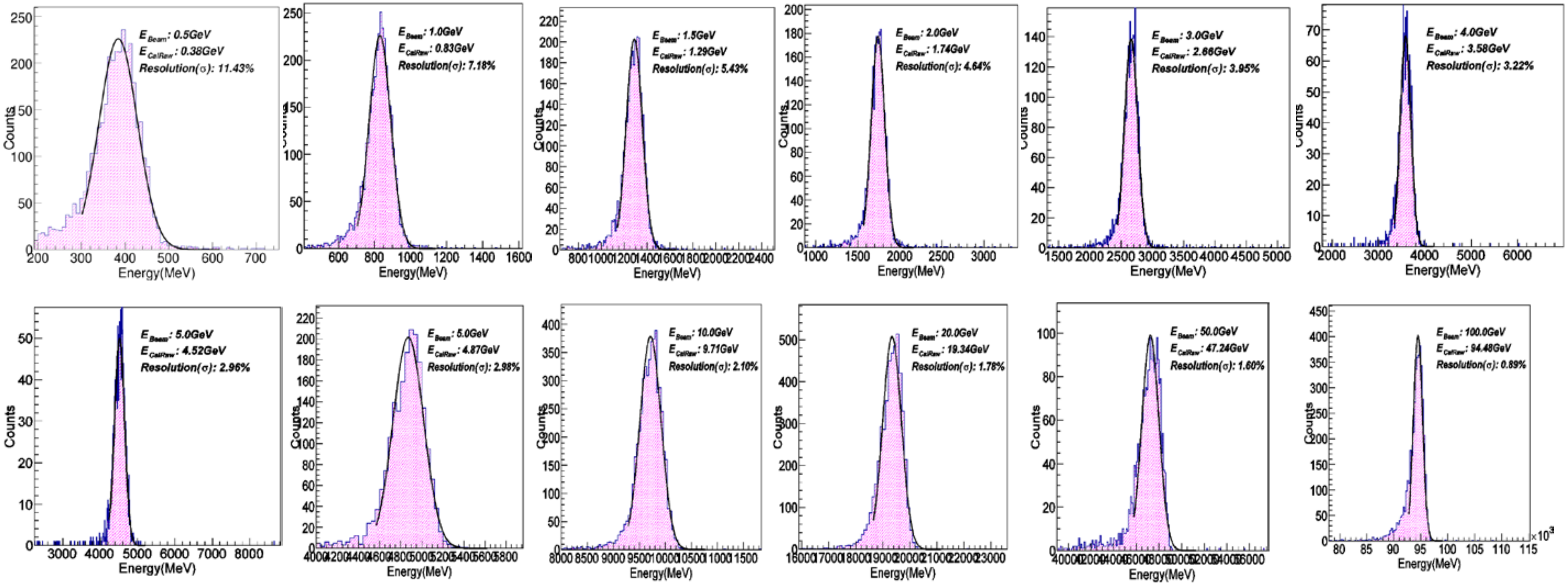
RE29 : DAMPE

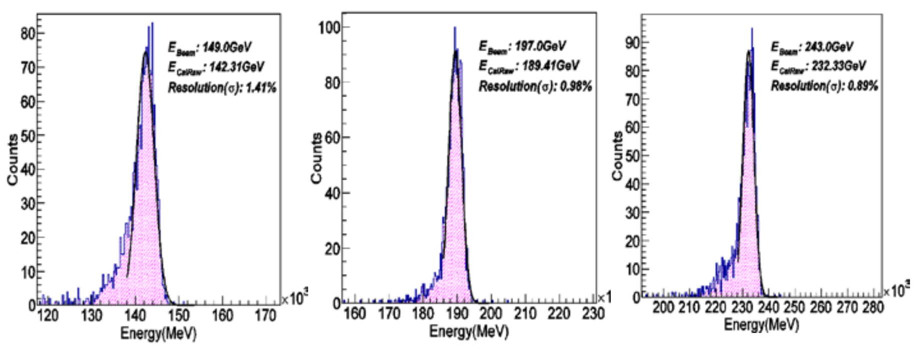
9 Institutions, 55 Participants

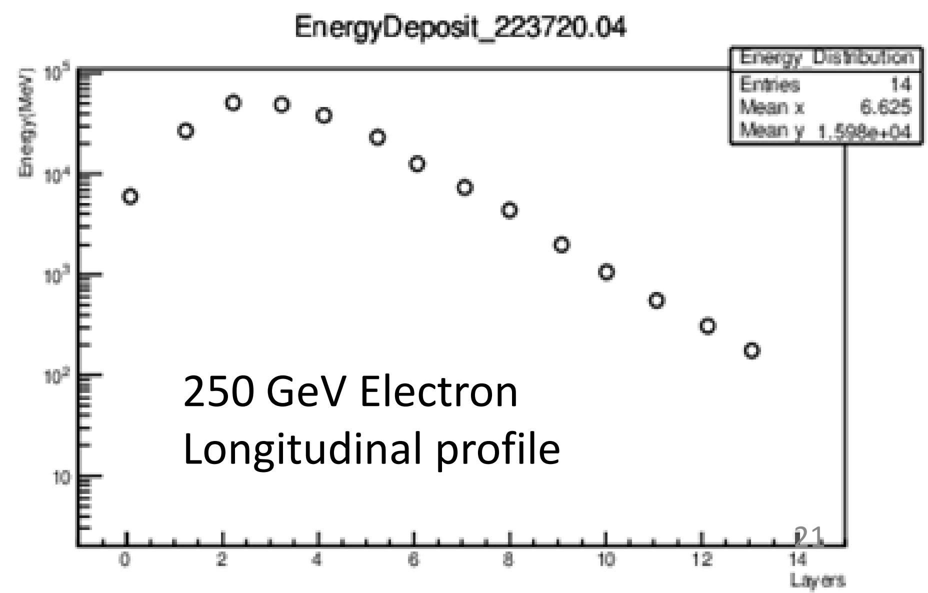

DAMPE



Electron Energy Reconstruction





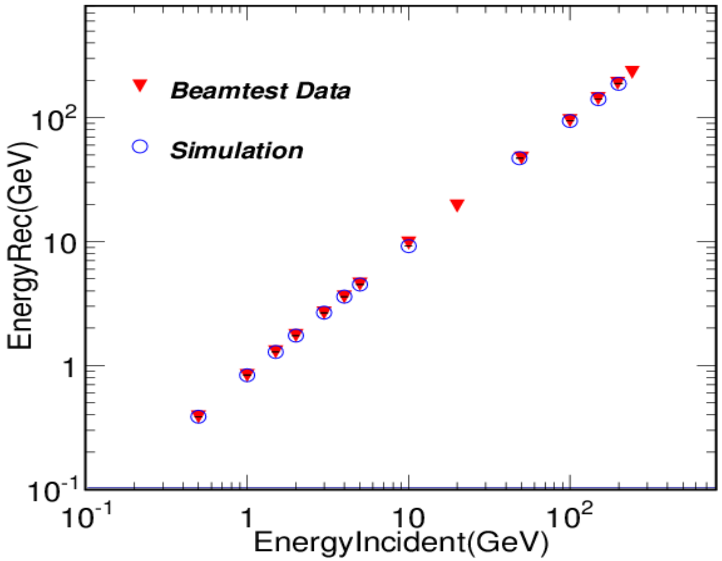


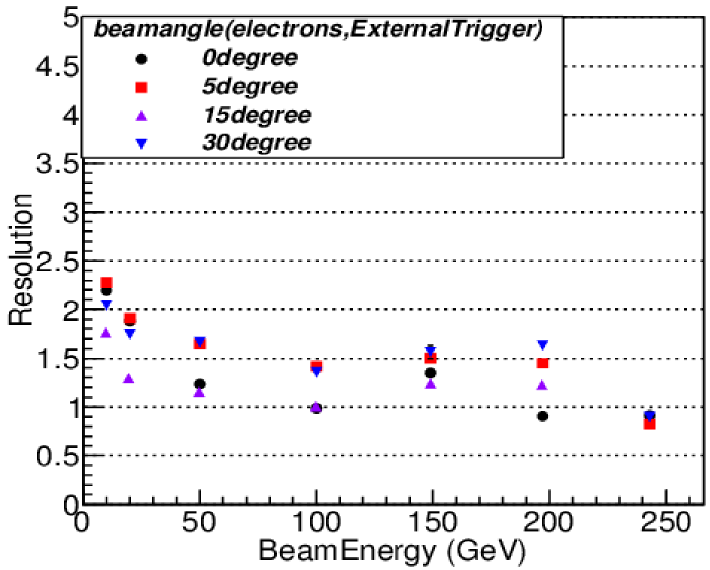
0.5, 1, 1.5, 2, 3, 4, 5 GeV @ PS

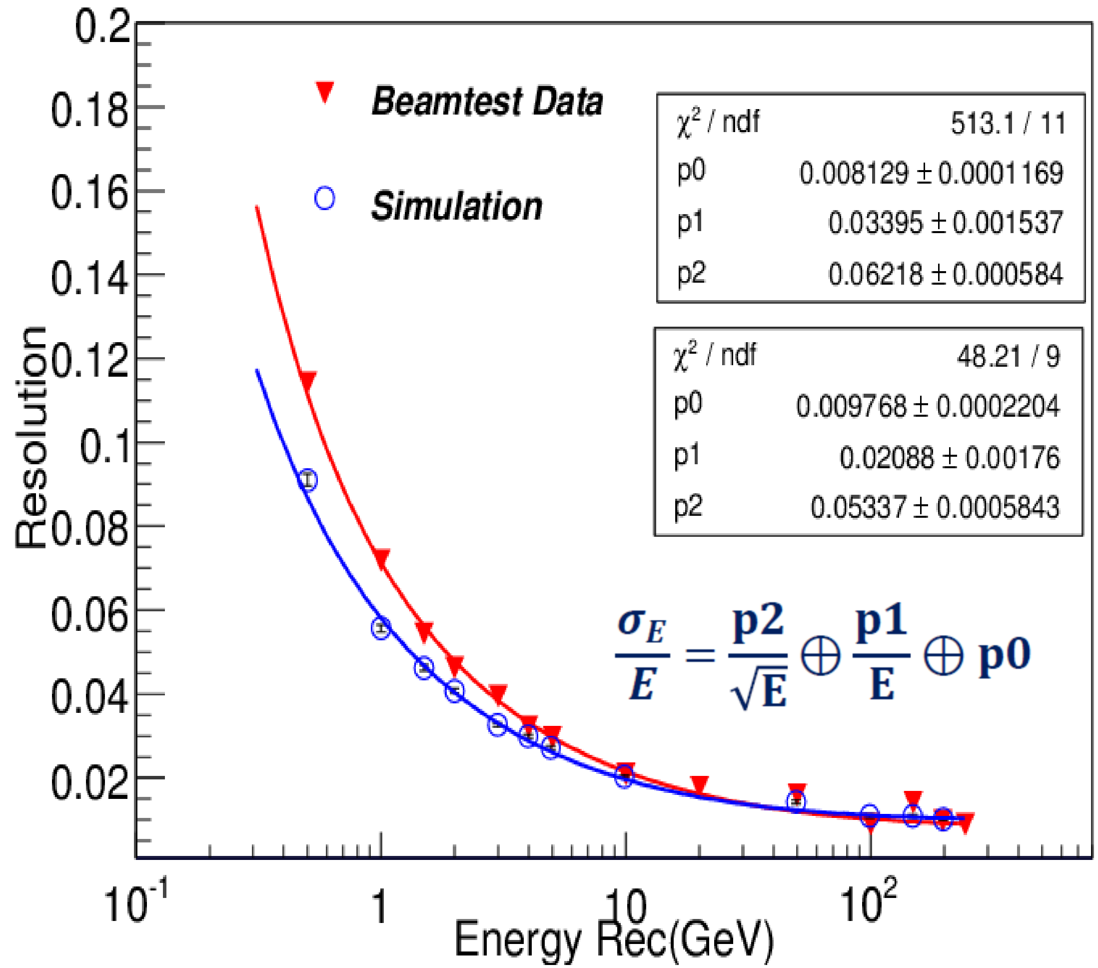
5, 10, 20, 50, 100, 149, 197, 243 GeV @ SPS

Electron Energy and Angle Reconstruction

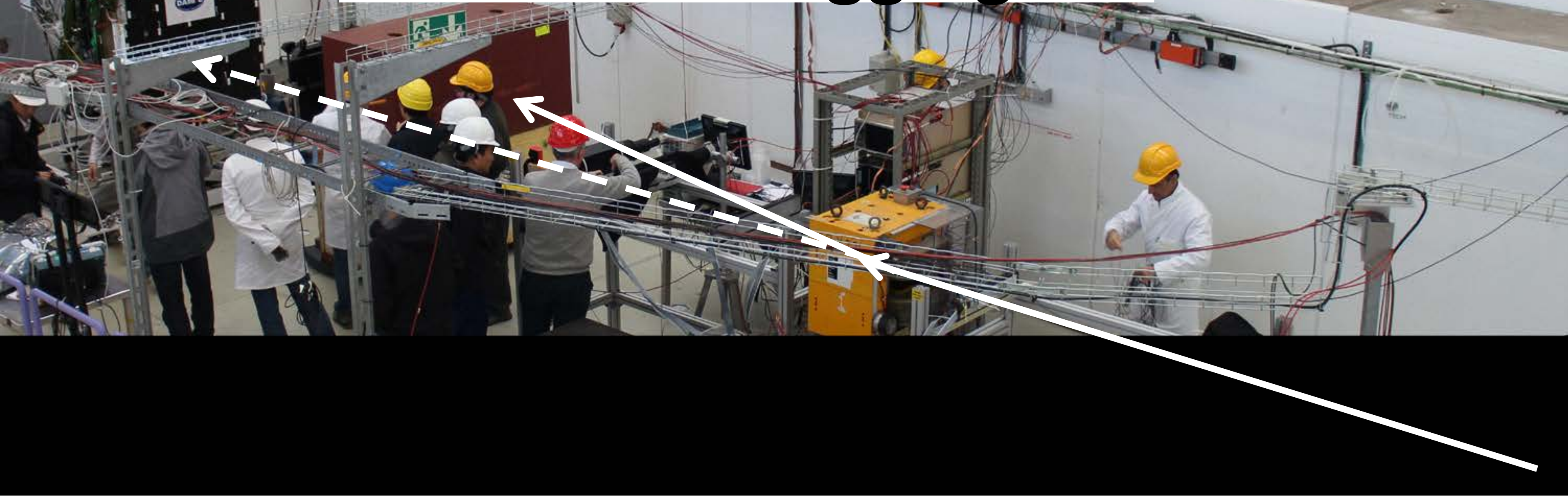
(linearity and resolutions)



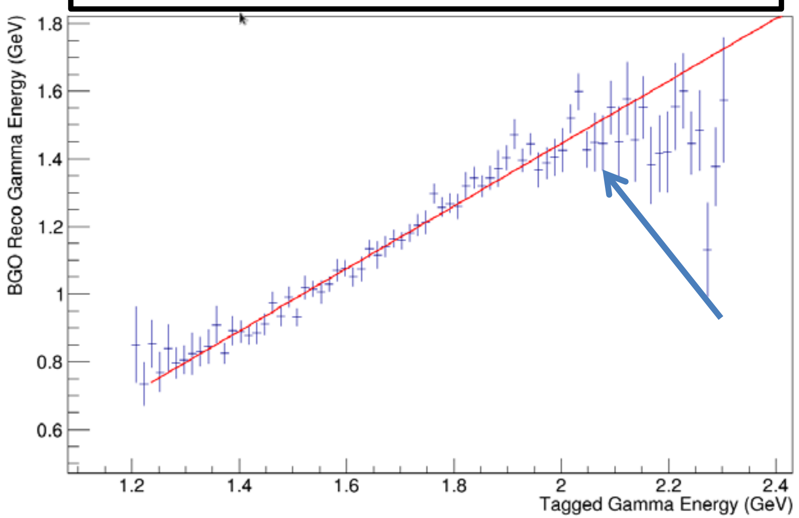




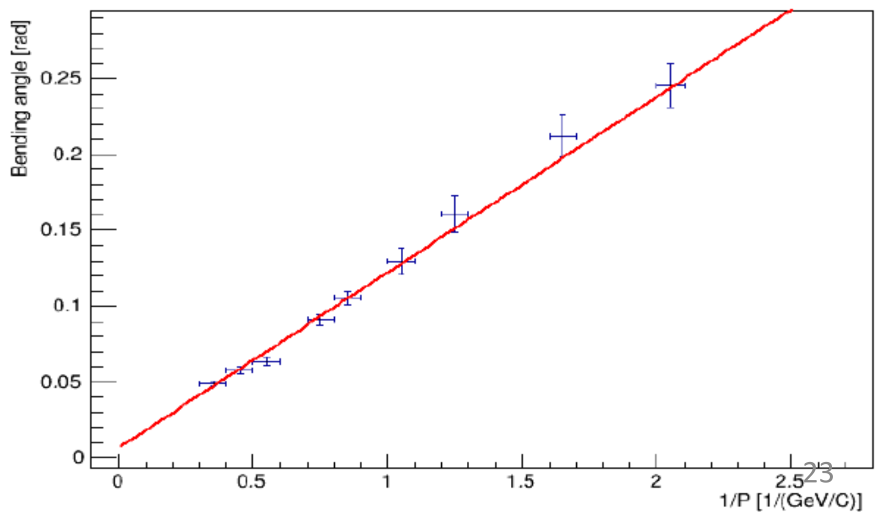
Photon tagging



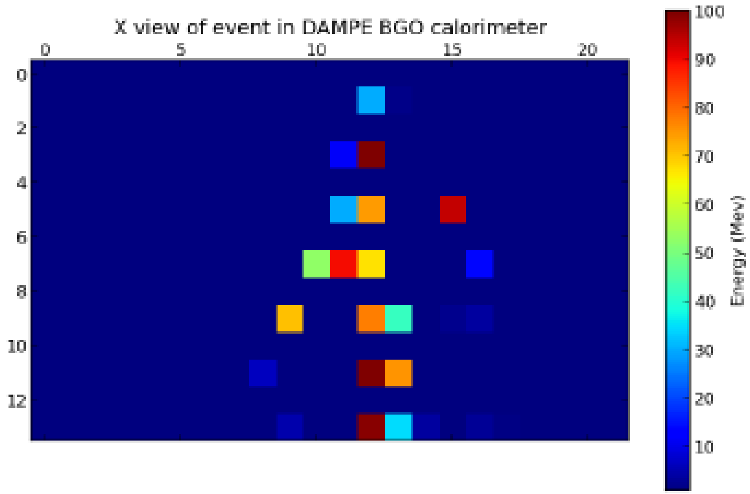
Photon energy measured by BGO
vs
Beam moment –Tagged electron

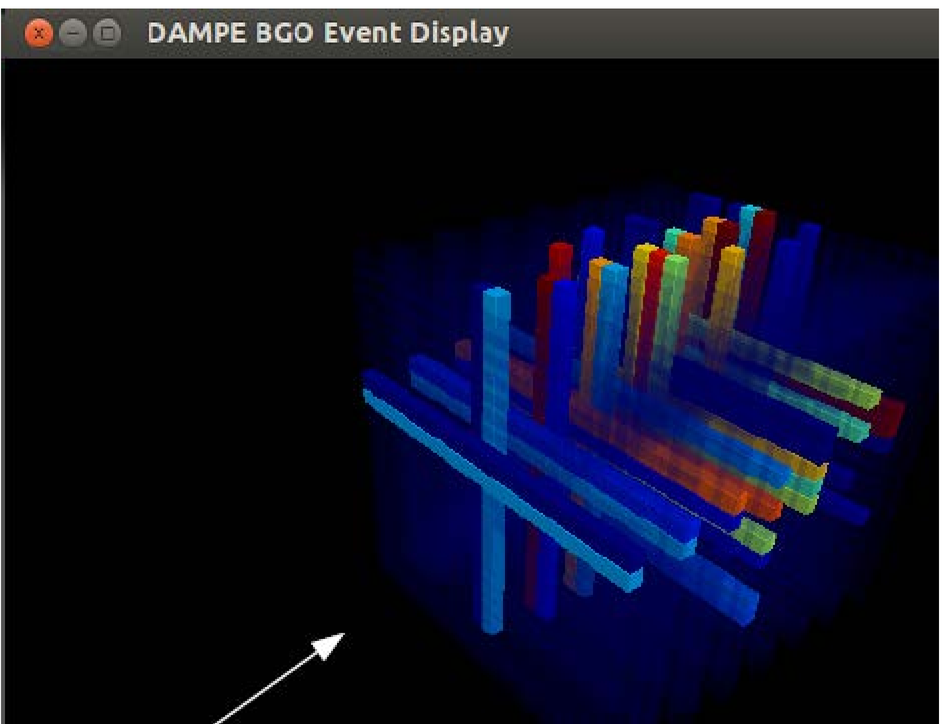


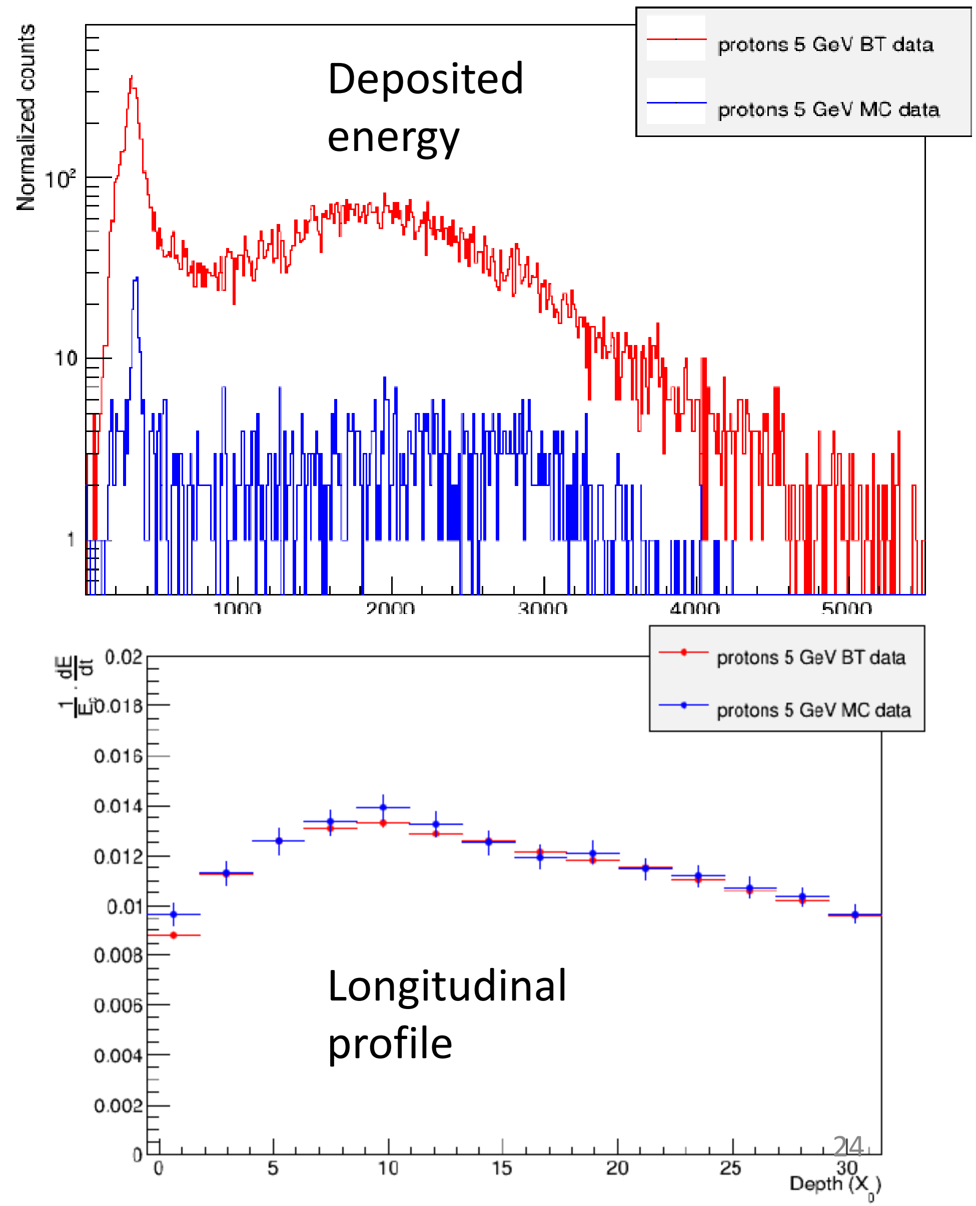
Electron bending angle
vs
1 / Electron Moment



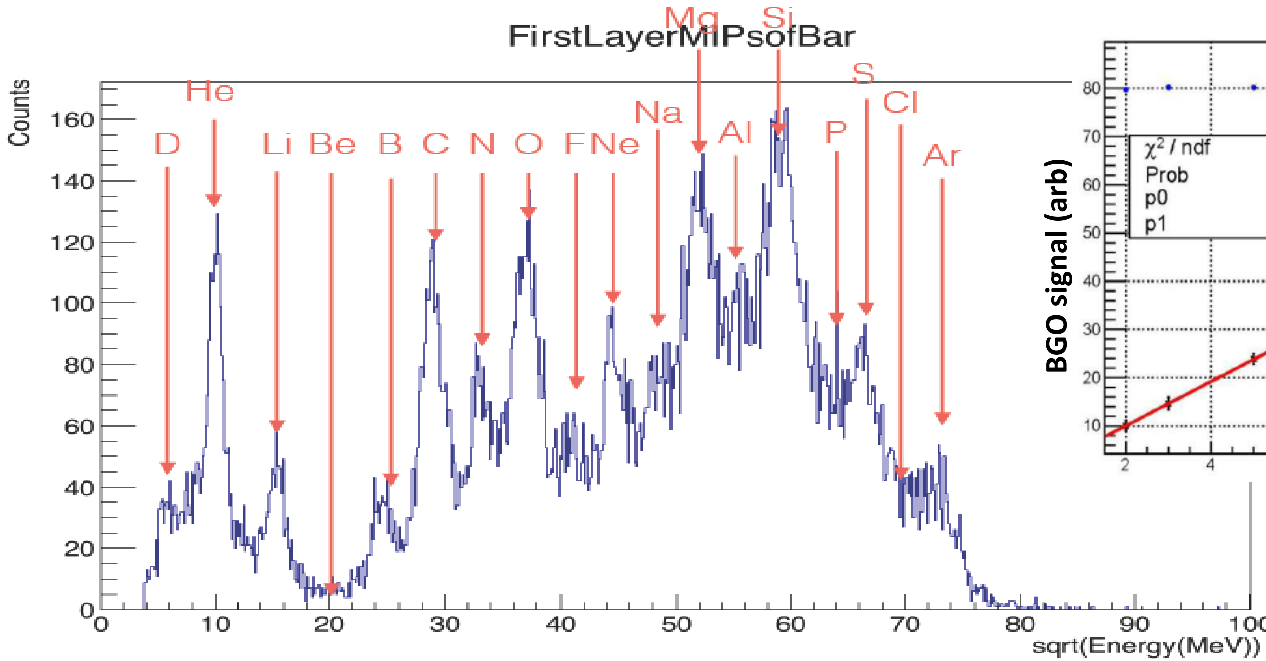
Protons @5 GeV

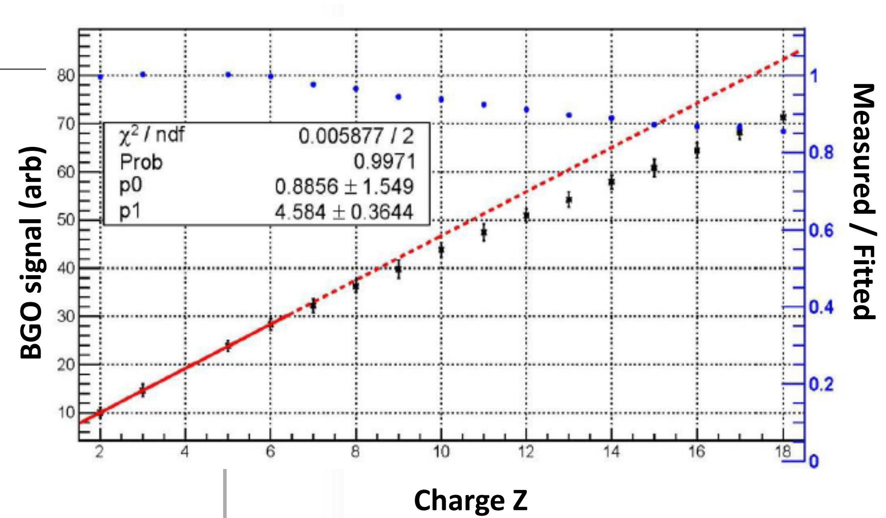


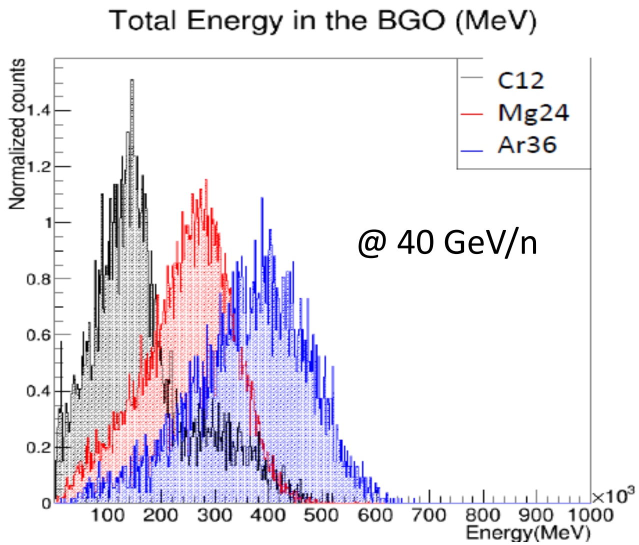


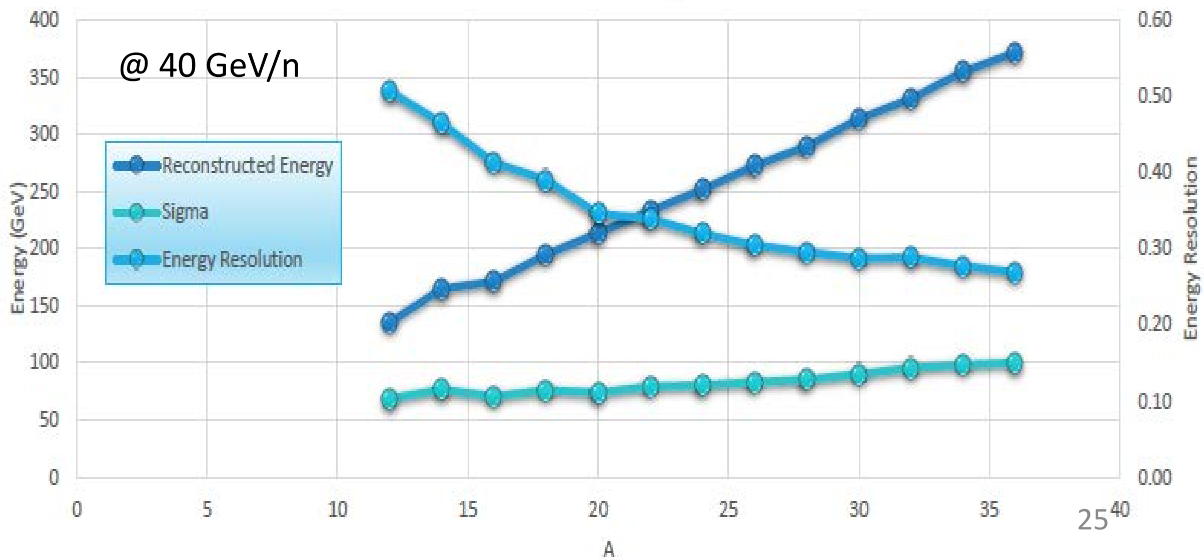


Ions in the BGO calorimeter



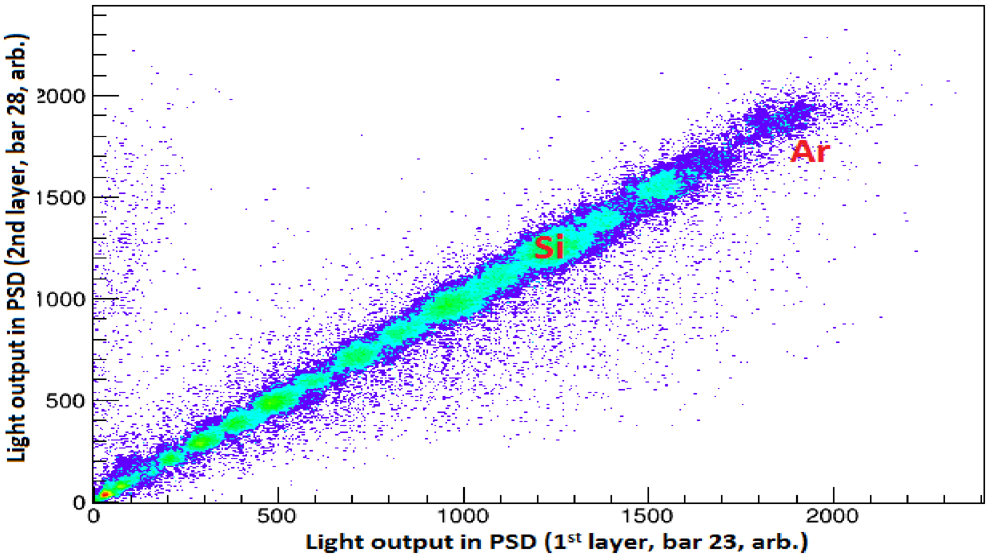


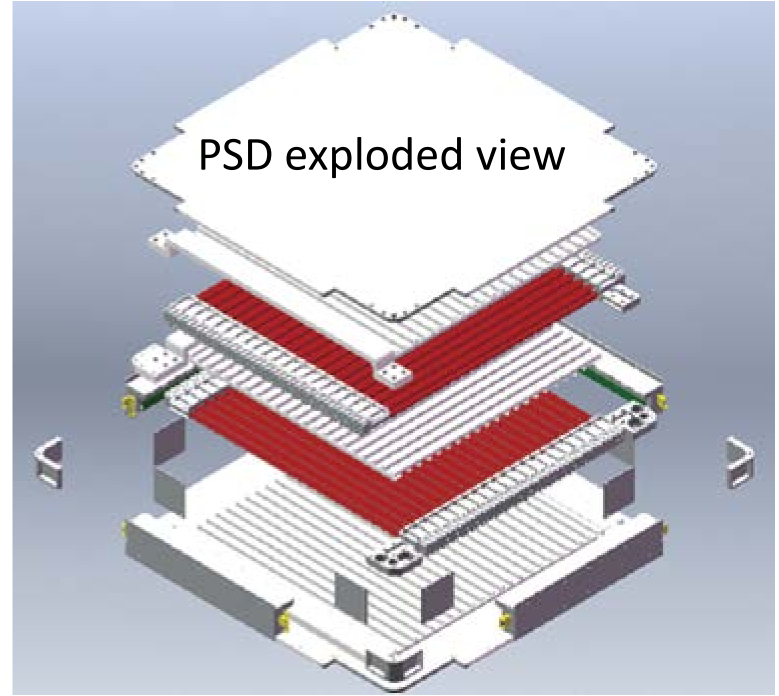


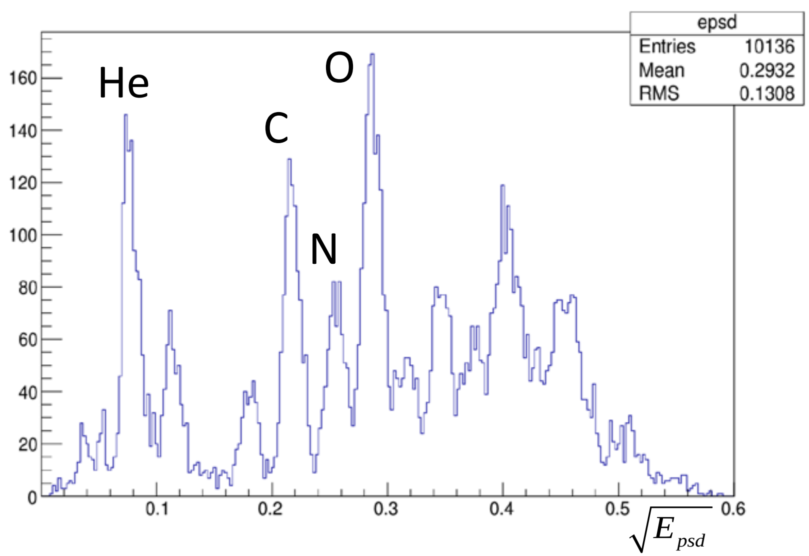


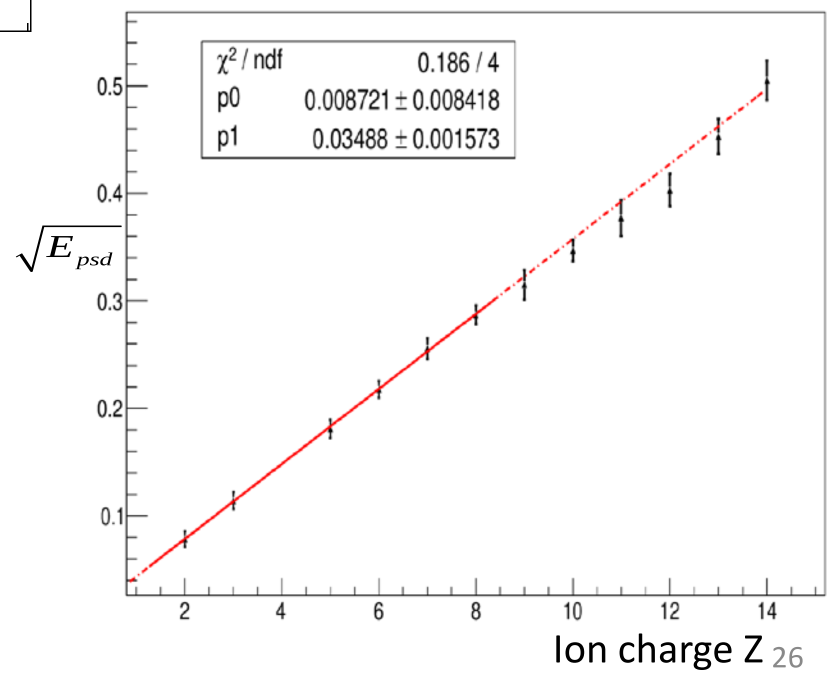
PSD

(Plastic Scintillator Detector)



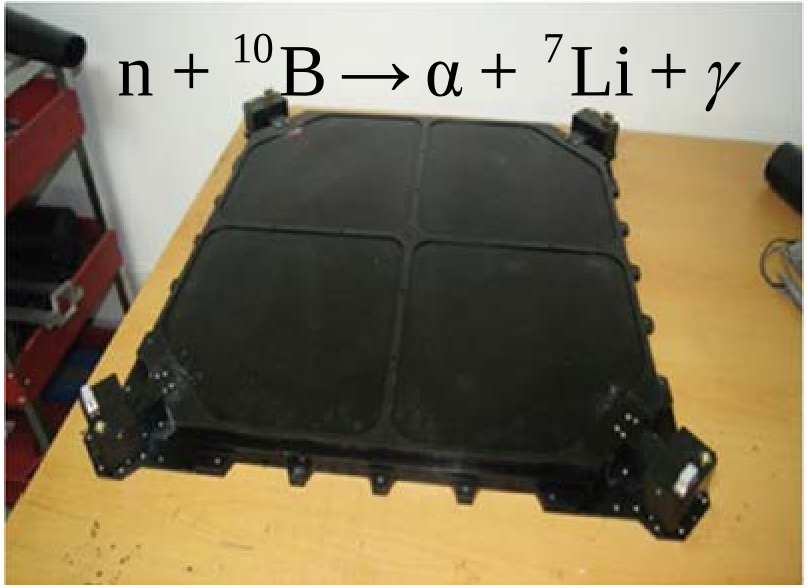


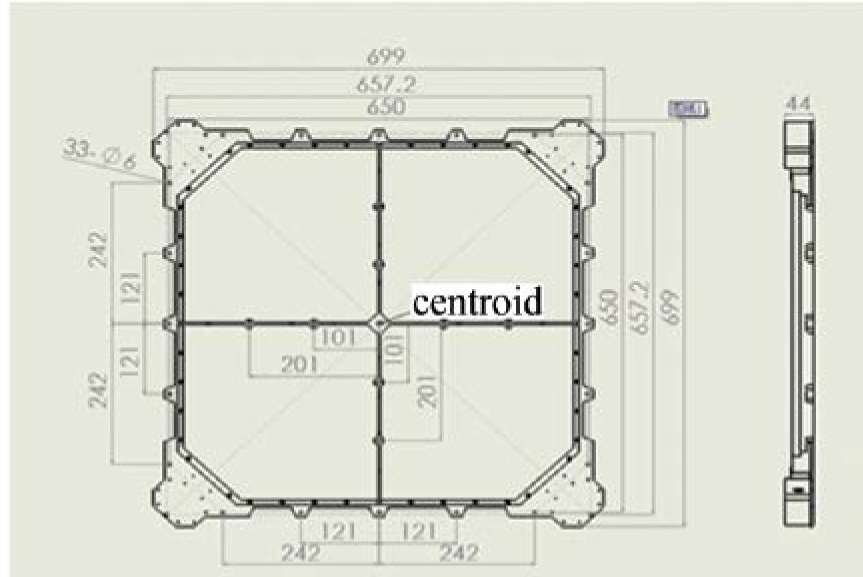


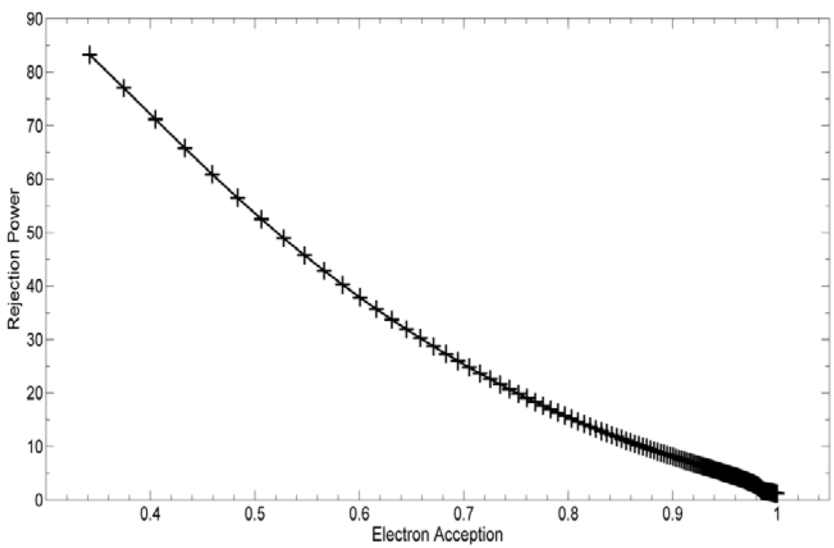


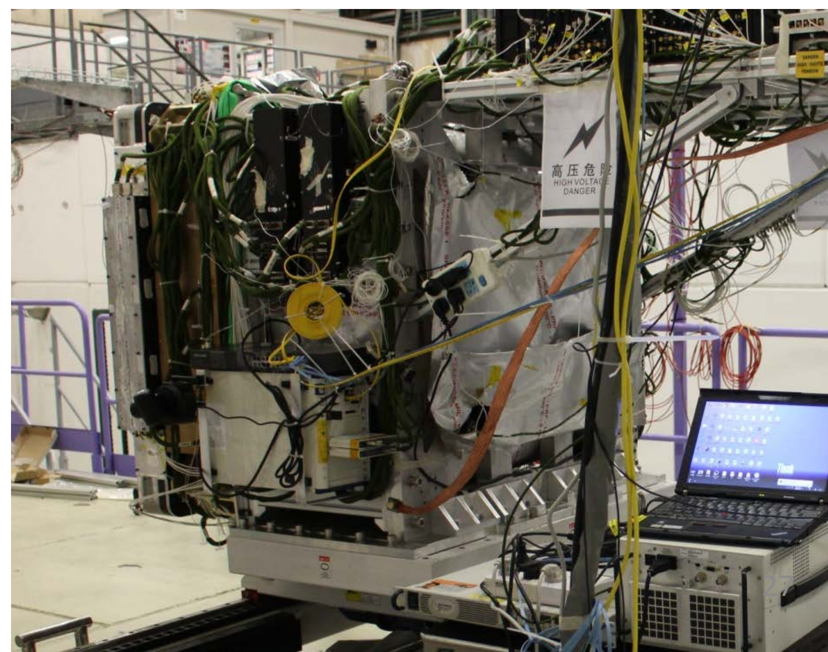
NUD: NeUtron Detector

(Boron doped scintillators)

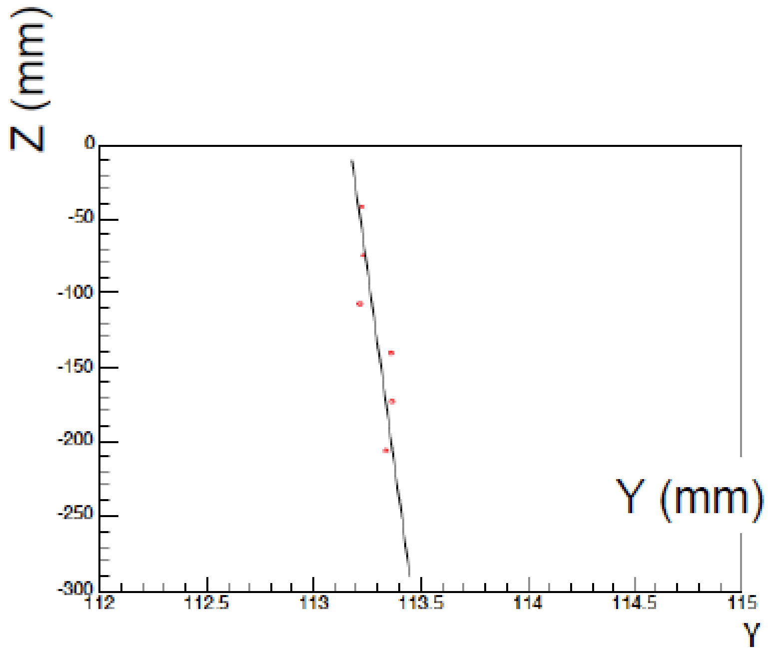


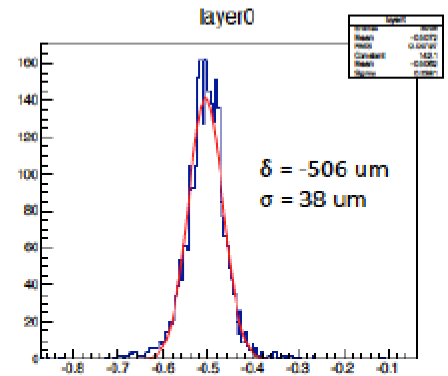


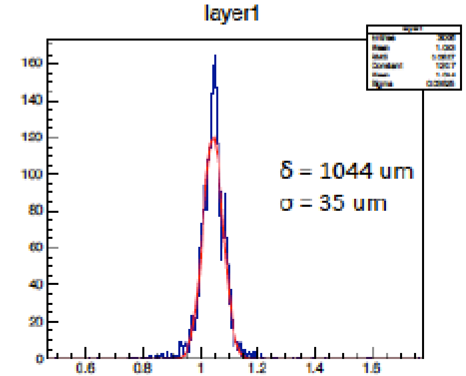


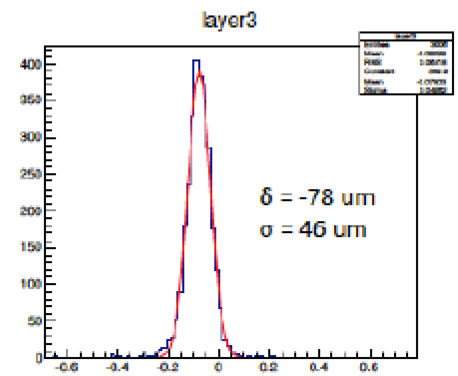


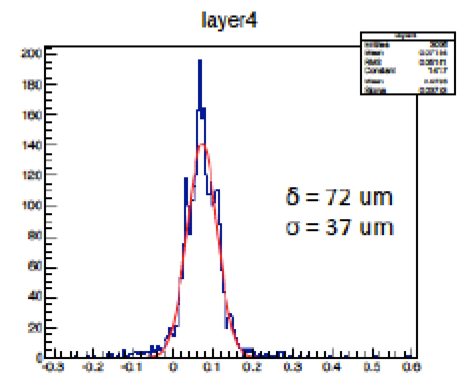
STK preliminary performance evaluation

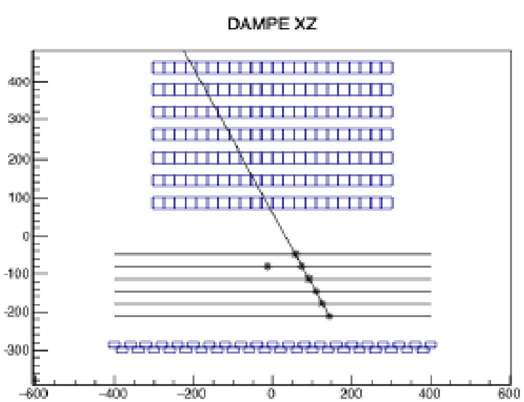


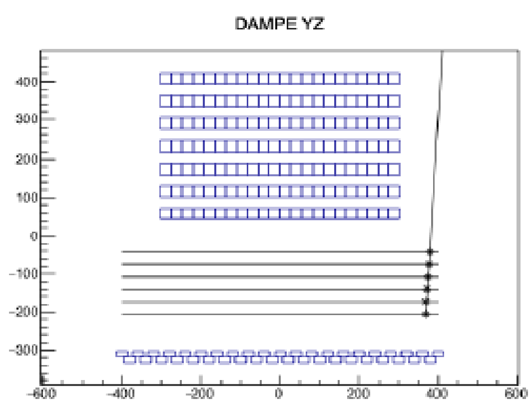


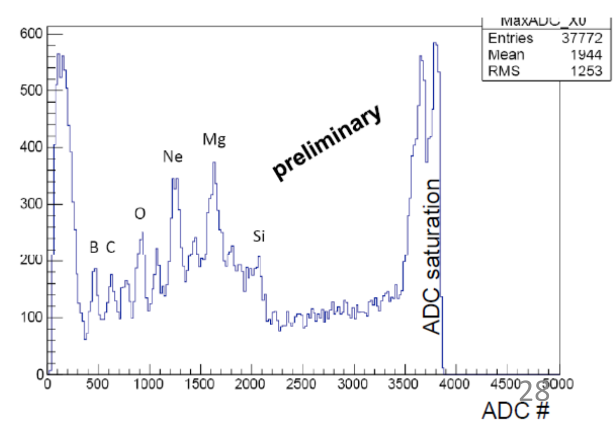












Conclusions (I)

Il gruppo di Lecce:

P. Bernardini
I. De Mitri
G. Marsella
A. Surdo
AdR biennale (UniSalento/INFN)

Elettronica: 1 m.u.

Tot. 2.8 FTE + 1.0 FTE

Richieste (quasi definitive)

MI	Test beams, meetings	30k
INV	CPU + spazio disco	6k
TOT		36k

Impegni:
- Partecipazione test beam e analisi dati
- Sviluppo tool di simulazione e analisi dati
- Studio performance e potenzialità nella fisica dei RC
- Analisi dati missione
- Partecipazione design/costruzione HERD (vedi prossime slides)

China's Space Station Program

2020

Phase -II

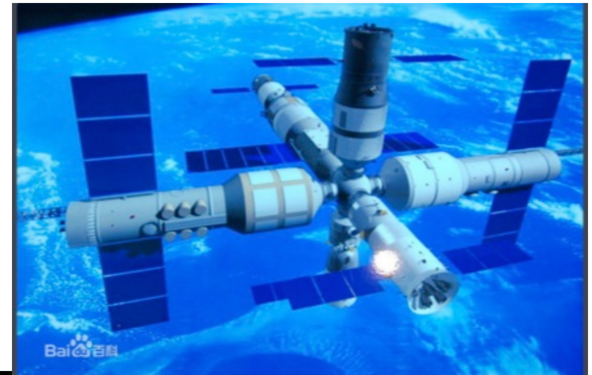
2016

Phase -II

2011

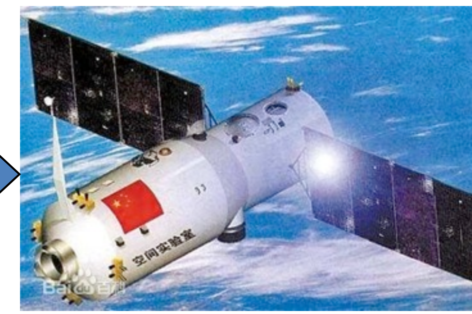
Phase -I

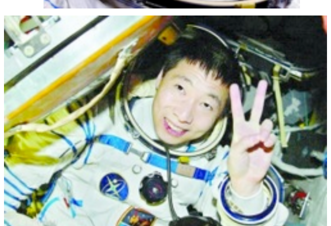
2003



Space Station
3 large modules
~ 60 tons
~10-year lifetime

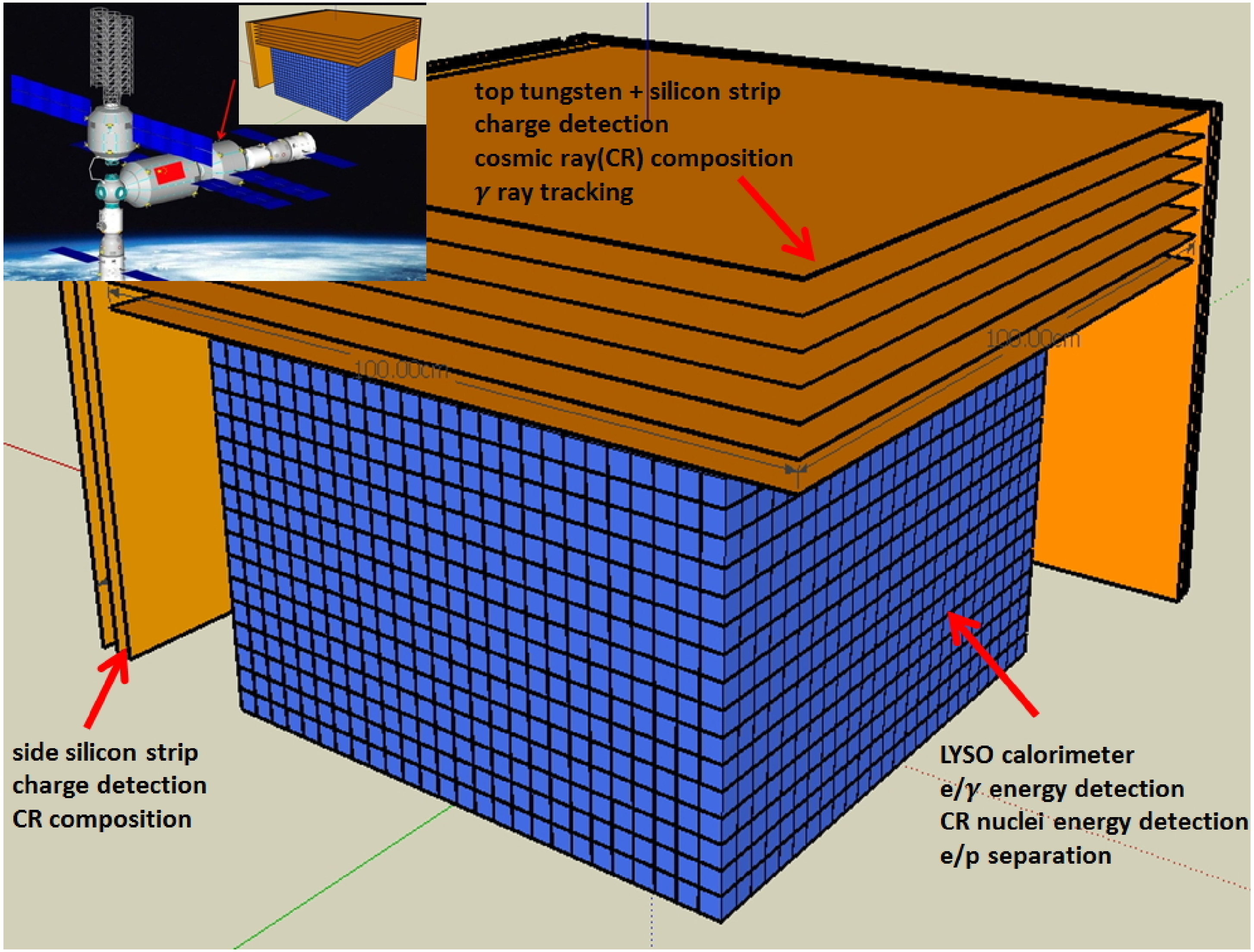
Space lab: no living cabin





10 astronauts in 5 flights → space walk

High Energy Radiation Detector



HERD: High Energy cosmic-Radiation Detector

Science goals	Mission requirements
Dark matter search	Better statistical measurements of e/γ between 100 GeV to 10 TeV
Origin of Galactic Cosmic rays	Better spectral and composition measurements of CRs between 300 GeV to PeV with a large geometrical factor

Other science goals:

- Monitoring of GRBs,
- Microquasars
- Blazars and other transients.

Expected performance of HERD

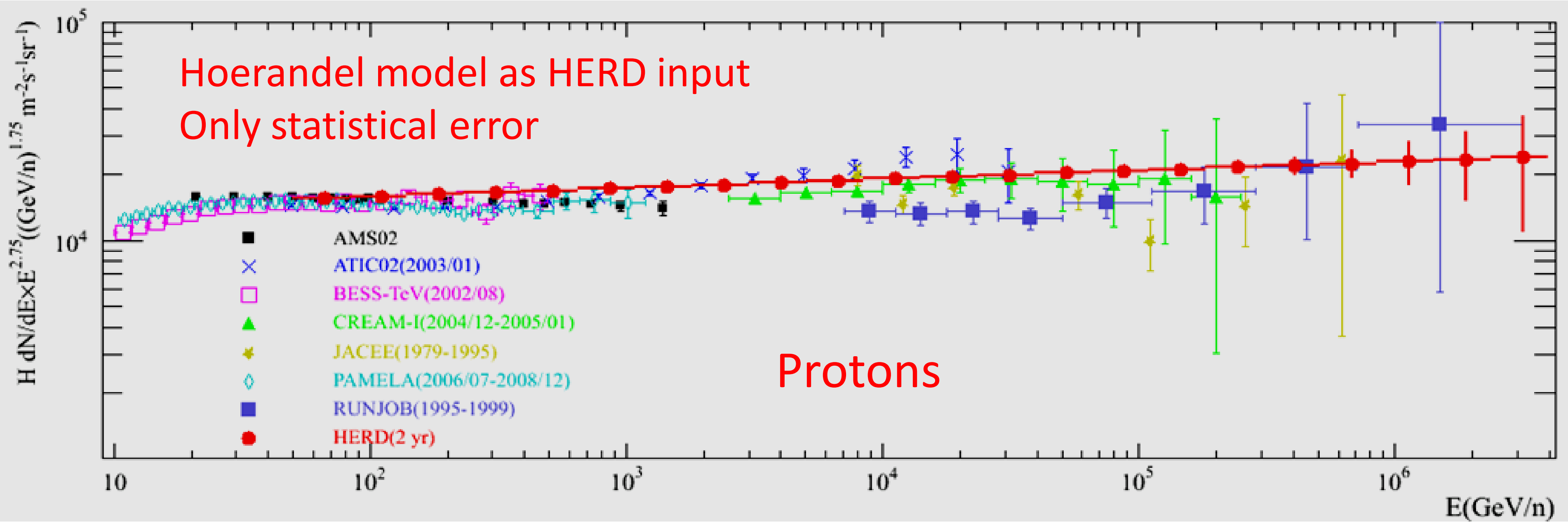
γ/e energy range (CALO)	tens of GeV-10TeV
nucleon energy range (CALO)	up to PeV
γ/e angular resol. (top Si-strips)	0.1^{o}
nucleon charge resol. (all Si-strips)	0.1-0.15 c.u
γ/e energy resolution (CALO)	<1%@200GeV
proton energy resolution (CALO)	20%
e/p separation power (CALO)	$<10^{-5}$
electron eff. geometrical factor (CALO)	3.7 m^2sr@600 GeV
proton eff. geometrical factor (CALO)	2.6 m^2sr@400 TeV

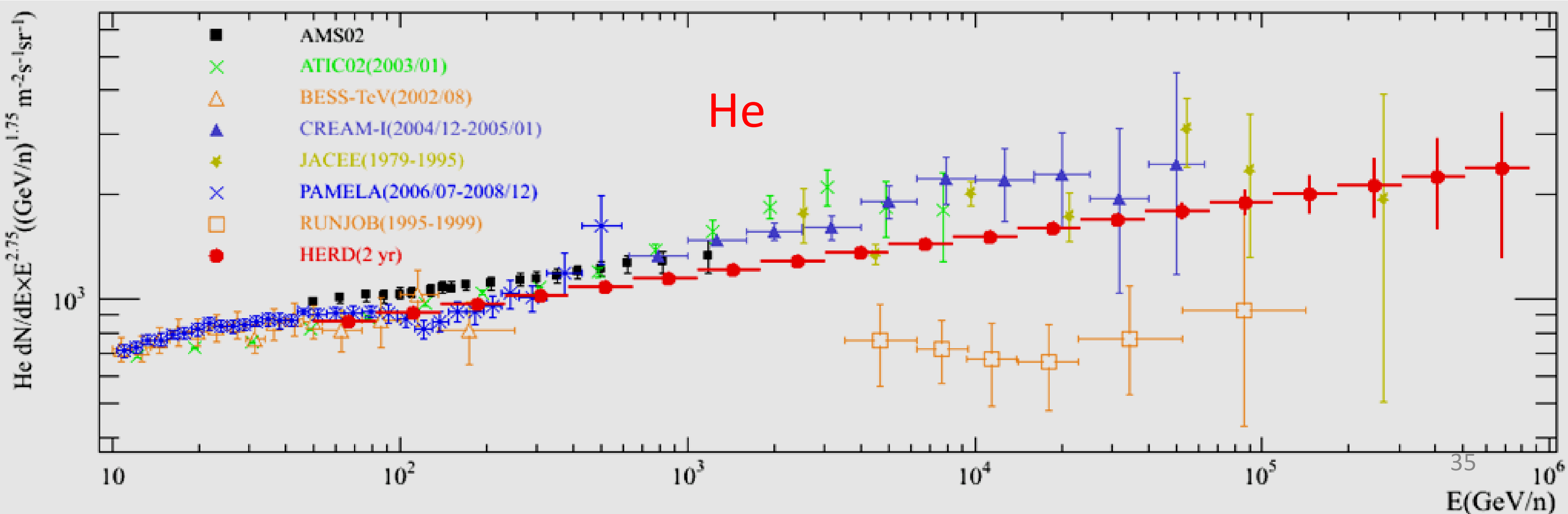
Characteristics of HERD components

	type	size	X_0 , λ	unit	main functions
tracker (top)	Si strips	70 cm × 70 cm	2 X_0	7 x-y (W foils)	Charge Early shower Tracks
tracker 4 sides	Si strips	65 cm × 50 cm	--	3 x-y	Nucleon Track Charge
CALO	~10K LYSO cubes	63 cm × 63 cm × 63 cm	55 X_0 3 λ	3 cm × 3 cm × 3 cm	e/γ energy nucleon energy e/p separation

Total detector weight: ~2000 kg

Expected HERD Proton and He Spectra





Conclusions (II)

- **DAMPE is among CAS funded projects for space**
- **Better performance than existing detectors for e/γ/CR**
- **Systematic activity on assembly, qualification, test beam and simulation**
- **Preparation for mission data analysis is ongoing**
- **Setting up the collaboration boards and working groups**
- **Launch on december 17, 2015**

- **HERD as an opportunity to further increase the energy range and the detection reach in CR measurement**

More Stuff

E.S. Seo/Astroparticle Physics 39–40 (2012) 76–87

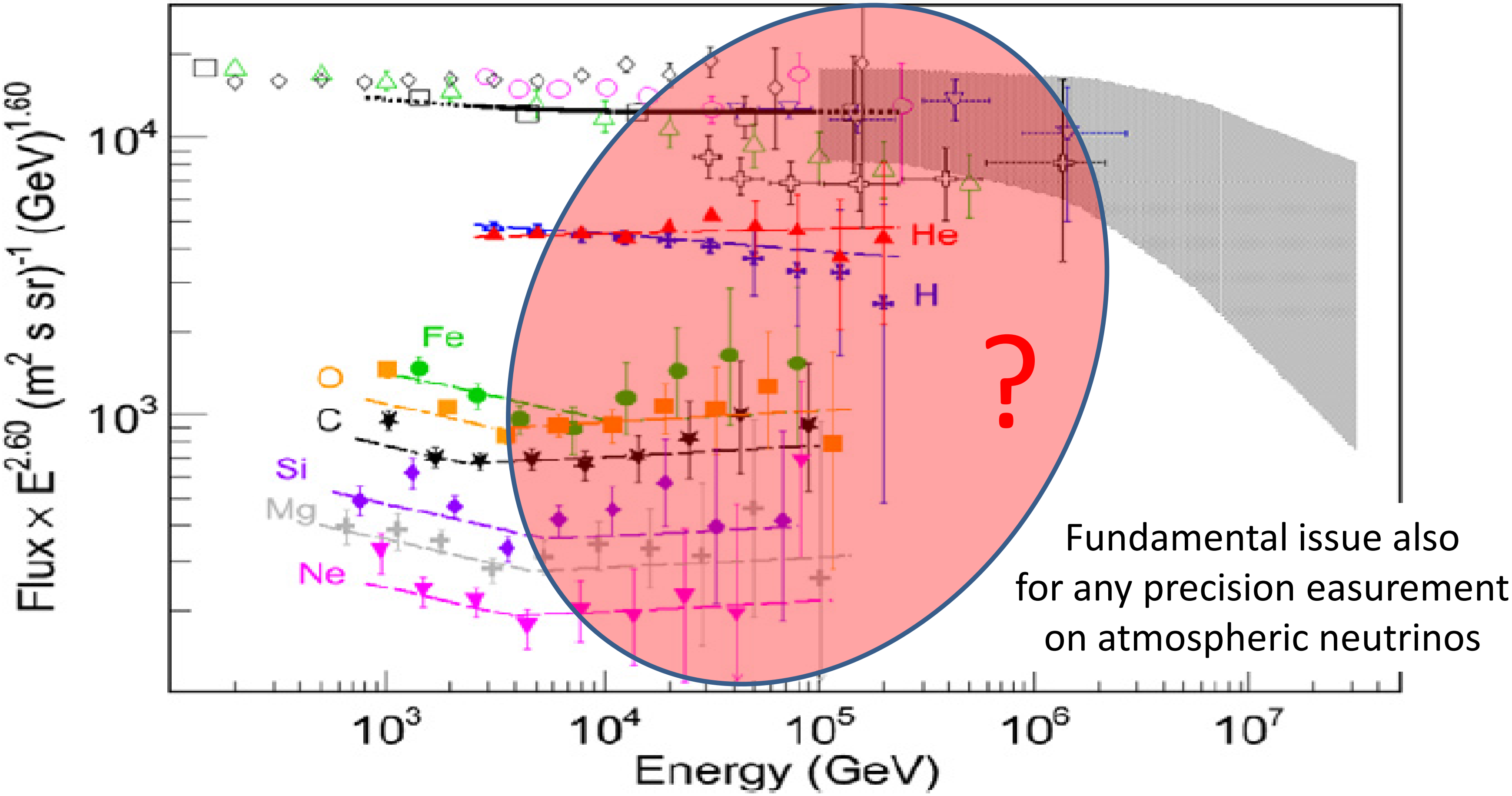
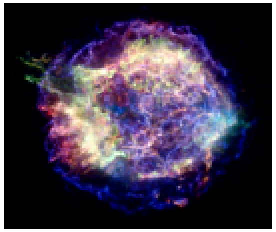


Fig. 11. The all-particle spectrum (black solid curve) obtained by summing up CREAM elemental spectra from p to Fe (filled symbols) is compared with previous measurements (open symbols): ATIC-1 [35], black squares; JACEE, blue downward triangles; RUNJOB, black crosses; Ichimura et al. [71], green upward triangles; SOKOL [72], pink circles. The gray shaded area indicates ground based indirect measurements. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(SNR) Maximum CR energy (for protons)

$$\varepsilon \approx 230\, n_e^{1/2}\, u_7^2\, R_{\rm pc}\ {\rm TeV}$$

Cas A



$$\varepsilon \approx 160\ {\rm TeV}$$

shock vel ~ 5,000 km s^{-1}

T. Bell
GSSI workshop
Sep. 2014

Sedov phase

$$\varepsilon \approx 20\, E_{44}^{1/3}\, n_e^{1/6}\, u_6^{4/3}\ {\rm TeV}$$

Blast wave energy in 10^{44}J

shock vel in 1,000 km s^{-1}

SN expansion into circumstellar wind

$$\varepsilon = 800 u_7^2 \sqrt{\frac{\dot{M}_5}{u_4}}\ {\rm TeV}$$

wind mass loss in 10^{-5} solar masses yr^{-1}

wind vel in 10 km s^{-1}

Difficult to get far beyond PeV (Schure & Bell 2013)

What is needed

- Focus on the 100TeV-10 PeV energy region
- Measure the "knees" of each species

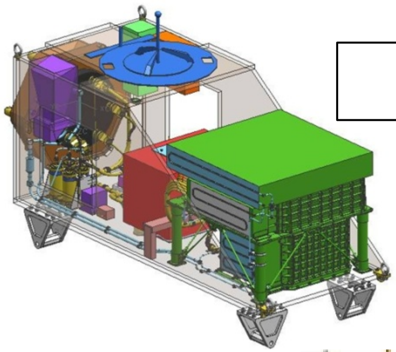
HECR spectroscopy

Together with high energy gamma and neutrinos astronomies

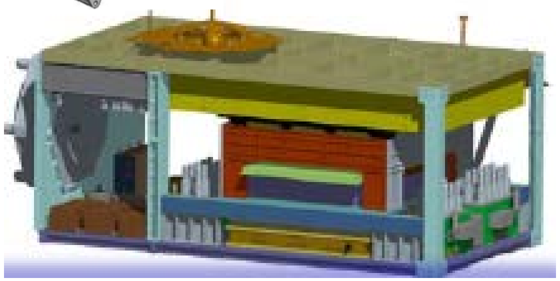
- Indentify galactic sources
- Understand acceleration and diffusion mechanisms
- Better understand the transition to extragalactic

Current and Future projects (space)

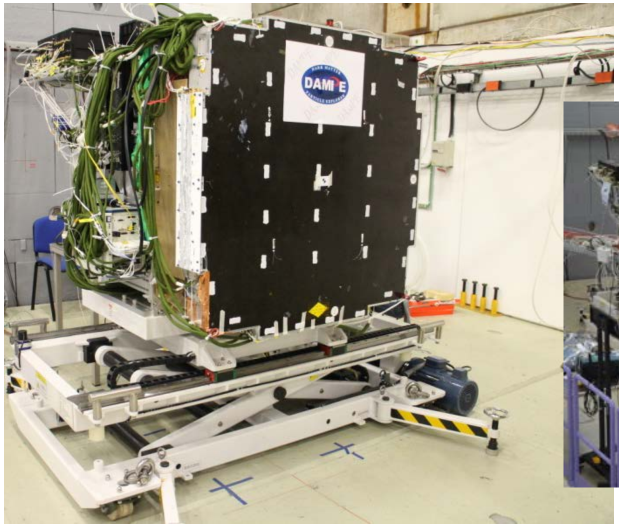
CALET



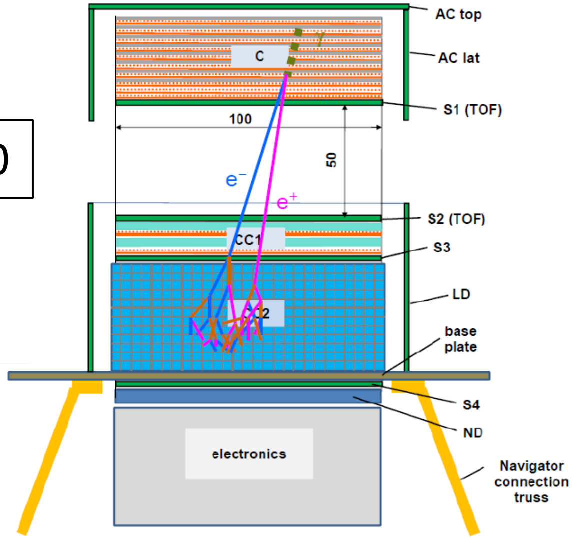
ISS_CREAM



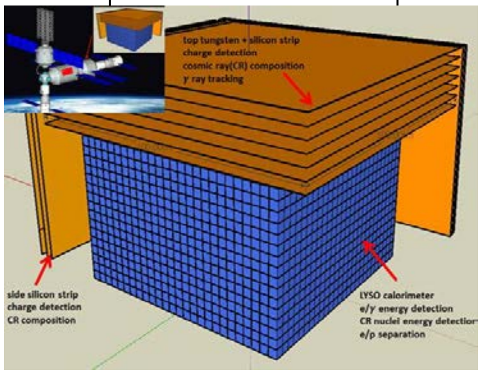
DAMPE



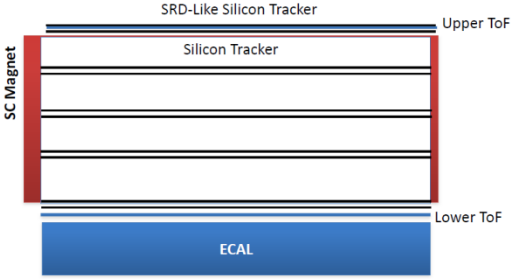
Gamma-400



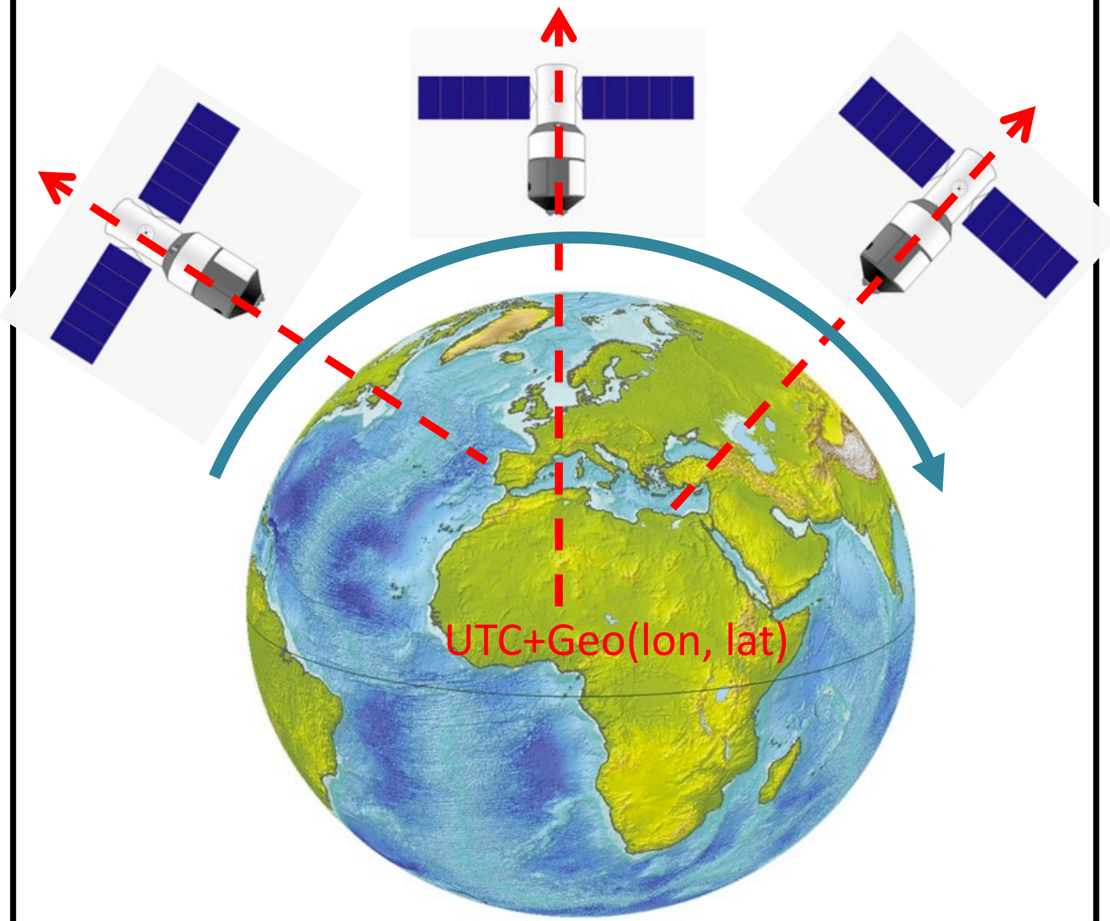
HERD



AMS-03



HERD in Space



schematic diagram of
ST orbit and pointing

schematic diagram of
HERD onboard ST