Swiss Space Experiments in High Energy Astroparticle Physics

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Disclaimer

- Highlights rather than overview
  - Subject not well defined: the boundary between astroparticle (narrow) and astrophysics (wide) is subjective
    - By energy of particles → by detection methods → by science goals
  - Not easy to cover: space astrophysics experiments done sometimes in the physics departments, sometimes in astronomy departments
    - The overlapping area is growing thanks to the multi-wavelength/ multi-messenger approach and more and more interactions between different communities
  - Impossible to cover all activities in details in 30 minutes
    - Choice of topics is biased by personal background (particle physics)
    - Try to avoid overlaps with other talks in this workshop
- My thanks to many colleagues for providing input
  - And my apology for omissions (intentional/unintentional)

Introduction

- The space is filled with high energy (≳MeV) particles
  – Mainly protons (~90%) and heavier ions
    - But also electrons, positrons : ≲ 1%
  – And also photons, neutrinos
    - Source pointing → gamma-ray astronomy, neutrino astronomy
- They are messengers of high energy processes at astronomical scale
  – Wide range of sciences: astronomy, cosmology, particle physics, …
  – Current focus
    - Cosmic ray physics: source, acceleration, propagation
    - Dark Matter search
    - Gamma ray astronomy
- Astroparticle physics space experiments employ similar detection techniques as on-ground particle physics experiments
  – With specific challenges related to launch and operation conditions

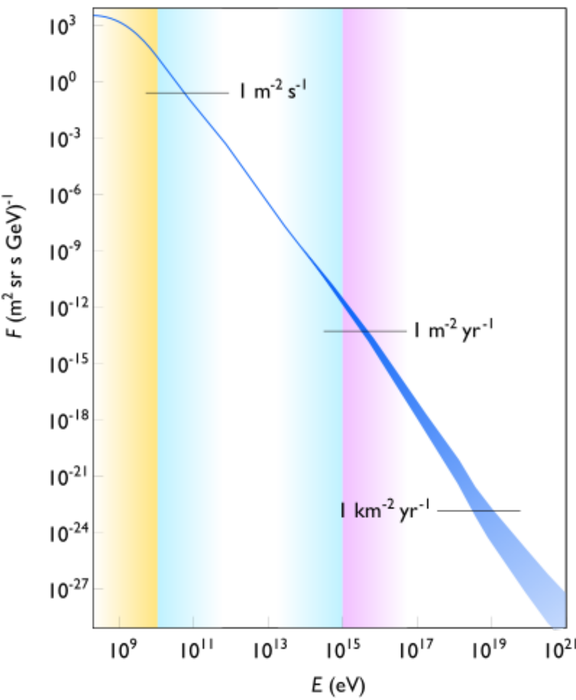
A Vibrant Research Field

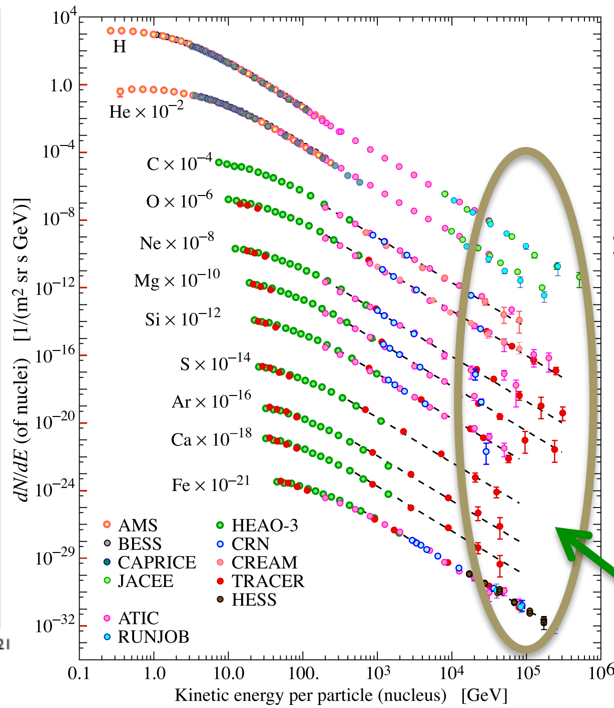
- AMS-02 and Fermi/LAT leading the way of precision measurements in space
  - AMS-02: focused on charged particles; Fermi: focused on photons
- High energy astroparticle space missions are becoming "general purpose"
  - Cosmic ray physics, DM search, gamma-ray astronomy
    - All at the same time
  - Photon, electron, proton and heavy ions
    - all measured with the same payload
  - Several missions are approved or in planning
    - Approved: ISS-CREAM(2014), CALET(2014), DAMPE (2015)
    - In planning: GAMMA-400(~2019), HERD (~2020)
- Specialized missions/long duration balloon flights are very competitive
  - JEM-EUSO, PANGU, SuperTIGER, BESS-ISO, GRAINE, …
- Cross pollination with keV-MeV range missions
  - INTEGRAL, POLAR, ASTRO-H, LOFT/XTP, ATHENA, …
- Close interaction with cosmology and fundamental physics missions
  - PLANK, LISA Pathfinder, EUCLIDE, eLISA, …

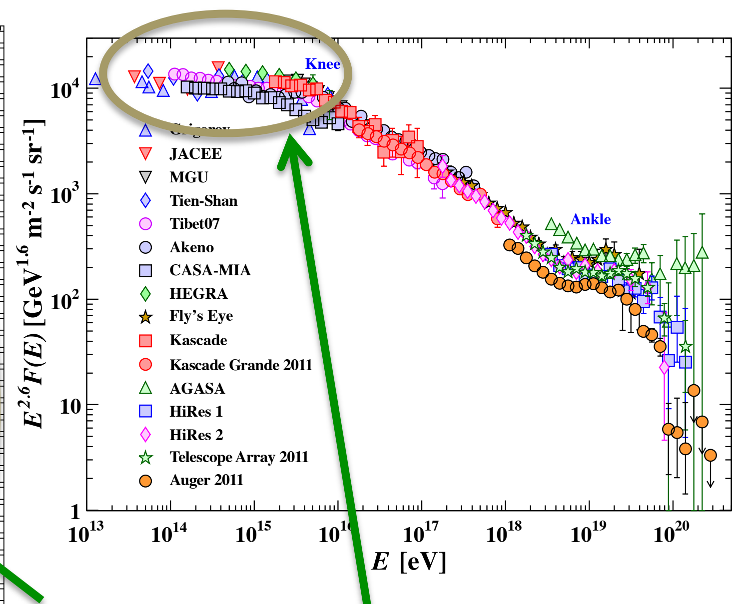
Very active participation from Switzerland! (in red)

Complementarity with ground experiments

- Flux (>10 GeV) follows a power law $F(E) \propto E^{-\gamma}$, $\gamma \sim 2.7$ up to 10^{16} eV ("knee")
- Up to the "knee region": mainly balloon and satellite experiments
  - Measure total flux and chemical composition
- Above $\sim 10^{14}$ eV: Extended Air Shower (ESA) experiments on ground
  - Mainly measure total flux





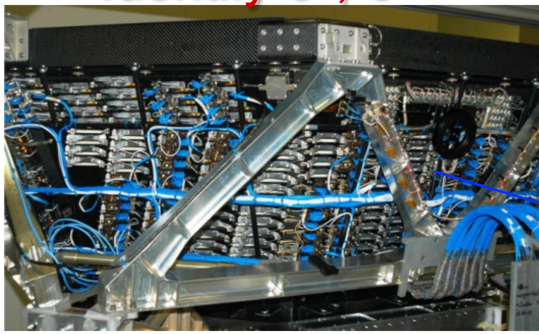


"Space" meets "Ground"

AMS: A GeV to TeV precision, multipurpose spectrometer

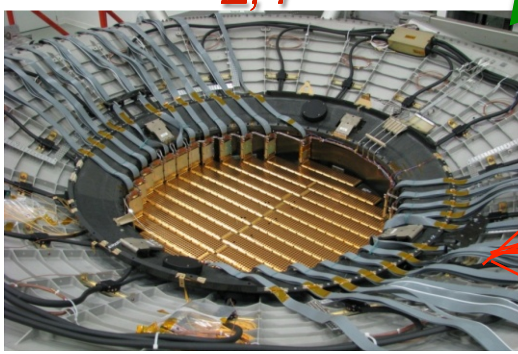
TRD

Identify e^+, e^-



Silicon Tracker

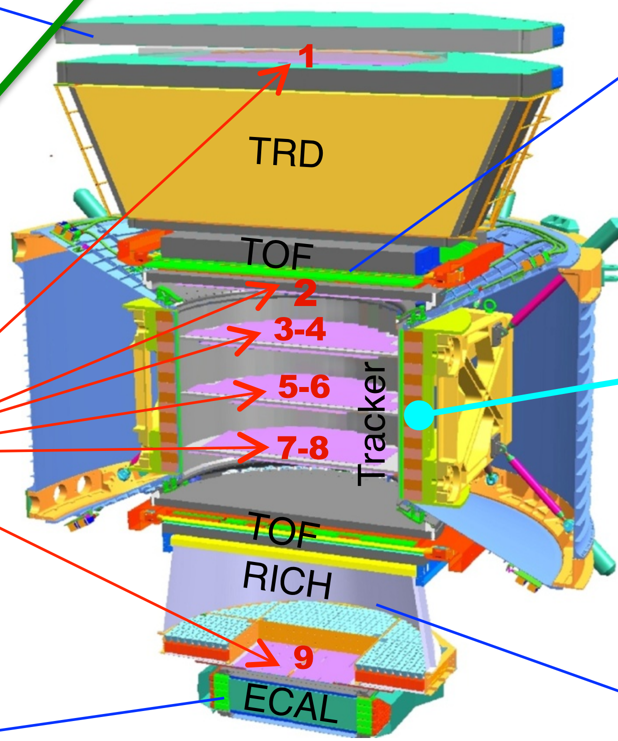
Z, *P*



ECAL

E of e^+, e^-, γ

UniGE, ETHZ

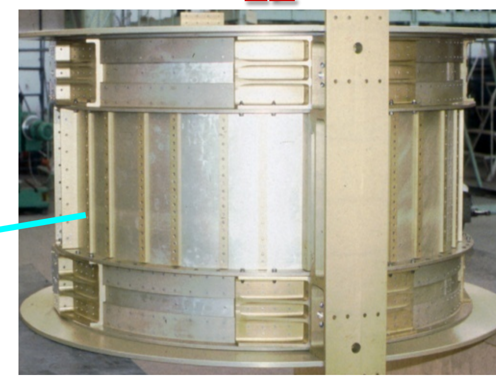


TOF

Z, *β*

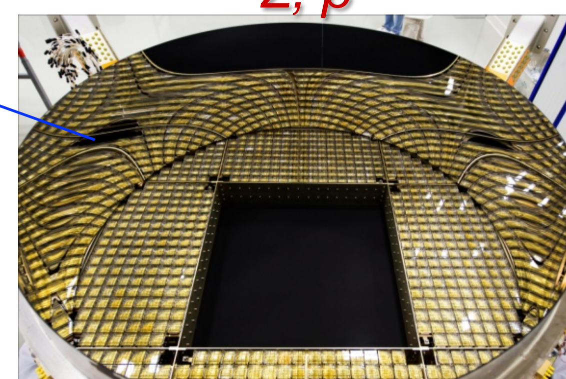
Magnet

±*Z*



RICH

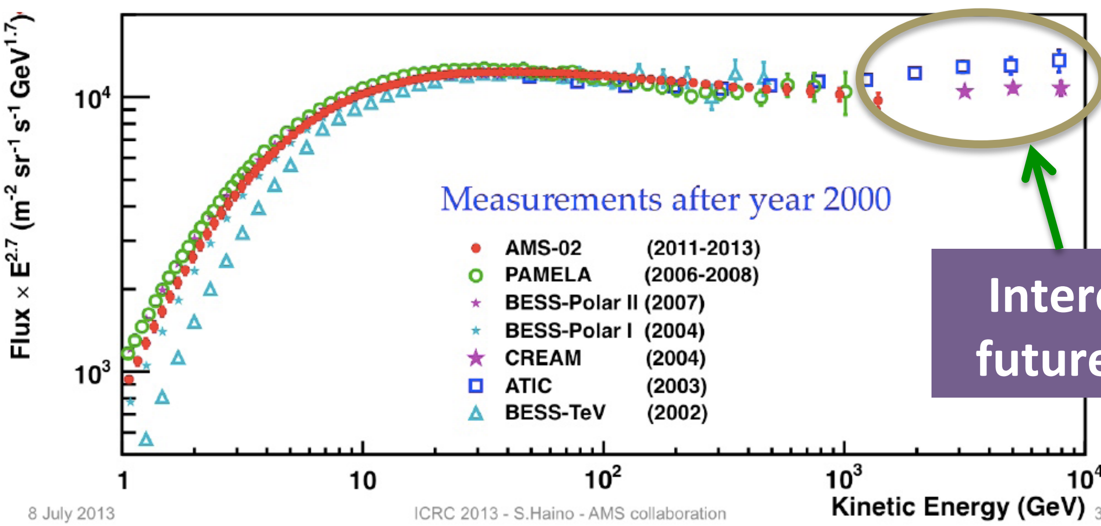
Z, *β*

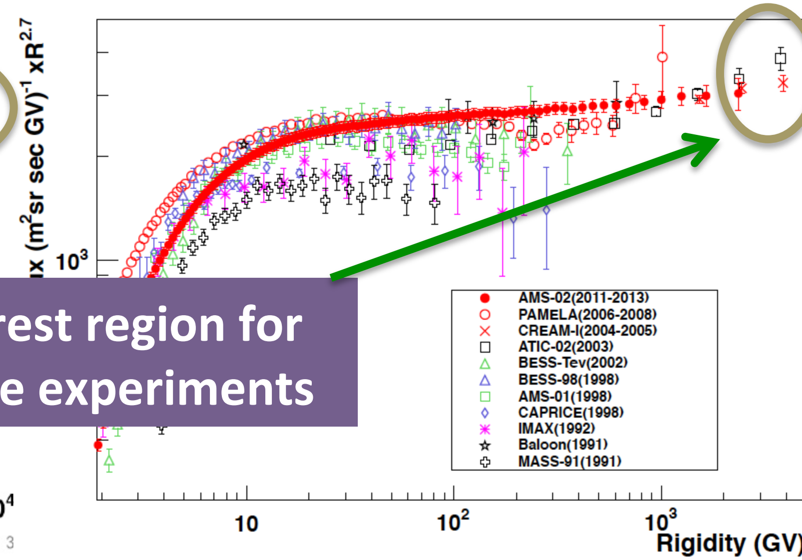


Z, *P* *are measured independently by the Tracker, RICH, TOF and ECAL*

Redundant measurements

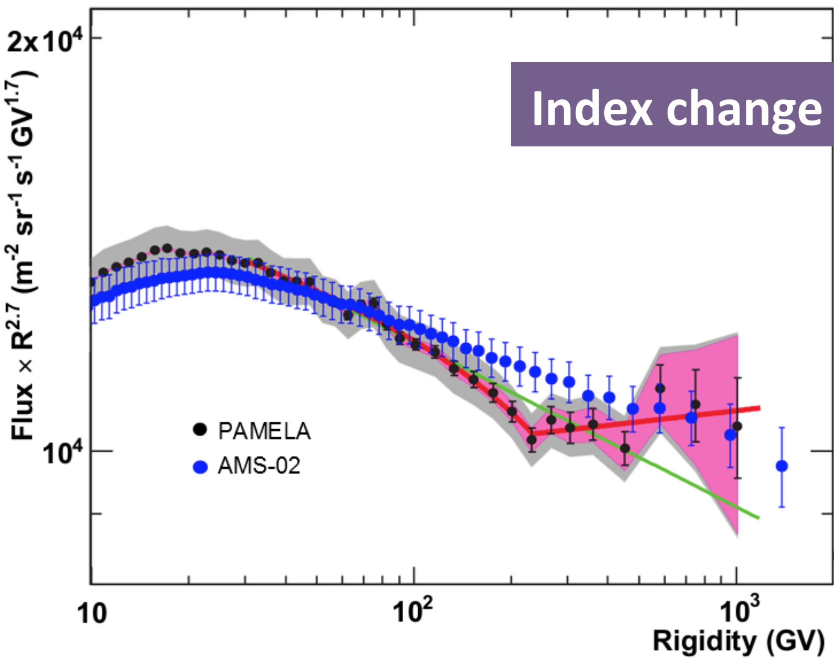
High Precision H and He Flux from AMS-02

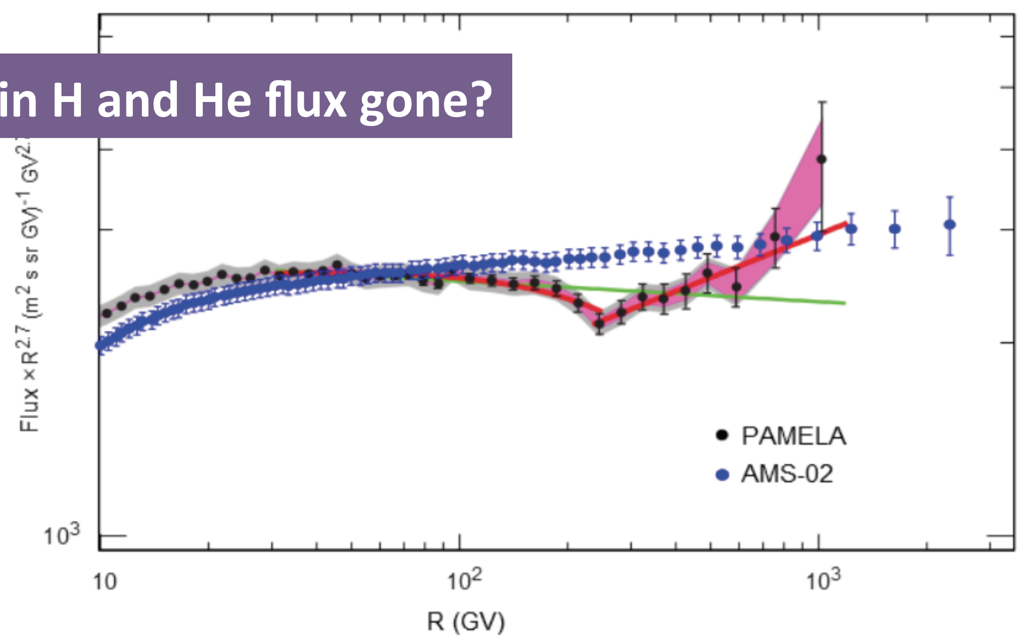




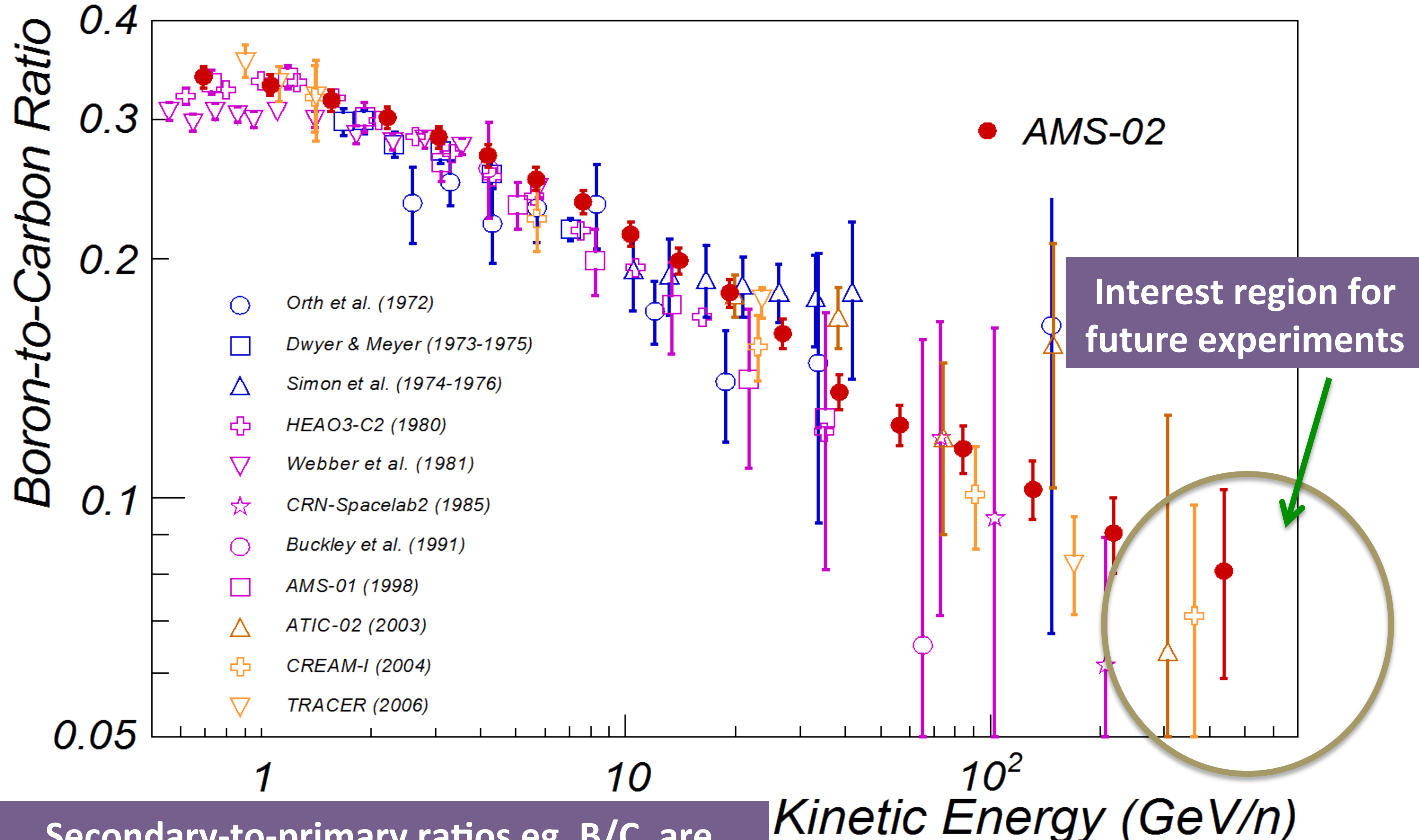
Interest region for future experiments

Index change in H and He flux gone?





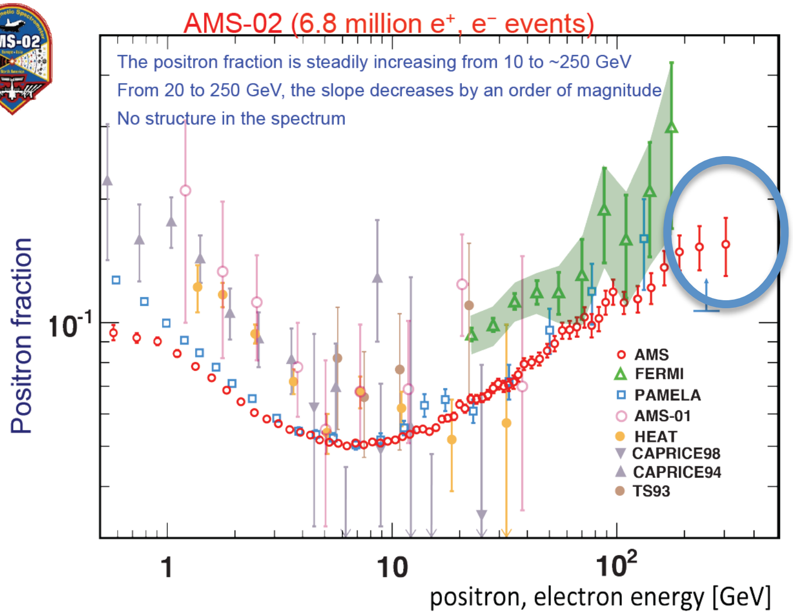
High Precision B/C from AMS-02

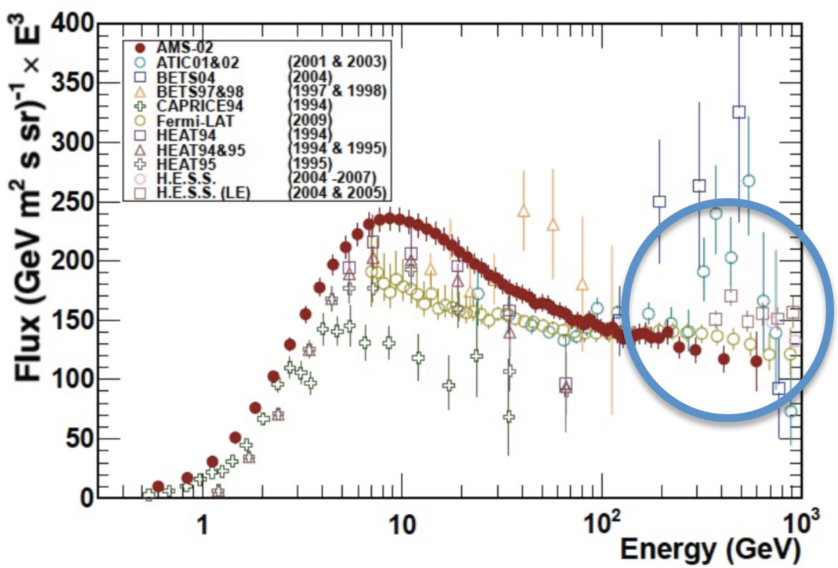


Secondary-to-primary ratios eg. B/C, are useful to determine propagation parameters!

Total Electron Spectrum and Positron Ratio

- **Electron and positron can be both primary and secondary**
  - **Primary: EM cascade in pulsar magnetic field and through pion production in shock acceleration (pulsar, SNR), or DM**
  - **Secondary: CR interaction with Interstellar medium**
- **Electron/positron closely related to gamma rays through synchrotron radiation and inverse Compton effects**

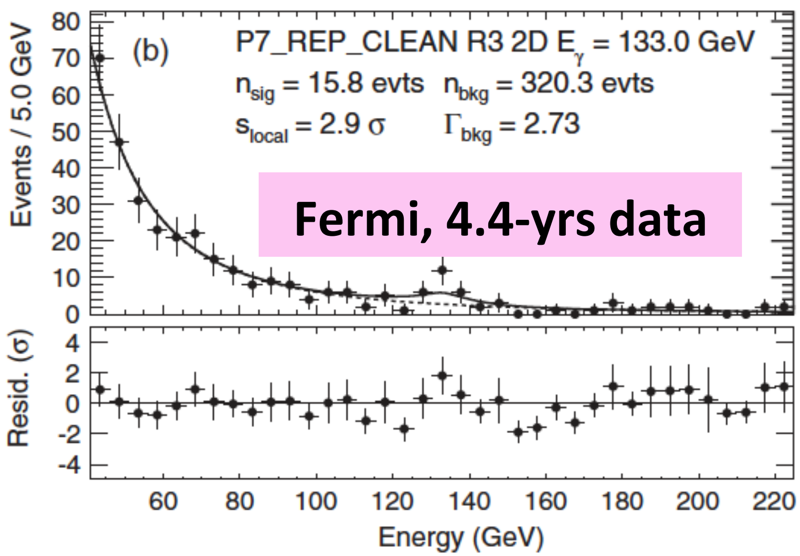


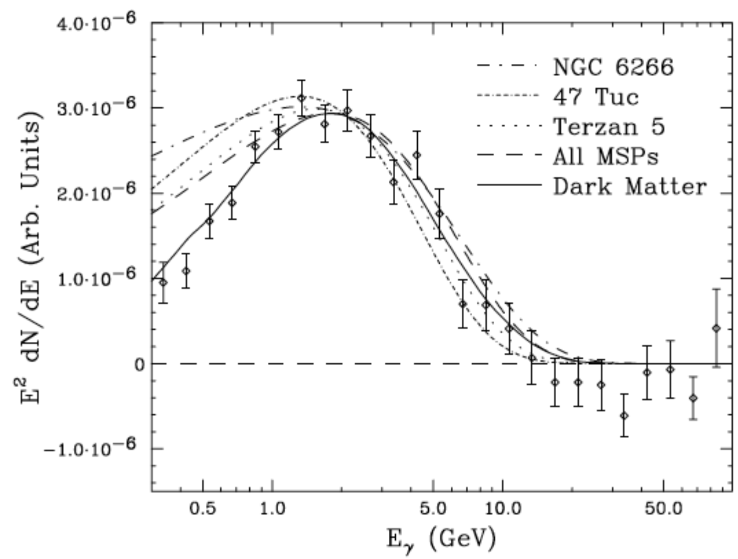


Something is happening in the TeV region
Better energy resolution will help!

Dark Matter Search with Gamma Rays

- **Search for monochromatic lines or diffused excess over background**
  - **χχ→γγ, γZ, γH or χχ→ SM particles → γ + …**
- **A few (2-3σ) claims in Fermi data in the past few years**
  - **133 GeV line at the Galactic Center**
  - **Small excess with 25 dwarf spheroidal satellite galaxies**
  - **GeV excess from Inner Galaxy**



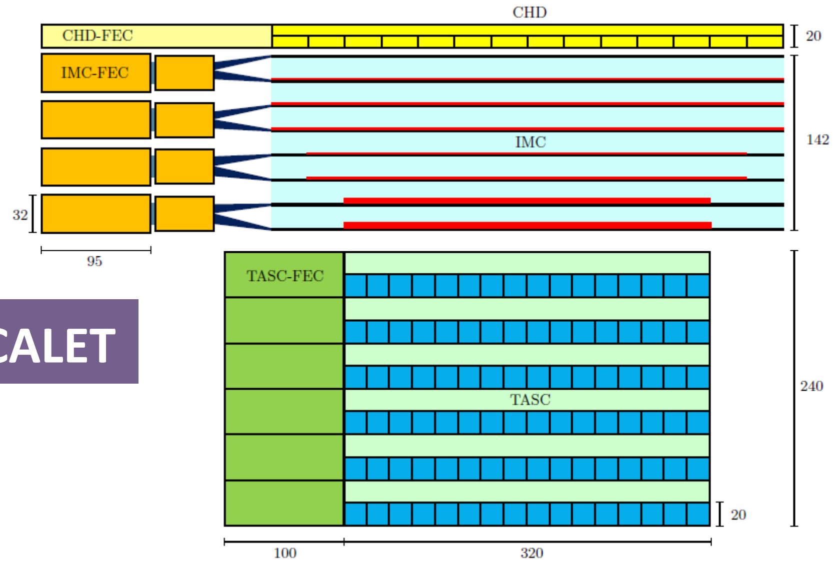


Need: better energy resolution ≳100GeV and better angular resolution at ~GeV ⟹ DAMPE, HERD, PANGU

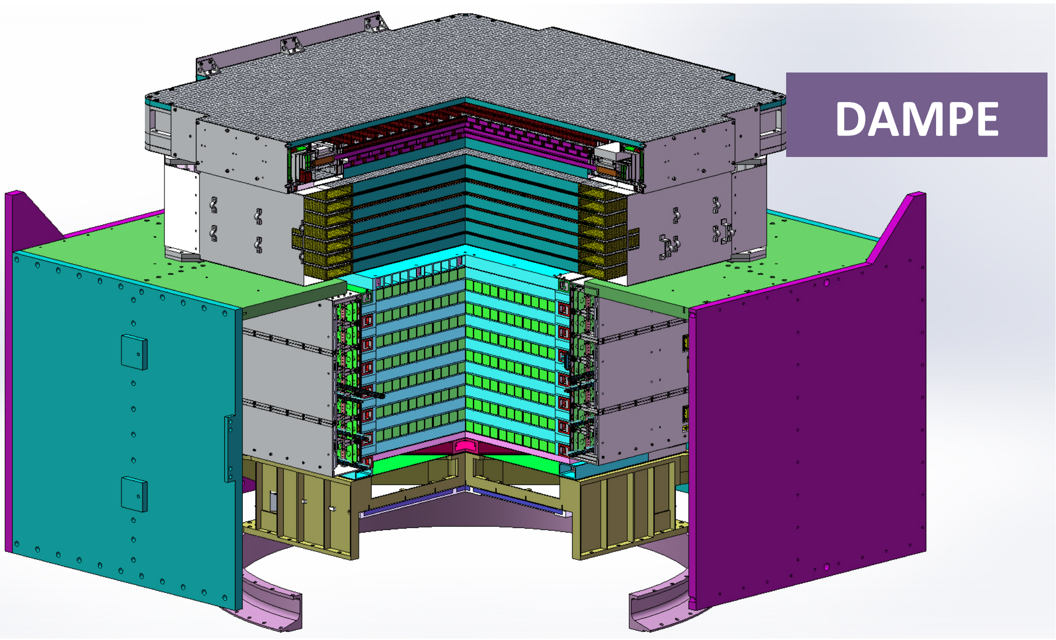
CALET, ISS-CREAM and DAMPE

- **3 majors high energy missions to be launched in next 2 years**
  - **Detect high energy photon, electron and cosmic rays**
- **Charge measurement**
  - **CALET** — 2 layers 1cm thick plastic scintillator
  - **ISS-CREAM** — 4 layers 380µm thick Silicon Pin diode
  - **DAMPE** — 2 layers 1cm thick plastic scintillator +
    2 layers 320 µm silicon strip detector (SSD)
    10 layers 320 µm SSD (after converters)
- **Calorimetry**
  - **CALET** — Total absorption: PWO, $32 \times 32\ cm^2$, $27\ X_0$, $1.2\ \lambda$
    IMG: $3\ X_0$ + Scint. fiber
  - **ISS-CREAM** — Sampling: Tungsten+Scint. Fiber, $50 \times 50\ cm^2$, $20\ X_0$, $0.7\ \lambda$
    Carbon target: $0.5\ \lambda / 1\ X_0$
  - **DAMPE** — Total absorption: BGO, $60 \times 60\ cm^2$, $31\ X_0$, $1.6\ \lambda$
    STK: $0.86\ X_0$ + SSD

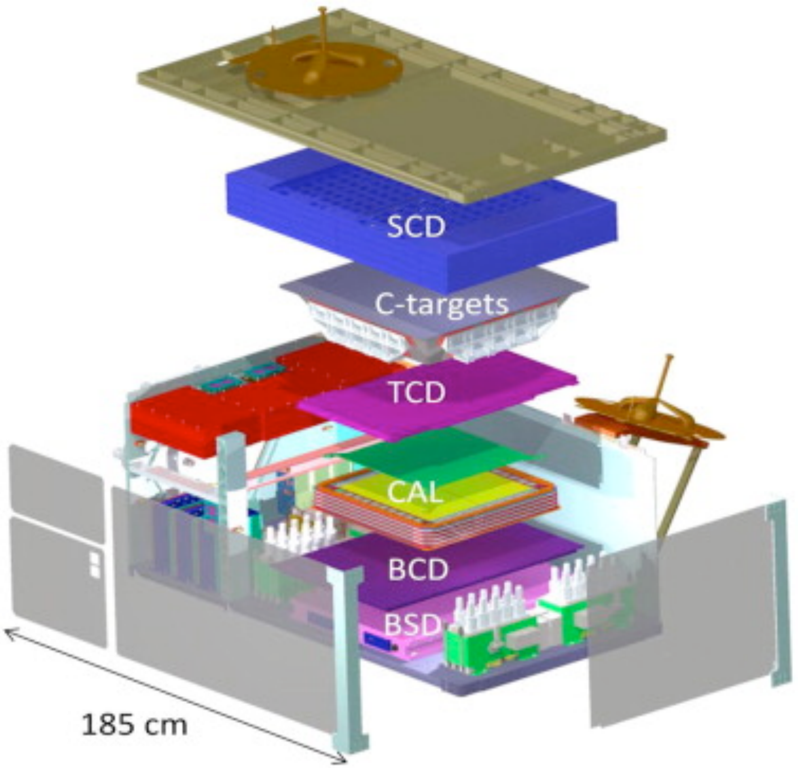
CALET, ISS-CREAM and DAMPE



CALET

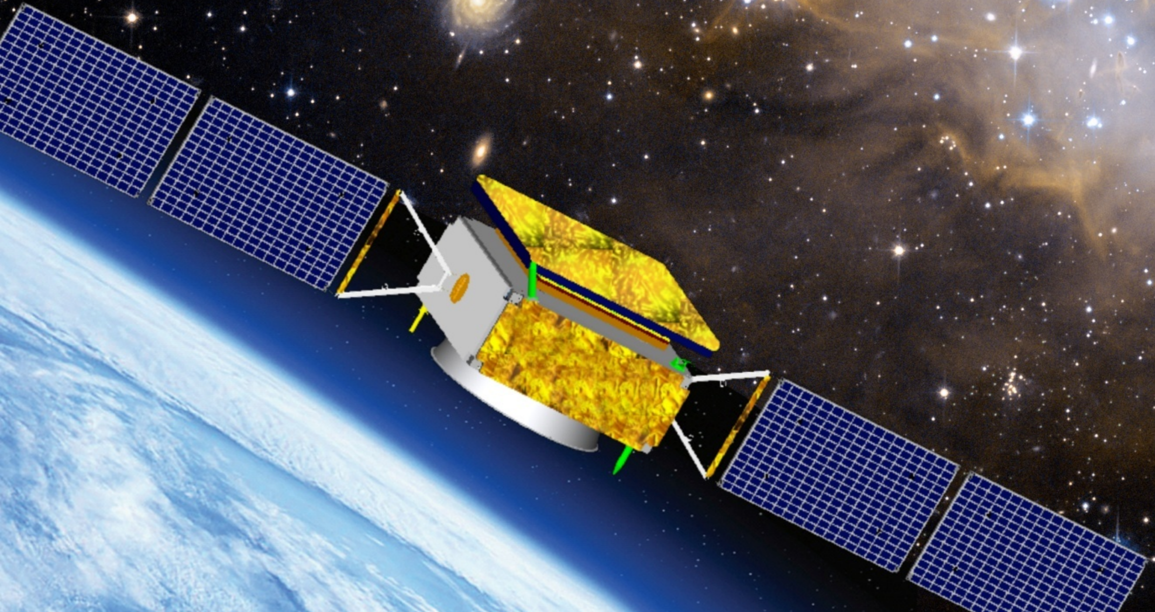


DAMPE



ISS-CREAM

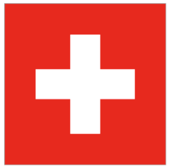
DAMPE: DArk Matter Particle Explorer



The DAMPE Collaboration

- China
  - Purple Mountain Observatory, CAS, Nanjing
  - 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 Perugia
  - INFN Bari

Also a CERN Recognized Experiment!

Grey Book http://greybook.cern.ch/

EXPERIMENTS AT CERN

INTRODUCTION
PROGRAMMES
INDEX TO INSTITUTES
RESEARCH COMMITTEES
ACCELERATORS AND BEAMS
MACHINE SCHEDULES
EXPERIMENTS / PROJECTS UNDER STUDY
CRITERIA FOR INCLUSION
CHANGES

Grey book experiment data are maintained by the larger experiments and the Users' Office: Grey.Book@cern.ch

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The Grey Book lists experiments, institutes and people participating in experiments. Appearance in the Grey Book gives no a priori rights to resources.

These pages have been produced by **GS-AIS**

RE29

DAMPE

ABSTRACT & FIGURES | HOME PAGE | NOTES & PUBLICATIONS

SPOKESPERSON: Jin CHANG
CONTACTPERSON: Xin WU
Experiment secretariat e-mail: grey.book@cern.ch

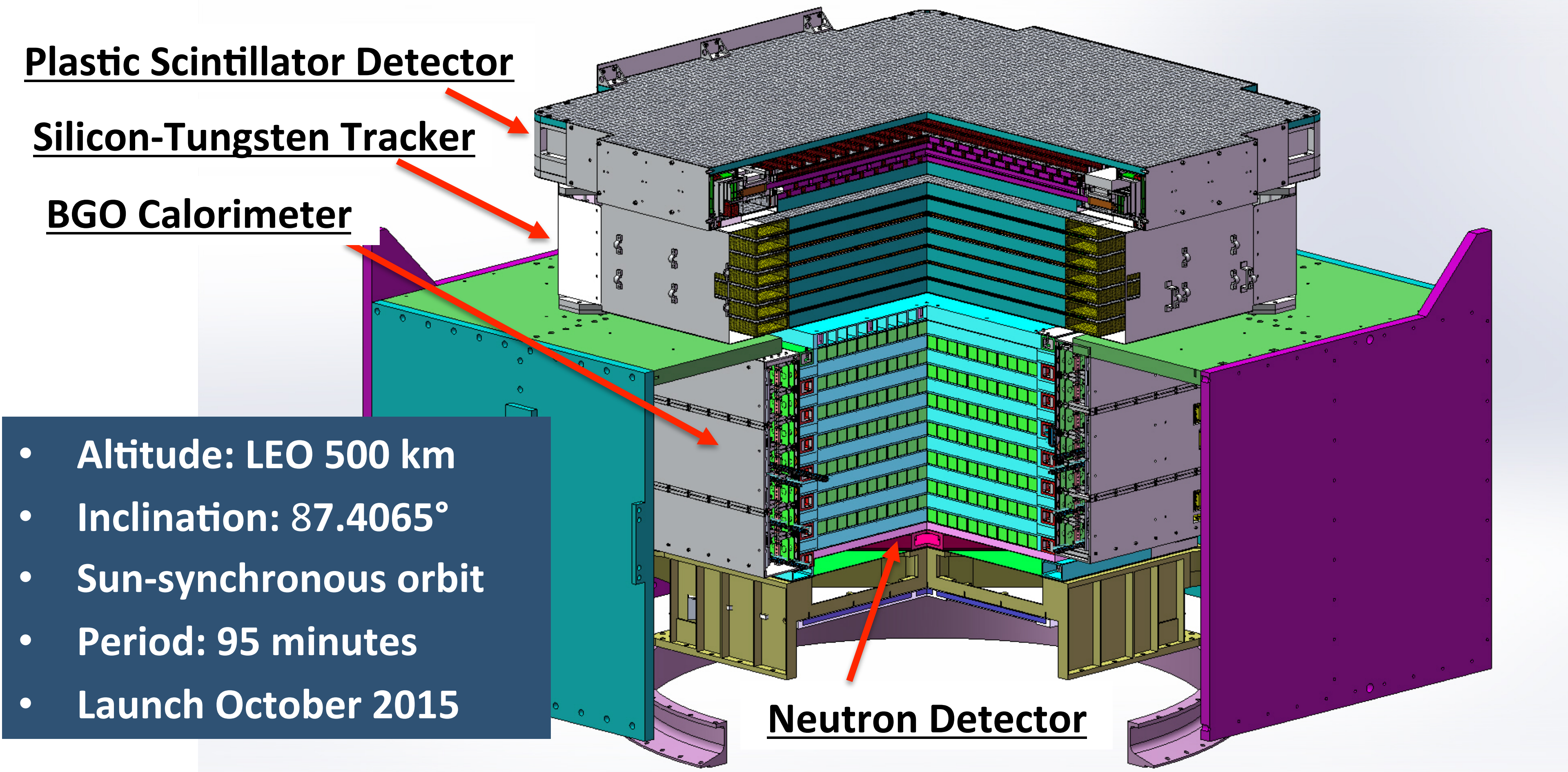
Beam:	
Approved:	12-03-2014
Status:	Preparation

Complete list of members per institute

Names indicated in BLUE are external participants.
Names indicated in PURPLE are CERN retired participating in experiments.

Last Updated: 13:40 23-MAY-2014

The DAMPE Detector

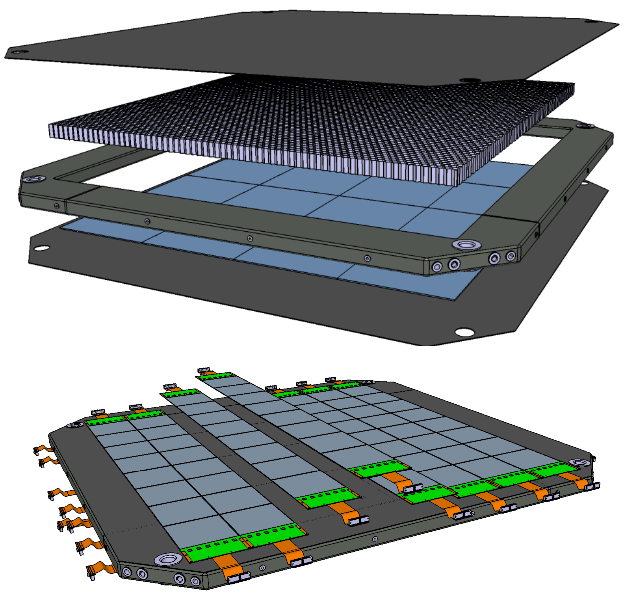


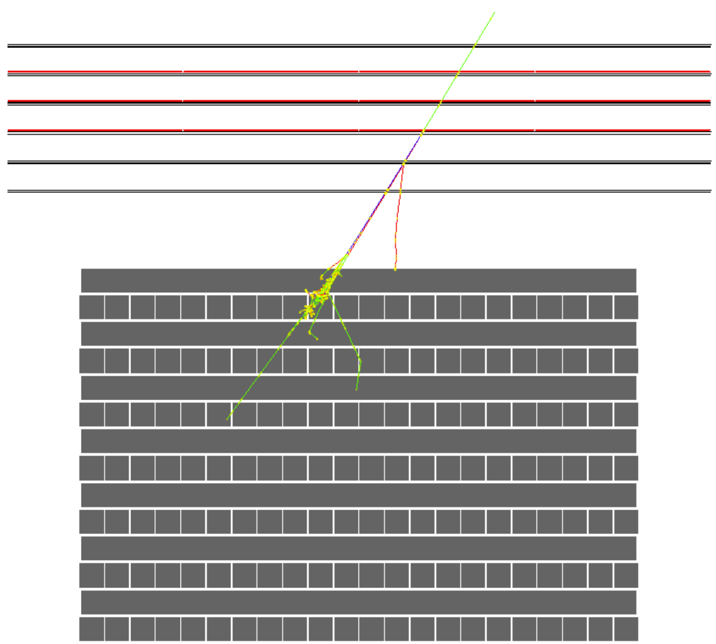
- Altitude: LEO 500 km
- Inclination: 87.4065°
- Sun-synchronous orbit
- Period: 95 minutes
- Launch October 2015

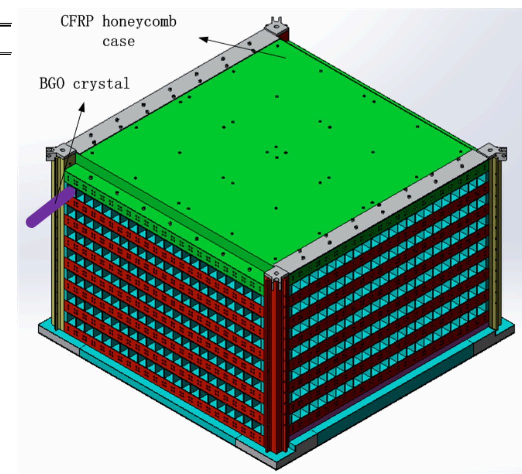
W converter + thick calorimeter (total 32 X_0) + precise tracking + charge measurement ➡ high energy γ-ray, electron and CR telescope

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

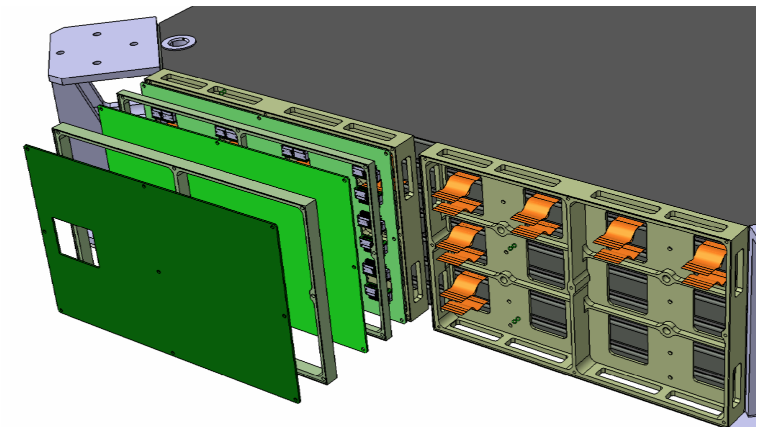


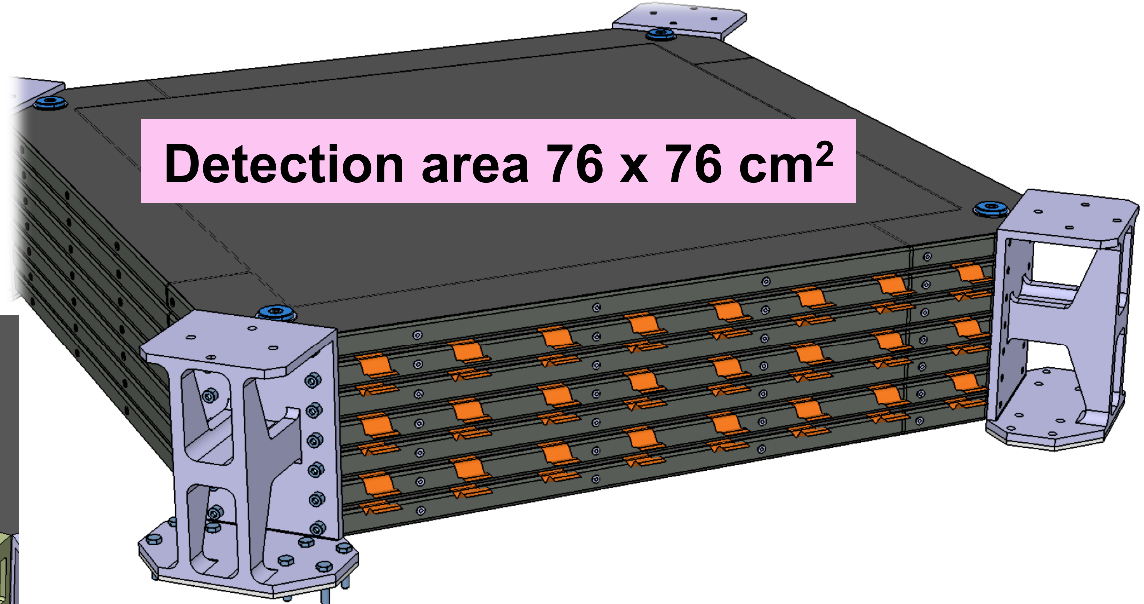




Silicon-Tungsten Tracker (STK)

DPNC, Perugia, Bari, IHEP



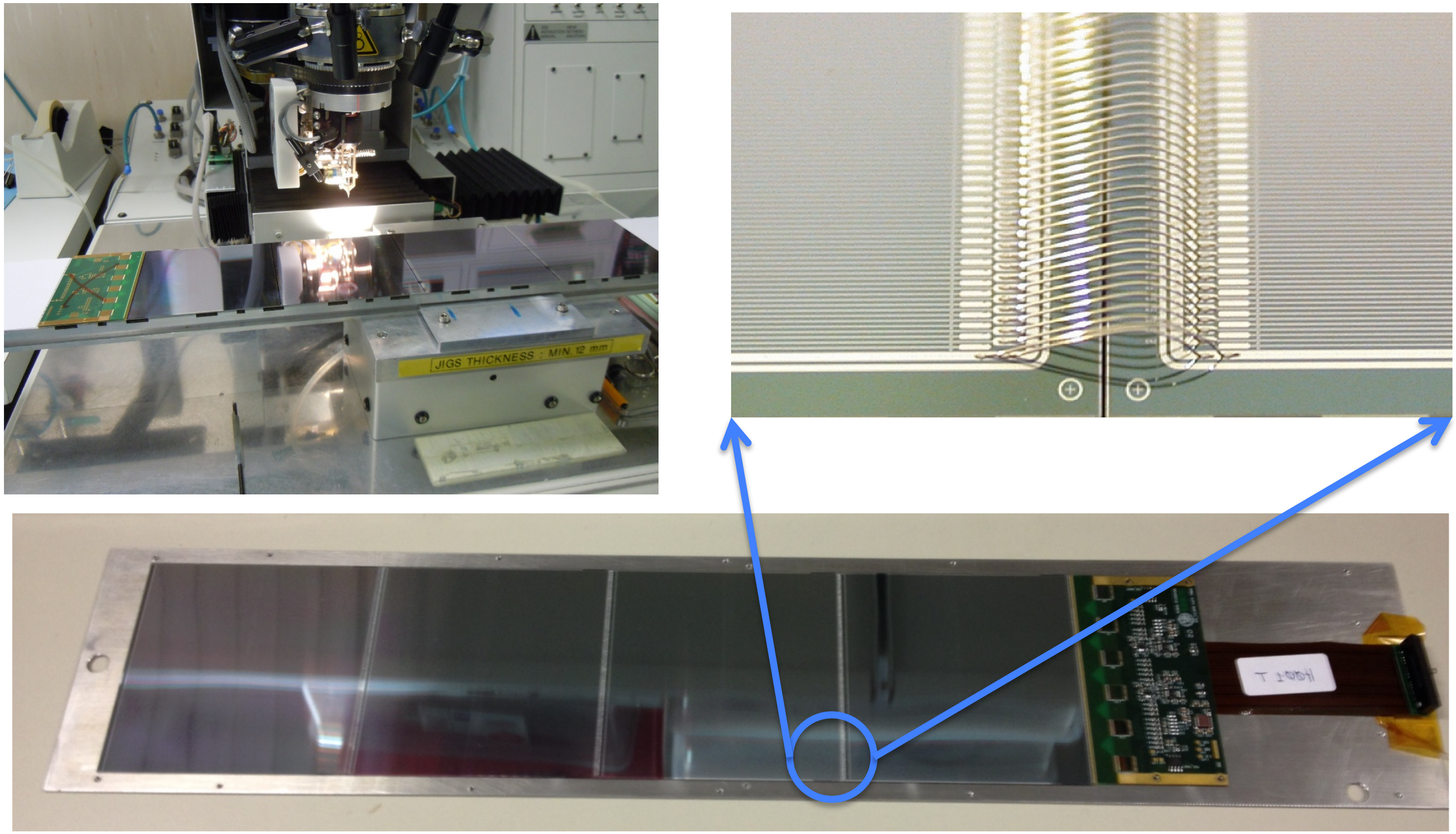


- 12 layers of silicon micro-strip detector mounted on 7 support trays
  - Tray: carbon fiber face sheet with Al honeycomb core
- Tungsten plates integrated in trays 2, 3, 4 (from the top)
  - Total ~1 X_0 for photon conversion
- 8 readout boards on 4 sides

- Weight: ~ 160 Kg
- Power consumption: ~85W

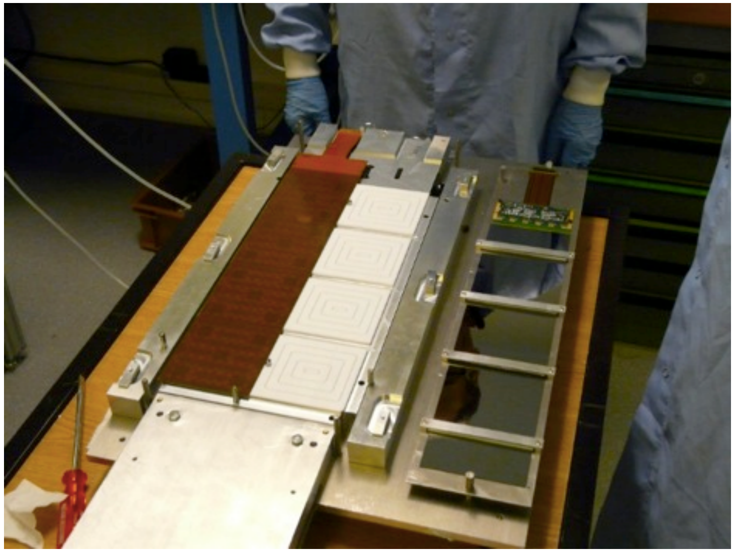
STK Support Trays

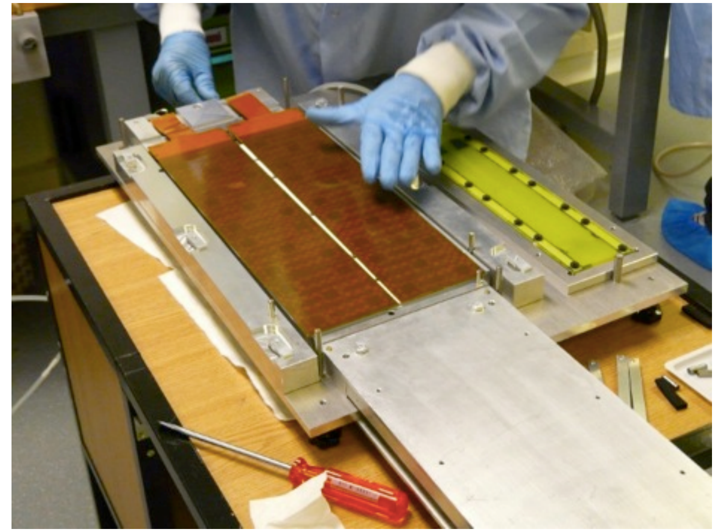
Ladder Assembly

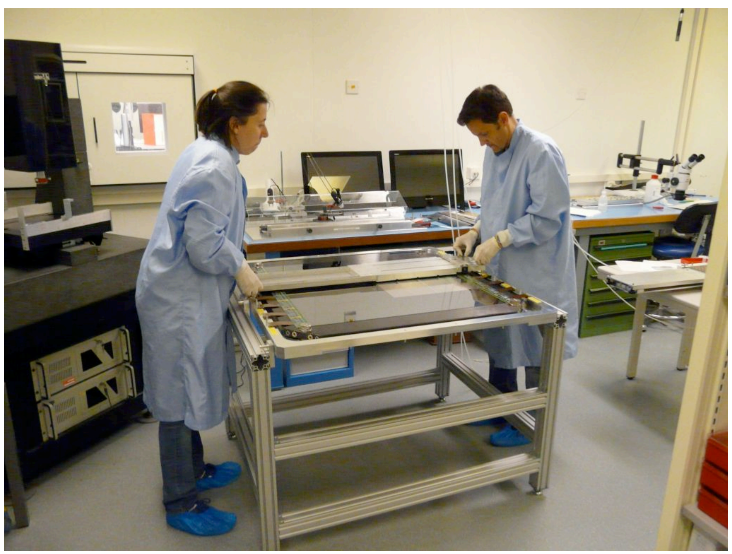


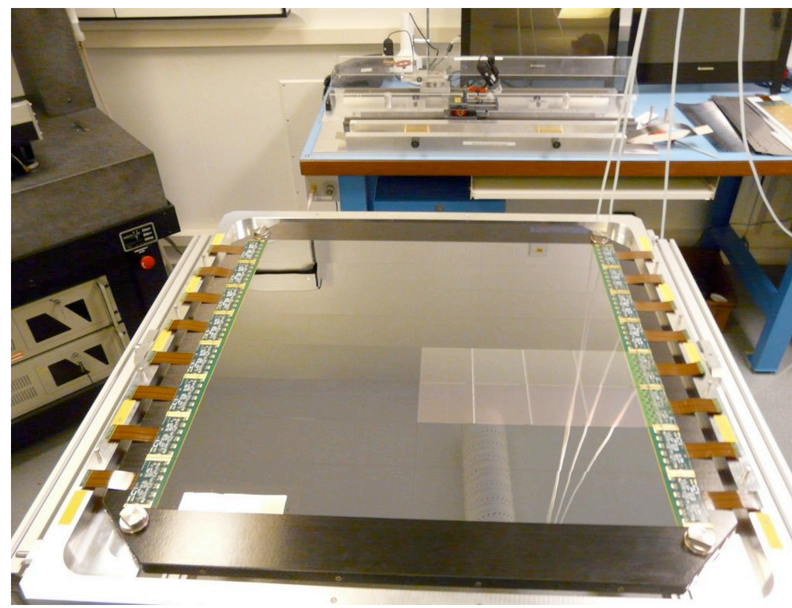
- **Precise jigs to assemble (align, glue and bond) 4 sensors to a ladder**
  - **20 µm alignment precision and planarity**

Plane Assembly at UniGE



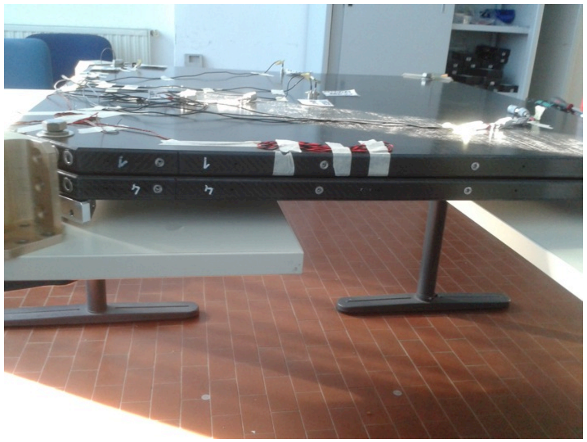


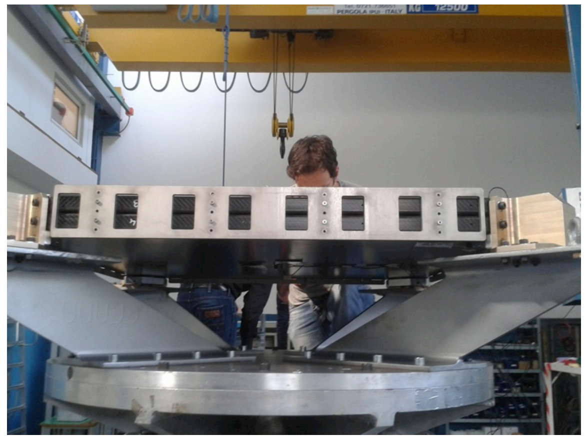


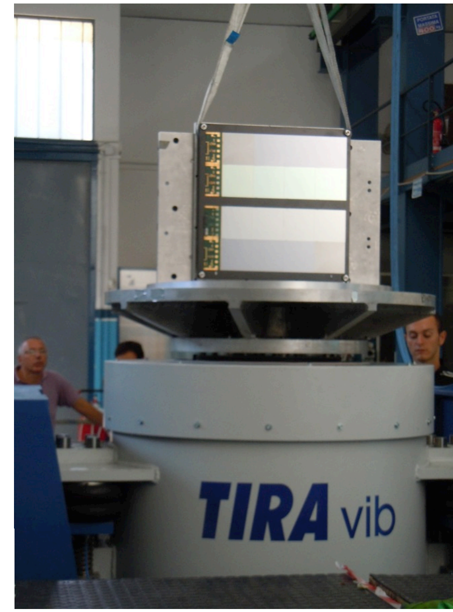


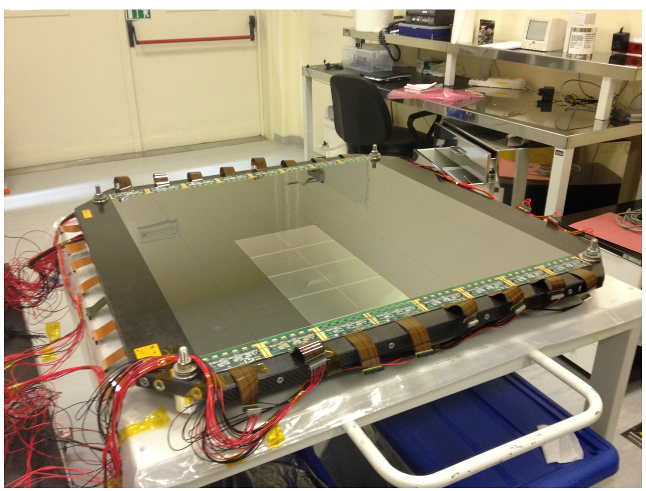
Space Qualification Tests

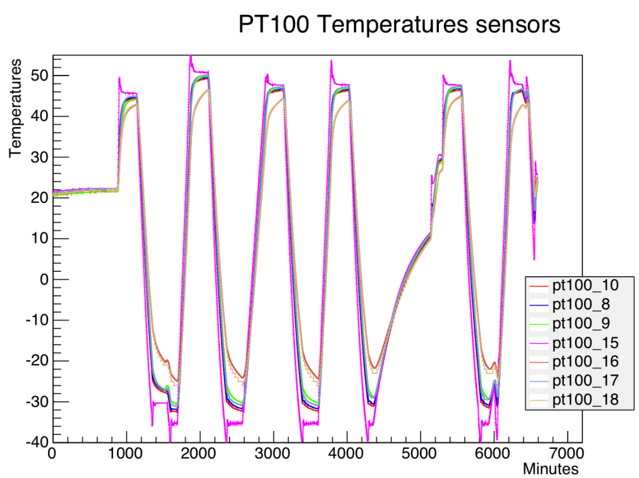
- **Mechanical and thermal vacuum tests done at SERMS at Terni (Italy)**



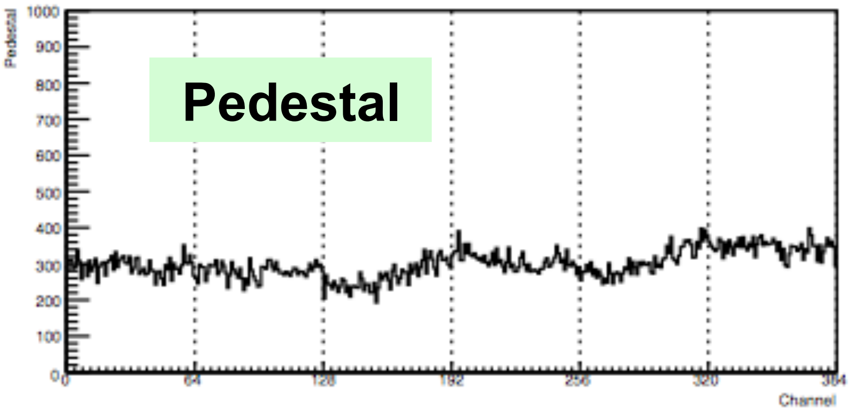


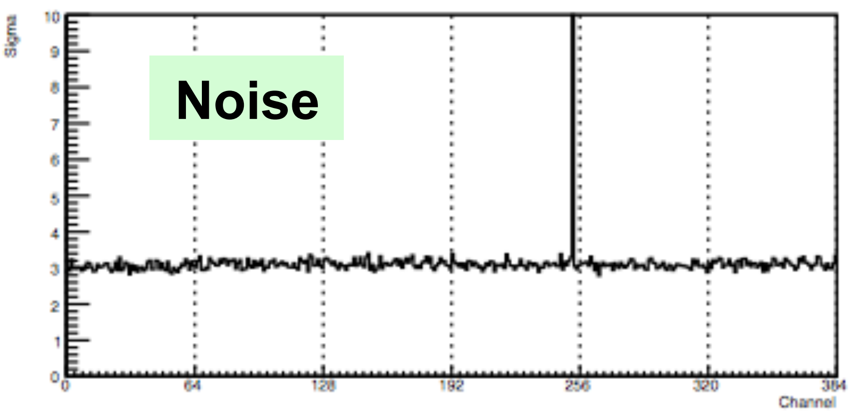


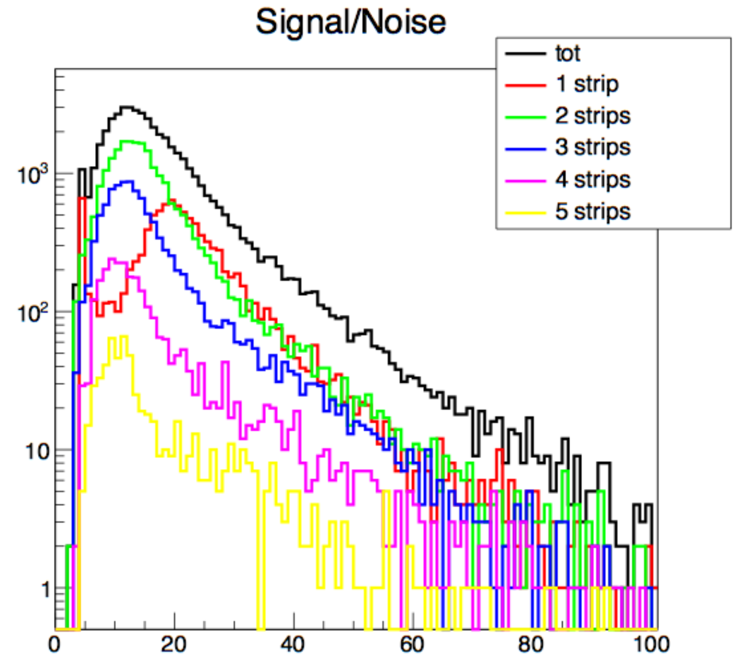


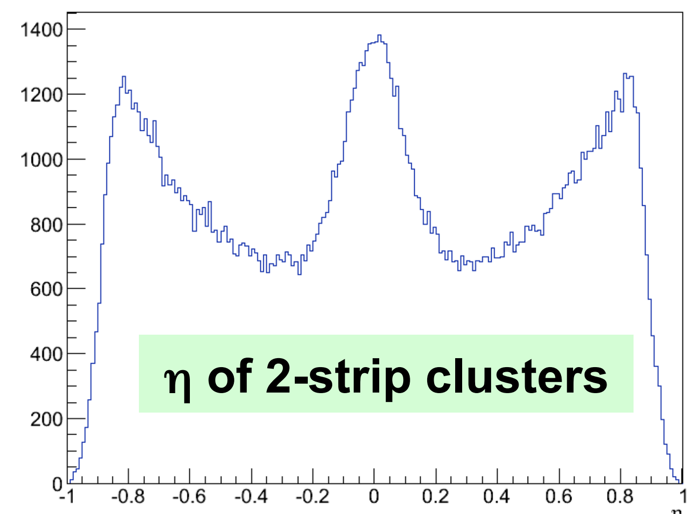


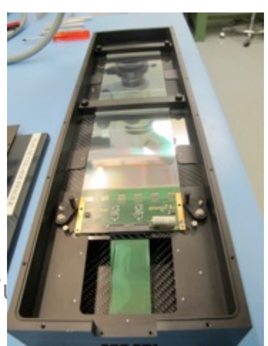
Cosmic Ray Tests with Ladders

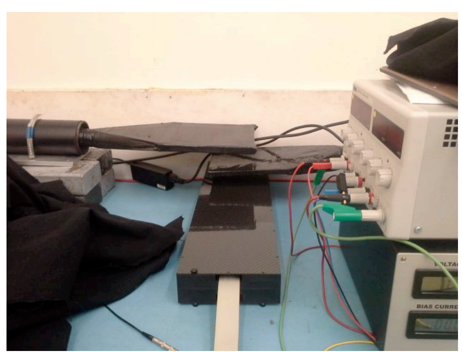








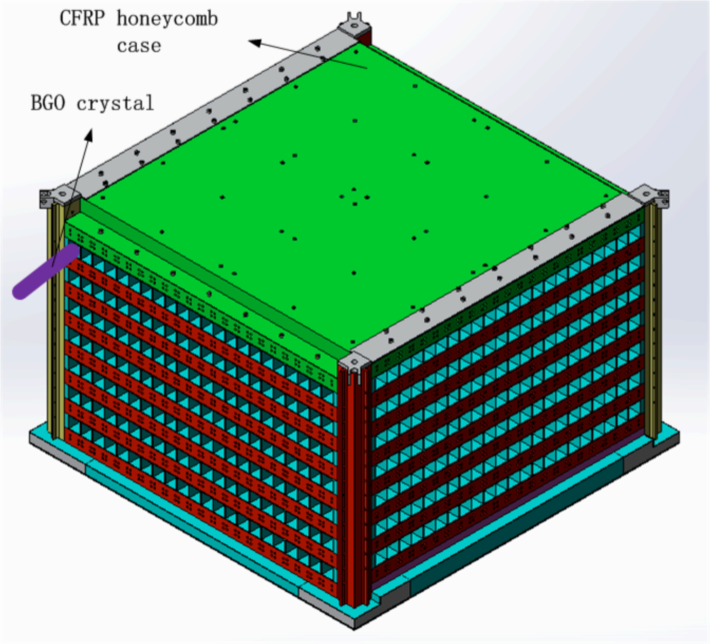


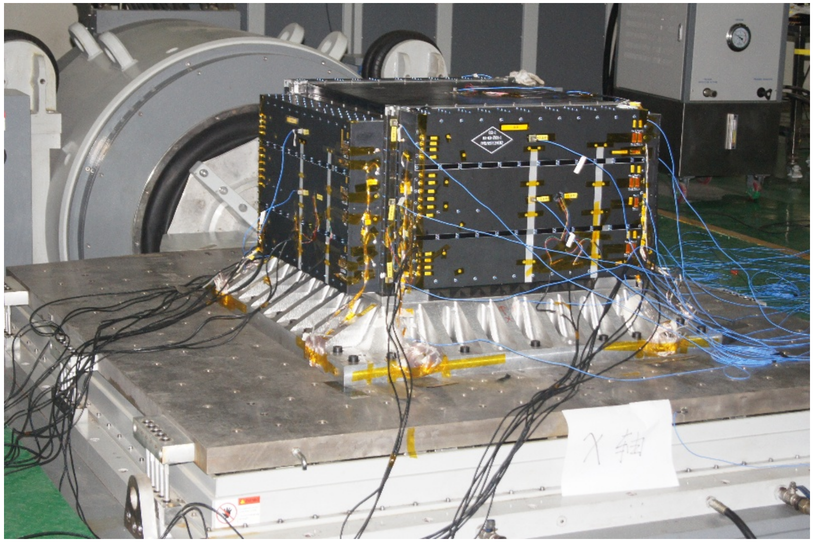


BGO Calorimeter (BGO)

PMO, USTC

- 14-layer BGO hodoscope, 7 x-layers + 7 y-layers
  - BGO bar 2.5cm×2.5cm, 60cm long, readout both ends with PMT
    - Use 3 dynode (2, 5, 8) signals to extend the dynamic range
  - Charge readout: VA160 with dynamic range up to 12 pC
  - Trigger readout: VATA160 to generate hit signal above threshold
    - Detection area 60cm×60cm

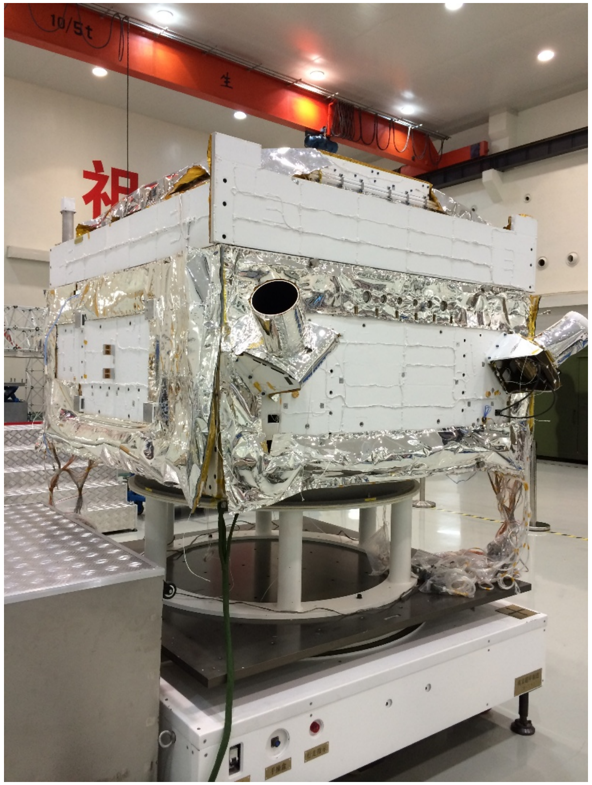


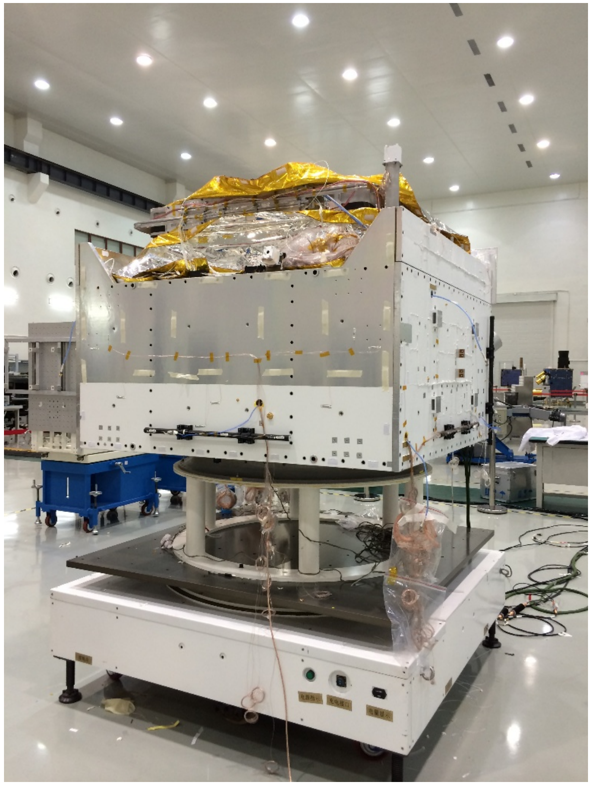


BGO EQM constructed and tested!

Total thickness $31X_0$

Satellite Integration in Shanghai

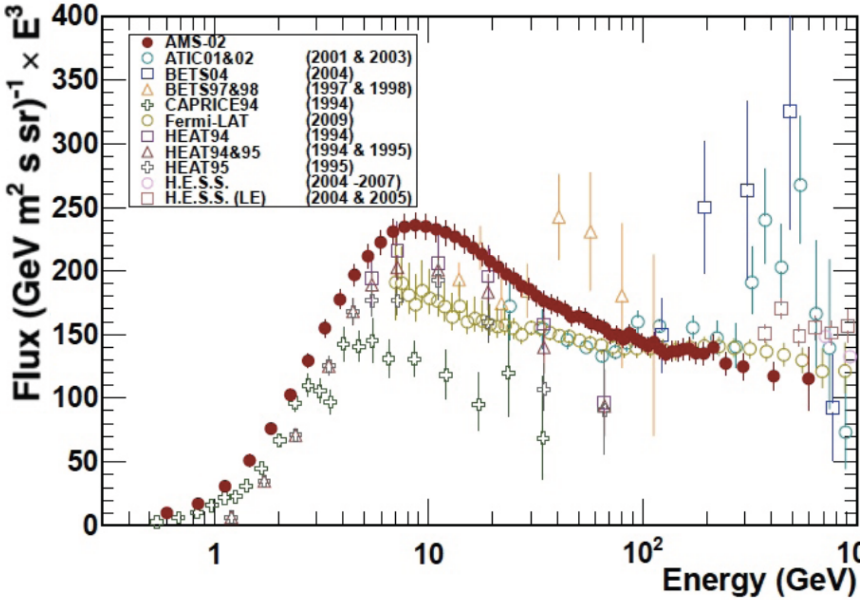


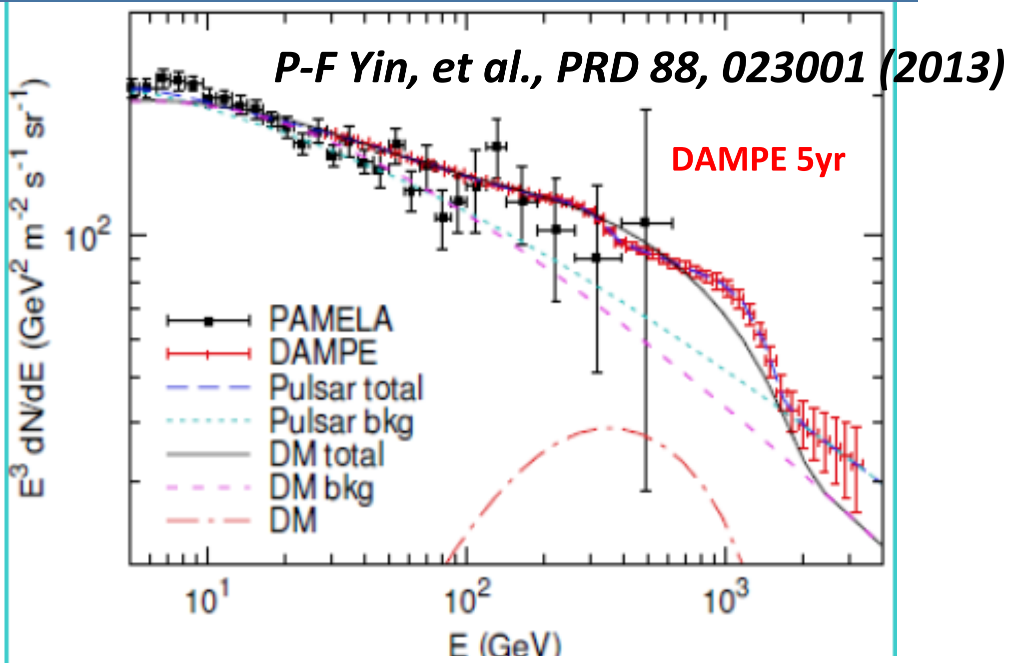


STK and DAMPE Planning

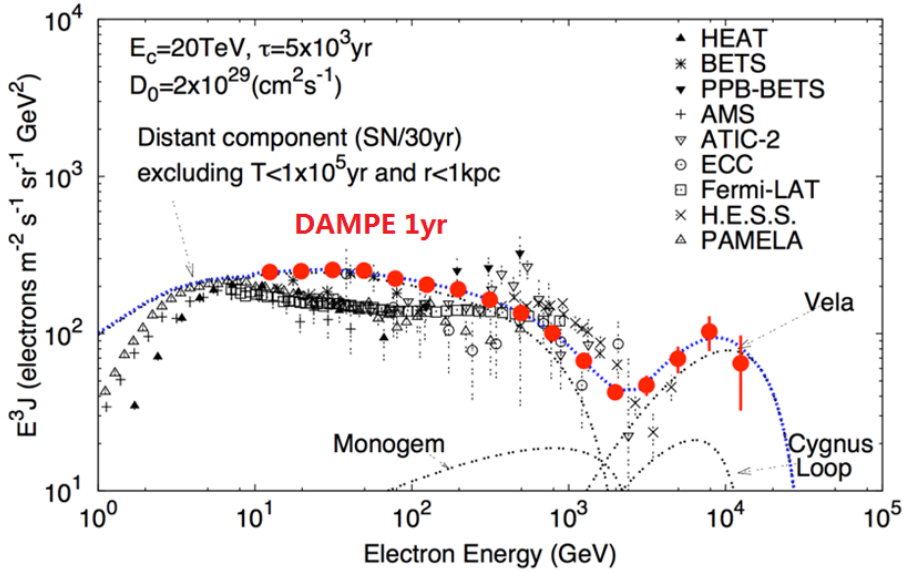
- July 2014
  - 18 July: STK EQM delivery to China
  - 21-24 July: STK test beam at CERN PS T9
- September 2014
  - Start STK ladder production for FM
- October –November 2014
  - 20 October: Full DAMPE EQM arrives at CERN
  - 29 October – 11 November: Full DAMPE EQM test beam at CERN PS
  - 12 – 19 November: Full DAMPE EQM test beam at CERN SPS H4
- Spring 2015
  - STK EQM delivery to China
- October 2015
  - DAMPE launch

DAMPE search for DM with electrons





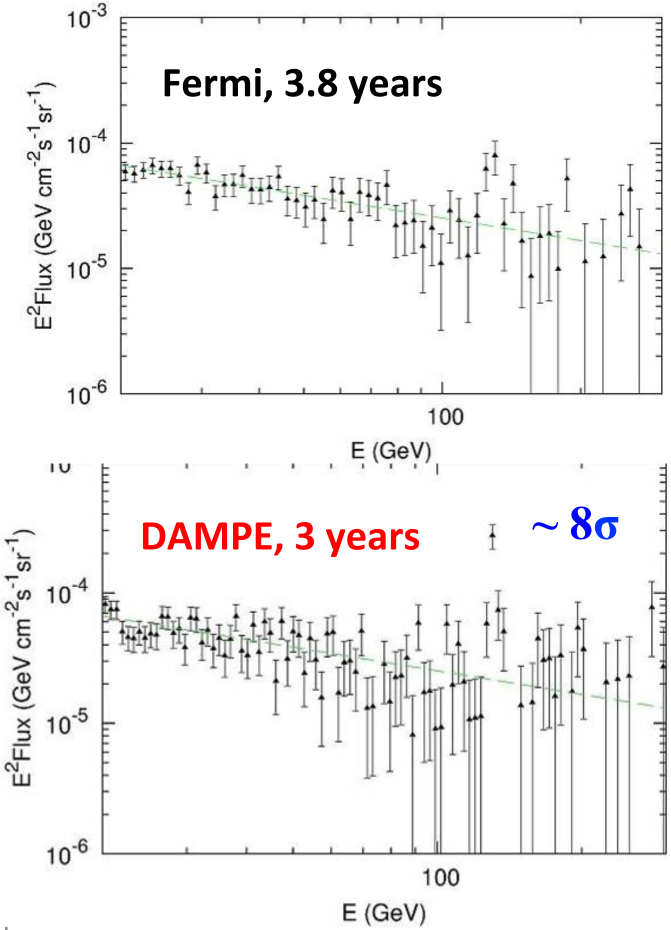
Need a detector in space that can detect electron around 1 TeV with very good energy resolution

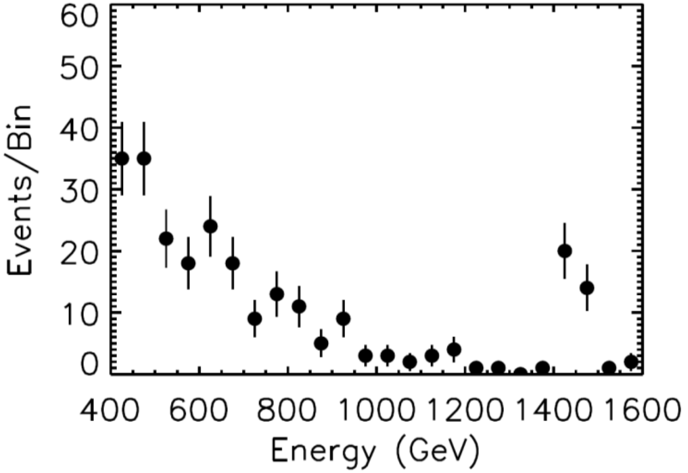


Xin Wu

DAMPE Gamma-ray Line Observation

DAMPE, with an excellent energy resolution of 1% above 100 GeV, is a suitable instrument to detect monochromatic gamma-ray signals from WIMP DM annihilation



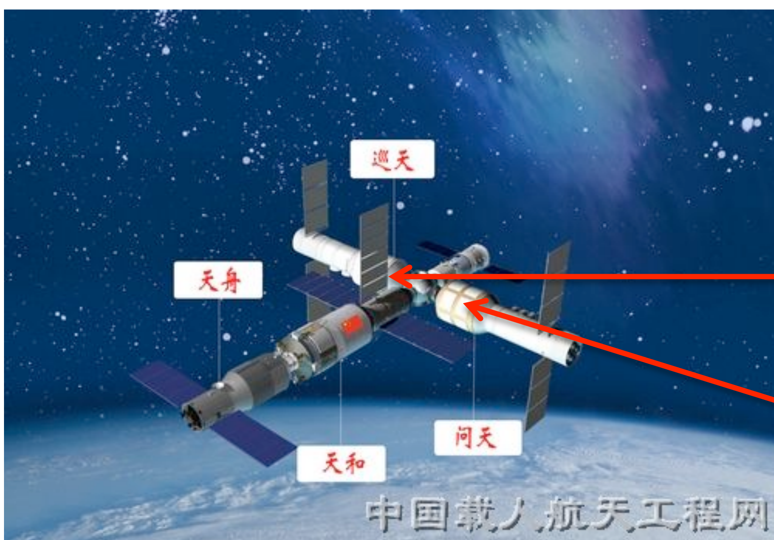


Simulated 1.4 TeV gamma-ray line from DM toward the Galactic center (300° < l < 60° , |b| <10°) including the Galactic diffuse background, for DAMPE 6 months observations


background
Gamma-ray
HERD
High
Energy
cosmic
Radiation
Detection
facility
electron
proton
He
Dark matter particle
Xin Wu

China's Space Station Program

- **Three phases**
  - **1st phase (Spaceflight): 10 astronauts have carried out 5 space flights with the Shenzhou spacecraft; Completed successfully**
  - **2nd phase (Spacelab): docking of 3 spacecrafts with astronauts delivering and installing scientific instruments**
    - **1st launch (Tiangong 1) on Sept. 29, 2011; Completed successfully**
    - **2nd launch (Tiangong 2) in 2015 (with POLAR)**
    - **3rd launch (Tiangong 3) may get skipped if Tiangong 2 is seccessful**



  - **3rd phase (Space station): 2 large experimental modules with astronauts working onboard**
    - **1st launch ~2018**

Module Wentian (WT: Inquire the Heaven)

Module Xuntian (ST: Scan the Heaven)

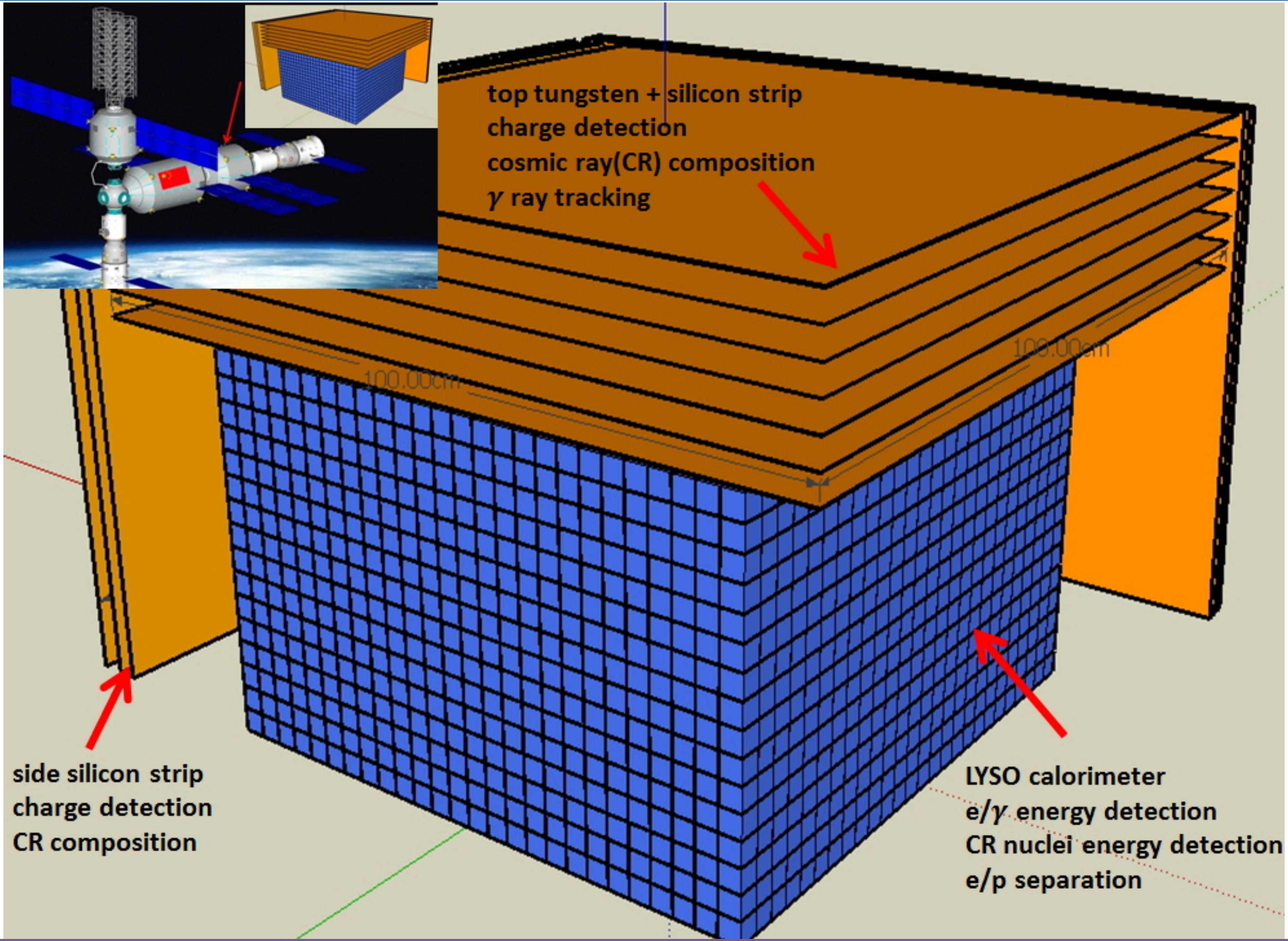
HERD

- **High Energy Cosmic Radiation Detection facility**
  - **High energy particle detector on board the Chinese Space Station**
  - **Requirement: accurate e/γ measurement, large GF for CR**
  - **Limitation: 2 tons and 2kW**

Science goals	Mission requirements
DM search	Measurements of e/γ from 100 GeV to 10 TeV
Origin of Galactic CRs	Spectral and composition measurements of CRs from 300 GeV to PeV with a large GF

- **"Secondary" science goals**
  - **Gamma-ray astronomy: monitoring of GRBs, microquasars, Blazars and other transients, …**
  - **May include a high precision sub-GeV gamma-ray detector (PANGU)**
- **UniGe is actively participating in HERD and is leading the tracker project**

HERD Conceptual Design



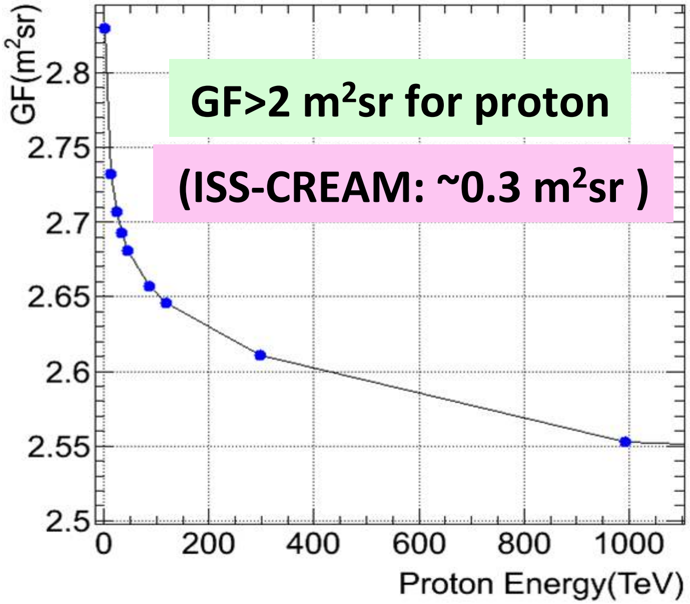
Silicon-Tungsten Tracker + LYSO Calorimeter

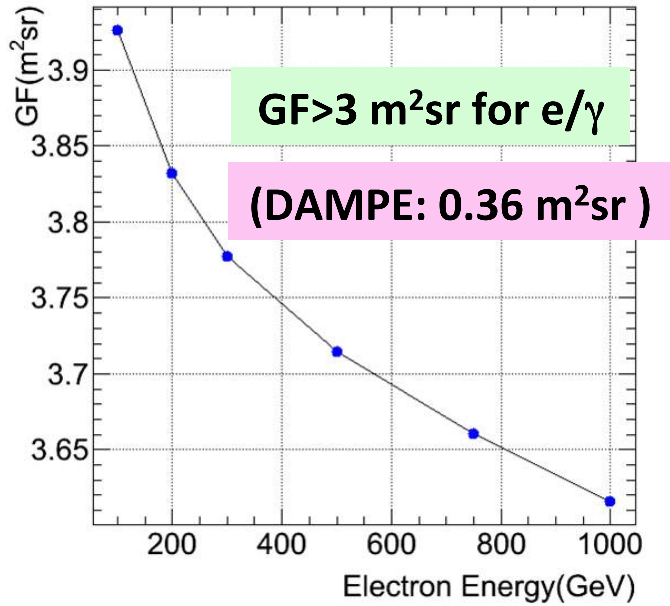
Detector Characteristics

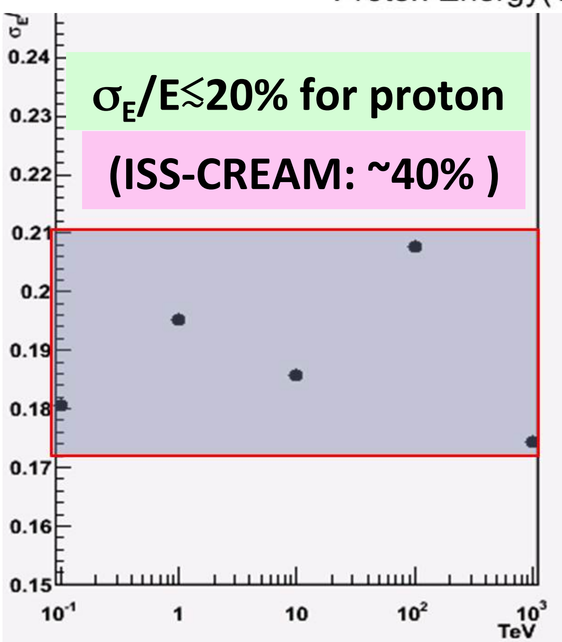
	type	size	X_0,λ	unit	main functions
tracker (top)	Si strips	70 cm × 70 cm	2 X_0	7 x-y (W foils)	Charge Photon conversion
tracker 4 sides	Si strips	65 cm × 50 cm	--	3 x-y	Nucleon Track Charge
CALO	~10K LYSO cubes	63 cm × 63 cm × 63 cm	55 X_0 3 λ	3 cm × 3 cm × 3 cm	e/γ energy nucleon energy e/p separation

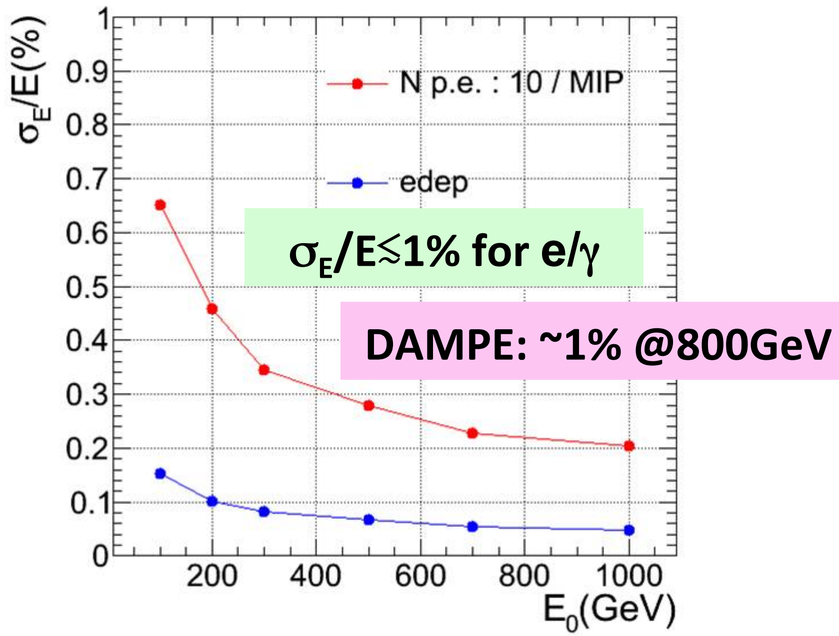
Crystal	ρ (g/cm³)	X_0 (cm)	λ_I (cm)	R_M (cm)	LY (%NaI)	t (ns)	λ (nm)	dL/dT(%°C)
PbWO	8.30	0.89	20.3	2.00	0.3	30	425	-2.5
LYSO	7.40	1.14	20.9	2.07	85	40	402	-0.2
BGO	7.13	1.12	22.8	2.23	21	300	480	-0.9
CsI(Tl)	4.51	1.86	39.3	3.57	165	1220	550	0.4
NaI(Tl)	3.67	2.59	42.9	4.13	100	245	410	-0.2

Big GF and Good Energy Resolution

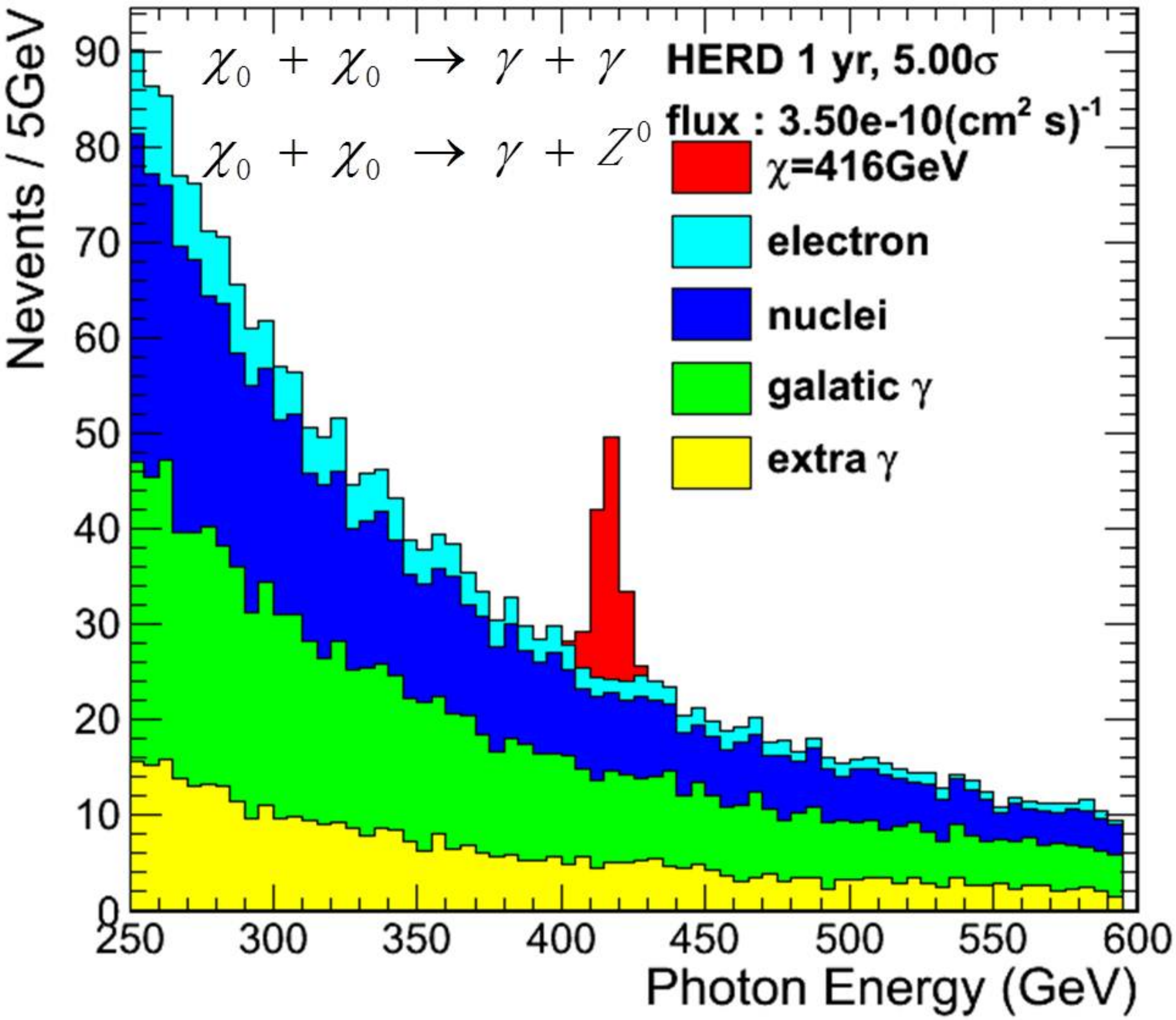




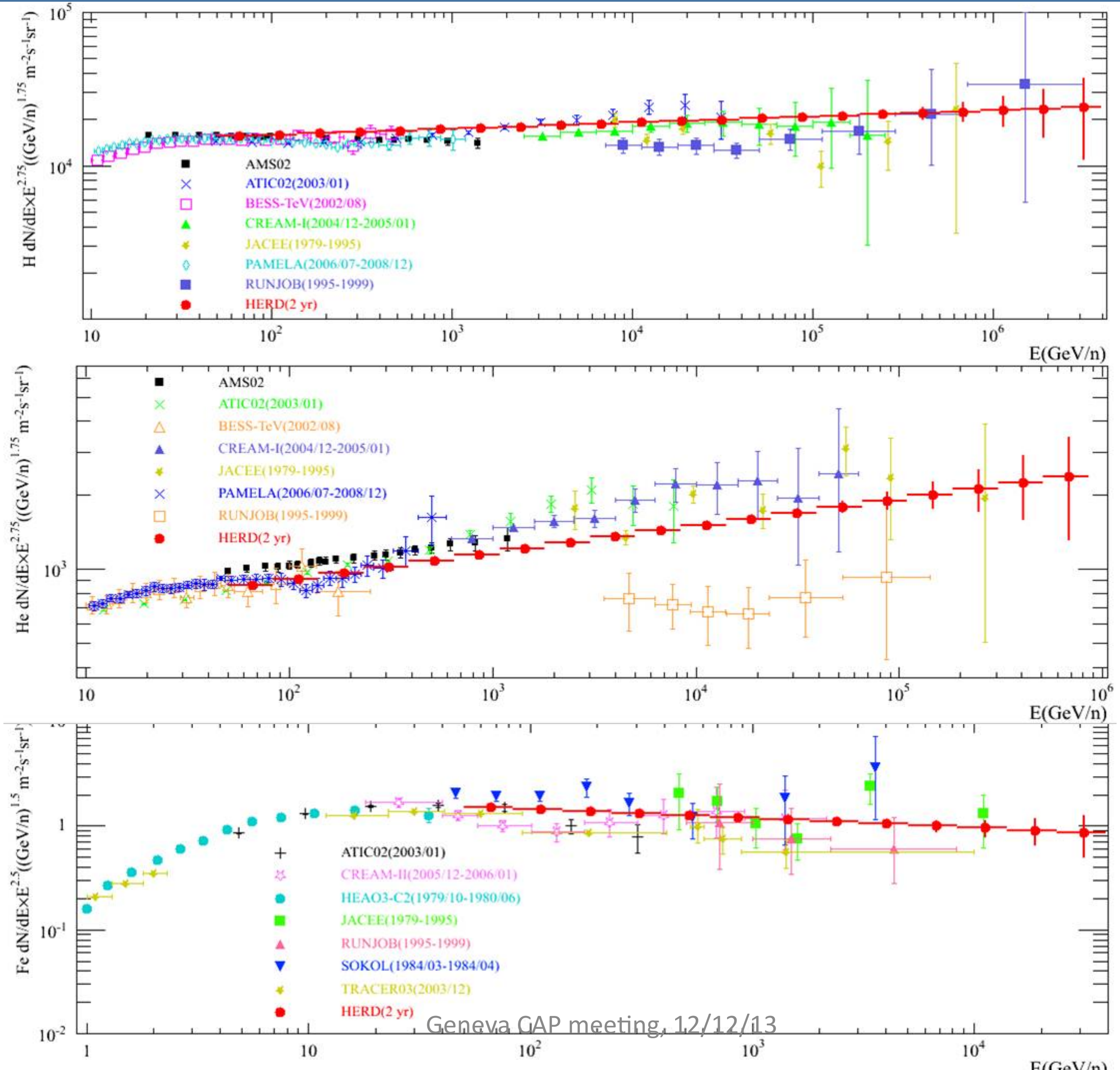




DM annihilation γ line with HERD



Expected HERD H, He, Fe Spectra

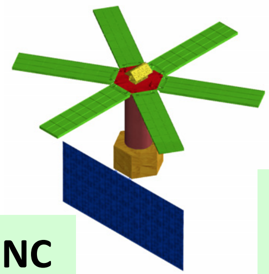


Astrophysics with keV-GeV γ-rays

- A wide range of topics of galactic and extragalactic astronomy and fundamental physics, large interest from the community
  - Extreme physics of extended/compact objects (black holes, neutron stars, …)
    - Excellent resolution power
  - Galactic and extragalactic cosmic rays (origin, acceleration mechanism)
    - Polarization measurement crucial
  - Search for Dark Matter in unique corner
    - Diffused; Excess of gamma-ray emission in the galactic center
  - Detect and determine the high-energy behavior of gamma-ray transients
    - GRB, Pulsation search in millisecond pulsar
  - Fundamental Physics, e.g. Baryon asymmetry in early universe
  - Solar and terrestrial high energy phenomena
- Multi-wavelength correlation studies across the electromagnetic spectrum with other space and on-ground telescopes

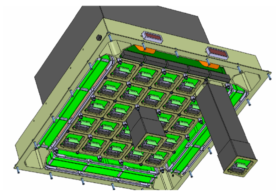
Photon Detection in keV-MeV Range

DPNC
ISDC



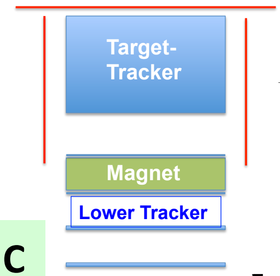
LOFT

DPNC
ISDC
PSI

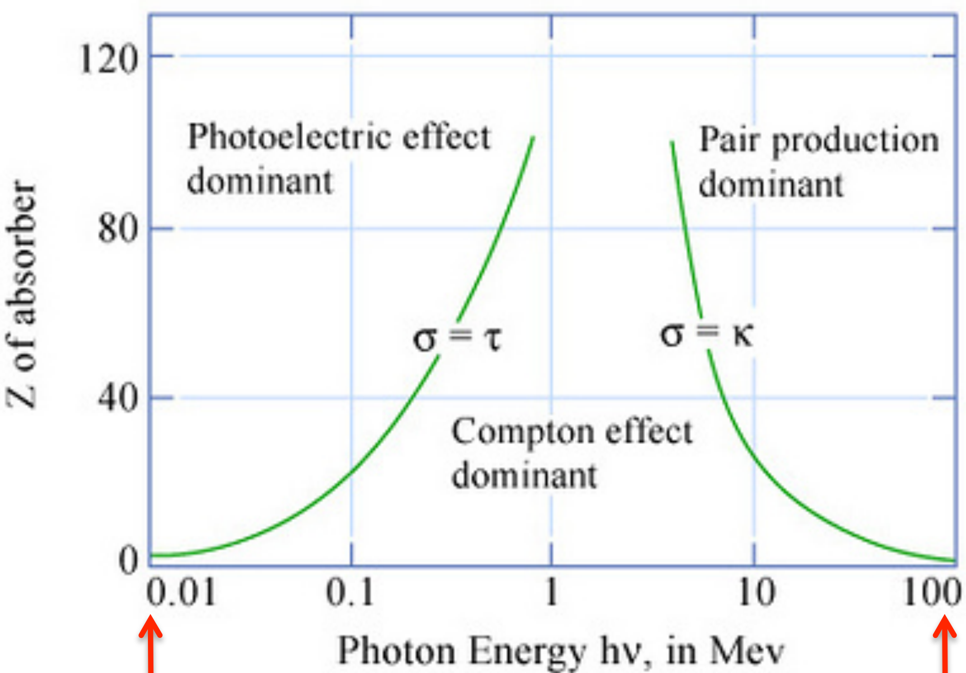


POLAR

DPNC
ISDC

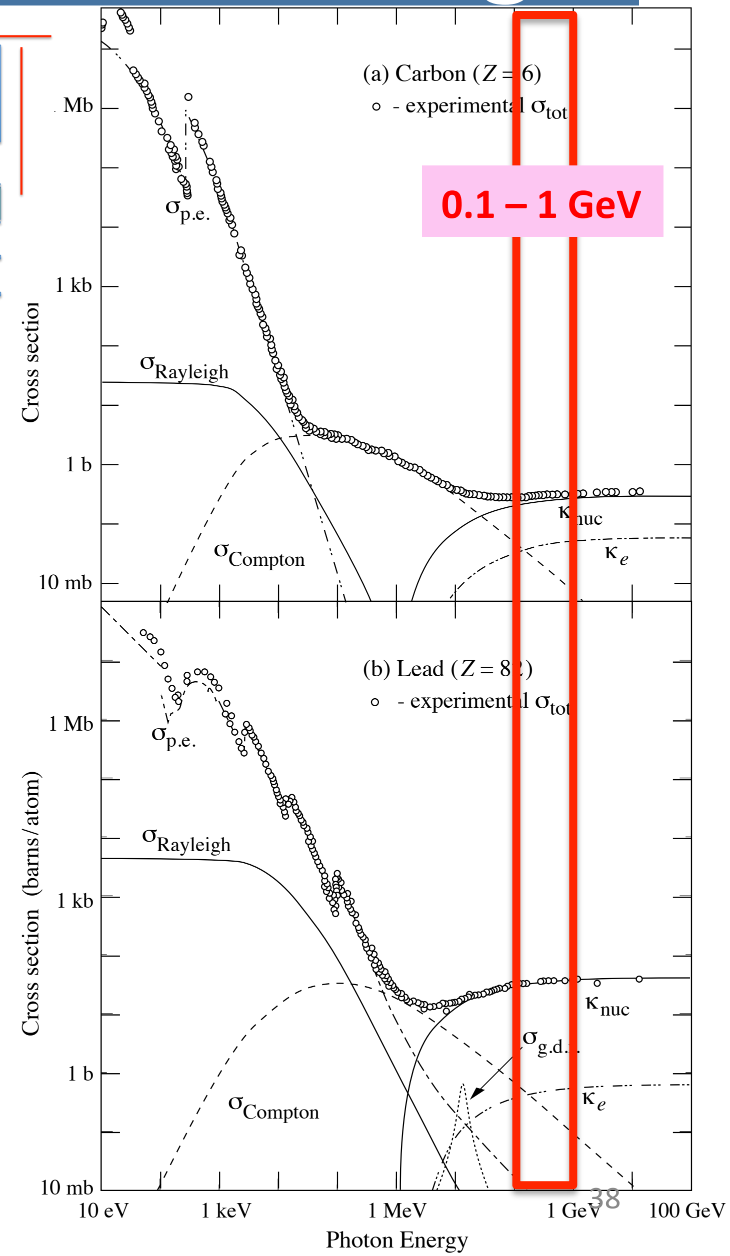


PANGU



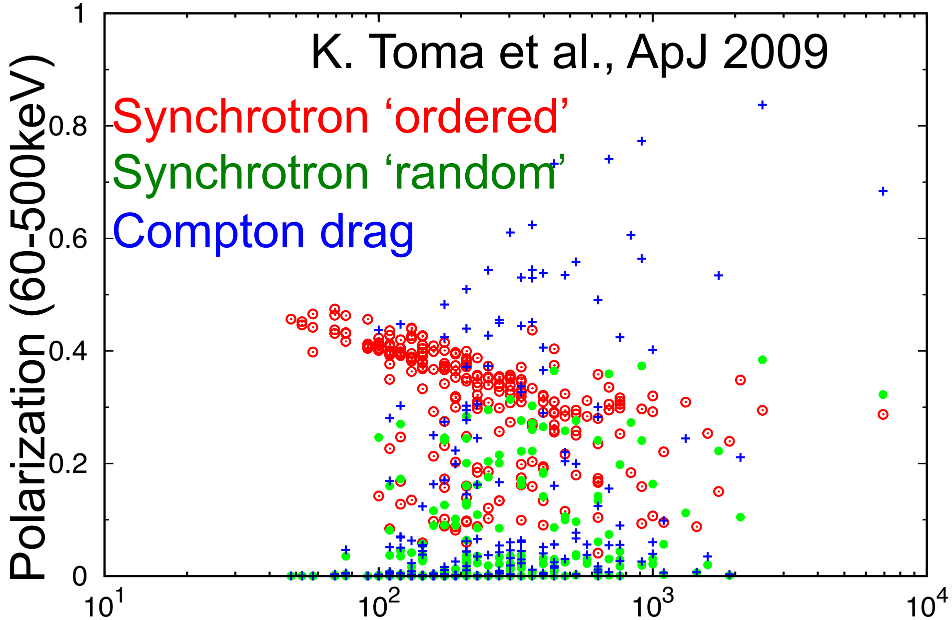
10 keV

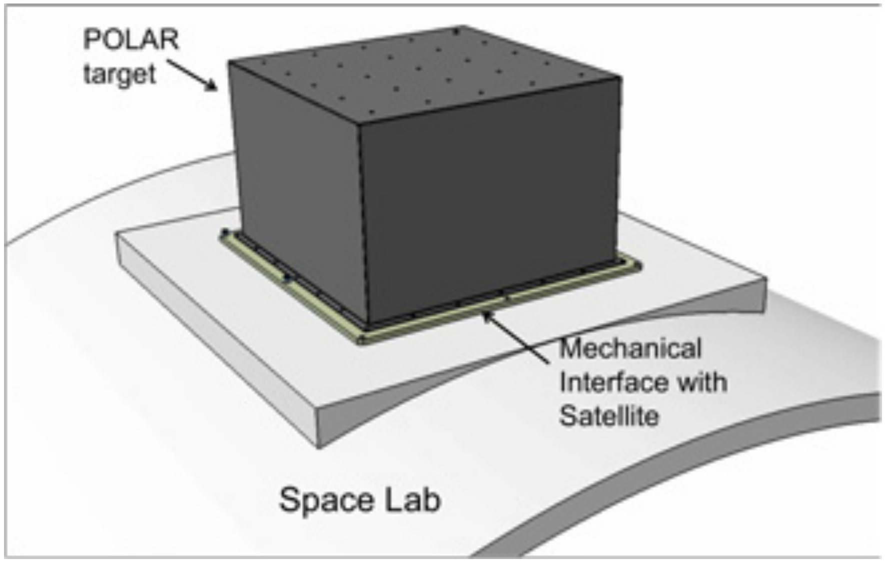
100 MeV



POLAR

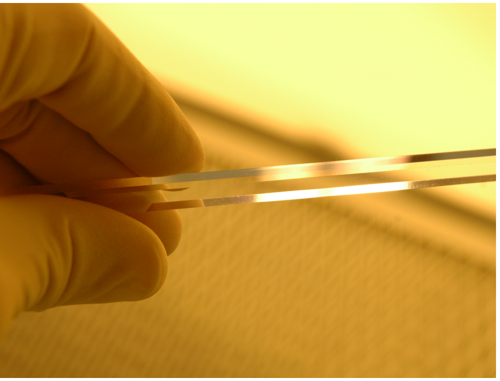
- **Gamma Ray polarimiter on board of the Tiangong-2 space lab, lifetime 3ys**
  - **Measure polarization to 10% to distinguish models of GRB**
  - **Sensitive to hard X-rays of 50–500 keV**
  - **Compact: 30kg**
  - **Wide field of view: ~1/3 full sky**
  - **During transients, flux up to tens of photons $cm^{-2}\,s^{-1}$: rate >10kHz**

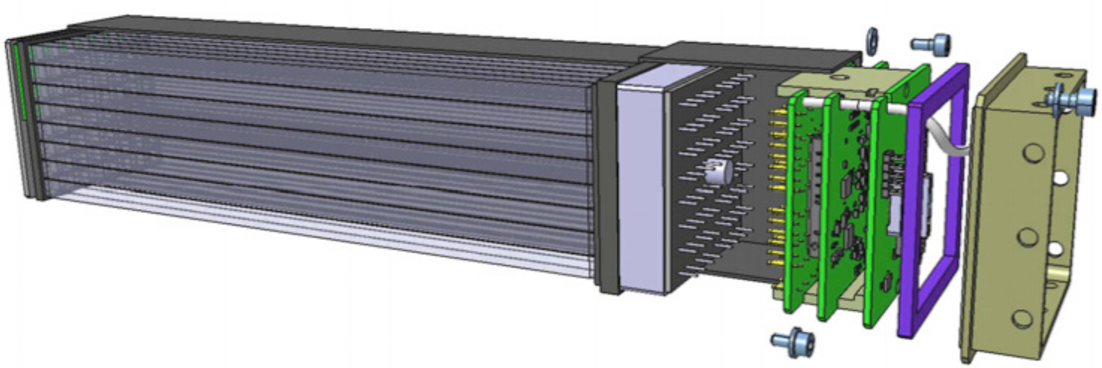


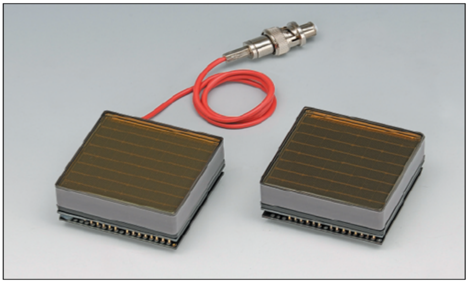


POLAR Detector

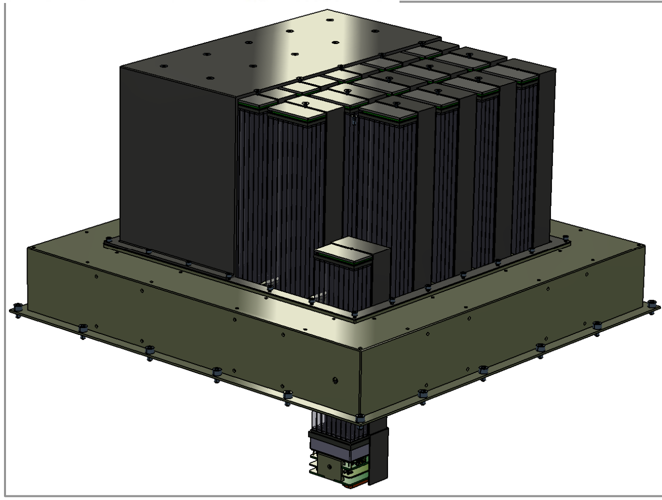
- **5x5 modules in carbon fibre box**
- **Each module has 8x8 schintillator bars of size 6x6x176cm^3**
  - **Coupled to a flat panel multi-anode PMT (H8500D, Hamamatsu)**
  - **Read out by multi-channel ASIC electronics (with PSI)**





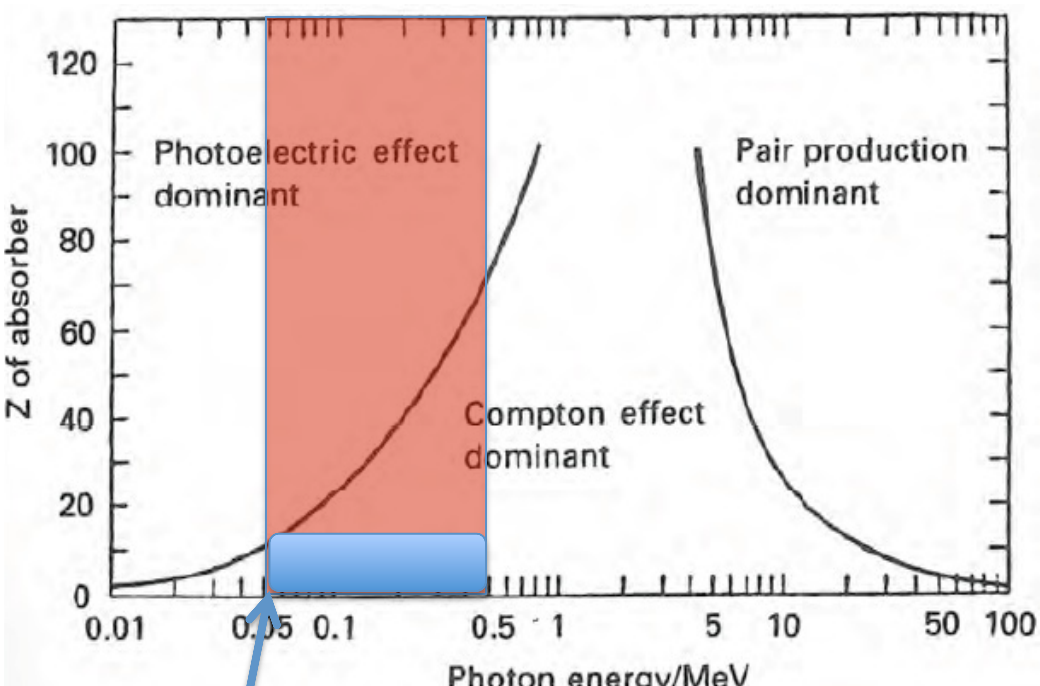


Hamamatsu H8500 MAPMT

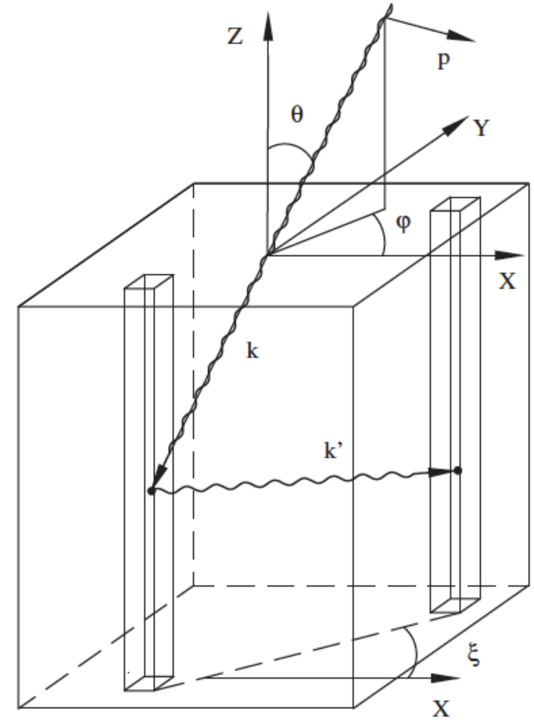


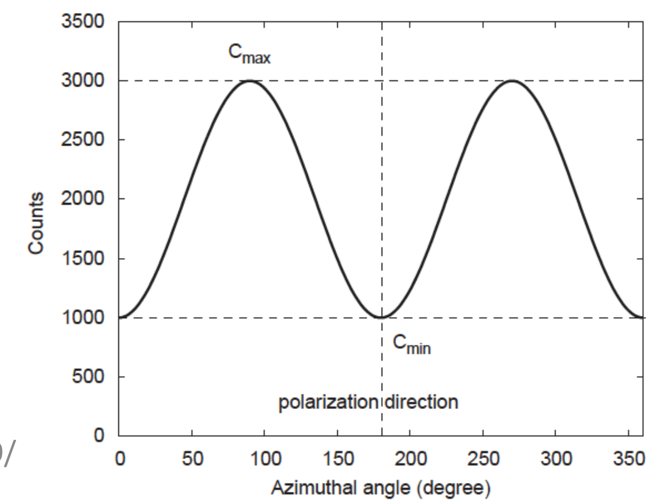
POLAR Detection Principle

- **Compton scattering of polarized photons**
  - **Measure rate as function of the azimuthal angle of the scatter plane**
  - **Plastic scintillators for optimal efficiency**



Plastic scintillators (low Z material)

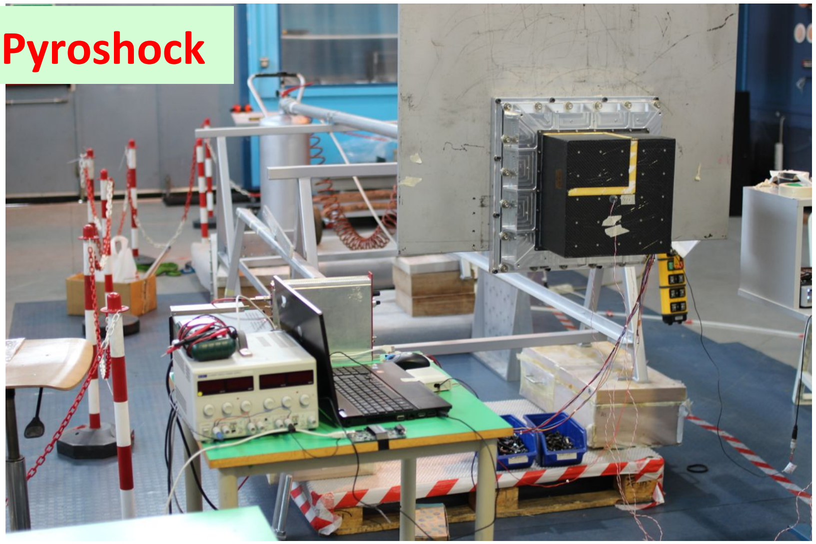




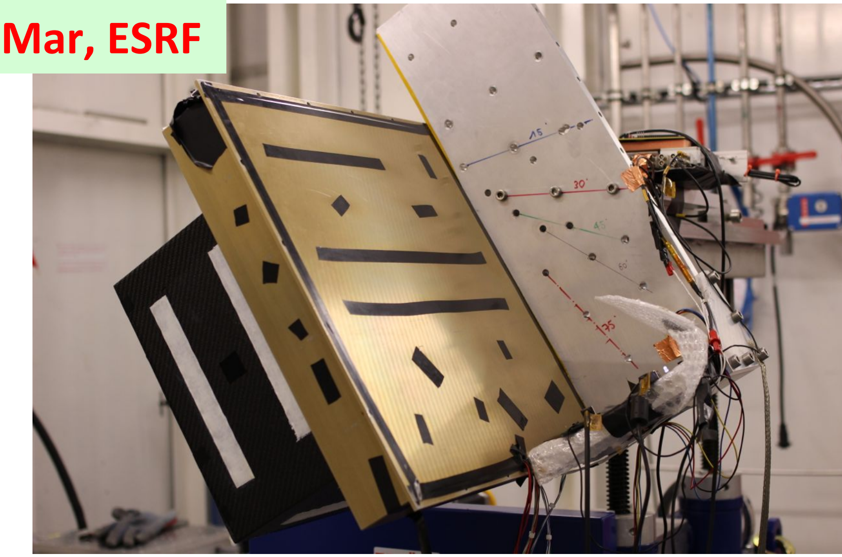
POLAR Status

- **Qualification campaign close to end with Qualification Model (QM)**

Feb, Pyroshock



Mar, ESRF



May, TVT

- **Flight Model (FM)**
  - **Currently under construction in UniGe**
  - **August: start tests on the FM in China**
- **Late 2015**
  - **Launch with the Tiangong-2 spacelab**

PANGU

盘古

A High Resolution Gamma-Ray Space Telescope

A. Bravar[1], M. Pohl[1], M. Su[2], R. Walter[3], X. Wu[1]

[1]DPNC, University of Geneva

[2]Kavli Institute for Astrophysics and Space Research, MIT

[3]ISDC, University of Geneva

Proposal Presented to the First Workshop on a CAS-ESA Joint Scientific Space Mission, 25-26 Feb. 2014, Chengdu

PANGU: PAir-productioN Gamma-ray Unit

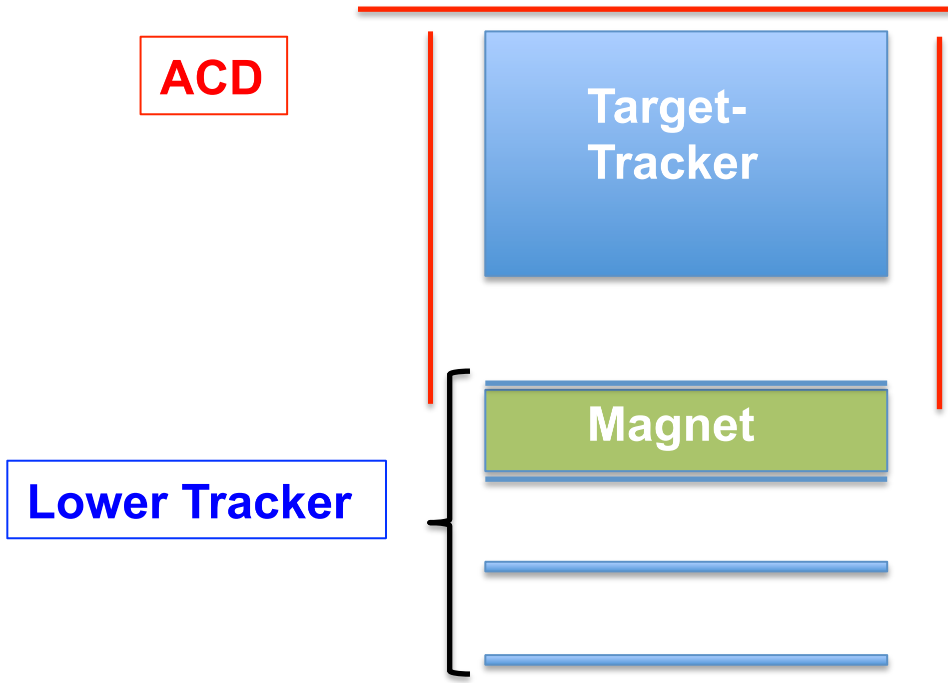
- **Sub-GeV γ-ray telescope with unprecedented angular resolution**
  - **$\lesssim$ 1° angular resolution in the ~100 MeV to ~1 GeV region**
  - **With polarization measurement capability**
- **Wide range of topics of galactic and extragalactic astronomy and fundamental physics**
  - **Complementary to the world-wide drive for a next generation Compton telescope (1-100 MeV)**
- **Innovative payload concept for a small mission**
  - **Thin target material (SciFi or Si) with magnetic spectrometer**

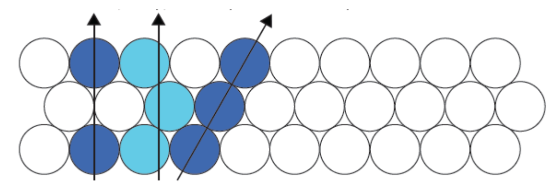
An unique instrument to open up a frequency window that has never been explored with great precision

Possible Detector Concepts

- To achieve ≲1° angular resolution passive material should be minimized and active detector should be thin or low density
  - To increase effective area (mass!) needs many layers or large volume
- Concepts for high resolution gamma pair telescope studied before
  - Low density gas TPC: *HARPO*, *AdEPT* (5-200 MeV), …
    - Potentially very good resolution
    - Need large pressure vessels (AdEPT: 6×1m^3 vessels for 20 kg gas)
  - All silicon, many optimized as Compton telescope (with calorimeter)
    - MEGA/GRM: Double-sided SSD, distance 5 mm, 500 μm thick
    - CAPSiTT: Double-sided SSD, distance 1 cm, 2 mm thick
    - TIGRE: Double-sided SSD, distance 1.52 cm, 300 μm thick
    - Gamma-Light: single-sided, distance 1 cm, 400 μm thick
  - Scintillating fiber
    - Previous concepts with converter: *SIFTER*, *FiberGLAST*
    - PANGU: a new all-fiber tracker concept

Sketch of a Possible PANGU Layout

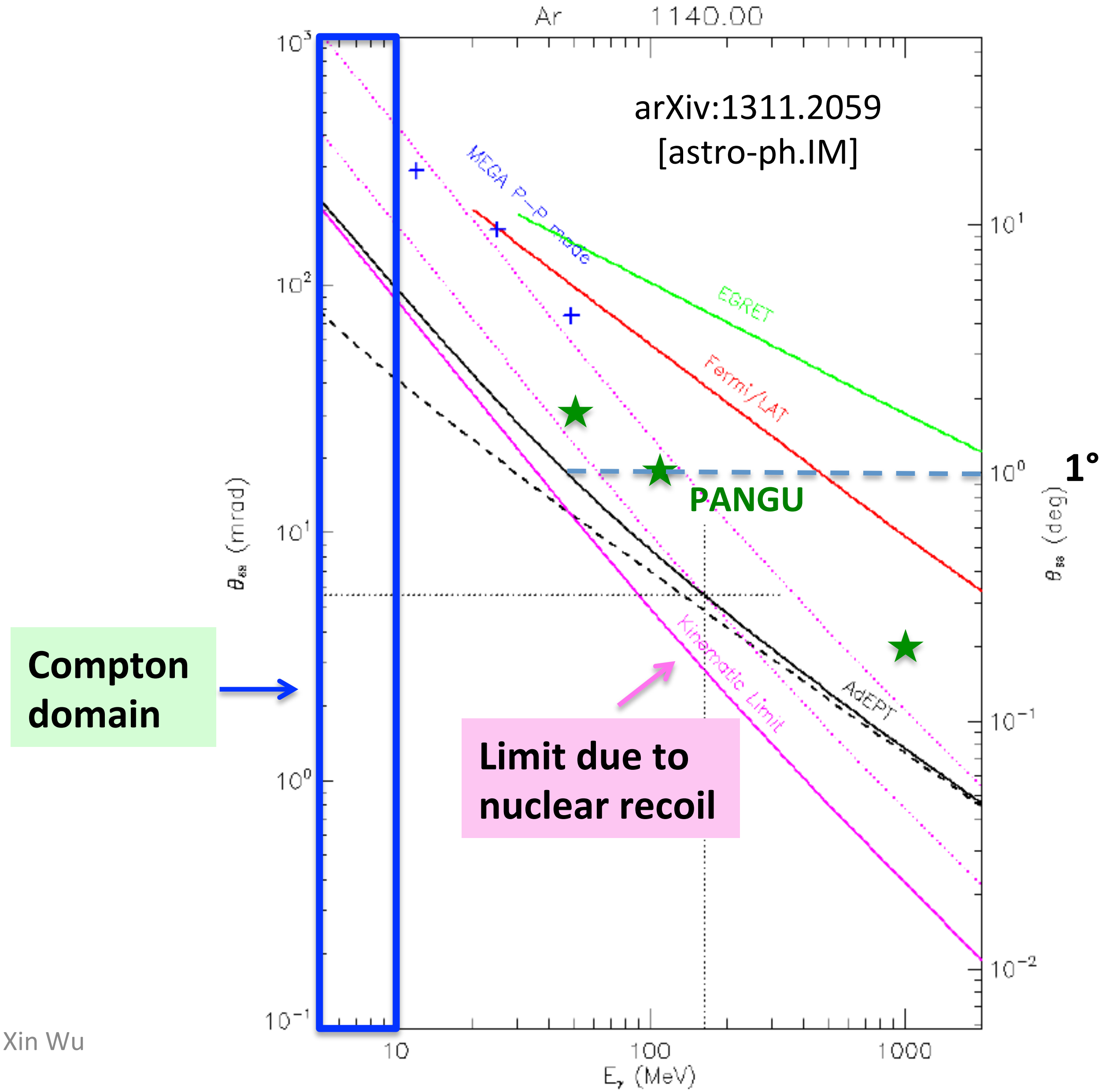




Target and magnet sizes can be easily scaled to fit with resource constraints!

- **3 sub-systems: target-tracker, magnet + lower tracker, Anticoincidence**
  - **Target-tracker : ~ 50 x 50 x 40 cm^3**
  - **Magnet: r_2 = 26 cm, r_1 = 25 cm, height 10 cm, field in +y direction**
  - **Lower tracker: one X-layer above, one X-layer, and two X-Y layers below, ~10 cm between layers, can also consider using Silicon**
  - **Anticoincidence detector (ACD) on 5 sides**

Angular resolution of pair telescopes

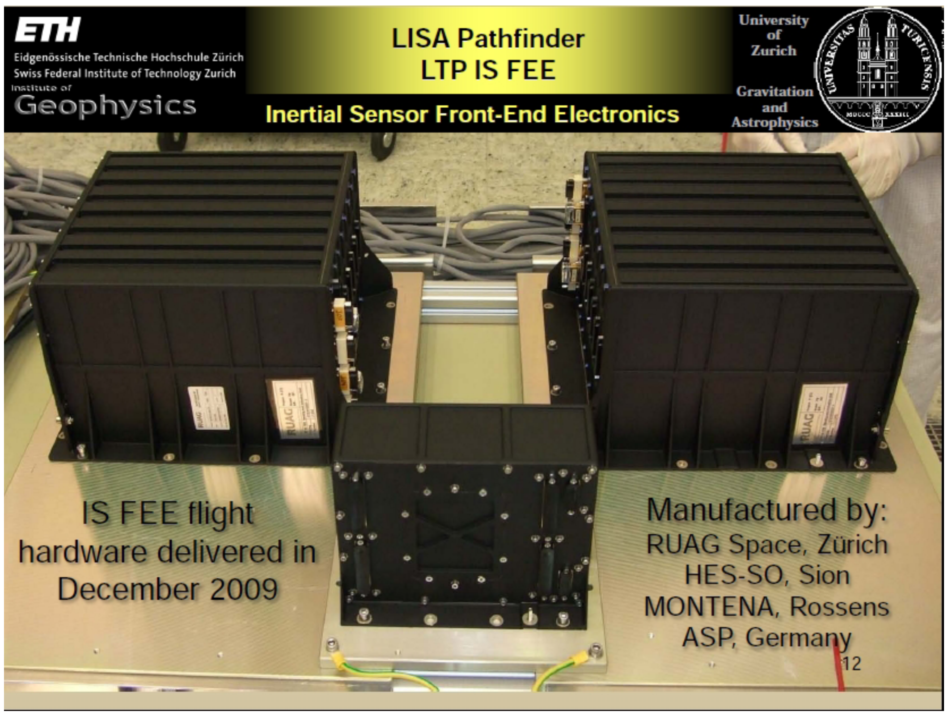


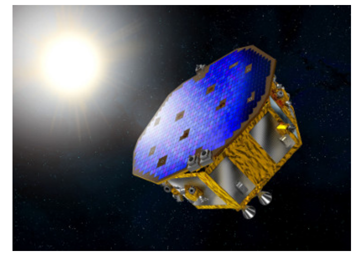
Gravitational Wave Detection: LISA Pathfinder

Theory group of Phys. Institute of UniZH + Institute of Geophysics of ETHZ

LISA Pathfinder launch in 2015

- **Technology verification mission for LISA (now eLISA)**





sub-nm sensing and positioning of the test mass in the ultra-low frequency band (mHz)

Conclusion

- Switzerland is participating in a healthy mixture of space astrophysics experiments that are in operation, in construction and in planning
- Astroparticle physics in space has entered a new era of precision measurements with AMS-02 and Fermi
  - Approaching TeV for electron/photon and multi-TeV for ions
- 3 major missions will go into operation in next 2 years
  - ISS-CREAM, CALET, DAMPE
  - Aim to improve energy resolution and acceptance in the TeV regime
- HERD may well be the next big step forward
  - Large acceptance and good energy resolution up to the PeV regime
  - High precision measurements of e/γ/ions all at the same time
- Growing synergy with keV-GeV missions both in science and detection

Exciting program of multi-messenger muilti-wavelength astroparticle physics research in the next 10-15 years!