Rencontres de Moriond - EW 2014
La Thuile, Aosta valley, Italy
15-22 March 2014

The AMS-02 detector on the International Space Station

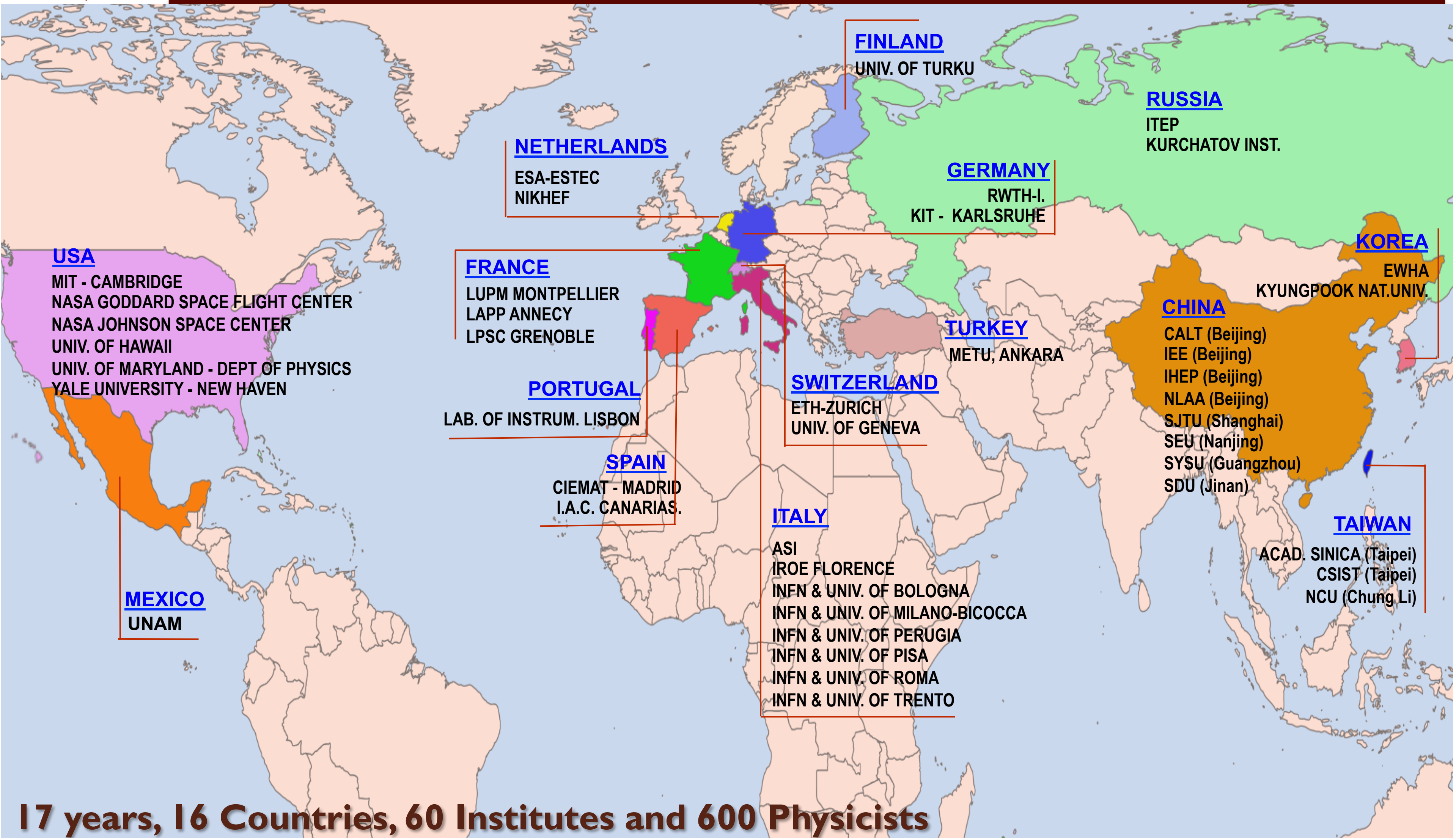
Status and perspectives after 1000 days on orbit

Matteo Duranti
INFN Sez. Perugia

INFN Sez. Perugia

on behalf of the AMS Collaboration

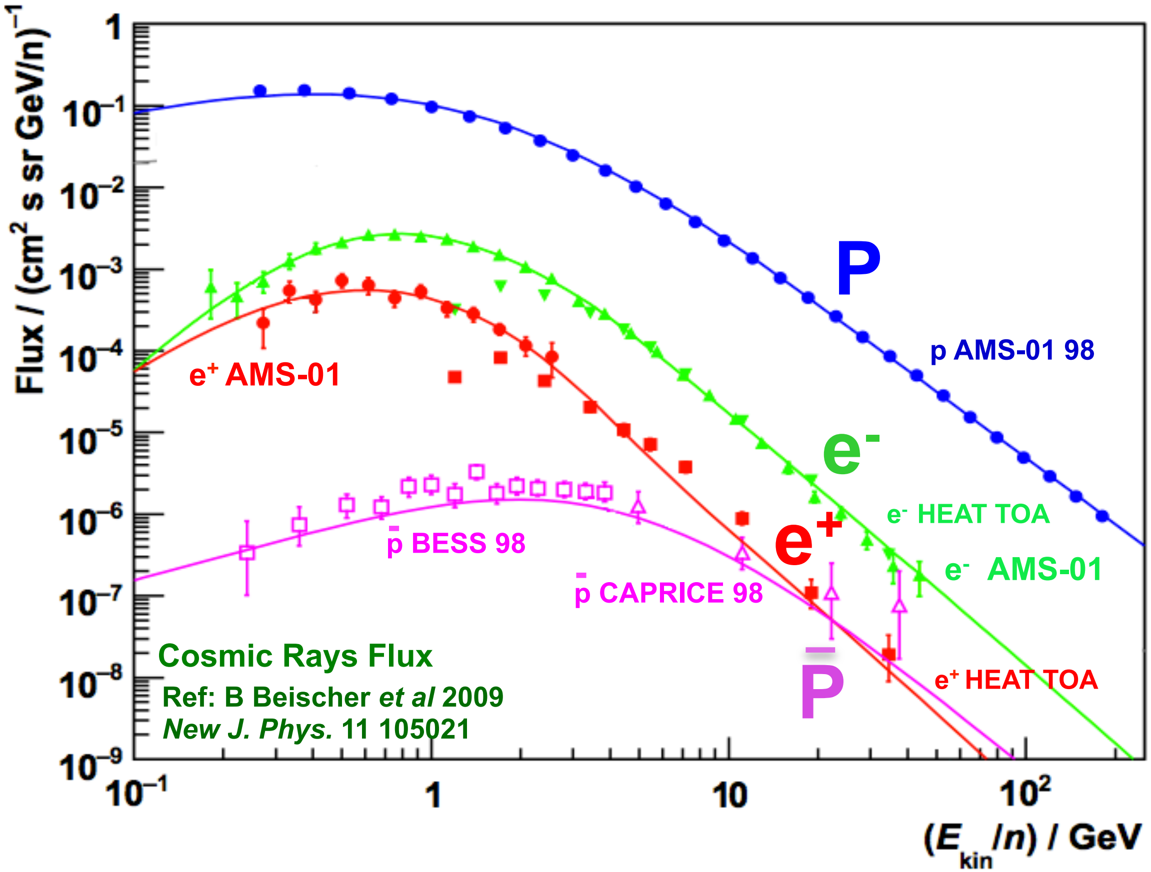
On behalf the AMS Collaboration



17 years, 16 Countries, 60 Institutes and 600 Physicists

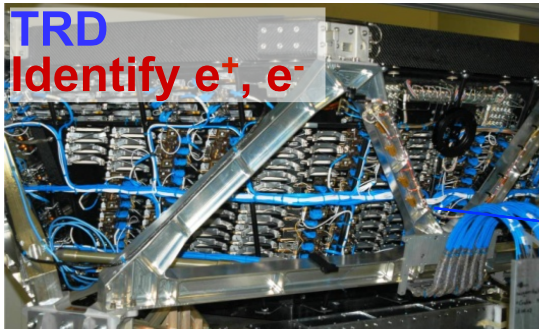
AMS on the International Space Station

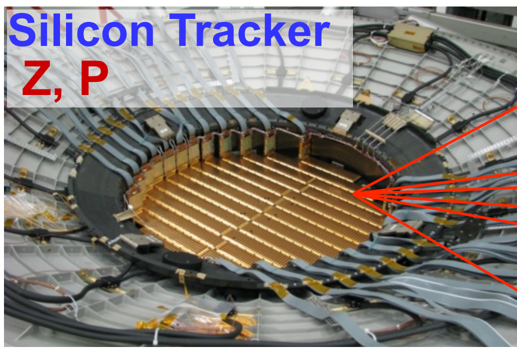
- Primordial Antimatter search with 10^{-9} sensitivity
- Indirect Dark Matter search ($e^+, \bar{p}, \gamma$)
- Relative abundances of nuclei and isotopes in primary cosmic rays
- γ rays astrophysics

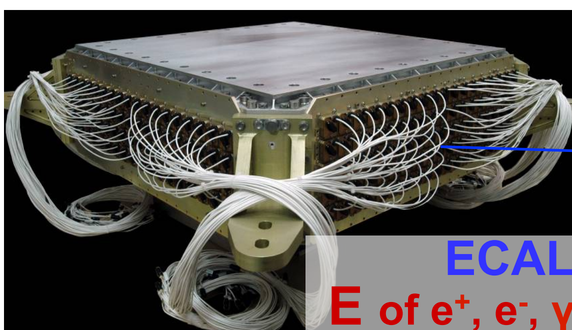


The purpose of the AMS experiment is to perform accurate, high statistics, long period measurements of charged cosmic rays (O(GV) - O(TV)) and γ rays (E>1GeV)

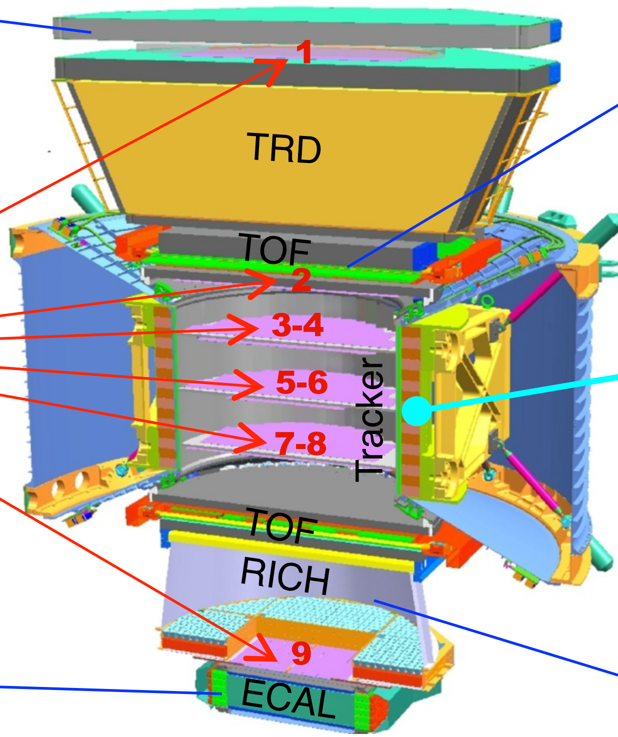
A precision, multipurpose, up to TeV spectrometer

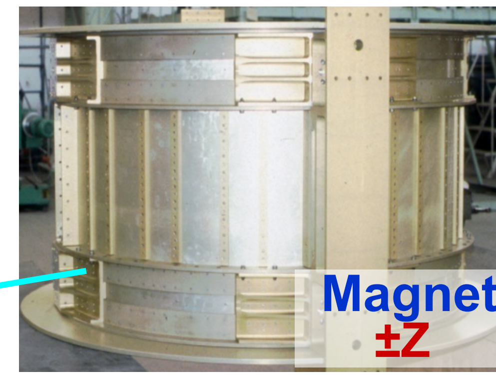


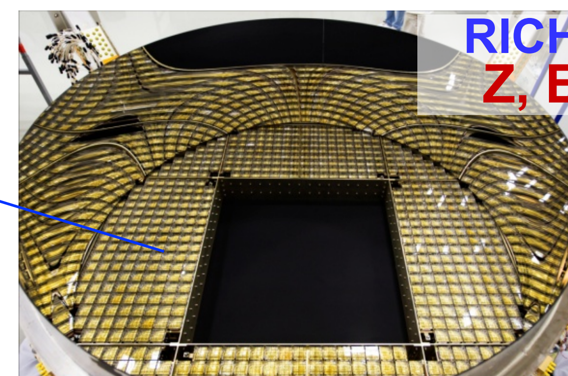




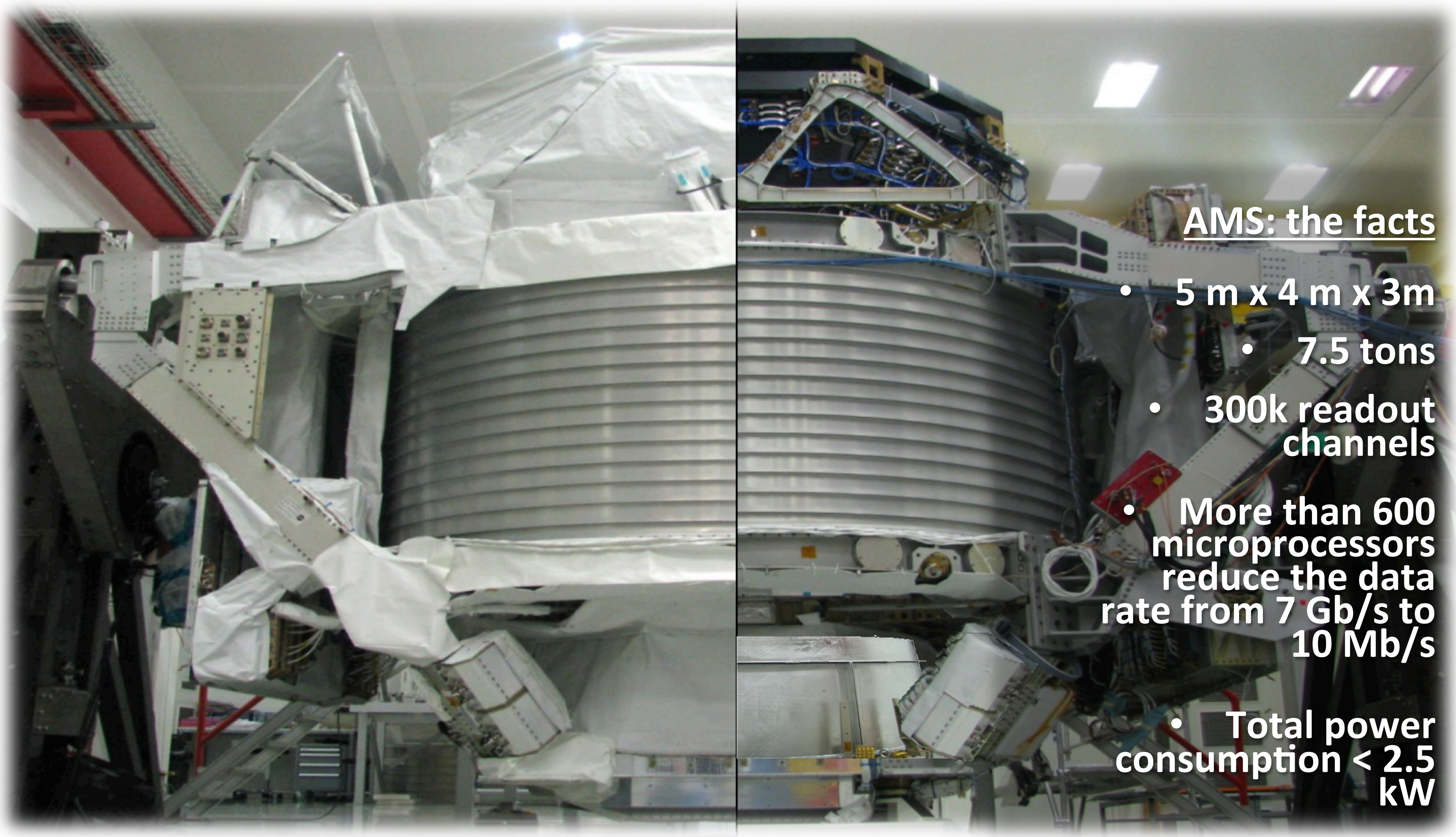
***Z, P** are measured independently by the Tracker, RICH, TOF and ECAL*







The detector



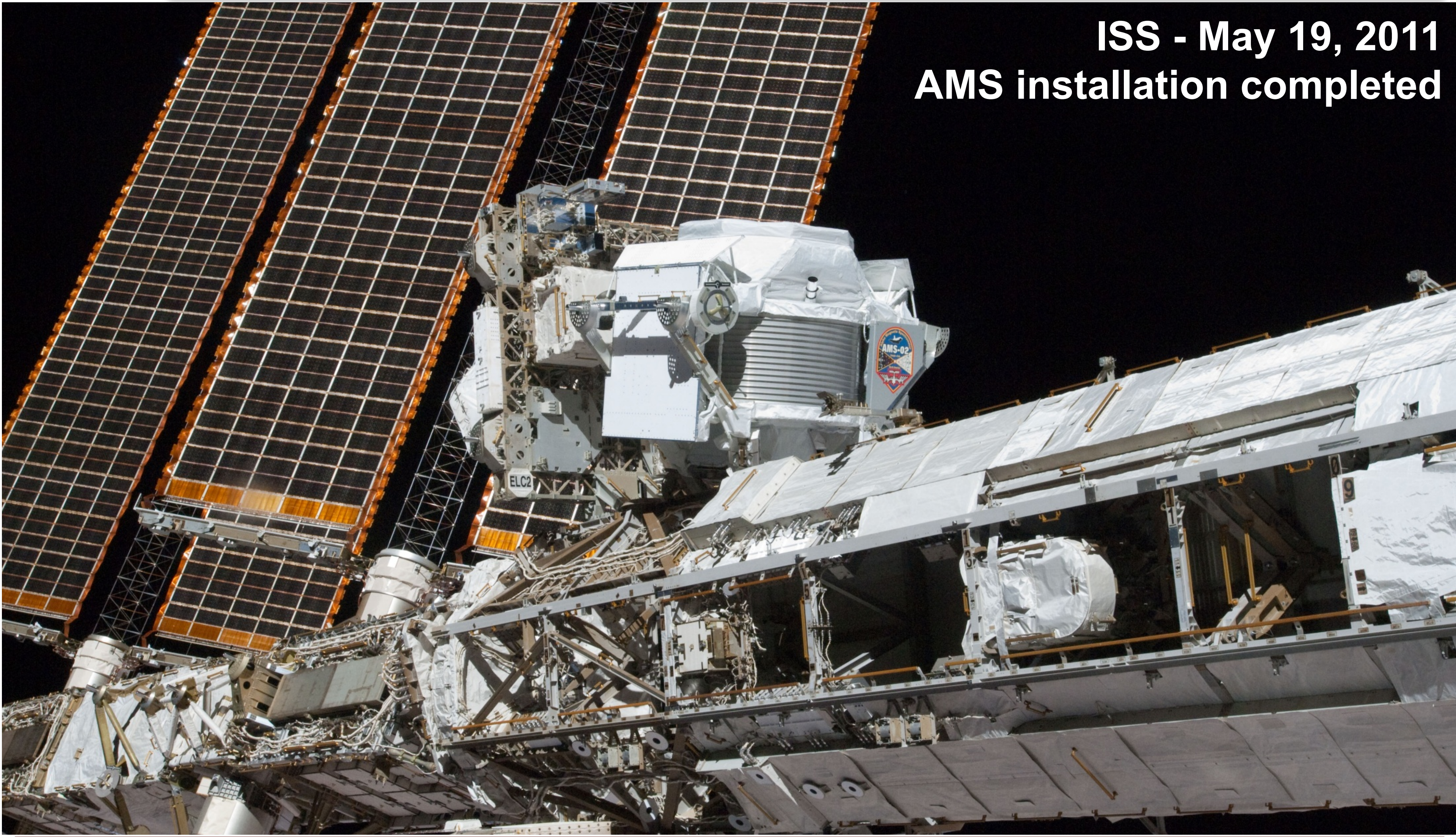
AMS: the facts

- 5 m x 4 m x 3m
- 7.5 tons
- 300k readout channels
- More than 600 microprocessors reduce the data rate from 7 Gb/s to 10 Mb/s
- Total power consumption < 2.5 kW

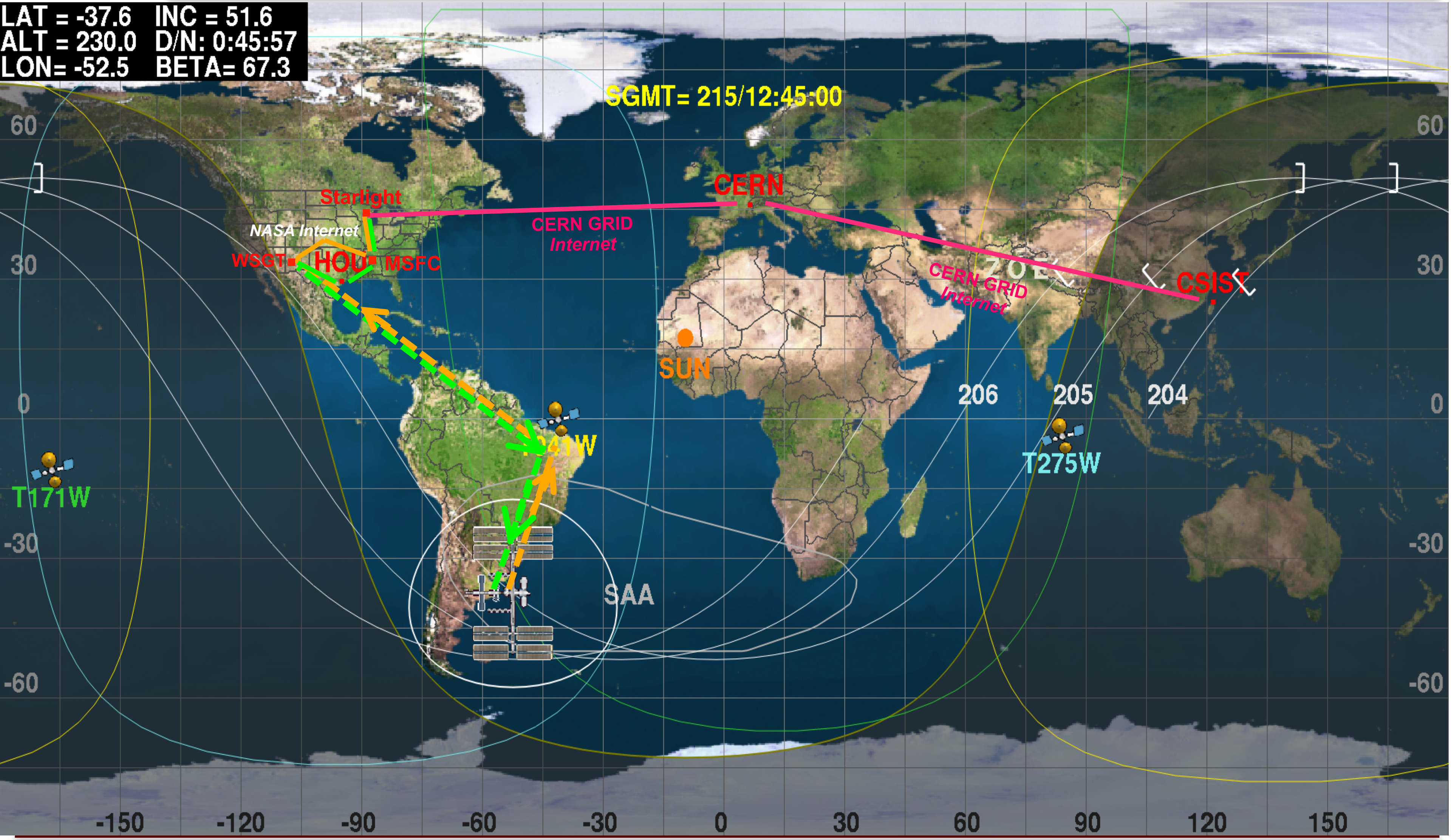
May 16th 2011: launch!

May 16th 2011: launch!

May 19th 2011: installation!



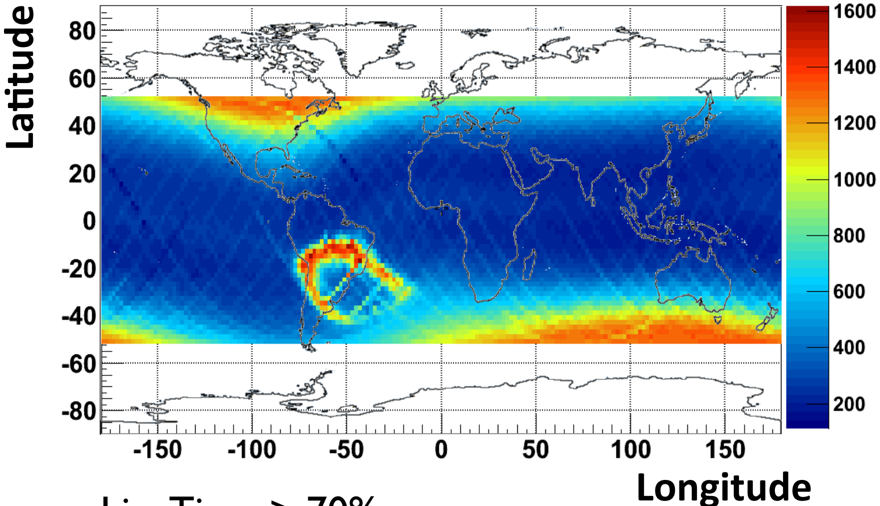
On orbit @ 400 km

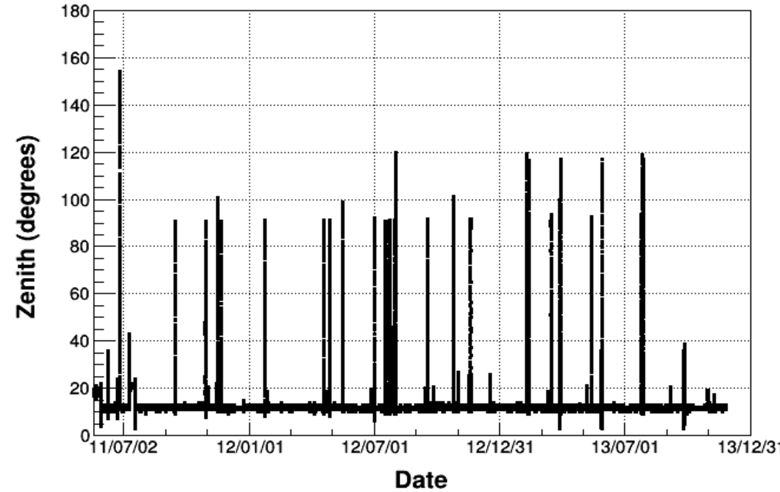


Payload Operation Control Center (POCC) @ CERN

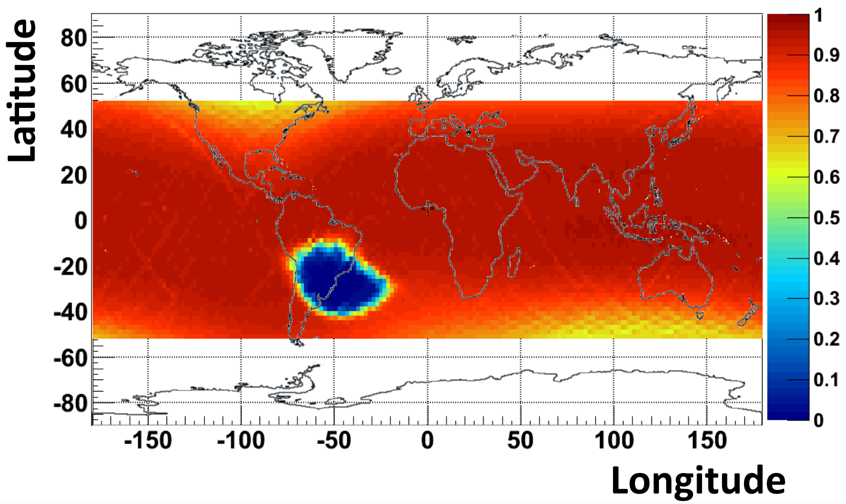
Orbital parameters

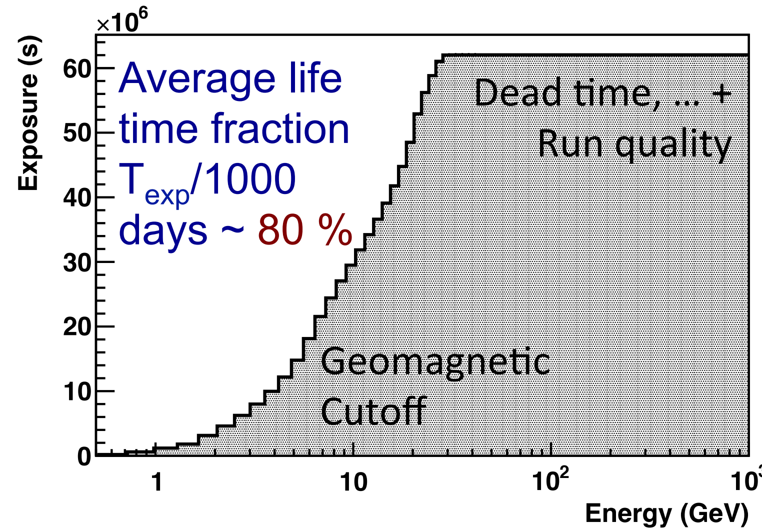
<Acquisition rate> ≈ 500 Hz





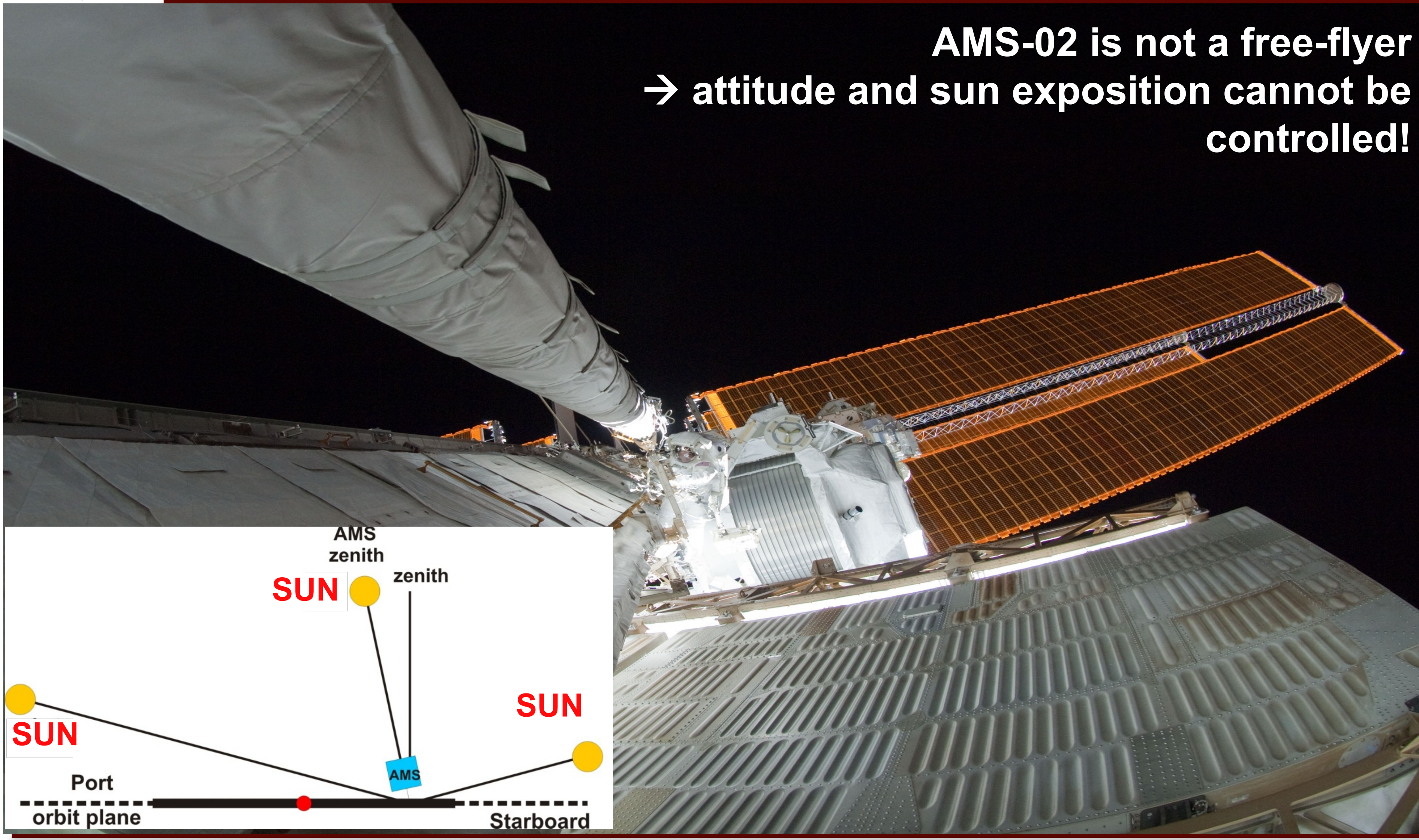
LiveTime > 70%





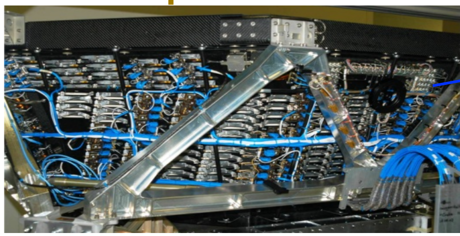
Thermal environment

AMS-02 is not a free-flyer
→ attitude and sun exposition cannot be controlled!



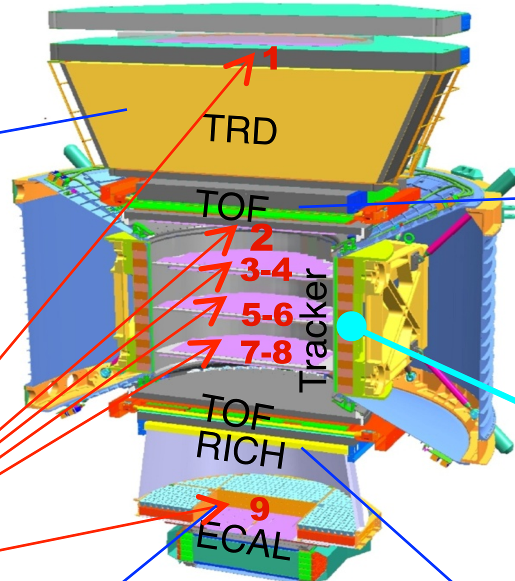
Flight electronics for thermal control

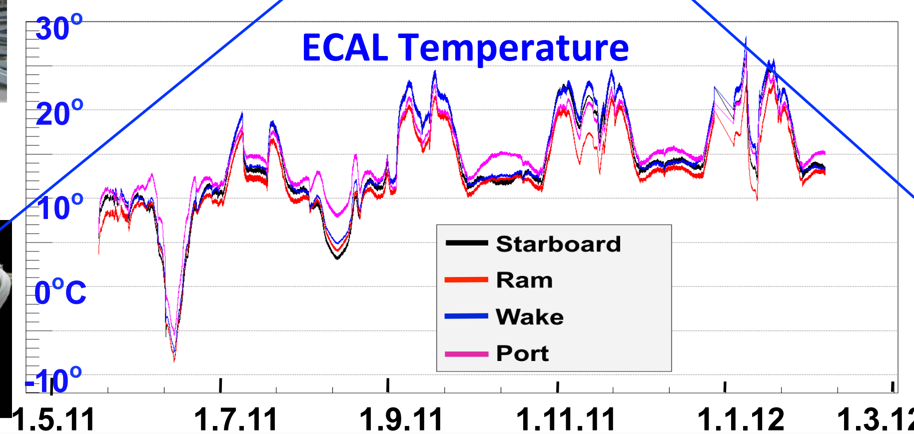
TRD
24 Heaters
8 Pressure Sensors
482 Temperature Sensors



Silicon Tracker
4 Pressure Sensors
32 Heaters
142 Temperature Sensors

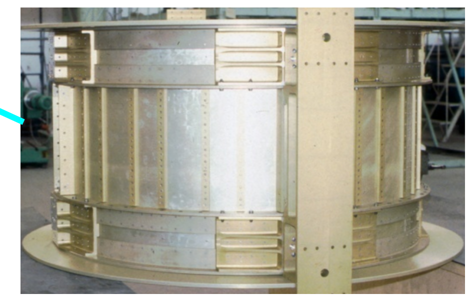
ECAL
80 Temperature Sensors



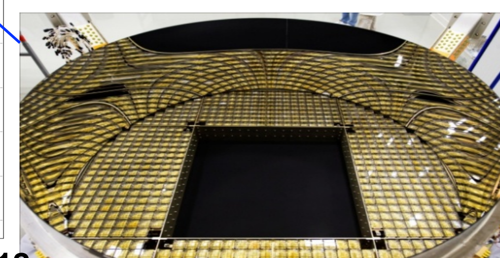


TOF & ACC
64 Temperature Sensors

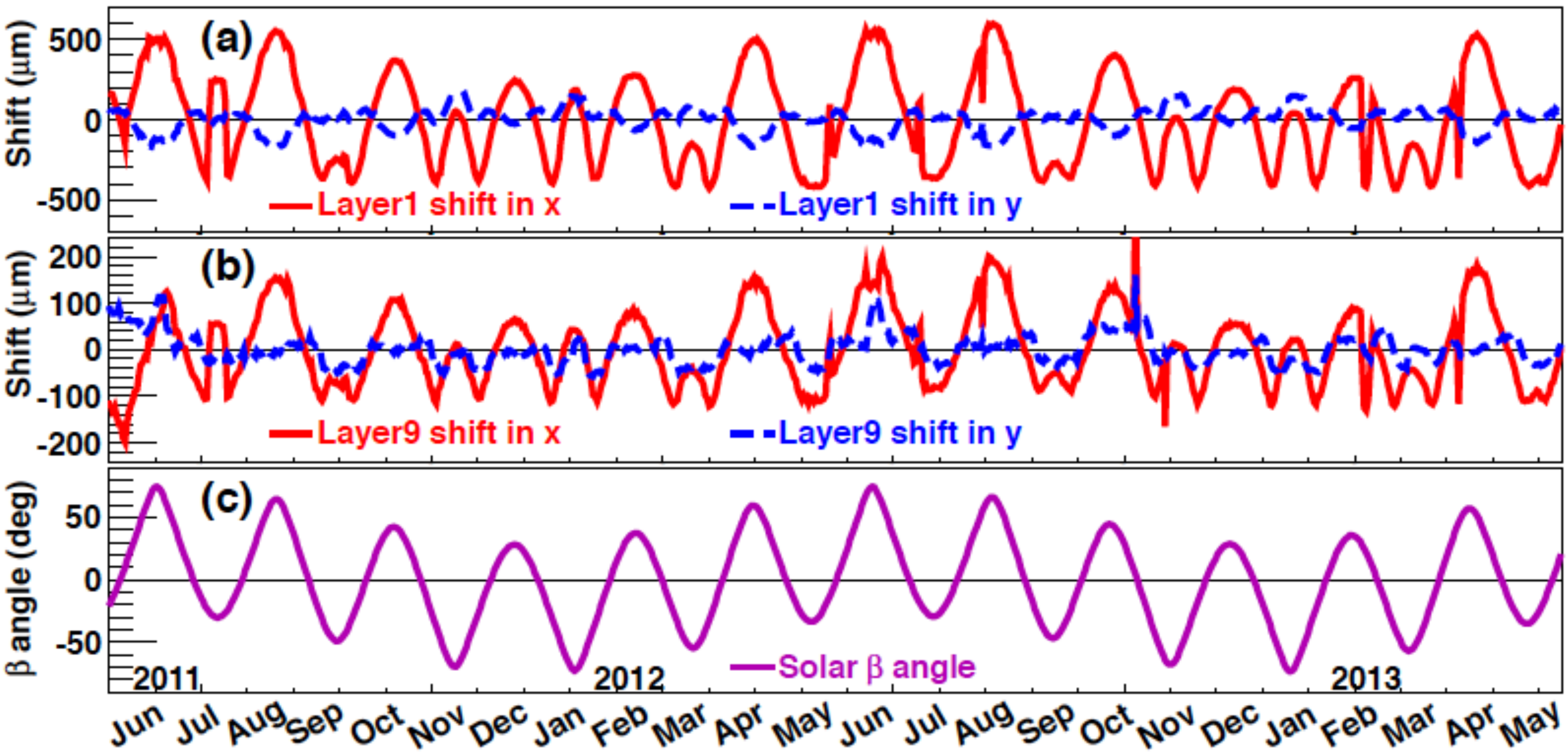
Magnet
68 Temperature Sensors



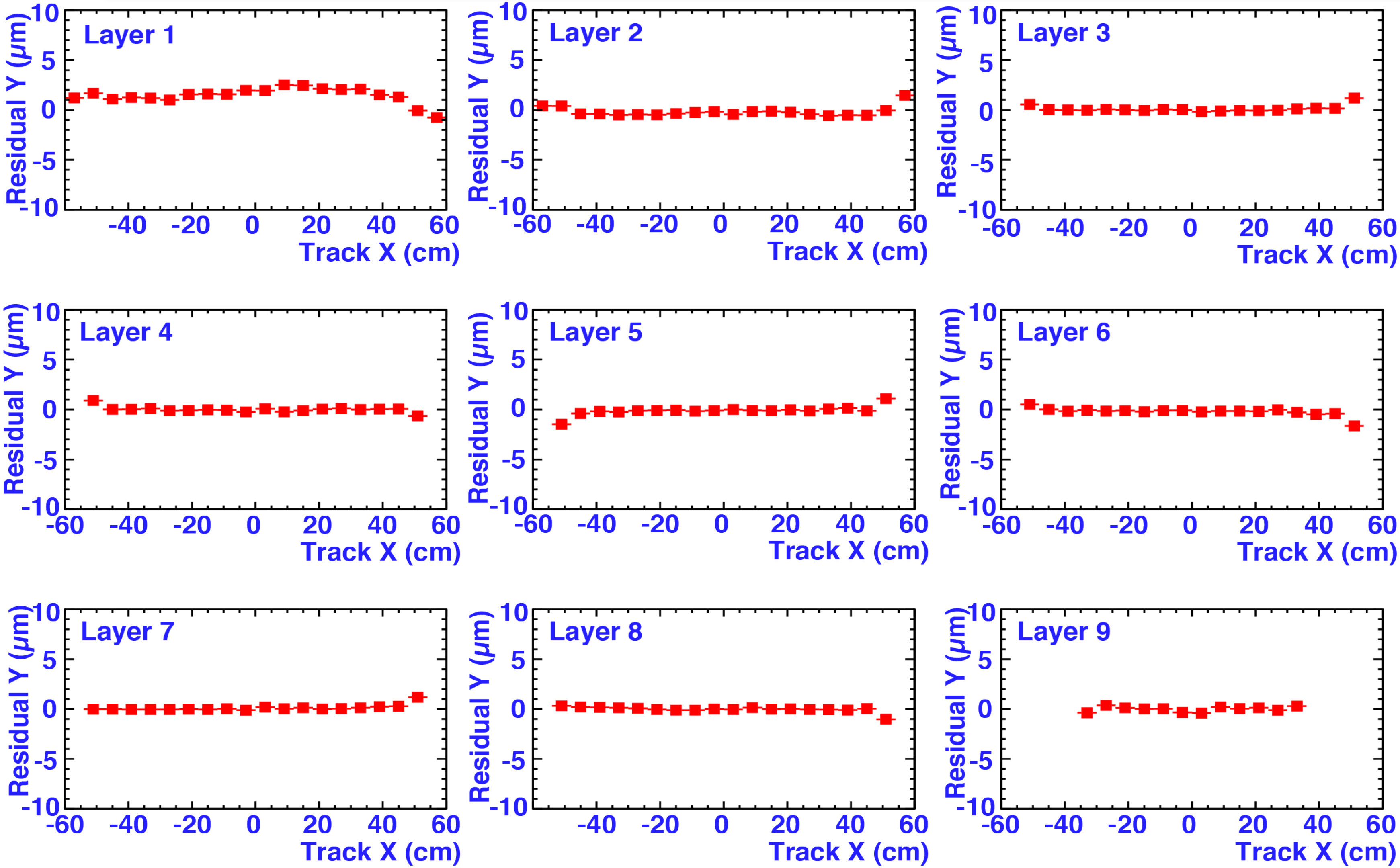
RICH
96 Temperature Sensors



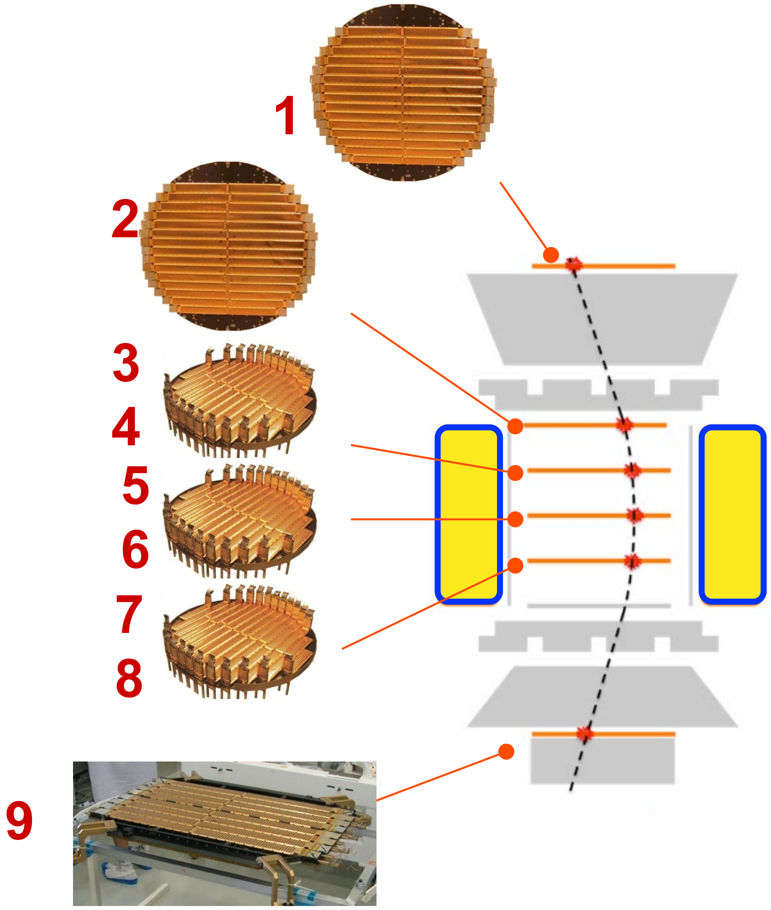
Seasonal effects on Tracker



Tracker layers alignment accuracy



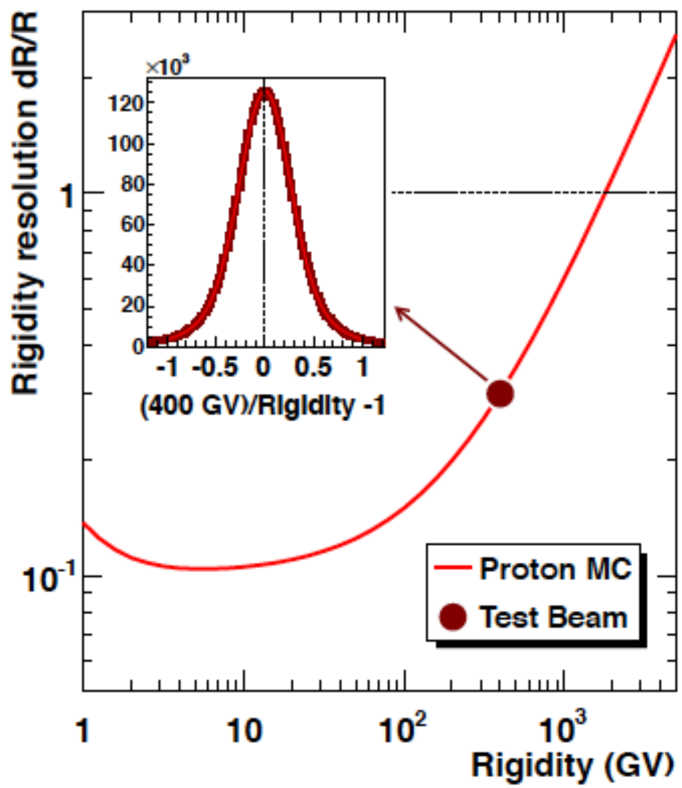
Silicon Tracker



Coordinate resolution 10 μm

→ 20–UV Lasers to monitor inner tracker alignment

→ Cosmic rays to monitor outer tracker alignment

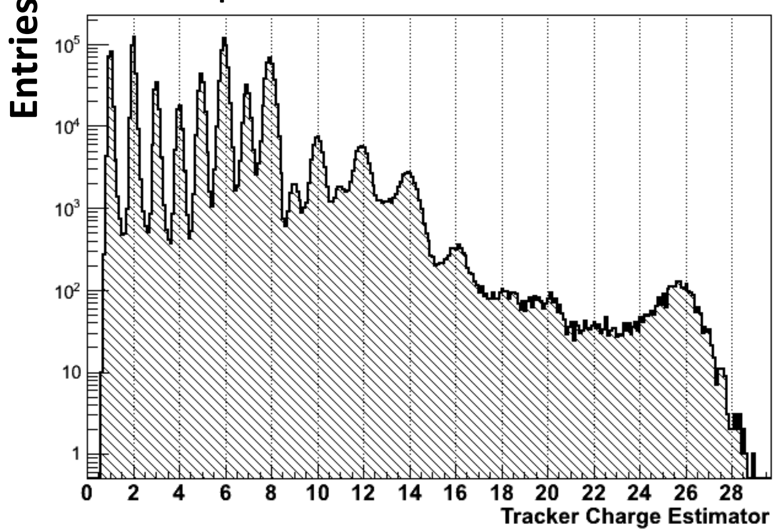


9 layers of double sided silicon microstrip detectors

192 ladders / 2598 sensors/ 200k readout channels

Silicon Tracker charge resolution

Abundances not corrected for detector efficiencies
H and He prescaled

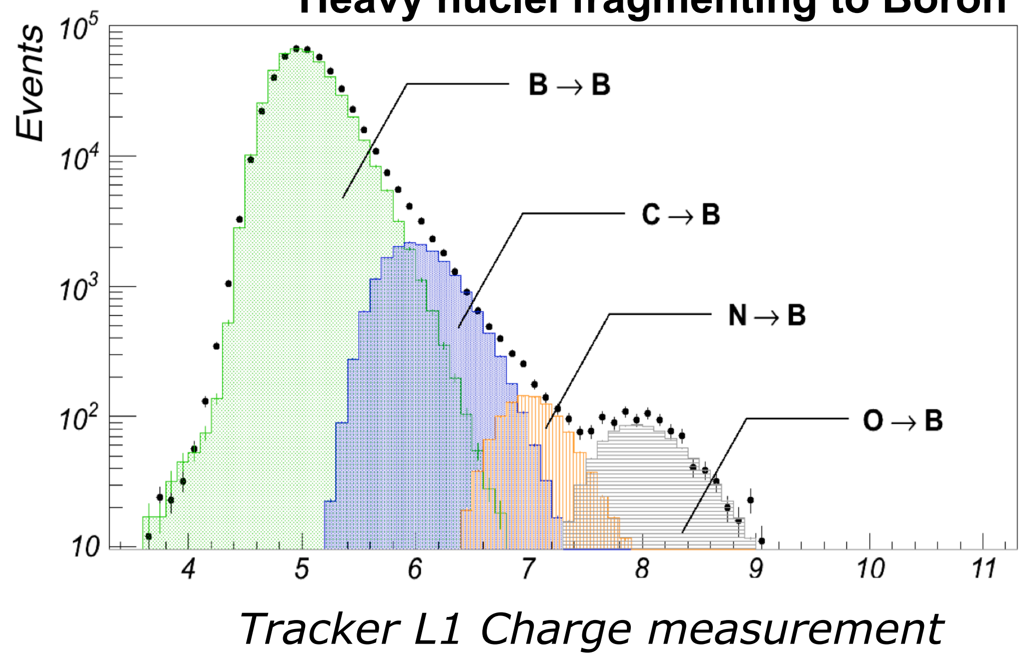


Thanks to several energy deposits in silicon and the High Dynamic Range of the Front End electronics, the Silicon Tracker has a very accurate charge resolution

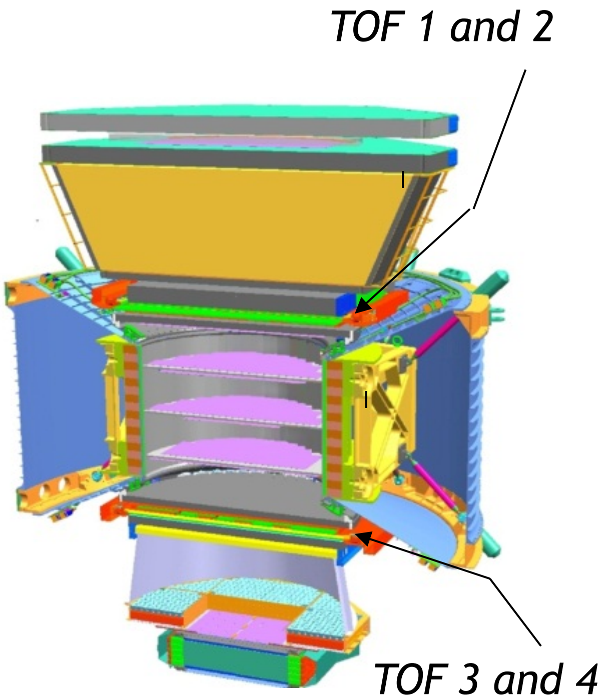
→ ~ 0.1 c.u.

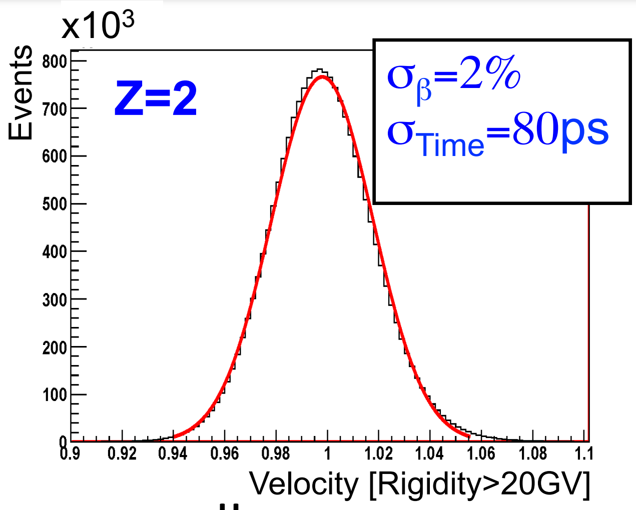
The first layer (L1), used as a standalone charge detector has a charge resolution (~ 0.3 c.u.) that allows the identification of the fragmentations, being at the top of the intrument (TOI)

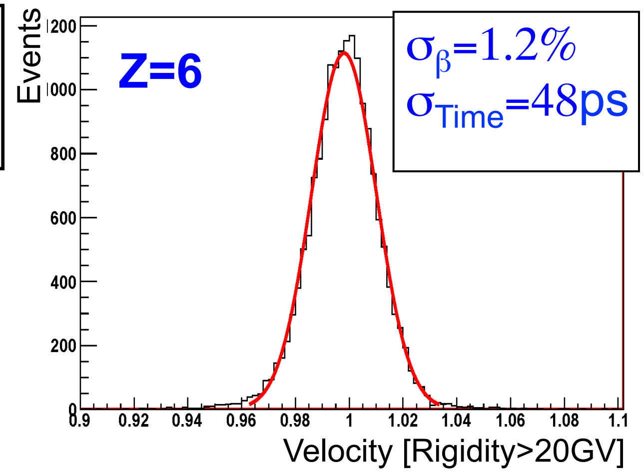
Heavy nuclei fragmenting to Boron

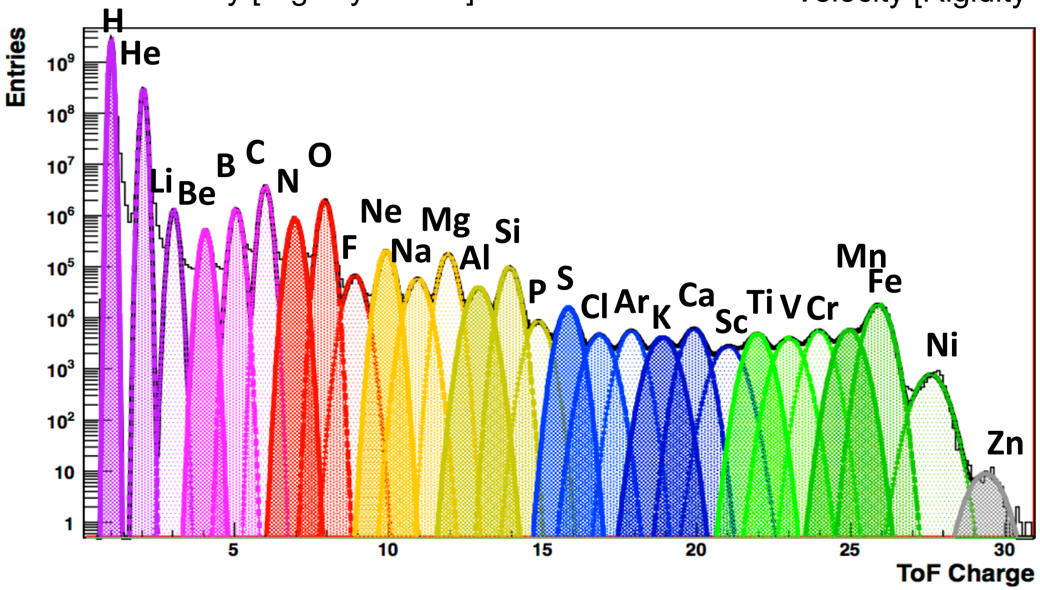


Time of Flight (TOF)



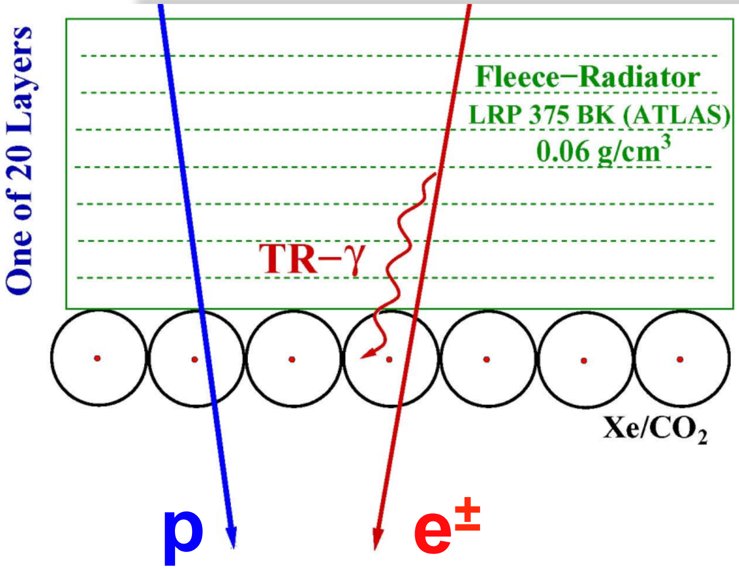


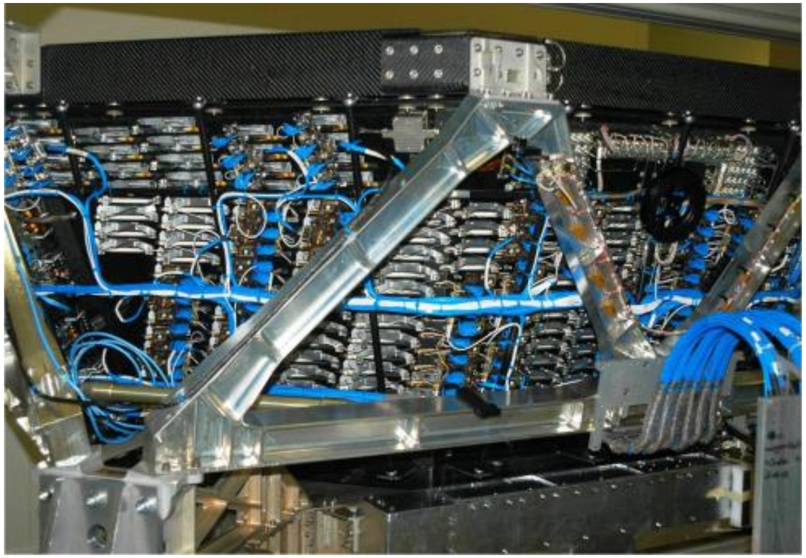


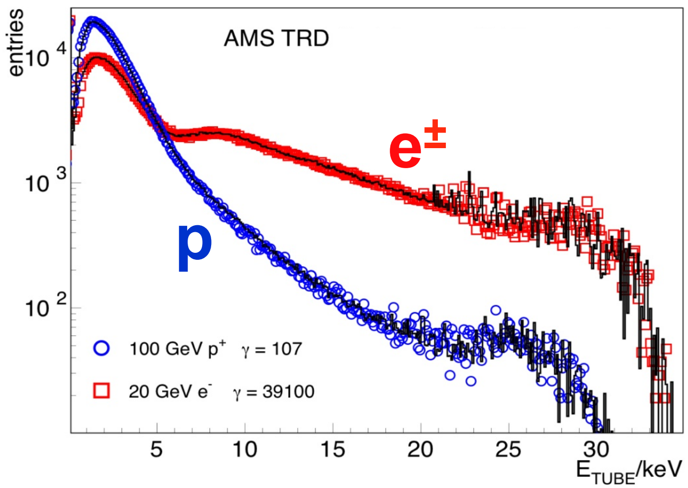


Up-going particles (fake anti-matter!) rejection up to 10^9

Transition Radiation Detector (TRD)



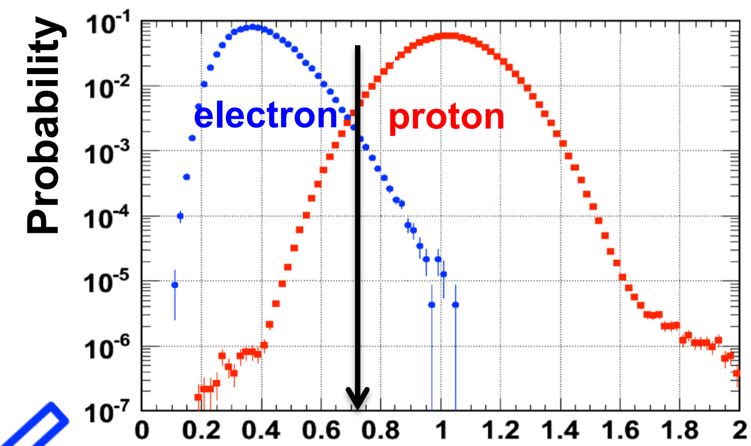




$$P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)}$$

$$P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)}$$

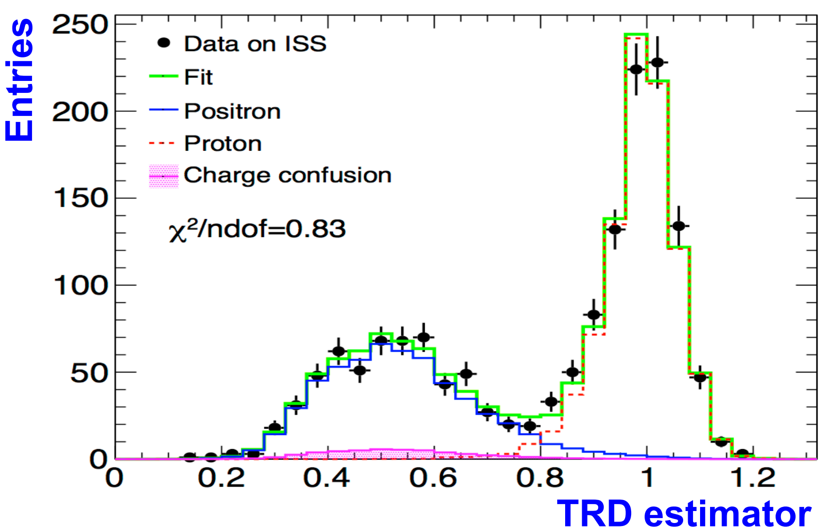
TRD e/p separation

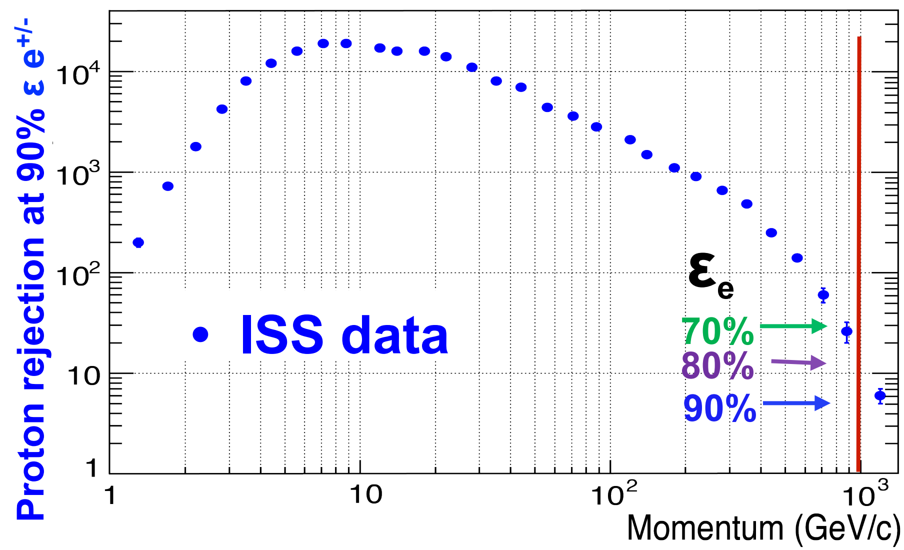


TRD estimator = $-\ln(P_e/(P_e+P_p))$

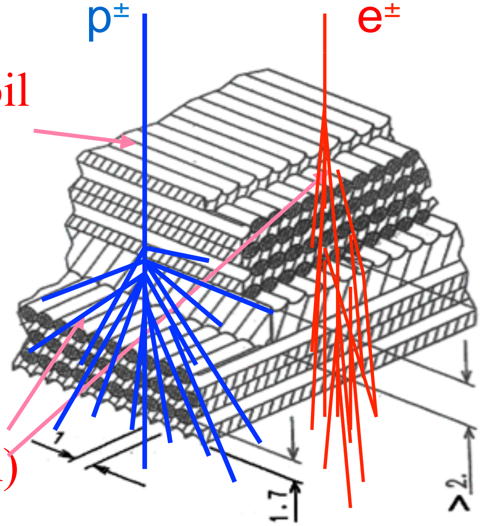
FIT

CUT

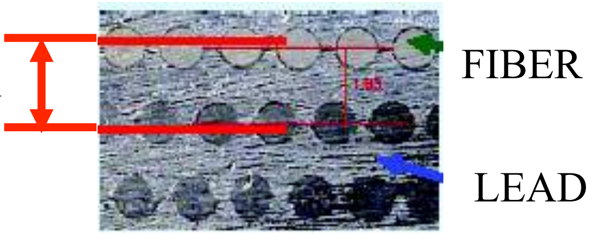




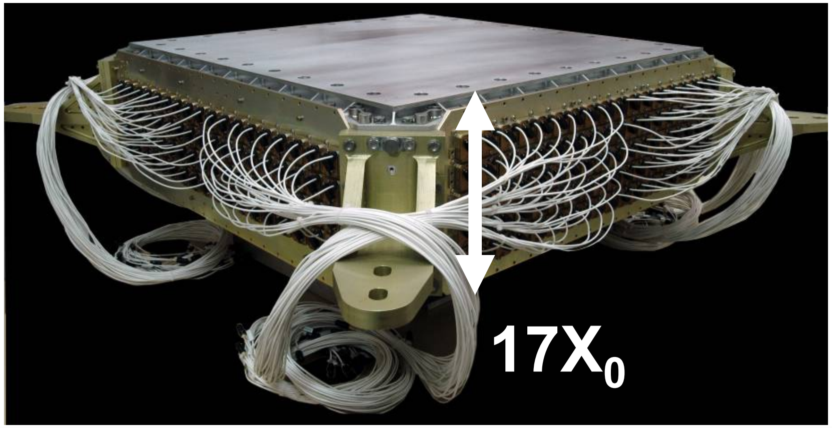
Electromagnetic Calorimeter (ECAL)

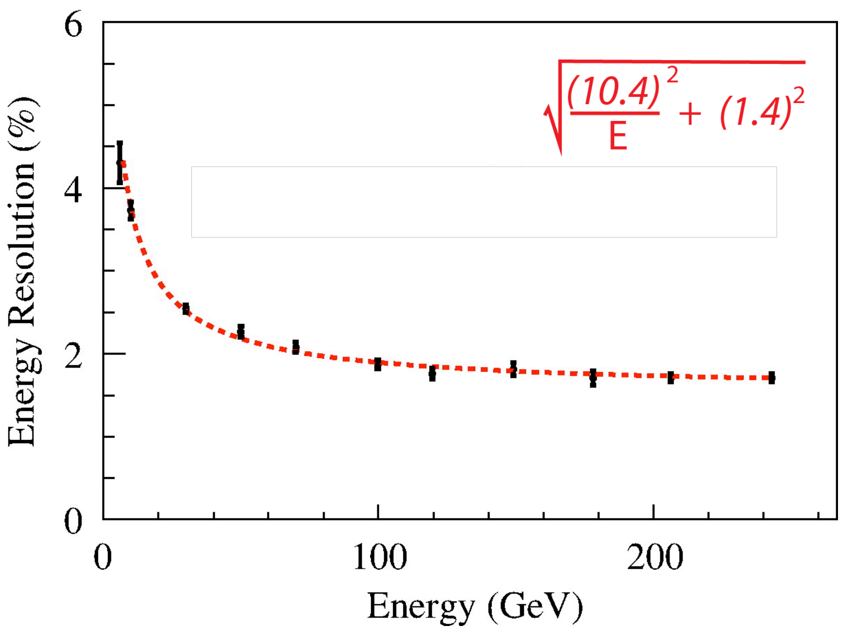


A precision, 3-D measurement of the directions and energies of gammas and electrons up to 1 TeV

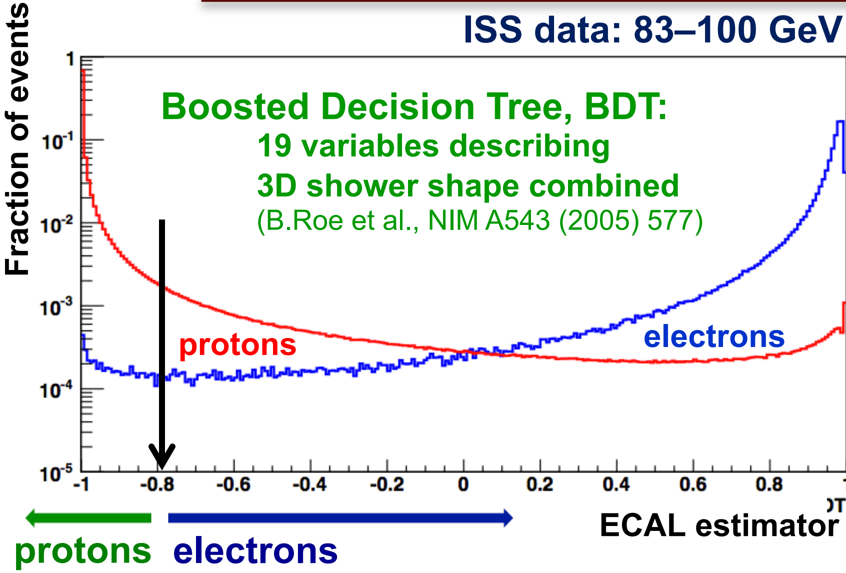


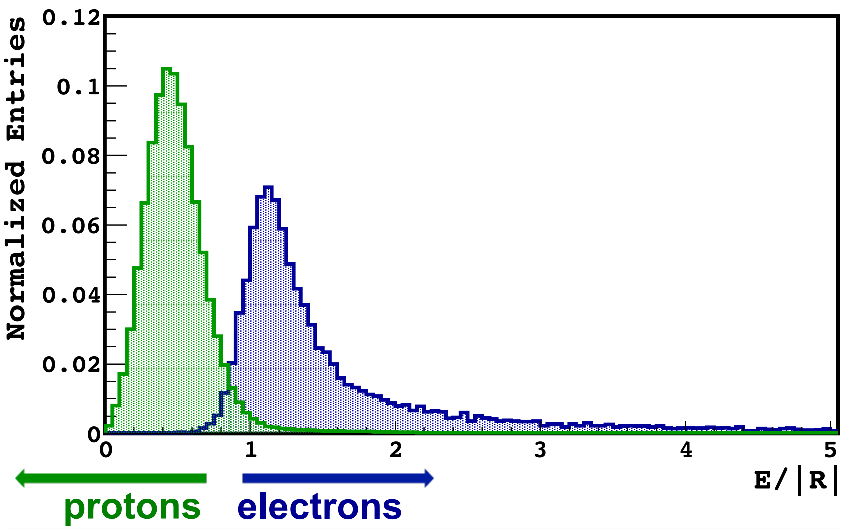
50,000 fibers, ϕ = 1 mm
distributed uniformly Inside 600 kg of lead

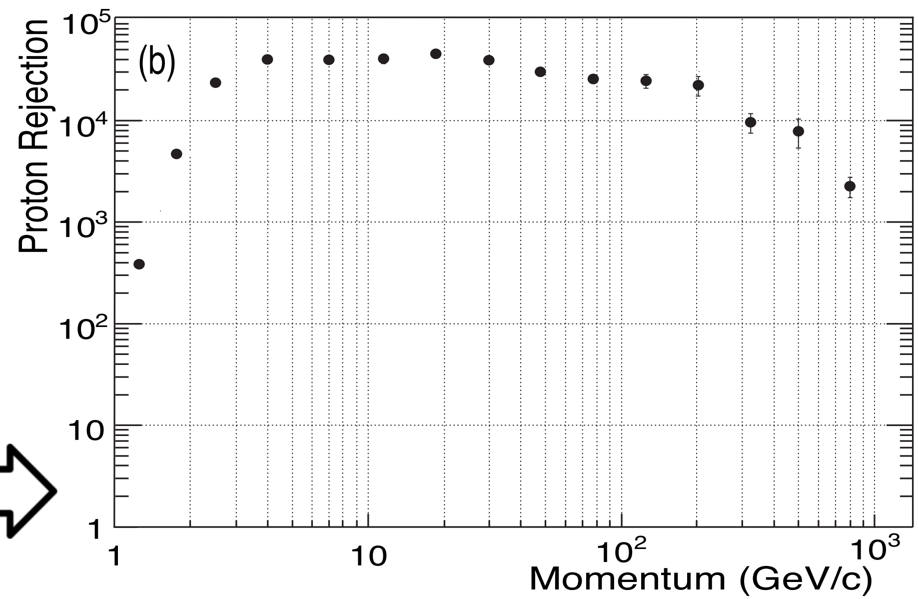




ECAL e/p rejection







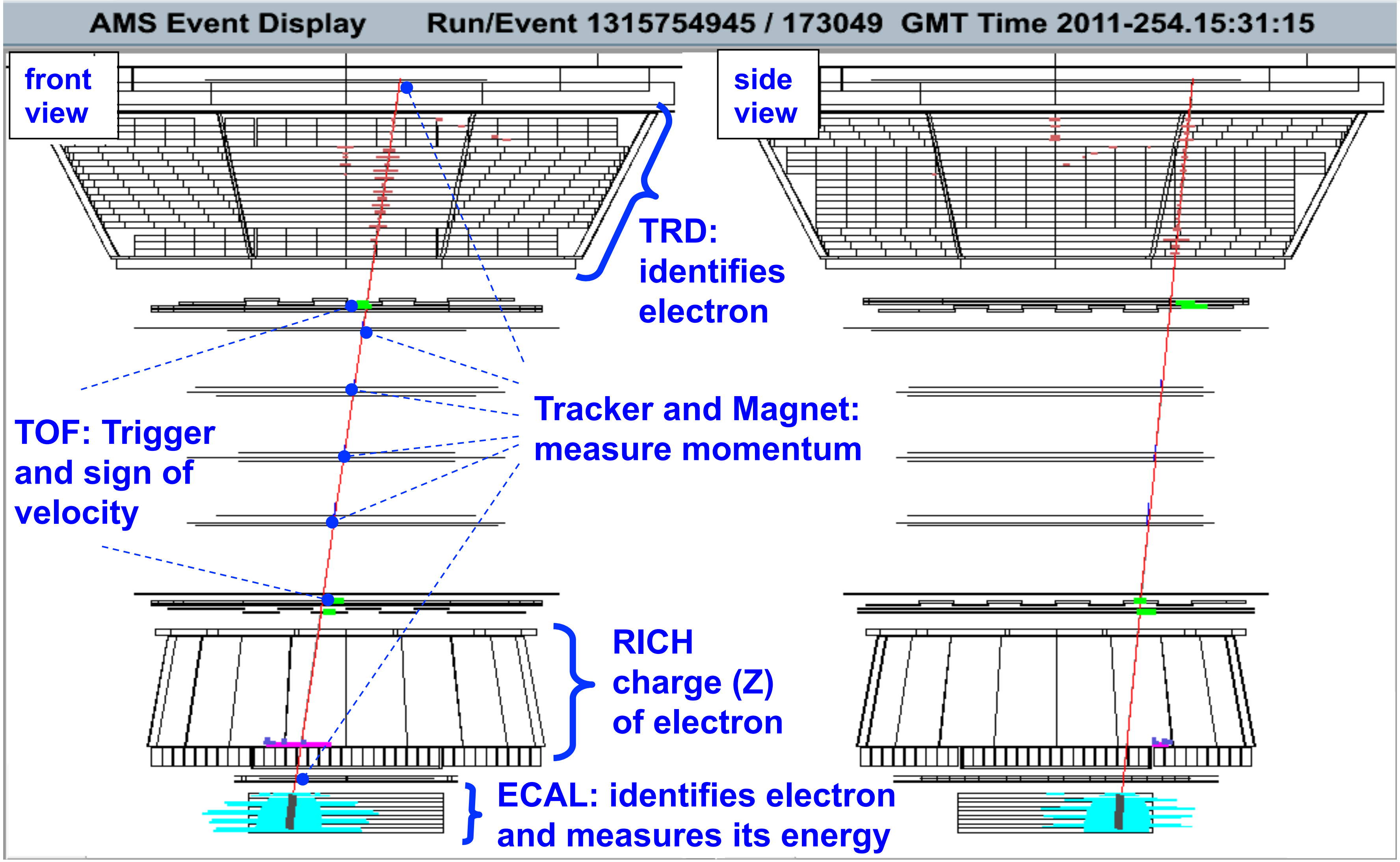
The Calorimeter thanks to its shower shape imaging capabilities can discriminate very sensibly eletromagnetic from hadronic showers

Combining the ECAL energy information with the Tracker Rigidity (E/R) the e/p rejection can be furtherly increased

Full coverage of anti-matter and CR physics

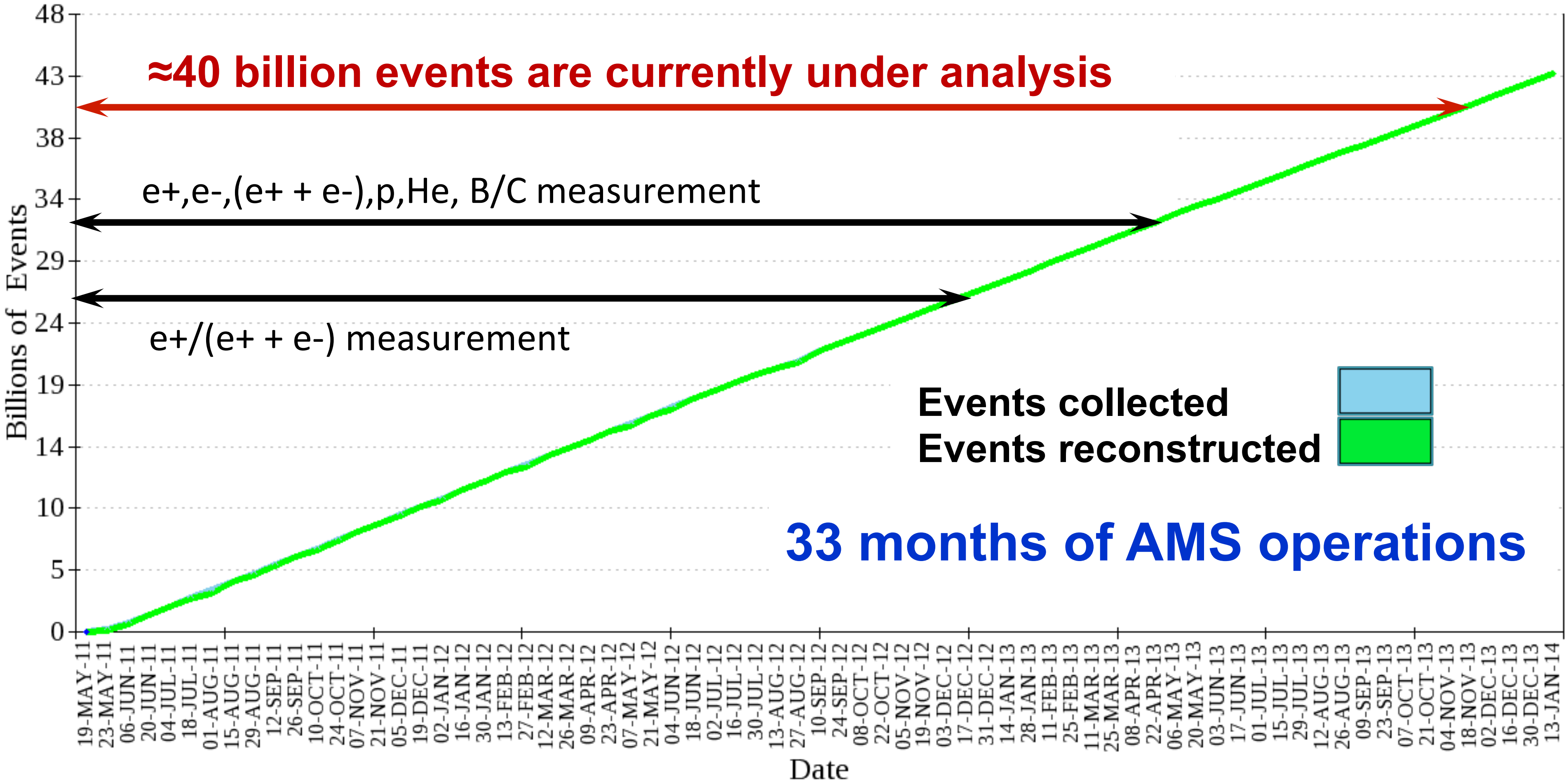
	e^-	P	He,Li,Be,..Fe	γ	e^+	$\bar{P}$	$\overline{He}$, $\bar{C}$
TRD							
TOF							
Tracker							
RICH							
ECAL							
Physics example	Cosmic Ray Physics				Dark matter		Antimatter

AMS data on ISS - 1.03 TeV electron



High statistics

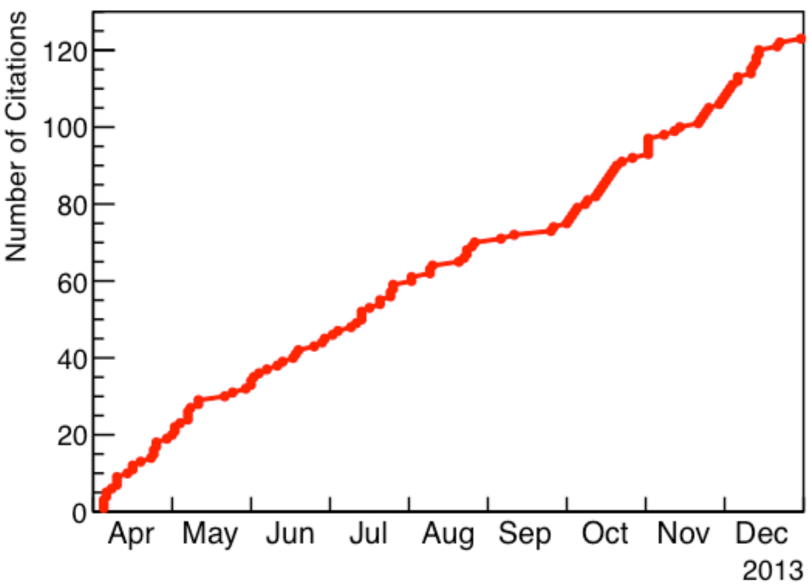
To date AMS collected ≈ 45 billion events

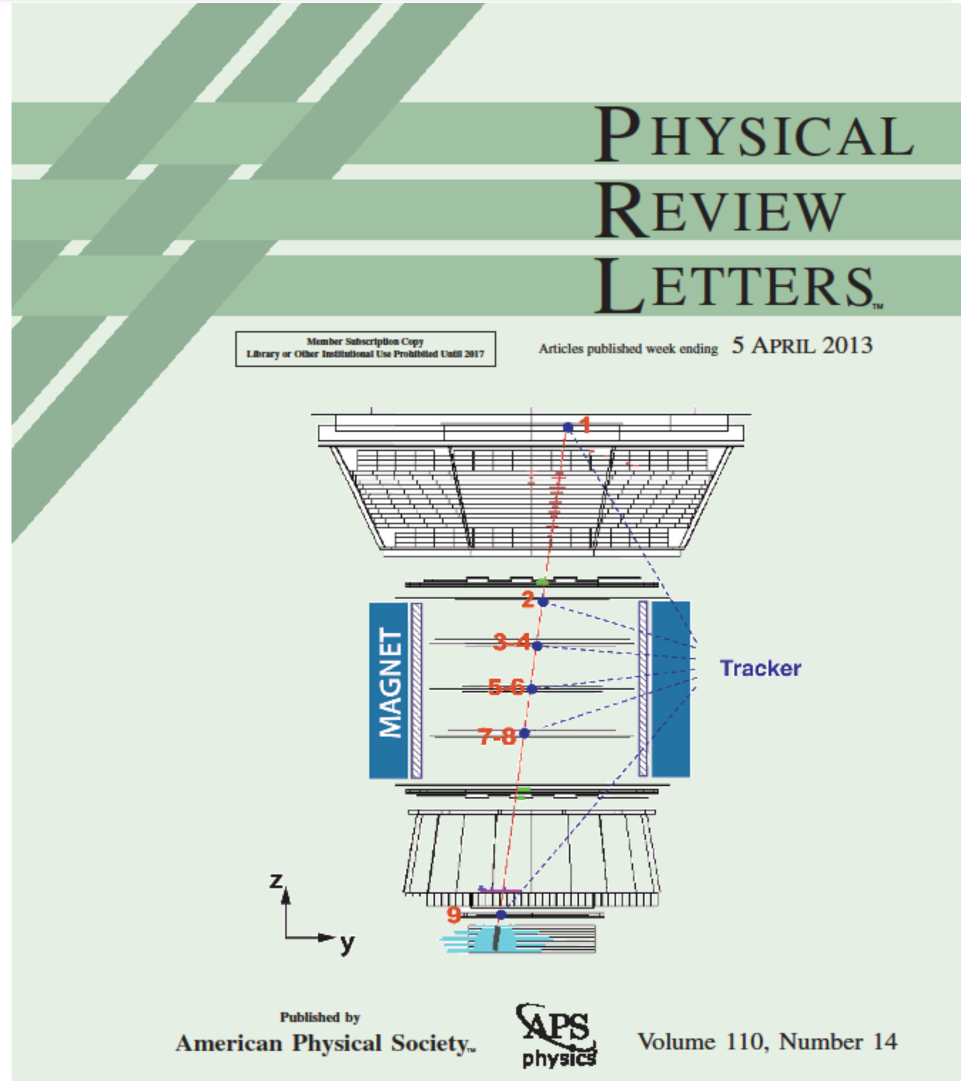


AMS-02 First Published Result

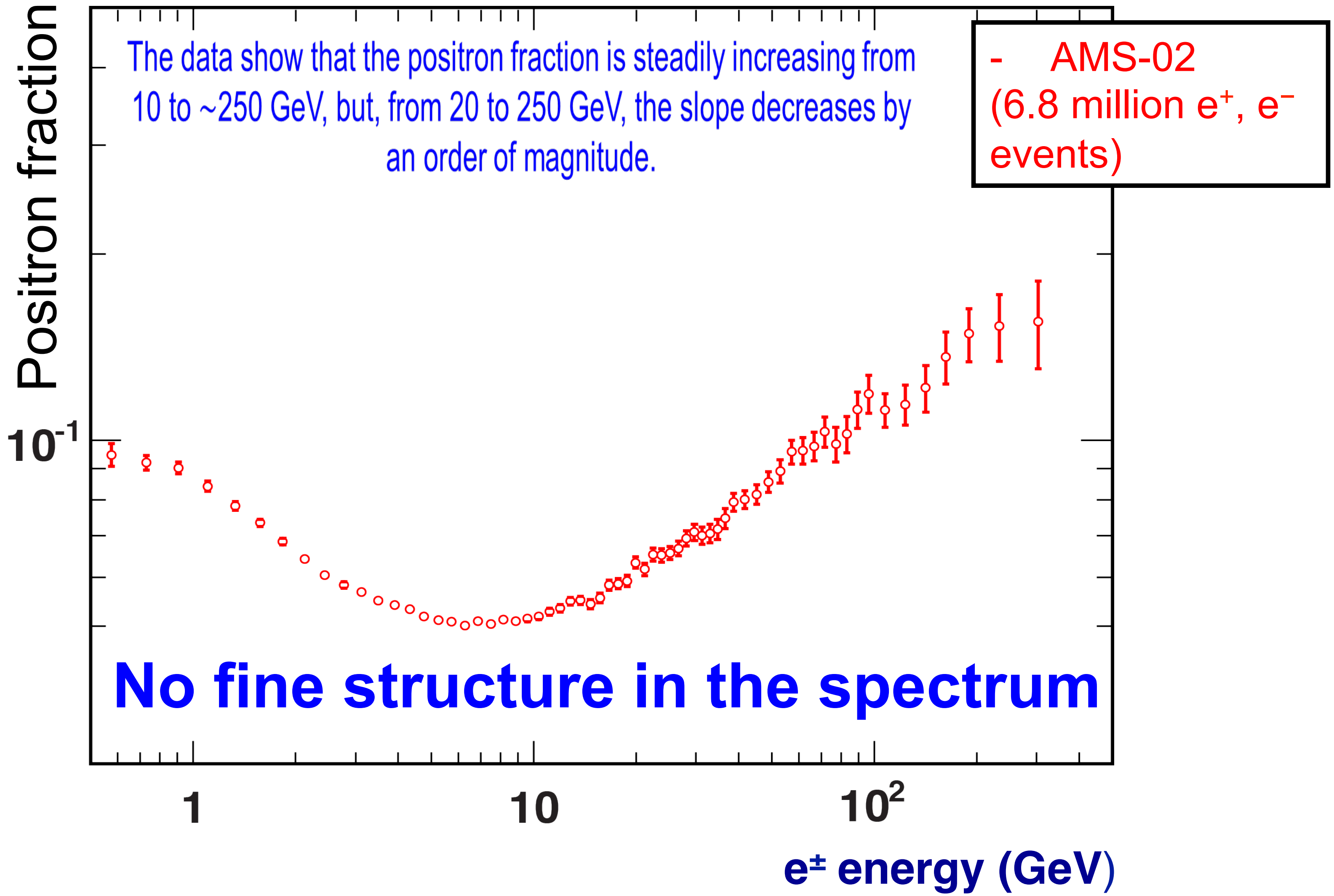
"First Result from the AMS on the ISS: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5-350 GeV"

Selected as a "Viewpoint" by APS

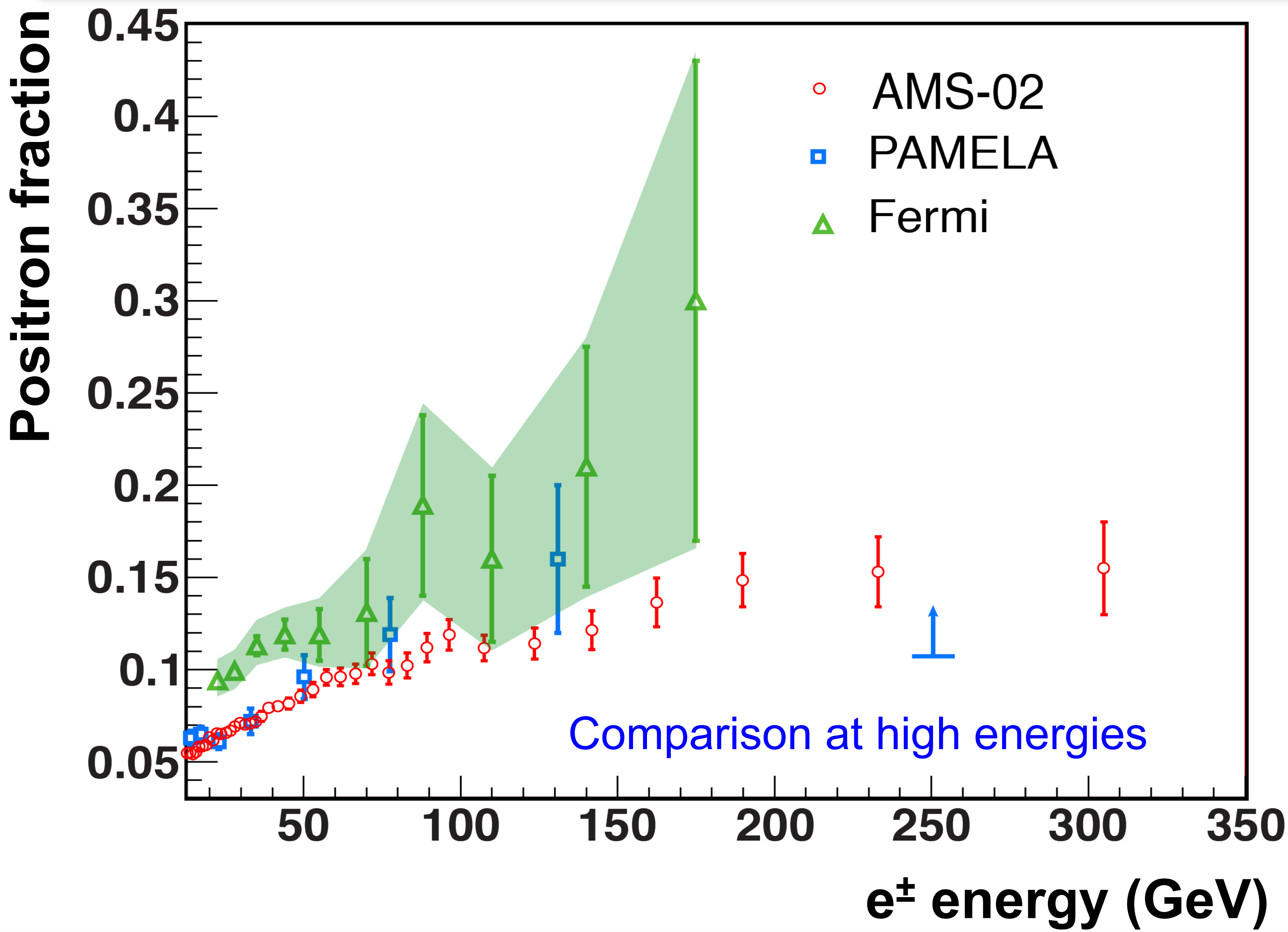




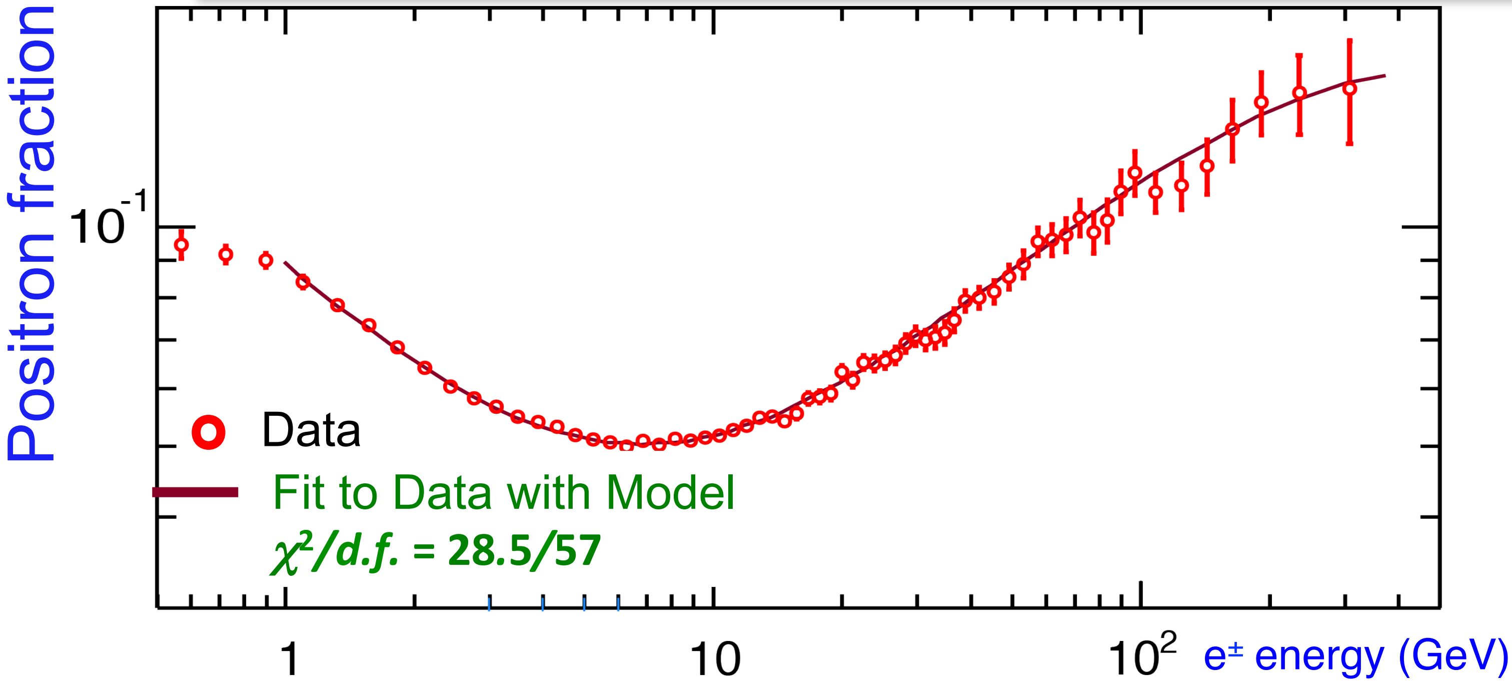
Positron fraction (0.5 – 350 GeV)



Positron fraction @ high energies



Minimal empirical model



Describe electron and positron fluxes as a sum of a **diffuse component** and a **common source** with a cutoff energy :

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$\gamma_{e-} - \gamma_{e+} = -0.63 \pm 0.03$

$\gamma_{e-} - \gamma_{S} = 0.66 \pm 0.05$

$C_{e+}/C_{e-} = 0.091 \pm 0.001$

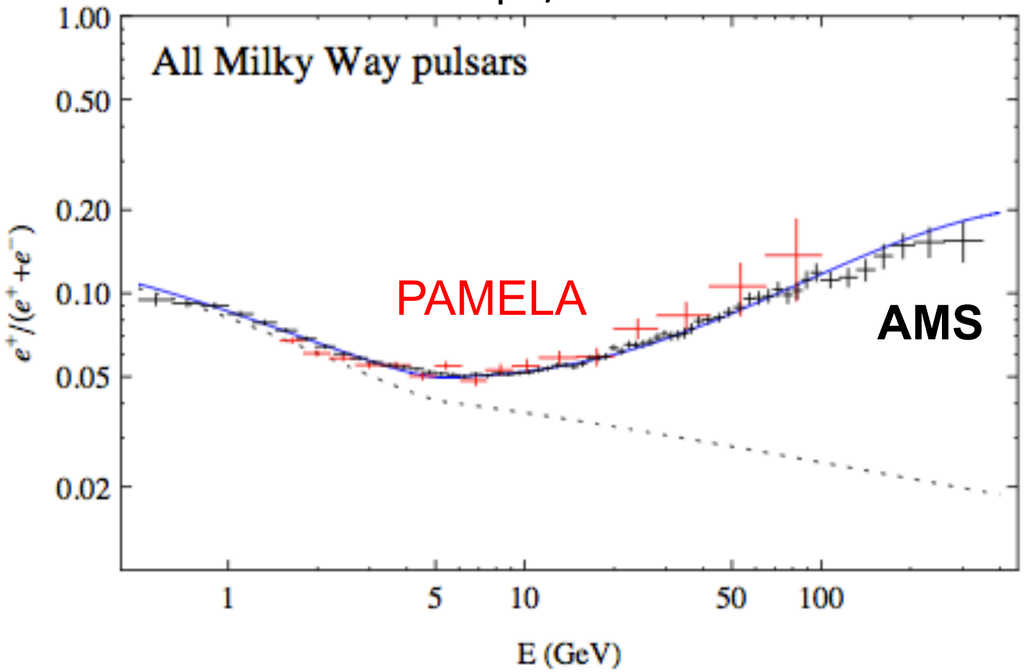
$C_S/C_{e-} = 0.0078 \pm 0.0012$

$1/E_s = 0.0013 \pm 0.0007\ \mathrm{GeV}^{-1}$, ($760^{+1000}$ GeV)

Origin of the excess

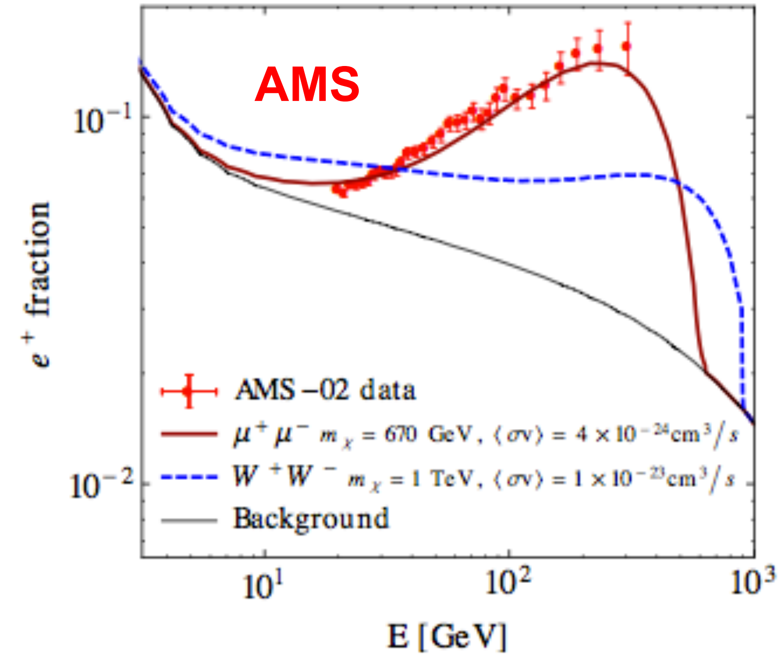
Astrophysical objects

Cholis arXiv: astro-ph/1304.1840



Dark Matter

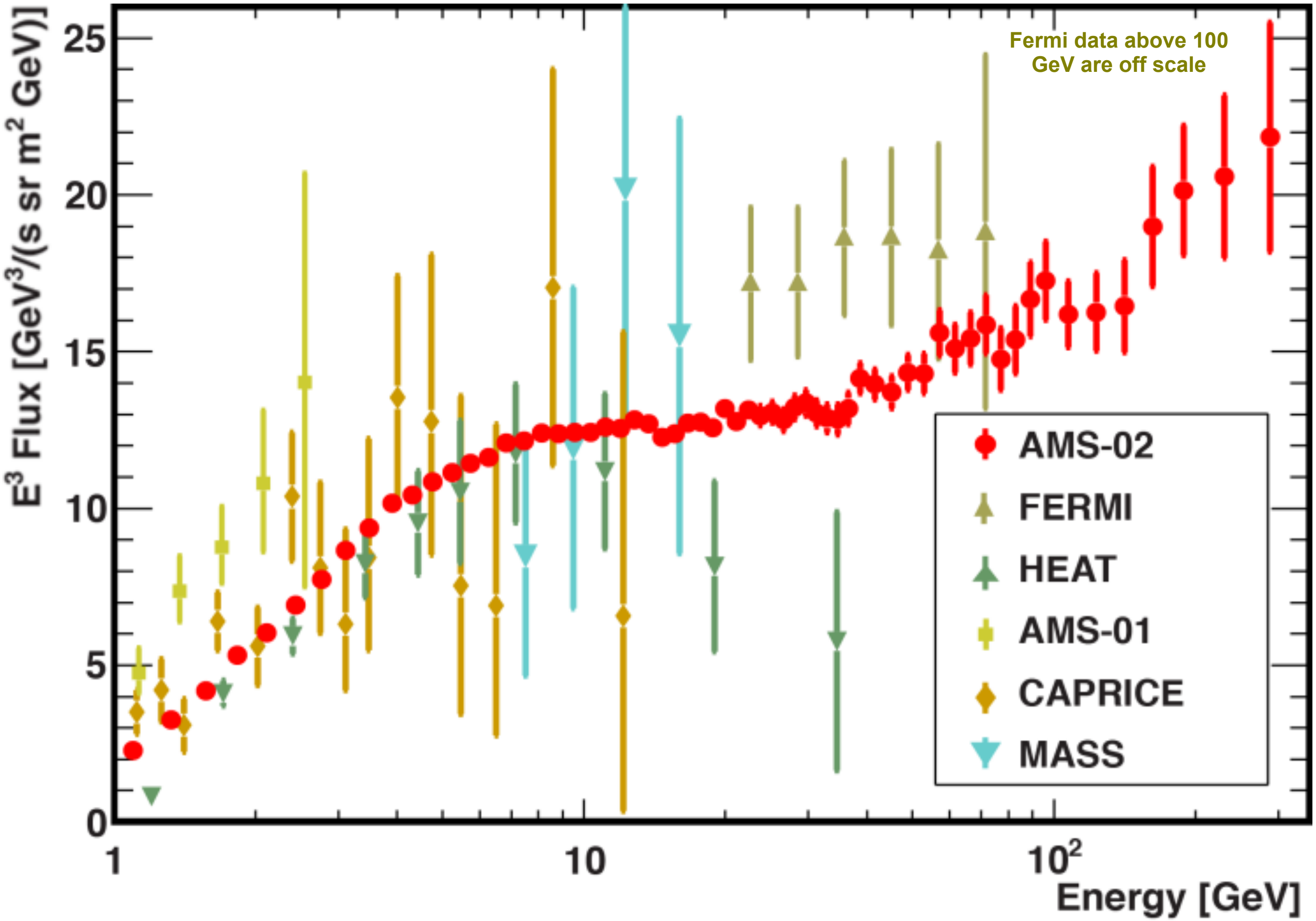
Kopp hep-ph/1304.1184



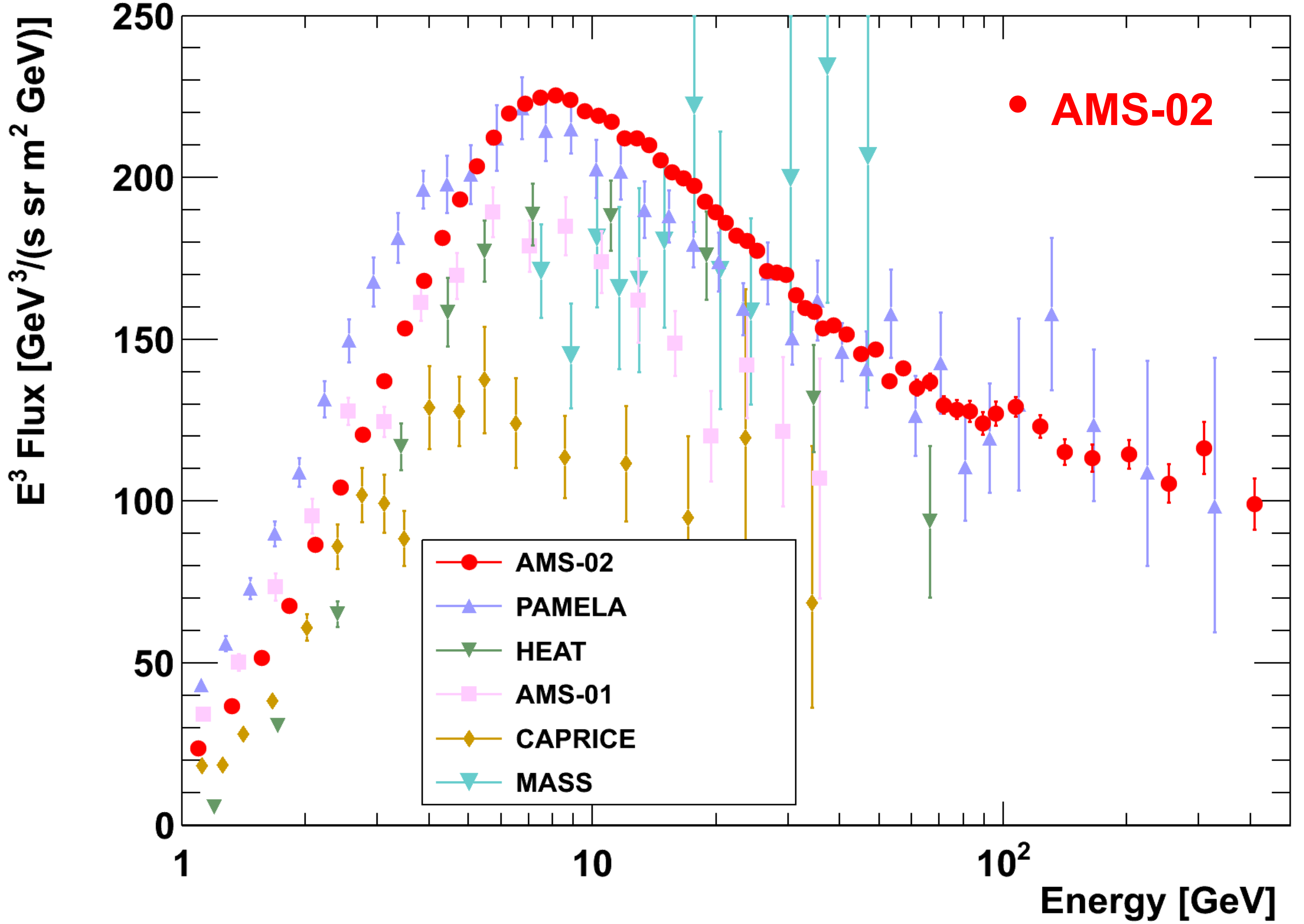
Different energy behavior of the positron fraction:

- **Pulsars predictions:**
  - **slow fall at high energies**
  - **anisotropic positron flux**
- **Dark Matter prediction:**
  - **steeper fall at high energies**
  - **isotropic positron flux**

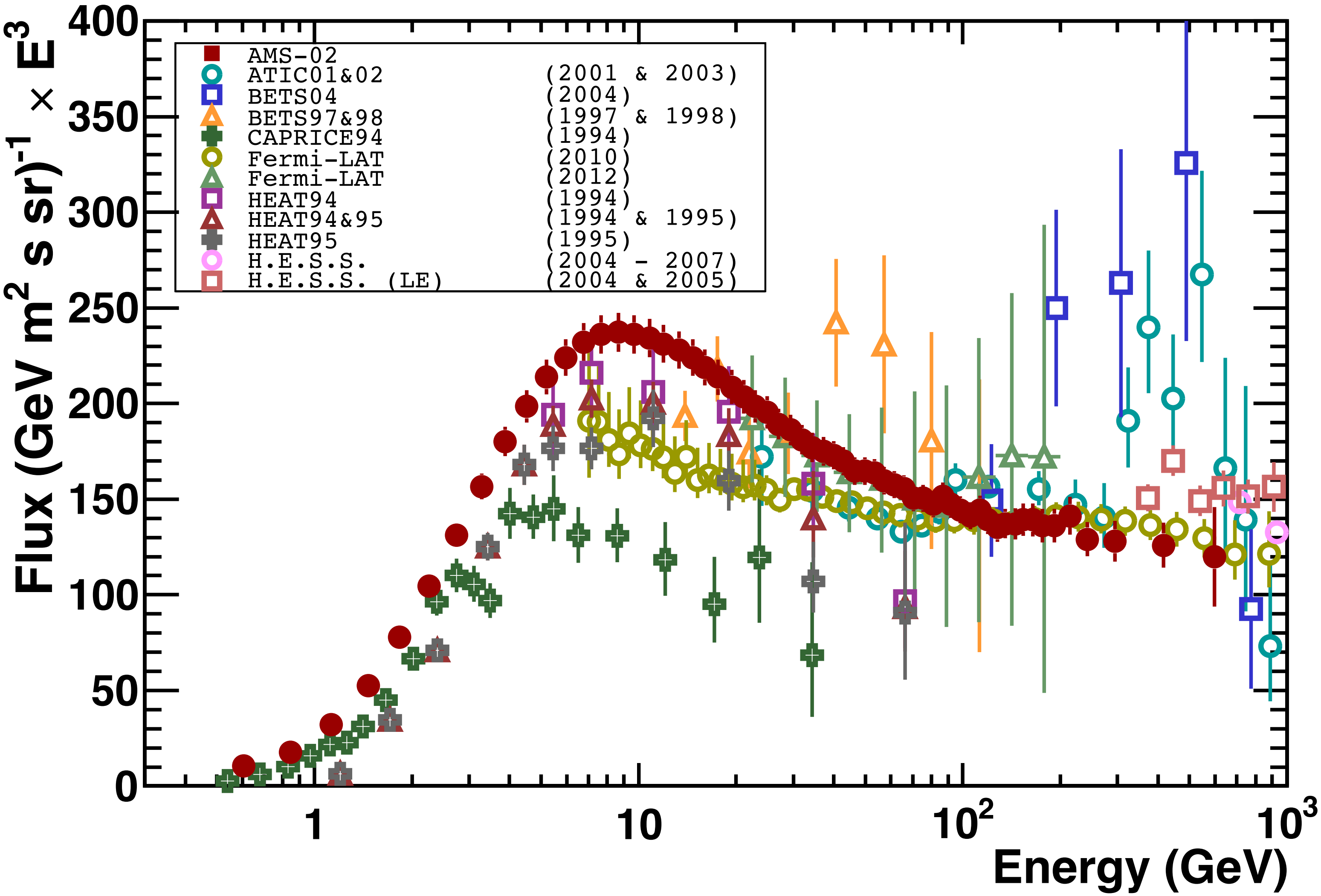
Positron (e^+) flux



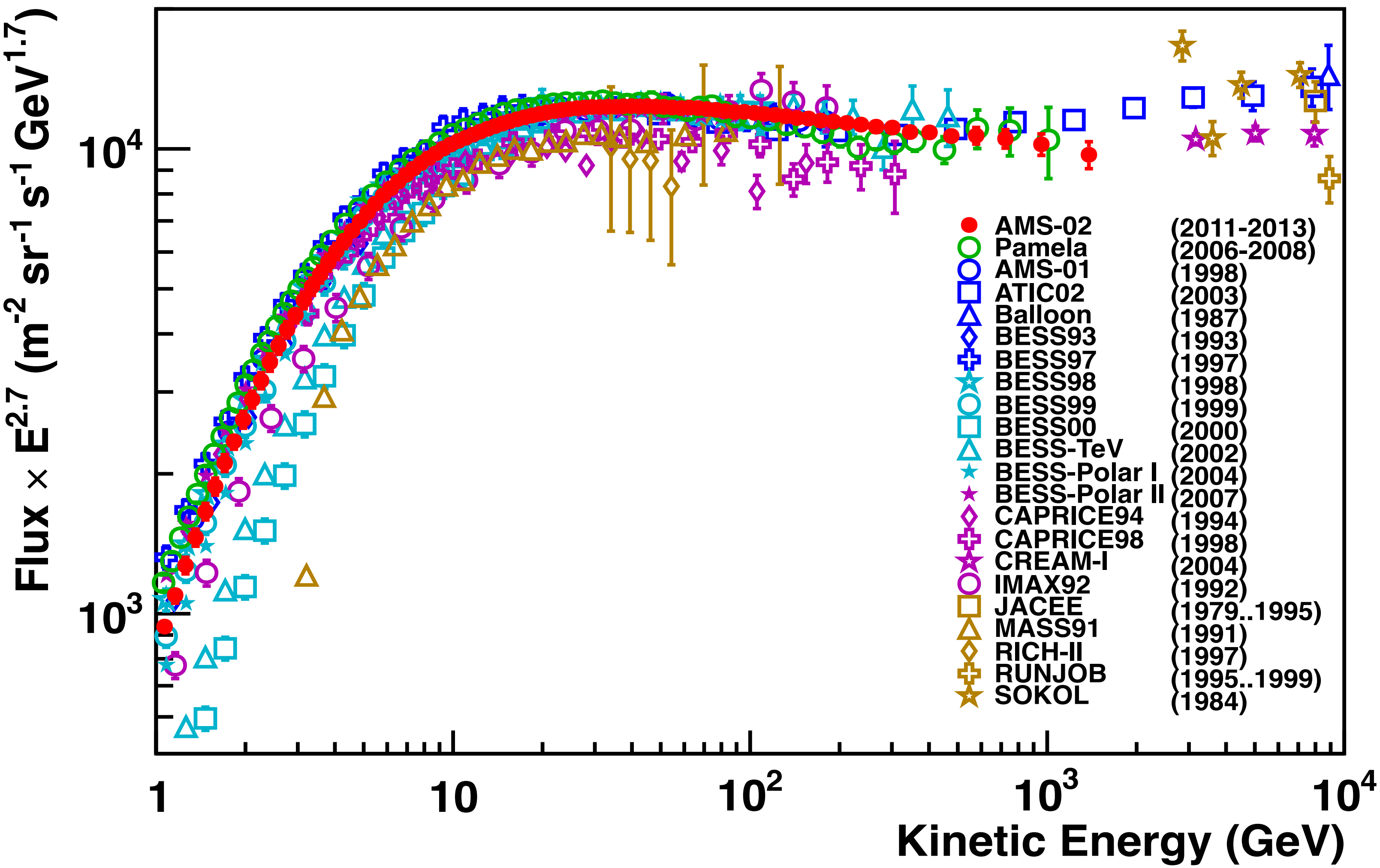
Electron (e^-) flux



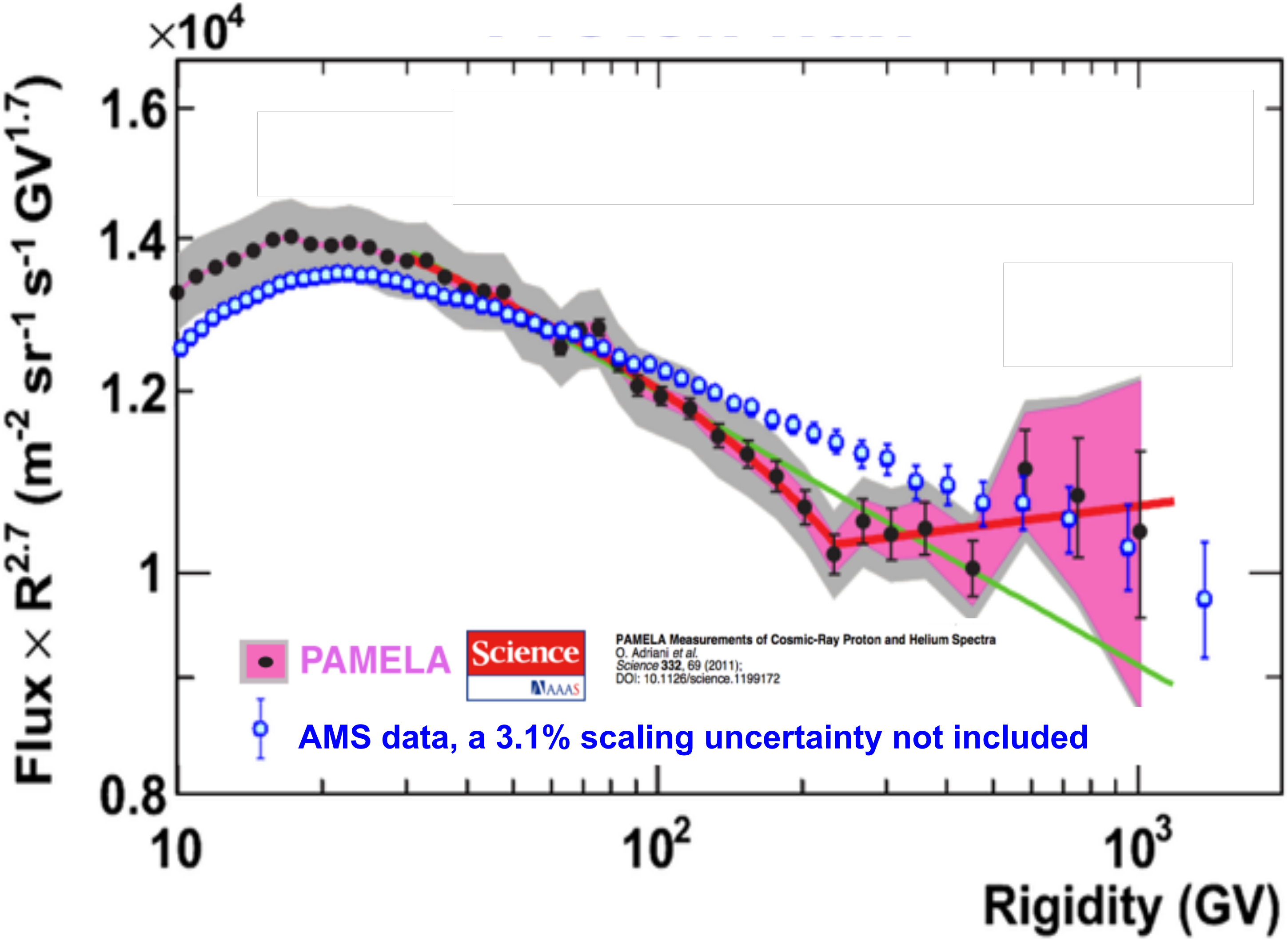
All-electron (e⁺+e⁻) flux



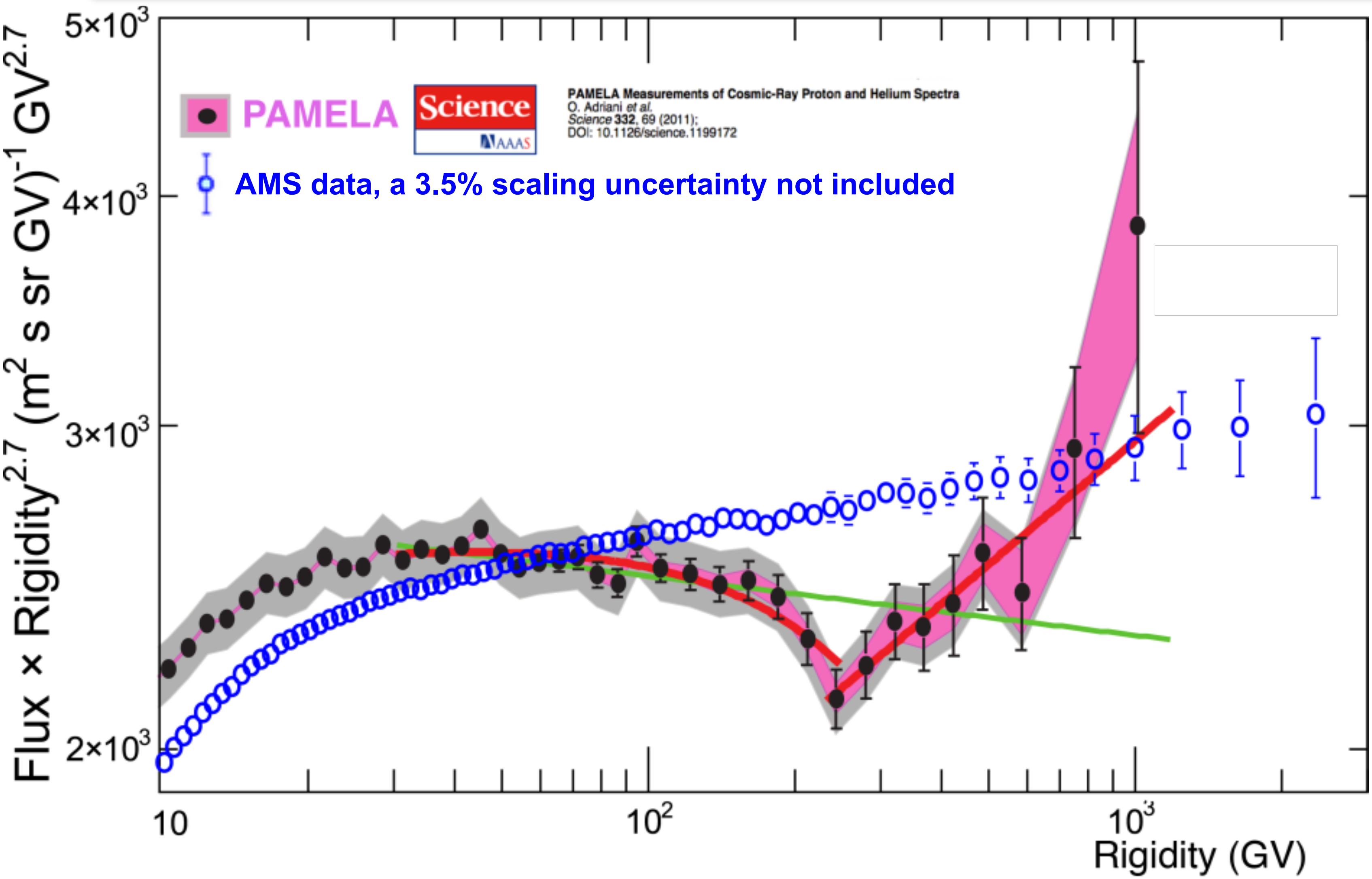
Proton flux


Flux × E^2.7 (m^-2 sr^-1 s^-1 GeV^1.7)
10^4
10^3
1
10
10^2
10^3
10^4
Kinetic Energy (GeV)
AMS-02 (2011-2013)
Pamela (2006-2008)
AMS-01 (1998)
ATIC02 (2003)
Balloon (1987)
BESS93 (1993)
BESS97 (1997)
BESS98 (1998)
BESS99 (1999)
BESS00 (2000)
BESS-TeV (2002)
BESS-Polar I (2004)
BESS-Polar II (2007)
CAPRICE94 (1994)
CAPRICE98 (1998)
CREAM-I (2004)
IMAX92 (1992)
JACEE (1979..1995)
MASS91 (1991)
RICH-II (1997)
RUNJOB (1995..1999)
SOKOL (1984)

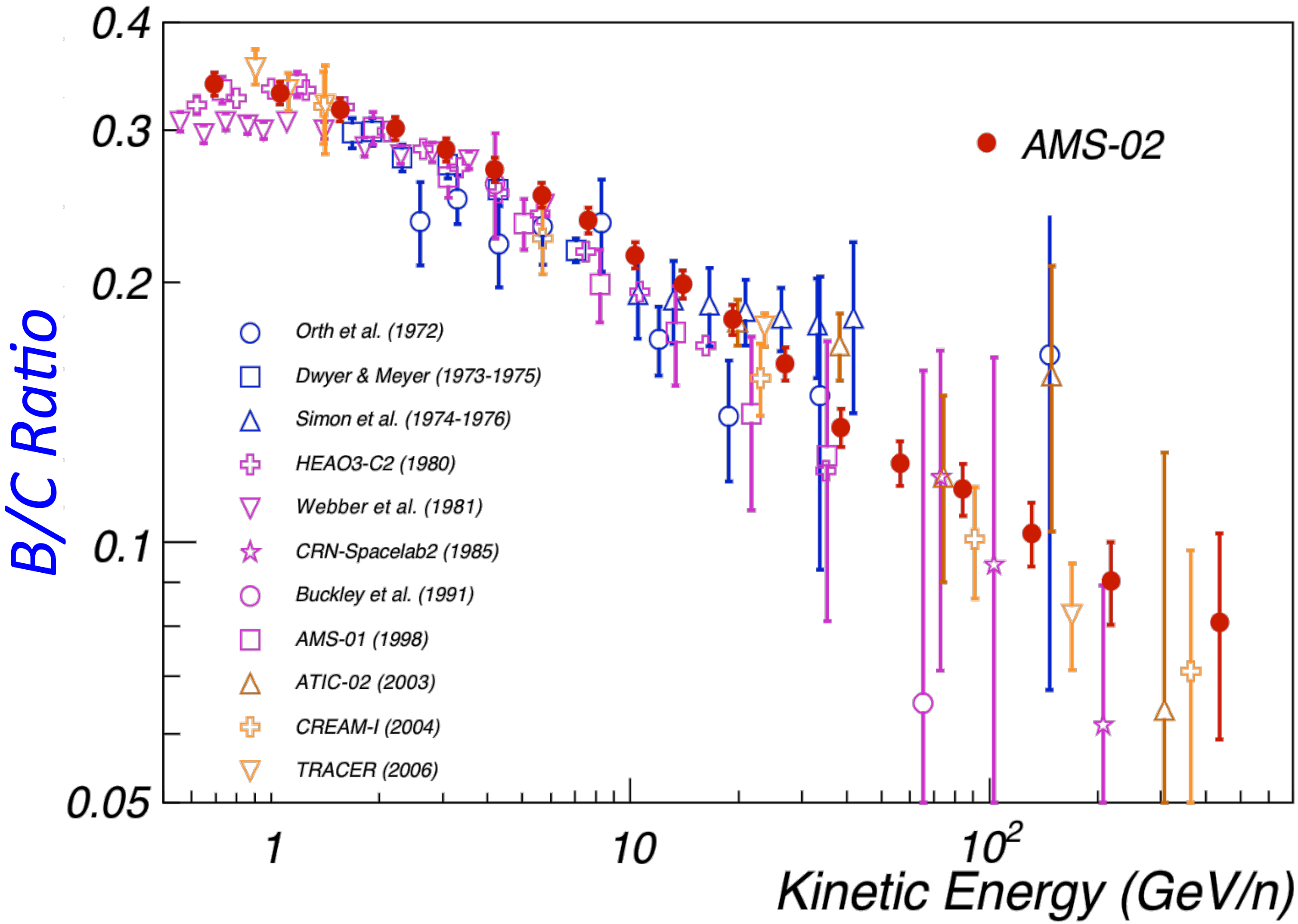
AMS-02 proton flux and the Pamela's break



AMS-02 helium flux and the Pamela's break



Boron to Carbon ratio



Conclusions

- AMS is the Cosmic Rays observatory of the next decade
- AMS data have potential to shed a light on the nature of the Dark Matter
- The observed positron excess may imply a heavy Dark Matter WIMP particle or a new mechanism of acceleration in the pulsars
- Observation of anomalies in the anti-proton spectrum would be an evidence of the DM hypothesis
- Accurate measurements of the CR primary components are being performed
- More statistic is needed
- AMS precise measurements are promising new Physics

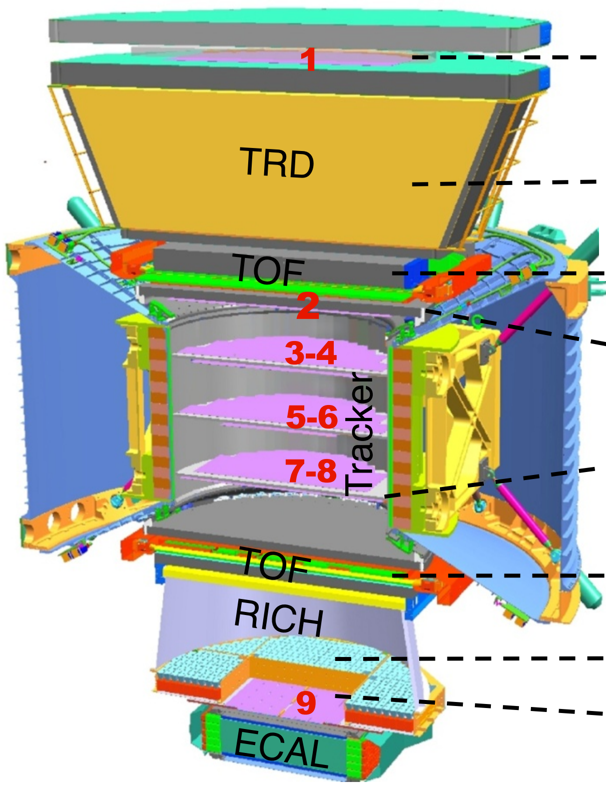
Stay tuned!


AMS-02
NASA
esa
JAXA
AMS Tracker
AMS Lead
STS-134
BFCR 7
Chips Ahoy!

Backup slides

Overall charge resolution

Multiple Independent Measurements of |Z|



	Carbon (Z=6) ΔZ (cu)
1. Tracker Plane 1	0.30
2. TRD	0.33
3. Upper TOF (1 counter)	0.16
4. Tracker Planes 2-8	0.12
5. Lower TOF (1 counter)	0.16
6. RICH	0.32
7. Tracker Plane 9	0.30

The $(e^{+}+e^{-})$ flux measurement

$$\Phi(\mathrm{E}, \mathrm{E}+\Delta\mathrm{E}) = \frac{N_{obs}(\mathrm{E}, \mathrm{E}+\Delta\mathrm{E})}{\Delta E \, \Delta T_{\mathrm{exp}} \, A_{\mathrm{eff}} \, \epsilon_{\mathrm{trig}}}$$

Φ = Absolute differential flux (m^{-2} sr^{-1} GeV^{-1})

N_{obs} = Number of observed events

ΔT_{exp} = Exposure time (s)

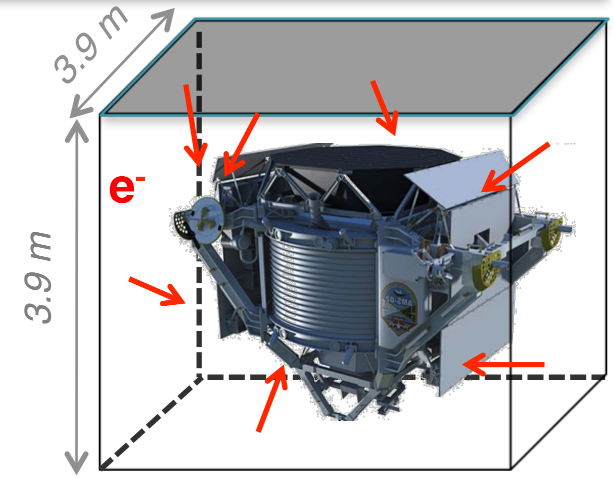
A_{eff} = Effective acceptance ($m^2 sr$)

E_{trig} = Trigger efficiency

Acceptance

Estimated with MC (Geant 4)

$$A_{eff.}(E) = A_{generated} \times \frac{N_{selected}(E)}{N_{generated}(E)}$$

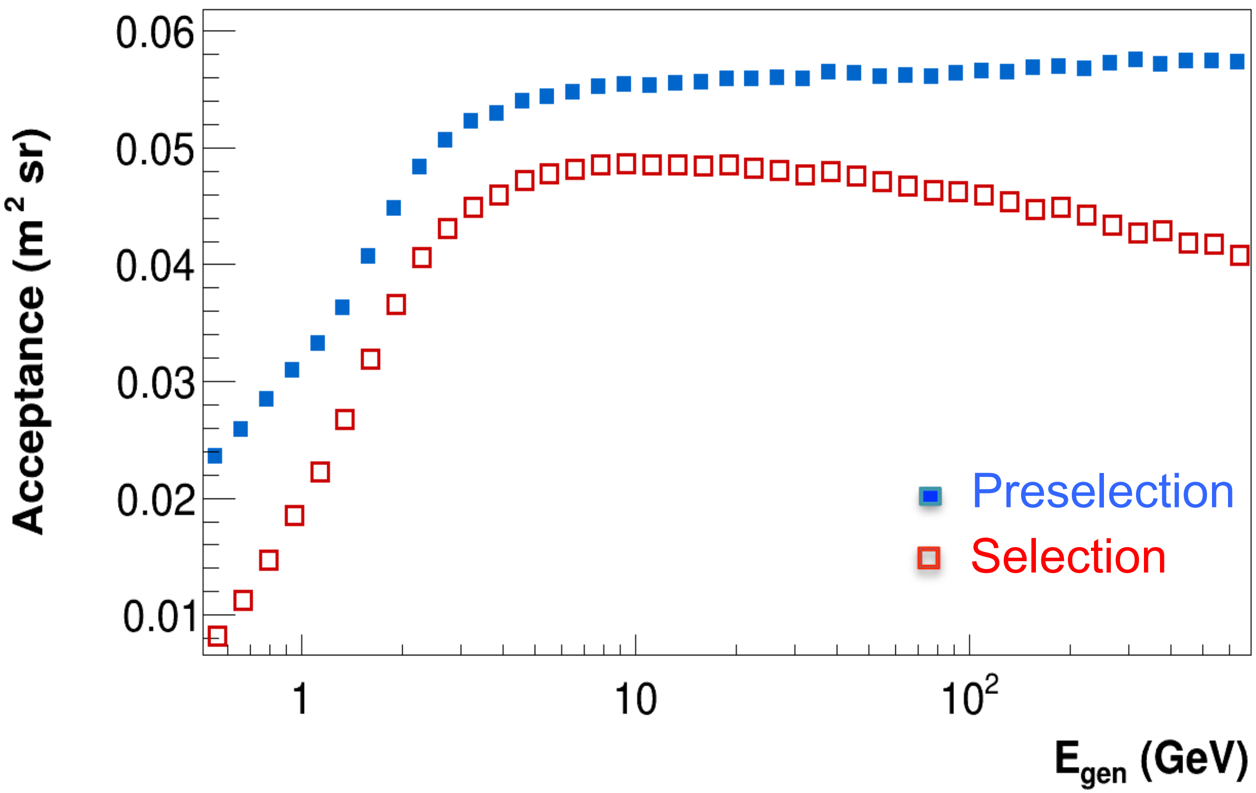


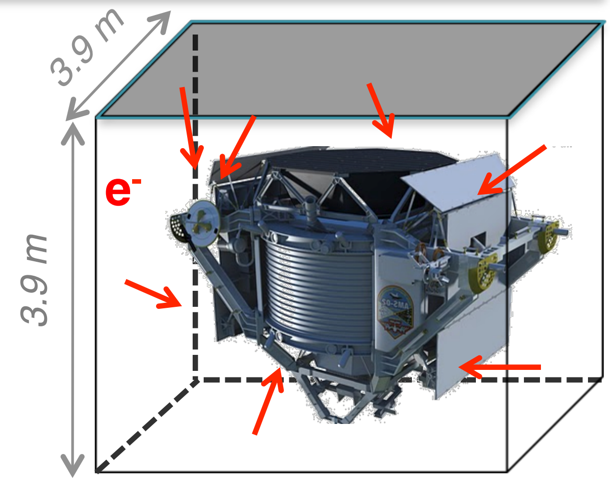
$A_{generated}$ = acceptance of the generation surface

$N_{selected}$ = events passing the selection criteria

Acceptance

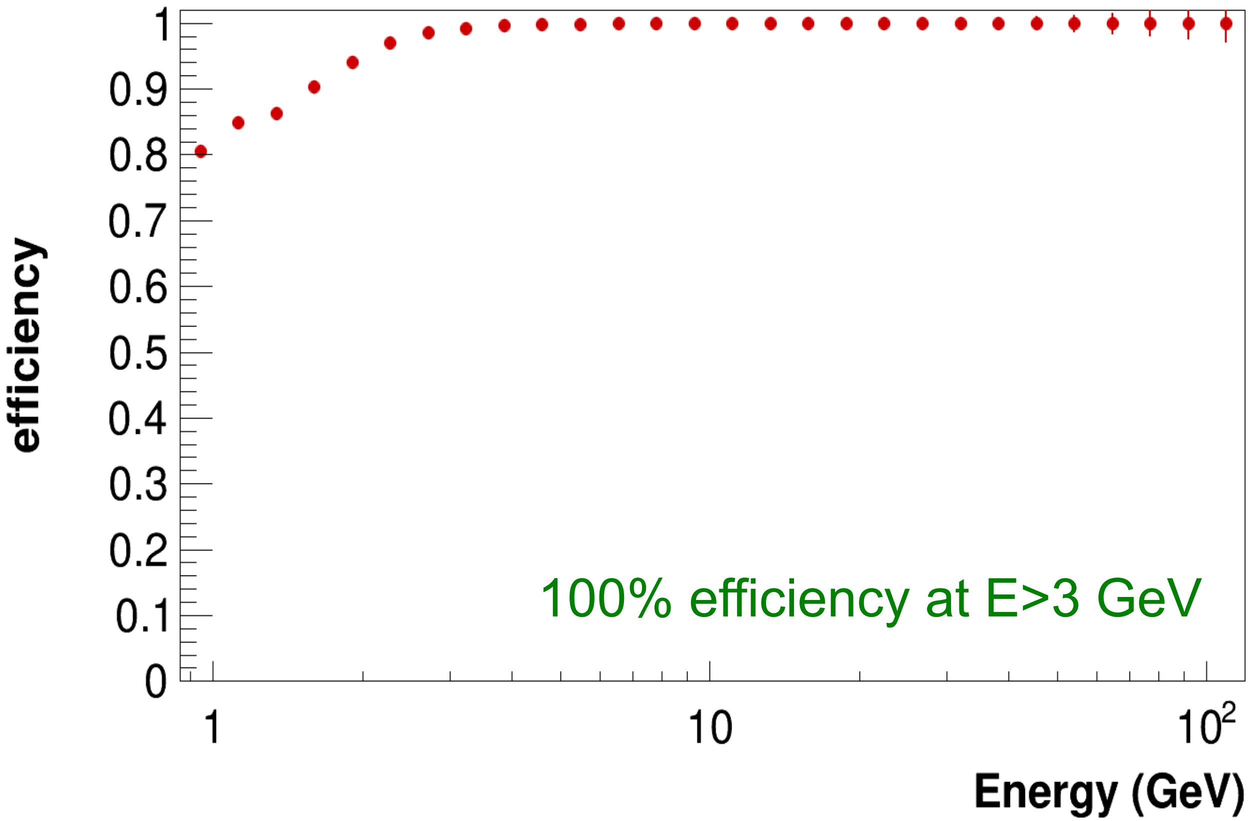
The final acceptance (i.e. after the selection cuts) is evaluated using MC





The effect of every cut has been checked on ISS data and, if needed, the value of acceptance "corrected" (O(%))

The trigger efficiency



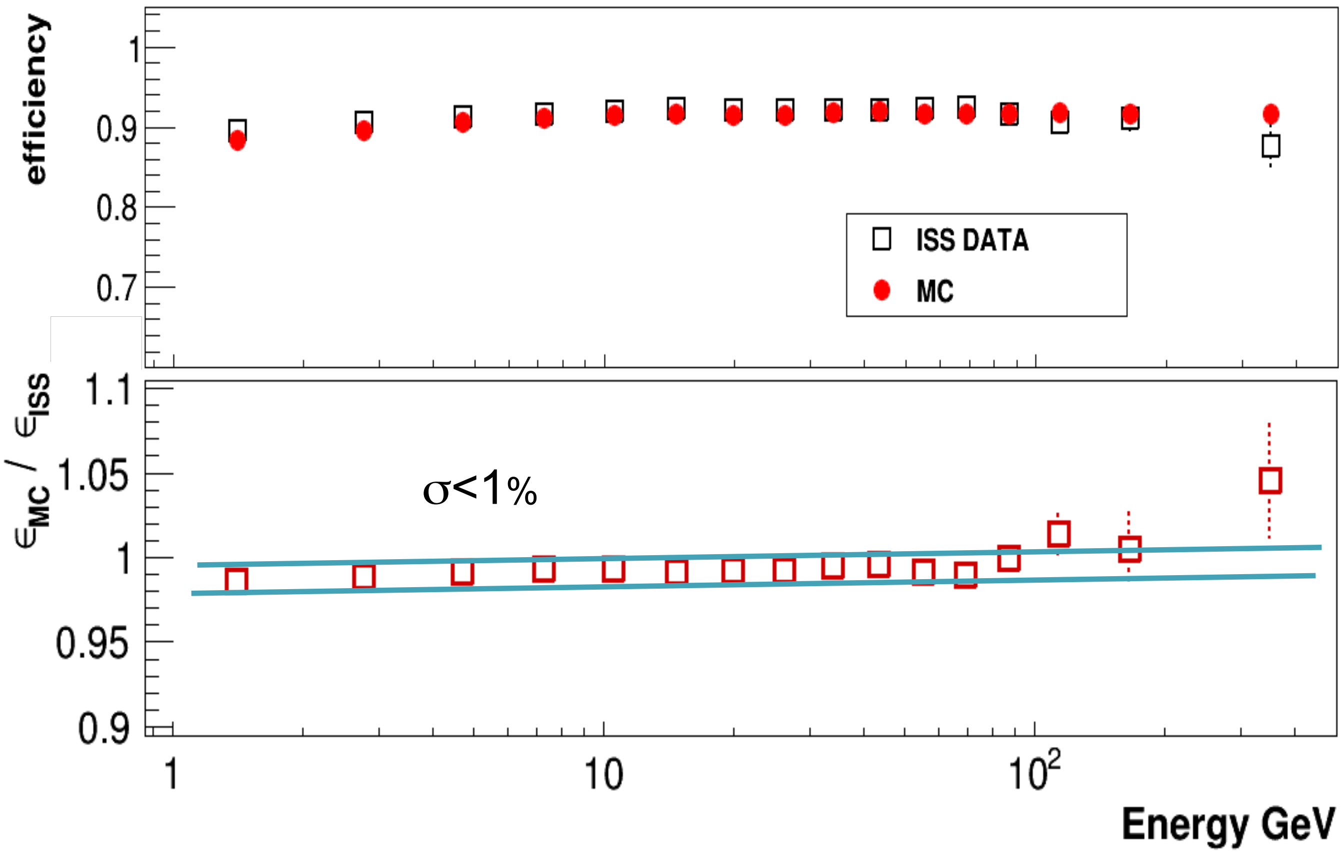
The trigger efficiency has been determined with ISS data using the “unbiased trigger” (a trigger with looser conditions, pre-scaled by 1/100)

Systematic error: acceptance

Track reconstruction: $\frac{\text{\# of } e^{\pm} \text{ with a track}}{\text{\# of } e^{\pm} \text{ through Trk acceptance}}$

The effect of <u>every</u> cut has been checked on ISS data and, if needed, the value of acceptance "corrected" (O(%))

The uncertainty on the MC/Data agreement has been quoted as systematic

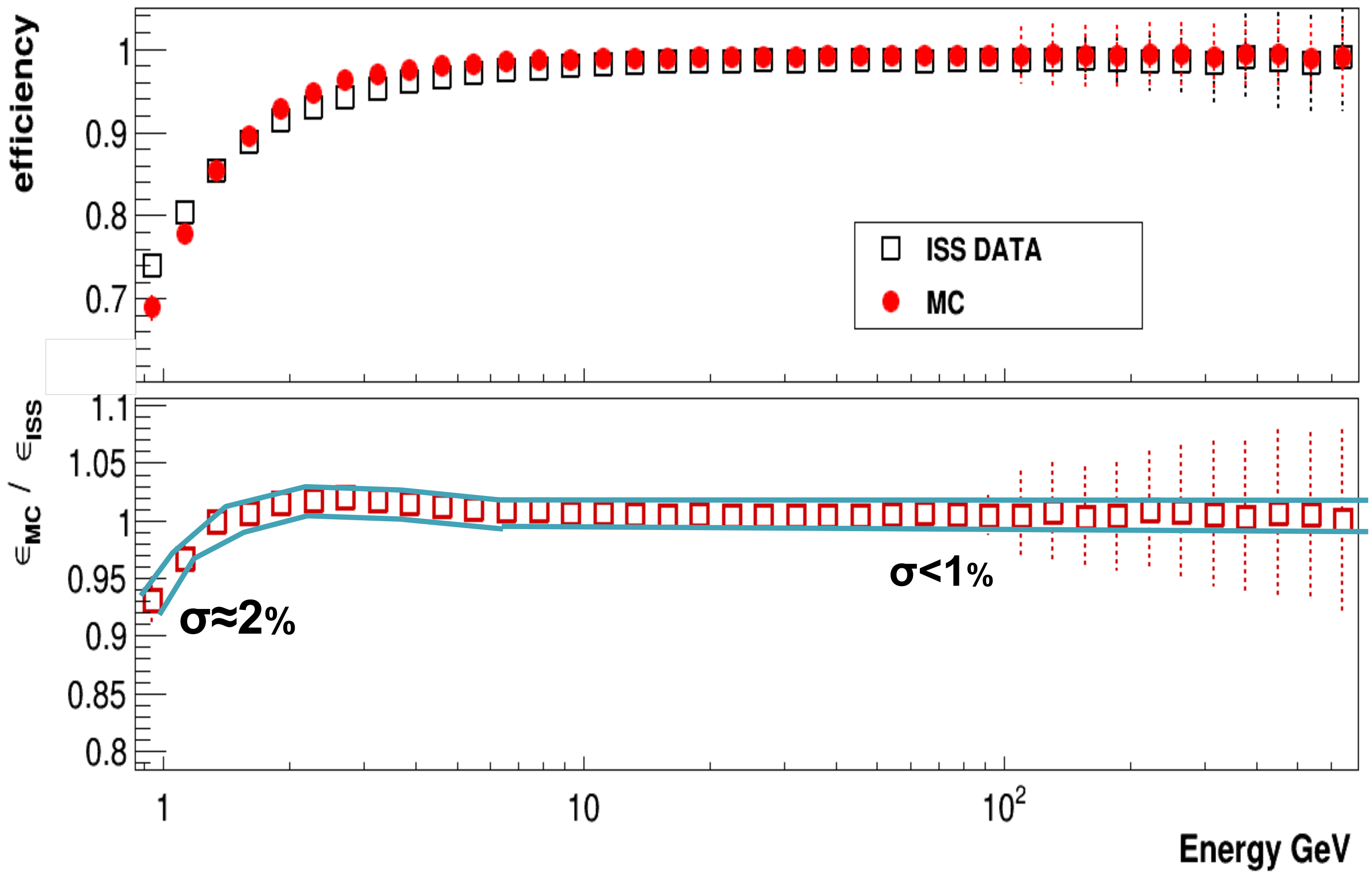


Systematic error: acceptance

The effect of every cut has been checked on ISS data and, if needed, the value of acceptance "corrected" (O(%))

The uncertainty on the MC/Data agreement has been quoted as systematic

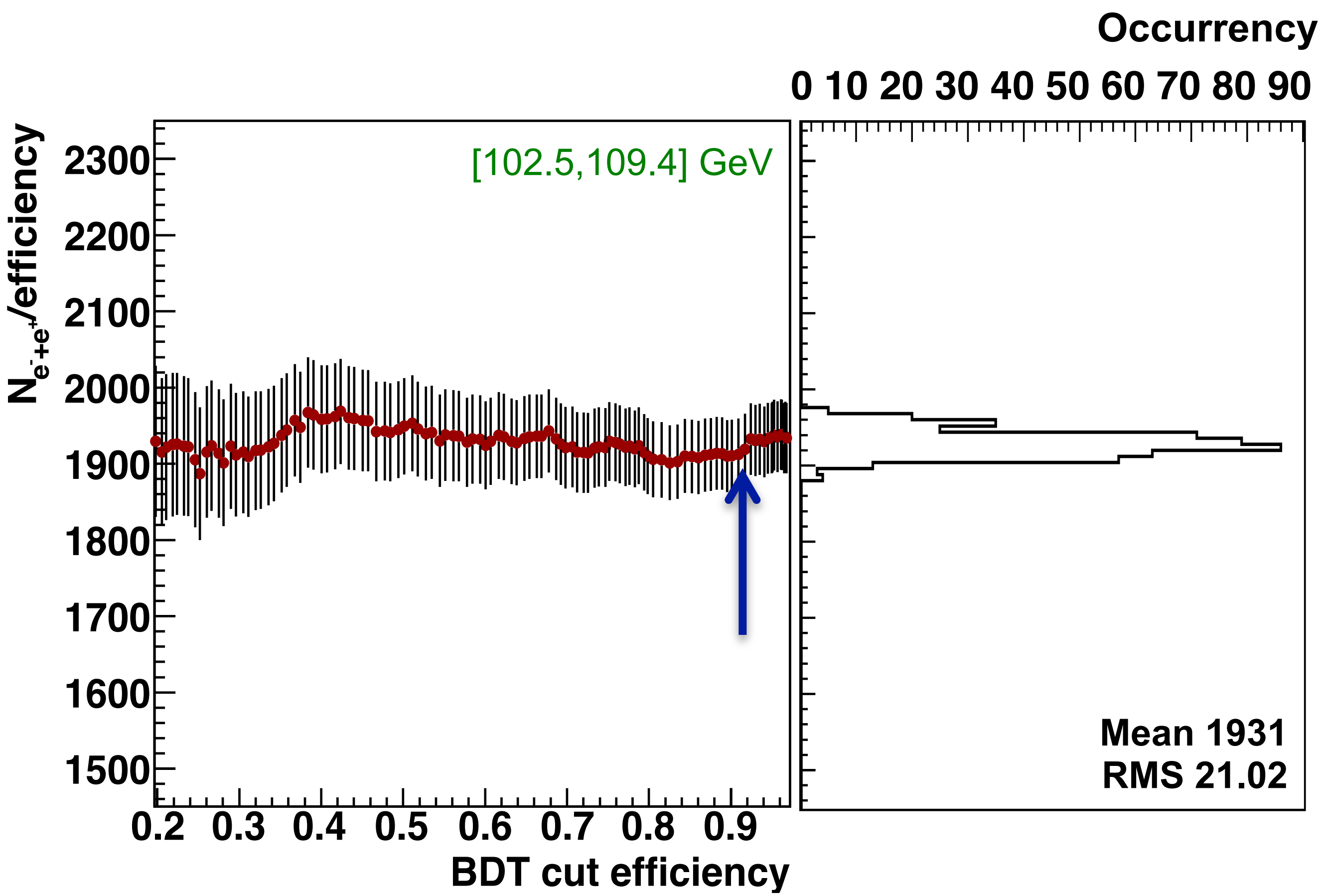
≥ 8 TRD hits used in the estimator



Systematic error: stability of the signal vs ECAL BDT cut

In each energy interval the cut on the ECAL BDT has been varied around the working point to verify the stability of the measurement.

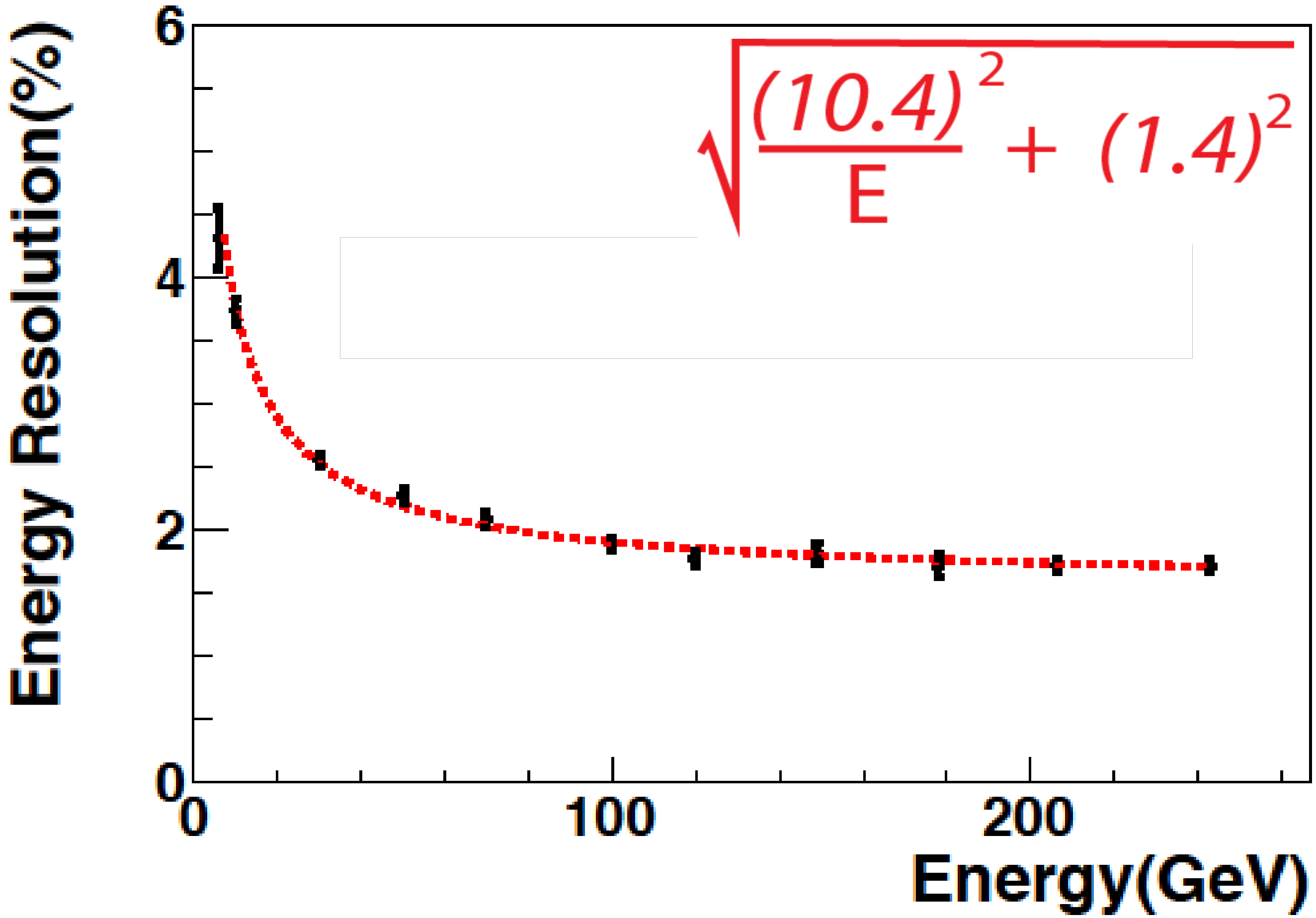
The RMS of the estimated number of e±, over a wide range of BDT cut efficiencies has been quoted as systematic



Systematics: bin-to-bin migration

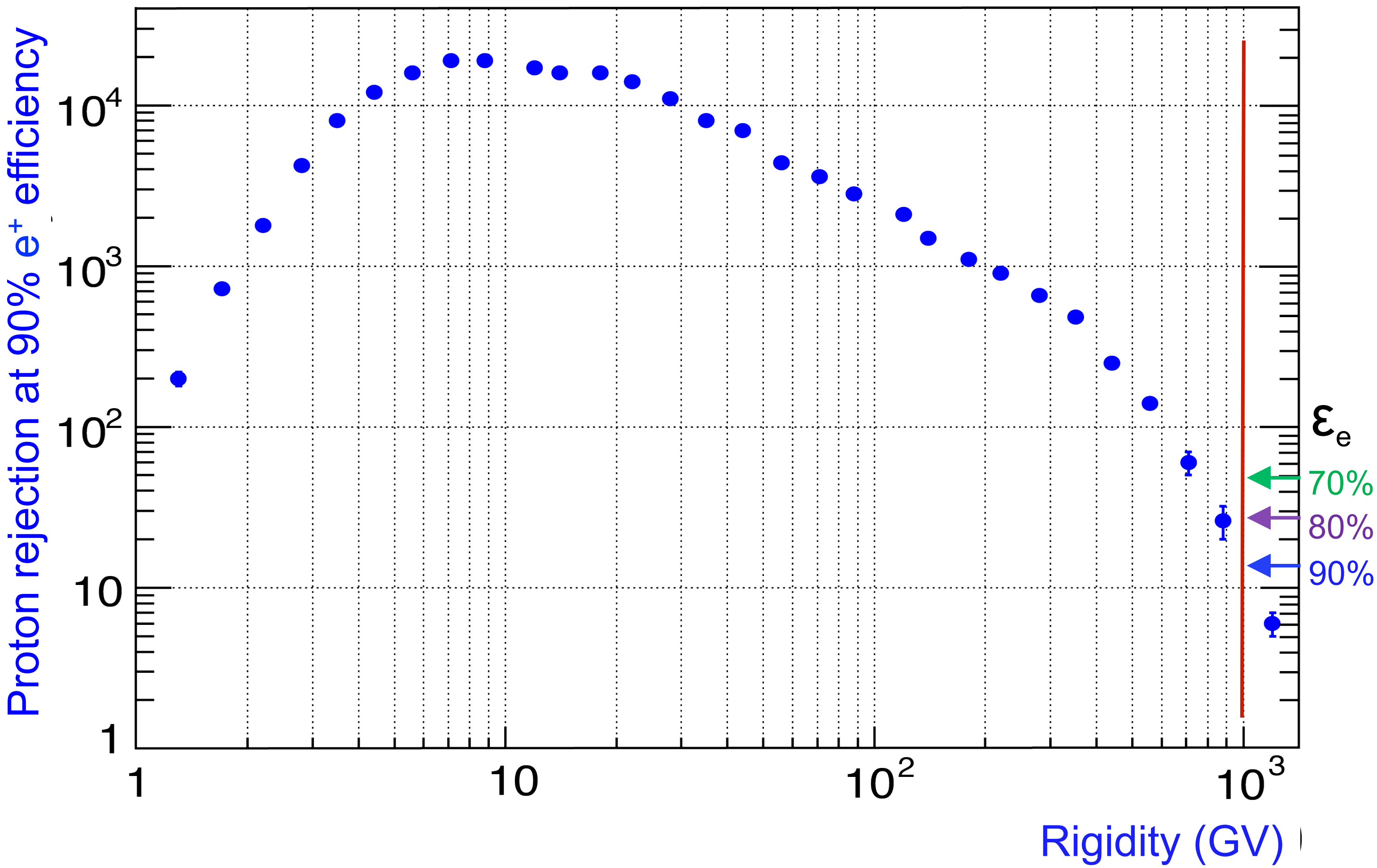
1.7% @ 100 GeV

The effect is not negligible only below few GeV



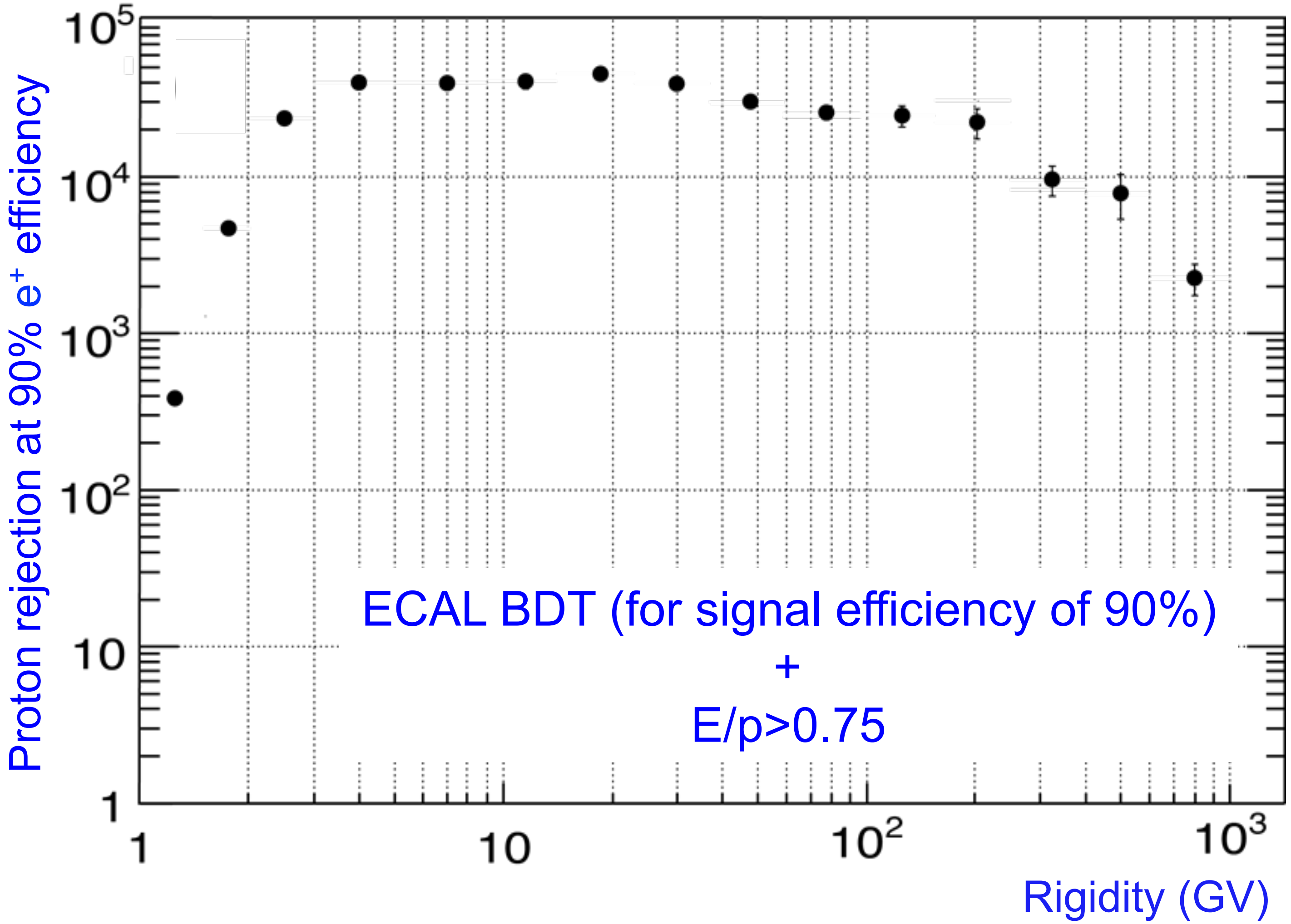
TRD e/p rejection on ISS

At high energies the rejection could be easily improved tightening the cut

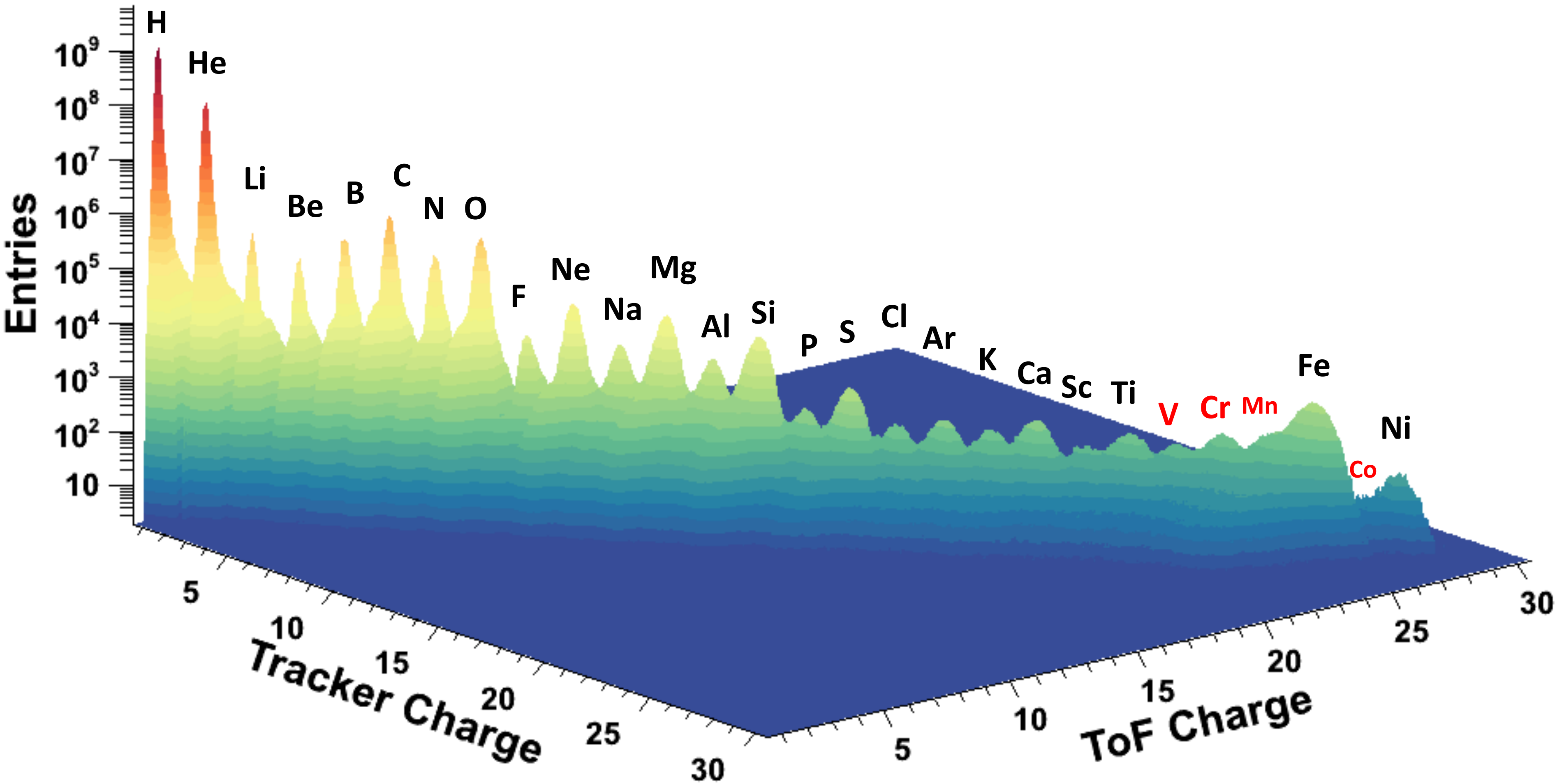


ECAL e/p rejection on ISS

ECAL classifier, combined with the energy-momentum matching, exceeds 10^4, below 200 GeV, and it becomes $\sim10^3$ at E~1TeV

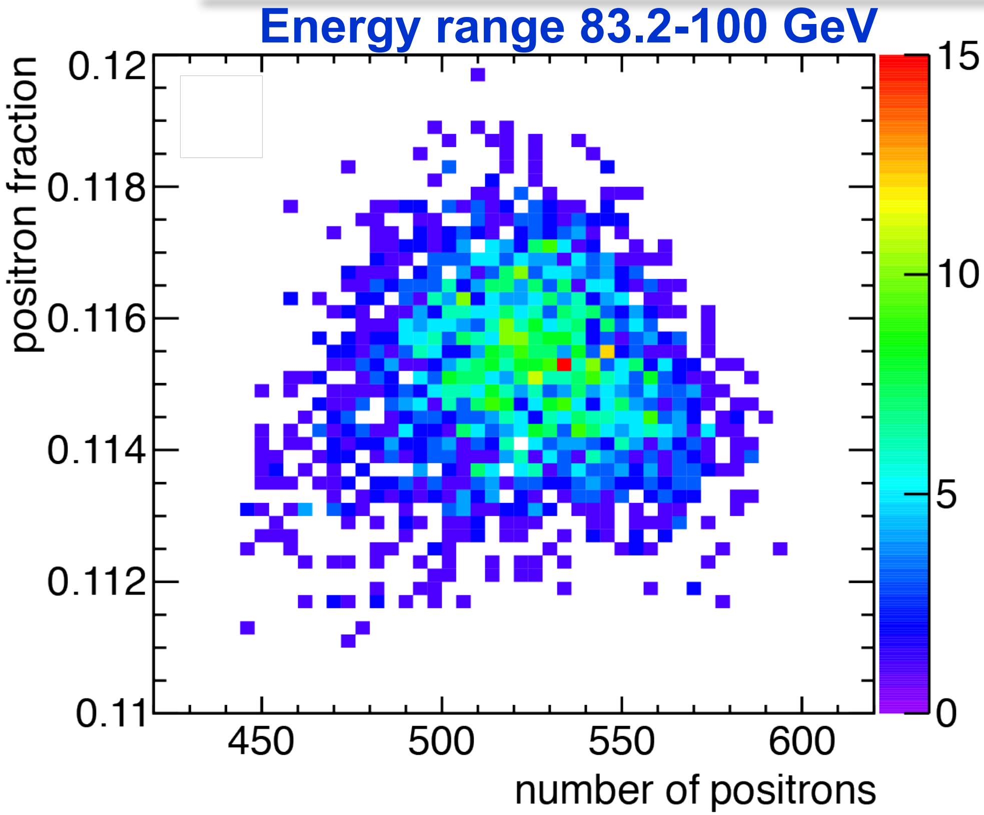


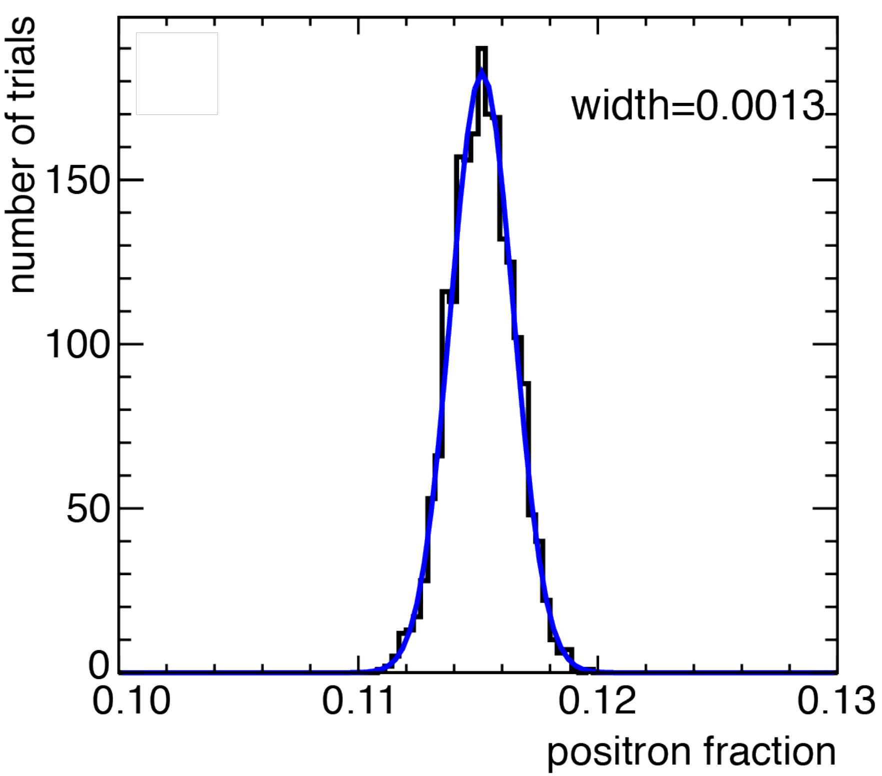
Charge resolution



Resolution: $\Delta Z \approx 0.05$ for $Z = 1$

Positron fraction stability



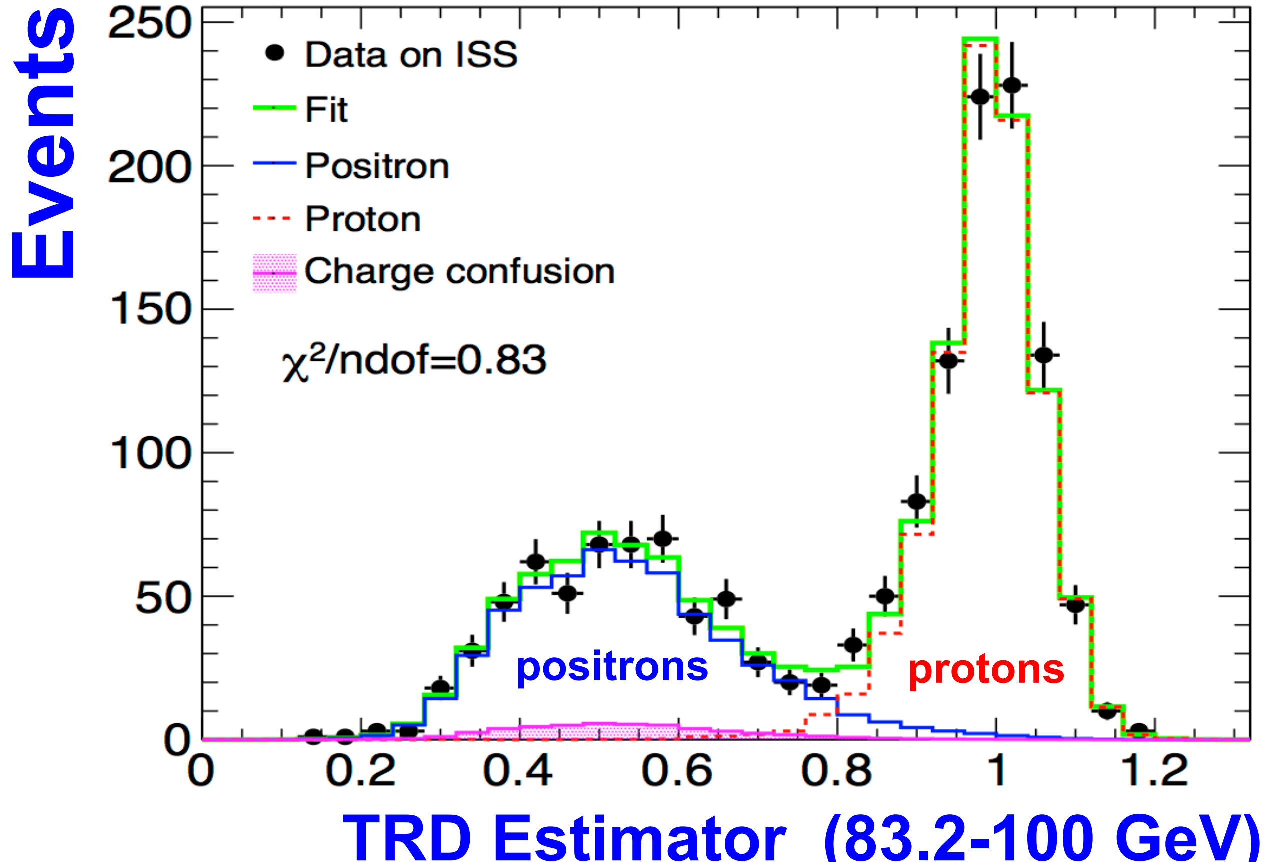


The measurement is stable over wide variations of the cuts in the TRD identification, ECAL Shower Shape, E (from ECAL) matched to |P| (from the Tracker), … For each energy bin, over 1,000 sets of cuts were analyzed.

Template fits (positron fraction)

Fit in e^+/e^-+e^+ measurement :

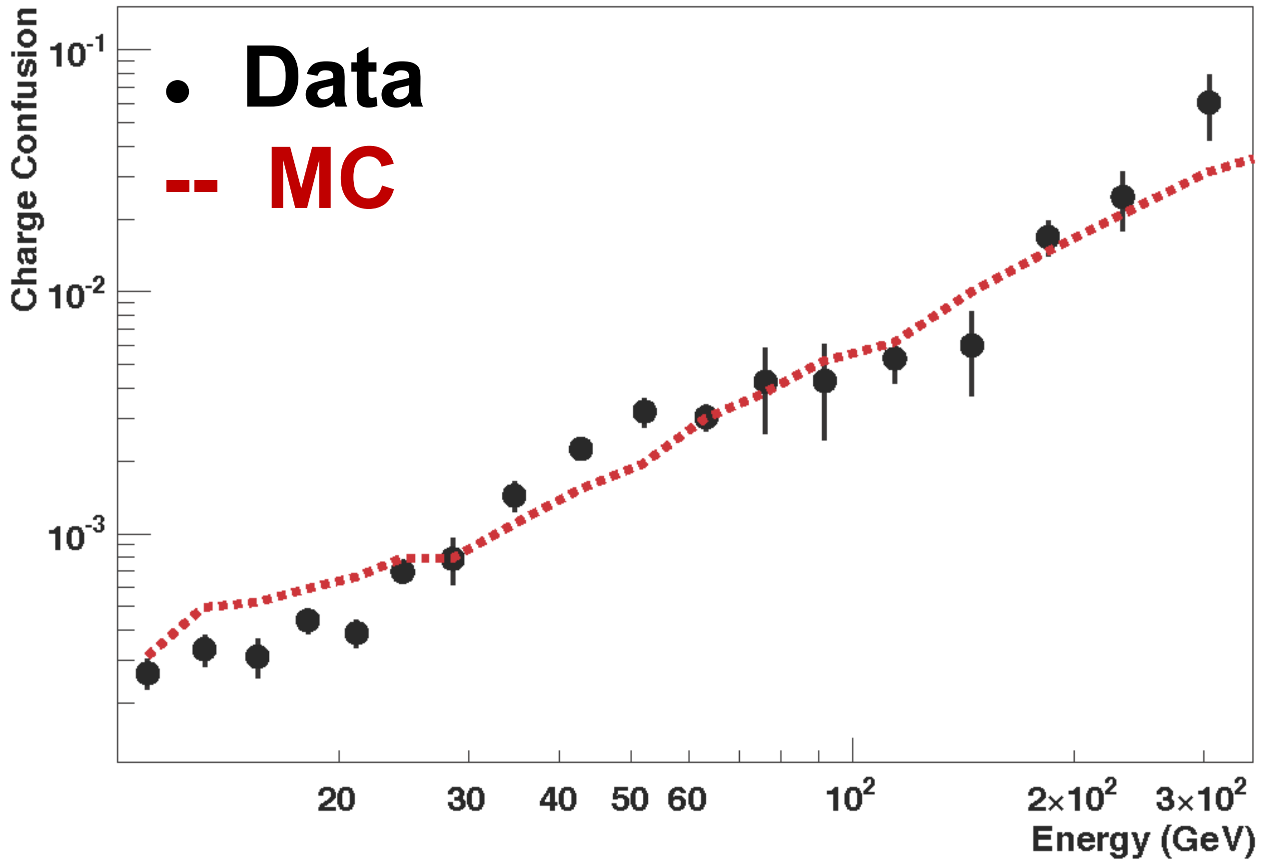
The TRD Estimator shows clear separation between protons and positrons with a small charge confusion background



Positron fraction errors

Positron events, positron fraction in each energy bin				Systematic Errors					
Energy [GeV]	N_{e+}	Fraction	statistical error	acceptance asymmetry	event selection	bin-to-bin migration	reference spectra	charge confusion	total systematic uncertainty
Energy[GeV]	N_{e+}	Fraction	$\sigma_{stat.}$	$\sigma_{acc.}$	$\sigma_{sel.}$	$\sigma_{mig.}$	$\sigma_{ref.}$	$\sigma_{c.c.}$	$\sigma_{syst.}$
1.00-1.21	9335	0.0842	0.0008	0.0005	0.0009	0.0008	0.0001	0.0005	0.0014
1.97-2.28	23893	0.0642	0.0004	0.0002	0.0005	0.0002	0.0001	0.0002	0.0006
3.30-3.70	20707	0.0550	0.0004	0.0001	0.0003	0.0000	0.0001	0.0002	0.0004
6.56-7.16	13153	0.0510	0.0004	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
09.95-10.73	7161	0.0519	0.0006	0.0001	0.0000	0.0000	0.0001	0.0002	0.0002
19.37-20.54	2322	0.0634	0.0013	0.0001	0.0001	0.0000	0.0001	0.0002	0.0003
30.45-32.10	1094	0.0701	0.0022	0.0001	0.0002	0.0000	0.0001	0.0003	0.0004
40.00-43.39	976	0.0802	0.0026	0.0002	0.0005	0.0000	0.0001	0.0004	0.0007
50.87-54.98	605	0.0891	0.0038	0.0002	0.0006	0.0000	0.0001	0.0004	0.0008
64.03-69.00	392	0.0978	0.0050	0.0002	0.0010	0.0000	0.0002	0.0007	0.0013
74.30-80.00	276	0.0985	0.0062	0.0002	0.0010	0.0000	0.0002	0.0010	0.0014
86.00-92.50	240	0.1120	0.0075	0.0002	0.0010	0.0000	0.0003	0.0011	0.0015
100.0-115.1	304	0.1118	0.0066	0.0002	0.0015	0.0000	0.0003	0.0015	0.0022
115.1-132.1	223	0.1142	0.0080	0.0002	0.0019	0.0000	0.0004	0.0019	0.0027
132.1-151.5	156	0.1215	0.0100	0.0002	0.0021	0.0000	0.0005	0.0024	0.0032
151.5-173.5	144	0.1364	0.0121	0.0002	0.0026	0.0000	0.0006	0.0045	0.0052
173.5-206.0	134	0.1485	0.0133	0.0002	0.0031	0.0000	0.0009	0.0050	0.0060
206.0-260.0	101	0.1530	0.0160	0.0003	0.0031	0.0000	0.0013	0.0095	0.0101
260.0-350.0	72	0.1550	0.0200	0.0003	0.0056	0.0000	0.0018	0.0140	0.0152

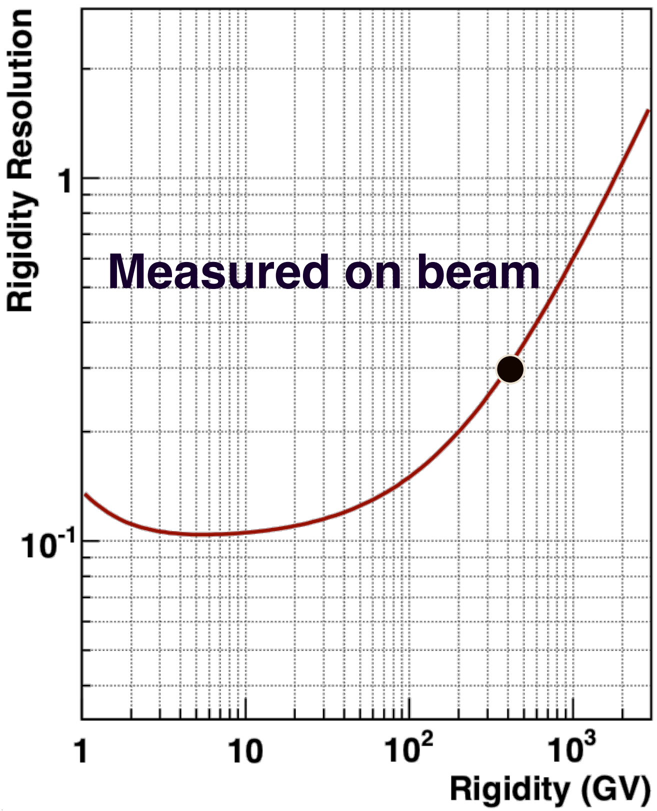
Charge confusion (positron fraction)

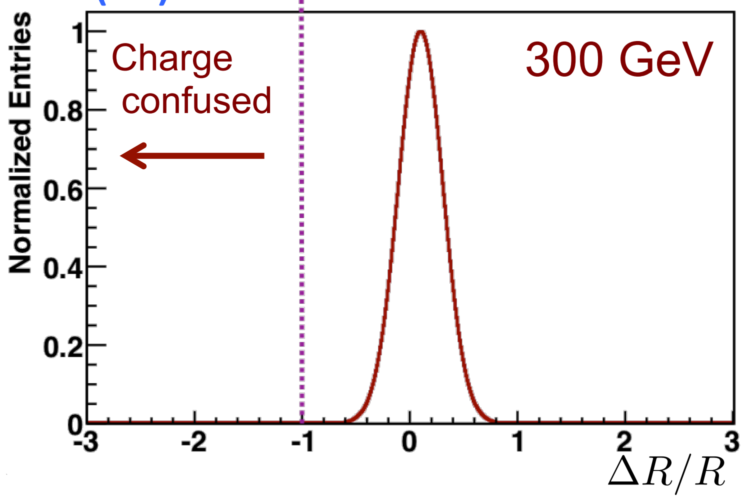


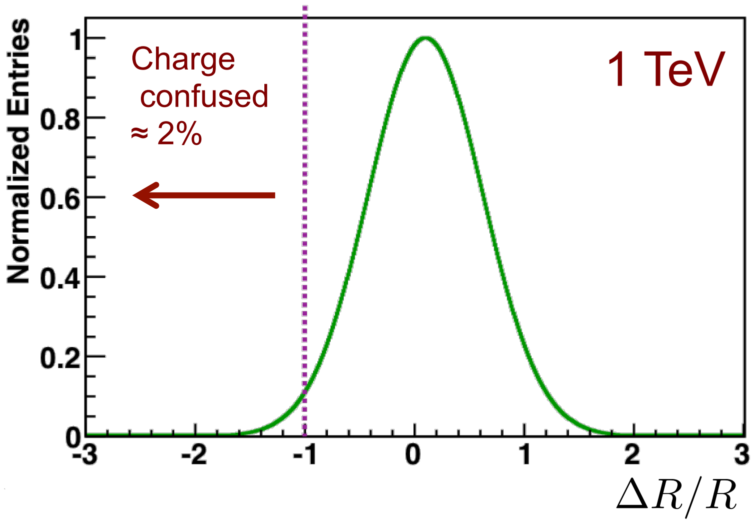
Two sources: large angle scattering and production of secondary tracks along the path of the primary track. Both are well reproduced by MC. Systematic errors correspond to variations of these effects within their statistical limits.

Spectrometer resolution and charge confusion

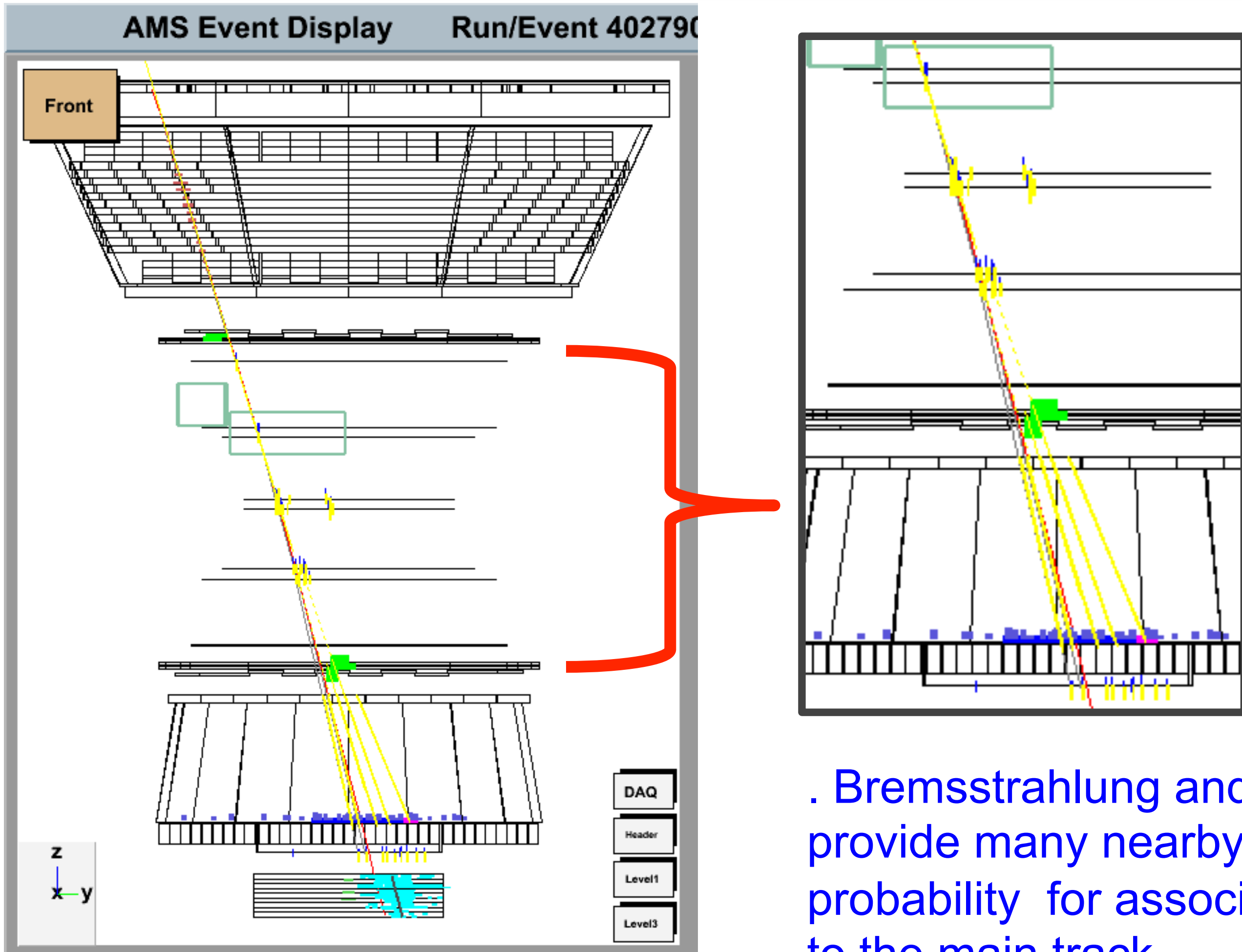
Momentum resolution contributes at the O(%) level in the charge confusion at the TeV energies







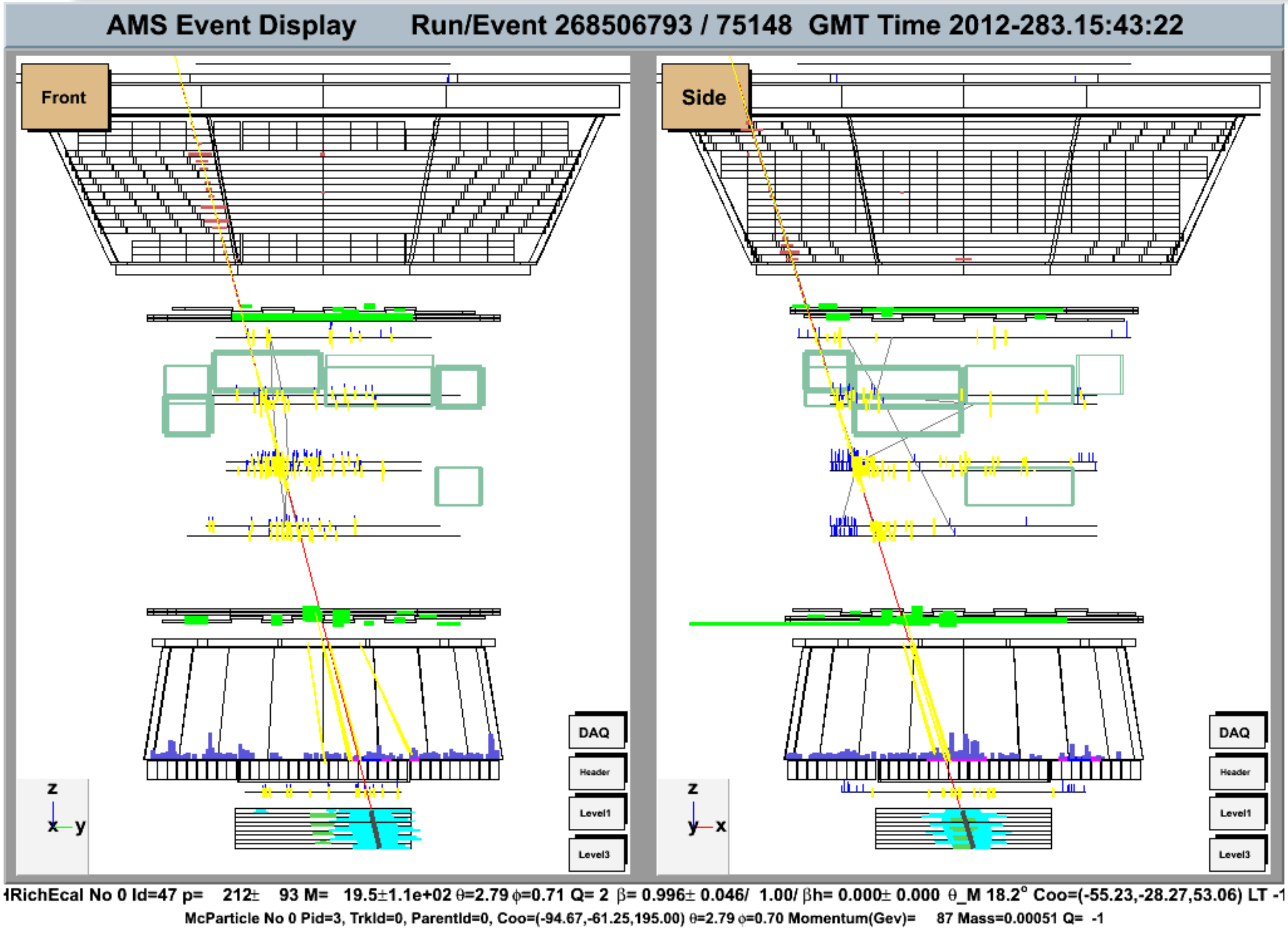
Charge confusion sources: interaction in the detector



. Bremsstrahlung and delta rays provide many nearby tracks with high probability for association of a wrong hit to the main track.

8 GeV electron reconstructed as 1 GeV positron

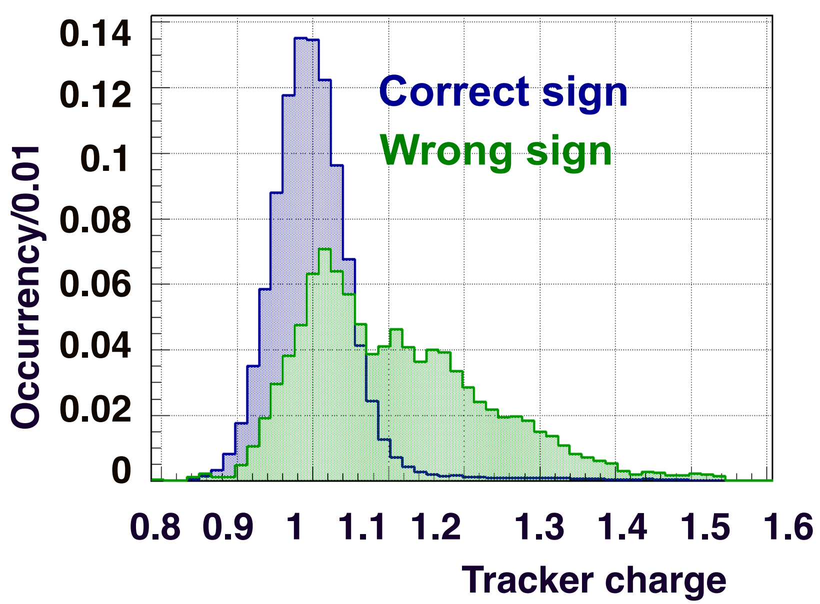
Charge confusion sources: interaction in the detector

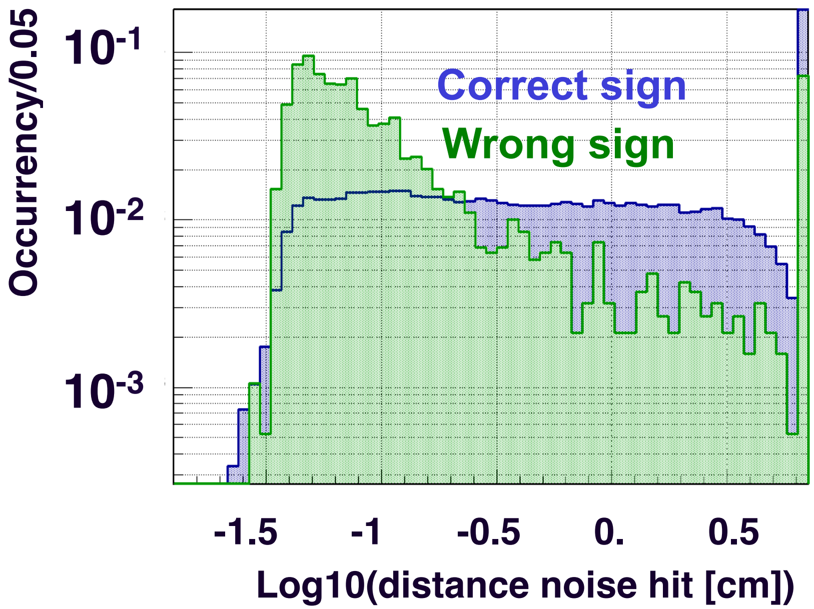


38 GeV electron reconstructed as 0.8 GeV positron.

Charge confusion from interactions

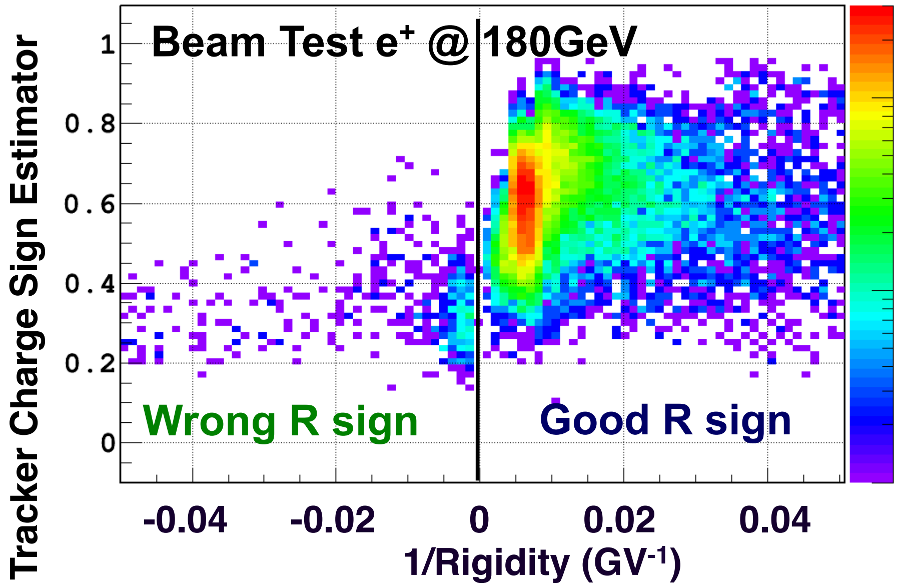
Different reconstructed quantities are sensitive to interactions and can be used to separate Correct and Wrong Charge Sign assignment

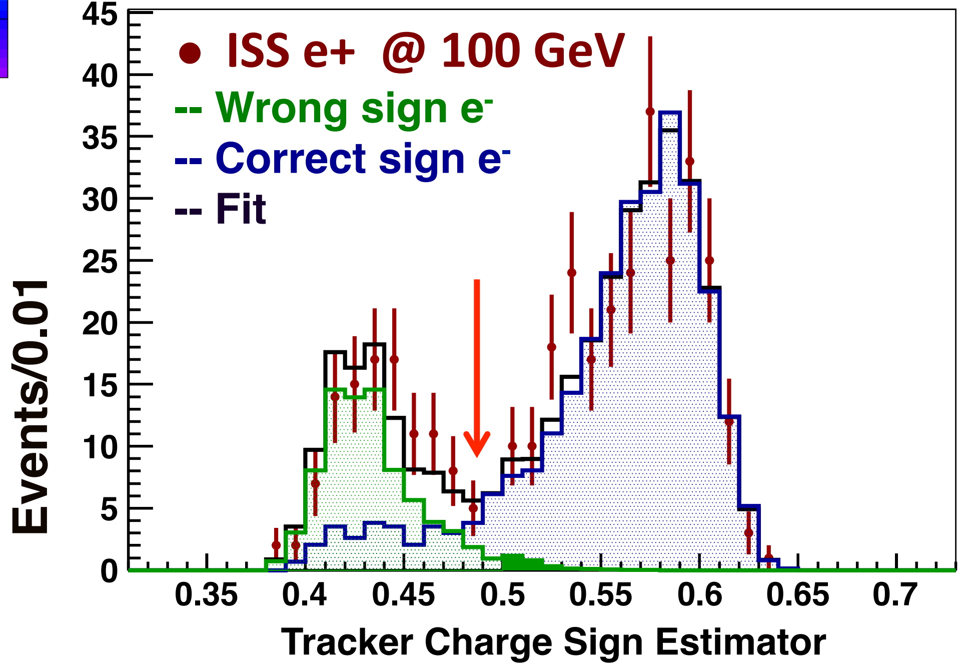




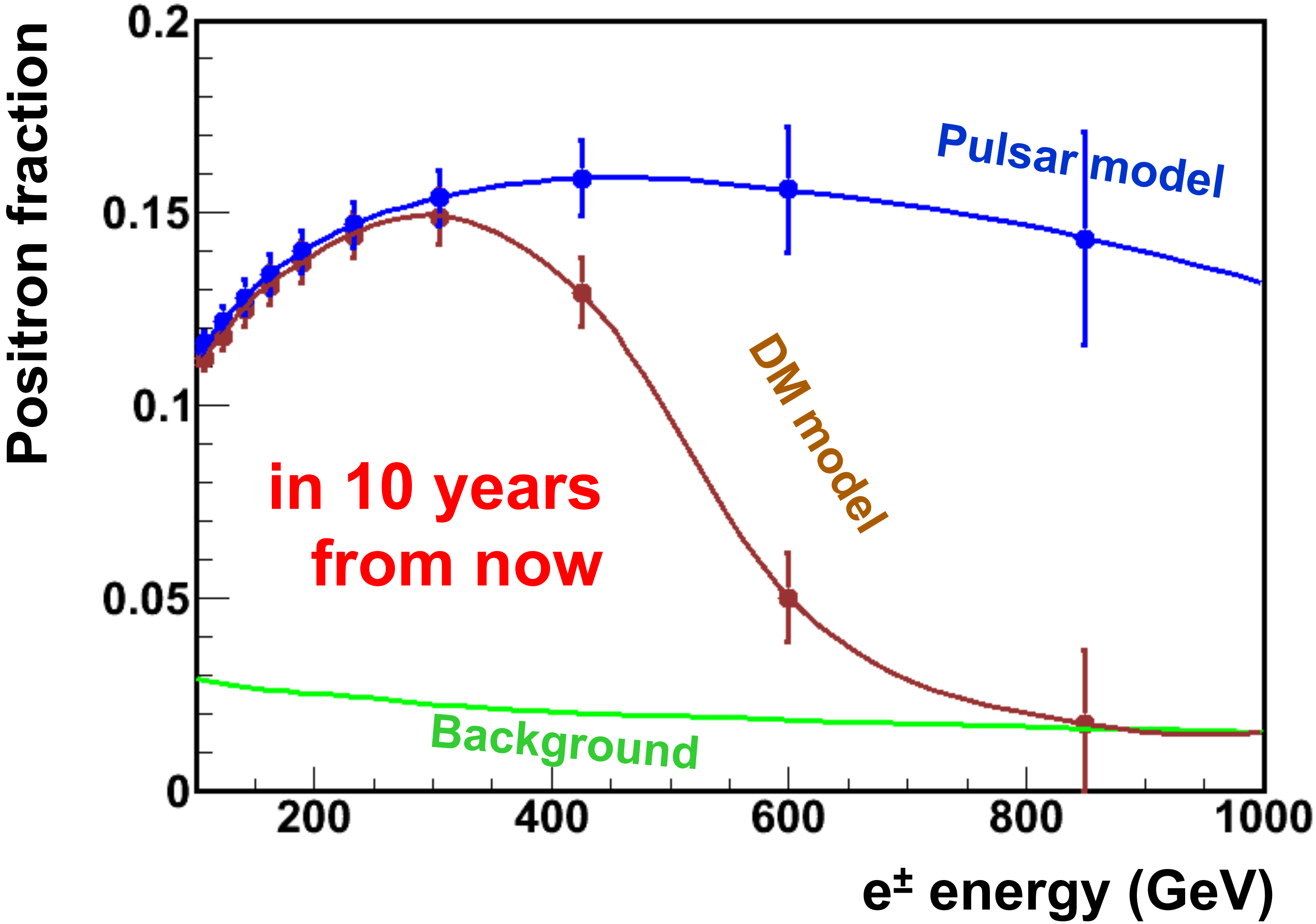
Use a statistical estimator to build a tracker charge sign discriminating variable

Tracker charge sign estimator





Excess origin understanding perspectives



The origin of the excess

…is there any privileged arrival direction?

Analysis of possible deviation of the measured ratio as a function of the arrival direction in galactic coordinates (b,l)

$$\frac{r_e(b,l)}{\langle r_e \rangle} - 1 = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell m} Y_{\ell m}(\pi/2 - b, l)$$

Power spectrum from the coefficient of the spherical armonics:

$$C_\ell = \frac{1}{2\ell+1} \sum_{m=-\ell}^{\ell} |a_{\ell m}|^2.$$

Compatible with isotropy in the dipolar mode $\delta = 3\sqrt{C_1/4\pi}$

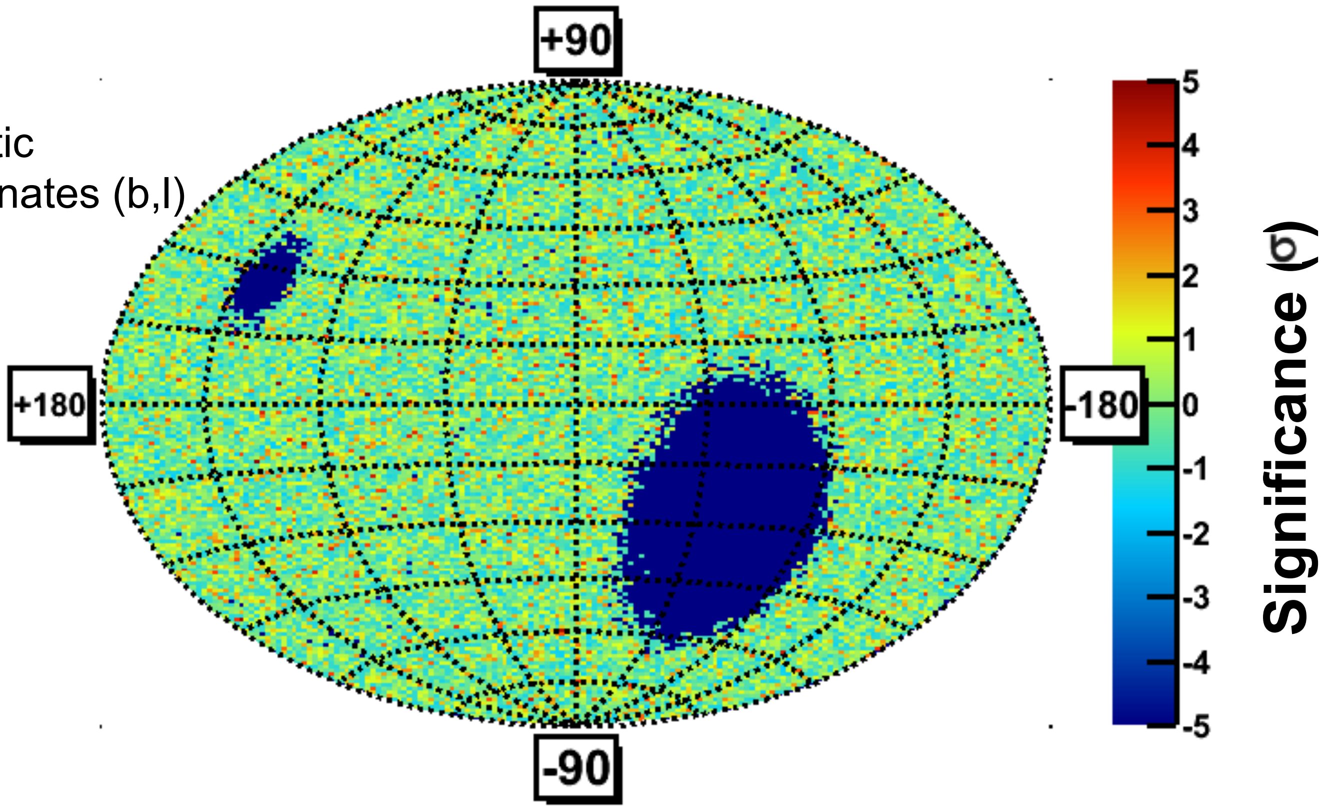
δ ≤ 0.036 at the 95% confidence level

Isotropic?

If the excess has a particle physics origin, it should be isotropic

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

Galactic coordinates (b,l)



Sensitivity to anisotropy

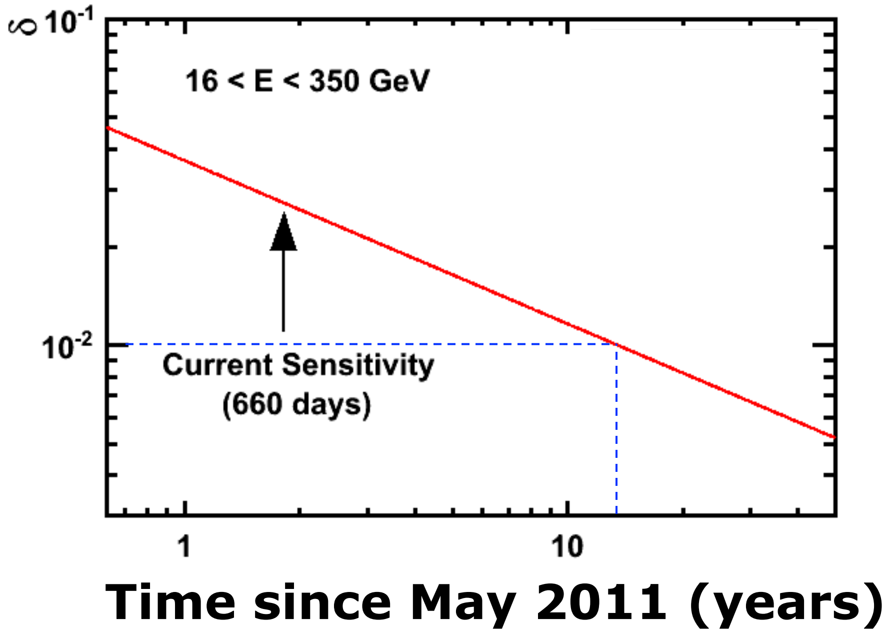
Current limits on the amplitude of a dipole anisotropy in any axis in galactic coordinates on the positron to electron ratio in the energy range from 16 GeV to 350 GeV

$\delta \leq 0.030$ at the 95% confidence level

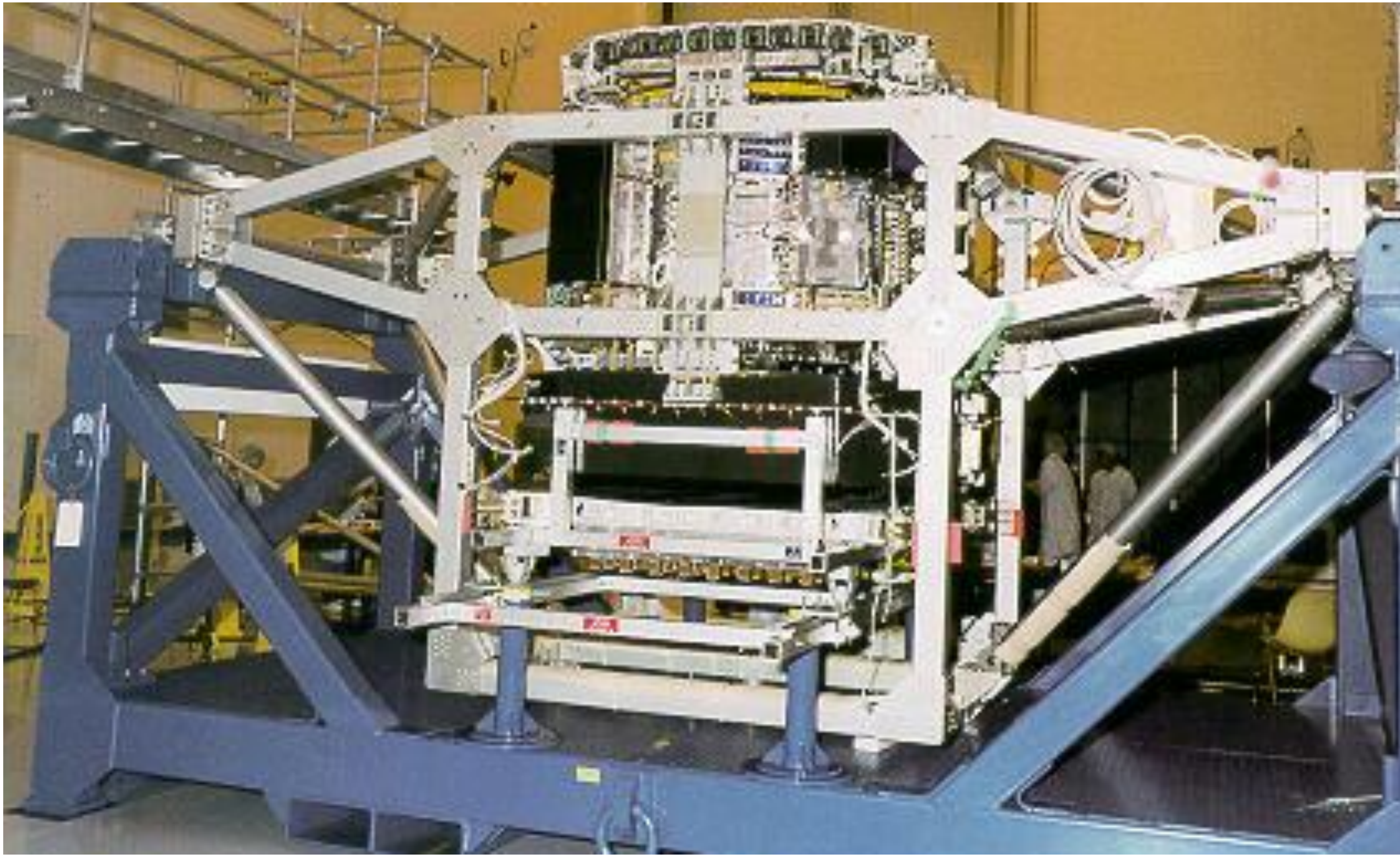
In 10 more years, AMS will reach a sensitivity of

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

for a dipole anisotropy in the positron to electron ratio



1998: AMS prototype at KSC (Florida)



June 2nd - 12th 1998:
AMS-01 pilot experiment on Discovery STS91

- 10 days of data taking in orbit:
  - 400 Km altitude
  - latitudes <51.7°
  - all longitudes
- 10^8 events recorded
- Physics results (Phys. Rep. 366 (2002) 331)
  - precise measurements of primary fluxes
  - detection of secondary fluxes (quasi-trapped)
  - antimatter limit at 10^{-6}