# Latest Results from the AMS-02 experiment


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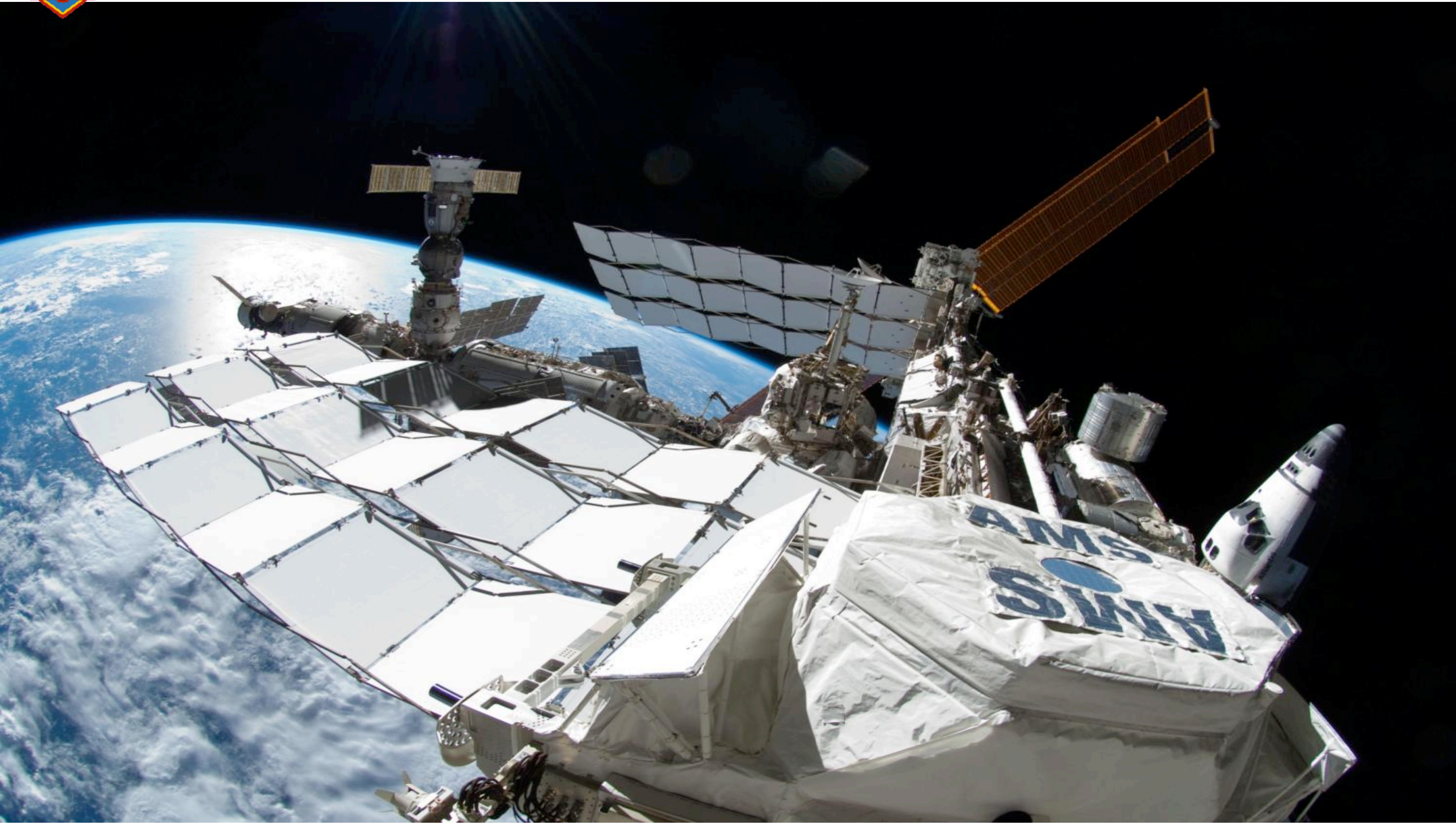
*University of Hawaii at Manoa*

# AMS is a US DOE lead International Collaboration

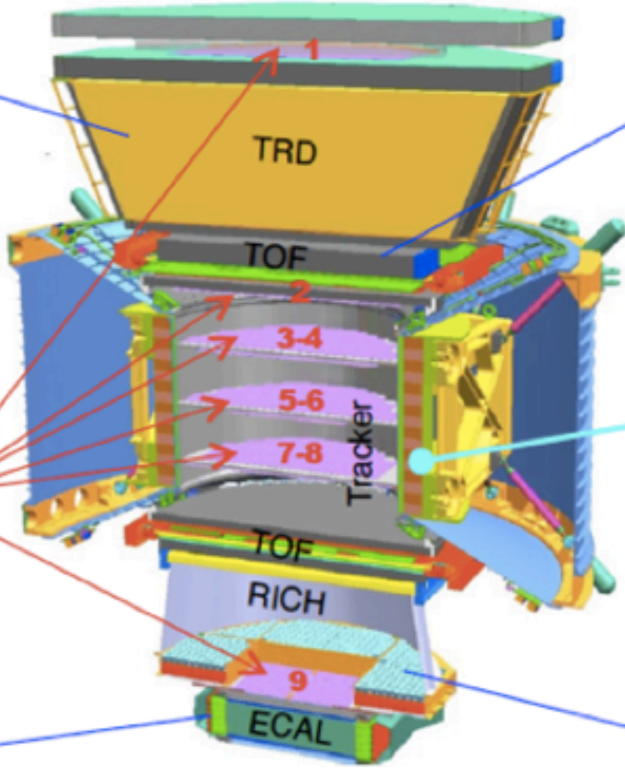
Spokesperson: Nobel laureate Prof. Dr. S. Ting from MIT



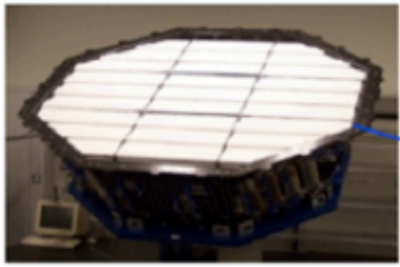

AMS-02 experiment has been installed
on the International Space Station on May 19th 2011

# The AMS-02 detector

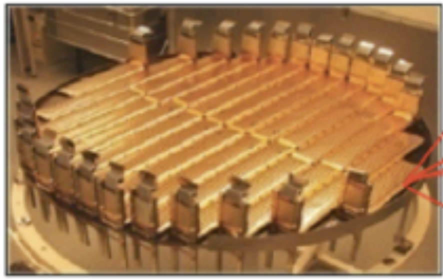
Particles and nuclei are defined by their charge (Z) and energy (E ~ P)




**TRD**
Identify e+, e-



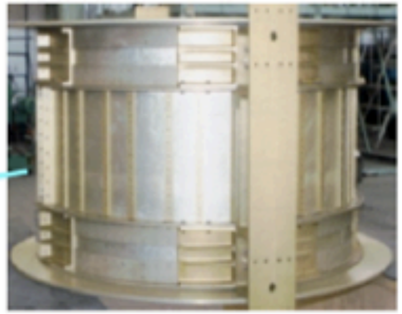
**Silicon Tracker**
Z, P



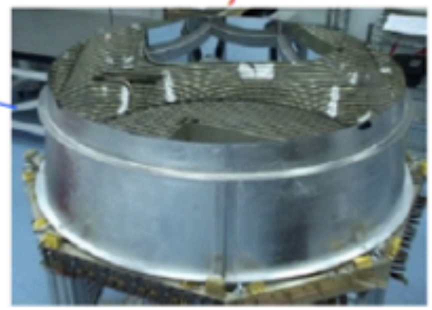
**ECAL**
E of e+, e-, γ

**TOF**
Z, V

**Magnet**
±Z



**RICH**
Z, V



Redundancy

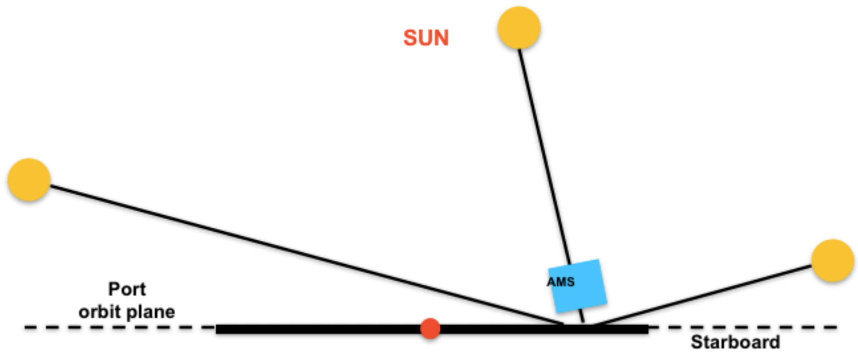
# Challenges

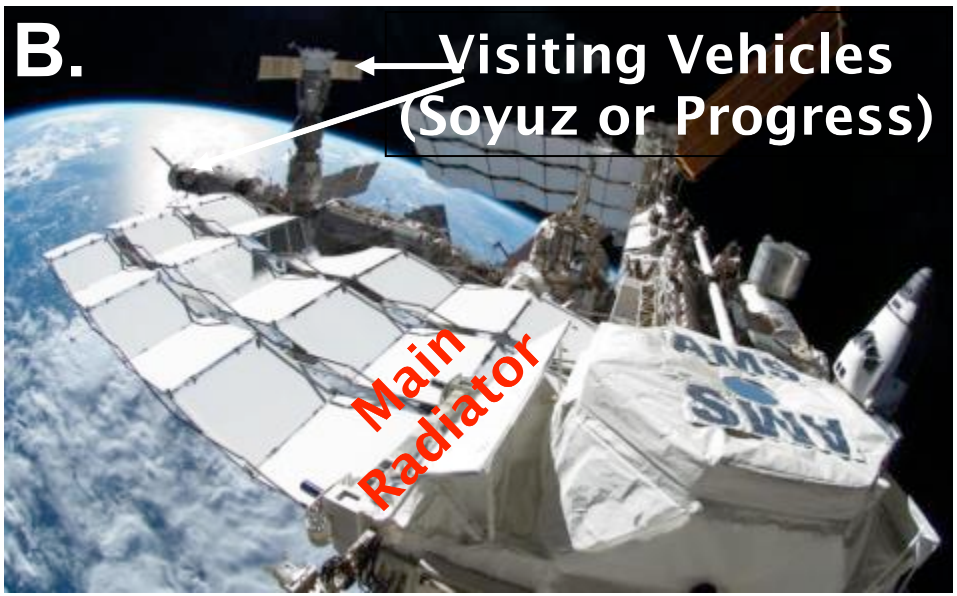
1) The thermal environment constantly changing (90 min orbit)

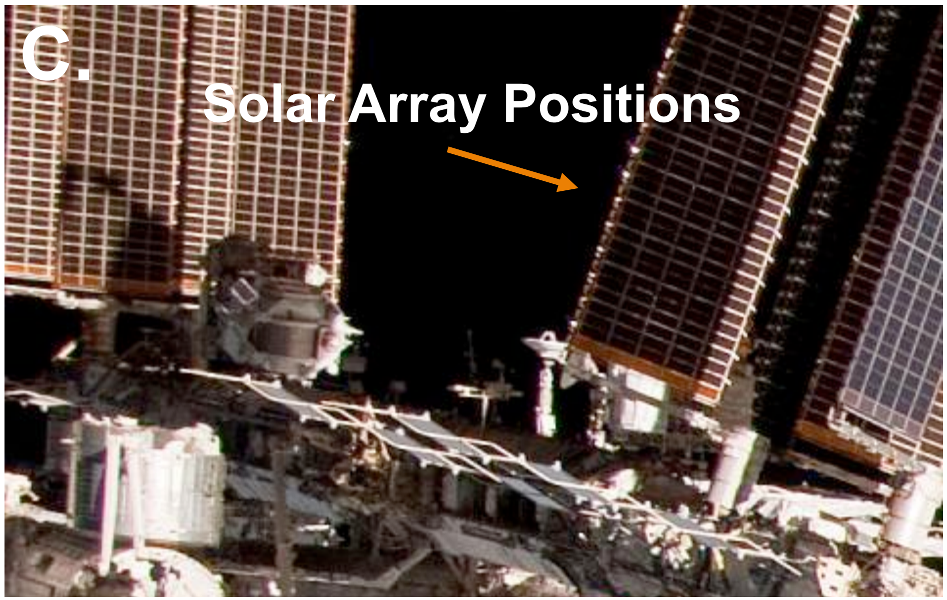
2) No control of the ISS

- Monitoring of the temperature sensors
- Improving of the thermal models
- Developing of safety procedures

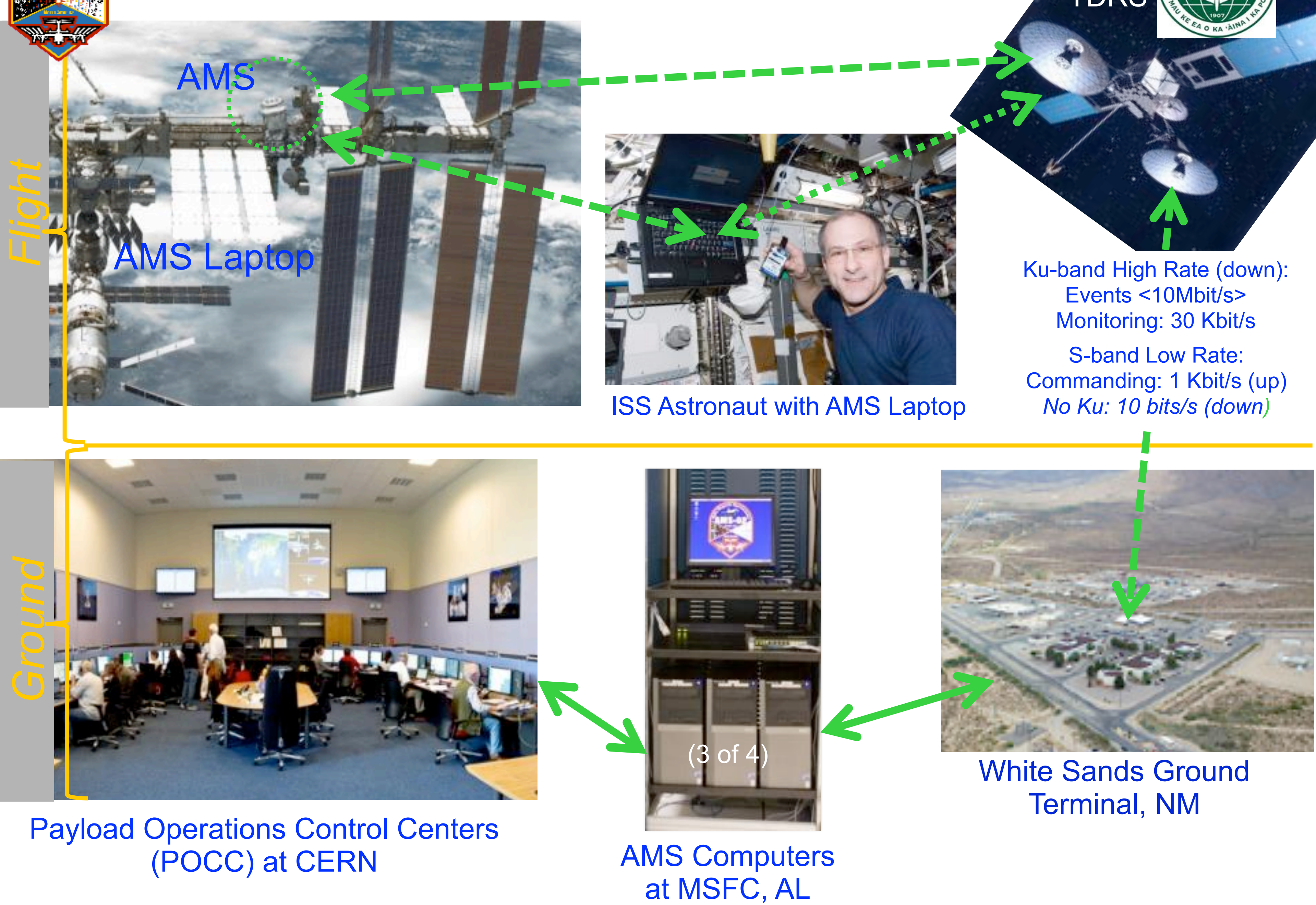
**A. The position of the Sun with respect to AMS**



# Flight and Ground Operations

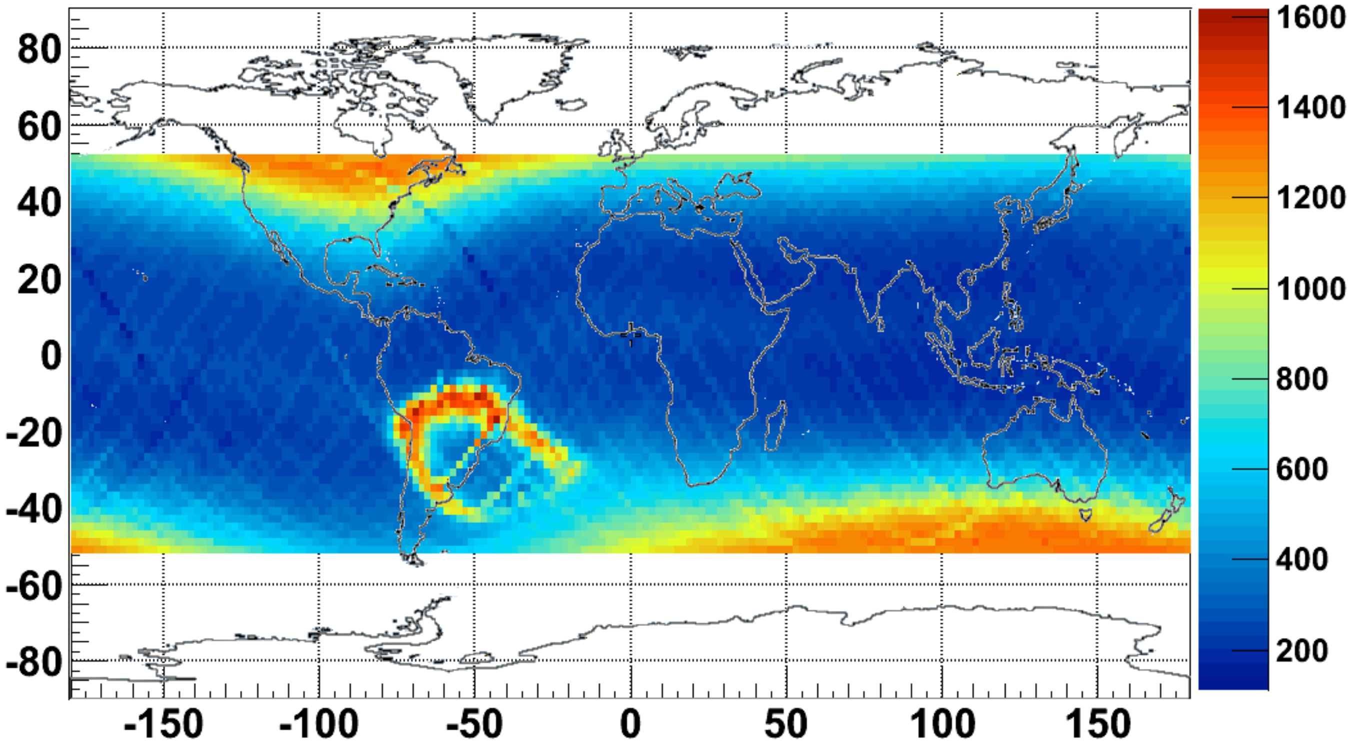


# AMS-02 data

## 3 year of AMS correspond to 50 billion events

The ISS orbits the Earth at 400 km altitude and 51.6° to the Equator.

Acquisition rate [Hz]

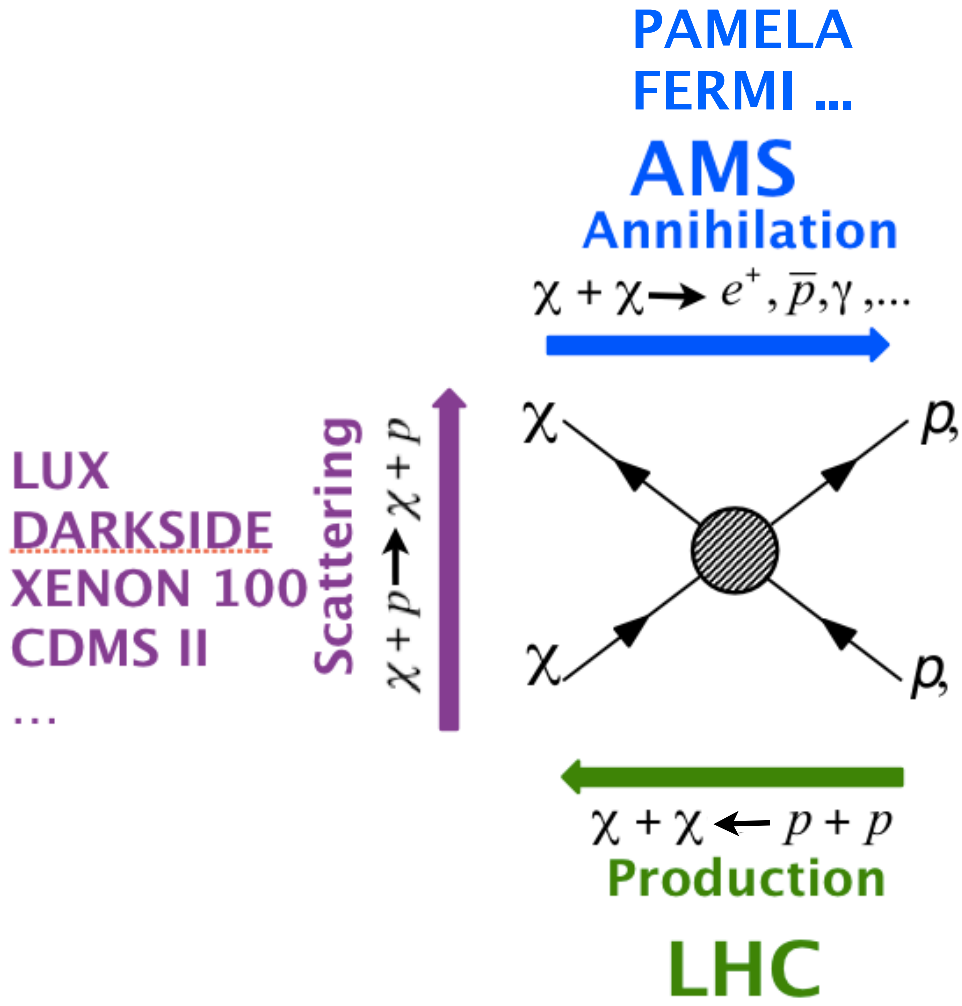



**Particle rates vary from 200 to 2000 Hz per orbit**

# Scientific goals of AMS

- **Measuring CR spectra up to the iron in GeV to TeV**: propagation models;
- **Indirect search of Dark Matter**: $e^+$, antiprotons, antideuteron, ɣ
- **Direct search of primordial antimatter**: Anti He, Anti C ...
- **New forms of matter**: strangelets
- **Identification of local sources of high energy photons**: SNR, Pulsars, ...
- **Solar activity and modulation**: CR spectra over 11 year solar cycle and SEPs
- **and many mores ...**

# Independent methods to search for Dark Matter



# Indirect search of dark matter

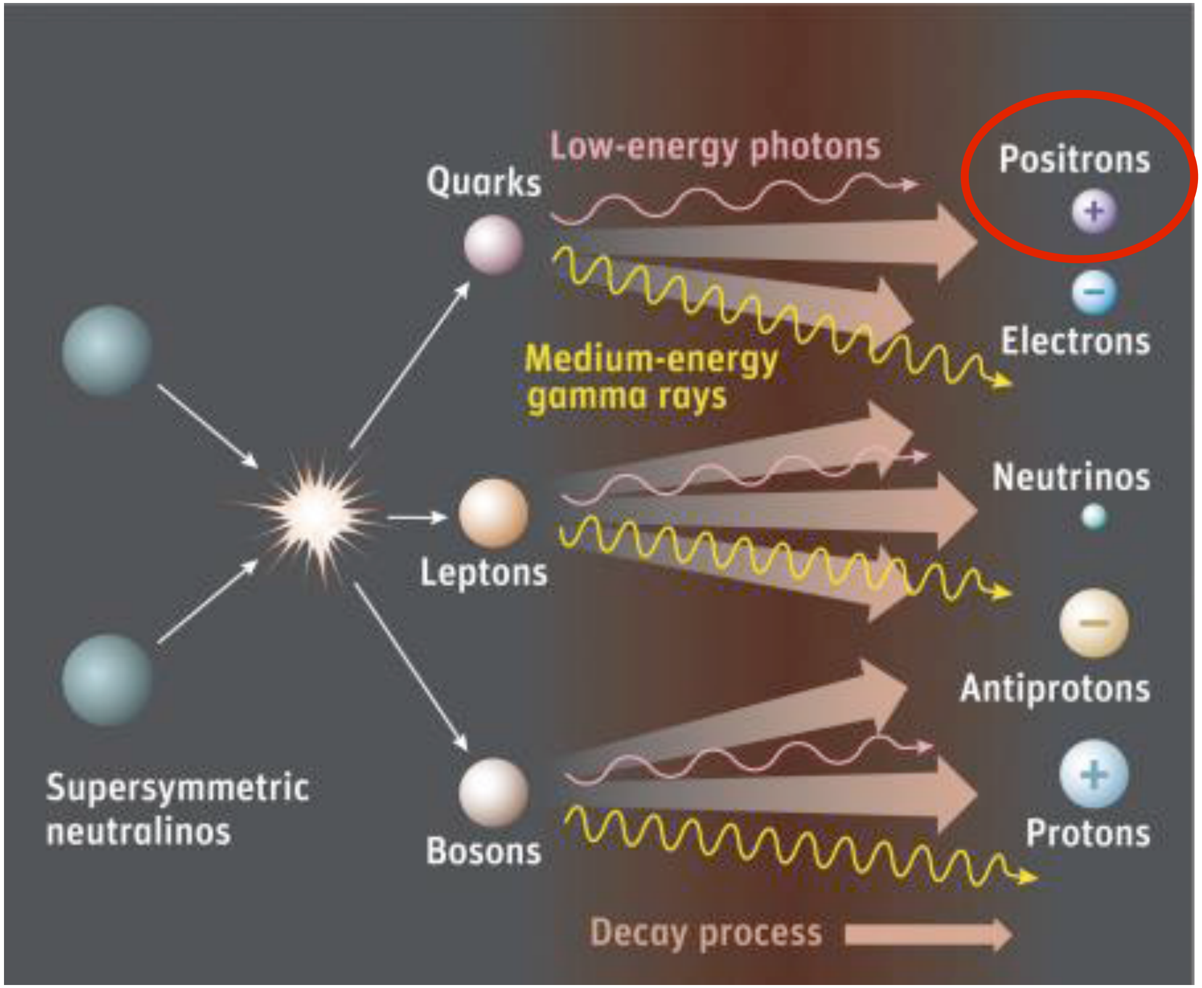
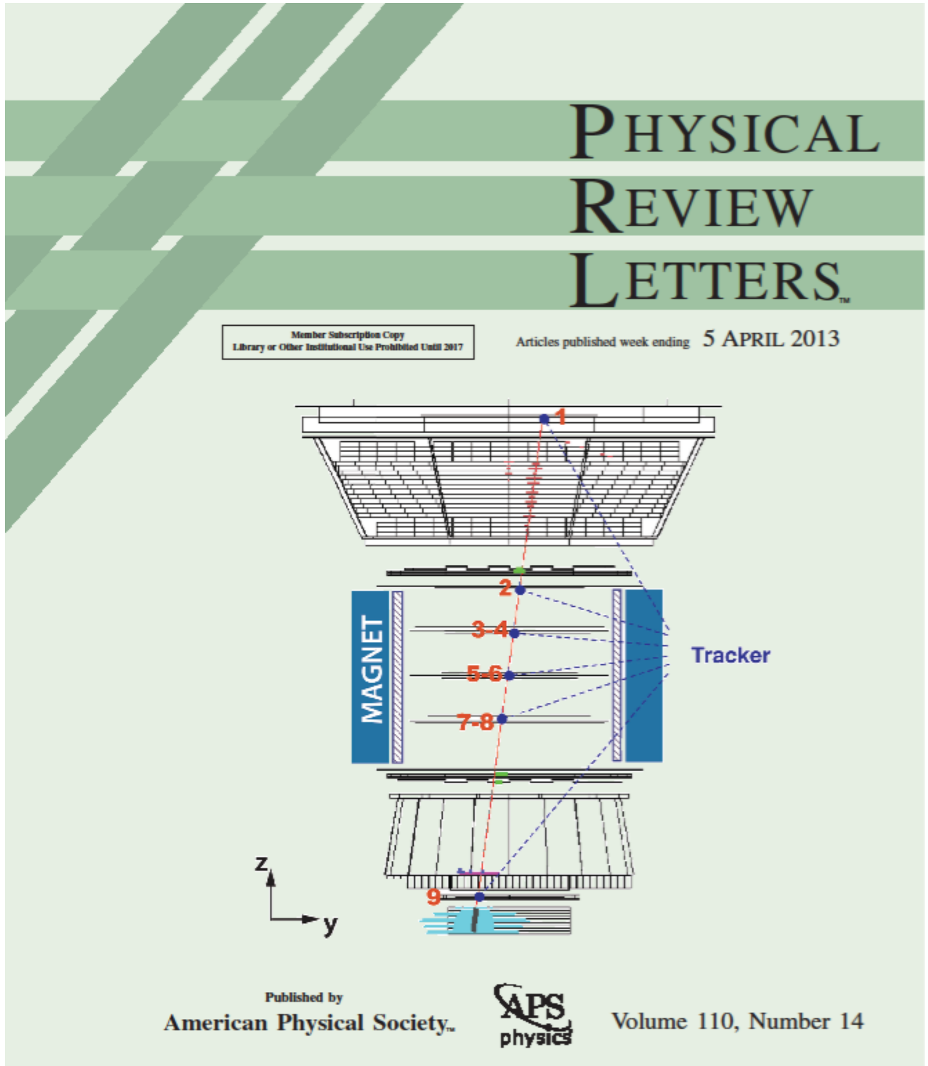



Image Credit: NASA/GLAST collaboration

# Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5-350 GeV

*Aguilar,M. et al (AMS Collaboration) Phys. Rev. Lett. 110, 1411xx (2013)]*

In the first 18 months in space, AMS has collected over 25 billion events. 6.8 million are electrons or positrons.

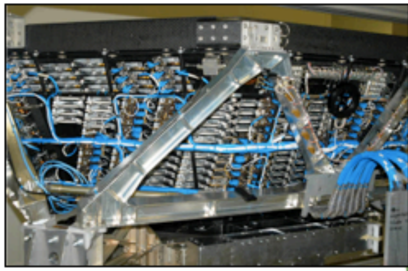


# Positron identification and Proton rejection

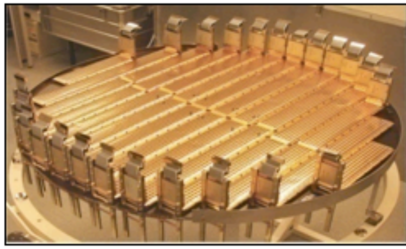
$e^+$ low signal and high P background: P ~ ($10^3 \div 10^4$) $e^+$

P rejection factor: $10^5 \div 10^6$ to identify $e^+$ with an error at % level

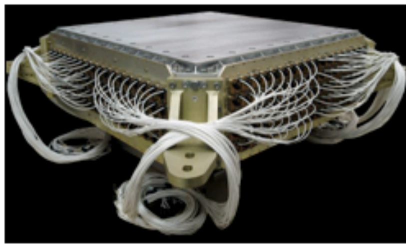
**TRD**
Distinguishes between e+ and P

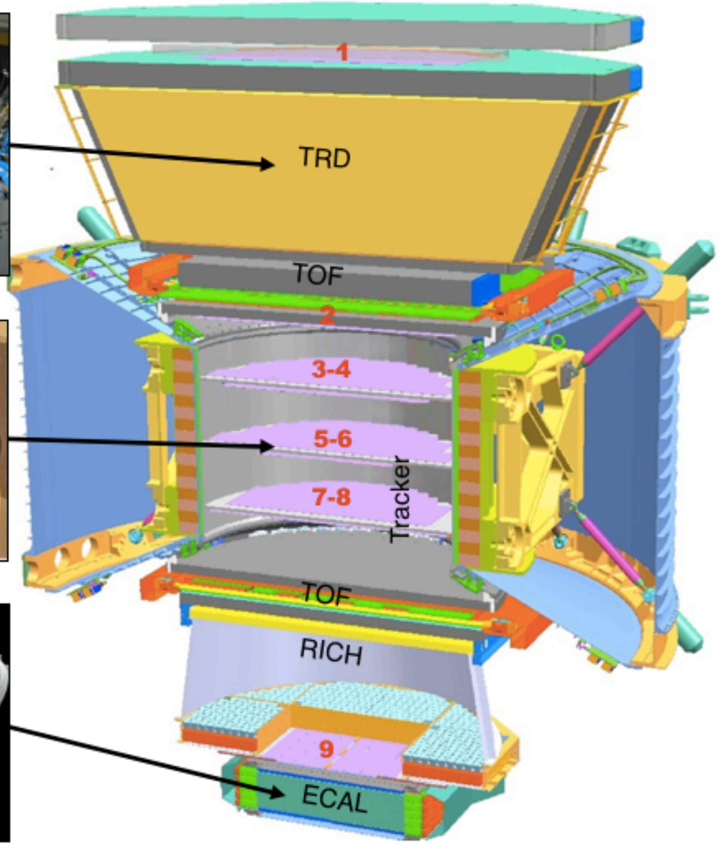


**SILICON TRACKER + MAGNET**
measure sign and momentum



**Electromagnetic CALorimeter**
measures energy,
Identifies 3D positron shower and
rejects hadronic showers

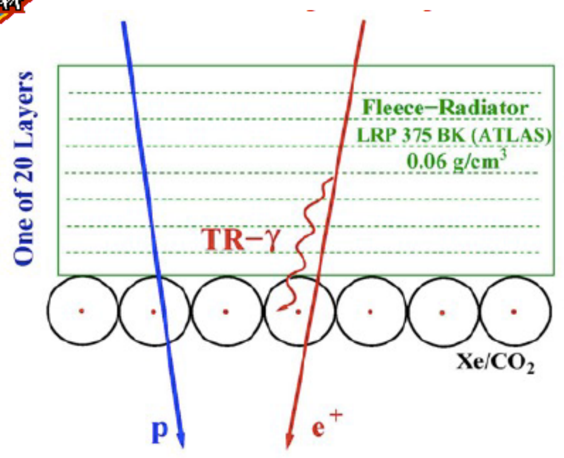


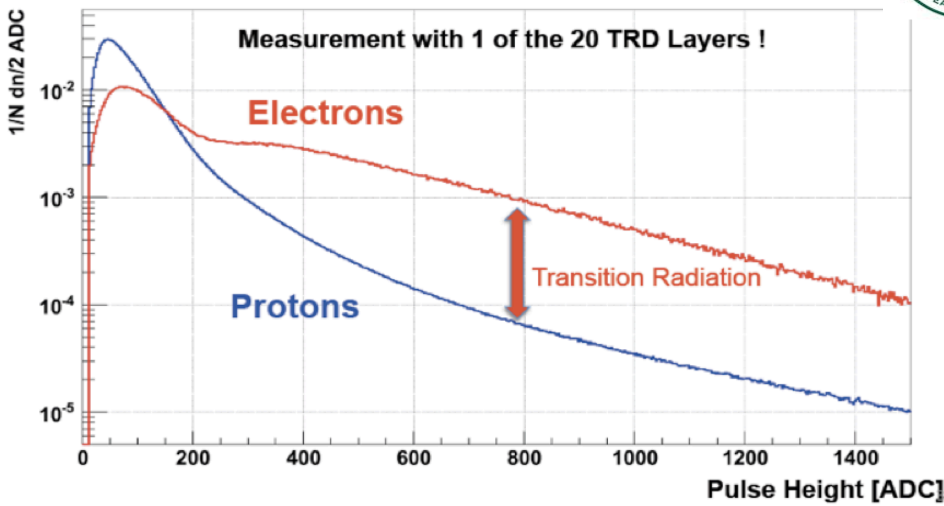



Total rejection of proton $10^6$

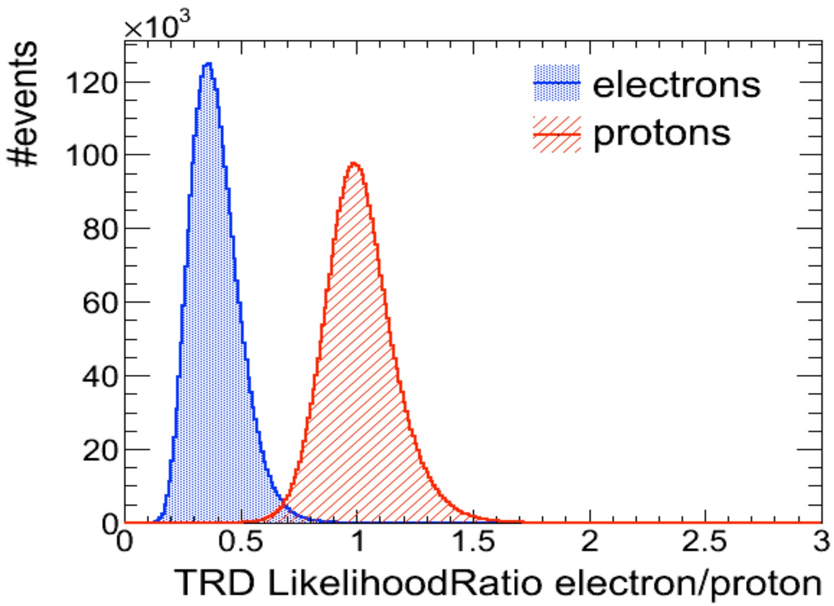
Verified in test beam at CERN

# TRD Proton rejection

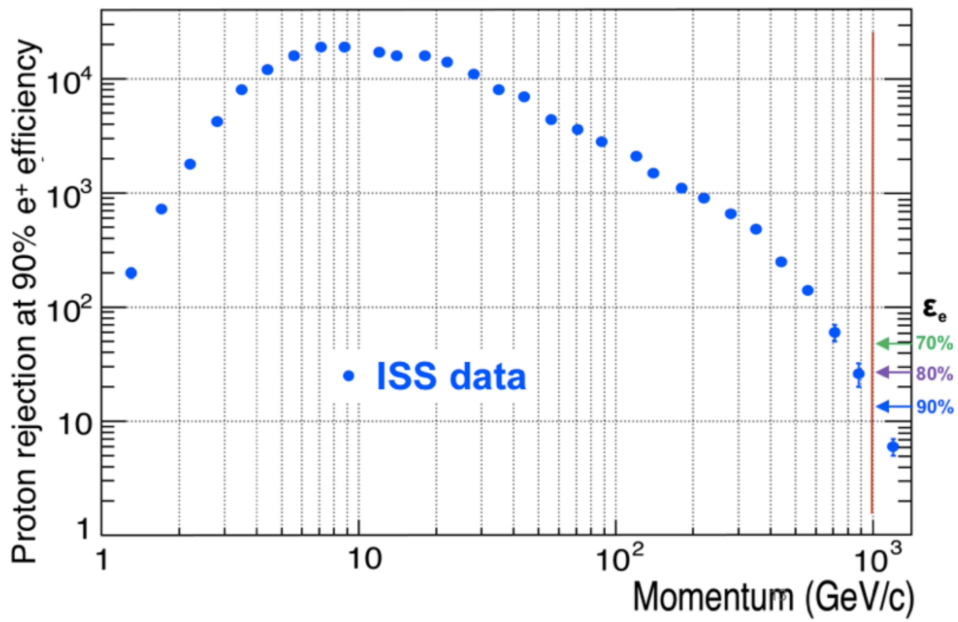



TRD likelihood estimator = $-\ln(P_e/(P_e+P_p))$

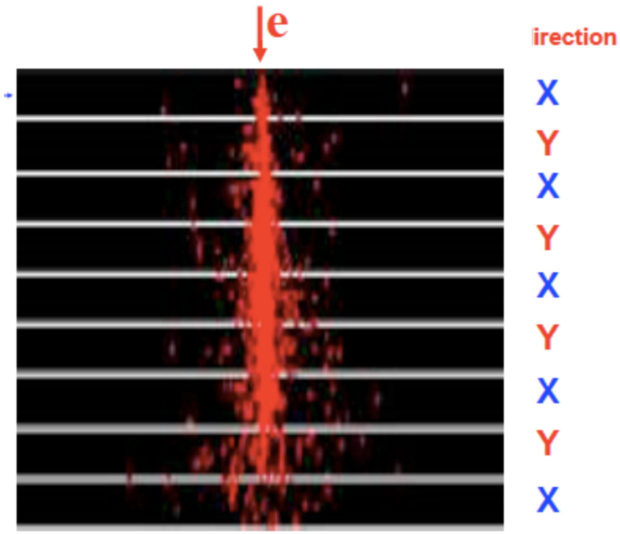


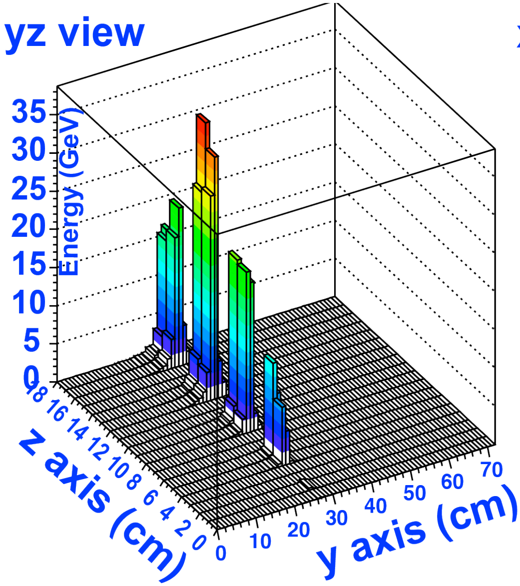

## TRD Proton rejection

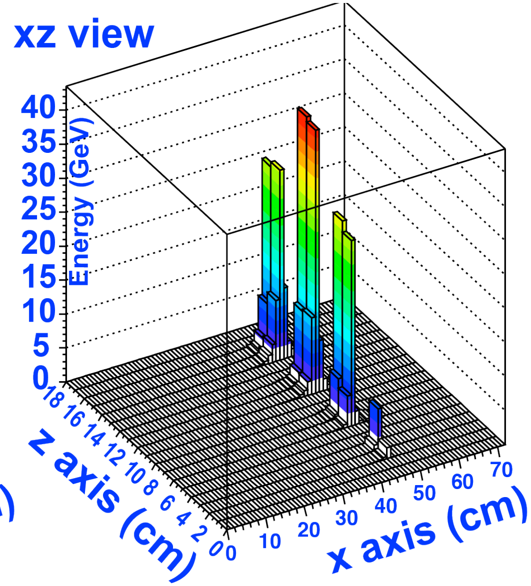


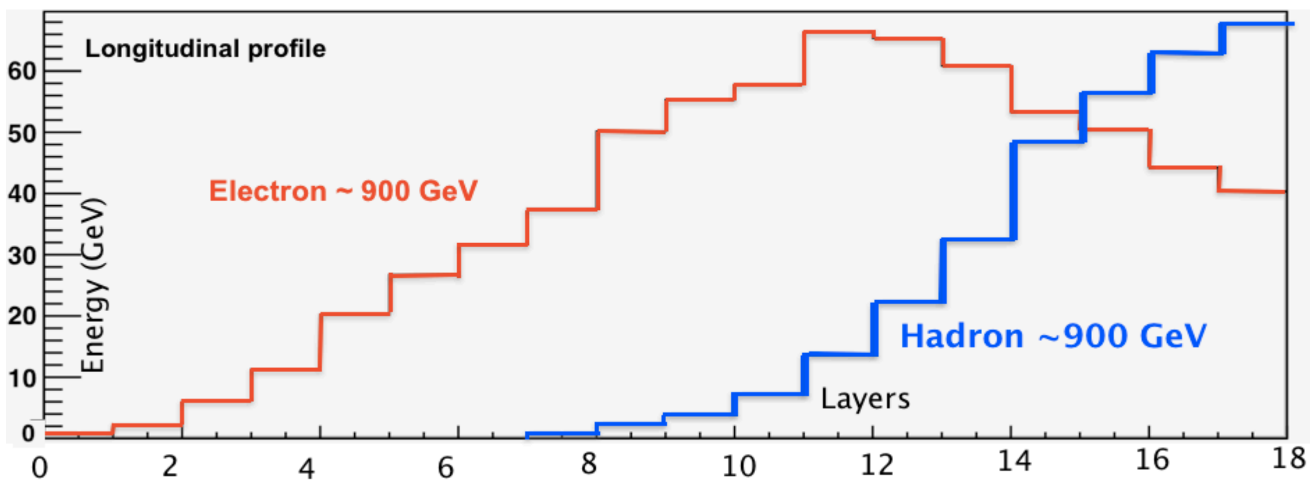
# The electron identification with ECAL

## 17 radiation length



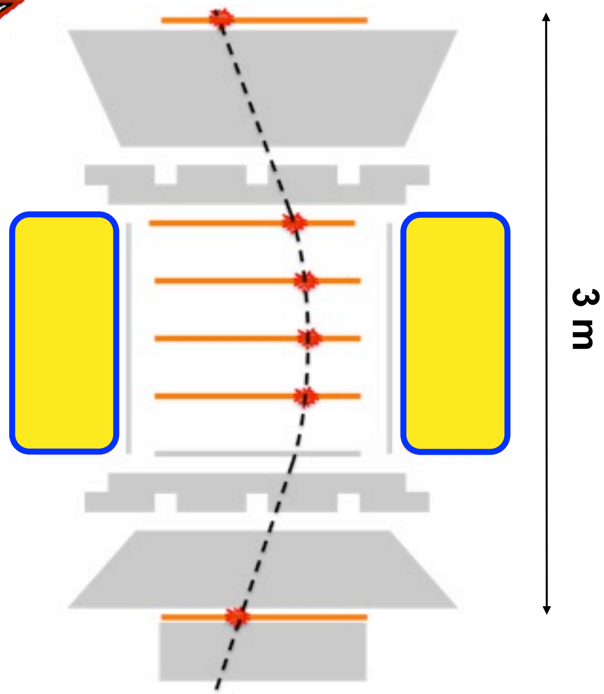



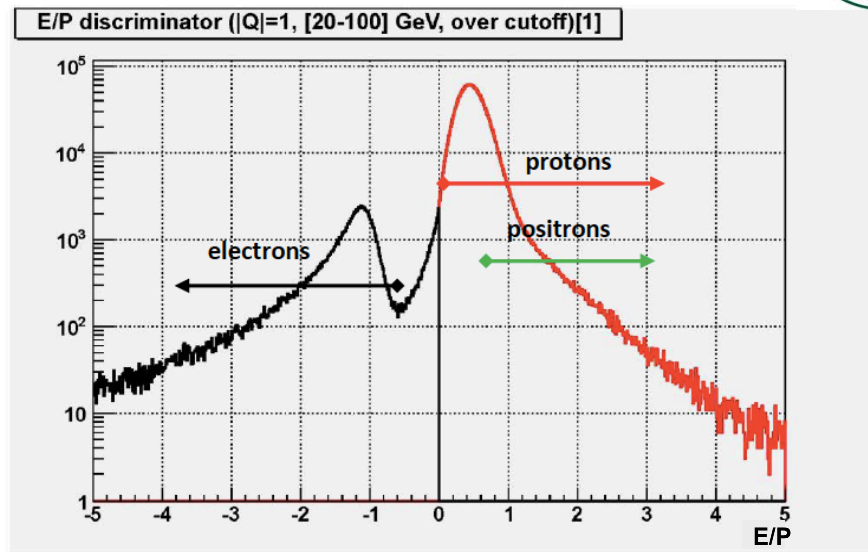




A BDT constructed on the basis of the shower shape in the ECAL distinguishes protons and electrons.

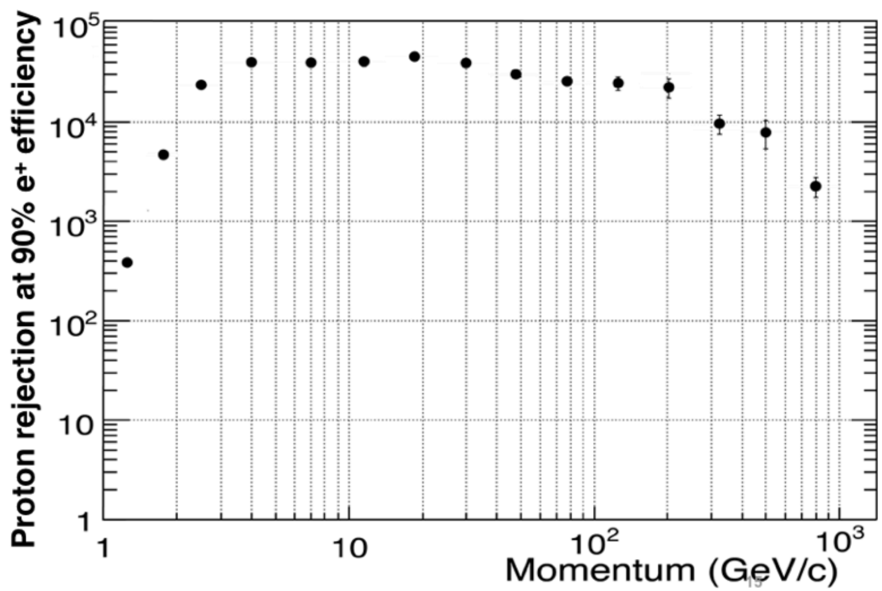
# Tracker e+ and e- identification and P rejection




$$R = pc/Ze$$



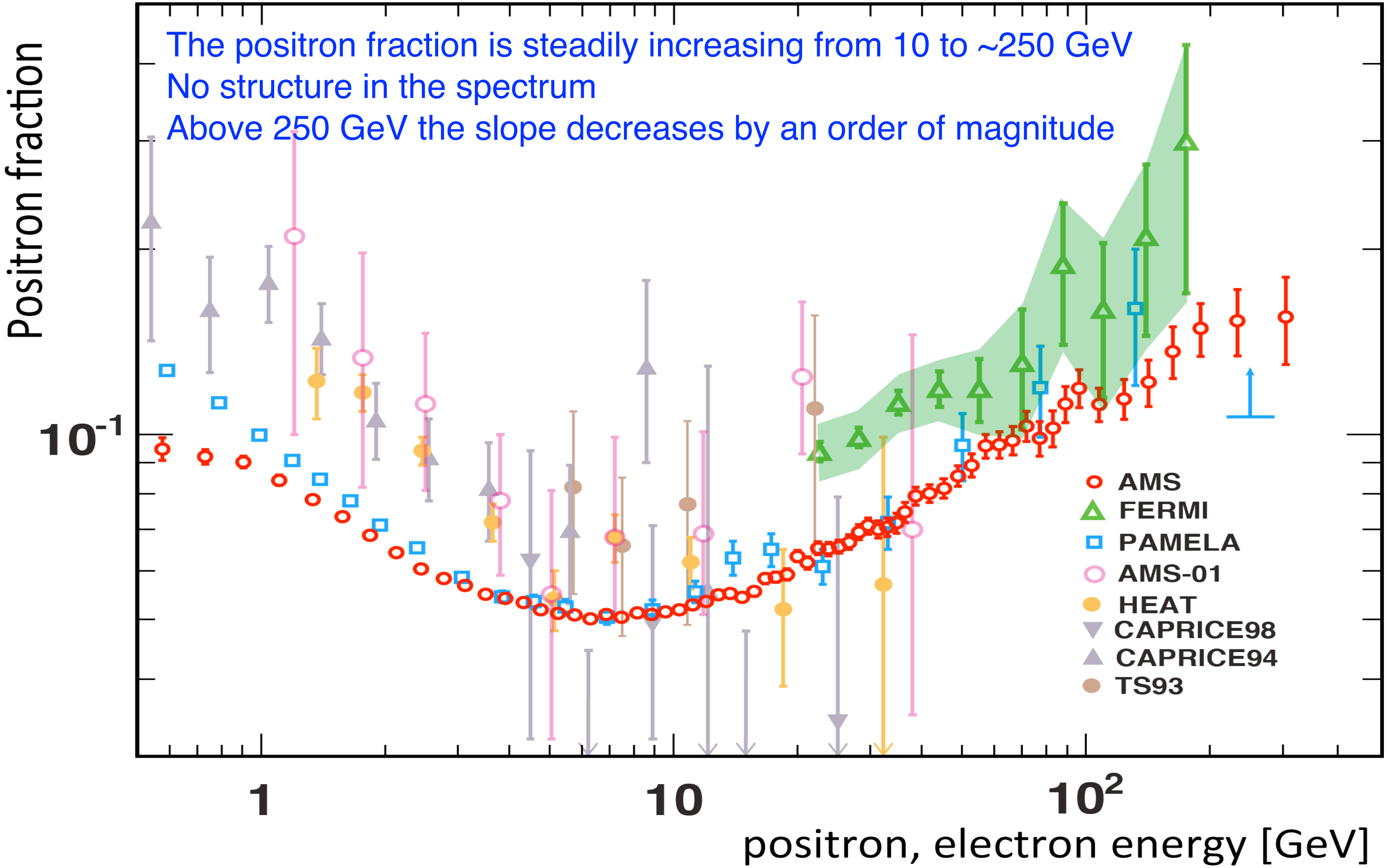

**Proton rejection from ECAL and E/P**




Tracker:

1) Used to suppress e-
2) Compared to the E measured by ECAL, E/P is used to suppress Protons

# Positron Fraction



# The Positron excess could be explained by ... dark matter

Despite some significant issues:

(i) Need very large annihilation rates

(<$\sigma$v> ~ $10^2$-$10^3$ x $10^{-26}$ cm$^3$/s)

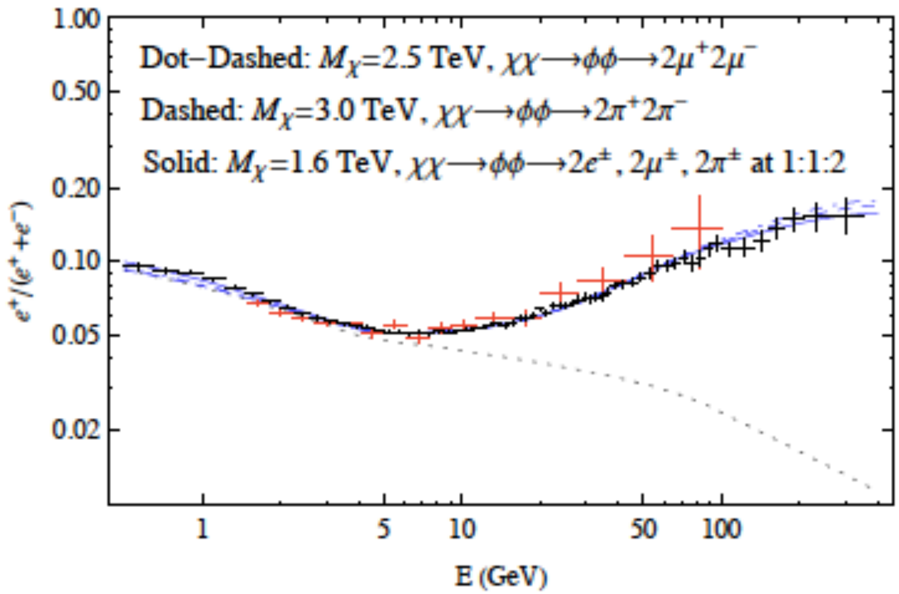
(ii) Need rather large masses (~TeV)

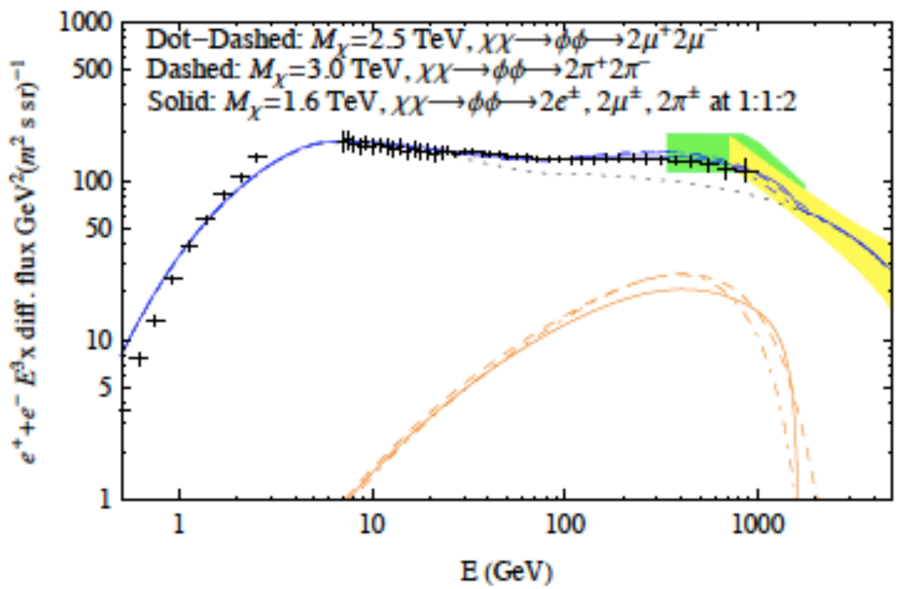
(iii) Need special annihilation or decay modes
-suppress antiprotons

# On the origin of the Positron excess

**Choolis & Hooper, 1304.1840**

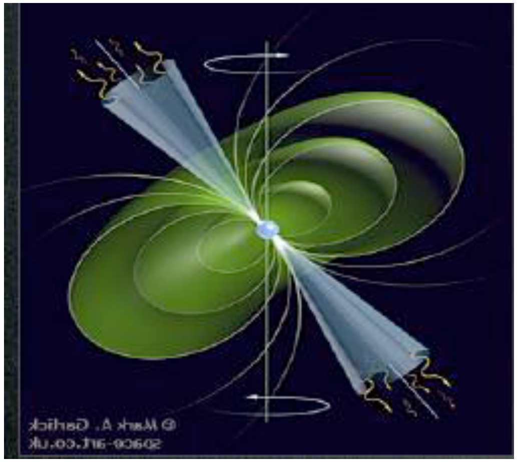
- Annihilation via light intermediate states into muons and pions consistent with data (positron fraction and total electrons) for DM masses of 1.5 - 3 TeV, $<\sigma v>$ as high as $(6 - 23) \times 10^{-24}$ cm$^3$/s
- Describing the FERMI all-electron spectrum at the same time requires spectral break in cosmic-ray electrons (if single or few local sources dominate.)



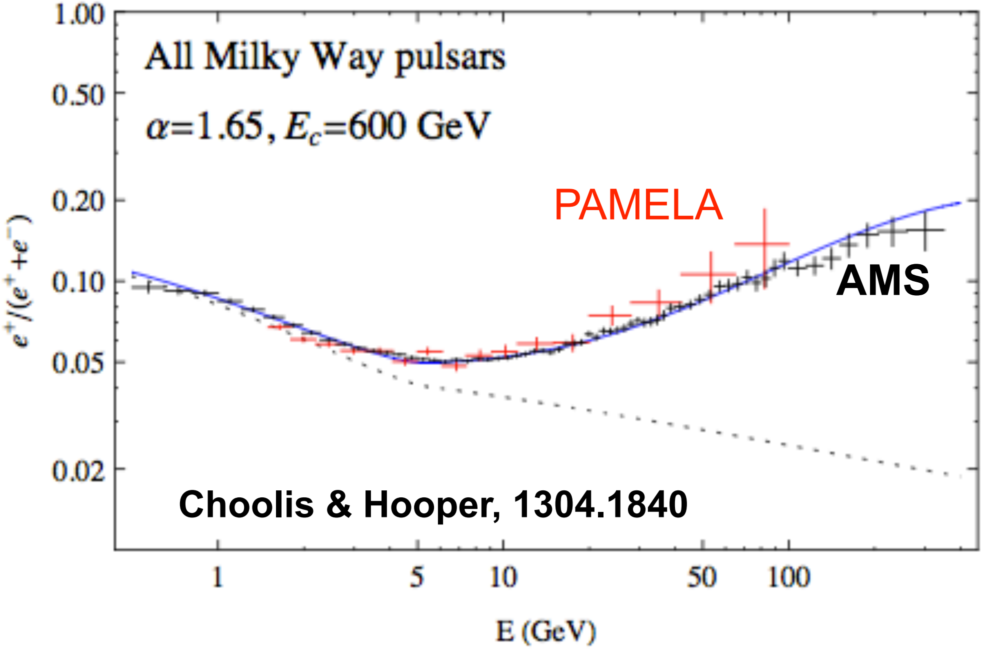
# The Positron excess could be explained by ... an astrophysical source

**Mechanism**: the spinning B of the pulsar strips $e^-$ that accelerated at the polar cap emit $\gamma$ that make production of $e^{\pm}$ that are trapped in the cloud, further accelerated and later released at $\tau \sim 10^5$ years.

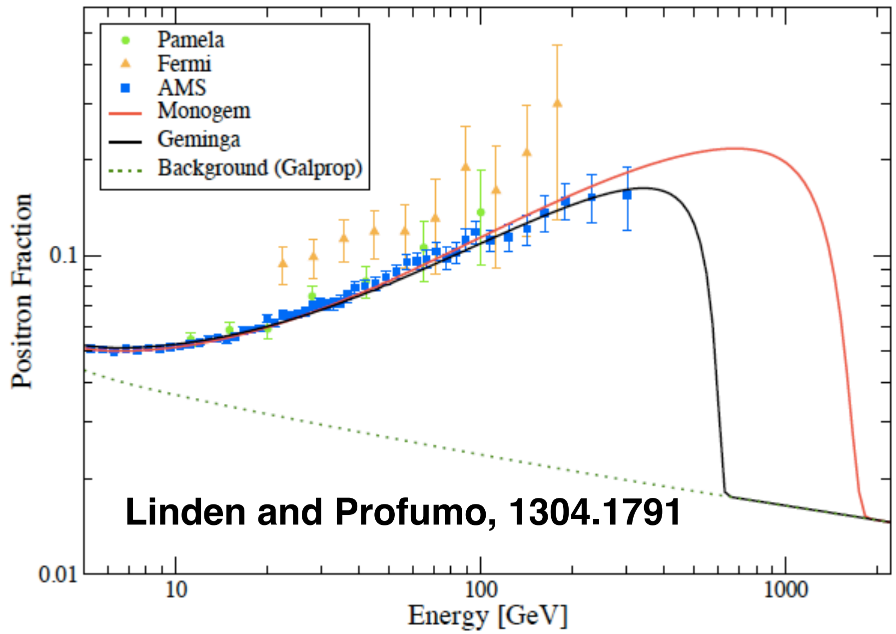


- **Young** ($T < 10^5$ years) **and nearby** (< 1 kpc)
- Geminga: 157 parsecs from Earth and 370,000 years old
- B0656+14: 290 parsecs from Earth and 110,000 years old.
- Diffuse mature pulsars

# The Positron excess could be explained by Pulsars




Contribution from diffuse mature &nearby young pulsars.



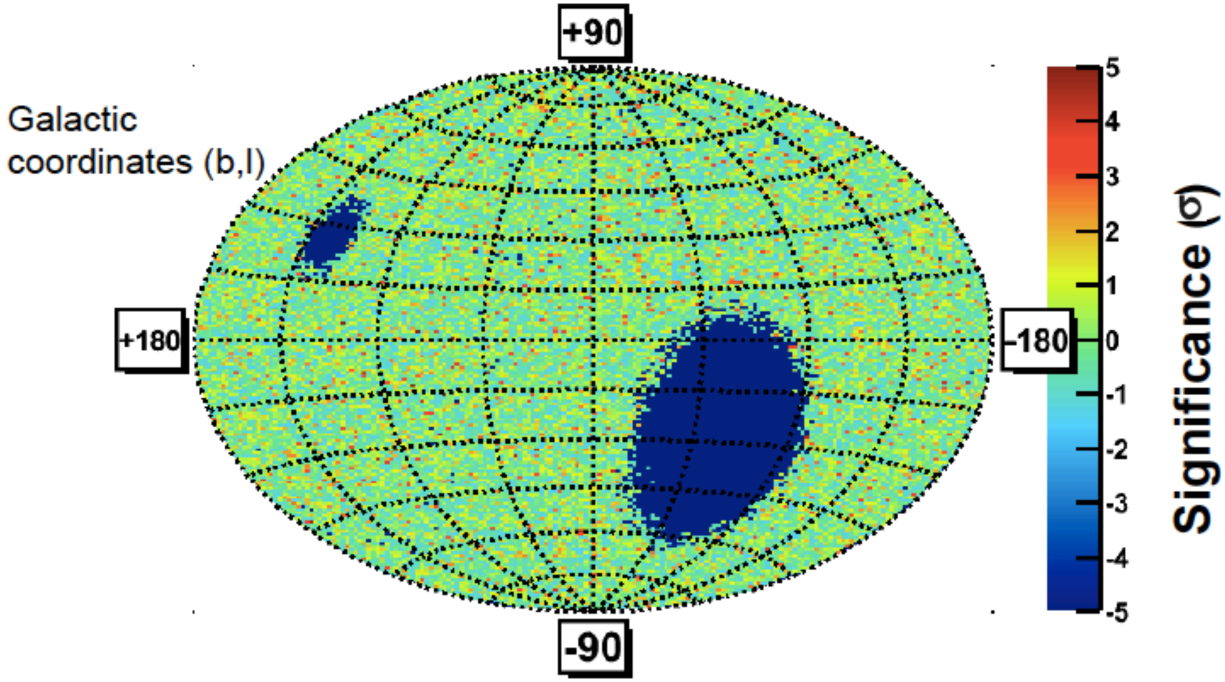

Distance and Age from observation (set the cutoff)

# Can we discriminate between dark matter and pulsars?

Nearby **Pulsar** → Anisotropy in the arrival direction *(sufficient, not necessary)*

**Dark Matter** → Diffuse secondary component

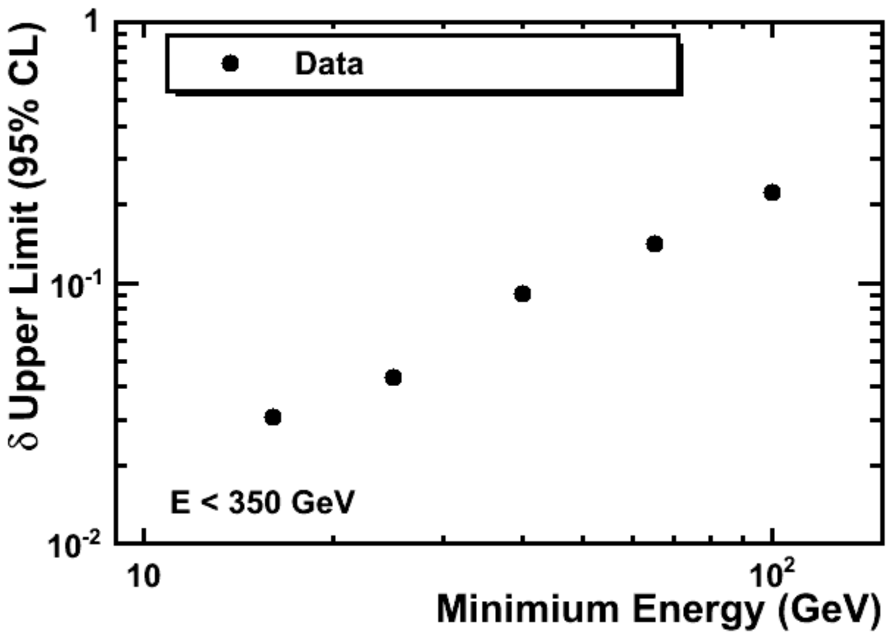
# Anisotropy studies

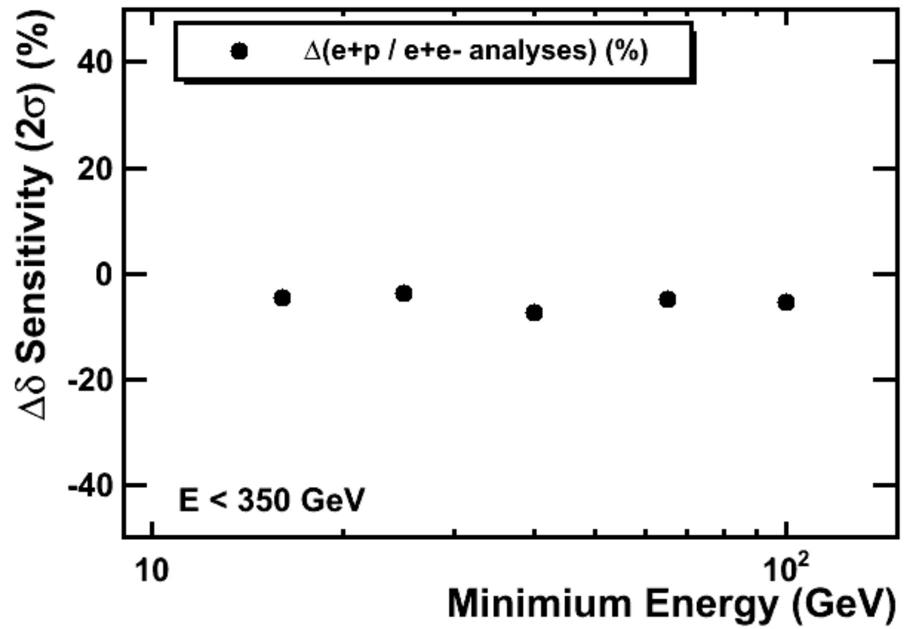



**The fluctuations of the positron ratio $e^+/e^-$ are isotropic**

The relative fluctuations of the positron ratio across the observed sky map show no evident pattern.

# AMS upper limits on dipole anisotropy




Limits on the amplitude of a dipole anisotropy in any axis in galactic coordinates on the positron to electron ratio in the energy range from 16 GeV to 350 GeV

The sensitivity to a dipole anisotropy using the positron to proton ratio is consistent with the one obtained on the positron to electron analysis

$\delta$ <0.030 for 16<E<350GeV

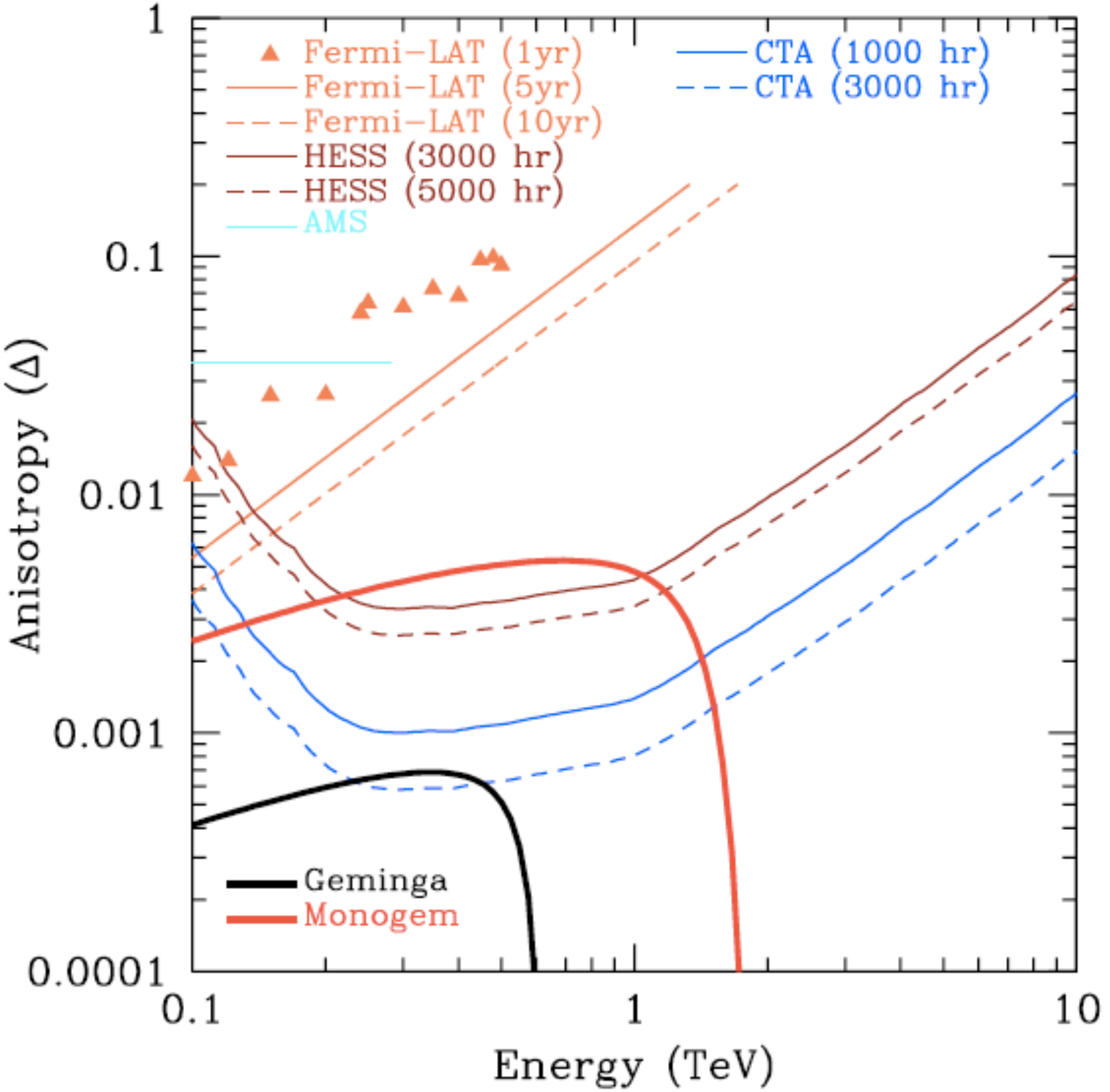
# On the origin of the Positron excess

Nearby **Pulsar** → **Anisotropy in the arrival direction** *(sufficient, not necessary)*

Can be ruled out the pulsars scenario?

**Our sensitivity is not enough!**

# Pulsar interpretation consistent with all data



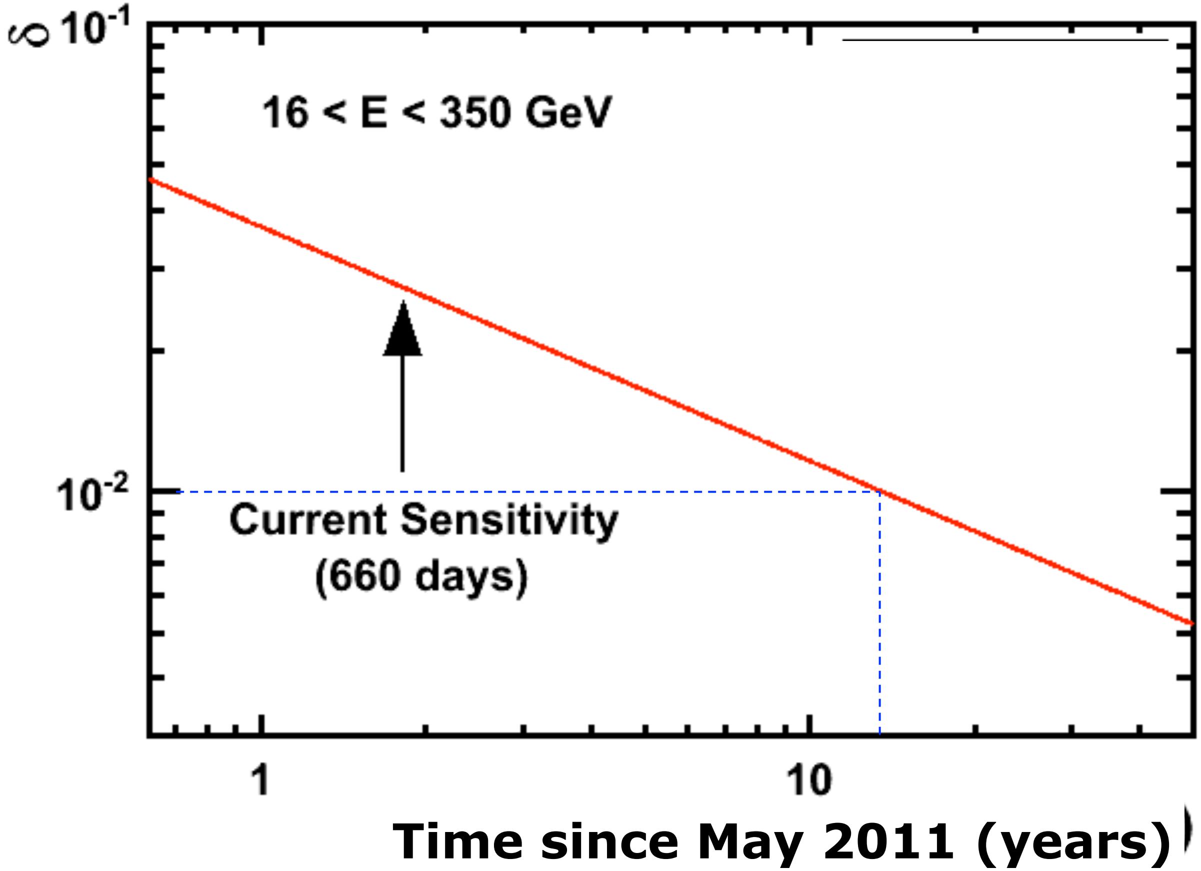

Linden and Profumo, Astroph. J (2013) 1304.1791

# Anisotropy on $e^+/e^-$: Projected sensitivity

**In 10 more years, AMS will reach a sensitivity of**

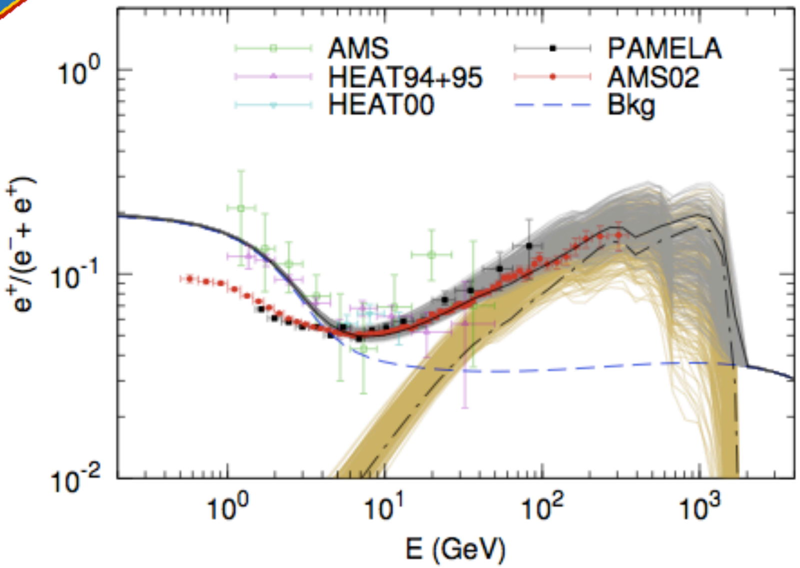
**$\delta$ = 0.010 at 95% C.L.**

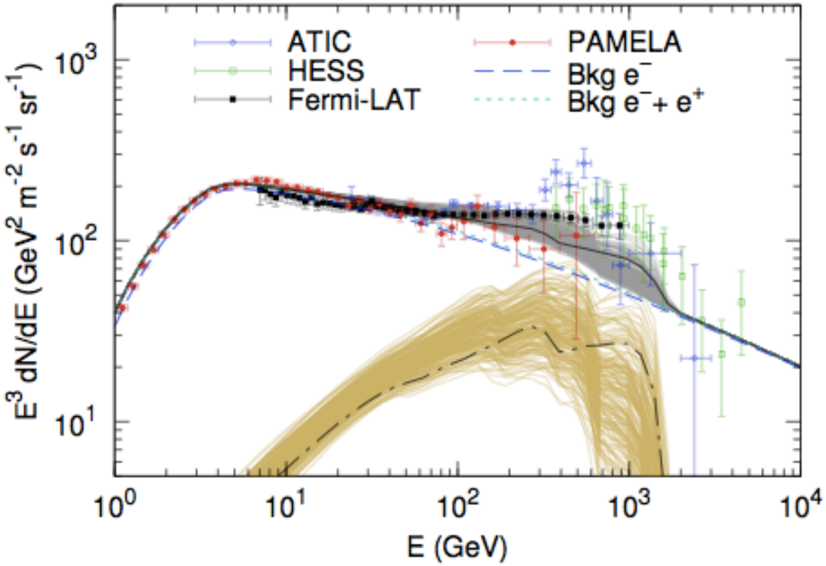
**for a dipole anisotropy in the positron to electron ratio**

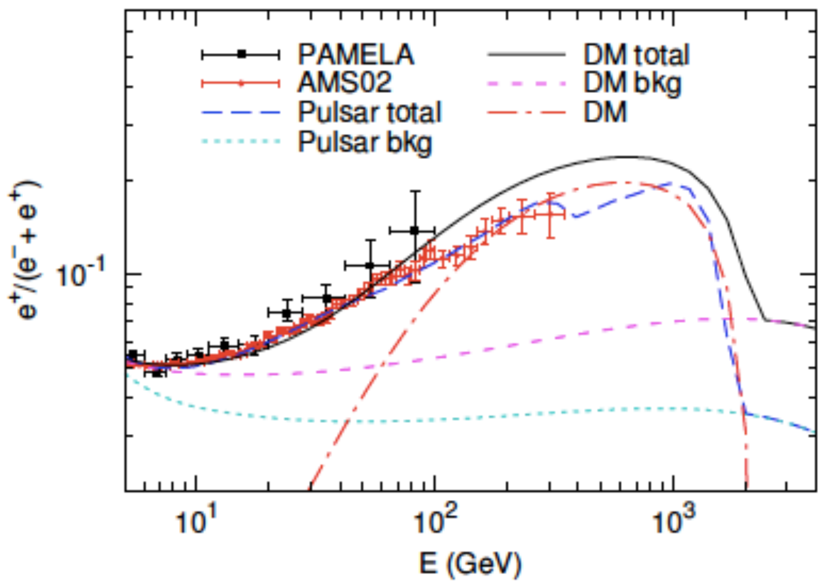


# Disentangling ...

Pulsars interpretation: **P.F Yin:1304.4128v1**



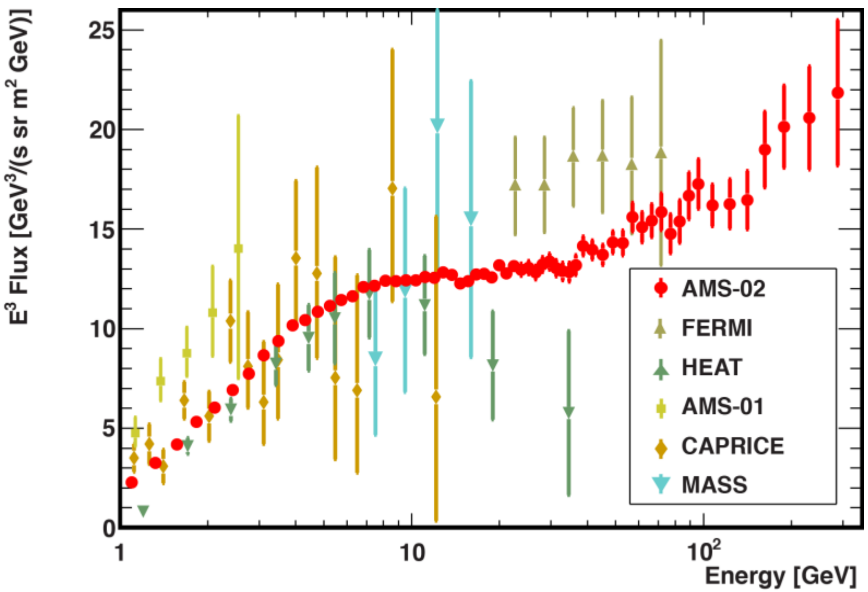



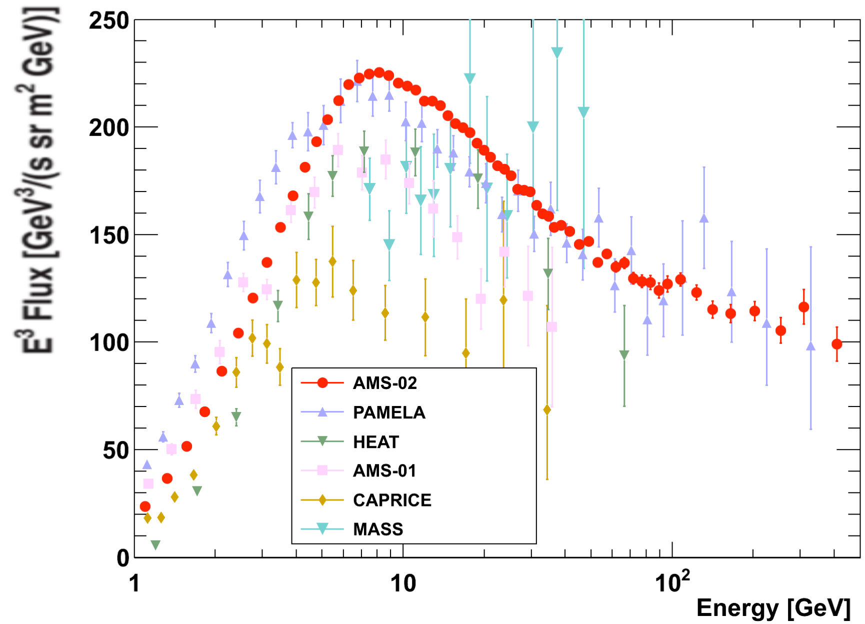

One bump/cut-off at high energy -> DM
Many bumps -> Pulsars

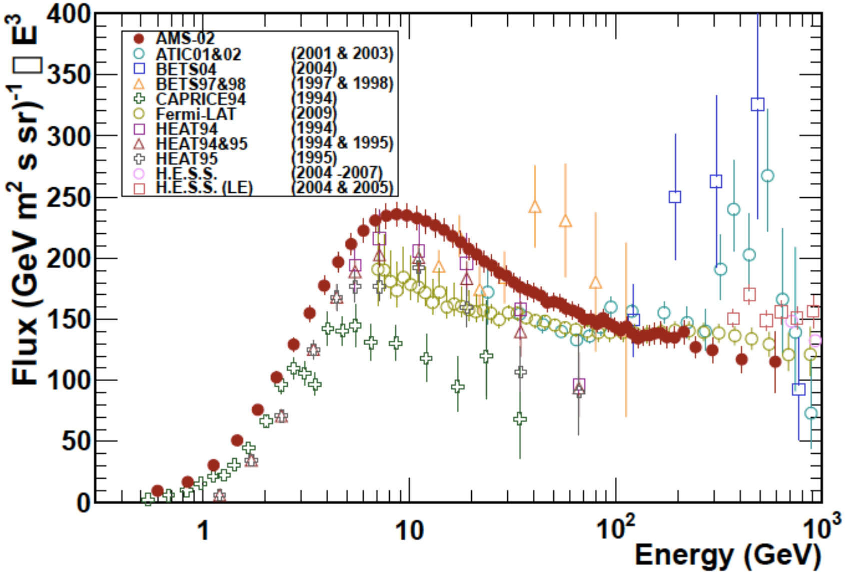
**AMS measurements at higher energy will be crucial to understand the source!**

# AMS-02 Electron, Positron and Electron+Positron fluxes

*Paper in preparation*



# Positrons excess of secondary origin

**Positrons (and electrons) produced from spallation of primaries in the sources (e.g. SNR) and accelerated before escaping in the ISM or re-acceleration of background CRs in strong shocks.**

P.Blasi, PRL 103 (2009) 051104; arXiv:0903.2794

**Also other secondaries are expected to be produced by spallation and accelerated in the source: significant increase expected in the pbar/p and B/C ratios.**

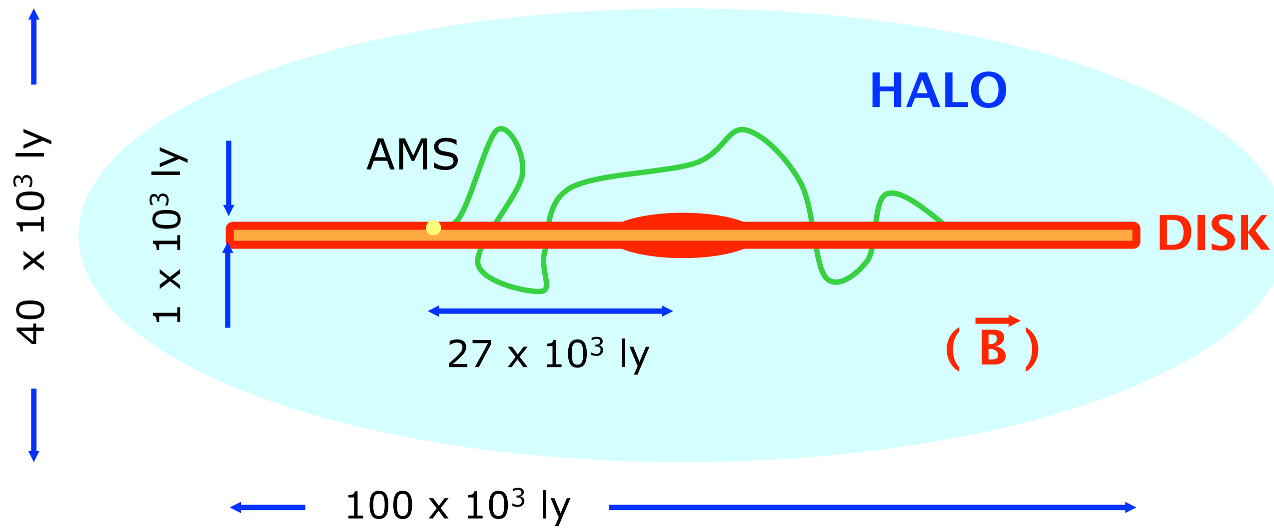
P. Blasi & P. Serpico -PRL 103 (2006) 081103
Ptuskinet al. -ApJ642 (2006) 902
Donato et al. PRL 102 (2009) 071301

# B/C

Precise measurement of the energy spectra of B/C
provides information on Cosmic Ray Interactions and Propagation

## Interactions with the Interstellar Medium:

$$C + (p,He) \rightarrow B + \ldots$$




Diffusion
Convection
Reacceleration

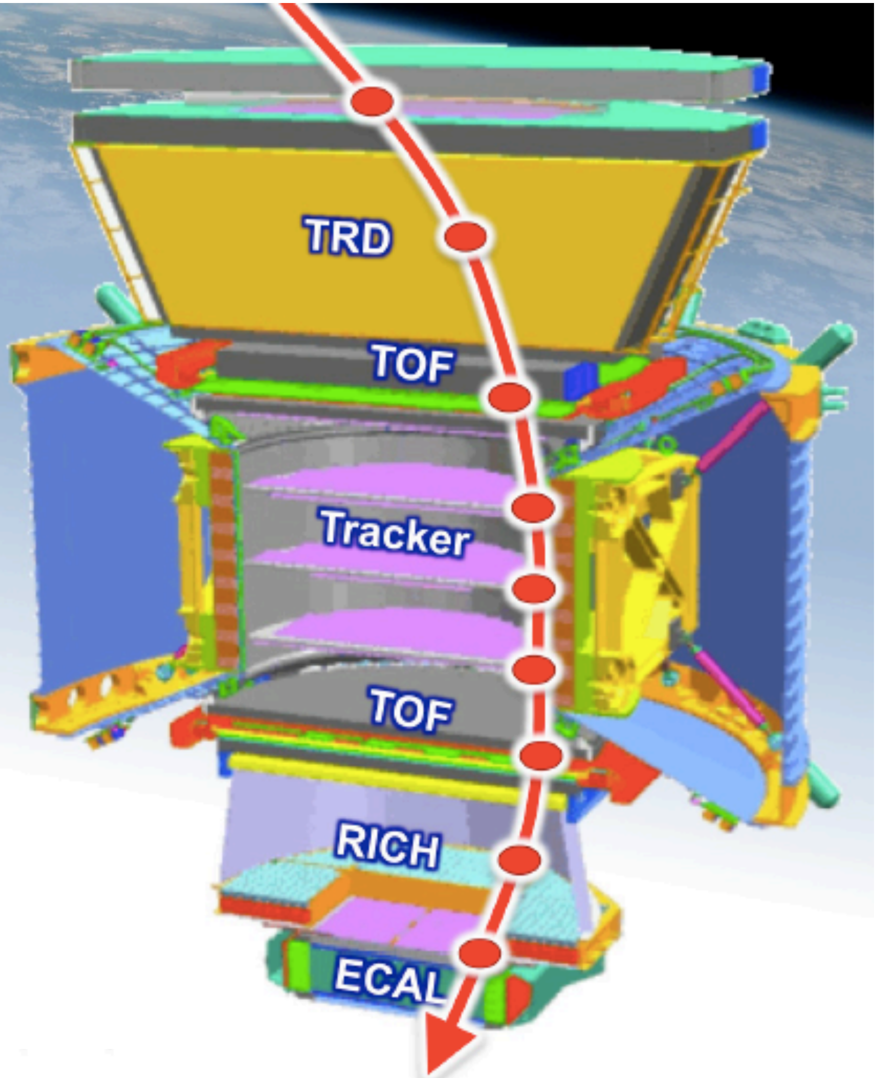
Interactions with the Interstellar Medium (ISM):

- Fragmentation
- Secondaries
- Energy loss

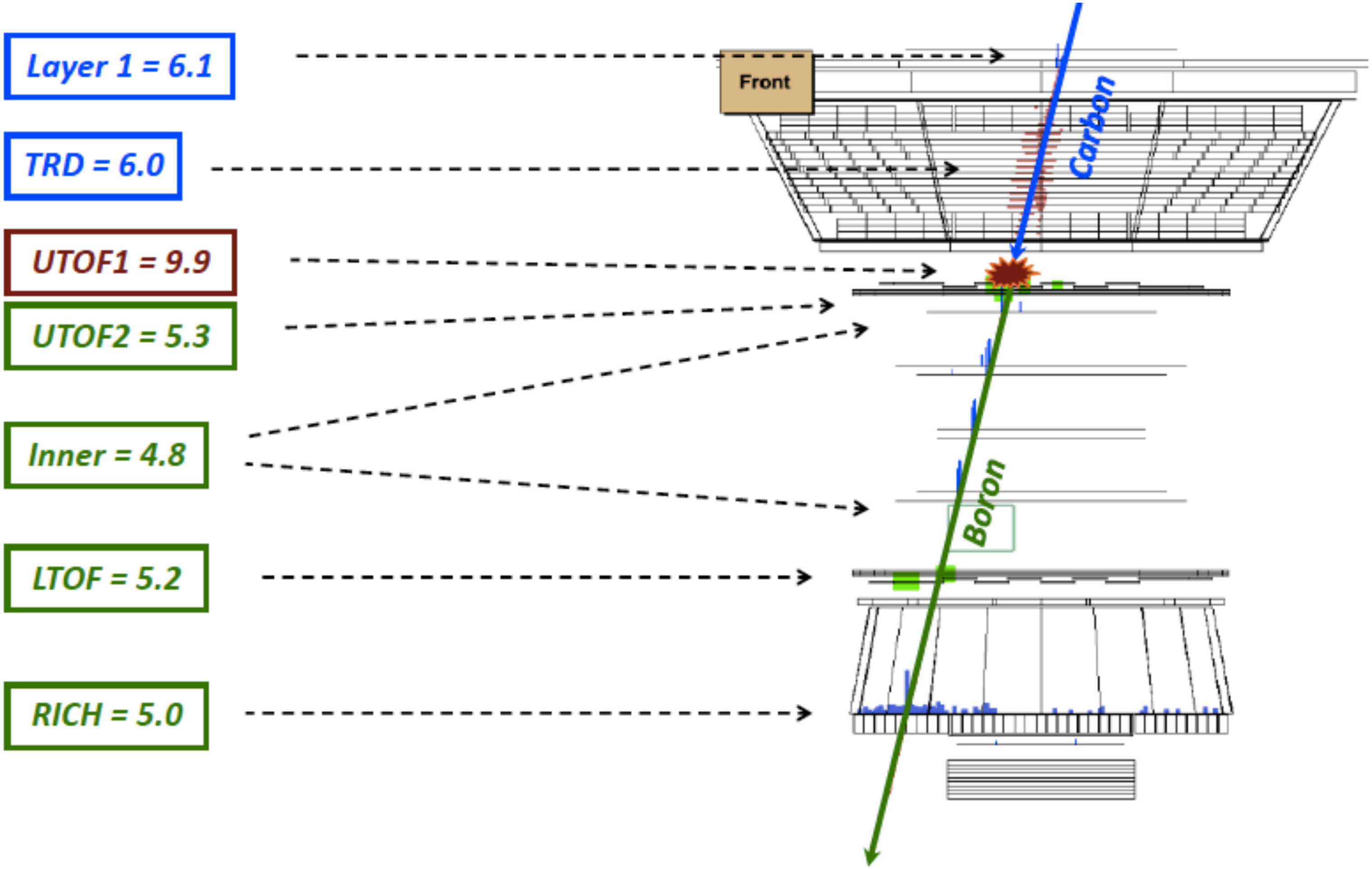
# Charge measurement in AMS-02

Charge resolution ΔZ (au)
for Carbon (Z=6)

- Tracker plane 1 : 0.30
- TRD : 0.33
- Upper TOF : 0.17
- Inner plane 2-8 : 0.15
- Lower TOF : 0.20
- RICH : 0.32
- Tracker plane 9 : 0.30

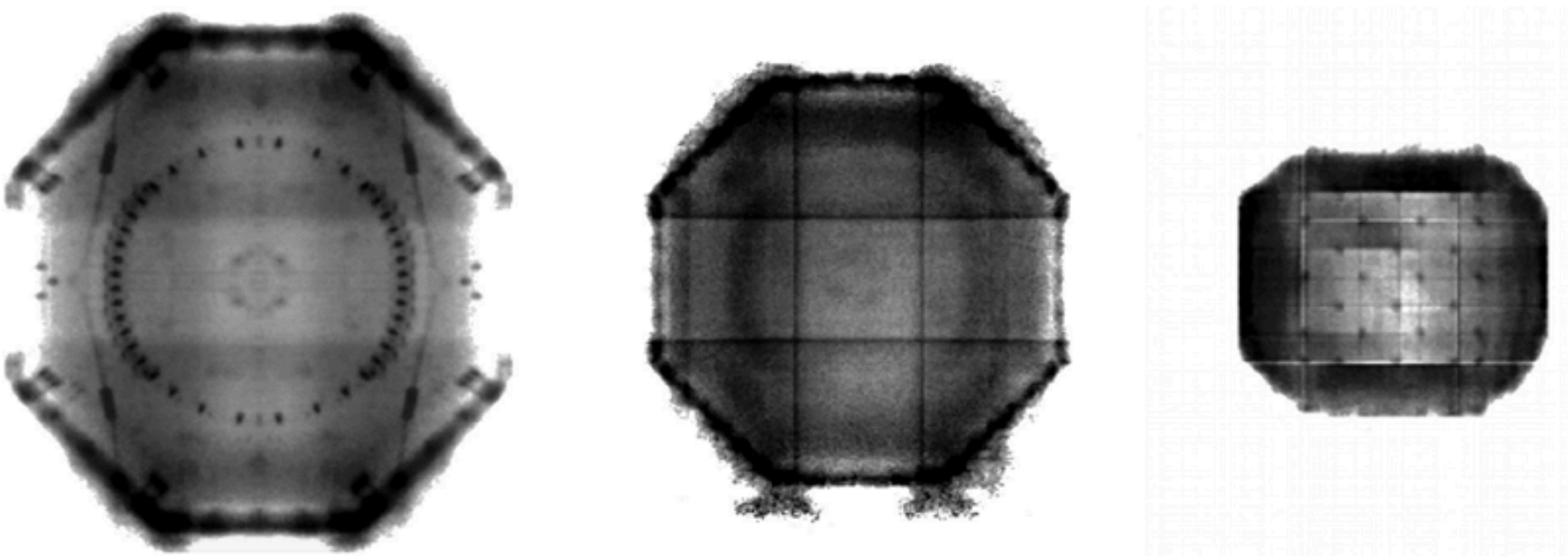


# Fragmentation inside the detector




Identification of fragmentation events

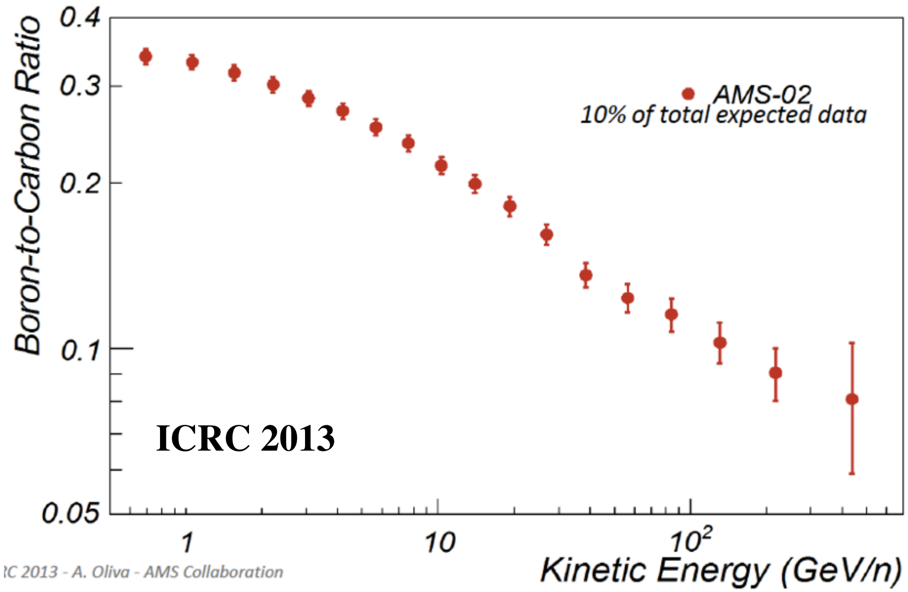
# Active and passive material in AMS-02



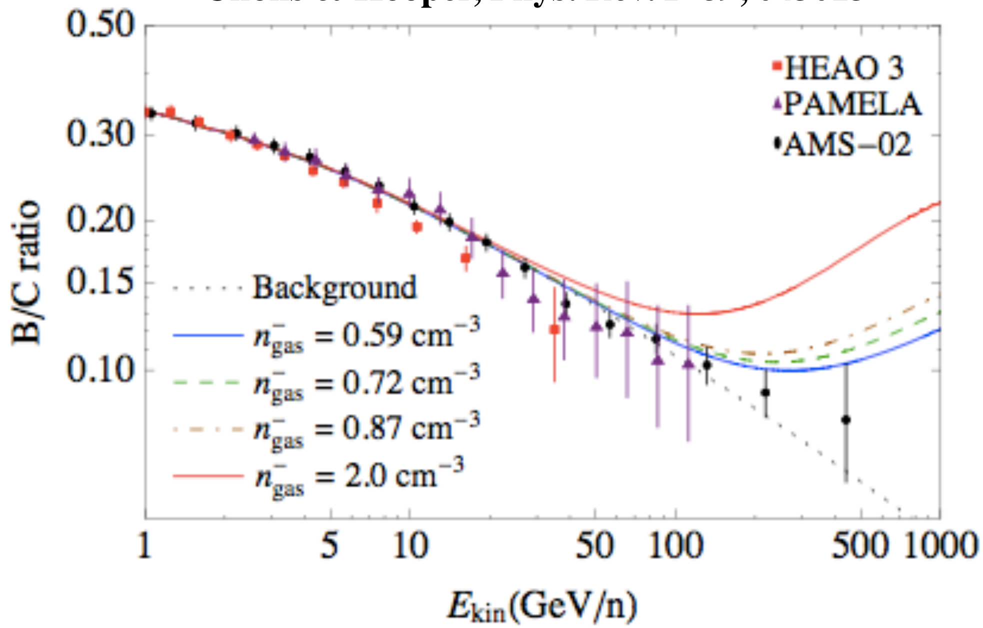
Tomographic reconstruction of the AMS material obtained using He/p from the cosmic rays

# Boron to Carbon ratio (May 2011 / May 2013)

Measurement of the B/C between 0.5 to 670 GeV/n measured by AMS:
- The B/C behavior at high energy will become more clear with more data

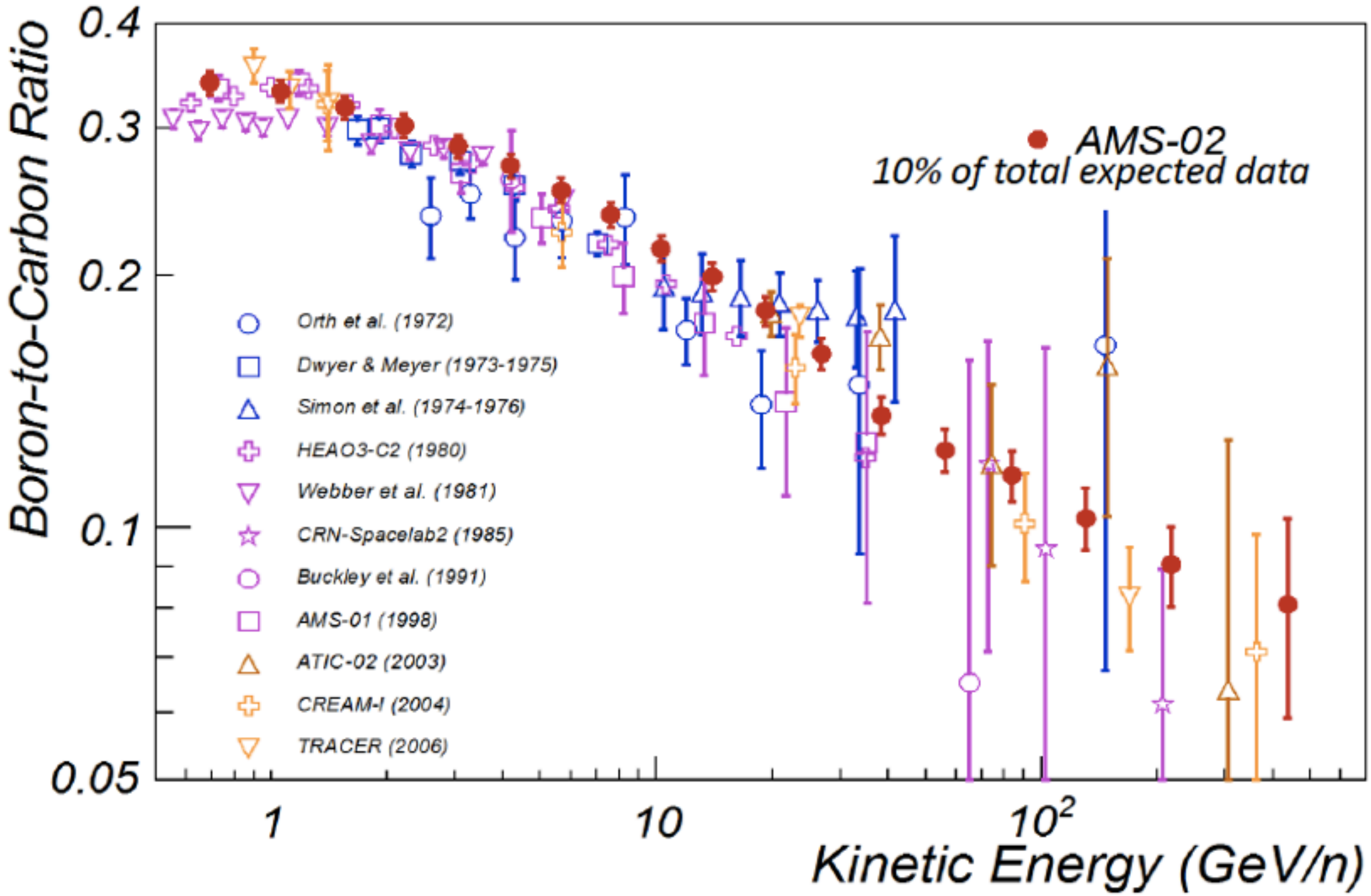



**Cholis & Hooper, Phys. Rev. D 89, 043013**



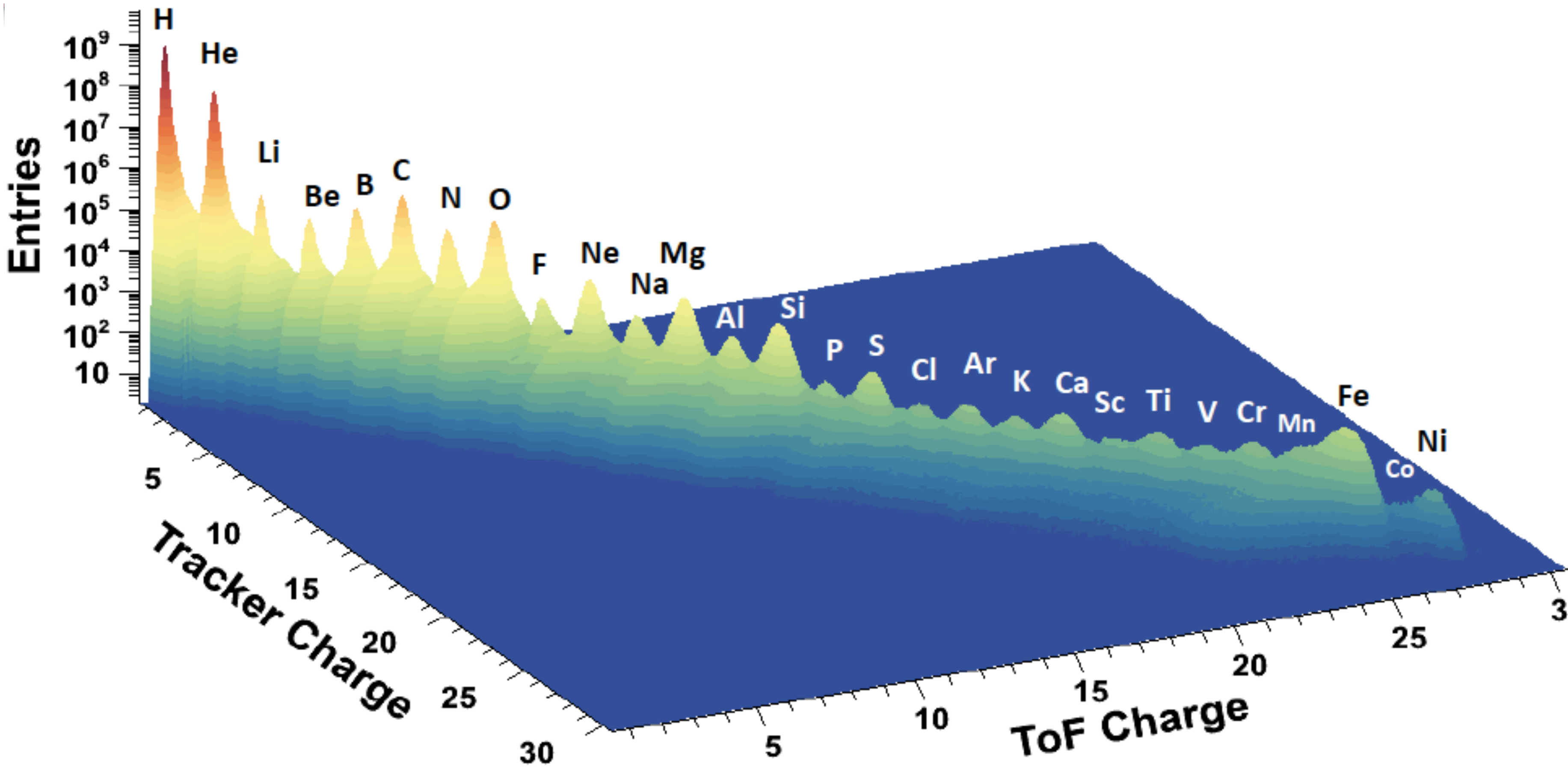

**The B/C ratio does NOT rise at high energies up to 700 GeV/n SNRs re-acceleration models are ill-favored.**

# Boron to Carbon ratio



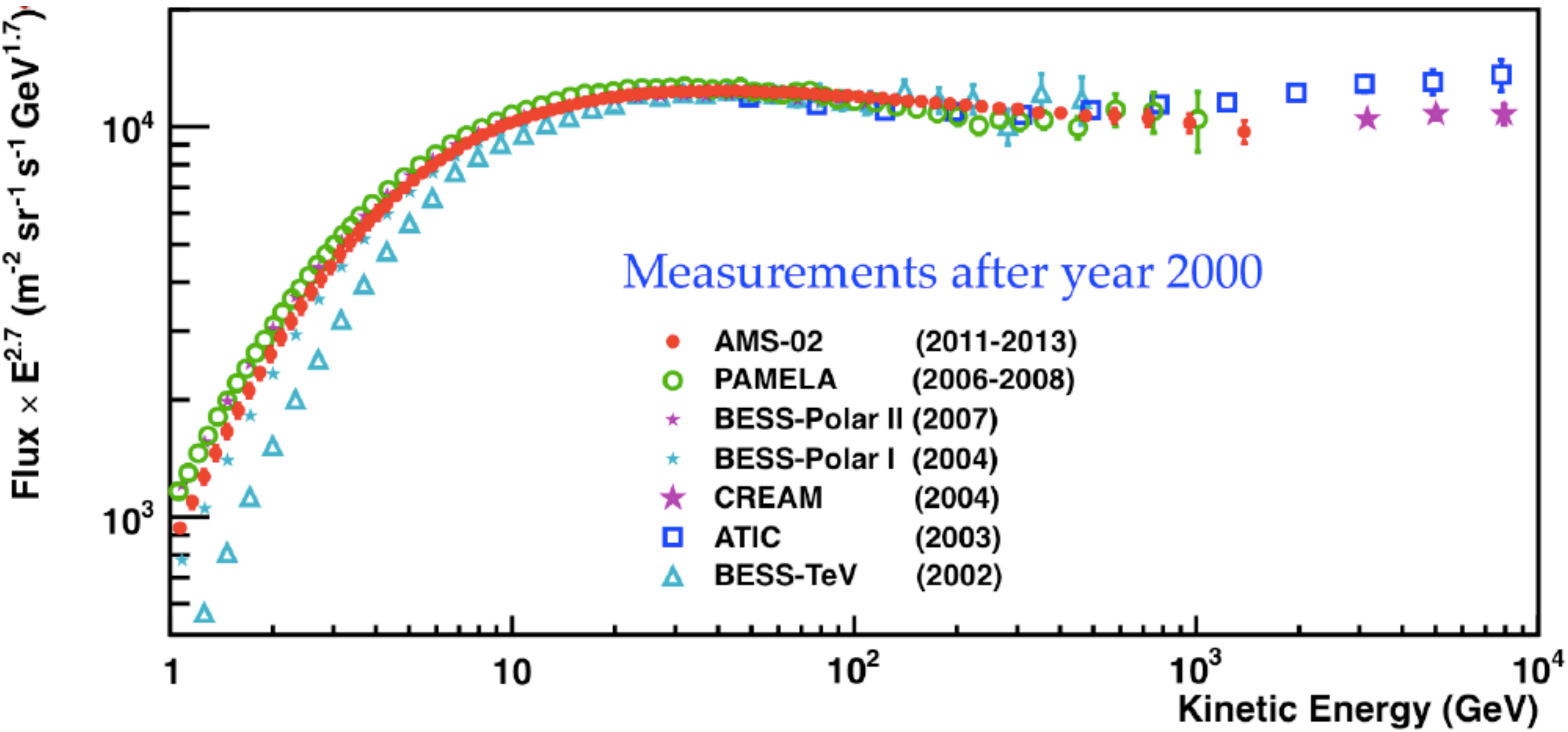

**Same study can be repeated with pbar/p, Li/C, Ni/O, F/Ne or Ti/Fe**

# Nuclei identification in AMS



# Proton flux (May 2011 / May 2013)

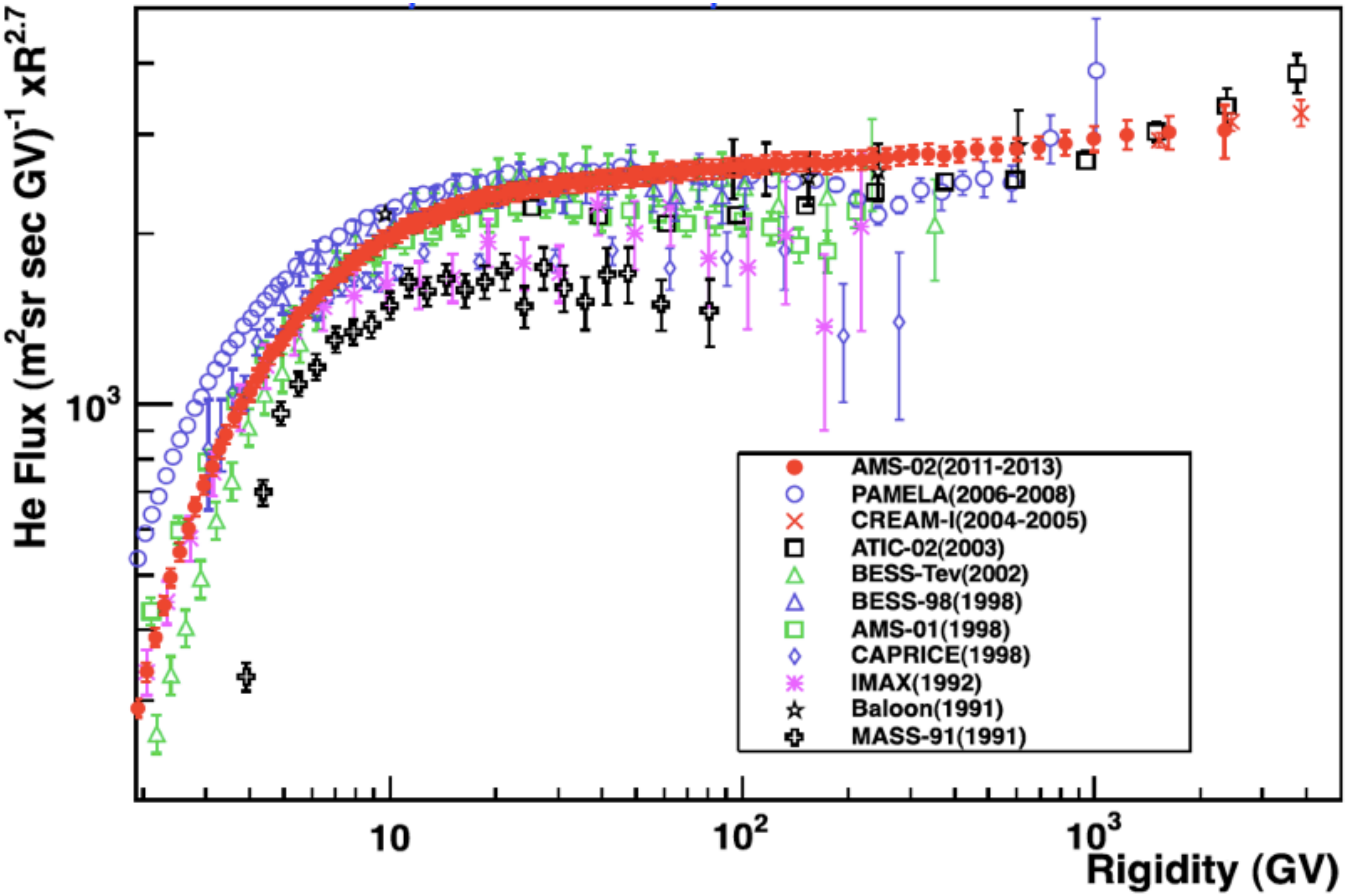
Proton flux from 1 GV to 1.8 TV:
- low rigidity range the flux is determined every day with < ~ 1% stat. errors
- high rigidity region the spectrum is consistent with a single power law without fine structures nor break.



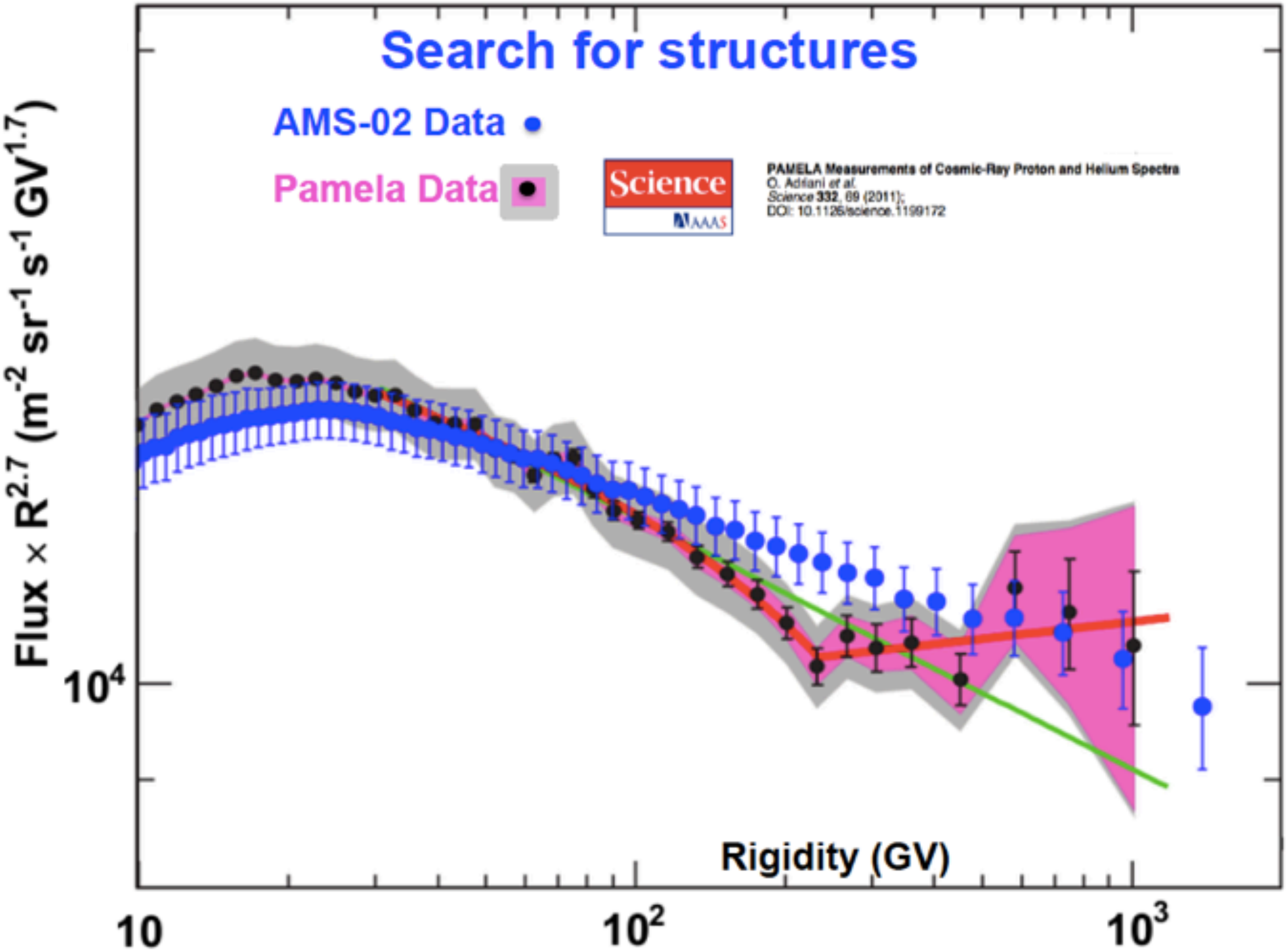
# Helium flux (May 2011 / May 2013)

Helium flux measured from 2 GV to 3.2 TV:

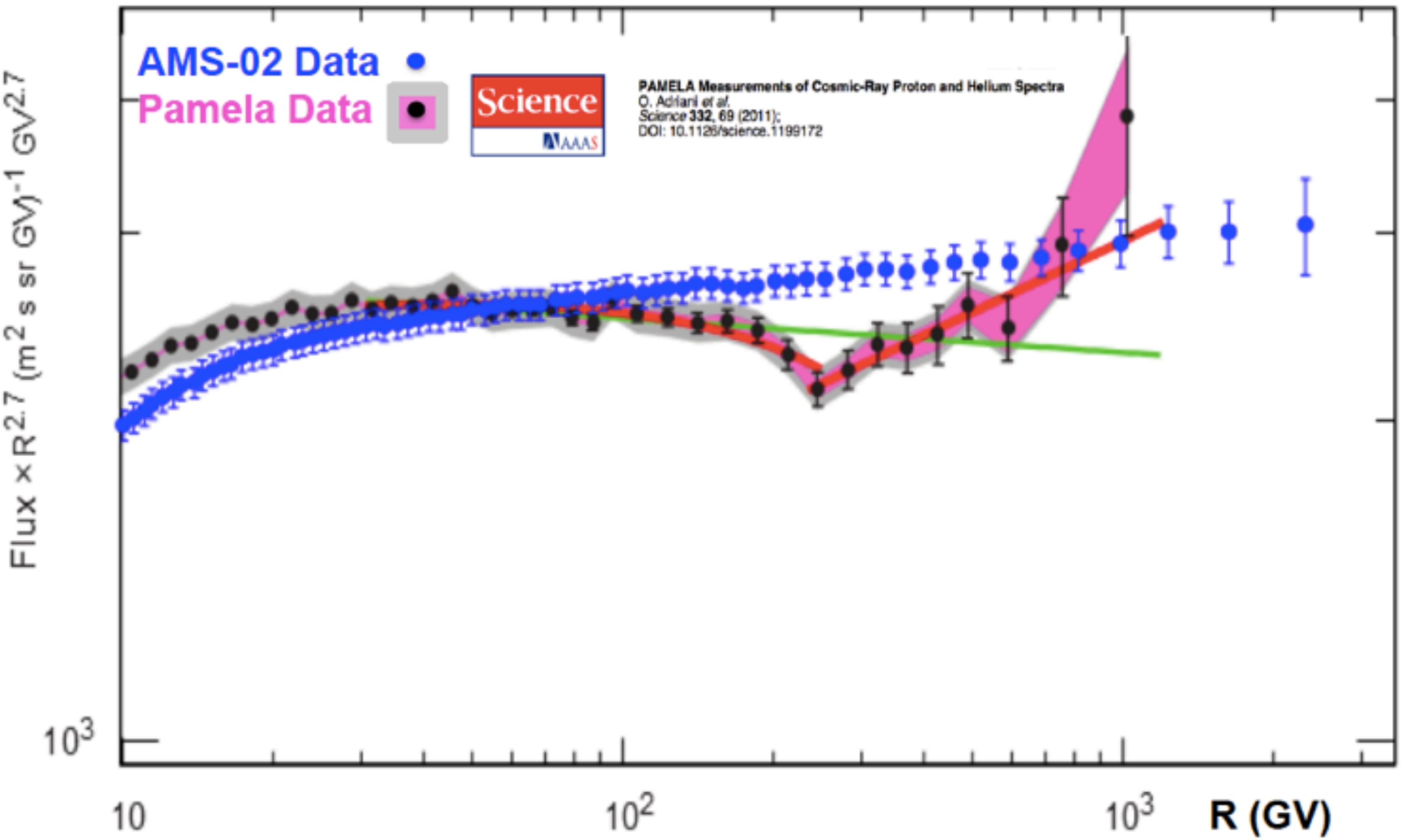
- Above 10 GV the spectrum can be parametrized by a single power law
- No fine structures were found on the spectrum



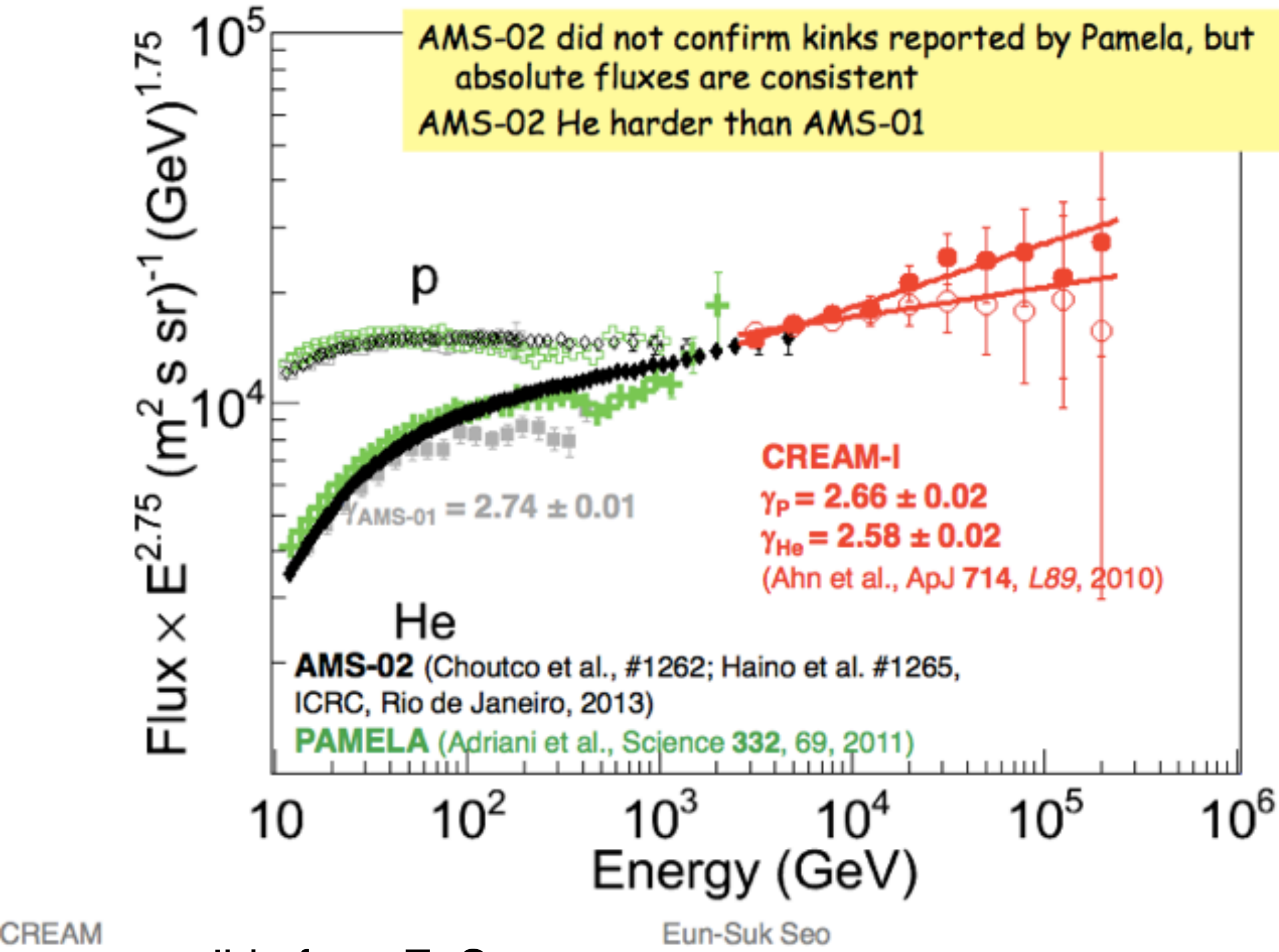
# Proton flux: Comparison with Pamela



# Helium flux:
# Comparison with Pamela



# CREAM consistent with AMS-02 where they overlap




slide from E. Seo

**He spectrum is harder than p spectrum**

Different types of sources or acceleration mechanisms? (e.g., Biermann, *A&A* 271, *649*,1993; Biermann et al. PRL 103, *061101*, 2009; ApJ 710, *L53*, 2010)

If the difference is the effects of spallation, the Galactic diffusion is characterized by a low value of δ (1/3 compared to 0.6), where $D(E) \propto E^{\delta}$ (Blasi & Amato, ArXiv: 1105.4521)

**Same study done for p and He can be repeated with other primaries as CNO and Fe**

# Conclusions

• Cosmic-ray research aims at answering fundamental questions.

• AMS-02 will be the leading instrument in its field for many years to come.

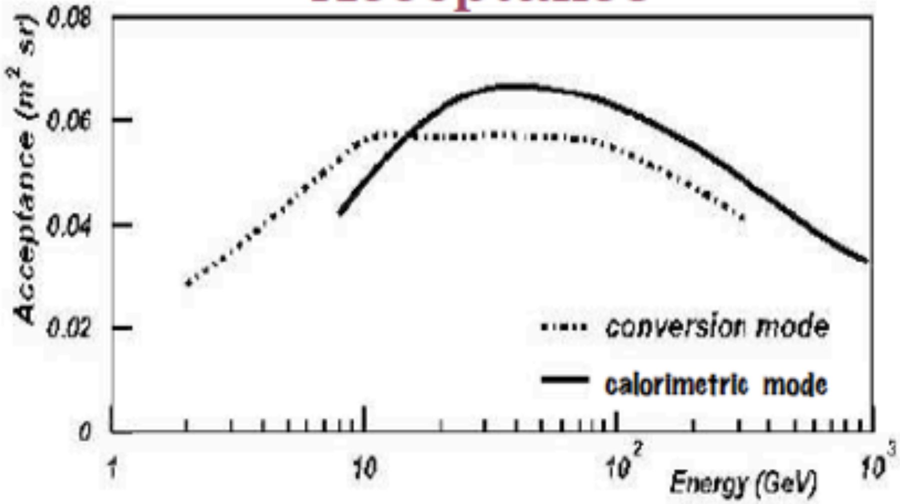
• Positron fraction confirms with unprecedented accuracy the increase above 10 GeV showing a flattening above 250 GeV. Its behavior at high energy will be crucial to constrain the scenarios.

• B/C and other secondary/primary CR species (d+, LiBeB, sub-Fe) will improve our understanding of the acceleration mechanism at the sources and the propagation models.

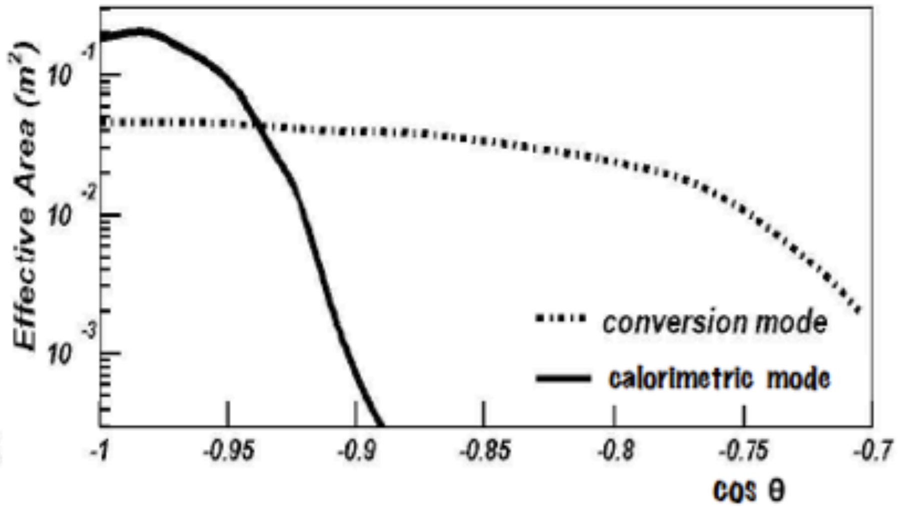
• Proton and Helium fluxes are consistent with a single power law and provide different spectral indexes. Studies of other primaries as CNO and Iron will clarify the acceleration mechanism at the sources.


**More science coming soon! Stay tuned!!!**

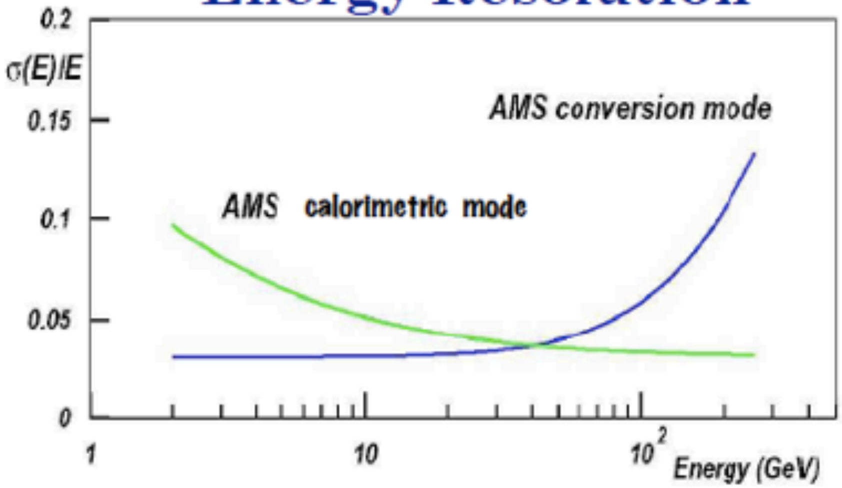
## Acceptance



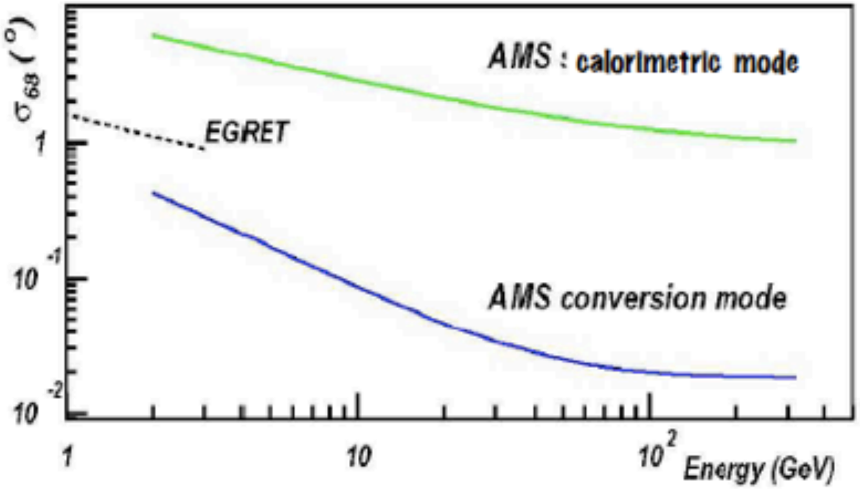

## Effective Area




## Energy Resolution




## Angular resolution



# Search for New Matter in the Universe

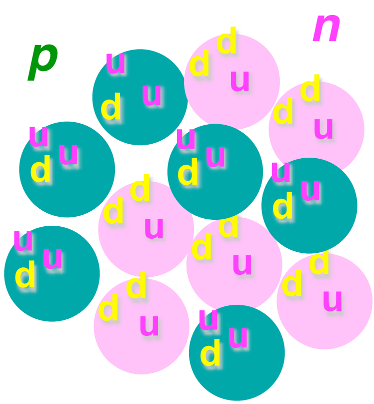
**After many years, the question of the existence of strange quark matter still remains without a definitive answer.**

***There are six types of Quarks found in accelerators (u, d, s, c, b, t).***

***All matter on Earth is made out of only two types (u, d) of quarks. "Strangelets" are new types of matter composed of three types of quarks (u, d, s) which should exist in the cosmos.***

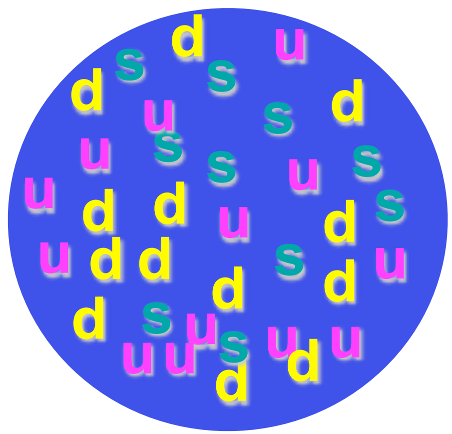
**Carbon Nucleus**

Z/A ~ 0.5



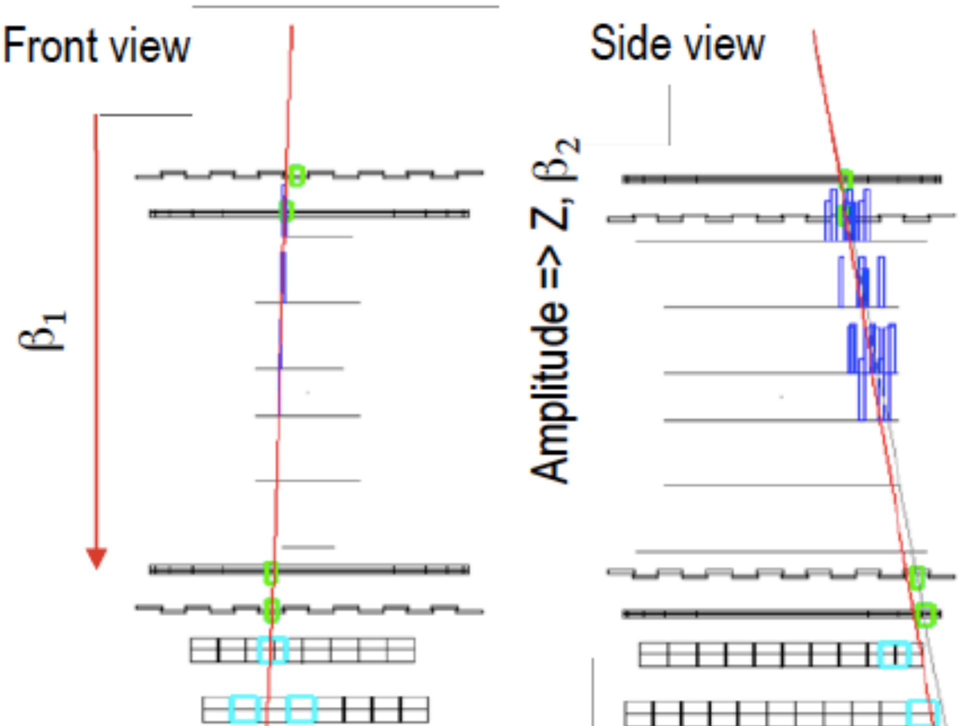

**Strangelet**

**Z/A ~ 0.1**



**E. Witten, Phys. Rev. D,272-285 (1984)**

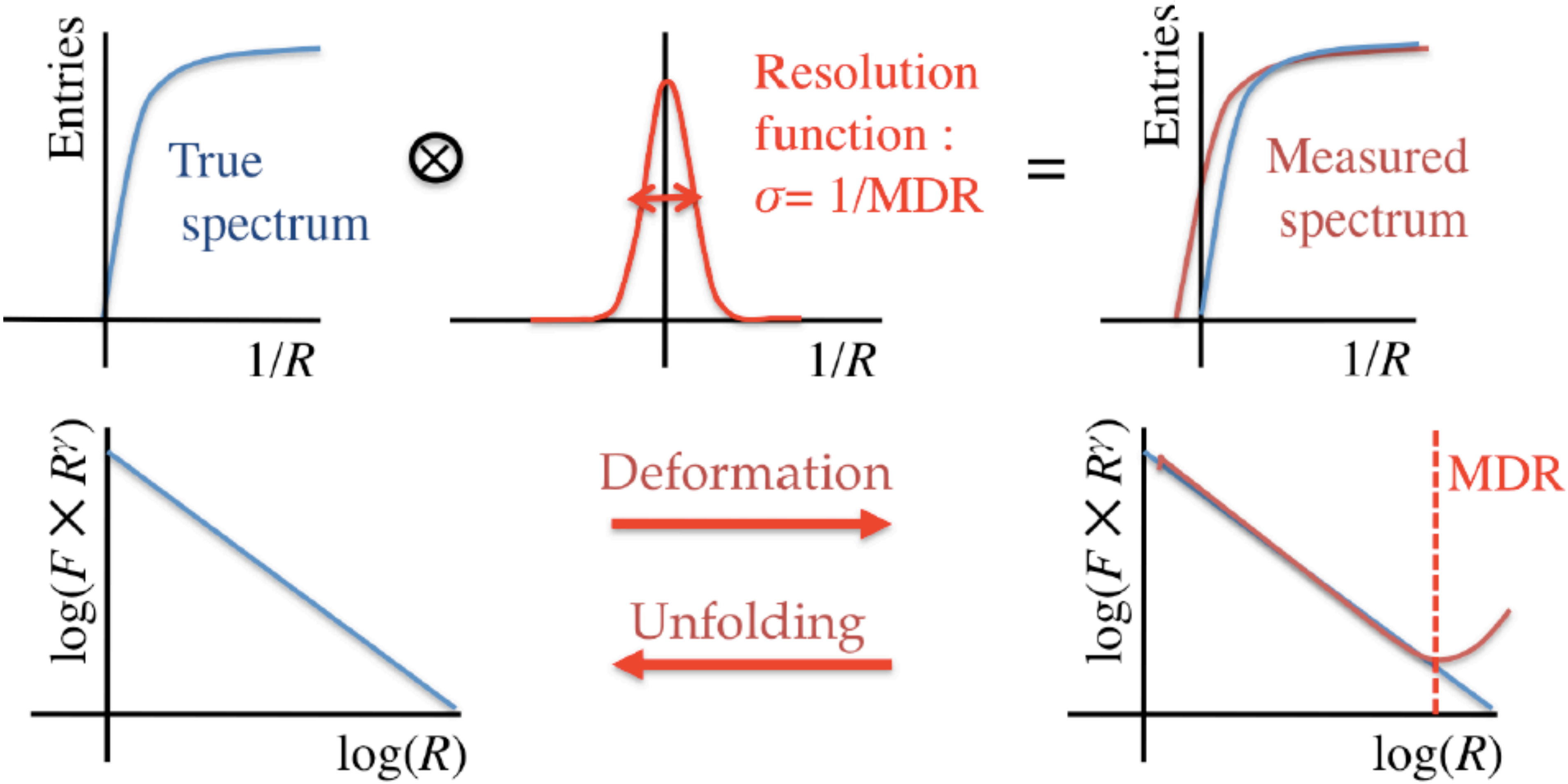
# Candidate observed with AMS-01 5 June 1998 11:13:16 UTC




Rigidity = 4.31 ± 0.38 GV
Charge Z = 2
$\beta_1 = \beta_2$ = 0.462 ± 0.005
Mass = 16.45±0.15 GeV/$c^2$
Z/A = 0.114 ± 0.01
Flux ($1.5 < E_K < 10$ GeV) = $5\times10^{-5}$ ($m^2$ sr sec)$^{-1}$

**Z/A~0.1**

# Spectrum Unfolding



# Proton flux
# Systematic errors

- Acceptance $\varepsilon_{\text{acc}} = 2.8\ \%$
- Trigger efficiency $\varepsilon_{\text{trg.}} = 1.0\ \%$
- Track reconstruction efficiency $\varepsilon_{\text{trk.}} = 1.0\ \%$
- Total systematic errors of normalization :

$$\varepsilon_{\text{norm.}} = (\varepsilon_{\text{acc}}{}^2 + \varepsilon_{\text{trg}}{}^2 + \varepsilon_{\text{trk}}{}^2)^{1/2} = 3.1\ \%$$

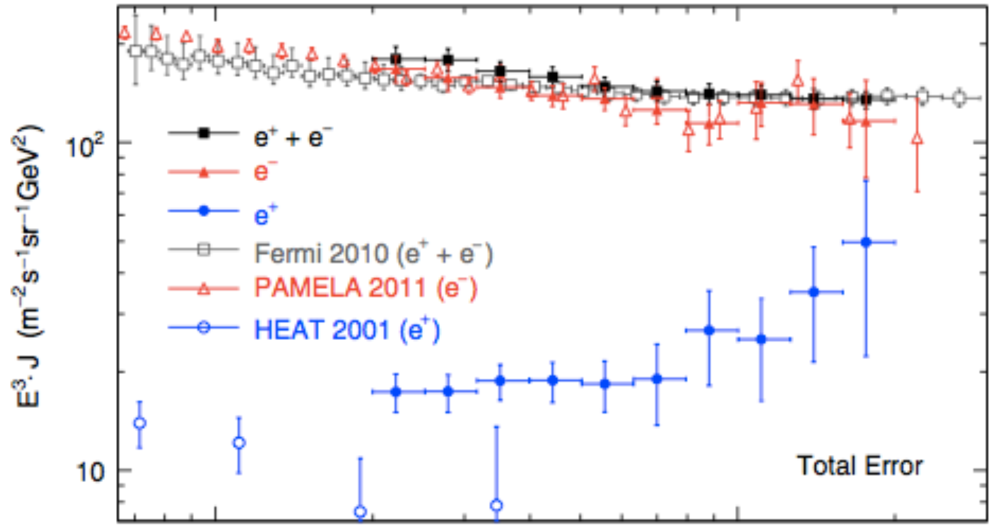
- Systematic error of unfolding

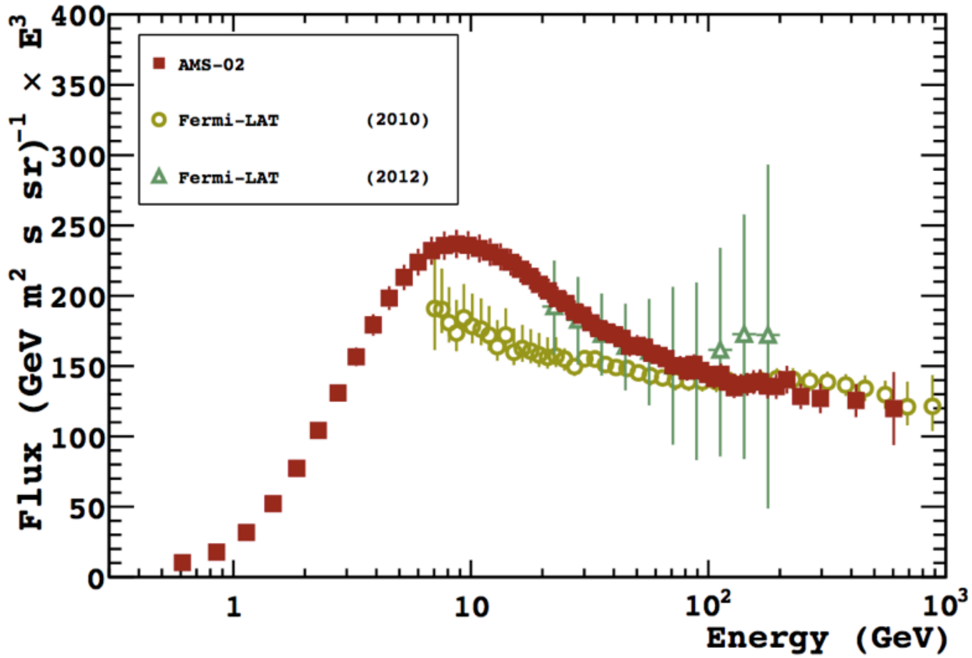
$$\varepsilon_{\text{unfold}} < 1\ \% \text{ at } R < 200 \text{ GV}$$

$$\varepsilon_{\text{unfold}} = 5.4\ \% \text{ at } R = 1 \text{ TV}$$

# Electron Flux comparisons with FERMI

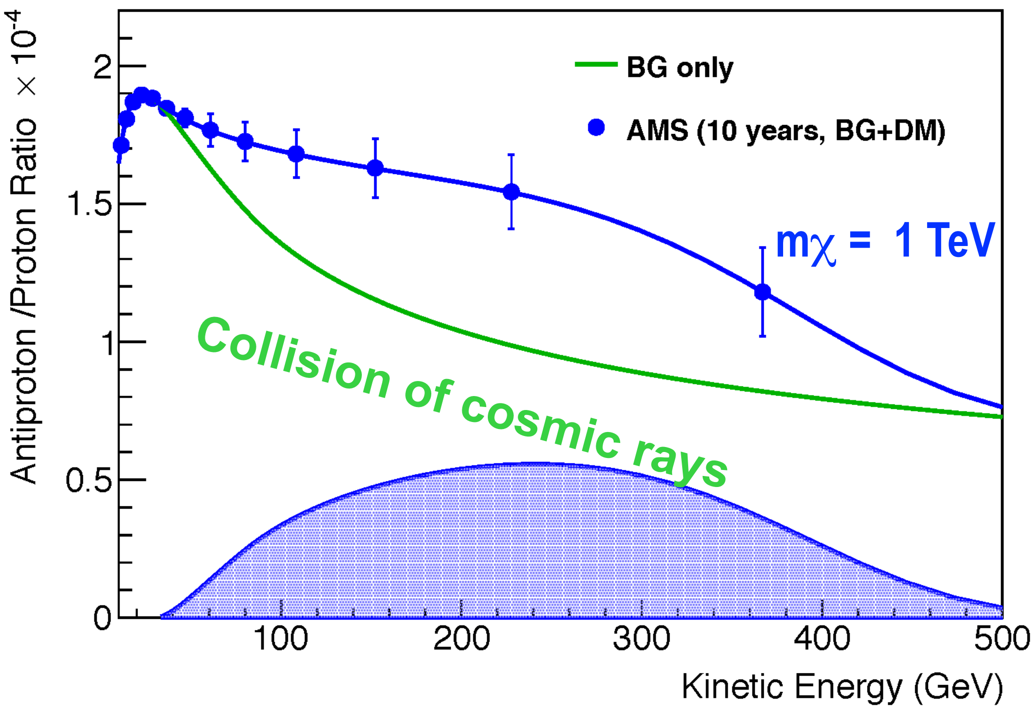
M. Ackermann, PRL 108, 011103 (2012)



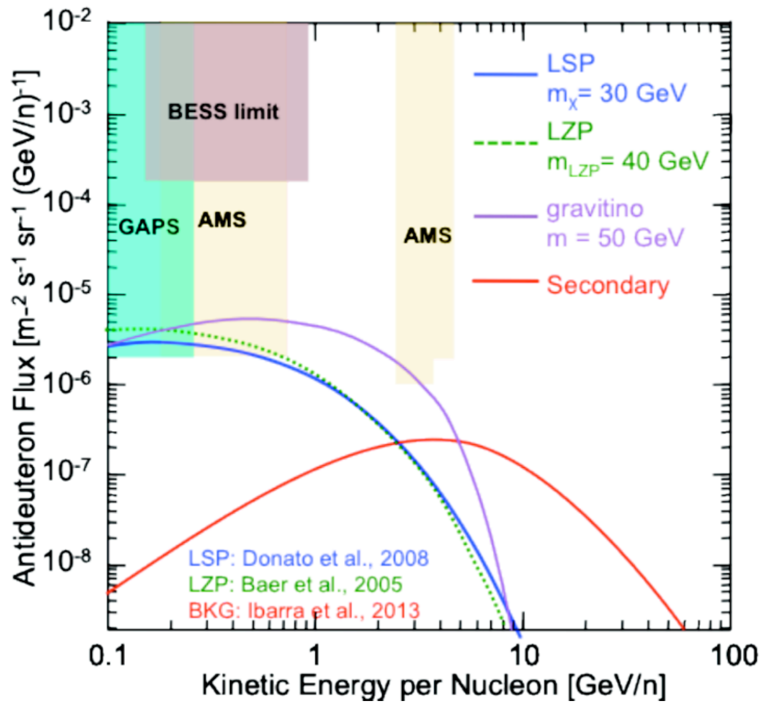



# Smoking gun... AMS-02 in 10 years

Aniprotons or antideuteron excess would be a major indicator of DM annihilation

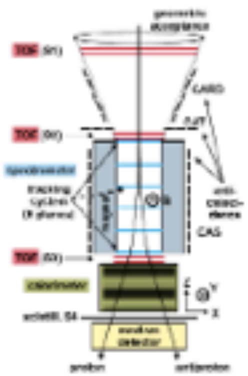



**Dark Matter (DM) Source**
**Ref: Donato et al., PRL 102, 071301 (2009)**

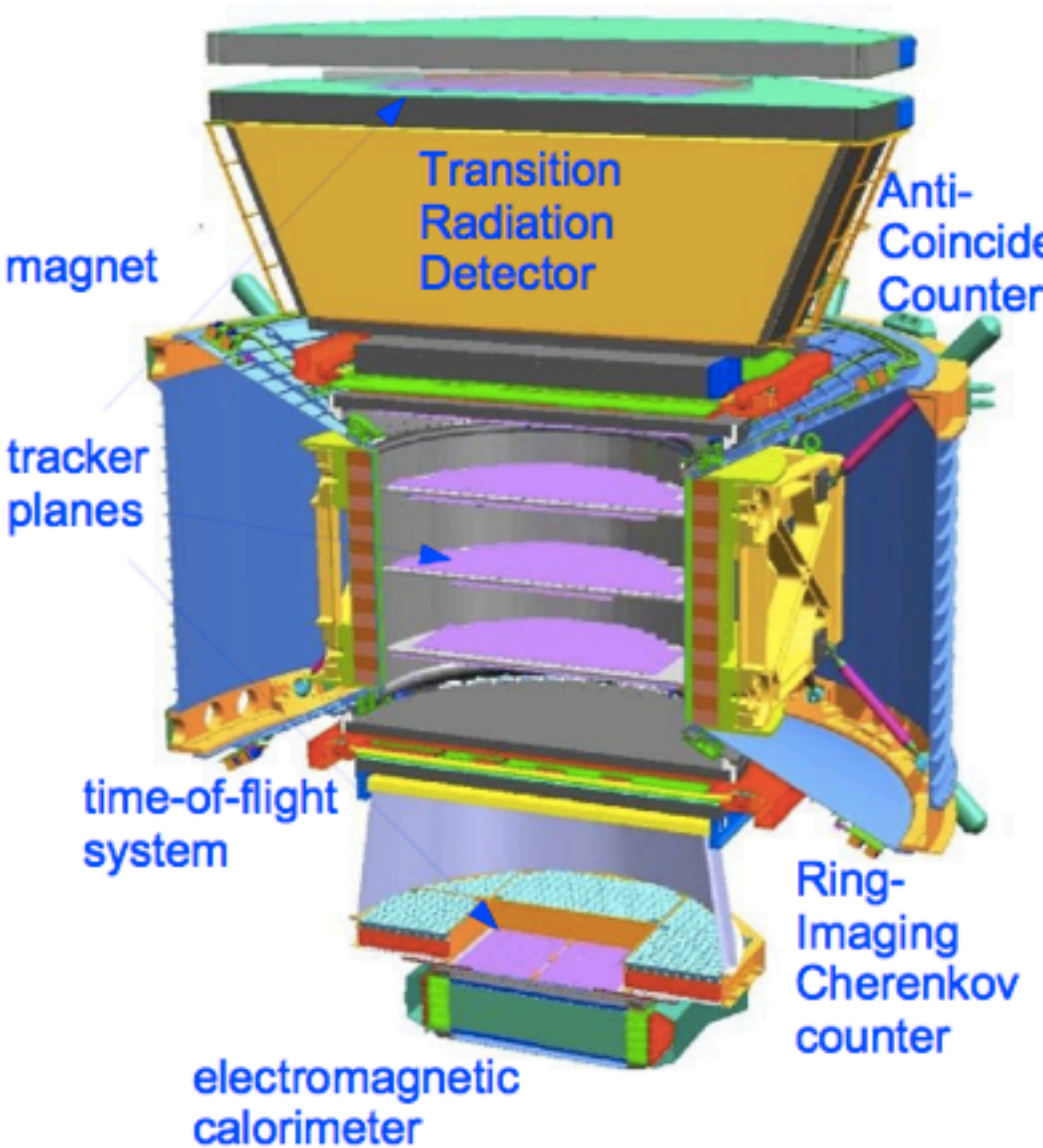



Very good background rejection
Very good knowledge of Cosmic Rays sources and propagation

# PAMELA vs AMS-02



GF: 21.5 cm² sr




GF: 250 – 3500 cm² sr, depending on physics analysis