Searching for new physics in CR with AMS-02

(and with a little help from ground)

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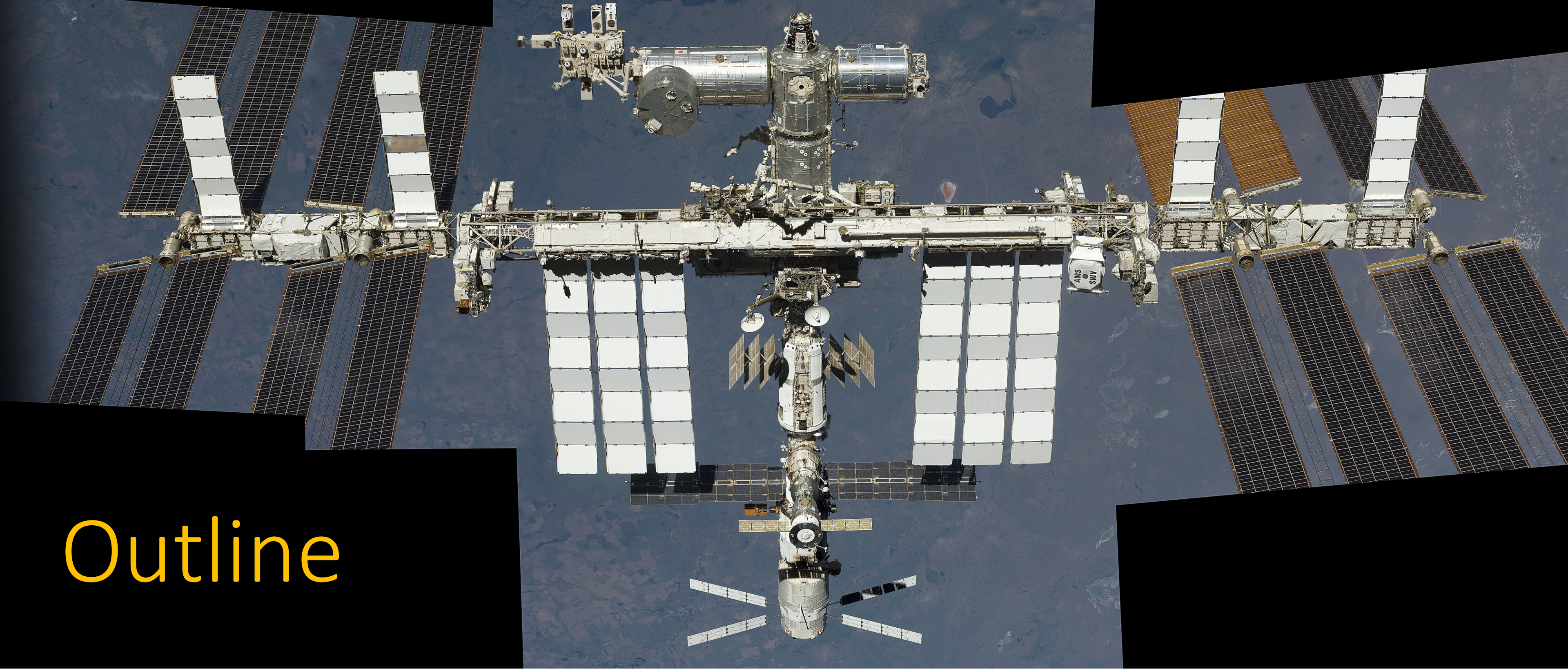
UNIVERSITÀ DEGLI STUDI DI TRENTO

TIFPA

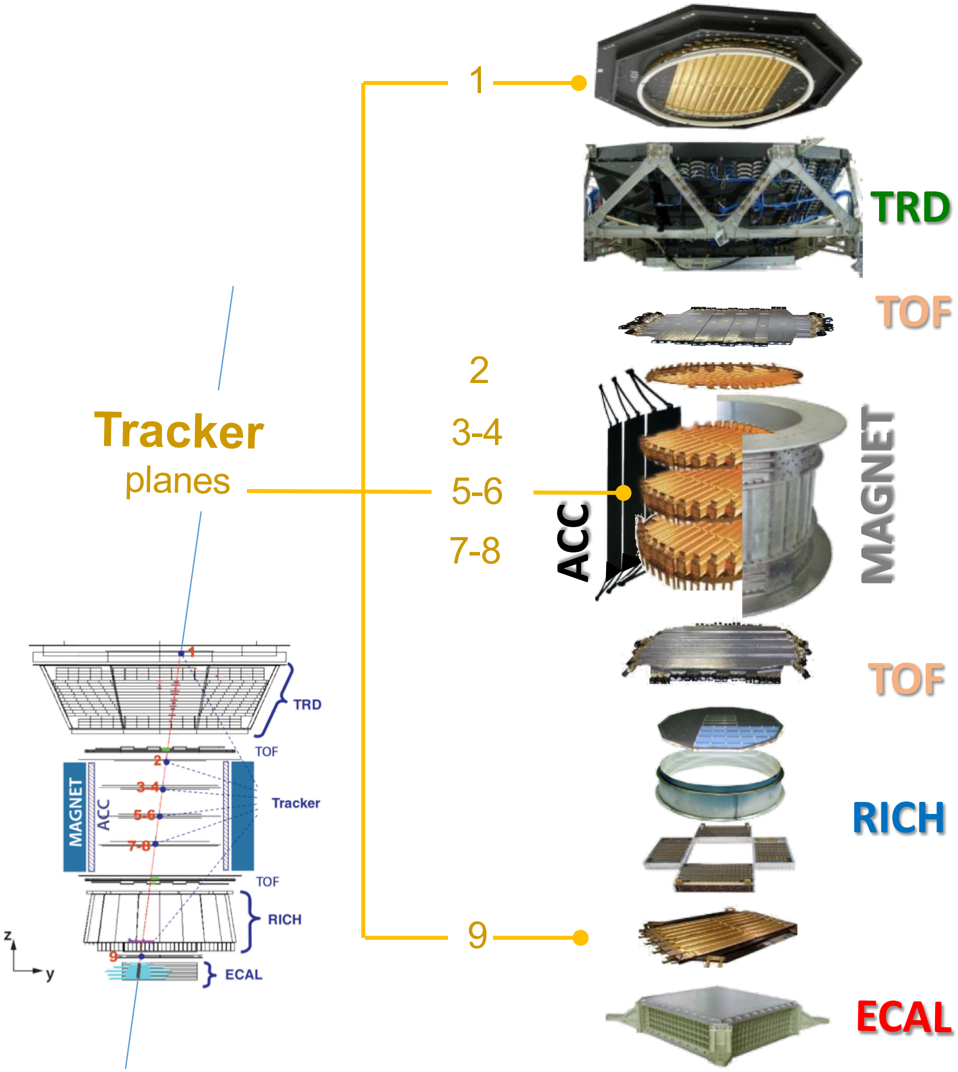


Outline

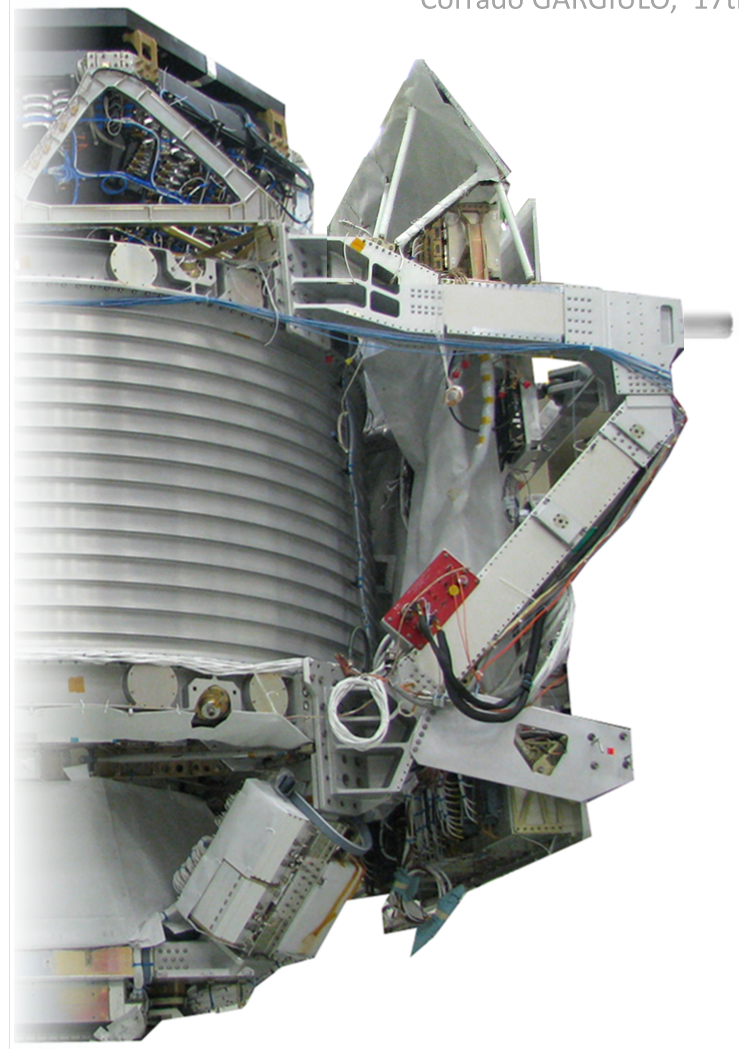
- AMS and the cooling system repairs
- Measurement of CR fluxes with AMS
- Anti-matter measurements with AMS
- Cross section for DM sensitivity
- What’s next ?

Alpha Magnetic Spectrometer

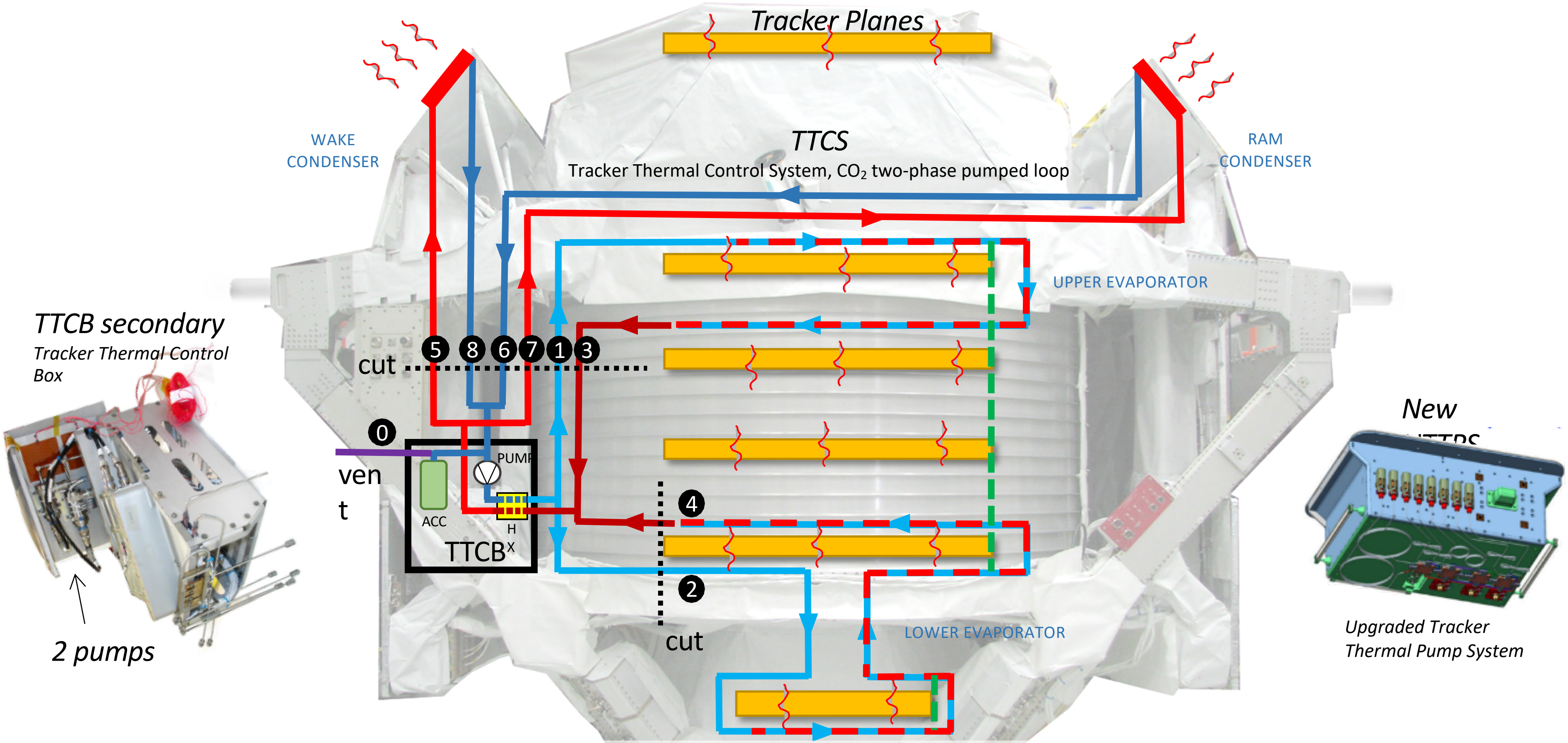
- AMS-02 is a particle physics detector devoted to the measurement of cosmic rays fluxes in the near Earth orbit in the range 0.1 GV – 2 TV
- It will take data data for the rest of the life of the ISS (extends to 2024)



Corrado GARGIULO, 17th May 2019



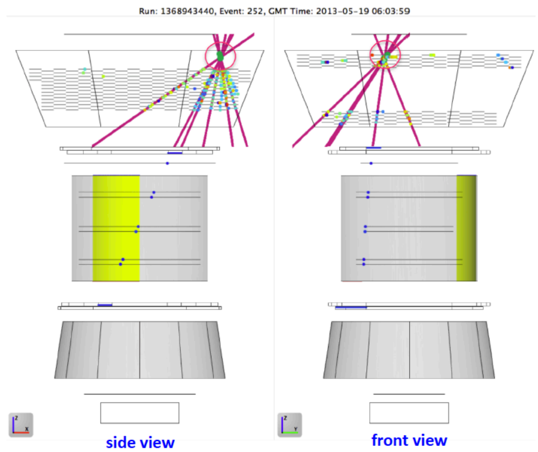
Corrado GARGIULO, 17th May 2019



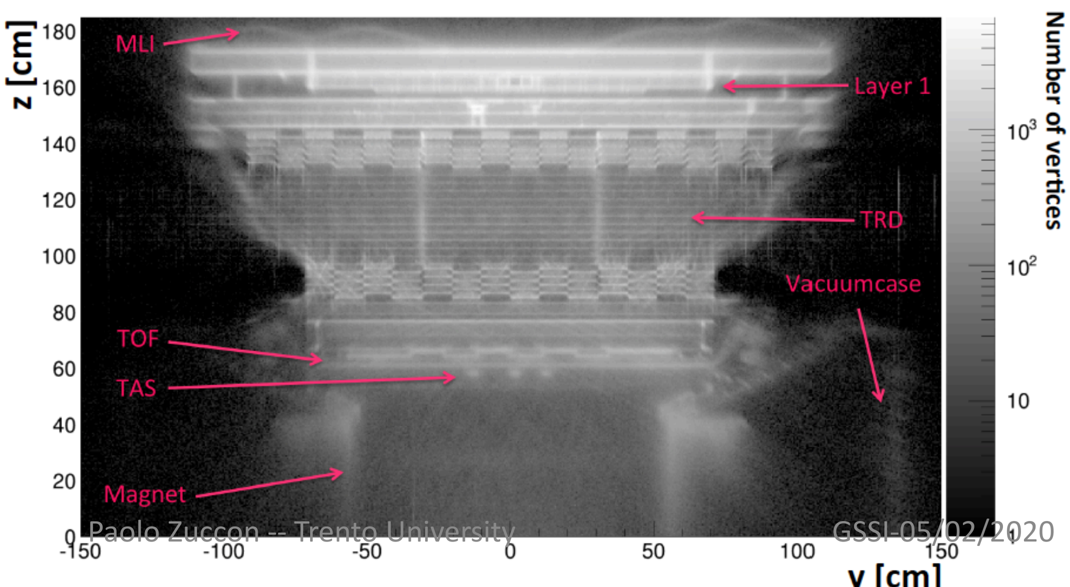
The Tracker Thermal Control System, TTCS, is the most complex system onboard AMS-02

The TTCS upgrade requires the replacement of the TTCB with the UTTPS, which implies the cut and reconnection of 8 ssteel tubes

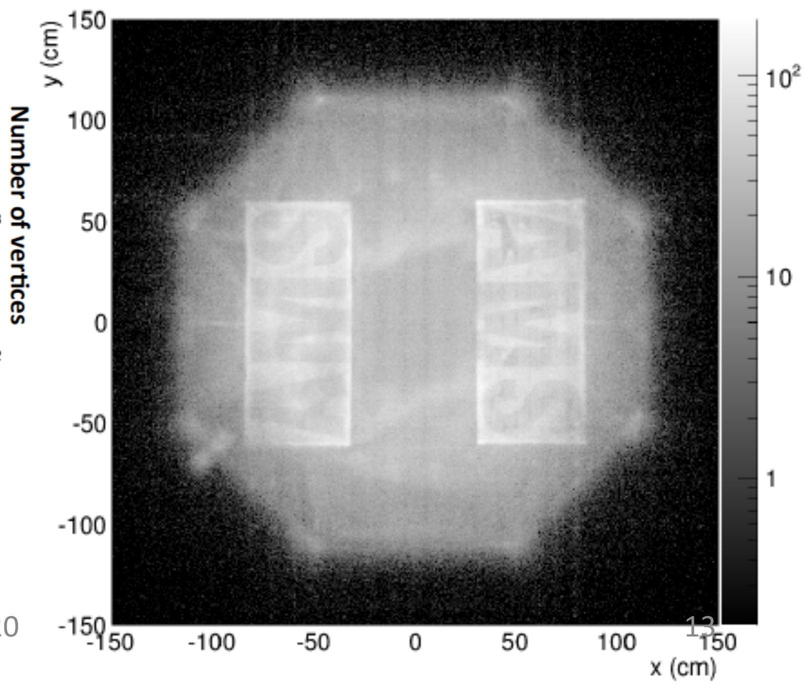
AMS "tomography" using rare nuclear interaction events



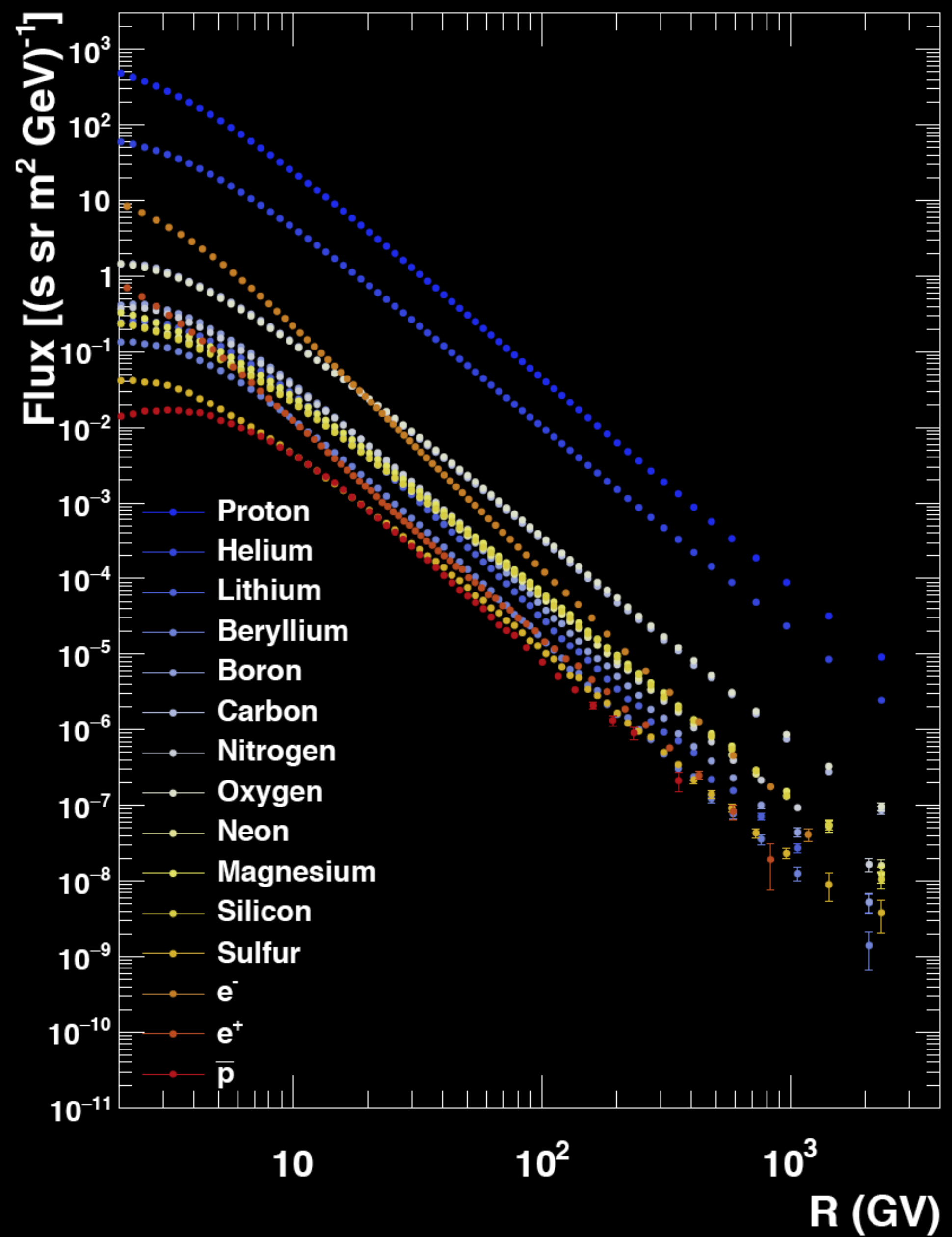
The gray scale is proportional the the number of found vertices



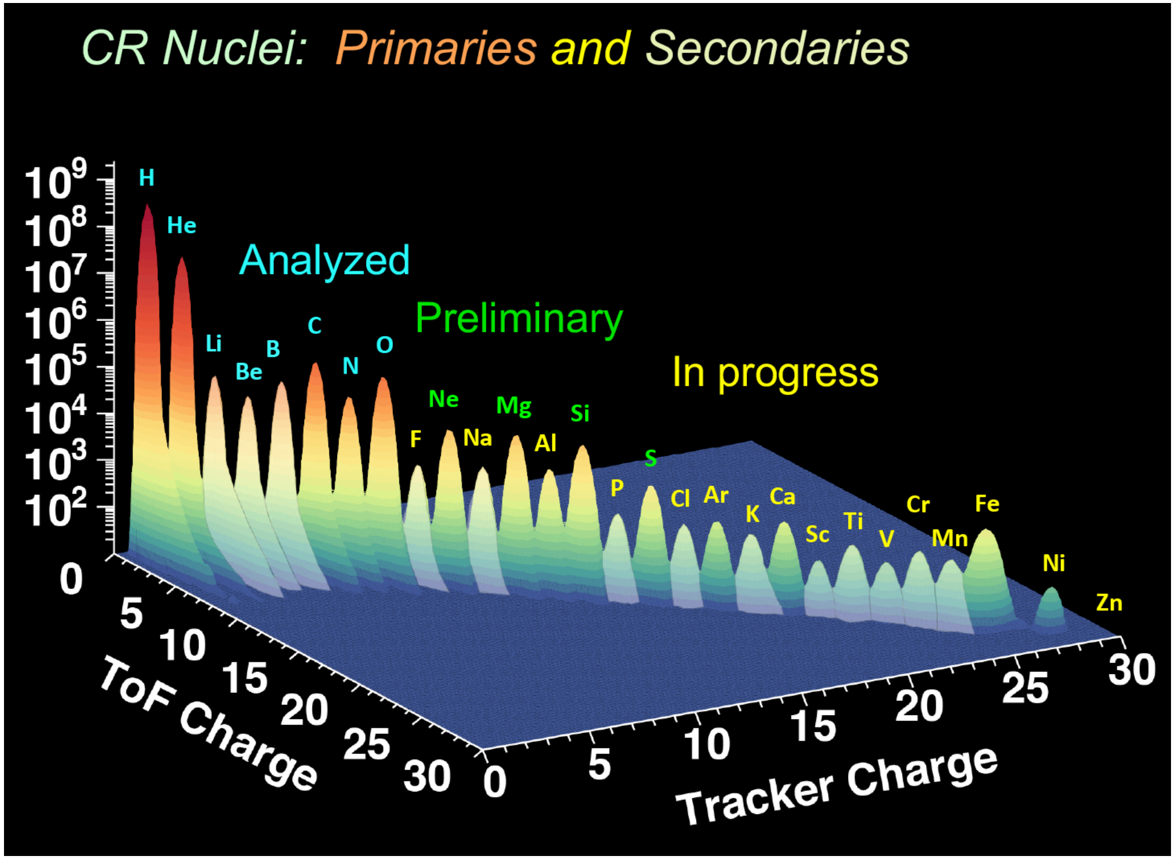
Z=178.5 cm

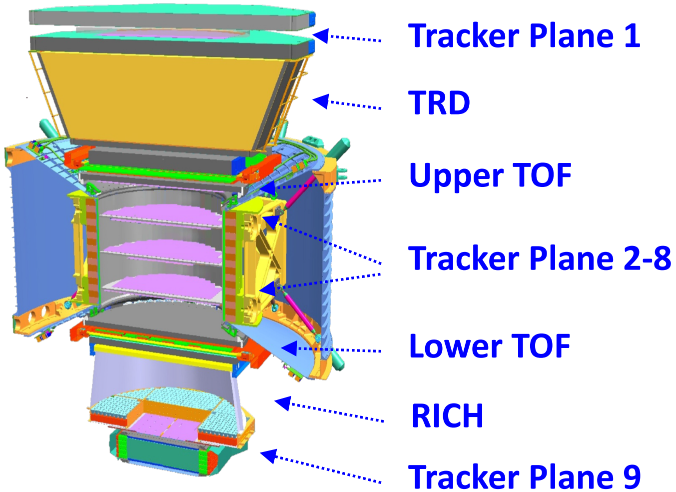


Summary of AMS Measurements

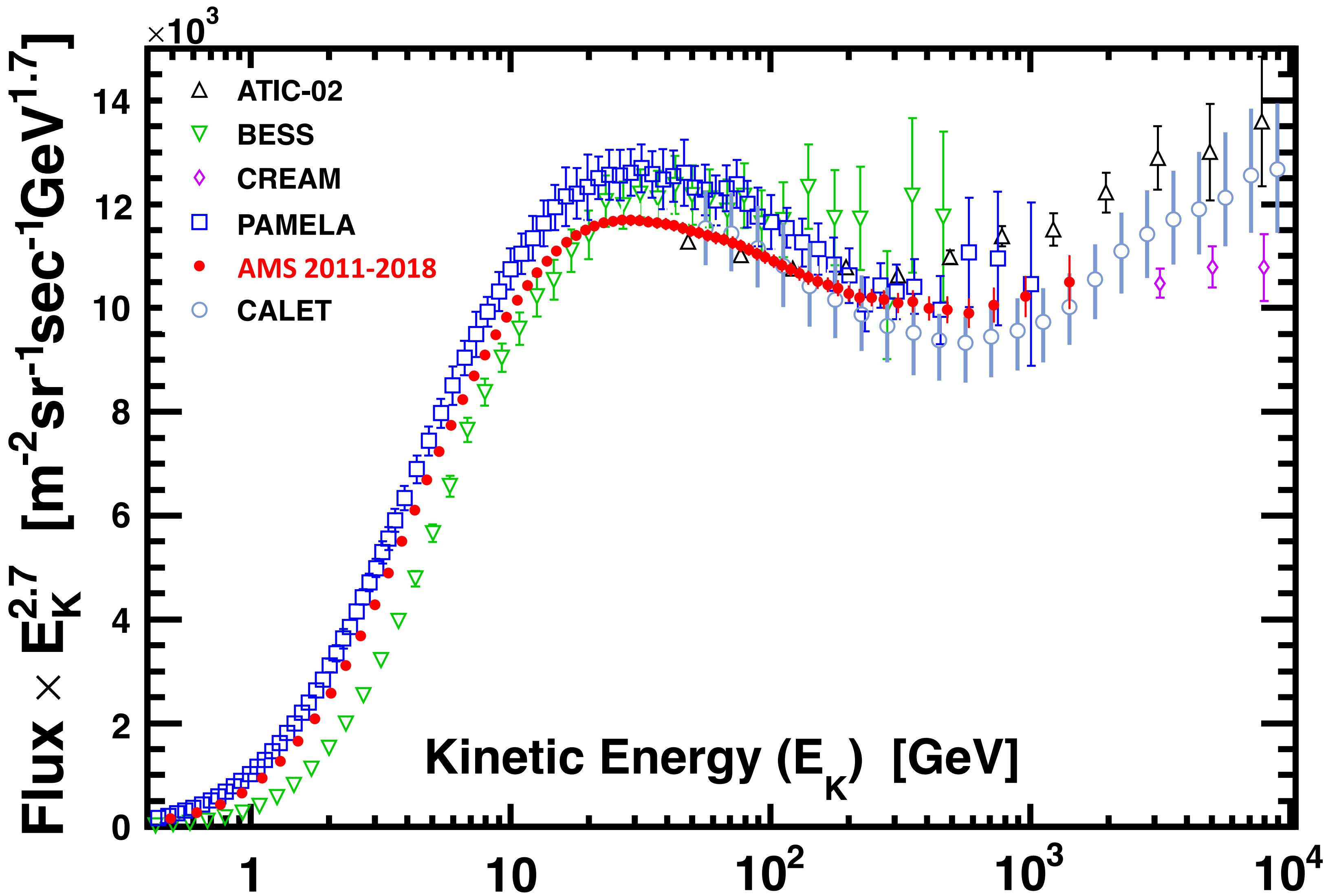


Charge Measurement in AMS



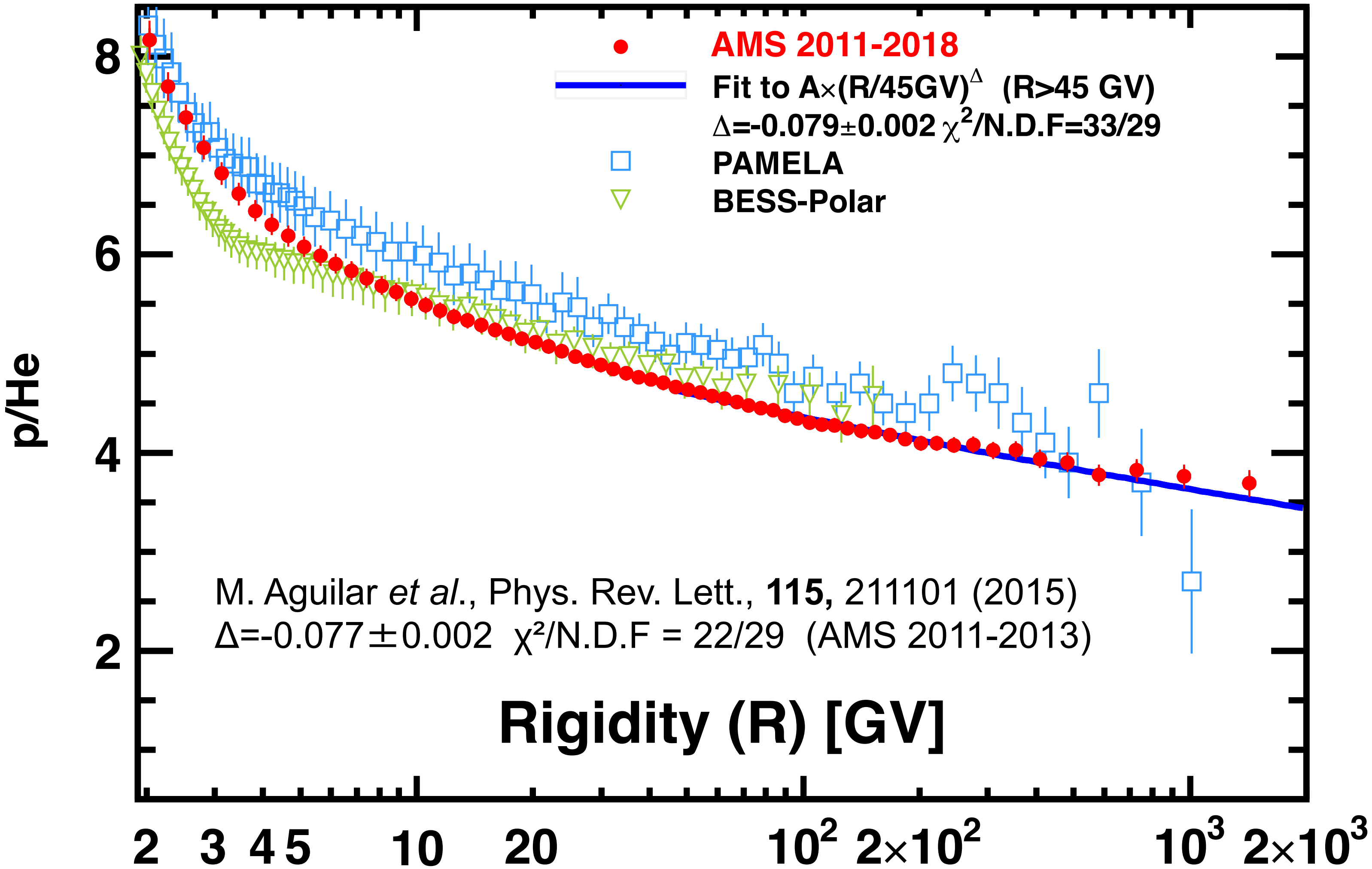


Measurement of proton spectrum with AMS

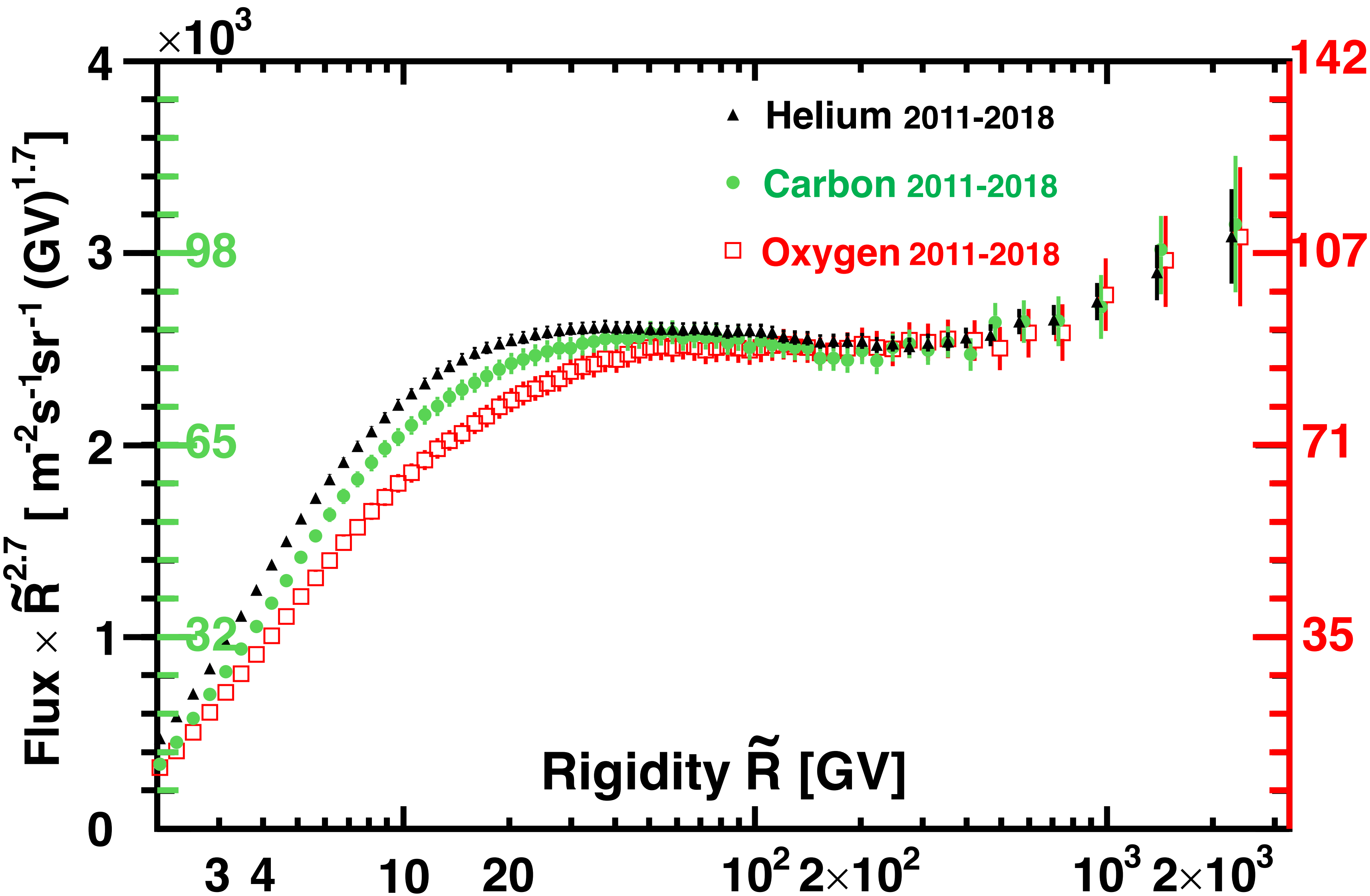


The AMS Result on the Proton/Helium Flux Ratio

Protons and helium are both primary cosmic rays.
Traditionally, they are assumed to be produced in the same sources

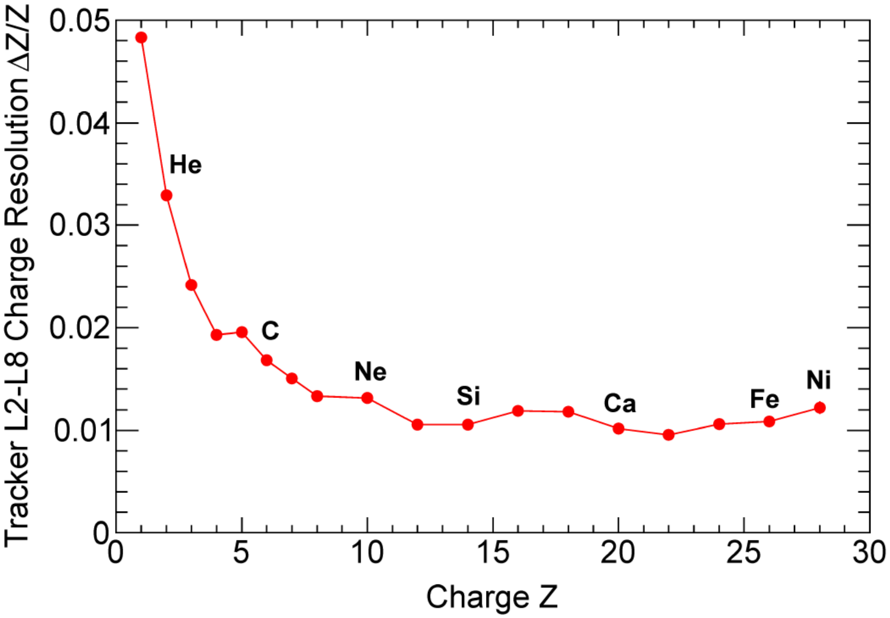


Latest AMS Measurement of He, C and O spectra

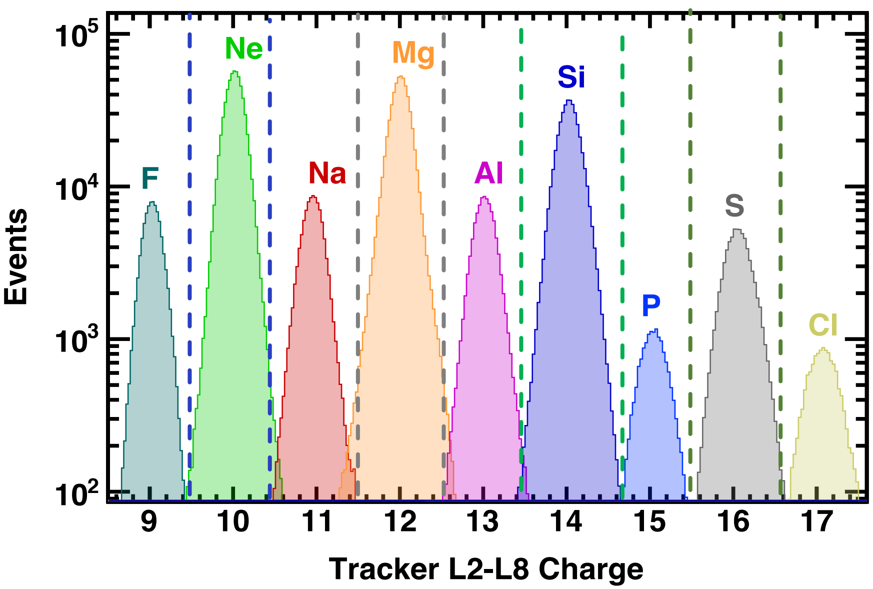


The new AMS result (2011-2018) is consistent with earlier AMS PRL result (2011-2016) "M. Aguilar *et al.*, Phys. Rev. Lett., **119**, 251101 (2017)" but with improved accuracy

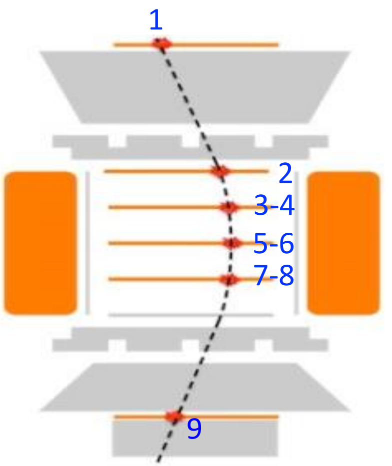
Charge resolution

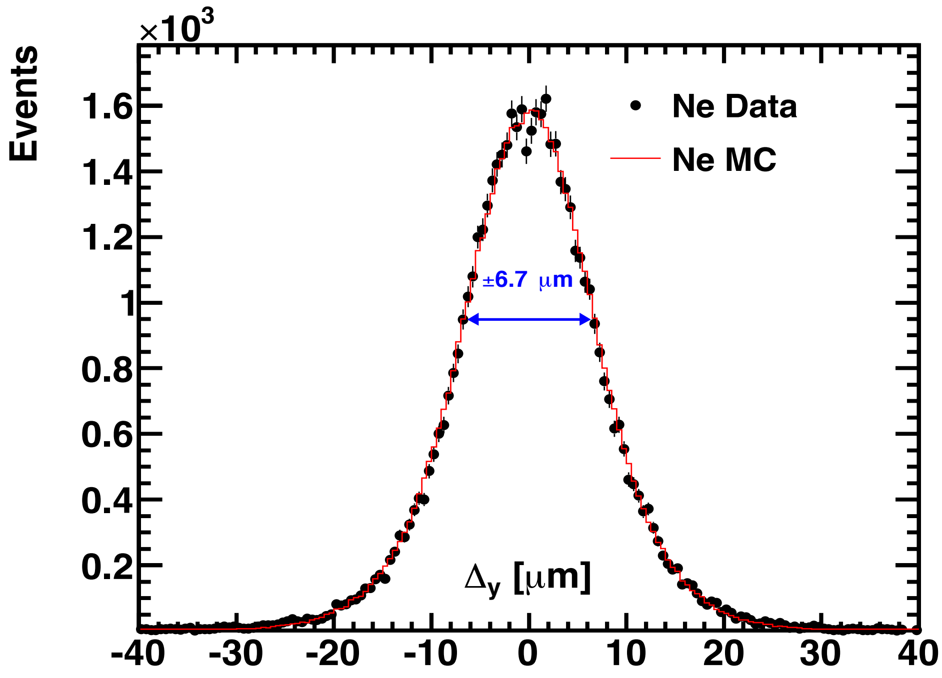


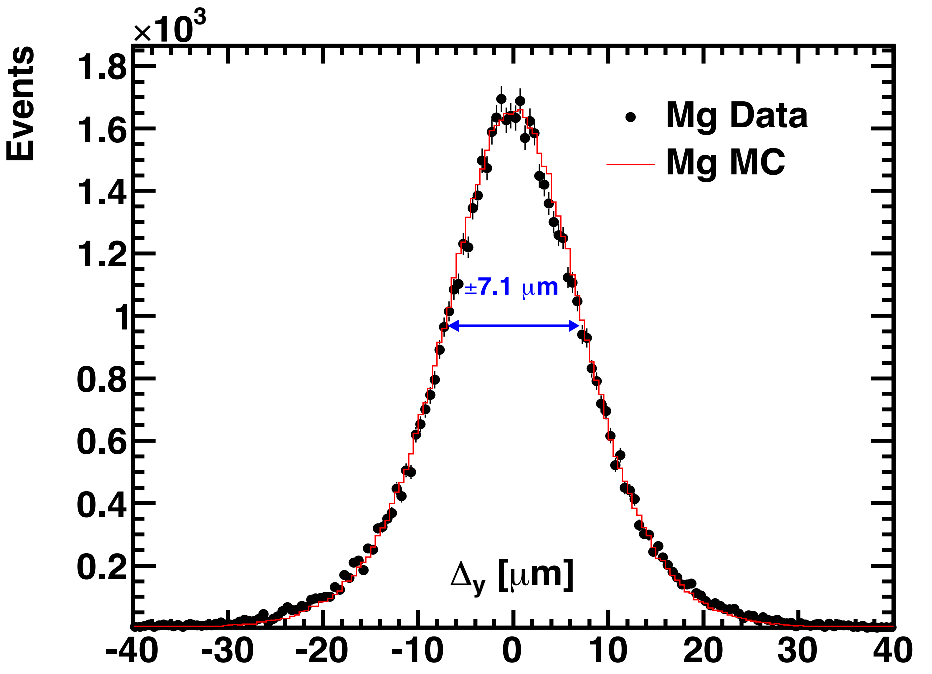
Ne, Mg, Si and S Events Selection



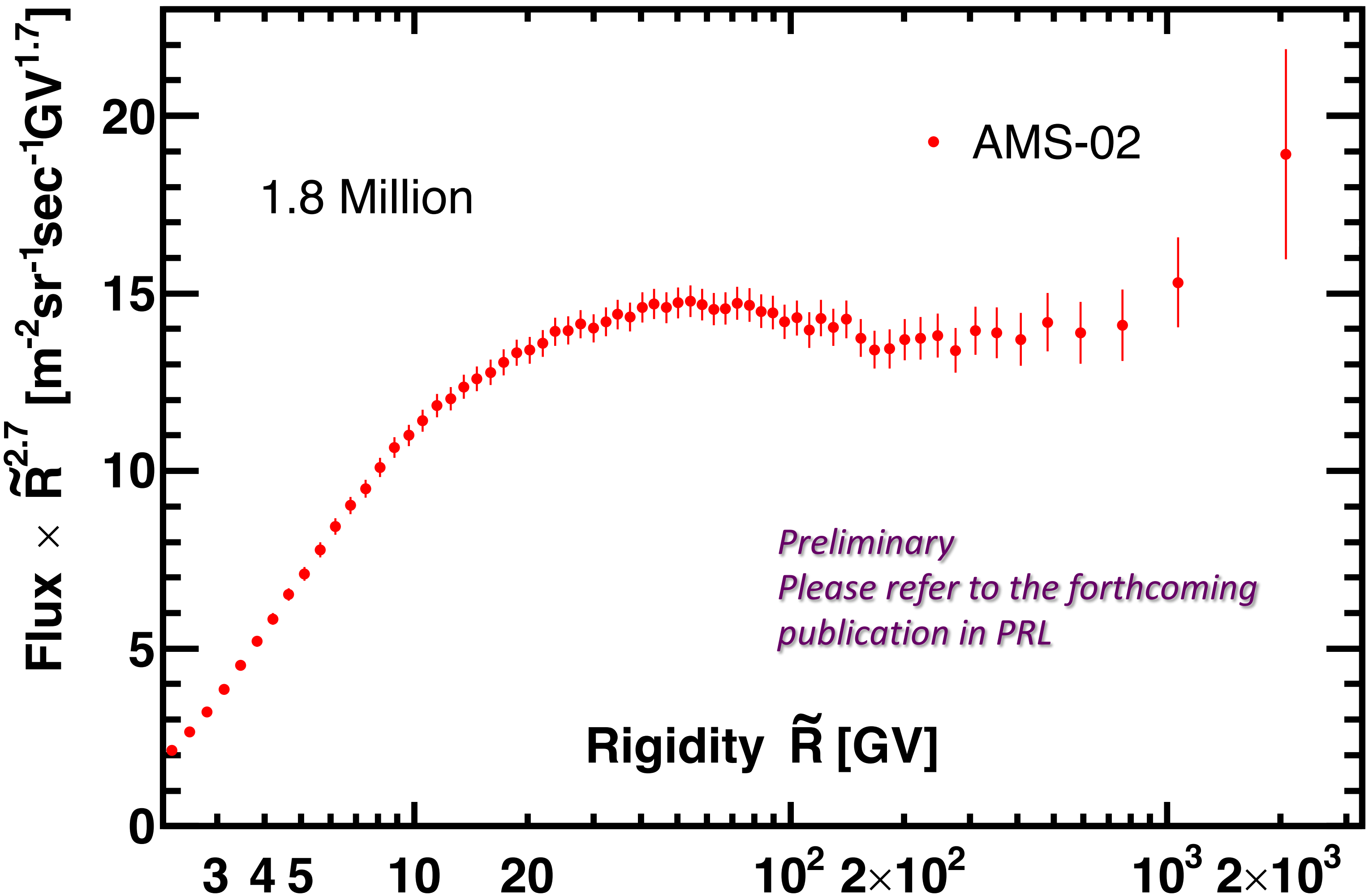
Tracker Coordinate Resolution Data and MC





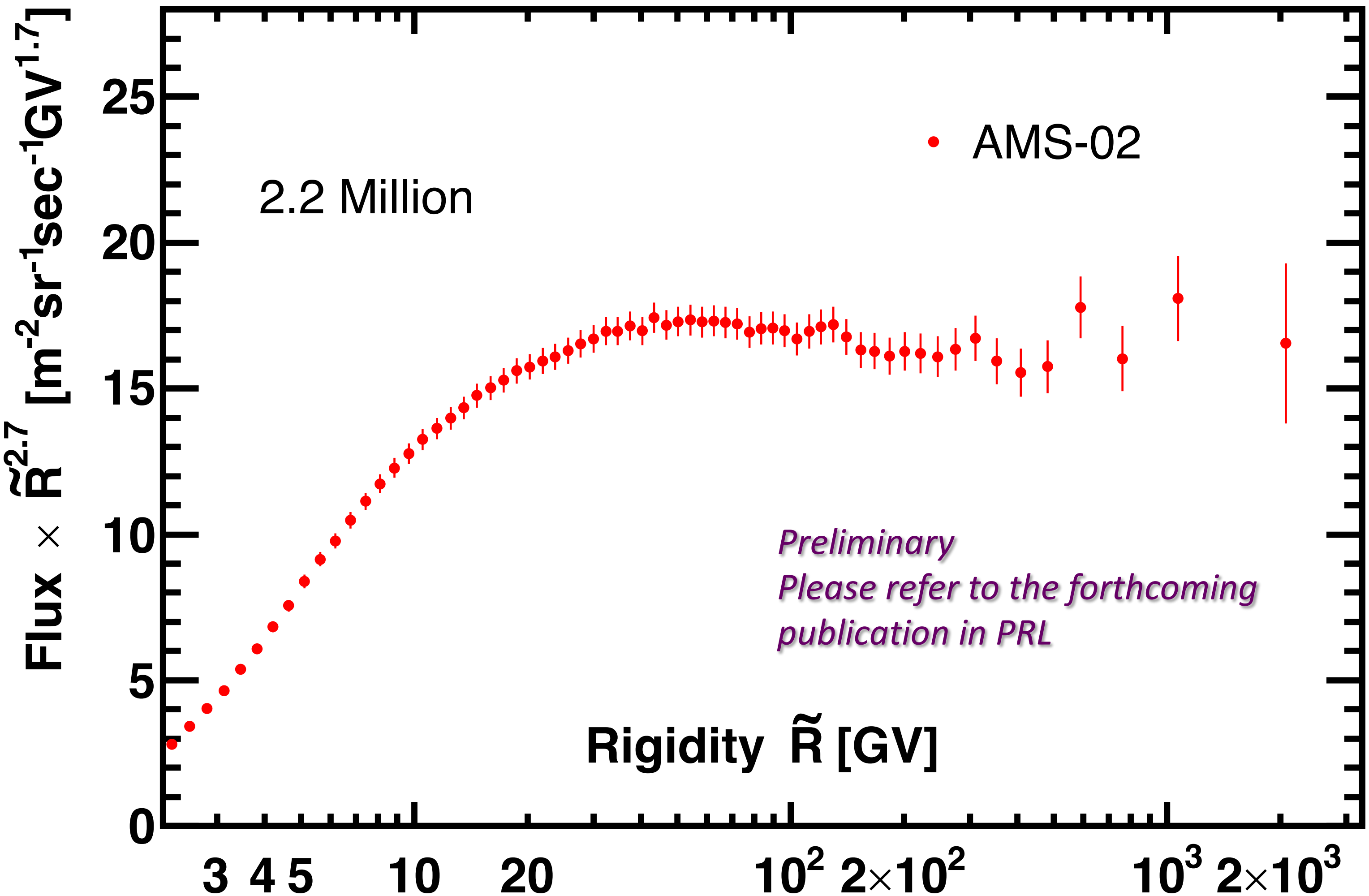


Neon Flux

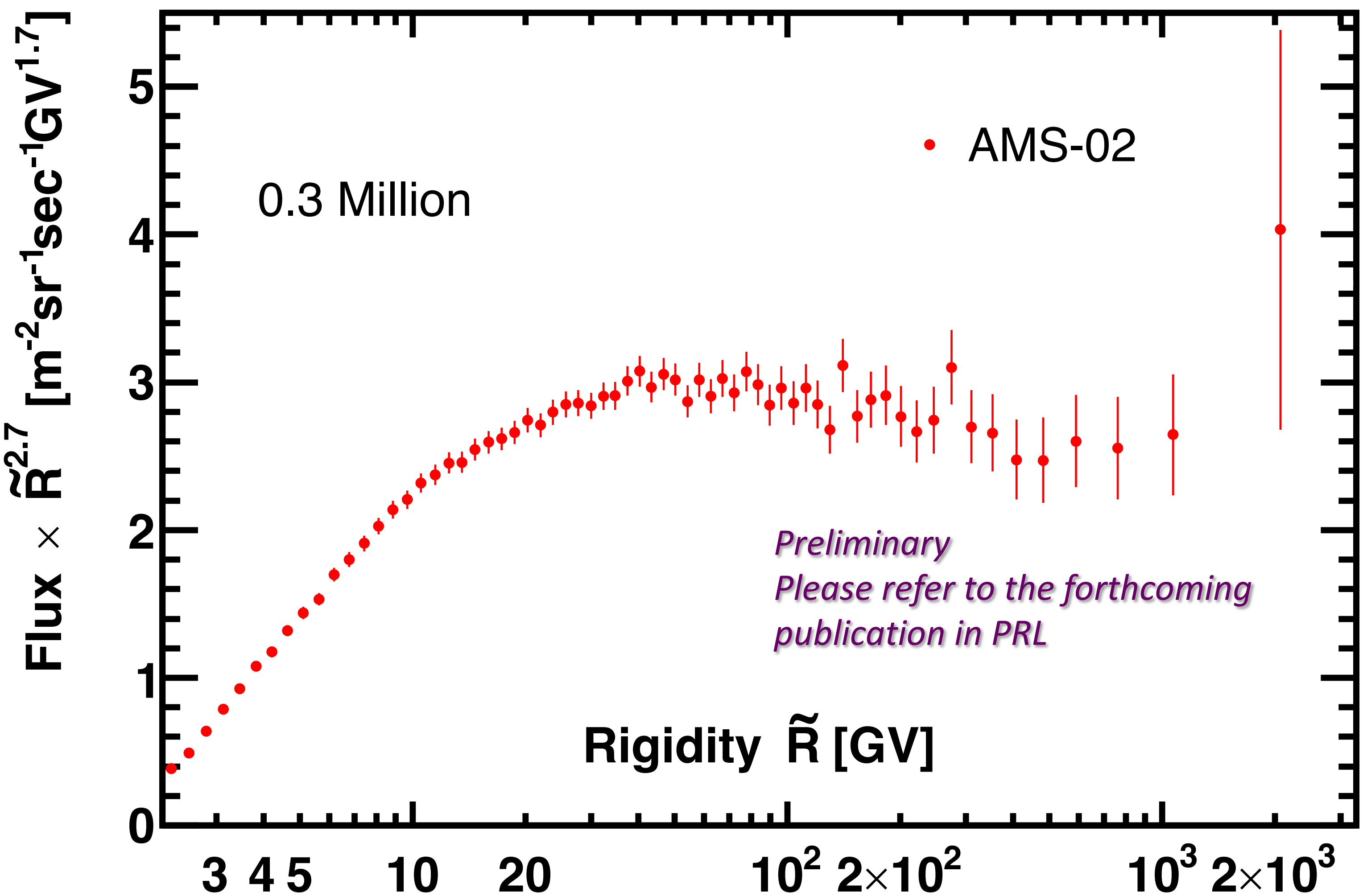


Flux × R̃^2.7 [m^-2sr^-1sec^-1GV^1.7]
1.8 Million
AMS-02
Preliminary
Please refer to the forthcoming publication in PRL
Rigidity R̃ [GV]
0
5
10
15
20
3
4
5
10
20
10^2
2×10^2
10^3
2×10^3

Magnesium Flux

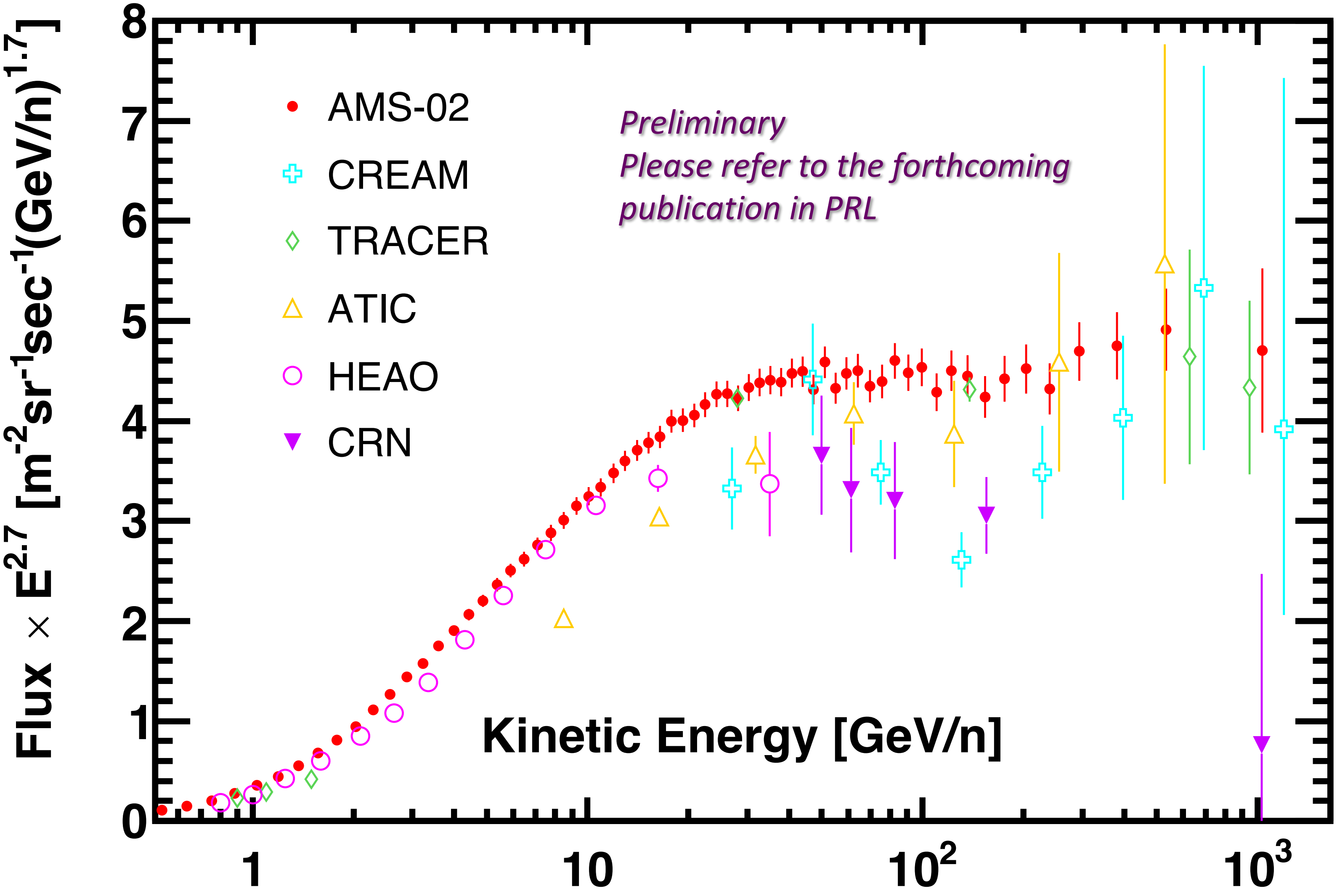


Sulfur Flux



Flux × $\tilde{R}^{2.7}$ [m^{-2}sr^{-1}sec^{-1}GV$^{1.7}$]
0.3 Million
AMS-02
Preliminary
Please refer to the forthcoming publication in PRL
Rigidity $\tilde{R}$ [GV]
0
1
2
3
4
5
3 4 5
10
20
10^2 2×10^2
10^3 2×10^3

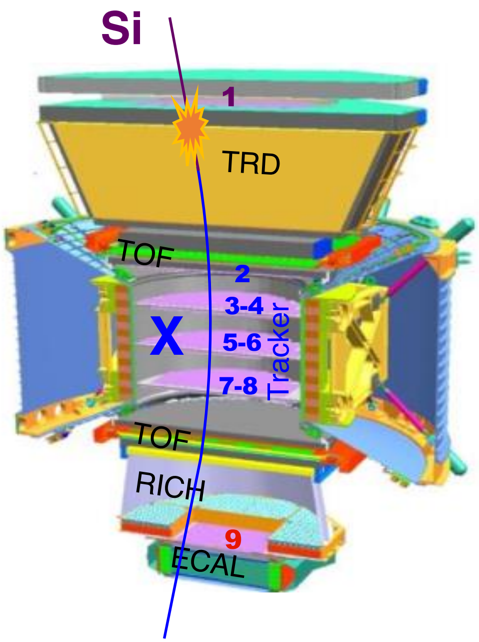
Compared with Other Experiments (Silicon Flux)

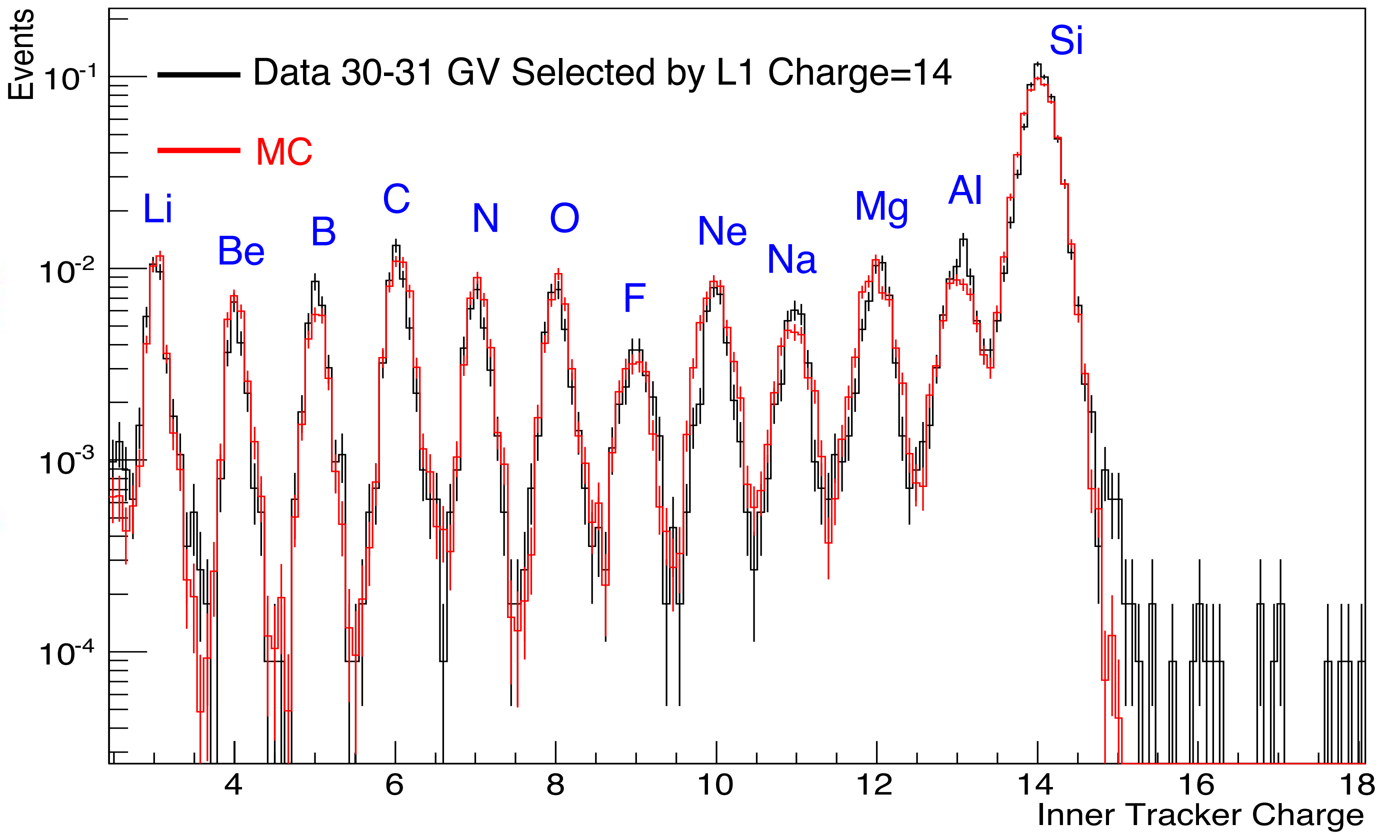


Nucleus Inelastic Interaction and Breaking-Up Channels Distribution (Silicon)

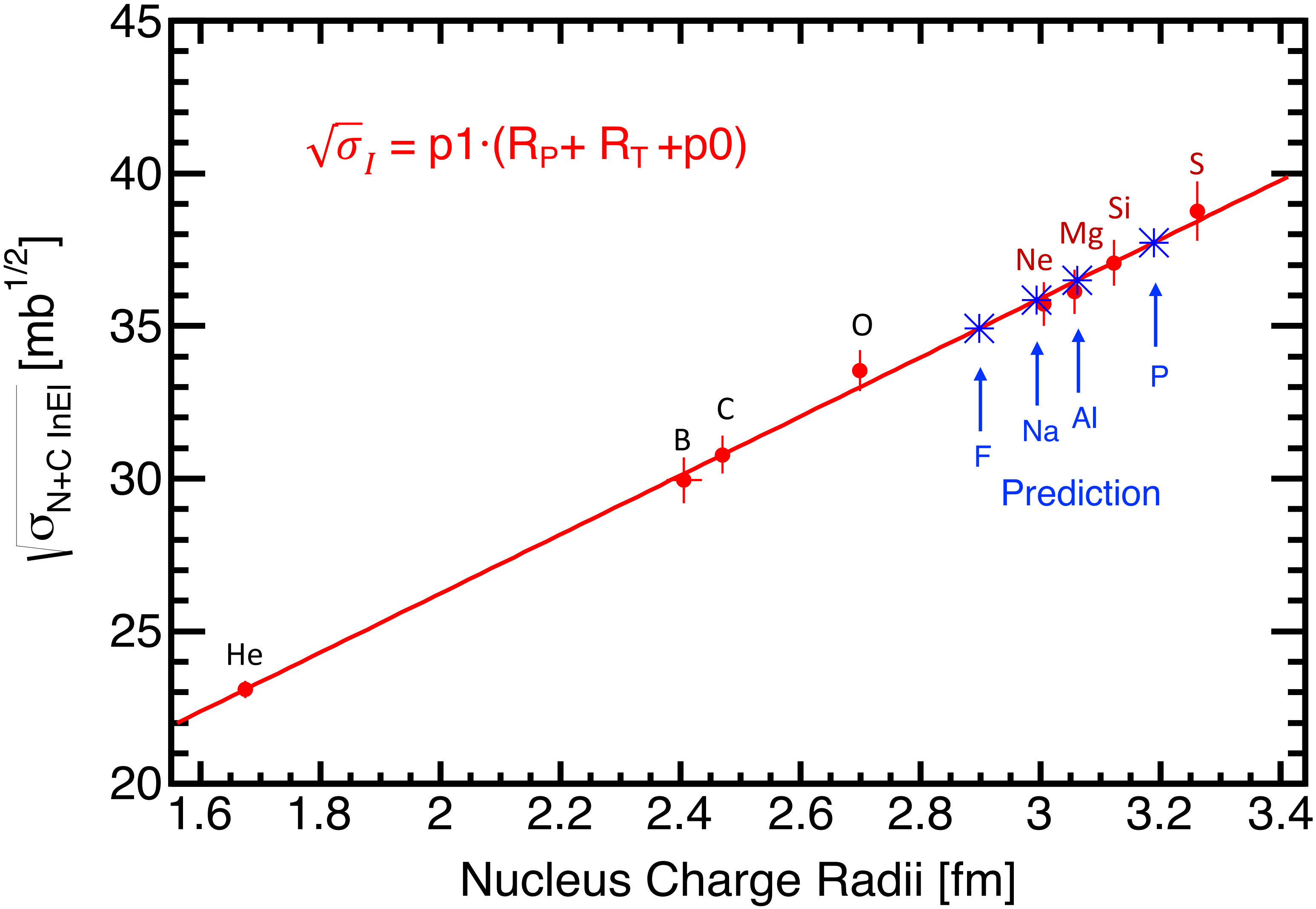
Statistics in "horizontal" runs are not sufficient for high Z survival probability evaluation, so different method was used

- Select primary nuclei by L1 charge
- Obtain survival probability by comparing charge measured with inner tracker



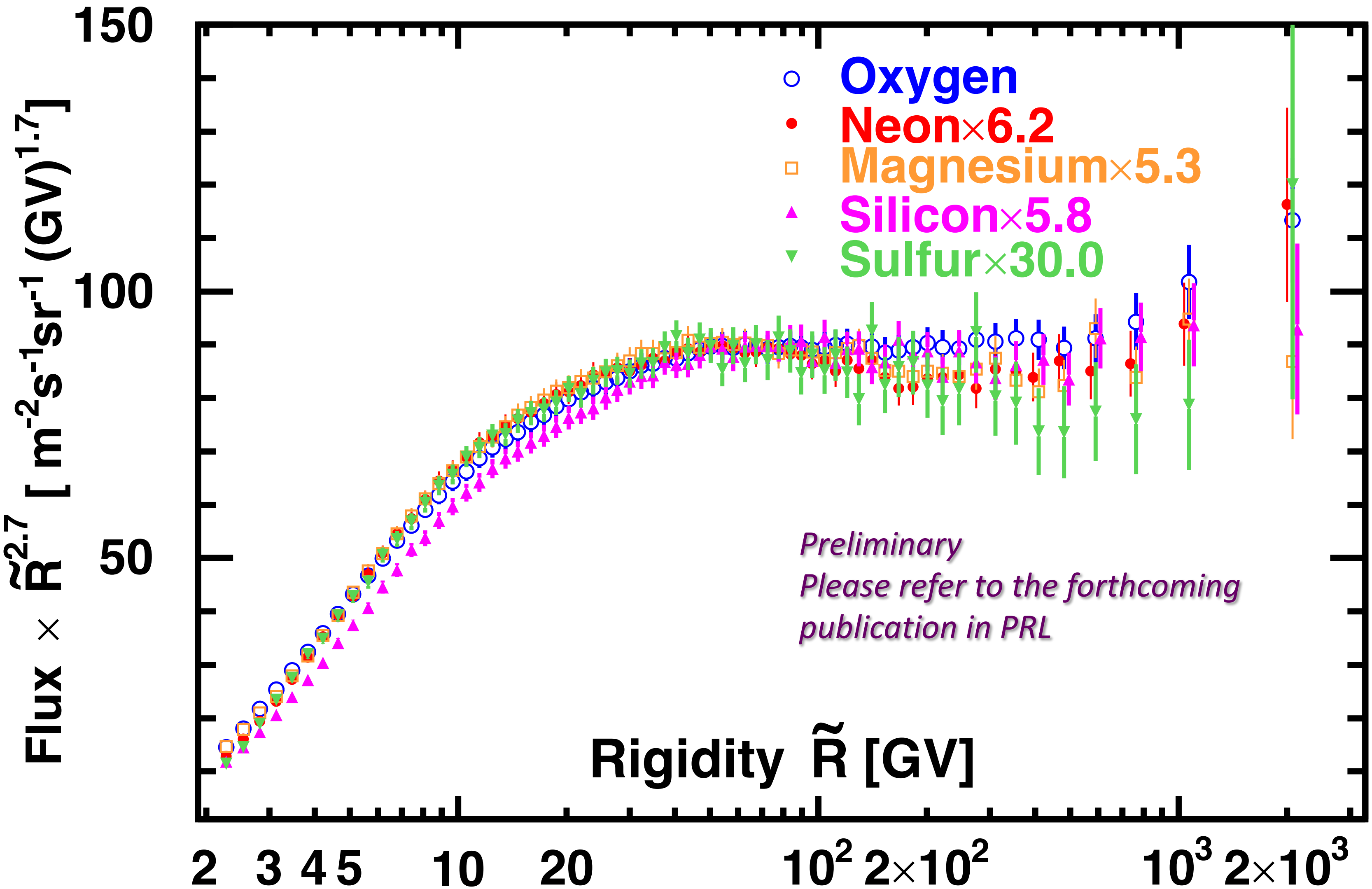


AMS Nucleus + C Inelastic Cross Section Measurements (5-100 GV Rigidity)

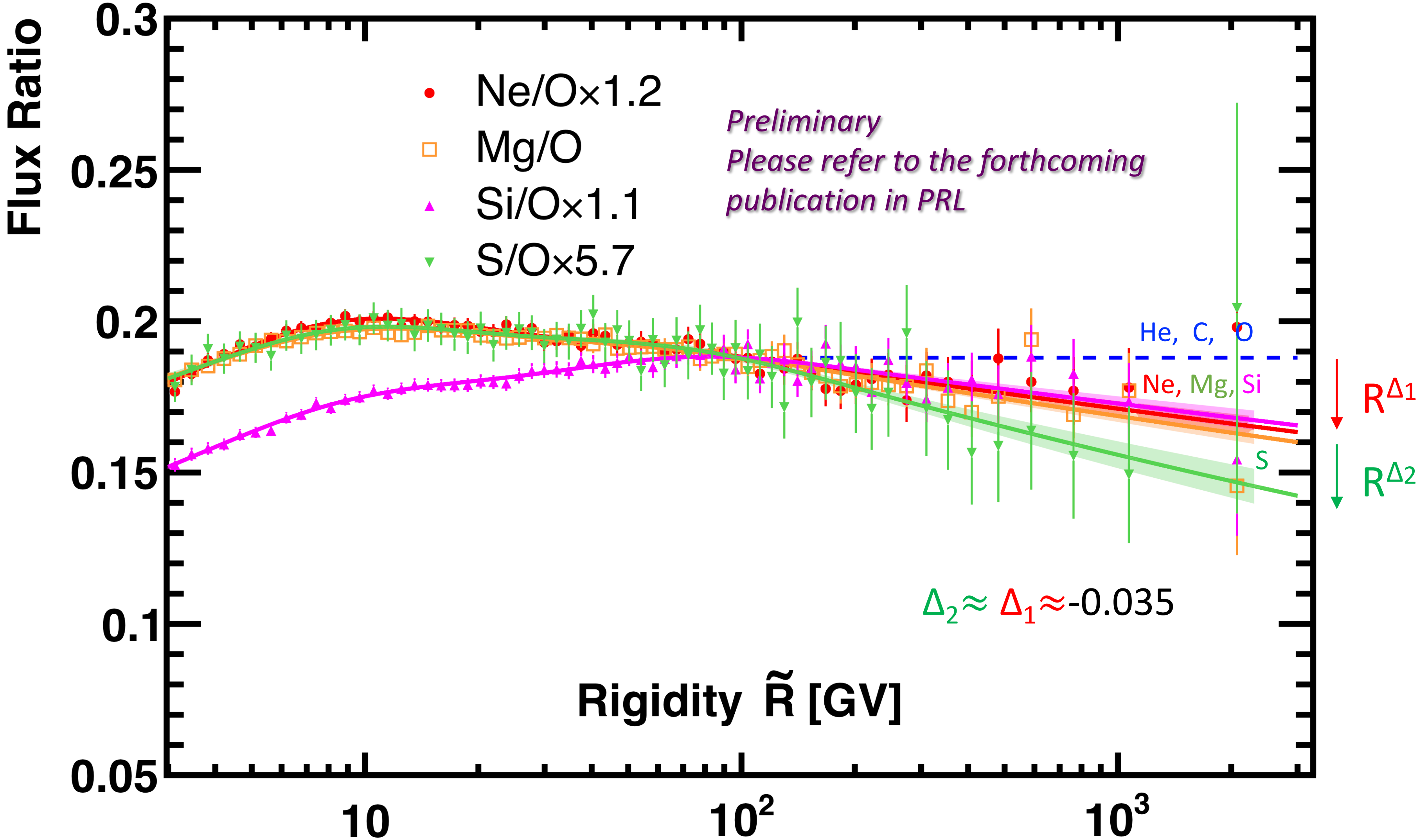


I. Angeli and K. P. Marinova. "Table of experimental nuclear ground state charge radii: An update." *Atomic Data and Nuclear Data Tables* 99.1 (2013): 69-95

O, Ne, Mg, Si and S Fluxes

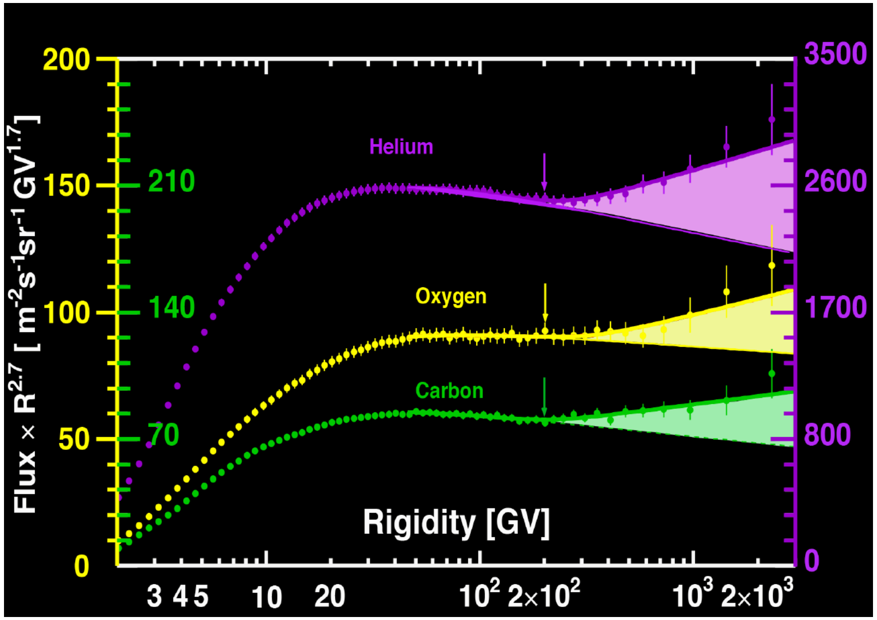


Flux Ratio to Oxygen (Ne/O, Mg/O, Si/O and S/O)

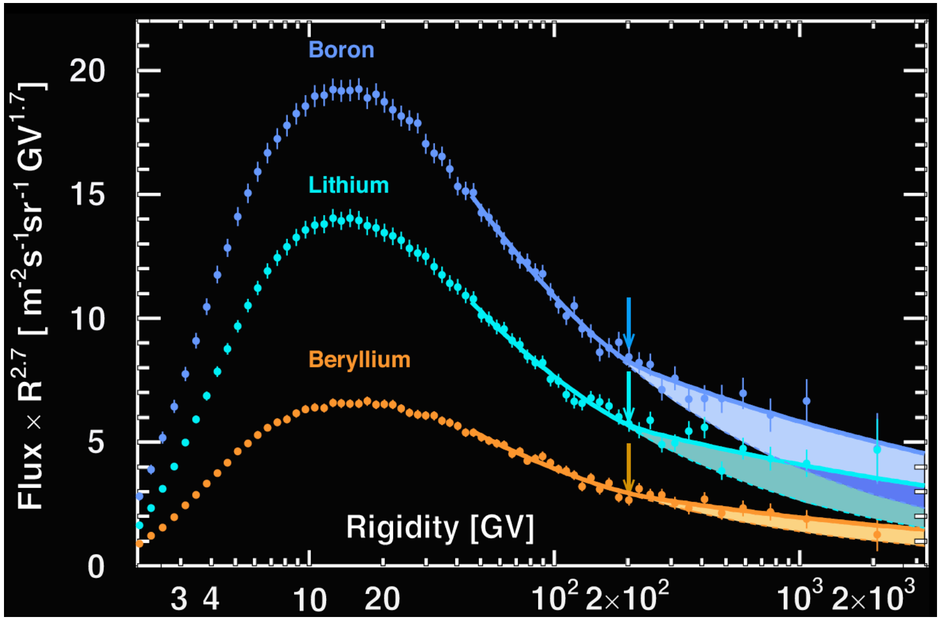


The spectral hardening > 200 GV

Primaries



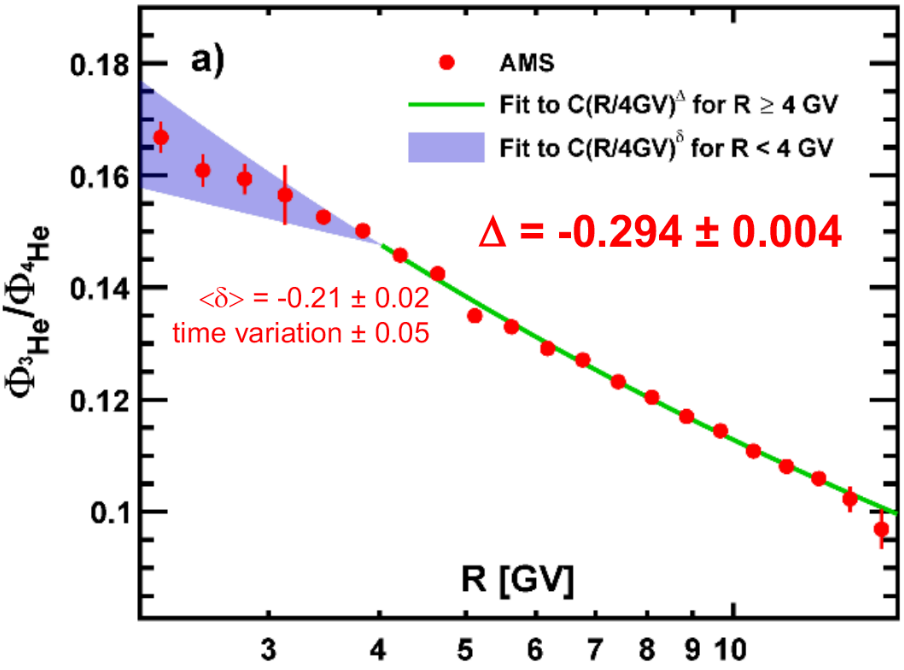
Secondaries



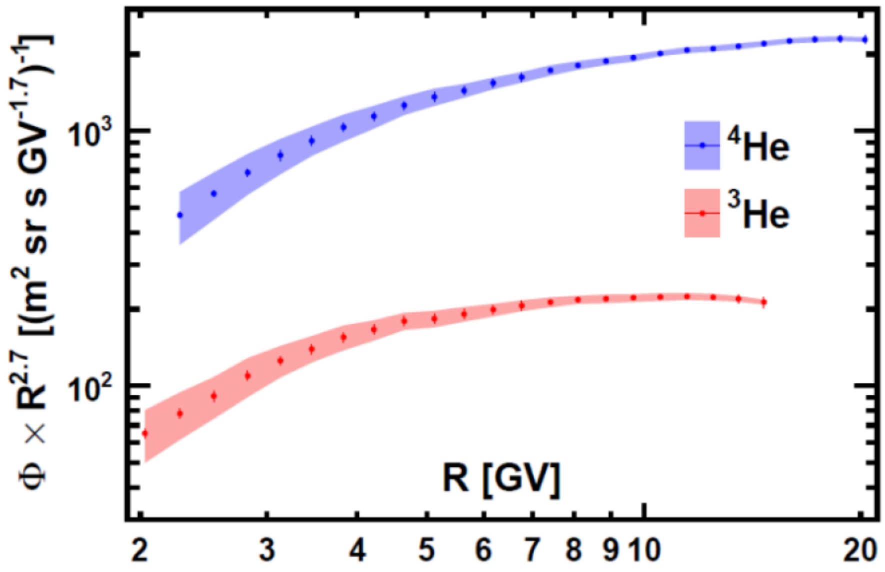
All measured fluxes exhibit a break ≈ 200 GeV
injection or propagation effect?

$^3He/^4He$ Flux ratio with AMS

$^3He/^4He$ Flux ratio

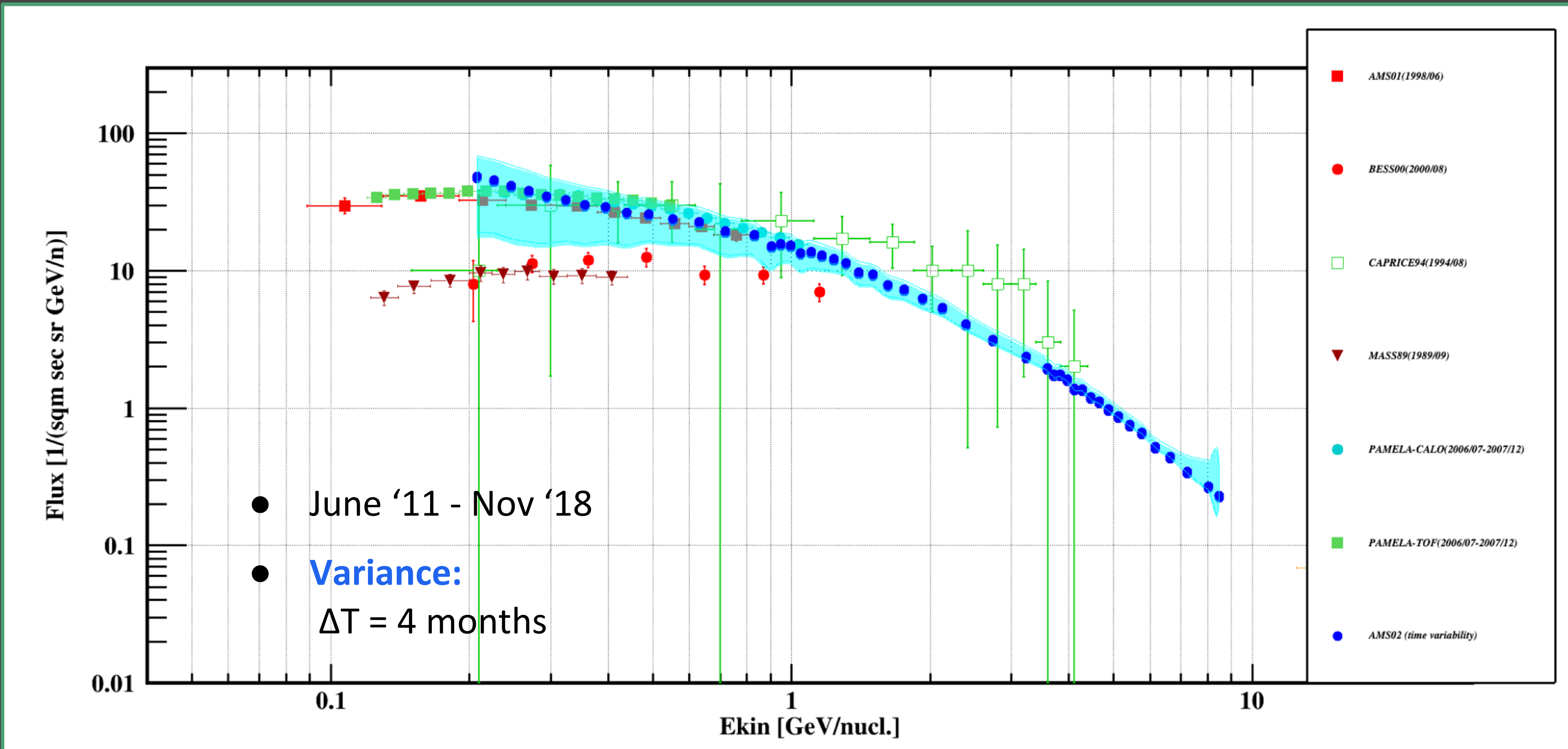


Fluxes vs Rigidity



Preliminary: please refer to our forthcoming publication on PRL

Deuteron Flux

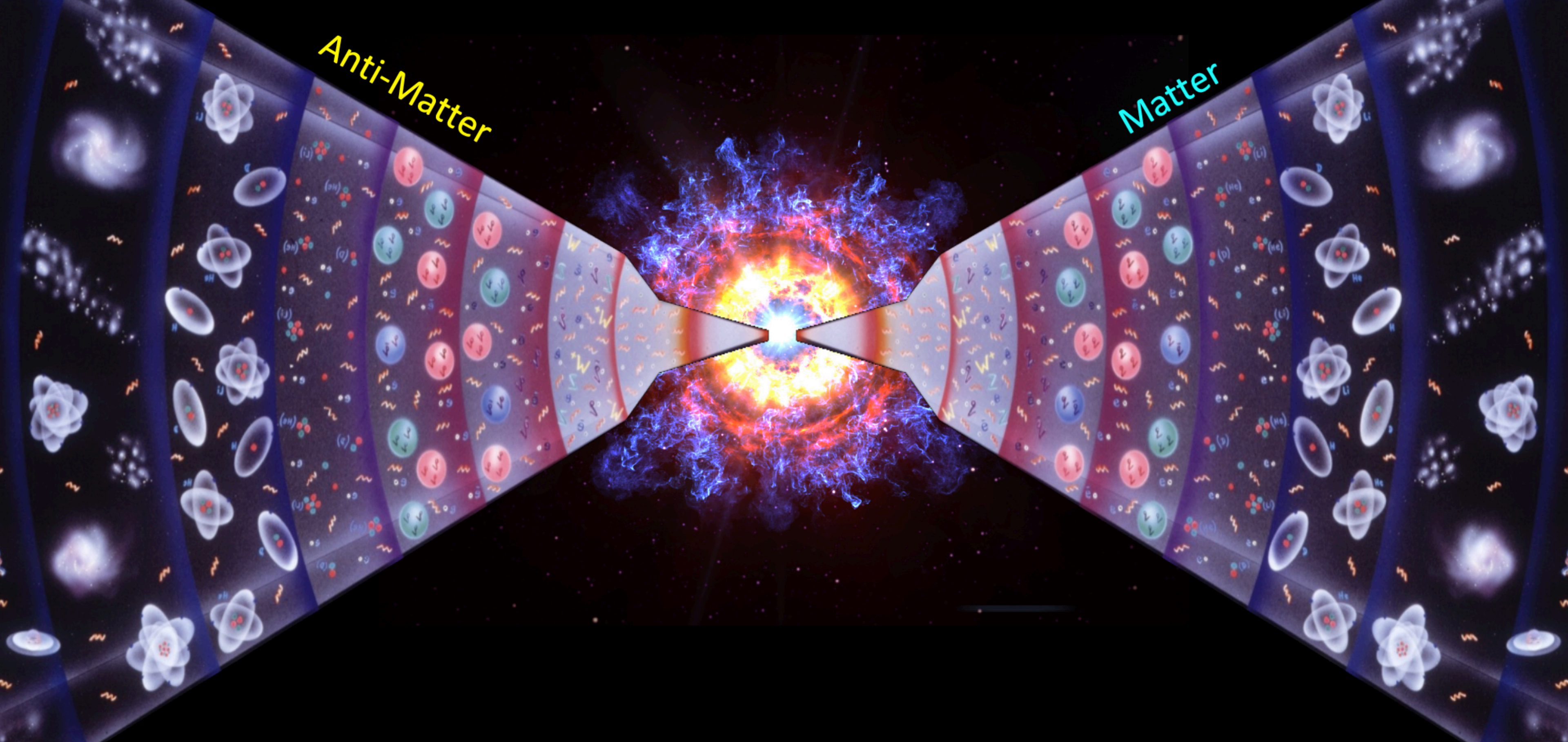


- June ‘11 - Nov ‘18
- **Variance:**
  ΔT = 4 months

Anti-Matter

Heavy Anti-Matter Search

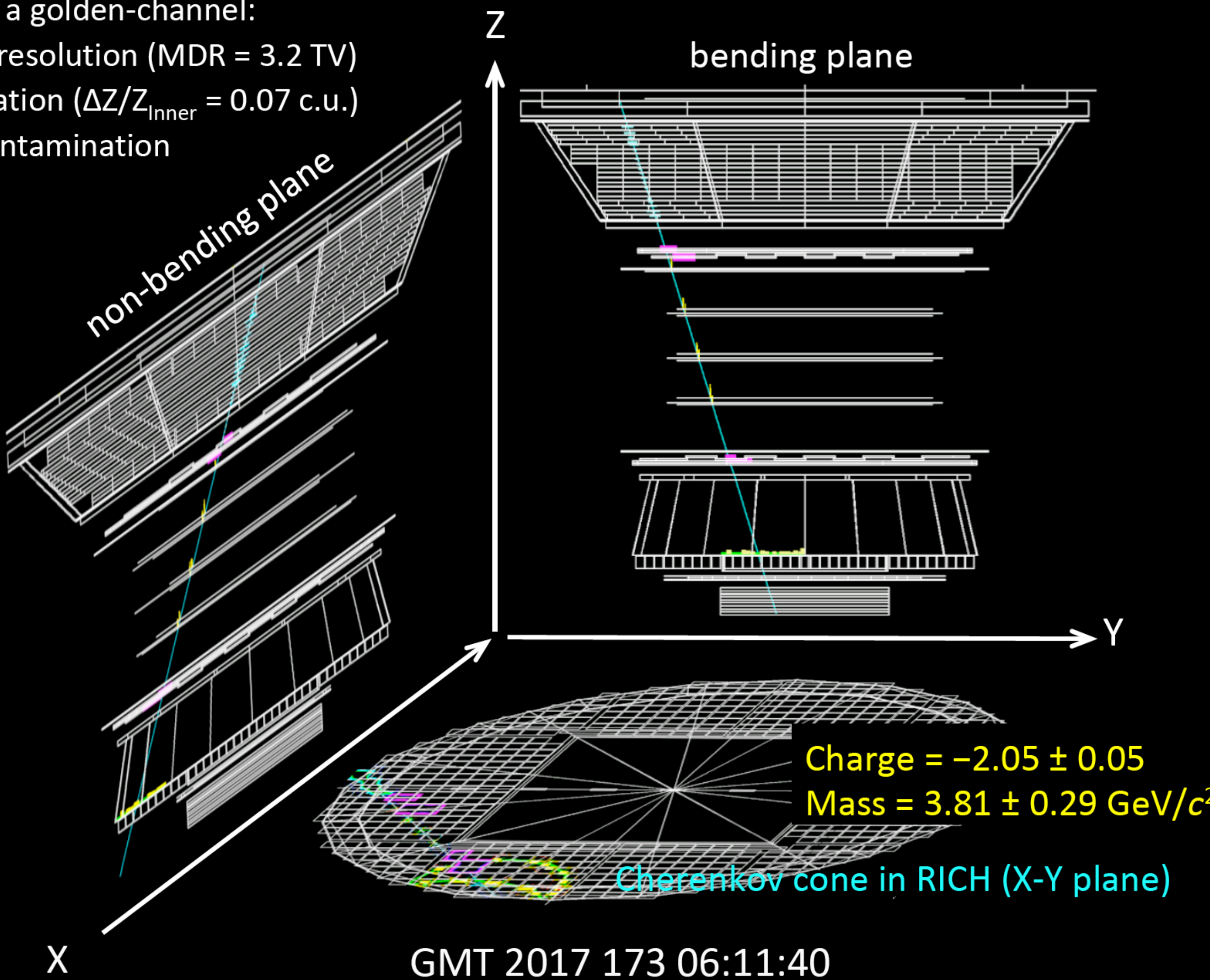
The standard Big Bang model requires matter and antimatter to be equally abundant.



As of today a experimental evidence of the mechanisms required for matter/anti-matter asymmetry (strong CP violation, proton decay, ...) has been found. Neither has a single anti-nucleus been seen in cosmic rays.

An Anti-Helium Candidate

Anti-helium is a golden-channel:
- Best rigidity resolution (MDR = 3.2 TV)
- Best Z separation ($\Delta Z/Z_{Inner}$ = 0.07 c.u.)
- No p, K, π contamination

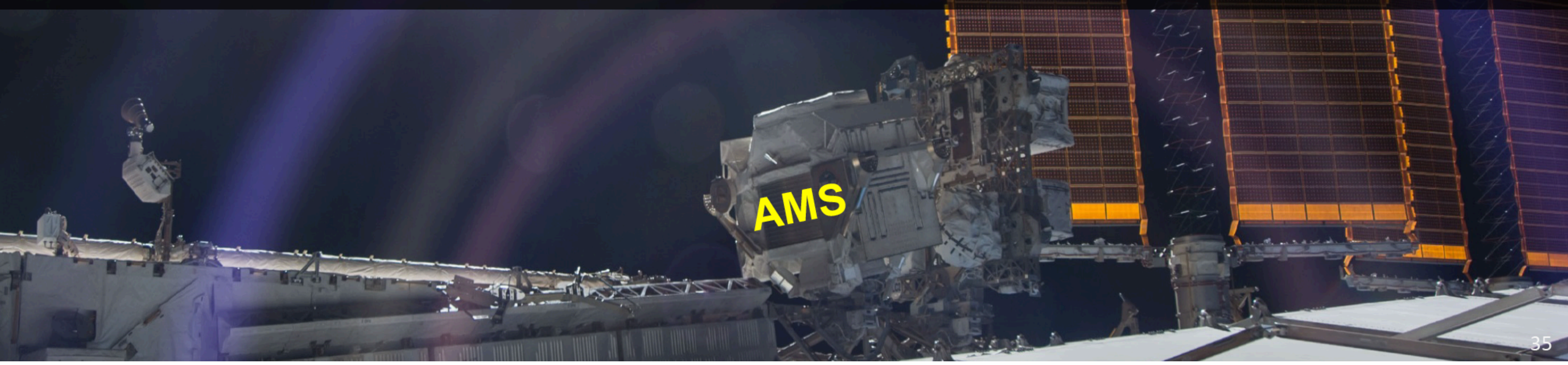


Anti-Helium Search Status

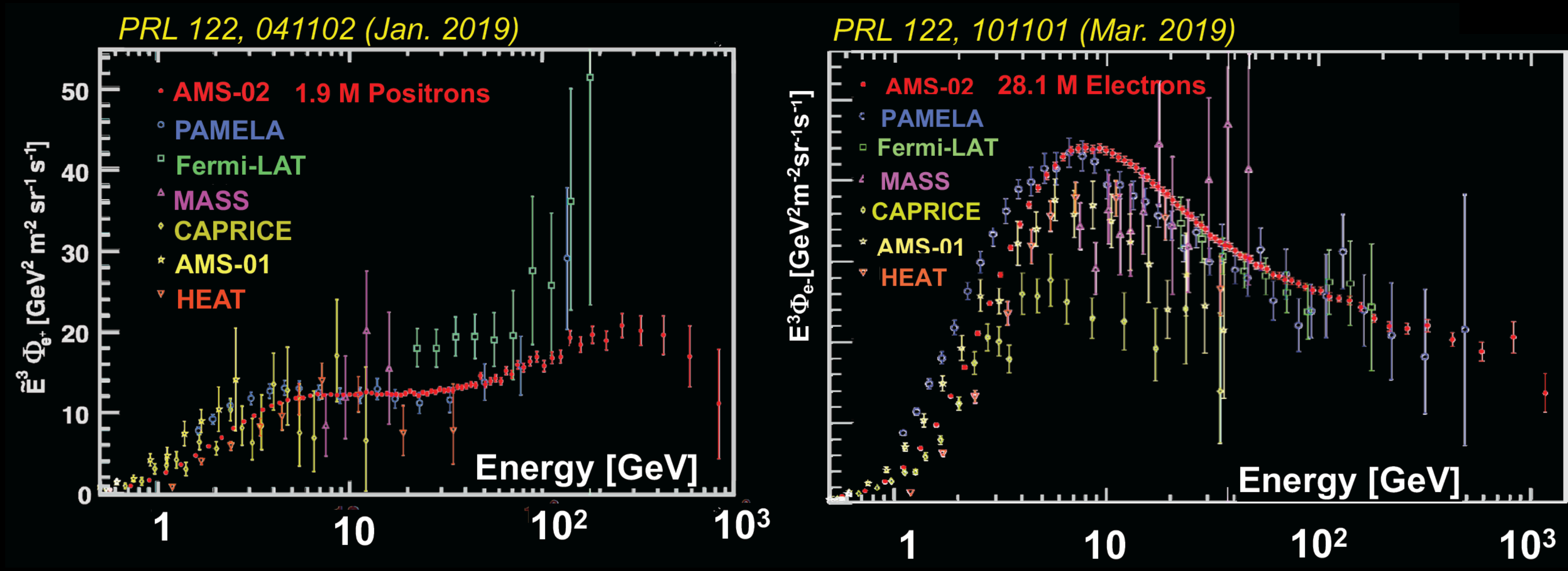
Currently, AMS observed 8 anti-helium candidates (mass region from 0-10 GeV/c^2) with rigidity <50 GV with respect to a sample of 700 million helium events selected.

The rate in AMS of antihelium candidates is less than 1 in 100 million helium.

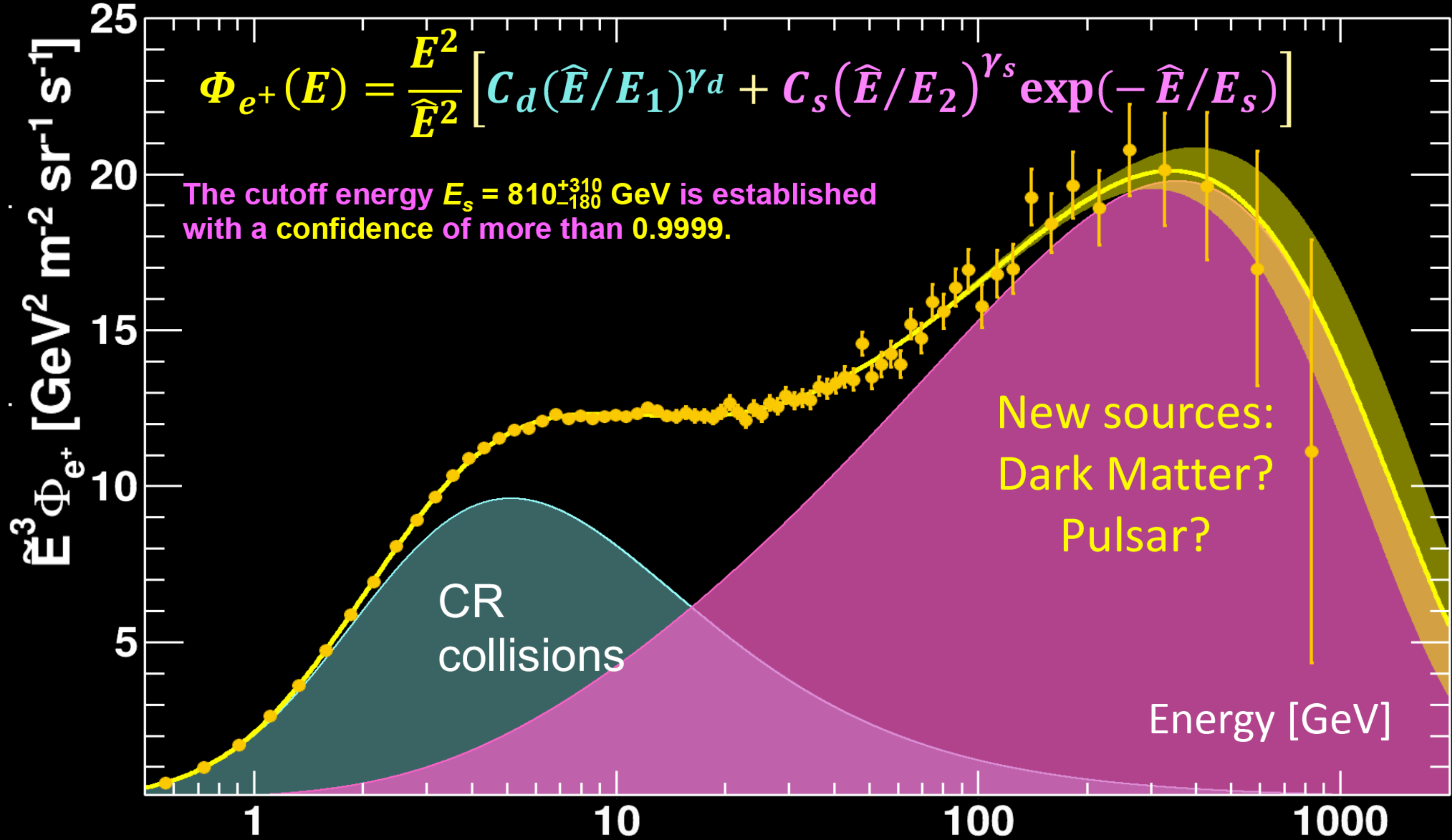
At this extremely low rate, more data (through the lifetime of the ISS) is required to further check the origin of these events.



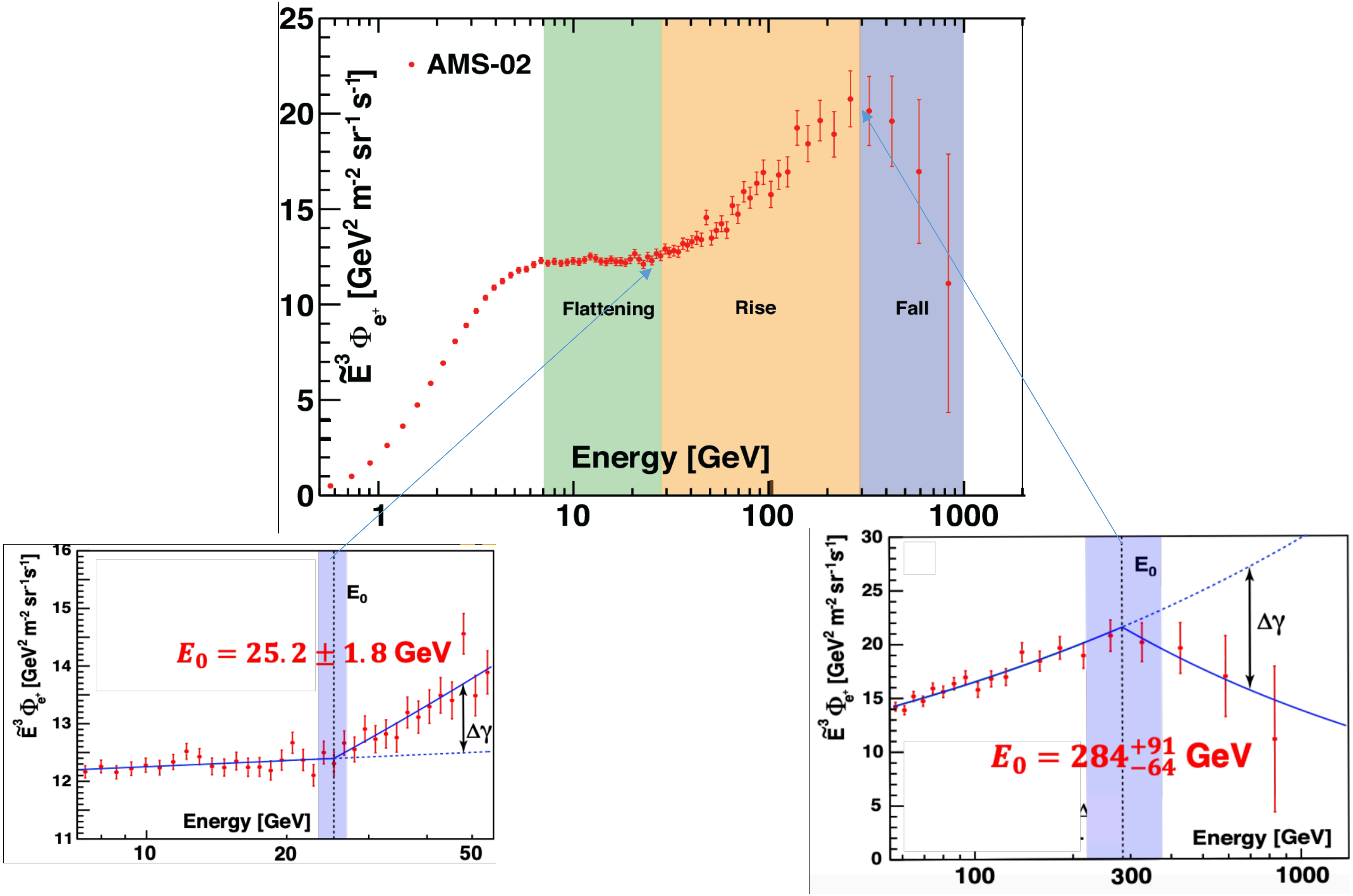
Positron and Electron fluxes



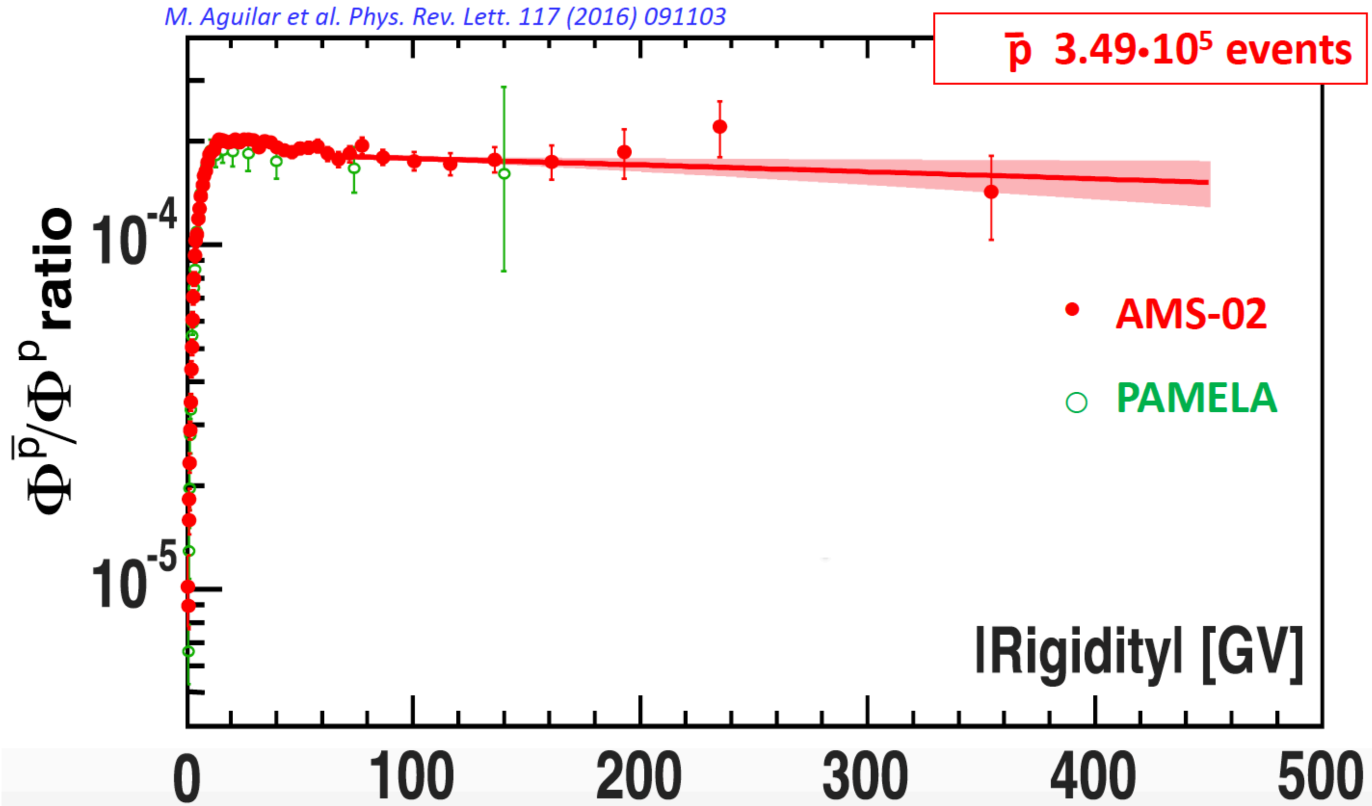
Positron Flux: two components



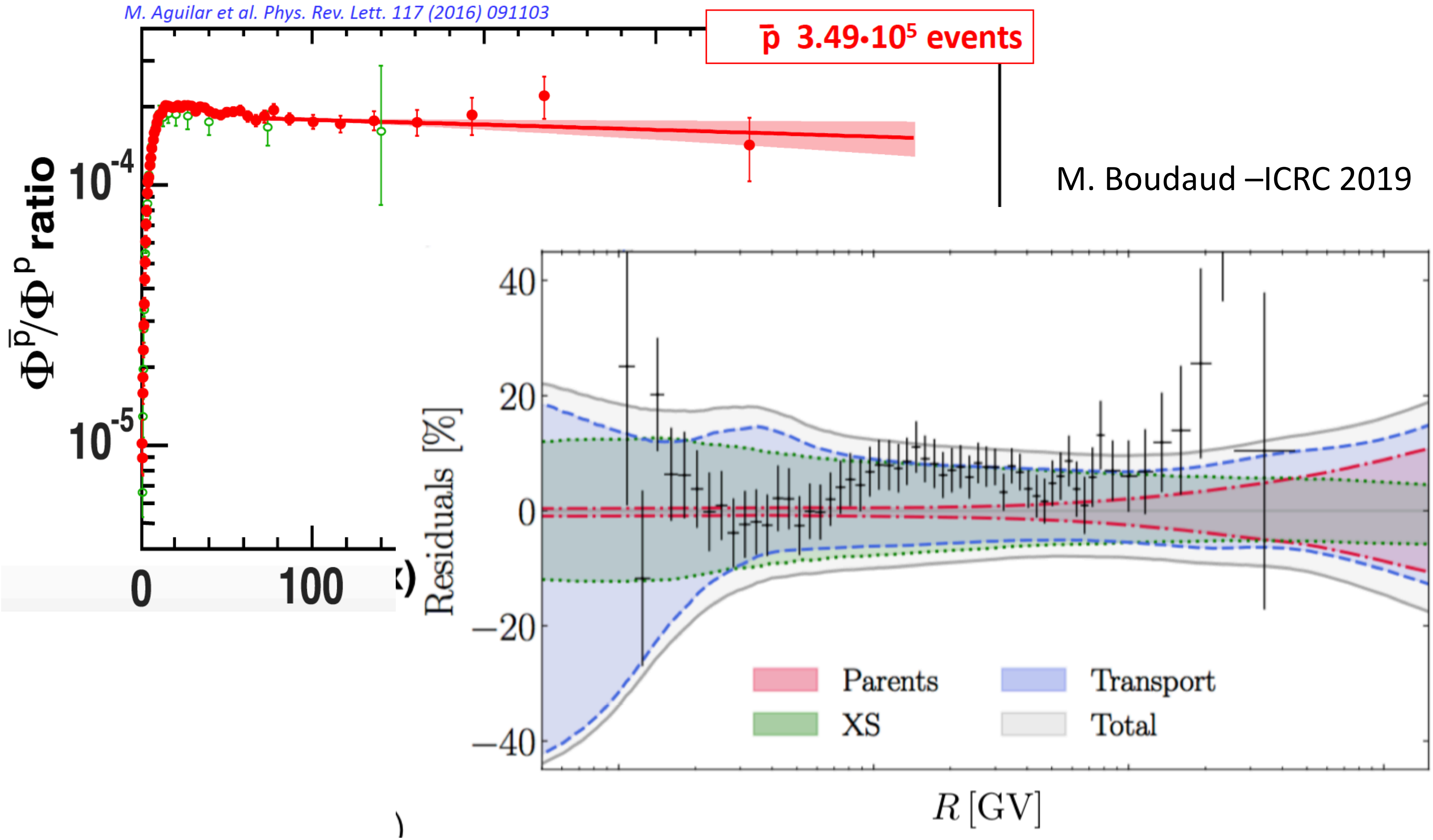
Positrons


AMS-02
$\tilde{E}^3 \Phi_{e^+}$ [GeV^2 m^{-2} sr^{-1} s^{-1}]
Flattening
Rise
Fall
Energy [GeV]
E0
$E_0 = 25.2 \pm 1.8$ GeV
Δγ
Energy [GeV]
E0
$E_0 = 284^{+91}_{-64}$ GeV
Δγ
Energy [GeV]

AMS anti-proton to proton ratio

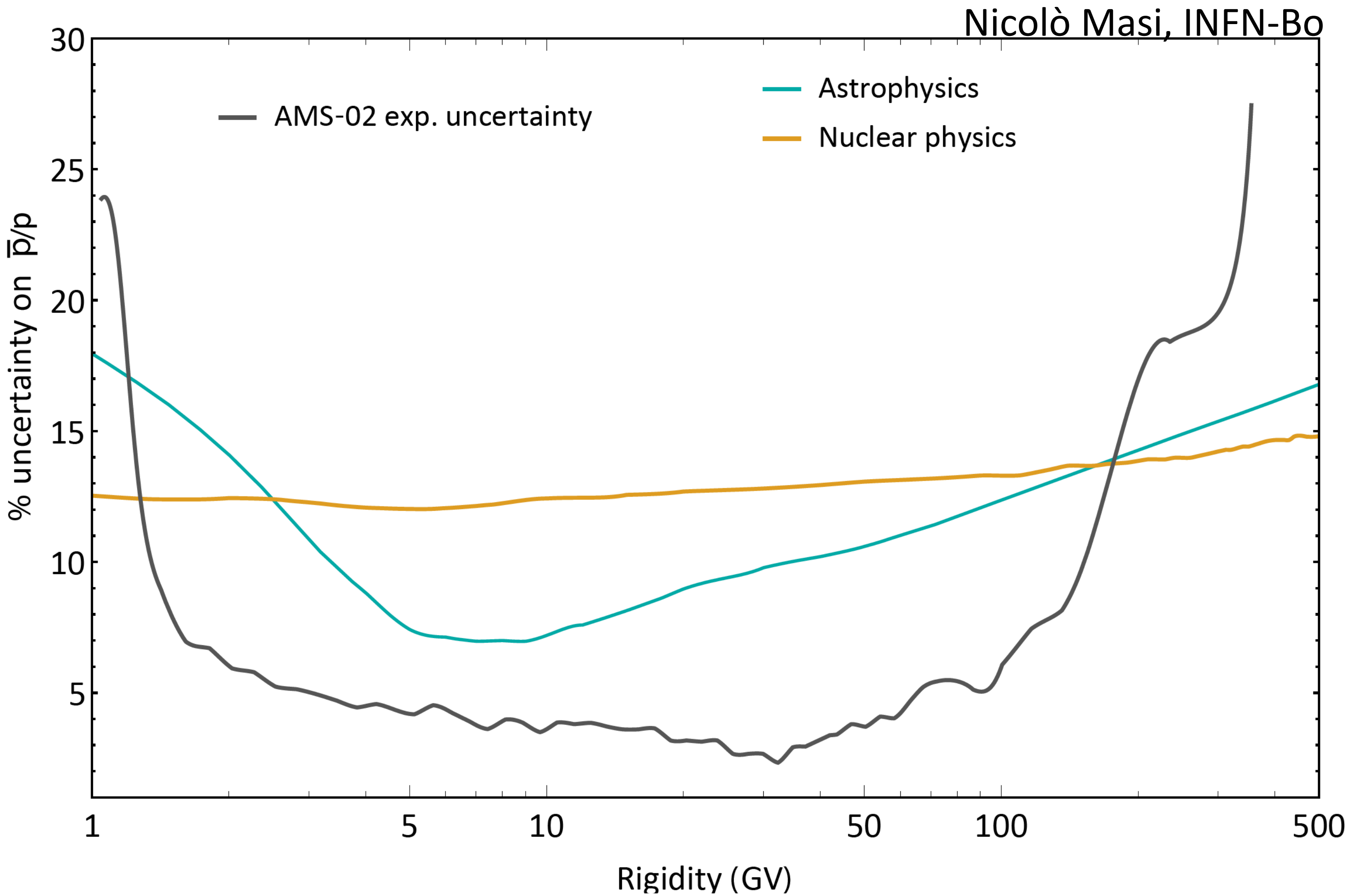


AMS anti-proton to proton ratio



M. Boudaud –ICRC 2019

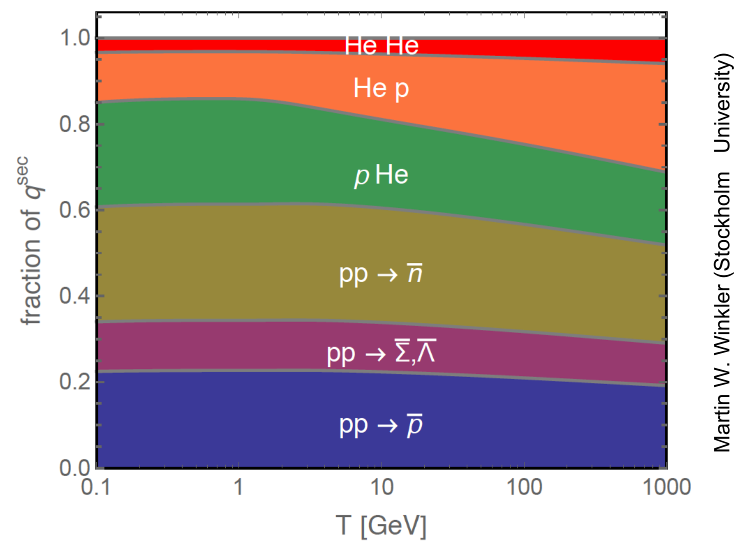
Overall Prediction Uncertainties



Limits to the p-bar prediction from XS

- anti-p production cross section from p-p and p-He interactions is poorly measured and cannot simply constrained from available measurements.
- an accurate prediction of the expected anti-p flux in cosmic rays in the rigidity range from few GeV to several hundreds of GeVs, is interesting to understand cosmic ray and possibly search for signals of new physics
- LHC-b collaboration reported a measurement the anti-p XS from 8 TeV p-He, and foresee a similar measurement with 4TeV protons.
- NA61 published p-p to anti-p at 20, 31, 40, 80, and 158 GeV/c
- we want to investigate the possibility to perform a measurement with the SPS protons between 50 and 280 GeV/c on fixed LH2 and LHe targets, and a magnetic spectrometer

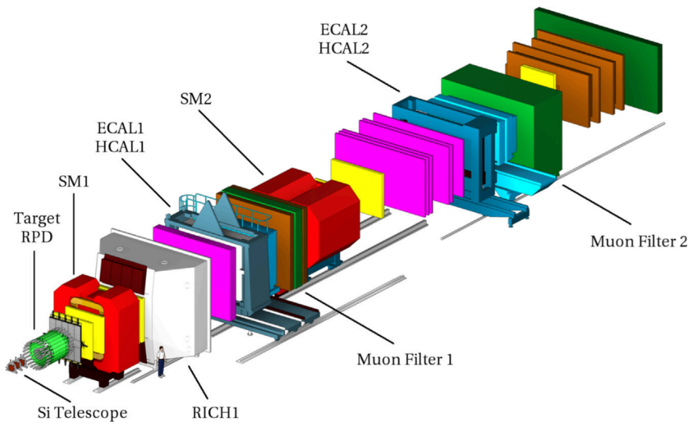
Fraction origin of anti-p from CR interaction with ISM

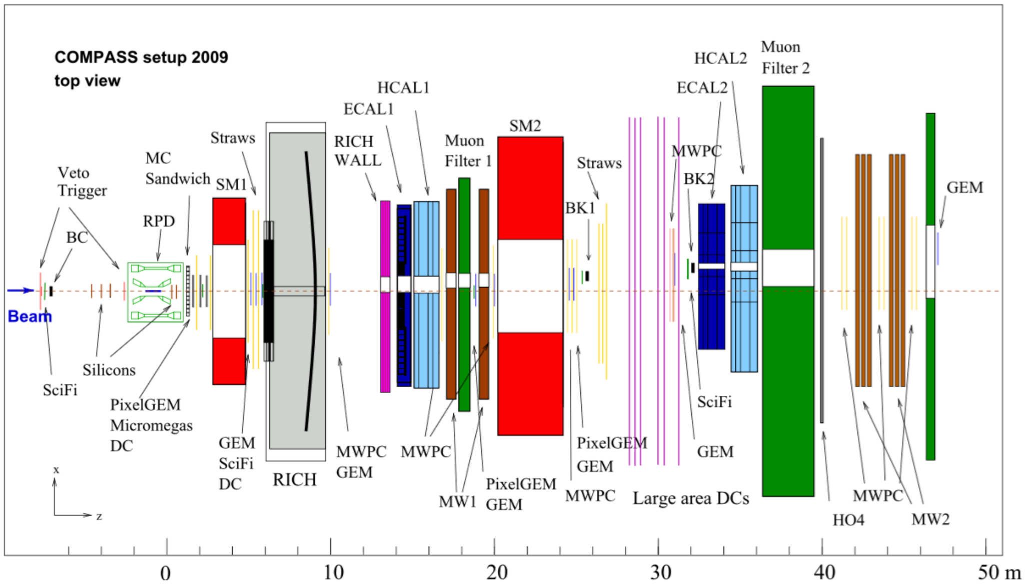


LHCb-CONF-2017-002
Measurement performed at 7 TeV
p-He -> pbar + X

NA61 p+p data beam momenta of
20, 31, 40, 80, and 158 GeV/c
Eur. Phys. J. C 77, 671 (2017)

COMPASS @ CERN





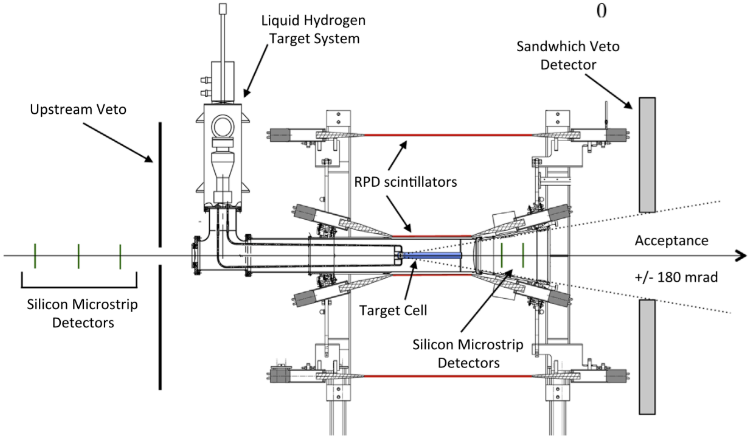


Fig. 4. Side view of the target region with the liquid hydrogen target system.

Acceptance:
+/- 180 mrad
+/- 10 deg
$2.4 < \eta < 6$

New anti-p cross sections with COMPASS++/AMBER

- Use secondary proton beam from SPS
  50, 100, 190, 280 GeV/c
- Use Liquid Hydrogen target and Liquid He target
- Use the COMPASS spectrometer to reconstruct the inelastic event and measure the momentum and charge sign of the tracks attached to the primary vertex
- Use the COMPASS RICH detector to identify anti-p
- Measure the anti-p production cross section for p-p and p-He.

COMPASS++/AMBER

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SPSC-2019–003
SPSC-I-250
January 28, 2019

Letter of Intent:

A New QCD facility at the M2 beam line of the CERN SPS*

COMPASS++†/AMBER‡

B. Adams[13,12], C.A. Aidala[1], R. Akhunzyanov[14], G.D. Alexeev[14], M.G. Alexeev[41], A. Amoroso[41,42],
V. Andrieux[44], N.V. Anfimov[14], V. Anosov[14], A. Antoshkin[14], K. Augsten[14,32], W. Augustyniak[46],

TION FOR NUCLEAR RESEARCH

CERN-SPSC-2019–022
SPSC-P-360
October 14, 2019

Proposal for Measurements at the M2 beam line of the CERN SPS

– Phase-1 –

COMPASS++*/AMBER†

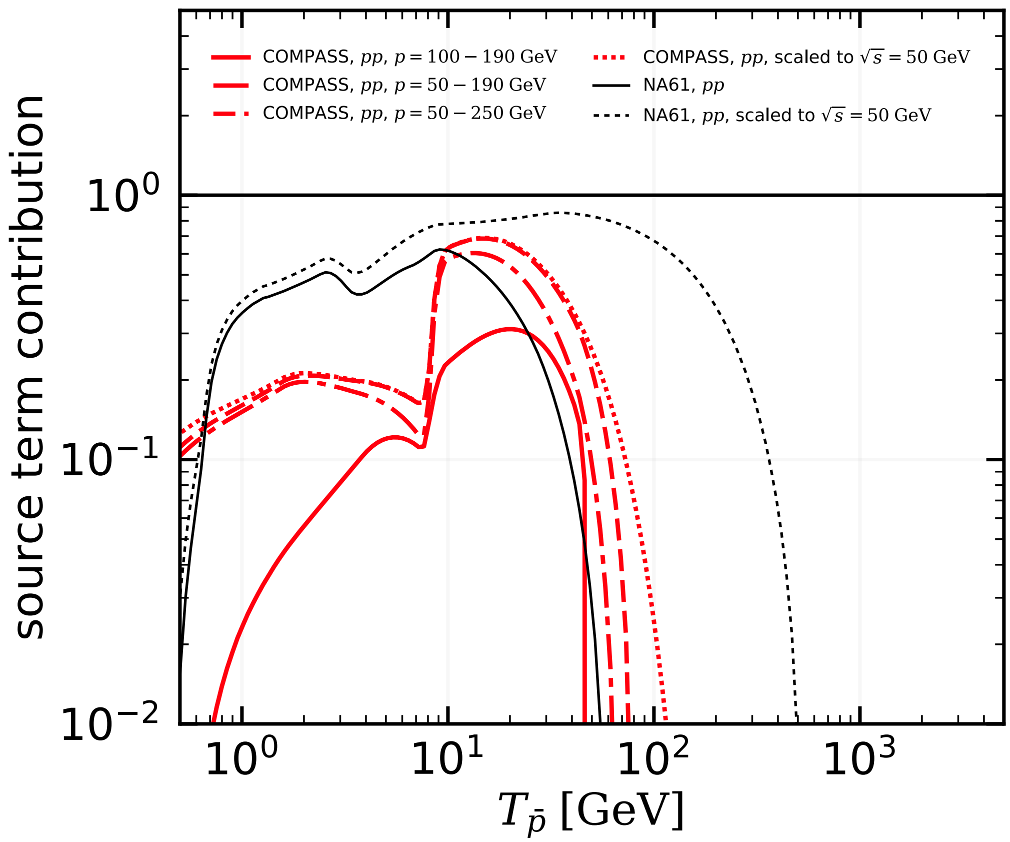
Relevance of the measurement

p-p source term coverage

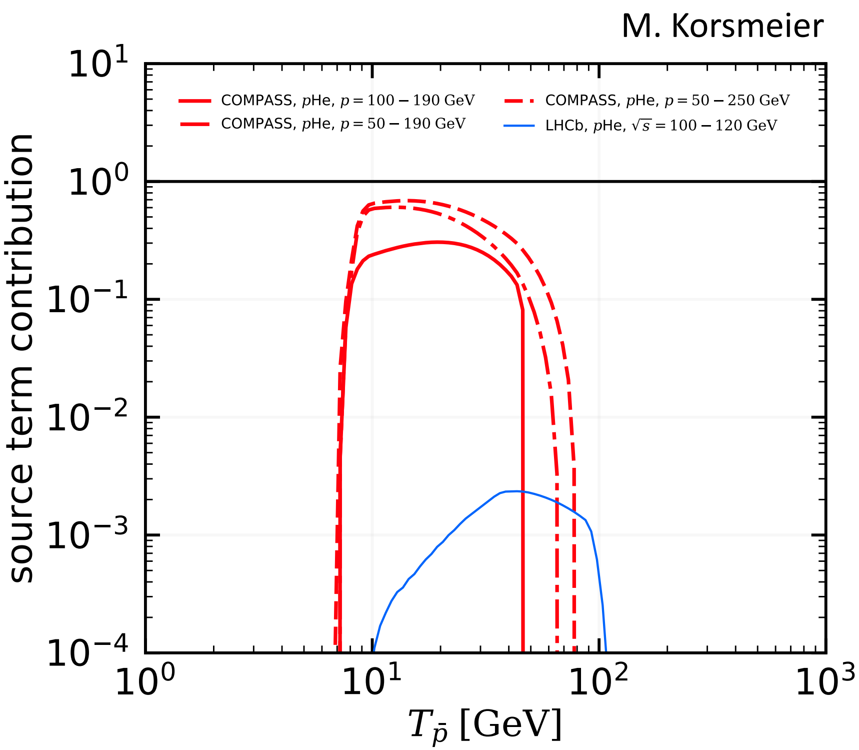
M. Korsmeier

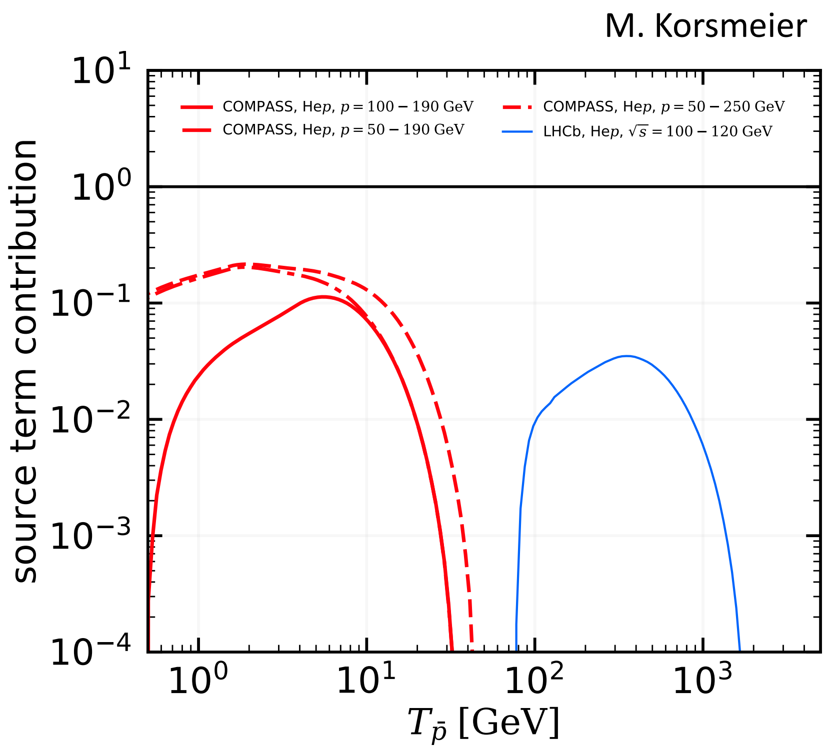
Red AMBER

Black NA61



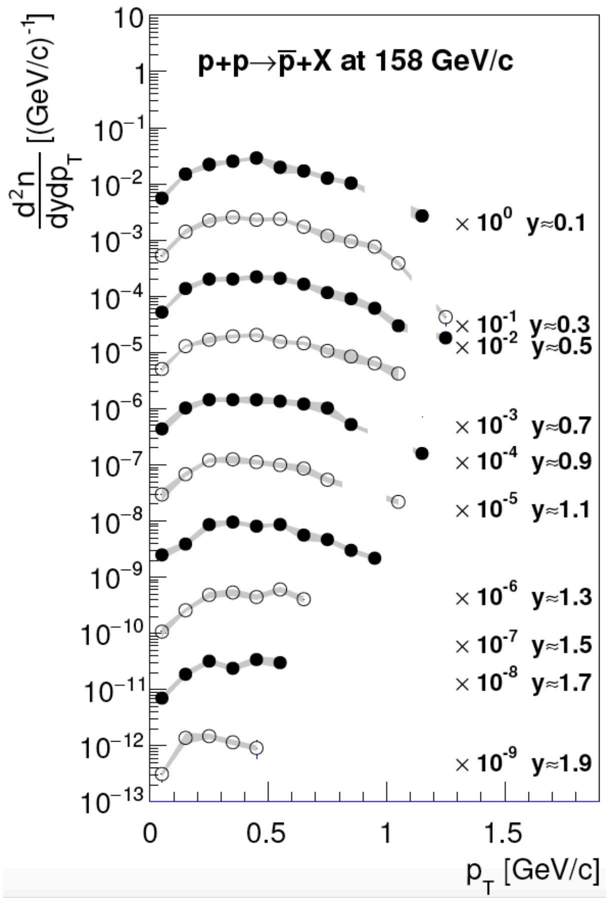
p-He He-p Source term coverage



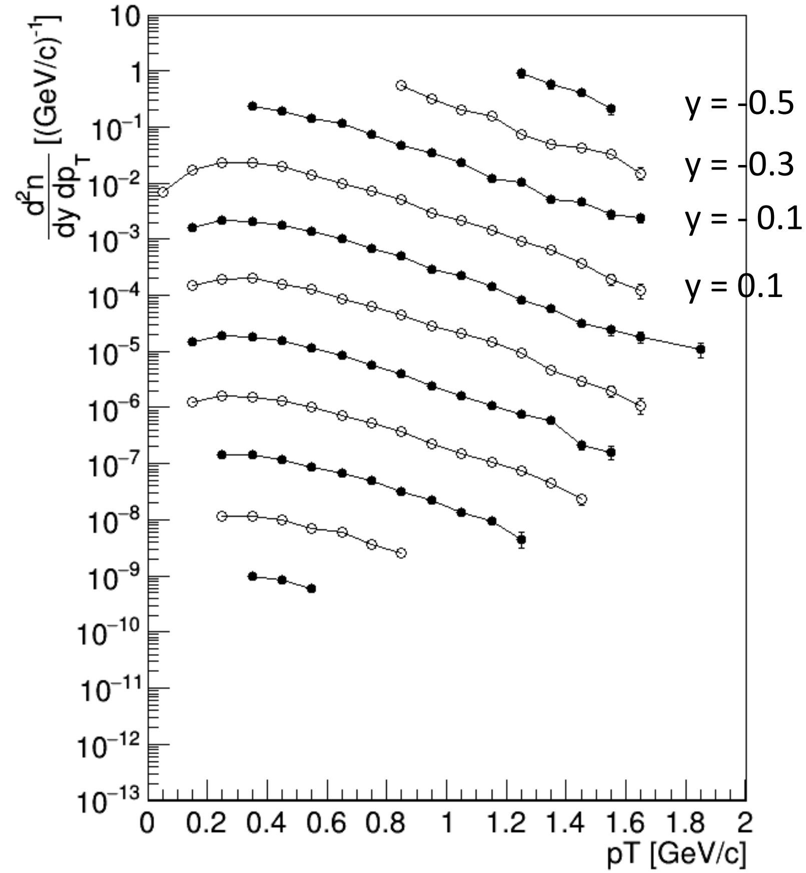


Comparison of p-p -> bar-p +X with NA61

NA61
158 GeV p on LH2

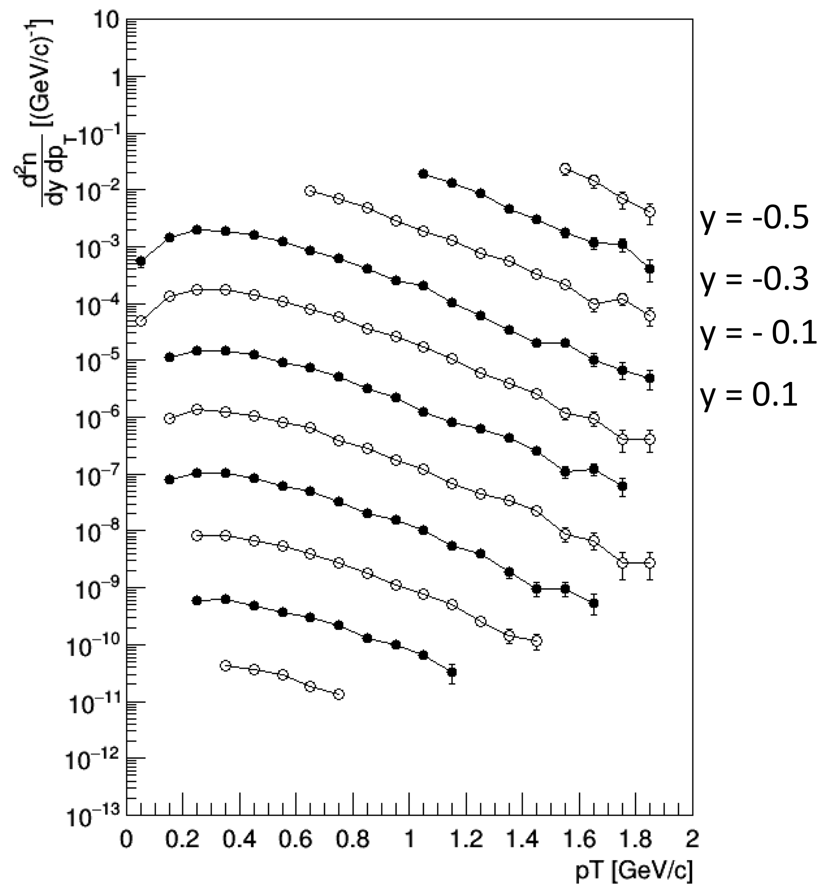


COMPASS++/AMBER
190 GeV/c on LH2



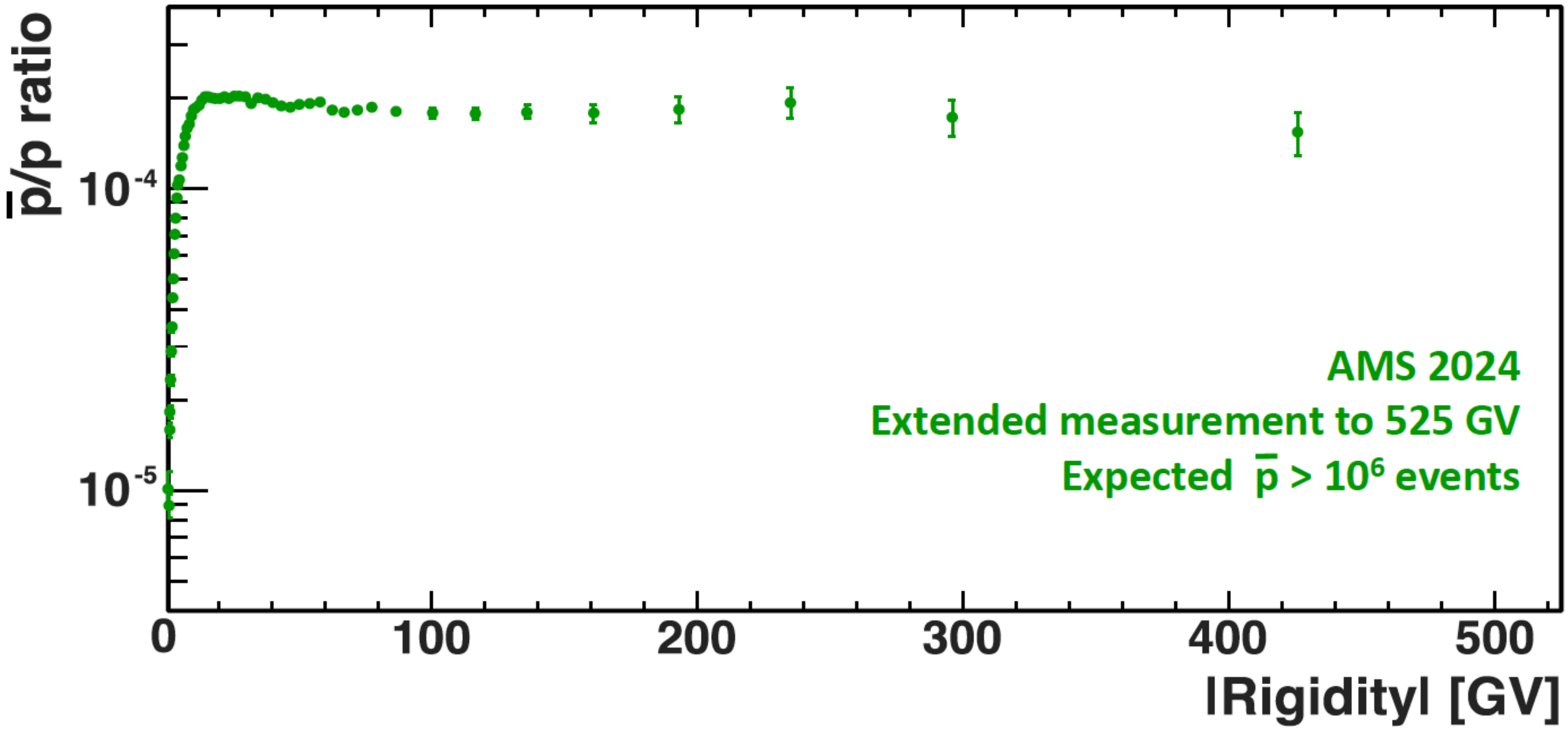
Expected cross section measurement p-He -> bar-p + X

p 190 GeV/c

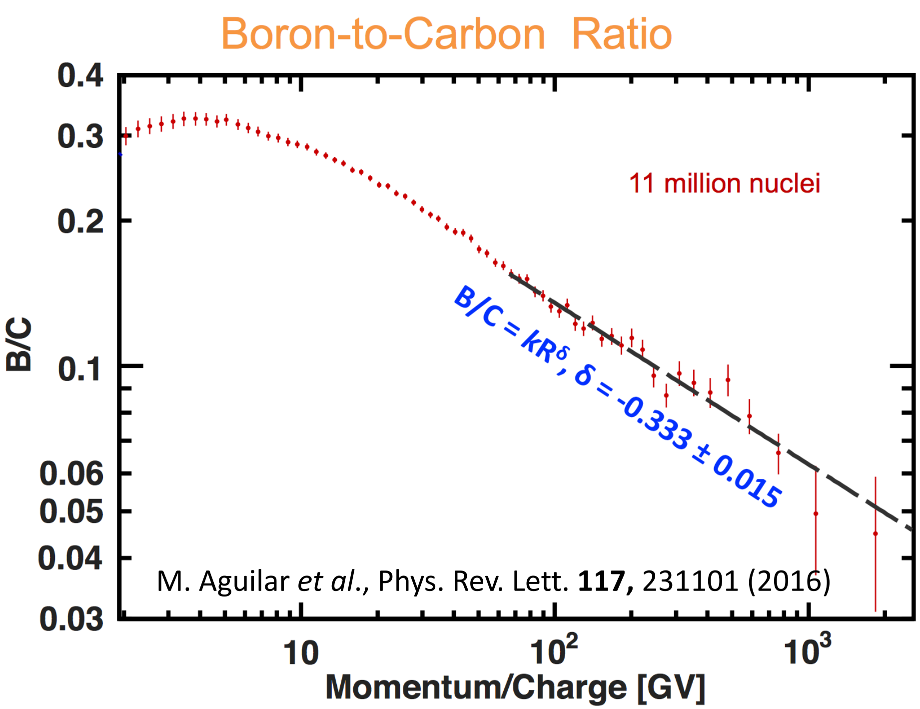


AMS anti-proton to proton ratio

Projection to 2024



Precision propagation constraints



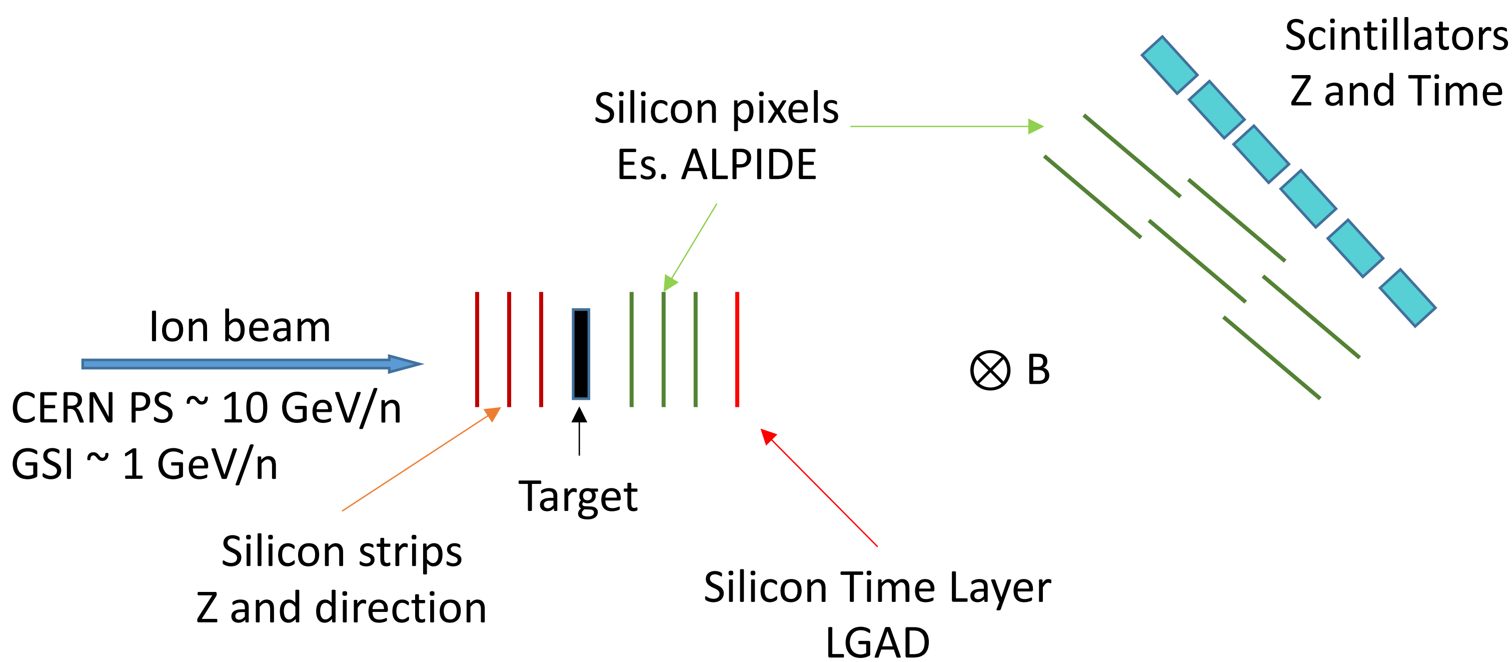
Most Important Cross-Section for B/C

Reaction $a + b \to c$	Flux impact f_{abc} [%] min	mean	max	σ [mb] range	Data	σ^c/σ
$\sigma(^{12}C + H \to {}^{11}B)$	18.0	**18.1**	19.0	30.0	✓	1.8
$\sigma(^{\mathbf{12}}\mathbf{C} + \mathbf{H} \to {}^{\mathbf{11}}\mathbf{C})$	16.0	**16.2**	17.0	26.9	✓	n/a
$\sigma(^{16}O + H \to {}^{11}B)$	11.3	**11.8**	12.0	18.2	✓	1.5
$\sigma(^{12}C + H \to {}^{10}B)$	7.20	**7.41**	7.60	12.3	✓	1.1
$\sigma(^{16}O + H \to {}^{10}B)$	6.82	**7.03**	7.21	10.9	✓	
$\sigma(^{\mathbf{16}}\mathbf{O} + \mathbf{H} \to {}^{\mathbf{11}}\mathbf{C})$	5.67	**5.89**	6.00	9.1		n/a
$\sigma(^{11}B + H \to {}^{10}B)$	4.00	**4.07**	4.20	38.9	✓	
$\sigma(^{12}C + He \to {}^{11}B)$	2.50	**2.59**	2.70	38.6		1.8
$\sigma(^{\mathbf{12}}\mathbf{C} + \mathbf{He} \to {}^{\mathbf{11}}\mathbf{C})$	2.10	**2.14**	2.20	32.0		n/a
$\sigma(^{15}N + H \to {}^{11}B)$	2.00	**2.03**	2.10	26.1	✓	1.2
$\sigma(^{\mathbf{12}}\mathbf{C} + \mathbf{H} \to {}^{\mathbf{10}}\mathbf{C})$	1.80	**1.87**	1.90	3.1	✓	n/a
$\sigma(^{16}O + He \to {}^{11}B)$	1.67	**1.75**	1.80	24.4		1.5
$\sigma(^{13}C + H \to {}^{11}B)$	1.50	**1.53**	1.60	22.2		1.7
$\sigma(^{12}C + H \to {}^{10}Be)$	1.40	**1.48**	1.50	4.0	✓	
$\sigma(^{14}N + H \to {}^{11}B)$	1.30	**1.34**	1.36	17.3	✓	1.7
$\sigma(^{12}C + He \to {}^{10}B)$	1.00	**1.06**	1.10	15.8		1.1
$\sigma(^{16}O + He \to {}^{10}B)$	0.99	**1.05**	1.09	14.6		
$\sigma(^{24}Mg + H \to {}^{11}B)$	0.98	**1.01**	1.00	10.4		1.6

Genolini et al. PhysRevC. 98,034611

We need new measurement of nuclei fragmentation cross-sections !

Example of Portable setup for nuclei frag. measurements



This detector are easily available within the Italian community

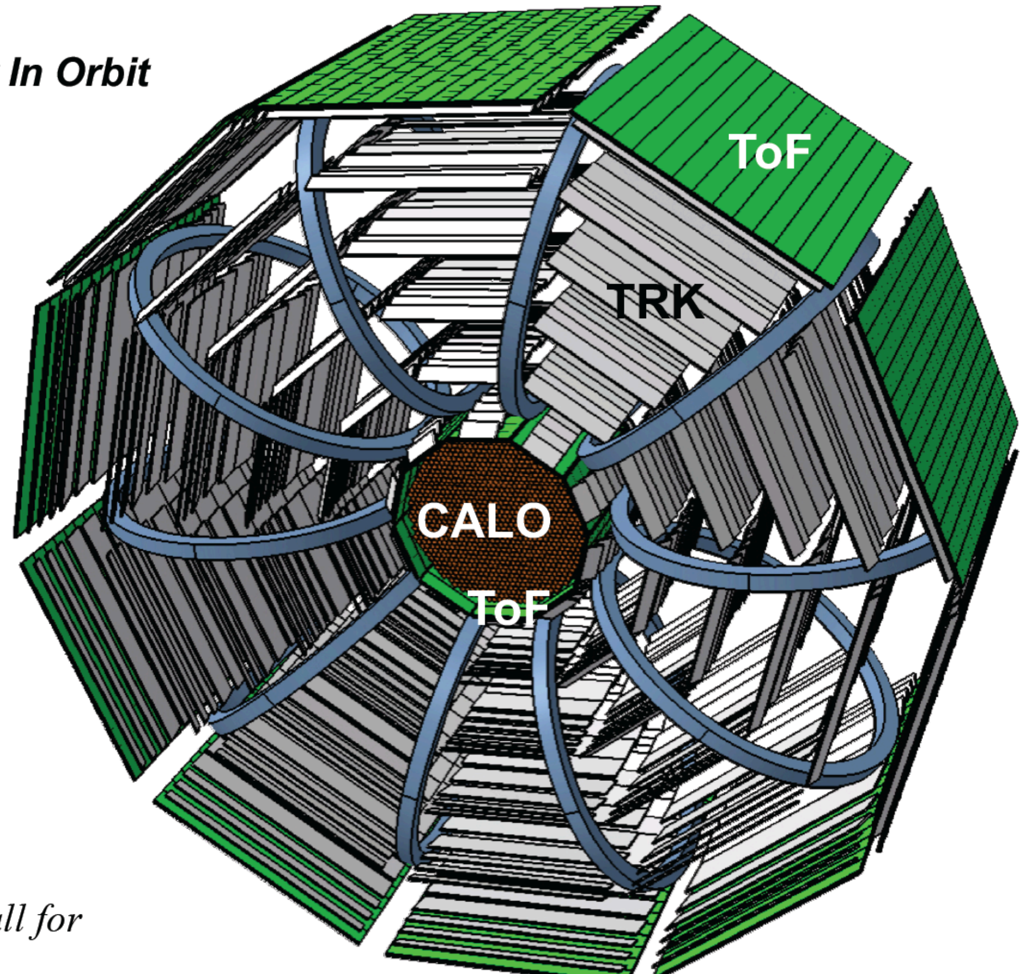
What’s next ?

High Precision Particle Astrophysics as a New Window on the Universe

with an Antimatter Large Acceptance Detector In Orbit

(ALADInO)

@ Lagrangian point L2



A White Paper submitted in response to ESA’s Call for the VOYAGE 2050 long-term plan

https://www.cosmos.esa.int/web/voyage-2050/white-papers

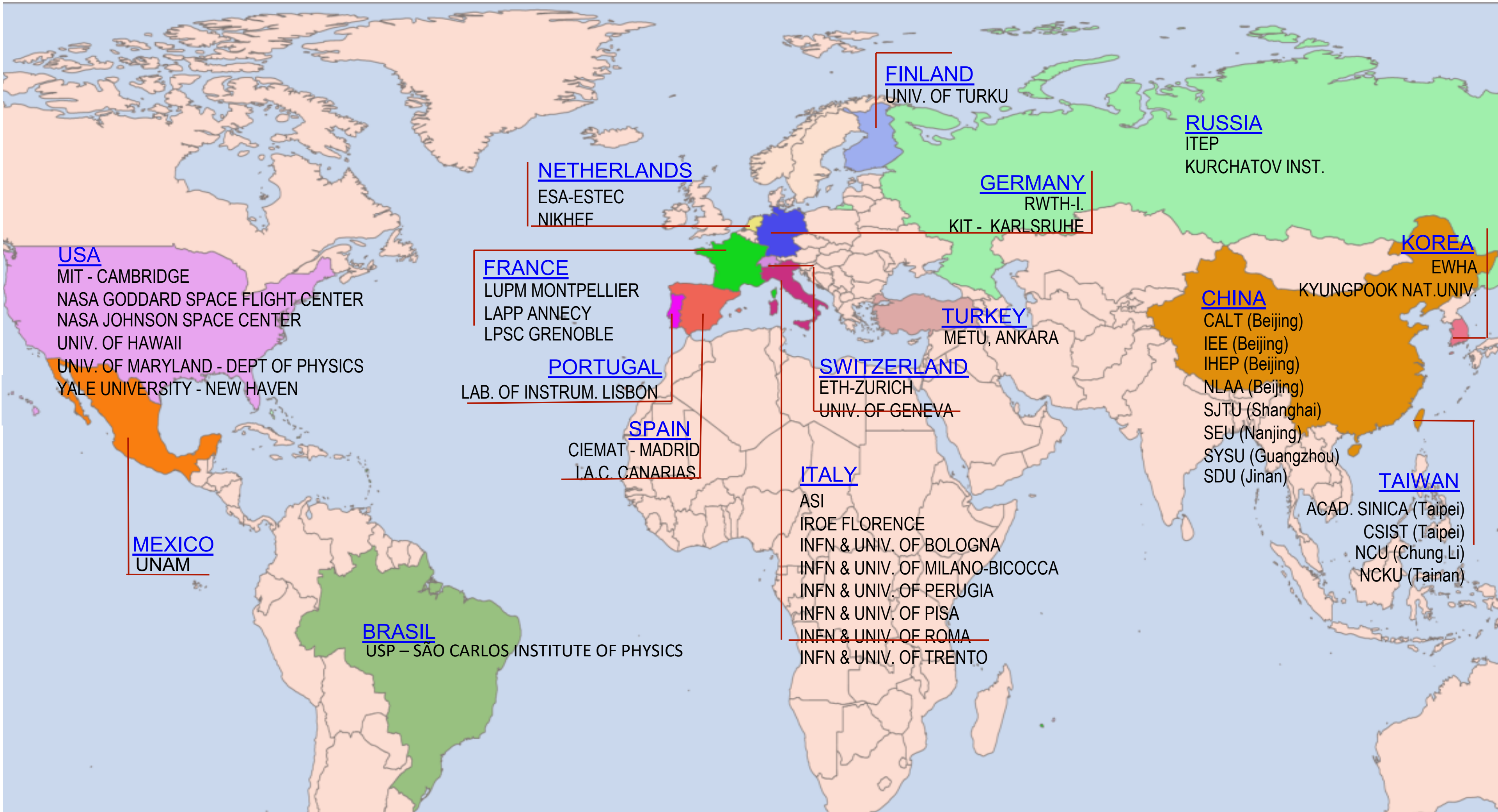
https://www.cosmos.esa.int/documents/1866264/3219248/BattistonR_ALADINO_PROPOSAL_20190805_v1.pdf

Conclusions

- AMS is providing simultaneous measurements of different cosmic ray species with
- O(%) accuracy in an extended energy range
- new phenomena are being highlighted by these measurements whose nature will be
- further clarified as more data will be collected by the experiment.
- AMS will match the lifetime of the Space Station: stay tuned !
- Cross-sections must be measured on ground

AMS is MIT led International Collaboration

16 Countries, 60 Institutes and 600 Physicists, 17 years

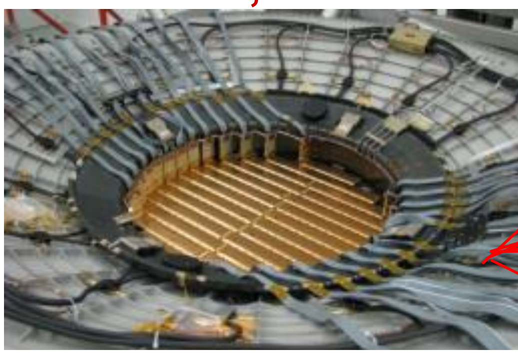


AMS-02 is controlled 24/7 from CERN, Geneva, Switzerland

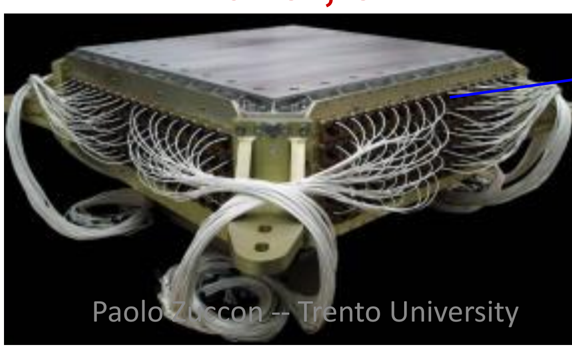
AMS: A TeV precision, multipurpose spectrometer

TRD
Identify e⁺, e⁻, Z

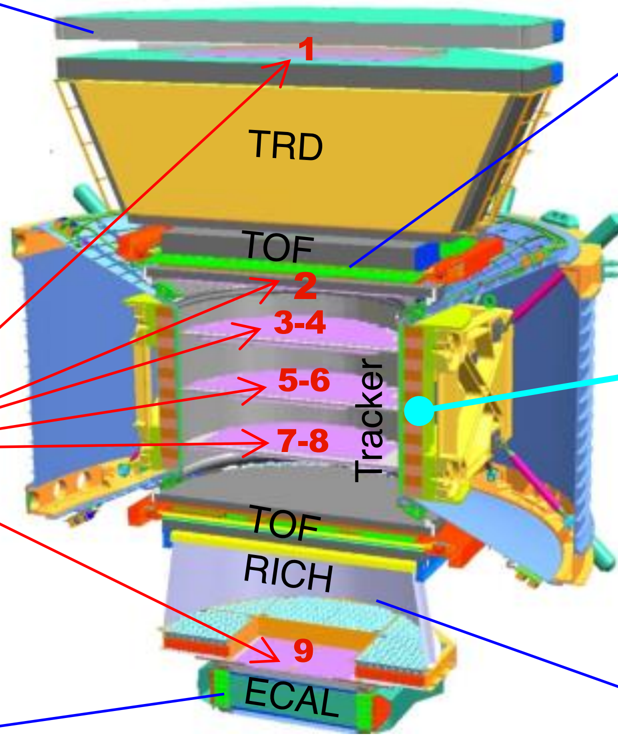
Silicon Tracker
Z, P



ECAL
E of e⁺, e⁻



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

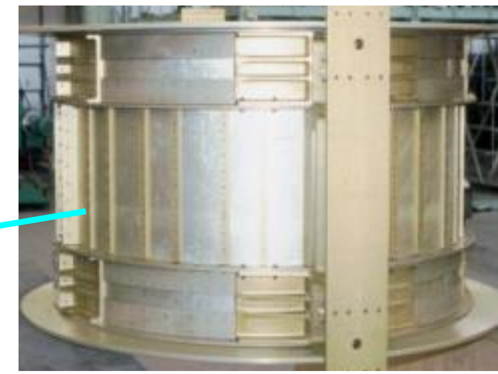


Z and P

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

TOF
Z, E

Magnet
±Z



RICH
Z, E