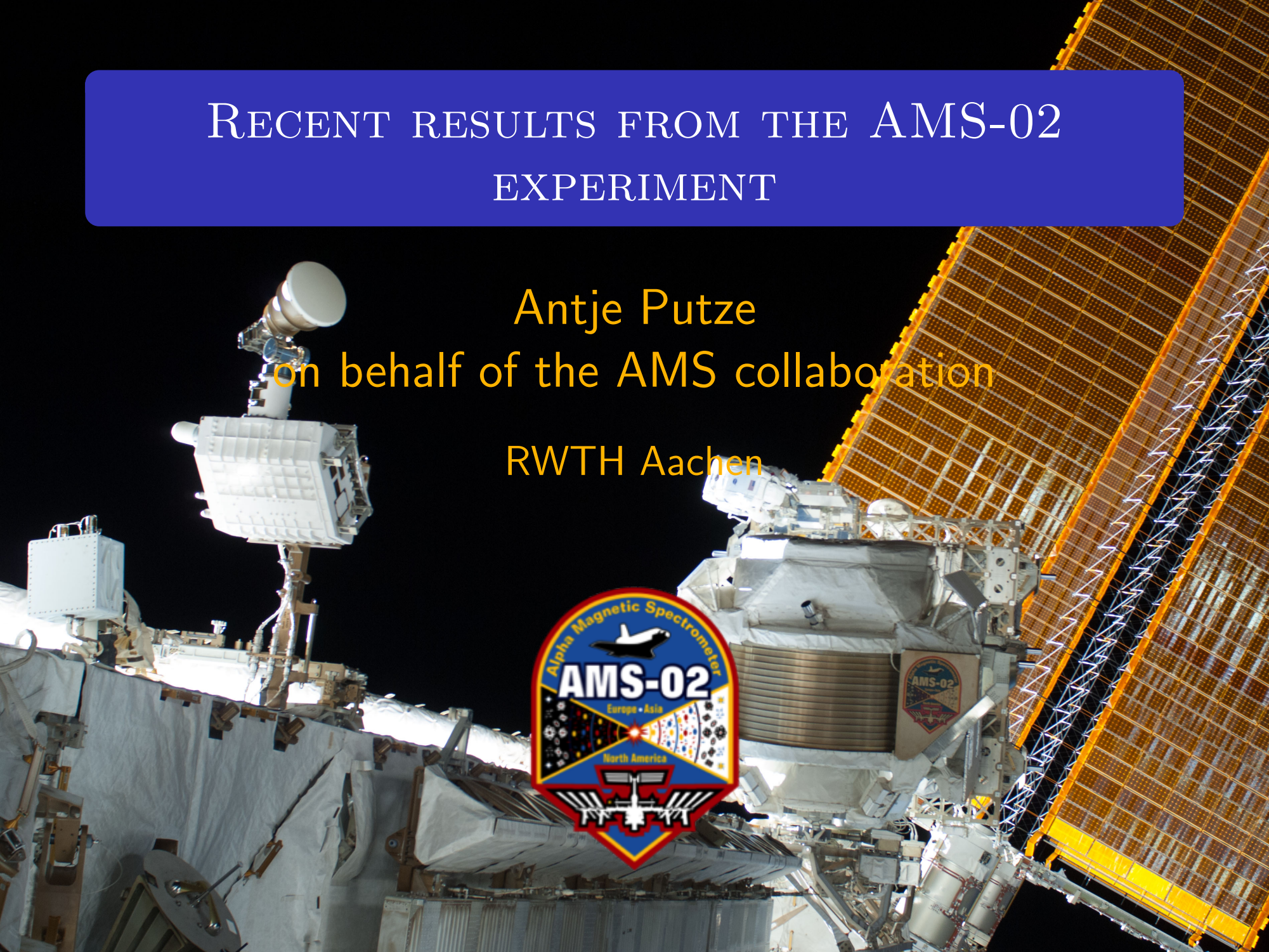
Recent results from the AMS-02 experiment



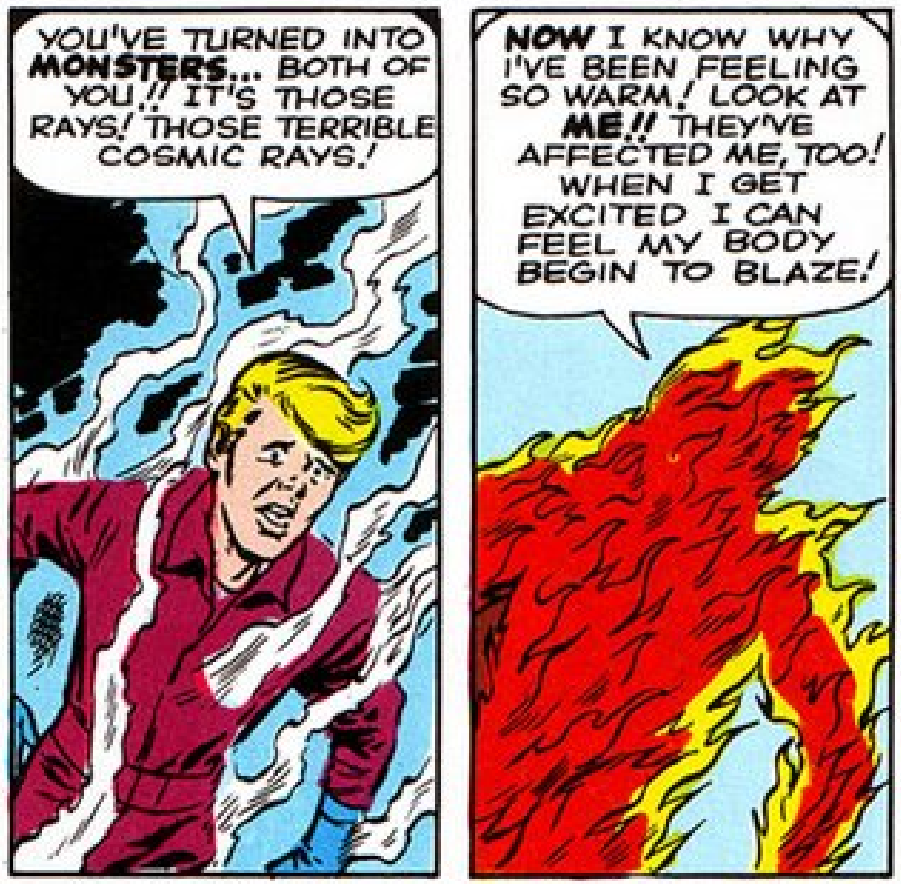
Antje Putze
on behalf of the AMS collaboration

RWTH Aachen

Nuclear cosmic rays – what we know today

Nuclear cosmic rays are

- energetic particles
  [Bothe & Kolhörster, Zeitschrift für Physik **56** (1929)]
- of extraterrestrial origin
  [Hess, Sitzungsberichte der kaiserl. Akademie **120** (1912)]
- bombarding Earth's atmosphere and
- producing atmospheric particle showers
  [Auger *et al.*, Reviews of Modern Physics **11** (1939)]



[Lee & Kirby, Marvel Comics (1961)]

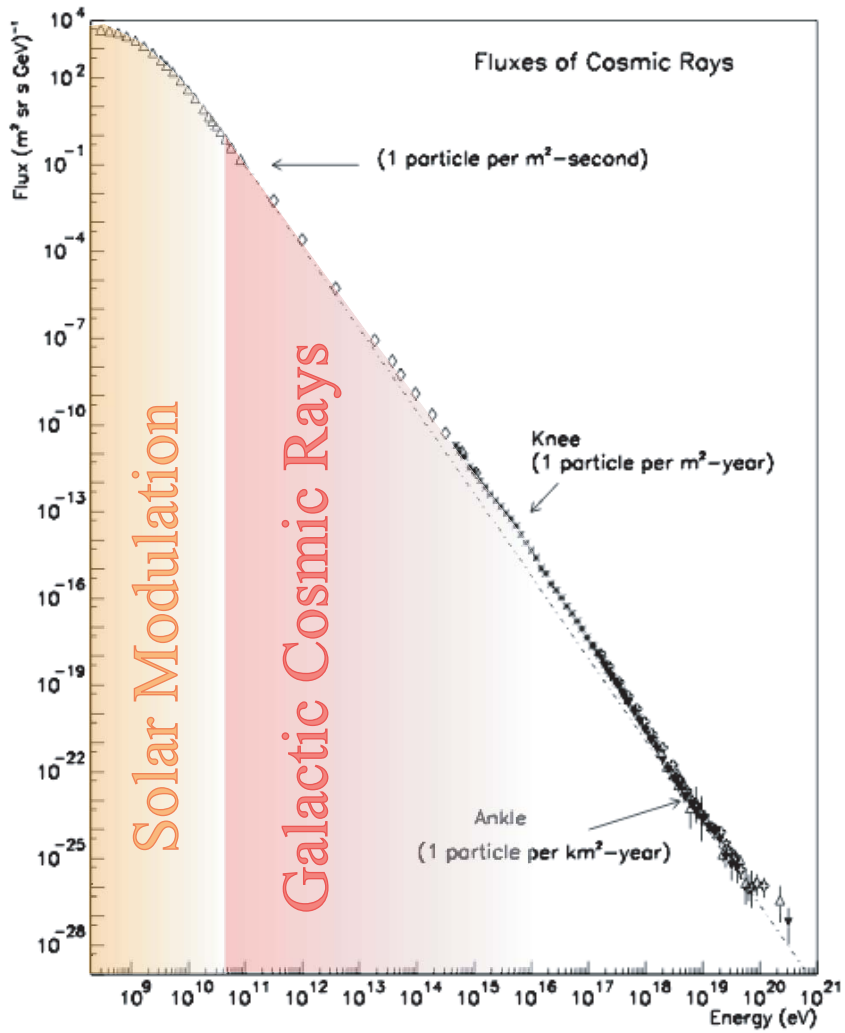
Energy spectrum

The cosmic-ray spectrum

- extends over 12 orders of magnitude in energy and 32 orders of magnitude in intensity;
- can be described by a simple power law:

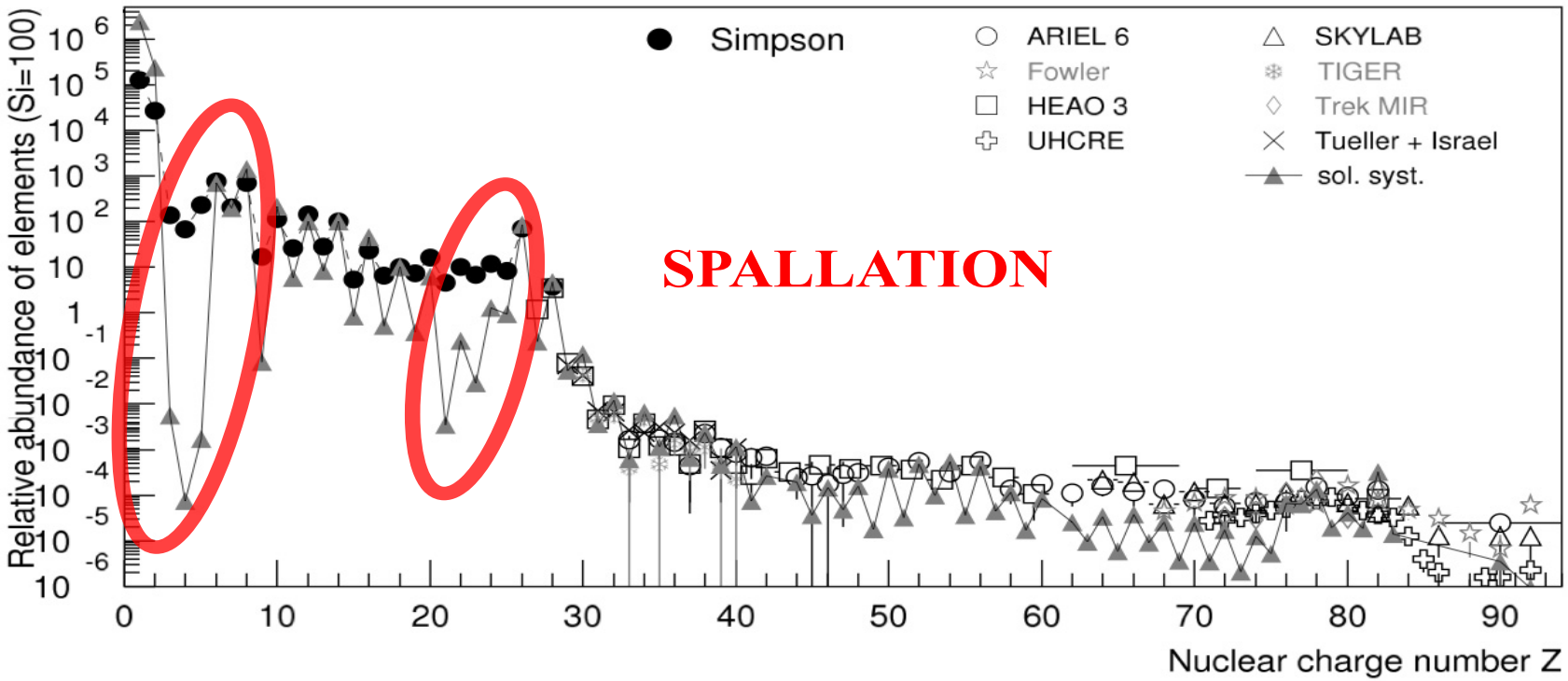
$$\frac{\mathrm{d}N(E)}{\mathrm{d}E} \propto E^{-\gamma};$$

- has three major features:
  1. the knee at $\sim 4.5 \times 10^{15}\,\mathrm{eV}$;
  2. the ankle at $\sim 4 \times 10^{18}\,\mathrm{eV}$;
  3. a cut-off at $\sim 4 \times 10^{19}\,\mathrm{eV}$.



[Swordy, Space Science Reviews **99** (2001)]

Abundances



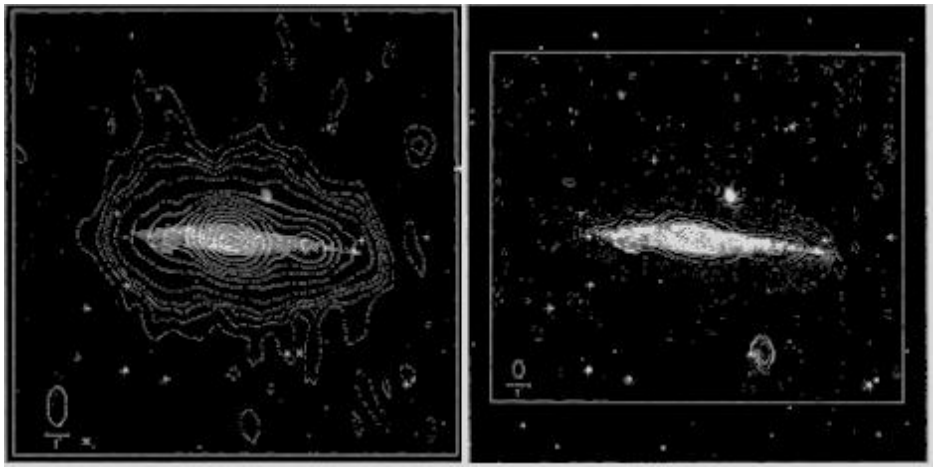
[Hörandel, Advances in Space Research **41** (2008)]

87 % hydrogen
12 % helium
1 % heavier nuclei

similar abundances to those of the solar system, but overabundance for elements $Z = 3 - 5, 20 - 25, \ldots$

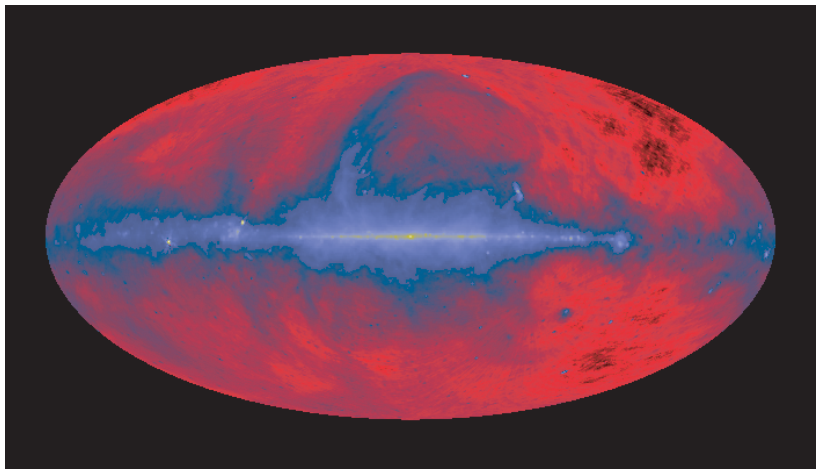
Spatial distribution of GCRs

NGC 4631 at 610 & 1412 MHz



[Ekers & Sancisi, A&A **54** (1977), 973]

Our Galaxy at 408 MHz

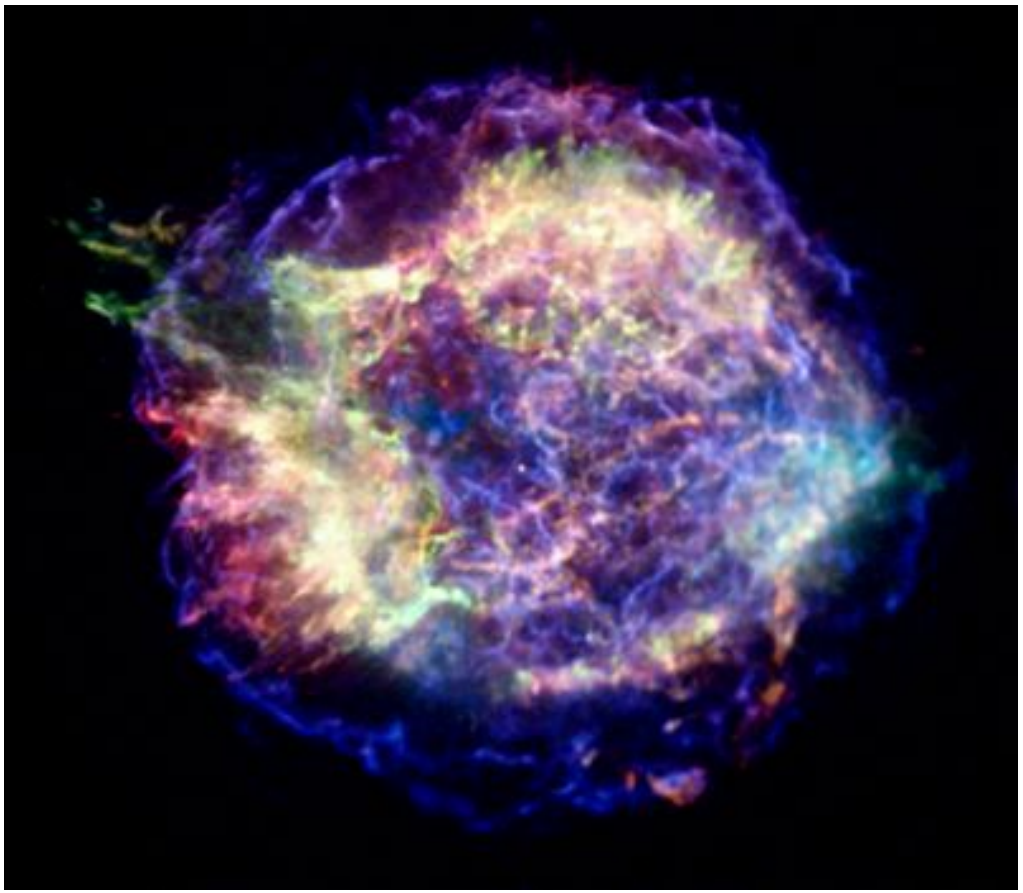


[Haslam, APOD]

radio halo (few kpc) due to cosmic rays around the galactic disc

$\Longrightarrow$ galactic diffusive halo

The journey of a galactic cosmic ray



Cassiopeia A (Chandra, X-rays), youngest supernova remnant in the Milky Way
[NASA/CXC/MIT/UMass Amherst/M.D.Stage et al.]

Sources - Acceleration

stars, supernova environments?
shock acceleration

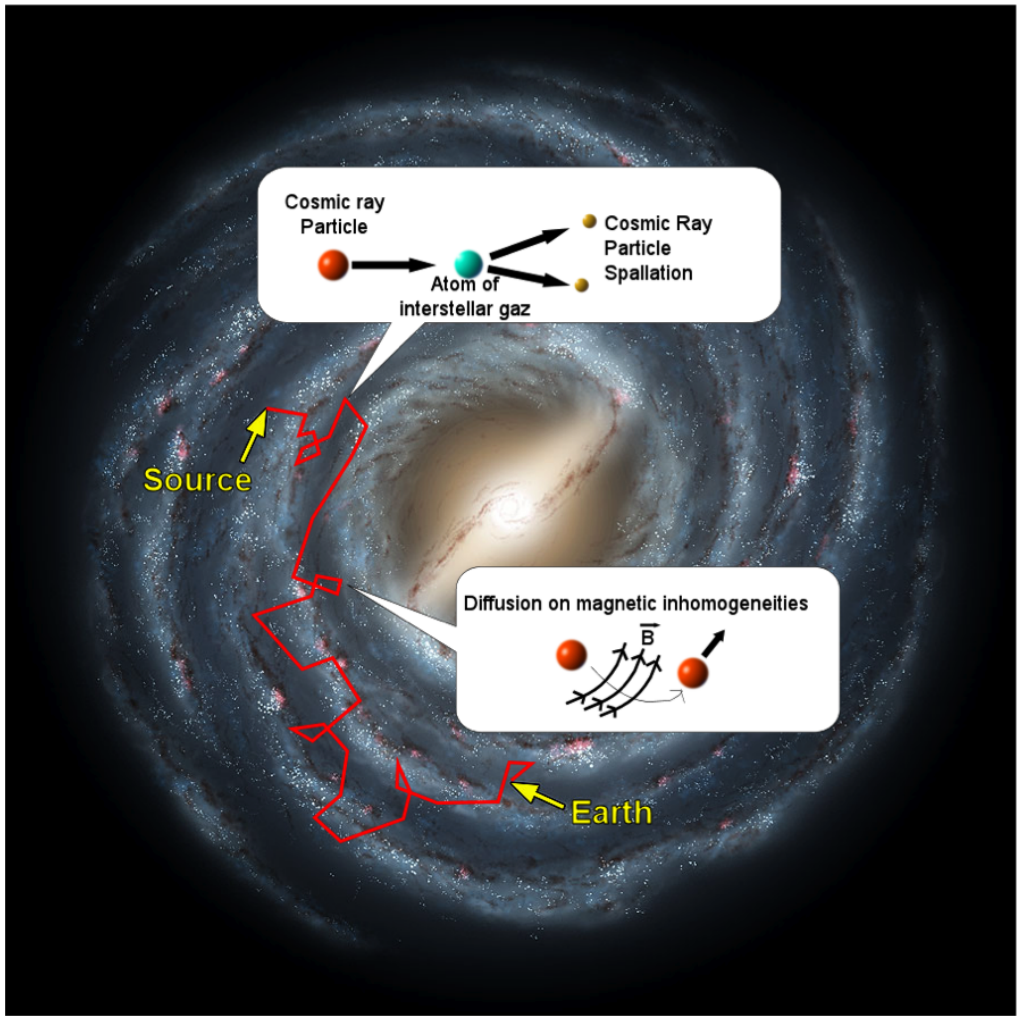
Propagation in the interstellar medium

diffusion on inhomogeneities of the Galactic magnetic field
convection, reacceleration

Solar System - Detection

solar modulation,
geomagnetic cut-off

The journey of a galactic cosmic ray



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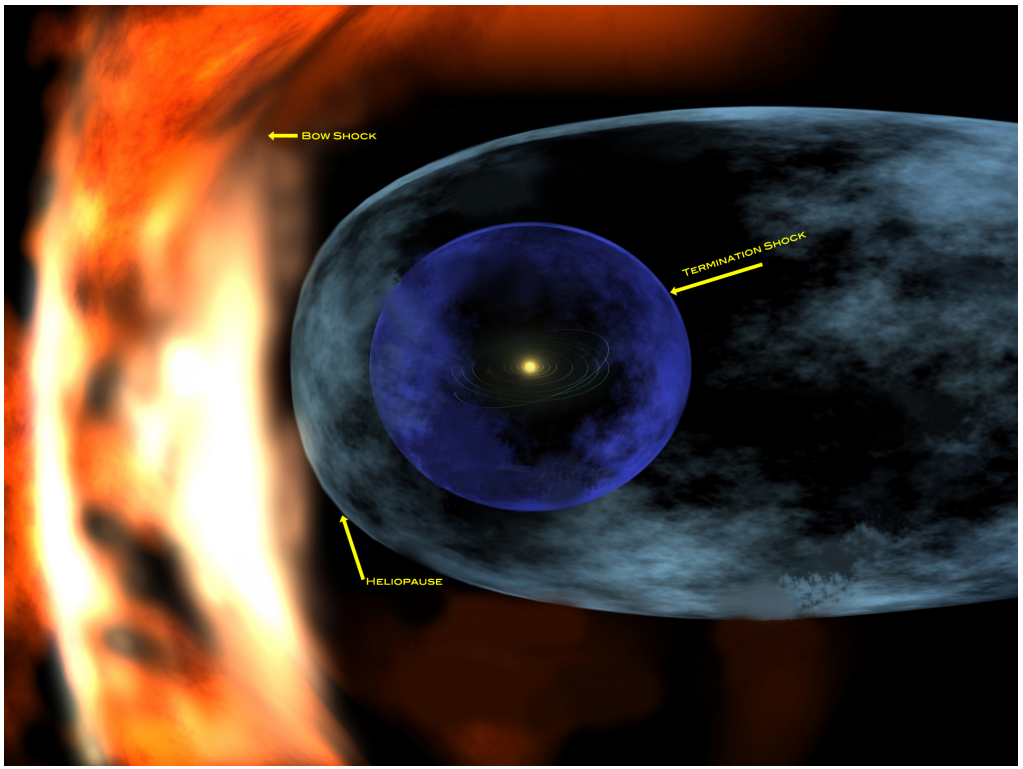


Heliosphere (artistic view)
[NASA]

Sources - Acceleration

stars, supernova environments?
shock acceleration

Propagation in the interstellar medium

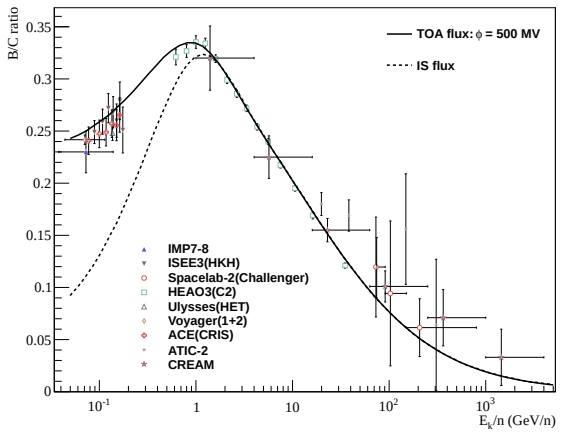
diffusion on inhomogeneities of the Galactic magnetic field
convection, reacceleration

Solar System - Detection

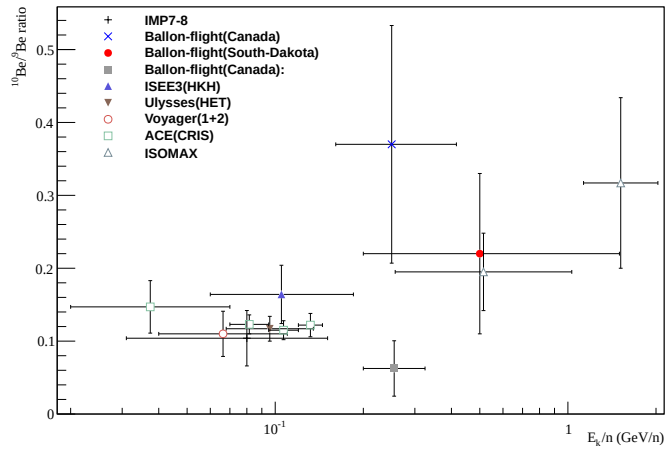
solar modulation,
geomagnetic cut-off

What are we looking for?

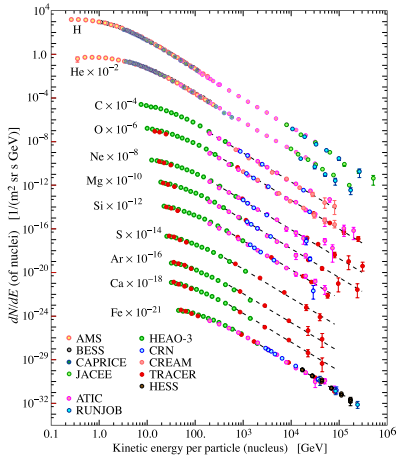
Secondary/primary ratios



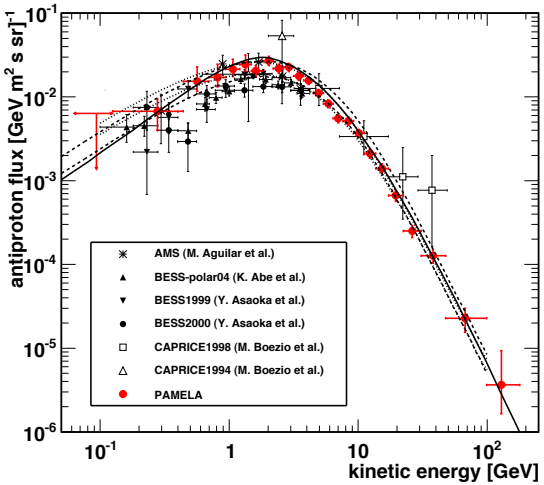
Radioactive species



Primary species

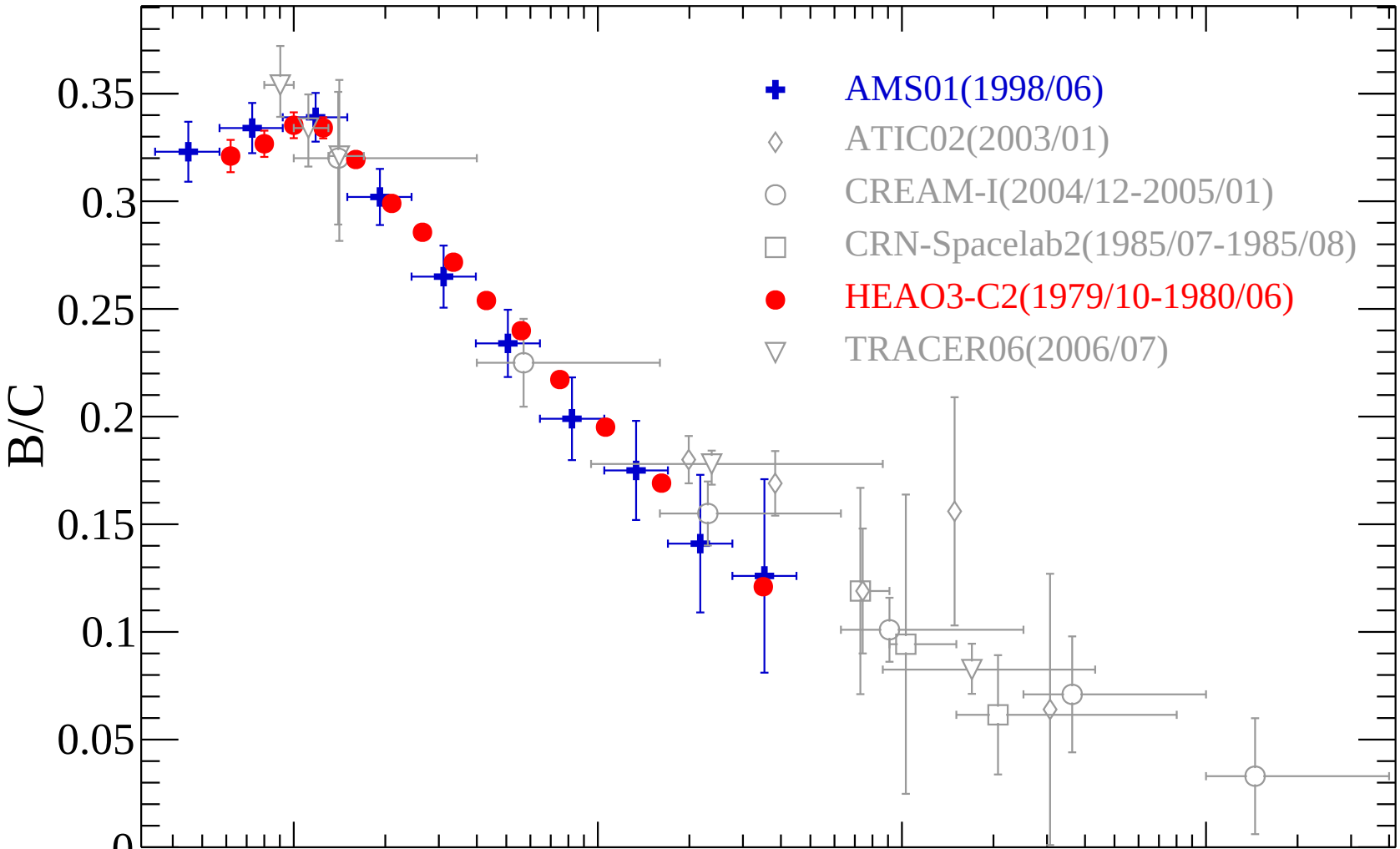


Antiparticles

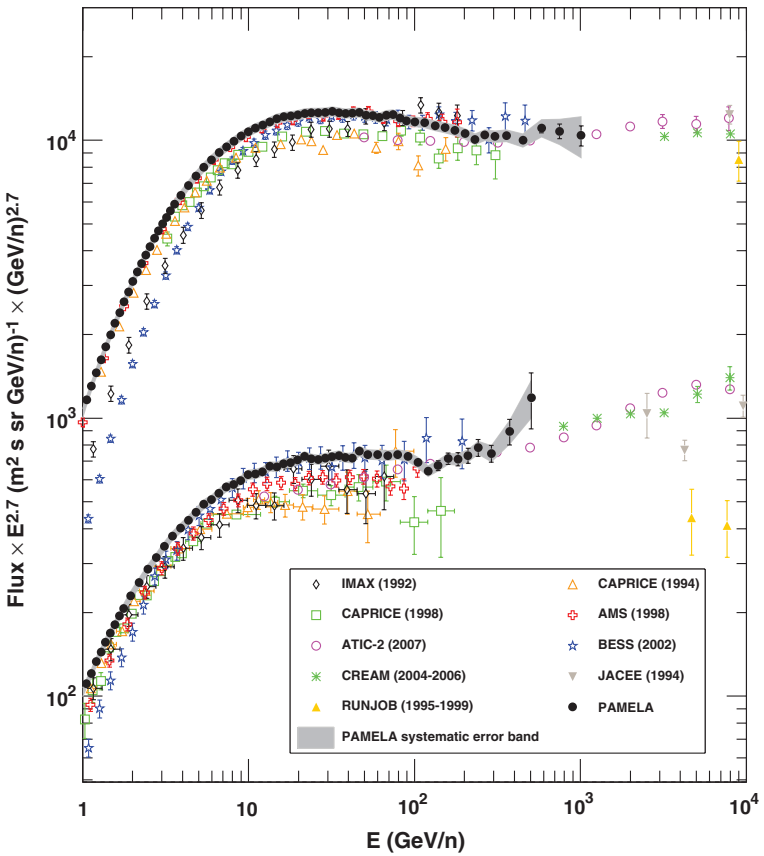


- S/P ratios: transport mechanisms
- Radioactive species: halo size
- Primaries species: injection mechanisms
- Antiparticles: exotic contributions

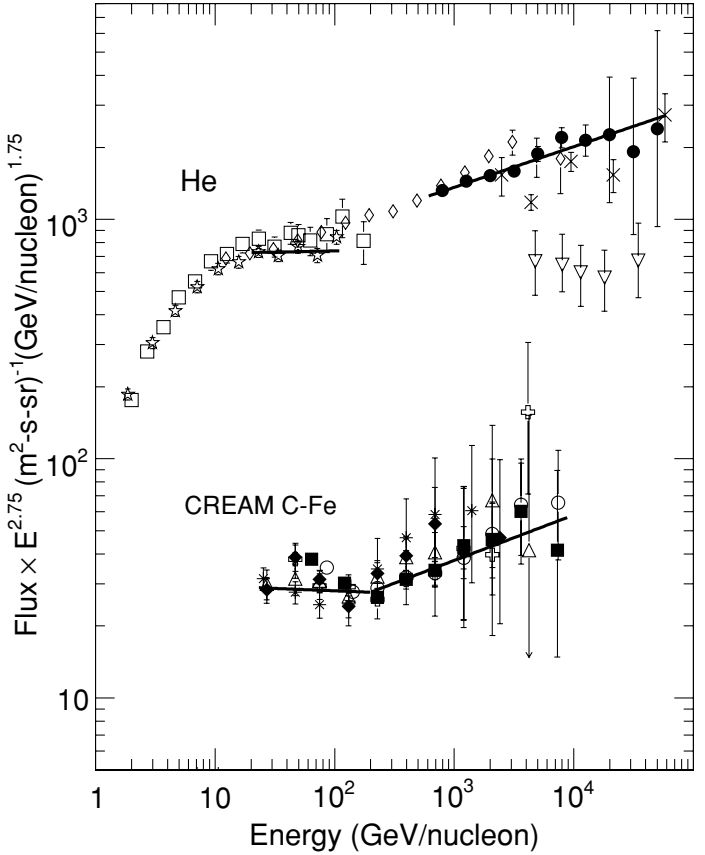
Boron/Carbon – What is happening at higher energies?



Primary nuclei – It is getting more complicated!



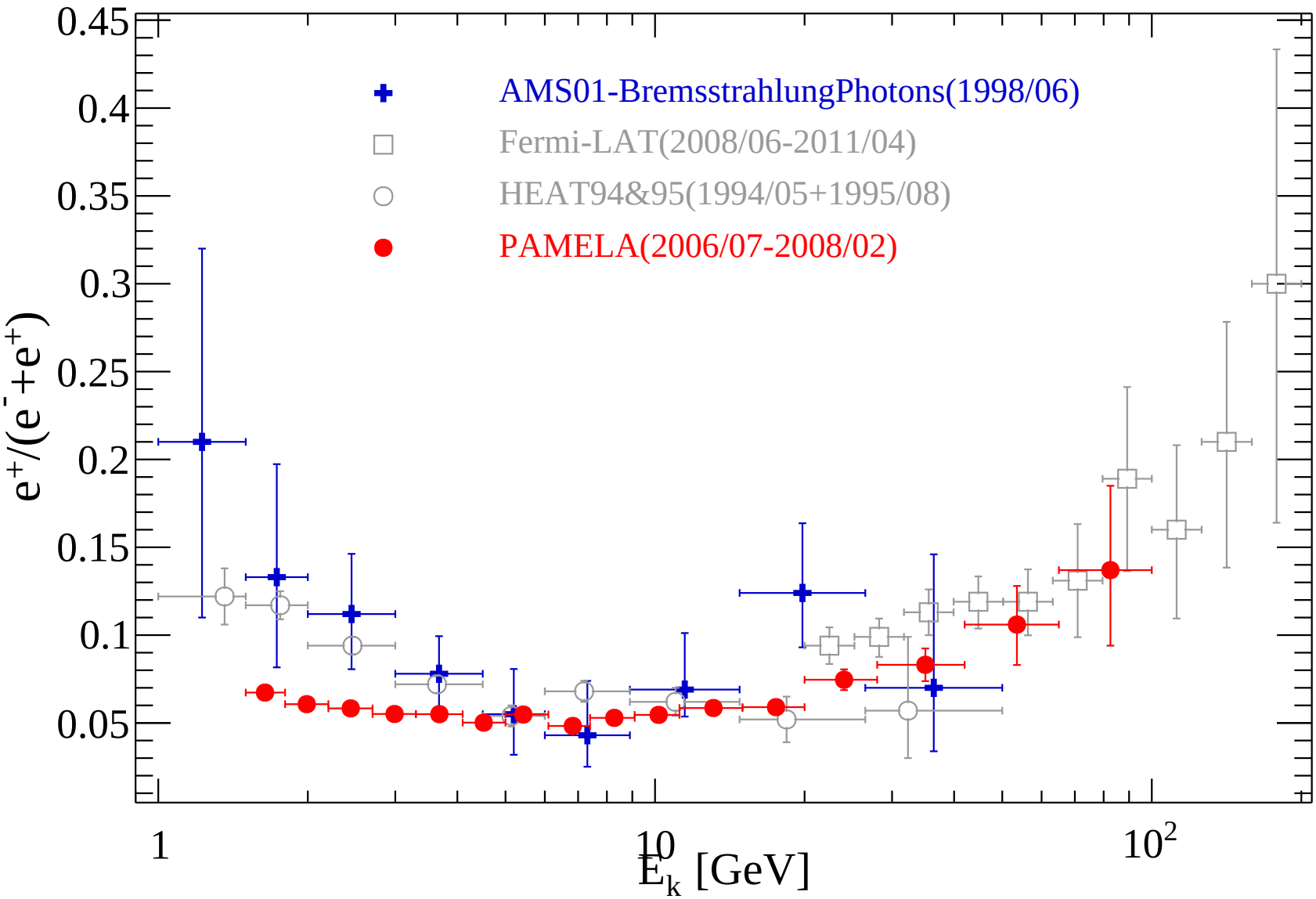
[Adriani *et al.*, Science **332** (2011)]



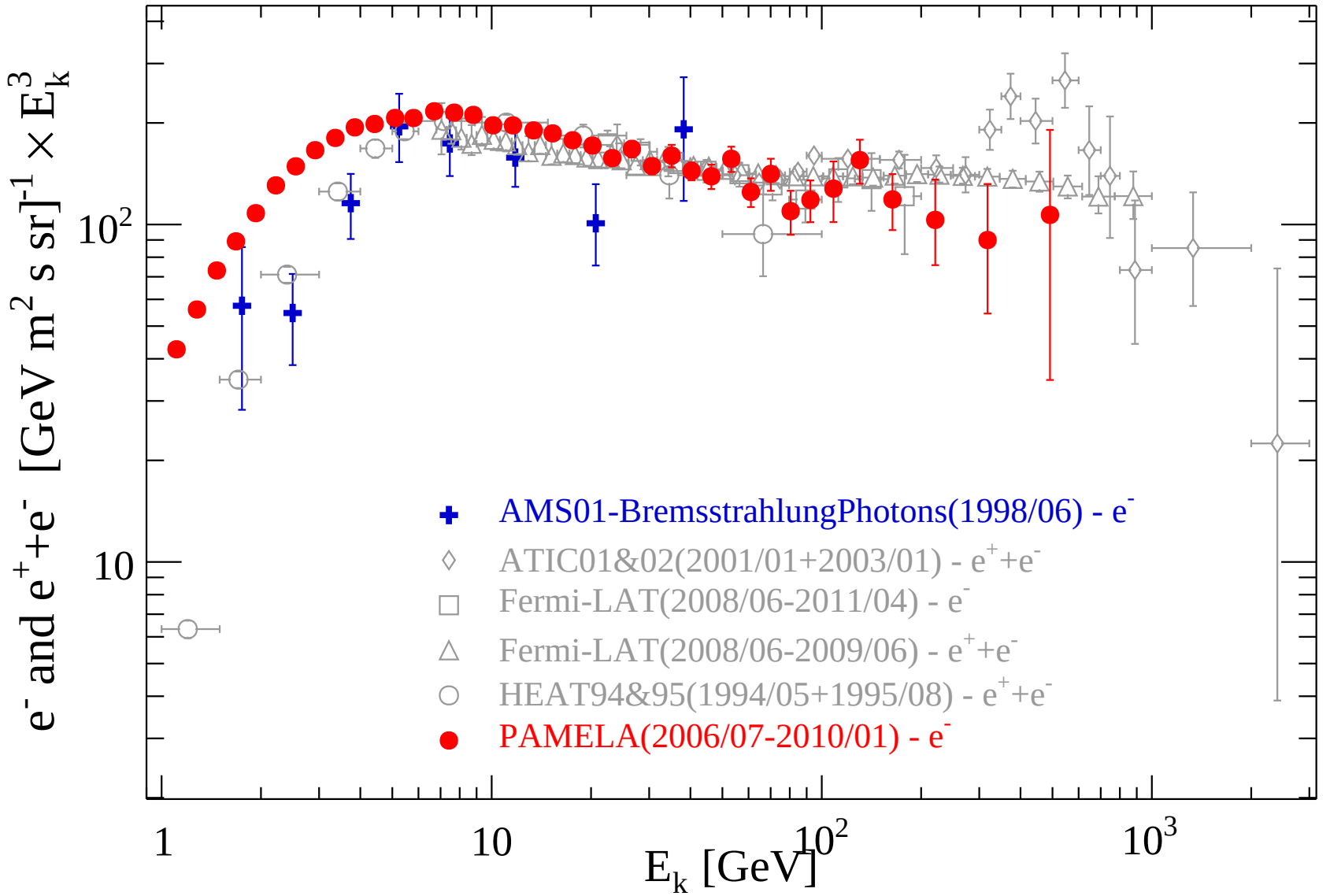
[Ahn *et al.*, ApJ **714** (2010)]

"Hardening" in primary spectra of $\Delta\gamma \sim 0.1$ observed at $\sim 200\,\mathrm{GeV/n}$

Positron fraction – An unexplained rise at high energies



Electron fluxes – What is the ATIC bump?



The Alpha Magnetic Spectrometer (AMS)

Space-borne detector

Installed on the ISS since 19 May 2011
direct detection of cosmic rays

Energy range

10^8 to 10^{12} eV

Scientific goals

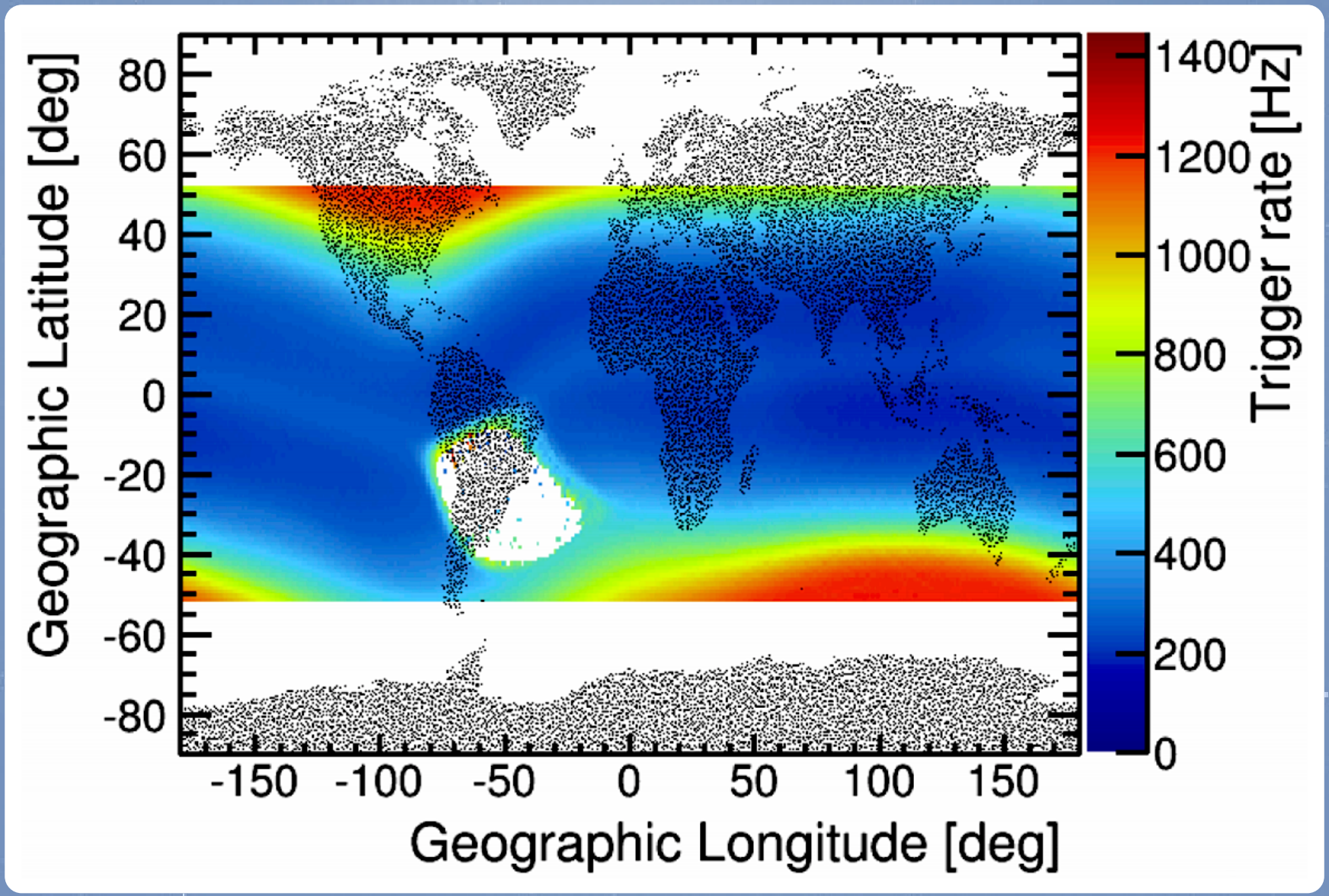
Measurement of:

- elemental cosmic-ray fluxes (H to Fe)
- isotopic cosmic-ray fluxes (^{1}H to ^{10}Be)
- antiparticles (e^+, $\bar{p}$, $\bar{d}$, $\bar{He}$)
- strangelets

[NASA]

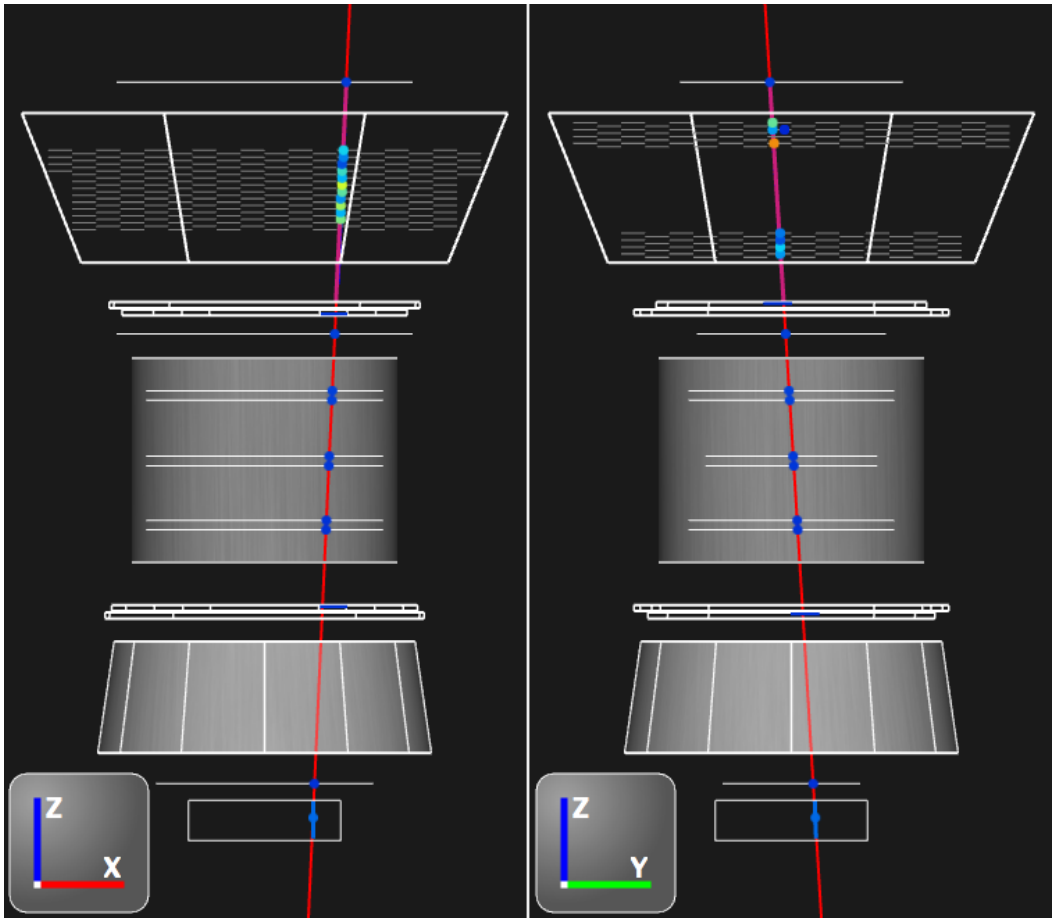
International collaboration: 17 countries, $>$ 50 institutes, 500 physicists

AMS orbit and trigger rate



The AMS-02 experiment

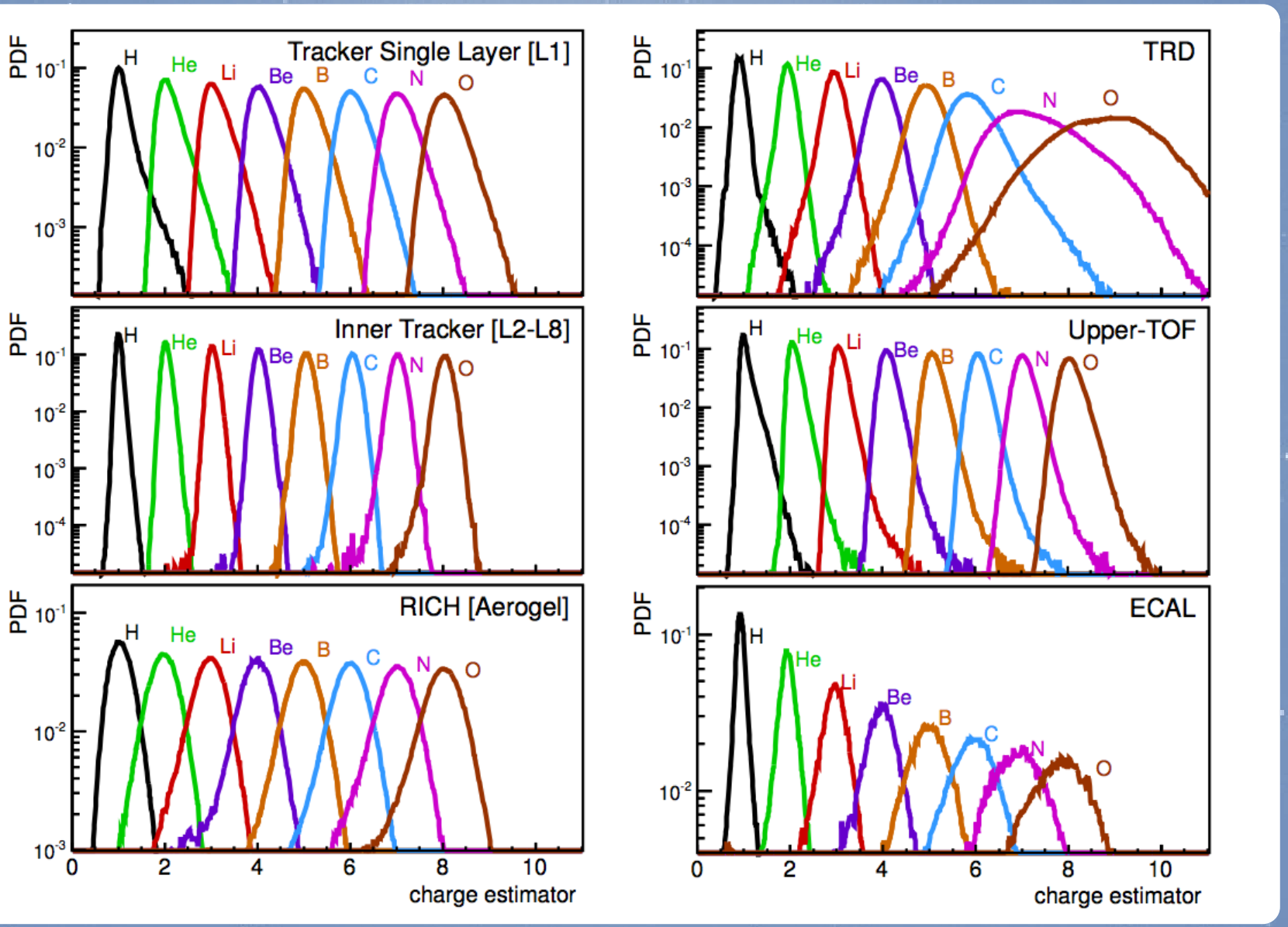
Proton-like event with $E \sim 30\,\text{GeV}$



[Eventdisplay by J. Wienkenhöver]

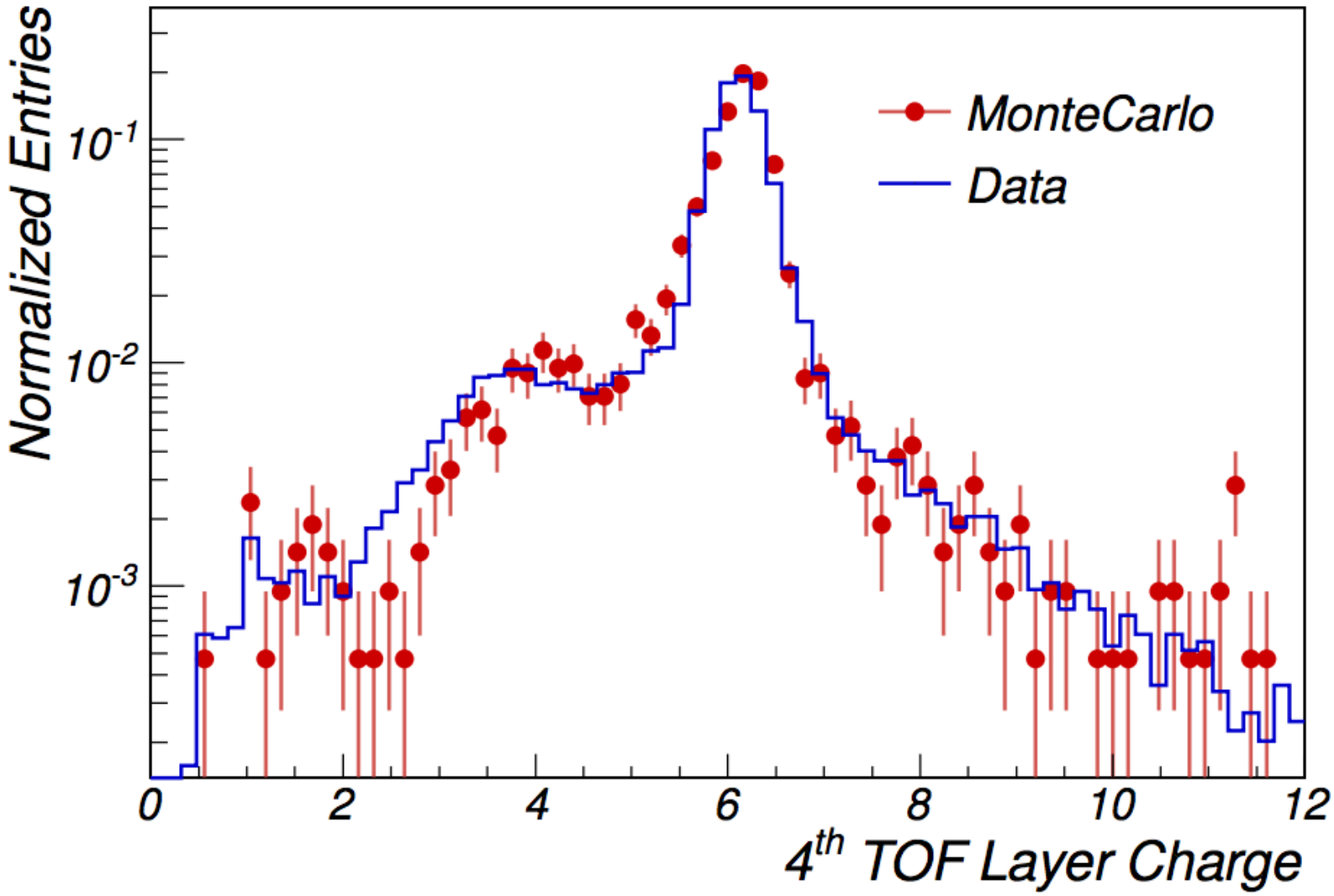
- Transition Radiation Detector:
  e-p separation, $|Z|$
- Time-of-Flight Counter:
  Trigger, $|Z|$, β
- Silicon Tracker + Permanent magnet:
  Z, R
- Anti-coincidence counter:
  Veto
- Ring-imaging Cherenkov Detector:
  $|Z|$, β
- Electromagnetic Calorimeter:
  e-p separation, E

Charge estimators: redundancy and complimentarity



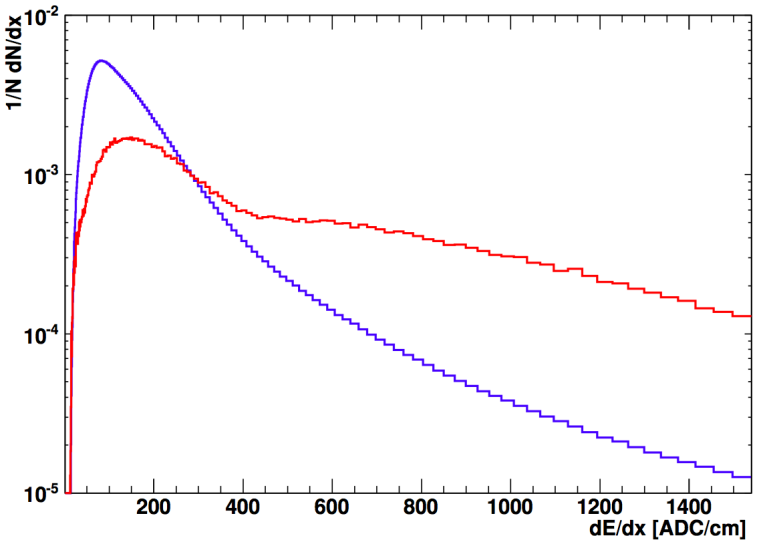
Fragmentation: AMS-02 is a thick detector

Carbon ($Z = 6$) sample at the top of AMS-02 (Tracker layer 1)



e-p separation: the TRD estimator

PDFs $p_{e,p}$ from ISS data

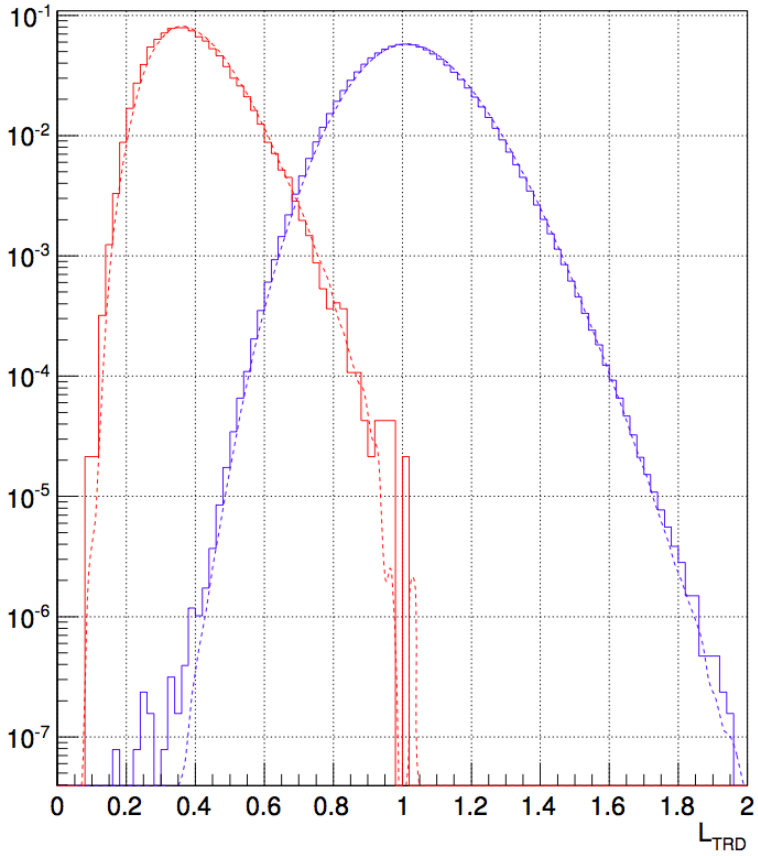


electrons and protons

$$\mathcal{L}_{e,p} = \sqrt[n]{\prod_i^n p_{e,p}(dE_i/dx_i)}$$

$$L_{TRD} = -\log \frac{\mathcal{L}_e}{\mathcal{L}_e + \mathcal{L}_p}$$

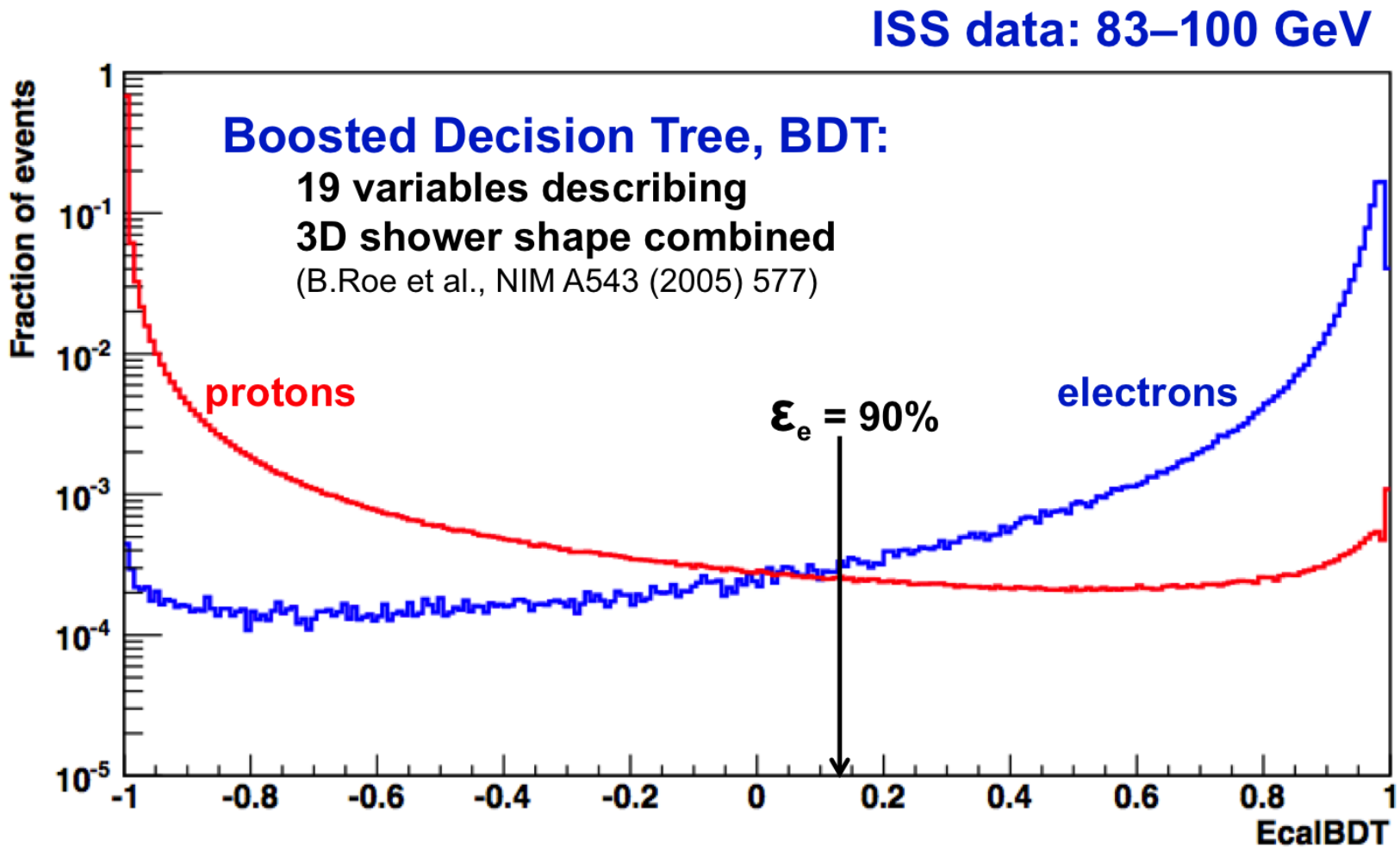
L_{TRD} from ISS data



electrons and protons

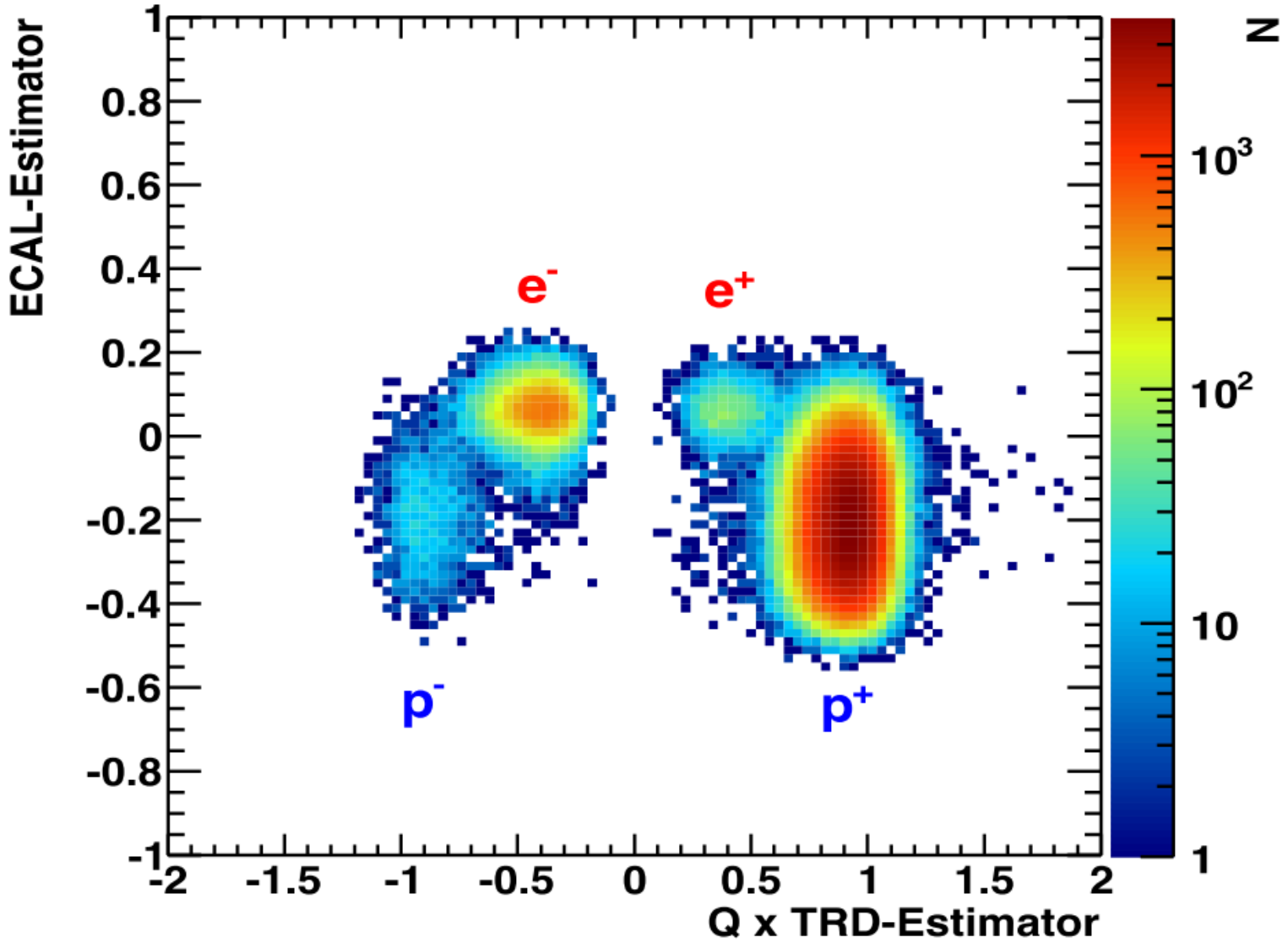
rejection $> 10^3$ at 90% efficiency

e-p separation: the ECAL estimator



rejection $> 10^4$ at 90% efficiency

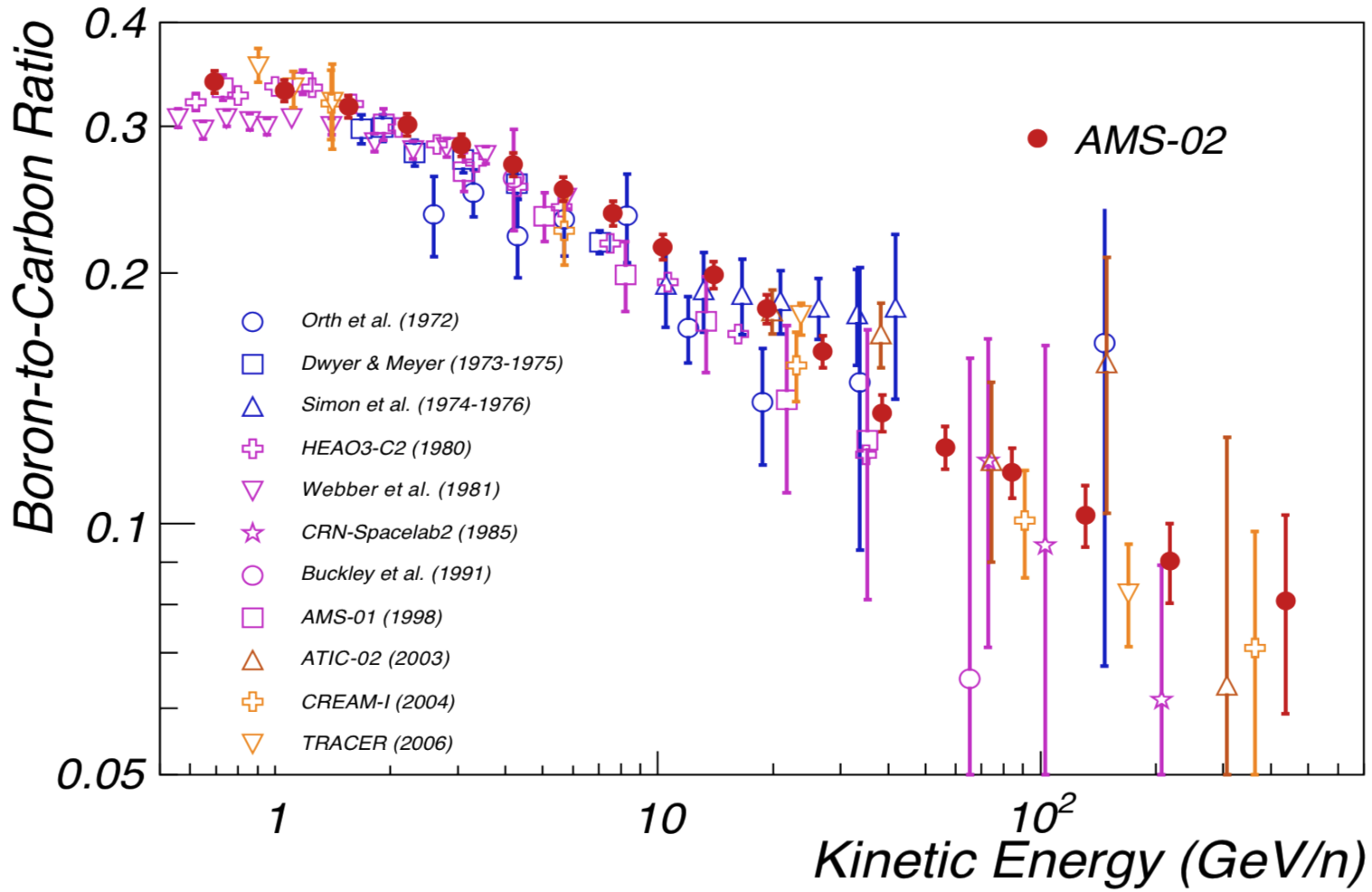
e-p separation



Overview of AMS-02 results

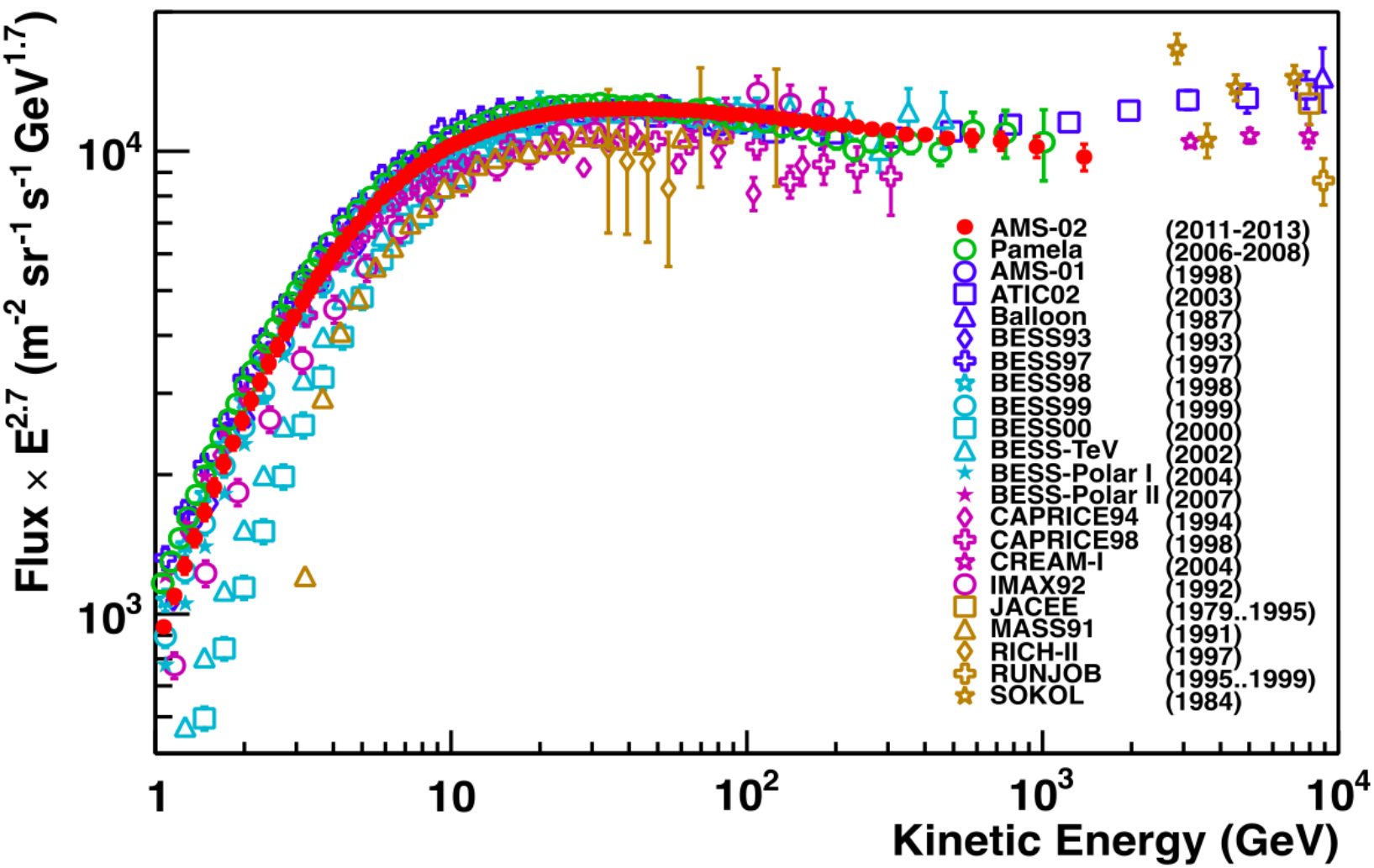
- First measurement presented on 3 April 2013:
  - positron fraction (0.5 – 350 GeV)
  - upper limit on dipole anisotropy parameter
- Preliminary results presented at ICRC (see `www.ams02.org`), systematics still under investigation:
  - B/C ratio (0.5 – 670 GeV/n)
  - Proton flux (1 GV – 1.8 TV)
  - Helium flux (2 GV – 3.2 TV)
  - Electron & positron fluxes (1 – 500 GeV & 1 – 300 GeV)
  - All electron ($e^- + e^+$) flux (0.5 – 700 GeV)

Secondary-to-primary ratio: Boron-to-Carbon



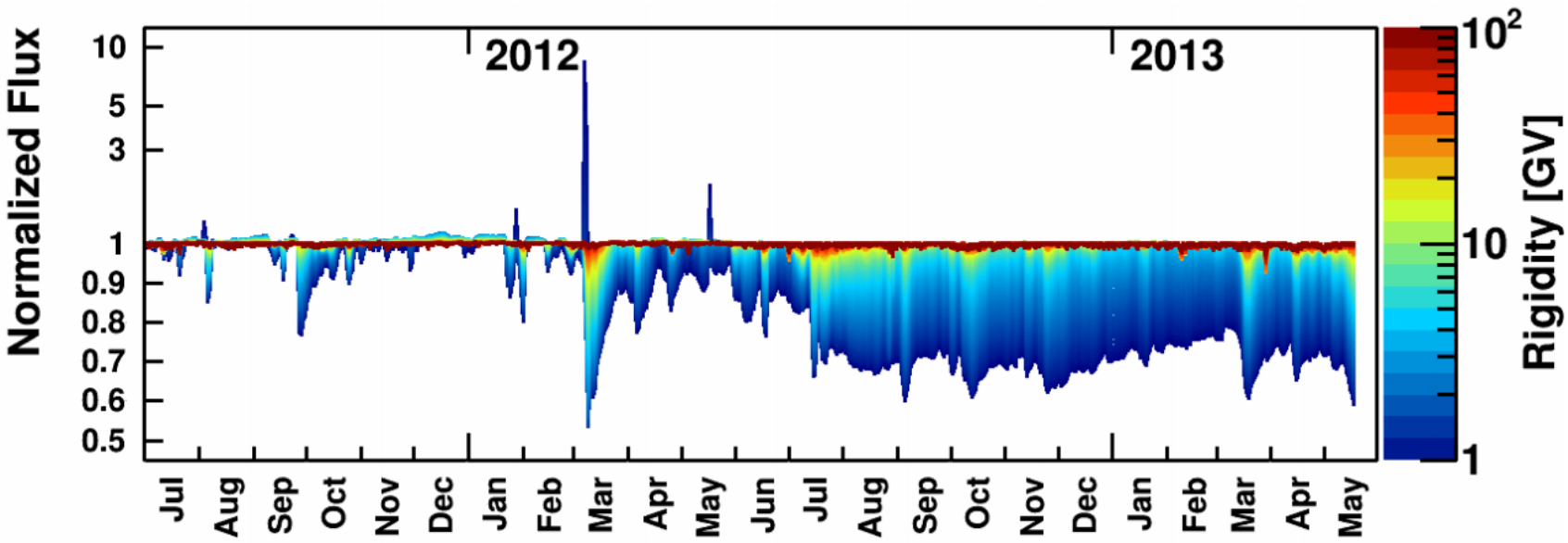
Most precise data since 1980, deviation from HEAO3 for $E_k > 8\,\mathrm{GeV/n}$

Primary species: proton flux



No “hardening” observed

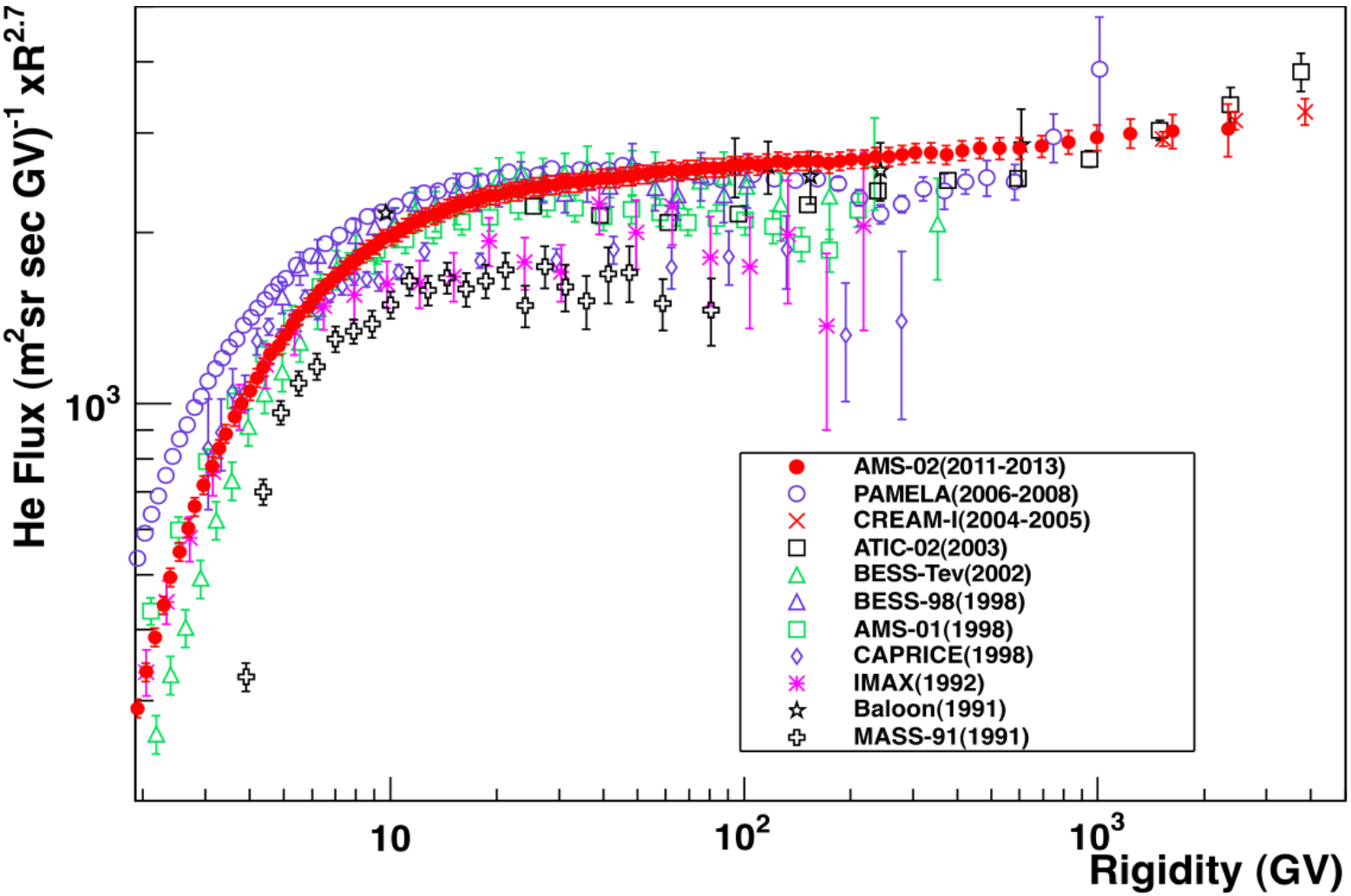
Primary species: proton flux daily variations



Study of solar activity

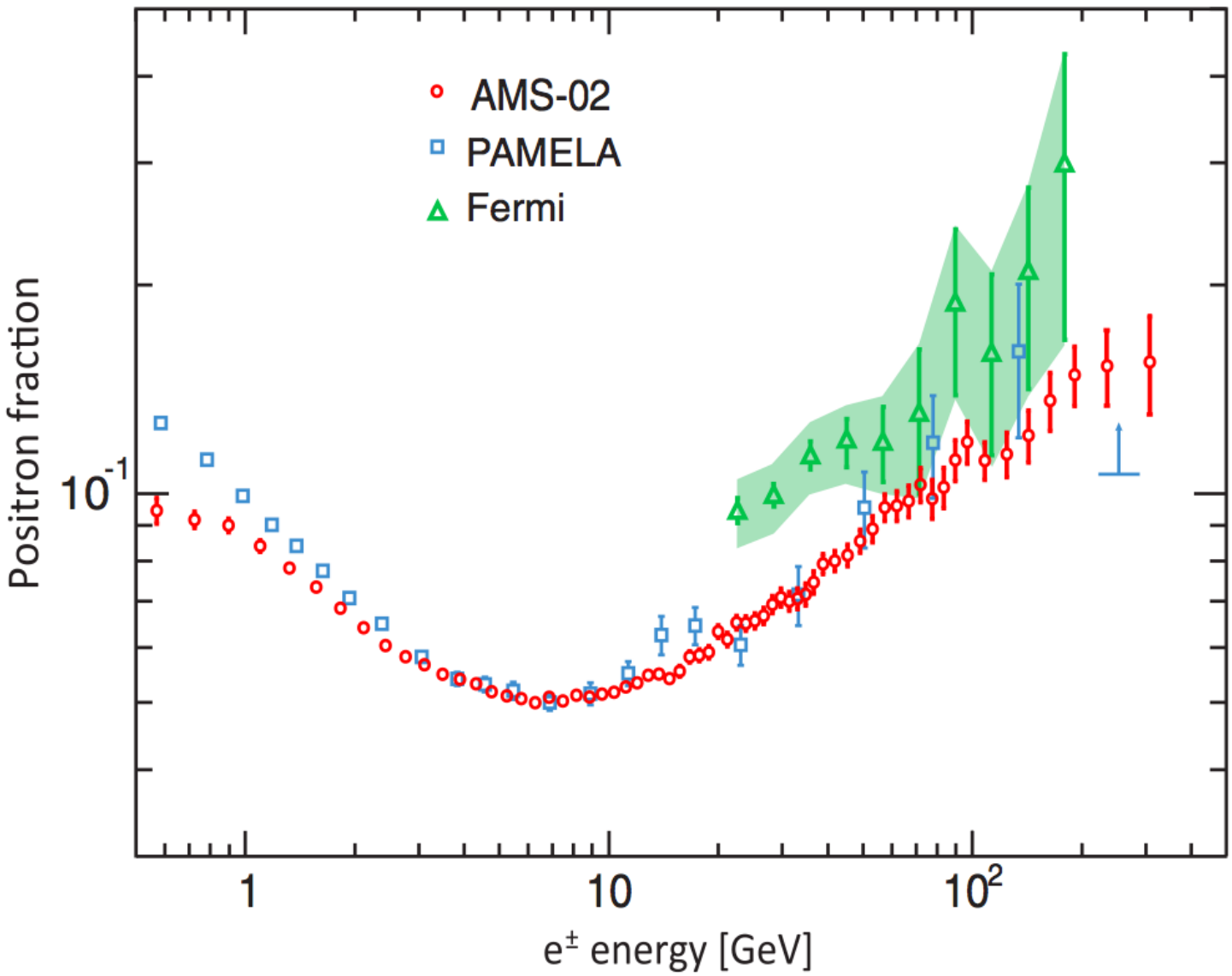
- Variations up to $R \sim 20\,\text{GV}$
  $\Longrightarrow$ solar modulation
- Spikes around $R \sim 1\,\text{GV}$
  $\Longrightarrow$ solar events on 9.8.2011, 27.1.2012, 7.3.2012, and 17.5.2012

Primary species: helium flux

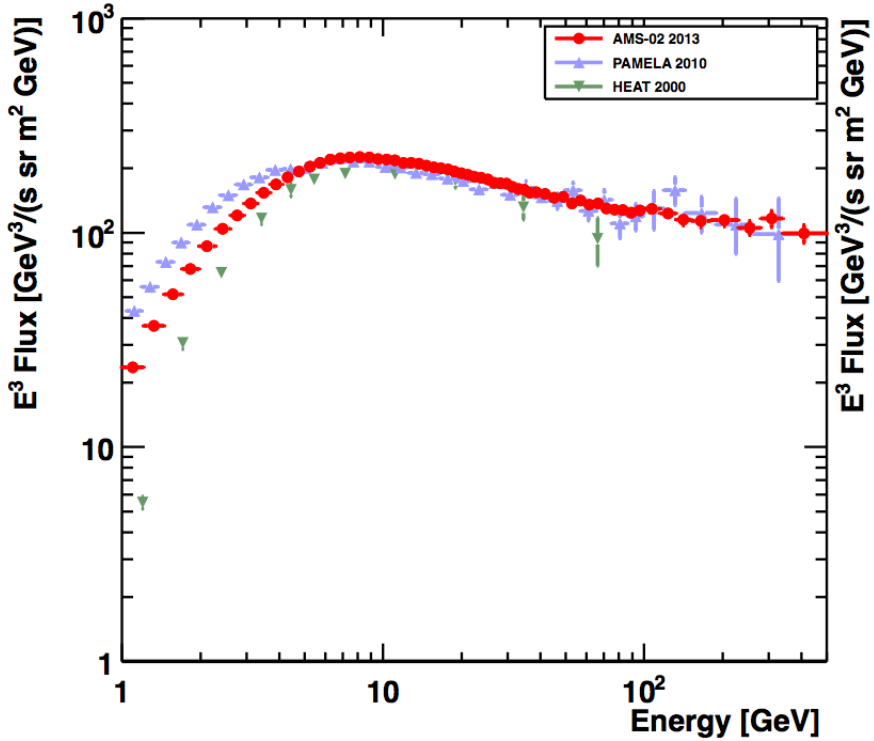


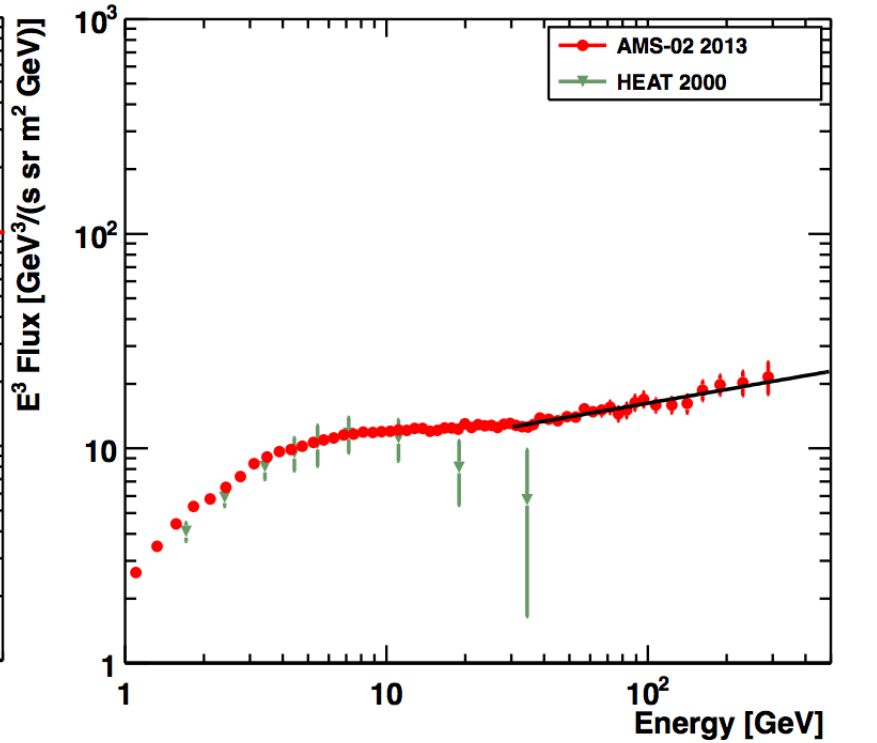
No "hardening" observed

Antiparticles: positron fraction



Antiparticles: electron & positron fluxes



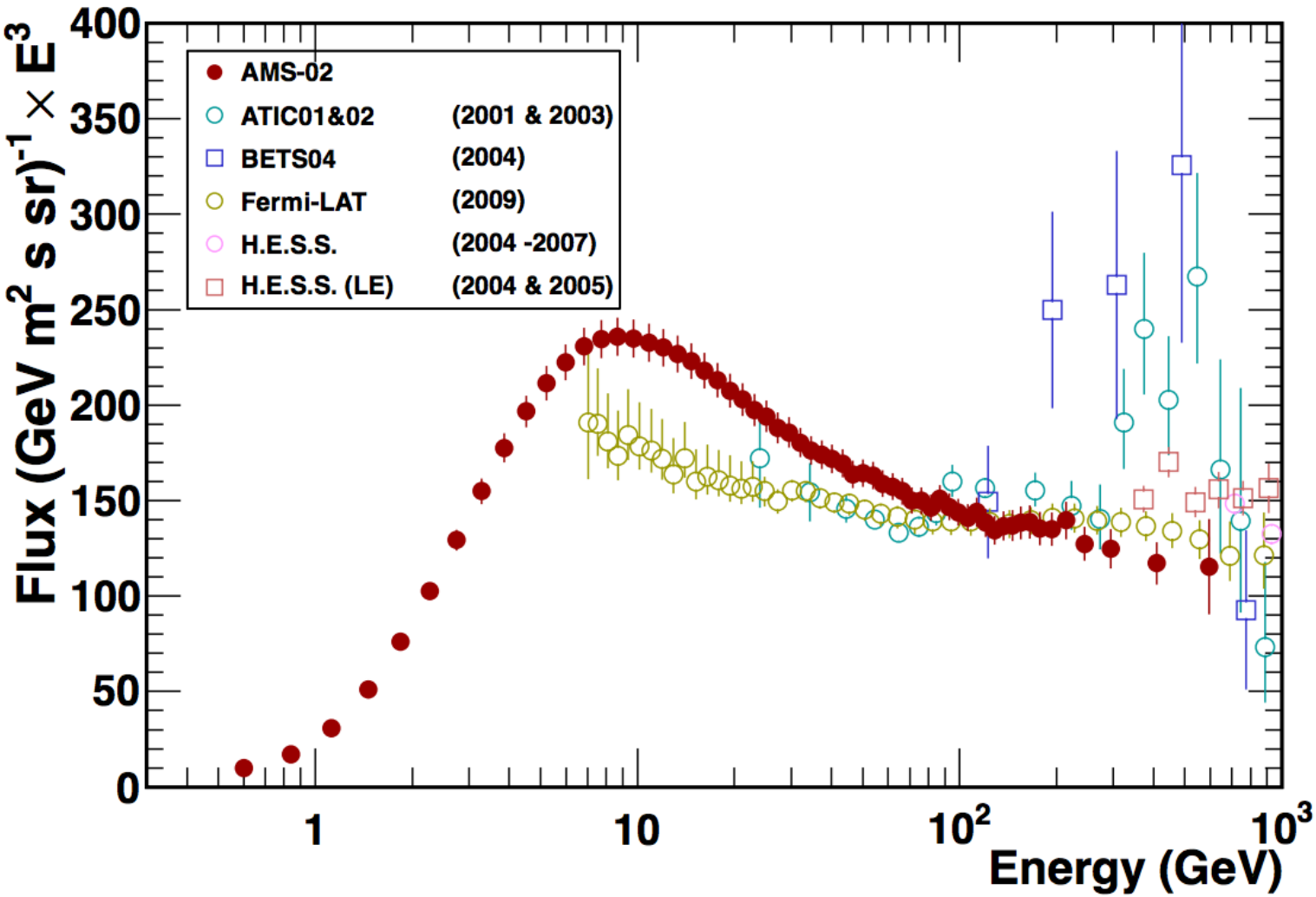


No bump detected

"Hardening" in positron spectrum around 30 GeV observed

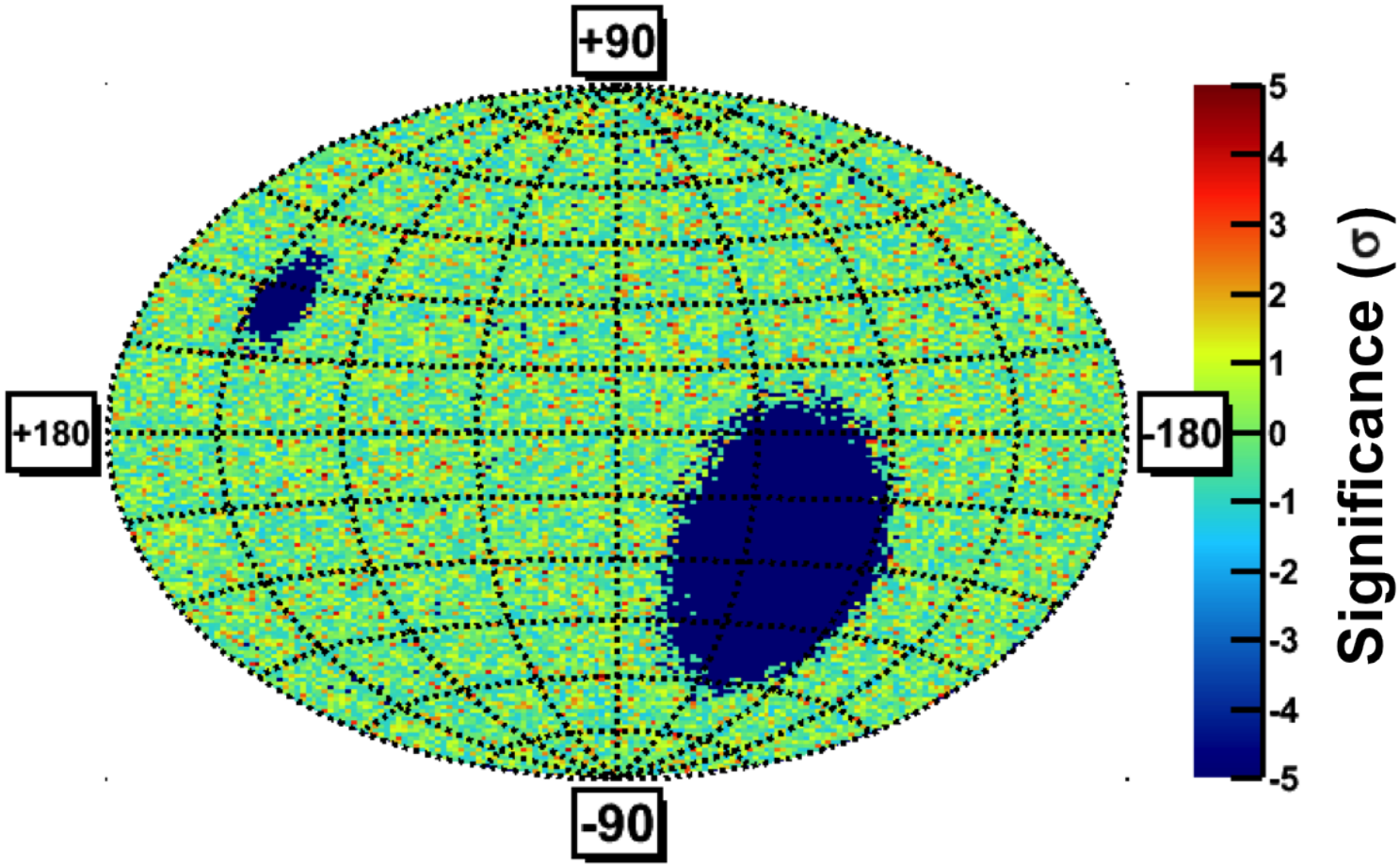
$\Longrightarrow$ systematics are still under investigation

Antiparticles: electron + positron flux



ATIC bump not seen

Antiparticles: positron/electron anisotropy



e^+/e^- show no evident pattern

dipole anisotropy parameter $< 3\%$ @ 95%CL

Conclusion

AMS-02 has been taking cosmic-ray data for over 2 years now

Results

Most precise data of cosmic rays covering a large energy range

- Secondary-to-primary ratios: B/C
- Primary species: e^-, p, He
- Antiparticles: $e^+/(e^- + e^+)$, e^+

Any surprises?

- no "hardening" seen in p & He spectra
- no bump seen in $e^\pm$ spectra, rising $e^+/(e^- + e^+)$ confirmed
- "hardening" in e^+ observed

Outlook – Stay tuned!

Analyses still in progress

Only 10% of total expected data recorded yet!