The new results from AMS

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Outline

- Introduction of AMS
- Review of published results (e+, e-)
- New results in AMS days ($\overline{p}$, p, He, ...)

AMS Days at CERN

The Future of Cosmic Ray Physics and Latest Results

CERN, Main Auditorium,
April 15-17, 2015

Live webcast at http://webcast.cern.ch

Speakers:
Roberto BATTISTON, ASI, Trento
Kfir BLUM, IAS, Princeton
John ELLIS, King's College, London, CERN
Jonathan FENG, UC Irvine
Masaki FUKUSHIMA, Tokyo
William GERSTENMAIER, NASA
John M. GRUNSFELD, NASA
Francis HALZEN, Wisconsin
Werner HOFMANN, MPI Heidelberg
Gordon KANE, Michigan
Peter F. MICHELSON, Stanford
Igor V. MOSKALENKO, Stanford
Angela OLINTO, Chicago
Piergiorgio PICOZZA, INFN, Tor Vergata
Vladimir S. PTUSKIN, IZMIRAN, Moscow
Lisa RANDALL, Harvard
Michael SALAMON, DOE
Subir SARKAR, Oxford, Niels Bohr Inst.
Eun-Suk SEO, Maryland
Tracy SLATYER, MIT
Edward C. STONE, Caltech
Michael TURNER, Chicago
Alan A. WATSON, Leeds
Yue-Liang WU, UCAS/ITP, CAS
Fabio ZWIRNER, Padua, CERN
and
presentations on the AMS latest results

AMS collaboration

From Asia, Europa, and America

Spokesperson: S.C.C Ting

It took ~18 years

For

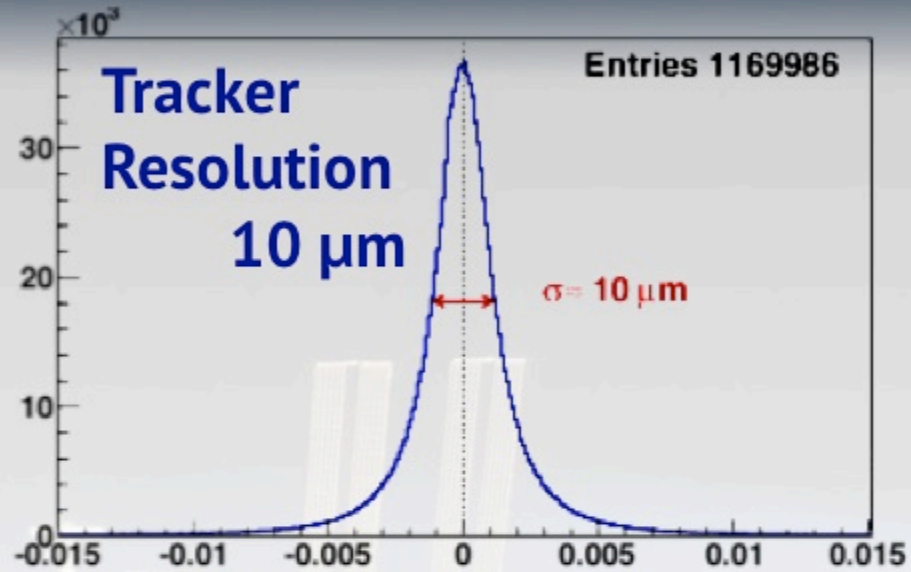
- Design
- Construction
- Space qualification tests of sub-systems

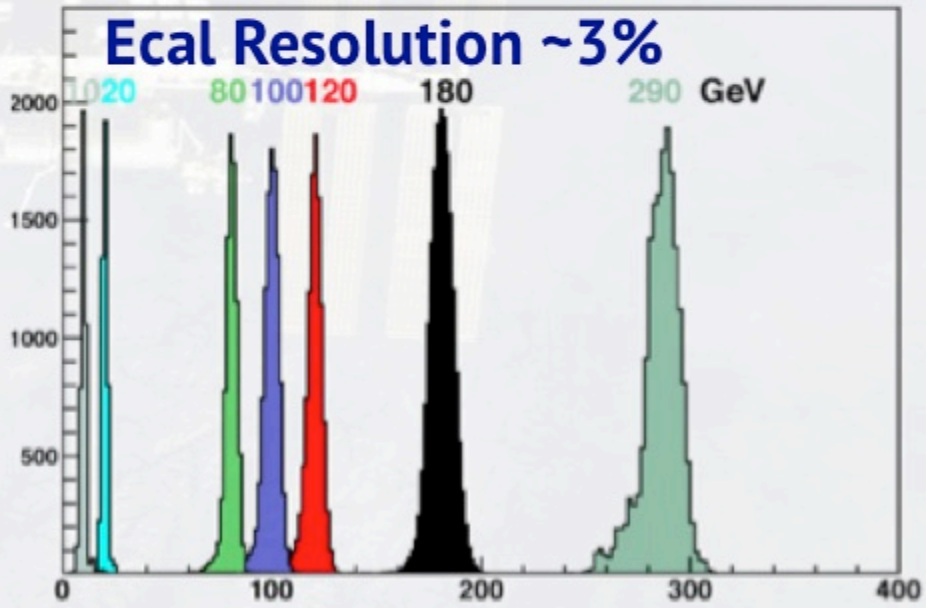
and

- Integration of AMS-02

CERN beam test (2010)

- Proton 400 GeV/c
- e^+, e^- 80 ~ 290 GeV





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
Positrons	10, 20, 60, 80, 120, 180	7 each	TRD, ECAL performance
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...

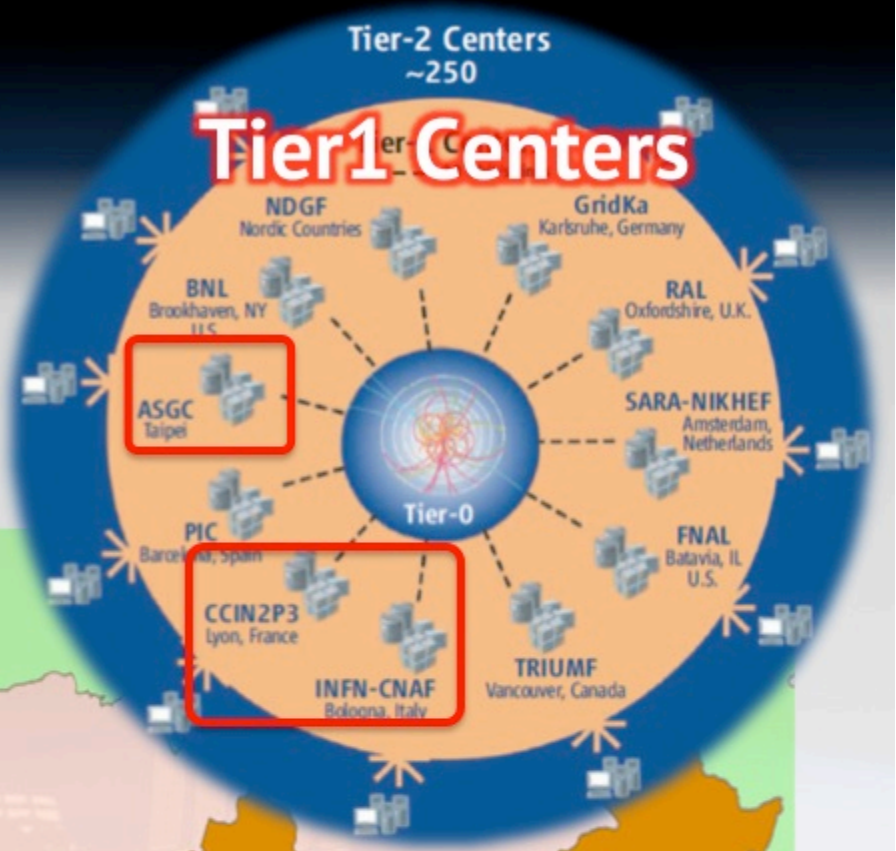
Operation and data link

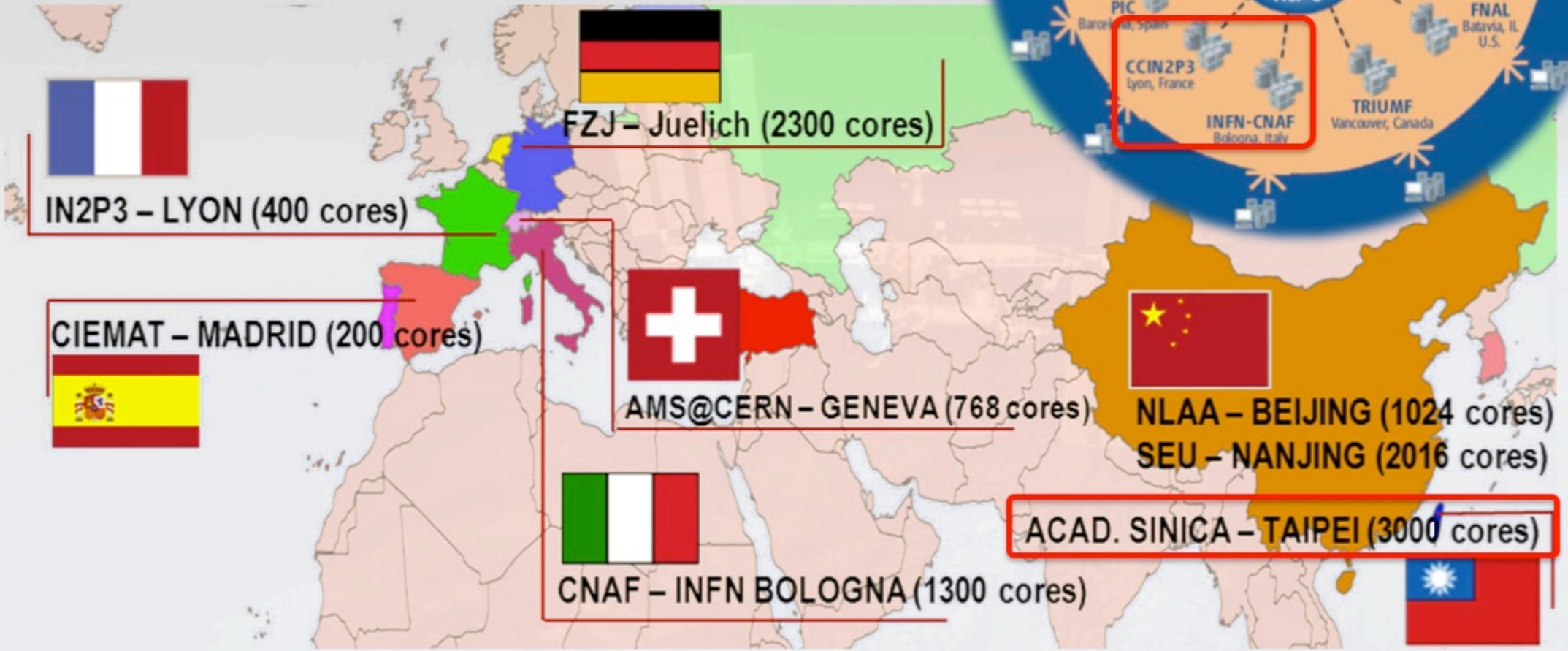
Ku-Band (down):
Events <10Mbit/s>

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

AMS computing

LHC Tier 1 : Academia Sinica, IN2P3, INFN



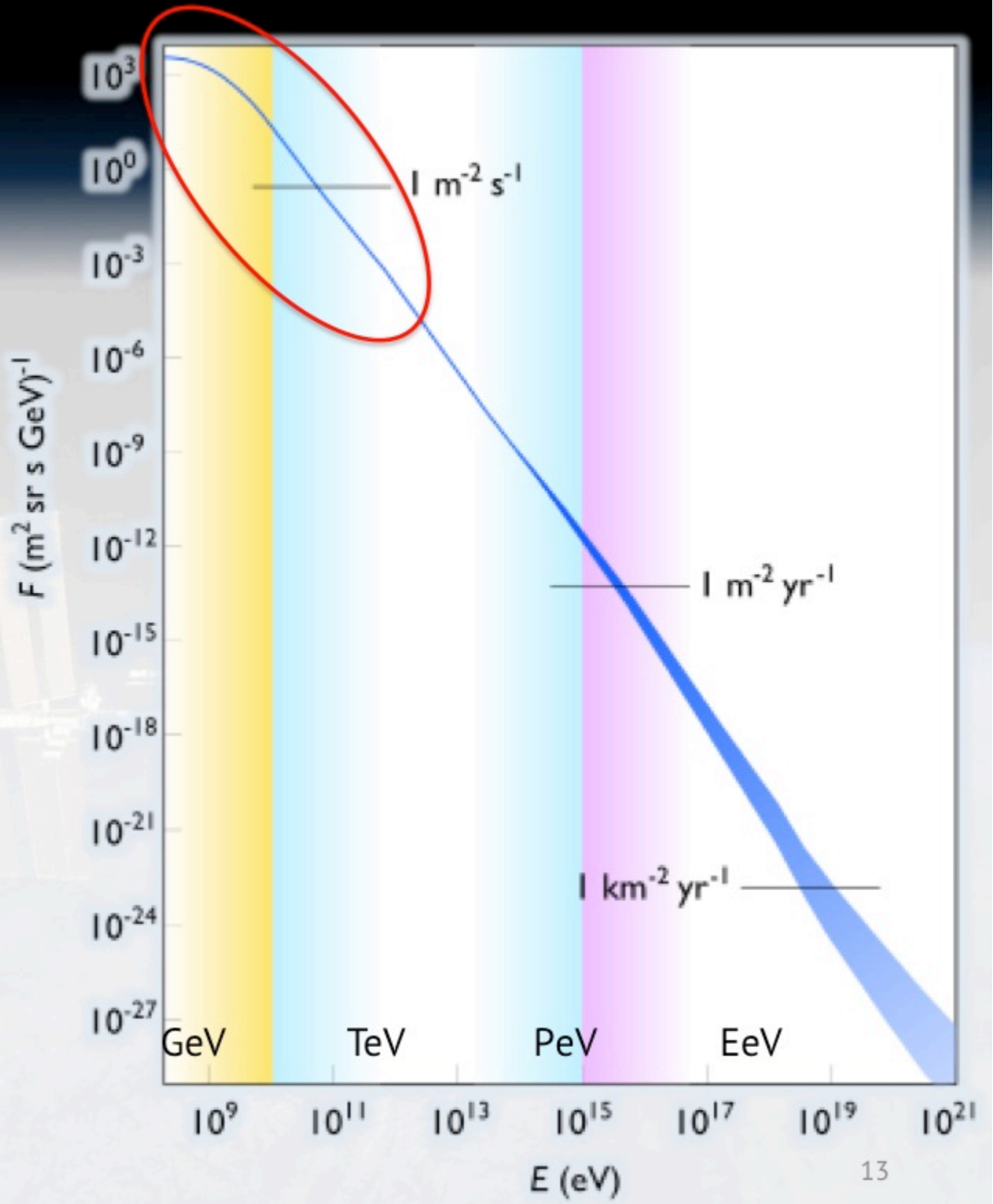


GeV-TeV :

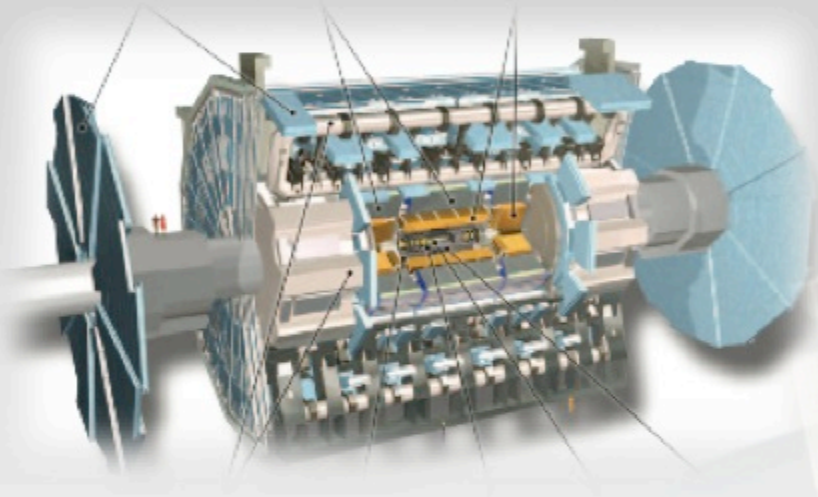
Direct measurements with balloons and in space

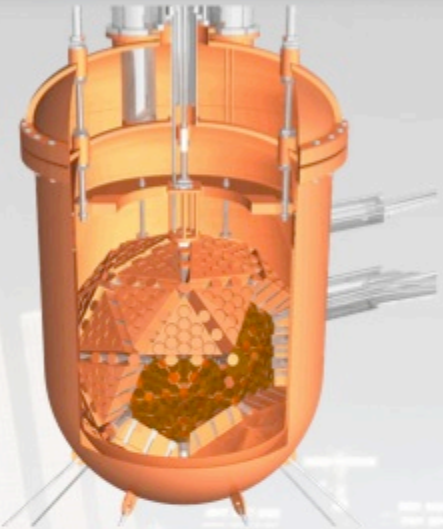
GeV :

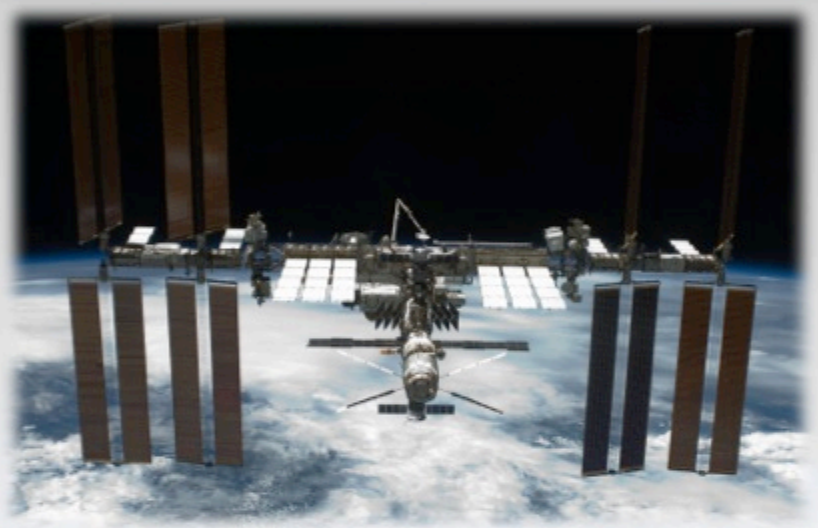
Fundamental physics with antiparticles



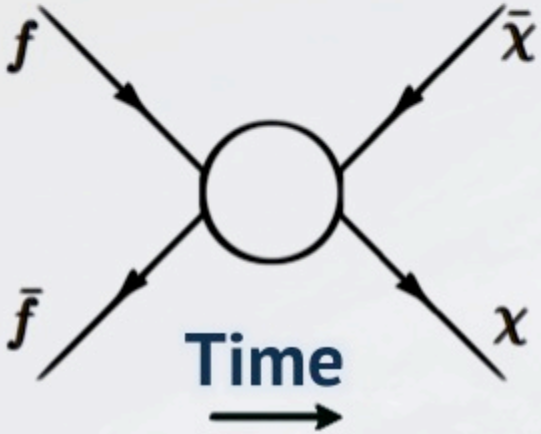
Dark Matter searches





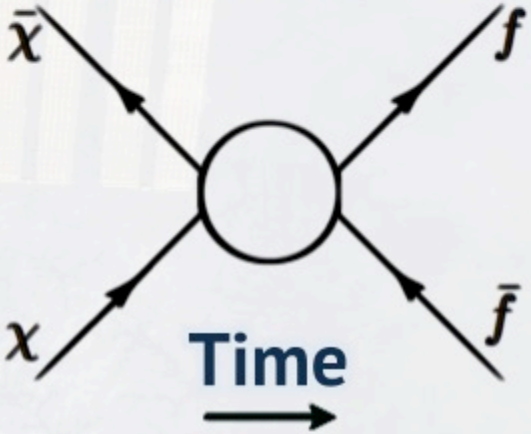


Colliders



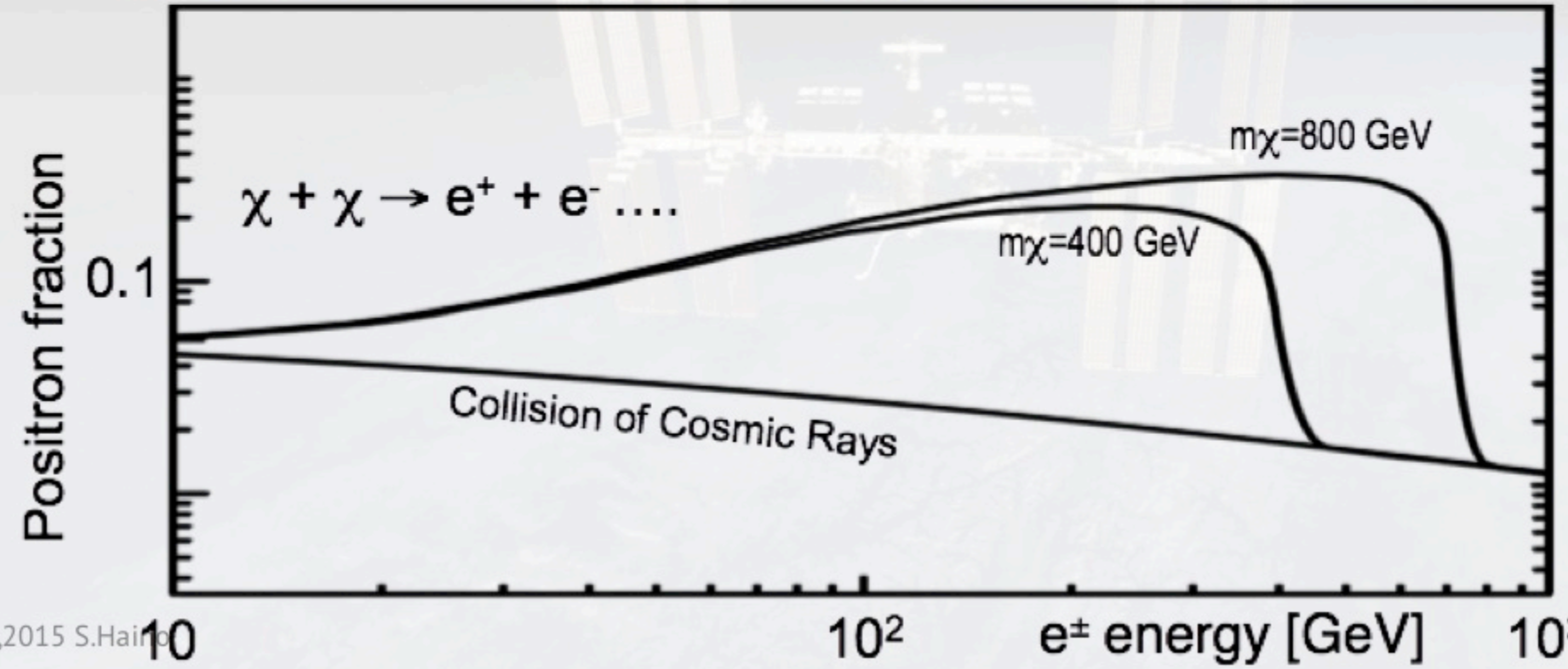
Direct search

Indirect search



Physics of CR Positron Fraction

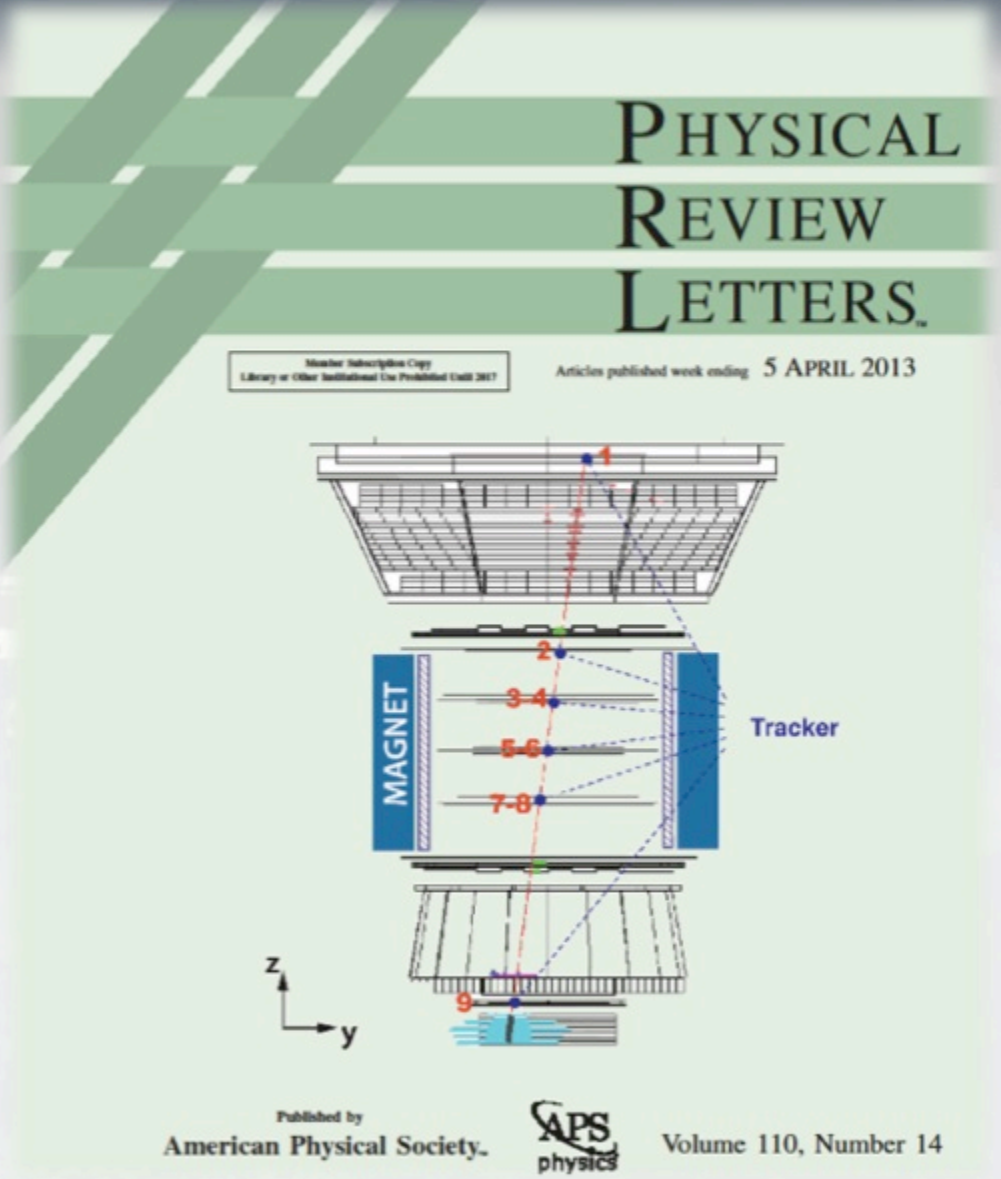
M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001;
J. Ellis, 26th ICRC Salt Lake City (1999) astro-ph/9911440;
H. Cheng, J. Feng and K. Matchev, Phys. Rev. Lett. 89 (2002) 211301;
S. Profumo and P. Ullio, J. Cosmology Astroparticle Phys. JCAP07 (2004) 006;
D. Hooper and J. Silk, Phys. Rev. D 71 (2005) 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



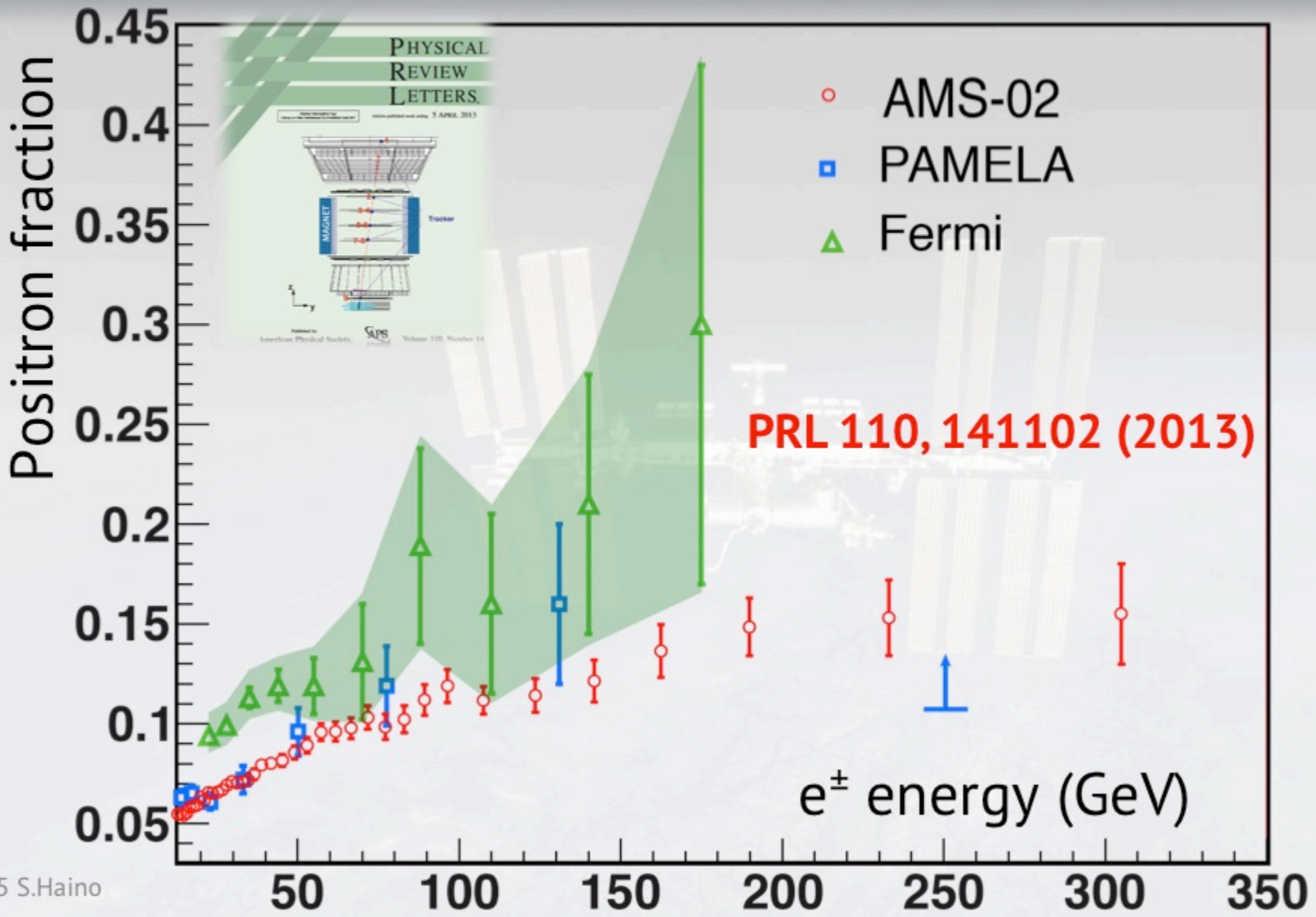
First results of AMS

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

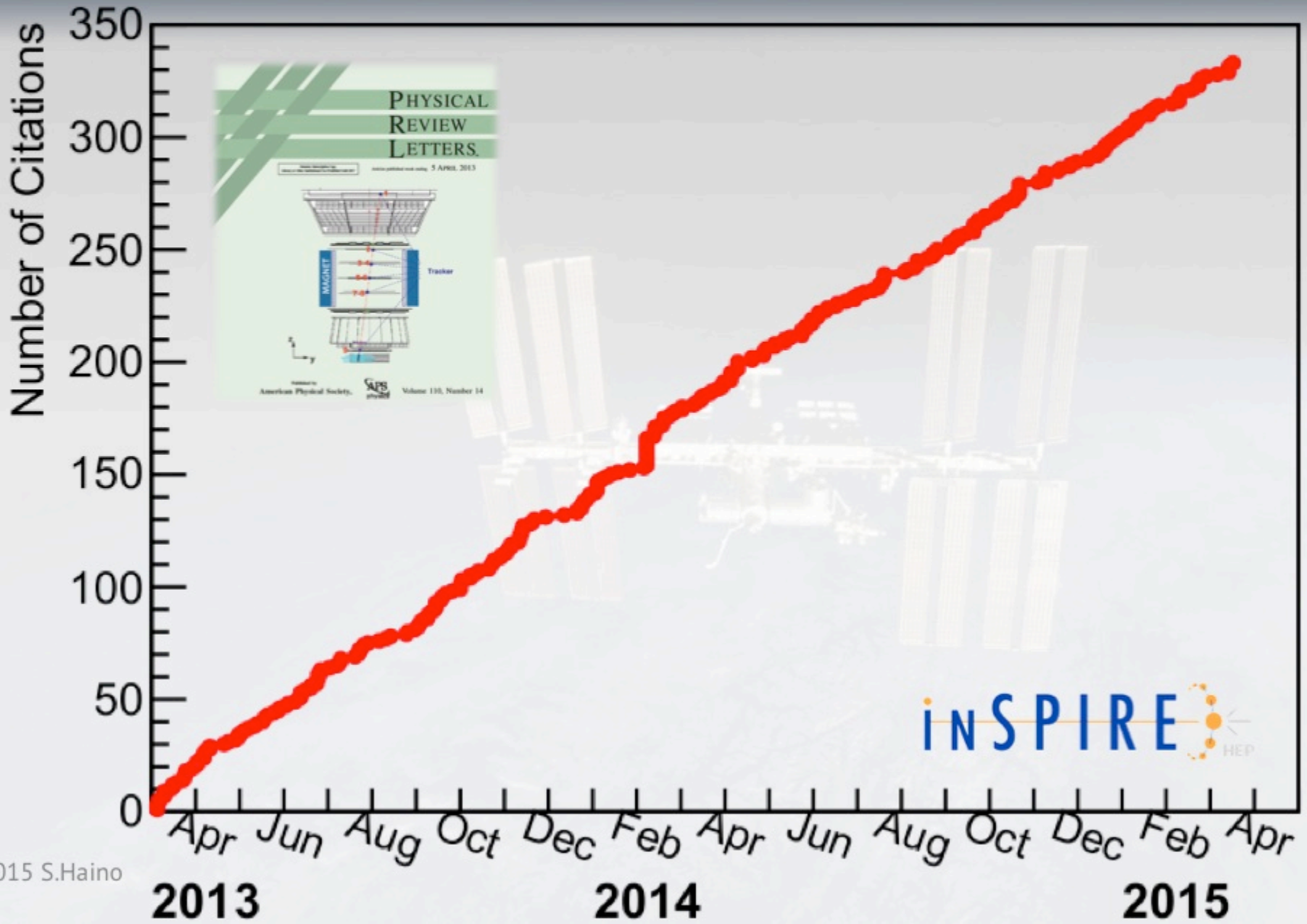
"Precision Measurement
of the Positron Fraction
in Primary Cosmic Rays"
of 0.5-350 GeV
(April/2013)



First results of AMS – e^+ fraction



Citation increasing ...



New AMS Results (Sep. and Nov., 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

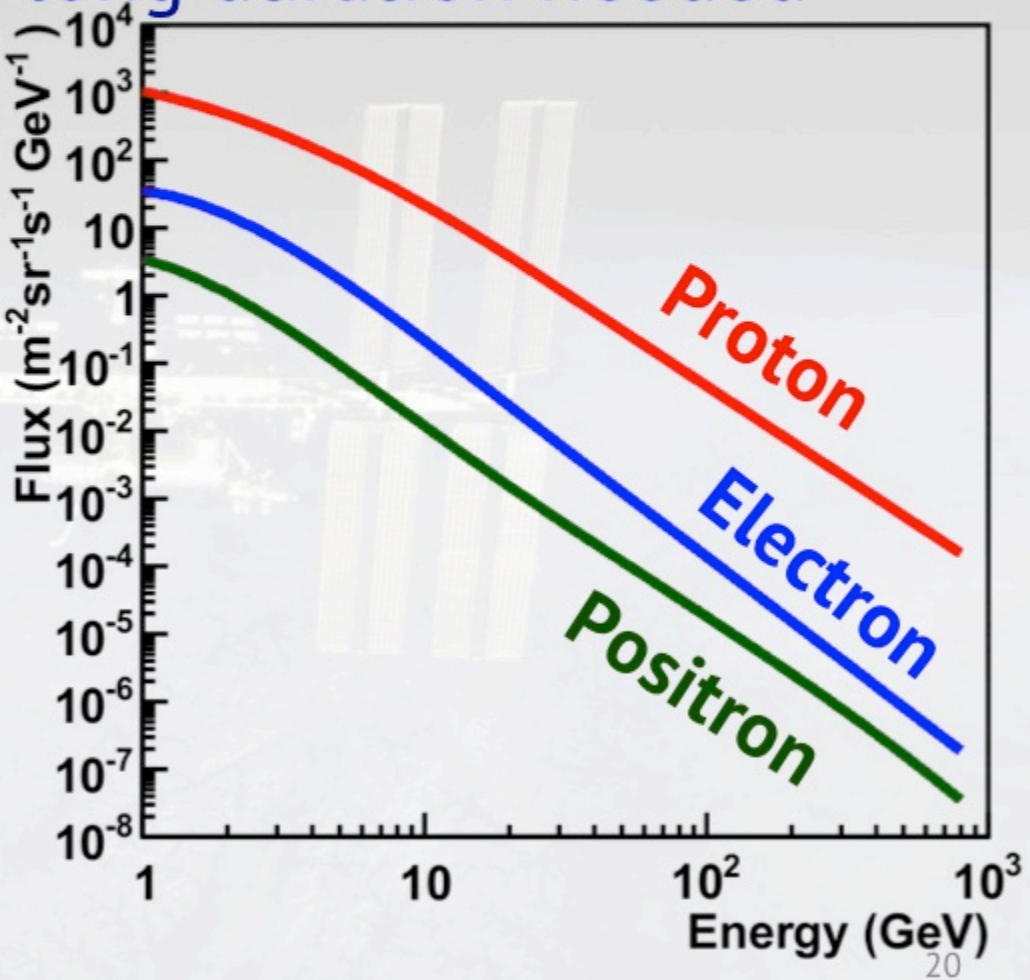
Electron and Positron Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station

PRL 113, 221102 (2014) PHYSICAL REVIEW LETTERS week ending 28 NOVEMBER 2014

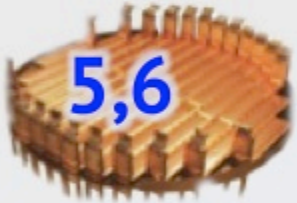
Precision Measurement of the $(e^+ + e^-)$ Flux in Primary Cosmic Rays from 0.5 GeV to 1 TeV with the Alpha Magnetic Spectrometer on the International Space Station

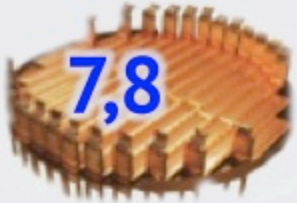
Difficulties – CR positron measurement

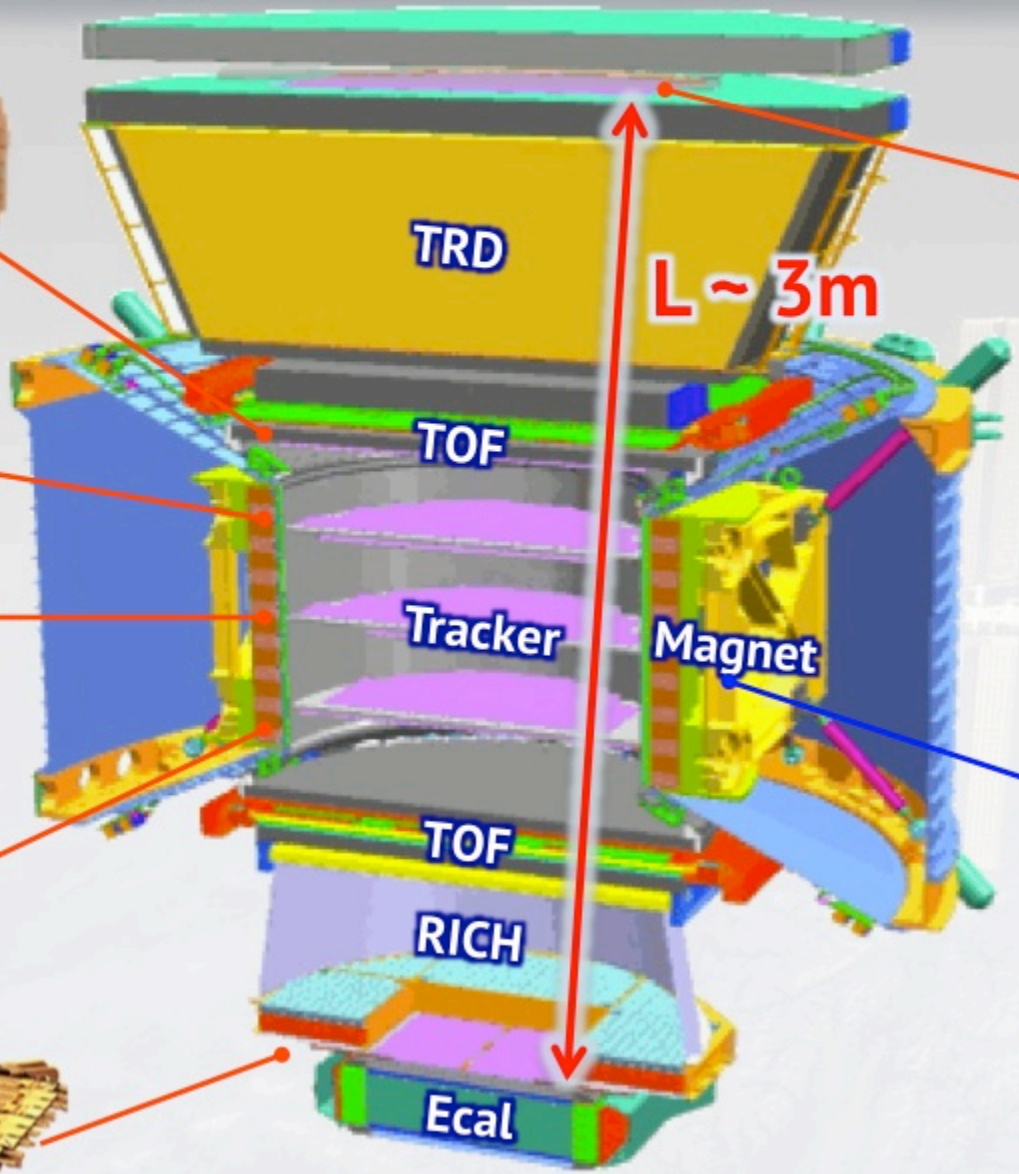
- **Low abundance : 0.01~0.1 % of Cosmic Rays**
  → Large acceptance and long duration needed
- **Large backgrounds**
  (1) **Protons (×10³~10⁴)**
  → Redundant e^+/p separation capability
  (2) **Electrons (×10~100)**
  → Deflection measurement in a magnetic field to determine charge sign



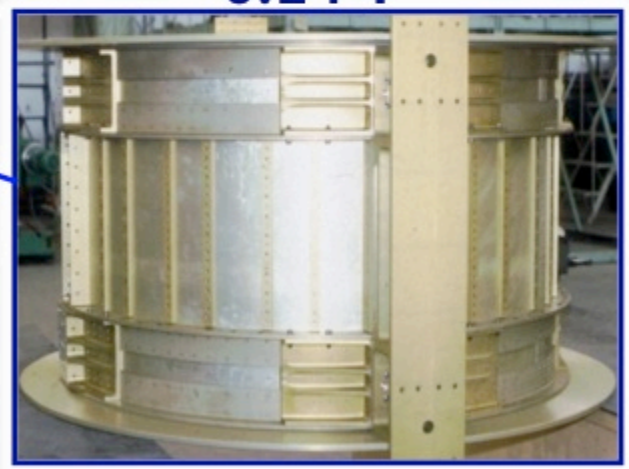
AMS – 9 layers of silicon tracker







Permanent Magnet
0.14 T

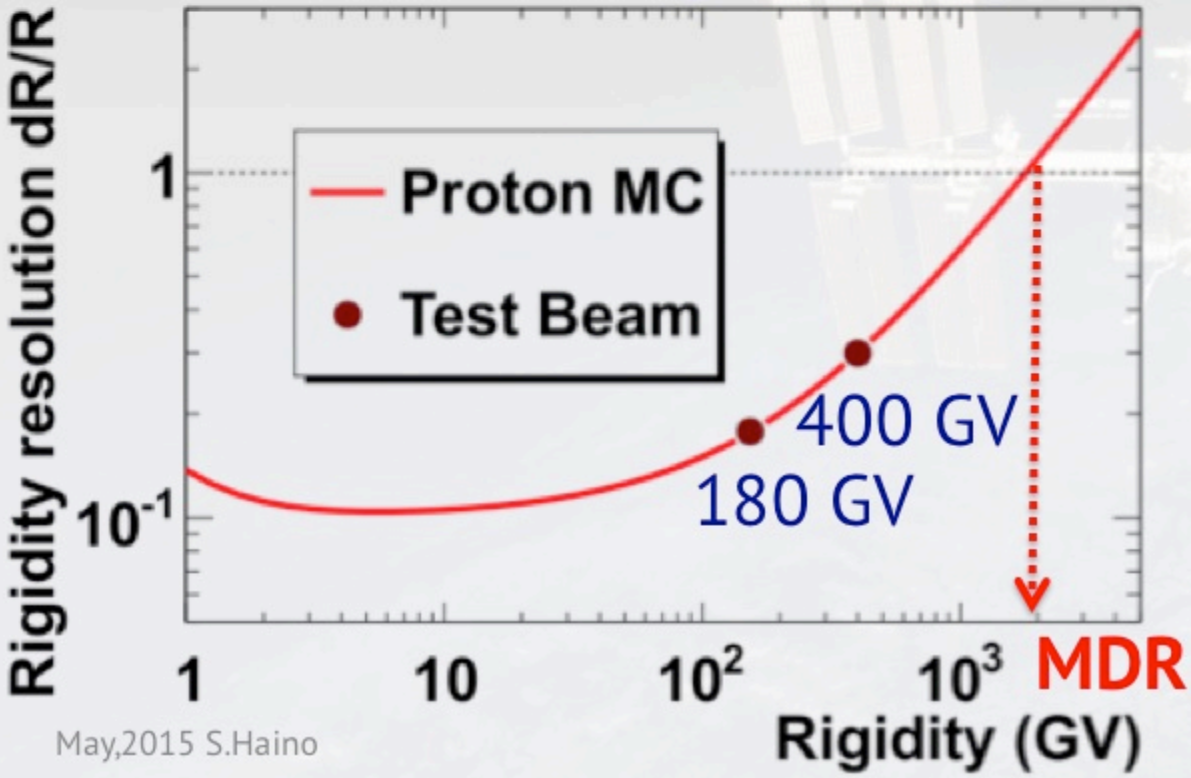


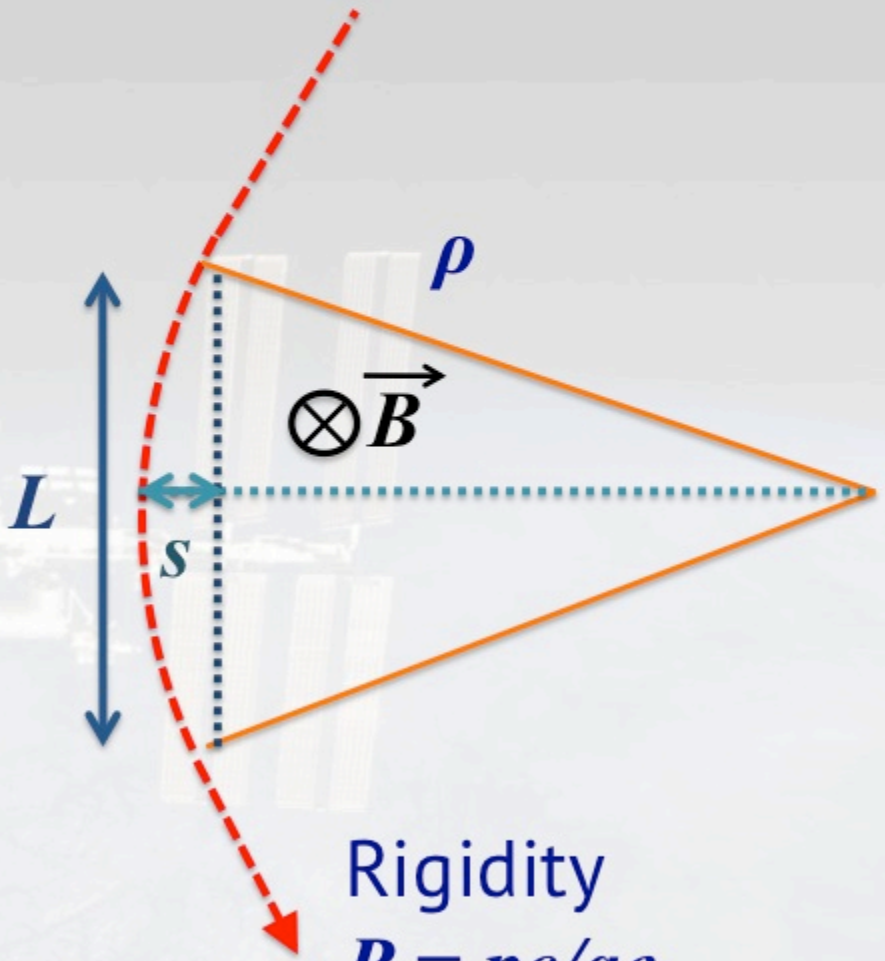
Magnetic Rigidity Measurement

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

Maximum Detectable Rigidity

MDR : ~2 TV

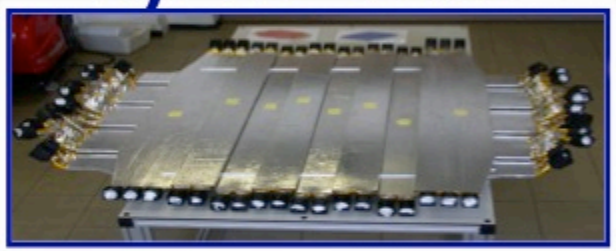


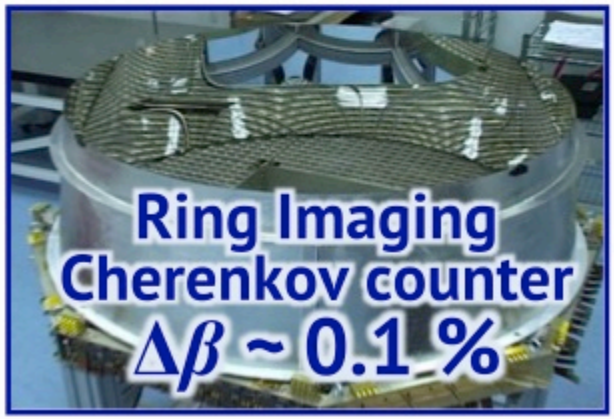


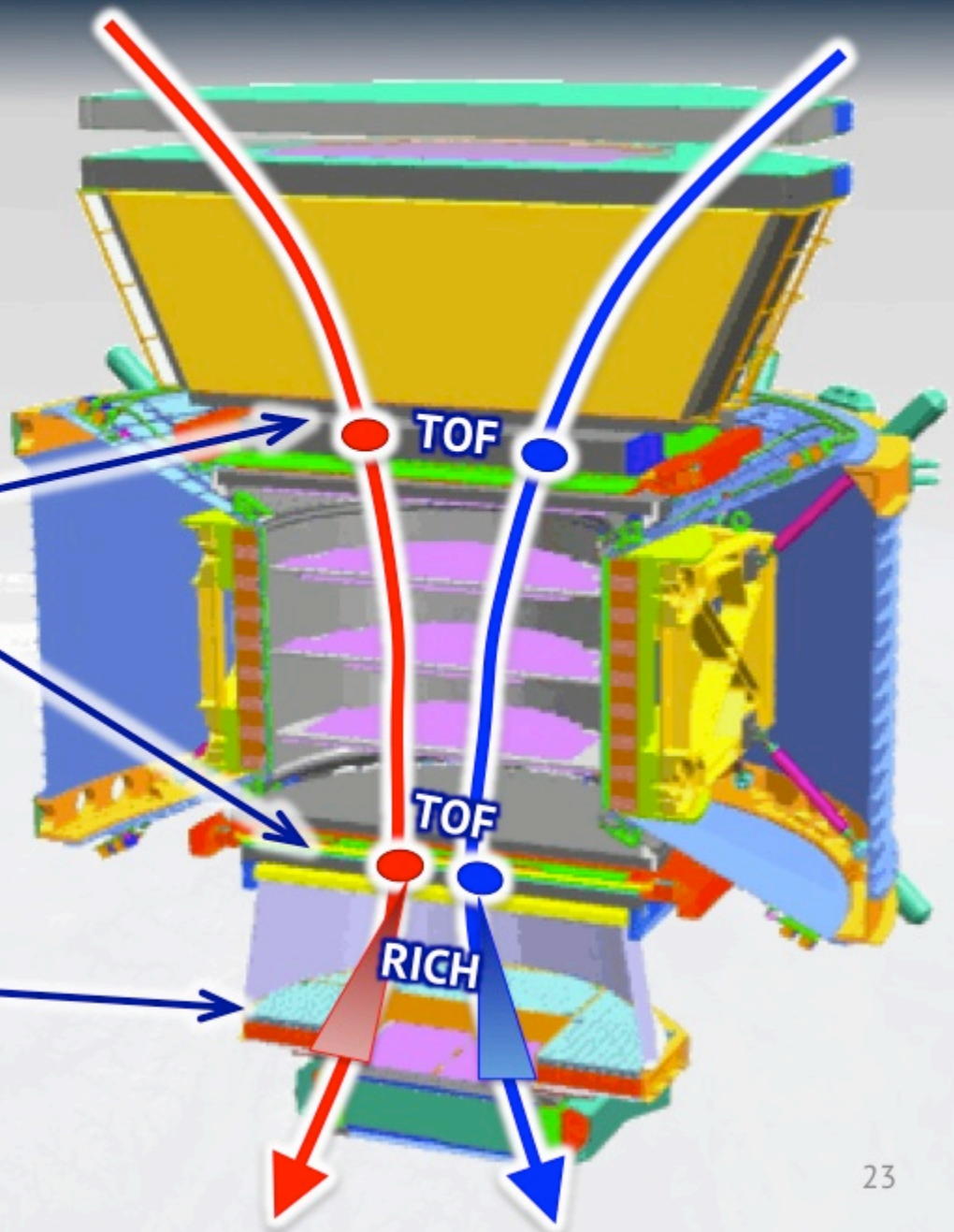
TOF and RICH

- **Determine direction and measure velocity**

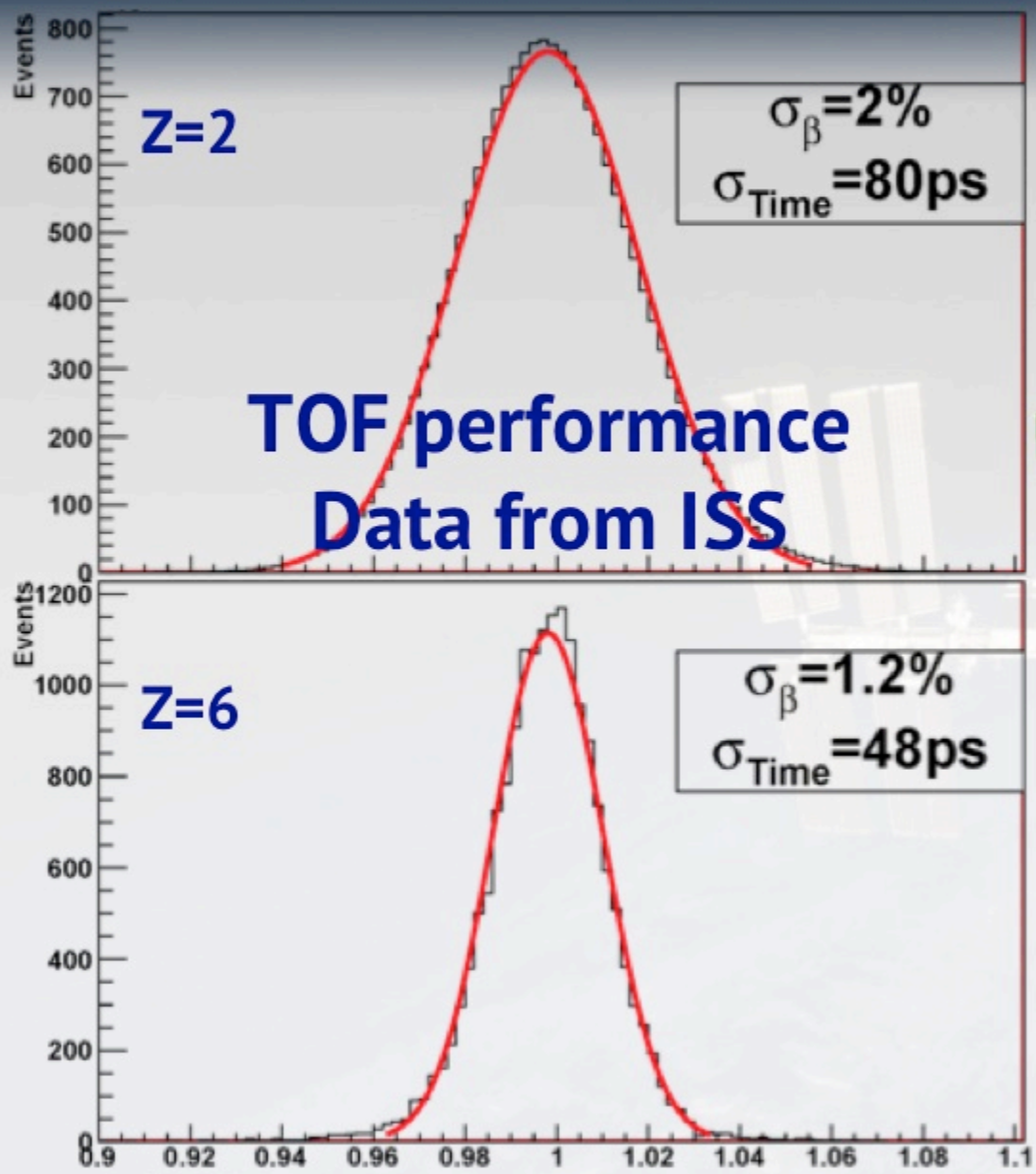
Time Of Flight
$\Delta\beta$: 1~ 2 %

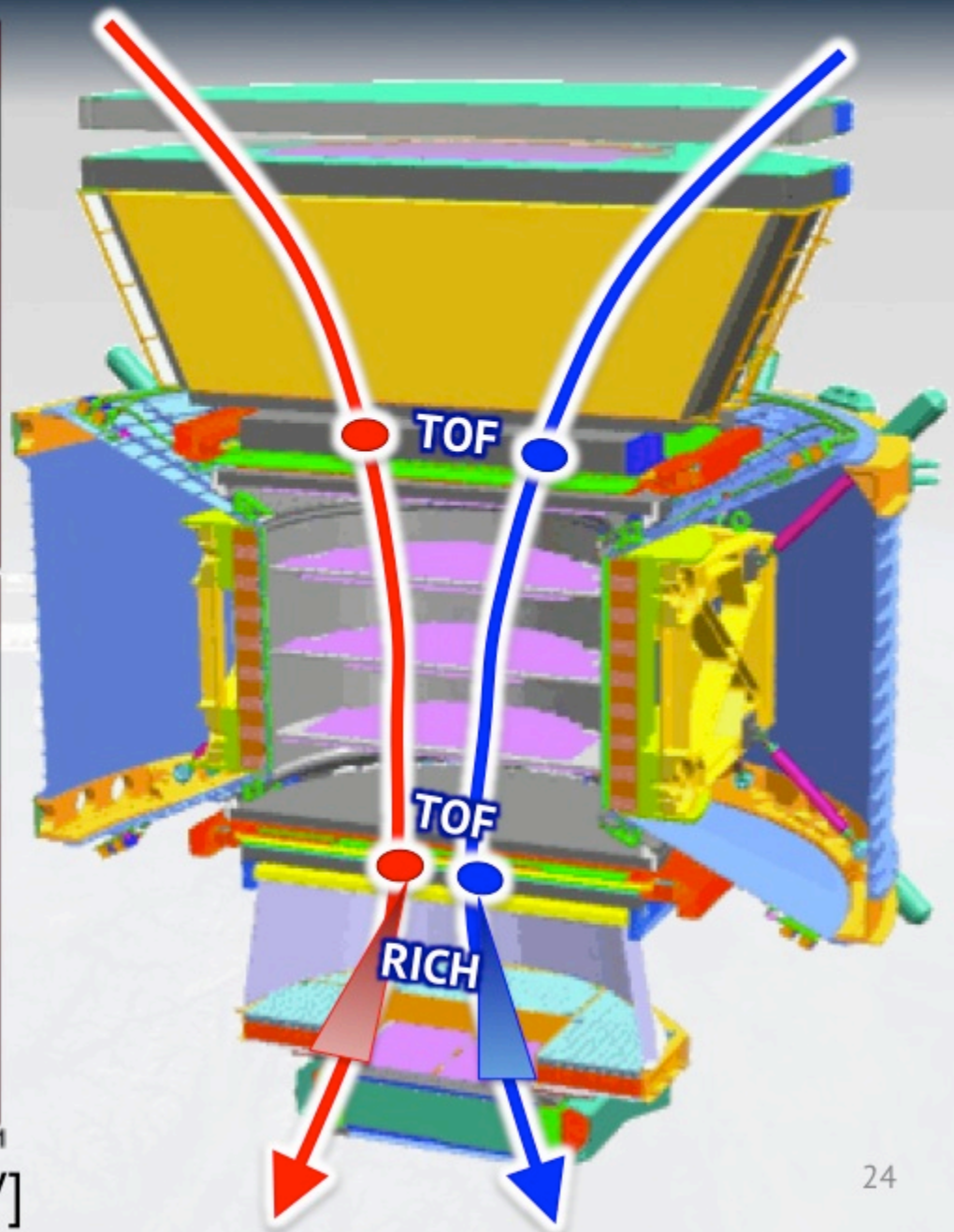






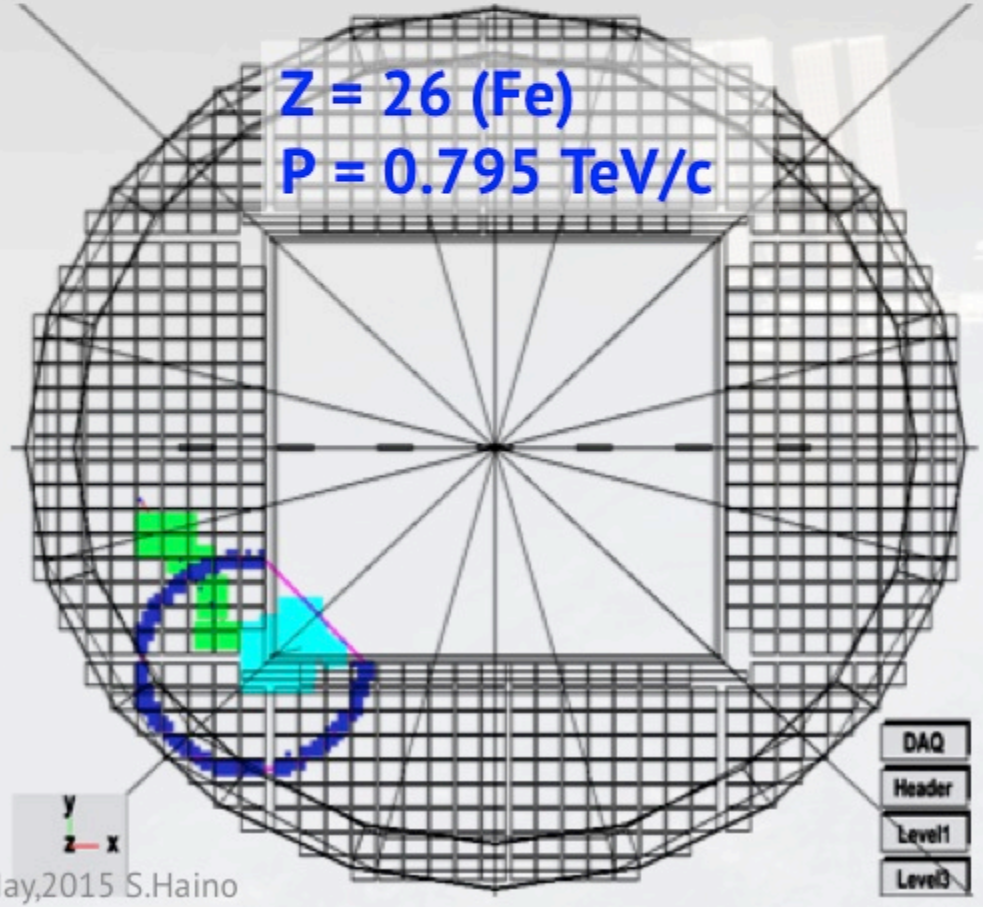
TOF and RICH

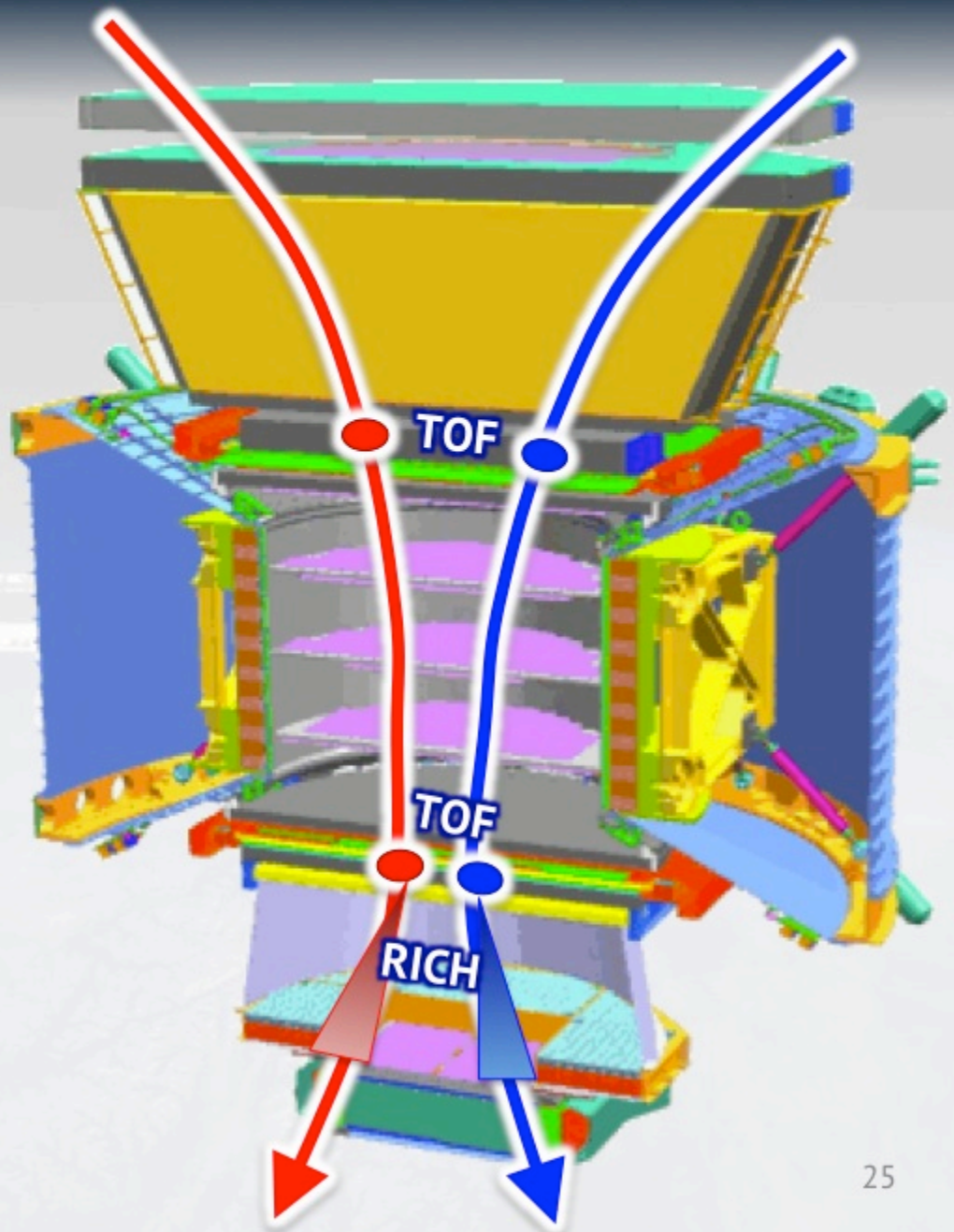

Events
Z=2
σ_β=2%
σ_{Time}=80ps
TOF performance
Data from ISS
Events
Z=6
σ_β=1.2%
σ_{Time}=48ps
Velocity [Rigidity>20GV]


TOF
TOF
RICH

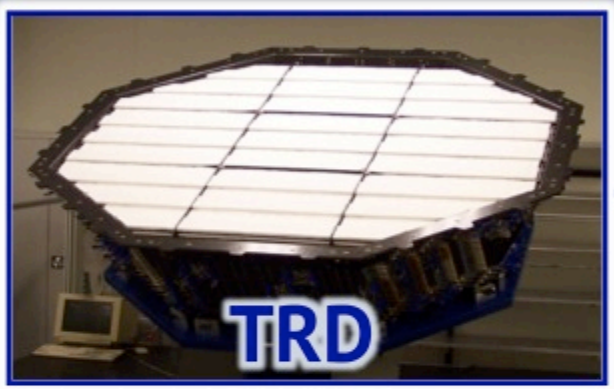
TOF and RICH

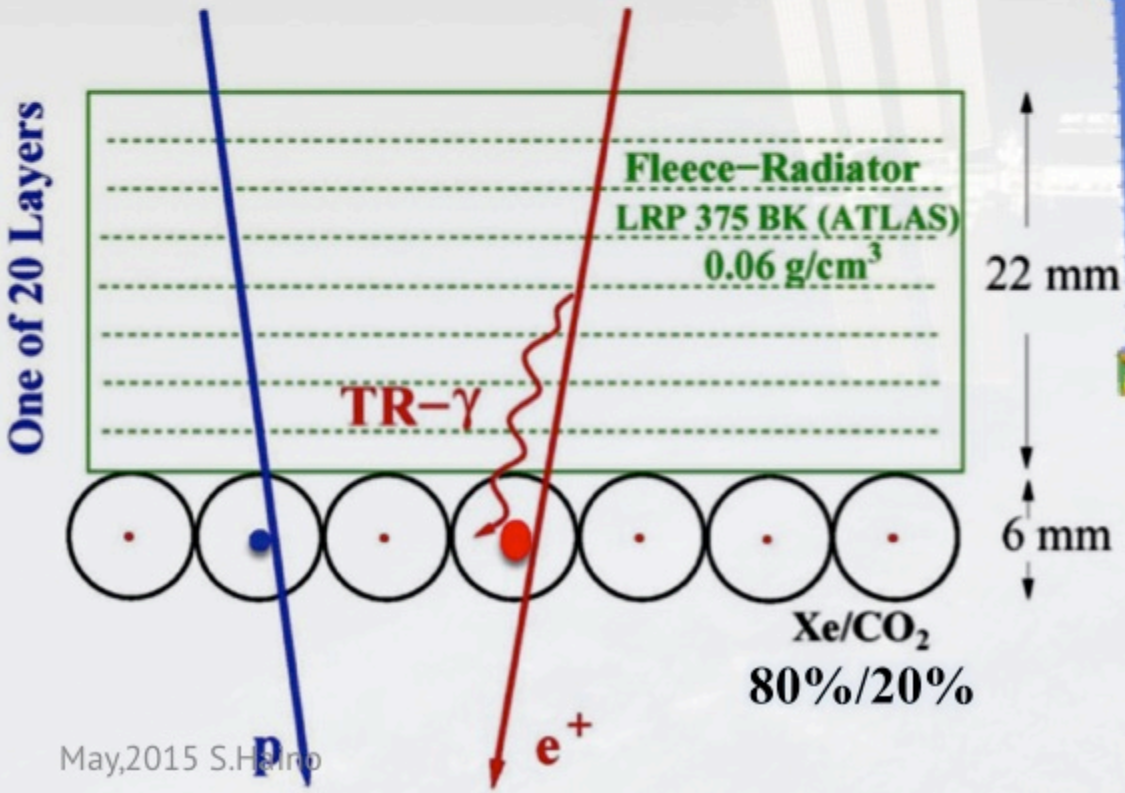
RICH event display
Data from ISS

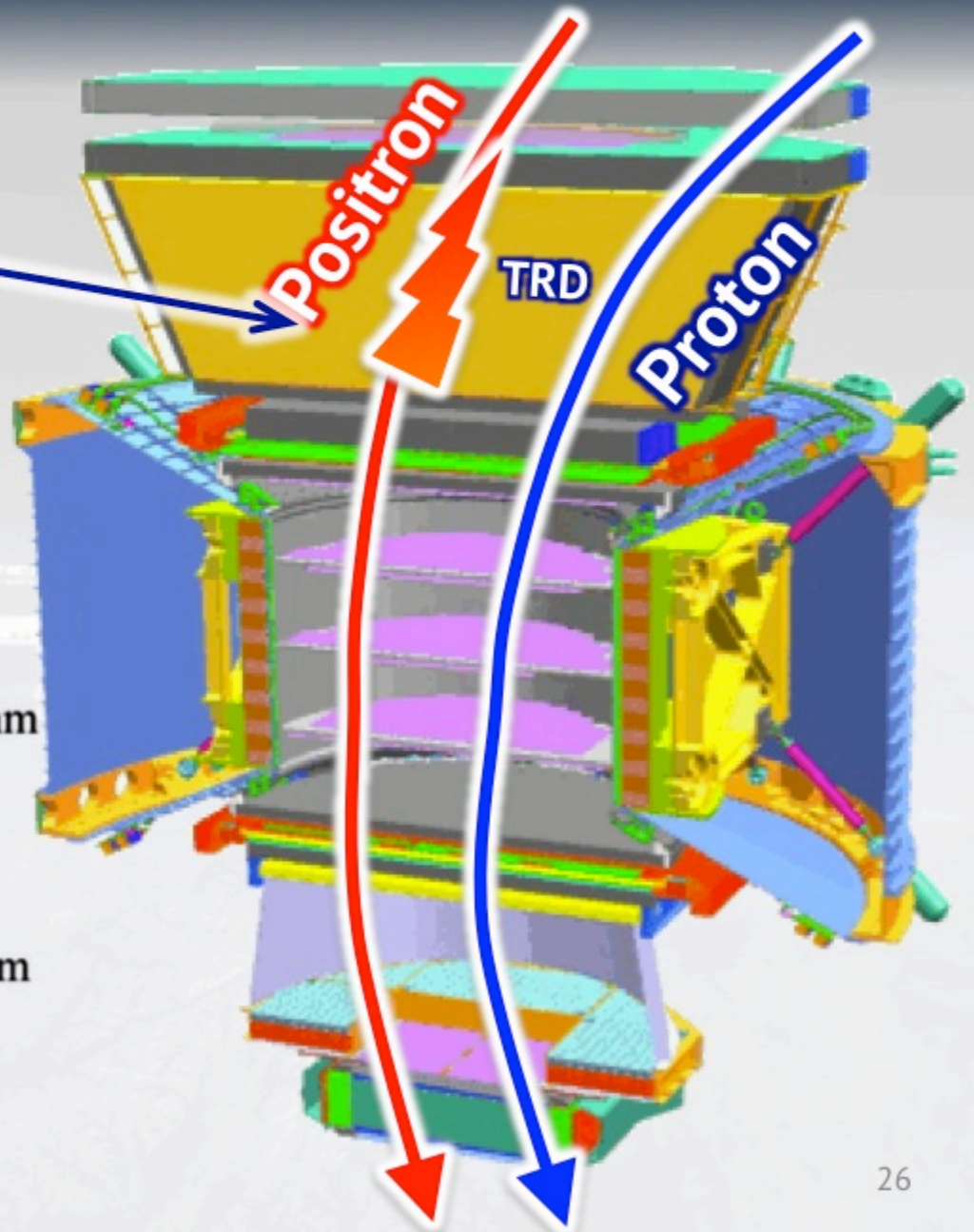




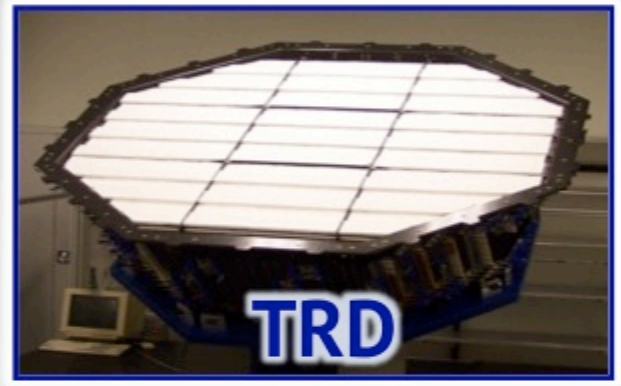
Transition Radiation Detector (TRD)

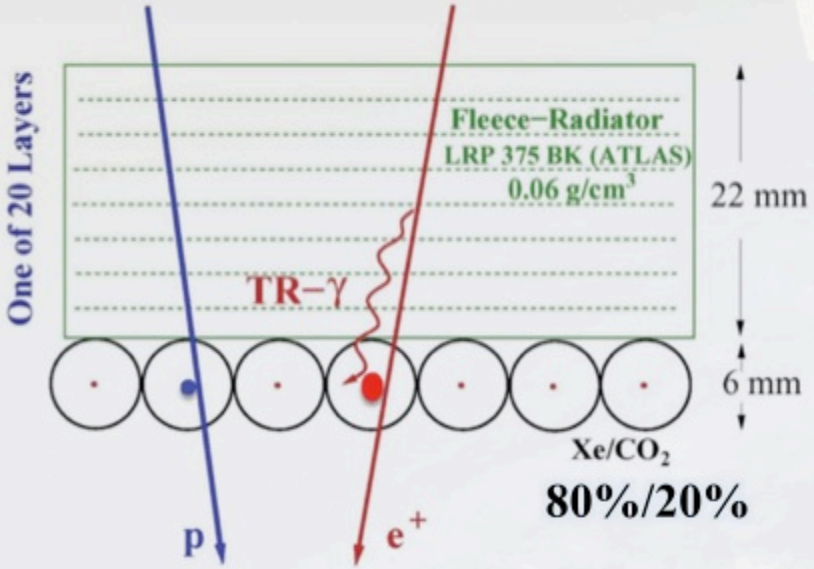


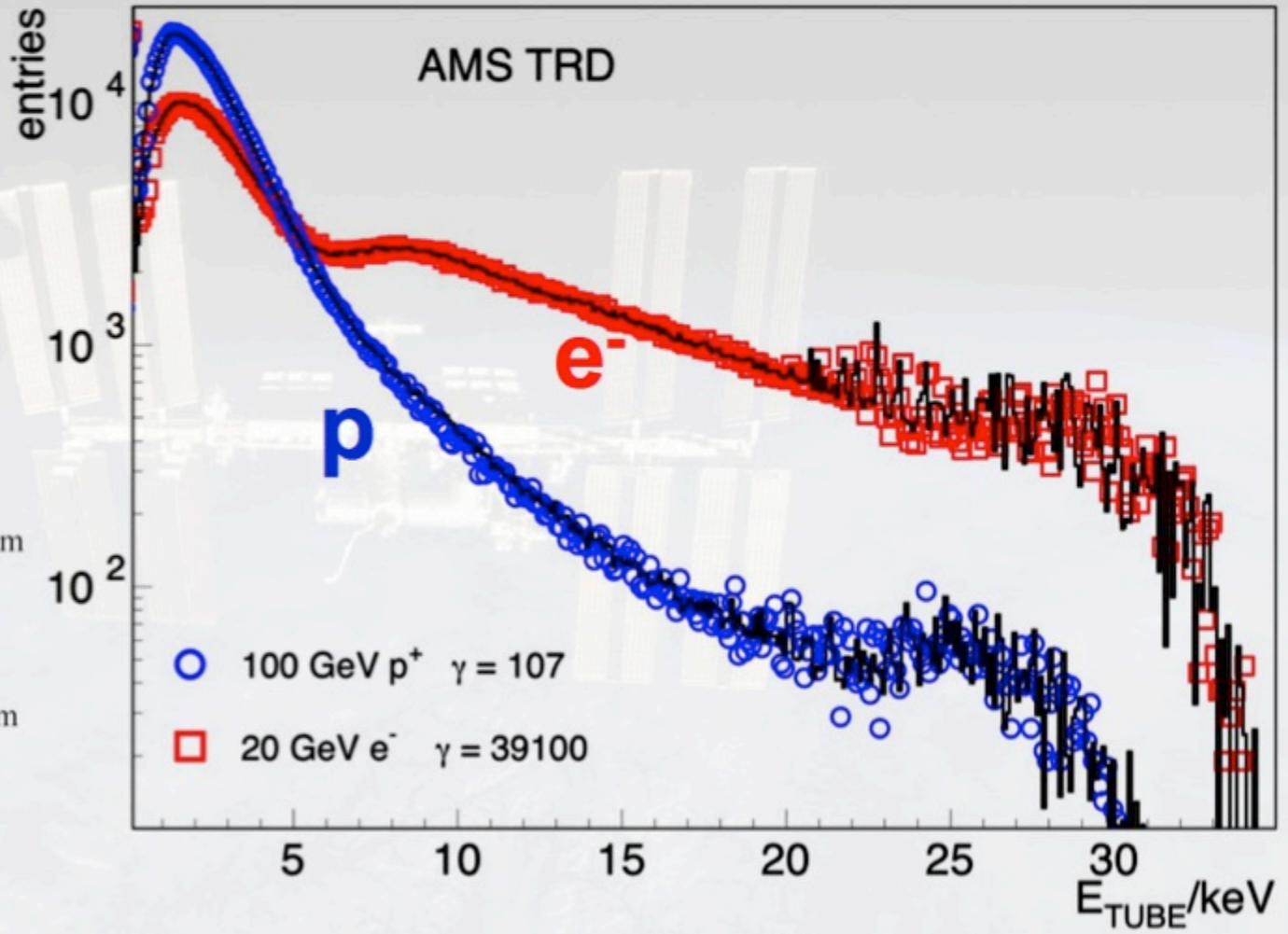




TRD signal


TRD

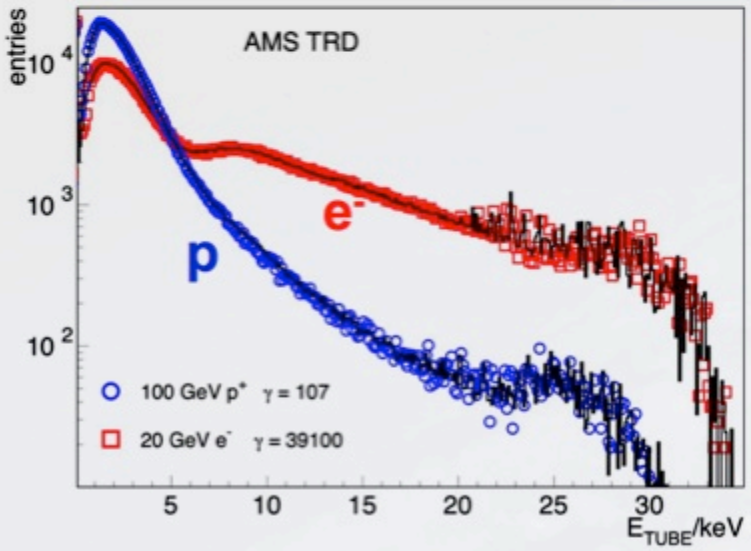

One of 20 Layers
Fleece−Radiator
LRP 375 BK (ATLAS)
0.06 g/cm3
22 mm
TR−γ
6 mm
Xe/CO2
80%/20%
p
e+


AMS TRD
entries
10 4
10 3
10 2
e-
p
100 GeV p+ γ = 107
20 GeV e- γ = 39100
5
10
15
20
25
30
E TUBE/keV

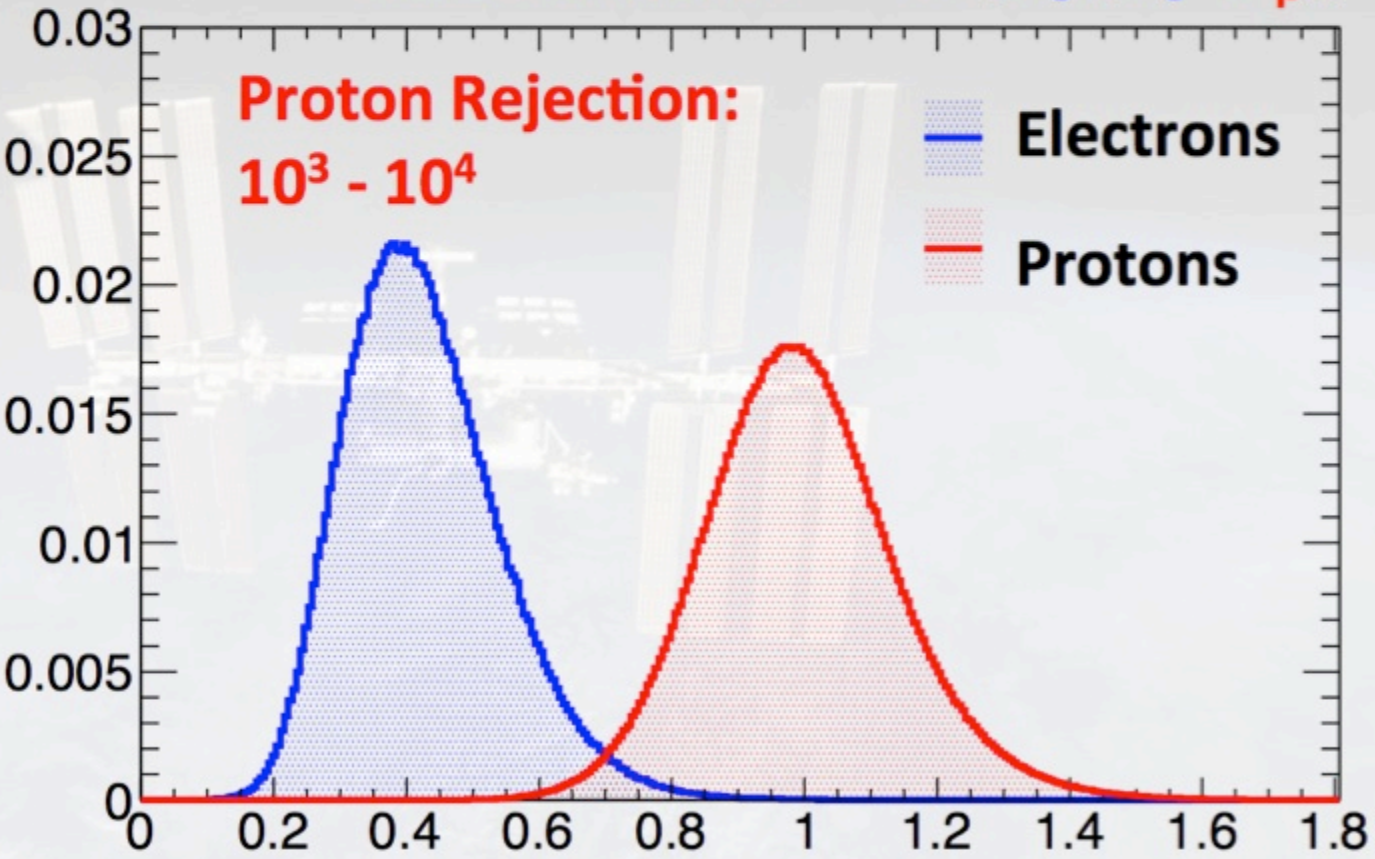
TRD estimator

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

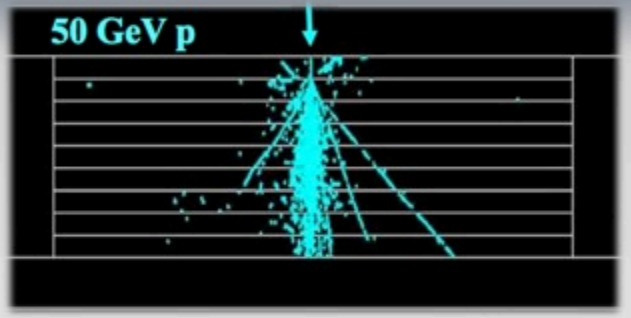
$$P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)}$$

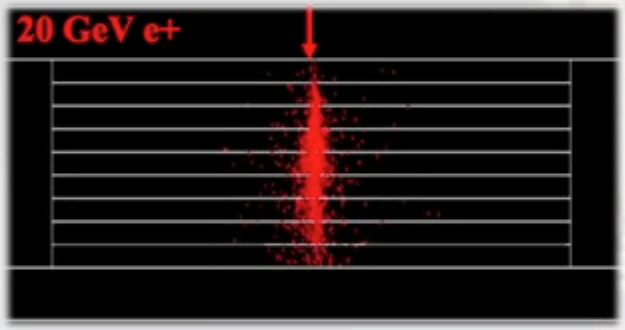


TRD estimator = -ln(P_e/(P_e+P_p))

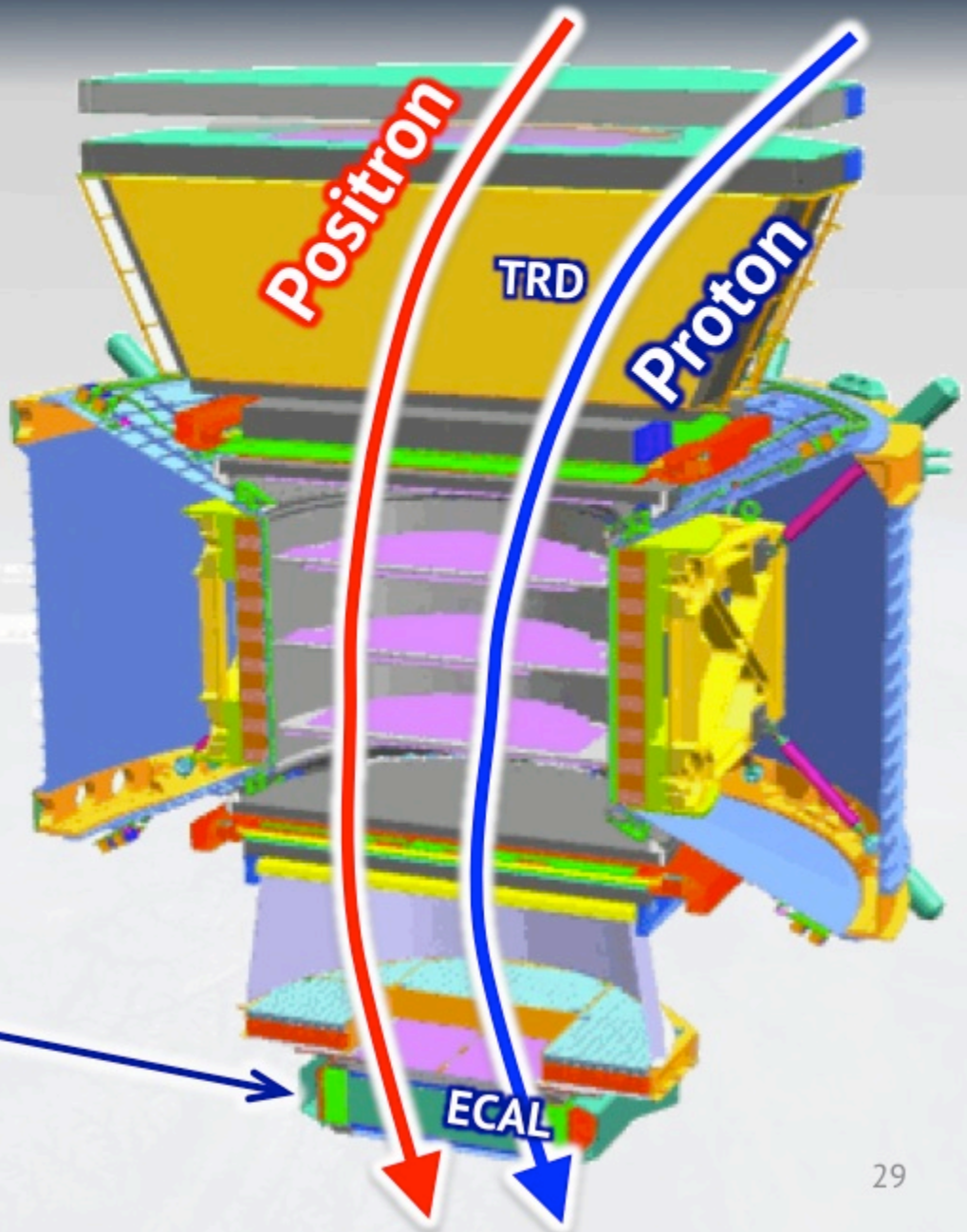


EM calorimeter (ECAL)

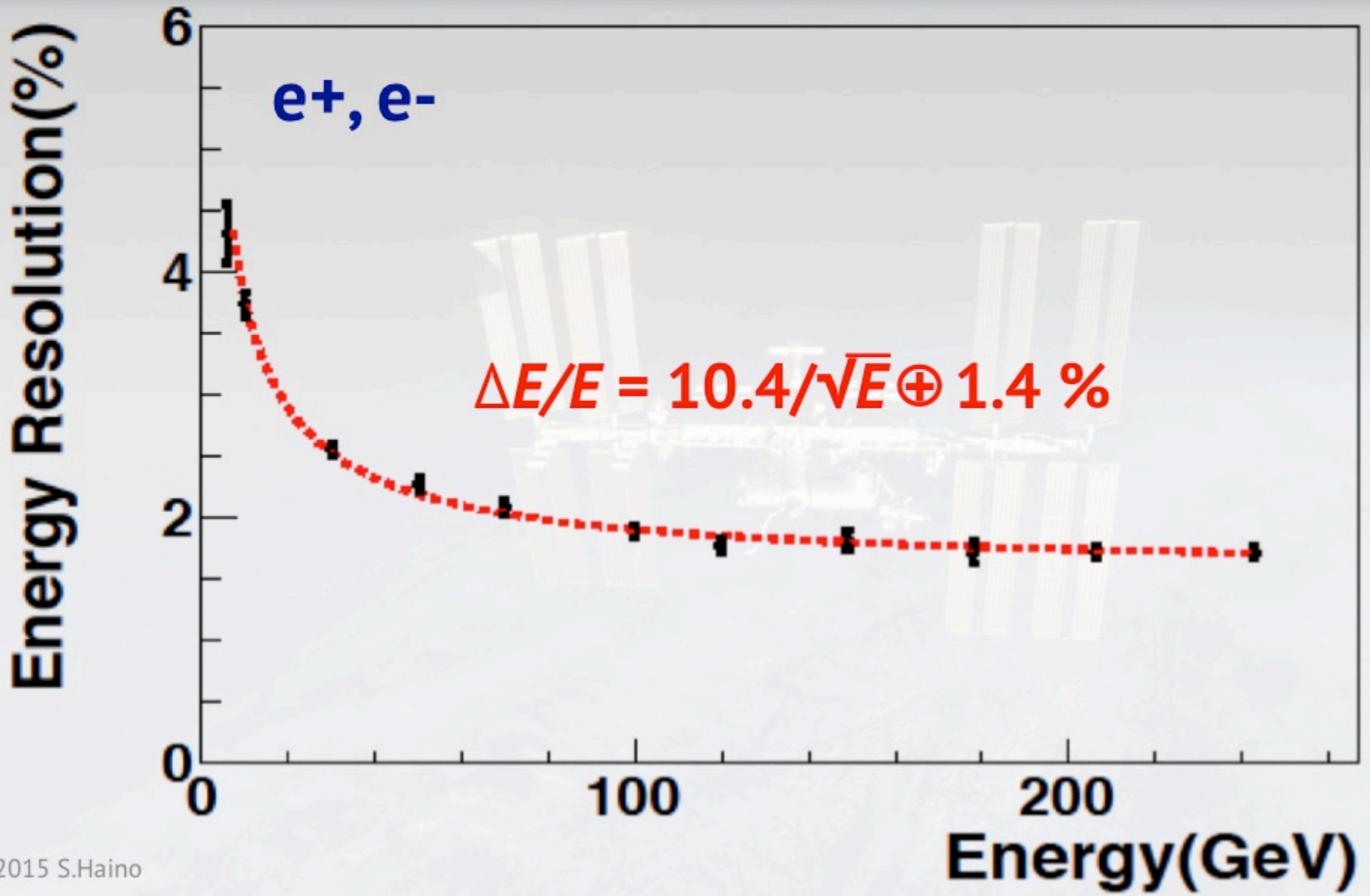




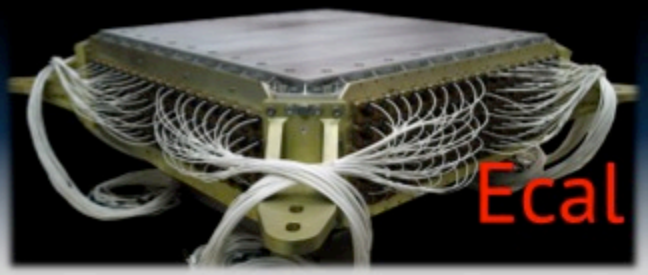
ECAL (17 X_0)



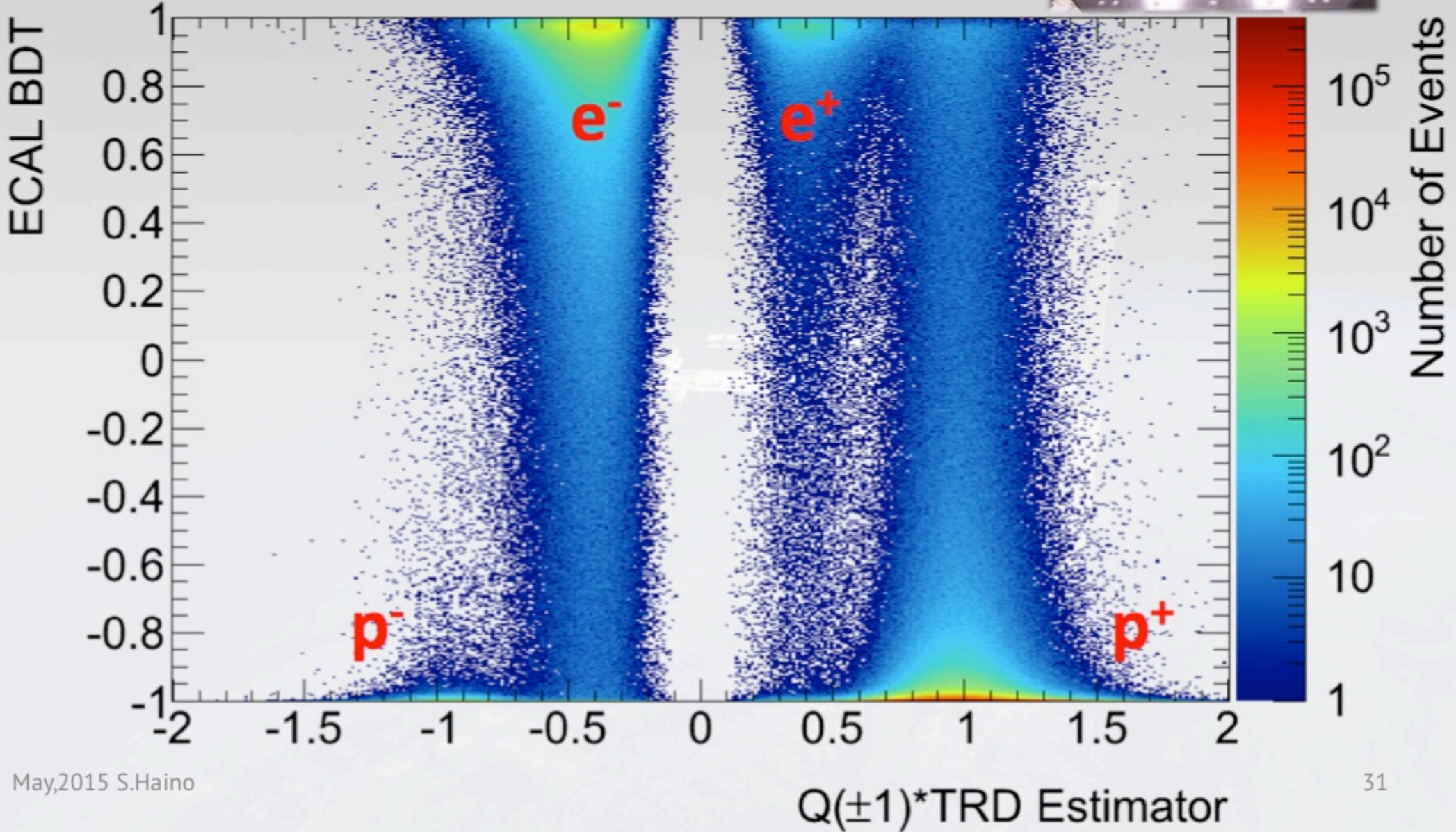
Ecal Energy resolution



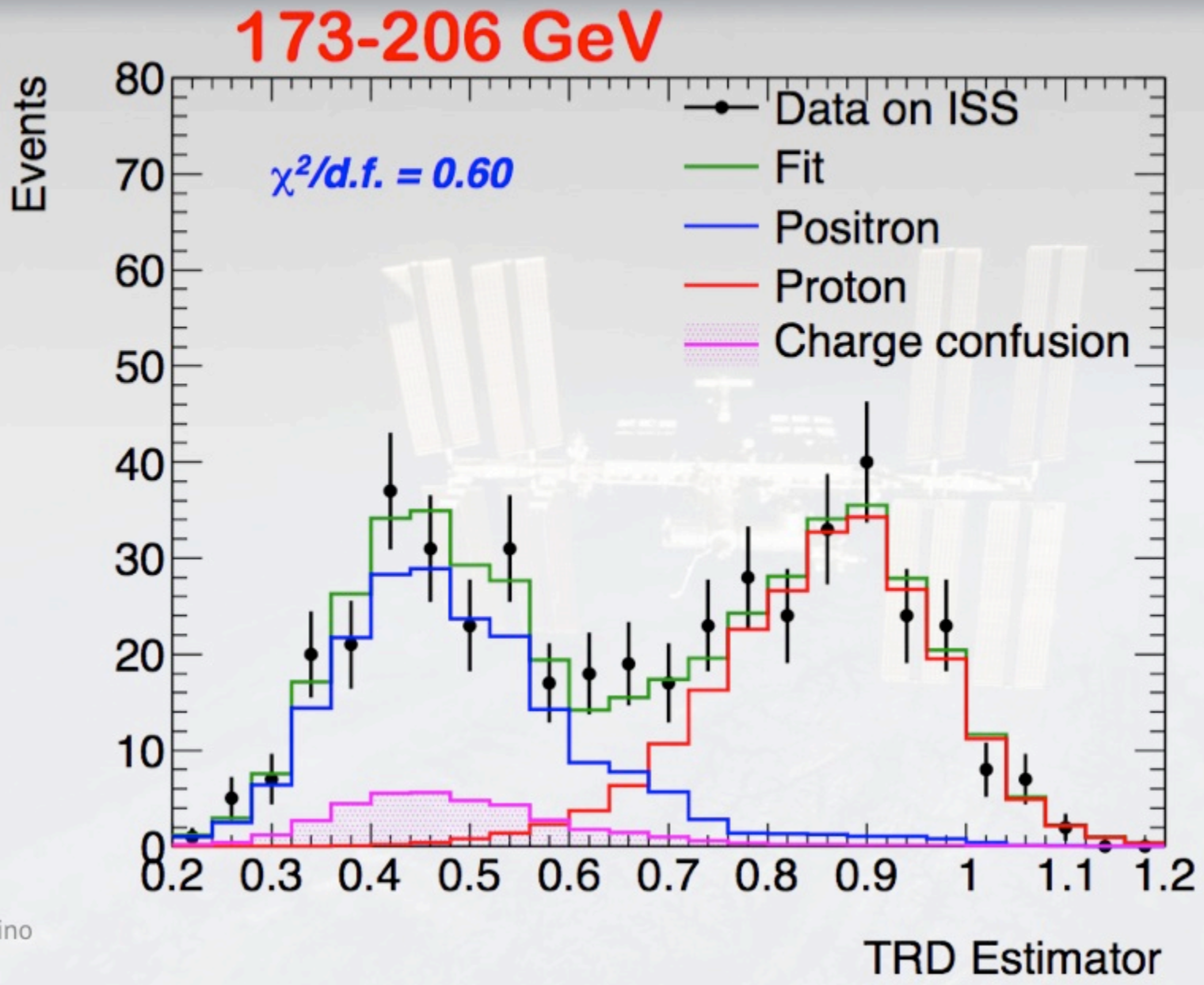
Particle ID


Ecal

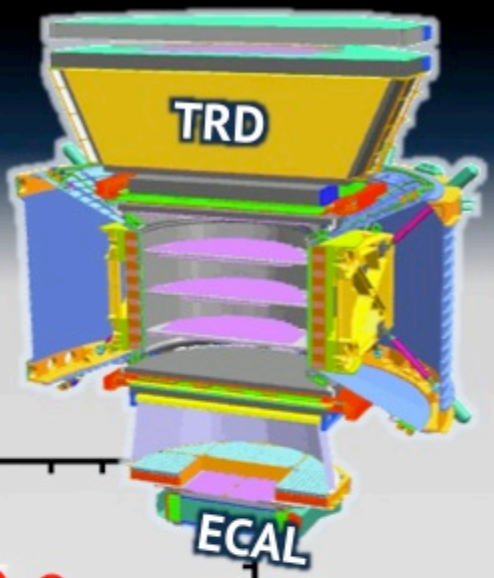

TRD
21/07/2005


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
10^5
10^4
10^3
10^2
10
1

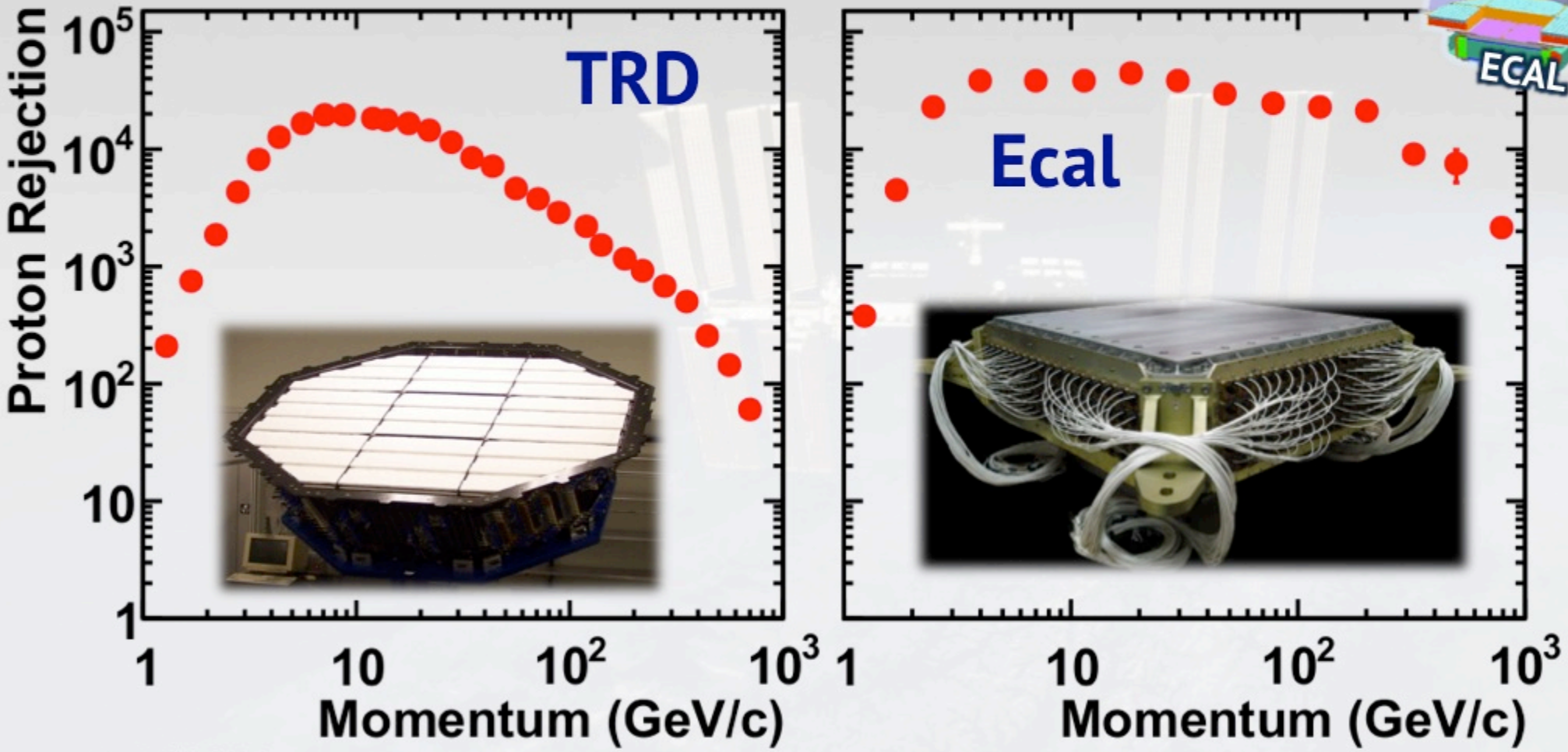
Projection (TRD estimator)



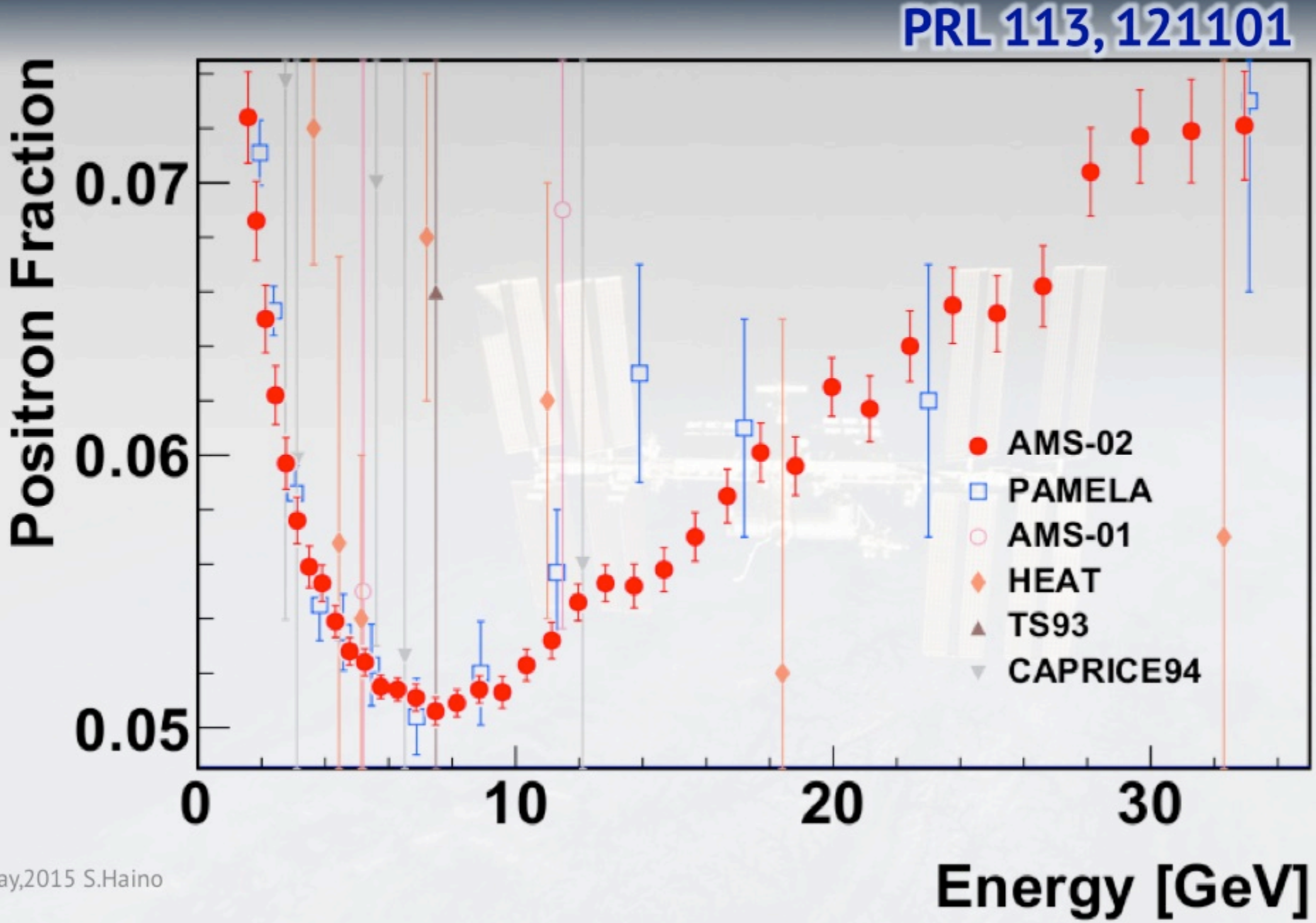
Proton rejection



With 90 % e^+ efficiency

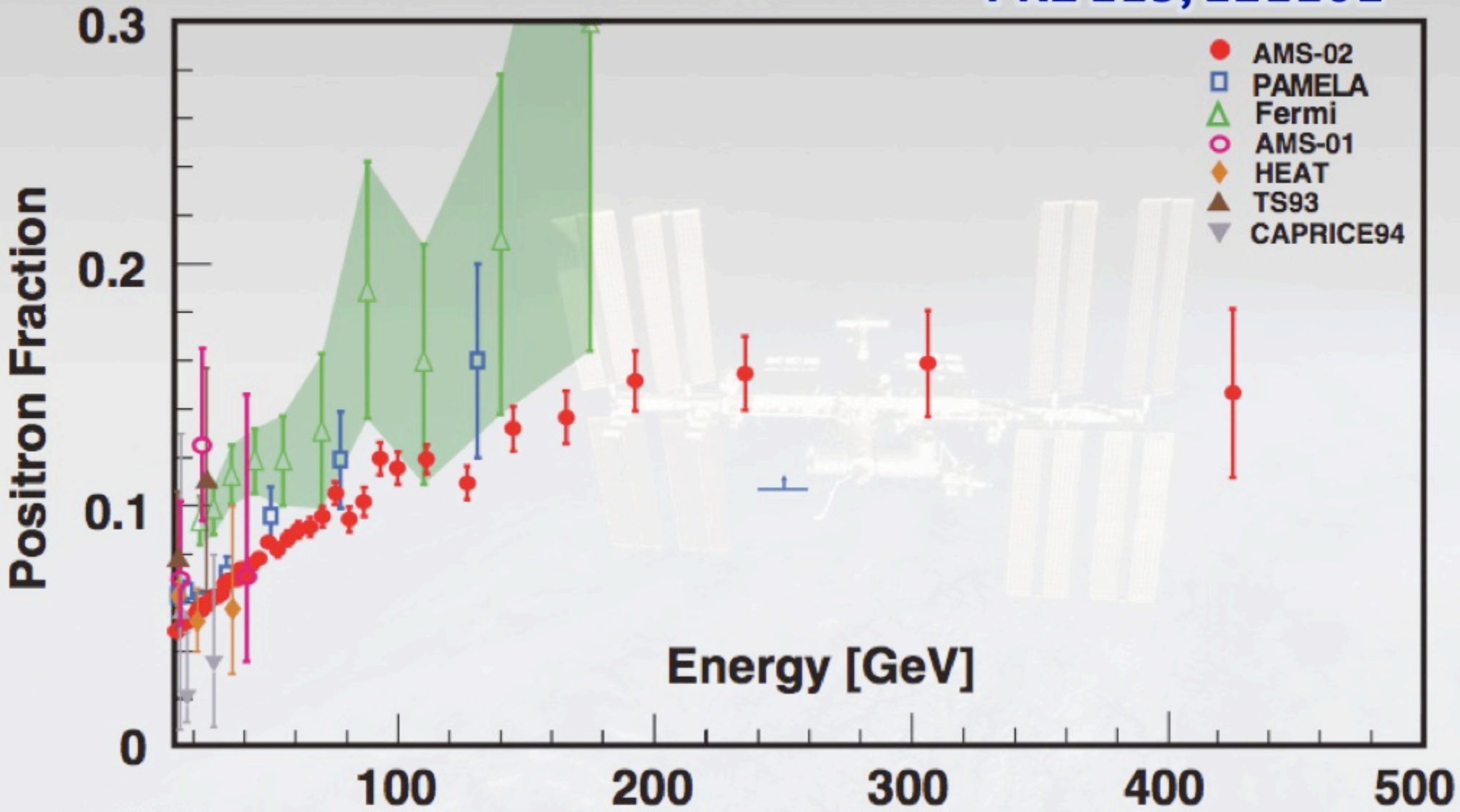


Positron fraction (low energy)



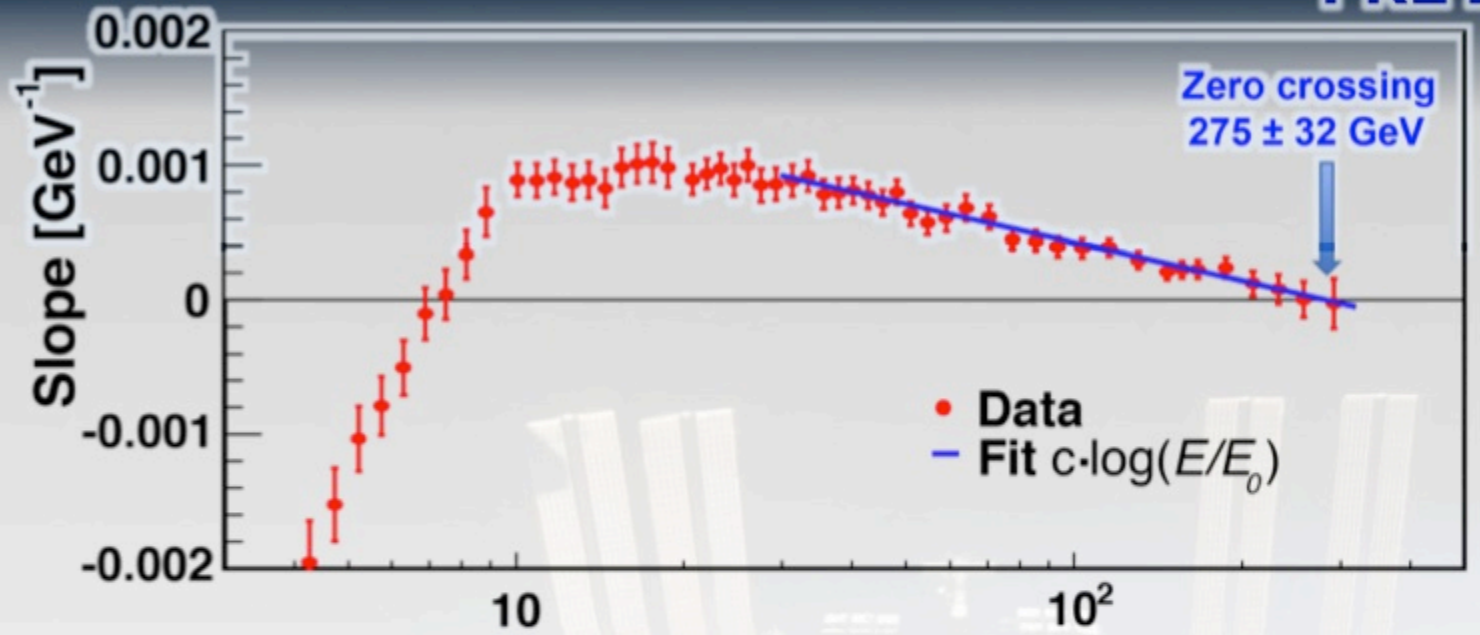
Positron fraction (high energy)

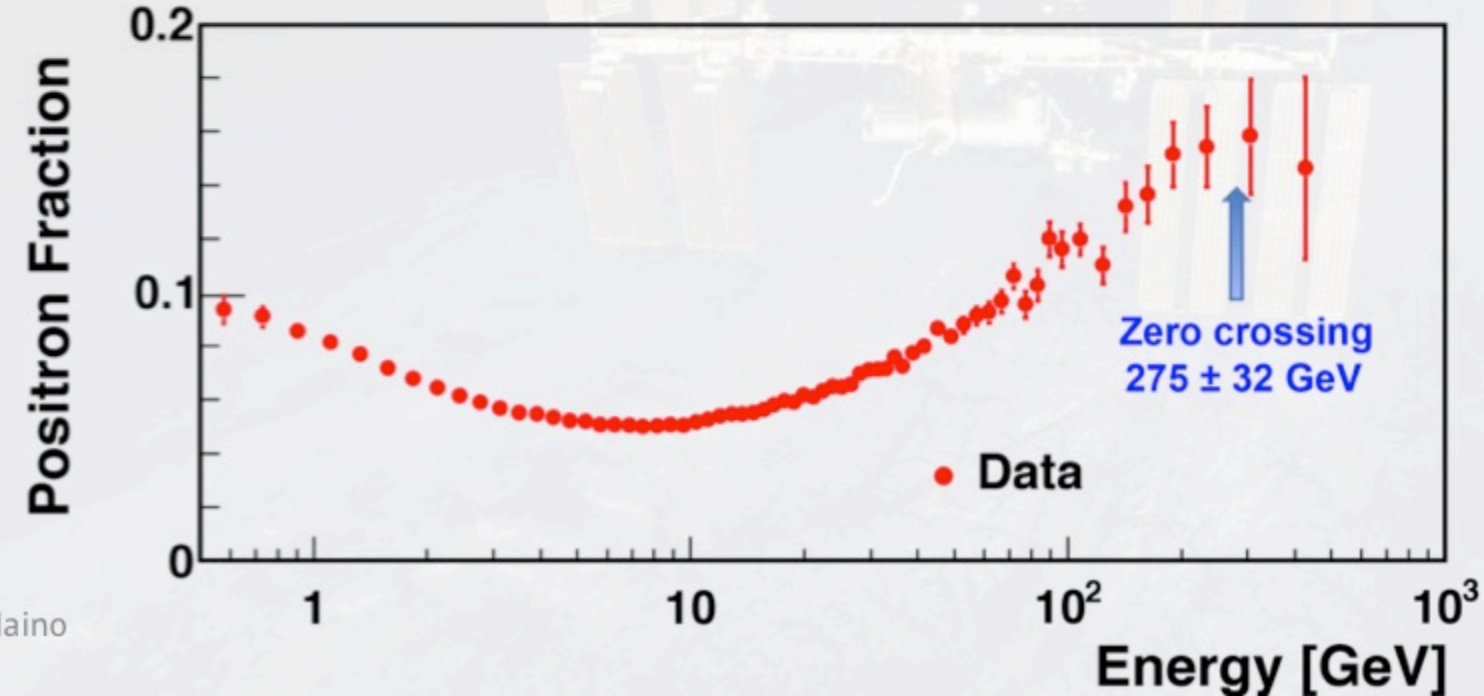
PRL 113, 121101



Positron fraction slope

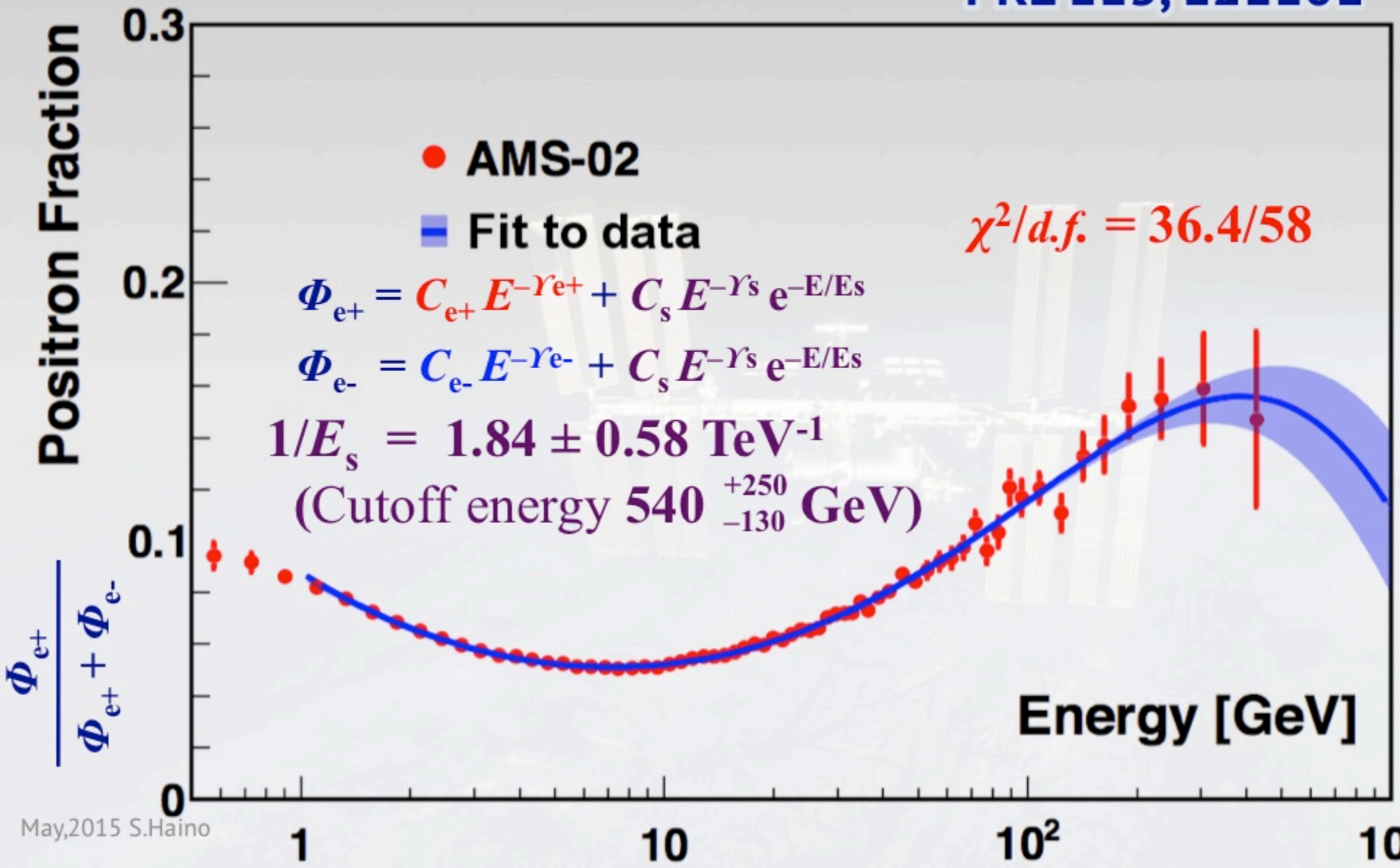
PRL 113, 121101





Fit to data

PRL 113, 121101

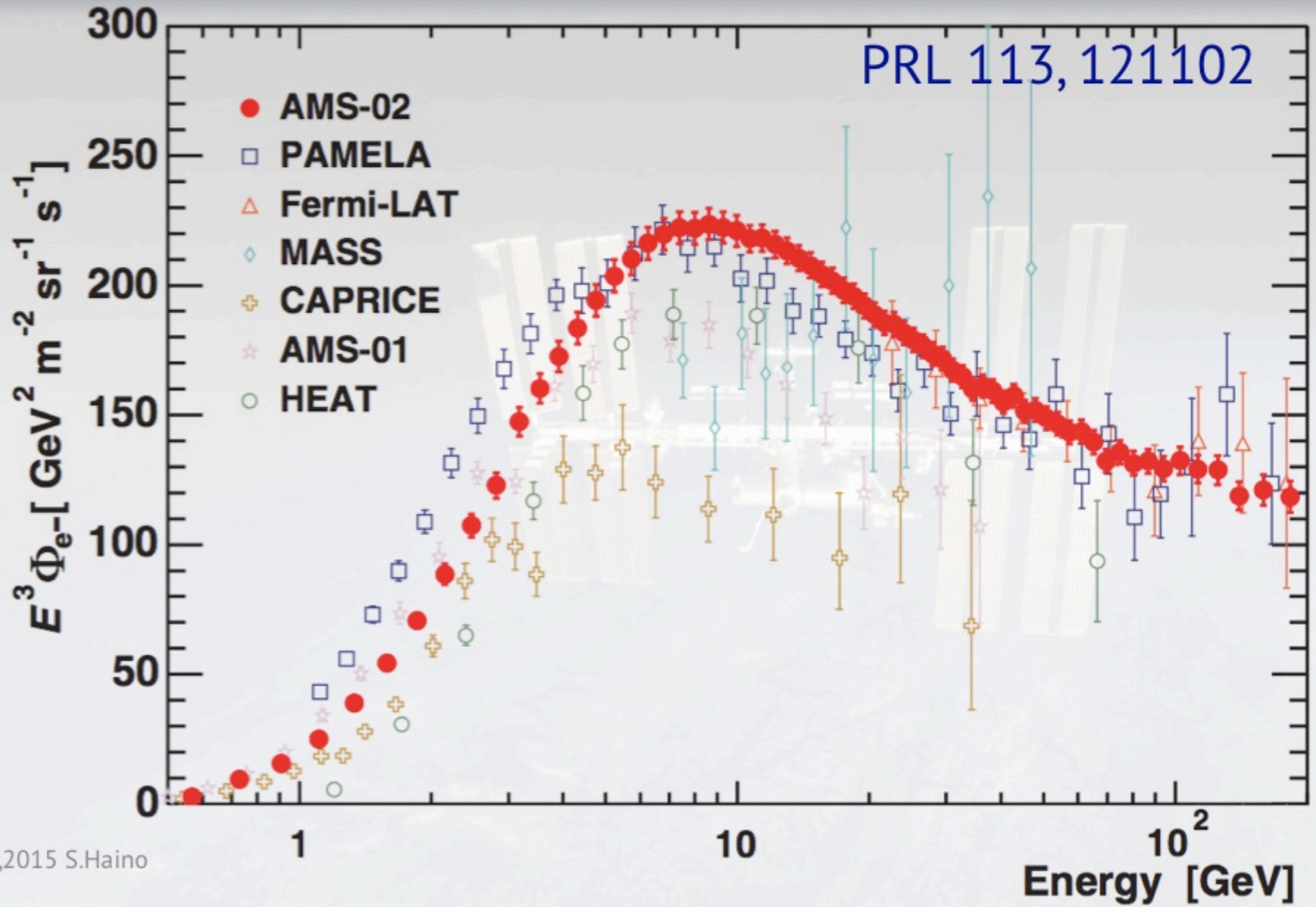


Flux determination

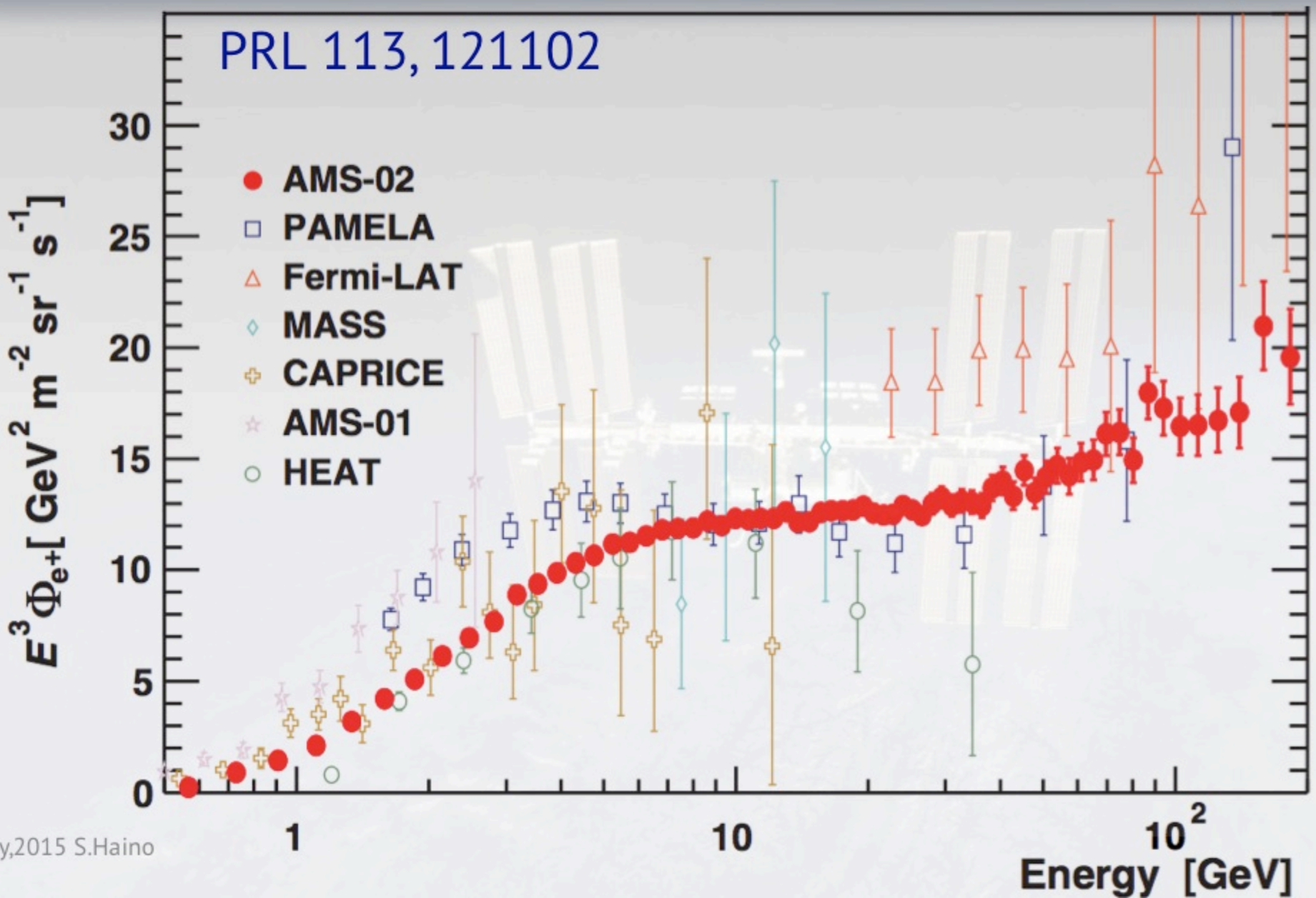
$$\Phi(E) = \frac{N}{T \cdot A_{\mathrm{eff}} \cdot \varepsilon_{\mathrm{trig.}} \cdot \Delta E}$$

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)
$\varepsilon_{\mathrm{trg.}}$	: Trigger efficiency	
ΔE	: Energy bin	(GeV)

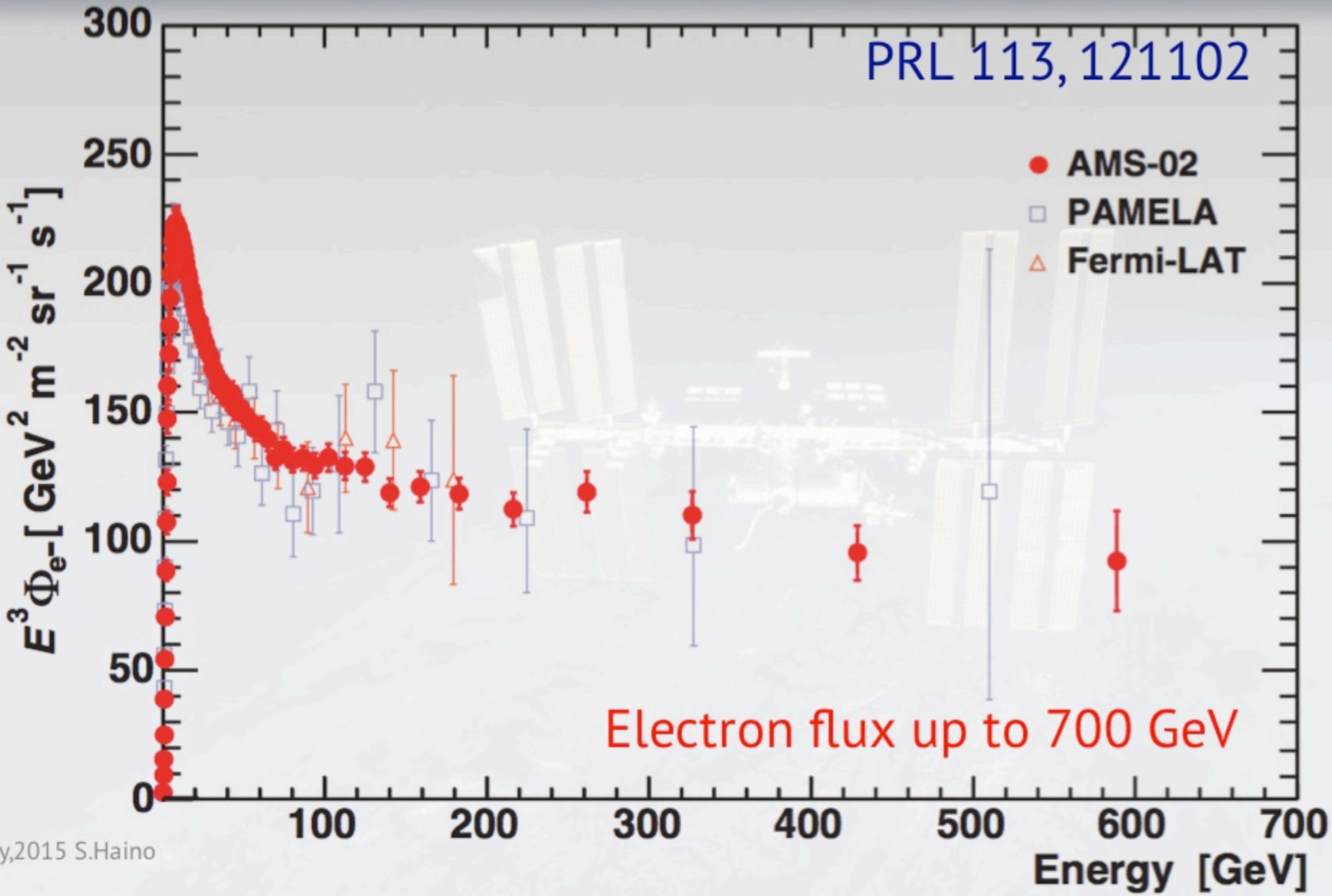
Electron flux



Positron flux



Electron flux (High energy)



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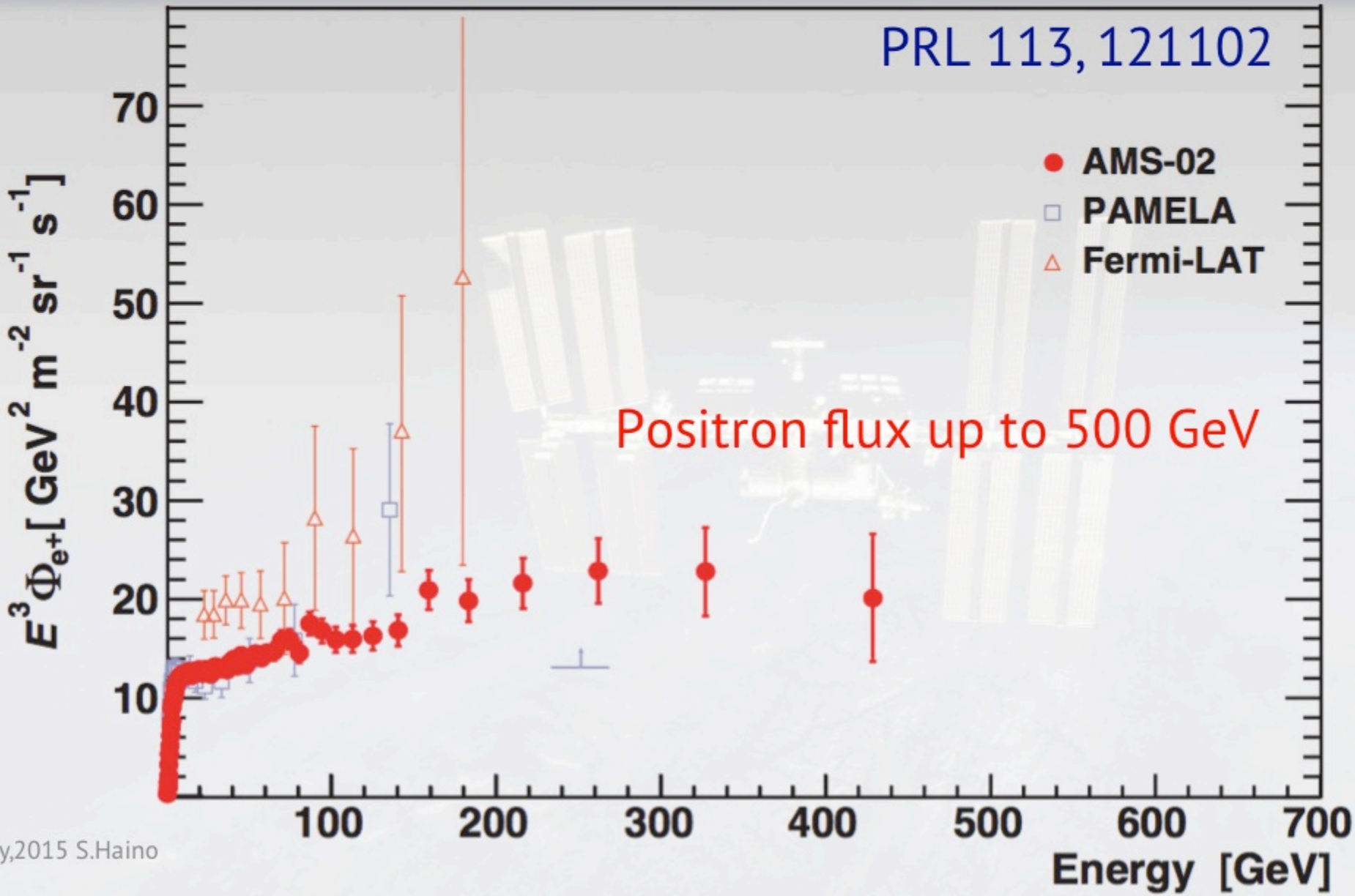
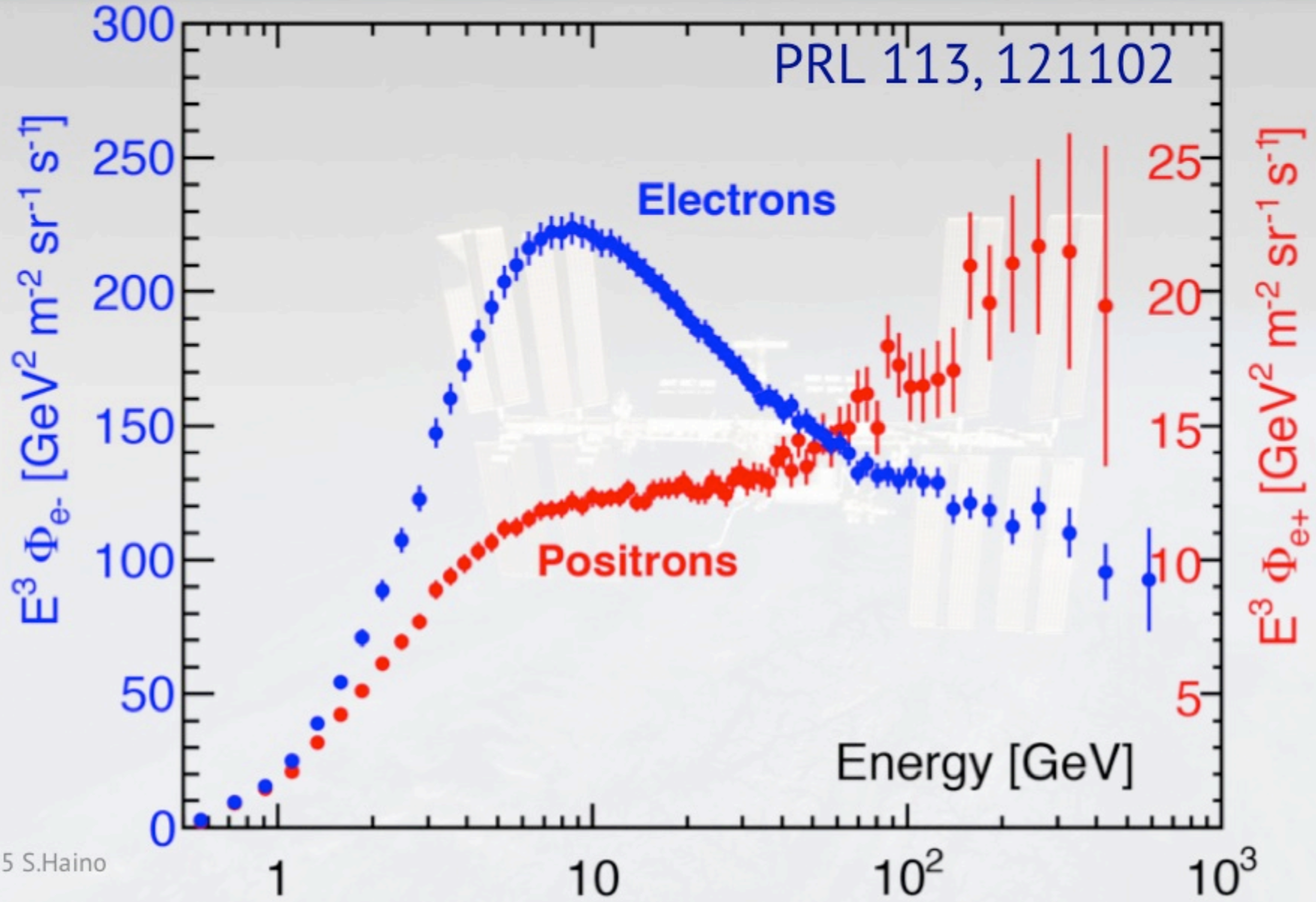
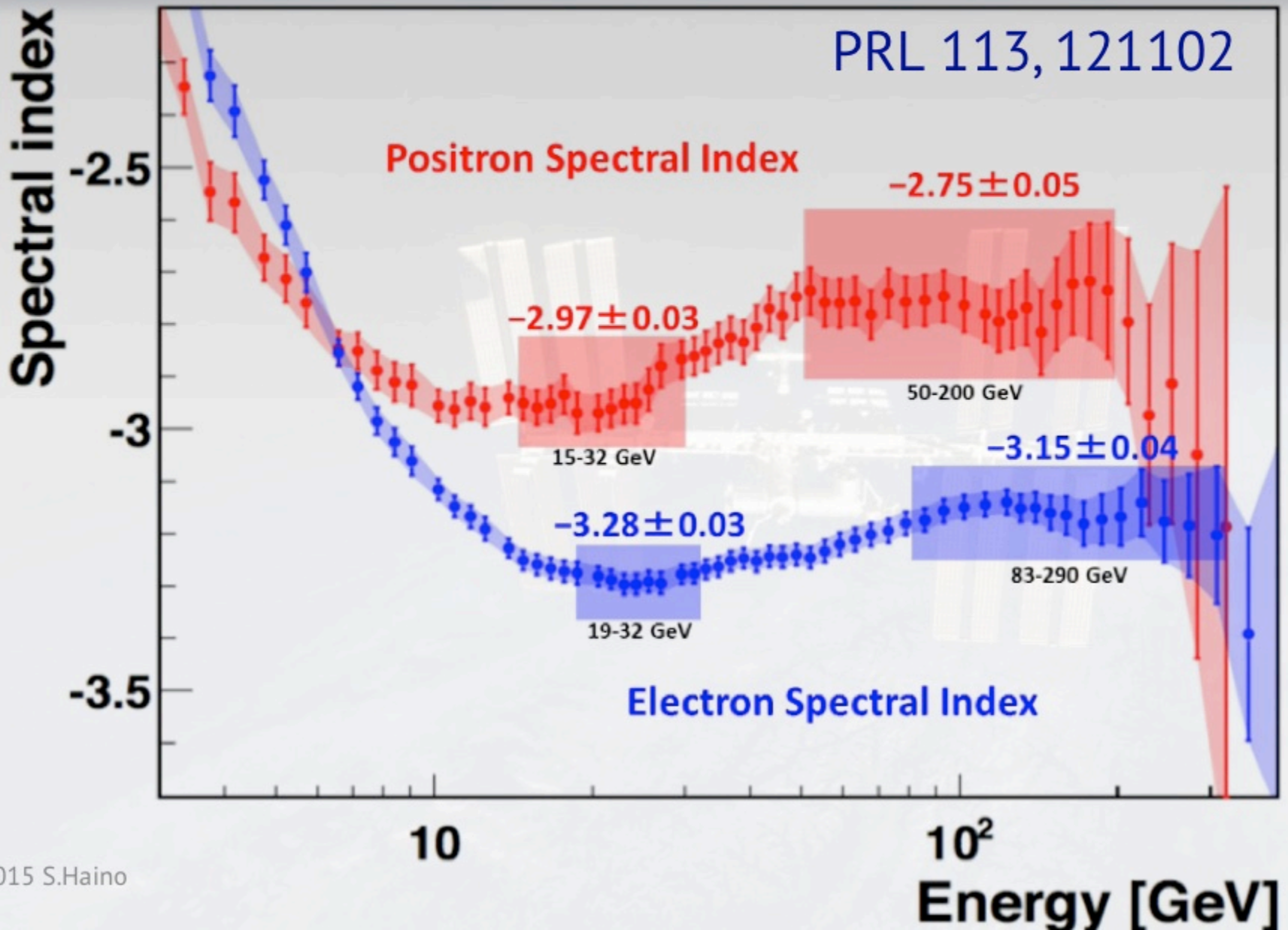


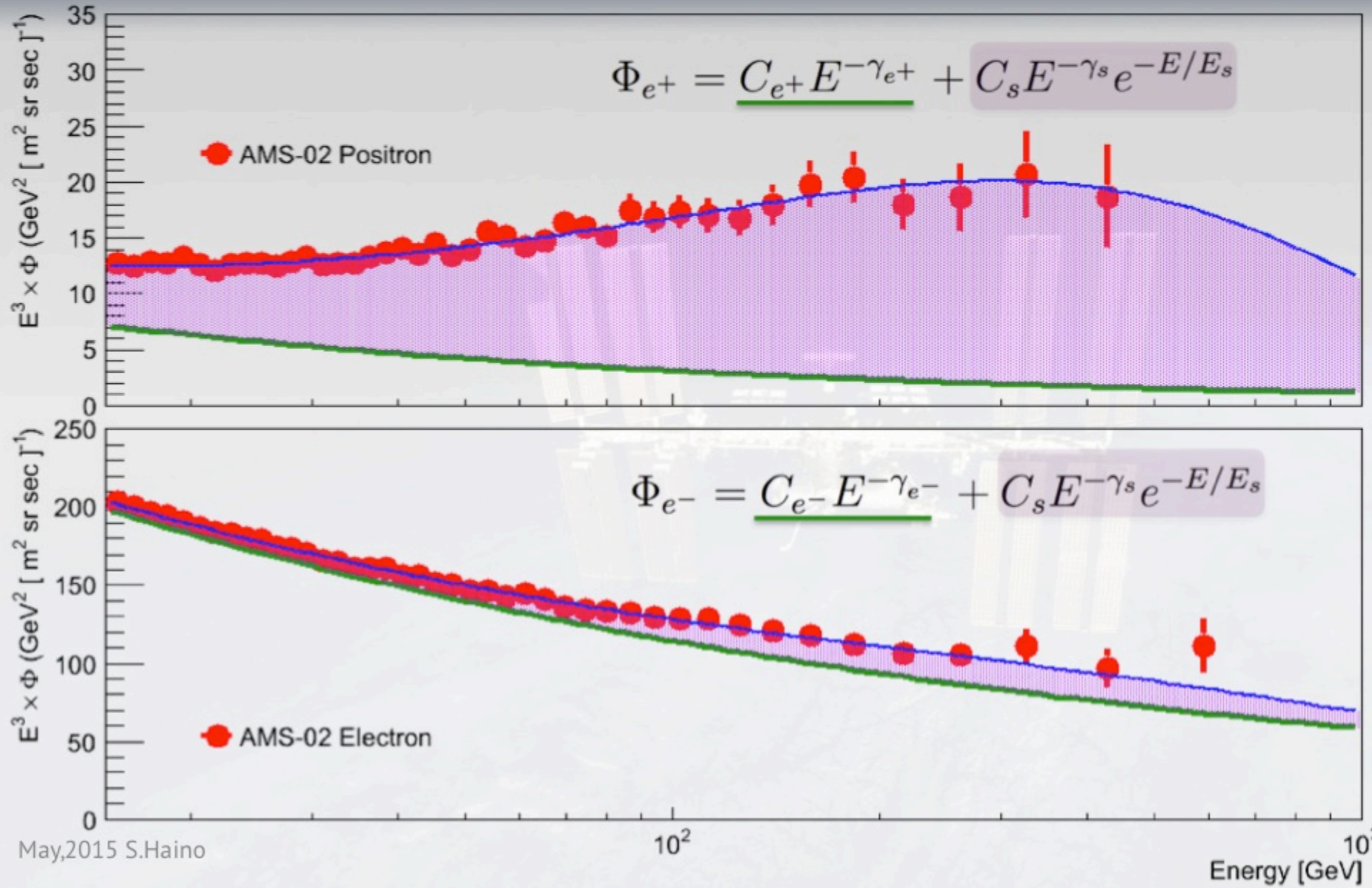
Flux comparison



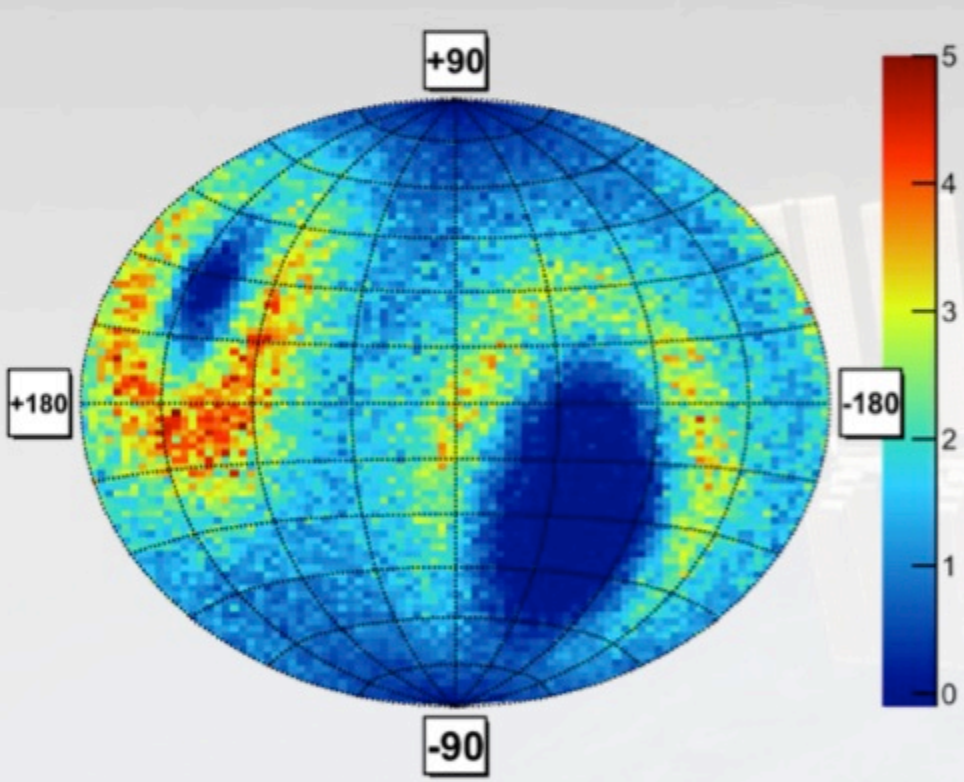
Spectral indices are not constant

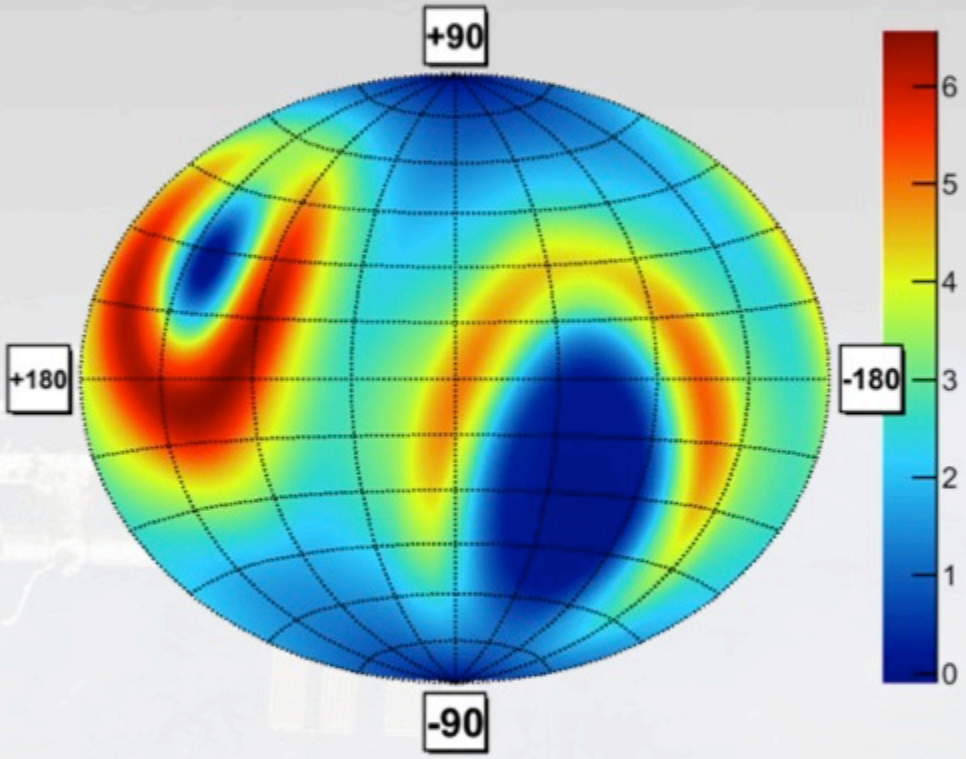


Fit to e+ and e– flux



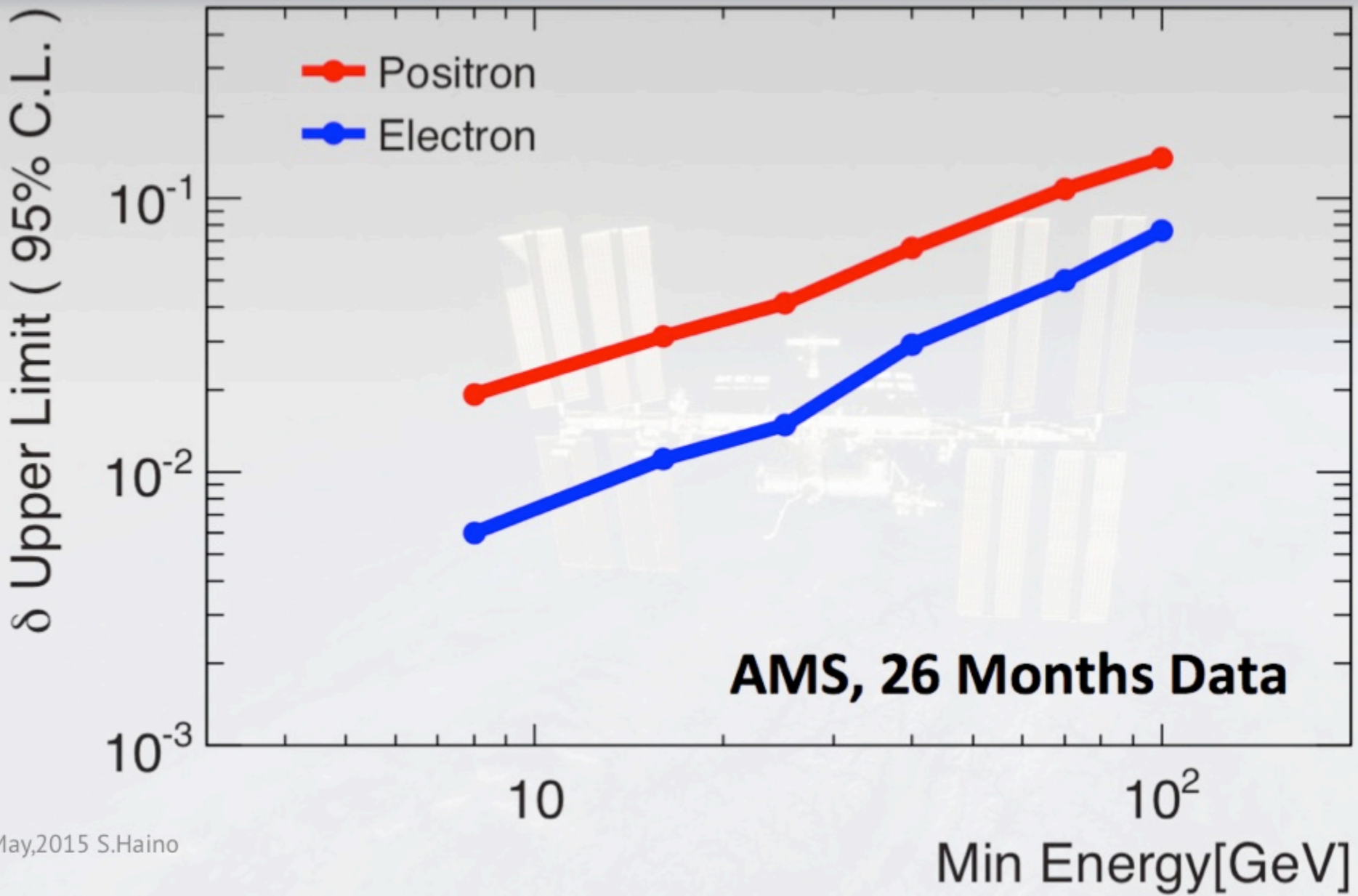
Electron anisotropy



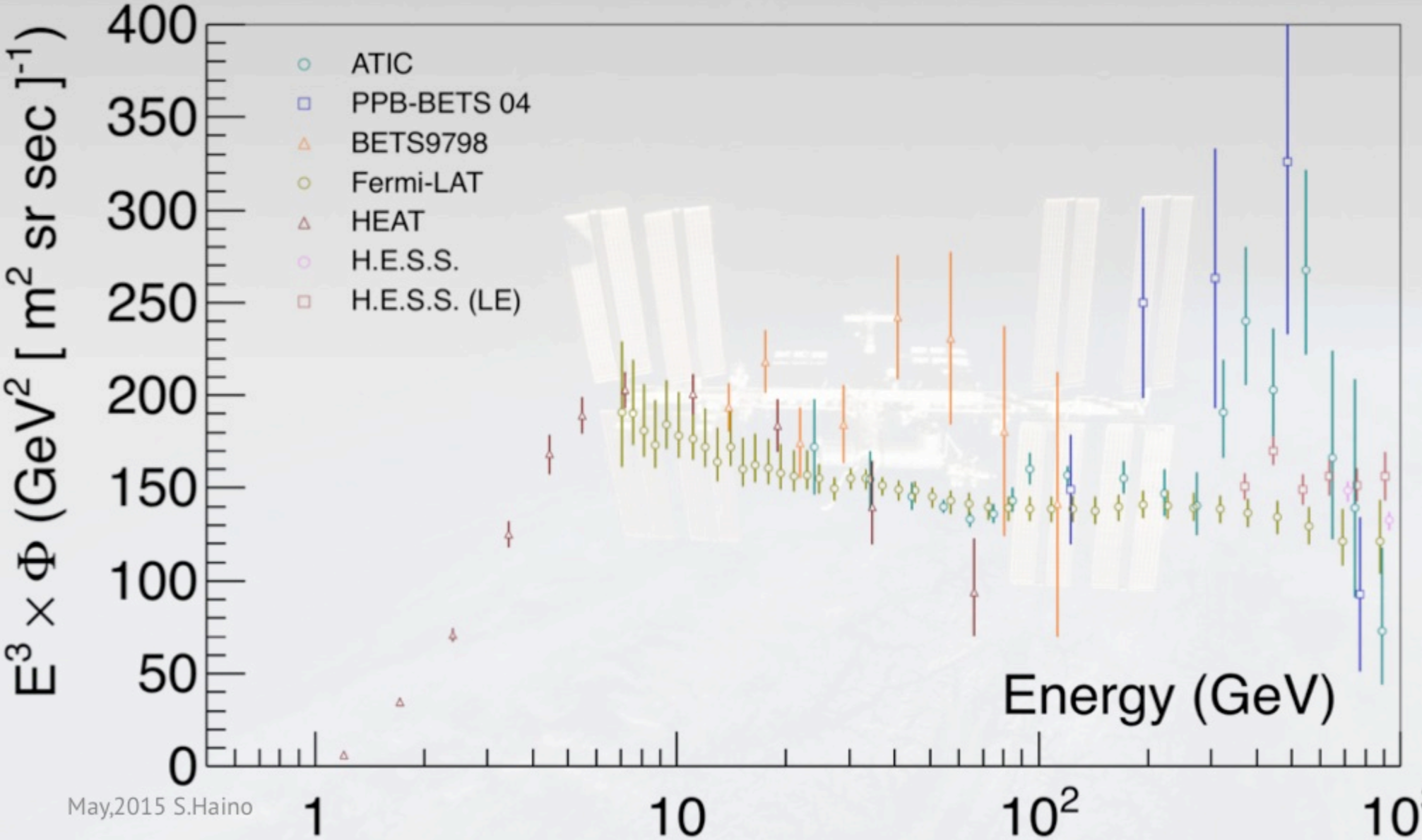


$$N = \int_b \int_l J(b,l) \times AT(b,l) \times \sin b \times db\, dl$$

Upper limits of dipole anisotropy



All (e^++e^-) flux before AMS



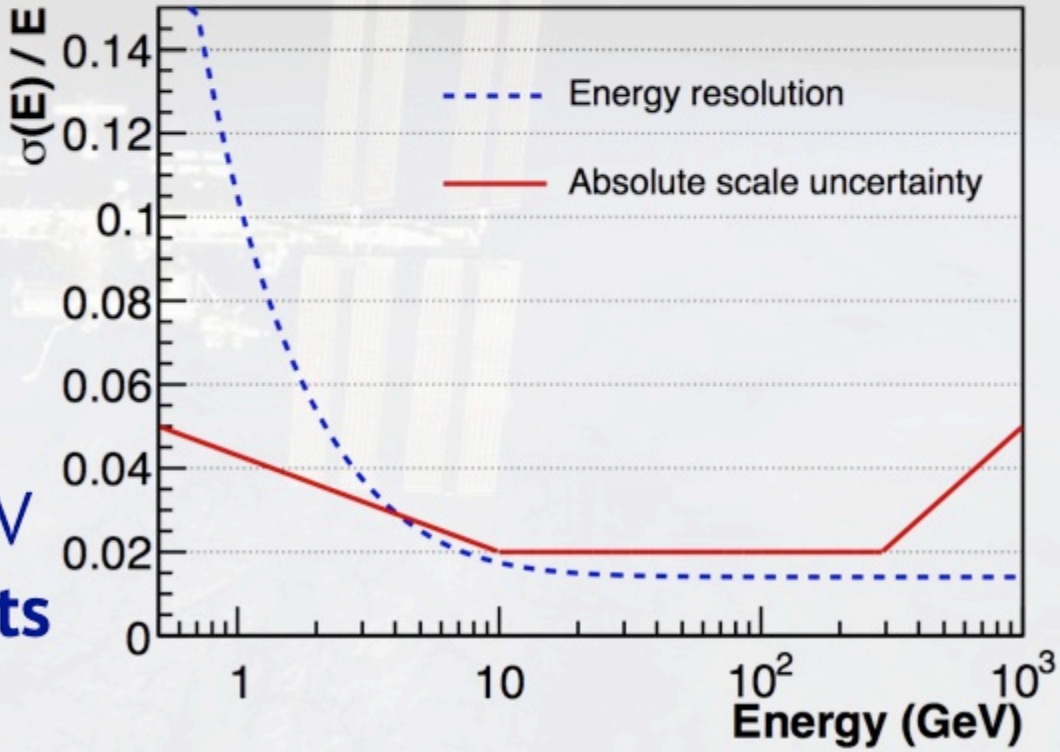
AMS all (e^++e^-) flux up to 1 TeV

PRL 113, 221102 (2014) PHYSICAL REVIEW LETTERS week ending 28 NOVEMBER 2014

Precision Measurement of the $(e^+ + e^-)$ Flux in Primary Cosmic Rays from 0.5 GeV to 1 TeV with the Alpha Magnetic Spectrometer on the International Space Station

No need to separate charge sign
→ Loose cut and large acceptance
→ Higher statistics
→ Higher energy reach (> ~1 TeV)

Good energy resolution ~2% at 1TeV
Energy scale calibrated by beam tests



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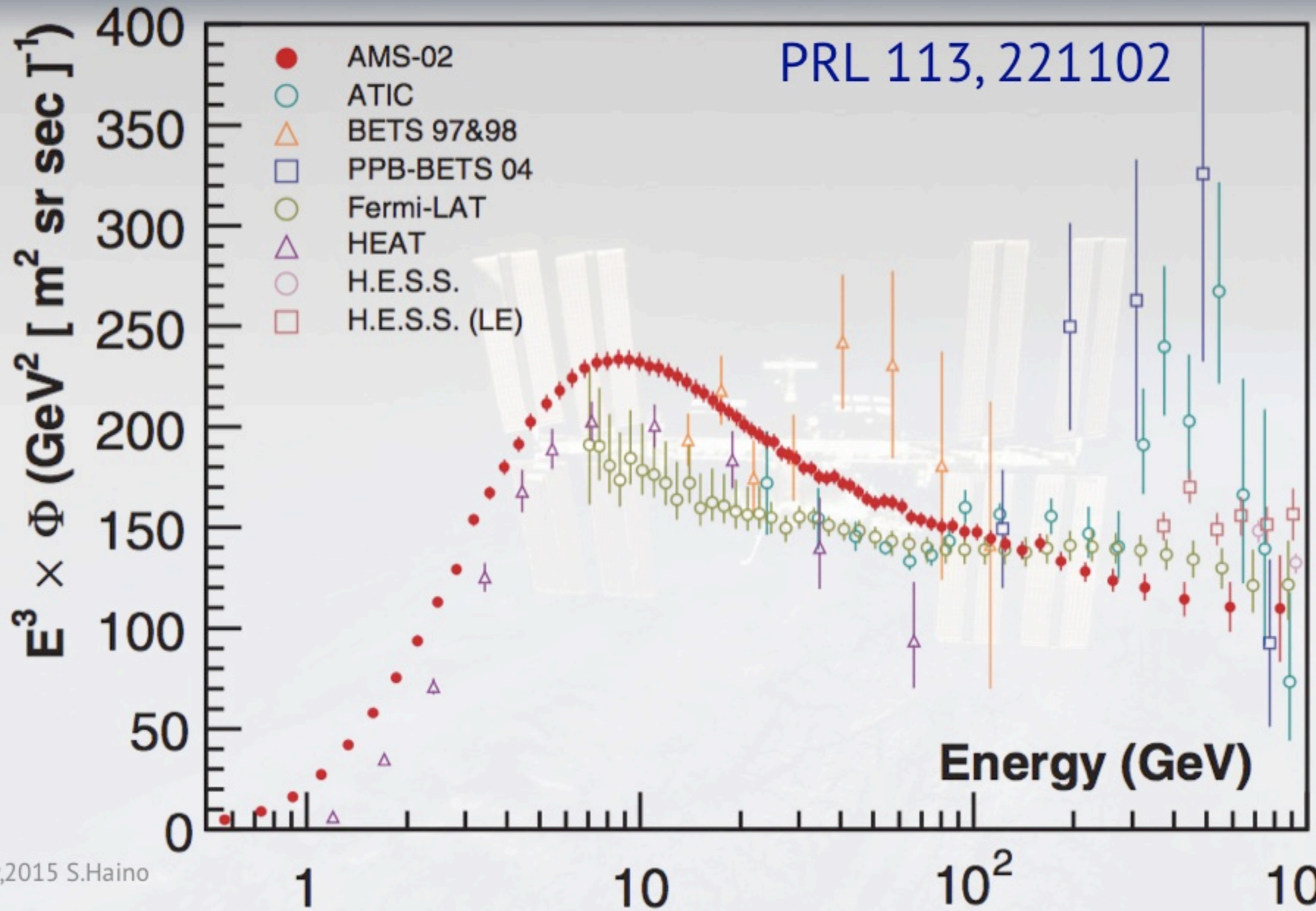

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April 15-17, 2015

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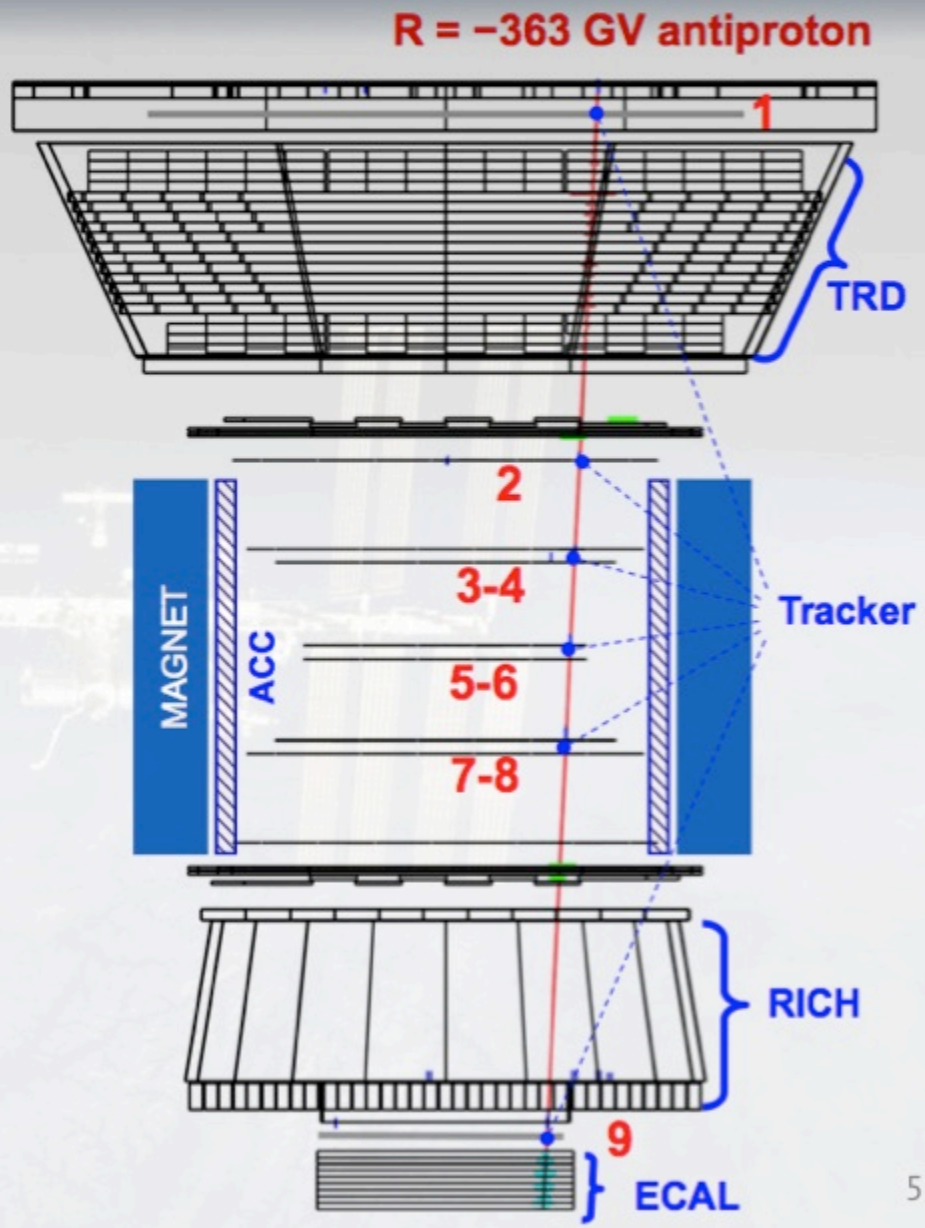
Antiproton analysis

Low energy (R < 10 GV)
- TRD (e^- B.G.)
- TOF/RICH (π^- B.G.)

Middle energy (R < 50 GV)
- TRD, Ecal (e^- B.G.)

High energy (R > 50 GV)
- TRD (e^- B.G.)
- Tracker (p B.G.)



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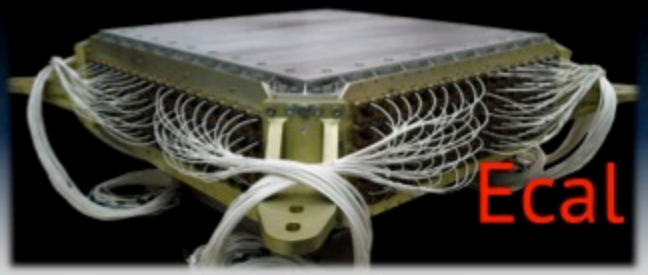
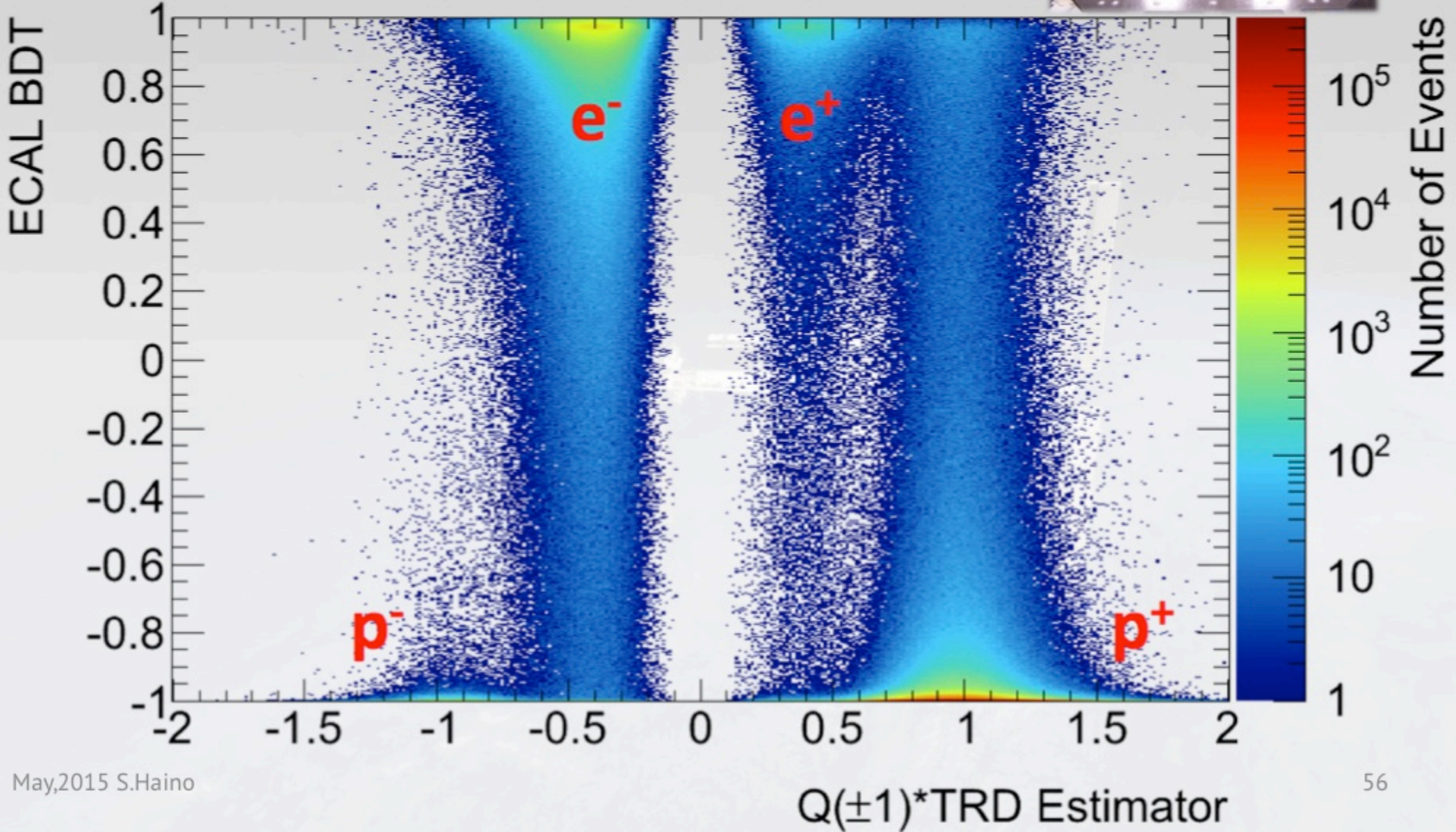
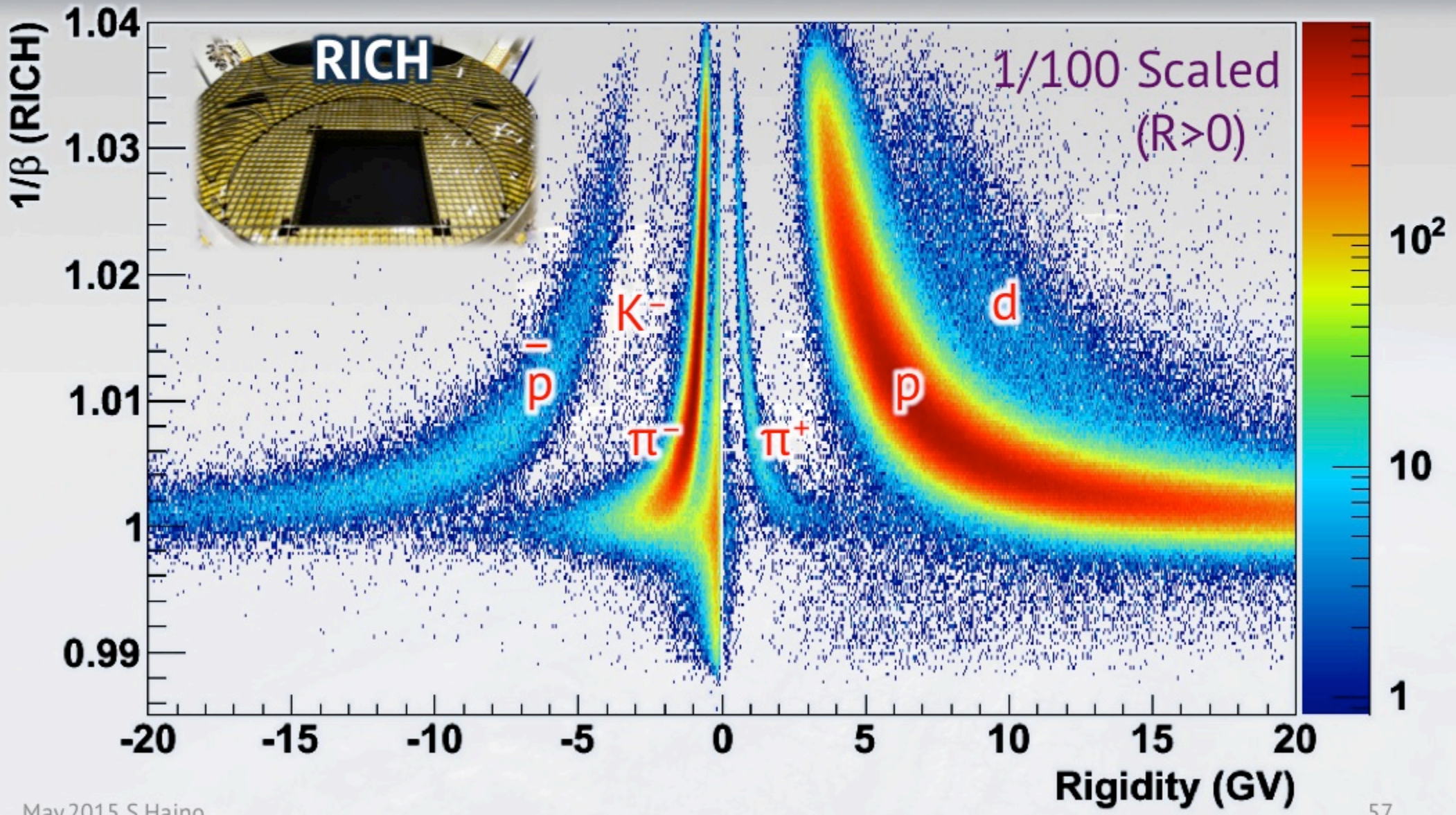

Ecal

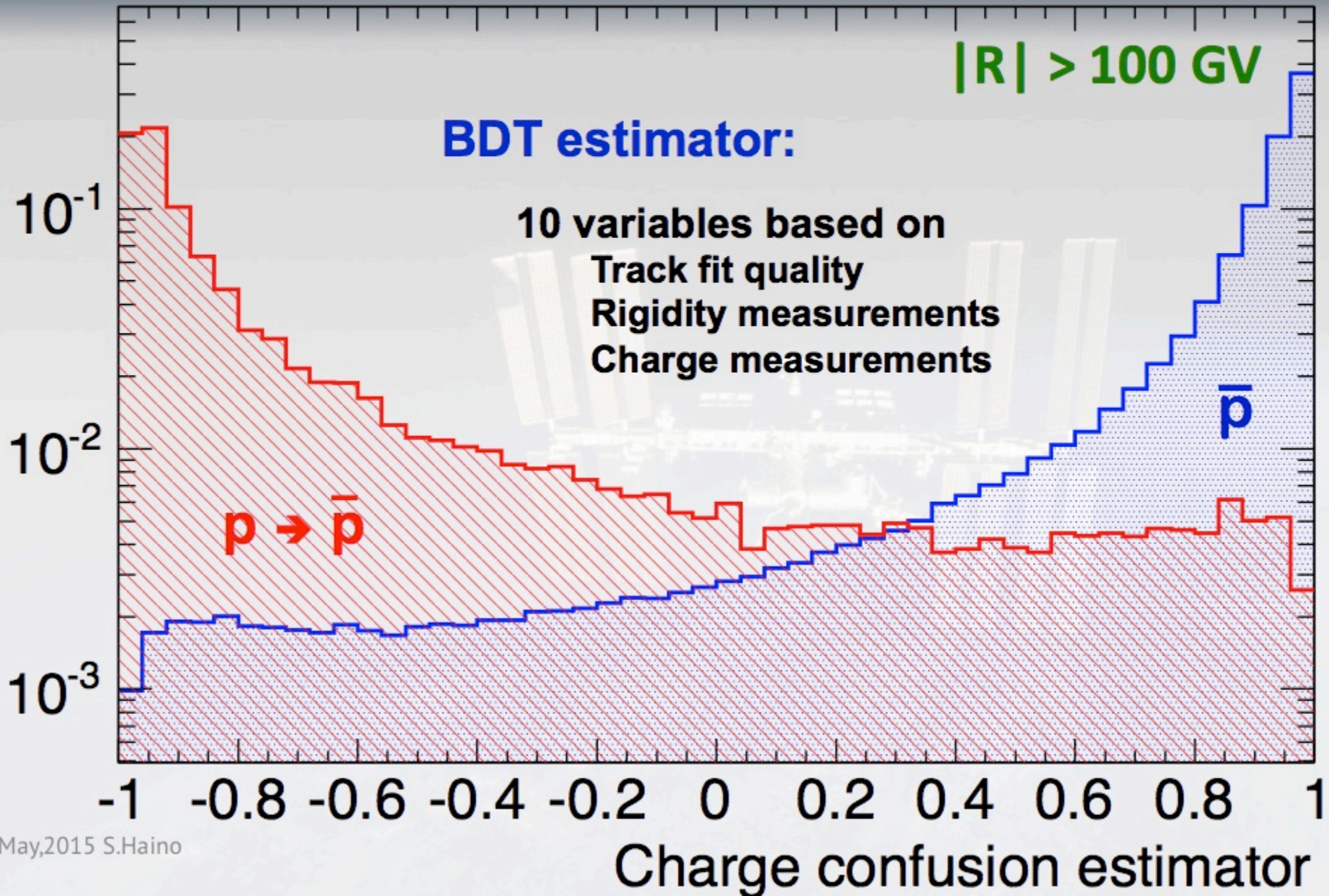

TRD
21/07/2005


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
10^5
10^4
10^3
10^2
10
1

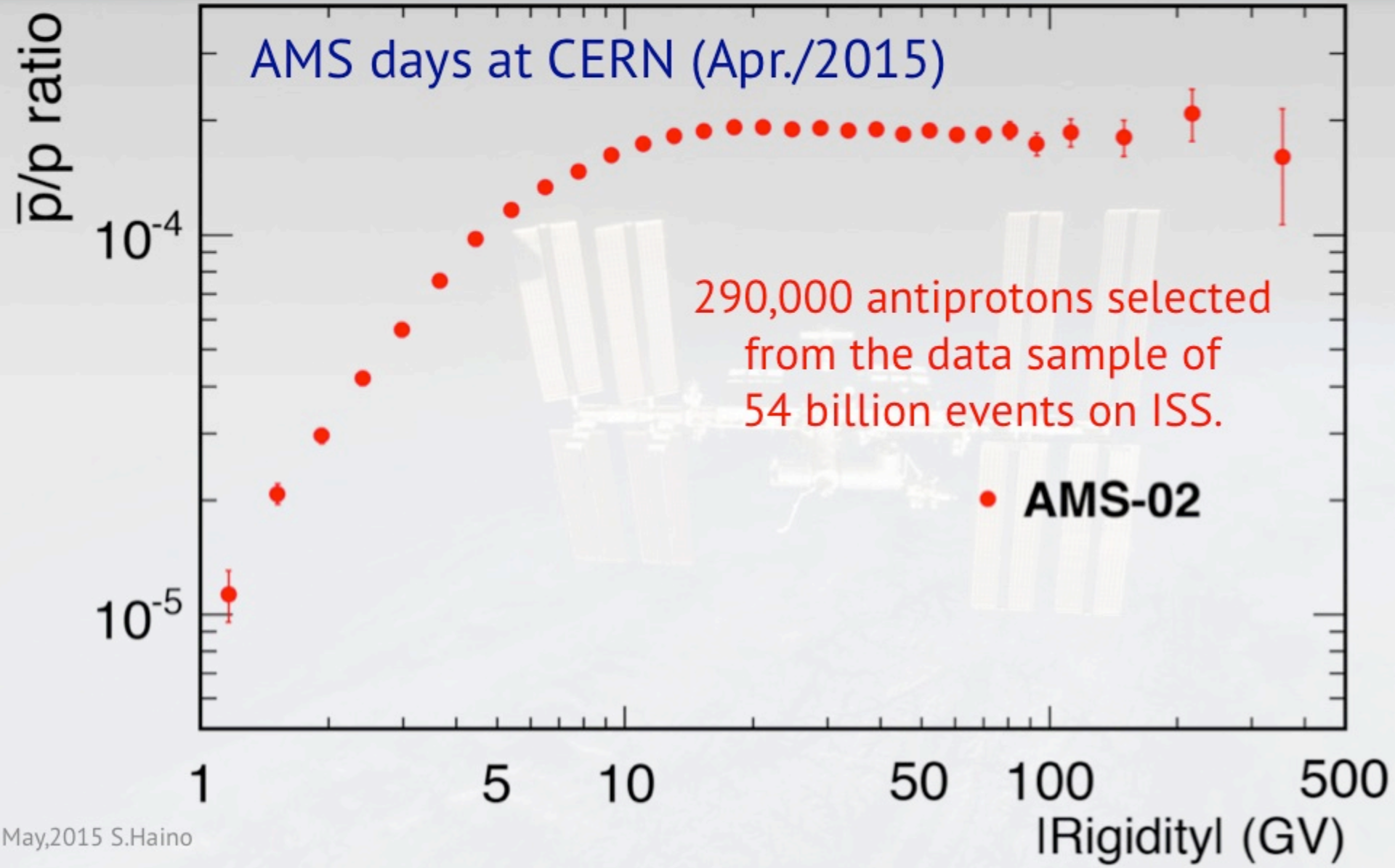
Mass ID


RICH
1/100 Scaled
(R>0)
1/β (RICH)
1.04
1.03
1.02
1.01
1
0.99
$\bar{p}$
K^-
π^-
π^+
p
d
10^2
10
1
-20
-15
-10
-5
0
5
10
15
20
Rigidity (GV)

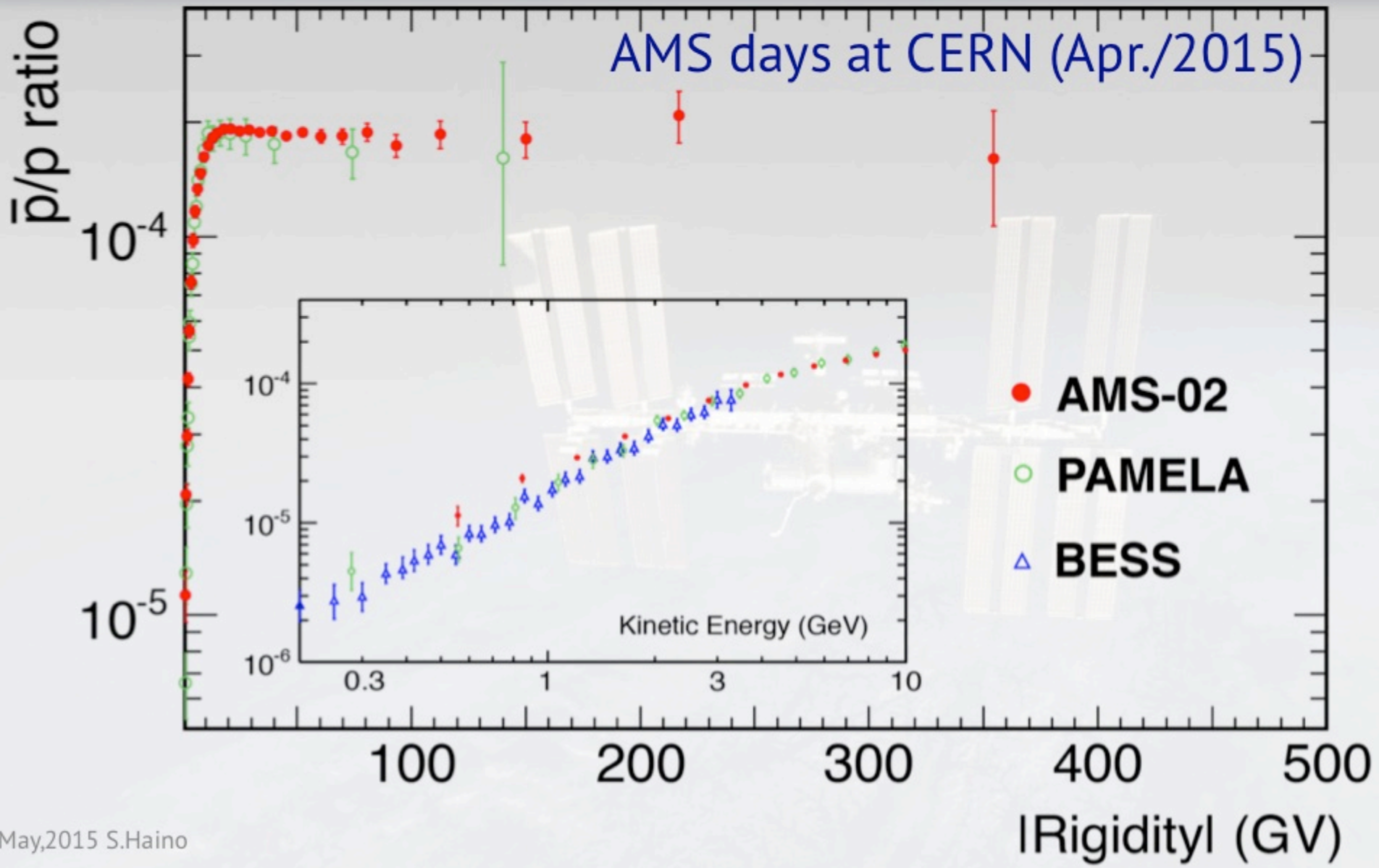
Charge sign determination



AMS Antiproton : current status



AMS Antiproton : current status



DM interpretations after AMS days

Propagation: MIN/MED/MAX

arXiv:1504.04276
arXiv:1504.04604
arXiv:1504.05554
arXiv:1504.05937
arXiv:1504.07848
…

Other propagation models

arXiv:1504.07230
…

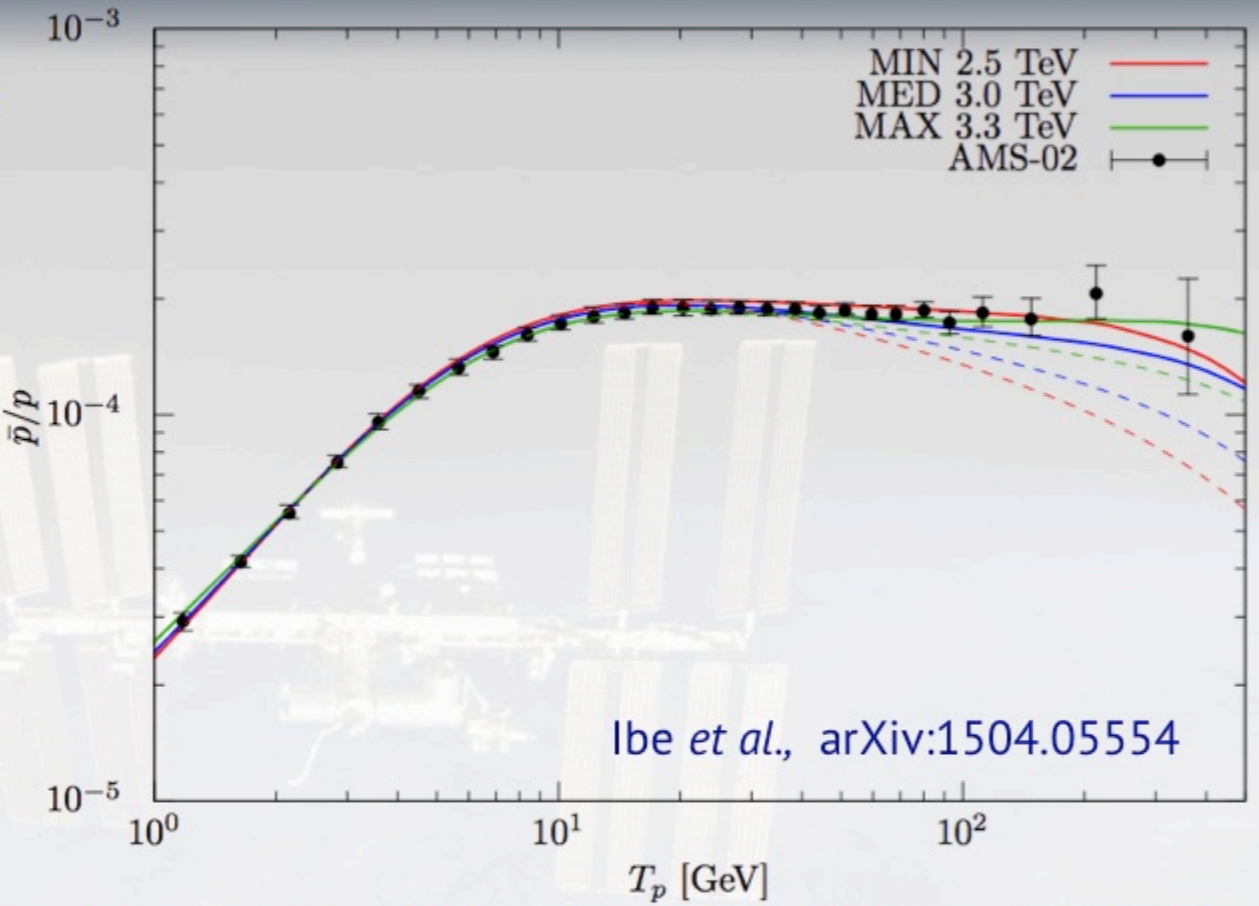
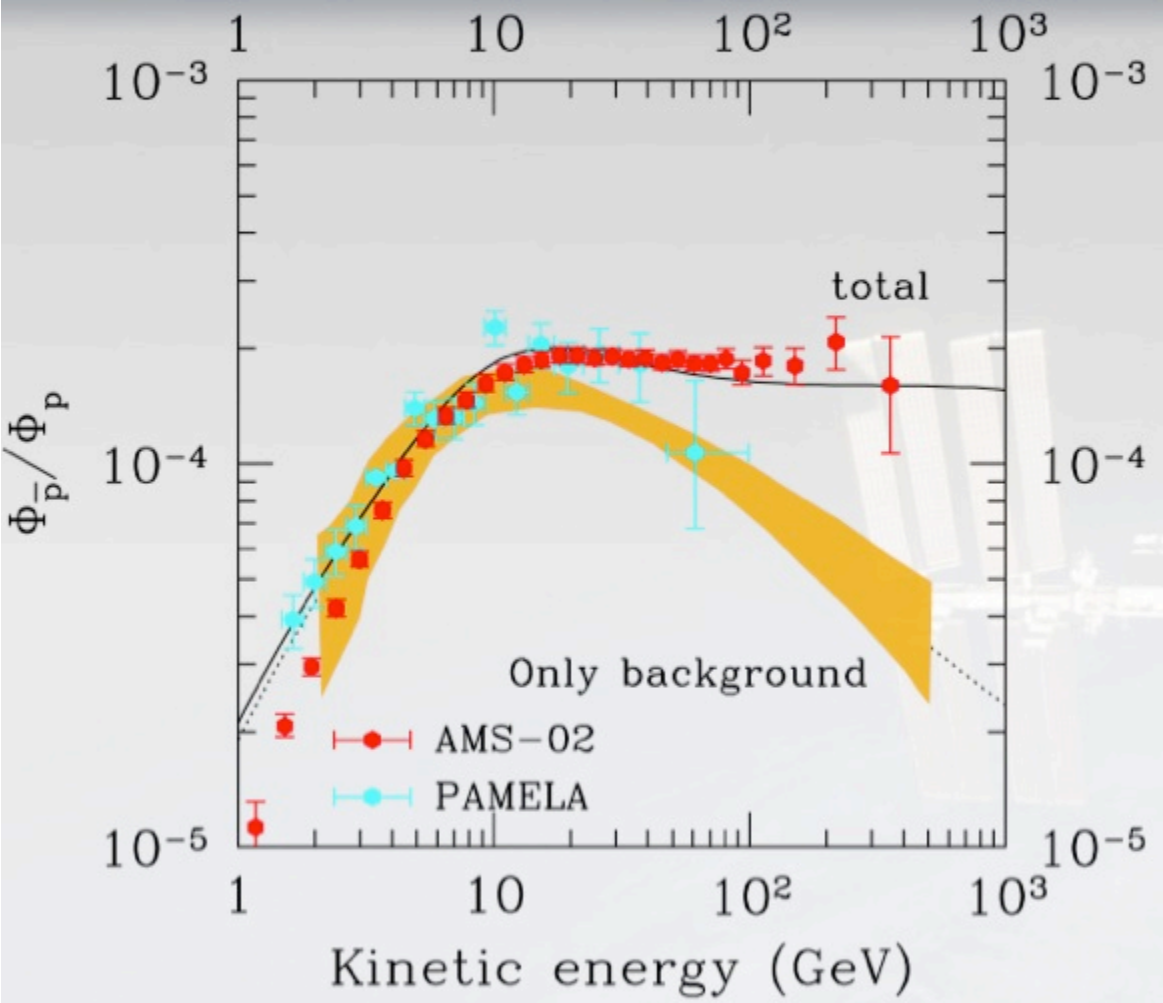


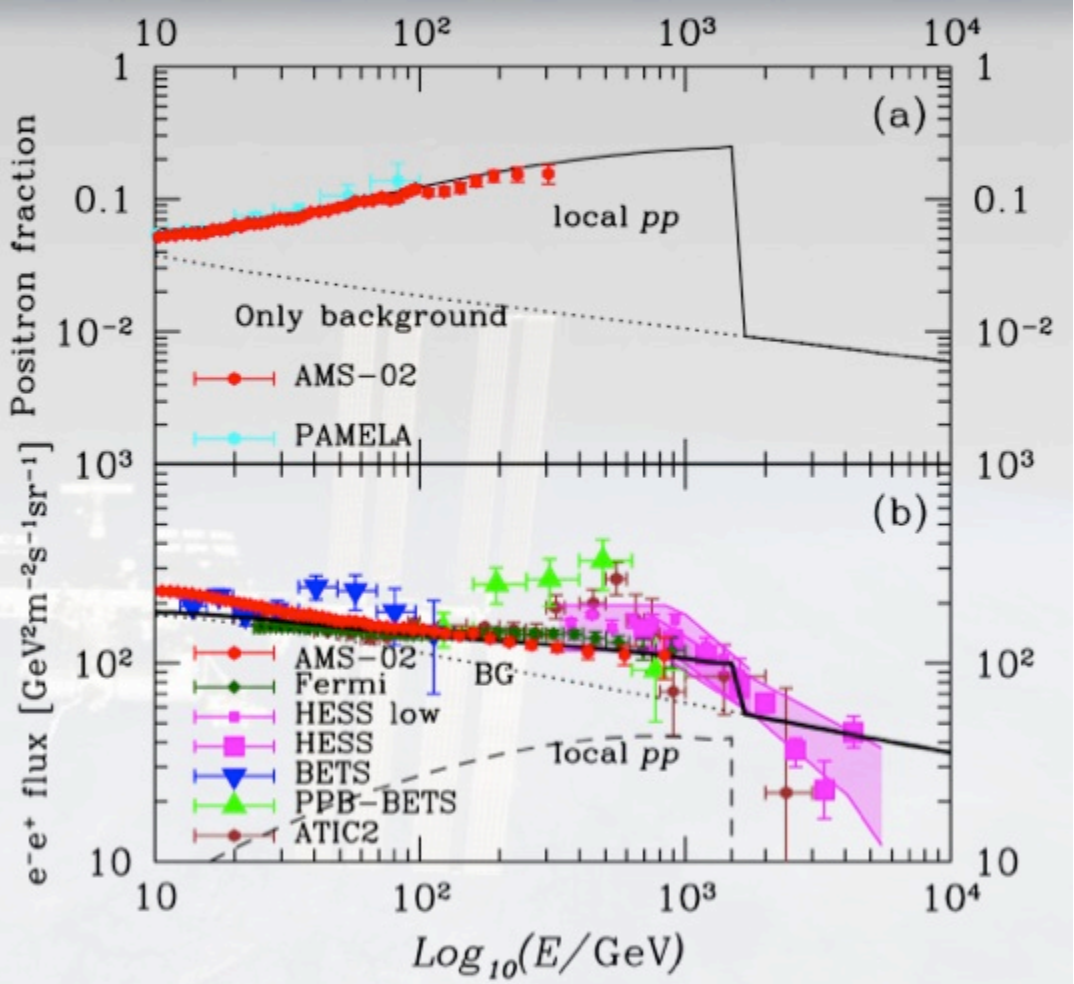
TABLE I: Astrophysical parameters giving the maximal, median and minimal supersymmetric antiproton flux and compatible wih B/C analysis ($\chi^2_{B/C} < 40$). It is also given in unit of r_w, r_{sp} (kpc) for two kinetic energies 1 GeV and 10 GeV.

case	δ	K_0 (kpc^2/Myr)	L (kpc)	V_c (km/sec)	V_A (km/sec)	$\chi^2_{B/C}$	r_w(kpc) [1GeV/10GeV]	r_{sp}(kpc) [1GeV/10GeV]
max	0.46	0.0765	15	5	117.6	39.98	29./73.	26./57.
med	0.70	0.0112	4	12	52.9	25.68	2.4/9.2	4.4/15.
min	0.85	0.0016	1	13.5	22.4	39.02	0.33/1.8	0.69/3.1

Donato *et al.*, PRD 69, 063501 (2004)

SNR interpretation after AMS days



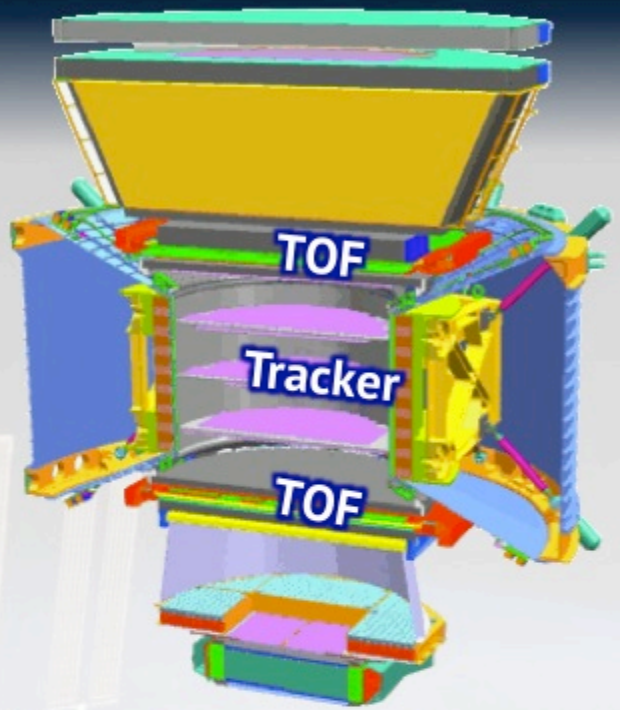


Kohri *et al.*, arXiv:1505.01236
6 May 2015

AMS is not only providing "signal" data : $e^+/(e^++e^-)$ and $\bar{p}/p$

Providing accurate "B.G." data is
another important goal of AMS : p, He, Li,... B,C,...

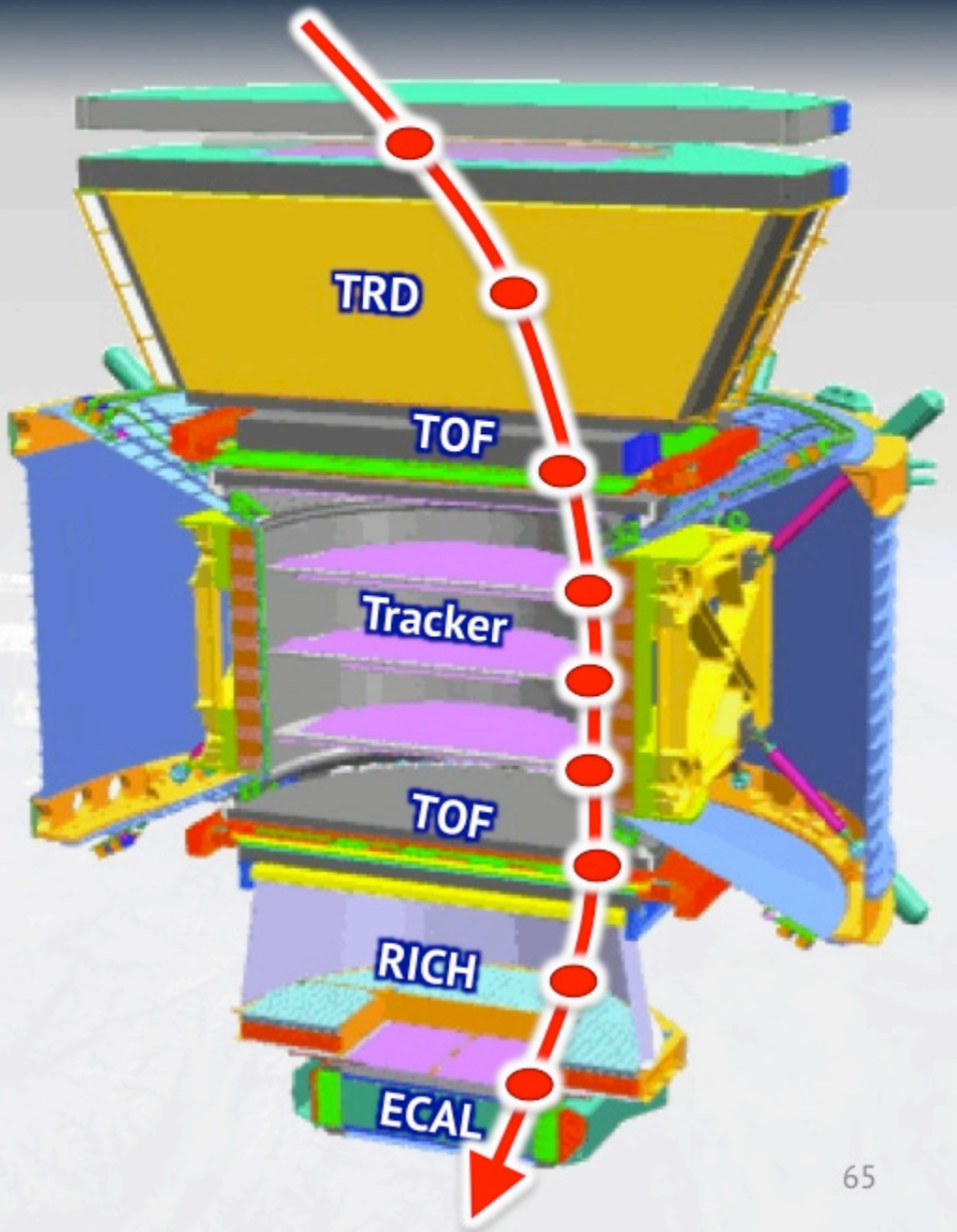
Nuclei identification in AMS



Multiple charge measurements

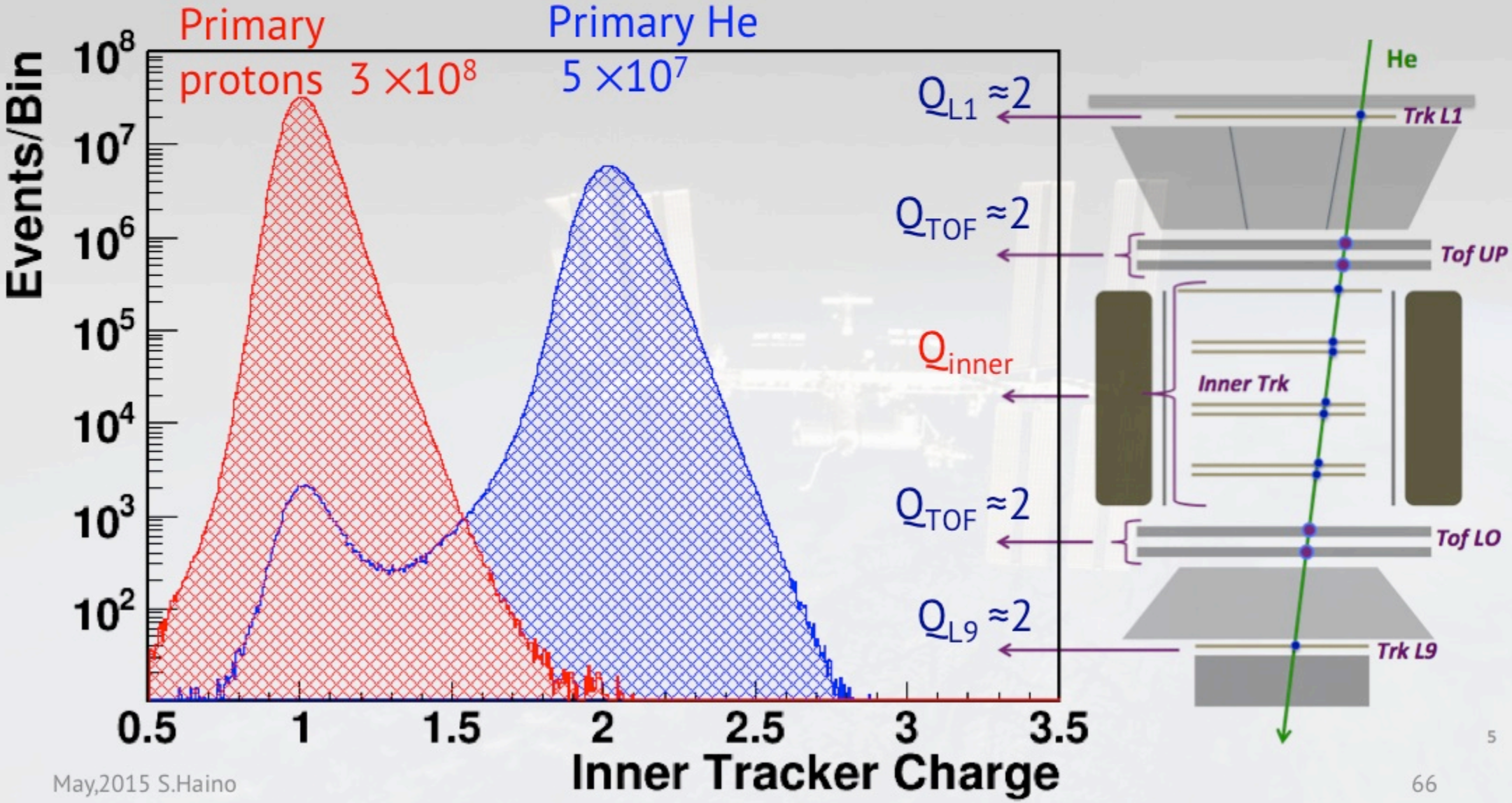
Charge resolution ΔZ (au) for Carbon (Z=6)

- **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**



Proton/He selection

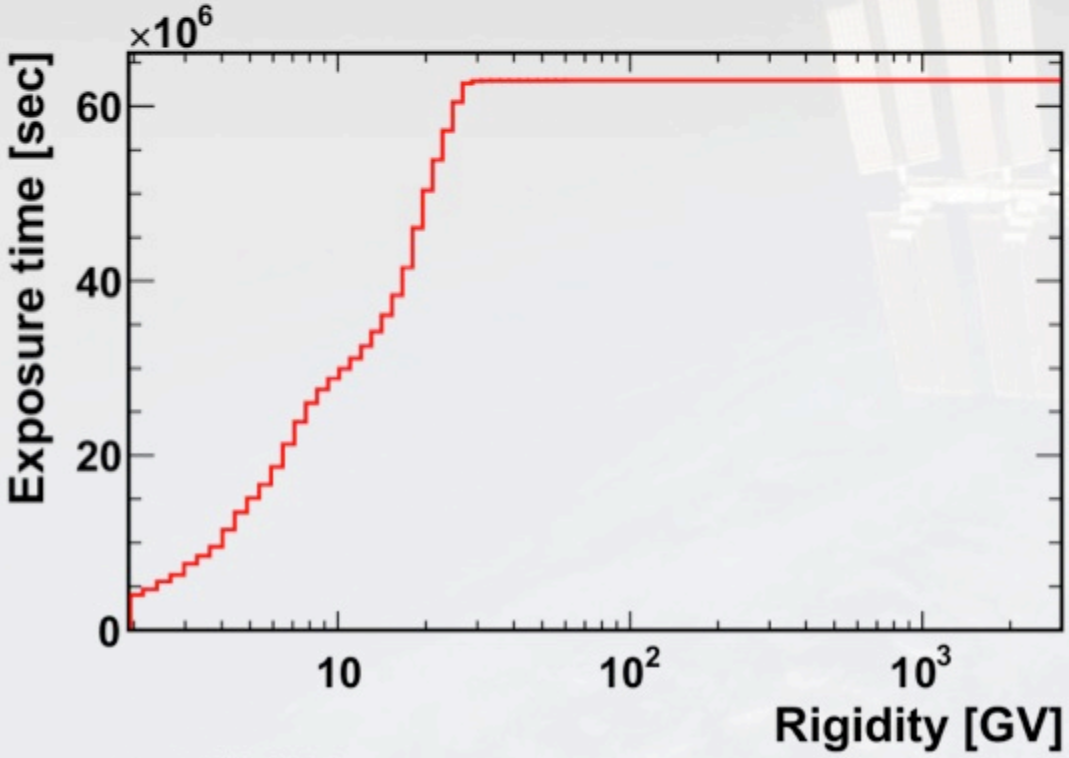
30 months ISS data (May/2011 ~ Nov/2013)



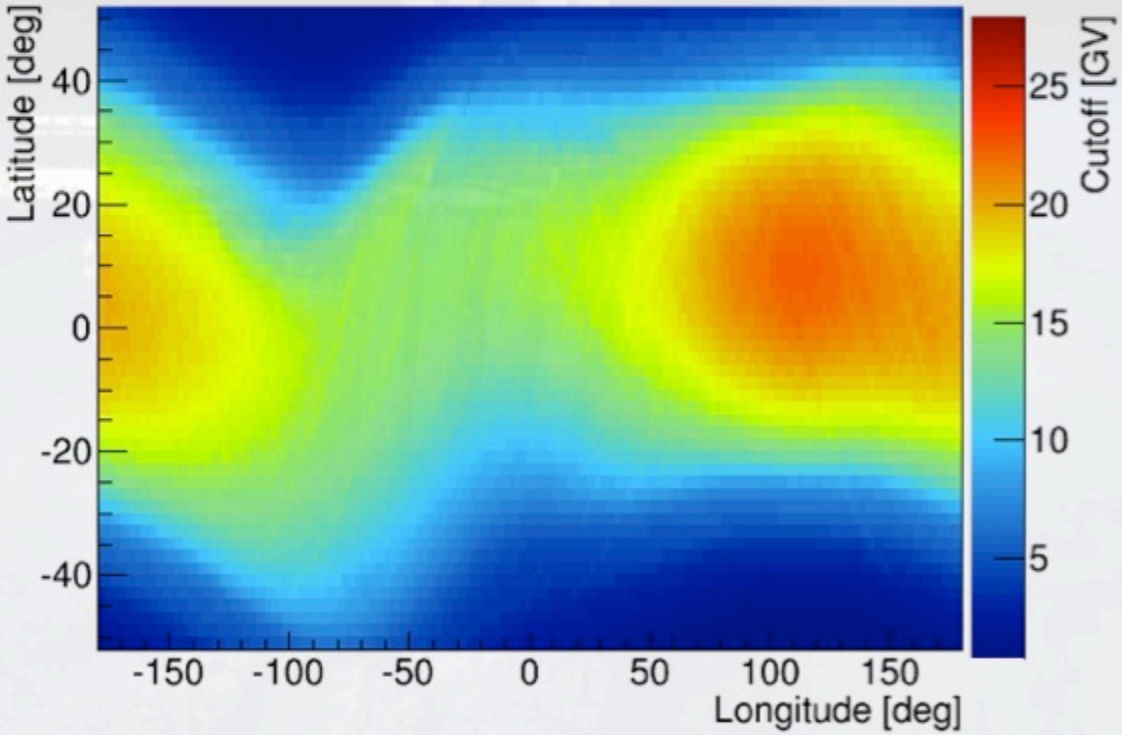
Flux determination

$$\Phi_i(R_i) = \frac{N_i}{T_i \, \varepsilon_i \, A_i \, \Delta R_i}$$

T_i : Exposure time



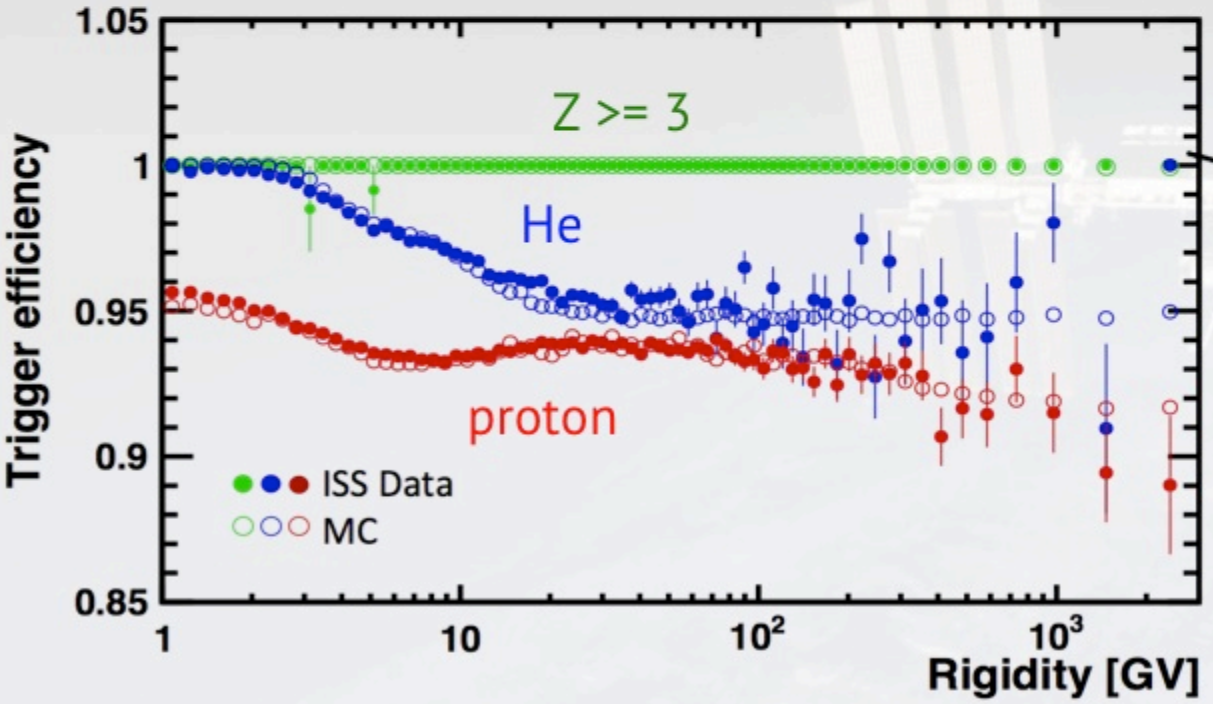
Cutoff Rigidity

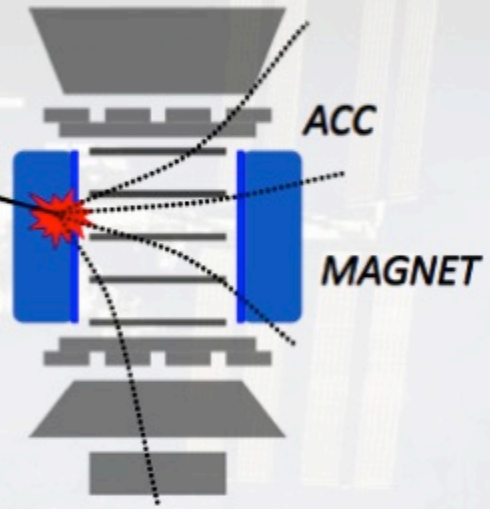


Flux determination

$$\Phi_i(R_i) = \frac{N_i}{T_i \, \varepsilon_i \, A_i \, \Delta R_i}$$

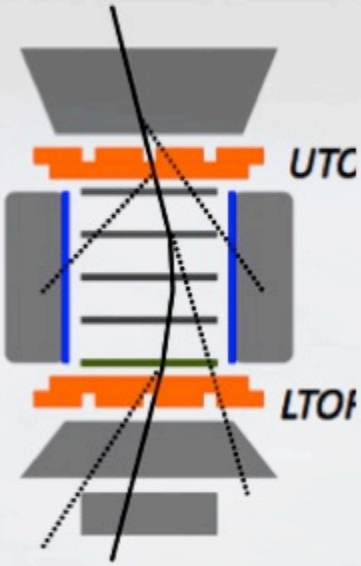
ε_i : Trigger efficiency





Horizontal Particle

Rejected



High-Z particle

Accepted

Flux determination

$$\Phi_i(R_i) = \frac{N_i}{T_i \, \varepsilon_i \, A_i \, \Delta R_i}$$

A_i : Acceptance

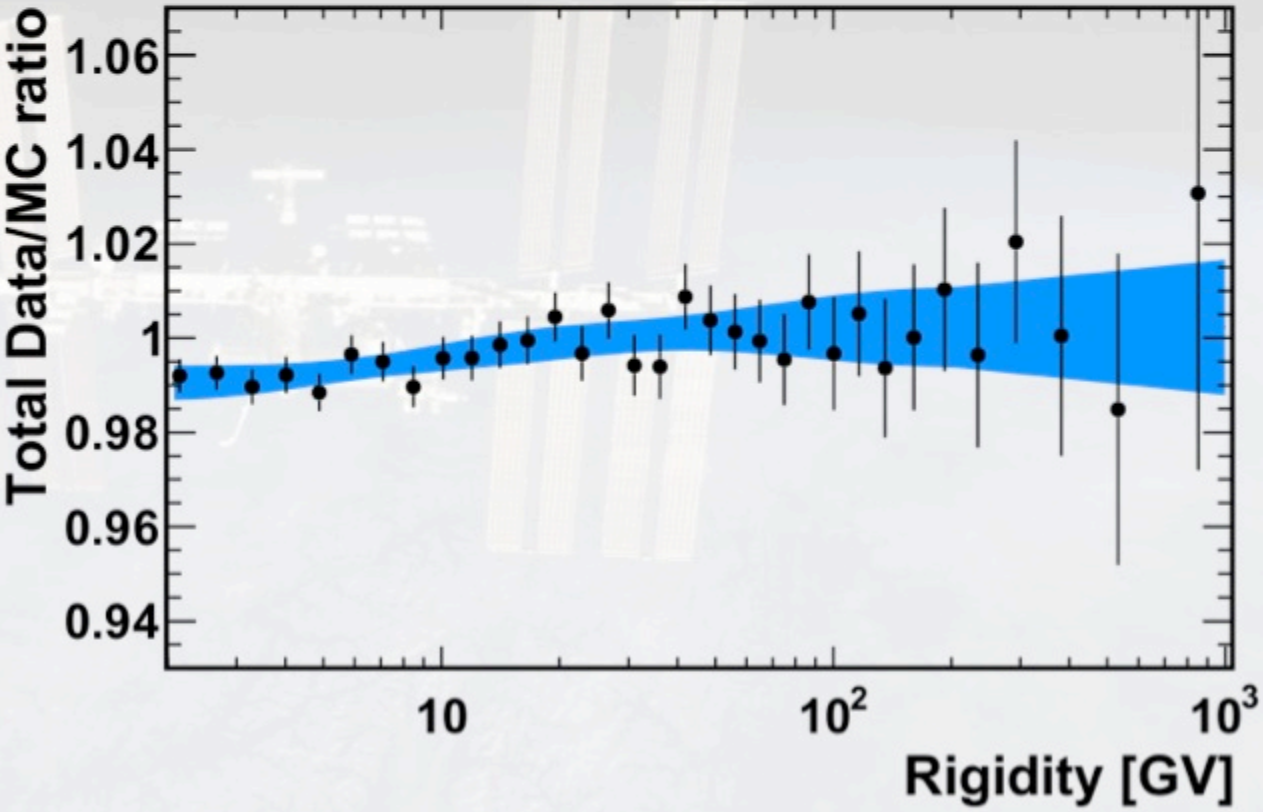
MC validation by comparing Data/MC on :

Track reconstruction efficiency

Track hit association efficiency

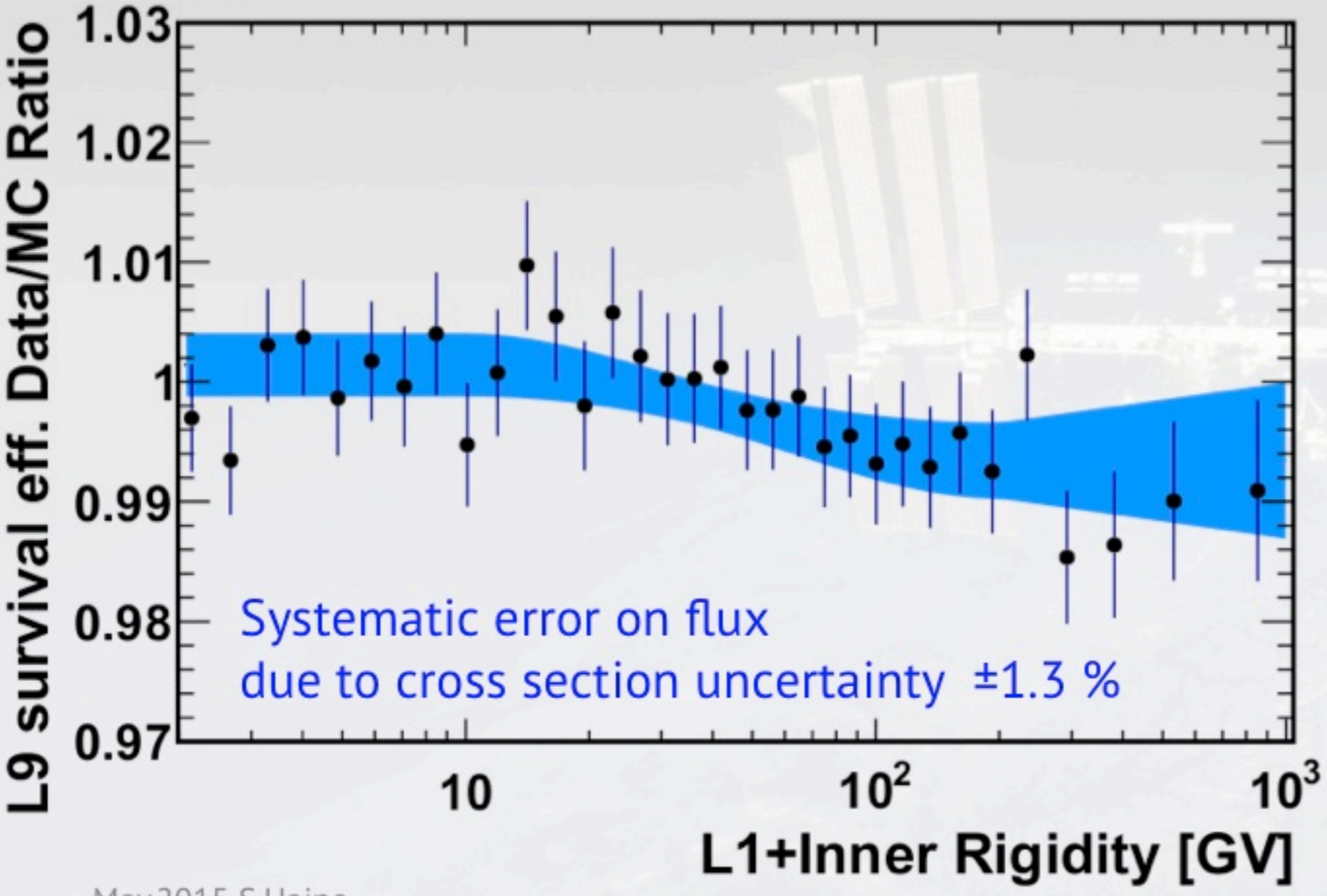
Survival probability in lower AMS

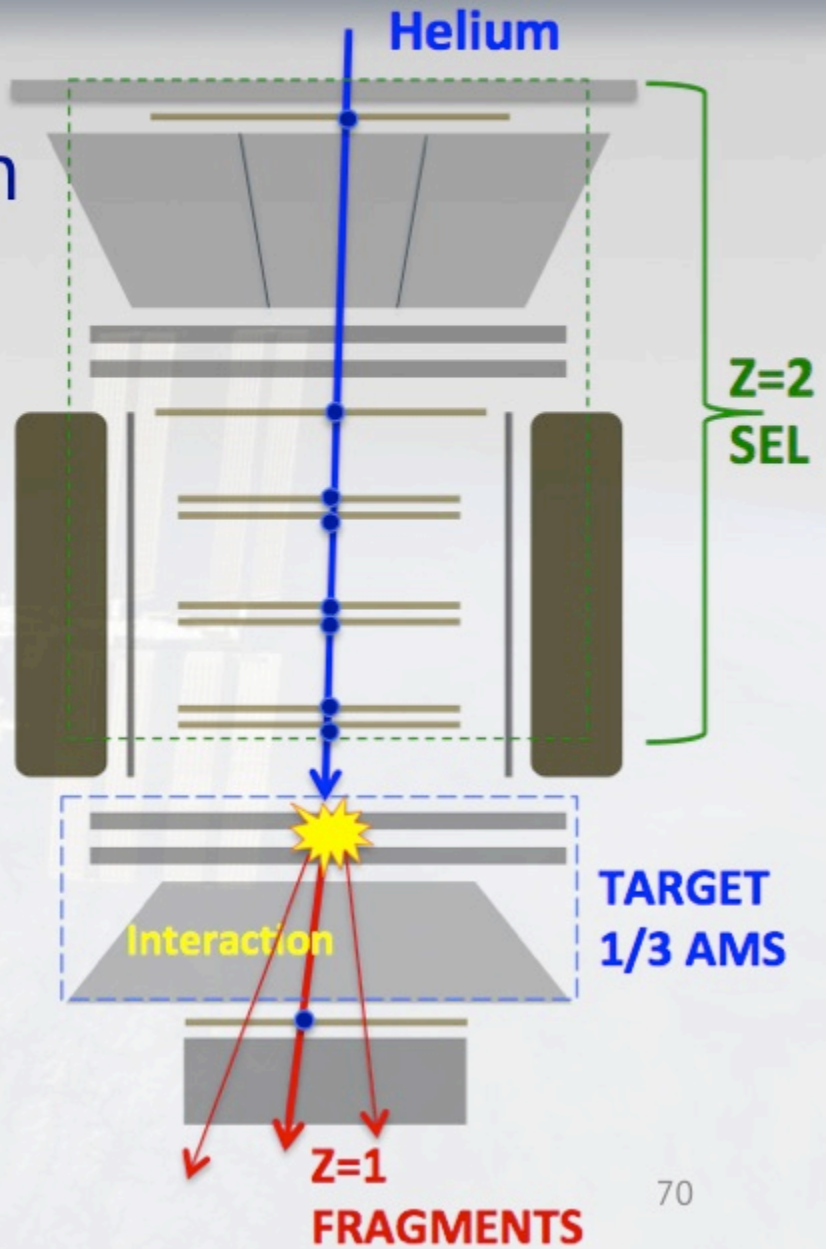
…



He survival Data/MC comparison

Validation of He inelastic cross section





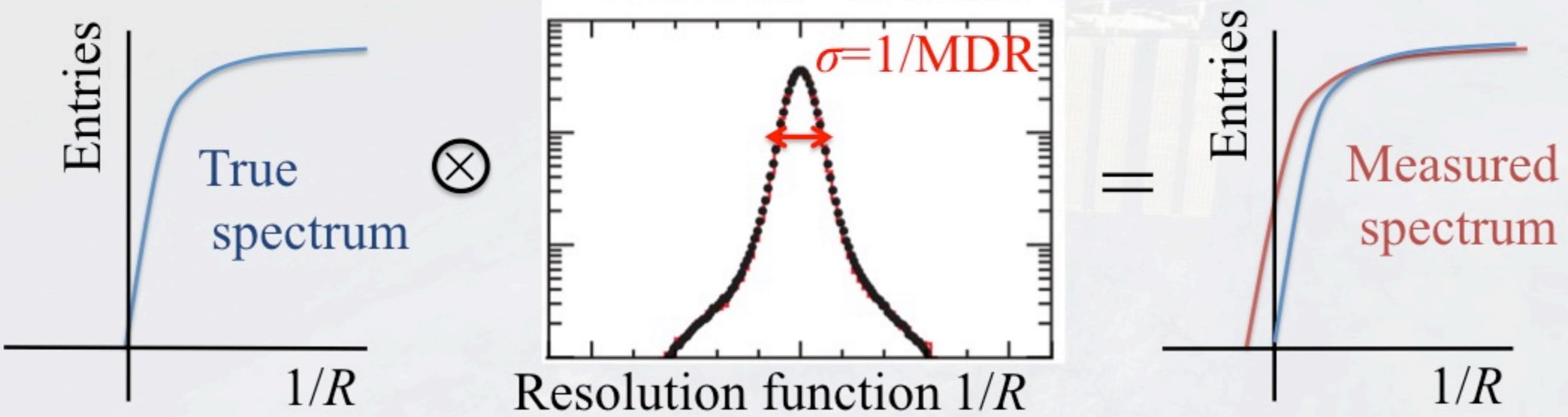
Unfolding

Correction of bin-to-bin migration due to the finite resolution function

$$\Phi_i(R_i) = \frac{N_i}{T_i\,\varepsilon_i\,A_i\,\Delta R_i}$$

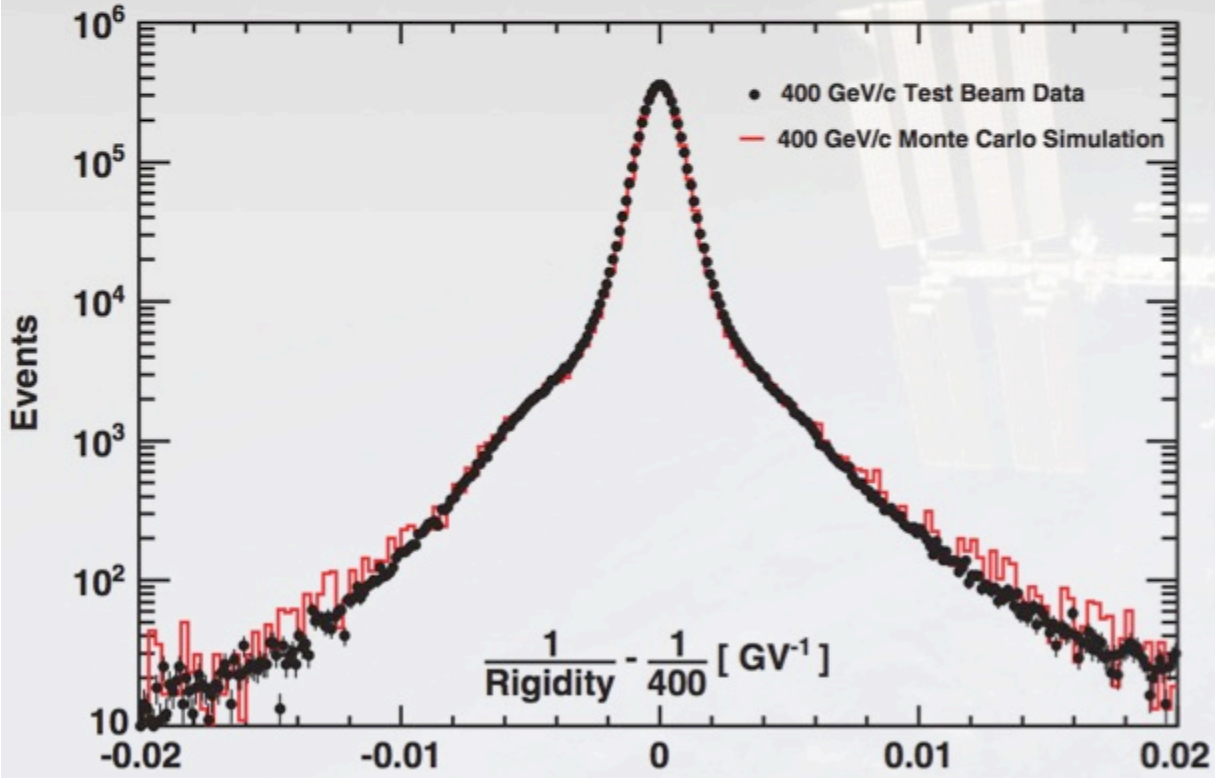
Bin-to-bin Migration

Unfolding

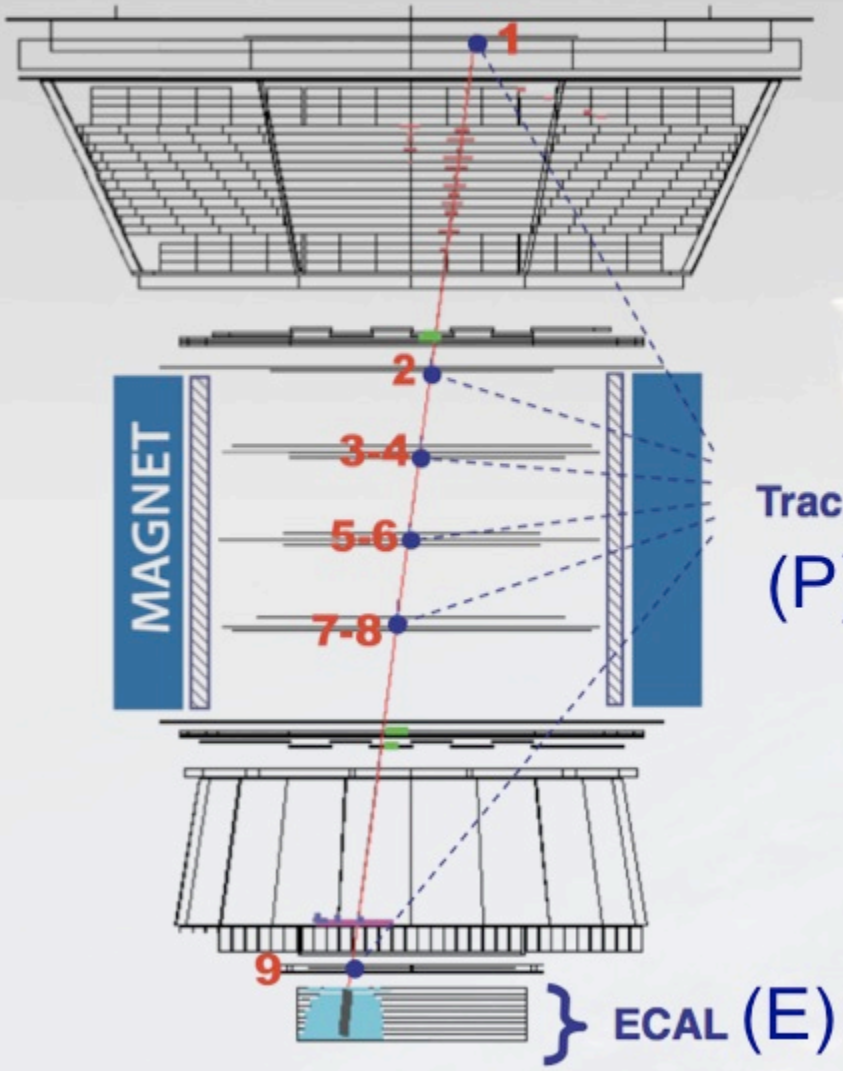


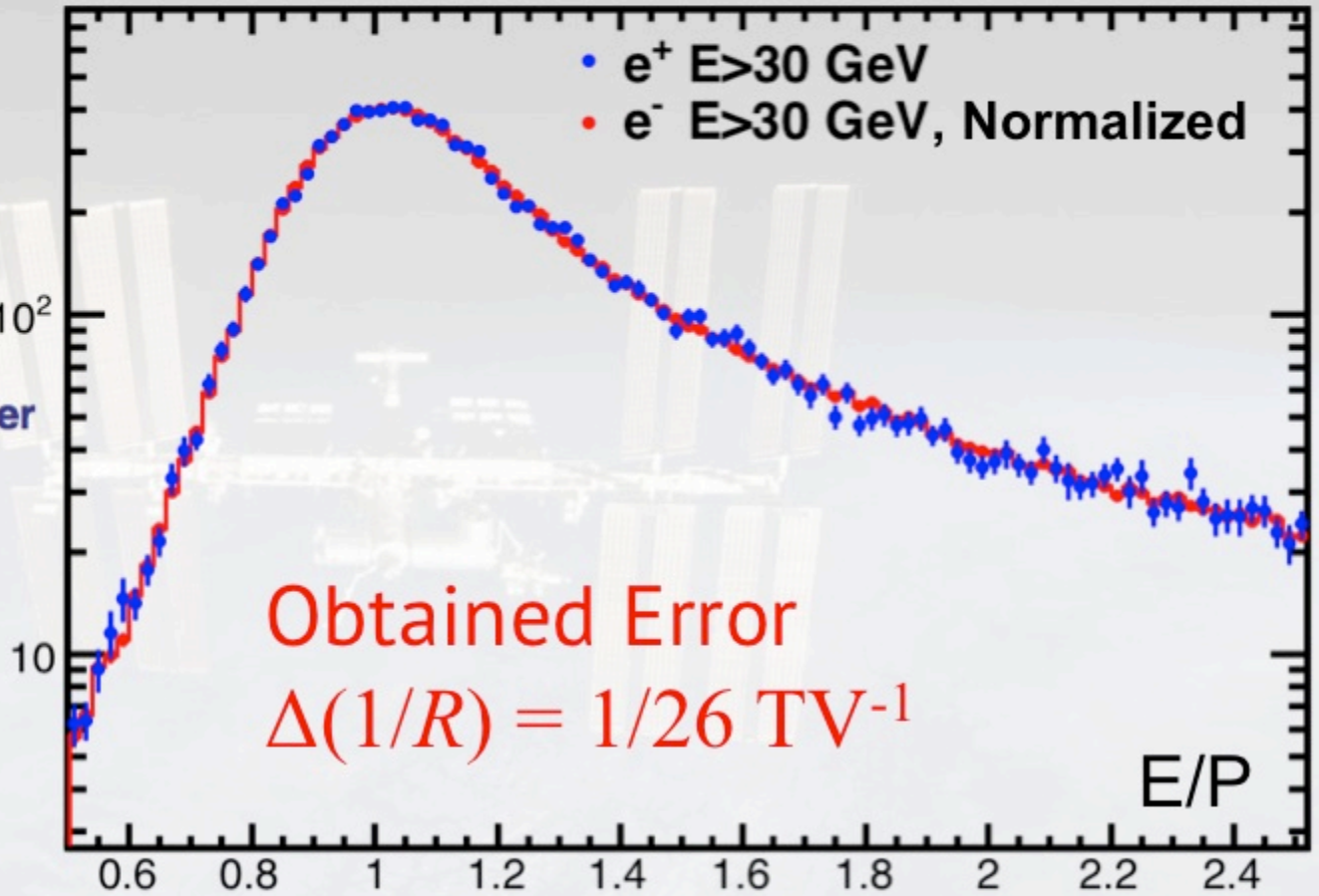
Resolution function

Proton : Calibration with CERN SPS 400 GeV primary beam
Aug. 2010 (just before the launch of AMS in May. 2011)

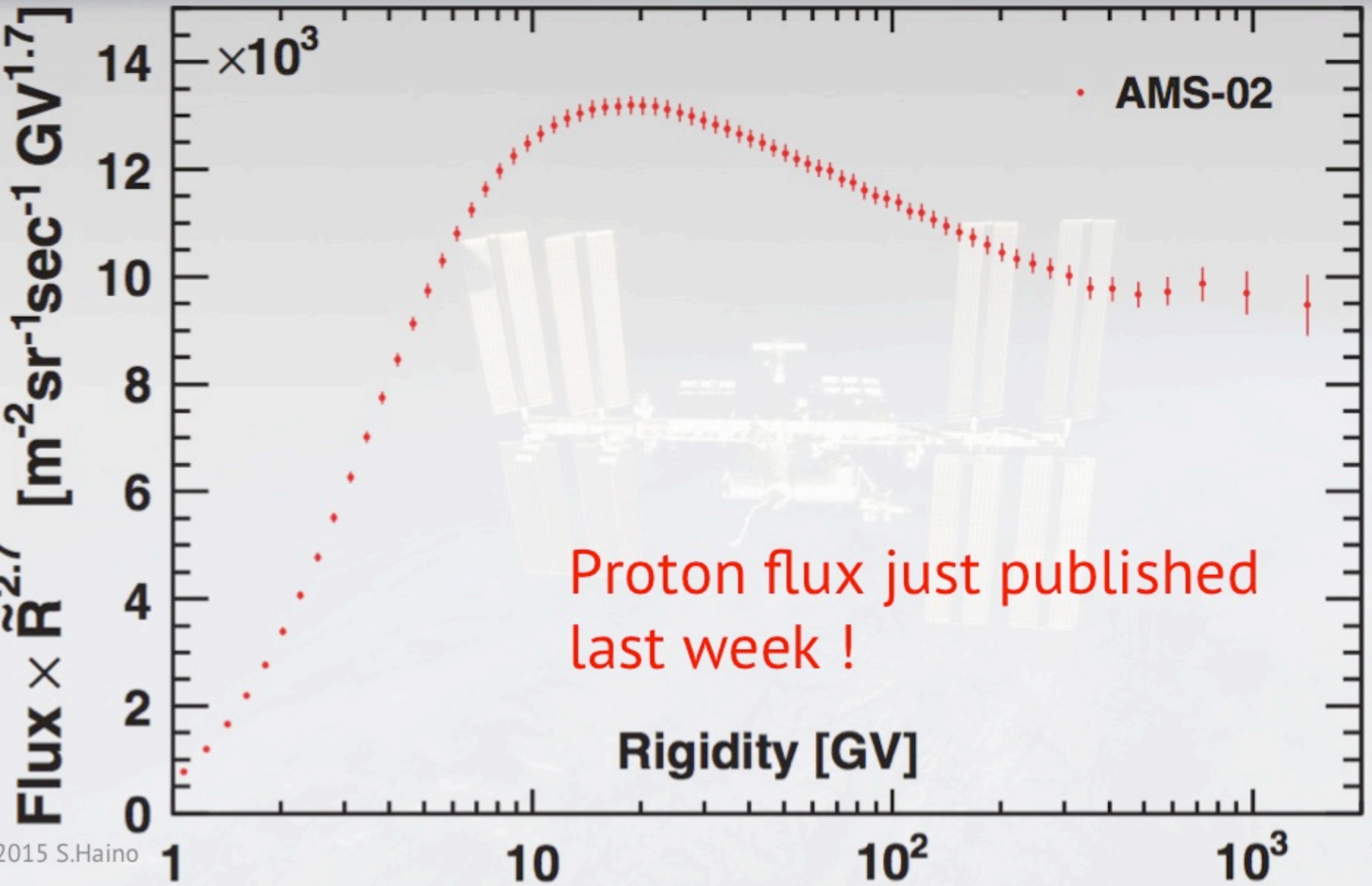


Verification of Tracker alignment





Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station



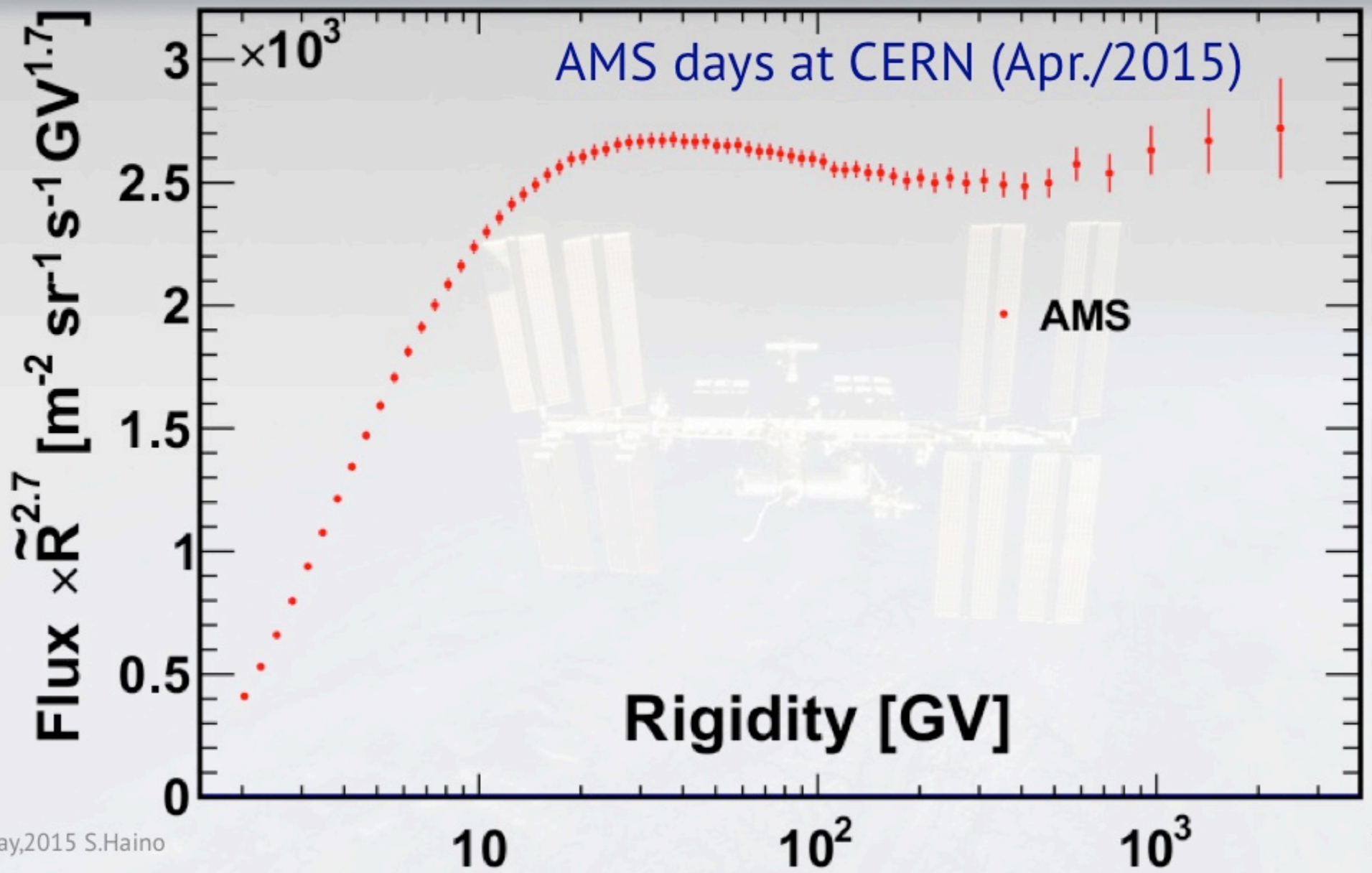
Proton flux just published last week !

Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station

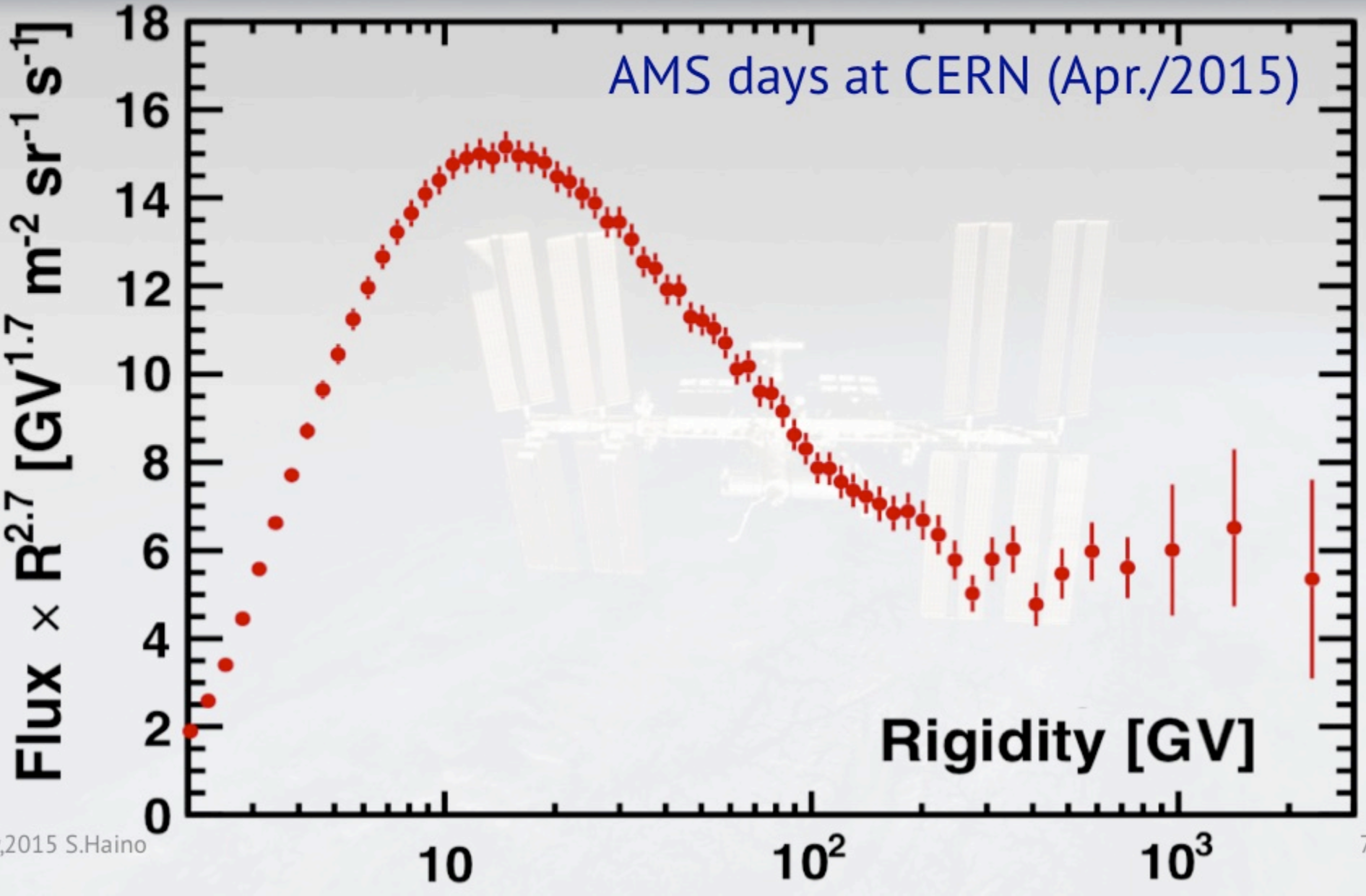
Supplemental Material

Rigidity [GV]	Φ	$\sigma_{\text{stat.}}$	$\sigma_{\text{trig.}}$	$\sigma_{\text{acc.}}$	$\sigma_{\text{unf.}}$	σ_{scale}	$\sigma_{\text{syst.}}$
100 – 108	(4.085	0.007	0.006	0.040	0.035	0.022	$0.058)\times10^{-2}$
108 – 116	(3.294	0.007	0.005	0.033	0.028	0.018	$0.047)\times10^{-2}$
116 – 125	(2.698	0.006	0.004	0.027	0.023	0.016	$0.039)\times10^{-2}$
125 – 135	(2.174	0.005	0.004	0.022	0.019	0.013	$0.032)\times10^{-2}$
135 – 147	(1.727	0.004	0.003	0.018	0.016	0.011	$0.026)\times10^{-2}$
147 – 160	(1.358	0.003	0.003	0.014	0.013	0.009	$0.021)\times10^{-2}$
...	...						
525 – 643	(3.357	0.017	0.018	0.047	0.052	0.057	$0.092)\times10^{-4}$
643 – 822	(1.860	0.010	0.012	0.028	0.032	0.040	$0.060)\times10^{-4}$
822 – 1130	(8.571	0.053	0.071	0.139	0.192	0.254	$0.355)\times10^{-5}$
1130 – 1800	(2.933	0.021	0.035	0.055	0.092	0.130	$0.173)\times10^{-5}$

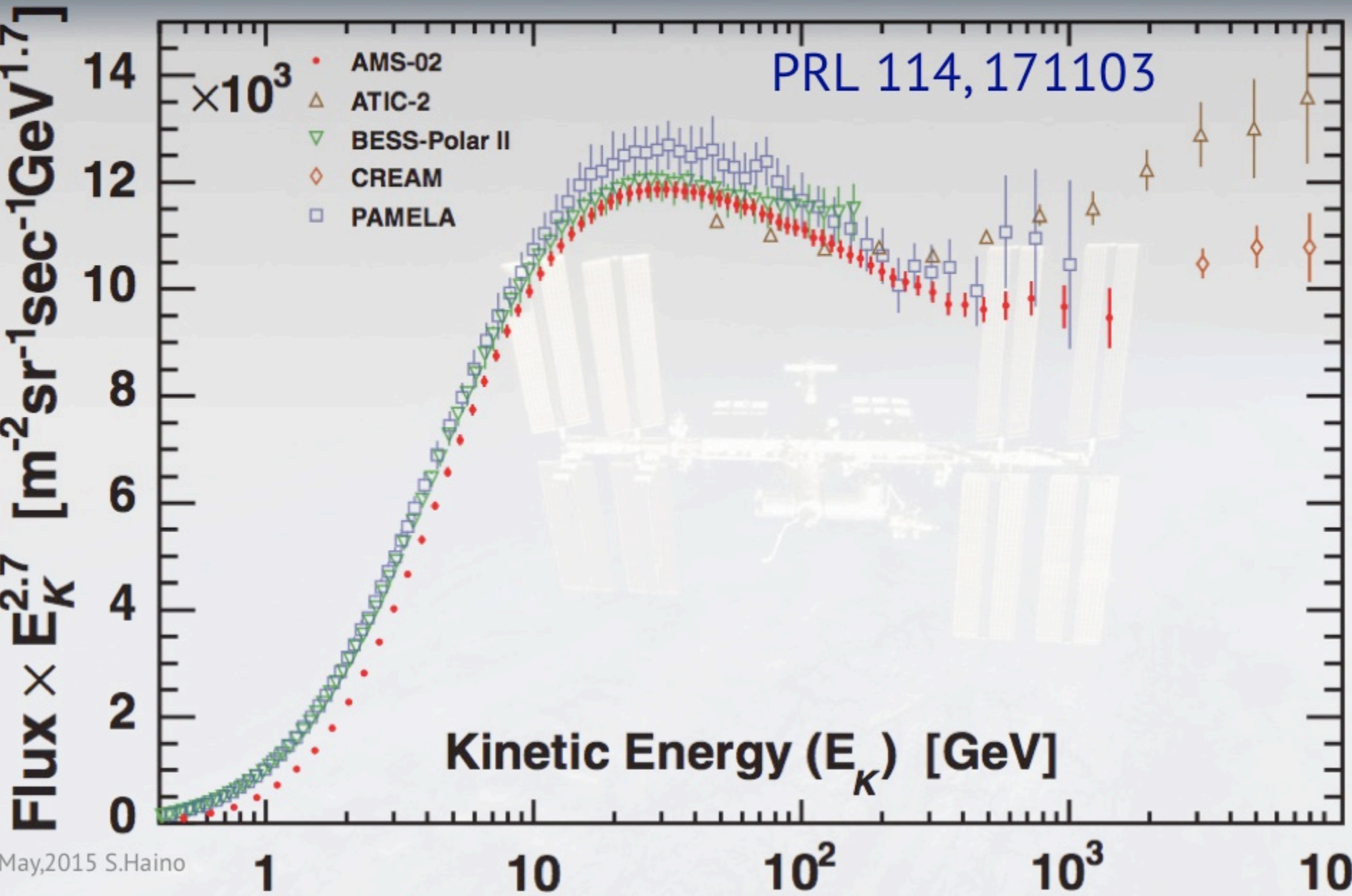
He flux is coming soon ...



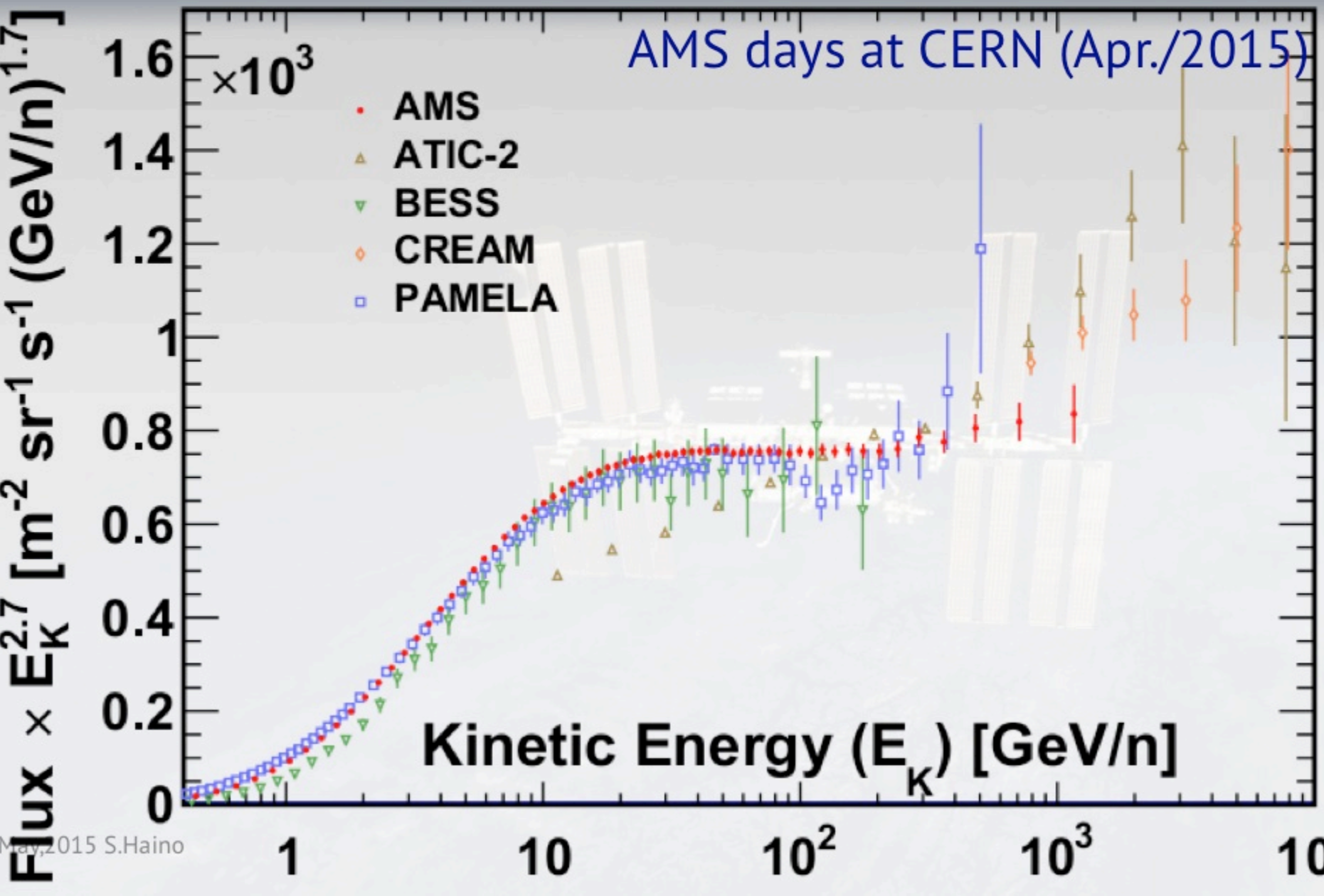
Li flux : current status



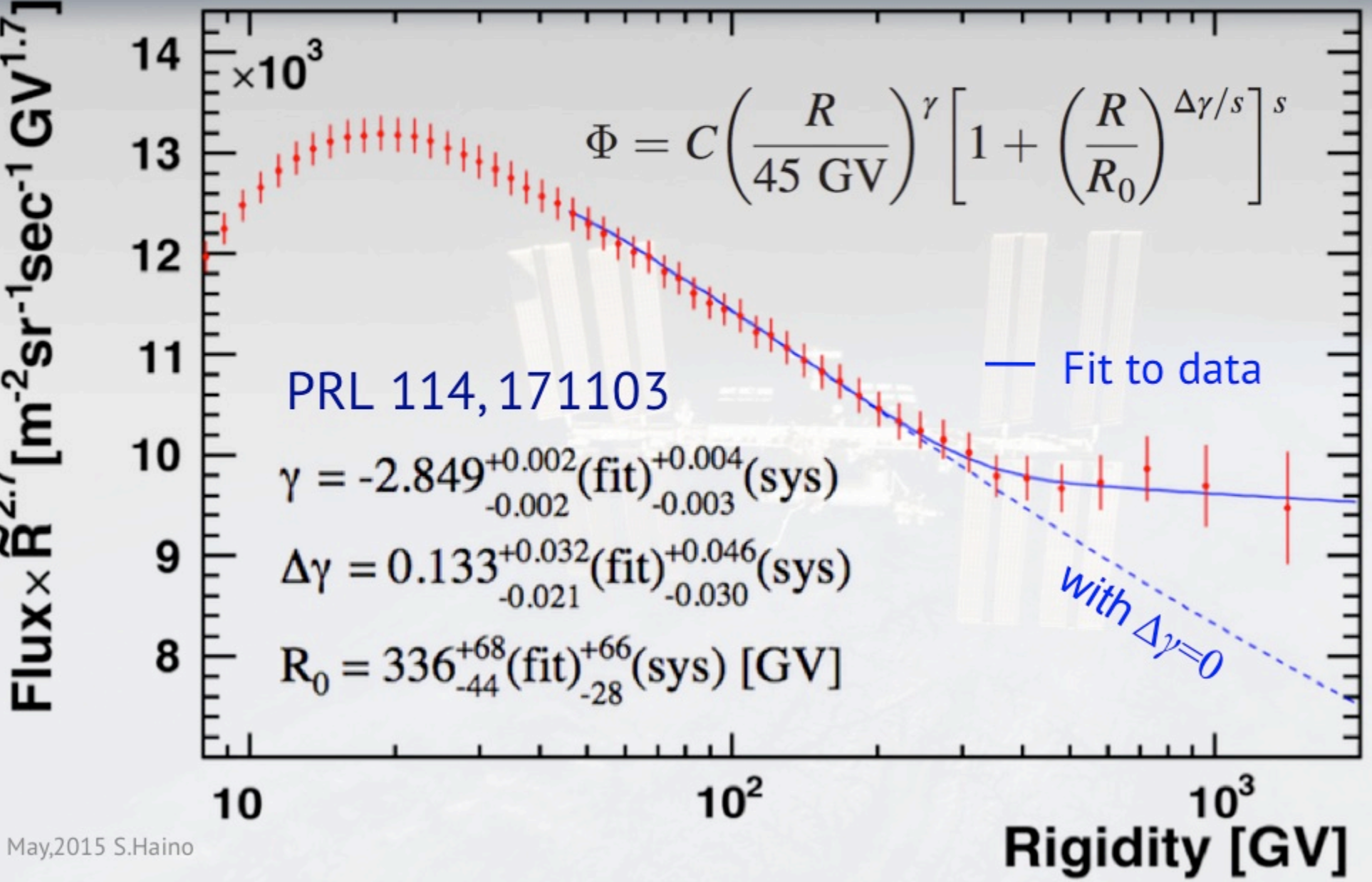
Proton flux with recent measurements



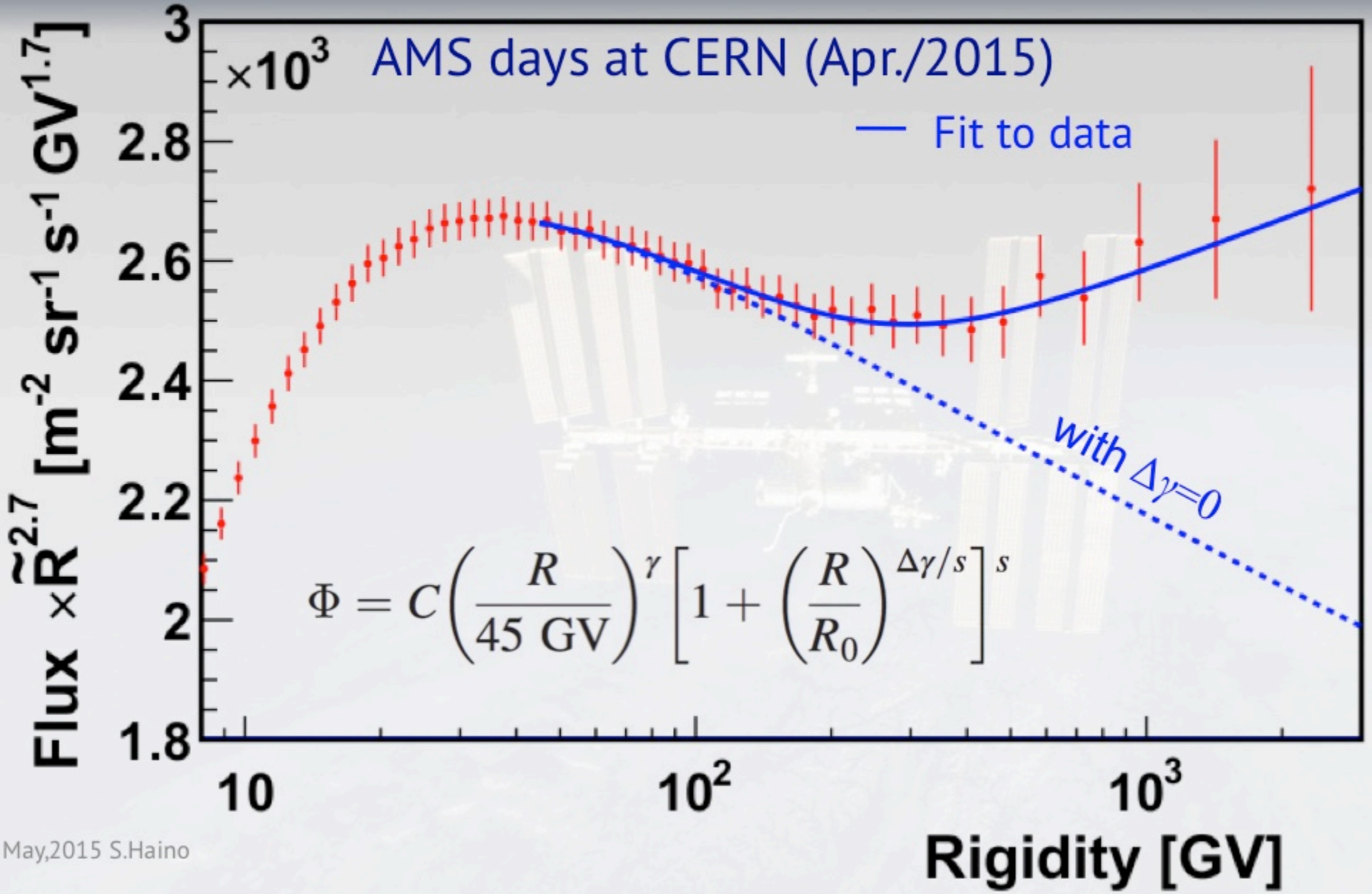
He flux with recent measurements



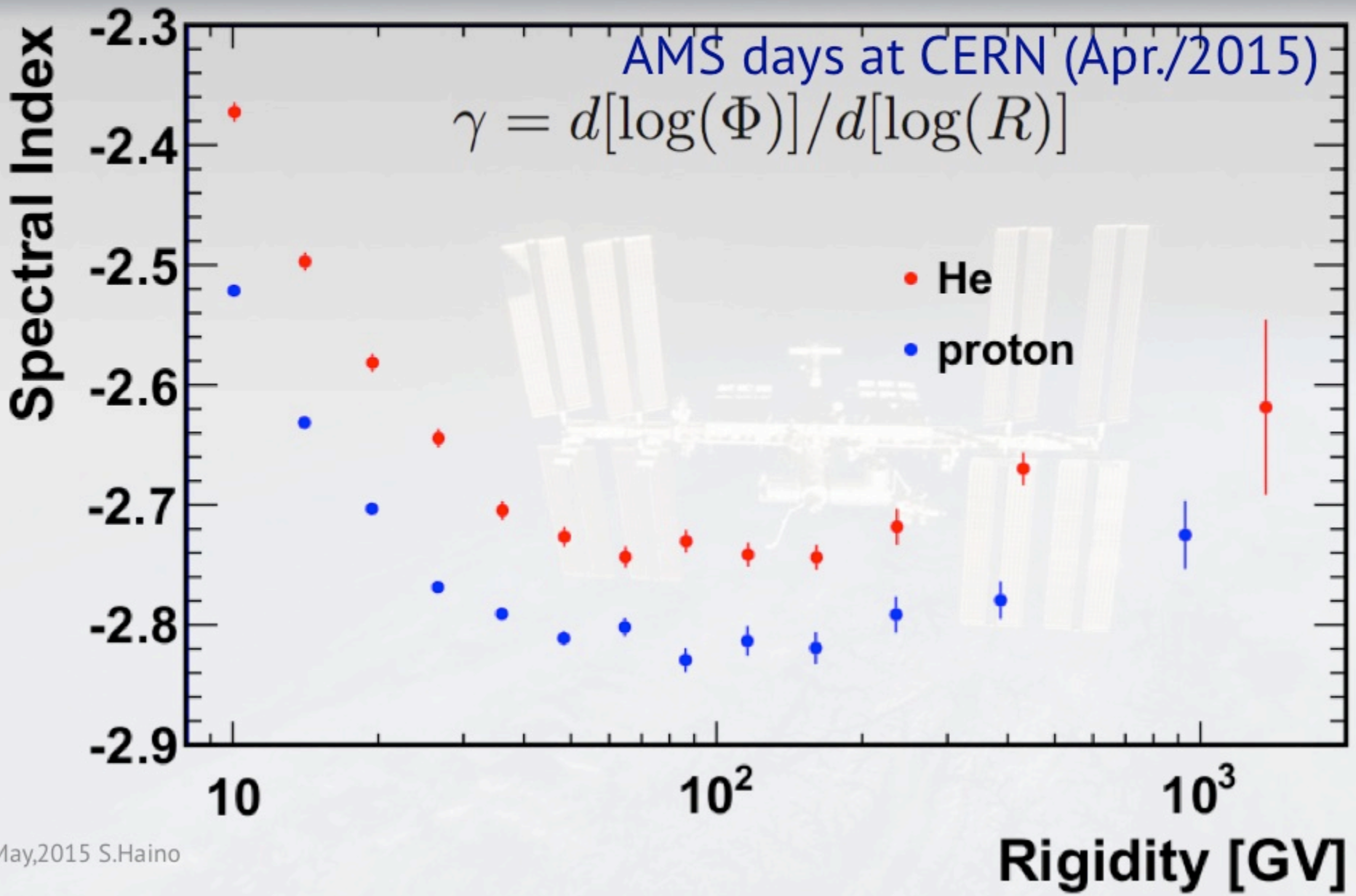
Proton flux fit with two power laws



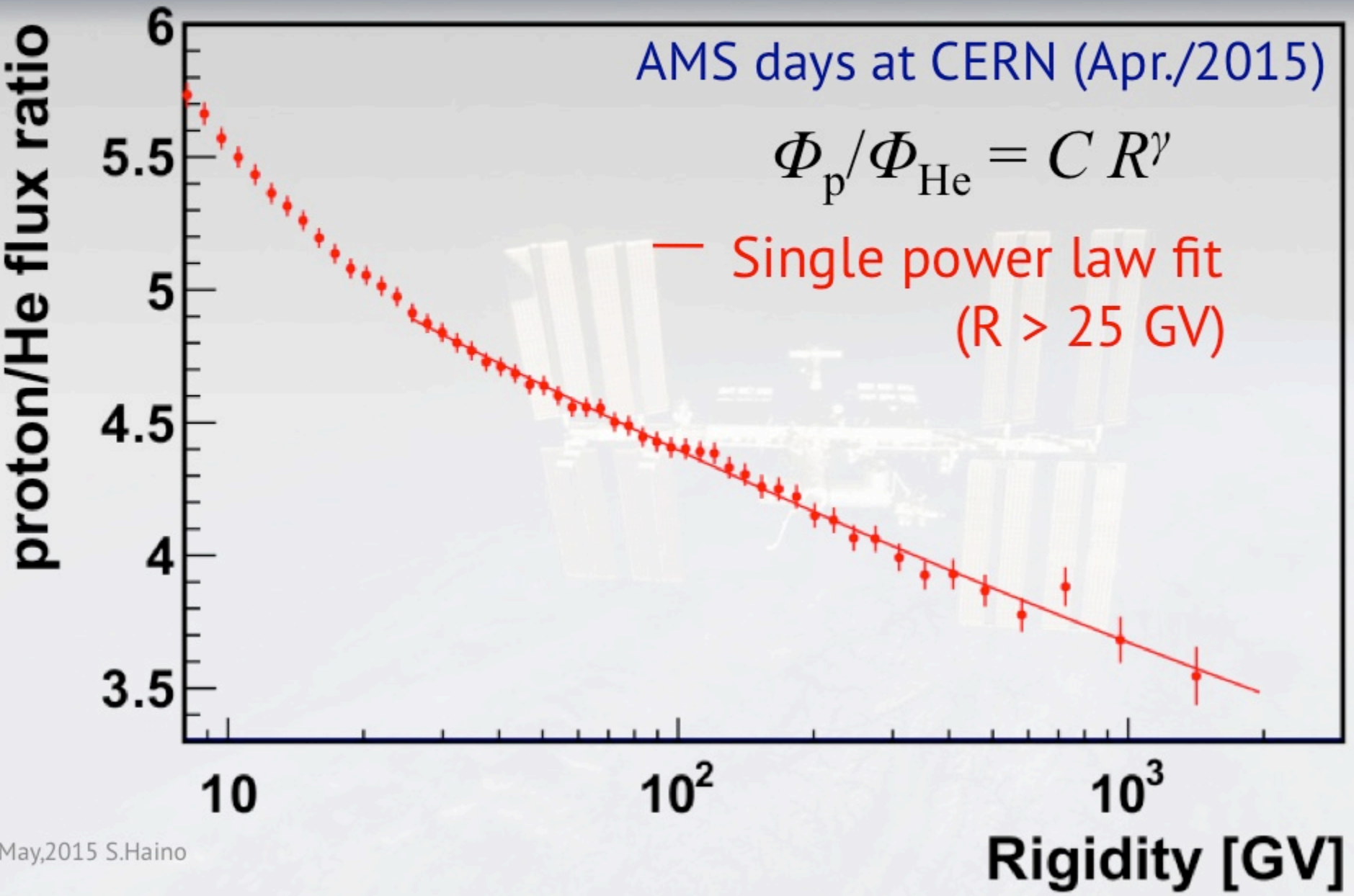
He flux fit with two power laws



Spectral indices for p and He



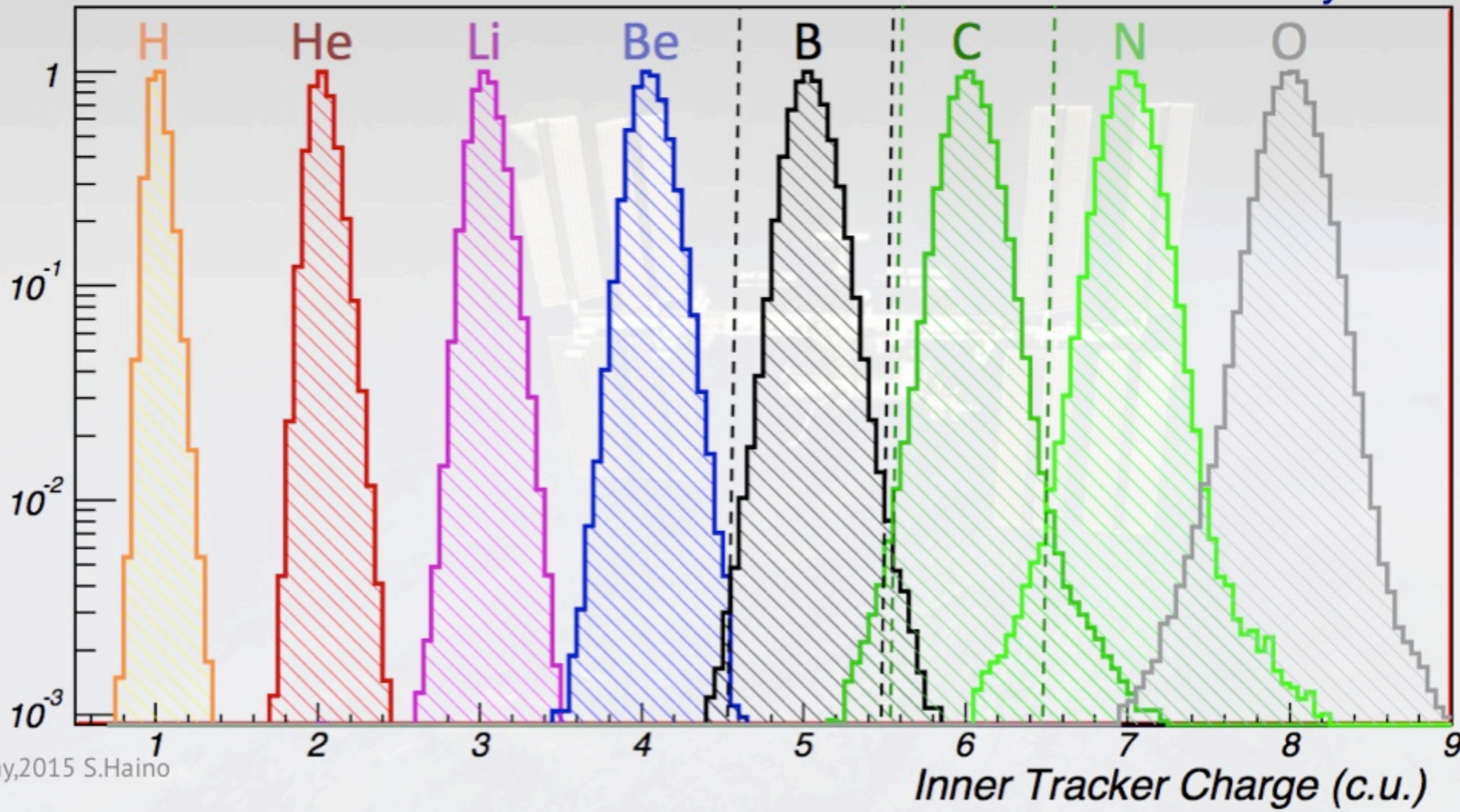
proton/He ratio



B/C selection

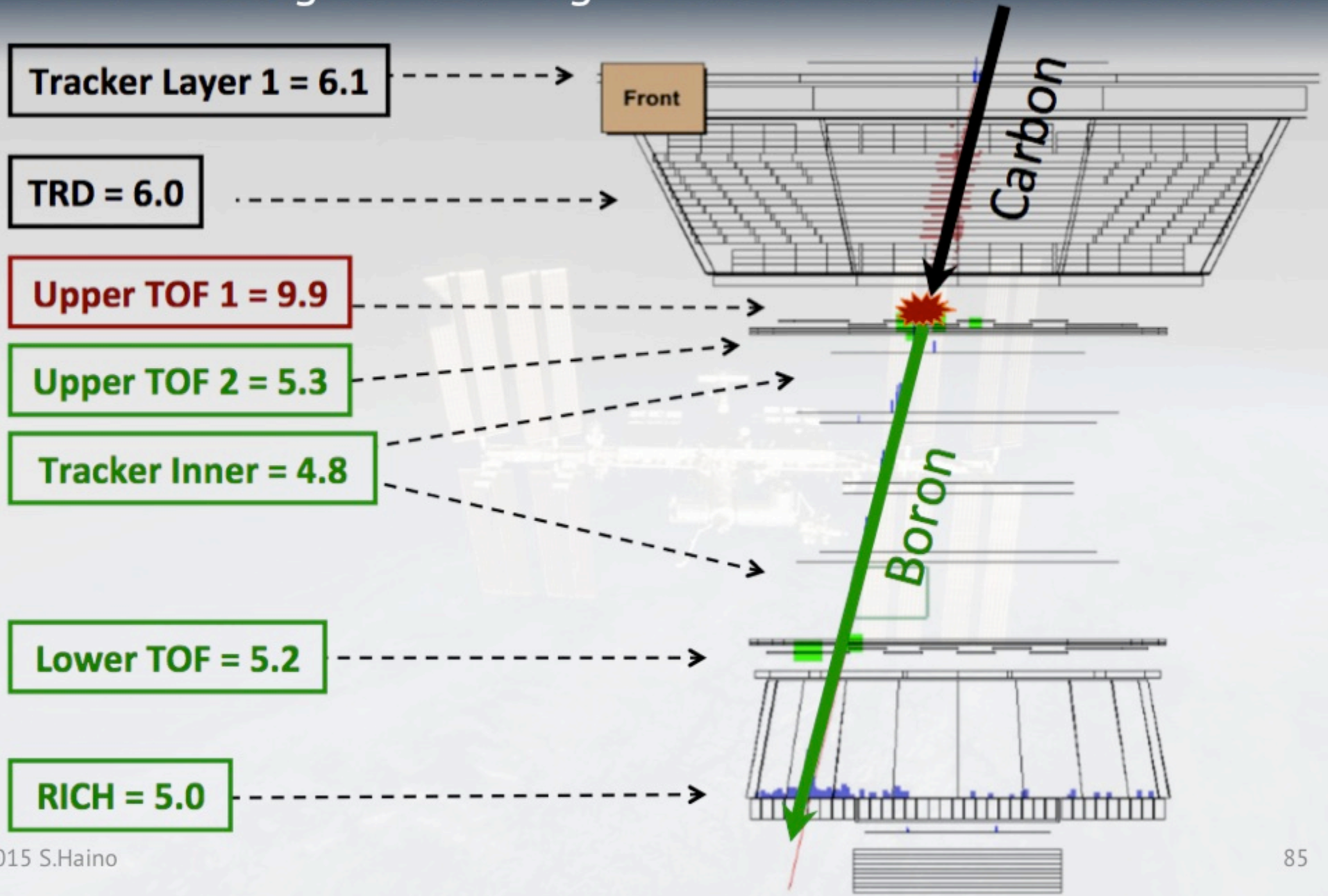
Truncated mean of Inner Tracker charge measurements

Misidentification < 0.1 % with > 98 % efficiency



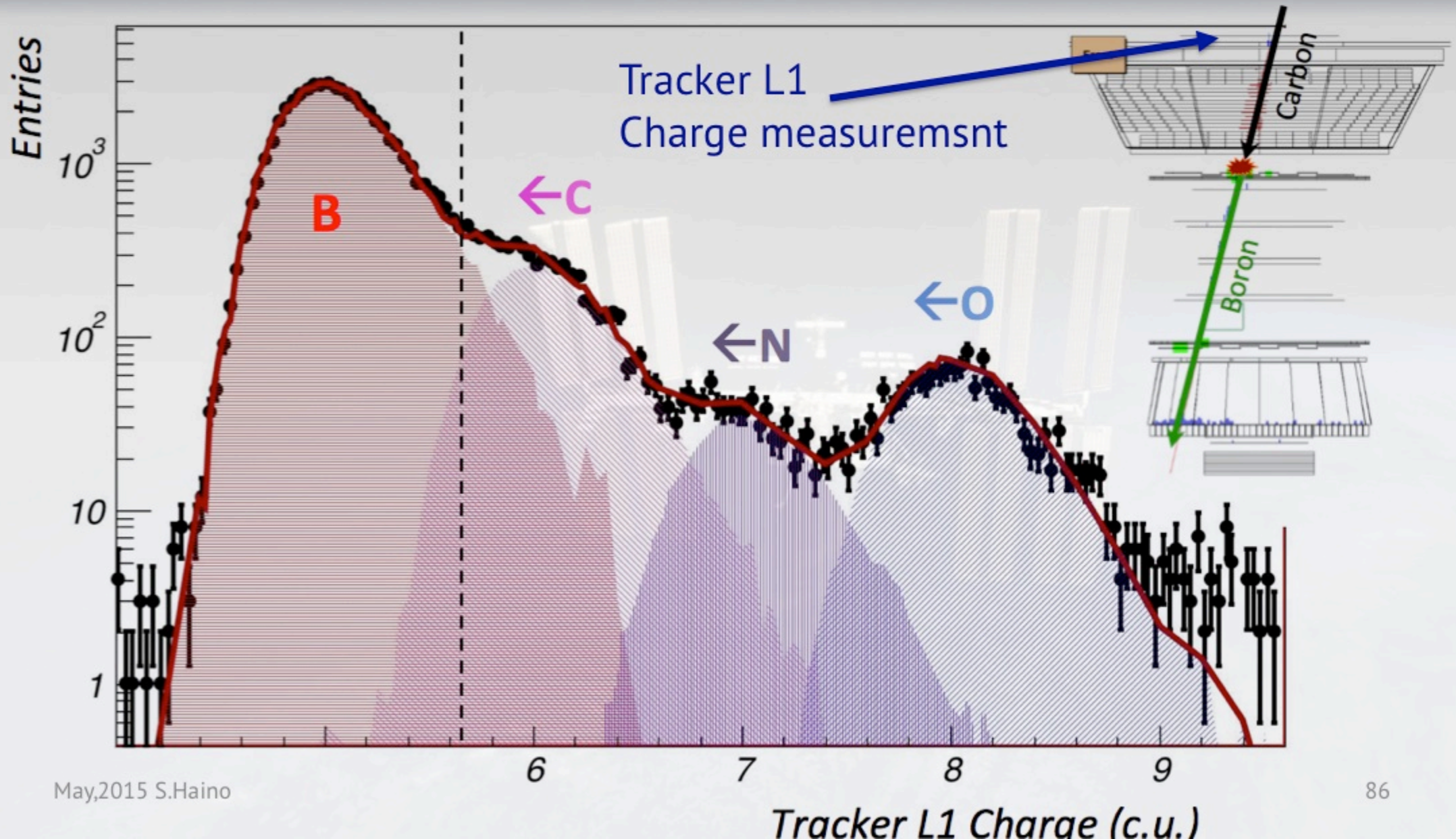
B/C sample purity control

The main backgrounds: Fragmentation events in the detector

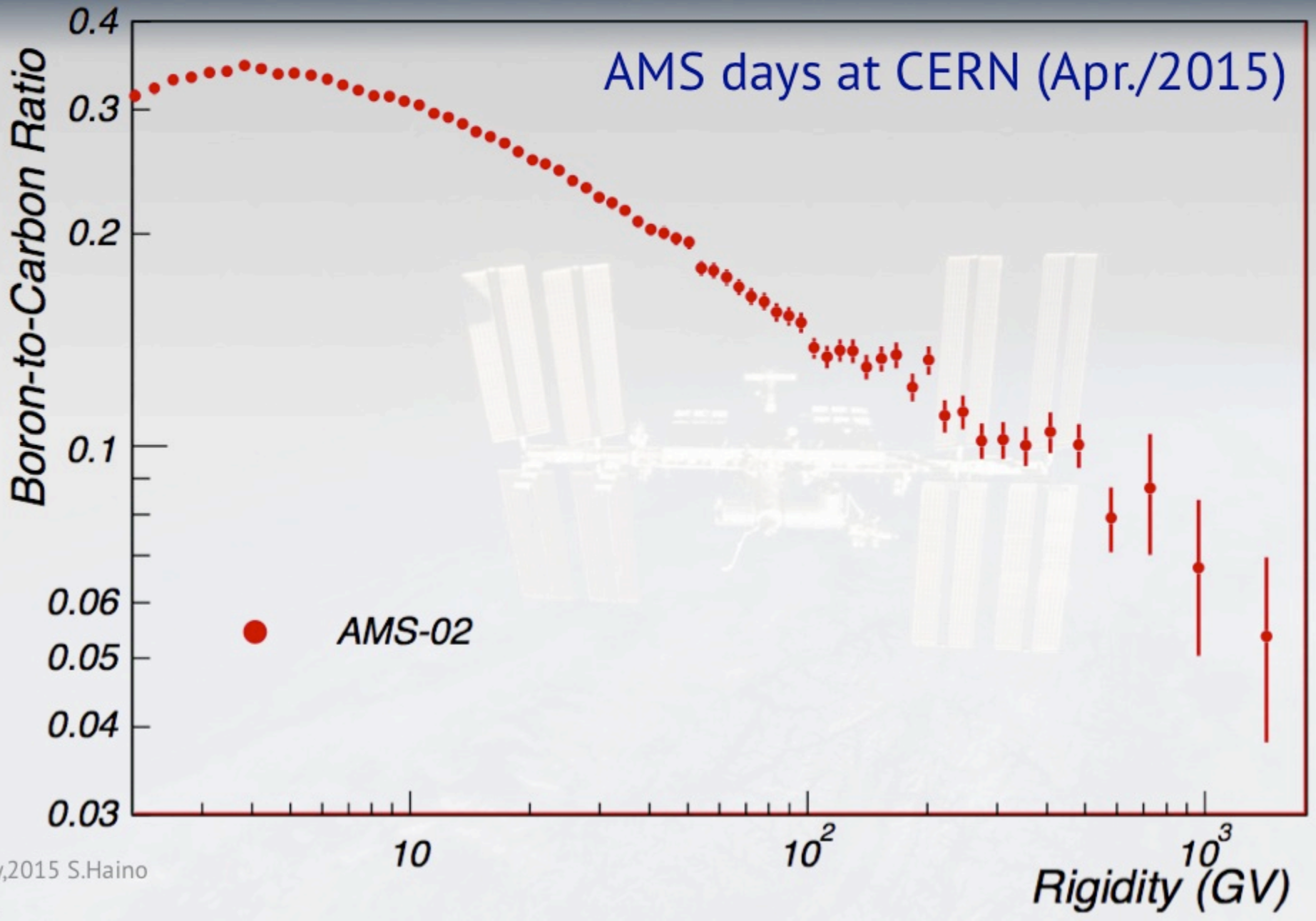


B/C sample purity control

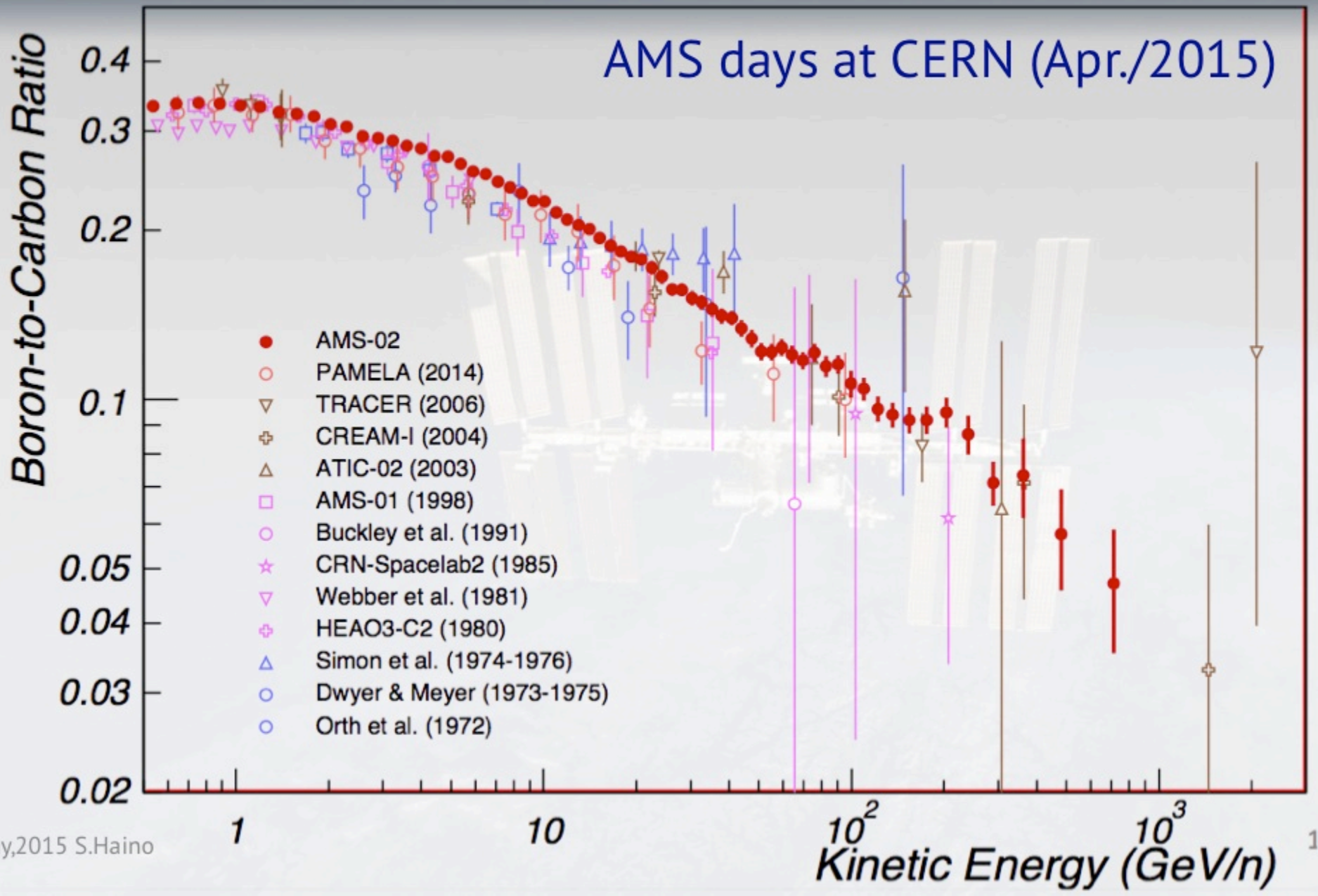
The main backgrounds: Fragmentation events in the detector



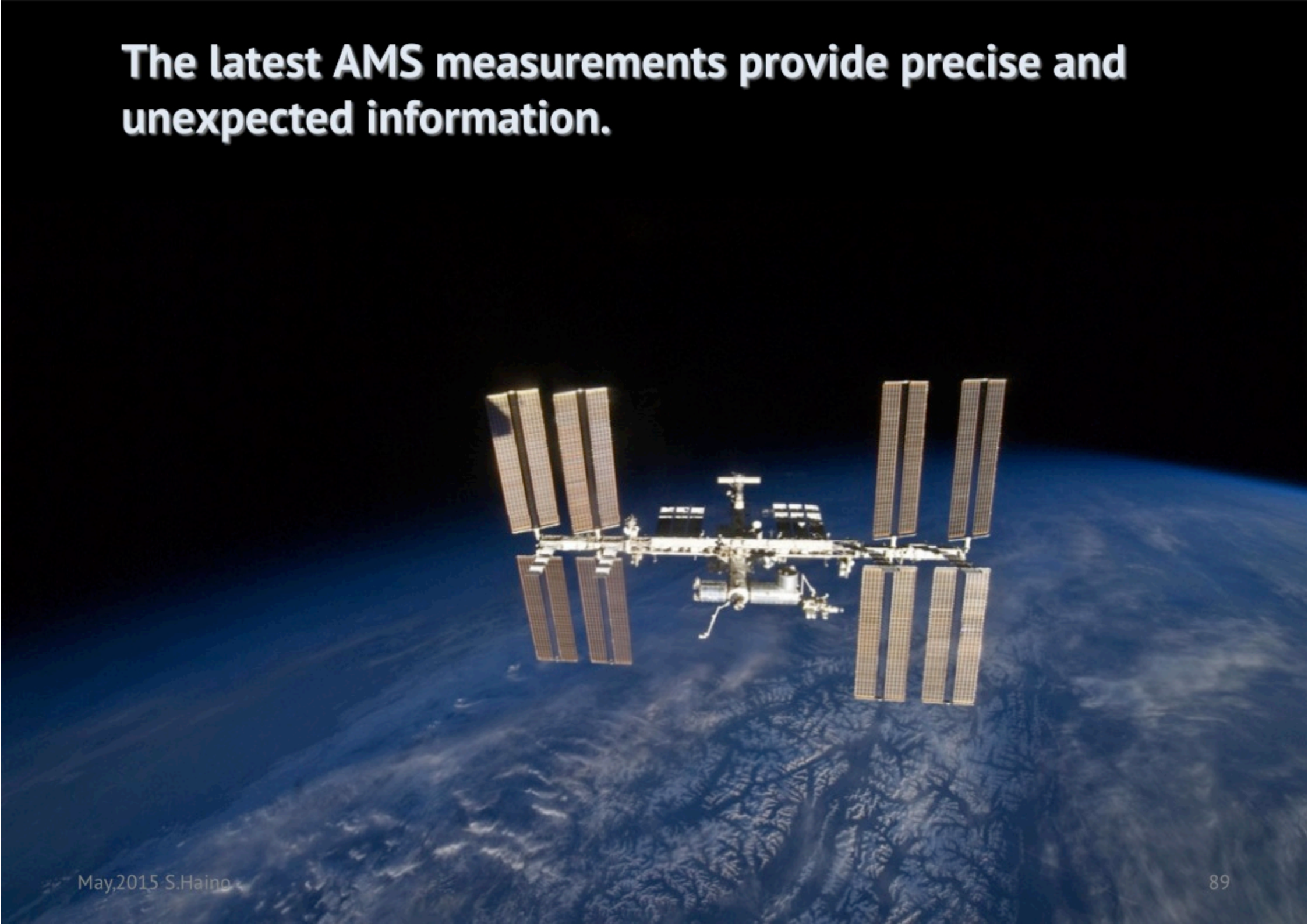
B/C ratio


AMS days at CERN (Apr./2015)
Boron-to-Carbon Ratio
0.4
0.3
0.2
0.1
0.06
0.05
0.04
0.03
AMS-02
10
10^2
10^3
Rigidity (GV)

B/C compared with other measurements

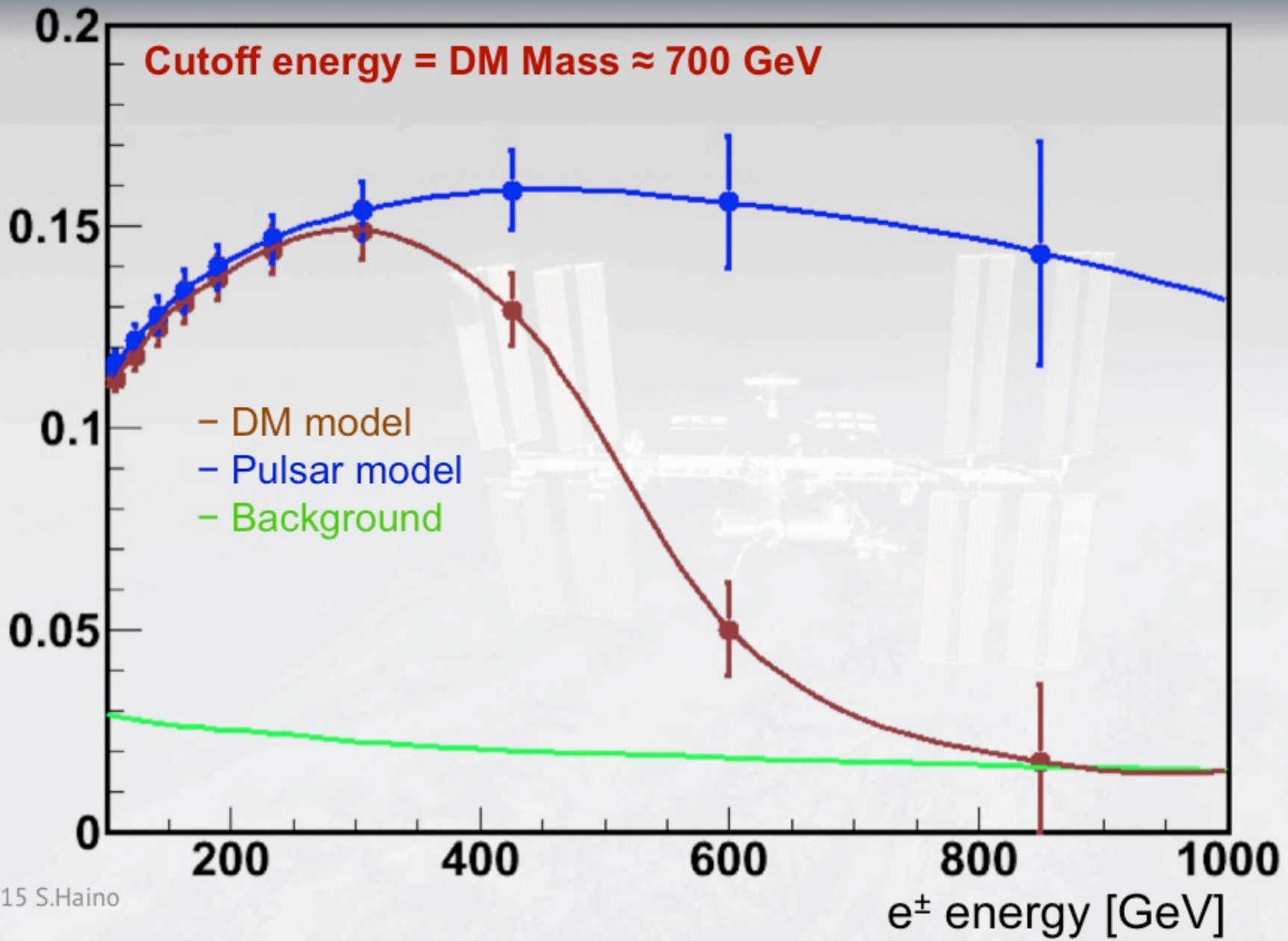


The latest AMS measurements provide precise and unexpected information.

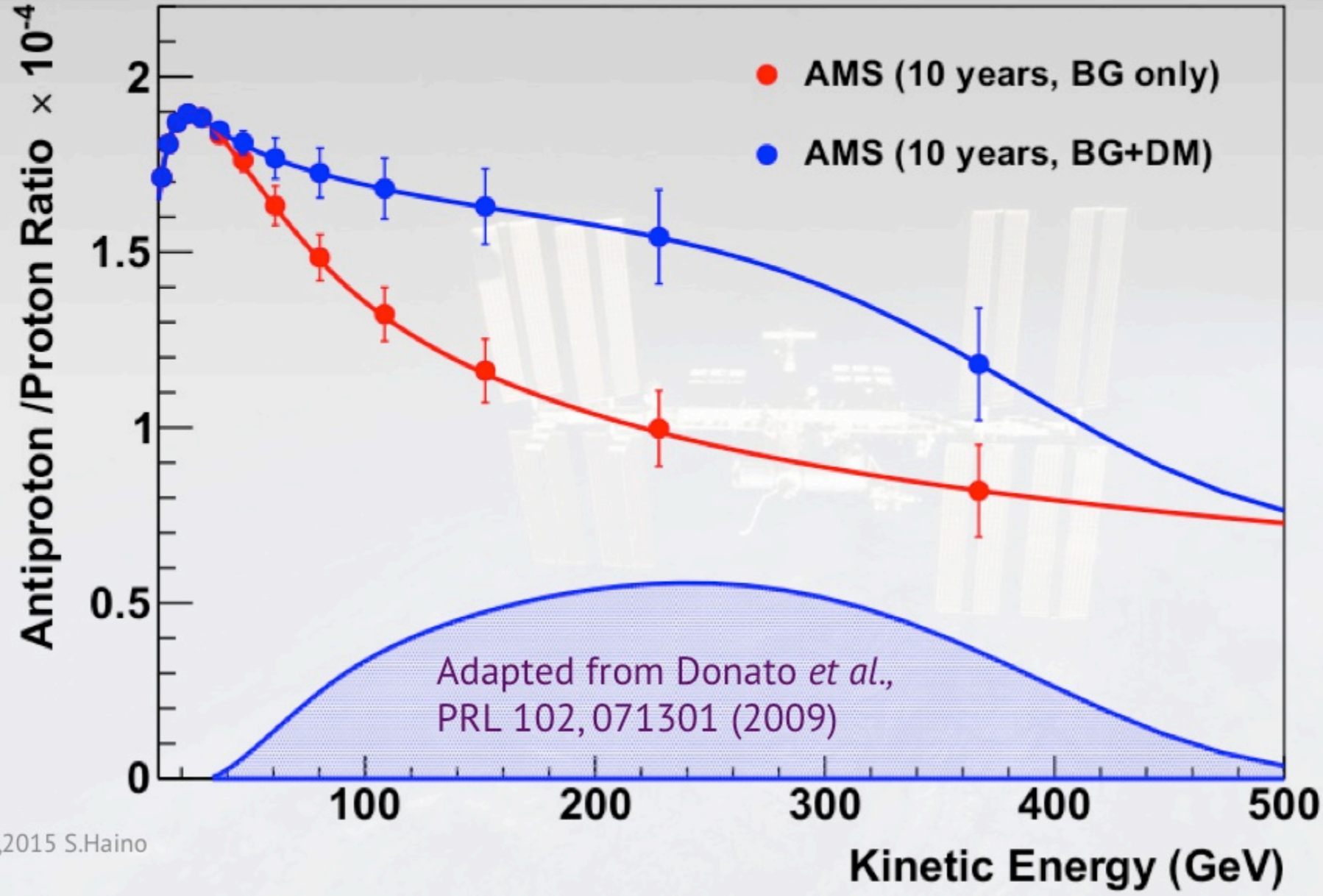


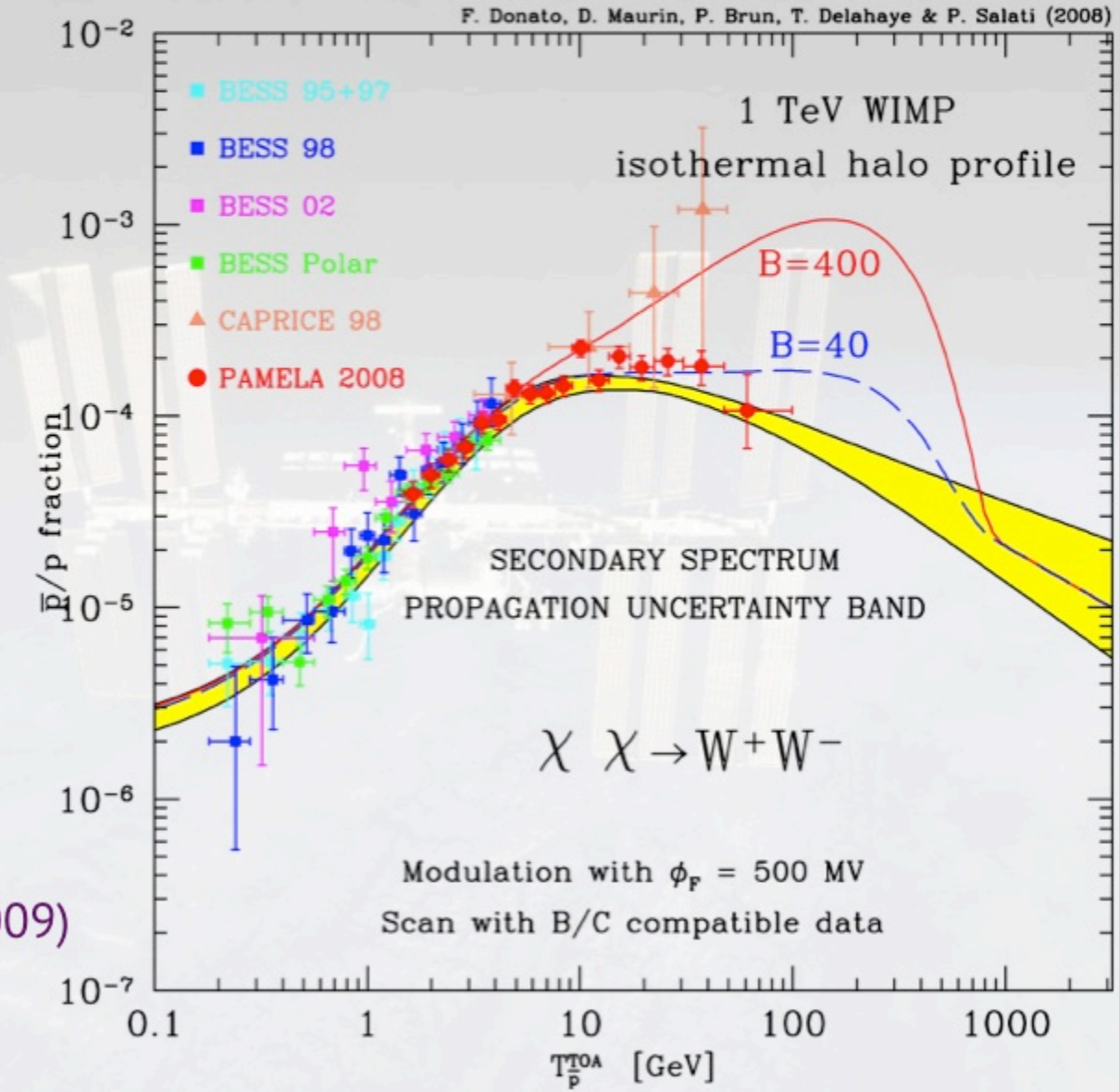
The latest AMS measurements provide precise and unexpected information.
The accuracy and characteristics of the data, simultaneously from many different particles, require a comprehensive model to ascertain if their origin is Dark Matter, Astrophysical sources or a combination.

AMS 10 years expectation



AMS 10 years expectation





Donato *et al.*,
PRL 102, 071301 (2009)