Direct measurements of cosmic rays in space

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4° Workshop on Air Shower Detection at High Altitude,
Naples (Italy), 31 January 2013

Galactic cosmic rays: open questions

What is the origin of Galactic cosmic rays (GCR)?

- Which are the possible astrophysical sources? Can they be detected individually?
- What can we learn about the source properties from GCR elemental composition?
- Does the GCR elemental composition change with energy?

How do the Cosmic Accelerators work?

- Stochastic acceleration in strong shocks in SN remnants
- Diffusive shock acceleration occurs in isolated SNR or inside superbubbles ("collective effects") ?
- Is the "knee" due to a limit in SNR acceleration? Does it depend on the particle rigidity?
- Are there different astrophysical sites associated with different energy/element regimes?

CRs propagation in the Galaxy

- What is the energy dependence of the confinment time of CR in the Galaxy?
- Is there a residual path length at high energy?

Are there signatures of new/exotic physics?

- Are there anti-matter regions in the universe?
- What is the nature of Dark Matter? Which possible signatures in CR spectra?

Main physics research lines

-- **The High Energy Frontier** (Sources, Acceleration)

-- **The Composition Frontier** (source material, dust/gas, nucleosynthesis, selection effects)

-- **The Anti-matter Frontier** (dark matter limits, anti-matter limits, non-SNR contributions, nearby sources)

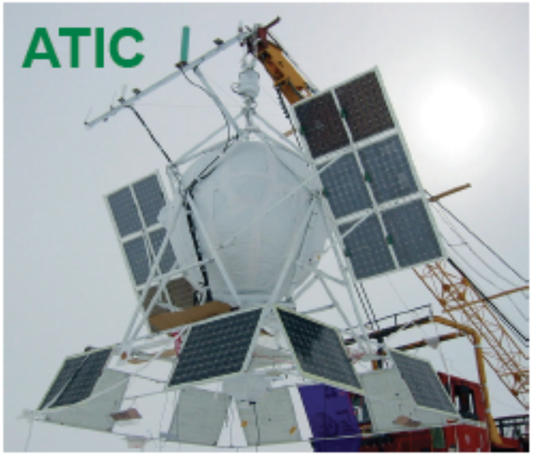
According to the physics line, different platforms and detections techniques have been adopted.

Existing platforms

- **Balloon experiments** (CREAM, ATIC, BESS-Polar, TRACER, TIGER)
- **Satellite experiments** (PAMELA, FERMI, *Gamma-400*, ...)
- **ISS experiments** (AMS, *Calet*, *ISS-Cream*, ...)

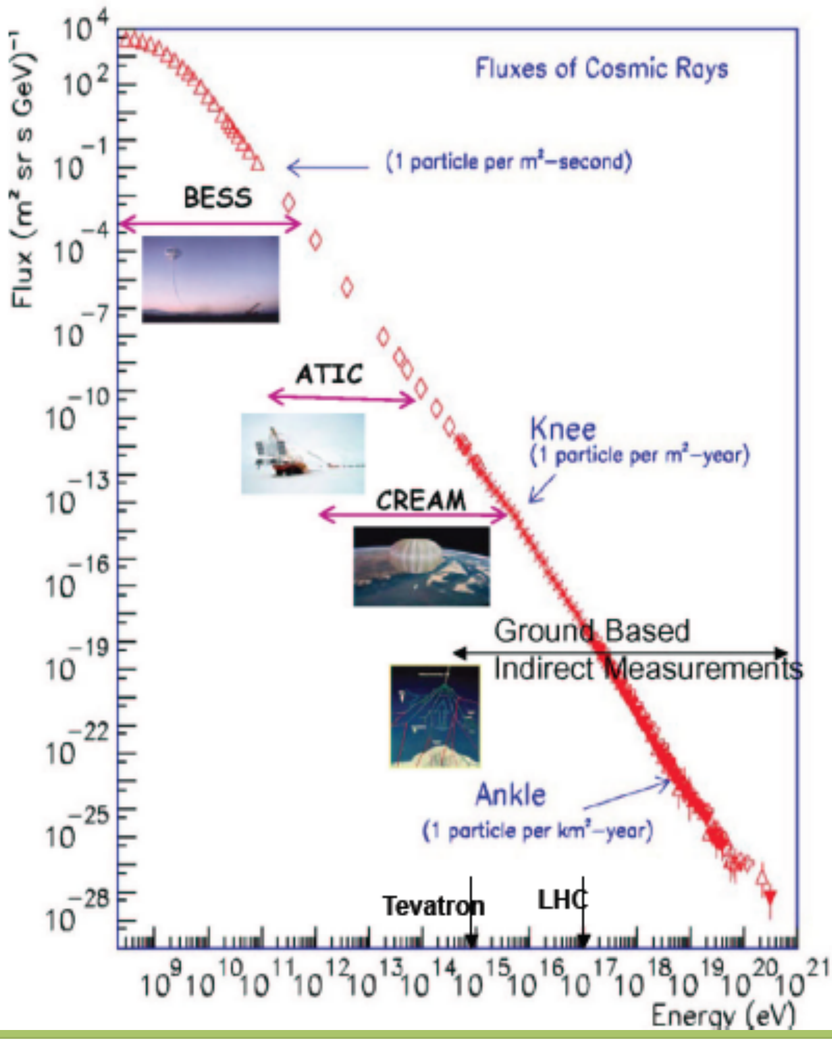
Balloon experiments

Long Duration Balloons (LDB)



In the last decade, direct measurements of VHE cosmic rays have been performed by several instruments flown on NASA Long-Duration Balloons.

Science goals



Science Objectives	Measurement	Payload	Energy range
CR acceleration	H-Fe individual spectra	CREAM TRACER ATIC	10 GeV - 100 TeV
CR Origin	Relative abundances Trans-Fe ions	CREAM TRACER TIGER	>100 GeV/n few GeV/n
CR propagation	B/C ratio	CREAM TRACER ATIC	0.01-2 TeV/n
Anti-matter	p-bar spectrum antiHe search	BESS	< 10 GeV
Dark Matter	e± spectrum	ATIC	10 GeV-1 TeV

Advanced Thin Ionization Calorimeter (ATIC)

J.H. Adams[2], H.S. Ahn[3], G.L. Bashindzhagyan[4], K.E. Batkov[4], J. Chang[6,7], M. Christl[2], A.R. Fazely[5], O. Ganel[3], R.M. Gunasingha[5], T.G. Guzik[1], J. Isbert[1], K.C. Kim[3], E.N. Kouznetsov[4], M.I. Panasyuk[4], A.D. Panov[4], W.K.H. Schmidt[6], E.S. Seo[3], N.V. Sokolskaya[4], J. Watts, J.P. Wefel[1], J. Wu[3], V.I. Zatsepin[4]

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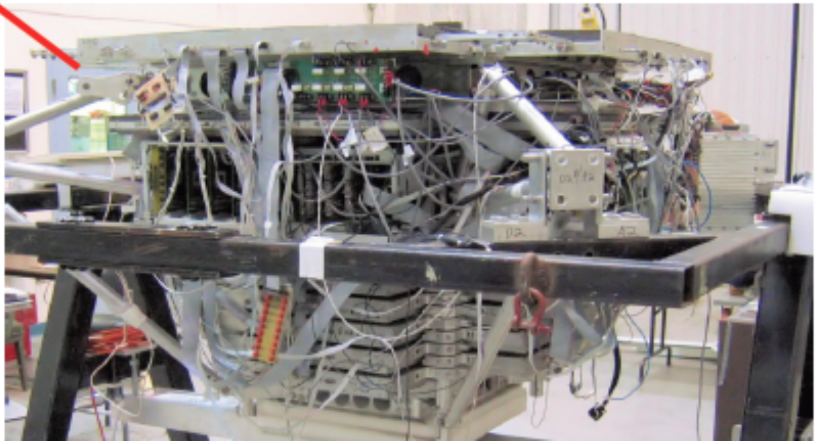
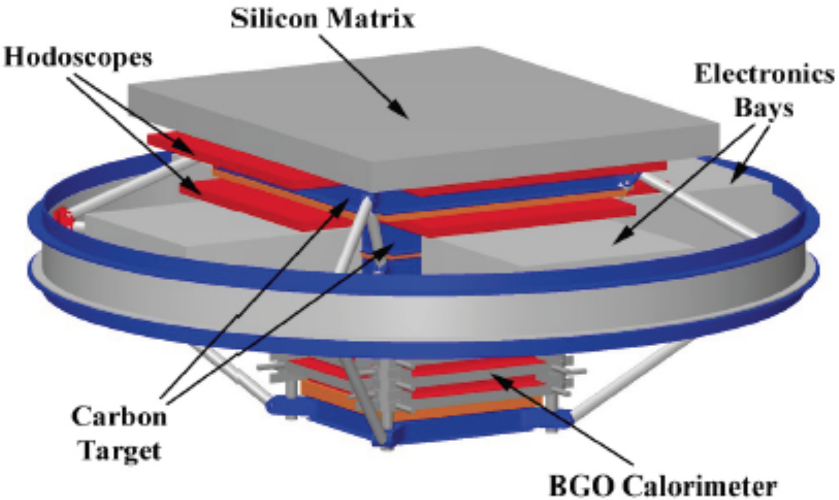


ATIC instrument

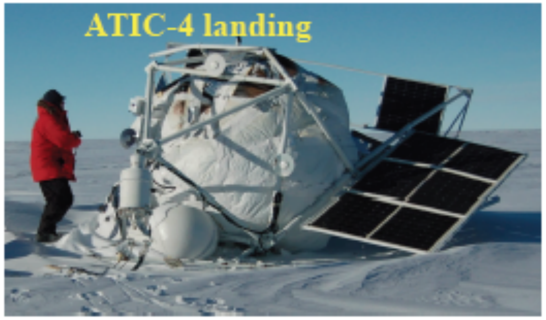


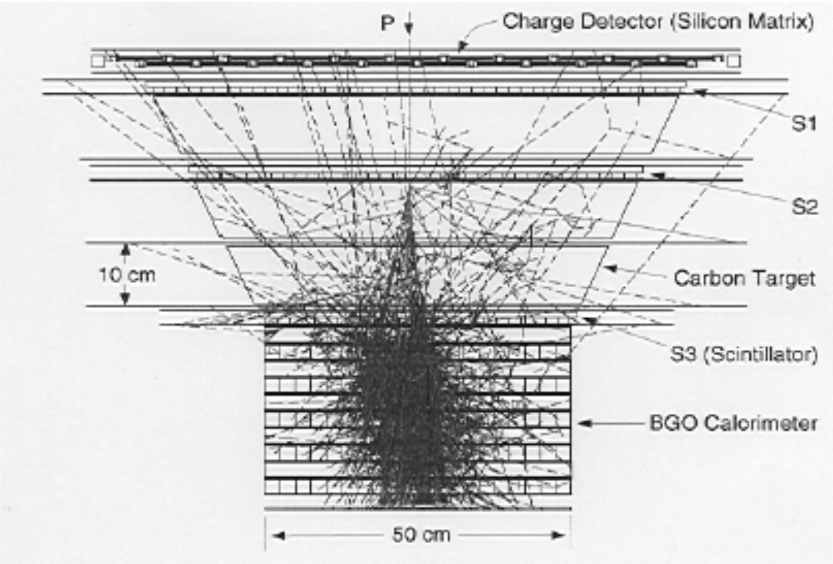
Si-Matrix: 4480 pixels (each 2 cm x 1.5 cm) to measure GCR charge in presence of backscattered shower particles.

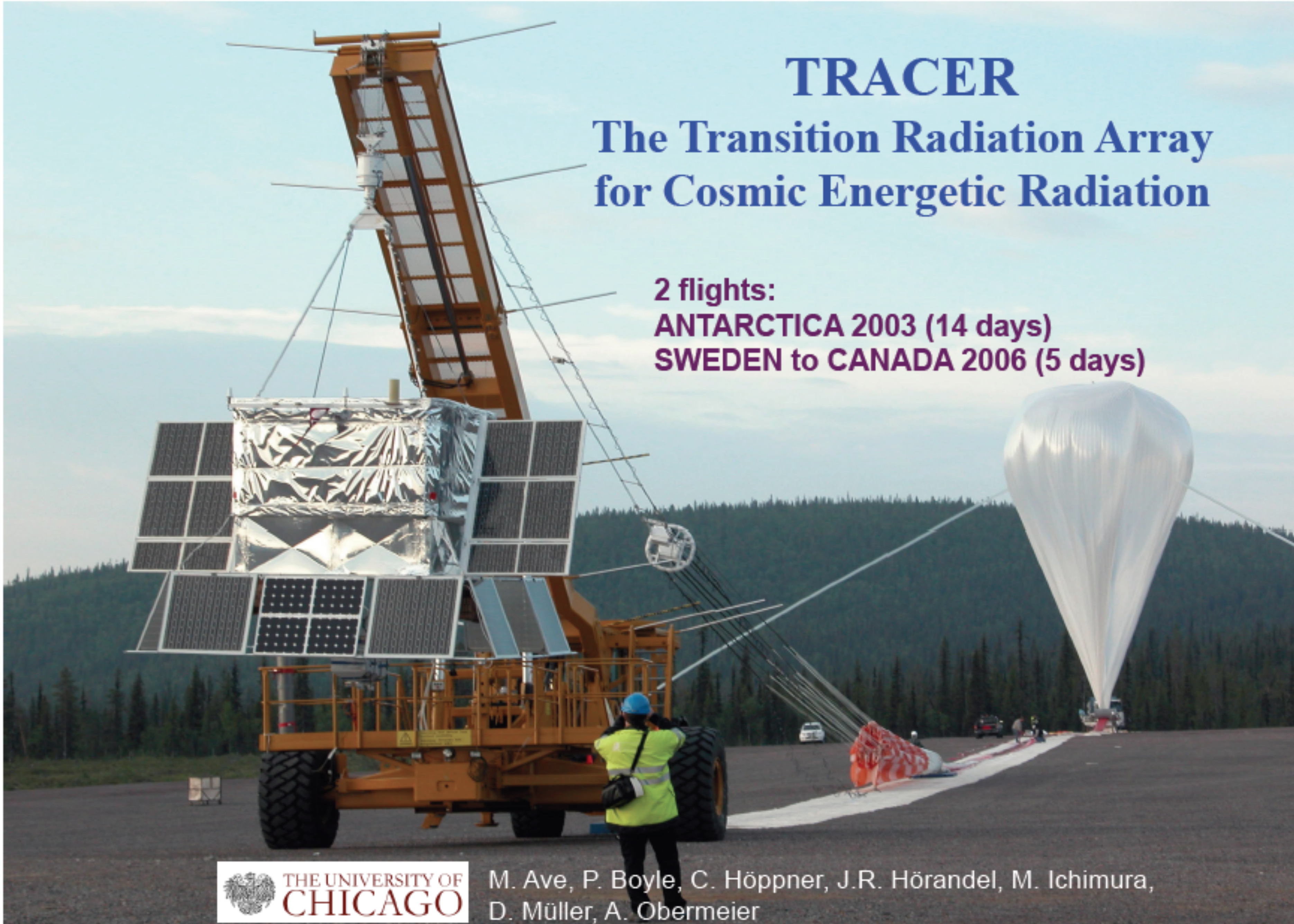
Plastic scintillator hodoscope, embedded in Carbon target, provides event trigger, charge and particle tracking.

Calorimeter: 10 layers BGO crystals, 40 per layer. Total depth 22 X_0, 1.14 λ. Measure the electromagnetic core of the nuclear shower.

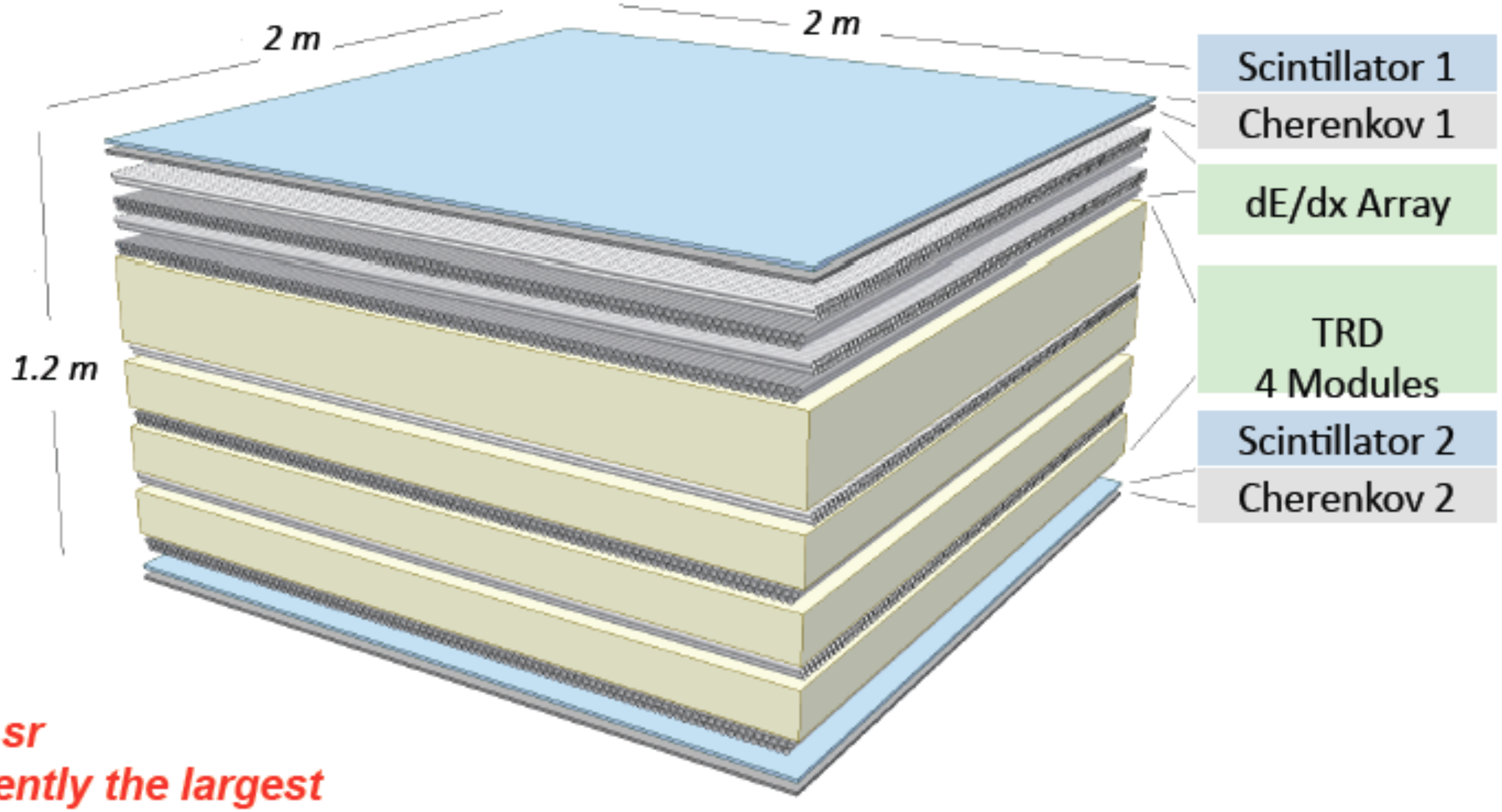
- Geometrical factor: 0.45 m^2 sr (calorimeter top) to 0.24 m^2 sr (calorimeter bottom)
- 3 successful antarctic flights: 2000, 2002, 2007 (~57 days in total)






TRACER
The Transition Radiation Array
for Cosmic Energetic Radiation
2 flights:
ANTARCTICA 2003 (14 days)
SWEDEN to CANADA 2006 (5 days)
THE UNIVERSITY OF CHICAGO
M. Ave, P. Boyle, C. Höppner, J.R. Hörandel, M. Ichimura,
D. Müller, A. Obermeier

TRACER detector



5 m² sr
Currently the largest balloon-borne cosmic-ray detector

1600 proportional tubes, 2 cm diam., 200 cm long

Cosmic Ray Energetics And Mass

H.S. Ahn[a], T. Anderson[b], L. Barbier[c], A. Barrau[d], R. Bazer-Bachi[e], J.J. Beatty[f], P. Bhoyar[a], G. Bigongiari[g], T. J. Brandt[f], M. Buénerd[d], N.B. Conklin[b], S. Coutu[b], L. Derome[d], M. A. DuVernois[h], J. Eaton[a], O. Ganel[a], M. Geske[b], J. H. Han[a], A. Haquea, J.A. Jeon[i], K.C. Kim[a], M.H. Kim[a], M. H. Lee[a], S. E. Lee[a], J. T. Link[c,j], L. Lutz[a], P. Maestro[g], A. Malinin[a], M. Mangin-Brinet[d], A. Menchaca-Rocha[k], P.S. Marrocchesi[g], J.W. Mitchell[c], S.I. Mognet[b], G. Nai, J. Nam[i], S. Nam[i], S. Nutter[l], O. Ofoha[a], I.H. Park[i], N.H. Park[i], A. Putze[d], S.S. Ryu[a], E.S. Seo[a,m], B.P. Smith[a], S. Swordy[n], A. Vartanyan[a], S.P. Wakely[n], P. Walpole[a], J. Wu[a], J. Yang[i], J. H. Yoo[a], Y.S. Yoon[a,m], R. Zei[g]

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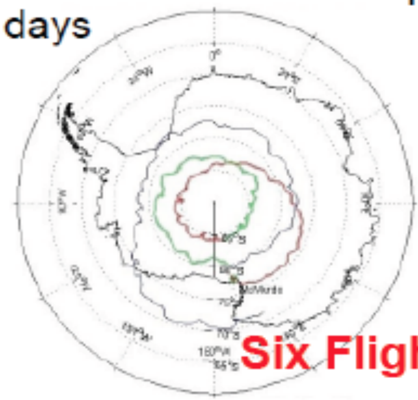
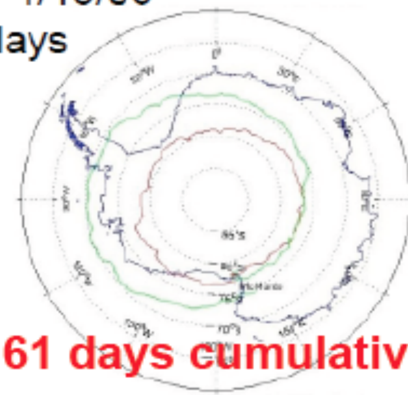
COLUMBIA SCIENTIFIC BALLOON FACILITY

CREAM flights

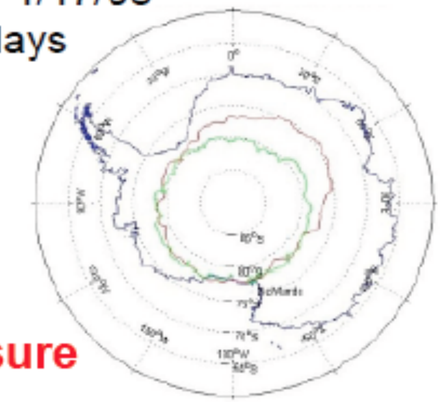
CREAM-I
12/16/04 – 1/27/05
42 days



CREAM-II
12/16/05-1/13/06
28 days

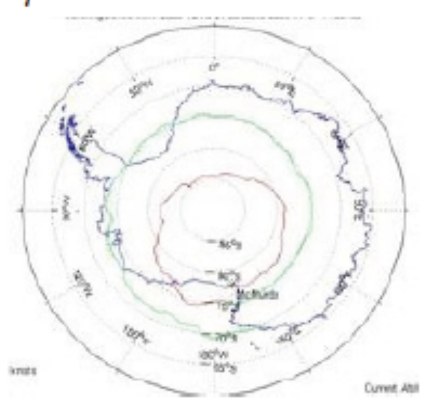


CREAM-III
12/19/07-1/17/08
29 days

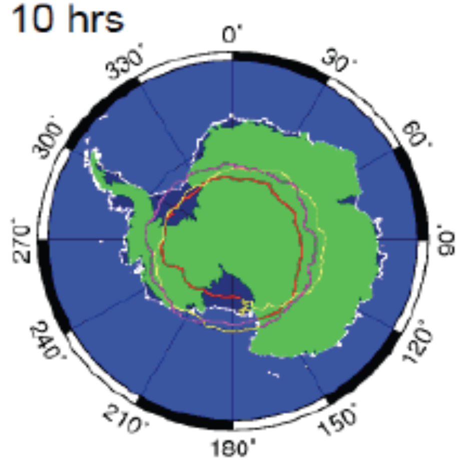


Six Flights: ~161 days cumulative exposure

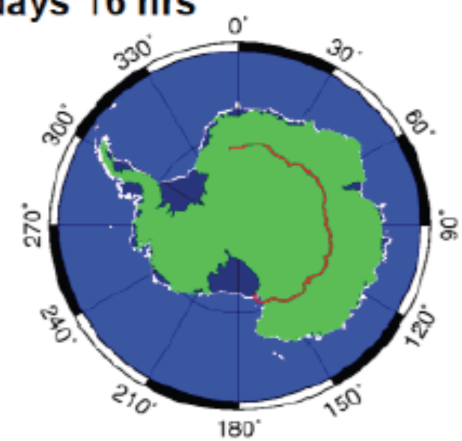
CREAM-IV
12/19/08 - 1/7/09
19 days 13 hrs



CREAM-V
12/1/09 – 1/8/10
37 days 10 hrs

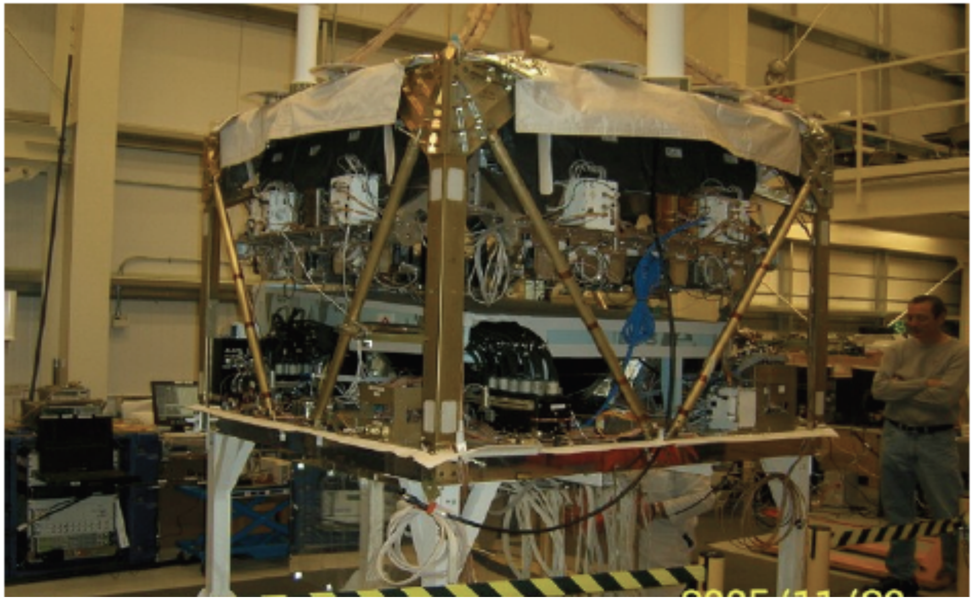


CREAM-VI
12/21/10 – 12/26/10
5 days 16 hrs

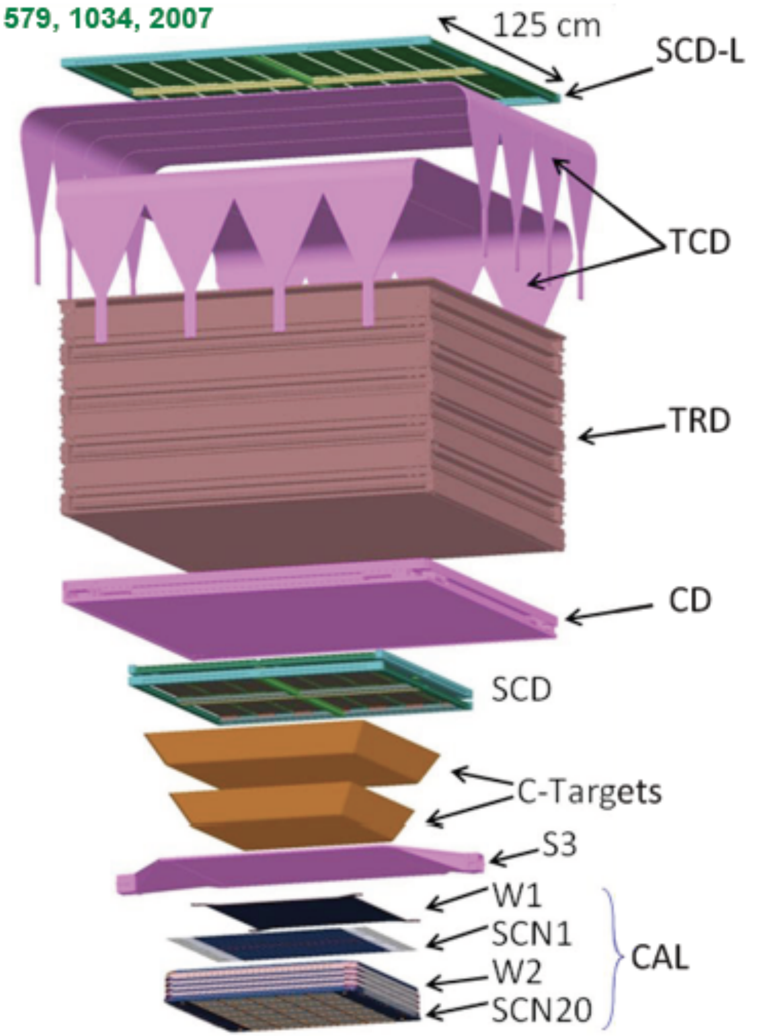


CREAM instrument

- ➢ 3 independent charge measurements
  - Timing-based Charge Detector (TCD)
  - Pixelated Silicon Detector (SCD)
  - Cerenkov counter (CD) and Camera (w/o TRD)
- ➢ 2 independent energy measurements + tracking
  - Transition Radiation Detector (Z > 3)
  - Tungsten Sci-Fi calorimeter (Z ≥ 1)
- ➢ GF ~ 0.3 m^2 sr for Z=1,2; ~ 1.3 m^2 sr for Z>3

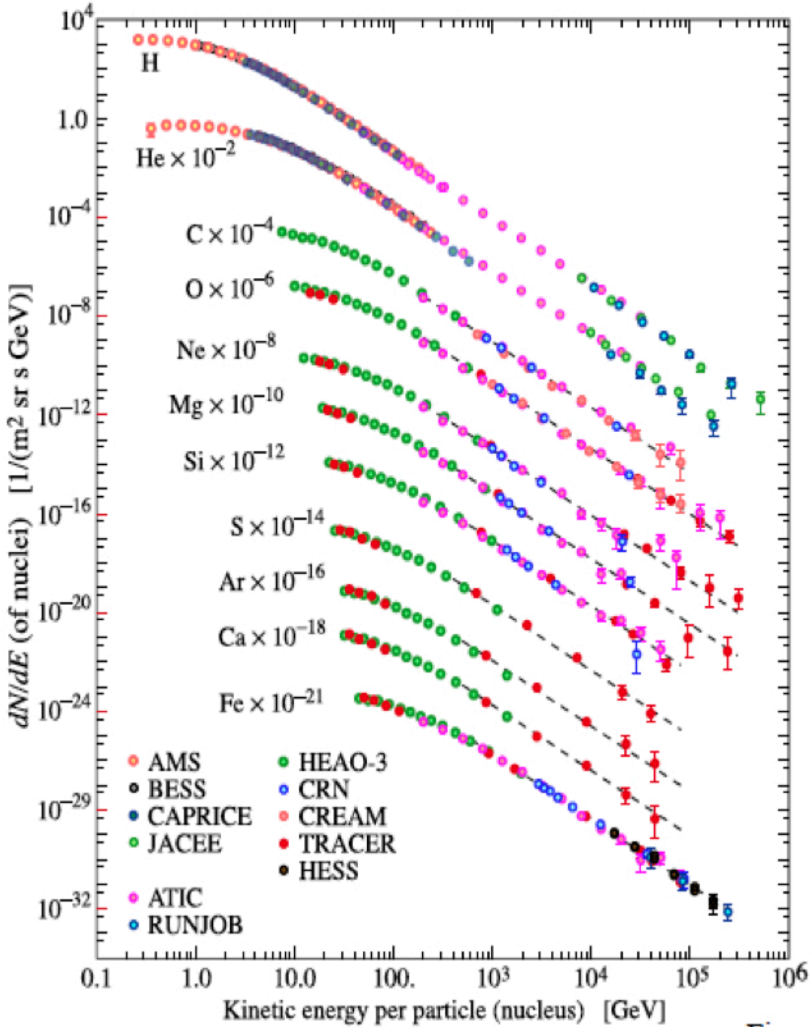


Ahn et al., NIM A, 579, 1034, 2007



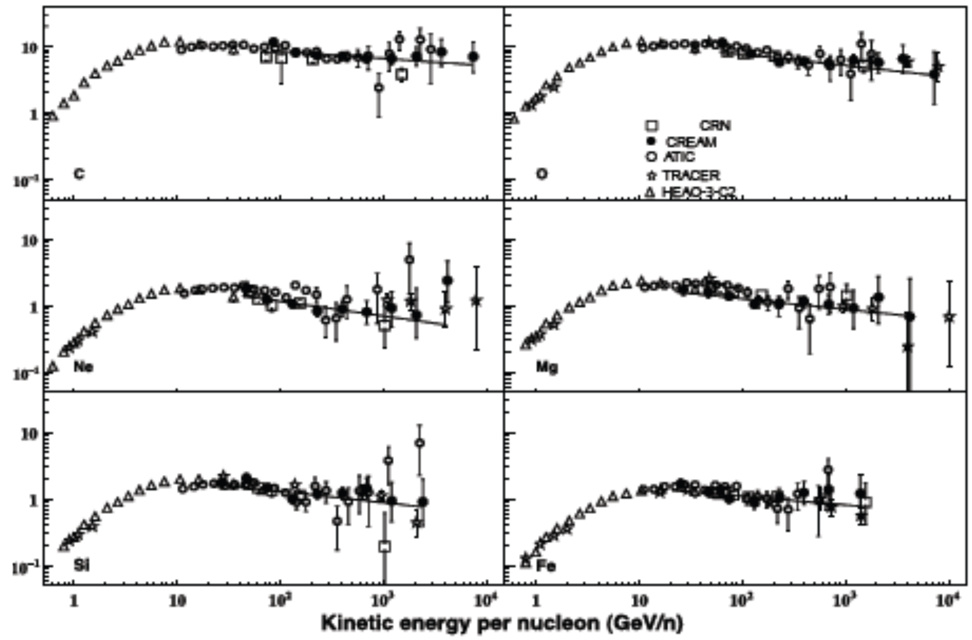
Exploded view: configuration with TRD

Comparison of experimental results

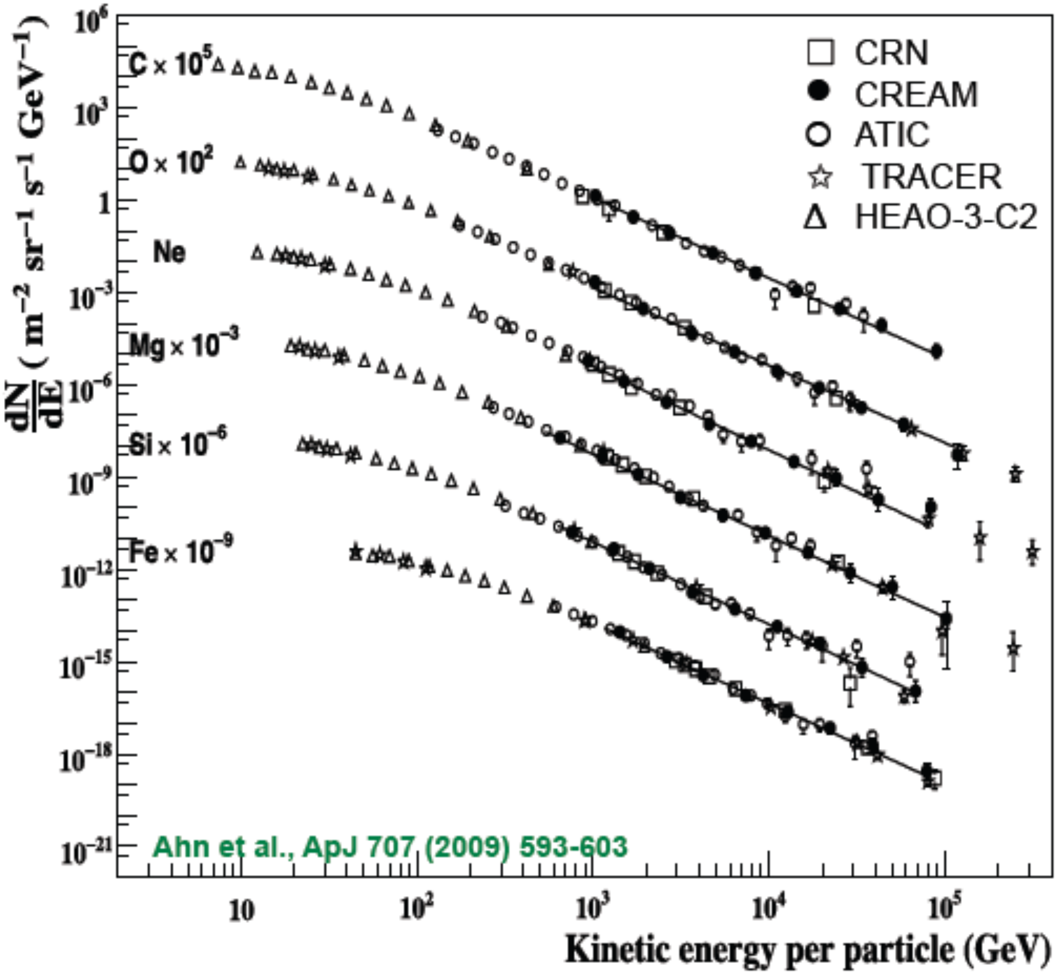


CREAM, ATIC & TRACER measured the individual energy spectra of **C, O, Ne, Mg, Si, Fe** in the particle energy range from some tens of GeV up to few hundreds of TeV.

CREAM & ATIC measured proton and He spectra too.



GCR energy spectra



All elements are well fitted to single power-laws in energy

$$\phi(E) = \phi_0 \times E^{-\gamma}$$

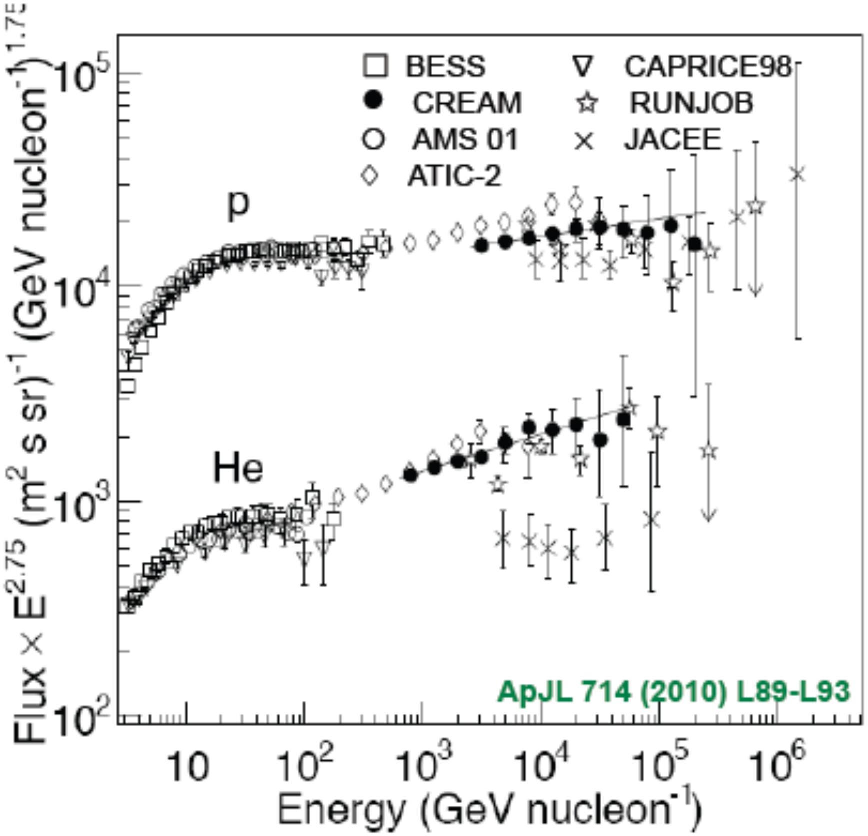
with very similar spectral indices γ.

Average γ of major heavy nuclei:
2.66 ± 0.04 CREAM
2.65 ± 0.05 TRACER

No evidence for any *Z* dependence in the spectral indices.

Points to *common origin* for all species and same mechanism of acceleration ?

Proton and helium spectra



➢ JACEE and RUNJOB (emulsion chambers) showed hint that p and He spectra 10 TeV/n are harder than low-energy spectra. But reported different spectral index for He.

➢ CREAM measured p and He spectra in the particle energy range 2-250 TeV with unprecedented statistics.

Energy	γ_p	γ_{He}	Exp.
10-200 GV	2.78±0.009	2.74±0.01	AMS
20-100 GeV/n	2.732±0.011	2.699±0.040	BESS
10-10^3 TeV	2.80±0.04	$2.68^{+0.04}_{-0.06}$	JACEE
10-300 TeV	2.78±0.05	2.81±0.06	RUNJOB
2.5-250 TeV	2.66±0.02	2.58±0.02	CREAM

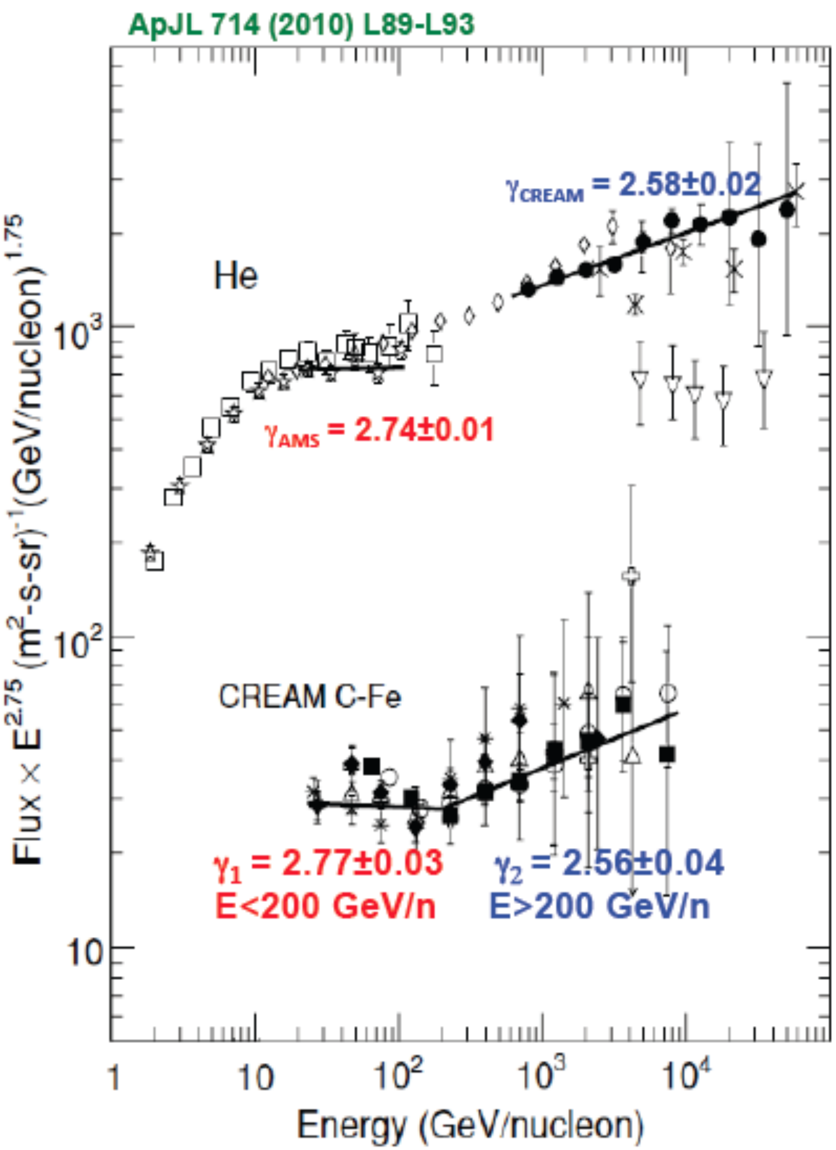
➢ **Proton and helium spectra at TeV are harder than the low-energy spectra.**

➔Evidence of CRs-shock interaction (Non linear acceleration models) ? **(ApJ 540 (2009) 292)**

➢ **Proton and helium spectra have different spectral shapes**

➔ Different types of sources or acceleration mechanisms? **(Biermann P. A&A 271 (1993) 649)**

Broken-law power spectra



Broken power-law fit to combined C-Fe spectra

γ_1 (E<200 GeV/n) agrees with AMS He index

γ_2 (E>200 GeV/n) agrees with CREAM He index

Is this coincidental ?

- **Hint of concavity due to CR interactions with the shock?**

Features of particle acceleration theories at SNR modified shock **(P. Blasi Rap. Talk 30th ICRC)**:

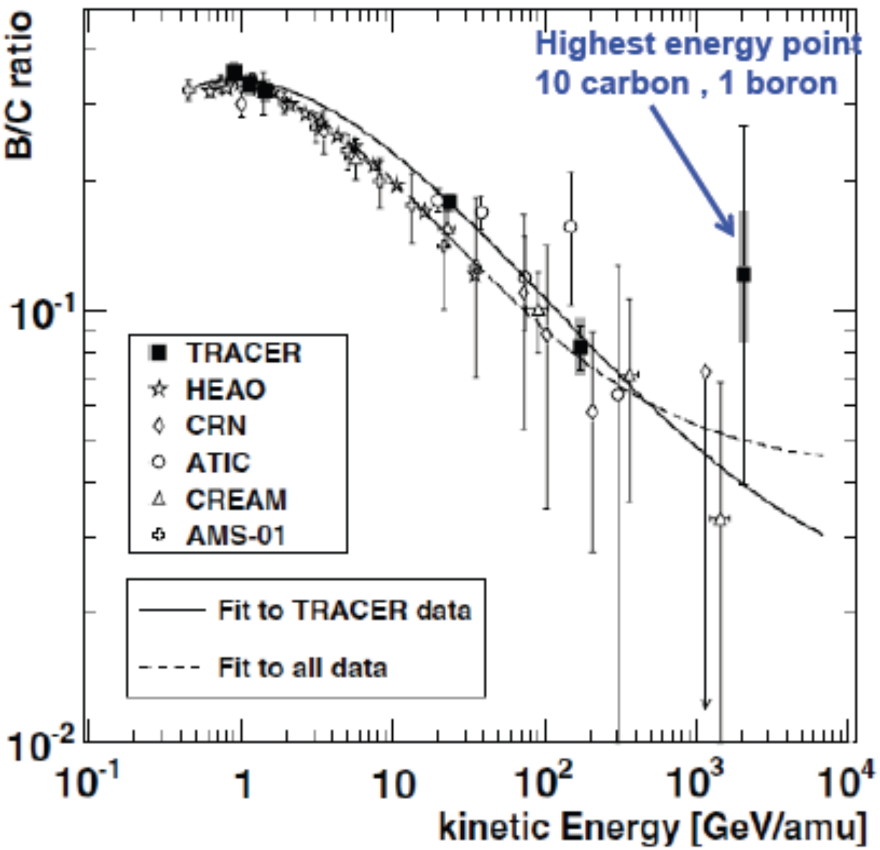
- CR spectrum is not a single power-law but shows a concavity before the knee and gets harder at HE

-Magnetic field amplification ➔ CRs can be accelerated efficiently up to $E_{max} \sim Z \times 10^6$ GeV

- **Effect of non-uniform distribution of sources?**
- **Effect of distributed acceleration by multiple SNR's? Superbubbles?** **(Butt & Bykov, *ApJ* 677, L21, 2008)**

Boron to Carbon ratio

A. Obermeier et al., ApJ 752 (2012) 69



CREAM & TRACER measured the B/C ratio up to ~2 TeV/n.

The interstellar propagation pathlength decreases fairly rapidly with energy, and can be described as

$$\lambda(E) = CE^{-\delta} + \lambda_0$$

where δ propagation index, λ_0 a residual pathlength. The best fit to data gives

$\delta = 0.53 \pm 0.06$
$\lambda_0 = 0.31^{+0.55}_{-0.31}$ g cm^{-2} TRACER

$\delta = 0.64 \pm 0.02$
$\lambda_0 = 0.7 \pm 0.2$ g cm^{-2} ALL DATA

Measurement of the Relative Abundances of the Ultra-Heavy Galactic Cosmic-Rays (30≤Z≤40) with TIGER

**Trans-
Iron
Galactic
Element
Recorder**

Washington University in St. Louis
B.F. Rauch, W.R. Binns, J.R. Cummings, M.H. Israel, J.T. Link, L.M. Scott

California Institute of Technology
S. Geier, R.A. Mewaldt, S.M Schindler, E.C. Stone

Goddard Space Flight Center
L.M. Barbier, E.R. Christian, J.W. Mitchell, G.A. de Nolfo, R.E. Streitmatter

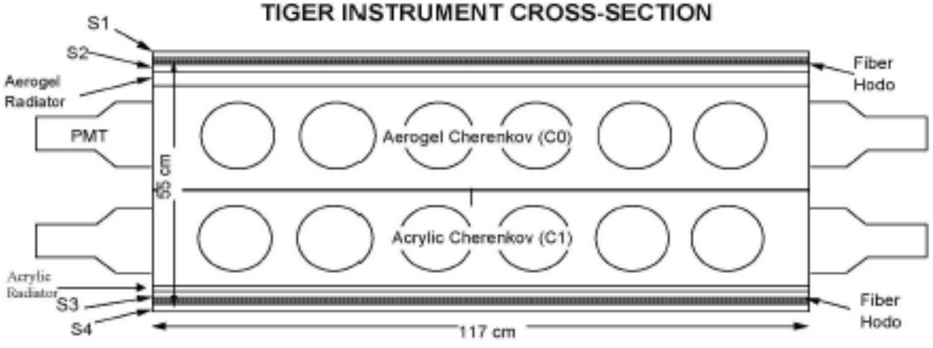
University of Minnesota
C.J. Waddington

2 antarctic flights

Dec. 2001 - Jan. 2002 32 days

Dec. 2003 - Jan. 2004 18 days

TIGER instrument



TIGER is composed of plastic scintillators, Cherenkov detectors with two different indices of refraction, and a scintillation fiber hodoscope.

Scintillator ~ dE/dx ~ (Z^2/β^2)x(logarithmic increase w. energy)

Cherenkov ~ $Z^2(1-1/n^2\beta^2)$

Acrylic n = 1.5 → threshold 325 MeV/nuc

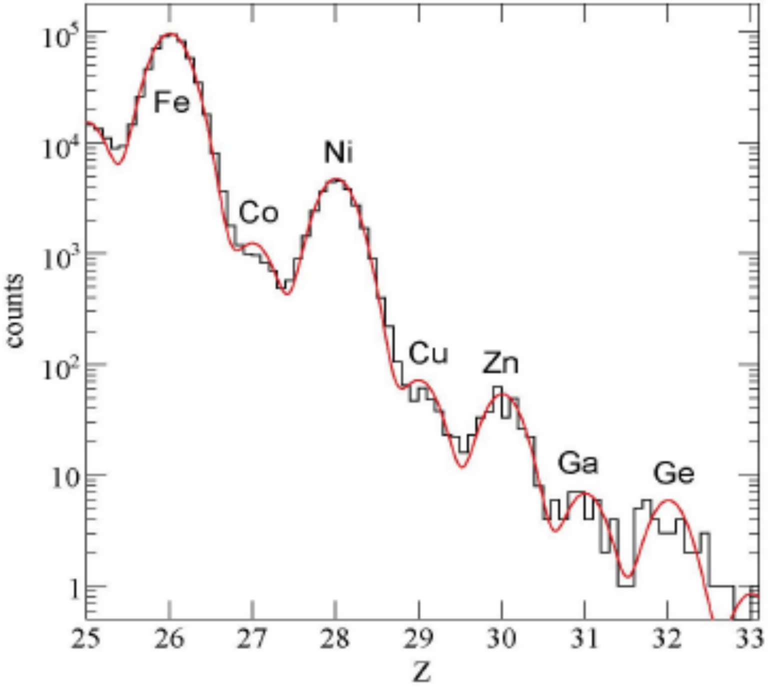
Aerogel n = 1.04 → threshold 2.5 GeV/nuc

Between 325 MeV/nuc and 2.5 GeV/nuc determine charge and energy from Scintillator and Acrylic Cherenkov.

Above 2.5 GeV/nuc determine charge from the two Cherenkov (and from Scintillaor and Aerogel Cherenkov.

- TIGER is a 1 m^2 electronic instrument measuring the elemental composition of the rare GCR's heavier than iron.
- Obtained best measurement to date of abundances of $_{31}$Ga, $_{32}$Ge, & $_{34}$Se.

Combined 2001 and 2003 TIGER Data with Maximum Likelihood Fit



GCR source abundances

Observed elemental and isotopic abundances of GCRs at the TOA are corrected for the effects of fragmentation in the ISM (by means of propagation models) to determine the source abundances, which provide information about:

➤ **the site of acceleration**

- $^{22}Ne/^{20}Ne$ ratio in GCRs is ~5 times (ACE/CRIS, Binns et al. ApJ 634 (2005) 351) higher than the Solar System value.
- Trans-Fe/Fe abundances (TIGER, Rauch et al. ApJ 697 (2009) 2083) show discrepancies with the solar system values ($^{31}Ga/^{32}Ge$ ~1 in GCRs vs. 0.3 in solar system)

These observations :

➔ are consistent with a **CR source mixture of about 20% ejecta of massive stars (including Wolf–Rayet stars and core–collapse supernovae) mixed with 80% material of solar system composition**

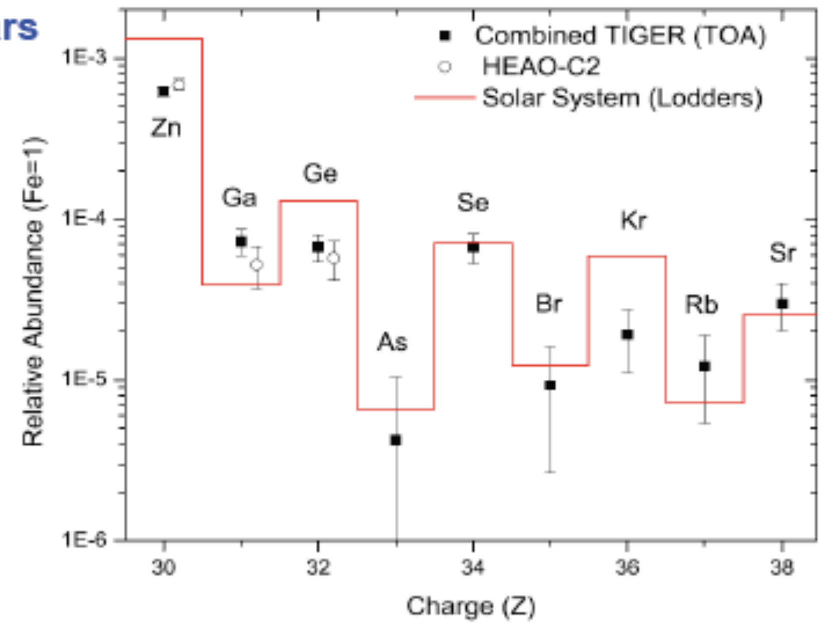
➔ support a model of GCR origin in **OB associations**

↓

Multiple SN shock acceleration in **superbubbles**

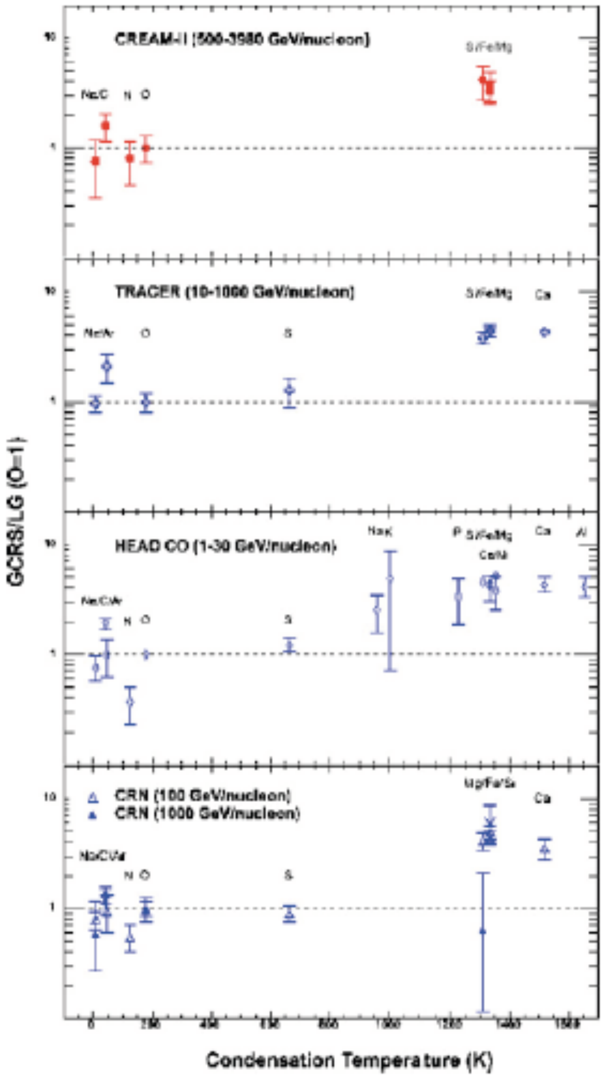
- $E_{max} \approx Zx10^{17}$ eV
- More efficient injection mechanism
- Spectrum hardening at high energy

(Parizot et al. A&A 424 (2004) 747)

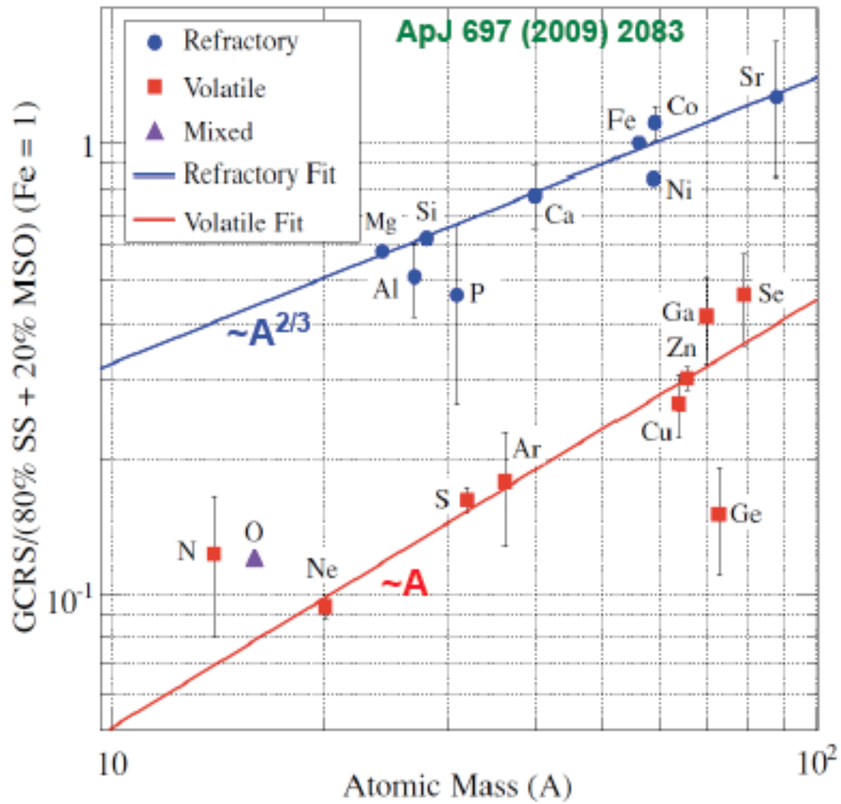


GCR source abundances

➤ the acceleration mechanism



Refractory elements (T_c>1200 K) are more abundant in CR source (relative to solar system abundances) than volatile ones (Meyer et al., ApJ 487 (1997) 182)

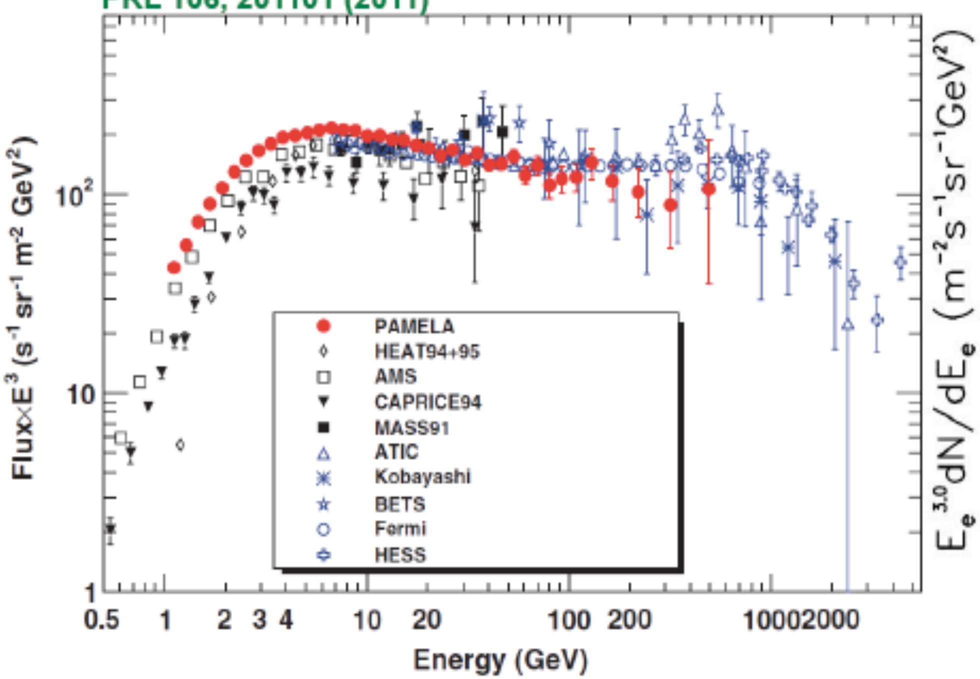


Refractory elements (dust grains) are more effectively accelerated than volatile ones (present in interstellar gas).

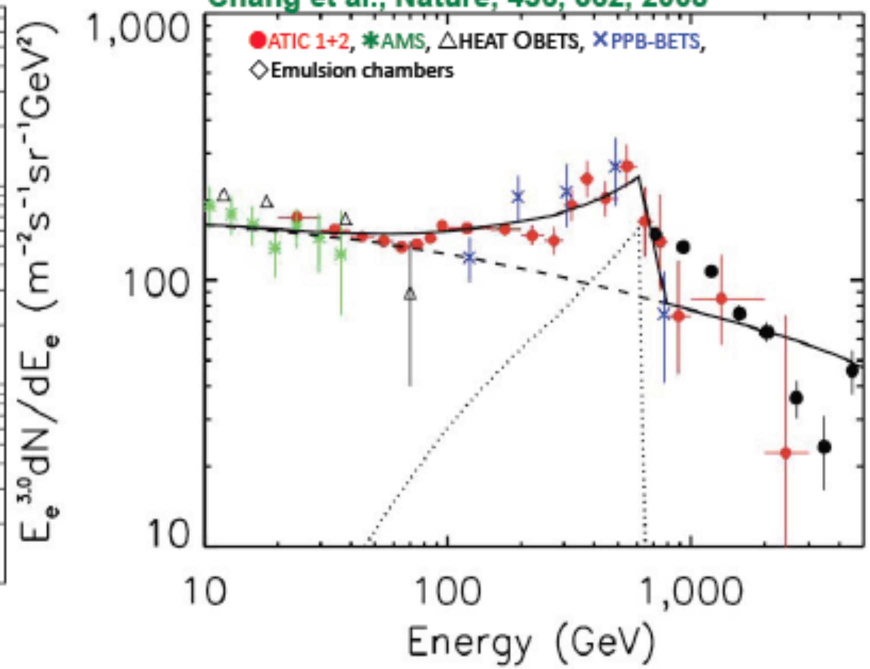
Cosmic ray electrons

For HE electrons, radiative energy losses (~E^2) are dominant during propagation→electrons observed at Earth likely originated in young sources (~10^5 yr) and few kpc far from the Solar System →Possible spectral features in electron spectrum.

PRL 106, 201101 (2011)



Chang et al., Nature, 456, 362, 2008



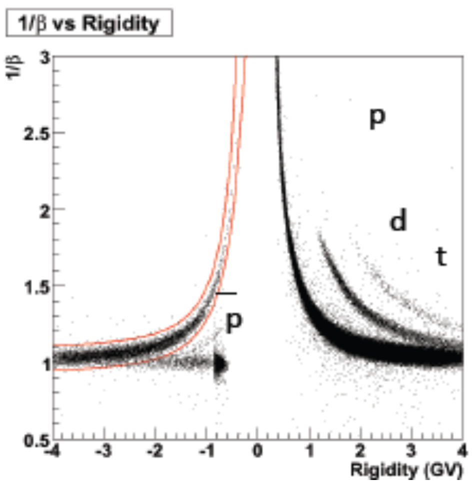
ATIC reported an excess of CR electrons at energies between 300–800 GeV

- **nearby sources of energetic electrons (SNR, pulsar, micro-quasar) ?**
- **annihilation of dark matter particles ?**

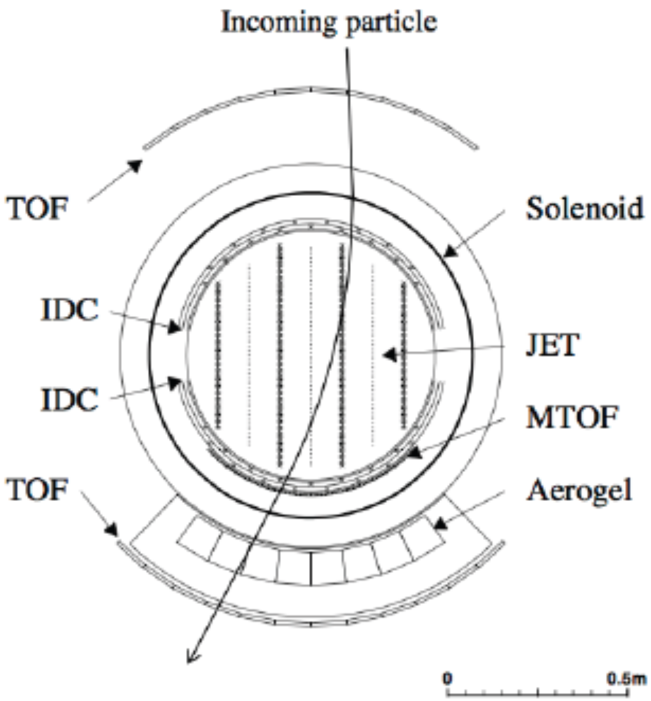
Spectral feature observed by ATIC not confirmed by Pamela and Fermi

BESS-Polar

- Original BESS (Balloon-borne Experiment with a Superconducting Spectrometer) was flown 9 times between 1993 and 2002.
- New BESS-Polar instrument flew from Antarctica in 2004 (8.5 days) and 2007 (24.5 days).
- Measures charge, charge-sign, momentum velocity and mass of the particles
- "JET" drift chamber with 52 points on trace, σ ~100 μm MDR 240 GV
- Time-of-flight system (TOF)
- Silica-aerogel Cherenkov detector



- **NASA/Goddard Space Flight Center** T.Hams, J.W.Mitchell, M.Sasaki, R.E. Streitmatter
- **KEK** S. Haino, M. Hasegawa, A. Horikoshi, Y.Makida, S. Matsuda, M. Nozaki, J.Suzuki, K.Tanaka, A. Yamamoto, K.Yoshimura
- **The University of Tokyo** J.Nishimura, K. Sakai, R. Shinoda
- **Kobe University** K. Abe, A. Kusumoto, Y. Matsukawa, R. Orito
- **University of Maryland** K.Kim, M.H. Lee, S.Lee, E.S. Seo
- **ISAS/JAXA** H. Fuke, T. Yoshida
- **University of Denver** J. Ormes, N. Thakur



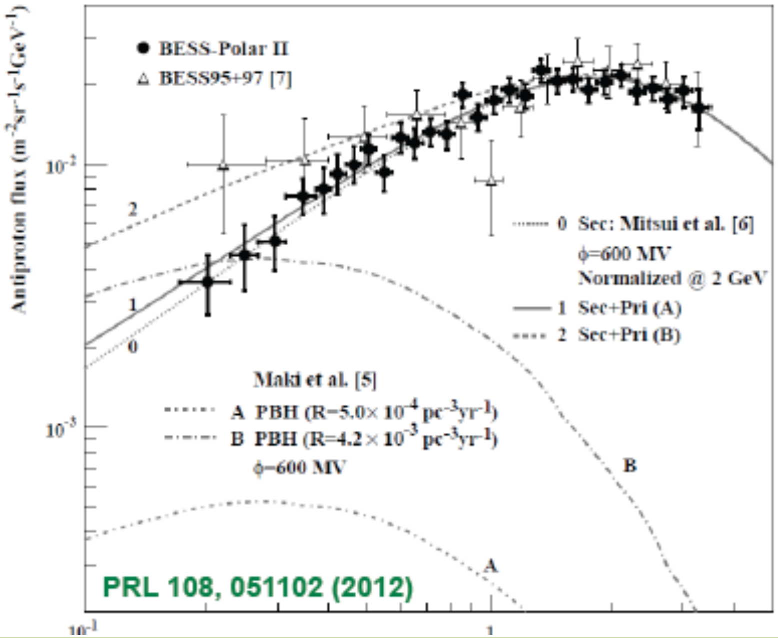
Antiproton spectrum

Cosmic-ray antiparticles probe the early Universe

Antiprotons are mainly of secondary origin (i.e. produced in CR interactions with ISM)

Possible small primary component:

- Evaporation of primordial black holes (PBH)
- Decay of dark-matter particles?



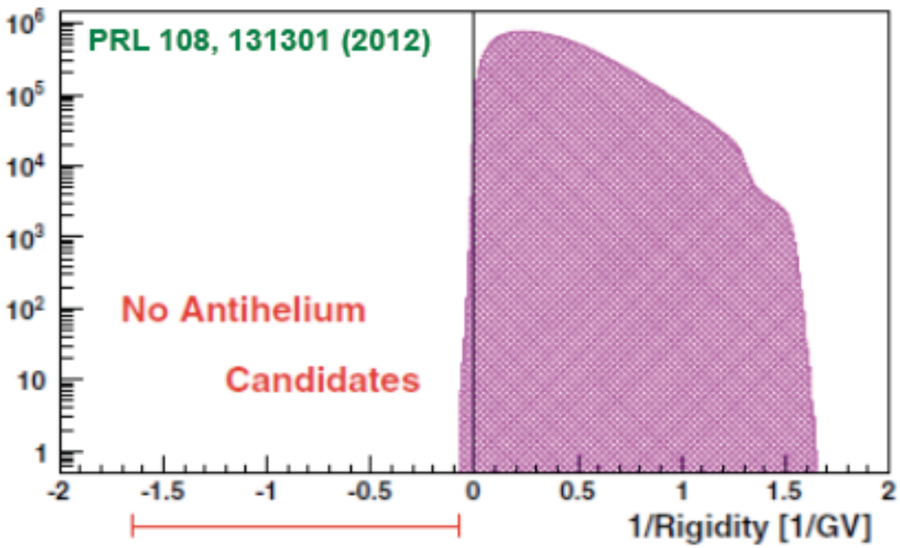
- BESS (95+97) Solar min. data show a possible *flattening of the antiproton spectrum at lower energies* compared to secondary production, suggesting possible excess.
- BESS-Polar I data taken at higher solar activity 851 MV are consistent with secondary production, as expected.
- BESS-Polar II detected 7886 antiprotons at Solar minimum: **no evidence of primary antiprotons from evaporation of primordial black holes.**

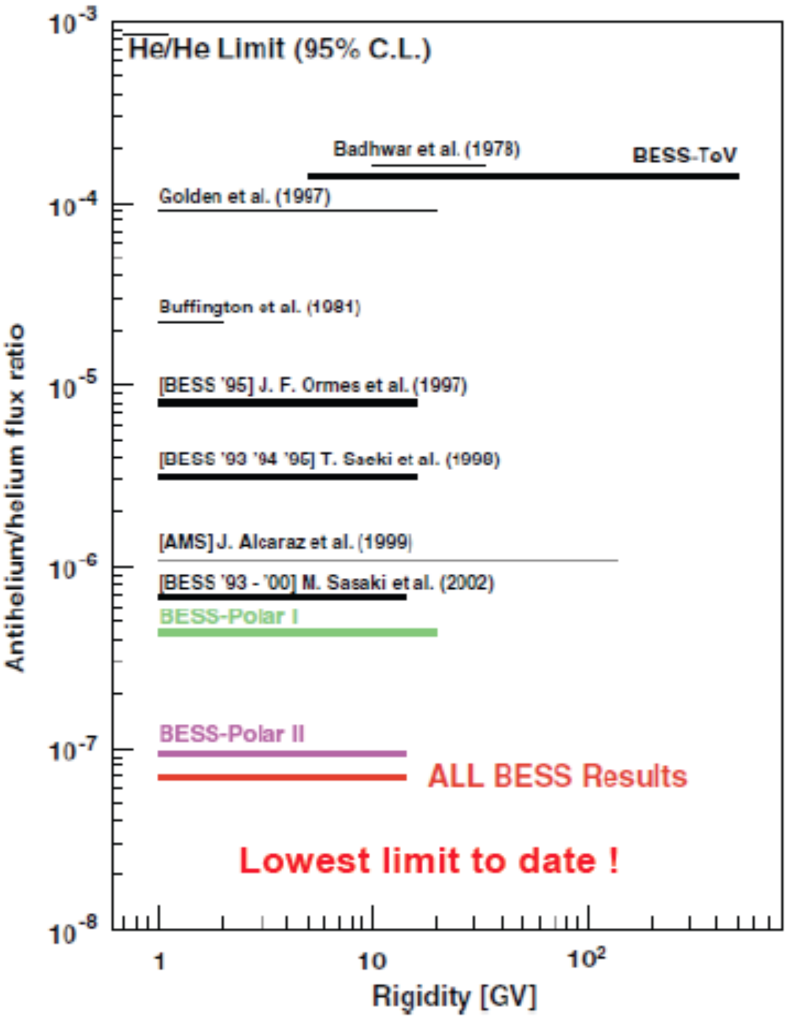
Search for antihelium

Asymmetry of particles and antiparticles is one of the fundamental problems in cosmology.

Small antimatter domains from which primordial antinuclei could reach the Earth are not excluded.

(A. D. Dolgov, Nucl. Phys. B, Proc. Suppl. 113, 40)





8.4×10^6 |Z|=2 nuclei identified by BESS-Polar I

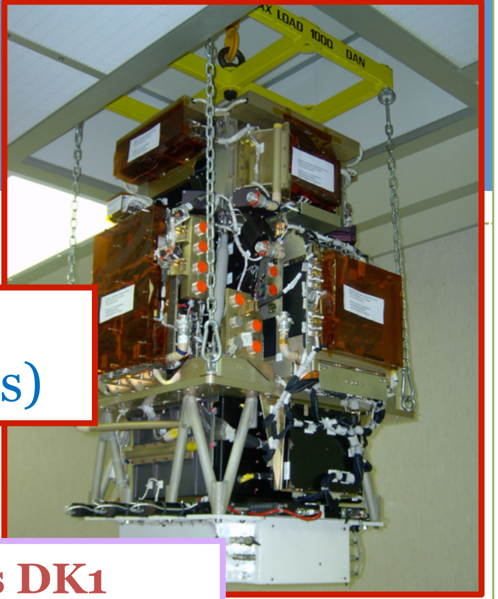
4.0×10^7 |Z|=2 nuclei identified by BESS-Polar II

No antiHe candidates were found

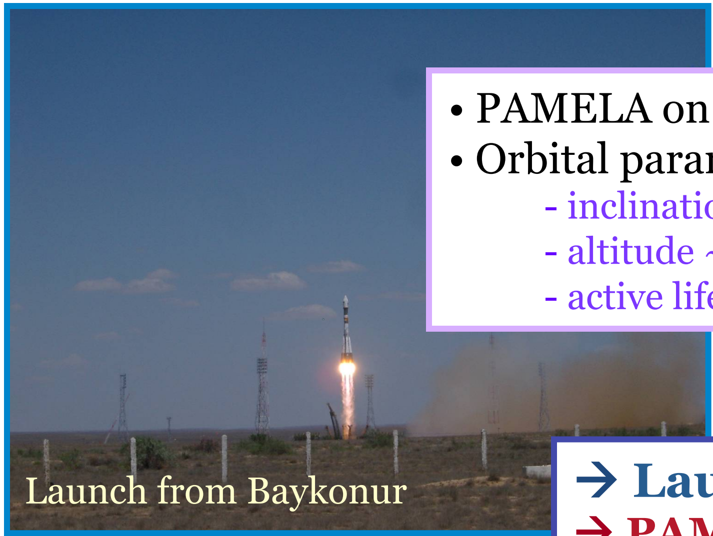

Satellite
experiments

PAMELA

Payload for Matter/antimatter Exploration and Light-nuclei Astrophysics

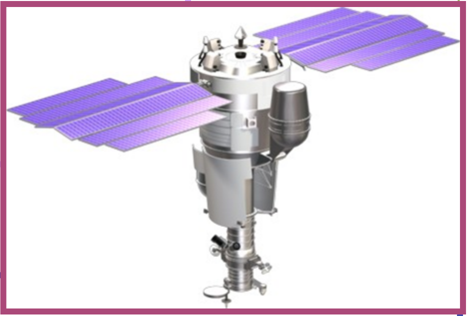


- **Direct** detection of CRs in space
- Main focus on **antiparticles** (antiprotons and positrons)



Launch from Baykonur

- PAMELA on board of Russian satellite **Resurs DK1**
- Orbital parameters:
  - inclination ~70° (⇒ low energy)
  - altitude ~ 360-600 km (elliptical)
  - active life >3 years (⇒ high statistics)

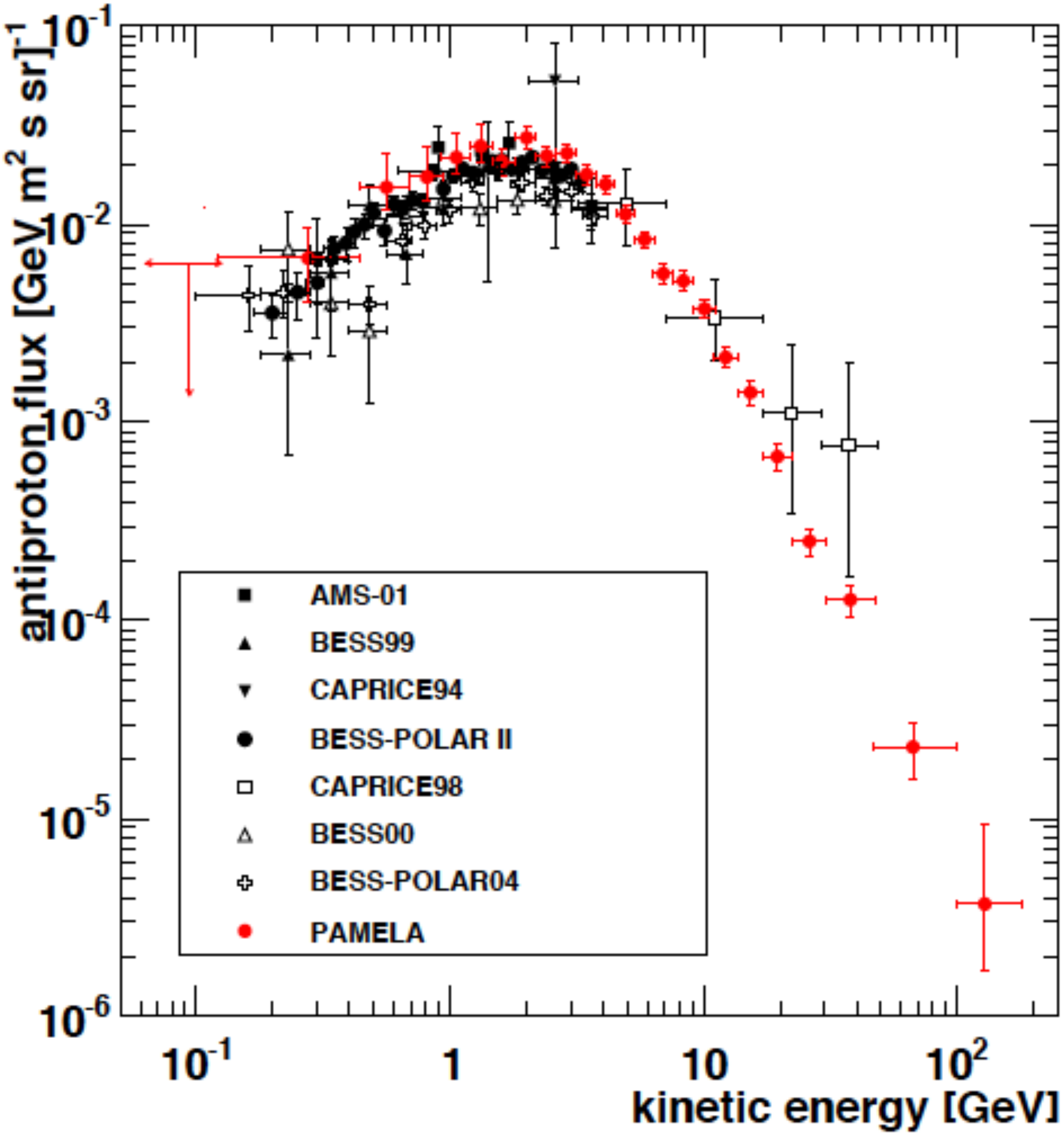


→ **Launched on 15th June 2006**

→ **PAMELA in continuous data-taking mode since then!**

Antiproton flux

Largest energy range covered so far !

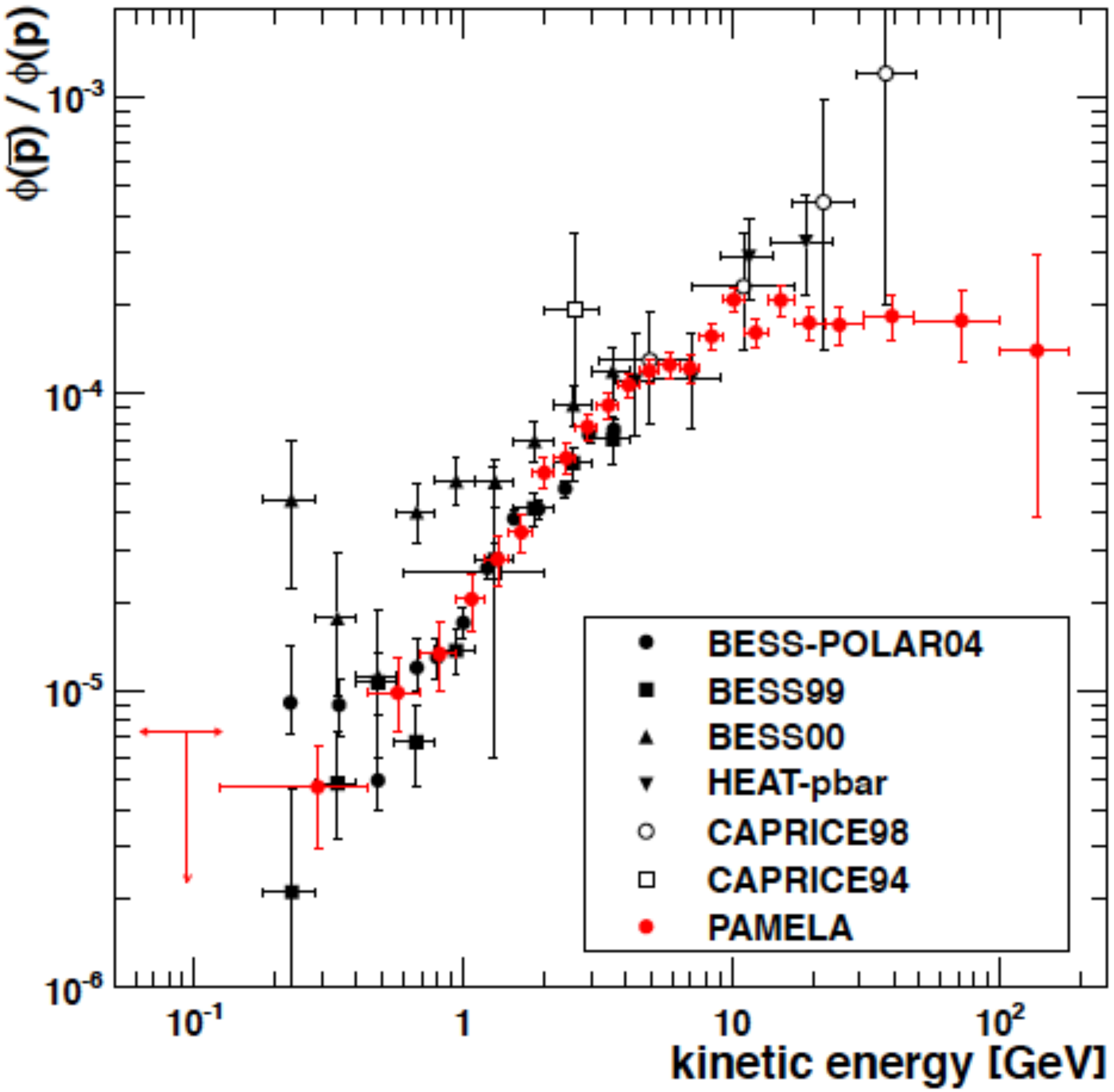


Adriani et al. - PRL 105 (2010) 121101

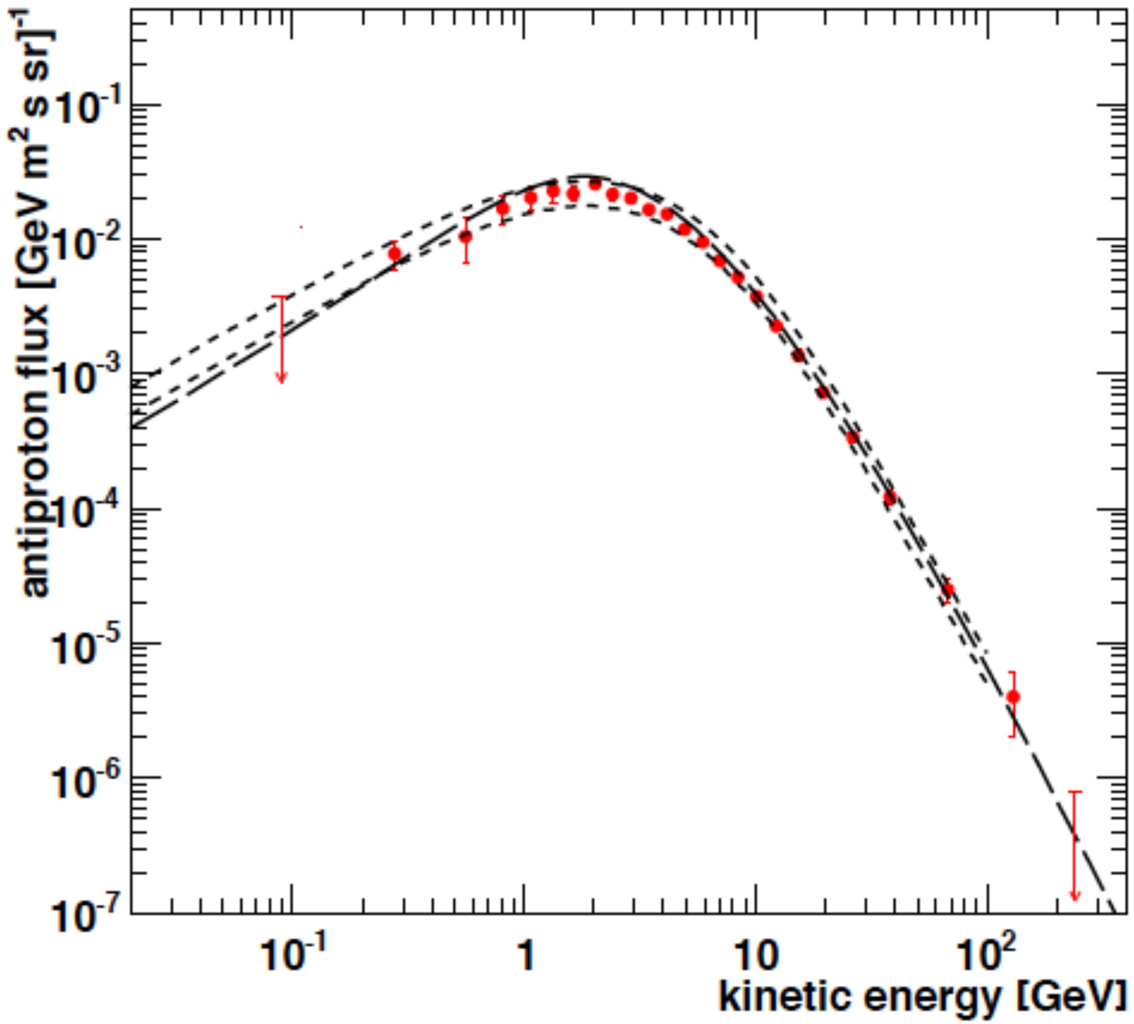
Adriani et al. - PRL 105 (2010) 121101

Antiproton-to-proton ratio

Largest energy range covered so far !



New antiproton flux –> 400 GeV

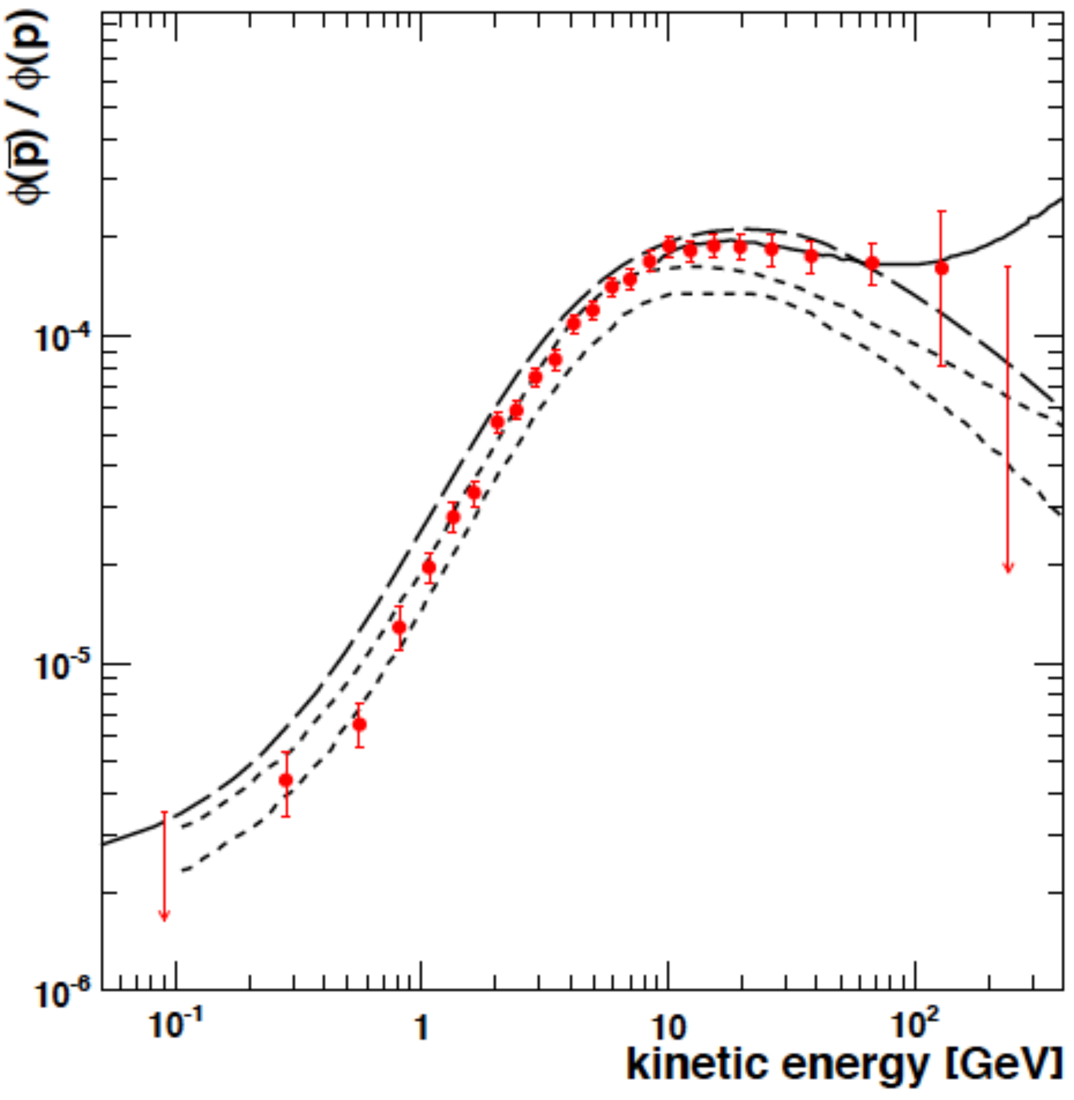


Using all data till 2010 and multivariate classification algorithms

40% increase in antip respect to published analysis

New antiproton/ proton ratio → 400 GeV

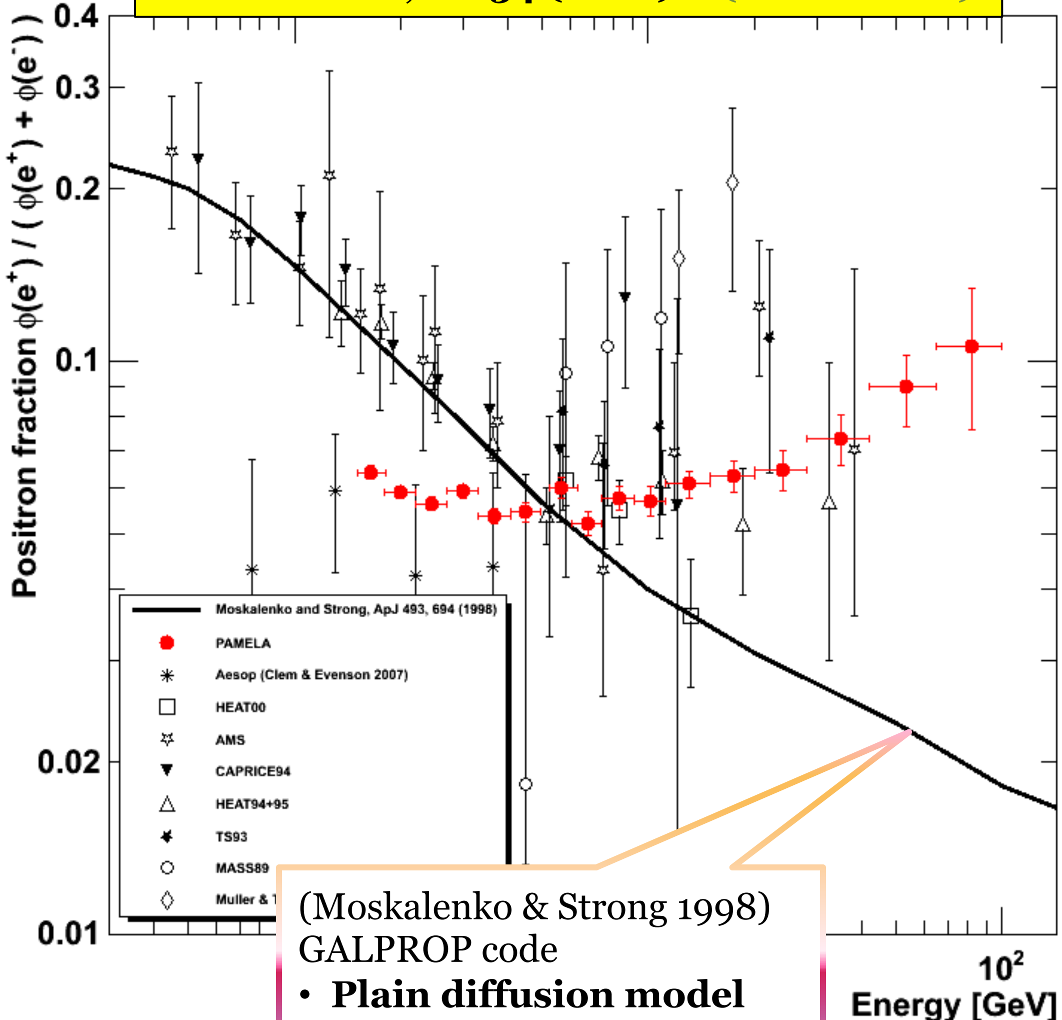
Overall agreement with models of pure secondary calculations for solar minimum **(constraints at low and high energy for DM models!)**



Positron fraction

- **Low energy** → charge-dependent solar modulation (see later)
- **High energy** → (quite robust) evidence of positron excess above 10 GeV

Adriani et al. , Nature 458 (2009) 607
Adriani et al., AP 34 (2010) 1 (new results)



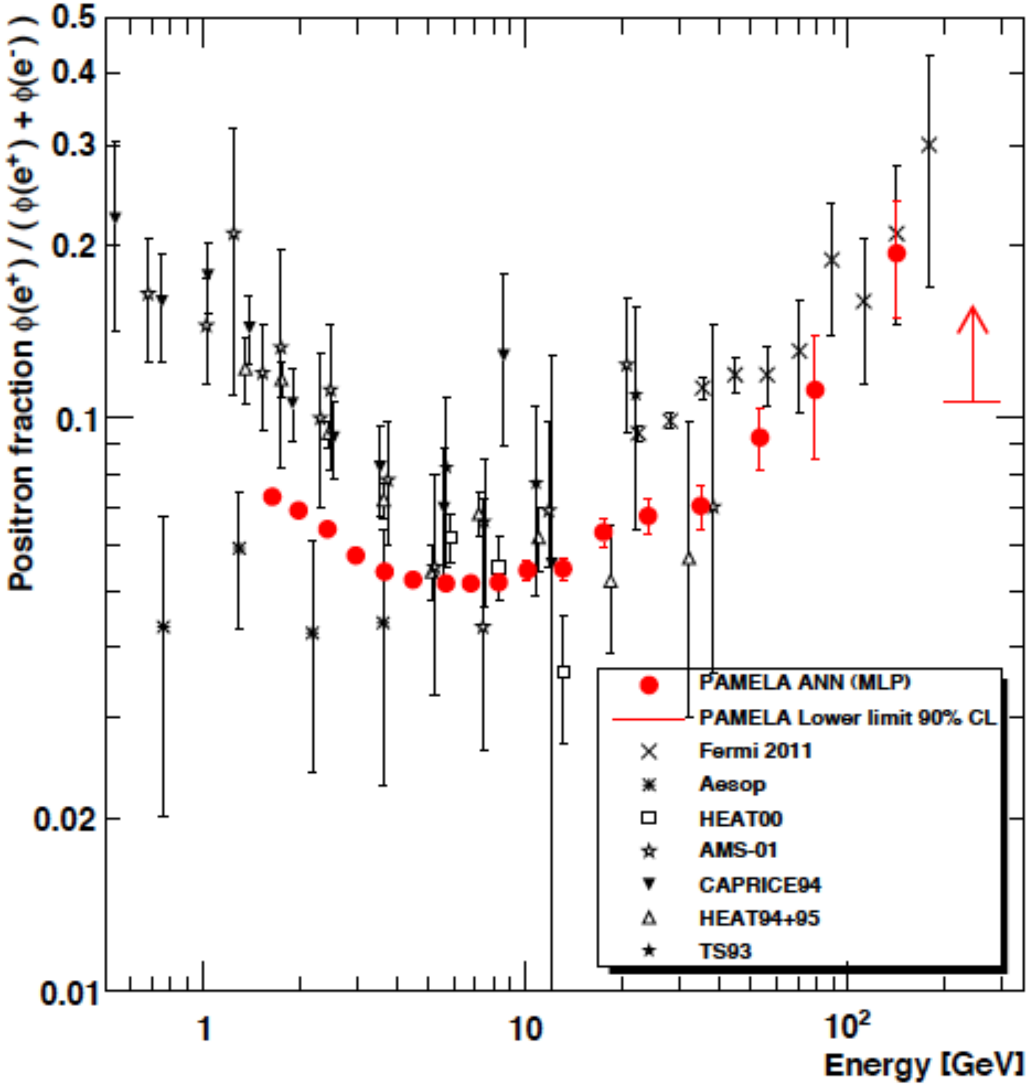
(Moskalenko & Strong 1998) GALPROP code

- **Plain diffusion model**
- Interstellar spectra

New positron fraction data

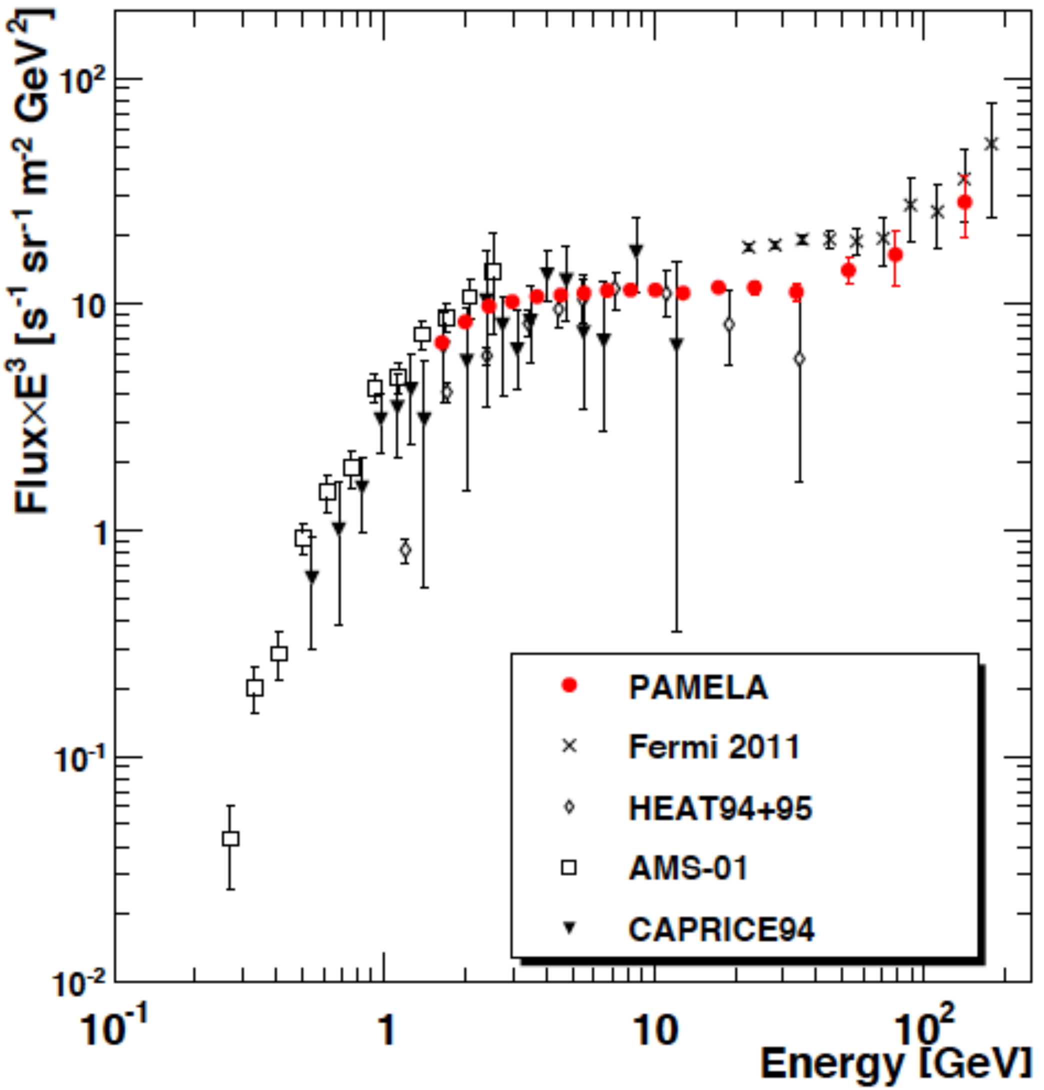
Using all data till 2010 and multivariate classification algorithms about factor 2 increase in positron statistics respect to published analysis

Good agreement with FERMI data (same increasing trend)



New positron flux

Good agreement with
FERMI data (same increasing trend)



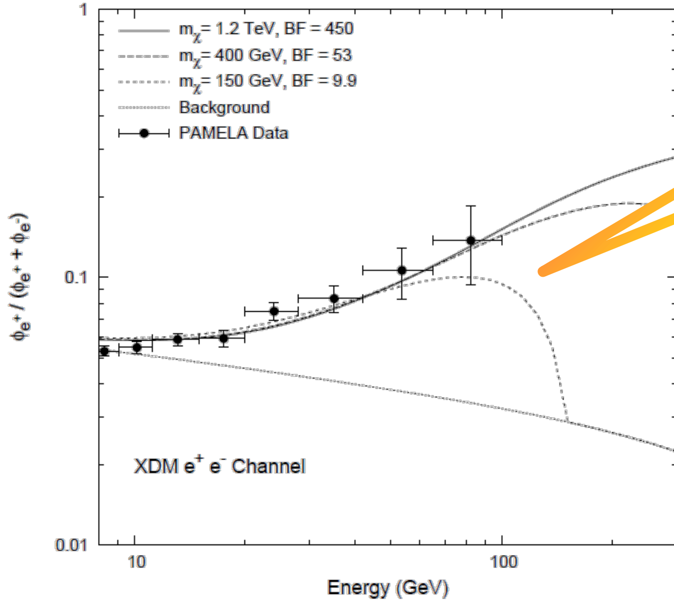
Positron-excess interpretations

Dark matter

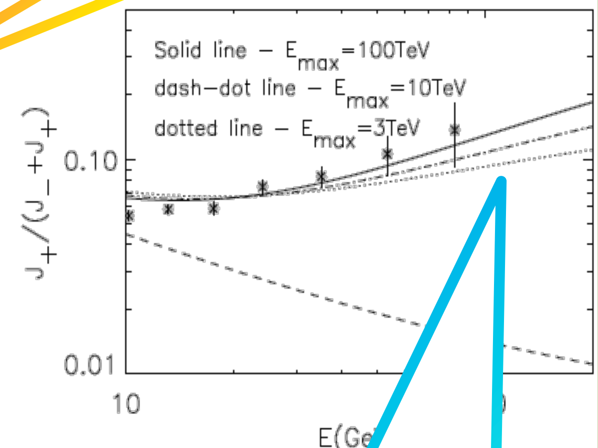
- boost factor required
- lepton vs hadron yield must be consistent with p-bar observation

Astrophysical processes

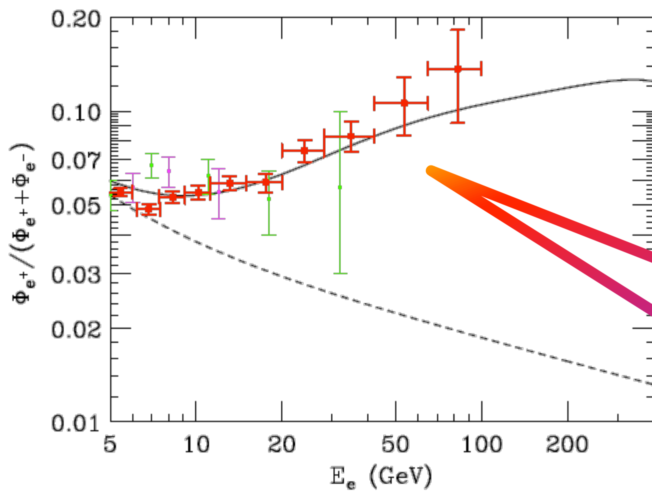
- known processes
- large uncertainties on environmental parameters



(Cholis et al. 2009)
Contribution from **DM annihilation**.



(Blasi 2009)
e+ (and e-) produced as **secondaries** in the CR acceleration sites (e.g. SNR)



(Hooper, Blasi and Serpico, 2009)
contribution from diffuse mature & nearby young **pulsars**.

Anisotropy studies (p up to 1 TeV)

Data set

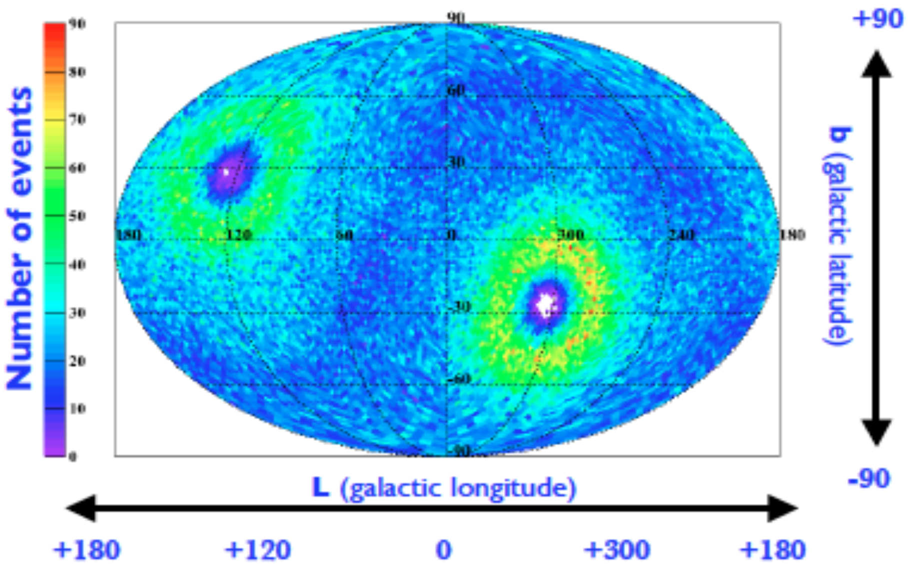
R <10 GV solar modulation effects dominate ⇒ only events with R >> 10 GV (30GV)

analyzed data July 2006 - June 2010 (~1200 days)

high quality data good pointing information

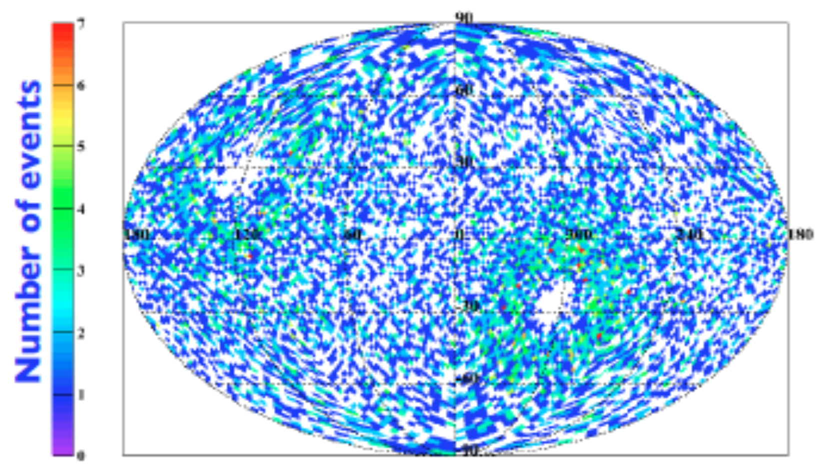
AR well below the angular scales used in this study

R ≥ 40 GV ~ *3.28 x 10^5 events*



the Galactic Center (l,b) =(0,0)
is in the middle of this map

R ≥ 230 GV ~ *1.10 x 10^4 events*



The sky is visualized using the healpix pixelization
-bins with same solid angle
-12288 equal are pixel (~10^{-3} sr)
(nside =32)

Data analysis

- *observed events (N_{on}-real map) in each angular window of the sky*

- *calculate the expected number of events (N_{off}) in each angular bin of the sky (background or coverage map) under the assumption of an isotropic proton flux*

background map obtained with:

-) shuffling technique

- *compare the real and the background map to study deviations from isotropy of the real map*

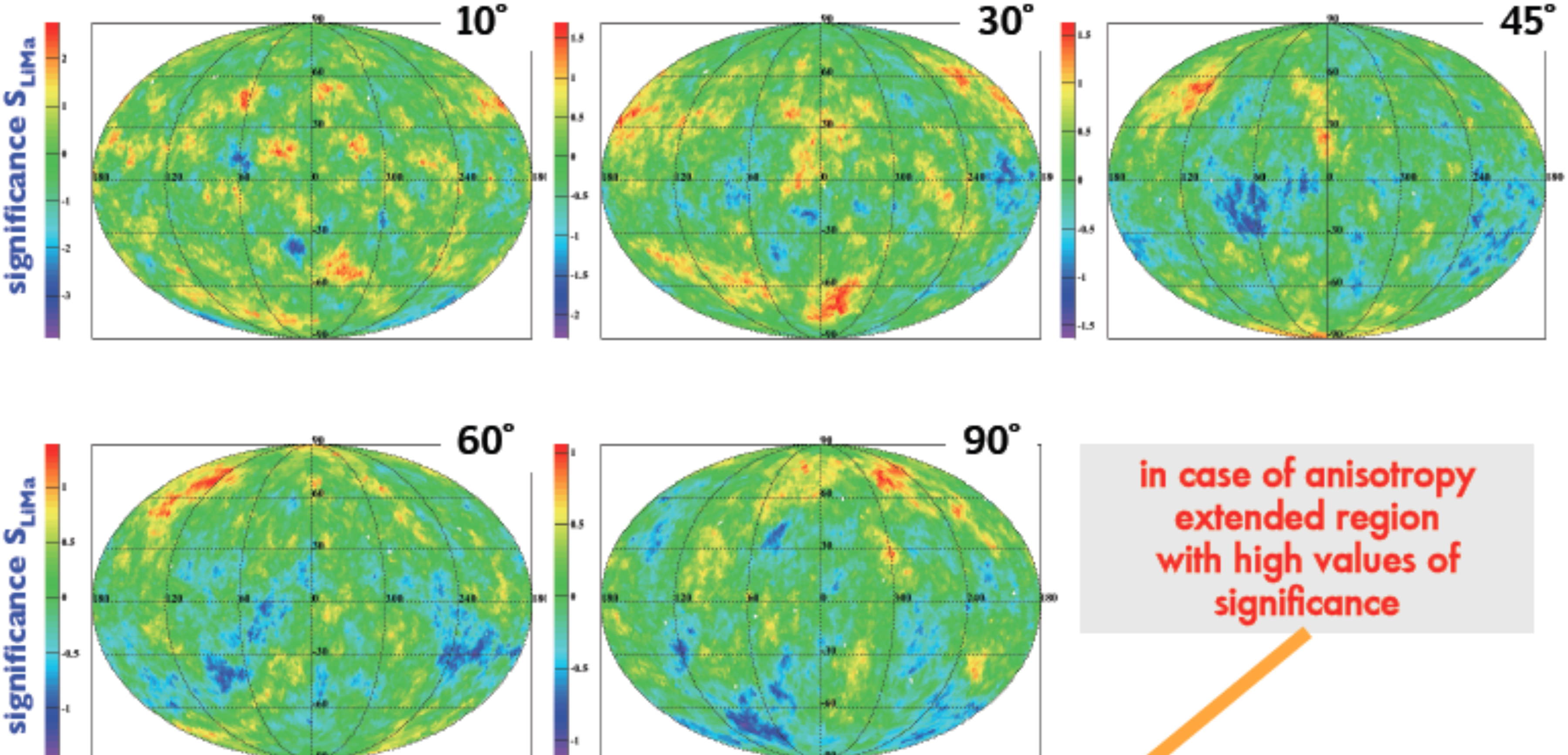
two approaches used to search flux excess:

-) significance test adopted by Li & Ma
-) spherical armonic analysis

Significance sky maps (I)

significance sky maps for events with R ≥ *40 GV*
as a function of the integration radius

galactic coordinates

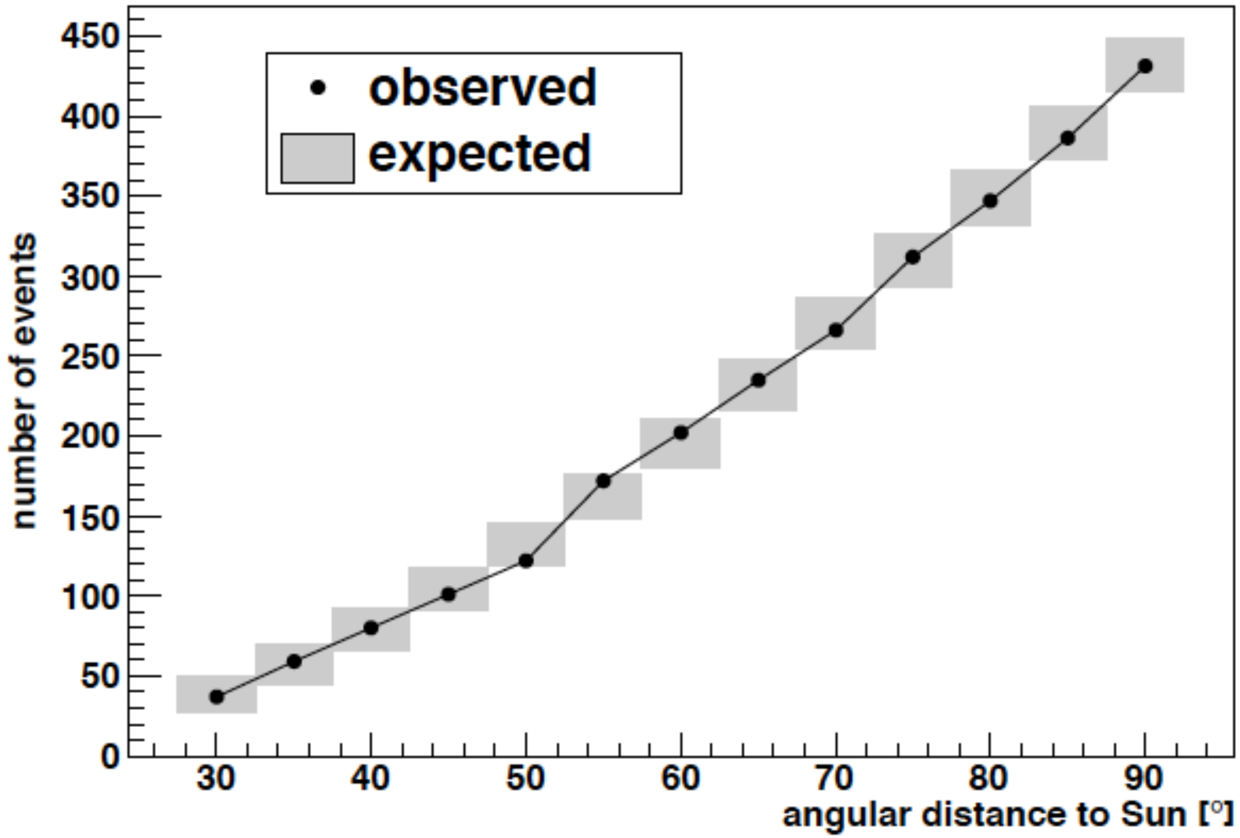


in case of anisotropy extended region with high values of significance

no evidence of excess for each opening angle

Search for an excess in the Sun direction

No significant departure from isotropy is observed



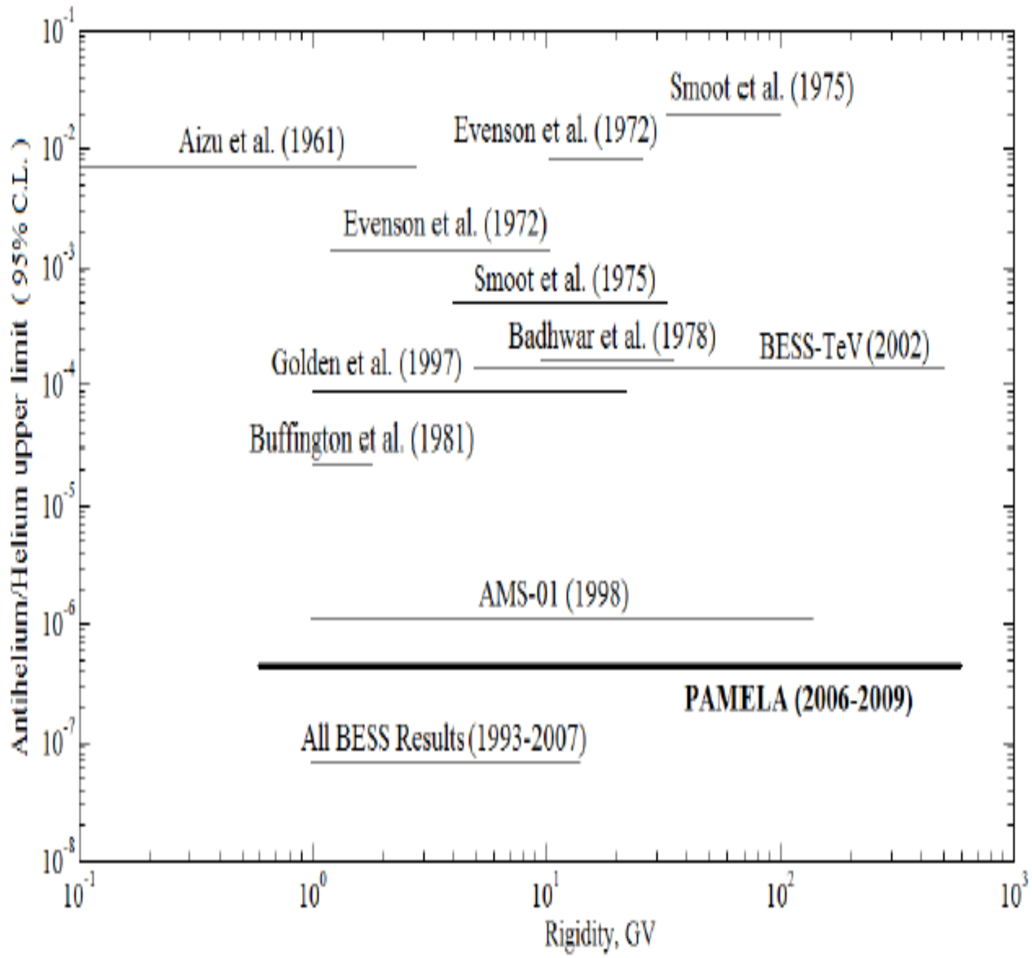
Cumulative number of events with E> 40 GeV as a function of the angular distance from the direction of the Sun. The grey boxes are the background.

AntiHe/He

No antiHe detected in a sample of 6.330.000 events with |Z|>=2,

from 0.6 to 600 GV.

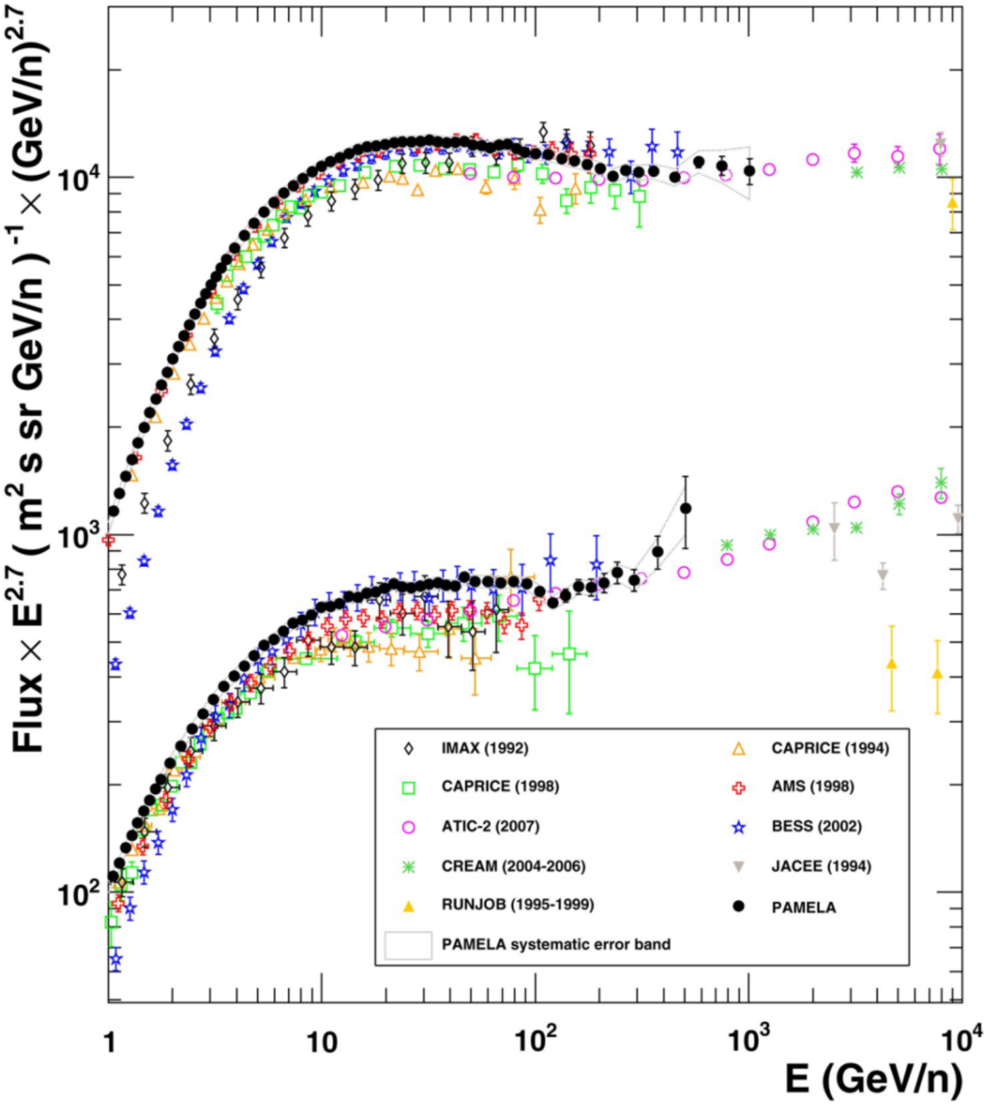
Widest energy range ever reached



H & He absolute fluxes

- First high-statistics and high-precision measurement over three decades in energy
- Dominated by systematics (~4% below 300 GV)
- **Low energy** → minimum solar activity (ϕ = 450÷550 GV)
- **High-energy** → a complex structure of the spectra emerges…

Adriani et al. , Science 332 (2011) 6025



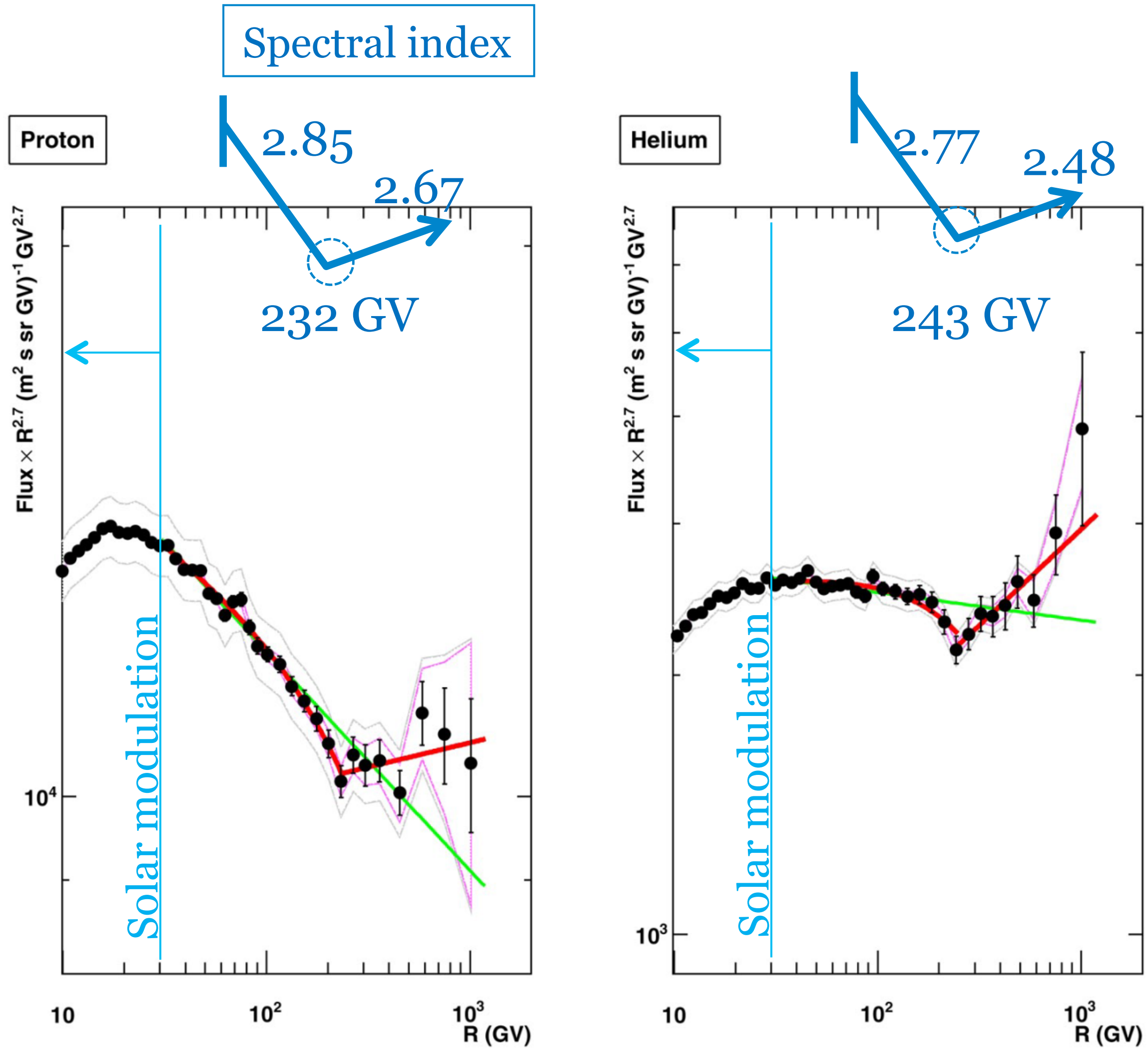
H & He absolute fluxes @ high energy

Deviations from single power law (SPL):

- Spectra gradually soften in the range 30÷230GV
- **Abrupt spectral hardening @ ~235GV**

Eg: statistical analysis for protons

- SPL hp in the range 30÷230 GV rejected @ >95% CL
- SPL hp above 80 GV rejected @ >95% CL



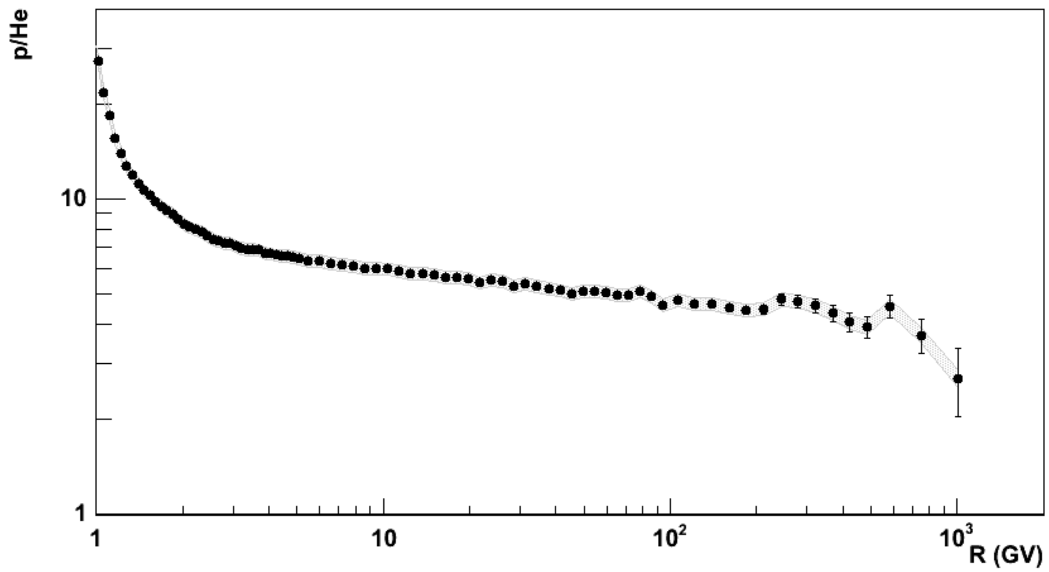
H/He ratio vs R

Instrumental p.o.v.

- Systematic uncertainties **partly cancel out** (livetime, spectrometer reconstruction, …)

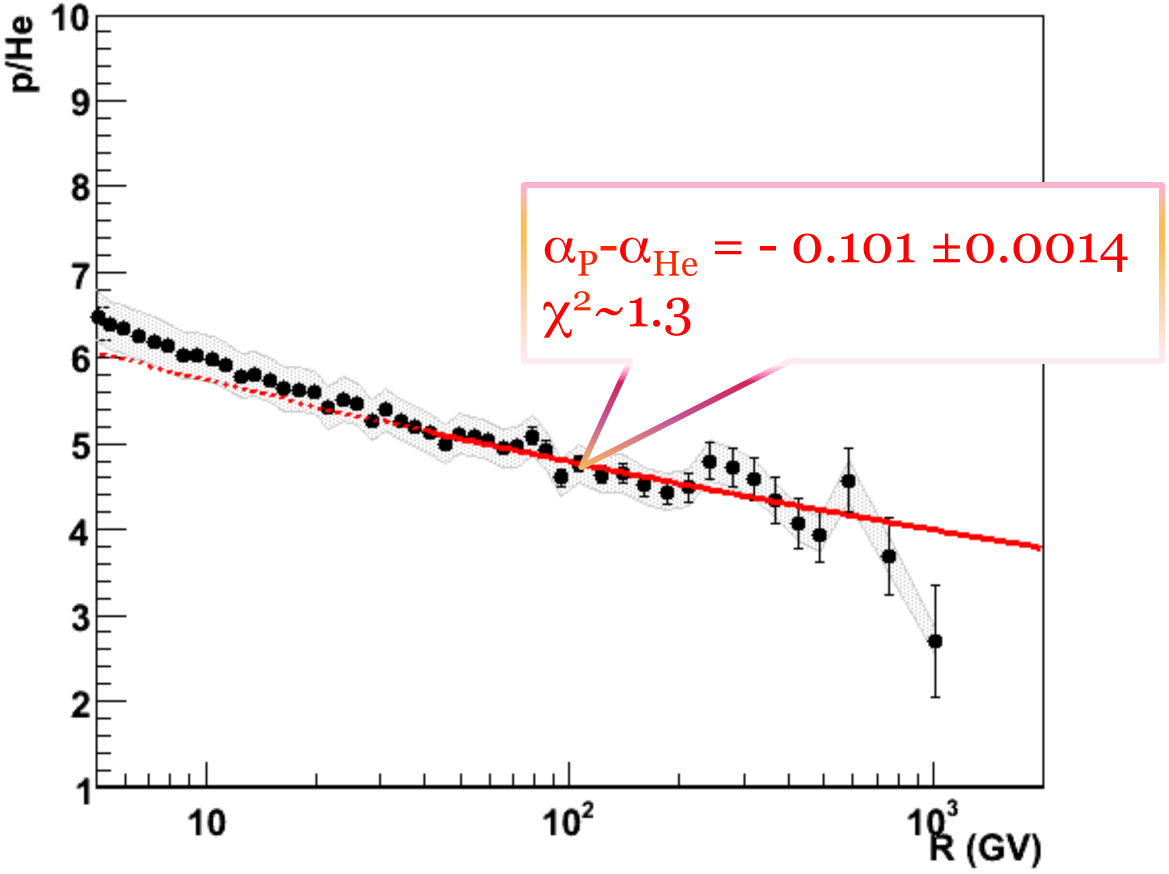
Theoretical p.o.v.

- Solar modulation negligible → information about IS spectra down to GV region
- Propagation effects (diffusion and fragmentation) negligible above ~100GV → information about source spectra



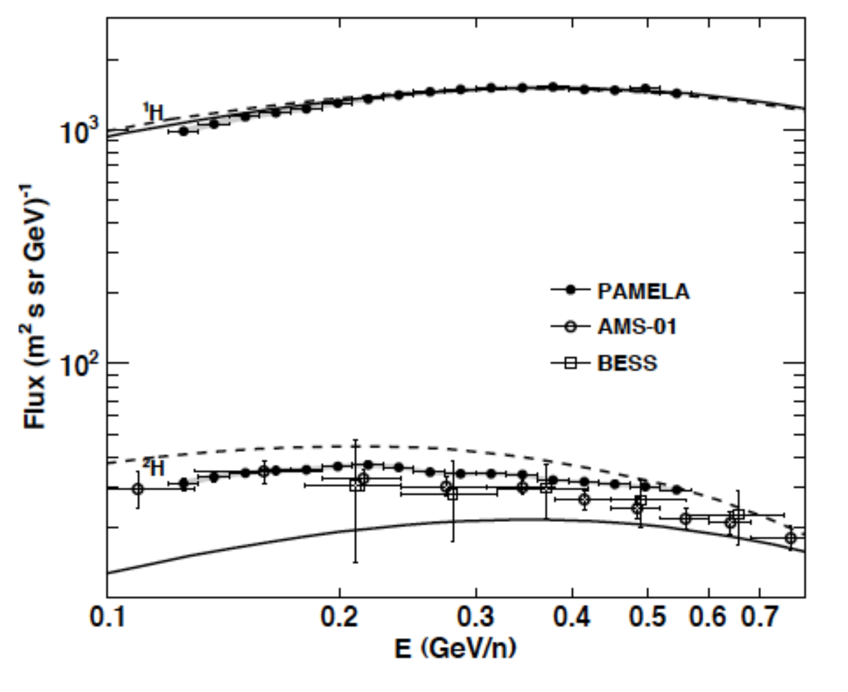
H/He ratio vs R

- First clear evidence of **different H and He slopes above ~10GV**
- Ratio described by a **single power law** (in spite of the evident structures in the individual spectra)

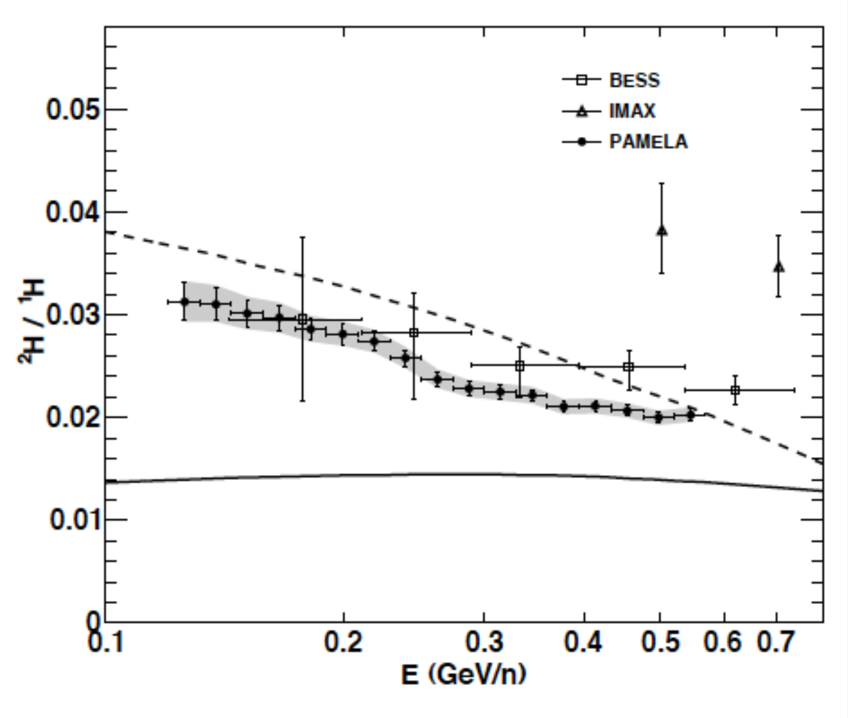


Isotopes

H isotope fluxes

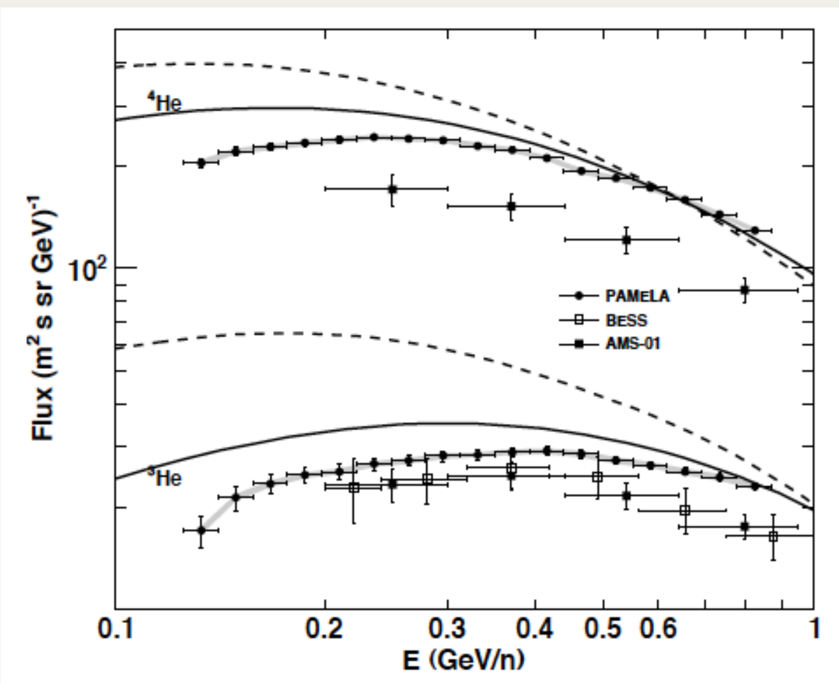


^{2}H/^{1}H ratio

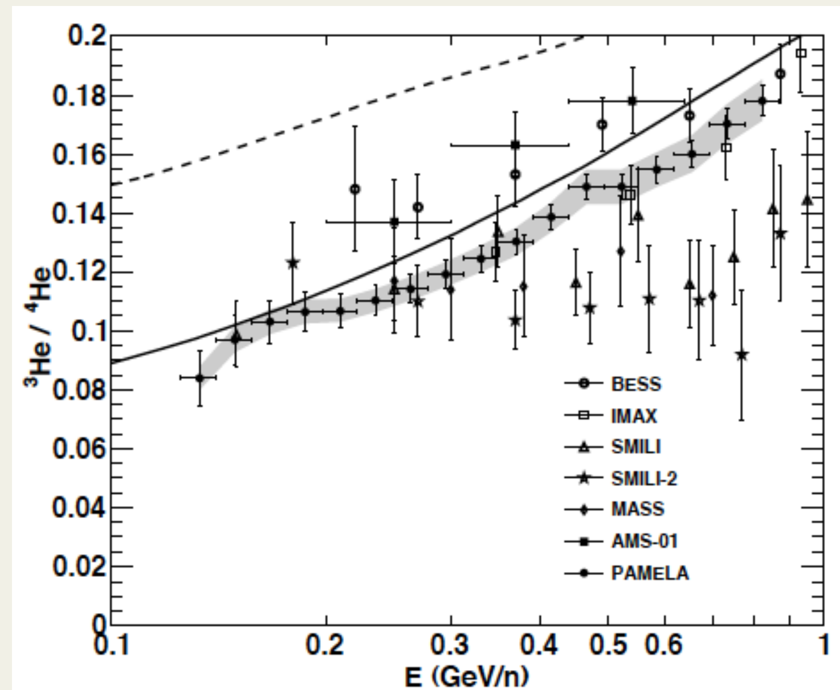


Isotopes

He isotope fluxes



$^3He/^4He$ ratio



Adriani et al. – submitted to AstroPh

Electron energy measurements

Two independent ways to determine electron energy:

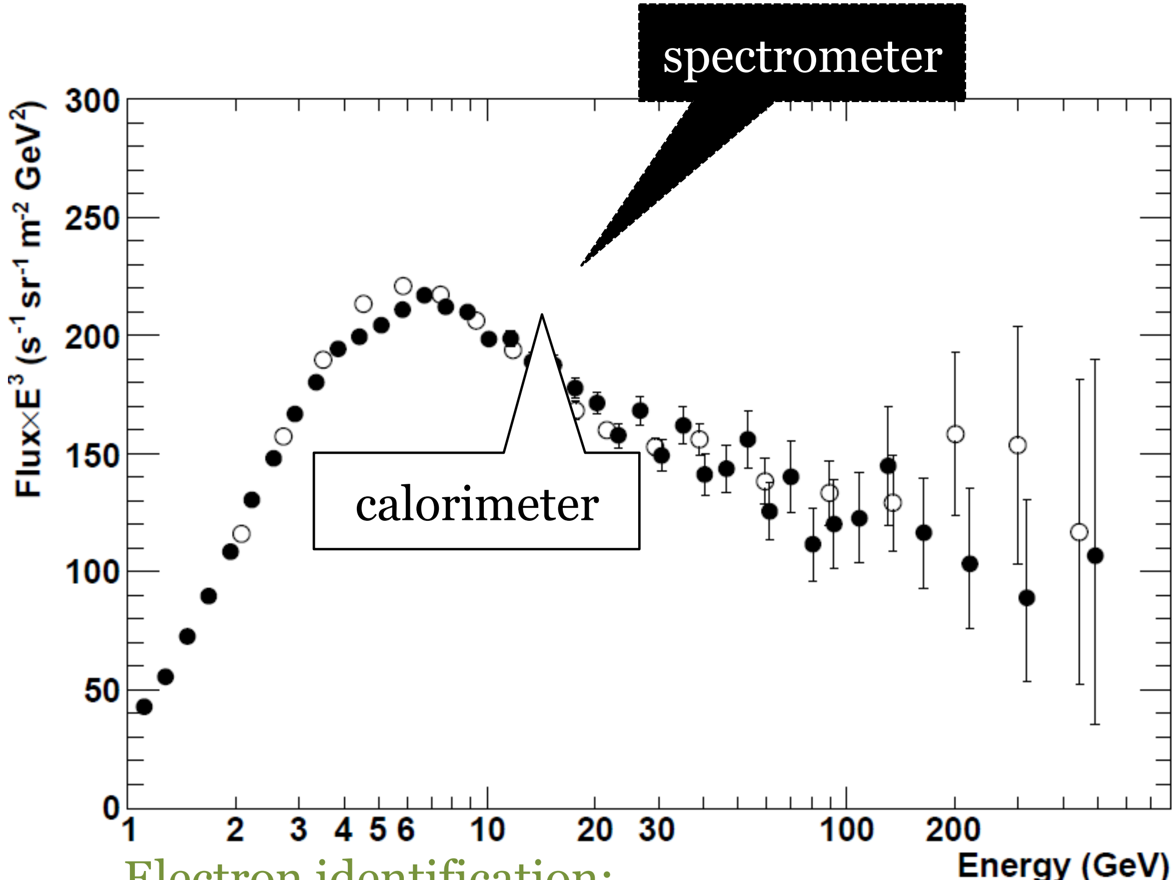
1. Spectrometer

- Most precise
- Non-negligible energy losses (bremsstrahlung) above the spectrometer → unfolding

2. Calorimeter

- Gaussian resolution
- No energy-loss correction required
- Strong containment requirements → smaller statistical sample

Adriani et al. , PRL 106, 201101 (2011)

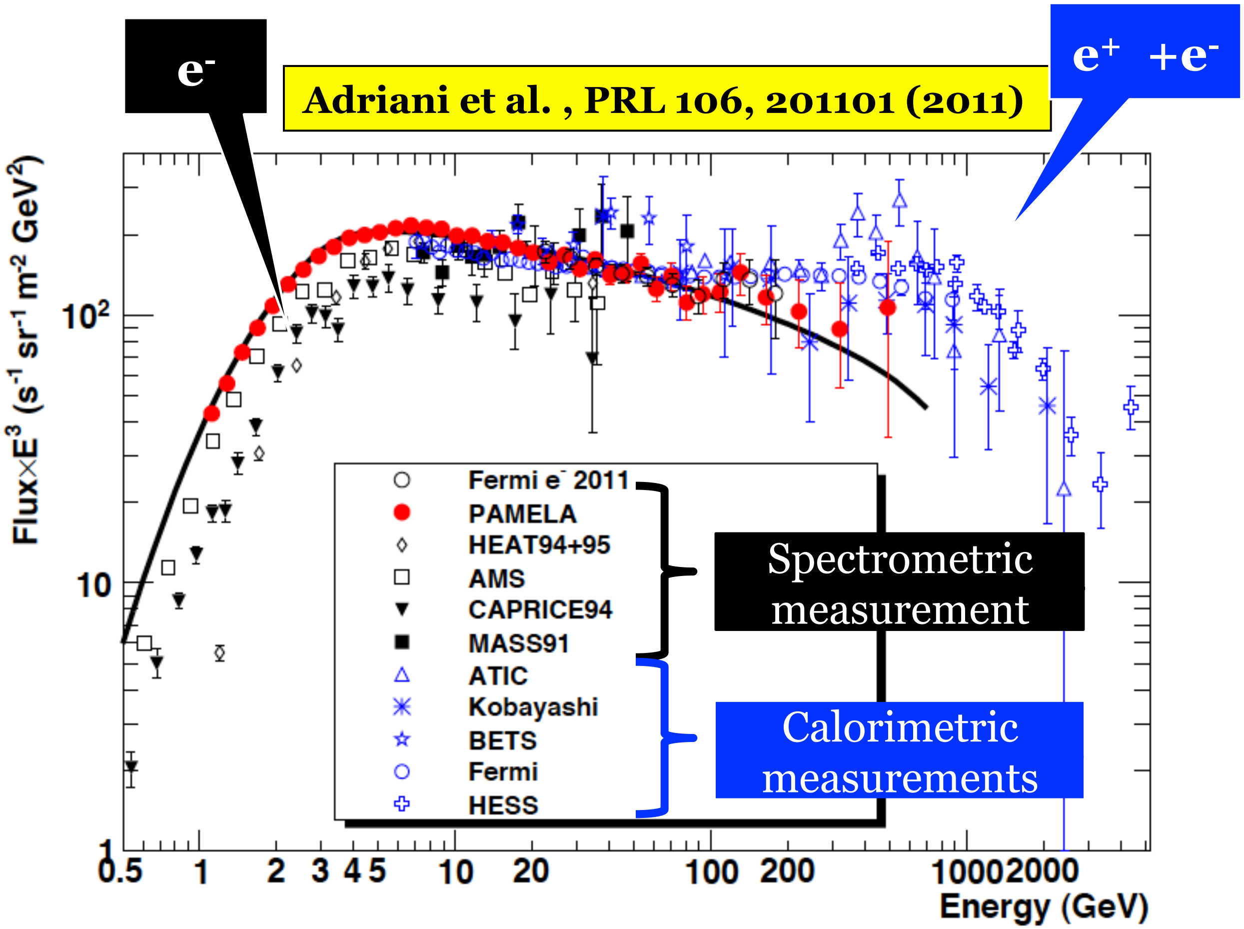


Electron identification:

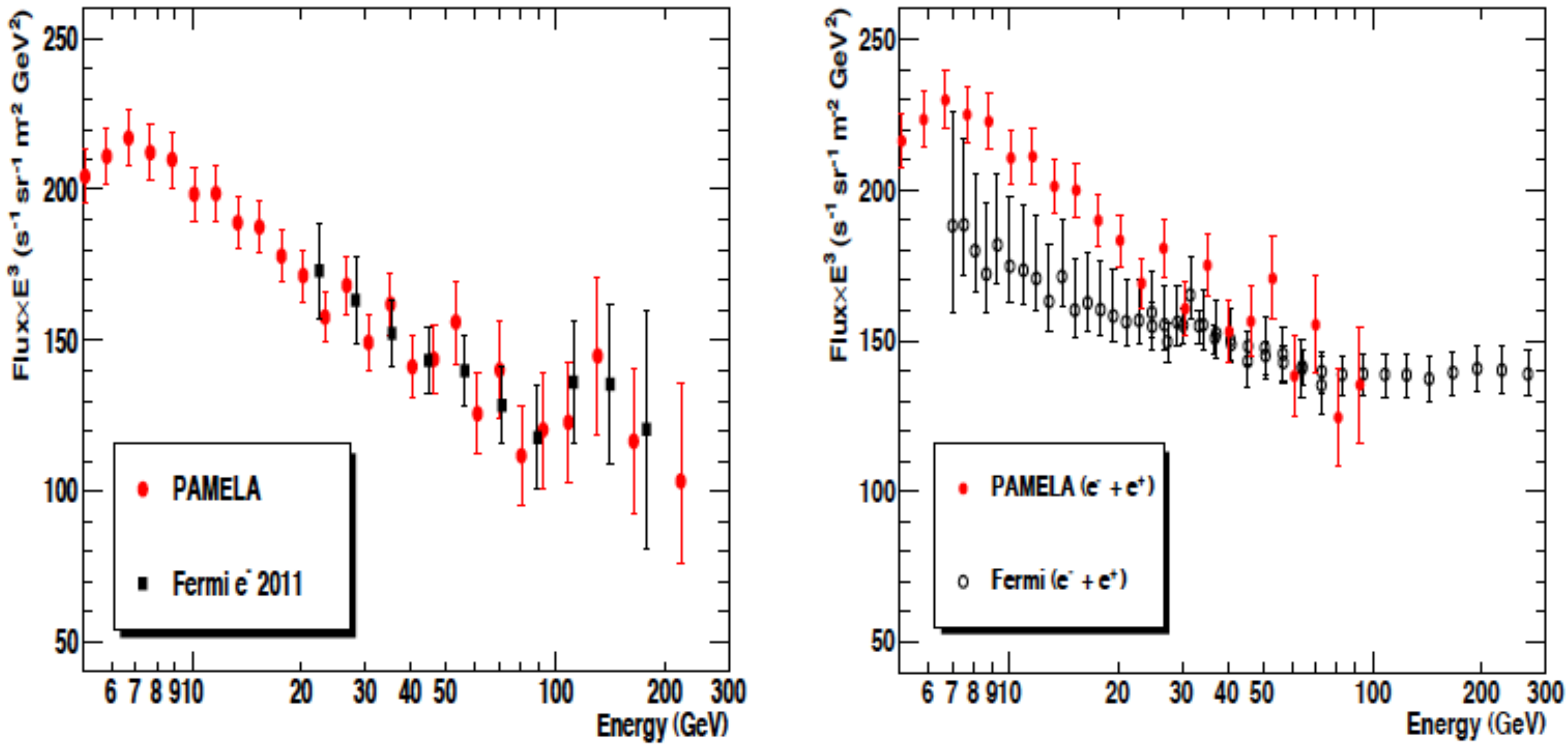
- Negative curvature in the spectrometer
- EM-like interaction pattern in the calorimeter

Electron absolute flux

- Largest energy range covered in any experiment hitherto with no atmospheric overburden
- **Low energy**
  - minimum solar activity (ϕ = 450÷550 GV)
- **High energy**
  - Significant disagreement with GALPROP calculations (that assumes a continuous distribution of the sources).



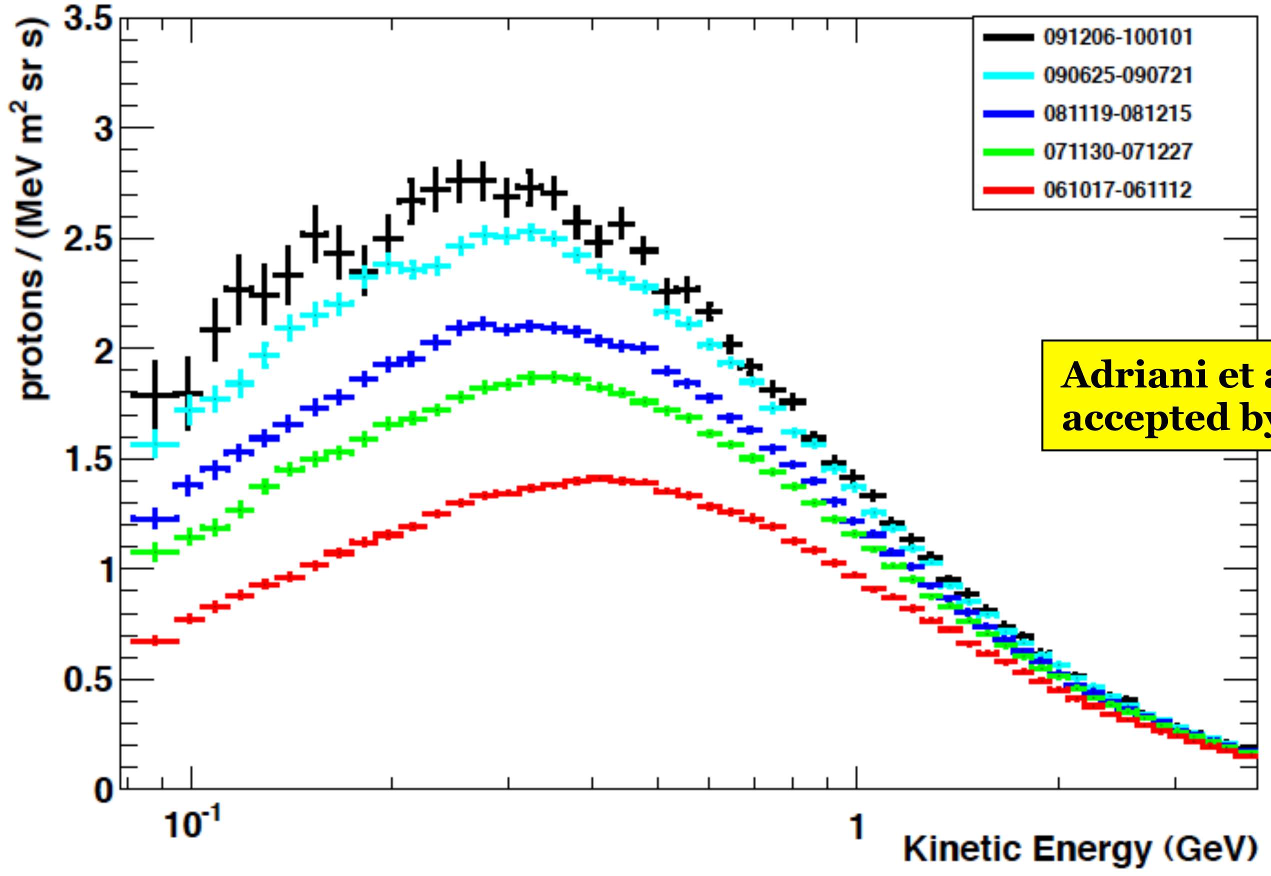
PAMELA & FERMI



Compatibility with FERMI electron data (left)

Compatibility inside one standard deviation with all particle FERMI spectrum(right)

Solar modulation: proton spectra



Adriani et al. – accepted by APJ

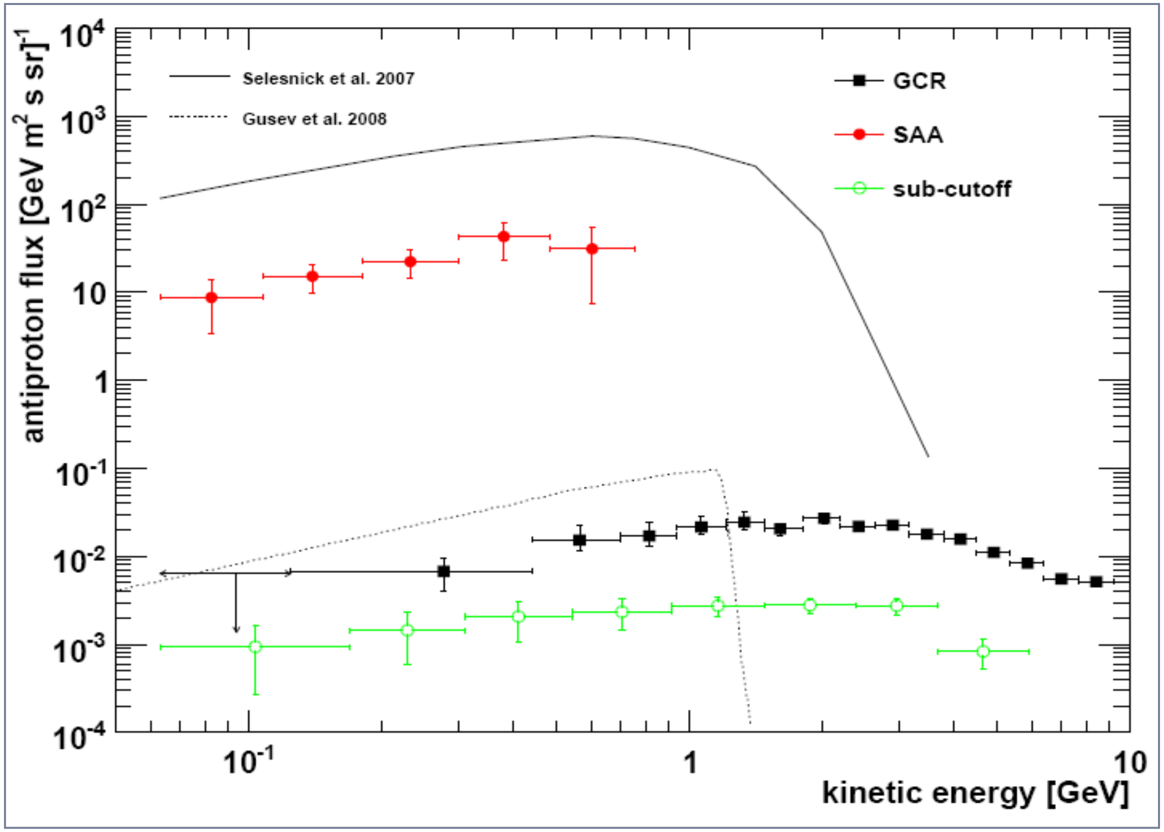
Figure 35: The galactic proton spectrum from 80 MeV to 4 GeV as measured by PAMELA over the following time periods: 17 October-12 November 2006 (red), 30 November-27 December 2007 (green), 19 November-15 December 2008 (blue), 25 June-21 July 2009 (cyan) and 06 December 2009-01 January 2010 (black).

Discovery of geomagnetically Trapped antiprotons

First measurement of p-bar trapped in the inner belt

29 p-bars discovered in SAA and **traced back to mirror points**

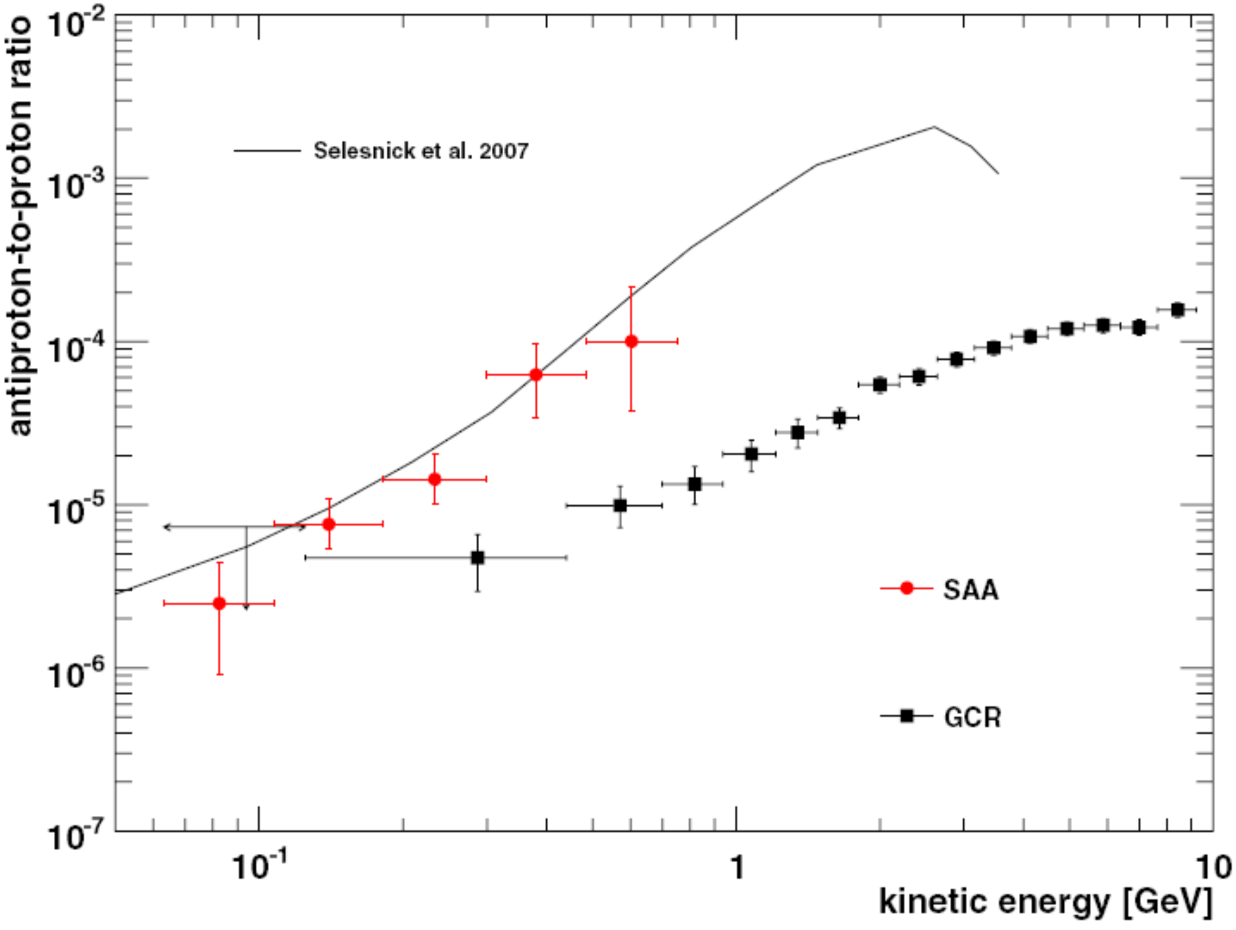
p-bar flux exceeds GRC flux by **3 orders of magnitude,** as expected by models



Adriani et al. –APJ Letters

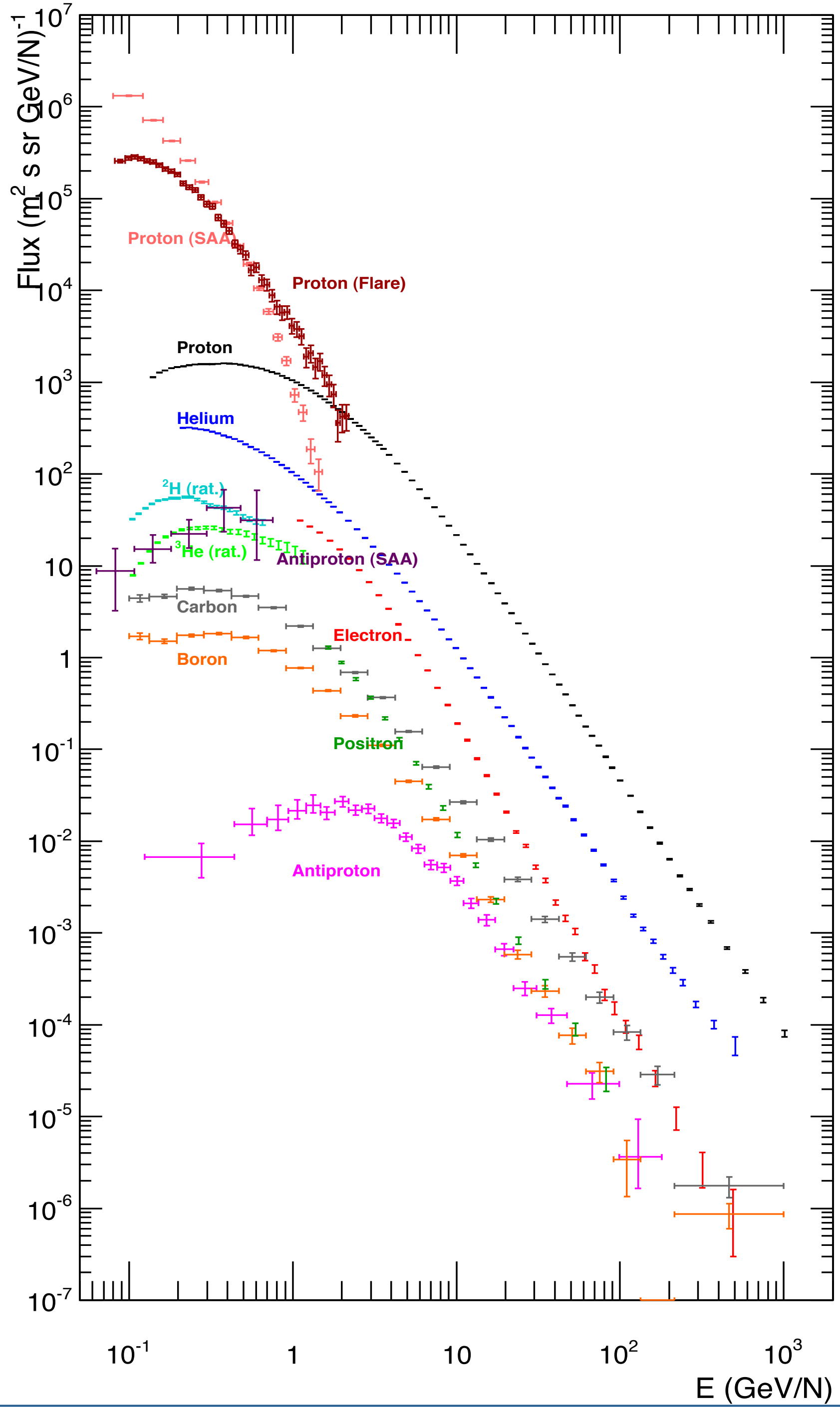
Discovery of geomagnetically Trapped antiprotons

The geomagnetically trapped antiproton-to-proton ratio measured by PAMELA in the SAA region (red)
compared with the interplanetary (black) antiproton-to-proton ratio measured by PAMELA,
together with the predictions of a trapped model.



All particles PAMELA results

Results span 4 decades in energy and 13 in fluxes



PAMELA on Physics Reports

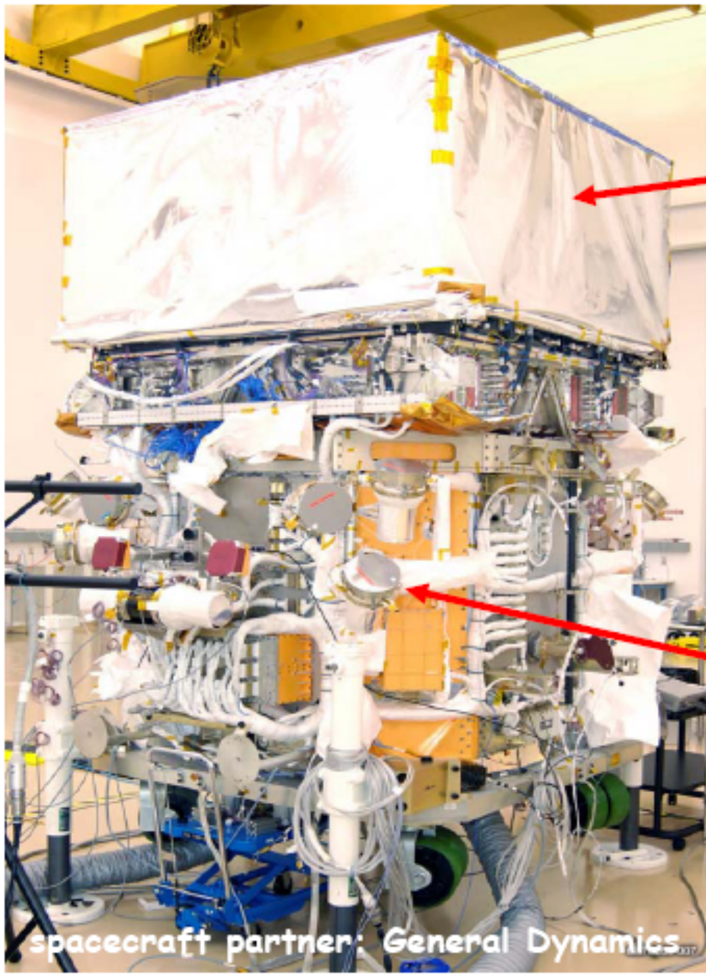
“**The PAMELA Space Mission: Heralding a New Era in Precision Cosmic Ray Physics**”

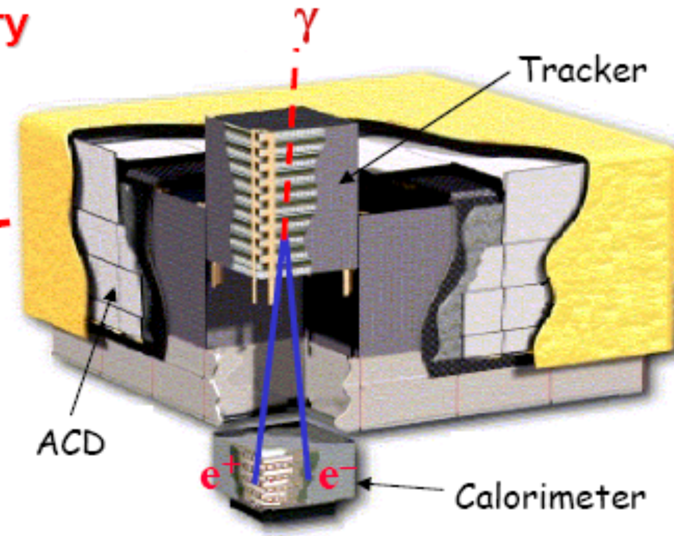
Ready to be
submitted to Physics Reports (74 pages).

Summarises published and unpublished (but final) PAMELA results.

FERMI OBSERVATORY

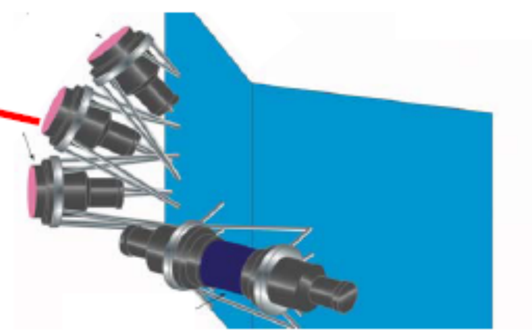
spacecraft and two instruments (LAT and GBM) now integrated and functioning as a single observatory





Large Area Telescope

(20 MeV – > 300 GeV)

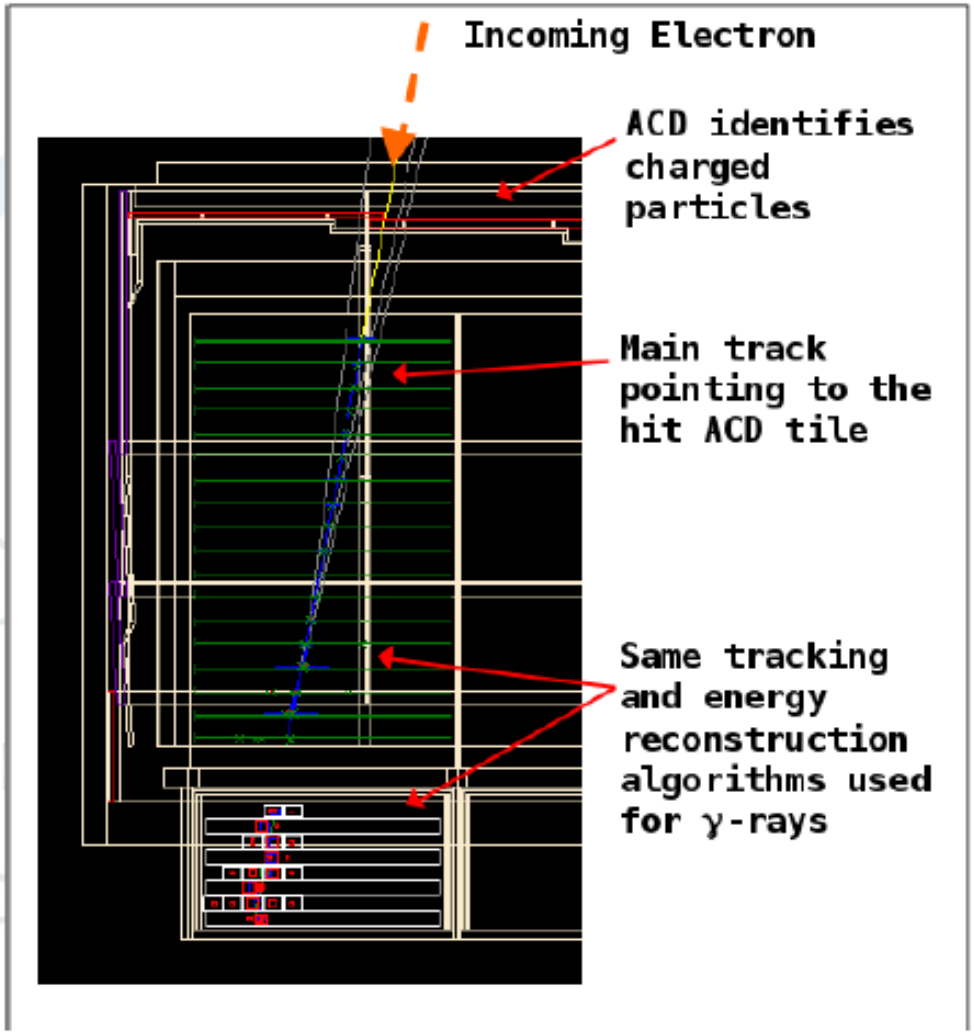


Glast Burst Monitor

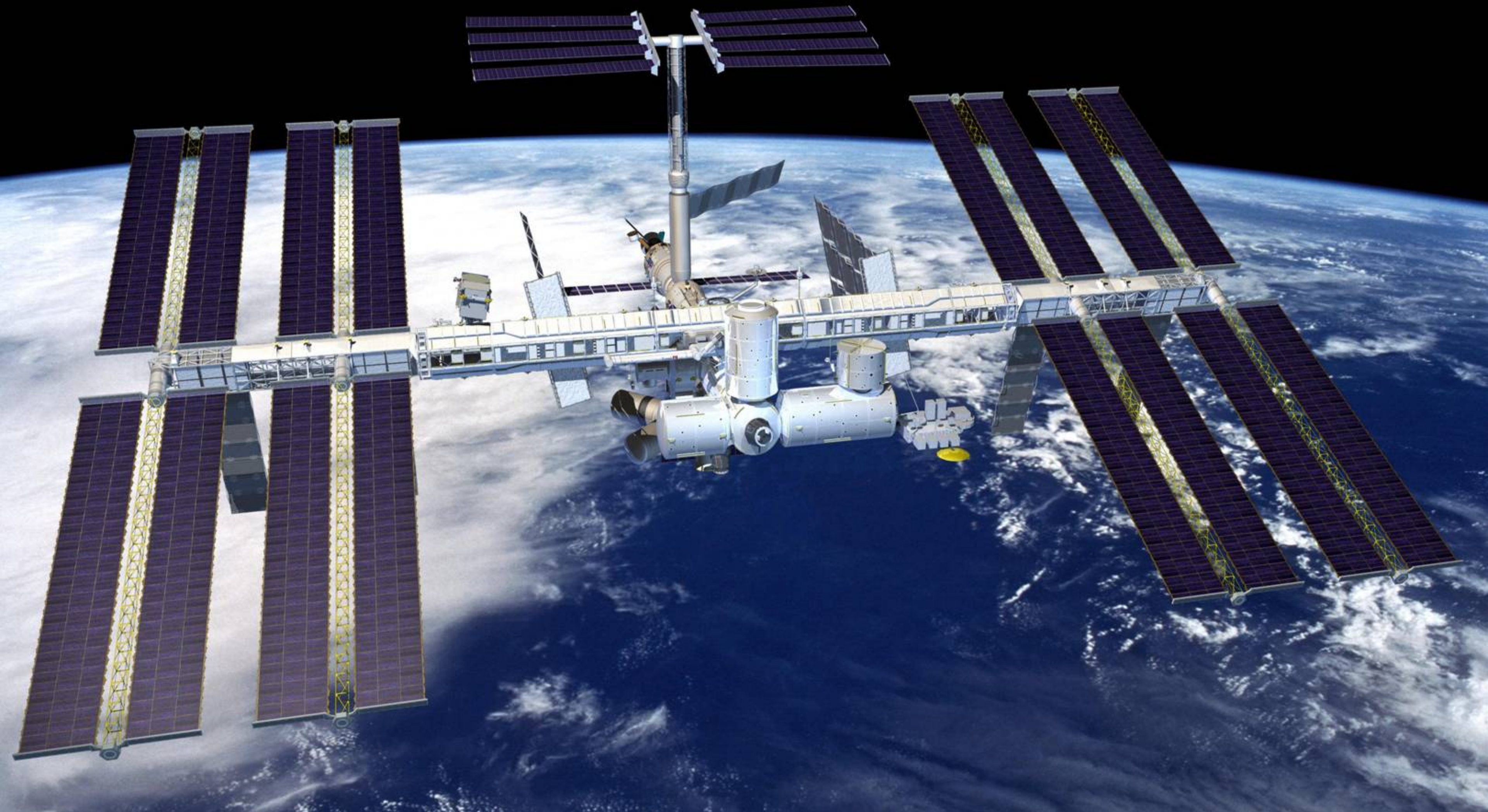
(10 keV – 25 MeV)

Not only γ rays

- Detector is designed for E. M. showers
  - Naturally including electrons $(e^+ + e^-)$
- Triggering on (almost) every particle that crosses the LAT
- On-board filtering to remove many charged particles
  - Keeps all events with more than 20 GeV in the CAL
  - Prescaled ($\times$250) unbiased sample of all trigger types
- Event reconstruction assumes a E.M. shower
  - Works fine for electrons
- Electron identification
  - Dedicated event selection
- No charge separation



ISS experiments



ALPHA MAGNETIC SPECTROMETER

→Search for primordial anti-matter
→Indirect search of dark matter
→High precision measurement of the energetic spectra and composition of CR from GeV to TeV

↓

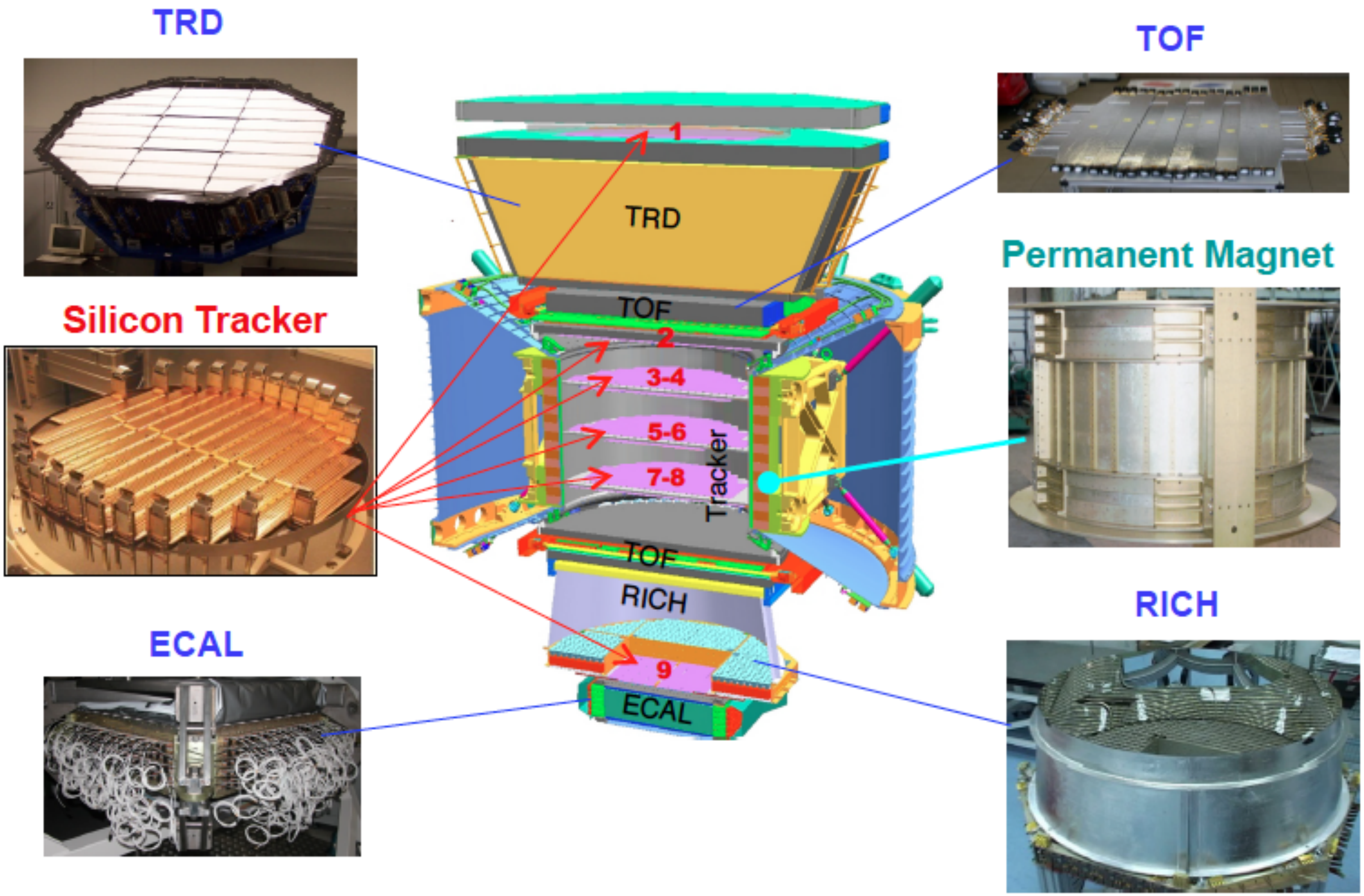
AMS-01: 1998 (10 days) - PRECURSOR FLIGHT ON THE SHUTTLE

AMS-02: **Since May 19th, 2011, safely on the ISS.** Four days after the Endeavour launch, that took place on Monday May 16th, the experiment has been installed on the ISS and then activated.

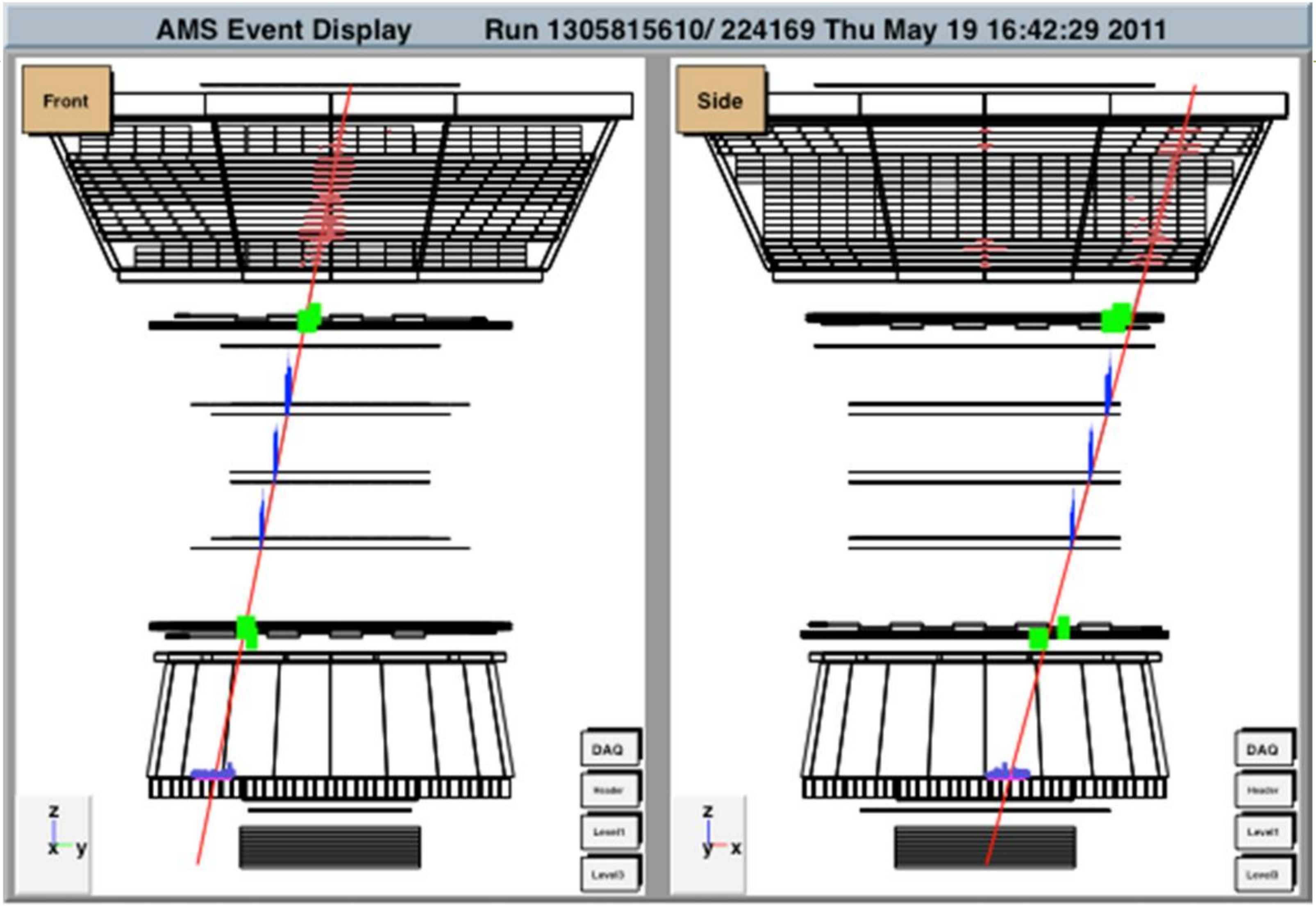
COMPLETE CONFIGURATION FOR >10 YEARS LIFETIME ON THE ISS

» 500 physicists, 16 countries, 56 Institutes

The AMS-02 detector

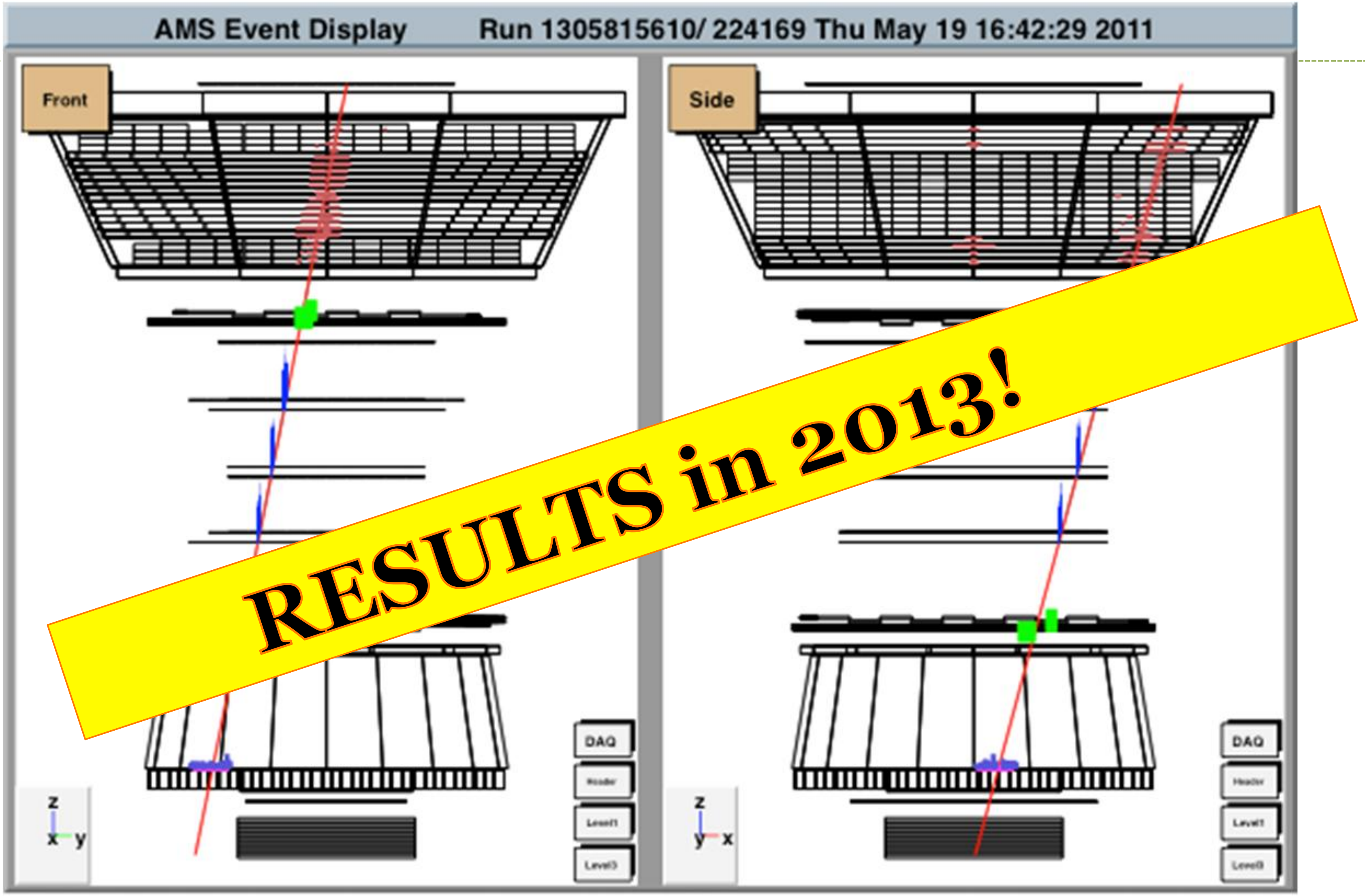


AMS first events



42 GeV Carbon nucleus

AMS first events



42 GeV Carbon nucleus


Future
experiments

CALET: Calorimetric Electron Telescope

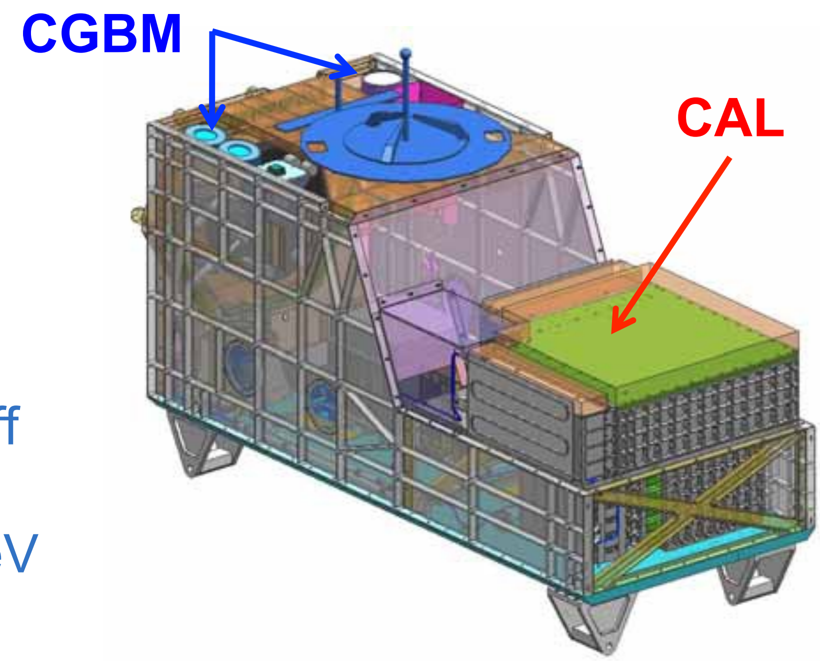
Main Telescope: Calorimeter (CAL)

- Electrons: 1 GeV – 20 TeV
- Gamma-rays: 10 GeV – 10* TeV
  (Gamma-ray Bursts: > 1 GeV)
- Protons and Heavy Ions:
  several tens of GeV – 1,000* TeV
- Ultra Heavy Ions: over the rigidity cut-off

Gamma-ray Burst Monitor (CGBM)

- X-rays/Soft Gamma-rays: 7keV – 20MeV

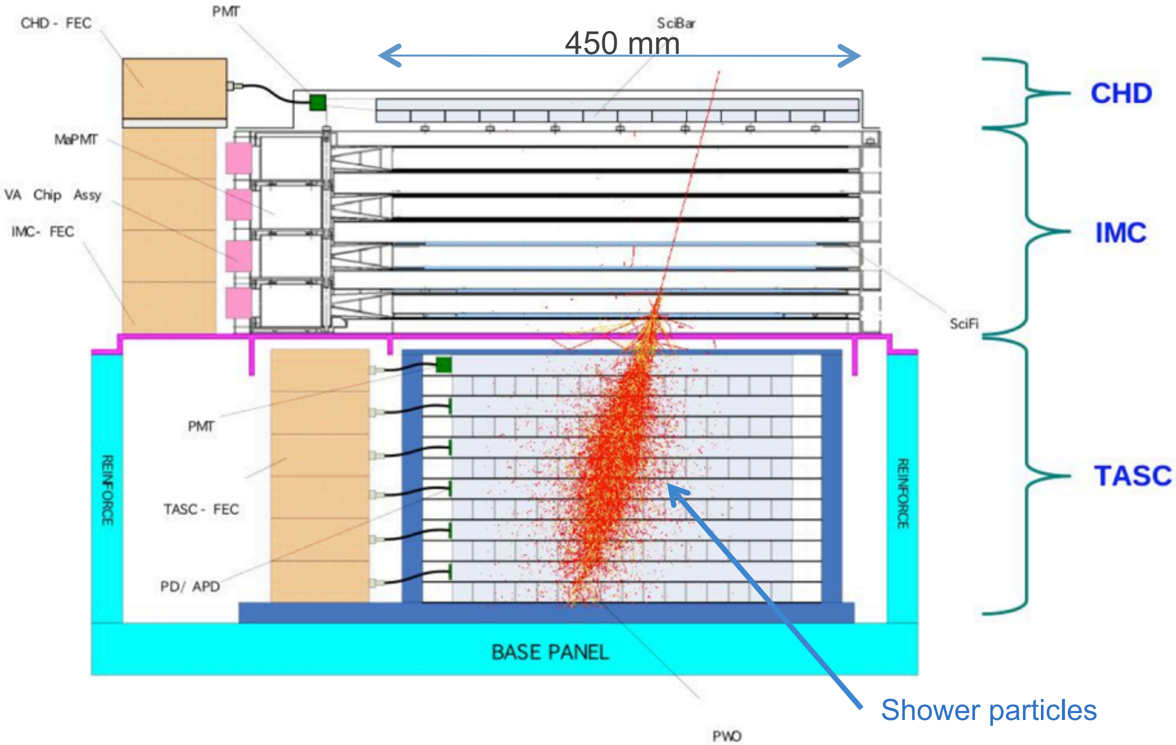
(* as statistics permits)



Science objectives:

- ☐ Nearby cosmic-ray sources through electron spectrum in the trans-TeV region
- ☐ Signatures of dark matter in electron and gamma-ray energy spectra in the 10 GeV – 10 TeV region
- ☐ Cosmic ray propagation in the Galaxy through p – Fe energy spectra, B/C ratio, and UH ions measurements
- ☐ Solar physics through electron flux below 10 GeV
- ☐ Gamma-ray transient observations

Main Telescope: CAL (Calorimeter)



- **CHD (Charge Detector):**
  - Double layer segmented plastic scintillator array (14 x 2 layer with a unit of 32mm x 10mm x 450mm)
  - Charge measurement (Z=1 – 40)

- **IMC (Imaging Calorimeter):**
  - 7 layers of tungsten plates with 3 r.l. separated by 2 layers of scintillating fiber belts which are readout by MA-PMT.
  - Arrival directions, Particle ID

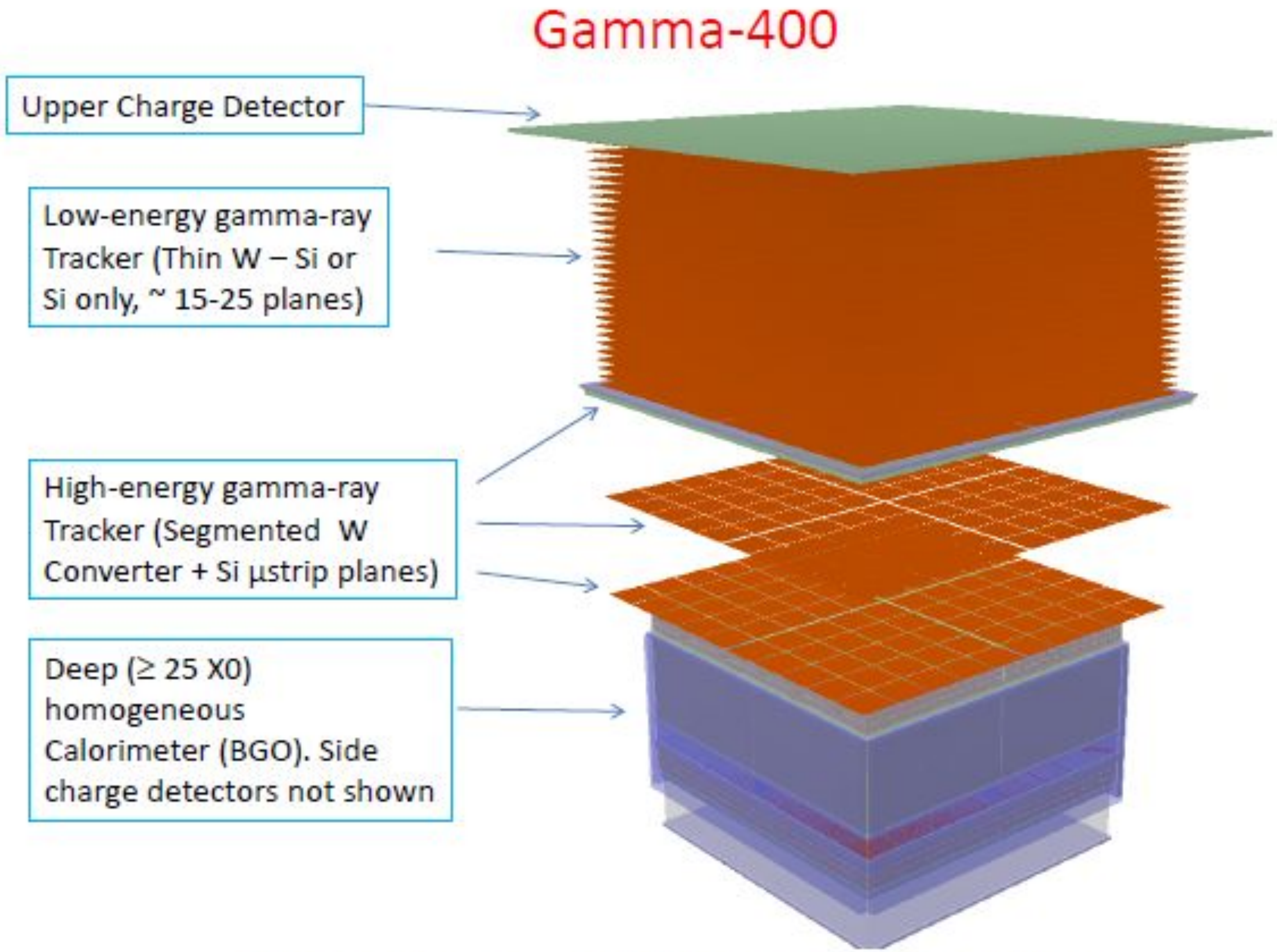
- **TASC (Total Absorption Calorimeter):**
  - 12 layers of PWO logs (19mm x 20mm x 326mm) with total thickness of 27 r.l. The top layer is used for triggering and readout by PMT. Other layers are readout by PD/APD.
  - Energy measurement, Particle ID

Gamma-400 on Russian satellite

It will combine for the first time photon and particle (electrons and nuclei) detection in a unique way

- **Excellent Silicon Tracker (30 MeV – 300 GeV),**
  - **breakthrough angular resolution 4-5 times better than Fermi-LAT at 1 GeV**
  - **improved sensitivity compared with Fermi-LAT by a factor of 5-10 in the energy range 30 MeV – 10 GeV**

- **Heavy <u>HOMOGENEOUS</u> Calorimeter (25 X_0) with optimal energy resolution and particle discrimination**
  - **Electron/positron detection up to TeV energies**
  - **Nuclei detection up to <u>10^{15} eV energies</u>**



apparatus versions used in one of the preliminary simulations.

ISS-CREAM

- The idea is to put the CREAM detector, developed as a Long Duration balloon experiment, onboard the ISS, at the Japanese Experiment Modules Exposed Facility (JEM-EF) KIBO.
- The 1,200 kg estimated mass of the payload is over twice the mass of any previously launched payload using the JAXA's HTV. The development team will modify the existing instruments to meet the new requirements of the launch vehicle and ISS.
- Very good chance to reach $\underline{10^{15}\ \text{eV}}$.

Conclusions

High energy line

- H and He spectra **are** different
- H and He spectra **harden with energy** (230 GV)
- Hi-Z spectra **might** show similar hardening
- Energy dependance of propagation **still undecided**

Composition line

- Source matter **must be** a composition of old ISM with newly synthetized matherial, in percentage 80%-20% (sites of acceleration rich in massive stars?)

Conclusions

Antimatter line

- All electron spectrum **shows enhancement** at high energy (hundreds GeV). Nearby source?
- Positrons **show enhancement** in the E>10 GeV region (new e+ e- source. Correlated to previous?)
- **No antiproton excess** observed both at low and high energy (several DM models and exotics ruled out)
- **No heavier anti-nucleus** observed (very stringent limits)

Conclusions

We are now facing a new era in CR physics:

Direct and indirect measurements are going to meet,
thank to the lowering of the threshold for ground based experiments and the improvements in the instrument GF for the space ones.

This conference will probably show this (ICE-CUBE, Argo...).