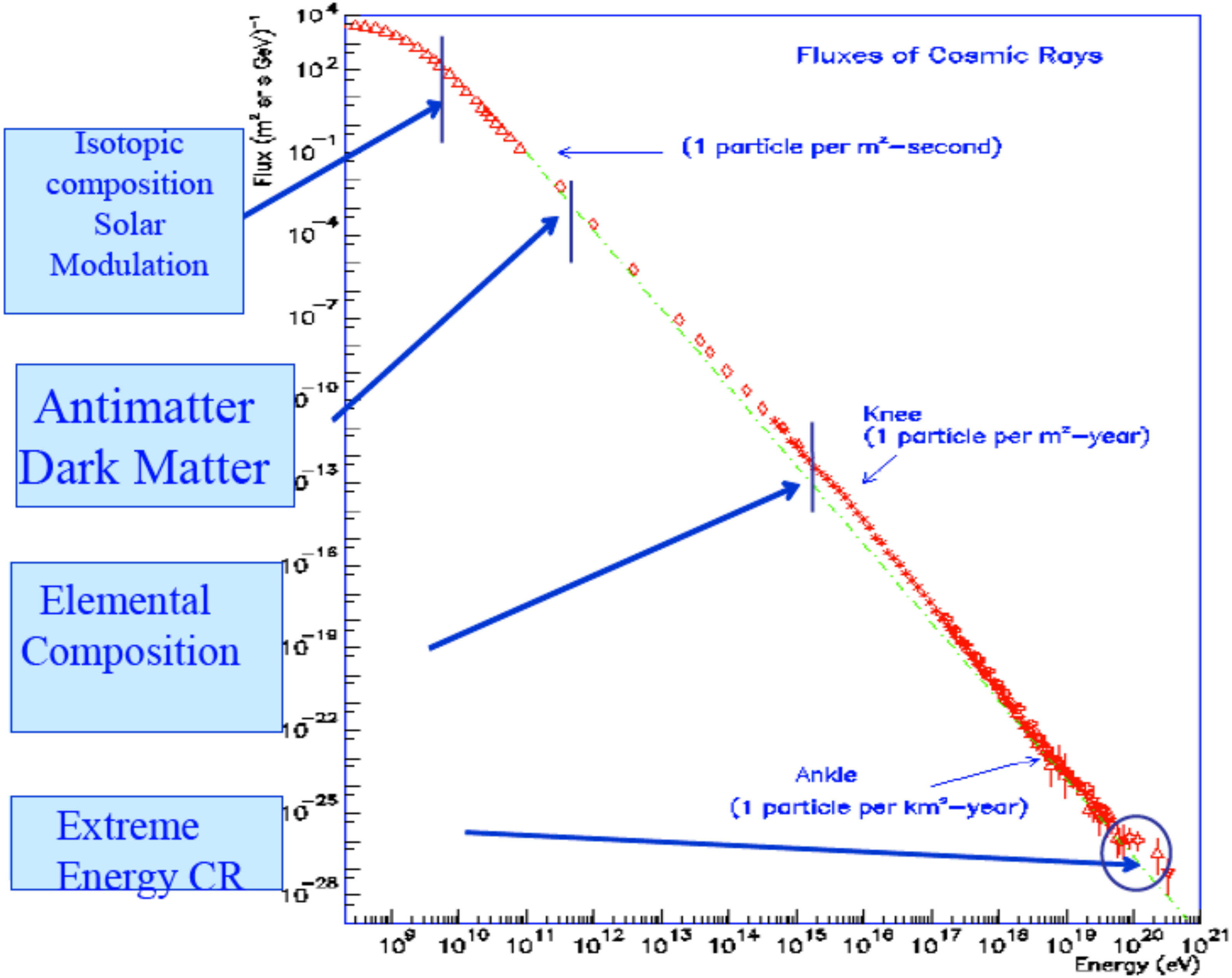
# Recent results from the Alpha Magnetic Spectrometer (AMS) Experiment on the International Space Station

**R. Battiston**

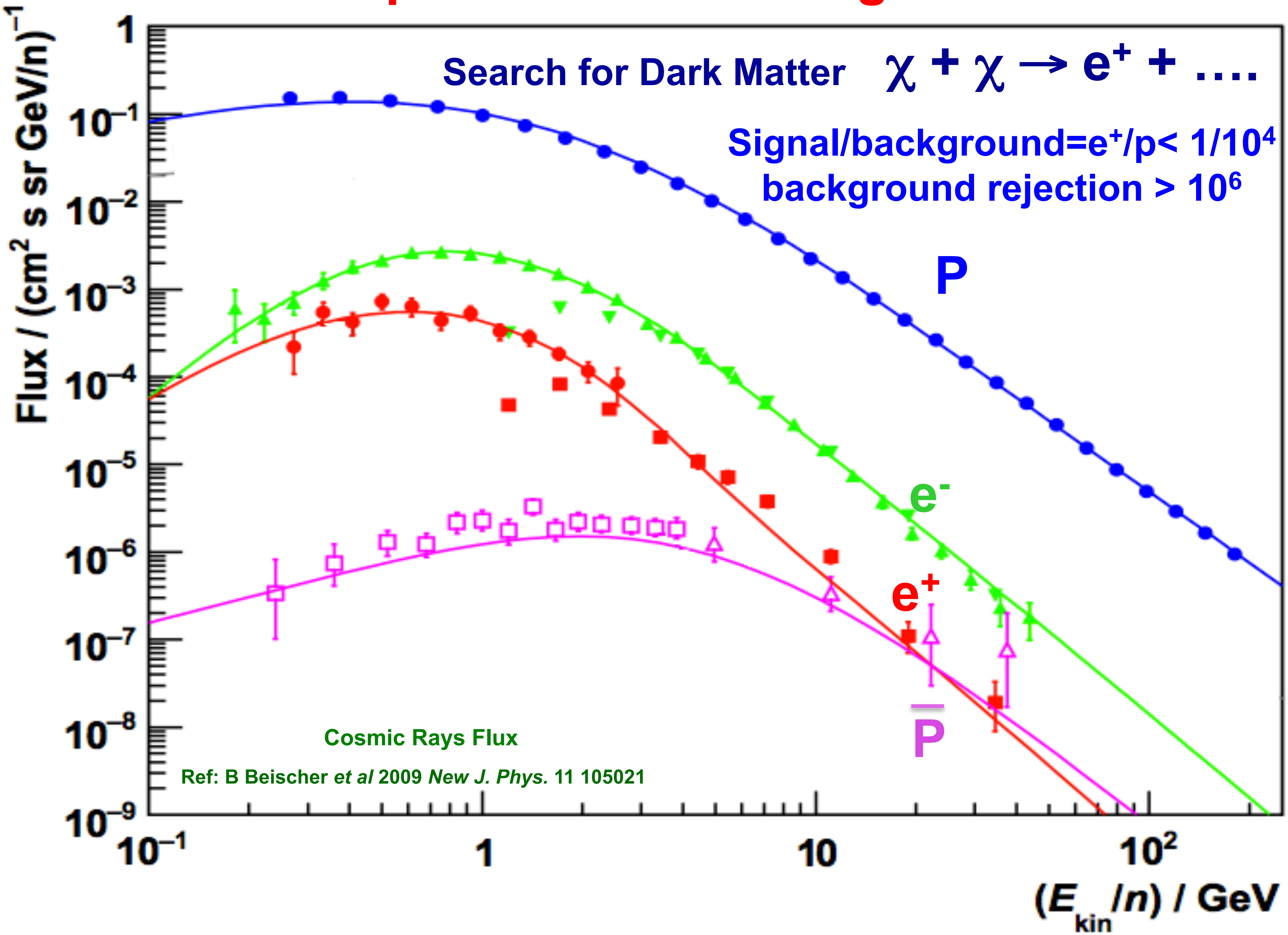
**University and INFN-TIFPA, Trento**

**La Thuile, February 24th 2014**

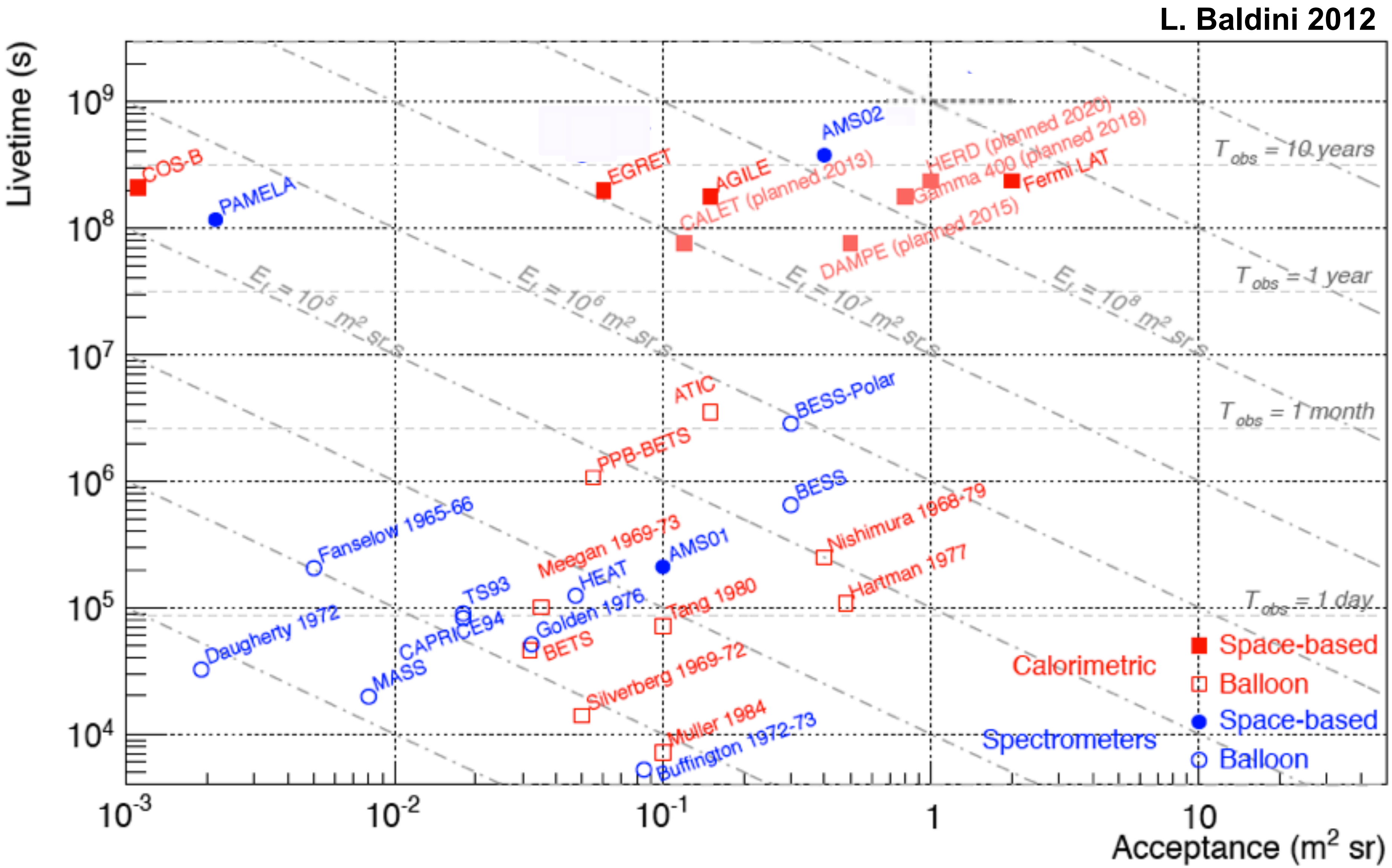



J. Cronin ,T.K. Gaisser & S.P. Swordy, Sci. Amer. 276 (1997) 44

# Experimental Challenges



# A Large Magnetic Spectrometer in Space :
# a game changing for the study of Cosmic Ray

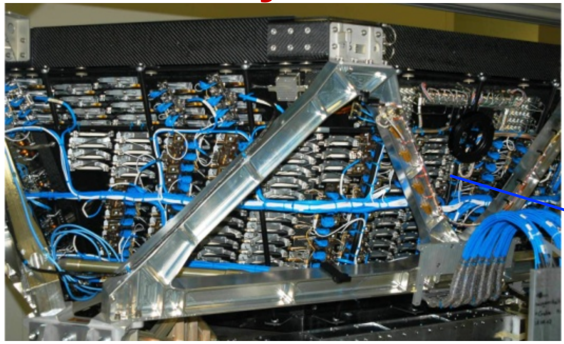


# AMS: A TeV precision, multipurpose spectrometer

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

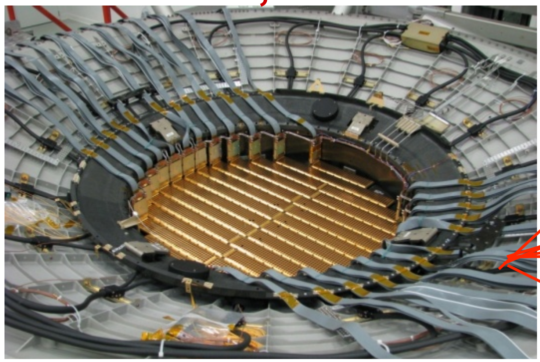
**TRD**

**Identify e⁺, e⁻**



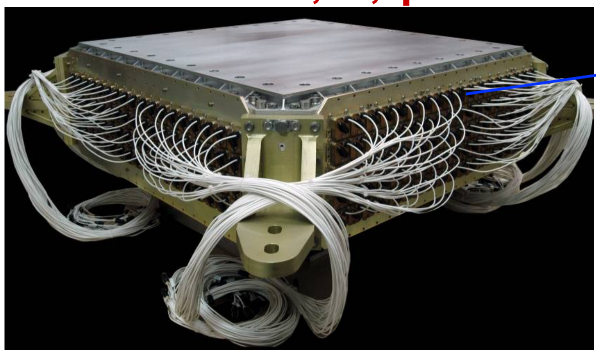
**Silicon Tracker**

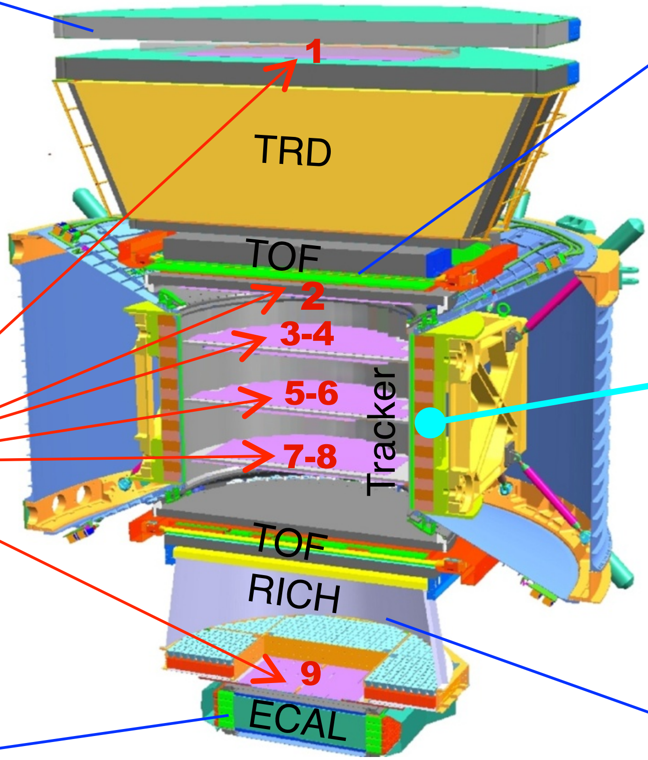
**Z, P**



**ECAL**

**E of e⁺, e⁻, γ**





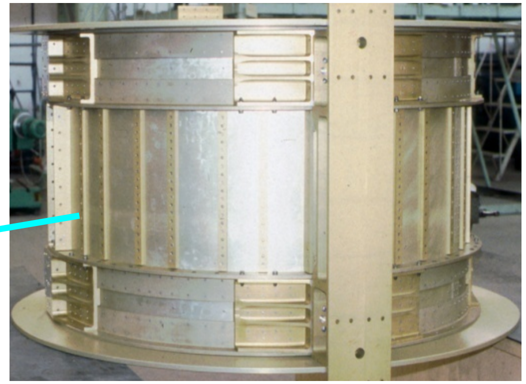

***Z, P* are measured independently by the Tracker, RICH, TOF and ECAL**

**TOF**

**Z, E**

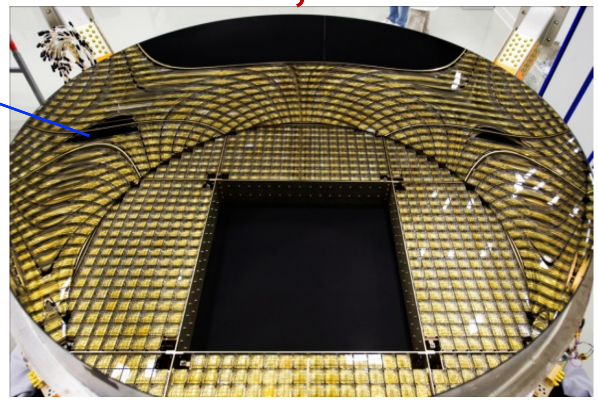
**Magnet**

**±Z**



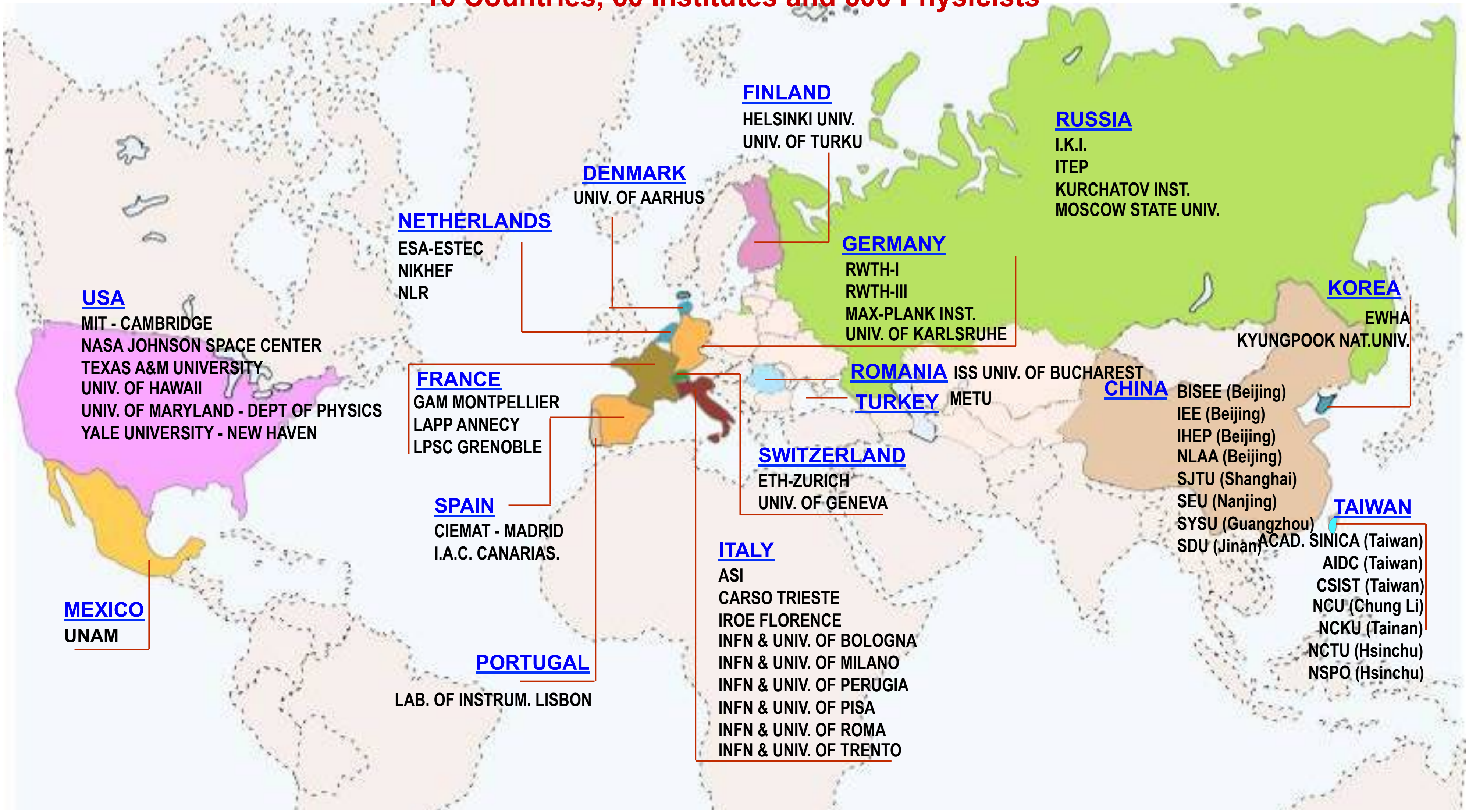
**RICH**

**Z, E**



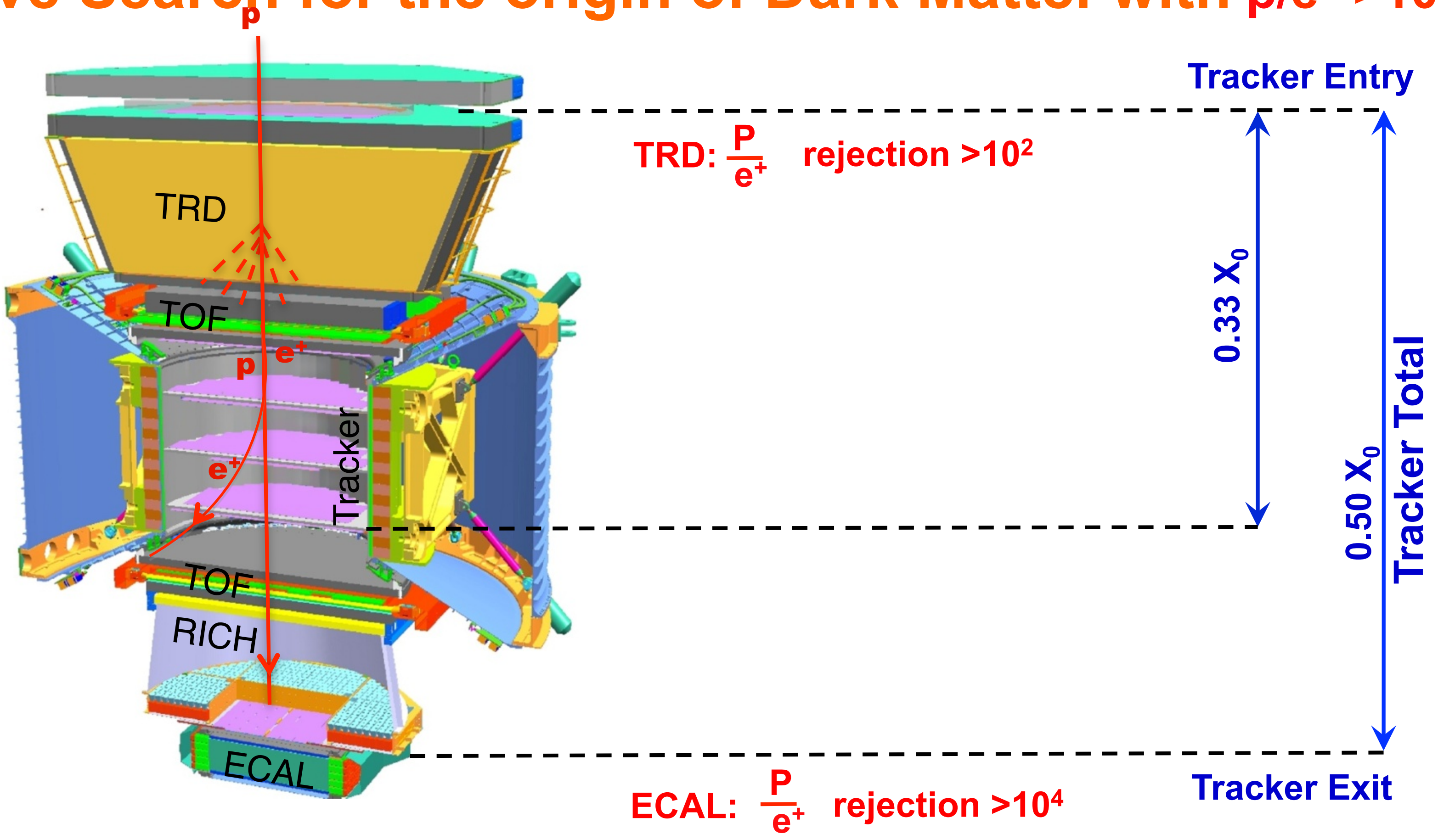
# AMS International Collaboration

16 Countries, 60 Institutes and 600 Physicists




# DOE sponsored experiment, NASA space operation
# 95% construction from Europe and Asia

# Sensitive Search for the origin of Dark Matter with $p/e^+ > 10^6$




a) Minimal material in the TRD and TOF
So that the detector does not become a source of $e^+$.

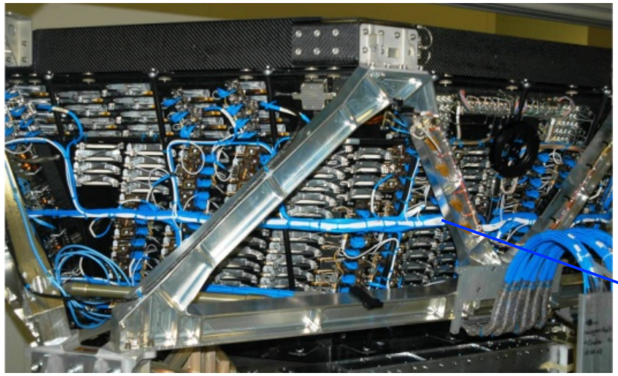
b) A magnet separates TRD and ECAL so that $e^+$ produced in TRD will be swept away and not enter ECAL
In this way the rejection power of TRD and ECAL are independent

c) Matching momentum of 9 tracker planes with ECAL energy measurements

# AMS Flight Electronics for Data Acquisition (DAQ)

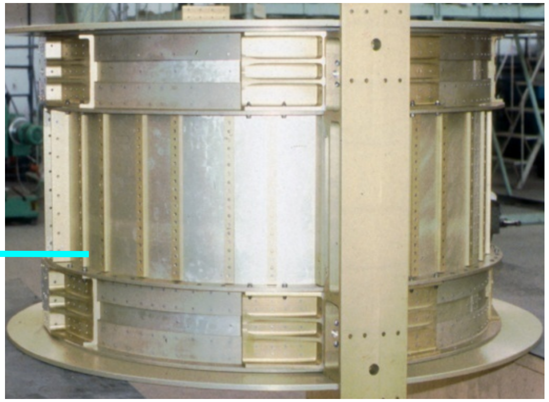
**300,000 channels at 2 KHz,**
**650 computers**
**designed and built by AMS**

**TRD: 5248 Signals**

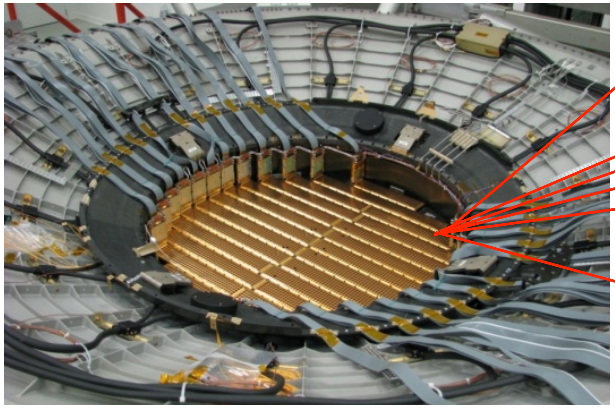


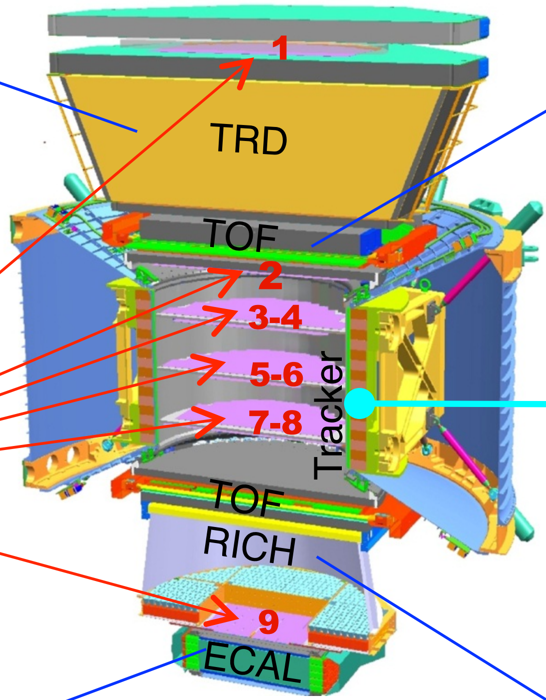
**TOF & ACC: 88 Signals**

**Magnet**



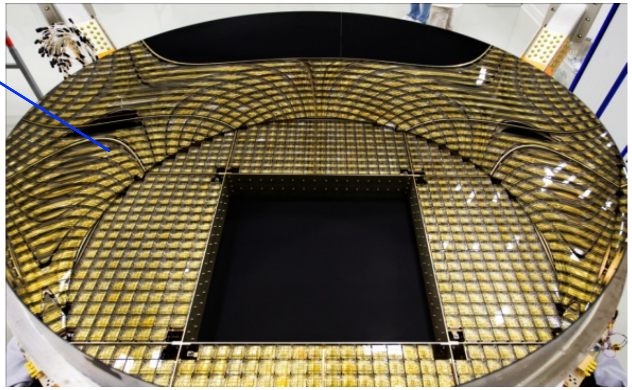
**Silicon Tracker:**
**196,608 Signals**






**ECAL: 2,916 Signals**

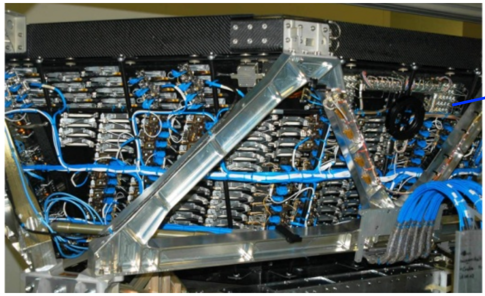
**RICH: 10,800 * 2 Signals**



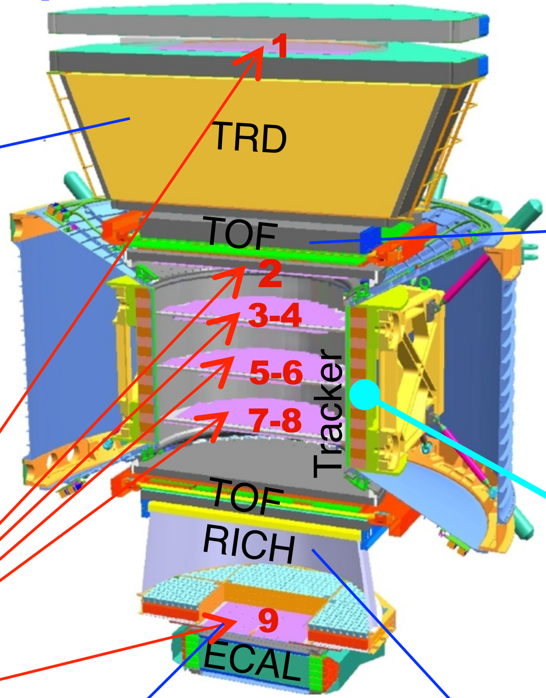
# AMS Flight Electronics for Thermal Control

## 1118 temperature sensors, 298 heaters

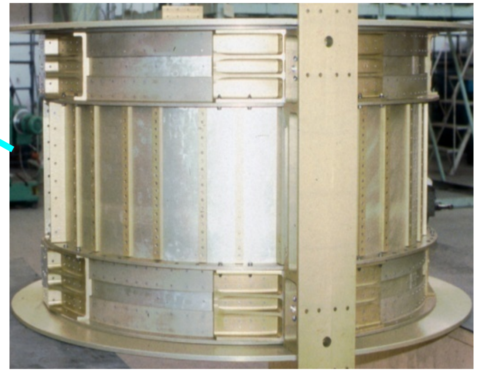
**TRD**
**24 Heaters**
**8 Pressure Sensors**
**482 Temperature Sensors**



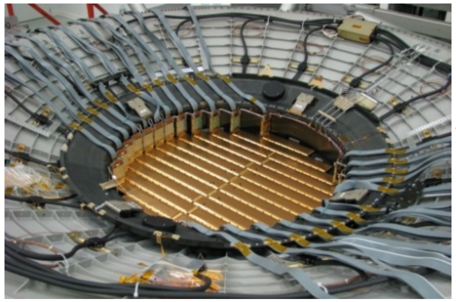
**TOF & ACC**
**64 Temperature Sensors**




**Magnet**
**68 Temperature Sensors**

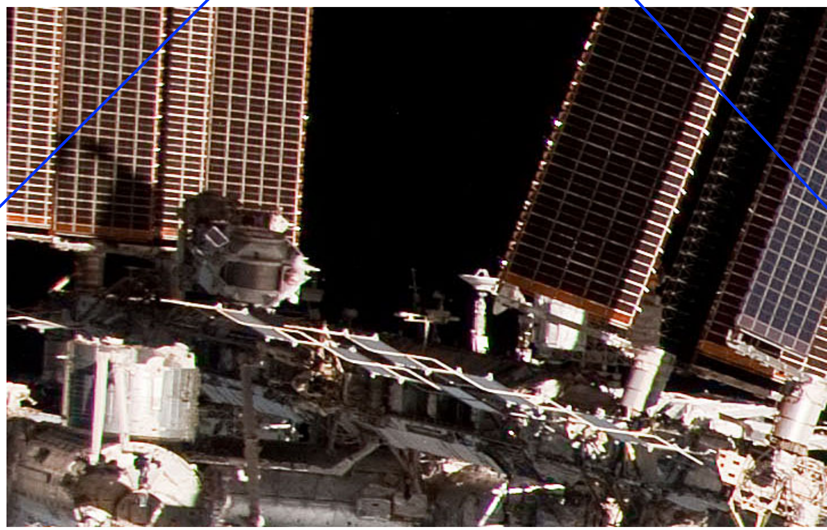


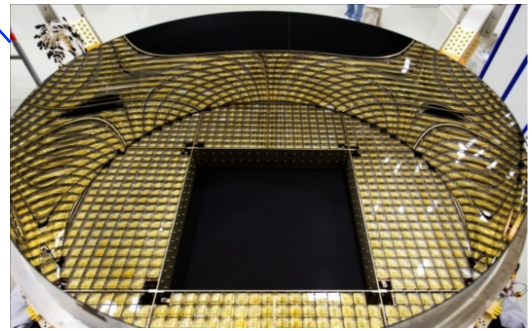
**Silicon Tracker**
**4 -Pressure Sensors**
**32 Heaters**
**142 Temperature Sensors**



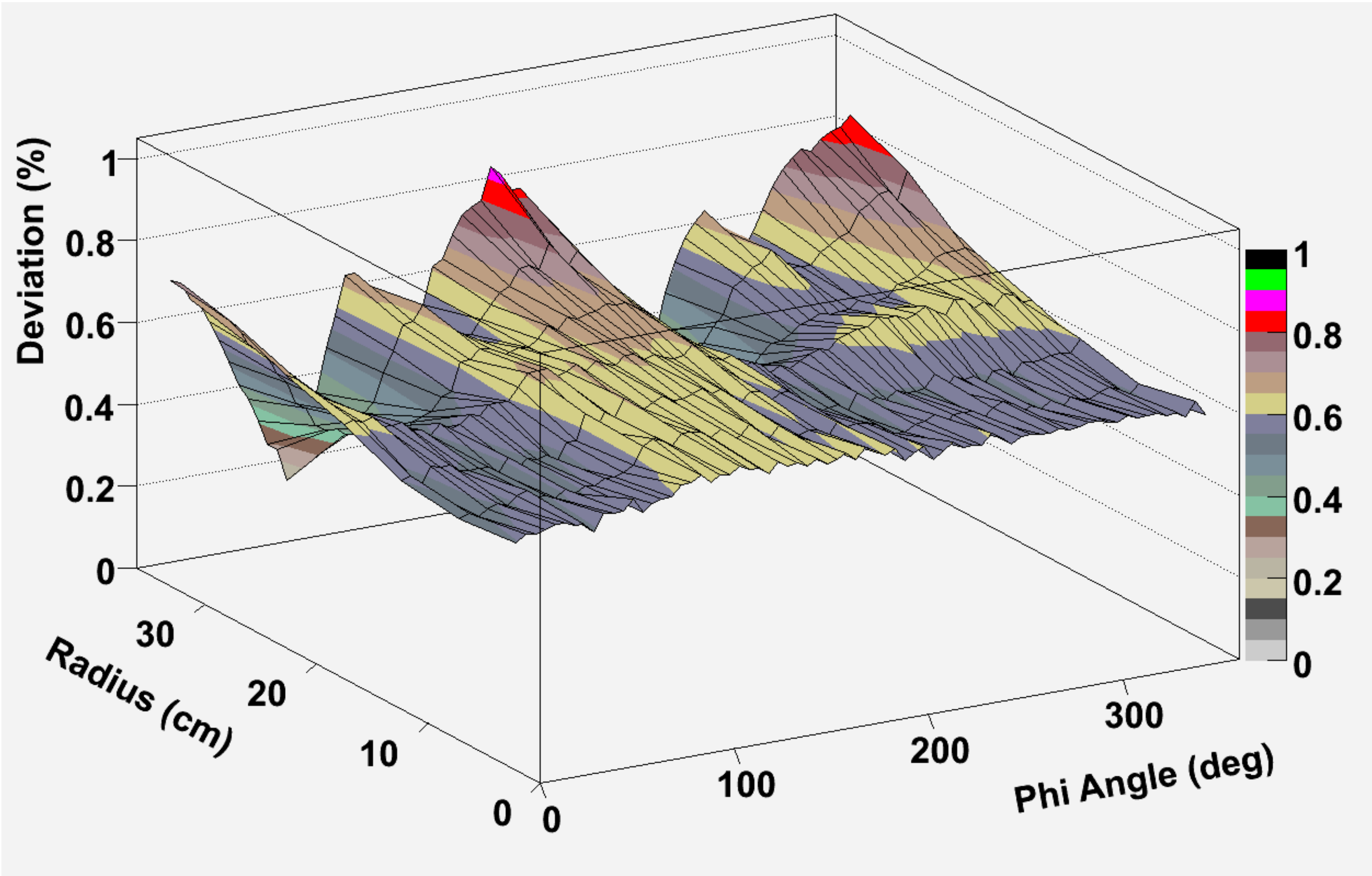
**RICH**
**96 Temperature Sensors**

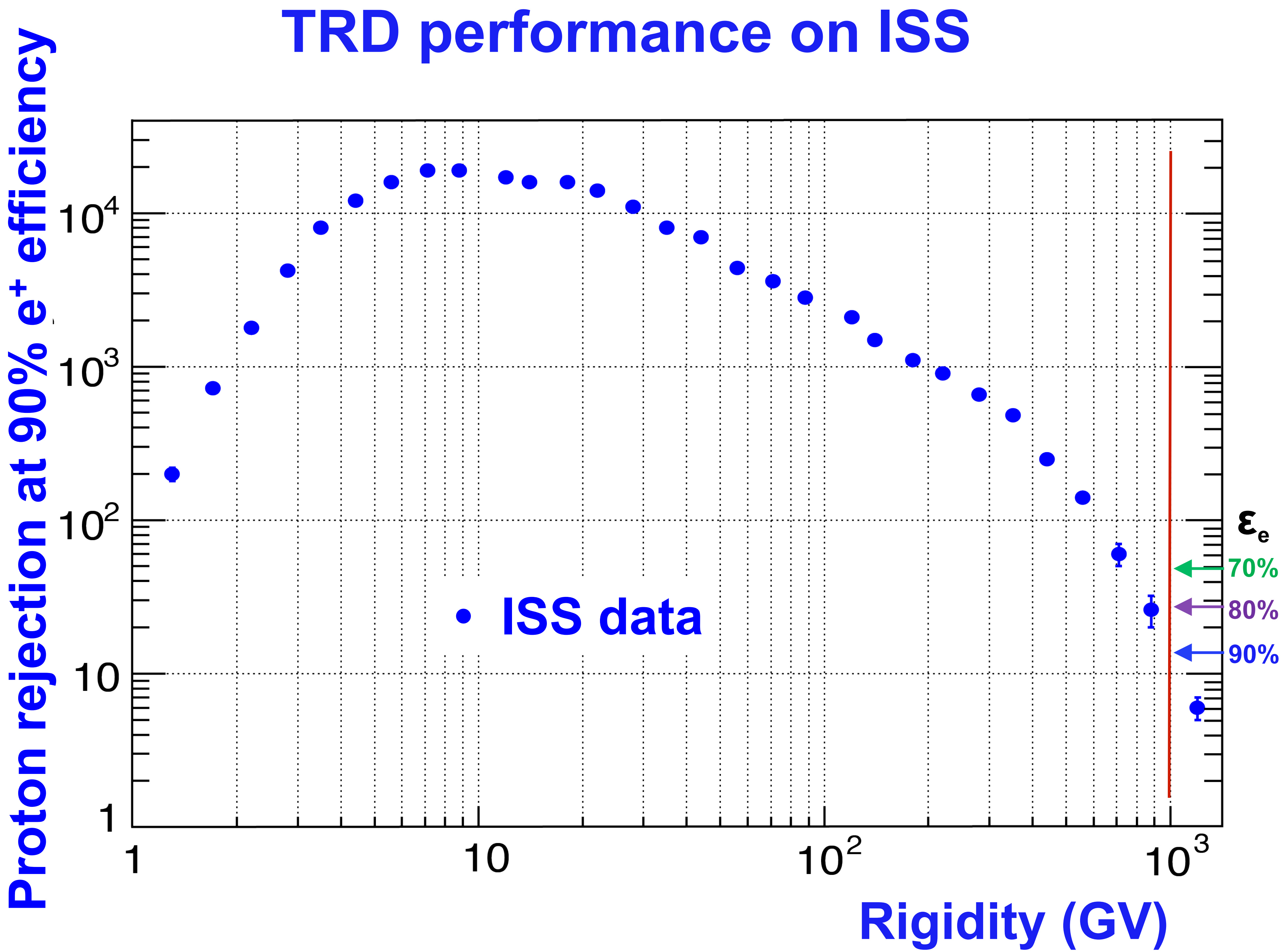
**ECAL**
**80 Temperature Sensors**





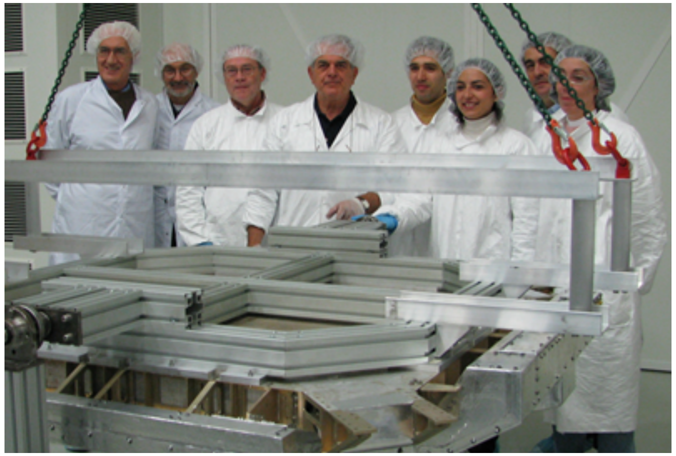
# Deviation from 1997 measurements in R-Phi coordinates, Z=0

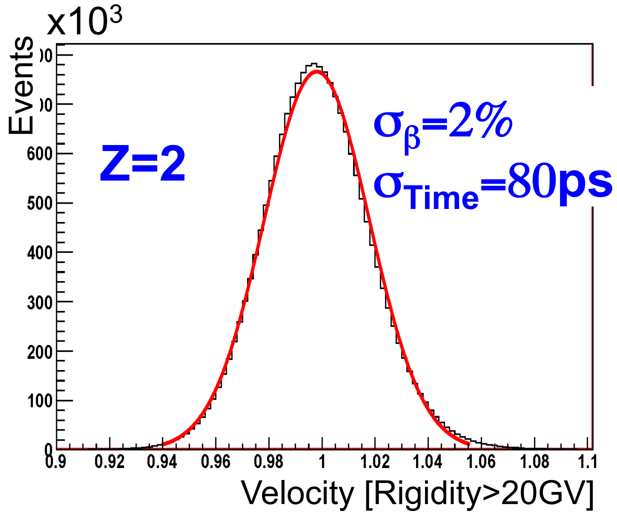


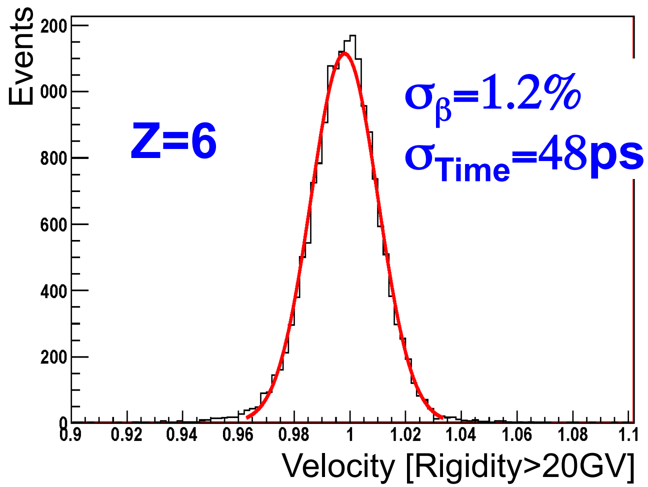

TRD performance on ISS
Proton rejection at 90% e+ efficiency
Rigidity (GV)
ISS data
εe
70%
80%
90%
1
10
10^2
10^3
10^4

# Data from ISS    Time of Flight System

## Measures Velocity and Charge of particles

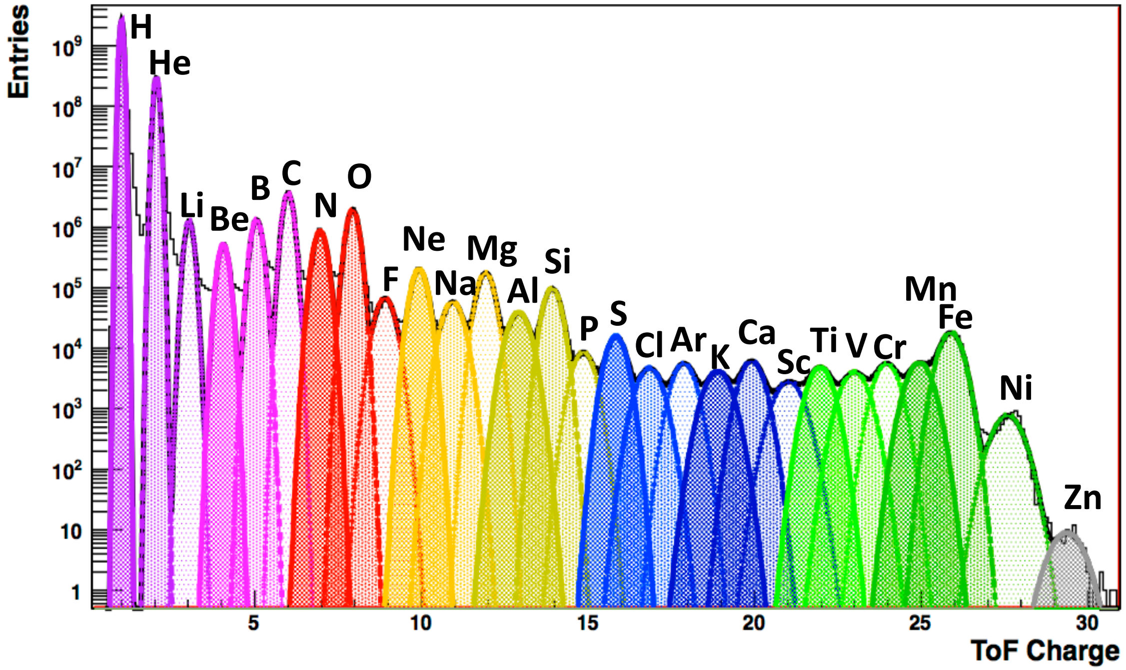




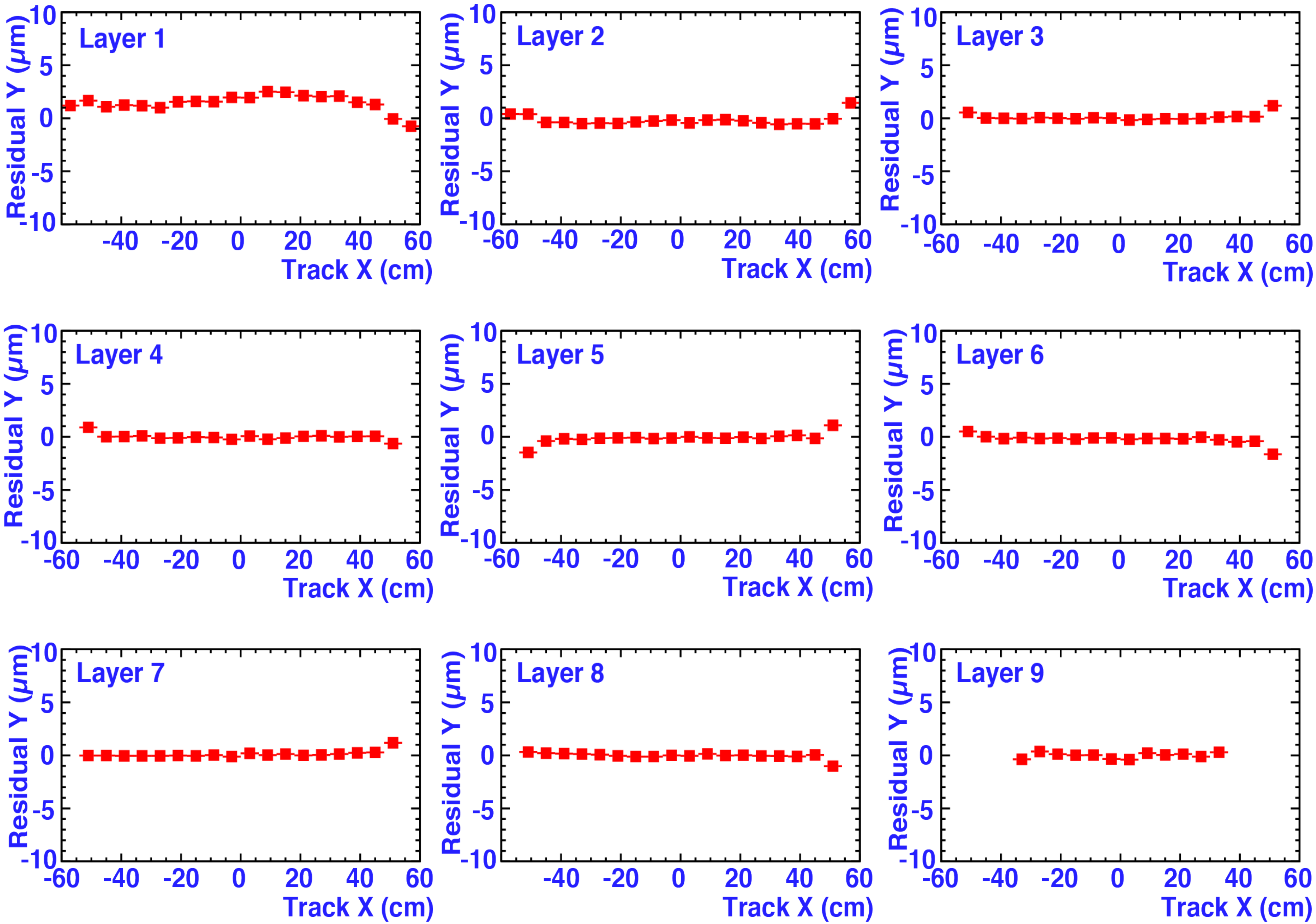




**Bologna**

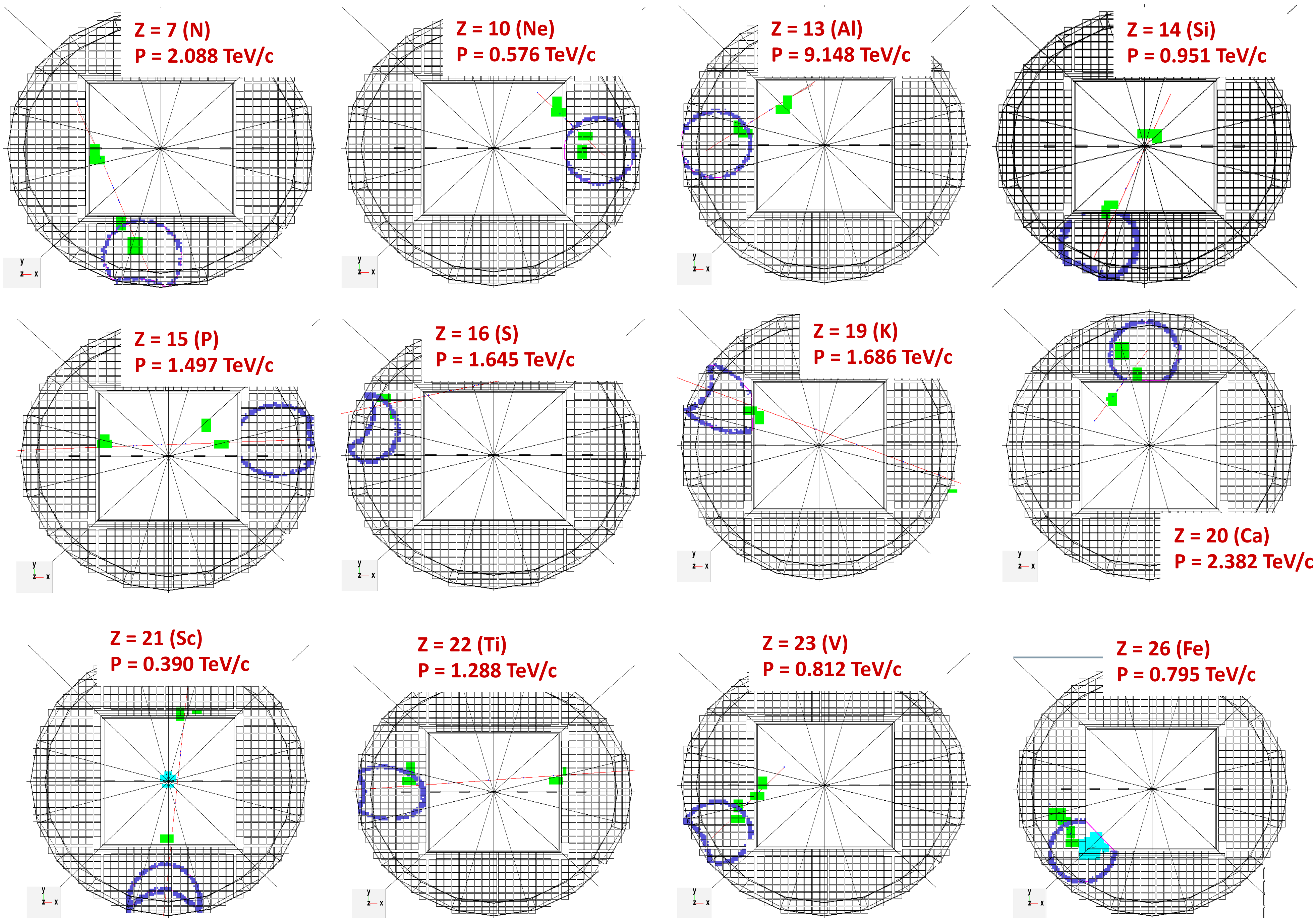
**Professors A. Contin, G. Laurenti, F. Palmonari**



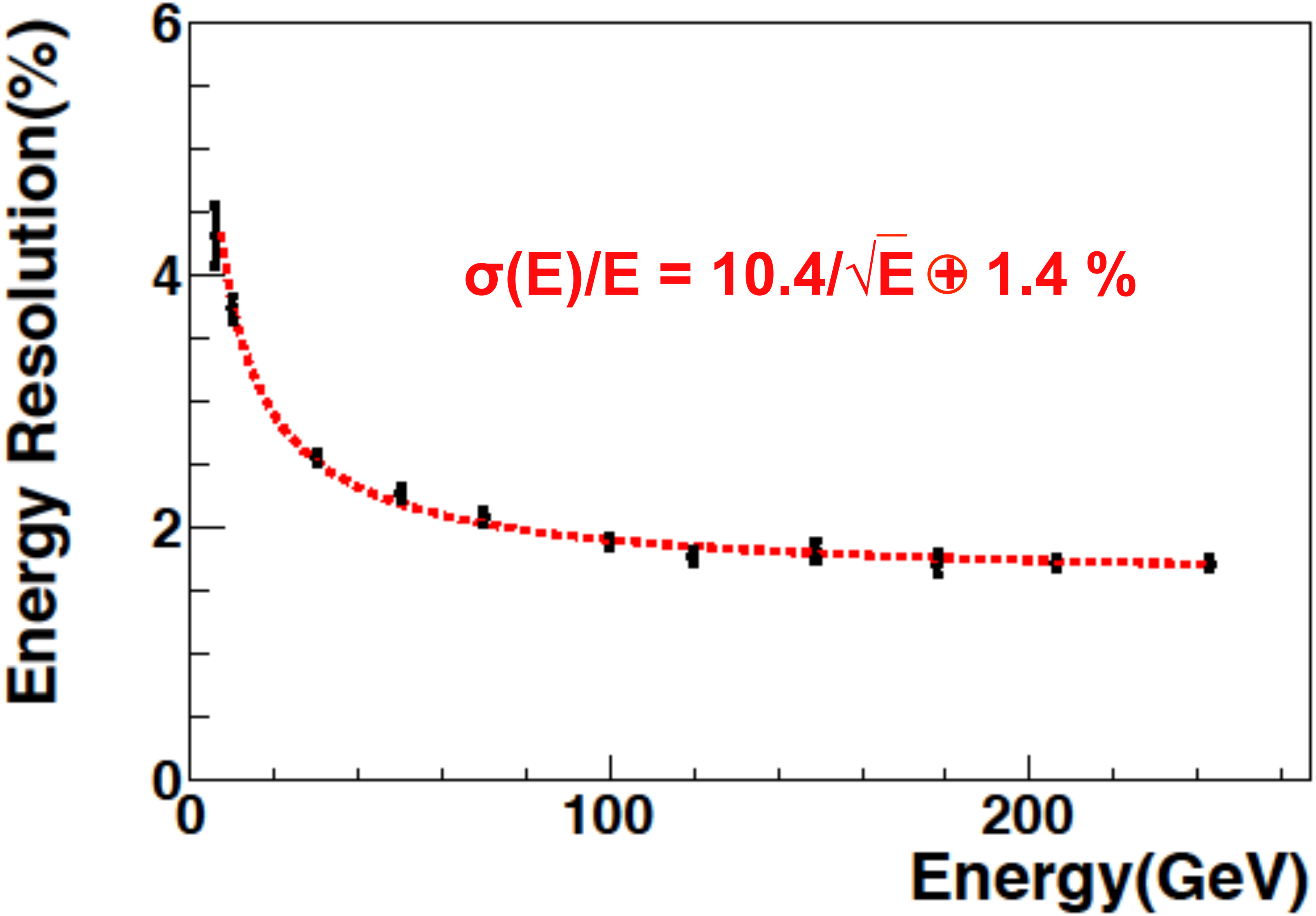
# Alignment accuracy of the 9 Tracker layers over 18 months



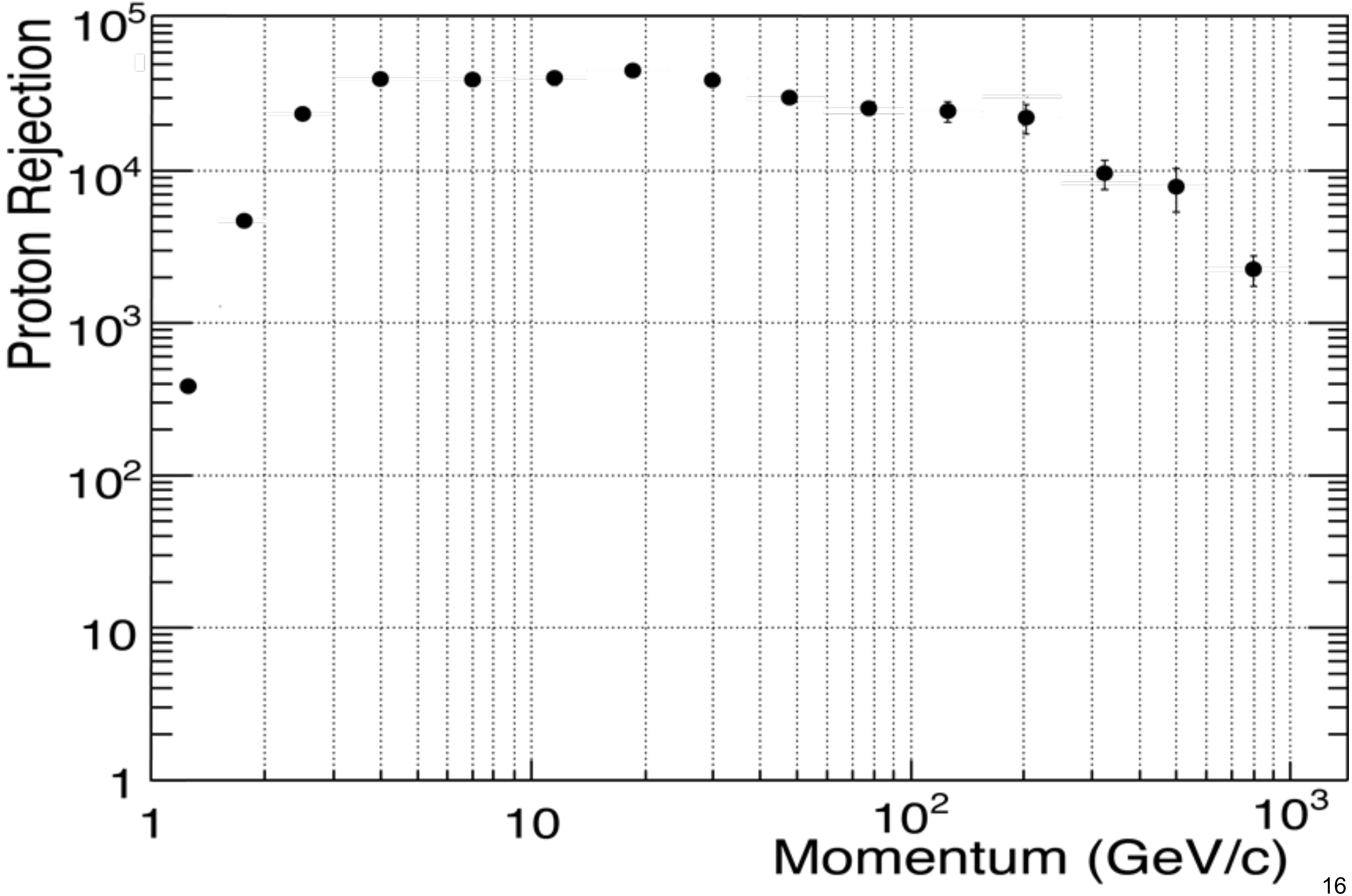
# Detector performance on ISS RICH



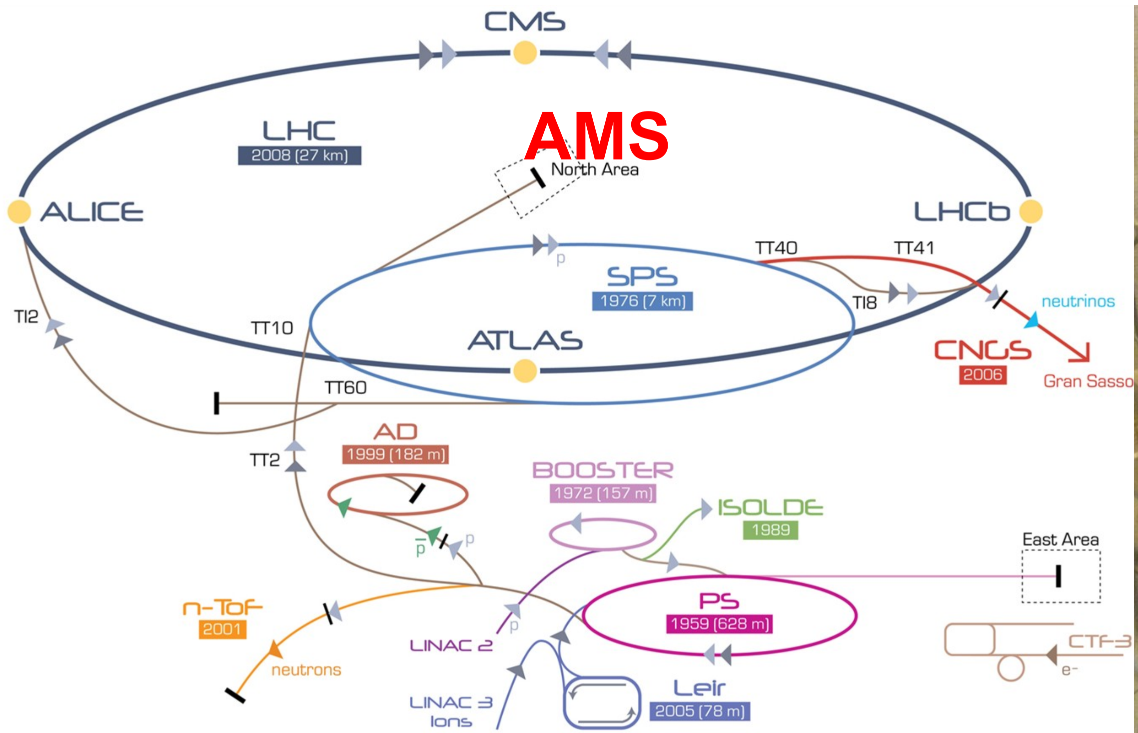
# ECAL Performance

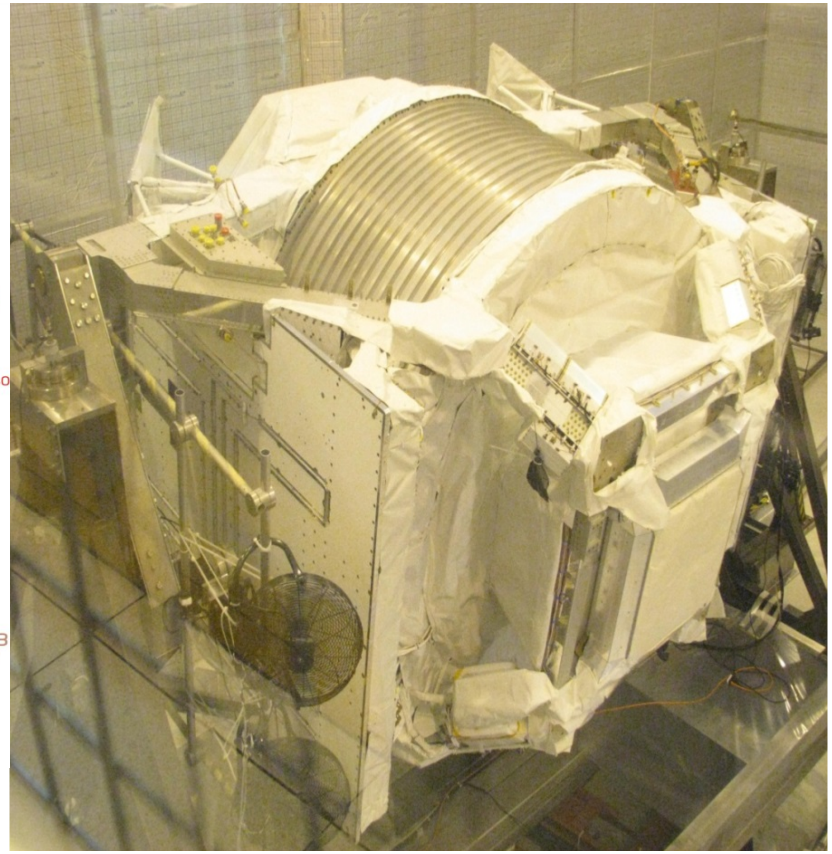


# Data from ISS: Proton rejection using the ECAL



# Intensive Beam Tests at CERN



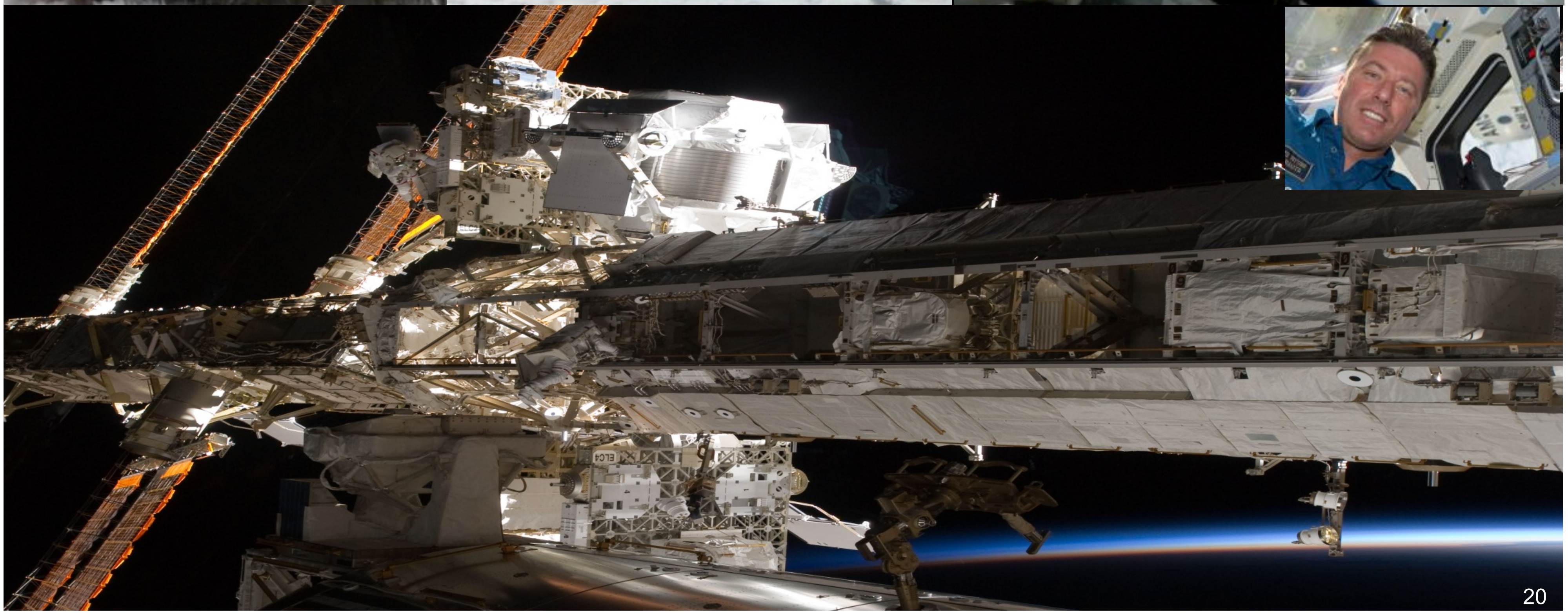



# AMS in SPS Test Beam, 2010

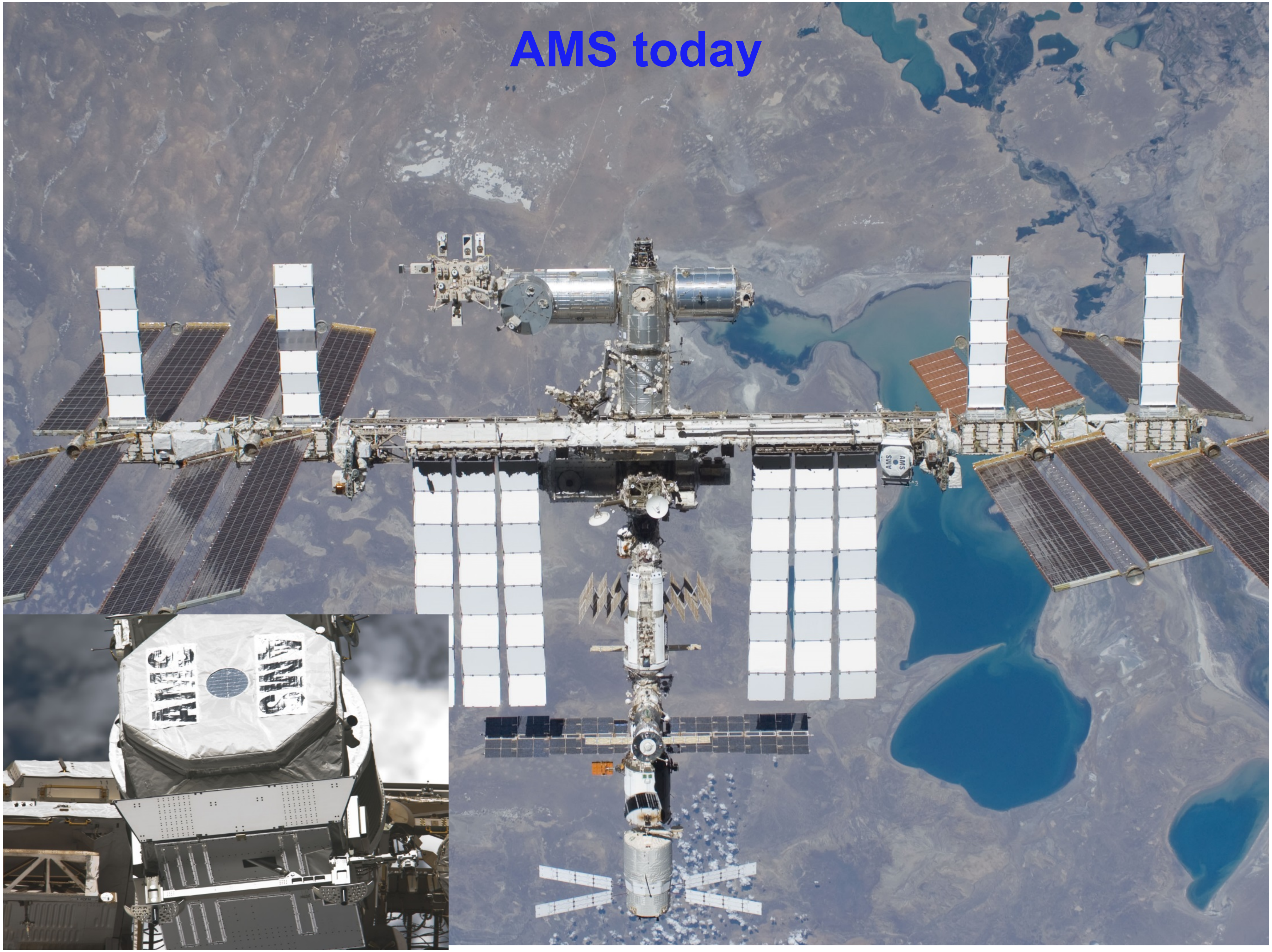
| Particle | Momentum (GeV/c) | Positions | Purpose |
|---|---|---|---|
| Protons | 400 + 180 | 1,650 | Full Tracker alignment,<br>TOF calibration,<br>ECAL uniformity |
| Electrons | 100, 120, 180, 290 | 7 each | TRD, ECAL performance study |
| Positrons | 10, 20, 60, 80, 120, 180 | 7 each | TRD, ECAL performance study |
| Pions | 20, 60, 80, 100, 120, 180 | 7 each | TRD performance to 1.2 TeV |


May 16, 2011

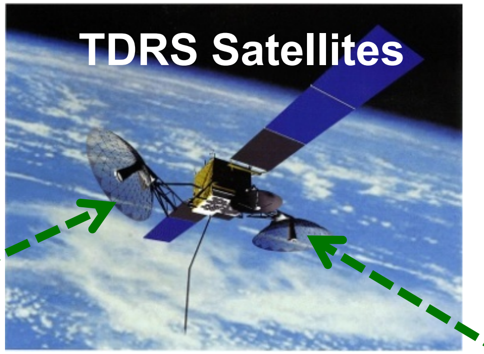

May 16th, 2011



# AMS today



# AMS Operations




White Sands, NM

24 hours
x 365 days
x 10-20 years

# AMS

# Physics results

# Data analysis in AMS (2 years of data)

## AMS is a very precise particle physics detector.

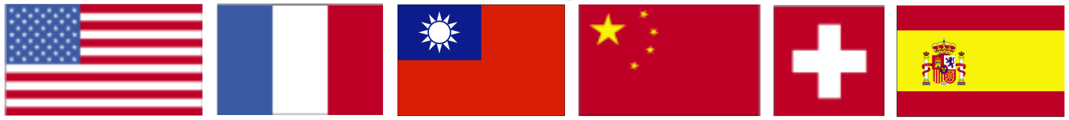
Precision physics results require attention to detail and a large analysis effort.

The data are analysed by two independent AMS international teams.

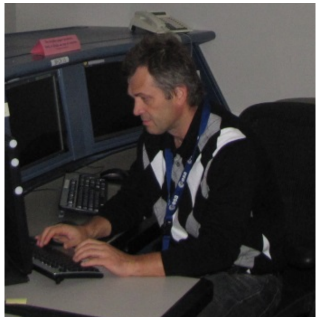
Example: the positron fraction paper

**Group A**

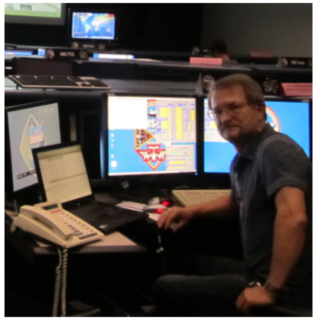
**Group α**



B. Bertucci



V. Choutko



A. Kounine

J. Berdugo

S. Schael

M. Incagli


S. Rosier-Lees

S. Haino, A. Oliva

J. Casaus, P. Zuccon

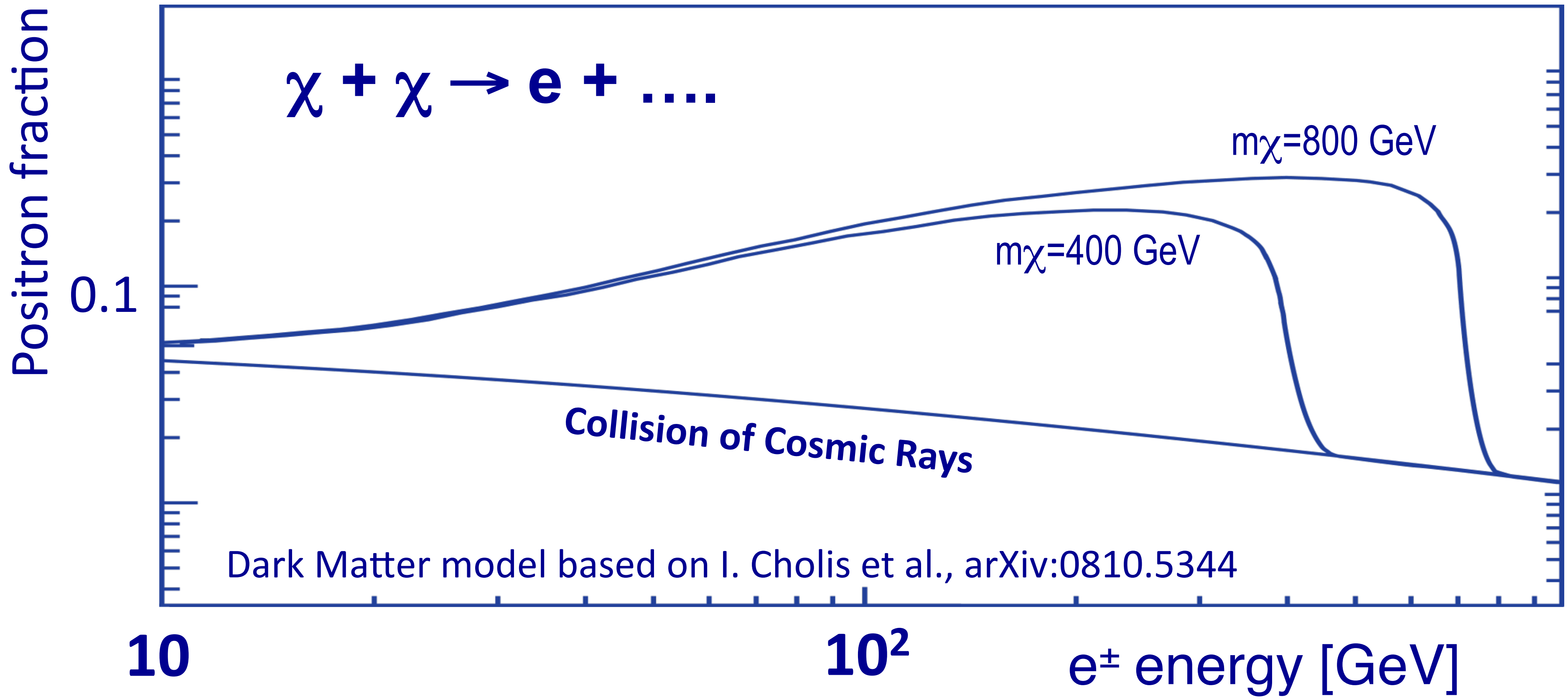
A. Contin

# Physics results (ICRC 2013)

1. $e^+/(e^+ + e^-)$ ratio and anysotropy
2. Proton spectrum
3. Helium spectrum
4. Electron Spectrum
5. Positron Spectrum
6. All electron spectrum
7. Boron-to-Carbon ratio

# Physics of Positron Fraction: $e^+/(e^+ + e^-)$

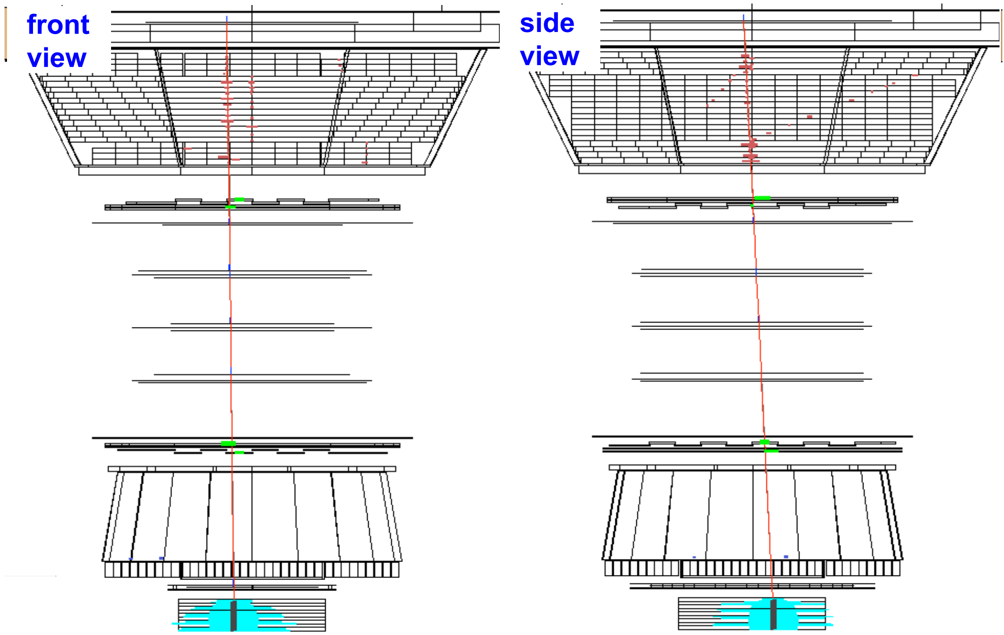
M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001;
J. Ellis, 26th ICRC Salt Lake City (1999) astro-ph/9911440;
H. Cheng, J. Feng and K. Matchev, Phys. Rev. Lett. 89 (2002) 211301;
S. Profumo and P. Ullio, J. Cosmology Astroparticle Phys. JCAP07 (2004) 006;
D. Hooper and J. Silk, Phys. Rev. D 71 (2005) 083503;
E. Ponton and L. Randall, JHEP 0904 (2009) 080;
G. Kane, R. Lu and S. Watson, Phys. Lett. B681 (2009) 151;
D. Hooper, P. Blasi and P. D. Serpico, JCAP 0901 025 (2009) 0810.1527; B2
Y–Z. Fan et al., Int. J. Mod. Phys. D19 (2010) 2011;
M. Pato, M. Lattanzi and G. Bertone, JCAP 1012 (2010) 020.



# In the first 1.5 years in space, AMS has collected over 25 billion events. 6.8 million are electrons or positrons.

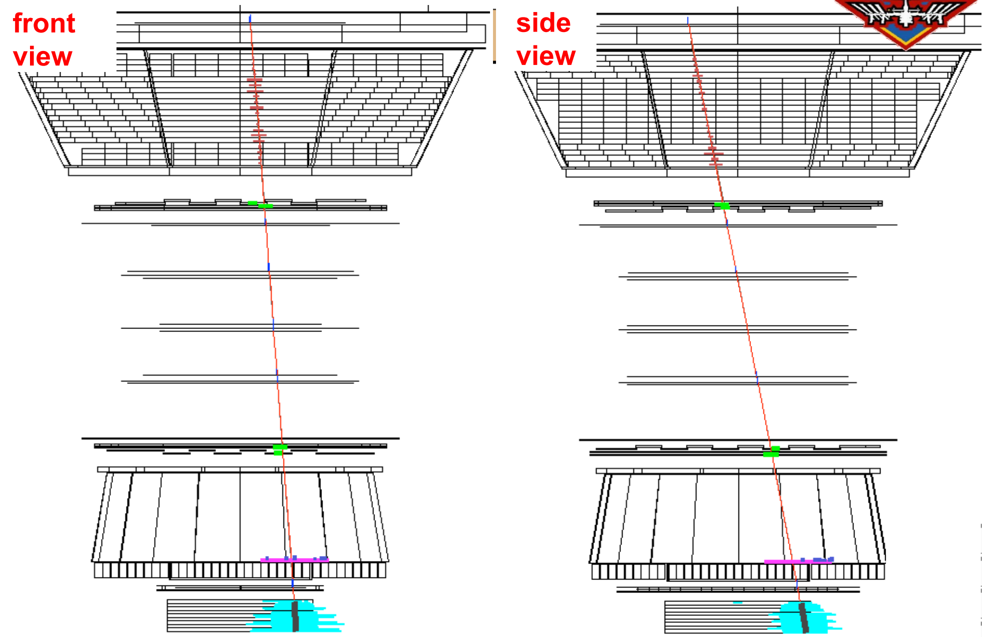
## Electron E=982 GeV

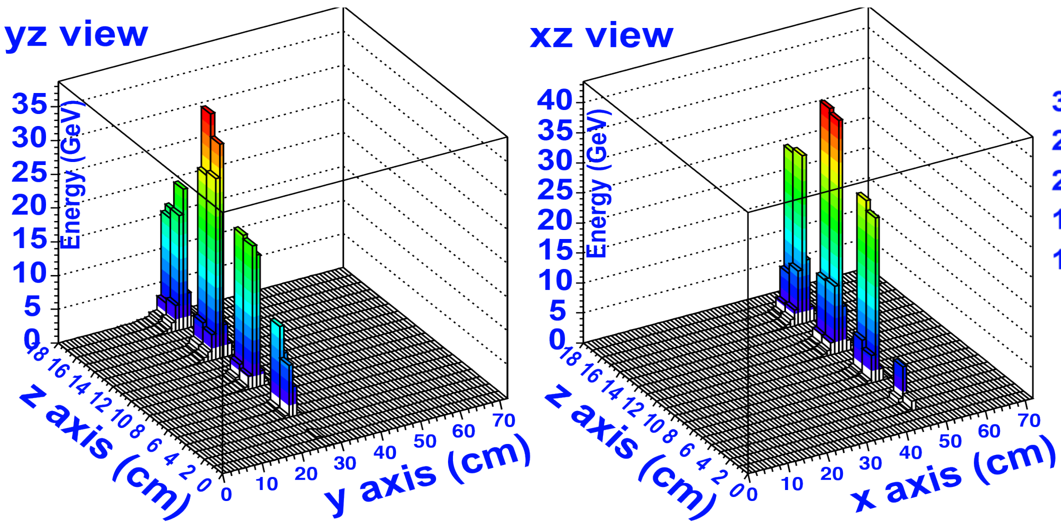
**Run/Event 1329775818/ 60709**

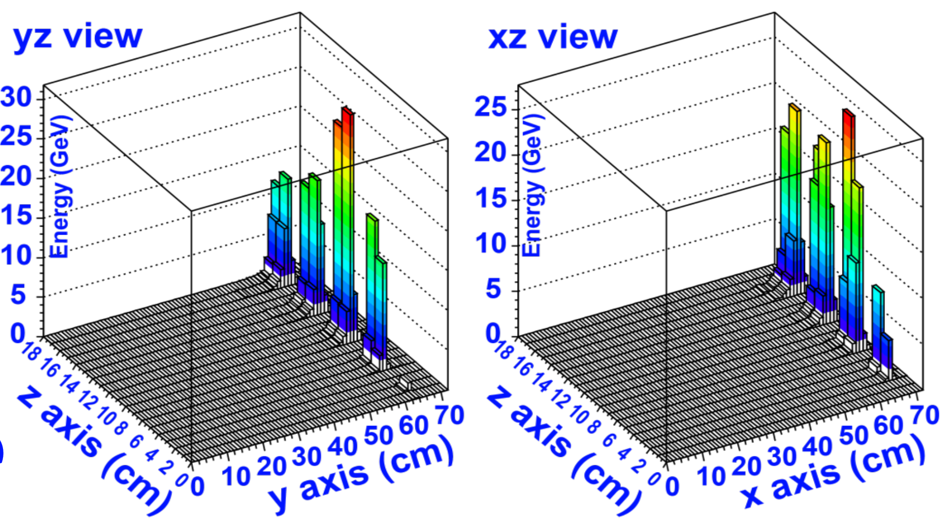



## Positron E=636 GeV

**Run/Event 133119-743/ 56950**

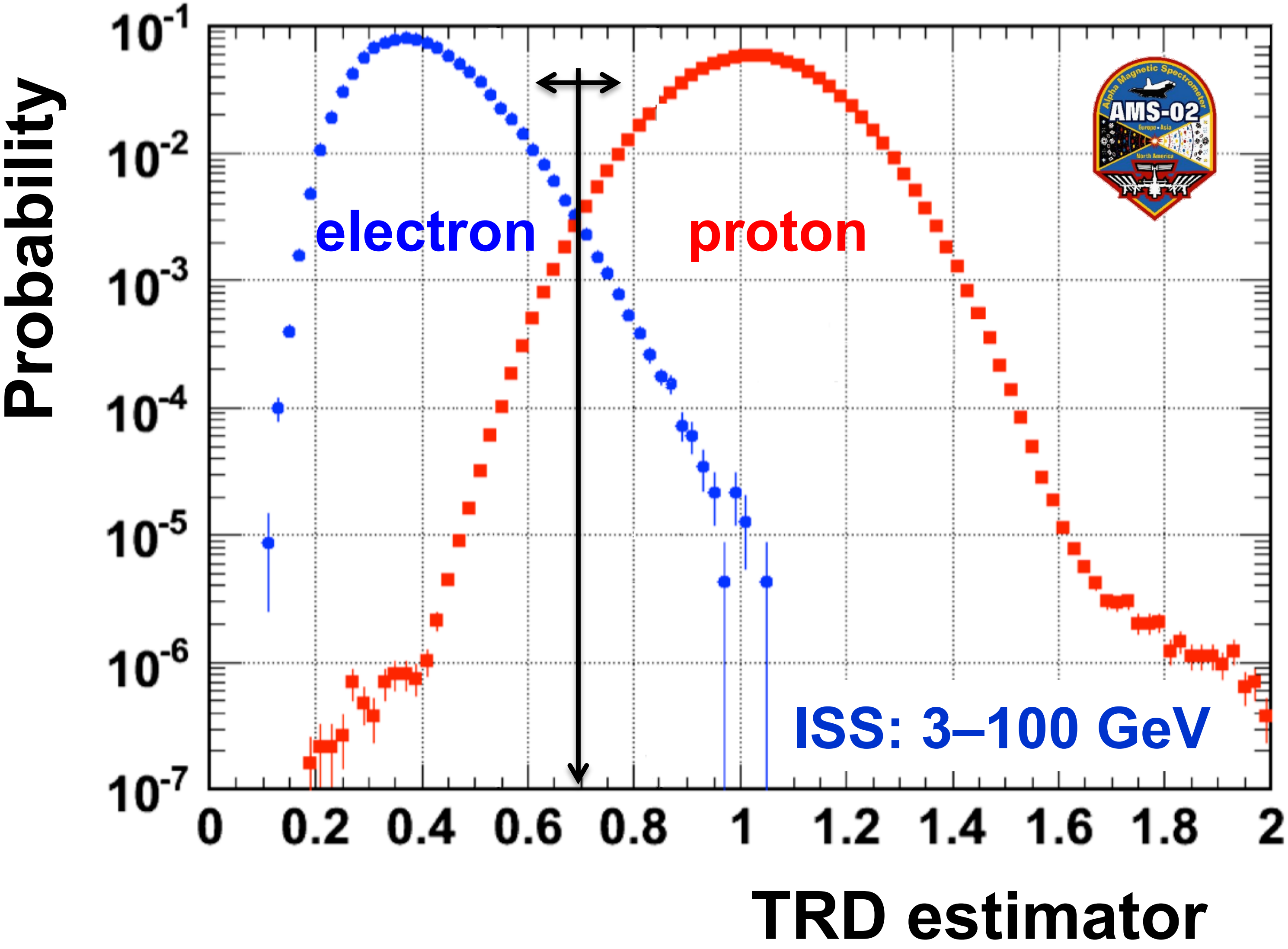


# TRD performance on ISS

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

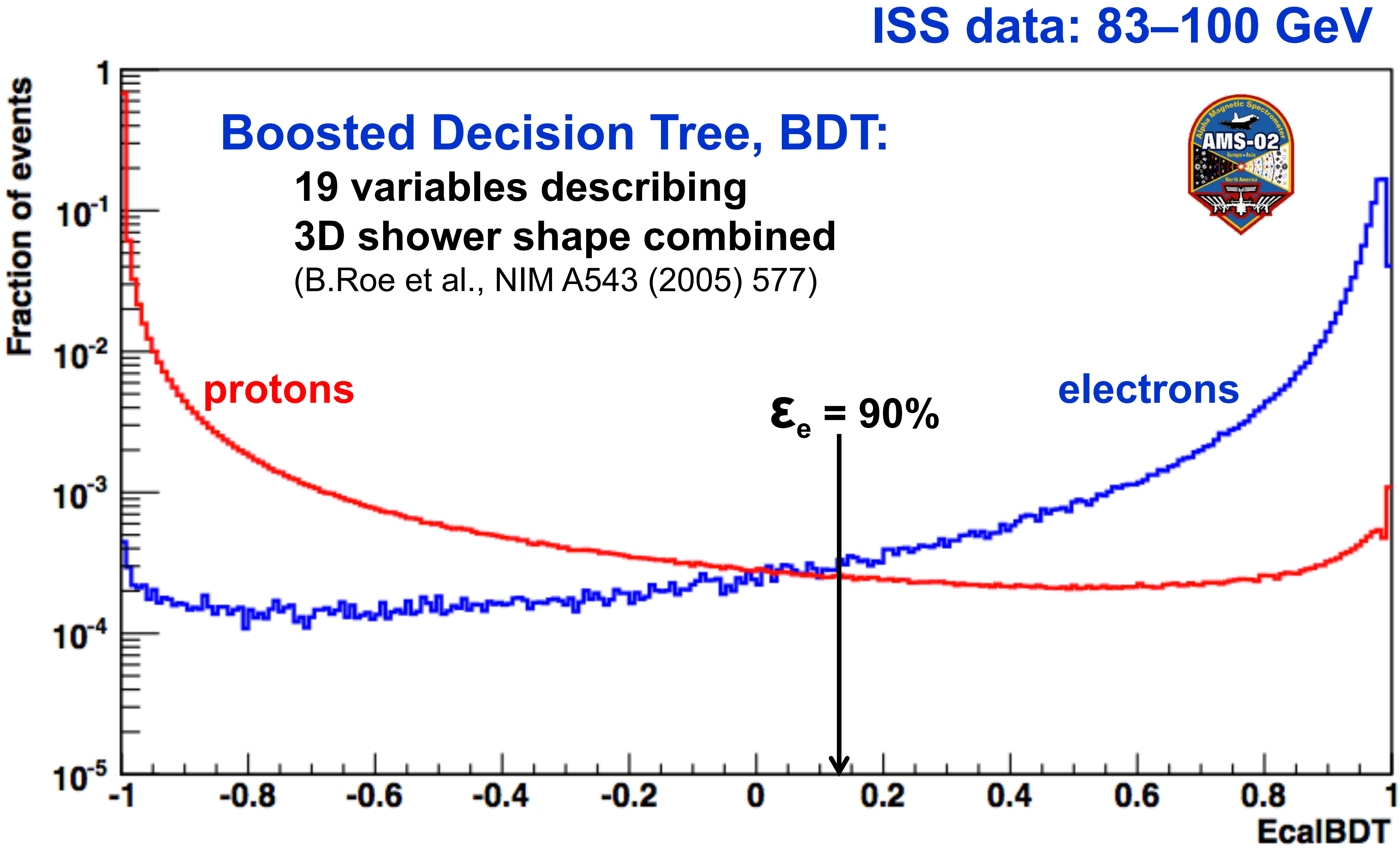



**Normalized probabilities $P_e$ and $P_p$**

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

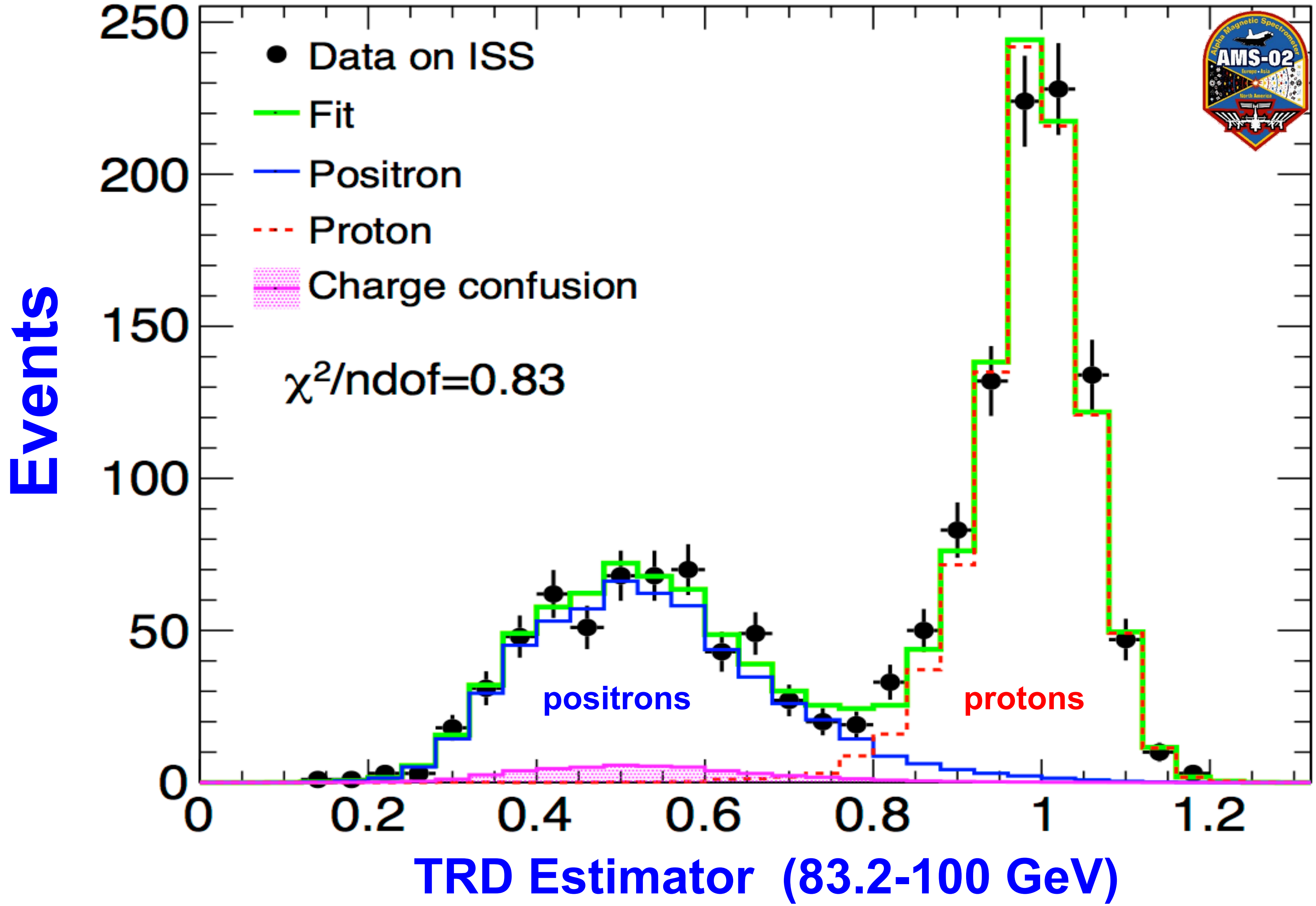
$$P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)}$$

# Separation of protons and electrons with ECAL



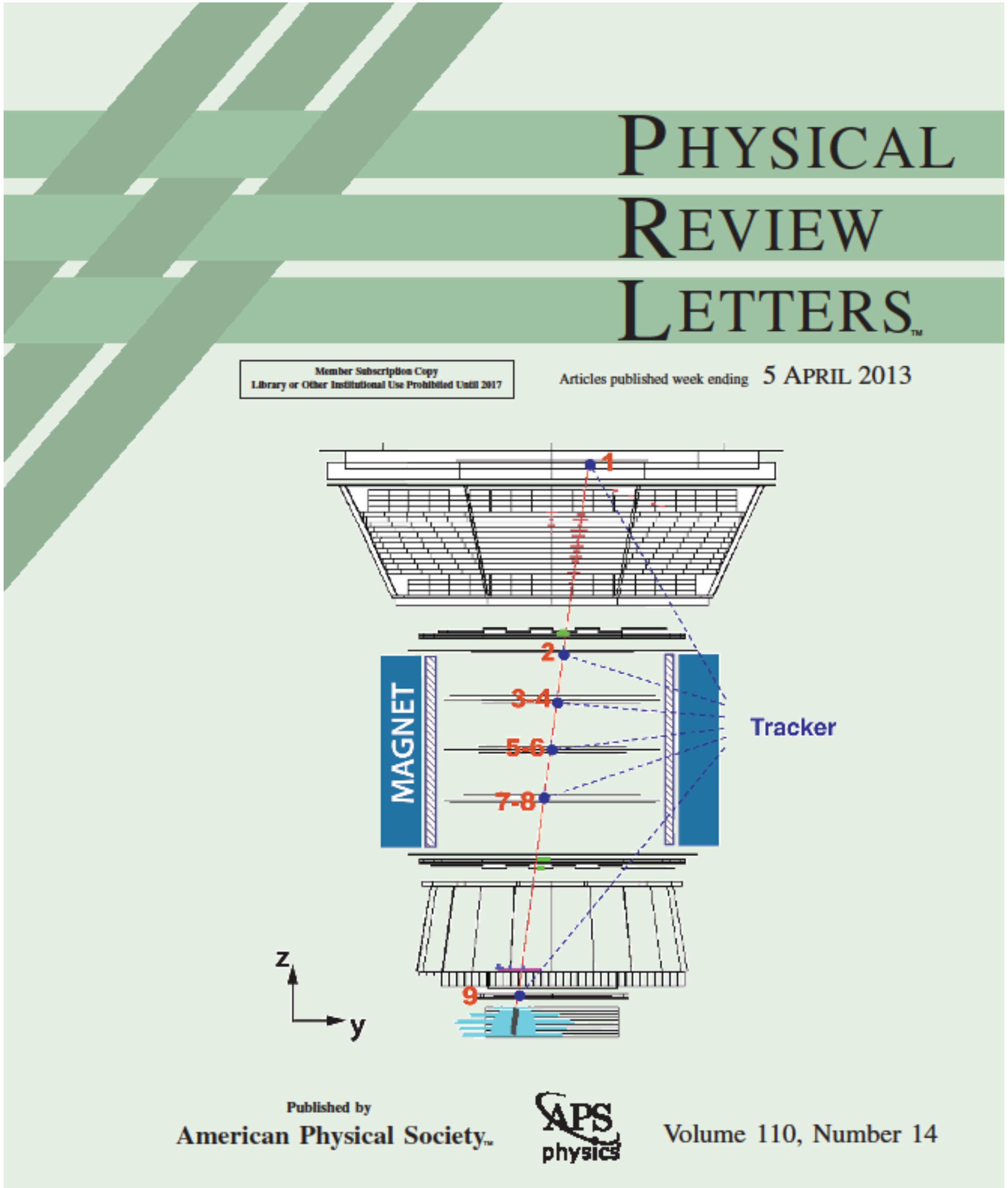
# Results of the fit:

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

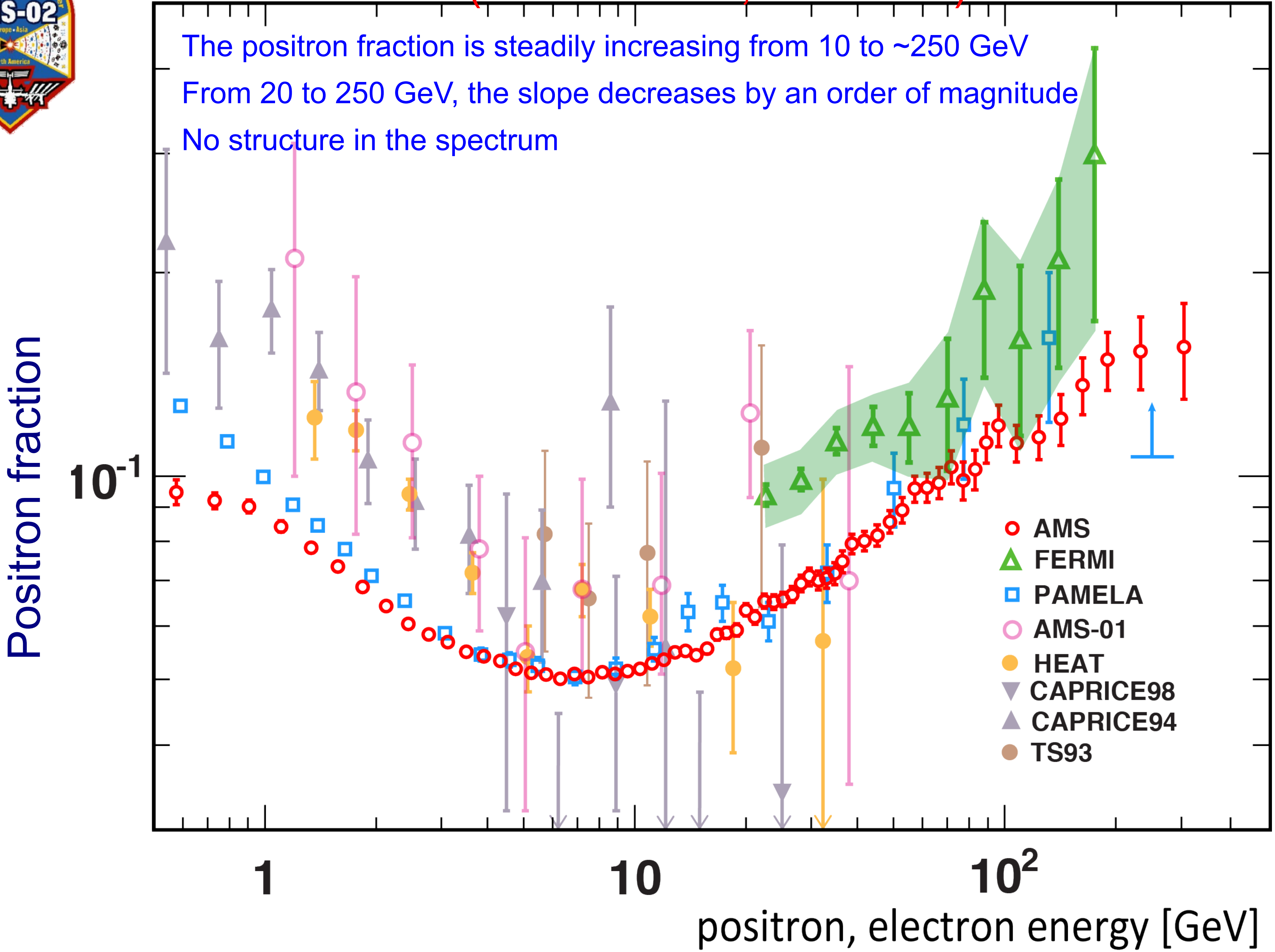


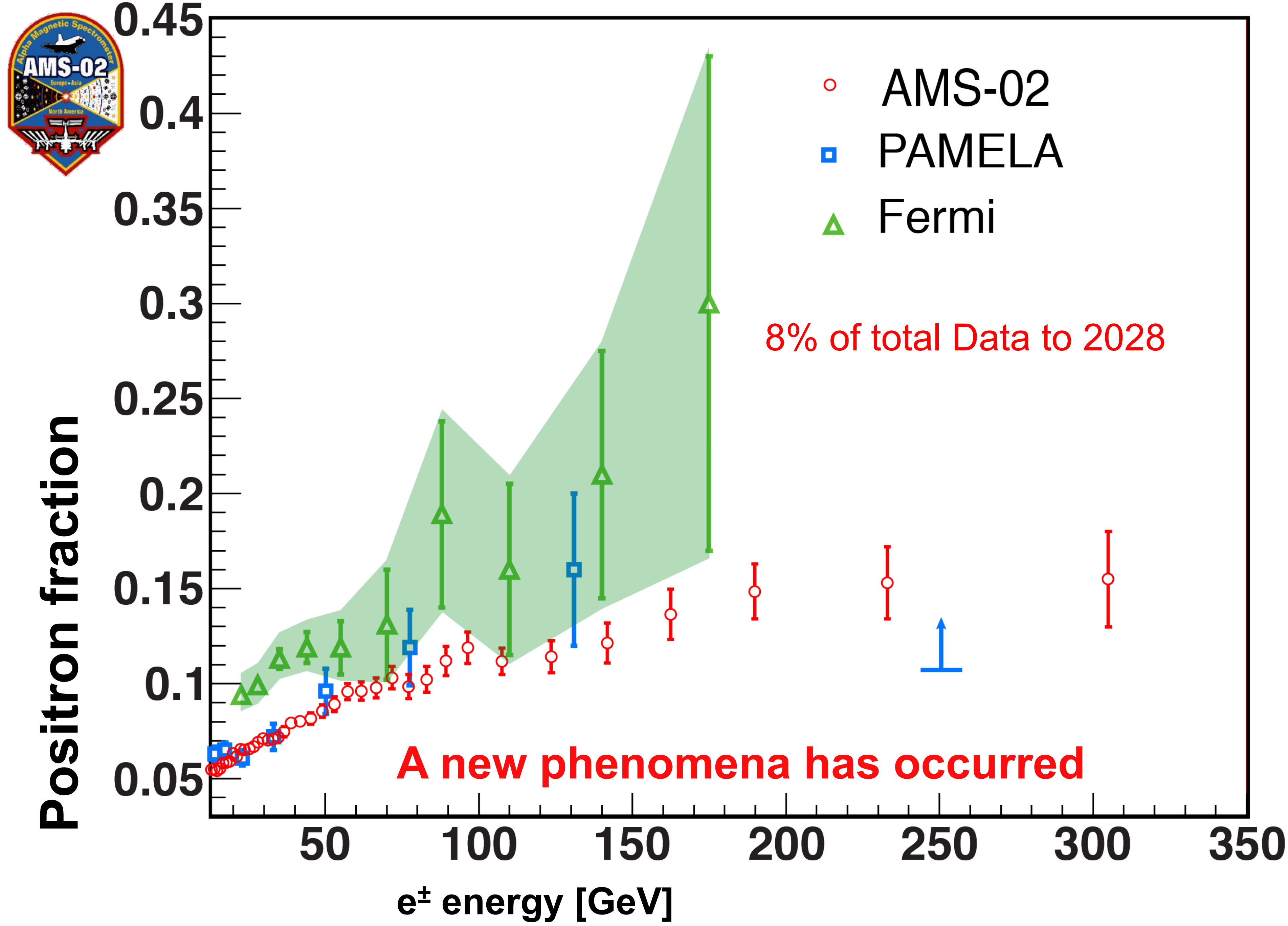
"First Result from the AMS on the ISS: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5-350 GeV"

Selected for a Viewpoint in Physics and an Editors' Suggestion [Aguilar,M. et al (AMS Collaboration) Phys. Rev. Lett. 110, 1411xx (2013)]



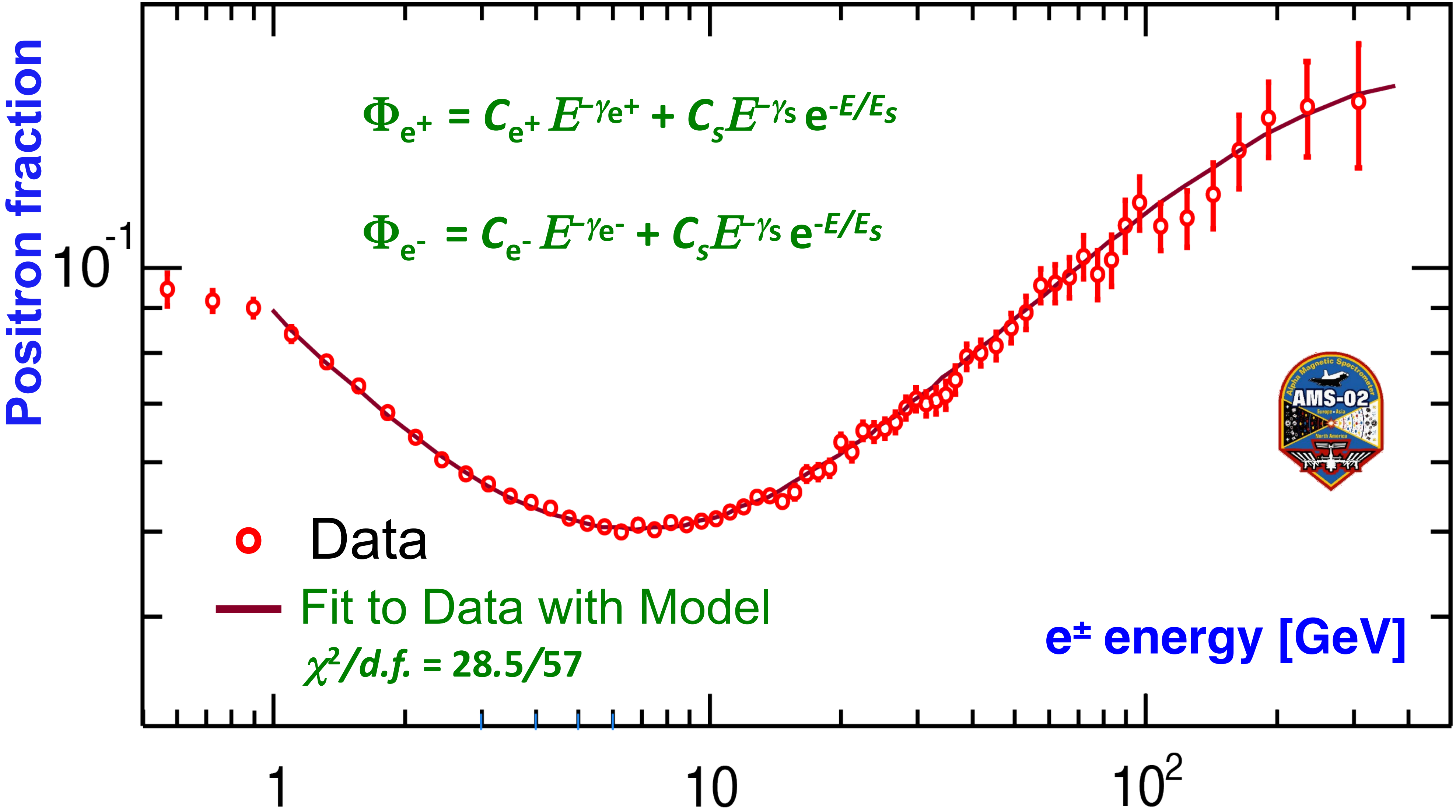
# AMS-02 (6.8 million $e^+$, $e^-$ events)





AMS-02
Alpha Magnetic Spectrometer
Europe • Asia
North America
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
Positron fraction
50
100
150
200
250
300
350
e± energy [GeV]
AMS-02
PAMELA
Fermi
8% of total Data to 2028
A new phenomena has occurred

# Physics Example: Comparing data with a minimal model.




The agreement between the data and the model shows that the positron fraction spectrum is consistent with e± fluxes each of which is the sum of its diffuse spectrum and a single common power law source.

**A fit to the data in the energy range 1 to 350 GeV yields:**

$\gamma_{e-} - \gamma_{e+}$ = **−0.63 ± 0.03**, *i.e.*, the diffuse positron spectrum is less energetic than the diffuse electron spectrum;

$\gamma_{e-} - \gamma_{S}$ = **0.66±0.05**, *i.e.*, the source spectrum is more energetic than the diffuse electron spectrum;

$C_{e+}/C_{e-}$ = **0.091 ± 0.001**, *i.e.*, the weight of the diffuse positron flux amounts to ~10% of that of the diffuse electron flux;

$C_{S}/C_{e-}$ = **0.0078 ± 0.0012**, *i.e.*, the weight of the common source constitutes only ~1% of that of the diffuse electron flux;

$1/E_s$ = **0.0013 ± 0.0007 GeV$^{-1}$**,

corresponding to a cutoff energy of **$760^{+1000}_{-280}$ GeV**.

**Bergstrom,Bringmann,Cholis,Hooper,Weniger 2013**

PRL **111,** 171101 (2013) PHYSICAL REVIEW LETTERS week ending 25 OCTOBER 2013

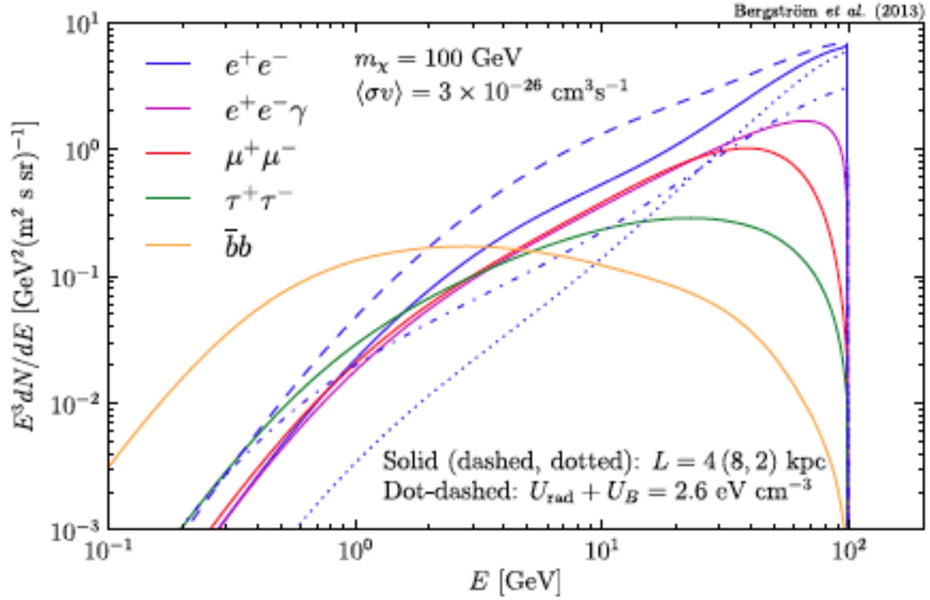



FIG. 1 (color online). The $e^{\pm}$ spectrum from annihilating DM, after propagation, for different annihilation final states, assuming $\langle\sigma v\rangle = 3\times10^{-26}$ cm$^3$ s$^{-1}$. Solid lines refer to reference diffusion zone ($L = 4$ kpc) and energy loss assumptions ($U_{\rm rad} + U_B = 1.7$ eV cm$^{-3}$). Dashed (dotted) lines show the effect of a different scale height $L = 8(2)$ kpc. The dotted-dashed line shows the impact of increasing the local radiation plus magnetic field density to $U_{\rm rad} + U_B = 2.6$ eV cm$^{-3}$.

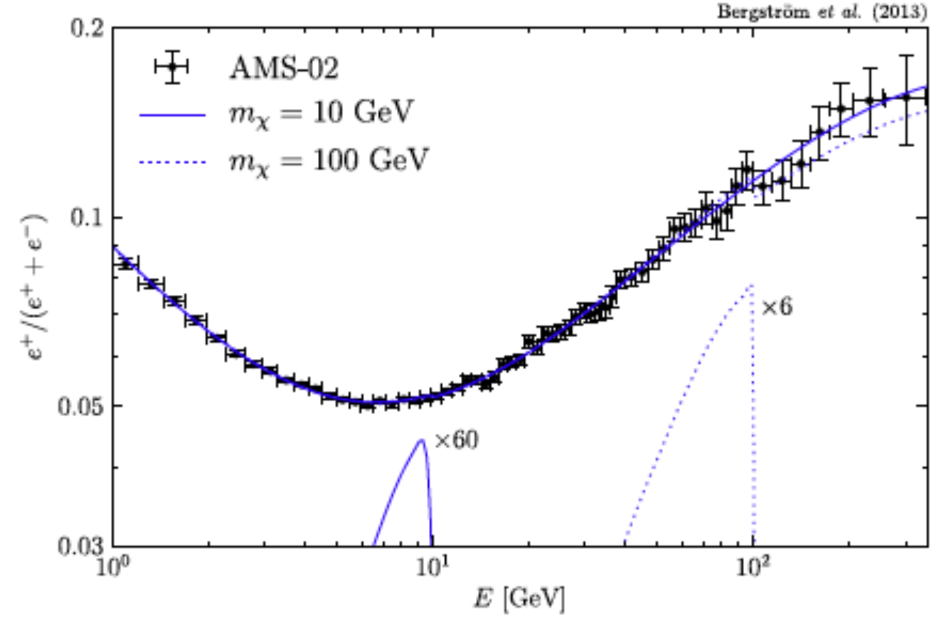



FIG. 2 (color online). The AMS positron fraction measurement [2] and background + signal fit for DM annihilating directly to $e^+e^-$, for $m_\chi = 10$ GeV and 100 GeV. The normalization of the DM signal in each case was chosen such that it is barely excluded at the 95% C.L. For better visibility, the contribution from DM (lower lines) has been rescaled as indicated.

**Also : Ibarra,Lamperstorfer,Silk 2013**

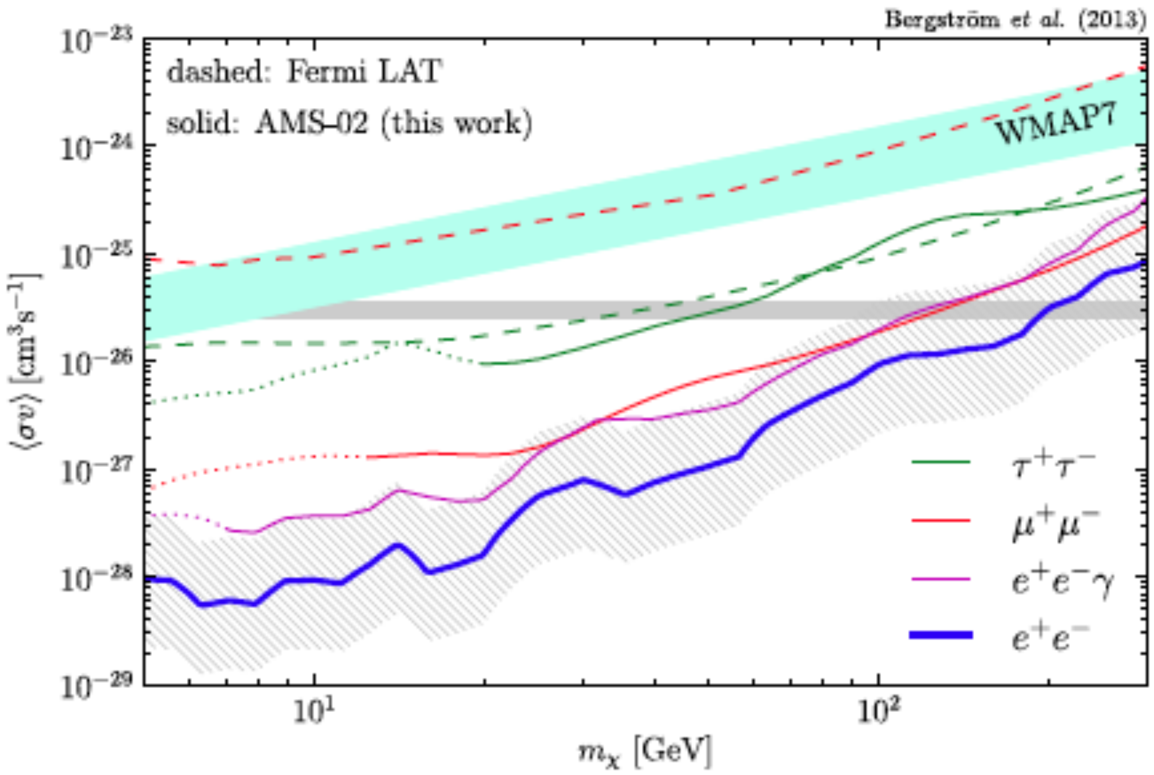
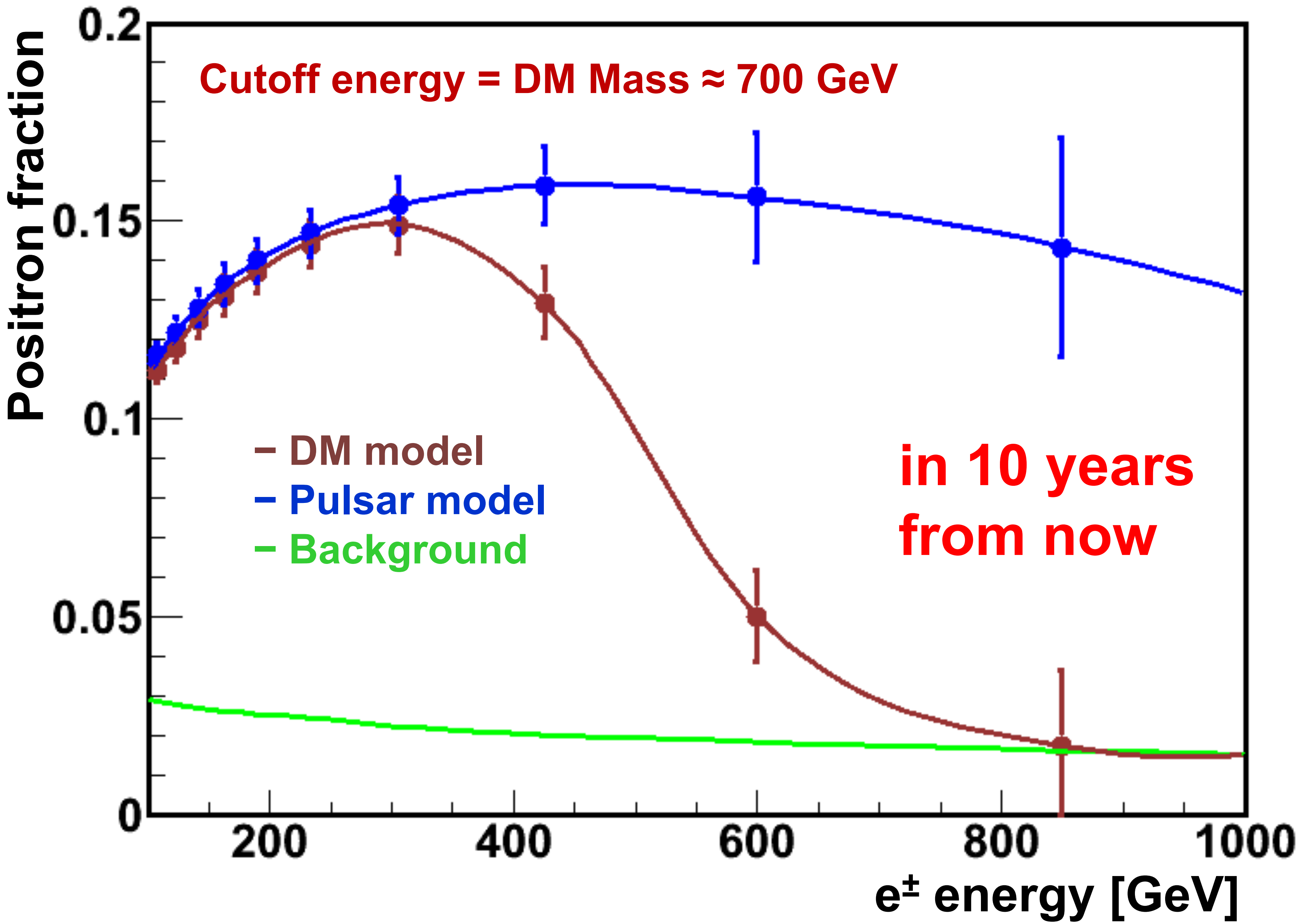
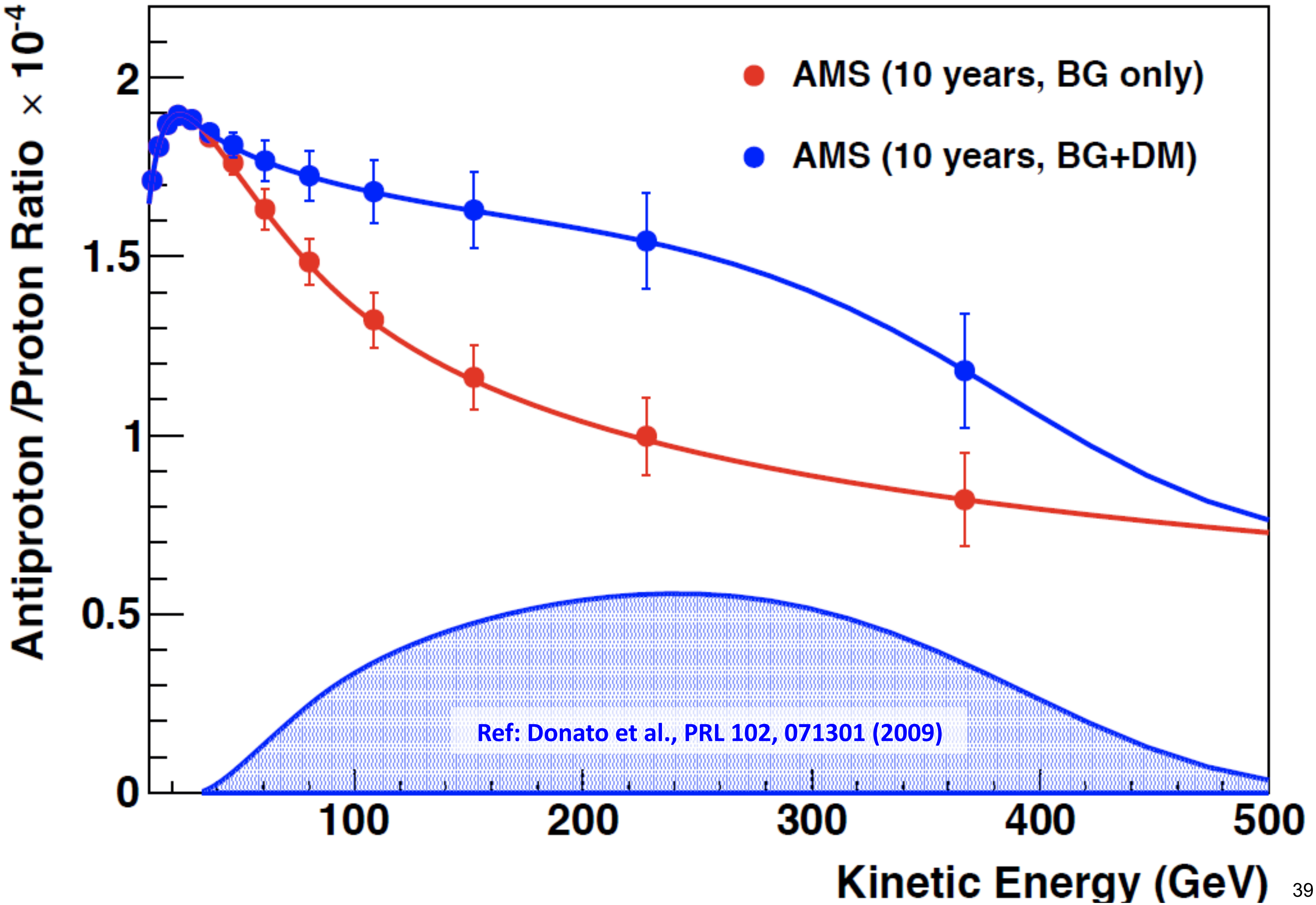



FIG. 3 (color online). Upper limits (95% C.L.) on the DM annihilation cross section, as derived from the AMS positron fraction, for various final states (this work), WMAP7 (for $\ell^+\ell^-$) [44], and Fermi LAT dwarf spheroidals (for $\mu^+\mu^-$ and $\tau^+\tau^-$) [43]. The dotted portions of the curves are potentially affected by solar modulation. We also indicate $\langle\sigma v\rangle_{\rm therm} \equiv 3\times10^{-26}$ cm$^3$ s$^{-1}$. The AMS limits are shown for reasonable reference values of the local DM density and energy loss rate (see text), and can vary by a factor of a few, as indicated by the hatched band (for clarity, this band is only shown around the $e^+e^-$ constraint).




**What will the Positron Fraction look like at high energy?**

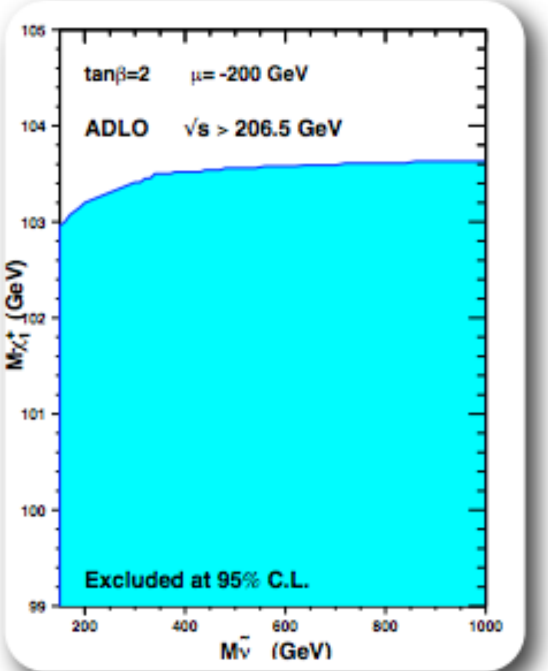
# Comparison of $\overline{p}/p$ with Models in 10 more years



# Current limits: neutralino/chargino

7

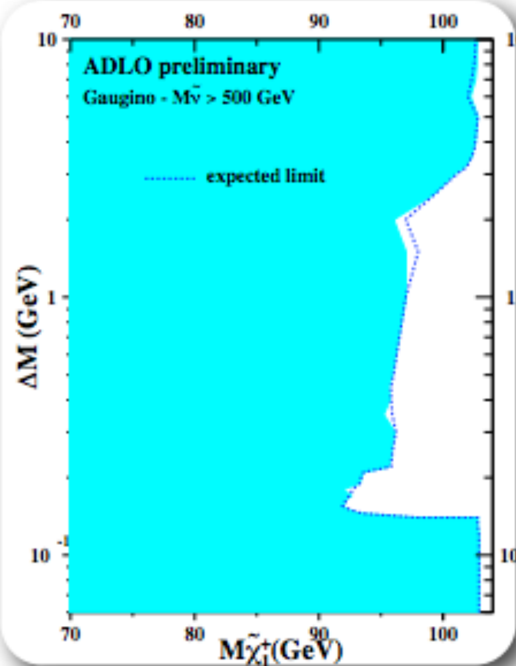
**canonical case**




**$m\chi_1^{\pm}$ > 103.5 GeV**
**for $m_{snue}$ > 300 GeV**

LEPSUSYWG/01-03.1

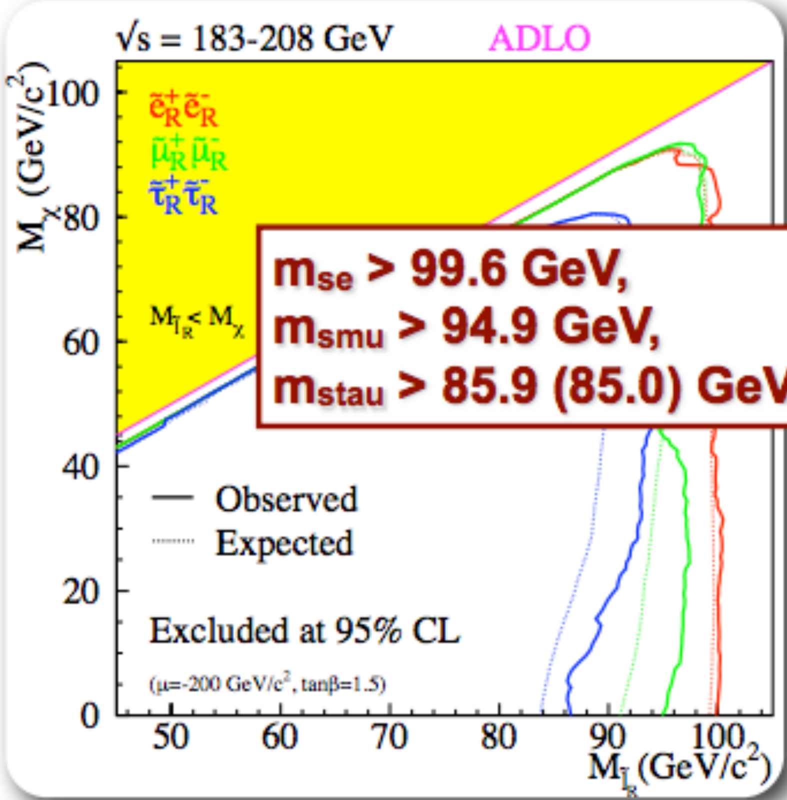
**degenerate case**




**$m\chi_1^{\pm}$ > 91.9 /92.4 GeV**

LEPSUSYWG/02-04.1

**$m\chi_1^{0}$ > 47/50 GeV**
**(CMSSM, mSUGRA)**
**No mass limit in general**




**$m_{se}$ > 99.6 GeV,**
**$m_{smu}$ > 94.9 GeV,**
**$m_{stau}$ > 85.9 (85.0) GeV**

LEPSUSYWG/04-01.1

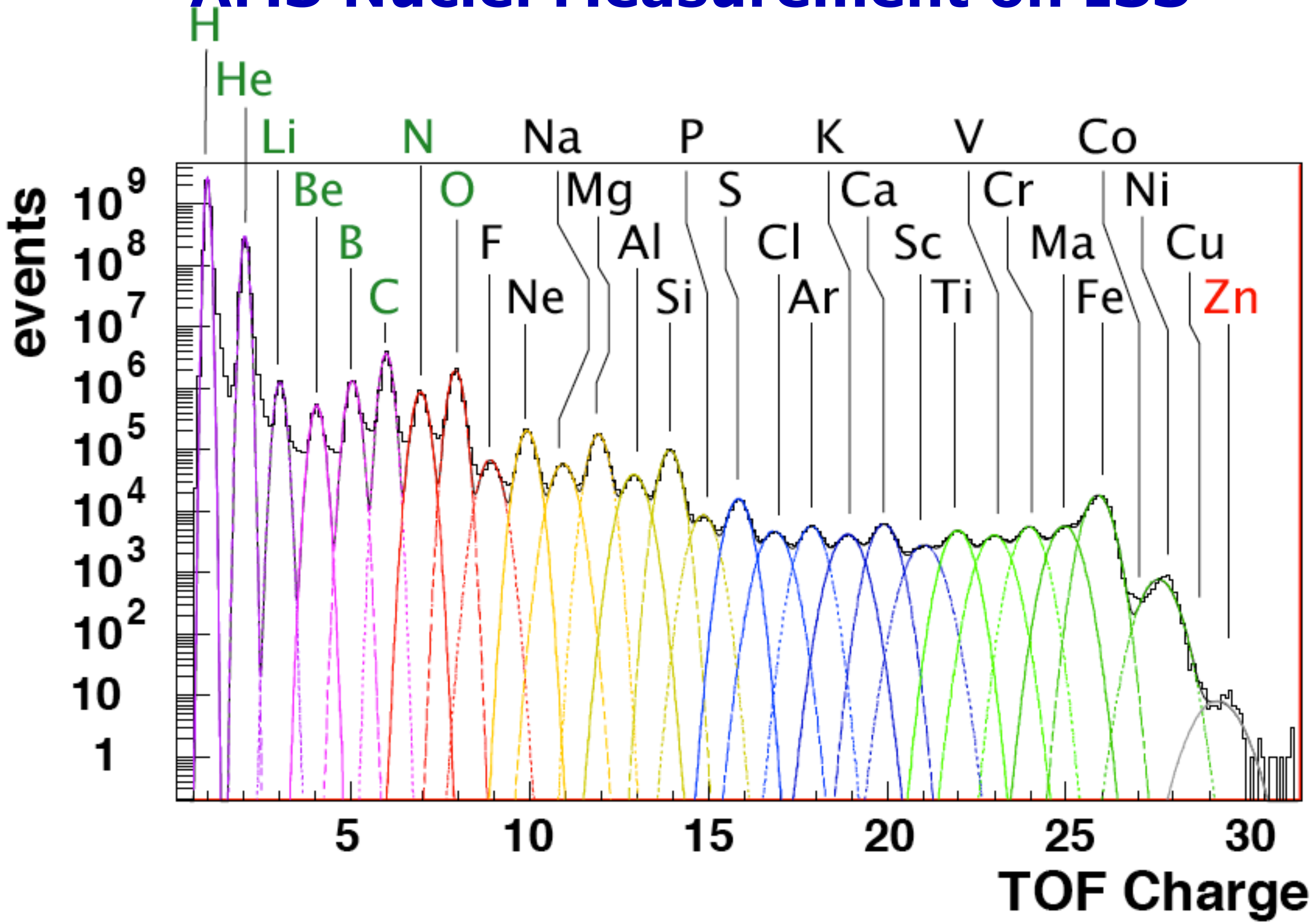
We now understand
the systematic errors to ~1%.

Studies with 1% statistical error
will take time to collect the data.

# Physics analysis nearing completion

1. Antiprotons (0.5-300 GeV)
2. Anti-He (@ few $10^8$ He events)
3. Ion fluxes
4. Solar physics
5. ….

# AMS Nuclei Measurement on ISS



# The Cosmos is the Ultimate Laboratory.

## Cosmic rays can be observed at energies higher than any accelerator.

**With AMS-02 on the ISS we have entered the era of precision Cosmic Ray physics to search for phenomena which exist in nature but we have not yet imagined nor had the tools to discover.**