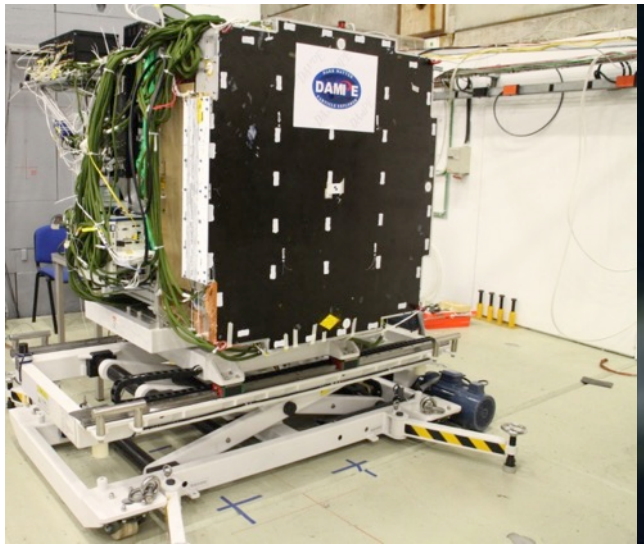



# DAMPE: a particle detector in space

Giovanni Ambrosi

INFN Perugia, Italy

(on behalf of DAMPE collaboration)

**CERN Detector Seminar**
**July 15°, Geneva**

# The physics goals

## High energy particle detection in space

- Study of the cosmic electron and photon spectra
- Study of cosmic ray protons and nuclei: spectrum and composition
- High energy gamma ray astronomy
- Search for dark matter signatures in lepton spectra

**Detection of**
**2 GeV - 10 TeV e/γ**
**50 GeV - 500 TeV protons and nuclei**
**with excellent energy resolution , tracking precision and particle identification capabilities**

- Exotica and "unexpected" , e.g. GW e.m. counterpart in the FoV

# The CR spectrum: the overall picture

**Direct measurements:**

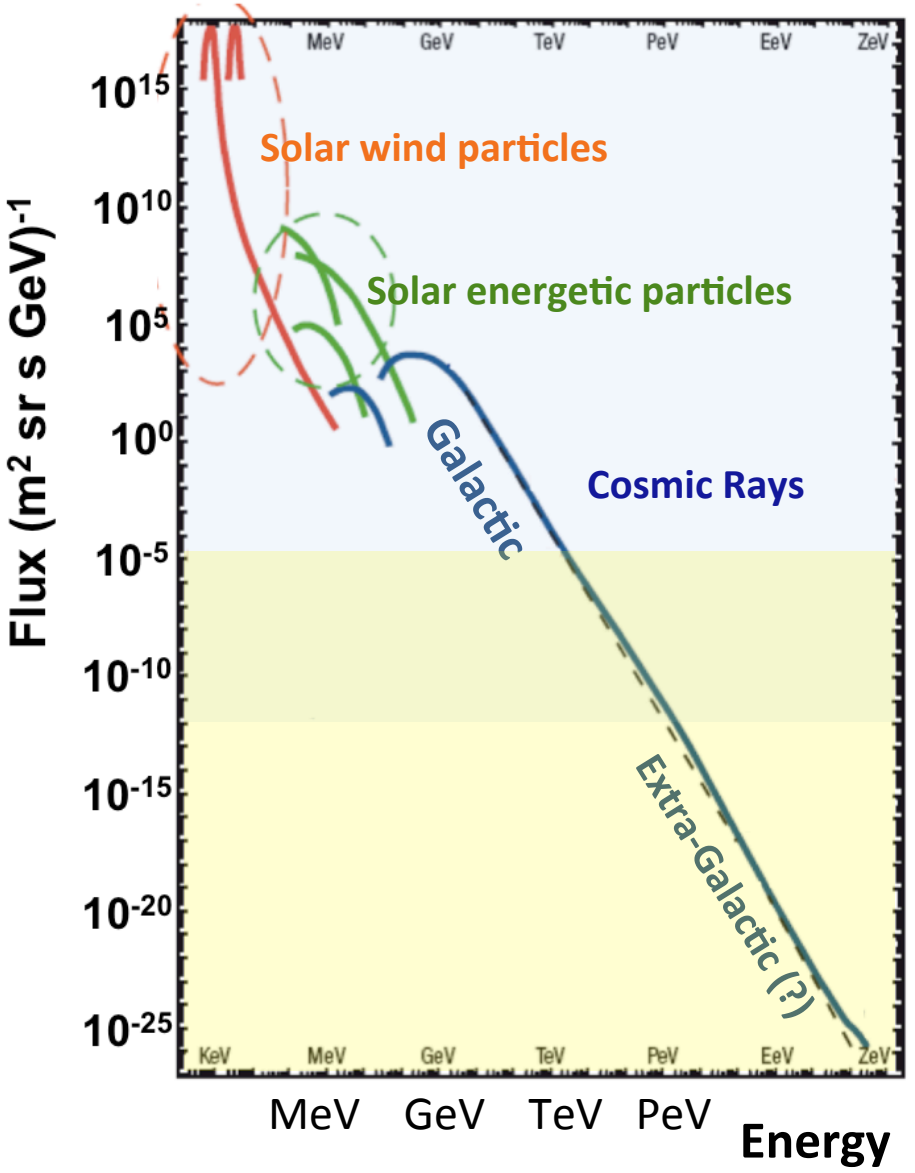
☺ Particle identification/Energy calibration, anti-matter

☹ Space: Weight/Size constraints limit the energy range (< PeV)

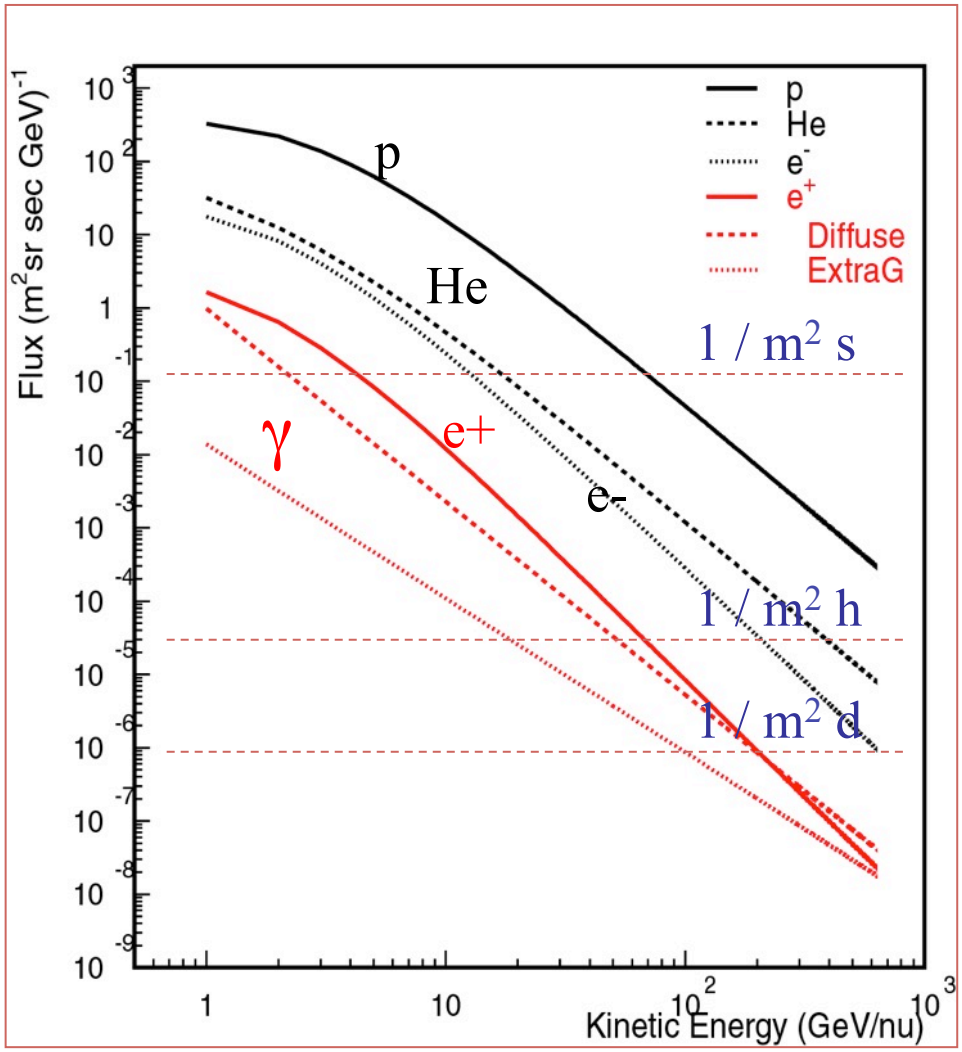
**Indirect measurements:**

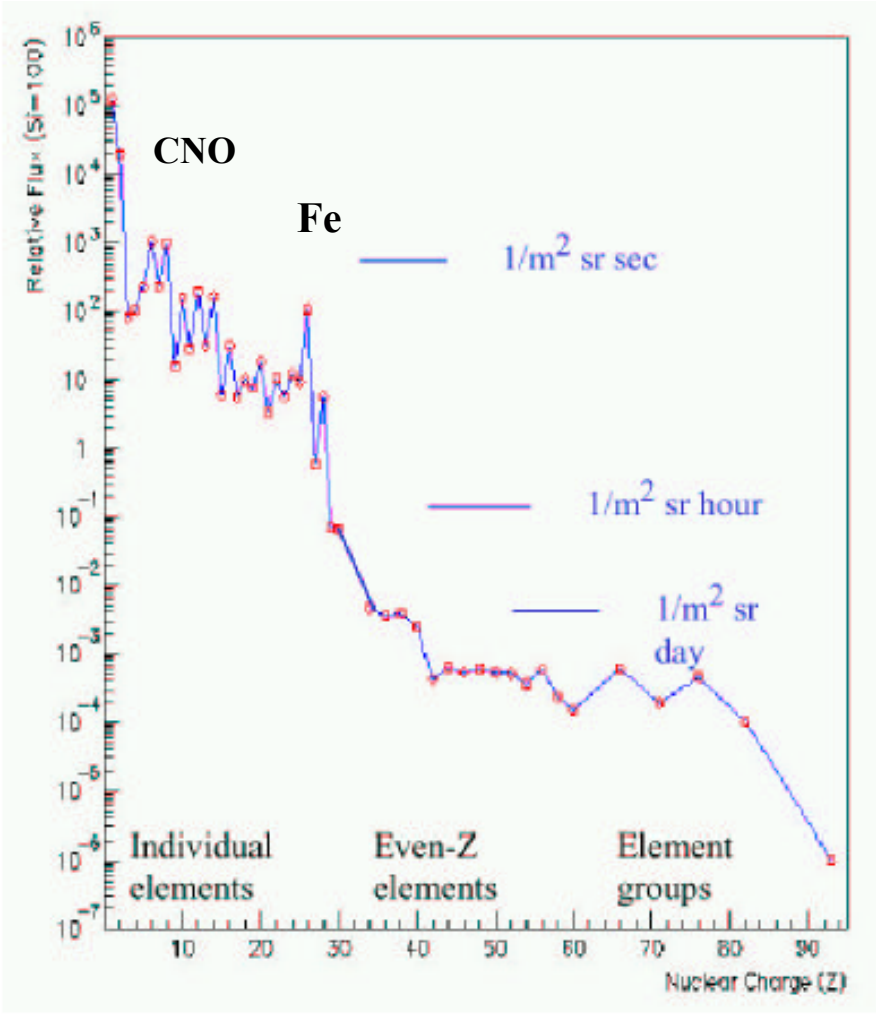
☺ Ground: Extended energy range (>PeV)

☹ Pid/Energy : dependence on modelling of atmospheric interactions

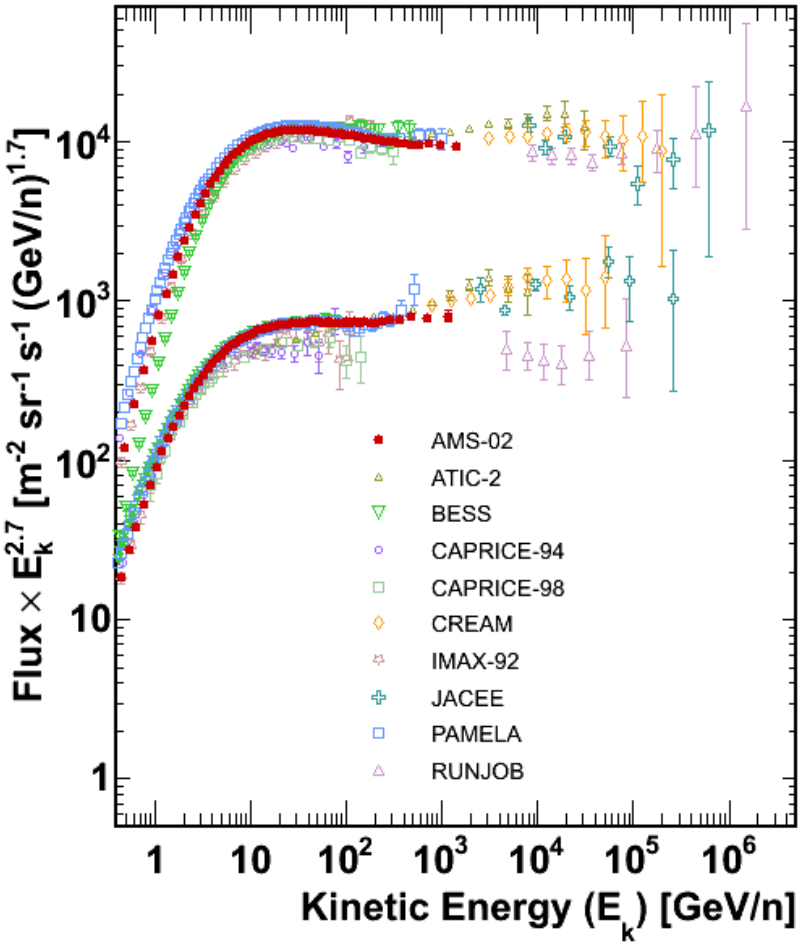


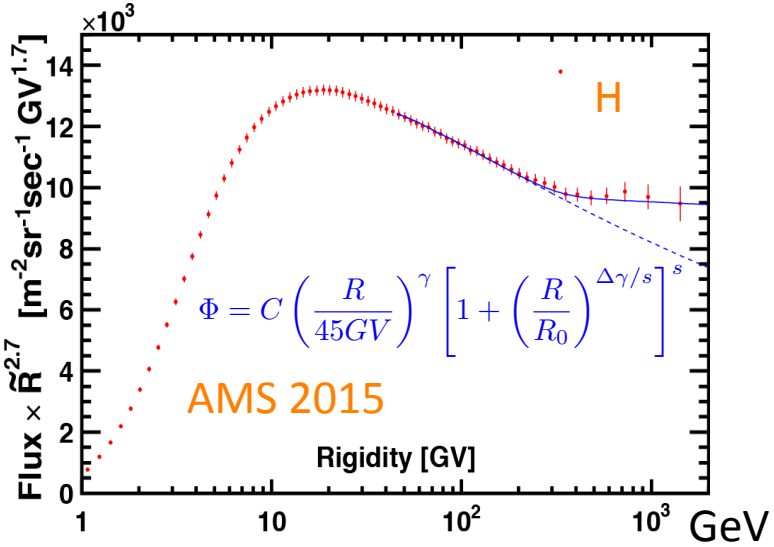
# CR flux and composition

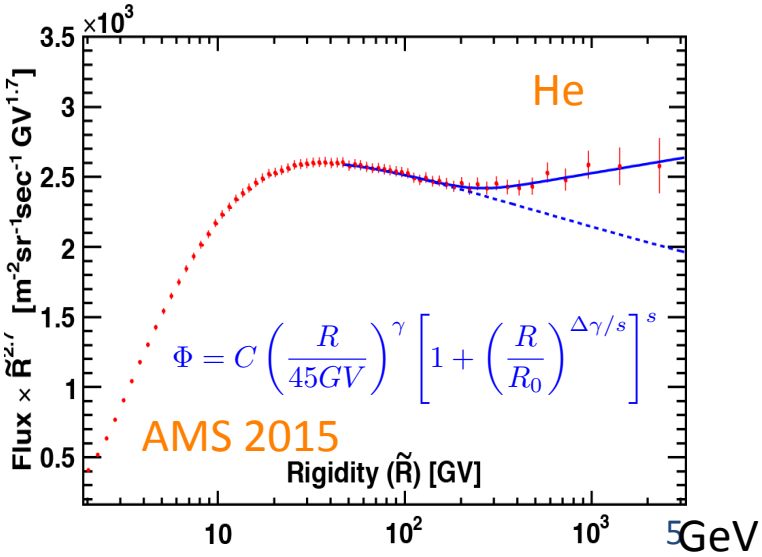


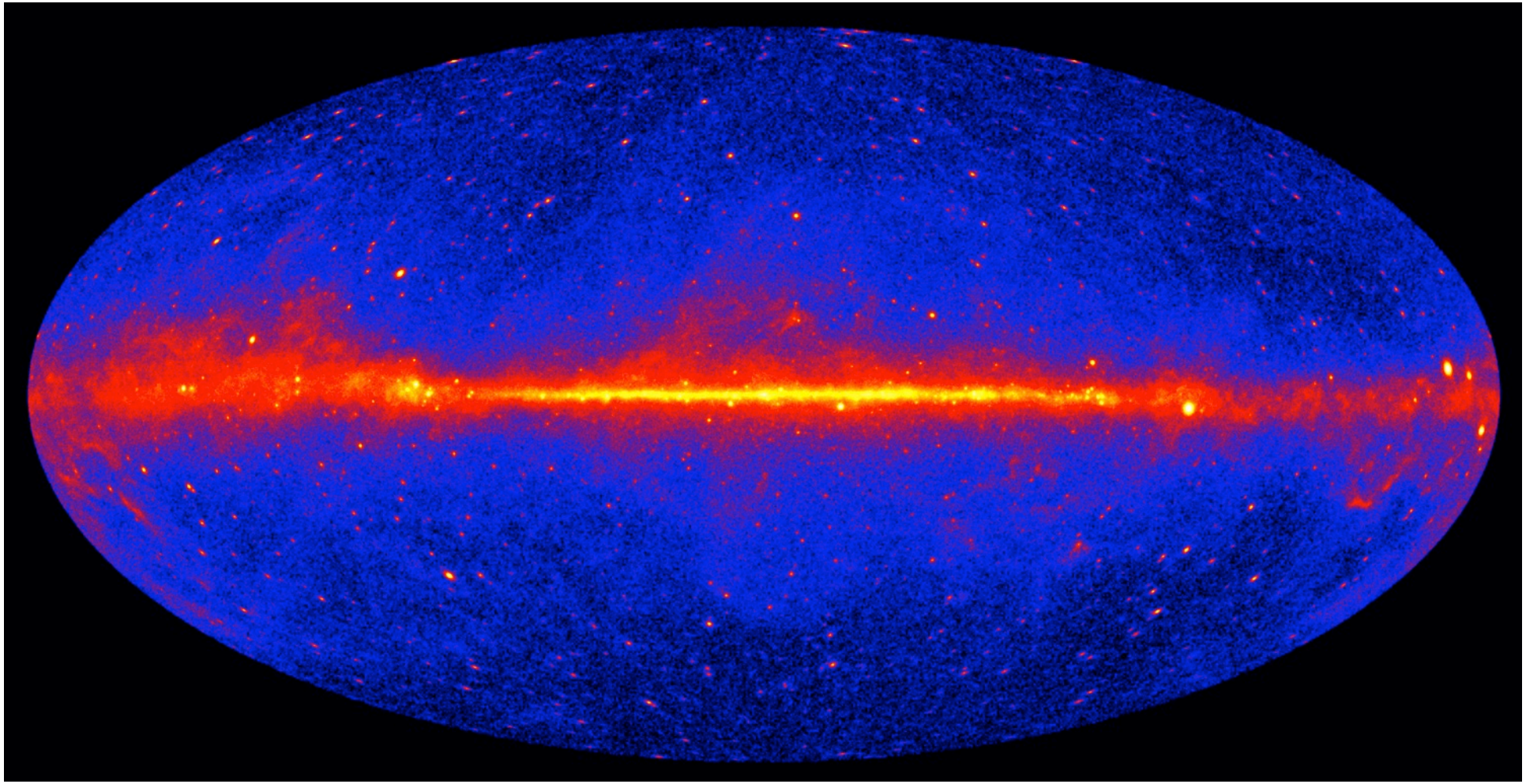
# AMS-02 : the smooth change of spectral index

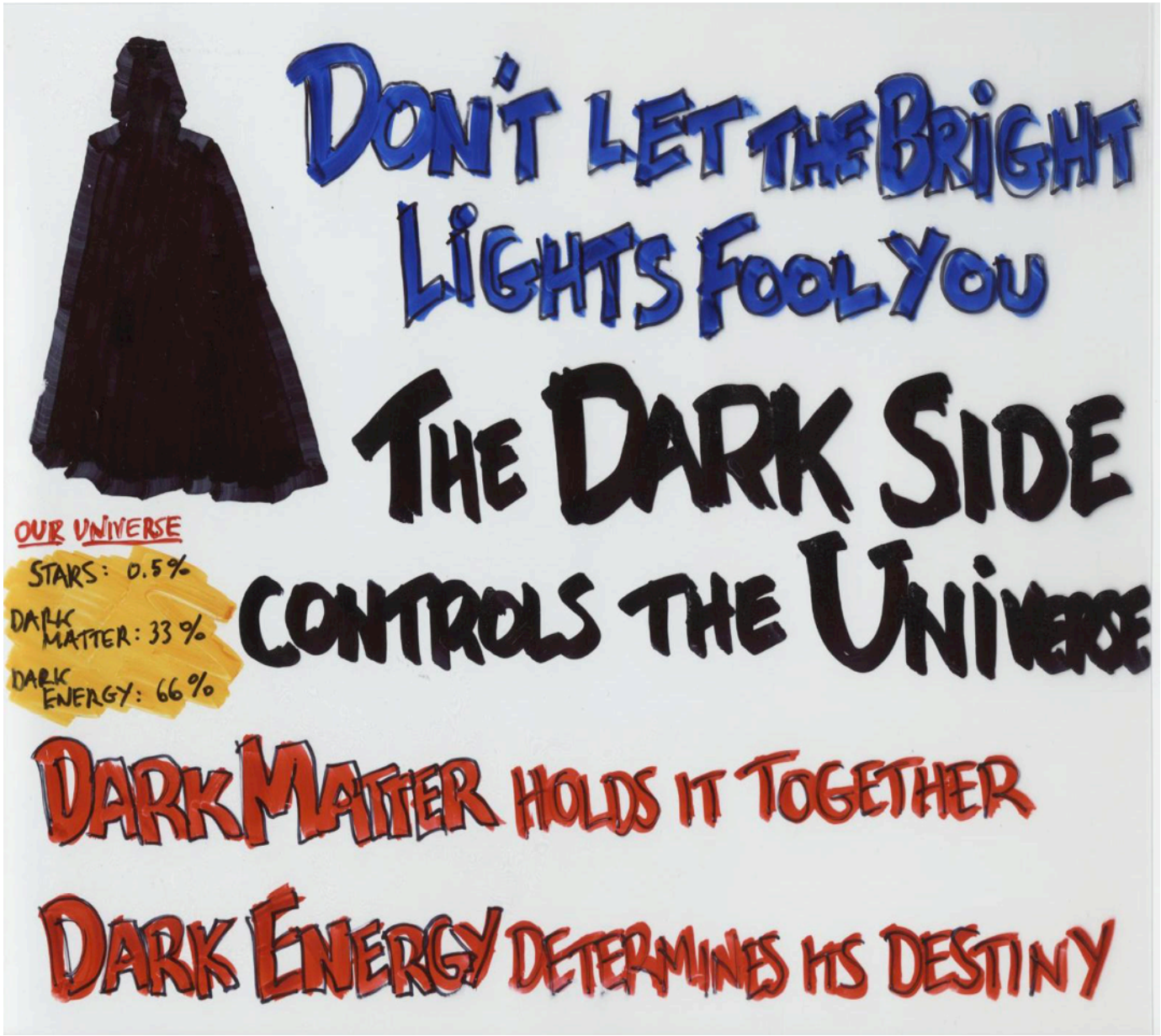


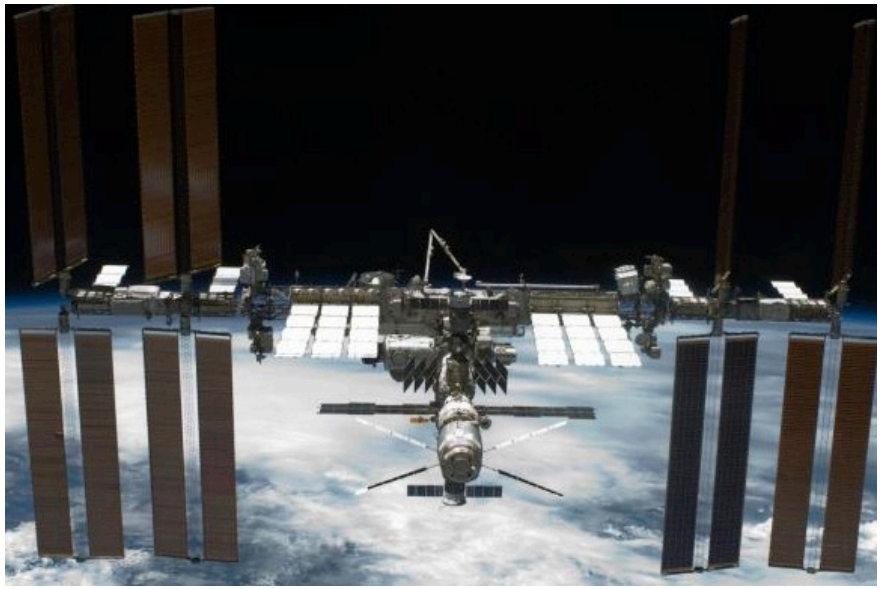
# FERMI all sky map






Turner @ ICRC 2003

# The experimental challenge



**DIRECT ≠ EASY**

**No atmosphere**: Stratospheric Balloons
Space

**Limits on size and time:** Detector design focused on specific measurements

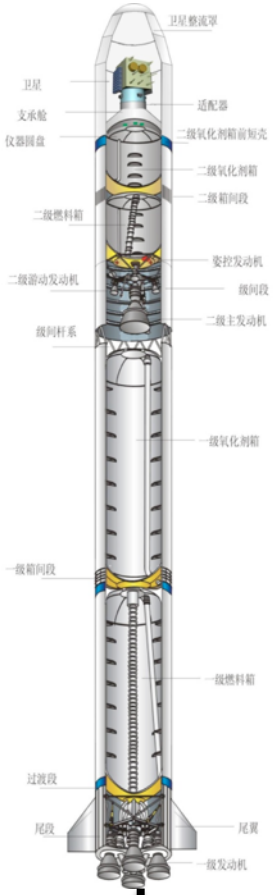
# The instrument we need has …

- performance a la 'particle physics':
  - high resolution measurements of energy, charge, particle id, momentum, velocity
- characteristics to properly work in the space environment:
  - Vibration (9 G rms) and acceleration (up to 500 G)
  - Temperature variation (day/night $\Delta T = 100^{o}C$)
  - Vacuum ($10^{-10}$ Torr)
  - Orbital debris and micrometeorites
  - Radiation (Single Event Effect)
- limitation in weight, power, bandwidth and maintenance
- compliant with EMI/EMC specs

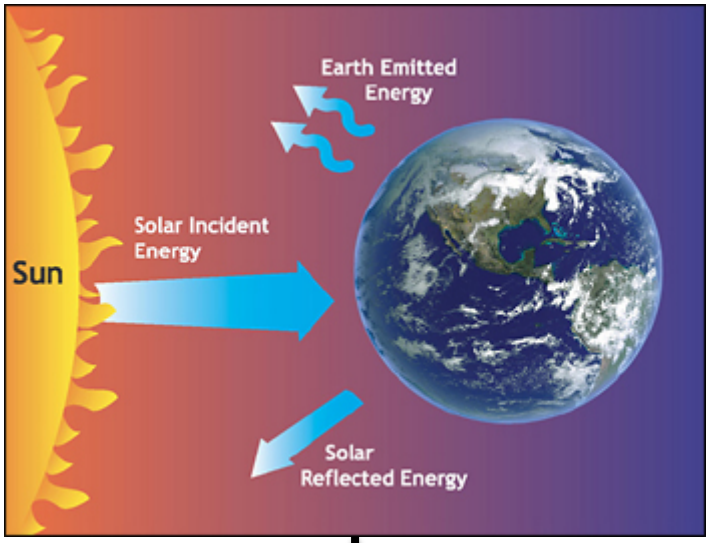
- Produce two pieces: Qualification Model and Flight Model

exact stress and limitation values depend from the detail of the mission

# Operation in space



Mechanical stress at launch:
- Static acceleration
- Random vibration
- Sinusoidal vibration
- Pyroshock




Life in space:
- Thermal stresses due to Sun-light (seasonal / day-night effects)
- Vacuum

Careful Design, Model validation and Qualification are needed to ensure *highest possible reliability*

# The physics goals

## High energy particle detection in space

- Study of the cosmic electron and photon spectra
- Study of cosmic ray protons and nuclei: spectrum and composition
- High energy gamma ray astronomy
- Search for dark matter signatures in lepton spectra

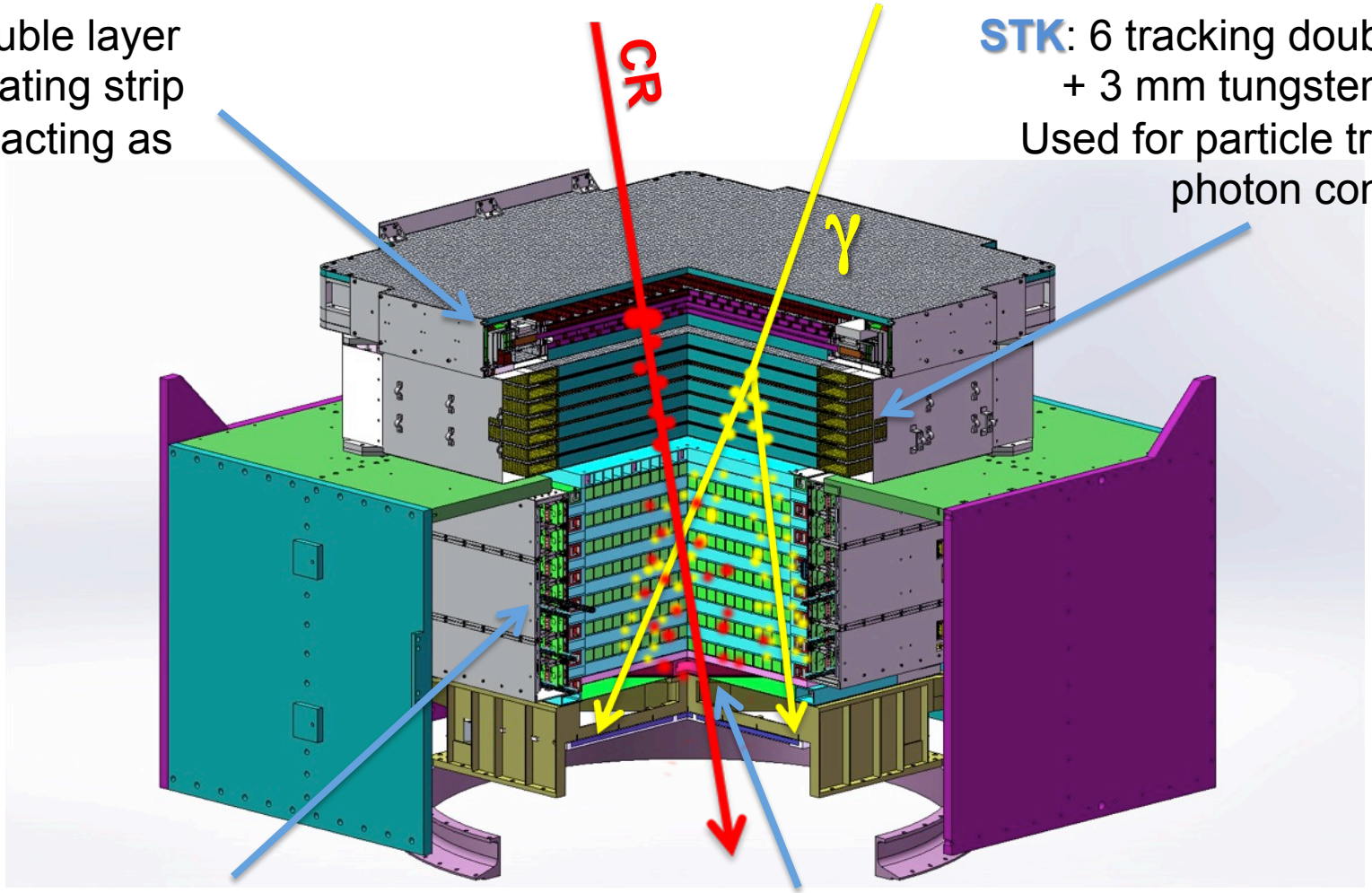
**Detection of**
**2 GeV - 10 TeV e/γ**
**50 GeV - 500 TeV protons and nuclei**
**with excellent energy resolution , tracking precision and particle identification capabilities**

- Exotica and "unexpected" , e.g. GW e.m. counterpart in the FoV

# The detector

**PSD**: double layer of scintillating strip detector acting as ACD

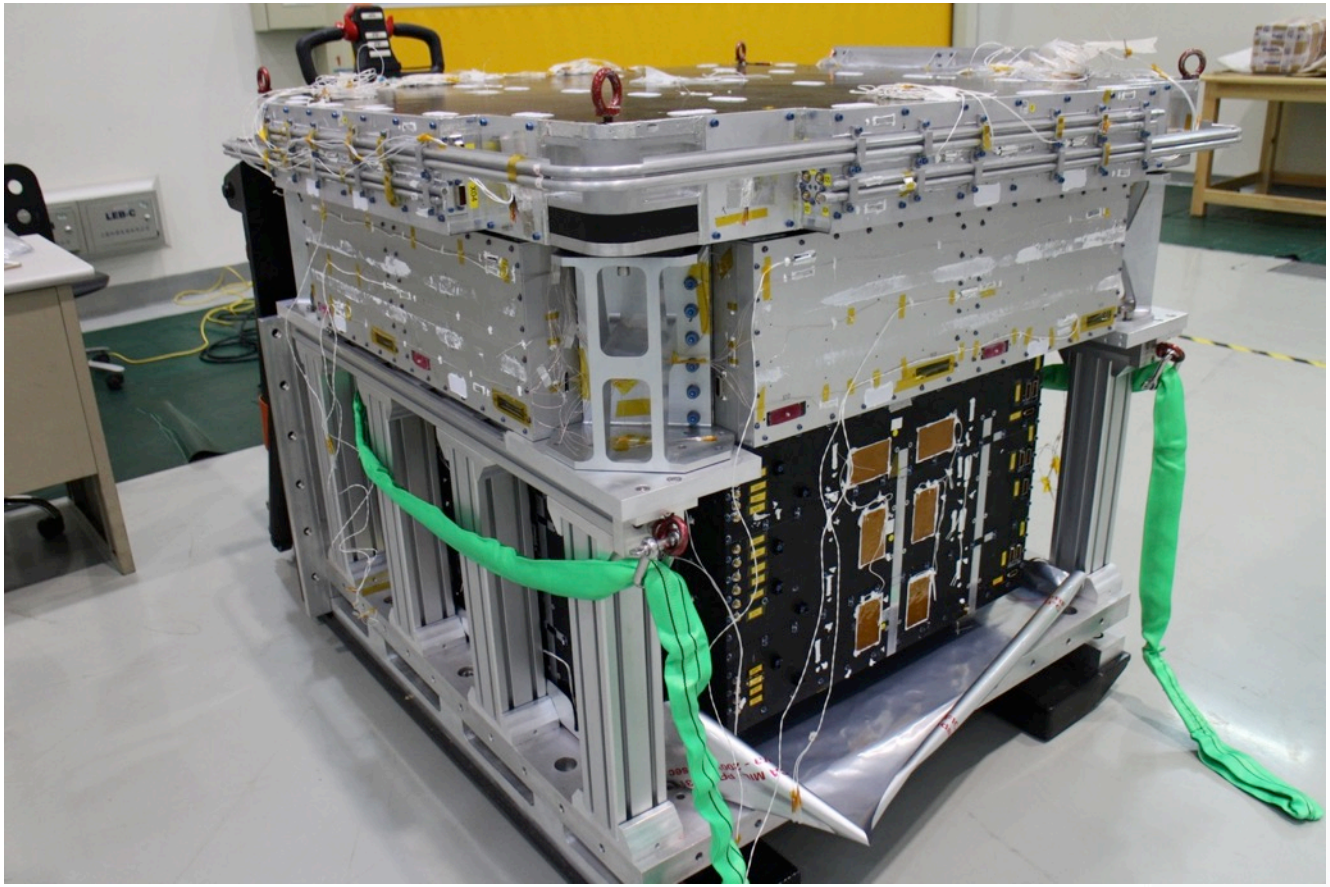
**STK**: 6 tracking double layer + 3 mm tungsten plates. Used for particle track and photon conversion

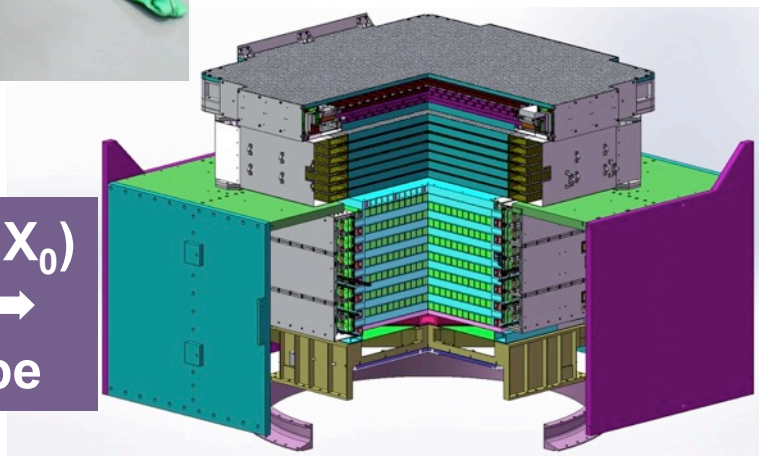



**BGO**: the calorimeter made of 308 BGO bars in hodoscopic arrangement (~31 radiation length). Performs both energy measurements and trigger

**NUD**: it's complementary to the BGO by measuring the thermal neutron shower activity. Made up of boron-doped plastic scintillator

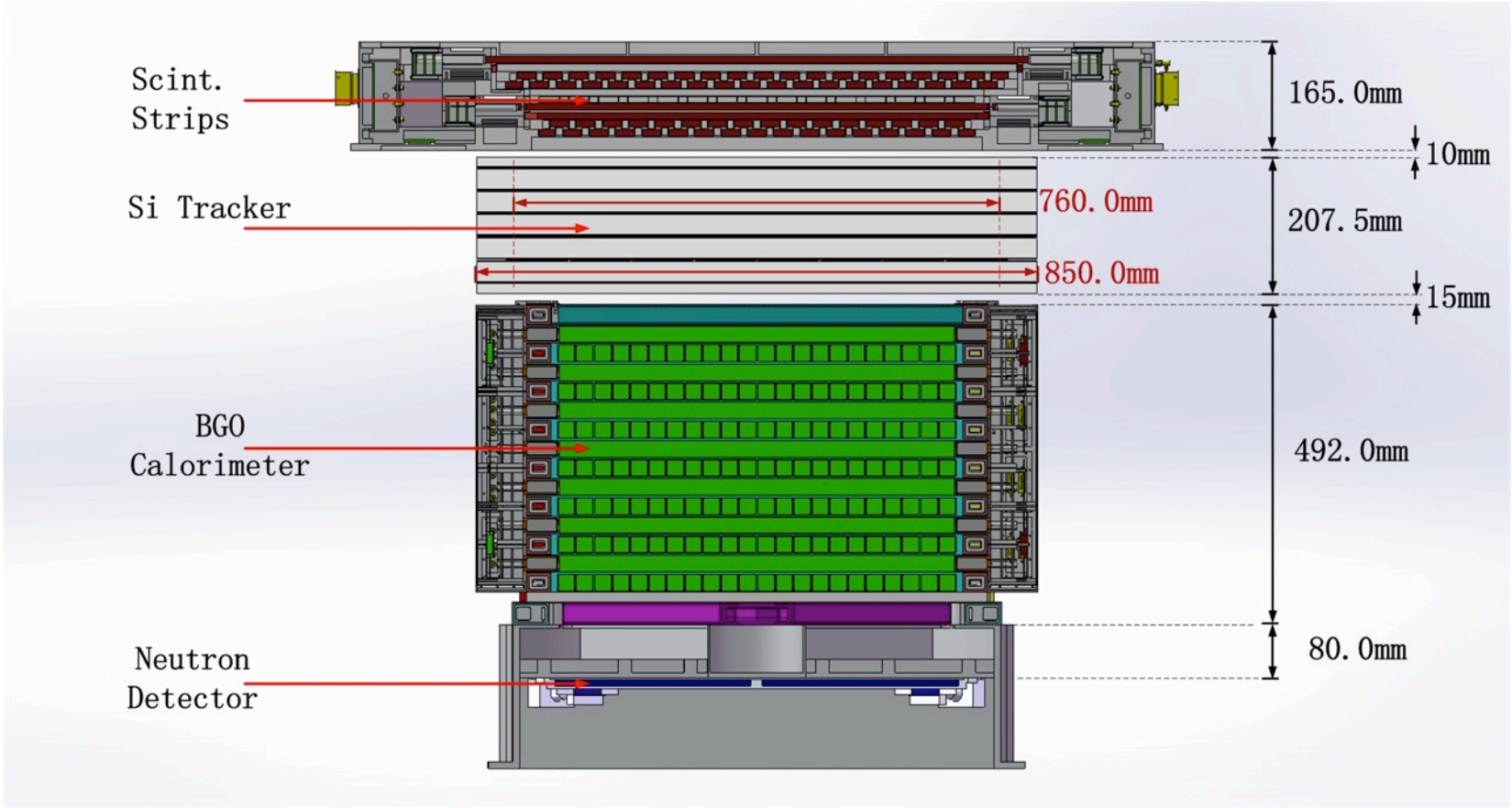
# The detector (1)





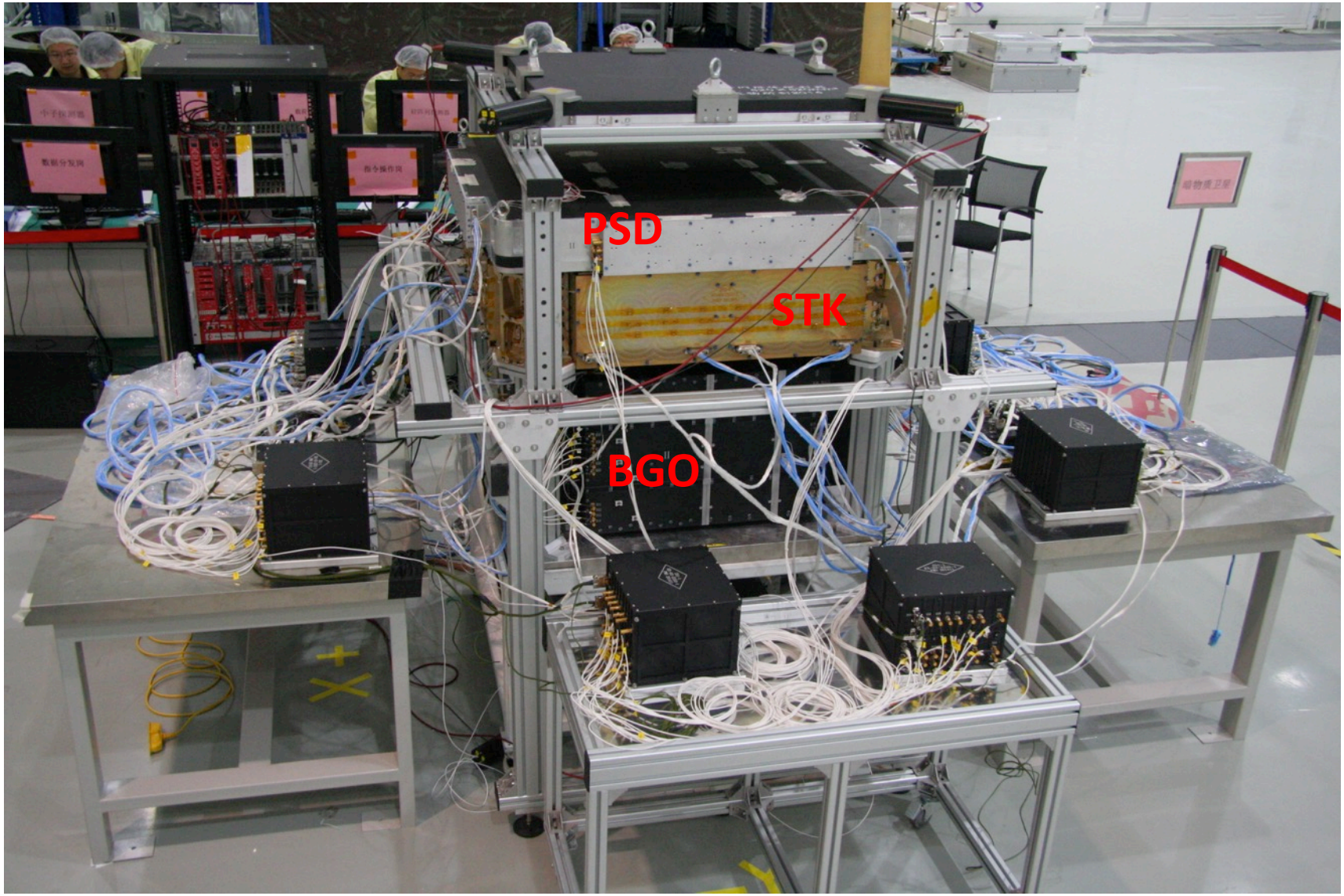
**W converter (1.43 $X_0$) + thick calorimeter (31 $X_0$) + precise tracking + charge measurement ➠ high energy $\gamma$-ray, electron and CR telescope**

# The detector (2)




**Mass: 1400 Kg**
**Power: ~ 400 W**
**Data: 12 Gbyte/day**
**Liftime: 5 years**

# FM final integration (06/2015)



# The collaboration

- **CHINA**
  - Purple Mountain Observatory, CAS, Nanjing — ***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

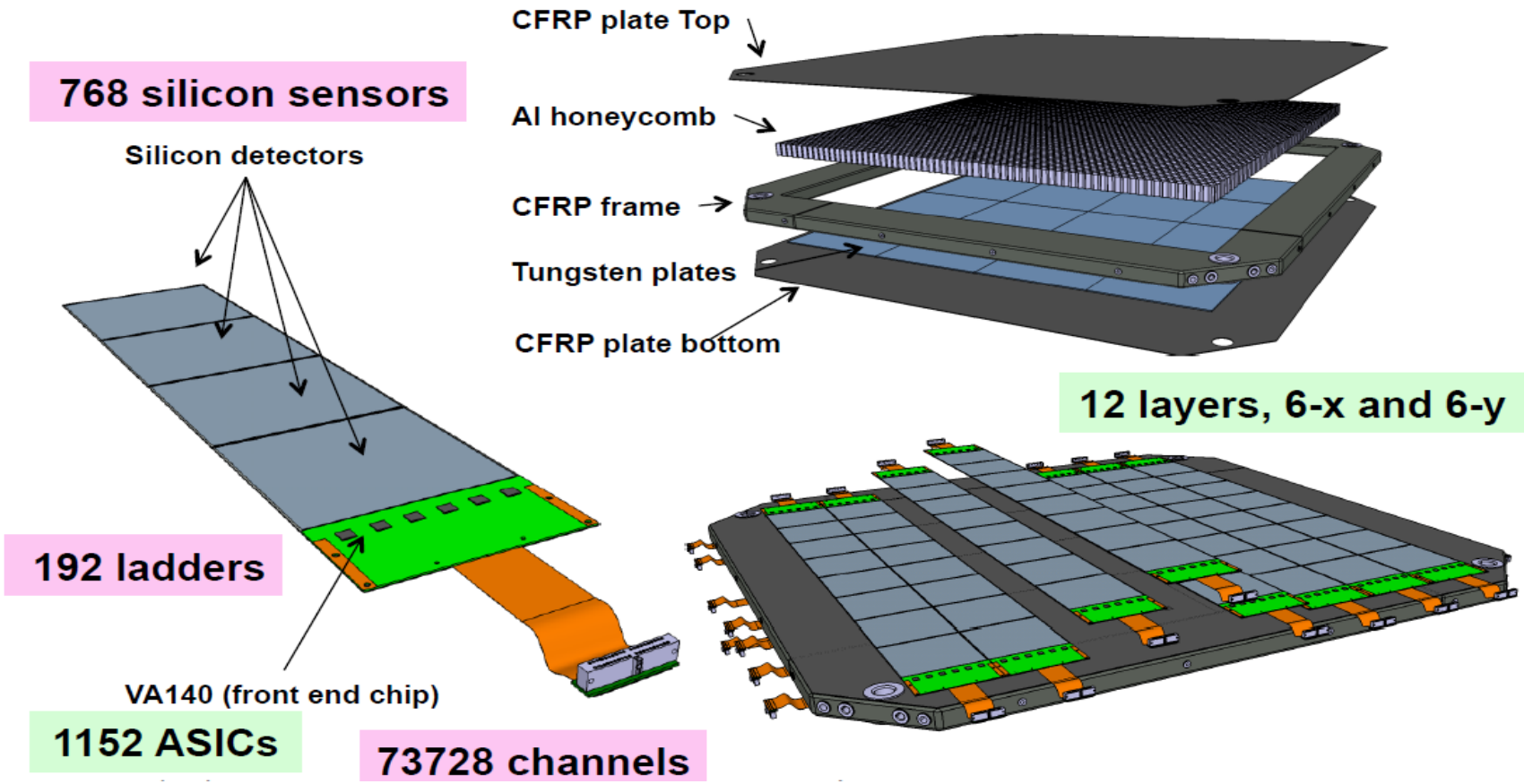
- **ITALY**
  - INFN Perugia and University of Perugia
  - INFN Bari and University of Bari
  - INFN Lecce and University of Salento

- **SWITZERLAND**
  - University of Geneva

# MoU signed on April 2013

CAS (China), Geneva Uni (Switzerland), INFN (Italy)

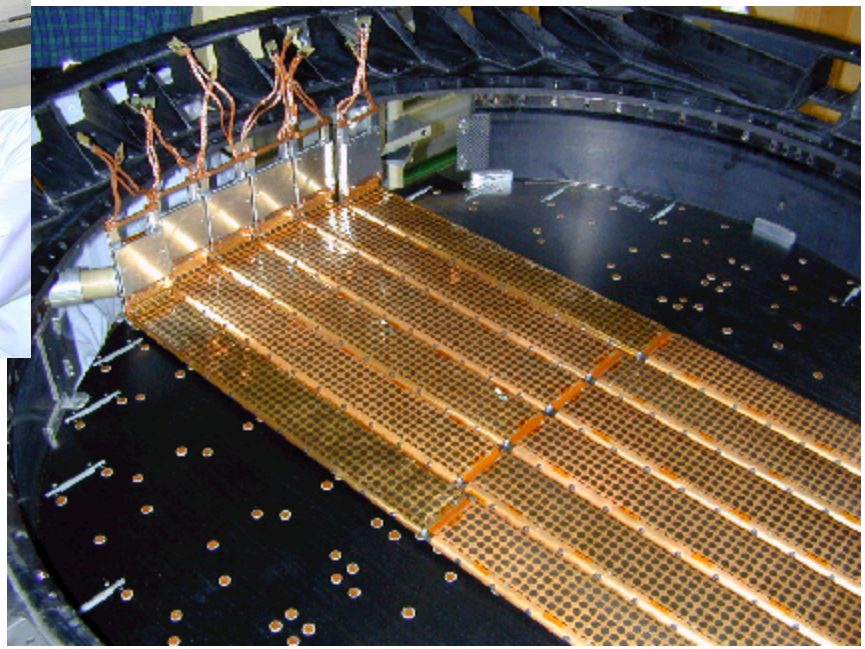
# The Silicon TracKer (STK)



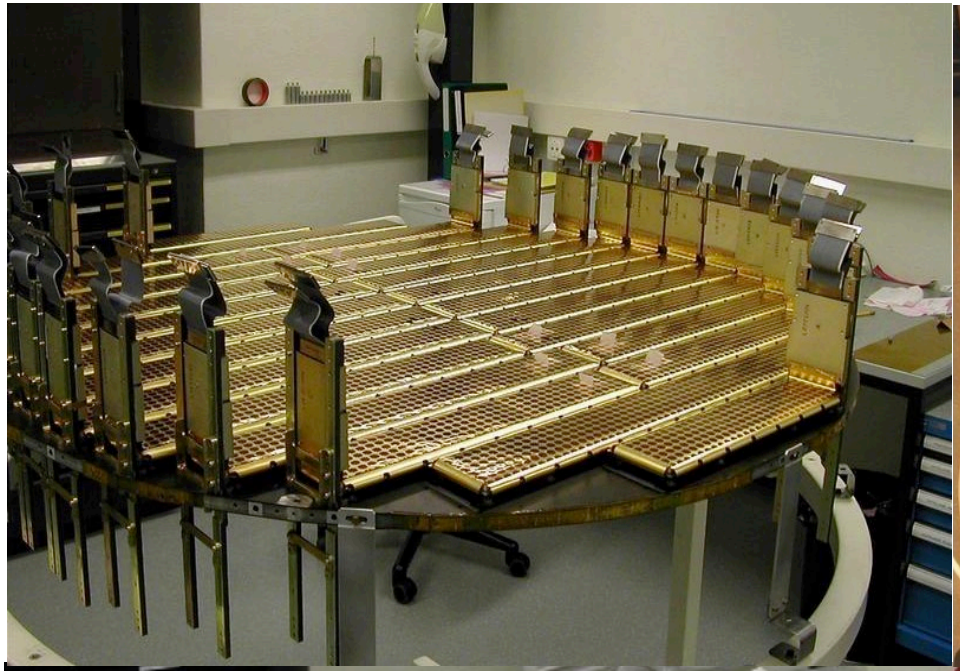

- 48 μm wide Si strips with 121 μm pitch
- (95 × 95 × 0.32 mm³) Silicon Strip Detectors (SSD) with 768 strips
- One ladder composed by 4 Silicon Strip Detectors (SSD)
- 16 Ladders per layer (76 cm × 76 cm )
- 12 layers (6x + 6y)

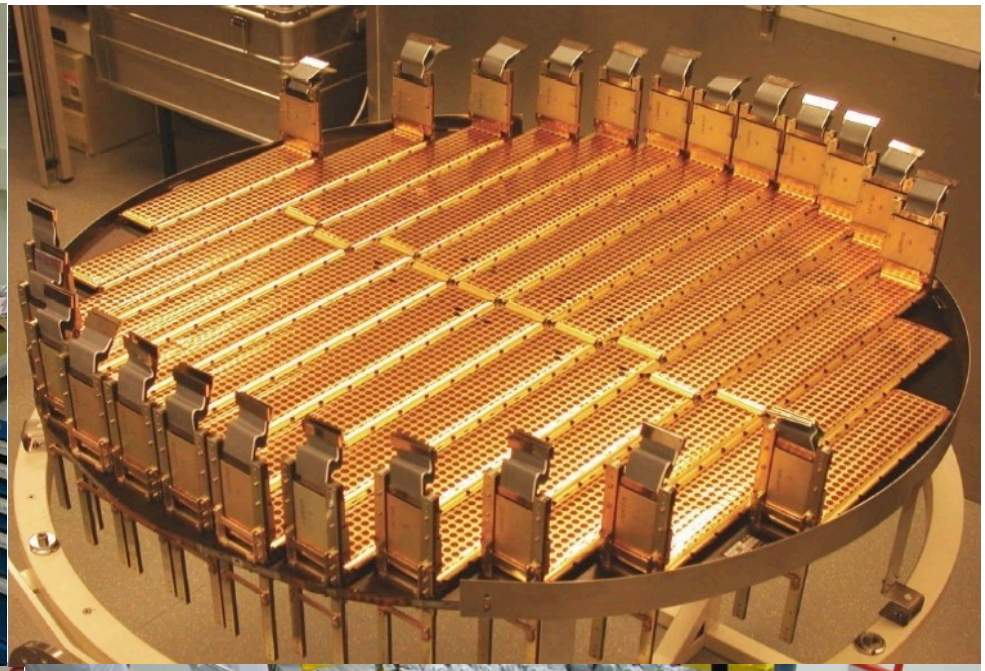
Analog Readout of each second strip:
384 channels / SSD- Ladder
Charge sharing

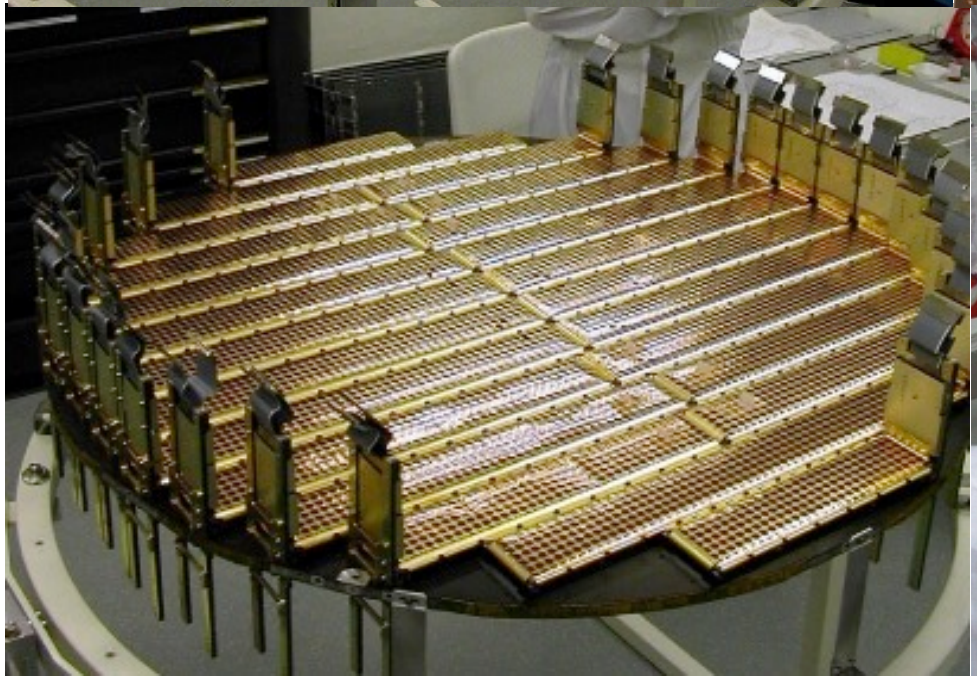
# AMS-01 Silicon Tracker



# AMS-02: 9 planes with 200,000 channels aligned to 10 microns

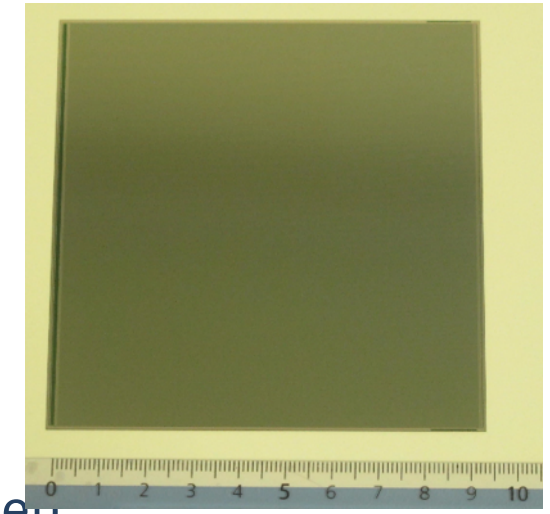


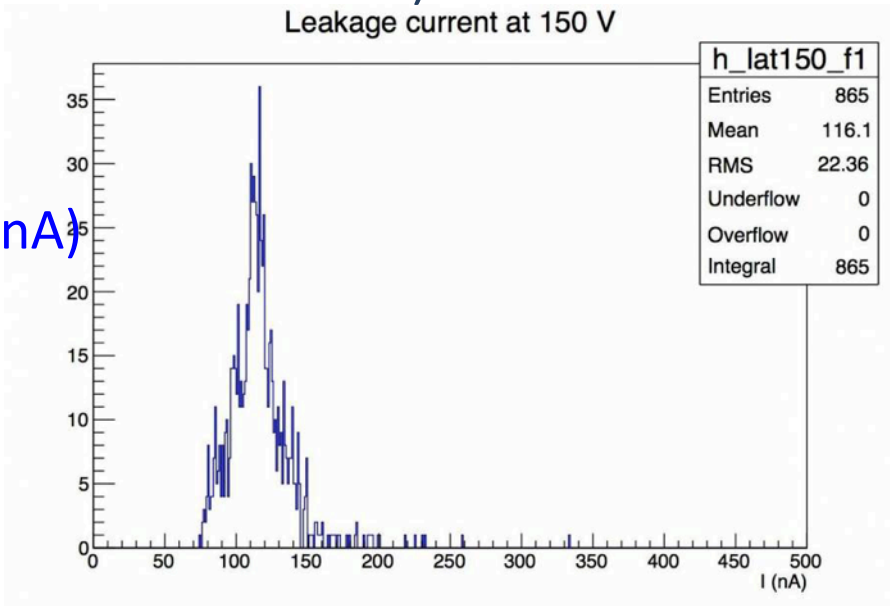




# STK Silicon Sensors

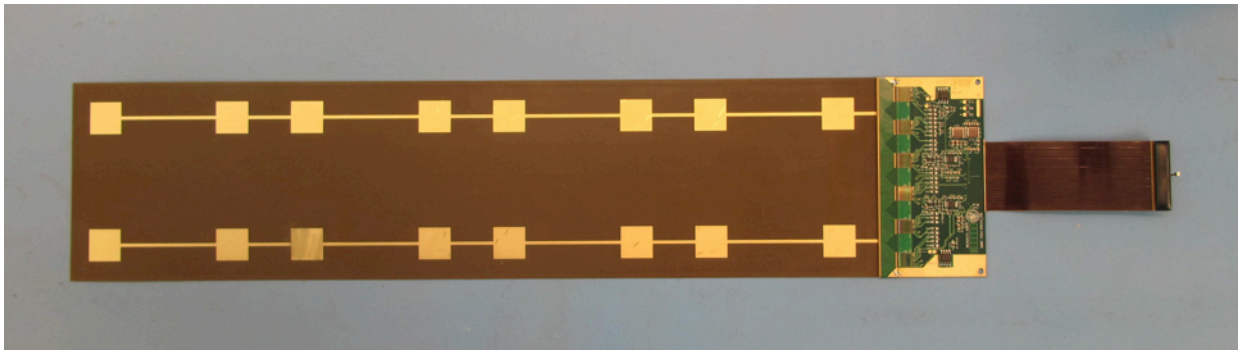
- Single-sided Silicon strip detectors produced by Hamamatsu
  - 9.5 x 9.5 $cm^2$, 768 strips, 121 µm pitch (AGILE geometry)
  - 320 µm thick (AGILE: 410 µm)
  - Resistivity 5-8 kΩ, $V_{fd}$ 10-80 V
  - Total strip capacitance 2.1 pF/cm
- 150 SSDs for EQM (Engineering and Qualification Model)
- 865 SSDs for FM (Flight Model)
  - Excellent quality
  - $<I_{leak}>$ ~120 nA @150V (spec: <900 nA)
  - $V_{fd}$ < 50 V
  - Very few bad channels
  - Cut precision: ~ few µm

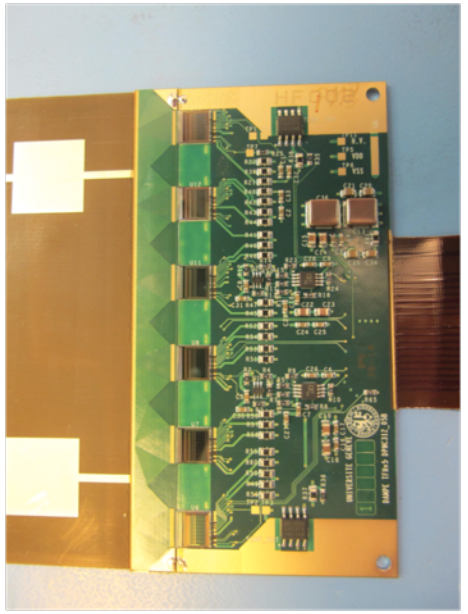




# STK Readout Electronics

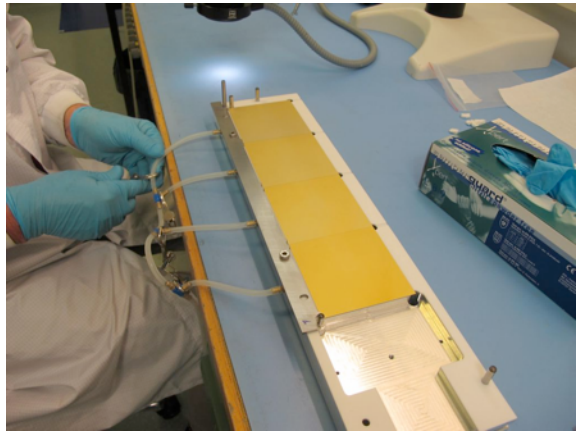
- Readout every other strip, readout pitch 242 µm
- ASIC: VA140 from IDEAS, updated version of VA64hdr of AMS-02
  - Low power (0.3 mW/channel) and large dynamic range (200 fC)
  - Analog readout
    - Charge measurement
    - Better position resolution with charge sharing
- Tracker Front-end Hybrid (TFH)
  - Thin bias circuit integrated with a PCB housing 6 ASICs, and a readout cable ("pigtail")
  - Support structure for the SSDs
  - Vias and copper bands for heat transfer

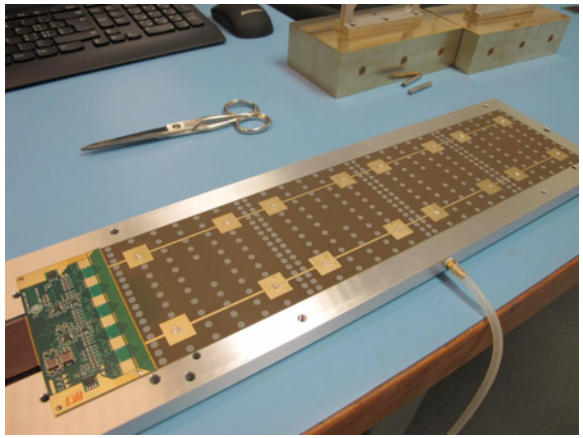


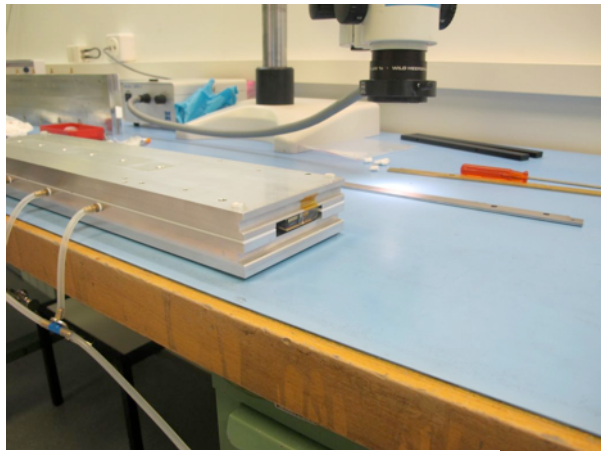


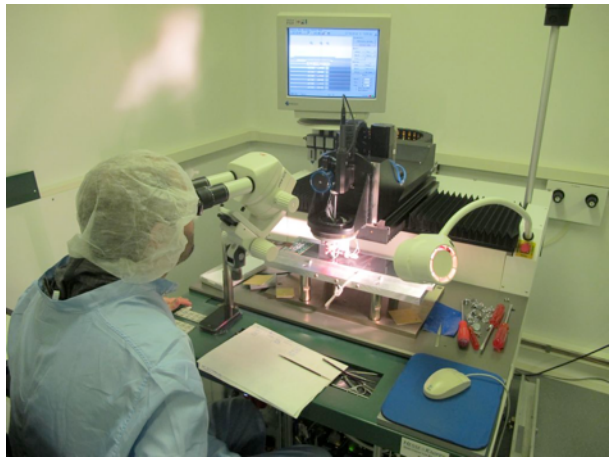
# STK Silicon ladders

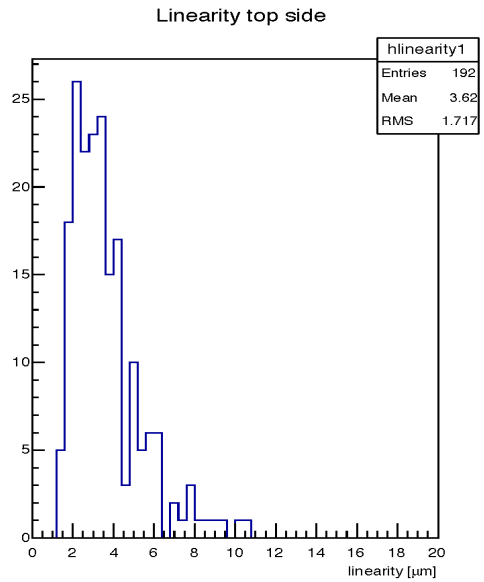
- Precise jigs to assemble (align, glue and bond) 4 sensors to form a ladder
  - require 20 µm alignment precision ⟹ achieved, most (~97%) <10 µm

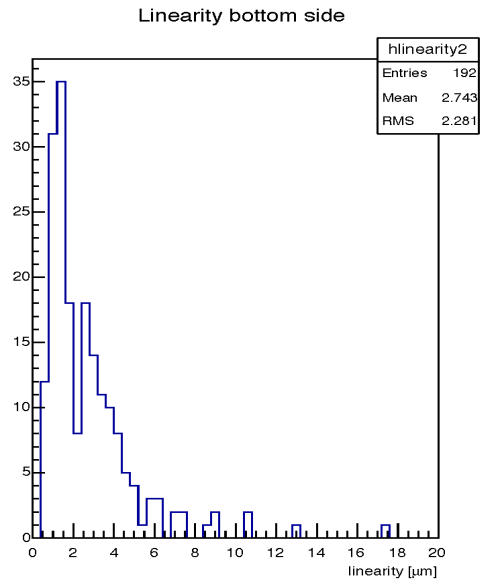






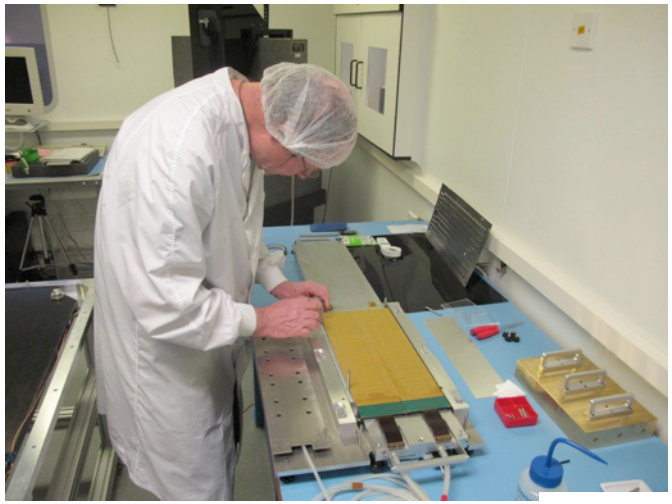


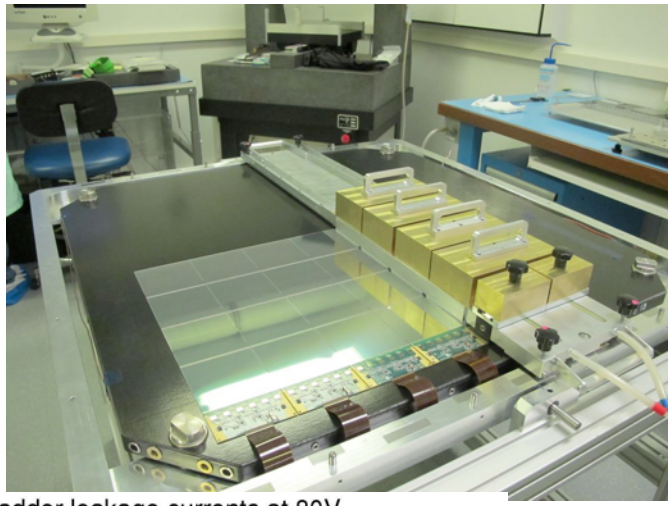


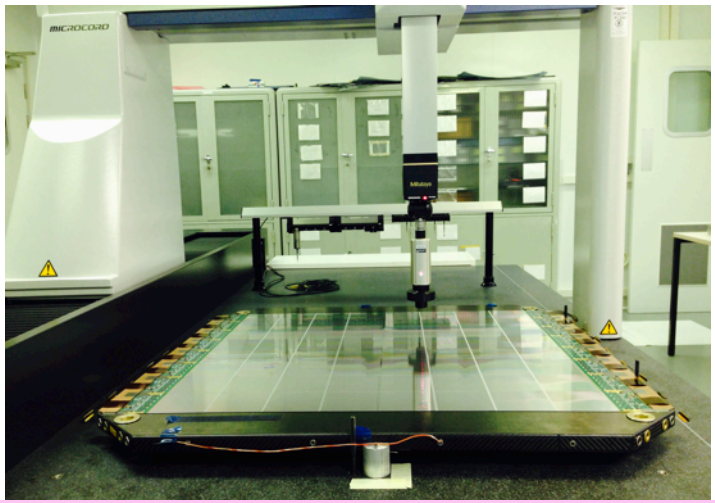



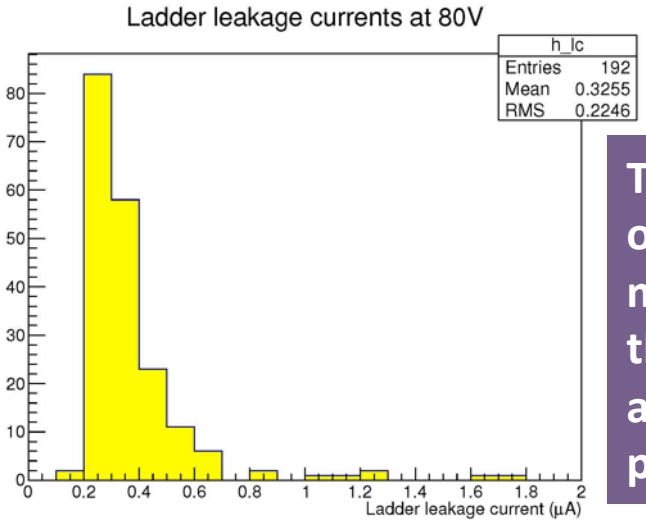
# STK Tracker planes

- 16 ladders glued to each surface of the support trays (except top and bottom)







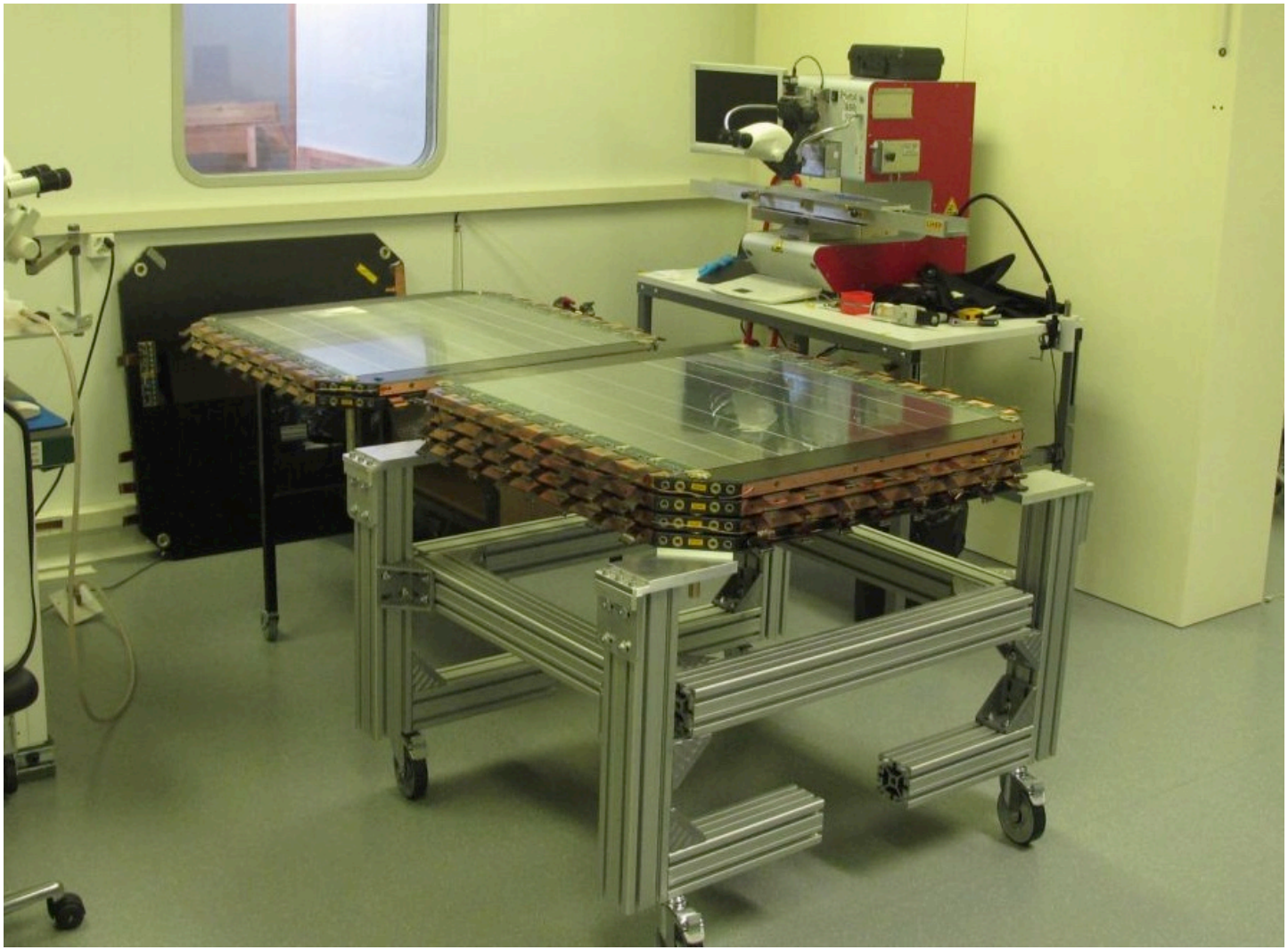



**The excellent quality of the silicon sensors maintained through the ladder production and plane assembly processes!**

Assembled planed are measured with metrology machine, flatness ~100 µm

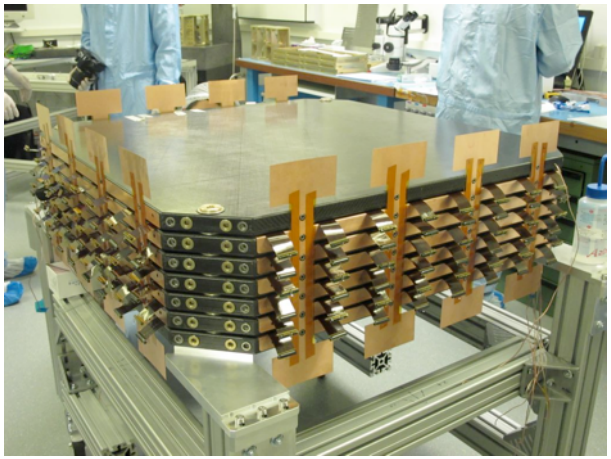
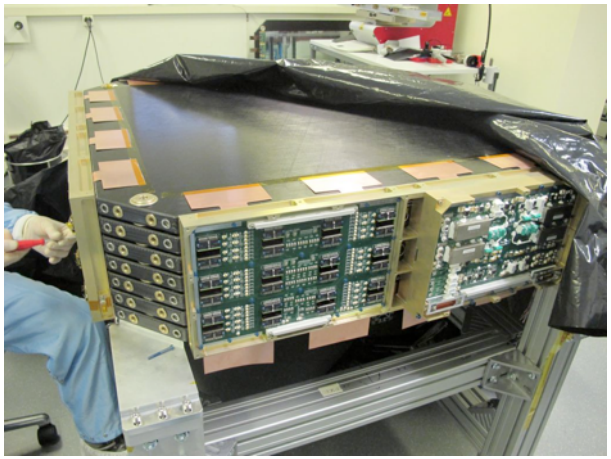
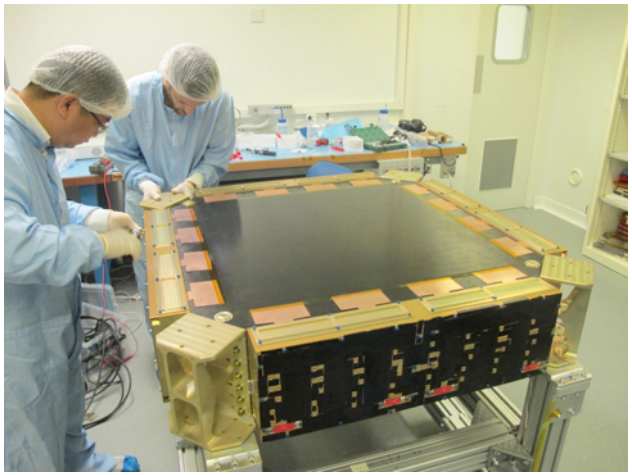
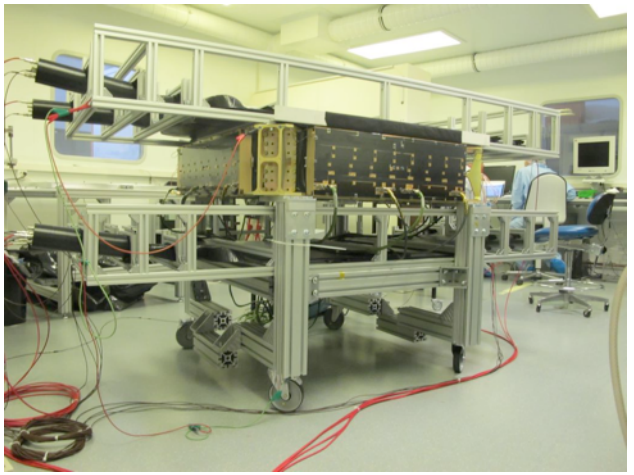
Leakage current of 192 ladders after plane assembly at 80 V

# Several layers

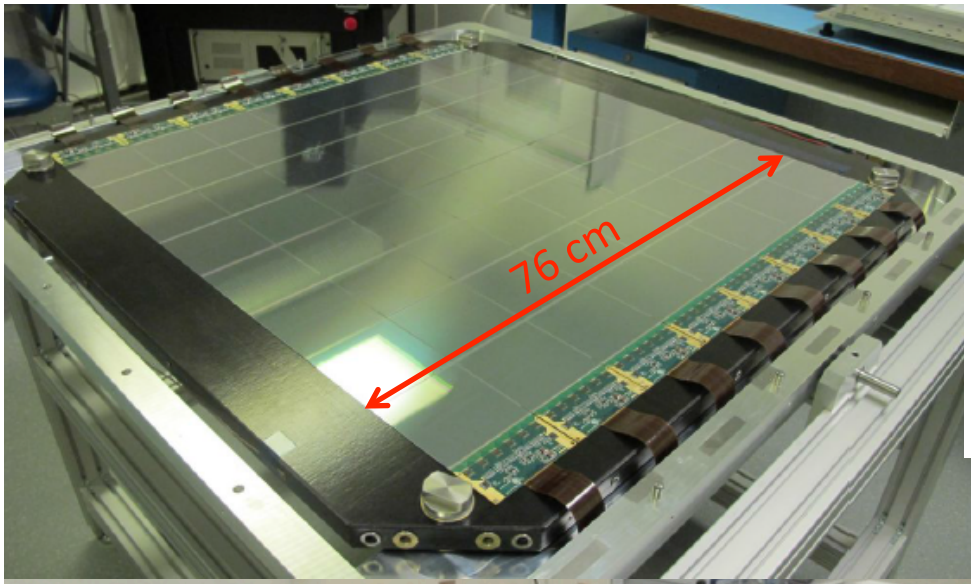


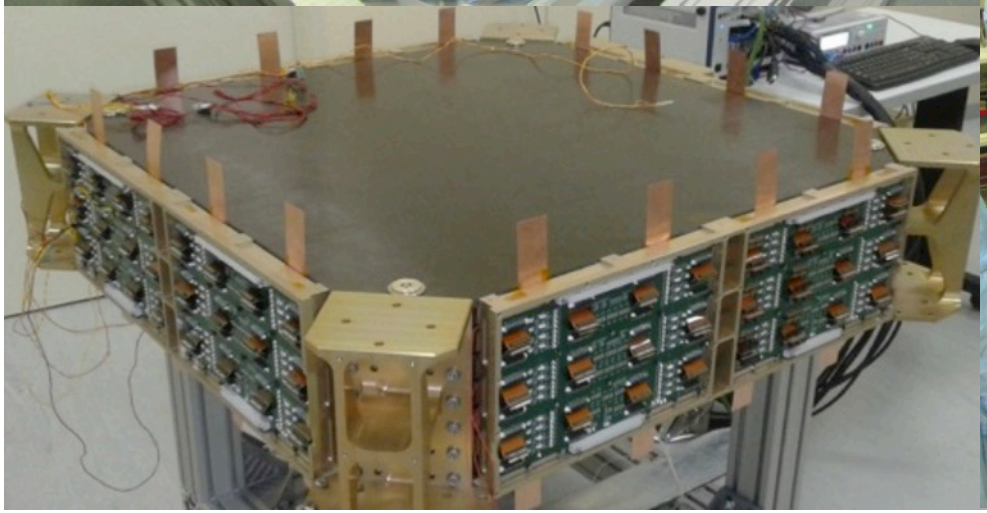
# Flight Model Assembly

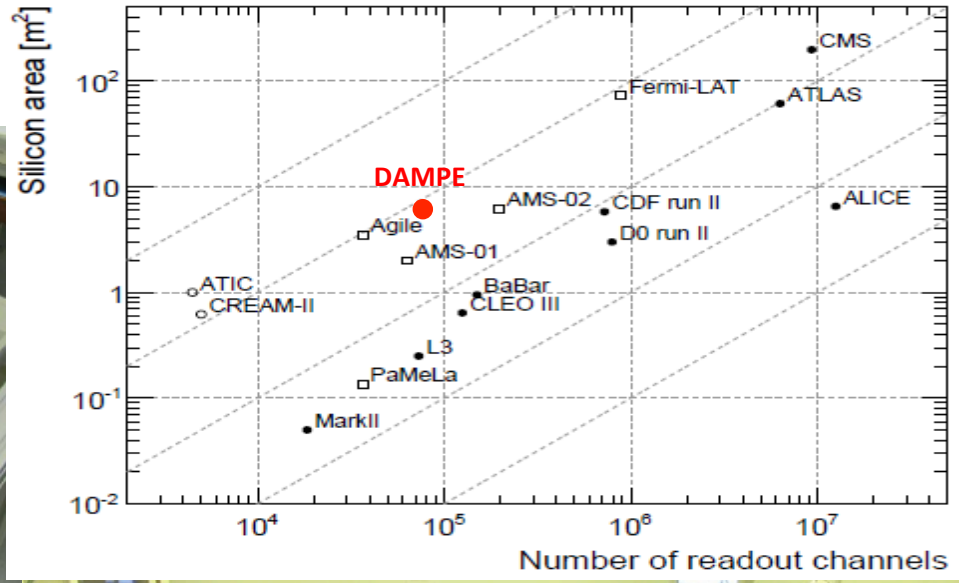
- The Flight Model assembly has been completed in April 2015
  - Tested with cosmic rays before delivered to China

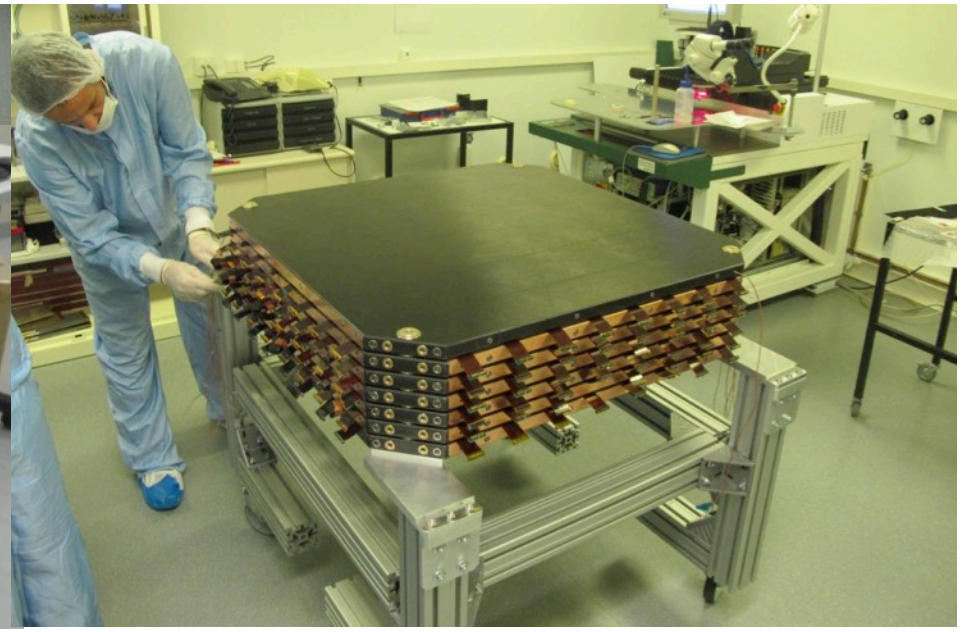






# The Silicon TracKer



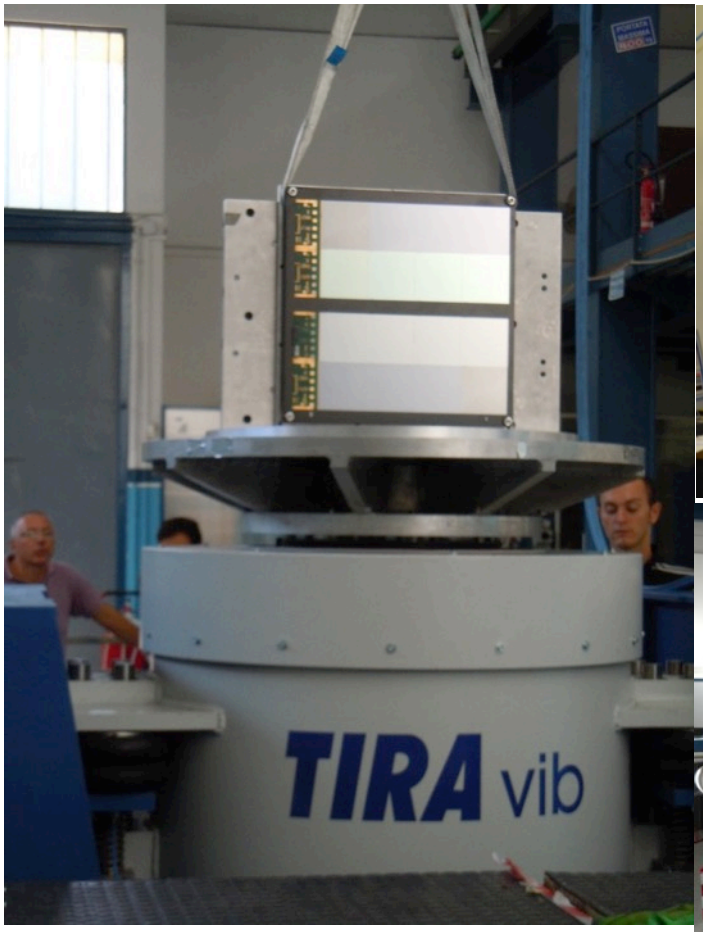





# Engineering and Qualification model

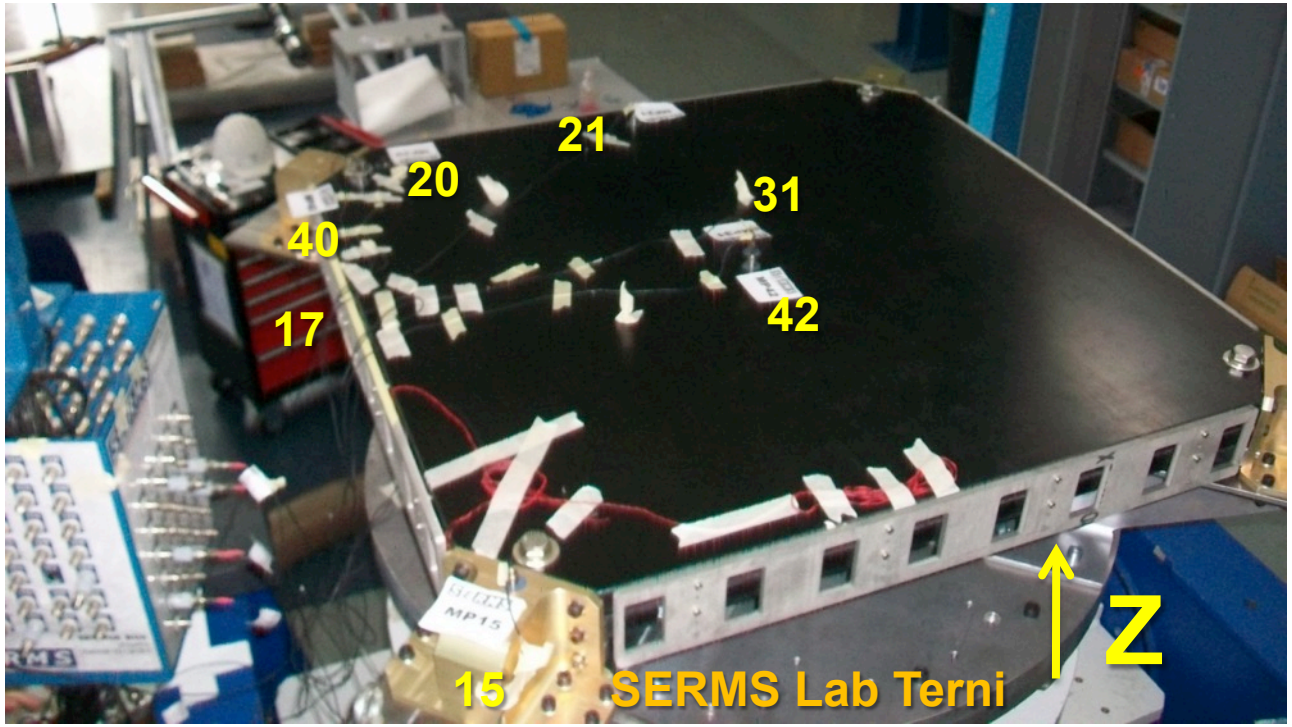
- An EQM has been constructed in July 2014
  - full size model as the final Flight Model (FM), but only 26 ladders with real silicon sensors, the rest with dummy sensors



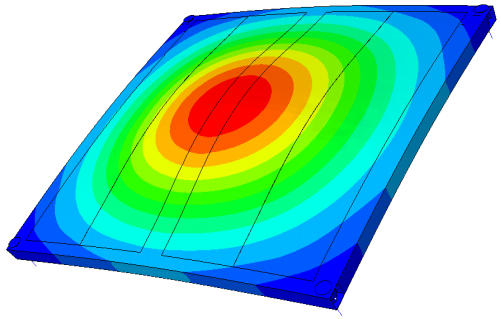

**EQM passed a series of space environmental qualification tests: vibration, acceleration, shock, thermal cycling, thermal vacuum**

SERMS laboratory
Terni - Italy

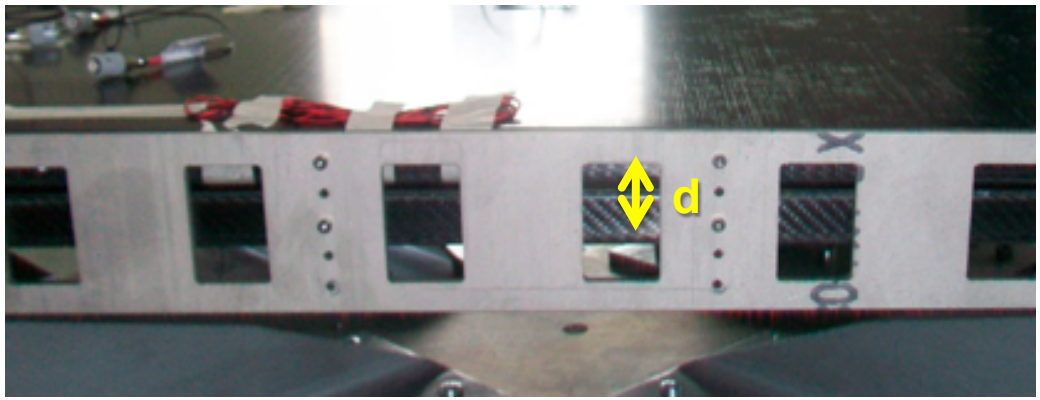
# DAMPE Mechanical testing:

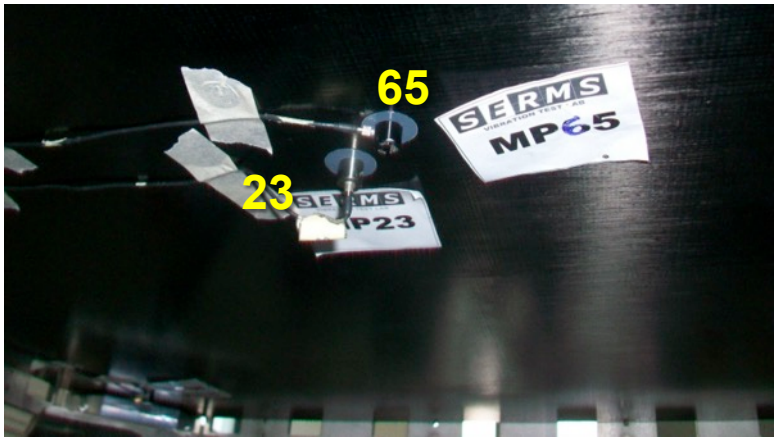



PHASE 5 Hardware:
- 2 bare trays (d=3,5mm)
- 0 ladders
- 0 dummy ladders



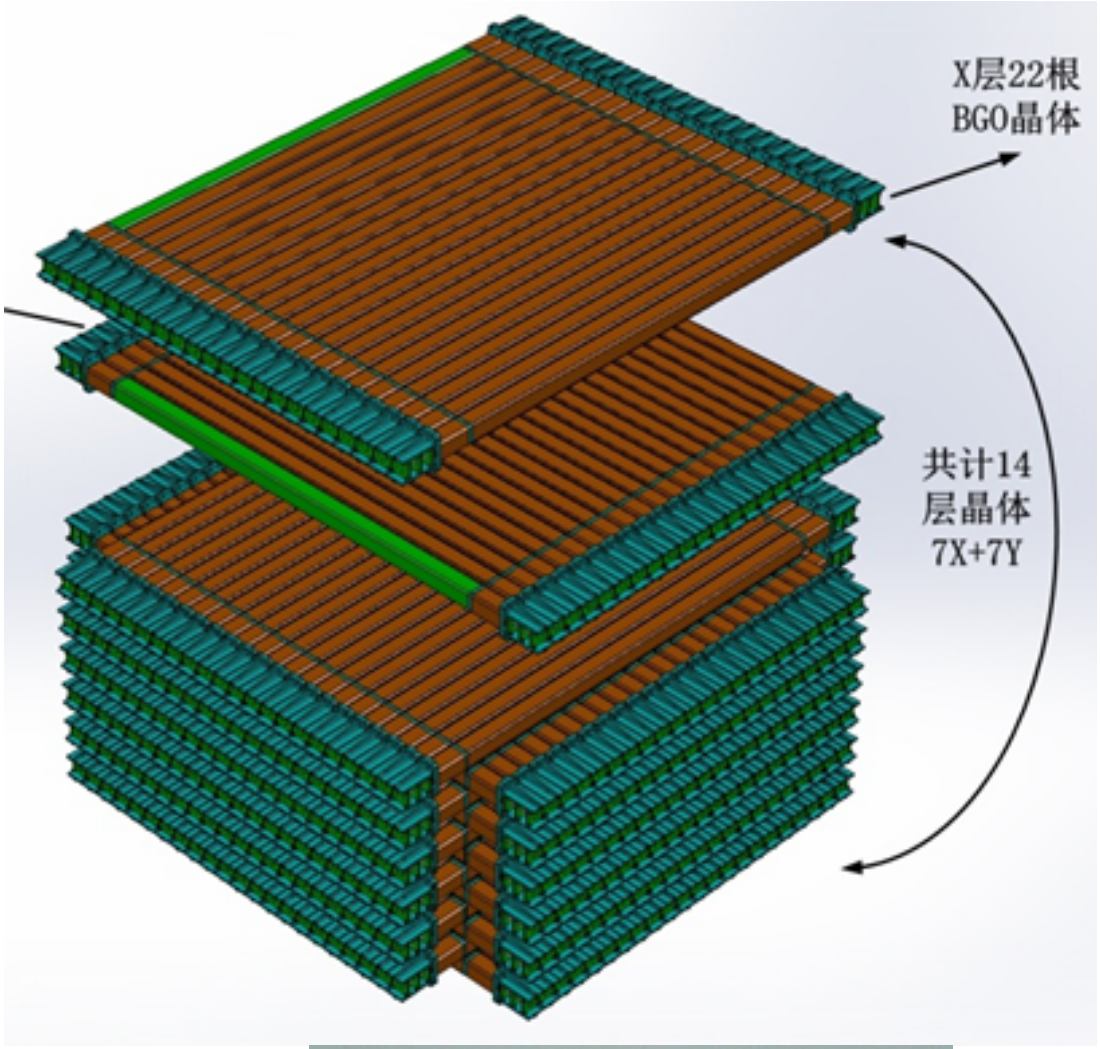
**Control Channels: 15 & 17**

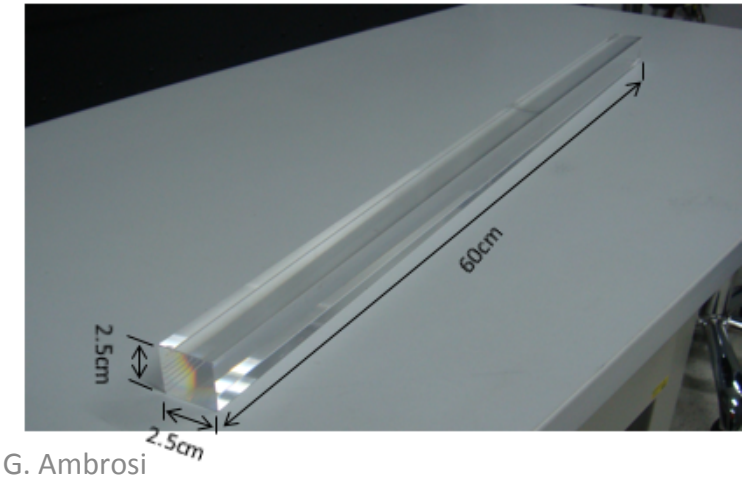


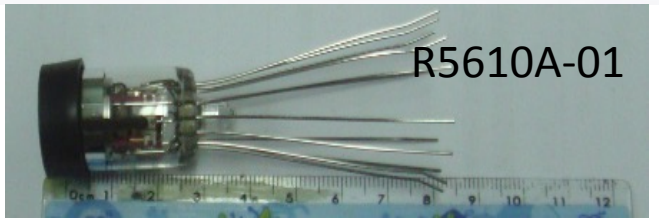
# The CALOrimeter

- 14 layers of 22 BGO bars
  - Dimension of BGO bar: 2.5×2.5×60 $cm^3$
  - 14 hodoscopic stacking alternating orthogonal layers
  - depth ~$32X_0$
- Two PMTs coupled with each BGO crystal bar in two ends

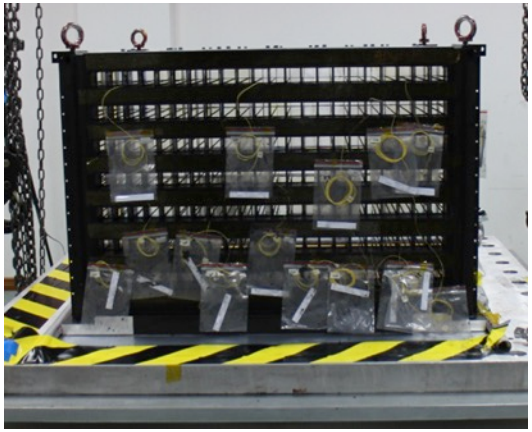



308 bars
616 PMTs

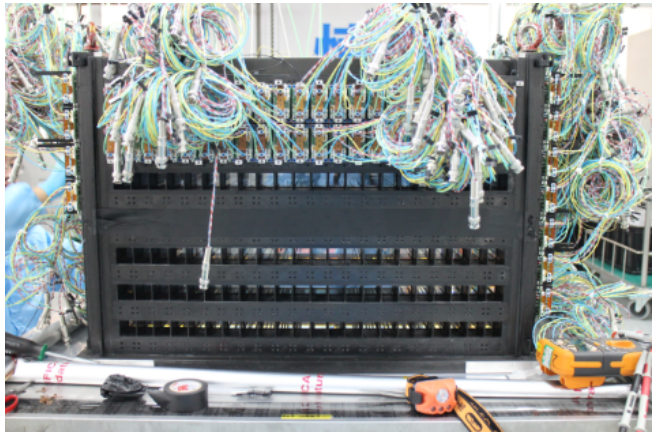


# The CALOrimeter -2

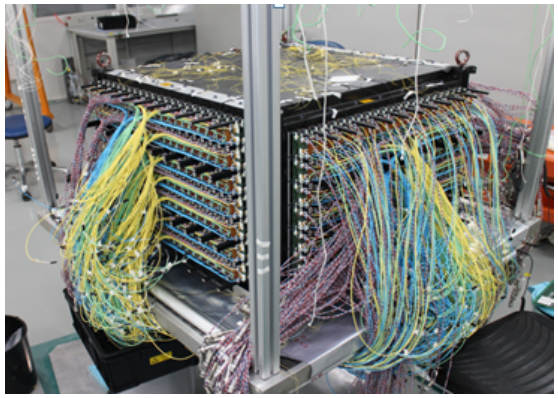


Carbon Fiber Structure

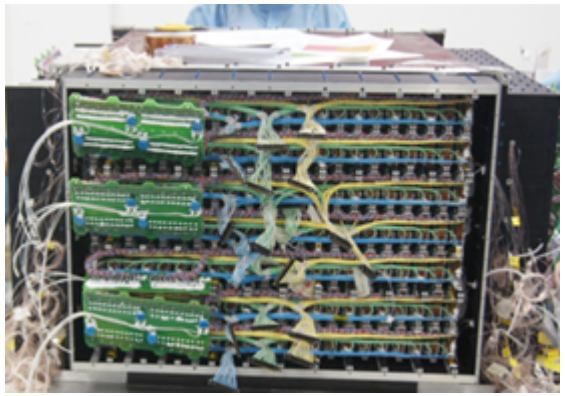
BGO crystal installation



PMT installation



Cable arranging

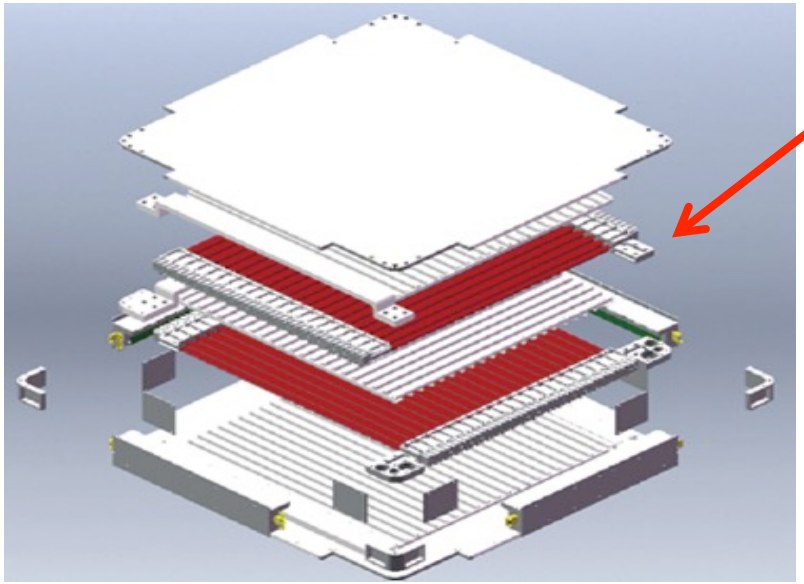


Cable connector

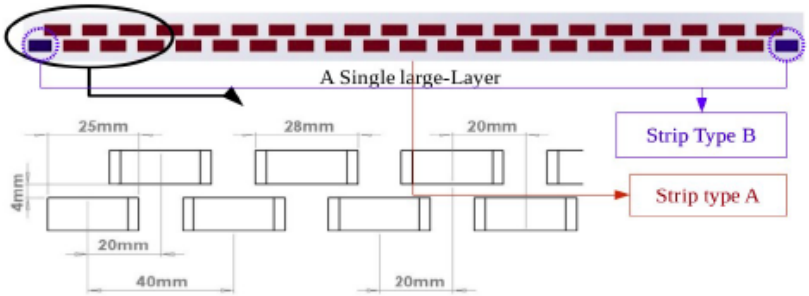
BGO Cal

# The PSD and the NUD

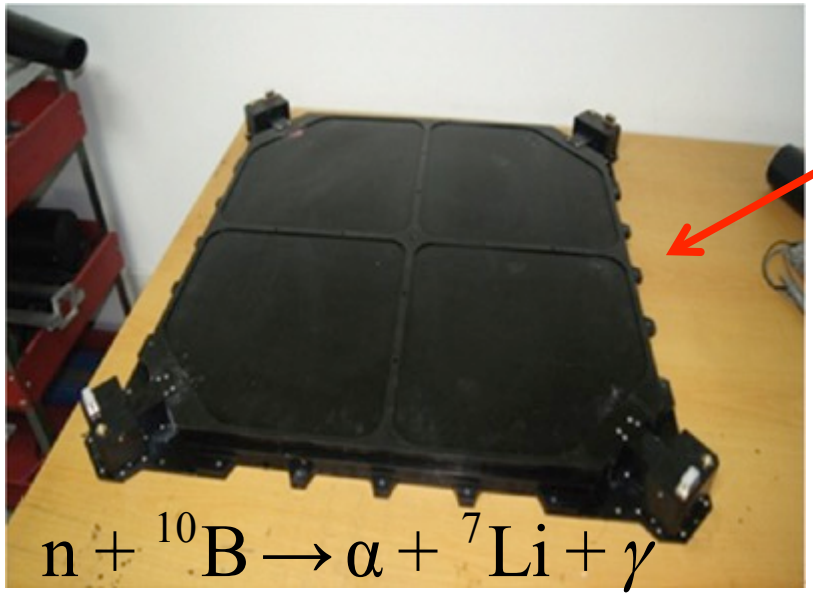
**PSD**



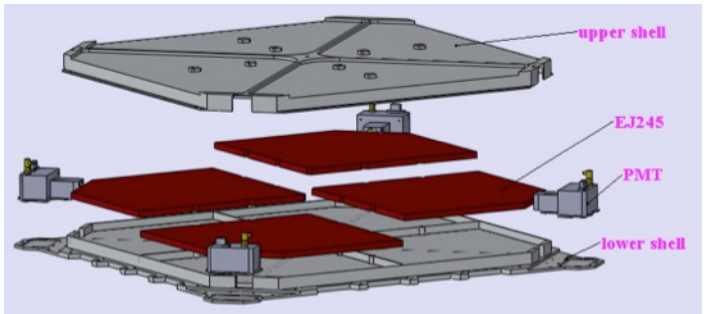
- 1.0 cm thick ,2.8cm wide and 82.0 cm long scintillator strips
- staggered by 0.8 cm in a layer
- 82 cm × 82 cm layers
- 2 layers ( x and y )




**NUD**

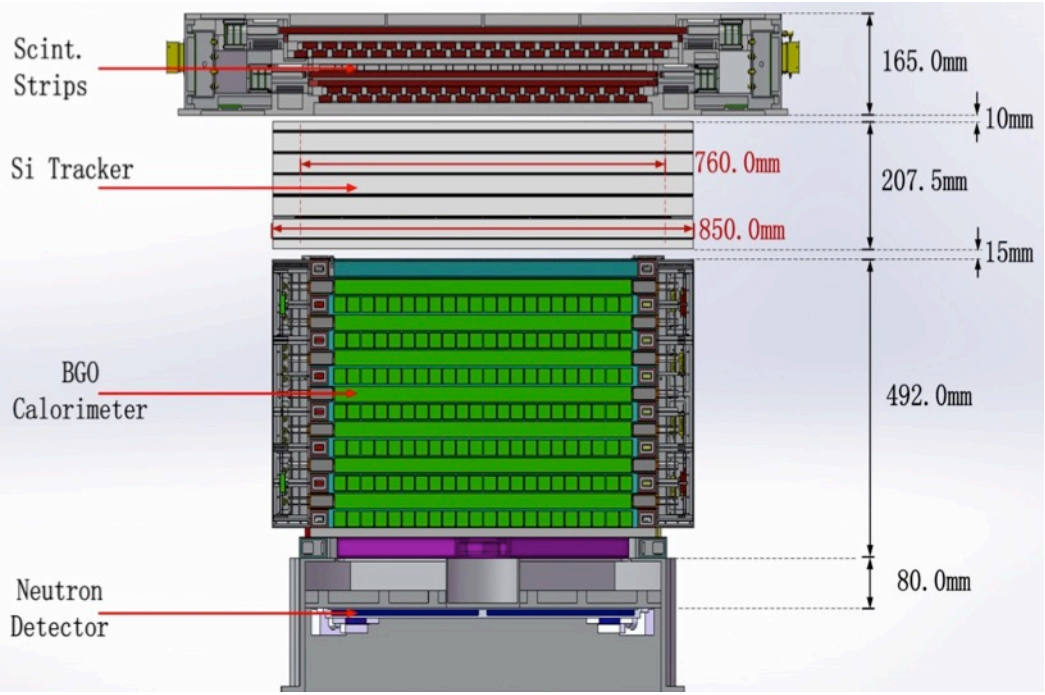


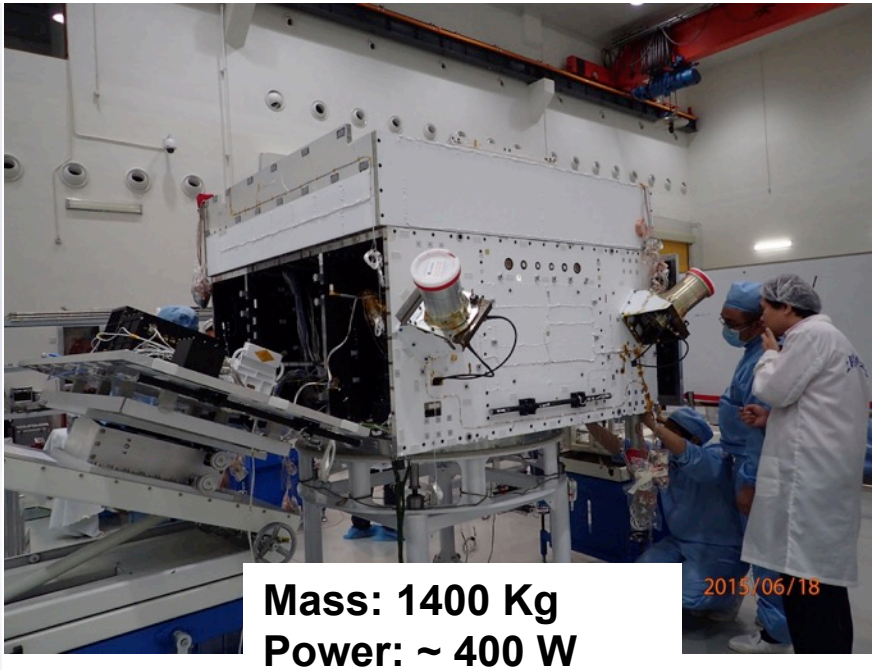

- 4 large area boron-doped plastic scintillators ( 30 cm × 30 cm × 1 cm)



# 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 ($X_0$) | **32** | 17 | 8.6 |
| Geometrical accep. ($m^2sr$) | **0.29** | 0.09 | 1 |

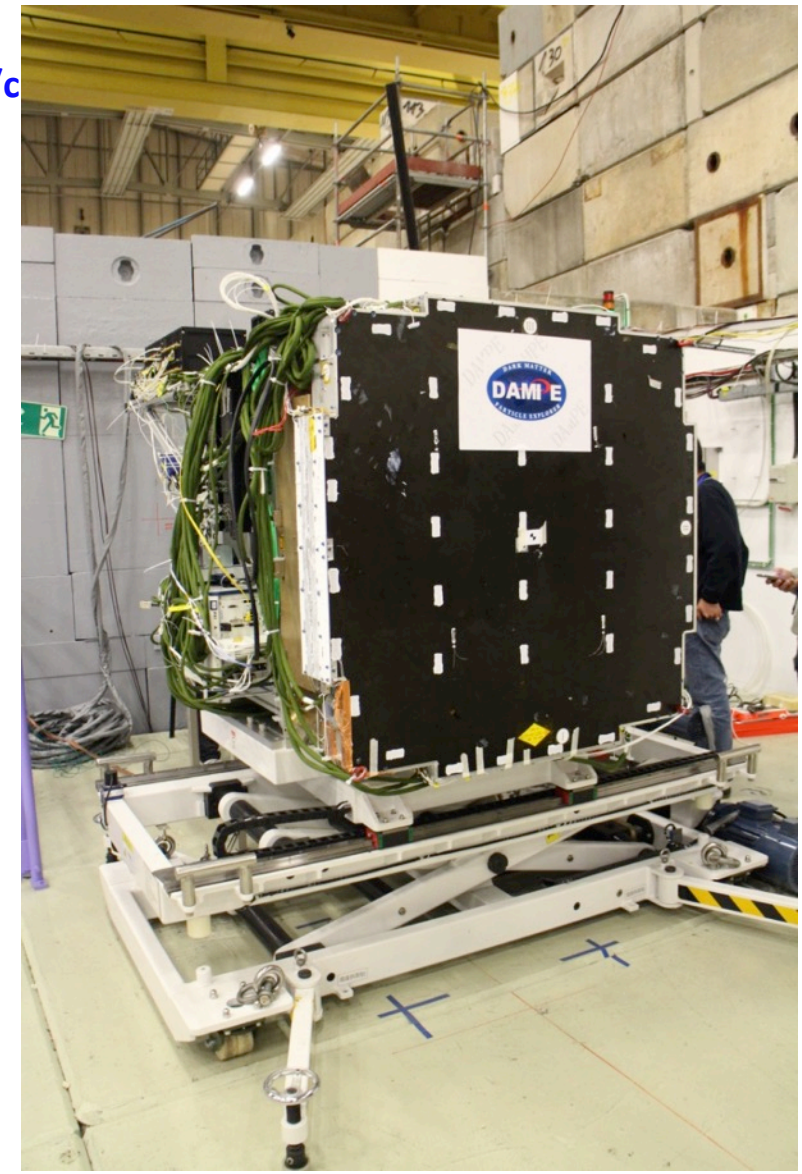



**Mass: 1400 Kg**
**Power: ~ 400 W**
**Livetime: > 3 years**

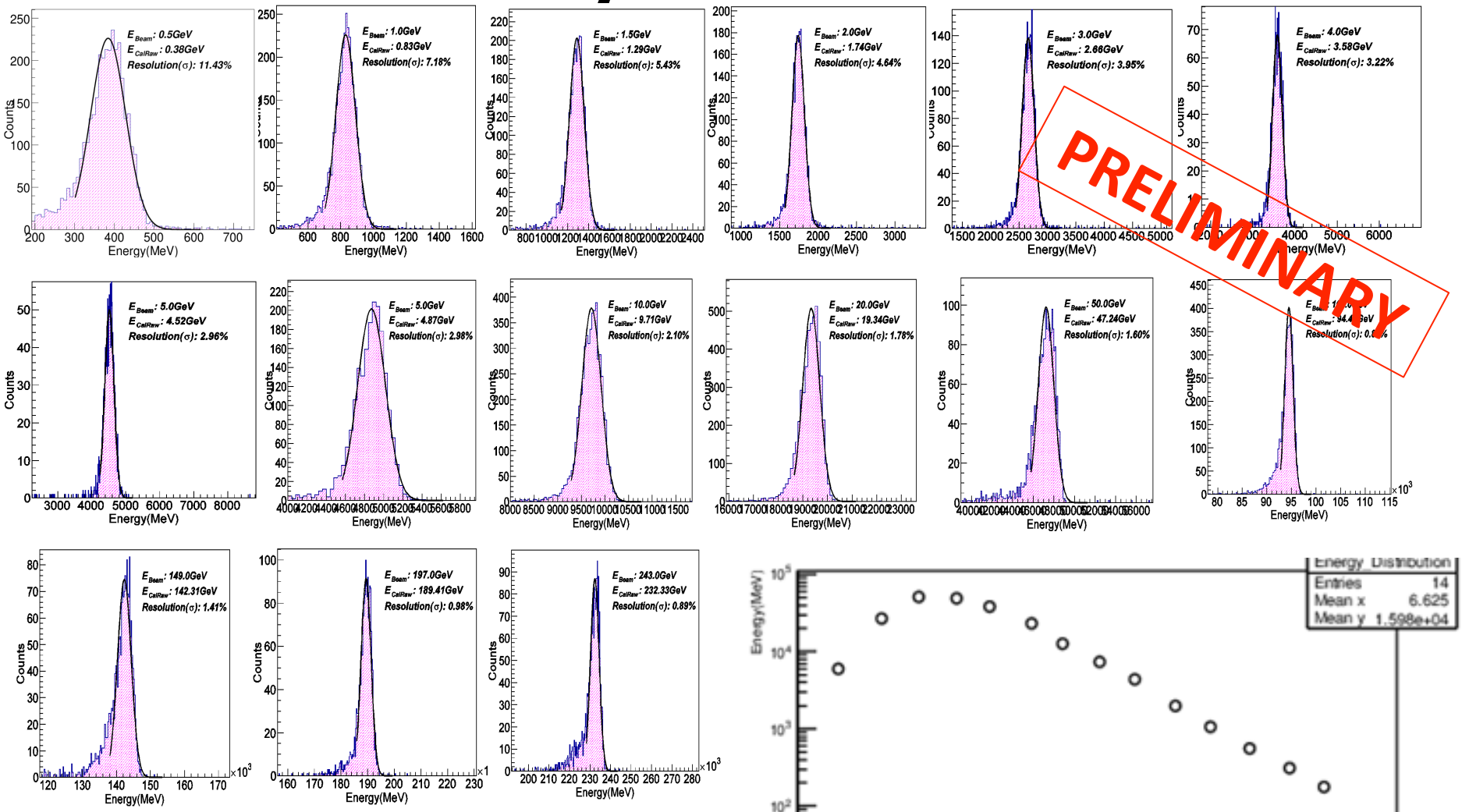
# Test beam activity at CERN

- 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)



# DAMPE first flight: EQM beam test

# Test beam activity at CERN: electrons





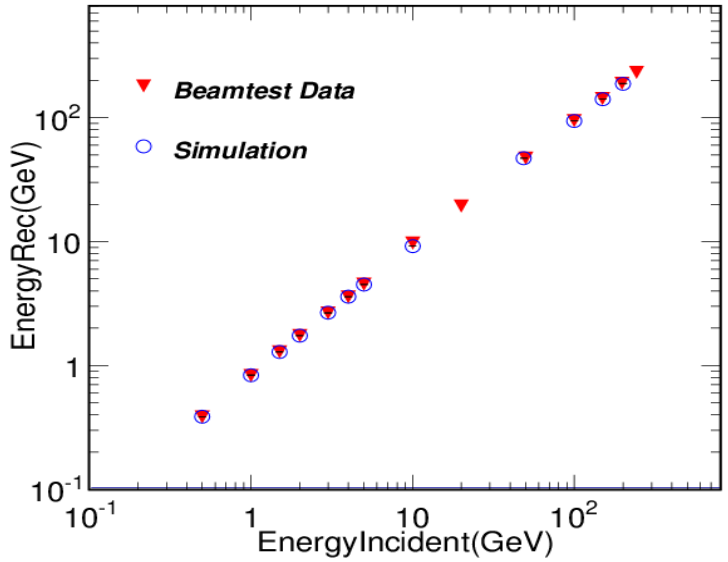


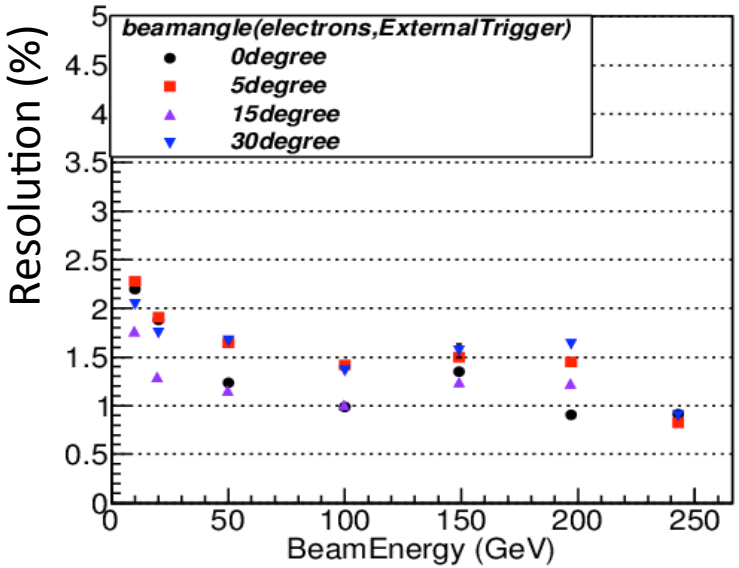
**Electrons**

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

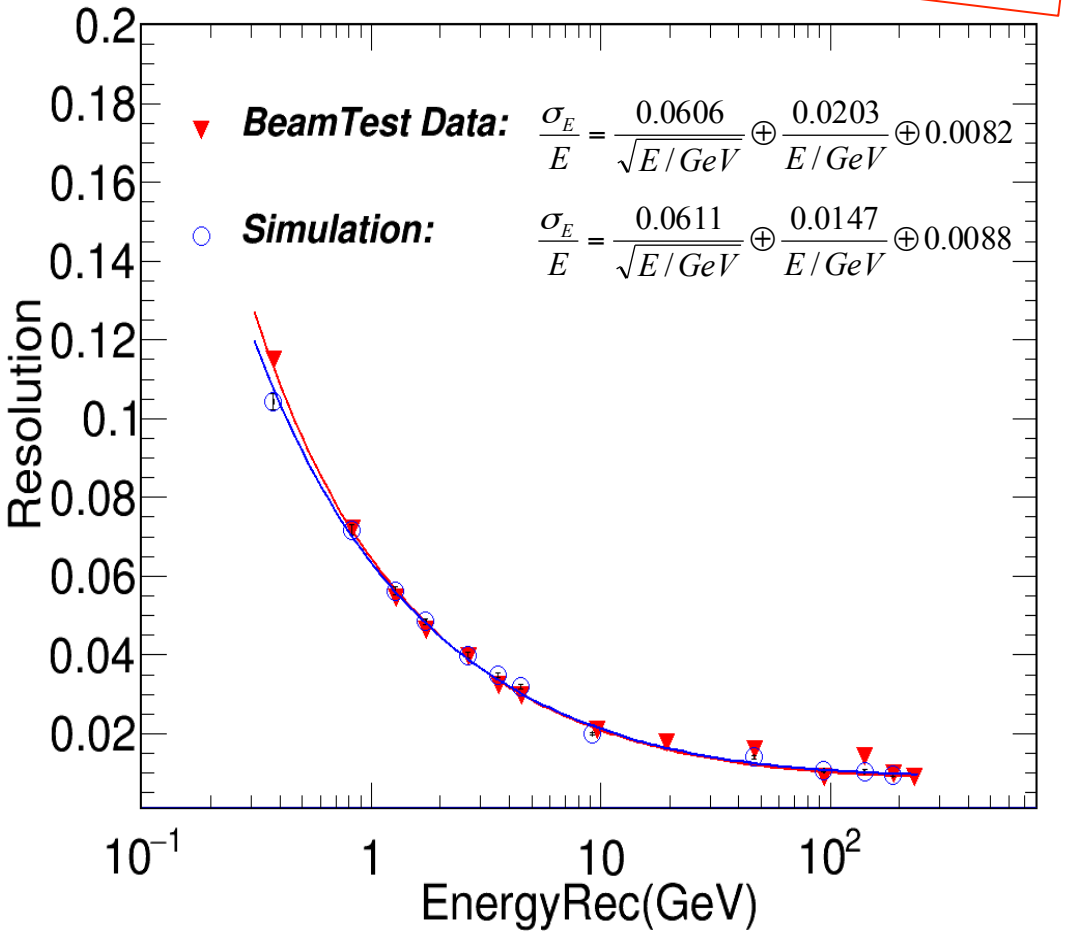
5, 10, 20, 50, 100, 149, 197, 243 GeV @ SPS

# Test beam activity at CERN: electrons

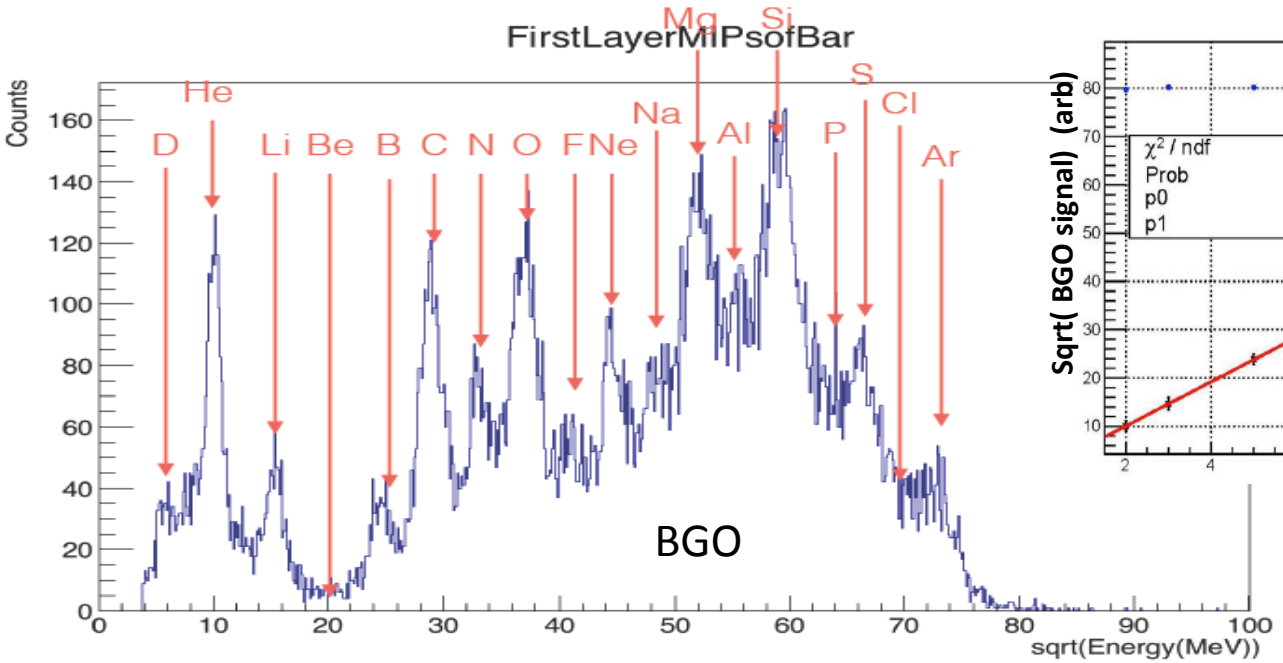


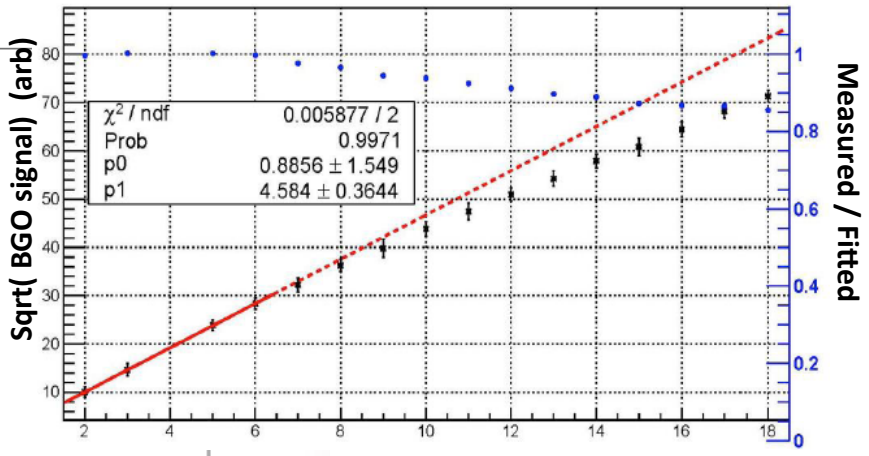




PRELIMINARY

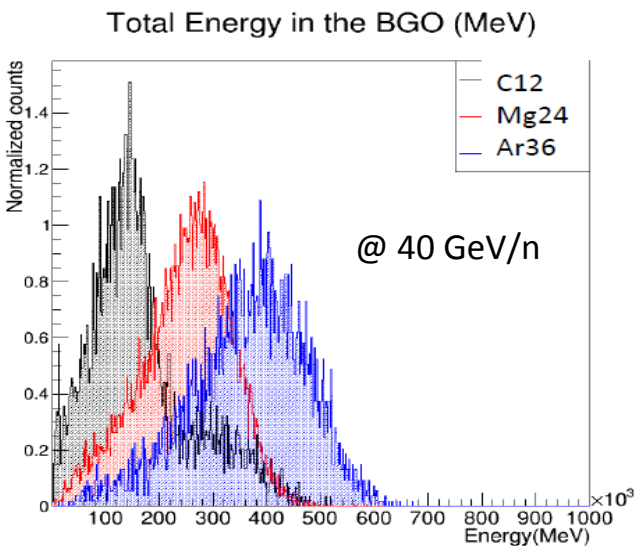


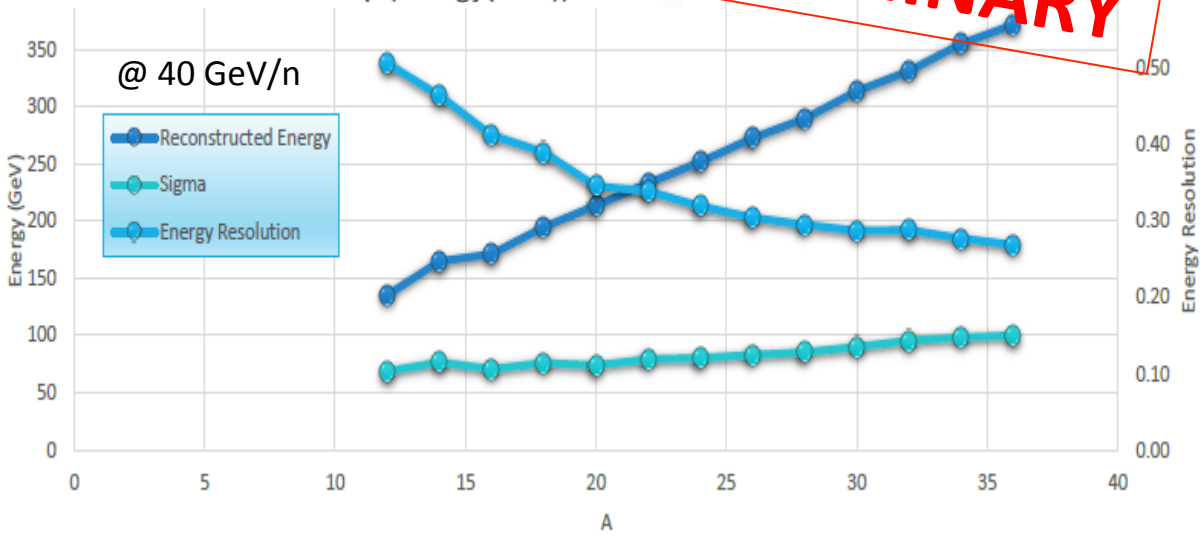
# Test beam activity at CERN: ions



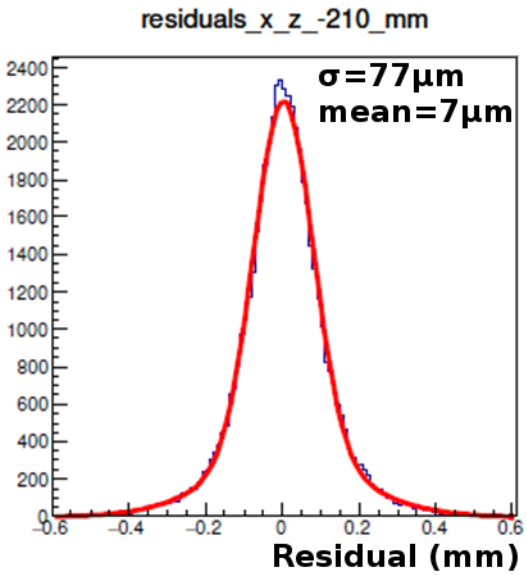



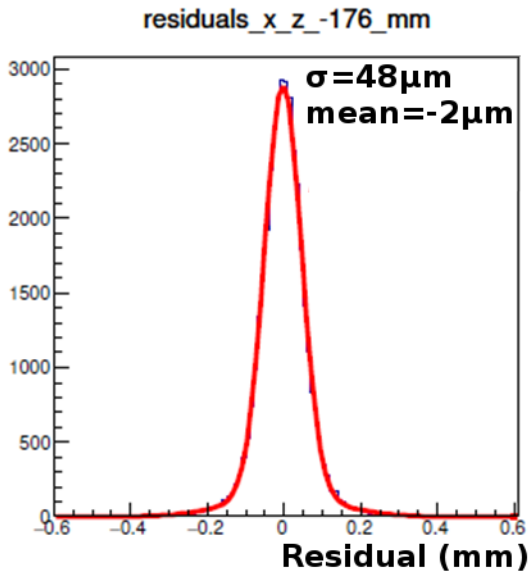

PRELIMINARY

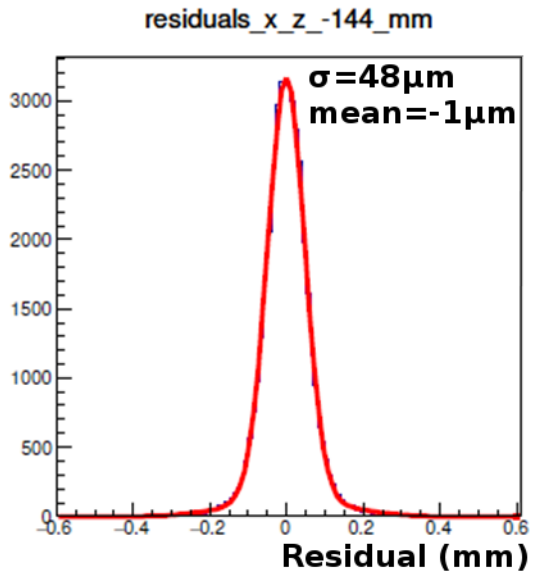


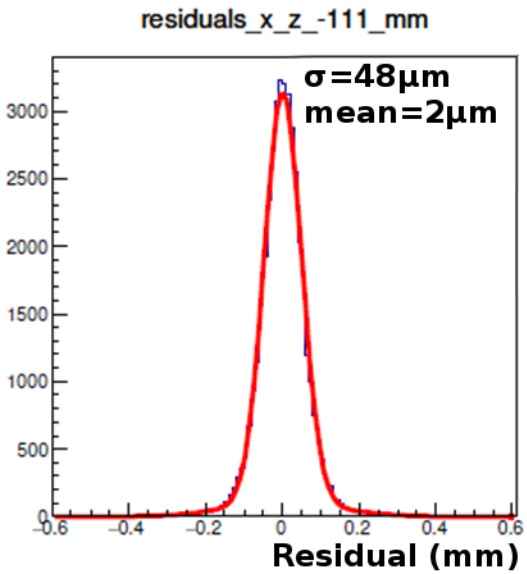



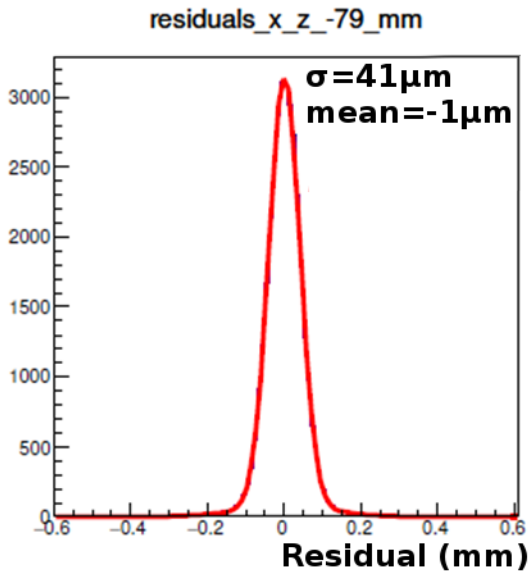
# STK resolution after alignment

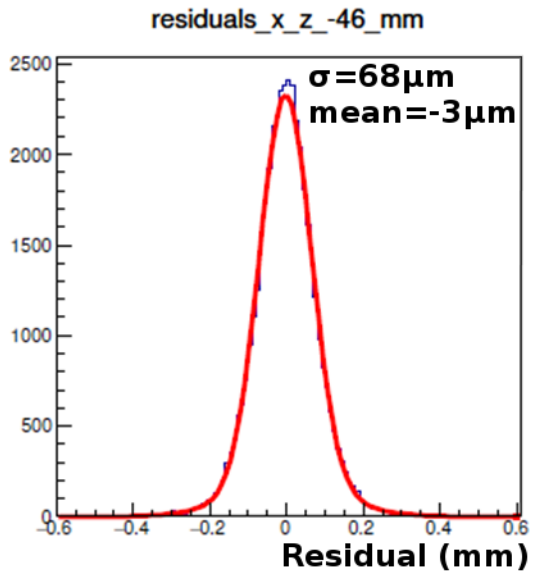


# The launch: Dec 17th 2015, 0:12 UTC

Jiuquan Satellite Launch Center
Gobi desert

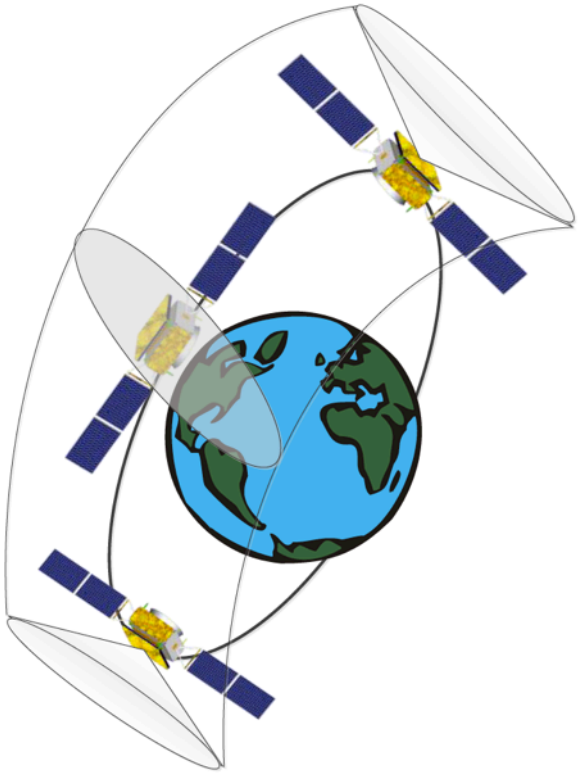
Orbit: sun syncronous , 500km

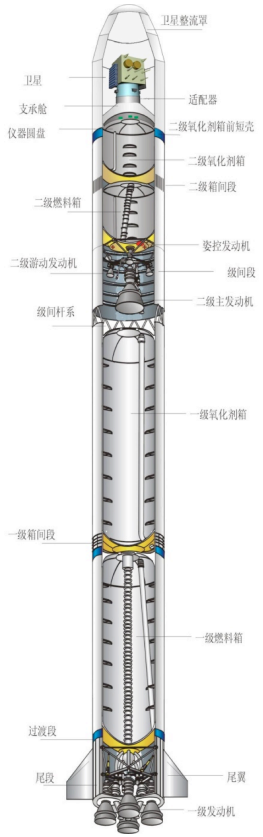
DAMPE → WUKONG

# DAMPE Satellite

- **Launch: December 17th 2015, CZ-2D rocket**
  - **Total weight ~1900 kg, power consumption ~640 W**
    - **Scientific payload ~1300 kg, ~400 W**
  - **Lifetime > 3 year**

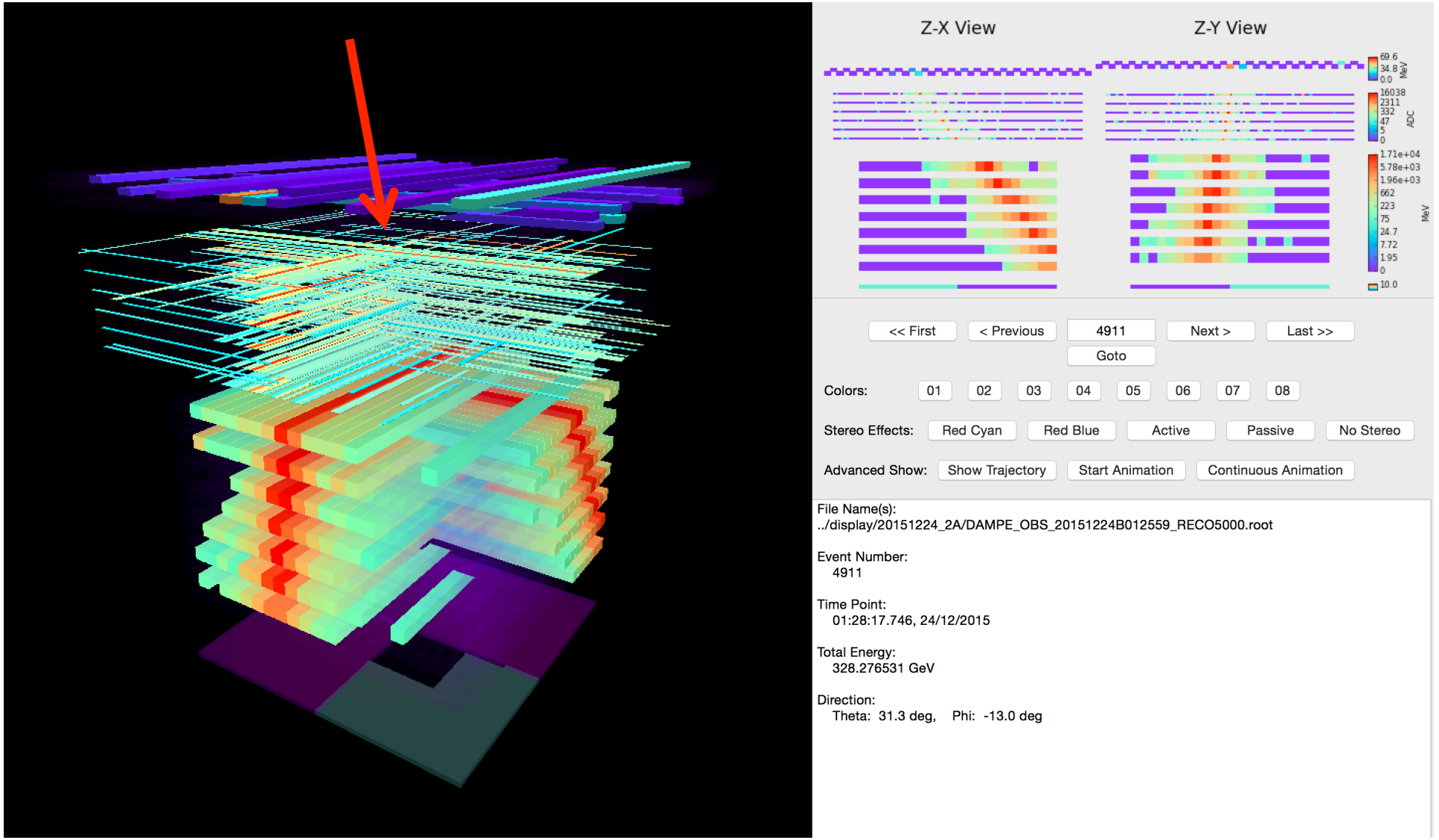
- **Altitude: 500 km**
- **Inclination: 97.4065°**
- **Period: 95 minutes**
- **Orbit: sun-synchronous**
- **12 GB/day downlink**





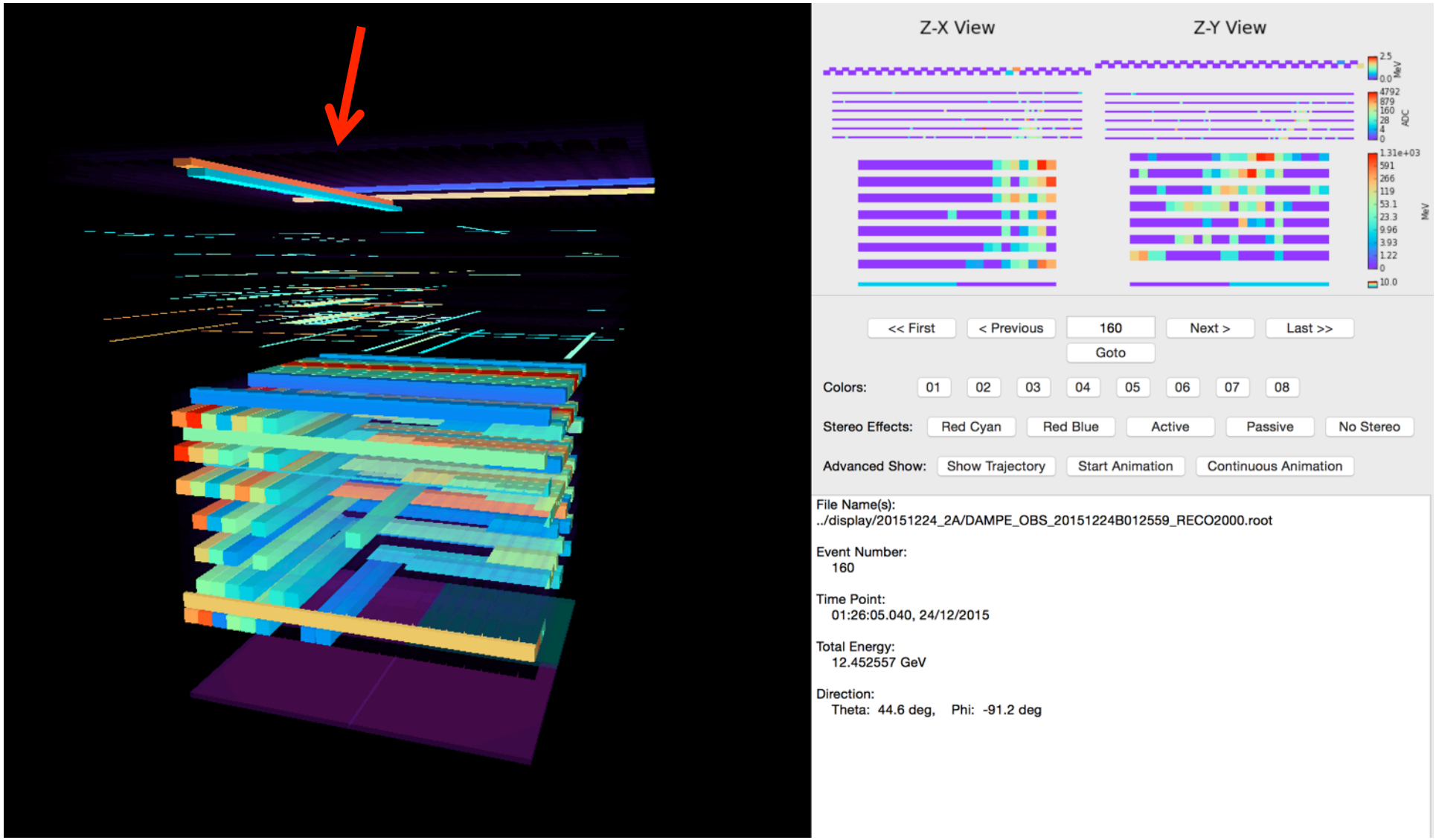
# Dec 24th 2015: HV on

## 330 GeV electron



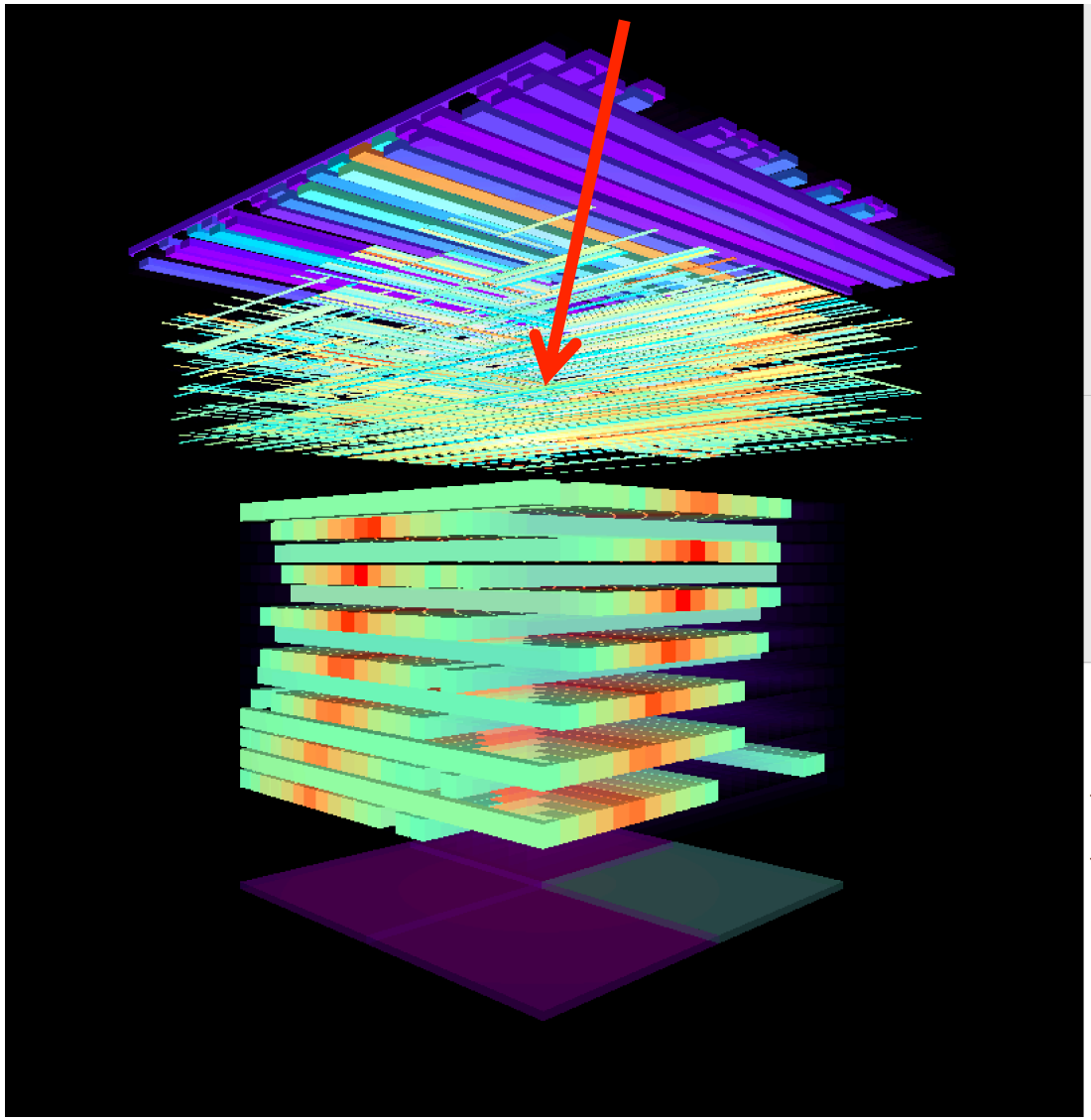
# Dec 24th 2015: HV on

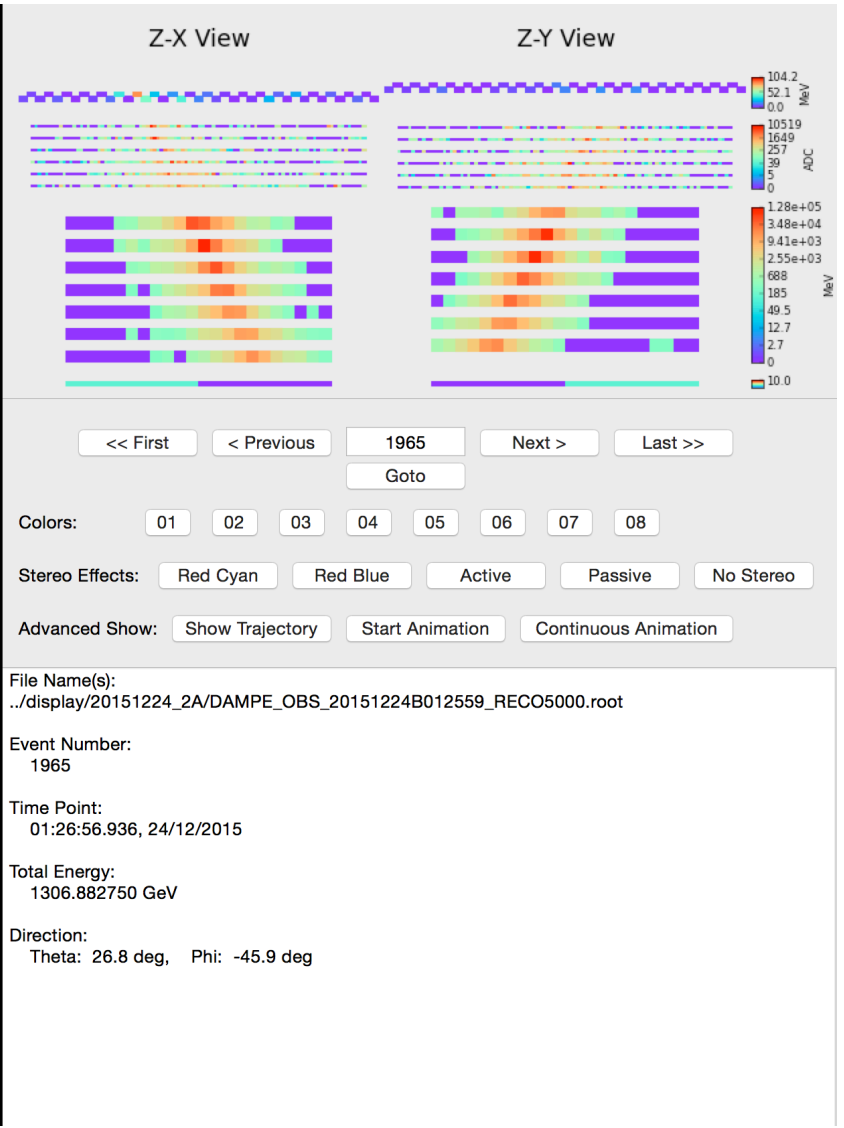
## 12 GeV proton



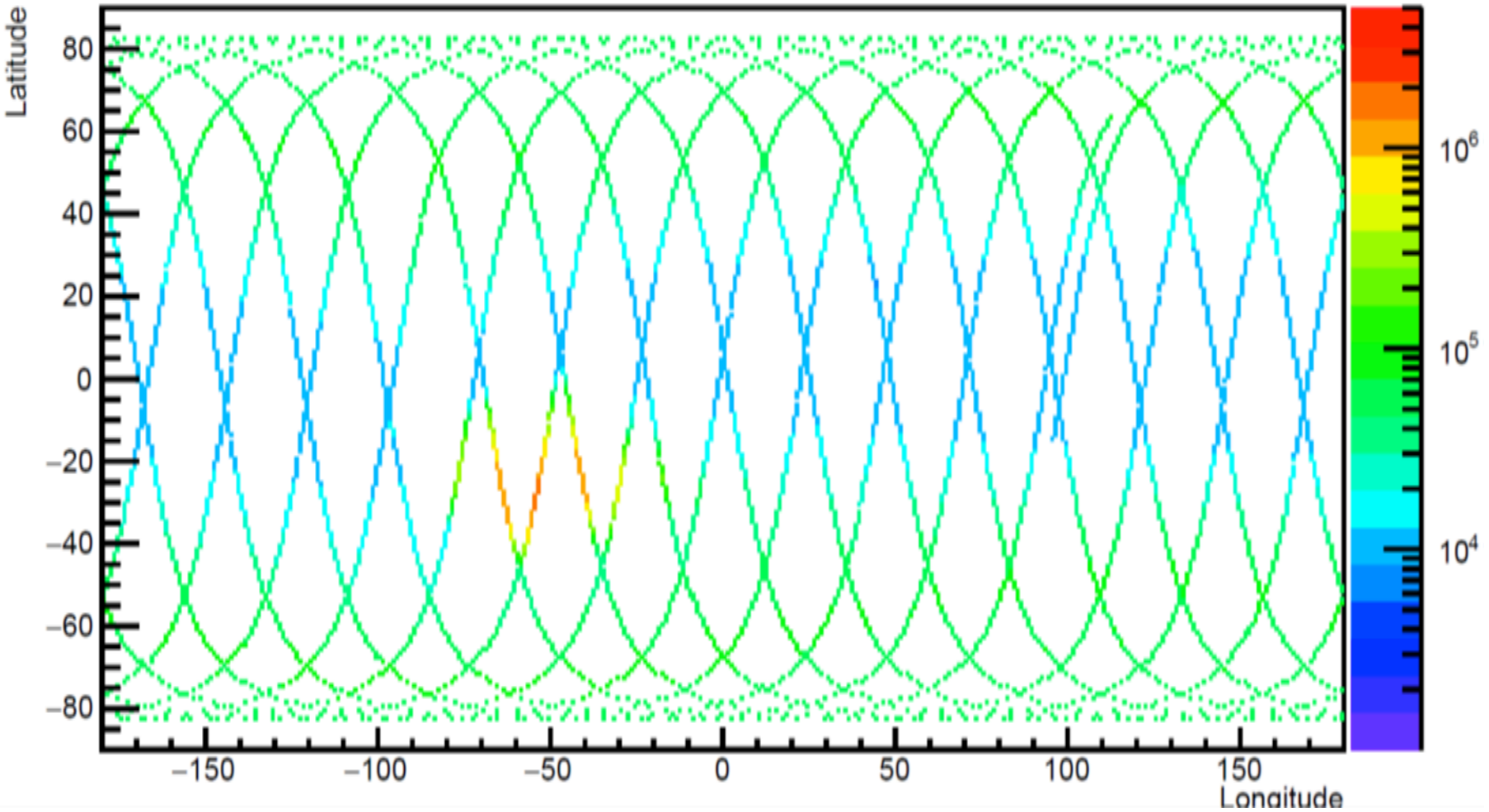
# Dec 24th 2015: HV on

## 1.3 TeV carbon





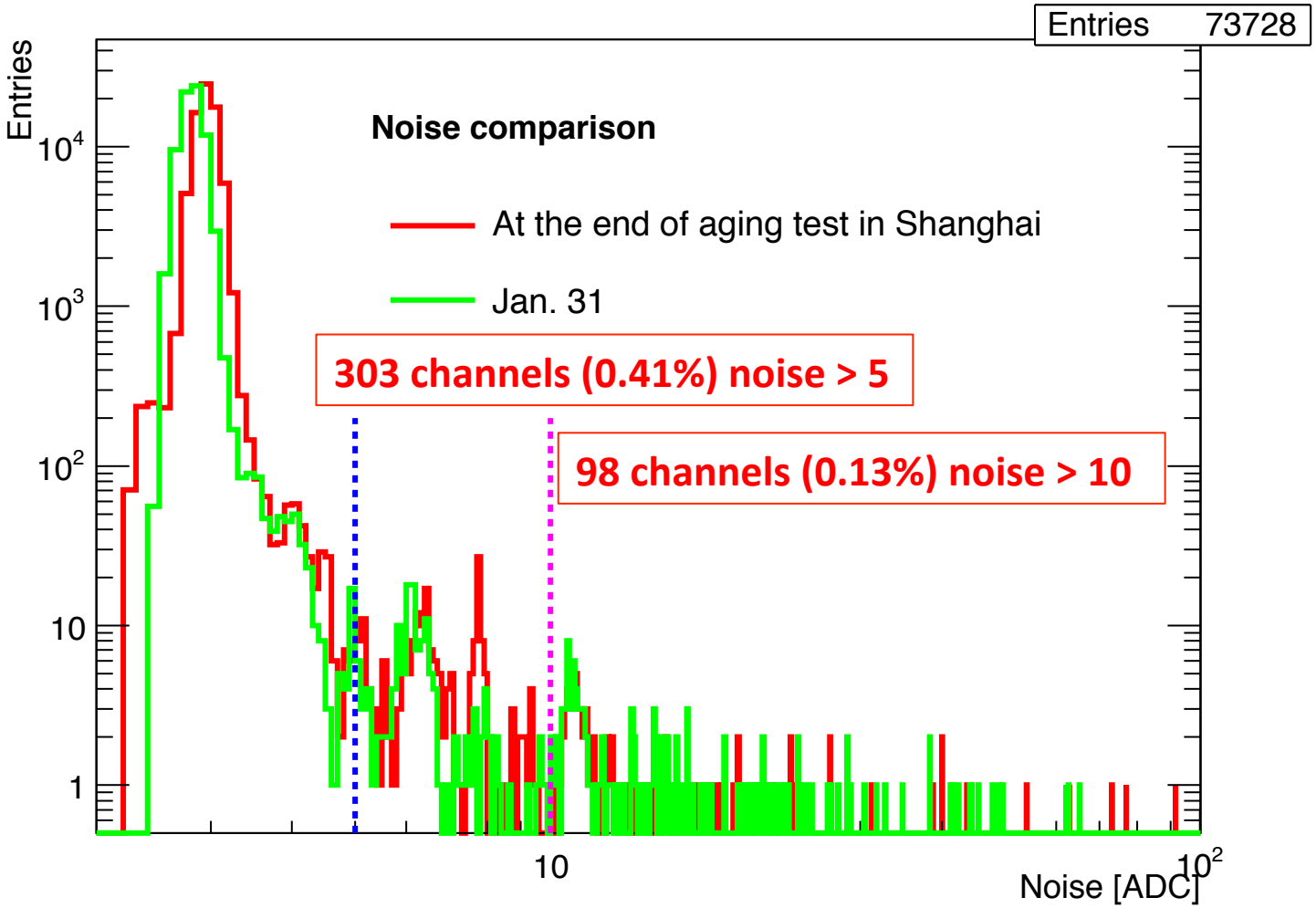
# Trigger rate in orbit




~50 Hz average trigger rate

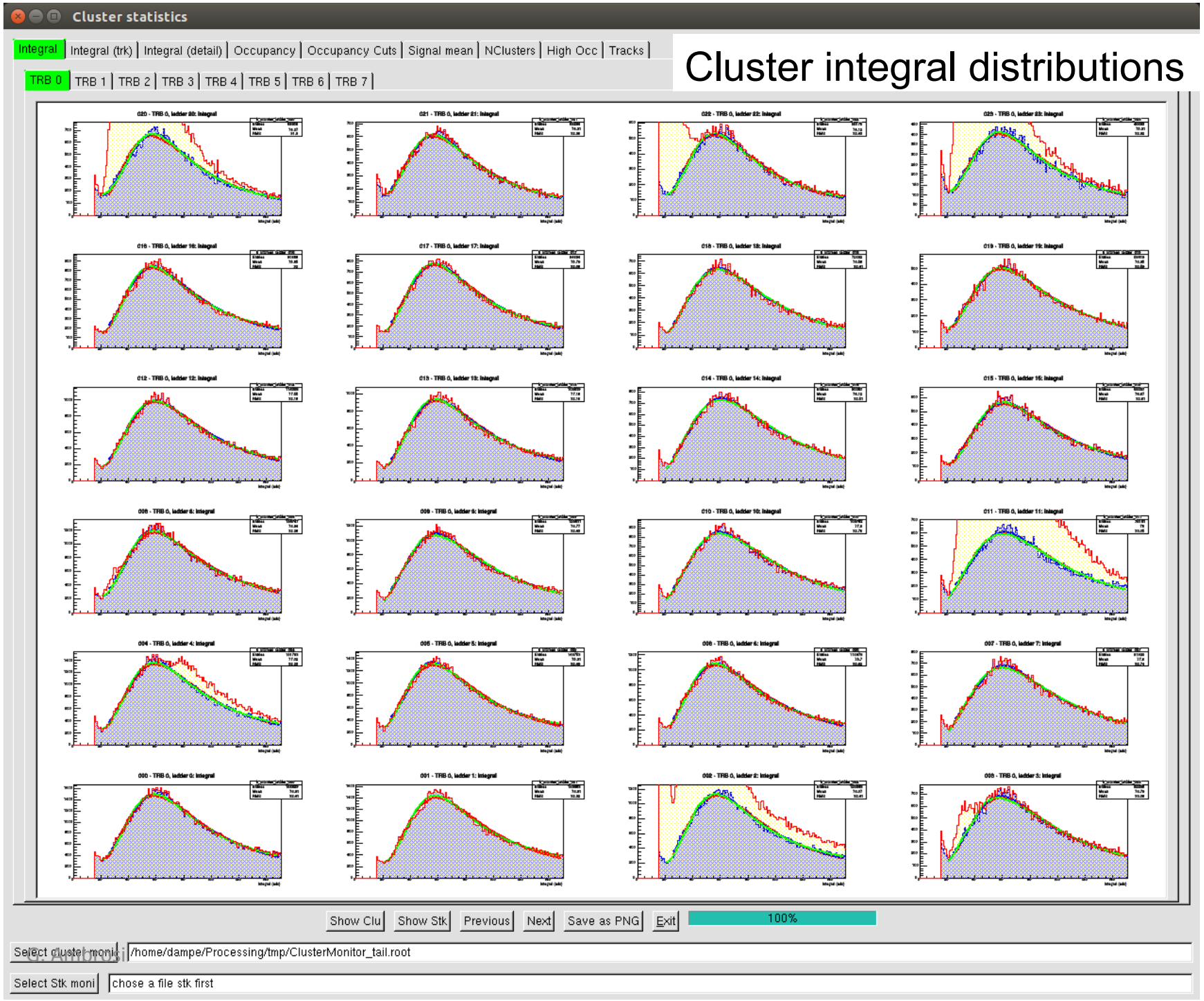
→100GB/day on ground (about 4 M events)

# STK noise behavior

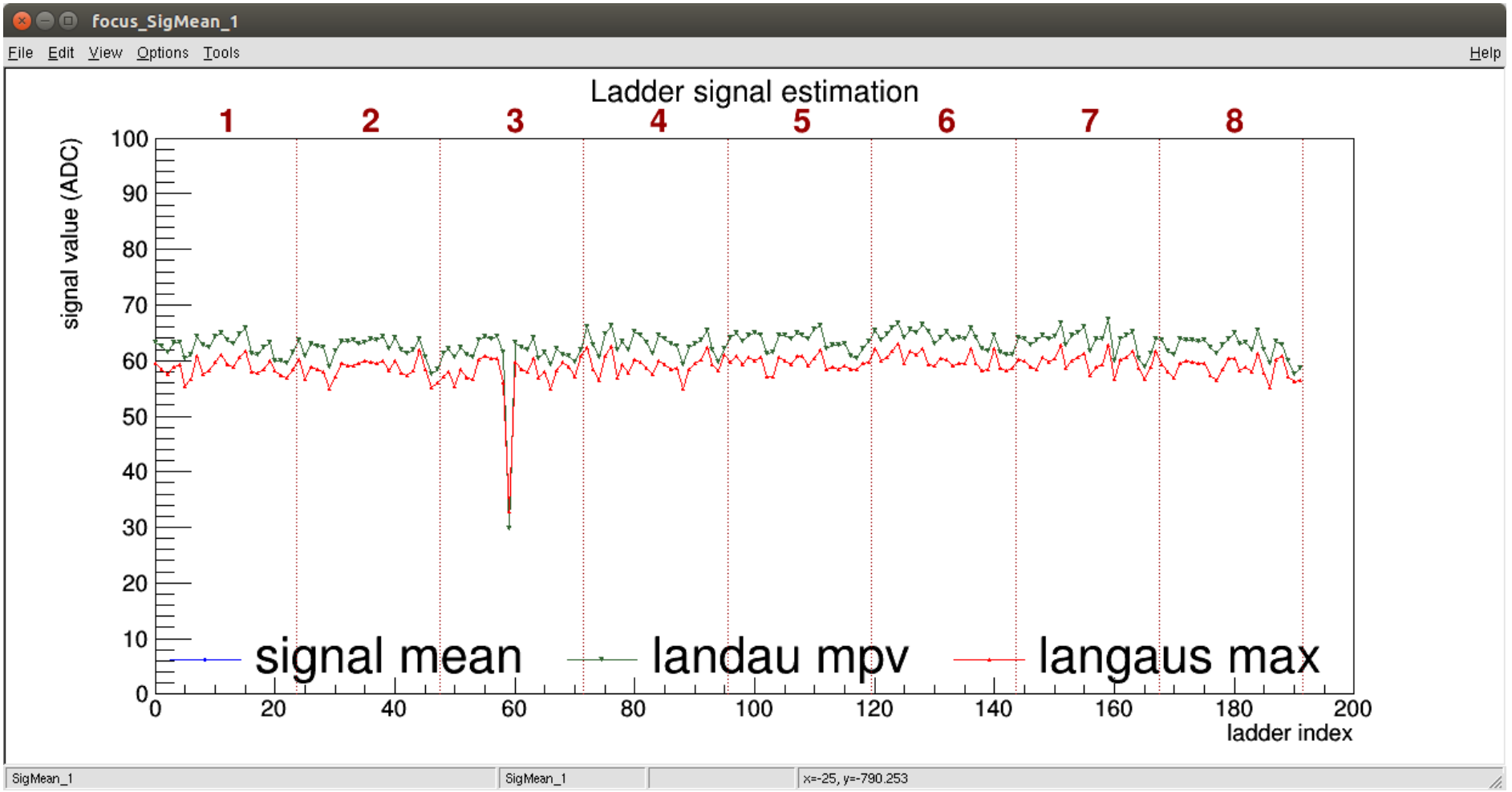



- Noise of the bulk significantly lower than on-ground

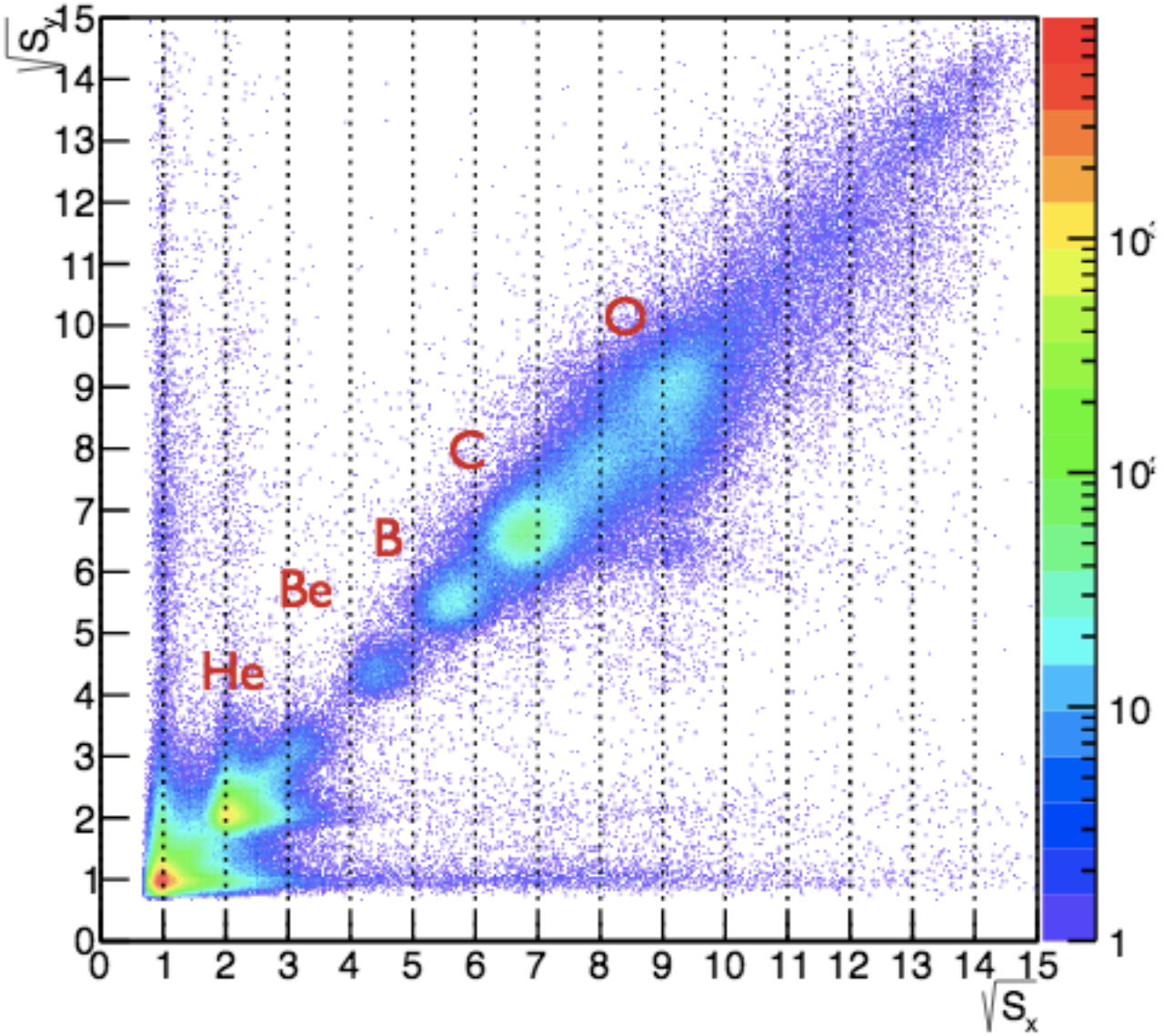
# Cluster integral distributions



# STK signal on all ladders

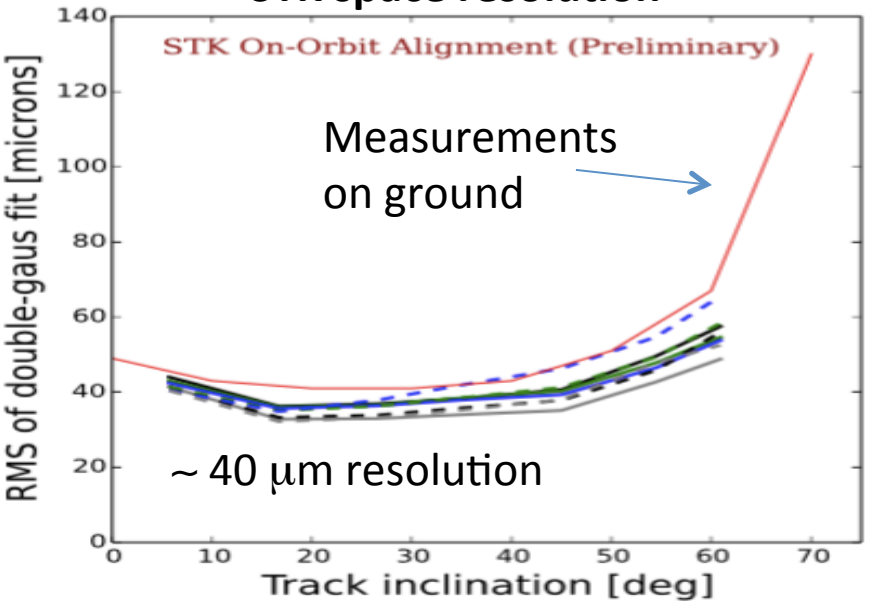


# STK preliminary charge ID

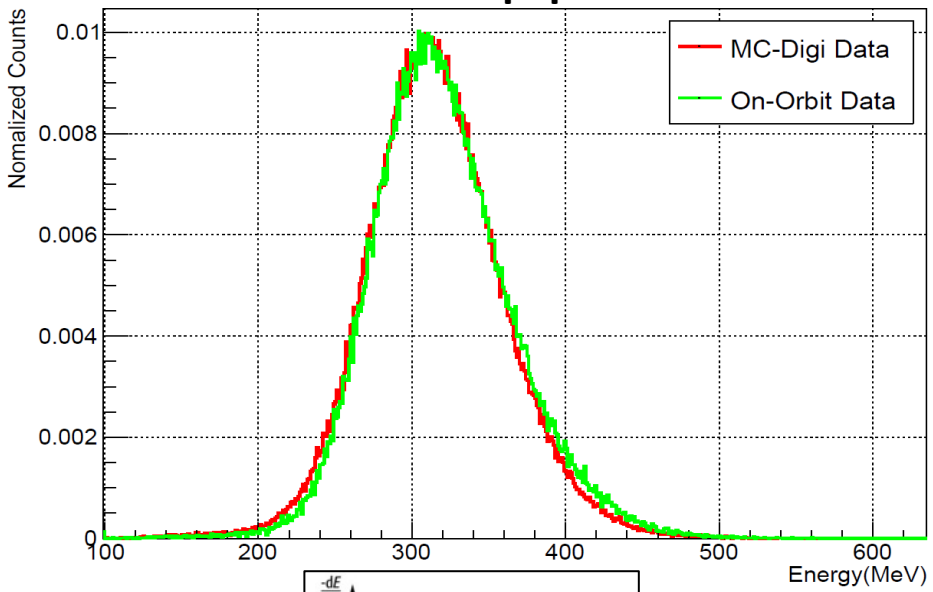


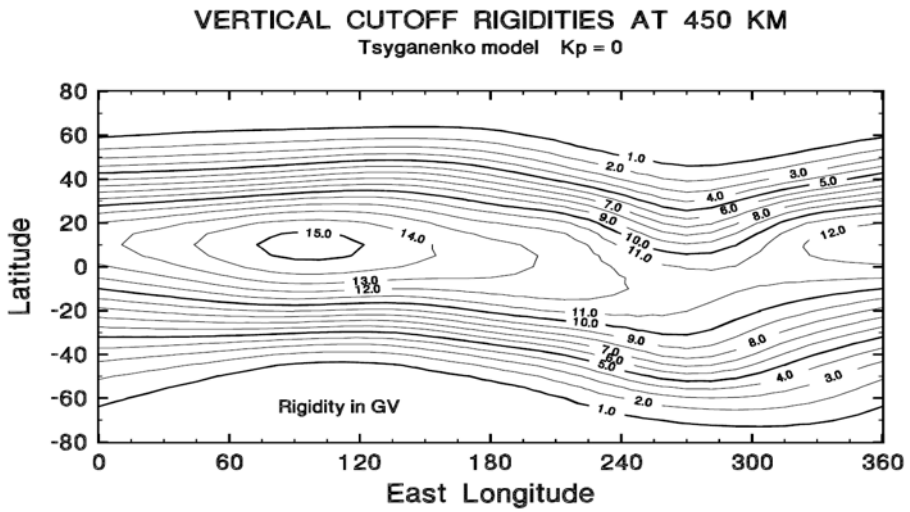
# More on-orbit performance plot

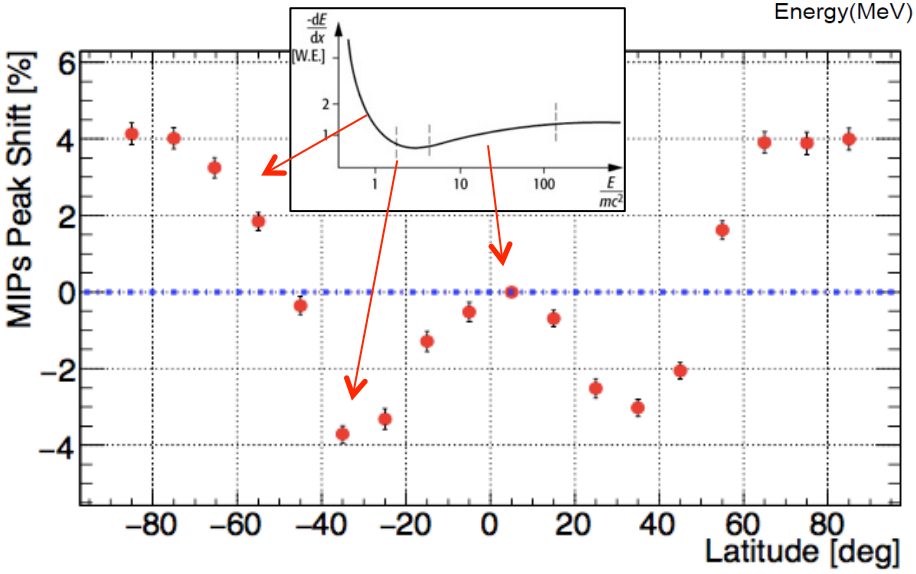
## STK space resolution




## BGO "mip"peak



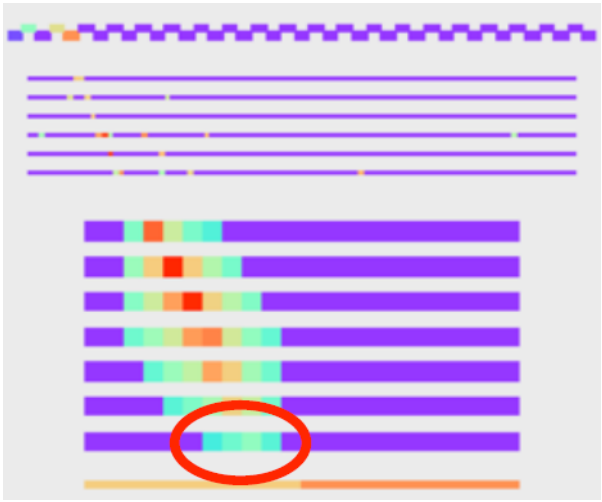



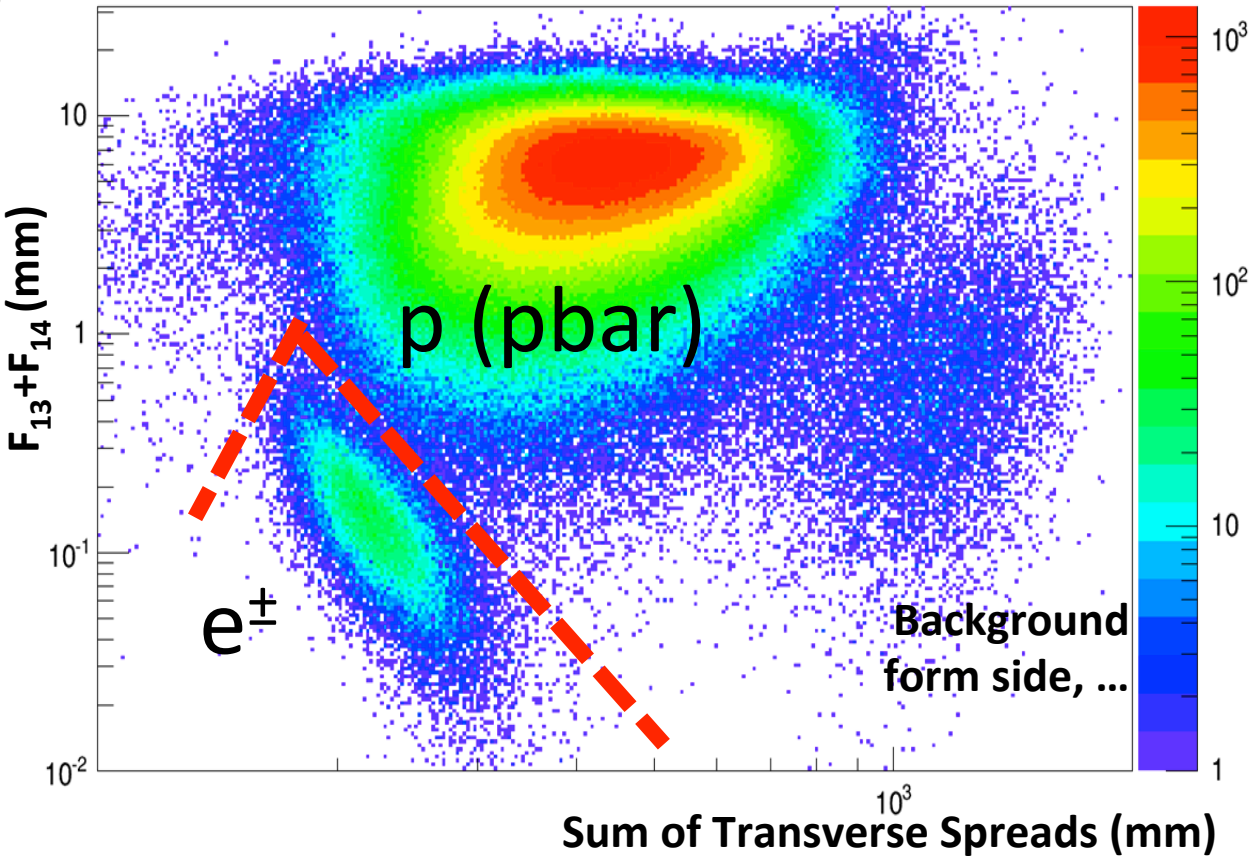
# Electron identification

One possible "shape parameter"

$$F_i = Spread_i \times \frac{E_i}{E_{tot}}$$

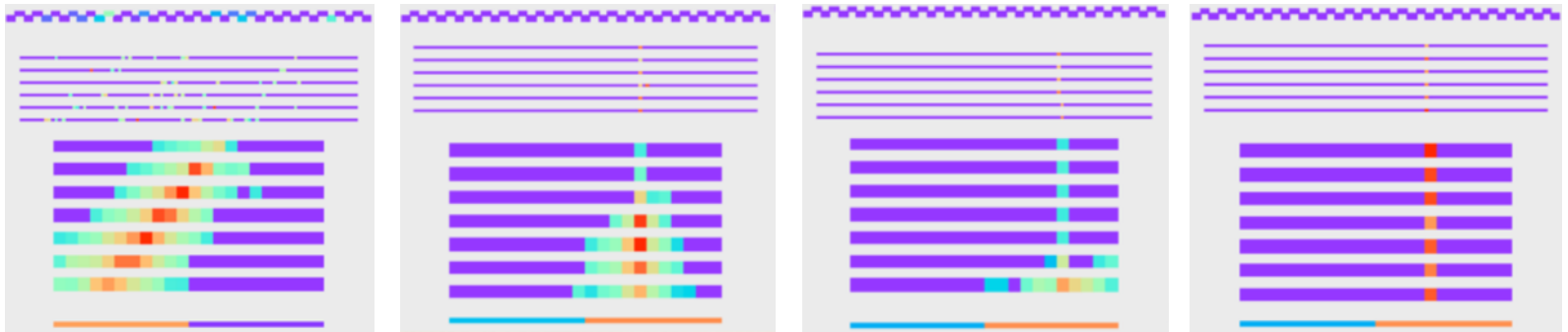
Rejection power > $10^5$





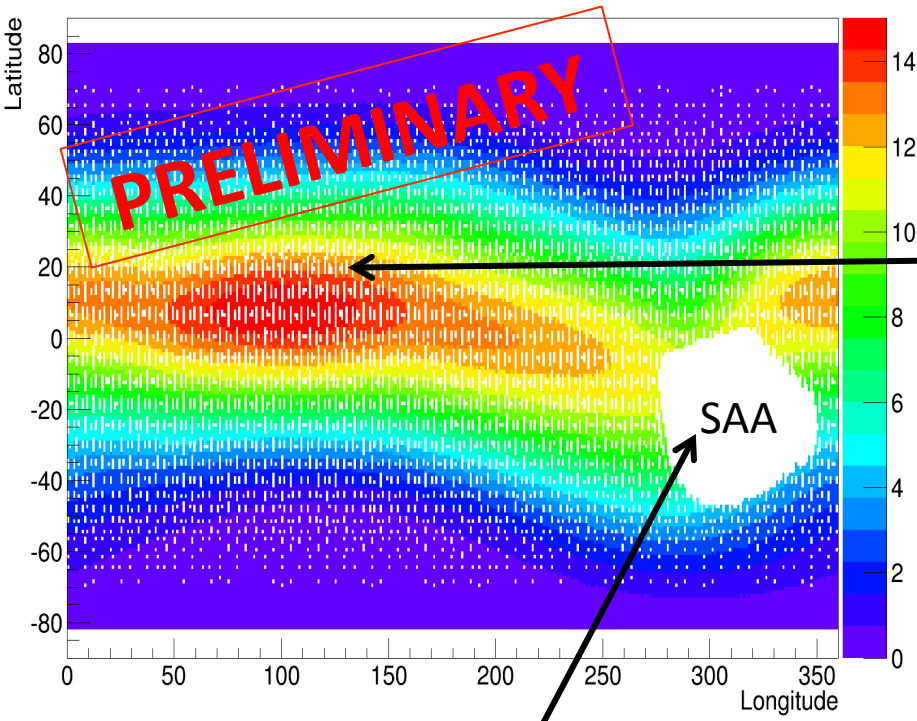

**Electrons and positrons**

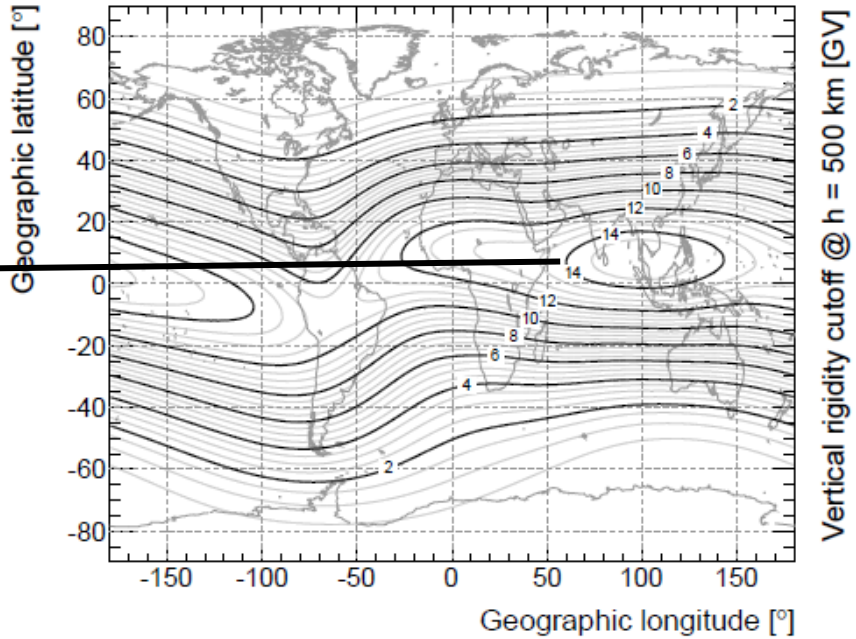
**Protons and nuclei**

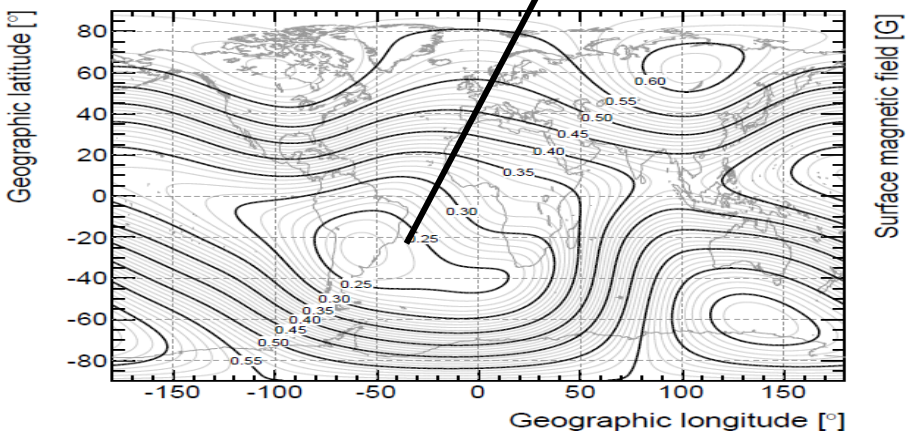


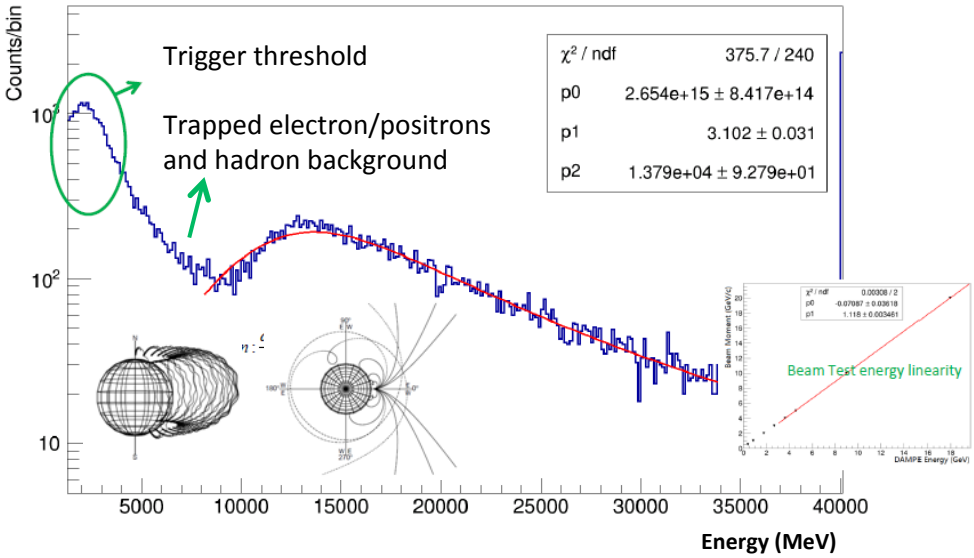
# On-orbit energy calibration

## $e^{\pm}$ rigidity cutoff with 1 month statistics



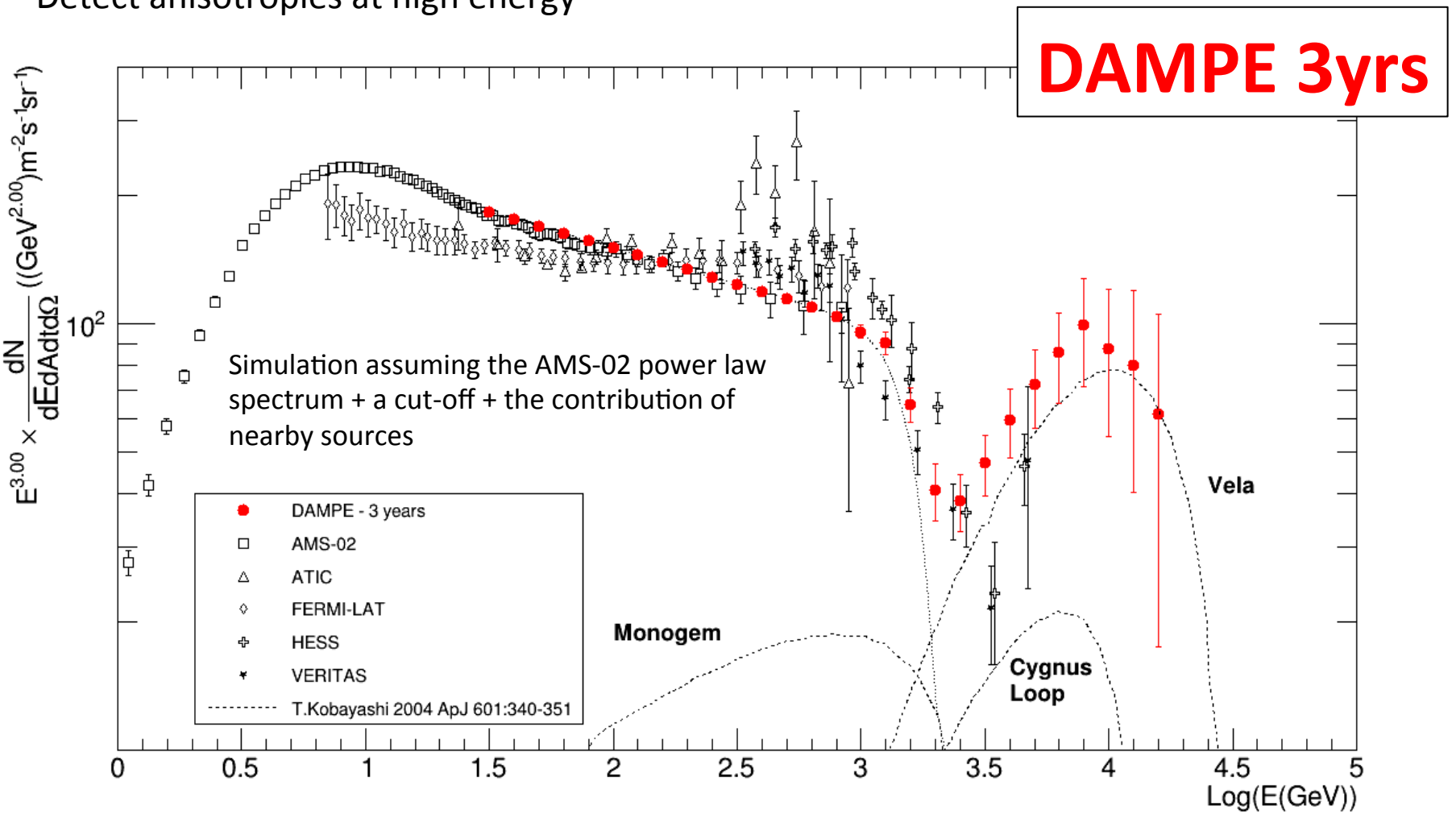



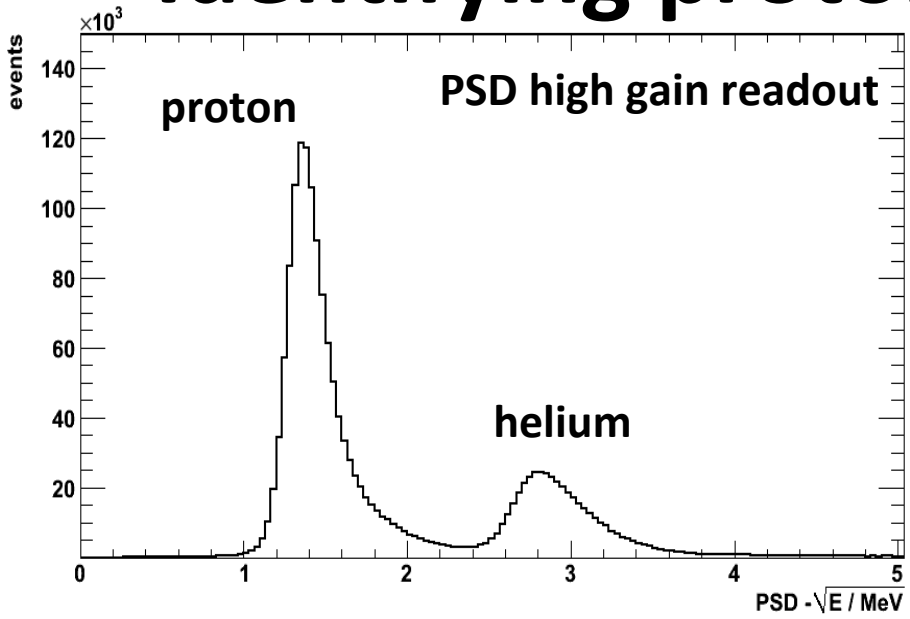



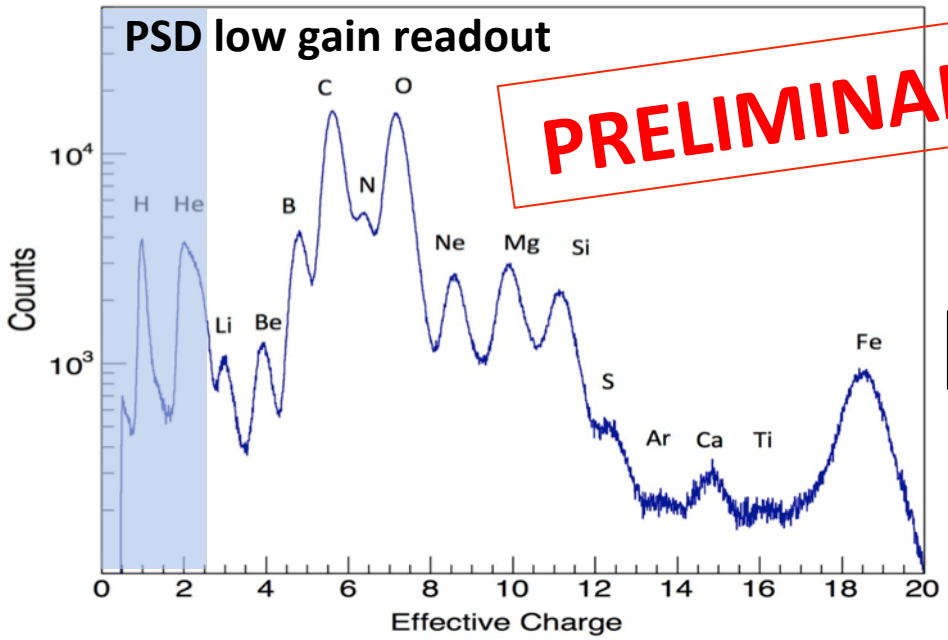
# All-electron spectrum

- Measure the all-electron flux up to about 10TeV
- Measure with high accuracy the sub-TeV region and the possible cut-off around one TeV
- Detect structures in the spectrum due to nearby sources and/or DM induced excesses
- Detect anisotropies at high energy

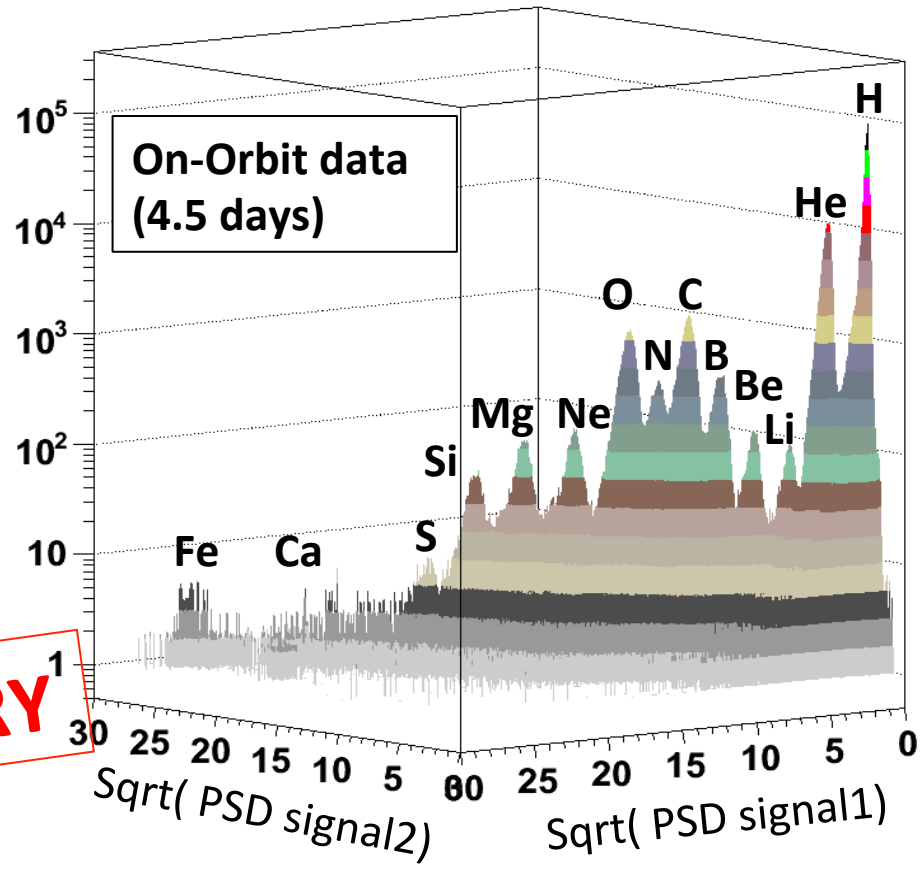


# Identifying protons and nuclei



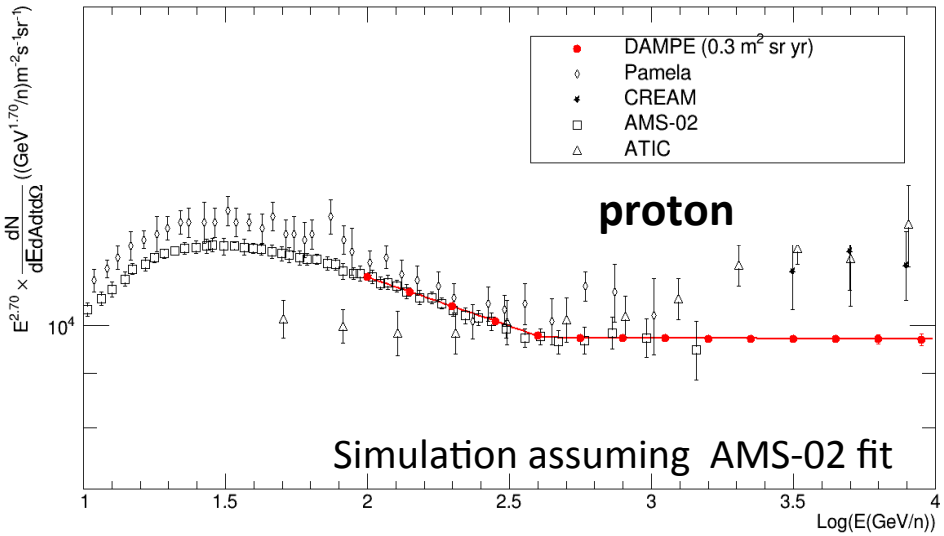

PRELIMINARY

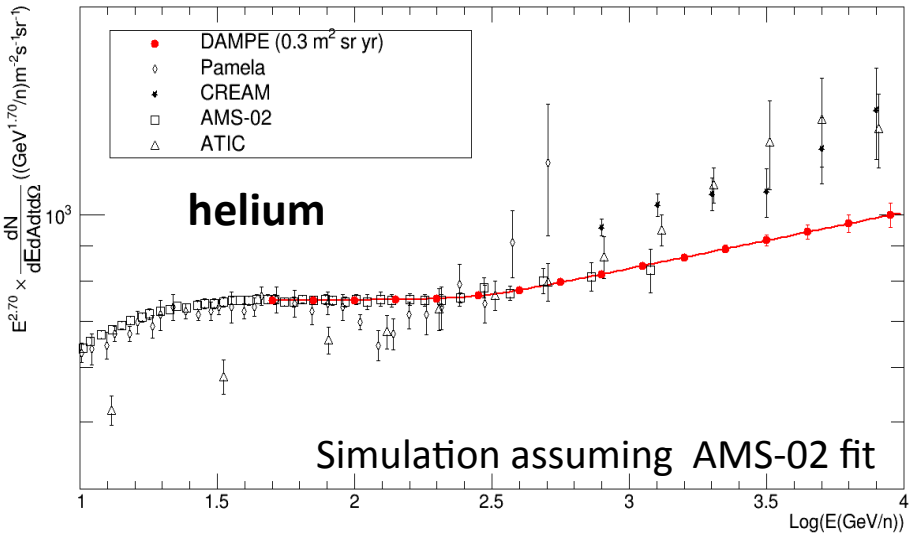


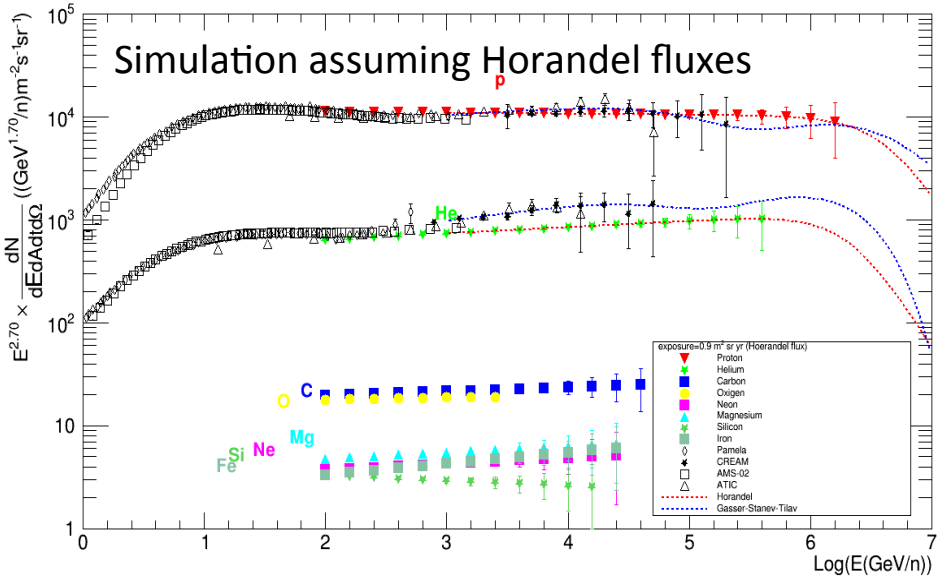

**Charge resolution ~ 0.2-0.3 e depending on Z**

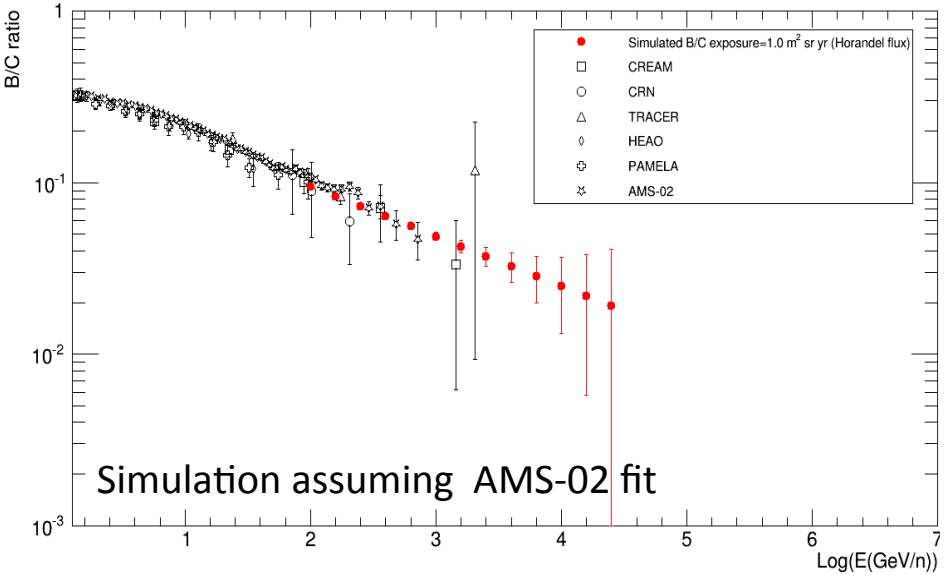
**Charge measurement also given by STK and (with lower precision) by the BGO bars**

# Protons and nuclei: DAMPE 3years

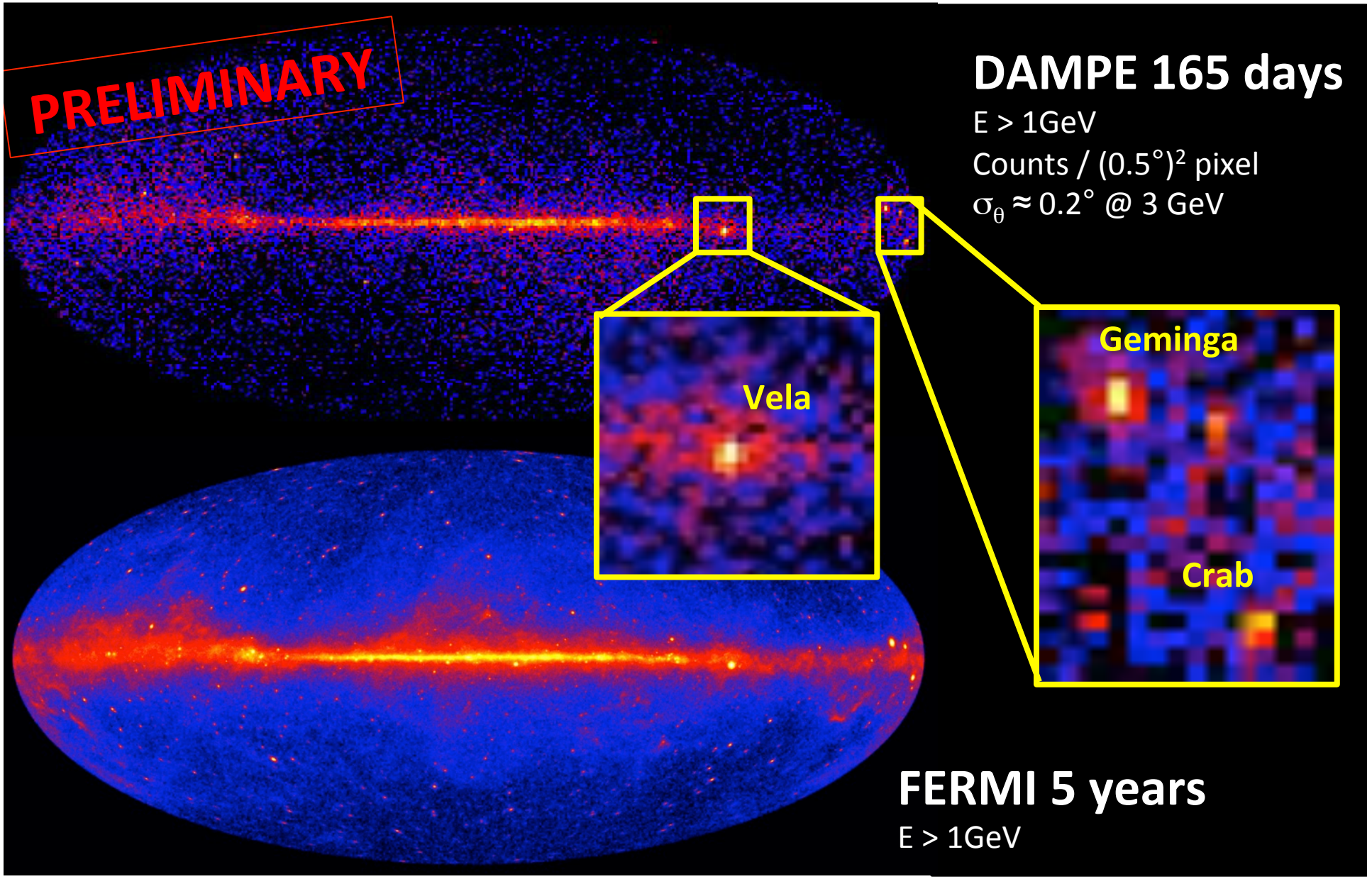


# Photons


PRELIMINARY
DAMPE 165 days
E > 1GeV
Counts / (0.5°)² pixel
σθ ≈ 0.2° @ 3 GeV
Vela
Geminga
Crab
FERMI 5 years
E > 1GeV

# Summary

## The detector

- Large geometric factor instrument (0.3 $m^2$ sr for p and nuclei)
- Precision Si-W tracker (40$\mu$m , 0.2°)
- Thick calorimeter (32 $X_0$ , $\sigma_E/E$ better than 1% above 50 GeV for e/$\gamma$ , ~35% for hadrons)
- "Mutiple" charge measurements (0.2-0.3 e resolution)
- e/p rejection power > $10^5$ (topology alone, plus neutron detector)

## Launch and performances

- Succesfull launch on Dec 17, 2015
- On orbit operation steady and with high efficiencies
- Absolute energy calibration by using the geomagnetic cut-off
- Absolute pointing cross check by use of the photon map

**Stay tuned for physics results**