A New Era for Galactic Cosmic Rays

AUGUST 7-11 COLUMBUS, OHIO

TeVPA 2017

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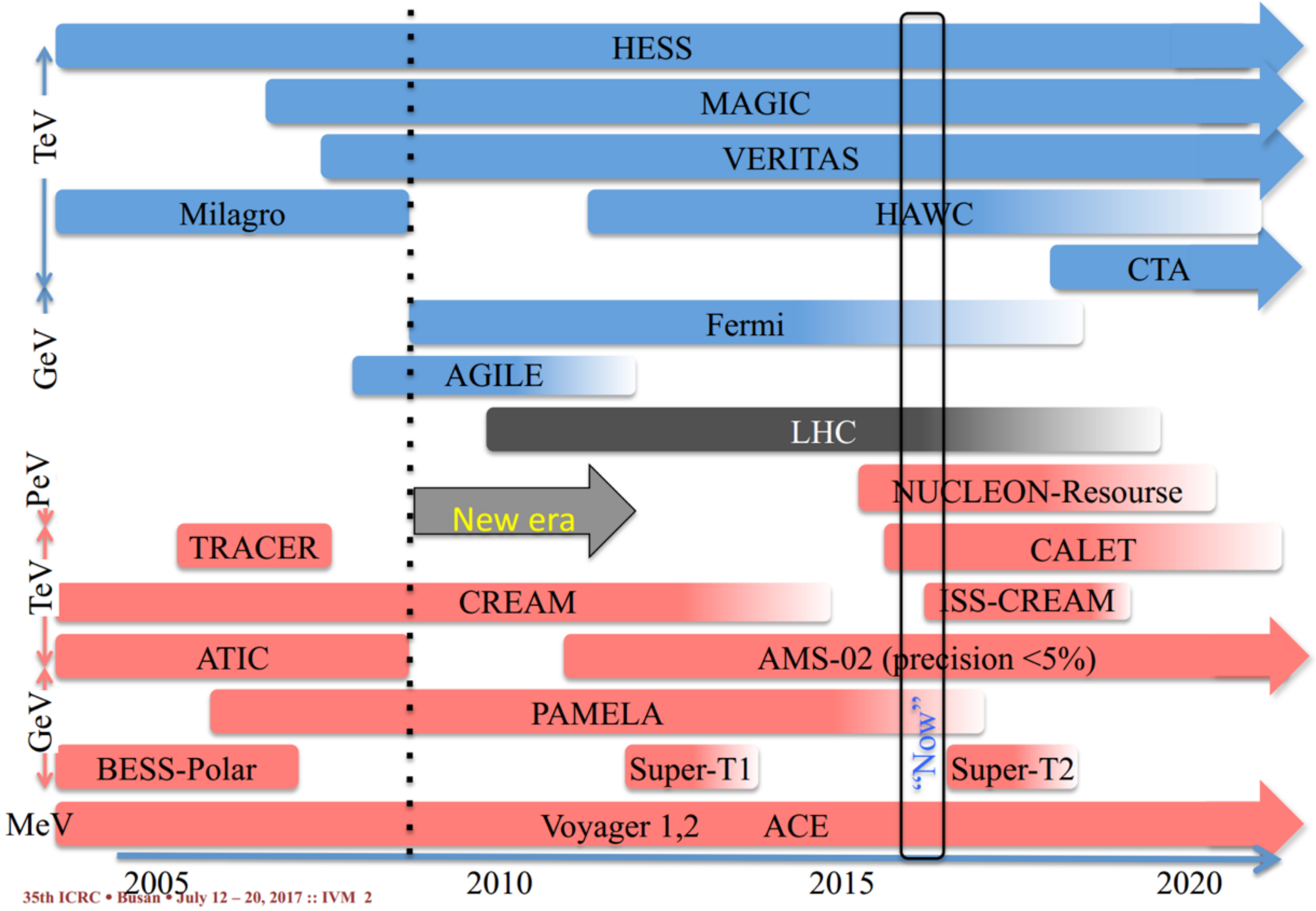
Timeline of γ-ray, CR, and particle experiments



Over the last 15 years the number of experiments in space and on ground looking at GCRs and gamma rays is increased dramatically.

- Interest in the field
- New data
- New discoveries

Open questions to address:

- Indirect search of Dark Matter in multiple channels (e+, antiP, antiD, gammas …)
- Anti-matter in space
- GCR composition, acceleration and their maximum energy
- GCR propagation in the galaxy and in the heliosphere
- GCR sources and anisotropies -> Gamma rays (Fermi and ground experiments)

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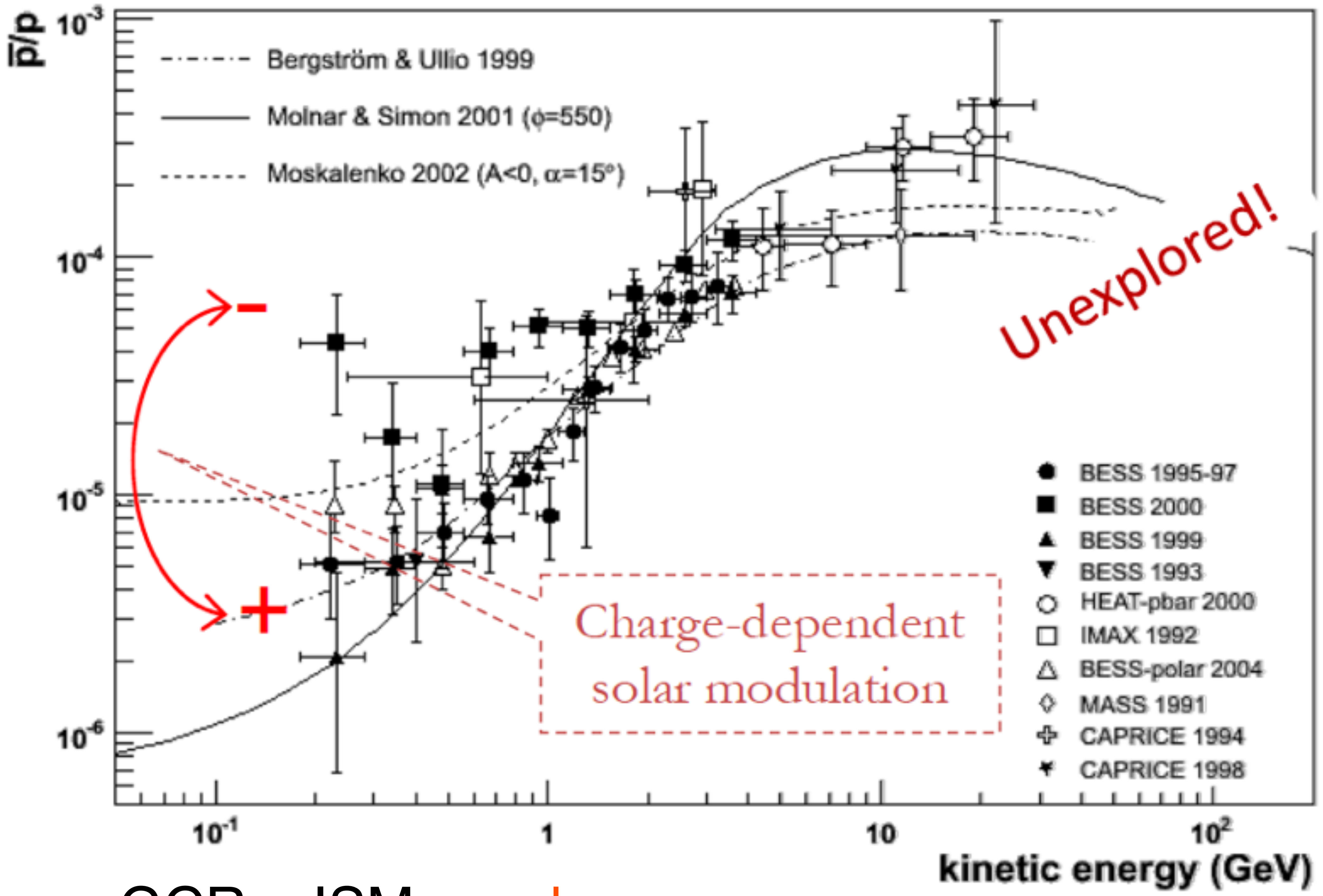
Talk Covers:
Balloon and space particle detectors

Leaves out: Gammas and ground experiments (covered by various talks at TeVPA)

Status at the beginning of 2000s

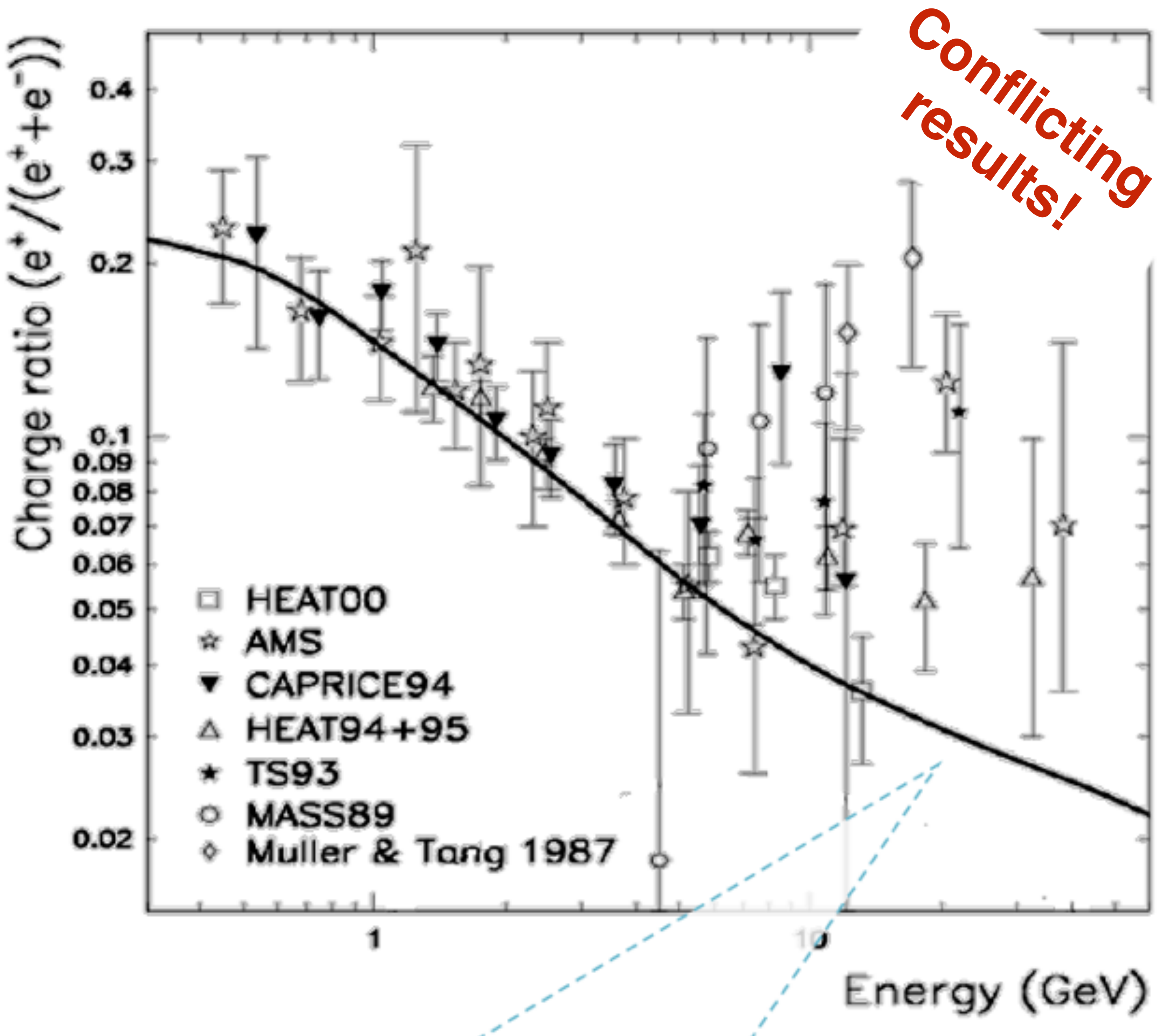
In the past, extensive campaign of daily balloon flights has been done:
Wizard (MASS, TS, CAPRICE), BESS, HEAT, IMAX…,

High-statistics measurement of
antiP@low energy->BESS-Polar



GCR + ISM -> p-bar + x

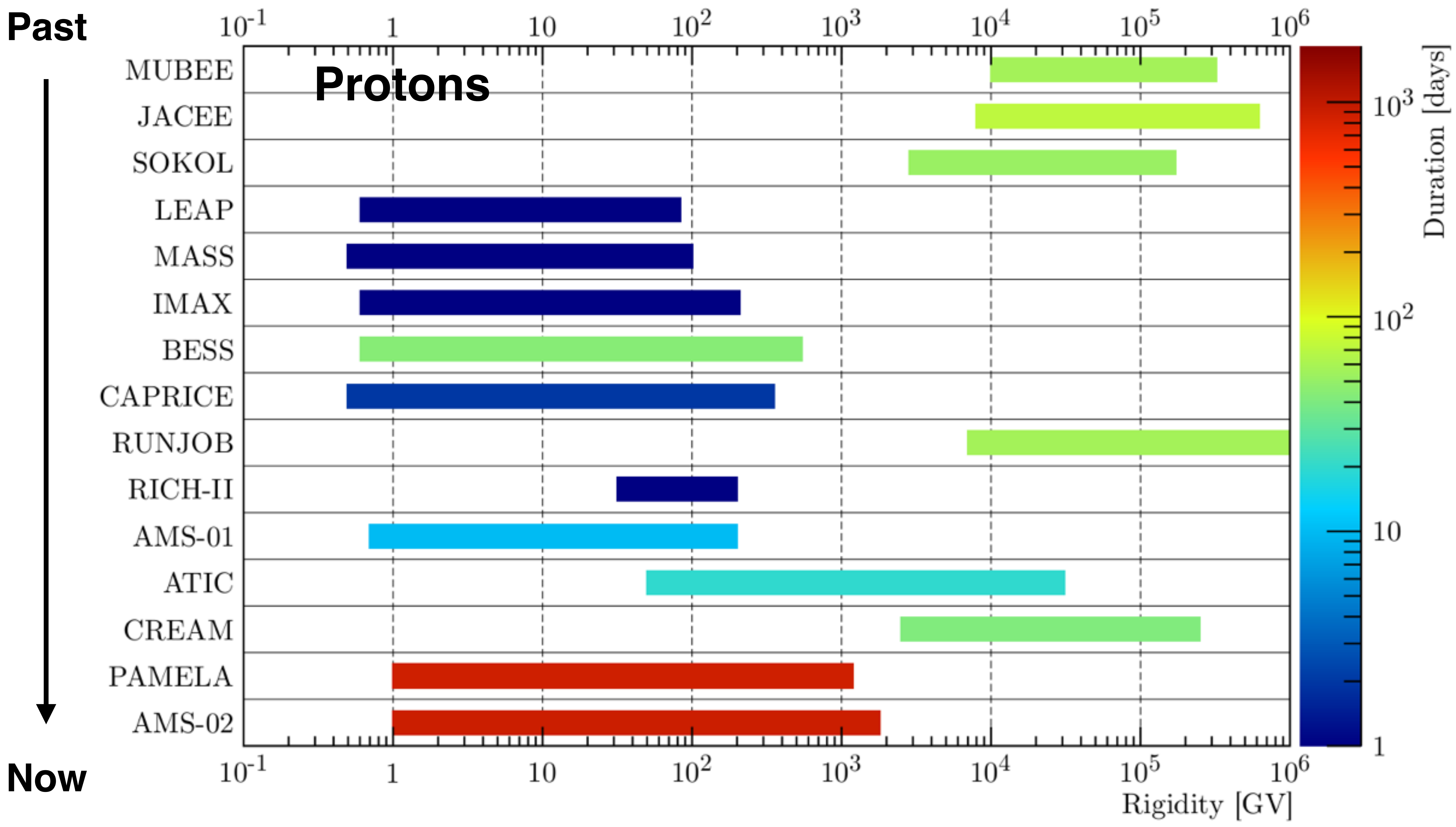
antiP and e+ measurement @ high energy



$$\mathrm{GCR + ISM} \rightarrow \pi^{\pm} + x \rightarrow \mu^{\pm} + x \rightarrow e^{\pm} + x$$

$$\mathrm{GCR + ISM} \rightarrow \pi^{0} + x \rightarrow \gamma\gamma \rightarrow e^{\pm}$$

Balloon and Space experiments: protons



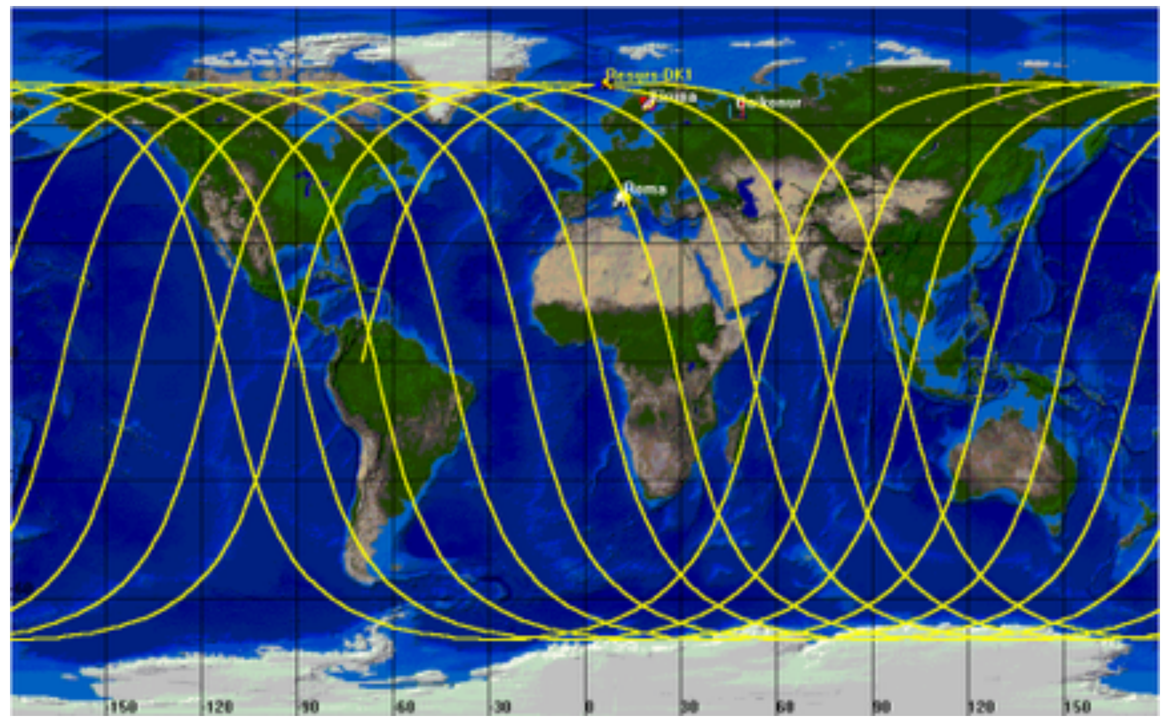
Experiments that measure above 30 GV

Measurements from balloons in the past have been mostly limited in statistics due to the short observation time.

Space experiments (or Long duration balloon flight) with long exposure time and large acceptance are the new standard.

The need of precise measurements led to PAMELA and AMS

PAMELA (2006 -2015)



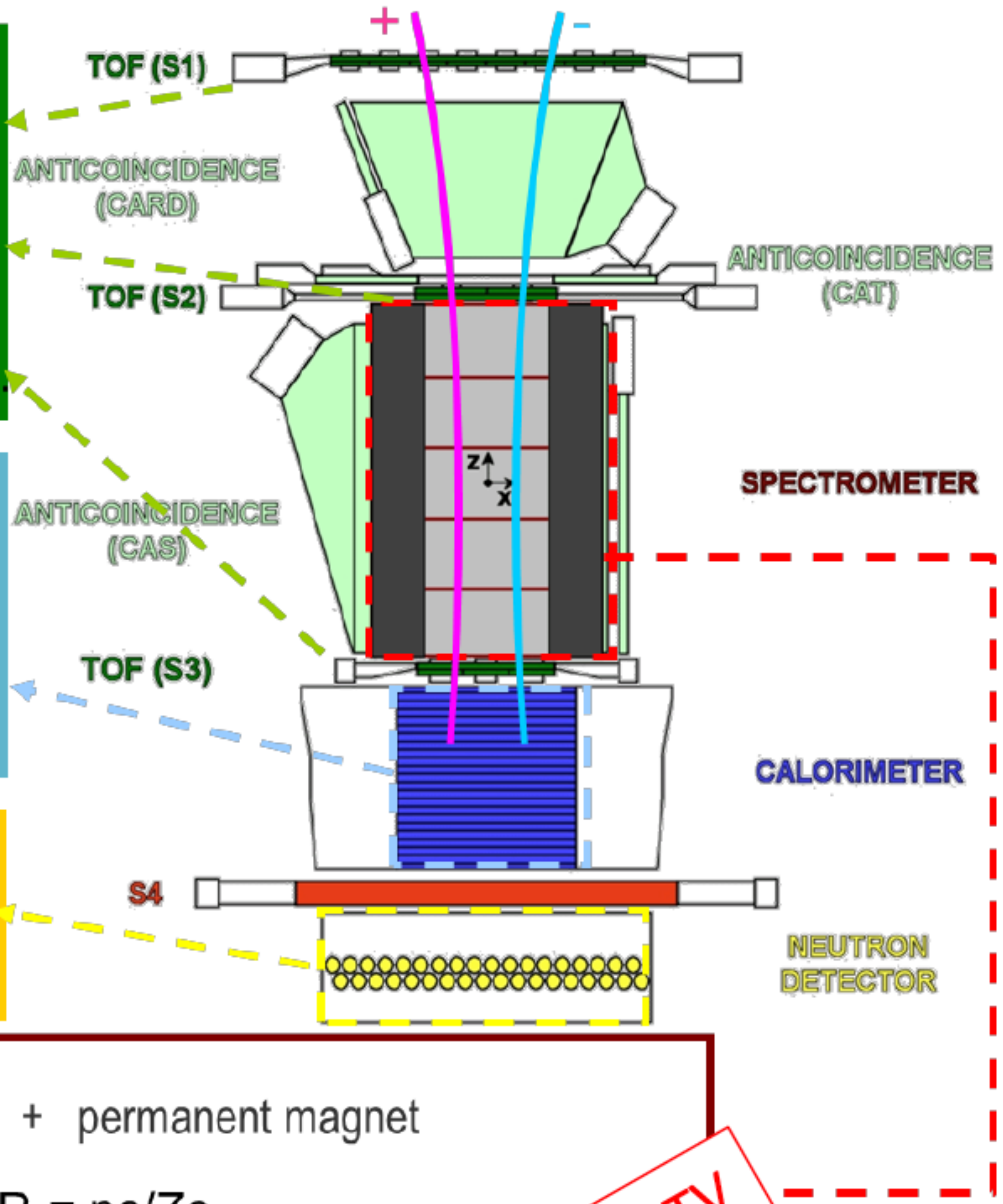
Resurs-DK1
Mass: 6.7 tonnes
Height: 7.4 m
Solar array area: 36 m^2

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

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
plastic scintillators + PMT:
- High-energy e/h discrimination

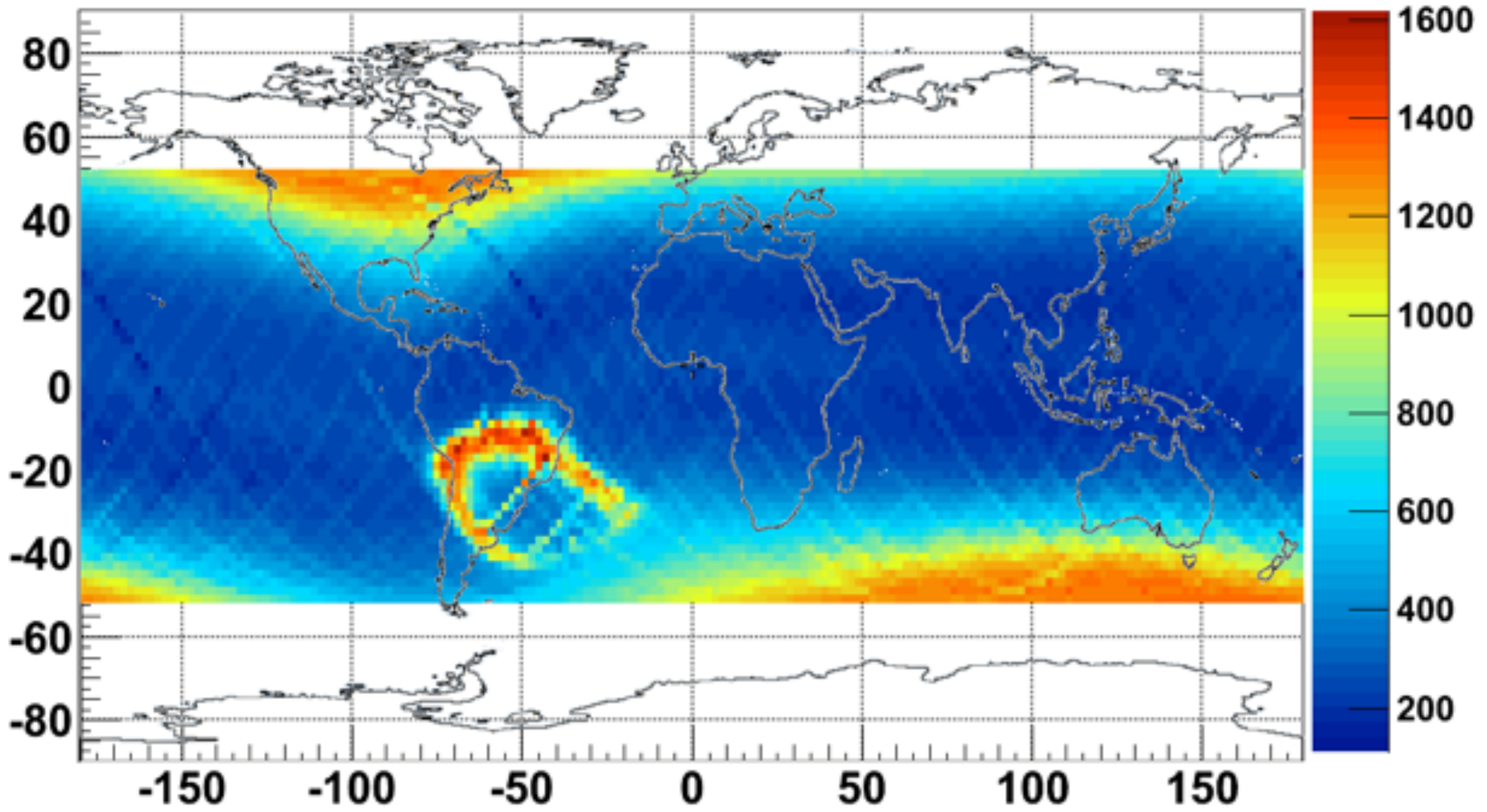


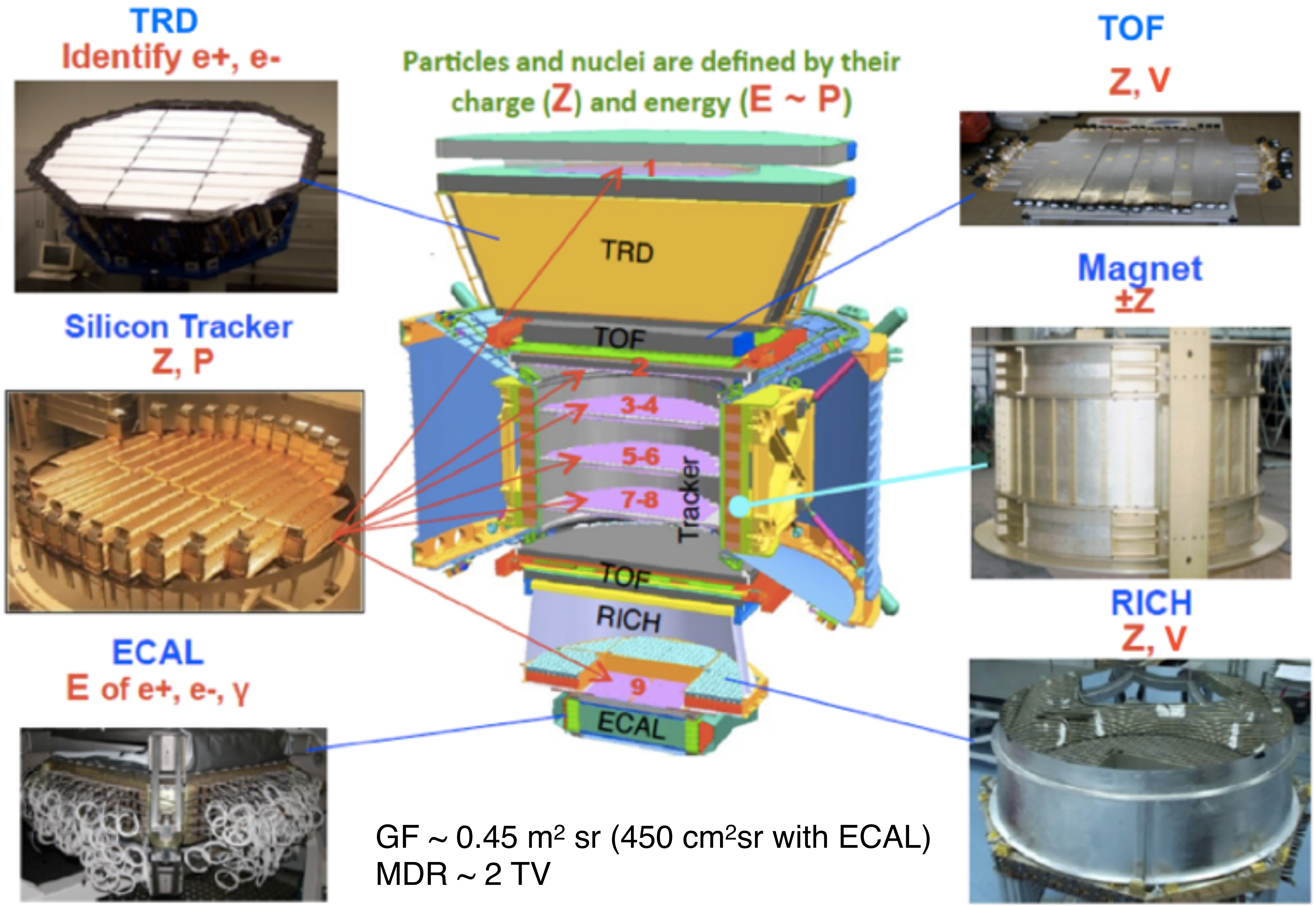
Spectrometer
microstrip silicon tracking system + permanent magnet
It provides:
- *Magnetic rigidity* → R = pc/Ze
- *Charge sign*
- *Charge value from dE/dx*

MDR ~1TV

AMS (2011-2024)

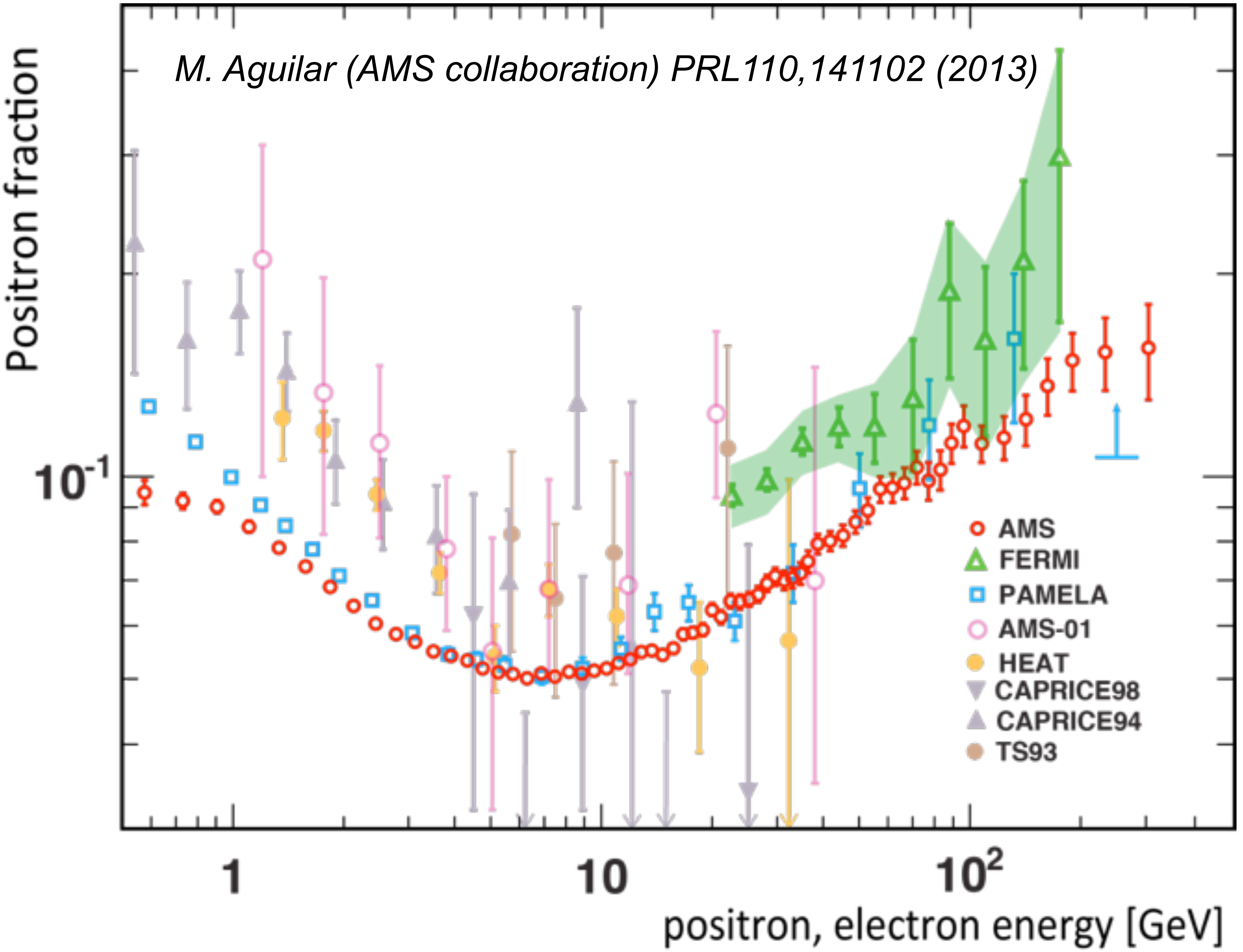
Acquisition rate [Hz]

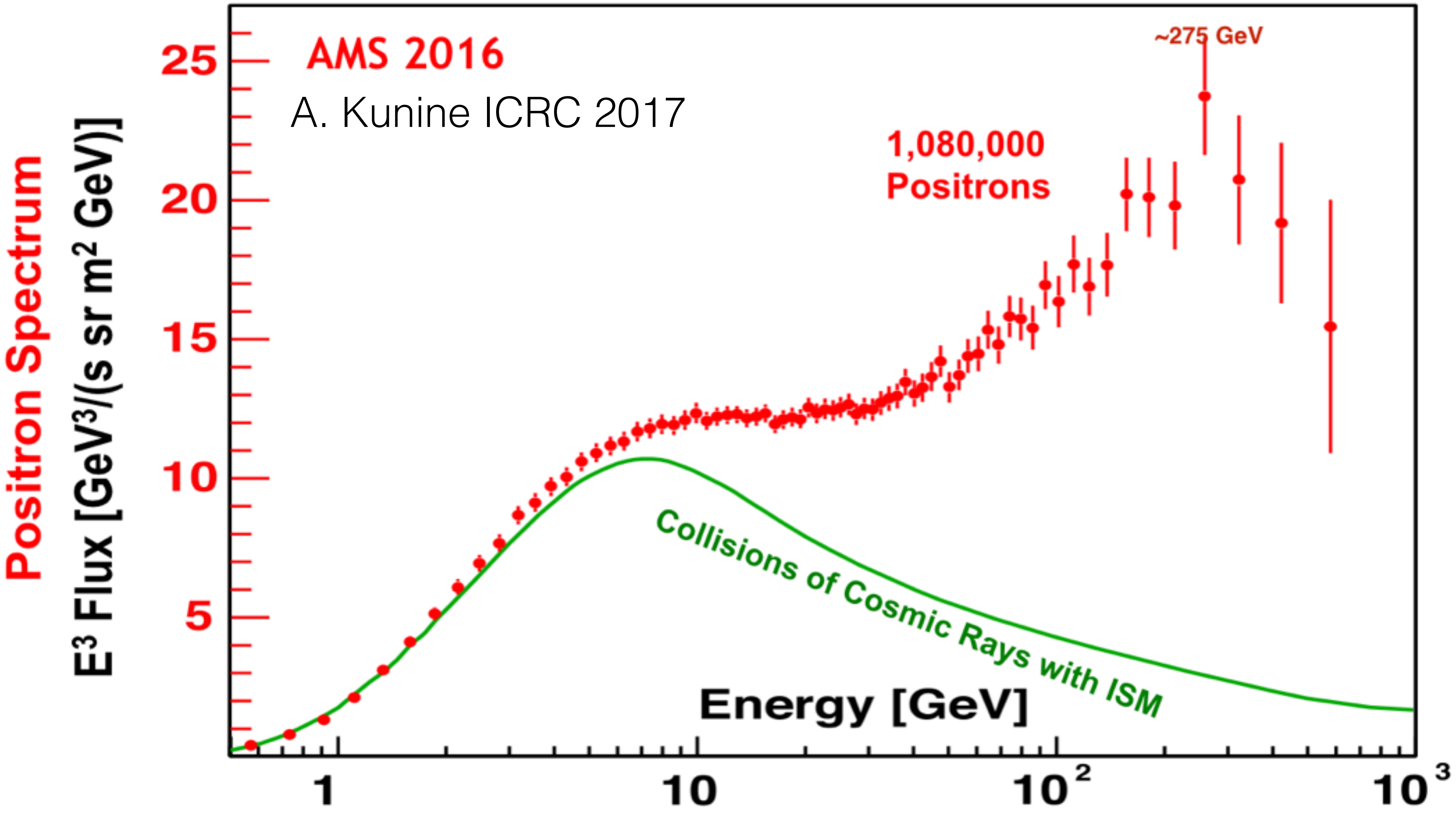




GF ~ 0.45 m² sr (450 cm²sr with ECAL)
MDR ~ 2 TV

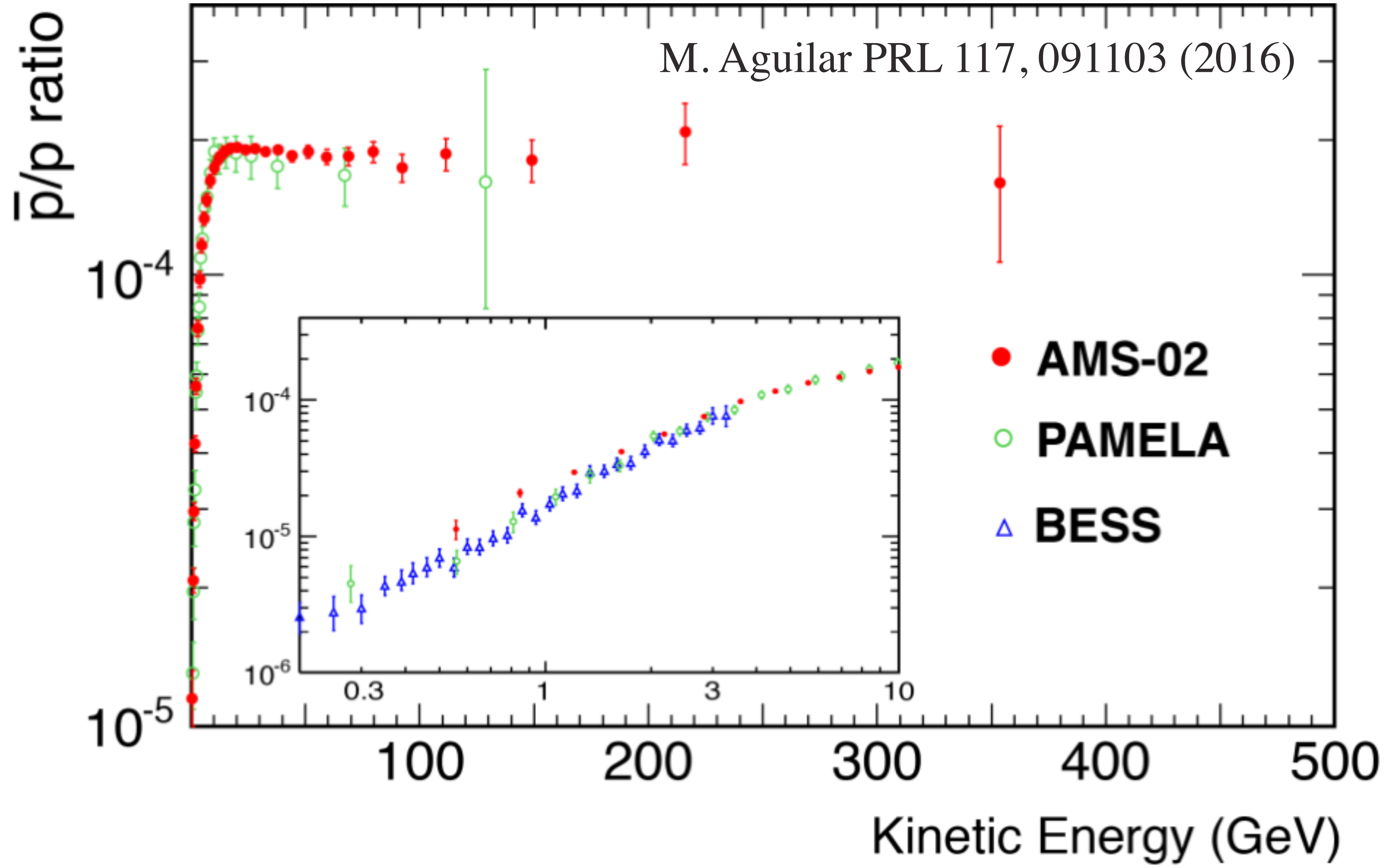
Current Positron Fraction



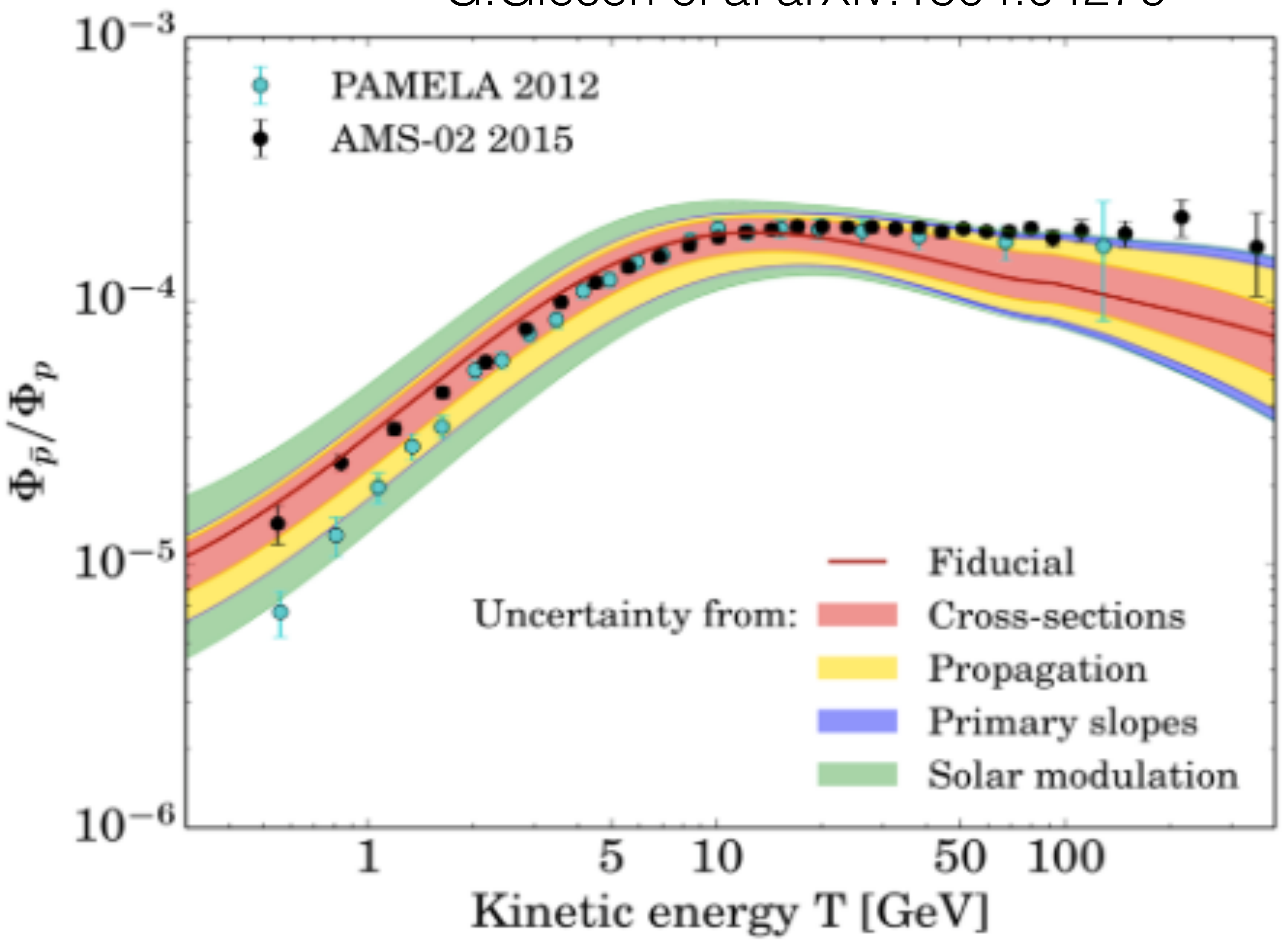


The excess is really there and now we have the new challenge:
Dark Matter annihilation or contribution from nearby young pulsars?

Antiprotons/Protons



G.Giesen el al arXiv:1504.04276



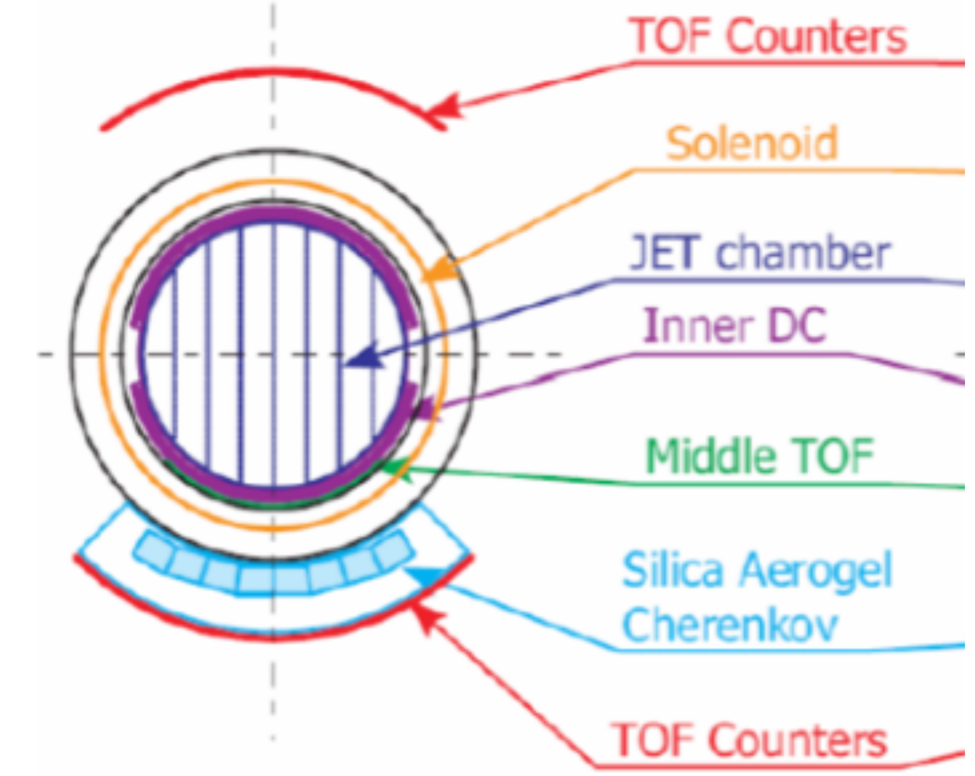
Cui et al ’17 and Cuoco et al ‘17 use AMS-02 antiproton data and B/C or the Helium flux to set limits on DM annihilation. Both papers claim detection of a possible excess due to DM annihilation.

Stay tuned!

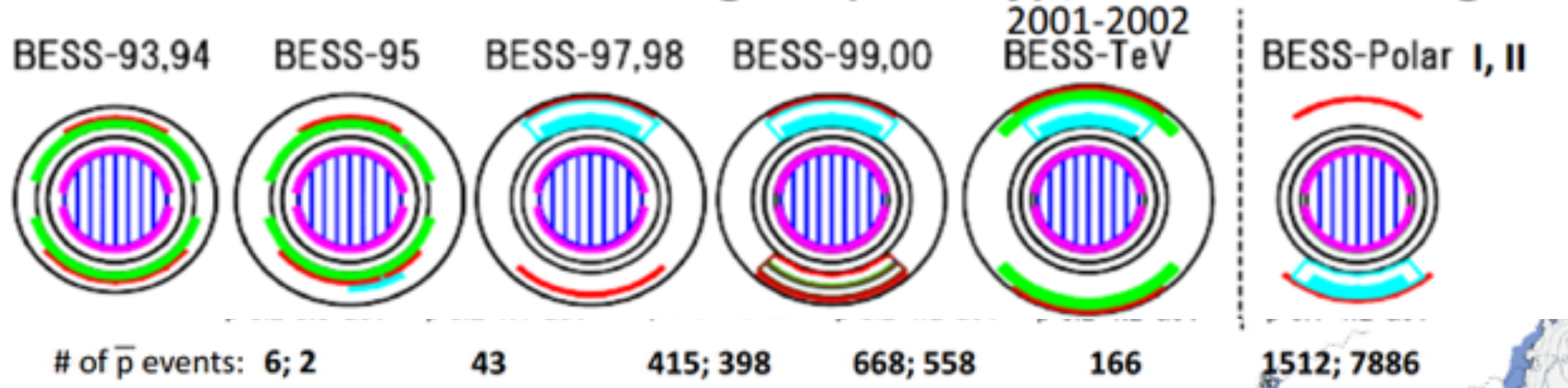
->Talk D. Gaggero TeVPA 2017

Antiproton at low energy

BESS Flights



9 Northern latitude balloon flights (~1 day) / 2 Antarctic flights

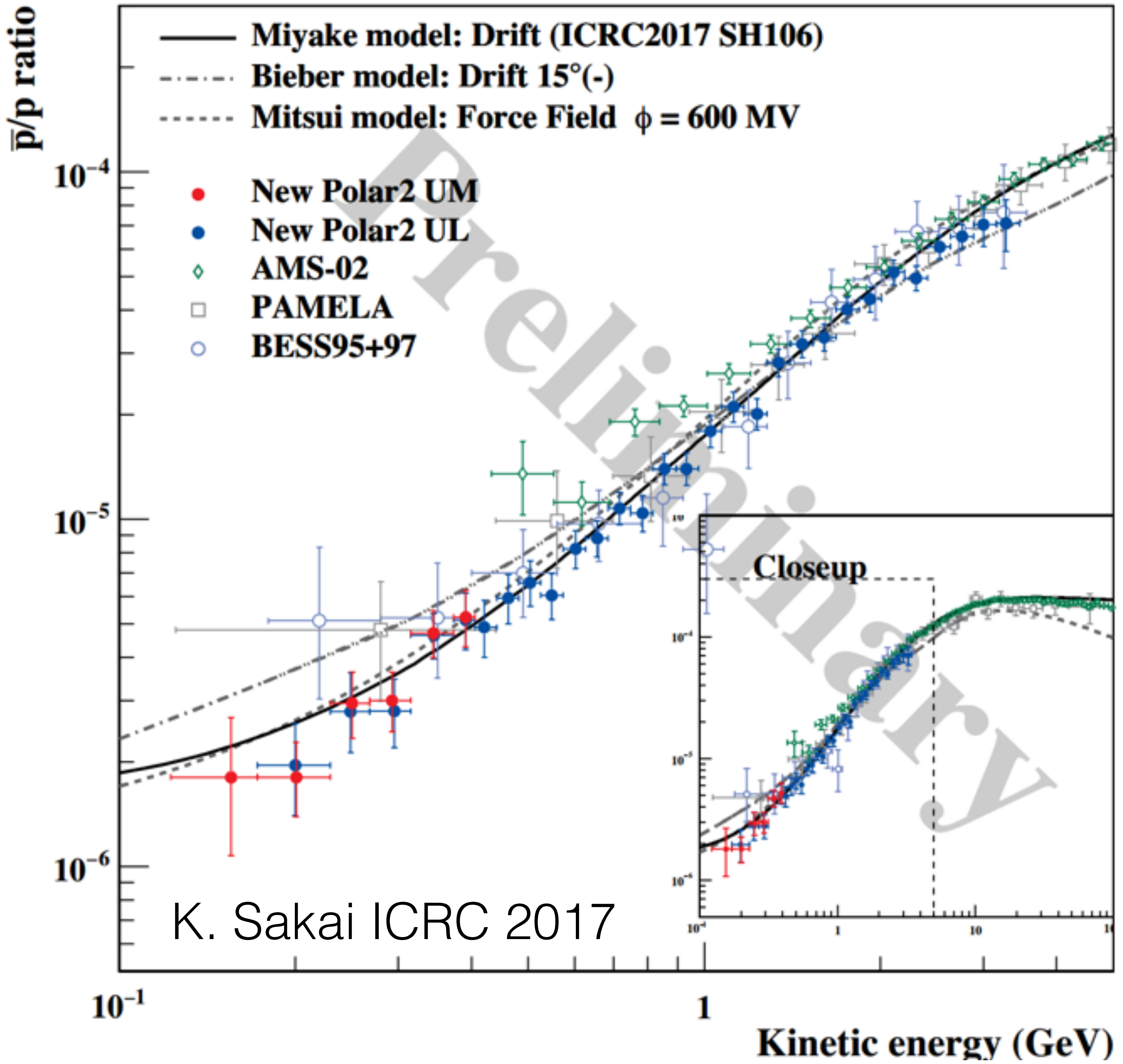


	BESS-Polar I	BESS-Polar II
Launch date	Dec. 13th, 2004	Dec. 23rd, 2007
Observation time	8.5 days	24.5 days
Cosmic-ray observed	9 x 10^8 events	4.7 x 10^9 events
Flight altitude	37-39 km (5-4 g/cm^2)	~36 km (~5 g/cm^2)

BESS-Polar II Flight Trajectory

5 times more events recorded with BESS-Polar II.

➡ **Significantly reduces statistical uncertainties** for H and He isotope flux measurements.



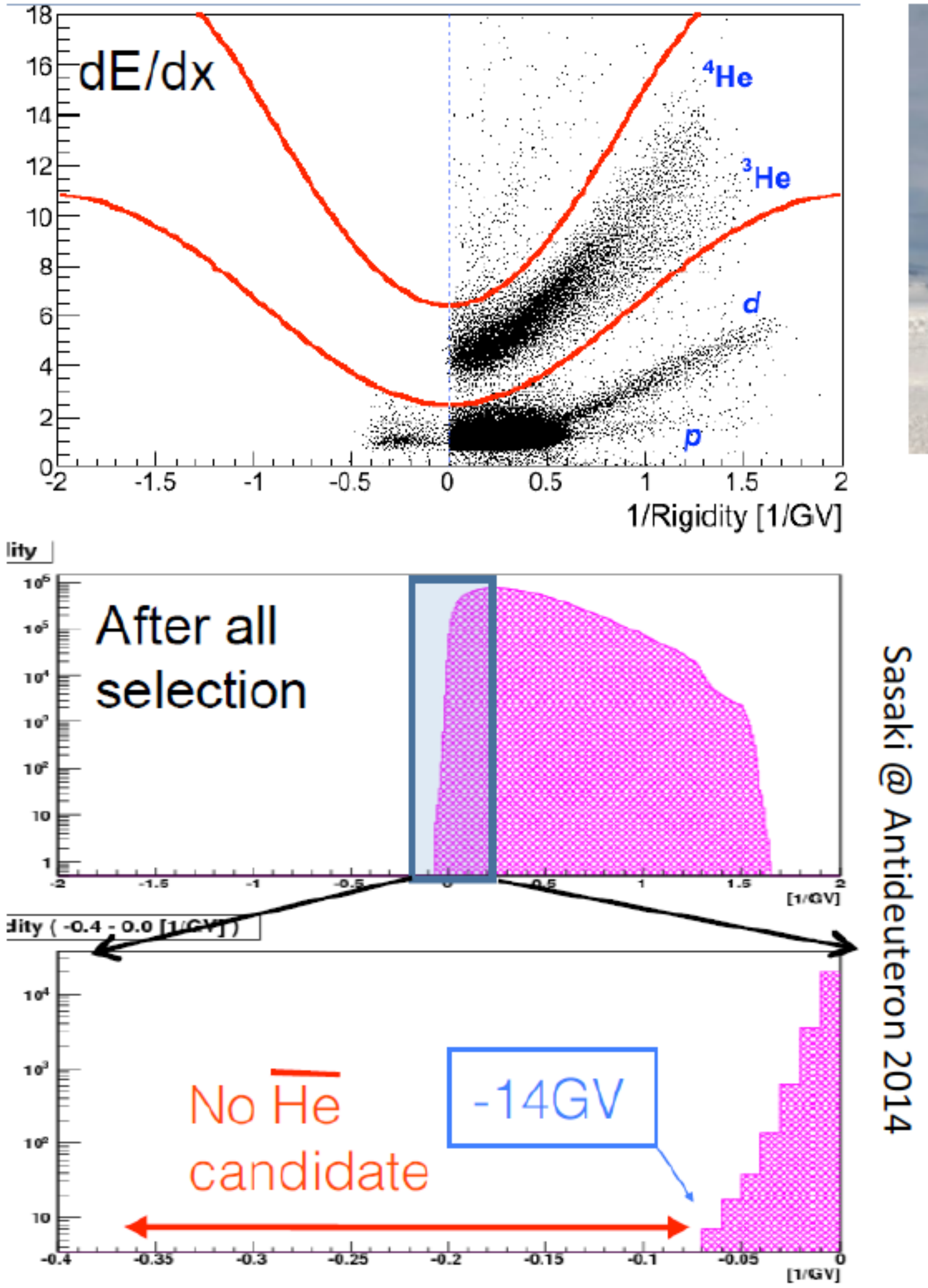
UM antiproton/proton ratio measured by BESS-Polar II together with BESS-Polar II UL measurement

- UM & UL antiproton/proton ratio show good consistency with the model calculation.

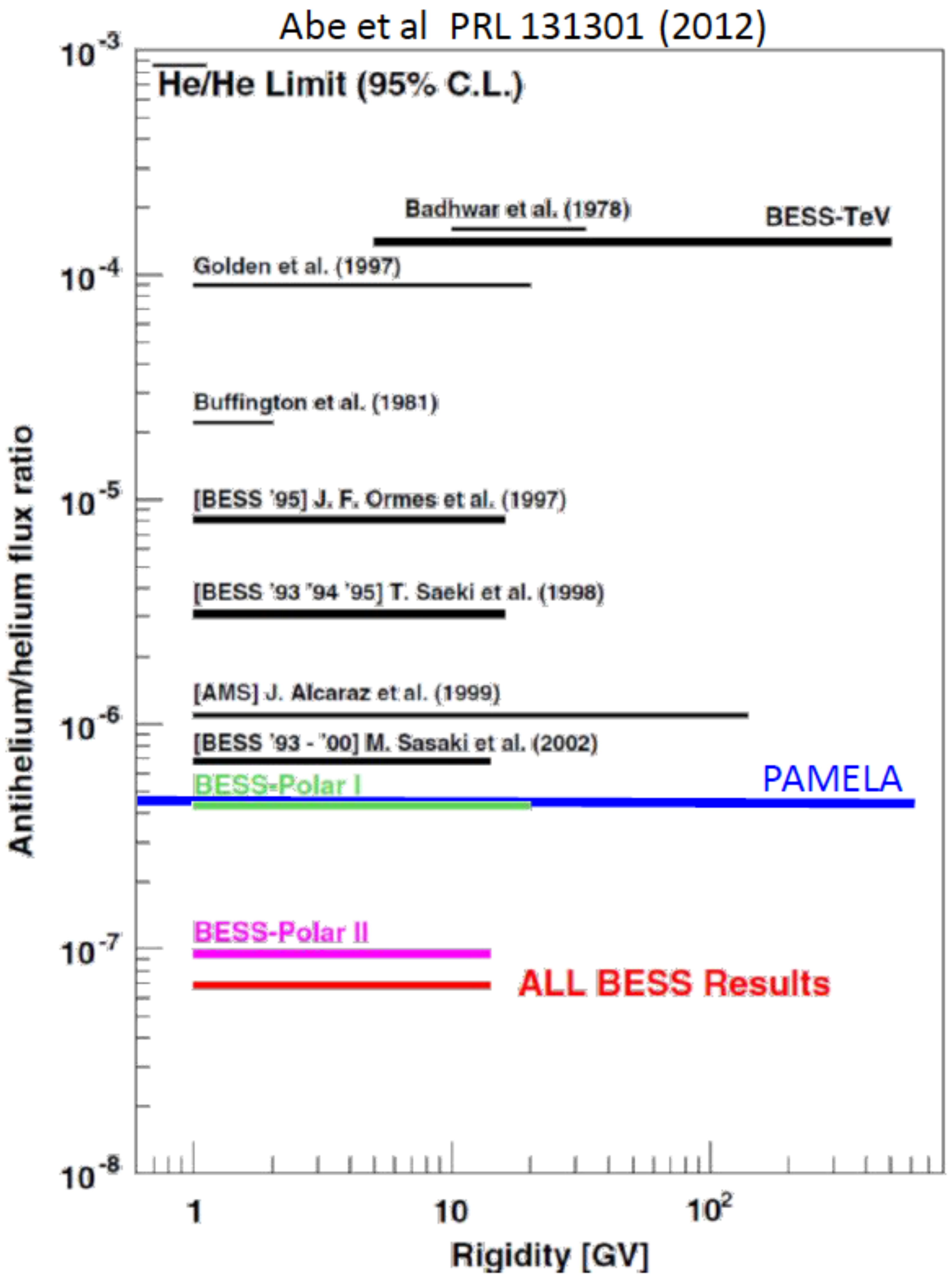
BESS confirms PAMELA and AMS data and extends the measurements at low energy.

Anti-nuclei

Most stringent limit of AntiHe/He paced so far from BESS-Polar II on anti-He



BESS-Polar II



Anti-Helium from AMS

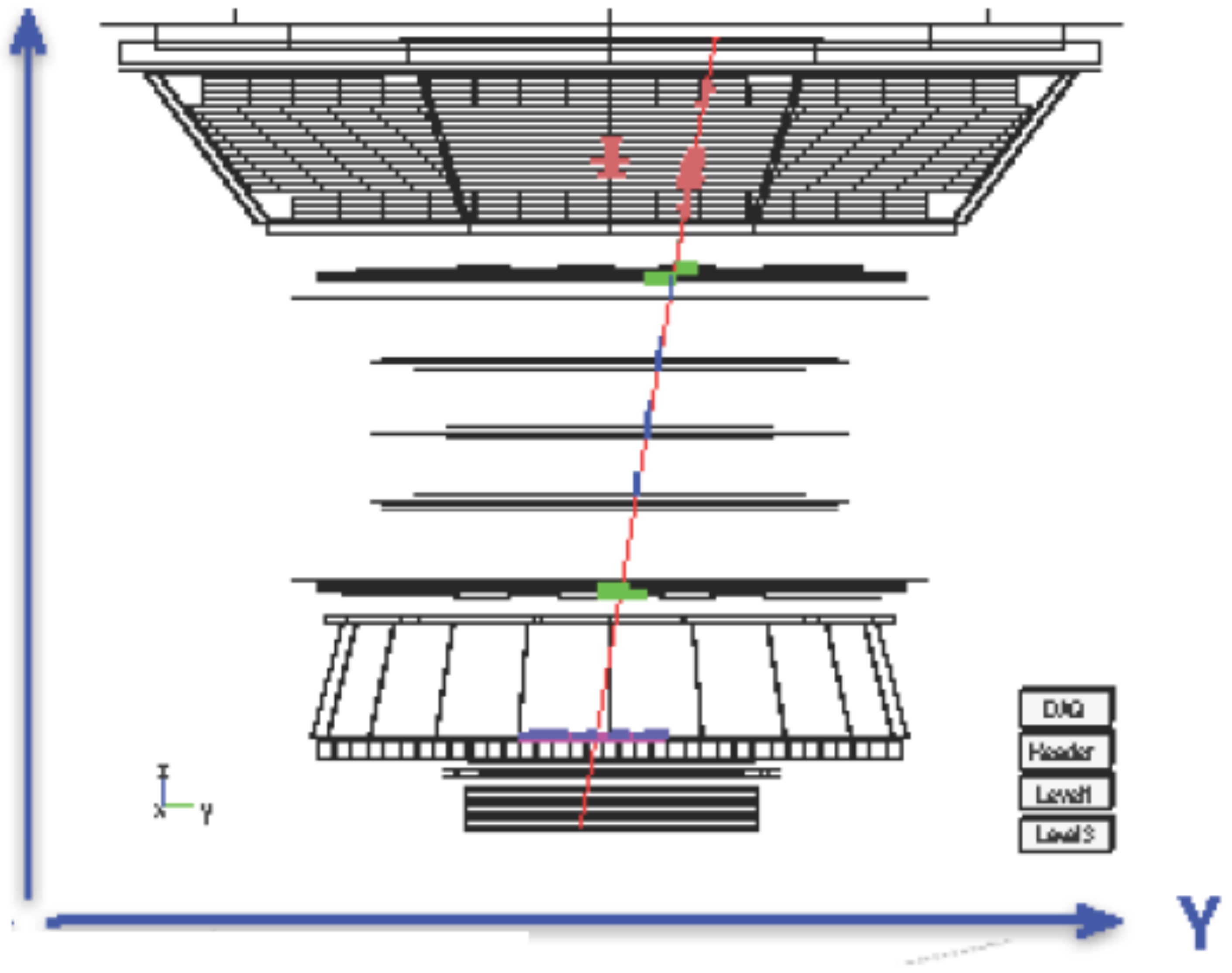
- To date AMS has observed a 5 Anti-He events, with mass around ^{3}He, at a rate of ~1 an antihelium in 100 million helium.

- It will take a few more years of detector verification and to collect more data to ascertain the origin of these events. At a signal to background ratio of one in one billion, detailed understanding of the instrument is required.

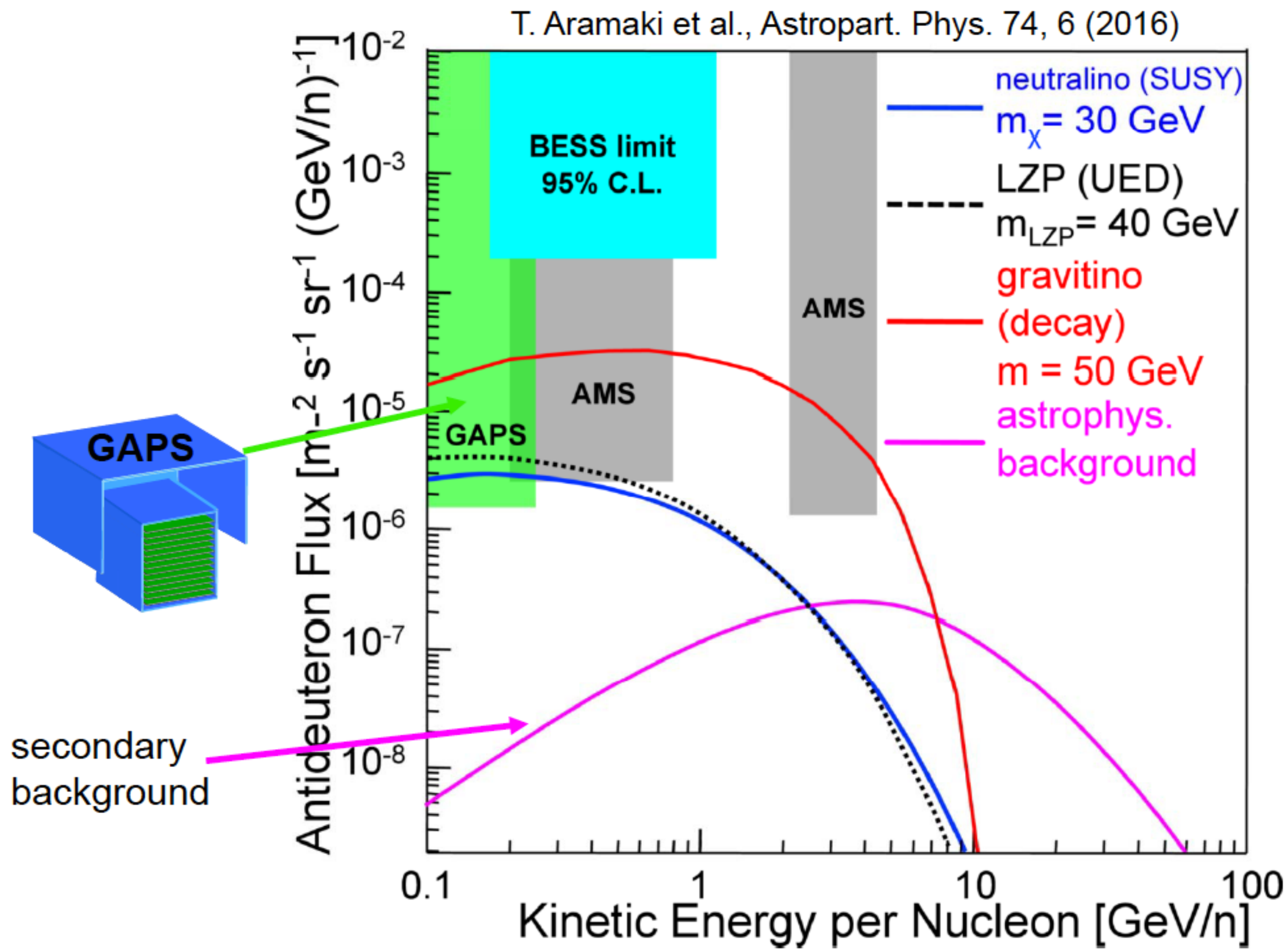
- Studies on **anti-deuteron** are ongoing.

Candidate Events

S.C.C. Ting, CERN Colloquium, https://indico.cern.ch/event/592392/



Anti-Deuteron



GAPS

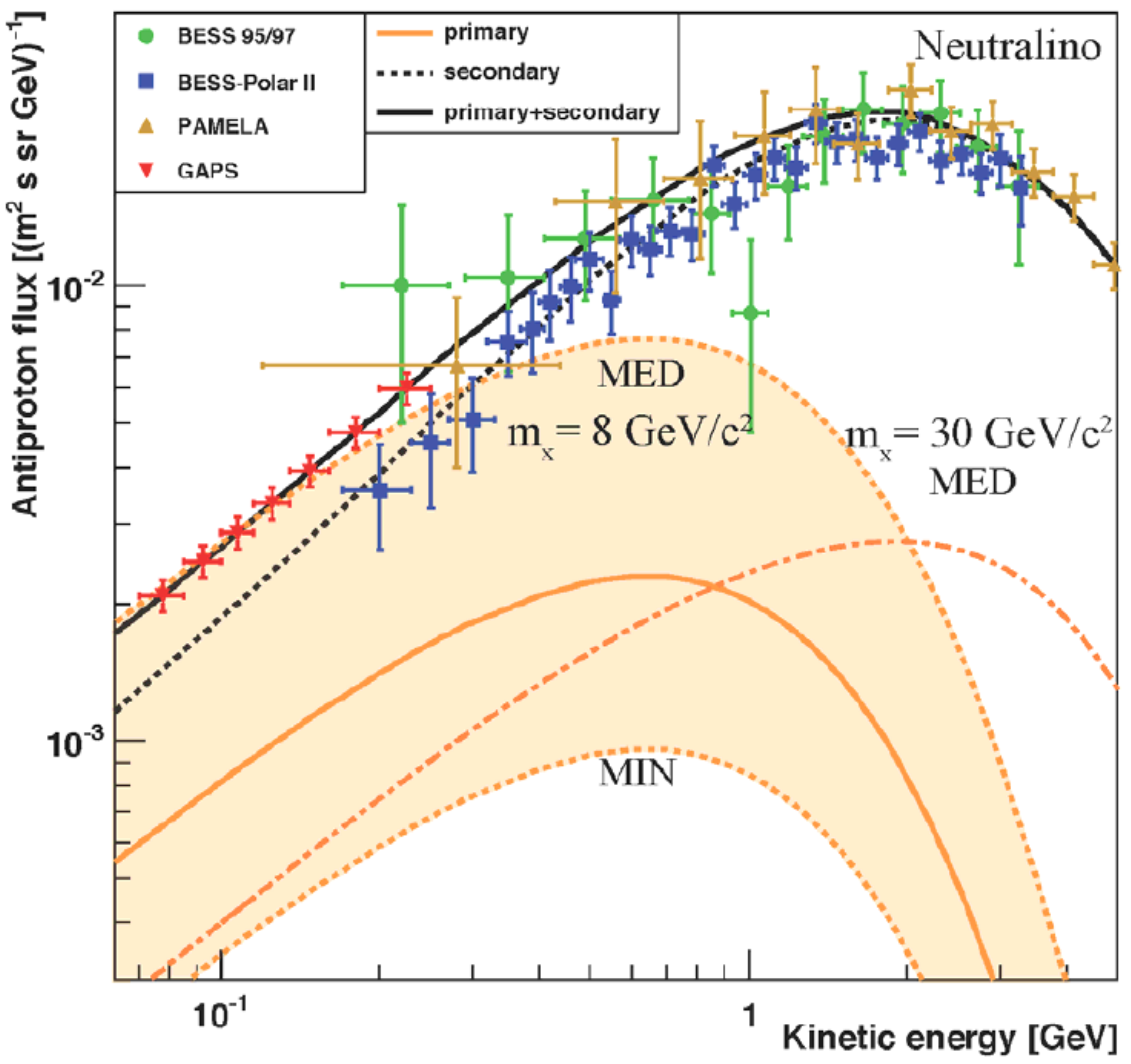
Dark matter search
using low-energy antimatter

Long-duration balloon (LDB) flight in Antarctic – low geomagnetic cutoff.

Now approved by NASA for funding and launch in late 2020

GAPS

T. Aramaki et al., Astropart. Phys. 59, 12 (2014)



GAPS will make precision measurement of the low energy **antiprotons**.

GAPS is expected to have x10 more statistics @0.25 GeV than BESS/ PAMELA and AMS.

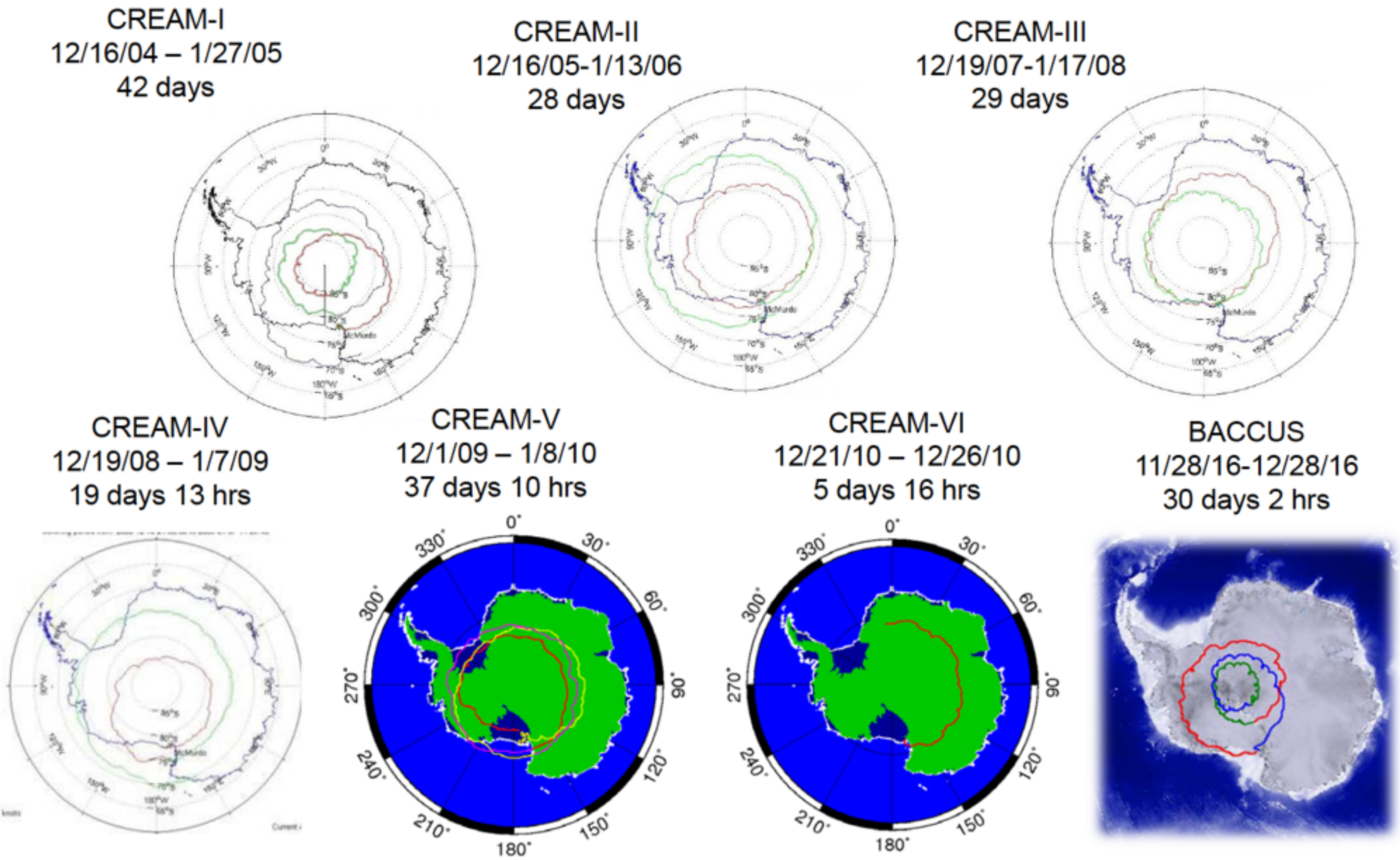
GAPS has also the capability for detection **anti-He** and studies to estimate the sensitivity are on going.

->Talk K. Perez TeVPA 2017

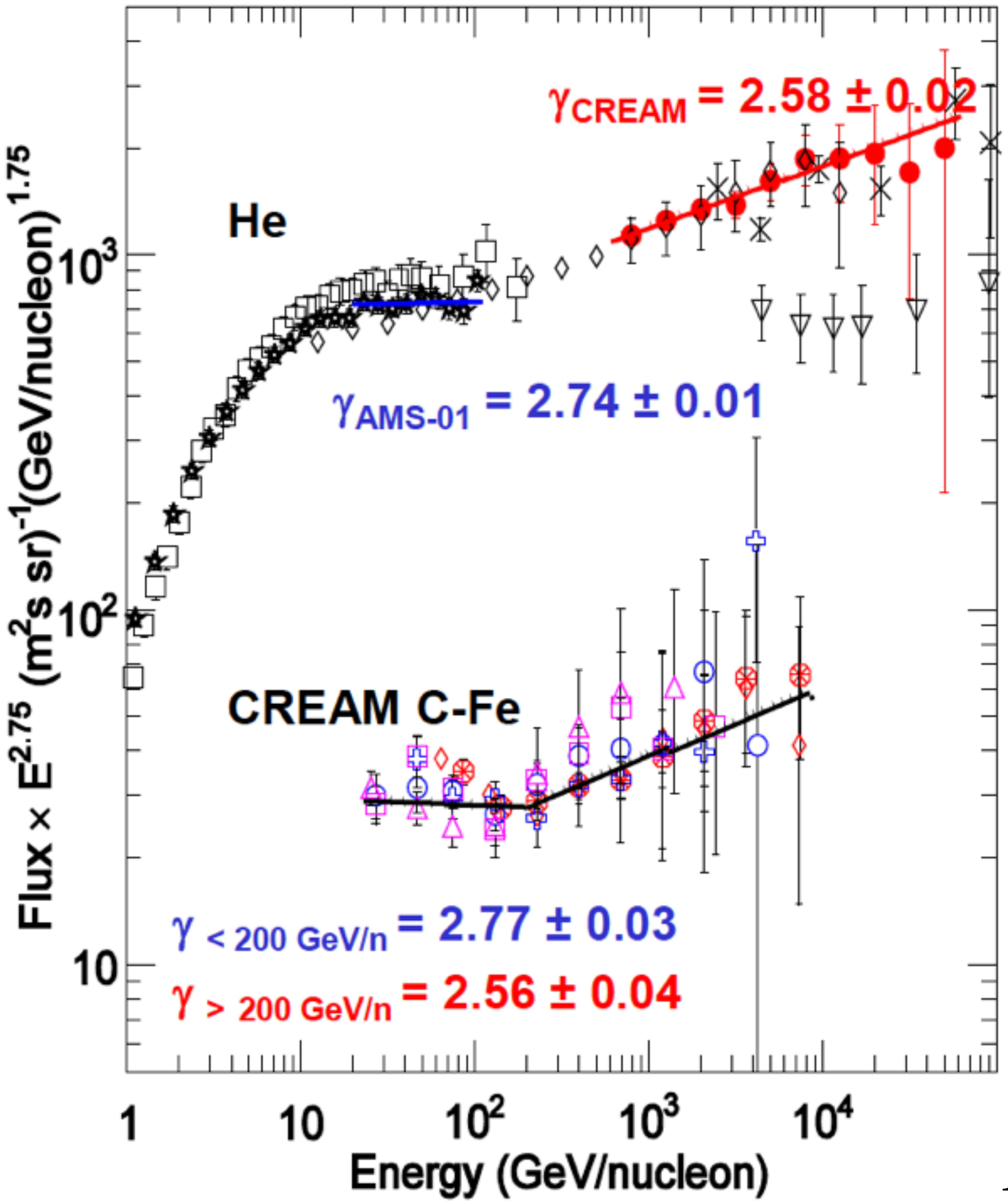
CREAM - is there an hardening in the spectra?

CREAM spectra harder than prior lower energy measurements: P, He and heavy nuclei.

SevenBalloon Flights in Antarctica: ~191 days Cumulative Exposure

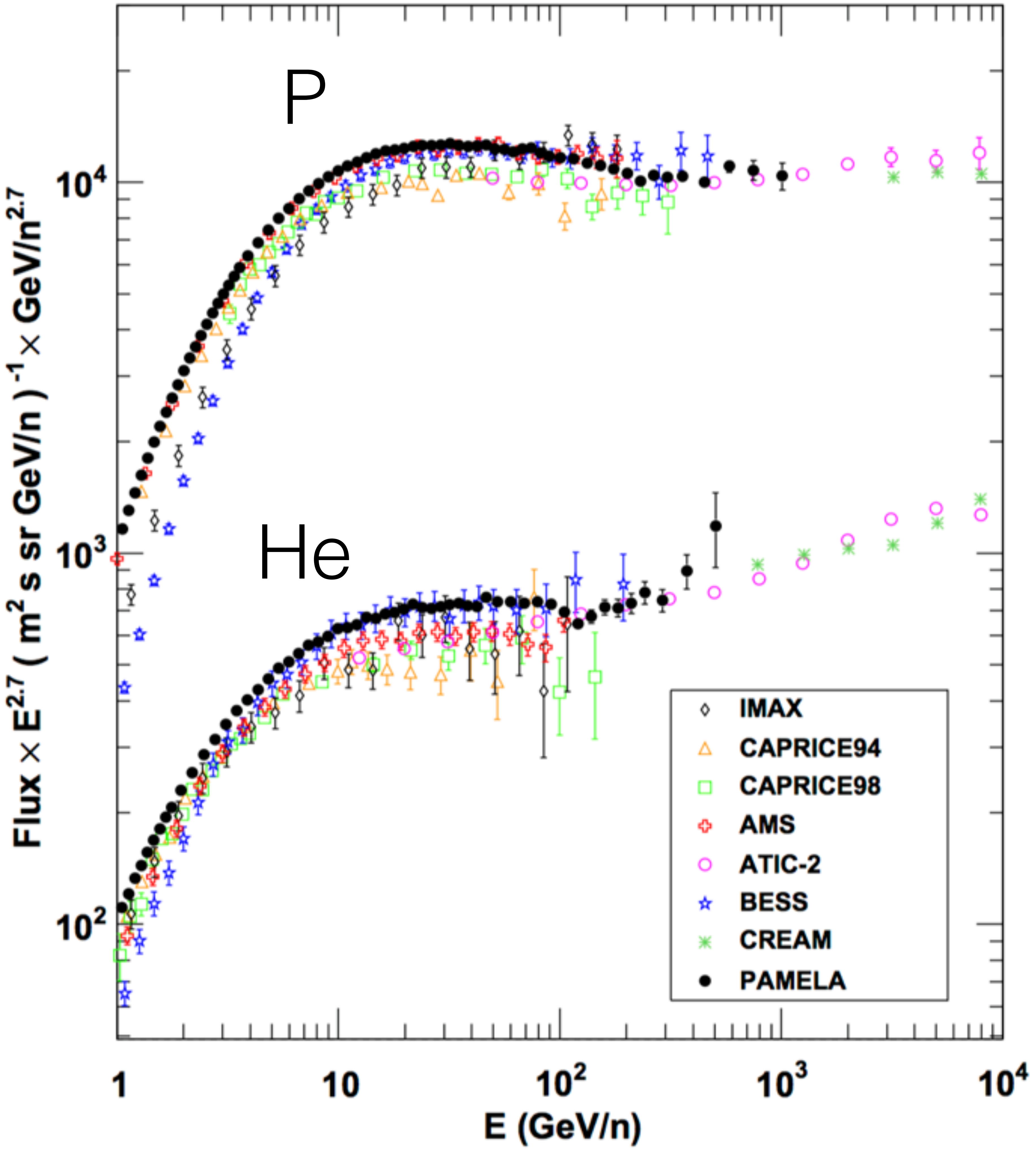


Yoon et al. ApJ **728**, *122*, 2011

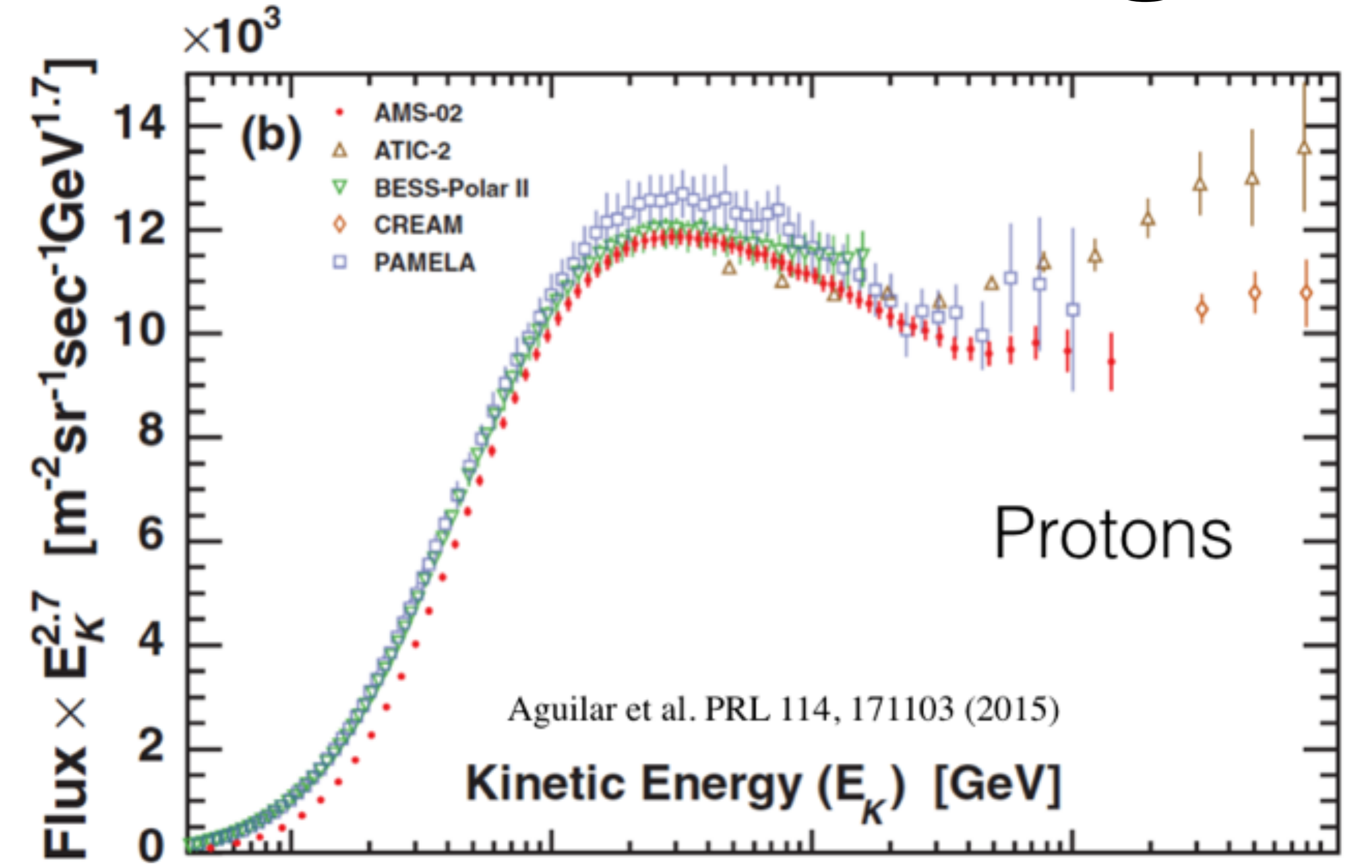


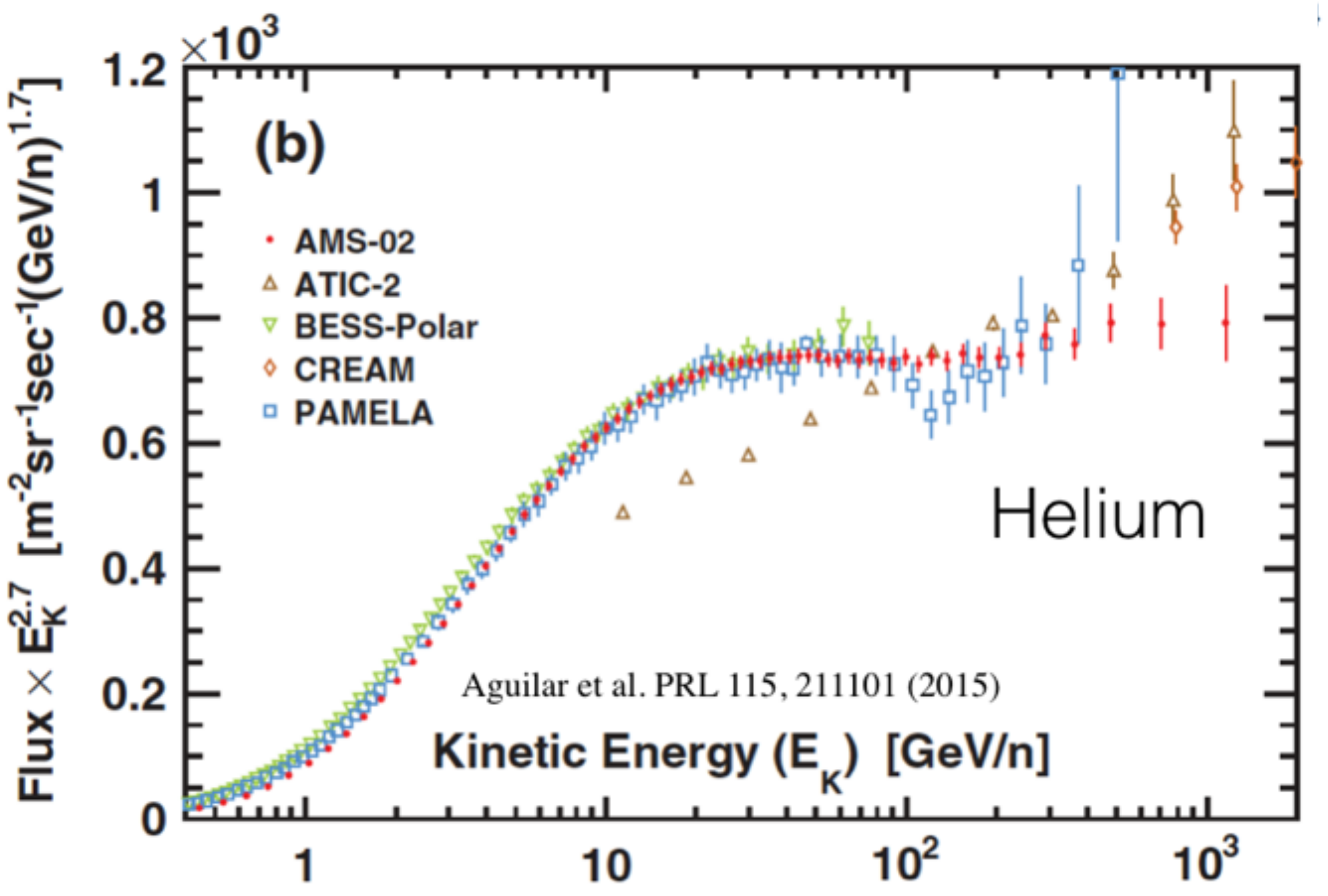
Confirmation of P and He hardening

- PAMELA measured a break for P and He around ~ 200 GV
- Consistent with high energy CREAM data.
- AMS measured a smooth hardening above 230 GV for both H and He.

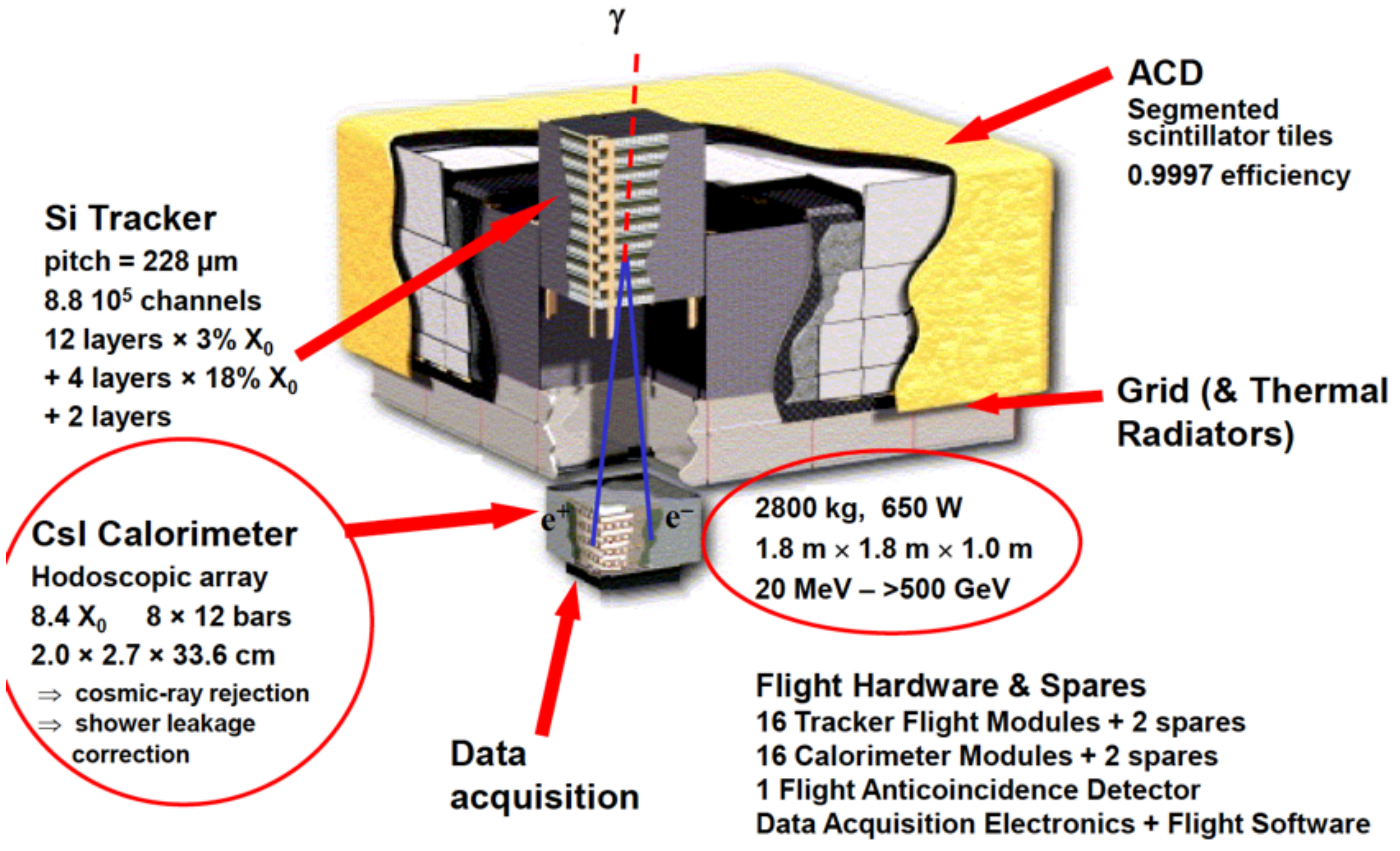


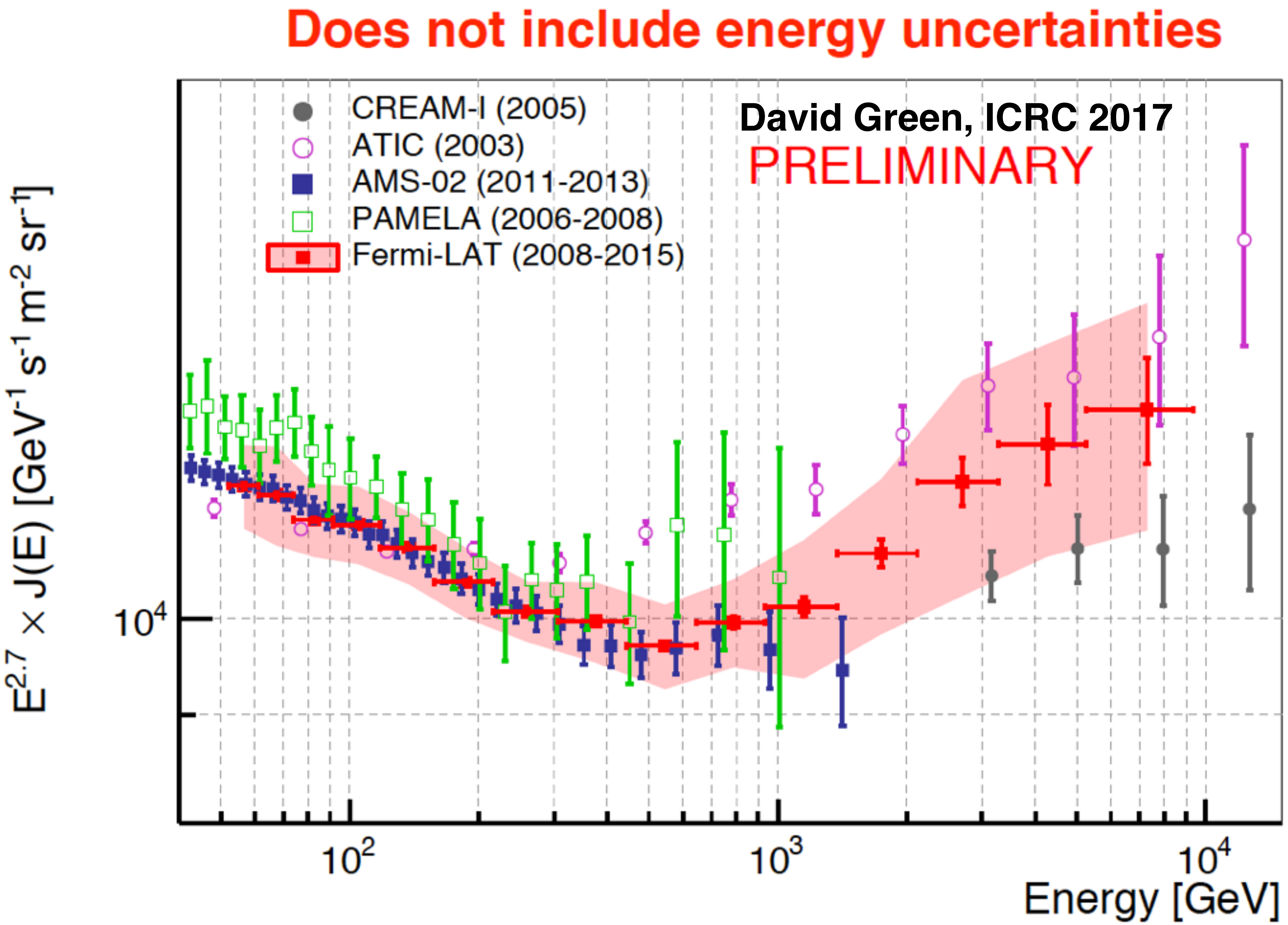
O. Adriani, Science, Vol 332, 2011





FERMI-LAT protons

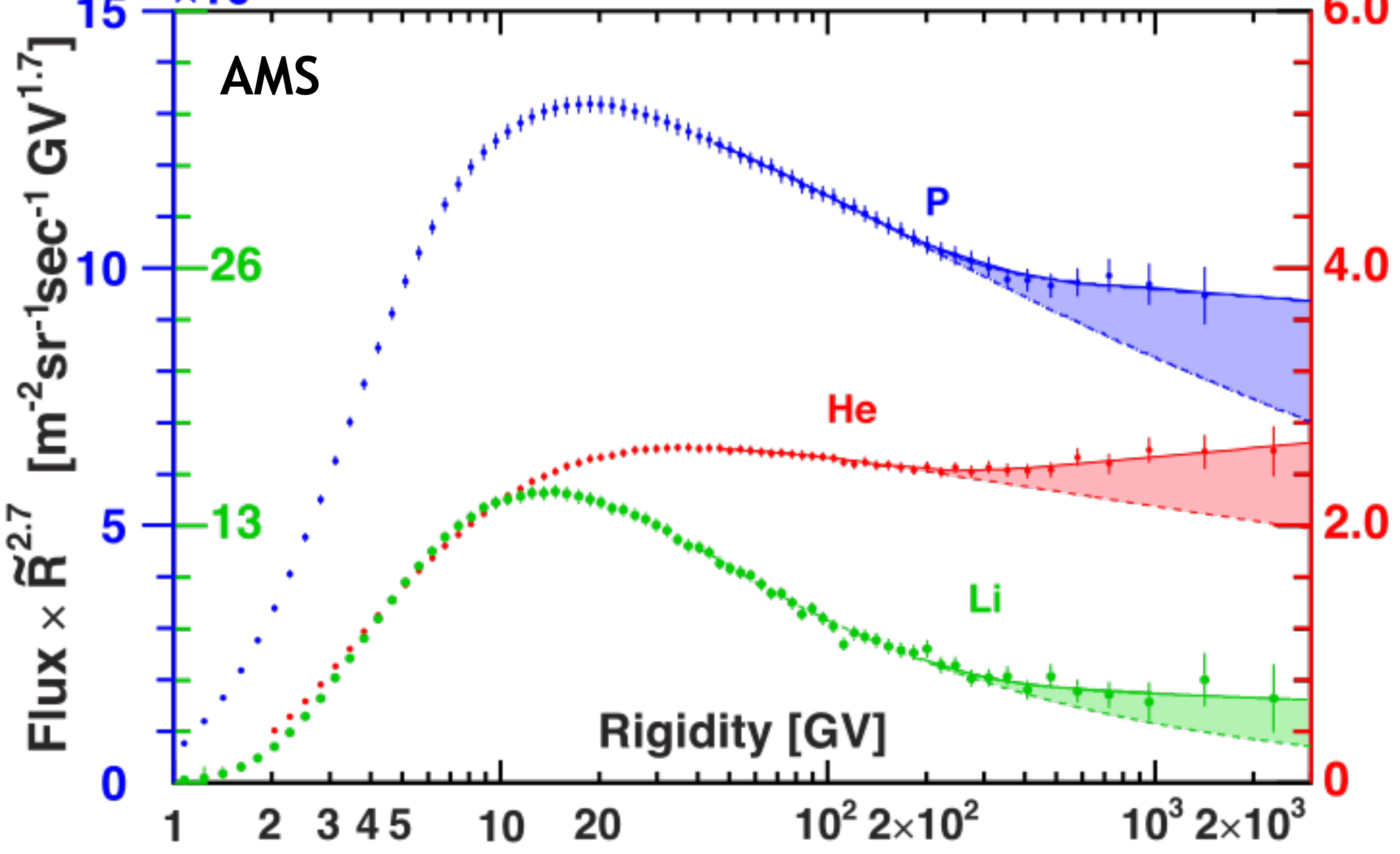




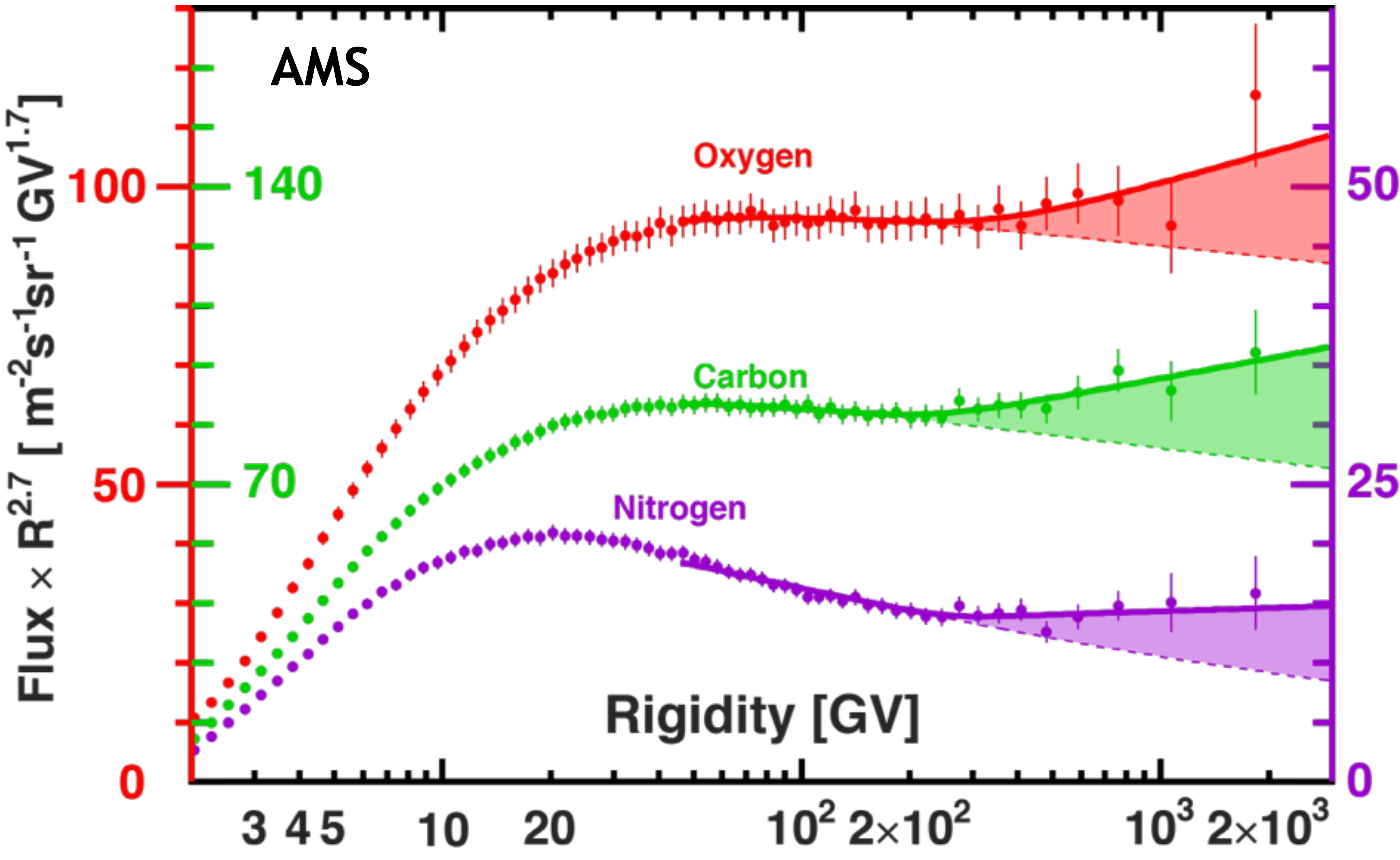
P hardening confirmed by FERMI-LAT
Using 7 years of LAT 2008-2015
Extend space-based measurement to 9.5 TeV

AMS Protons, helium and higher nuclei change their behavior at the same rigidity.

A. Kunine ICRC 2017



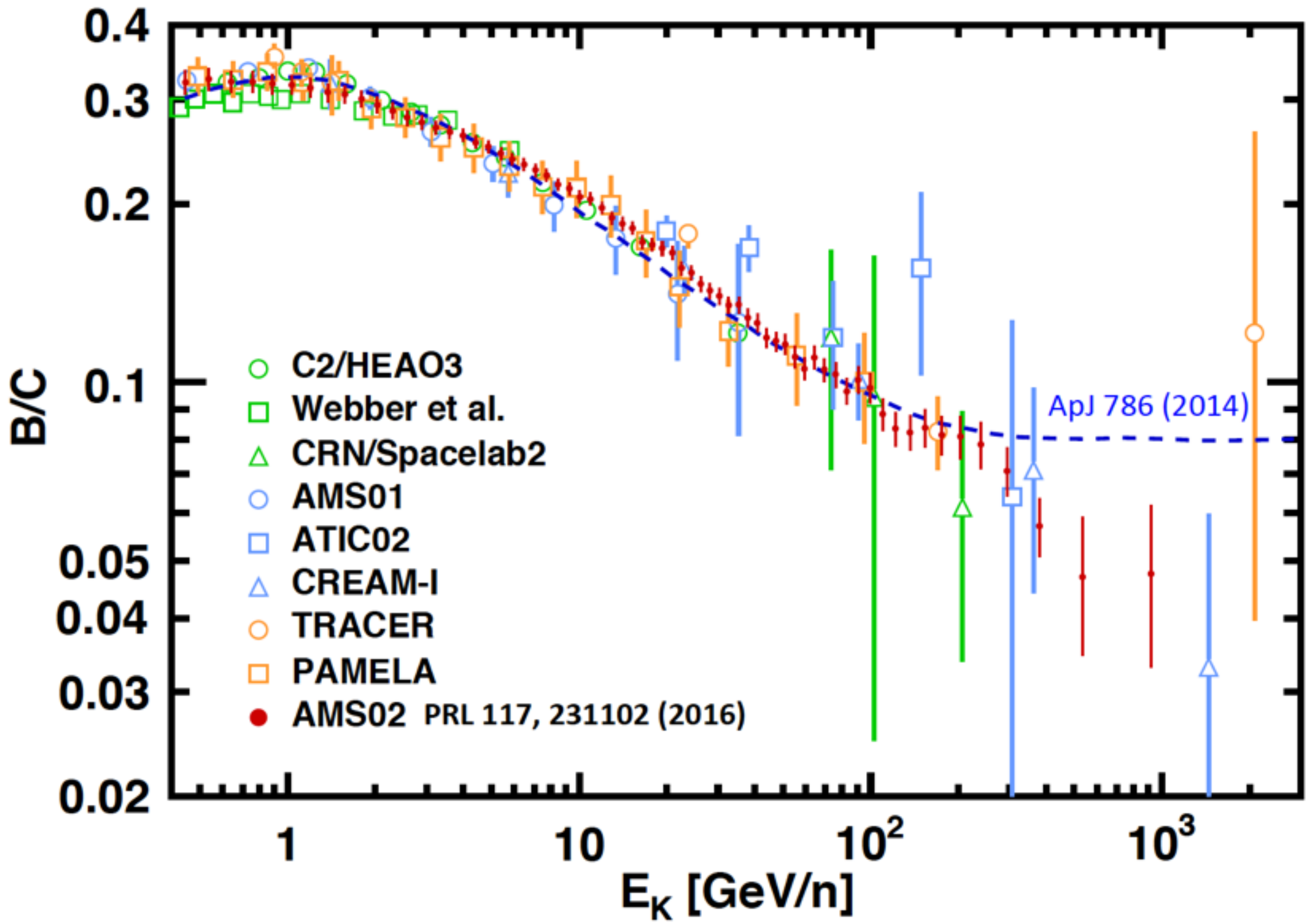
A. Kunine ICRC 2017



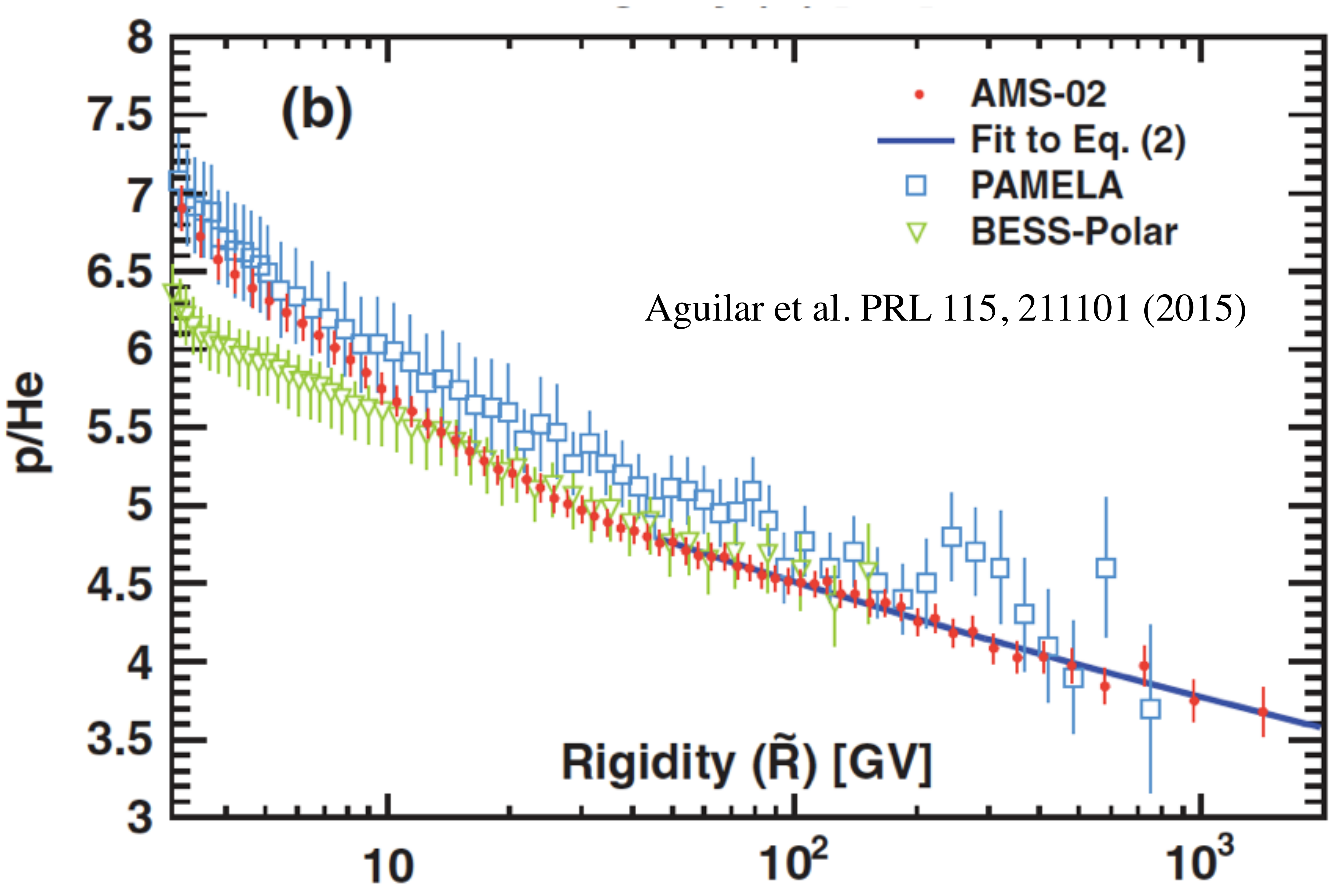
AMS measured a smooth hardening above 230 GV for heavier elements at the same rigidity.

Why the hardening? re-acceleration at the source? propagation? nearby source?

Ratios rigidity dependent



The B/C ratio does not show any significant structures and it is described by a single power law. (Exclude some propagation models). Other secondaries/primaries will be studied.



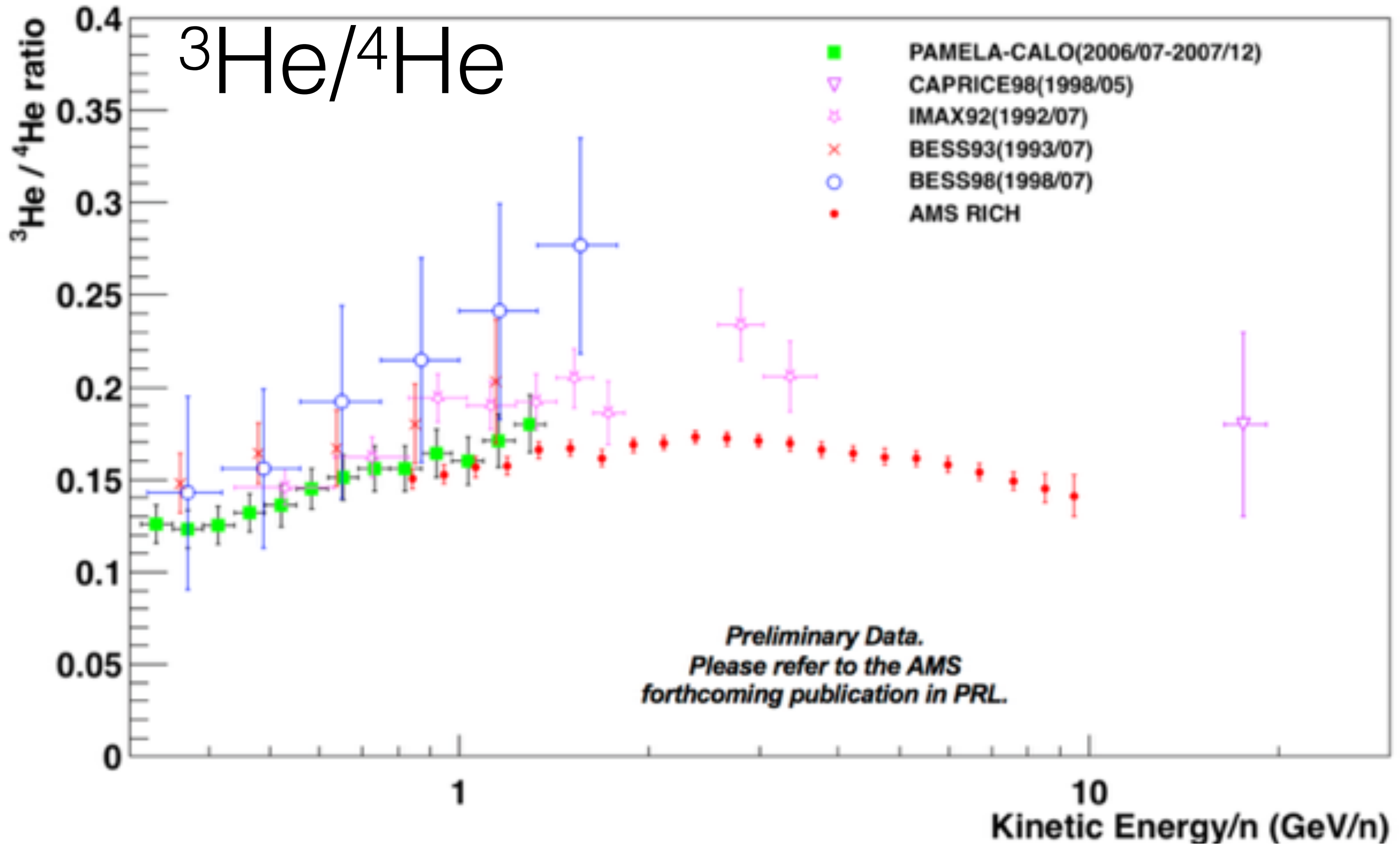
Protons and helium are both primaries and produced by the same source, therefore their flux ratio should be flat. The ratio varies with rigidity.

P and He have different slopes. Why?

Isotopes

AMS-02

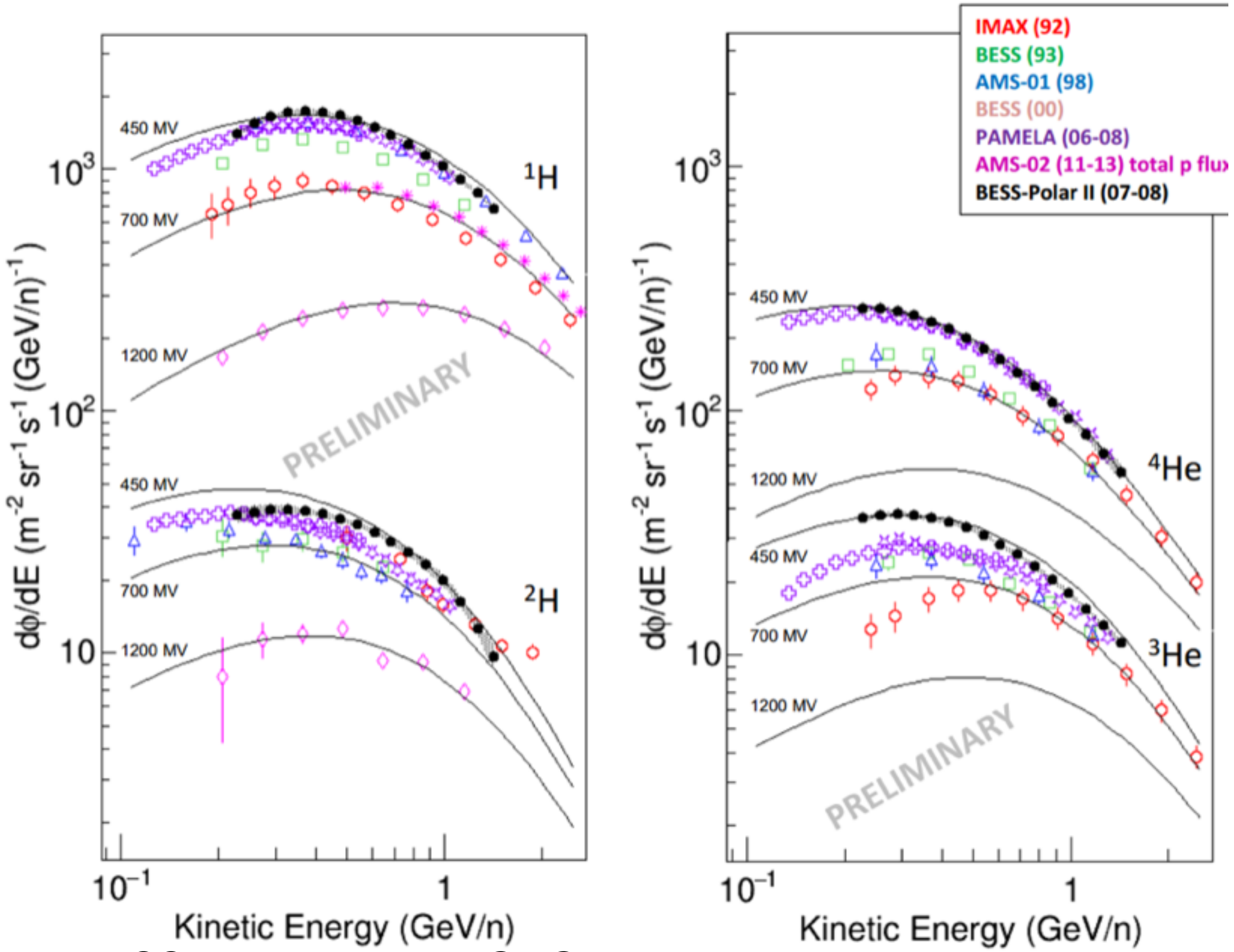
-> Talk F. Giovacchini TevPA 2017



BESS Polar II

Same solar modulation with PAMELA: good agreement ^1H and ^4He

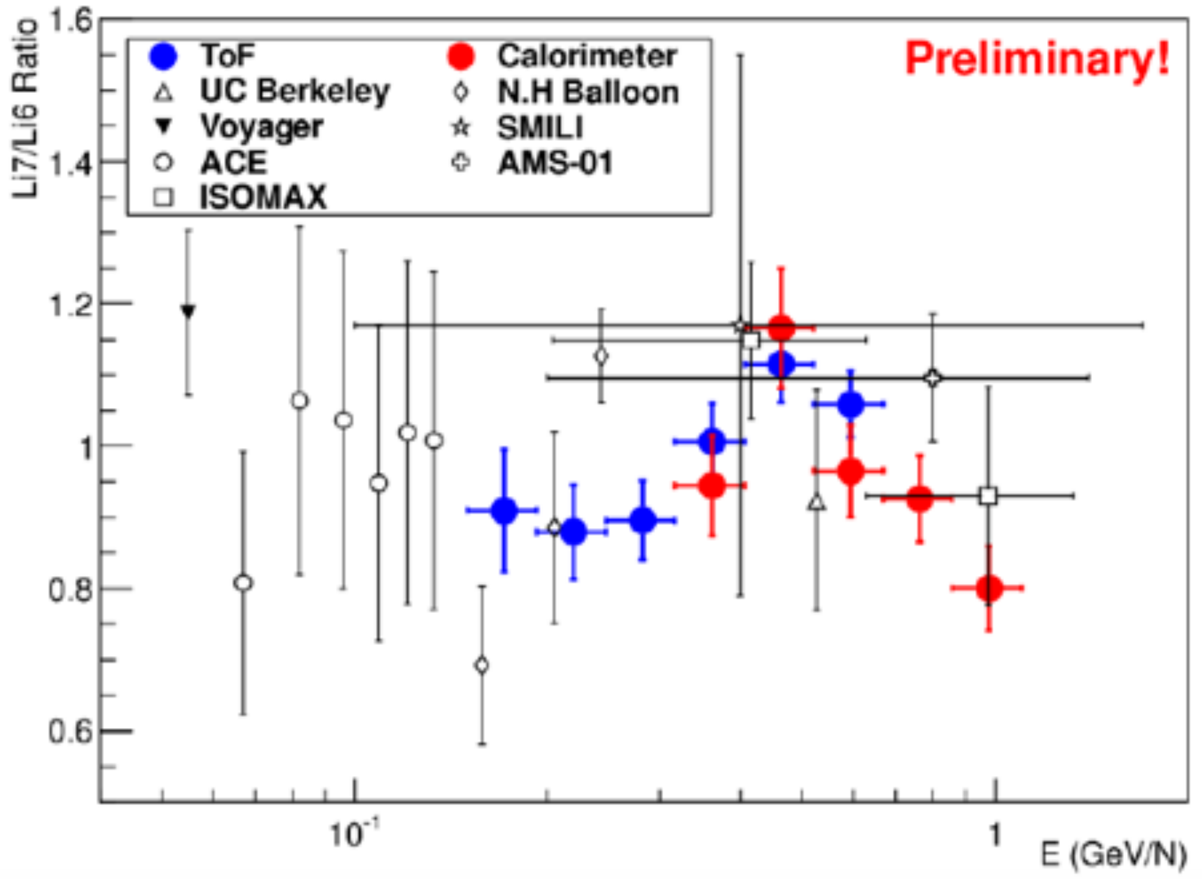
^2H and ^3He significantly higher



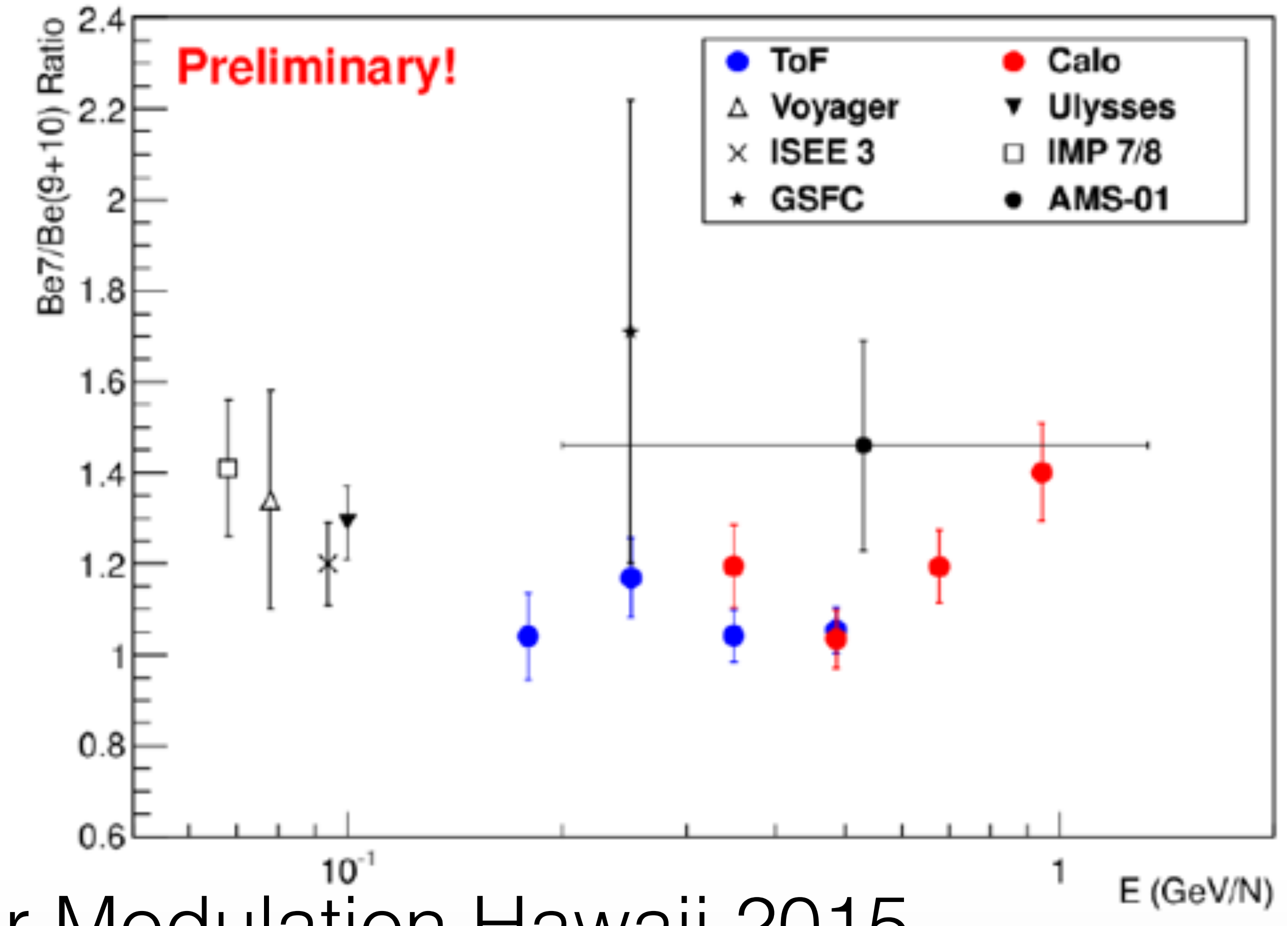
BESS collaboration ICRC 2017

PAMELA

Ratio ^7Li / ^6Li



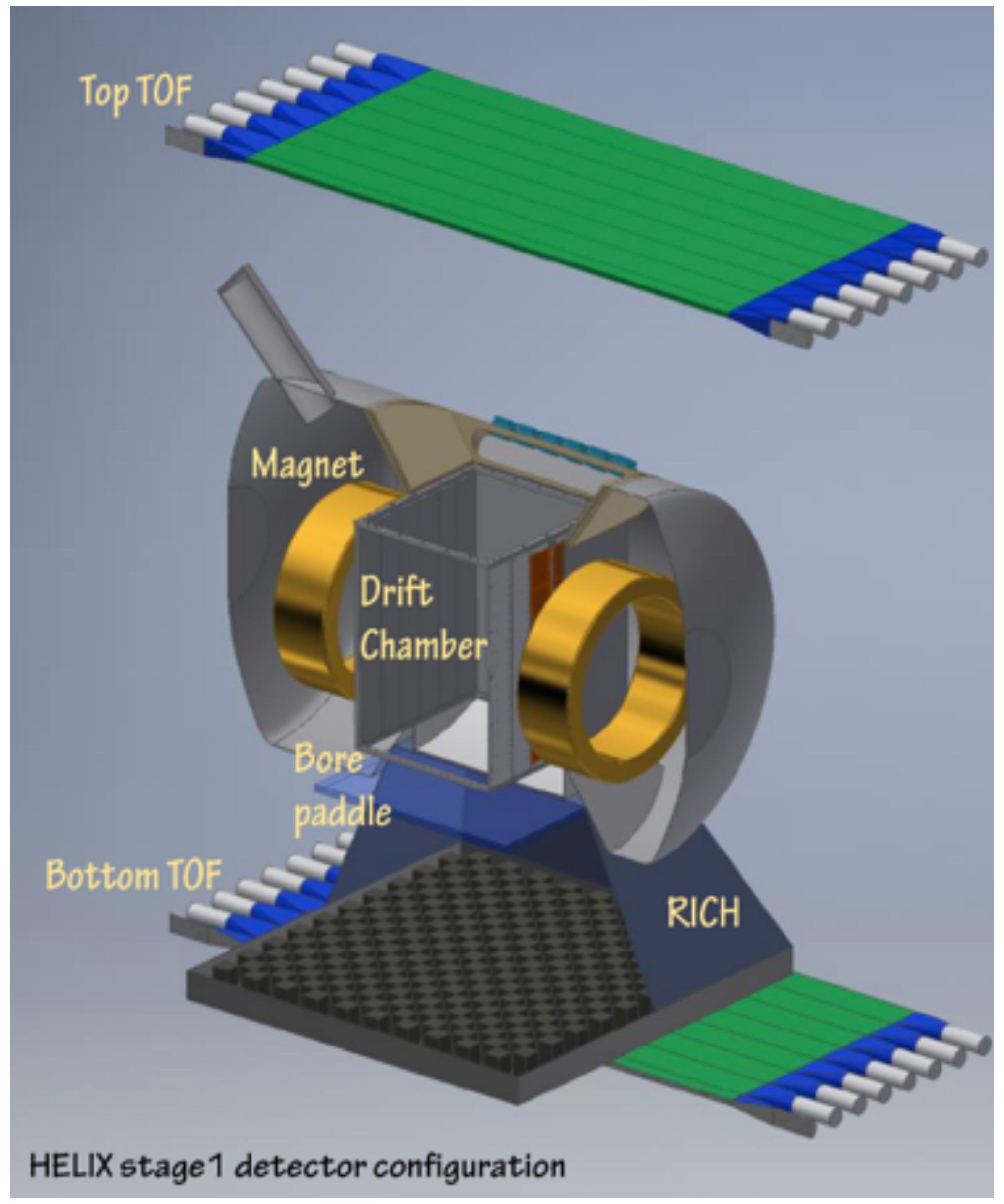
^7Be / (^9Be + ^{10}Be)

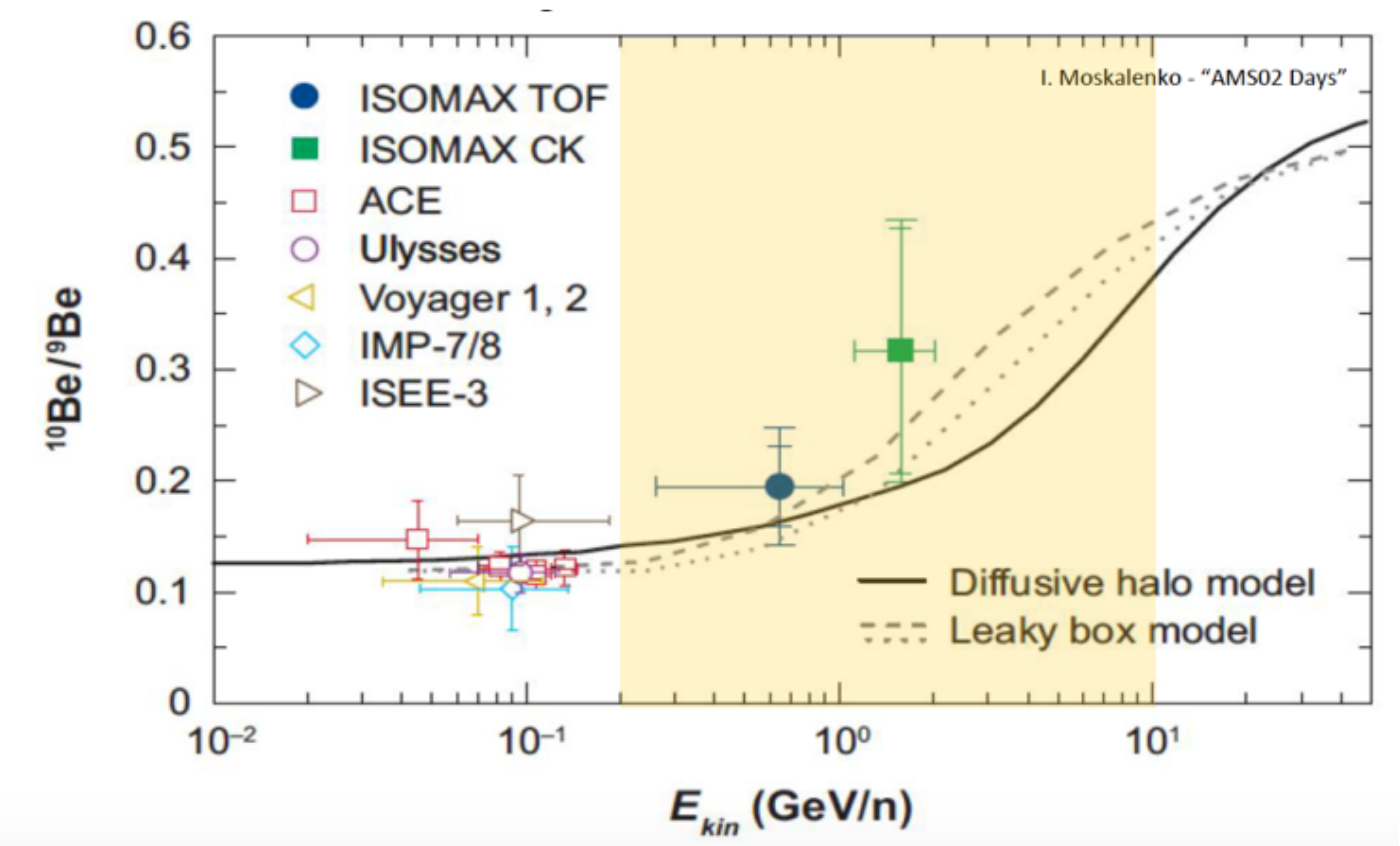


M. Boezio Workshop Solar Modulation Hawaii 2015

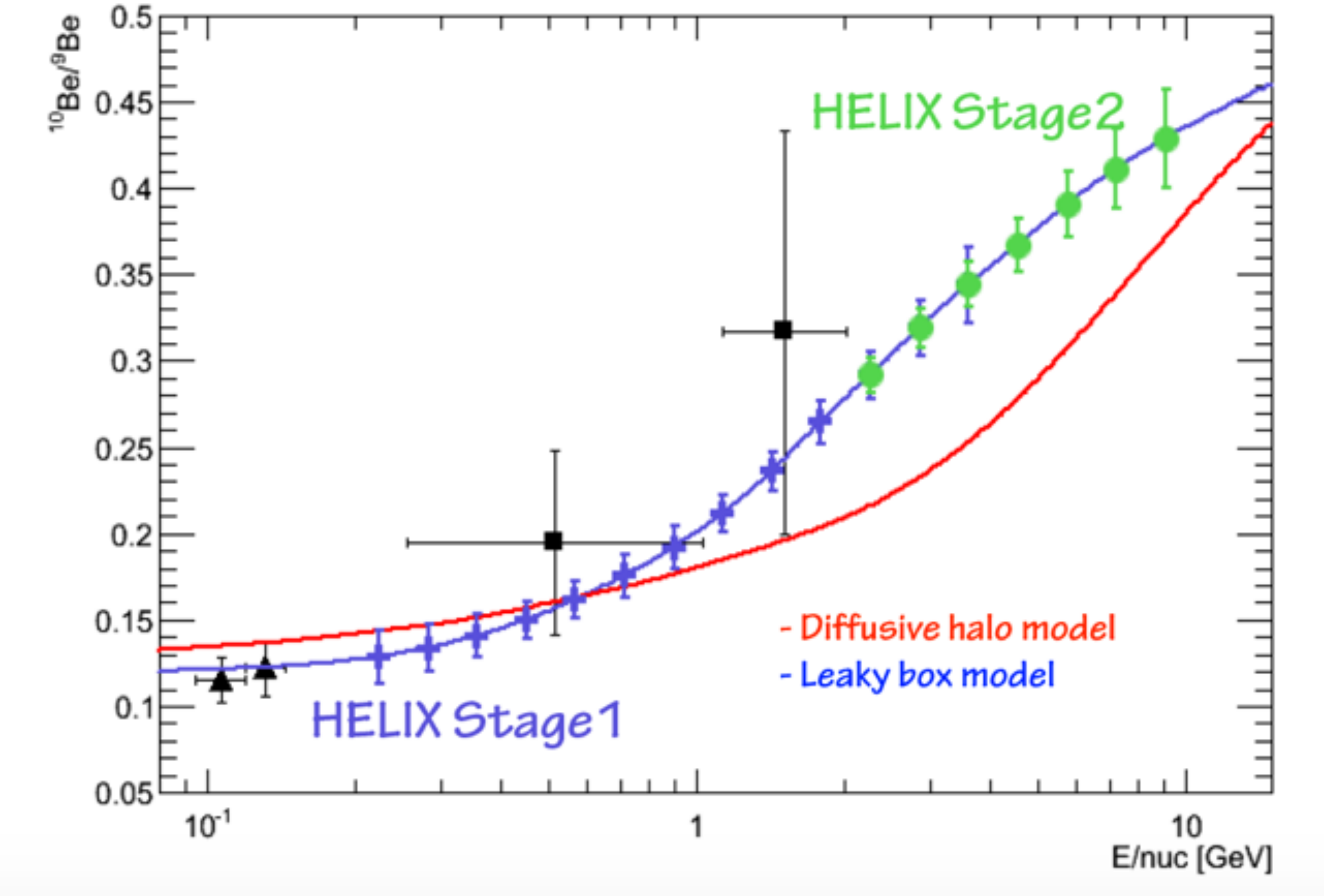
Isotopes: HELIX $^{10}Be/^{9}Be$

To fly in 2019 with LDB





N. Park ICRC 2017

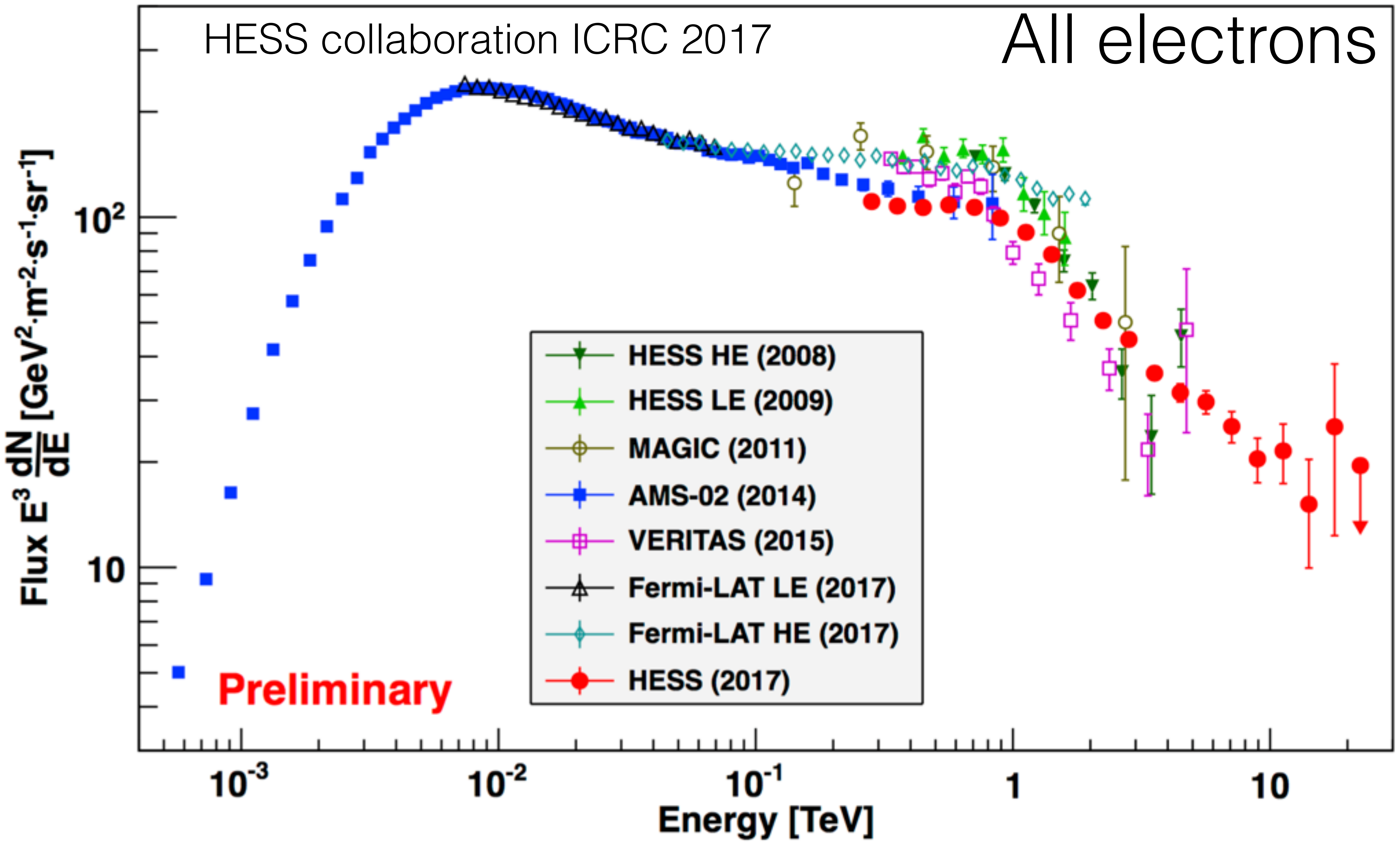


^{10}Be : Unstable isotope w/ known half life of 1.5×10^6 yr

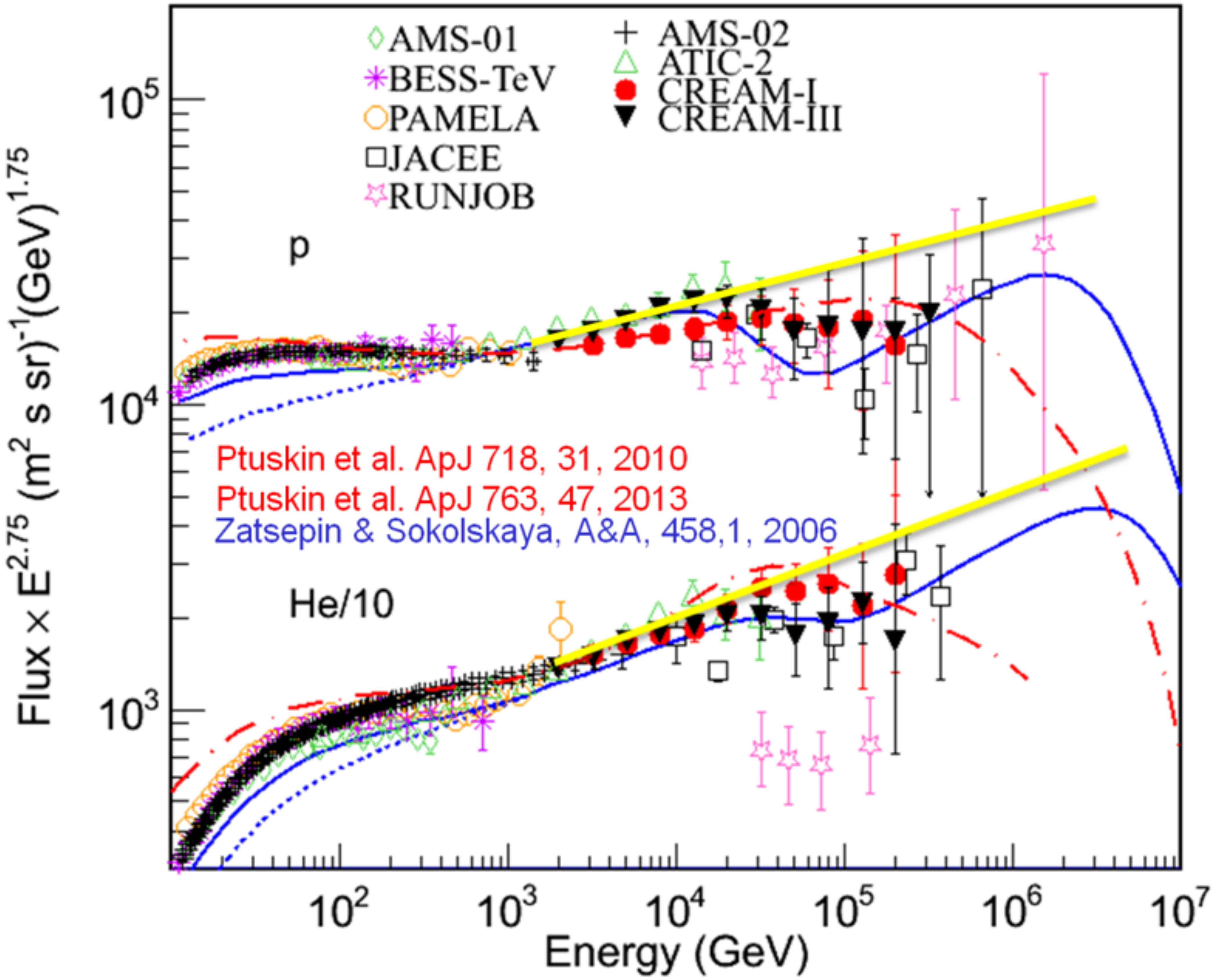
- ^{10}Be/^{9}Be ratio provides strong constraints for the propagation models

Need to extend to higher energies

To search for spectral features from nearby/young sources and acceleration effects in the TeV range.

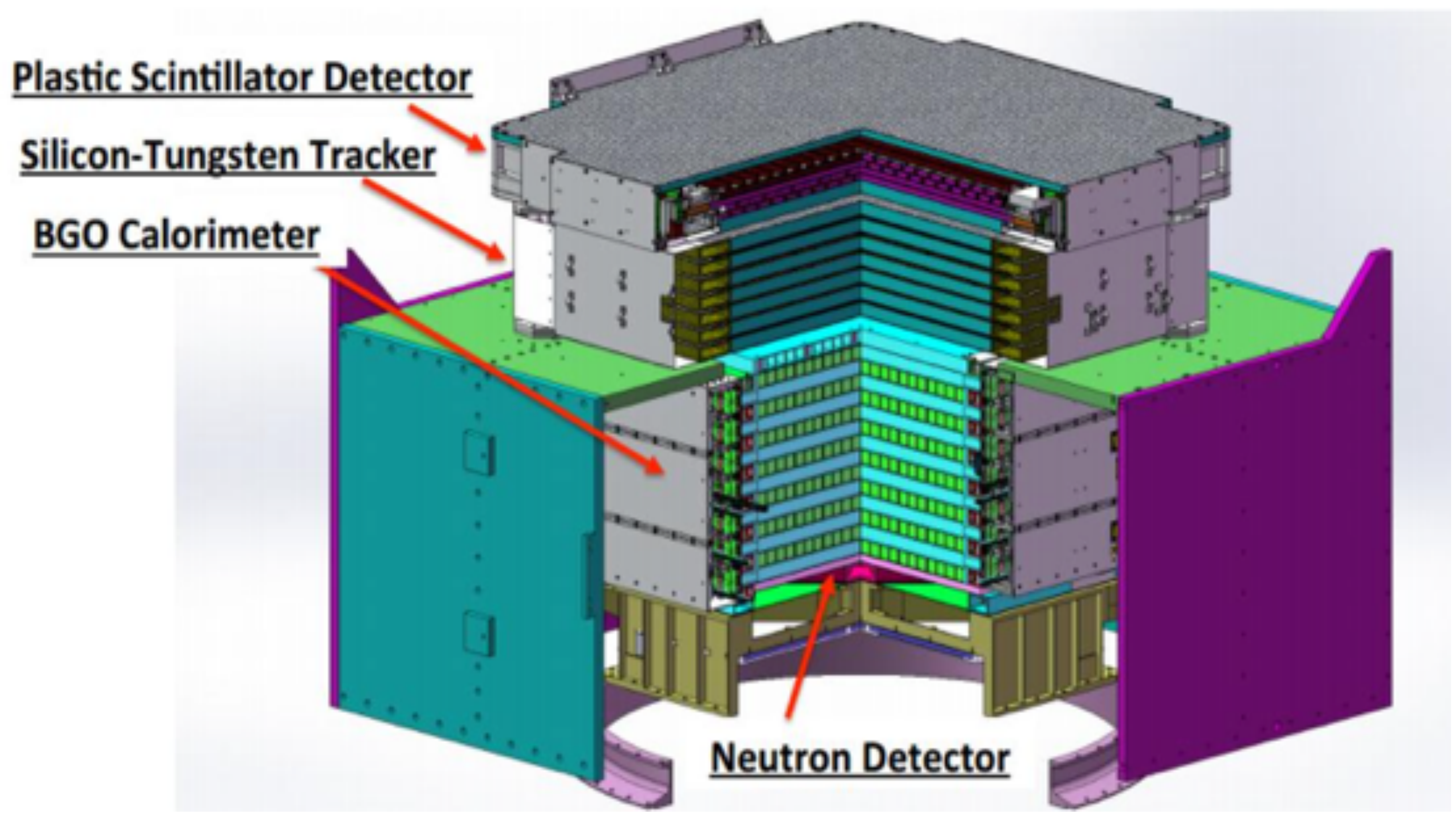


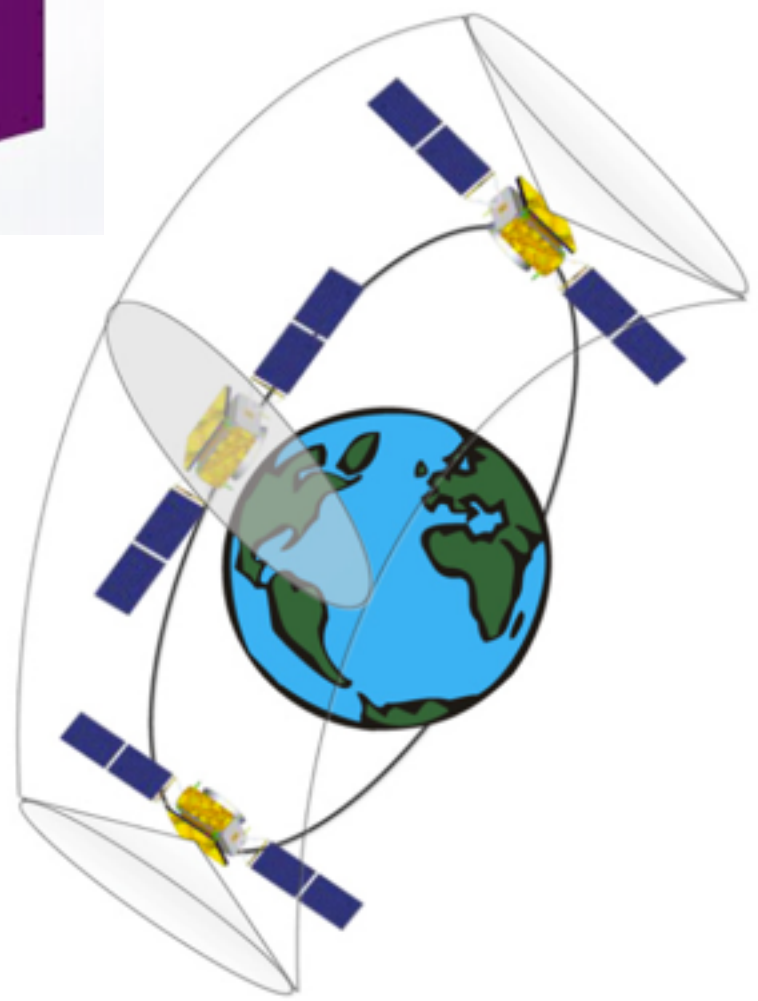
Yoon et al. (CREAM Collaboration) ApJ 839:5, 2017

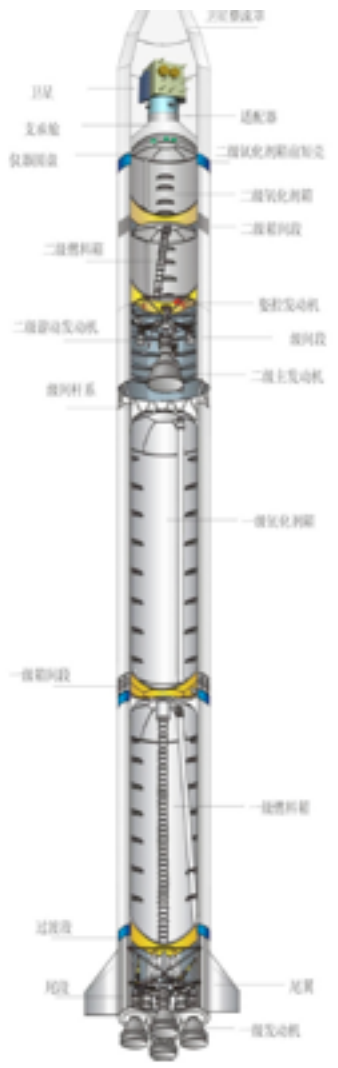


DAMPE

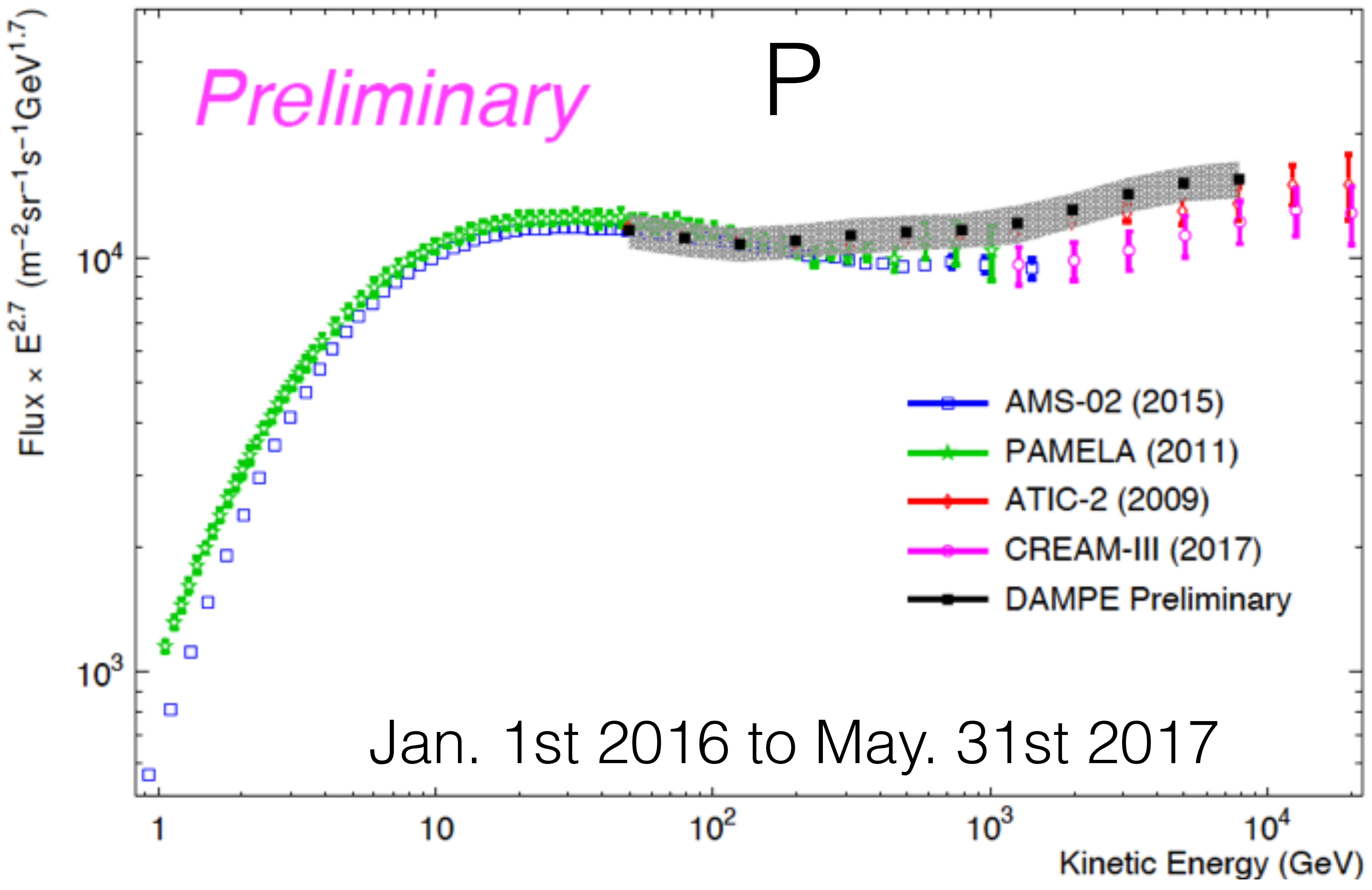
Launched: December 2015 with a rocket
Lifetime: greater than 3 years
Electrons and photons: 5 GeV – 10 TeV
Protons and heavy ions: 100 GeV – 100 TeV

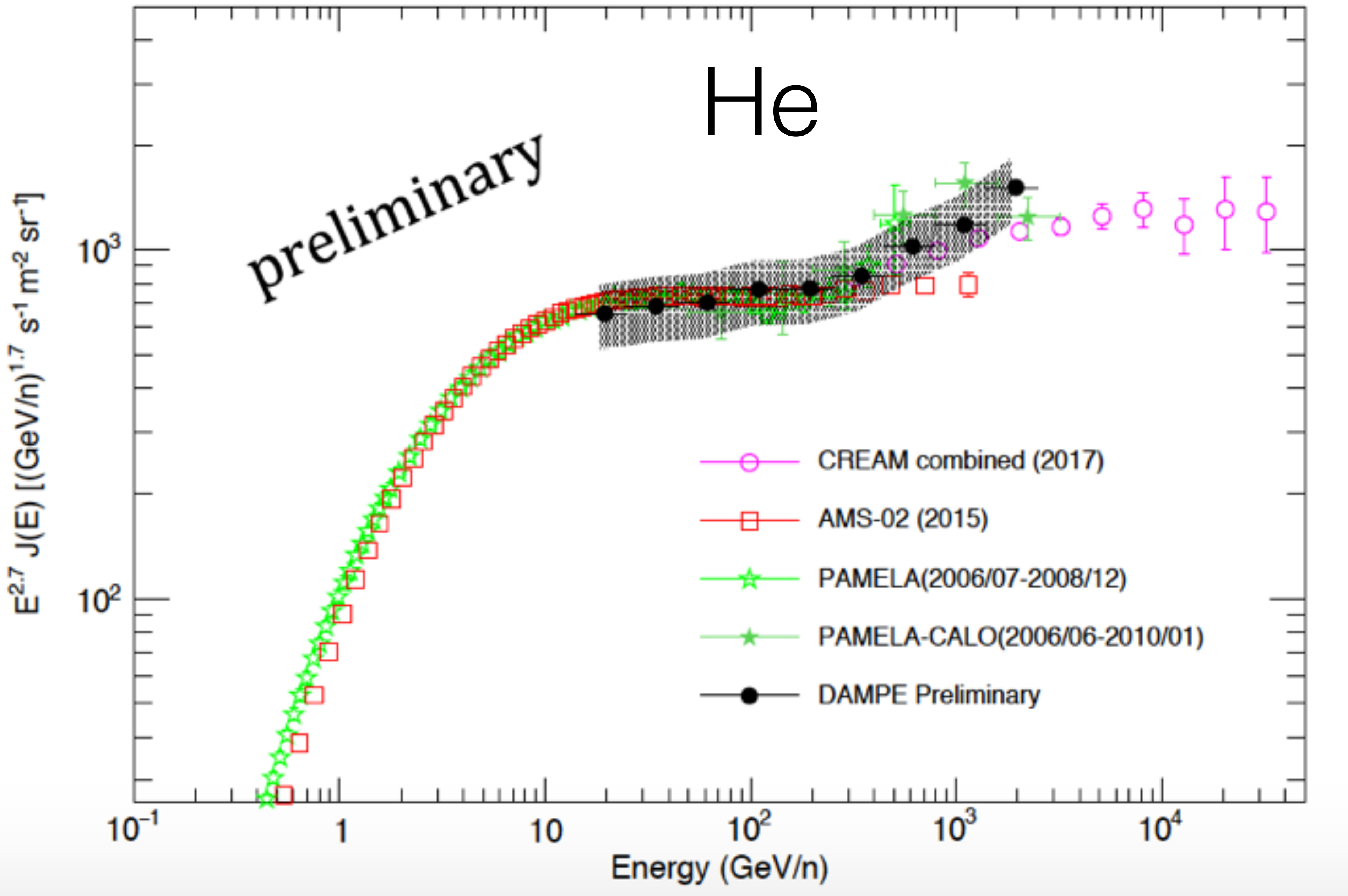






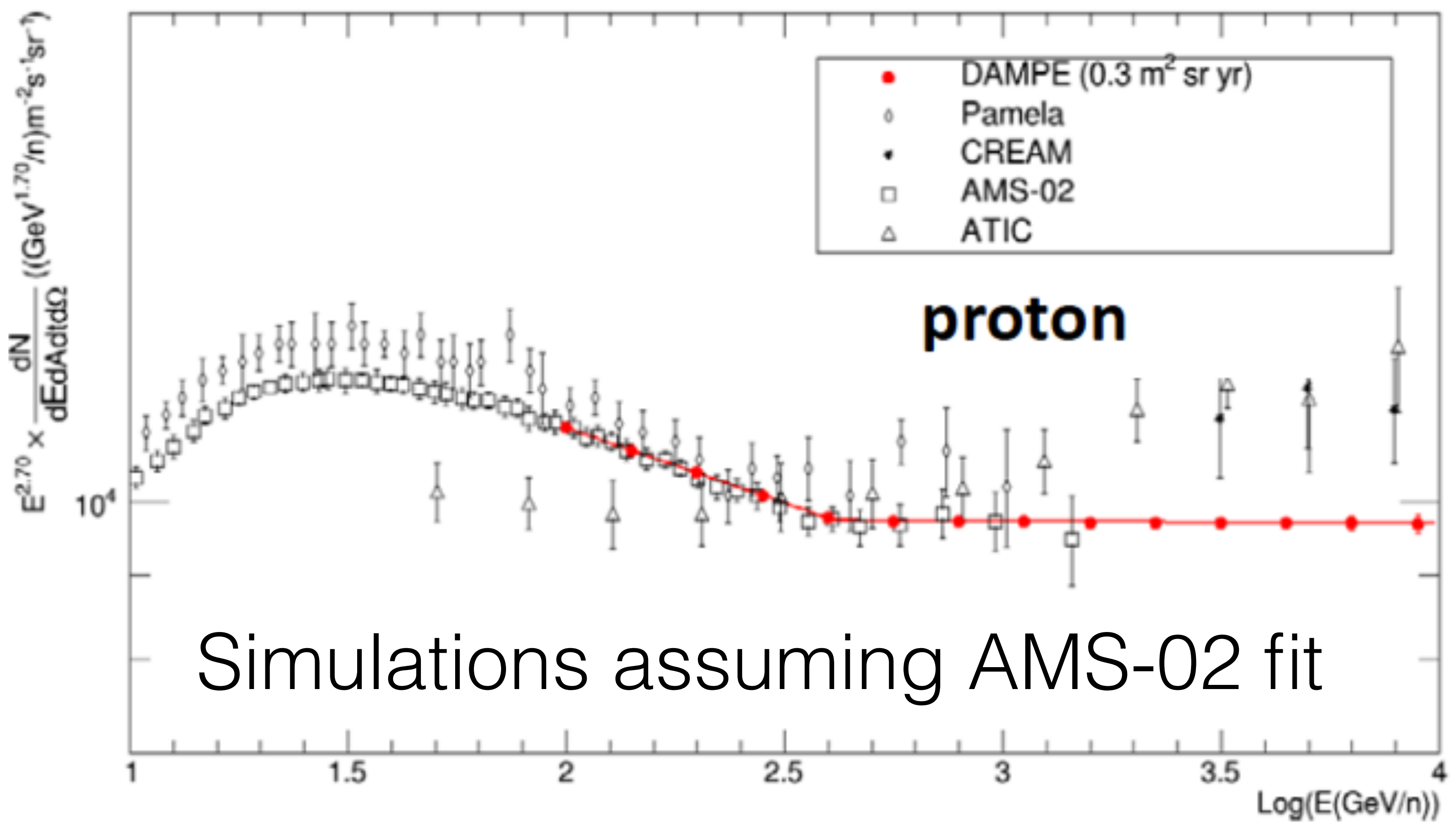
DAMPE collaboration ICRC 2017

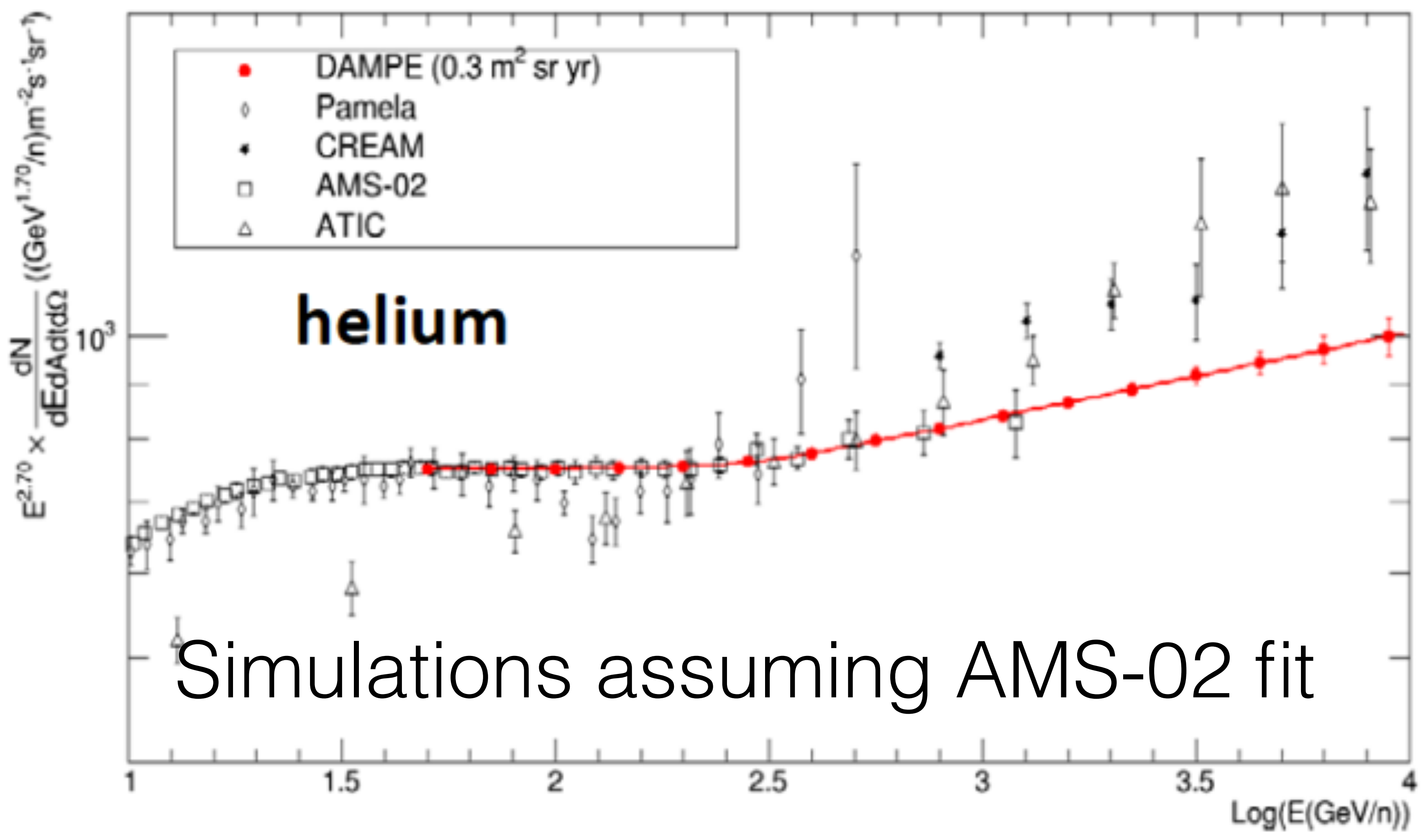


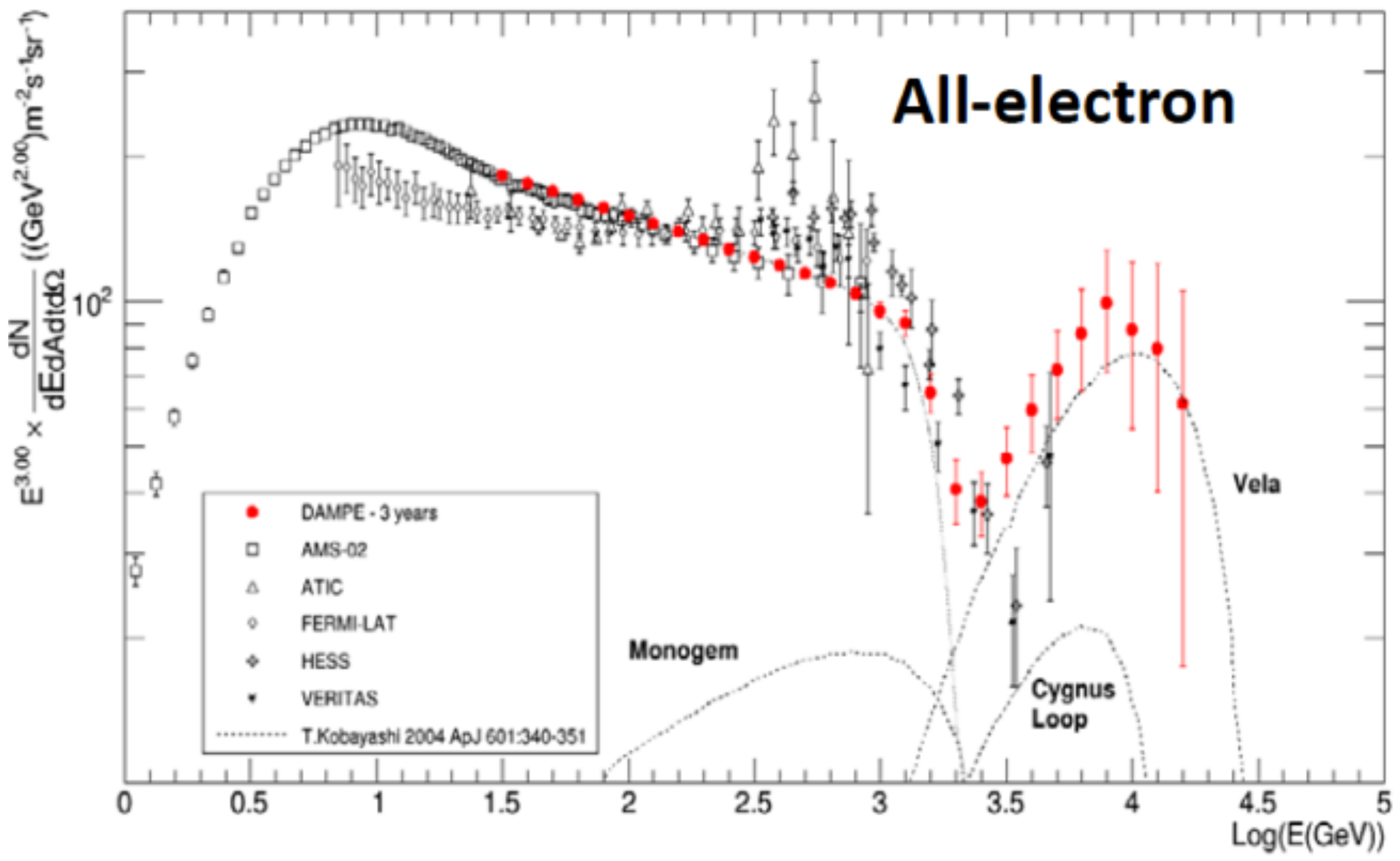


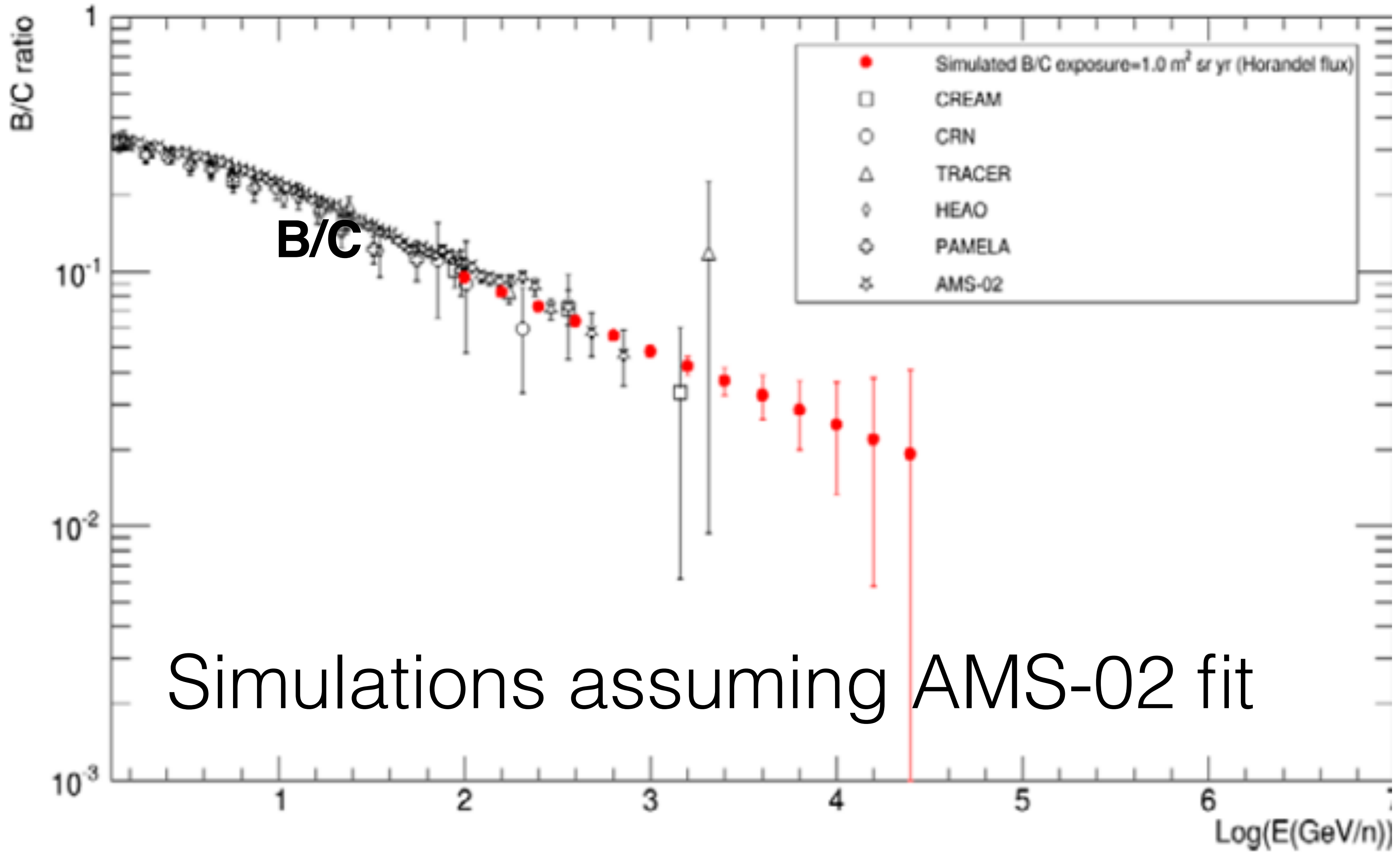
DAMPE: 3 years

DAMPE collaboration ICRC 2017









->Talk S. Zimmer TeVPA 2017

NUCLEON

NUCLEON apparatus is placed on board of the RESURS-P regular satellite as an additional payload. The spacecraft orbit is a Sun-synchronous one with inclination 97.276° and an average altitude of 475 km.

Lanched December 28, 2014.

Switched on January 11, 2015.

Flight test January-February 2015

From March 2015 up to now - regular measuremetns

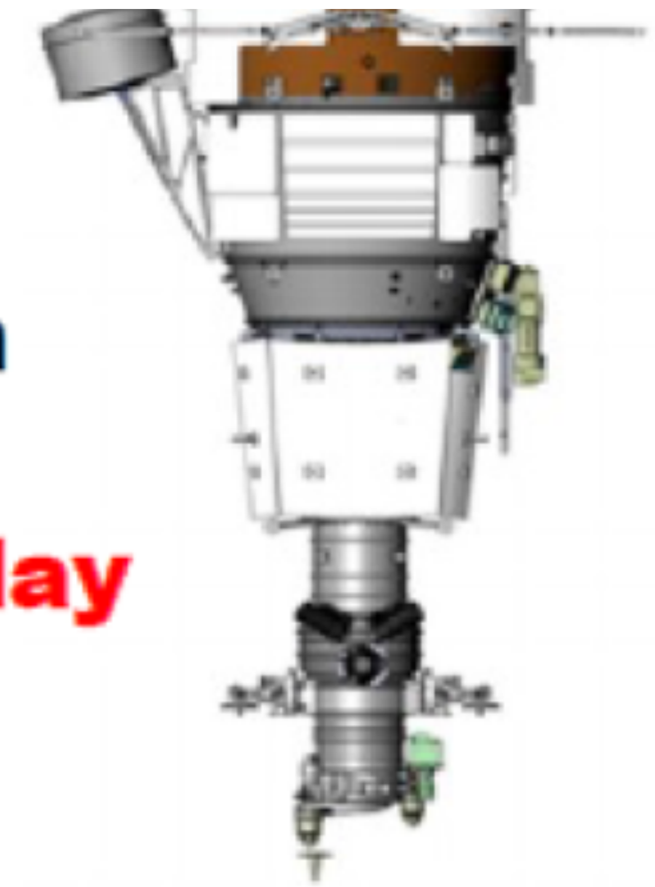
Lifetime: more than 5 years

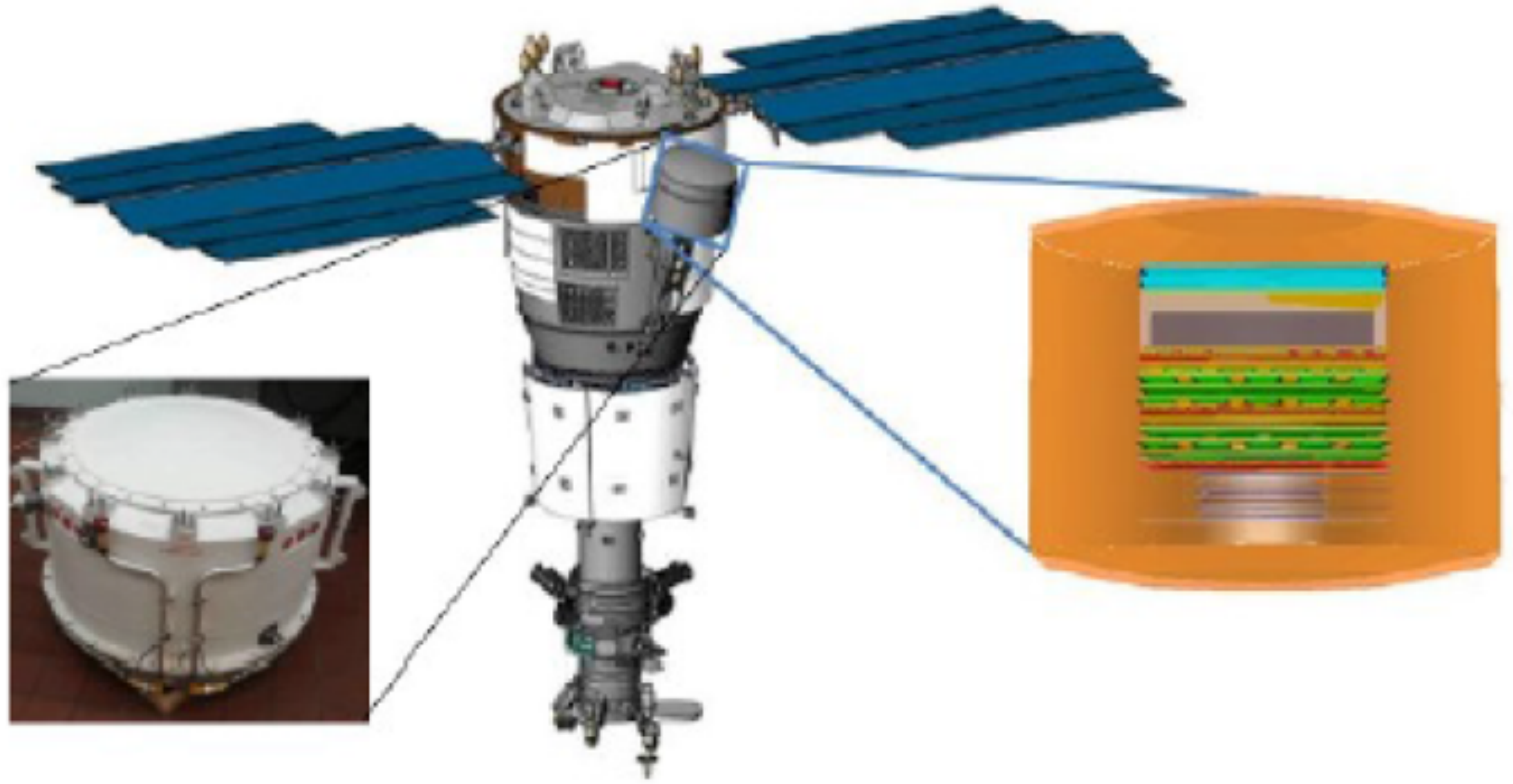
Vessel:

Weight ~360 kg

Power consumption ~160 W

Telemetry ~10 GB/day

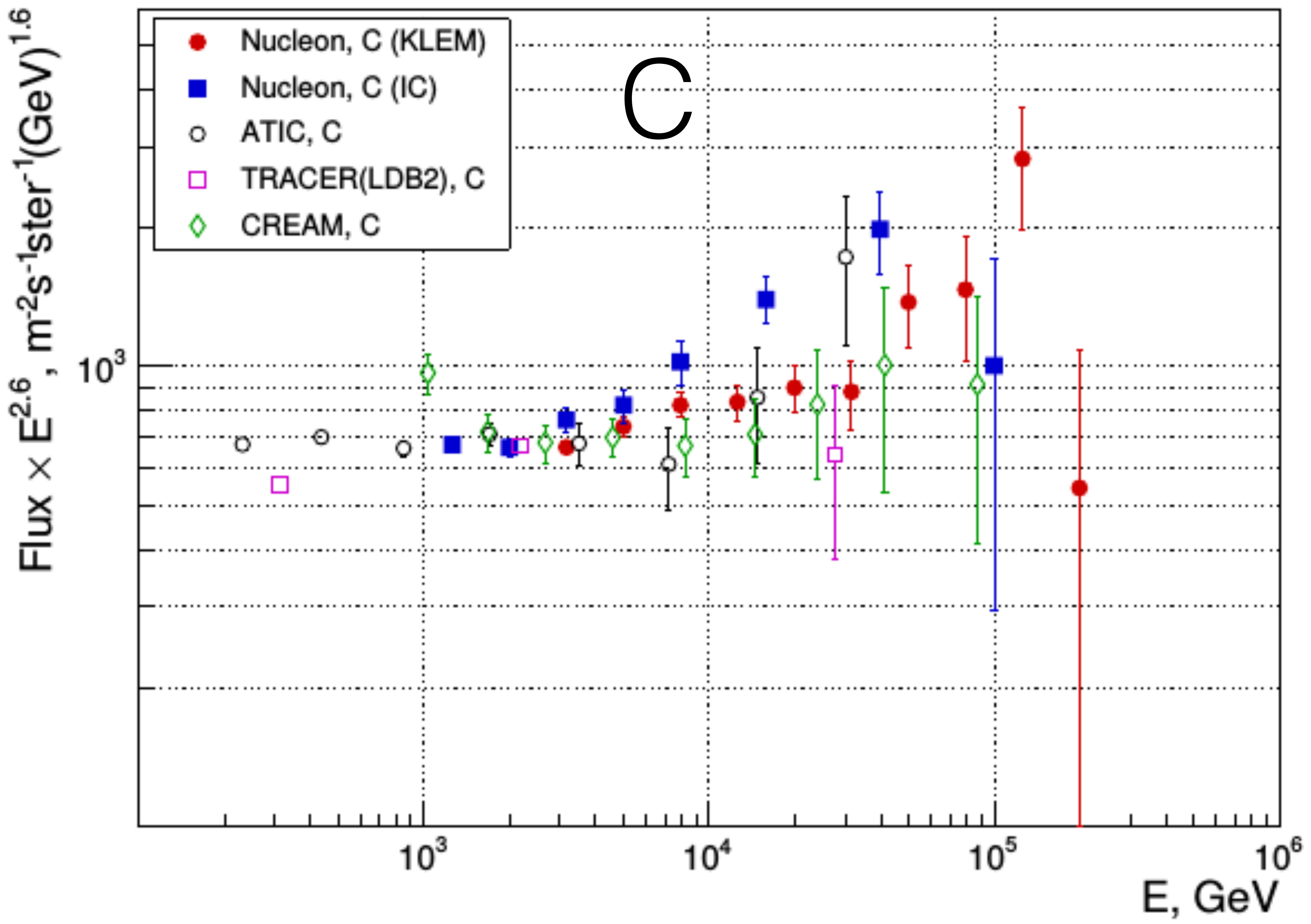


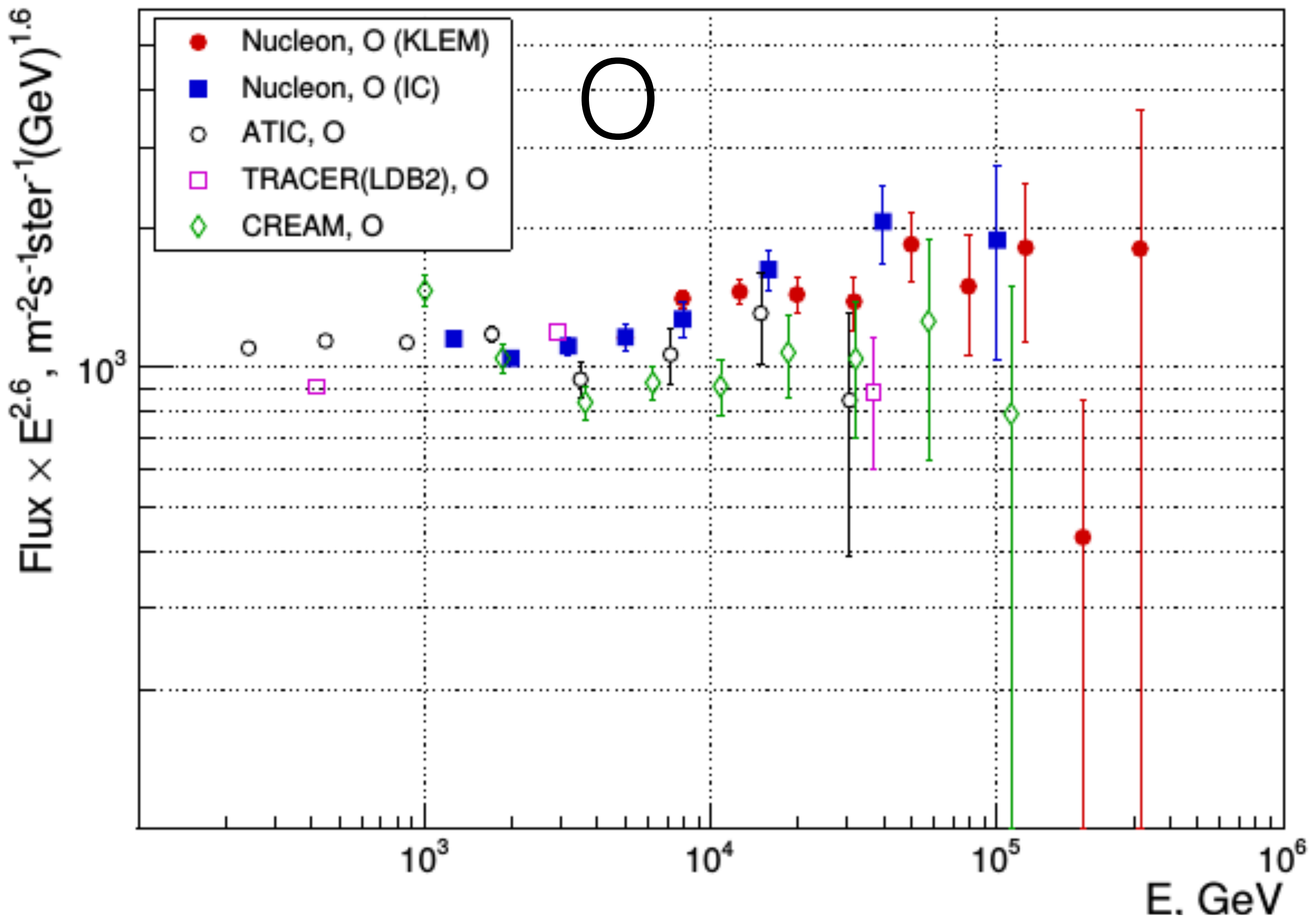


NUCLEON: 2 years of data (preliminary)

New preliminary data for several species of GCRs from a few TeV till 100 TeV.

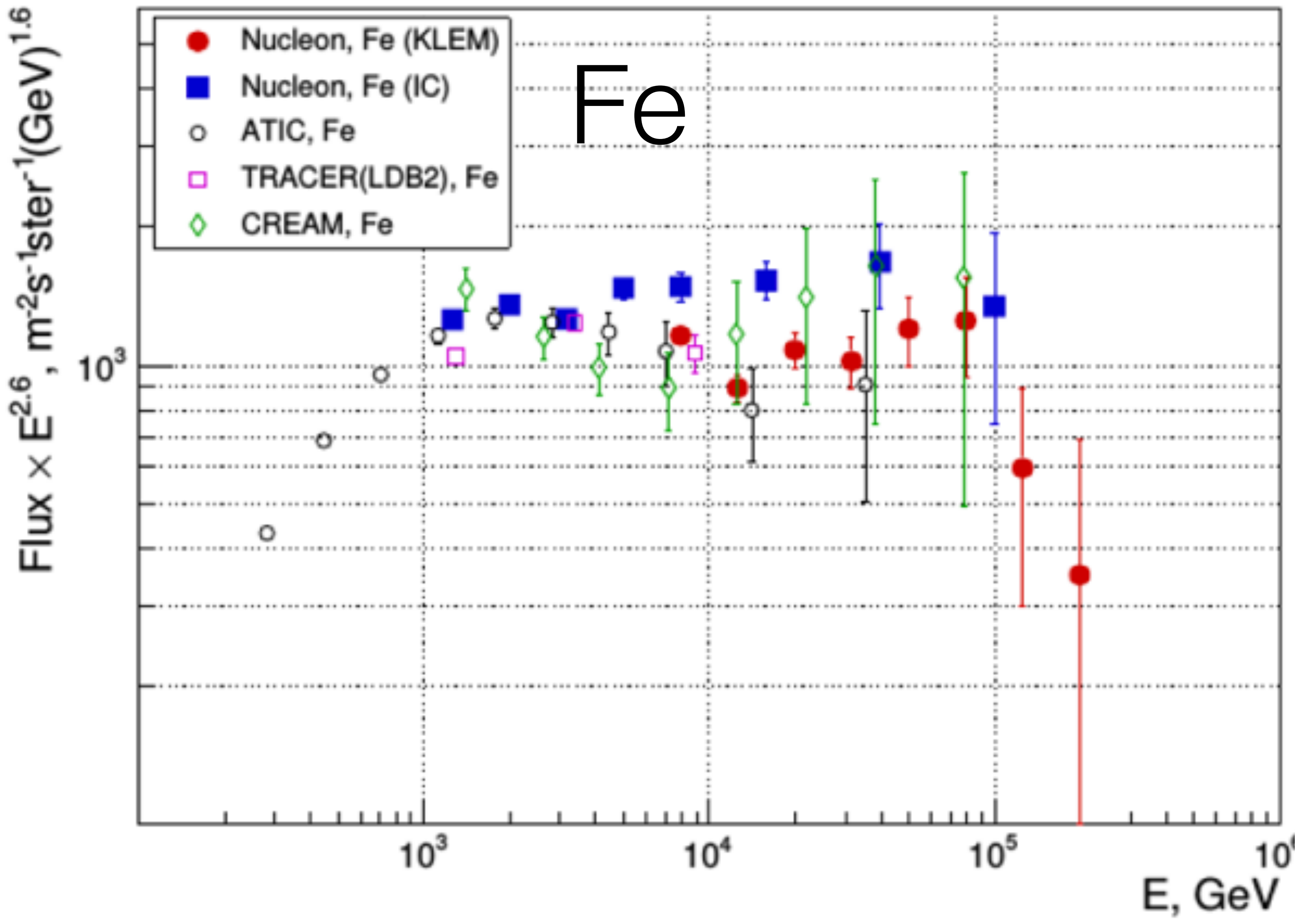
Are there hardening or structures?

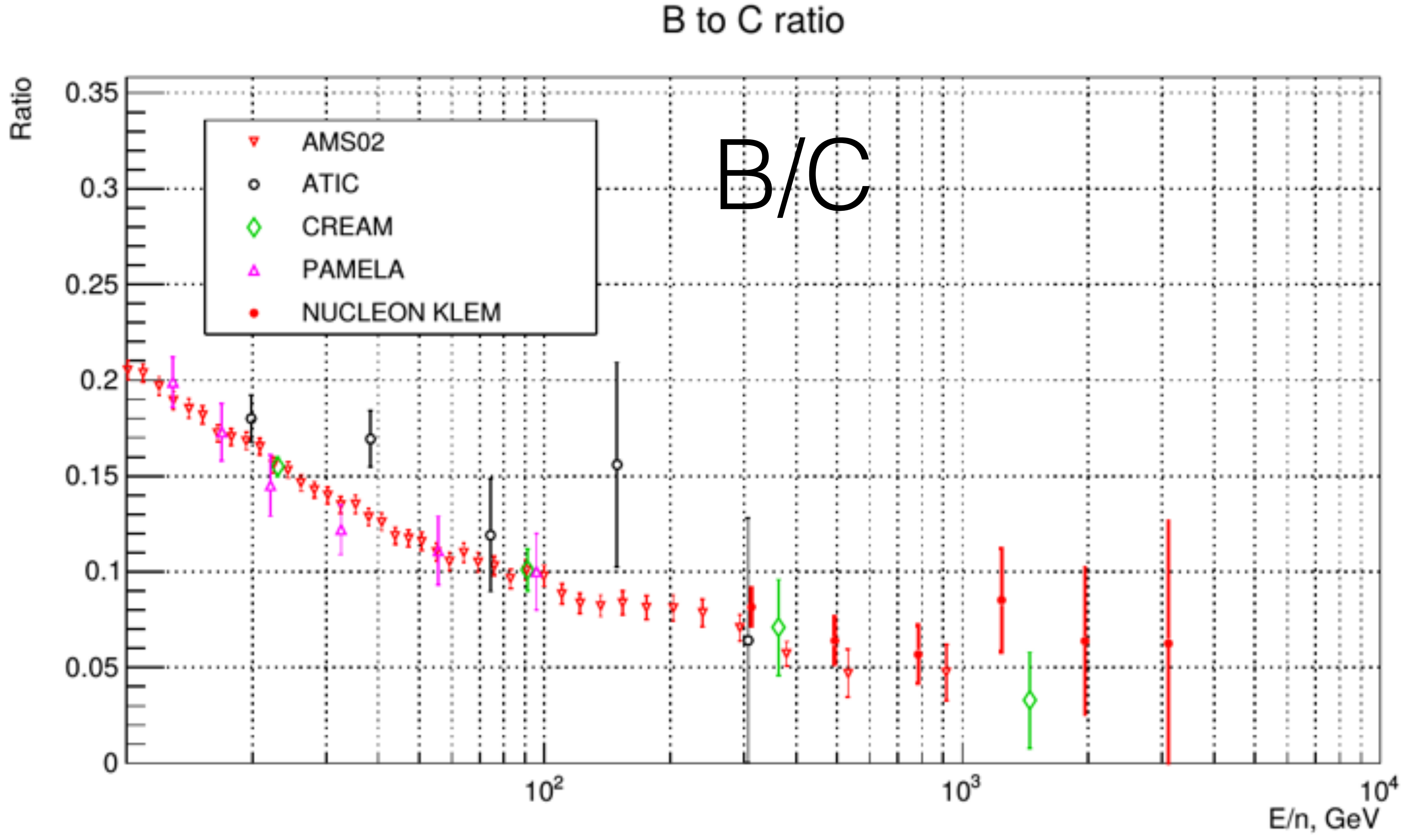




Two different methods of measuring of the energy of particles are implemented in the NUCLEON experiment:

1. The kinematic method KLEM
   (Kinematic Lightweight Energy Meter)
   -for the first time (main)
2. The calorimetric method
   -usual and well studied

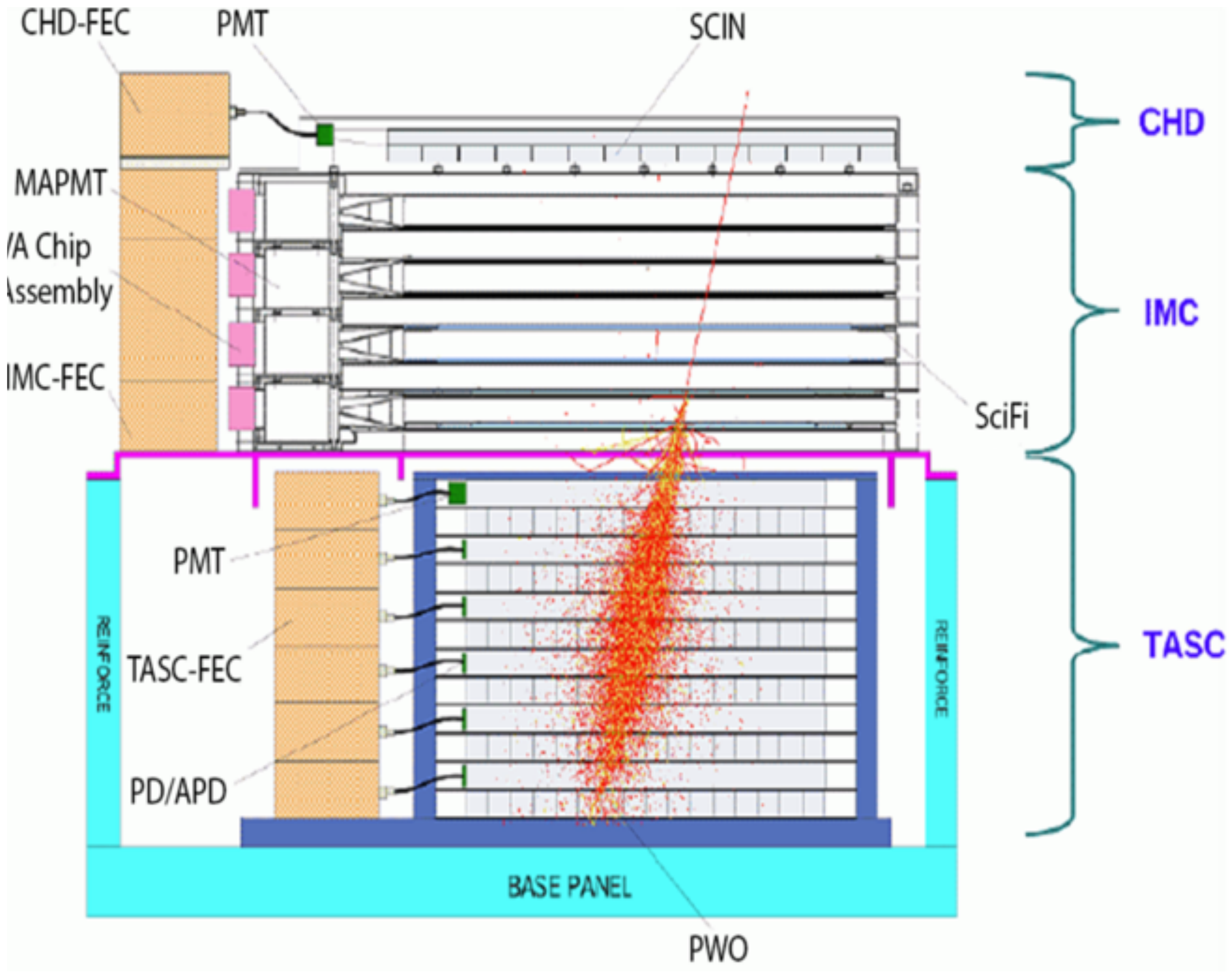




Panov ICRC 2017

CALET

- 15 months of observation from December 1st , 2015 to February 28th, 2017
- subset of total acceptance: acceptance A (fiducial) with $S\Omega$ = 416 cm^2 sr
- Assessment of the systematic errors: IN PROGRESS



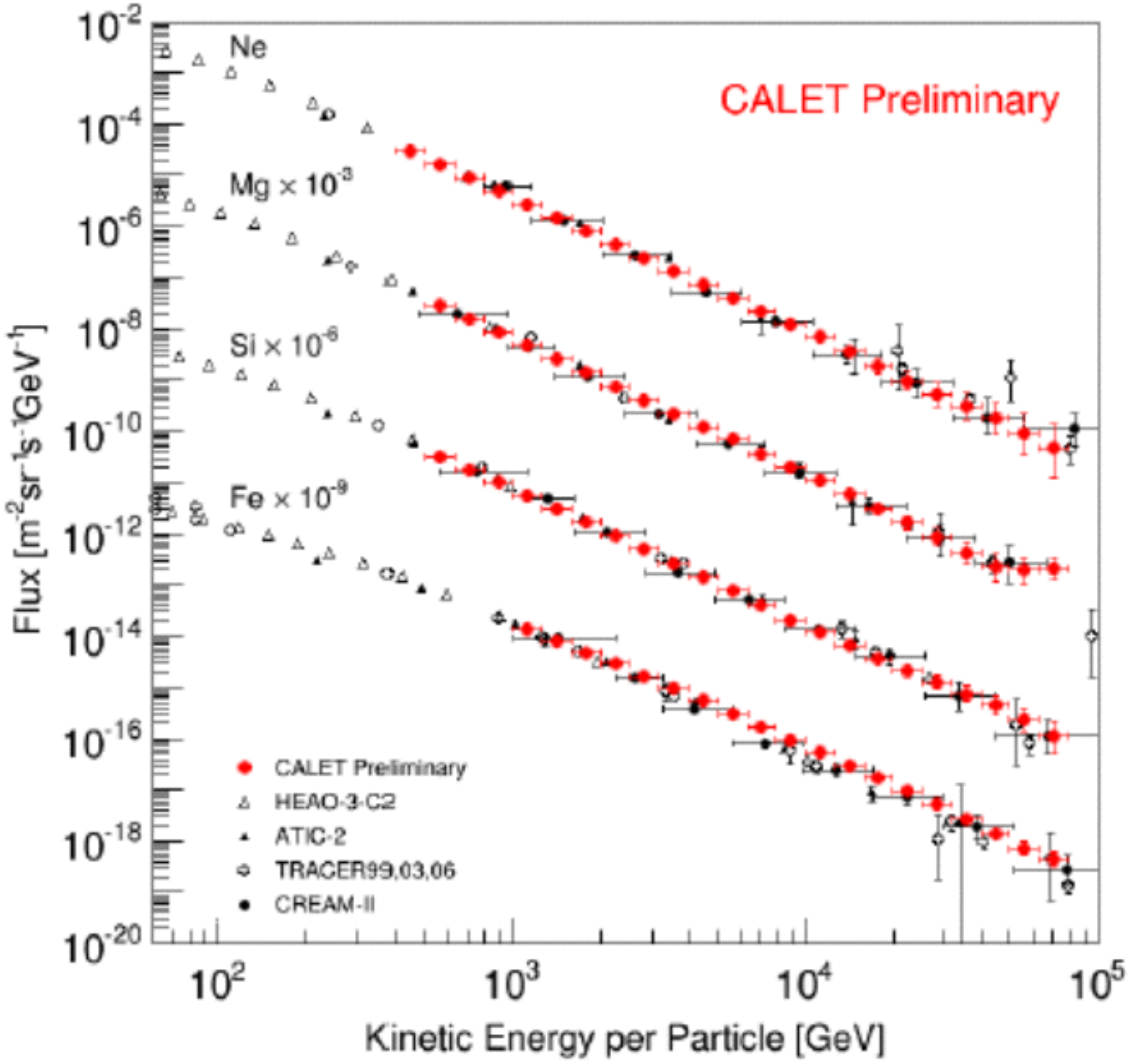
- **CHarge Detector (CHD)**
  (Charge Measurement Z=1-40)
- **Imaging Calorimeter (IMC)**
  (Particle ID, Direction)
  Total Thickness of Tungsten (W): **3 X_0 , 0.1 λ_I**
  Layer Number of Scifi Belts: 8 Layers × 2(X,Y)
- **Total Absorption Calorimeter (TASC)**
  (Energy Measurement, Particle ID)
  PWO 20mm x 20mm x 320mm
  Total Depth of PWO: **27 X_0** (24 cm) , **1.2 λ_I**

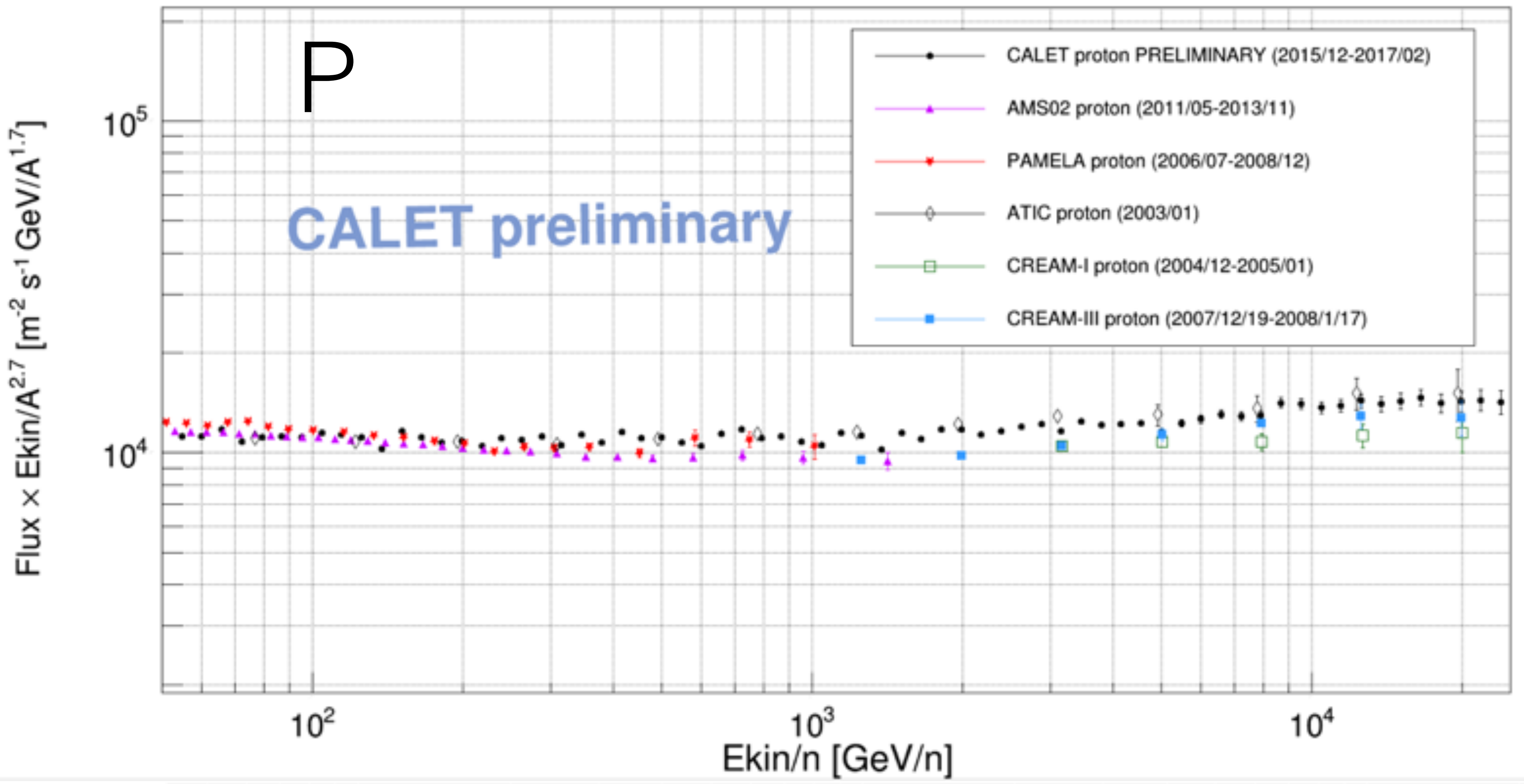
CALET Energy reach in 5 years:

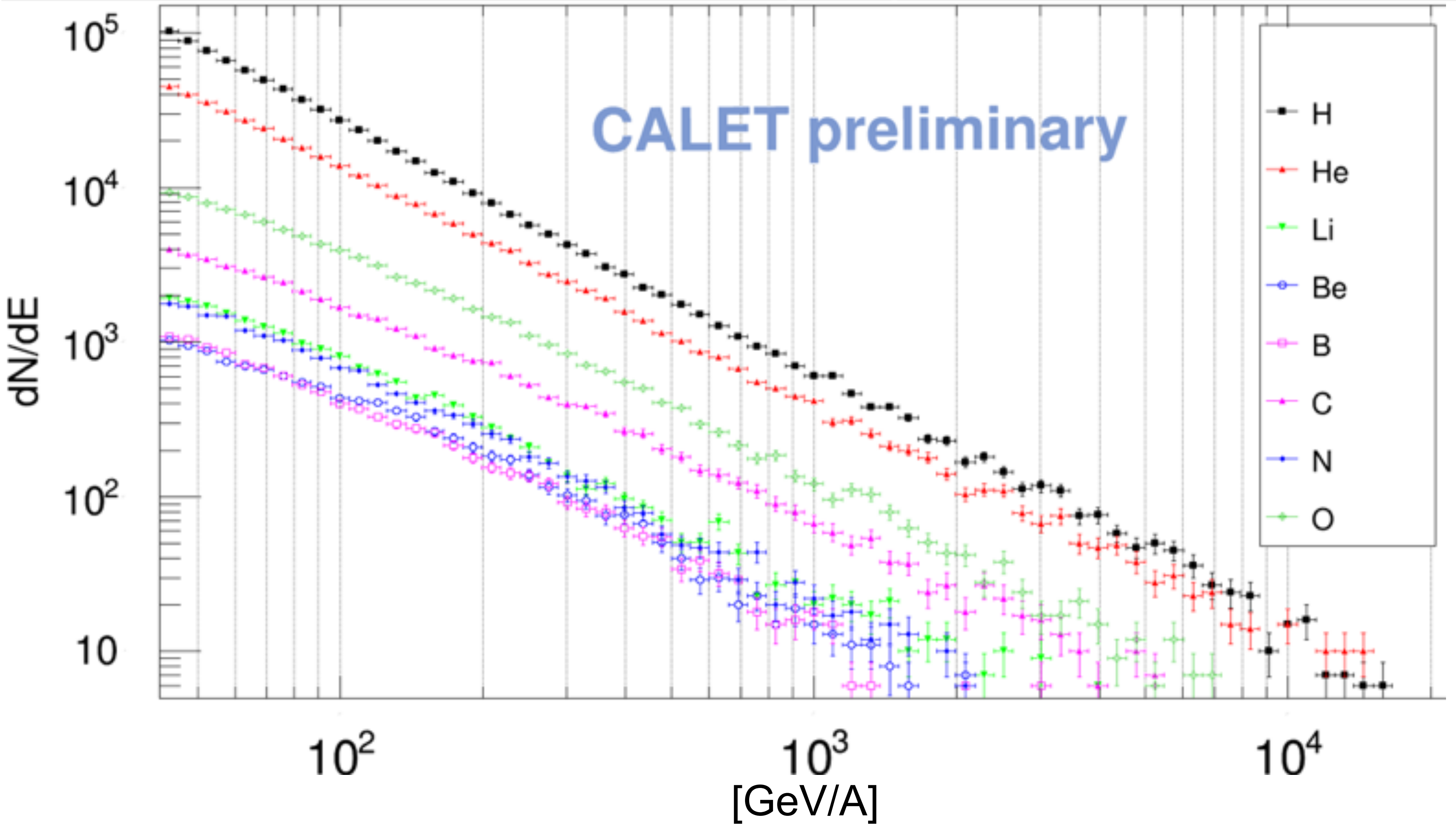
- Proton spectrum to ≈ 900 TeV
- He spectrum to ≈ 400 TeV/n
- Spectra of C,O,Ne,Mg,Si to ≈ 20 TeV/n
- B/C ratio to ≈ 4 - 6 TeV/n
- Fe spectrum to ≈ 10 TeV/n

CALET

CALET collaboration ICRC 2017



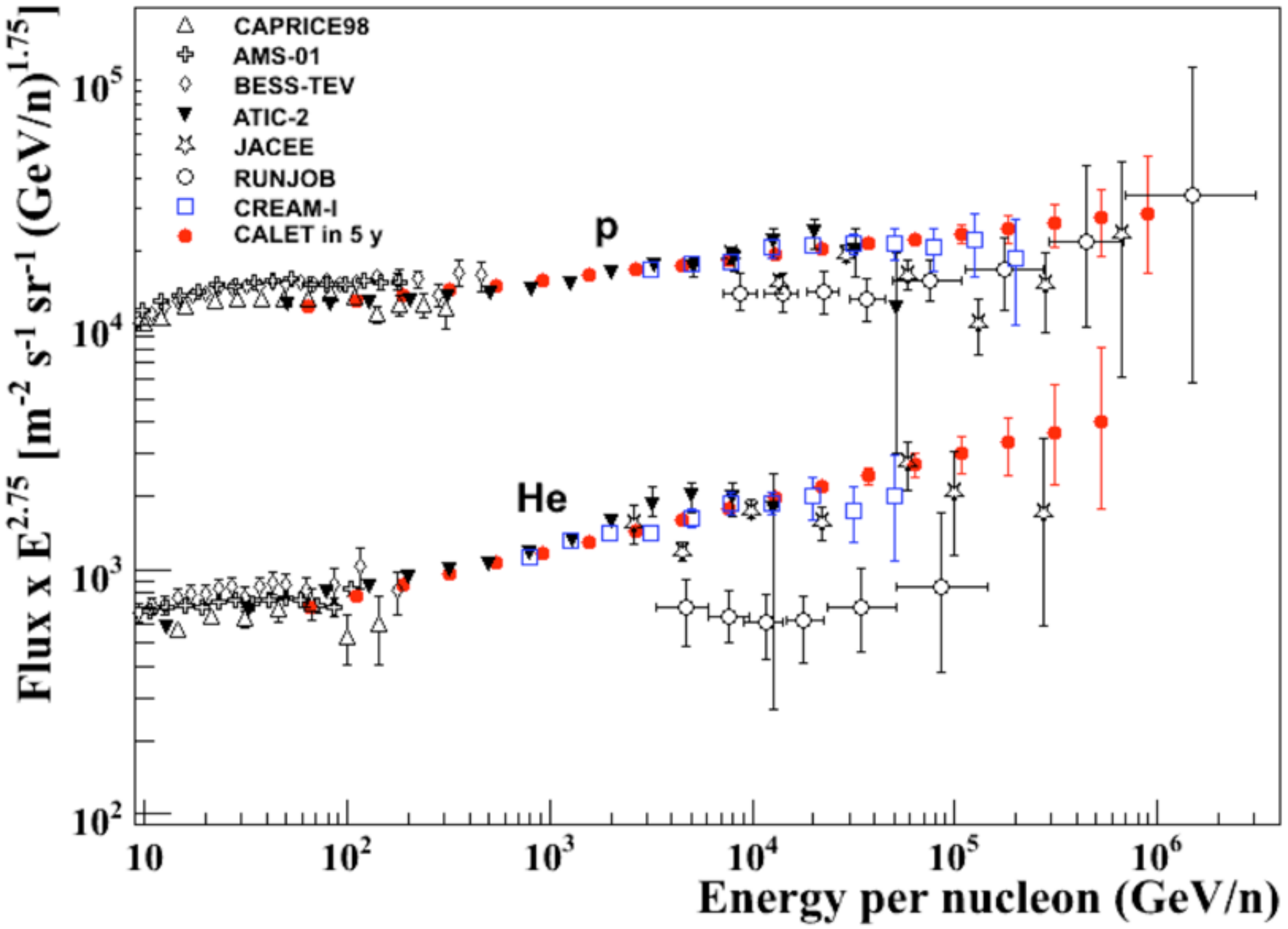




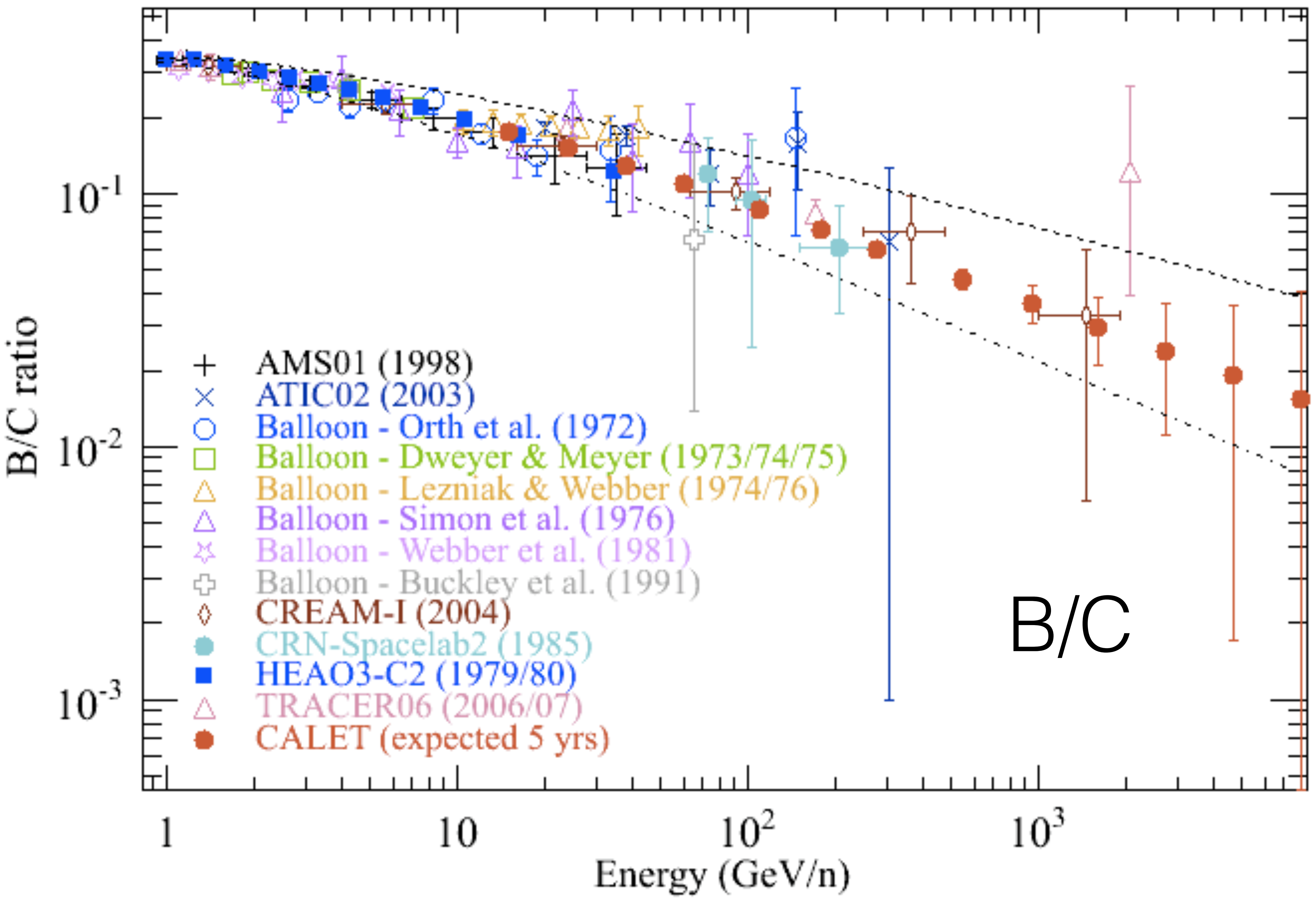
CALET (5 years)

Nicely bridge the low energy measurements with the high energy measurements and extend them close to the PeV.

CALET collaboration ICRC 2017

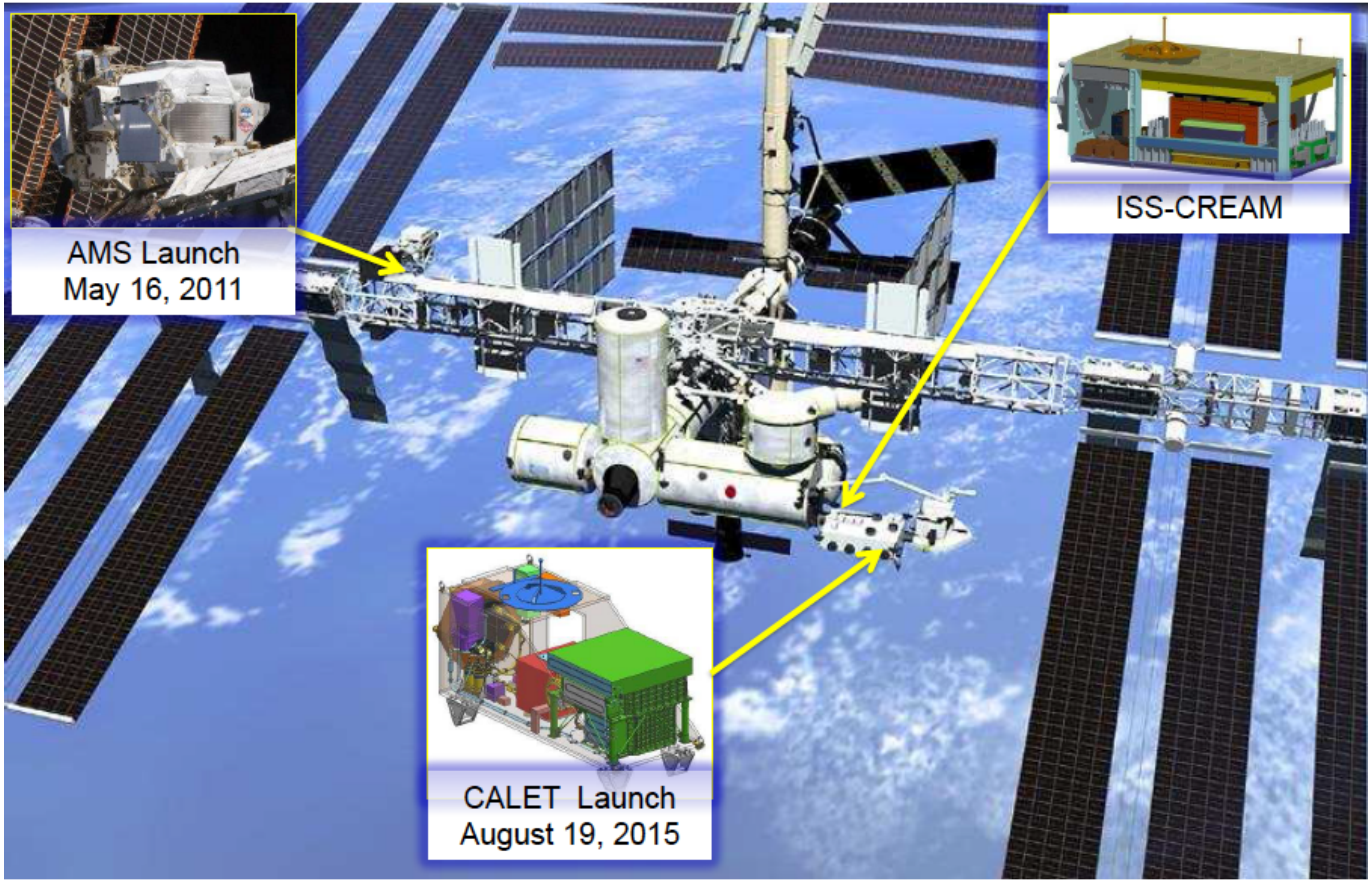


CALET collaboration ICRC 2017



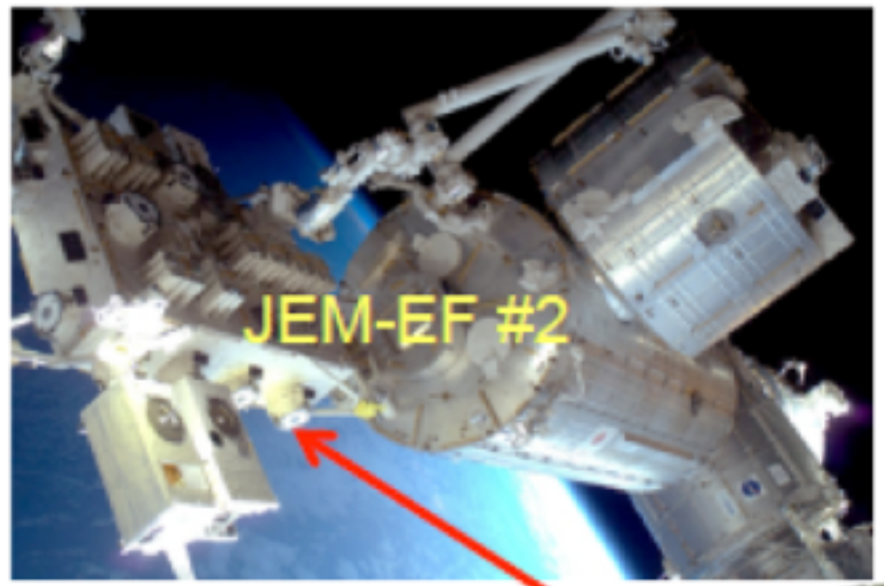
->Talk S. Torii TeVPA 2017

ISS: new cosmic ray observatory

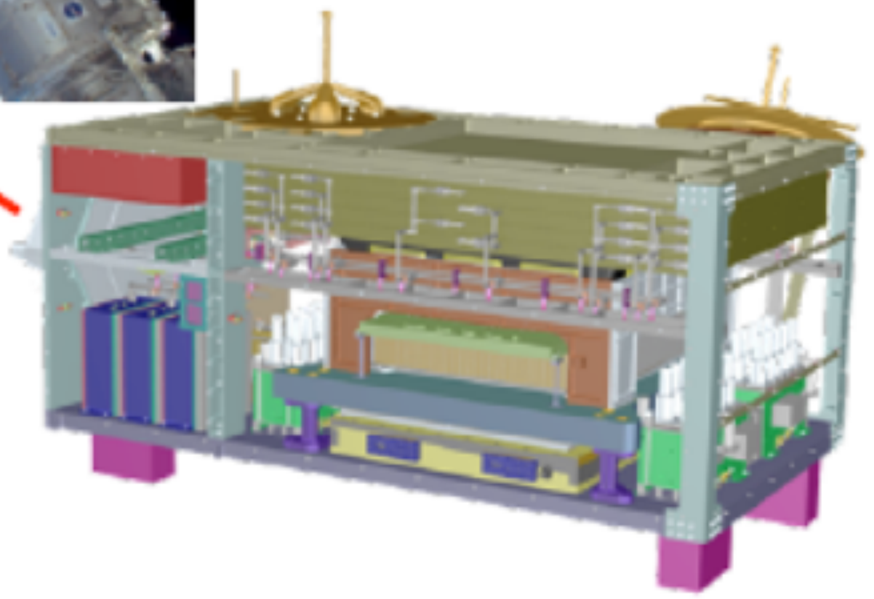


ISS-CREAM

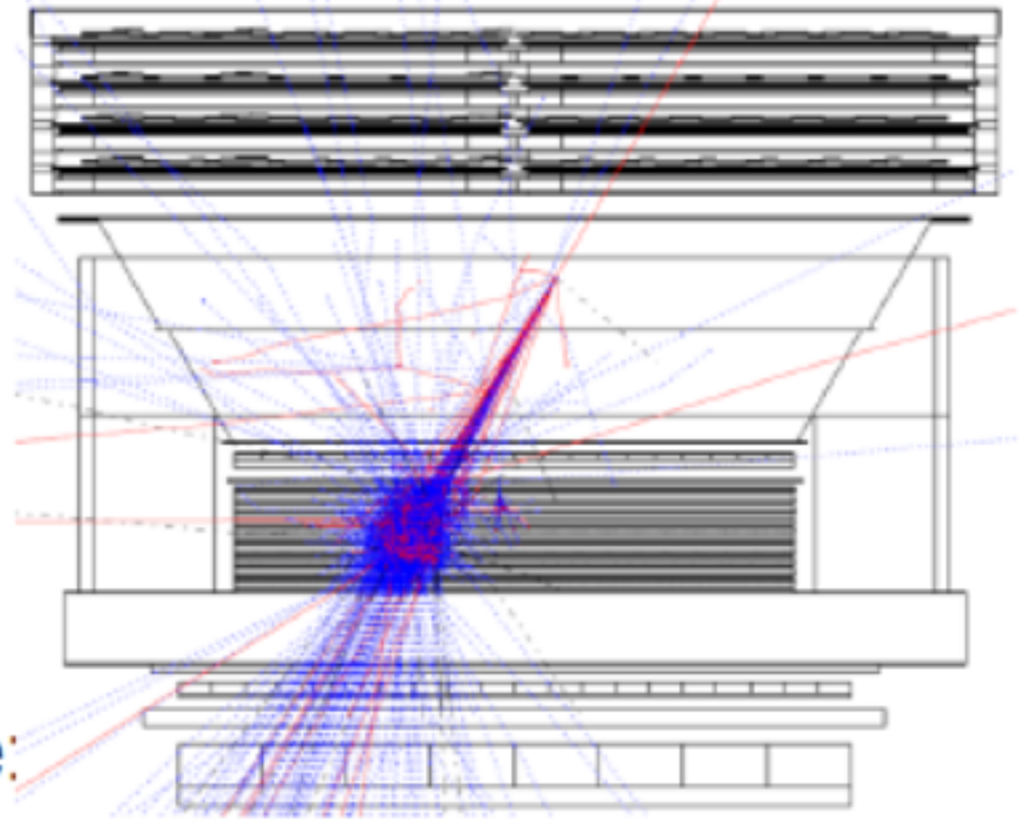
Protons to iron individual energy spectra from 1 TeV to 1 PeV



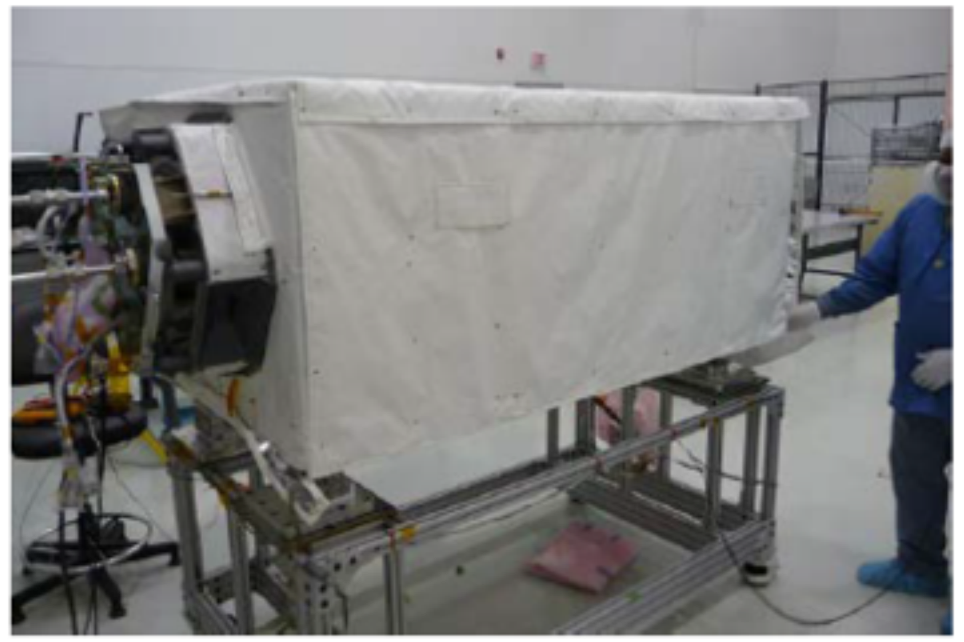
To be installed on the ISS
by SpaceX-12 in 2017

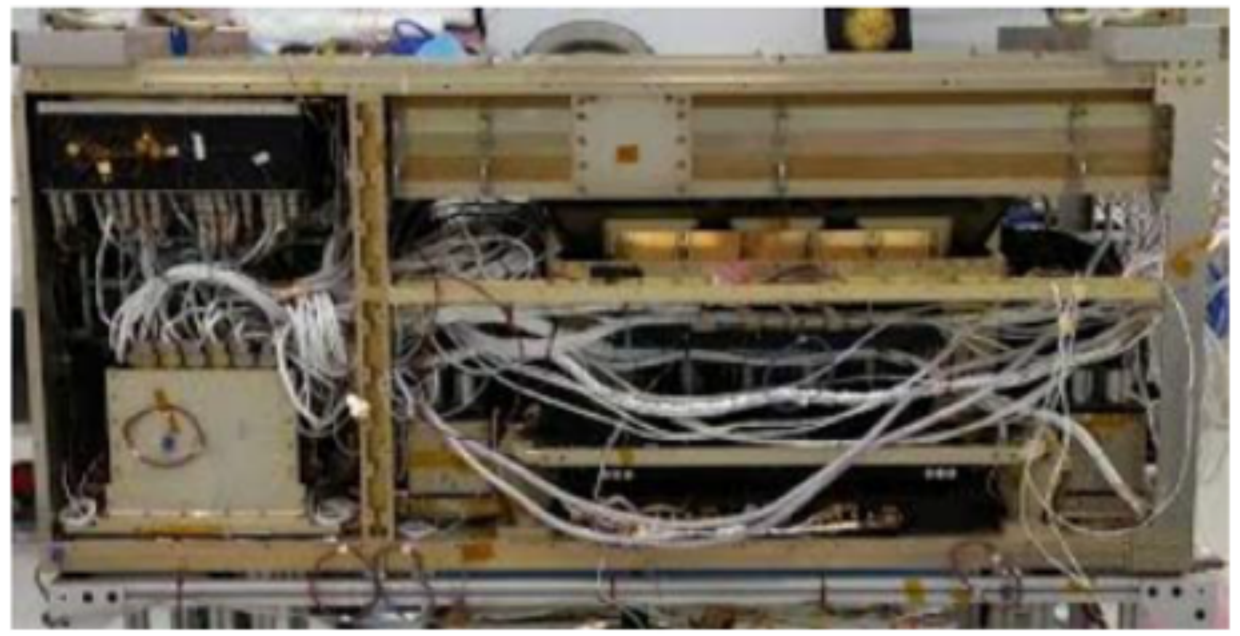


Mass: ~1392 kg
Power: ~ 550 W
Nominal data rate:
~350 kbps



The CREAM payload has been transformed for accomodation on the International Space Station, in order to increase the exposure by one order of magnitude wrt ballon flights

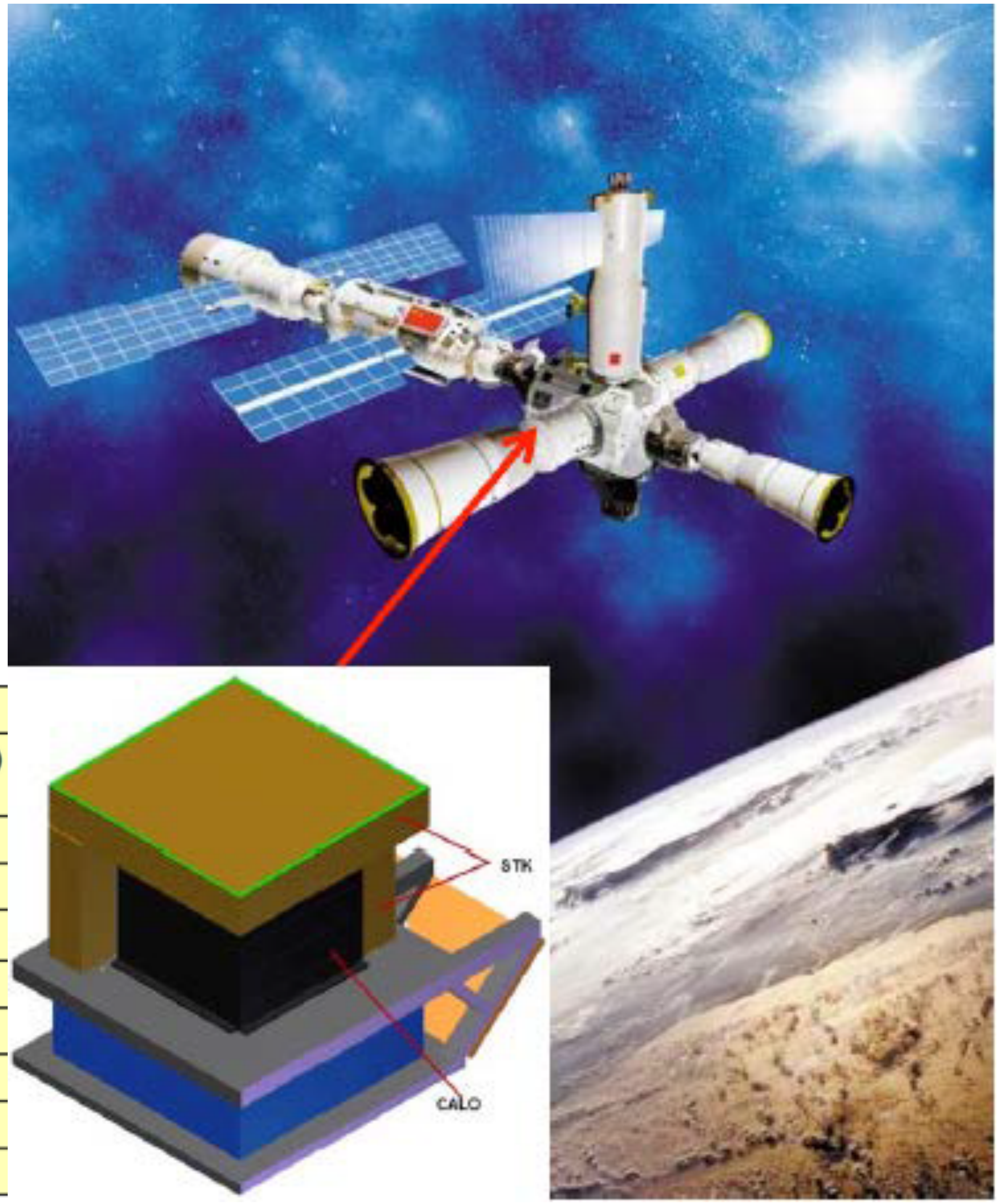




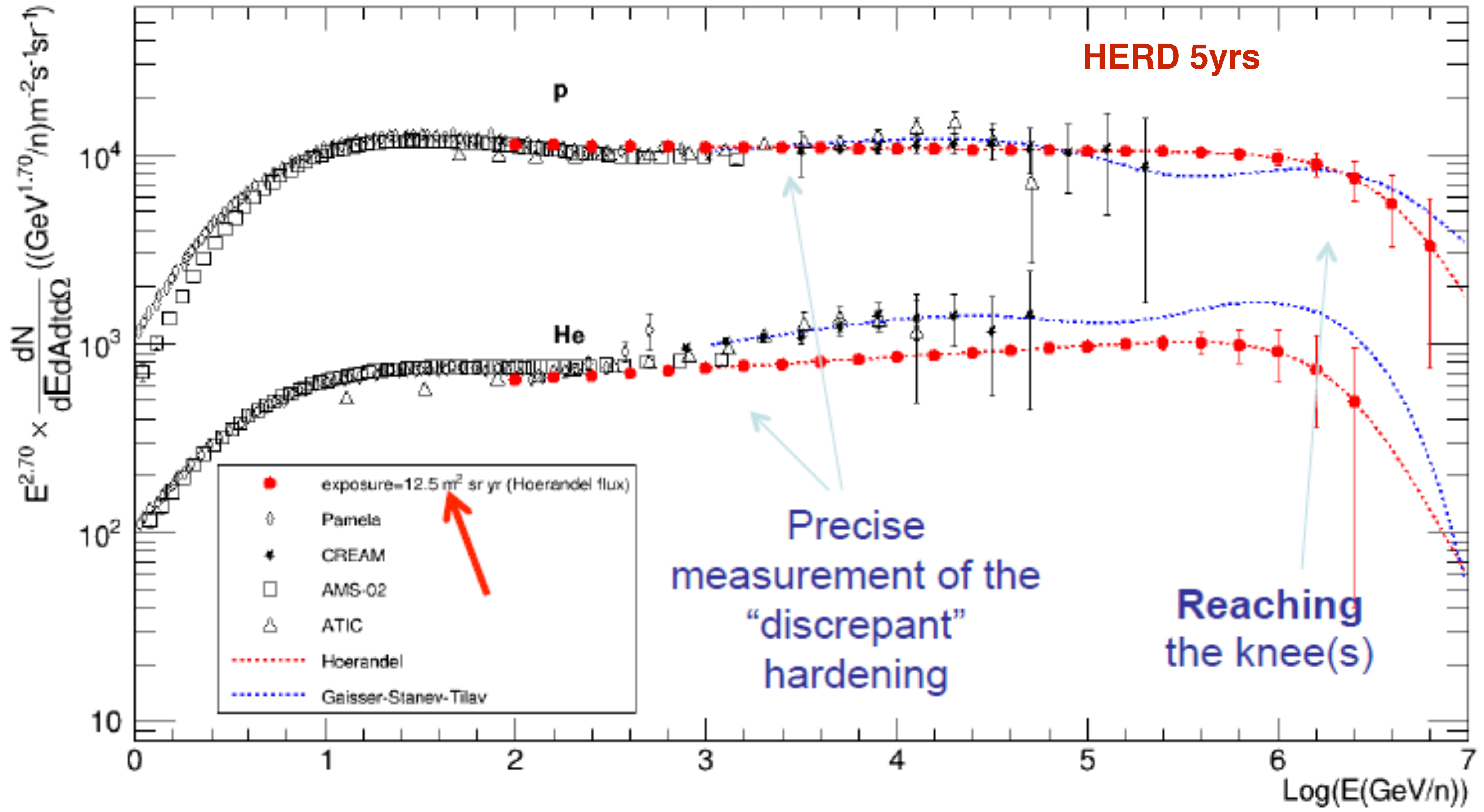
HERD: High Energy cosmic Ray Detector

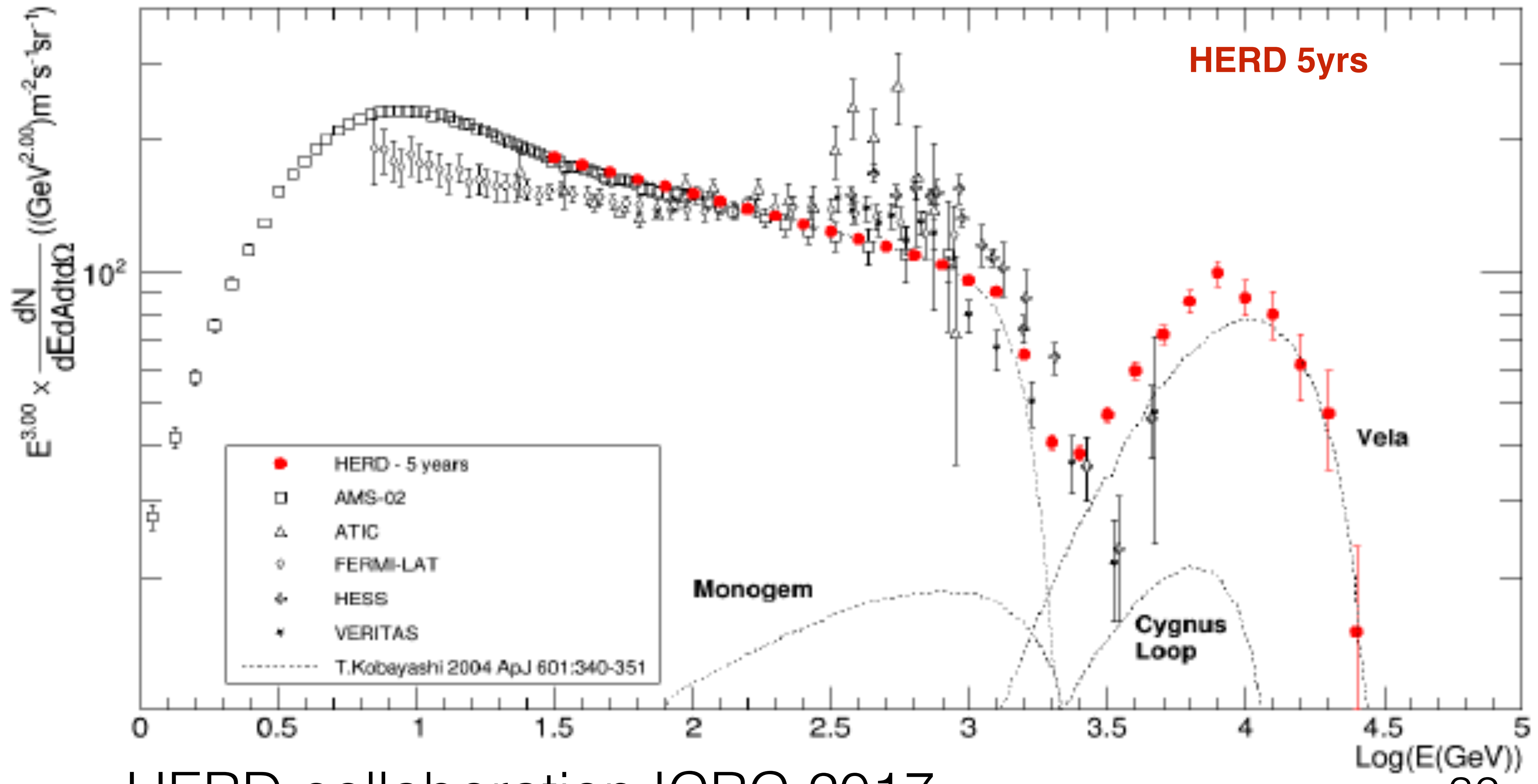
CSS (2022-2025) E~10 GeV to the PeV

Large acceptance, deep, 3D calorimeter, equipped with silicon tracker and plastic scintillators, onboard the CSS for long duration mission.



Item	HERD
Energy range(e/γ)	10 GeV - 10 TeV (e/γ) 0.5GeV - 10 GeV(γ)
Energy range (CR)	30 GeV - PeV
Angle resolution	0.1 deg.@10 GeV
Charge measurement	0.1-0.15 c.u
Energy resolution (e)	1%@200 GeV
Energy resolution (p)	20%@100 GeV-PeV
e/p discrimination	~10^{-6}
Geometric factor (e)	3.8 m^2sr@200 GeV
Geometric factor (p)	2.6 m^2sr@100 TeV





HERD collaboration ICRC 2017

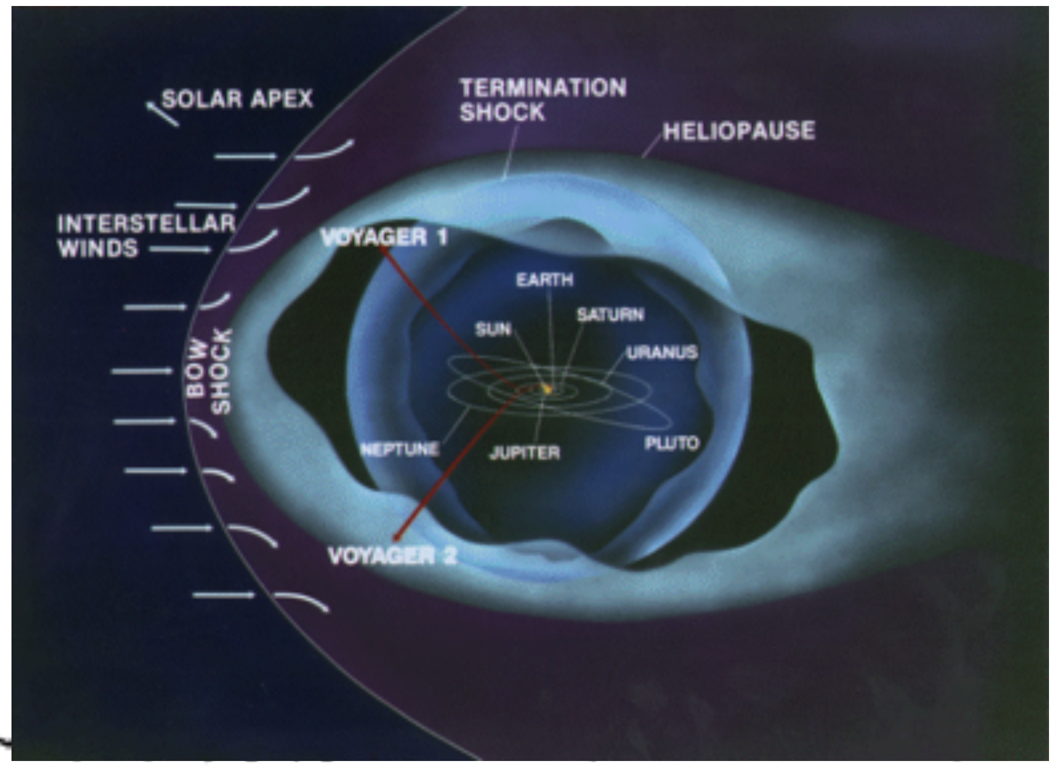
Experiment	e^+ | e^- (present data)	$e^+ + e^-$ (Energy range)	CR nuclei (Energy range)	charge	Gamma-ray	Type	Launch
PAMELA	e^+ < 300 GeV e^- < 625 GeV	1-700 GeV (3 TeV with cal)	1 GeV-1.2 TeV (extendable -> 2TeV)	1-8	-	SAT	2006 Jun 15
FERMI	-	7 GeV – 2 TeV	50 GeV-1 TeV	1	20 MeV – 300 GeV GRB 8 KeV – 35 MeV	SAT	2008 Nov 11
AMS-02	e^+ < 500 GeV e^- < 700 GeV	1 GV-1 TV (extendable)	1 GV-1.9 TV (extendable)	1-26 ++	1 GeV-1 TeV (calorimeter)	ISS	2011 May 16
NUCLEON	-	100 GeV-3 TeV	100 GeV-1 PeV	1-30	-	SAT	2014 Dec 26
CALET	-	1 GeV-20 TeV	10 GeV-1 PeV	1-40	10 GeV-10 TeV GRB 7-20 MeV	ISS	2015 Aug 19
DAMPE	-	10 GeV-10 TeV	50 GeV-500 TeV	1-20	5 GeV-10 TeV	SAT	2015 Dec 17
ISS-CREAM	-	100 GeV-10 TeV	1 TeV-1 PeV	1-28 ++	-	ISS	2017
CSES	-	3-200 MeV	30-300 MeV	1	-	SAT	2017
GAMMA-400	-	1 GeV-20 TeV	1 TeV-3 PeV	1-26	20 MeV-1 TeV	SAT	~2023-25
HERD	-	10(s) – 10^4 GeV	up to PeV	TBD	10(s) – 10^4 GeV	CSS	~2022-25
HELIX	-	-	< 10 GeV/n	light isotopes	-	LDB	proposal
HNX	-	-	~ GeV/n	6-96	-	SAT	proposal
GAPS	-	-	< 1GeV/n	Anti-p, D	-	LDB	

P.S. Marocchesi ICRC 2017

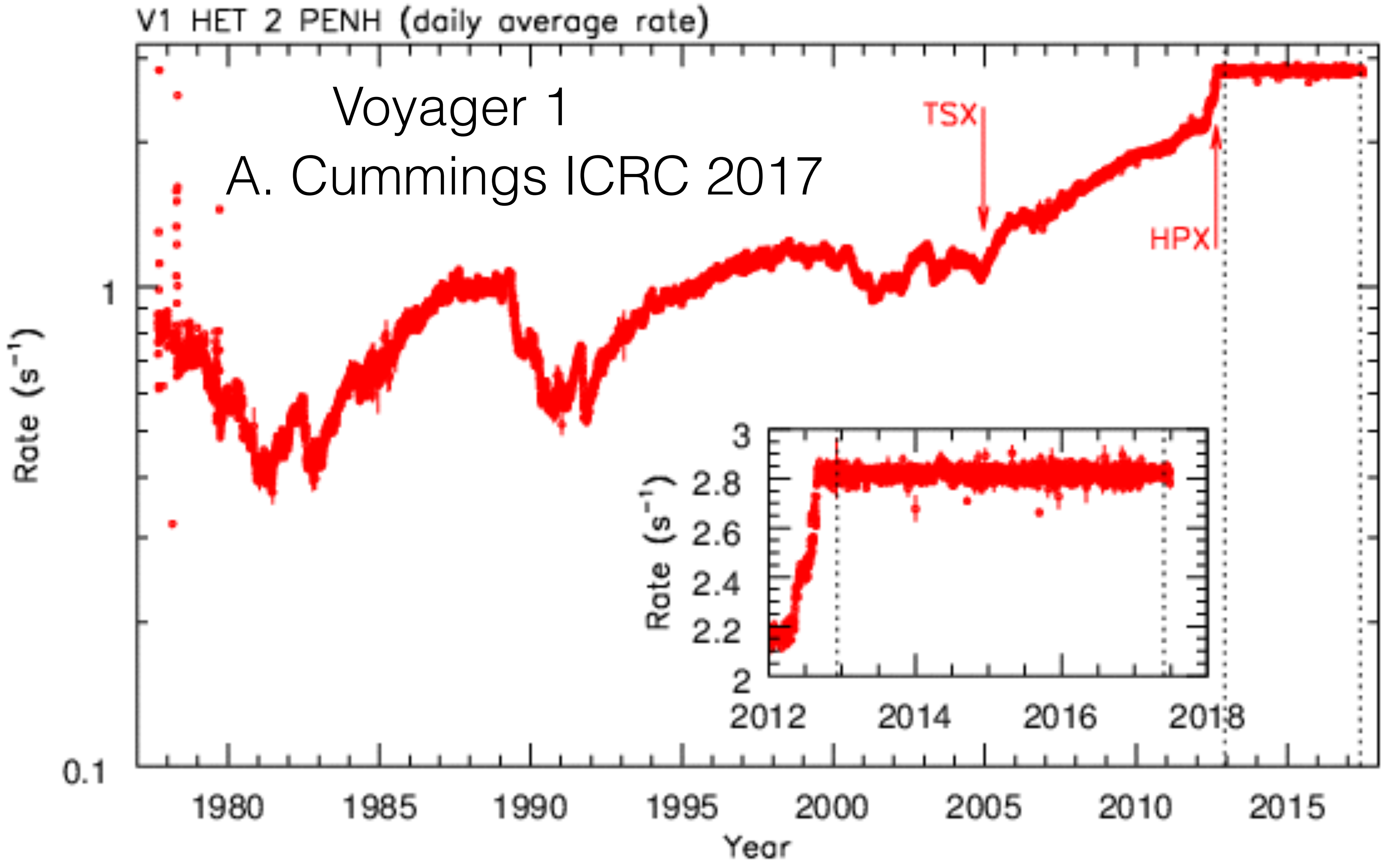
and many more …
ACE/CRIS, TIGER, SUPERTIGER …

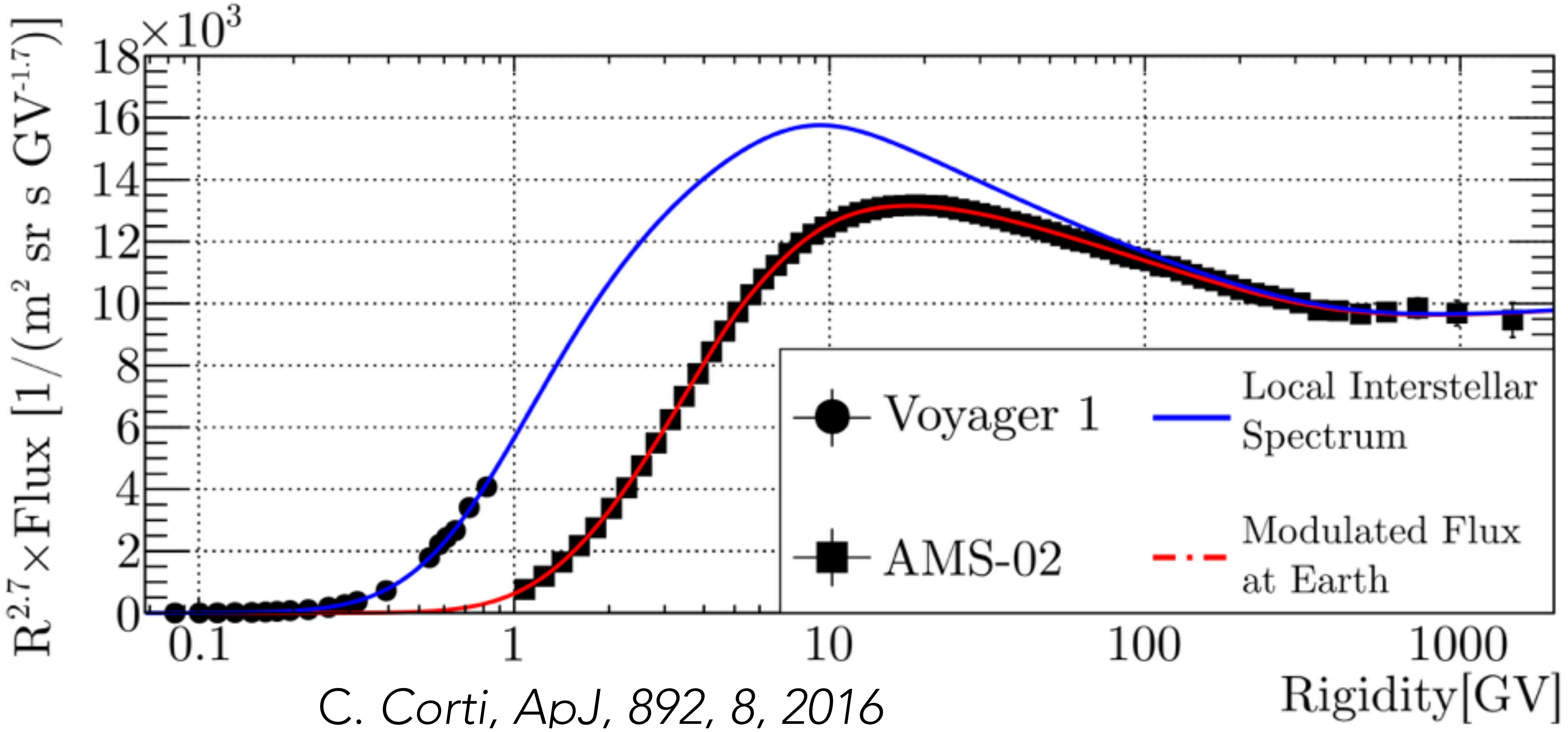
it is a very exciting time!

Low Energy Spectra



Exciting time also at low energy!
Voyager 1 is outside the heliosphere.
First measurements of the LIS at low energies.

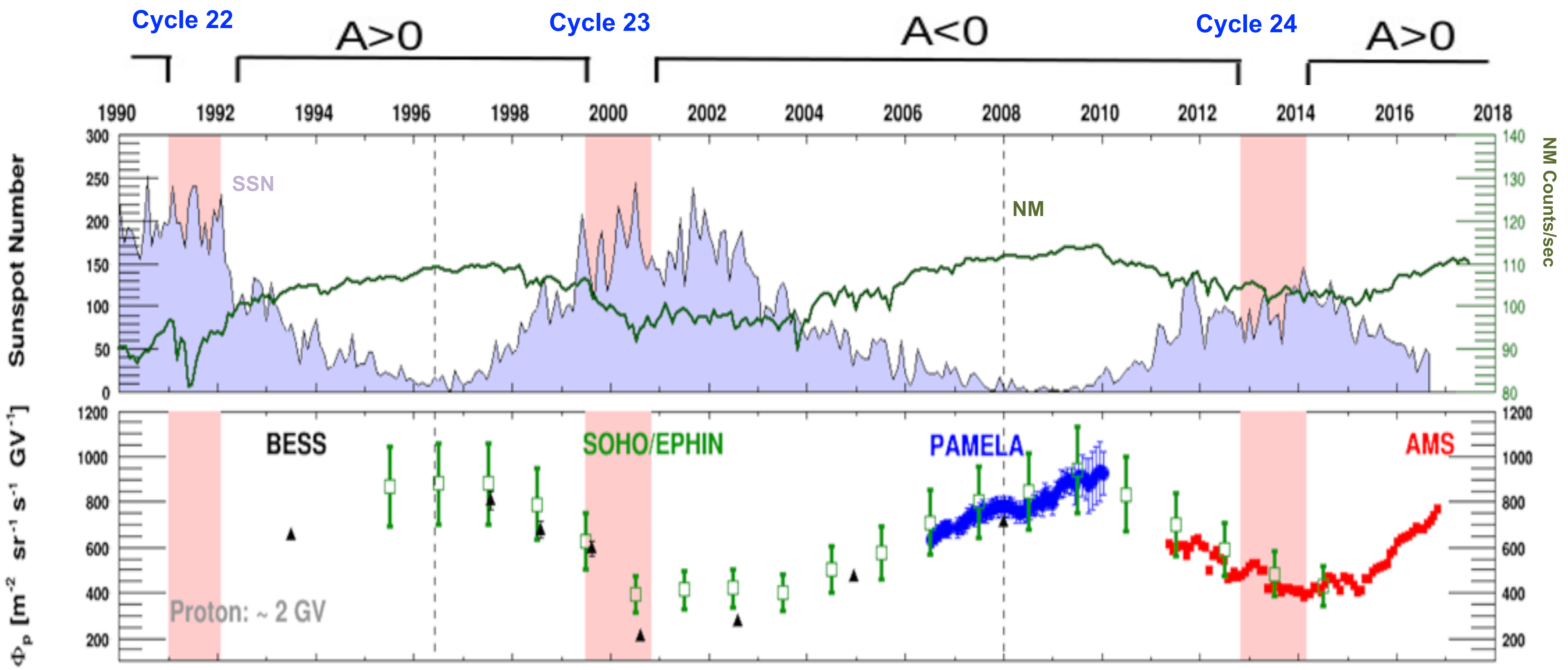




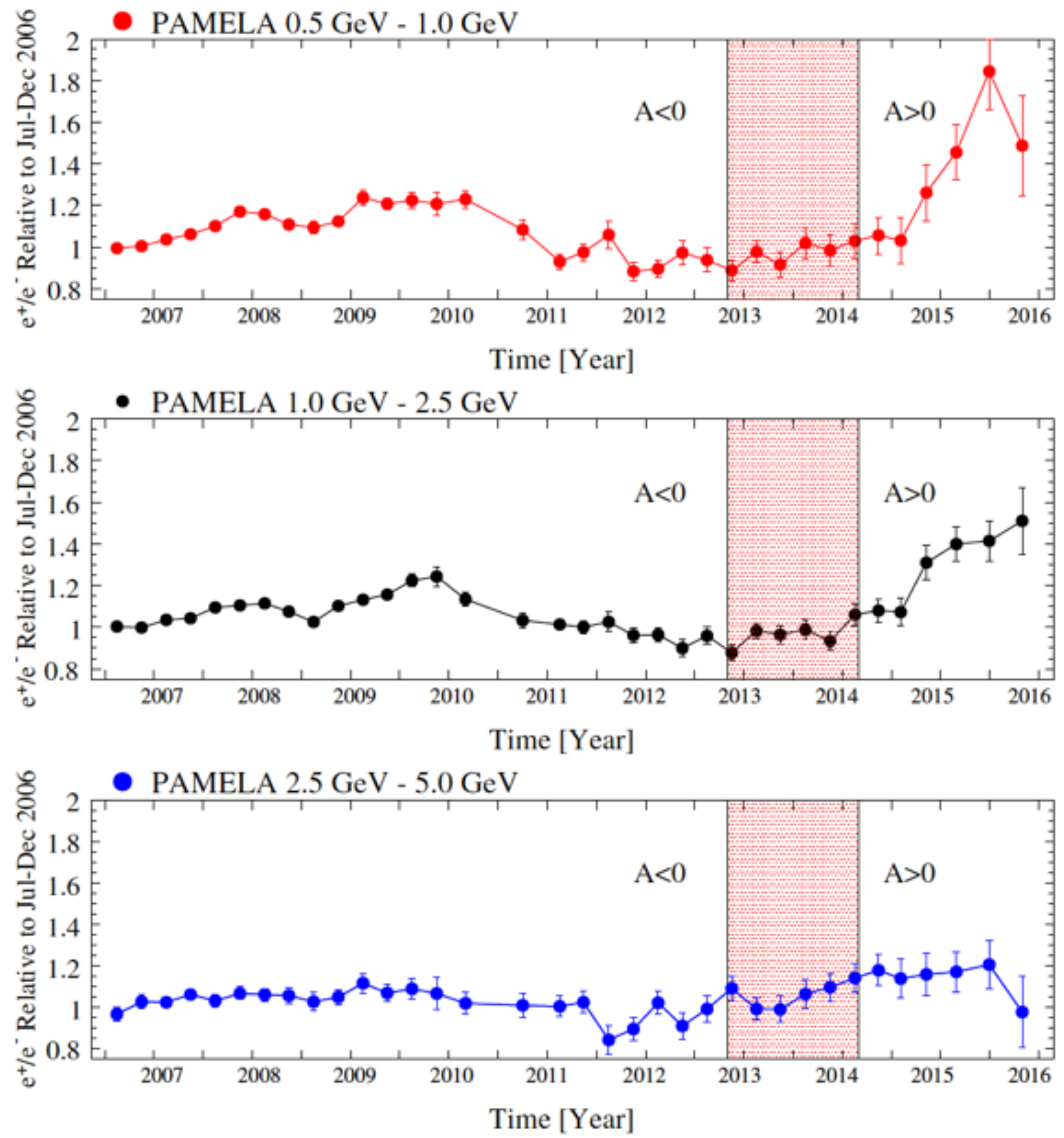
C. Corti, ApJ, 892, 8, 2016

Monitor solar activity from Space

Understand GCR propagation into the heliosphere
Decrease uncertainties in DM indirect search
Look for new phenomena at low energy



O.Adriani PRL 116, 241105 (2016)



Lots of new measurements from current and future experiments (HEPD, Solar Probe, Solar orbiter..) are expected. Stay Tuned!

Conclusions

- Precise measurements from space experiments provided answers and opened new questions. => Positron excess, antiproton spectrum, change in the power law slope of proton helium and heavy nuclei, different slopes for primary elements, anti helium candidates… The results challenge the standard paradigm of GCR origin and propagation.

- Current experiments and new ones will make significant progress in understanding GCR => sources, acceleration and propagation, new physics over GCR background.

- Measurements from Voyager of the LIS at low energies and continuos observation from space of the solar modulation activity => propagation into heliosphere, LIS, constrain in DM search and look for new phenomena.