Latest results from AMS

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Academia Sinica

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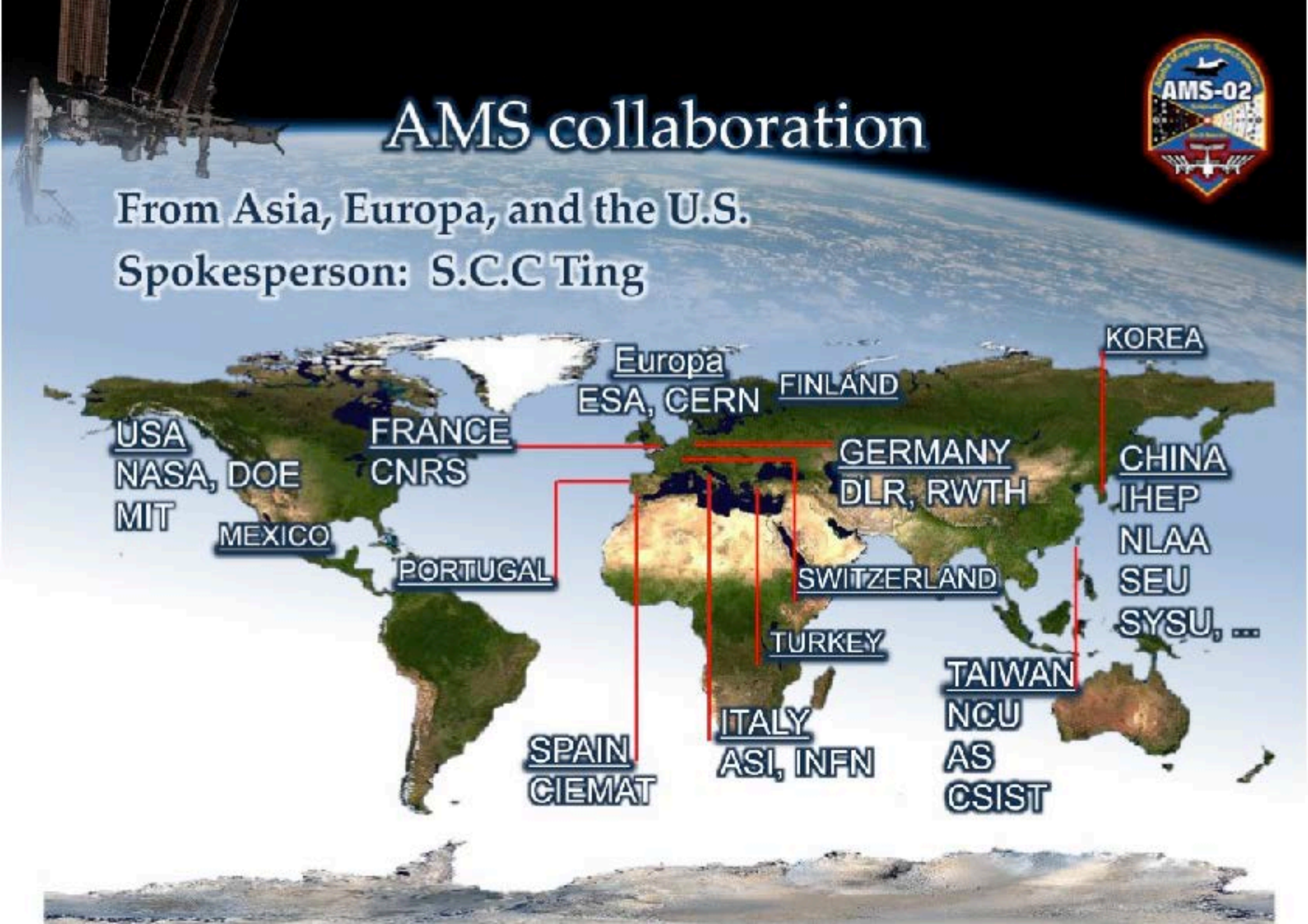
APEC & ICRR Seminar

中央研究院
Academia Sinica

AMS collaboration

From Asia, Europa, and the U.S.

Spokesperson: S.C.C Ting



Taiwan in AMS

AMS is the only project supported by Academia Sinica, National Science Council as well as the defence and the space agencies, all with the highest priority

NCU

National ChiaoTung University

AIDC

National Cheng Kung University

Academia Sinica

Chung-Shan Institute of Science and Technology

NSPO

National Space Organization

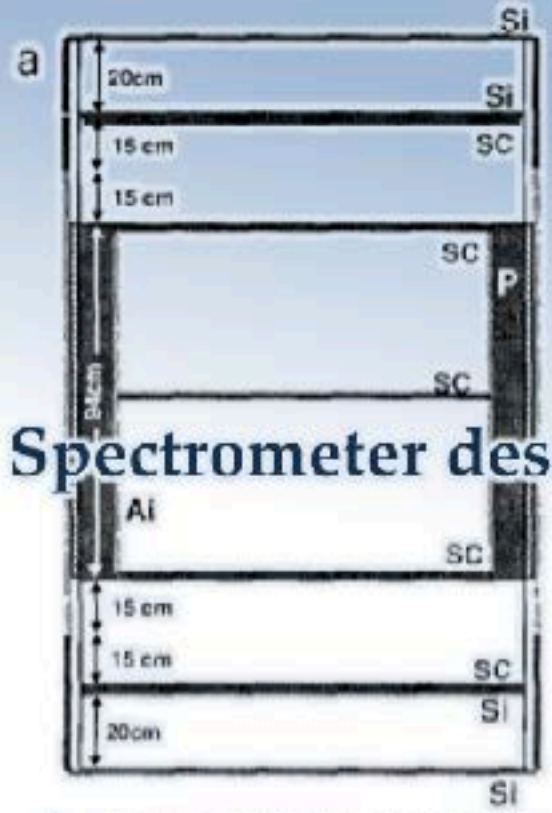
Original idea of AMS (1994)

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

An antimatter spectrometer in space

Antimatter Study Group

Spectrometer design



P permanent magnet with supporting structure
SC Double sided silicon detector resolution (7μ) and $\frac{dE}{dx}$ (charge) measurements
Si scintillators for time a flight and $\frac{dE}{dx}$ (charge)
Al veto scintillators

Magnet design

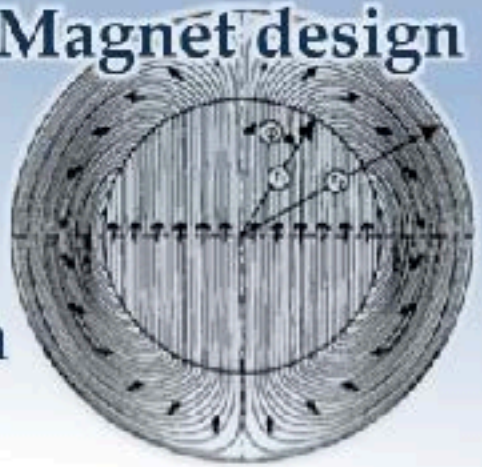


Fig. 6. Magnetic field distribution at a cross-section of the center of the magnet.

Anti-He/He Ratio

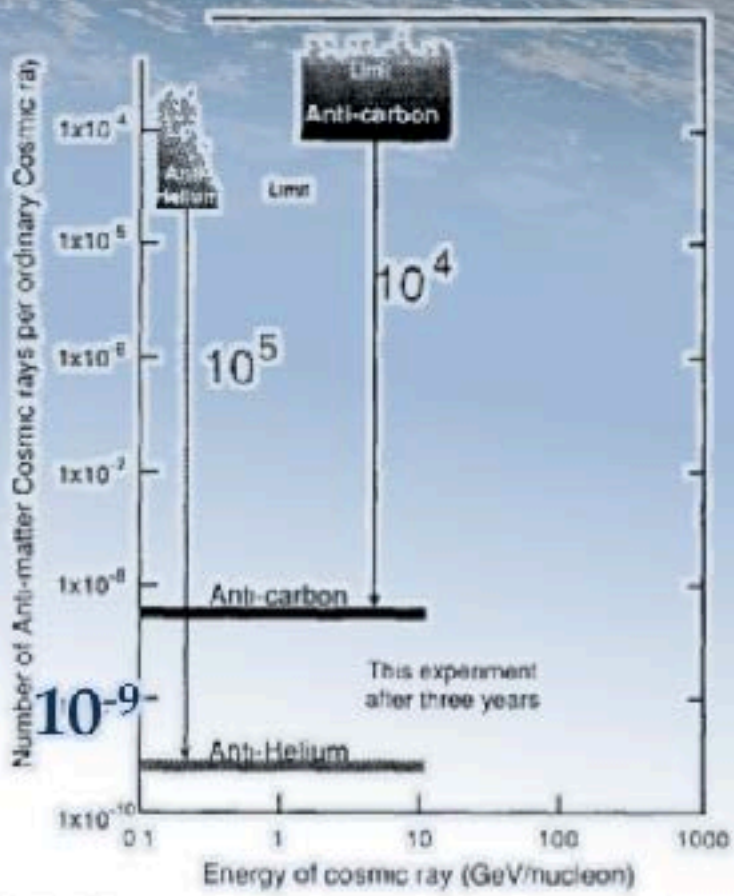
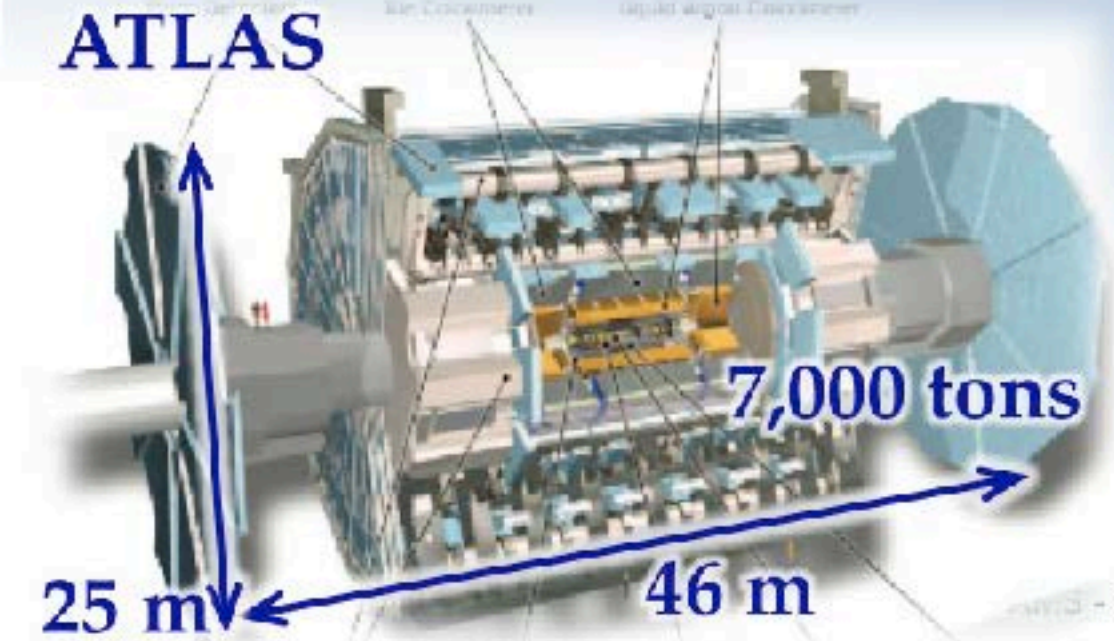
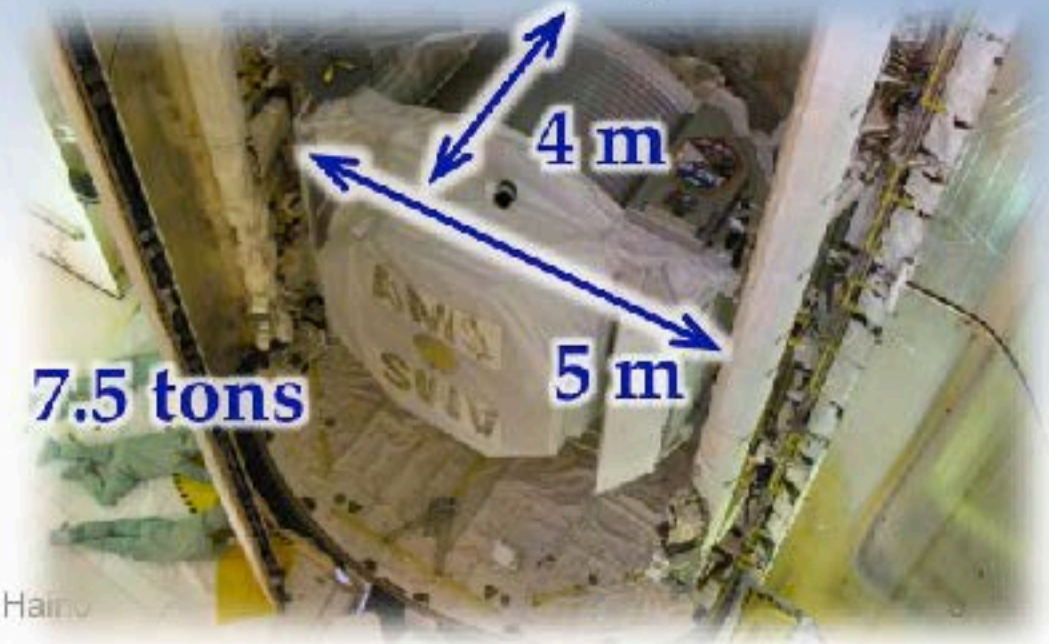


Fig. 30. Current limits and sensitivity of this experiment for antimatter. In addition to the search for antimatter, our detector could be easily modified (particularly for options 2 and 4) to explore the search of $\bar{p}$ and e^+.

Technical challenges

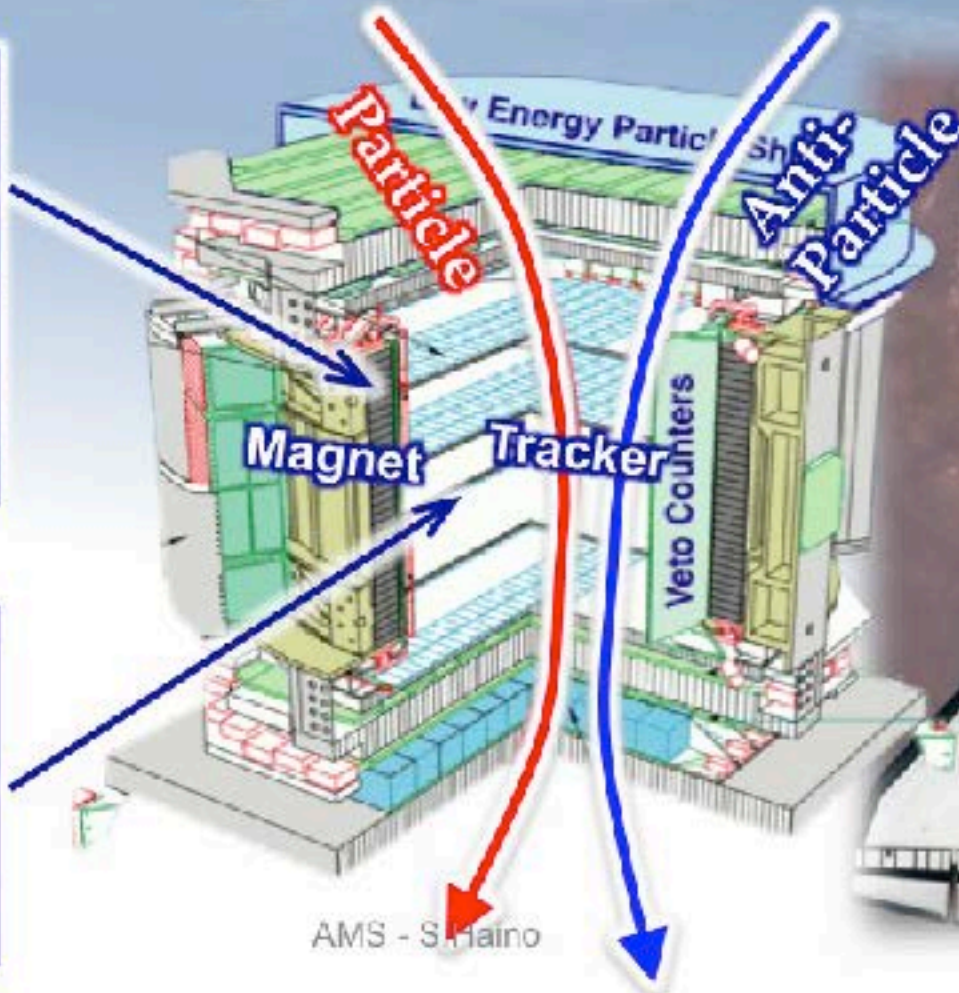
- AMS is designed with the same capability as state-of-art CERN-LHC detectors
  but small enough to fit in space shuttle
- AMS needs to work for 20 years in extreme space enviroment without access nor repair





Test flignt : AMS-01 (1998)

- One week flight on space shuttle Discovery with the same magnet as AMS-02



... and it took ~12 years

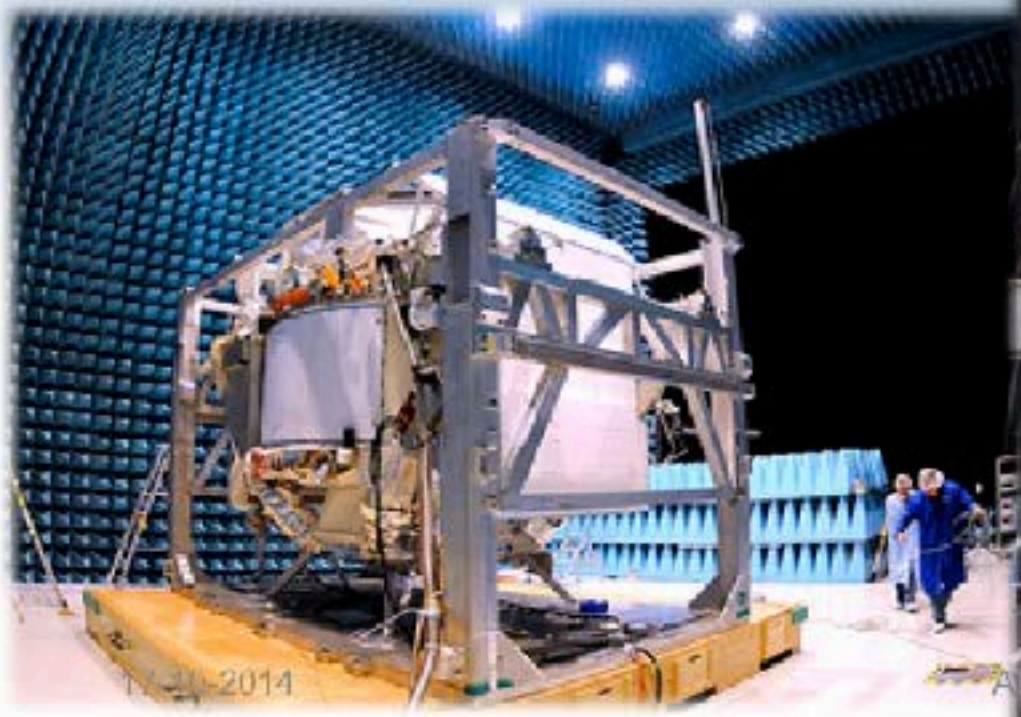
For

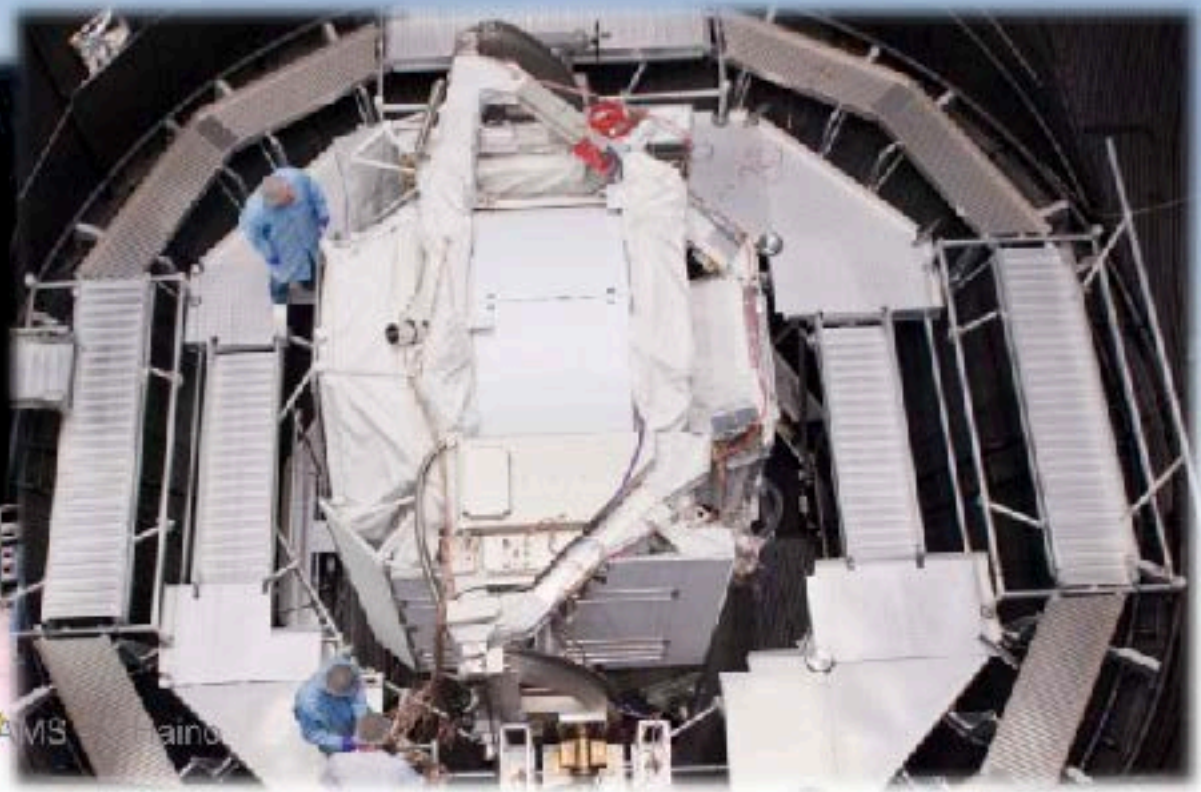
- Design
- Construction
- Space qualification tests of sub-systems and
- Integration of AMS-02

Space qualification at ESA

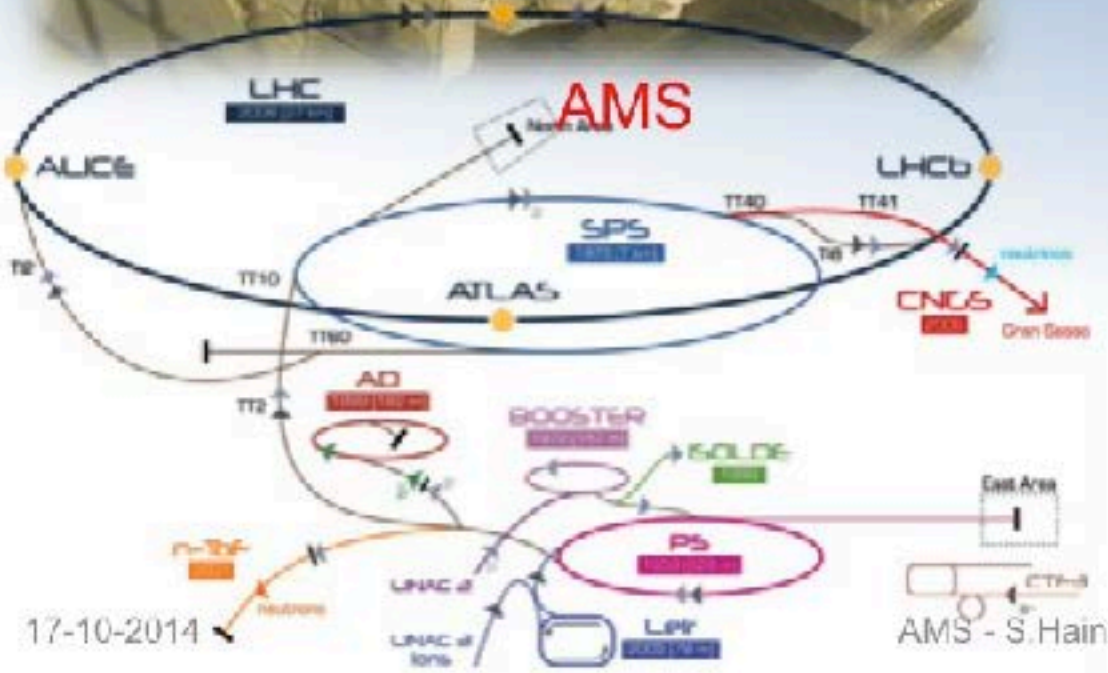
Mar~Apr/2010

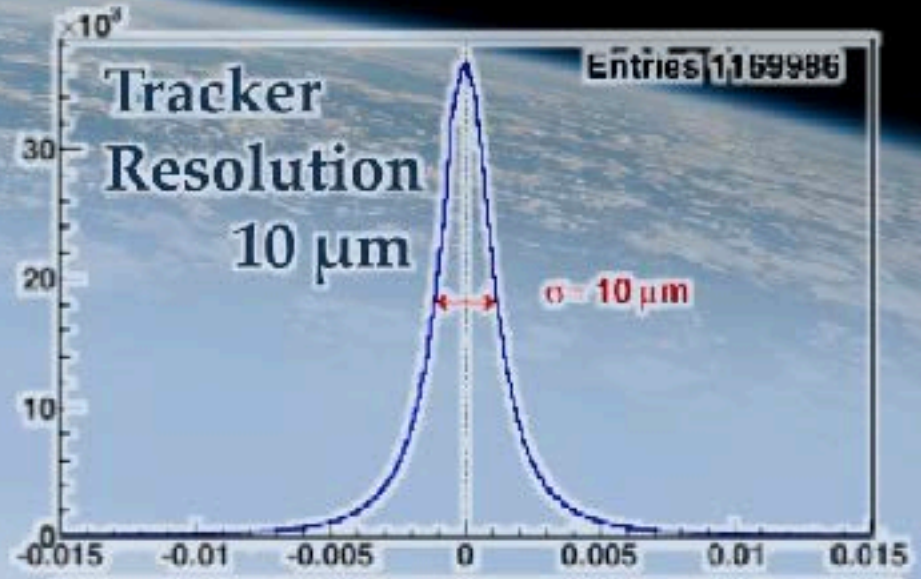
- EMI (Electro Magnetic Interference) test
- Thermal Vacuum test
  Pressure < 10^{-9} bar, Temperature -40 ~ +90 °C

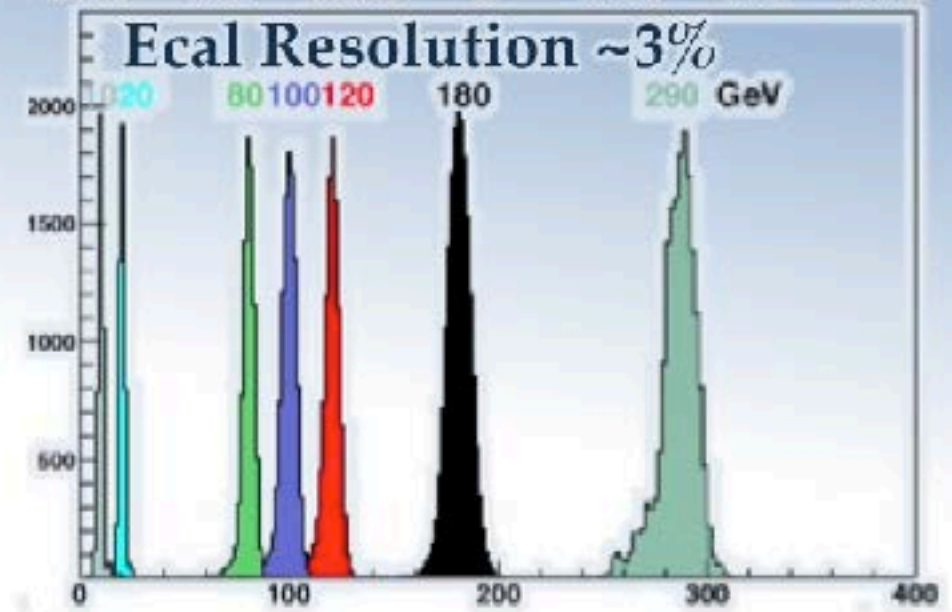




CERN beam test (2010)







CERN beam test (2010)

Particle	Momentum (GeV/c)	Positions	Purpose
Protons	400 + 180	1,650	Full Tracker alignment, TOF calibration, 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

AMS installed in Space Shuttle

Kennedy Space Center 2010~2011

Final inspection
by S. Ting

Closing Endeavour's Payload Bay Doors
at the Launch Pad

Launch of AMS-02

- May/16/2011
- Last Endeavor flight
- Total weight 2008 t
- AMS 7.5 t

After 123 seconds,
1,000 tons of fuel was spent

AMS installed on the ISS

19/May/2011

Start taking data only 4 hours later

Since then, AMS is continuously recording
16 billion Cosmic-Ray events every year...

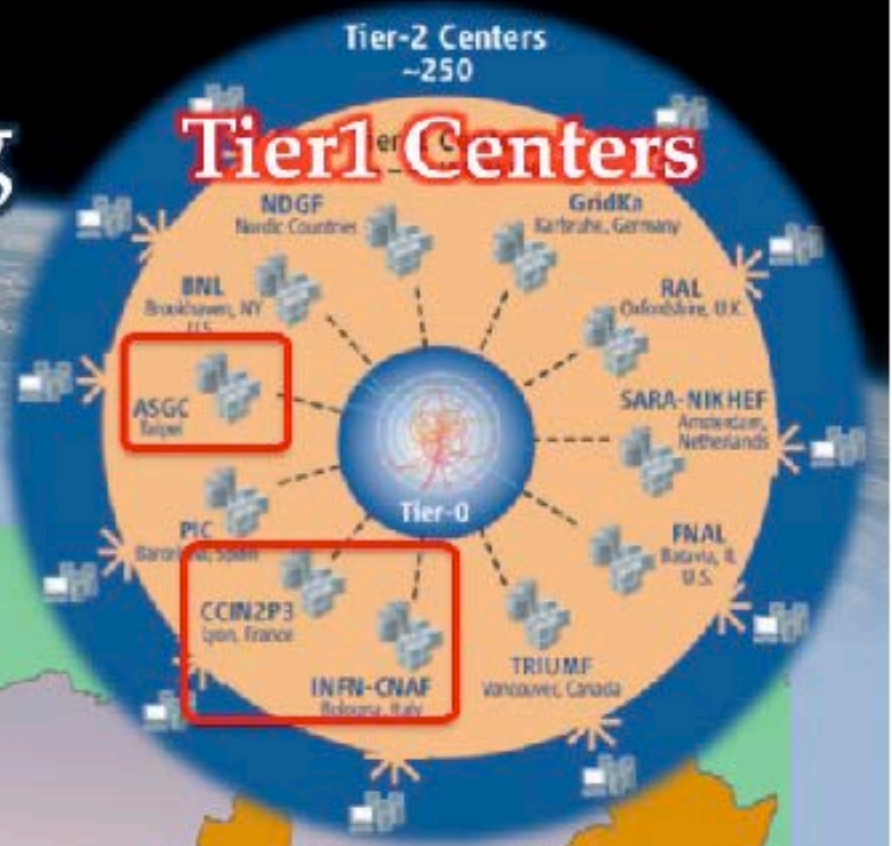
Operation and data link

Ku-Band (down):
Events <10Mbit/s>

S-Band (up & down):
Commanding: 1 Kbit/s
Monitoring: 30 Kbit/s

AMS computing

LHC Tier 1 : Academia Sinica, IN2P3, INFN



FZJ – Juelich (2300 cores)

IN2P3 – LYON (400 cores)

CIEMAT – MADRID (200 cores)

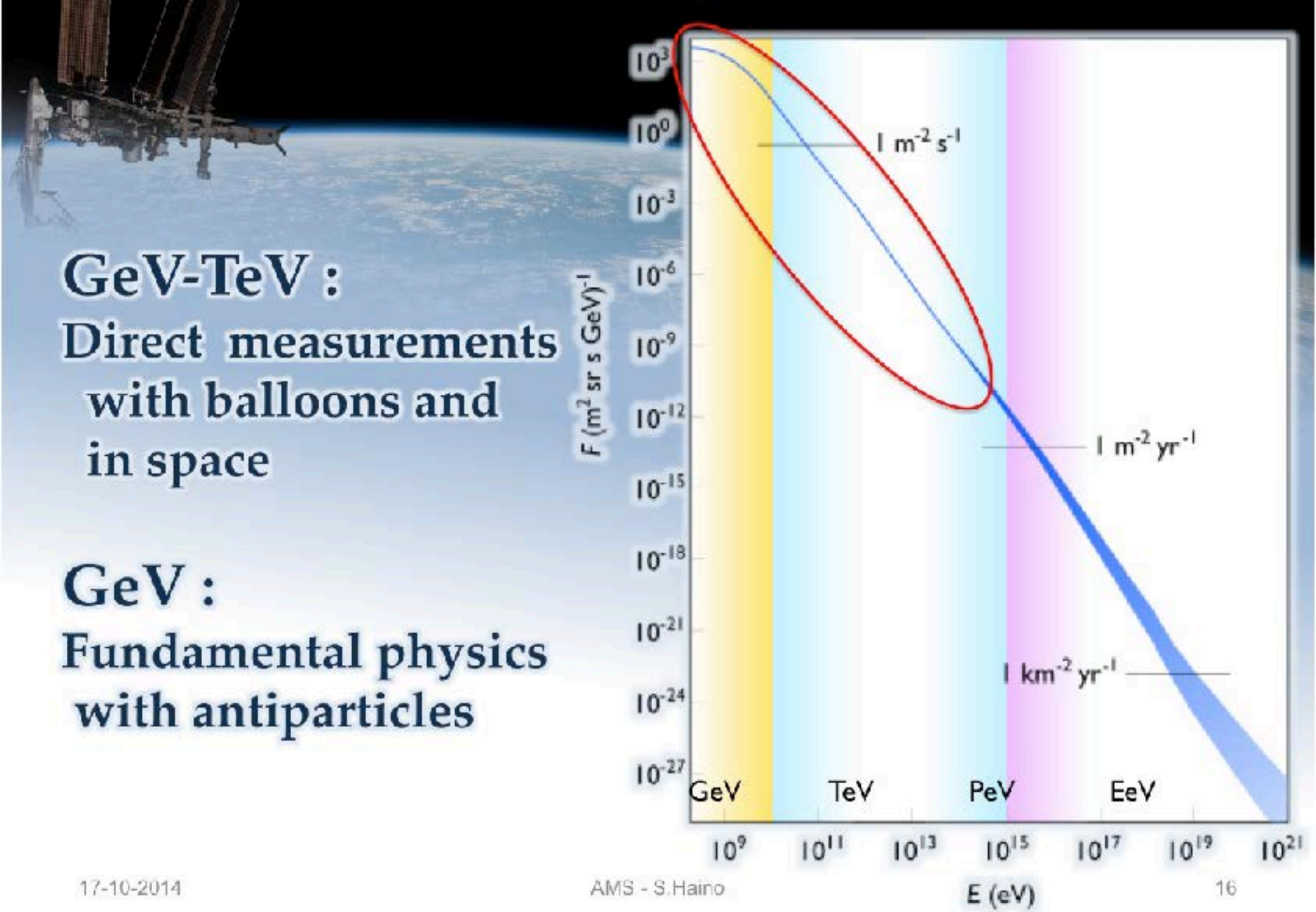
AMS@CERN – GENEVA (768 cores)

NLAA – BEIJING (1024 cores)

SEU – NANJING (2016 cores)

ACAD. SINICA – TAIPEI (3000 cores)

CNAF – INFN BOLOGNA (1300 cores)


GeV-TeV :
Direct measurements with balloons and in space
GeV :
Fundamental physics with antiparticles
F (m² sr s GeV)⁻¹
10³
10⁰
10⁻³
10⁻⁶
10⁻⁹
10⁻¹²
10⁻¹⁵
10⁻¹⁸
10⁻²¹
10⁻²⁴
10⁻²⁷
1 m⁻² s⁻¹
1 m⁻² yr⁻¹
1 km⁻² yr⁻¹
GeV
TeV
PeV
EeV
10⁹
10¹¹
10¹³
10¹⁵
10¹⁷
10¹⁹
10²¹
E (eV)

Latest AMS Results and Future plans

Cosmic rays

Proton spectrum
Helium spectrum
e- spectrum
B/C ratio
Nuclei spectrum

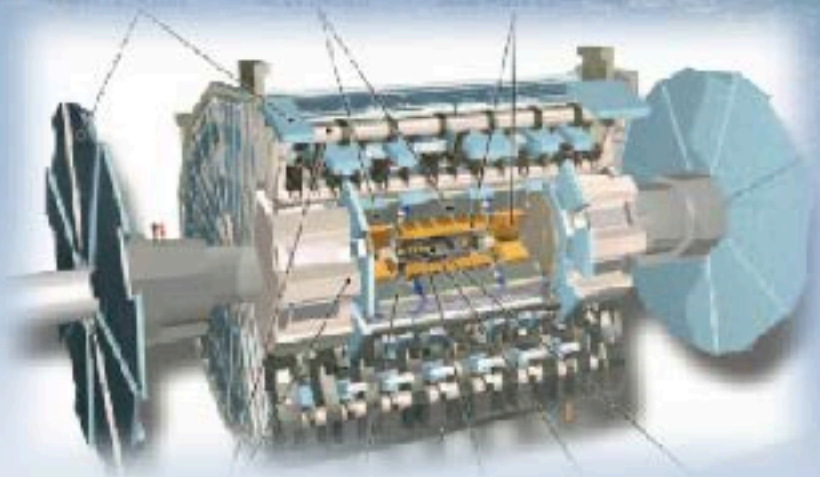
Dark Matter

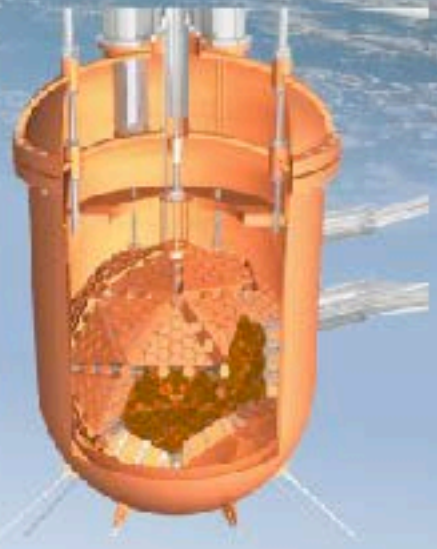
e^+ fraction
e^+ flux
Anisotropy

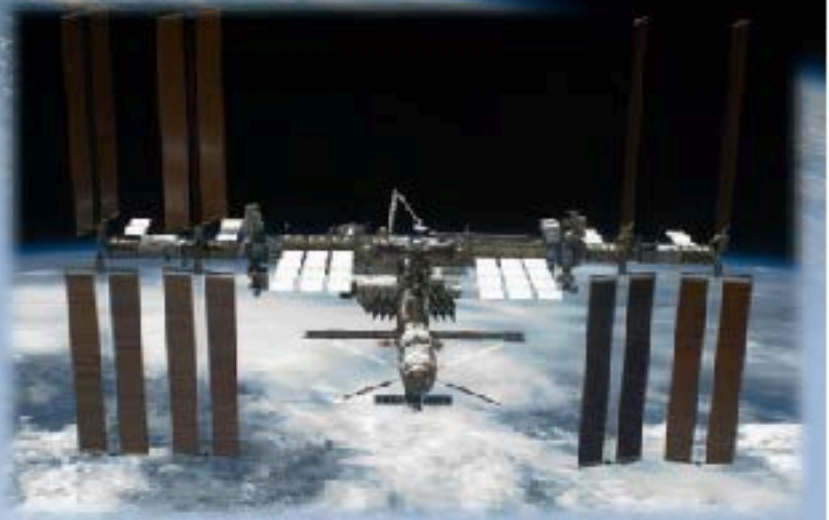
Future Plans

e^+ to TeV
$\bar{p}/p$ ratio
Antimatter
New physics, ...

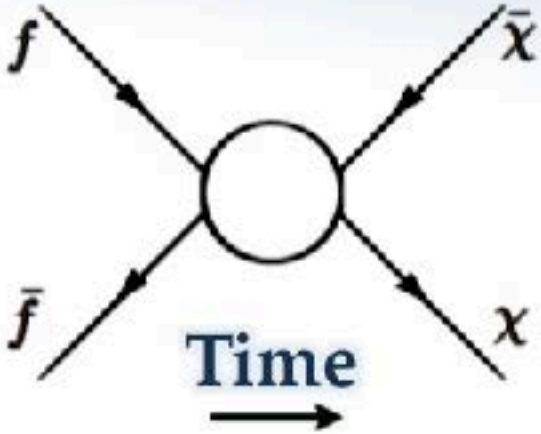
Dark Matter searches



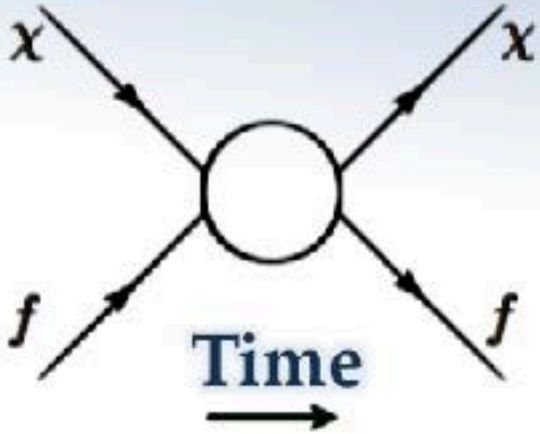




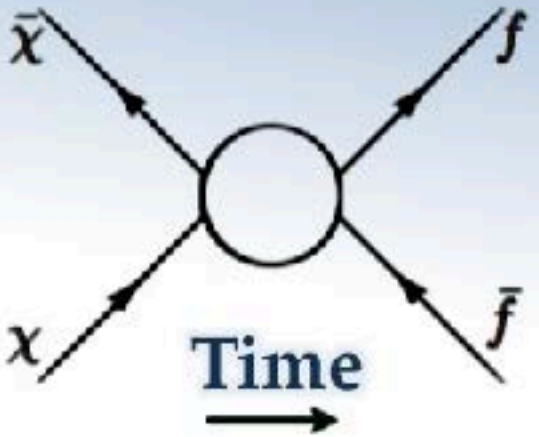
Colliders



Direct search

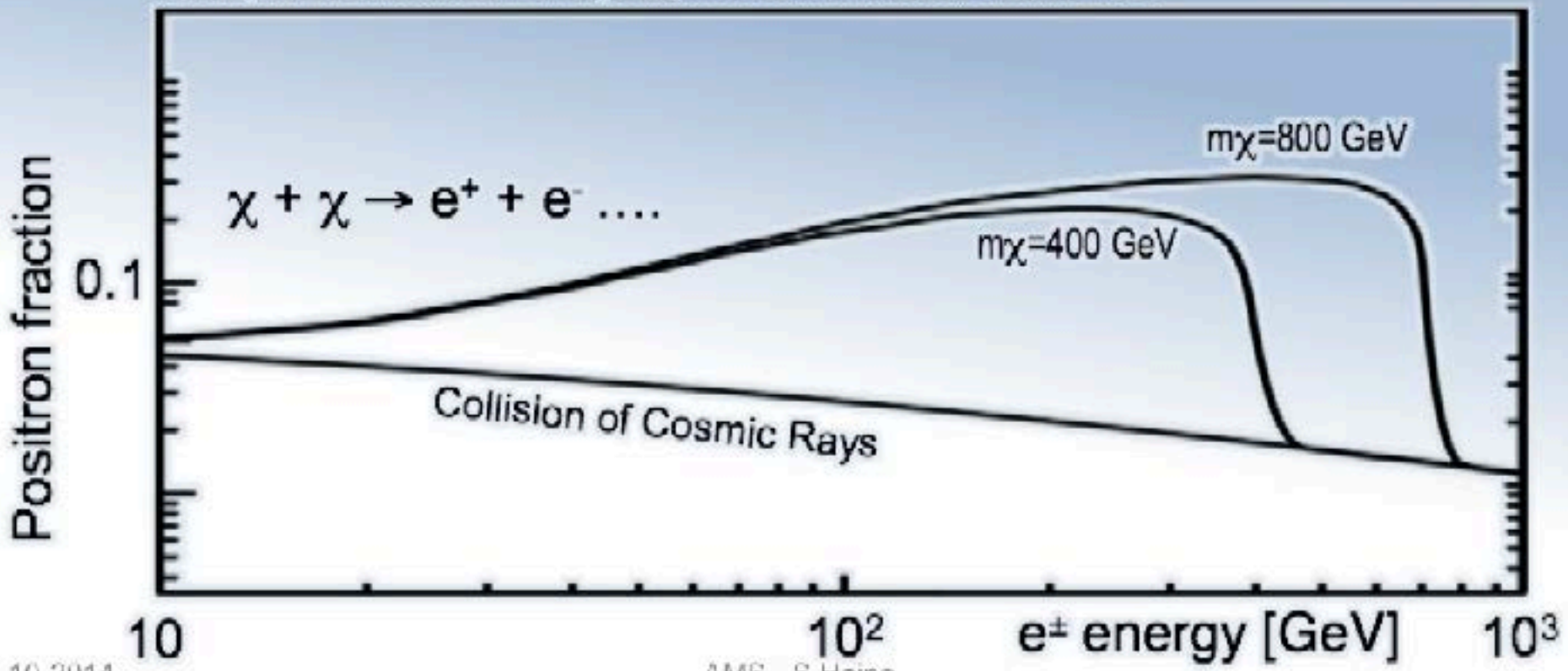


Indirect search



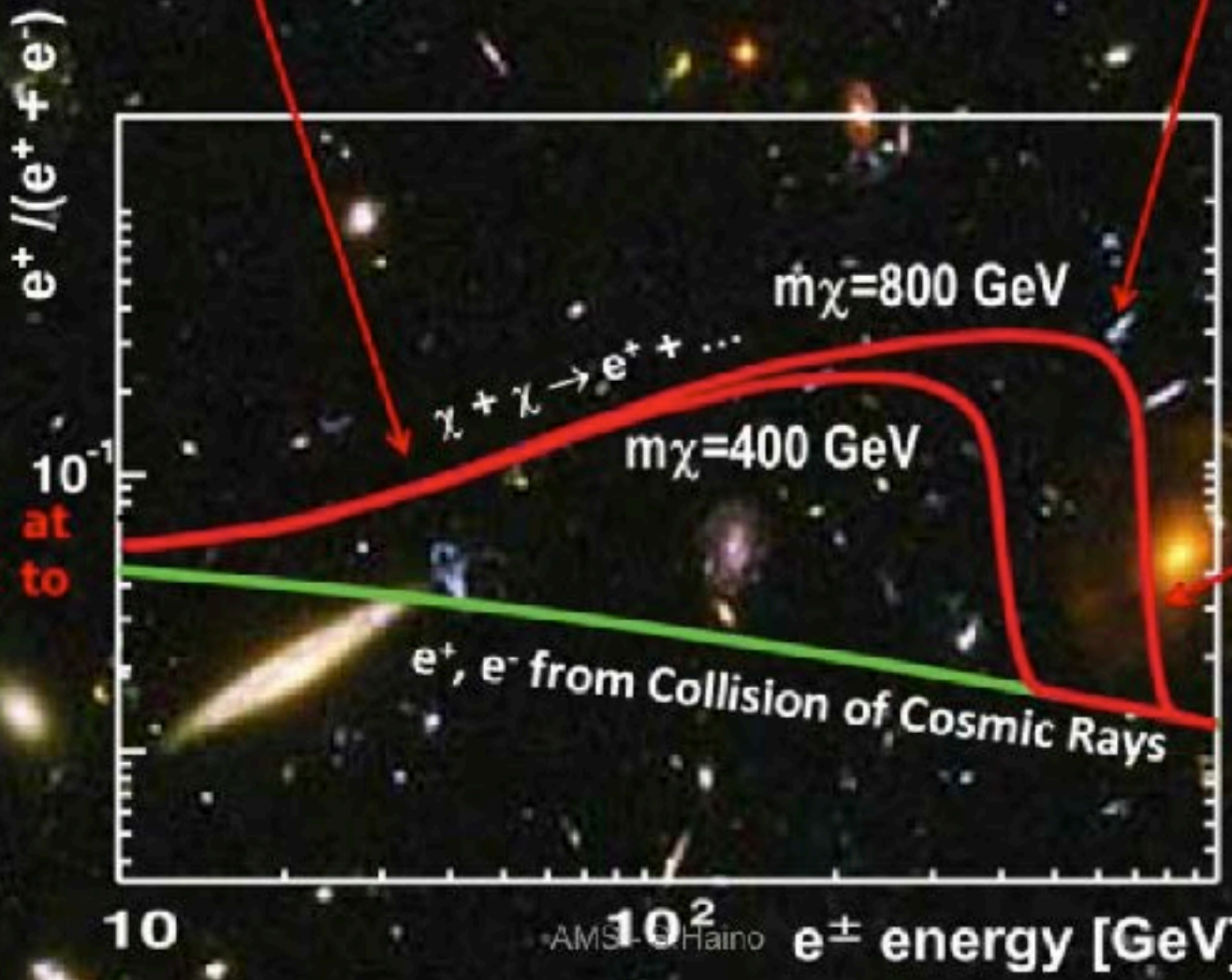
Physics of CR Positron Fraction

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



2. The rate of increase with energy
3. The existence of sharp structures.

4. The energy beyond which it ceases to increase.



5. The rate at which it falls beyond the turning point.

1. The energy at which it begins to increase.

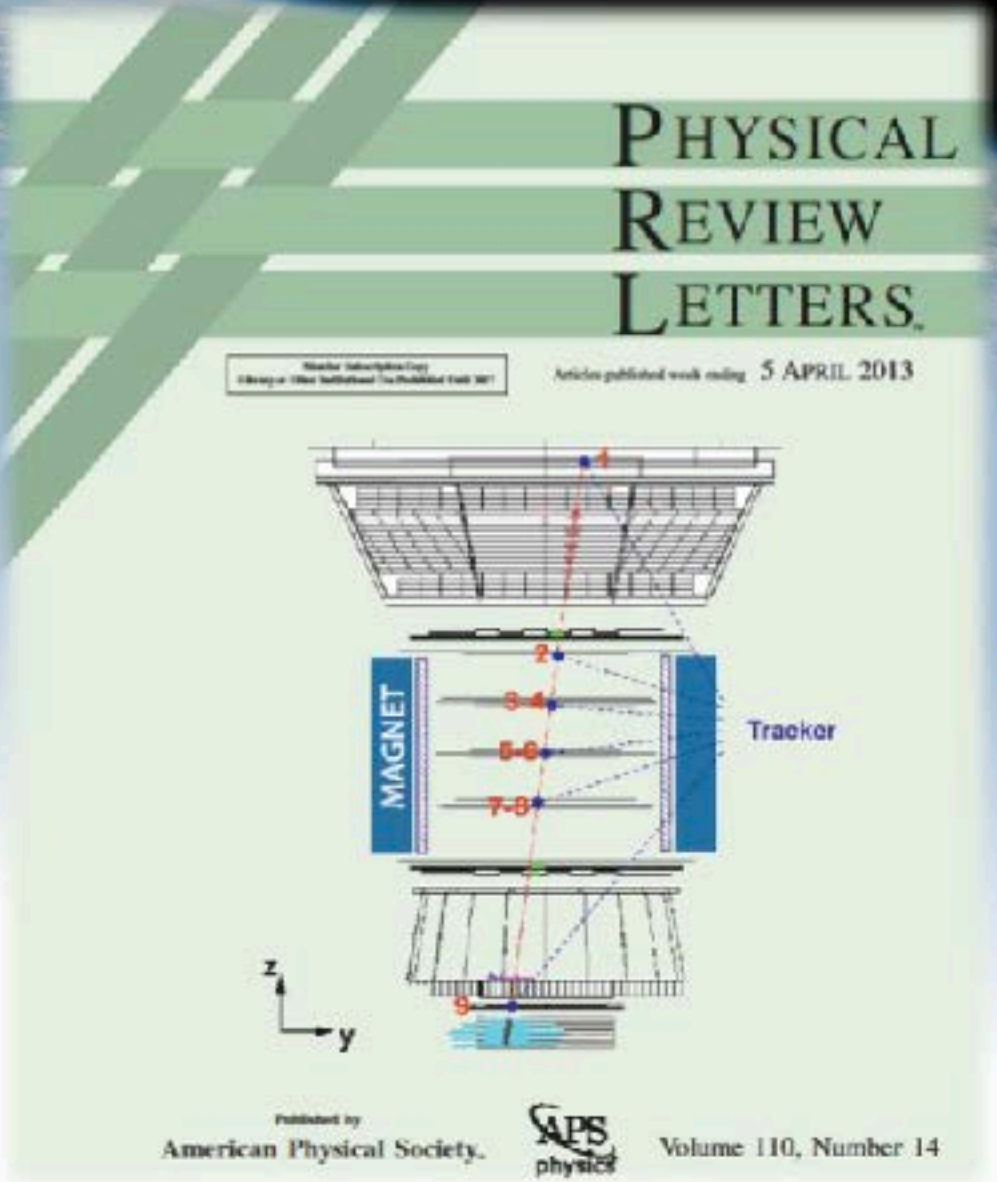
6. Isotropy.

First results of AMS

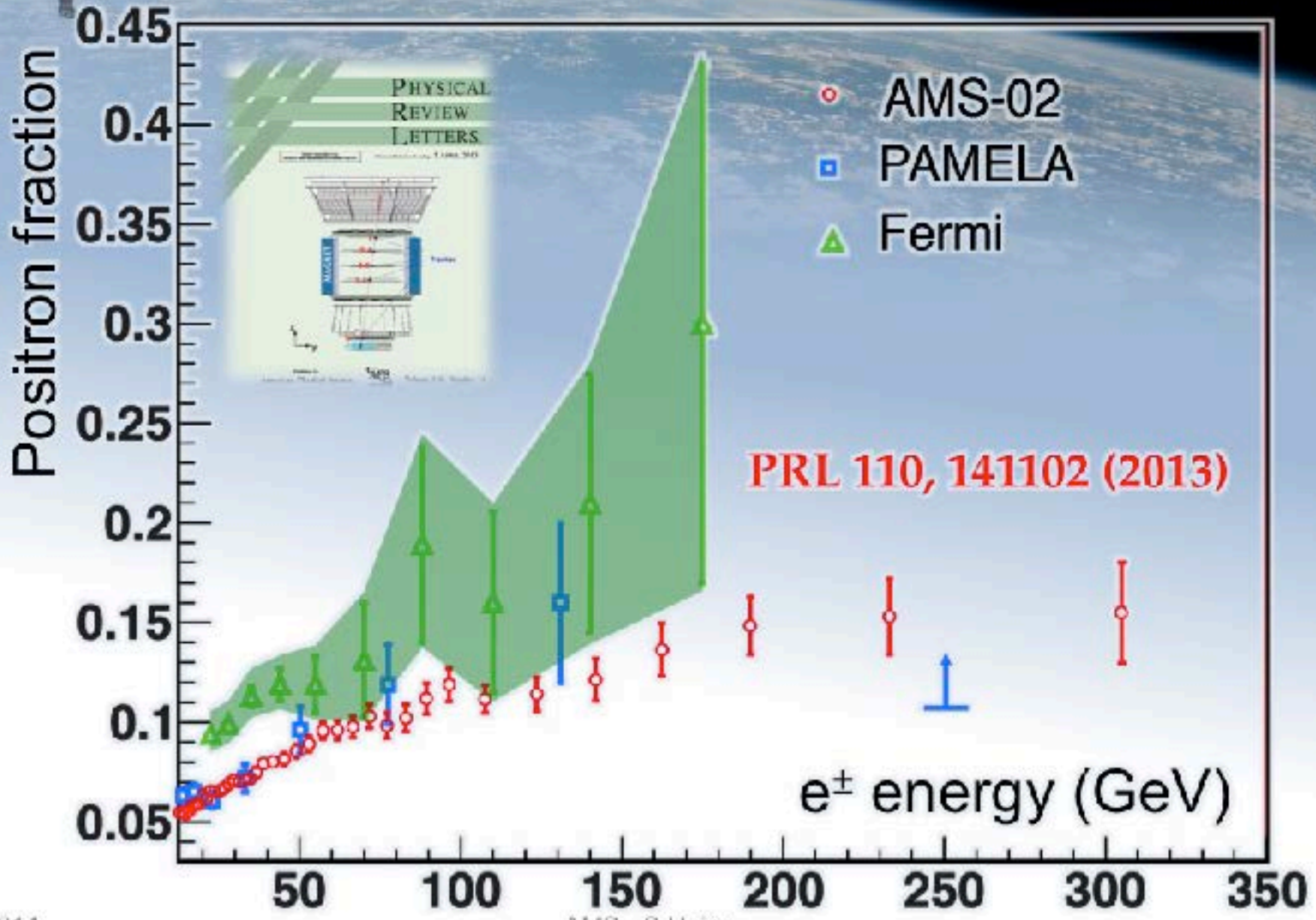
M. Aguilar *et al.*,
PRL 110, 141102 (2013)

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

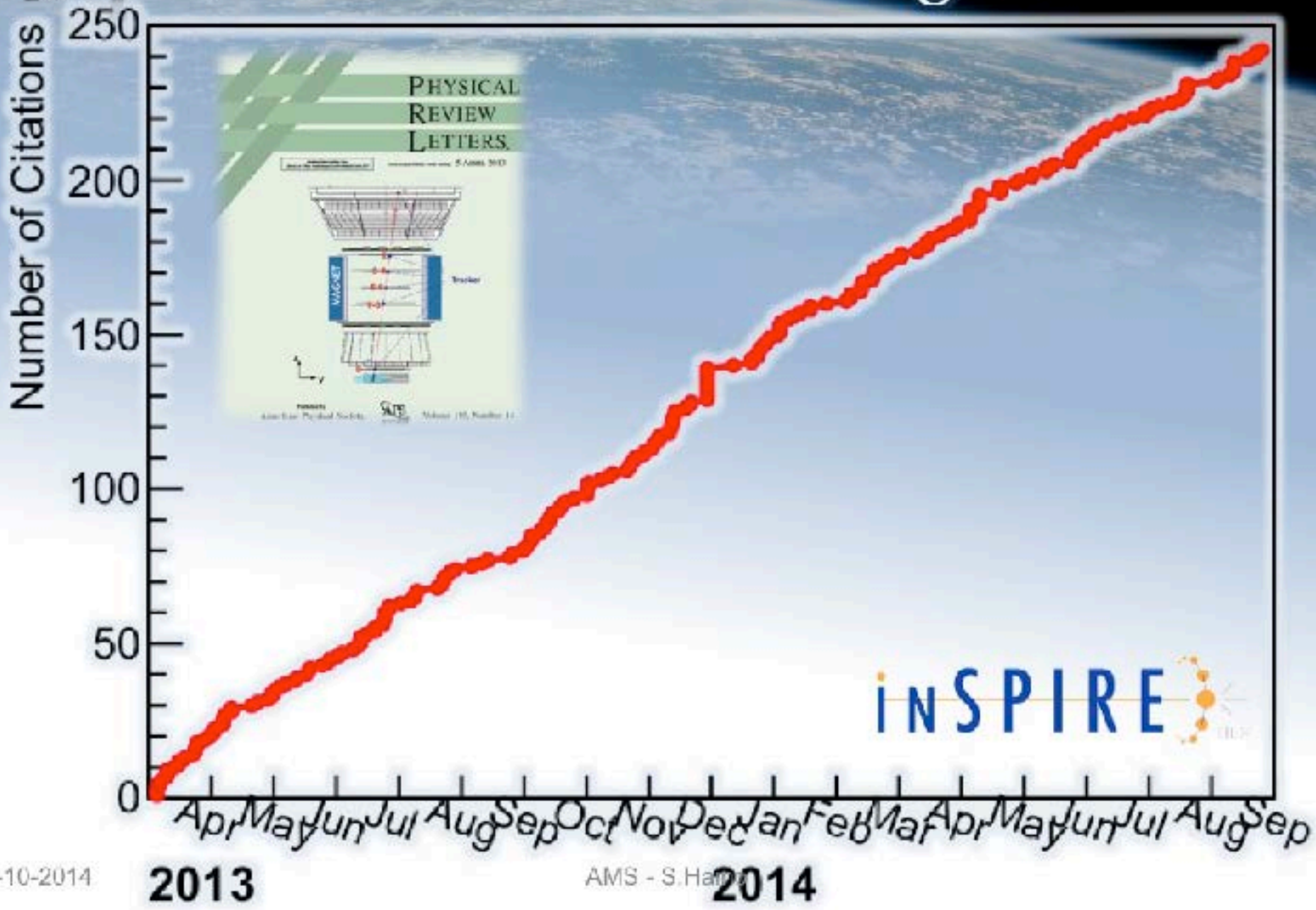
(April/2013)



First results of AMS – e^+ fraction



Citation increasing ...



New AMS results (2014)

PRL 113, 121101 (2014) PHYSICAL REVIEW LETTERS week ending 19 SEPTEMBER 2014

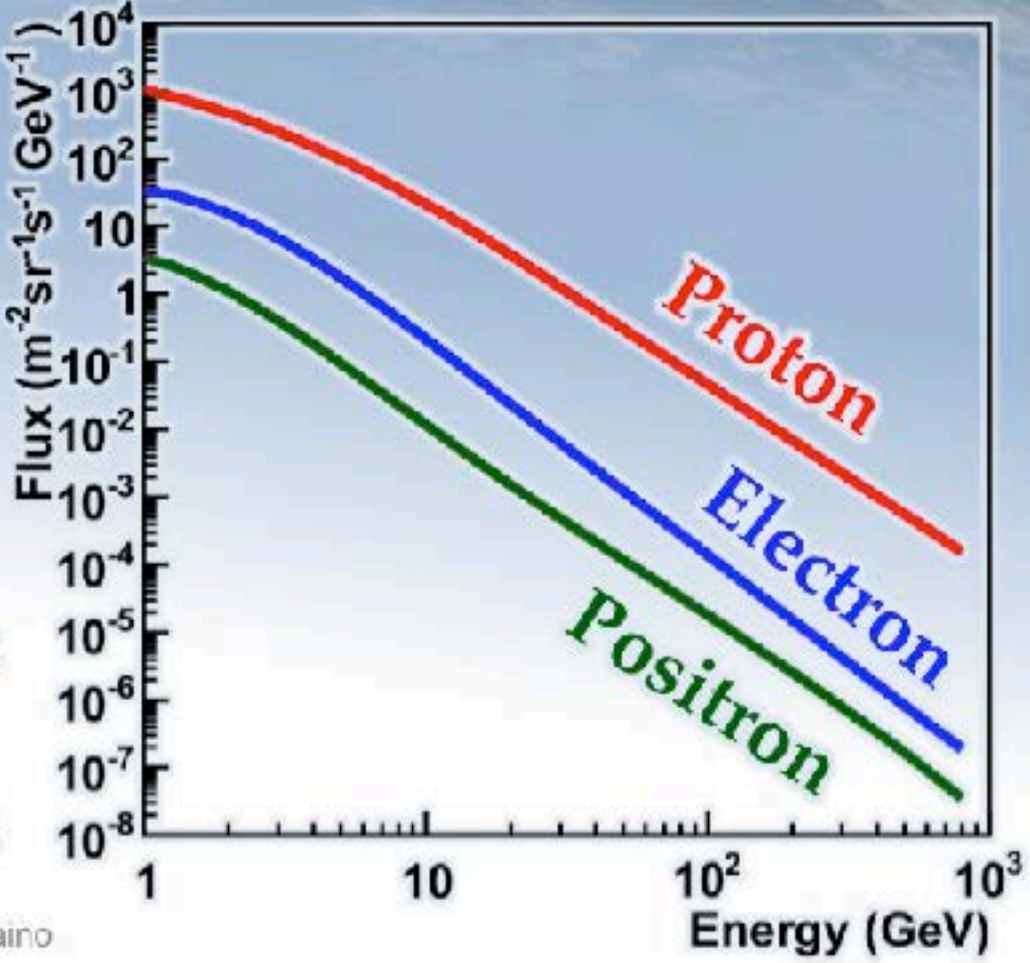
High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–500 GeV with the Alpha Magnetic Spectrometer on the International Space Station

PRL 113, 121102 (2014) PHYSICAL REVIEW LETTERS week ending 19 SEPTEMBER 2014

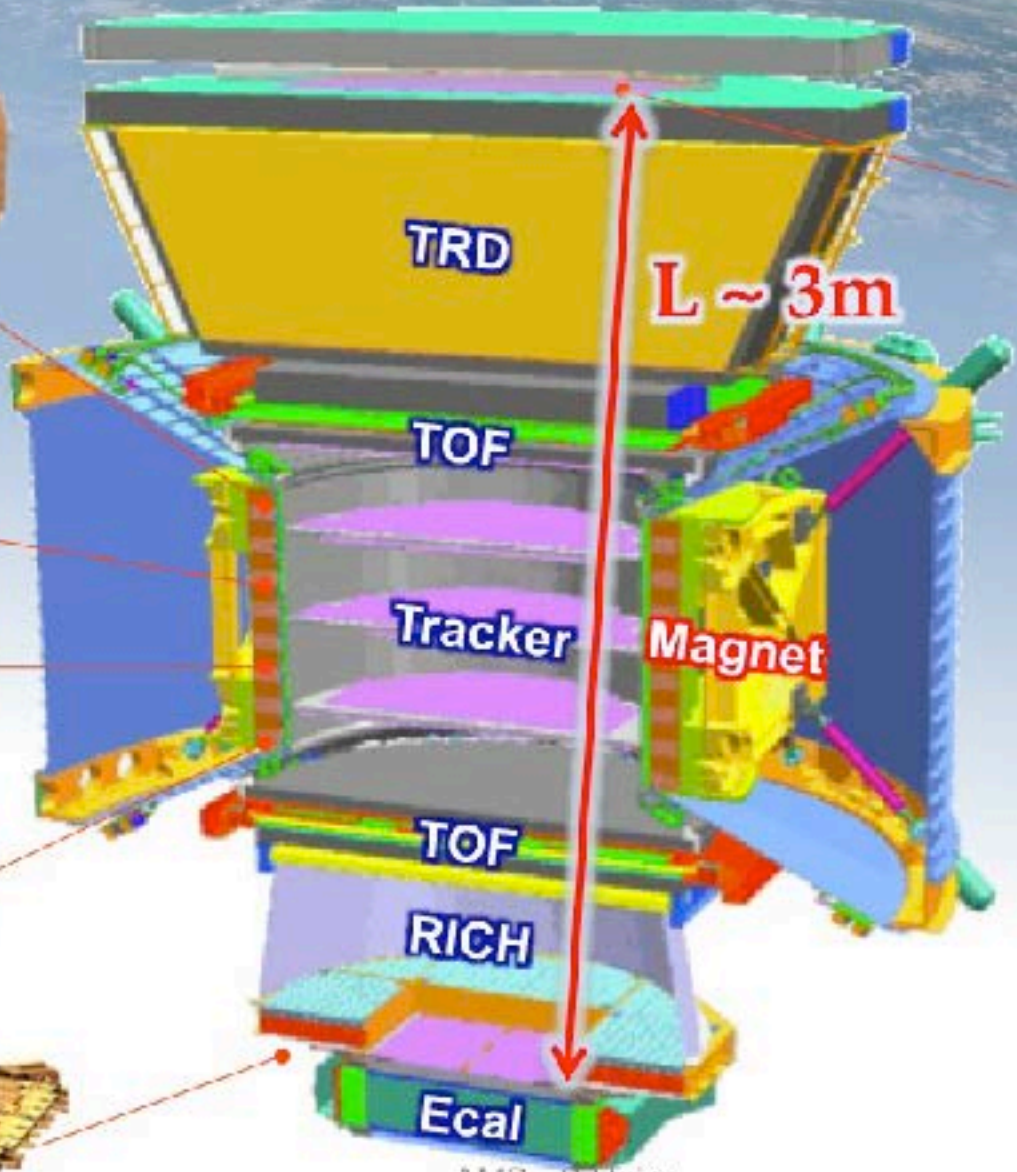
Electron and Positron Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station

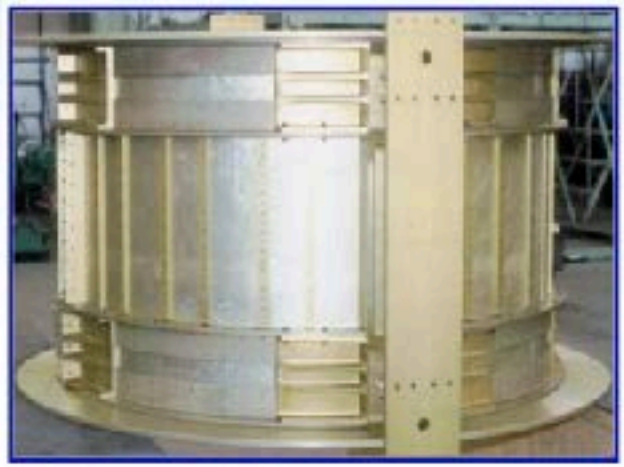
Difficulties – CR positron measurement

- Low abundance : 0.01~0.1 % of Cosmic Rays
  → Large acceptance and long duration needed
- Large backgrounds
  (1) Protons × 10^3~10^4
  → Redundant
  e^+/p separation
  capability
  (2) Electrons × 10~100
  → Deflection measurement
  in a magnetic field
  to determine charge sign



AMS – 9 layers of silicon tracker

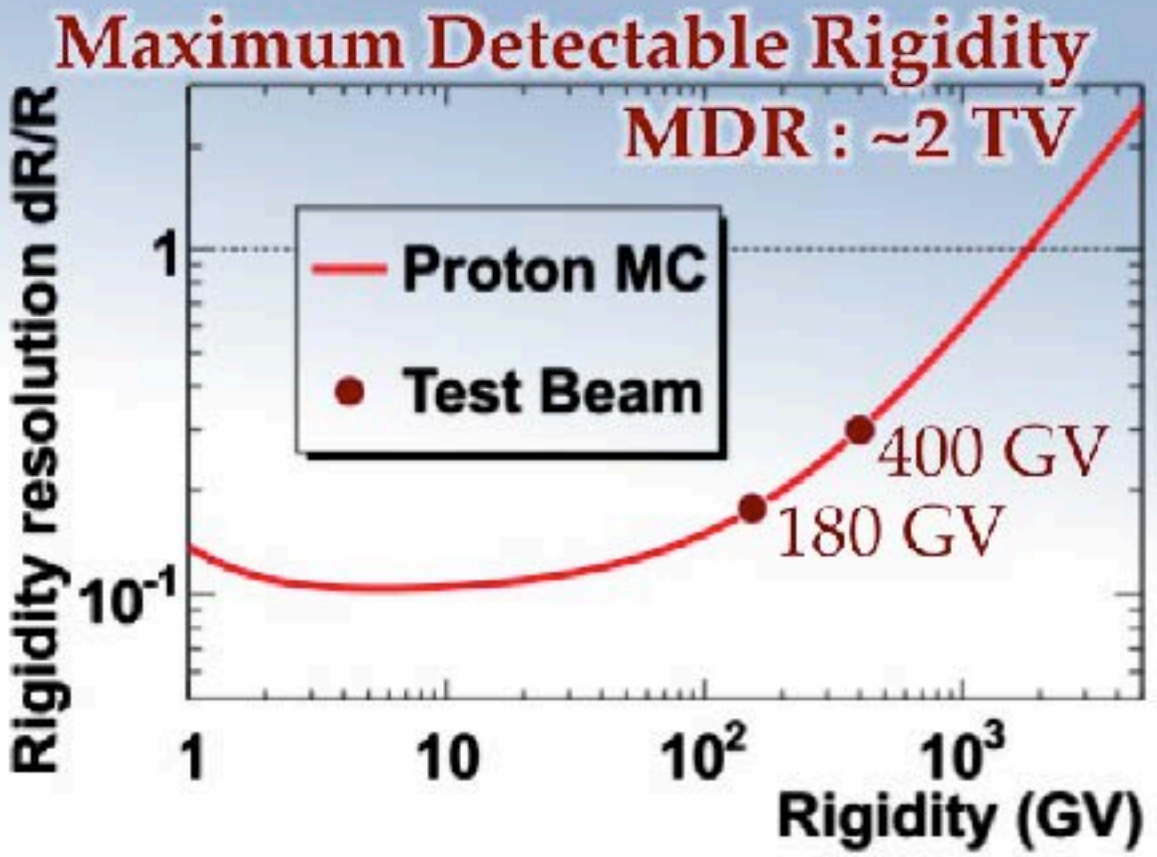


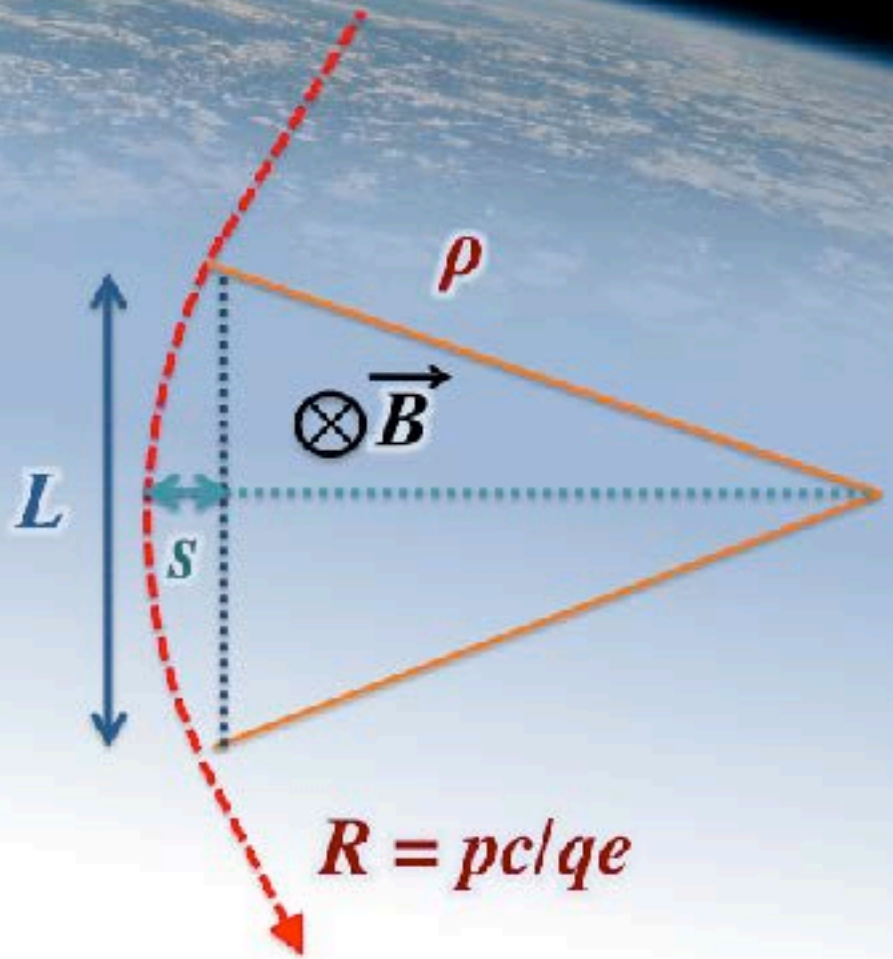


Magnet

Magnet and Silicon Tracker

$$\Delta(1/R) = \frac{\Delta R}{R^2} \approx \frac{8\Delta s}{0.3BL^2}$$

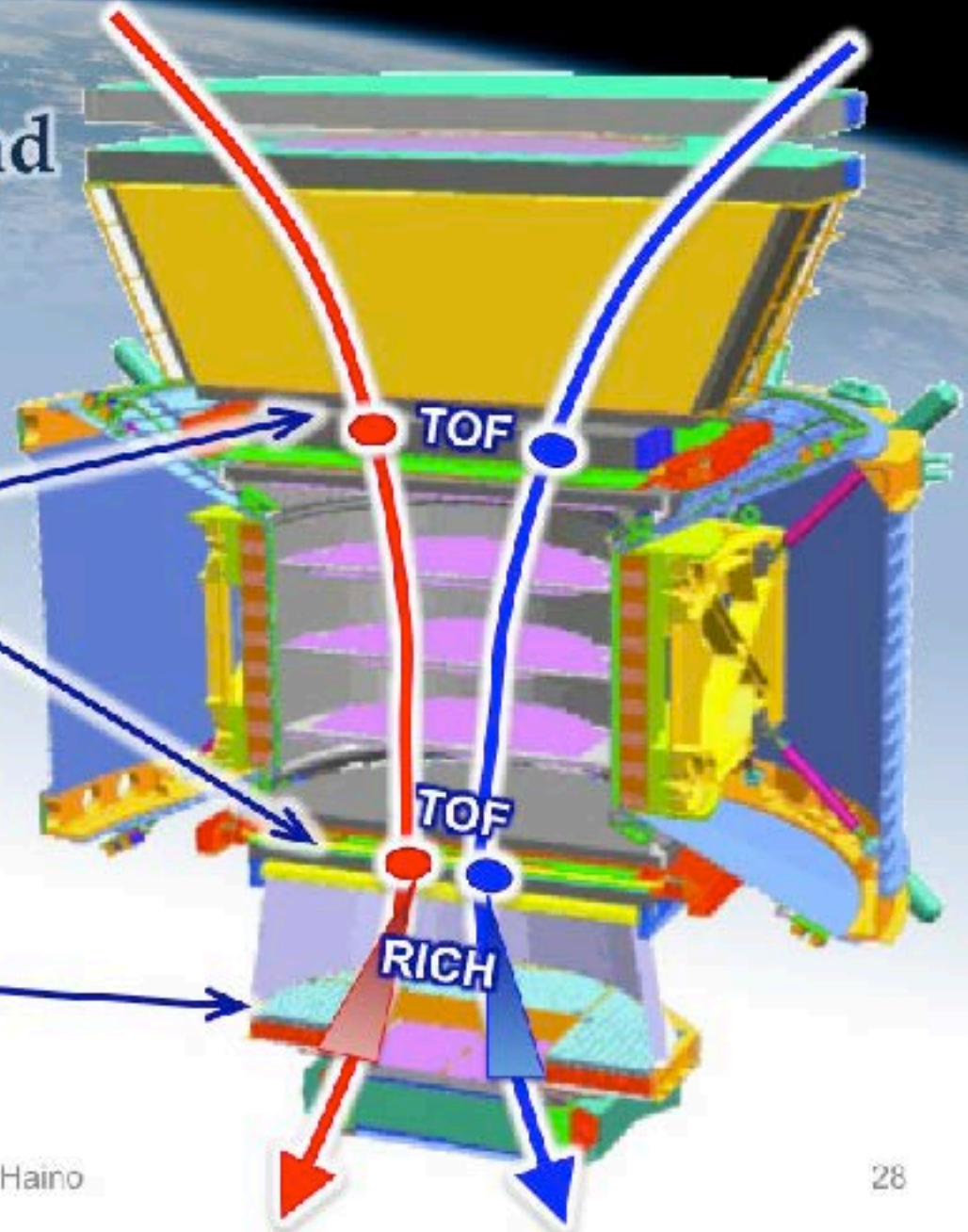




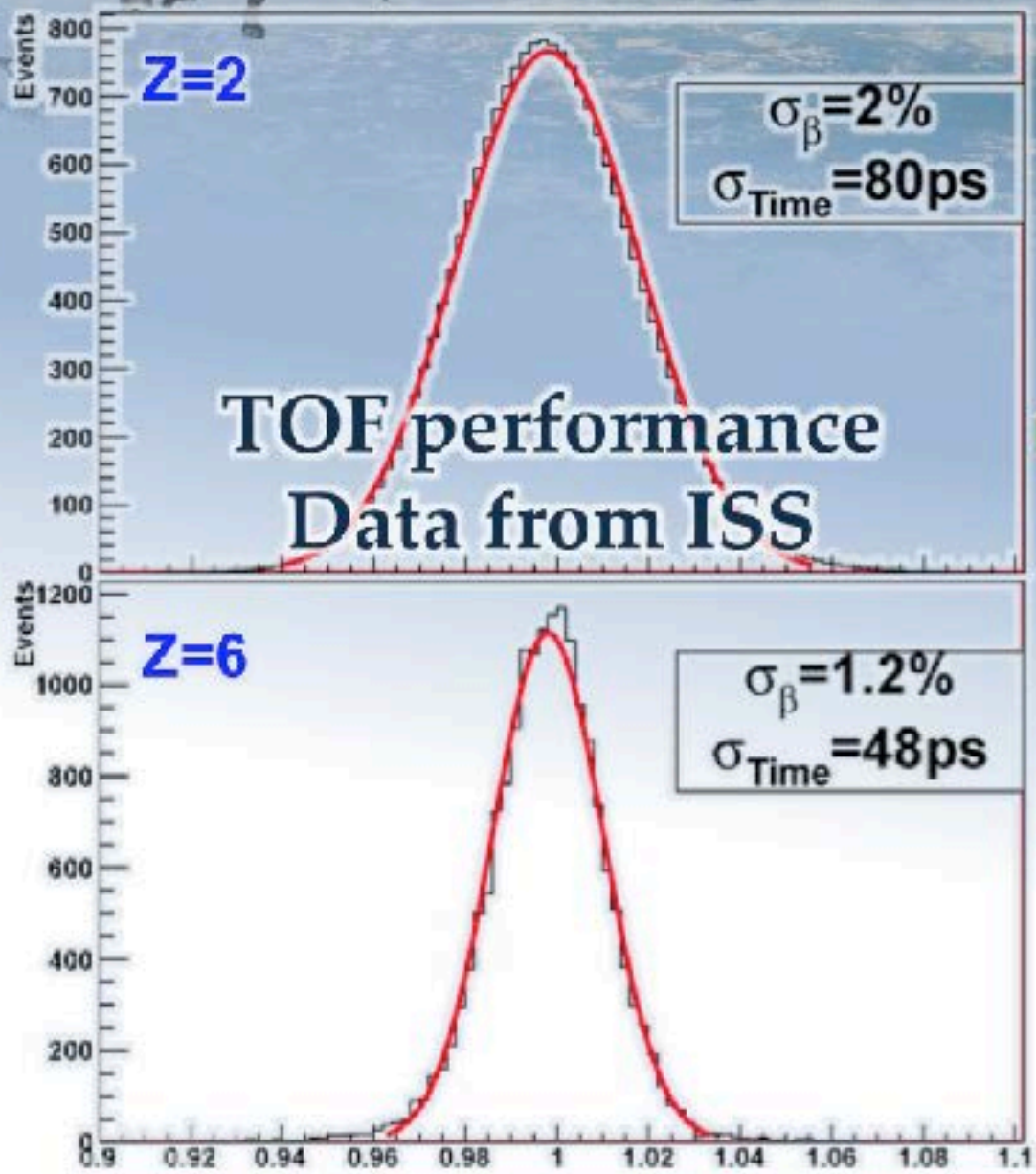
TOF and RICH

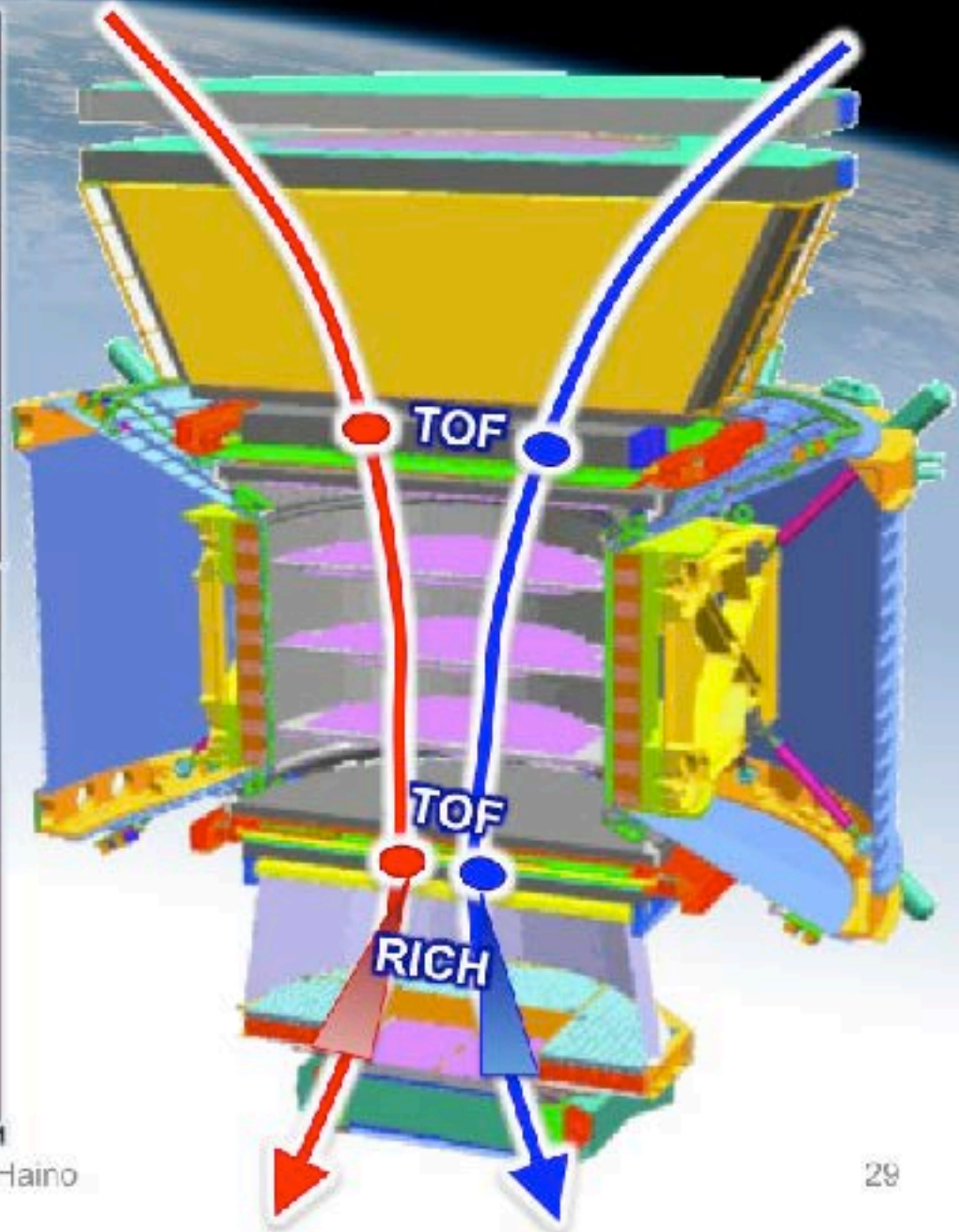
- Determine direction and measure velocity

Time Of Flight
$\Delta\beta$: 1~ 2 %



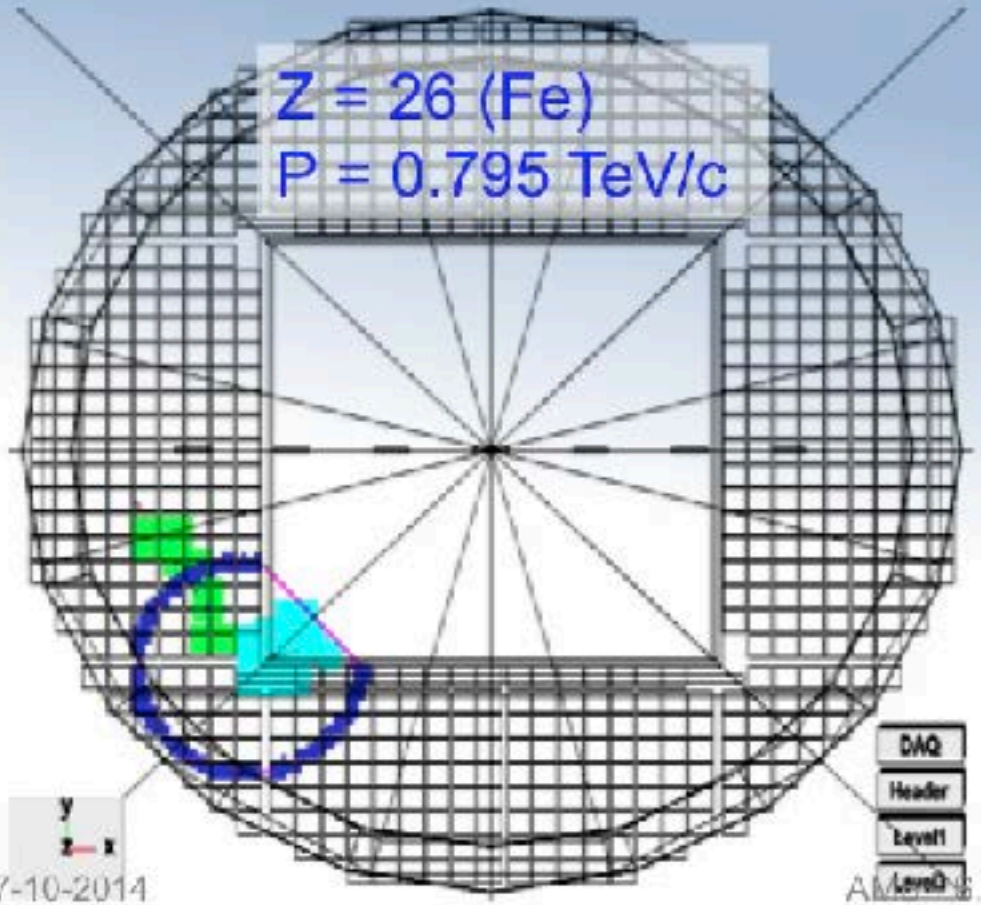
TOF and RICH

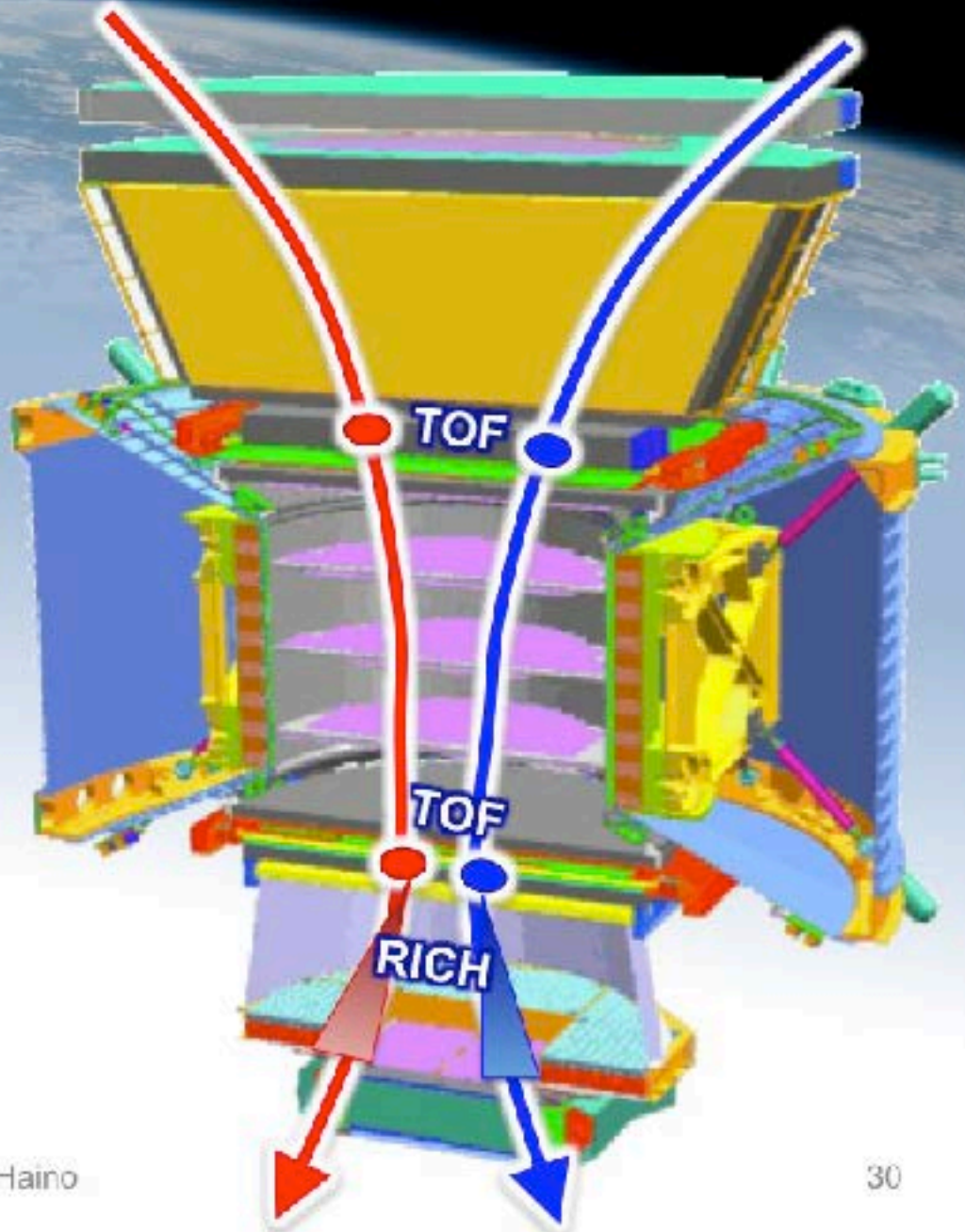

Events
Z=2
σ_β=2%
σ_{Time}=80ps
TOF performance
Data from ISS
Events
Z=6
σ_β=1.2%
σ_{Time}=48ps
Velocity [Rigidity>20GV]


TOF
TOF
RICH

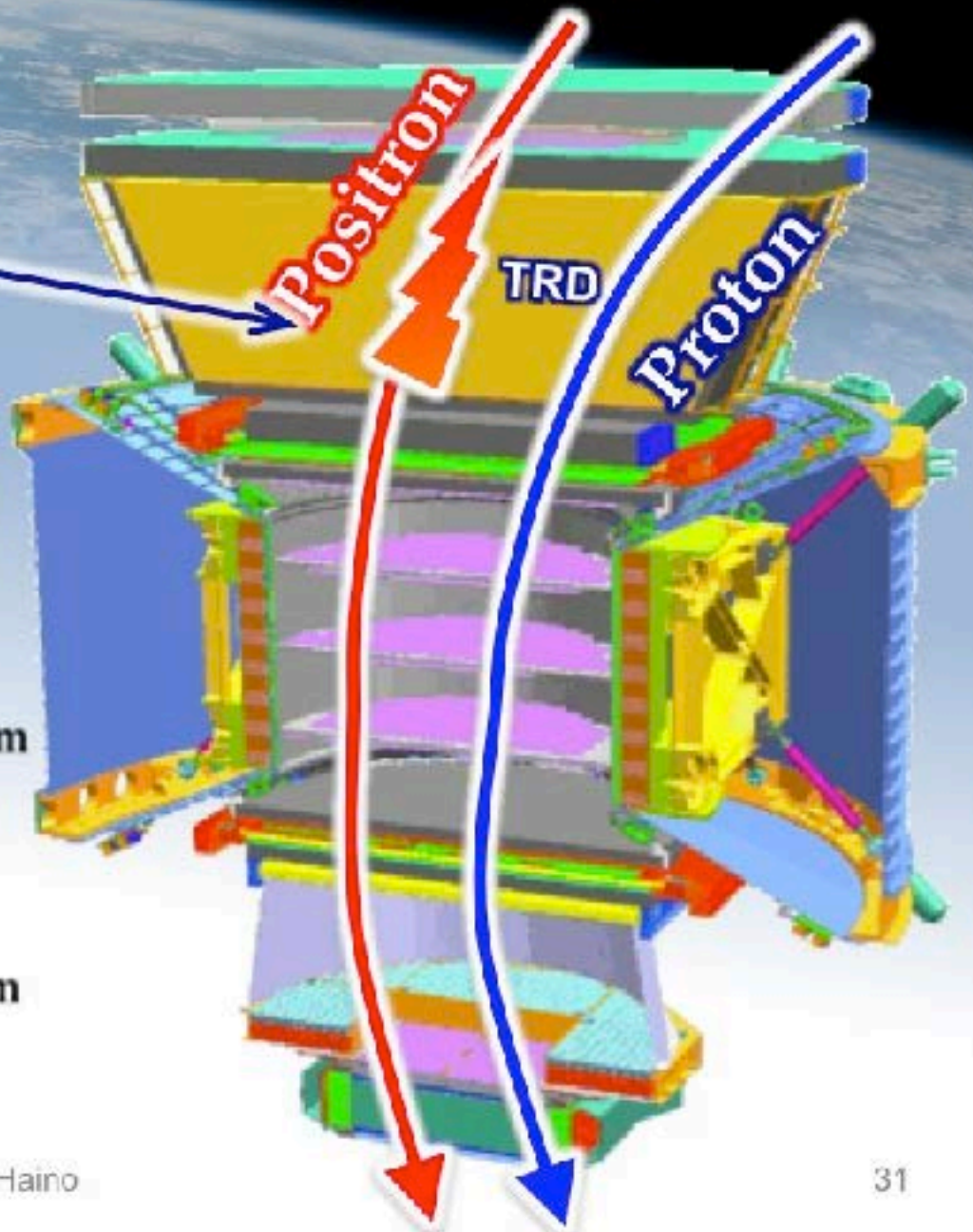
TOF and RICH

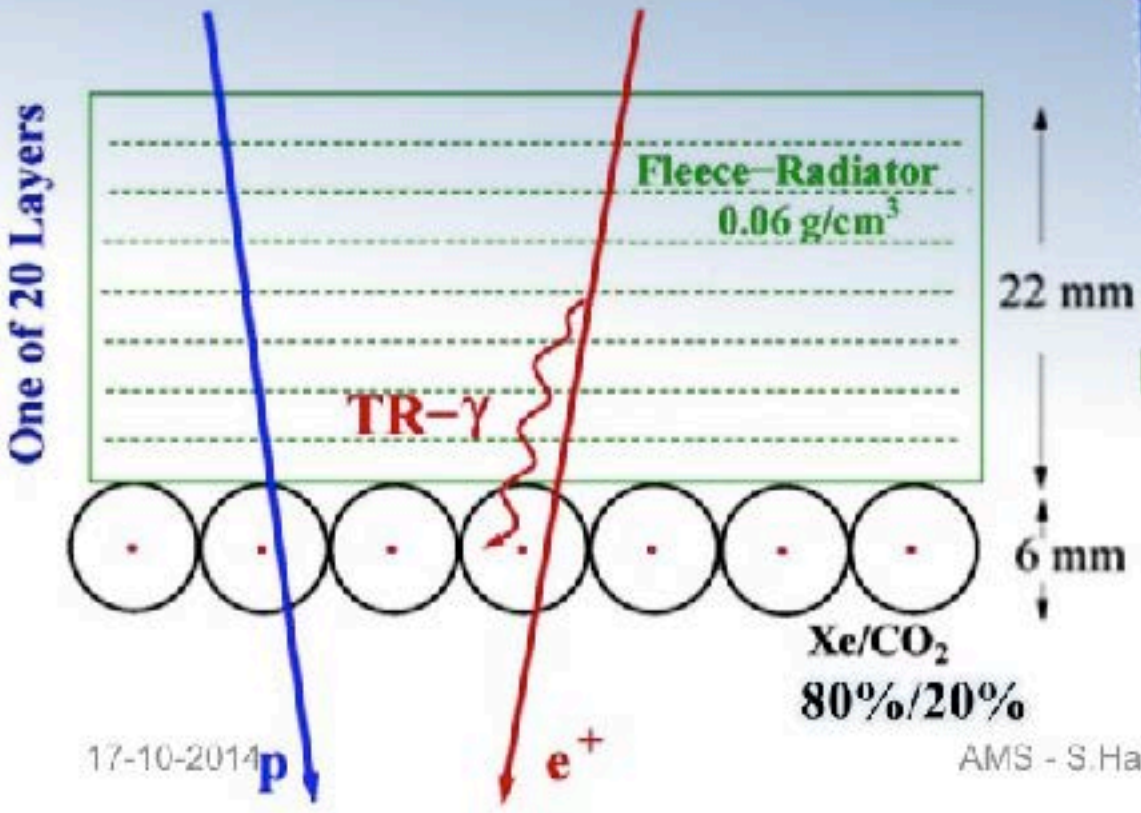
RICH event display
Data from ISS



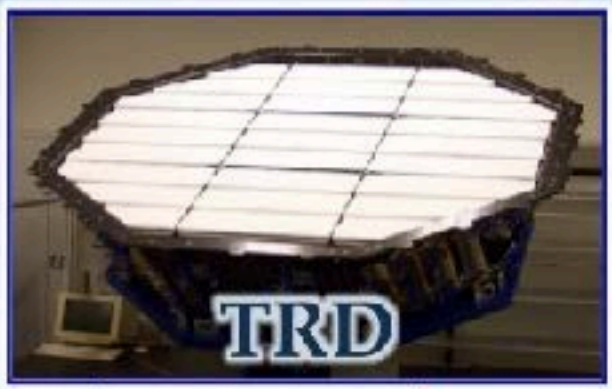


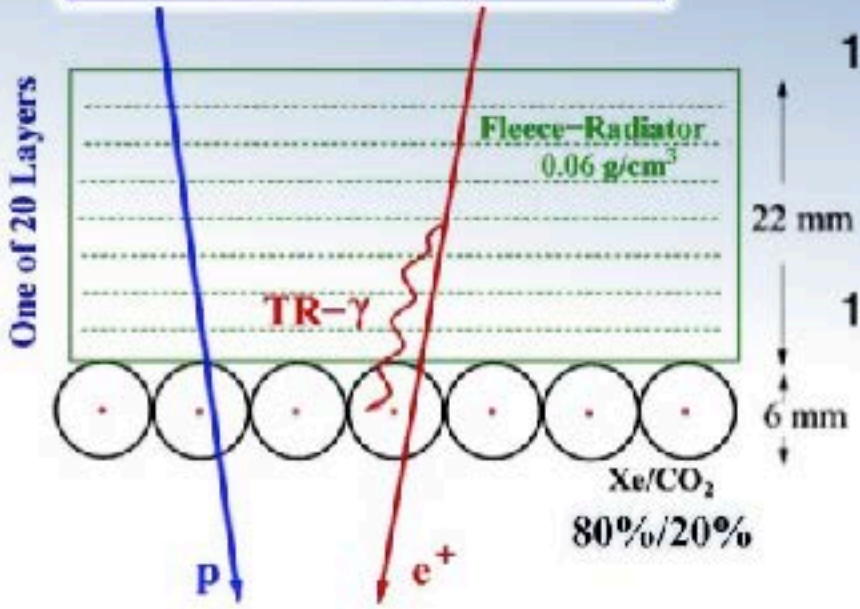
Transition Radiation Detector

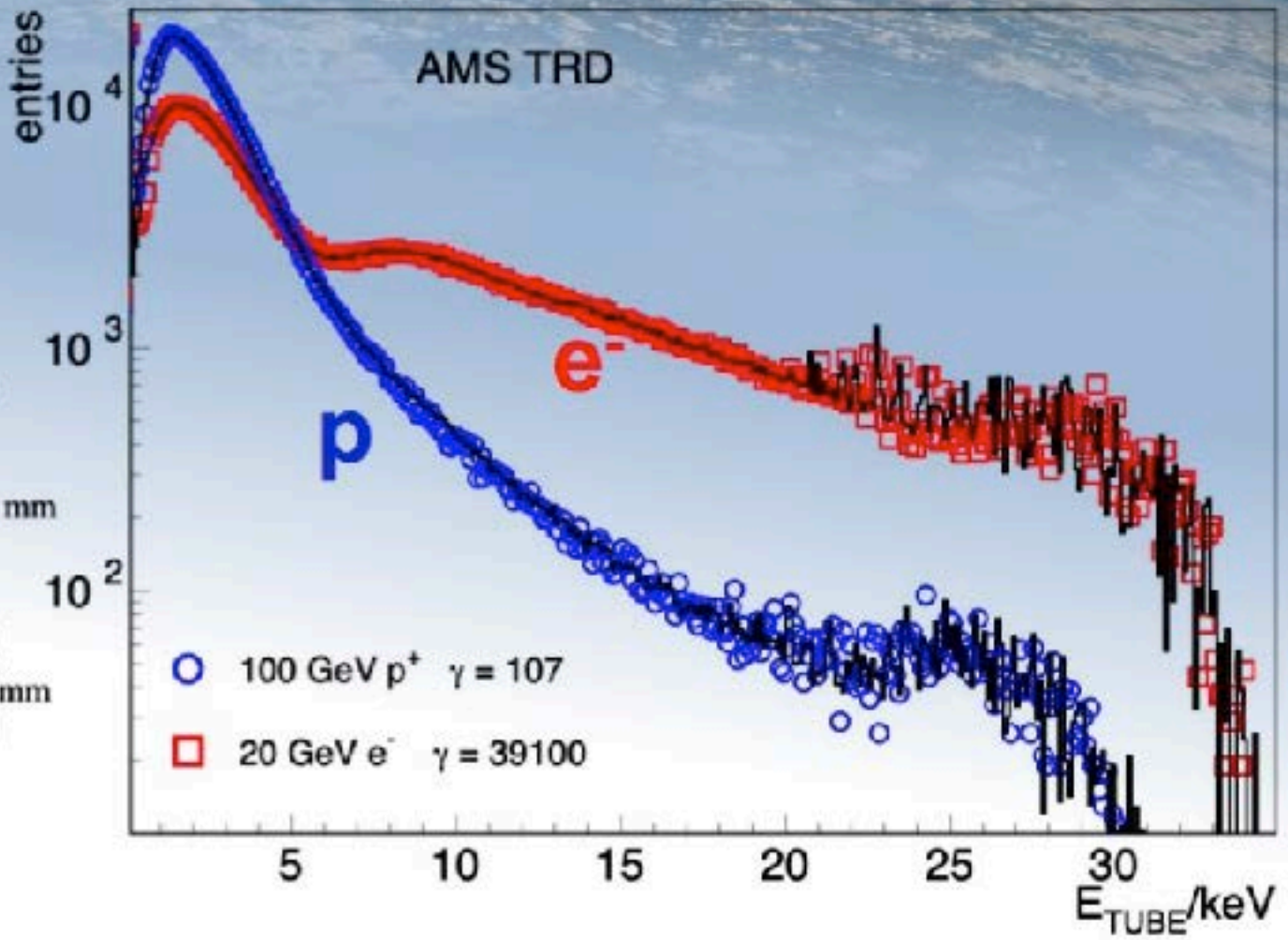




TRD estimator



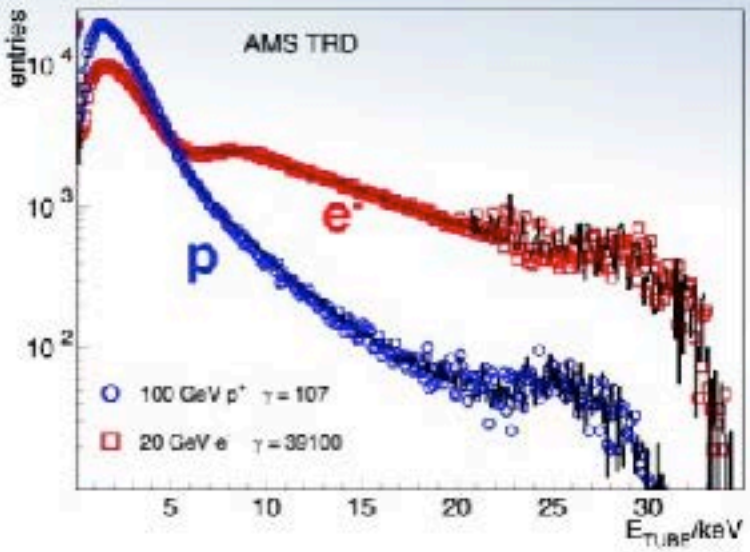


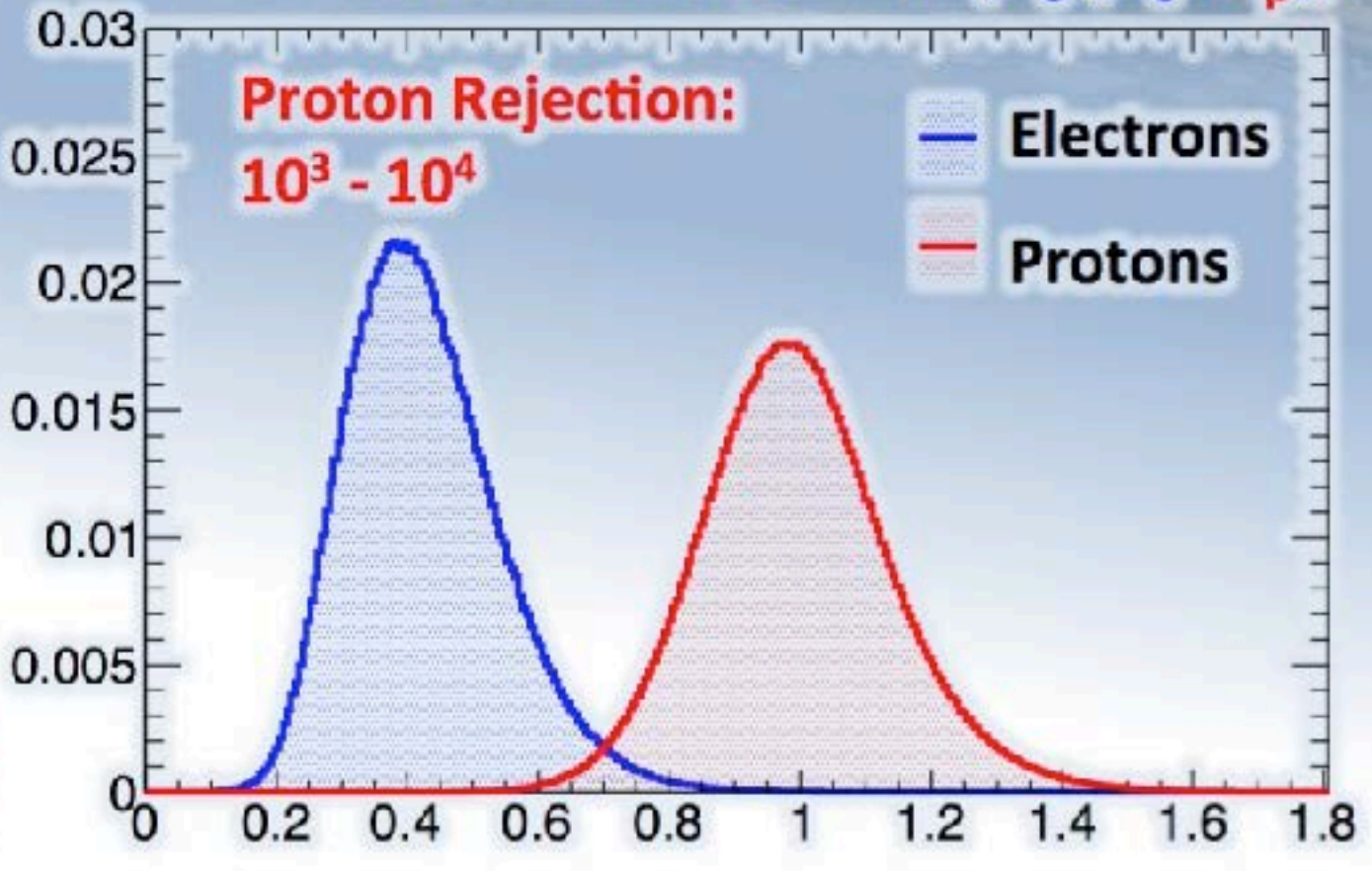


TRD estimator

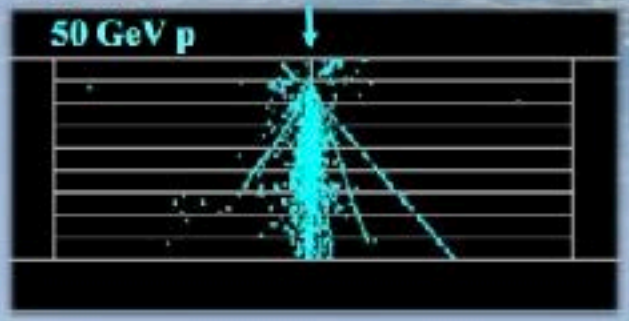
$$P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)}$$

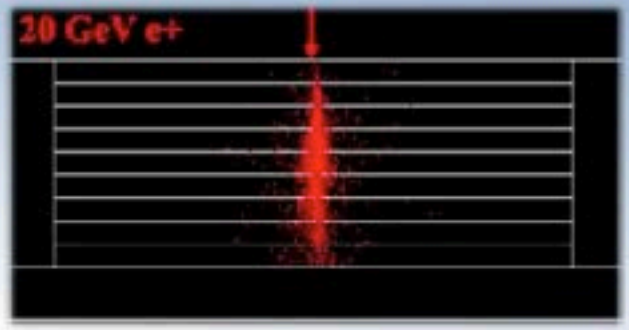
$$P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)}$$



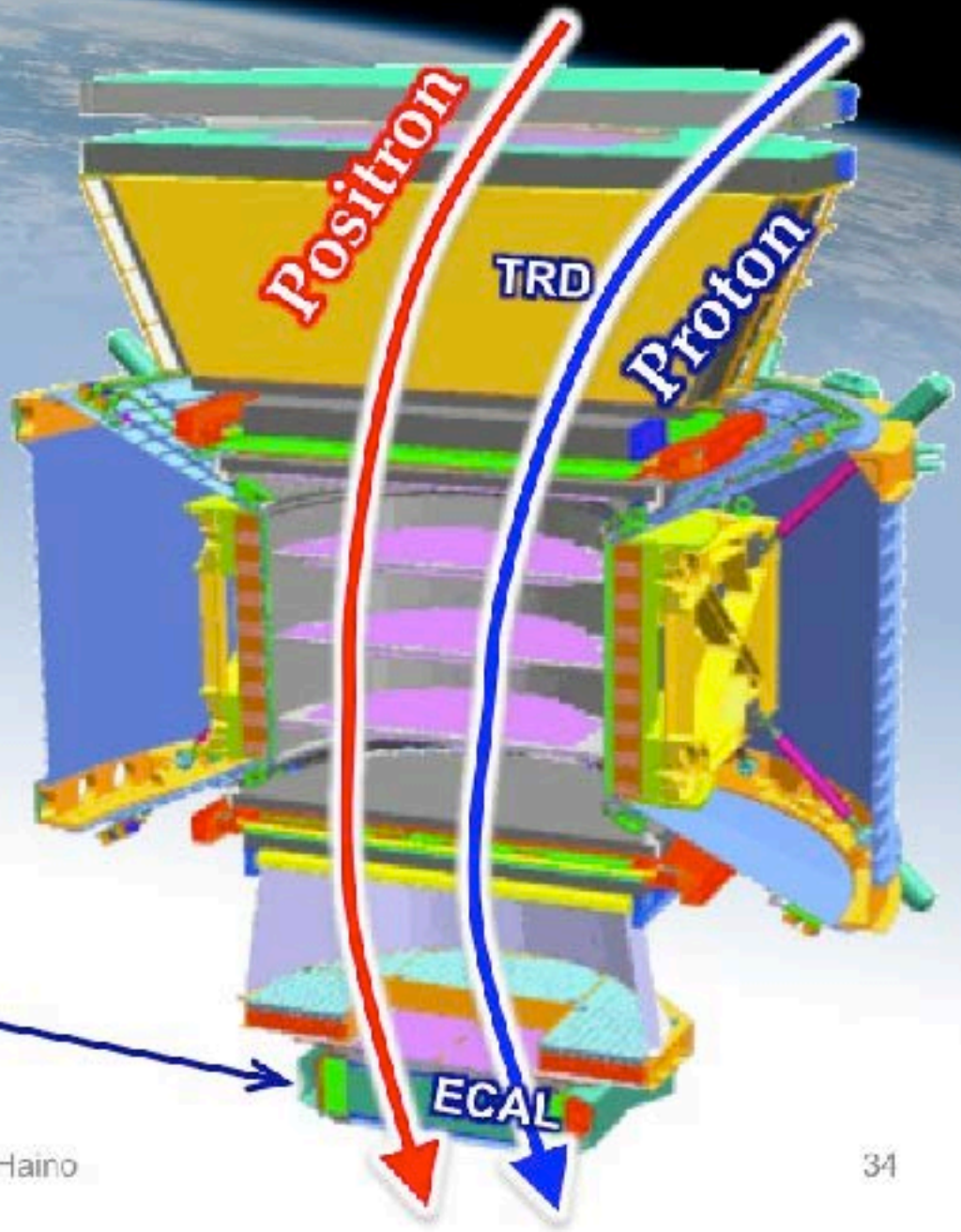


EM calorimeter

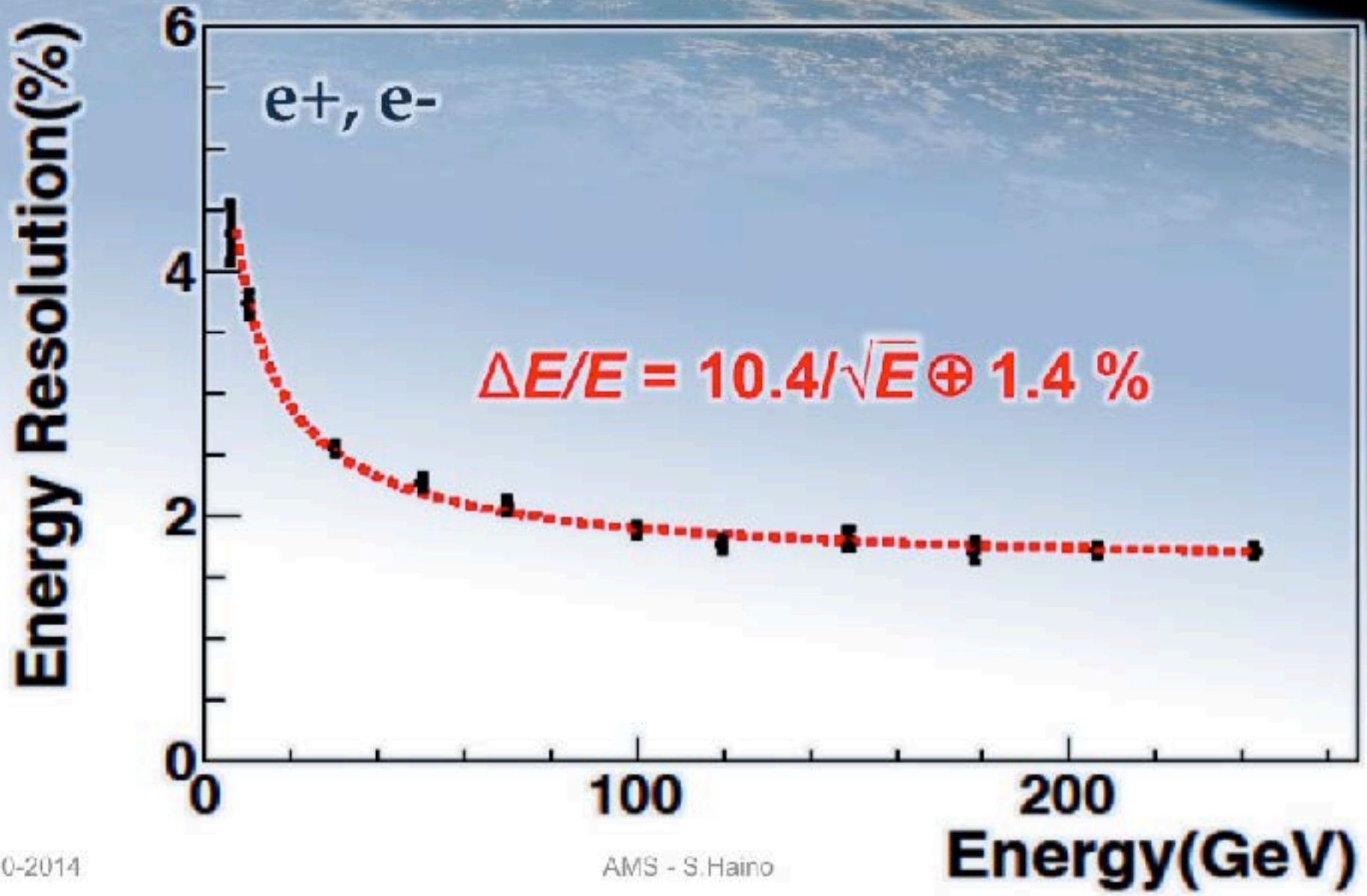




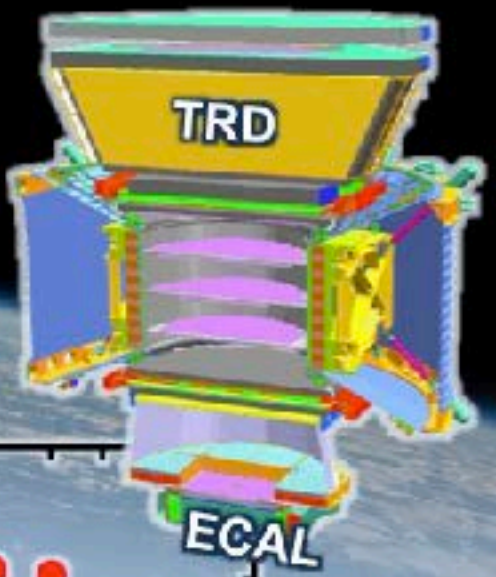
Calorimeter (17 X_0)



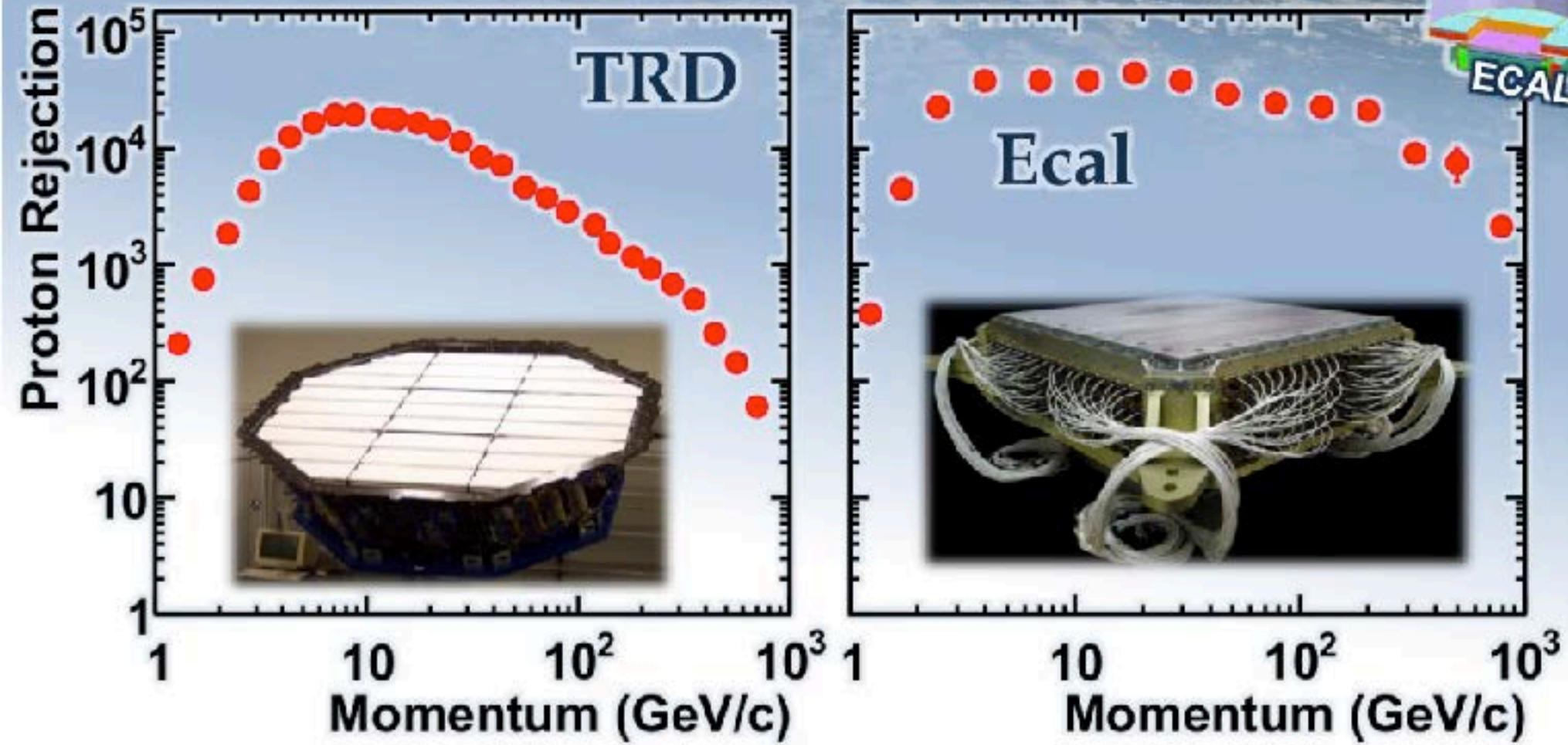
Ecal Energy resolution



Proton rejection

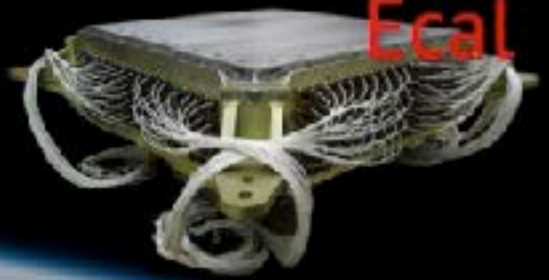


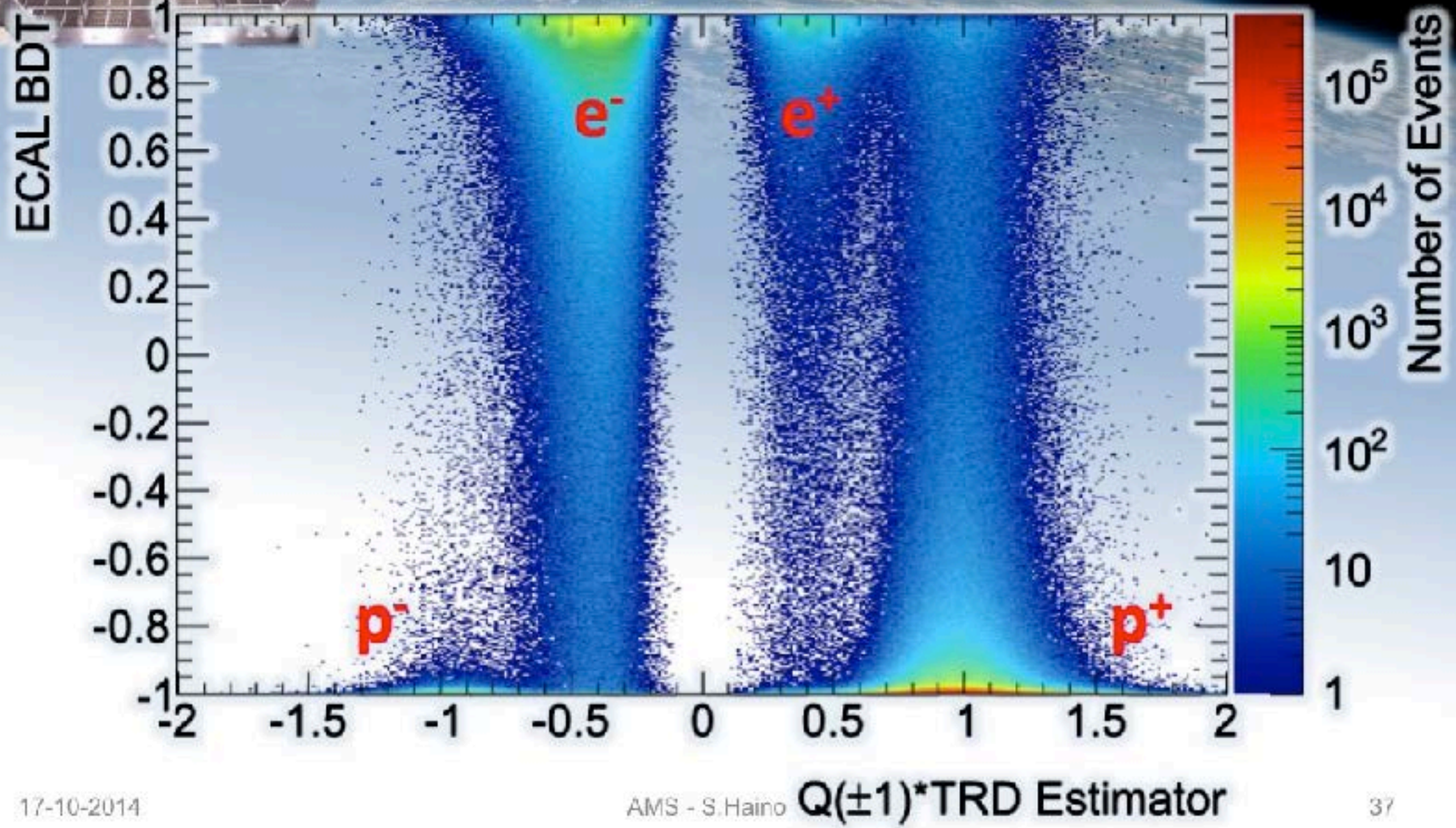
With 90 % e^+ efficiency



Particle ID

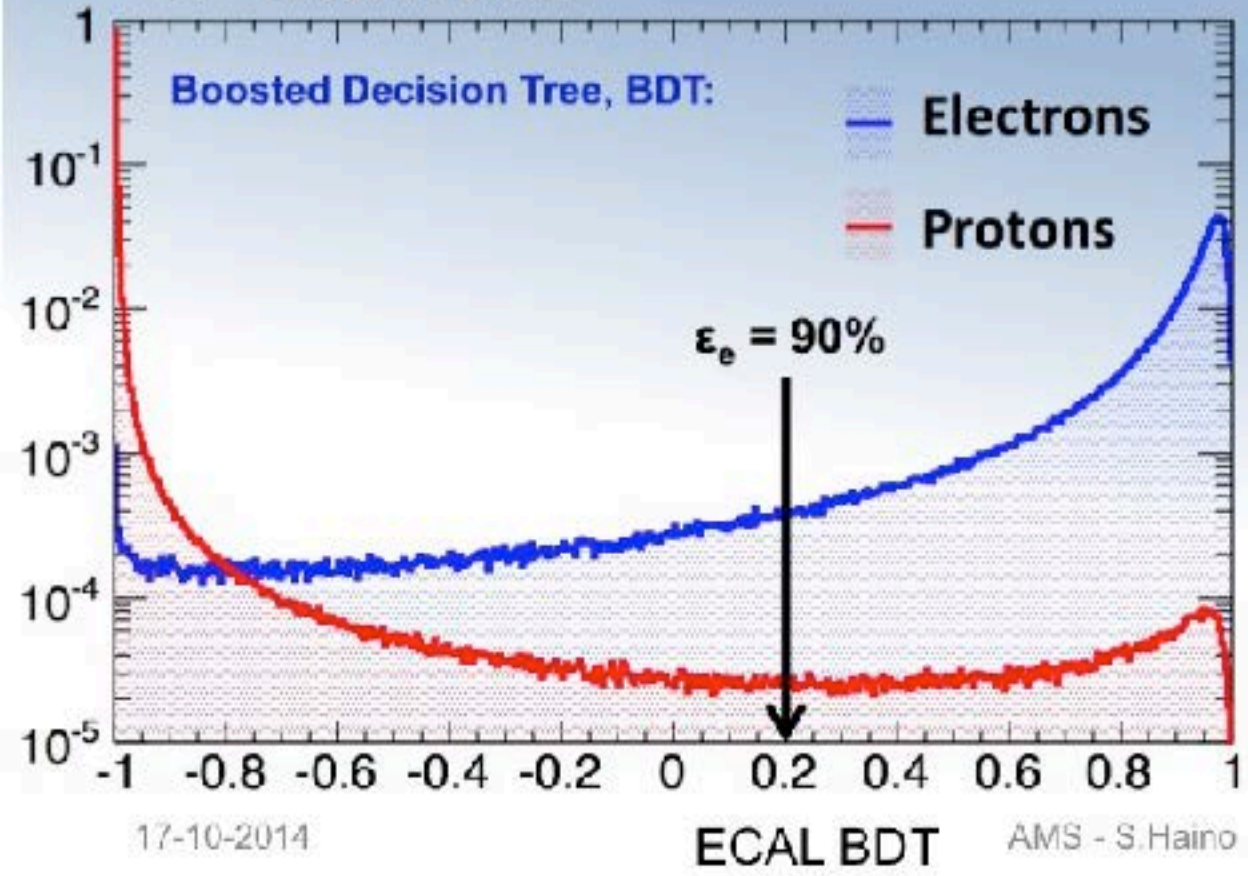

TRD

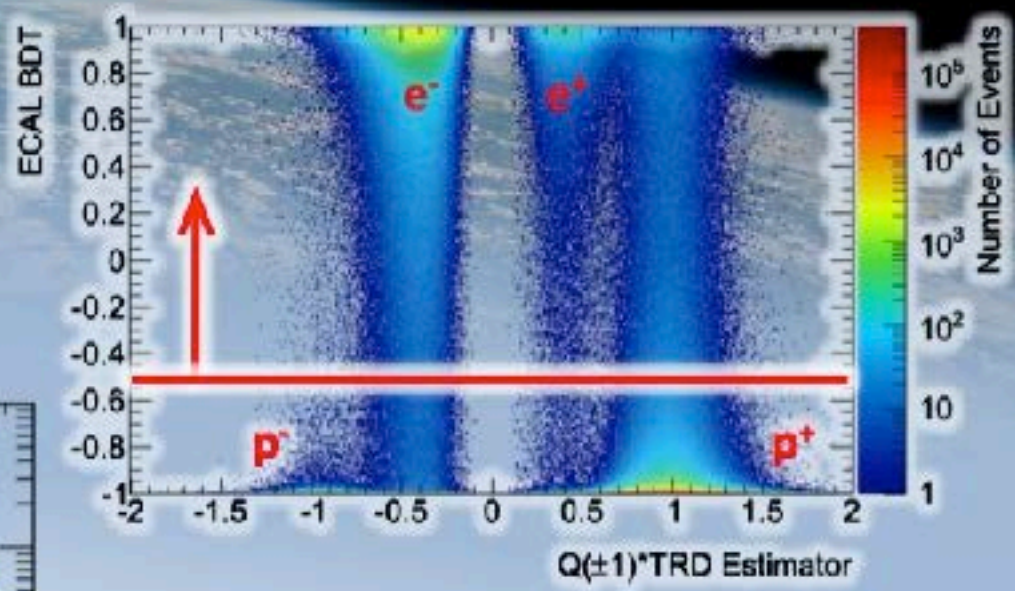

Ecal


ECAL BDT
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
e⁻
e⁺
p⁻
p⁺
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Q(±1)*TRD Estimator
Number of Events
10⁵
10⁴
10³
10²
10
1

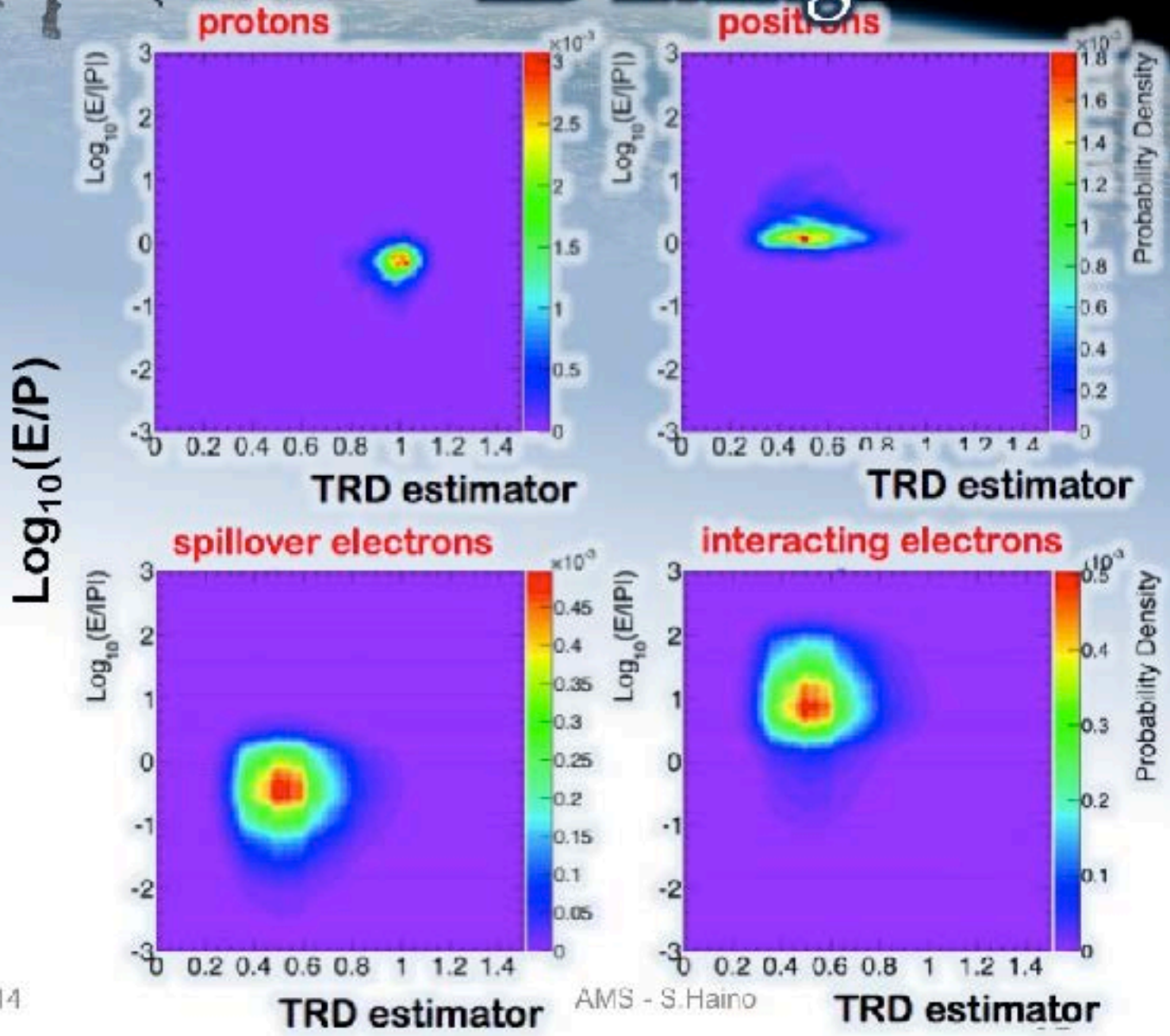
Particle ID

Cut on ECAL BDT
Reduce proton BG, Minimal effect on e^+ fraction

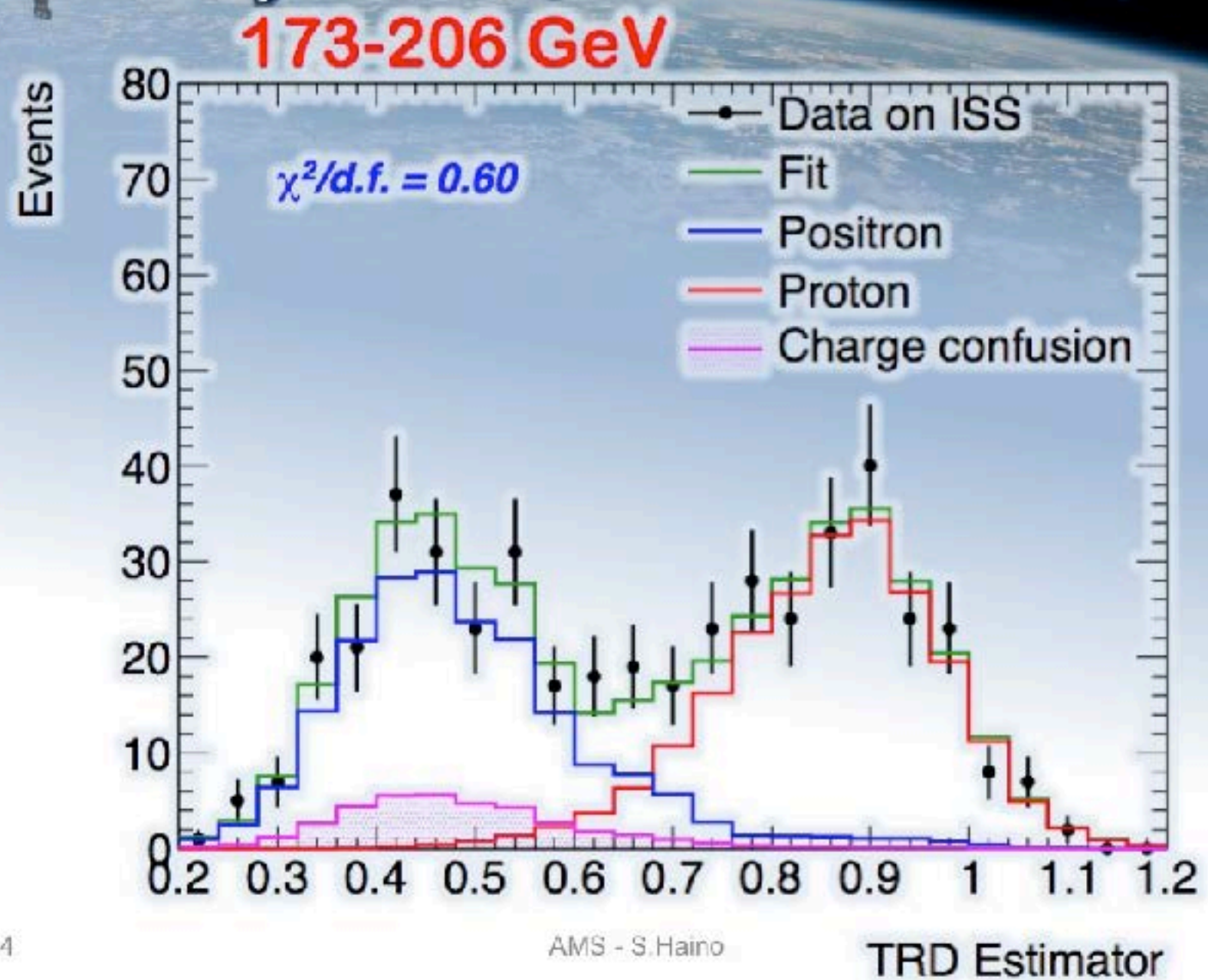




2D fitting

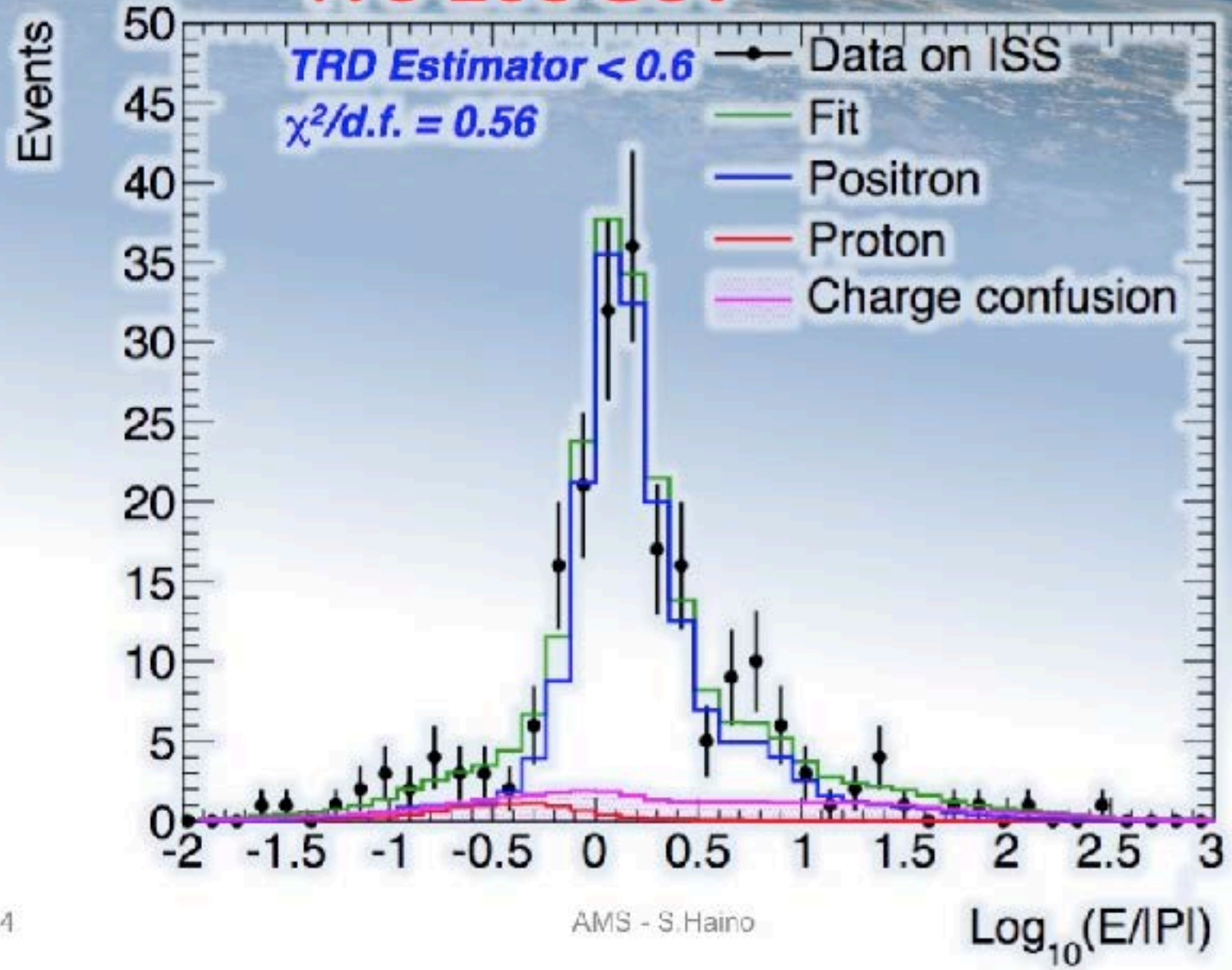

protons
positrons
spillover electrons
interacting electrons
Log10(E/P)
Log10(E/|P|)
TRD estimator
Probability Density

Projection (TRD estimator)

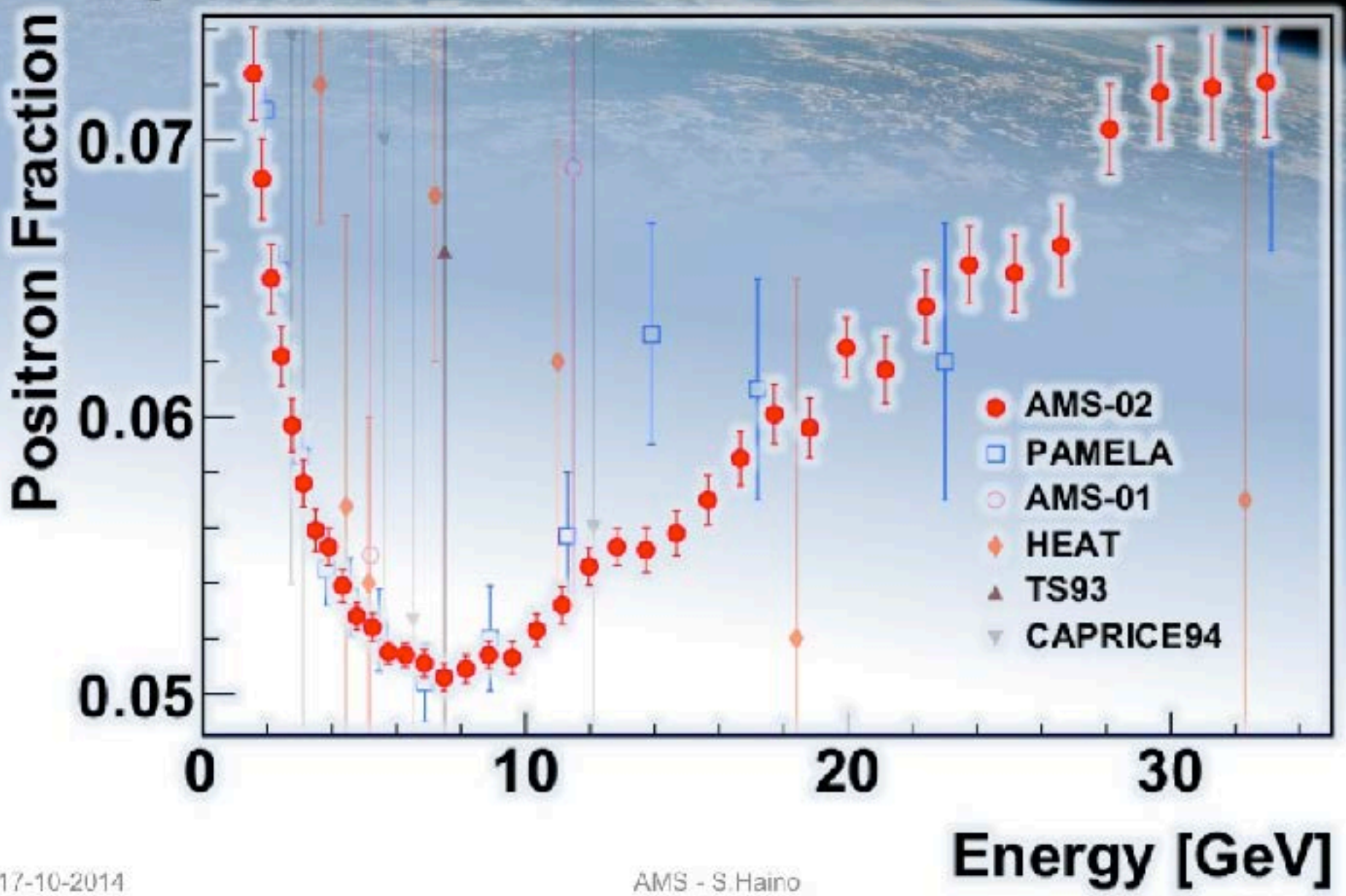


Projection (E/P)

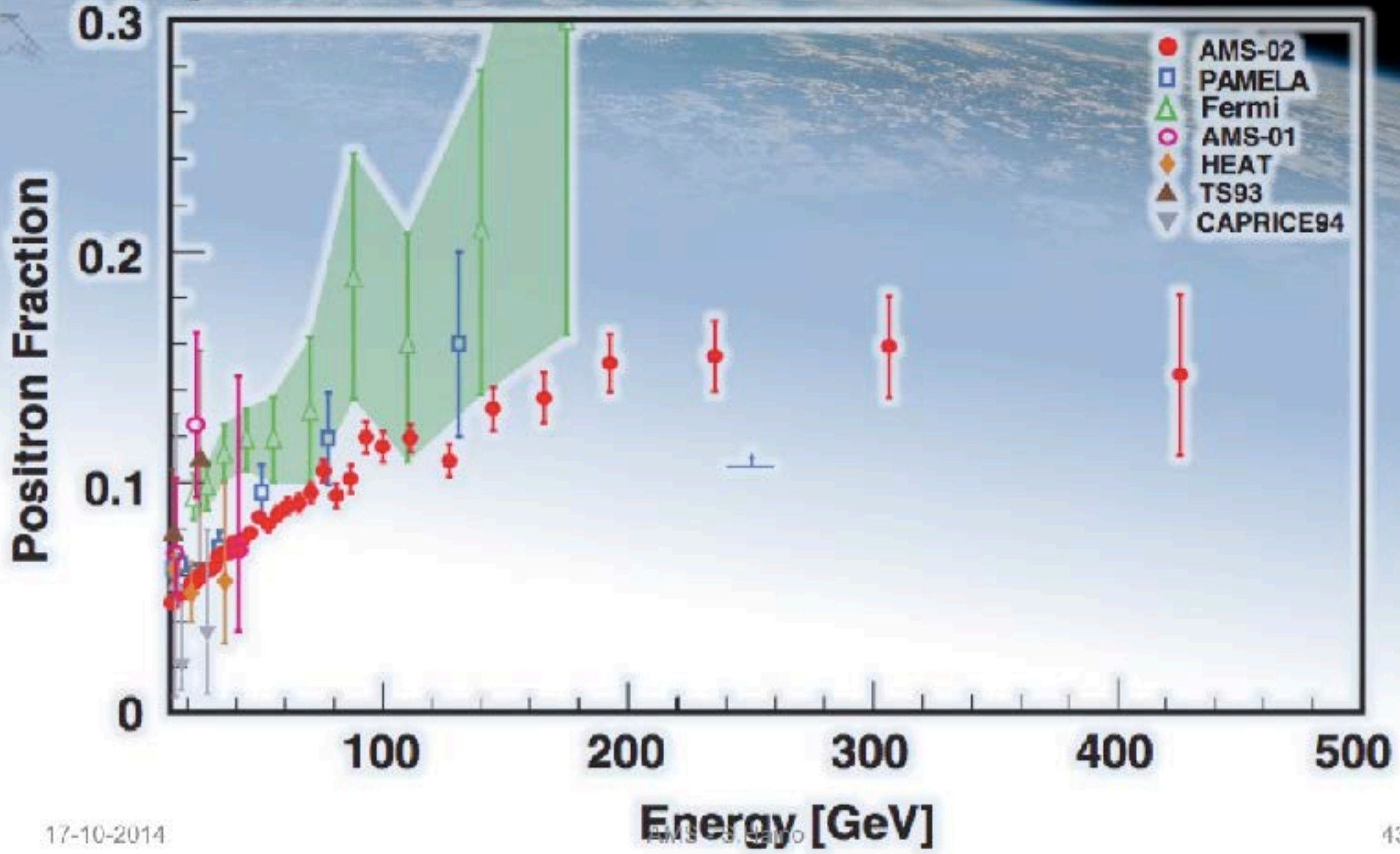
173-206 GeV



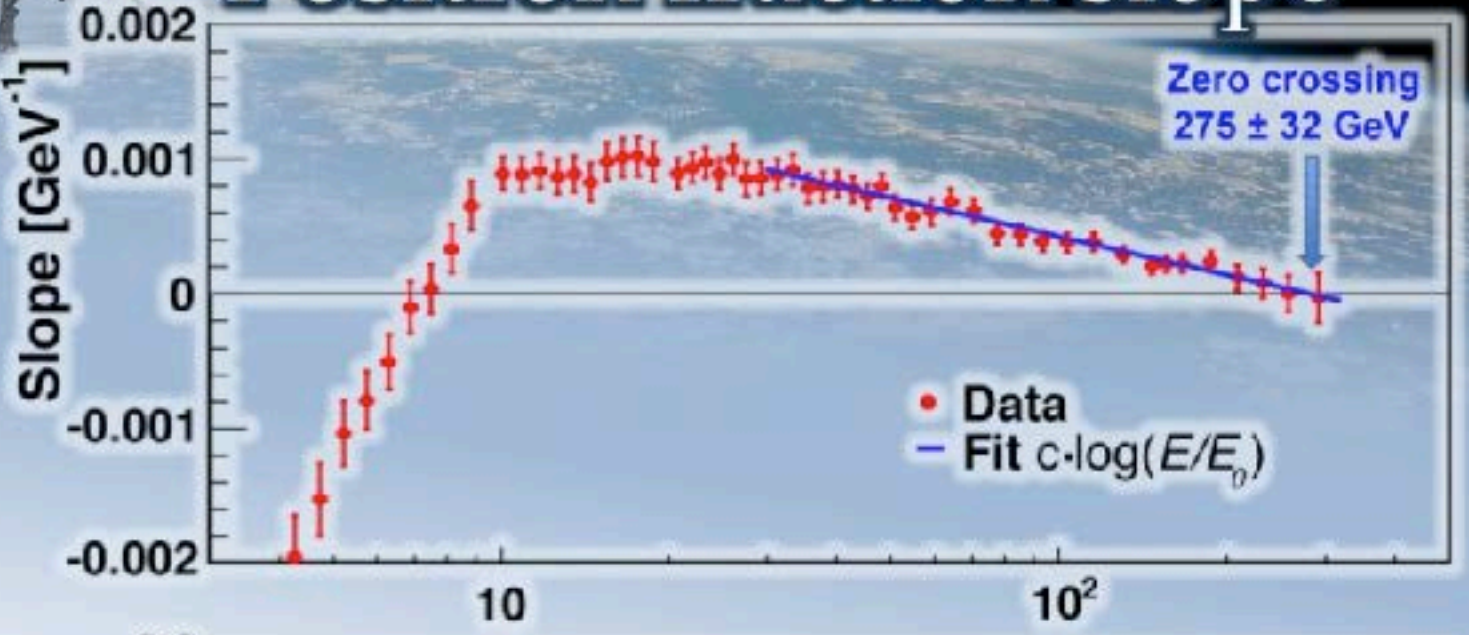
Positron fraction (low energy)

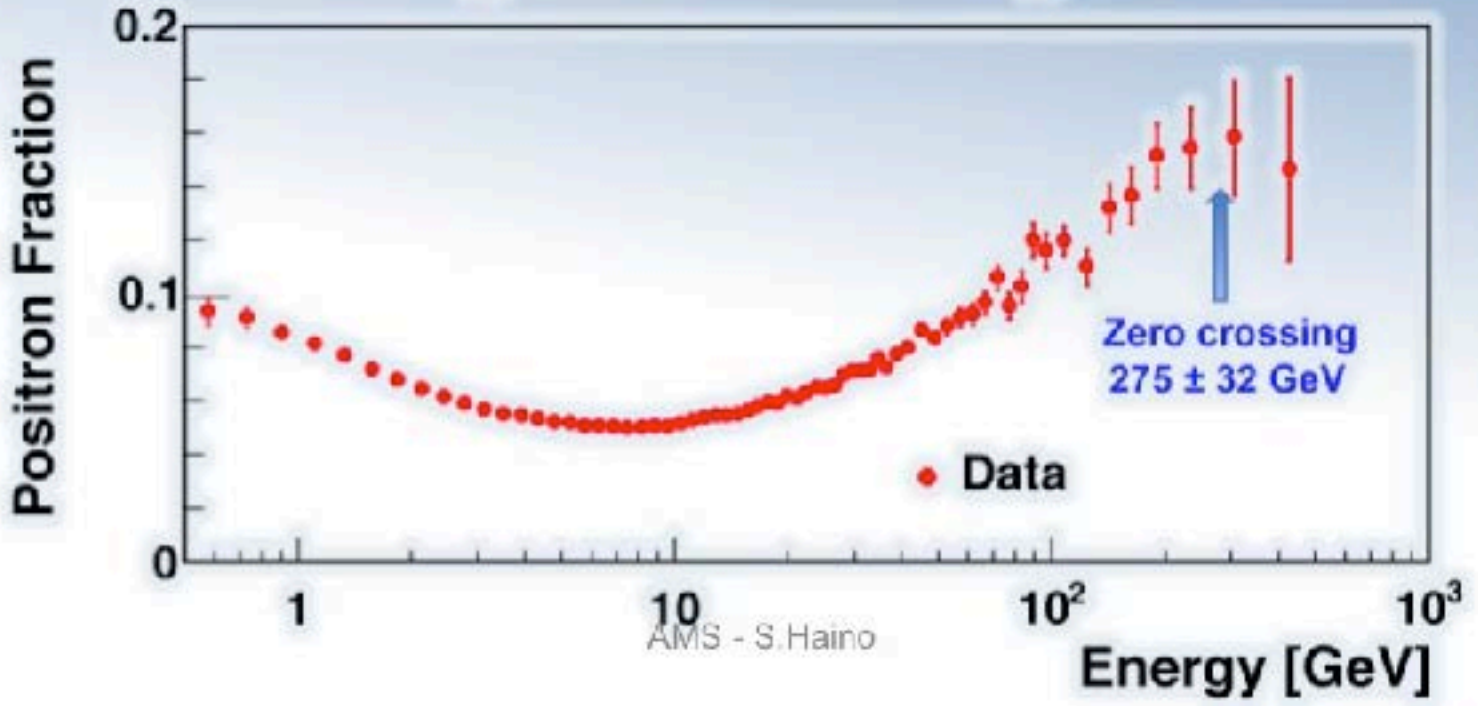


Positron fraction (high energy)

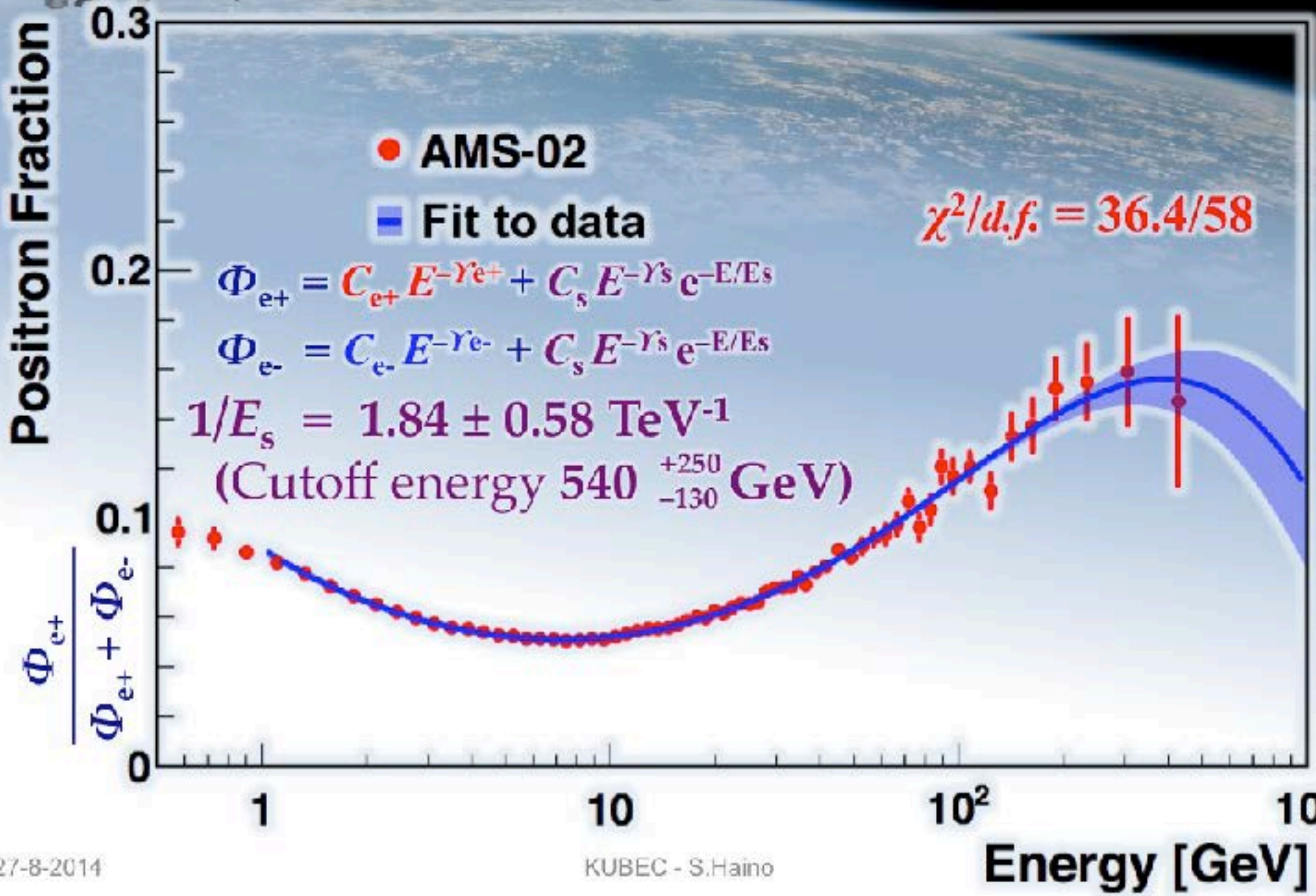


Positron fraction slope





Fit to data


Positron Fraction
$\frac{\Phi_{e+}}{\Phi_{e+}+\Phi_{e-}}$
0.3
0.2
0.1
0
AMS-02
Fit to data
$\chi^2/d.f. = 36.4/58$
$\Phi_{e+} = C_{e+} E^{-\gamma e+} + C_s E^{-\gamma s} e^{-E/Es}$
$\Phi_{e-} = C_{e-} E^{-\gamma e-} + C_s E^{-\gamma s} e^{-E/Es}$
$1/E_s = 1.84 \pm 0.58$ TeV^{-1}
(Cutoff energy $540\ ^{+250}_{-130}$ GeV)
1
10
10^2
10^3
Energy [GeV]

Flux determination

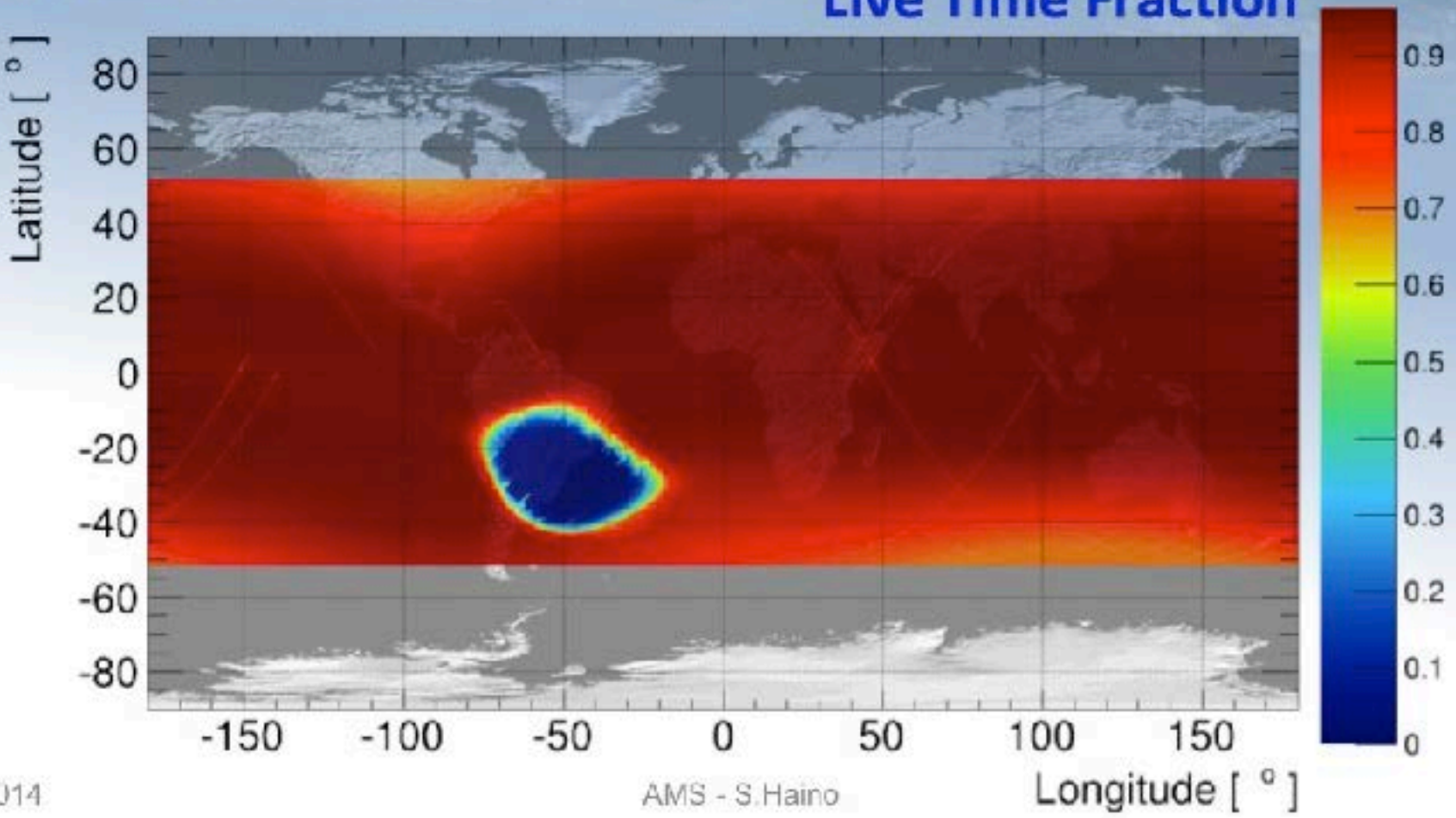
$$\Phi(E) = \frac{N}{T \cdot A_{\text{eff}} \cdot \varepsilon_{\text{trig.}} \cdot \Delta E}$$

Φ	: Absolute differential flux	($m^{-2}sr^{-1}s^{-1}GeV^{-1}$)
E	: Measured energy	(GeV)
N	: Number of events after proton selection	
T	: Exposure life time	(s)
A_{eff}	: Effective acceptance	(m^2 sr)
$\varepsilon_{\text{trg.}}$	: Trigger efficiency	
ΔE	: Energy bin	(GeV)

Exposure time

Data period : May/2011 – Nov./2013 (30 months)

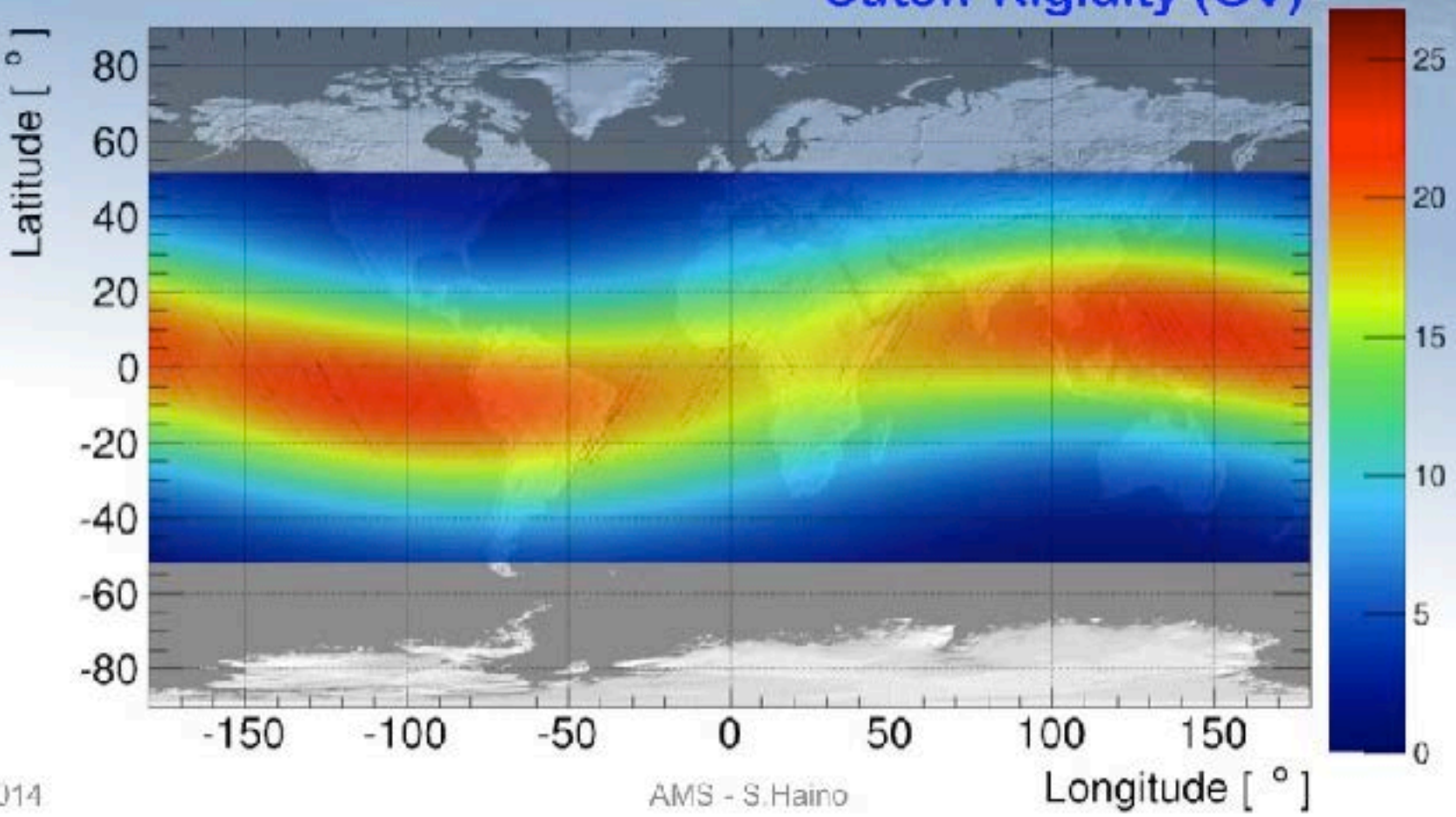
Live time : 6.1×10^7 s



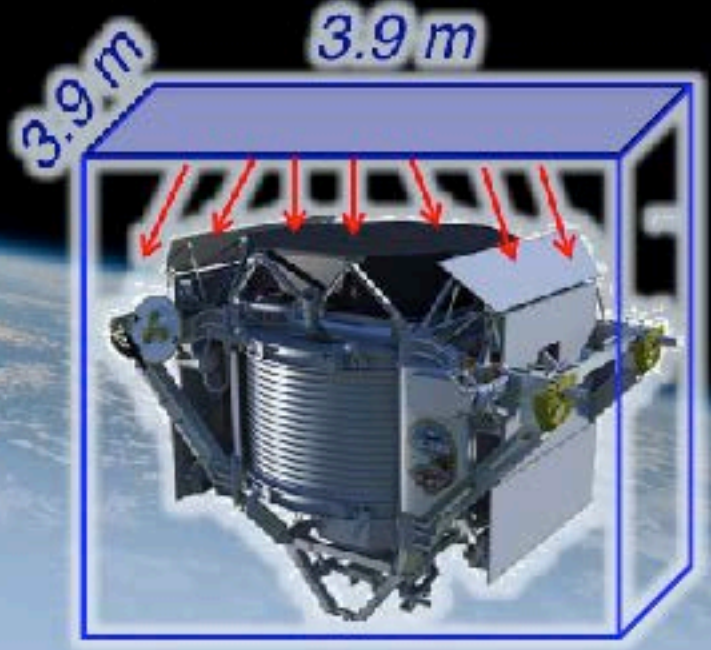
Exposure time

Data period : May/2011 – Nov./2013 (30 months)

Live time : 6.1×10^7 s



Acceptance



$$A_{eff} = A_{geom} \cdot \varepsilon_{sel} \cdot \varepsilon_{id} \cdot (1+\delta)$$

A_{eff} : Effective acceptance

A_{geom}: Geometrical acceptance (~550 cm^2 sr)

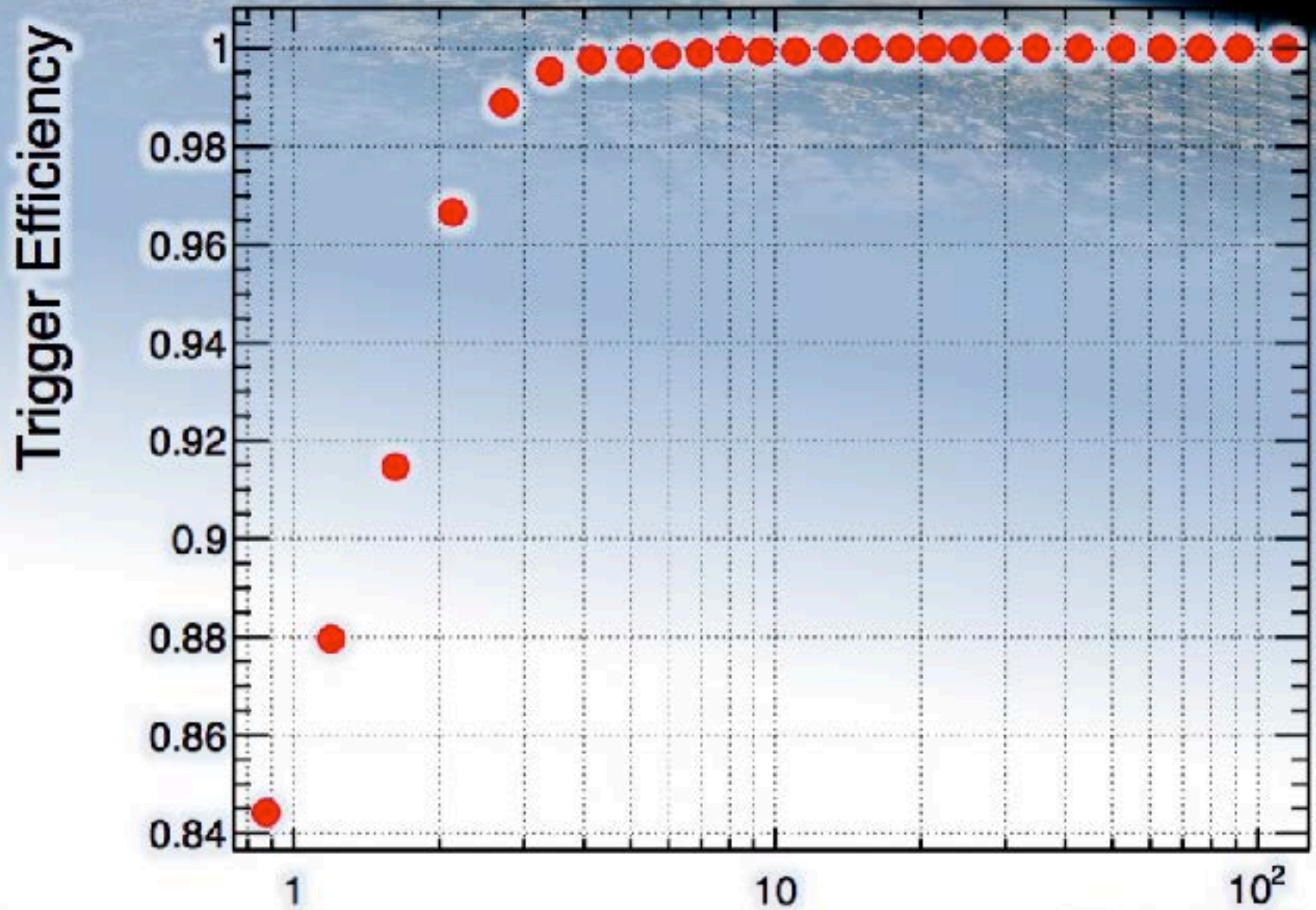
ε_{sel} : Selection efficiency

ε_{id} : $e^{\pm}$ identification efficiency

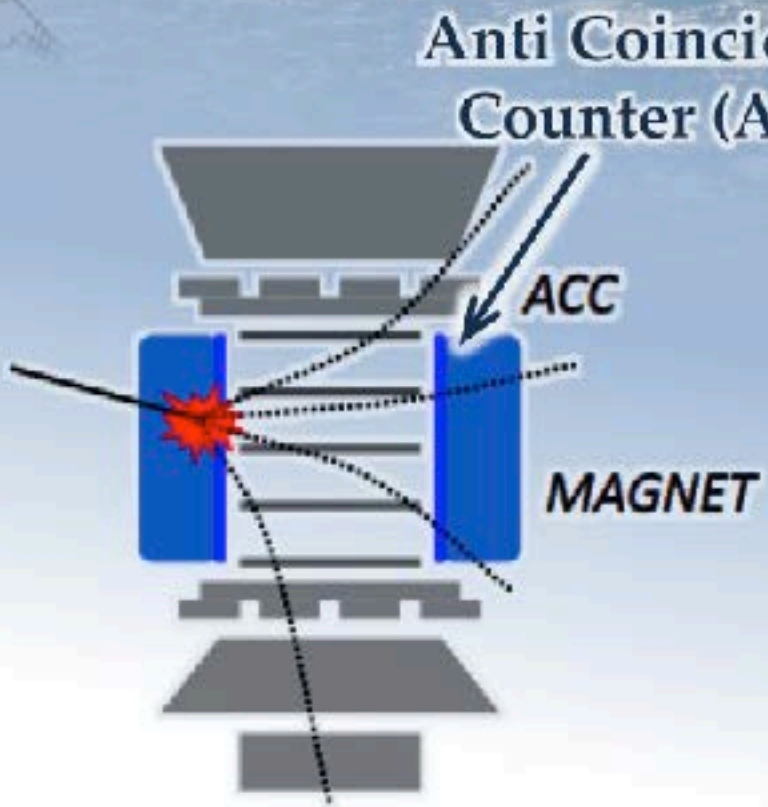
δ : Minor correction from Data/MC comparison

(2% at 10 GeV to 6% at 700 GeV)

Trigger efficiency

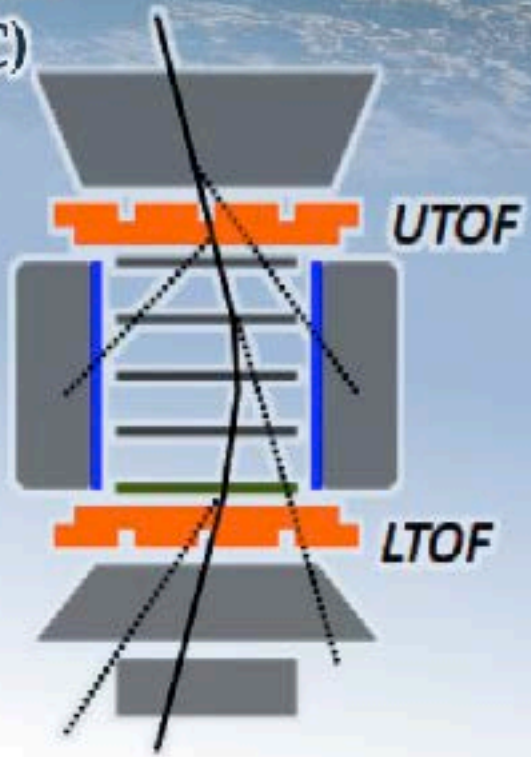


Trigger scheme



Horizontal Particle

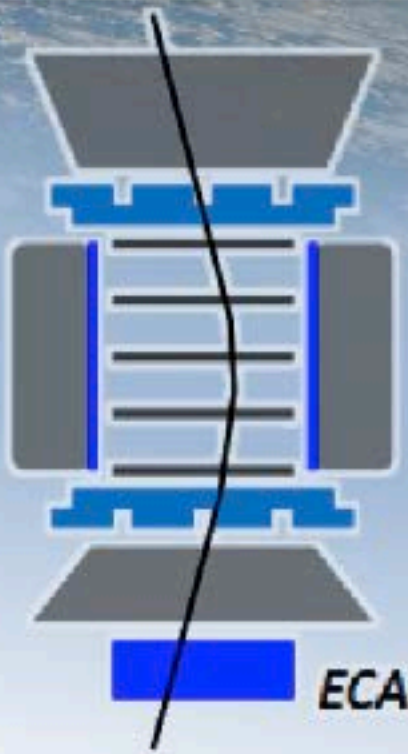
Rejected



High-Z particle

Accepted

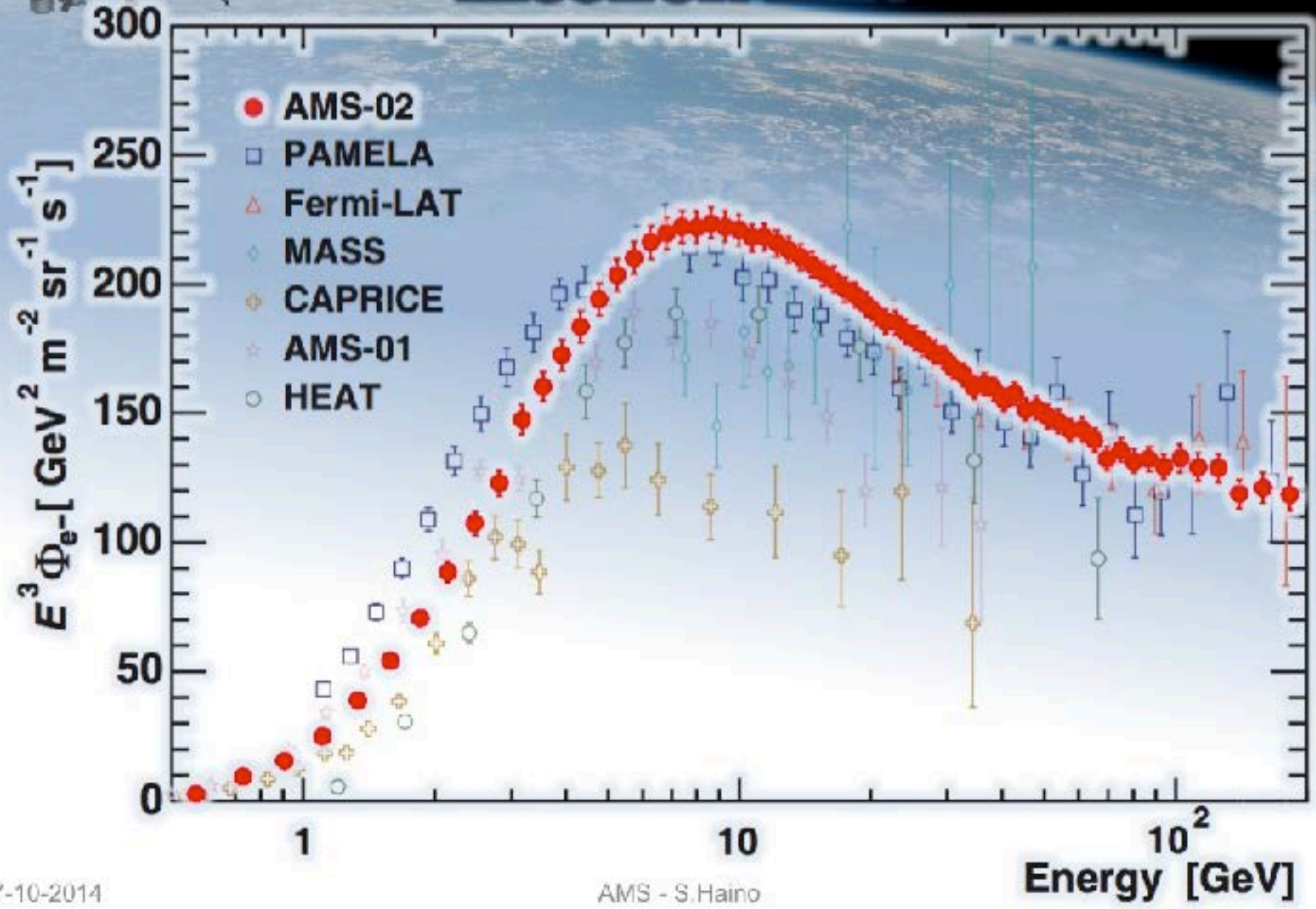
$e^{\pm}$ flux



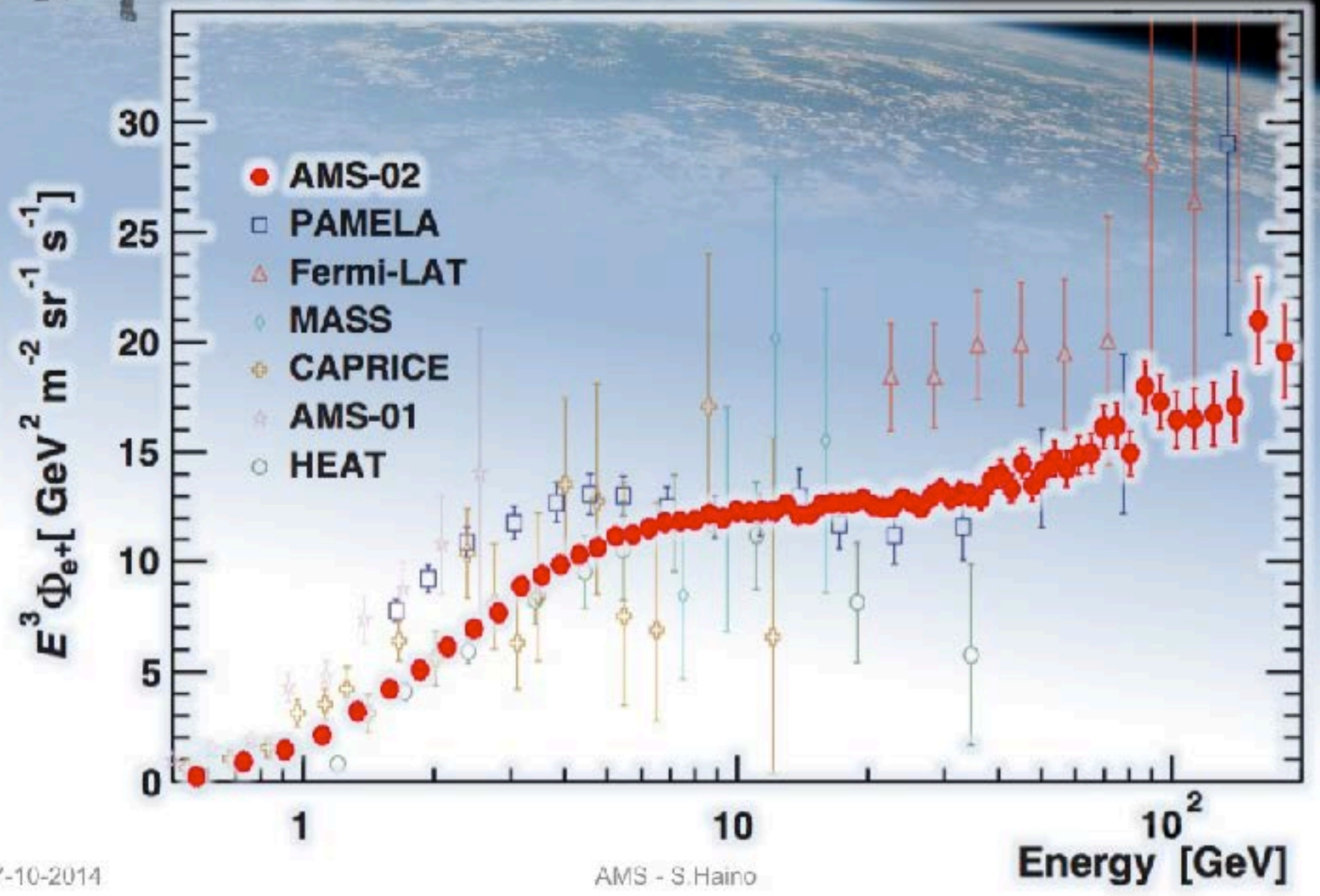
TOF + ECAL Trigger

Accepted

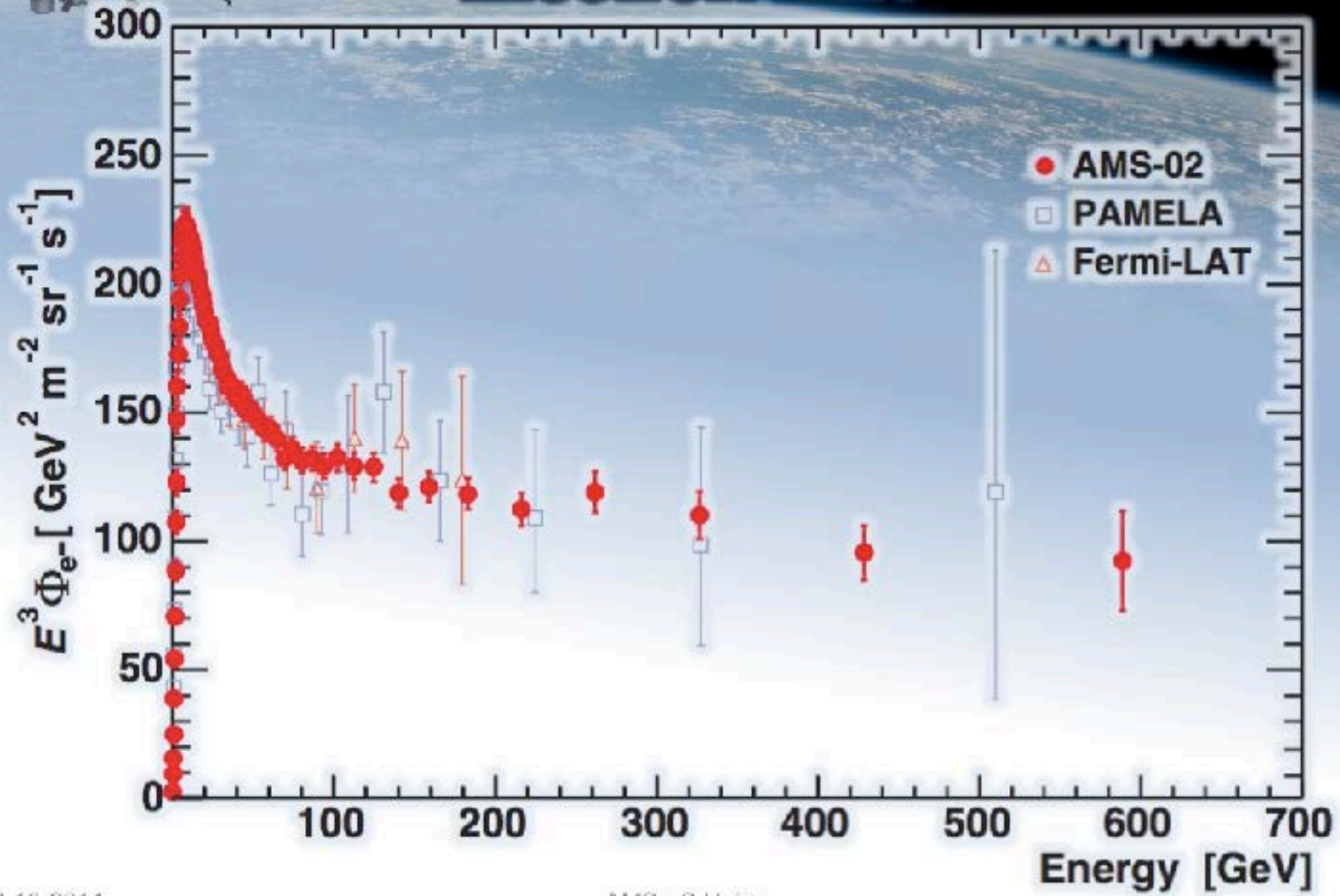
Electron flux



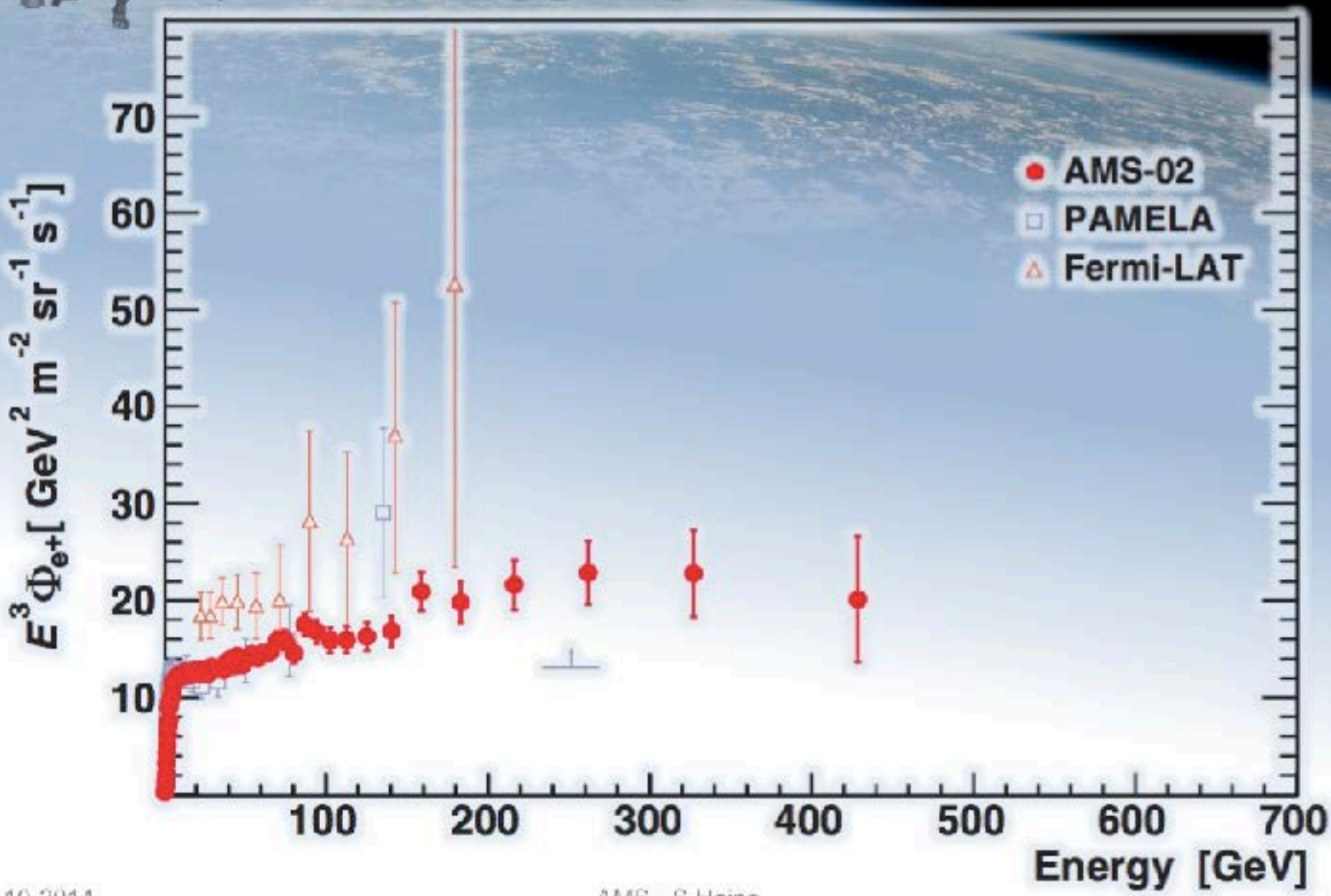
Positron flux



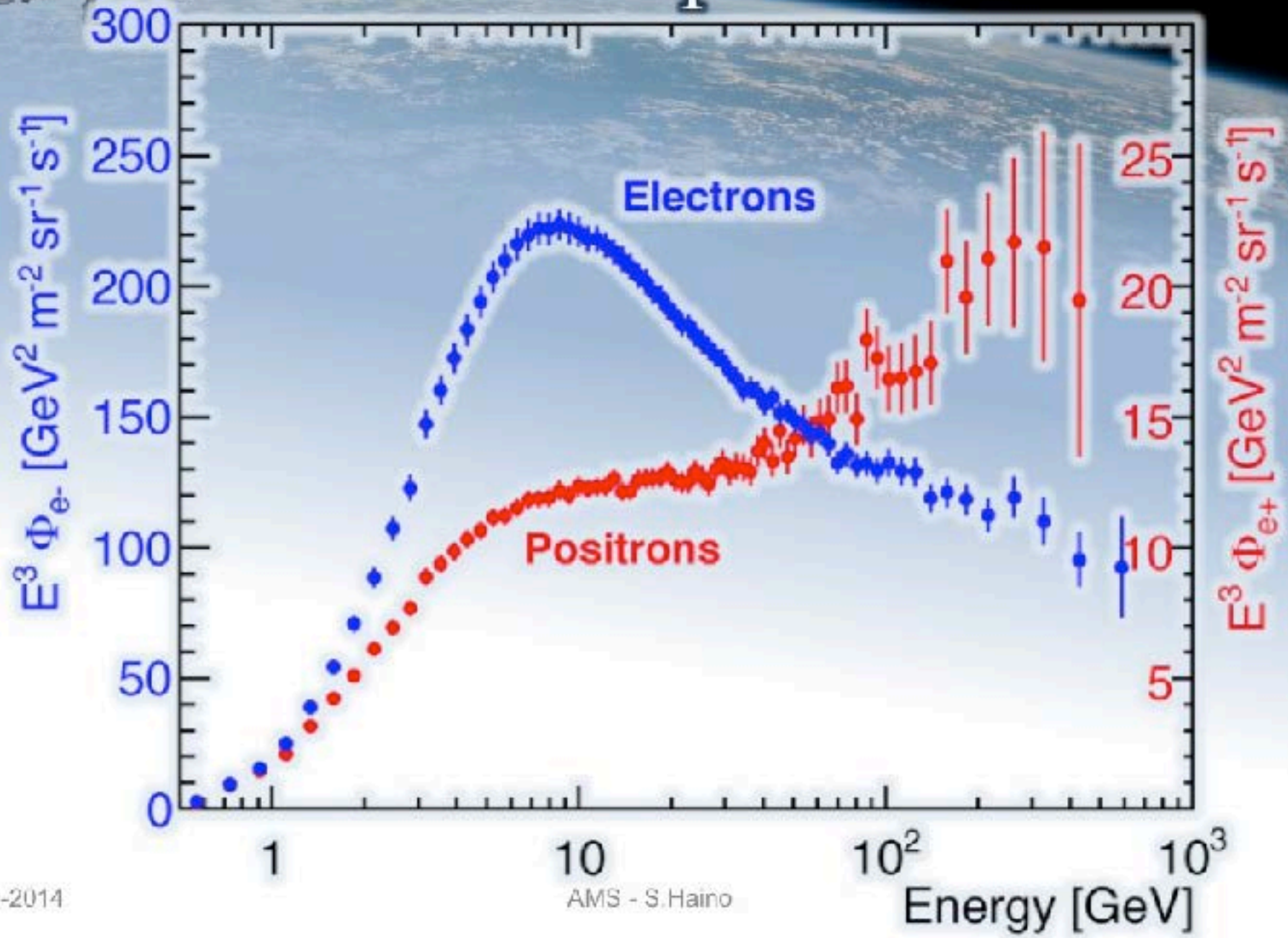
Electron flux



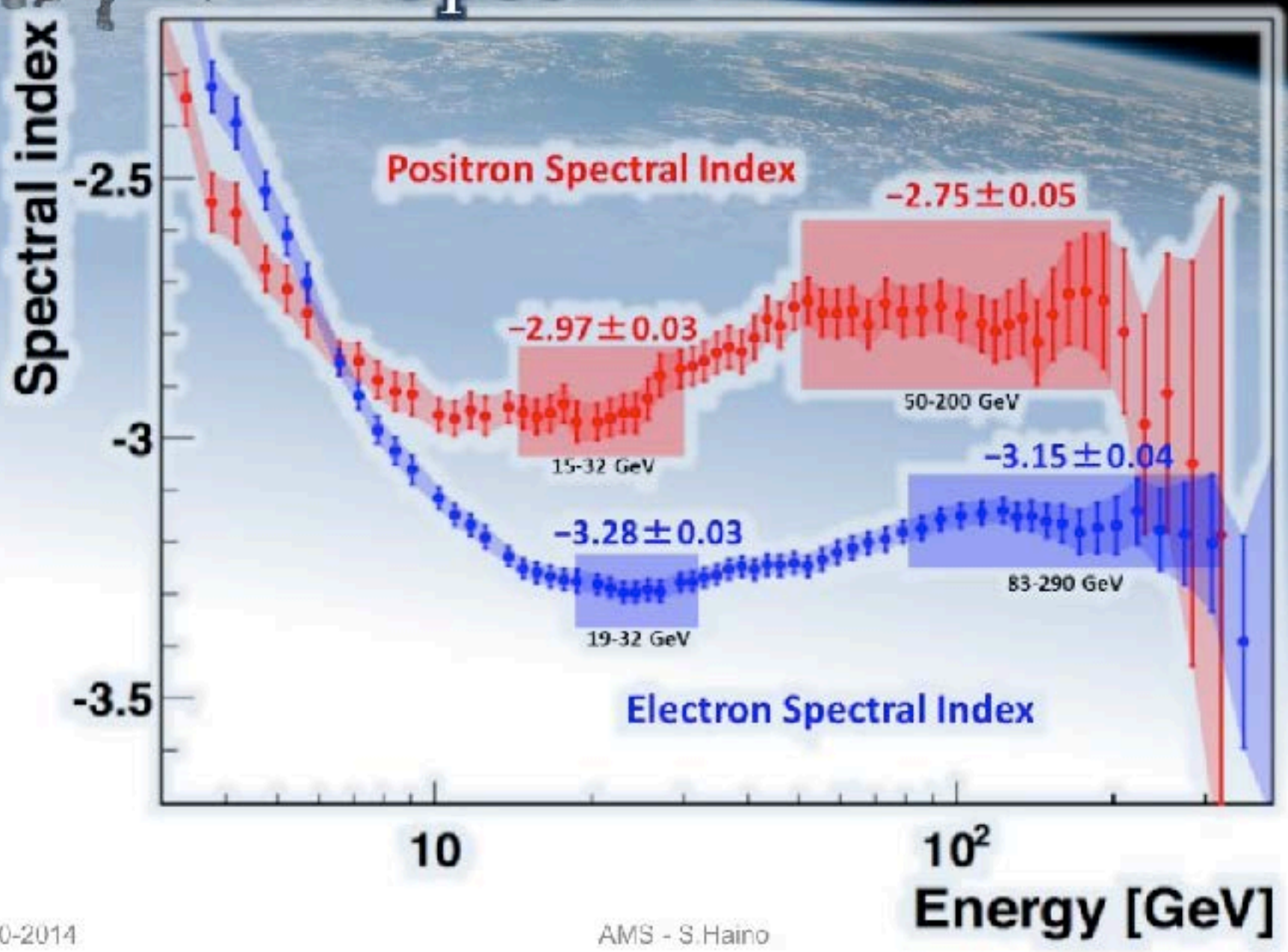
Positron flux



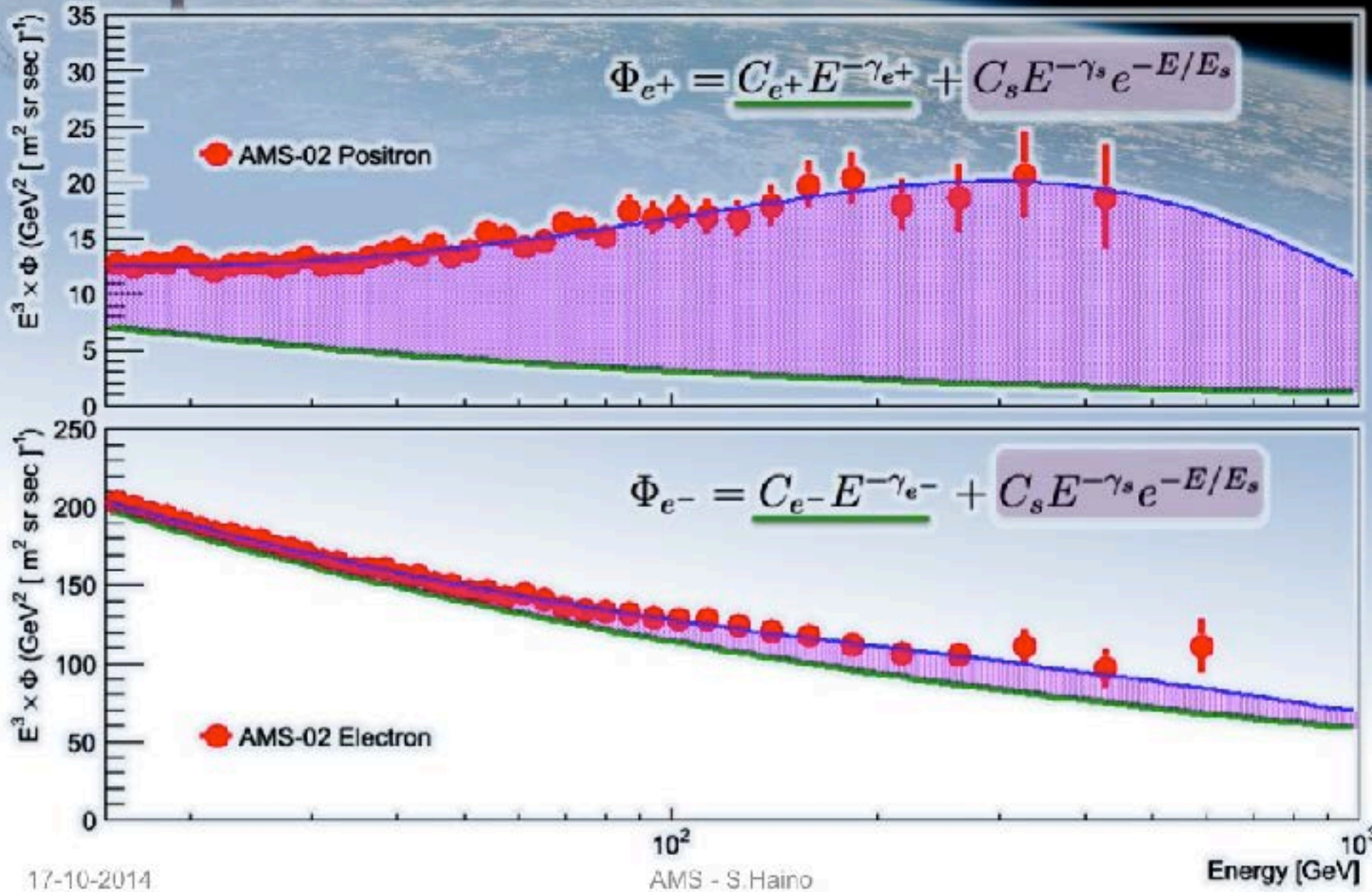
Flux comparison



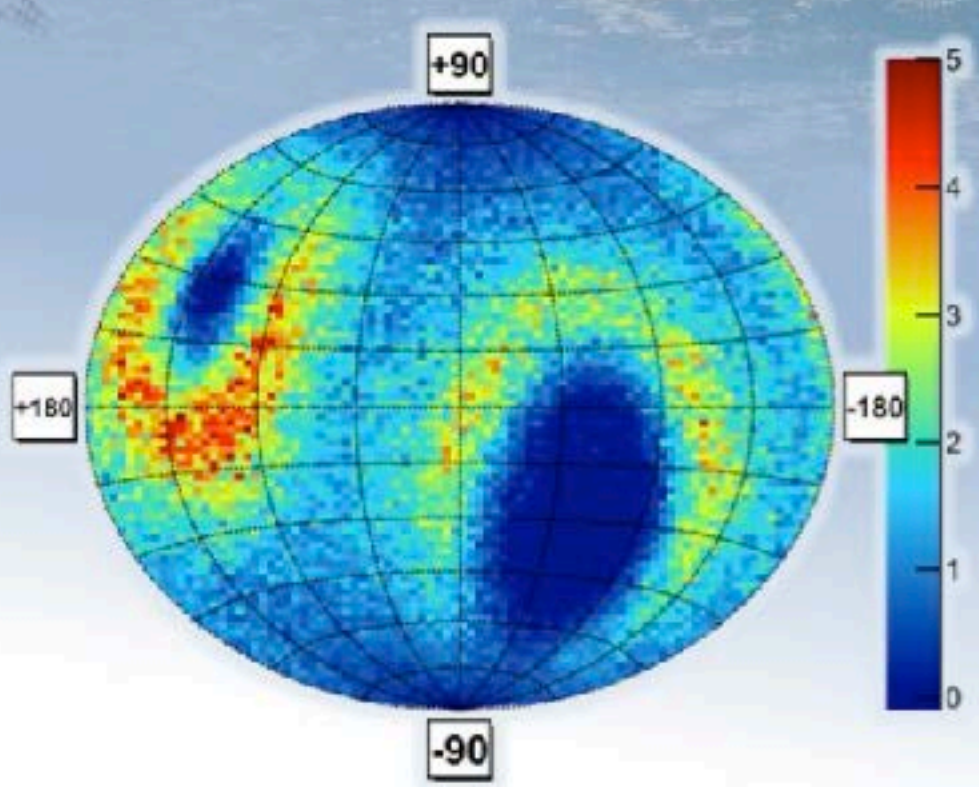
Spectral indices

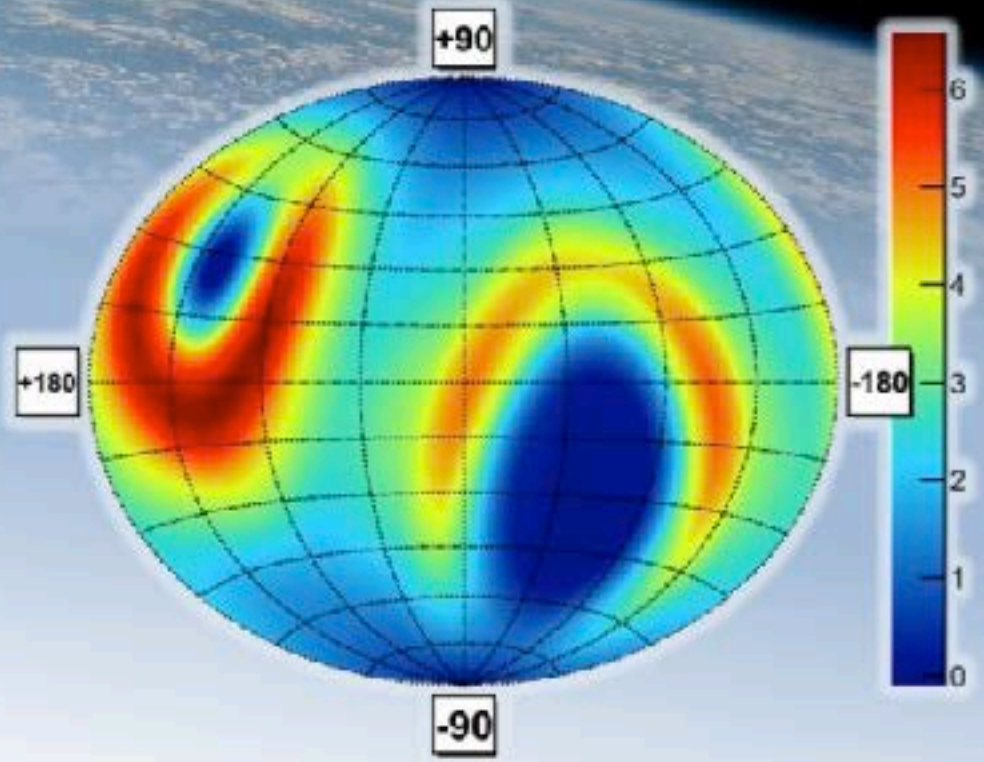


Fit to AMS e^+ and e^- flux



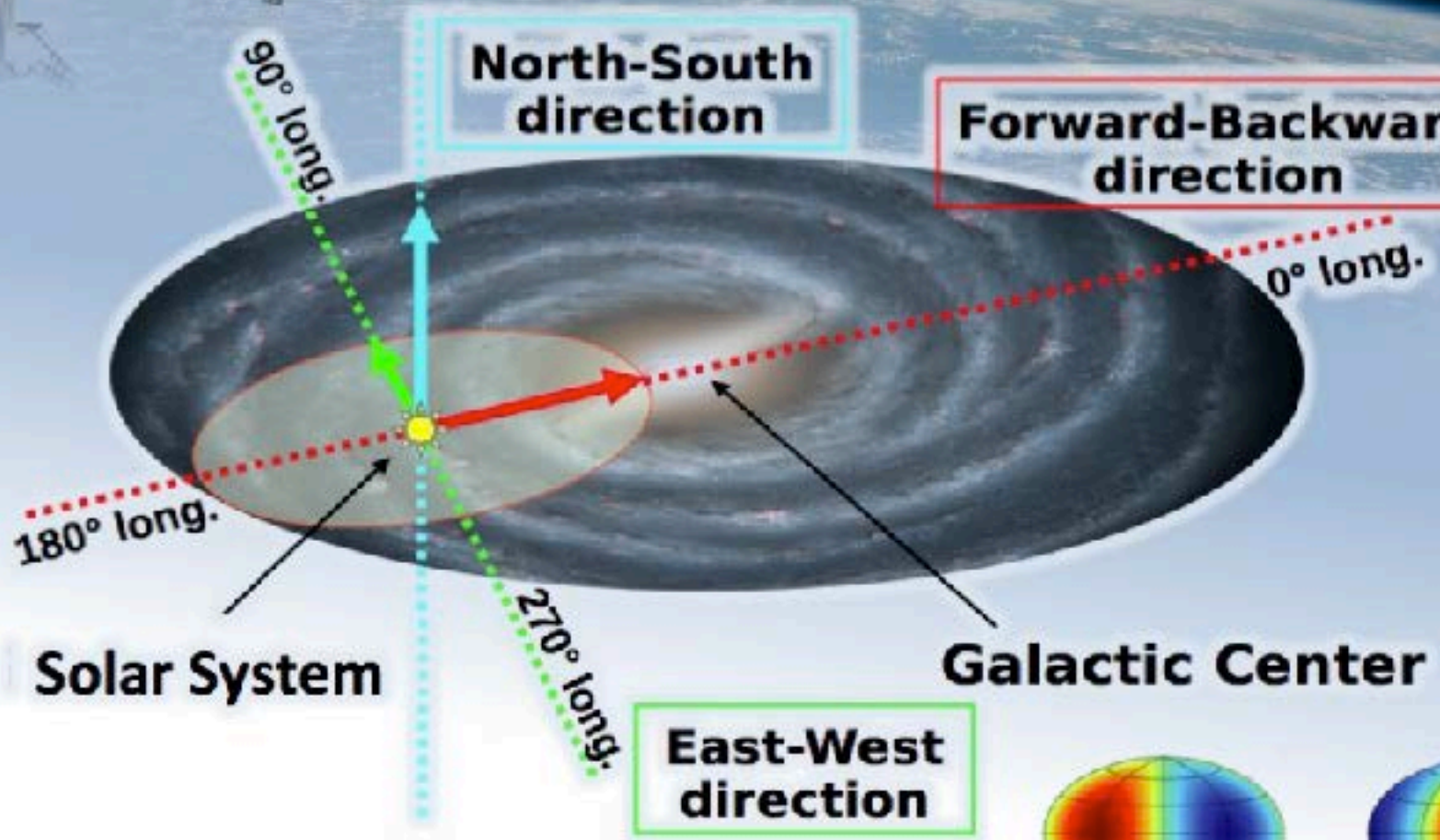
Electron anisotropy

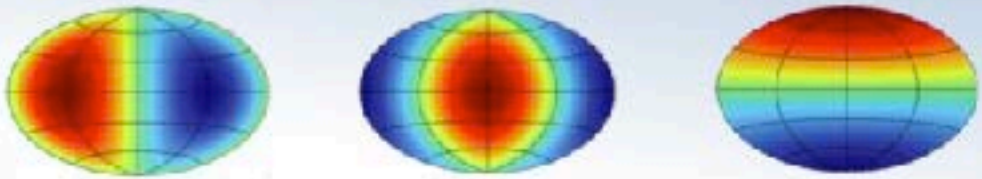




$$N = \int_b \int_l J(b,l) \times AT(b,l) \times \sin b \times db\, dl$$

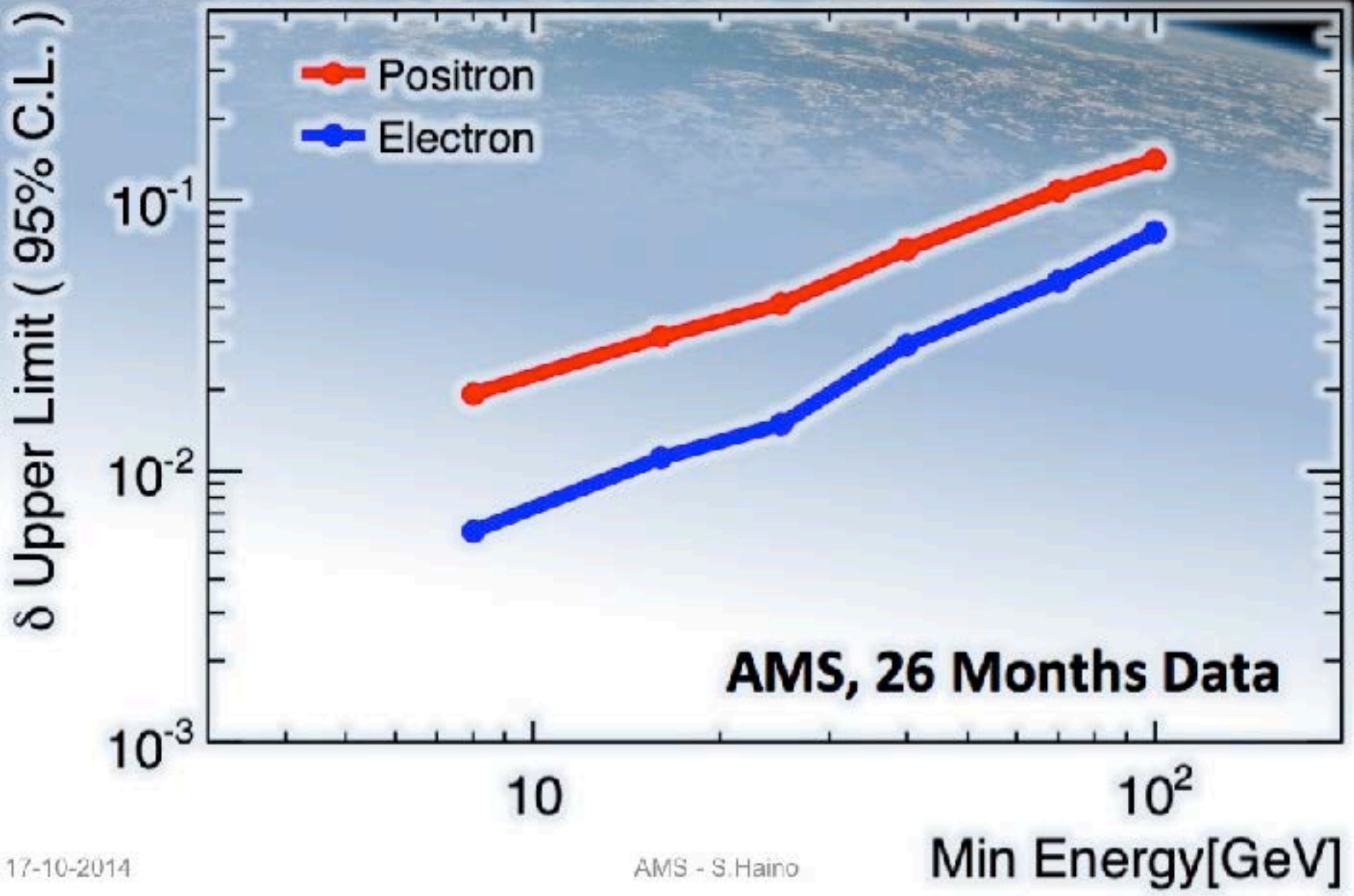
Galactic coordinates (b, l)



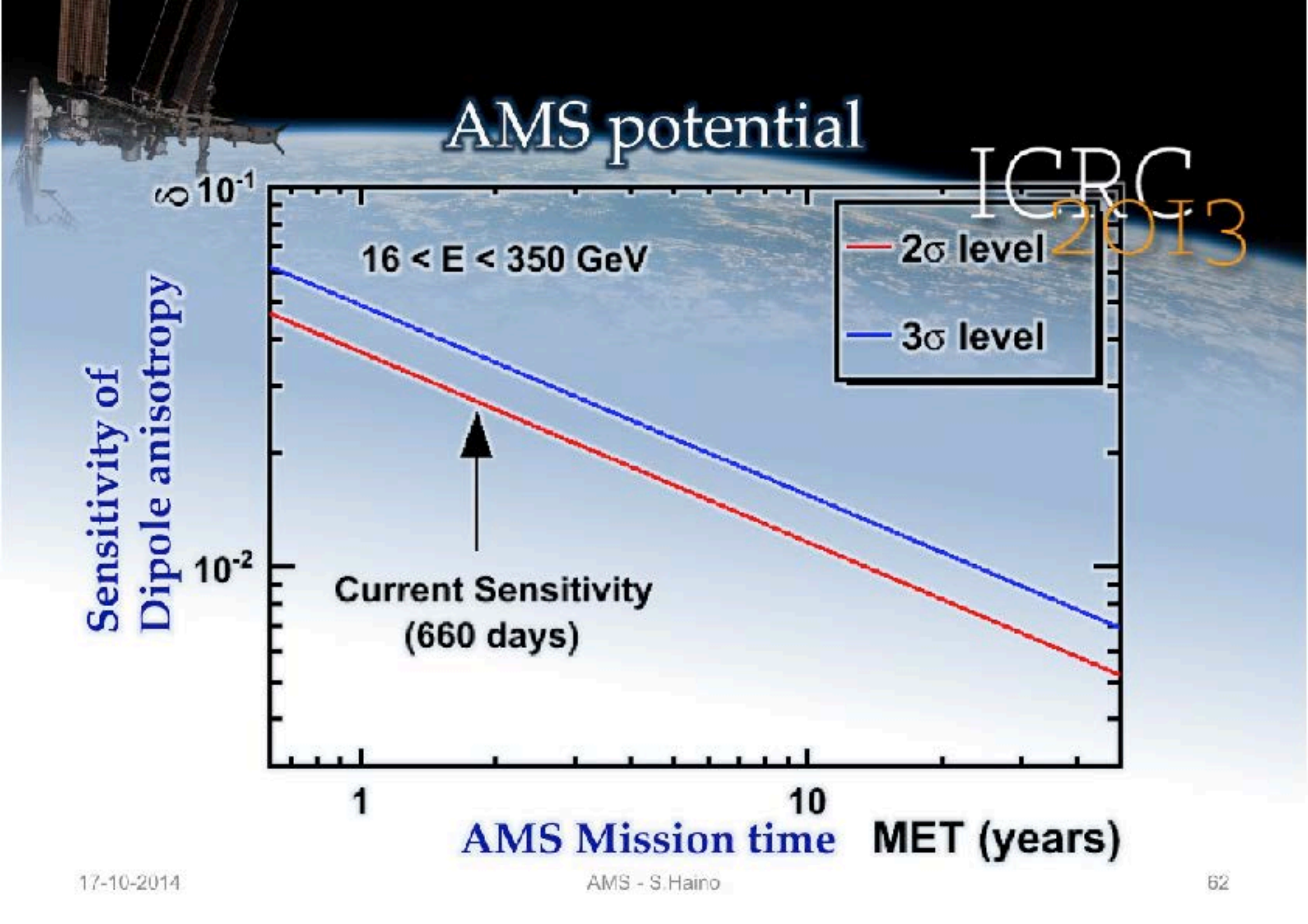


$$J(b,l) = J \times (1 + \sum_{\ell=1}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell m} Y_{\ell}^{m}(b,l))$$

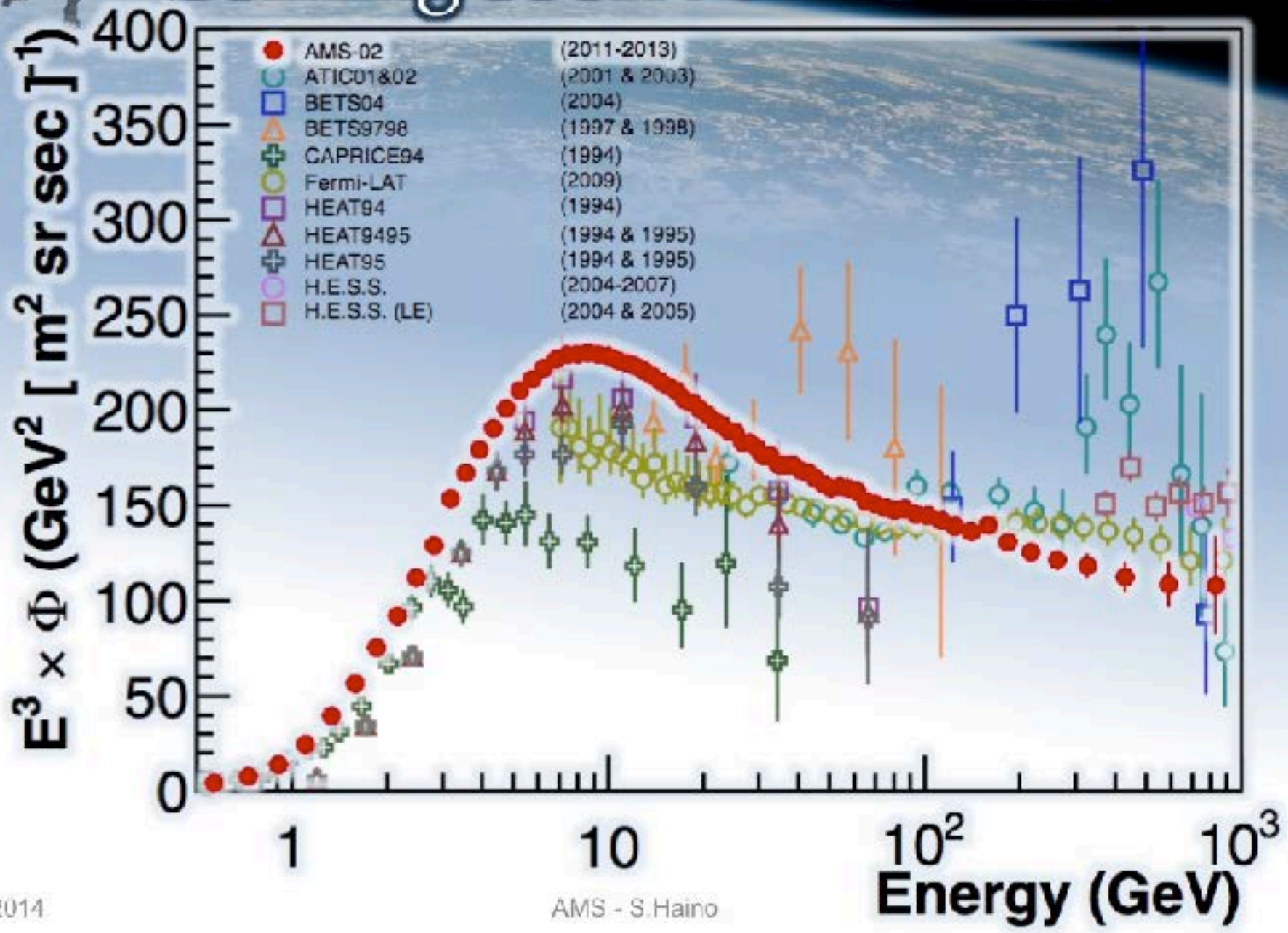
Upper limits of $e^{\pm}$ dipole anisotropy



AMS potential



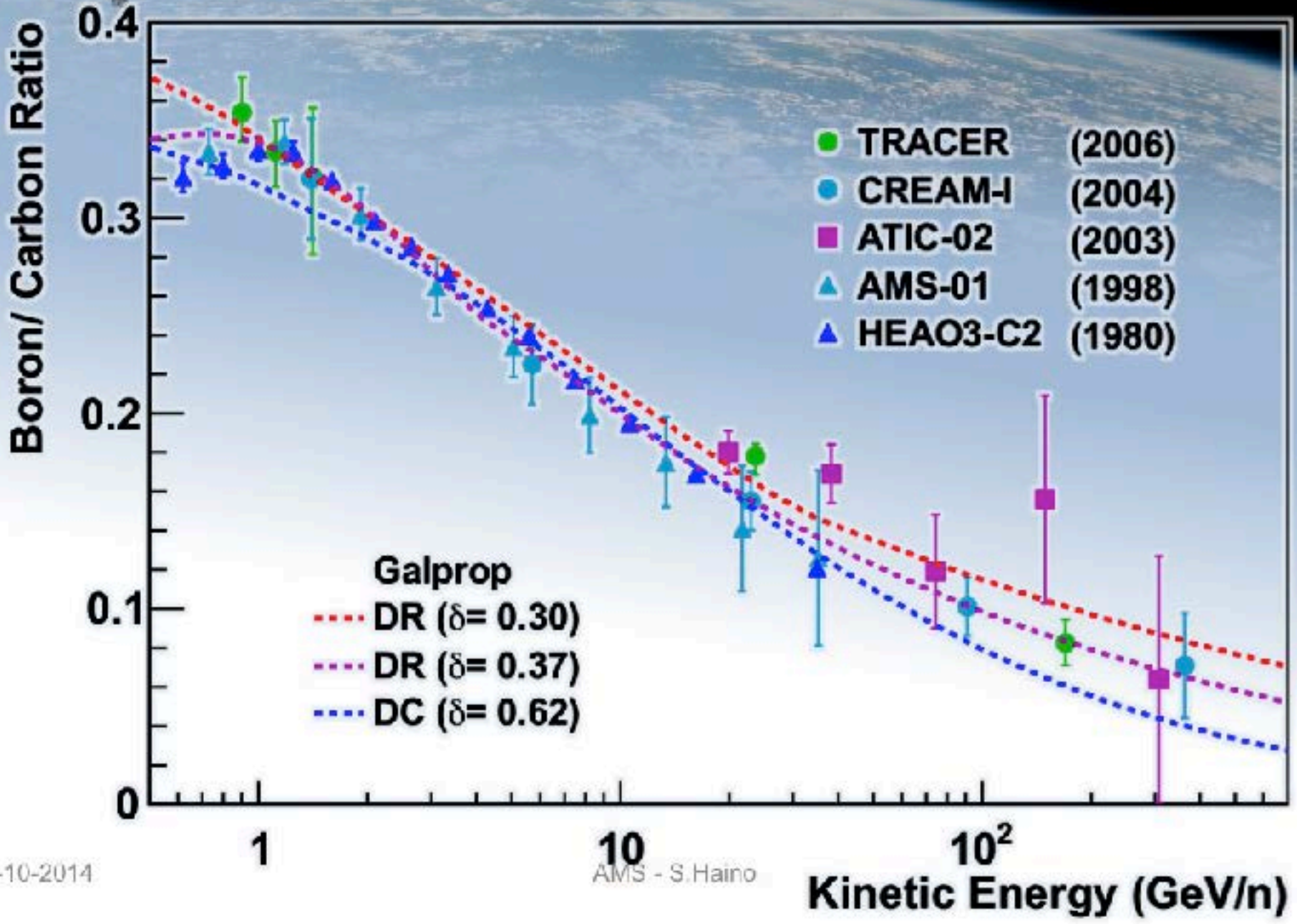
Coming soon : $e^+ + e^-$ flux



Latest AMS Results and Future plans

Cosmic rays	Dark Matter	Future Plans
Proton spectrum	e^+ fraction	e^+ to TeV
Helium spectrum	e^+ flux	$\bar{p}/p$ ratio
e- spectrum	Anisotropy	Antimatter
B/C ratio		New physics, ...
Nuclei spectrum		

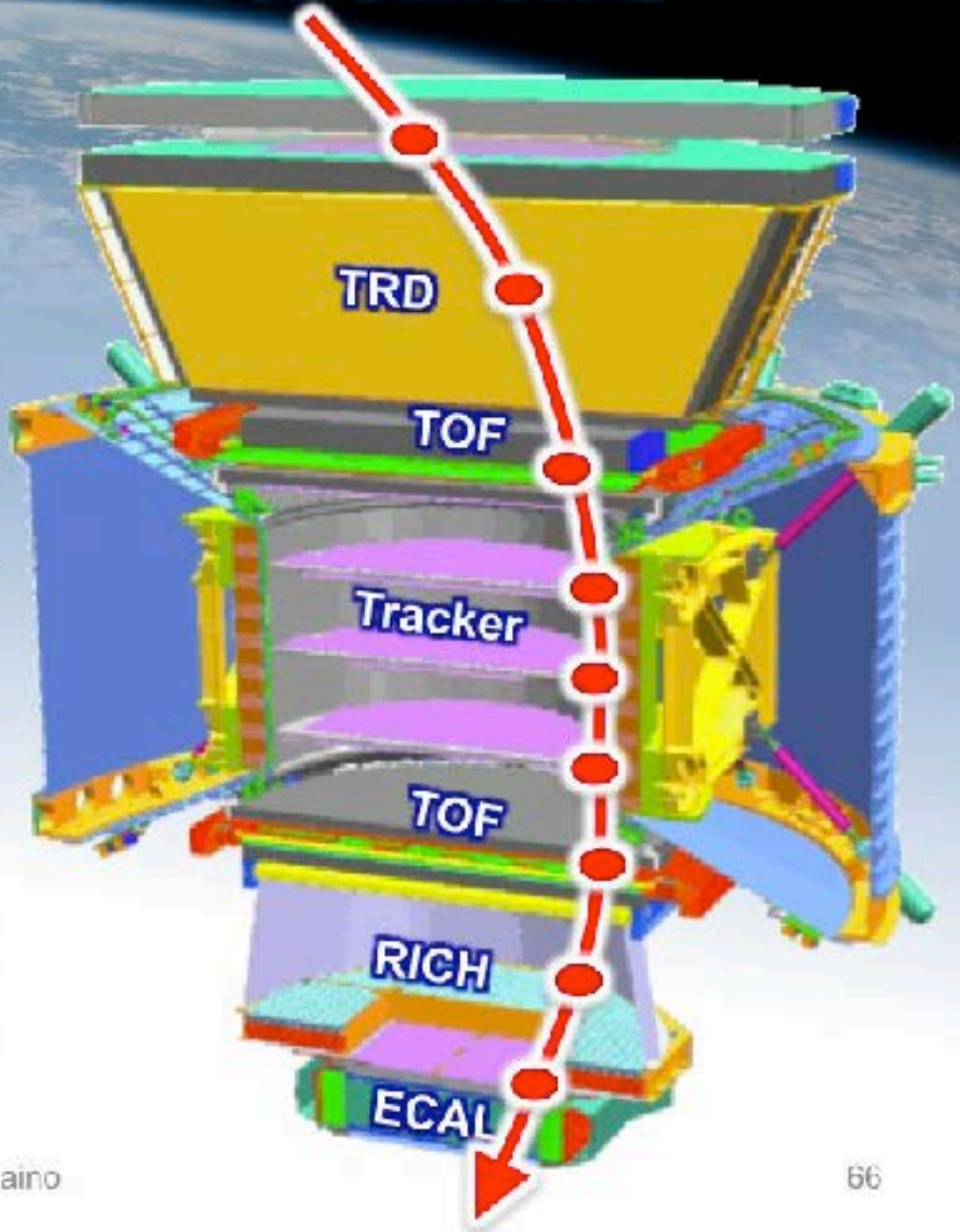
B/C ratio – before AMS



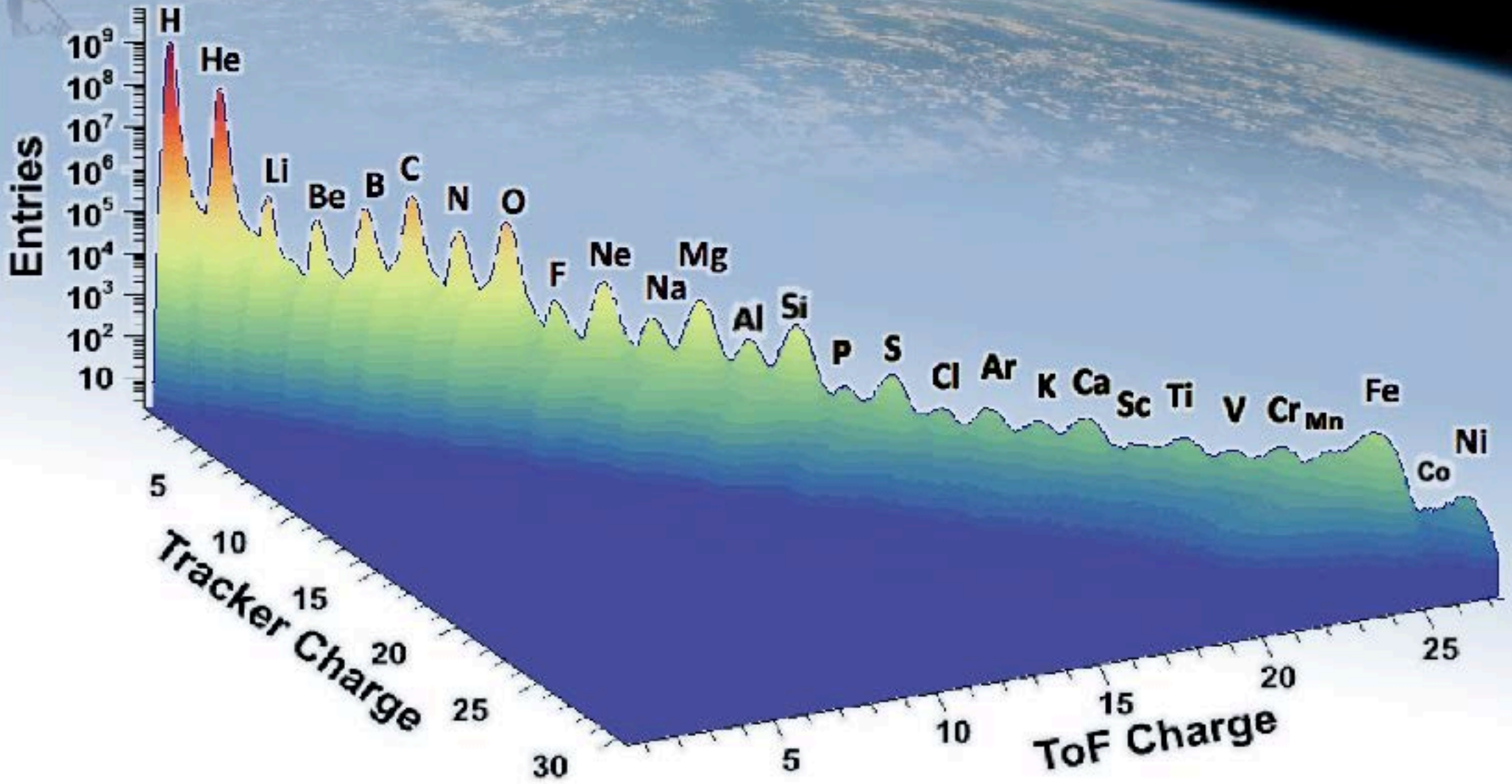
Multiple charge measurements

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

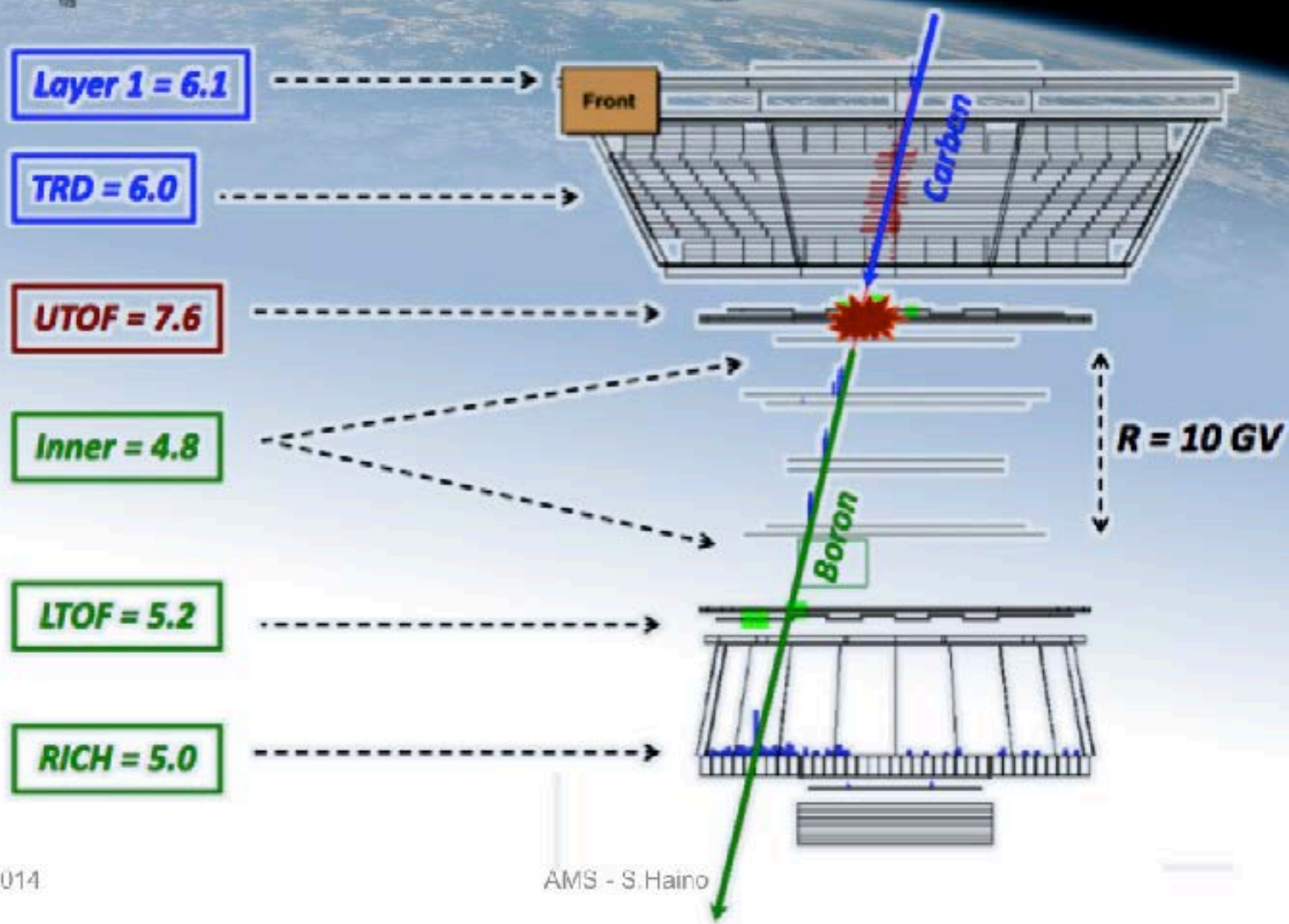
- Tracker plane 1 : 0.30
- TRD : 0.33
- Upper TOF : 0.17
- Inner plane 2-8 : 0.15
- Lower TOF : 0.20
- RICH : 0.32
- Tracker plane 9 : 0.30



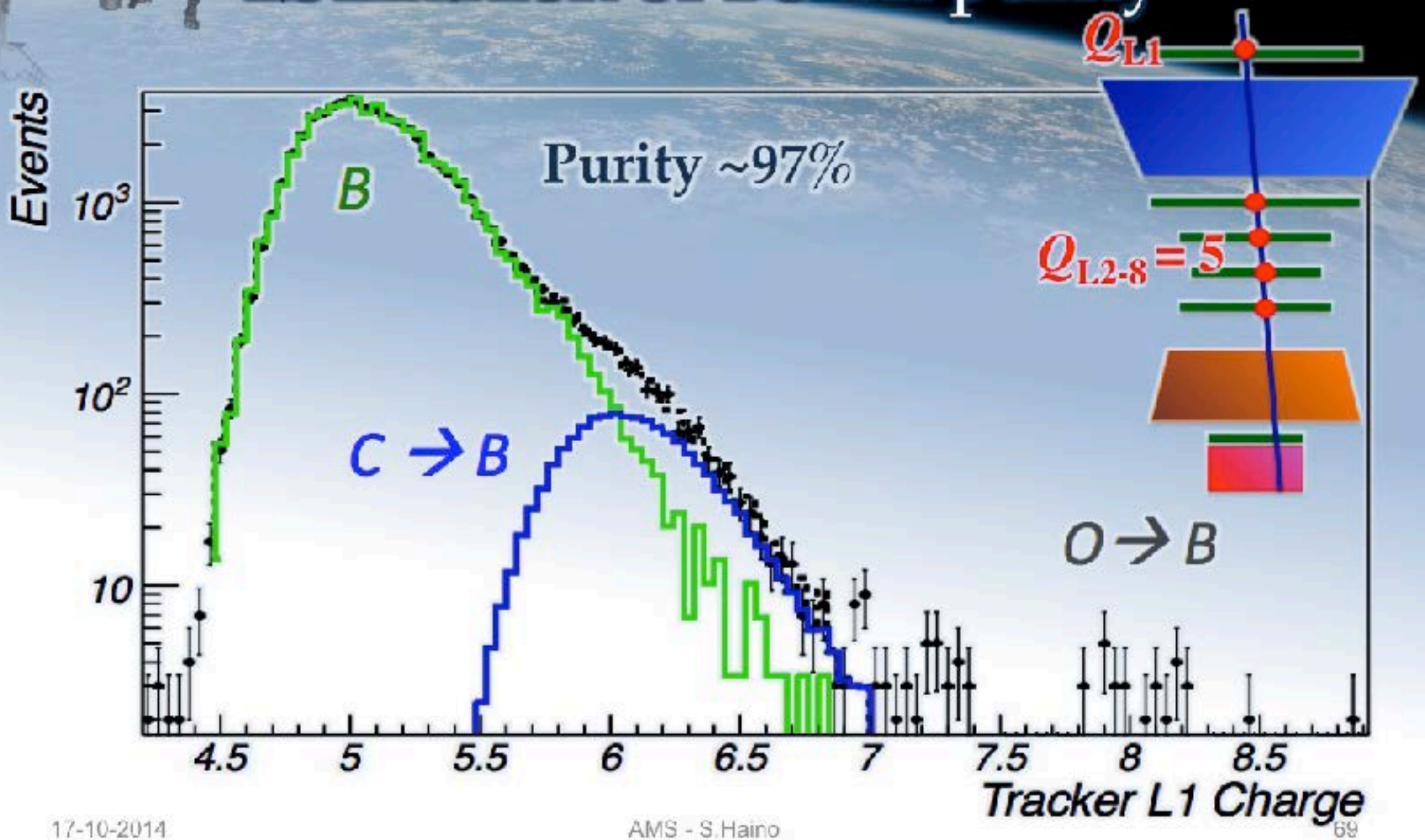
Nuclei identification in AMS



Detection of fragmentation

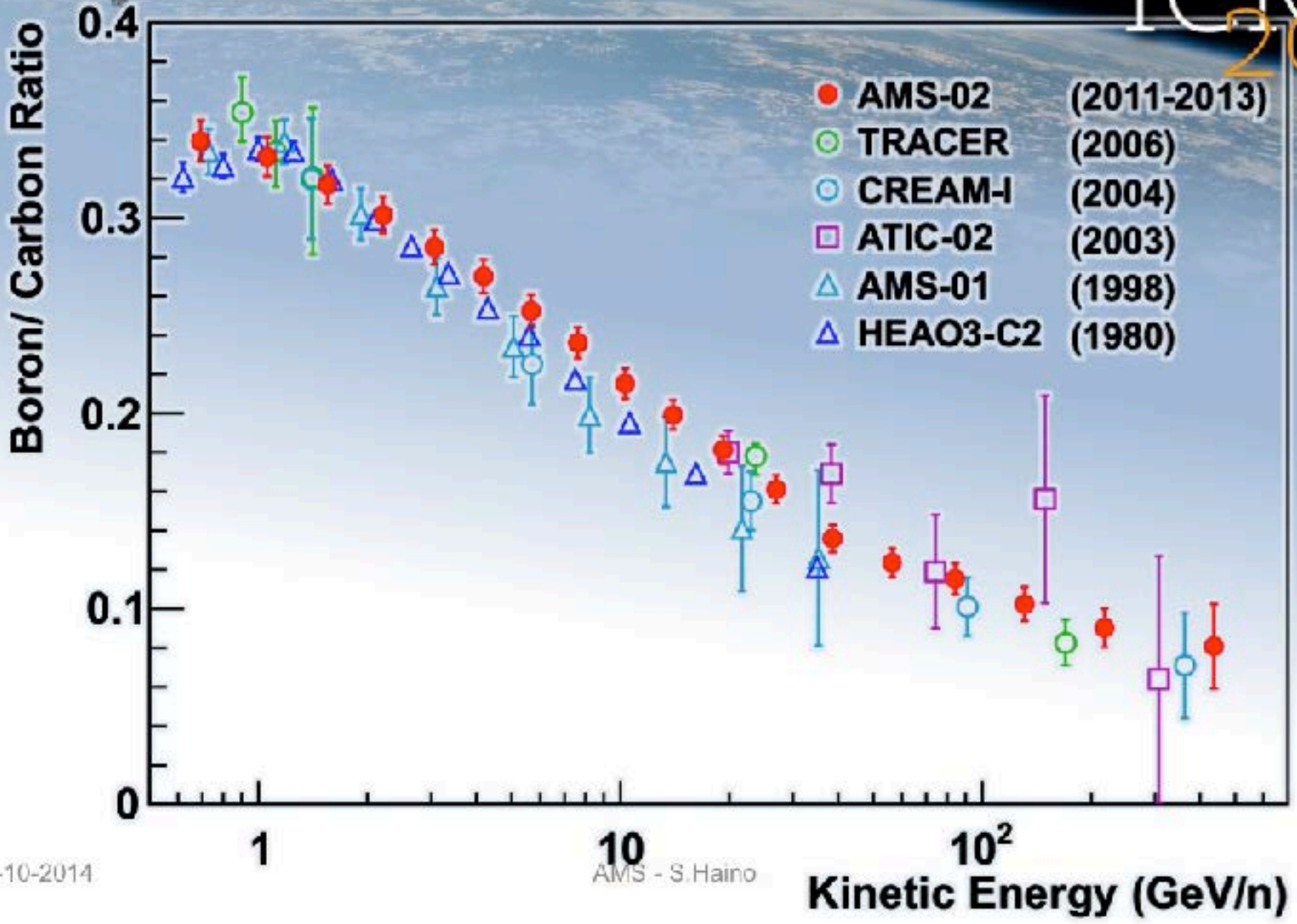


Estimation of Boron purity



B/C ratio

ICRC 2013



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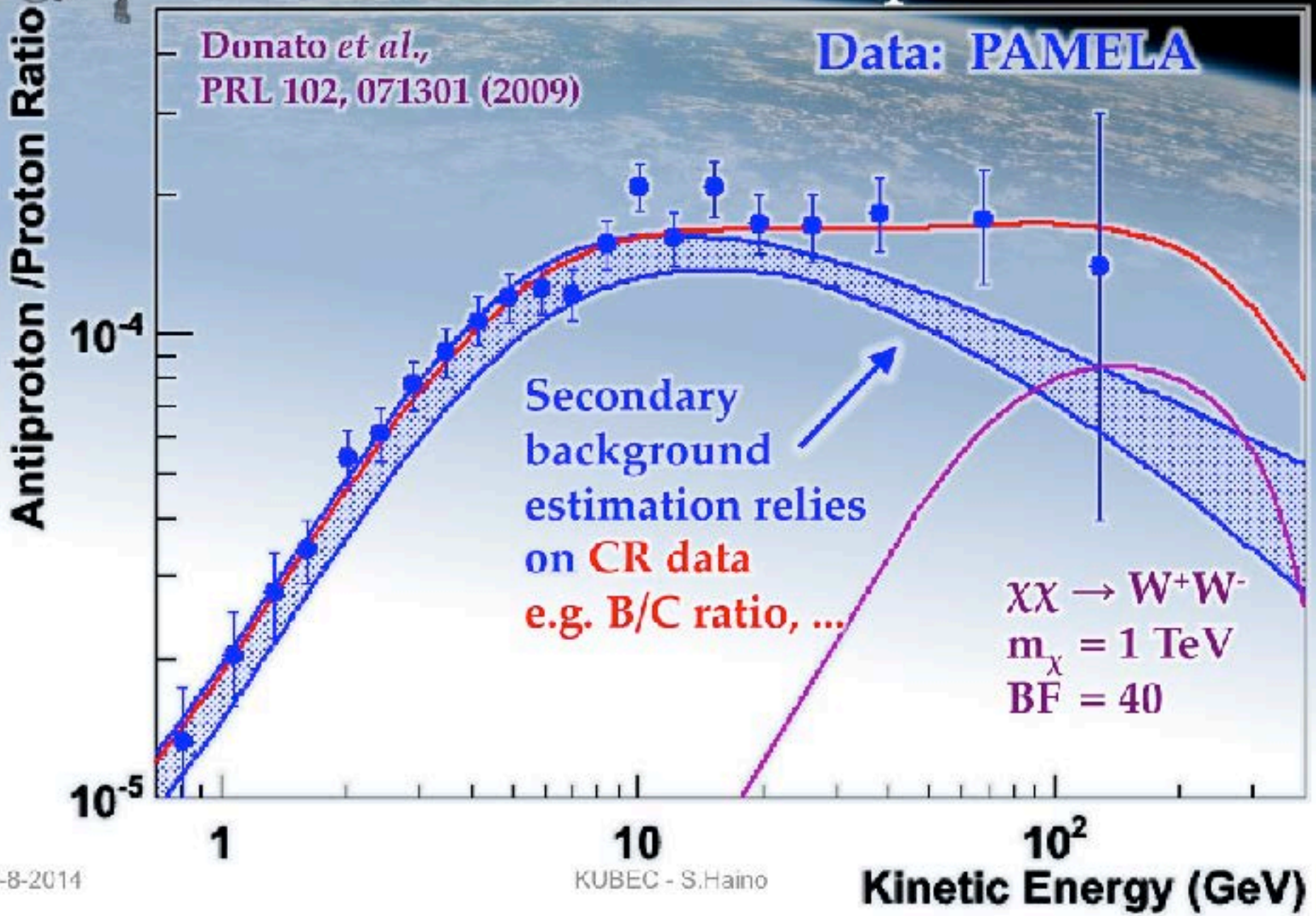
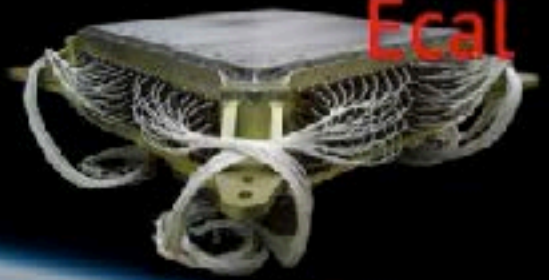
Helium spectrum	e^+ flux	$\bar{p}/p$ ratio
e- spectrum	Anisotropy	Antimatter
B/C ratio		New physics, ...
Nuclei spectrum		

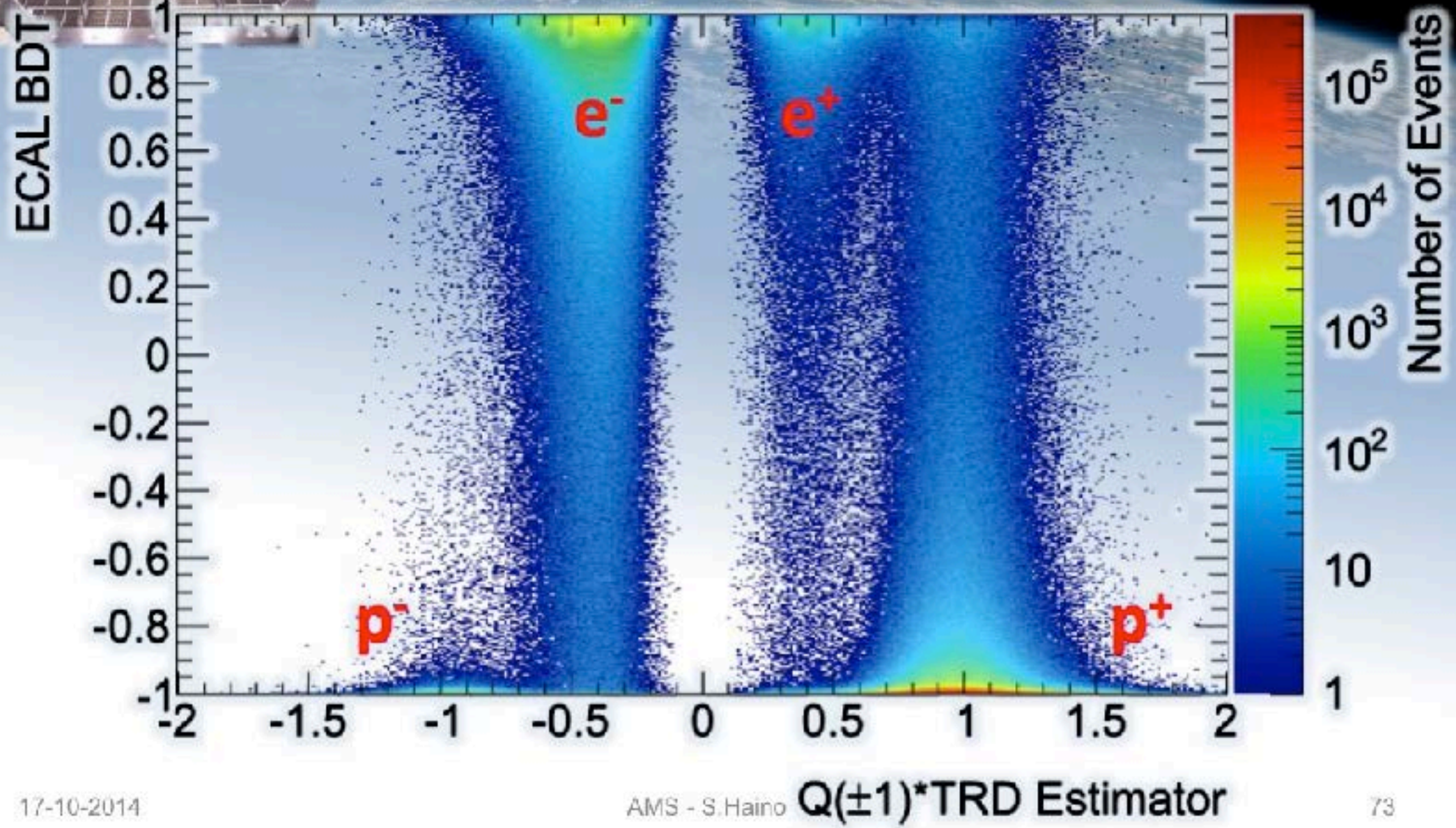
DM search with antiprotons



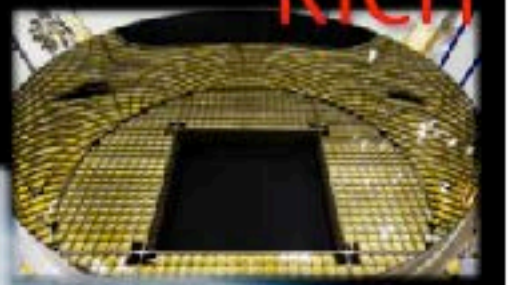
Particle ID

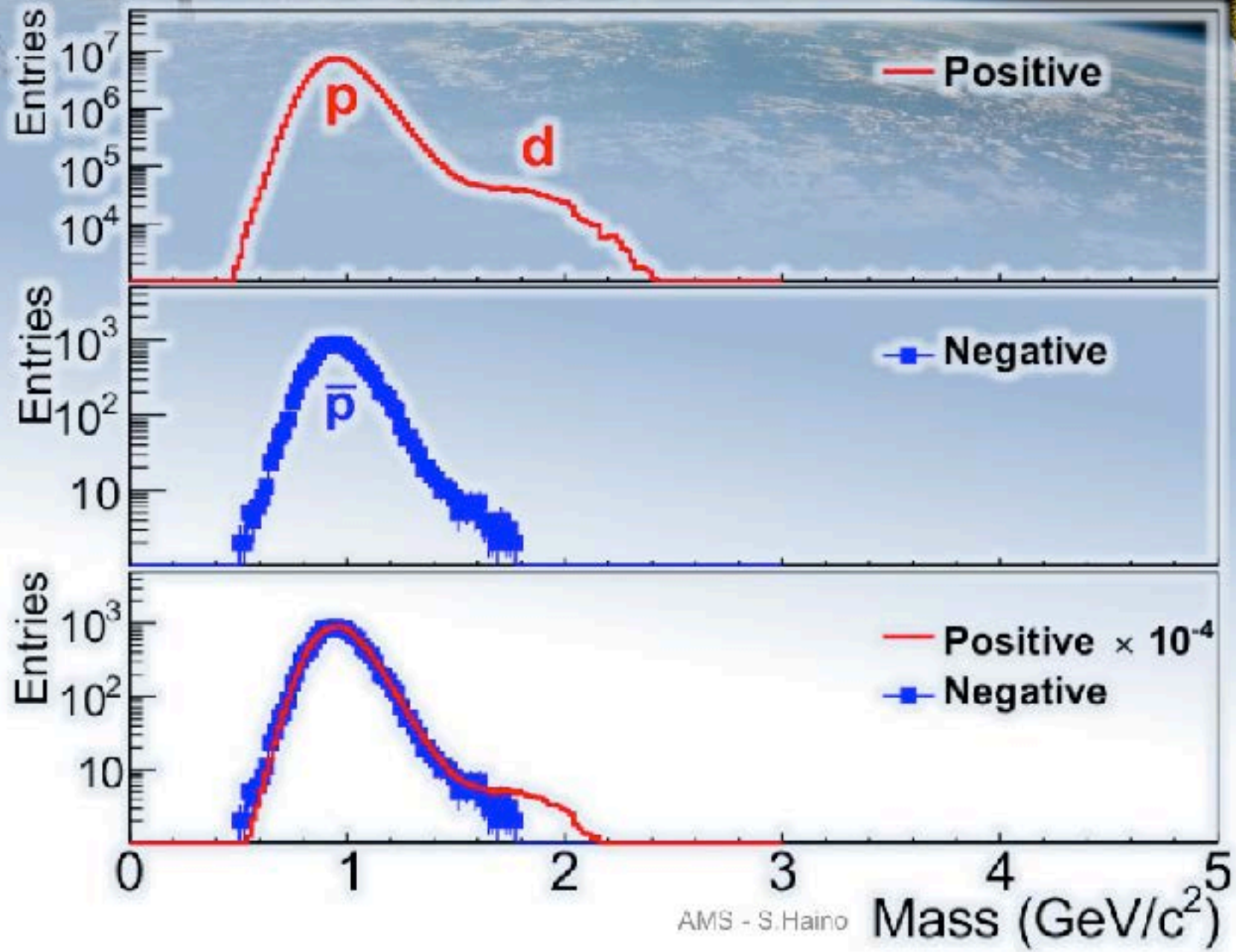

TRD


Ecal

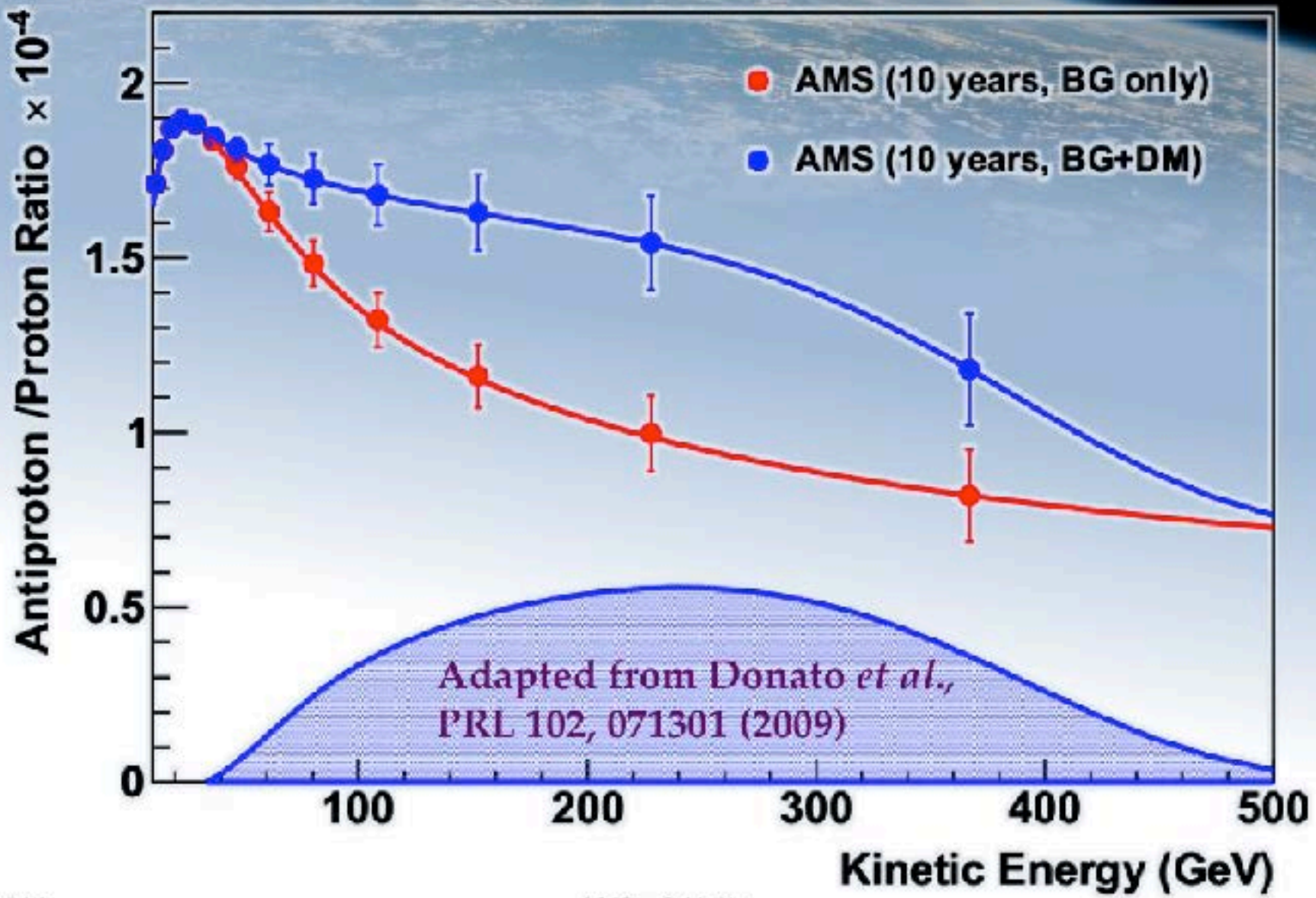

ECAL BDT
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
e⁻
e⁺
p⁻
p⁺
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Q(±1)*TRD Estimator
Number of Events
10⁵
10⁴
10³
10²
10
1

Mass identification





AMS Potential of DM search



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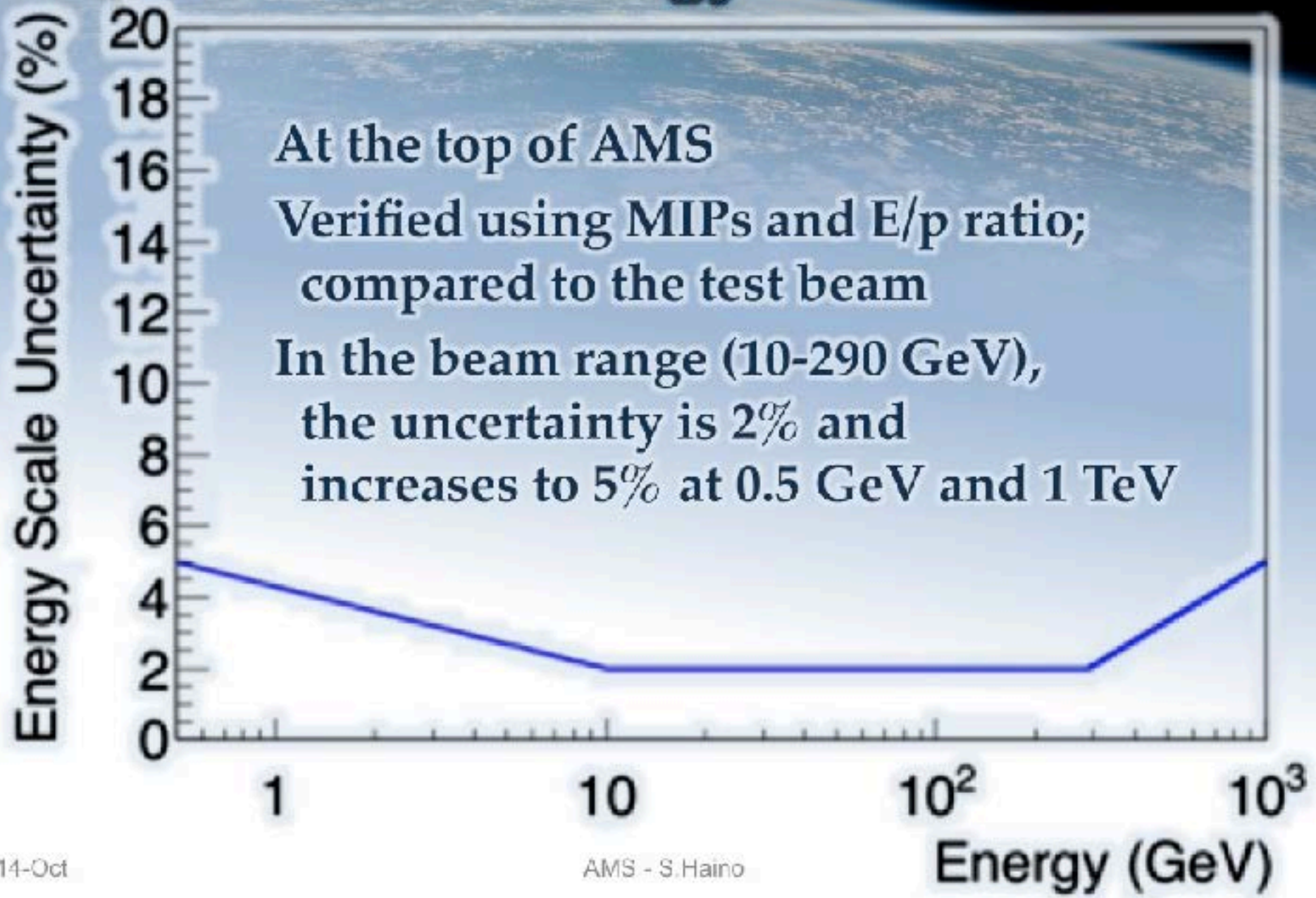
e- spectrum	Anisotropy	Antimatter
B/C ratio		New physics, ...
Nuclei spectrum		

Absolute energy scale for $e^{\pm}$



At the top of AMS

Verified using MIPs and E/p ratio; compared to the test beam

In the beam range (10-290 GeV), the uncertainty is 2% and increases to 5% at 0.5 GeV and 1 TeV