Cosmic Ray Physics

External Scientific Advisory Committee meeting
CIEMAT (Madrid)
11-12 January 2023

Jorge Casaus on behalf of CIEMAT Cosmic Ray Physics Group

Projects

Active:

- **AMS (Alpha Magnetic Spectrometer on the International Space Station ISS),** in operation since May 19th 2011, expected to continue during the ISS lifetime (2030+)

In preparation:

- **HERD (High Energy cosmic Radiation Detection facility for the China Space Station CSS),** planned for operation starting around 2027 for about 10 years

Possible Future Projects:

- **AMS-100**
- **ALADInO**

Current Personnel

Scientific Personnel

Seniors: **J. Berdugo (AMS), J. Casaus (PI, AMS, HERD), C. Delgado (AMS), C. Mañá (co-PI, AMS), F. Giovacchini (AMS, HERD)**

Postdocs: **M. Velasco (AMS,HERD)**

Students: **J. Ocampo (Phd for 2024, AMS), I. Rodríguez (PhD for 2025, AMS)**

Technical Staff

Mechanics: **C. Díaz (HERD, R&D)**

Electronics (Tech. Dept.): **J. Marín (HERD, R&D), G. Martínez (HERD), Ll. Freixas (R&D)**

Changes in 2024

Scientific Personnel

Retirement (senior): **J. Berdugo, C. Mañá**

Estabilización (senior): **M. Velasco**

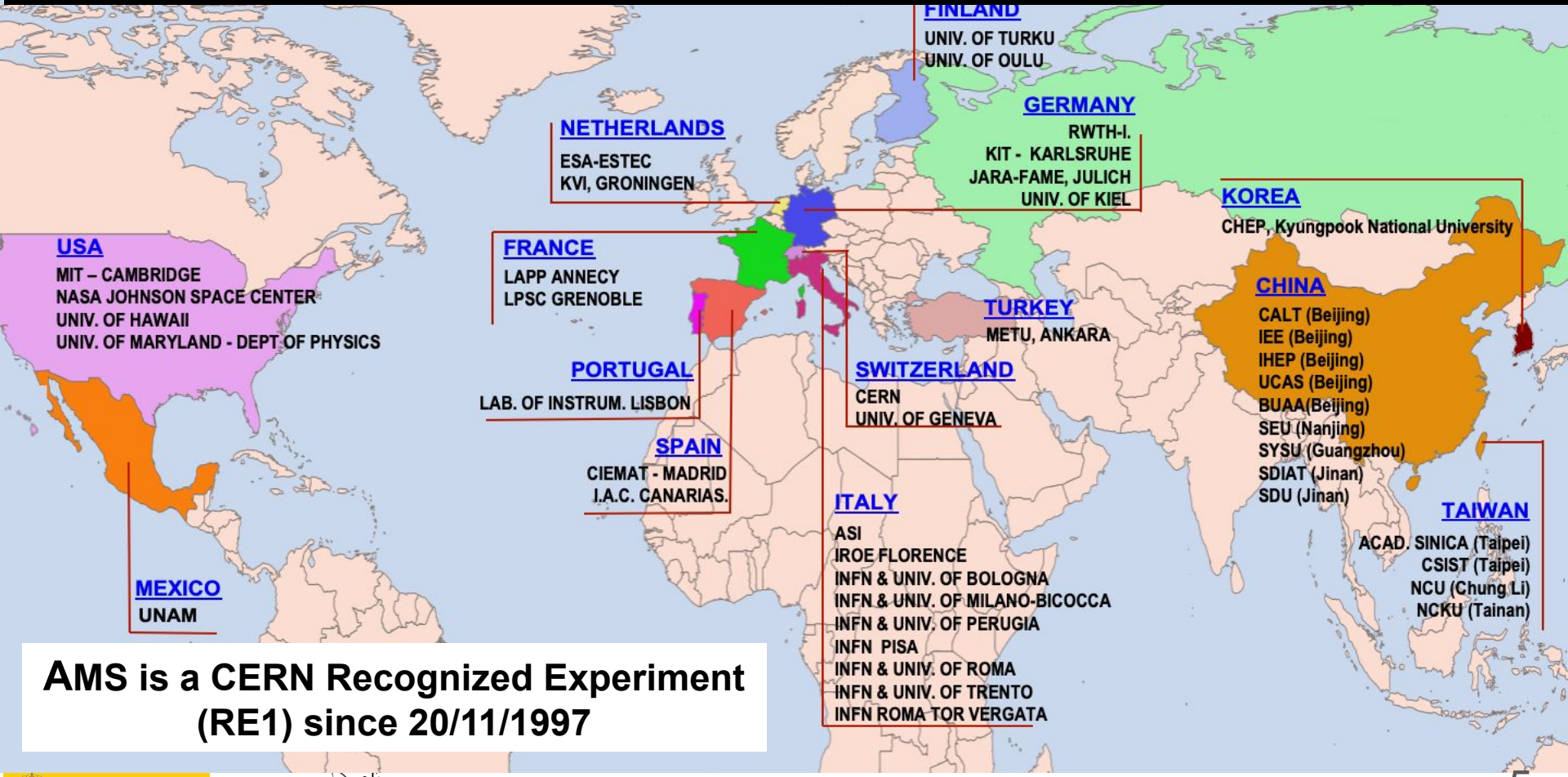
+1 Electronics Engineer + 1 PhD Student

Funding

Spain - AEI
Project: **Participation in the AMS Experiment on the ISS, in the HERD Experiment for the CSS, and R&D Activities for Future Detectors in Space**
Funding Agency: MICINN (PID2022-137810NB-C21)
Duration, from: **2023** to: **2026 (AMS Science Activities, HERD Prototype, R&D)**
Funding: **506,250 €**
PI: **Jorge Casaus**; co-PI: **Carlos Mañá**

Spain - AEI
Project: **Participation in the AMS Experiment**
Funding Agency: MICINN (PCI2023-145945-2)
Duration, from: **2023** to: **2026 (Contribution to AMS Operation and Computing)**
Funding: **300,080 €**
PI: **Jorge Casaus**

AMS is an international collaboration with 250 members from 44 institutions



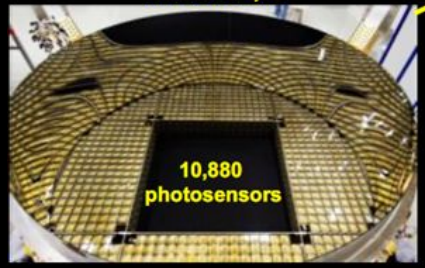
AMS is a CERN Recognized Experiment (RE1) since 20/11/1997

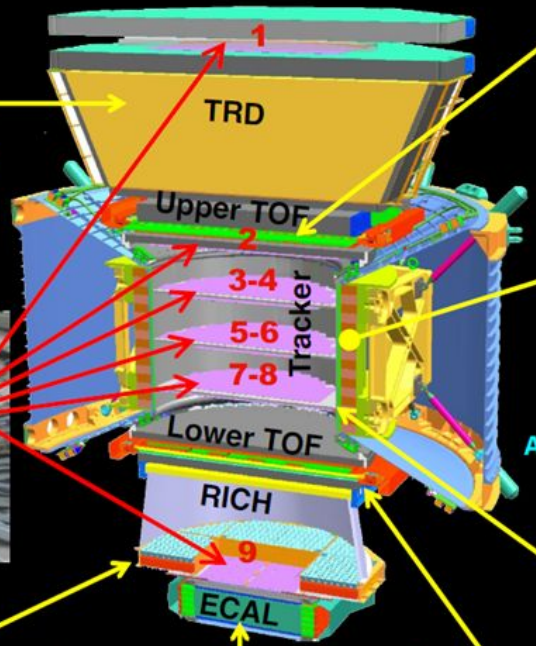
AMS is a space version of a precision detector used in accelerators

Transition Radiation Detector (TRD)
identify e^+, e^-

Silicon Tracker
measure Z, P

Ring Imaging Cerenkov (RICH)
measure Z, E

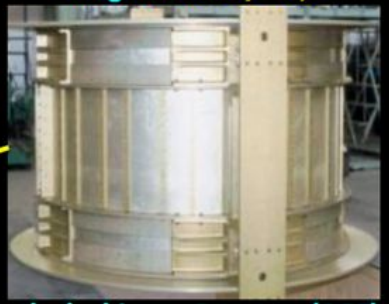




Electromagnetic Calorimeter (ECAL)
measure E of e^+, e^-

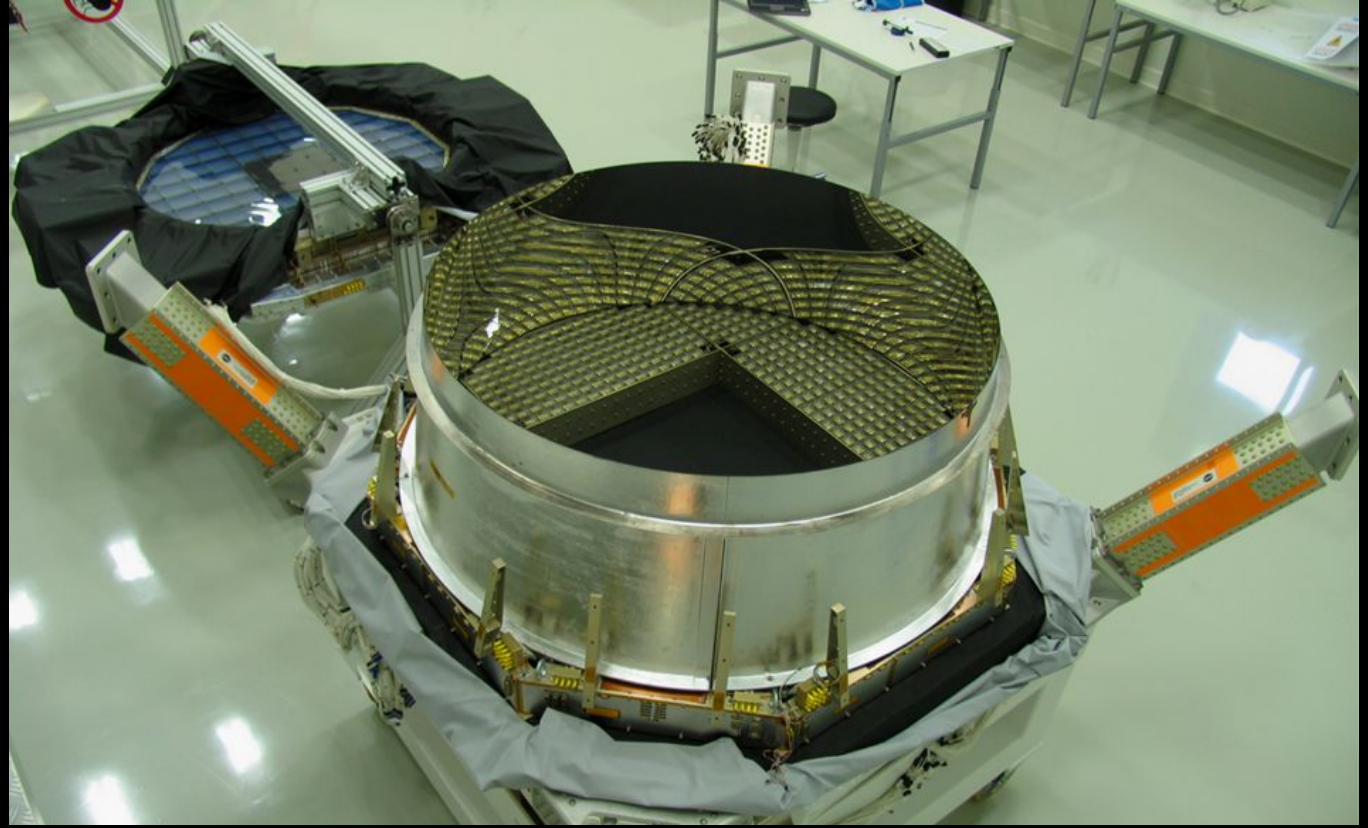
Upper TOF measure Z, E

Magnet identify ±Z, P



Anticoincidence Counters (ACC)
reject particles from the side

Lower TOF measure Z, E

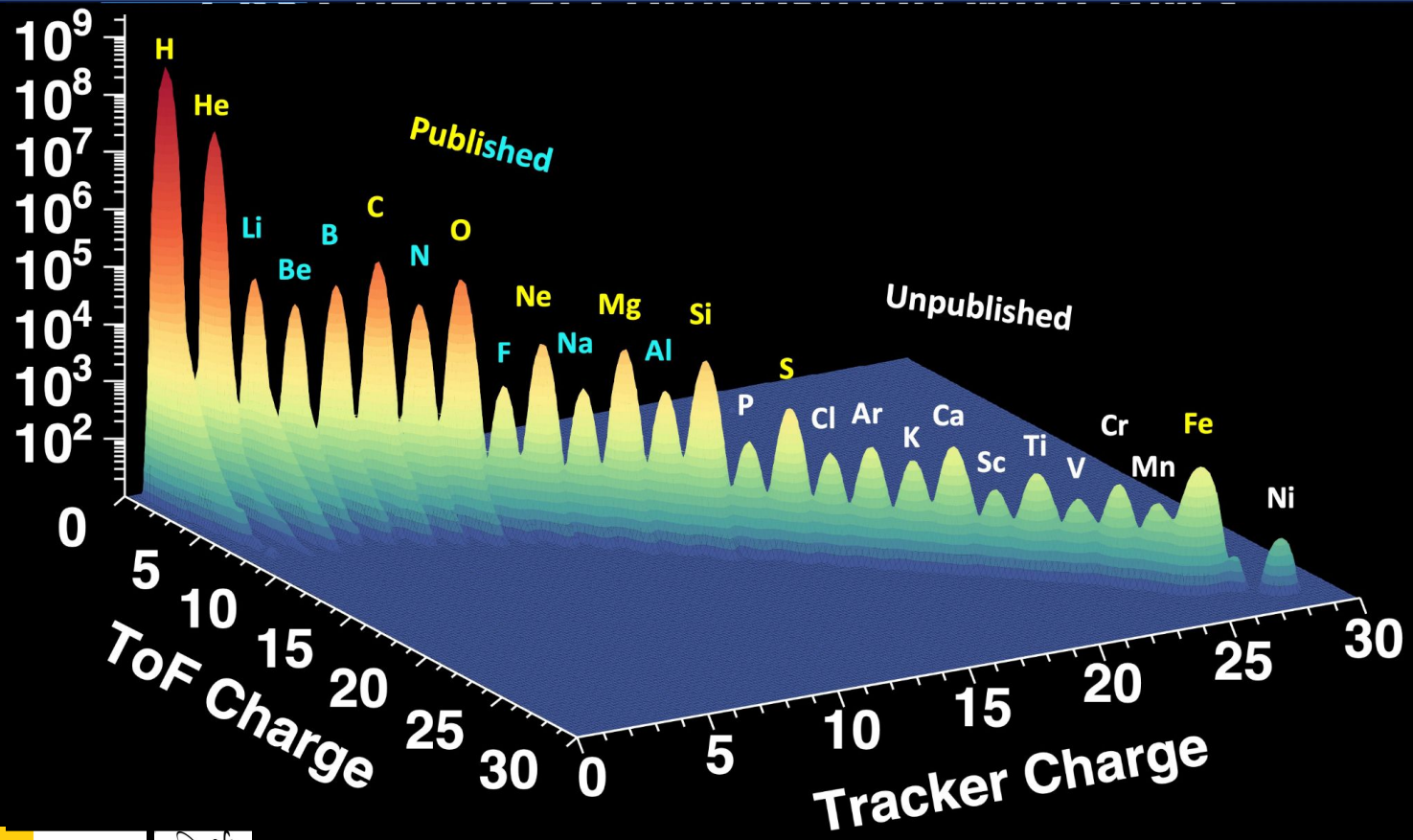


CIEMAT made a major contribution in the design and construction of the RICH detector, and is responsible for the RICH operation from CERN

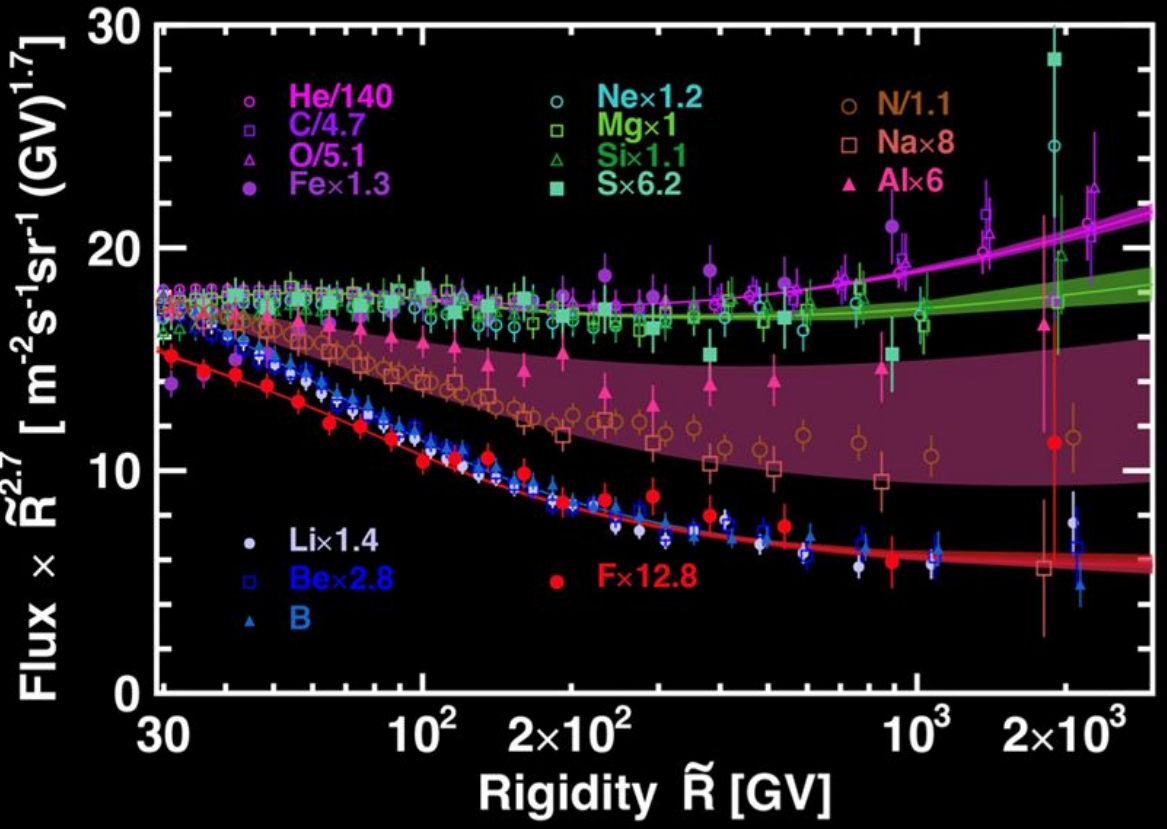
Main analysis topics:

- Cosmic Rays nuclei fluxes and ratios (p, He,…Fe)
  (11 PRL, 7 of them selected as Editors' Suggestion)
- Cosmic Rays isotopic composition (D, 3He)
  (1 PRL, selected as Editors' Suggestion + 1 in preparation)
- **Flux Anisotropy** in e+, e-, protons and light nuclei fluxes
  (in 3 PRL, selected as Editors' Suggestion)
- Time evolution of electron and positron fluxes
  (2 PRL, 1 of them selected as Editors' Suggestion, Featured in Physics, and Physics Viewpoint)

Precision Measurements of Cosmic Nuclei by AMS



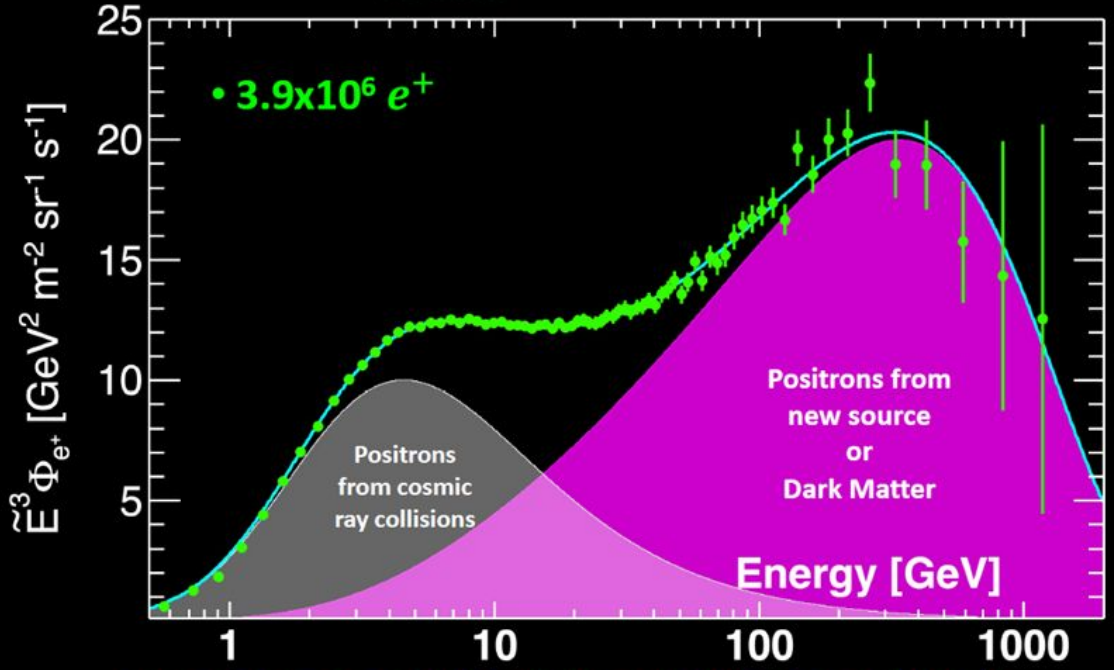
Precision Measurements of Cosmic Nuclei by AMS



The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from pulsars or dark matter both with a cutoff energy E_S.

$$\Phi_{e^+}(E) = \frac{E^2}{\widehat{E}^2}\left[C_d(\widehat{E}/E_1)^{\gamma_d} + C_s(\widehat{E}/E_2)^{\gamma_s}\exp(-\widehat{E}/E_s)\right]$$

Solar Collisions Pulsars or Dark Matter

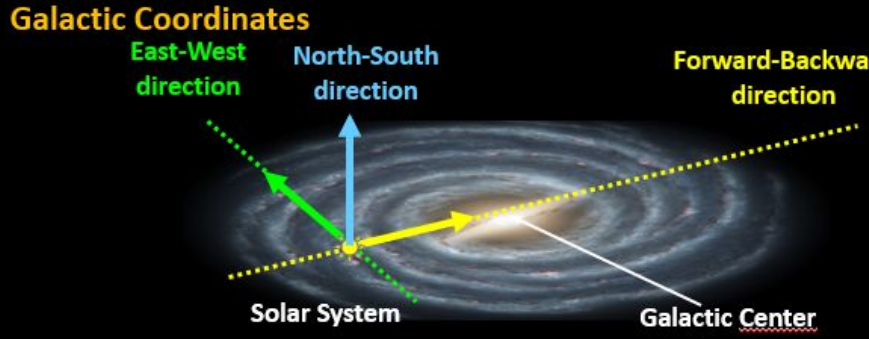


The existence of the finite cutoff energy (4.7σ) is a new and unexpected observation

Origin of Cosmic Ray Positrons: Anisotropy

Disentangle among possible origins measuring the **directionality** of the signal.

Astrophysical point sources like pulsars imprint a higher anisotropy on the arrival directions of energetic positrons than a smooth dark matter halo

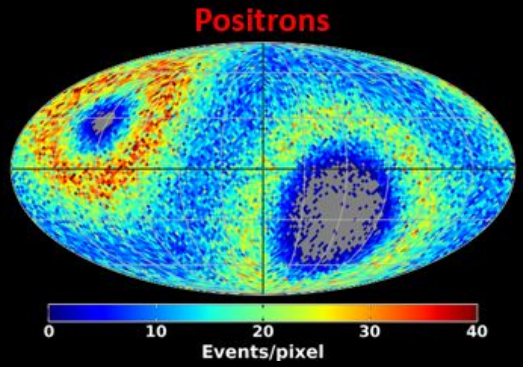


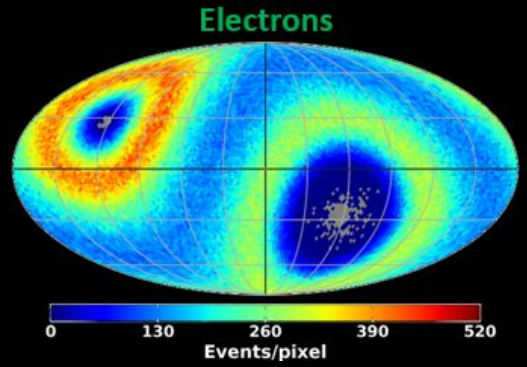
Dipole anisotropy

$\delta = 3\sqrt{C_1/4\pi}$

C_1 is the dipole moment

$\delta < 1.50\%$ at the 95% C.L. for $E > 16$ GeV (11 years)

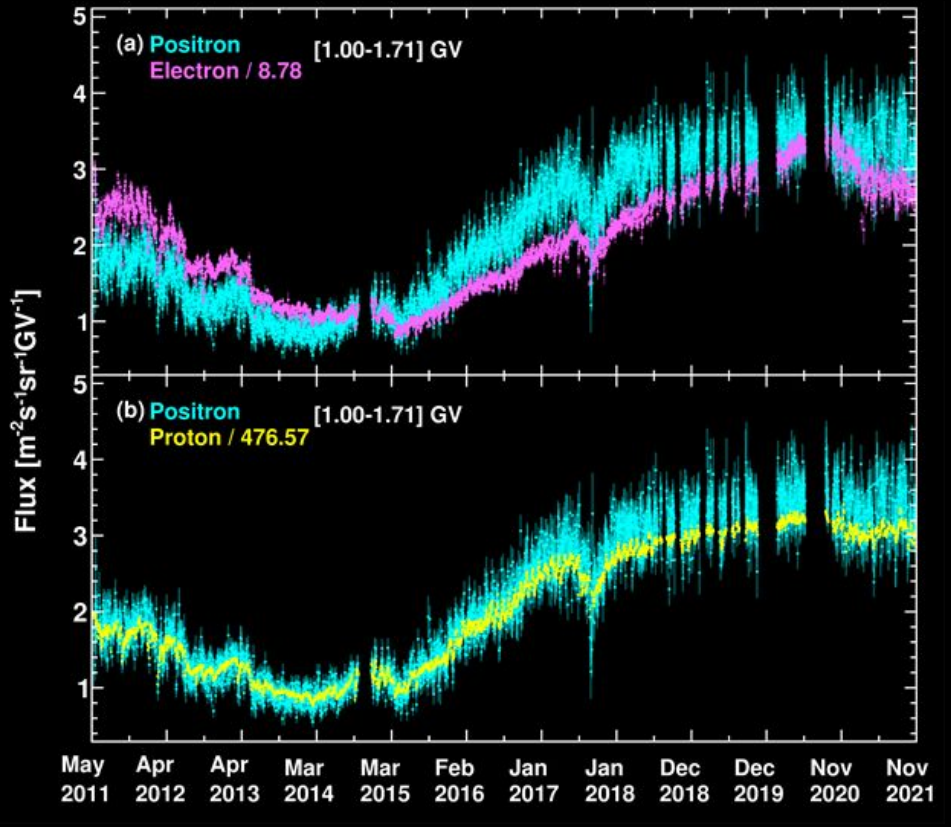




Temporal Structures in e+ and e- Spectra and Charge-Sign Effects in CR

Same mass
Opposite charge

Same charge
Different mass



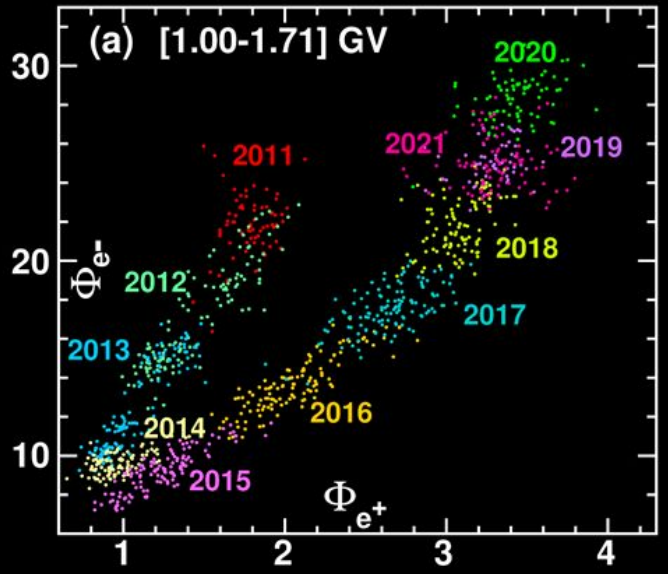
The long-term evolution of **positron** and **electron** fluxes is clearly **different**.

On the contrary, **positron** and **proton** fluxes present a **similar** behavior over time.

Temporal Structures in e+ and e- Spectra and Charge-Sign Effects in CR

Same mass

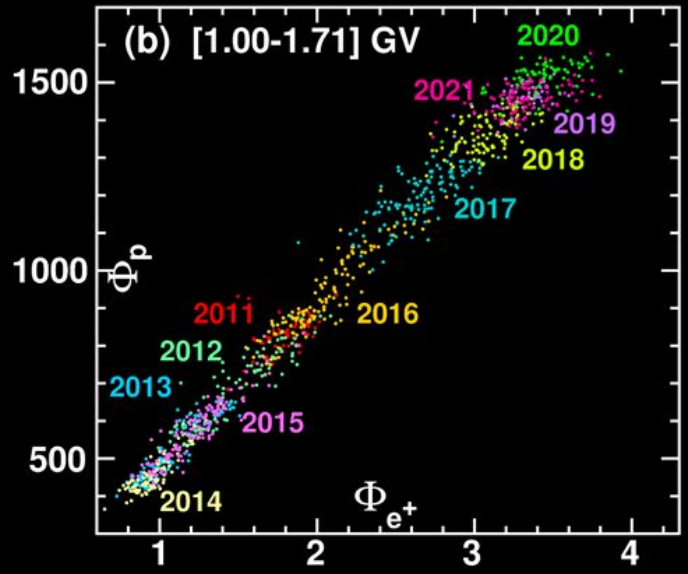
Opposite charge



Electron-Positron: hysteresis

Same charge

Different mass



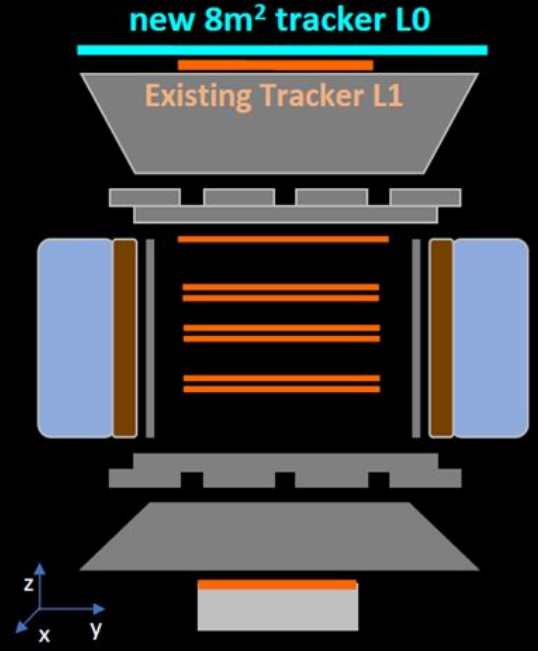
Proton-Positron: linear relation

AMS on the ISS

AMS 2011-2025
Continuous data taking

Latest results 2011 - 2022: 220 billion cosmic rays

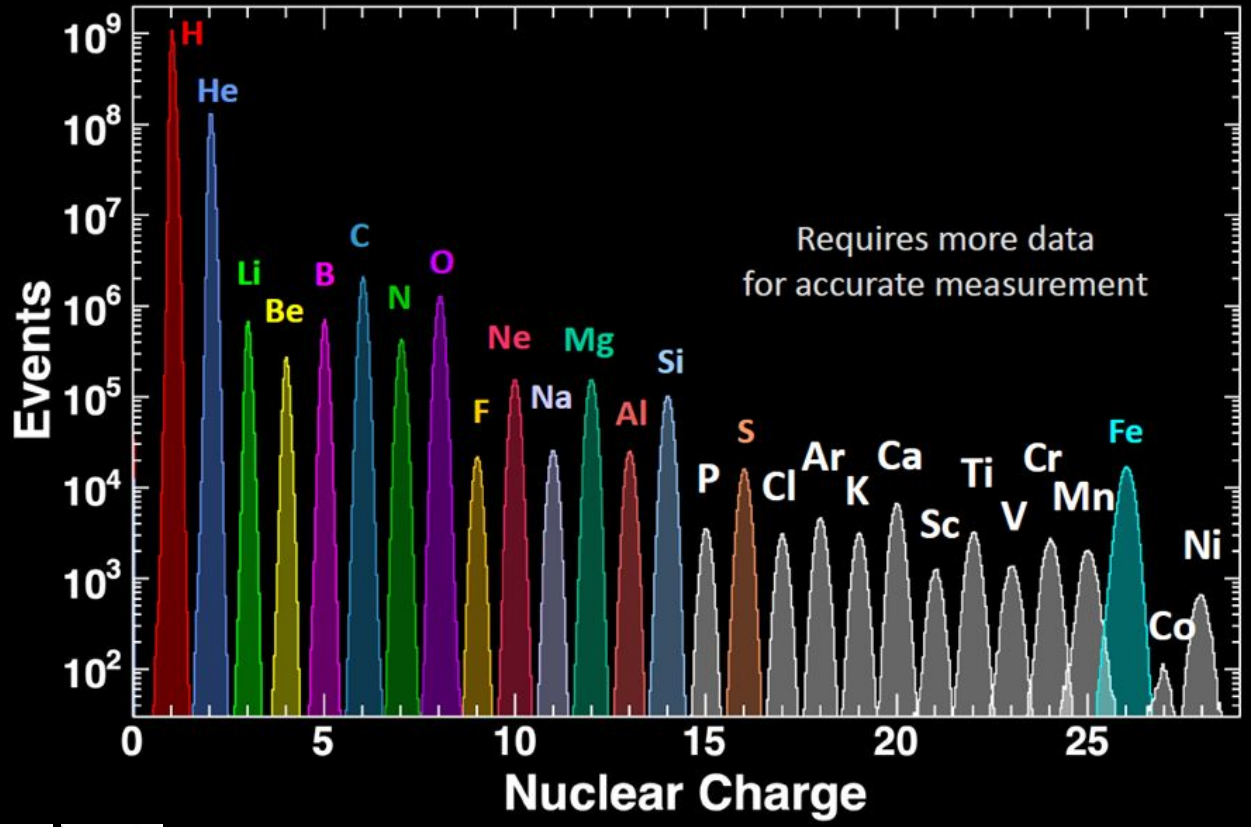
AMS 2025-2030
Acceptance increased to 300%



and projections

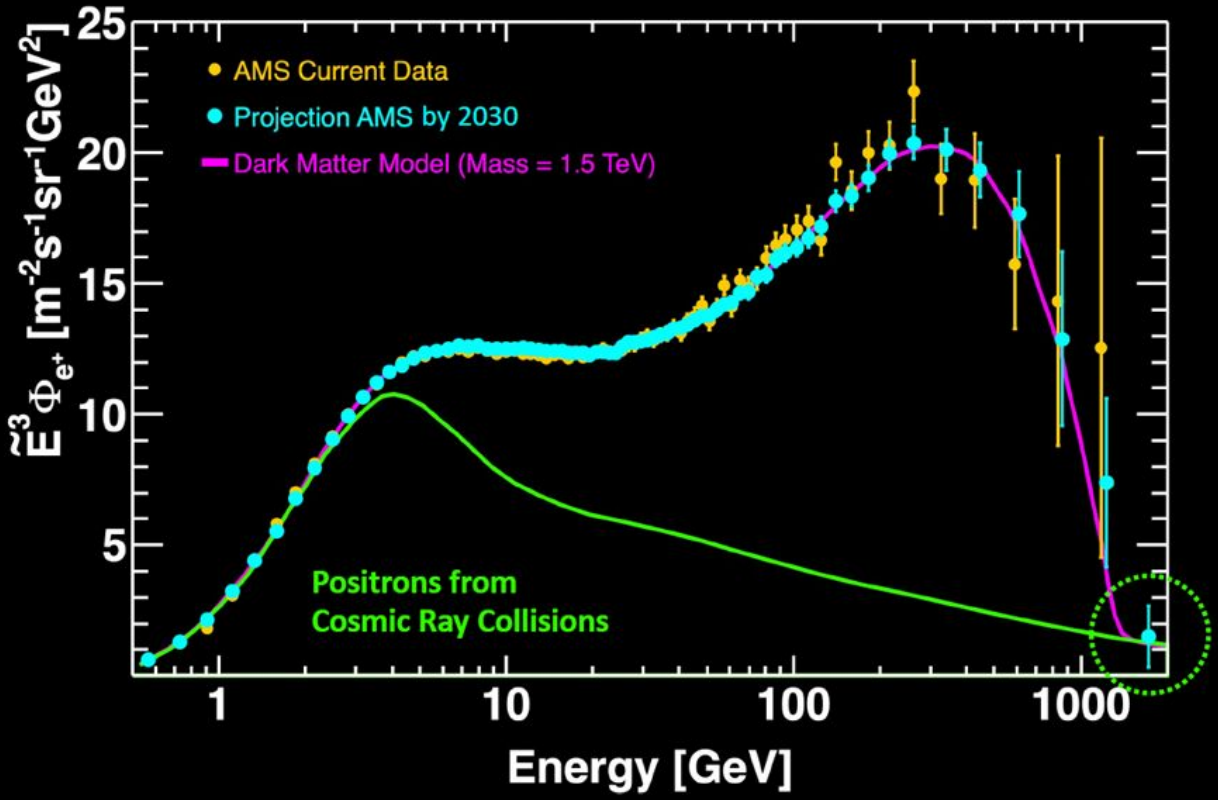
Cosmic Ray Nuclei by 2030

AMS will provide complete and accurate spectra for the
29 elements and provide the foundation for a comprehensive theory of cosmic rays.



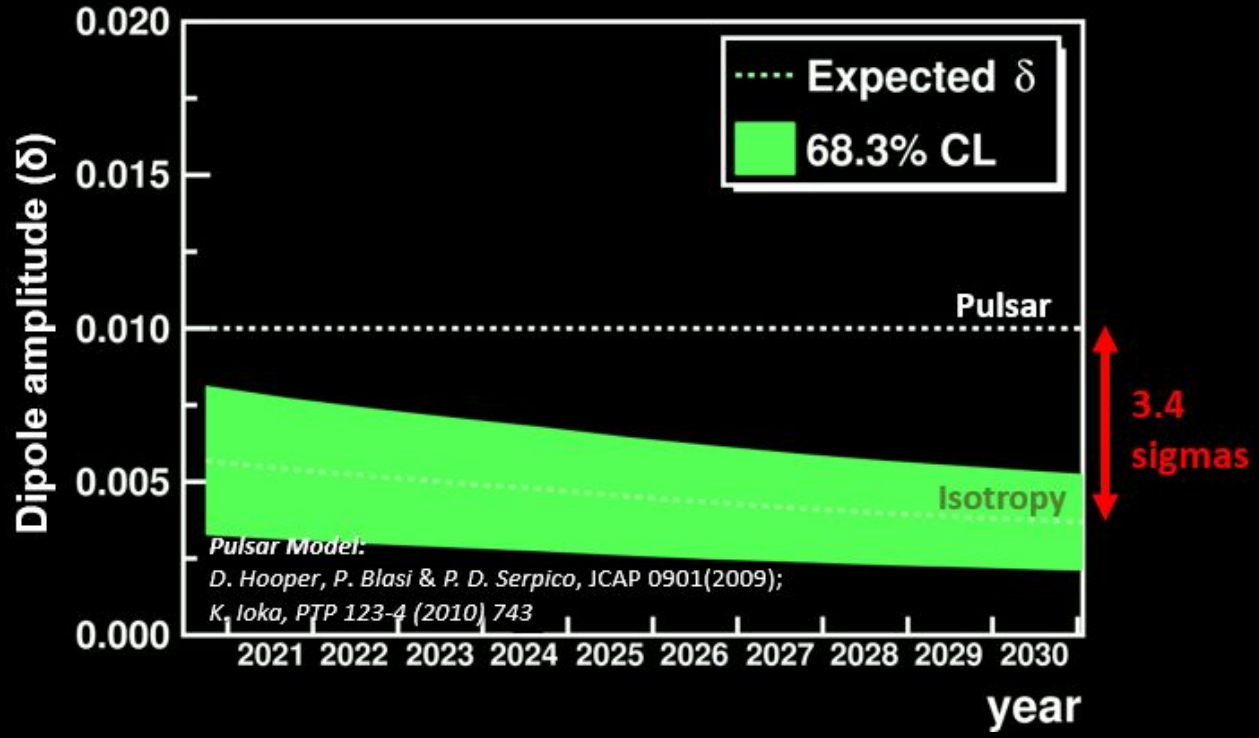
Determination of the Origin of Cosmic Positrons by 2030

AMS will ensure that the measured high energy positron spectrum indeed drops off quickly and, at the highest energies, the positrons only come from cosmic ray collisions as predicted by dark matter models

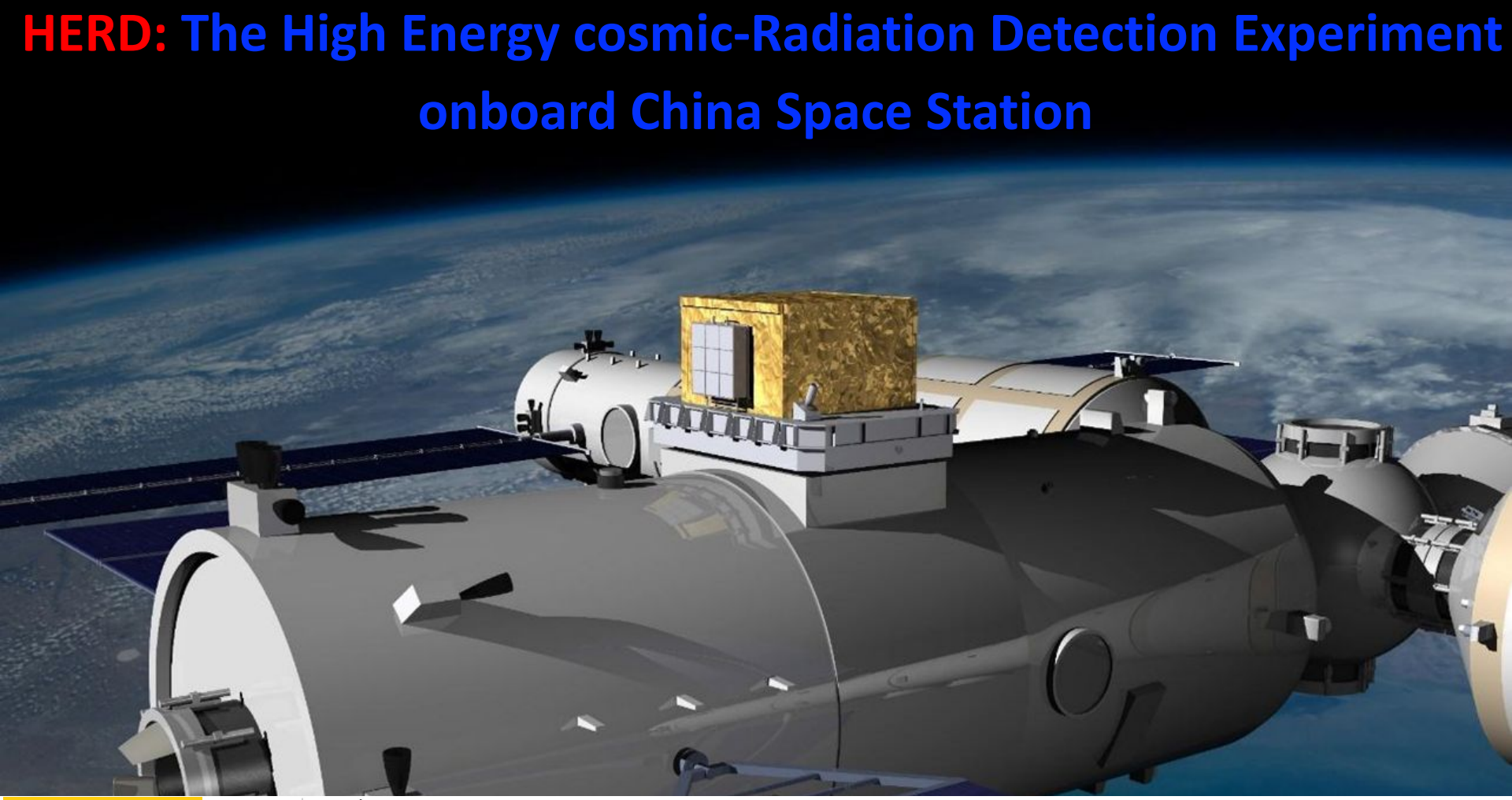


Origin of Cosmic Ray Positrons: Anisotropy

By 2030, AMS will be **sensitive** to anisotropies below the **1% level**, as predicted by **pulsar models** that reproduce the positron excess



HERD: The High Energy cosmic-Radiation Detection Experiment onboard China Space Station

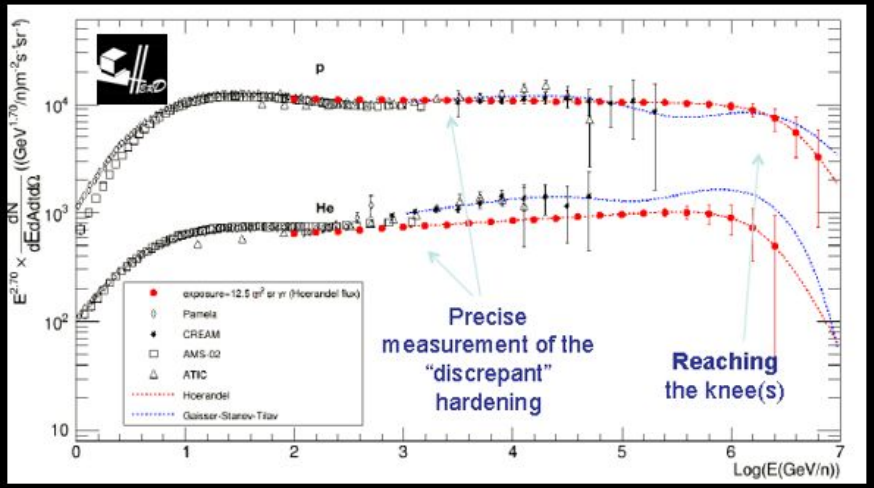


HERD: The High Energy cosmic-Radiation Detection Experiment onboard China Space Station

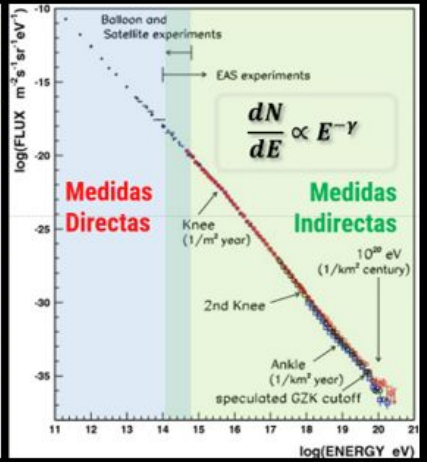
- HERD is a spaceborne cosmic ray detector and gamma ray observatory
- As a flagship scientific experiment, HERD is proposed to be installed at China's Space Station (CSS) in 2027 and operate for a period of 10 years
- HERD is a China-led large international collaboration with key European contributions including Italy, Spain and Switzerland.
- Main Scientific Objectives include the indirect search for dark matter, the extension of the direct measurement of CRs to higher energies and gamma-ray monitoring and full sky survey

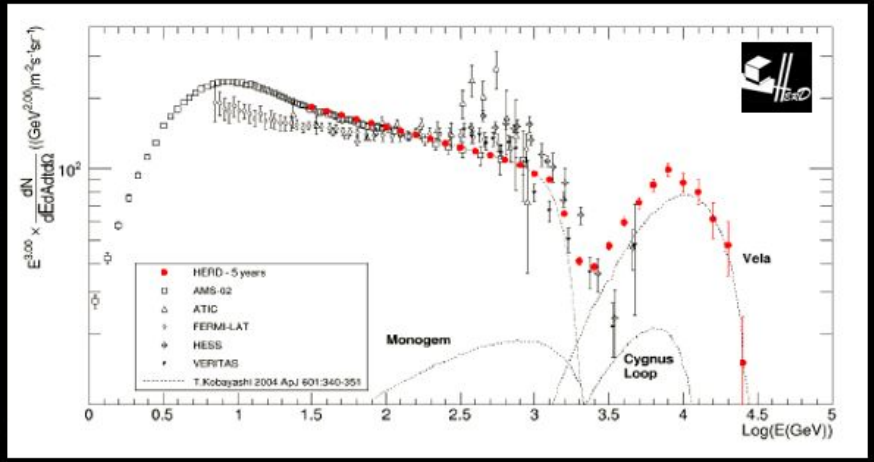
HERD will extend the energy range of direct CR measurements

- Measure the spectra and composition of cosmic rays to 1 PeV
- Search for dark matter signatures in the spectra of high energy electrons and γ-rays up to 100 TeV
- Continuous high energy γ ray sky monitoring



Item	Value
Energy range (e/γ)	10 GeV - 100 TeV (e); 0.5 GeV - 100TeV (γ)
Energy range (CR)	30 GeV - PeV
Angular resolution	<0.6° @1GeV, 0°
Charge measurement	Z=1 to 26
Charge resolution	0.15c.u.@Z=1, 0.2c.u.@Z=6
Energy resolution (e)	<1.5%@200GeV
Energy resolution (p)	<22%@400GeV
e/p separation	>3*10⁵@effi. 90% 100GeV e-
G.F. (e)	>3m²sr @200 GeV
G.F. (p)	>2m²sr @100 TeV





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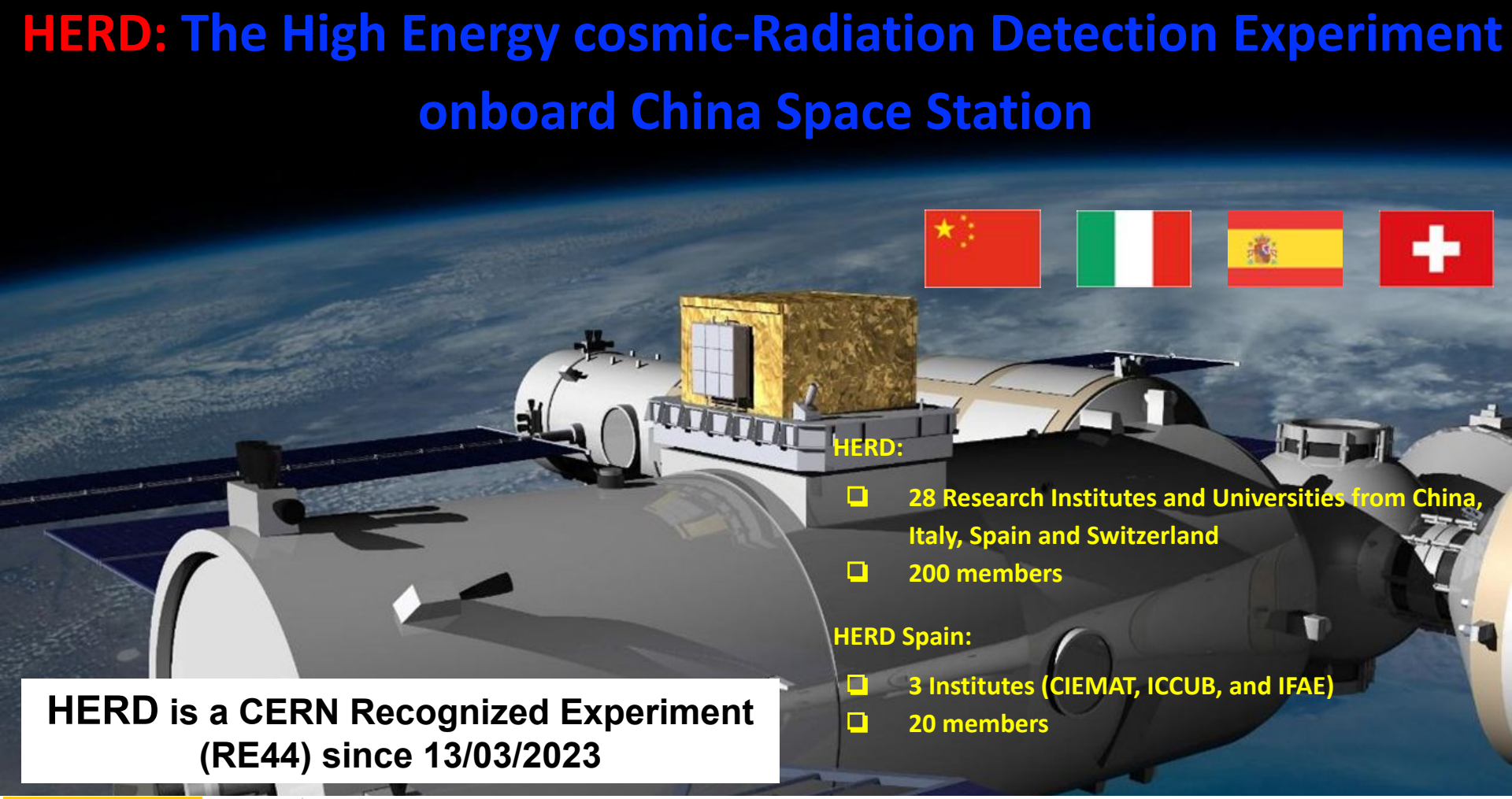


HERD:

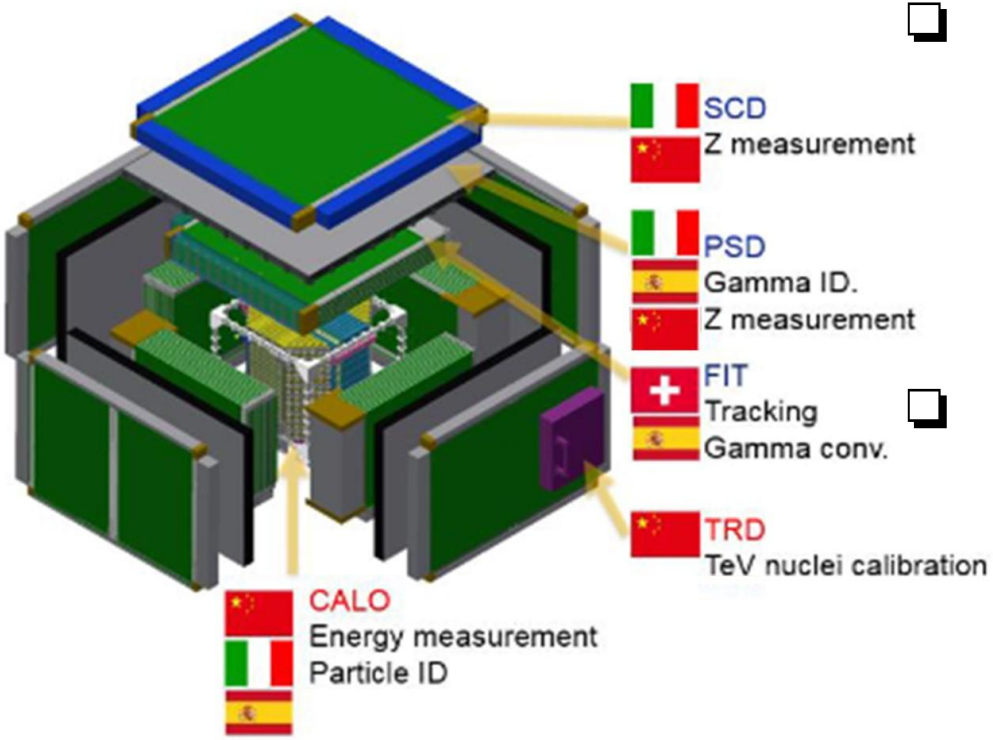
- 28 Research Institutes and Universities from China, Italy, Spain and Switzerland
- 200 members

HERD Spain:

- 3 Institutes (CIEMAT, ICCUB, and IFAE)
- 20 members

HERD is a CERN Recognized Experiment (RE44) since 13/03/2023

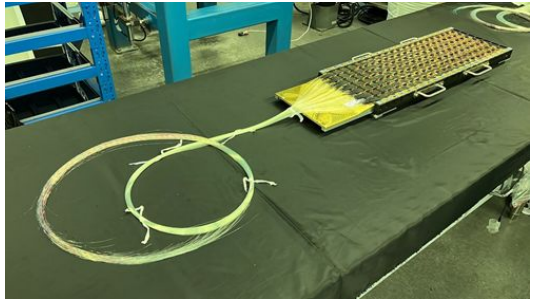
HERD: The High Energy cosmic-Radiation Detection Experiment onboard China Space Station



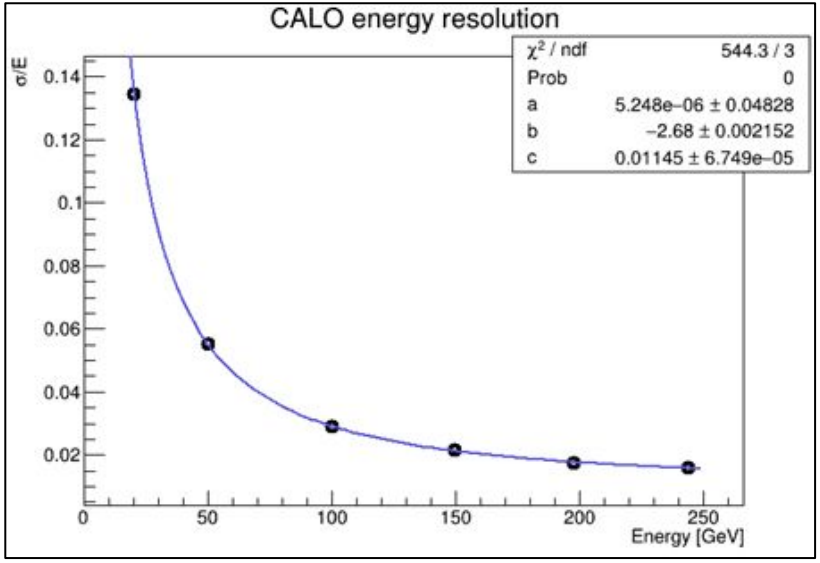
- CIEMAT joined HERD collaboration in 2017 as a natural continuation of its R&D activities within the Calocube project in collaboration with INFN

- CIEMAT leads the development of the **readout and trigger electronics** of the photodiode system of the 7,500 LYSO crystal **CALO** and co-coordinates the **HERD trigger** WG**.**

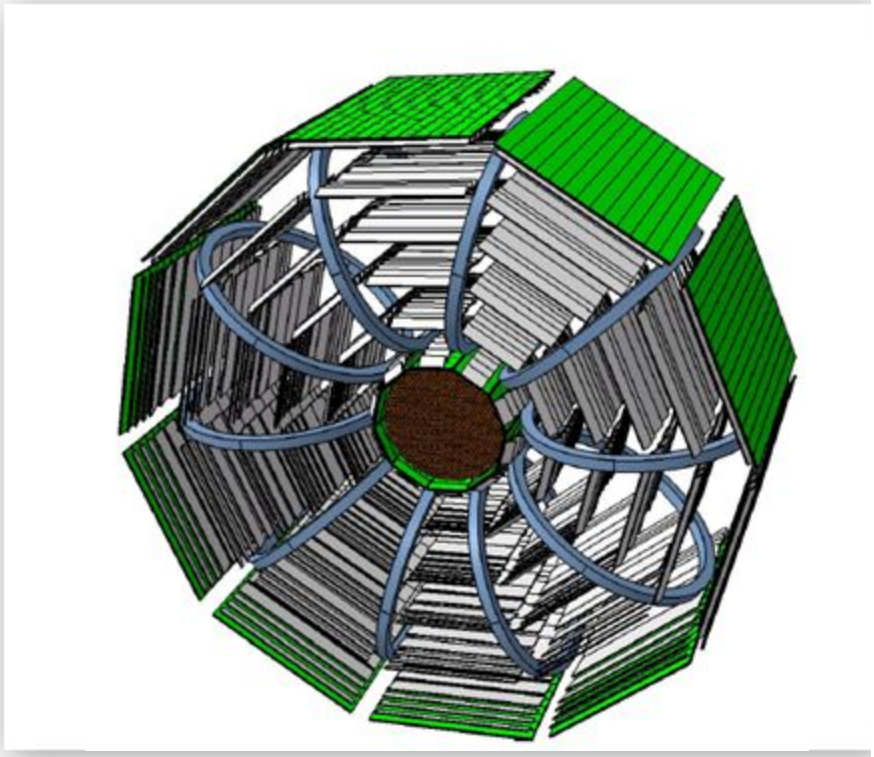
- HERD CALO-PD prototypes have been extensively tested at CERN PS and SPS
- Preliminary analysis of the 1,000 LYSO crystal prototype tests at SPS 09/2023 provides electron resolution consistent with specification

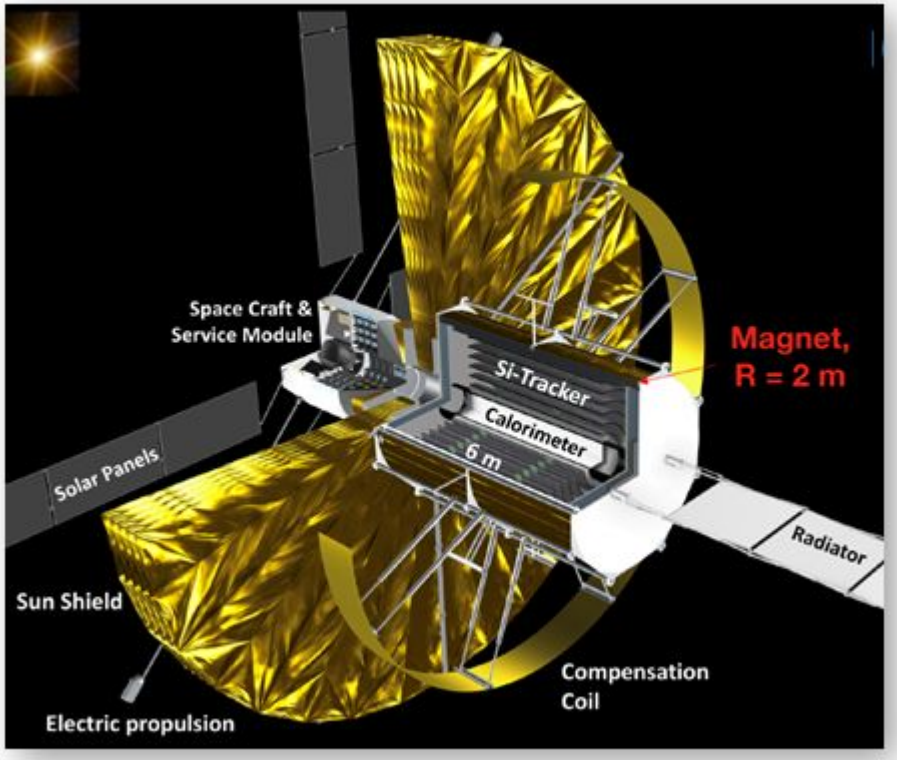


- A 2,500 crystal QM prototype will be tested in 2025

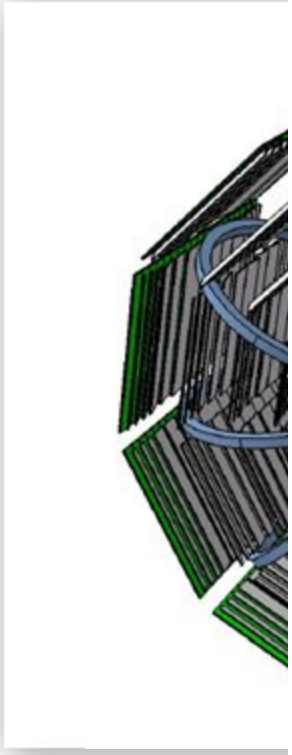


ALADInO y AMS-100: *next(-to-next) generation of cosmic ray magnetic spectrometers in space*

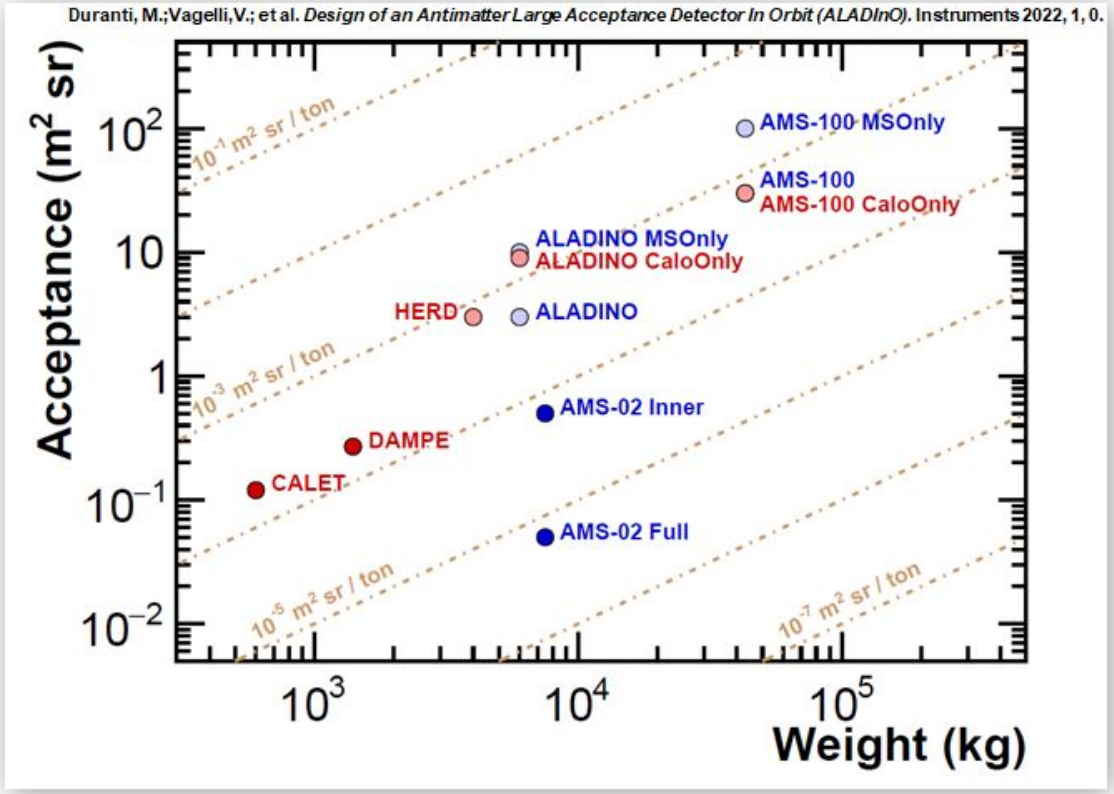


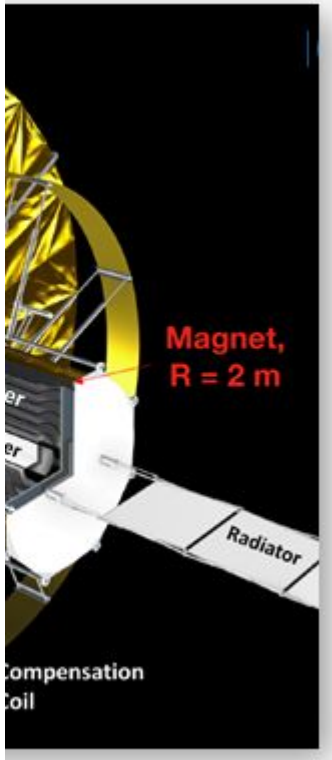


ALADInO y AMS-100: *next(-to-next) generation of cosmic ray magnetic s*

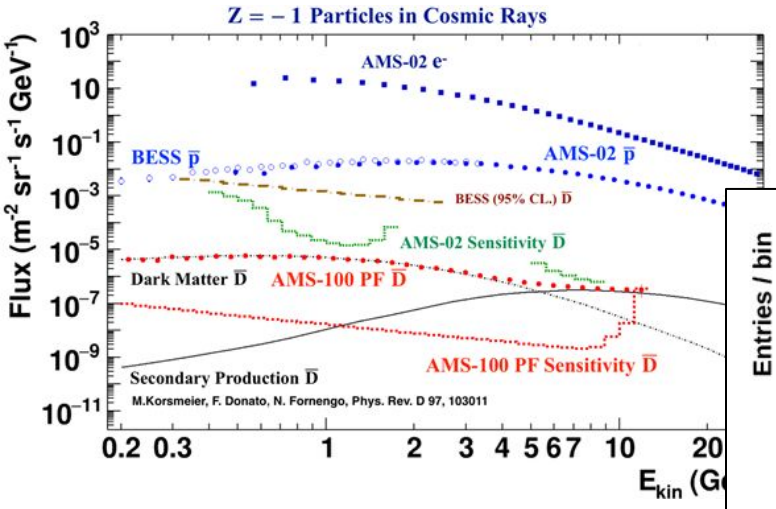


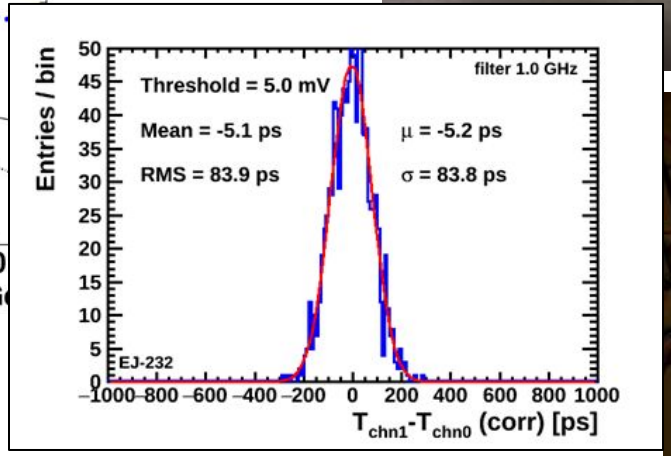
Duranti, M.;Vagelli,V.; et al. *Design of an Antimatter Large Acceptance Detector In Orbit (ALADInO).* Instruments 2022, 1, 0.

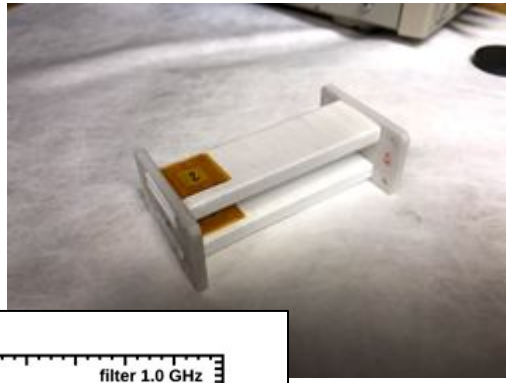


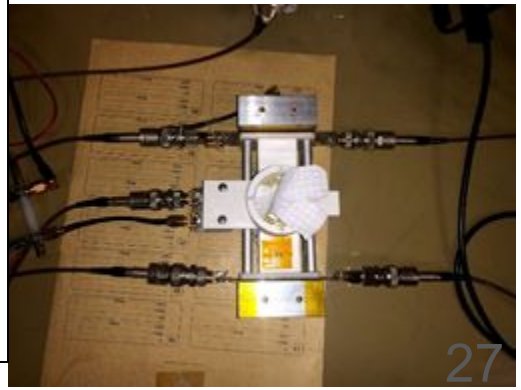


- Precise ToF system for isotope identification in a wide energy range
- Development of a ToF based on SiPM with better time resolution than current state-of-the-art ground based detectors (PANDA, MEG II)
- First results already provide a 20% improvement (~42 ps)









Current Responsibilities in Collaborations

AMS:

Collaboration Deputy PI
Member Finance Review Committee
RICH Operations Coordinator
RICH Calibration and Offline Software Coordinator

HERD:

Member Executive Board
Member Institute Leader Board
CALO PD Readout Electronics Coordinator
Trigger Working Group co-Coordinator

Summary & Challenges

Precision measurements of cosmic rays provide a unique tool for discovery of new phenomena in the cosmos

CIEMAT participates in the state-of-the-art active and proposed experiments

Group needs to face two short-term challenges:

- **Personnel Reinforcement:**
  - 2 leading physicists (J. Berdugo, C. Mañá) retirement in 2024.
  - Lack of staff personnel in the engineering group (engineers and technicians)
- **HERD Project Programmatics:**
  - Agency level agreement with China needs to be cleared. The newly created Spanish Space Agency (AEE) is expected to take leading role

The success of the AMS and HERD will pave the path to the future (AMS-100, ALADInO) ambitious missions for the next decades