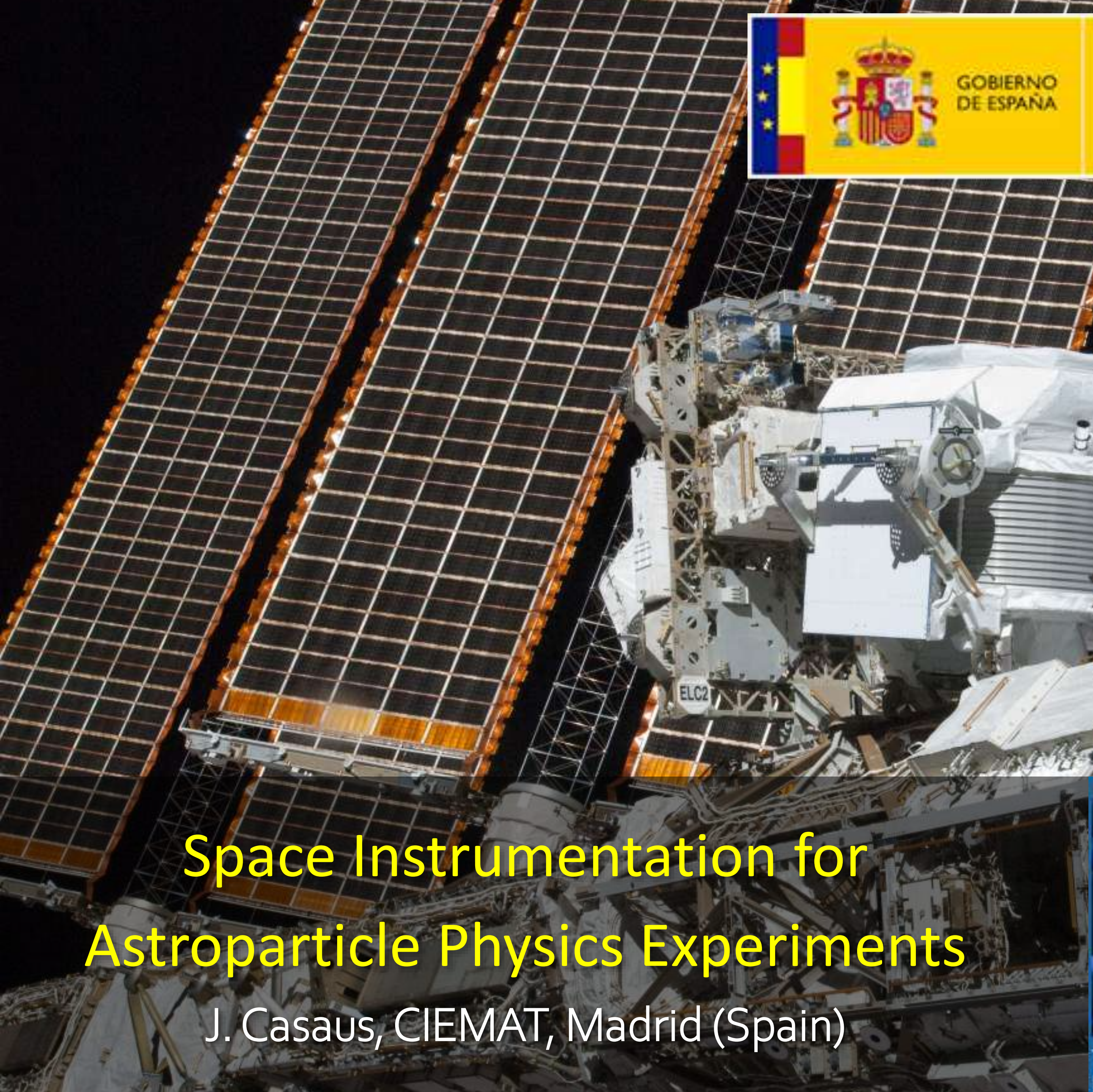
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
cfp CIEMAT física de partículas
CPAN NETWORK ON INSTRUMENTATION AND DETECTORS

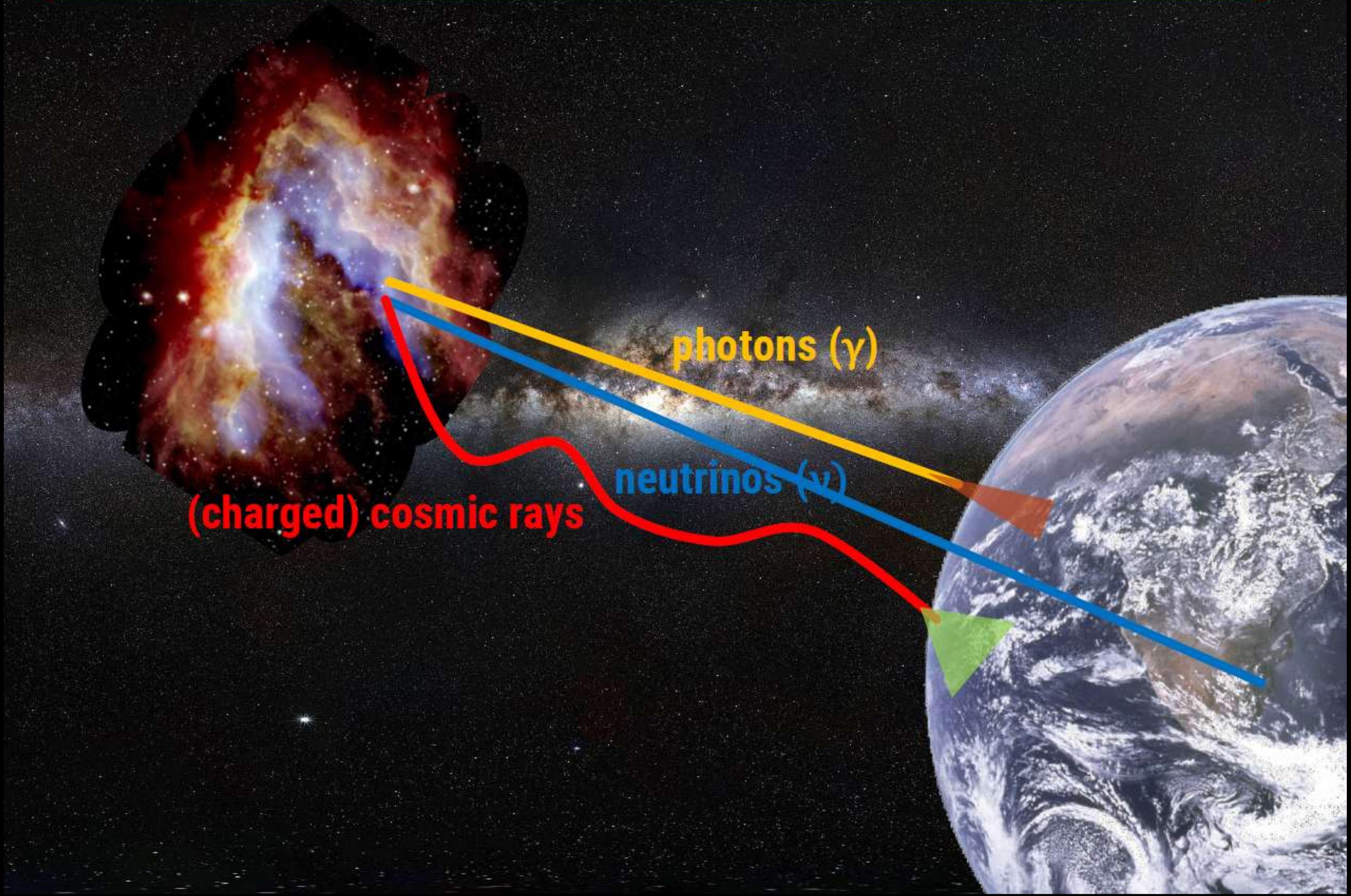


# Space Instrumentation for Astroparticle Physics Experiments

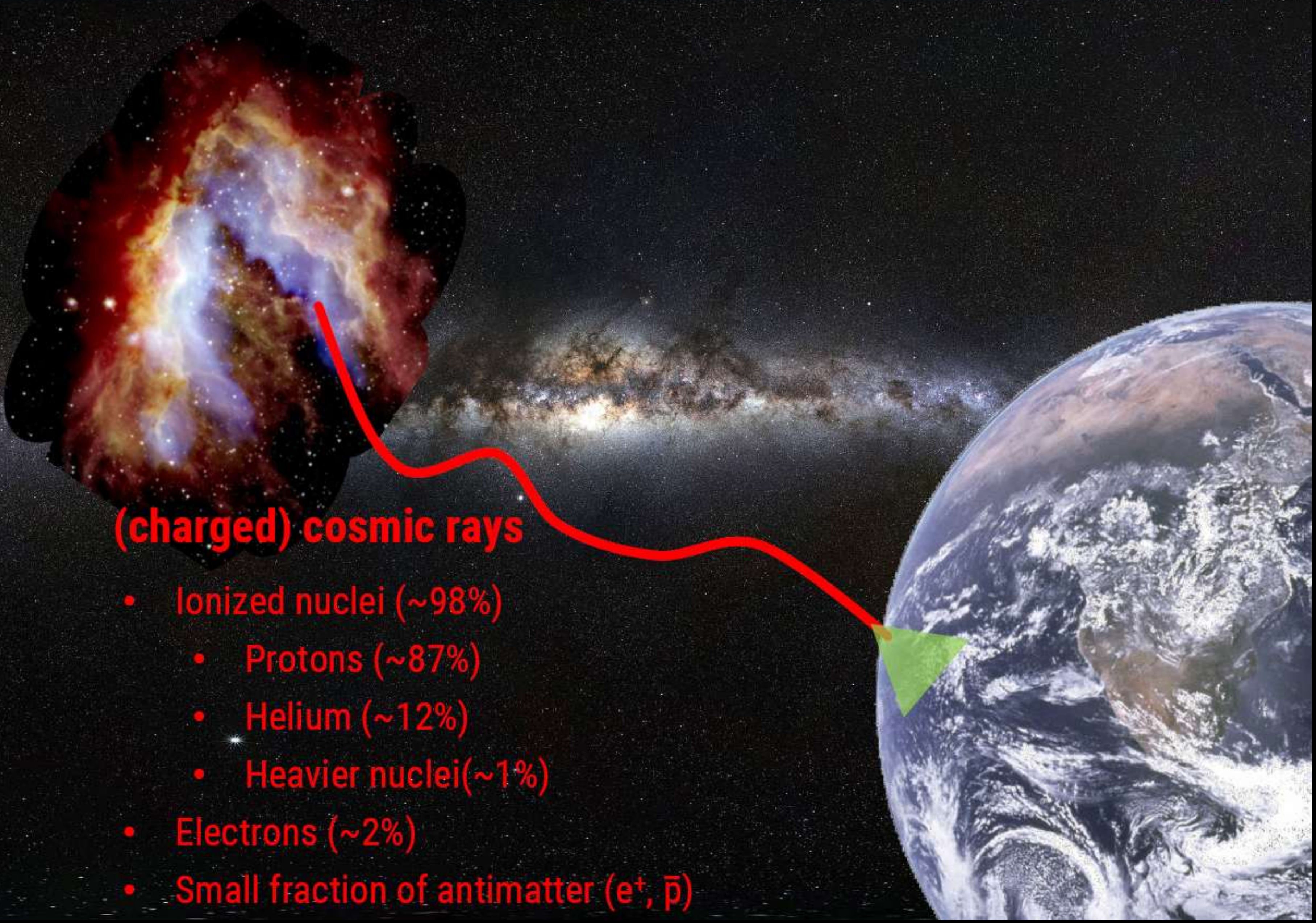
J. Casaus, CIEMAT, Madrid (Spain)

TIDPAN 2026 - Taller de Instrumentación y Detectores en Física de Partículas, Astropartículas y Nuclear

# MESSENGERS



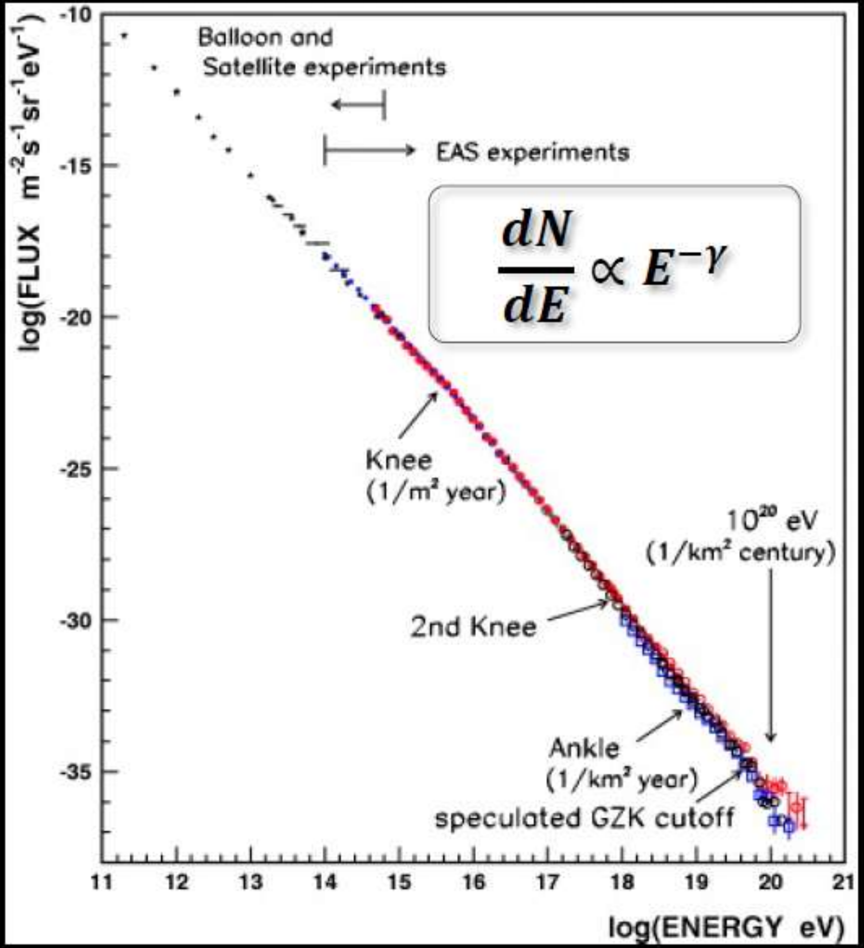
# MESSENGERS



**(charged) cosmic rays**

- Ionized nuclei (~98%)
  - Protons (~87%)
  - Helium (~12%)
  - Heavier nuclei(~1%)
- Electrons (~2%)
- Small fraction of antimatter ($e^+$, $\bar{p}$)

# COSMIC RAY ENERGY SPECTRUM



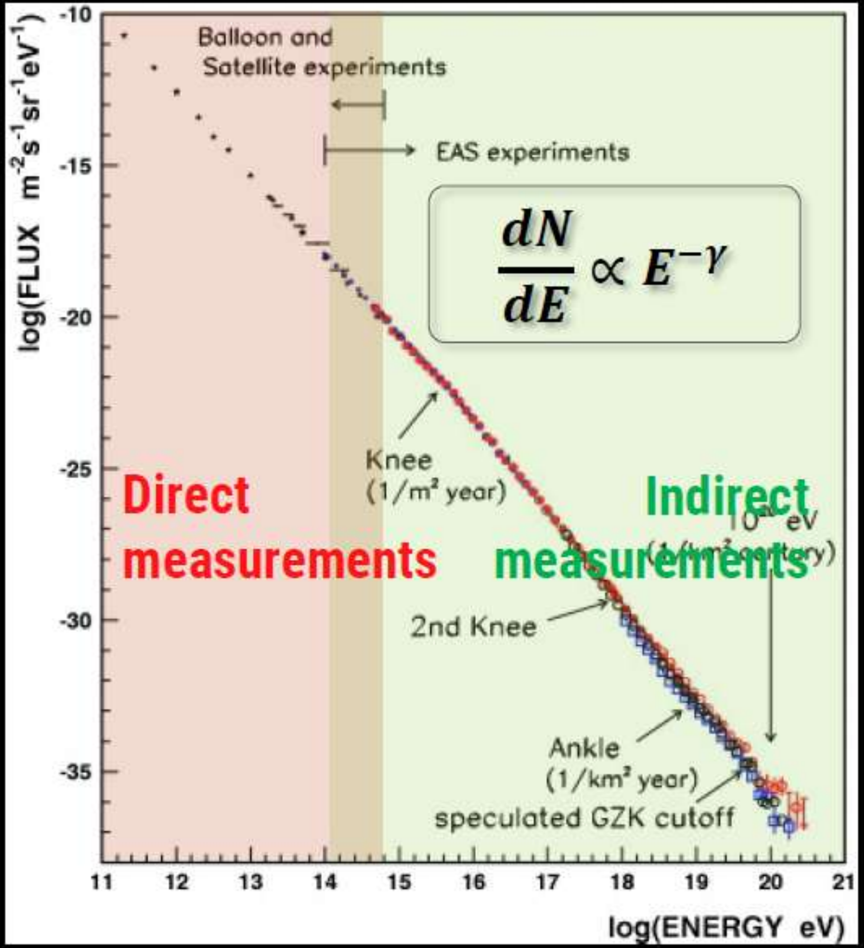

[M. Nagano, New J. Phys. **11** 065012 (2009)]

- **32** orders of magnitude in **intensity**
- **14** orders of magnitude in **energy**

**Changes of the spectral index:**

- ***Knee:*** @~$3\times10^{15}$ eV/nucleon
  $\Rightarrow \gamma$: ~2.7 to ~3.1
- ***2nd knee:*** @~$4\times10^{17}$ eV/nucleon
  $\Rightarrow \gamma$: ~3.1 to ~3.3
- ***Ankle:*** @~$5\times10^{18}$ eV/nucleon
  $\Rightarrow \gamma$: ~3.3 to ~2.7
- ***Suppression:*** @~$5\times10^{19}$ eV/nucleon

# COSMIC RAY ENERGY SPECTRUM




[M. Nagano, New J. Phys. **11** 065012 (2009)]

**Direct measurements (space-based/balloon-borne)**

☺ Particle identification

☹ Weight/size constrains: limits in the energy range

**Indirect measurements (ground-based)**

☺ Extended energy range

☹ Particle identification: dependence on models about atmospheric interactions

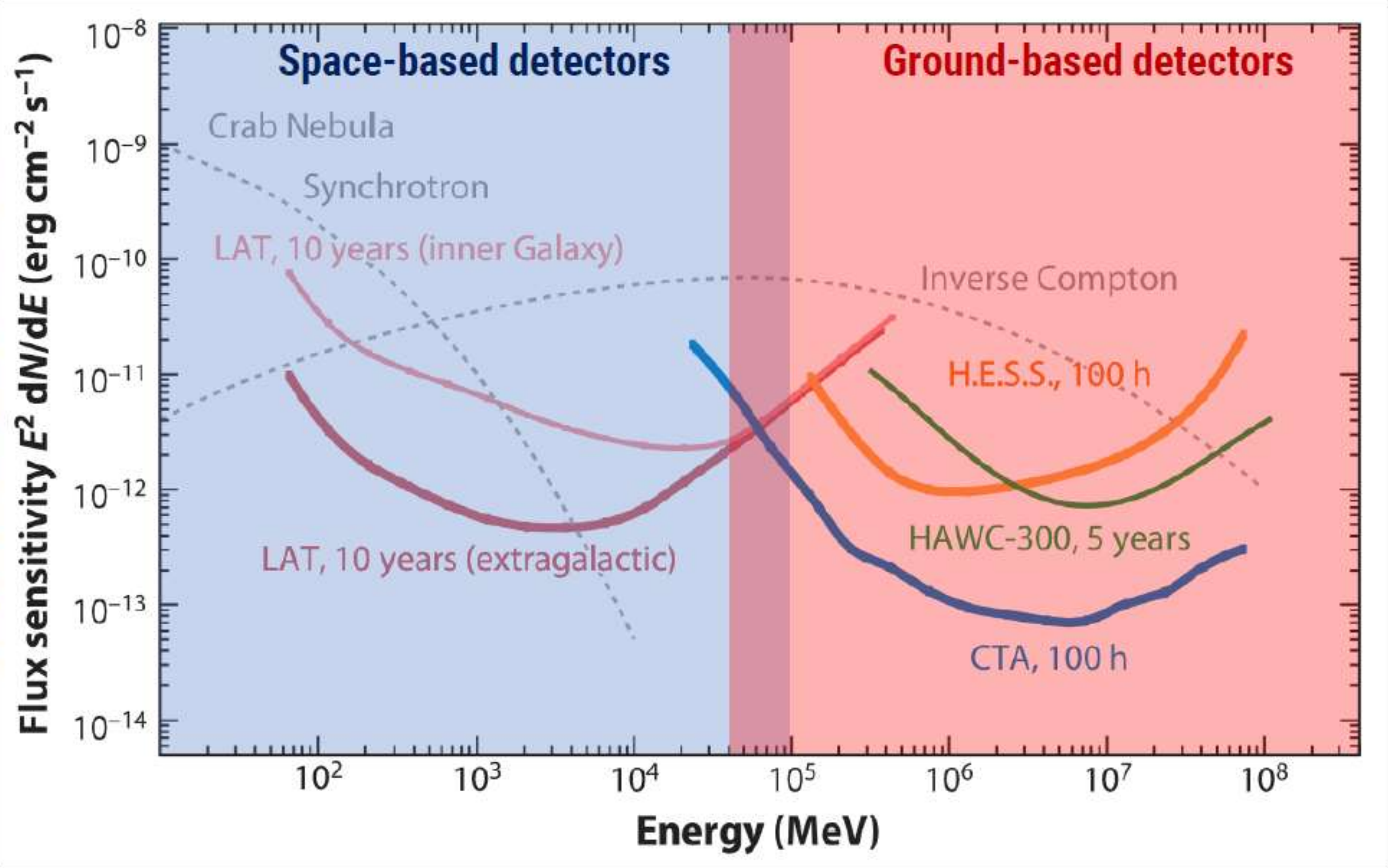
**DIRECT & INDIRECT MEASUREMENTS PROVIDE COMPLEMENTARY INFORMATION**

# EXPLORING GAMMA RAYS

Gamma rays span an **energy range** of about **7 decades** and have typical **flux difference of 14 decades** between the lowest and highest energy parts

Therefore, **different techniques** have to be used to explore the whole energy range

Based on G. Zaharijas @ TAUP 2021



# EXPLORING GAMMA RAYS

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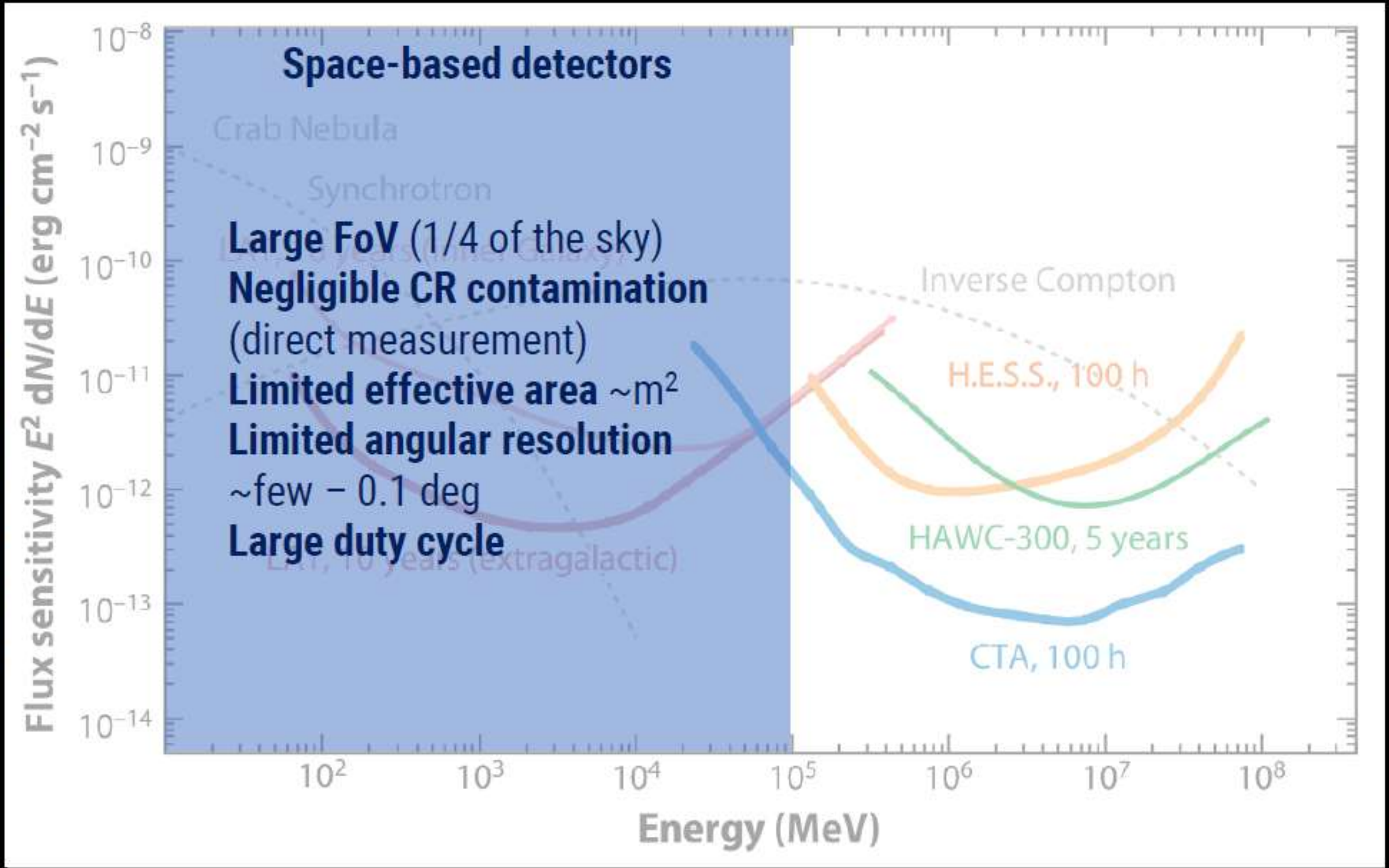


Based on G. Zaharijas @ TAUP 2021

# EXPLORING GAMMA RAYS

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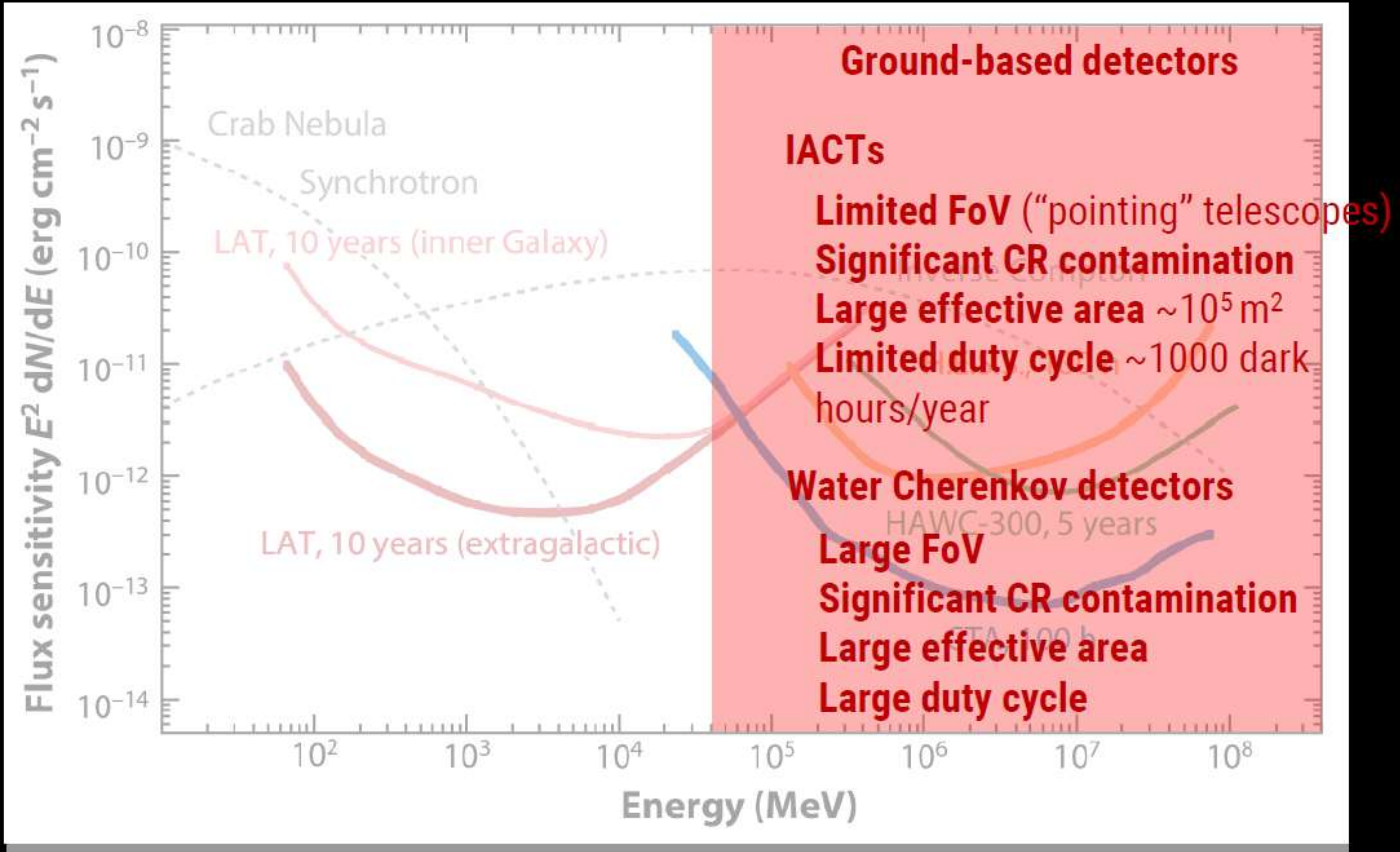
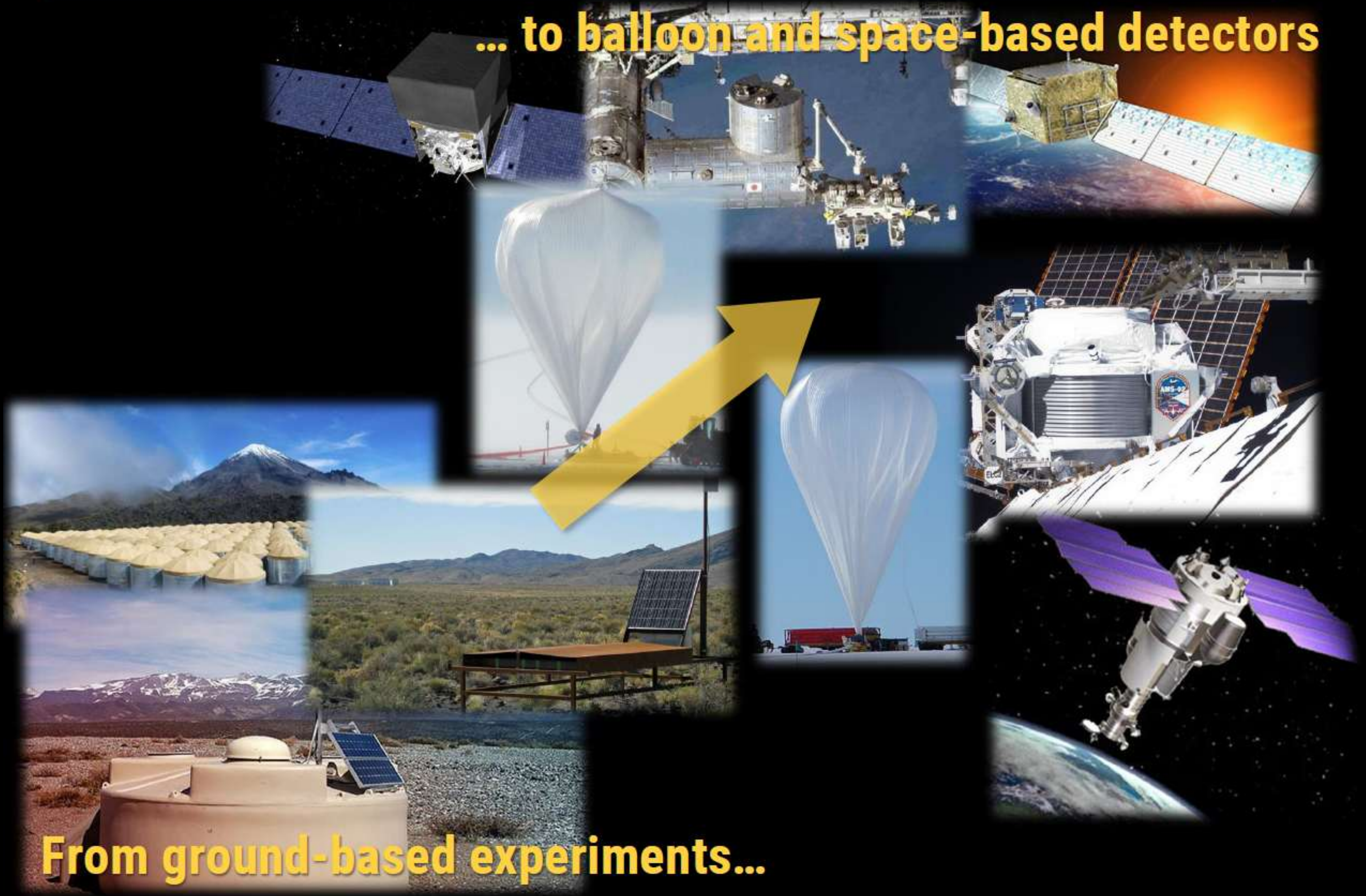
Based on G. Zaharijas @ TAUP 2021



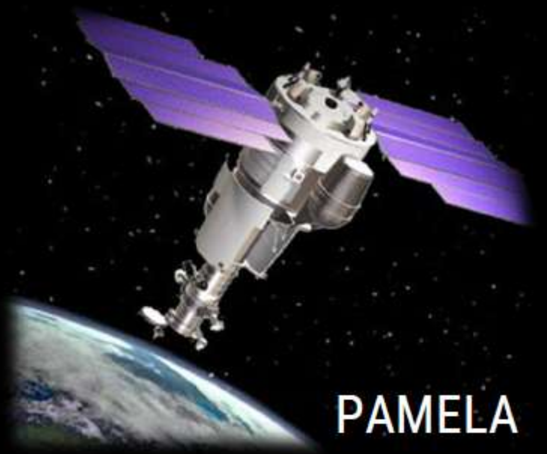
# OUTLINE: FROM GROUND… TO SPACE!



# SPACE-BASED DETECTORS

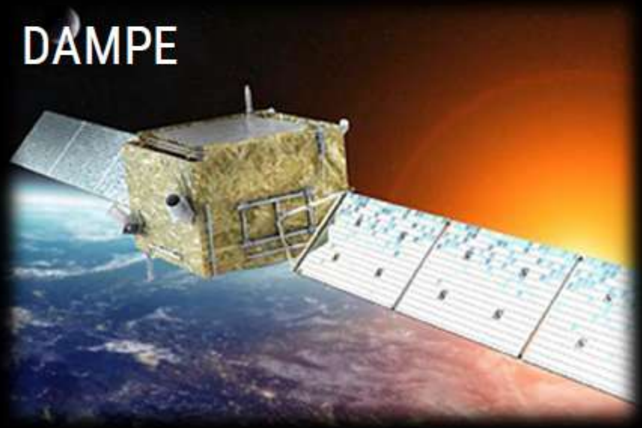
## Detection techniques

**Magnetic spectrometers**





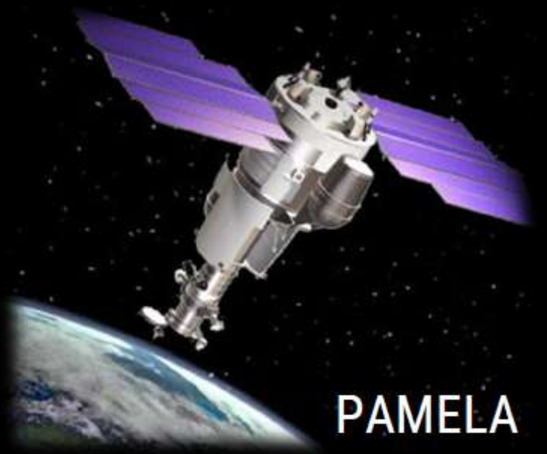
**Calorimeters**

# SPACE-BASED DETECTORS

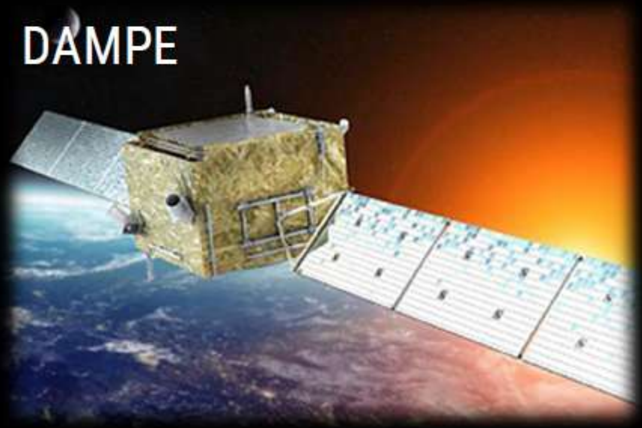
## Detection techniques

### Magnetic spectrometers





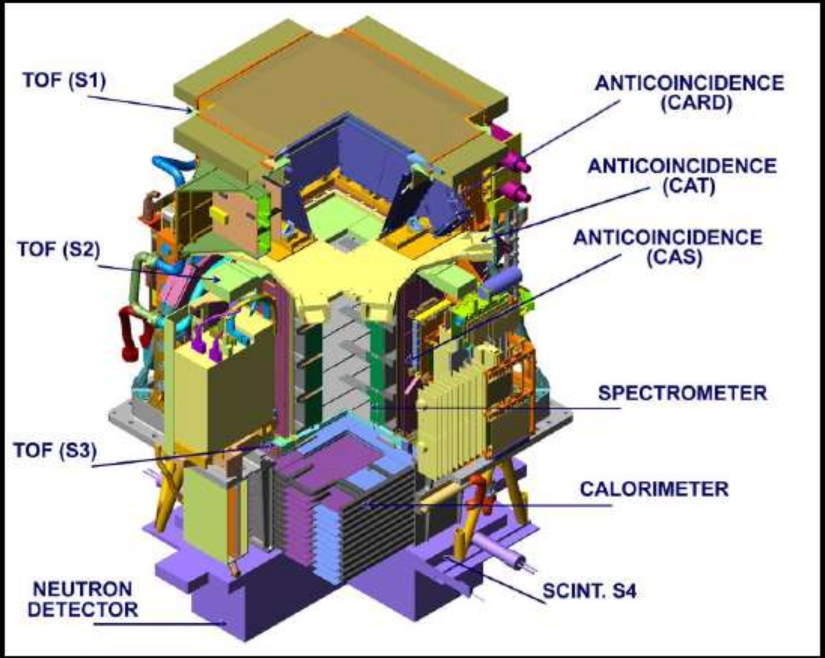
### Calorimeters

# SPACE-BASED DETECTORS

## PAMELA

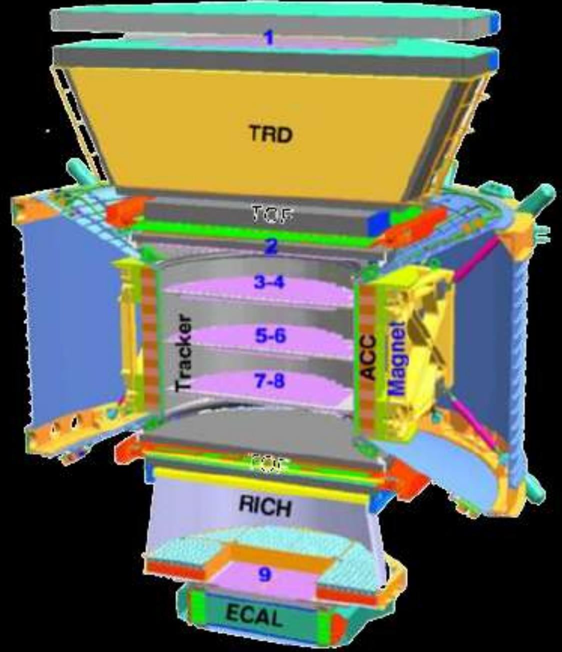
*(Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics)*




- Data taking: from 2006 to 2016
- Geom. Factor: ~0.002 $m^2sr$
- Magnetic spectrometer + Electr. Calorimeter (16.3 $X_0$)
- Energy range: up to few hundred GeV

## AMS-02

*(Alpha Magnetic Spectrometer)*

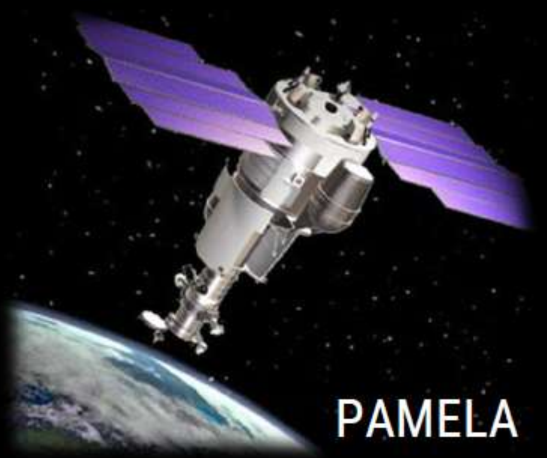



- Data taking: from 2011 (up to 2028)
- Geom. Factor: ~0.5 $m^2sr$ (Inner)
  ~0.04 $m^2sr$ (ECAL)
- Magnetic spectrometer + Electr. Calorimeter (17$X_0$)
- Energy range: up to few TeV

# SPACE-BASED DETECTORS

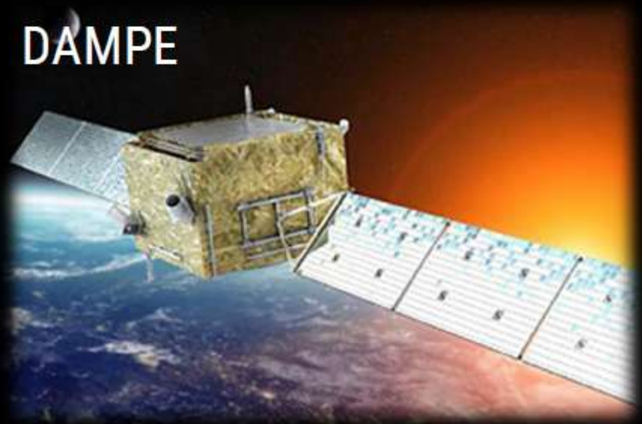
## Detection techniques

### Magnetic spectrometers





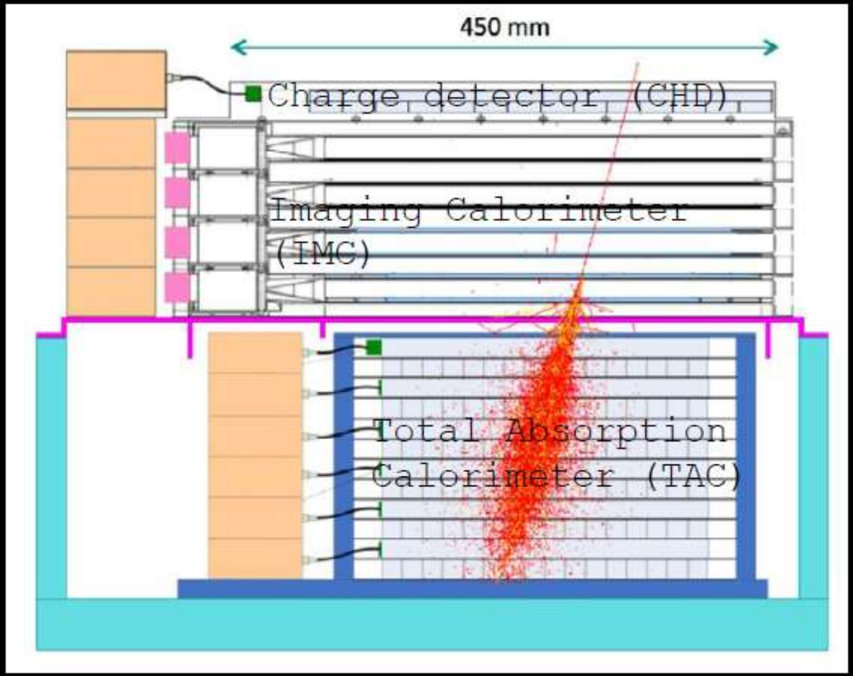
### Calorimeters

# SPACE-BASED DETECTORS

## CALET

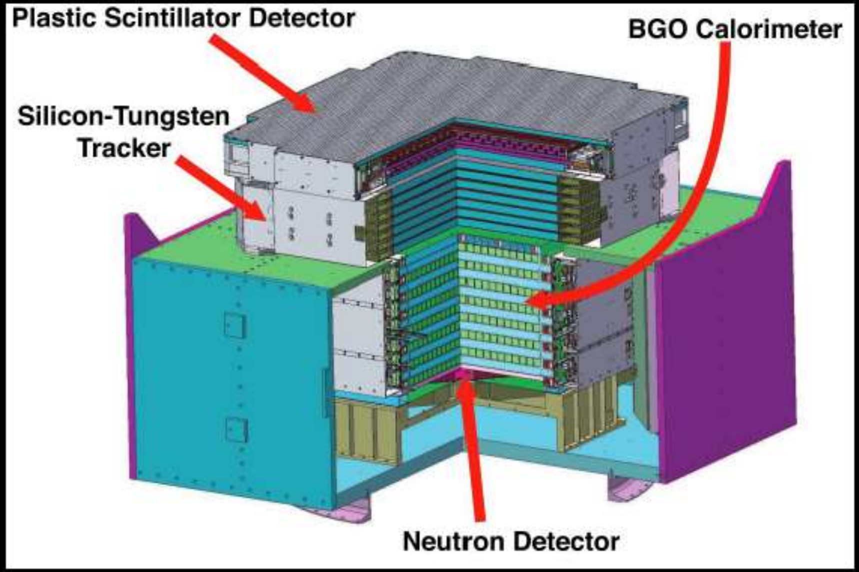
*(CALorimetric Electron Telescope)*




- Data taking: from 2015
- Geom. Factor: ~0,1 m²sr
- Calorimeter (30 $X_0$)
- Energy range: up to few tens of TeV

## DAMPE

*(DArk Matter Particle Explorer)*



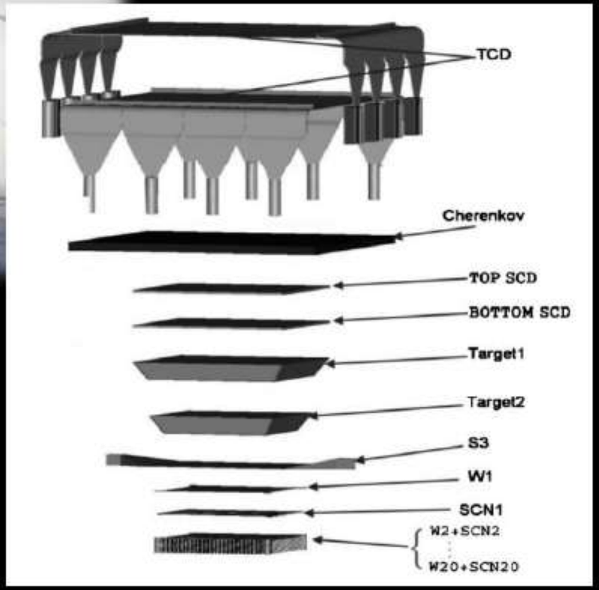

- Data taking: from 2015
- Geom. Factor: ~0.3 m²sr (e-)
- Calorimeter (32 $X_0$)
- Energy range: up to 10 TeV (e-)
  up to 100 TeV (nuclei)

# BALLOON-BORNE DETECTORS

## CREAM

*(Cosmic Ray Energetics And Mass)*

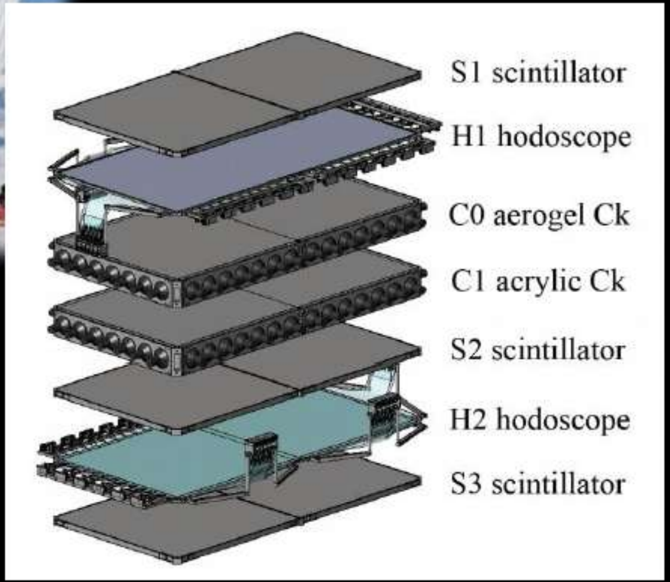
**CREAM-II**




- Six flights from 2004 to 2010
- Geom. Factor: 2 $m^2sr$ (p, He)
- Calorimeter (20 $X_0$) / TRD
- Energy range: up to 100 TeV
- Mass composition up to Z = 28

## Super-TIGER

*(Super Trans-Iron Galactic Element Recorder)*



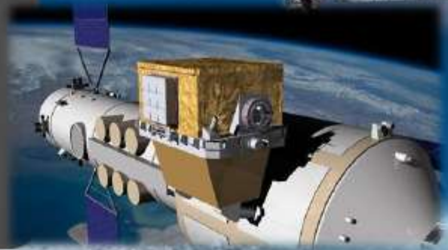

- Flight: 2012-2013 (55 days)
- Geom. Factor: 4 $m^2sr$
- Energy range: ~0.8–10 GeV/nucleon
- Mass composition: $10 \leq Z \leq 40$ (60)

# THE NEAR FUTURE: DIRECT MEASUREMENTS

**AMS-02**, **CALET** and **DAMPE** will continue providing precise measurements on cosmic rays.
Efforts to extend the energy range of current results

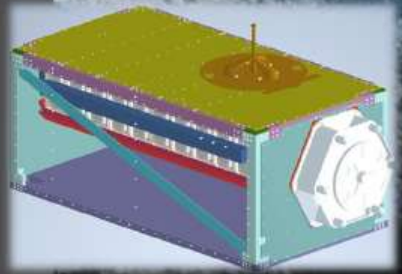
## HERD at the CSS

- 3D LYSO Calorimeter (55 $X_0$) + Silicon Tracker
- Energy range: up to 10 TeV ($e^{\pm}$) and 3 PeV (p)
- Geom. Factor : 3 $m^2sr$ ($e^{\pm}$) ; 2 $m^2sr$ (p)



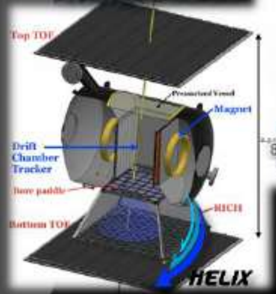
## TIGERISS at the JEM of the ISS

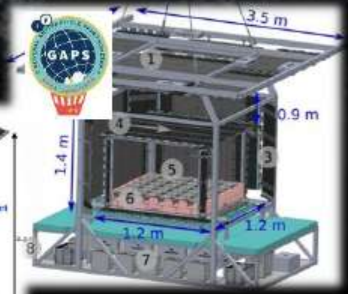
- Improvement of the SuperTIGER experiment
- Measurement of the charge of all GCR from $_5B$ to $_{82}Pb$ with energies greater than ~0.2 GeV/nucleon
- Geom. Factor : 1.1 – 1.7 $m^2sr$



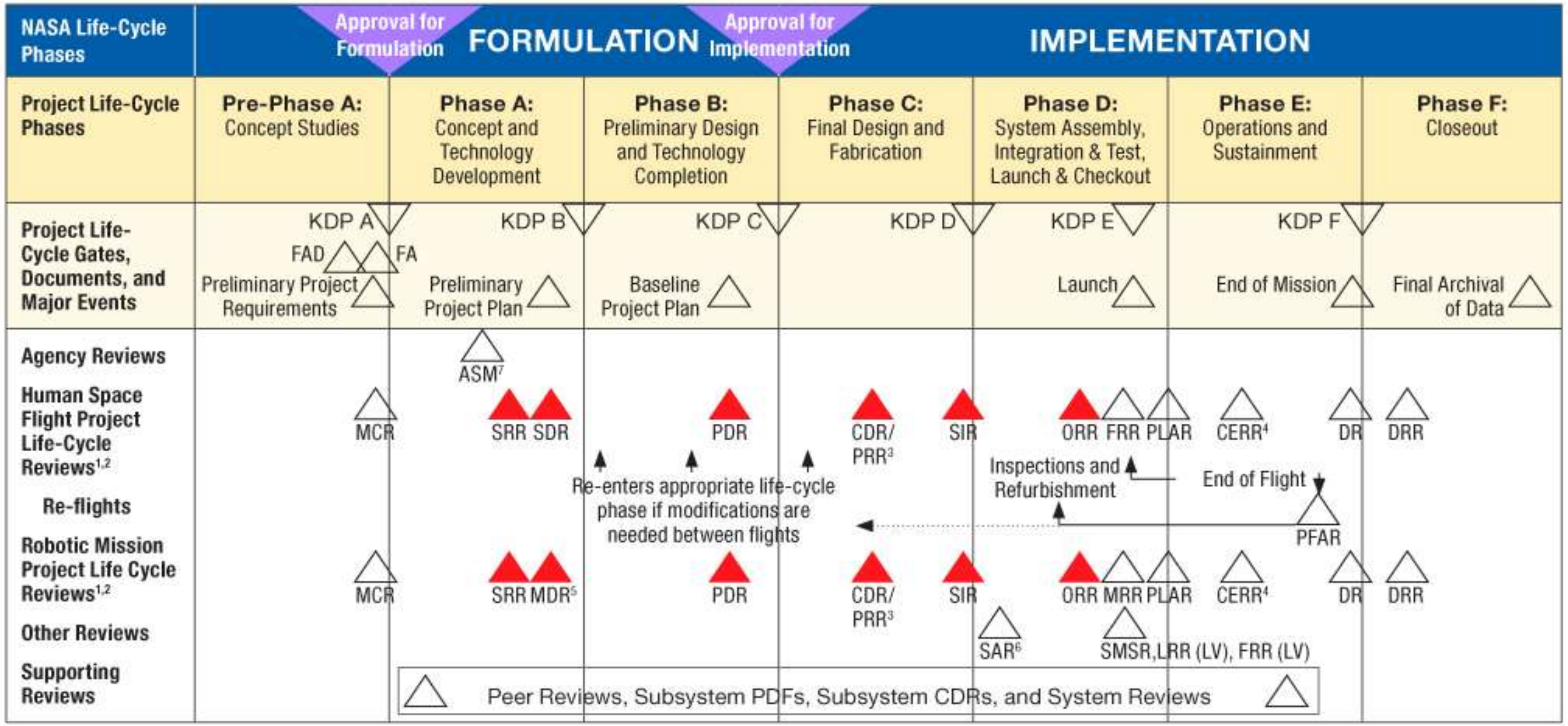
## HELIX and GAPS long duration balloon flights

- Expected in 2022
- **HELIX**: superconducting spectrometer to measure the isotopic composition up to 10 GeV/n
- **GAPS**: search for low-energy (< 0.25 GeV/n) CR antinuclei using an exotic atom technique to identify antiparticles



# PROJECT TIMELINE: PHASES & MILESTONES




**FOOTNOTES**

1. Flexibility is allowed as to the timing, number, and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan.
2. Life-cycle review objectives and expected maturity states for these reviews and the attendant KDPs are contained in Table 2-5 and Appendix D Table D-3 of this handbook
3. PRR is needed only when there are multiple copies of systems. It does not require an SRB. Timing is notional.
4. CERRs are established at the discretion of program .
5. For robotic missions, the SRR and the MDR may be combined.
6. SAR generally applies to human space flight.
7. Timing of the ASM is determined by the MDAA. It may take place at any time during Phase A.

▲ Red triangles represent life-cycle reviews that require SRBs. The Decision Authority, Administrator, MDAA, or Center Director may request the SRB to conduct other reviews.

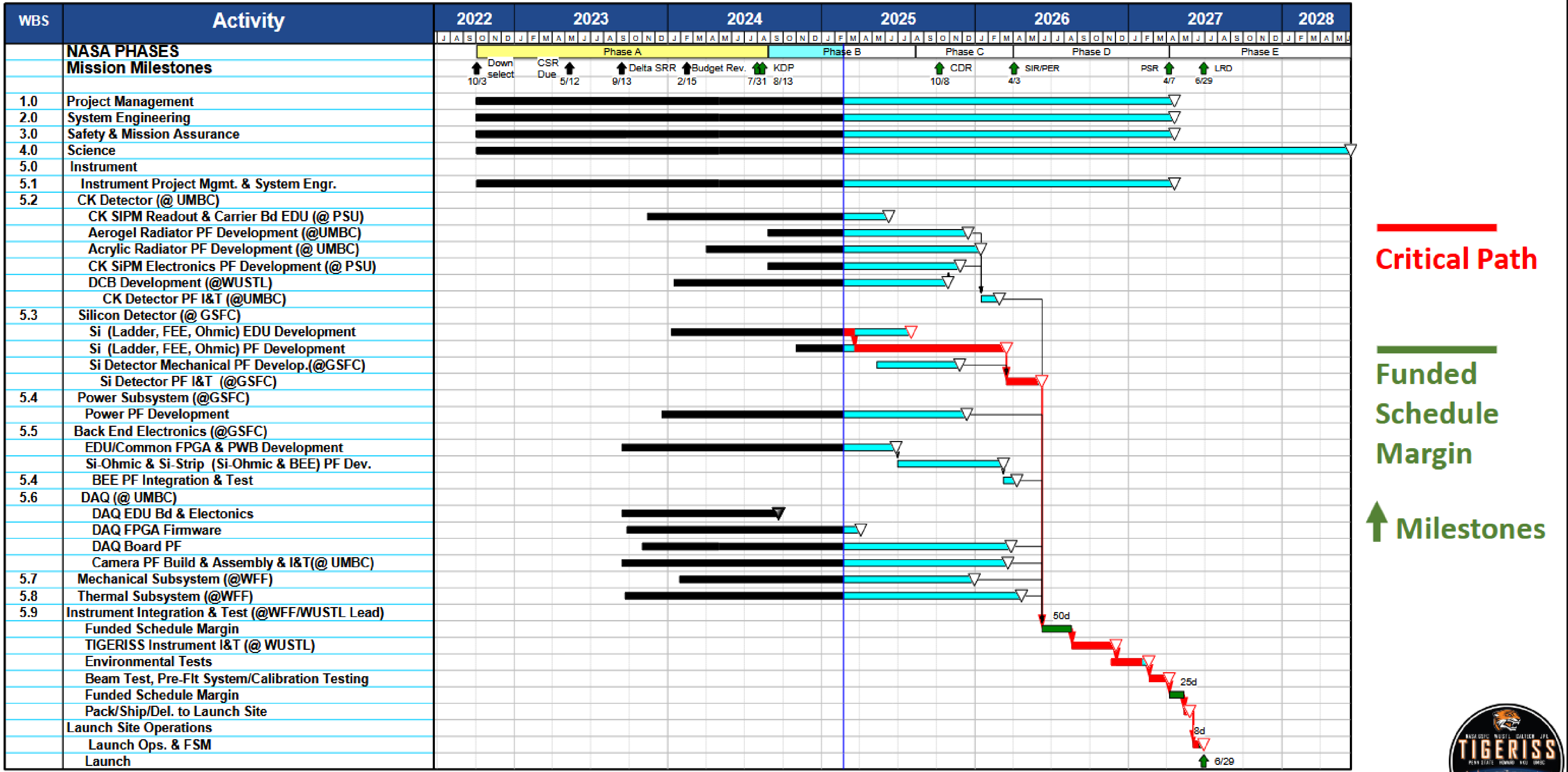
**ACRONYMS**

ASM – Acquisition Strategy Meeting
CDR – Critical Design Review
CERR – Critical Events Readiness Review
DR – Decommissioning Review
DRR – Disposal Readiness Review
FA – Formulation Agreement
FAD – Formulation Authorization Document
FRR – Flight Readiness Review
KDP – Key Decision Point
LRR – Launch Readiness Review
LV – Launch Vehicle
MCR – Mission Concept Review
MDR – Mission Definition Review
MRR – Mission Readiness Review
ORR – Operational Readiness Review
PDR – Preliminary Design Review
PFAR – Post-Flight Assessment Review
PLAR – Post-Launch Assessment Review
PRR – Production Readiness Review
SAR – System Acceptance Review
SDR – System Definition Review
SIR – System Integration Review
SMSR – Safety and Mission Success Review
SRB – Standing Review Board
SRR – System Requirements Review

**FIGURE 3.0-1** NASA Space Flight Project Life Cycle from NPR 7120.5E

# TIGERISS Schedule

2/21/25



N. Park, ASAPP 2025

# HELIX Flight 2024

**Total flight time:** 6 days 8 hrs 27 min

- 125 M triggers
- Relatively smooth operation for most of the flight

14

# HELIX Recovery

**Completed in July, 2024**

- Most of detectors were recovered without any damage

# HELIX Upgrade (for 2028 flight)

**Aiming for an Antarctic flight**

**Adding a single layer of silicon strip detector outrigger**

- Will be installed on top of DCT with active area of ~90 × 90 cm²
  - -Baseline design: readout pitch of 100 μm to achieve ~ 30 μm spatial resolution
- Expect to provide a boost to MDR
- Pathfinder/prototype for stage2 tracker (all-silicon)

**Several updates on the payload from lessons learned from the previous flight**

- Updates on power/HSK system

# First NASA Scientific Balloon Launches from Antarctica

Jamie Adkins
NASA Goddard Digital Lead

DECEMBER 16, 2025 2:35PM

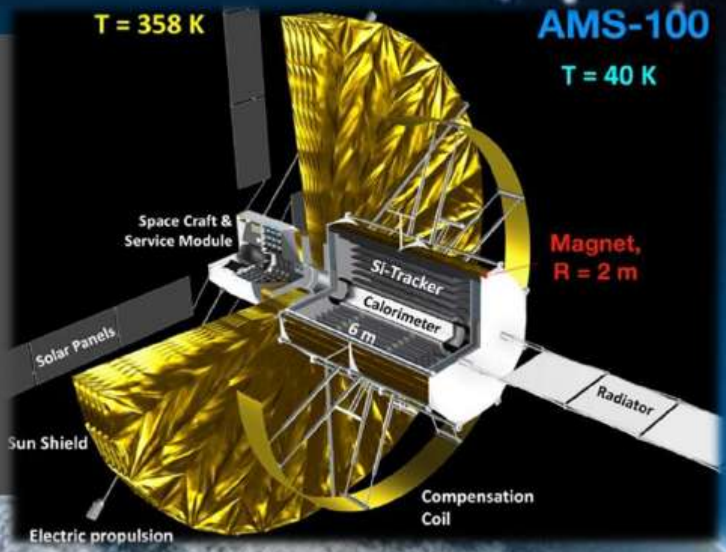
The GAPS experiment prepares to launch from Antarctica Rubilotta

NASA/Andy Hamilton

# THE FAR FUTURE: DIRECT MEASUREMENTS

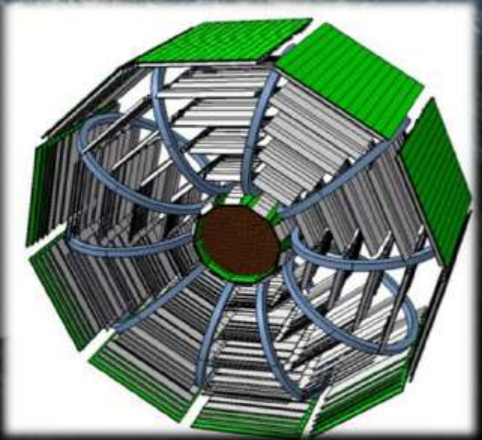
## AMS-100

- Placed at the Lagrange point 2
- Geometrical acceptance 100 $m^2 sr$
- 1 Tesla magnetic solenoid
- Tracker, MDR = 100 TV
- Central calorimeter (reverse-collider layout) (70 $X_0$)
- Goals: $e^+$, e-, nuclei (beyond the knee), antinuclei

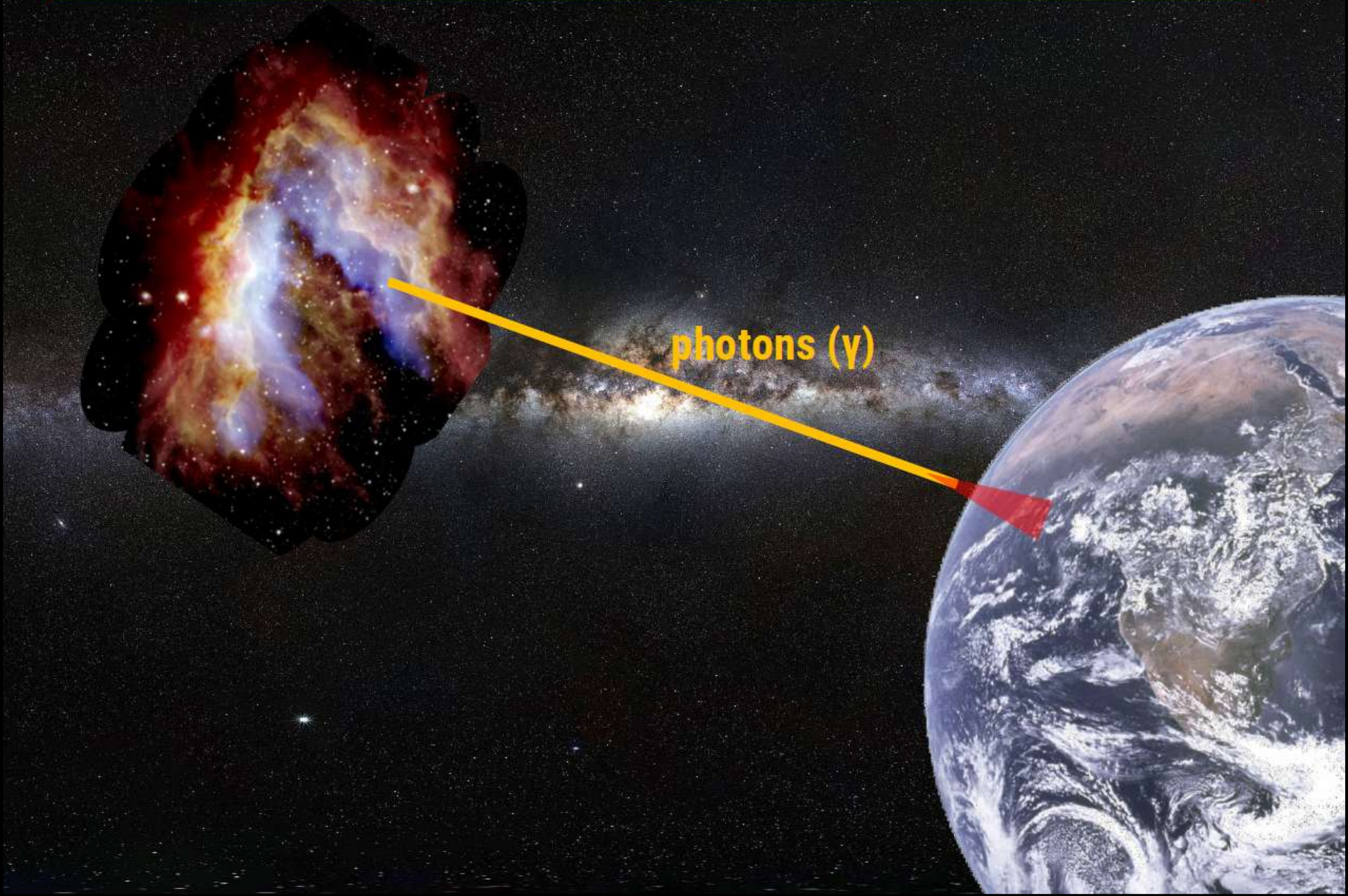



## ALADInO

- Placed at the Lagrange point 2
- High Temperature Supercondactic Spectrometer: MDR = 20 TV
- Hexagonal-prysm 3D calorimeter
- Goals: e+, e-, nuclei, antinuclei



# MESSENGERS



# SPACE-BASED DETECTORS

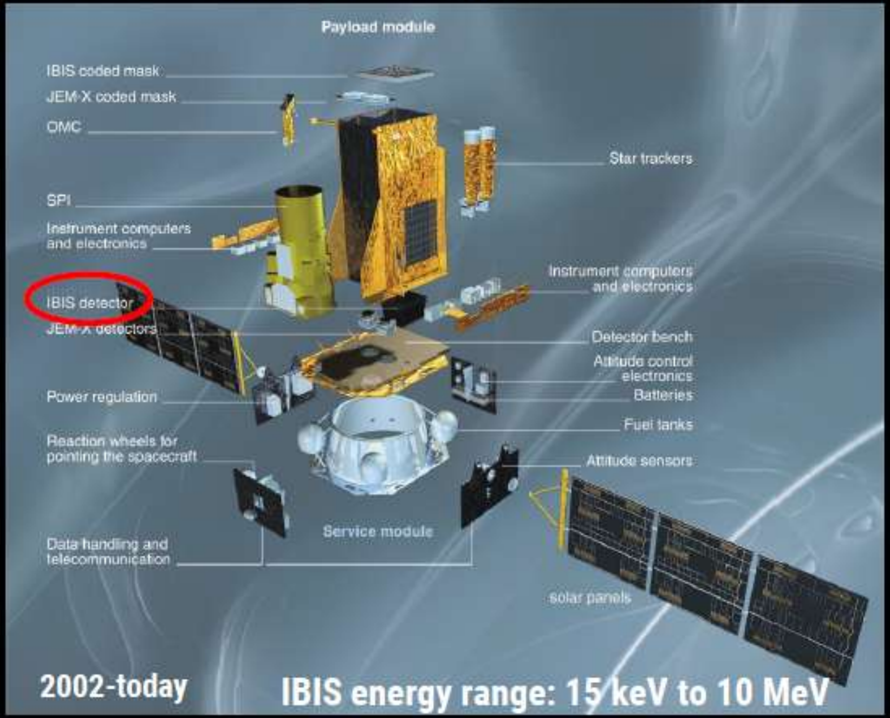
## Detection techniques

### Compton detectors

- Based on the **Compton scattering** of a photon inside a scintillator
- The **trajectory deviation** is then measured to reconstruct its original **direction**
- Suitable for the measurement of γ-rays in the **MeV range**, where the Compton scattering dominates

**COMPTEL detector of the NASA's CGRO experiment**


**IBIS detector of the ESA's INTEGRAL experiment**



# SPACE-BASED DETECTORS

## Detection techniques

### Pair production detectors

- A photon passing near a nucleus has a probability to **produce an electron-positron pair** if its energy is at least twice the rest mass of the electron
- A pair production detector consists of a **tracker** with several layers to promote the **conversion** and measure the **incoming direction** of the photon
- Suitable for the measurement of photons with energies **above few tens of MeV**

**EGRET detector of the NASA's CGRO experiment**


**AGILE's ASI experiment**

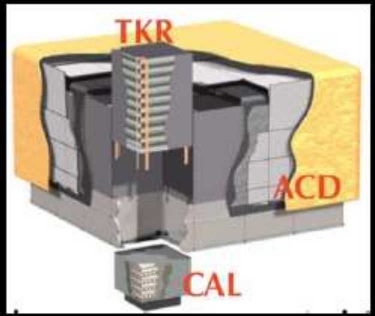
# SPACE-BASED DETECTORS

## Detection techniques

### Pair production detectors: Fermi

**Fermi Gamma Ray Space Telescope (NASA)**


**Large Area Telescope (LAT)**




- Geom. acceptance: ~0.95 $m^2sr$
- Pair conversion telescope
- Calorimeter (8.6 $X_0$)
- Energy range: up to few TeV

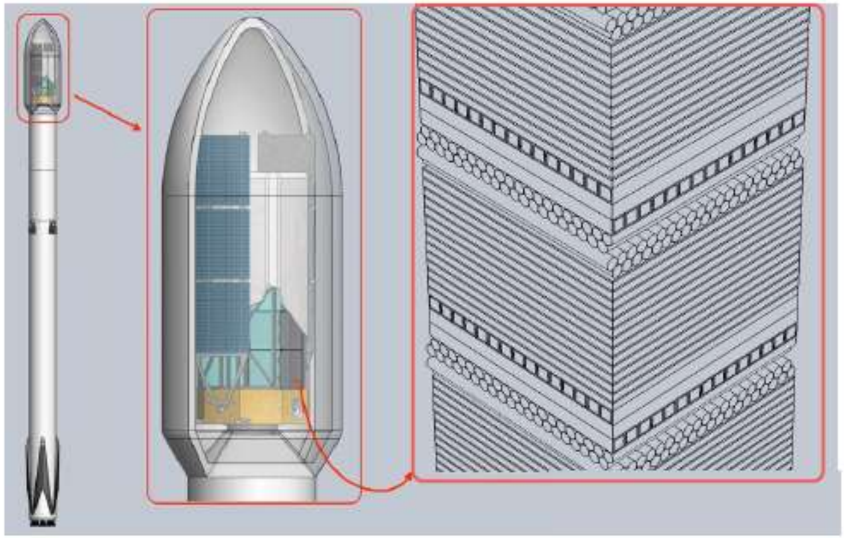
**Gamma-Ray Burst Monitor (GBM)**

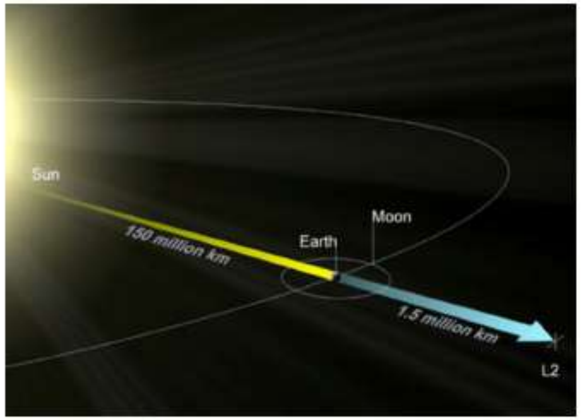

- Detection and quick alert of GRBs
- 12 NaI and 2 BGO scintillator detectors
- Energy range: 8 keV to 40 MeV

# THE ~~NEAR~~ FUTURE: DIRECT MEASUREMENTS

## The Advanced Particle-astrophysics Telescope (APT) mission concept

3

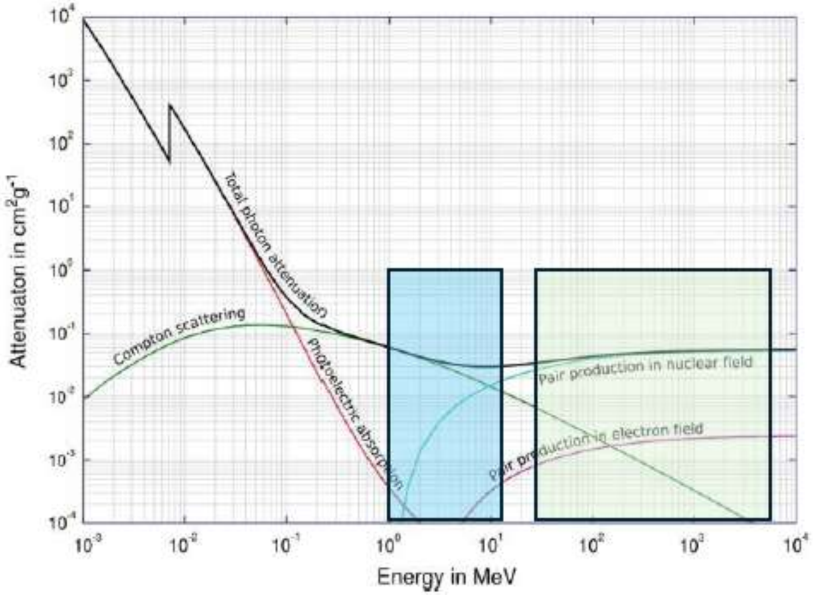





**L2 orbit**

- Minimize Earth obscuration
- Challenging prompt notification to ground base observatory
- One 4h contact per day: On-board real time reconstruction to reduce the data load

Compton telescope (few MeV – 10 MeV)
Pair Telescope (50MeV - 50GeV)




F.Gargano - ASAPP2025 - Girona 13-16 May 2025

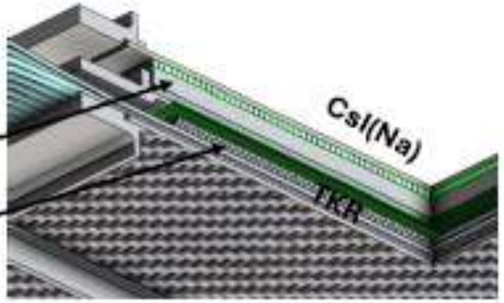
*F. Gargano, ASAPP 2025*

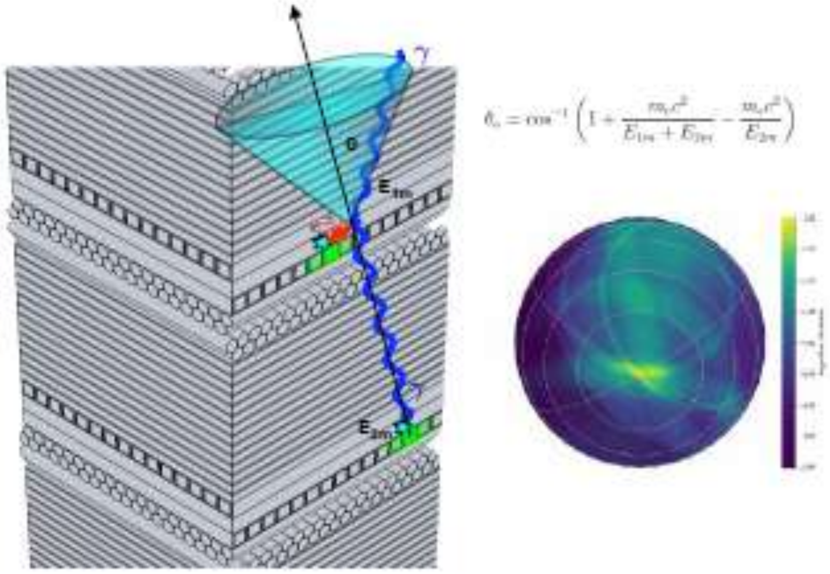
# THE ~~NEAR~~ FUTURE: DIRECT MEASUREMENTS

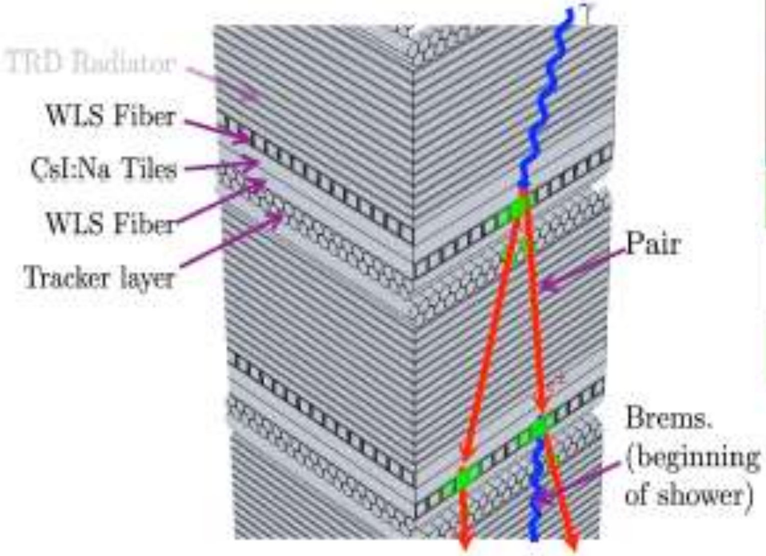
## The Advanced Particle-astrophysics Telescope (APT) mission concept

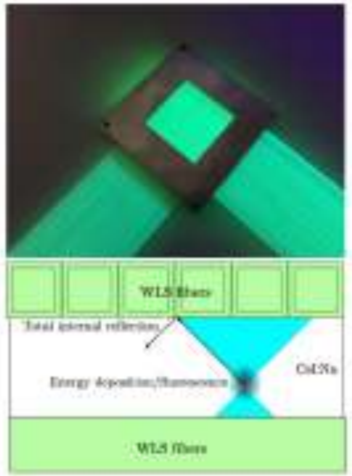


- 3m x 3m x 2.5m single module detector
- 20 X-Y **tracker** and **active converter** layers
  - Active pair converter layers composed by 20 layers of CsI:Na detectors (5mm)
    - Green squared WLS fibers (2mm) convert and guide the photons to SiPM
  - The tracker layers are formed from 2 close-packed, staggered layers of 1.5mm diameter round scintillating fibers
- An ACD made of plastic scintillating tiles surround the whole detector module





**Compton Scattering**

**Pair Production**

*F. Gargano, ASAPP 2025*

F.Gargano - ASAPP2025 - Girona 13-16 May 2025

# THE NEAR FUTURE: DIRECT MEASUREMENTS

## The Antartic Demonstrator for APT



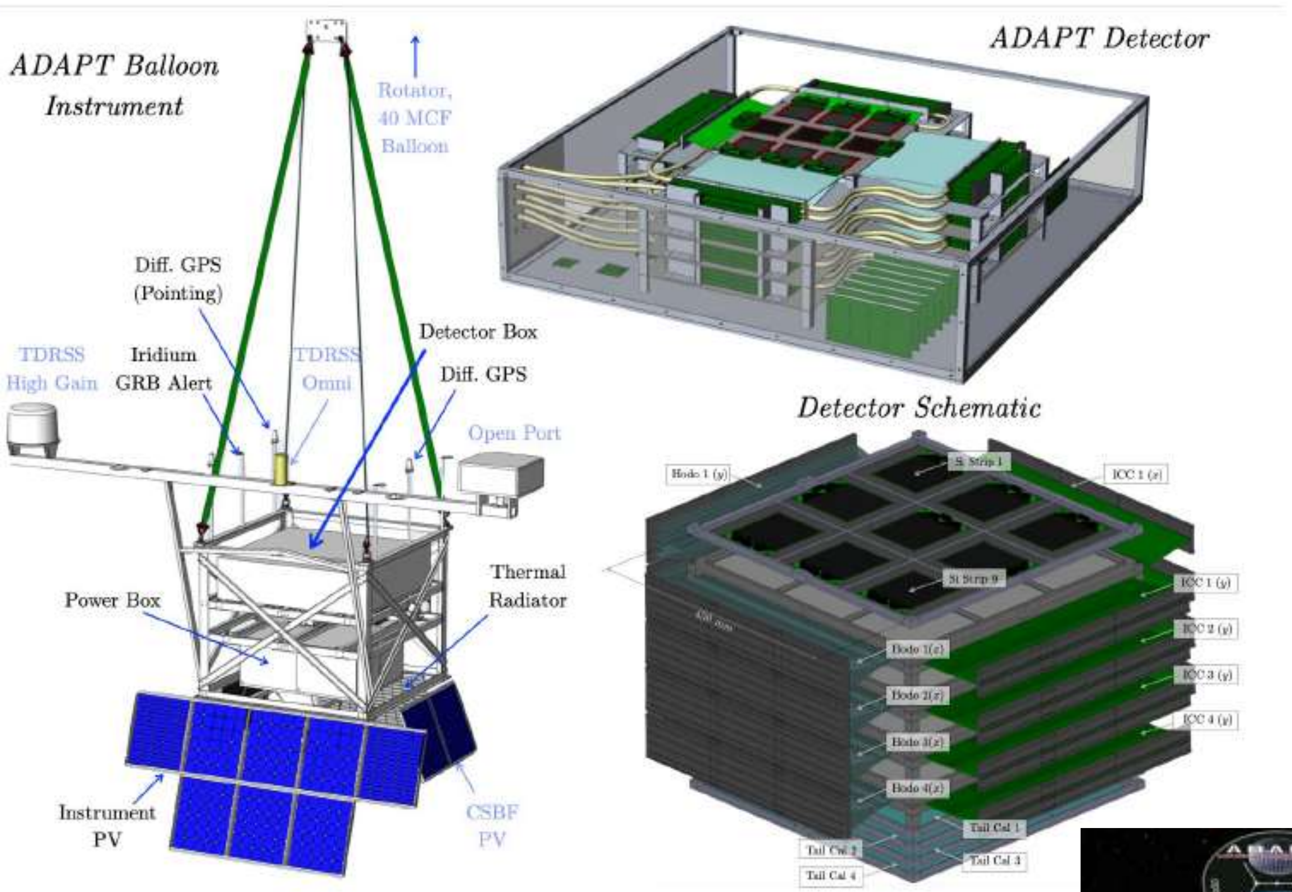
**NASA APRA grant** to develop a ful' suborbital mission

**Long-duration flight** on a 60 millic cubic-foot balloon flight from Antarctica in the ~~FY25~~ FY26 –FY27 season

### Why?

The goal is to demonstrate APT's Compton and pair detection capabilities, **validate the Compton reconstruction** mechanism, and **provide real-time positional alerts for transient astrophysical phenomena** such as gamma-ray bursts (GRBs)

few expected in 36 days of flight



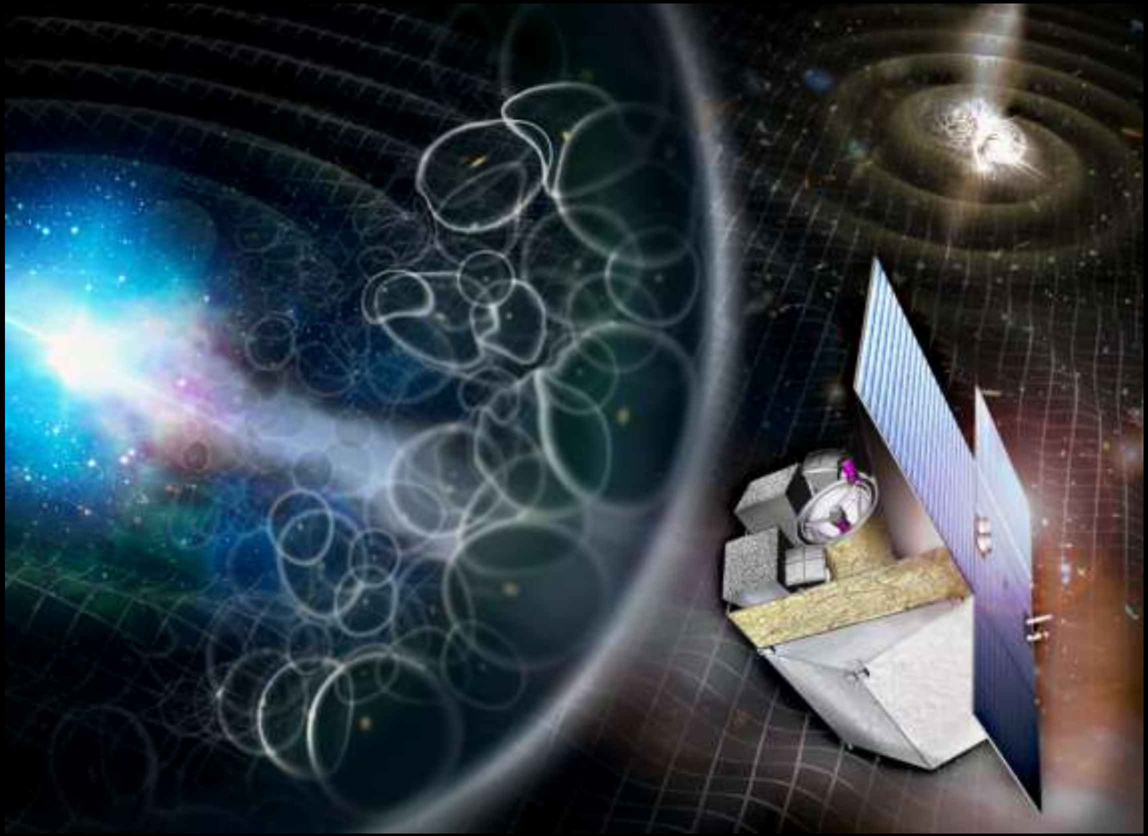

ADAPT
Antarctic Demonstrator for the Advanced Particle-astrophysics Telescope

*F. Gargano, ASAPP 2025*

F.Gargano - ASAPP2025 - Girona 13-16 May 2025

# theseus
## TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

Under study by ESA since 2018 as candidate for a medium-size mission



- **Soft X-ray Imager (SXI, 0.3 – 5 keV):**

2 lobster-eye telescopes units, with a total FOV of ~0.5sr with source location accuracy <1-2’

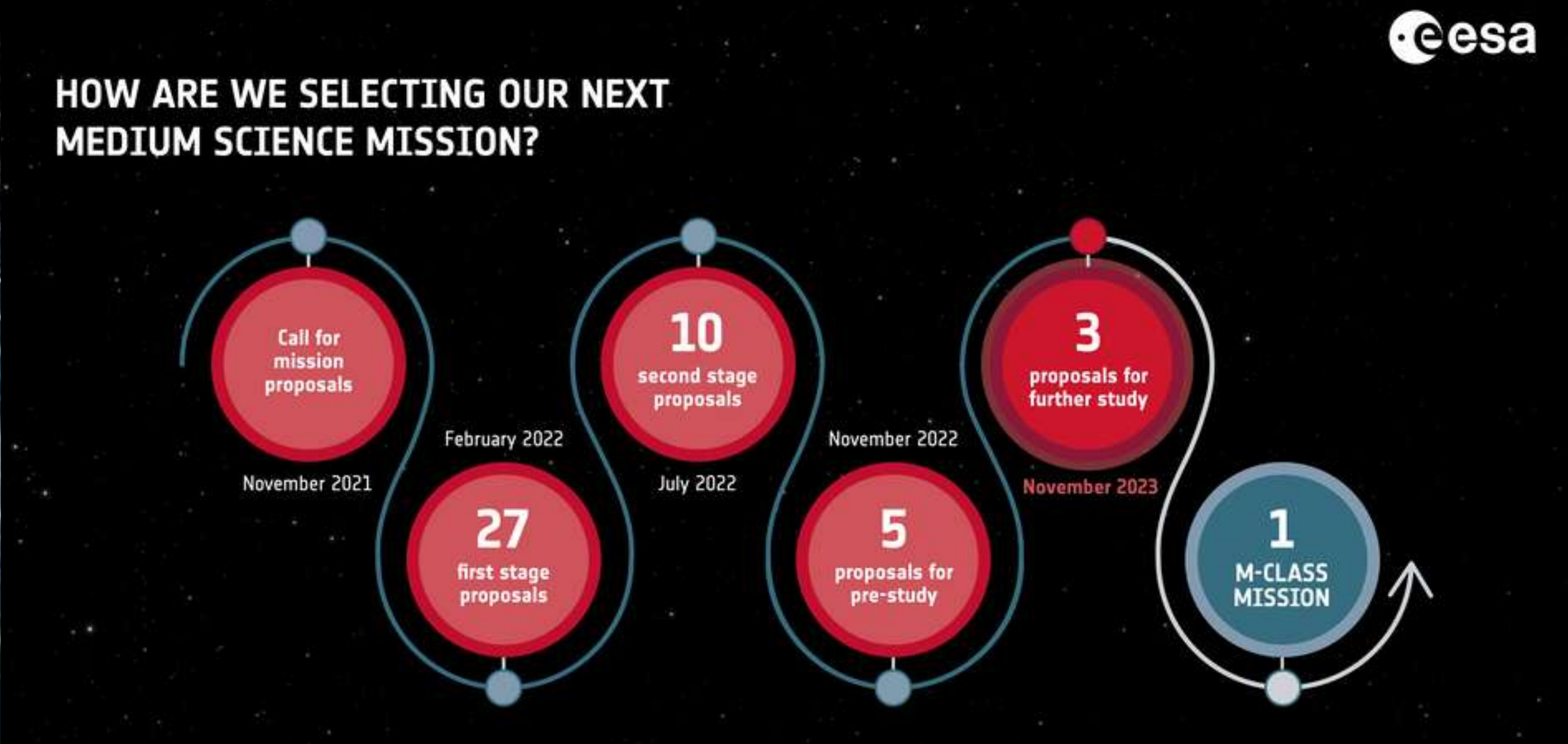
- **InfraRed Telescope (IRT, 0.7 – 1.8 μm)**:

a 0.7m class IR telescope with 15’x15’ FOV, for fast response, with imaging and spectroscopy capabilities

- **X-Gamma ray Imaging Spectrometer (XGIS, 2–20 MeV)**:

2 coded-mask cameras of monolithic X-gamma rays detectors based on bars of Silicon diodes coupled with CsI scintillator, with ~2sr FOV and source location of ~10’ in the 2-150 keV range and >4sr for E >150 keV


Selected by ESA in 2023 in the shortlist of candidates for the M7 call




**5 keV):**
a total FOV of
-2'

**– 1.8 μm):**
5' FOV, for fast
y capabilities

**Spectrometer**

X-gamma rays
les coupled with
urce location of
r E >150 keV

# theseus

TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

Selected by ESA in 2023 in the shortlist of candidates for the M7 call

At its meeting on June 10 and 11, 2026, at the Instituto Astrofísico de Canarias in Tenerife, the ESA Science Program Committee recommended the selection of Plasma Observatory as the agency's next medium-class (M7) mission under its science program.

Plasma Observatory was among three finalists—along with THESEUS and M-MATISSE—selected by ESA in 2023. It would thus be the first medium-class mission to join Voyage 2050, ESA's future science program, with a launch scheduled for the mid-2030s.

~10' in the 2-150 keV range and >4sr for E >150 keV

## 1. Large Missions (L-class)

•**Description:** Flagship European-led missions with large-scale international collaboration
•**Cost at Completion:** 1.5-2 Billion EUR
•**Calendar:** Long development cycles (up to 12-15+ years). Launched at a rate of one per decade.
(JUICE, NewAthena, LISA)

## 2. Medium Missions (M-class)

**Description:** ESA-led medium-scale missions or primary contributions to international missions
**Cost at Completion:** capped at 700 Million EUR
**Calendar:** Nominal development duration of 10 to 12 years. Aiming for 1 mission every ~3 to 4 years.
(SolarOrbiter, Euclid, Plato, ARIEL, EnVision)

## 3. Fast Missions (F-class)

**Description:** ESA-led missions that are smaller in scale and designed with a faster implementation phase
**Cost at Completion:** Capped between 150-175 Million EUR
**Calendar:** Short development duration of less than 8 years from selection to launch
(Comet Interceptor, ARRAKIHS)

## 4. Mini-Fast Missions (mini-F)

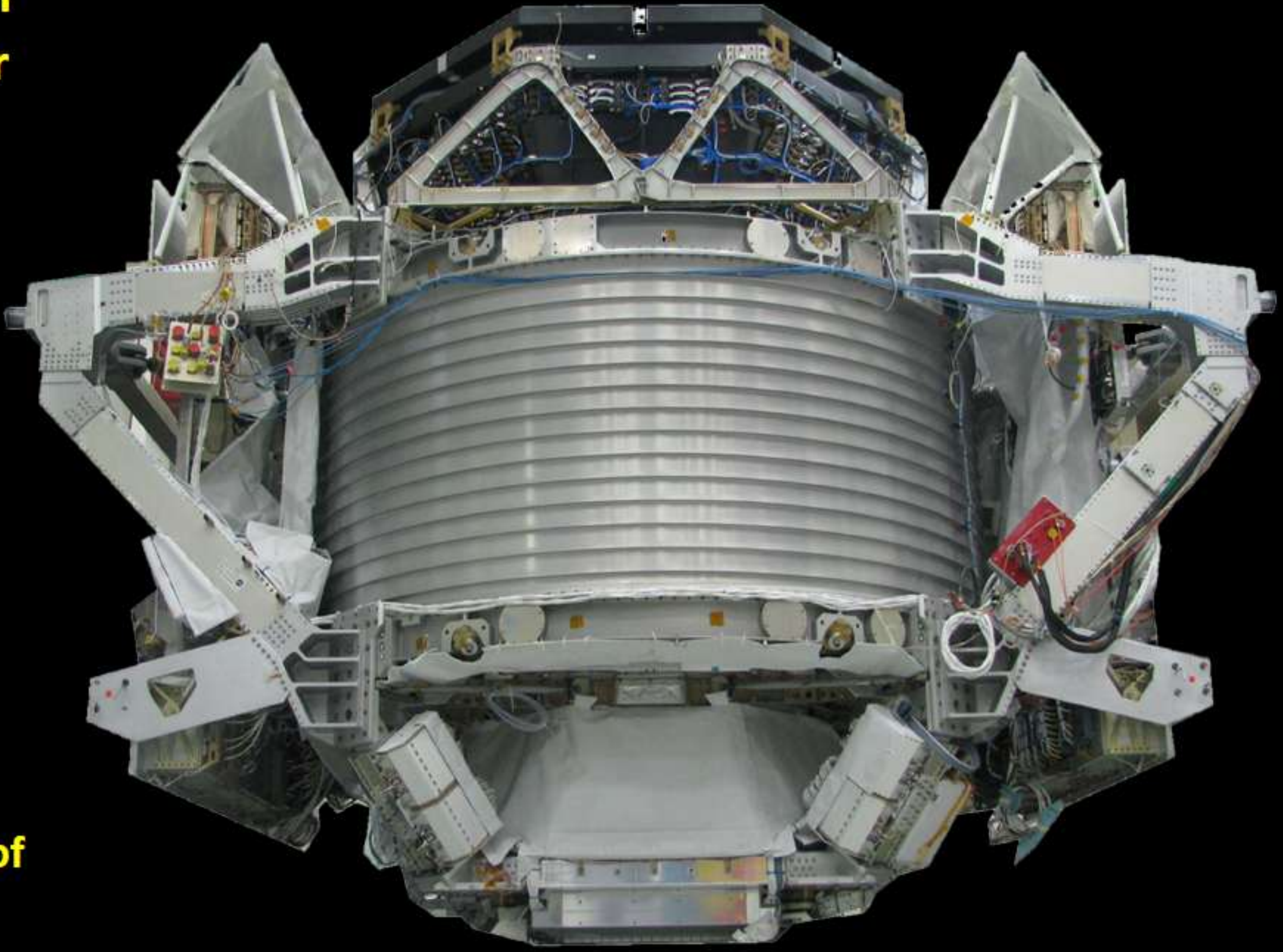
**Description:** Exploratory mission class targeting innovative space science utilizing fully available technology
**Cost at Completion:** ≤ 50 Million EUR (ESA Exploratory Call)
**Calendar:** Compressed calendar from selection to launch in less than 5 years

AMS is a space version of a precision detector used in accelerators

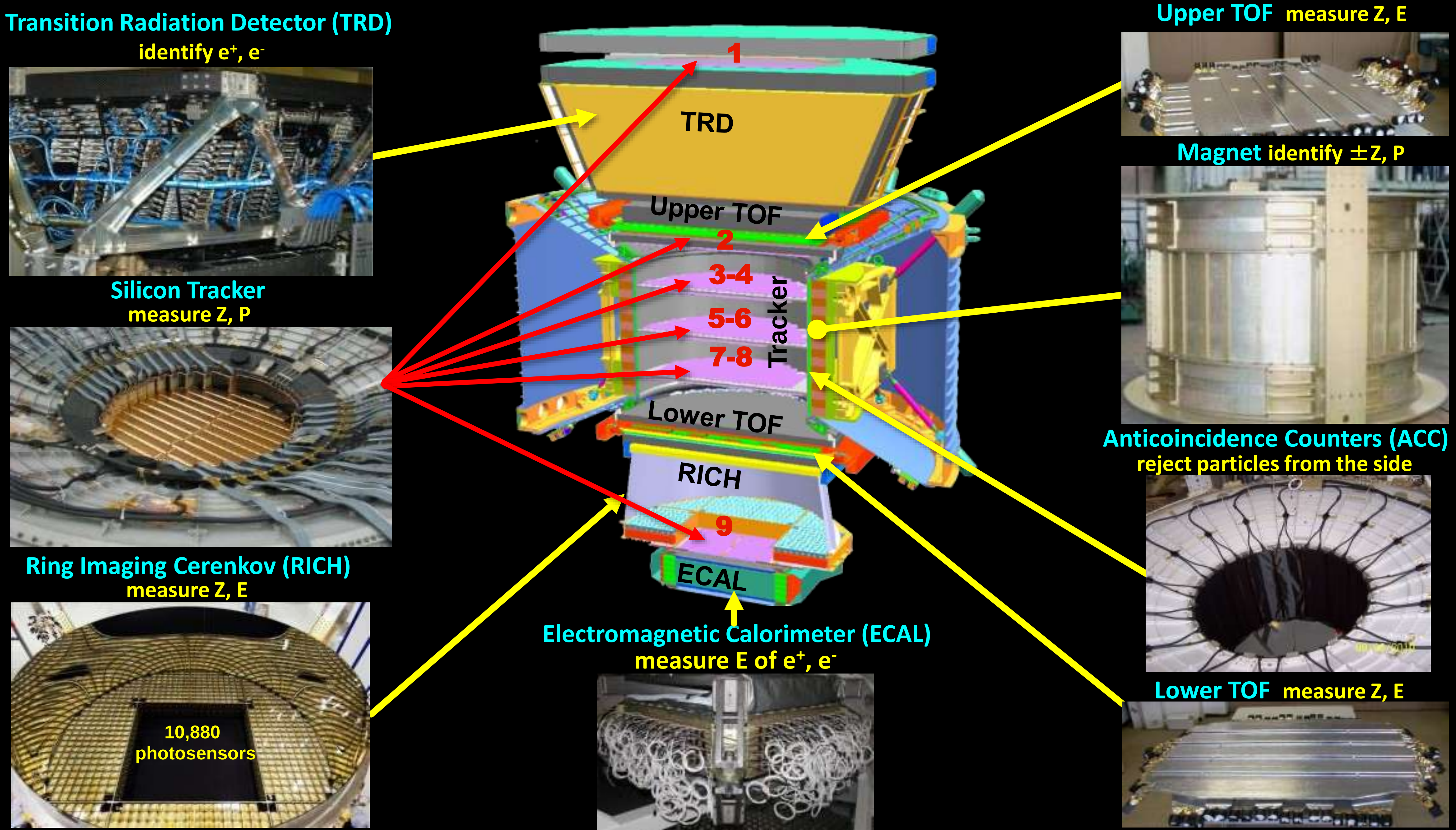
It was constructed in Europe and Asia, assembled and tested at CERN with strong support from MIT-DOE and NASA

5m x 4m x 3m, 7.5 tons

The detectors provide independent information of cosmic rays

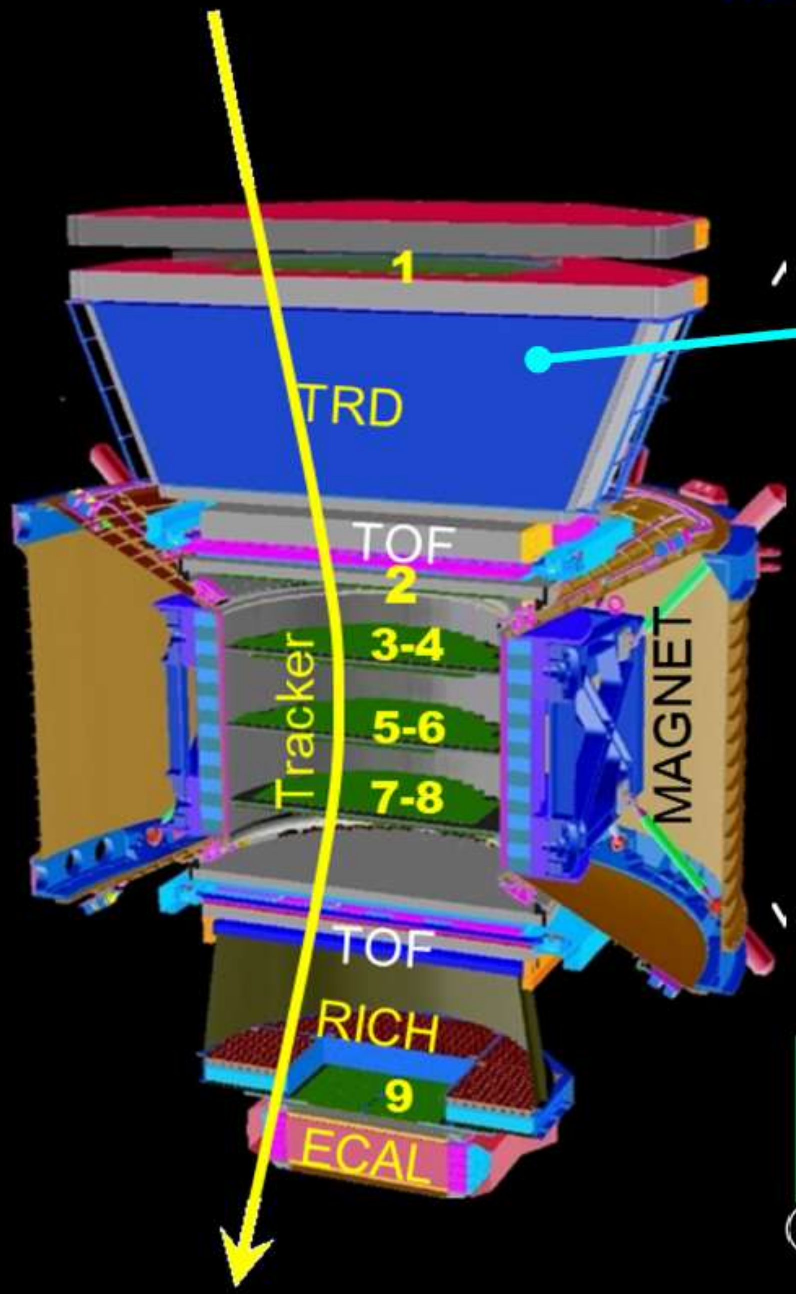


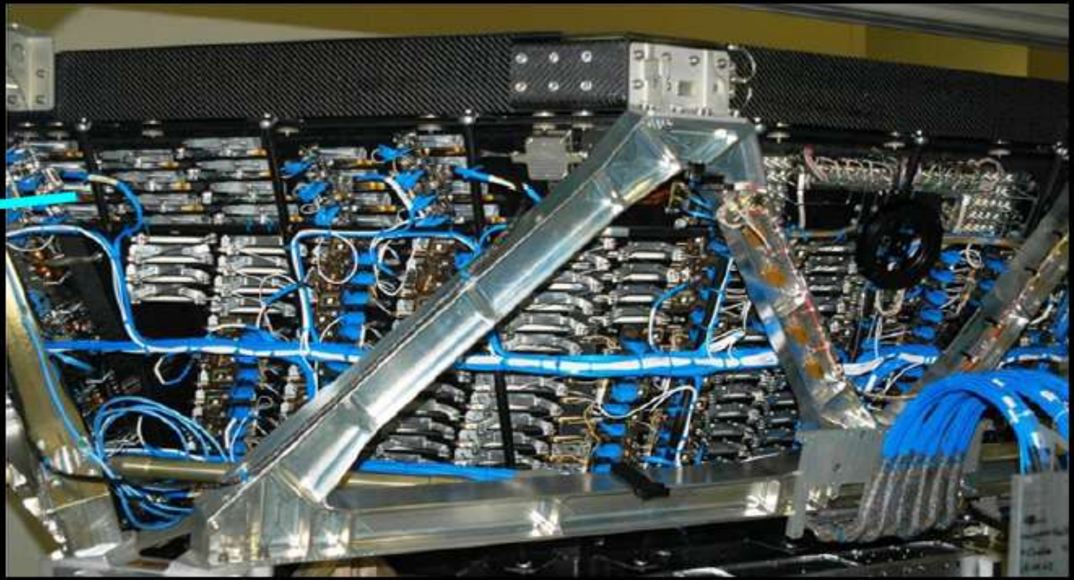
# AMS is a TeV precision magnetic spectrometer in space



# Transition Radiation Detector (TRD)

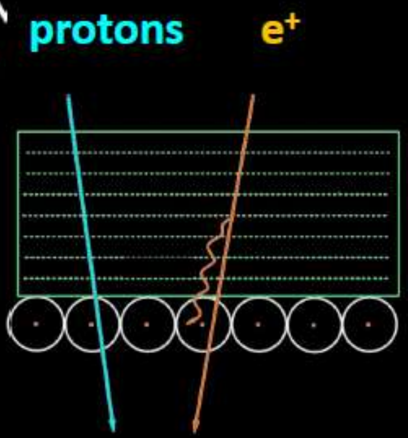
## identifies Positrons and Electrons

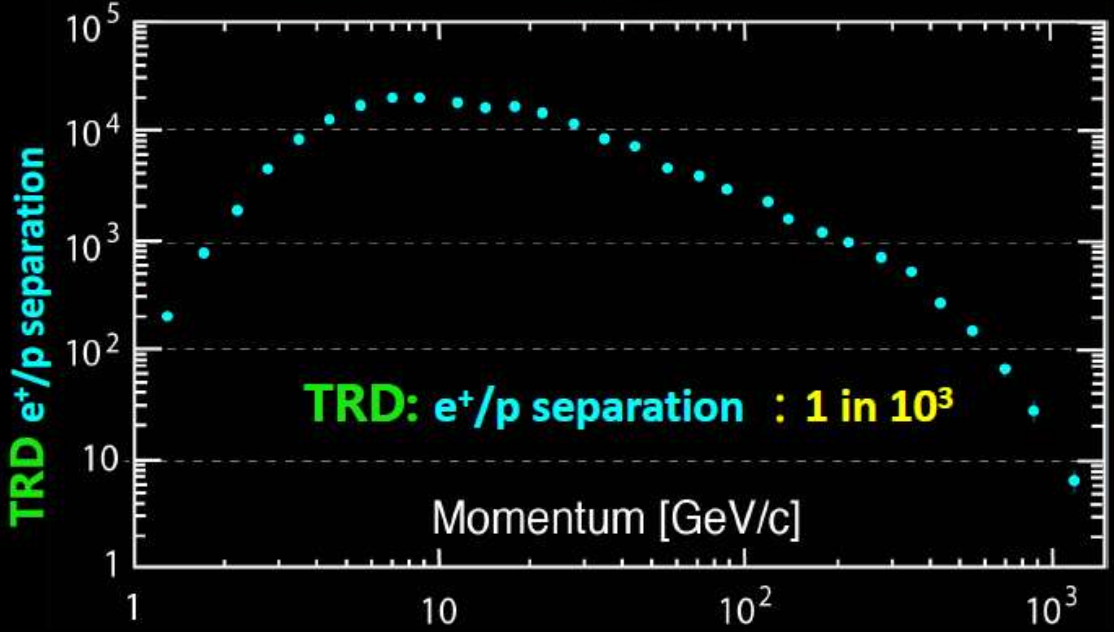


**5248 proportional tubes**

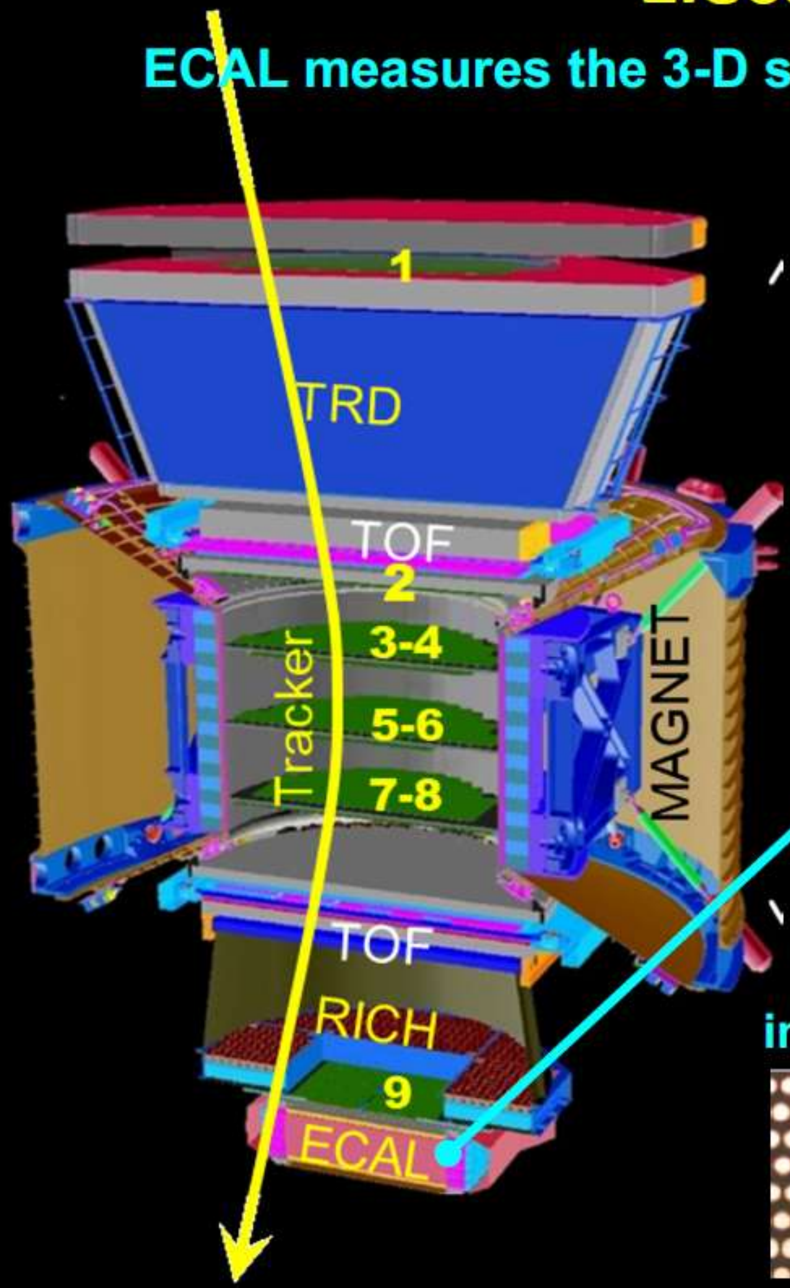
**90:10 Xe:$CO_2$ gas**

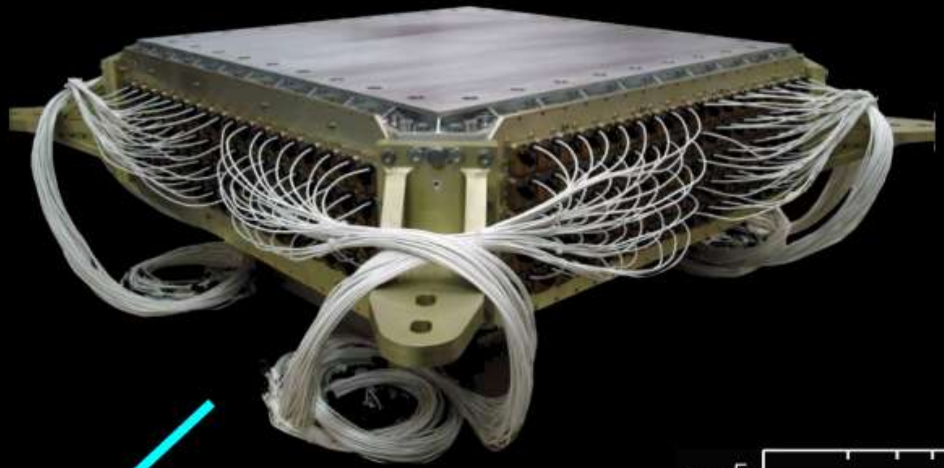


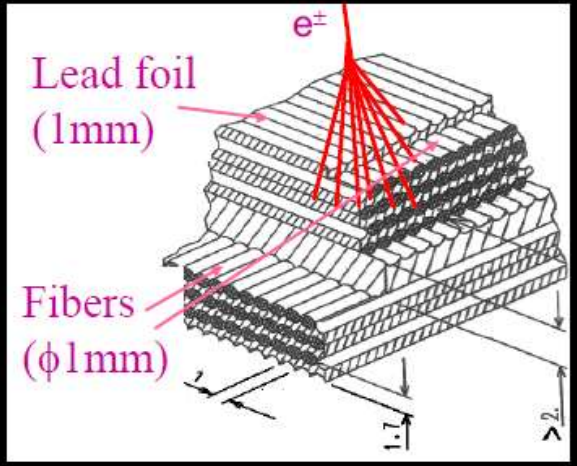




# Electromagnetic Calorimeter (ECAL)

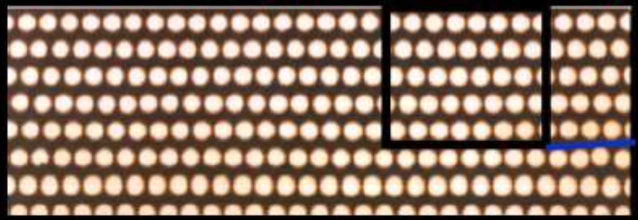
**ECAL measures the 3-D shower development of electrons and positrons up to multi-TeV.**

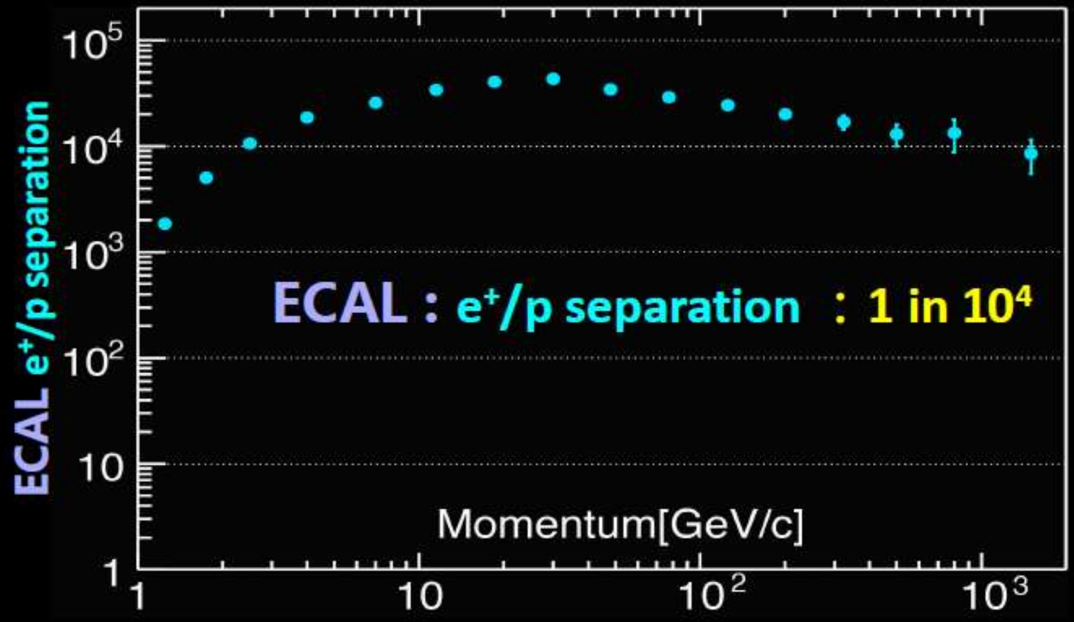




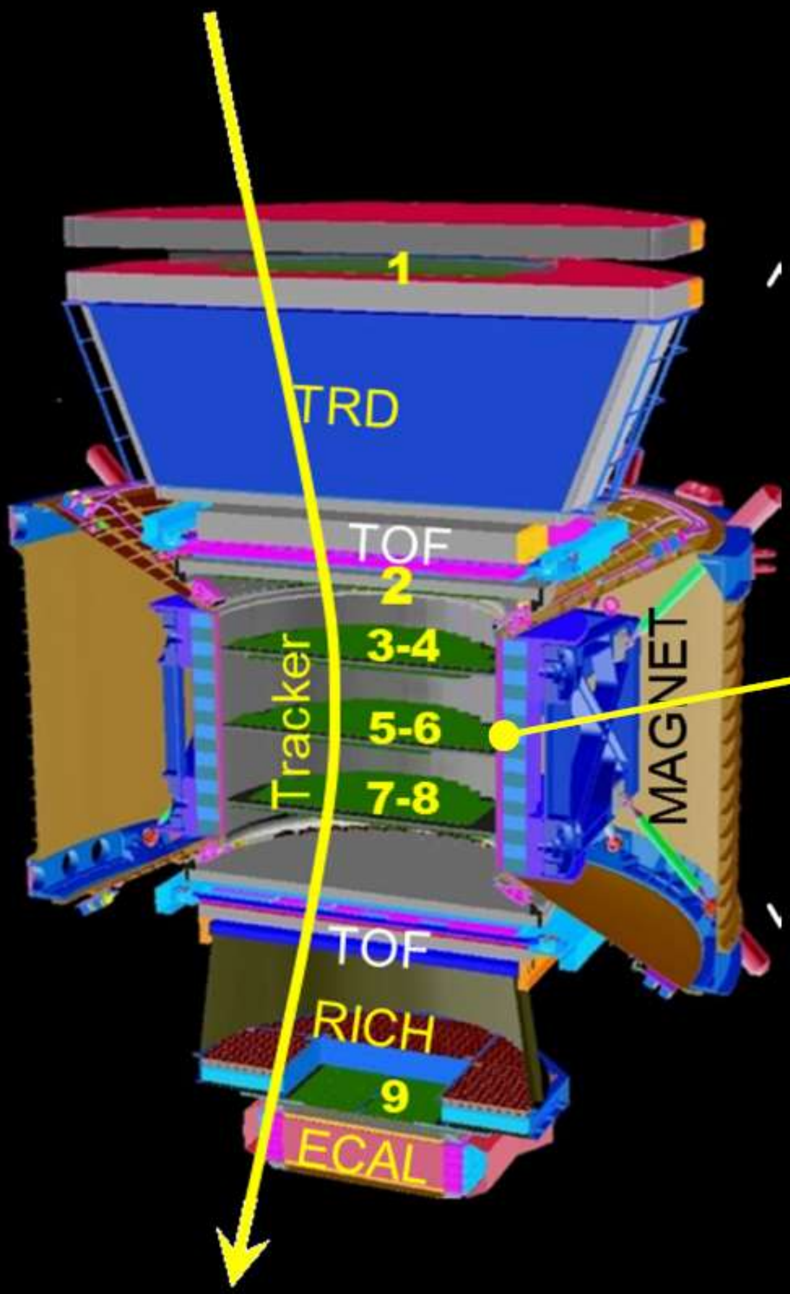

**50,000 fibers(ϕ=1mm)**
**distributed uniformly**
**inside 600 kg of lead (17 $X_0$)**

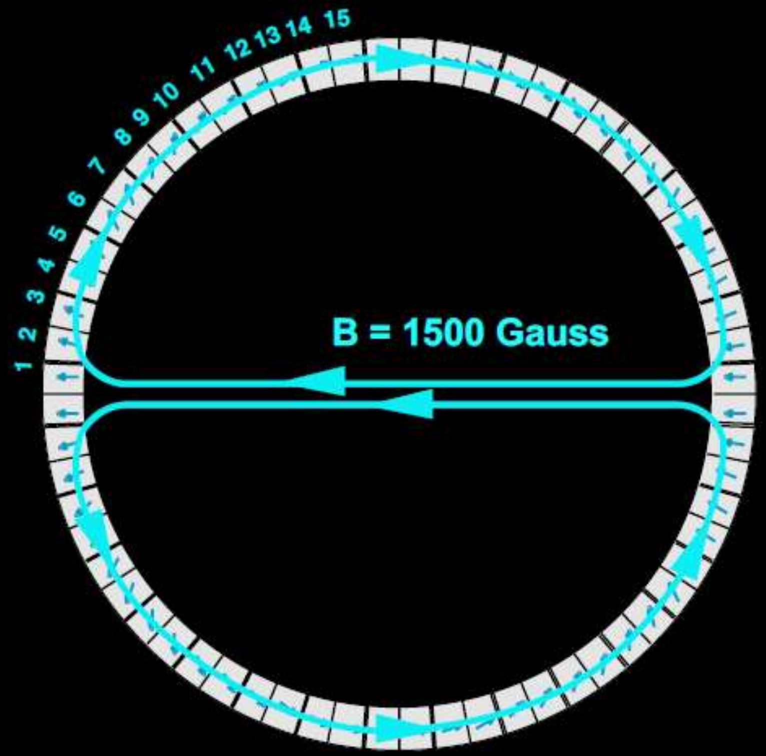




# The Magnet

## Identify ±Z, P



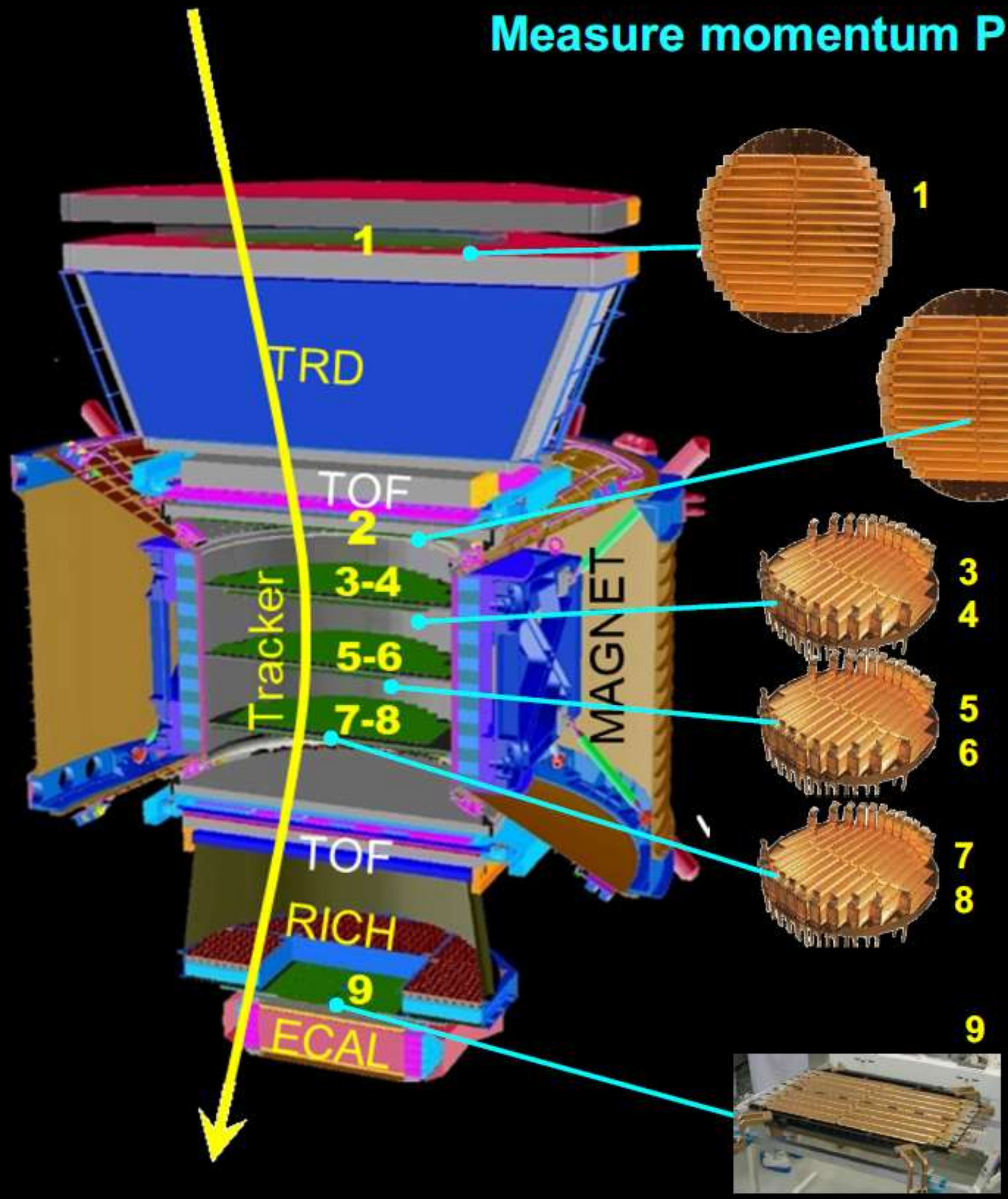



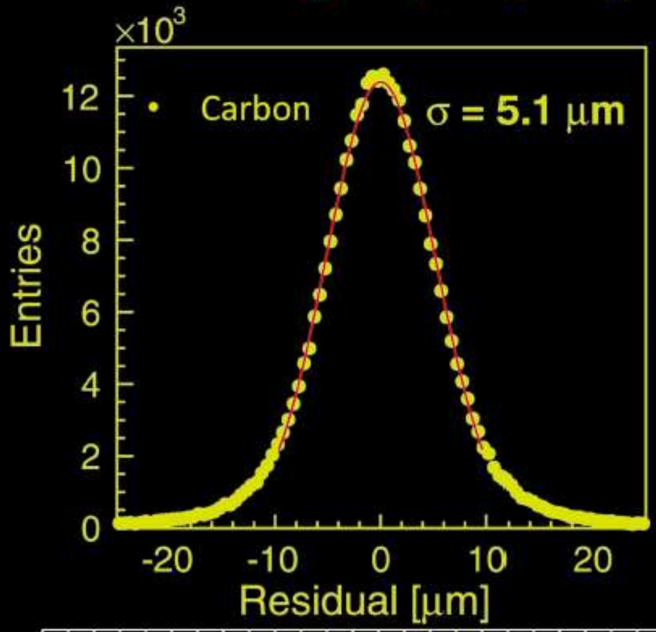

**Low energy $e^{\pm}$ produced in TRD are swept away by the magnet and do not enter into ECAL:**

**Independent rejection of TRD and ECAL: $e^{+}/p$ separation : > $10^{6}$**

# Silicon Tracker

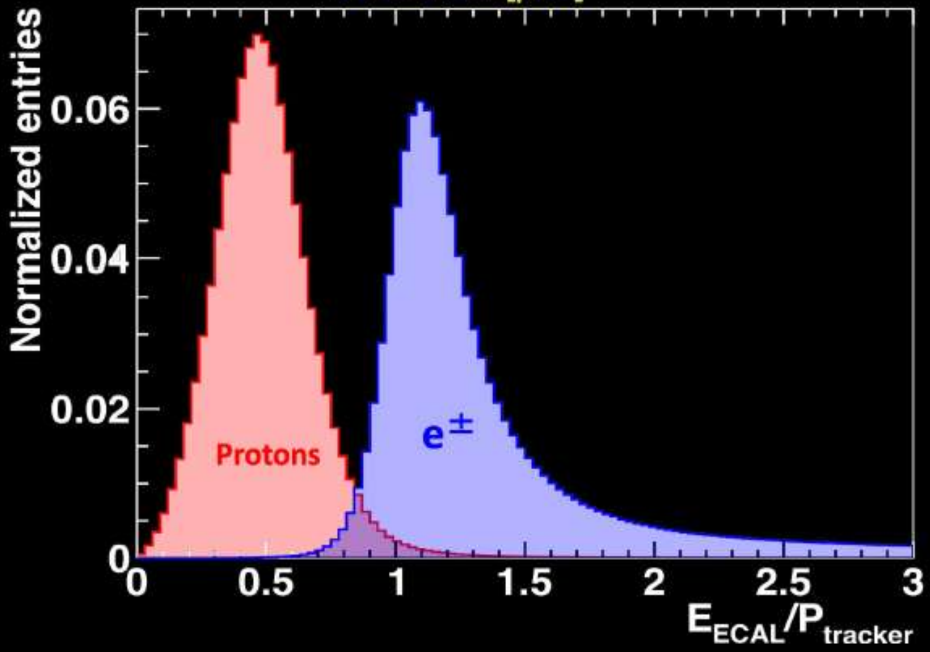
**Measure momentum P and nuclear charge Z, Rigidity: P/Z**




Spatial resolution: 5-10 μm in bending plane.

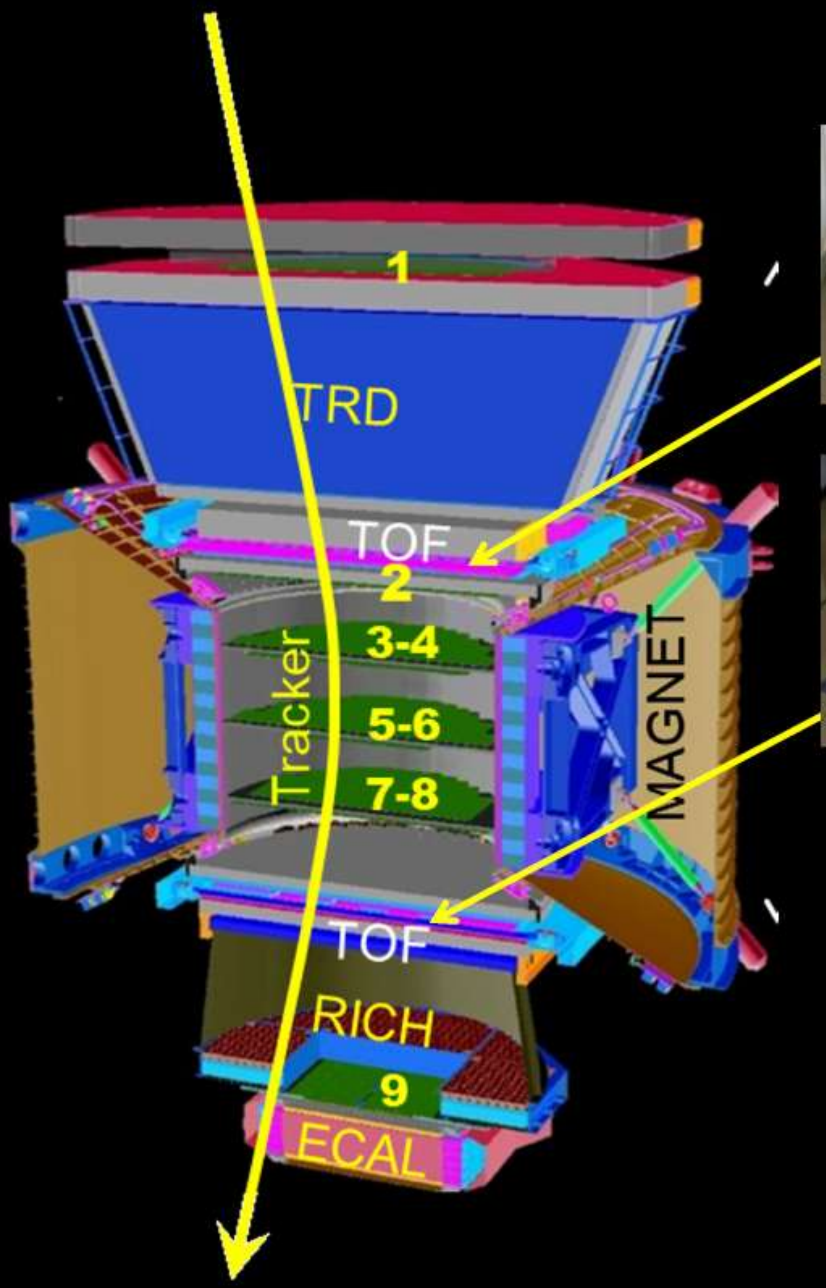
Maximum Detectable Rigidity:
~2TV for protons,
~3.7 TV for heavy nuclei




Independent Momentum and Energy measurement.
For electron and positron require: E=P

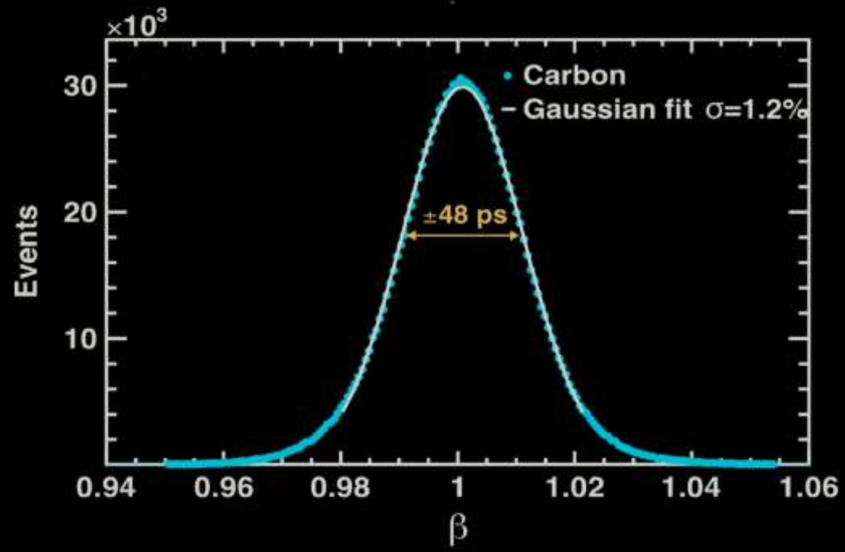
# Time of Flight (TOF)

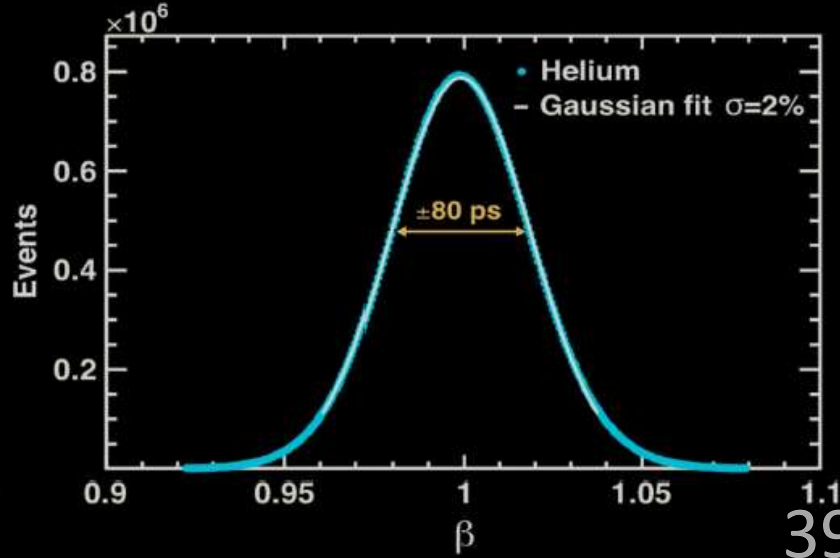
## *Measure velocity β , charge Z*




**Measures velocity, charge, direction, and trigger.**

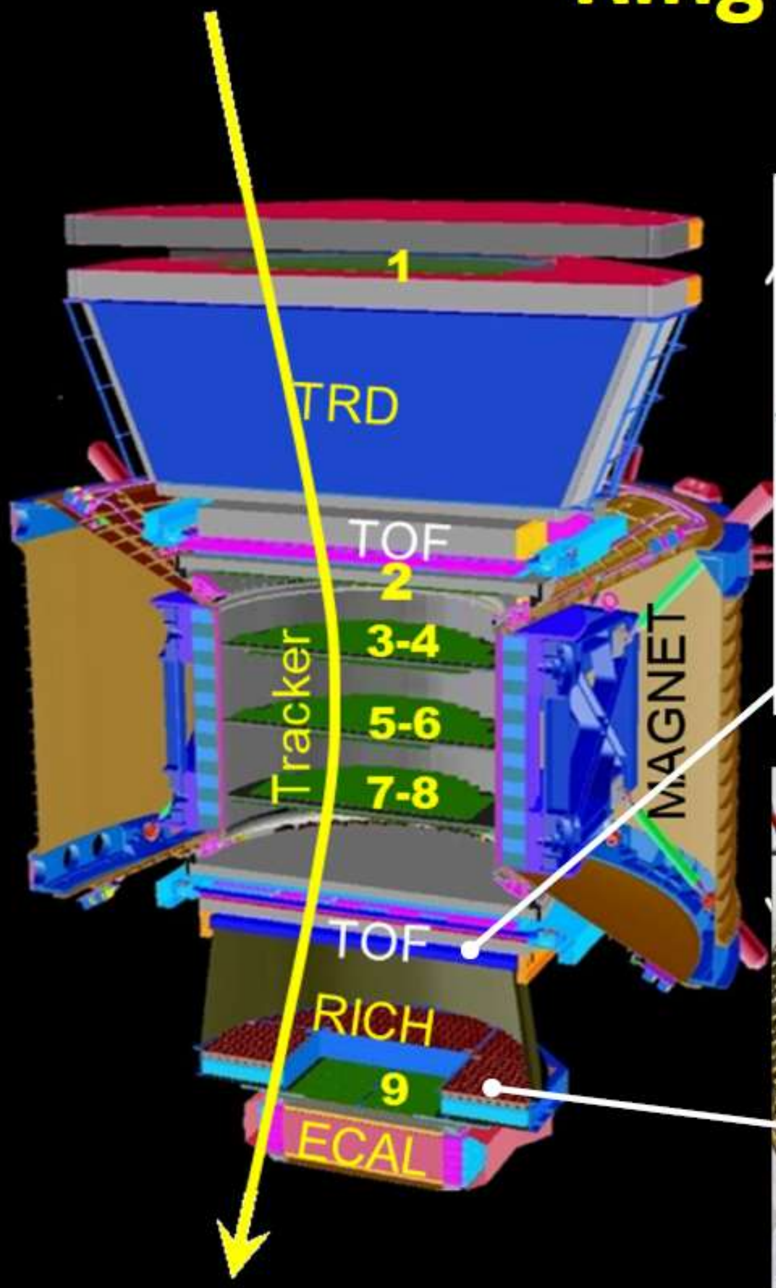
**Time resolution:**
**~50-160 ps**
**Velocity resolution:**
**1% (Z>6) to 4% (Z=1)**

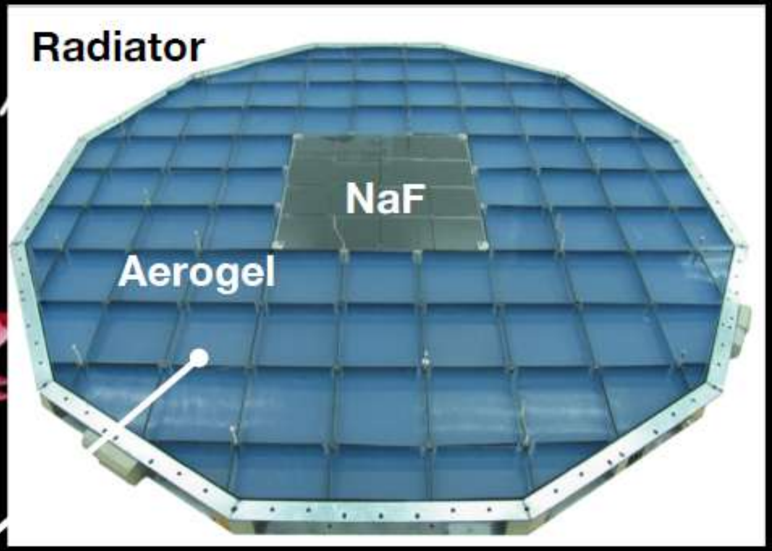


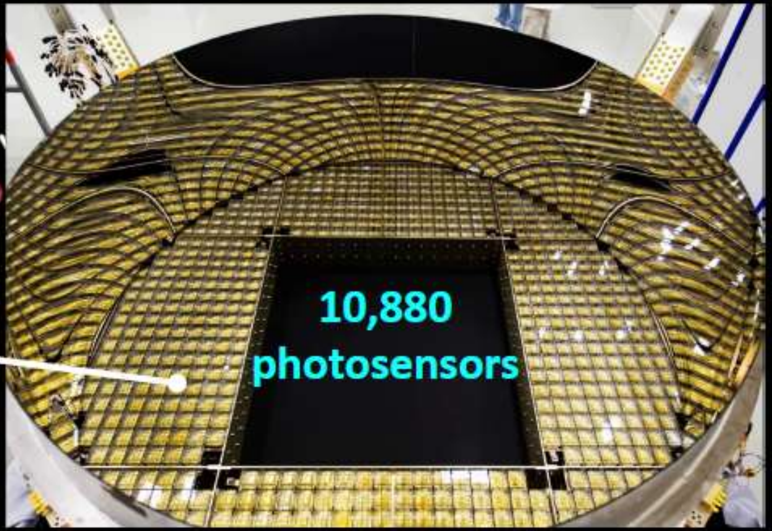



# Ring Imaging CHerenkov (RICH)

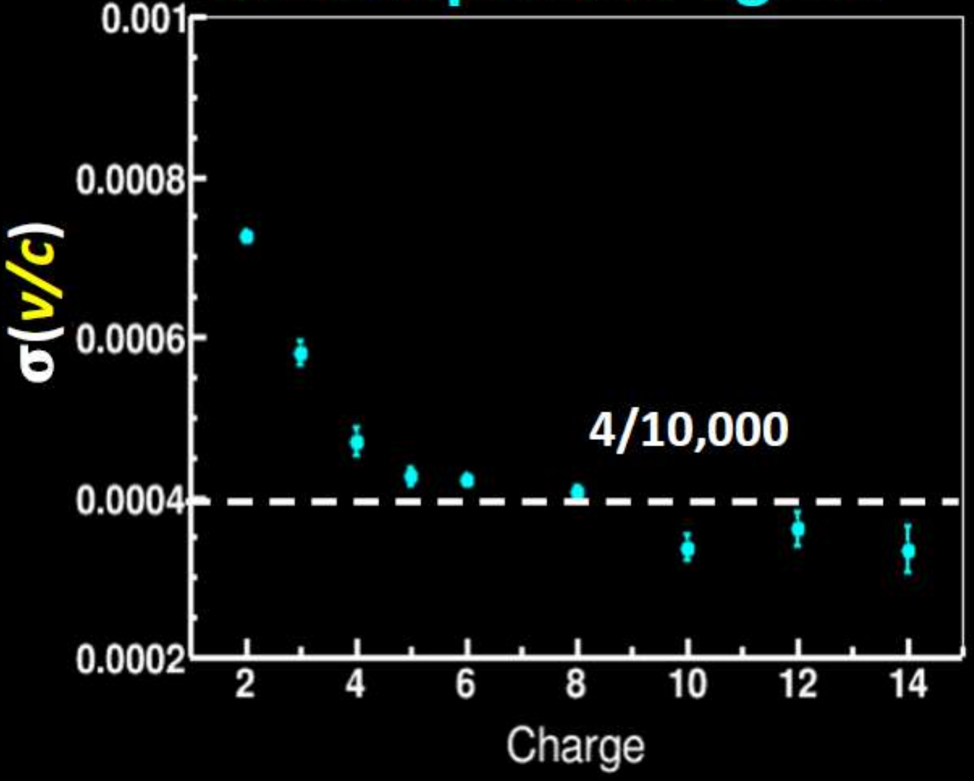
*Measure velocity β , charge Z*



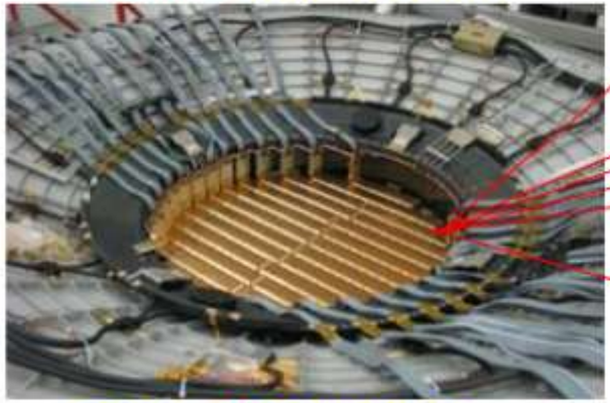

**RICH velocity *v* resolution at the speed of light *c***



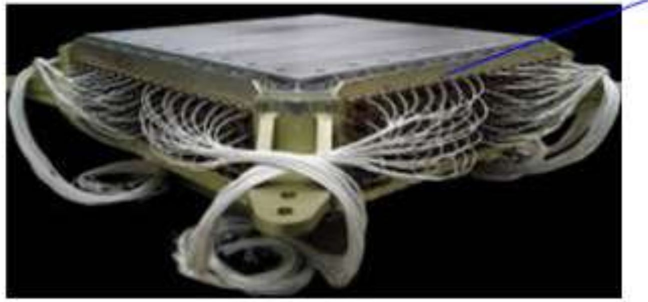
# Flight Electronics for DAQ

TRD, 30 Computers
5248 Pulse Heights

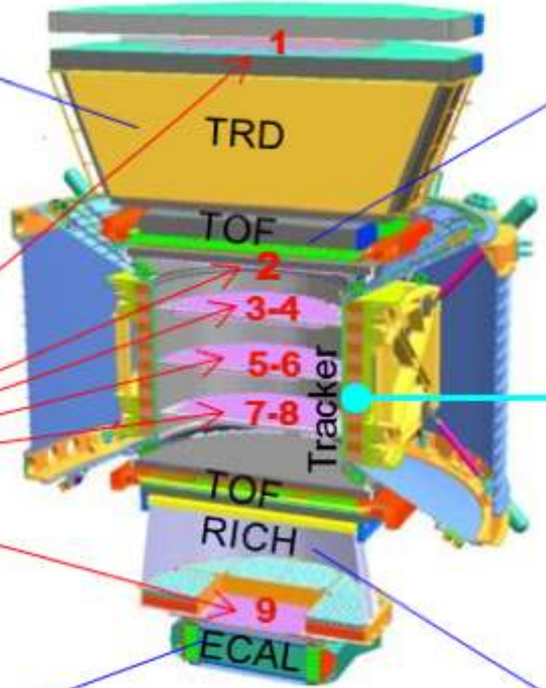
Silicon Tracker, 212 Computers
196,608 Pulse Heights



ECAL, 32 Computers
2,916 Pulse Heights



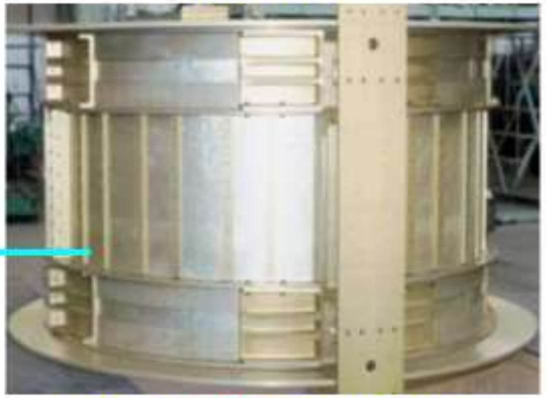
300,000 channels
producing 3.7 Mbit/event
at rates up to 2 kHz.



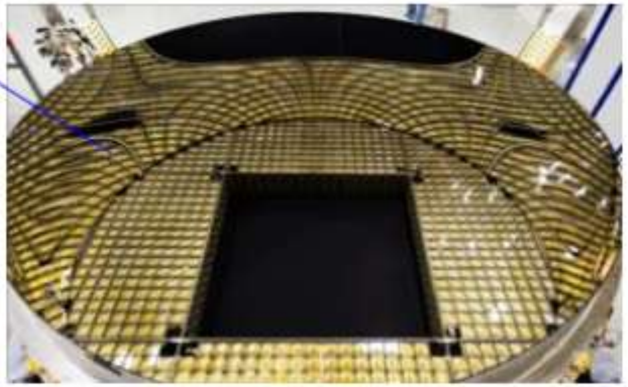

7 Gbit/s processed by
650 computers
to <10 Mbit/s>.

TOF & ACC, 48 Computers
84 Signals

Magnet



RICH, 28 Computers
21,760 Pulse Heights



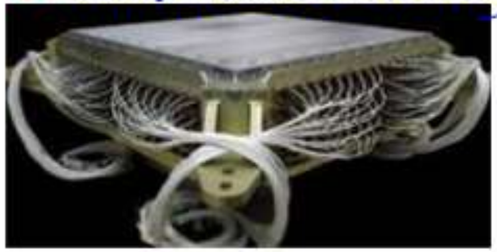
# AMS has no control of ISS orbits and movements of Solar Panels and Radiators.

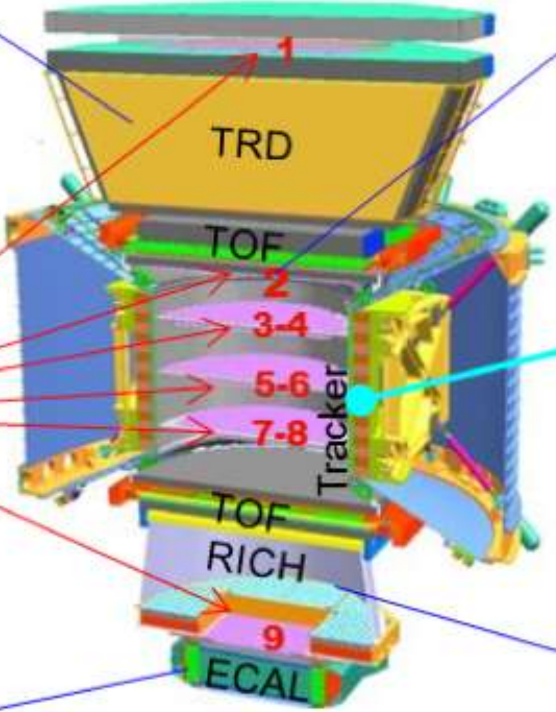
**Temperatures must be kept within limits. There are 1118 temperature sensors and 298 heaters**

**TRD**
**24 Heaters**
**482 Temperature Sensors**

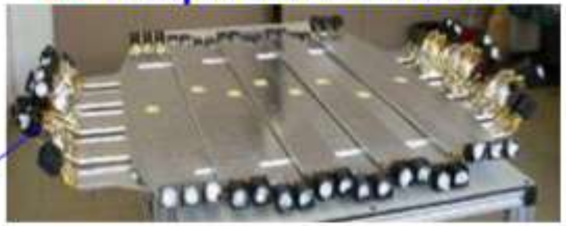
**Silicon Tracker**
**32 Heaters**
**142 Temperature Sensors**

**ECAL**
**16 Heaters**
**80 Temperature Sensors**



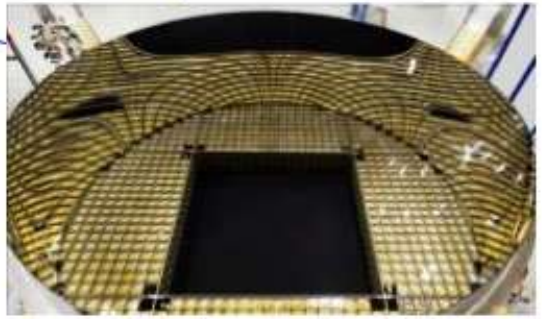


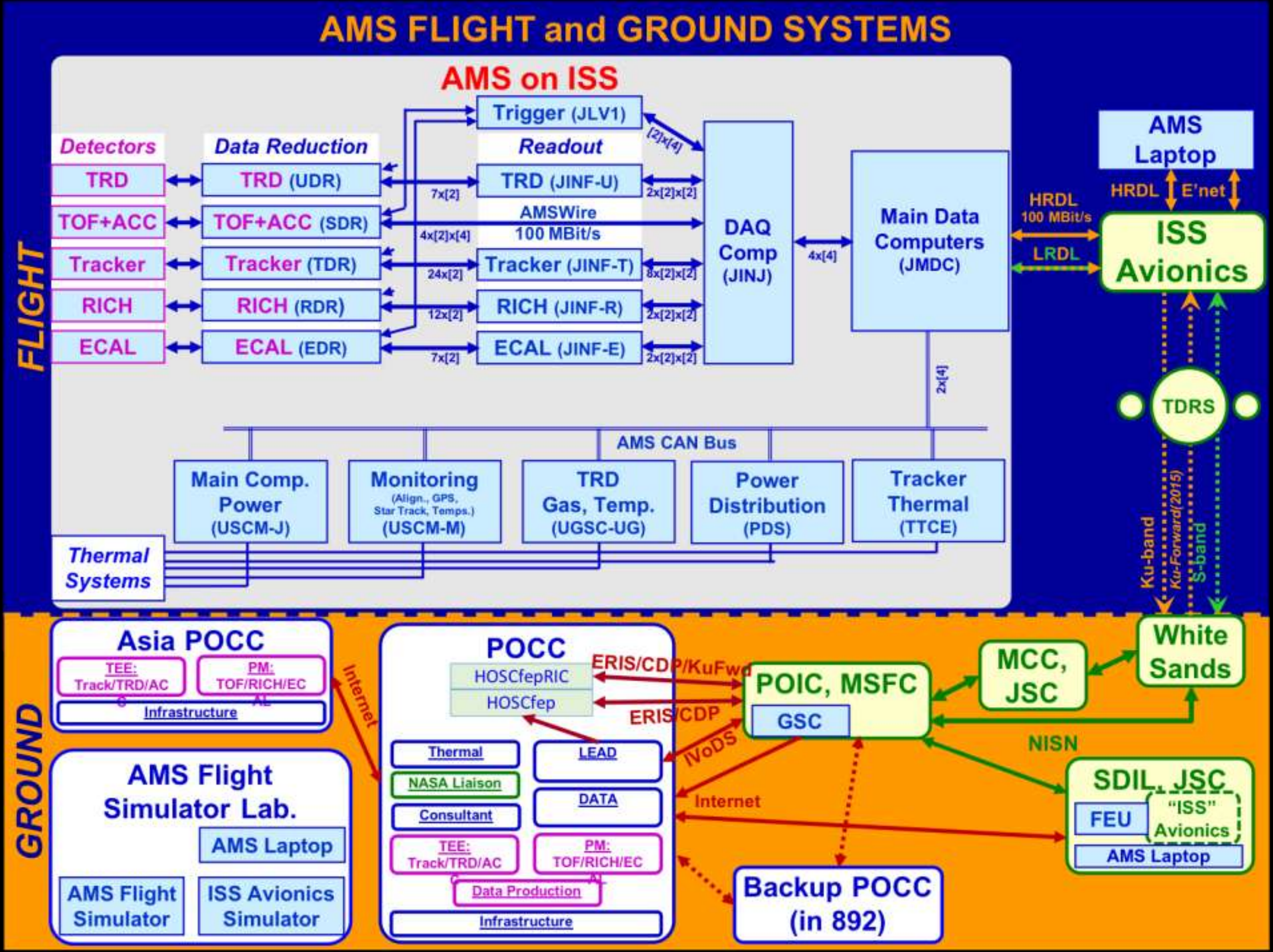

**TOF & ACC**
**16 Heaters**
**64 Temperature Sensors**



**Magnet**
**68 Temperature Sensors**

**RICH**
**16 Heaters**
**96 Temperature Sensors**





AMS FLIGHT and GROUND SYSTEMS
FLIGHT
AMS on ISS
Detectors
TRD
TOF+ACC
Tracker
RICH
ECAL
Data Reduction
TRD (UDR)
TOF+ACC (SDR)
Tracker (TDR)
RICH (RDR)
ECAL (EDR)
Trigger (JLV1)
Readout
TRD (JINF-U)
AMSWire
100 MBit/s
Tracker (JINF-T)
RICH (JINF-R)
ECAL (JINF-E)
7x[2]
4x[2]x[4]
24x[2]
12x[2]
7x[2]
[2]x[4]
2x[2]x[2]
8x[2]x[2]
2x[2]x[2]
2x[2]x[2]
DAQ
Comp
(JINJ)
4x[4]
Main Data
Computers
(JMDC)
2x[4]
AMS CAN Bus
Main Comp.
Power
(USCM-J)
Monitoring
(Align., GPS,
Star Track, Temps.)
(USCM-M)
TRD
Gas, Temp.
(UGSC-UG)
Power
Distribution
(PDS)
Tracker
Thermal
(TTCE)
Thermal
Systems
AMS
Laptop
HRDL
E'net
HRDL
100 MBit/s
LRDL
ISS
Avionics
TDRS
Ku-band
Ku-Forward(2015)
S-band
GROUND
Asia POCC
TEE:
Track/TRD/ACC
PM:
TOF/RICH/ECAL
Infrastructure
Internet
AMS Flight
Simulator Lab.
AMS Laptop
AMS Flight
Simulator
ISS Avionics
Simulator
POCC
HOSCfepRIC
HOSCfep
Thermal
NASA Liaison
Consultant
LEAD
DATA
TEE:
Track/TRD/ACC
PM:
TOF/RICH/ECAL
Data Production
Infrastructure
ERIS/CDP/KuFwd
ERIS/CDP
IVoDS
Internet
POIC, MSFC
GSC
MCC,
JSC
White
Sands
NISN
SDIL, JSC
FEU
"ISS"
Avionics
AMS Laptop
Backup POCC
(in 892)

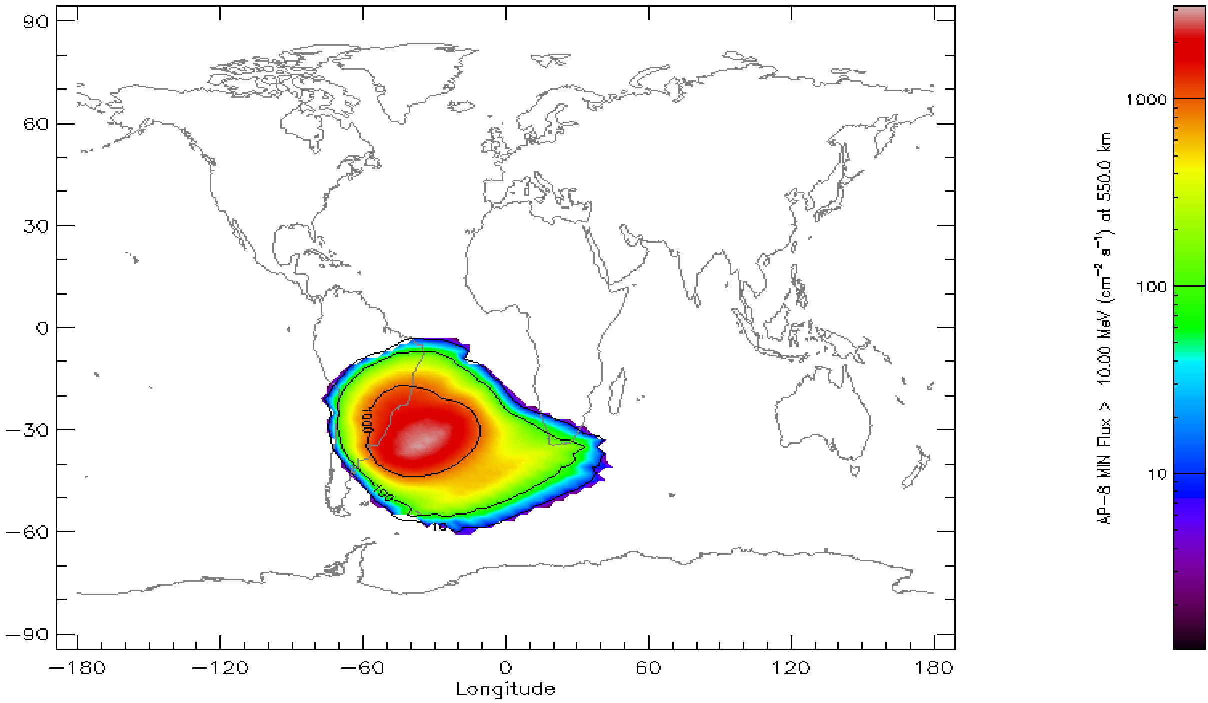
# Flight and Ground Operations

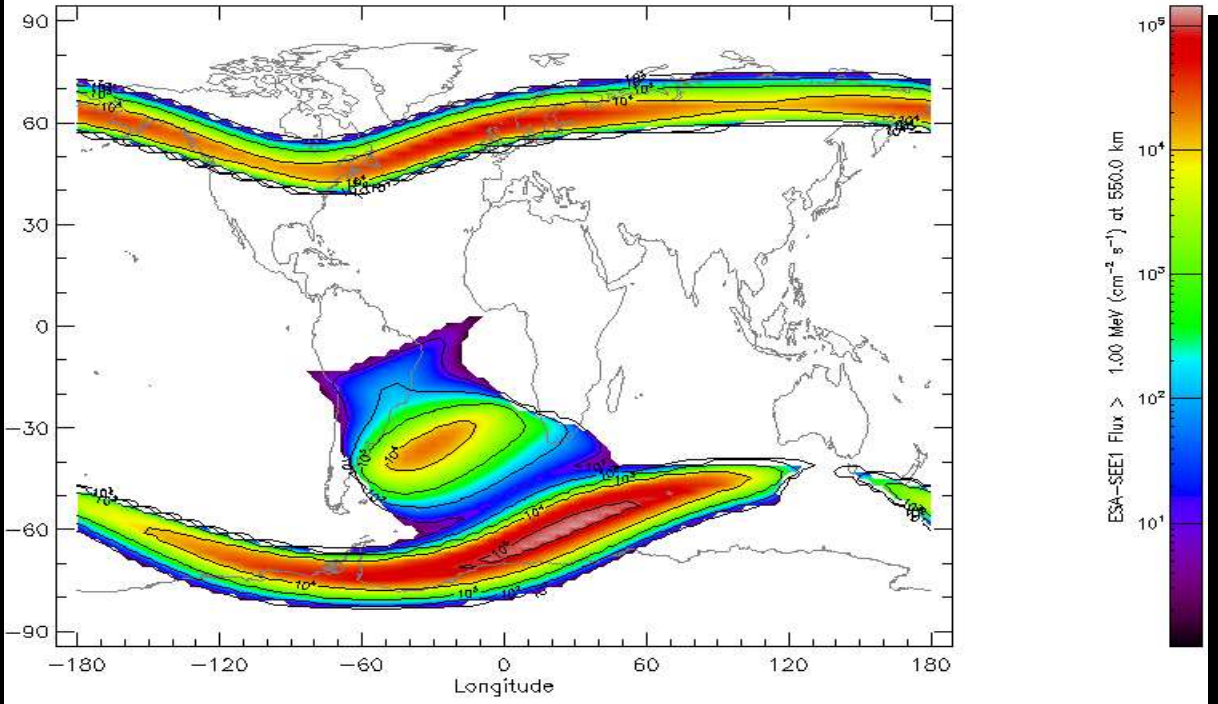
Maps of fluxes of high energy **trapped protons and electrons at 550 km** have been obtained with **SPENVIS** (AP-8, AE-8 models).

Protons with energies below 10 MeV are not considered, as they are shielded by the MLI cover of the instrument. Electrons with energies below 1 MeV are not considered, as they are effectively below the veto threshold

**Protons** (E>10 MeV) are mainly present in the **inner radiation belt,** which is crossed at the South Atlantic Anomaly.

**Electrons** (E>1 MeV) are also present at relatively high latitudes, i.e. in the crossing of the **outer radiation belt**.



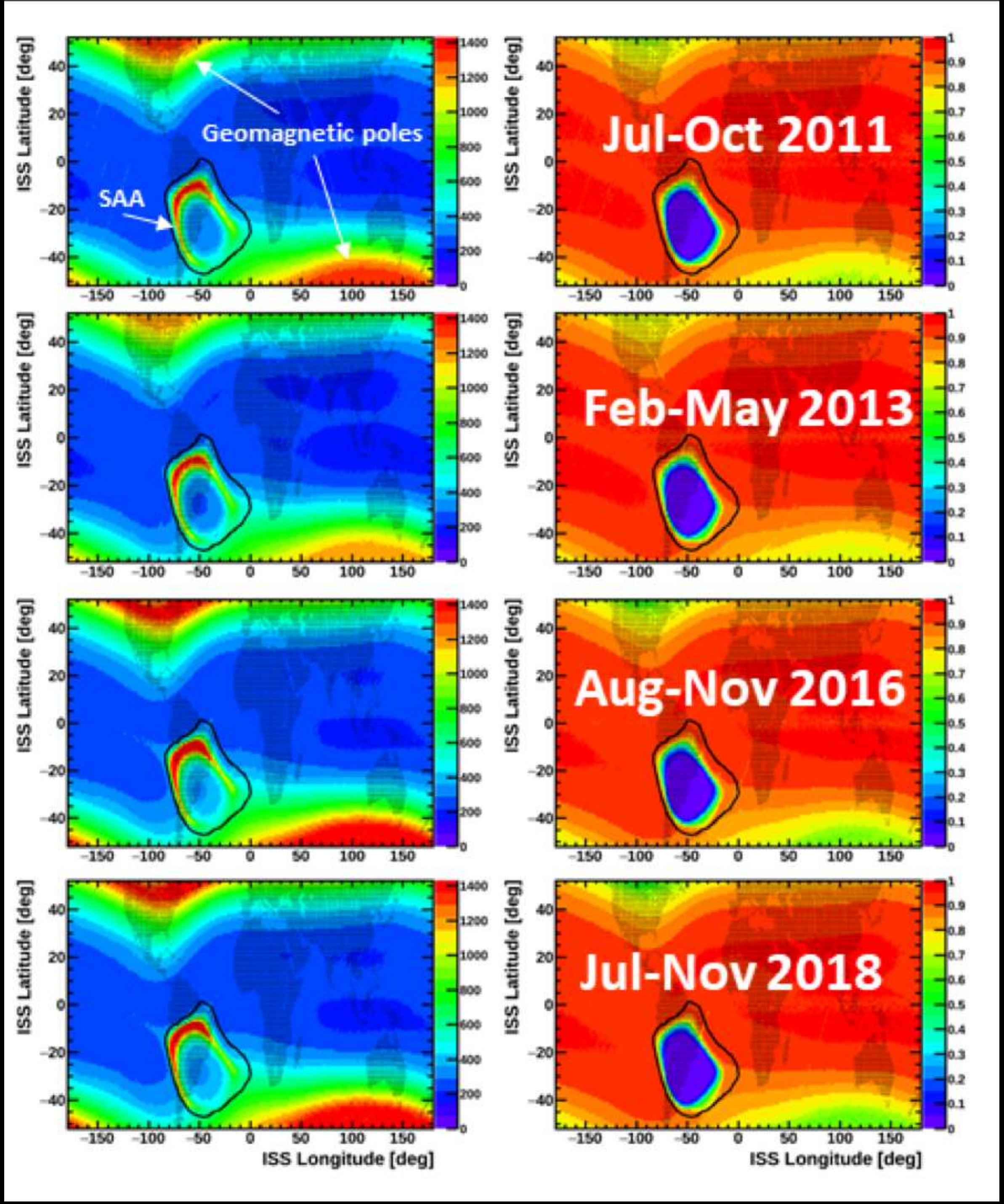



**AMS ON THE ISS:**

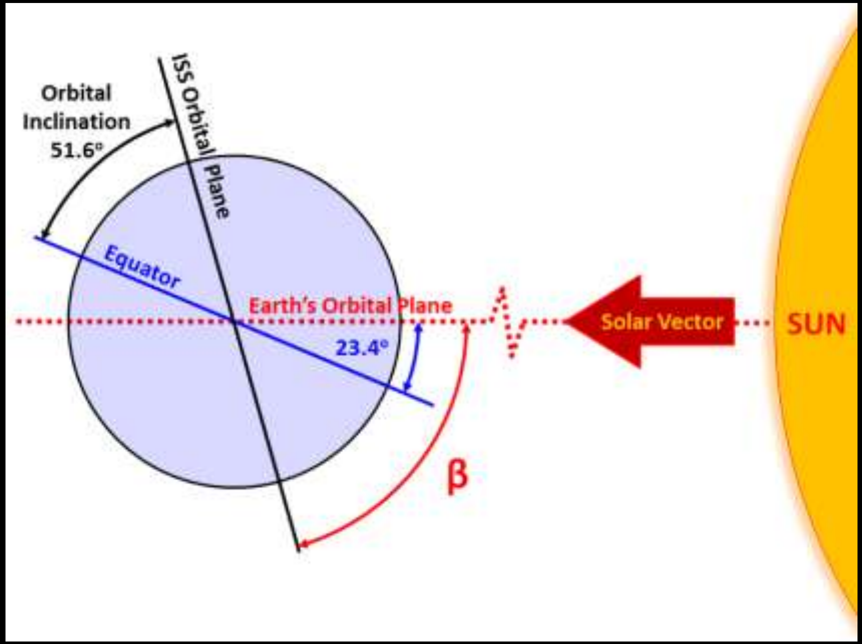
**Orbital DAQ parameters for different running periods as a function of latitude vs. longitude:**

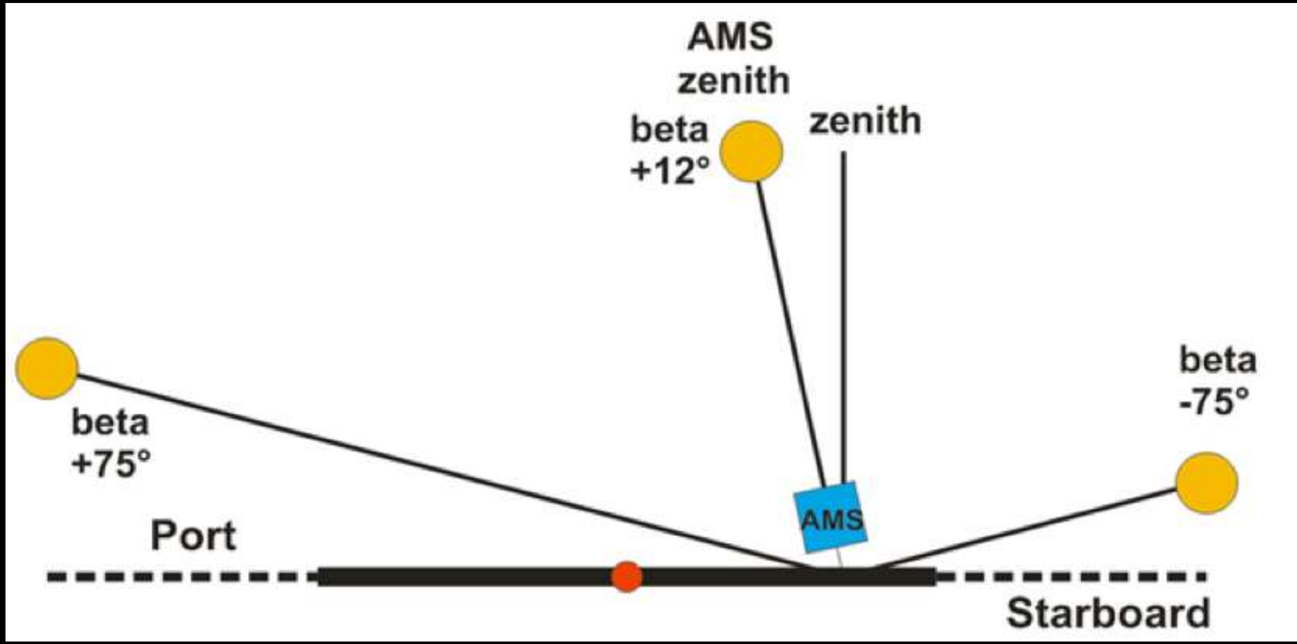
**(Left) Event acquisition rate. Outside of the South Atlantic Anomaly (SAA, indicated by the black curve), the rate of cosmic rays varies between 200 and 1400 Hz with an average of ~700 Hz.**

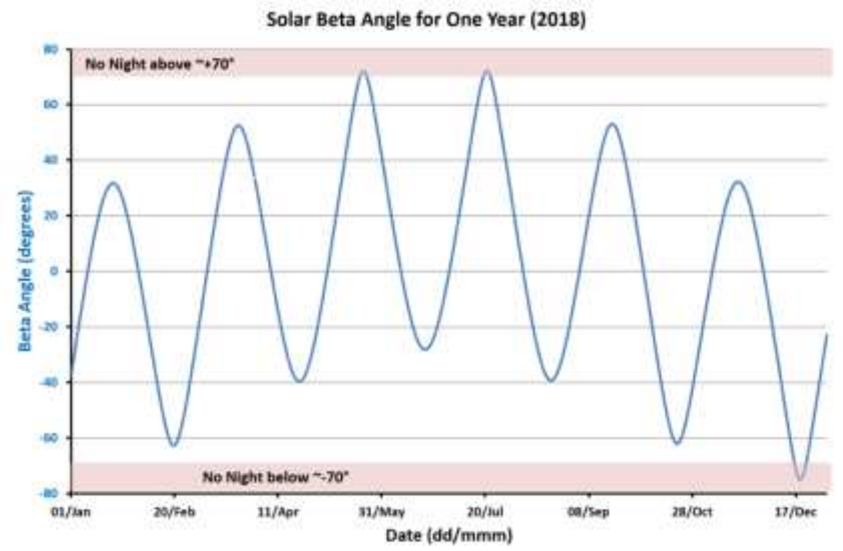
**(Right) Data acquisition efficiency (live-time). The average efficiency is 85% including the SAA.**

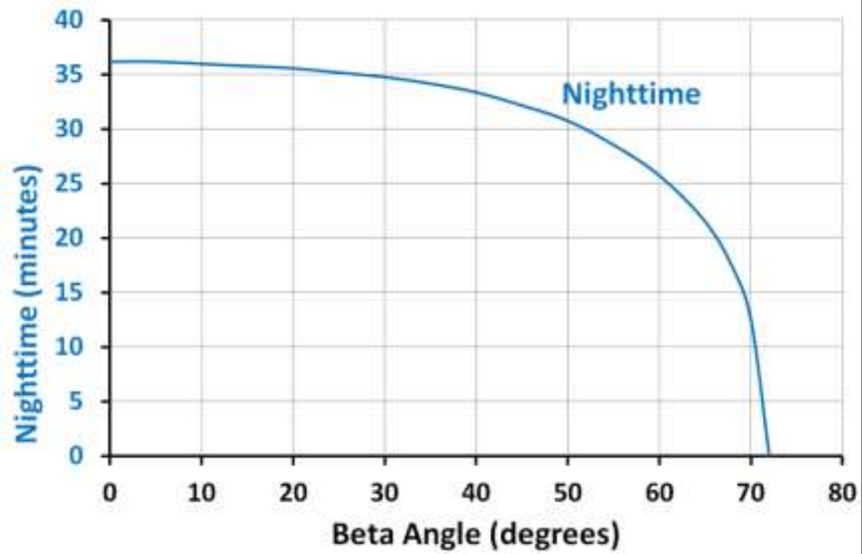


# THERMAL ENVIRONMENT AT LOW EARTH ORBIT: BETA ANGLE



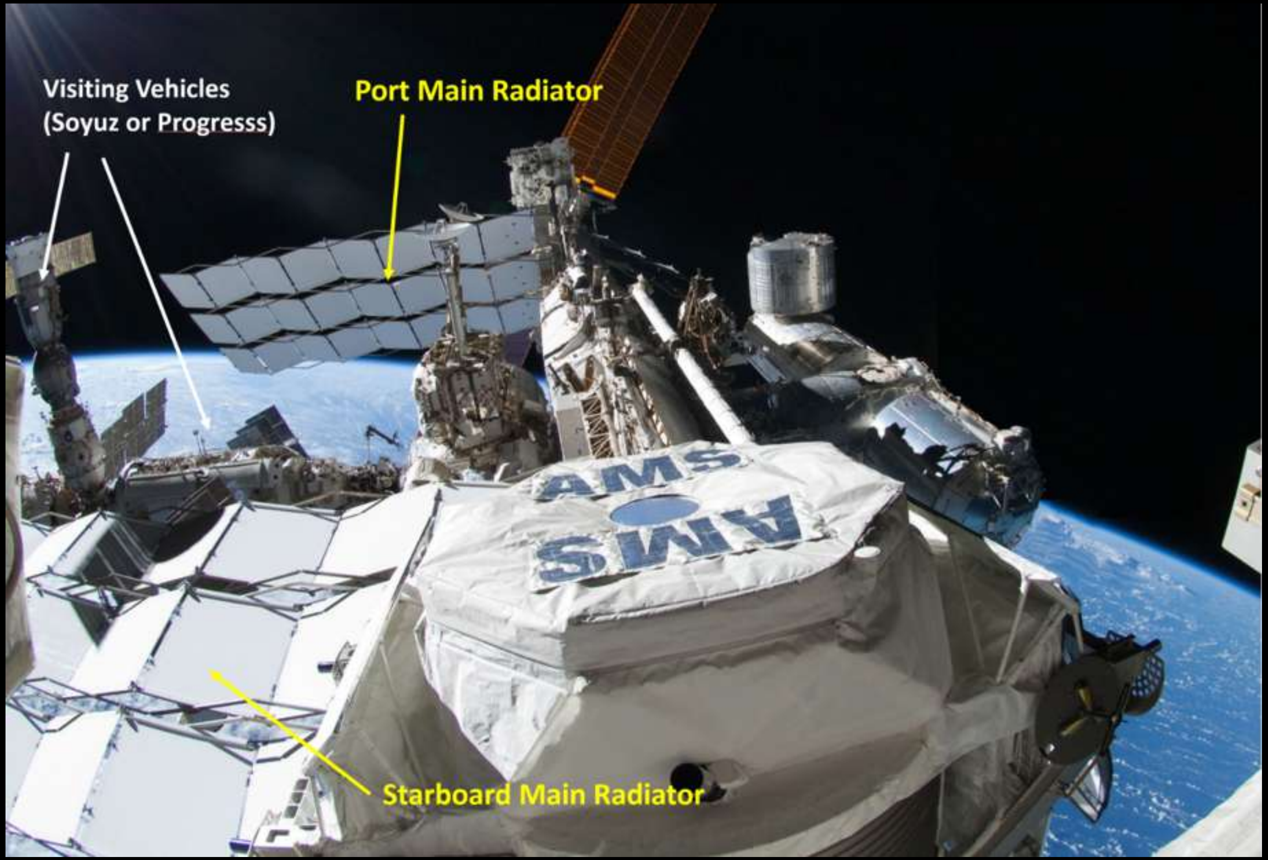



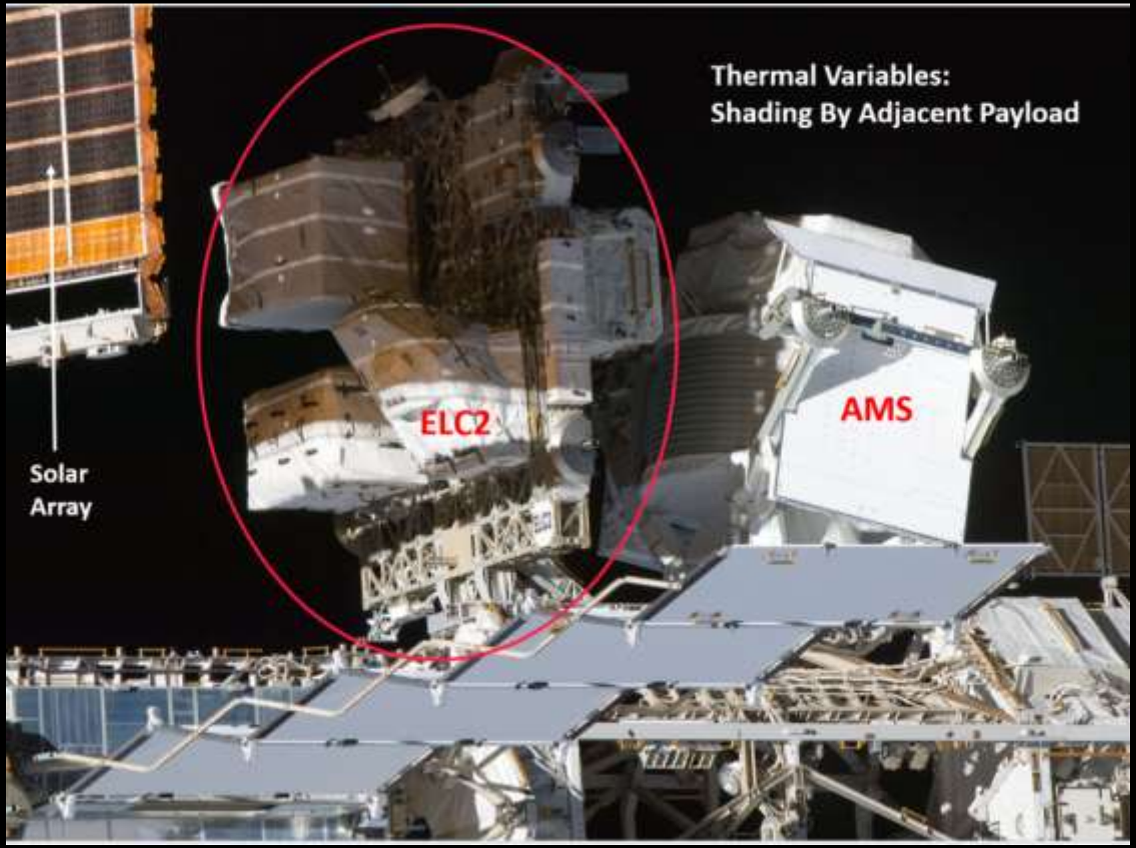



# THERMAL ENVIRONMENT AT ISS: OPERATIONS & PAYLOADS

- ❑ The ISS starboard radiator can be rotated, blocking the view of the payload structure and radiators to deep space and reflecting differing amounts of radiation and reflecting differing amounts of radiation to the payload

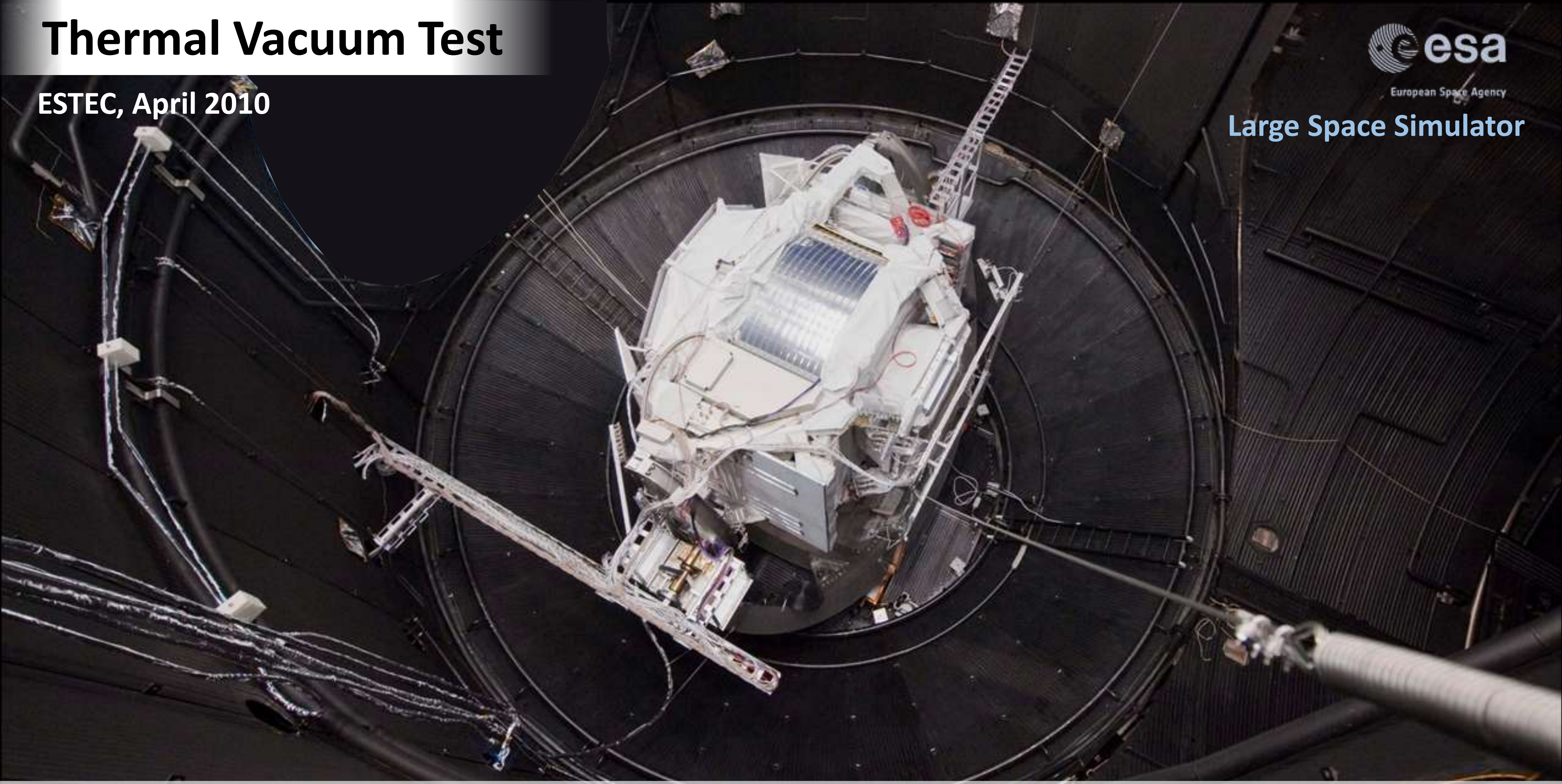



- ❑ The solar arrays usually track the sun but are occasionally parked in a fixed position that shades the payload.
- ❑ The ISS attitude can change due to the docking/undocking of vehicles (e.g. Soyuz, Progress…).
- ❑ The adjacent payload (Express Logistics Carrier 2) may also shade during periods of large negative beta angle

# Thermal Vacuum Test

ESTEC, April 2010

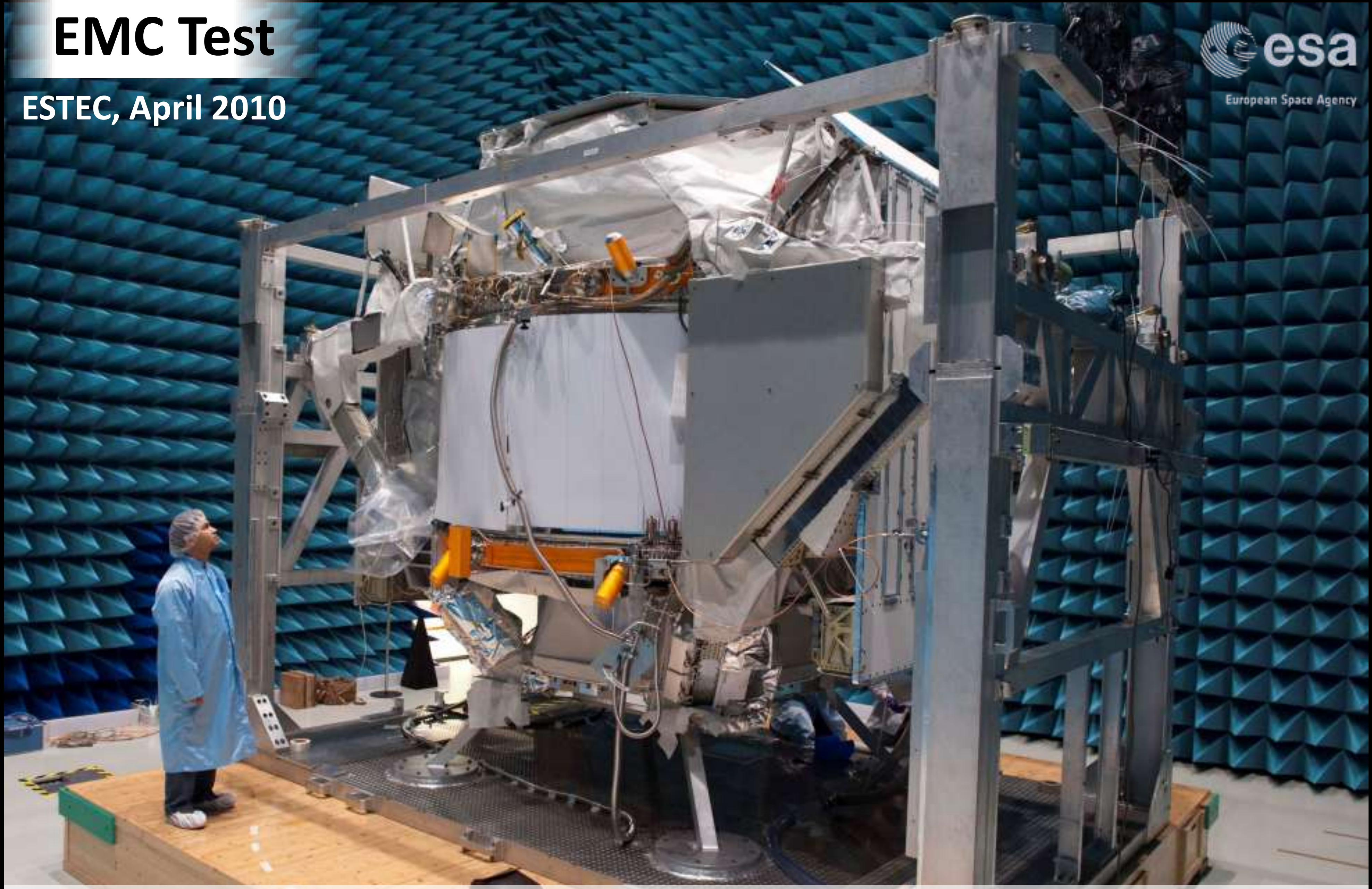



**AMS-02 Thermal Vacuum test at ESTEC**

**CERN** engineer team in charge for interface with ESA for AMS-02 Thermal Vacuum and EMC tests setup

# EMC Test

**ESTEC, April 2010**



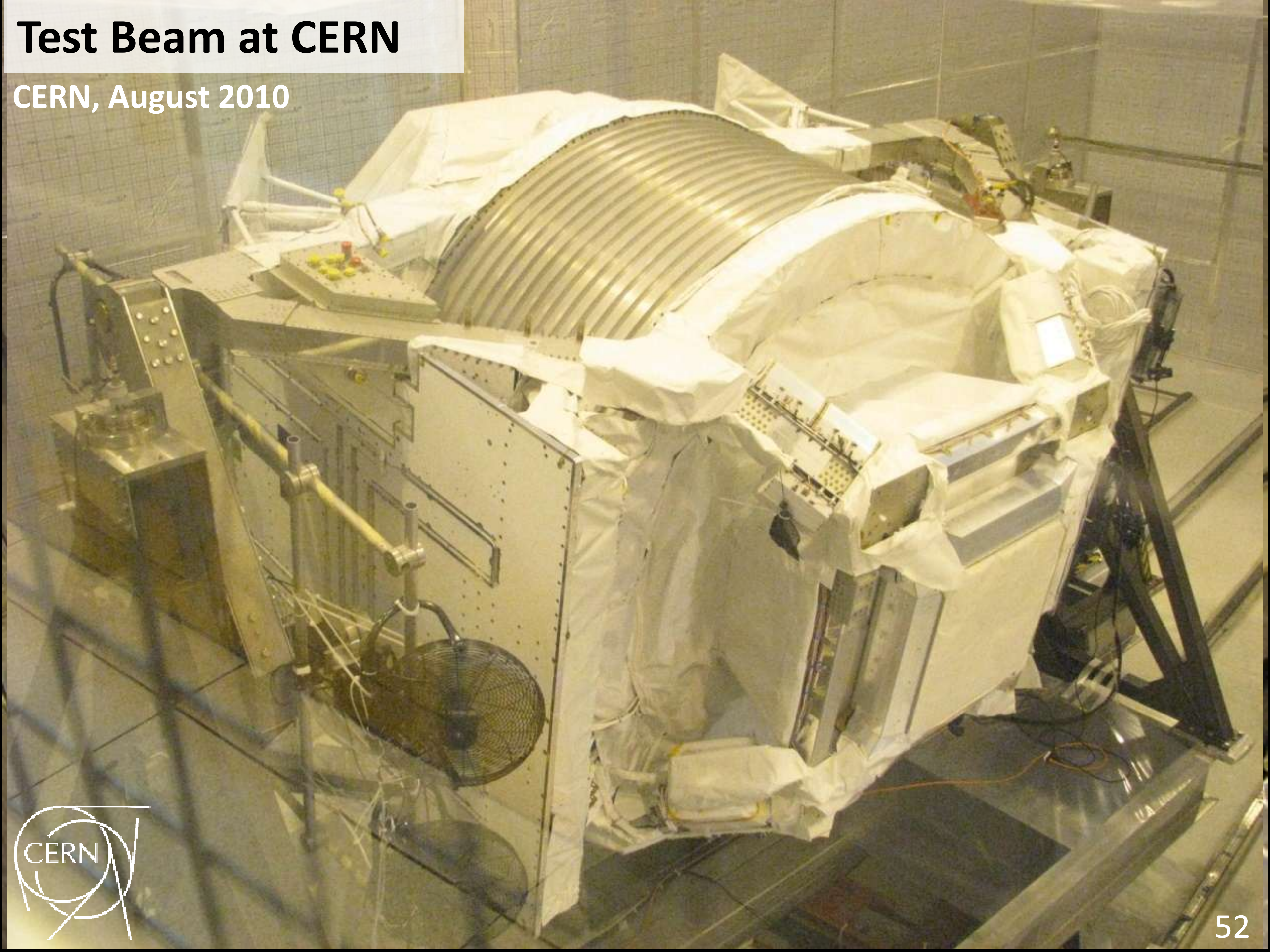

**Electro Magnetic Compatibility at ESTEC**

**CERN** engineer team in charge for interface with ESA for AMS-02 Thermal Vacuum and EMI tests

# Test Beam at CERN

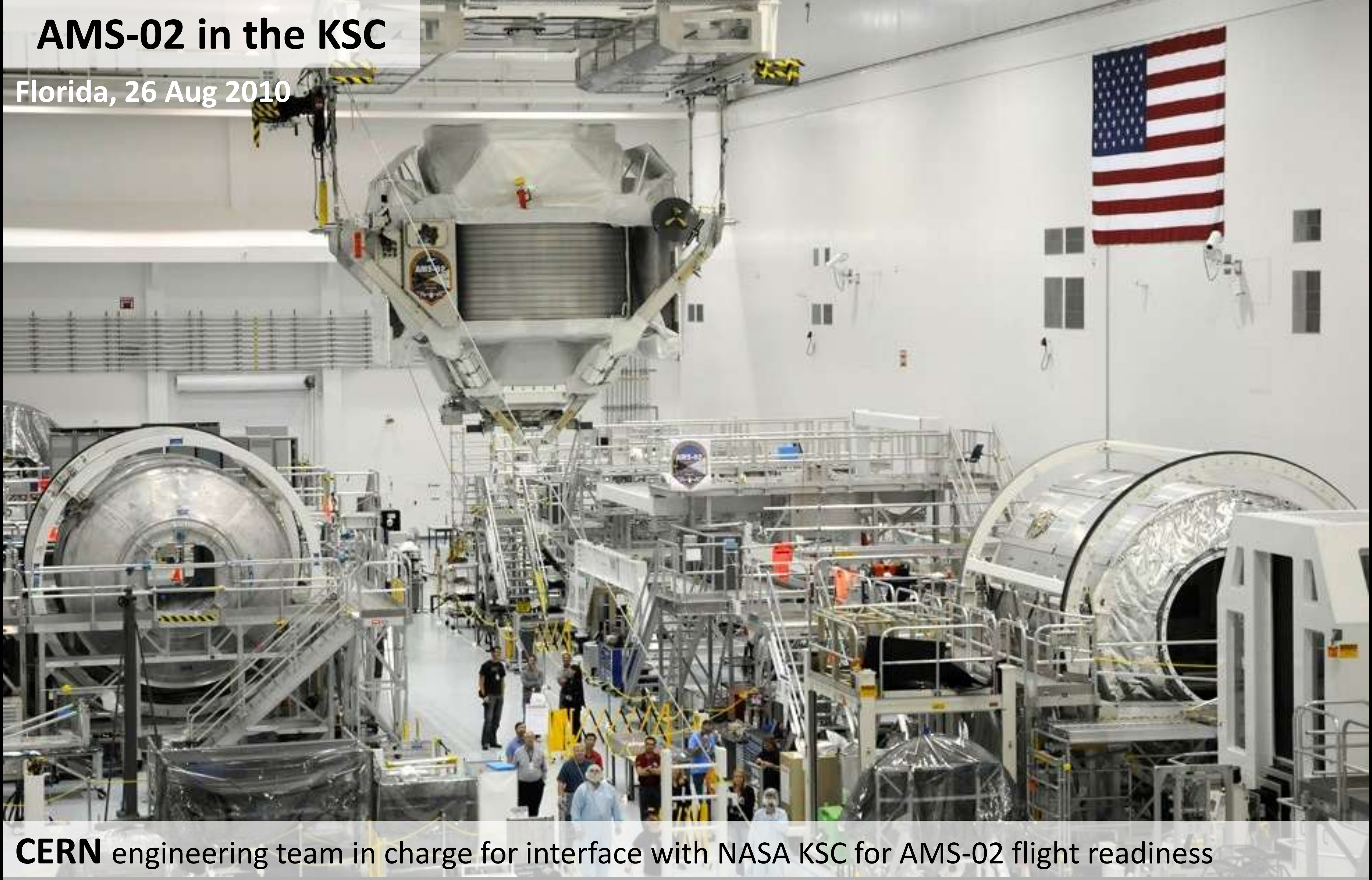

Final Detector Calibration

# Test Beam at CERN



# AMS-02 in the KSC

Florida, 26 Aug 2010

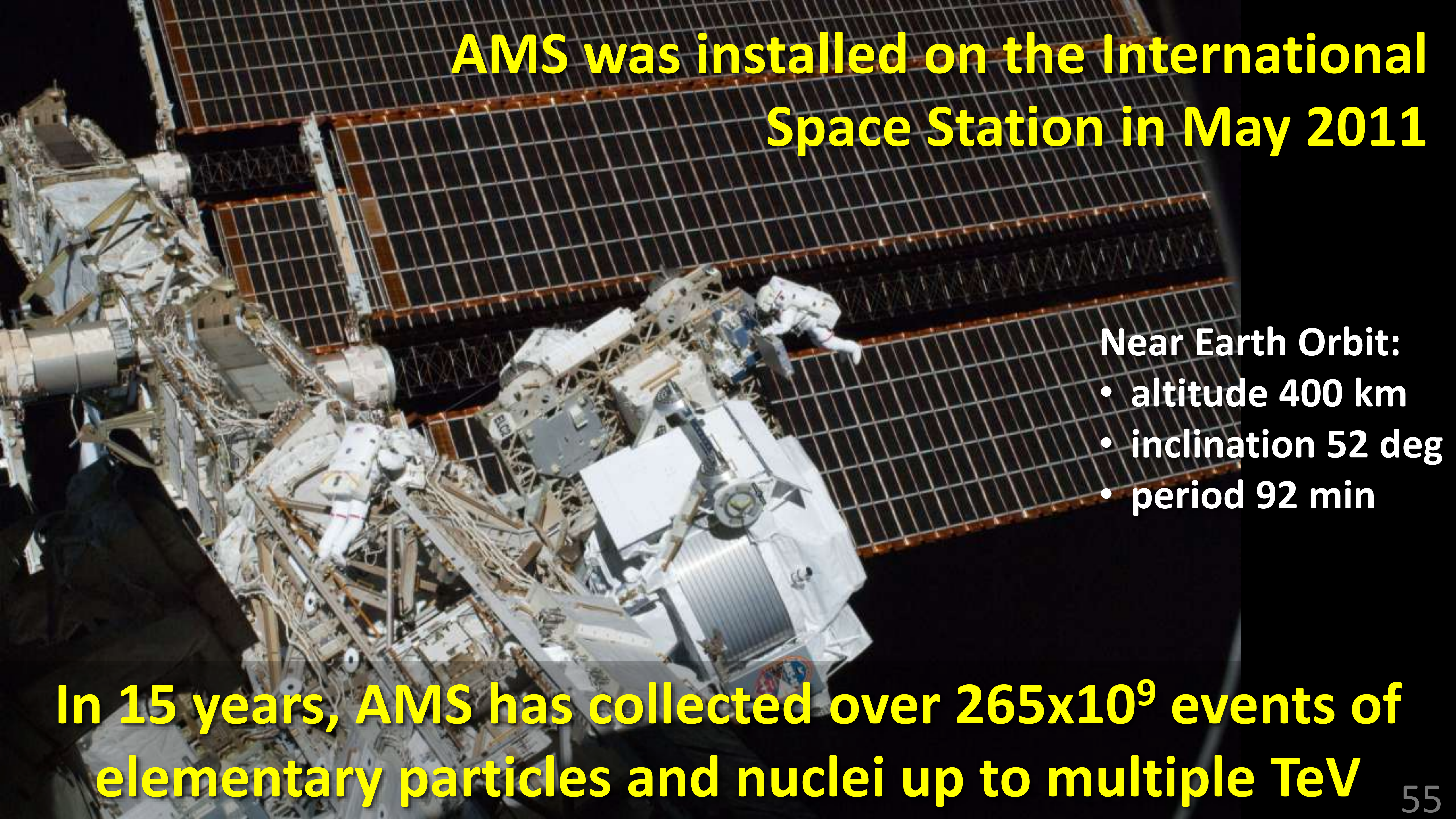



**CERN** engineering team in charge for interface with NASA KSC for AMS-02 flight readiness


Launch Pad 39
May, 2011


ISS
May 2011

# AMS was installed on the International Space Station in May 2011



**Near Earth Orbit:**

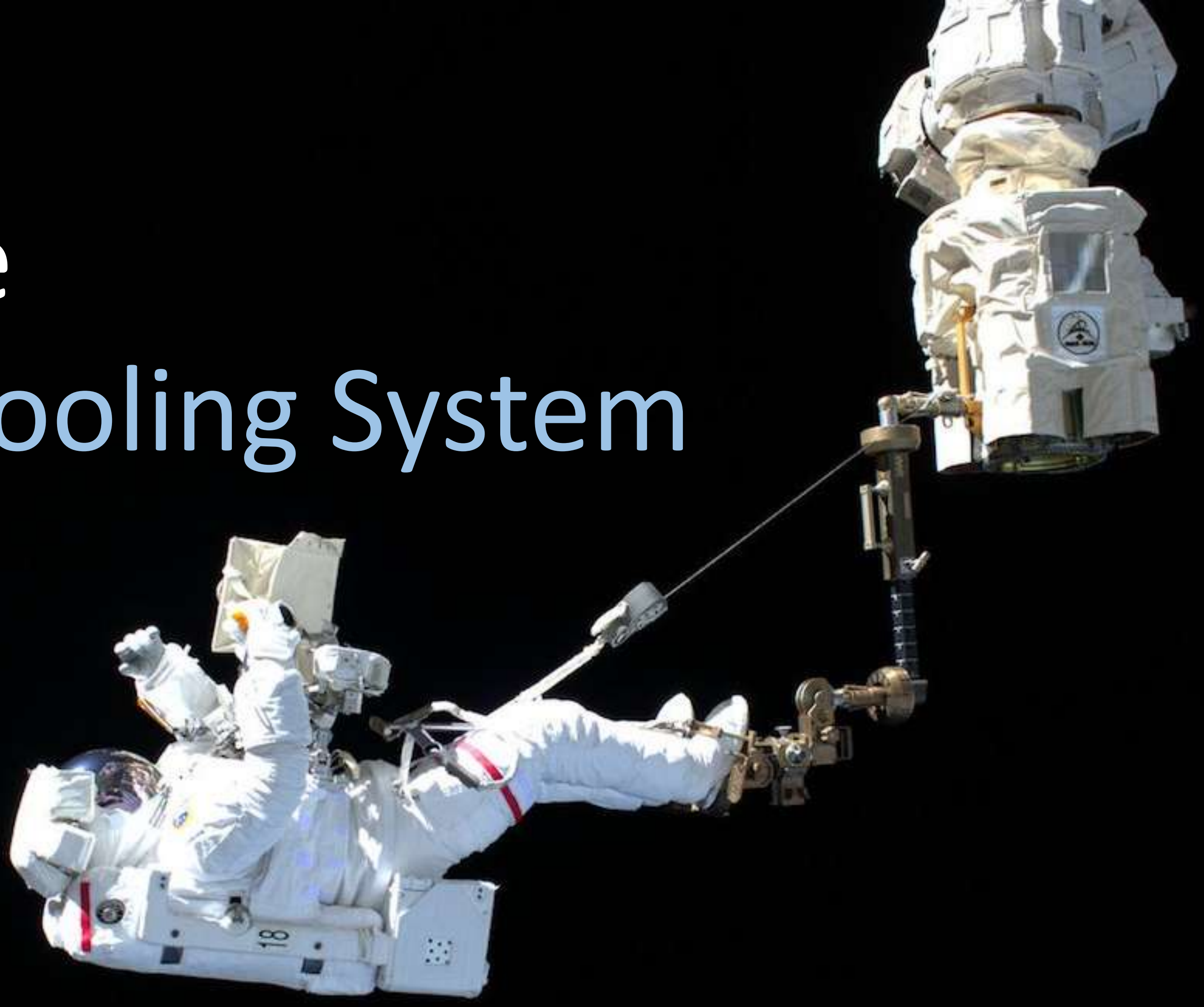
- altitude 400 km
- inclination 52 deg
- period 92 min

**In 15 years, AMS has collected over $265 \times 10^{9}$ events of elementary particles and nuclei up to multiple TeV**

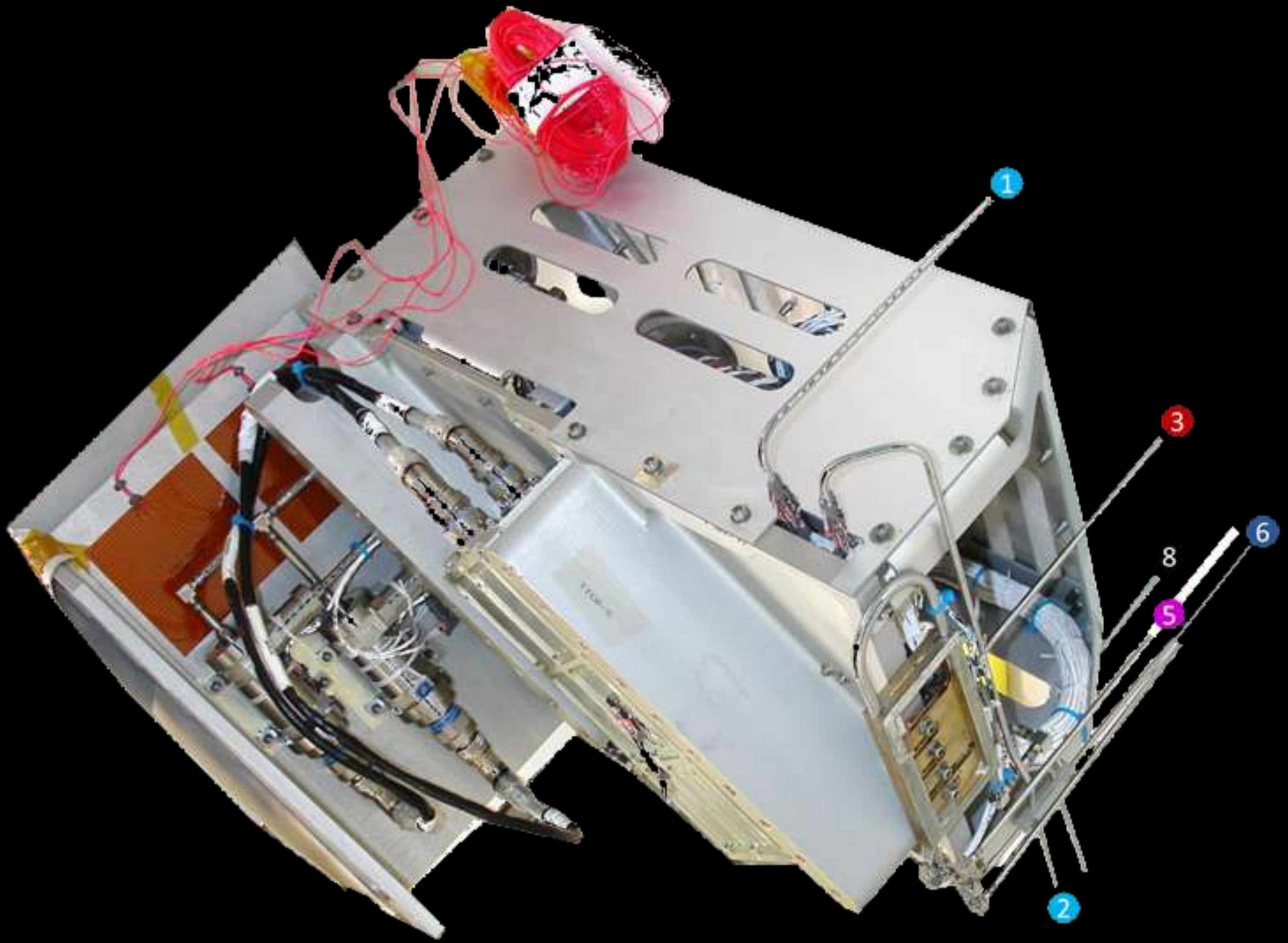
# **AMS-02**

First Upgrade

New Pump Cooling System

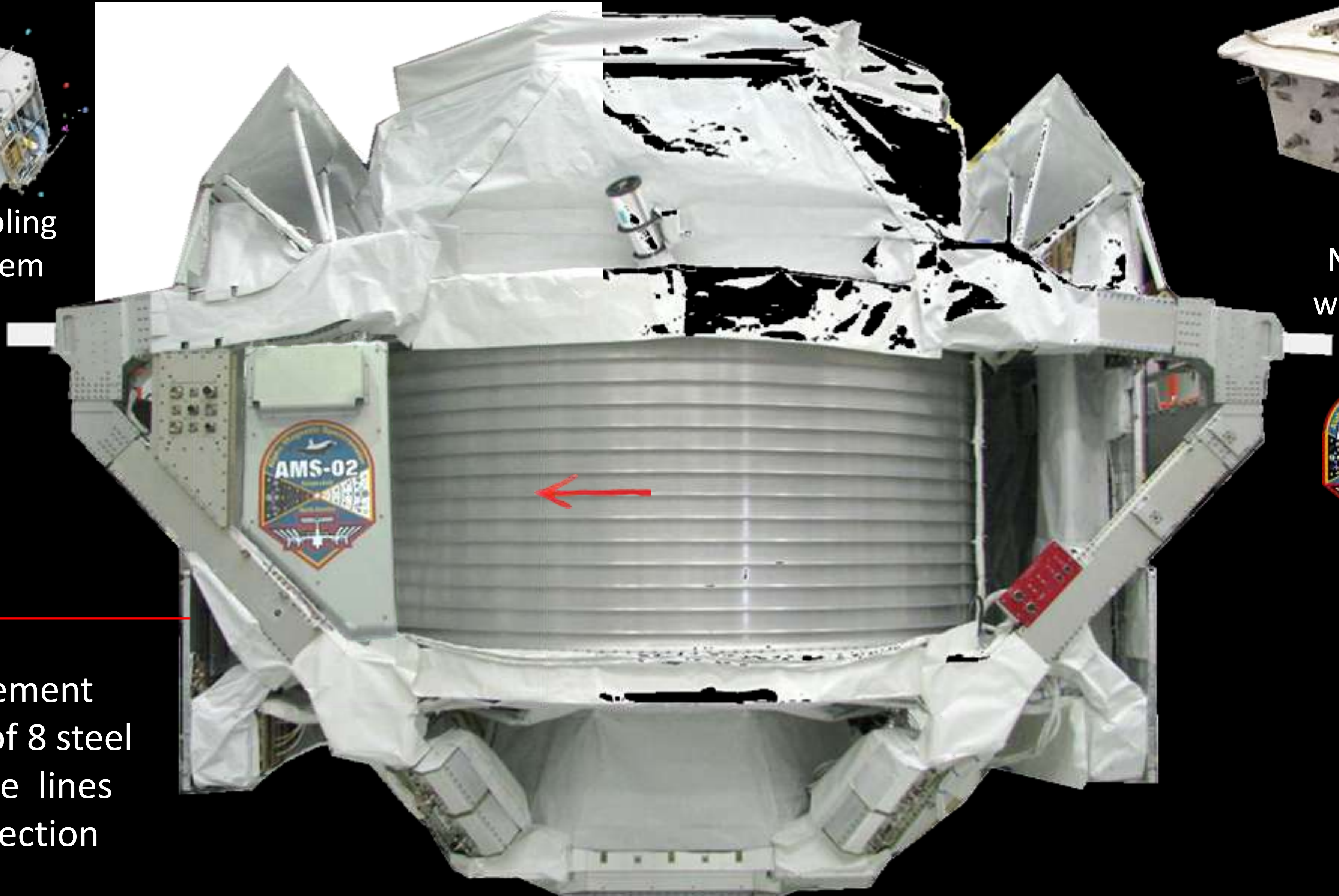


# After several years of operation, the tracker cooling pump system begins to show anomalies



# AMS was not designed to be serviced by astronauts

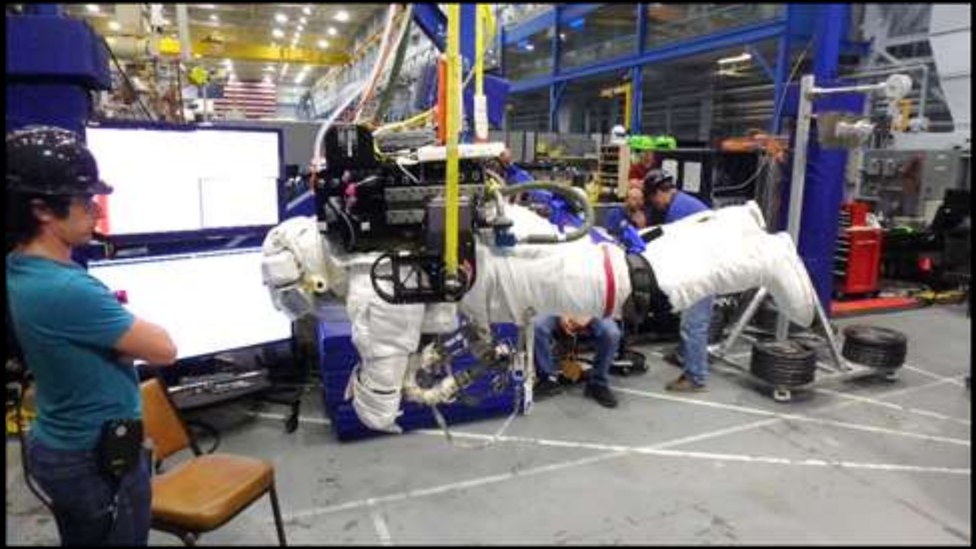
Tracker Cooling Pump System



Box replacement requires cut of 8 steel high pressure lines and reconnection


New Pump System was built by AMS for EVA installation

# 4 Exceptional EVAs: intensive astronauts training

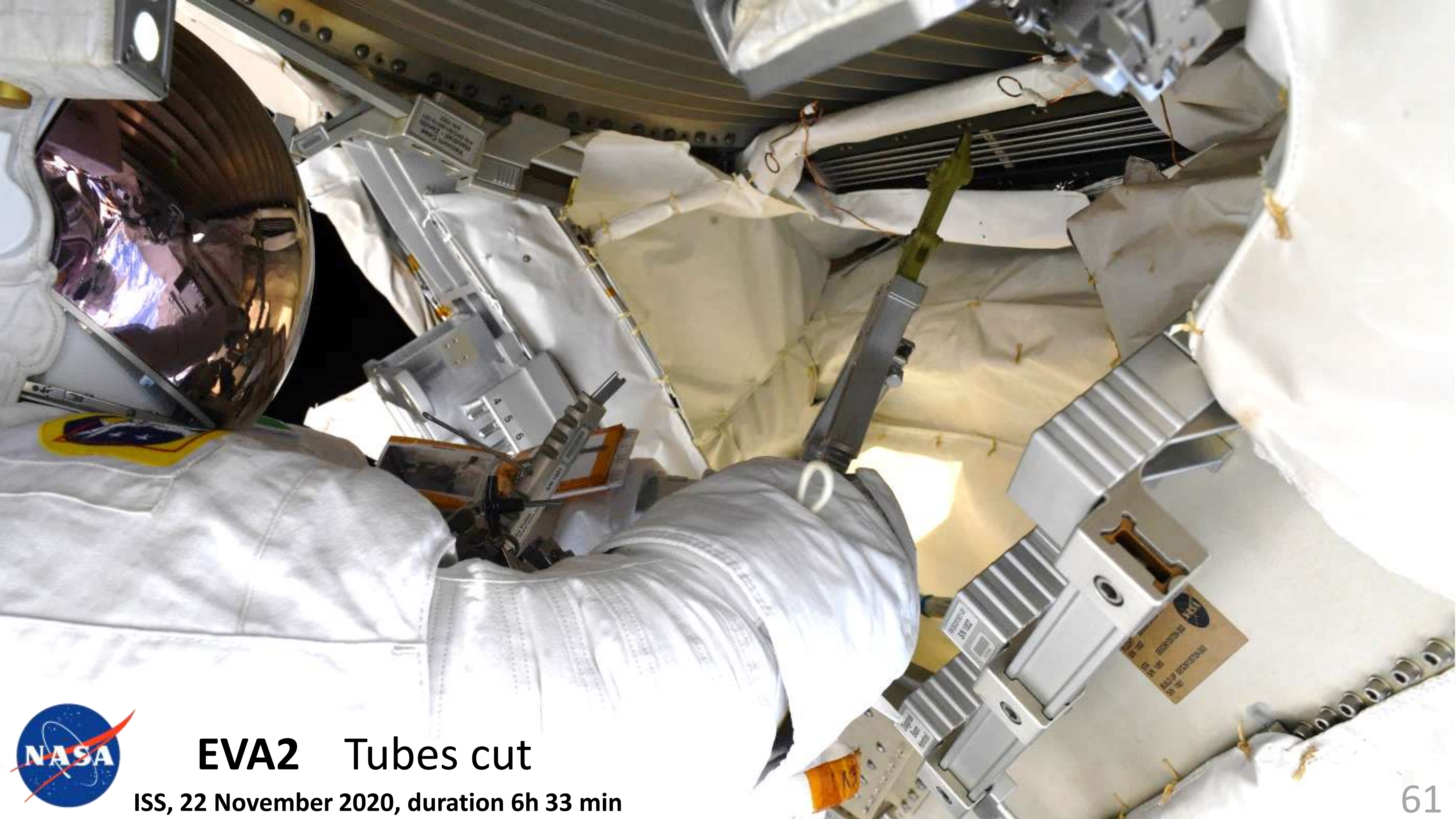


Active Response Gravity Offload System

Neutral Buoyancy Laboratory

# **EVA1** Debris shield removal

ISS, 13 November 2019, duration 6h 36 min



# **EVA2** Tubes cut

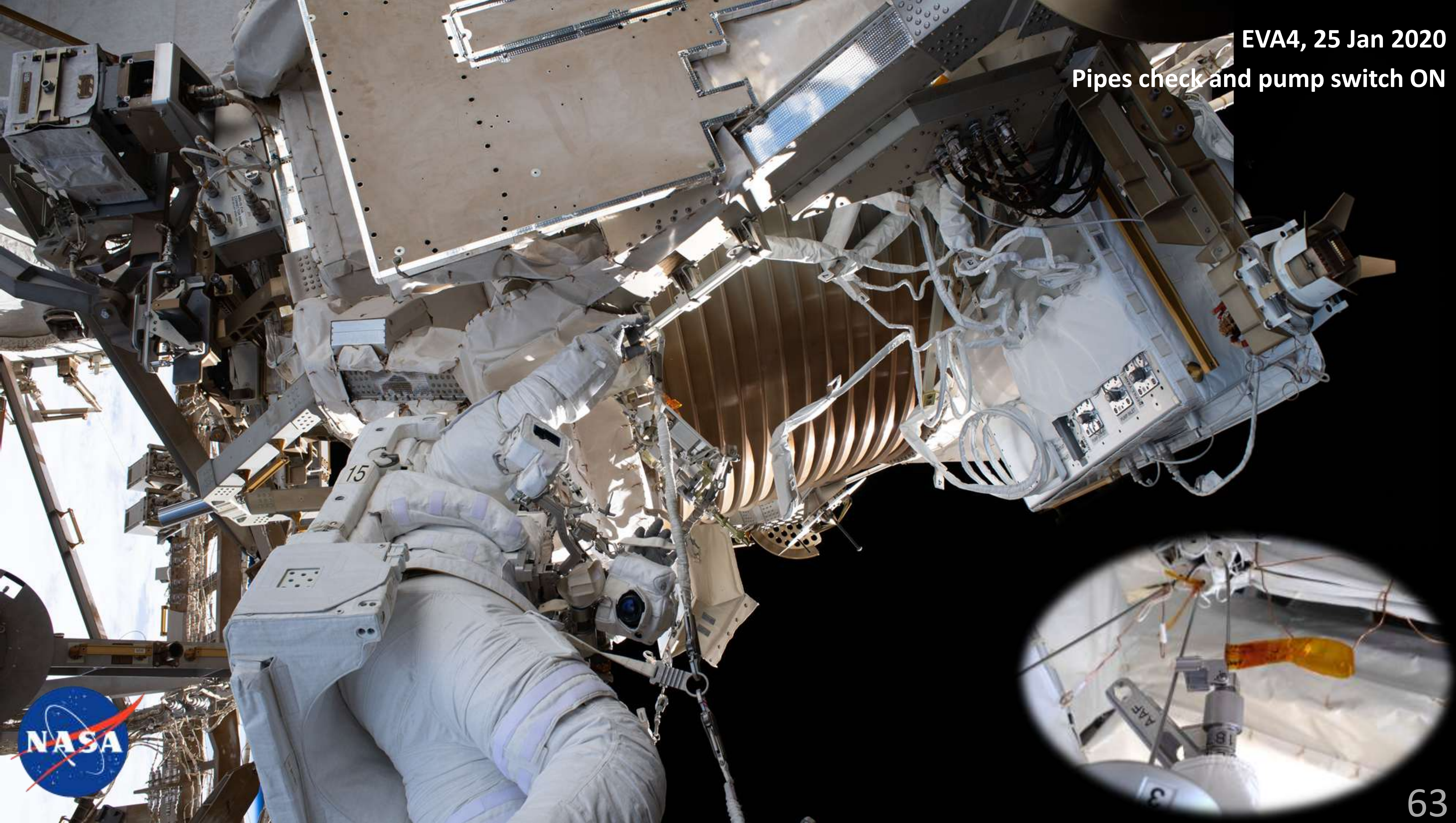
**ISS, 22 November 2020, duration 6h 33 min**

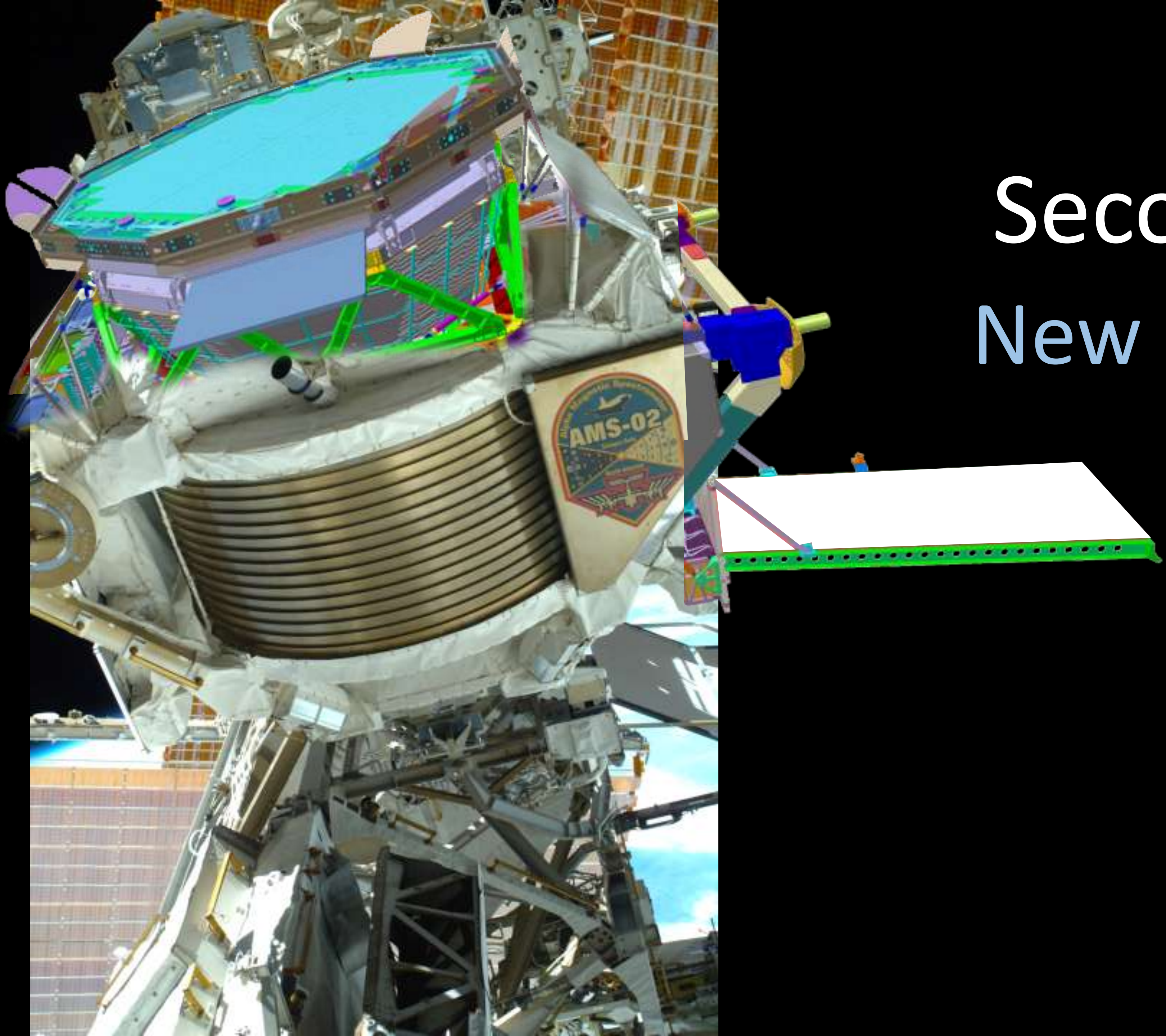
# **EVA3** New Pump System installation

**ISS, EVA3, 2 December 2019, duration 6h 03 min**

**EVA4, 25 Jan 2020**

**Pipes check and pump switch ON**



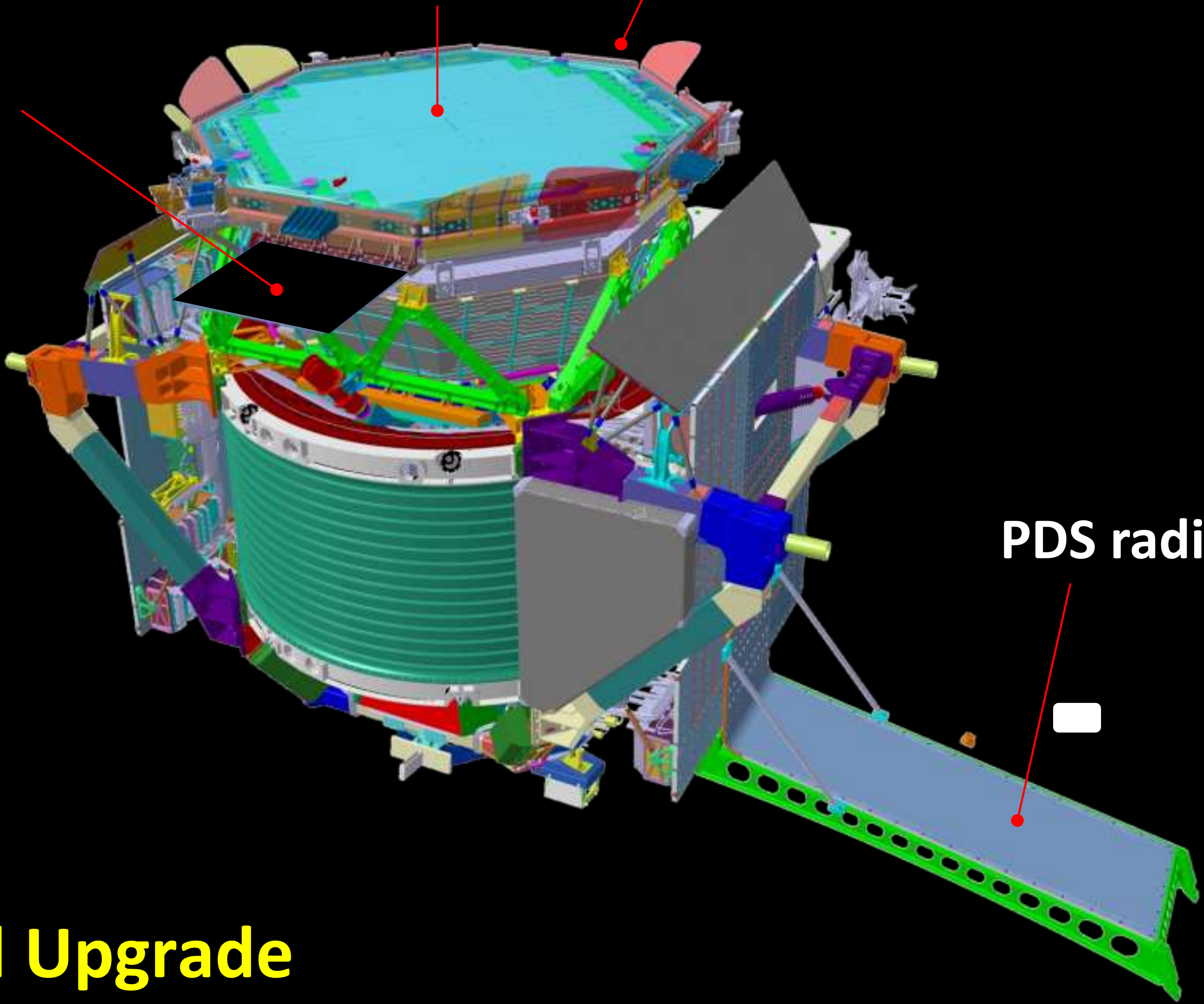



# AMS-02

## Second Upgrade

New Detector Layer

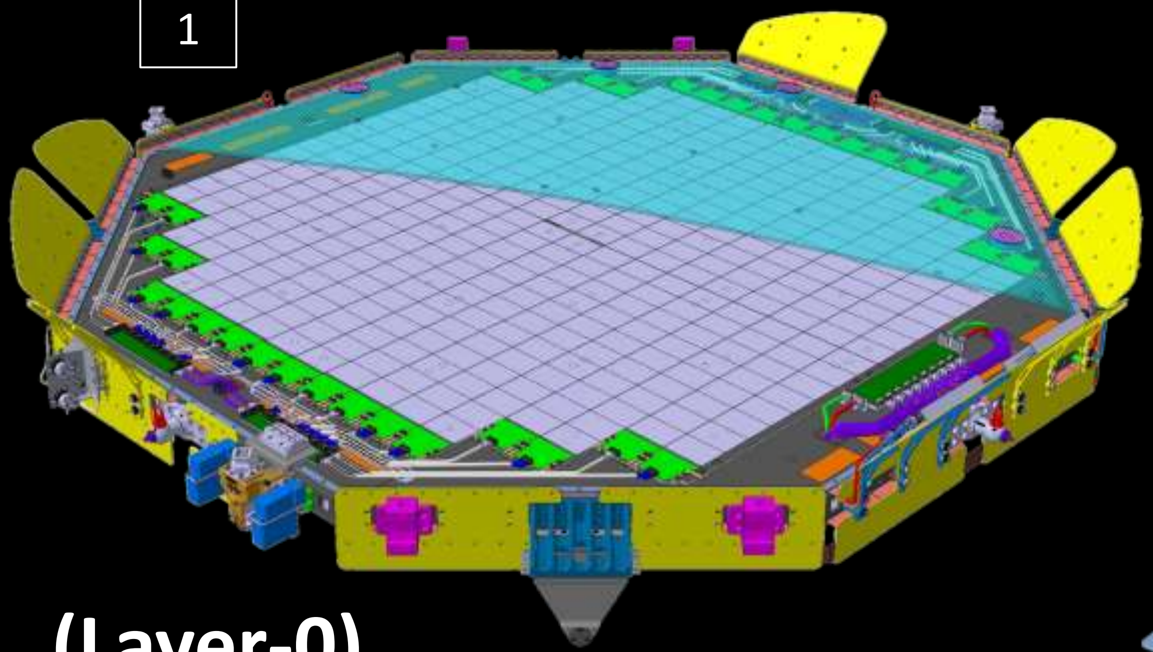
New Radiators




AMS Second Upgrade

# AMS parts to send to space

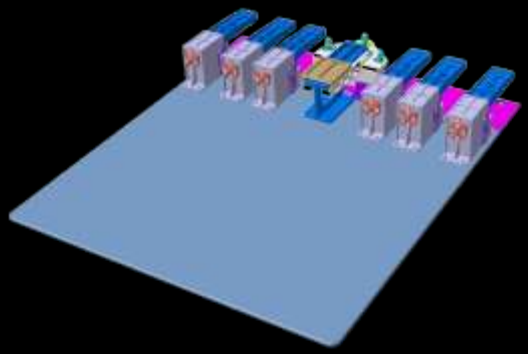
1



## (Layer-0)

~350 Kg (includes SpX hardware 57 kg)
~ 2.8m x 2.8m x 0.45m

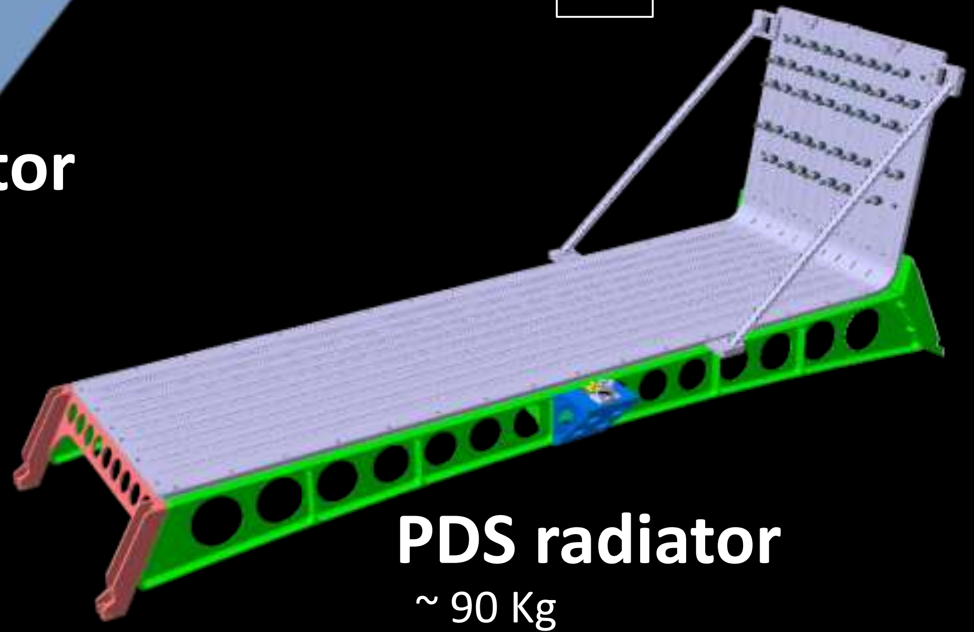
2



## 2x (Layer-1) radiator

2x
~ 30 kg
~ 0.96 m x 0.84 m x 0.18 m

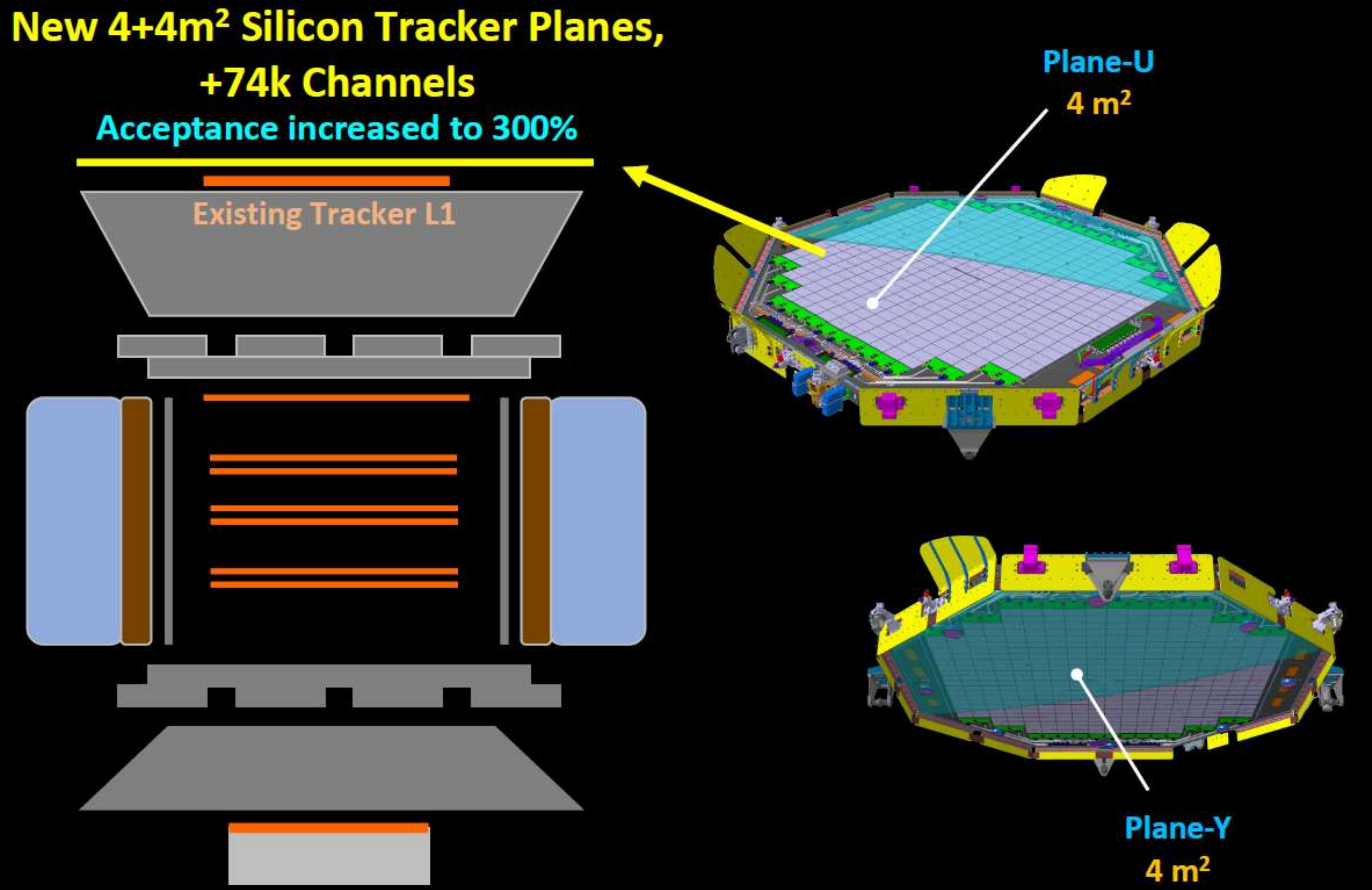
3



## PDS radiator

~ 90 Kg
~ 2.8 m x 1 m x 1 m

# AMS on ISS: 2027-2030+



# Qualification Model: Vibration test

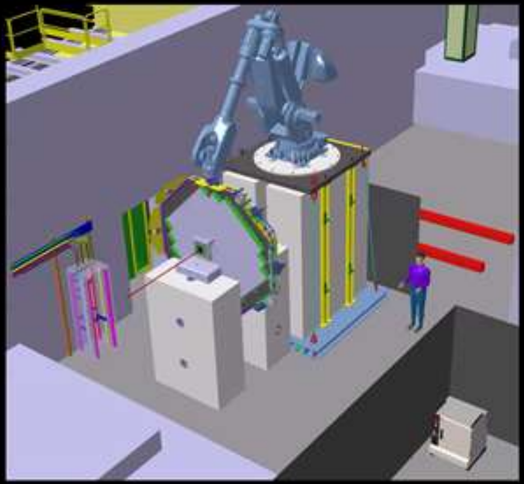
Payload must remain structurally unchanged and functional, after random vibration at levels enveloping the launch



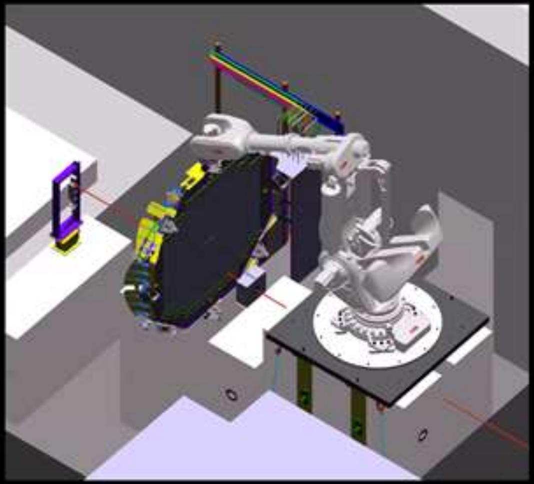
# AMS L0 Flight Hardware Integration & Metrology @CERN


Detector mapping performed at several steps during integration and a final one after all tests and before test beam

*North Area Installation*



*Virtual Environment*



April 20th, 2026: Vibration test
May 11th, 2026: Thermal Vacuum Test
June 8th, 2026: EMI Test
June 26th, 2026: NASA/DOE visit
July 20th, 2026: Test Beam @SPS

*08/2026: Ready for Delivery to NASA KSC*
*03/2027: Launch on SpaceX-36*

- Space provides unique scientific opportunities and technical challenges
- Space instrumentation needs to meet
  - Strict design constraints on mass and power
  - Environmental conditions: vibrations at launch, temperature ranges, space radiation
  - Appropriate component selection, implement redundancies, thermal control systems
  - On-board software design to minimize remote operations
- Detailed programmatic design and implementation phases

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- … and get your mission selected by your Space Agency!