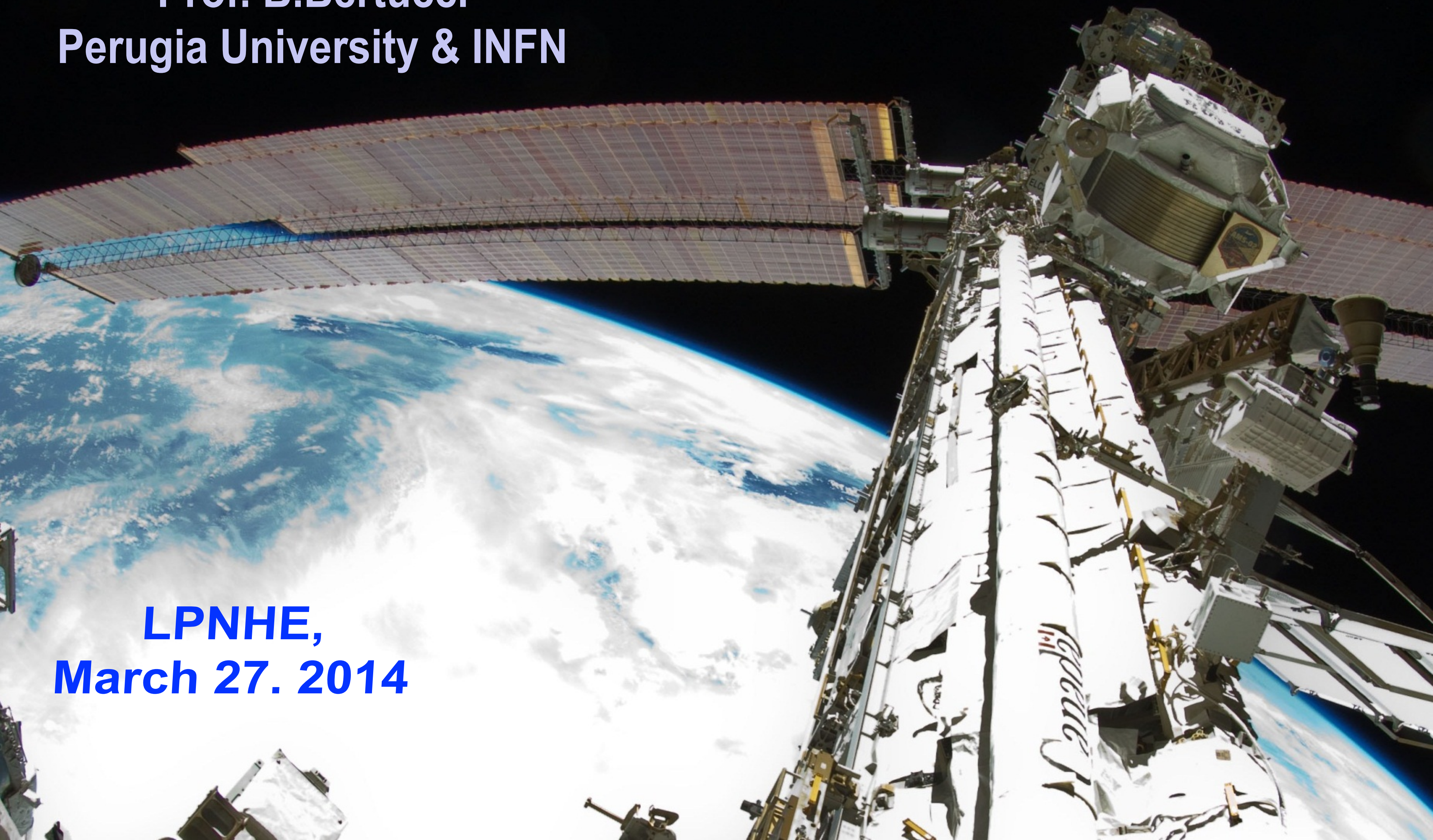
1000 days on orbit with AMS-02

Prof. B.Bertucci
Perugia University & INFN



LPNHE,
March 27. 2014

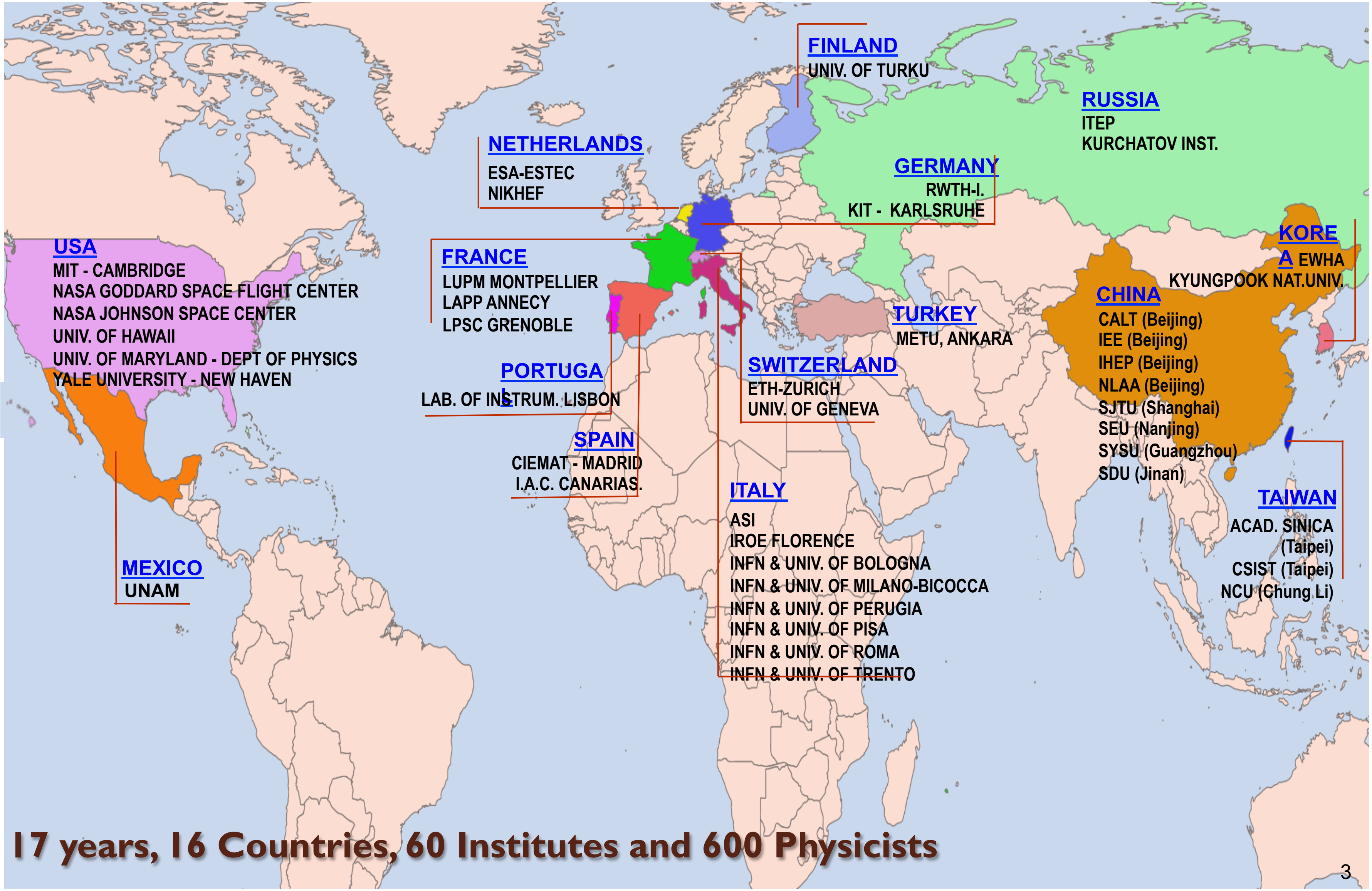
Alpha Magnetic Spectrometer

- AMS-02 is a particle physics detector devoted to the precision measurement of cosmic radiation in the near Earth orbit in the GeV – TeV energy range
- It has been installed on the International Space Station (ISS) on May 19, 2011
- It will take data data for the rest of the life of the ISS (2024)

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

The AMS Collaboration



AMS-02 :
(part) of the Collaboration @ NASA-JSC

AMS-02 @ Perugia: 1 month before the launch !

PART 1 : The scientific objectives

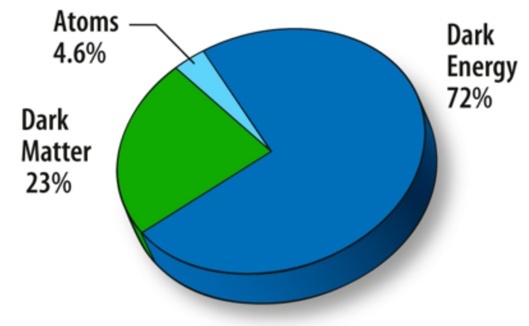
Objectives

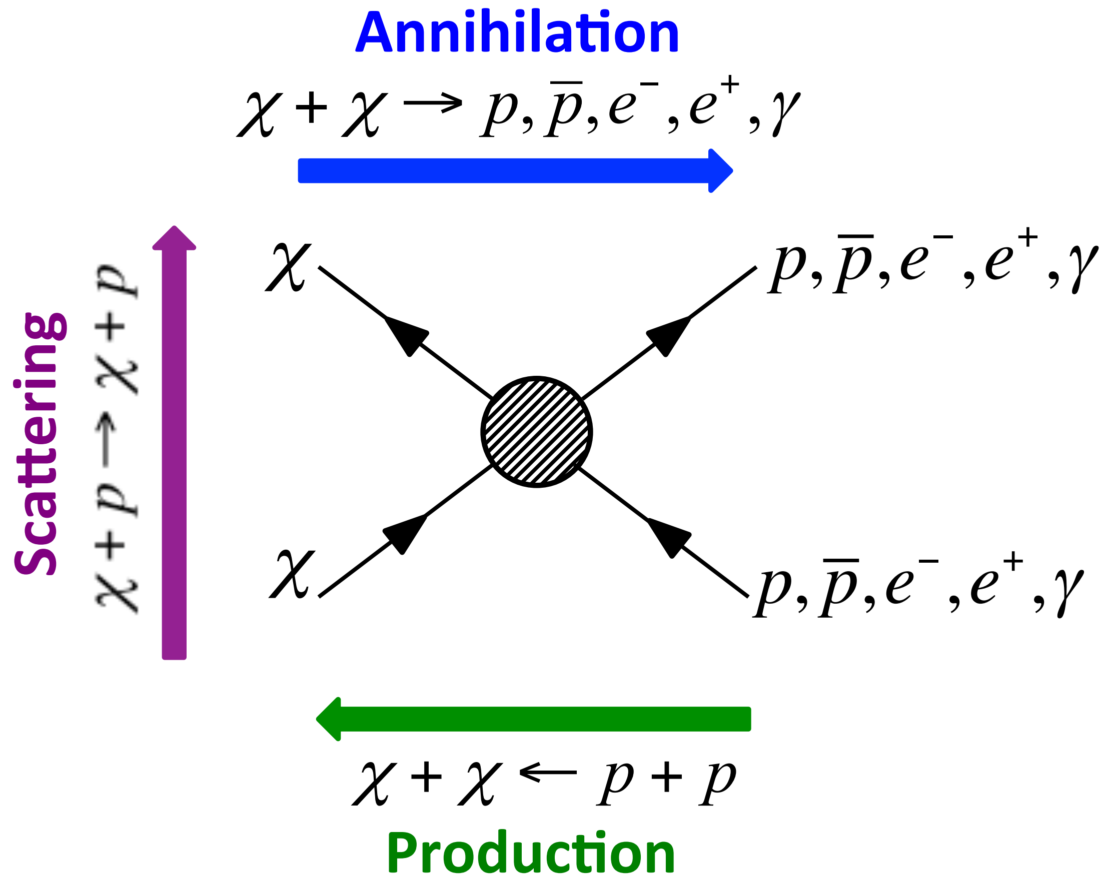
- Fundamental physics & Antimatter :
  - Primordial origin (Signal: anti-nuclei)

Dirac's Nobel speech

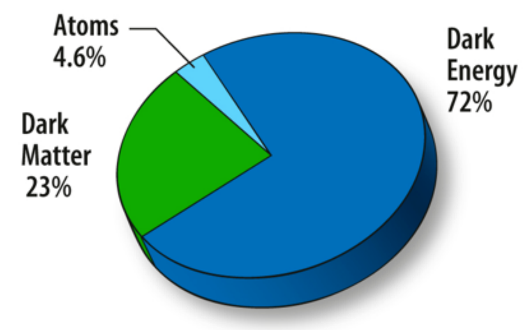
"We must regard it rather as an accident that the Earth [...] contains a preponderance of negative electrons and positive protons. It is quite possible that for some stars it is the other way about."

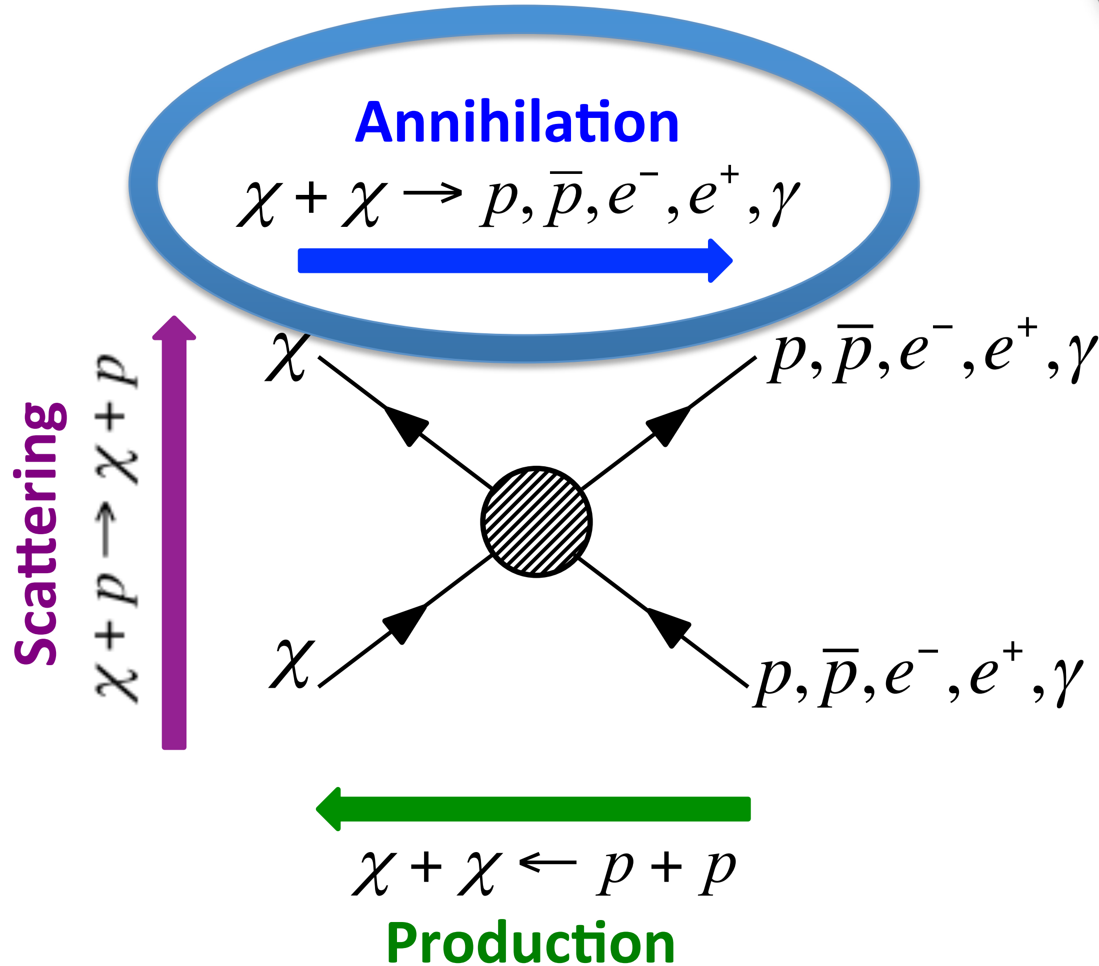
The quest for Dark Matter





The quest for Dark Matter

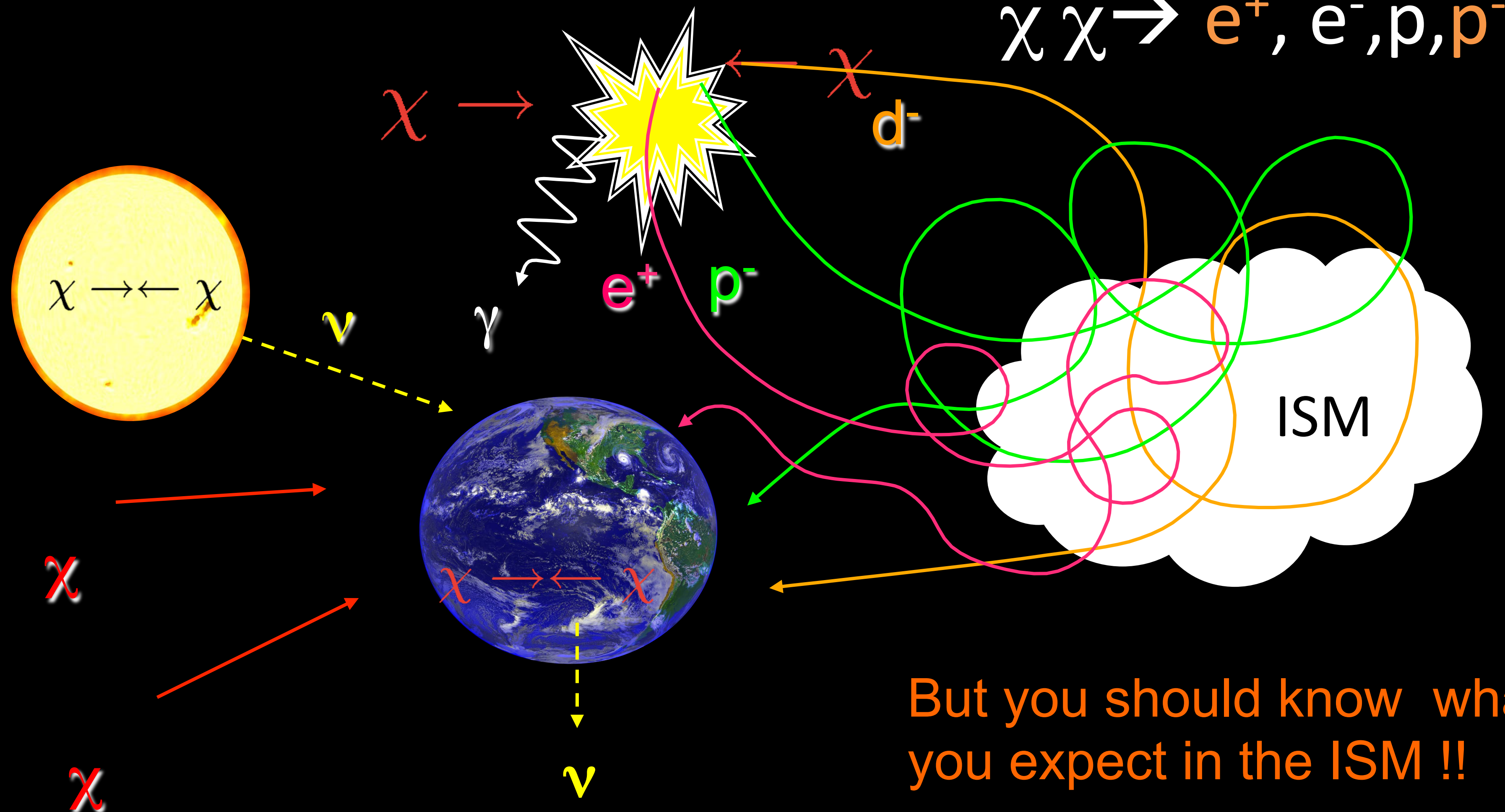




Anti-Matter & Dark Matter

WIMP as the responsible of Dark Matter (?)
Direct Searches
Indirect DM search → search for (RARE IN CR) products from their annhilation….

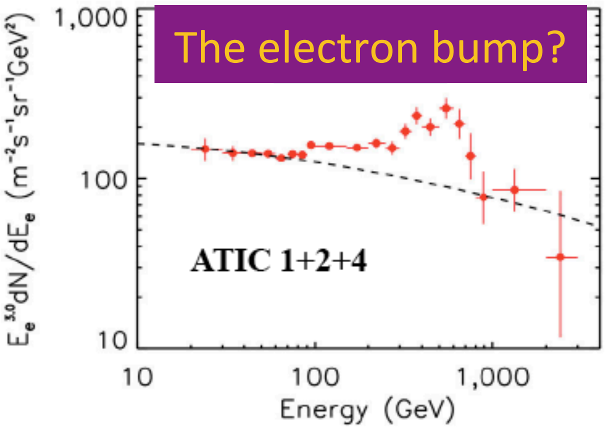
$\chi\chi \rightarrow e^{+}, e^{-}, p, p^{-}, \gamma$



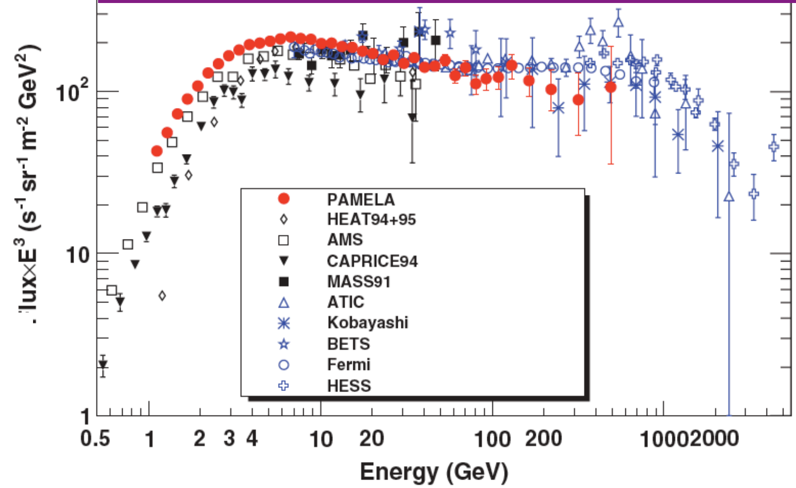
But you should know what you expect in the ISM !!

Anti-matter & Exotic sources (DM ?)

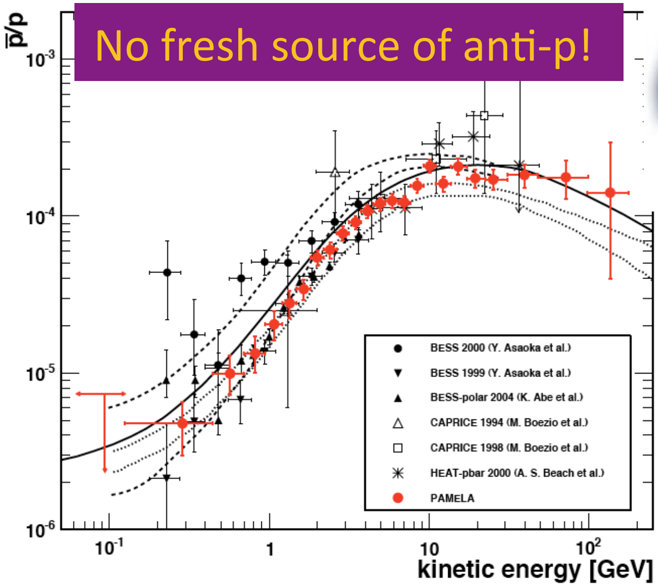
The electron bump?



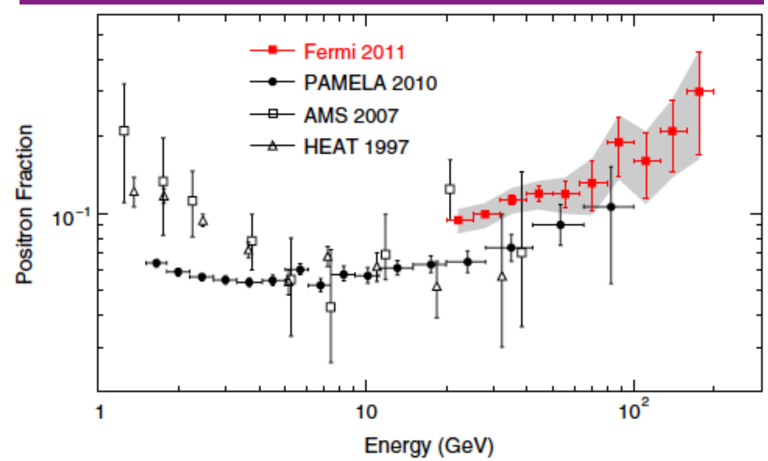
No bump in Fermi / PAMELA data



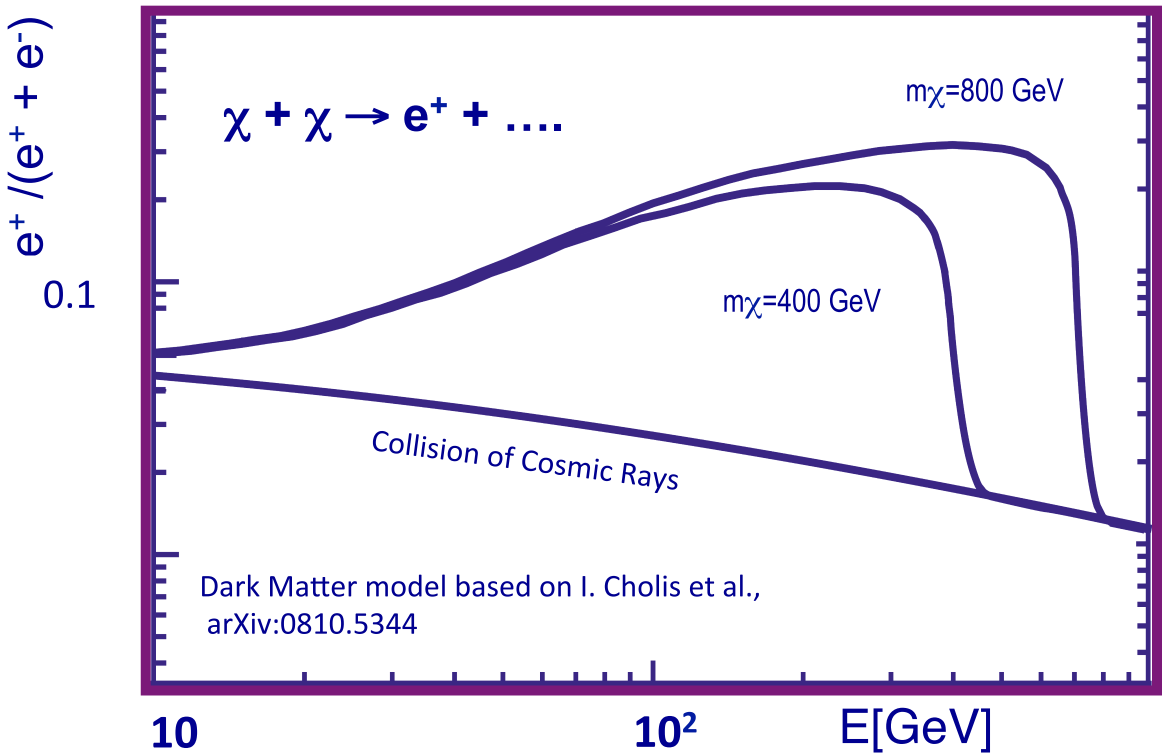
No fresh source of anti-p!



A confirmed positron "excess"



What is needed?



Leptophilic dark matter or astrophysical sources ??

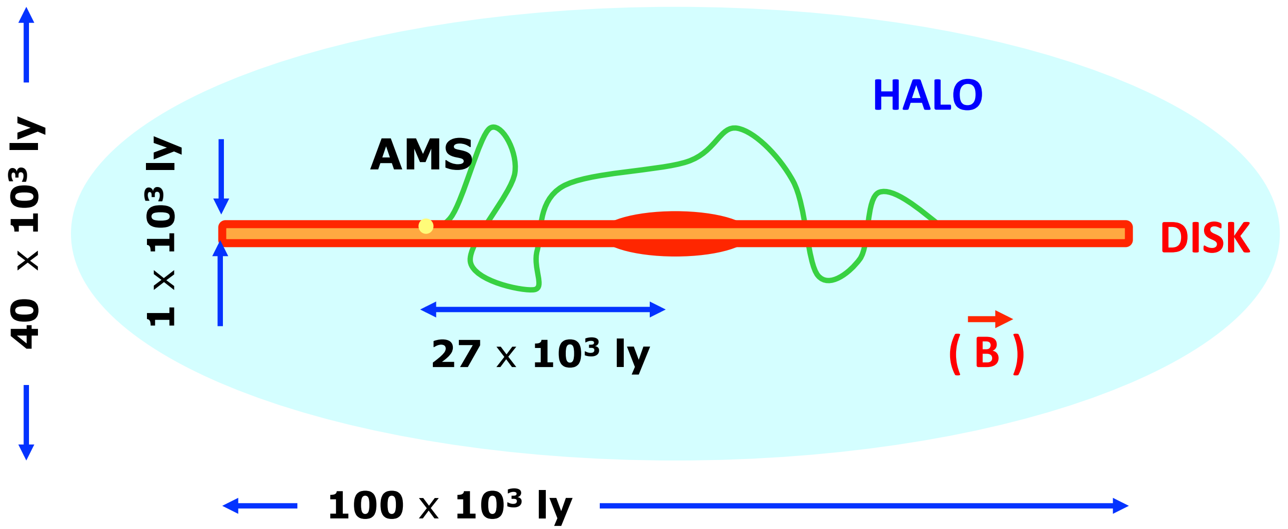
- Shape of the excess accurately measured over an extended energy range
- Knowledge of "cosmic background"

Knowledge of cosmic background

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) → B + …



Diffusion
Convection
Reacceleration

Interactions with the Interstellar Medium (ISM):
- Fragmentation
- Secondaries
- Energy loss

AMS Objectives according to some blogs…

http://www.rumormillnews.com/cgi-bin/archive.cgi?read=204750

…Shuttle Endeavor's official mission is to haul a deliberately-mislabeled "Alpha Magnetic Spectrometer" (AMS-02) to the International Space Station and install it. NASA claims that the AMS-02 is a state-of-the-art particle physics detector. In actuality the AMS-02 is an advanced extreme-energy neutral-particle-beam space weapon intended to shoot down Star Visitor craft (UFOs). And instead of the International Space Station, Shuttle Endeavor will deliver the AMS-02 Star Wars weapon to a secret military space station, also in orbit….

….

You are invited to join in a Joint Psychic Exercise to address these problems.

…

We will focus on one or both of two things. First is to direct telekinetic, electrical-pulse, disruptive-magnetic, and/or other energies to deactivate the AMS-02 neutral-particle-beam weapon and render it inoperative. Thus there will be nothing useful to deliver to the military space station.

AMS Objectives

- **Fundamental physics & Antimatter :**
  - **Primordial origin (anti-nuclei ?)**
  - **Exotic sources a.k.a DARK MATTER (positrons, anti-p, anti-D?,gammas)**

- **The CR composition and energy spectrum**

  (how to understand the beam)
  - **Sources & acceleration : Proton and He**
  - **Propagation in the ISM: (nuclear and isotopic composition)**

What is needed?

- **Particle identification and E measurement up to TeV:**
  - e/p separation at the 10^4 level by means of independent detectors
  - Z : redundant measurements to evaluate fragmentation along the detector
  - Charge sign: matter to anti-matter separation (magnetic field!)

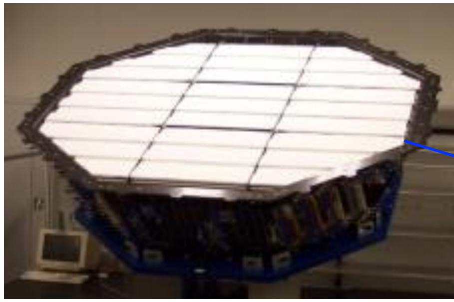
- **Statistics**
  - acceptance & efficiency
  - Exposure time

PART 2 : The experimental challenge

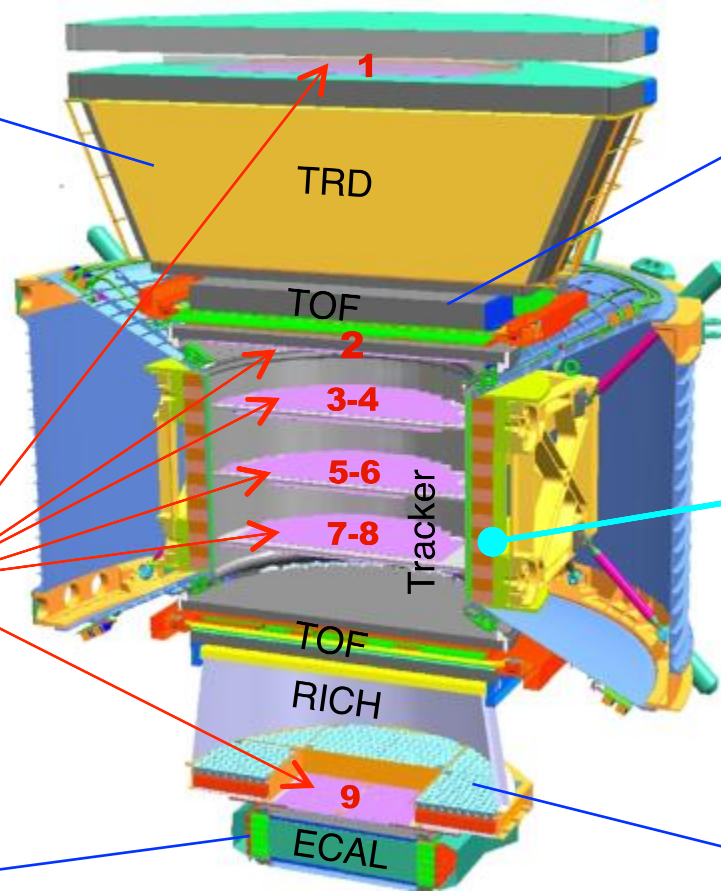
- a) DESIGN: the detectors
- b) TEST: test on ground
- c) Operation & Monitoring on orbit: calibration on flight

AMS: A TeV precision, multipurpose spectrometer

Transition Radiation Detector (TRD)
Identify e^+, e^-

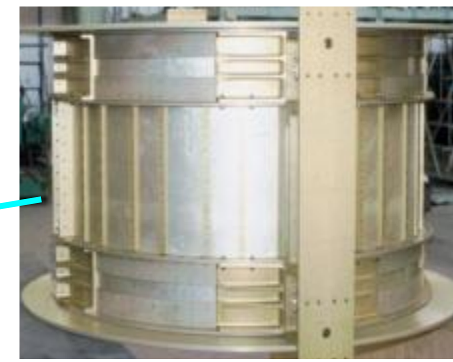


Particles and nuclei are defined by their charge (Z) and energy (E)

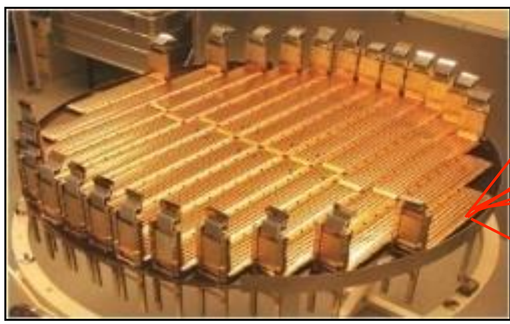


Time of Flight (TOF)
Z, E

Magnet
±Z



Silicon Tracker
Z, P



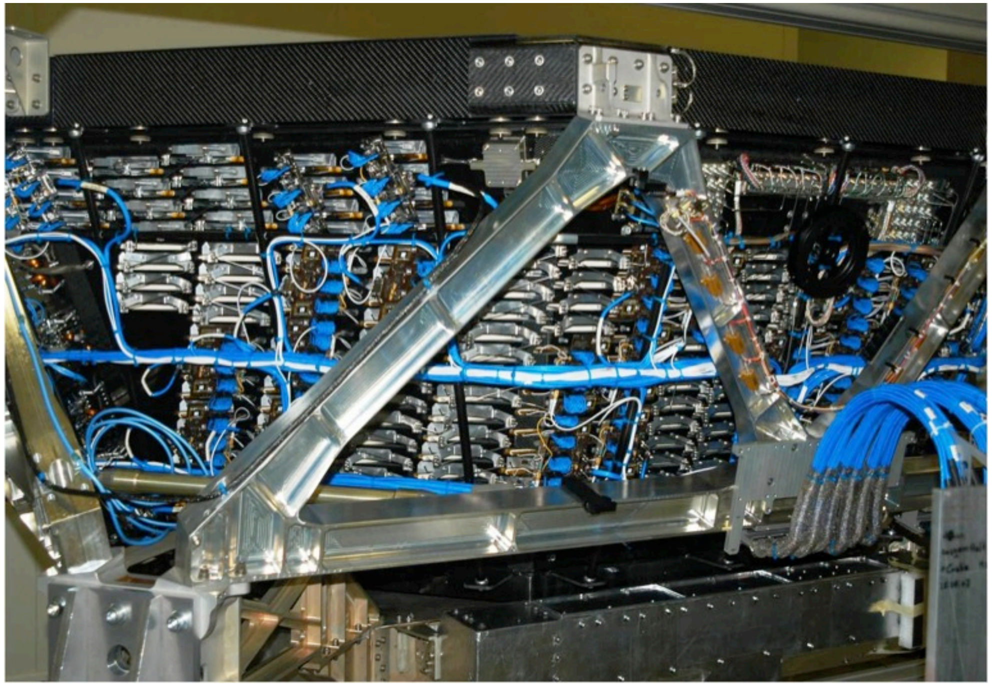
Electromagnetic Calorimeter (ECAL)
E of e^+, e^-, γ

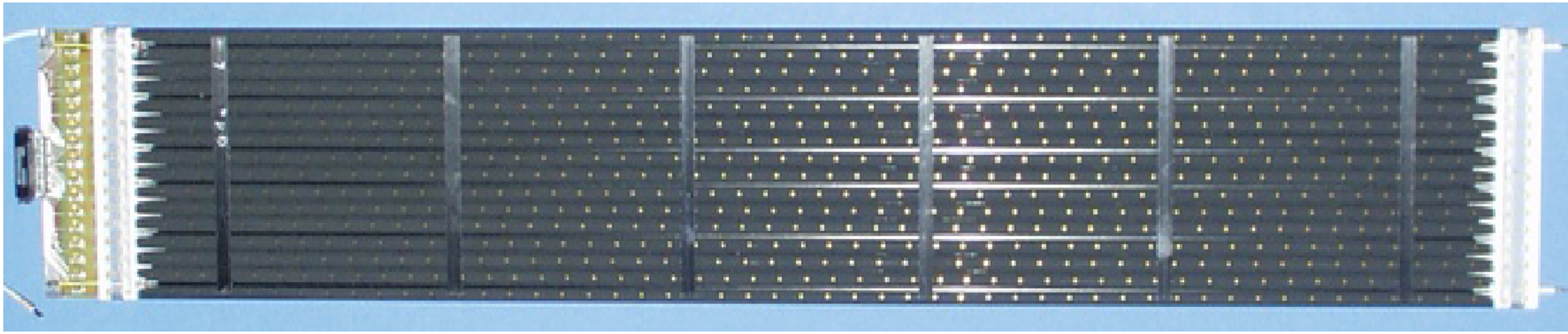
Ring Imaging Cherenkov (RICH)
Z, E

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

18

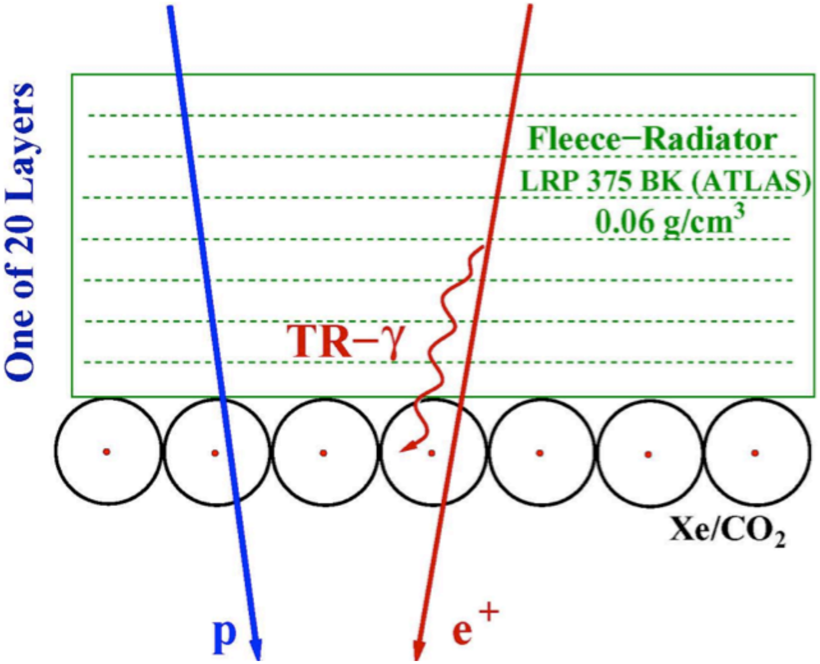
Transition Radiation Detector (TRD) Identifies Positrons, Electrons by transition radiation and Nuclei by dE/dX

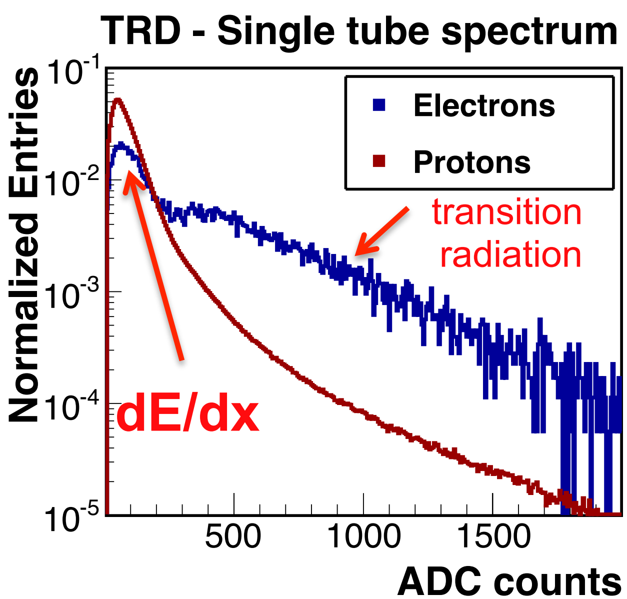




5,248 tubes selected from 9,000, 2 m length centered to 100μm, verified by CAT scanner

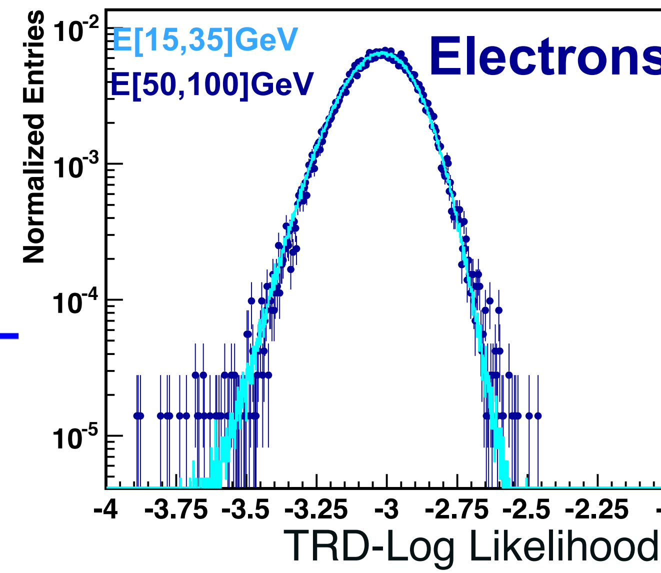
ep discrimination with TRD

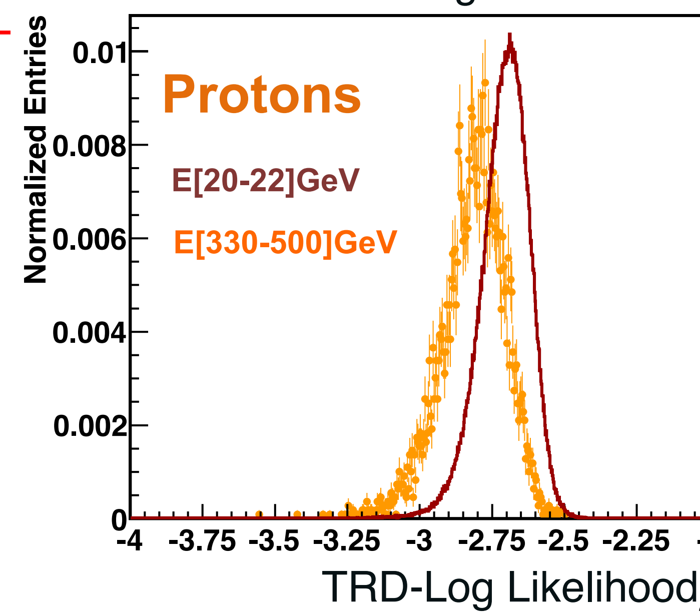




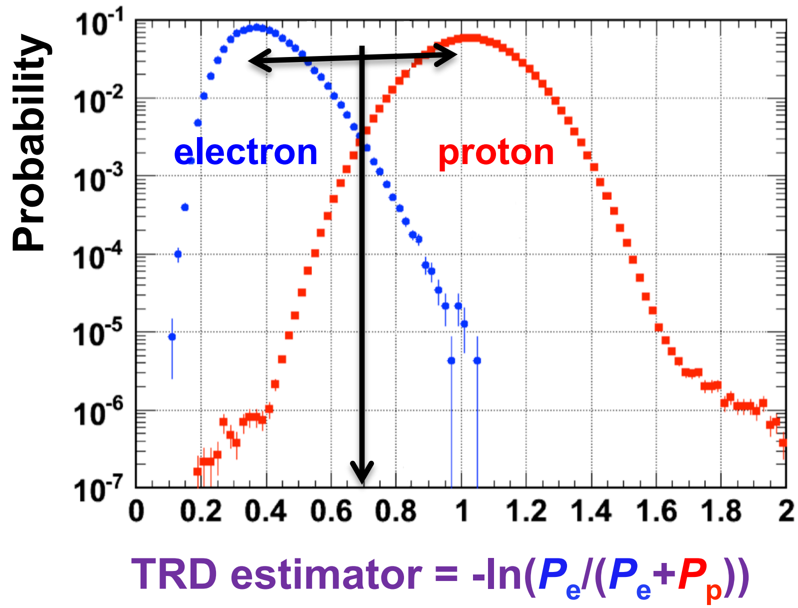
$$P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)}$$

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



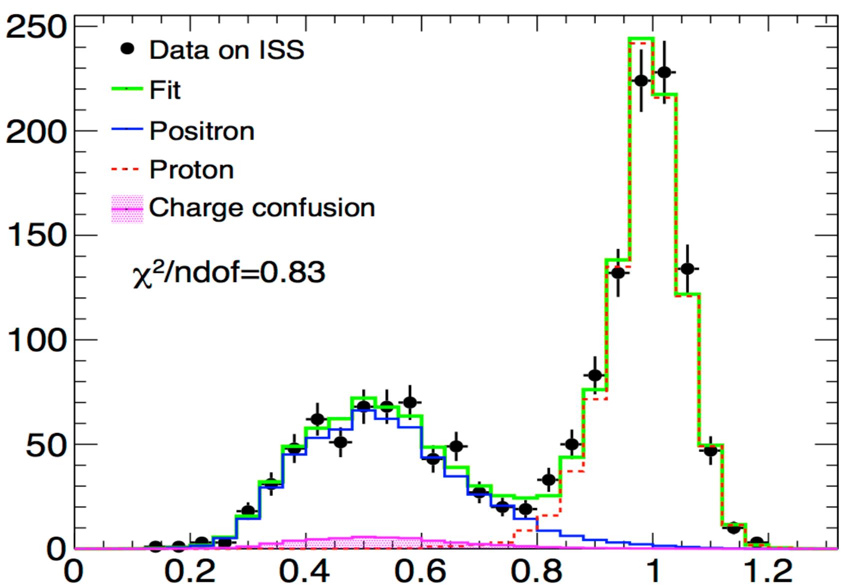


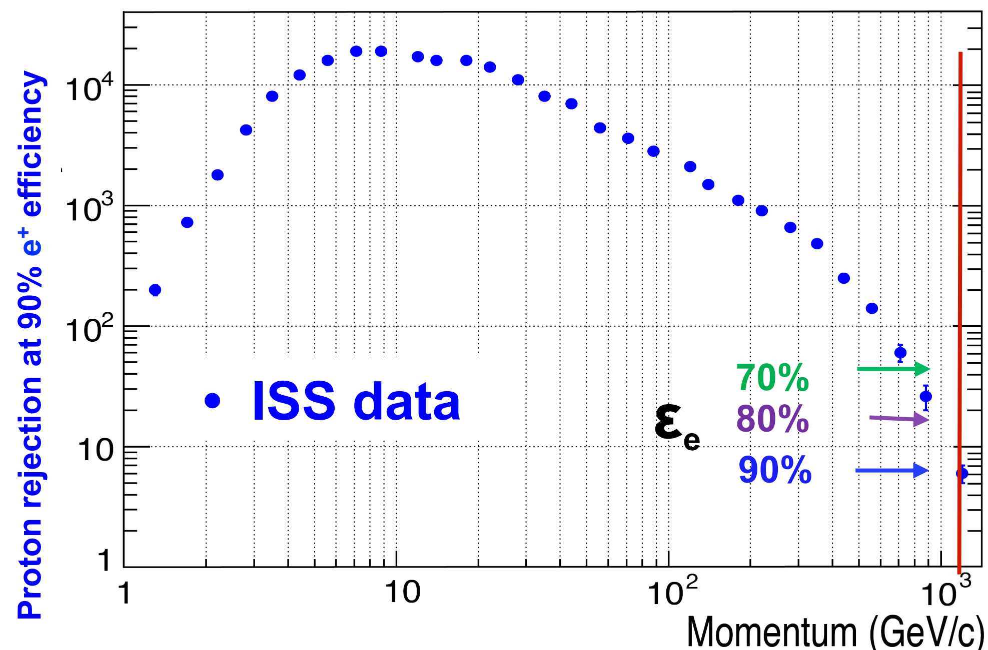
TRD e/p separation



FIT

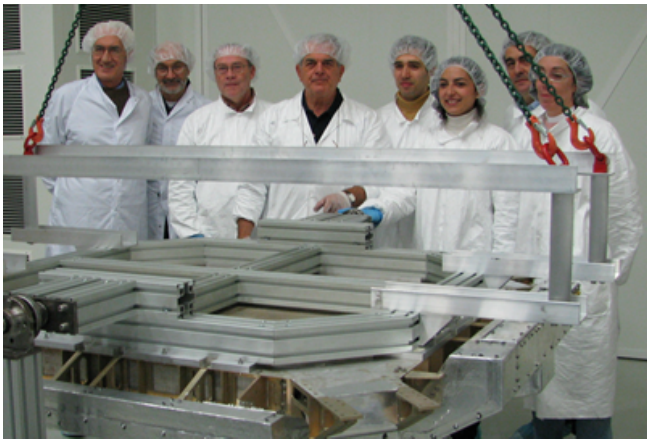
CUT



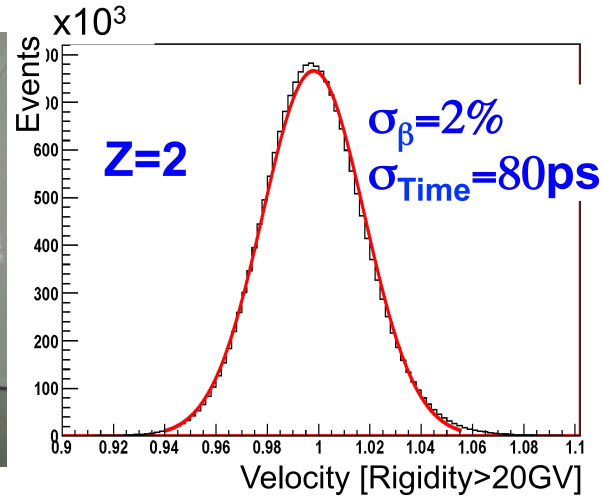


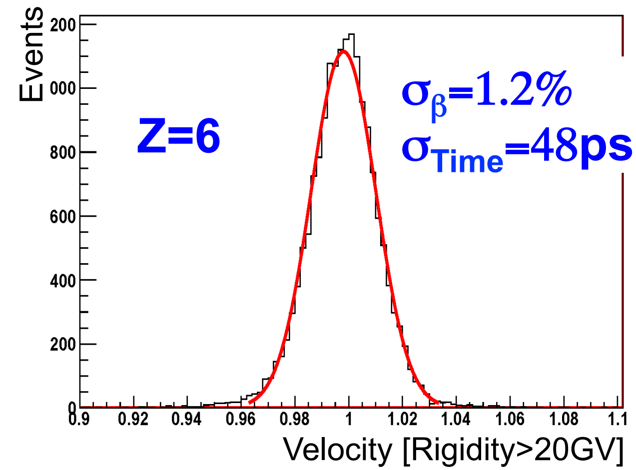
Time of Flight System

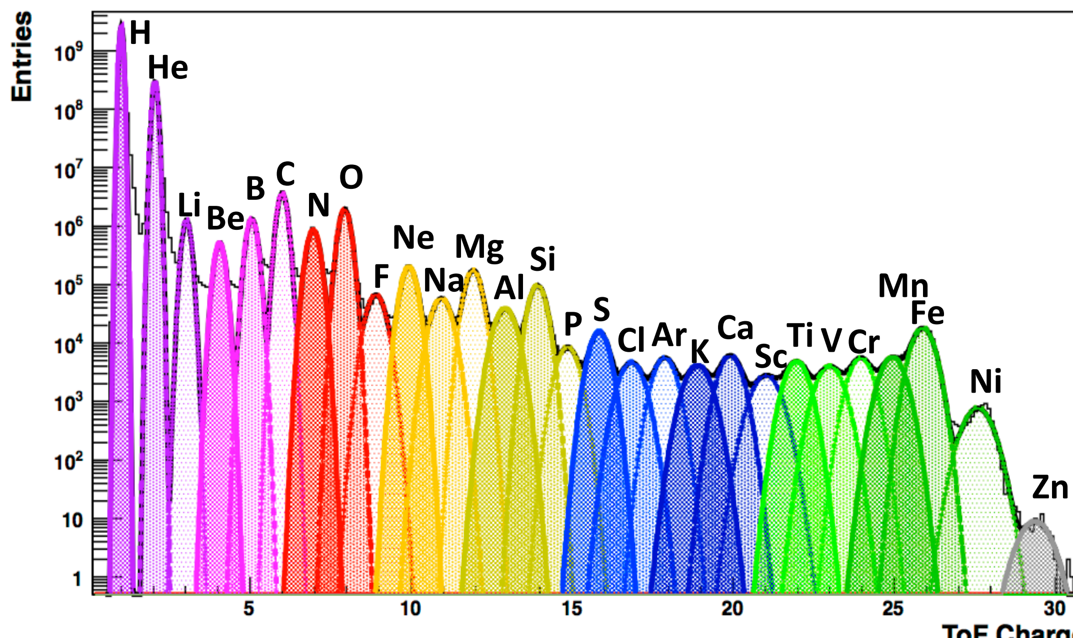
Measures Velocity and Charge of particles



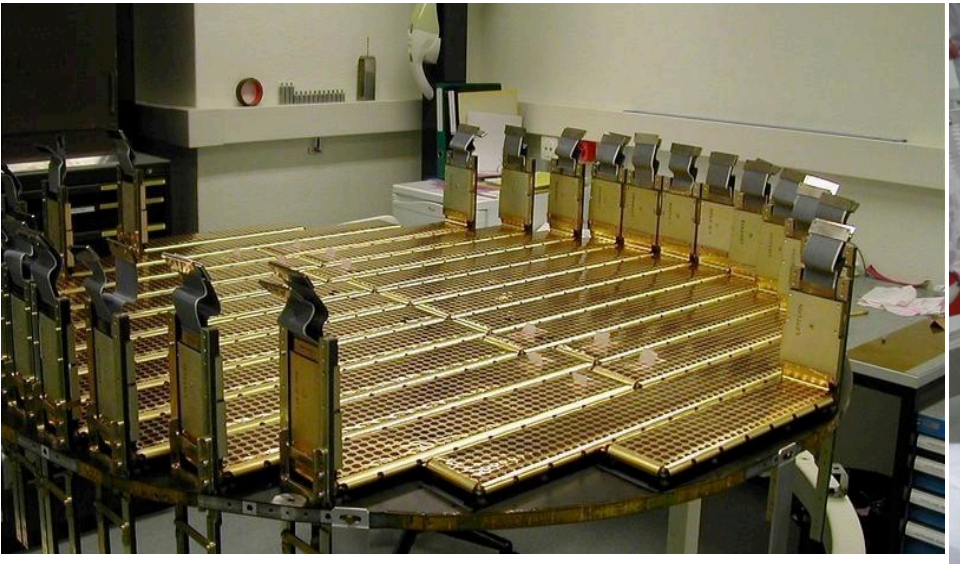
INFN Bologna







Tracker



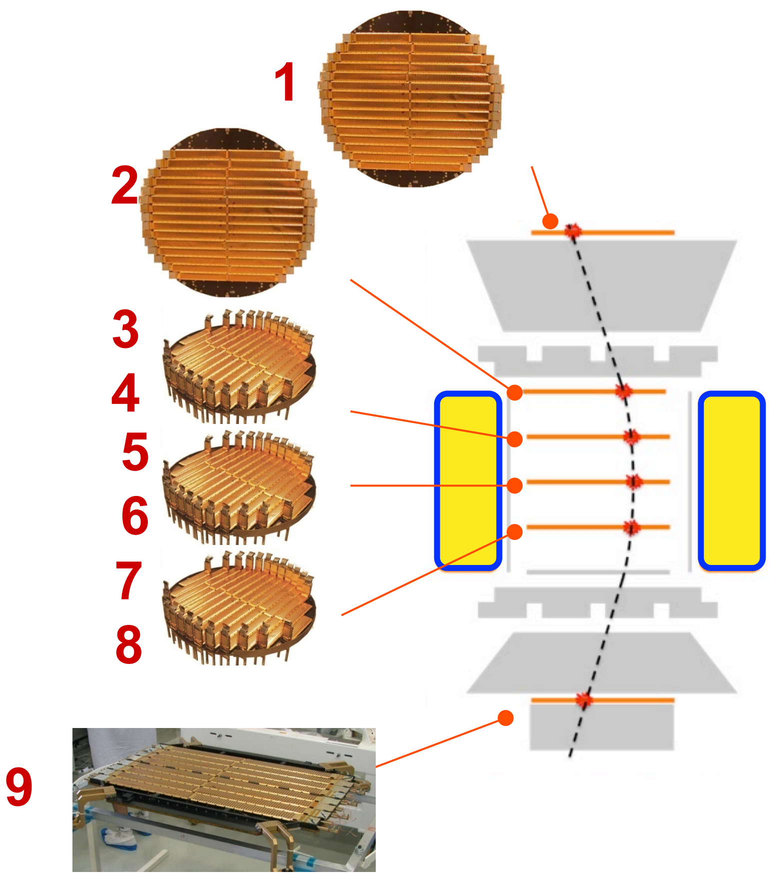
Perugia and Geneva groups

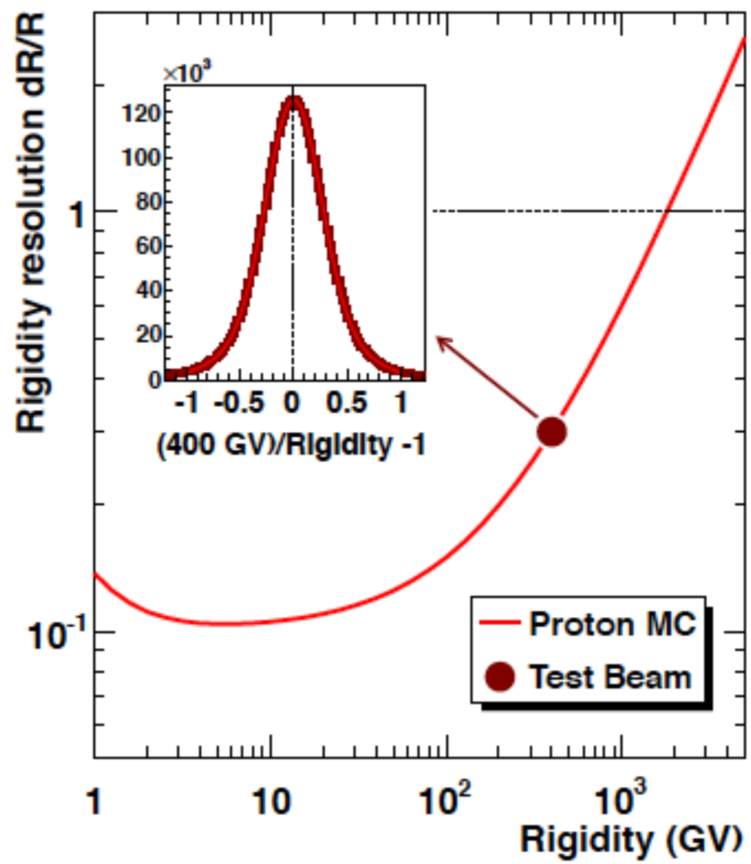
Tracker: ≈2600 Si sensors, 192 ladders, 200 kchannels

9 layers of double sided silicon microstrip detectors to reconstruct the particle trajectory with 10 μ resolution in the bending plane

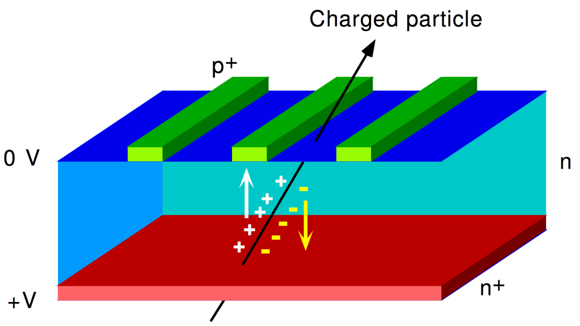
→ 20 –UV Lasers to monitor inner tracker alignment

→ Cosmic rays to monitor outer tracker alignment

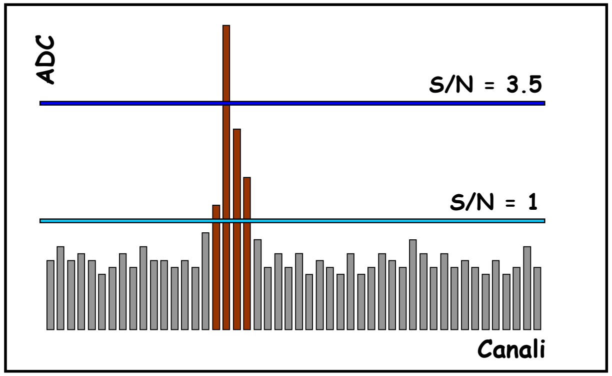




Identification of light nuclei with the tracker



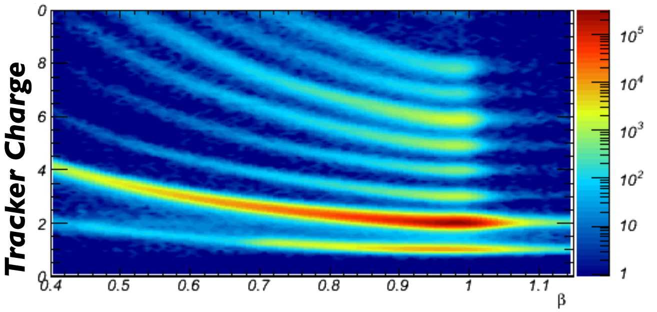
$$A \sim \left\langle \frac{dE}{dx} \right\rangle \propto \frac{Z^2}{\beta^2} \log \gamma$$

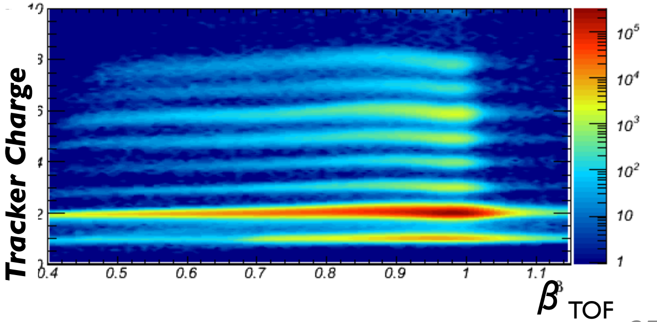


9 (x 2) independent measurements of the particle energy deposit in silicon + High dinamic range VA chips

=

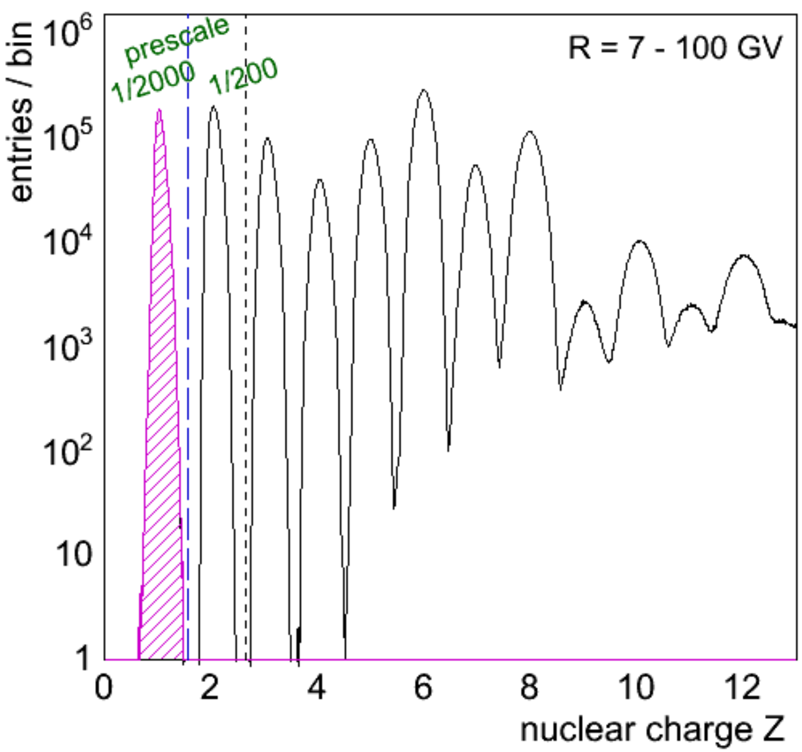
Charge identification up to Fe



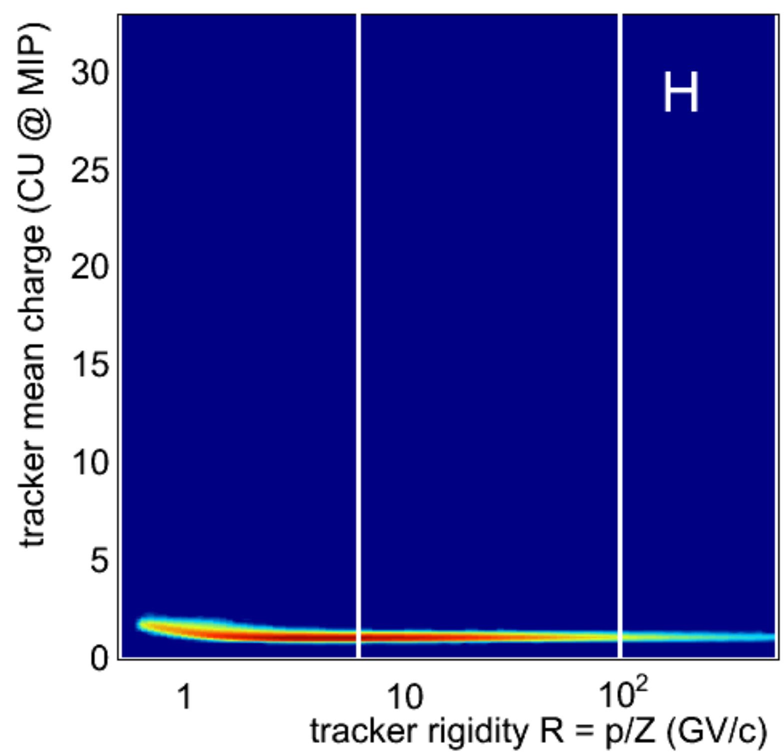


Identification of light nuclei with the inner tracker

Selected charge: Z = 1 [Hydrogen]



Tracker <dE/dX> VS Rigidity



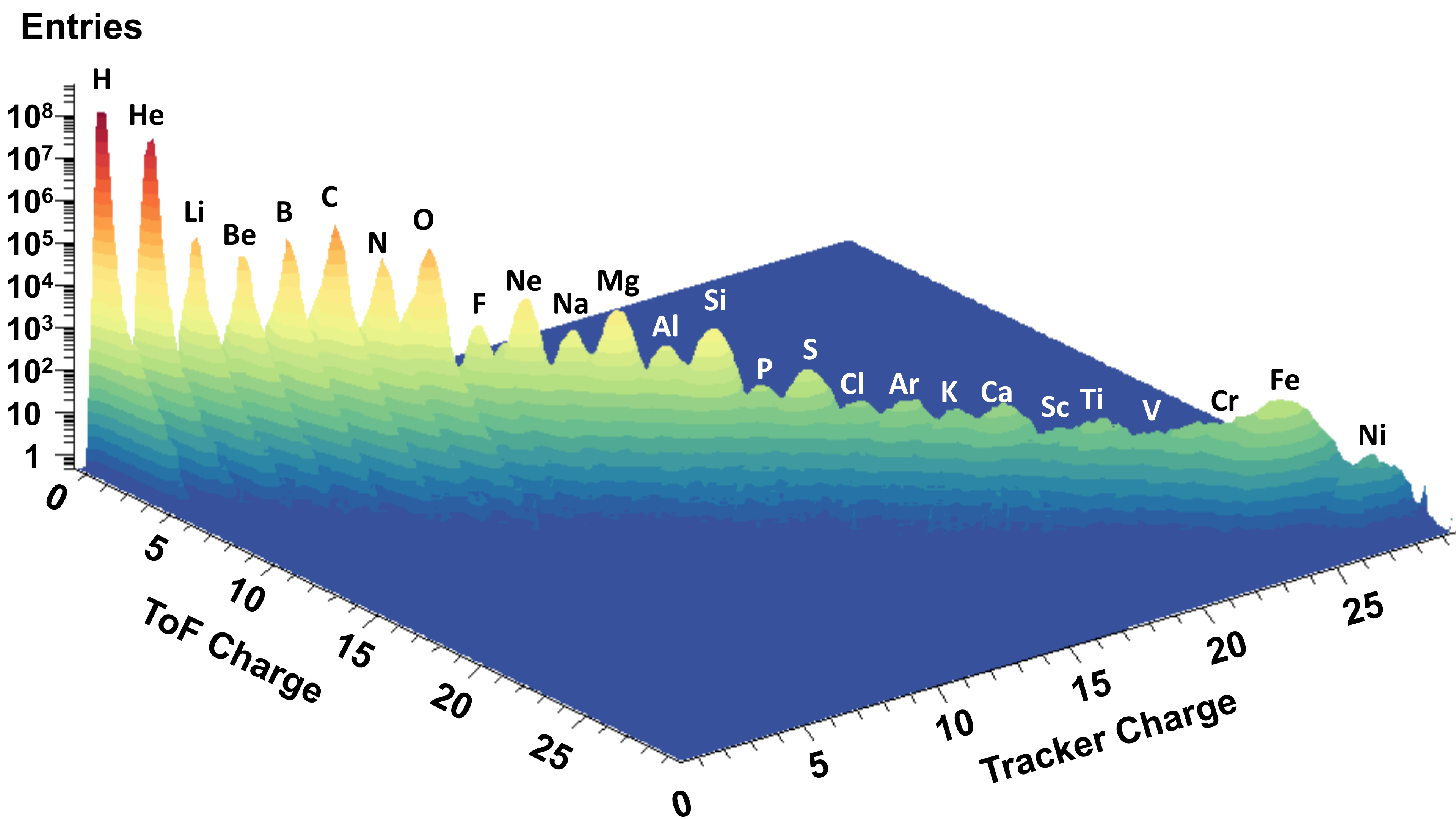
→ Truncated mean of the energy deposit

$$A \sim \left\langle \frac{dE}{dx} \right\rangle \propto \frac{Z^2}{\beta^2} \log \gamma$$

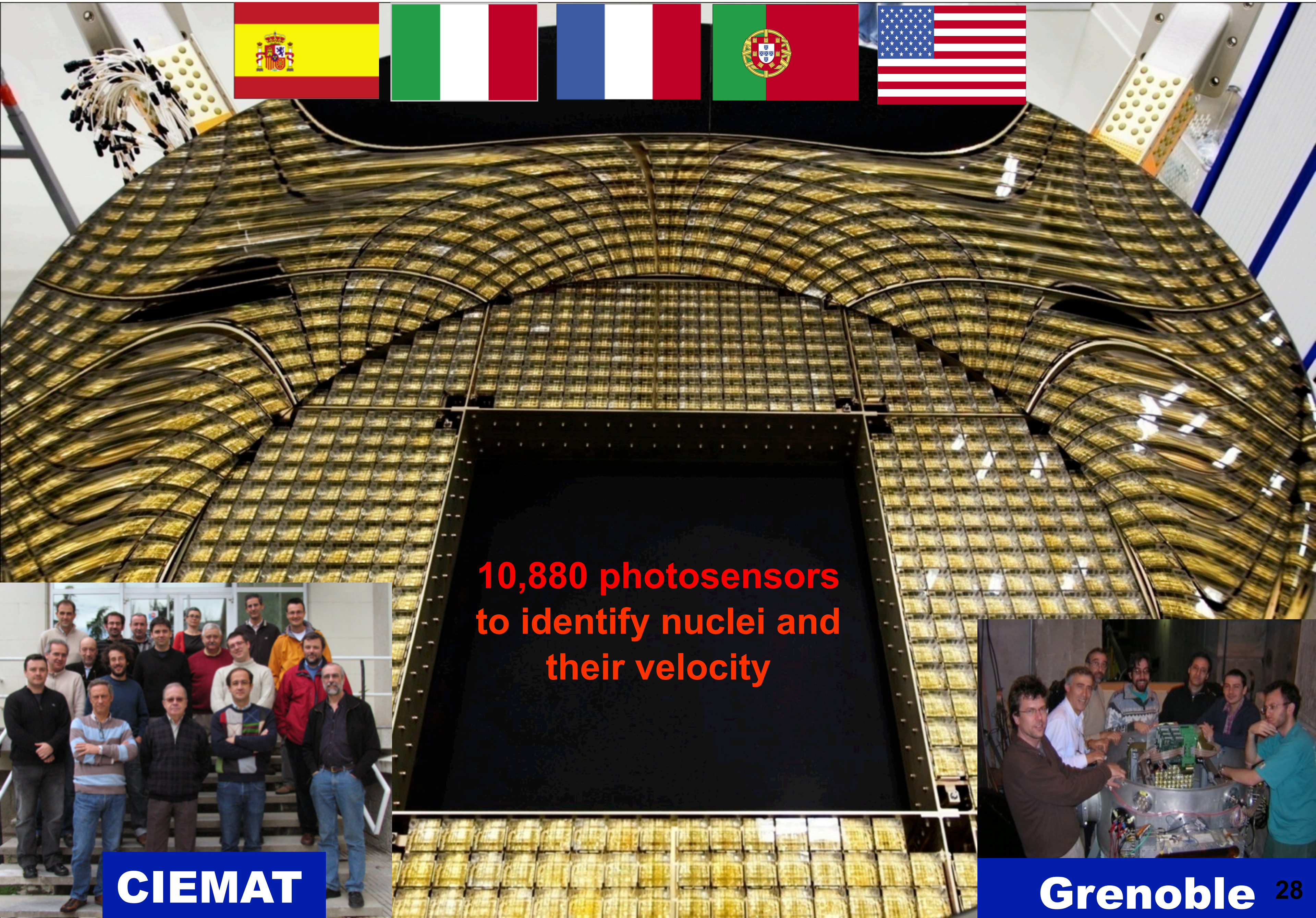
AMS Collaboration

→ Shaded area corresponds to the selection of a given Z with likelihood charge estimator

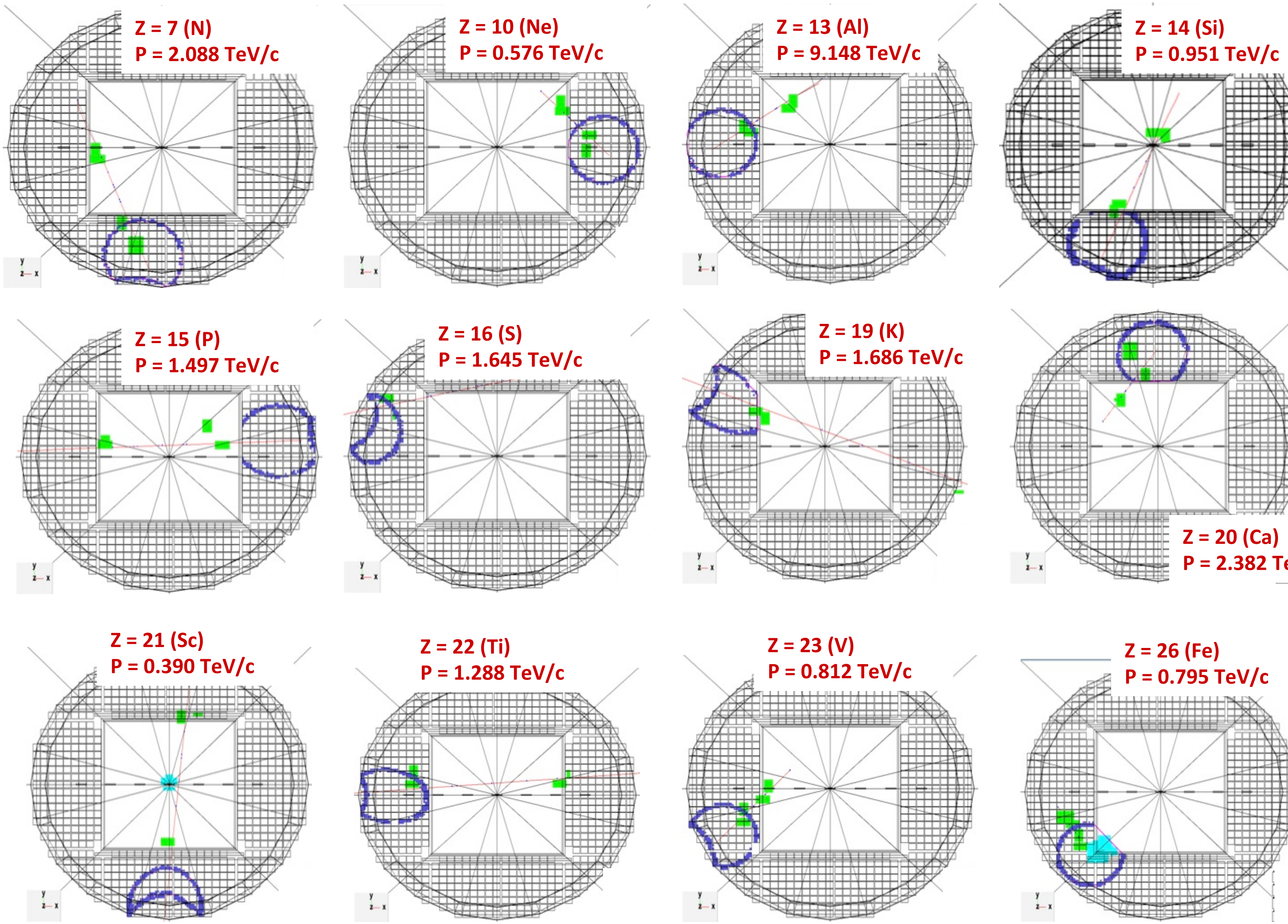
AMS Nuclei Measurement on ISS



Ring Imaging CHerenkov (RICH)



Detector performance on ISS RICH

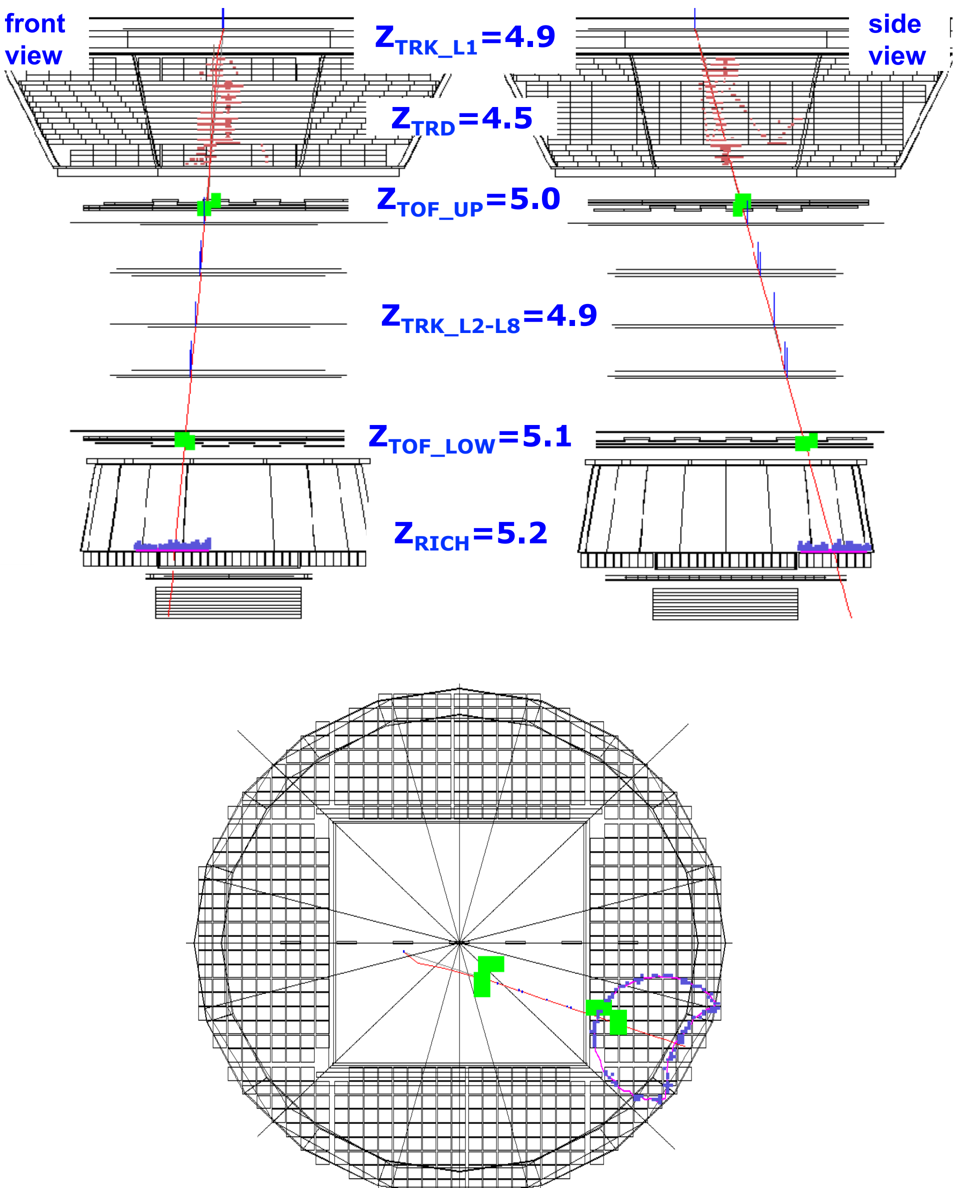


Rigidity ~ 200 GV

Boron

Rigidity=187 GV

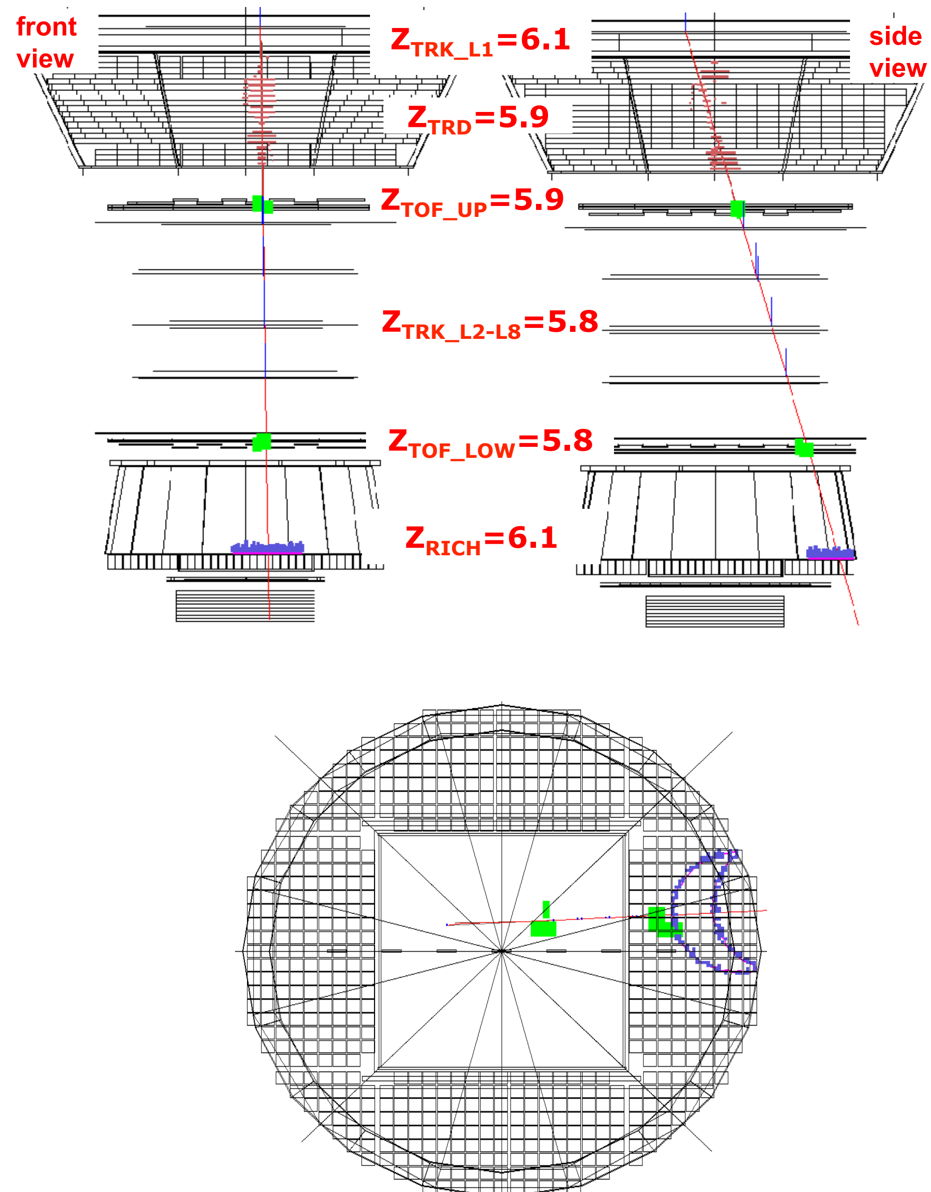
Run/Event 1329086299/ 747549



Carbon

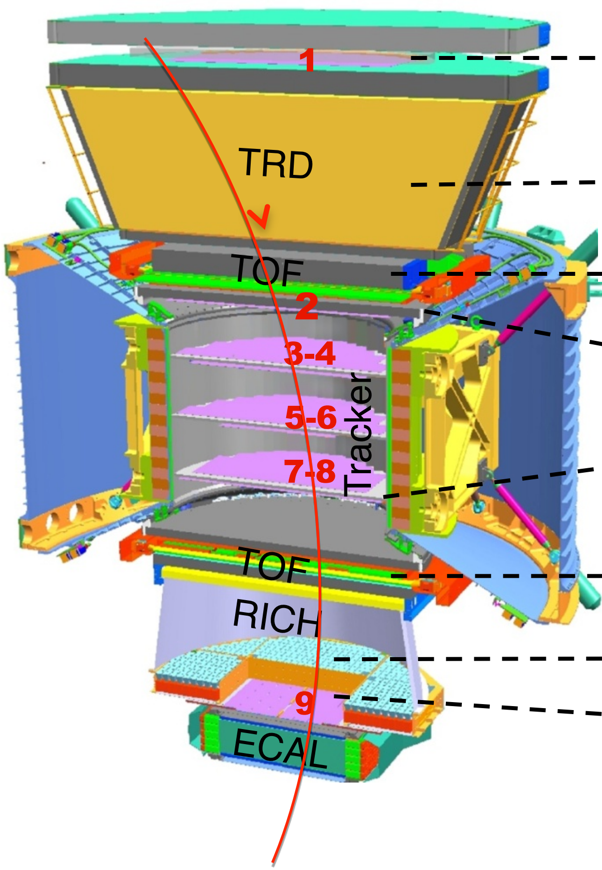
Rigidity=215 GV

Run/Event 132643580/ 132197



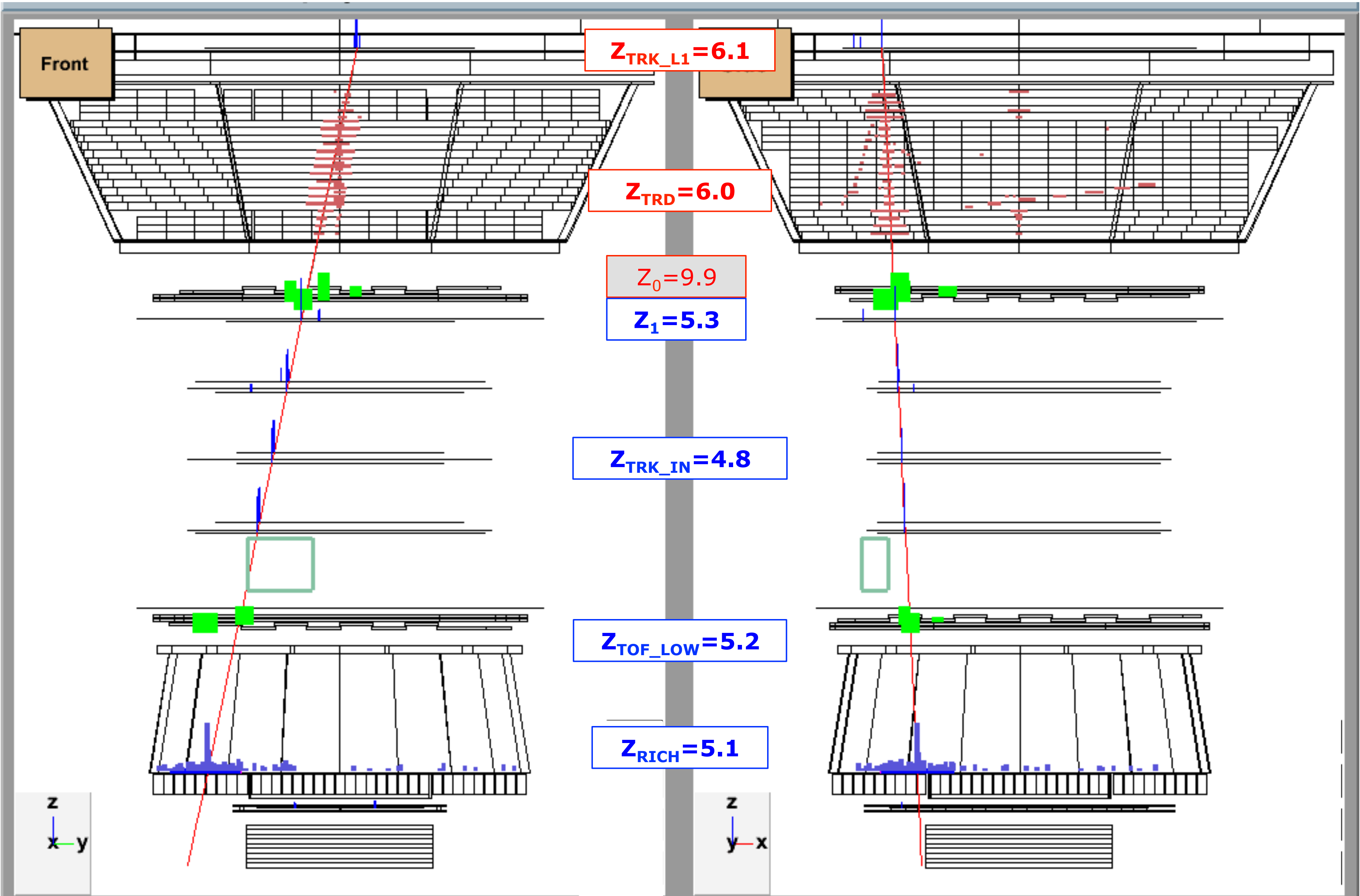
Particle Charge Measurement

Multiple Independent Measurements of |Z|



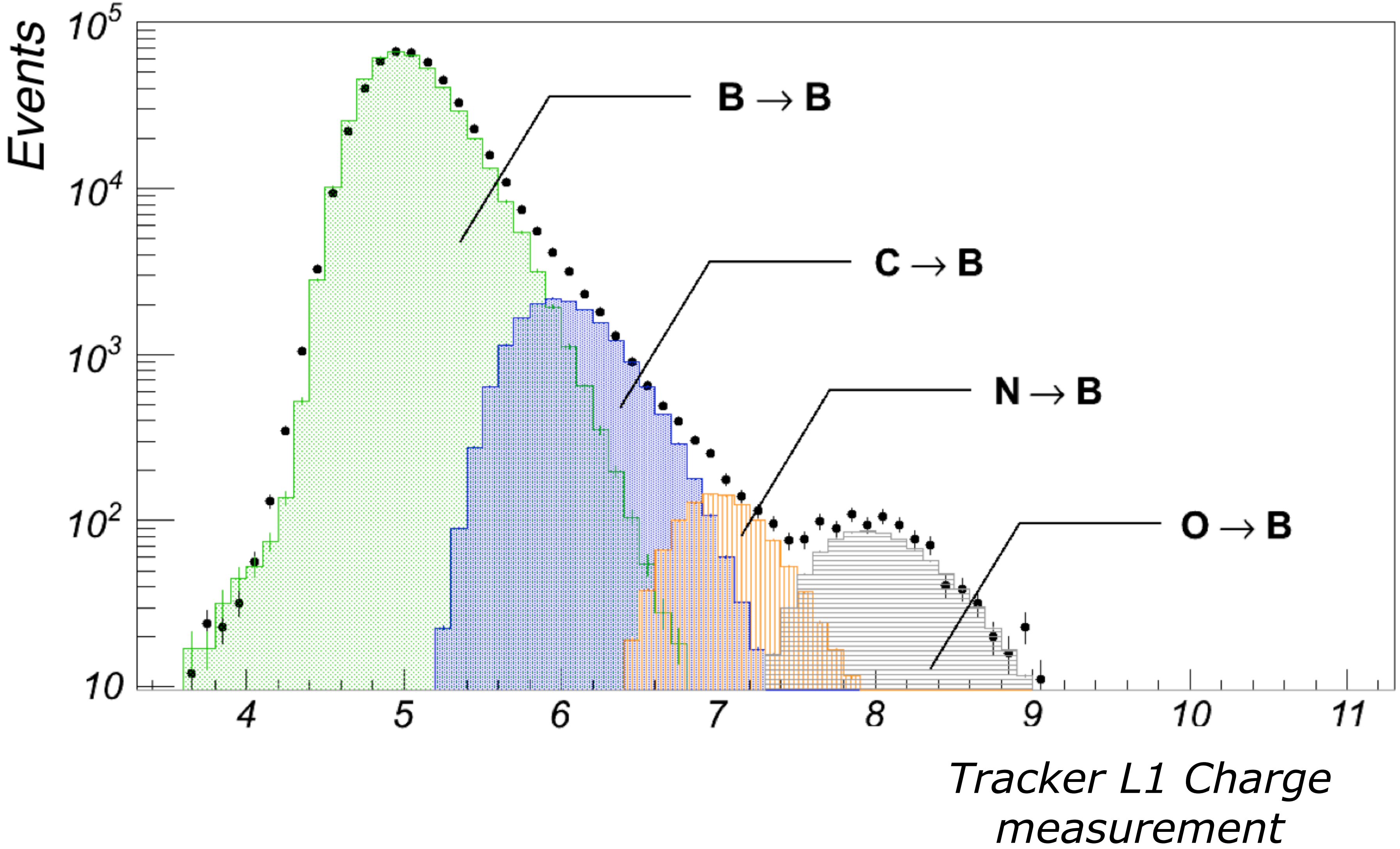
	Carbon (Z=6) ΔZ (cu)
1. Tracker Plane 1	0.30
2. TRD	0.33
3. Upper TOF (1 counter)	0.16
4. Tracker Planes 2-8	0.12
5. Lower TOF (1 counter)	0.16
6. RICH	0.32
7. Tracker Plane 9	0.30

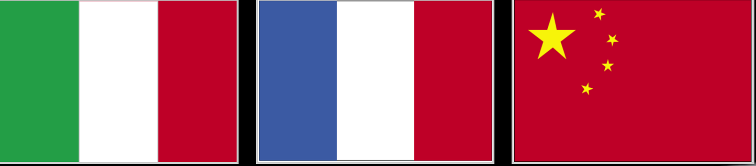
Carbon Fragmentation to Boron in Upper TOF
Rigidity 10.6 GV



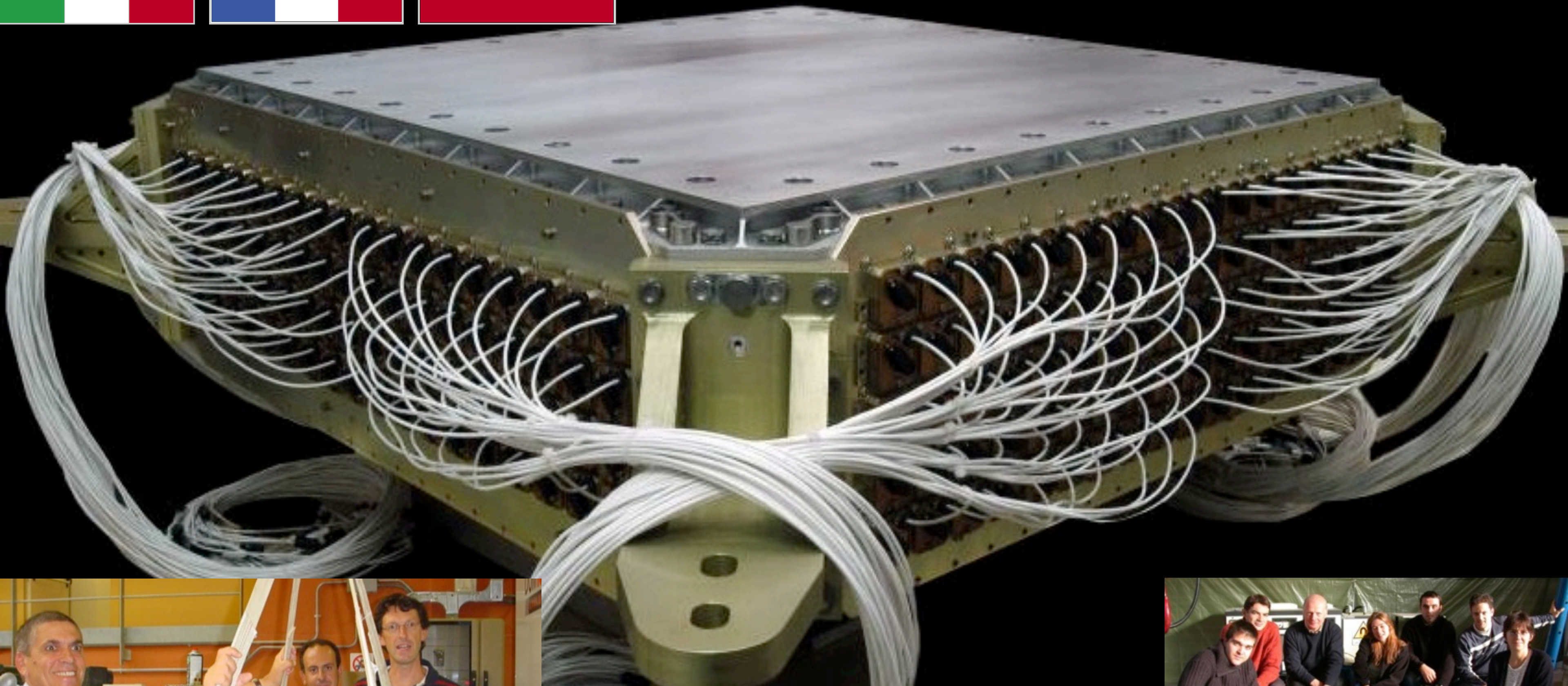
Boron and Carbon: Sample composition

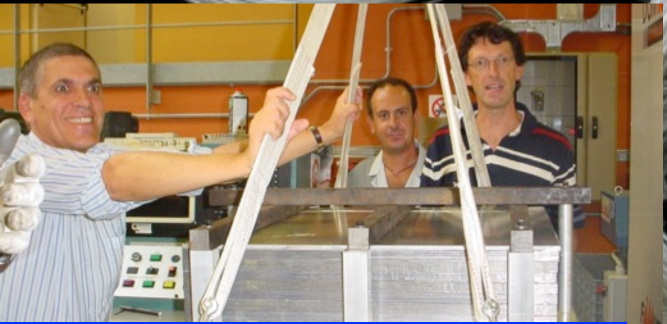
Particles Identified as Boron in the Inner AMS show signals compatible with higher charges on the 1st



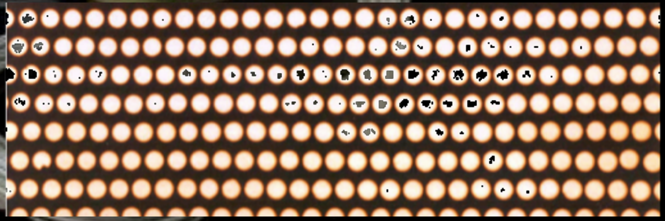


Calorimeter (ECAL)





PISA

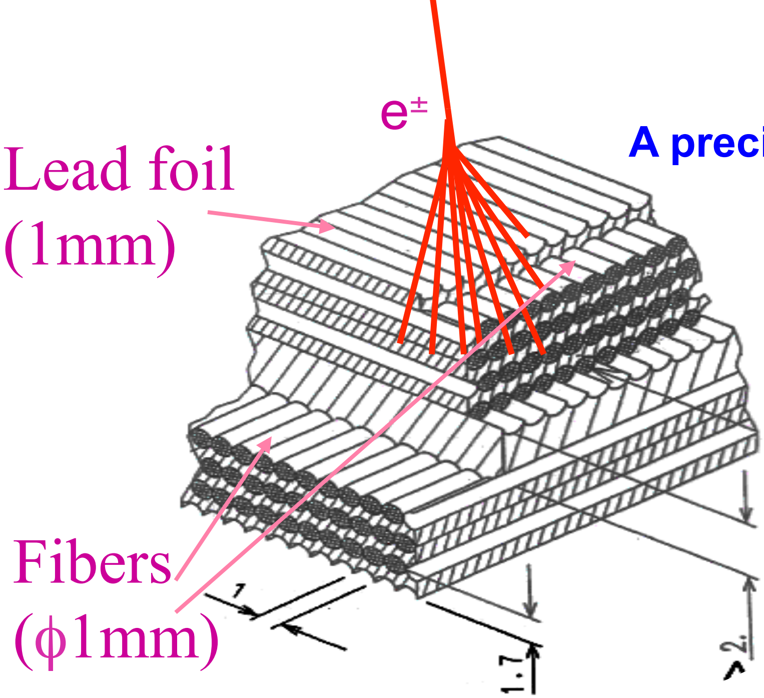


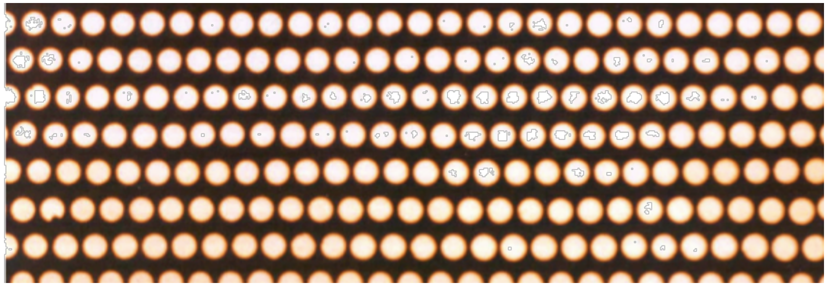
LAPP

50,000 fibers, $\phi = 1$mm, distributed uniformly inside 450 kg of lead which provides a precision, 3-dimensional, $17X_0$ measurement of the directions and energies of light rays and electrons up to 1 TeV

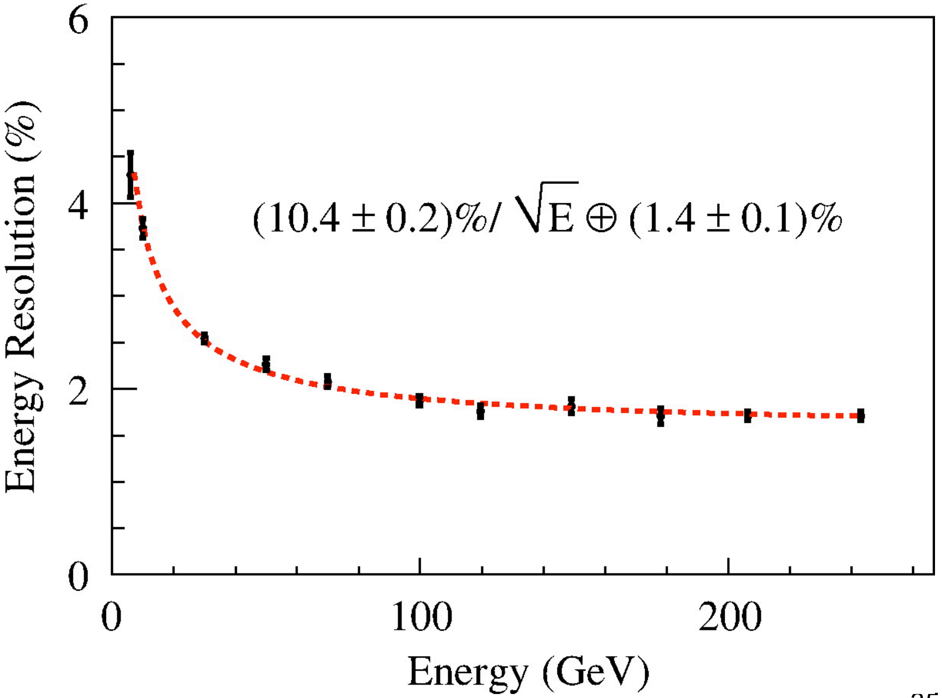
Calorimeter (ECAL)

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



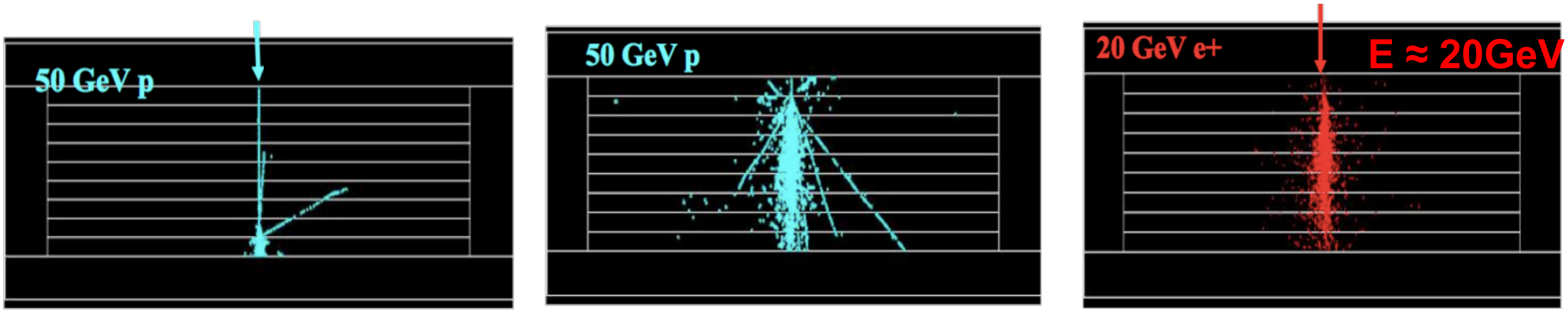


50,000 fibers, $\phi = 1$ mm
distributed uniformly Inside 600 kg of lead:



e/p separation with ECAL

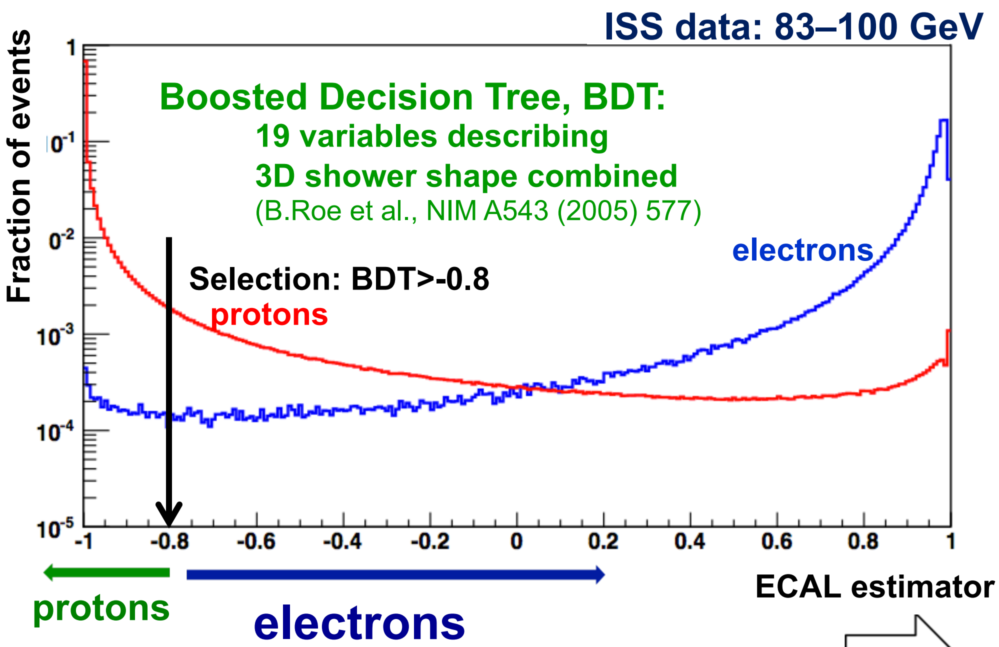
electrons and protons behave differently when entering the ECAL

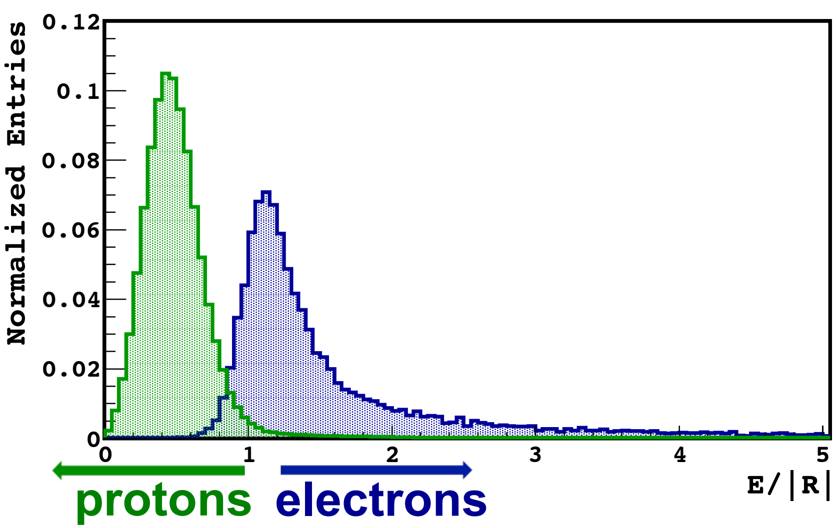


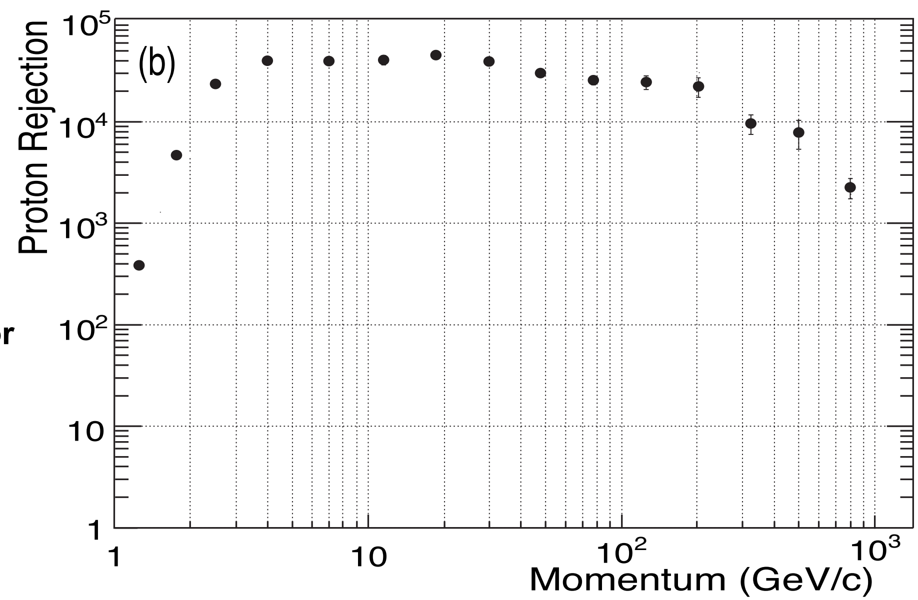
Two complementary techniques can exploit electron/proton differences in ECAL

1) 3D imaging of the energy shower allows to discriminate electron or proton initiated showers
2) Matching measured momentum in tracker with the deposited energy in ECAL

e/p separation with ECAL+trk







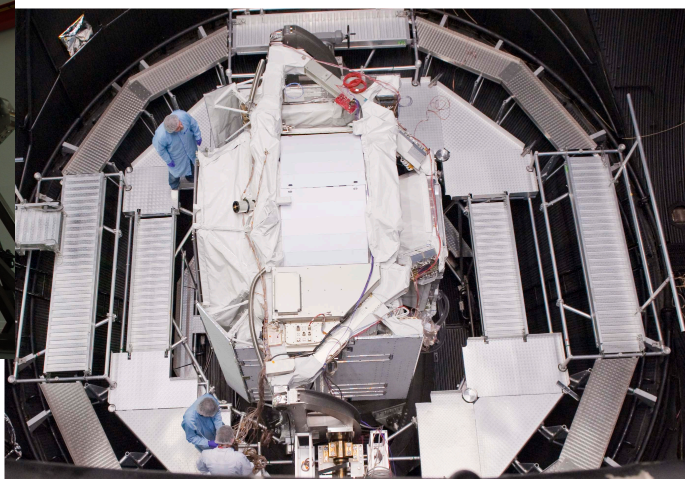
Full coverage of anti-matter & CR physics

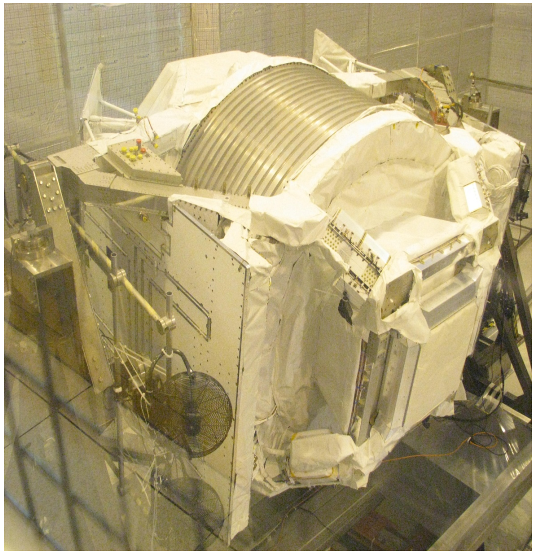
	e^-	P	He,Li,Be,..Fe	γ	e^+	$\bar{P}$, $\bar{D}$	$\bar{He}$, $\bar{C}$
TRD							
TOF							
Tracker							
RICH							
ECAL							
Physics example	Cosmic Ray Physics				Dark matter		Antimatter

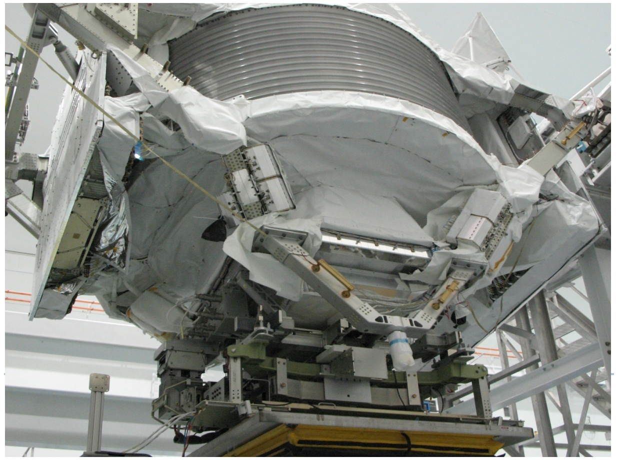
Test….for all detectors:

Before assembly : Beam test, Thermal, Vibration, TVT,EMI
After assembly : EMI, TVT, Beam Test

5m x 4m x 3m
7.5 tons







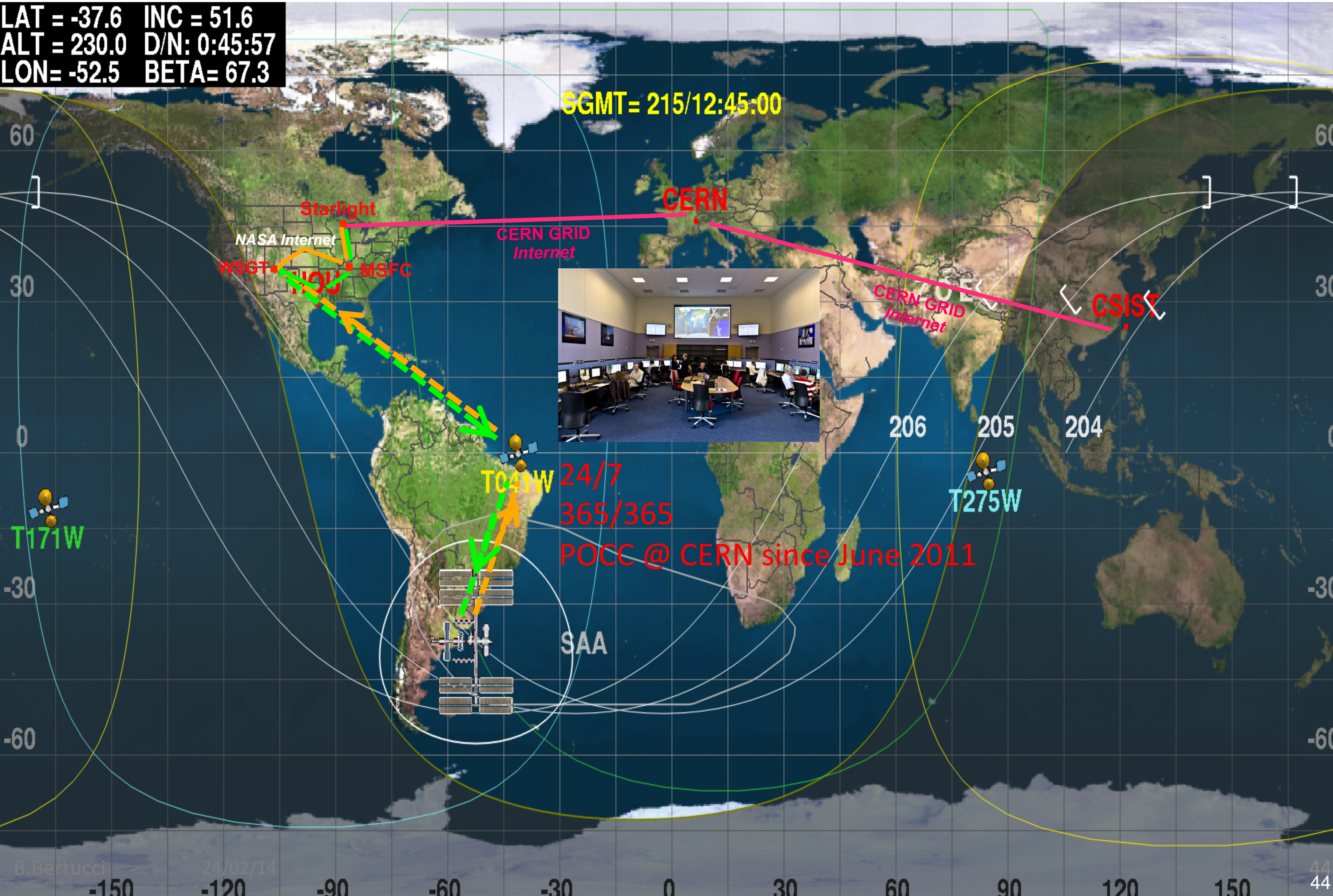
AFTER 9000 hrs of Thermal-Vacuum Tests
THE END OF SUB-SYSTEMs TESTS AT SERMS


May 16, 2011


AMS
AMS

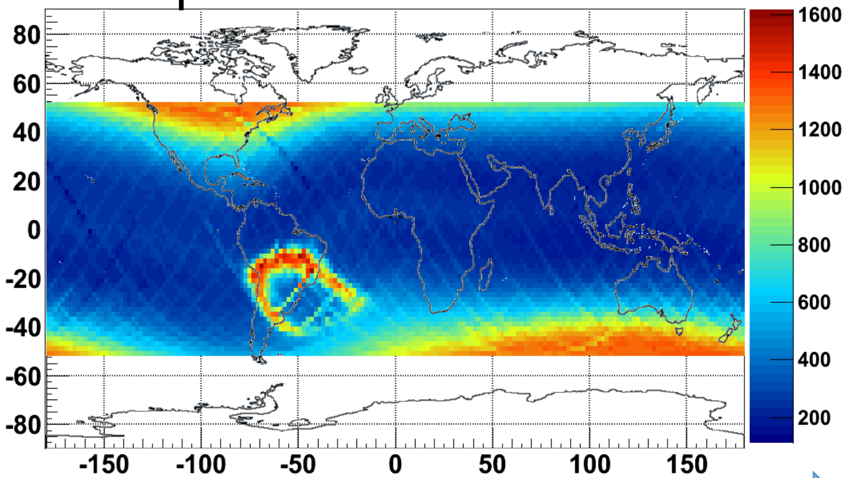
May 19, 2011: AMS installation completed.

AMS on ISS

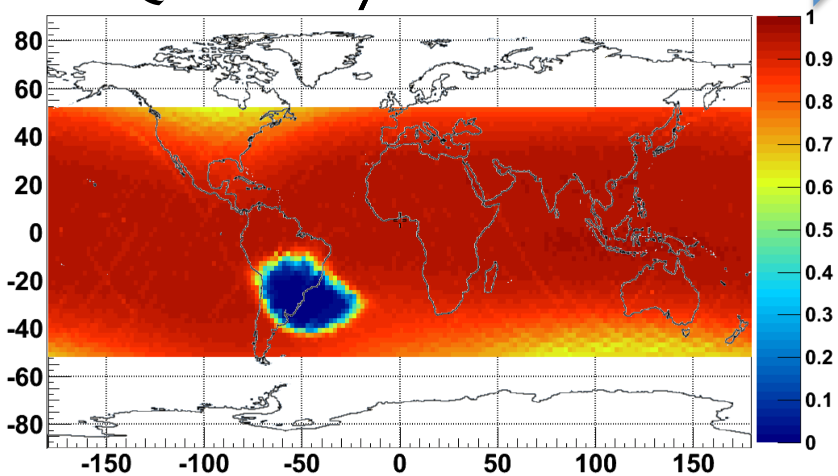

LAT = -37.6 INC = 51.6
ALT = 230.0 D/N: 0:45:57
LON= -52.5 BETA= 67.3
SGMT= 215/12:45:00
Starlight
NASA Internet
WSGT
MSFC
CERN
CERN GRID
Internet
CERN GRID
Internet
CSIST
T041W
T171W
T275W
206
205
204
SAA
24/7
365/365
POCC @ CERN since June 2011

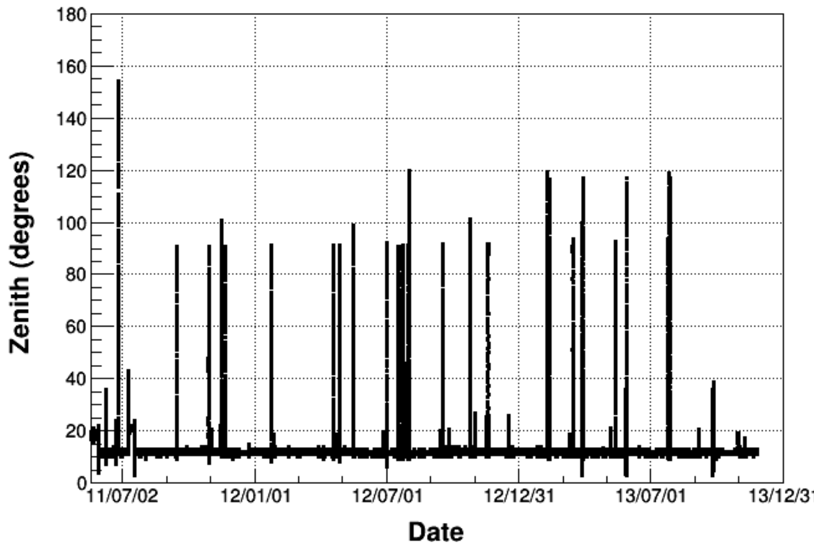
Orbital DAQ parameters

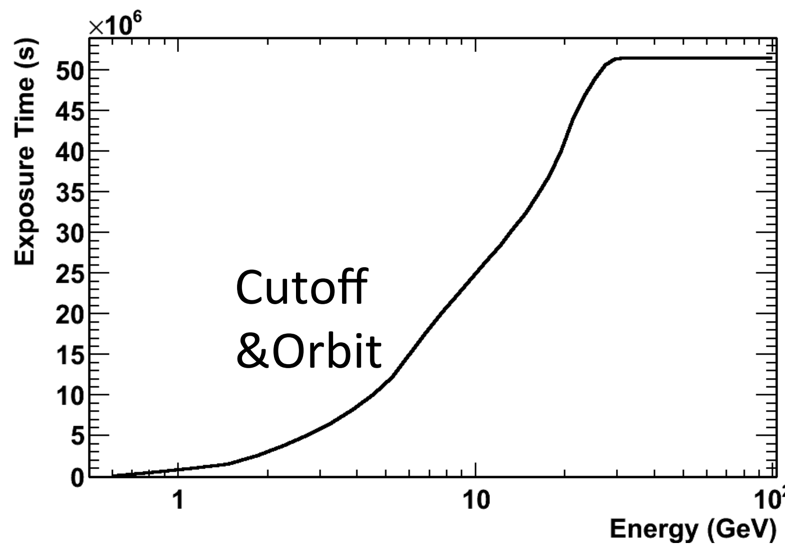
<Acquisition rate> ≈ 500 Hz



<DAQ efficiency> ≈ 85%

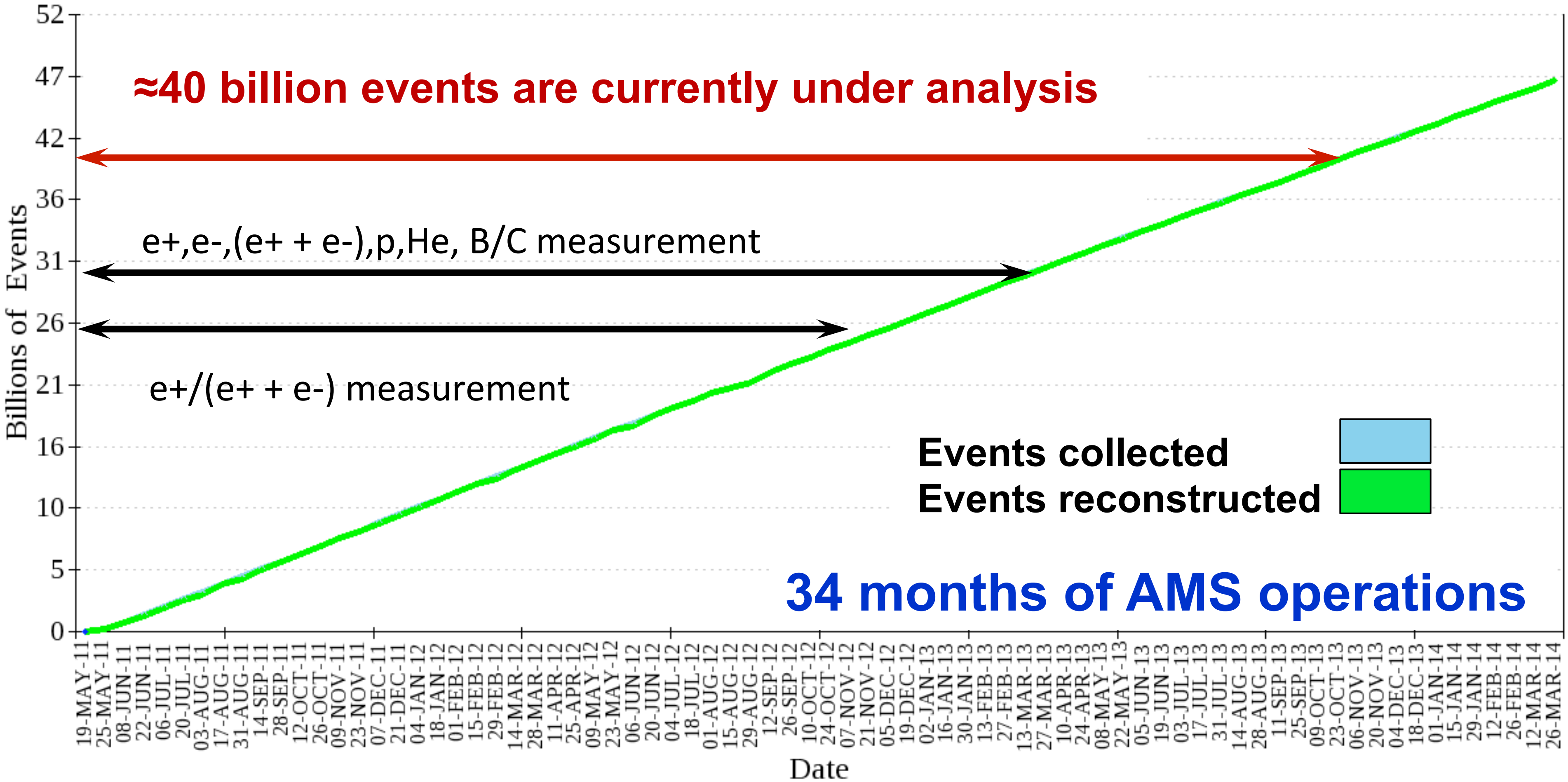




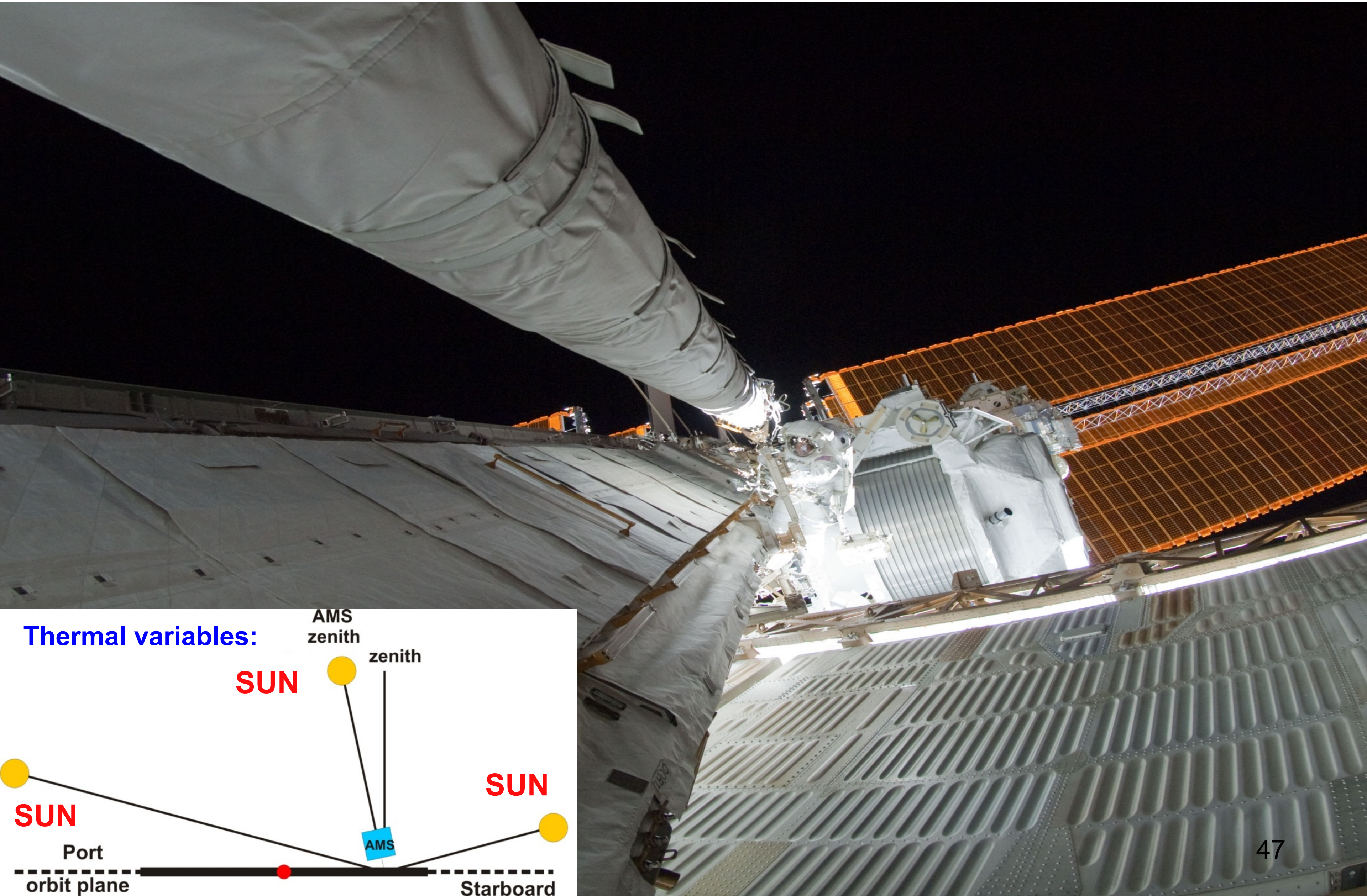


Average life time fraction T_{exp}/2 years = 81.6 %

To date AMS collected > 45 billion events

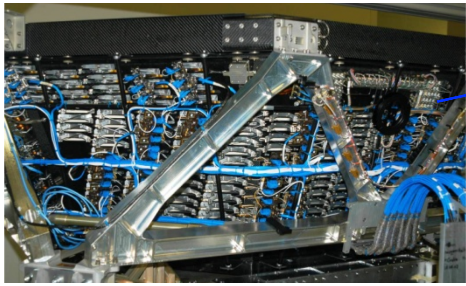


The Thermal environment

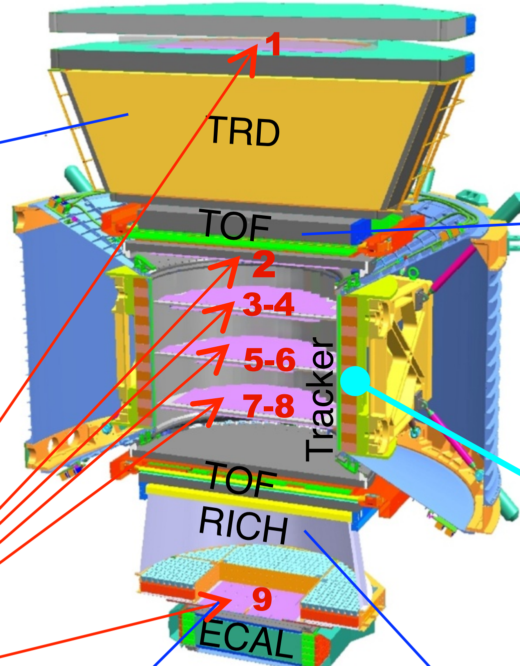


AMS Flight Electronics for Thermal Control

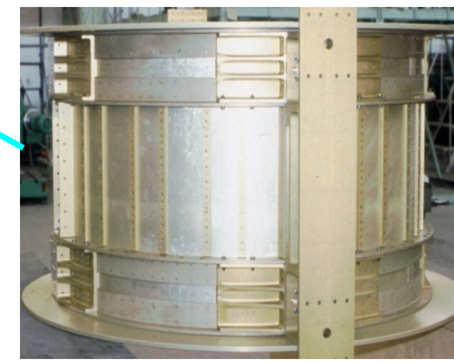
TRD
24 Heaters
8 Pressure Sensors
482 Temperature Sensors



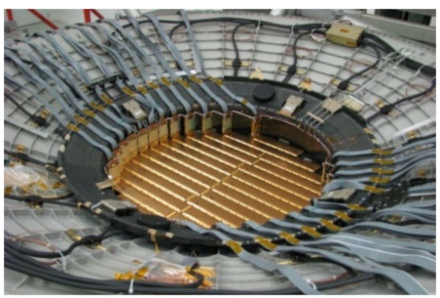
TOF & ACC
64 Temperature Sensors



Magnet
68 Temperature Sensors

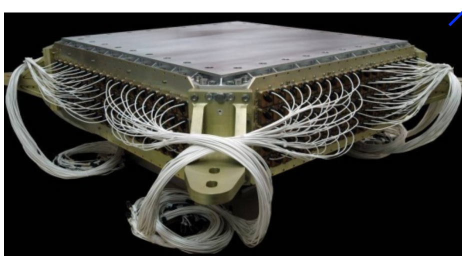


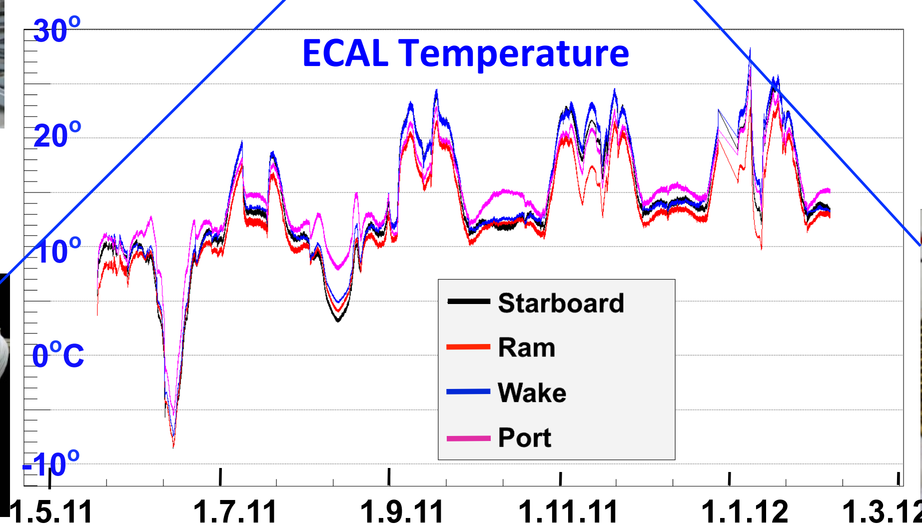
Silicon Tracker
4 -Pressure Sensors
32 Heaters
142 Temperature Sensors



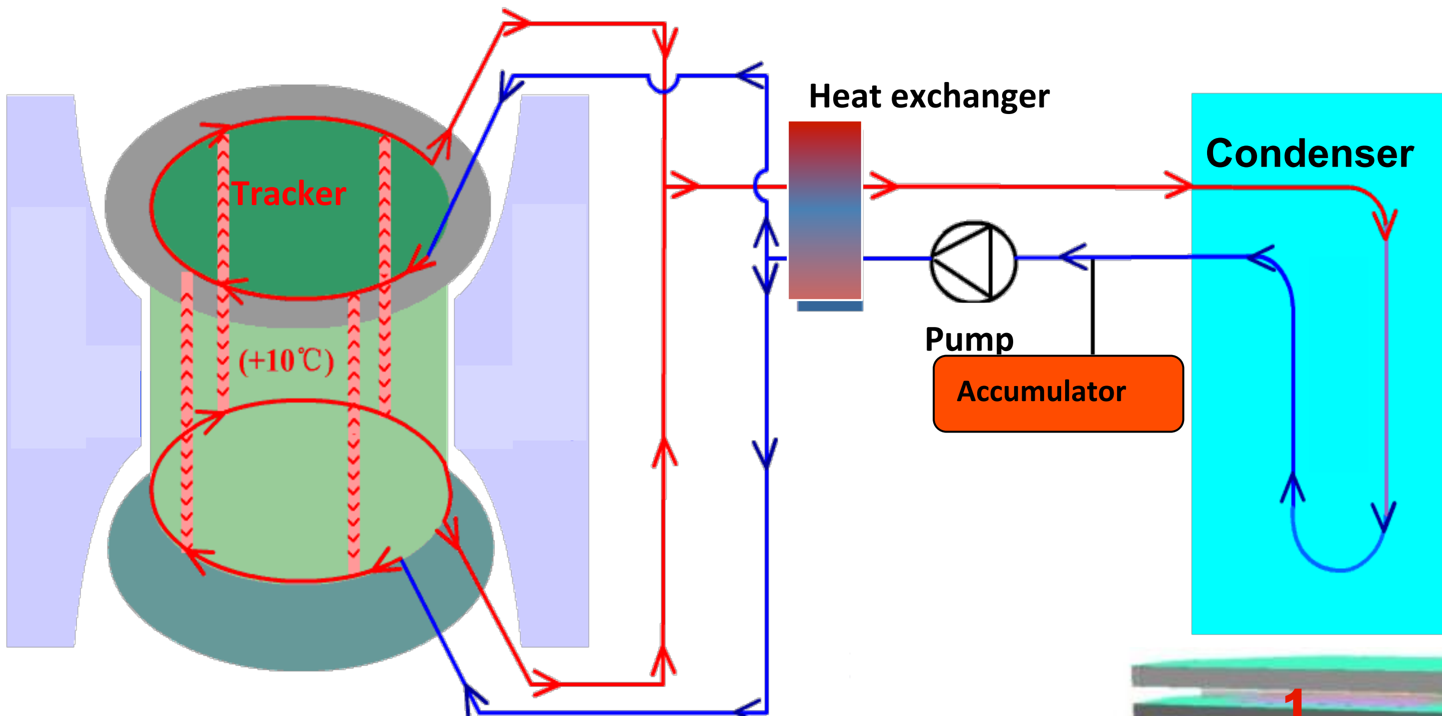
RICH
96 Temperature Sensors

ECAL
80 Temperature Sensors

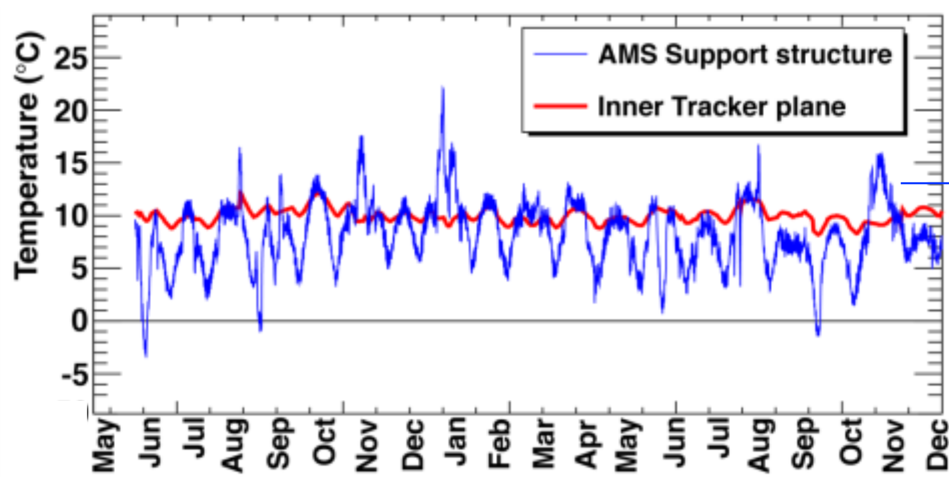




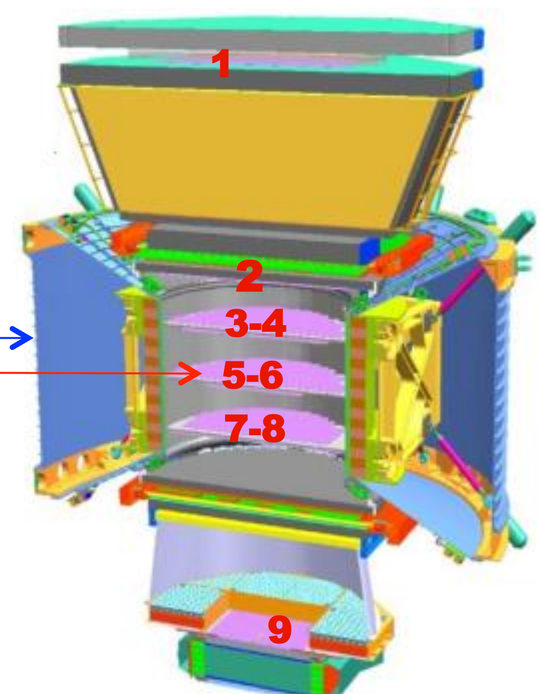
Tracker Thermal Control System



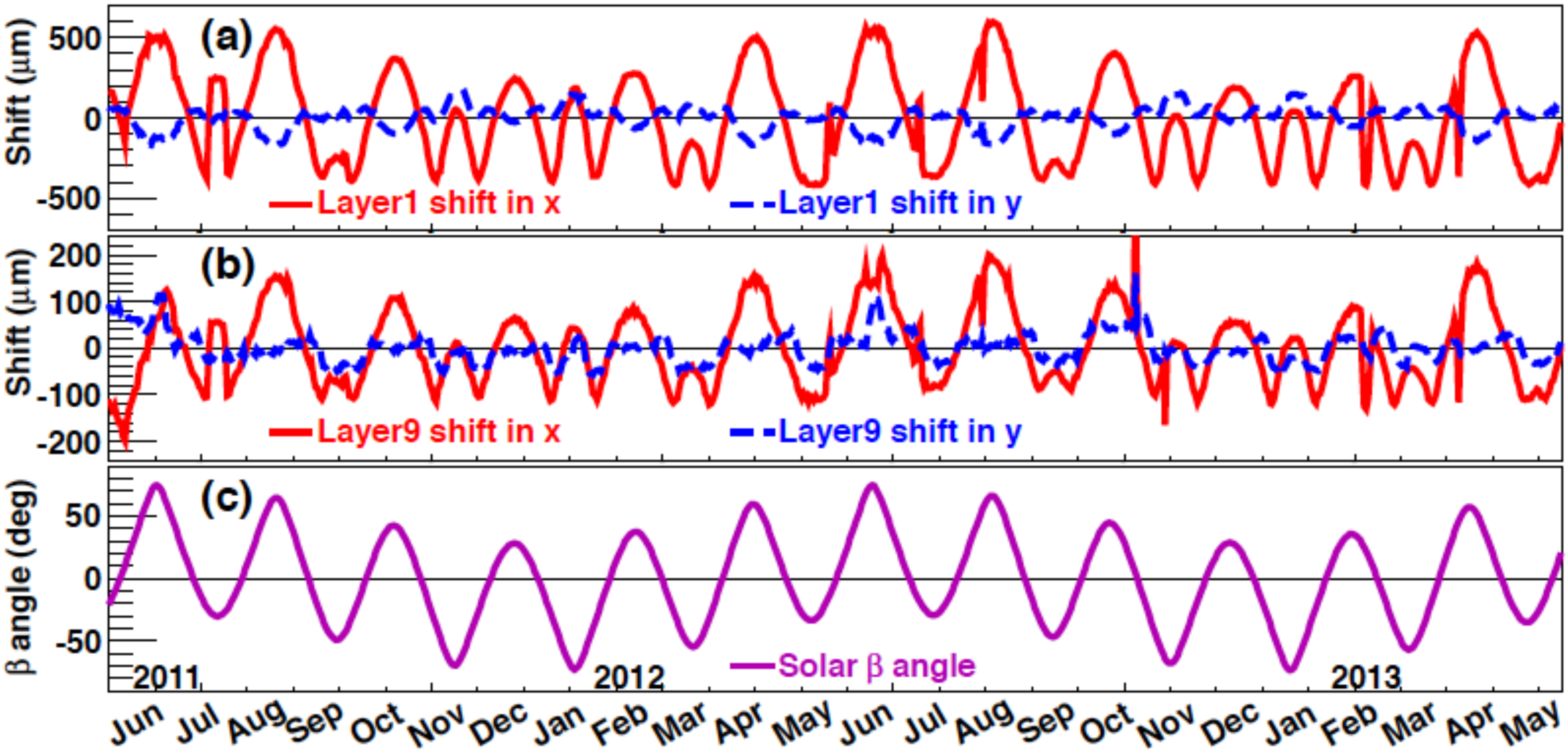
Red line: CO_2 gas/liquid two phase   Blue line: CO_2 liquid phase



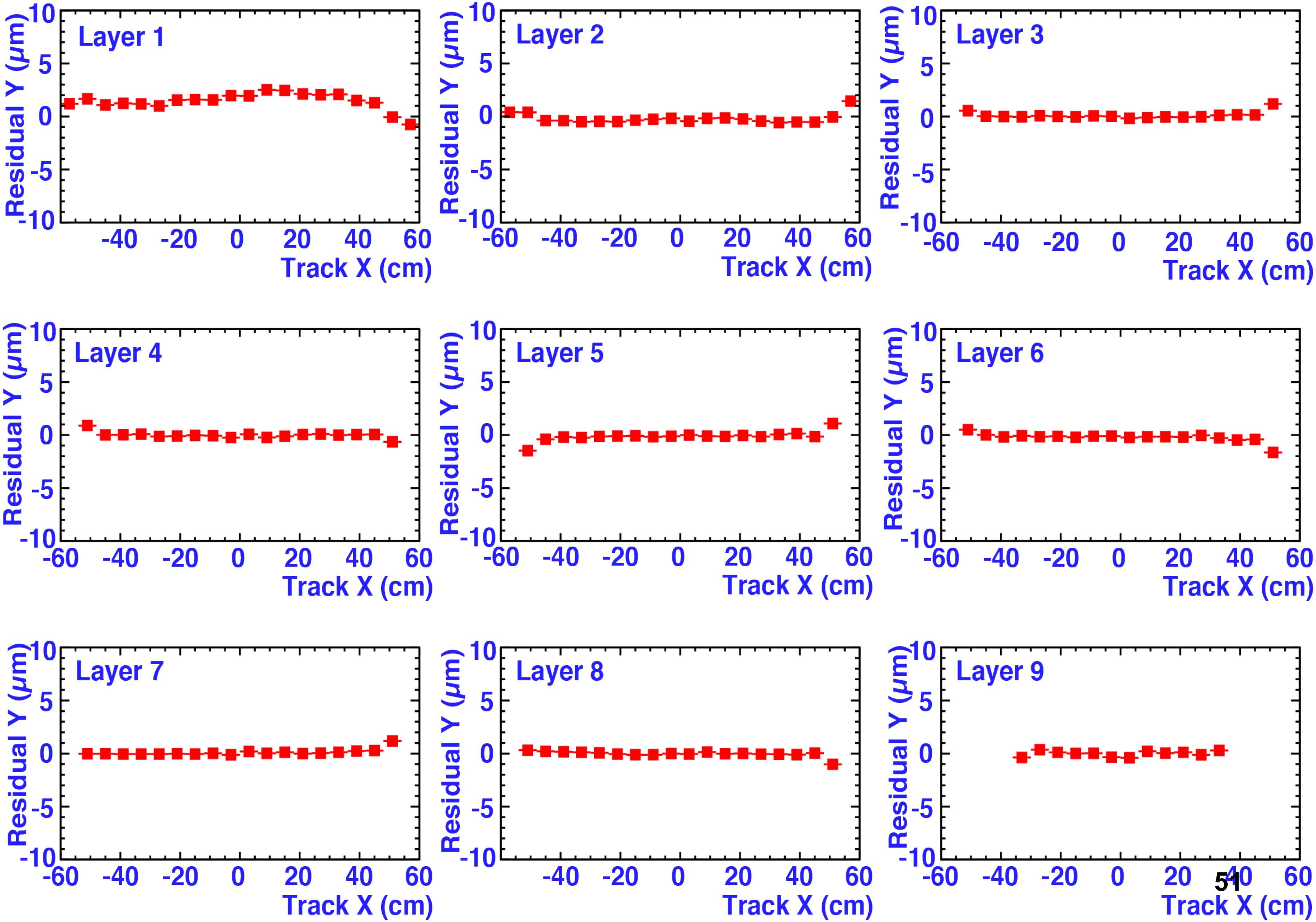
10±3°C



Seasonal effects on external Tracker planes



Alignment accuracy of the 9 Tracker layers over 18 months

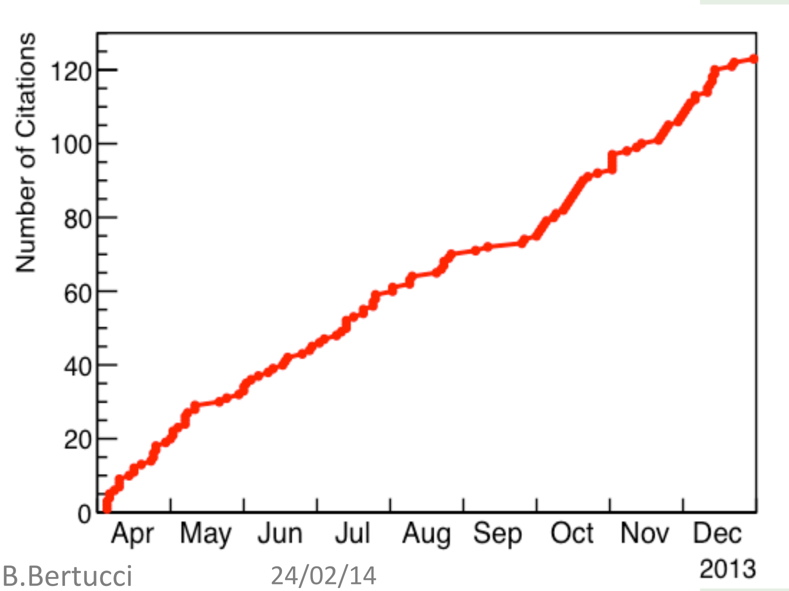


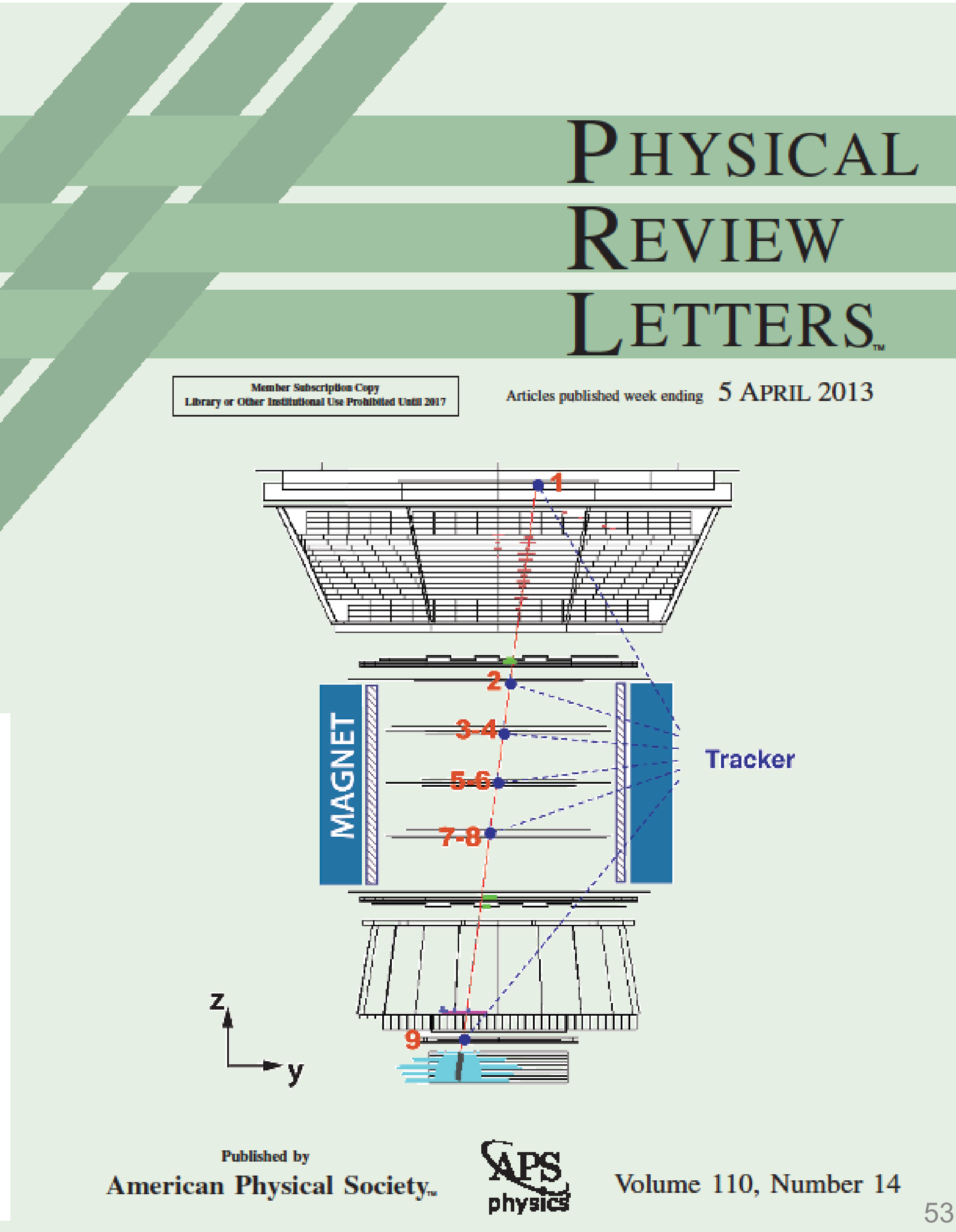
PART 3 : The results

- **Positron fraction**
- **Electron/Positron fluxes**
- **Proton/He fluxes**
- **B/C ratio**
- **…..**

“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





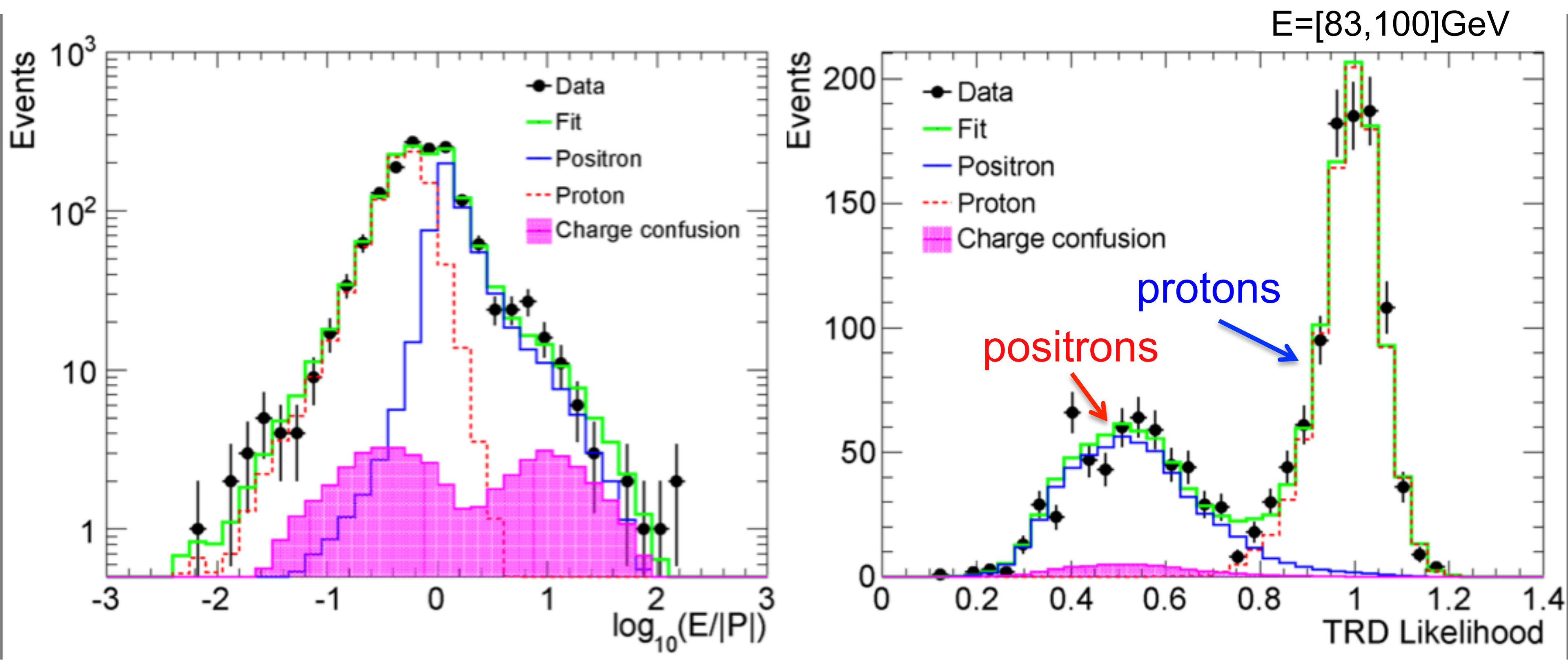
Analysis: the template method

1. The *ecal classifier* is used to *remove most of the* ***protons*** *with high efficiency on* ***positrons***
2. *Reference spectra* (or *templates*) are built for
   - protons and electrons → from data
   - CC spillover and interactions → from MC

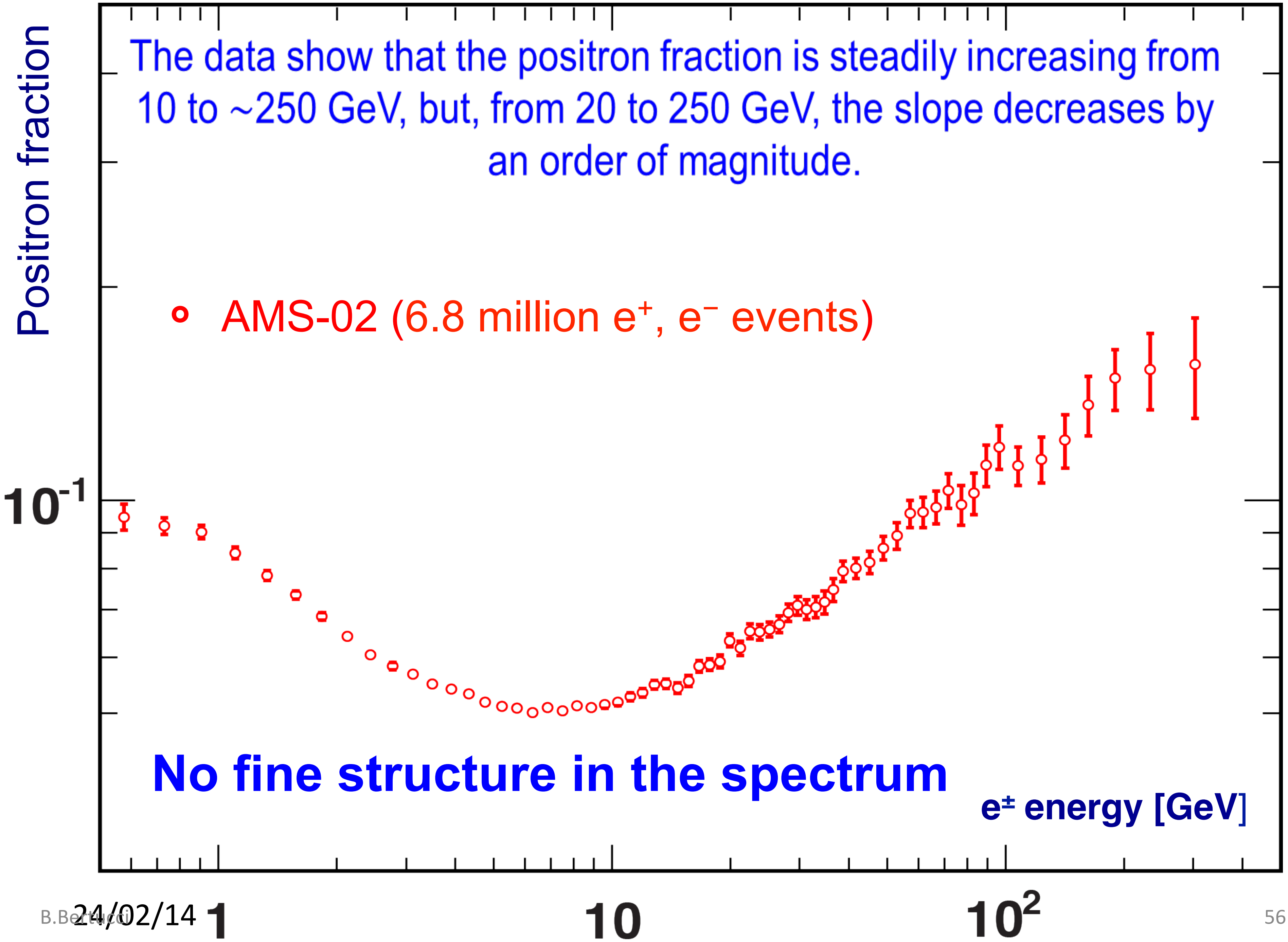
   in the variables **E/p** and in **TRD likelihood**
3. The templates are *fit to data* , in each energy bin, to obtain the relative contributions

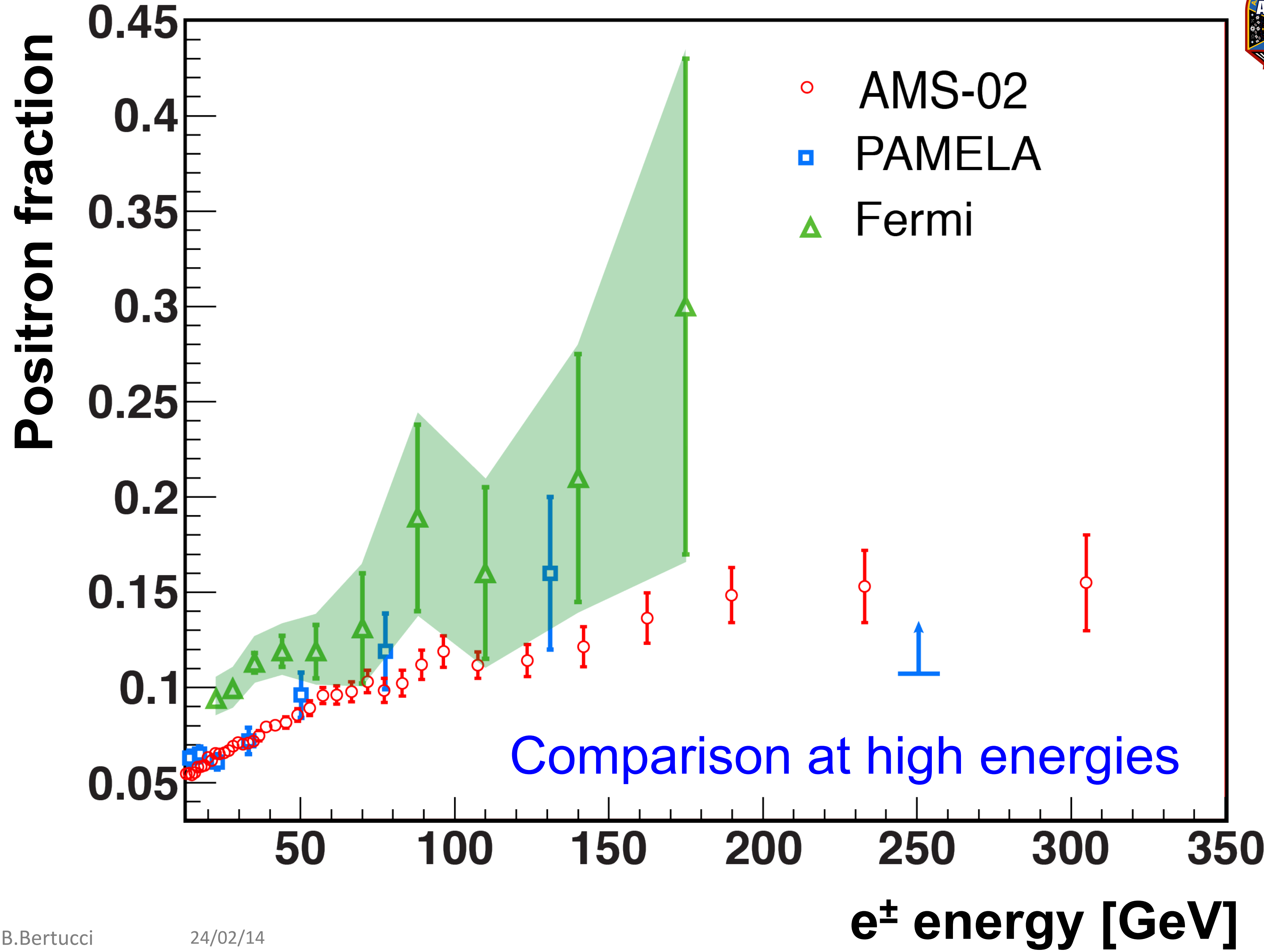
- This method maximizes the signal efficiency, since no further cut is esplicitely applied after ecal classifier

fit to data



- Fit on E/p (left) and on TRD Likelihood (right)
- The fit is repeated at each energy bin


The data show that the positron fraction is steadily increasing from 10 to ~250 GeV, but, from 20 to 250 GeV, the slope decreases by an order of magnitude.
Positron fraction
AMS-02 (6.8 million e⁺, e⁻ events)
10^{-1}
No fine structure in the spectrum
e± energy [GeV]
1
10
10^2

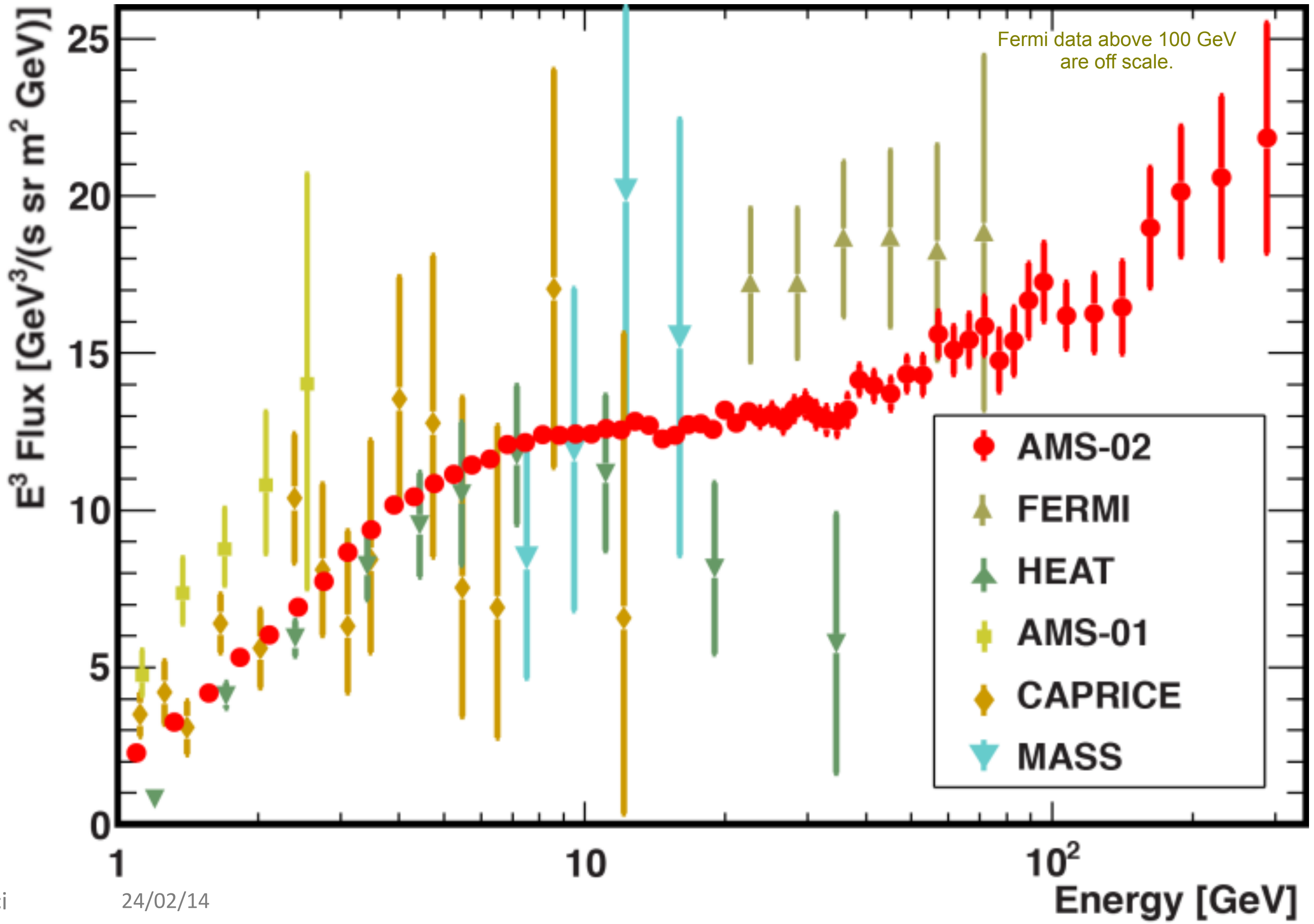


AMS-02
PAMELA
Fermi
Comparison at high energies
Positron fraction
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
50
100
150
200
250
300
350
e± energy [GeV]

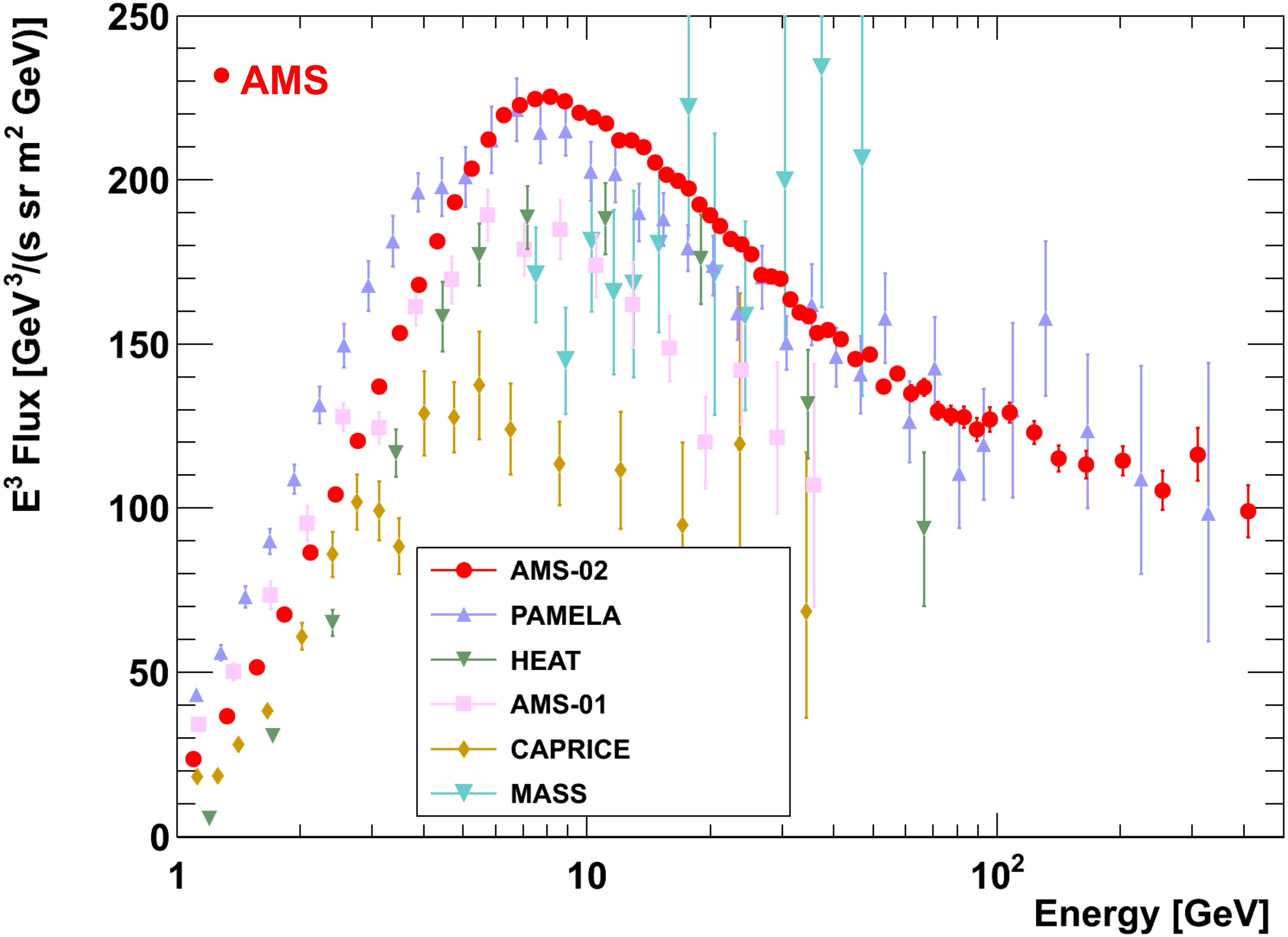
AMS Result: Measurement of the positron fraction

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

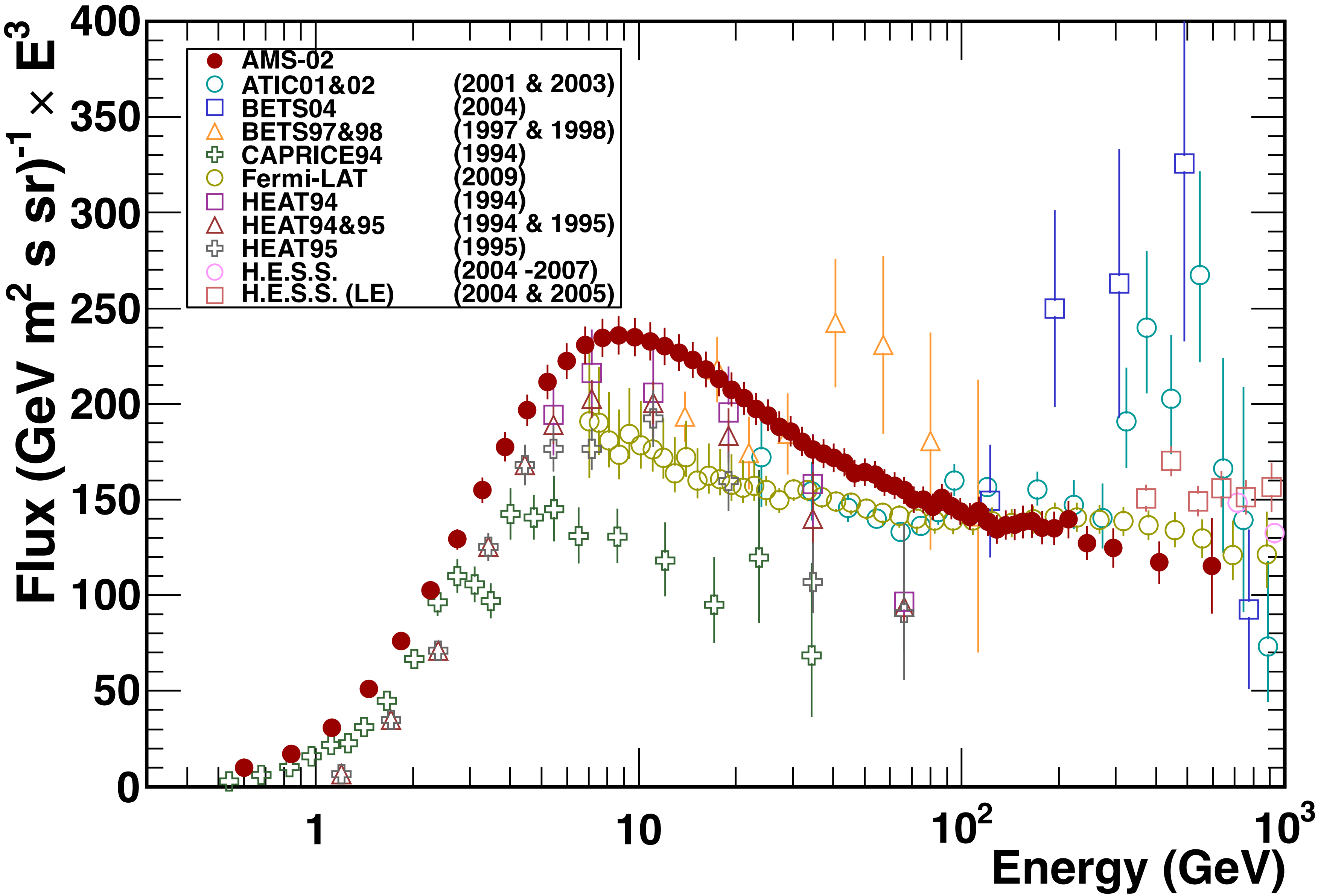
AMS Physics: Positron Flux



AMS Physics: Electron Flux



(Electron plus Positron) Spectrum

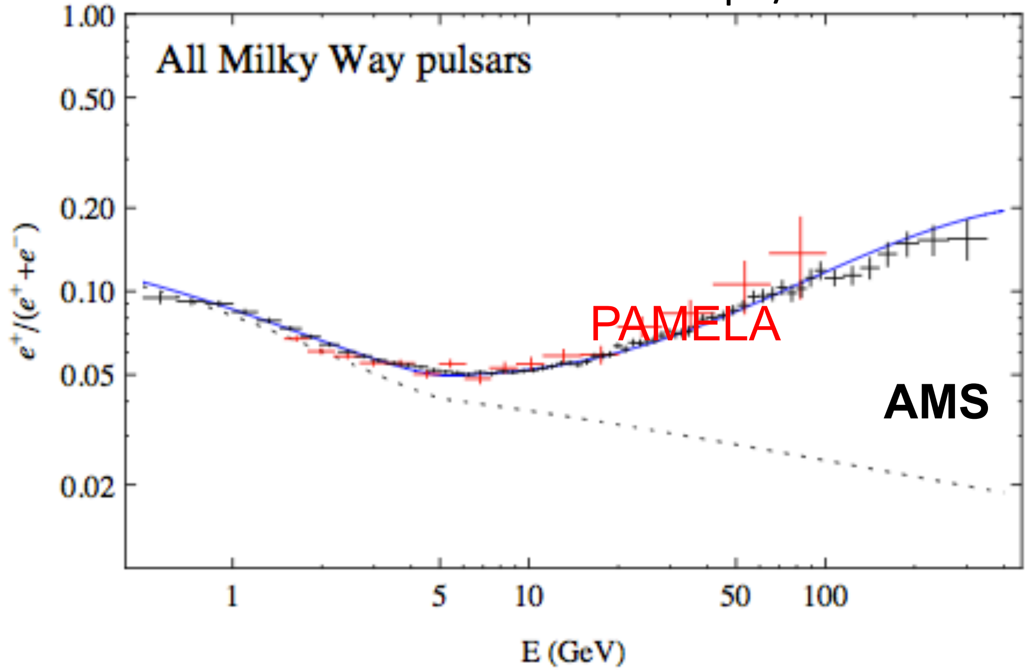


61

What is AMS observing?

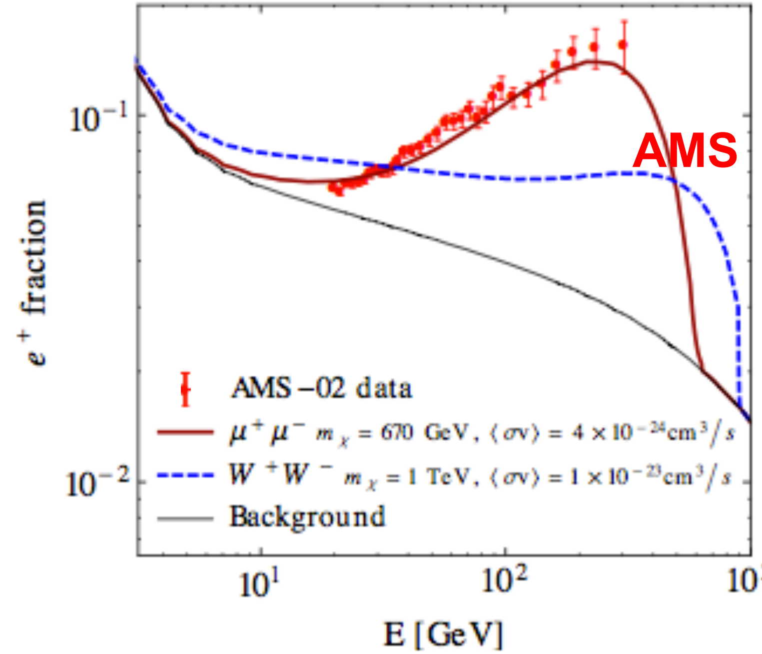
Astrophysical objects

Cholis arXiv: astro-ph/1304.1840



Dark Matter

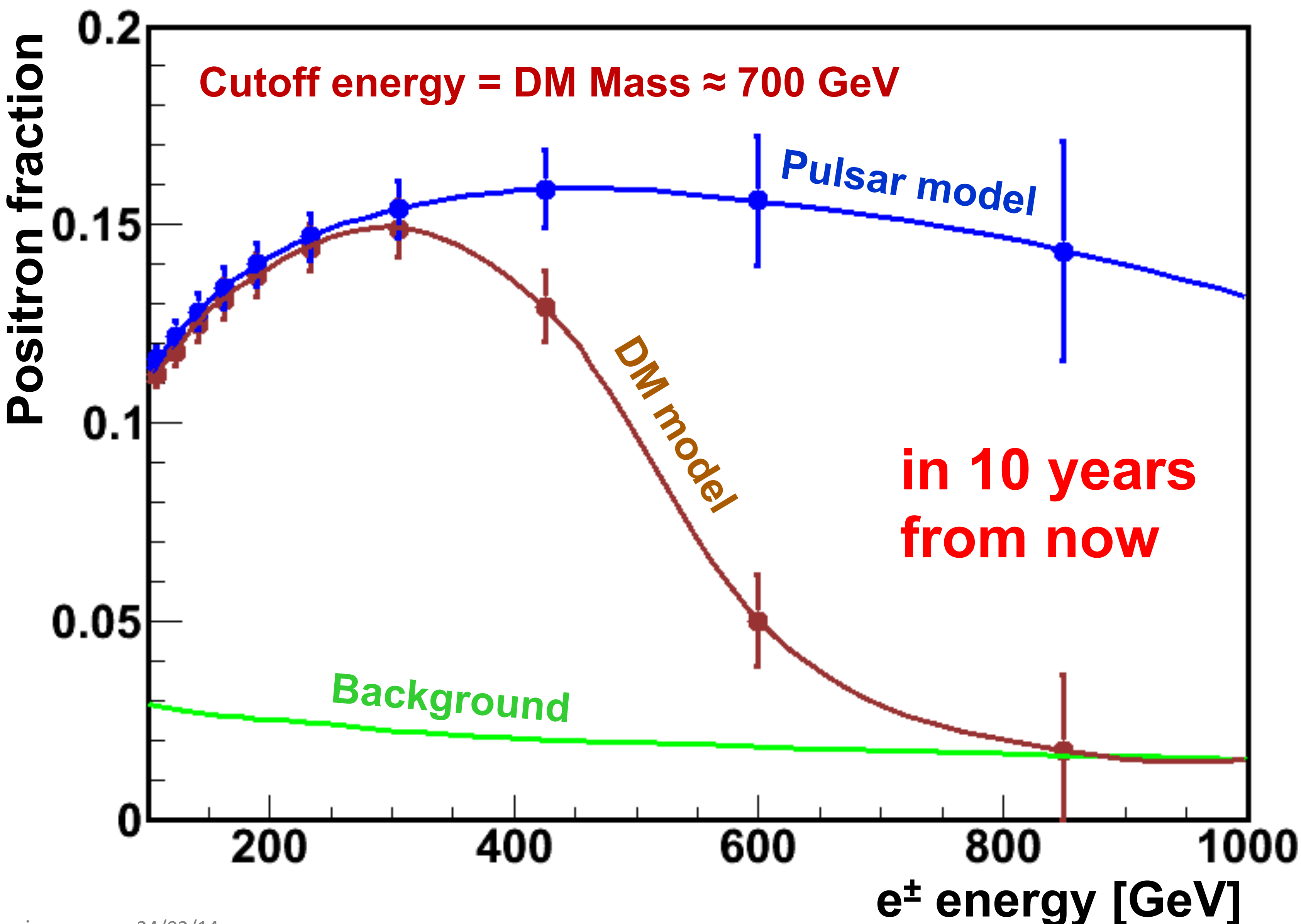
Kopp hep-ph/1304.1184



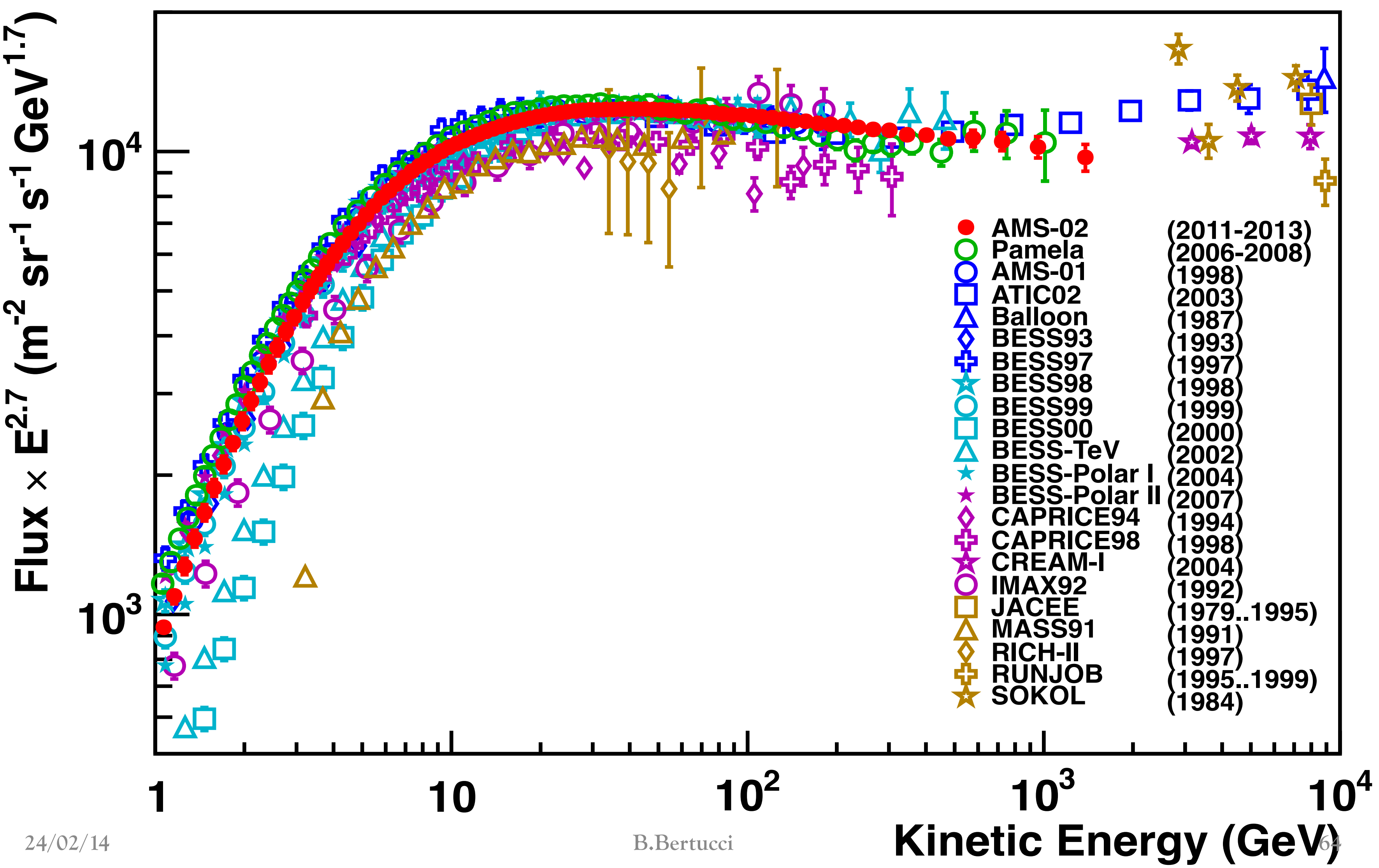
Different energy behavior of the positron fraction:

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

AMS future data and phenomenological models

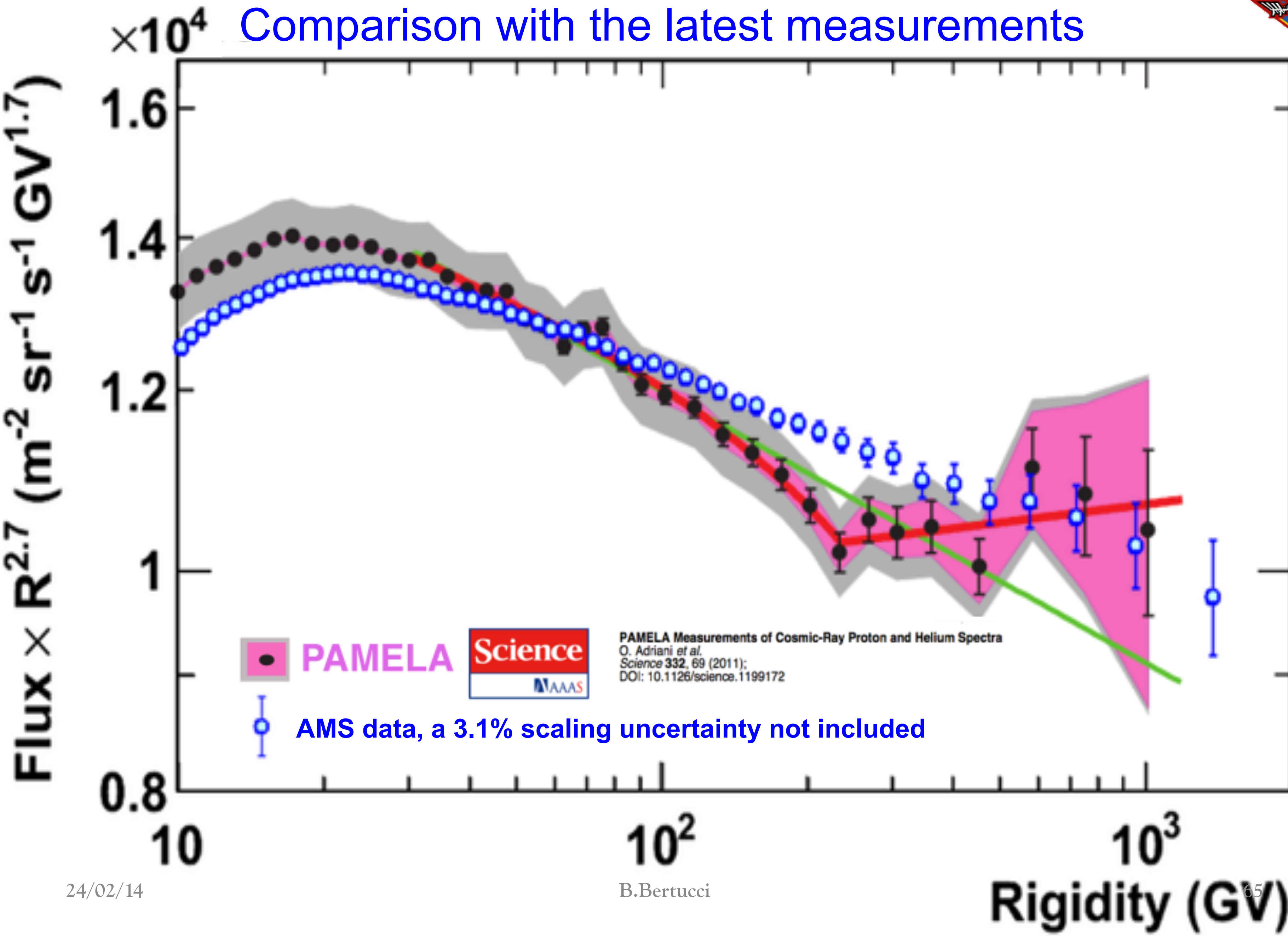


Proton flux
Comparison with past measurements



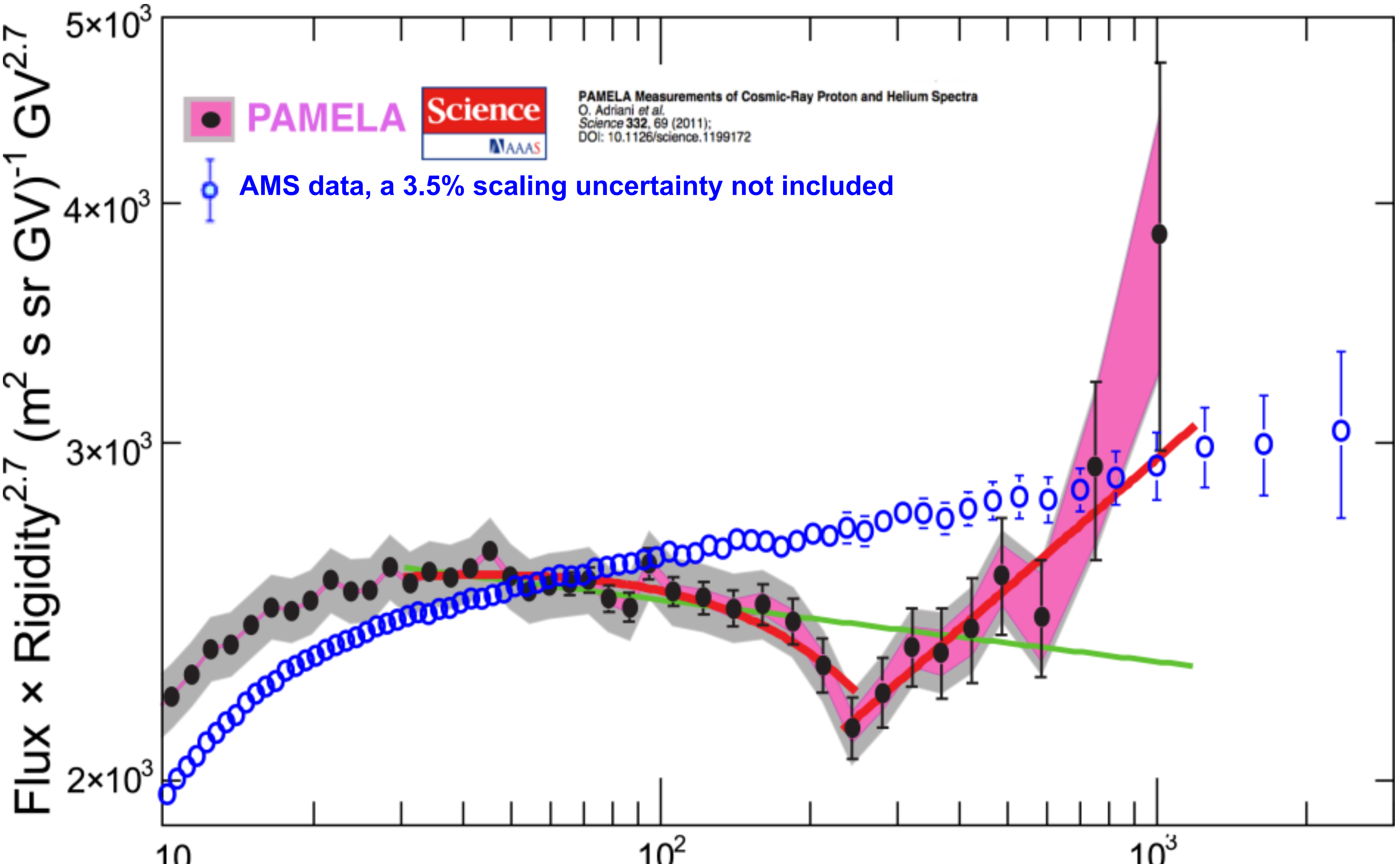
Proton flux

Comparison with the latest measurements

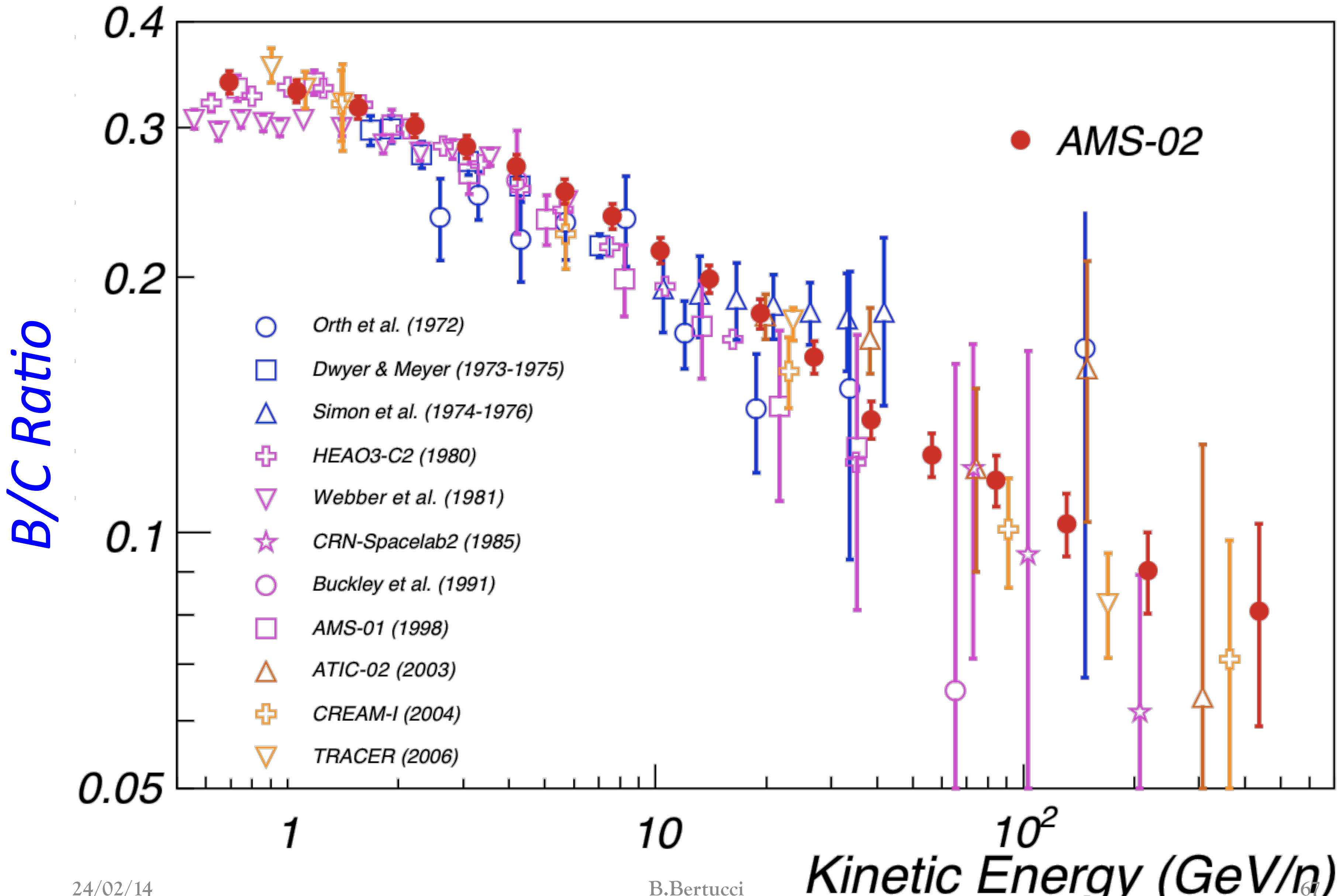


Helium flux

Comparison with the latest measurements

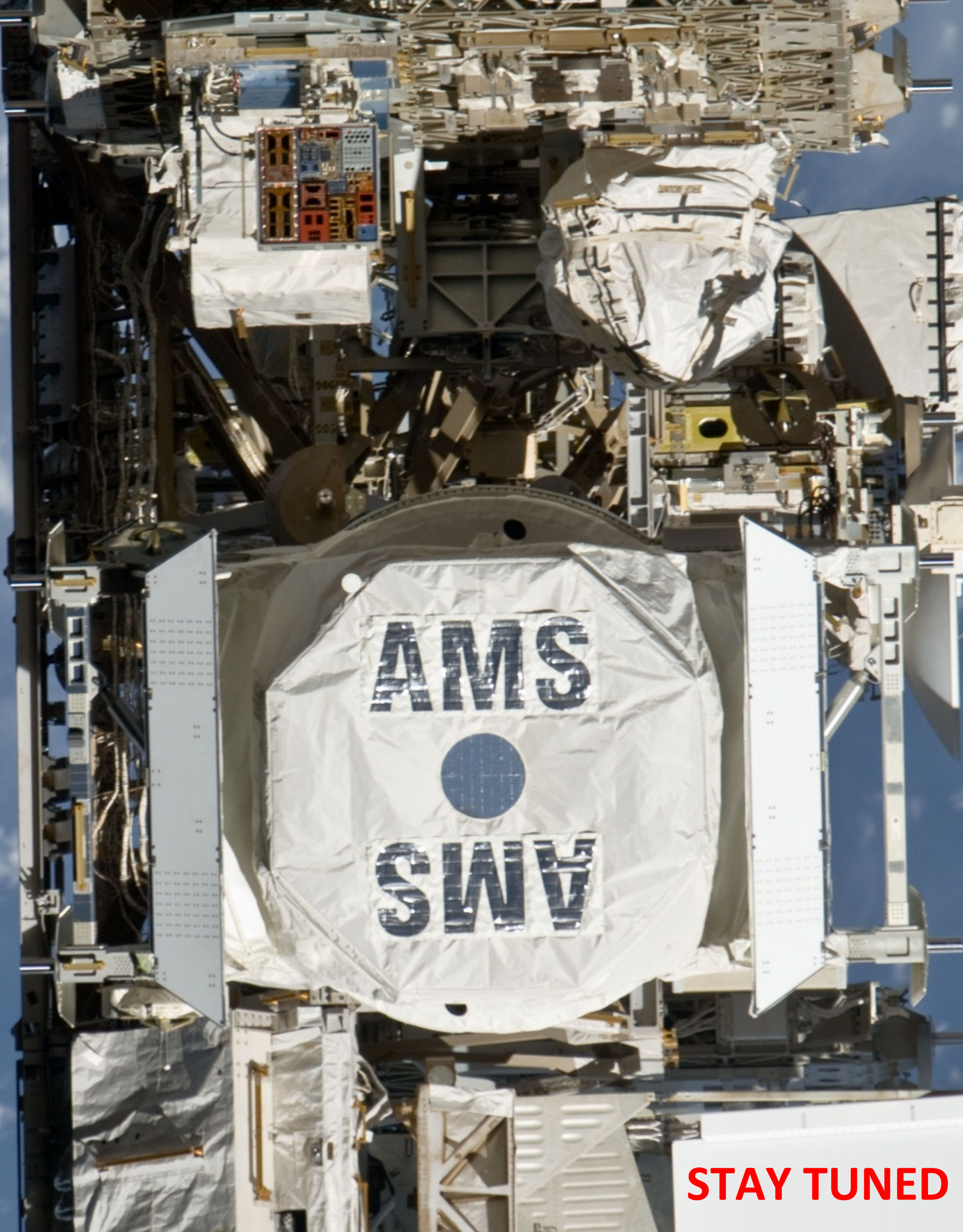


Boron-to-Carbon ratio



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 been performed
- More statistic is needed
- AMS precise measurements are promising new Physics



STAY TUNED


Thanks for your attention
&
Greetings from Perugia !