# Direct detection of cosmic rays: Recent observational progresses

**CRISM-2014**

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# Outline

- Recent results from CR direct detection experiments:
  - Charged cosmic rays: Z=1..26
  - Energy range from ~1 GeV-> ~10 TeV
- Main topics adressed by current experiments
  - Modulation of CR by Solar activity
  - Propagation of cosmic rays
  - Source/Acceleration of cosmic
  - Indirect search of DM
- Futur experiments

# Recent CR experiments

## Balloon-borne Experiments

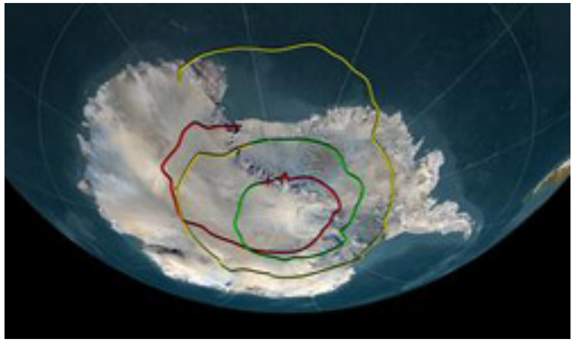
- MASS (1989-1991)
- IMAX (1992)
- CAPRICE (1994-1998)
- HEAT (1994-1995)
- BESS (1994-2000)
- ATIC (2000-2007)
- TRACER (2006)
- CREAM (2004-2010)

## Spatial Experiments

- HEAO3 (1979-1981)
- AMS01 (1998)
- PAMELA (2006-2013)
- FERMI (2008-2014)
- AMS02 (2011-?)

Major Detection Technology:
CALORIMETER MAGNET SPRECTROMETER

# Balloon/Space flights Pros and Cons



- \+ « short » time development
- \+ Environment close to spatial but « standard » technologies can be used.
- \+ Moderate costs
- \+ Moderate risk (Launch failure, delays, …)
- \+ NASA Flight Facility (McMurdo – Antarctic) up to 3 LDB flights/season.
- \+ Possibility to recover and refurbish the detector.
- \+ Close to magnetic pole, low geomagnetic cutoff.
- − LDB Flights limited to ~30 days, ULDB still under development.
- − Flight altitude < 40 km, 4-5 g/cm$^2$ of residual atmosphere.

*Major current and future results will come from spaceborne experiments but balloon have and will continue to play a key role in the measument of CR and the development of the instruments*

# CR experiments

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- AMS01 (1998)
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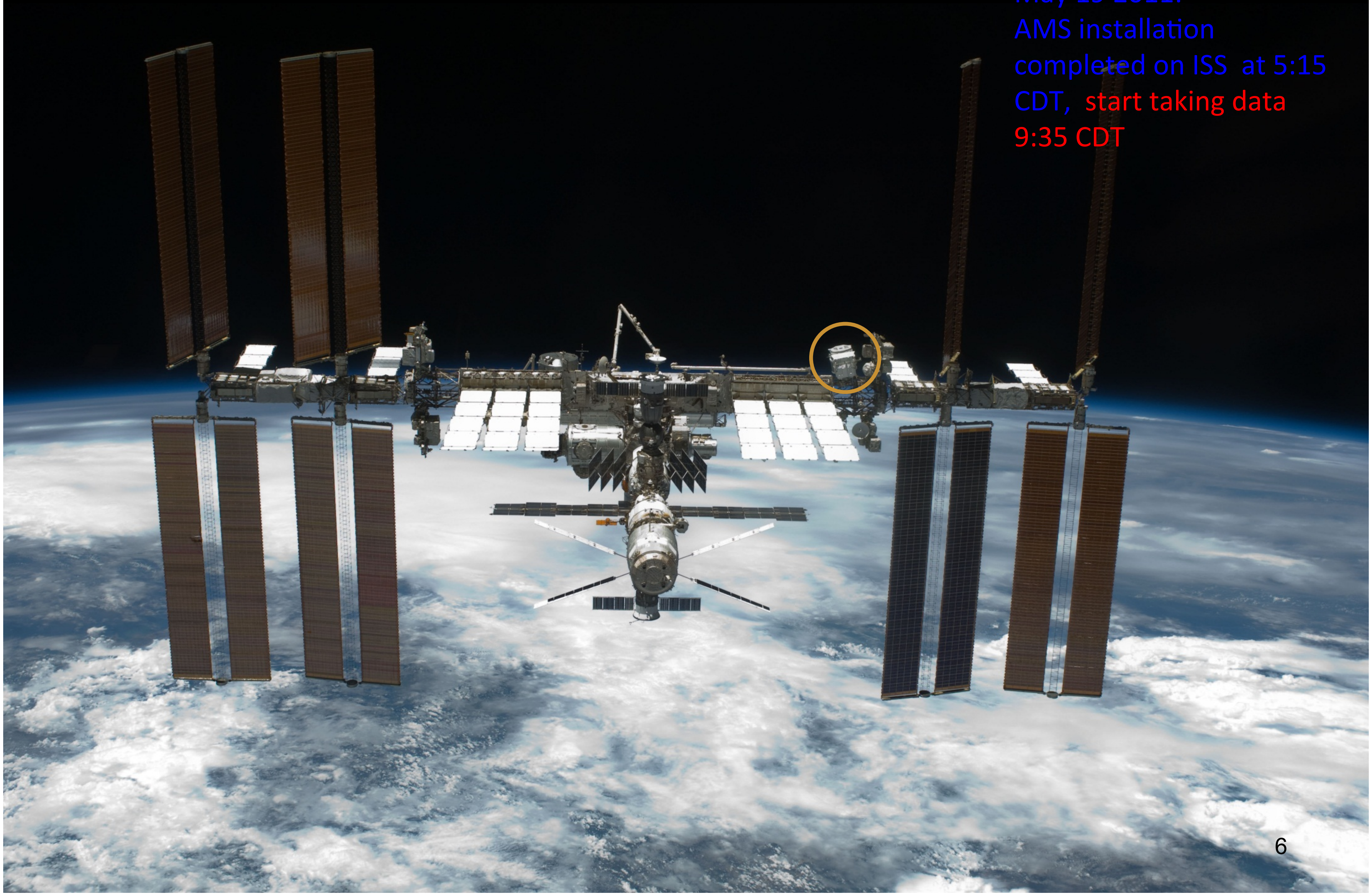
# AMS

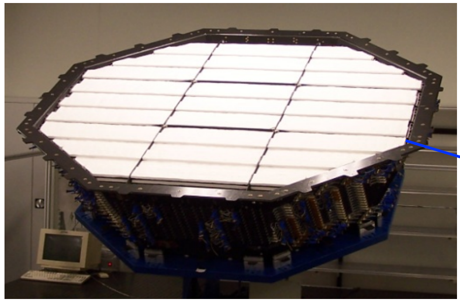
May 19 2011:
AMS installation completed on ISS at 5:15 CDT, start taking data 9:35 CDT



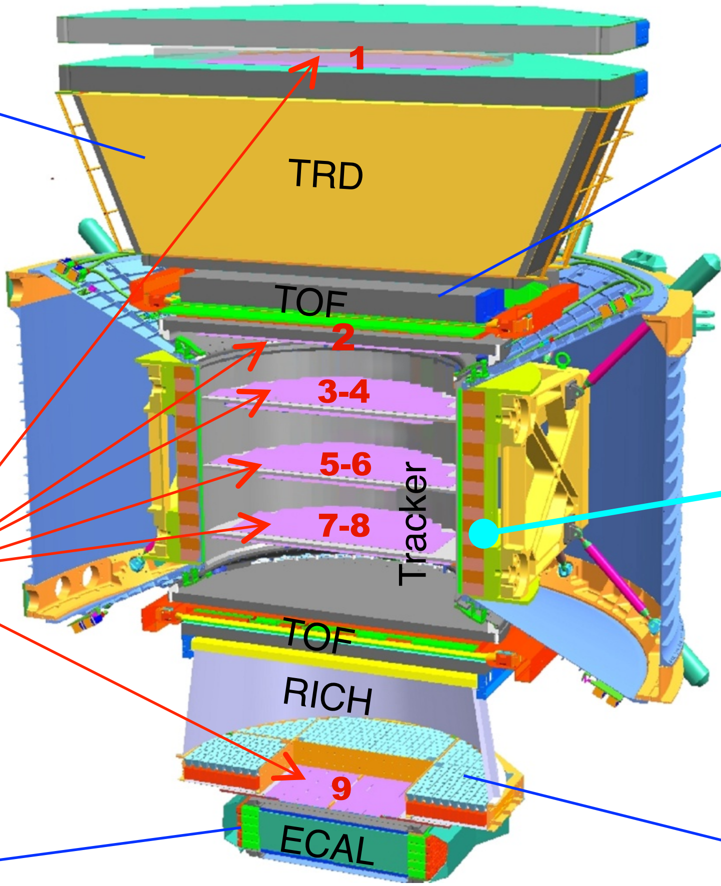

Alpha Magnetic Spectrometer
AMS-02
Europe • Asia
North America
ELC2

# AMS: A TeV precision, multipurpose spectrometer in space.

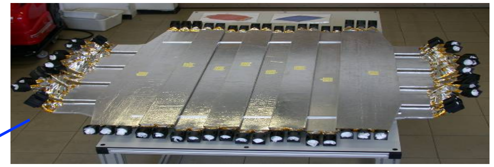
TRD
Identify e+, e-



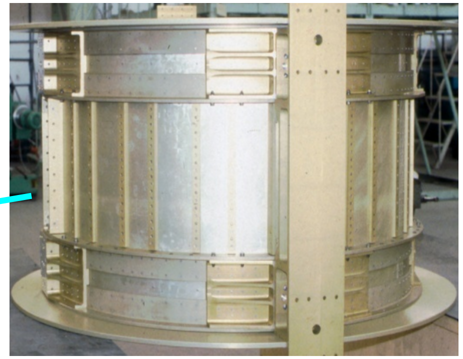
Particles and nuclei are identified by their charge (Z) and energy (E ~ P)



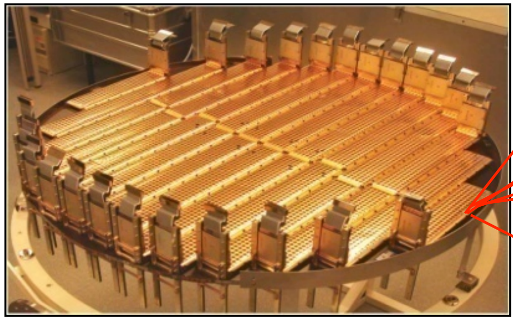

TOF
Z, Beta



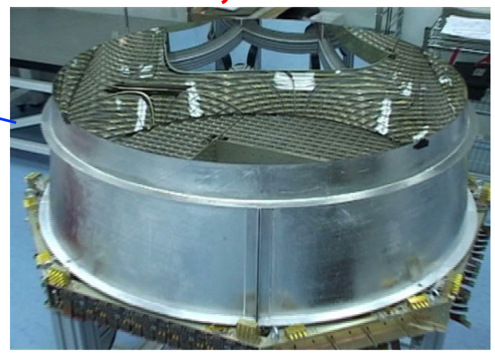
Magnet
±Z



Silicon Tracker
Z, P



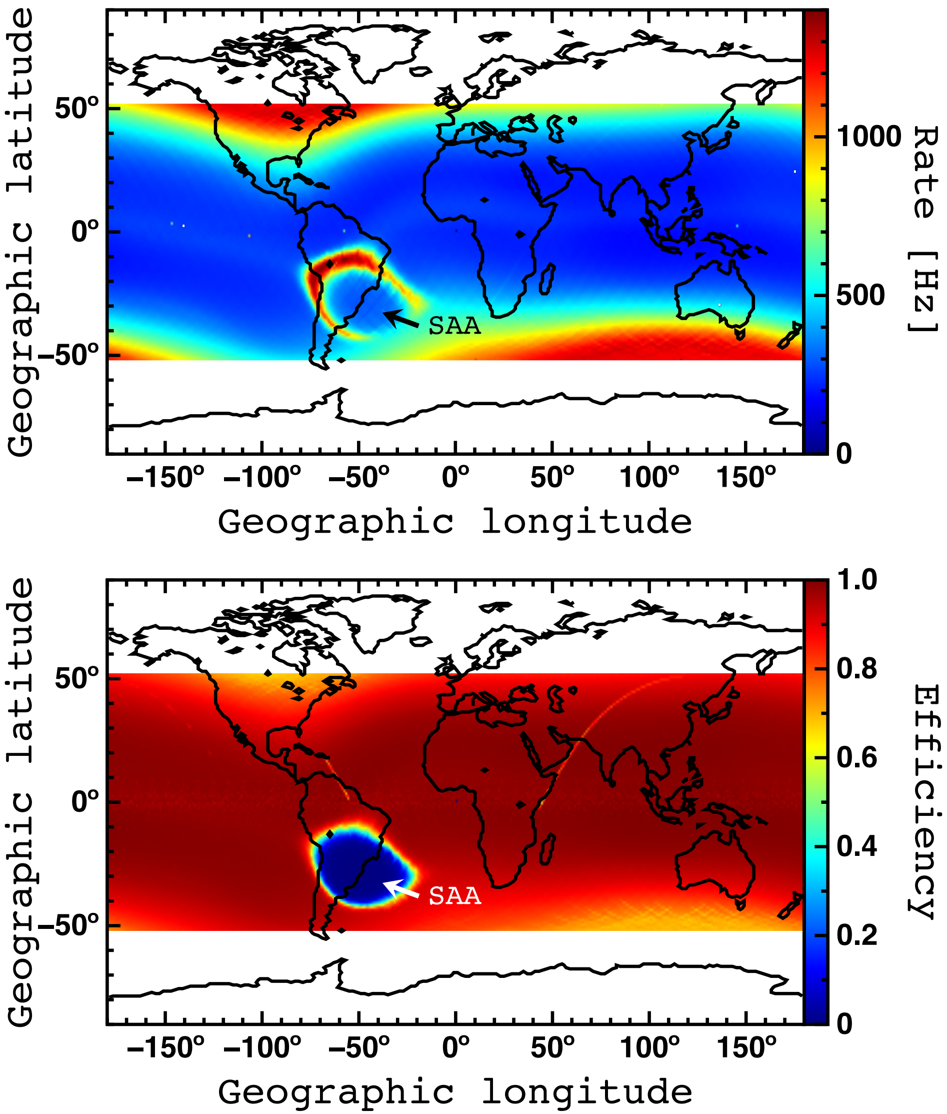
RICH
Z, Beta



ECAL
E of e+, e-, γ

5m x 4m x 3m 7.5 tons

# Orbital DAQ parameters

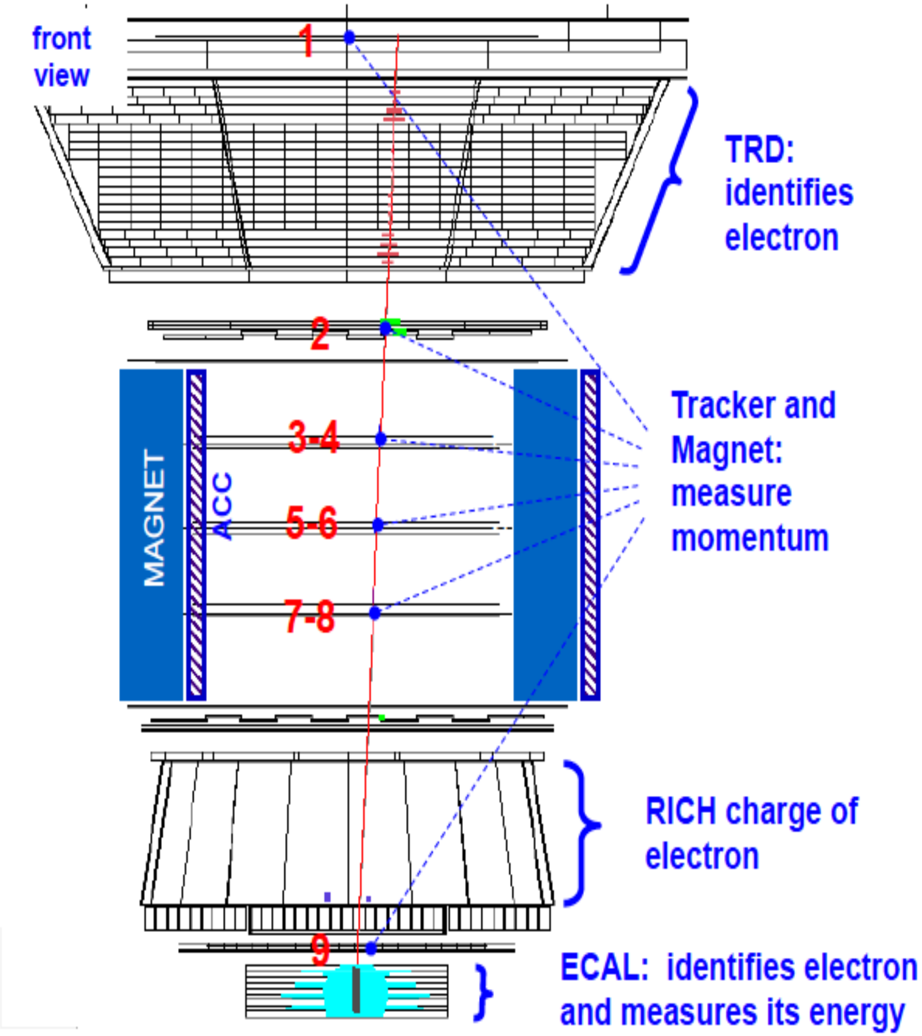



- Particle rate 200 Hz – 1000 Hz
- DAQ efficiency ~ 85%
- ~40 millions of events / day
- ~100 Gbytes downloaded per day

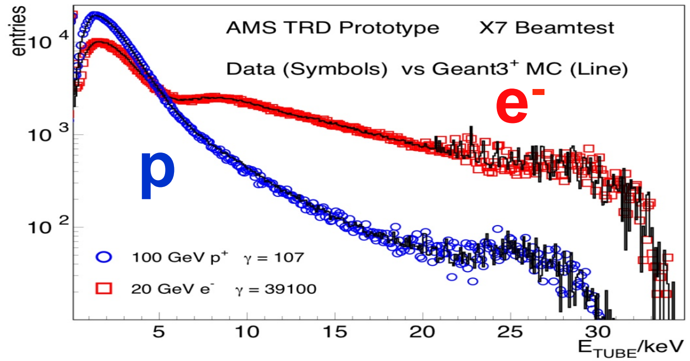
- 39 TB raw data/yr
- 200 TB reconstructed data/yr
- ~50 billion of events collected today.

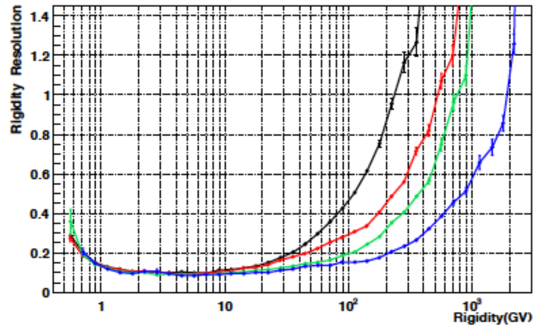
# e+,e- Identification in AMS

Proton rejection goal > 1/100000 => 3 independent detectors are used

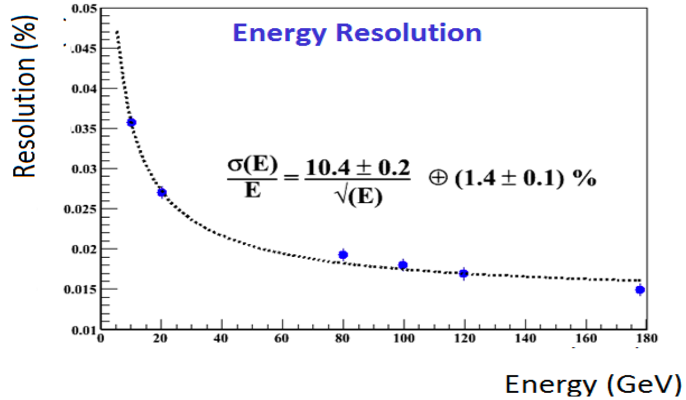



AMS data on ISS: 424 GeV positron

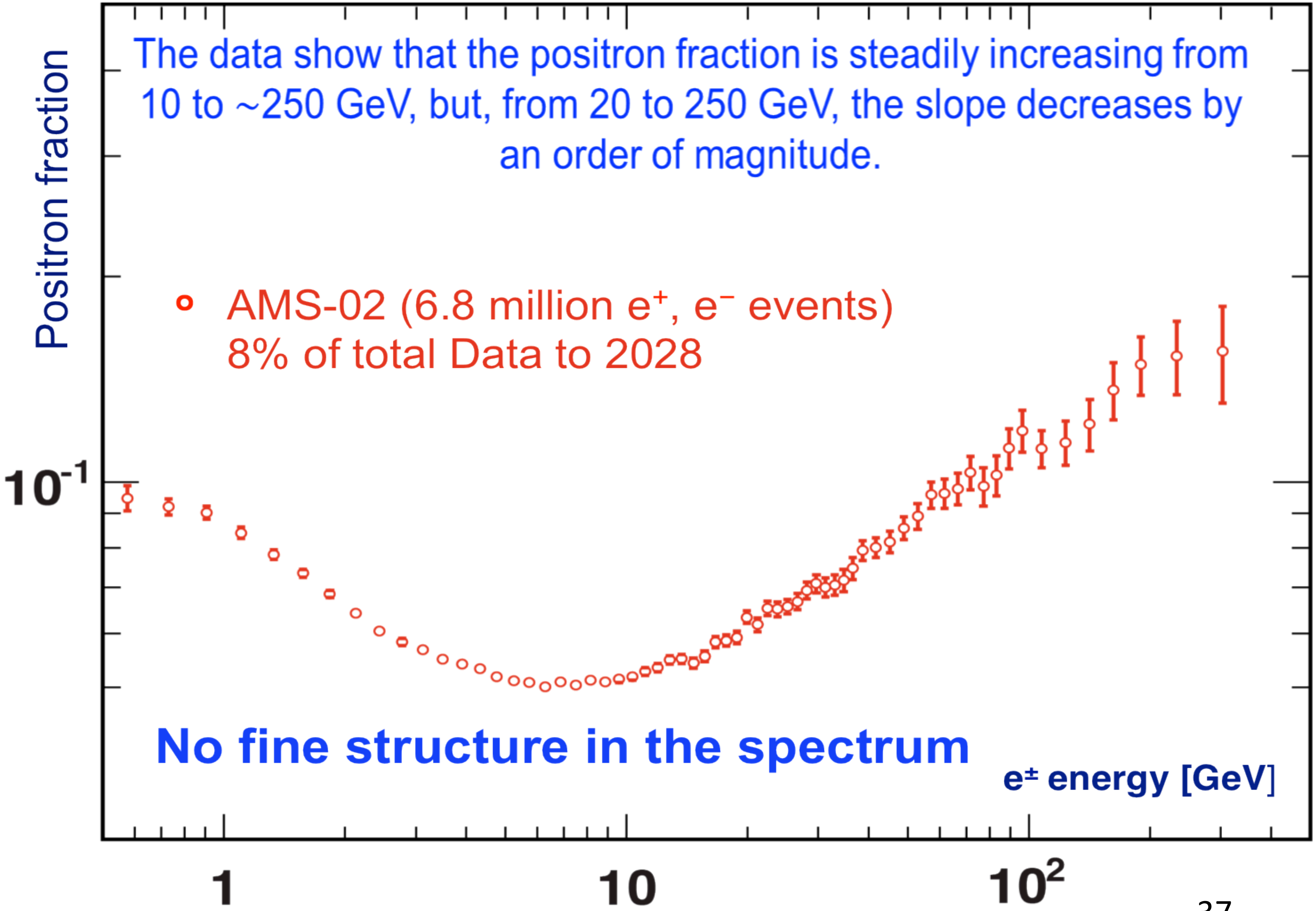


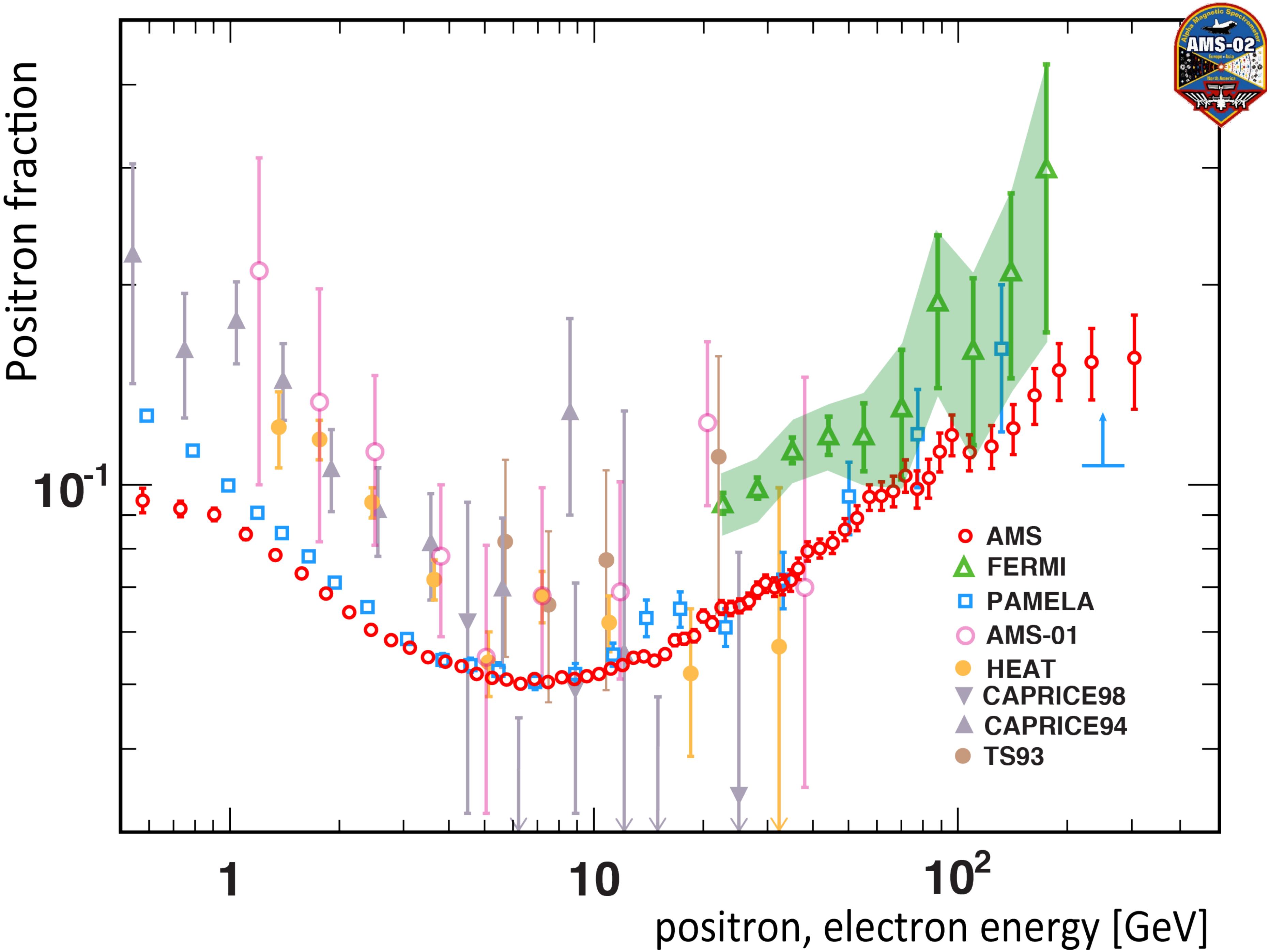




MDR=2 TV



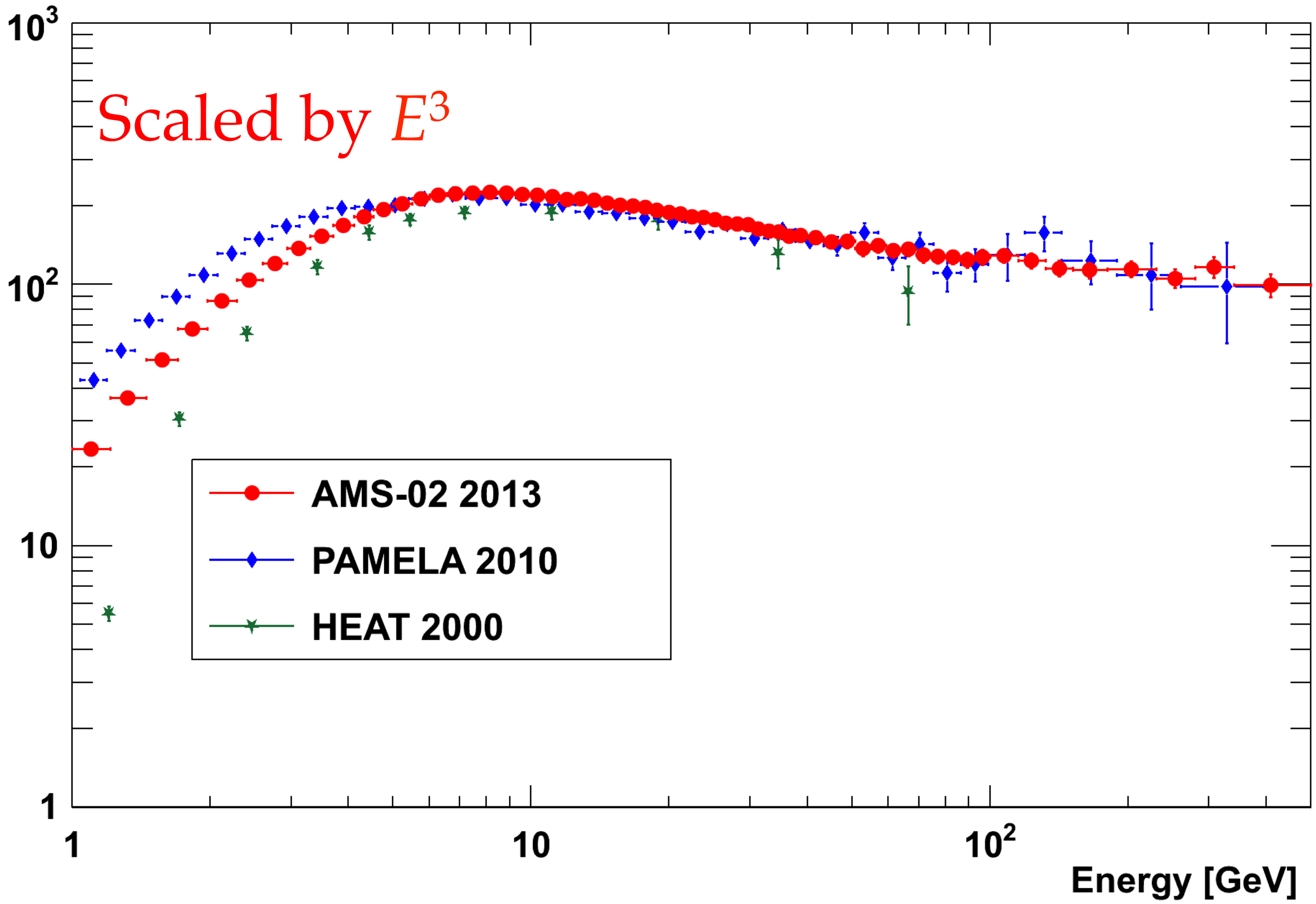
Positron fraction





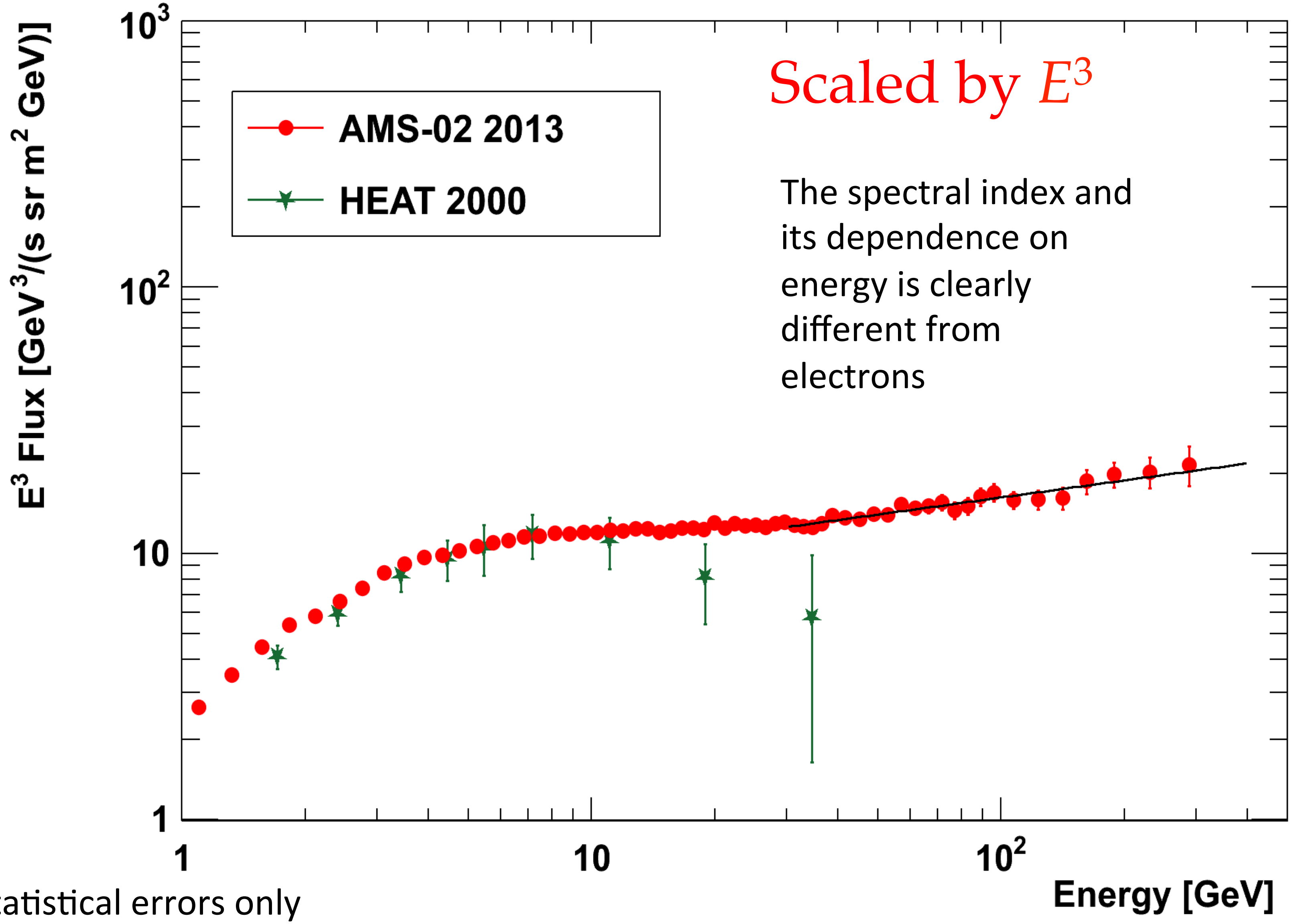
Positron fraction
$10^{-1}$
1
10
$10^2$
positron, electron energy [GeV]
AMS
FERMI
PAMELA
AMS-01
HEAT
CAPRICE98
CAPRICE94
TS93
AMS-02

# AMS-02 Electron Flux up to 500 GeV



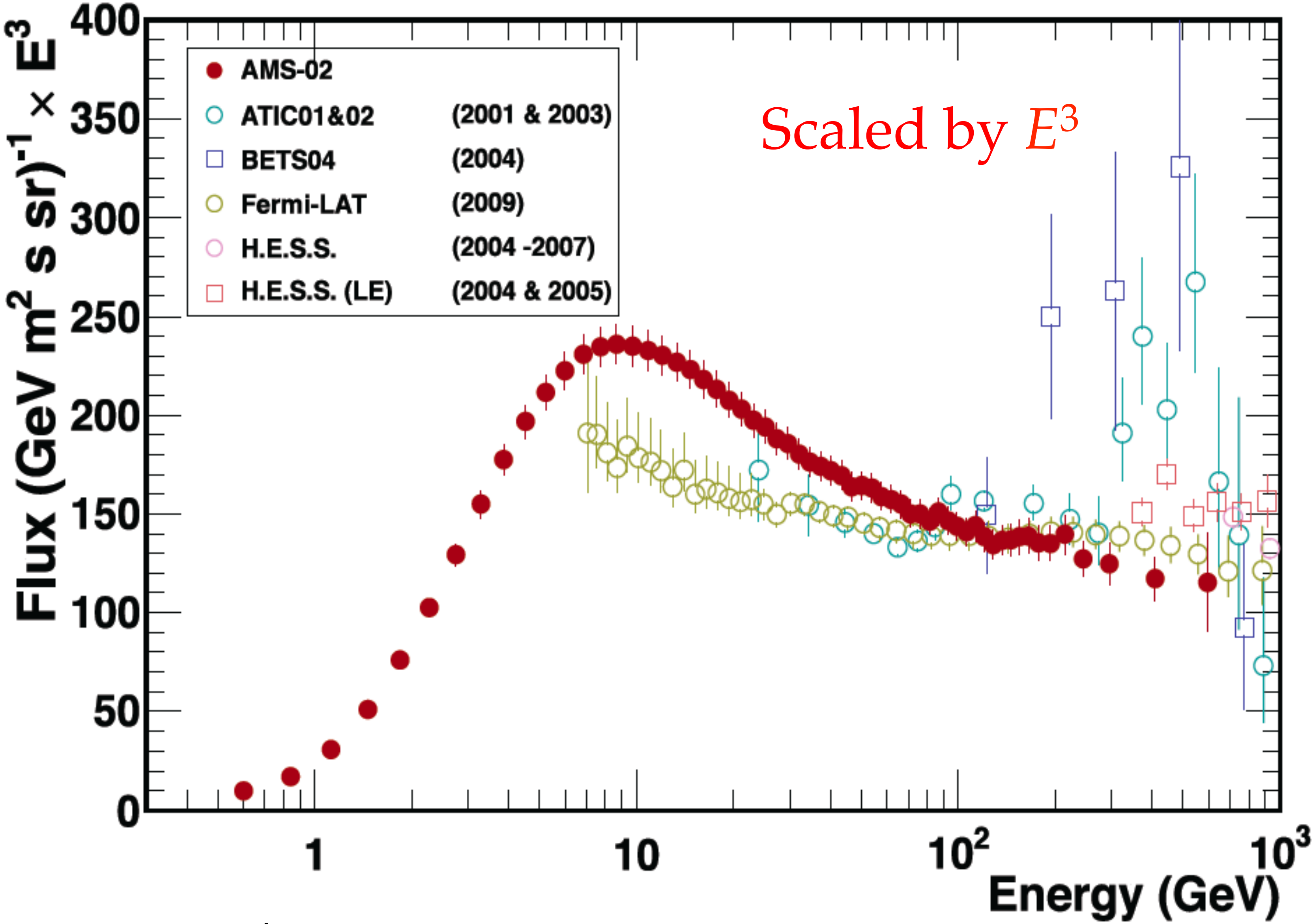

Statistical errors only

# AMS-02 Positron Flux up to 350 GeV

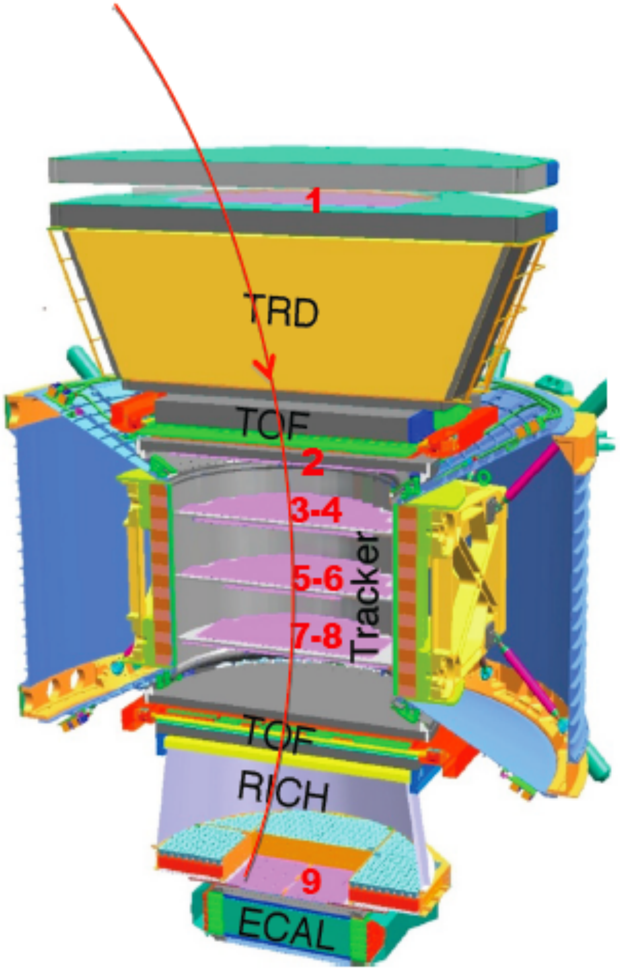



Statistical errors only

# AMS-02 lepton Flux up to 350 GeV



# AMS-02 Nuclei Measurement




Rigidity, Direction and Charge Sign

**Tracker**

Bending Coordinate Resolution 6 to 7 μm

MDR (Z=2) ≈ 3.2 TV

Velocity and Direction

**TOF**

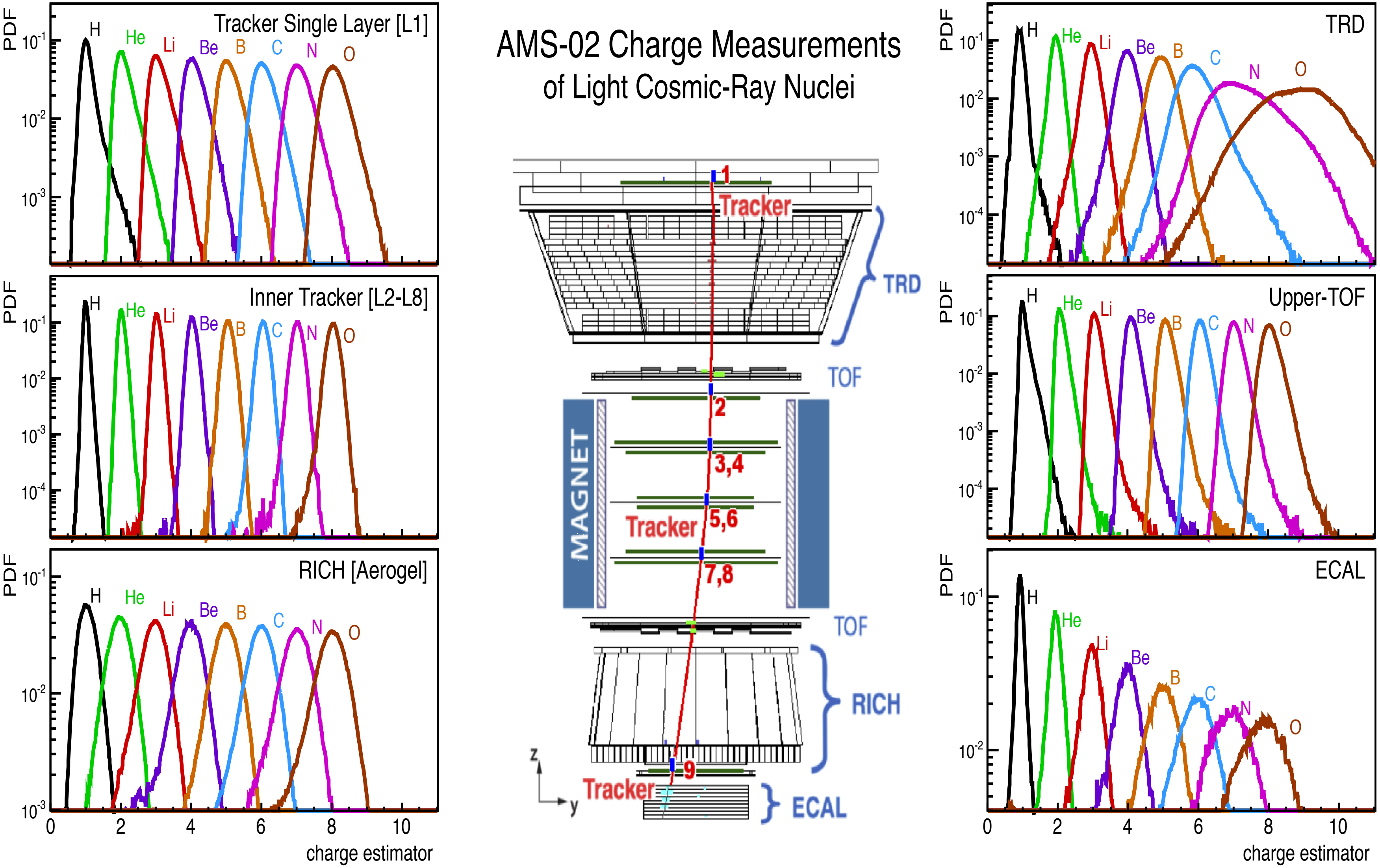
$\Delta\beta/\beta^2(Z=2) \approx 2\%$

Charge Magnitude Along He Trajectory

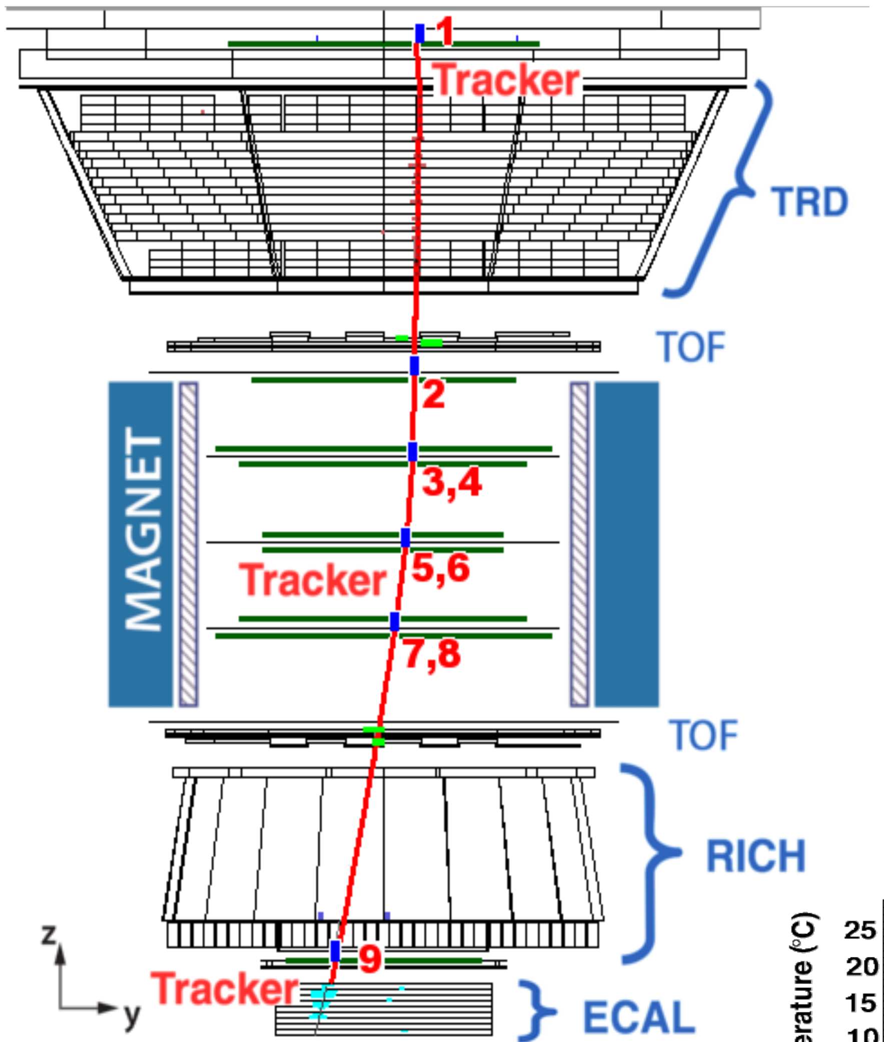
**TRD, Tracker, RICH ,TOF, ECAL**

$\Delta Z\ (Z=2) \approx 0.08\text{-}0.2$

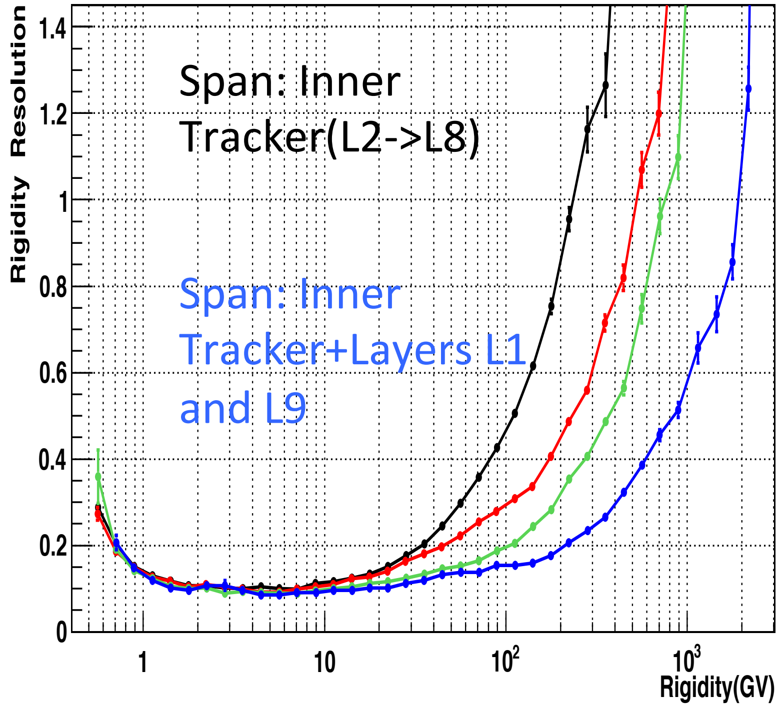
# Charge Measurement



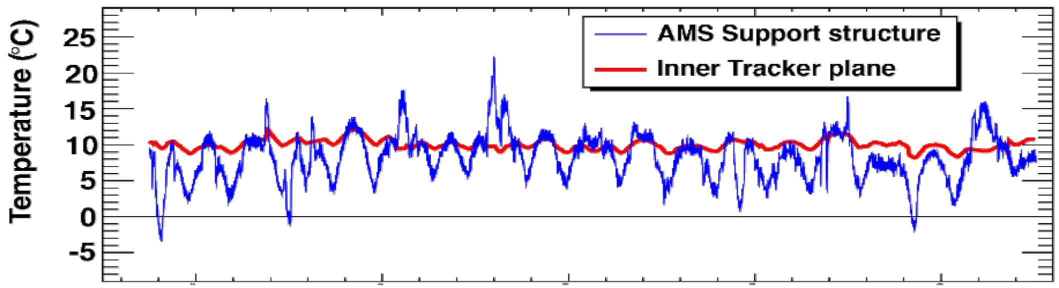
# Rigidity measurement




Track resolution depends on the number of layers included in the reconstruction




Challenge: alignment of Inner and external layers (temperature variations on the ISS)



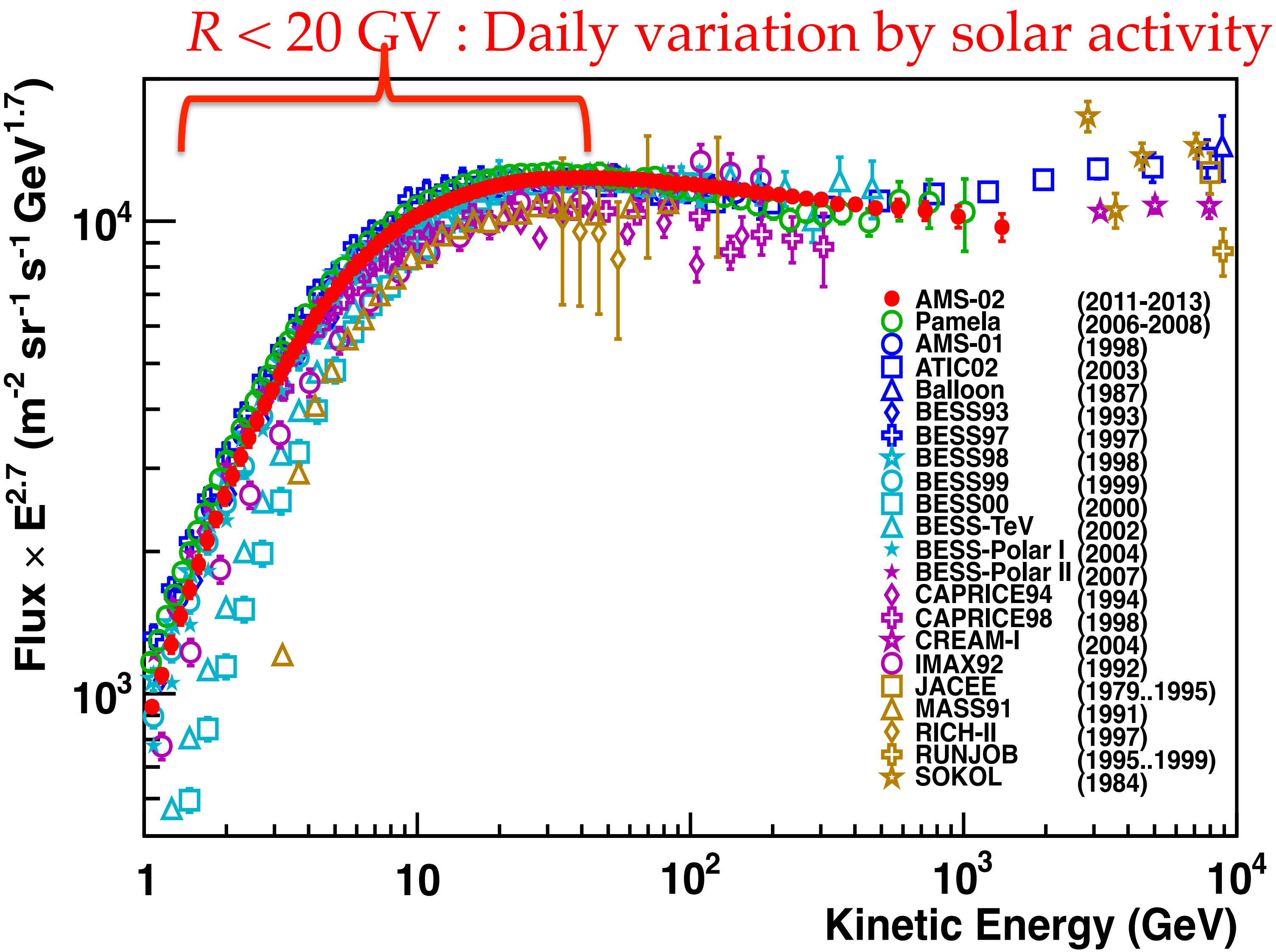
# Proton flux analysis in AMS-02

$$F(R) = \frac{N_{\mathrm{obs.}}(R)}{T_{\mathrm{exp.}}(R)\, A_{\mathrm{eff.}}(R)\, \varepsilon_{\mathrm{trig.}}(R)\, \mathrm{d}R}$$

- $F$ : Absolute differential flux ($\mathrm{m^{-2}sr^{-1}s^{-1}GV^{-1}}$)
- $R$ : Measured rigidity (GV)
- $N_{\mathrm{obs.}}$ : Number of events after proton selection
- $T_{\mathrm{exp.}}$ : Exposure life time (s)
- $A_{\mathrm{eff.}}$ : Effective acceptance ($\mathrm{m^2\ sr}$)
- $\varepsilon_{\mathrm{trg.}}$ : Trigger efficiency
- $\mathrm{d}R$ : Rigidity bin (GV)

→ Mode details in A. Ghelfi poster

# AMS-02 Proton Flux



# Cosmic ray modulation

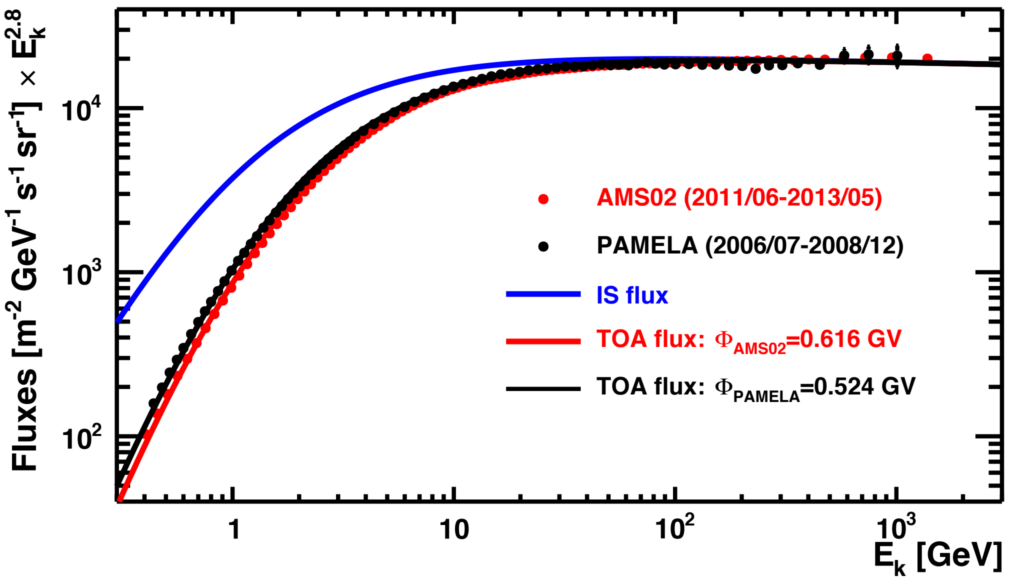
- Simplest model for Solar Modulation: Force-Field

$$J(E,t) = \frac{E^2 - M^2}{(E + \Phi(t))^2 - M^2} J^{IS}(E + \Phi(t))$$

Where $\Phi(t)$ is the modulation parameter
→ all time dependence contained in $\Phi(t)$

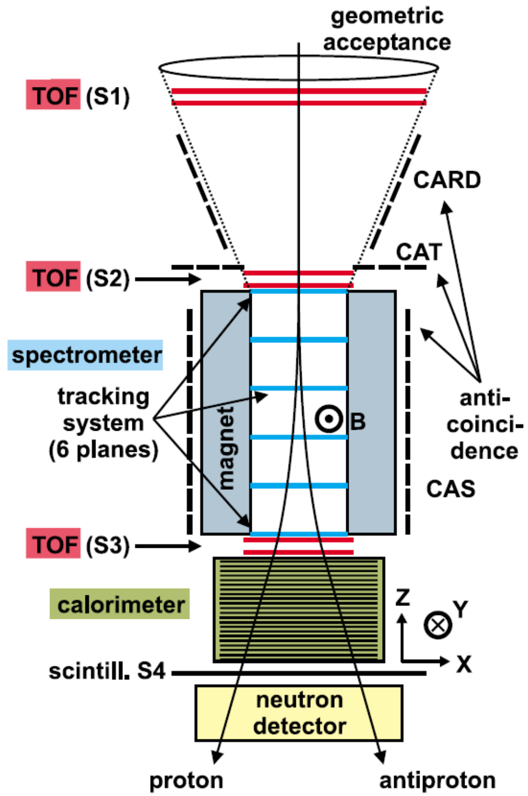
- Flux fitted on data:

$$\boxed{J^{IS}(E) = a_0 \beta^{a_1} R^{-a_2}}$$

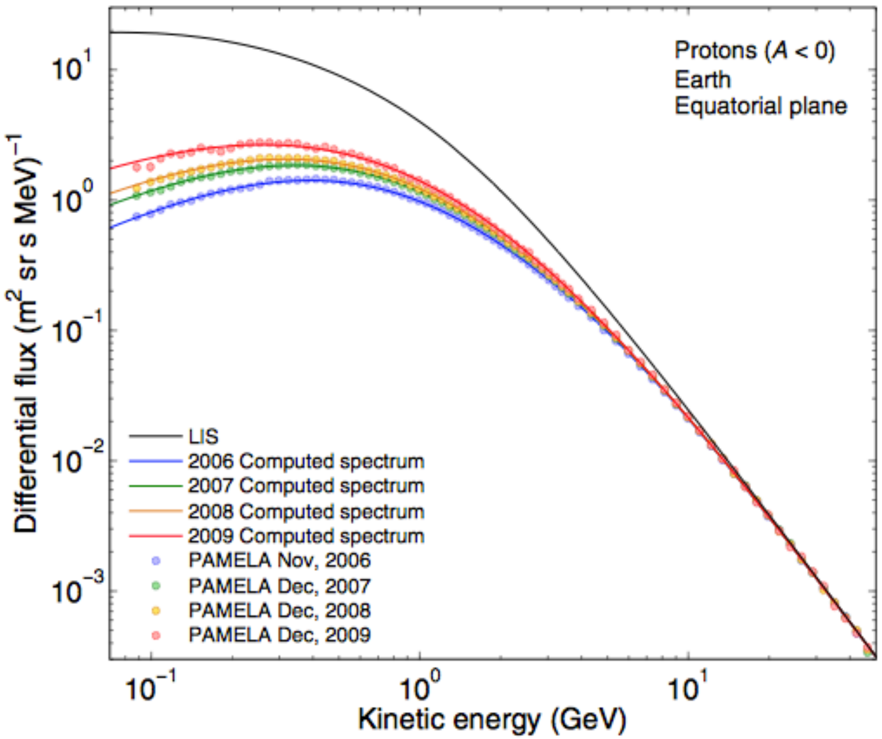



- High statistics of AMS: possibility to reconstruct a flux for each day and then to study the time fluctuation.

# Time dependence of the proton flux measured by PAMELA



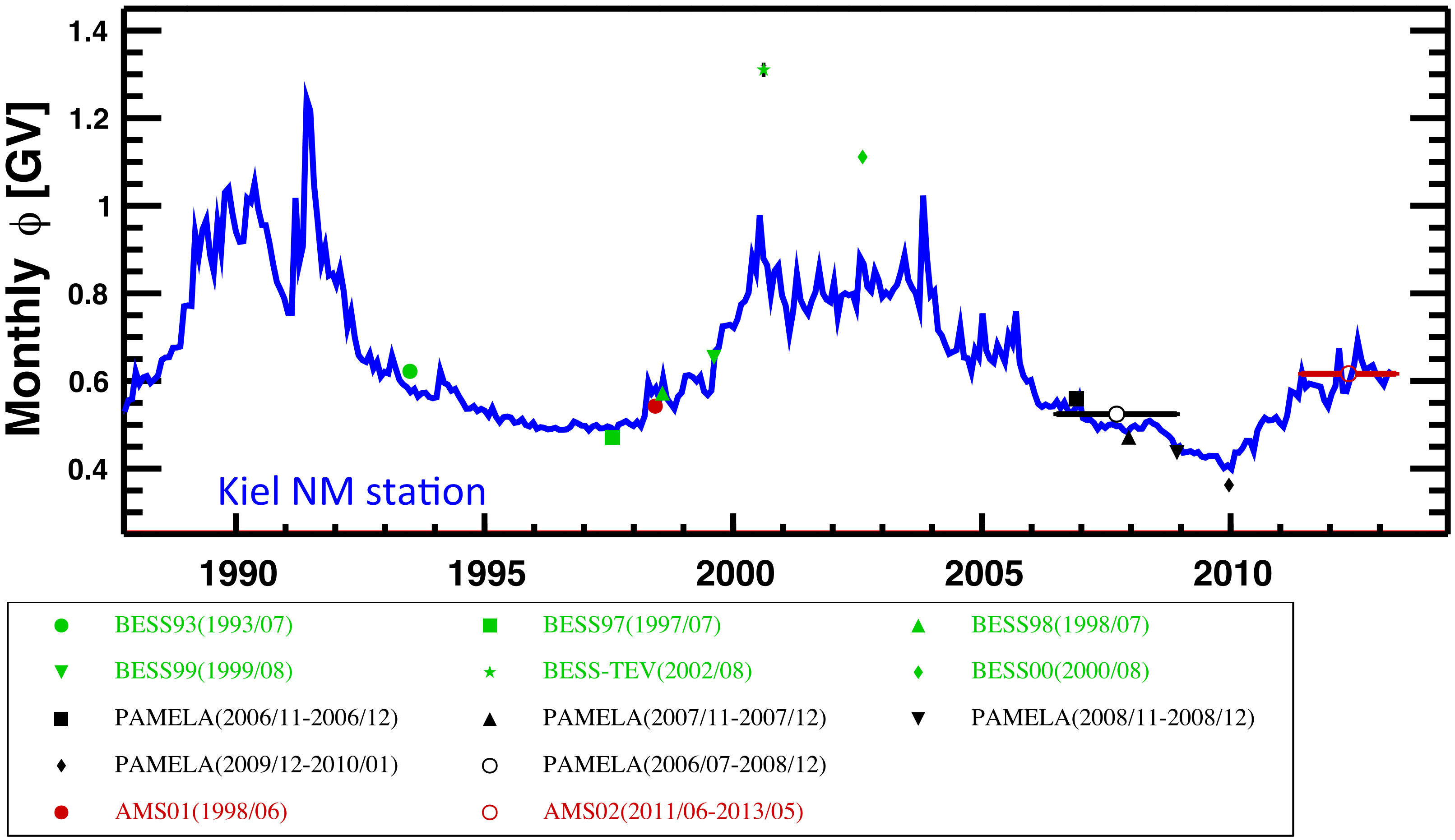

during the July 2006 - December 2009 solar minimum:




[Adriani, O. *et al.* Astrophys.J. 765 (2013)]

# Modulation of CR spectra

Comparison between Neutron Monitor and Direct measurements:

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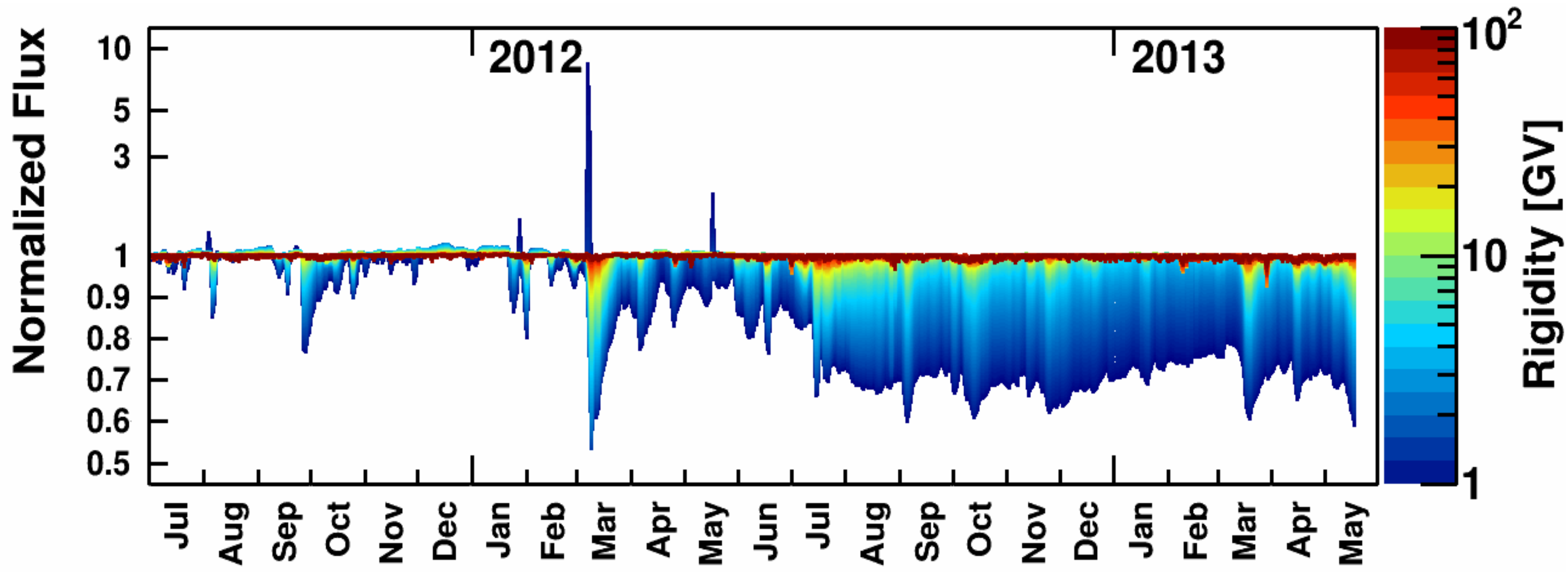
# AMS02 - Daily normalized flux

→ Mode details in A. Ghelfi poster

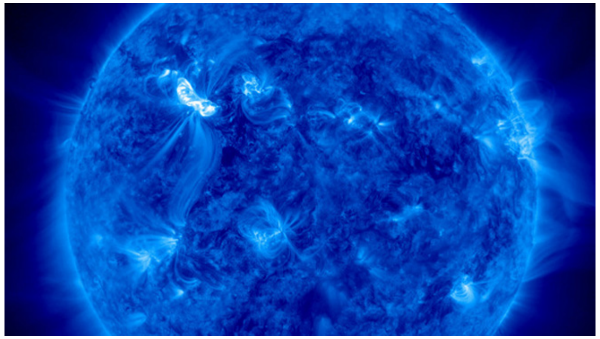
Time fluctuation of proton rate for different rigidities from AMS02 data:

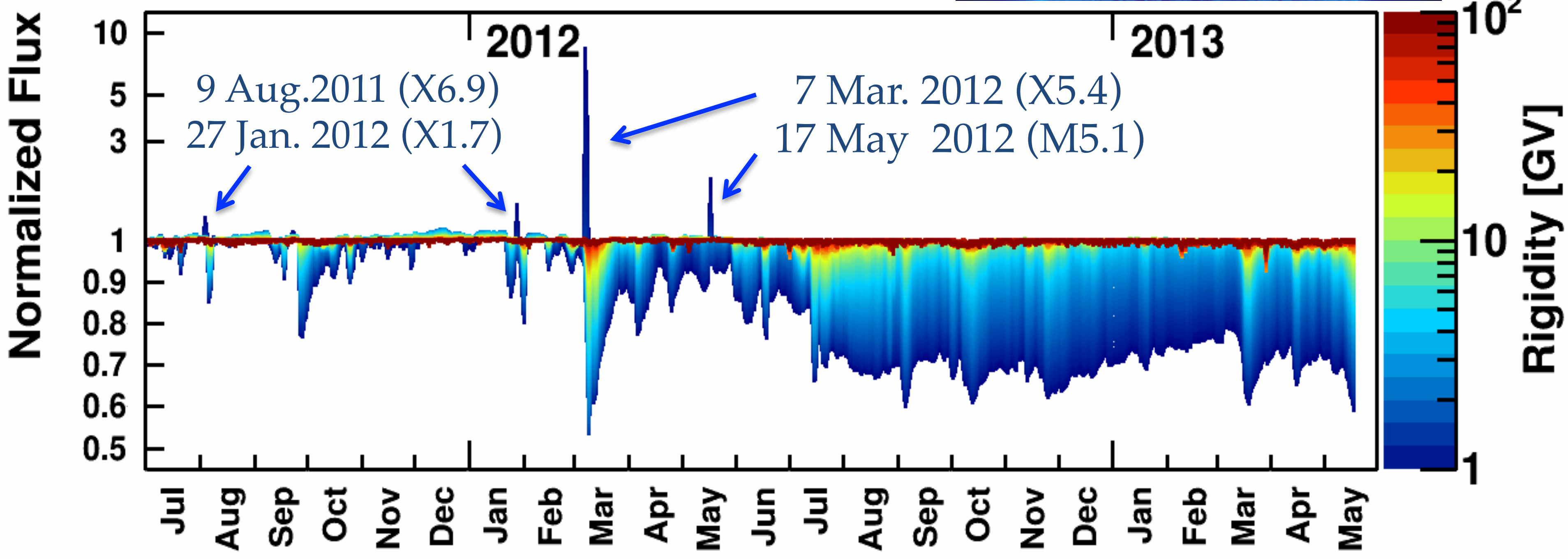



→ AMS proton daily fluxes represent a unique set of data for the Solar physics community, and to understand Solar modulation

# Daily normalized flux

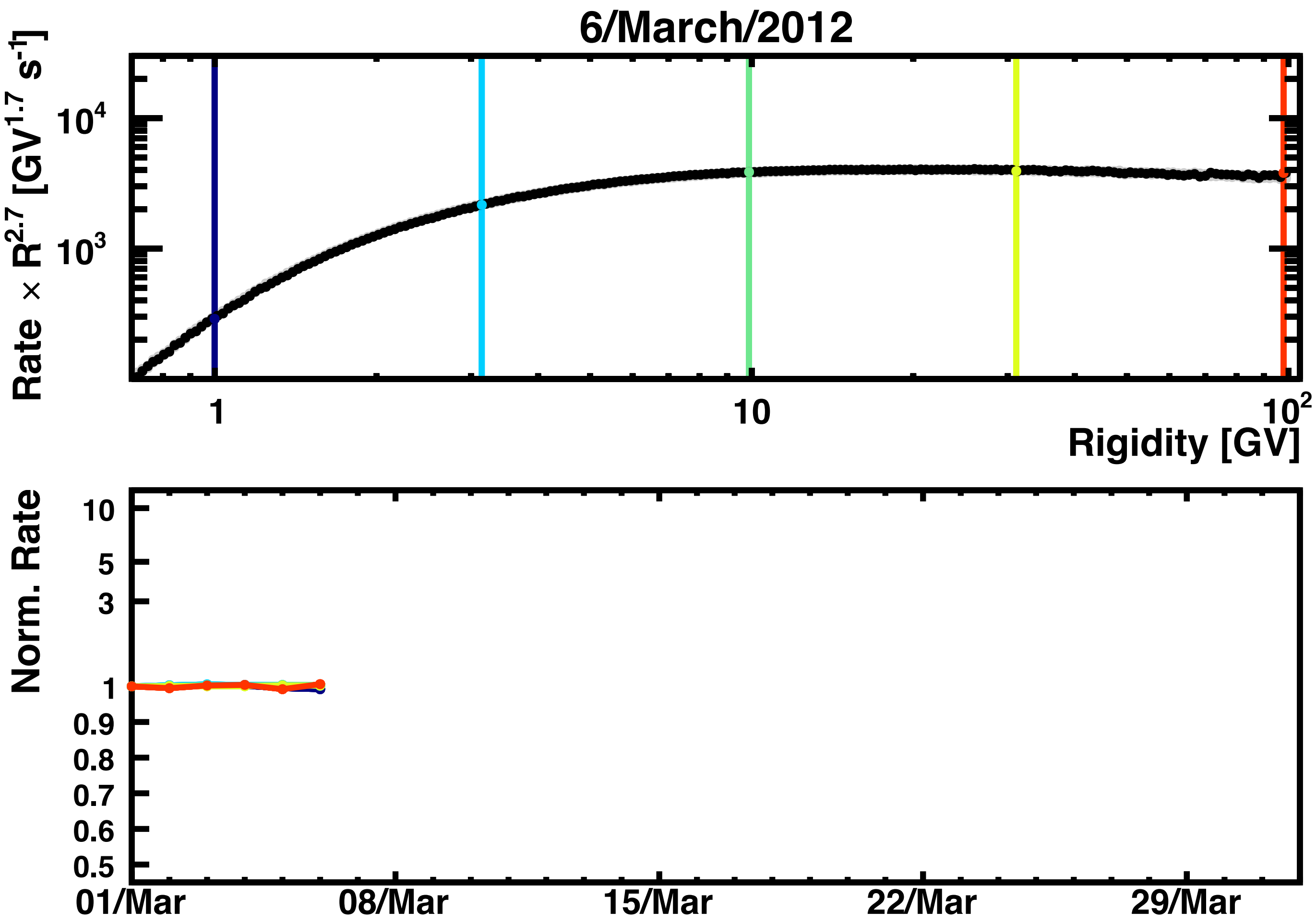
*R* < ~3 GV : Peaks associated with Solar flares (SEP)





# March 2012 solar event

Daily proton rate reconstructed from AMS02 data:



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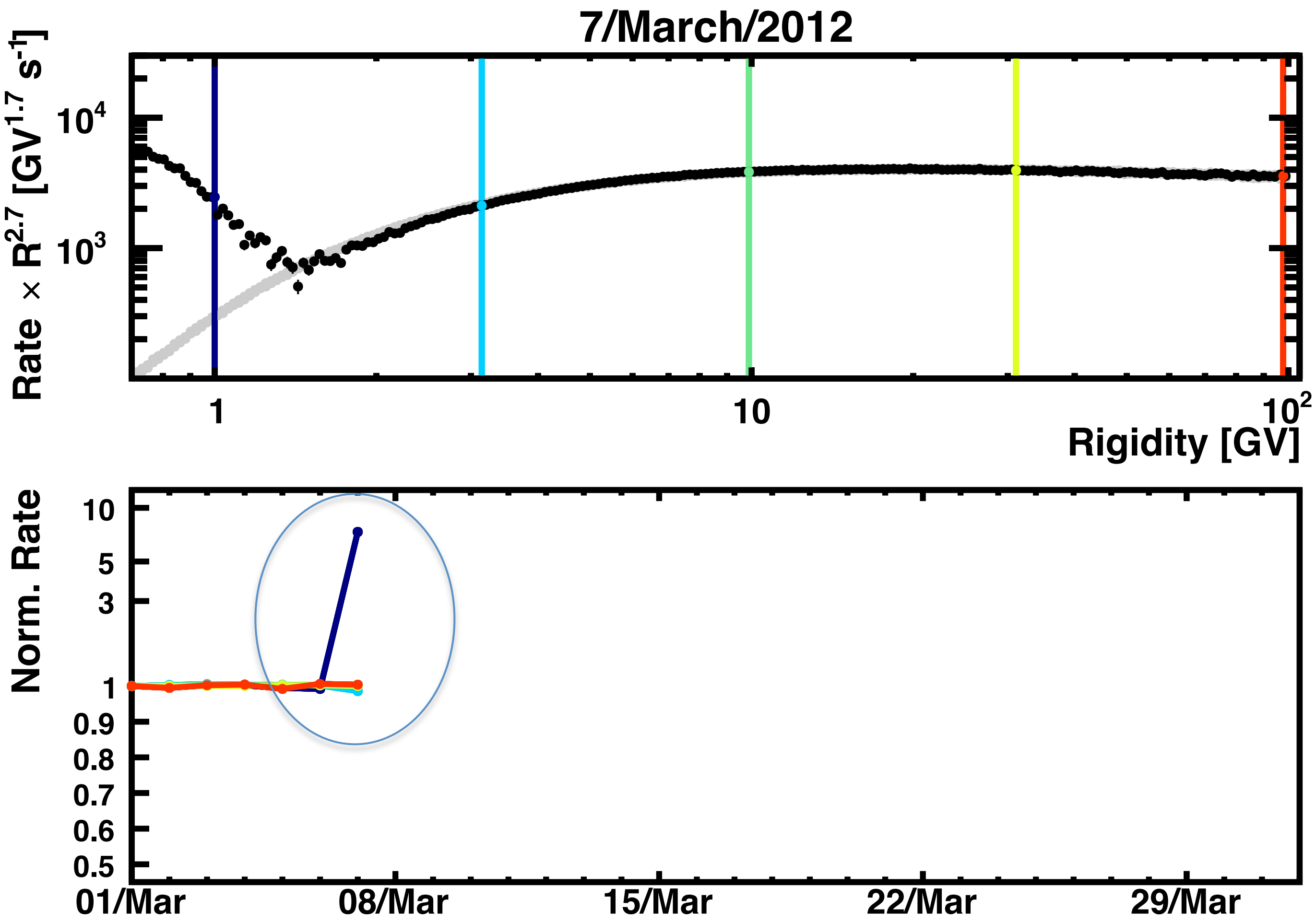


Bunch of low energy particle produced by the flare

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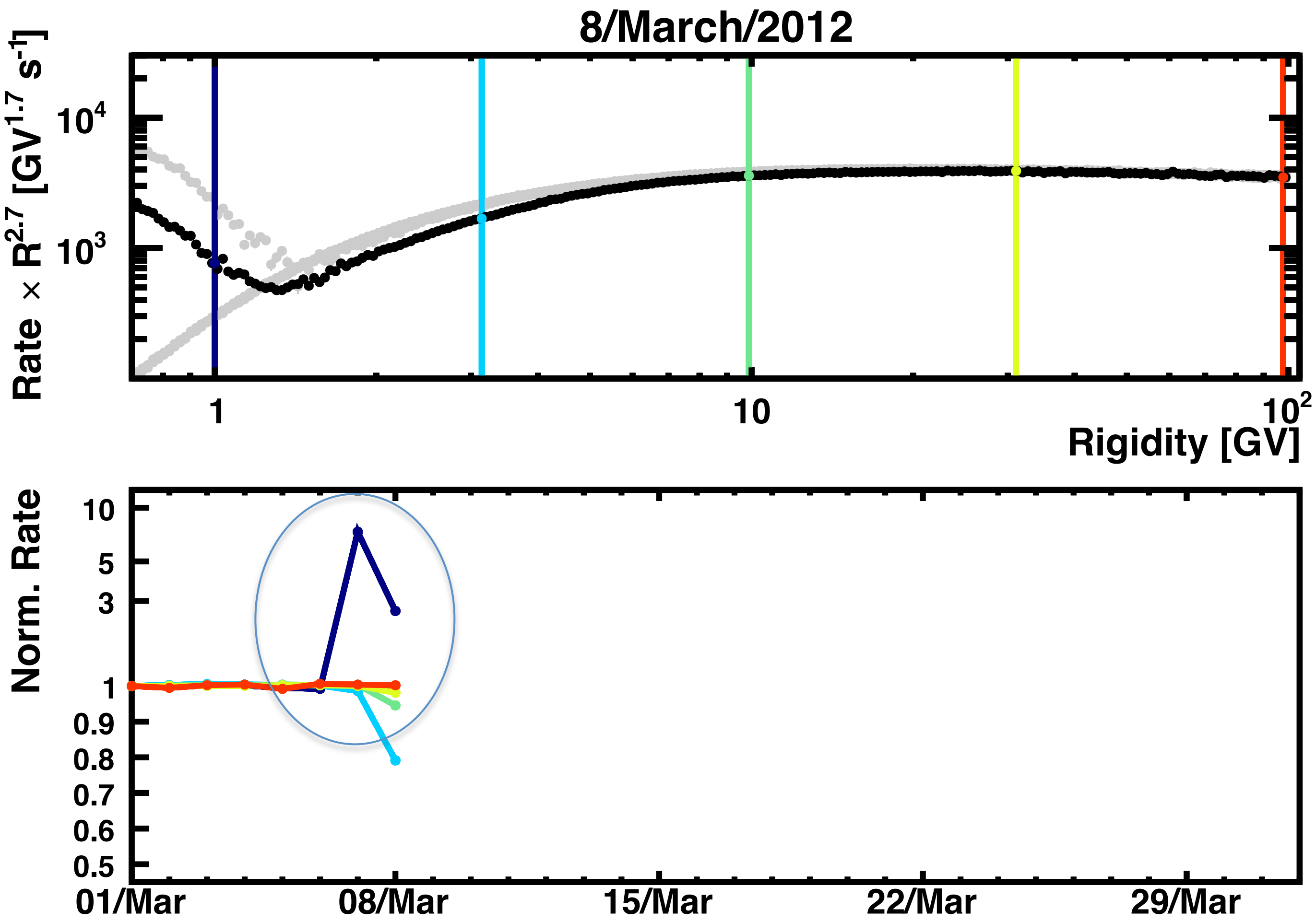


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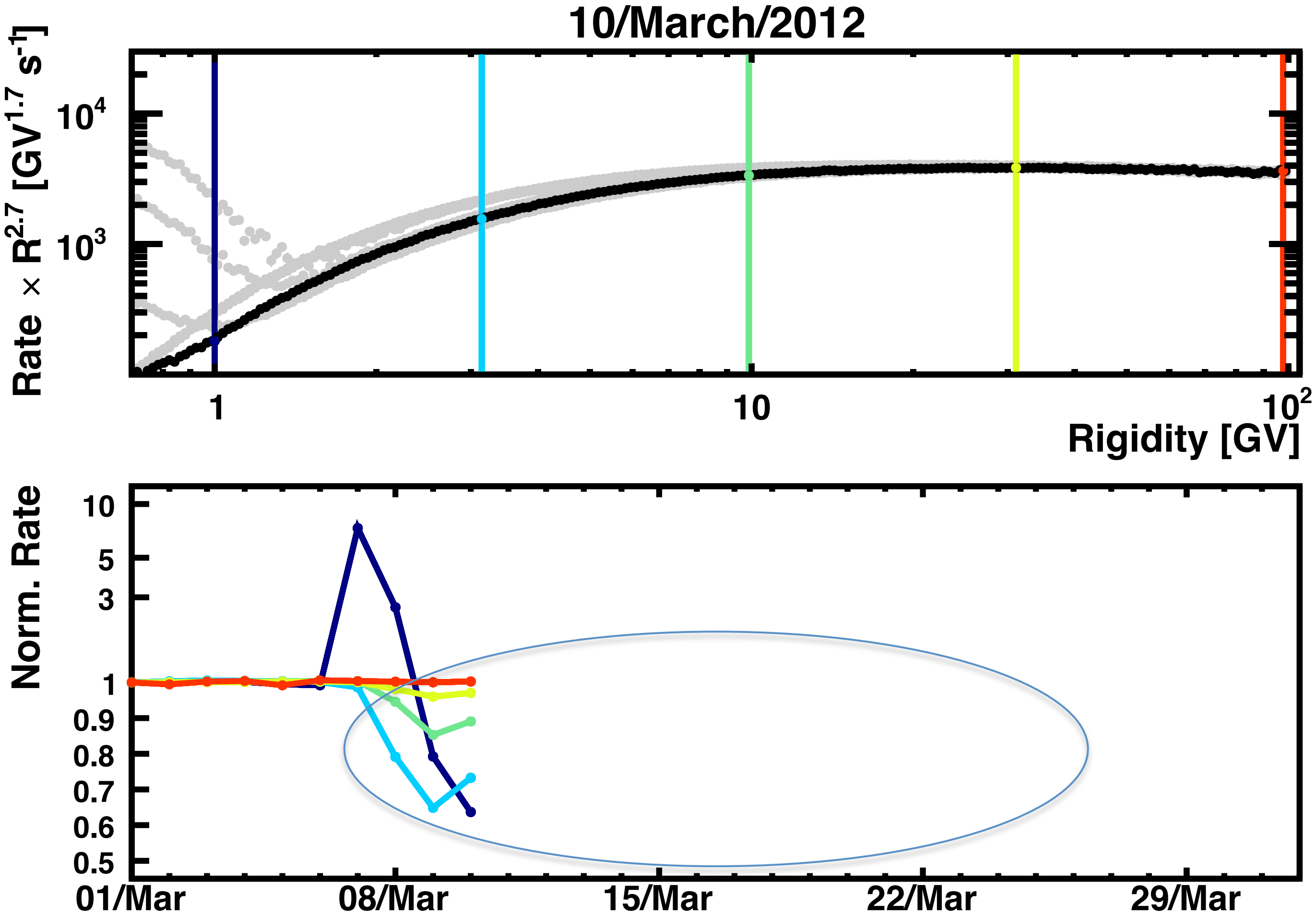


Forbush decrease (due to the large magnetic disturbance) lasting ~20 days

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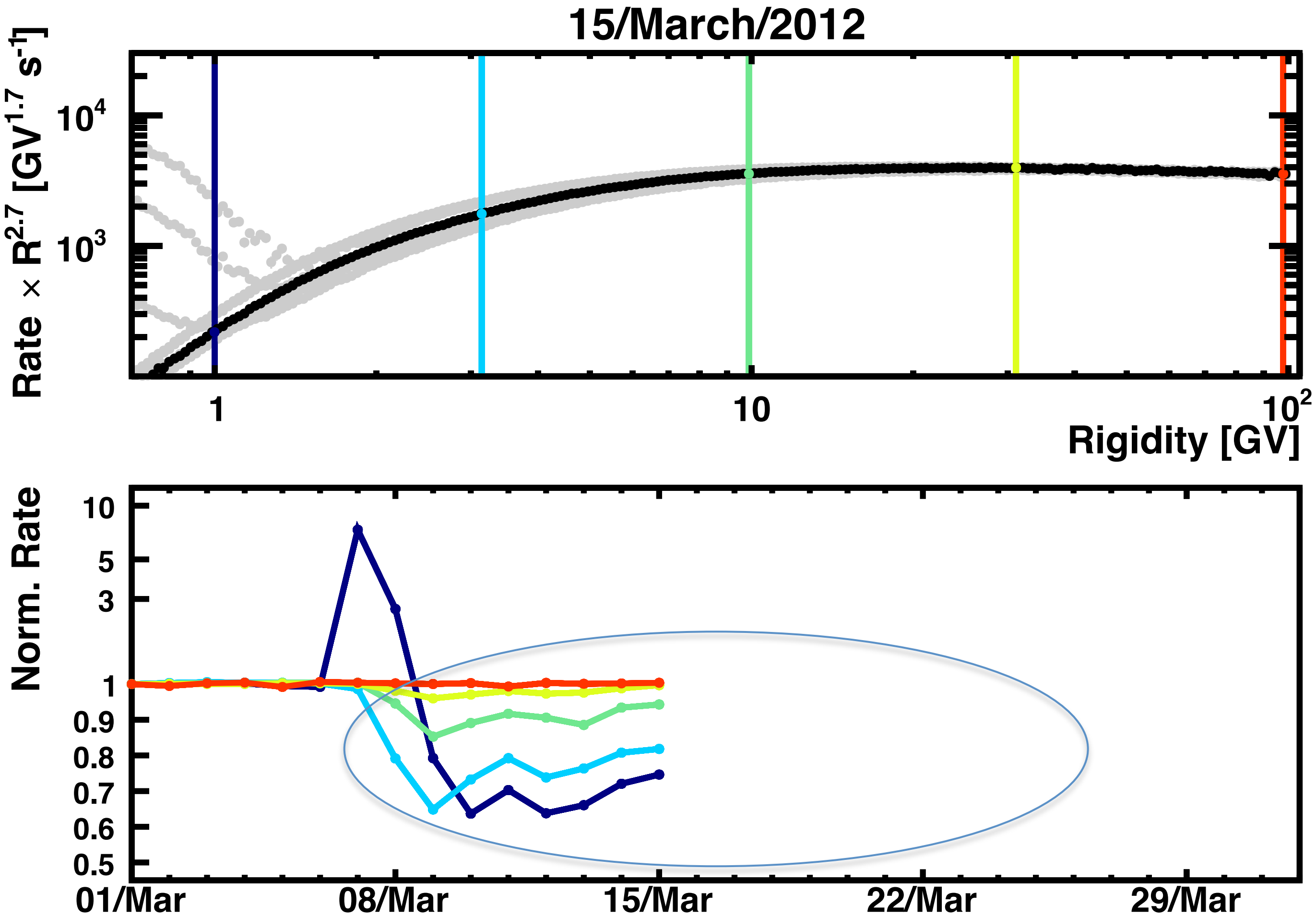
Daily proton rate reconstructed from AMS02 data:

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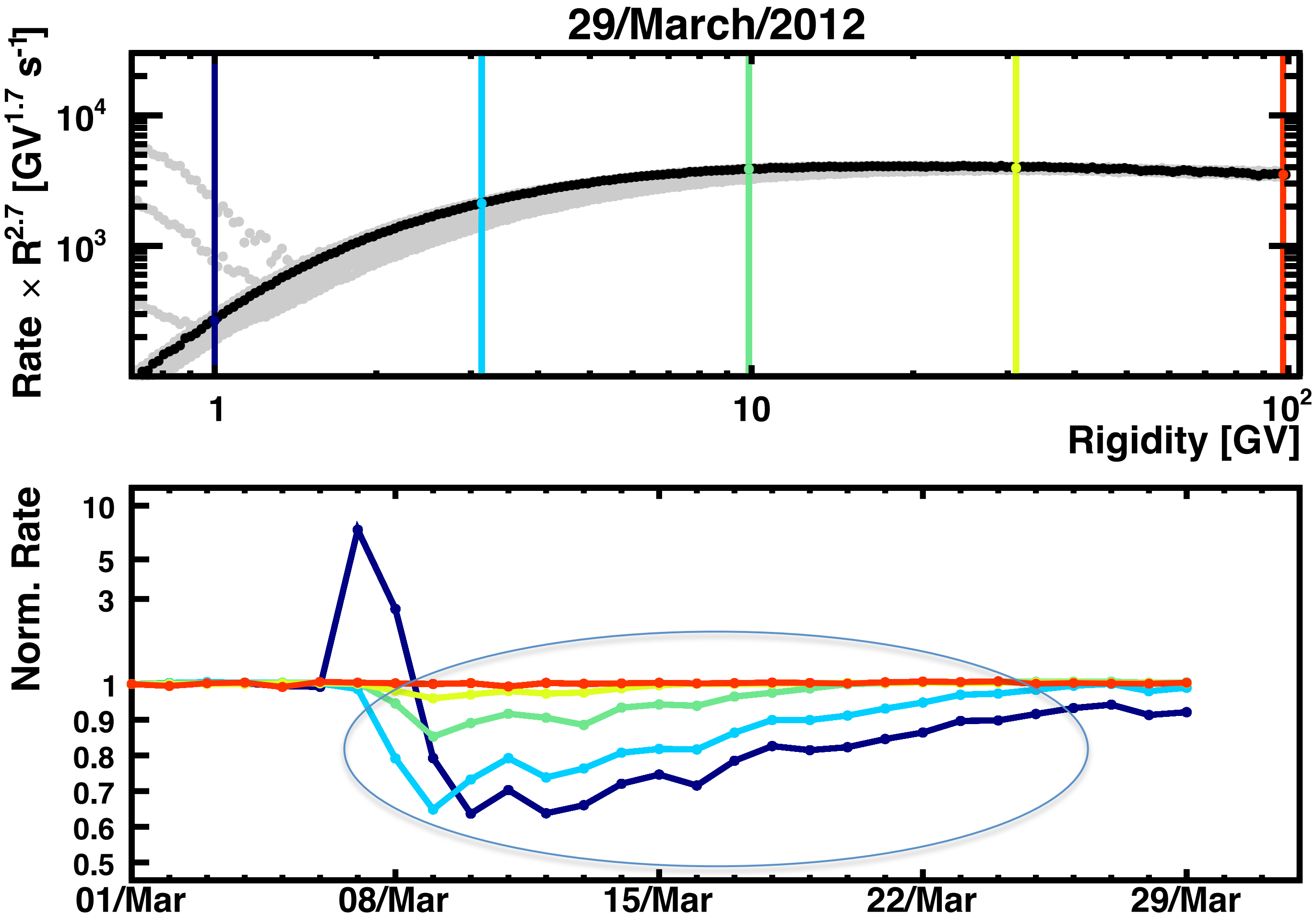
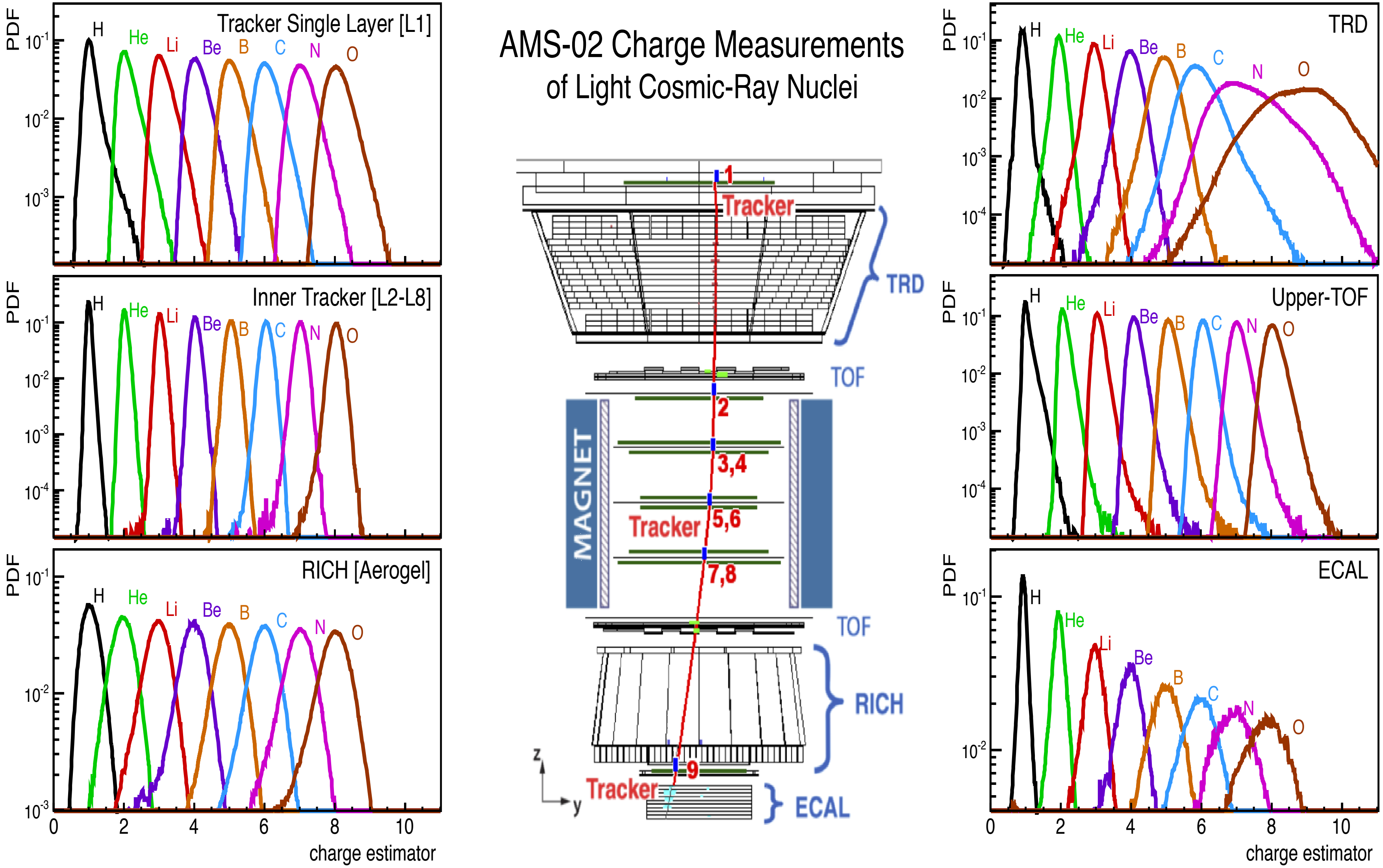


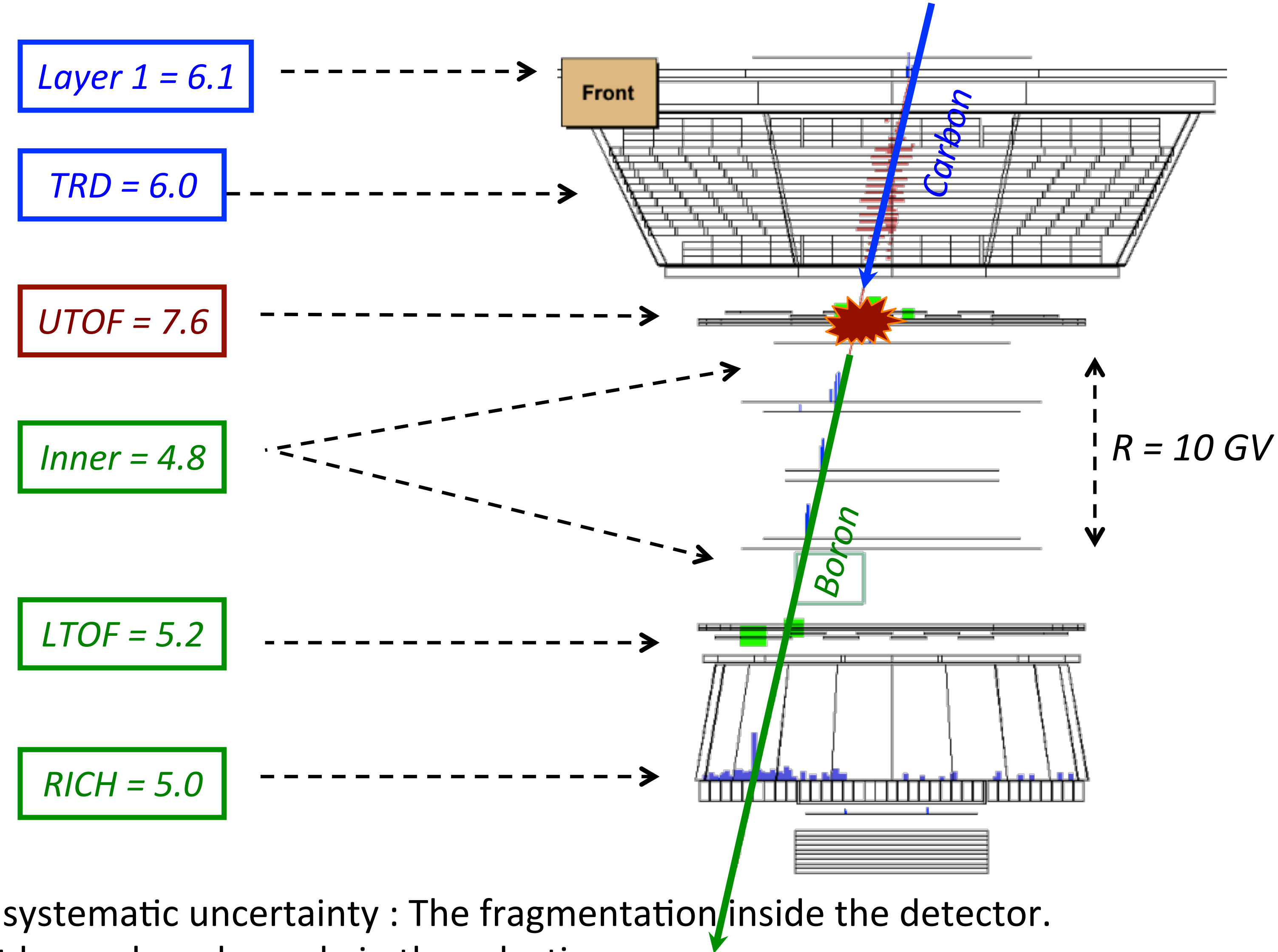

Forbush decrease (due to the large magnetic disturbance) lasting ~20 days

# B/C: Charge Measurement



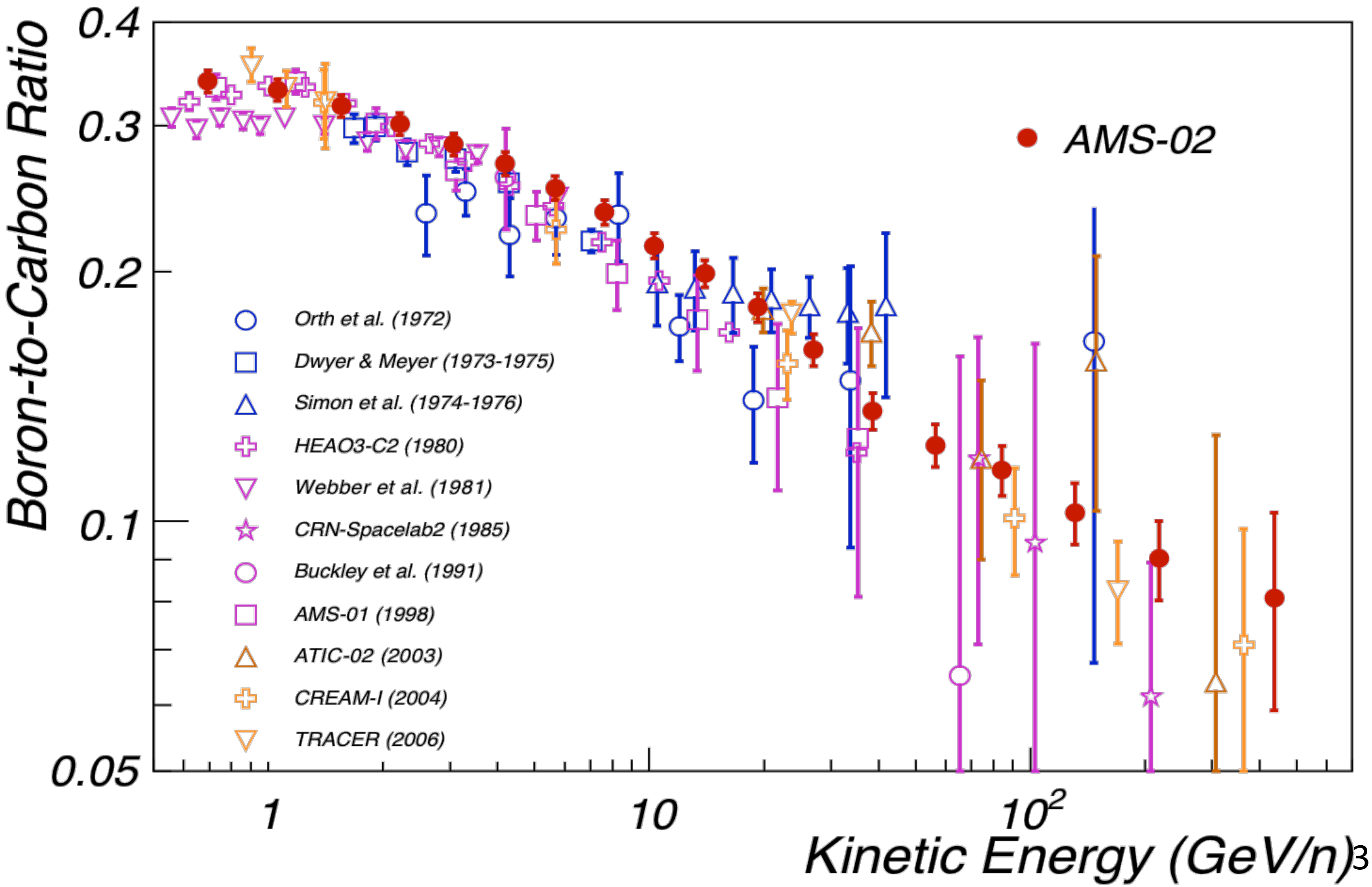

Charge measurement redundancy → Low level of charge confusion

# Fragmentation in the detector



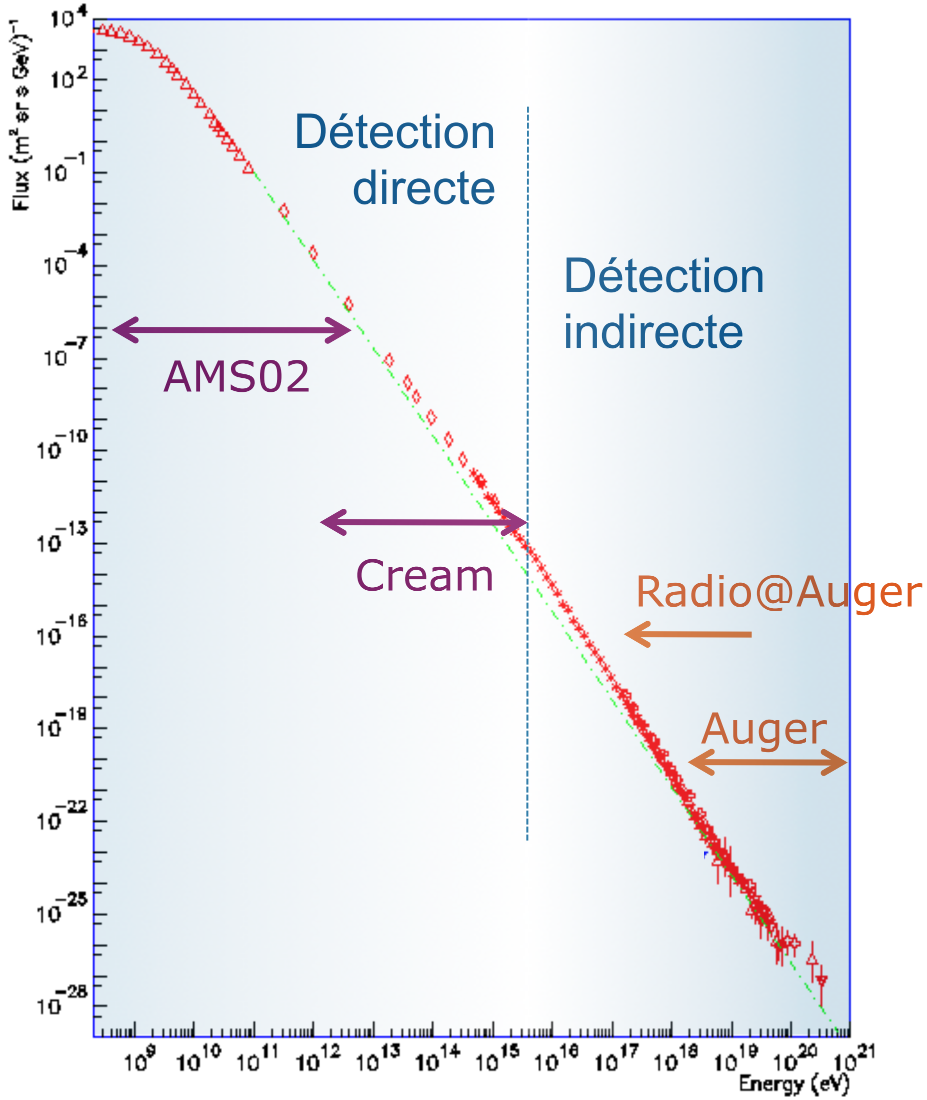

Largest systematic uncertainty : The fragmentation inside the detector.
The first layer play a key role in the selection

# AMS-02 Boron/Carbon Ratio



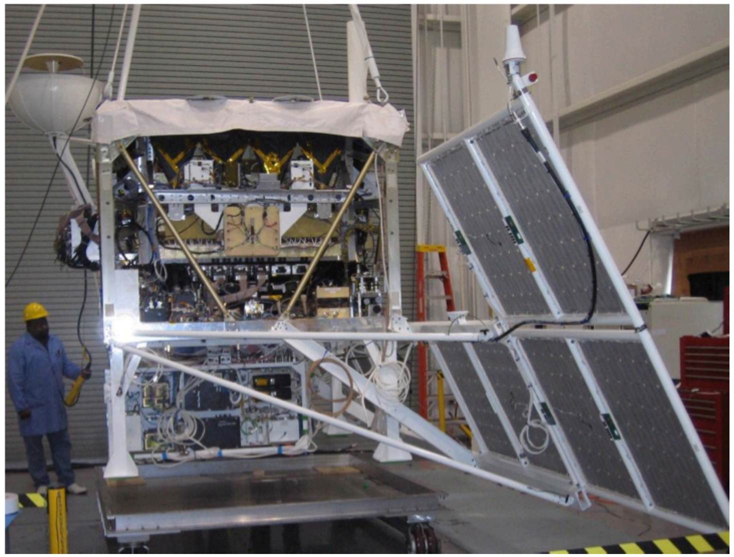
# CREAM

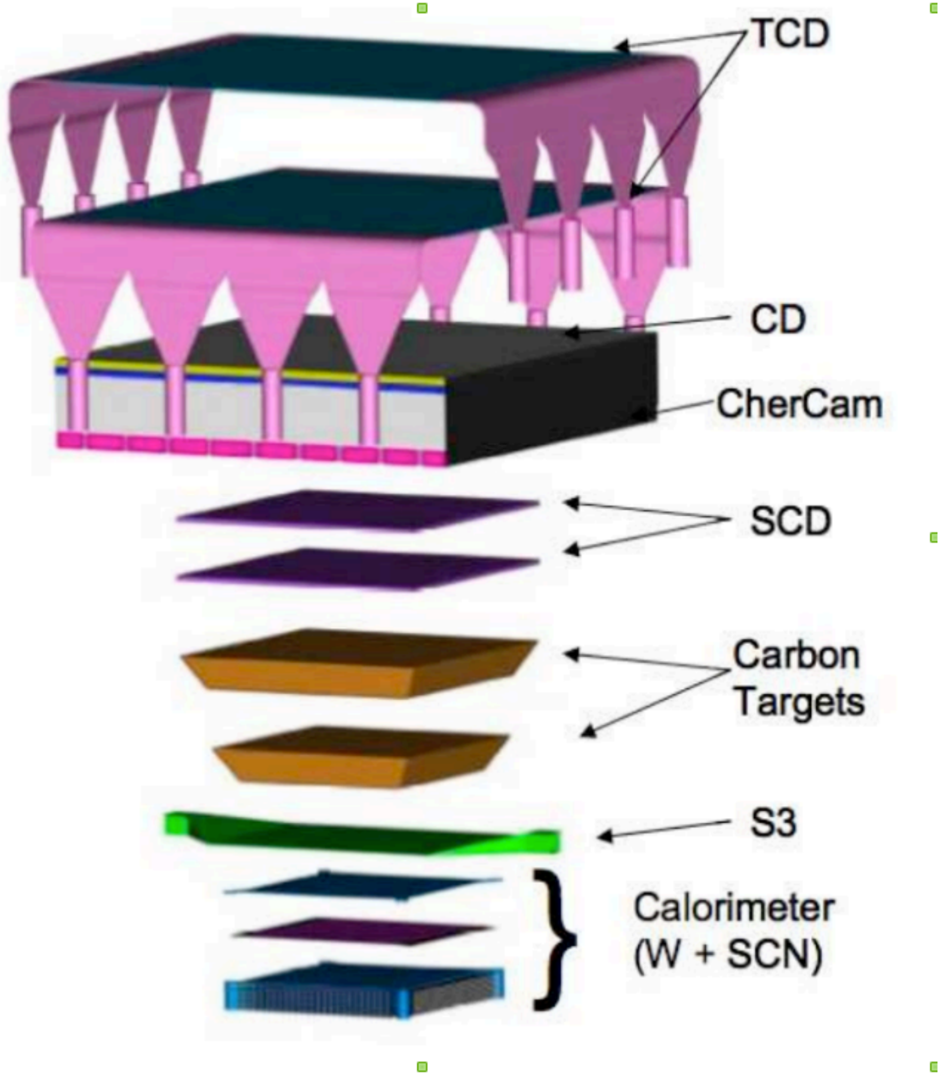
CREAM : Balloon experiment dedicated to direct measument of CR from 1 TeV to 1000 TeV



# CREAM - Instrument

- CAL : 20 layers of tungsten interleaved with layers of scintillating fiber ribbons (~20 $X_0$)
- Charge Measurement:
  - SCD: Silicon pixel detector
  - TCD: Timing-based charge detector.
- 2 configurations of the instrument:
  - TRD: Energy meas. Z>2
  - Chercam: Charge Measurement

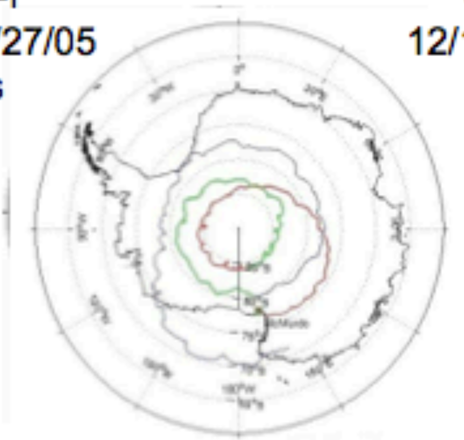




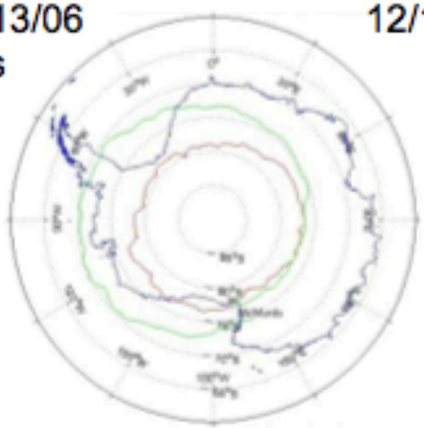
# CREAM: Flight campaigns

6 flights – total duration of 161 days.

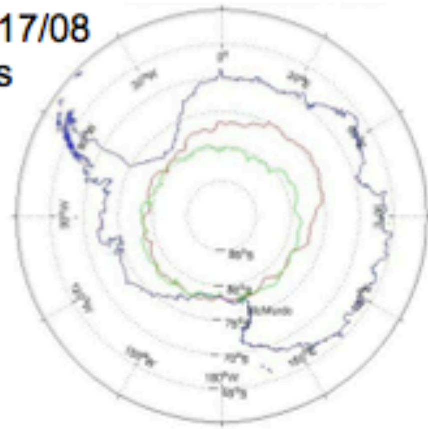
CREAM-I
12/16/04 – 1/27/05
42 days



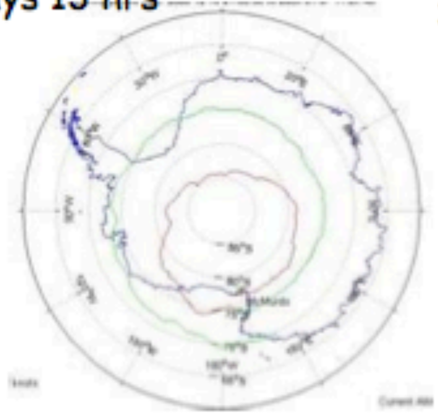
CREAM-II
12/16/05-1/13/06
28 days



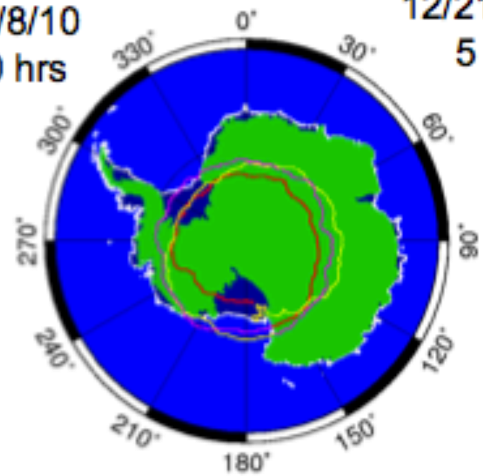
CREAM-III
12/19/07-1/17/08
29 days



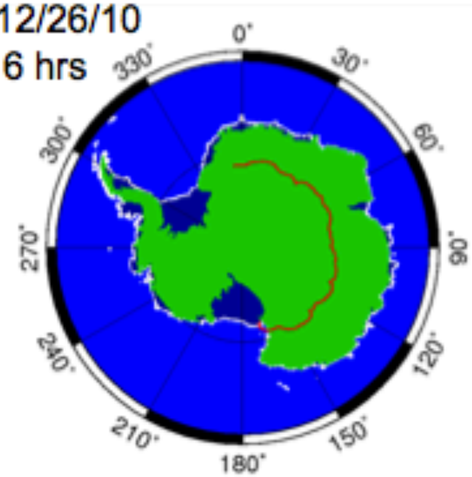
CREAM-IV
12/19/08 - 1/7/09
19 days 13 hrs



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

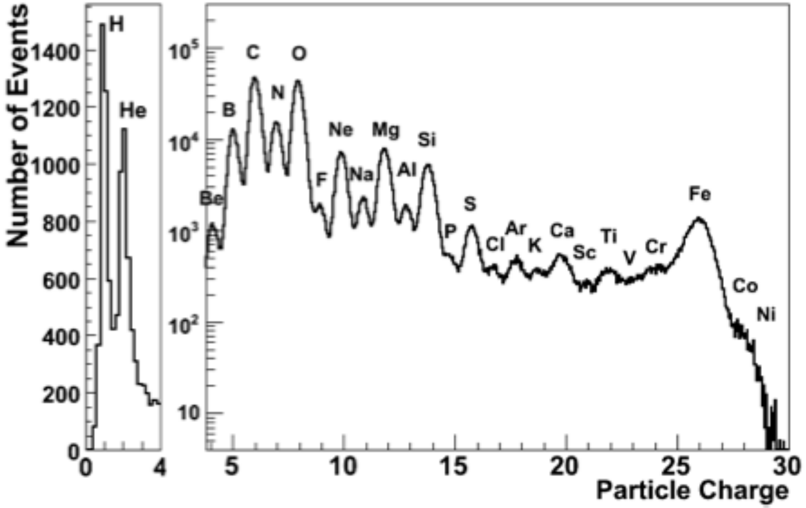



CREAM-VI
12/21/10 – 12/26/10
5 days 16 hrs

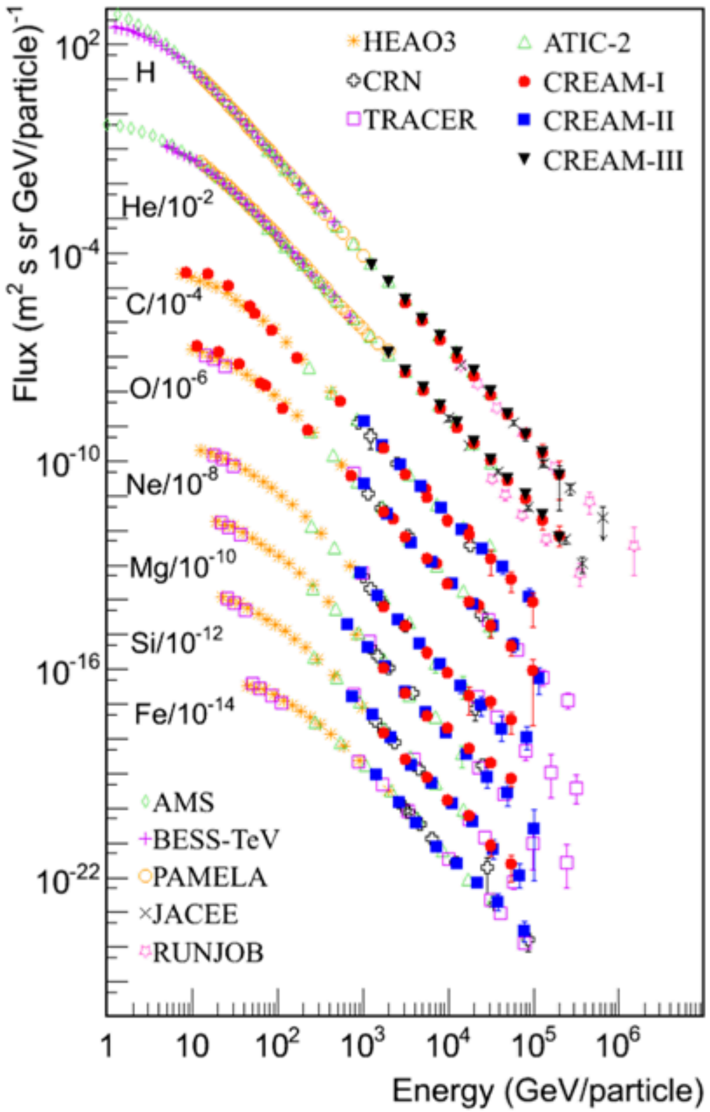


# CREAM: results

- Charge identification:

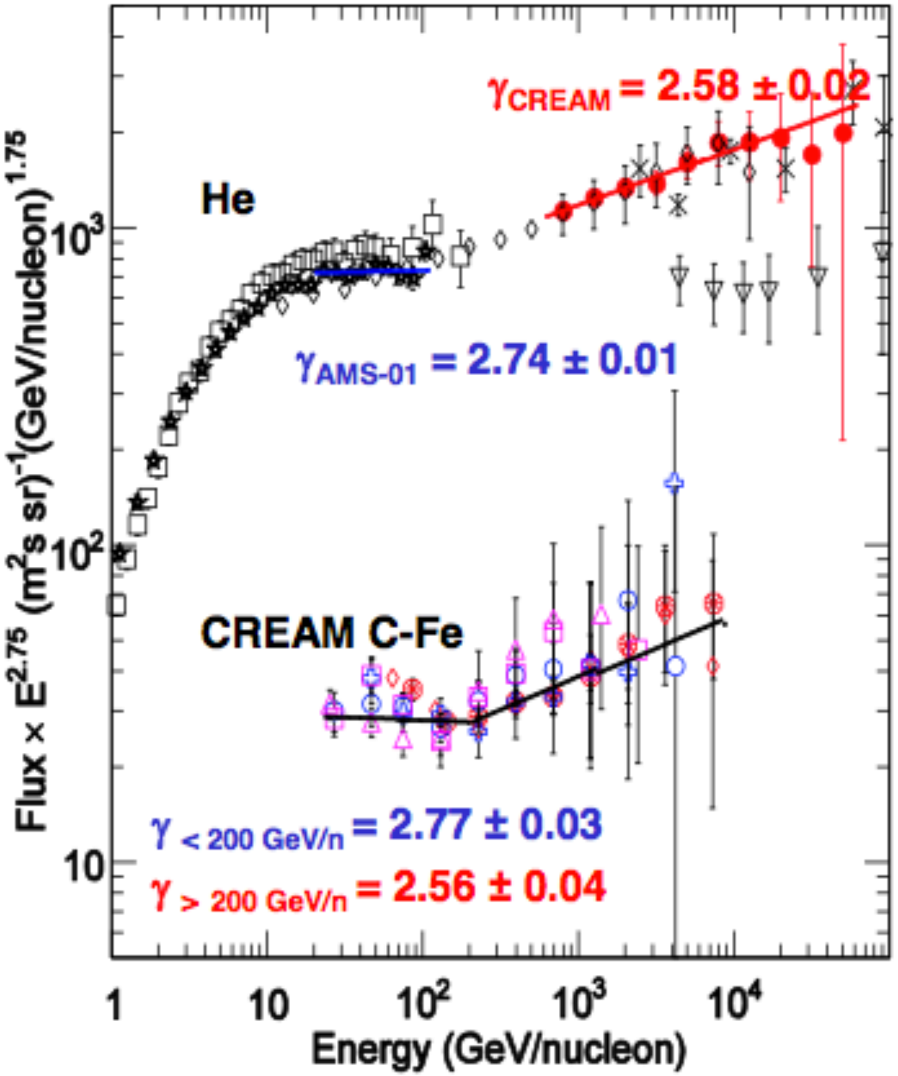


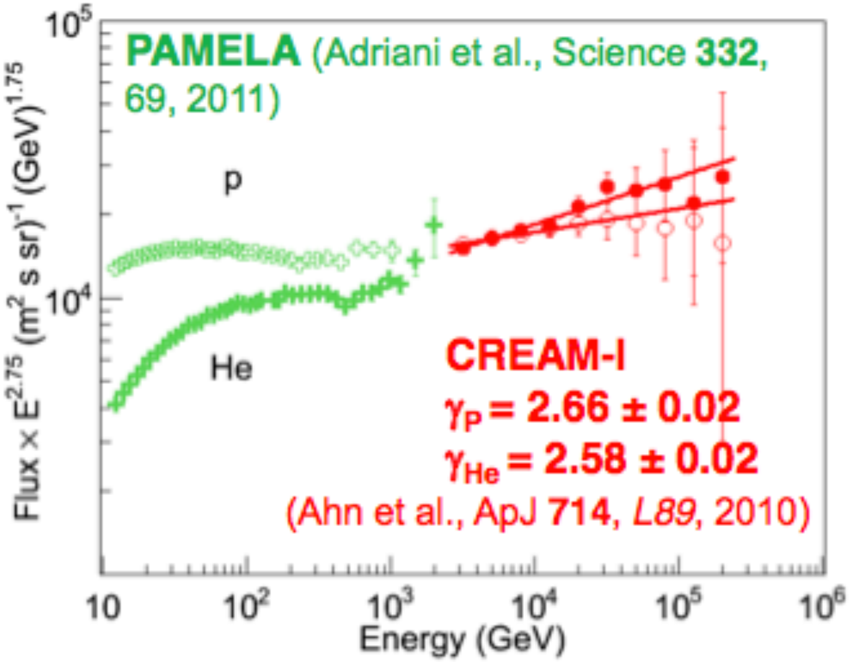

- Mesure from H to Fe over 3 decades in energy.



# CREAM: results

Yoon et al. ApJ **728**, *122*, 2011; Ahn et al. ApJ 714, L89, 2010




- Features (breaks, He harder than p) in the spectra which challenge classical acceleration and propagation models.

# Future experiments

## Balloon-borne Experiments

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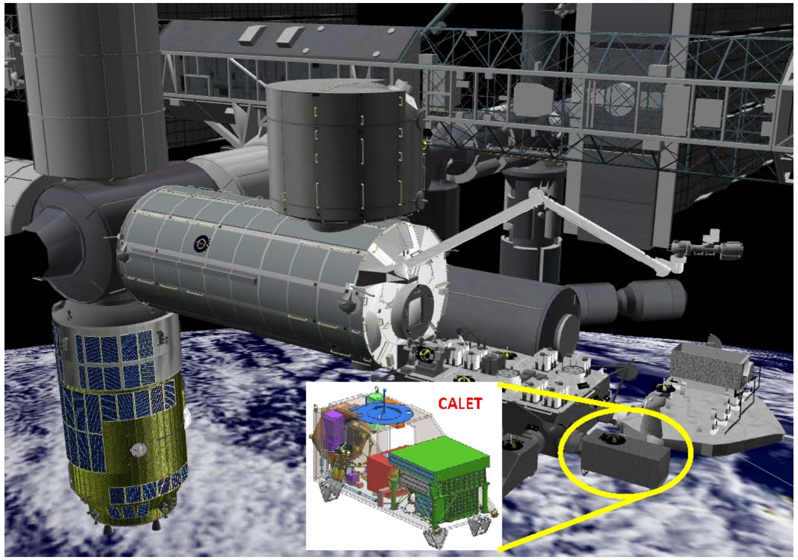
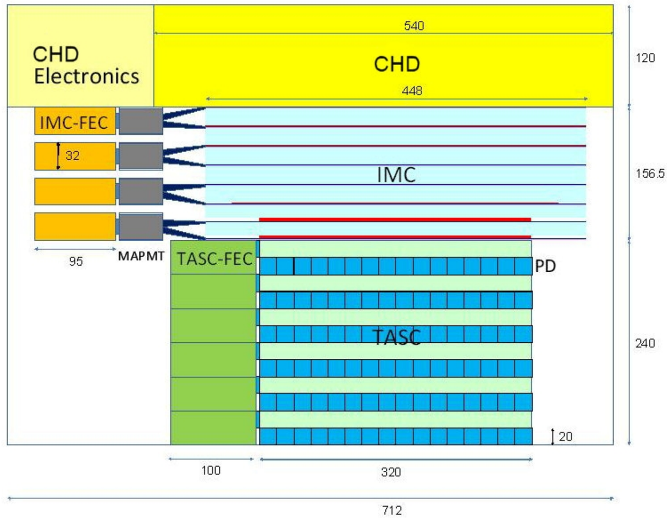
- FERMI (2008-?)
- AMS02 (2011-?)
- CALET (2015-....)
- ISS-CREAM (2015-...)

# Future experiments: CALET (2015-…)

- The CALorimeteric Electron Telescope (CALET) : High Energy Electron and Gamma-Ray Telescope
- To be launch in Feb. 2015 (H-II-B rocket / H-II Transfer Vehicle)
- To be Installed on JEM-EF




- Instruments:
  - Charge Detector (CHD) Z=1-40
  - Imaging Calorimeter (IMC) $3X_0$
  - Total Absorption Calorimeter (TASC) $27X_0$

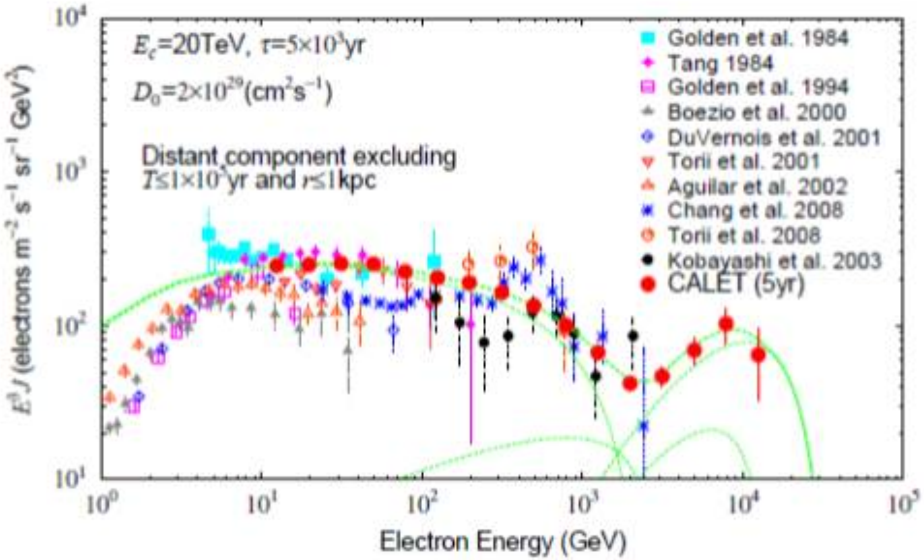


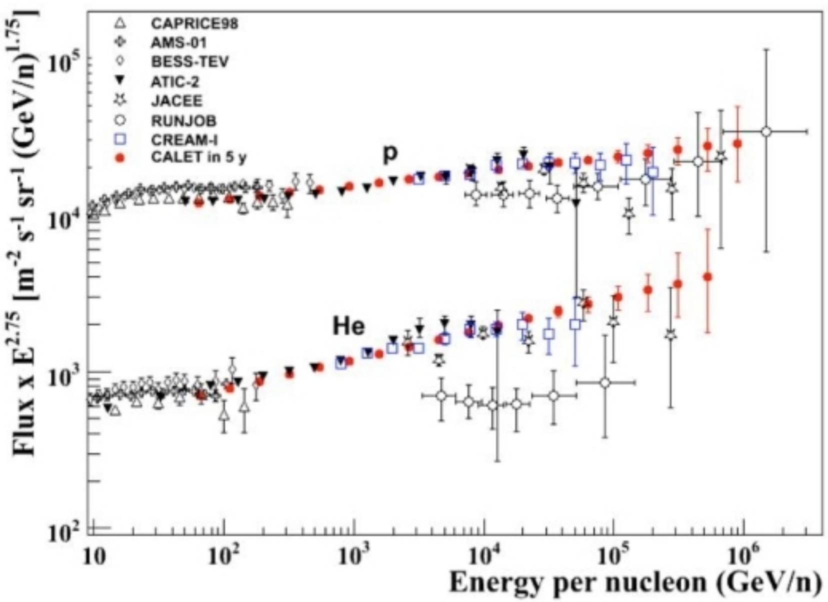
# Future experiments: CALET (2015-...)

**Observations:**

- Electrons : 1 GeV - 10 TeV
- Gamma-rays : 10 GeV-10 TeV
- Protons, Heavy Nuclei:

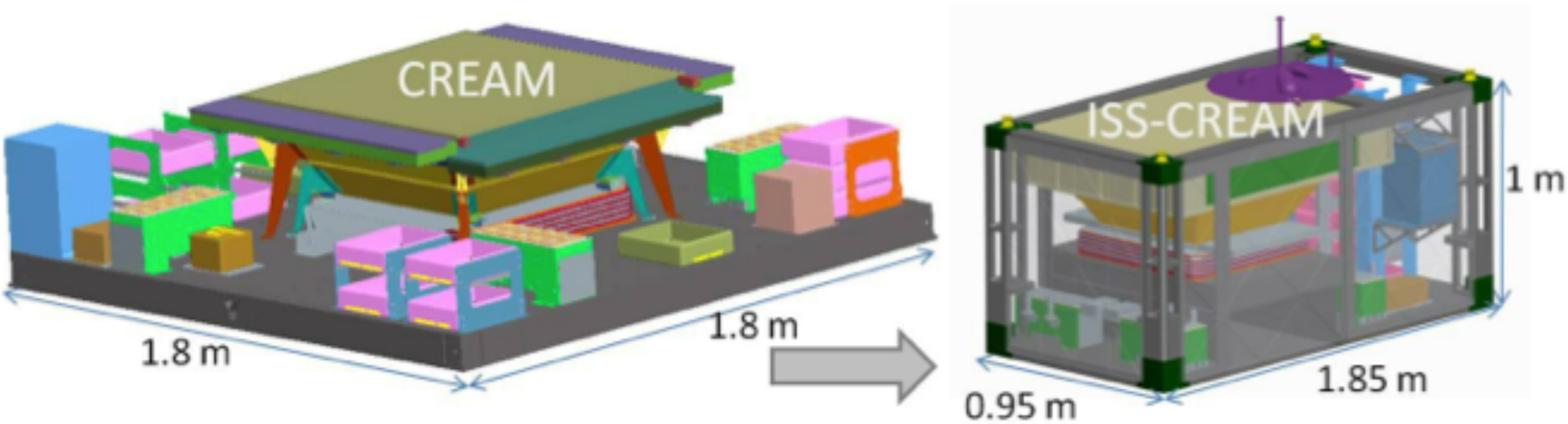
  several 10 GeV- 1000 TeV



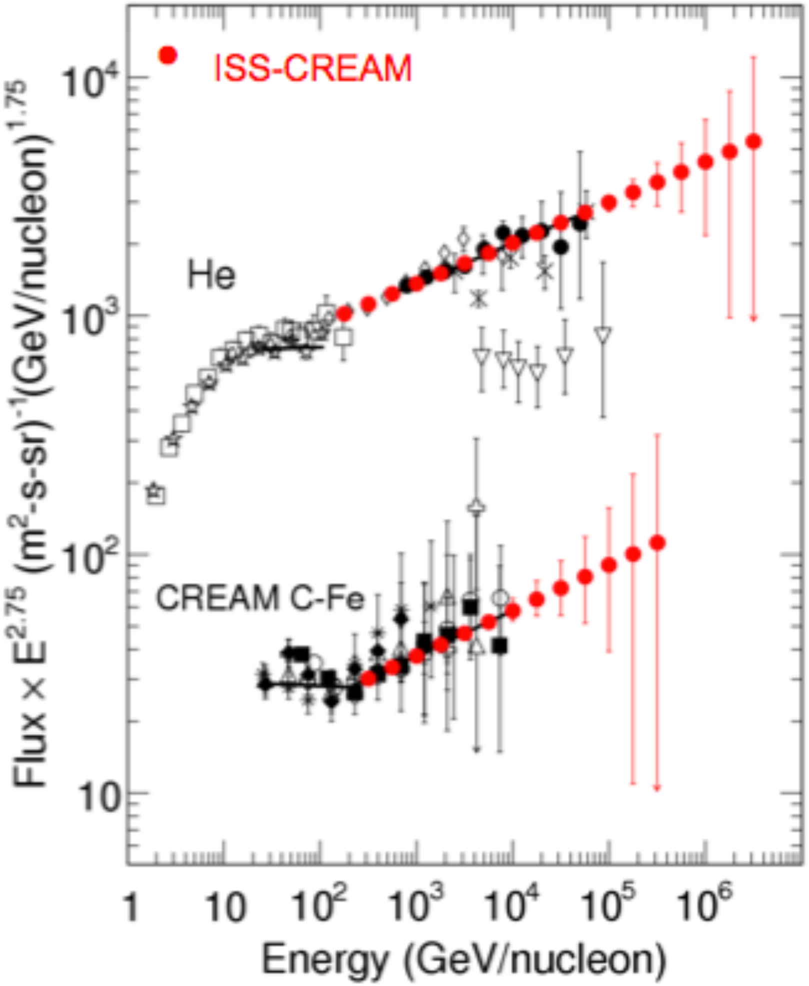
# Future experiments: ISS-CREAM

- Rearrangement of the balloon experiment for ISS
- CREAM calorimeter including carbon targets for energy measurements and four layers
- 4 layers of finely segmented SCD (Silicon Charge Detector) for charge measurements



# Future experiments: ISS-CREAM

- Launch (Space X Dragon cargo) in december 2014
- To be installed on JEM-EF for a period of at least three year
- The elemental spectra for Z = 1–26 nuclei over the energy range $10^{11}$ to $10^{14}$ eV
- Additional capability for electron separation from protons.



# Conclusions

- Important results from past years from several experiments:
  - Modulation of CR by Solar activity:

    High accuracy daily proton over long period (AMS)

  - Propagation of cosmic rays:

    Precise B/C ratio (AMS), light isotopes ratio (PAMELA, BESS)

  - Source/Acceleration of cosmic rays:

    Precise measument up to TeV region p & He (AMS)

  - Indirect search of DM

    Positron fraction up to 350 GeV (AMS)

# Conclusions

- Important results from past years from several experiments:
  - Modulation of CR by Solar activity:

    High accuracy daily proton over long period (AMS)

    + other species: He, e- and e+ → charge sign dependence (AMS)
  - Propagation of cosmic rays:

    Precise B/C ratio (AMS), light isotopes ratio (PAMELA, BESS)

    + Li, Be (AMS) + higher energy (CALET, ISS-CREAM)
  - Source/Acceleration of cosmic rays:

    Precise measument up to TeV region p & He (AMS)

    + High energy measurement (CALET, ISS-CREAM)
  - Indirect search of DM

    Positron fraction up to 350 GeV (AMS)

    + Positron fraction up to HE, pbar, Dbar (AMS)