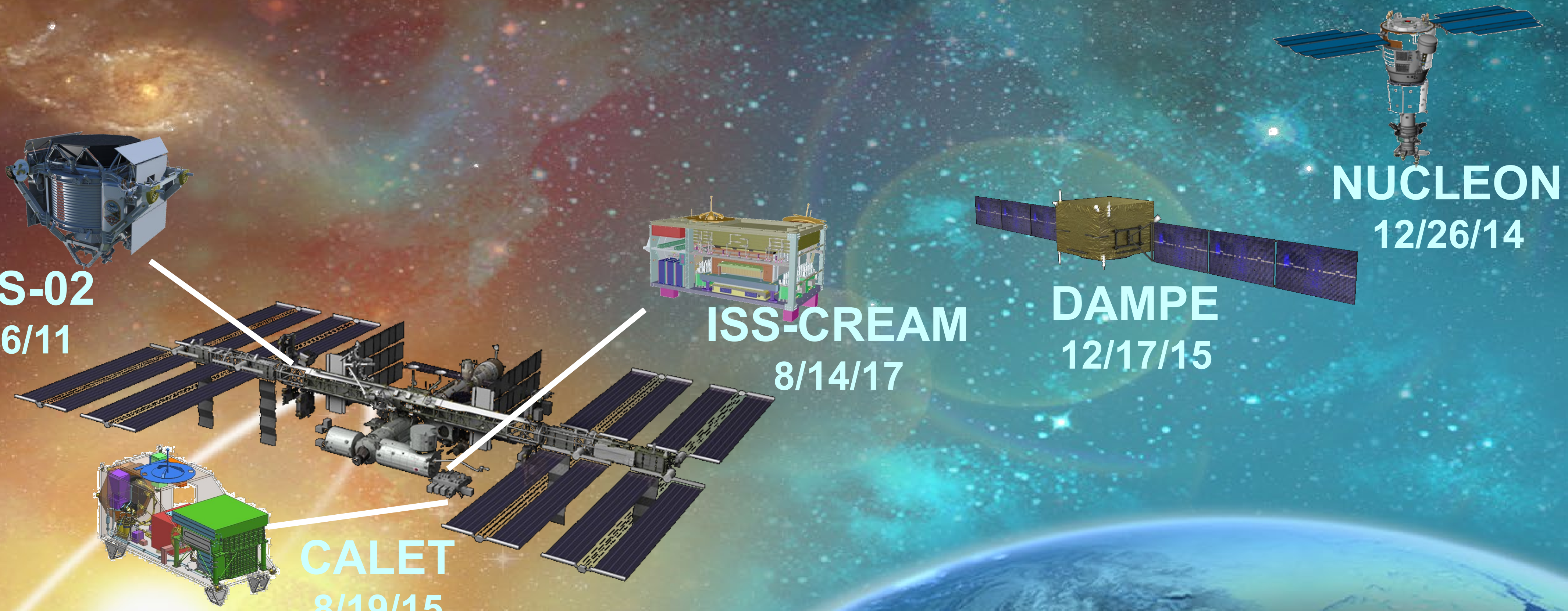
APS physics APRIL MEETING 2022

quarks Q2C cosmos

April 9–12 New York, NY

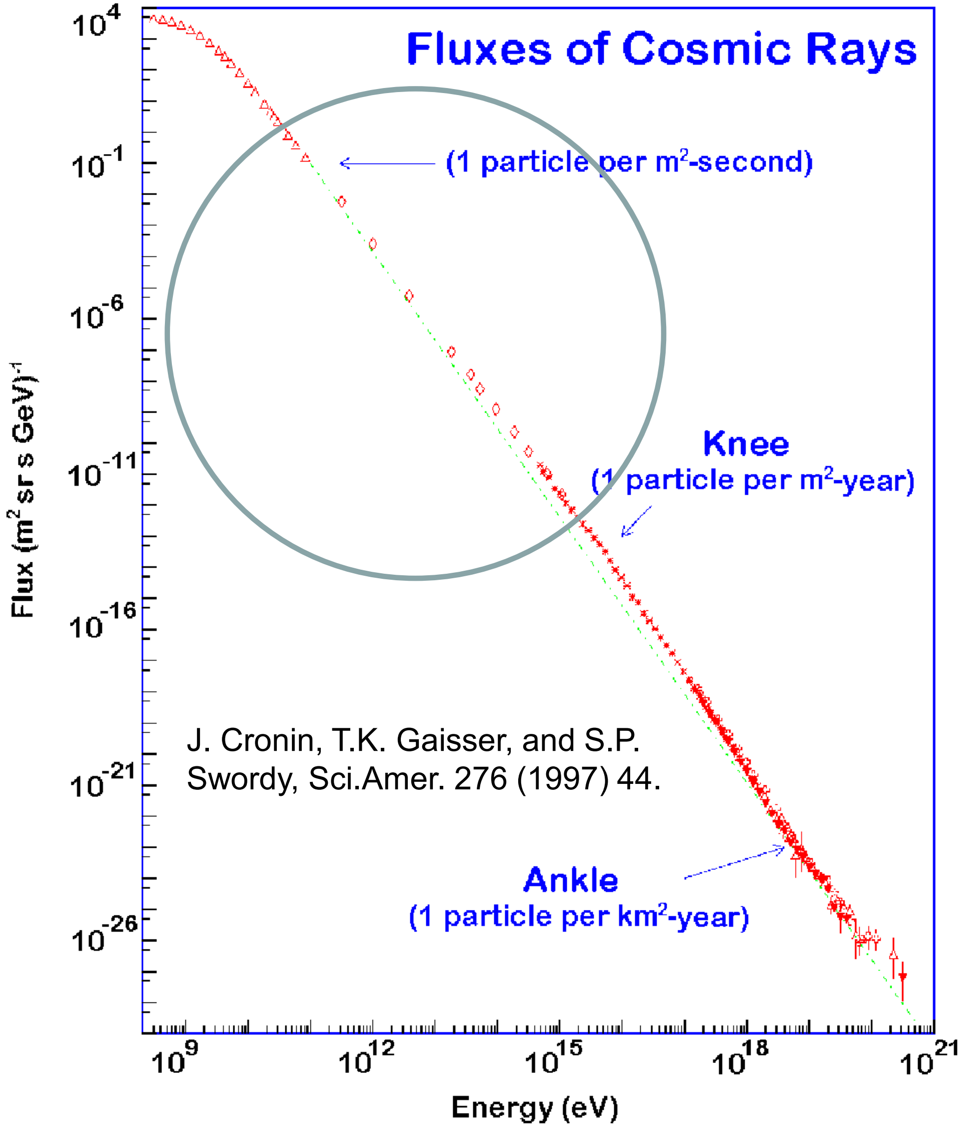
Cosmic Ray Science Interest Group (CR SIG), April 11, 2022

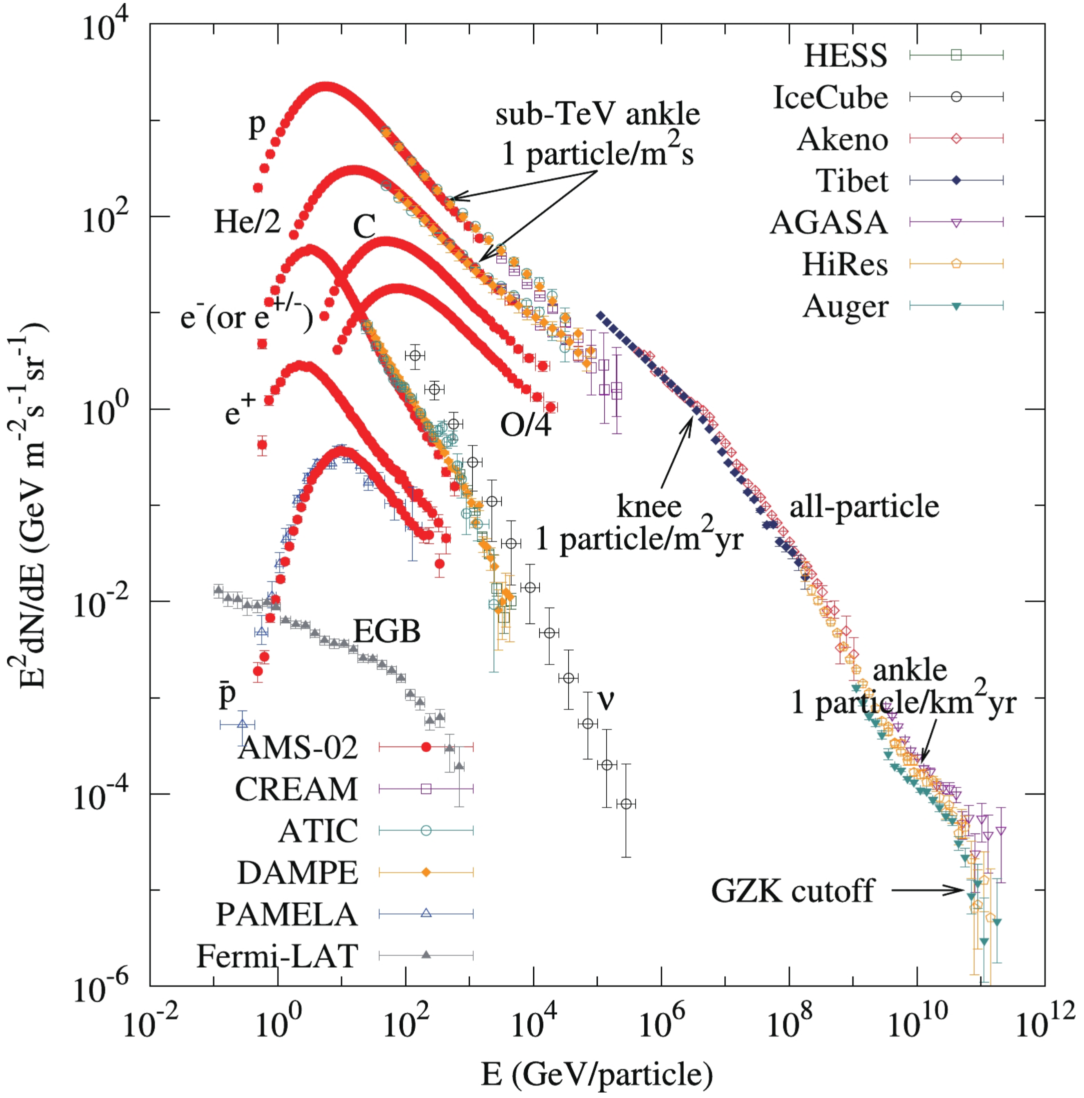
Direct Measurements of Cosmic Rays



Eun-Suk Seo
University of Maryland

Recent experiments fill the data gap

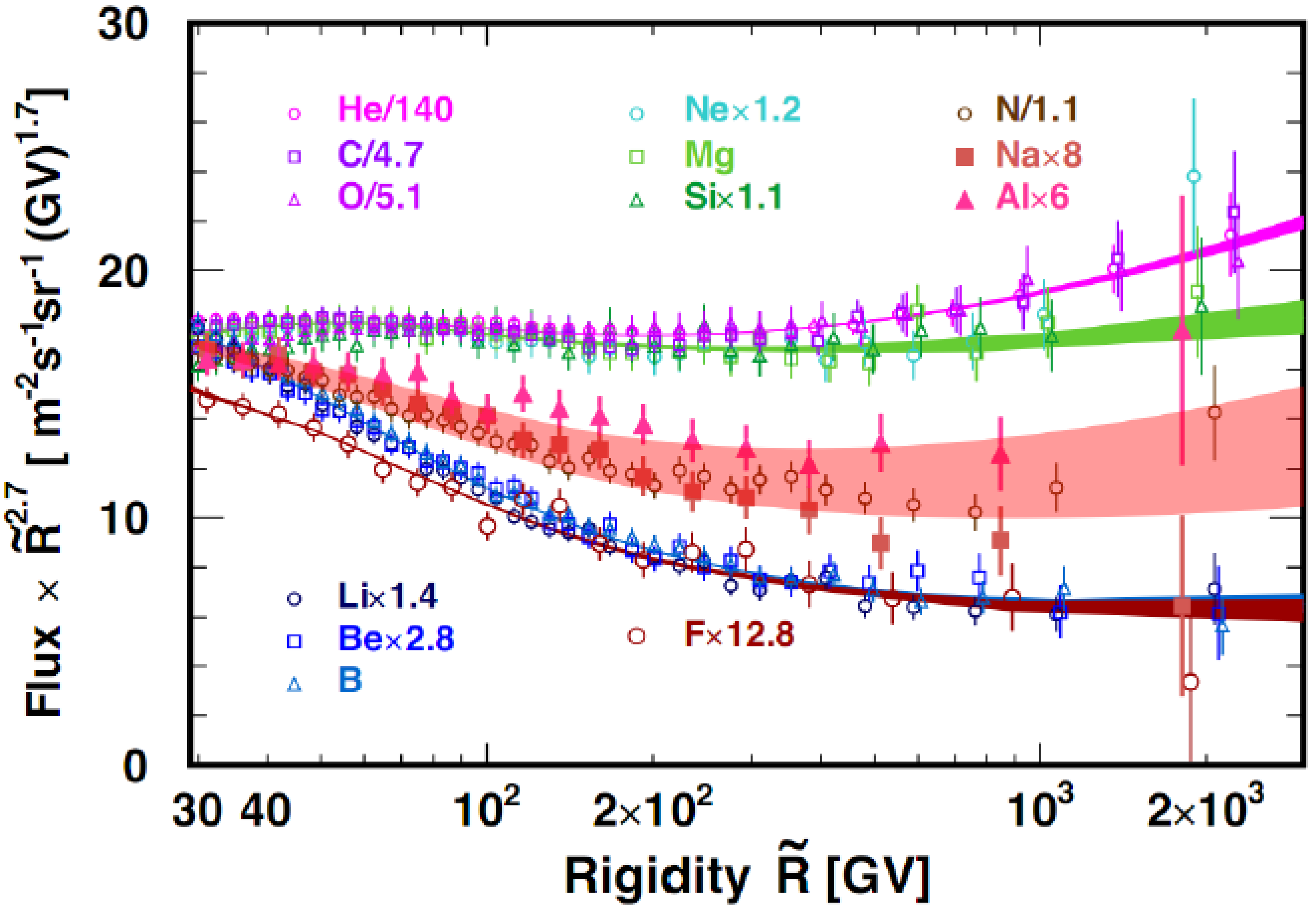




S. Liu et al., Ch. Phys. 46/3 (2022) 030004

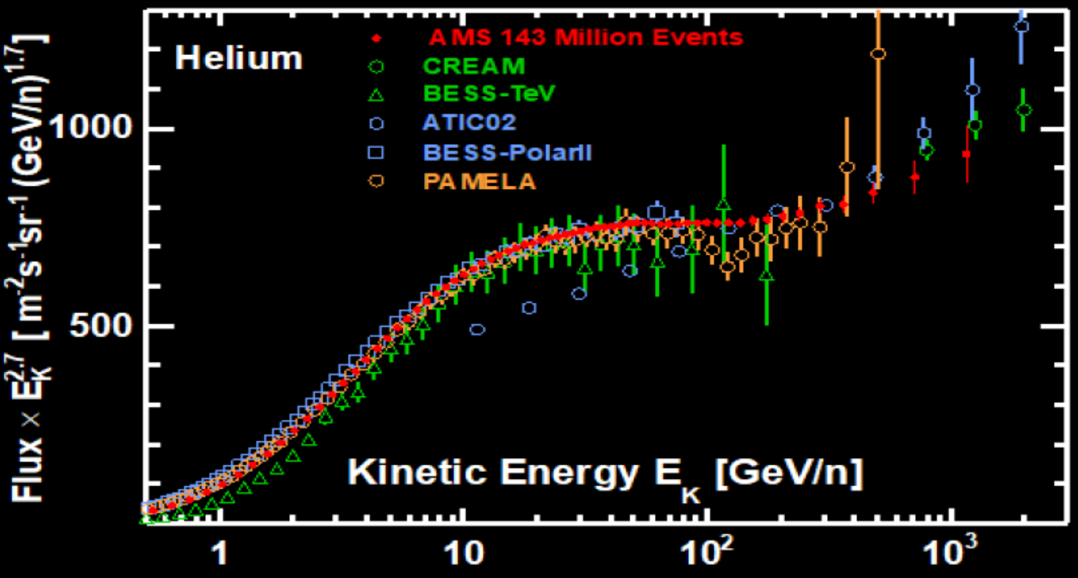
Groups of CR nuclei ($2 \leq Z \leq 14$)

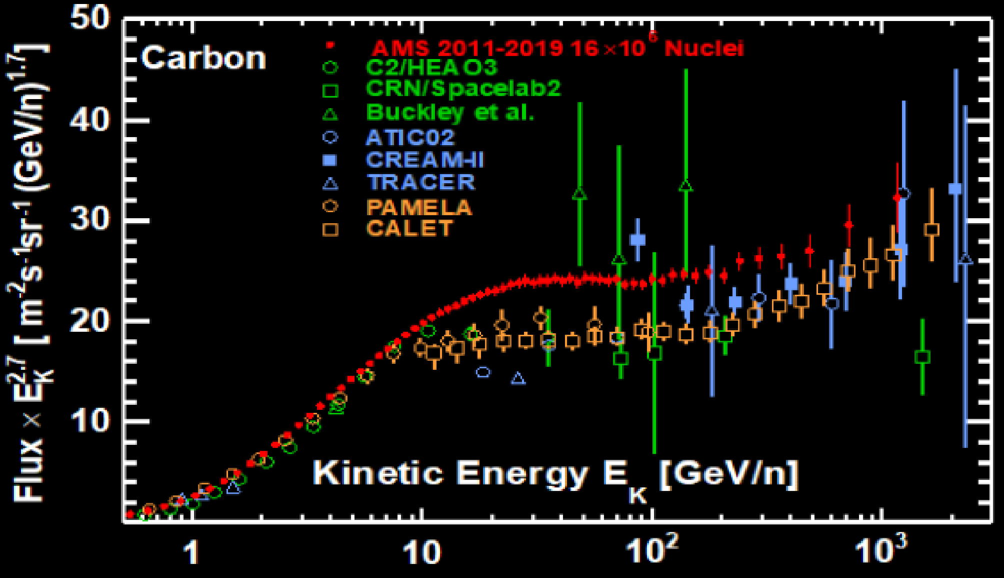
Aguilar et al. (AMS collaboration), PRL 127, 021101, 2021

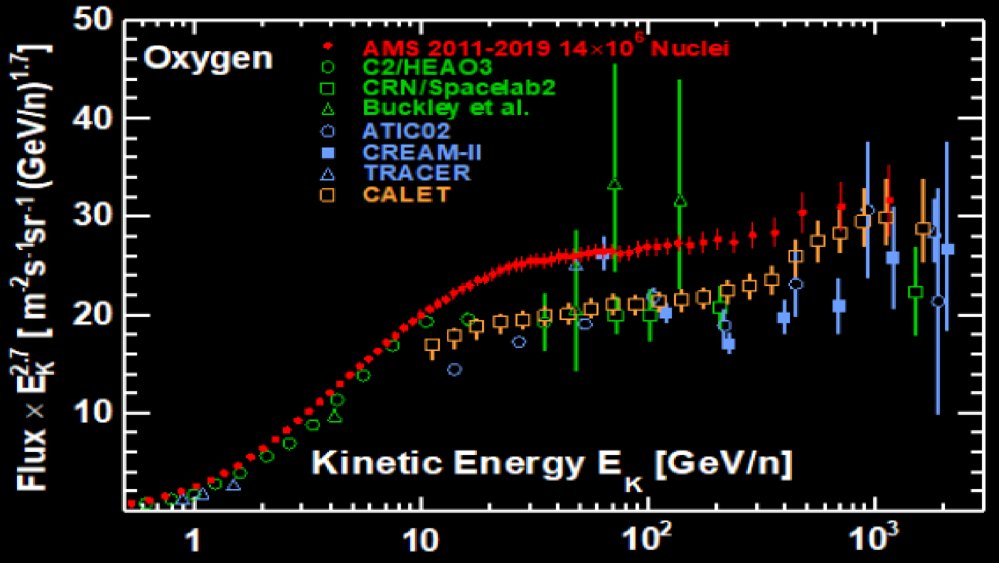


Helium, Carbon, and Oxygen (~ 2 GV – 3 TV)

Henning Gast for the AMS Collaboration PoS(ICRC2021)121



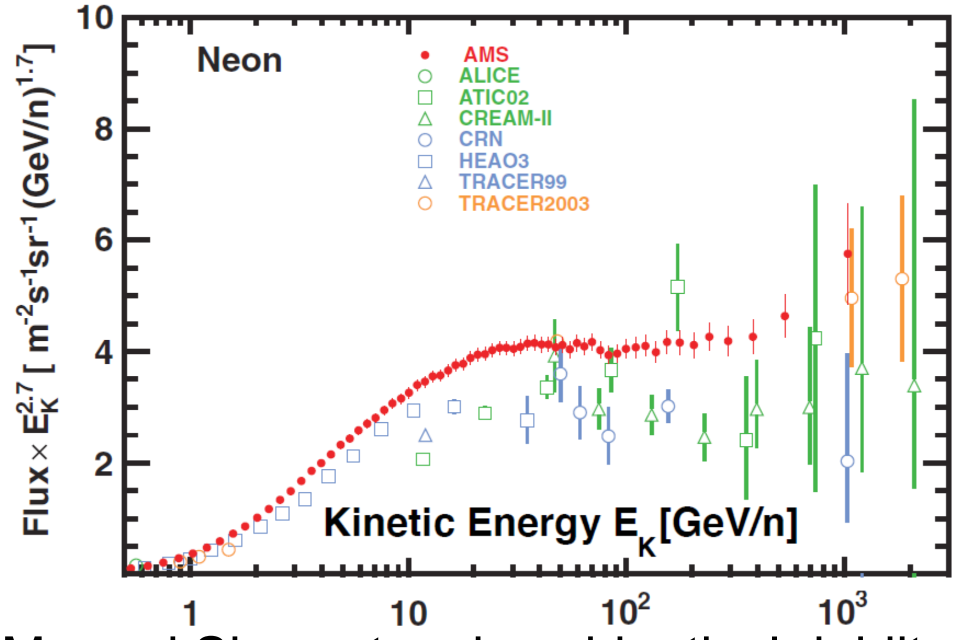


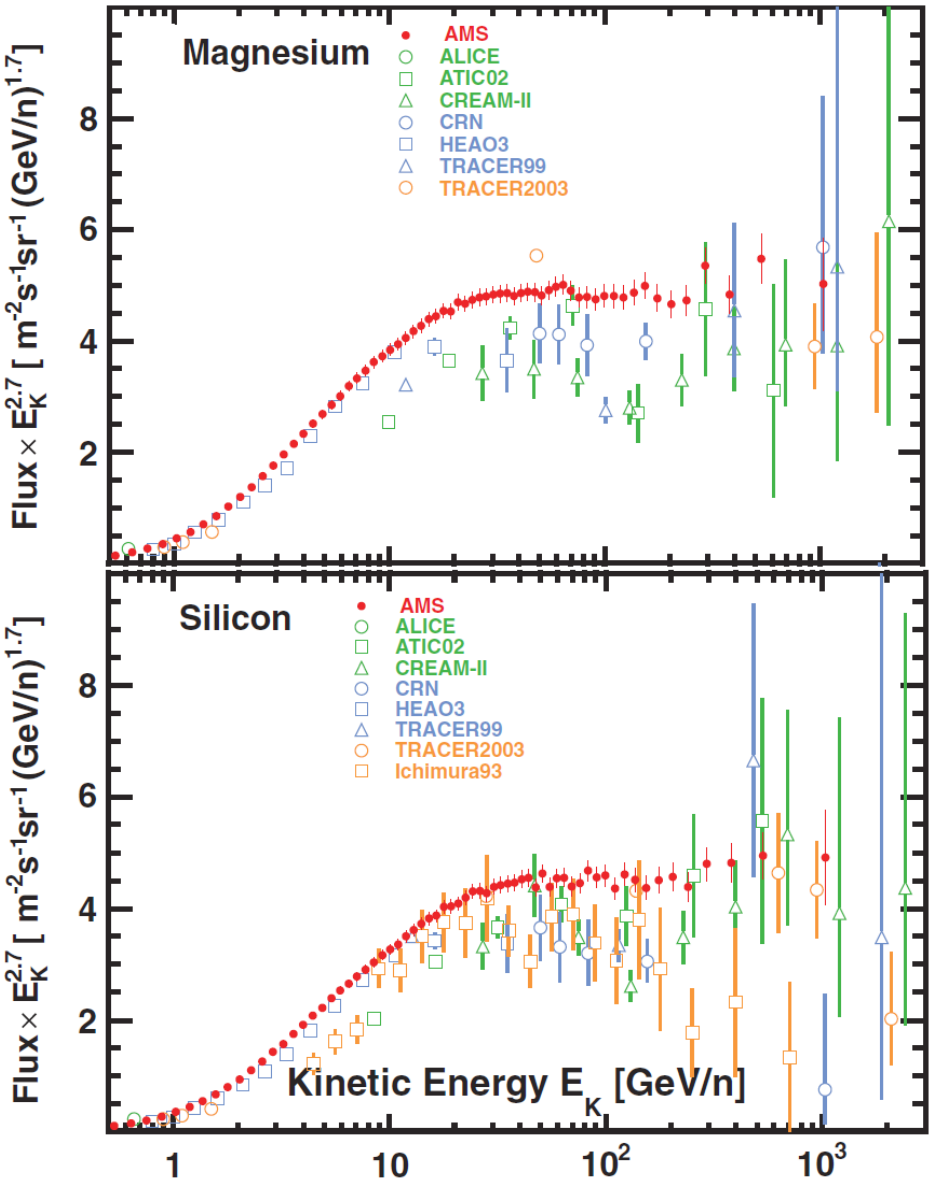


- He, C, and O spectra show identical rigidity dependence above 60 GV.
  - He/O = 27.6 ± 0.6
  - C/O = 0.91 ± 0.02
- The spectra progressively harden above 200 GV.

Neon, Magnesium and Silicon (2.15 GV to 3 TV)

Alberto Oliva for the AMS Collaboration PoS(ICRC2021)107; M. Aguilar et al., PRL 124, 211102 (2020)



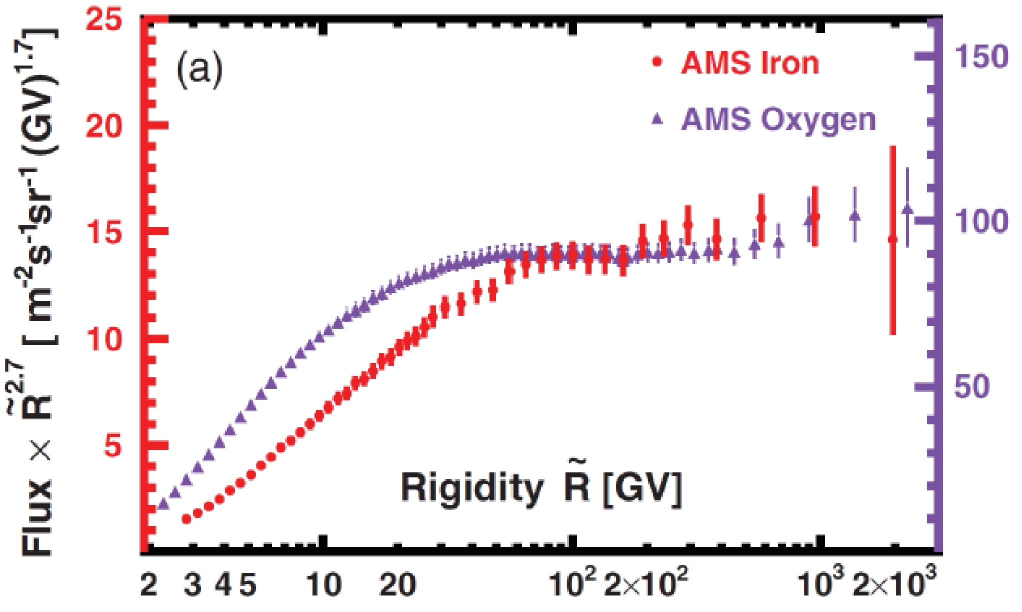


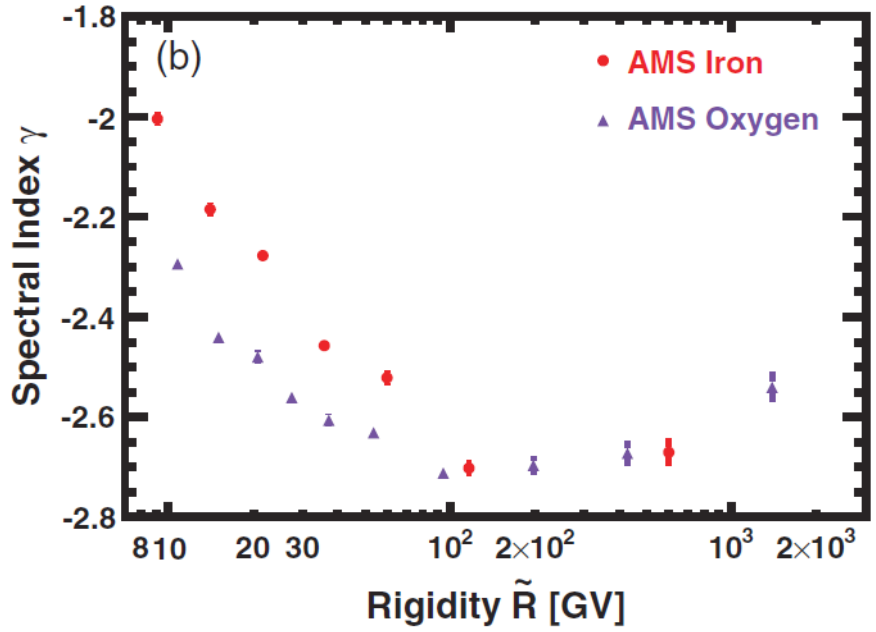
- Ne, Mg and Si spectra show identical rigidity dependence above 86.5 GV.
- It is different from the rigidity dependence of primary cosmic rays He, C, and O.
  - Indicating Ne, Mg, and Si forms a different class of primary cosmic rays.
- The spectra progressively harden above 200 GV.

Iron (2.65 GV to 3 TV)

Yao Chen for the AMS Collaboration PoS(ICRC2021)129; M. Aguilar et al., PRL 126, 041104 (2021)

Based on 8.5 years of data (2011-2019)

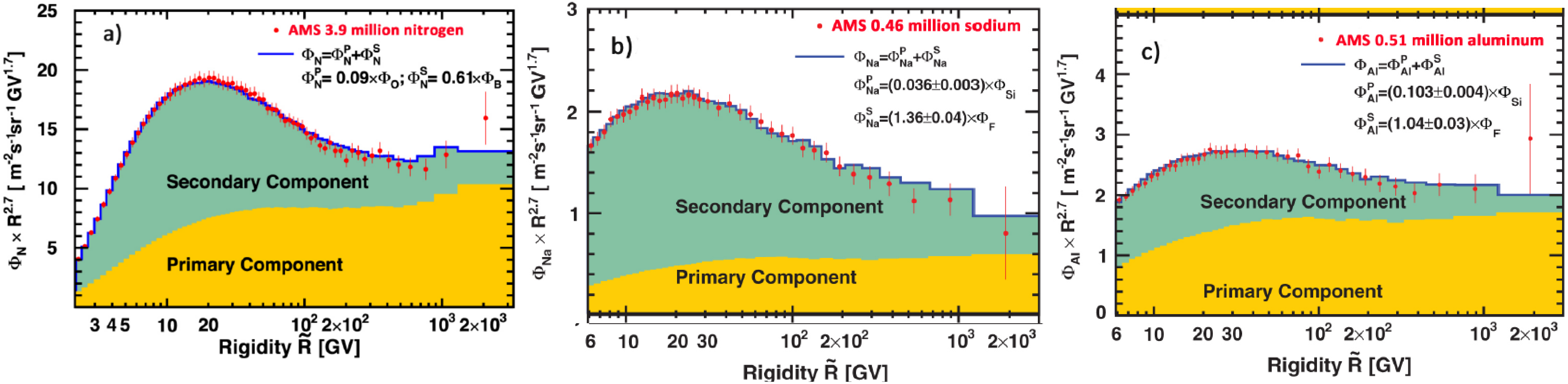




- Fe rigidity spectrum is identical to the primary cosmic ray He, C, and O spectra above 80.5 GV.
  - Fe/O = 0.155 ± 0.006
- Fe belong to the same class of primary cosmic rays as He, C, and O, which is different from the Ne, Mg, and Si class.
- The same hardening above ~200 GV.

Nitrogen, Sodium and Aluminum

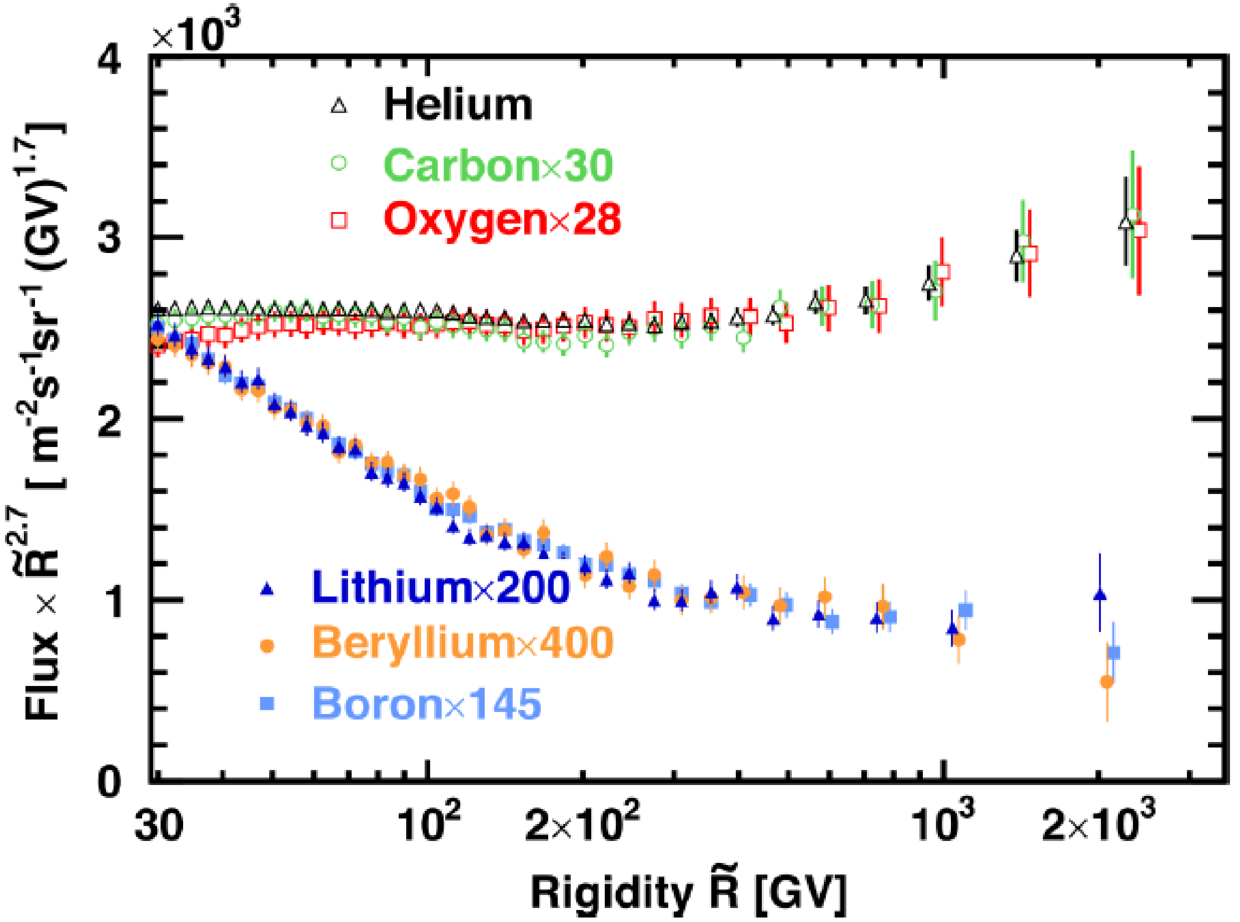
Aguilar et al., PRL 127, 021101, 2021; Cheng Zhang et al. PoS(ICRC2021)106; Zhen Liu et al. PoS(ICRC2021)110

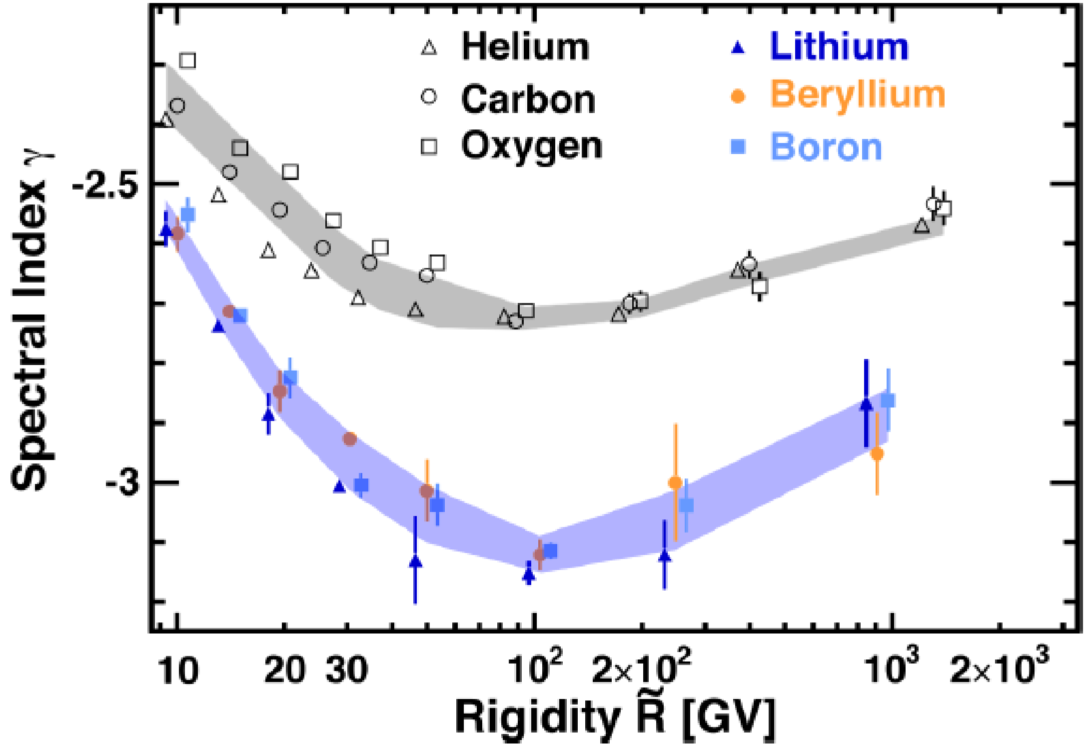


- Na and Al, together with N, belong to a distinct cosmic ray group and are the combinations of primary and secondary cosmic rays.
- The fraction of the primary component increases with rigidity for the N, Na, and Al fluxes and becomes dominant at the highest rigidities.
  - The abundance ratios Na/Si = 0.036 ±0.003 and Al/Si = 0.103 ± 0.004 at the source independent of cosmic ray propagation.

Light nuclei: Lithium, Beryllium, Boron vs He, C, O

Henning Gast
for AMS



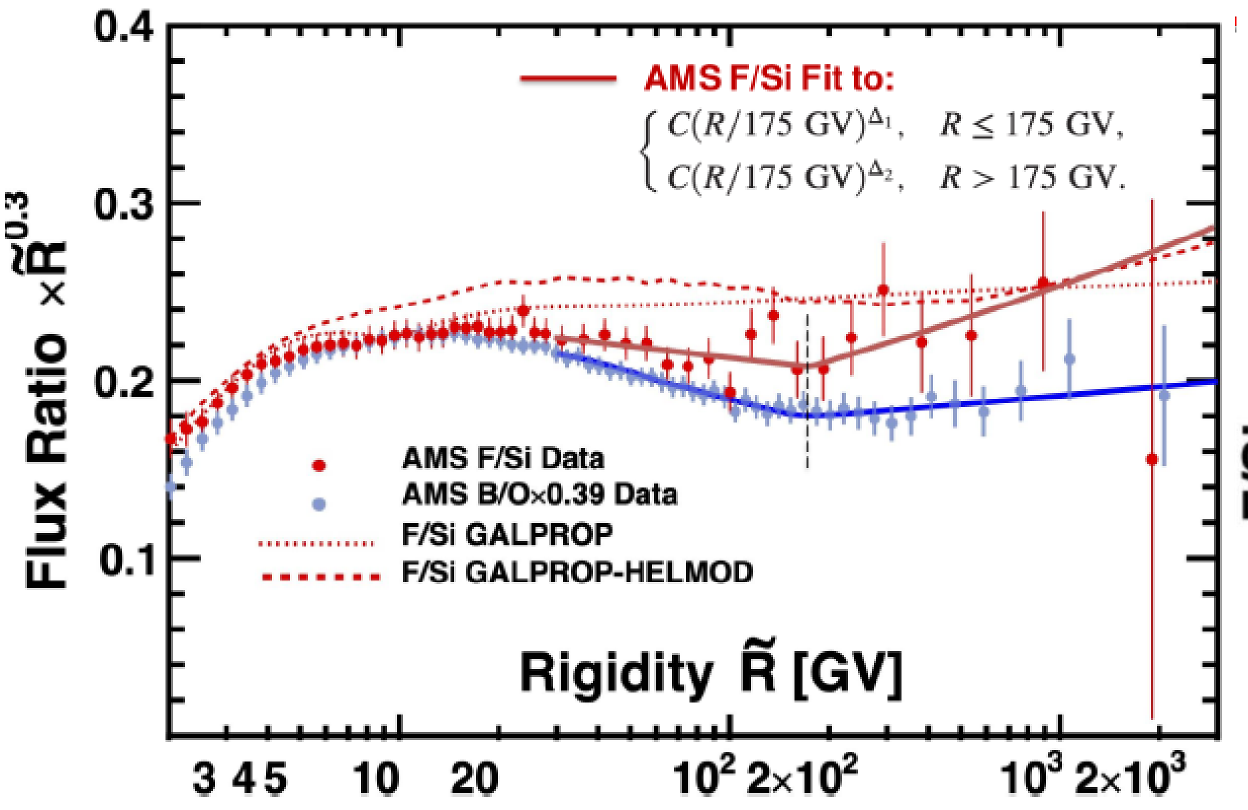


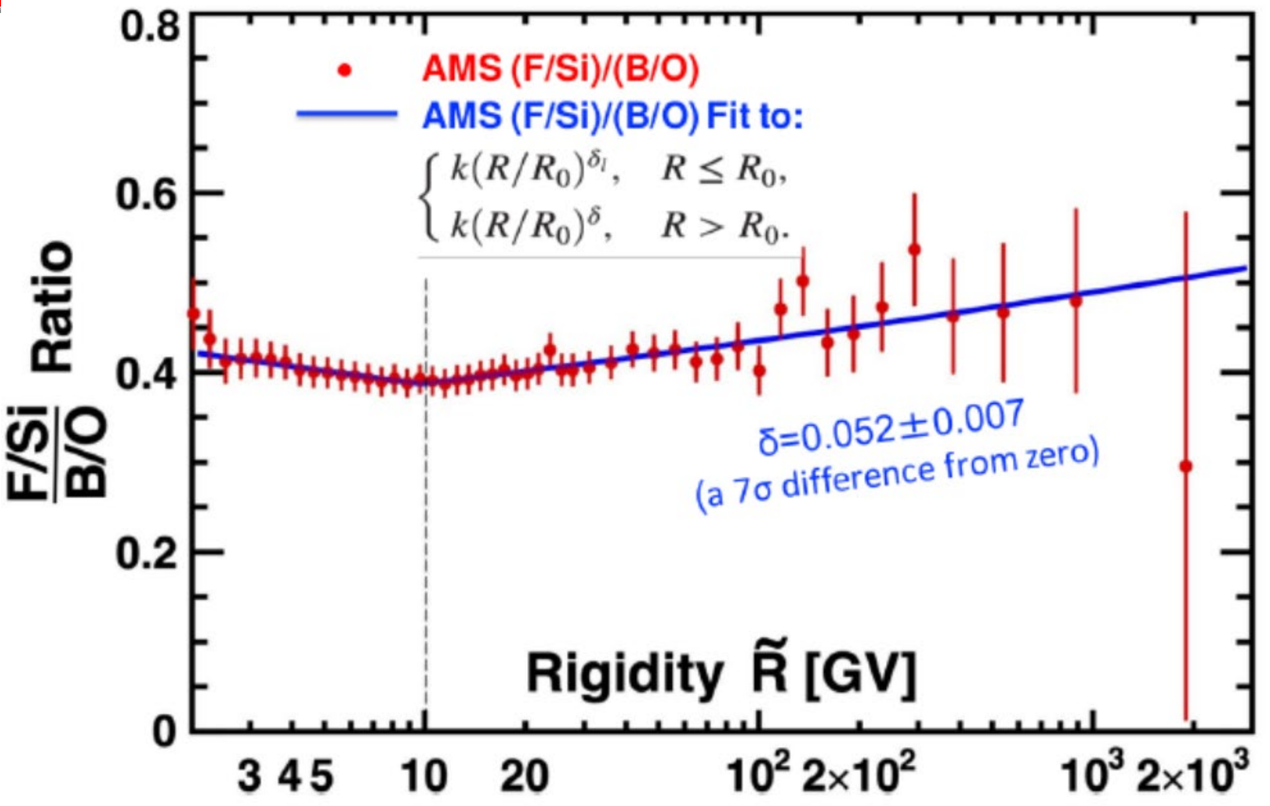
Above ~200 GV, the light secondaries Li, Be, B harden more than the primaries He, C, O.

Average hardening of secondary/primary ratios: $\Delta_{[192-3300]\,\mathrm{GV}} - \Delta_{[60.3-192]\,\mathrm{GV}} = 0.140 \pm 0.025$

Heavy secondary: Flourine

Qi Yan
for AMS



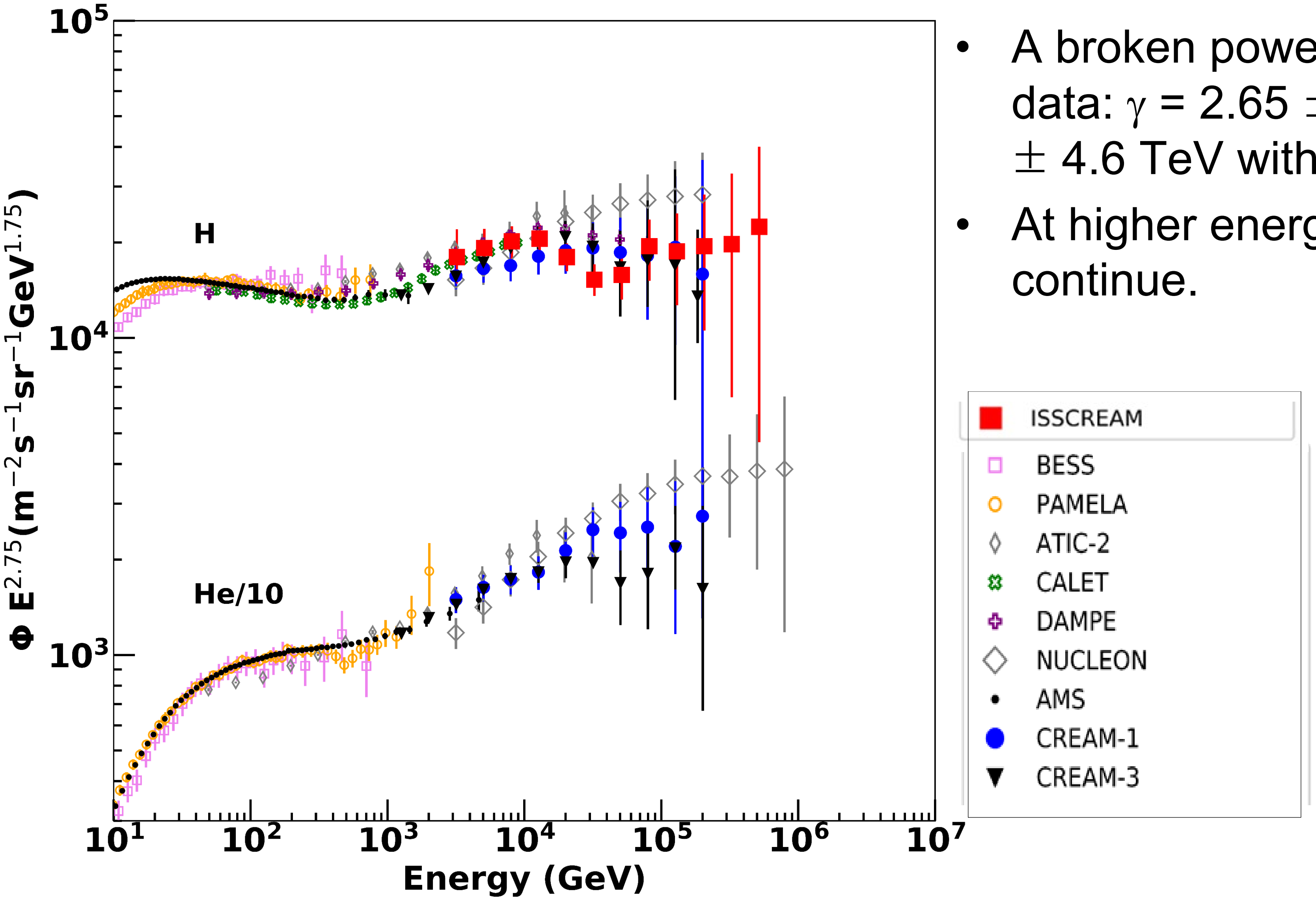


Above 175 GV, the F/Si ratio exhibits a hardening ($\Delta_2^{F/Si} - \Delta_1^{F/Si}$) = 0.15±0.07, compatible with the AMS result on the hardening of the lighter secondary/primary flux ratios.

Above 10 GeV, the (F/Si) / (B/O) ratio can be described by a single power law with δ=0.052±0.007, revealing that the propagation properties of heavy cosmic rays, from F to Si, are different from those of light cosmic rays, from He to O.

ISS-CREAM Proton Spectrum (2.5 – 655 TeV)

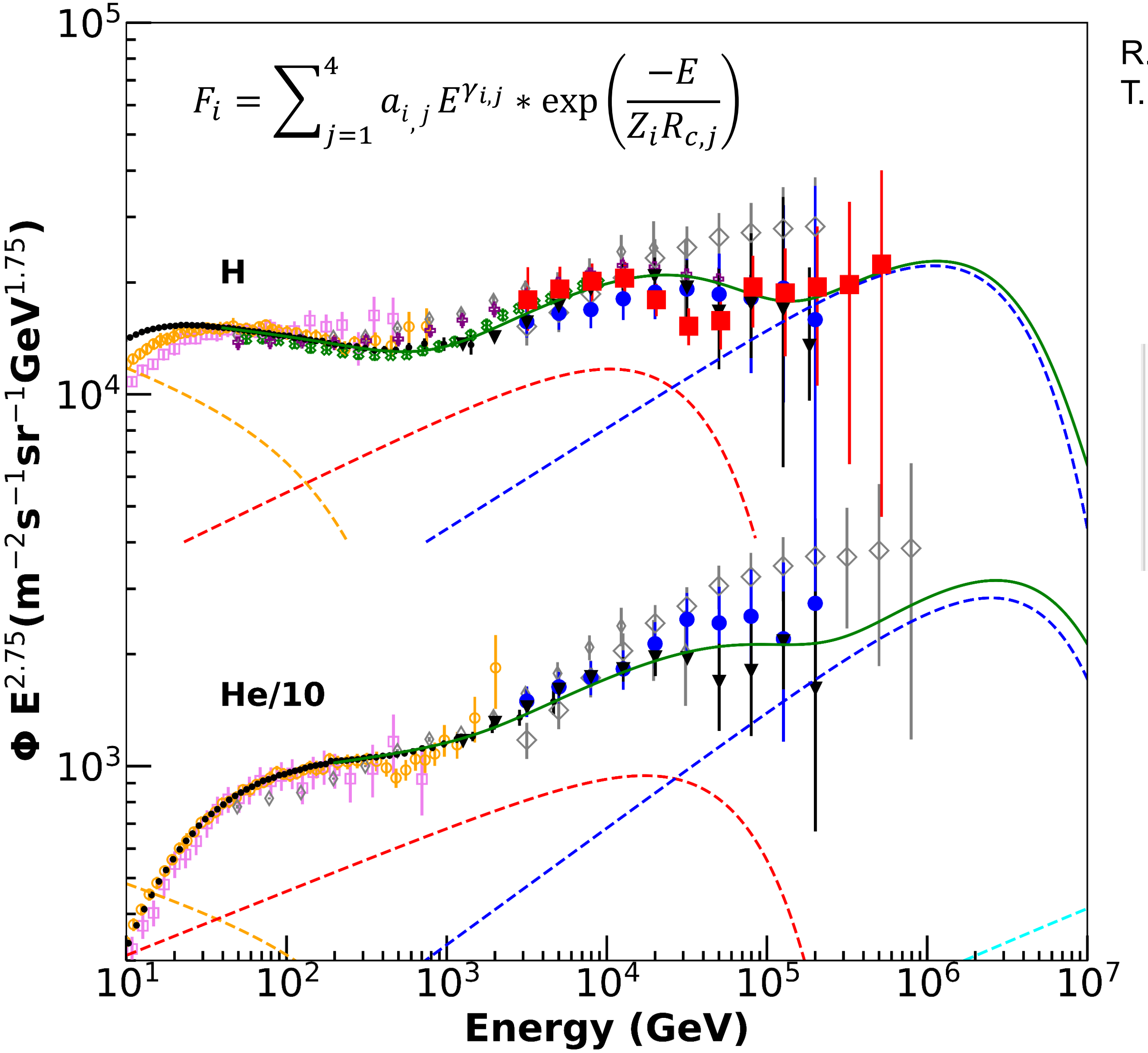
G. H. Choi for the ISS-CREAM Collaboration PoS(ICRC2021)094



- A broken power law fit to 2.5 – 100 TeV data: γ = 2.65 $\pm$ 0.06 and a break at ~9.94 $\pm$ 4.6 TeV with $\Delta\gamma$ = 0.26 $\pm$ 0.1.
- At higher energies, the softening does not continue.
- The deviation from a single power law near 10 TeV is consistent with the softening reported by CREAM-I &III, DAMPE, and NUCLEON, but ISS-CREAM extends measurements to higher energies than those prior measurements.

Transition from one type of source to another?

E. S. Seo for the ISS-CREAM Collaboration, PoS(ICRC2021)095



R. Scrandis, D.P. Bowman & E.S. Seo, PoS(ICRC2021)1220
T. Gaisser, T. Stanev, S. Tilav, Frontiers of Phys. 8 (2013) 248.

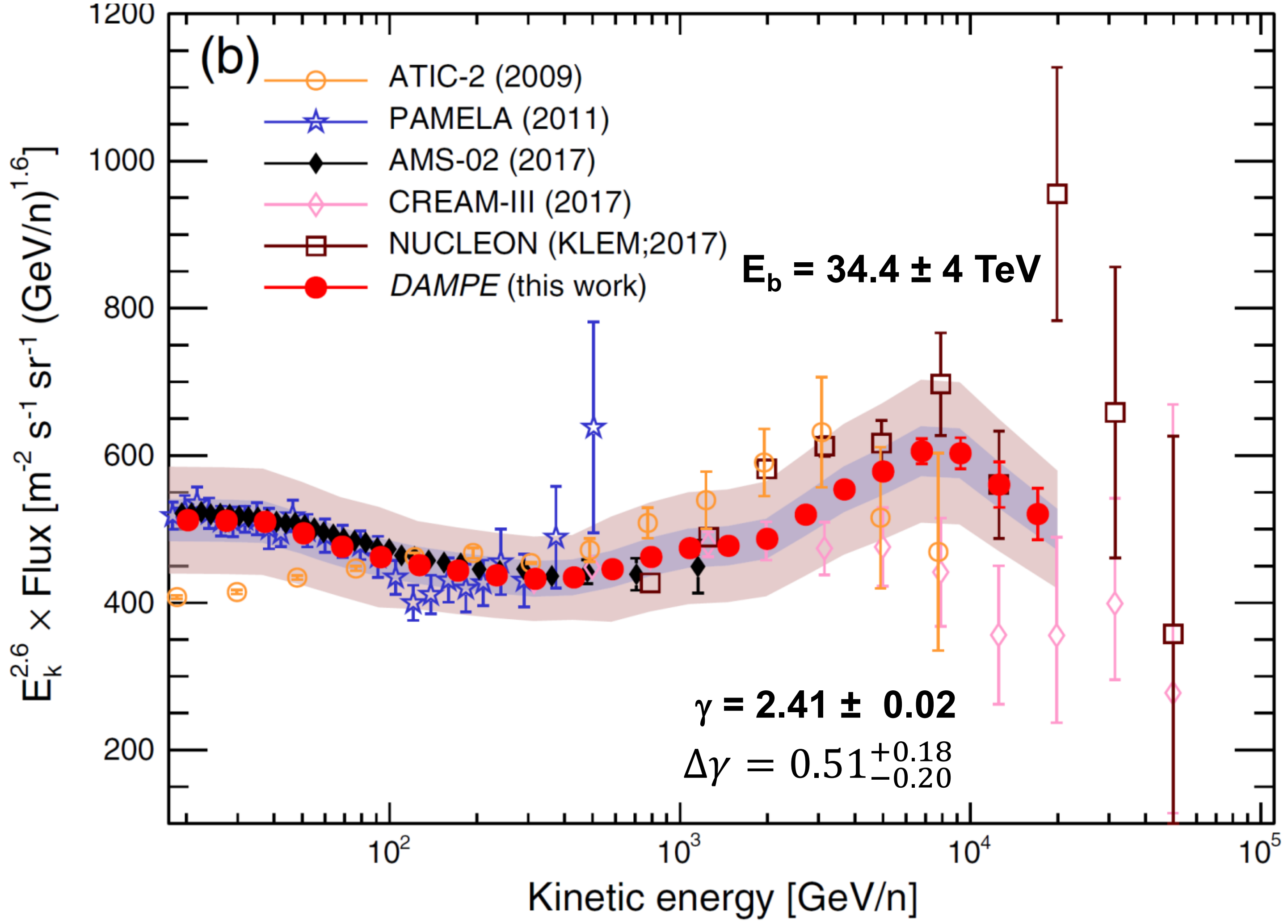
Acceleration limit:
$E_{max\_z} = Z \times E_{max\_p}$,

Pop 0	E_{max_p} = 400 GV
Pop 1	E_{max_p} = 50 TV
Pop 2	E_{max_p} = 4 PV
Pop 3	E_{max_p} = 500 PV

- The spectral hardening at ~ 200 GV and softening ~ 10 TeV could indicate a transition from one type of source to another.

DAMPE Helium Spectrum (70 GeV – 80 TeV)

Margherita Di Santo for the DAMPE Collaboration PoS(ICRC2021)114



Fit of the softening structure with a Smoothly Broken Power-Law (SBPL) in the energy range [6.8 TeV - 80 TeV].

$$\Phi(E) = \Phi_0 \left(\frac{E}{\mathrm{TeV}}\right)^{\gamma} \left[1 + \left(\frac{E}{E_b}\right)^{s}\right]^{\Delta\gamma/\omega}$$

$E_b = 34.4^{+6.7}_{-9.8}$ TeV

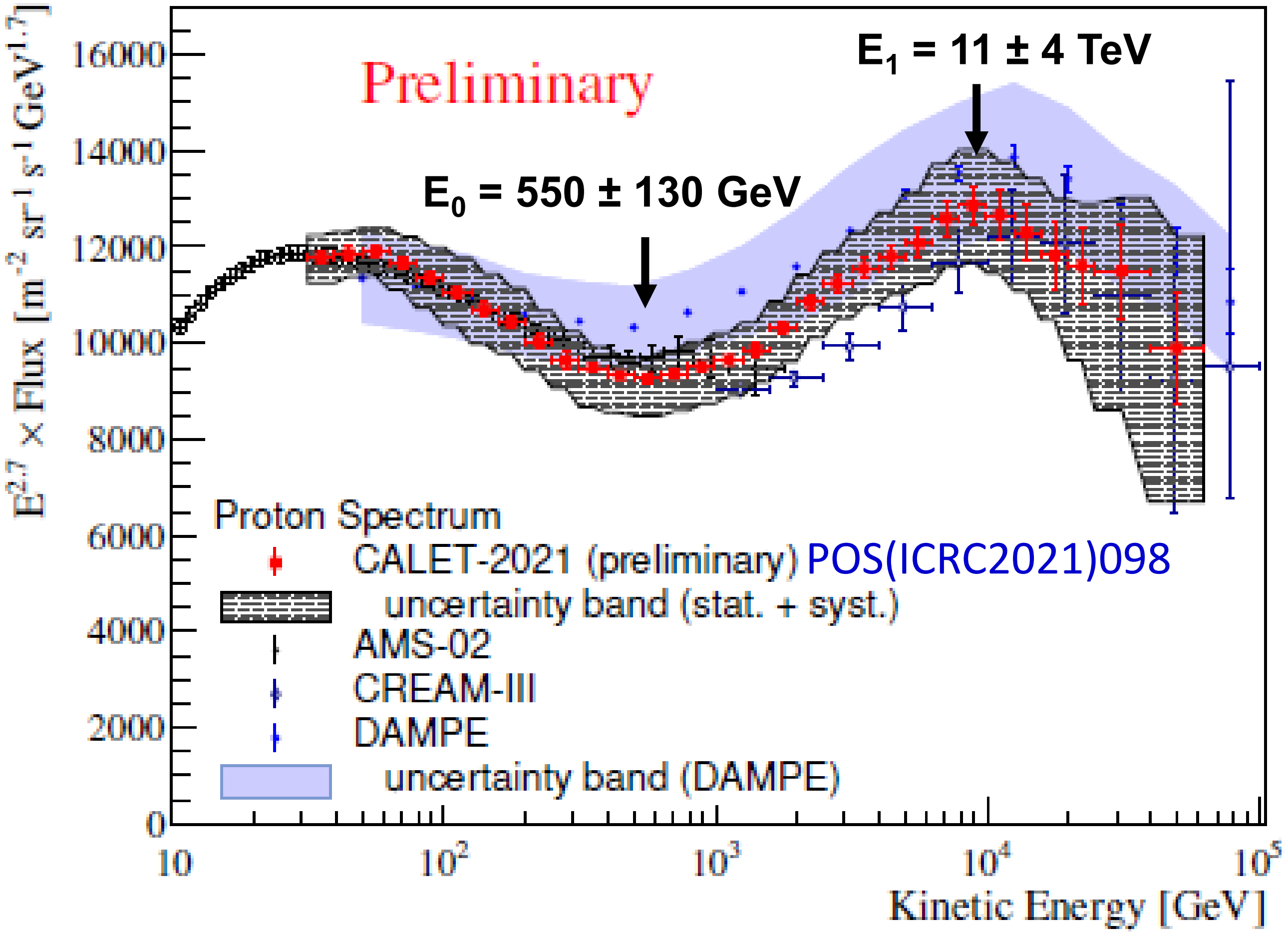
$\gamma = 2.41^{+0.02}_{-0.02}$

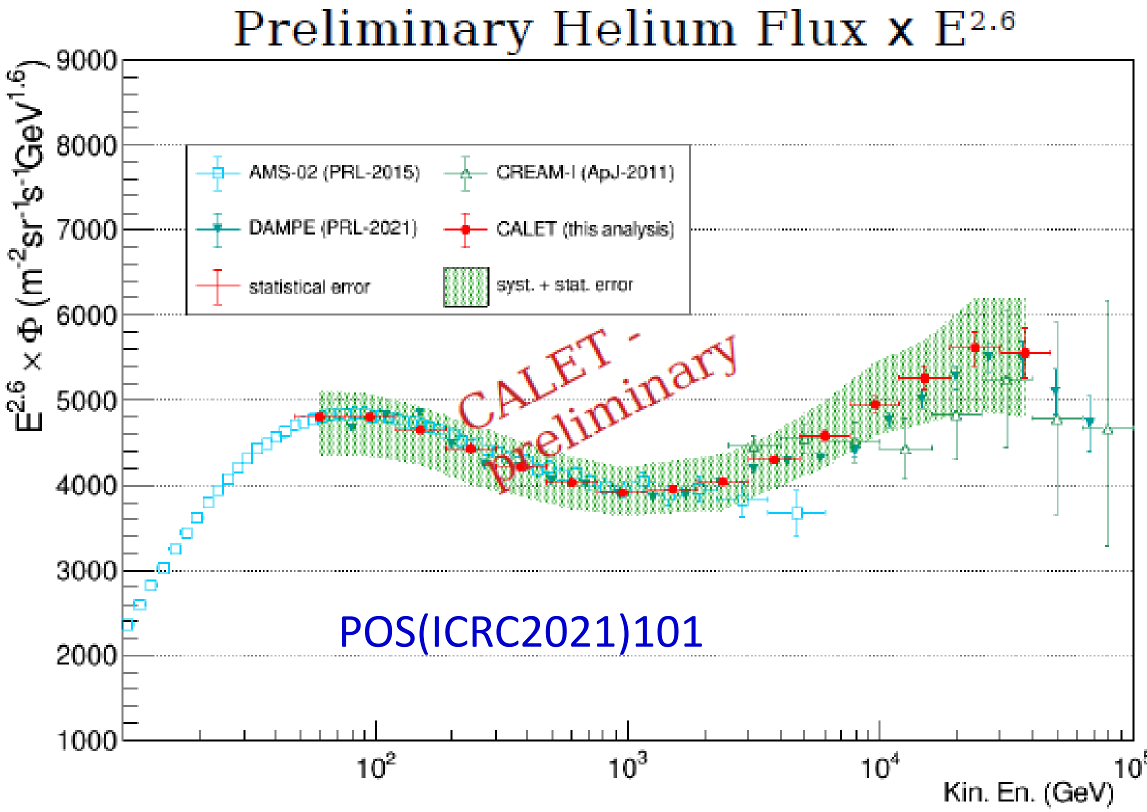
$\Delta\gamma = -0.51^{+0.18}_{-0.20}$

$s = 5.0\ (fixed)$

Significance of the softening: ~ 4.3 σ

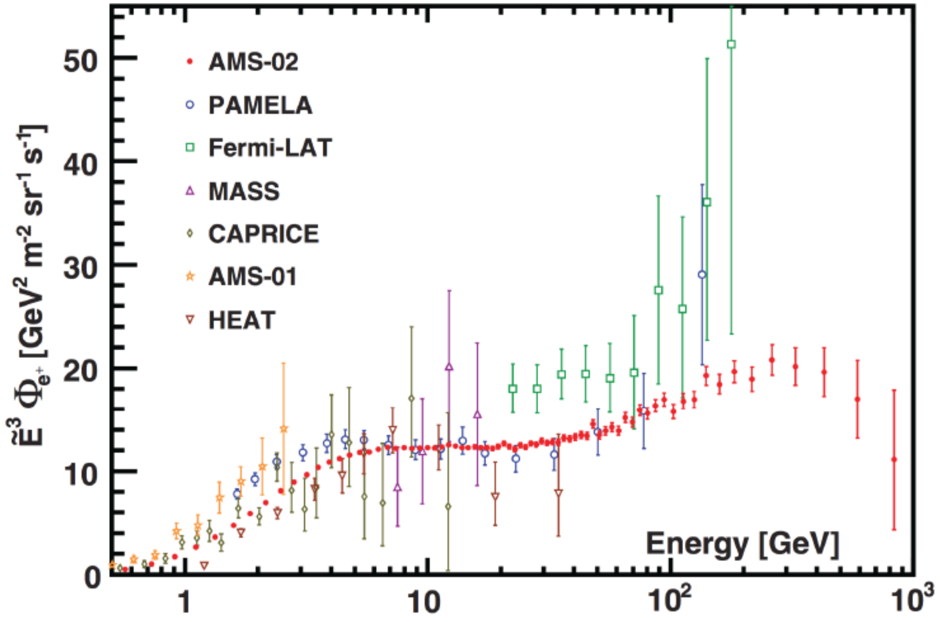
CALET Proton (30 GeV – 60 TeV) Helium (50 GeV – 50 TeV) Spectra

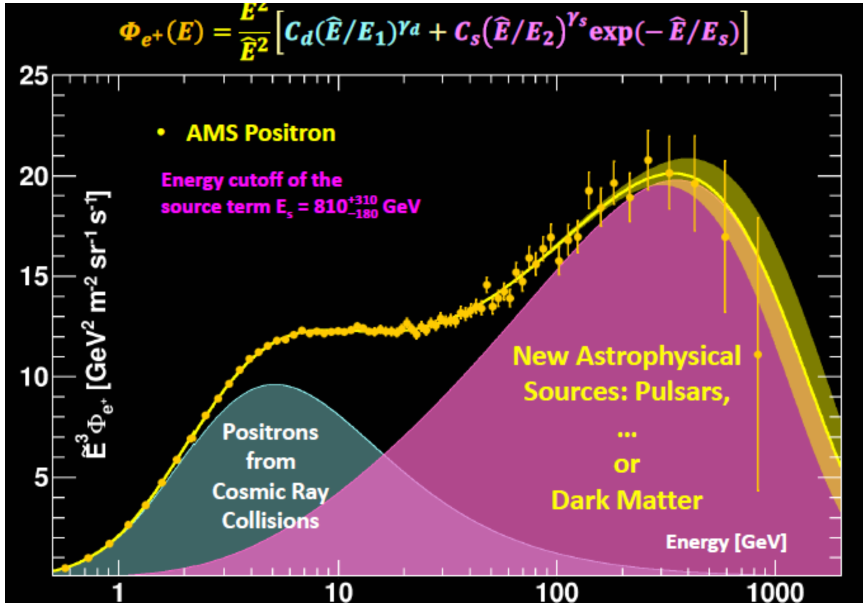


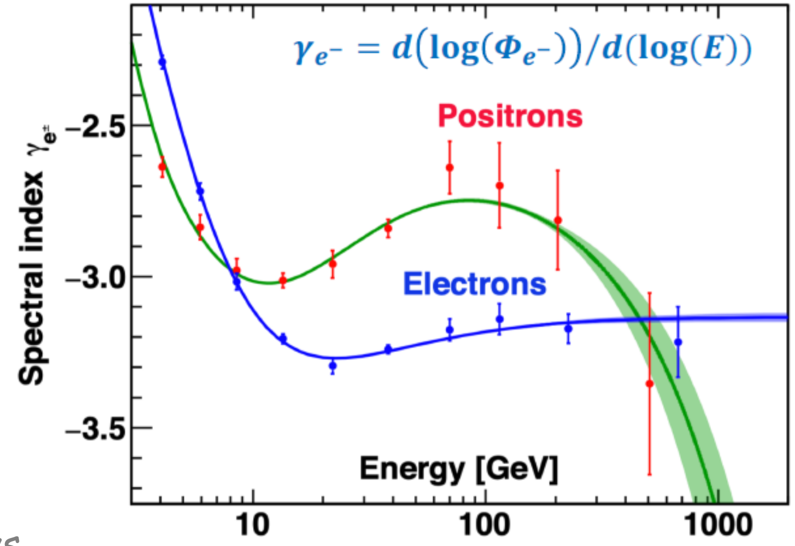


Positrons and Electrons

Aguilar et al., Phys. Rev. Lett., 122, 101101, 2019; Z. Weng et al., PoS(ICRC2021)122D; Krasnopevtsev et al., PoS(ICRC2021)111







- An excess in positron spectrum > 25 GeV with a peak at ~284 GeV
- The positron flux is well described with a sum of a diffuse term and an additional source with an exponential cutoff at 810 GeV
- The electron spectrum does not show such a cutoff.
- Electron spectrum hardening > 42 GeV

Summary

Significant advances in CR measurements have been made in recent years

- An excess in positron spectrum > 25 GeV with a peak at ~284 GeV indicates an additional source with an exponential cutoff at 810 GeV.
- Not only primaries (p, He, C, O, Ne, Mg & Si) but also secondaries (Li, Be, B & F) exhibit spectral hardening above ~200 GV.
- Proton spectrum softening at ~10 TeV was reported by CREAM/ISS-CREAM, DAMPE, NUCLEON and CALET; He sofening at ~34 TeV was reported by DAMPE; more statistics is needed for heavier nuclei.
- The He spectrum is harder than the proton spectrum.
- He, C, O, and Fe show a consistent rigidity dependence indicating the same class of primary CR.
- Ne, Mg, and Si show a consistent rigidity dependence different from He, C and O indicating a different class of primary cosmic rays.
- A group of N, Na and Al belong to a distinct cosmic ray group of a combinations of primary and secondary cosmic rays.

Summary – cntd

- These results contradict the traditional view that a simple power law can represent CR without deviations below the "knee", and they should be incorporated in a coherent model for CR origin/propagation.
- Many open questions remain:
  - What is the origin of the excess positrons above 25 GeV?
  - What is the origin of the hardening in the CR nuclei above ~200 GV?
  - What is the origin of the possible softening at an energy of ~10 TeV/n?
  - What causes different classes of the primary CR spectra with different rigidity dependence?
- More updates are expected at the COSPAR-2022, 44th Scientific Assembly, Event E1.3 "Origins of Cosmic Rays", Athens, Greece, July 16-24, 2022.
  - Special AMS day to celebrate Ten Years of AMS on the ISS