IFAE 2024
Firenze,
3-5 aprile 2024

Risultati Recenti e Futuri Esperimenti nel campo della Fisica delle AstroParticelle

Francesco Dimiccoli
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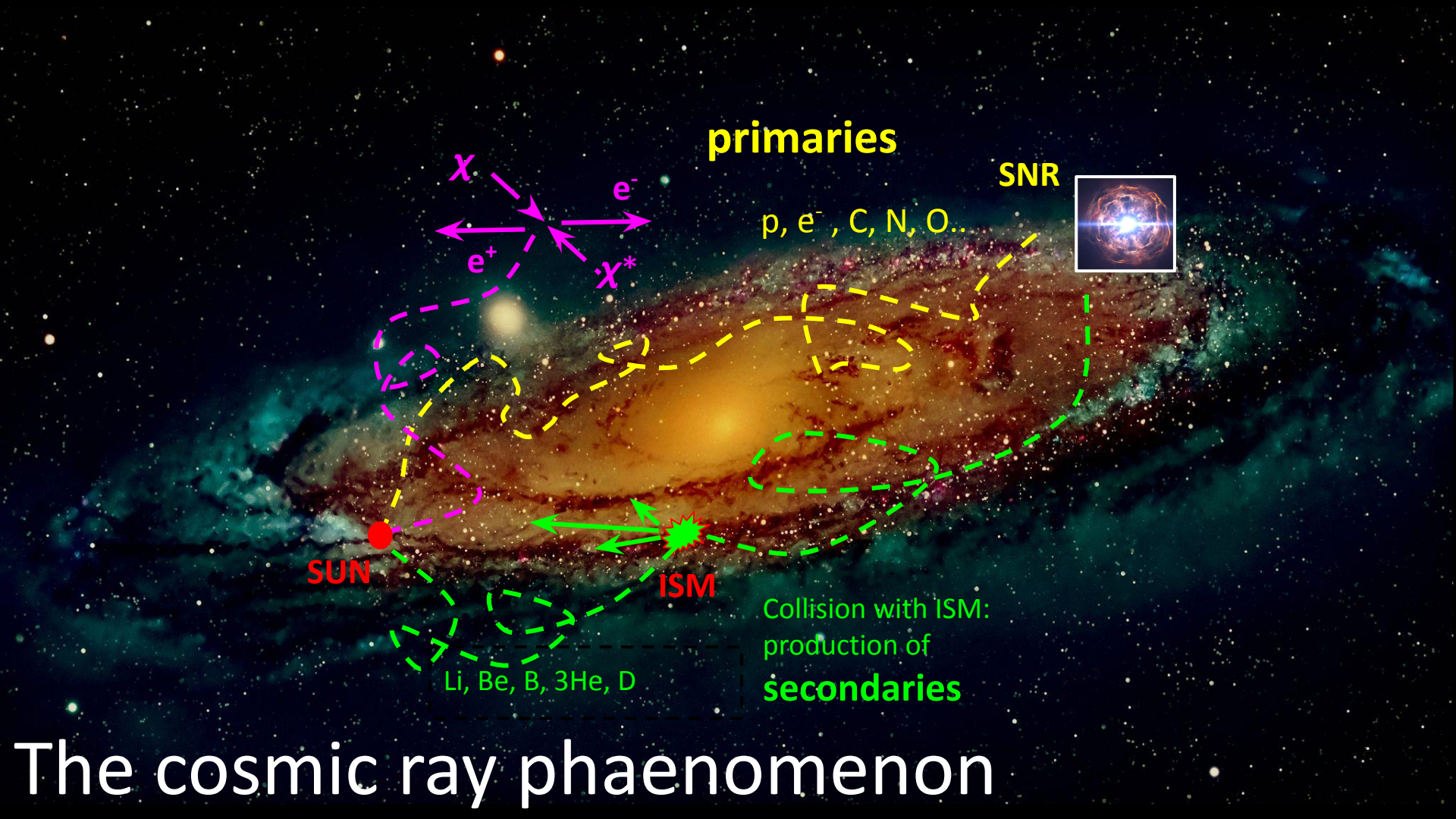
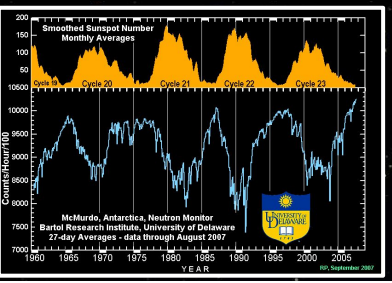
INFN-TIFPA

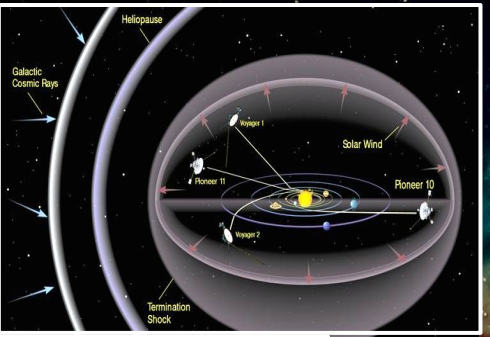


The cosmic ray phaenomenon



$$\frac{\partial \psi_i(\vec{r},p,t)}{\partial t} = q(\vec{r},p,t,) + \vec{\nabla}\cdot(D_{xx}\vec{\nabla}\psi_i - \vec{V}\psi_i) + \frac{\partial}{\partial p}p^2 D_{pp}\frac{\partial}{\partial p}\frac{1}{p^2}\psi_i - \frac{\partial}{\partial p}[\dot{p}\psi_i] - \frac{p}{3}(\vec{\nabla}\cdot\vec{V})\psi_i] - (\frac{1}{\tau_f} - \frac{1}{\tau_r})\psi_i$$

Source Term | Diffusion | Energy loss | Convection | Nucl. proc.

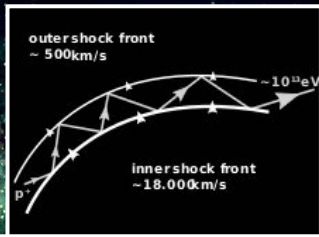


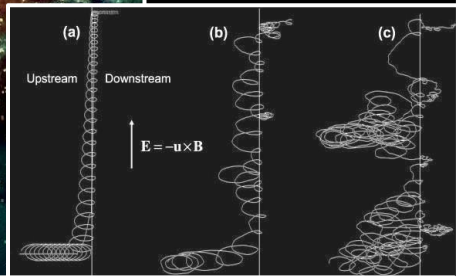
χ e^- e^+ χ^*

SNR

p, e^-, C, N, O..

Shock acceleration in SNR





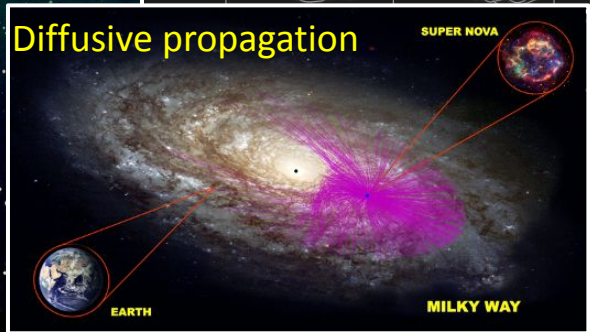
SUN

ISM

Li, Be, B, 3He, D

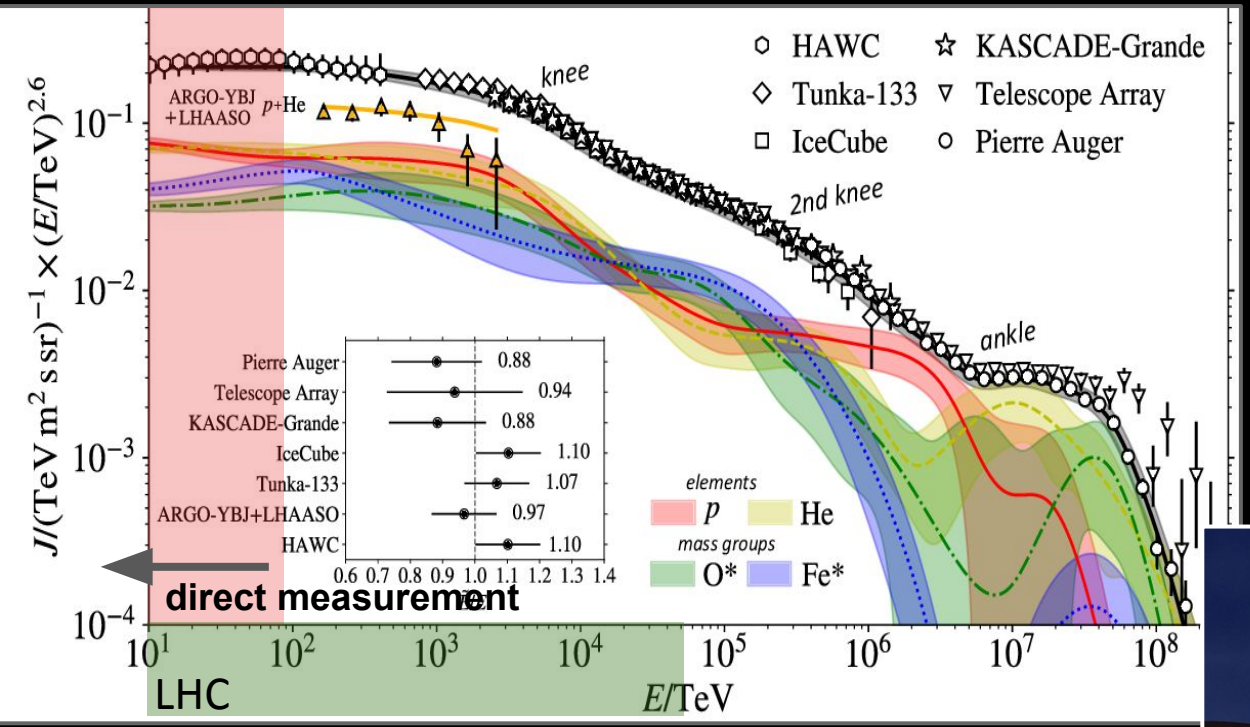
Collision with ISM: production of **secondaries**

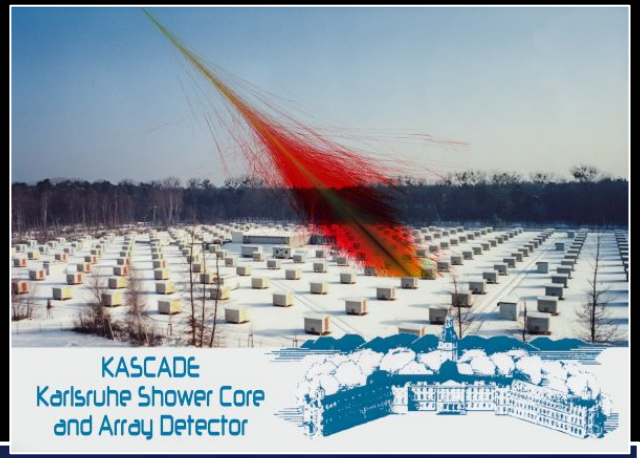
Diffusive propagation



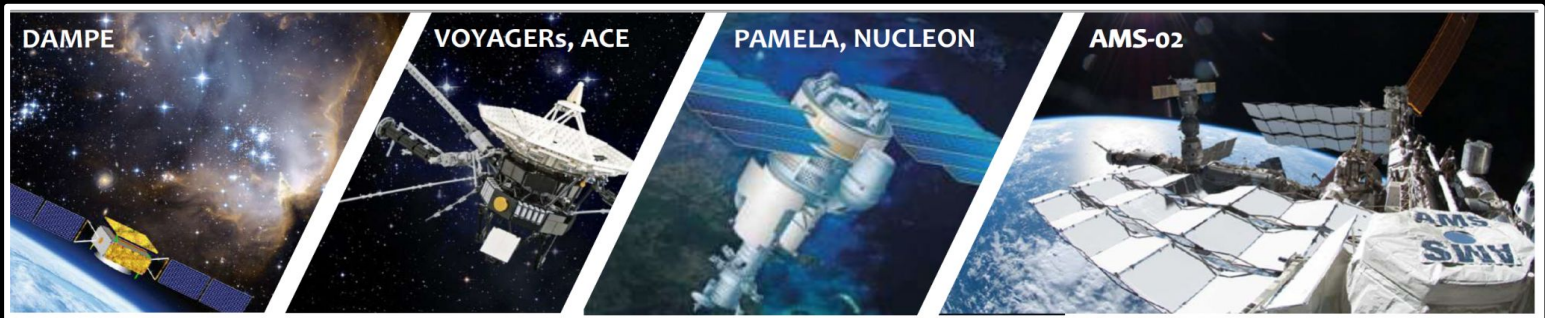
The cosmic ray phaenomenon

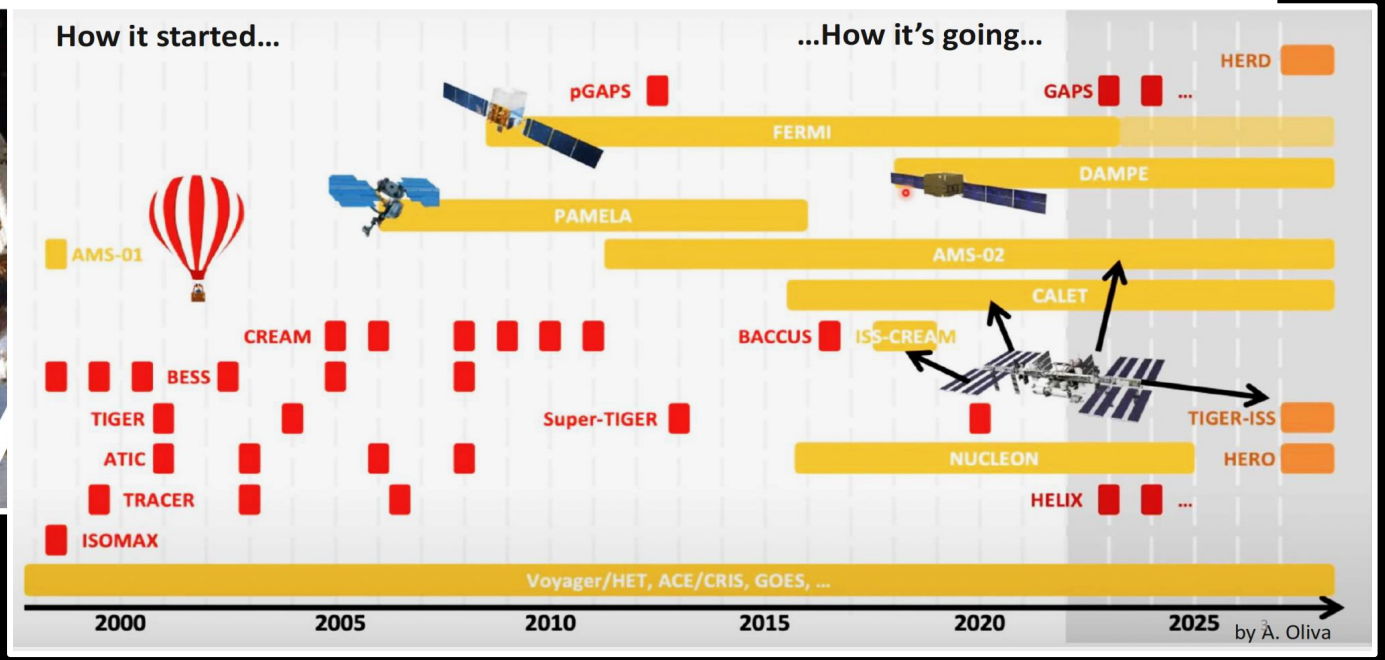
The full energy spectrum (indirect measurements)





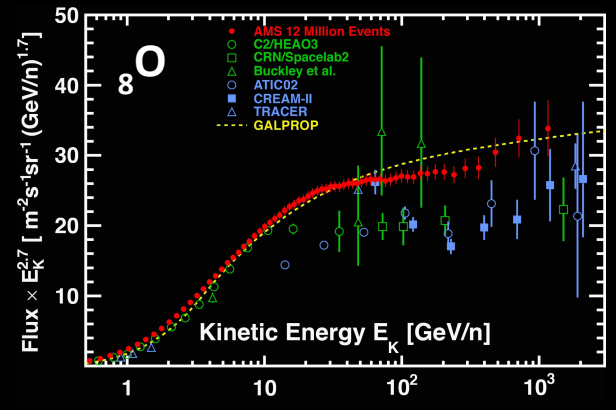
- highest energies accessible only from indirect measurements on ground

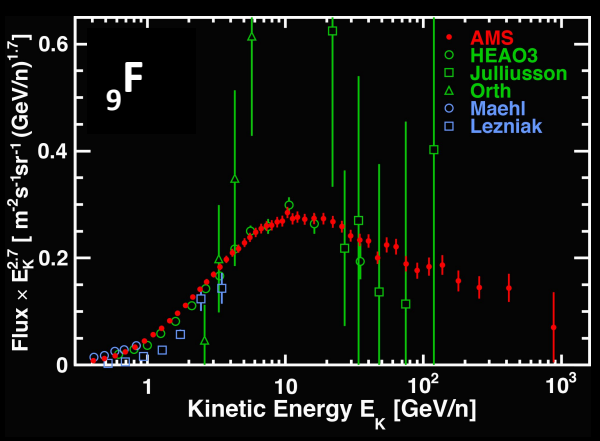


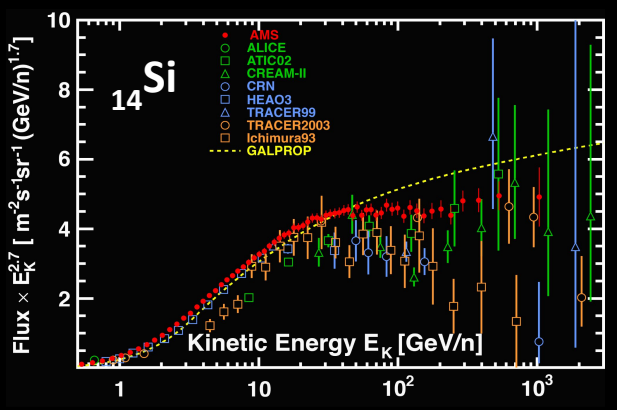


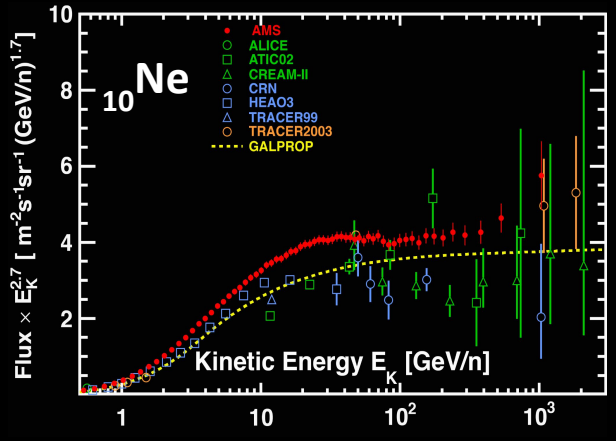
Direct measurements from space

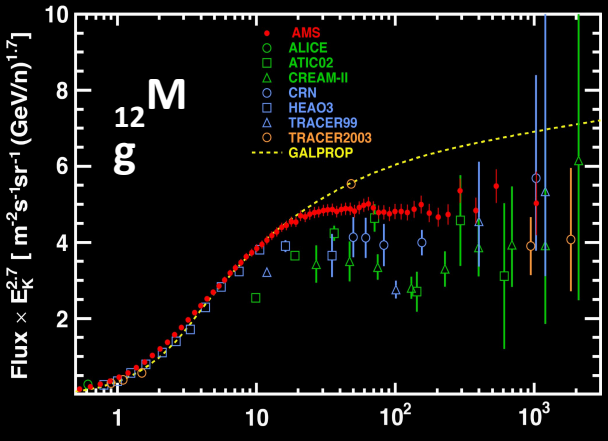
Entering the High precision era in CR measurements: AMS 02

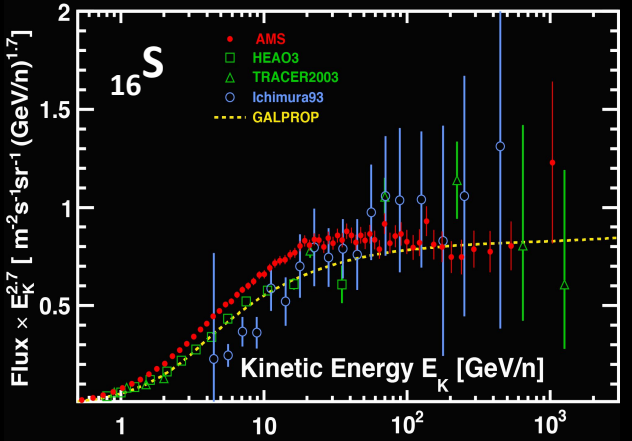










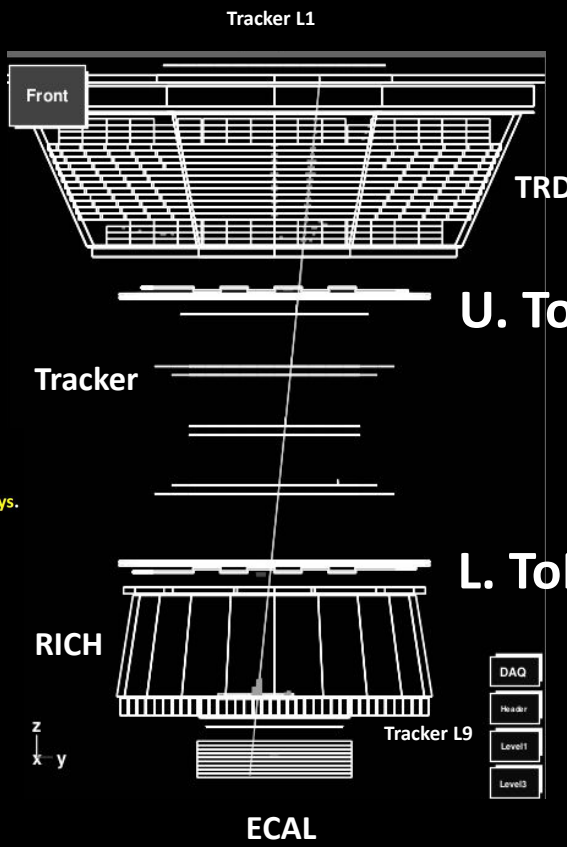


AMS - 02

AMS was installed on ISS in May 2011.

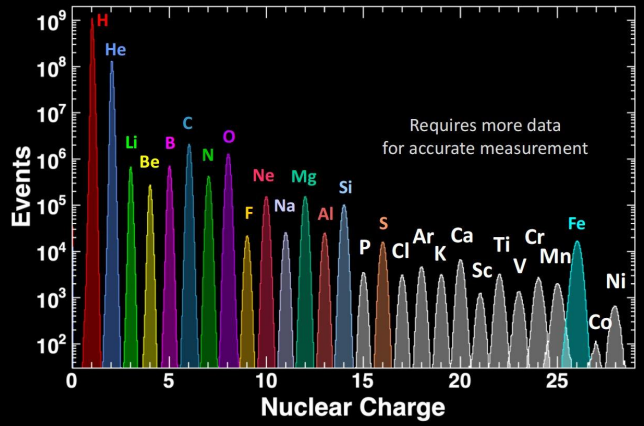
An unique TeV precision, accelerator-type spectrometer in space

0.45 m^2 sr T>20Yrs MDR~TeV

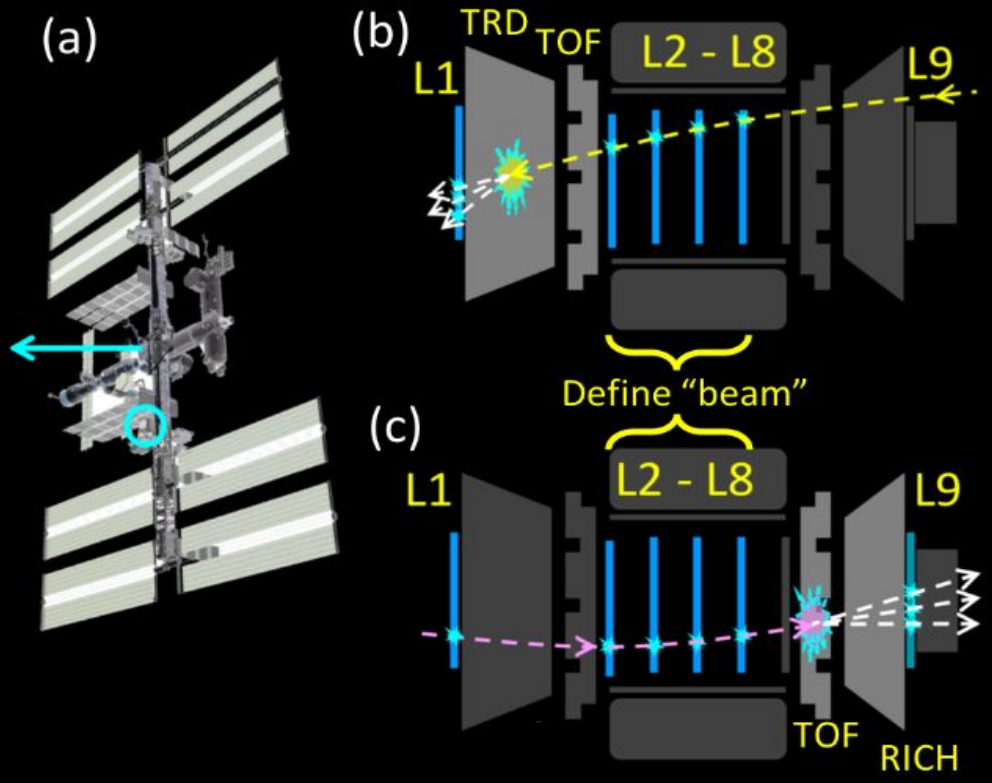


AMS determination of Cosmic Ray Nuclei

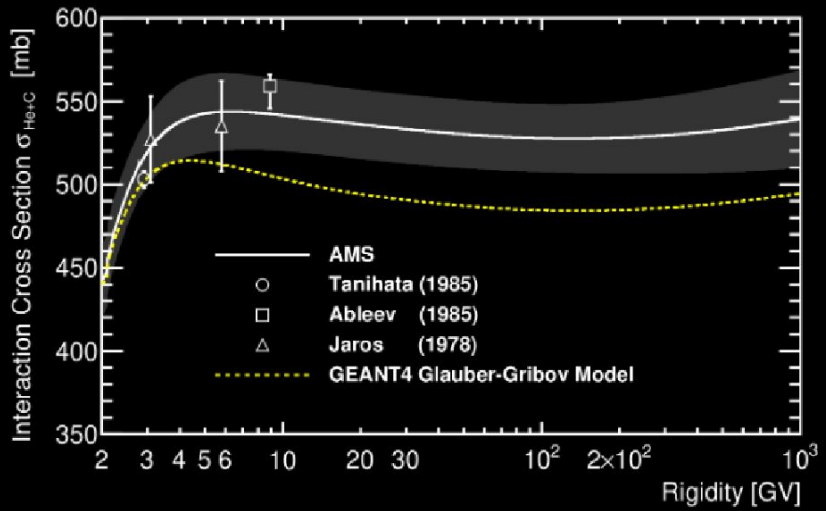
AMS will provide complete and accurate spectra for the 29 elements and provide the foundation for a comprehensive theory of cosmic rays.



An extreme example of "Multipurpose": Cross section measurements from space(!)

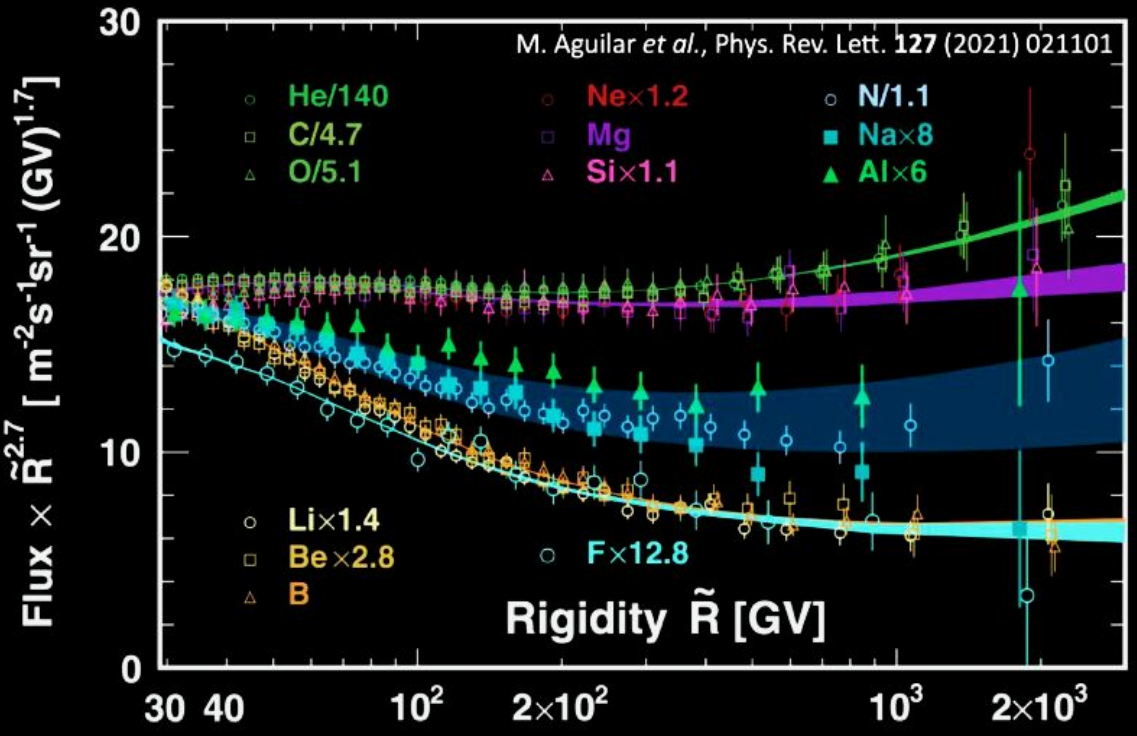


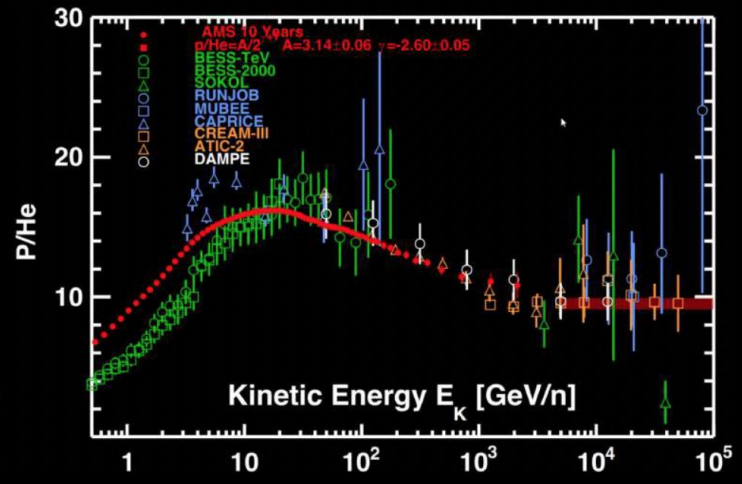
Q. Yan, V. Choutko, A. Oliva, and M. Paniccia, Nuclear Physics A, 996, 121712 (2020)]



p(He) + C -> hadrons

A complex picture is emerging



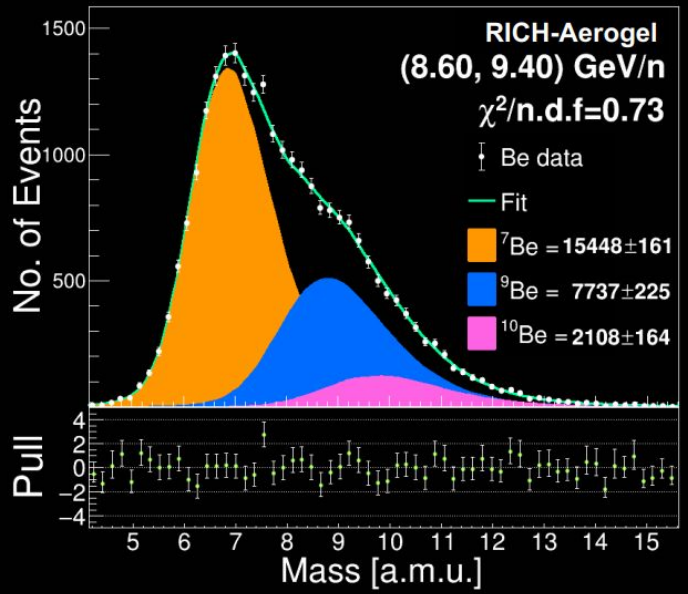


- p/He Anomaly: **ratio is decreasing**!
- Two classes of primaries
  - light (He, C, O)
  - heavy (Ne, Mg, Si)
- Mixed: N, Na, Al prim + sec with different composition
- Iron and Ni: same class of light primaries

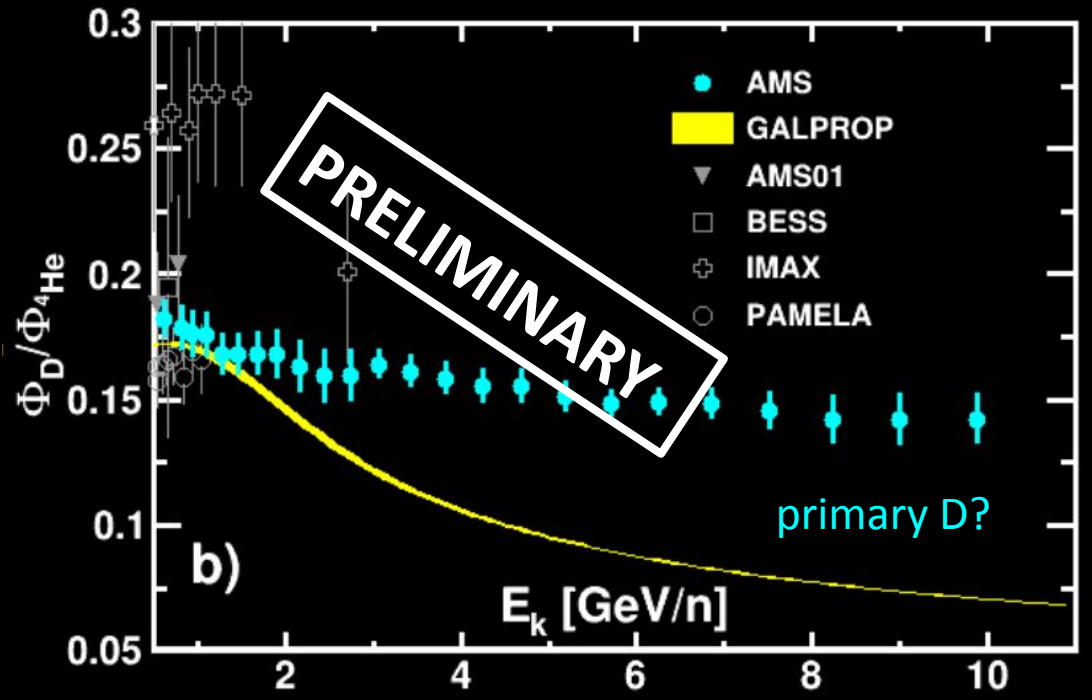
… Hints for non-universality in propagation for Z>1 nuclei?

Surprises From Isotopes

- m = p/βγ
- p from tracker
- β from TOF, RICH
- Fit on data

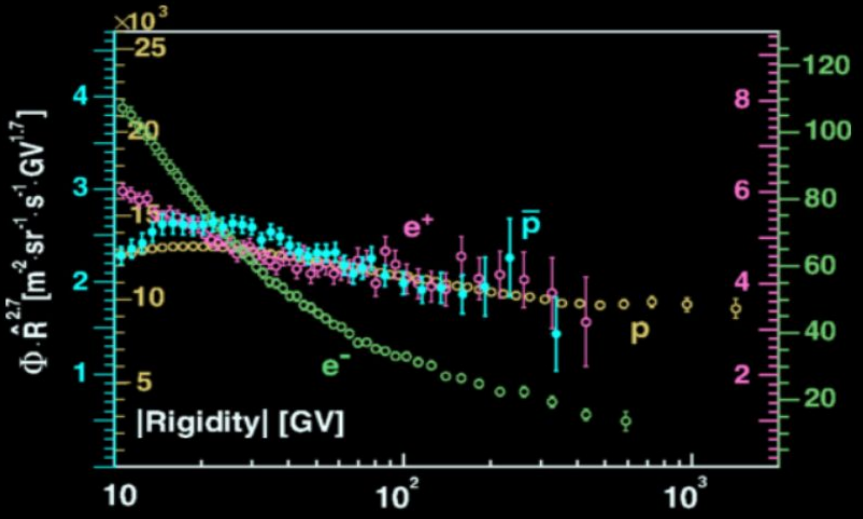


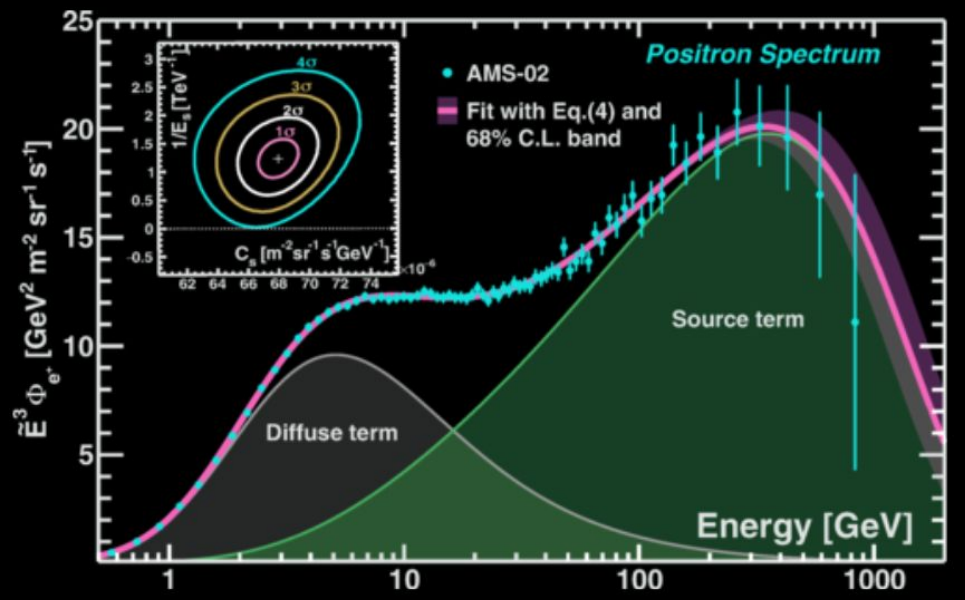
D is expected to be completely secondary (Fragm. of 4He)

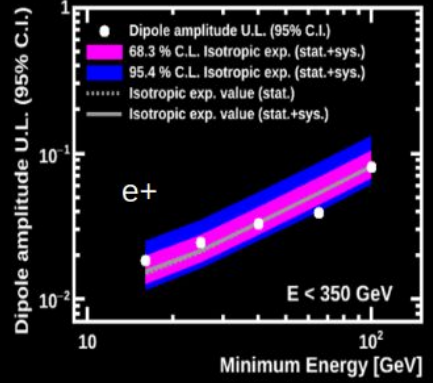


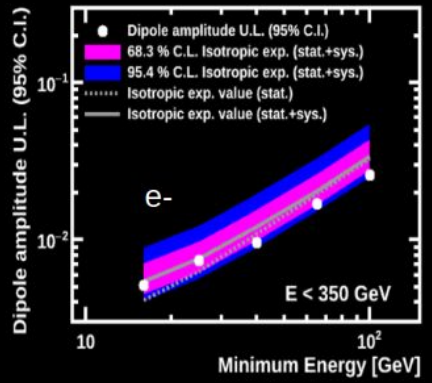
Antimatter in CR: hints for DM?

- **positrons:**
  - excess measured by many experiments, compatible with a source term
  - Nearby sources or DM annihil.?
- AntiP: same spectral index as e+ and p

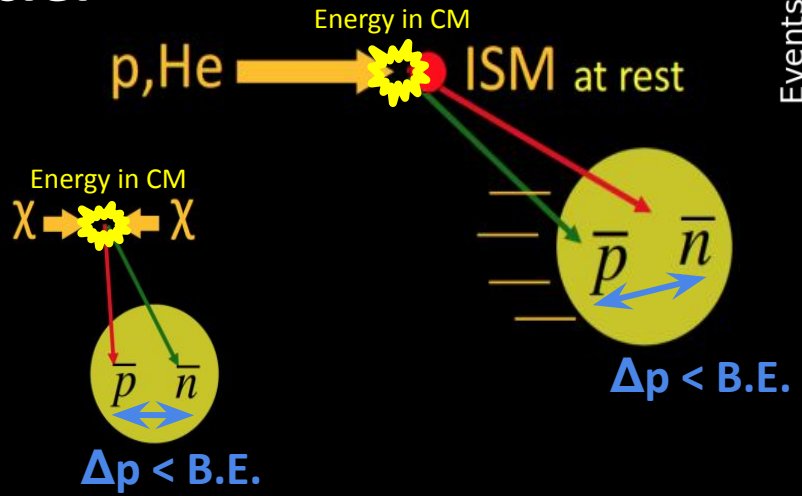


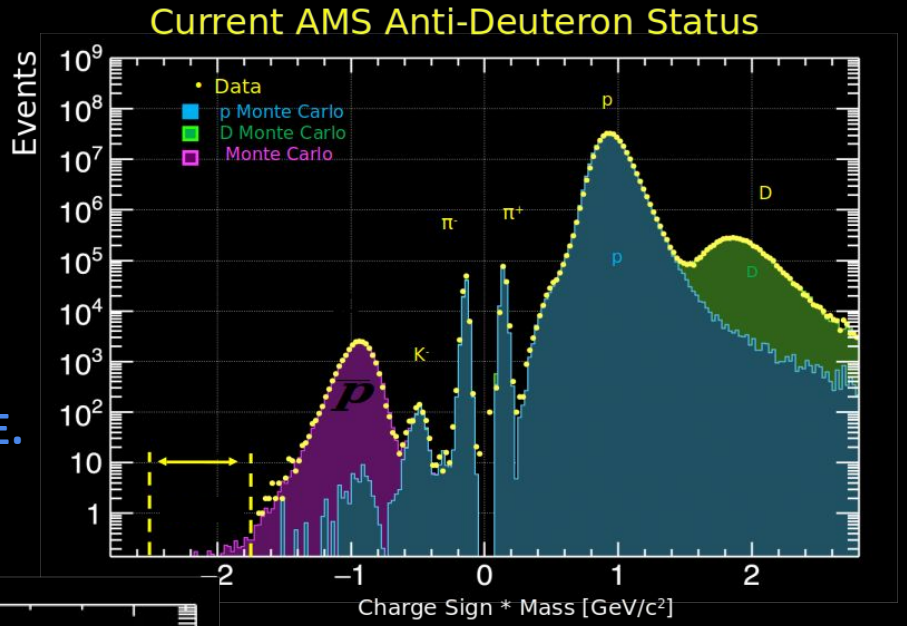


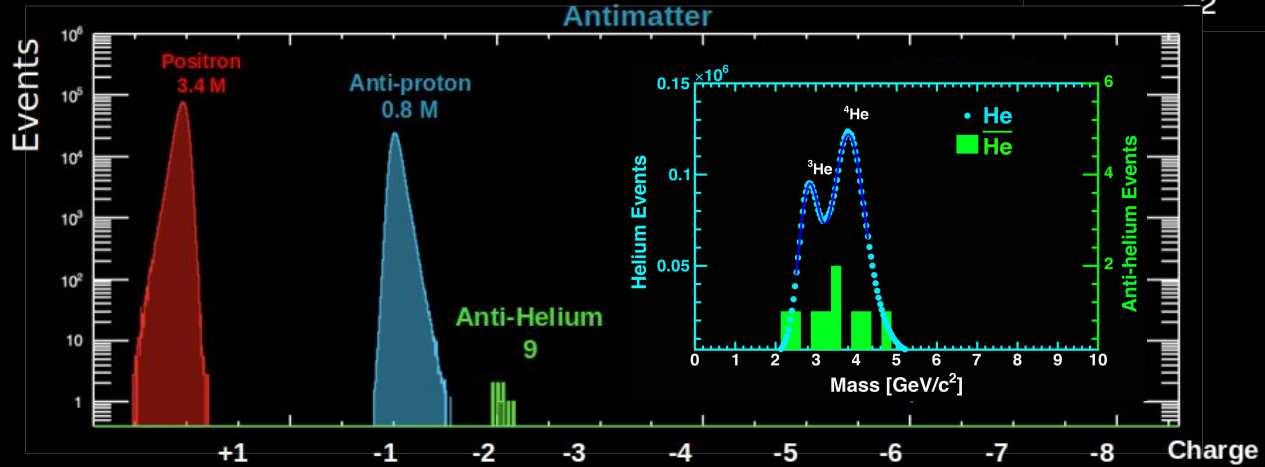




AntiNuclei in CR



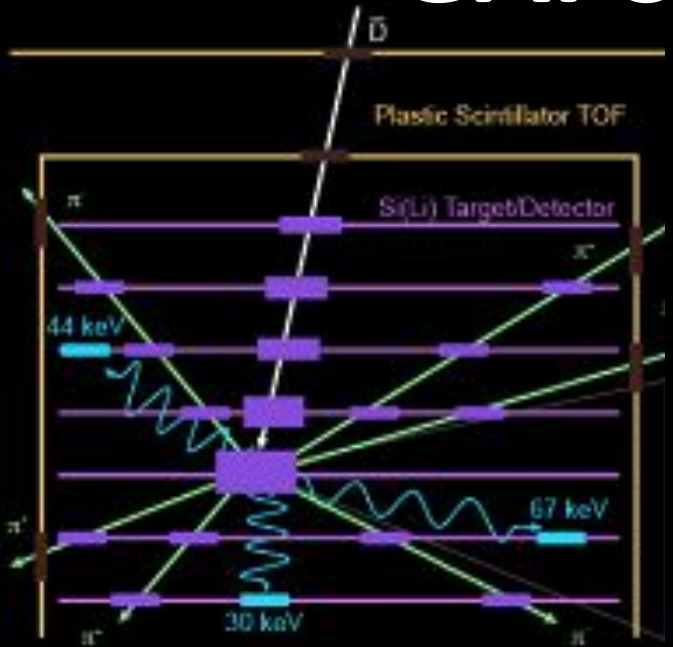




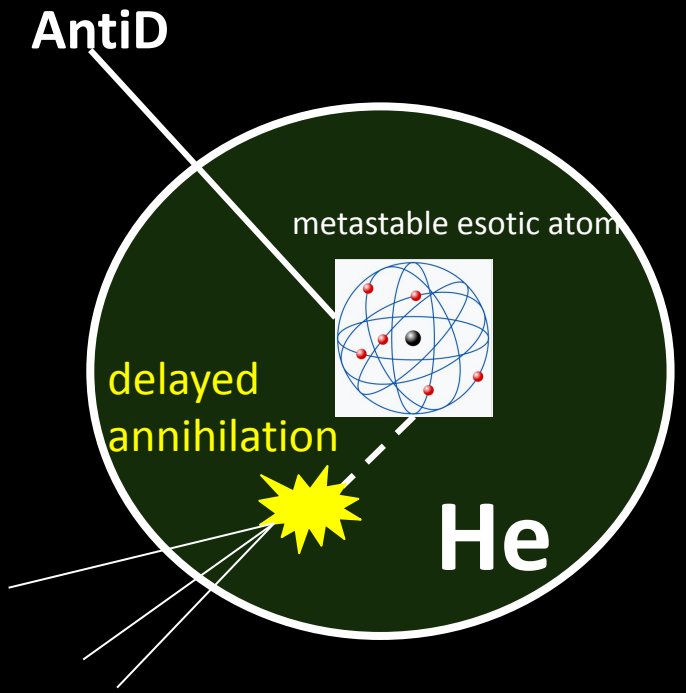
- AntiD: Never detected so far in CR
- Hints of DM: (AntiD and 3He)
- 4He are completely unexpected

AntiDeuton dedicated future experiments

GAPS



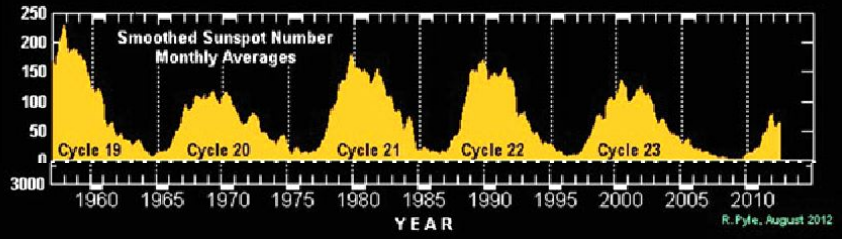
ADHD (PHeSCAMI)



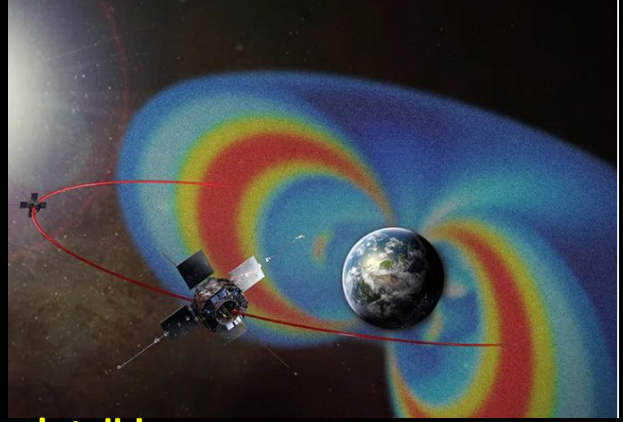
See Francesco's and Gregorio's Posters!

The Low Energy sector

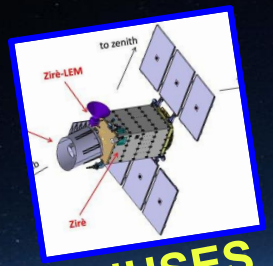
Dominated by local magnetic fields



- Heliospere
- Magnetosphere



See Pierpaolo's talk!



NUSES

See Fatma's talk!

CSES

See Riccardo's talk!

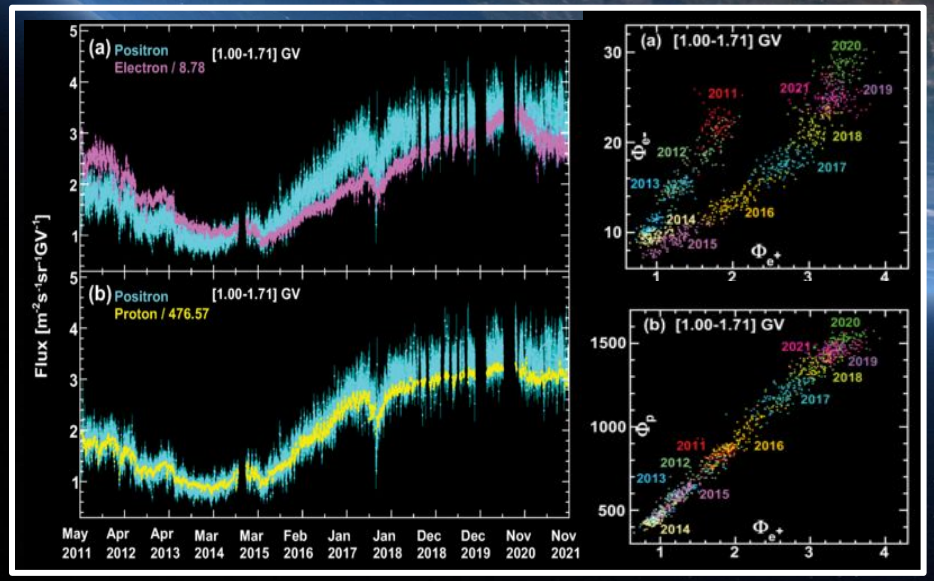
Space Rider

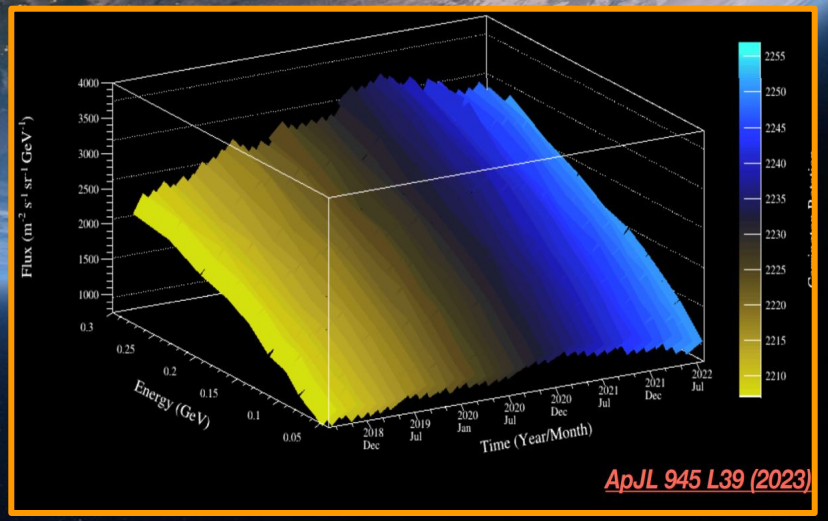
AMS-02

- **TERZINA** Optical Cherenkov
- **ZIRE' (LEM):** SiPM: e-,p, Nuclei up to O(100 MeV)

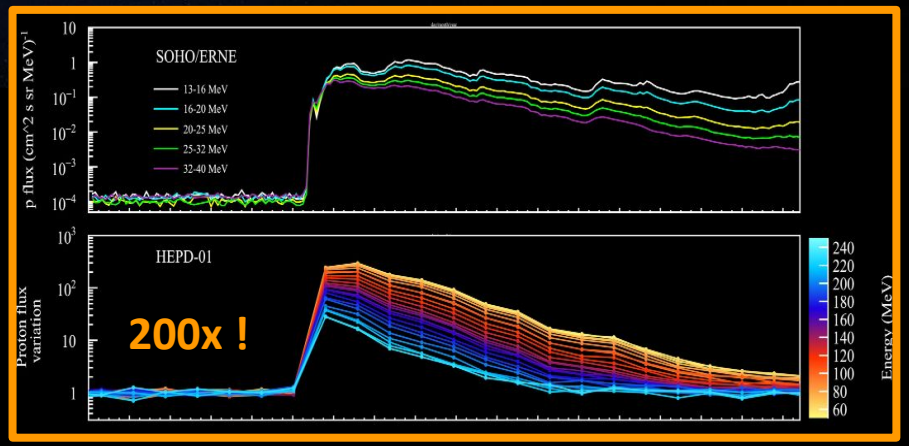
- Multisat mission
- **HEPD (1/2):** Calo + silicon Tracker
- HEPP

- Europe's first reusable space vehicle
- SPARKLE!

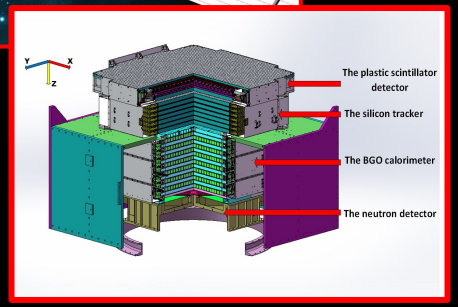




- **Time dependence of CR fluxes**
  - Test of universality in Heliospheric propagation
- **Space weather**
  - High stat. measurements allow to monitor solar activity
  - **SEP, GRB**
- **Trapped particles: Study of Van Allen Belt -> correlation with seismology?**

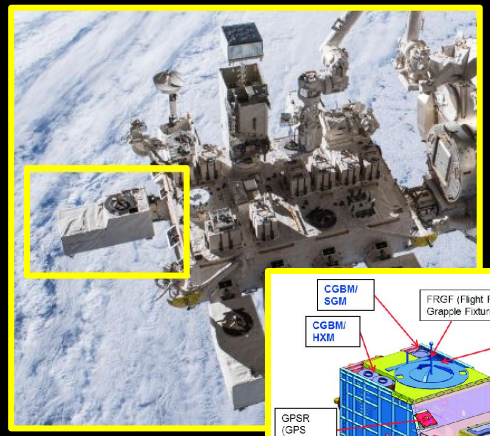


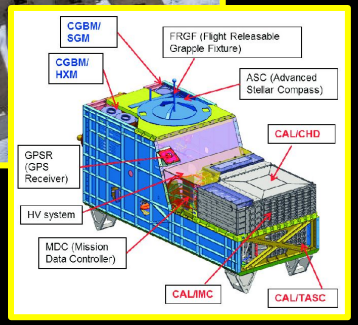
Beyond AMS-02: Multi-TeV, the calorimetric approach



DAMPE

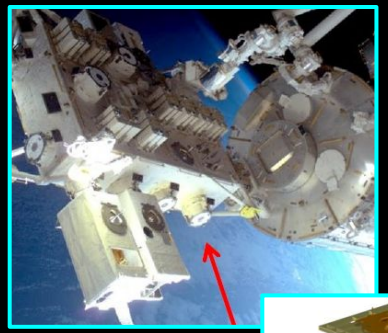
- plastic scintillator detector (PSD) -> Trigger
- Silicon-tungsten Tracking (STK)-> photon conversion & tracking
- 31 X0 BGO calorimeter, measuring energy of couples
- neutron detector (Boron-doped PS) to increase e+/p discrimin.

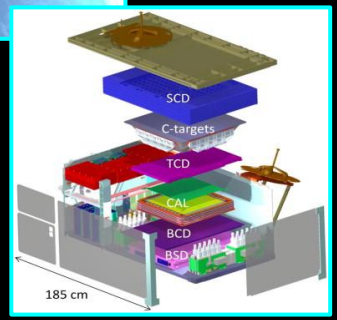




CALET

- plastic scintillator -> Trigger
- 3 X0 sampling calorimeter
- 27 X0 PWO homogeneous calorimeter
- CALET Gamma-ray Burst Monitor gamma from 7 keV to 20 MeV



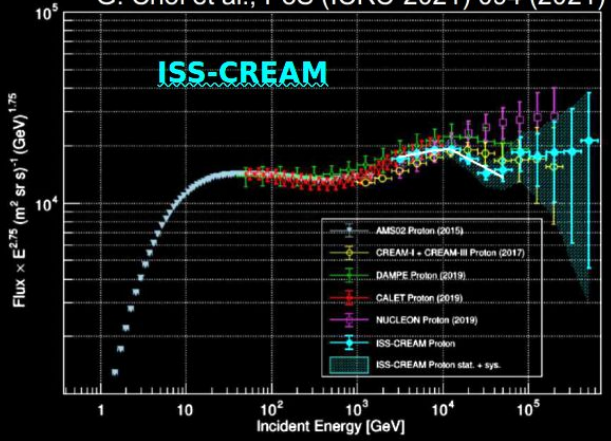


ISS-CREAM

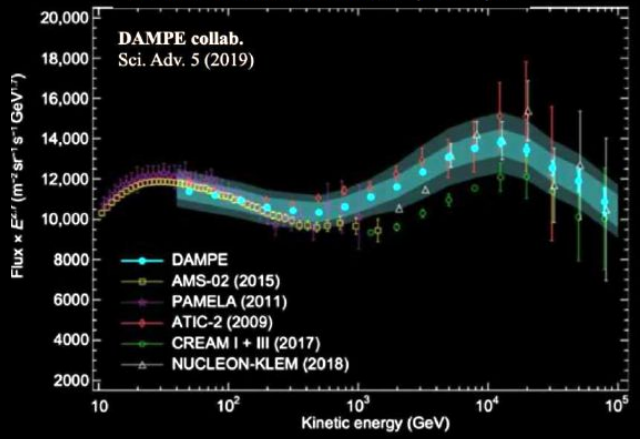
- SCD (Silicon Charge Detector)
- Carbon targets to induce interactions + plastic scintill. & photodiodes
- Boronated scintillators for n

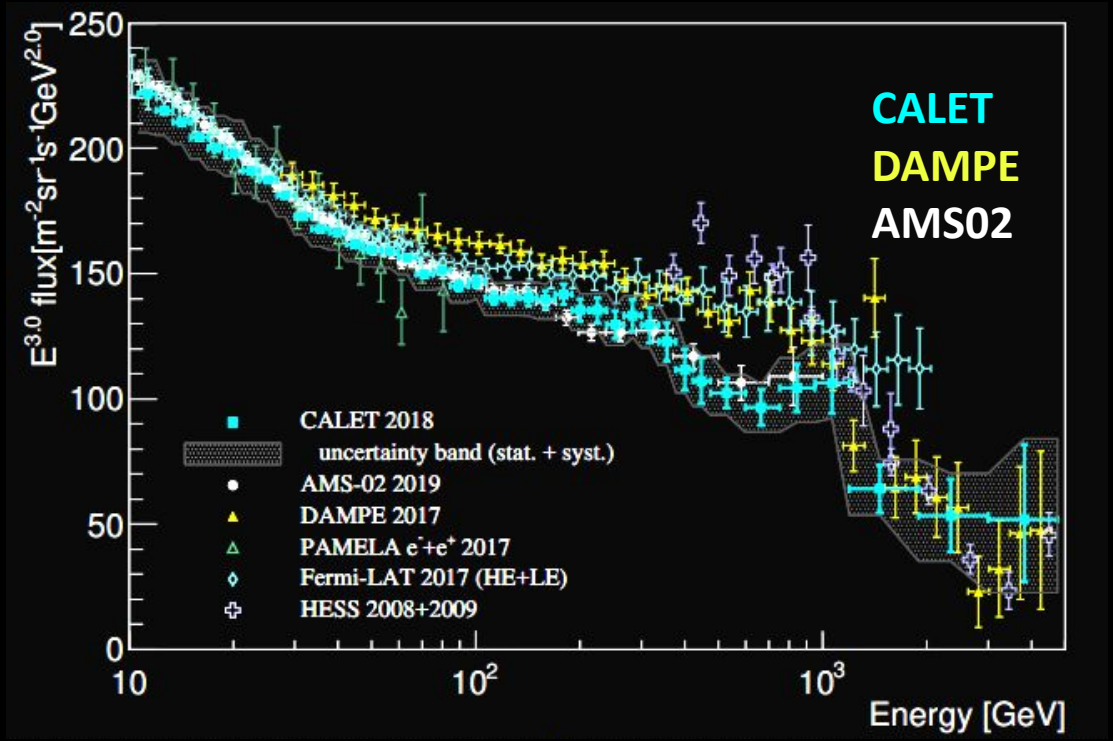
Multi-TeV measurements: p, He, “all-electron”

G. Choi et al., PoS (ICRC-2021) 094 (2021)



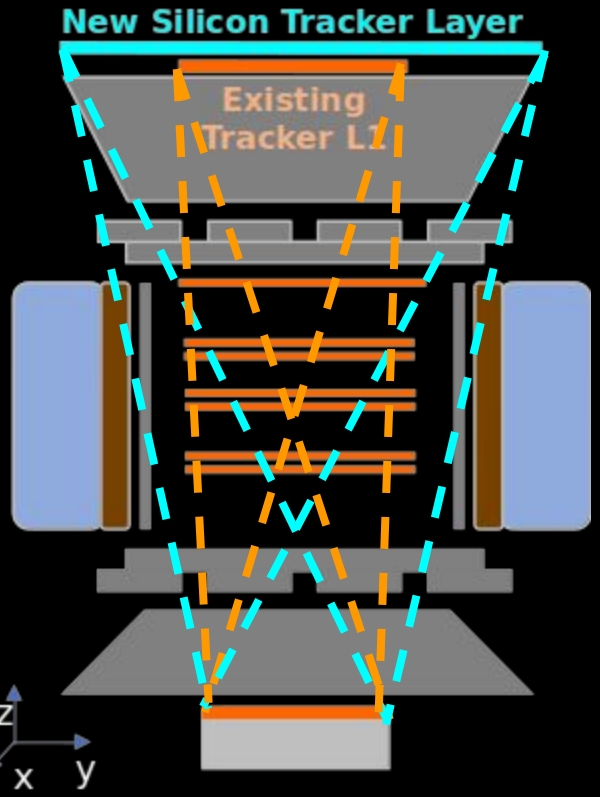
Q. An et al., Sci. Adv. 5 (2019) 9





New bump-like structure confirmed by ISS-CREAM and DAMPE

Beyond AMS-02 in another sense: Upgrade

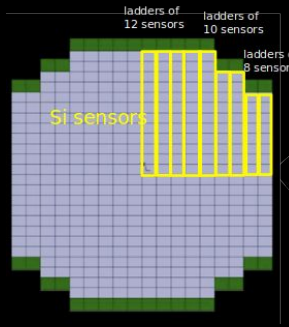


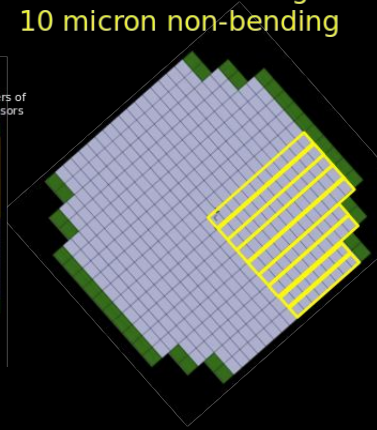
- 1 new layer, 2 planes (45° X-Y)
- Silicon microstrip sensors (27um pitch)
- New (10% reso) Z measurement ABOVE detector -> Fragmentation eval.
- Factor 3x acceptance (10 yrs -> 30 yrs)
- ¼ plane Qualif. Model
  - Integration
  - Vibration Test
  - Performance

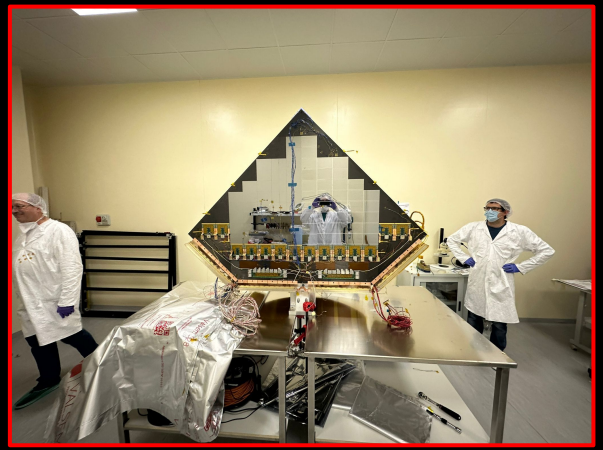
See Yaozu's talk!

L0-Y
bending direction
7 micron

L0-U
rotated 45°
10 micron bending
10 micron non-bending

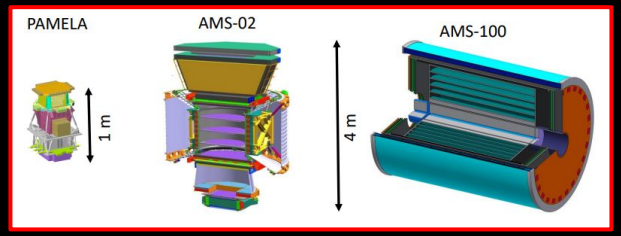


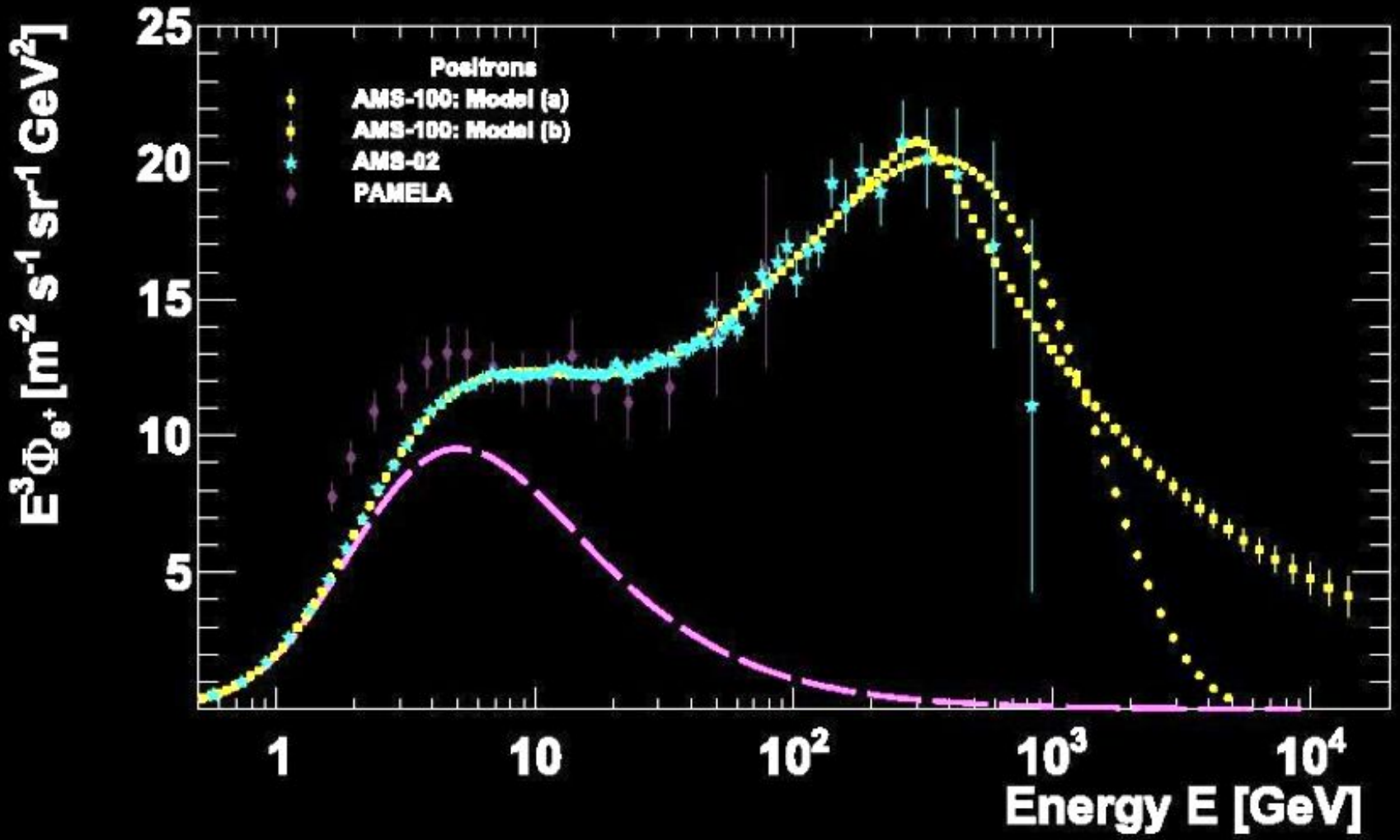




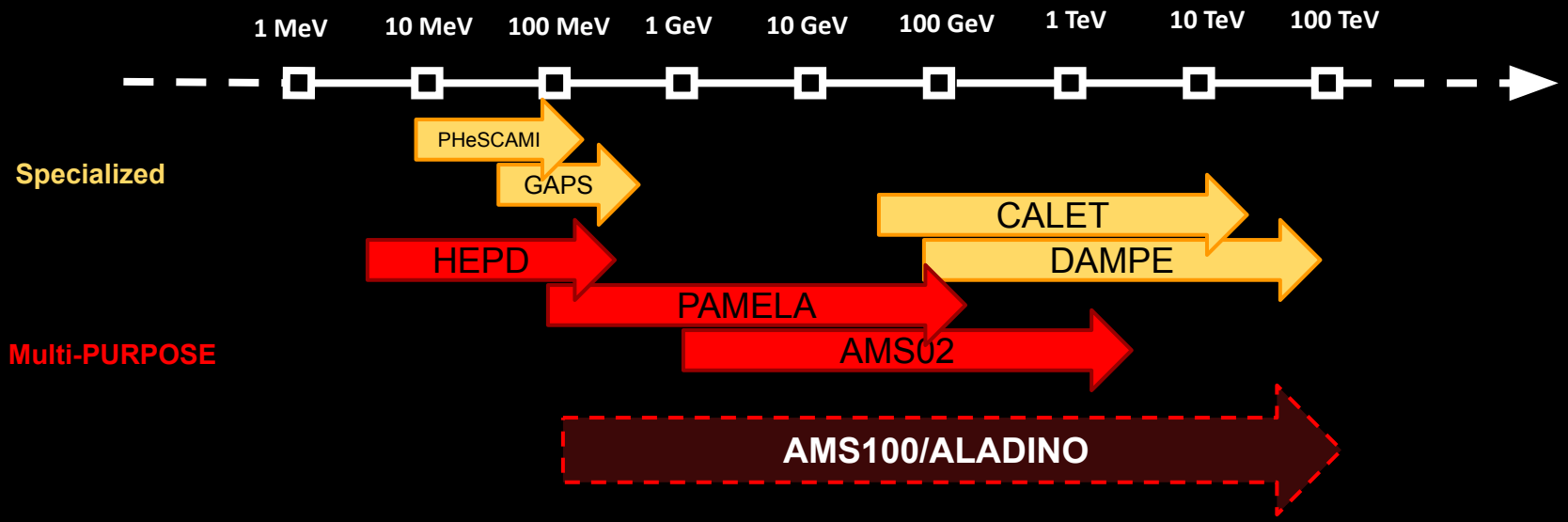
Beyond AMS-02 in another sense: Future Spectrometers (1)

- 1 Tesla magnetic Tracker, **MDR = 100 TV**
- Central calorimeter
- Targets e+, e-, nuclei (beyond the knee), antinuclei
- 40 tons -> needs heavy lifter rocket




Positrons
AMS-100: Model (a)
AMS-100: Model (b)
AMS-02
PAMELA
$E^3\Phi_{e^+}$ [m^{-2} s^{-1} sr^{-1} GeV^2]
25
20
15
10
5
1
10
10^2
10^3
10^4
Energy E [GeV]

In Conclusion…



- We live in the era of precision Cosmic Rays physics
- Accurate data about elementary particle and nuclei fluxes and new windows open at high energies
- New hints about cosmic anti-matter are fascinating -> dedicated mission
- We need a wide effort to launch in space the next generation magnetic spectrometer

Thanks for your attention

Backup

Questions:

- Which sources contributes at which energies?
- Are different CR types accelerated from the same sources?

SNR

p, e⁻ , C, N, O..

SUN

ISM

Li, Be, B, 3He, D

- What's the CR composition in their sources?
- How's the acceleration mechanism works
- How CR propagation is related to the Galactic turbulence?

The cosmic ray phaenomenon

Beyond AMS-02 in another sense: Future Spectrometers (2)

- 10 m^2 sr (20 times AMS02)
- Central calorimeter
- MDR 20 TV
- 2% reso Calo
- TOF-> AntiDeuterons

Sun

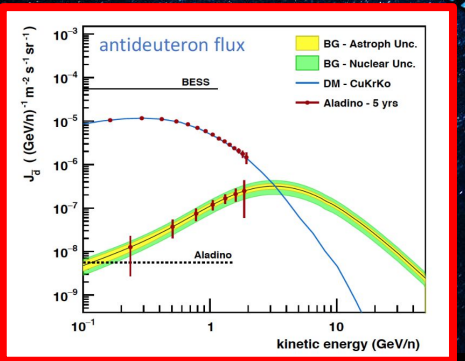
Moon

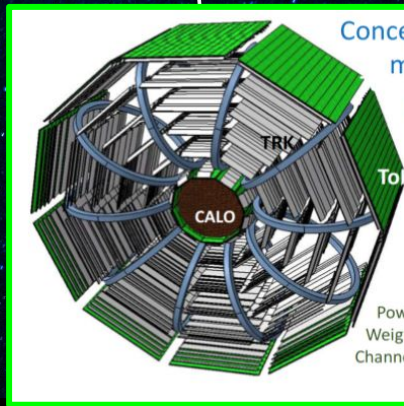
Earth

150 Million Km

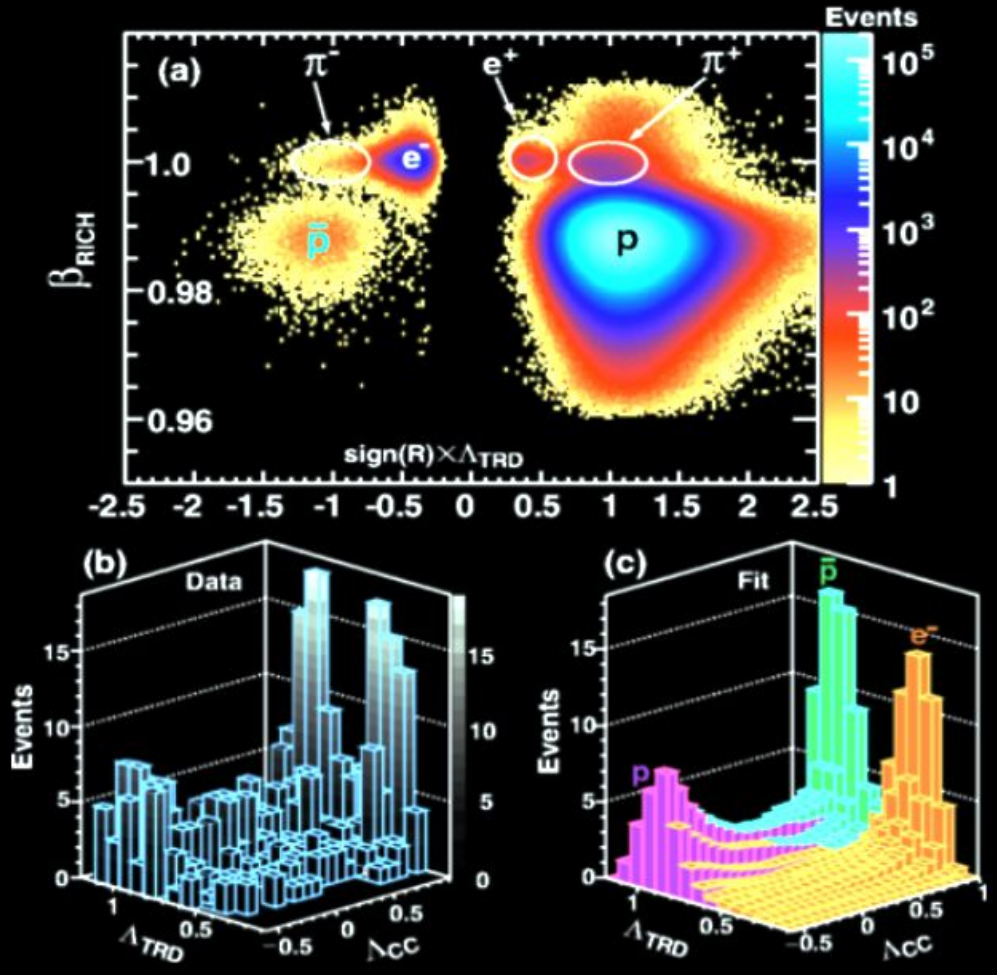
1.5 Million Km

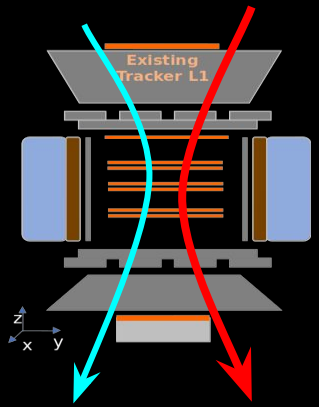
L2





Magnetic spectrometer: Antimatter detection



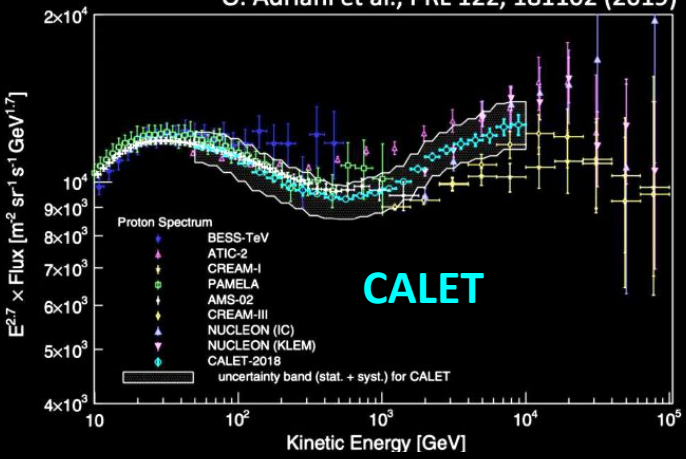


- Charge sign from bending direction
- Momentum from curvature radius
- discrimination of Antip/positrons from velocity or gamma factor (TOF, RICH, TRD)
- **High energy:** Charge Confusion alert!

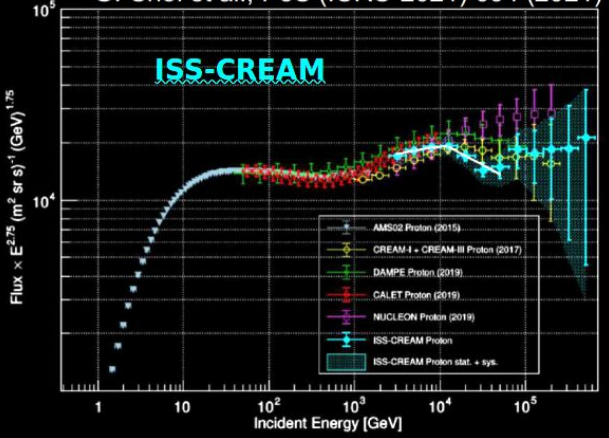
Multi TeV p spectrum

- New bump-like structure confirmed by ISS-CREAM and DAMPE
- Softening at ~ 10-20 TeV

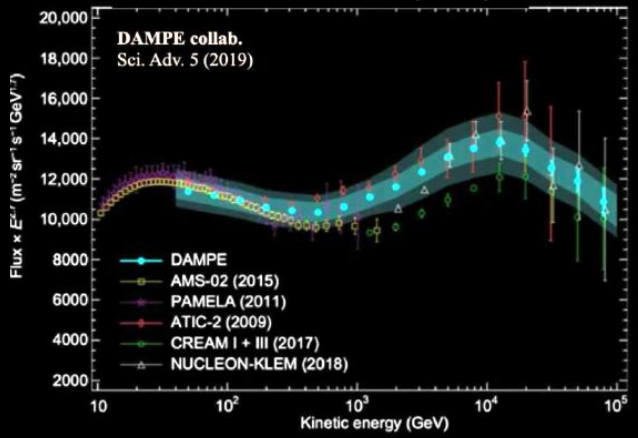
O. Adriani et al., PRL 122, 181102 (2019)



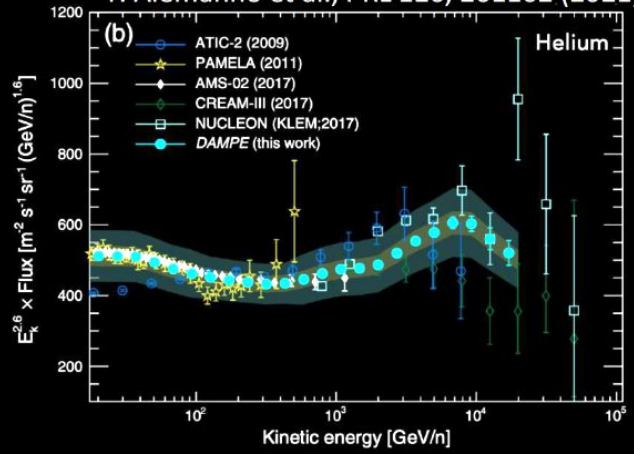
G. Choi et al., PoS (ICRC-2021) 094 (2021)



Q. An et al., Sci. Adv. 5 (2019) 9



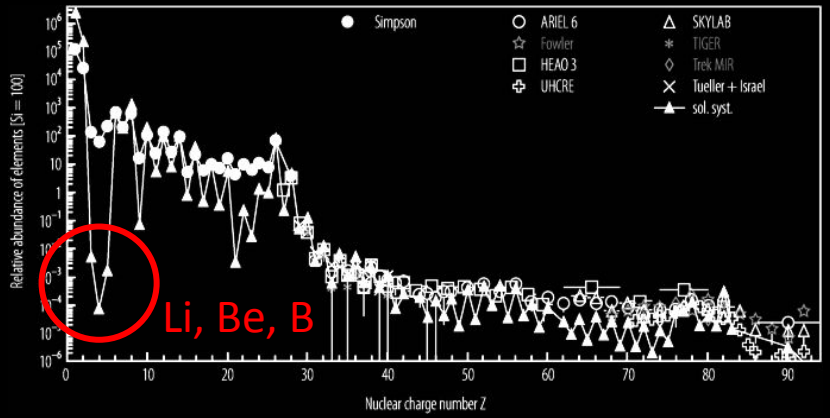
F. Alemanno et al., PRL 126, 201102 (2021)



DAMPE: spectral break at 20 TeV both in p and He

Primary and Secondary nuclei in Cosmic Rays (CR)

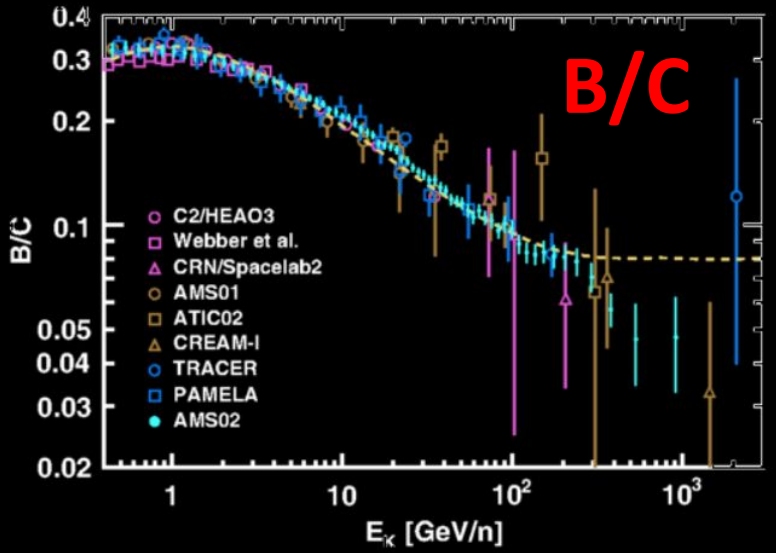
Secondary CR are produced from collisions of **primary CR** with the **interstellar medium (ISM)**



- They carry information on the history of the travel and **properties of ISM**
- Most abundant species: **Li, Be, B and light isotopes (^{3}He, ^{10}Be and D)**

Secondary/primary ratio is a powerful investigation tool

- Nucl. interaction conserve Ek/n
- Many systematics factorize

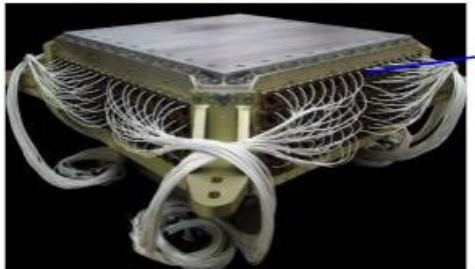


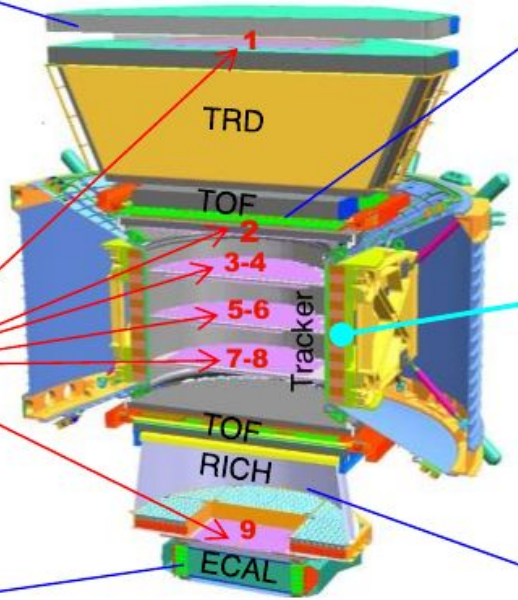
Particles and nuclei are defined
by their charge (Z)
and energy (E)
or momentum (P).
Rigidity R = P/Z

TRD: Identify e^+, e^-, Z

Silicon Tracker: Z, P

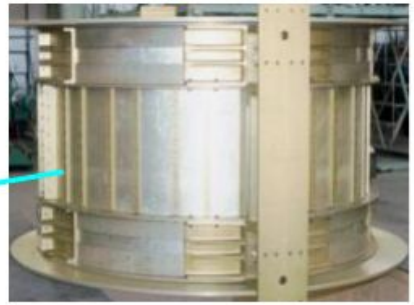
ECAL: E of e^+, e^-



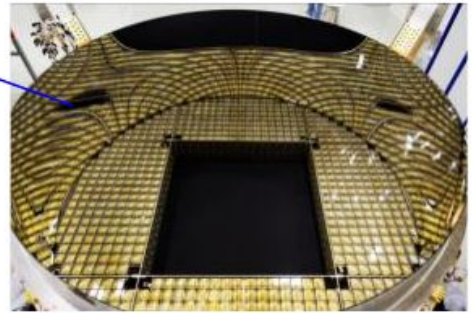


TOF: Z, E

Magnet: ±Z

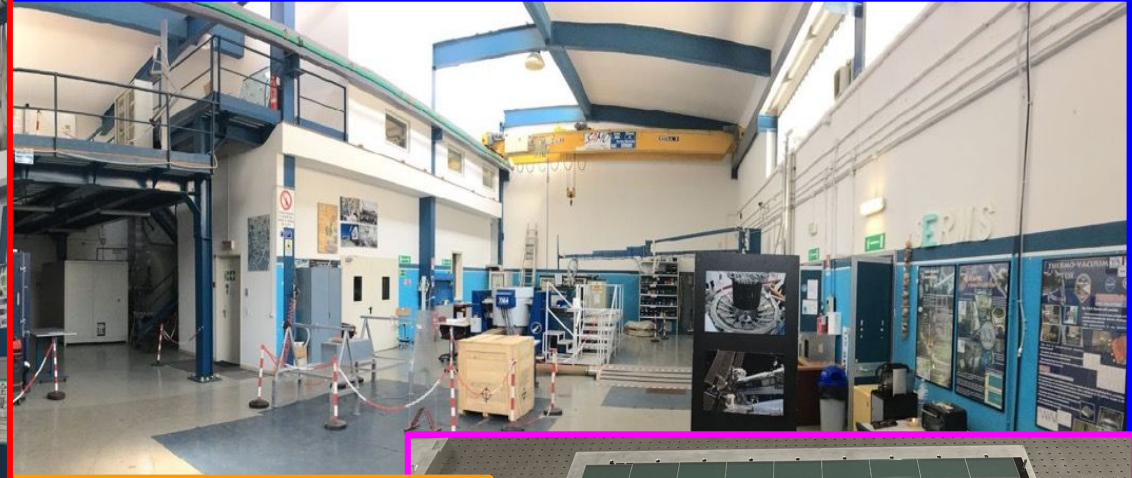


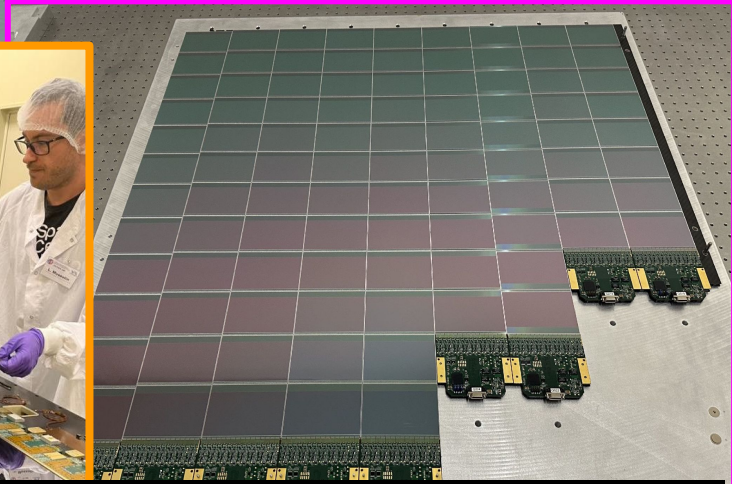
RICH: Z, E



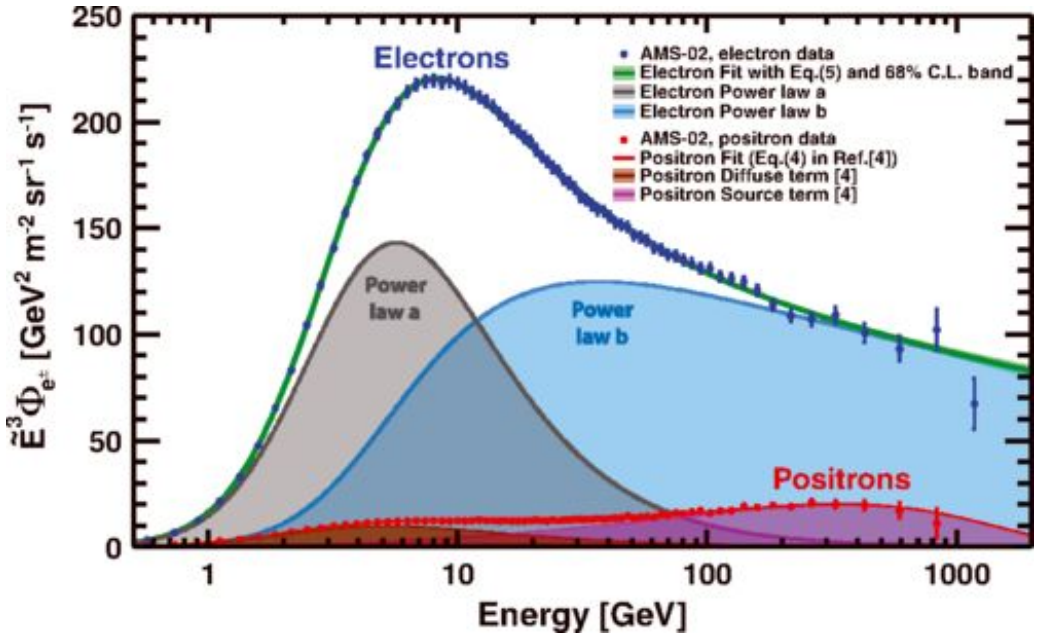
Z and P

are measured independently by the
Tracker, RICH, TOF and ECAL

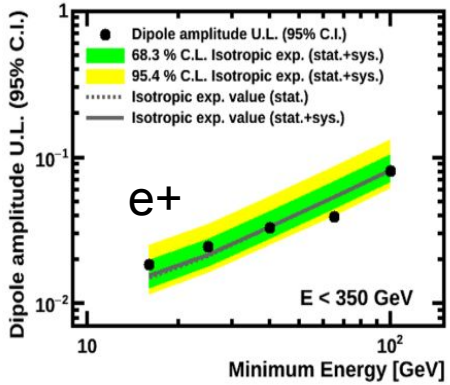


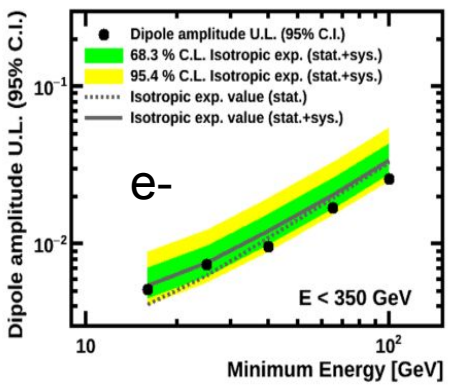


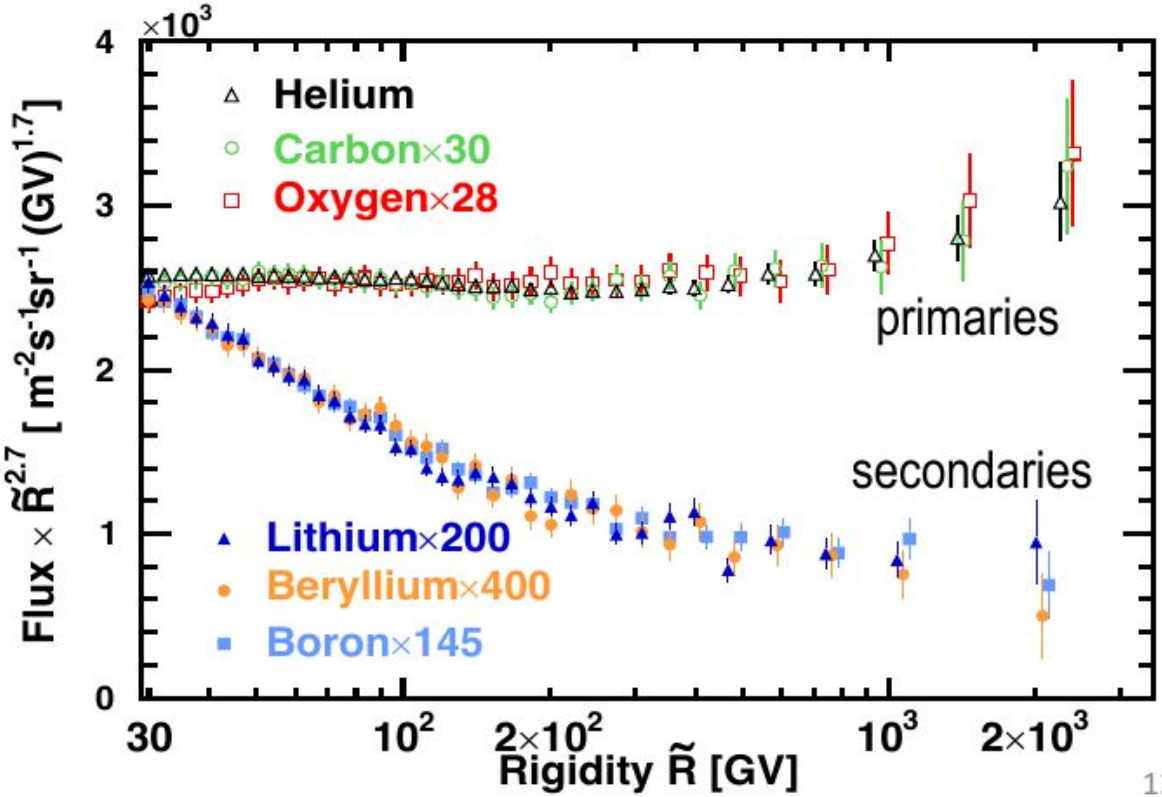
INFN UniPG lab. for space qualification, Terni

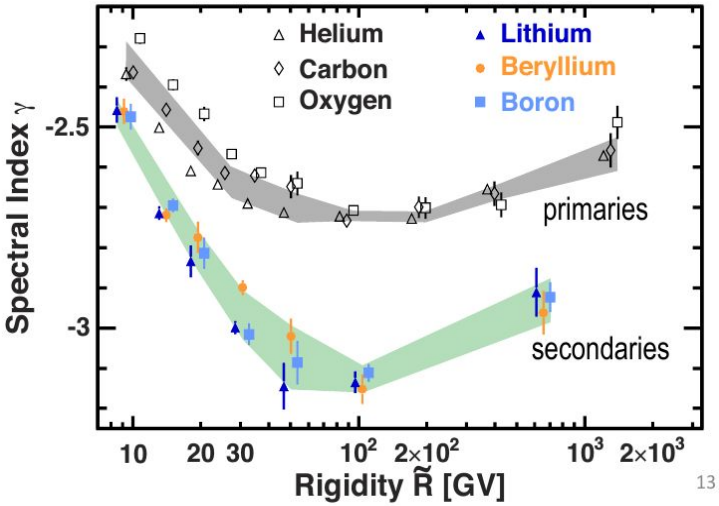


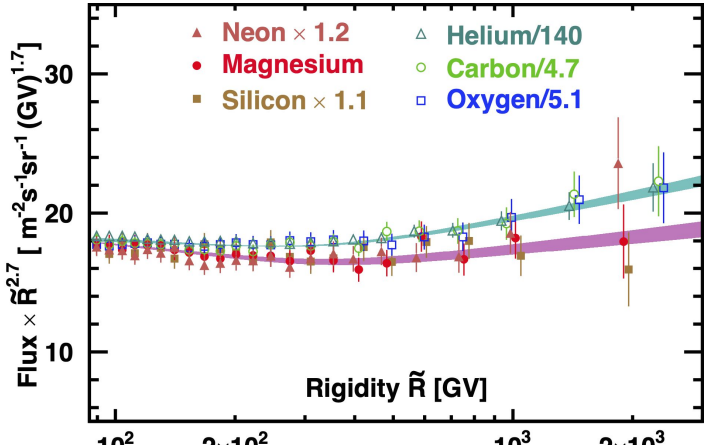
- orientamento (sist di rif -> gal coo)
- prendere le due metà (asimmetria di dipolo)
- direzione: dir traccia (su in energia) + esposizione

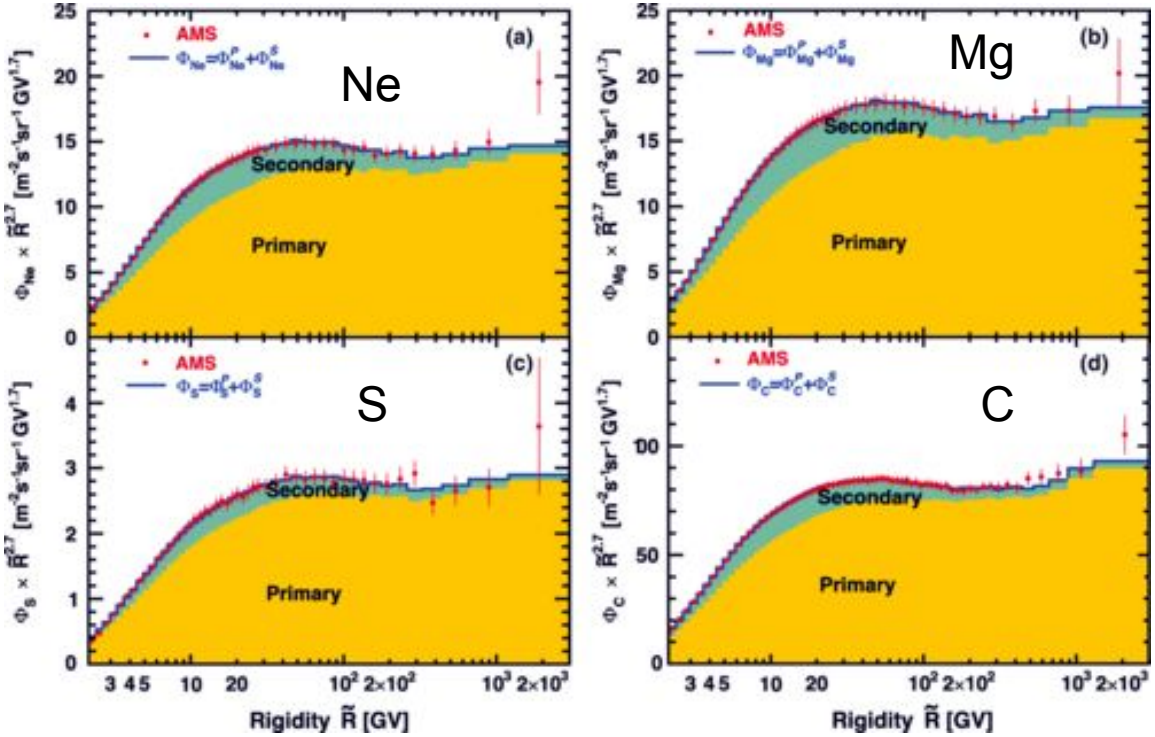


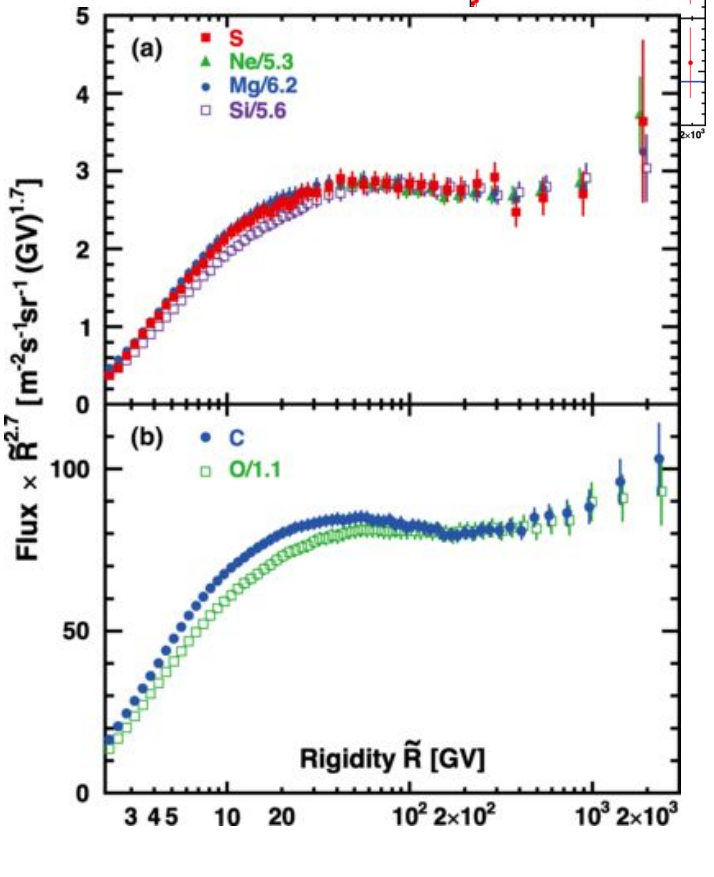



×10³
Helium
Carbon×30
Oxygen×28
primaries
secondaries
Lithium×200
Beryllium×400
Boron×145
Flux × R̃^2.7 [m^-2 s^-1 sr^-1 (GV)^1.7]
Rigidity R̃ [GV]


Helium
Carbon
Oxygen
Lithium
Beryllium
Boron
primaries
secondaries
Spectral Index γ
Rigidity R̃ [GV]


Neon × 1.2
Magnesium
Silicon × 1.1
Helium/140
Carbon/4.7
Oxygen/5.1
Flux × R̃^2.7 [m^-2 s^-1 sr^-1 (GV)^1.7]
Rigidity R̃ [GV]

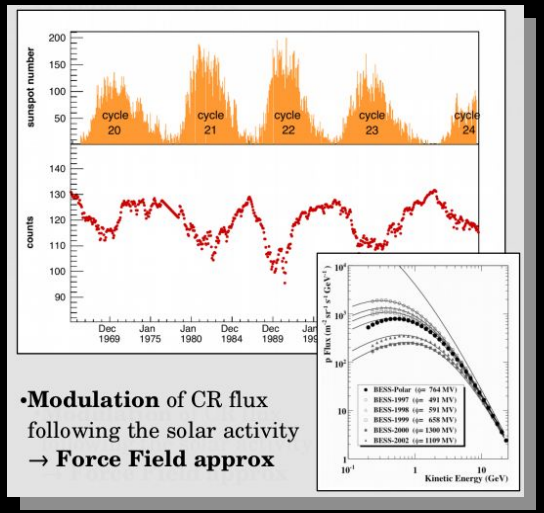

AMS
(a)
Ne
Secondary
Primary
(b)
Mg
(c)
S
(d)
C
Rigidity R̃ [GV]


(a)
S
Ne/5.3
Mg/6.2
Si/5.6
(b)
C
O/1.1
Flux × R̃^2.7 [m^-2 s^-1 sr^-1 (GV)^1.7]
Rigidity R̃ [GV]

Once arrived in proximity of Solar system, CR propagation is affected by **local environment**

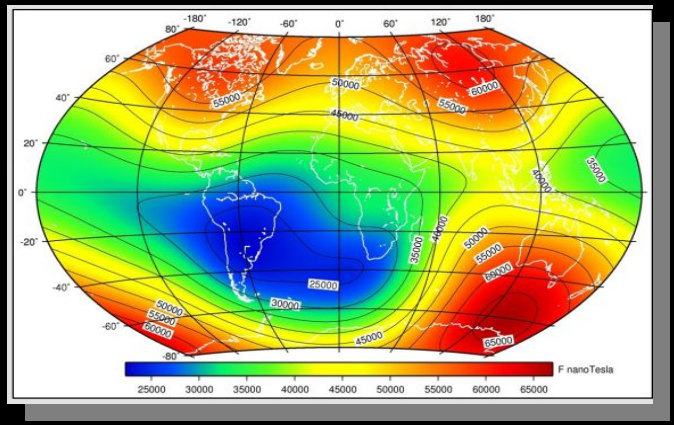
Solar magnetic influence: Heliosphere

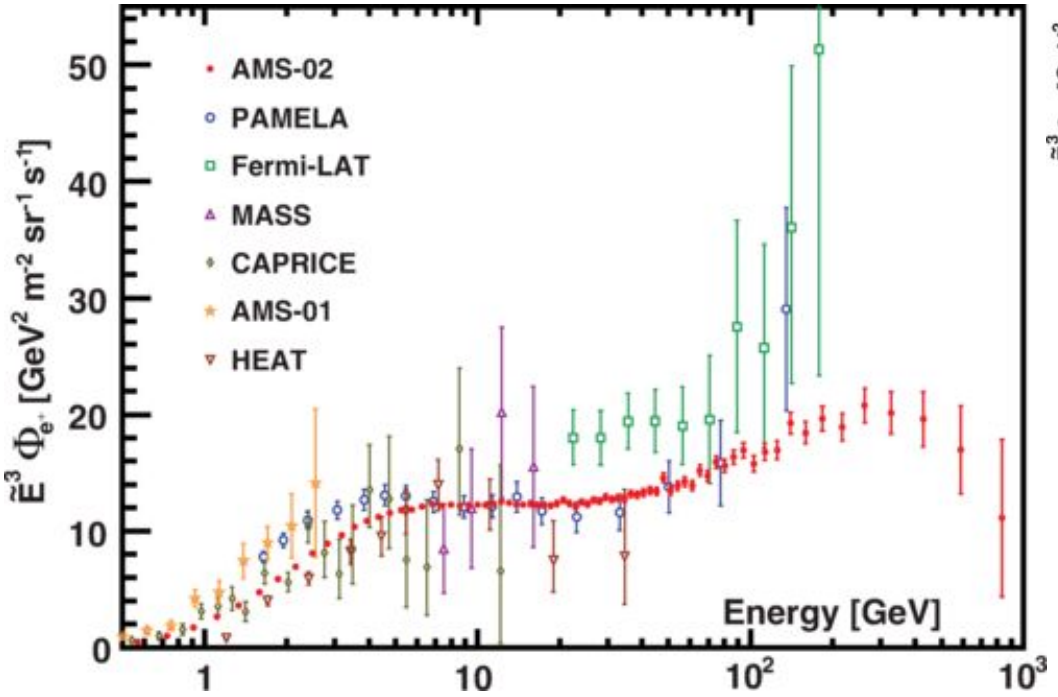
- **IMF:** Interplanetary Magnetic Field
- **Cyclical activity:** 11 Yrs

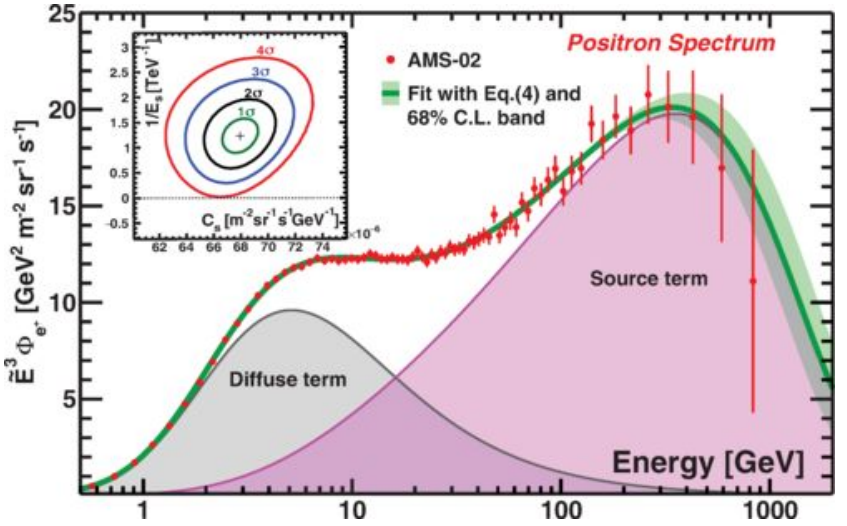


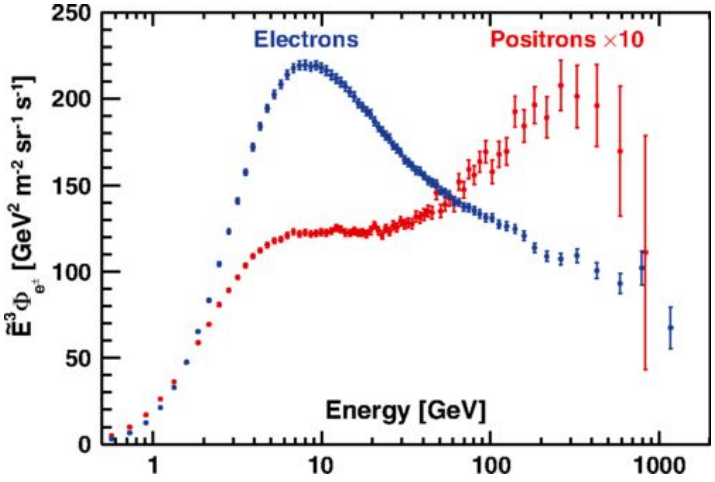
Earth magnetic influence: Magnetosphere

- **Shielding given by Earth dynamo field**
- **Latitude Dependence, Cutoff**
- **South Atlantic Anomaly (SAA)**




AMS-02
PAMELA
Fermi-LAT
MASS
CAPRICE
AMS-01
HEAT
$\tilde{E}^3 \Phi_{e^+}$ [GeV^2 m^{-2} sr^{-1} s^{-1}]
Energy [GeV]


Positron Spectrum
AMS-02
Fit with Eq.(4) and
68% C.L. band
Source term
Diffuse term
$\tilde{E}^3 \Phi_{e^+}$ [GeV^2 m^{-2} sr^{-1} s^{-1}]
Energy [GeV]
$1/E_s$ [TeV^{-1}]
C_s [m^{-2}sr^{-1}s^{-1}GeV^{-1}]
4σ
3σ
2σ
1σ


Electrons
Positrons ×10
$\tilde{E}^3 \Phi_{e^+}$ [GeV^2 m^{-2} sr^{-1} s^{-1}]
Energy [GeV]