Results from high energy direct measurements and future prospects

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Outline of the presentation

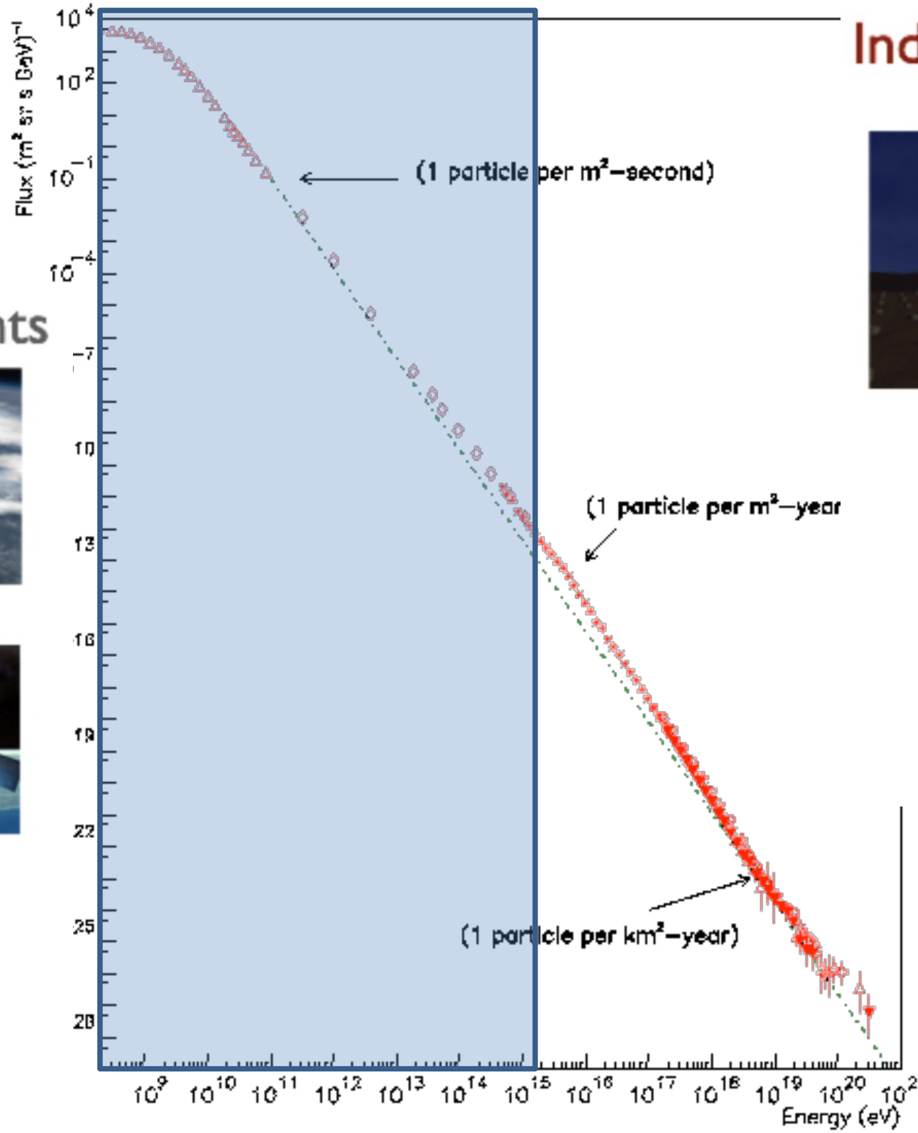
- **A short introduction**
- **Recent measurements on:**
    - Primary Cosmic Rays
    - Secondary Cosmic Rays
    - Antimatter
    - Electrons & Positrons

- New plots and measurements taken mainly from ECRS 2022 (July 2022)

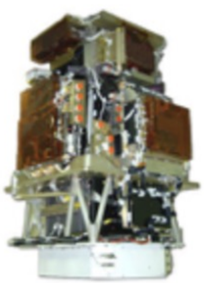
- **Due to time limitation, I will not strongly focus on:**
    - **'Classical' Secondary/Primary ratios**
    - **Very heavy Nuclei**
    - **Isotopes**
    - **Anti-Helium**

The spectrum of Cosmic Rays

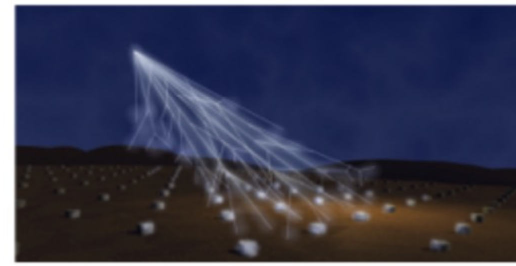
All Particle flux

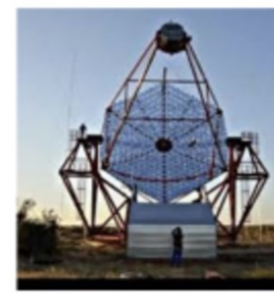


Direct measurements



Indirect measurements





At first sight:
A featureless power law below 10^{15} eV

The "conventional scenario" of galactic cosmic rays

- Cosmic ray fluxes below the knee can be described by a single power law, the spectral index being the result of the following processes:
  - production
  - acceleration
  - propagation

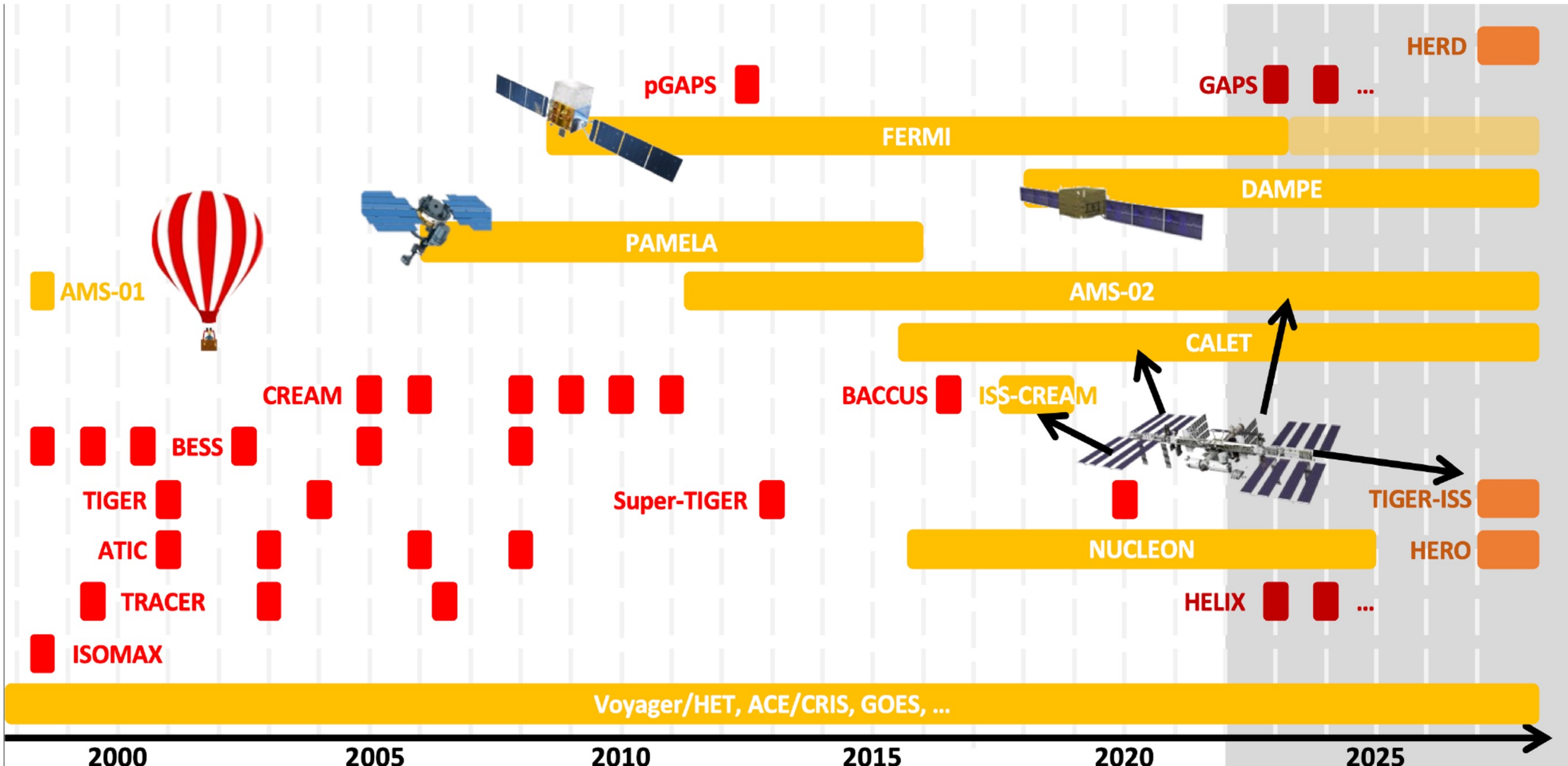
- Primary cosmic ray fluxes have universal (species independent) spectral indices.

- Antimatter component is purely of secondary origin (no sources of CR antimatter)

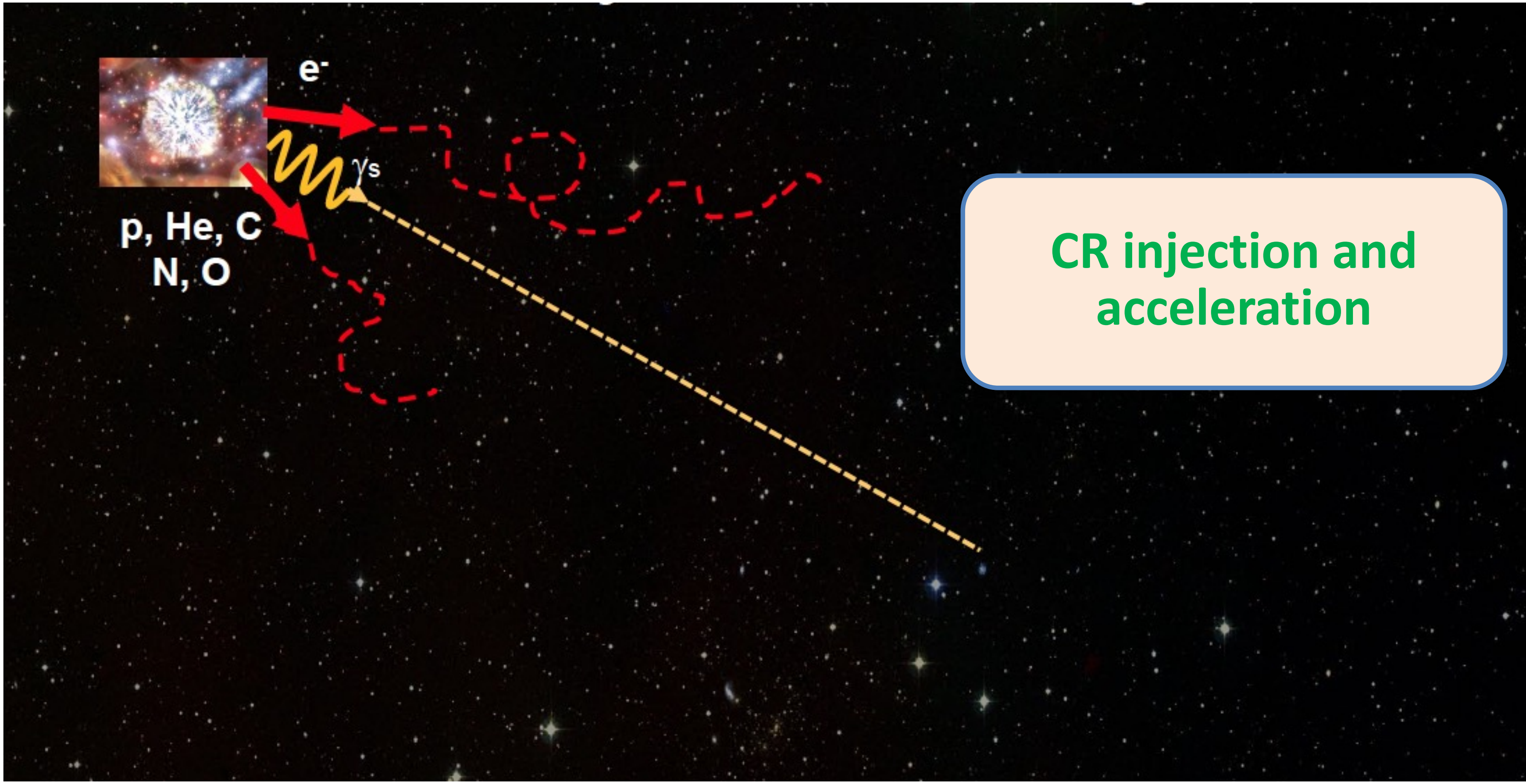
- However….
  - Life is not so simple!!!!
  - Very detailed measurements carried out in the last dacade dramatically created serious problems to this 'conventional scenario'
  - Results with many different (and complementary) probes will be shown in this presentation

A new age of experiments (from ~2000)

- Balloon → space spectrometers → space calorimeters → future...



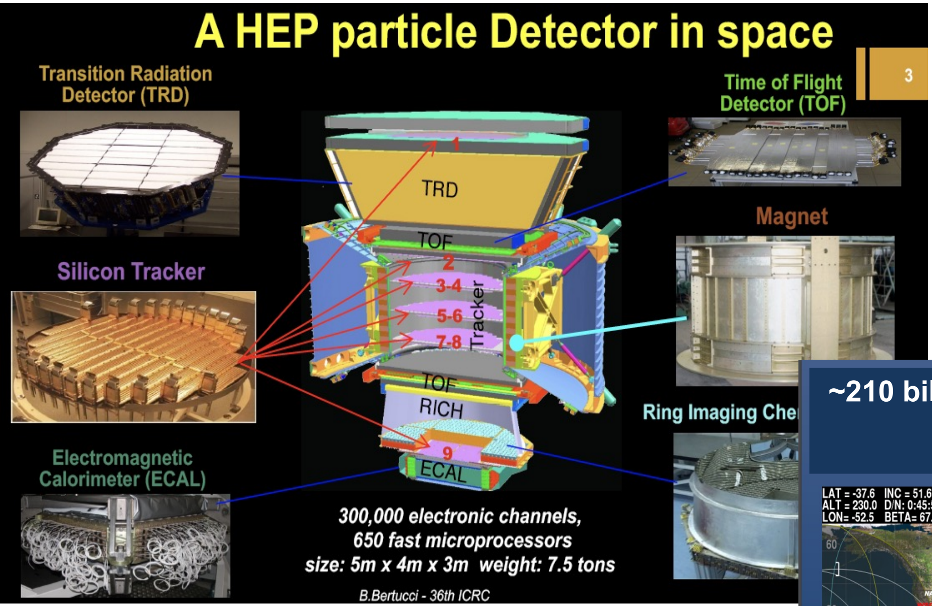
By A. Oliva



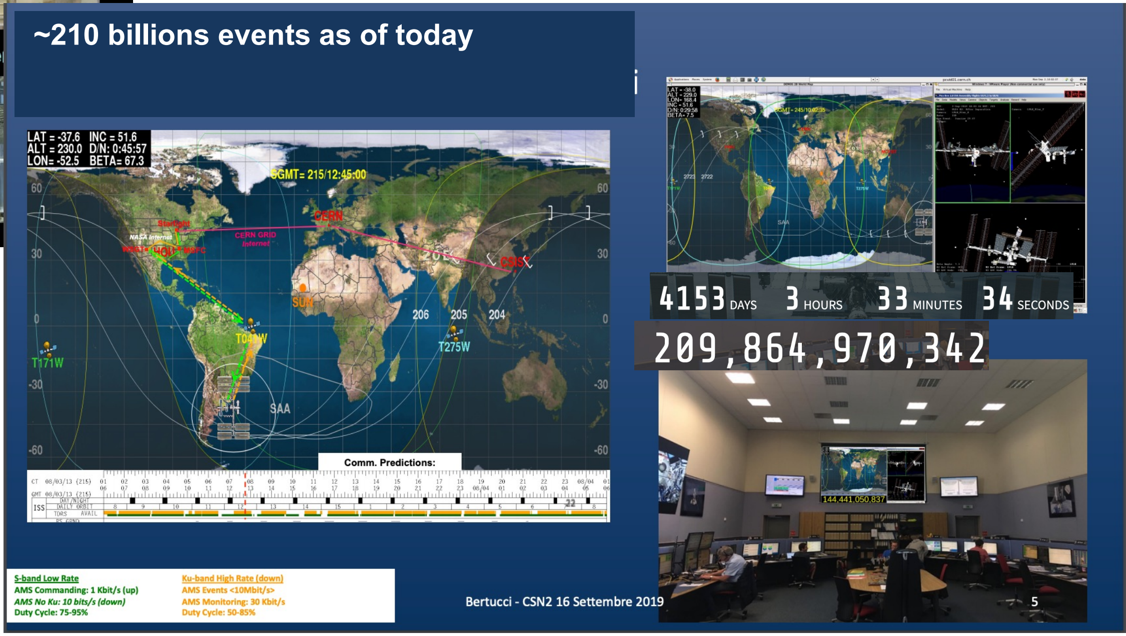
Absolute fluxes of primary GCRs

- Protons, helium nuclei, light nuclei
- Electrons postponed at the end of the talk….

Alpha Magnetic Spectrometer AMS-02



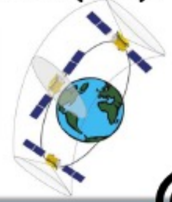
Installed on ISS on 19th May 2011



Dark Matter Particle Explorer DAMPE

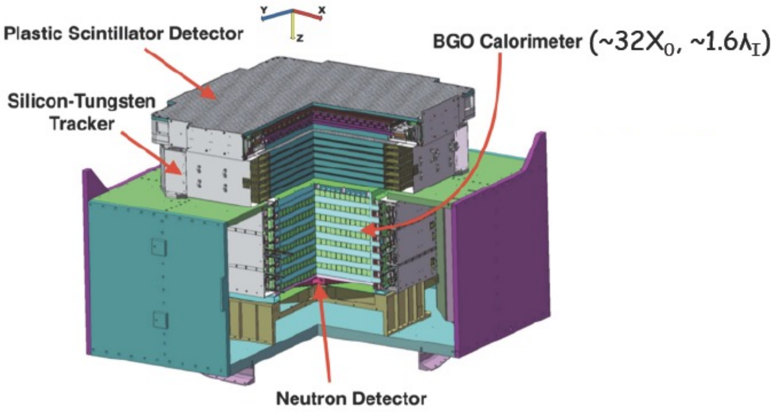
Satellite-borne particle detector, project of the *Strategic Pioneer Program on Space Science*, promoted by *the Chinese Academy of Sciences* (CAS).

ALTITUDE: 500 km
PERIOD: 95 minutes
ORBIT: Sun-synchronous



- Study of Cosmic Rays composition, origin and propagation
- Search for Dark Matter signatures in lepton and photon spectra
- High Energy Gamma-Ray Astronomy

DAMPE Instrument

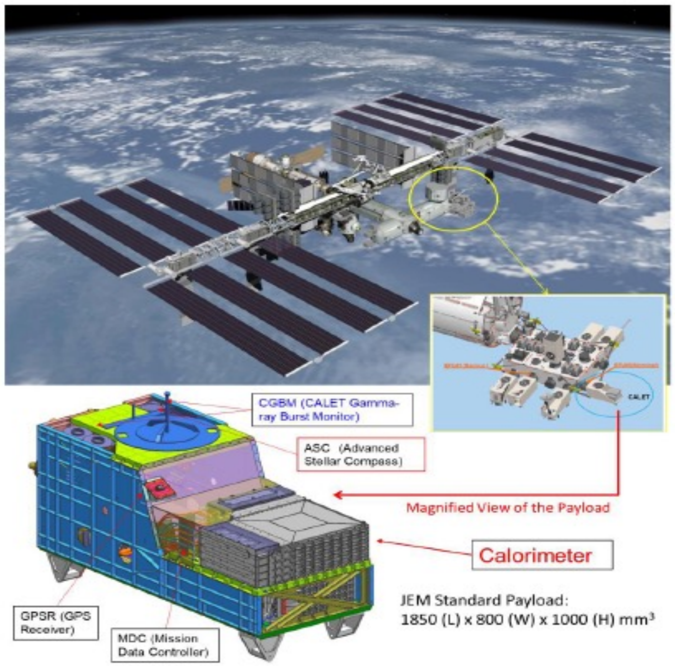


- Charge measurement (dE/dx in PSD, STK and BGO)
- Gamma-ray converting and tracking (STK and BGO)
- Precise energy measurement (BGO Crystals)
- Hadron rejection (BGO and Neutron Detector)

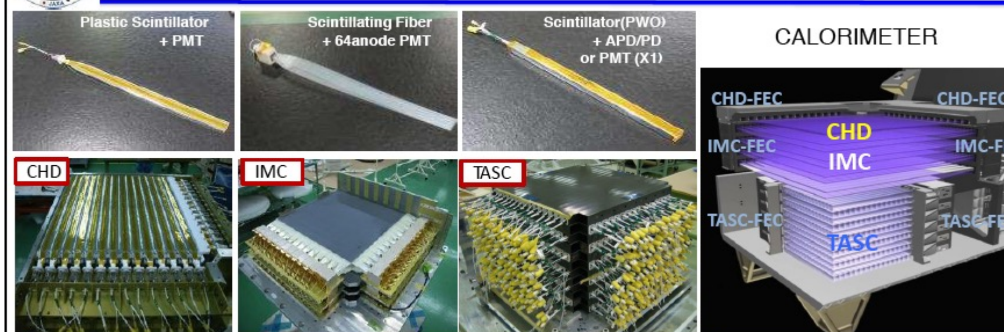
(Chang et al. Astropart.Phys. 95 (2017) 6–24)

CALorimetric Electron Telescope CALET

Launched August 19th, 2015



CALET Instrument

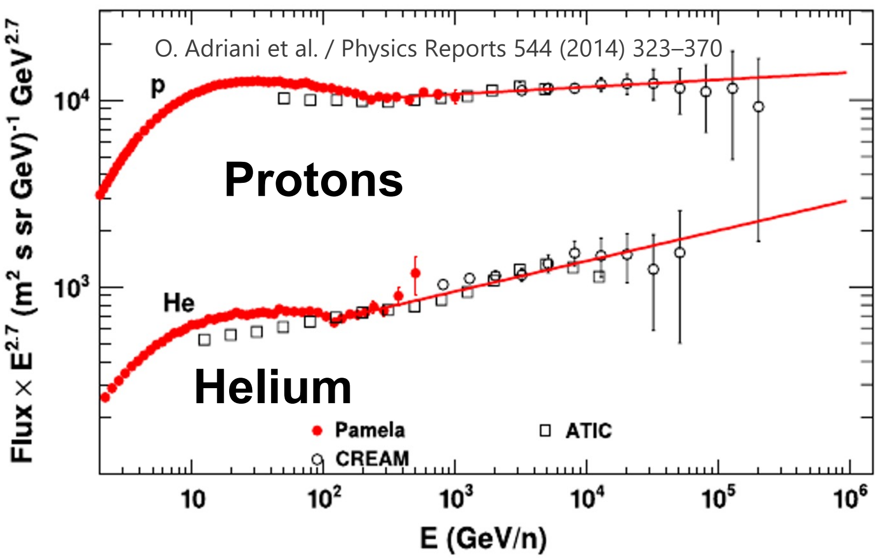


	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Measure	Charge (Z=1-40)	Tracking , Particle ID	Energy, e/p Separation
Geometry (Material)	Plastic Scintillator 14 paddles x 2 layers (X,Y): 28 paddles Paddle Size: 32 x 10 x 450 mm^3	448 Scifi x 16 layers (X,Y) : 7168 Scifi 7 W layers ($3X_0$): $0.2X_0$ x 5 + $1X_0$ x2 Scifi size : 1 x 1 x 448 mm^3	16 PWO logs x 12 layers (x,y): 192 logs log size: 19 x 20 x 326 mm^3 Total Thickness : 27 X_0, ~1.2 λ_I
Readout	PMT+CSA	64-anode PMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)@top layer

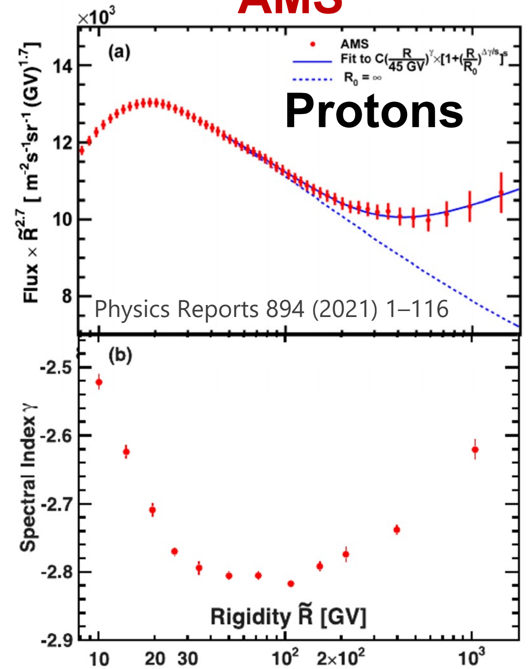
First unexpected proton and helium features

- Proton and helium hardening above 100 GV .
- Suggested by CREAM, first measured by PAMELA, confirmed by AMS-02, CALET, DAMPE.

Pamela



AMS

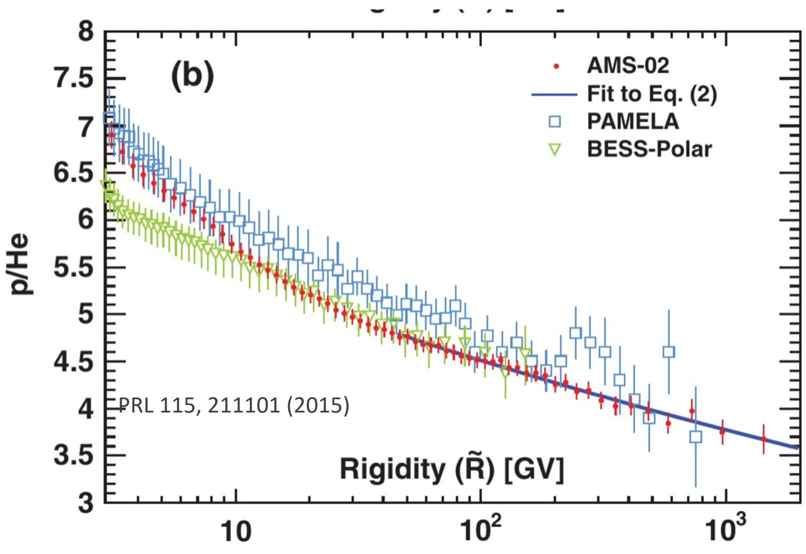


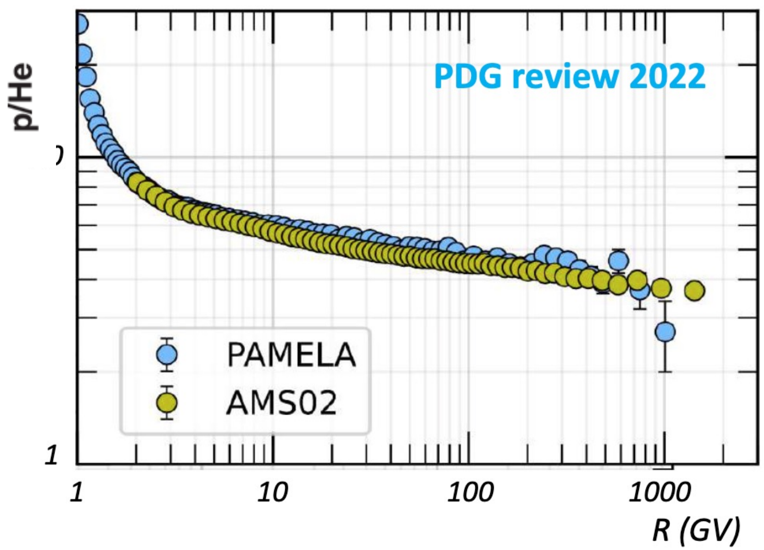
Important feature: confirmation of the deviation from a single power-law in both species at roughly 200 GV firstly suggested by CREAM and later clearly observed by Pamela in 2011

Origin of the hardening?
- At the sources: multi-populations, etc.?
- Propagation effects? Is it present in other species?

Proton/helium ratio anomaly

- Standard CR model: He spectral index ~ proton spectral index, i.e. p/He should be flat.
- p/He measured with spectrometers:

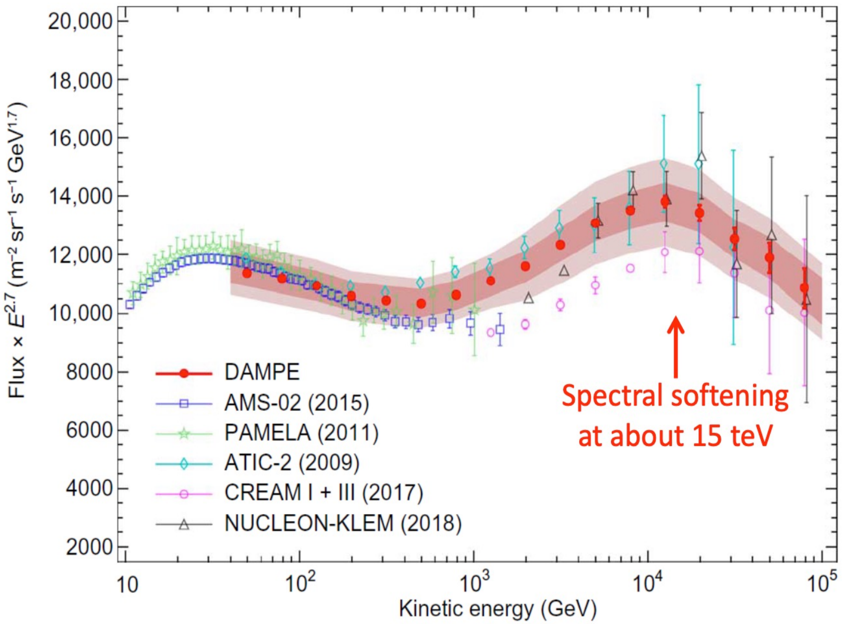




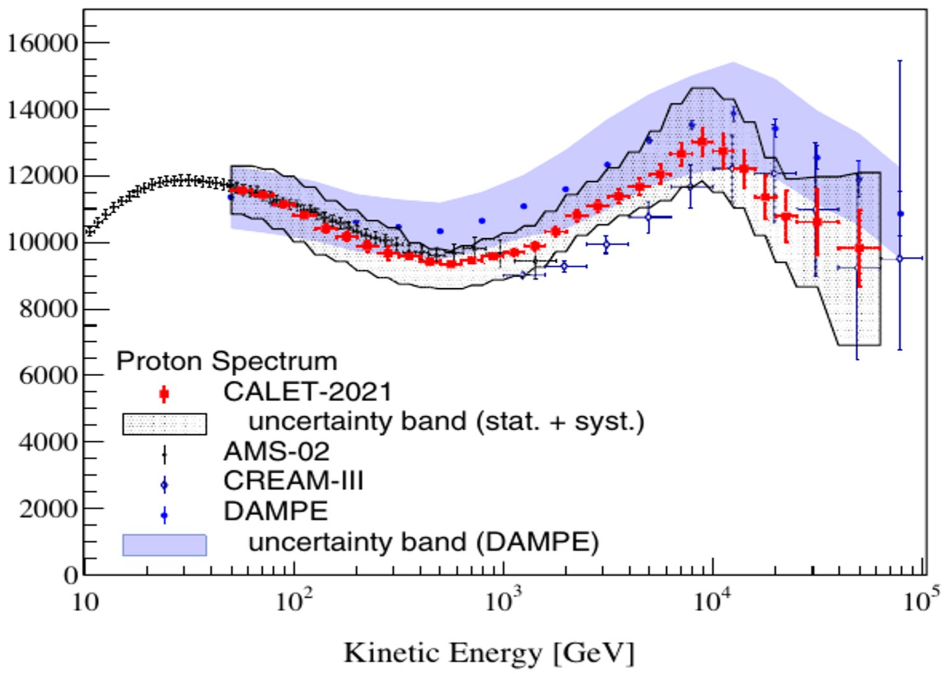
- **The He spectrum is harder even if p/He does not feature structures.**
- **This is not explained by the basic CR standard model.**

Another new feature is appearing from DAMPE and CALET data in the above TeV region!!!!

Proton flux with DAMPE (40 GeV –> 100 TeV)



Proton flux with CALET (50 GeV –> 50 TeV)



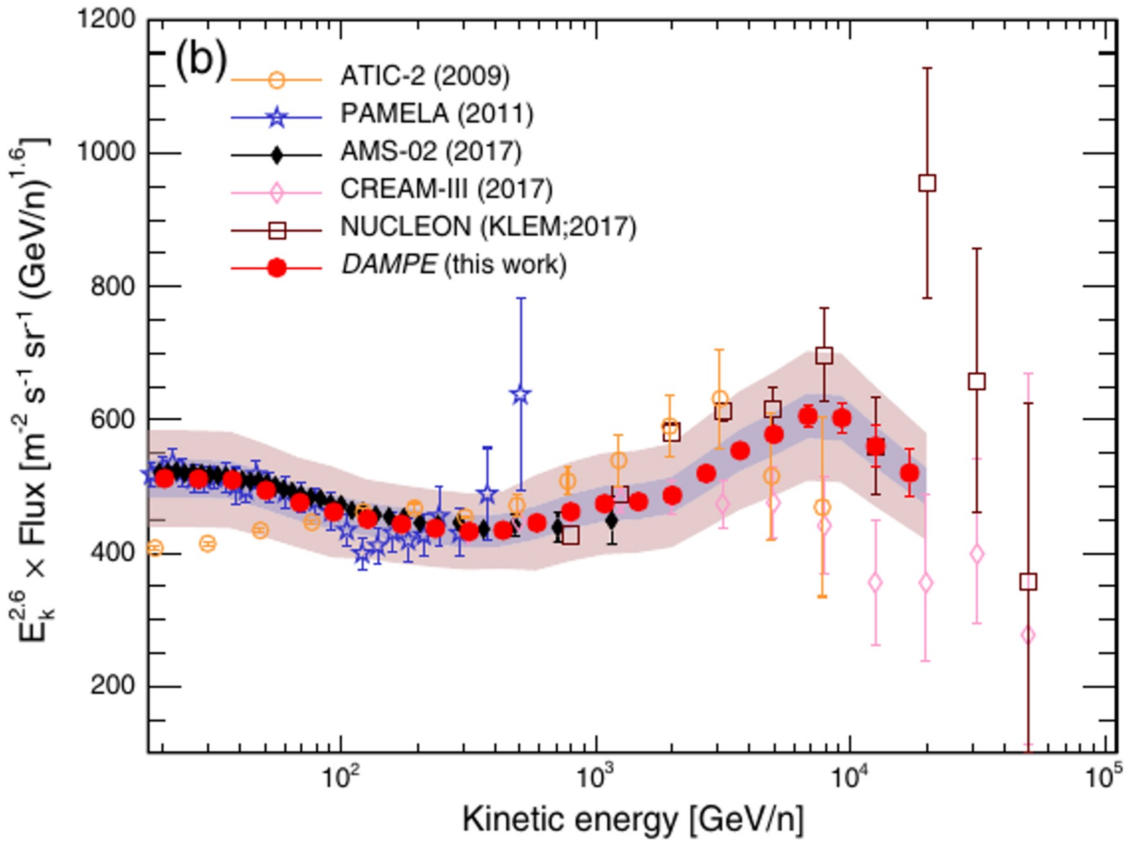
Important feature:

- Confirmation of spectral hardening.
- A new spectral break above 10 TeV/n (~14 TeV)

Open questions, e.g.:

- Is it due to new sources of galactic CR?
- Yet another change of regime in the diffusion?

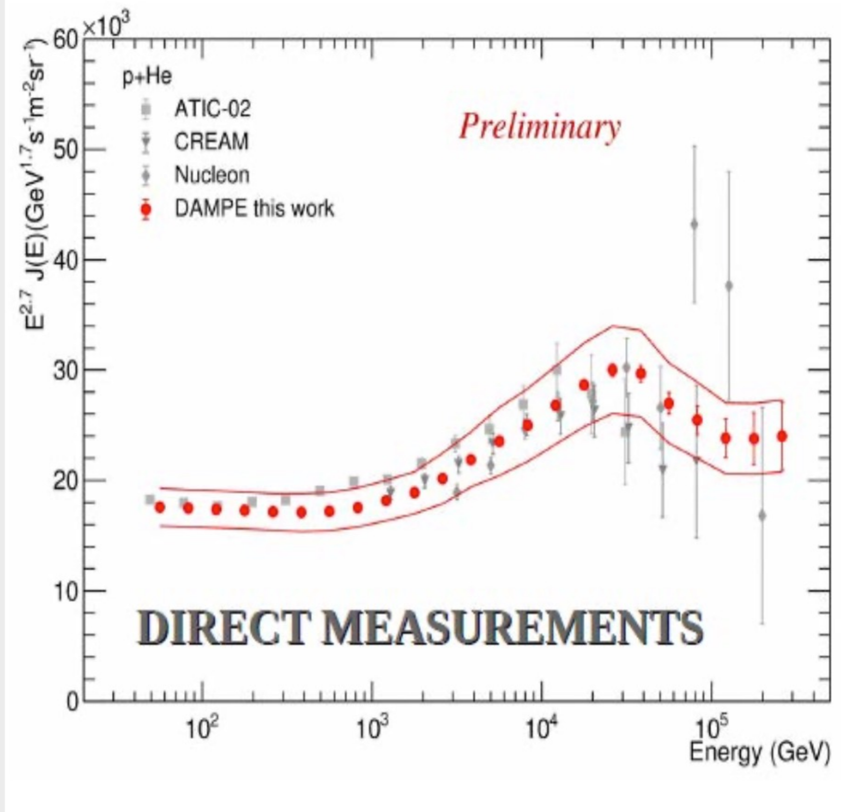
Helium spectrum with DAMPE (20 GeV/n –> 20 TeV/n)

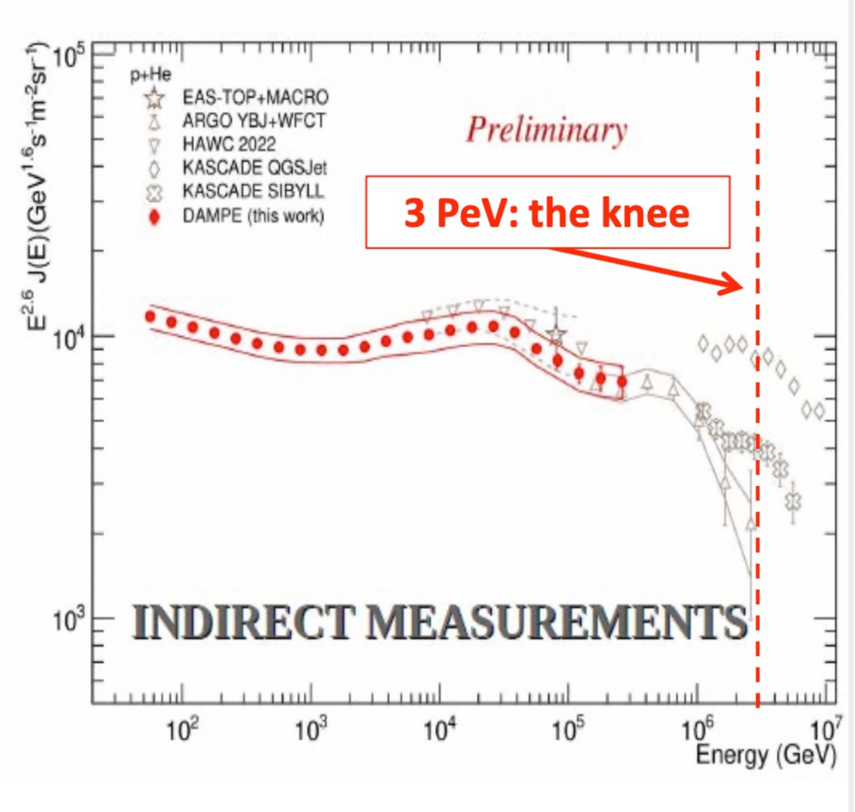


Important features:

- **Confirmation of the break at ~400 GeV/n**
- **Clear softening of the helium spectrum at ~10 TeV/n (~34 TeV)**

The p+He DAMPE spectrum



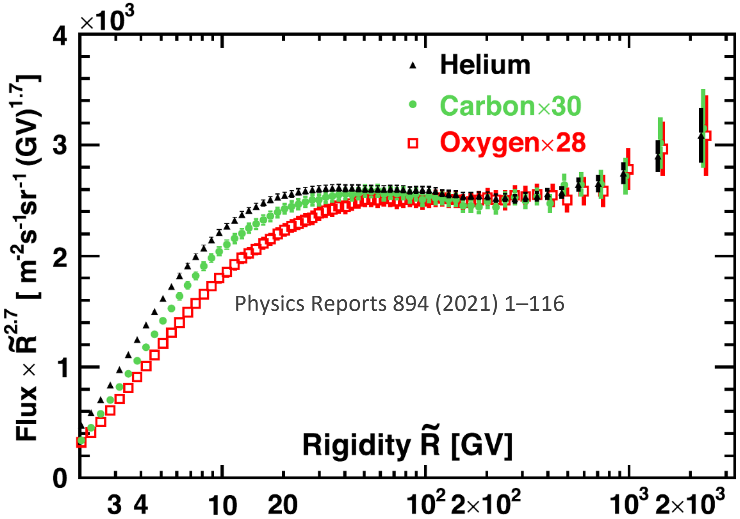


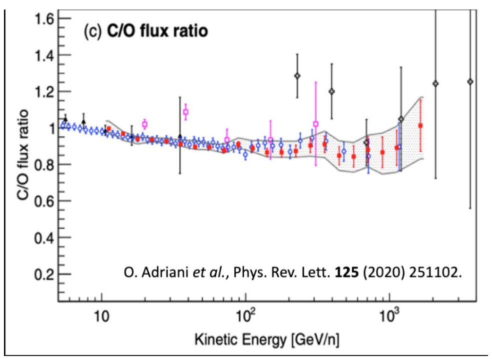
Confirmation of the softening
(at about 25 TeV due to the combination of p and He spectra)

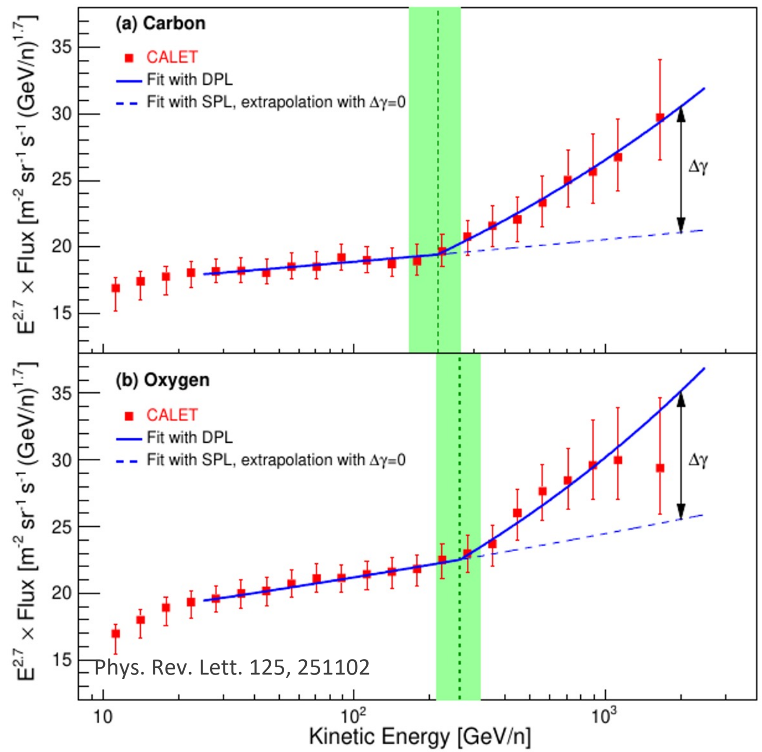
- Extension to 300 TeV
- Overlapping with indirect measurements

Carbon and Oxygen with AMS-02 and Calet

- Beside p and He, is the hardening an universal feature?



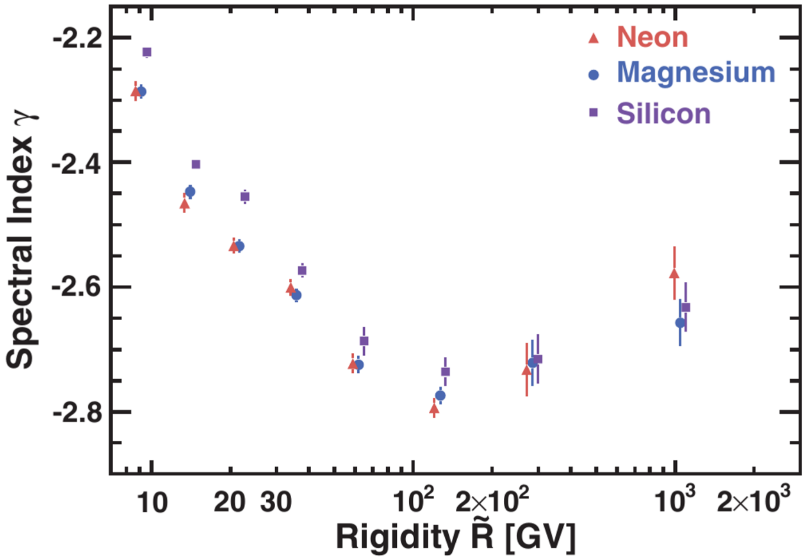


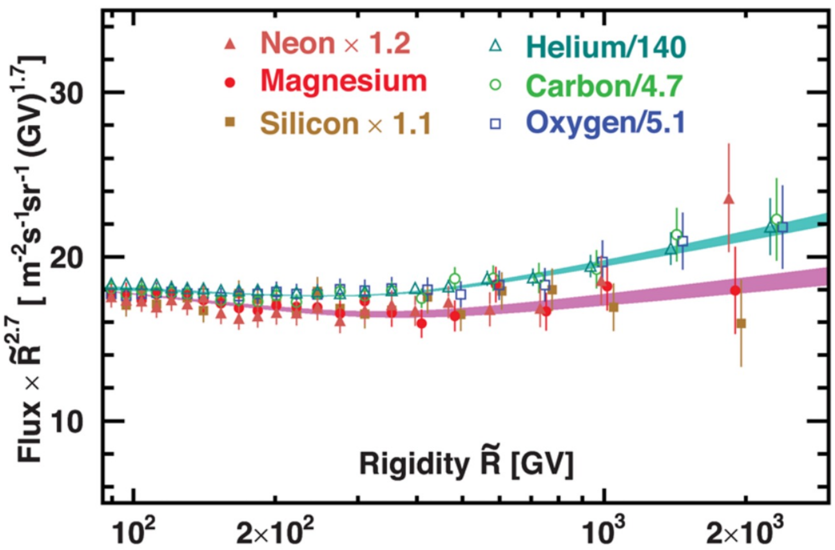


- **A similar break is present in C and O (measured by AMS-02 and confirmed by CALET)**
- **Important features:**
  - **deviation from a single power-law in all species at few hundreds GV**
  - **same spectral behavior for He, C, O above 60 GV**

Other primary nuclei by AMS-02: Ne, Mg and Si

- Ne, Mg and SI spectra are compatible with the hardening.



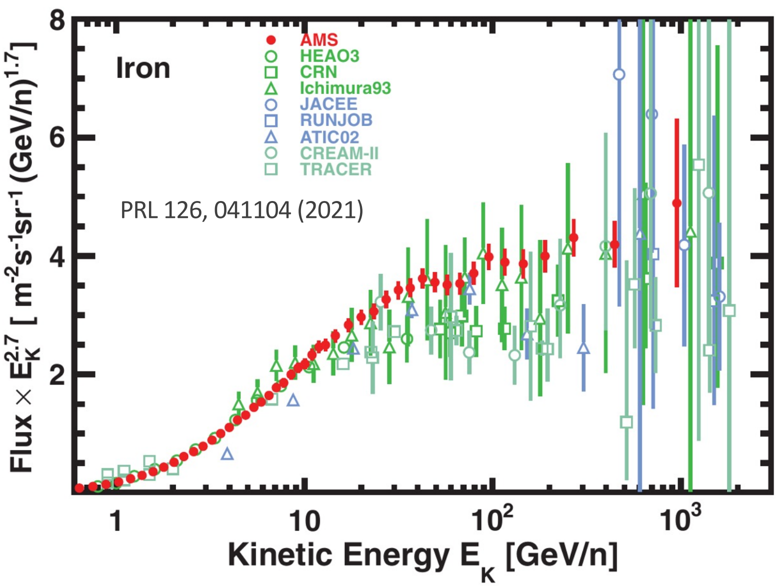


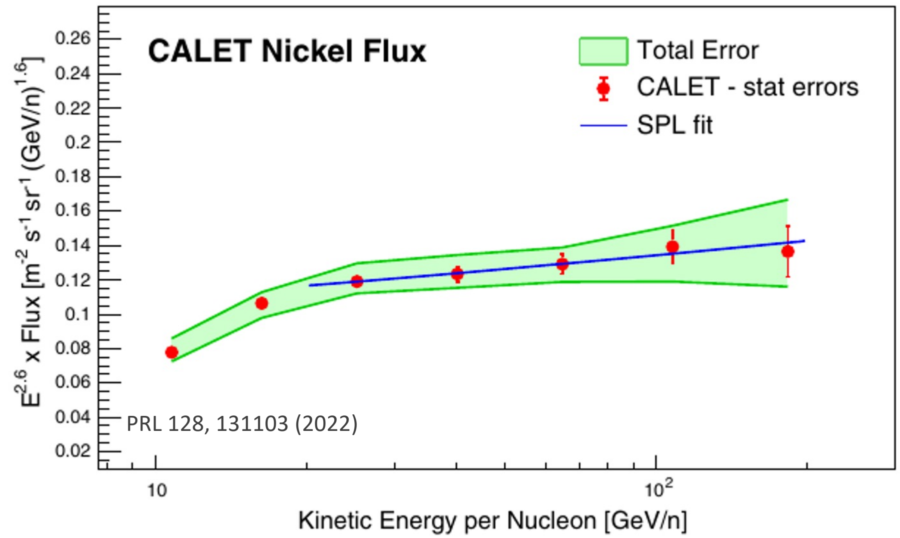
AMS-02 data suggests that Ne, Mg and Si spectra above 100 GV are different with respect to He, C and O ones.

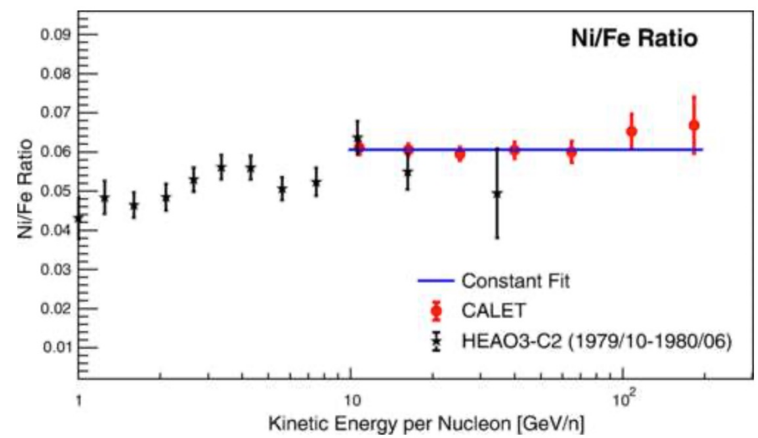
- **Is this due to the spallation mechanism?**
- **A better knowledge of the cross sections is certainly important!**

Heavy nuclei by CALET and AMS-02

- Iron measured by CALET and AMS-02.
- Nickel measured by CALET.







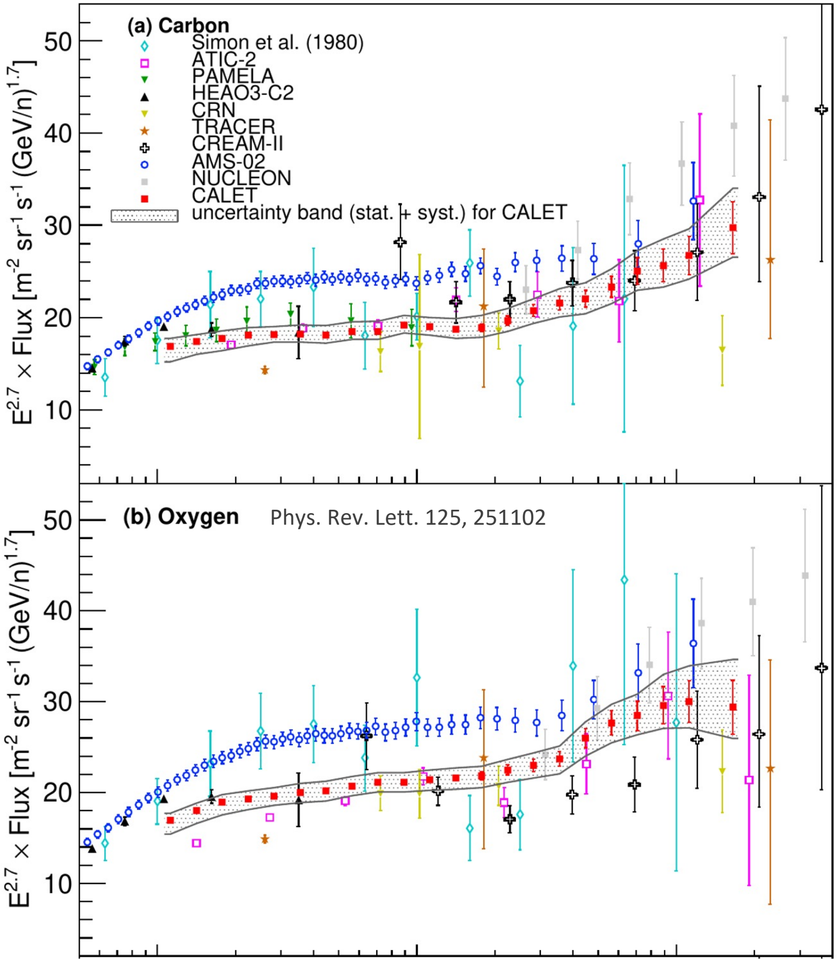
- **AMS-02 suggests that the Iron spectrum is similar to light nuclei flux.**
- **CALET data shows that Nickel/Iron flux is flat above 10 GeV.**
- **Limited statistic → spectral break is not clearly confirmed.**

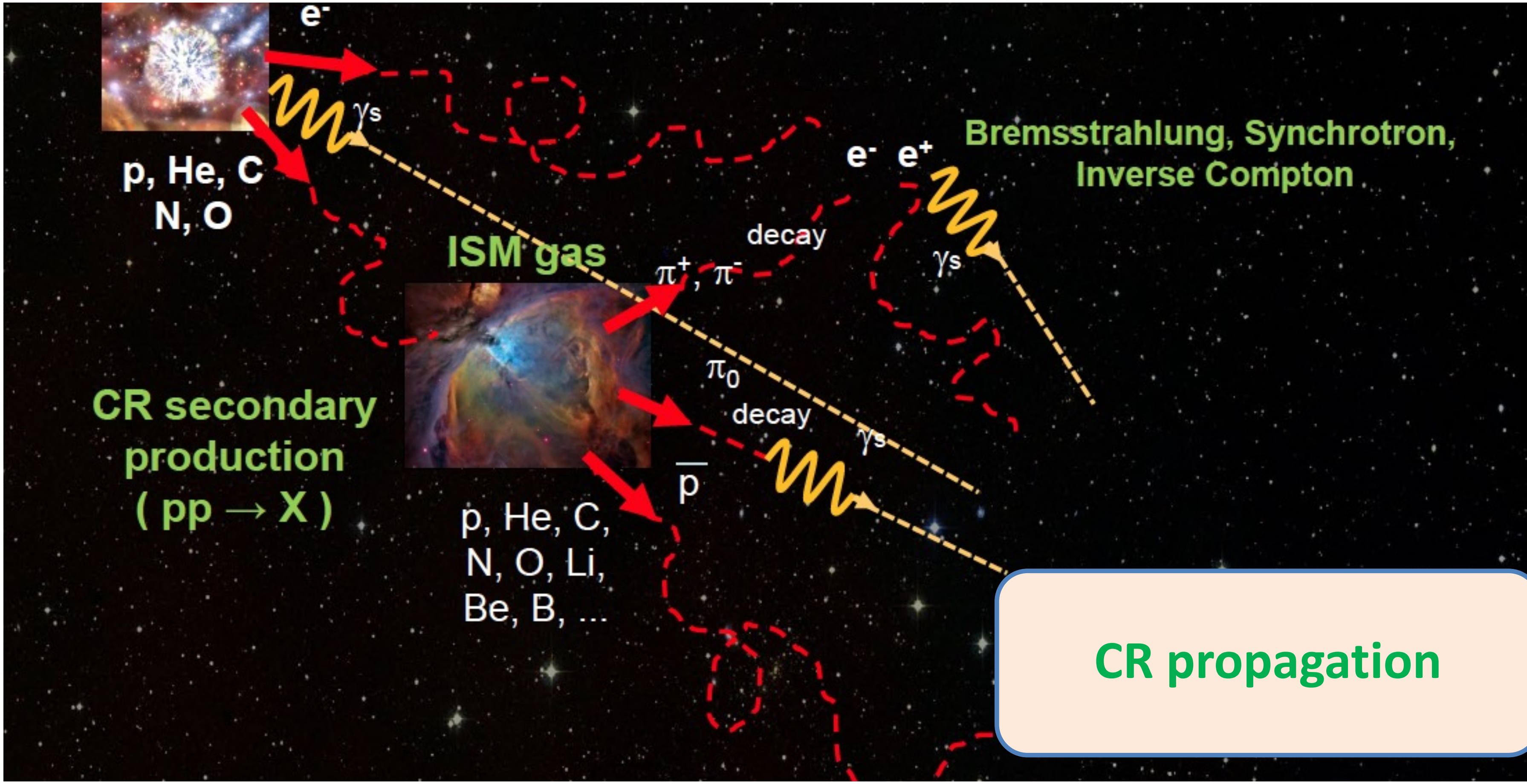
The nuclei normalization open question

- Nuclei (C, O, Fe) spectral shape measured by AMS-02 and Calet are very similar.

- The normalization of nuclei (C, O, Fe) measured by AMS-02 is larger than the one measured by Calet and previous experiments.

- Understanding the nuclei normalization is a challenge for current and future experiments.



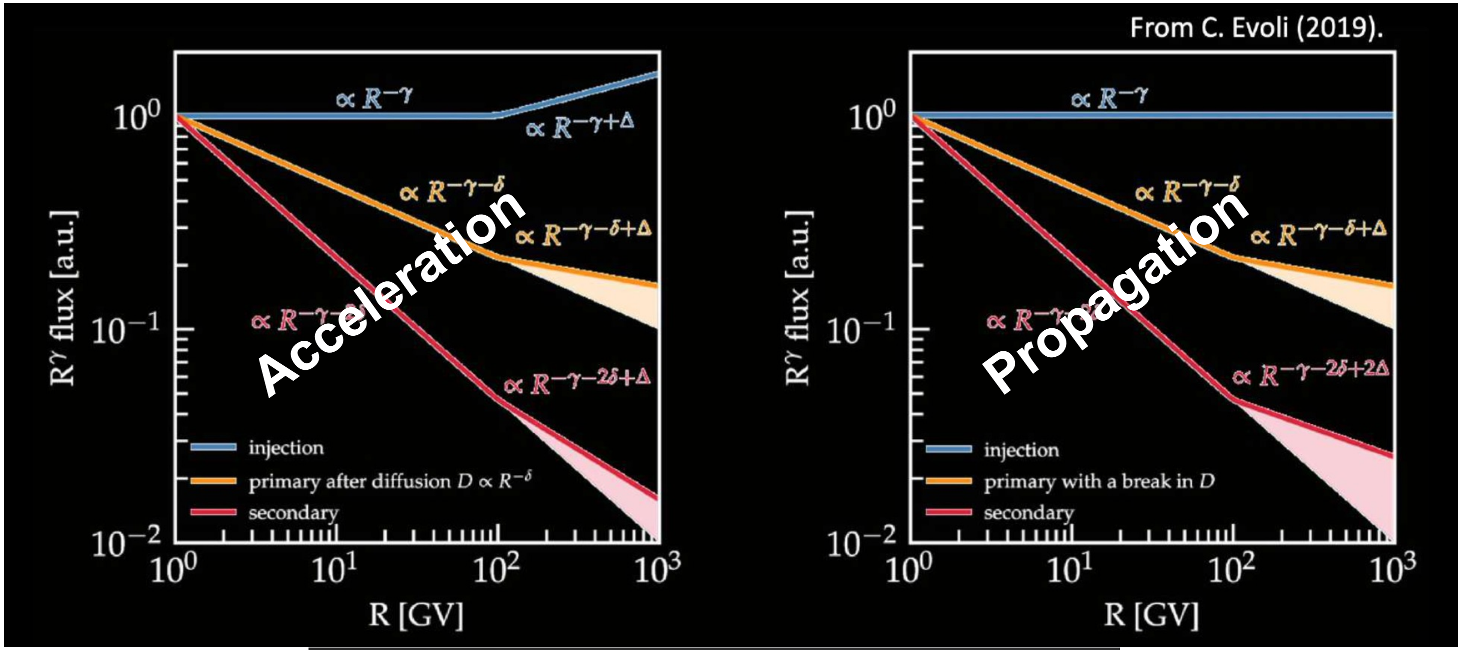


Secondary cosmic rays

- Secondaries from homogeneously distributed interstellar matter (light nuclei)

Secondary-to-Primaries ratio

- Li, Be, B are produced by spallation of heavier nuclei, mostly C, N, O, on H and He
- Secondary/Primary is very sensitive to propagation effects

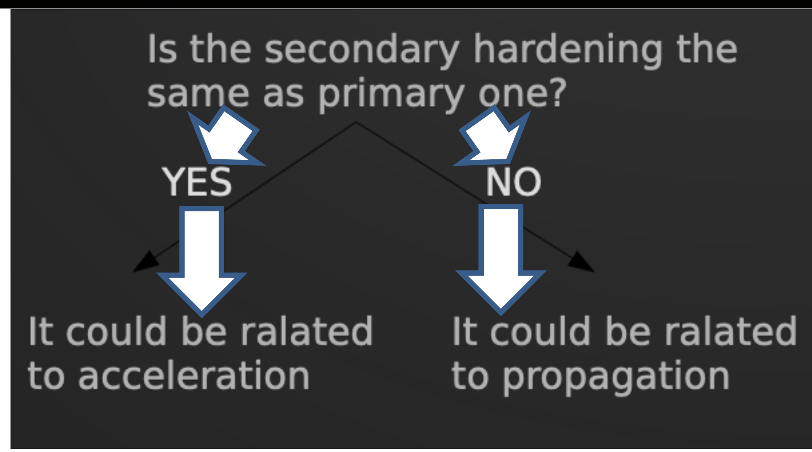


B/C = Sec/Prim

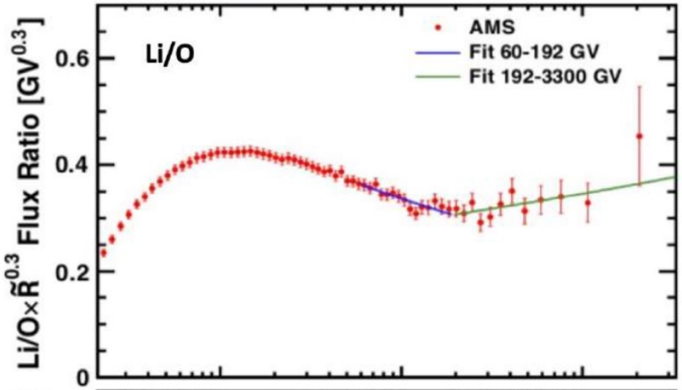
~ $Q_{sec}(E)/Q_{prim}(E)$

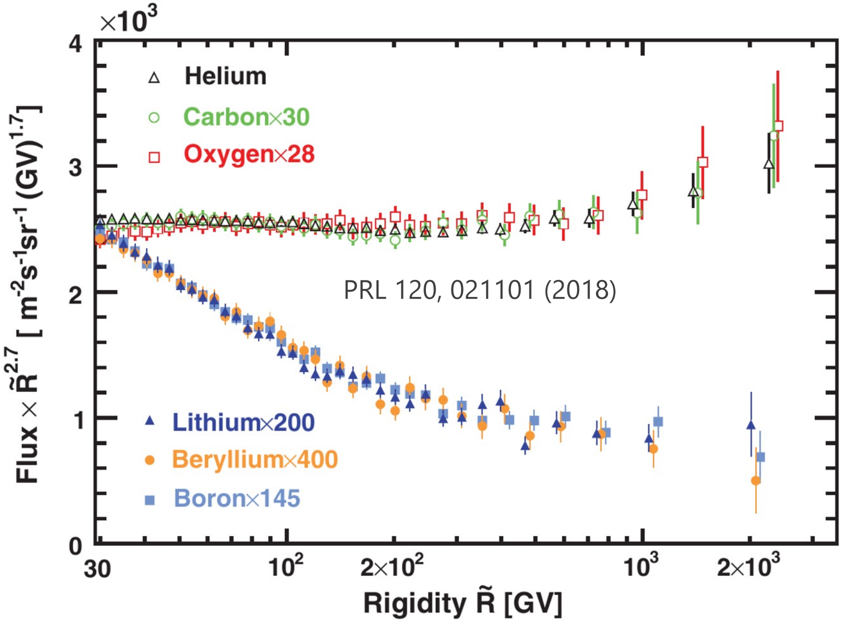
~ $Q_{prim}(E)/D(E)$ / $Q_{prim}(E)$

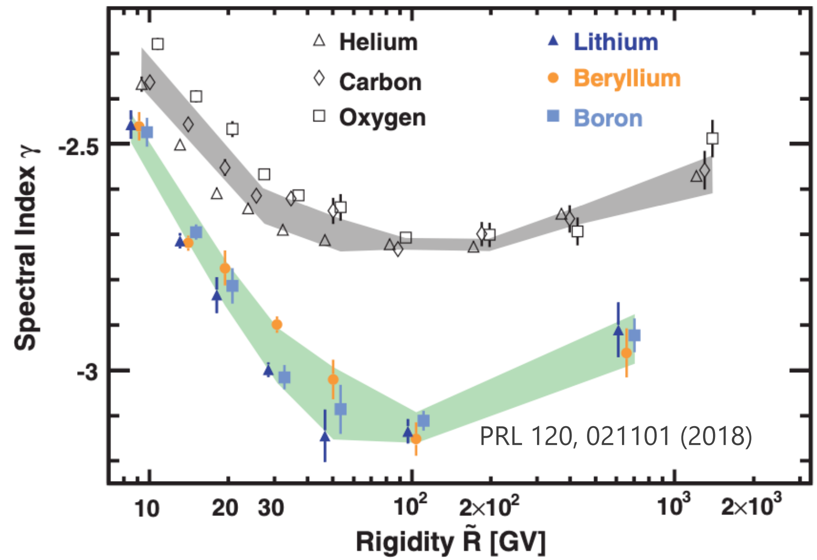
~ 1/D(E)



Li, Be, B with AMS-02







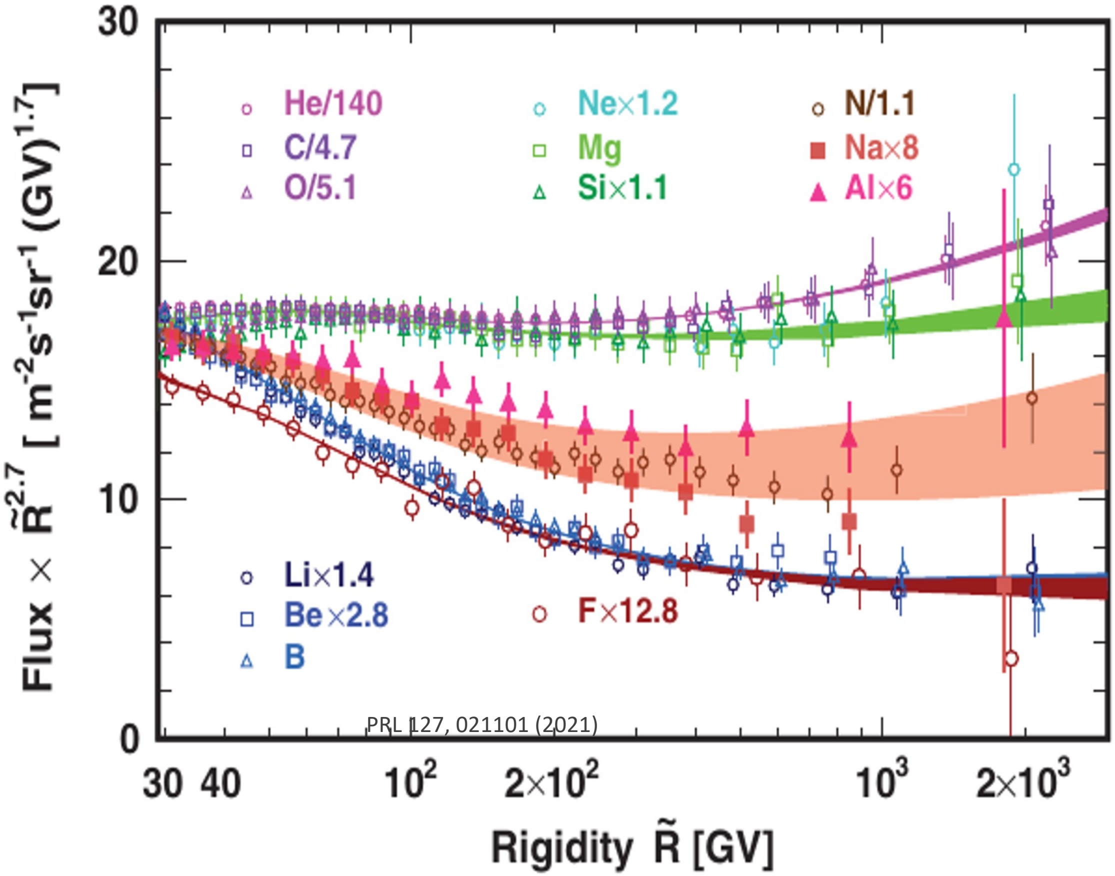
Also the secondaries nuclei show a spectral break

Very clear indications of Secondary/Primary ratio Rigidity dependent

Different change of slope: the Li-Be-B hardening is more pronounced.

- **Secondary/Primary ratio hardening**
- **The hardening seems to be related to CR propagation!**

A summary of recent measurements by AMS-02



Primaries

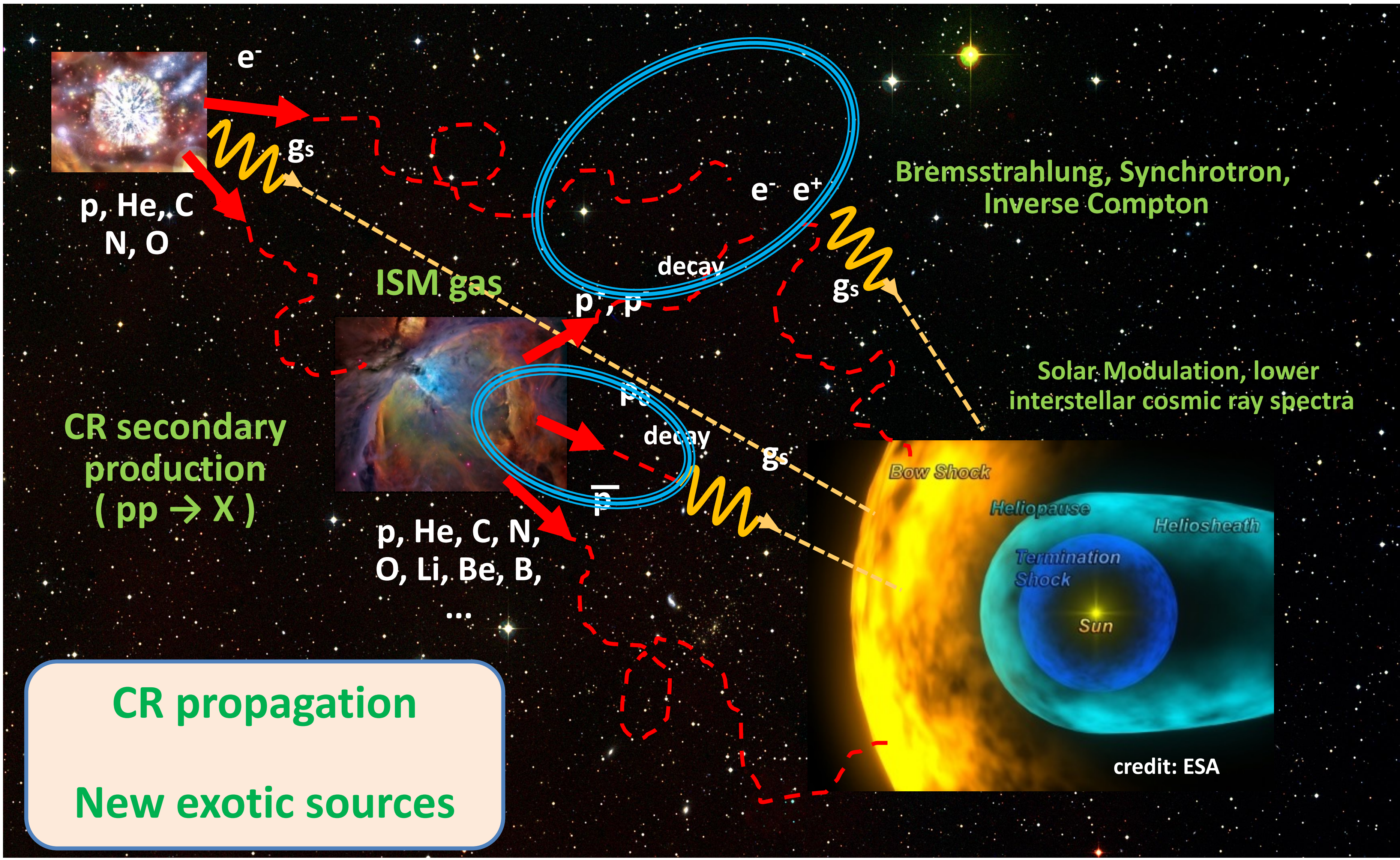
Primaries+Secondaries

Secondaries

N, Na, Al are a mixture of primary and secondary.

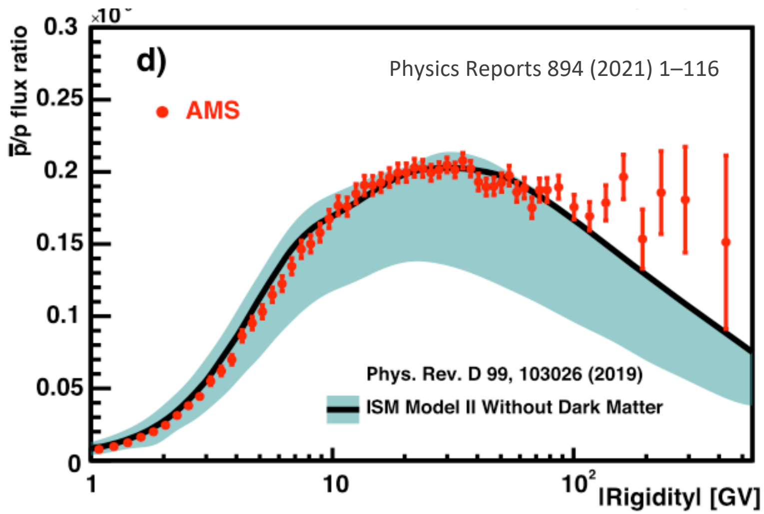
- **Life is becoming really challenging….**
- **Complex models required to explain the different nuclei spectra**
- **And cross section measurements could play a very important role!!!**

Cosmic Rays and Heavy Anti-Particles

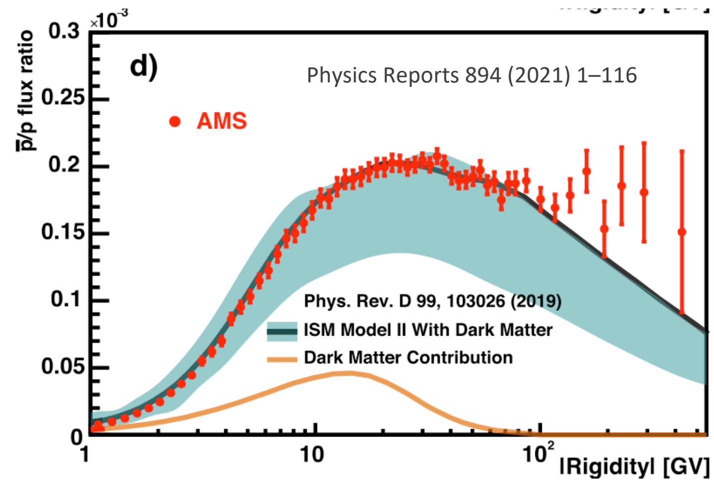


The anti-proton puzzle

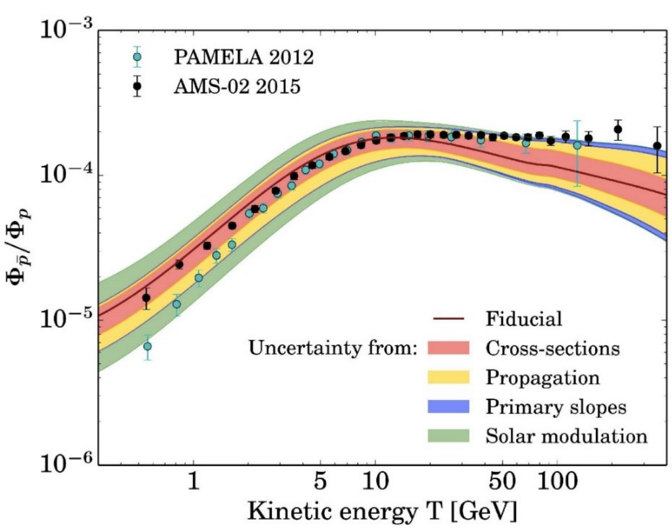
- Anti-proton spectra measured by Pamela (up to ~200 GeV) and by AMS-02 (up to ~500 GeV)
- Are Anti-protons purely secondaries?



Model without Dark Matter



Model with Dark Matter



Anti-proton/proton ratio is essentially flat above tens GV up to 500 GV → quite unexpected

The precision of the existing models is not enough to discriminate btw purely secondary production and Dark Matter hypothesis

A possible Dark Matter contribution would be a tiny effect

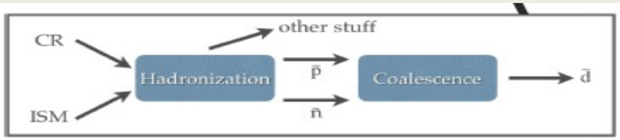
Theoretical predictions should be improved (cross sections!)

INFN

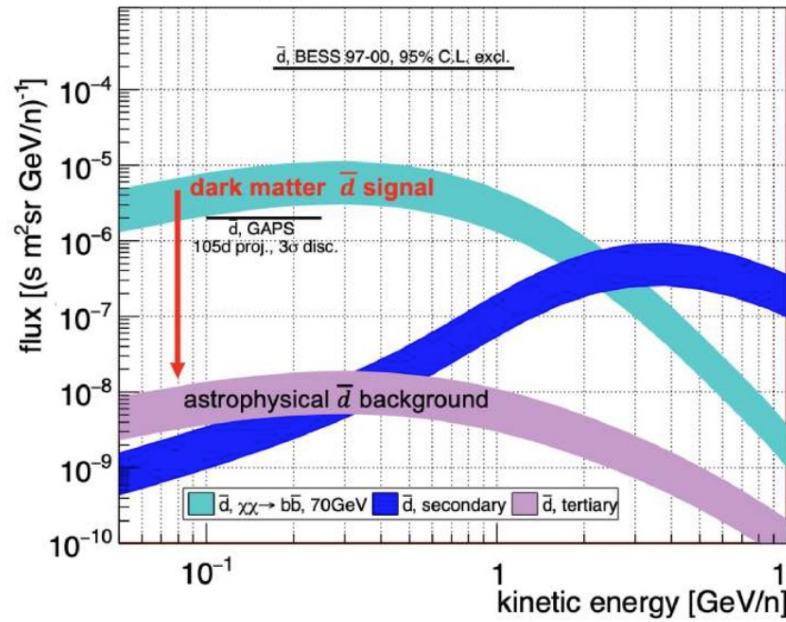
BESS-Polar II Antideuteron flux upper limit

Why antideuterons ?

High Signal-to-Background ratio = good channel for search.

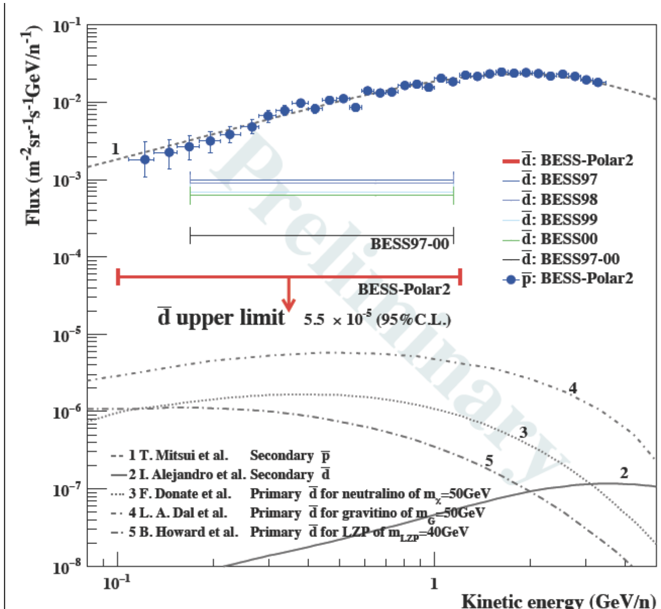


Low energy antinuclei are hard to produce due to kinematic effects



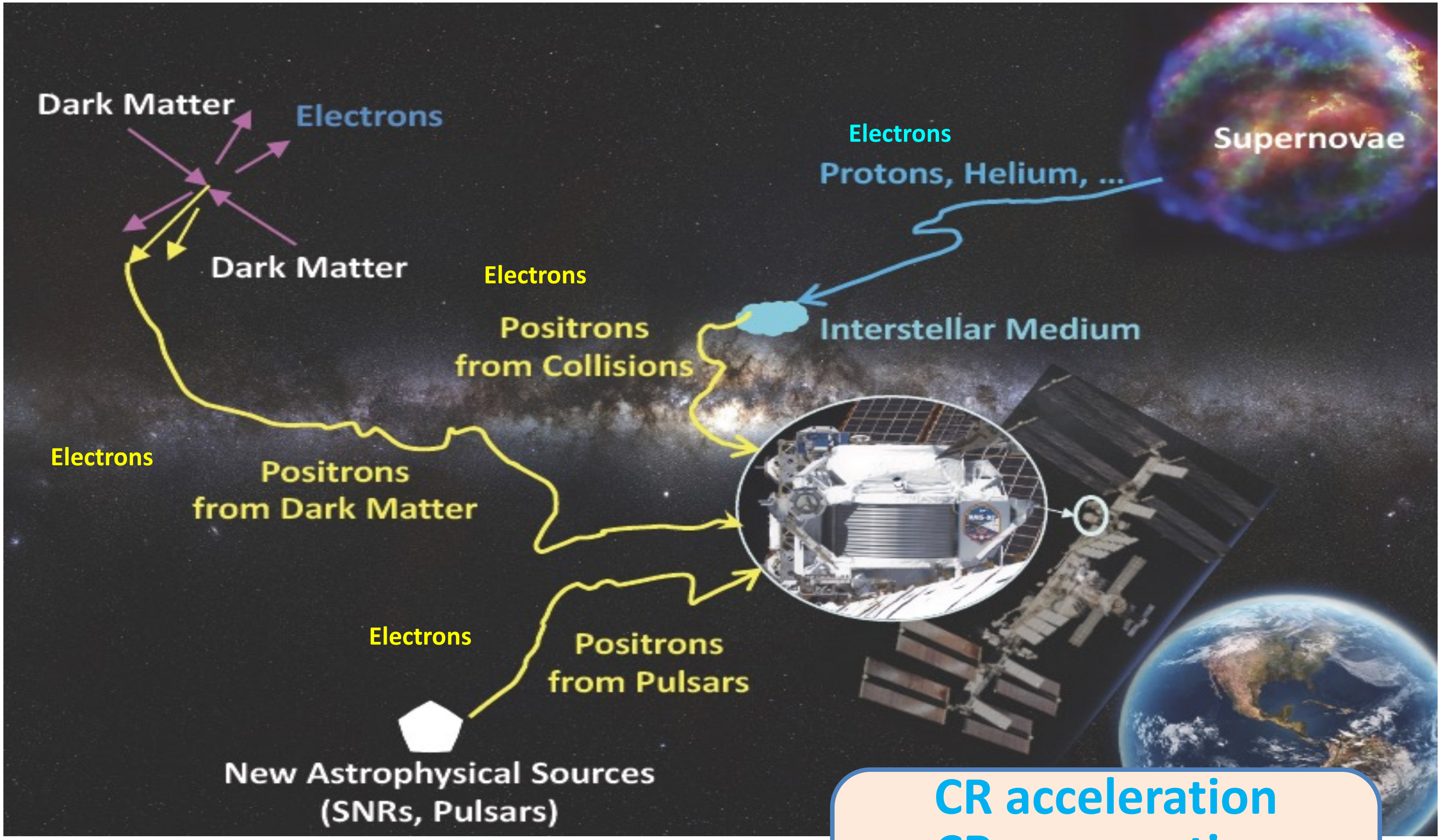
Bands = coalescence uncertainties

Low energy antideuterons are an excellent probe for DM, because the production of low energy secondary anti-deuterons is strongly suppressed



No Antideuteron candidate found in BESS-Polar II data

Electrons and positrons



CR acceleration
CR propagation

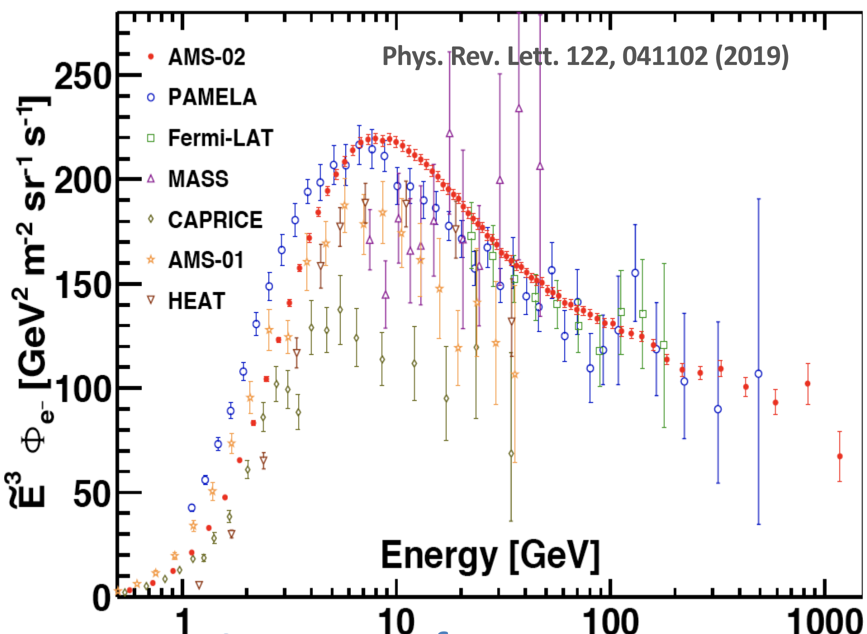
New sources

Electrons and positrons

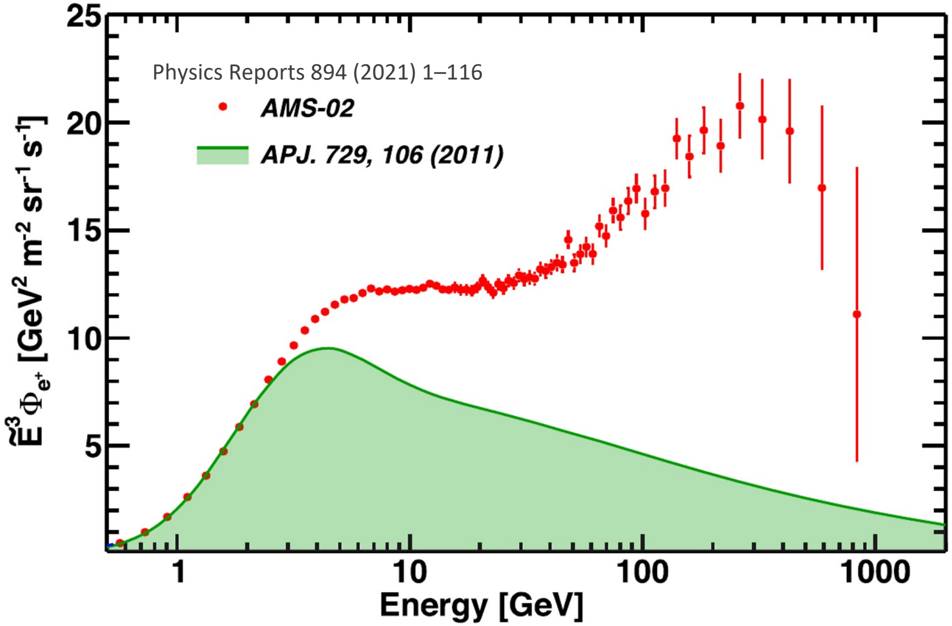
Positron excess detected by PAMELA and confirmed by AMS-02

Latest AMS-02 measurement features a peak @ ~ 300 GV

Electron flux x E^3

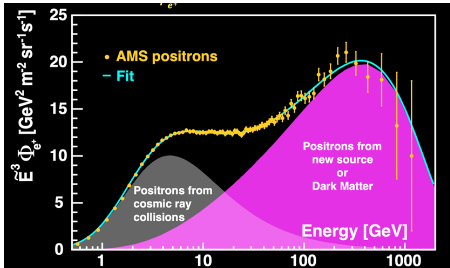


Positron flux x E^3

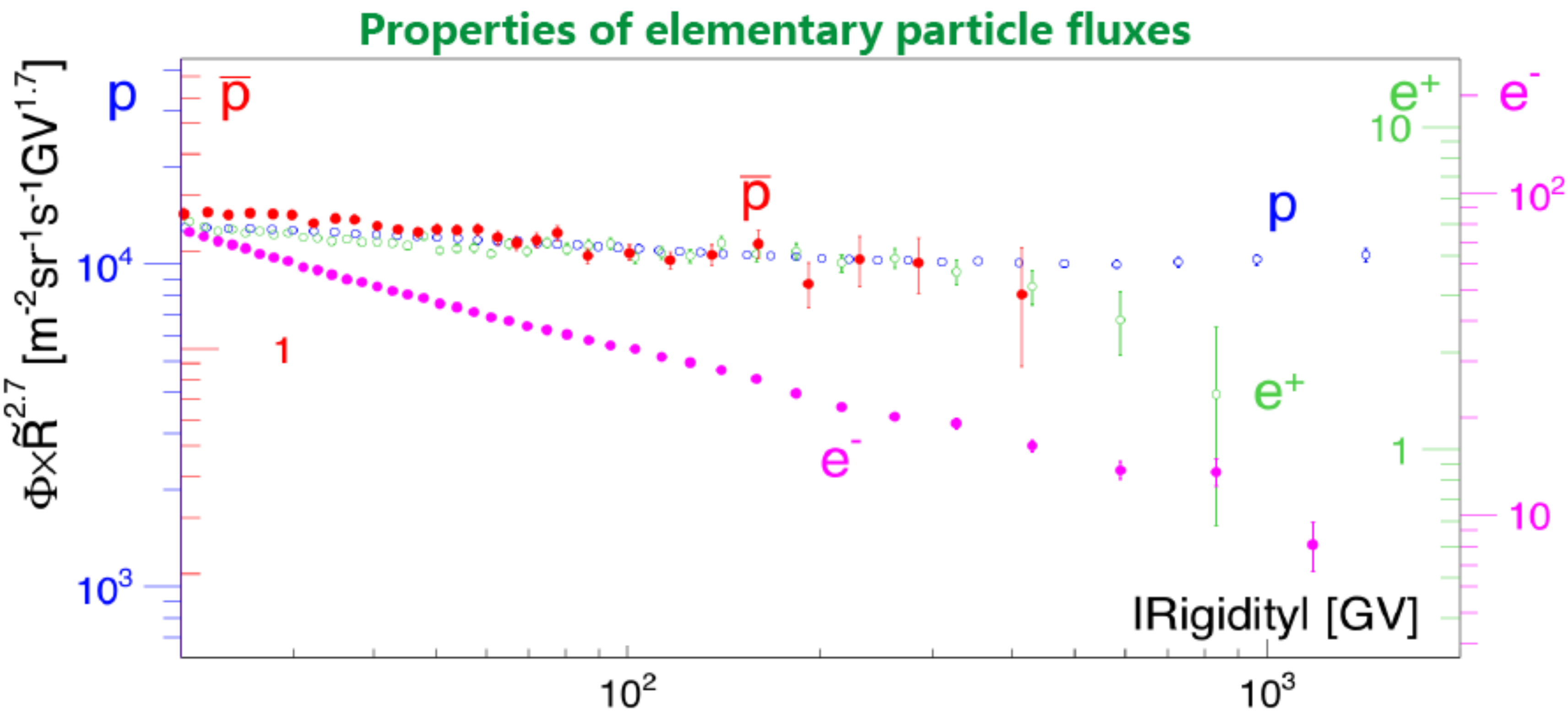


Important feature:
The spectral shape of e^- and e^+ is completely different!!!
Why the spectral index of e^+ flux is so complex and rigidity dependent?

- New models related to positrons take into account:
  - nearby positron sources (e.g. pulsar)
  - DM interaction or decay.



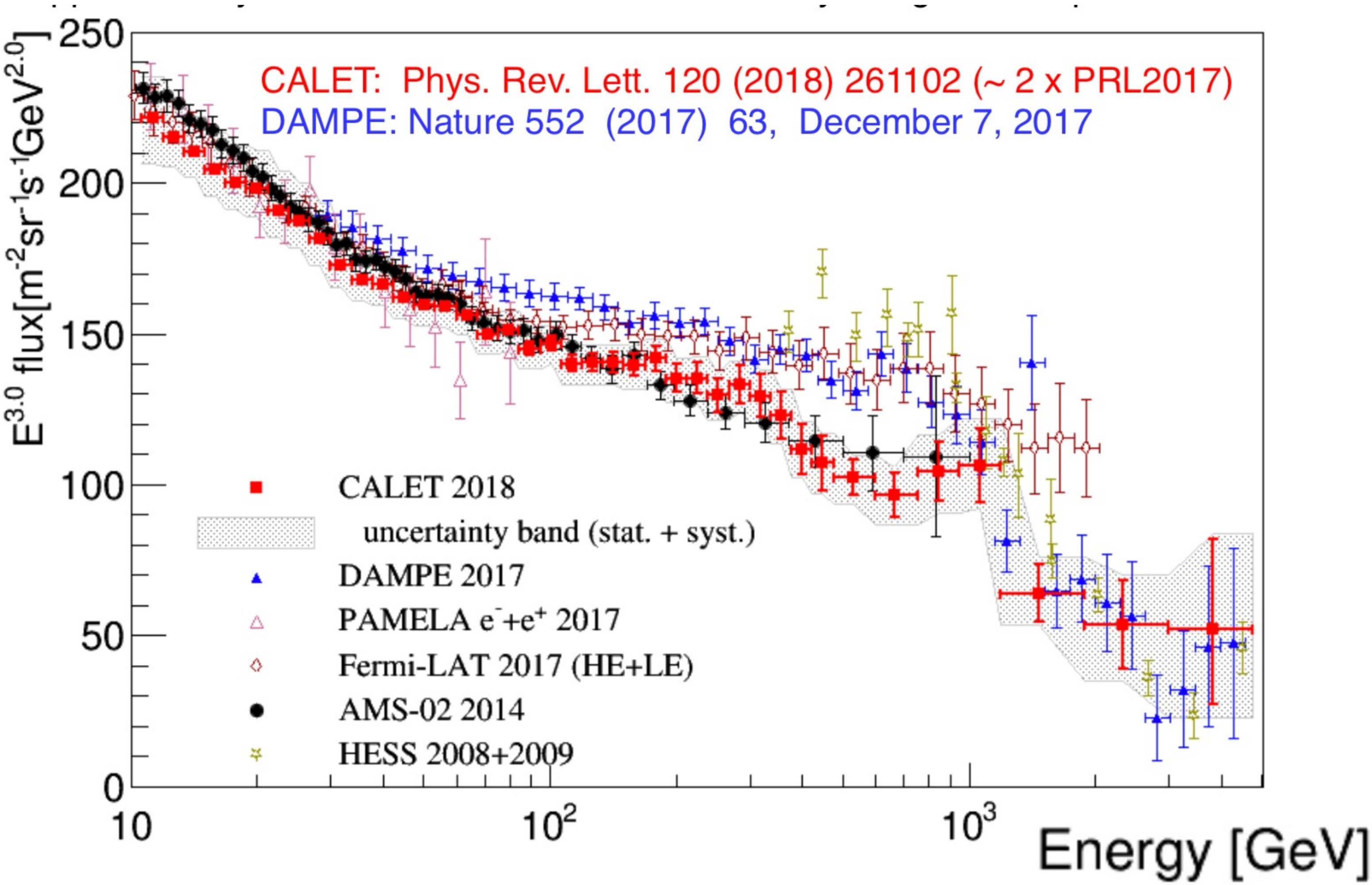
Electron/positrons/protons/antiprotons by AMS-02



Important feature:

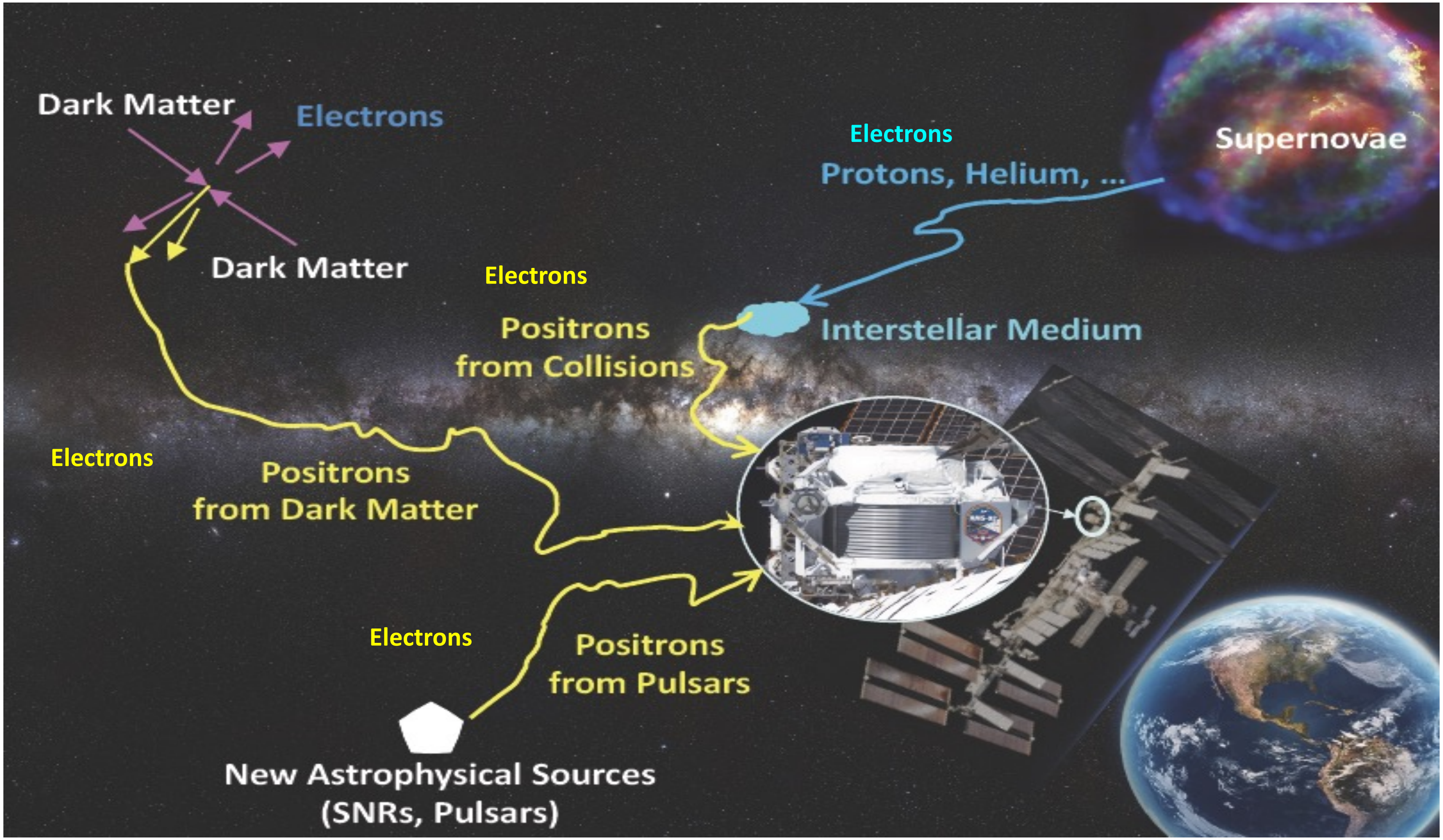
- The spectra of positrons, antiprotons and protons are nearly identical
- Positron spectrum shows a drop off at ~300 GV
- Electron spectrum is steeper
- Currently very few ideas to explain these points….

Electrons + positrons with CALET and DAMPE



Confirmed electron flux suppression seen by ground experiments at E > 1 TeV
Some tension between data (CALET-AMS vs DAMPE-FERMI)
Is something happening above few TeV?

Future experiments



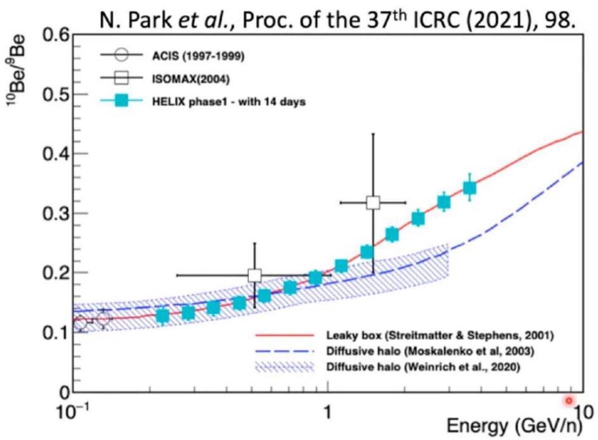
HELIX: High Energy Light-Isotope Experiment

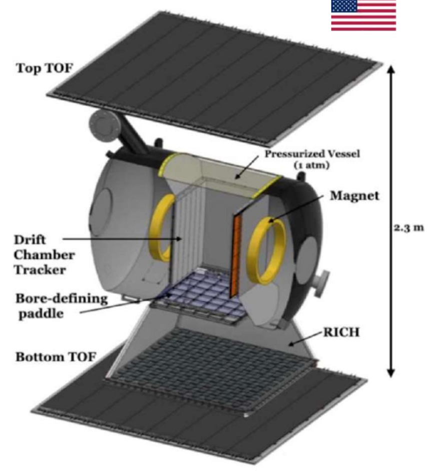
Experiment of CR isotopic composition measurement. Prime goal: $^{10}Be/^{9}Be$

Isotopic separation up to Neon. Basic spectrometer with drift chamber, B=1T, mass resolution <3%

HELIX is moving forward to be ready for integration in 2023

N. Park *et al.*, Proc. of the 37th ICRC (2021), 98.





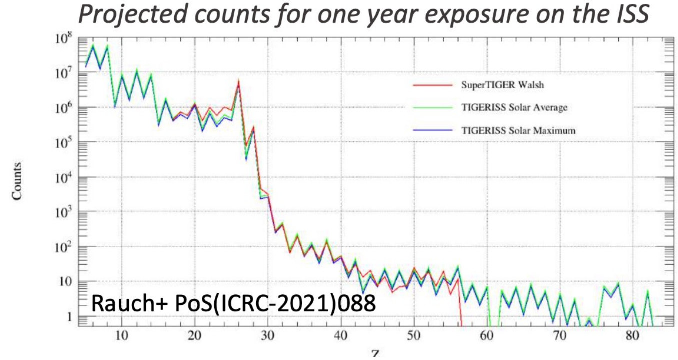
TIGERISS: Super-Heavy CRs from the ISS

TIGERISS: The Trans-Iron Galactic Element Recorder for the International Space Station

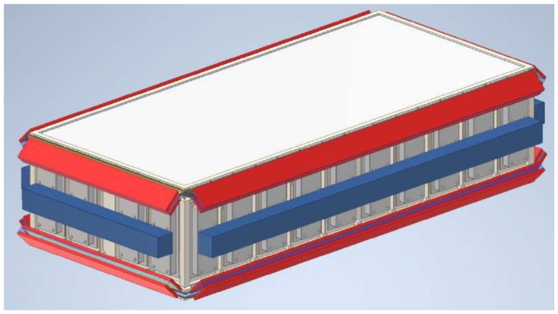
Based on SuperTIGER, to be installed on the ISS for a long-term mission.

Composition of the ultra-heavy CRs with single-element resolution from Z=6 (C) to Z=82 (Pb) or even Z=96 (Cm).

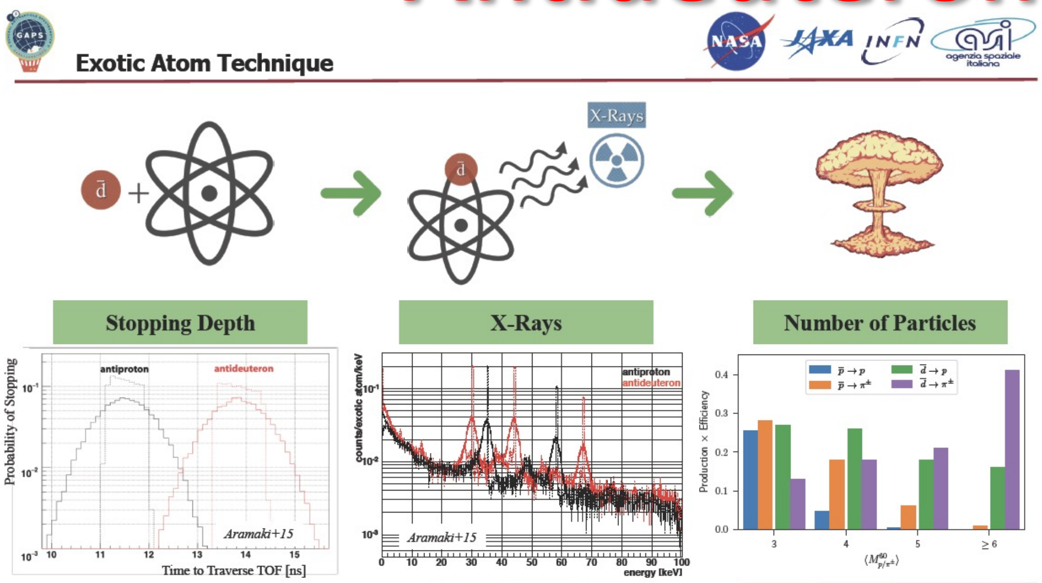
Projected counts for one year exposure on the ISS



Technical model of the detector stack

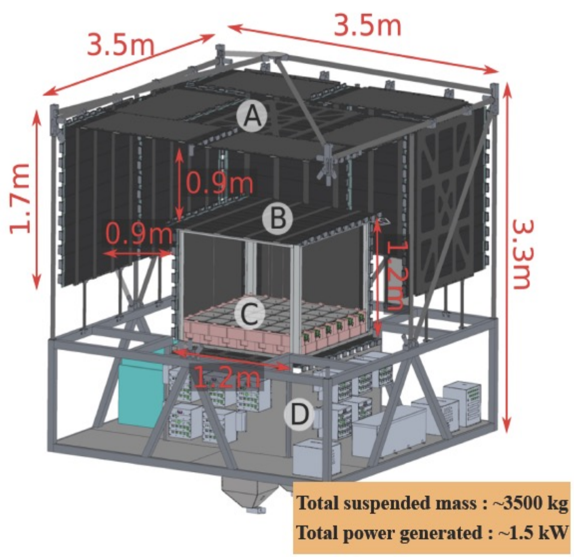


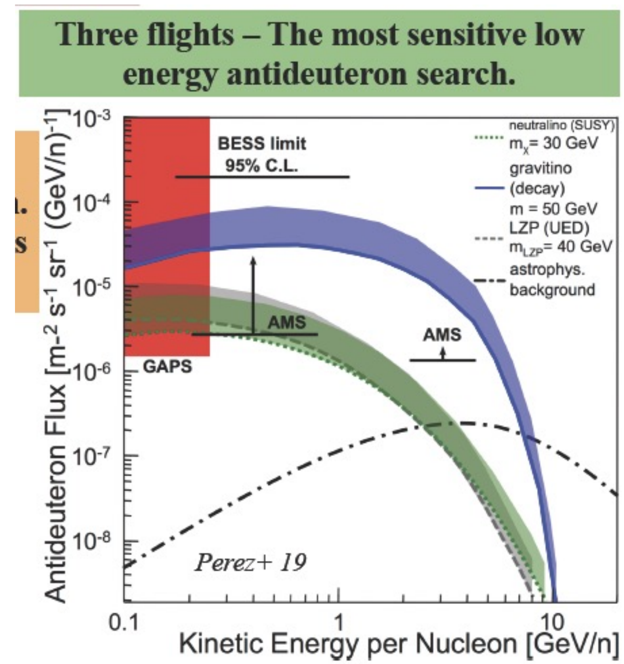
Antideuterons: GAPS



GAPS Detector – Overview

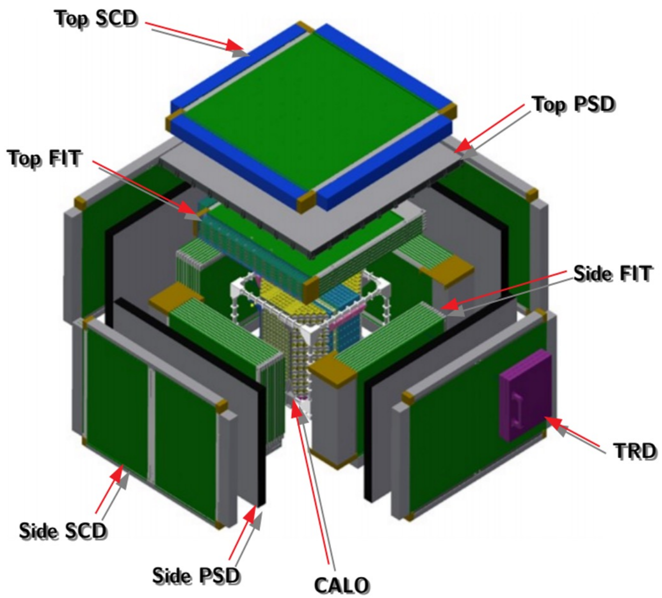
- The detector consists of 2 instruments.
  - Si(Li) Tracker (C):
    - 1440 10 cm-diameter Si(Li) detectors over 10 layers.
    - Stops primary, detects X-rays, tracks secondaries
  - Time-Of-Flight (A, B):
    - Two layers of plastic scintillator paddles providing near 100% coverage.
    - Characterizes primary, counts secondaries, provides trigger
- In addition:
  - Cooling, power & thermal insulation (not shown)
  - Support systems (D)

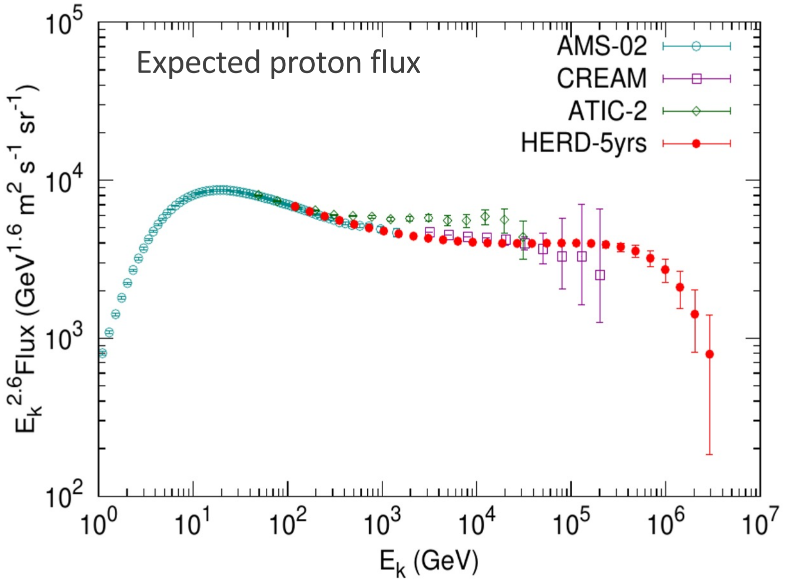




The future space calorimeter: HERD

- HERD is 3D detector with an acceptance at least ten times larger than current experiments (Gf_{eff}>3 m^2sr)
- Very Deep and fully 3D Calorimeter
- It will be installed aboard the Chinese Space Station around 2027.

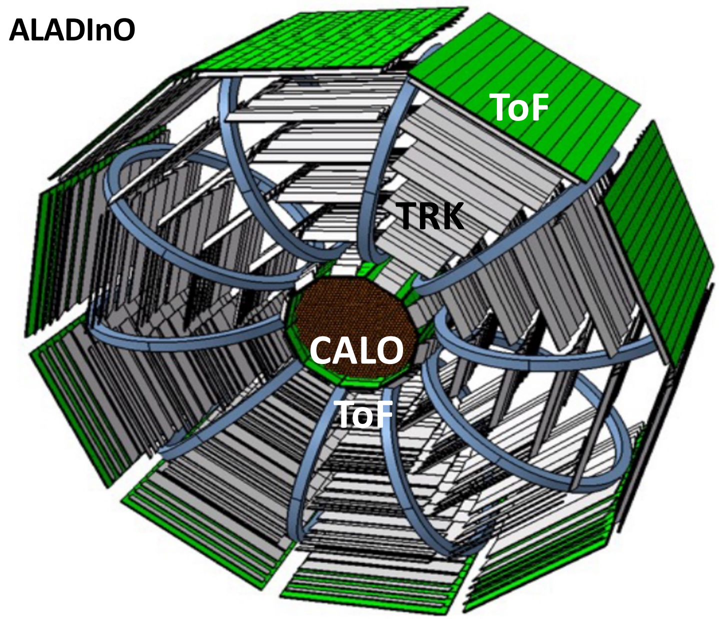




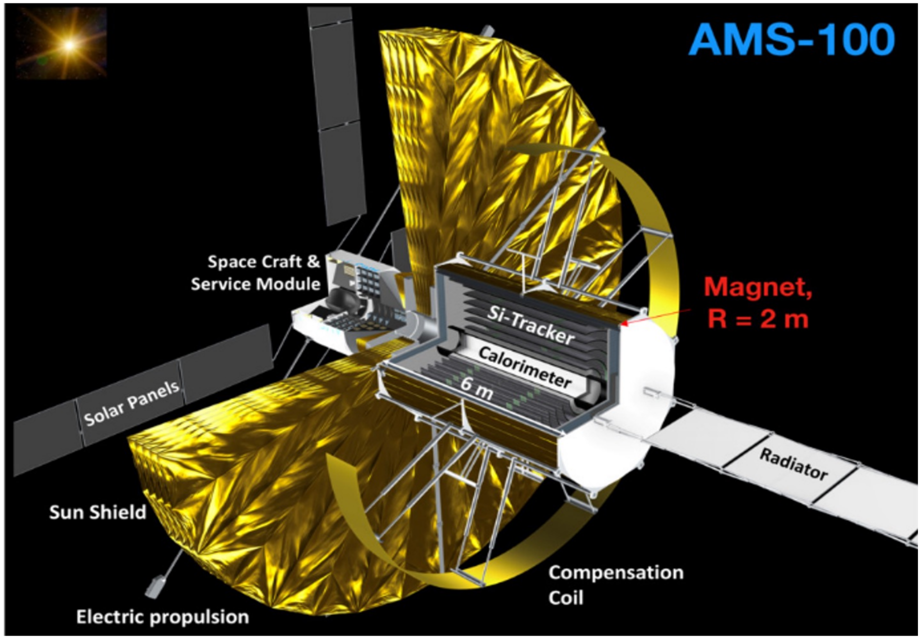
- **Main goal: first direct observation of protons up to the “knee”.**
- **Other goals: extension of nuclei and all-electron spectra.**

Projects for next generation spectrometers

- Long term projects @ L2 Lagrangian point: ALADInO and AMS-100



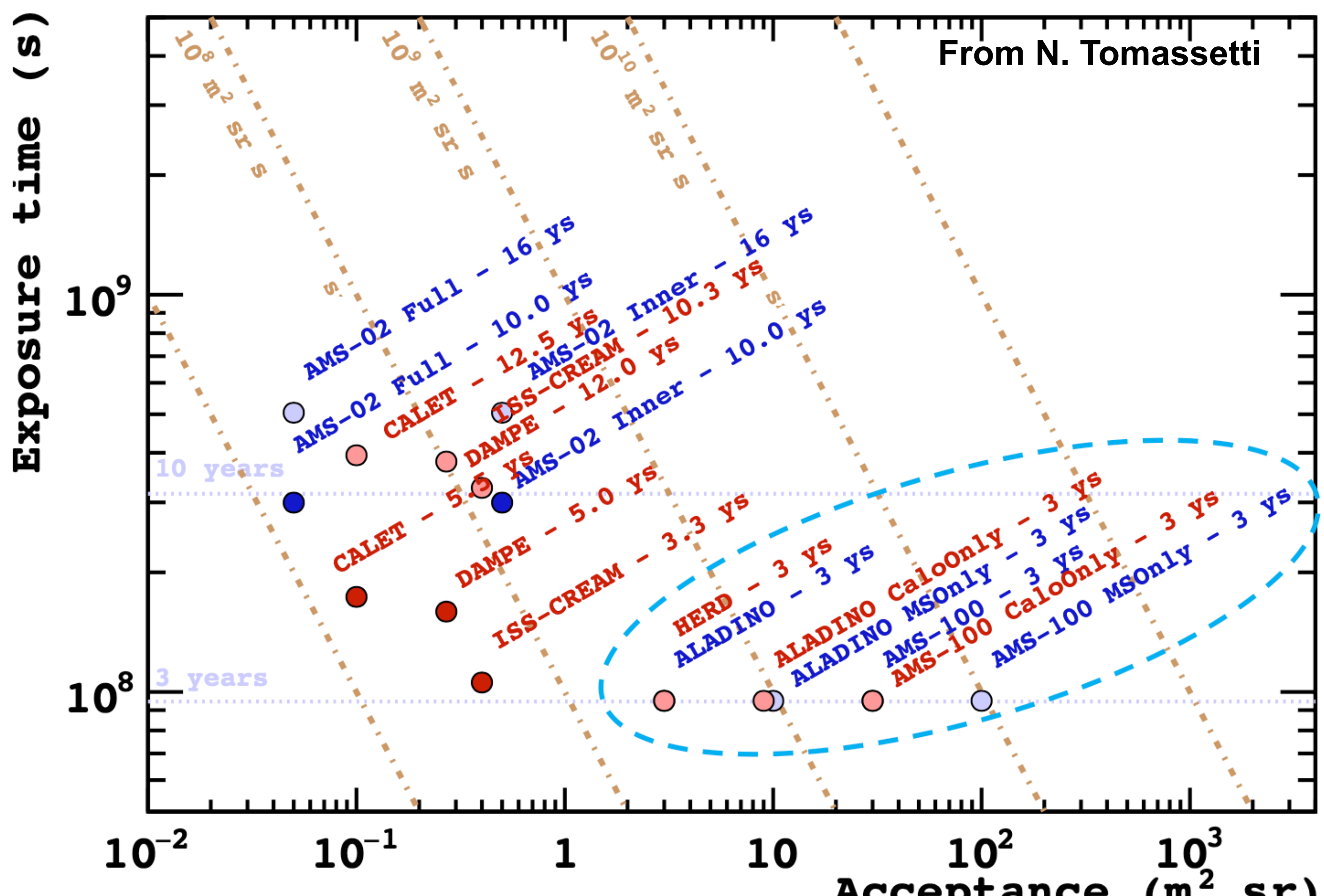
Instruments 2022, 6, 19. https://doi.org/10.3390/instruments6020019



Shael et al. NIM A 944 162561 (2019)

- Main goals:
  - electrons, positrons, and antiprotons up to 10 TeV,
  - nuclear cosmic rays up to PeV energies,
  - detection of low-energy antideuteron and antihelium.

Future facilities w/ 3 yrs data



Assumed 3 years of observation (after launch)

Conclusions: still many open questions !

The observational improvements occurred during the past decade allowed to identify a lot of unexpected features below the knee, revealing new physics phenomena that should be incorporated in a coherent model for cosmic ray origin/propagation.

Many new open questions have appeared and still need to be clarified:

I. What is the origin of the **hardening observed in the spectra of CR nuclei** at a rigidity of 300 GV?
II. Why is the slope of the spectrum of CR **proton and helium different**?
III. What is the origin of the cutoff observed at a particle energy of **1 TeV in the electron spectrum**?
IV. Why do the **proton, positron, and antiproton spectra have roughly the same slope at particle energies larger than 10 GeV**?
V. What is the origin of the **rise in the positron fraction** at particle energies above 10 GeV?
VI. Why the **antiproton/proton ratio is constant above 60 GeV**?

- The increase in statistics of the existing experiment and the new future experiments (GAPS, HERD, ALADINO, AMS-100…) will allow to significantly extend the current measurements, and will allow us to improve our still quite limited knowledge on CR

A common effort between experimentalist (in different fields) and theorists is currently under way and is absolutely necessary to shade light on the many still open questions

Backup slides

Conclusions

Matter

- An impressive precision level in the nuclei measurements in the GeV to multi TeV energy region has been reached
- Spectral hardening at high energy observed both in primaries and secondaries (p, He, C, O, Be, B, Li, etc.)
  - Changes in the propagation properties in the Galaxy
    - Stronger hardening expected for Secondaries
- Spectral softening in p and He in the Multi-TeV region
  - New source? Diffusion effect?
- Uncertainties in the measured values of the cross sections are a critical ingredient

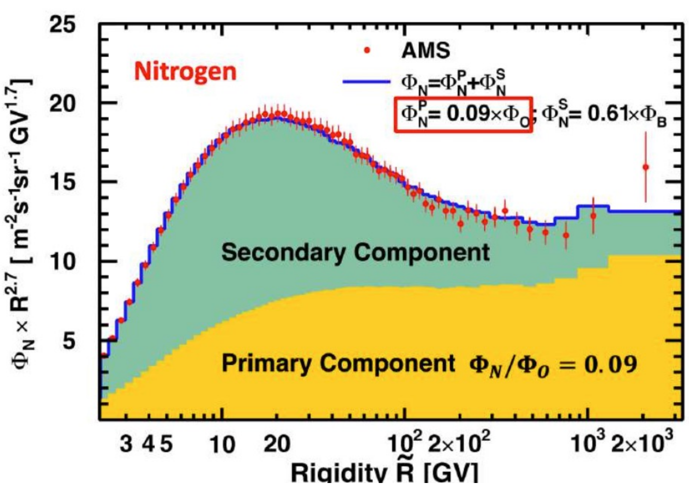
Antimatter

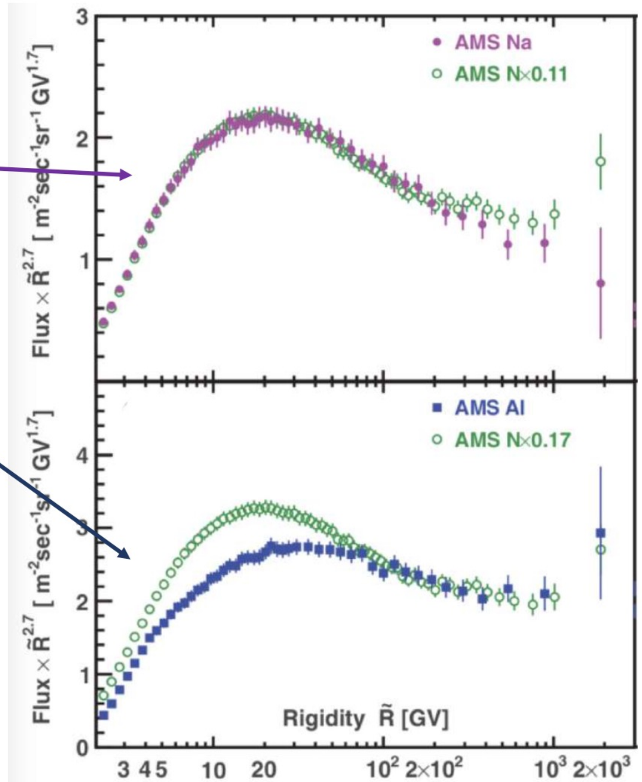
- For sure there is an excess of positrons
  - Positron measurements are inconsistent with pure secondary hypothesis. We do need a nearby source to reproduce the data (PWN? DM?)
- Is there an excess of antiprotons?
  - A flat antiproton-to-proton ratio is quite unexpected. Is it an anomaly? Astrophysical background affected by large uncertainties (Cross section, possibily measured also at LHC)
- The spectra of protons, positrons and antiprotons have identical rigidity dependence above 60 GV.
  - Currently very few ideas.

High-energy spectra of other nuclei: N, Na & Al

Nitrogen is a known mix of primary & secondary CRs.
Similarly for Na and Al, but with different mixtures.

- Below 100 GV, the Sodium flux and its spectral index are similar to Nitrogen
- Above 100 GV, the Aluminum flux and its spectral index are similar to Nitrogen

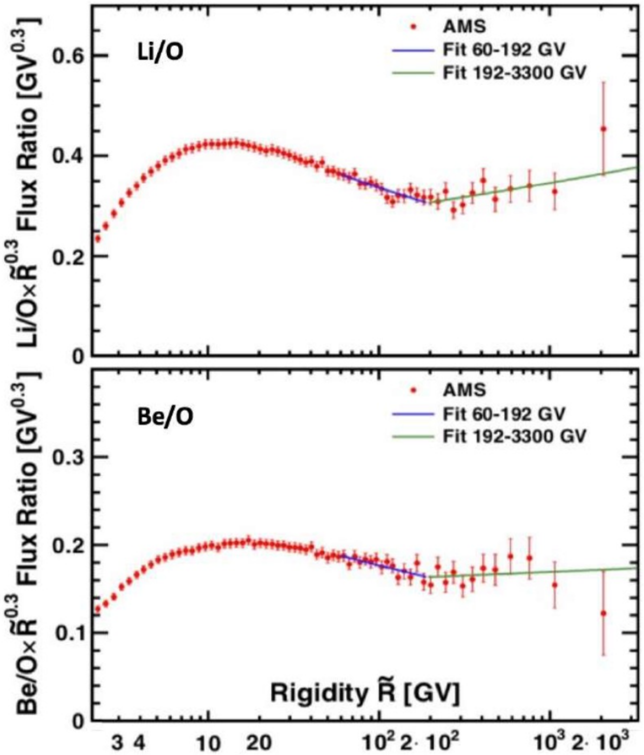




Spectral hardening in secondary/primary ratios

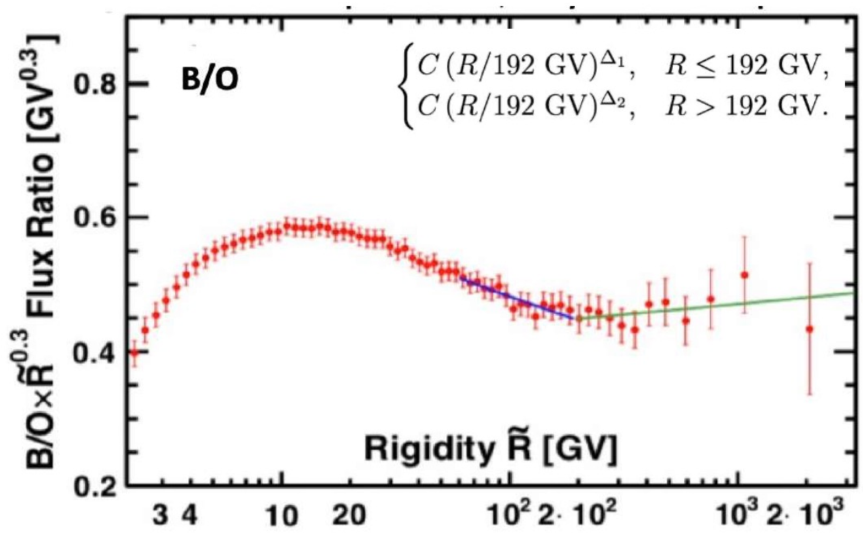
The break is seen not only in secondary CRs, but also in **secondary/primary** ratios.

The hardening seems not related to CR injection/acceleration, but to **CR propagation**

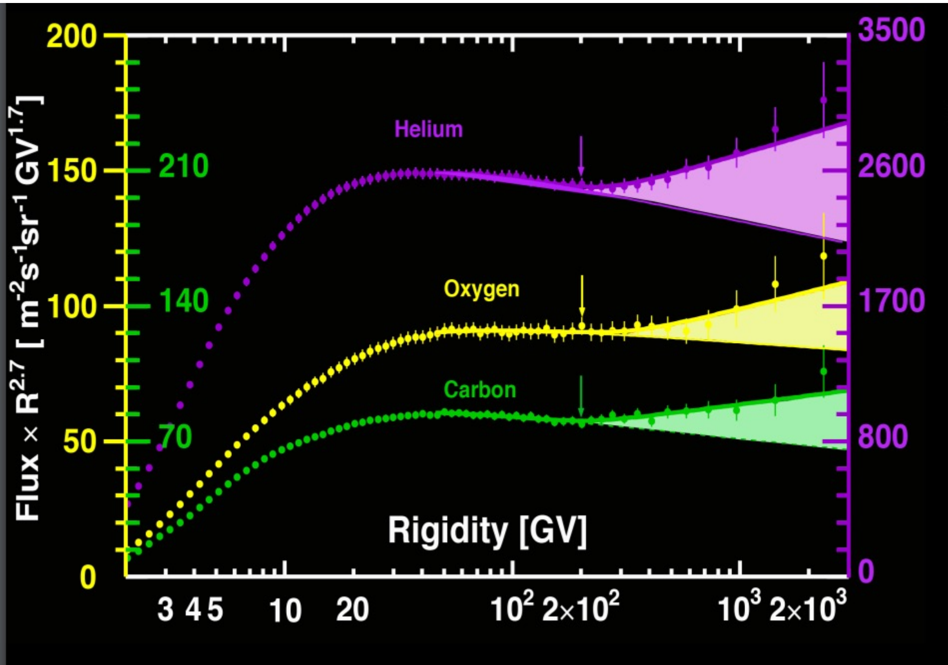


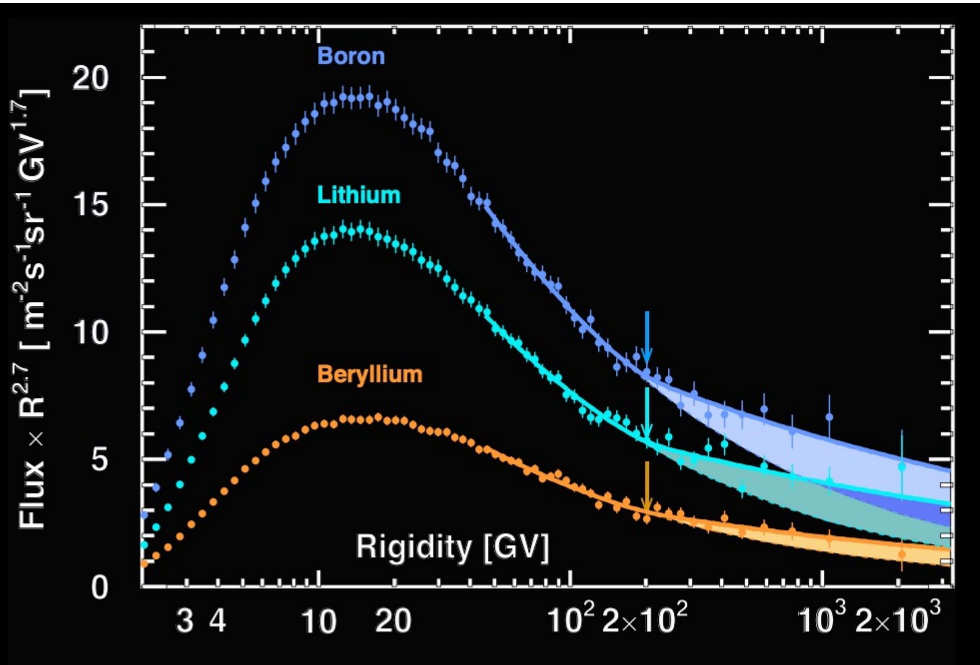
The diffusive origin of the breaks is discussed in many models:

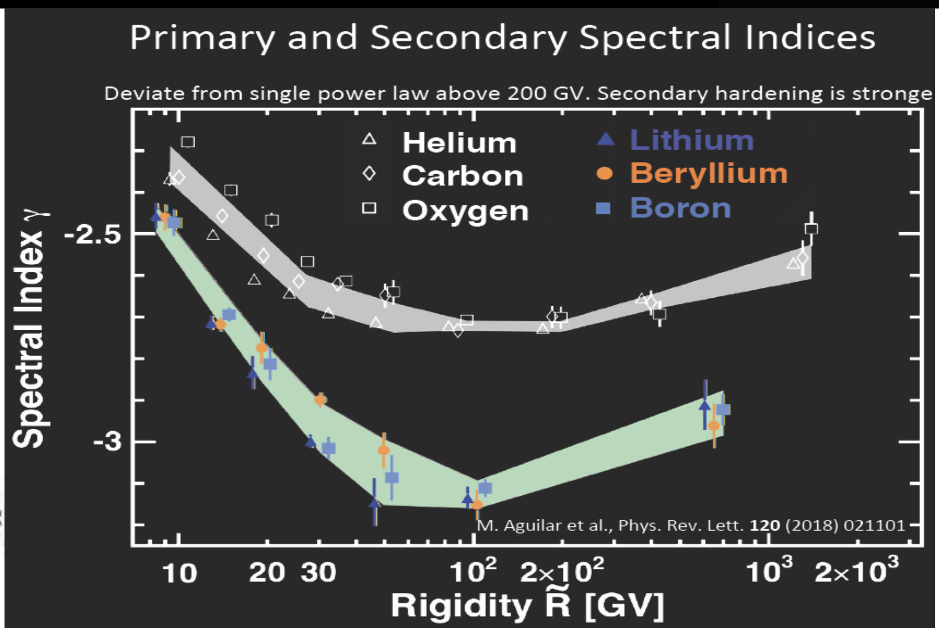
- NT, ApJL 715, L13 (2012) [arXiv:1204.4492],
- Blasi et al., PRL 109, 061101 (2012) [arXiv:1207.3706]
- Evoli et al. PRL 121, 021101 (2018) [1806.04153]



Li, Be, B with AMS-02: spectral hardening







Clear indication that also the secondary nuclei show a spectral break at ~200 GV

The hardening is different for Primaries and Secondaries

Is It a confirmation that hardening is due to propagation?

From F. Donato

Possible origin of anti-helium: anti-clouds, anti-stars

V. Poulin et al. PRD 2019

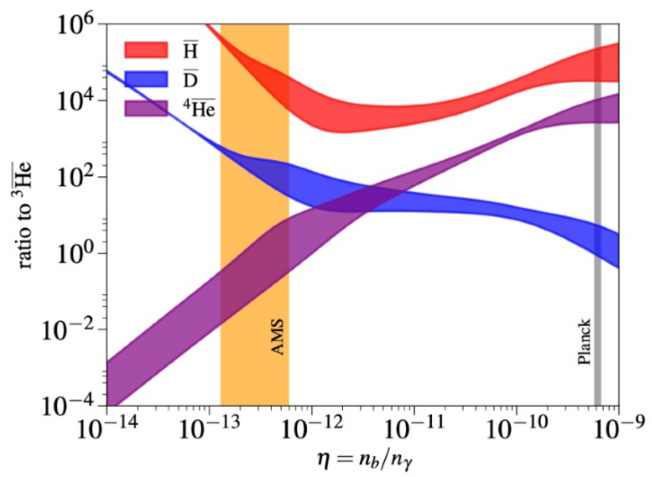


FIG. 4. Abundance of $\overline{\mathrm{H}}$, $\overline{\mathrm{D}}$ and $^4\overline{\mathrm{He}}$ with respect to that of $^3\overline{\mathrm{He}}$ as a function of the (anti-)baryon-to-photon ratio $\bar{\eta}$. The *Planck* value is represented by the grey band. The value required by the *AMS-02* experiment is shown by the orange band.

Anti-clouds: require anisotropic BBN for the right ^{3}He/^{4}He
AMS-02 measures are local, Planck's ones averaged over the Universe

Exotic mechanism for segregation of anti-clouds is needed
Traces in p-bar and D-bar

One anti-star could make the job.
How did they survive?

Bess-Polar I and II

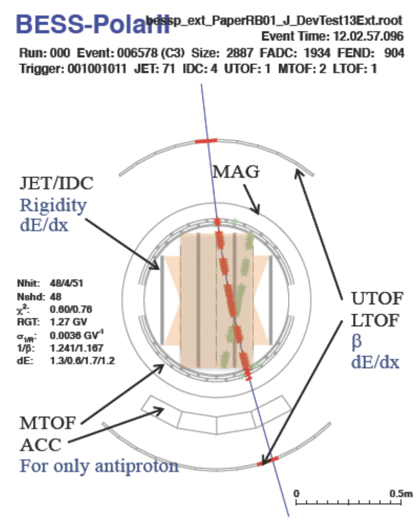
2 BESS-Polar I and II experiment

BESS-Polar I & II flights were carried out over Antarctica.

BESS-Polar I (green),
BESS-Polar II (1^{st} :blue, 2^{nd} :red)

	BESS-Polar I	BESS-Polar II
Launch date	Dec. 13^{th} ,2004	Dec. 23^{rd} , 2007
Observation time	8.5 days	24.5 days
Cosmic-ray observed	9 x 10^8 events	4.7 x 10^9 events
Flight altitude	37~39km (5~4g/cm^2)	~36km (6~5g/cm^2)

3 BESS spectrometer



Event display with reconstructed proton track is shown.

Rigidity (MDR:200GV)

Solenoid: Uniform field (ϕ=0.9m, B=0.8T)
Thin material (2.4 g/cm²/wall)

Drift chamber: Redundant hits
(σ~150μm, 32~48+4hits)

Charge, Velocity

TOF, Chamber: dE/dx measurement
(Z = 1, 2, ...)

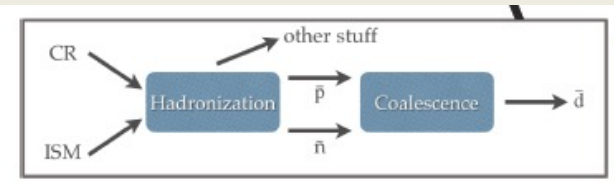
TOF: 1/β measurement (σ~1,2%)

$$m = ZeR\sqrt{1/\beta^2 - 1}$$

Antideuteron searches with BESS-Polar II

Why antideuterons ?

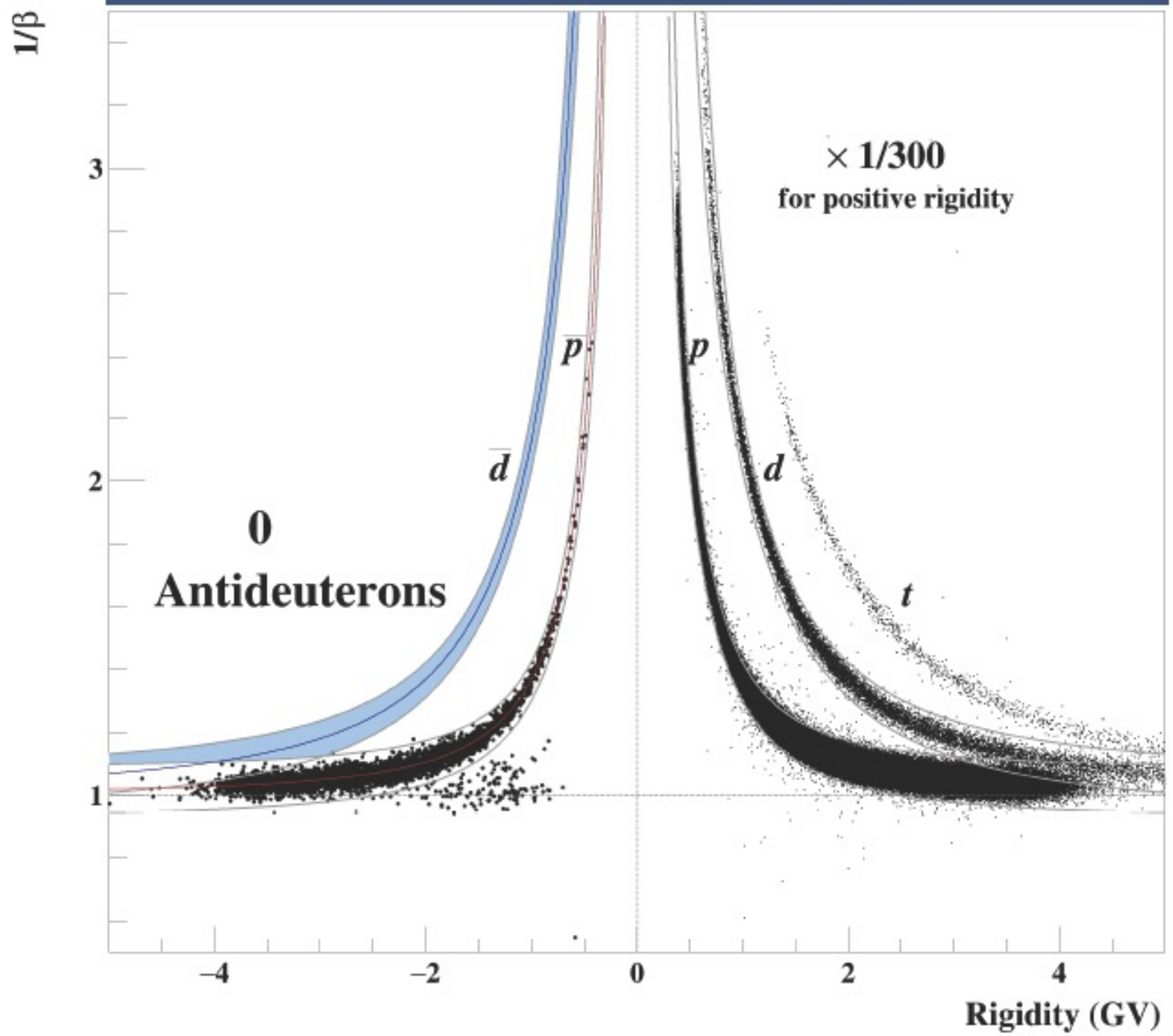
High Signal-to-Background ratio = good channel for search.



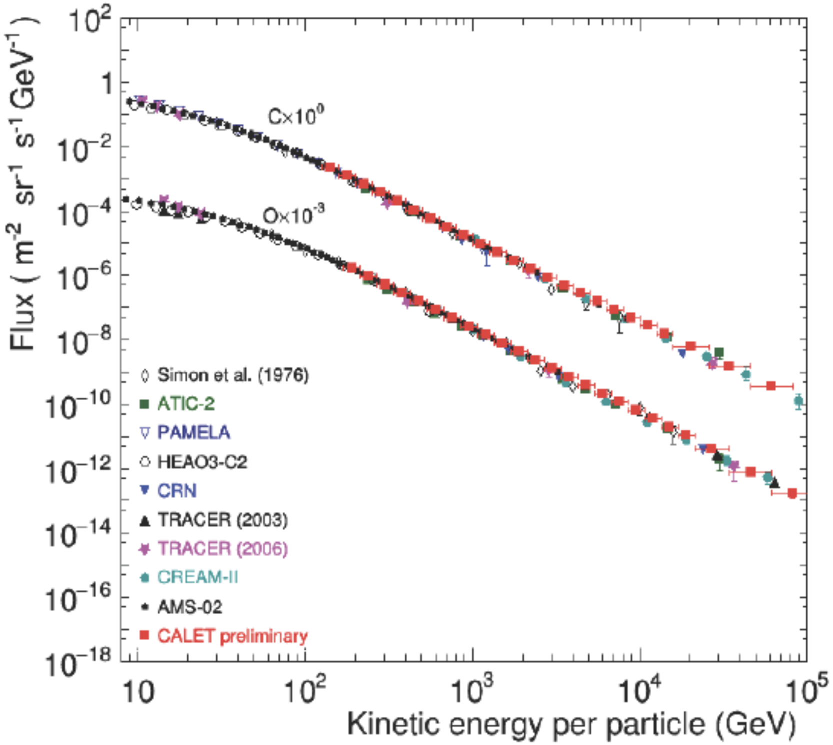
Low energy antinuclei are hard to produce due to kinematic effects

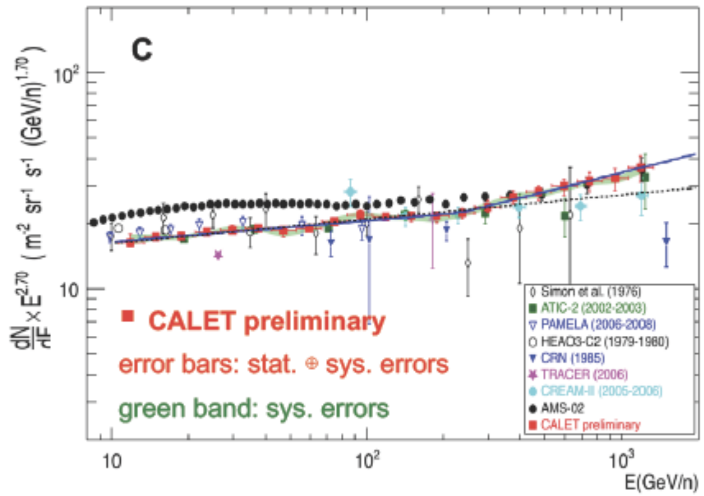
No Antideuteron candidate found in BESS-Polar II data

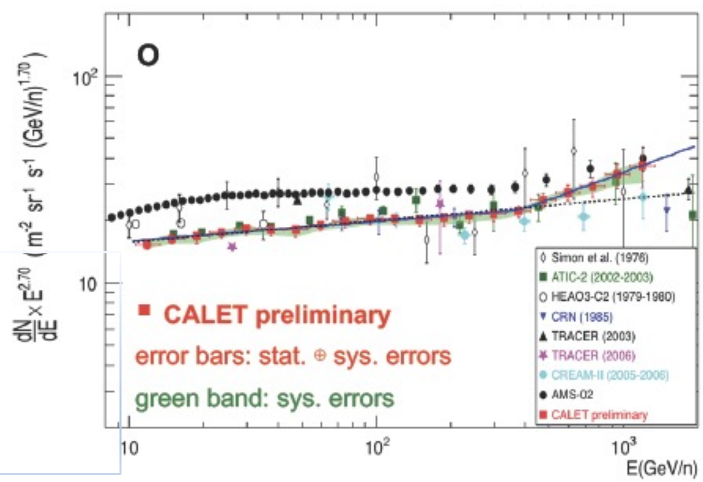
The $1/\beta_{UL}$ VS rigidity plot



Carbon and Oxygen with CALET



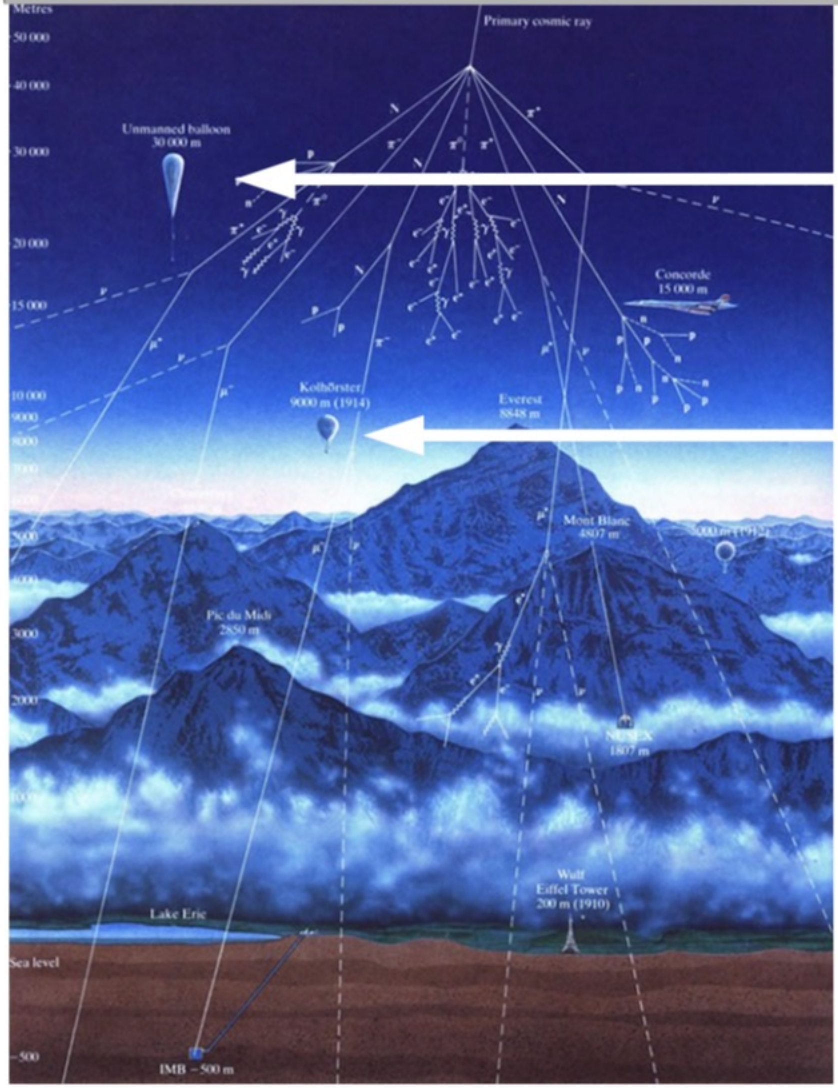




Important feature:

- confirmation of spectral hardening. some tension with AMS data (20% discrepancy)

ISS: 400 km
AMS-02
CALET
ISS-CREAM

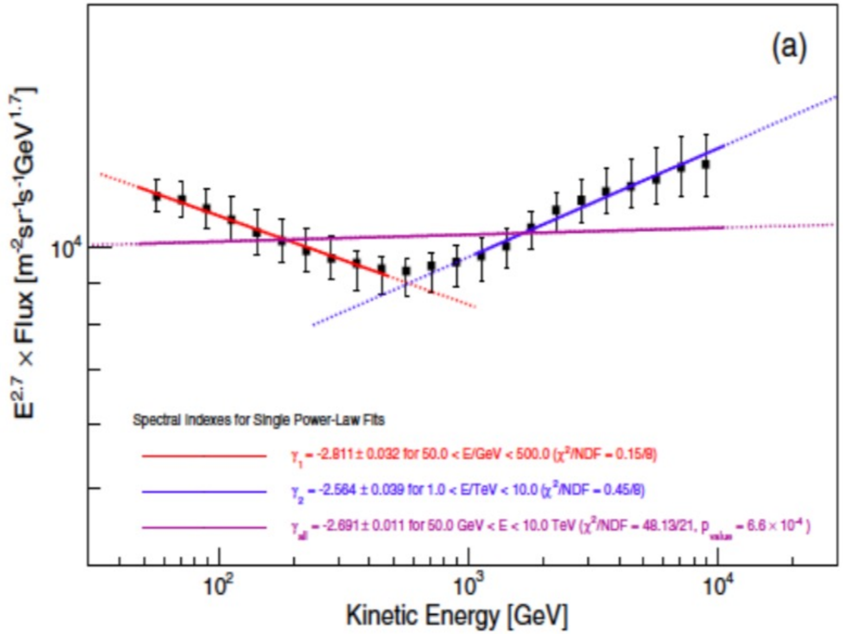


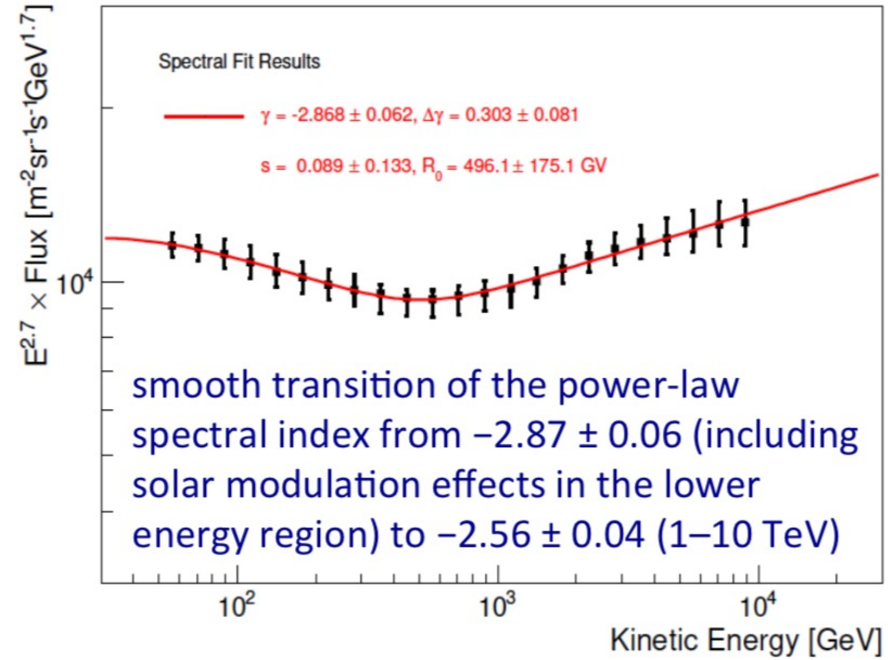
Modern balloons
~30 km

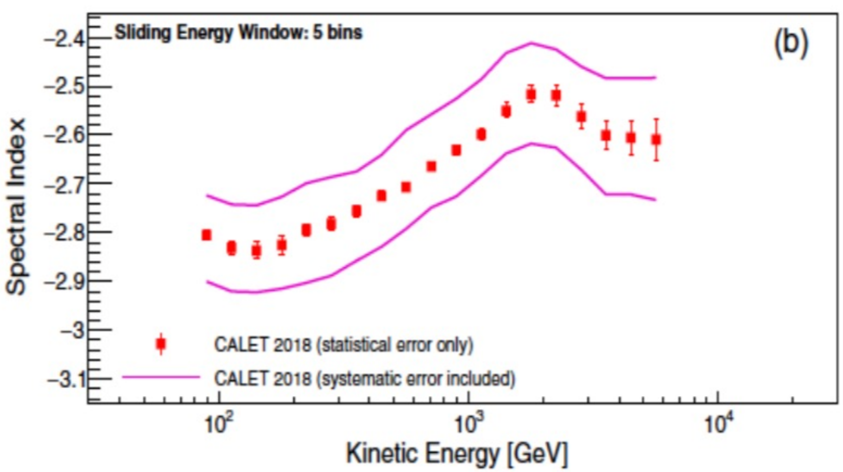
Kolhörster
9 km

Many different observatories!!!!
Sensitive to different energy regions and particle types

Proton flux with CALET: spectral behaviour

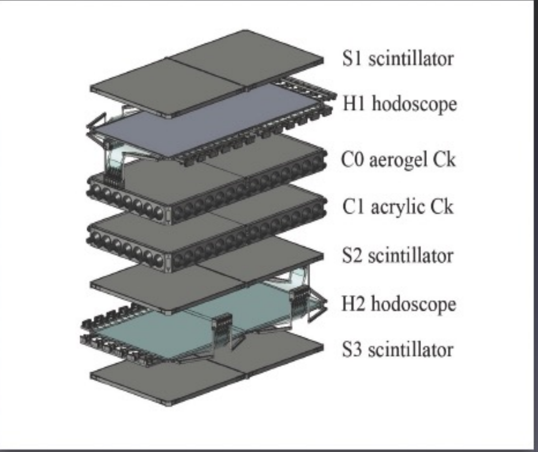






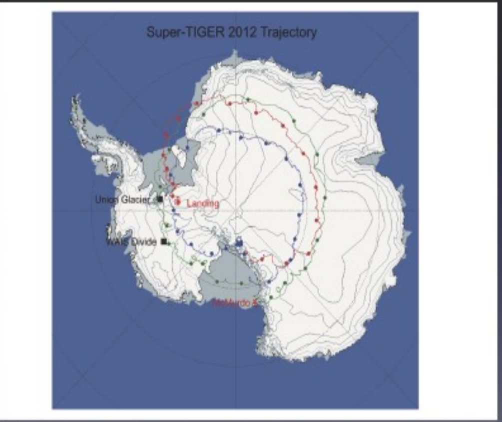
1. Subranges of 50—500GeV, 1-10TeV can be fitted with single power law function, but not the whole range (significance > 3σ).
2. Progressive hardening up to the TeV region was observed.
3. "smoothly broken power-law fit" gives power law index consistent with AMS-02 in the low energy region, but shows larger index change and higher break energy than AMS-02.

Super Trans Iron Galactic Element Recorder
Super-TIGER



2 modules (1 shown), effective geometry 3.9 m² sr
Plastic scintillators (for Z)
Acrylic (n=1.49) and Aerogel (n=1.043, 1.025)
Cherenkov Detectors (for Z, β)

- “Super” Trans-Iron Galactic Element Recorder
- A balloon-borne cosmic ray instrument that can measure galactic cosmic ray abundances for Z=~10–60 for energies ~0.8-10 GeV/nuc
- Primary Goals: Measure Z=30–60 abundances to test OB association models for cosmic ray origins
  - R.P. Murphy et al., ApJ 2016
  - N.E. Walsh et al., COSPAR 2018, E1.5-0040-18
  - **N.E. Walsh et al., ICRC 2019, CRD3a**
- Secondary Goals: Spectra, spectral features



December 8, 2012 — February ~2, 2013
Record 55 day flight, avg altitude 125k ft.
~5x10⁶ Fe events (used to map detector responses)

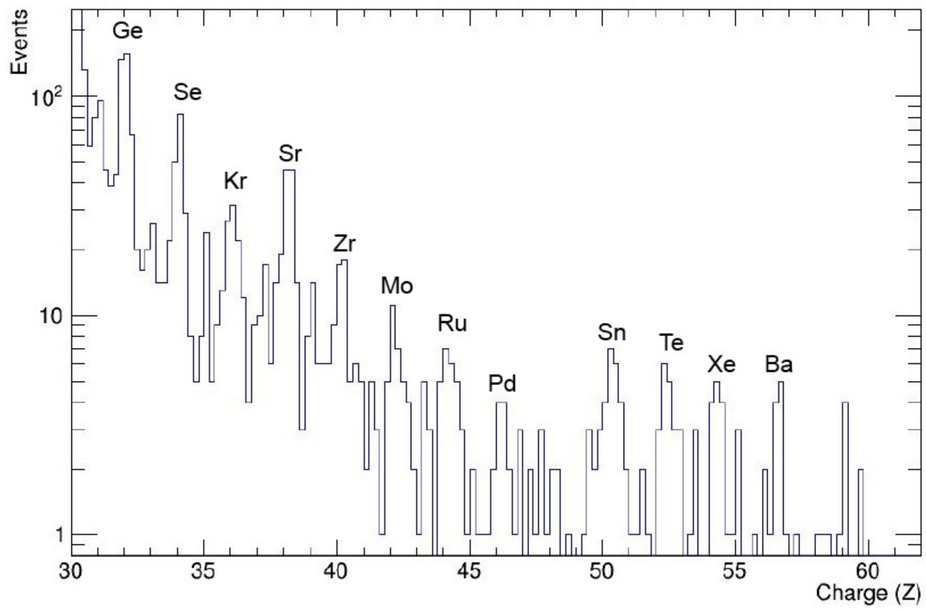
Super-Tiger UH CR Z→ 41-56

SuperTIGER measures UHGCR to test the OB association origin of cosmic rays at higher Z, in which:

1) the GCRs are a mix of massive star material and normal ISM
2) refractory elements that condense in dust grains are preferentially accelerated compared to volatile elements residing in gas.

Both supernovae in OB associations and binary neutron star mergers produce r-process nuclei.

Measurements up to Barium (Z=56) will be able to put constraints on the r-process production models of SNE and BNSM.



Improve upon the SuperTIGER charge assignment analysis done in APJ, 831, 2016 in the Z=30-40 charge range.

Extend the charge assignment analysis to higher charges (up to Z=56)

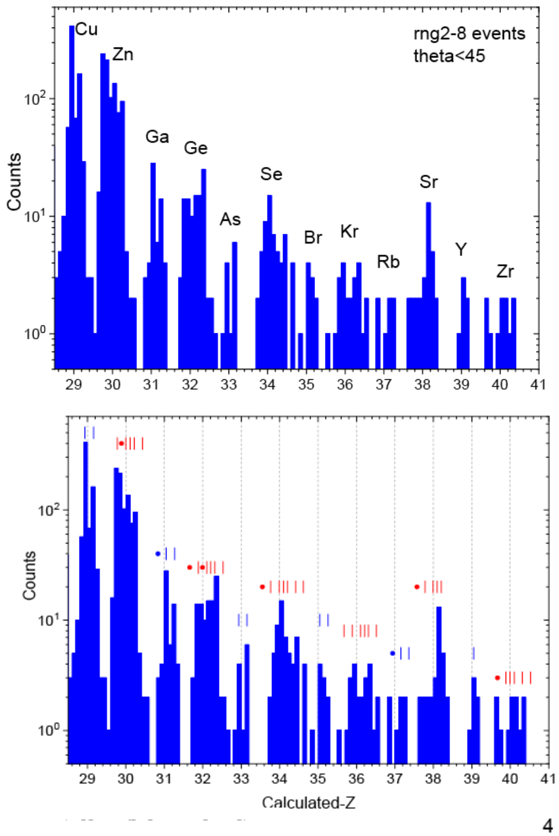
Ultra-Heavy nuclei with CRIS (ACE) → 21 years !

Data taken over time interval from Dec. 4, 1997 through Feb. 18, 2019

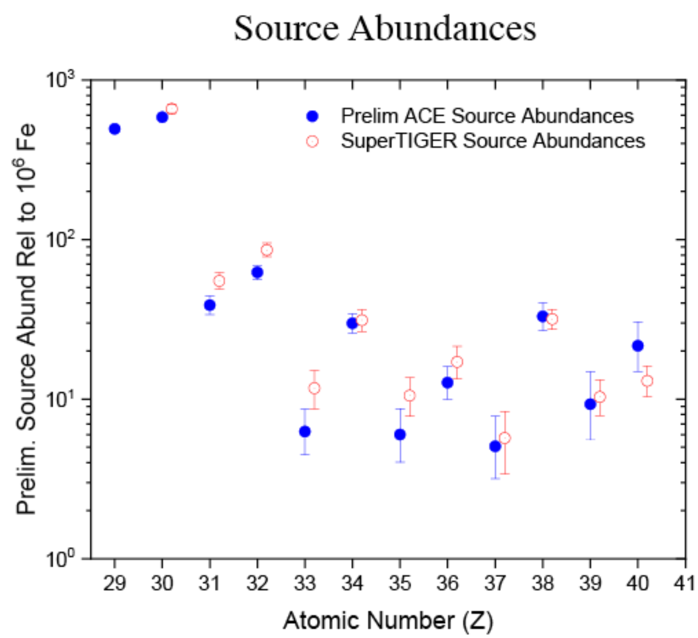
A total of 7406 days of actual data

Excellent resolution in charge for UH nuclei

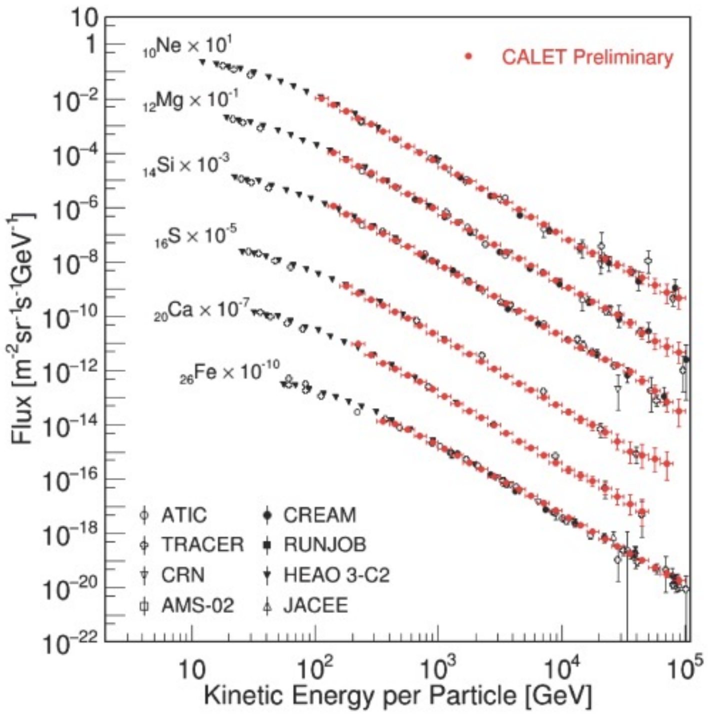
Data set corresponds to 1.5 x 10^6 Fe nuclei

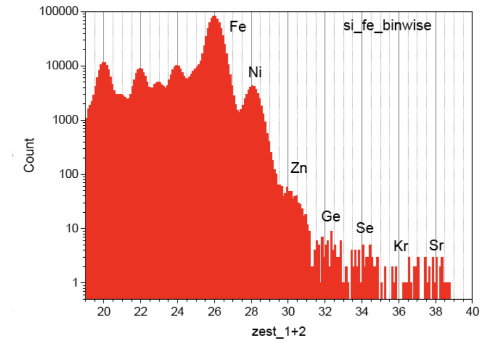


- Width of element distributions is primarily dependent upon the number of stable isotopes for each element.
- Red and blue lines show the calculated position of each stable isotope for an element.
- Red and blue circles show the calculated position of isotopes that can only decay by electron-capture and thus are stable when fully stripped.
- (Red lines and circles for even-Z elements, blue for odd-Z elements).

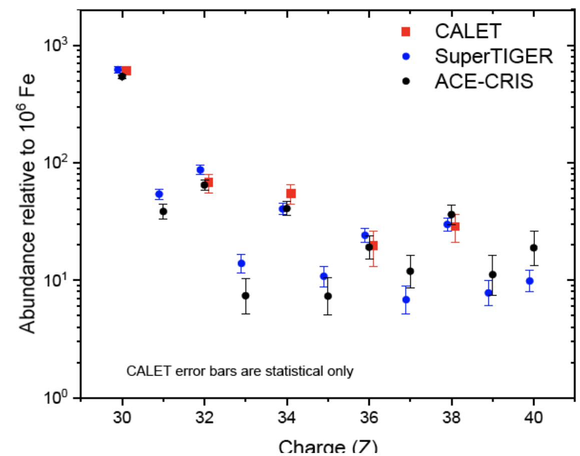


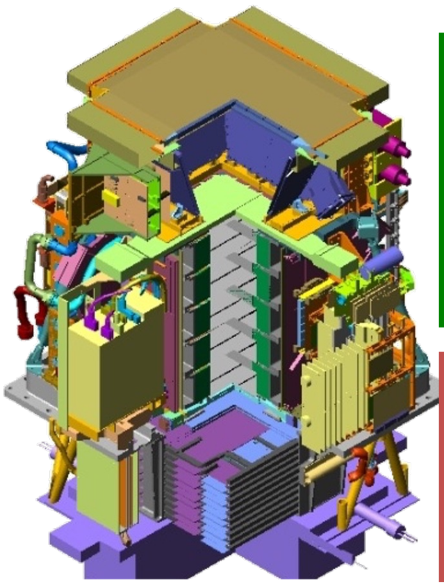
Ultra-Heavy nuclei with CALET: 3 years data





- The ACE and ST data are “in-space” abundances.
- The CALET data have not yet been corrected to the top of the instrument.
  - Those corrections will be small, so they will not change things materially.
- The agreement with ST and ACE-CRIS appears to be quite good.
- Additional data and anticipated improved resolution should result in reduced error bars.

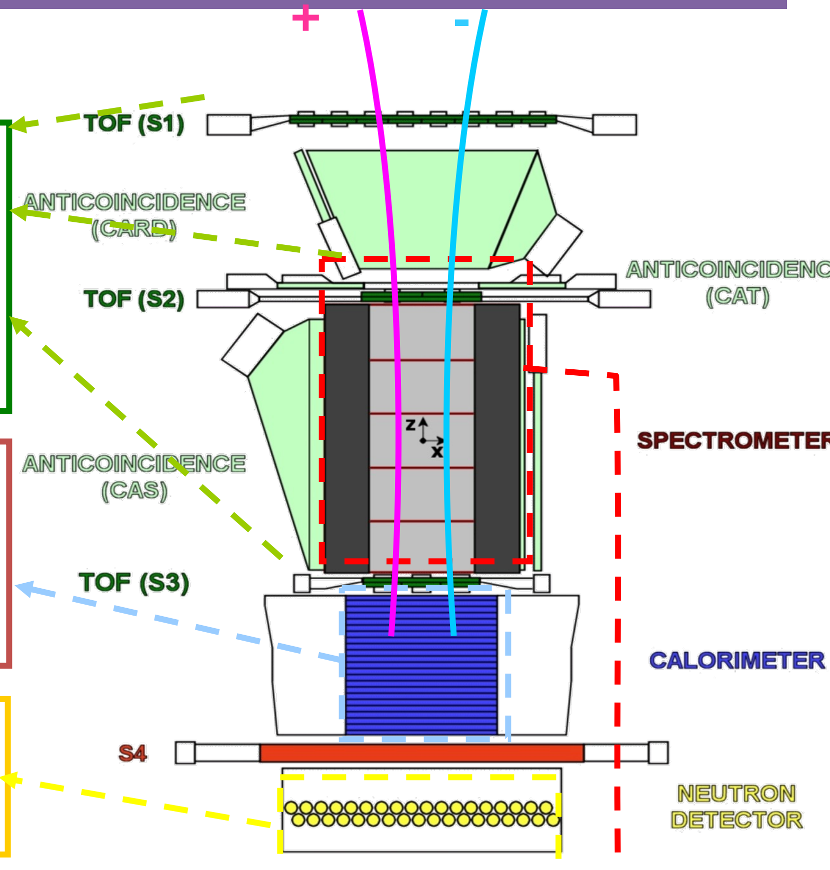




Time-Of-Flight
plastic scintillators + PMT:
- Trigger
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX.

Electromagnetic calorimeter
W/Si sampling (16.3 X0, 0.6 λI)
- Discrimination e+ / p, anti-p / e^- (shower topology)
- Direct E measurement for e^-

Neutron detector
36 He^3 counters :
- High-energy e/h discrimination



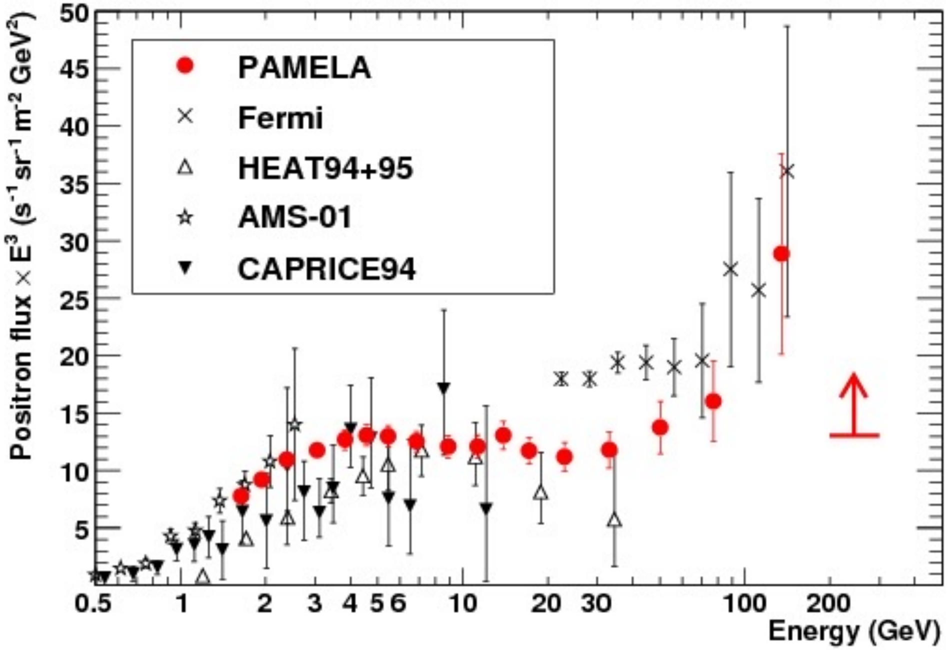
PAMELA detectors

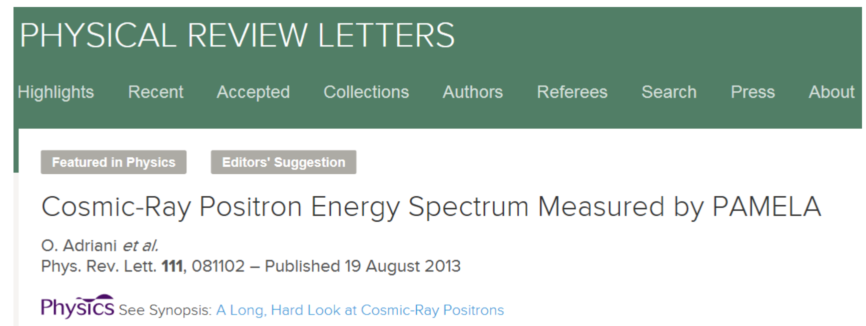
Main requirements:
- **high-sensitivity antiparticle identification**
- **precise momentum measurement**

Spectrometer
microstrip silicon tracking system + permanent magnet
It provides:
- *Magnetic rigidity* → R = pc/Ze
- *Charge sign*
- *Charge value from dE/dx*

GF: 21.5 cm^2 sr
Mass: 470 kg
Size: 130x70x70 cm^3
Power Budget: 360W

PAMELA Results: Positrons

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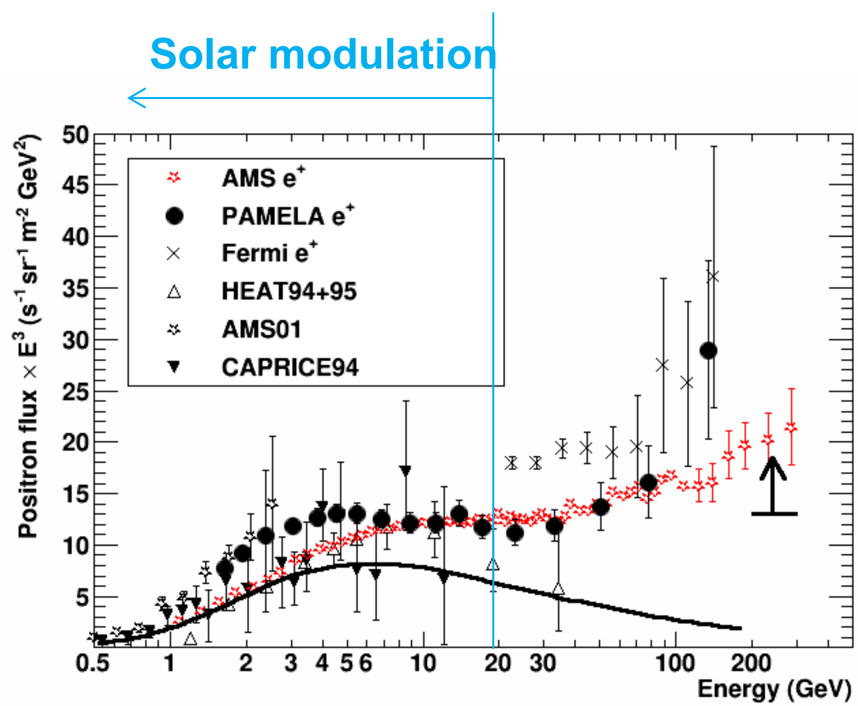
Cosmic-Ray Positron Energy Spectrum Measured by PAMELA

O. Adriani *et al.*

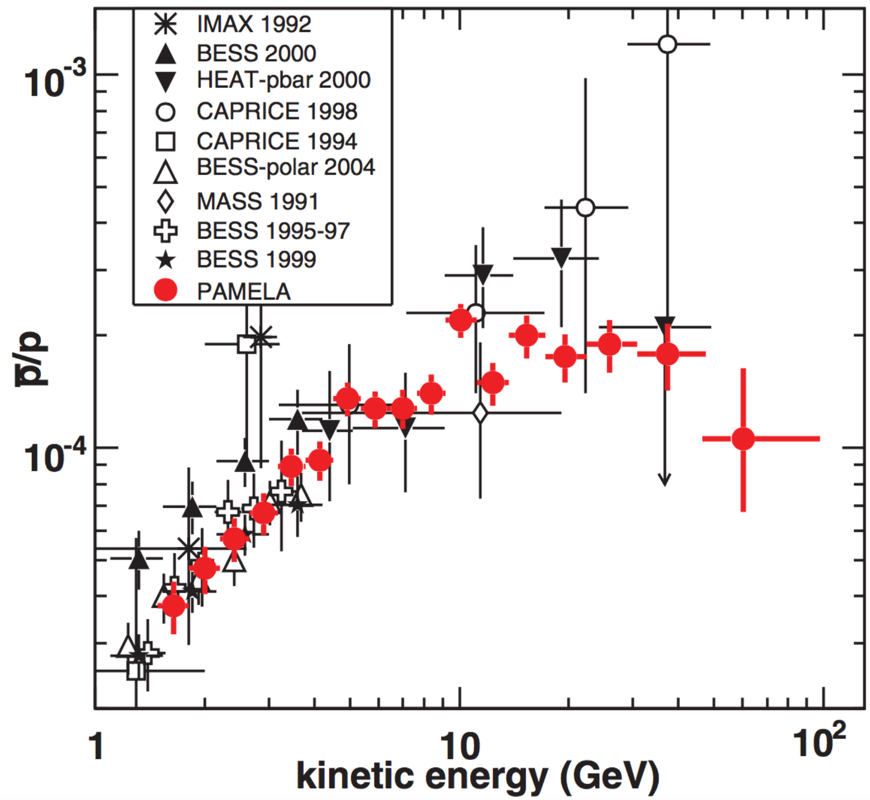
Phys. Rev. Lett. **111**, 081102 – Published 19 August 2013

Physics See Synopsis: A Long, Hard Look at Cosmic-Ray Positrons



Results confirmed by AMS-02!

PAMELA Results: Antiprotons



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O. Adriani *et al.* (PAMELA Collaboration)
Phys. Rev. Lett. **102**, 051101 – Published 2 February 2009

Physics See Viewpoint: Debating the source of a rare particle

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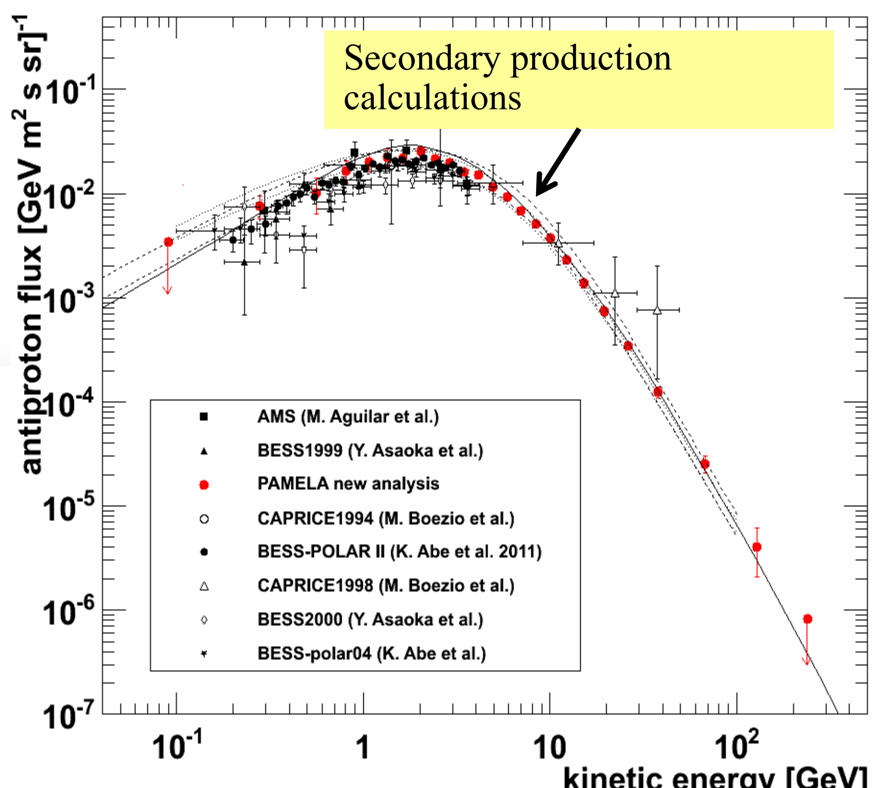
PAMELA Results on the Cosmic-Ray Antiproton Flux from 60 MeV to 180 GeV in Kinetic Energy

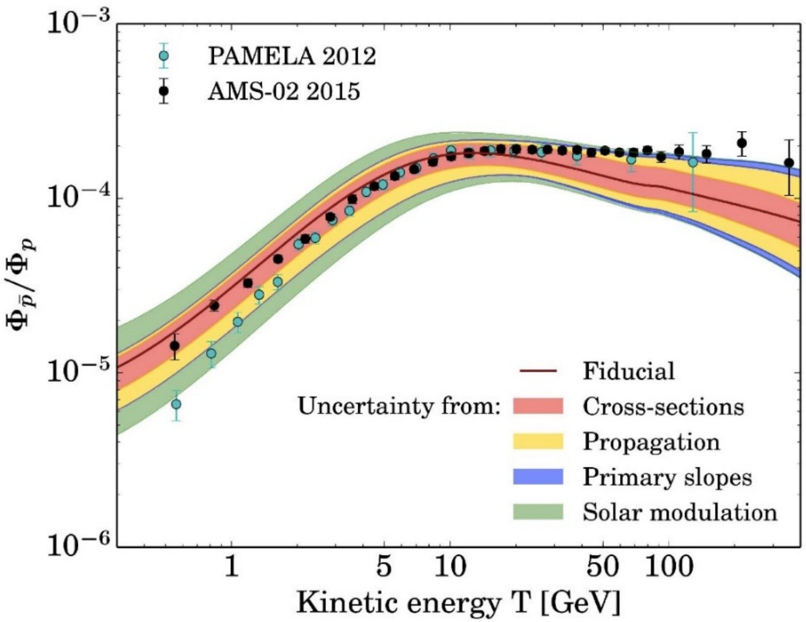
O. Adriani *et al.*
Phys. Rev. Lett. **105**, 121101 – Published 13 September 2010

Physics See Synopsis: Uncertain sources

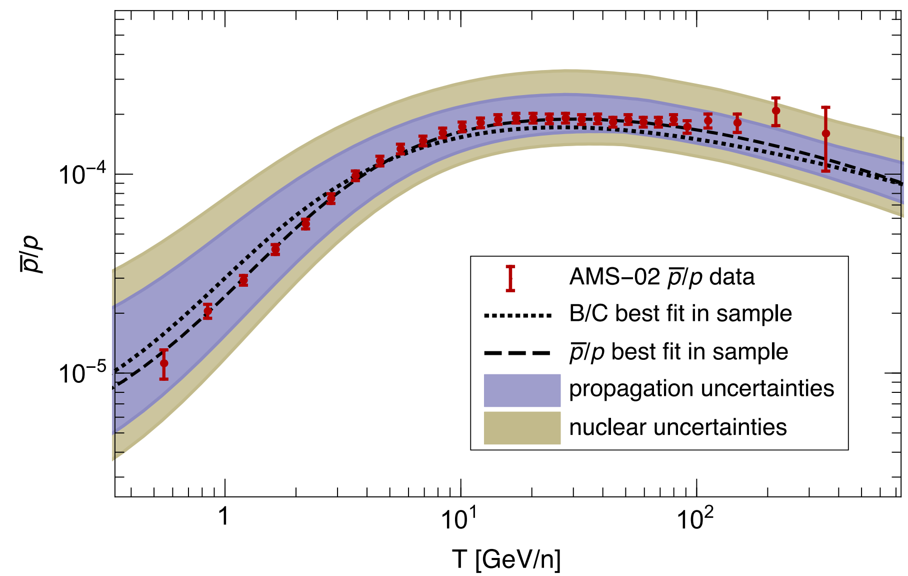


Antiproton Data

G. Giesen et al., JCAP 1509 (2015) 023



Kappl, Reinert, Winkler JCAP 2015



Propagation model fitted on preliminary AMS-02 B/C data
Greatest uncertainty set by nuclear cross sections

An interesting multi disciplinary application:
Measurement of antiproton production cross section in p-He interactions at LHC by the SMOG system of LHCb

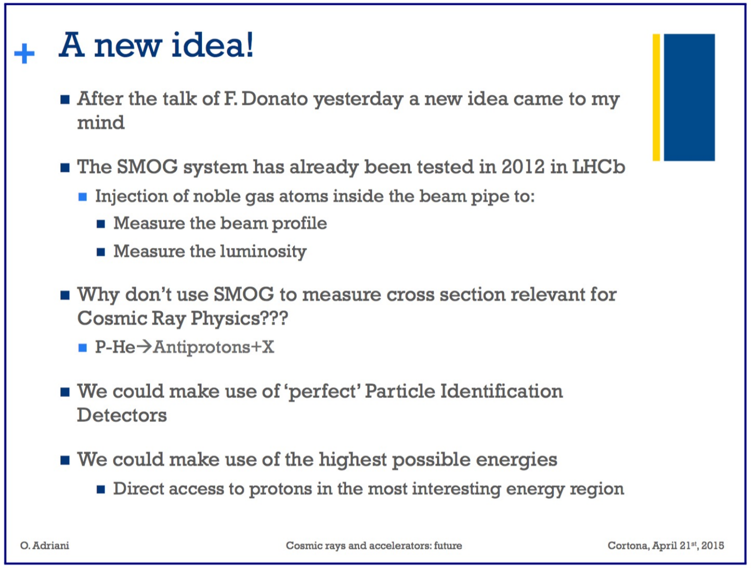
Antiproton production in p-He collisions at the LHC

LHCb on a Space Mission

Giacomo Graziani
(INFN Firenze)

Consiglio di Sezione
INFN Firenze
4 aprile 2017

A cosmic call to LHCb



A new idea!

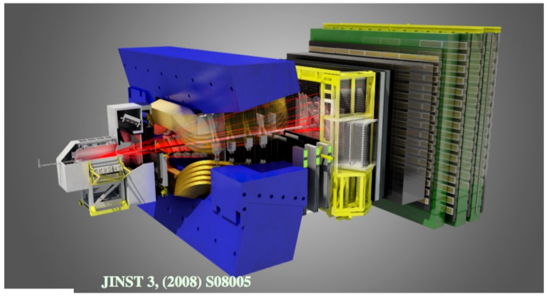
- After the talk of F. Donato yesterday a new idea came to my mind
- The SMOG system has already been tested in 2012 in LHCb
  - Injection of noble gas atoms inside the beam pipe to:
    - Measure the beam profile
    - Measure the luminosity
- Why don't use SMOG to measure cross section relevant for Cosmic Ray Physics???
  - P-He→Antiprotons+X
- We could make use of 'perfect' Particle Identification Detectors
- We could make use of the highest possible energies
  - Direct access to protons in the most interesting energy region

O. Adriani — Cosmic rays and accelerators: future — Cortona, April 21st, 2015

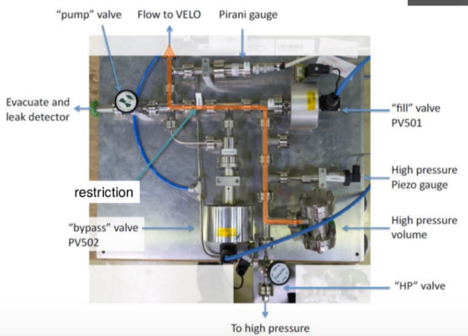
Idea from NPCQD2015 Workshop, April 2015 (from O. Adriani's talk)
Proposal to LHCb soon after (talk by L. Bonechi at LHCb Meeting, May 12 2015)

SMOG: the LHCb internal gas target

- LHCb is the LHC experiment with "fixed-target like" geometry
- very well suited for…fixed target physics!



JINST 3, (2008) S08005
Int.J.Mod.Phys.A30 (2015) 1530022



- The System for Measuring Overlap with Gas (SMOG) allows to inject small amount of noble gas (He, Ne, Ar, …) inside the LHC beam around ($\sim \pm 20$ m) the LHCb collision region

  Expected pressure $\sim 2 \times 10^{-7}$ mbar

The p-He run

LHCb-CONF-2017-002

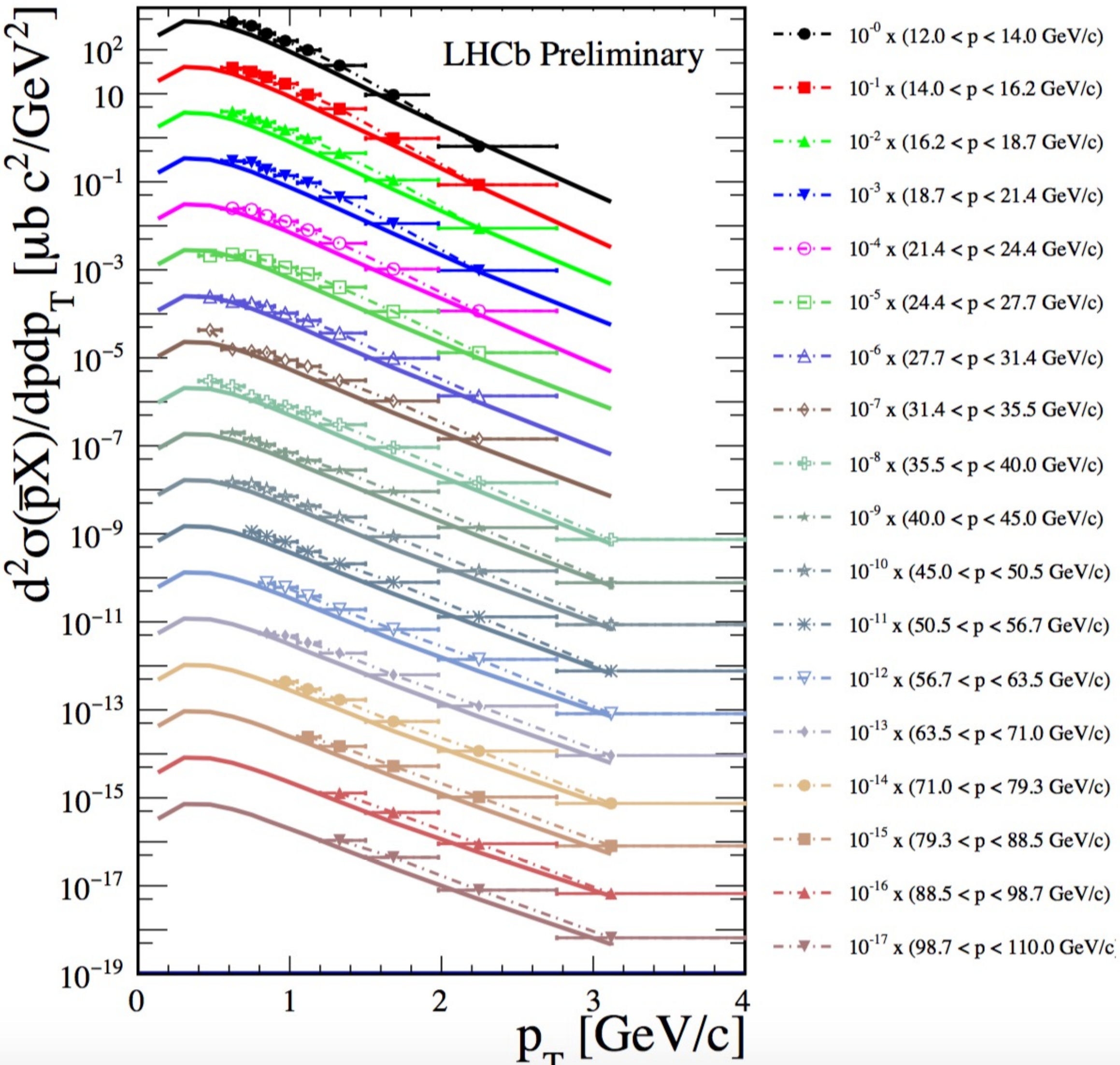
- Data collected in May 2016, with proton energy 6.5 TeV, $\sqrt{s_{\rm NN}} = 110$ GeV
- Using fill for Van der Meer scan (parasitic data taking)
- Most data from a single fill (5 hours)
- Minimum bias trigger, fully efficient on candidate events
- large control samples (random triggers) to check trigger efficiencies, deadtime, pileup
- Exploit excellent particle identification (PID) capabilities in LHCb to count antiprotons in $(p, p_{\rm T})$ bins within the kinematic range

$$12 < p < 110\,{\rm GeV}/c$$

$$p_{\rm T} > 0.4\,{\rm GeV}/c$$

Result for cross section, compared with EPOS LHC

LHCb-CONF-2017-002



Result for **prompt** production (excluding weak decays of hyperons)

The total inelastic cross section is also measured to be

$$\sigma_{inel}^{\mathrm{LHCb}} = (140 \pm 10)\ \mathrm{mb}$$

The EPOS LHC prediction

[T. Pierog at al, Phys. Rev. C92 (2015), 034906]

is 118 mb, ratio is 1.19 ± 0.08.

Extended gamma-ray sources around pulsars constrain the origin of the positron flux at Earth

A. U. Abeysekara,[1] A. Albert,[2] R. Alfaro,[3] C. Alvarez,[4] J. D. Álvarez,[5] R. Arceo,[4]

We report the detection, using the High-Altitude Water Cherenkov Observatory(HAWC), of extended tera–electron volt gamma-ray emission coincident with the locations of two nearby middle-aged pulsars (Geminga and PSR B0656+14). The HAWC observations demonstrate that these pulsars are indeed local sources of accelerated leptons, but the measured tera–electron volt emission profile constrains the diffusion of particles away from these sources to be much slower than previously assumed. **We demonstrate that the leptons emitted by these objects are therefore unlikely to be the origin of the excess positrons, which may have a more exotic origin.**

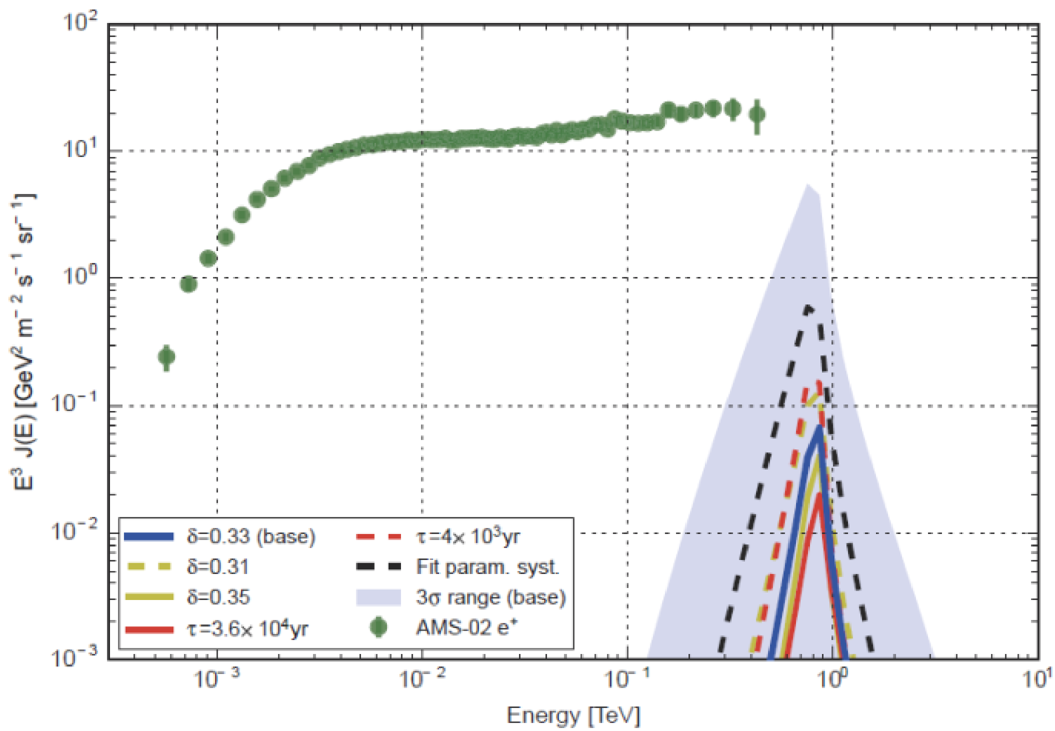
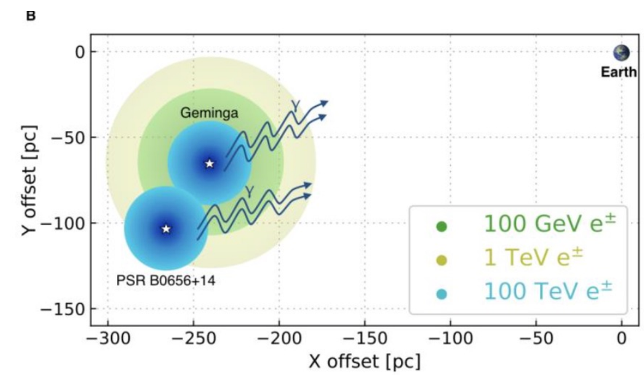
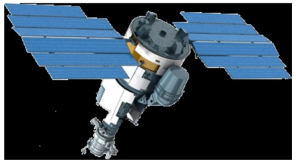


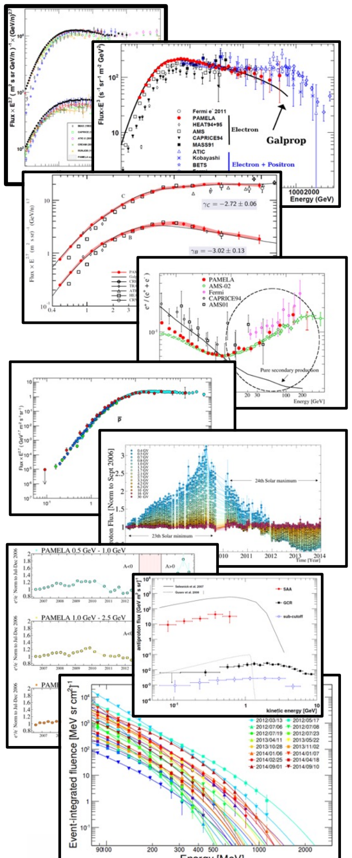
Fig. 3. Estimated positron energy flux at Earth from Geminga (blue solid line), compared with AMS-02 experimental measurements (green dots). The shaded blue region indicates the 3σ (99.5% confidence) statistical uncertainty from simulations (*12*). Additional lines represent the effect



We therefore favor the explanation that instead of these two pulsars, the origin of the local positron flux must be explained by other processes, such as different assumptions about secondary production [although that has been questioned (33; 34)], other pulsars, other types of cosmic accelerators such as micro-quasars (35) and supernova remnants (34), or the annihilation or decay of dark matter particles (9).

Ten years of PAMELA data





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The PAMELA Mission: Heralding a new era in precision cosmic ray physics

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Ten years of PAMELA in space

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