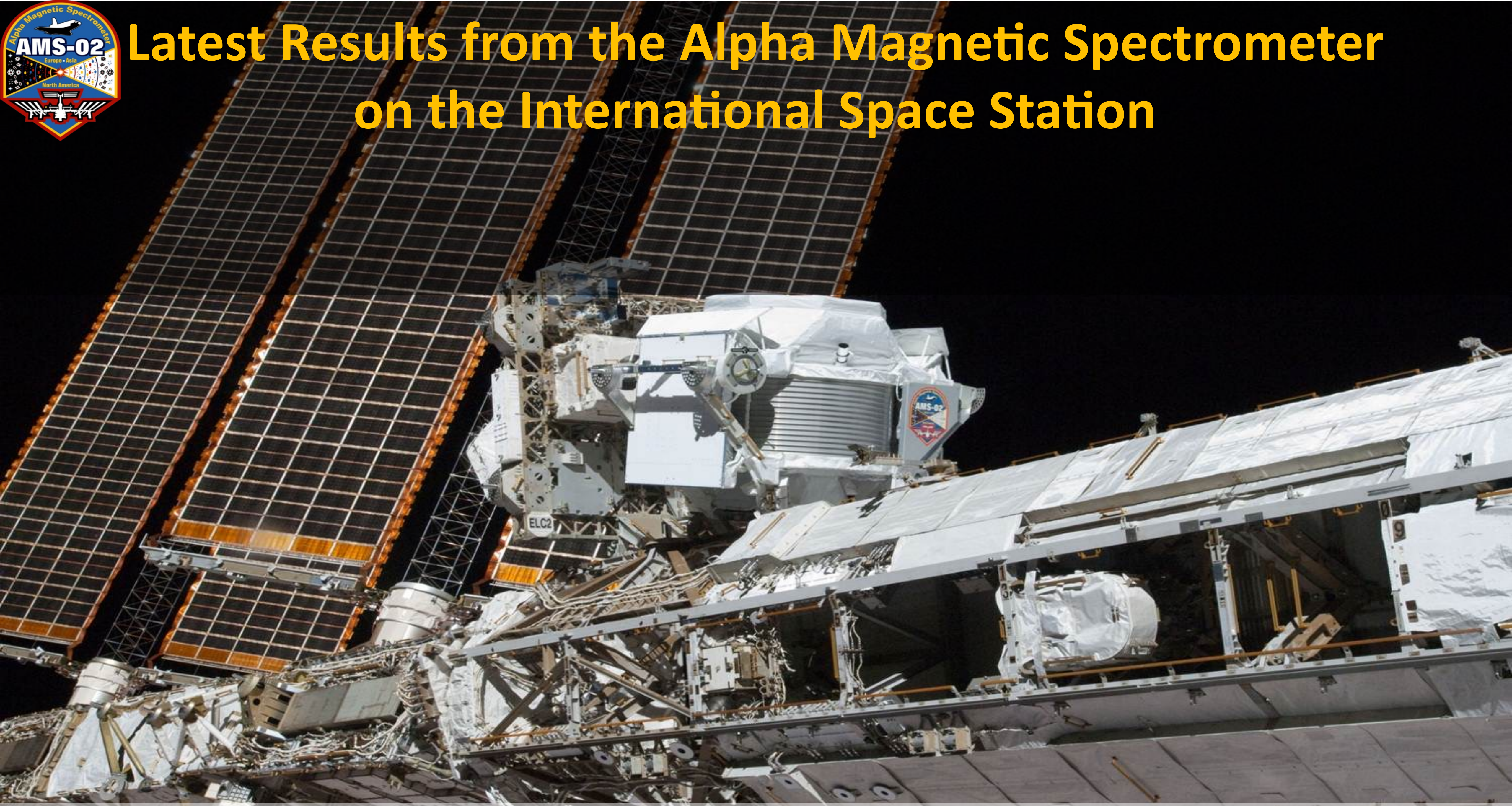
Latest Results from the Alpha Magnetic Spectrometer on the International Space Station

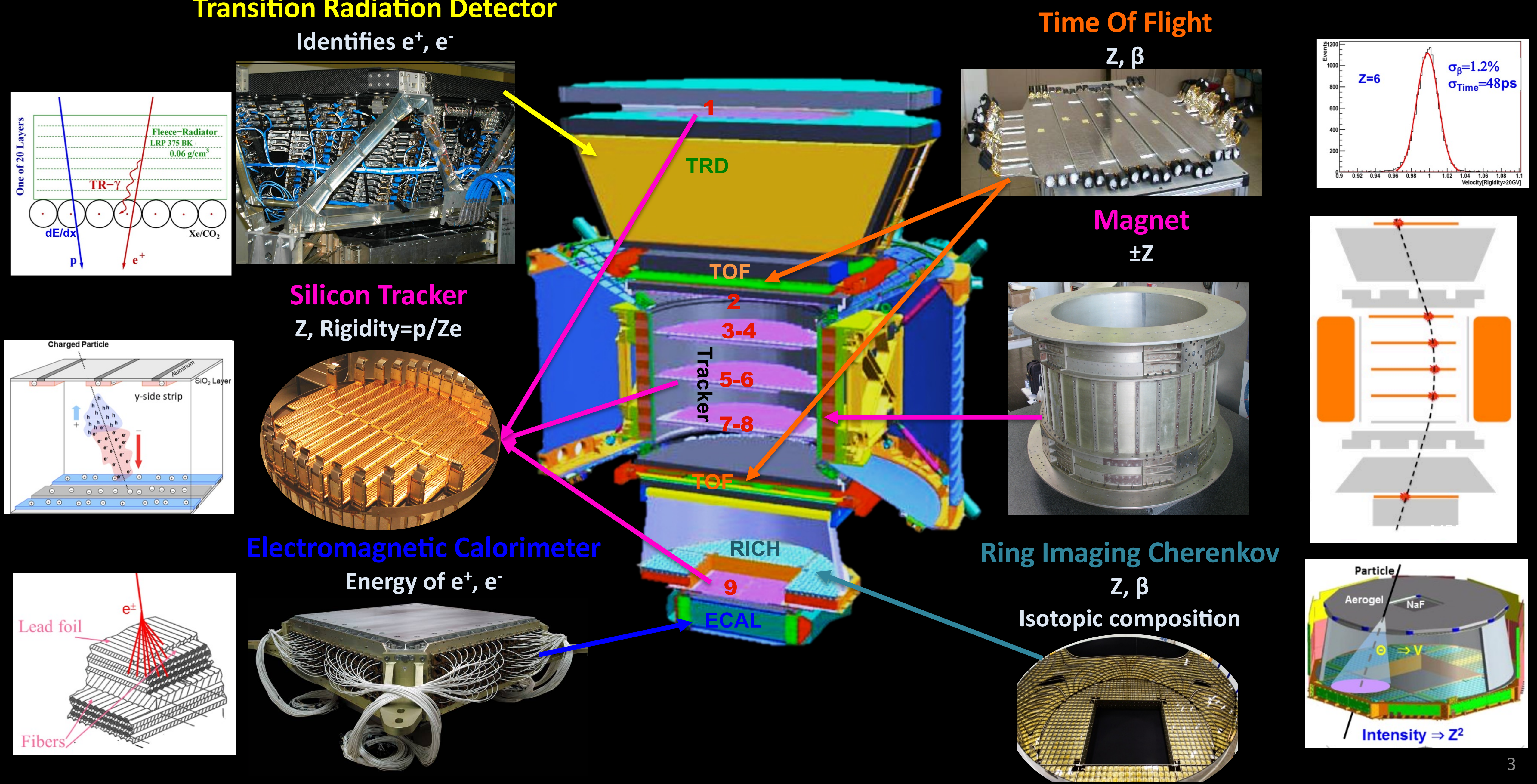


August 26th, 2025 TAUP 2025, Xichang, China V. CHOUTKO MIT

AMS Launched May 2011
Space Shuttle Endeavour
Mission STS-134

AMS installed on the ISS
Near Earth Orbit:
altitude 400 Km
inclination 52°

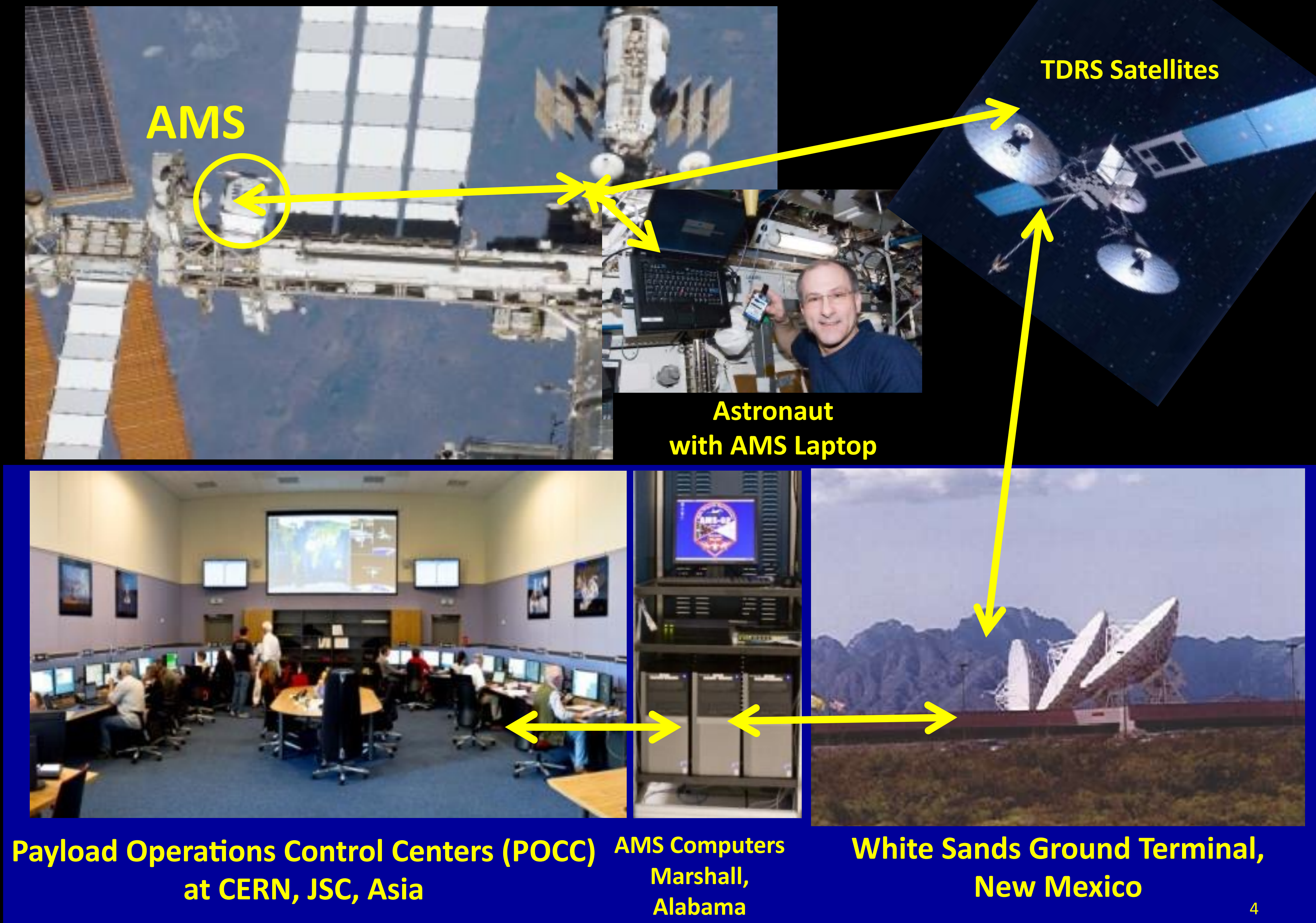
AMS-02: A TeV precision magnetic spectrometer in space



AMS Continious Data Flow ISS to POCC

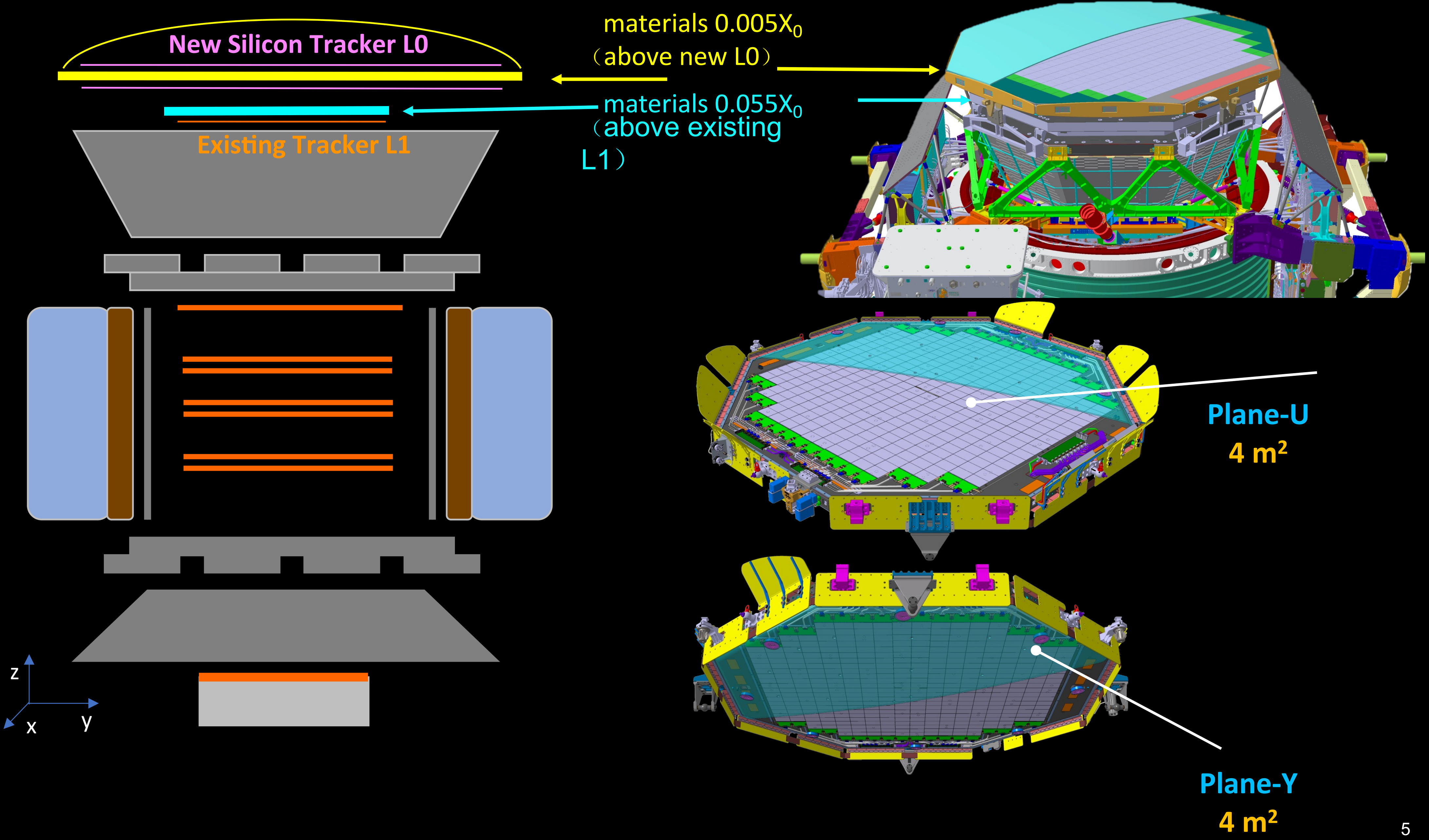
To date 253 billion particles have been measured by AMS: e^+, e^-, p, $\bar{p}$, nuclei, γ,…

360 billion events expected to 2030

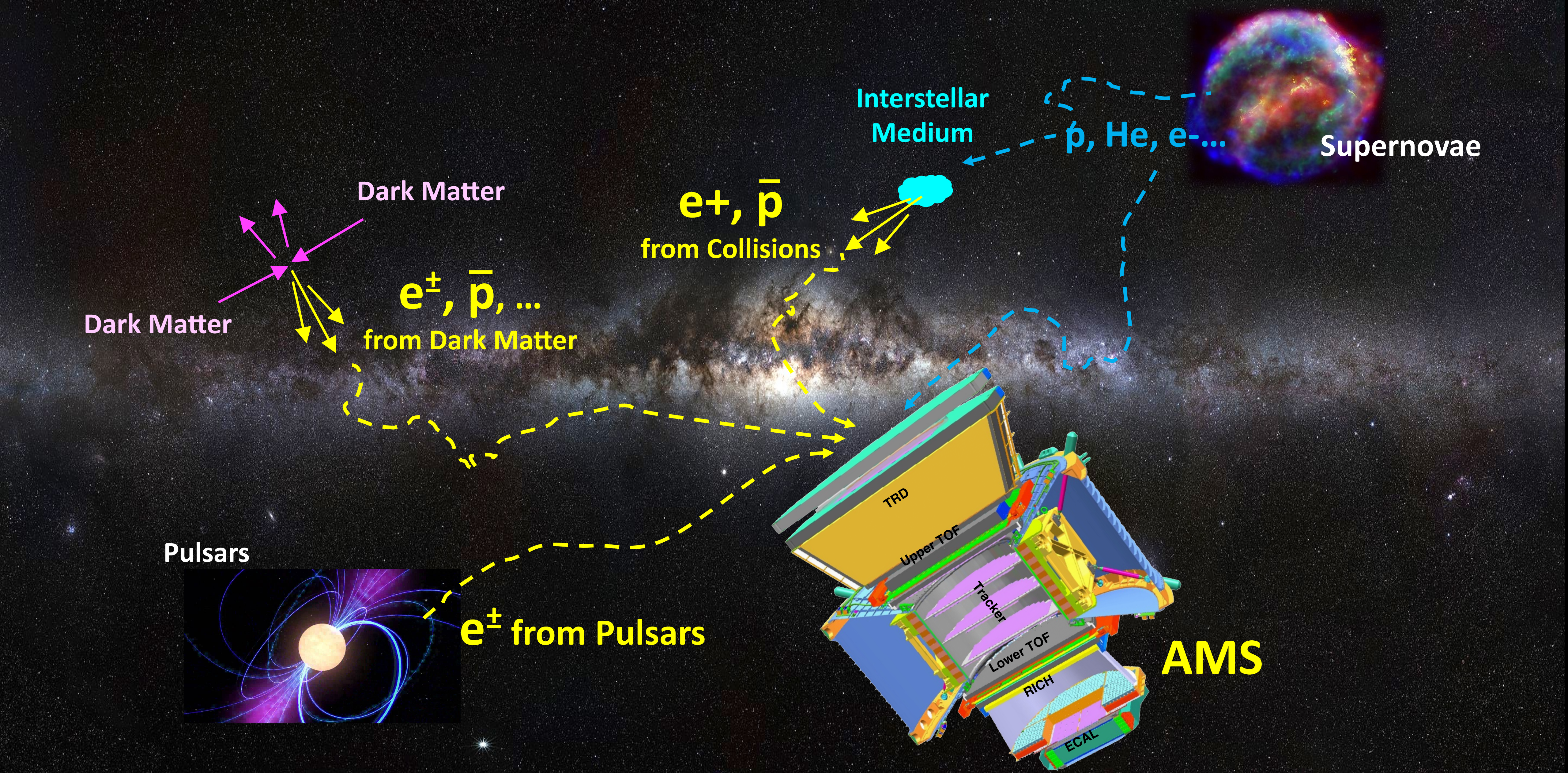


AMS on ISS: 2026-2030+

With Completion of L0 Upgrade AMS Acceptance will be Increased by 300% with Minimal Materials Above



Latest Results on e+, e−, and $\bar{p}$



will be presented by Shanglin Li

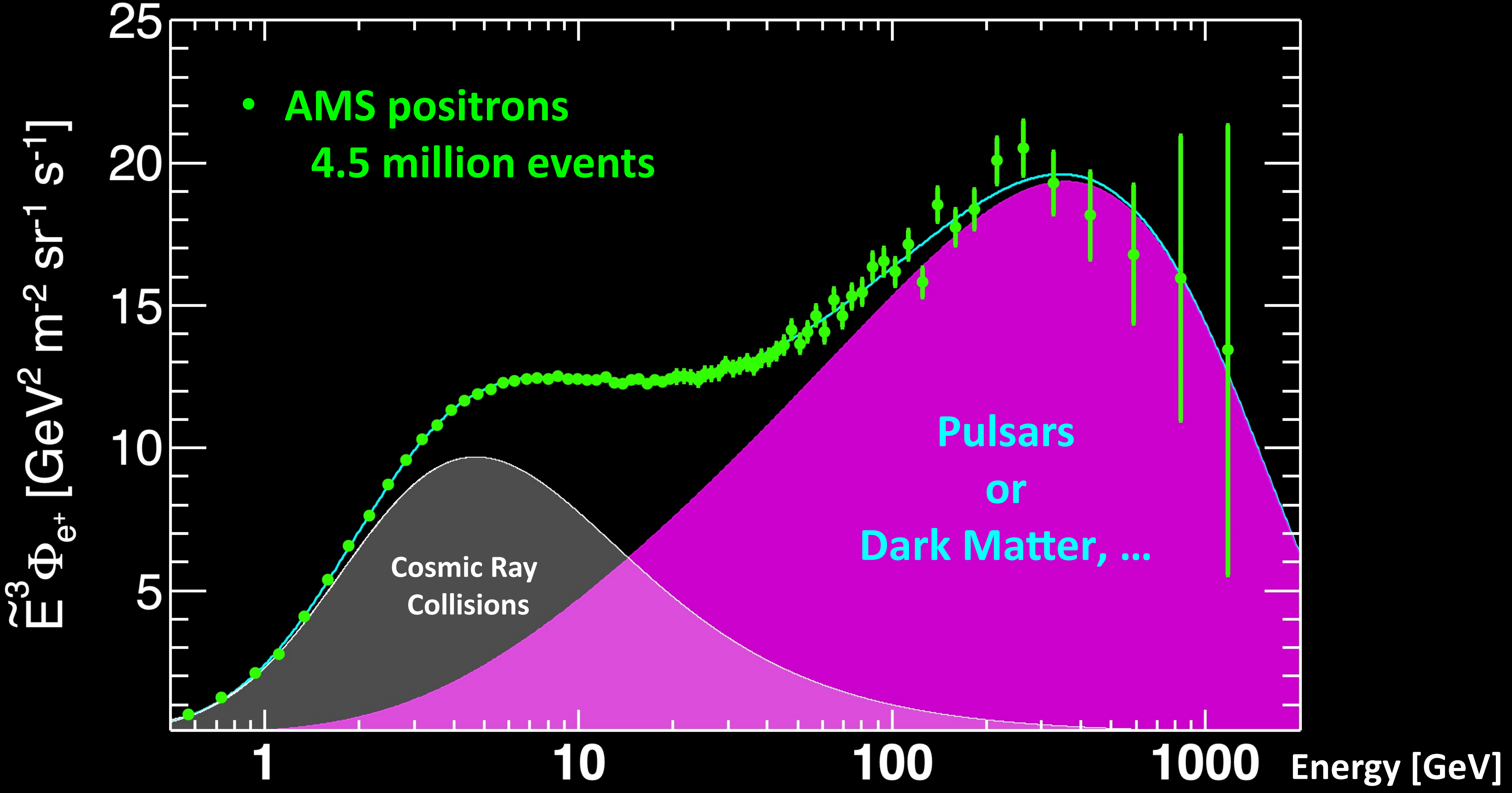
The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from pulsars or dark matter with a cutoff energy

Empirical model:

χ^2/dof = 40/66

$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_d(\hat{E}/E_1)^{\gamma_d} + C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right]$$

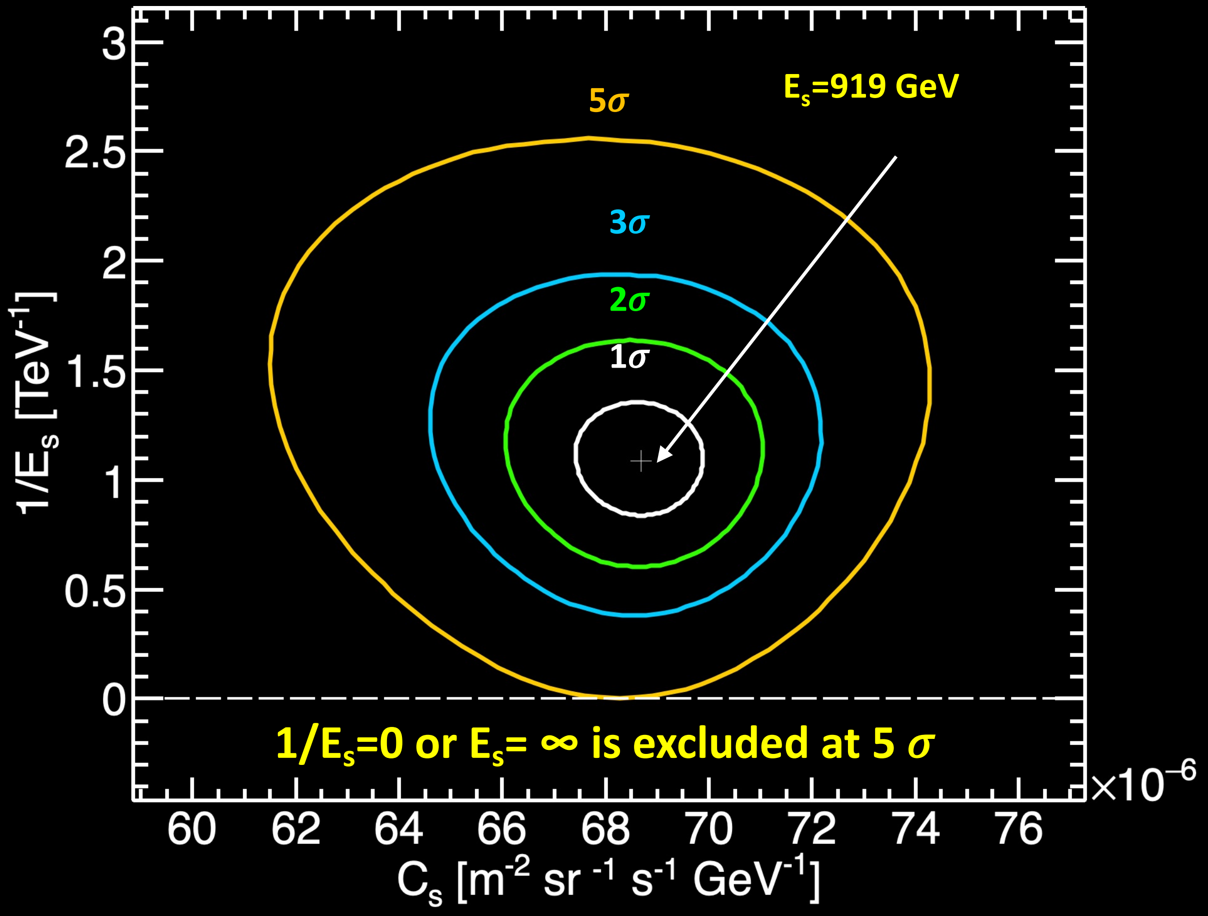
Solar Collisions Pulsars or Dark Matter

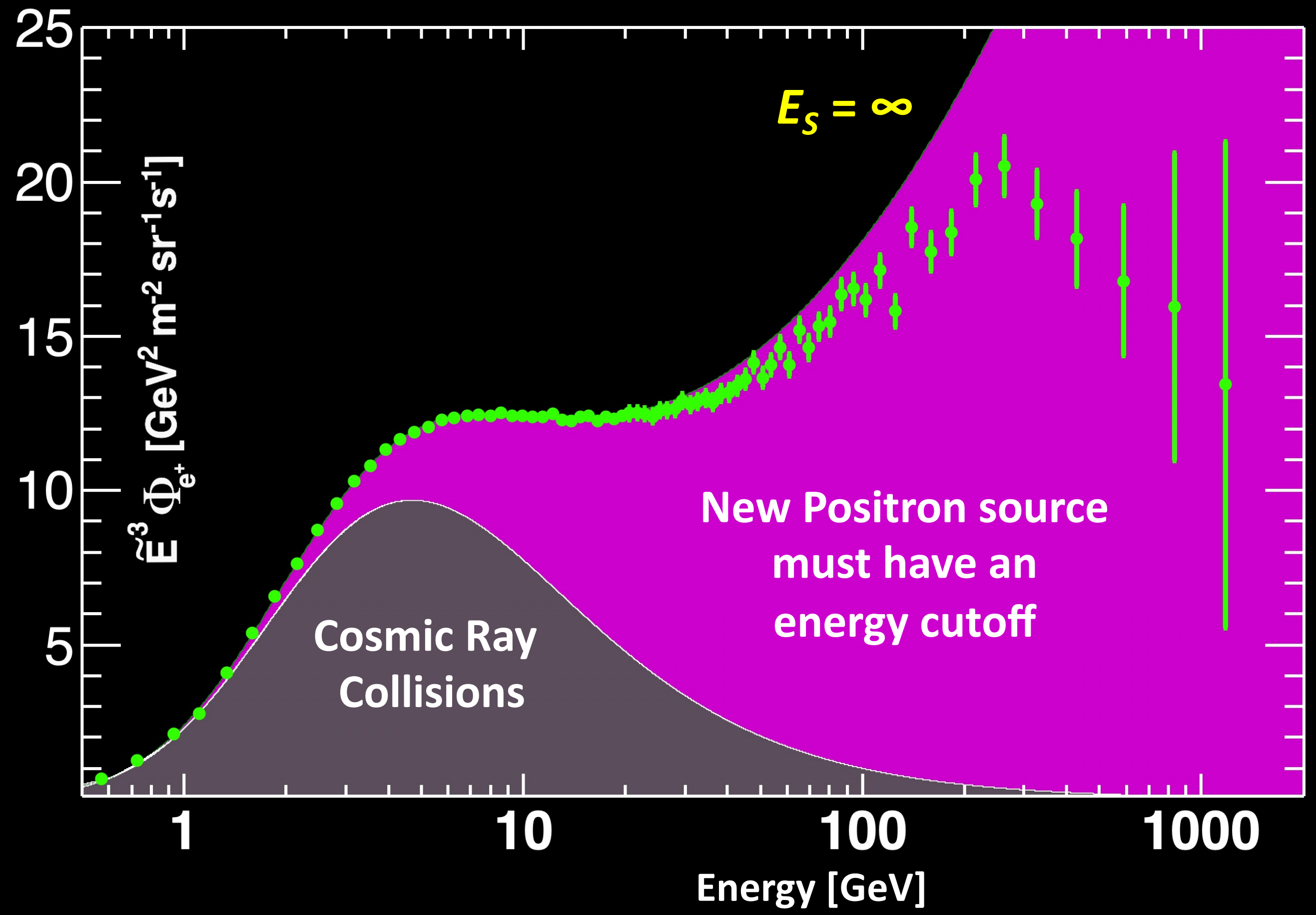


Surprising Observation: The existence of a finite cutoff energy E_S

$$\Phi_{e^+}(E) = \frac{E^2}{\widehat{E}^2}\left[C_d(\widehat{E}/E_1)^{\gamma_d} + C_s(\widehat{E}/E_2)^{\gamma_s}\exp(-\widehat{E}/E_s)\right]$$

Collisions   Pulsars or Dark Matter Collisions





$1/E_S = 0$ or $E_S = \infty$ is excluded at 5σ

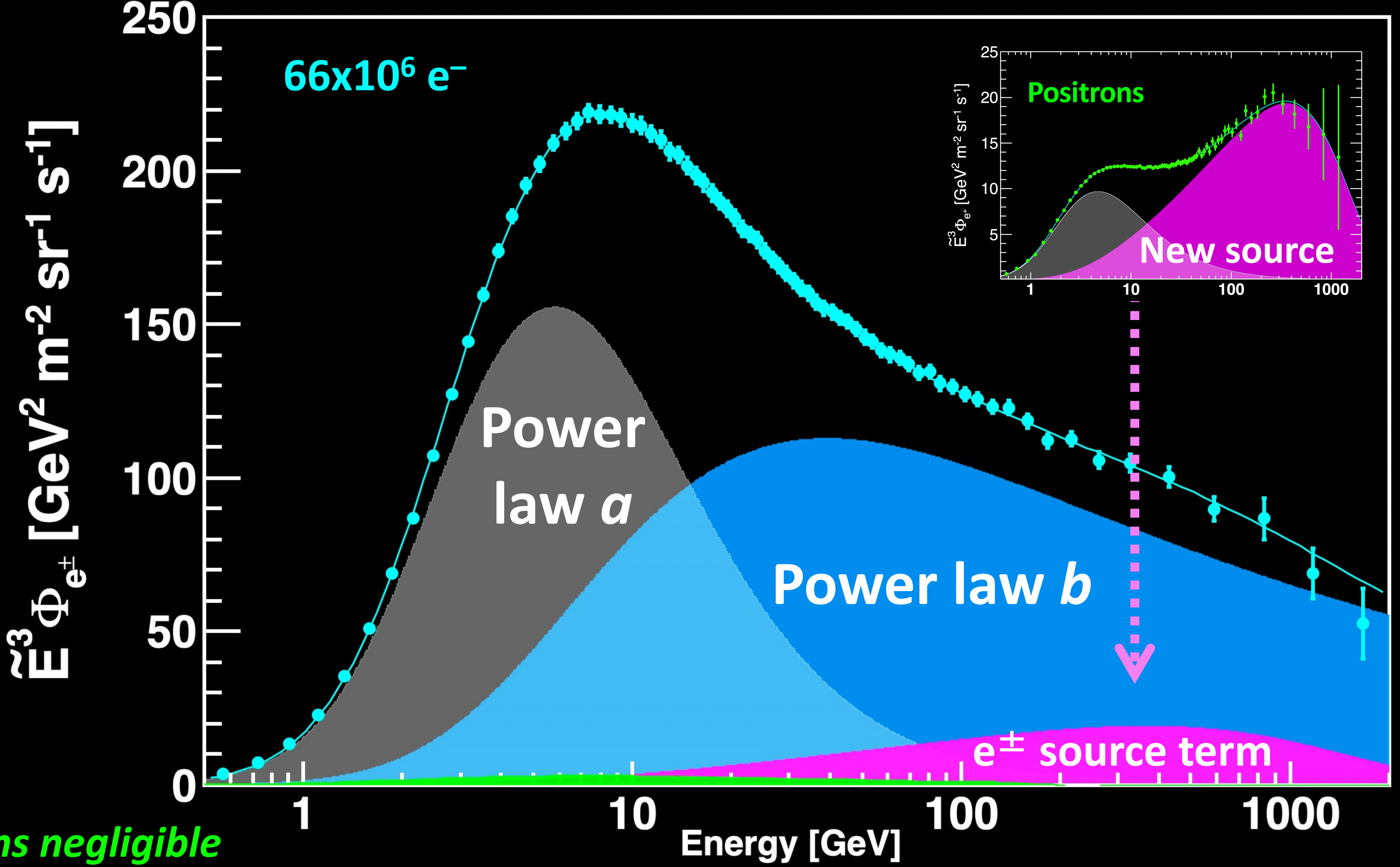
Latest Result on the electron spectrum

The spectrum fits well with two power laws (*a*, *b*) and the measured positron source term

Empirical model:
χ^2/dof = 25/67

$$\Phi_{e^-}(E) = \frac{E^2}{\hat{E}^2}\left(C_a \hat{E}^{\gamma_a} + C_b \hat{E}^{\gamma_b} + \text{Positron Source Term}\right)$$

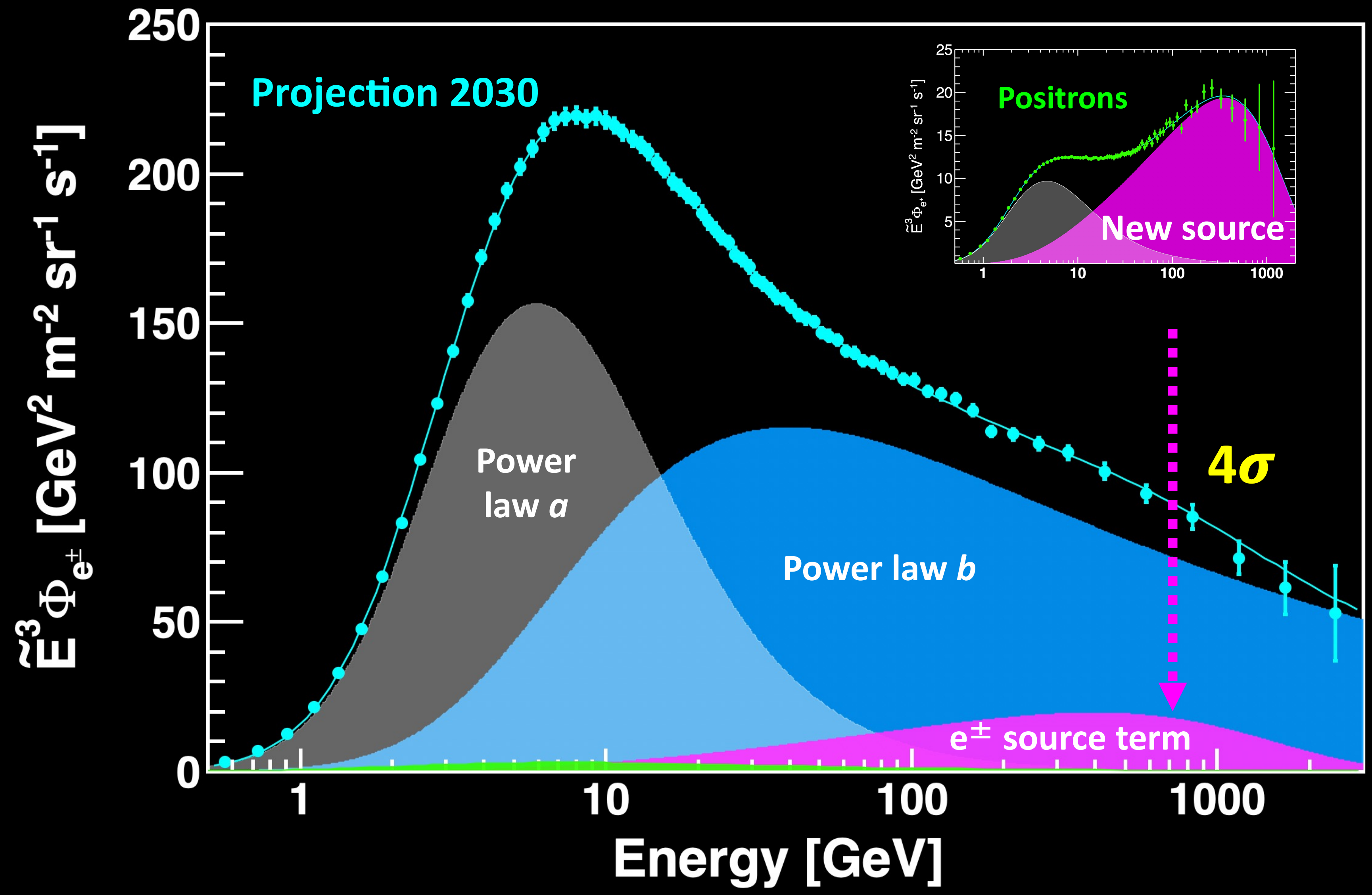
Solar Power law *a* Power law *b*



e⁻ from collisions negligible

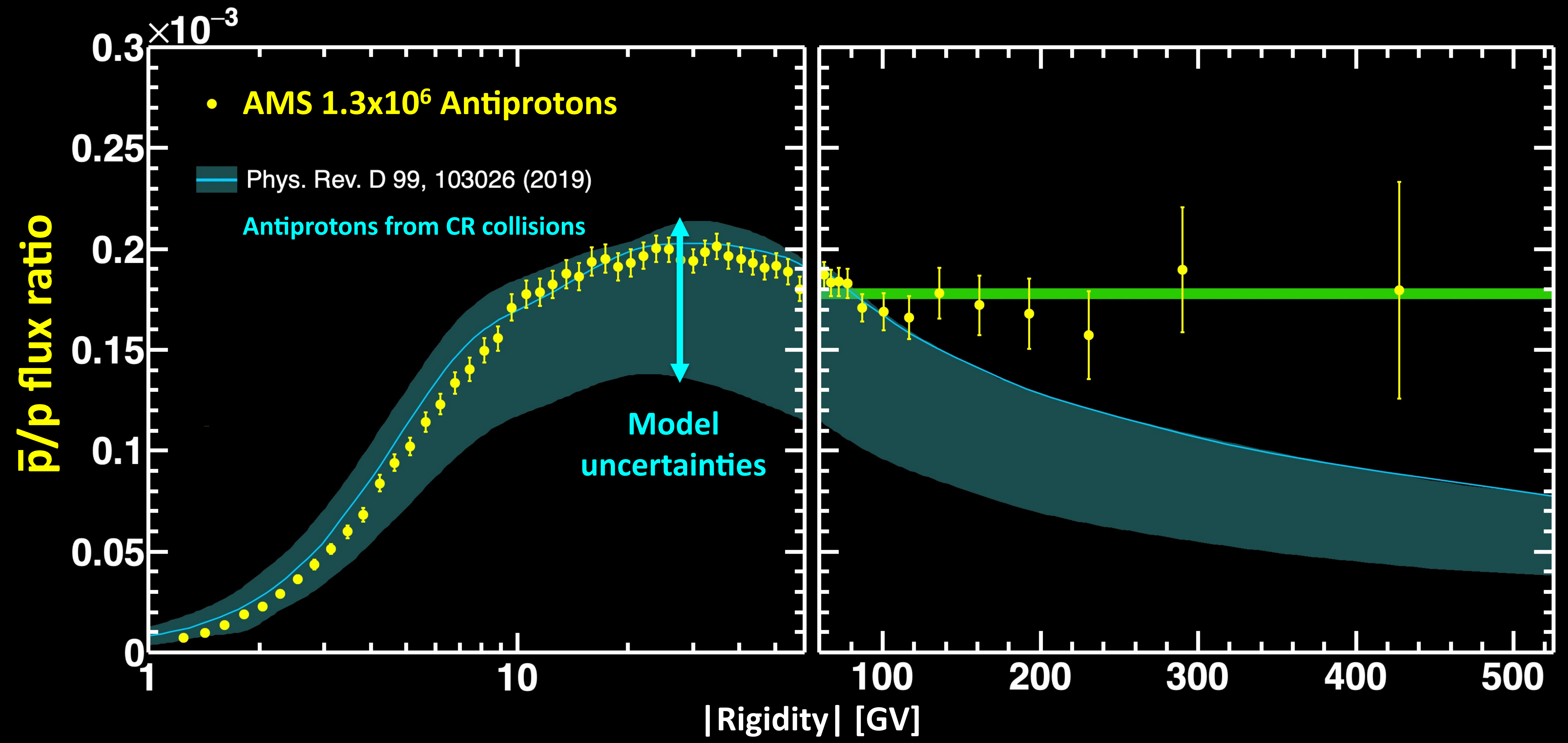
New sources, like Dark Matter or Pulsars, produce equal amounts of e+ and e–

By 2030, the charge-symmetric nature of the high energy source will be established at the 4*σ* level, due to increase of statistics and energy range



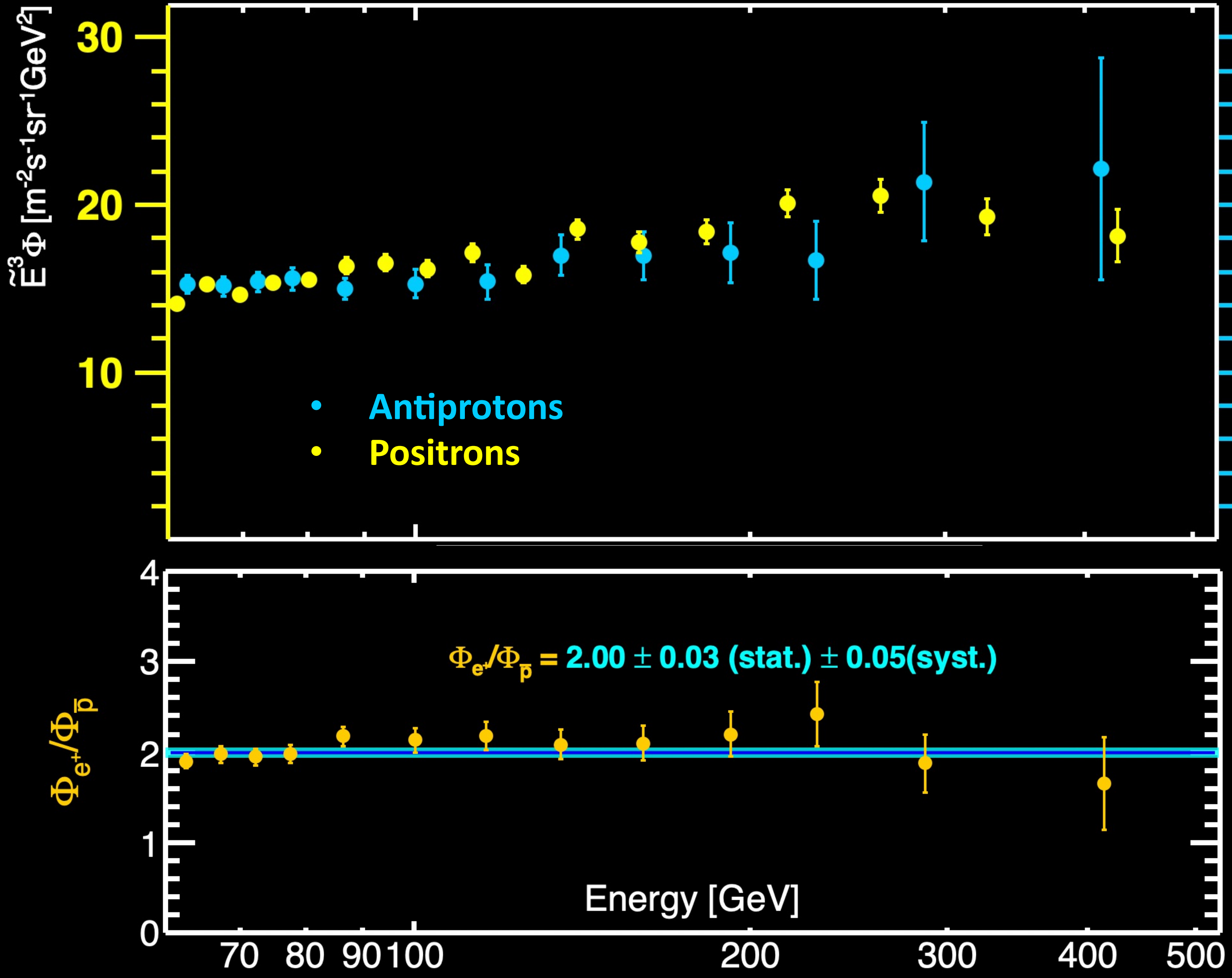
Properties of Cosmic Antiprotons

Above 60 GV, the antiproton-to-proton flux ratio is energy independent.



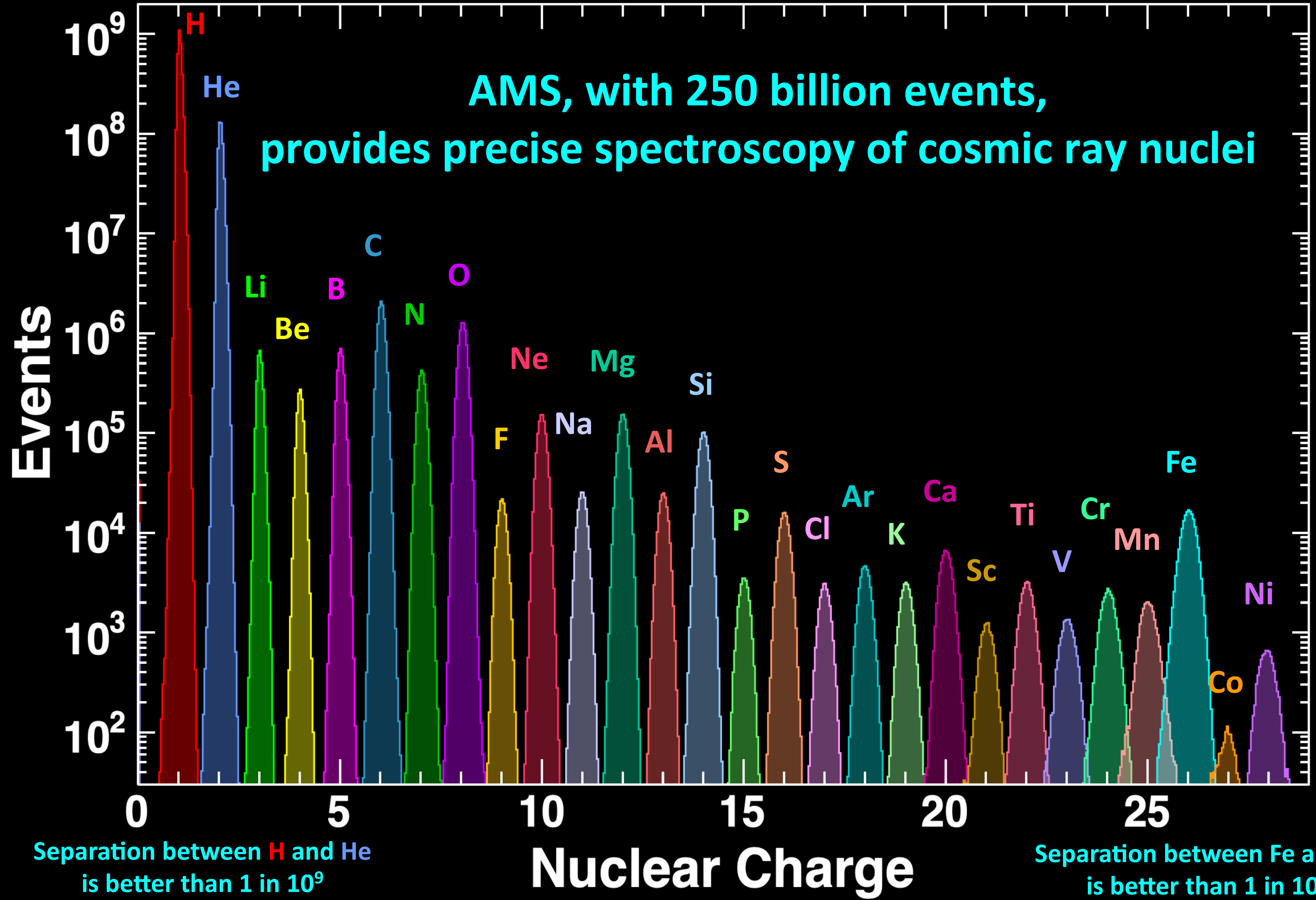
Cosmic Antiprotons and Positrons

Above 60 GeV, the p̄ and e⁺ fluxes have identical rigidity dependence



The identical behavior of positrons and antiprotons

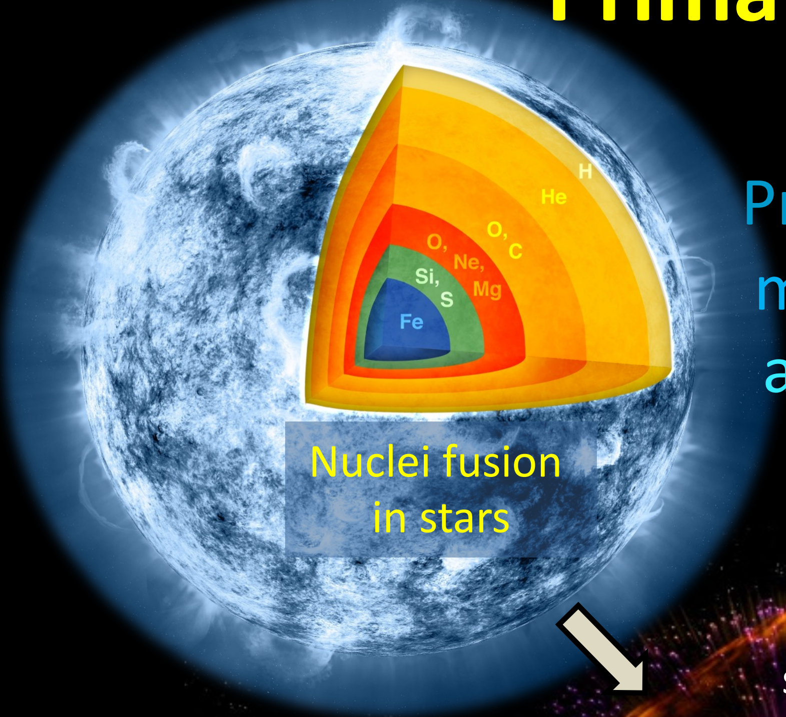
excludes the pulsar origin of positrons



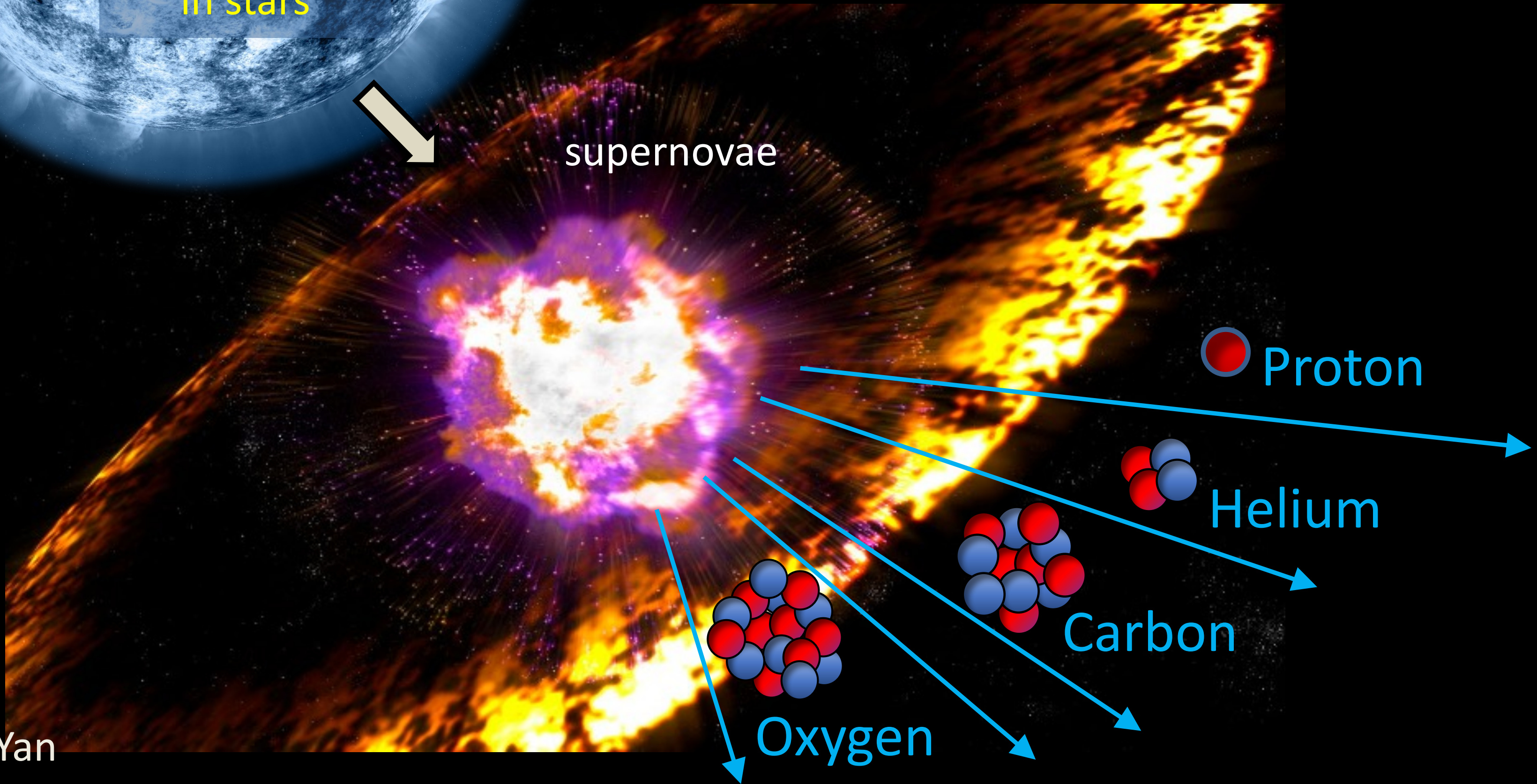
Separation between H and He is better than 1 in 10^9

Separation between Fe and Co is better than 1 in 10^2

Primary Cosmic Rays

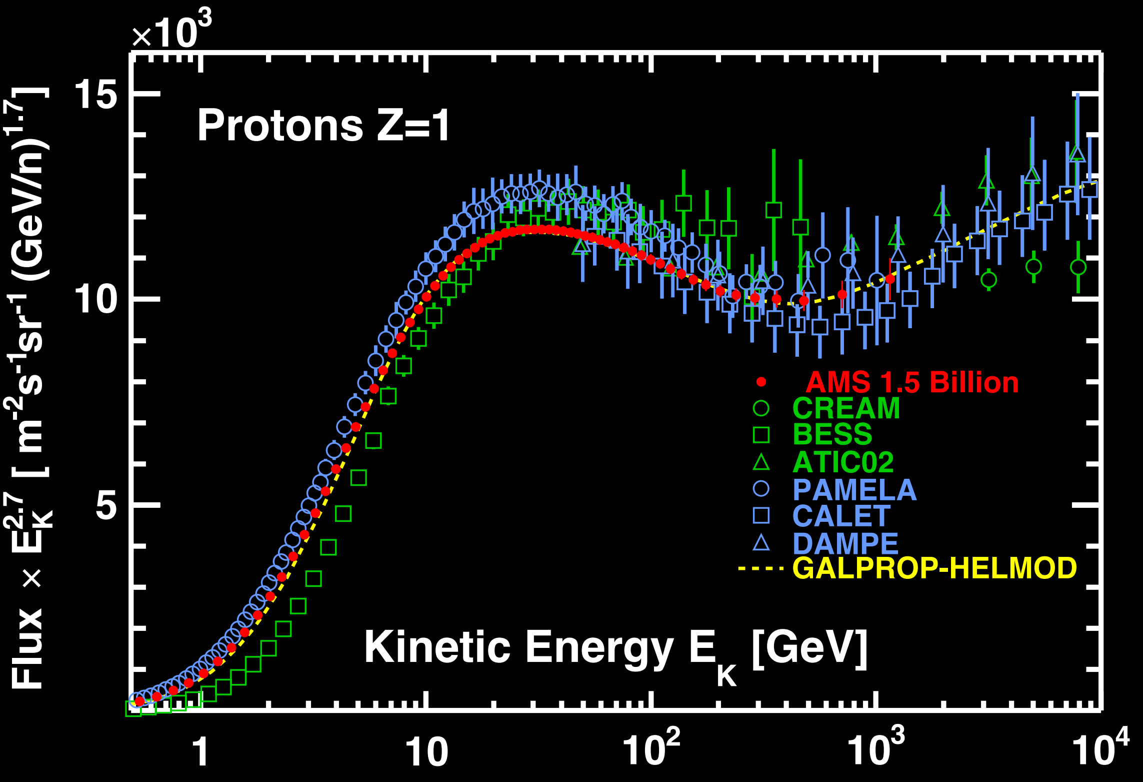


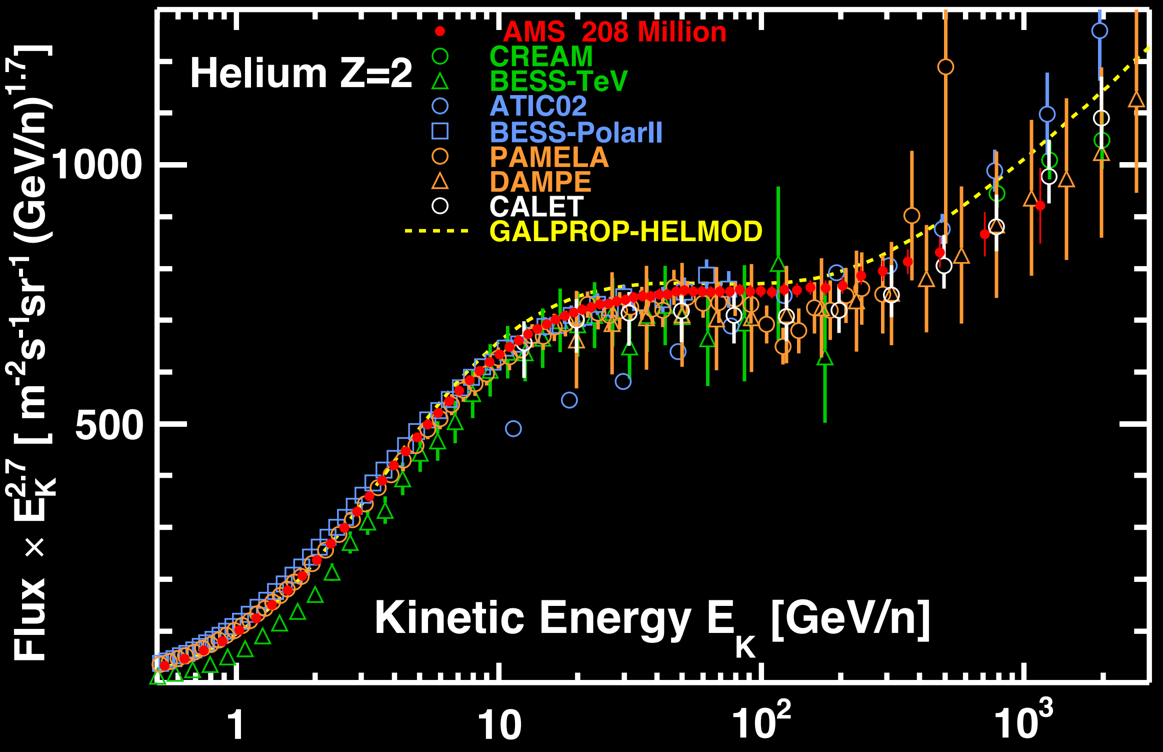
Primary cosmic rays (p, He, C, O, Ne, Mg, S ..., Fe) are mostly produced during the lifetime of stars and are accelerated in supernovae shocks, whose explosion rate is about 2-3 per century in our Galaxy.



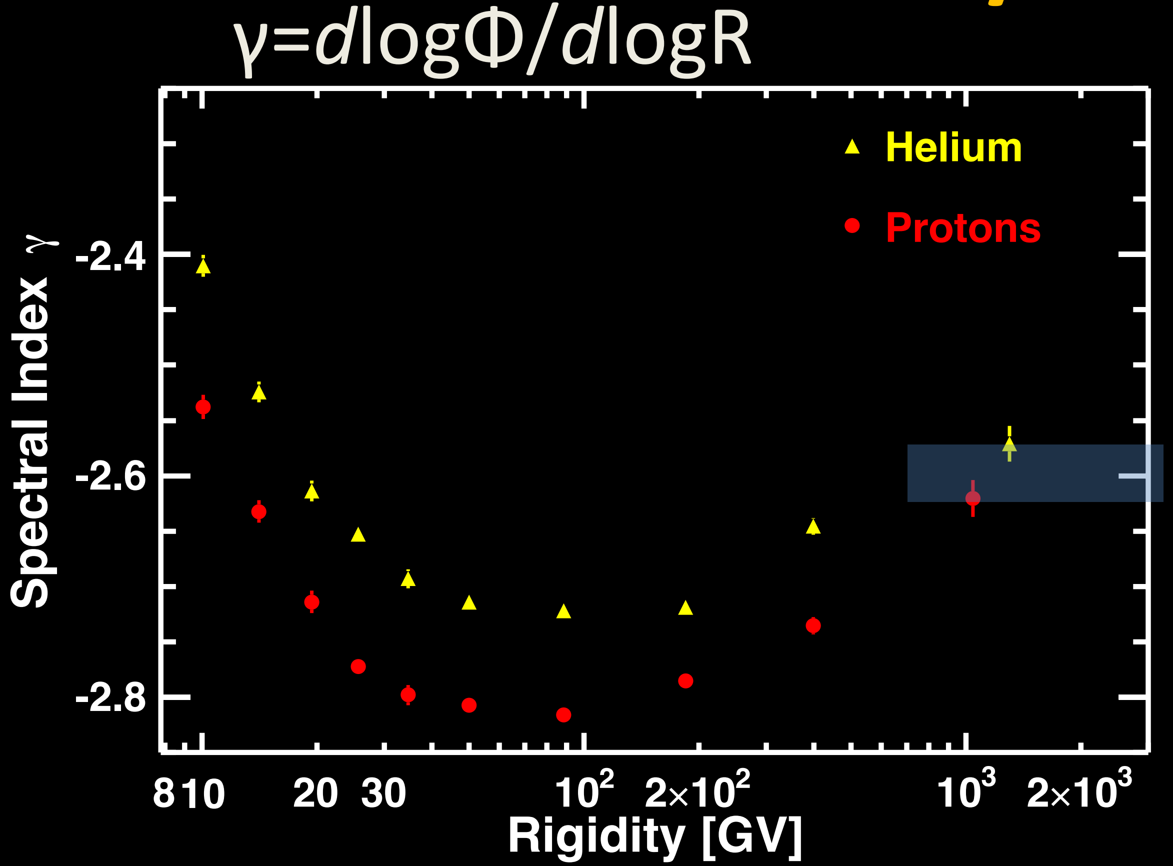
will be presented by Qi Yan

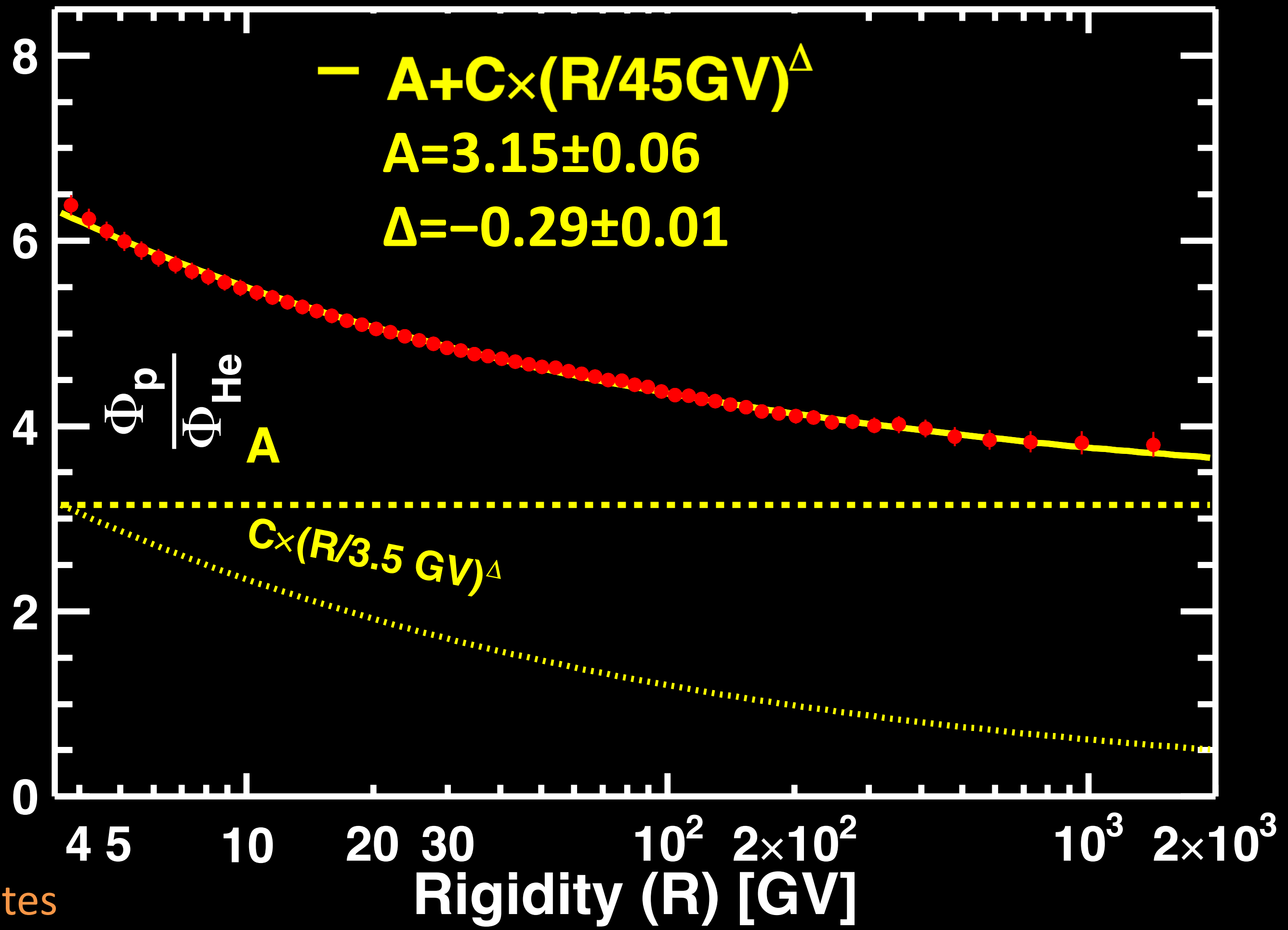
Latest AMS proton and He flux measurement





Proton/Helium Flux Ratio

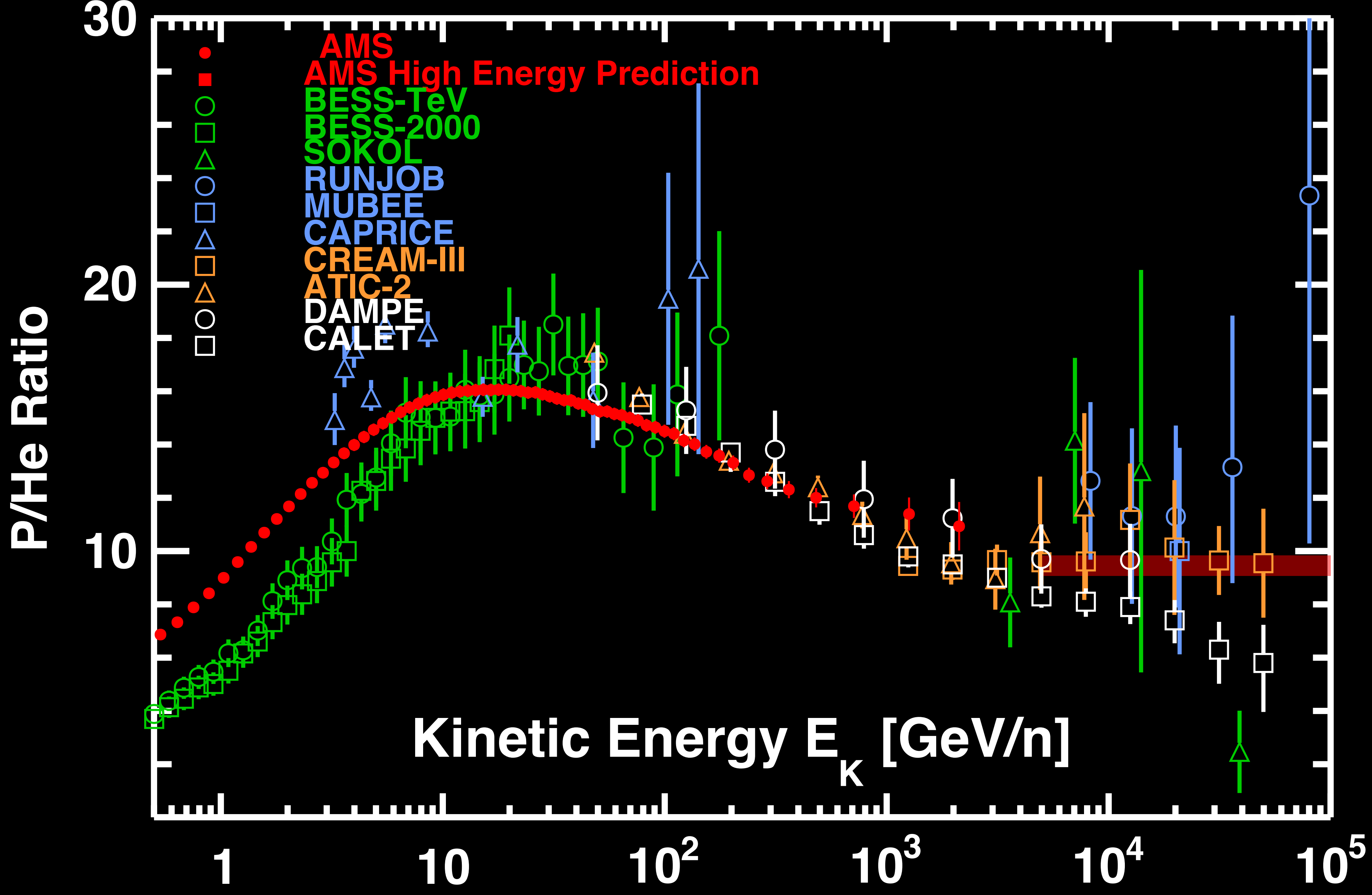




P and He may have same spectral index at highest rigidites

Physics Reports, 894, 1 (2021) :
AMS found that proton flux have two components, one is like Helium and another is unique to proton flux.

Proton/Helium Flux Ratio

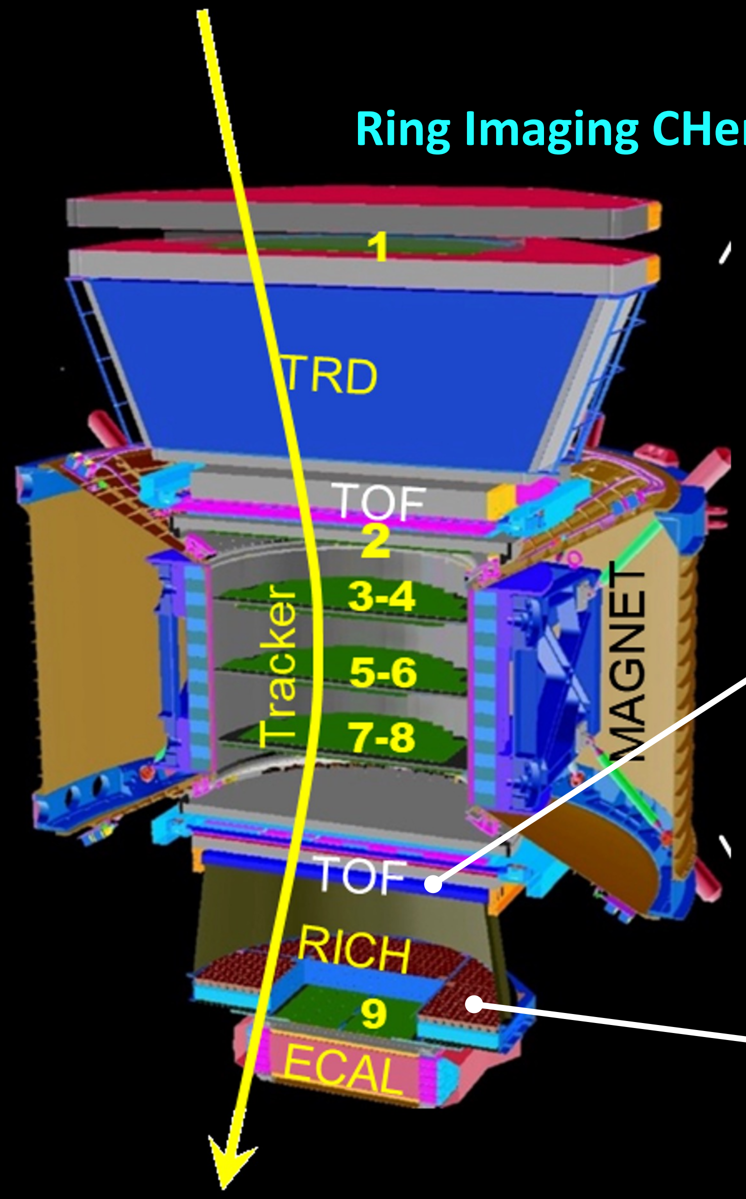


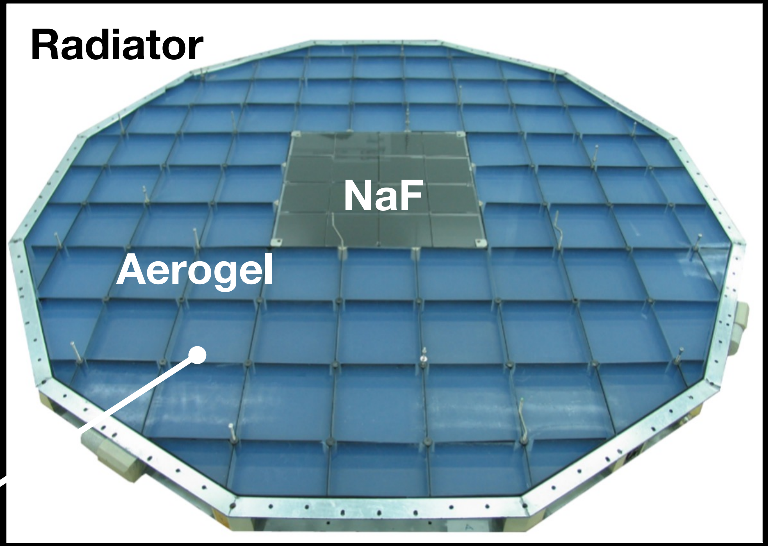
What about other Z=1 heavy cosmic rays? Let's look on Deuterons.

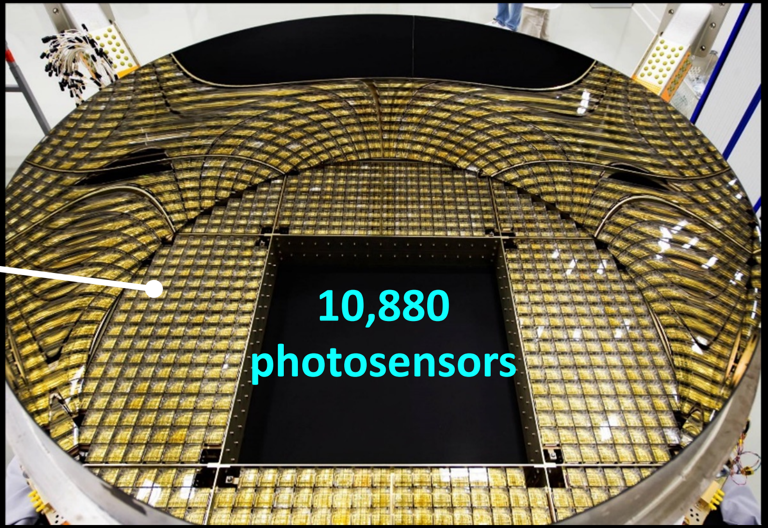
Precision measurement of isotopes

Isotopes: Same Z, different m

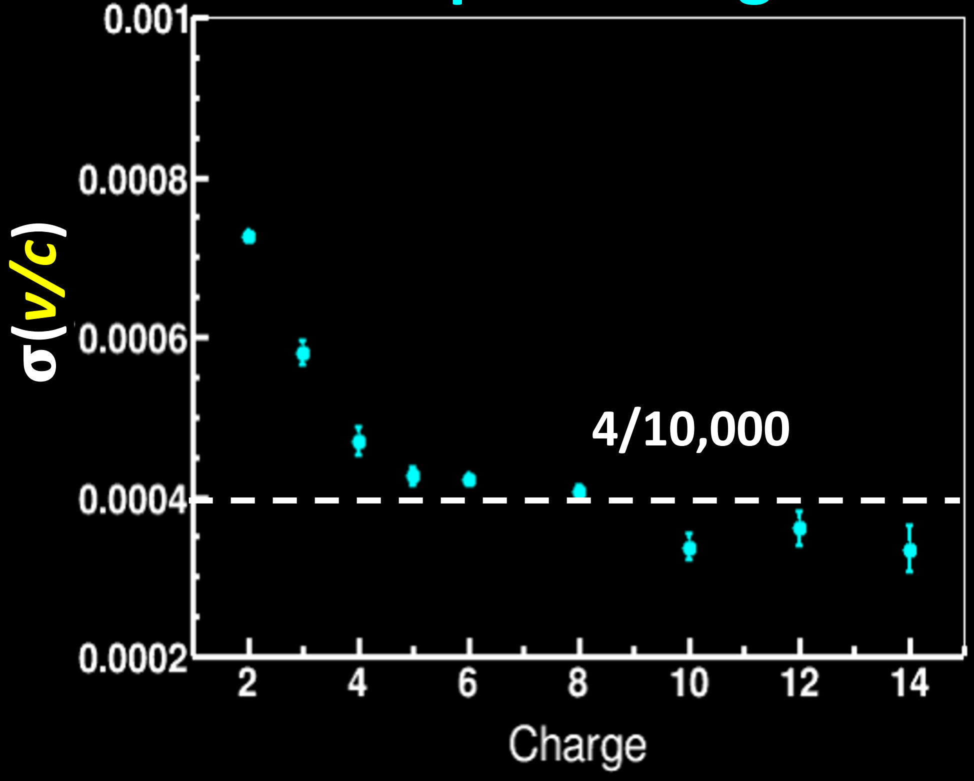
Ring Imaging CHerenkov (RICH)







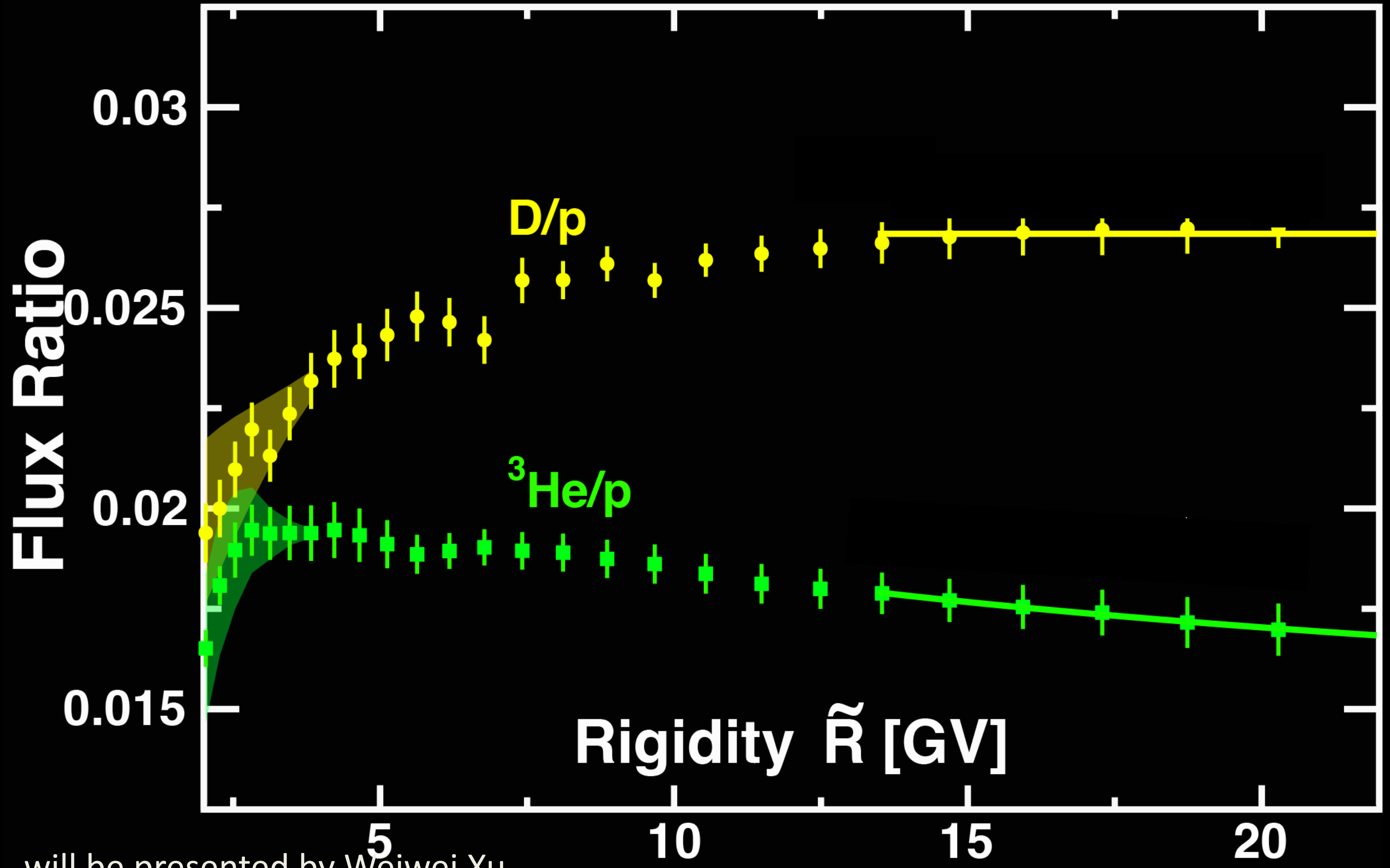
RICH velocity *v* resolution at the speed of light *c*



Origin of Cosmic Deuterons D

He, C, O, … + Interstellar Media → (D, ^{3}He) + *X*

D and ^{3}He are both known to be secondary cosmic rays



The flux ratio of ^{3}He/*p* decreases with rigidity above 4 GV.

If D is pure secondary, the flux ratio of D/p must also decrease with rigidity above ~4 GV

The flux ratio of D/*p* increases with rigidity and is about to be constant above 13 GV.

D must have an additional primary source

will be presented by Weiwei Xu

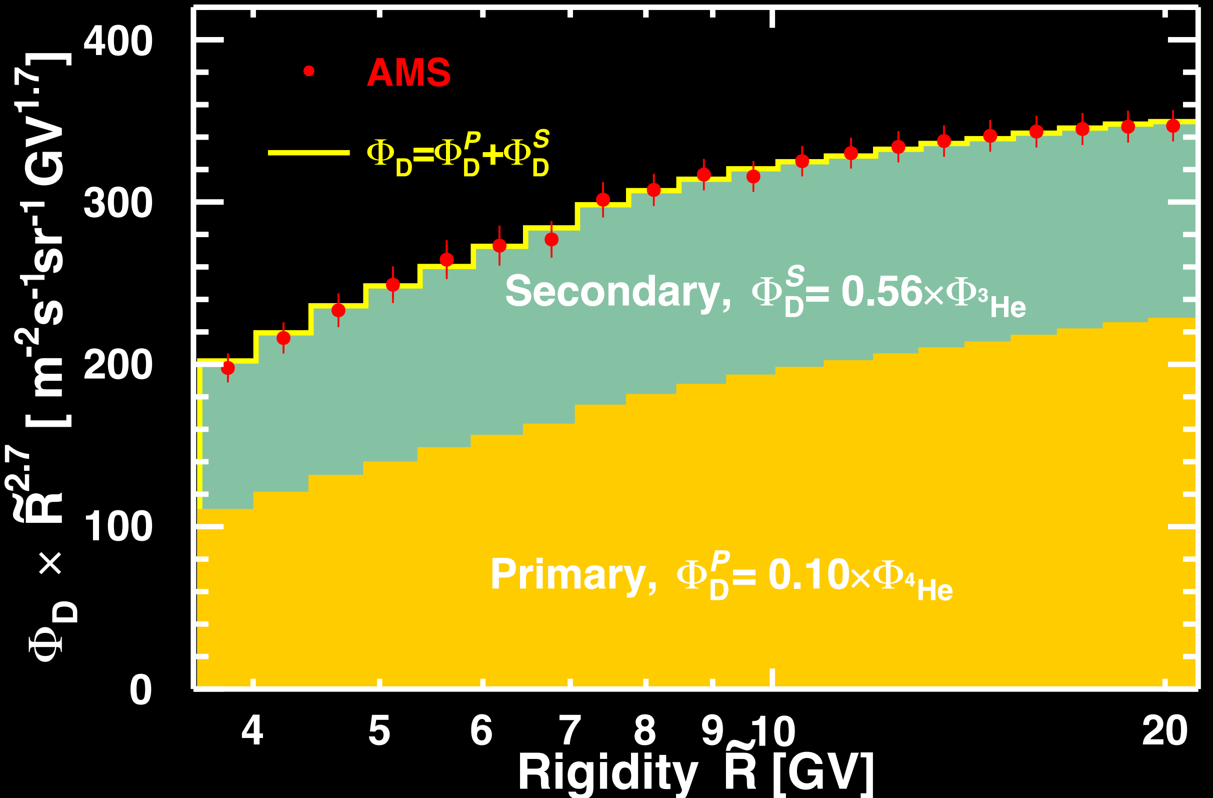
To find the D/p flux ratio rigidity dependence and to predict its value at high rigidities we note that

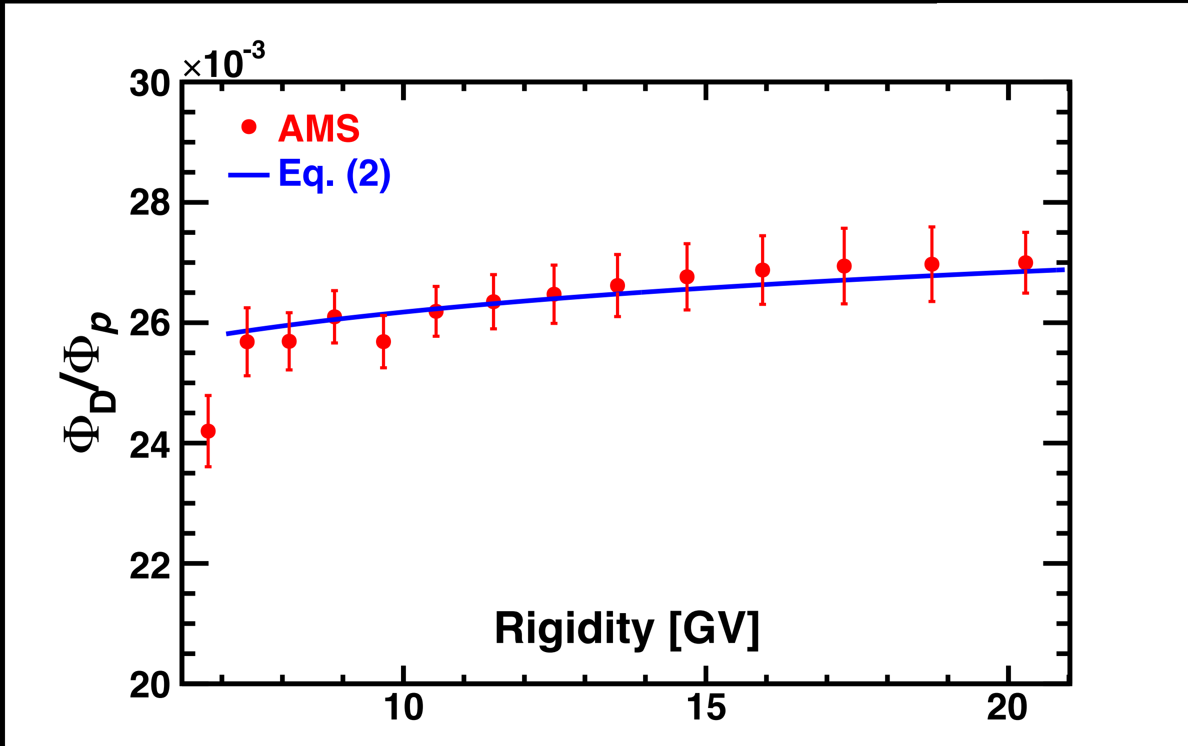
$$\frac{D/p}{1+D/p} \equiv D/(^3\mathrm{He} + ^4\mathrm{He}) \times \mathrm{He}/(p+D) \quad (1)$$

We then evaluate the D flux rigidity dependence as a weighted sum of primary and secondary fluxes D = $0.56\times^3\mathrm{He}+0.1\times^4\mathrm{He}$, $^3\mathrm{He}/^4\mathrm{He} = 0.153\times(R/3.5GV)^{-0.29}$ and the He/(p+D)=$3.15+3.18\times(R/3.5\ \mathrm{GV})^{-0.29}$

$$\frac{D/p}{1+D/p} = \frac{1+0.90(R/3.5GV)^{-0.29}}{1+0.153(R/3.5GV)^{-0.29}} \times \frac{0.030}{(1+1.01\times(R/3.5GV)^{-0.29}} \quad (2)$$

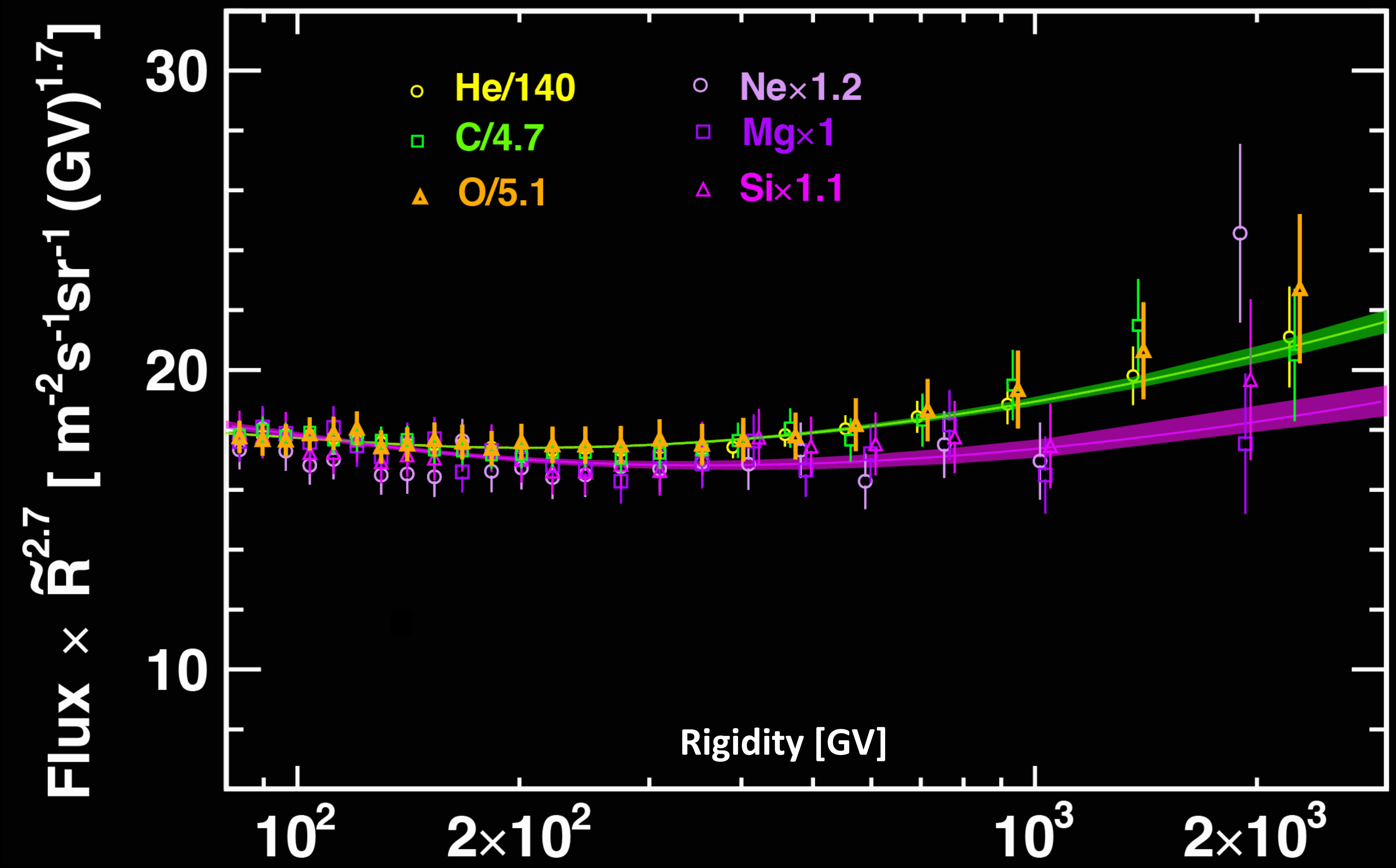
From the equation, we got for the D/p flux ratio at high rigidities, $D/p^{R\to\infty} = 0.031 \pm 0.001$.



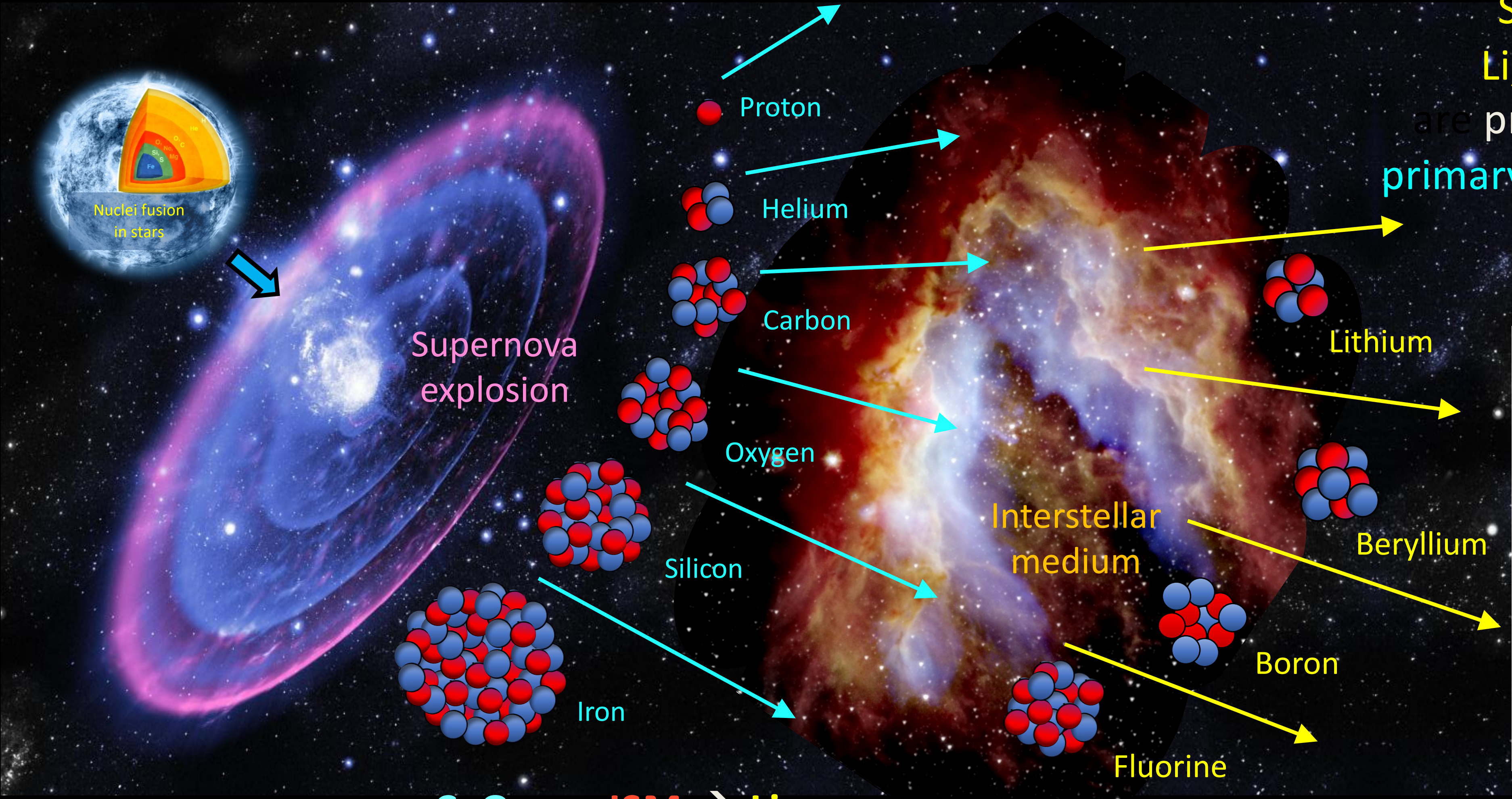


AMS Results: Primary cosmic rays have two classes

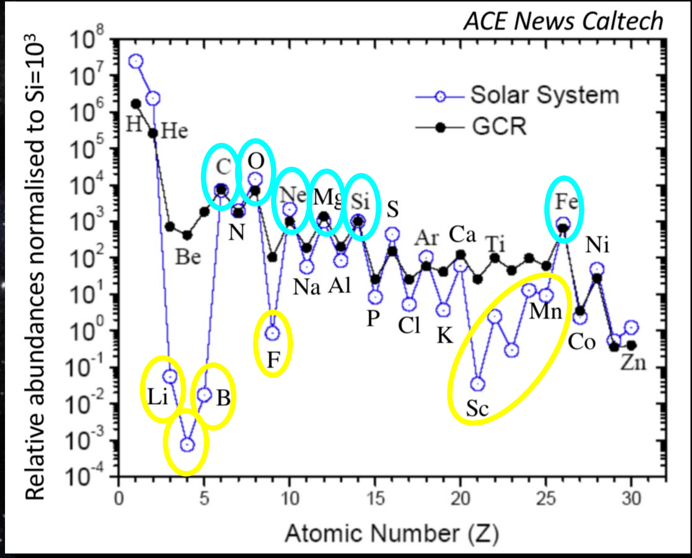
Light elements He-C-O and Heavier elements Ne-Mg-Si
each have their own rigidity dependence



Secondary Cosmic Rays



Secondary
Li, Be, B, F, sub-Fe nuclei
are produced by the collision of
primary cosmic rays C, O, Si, … , Fe
with the
interstellar medium



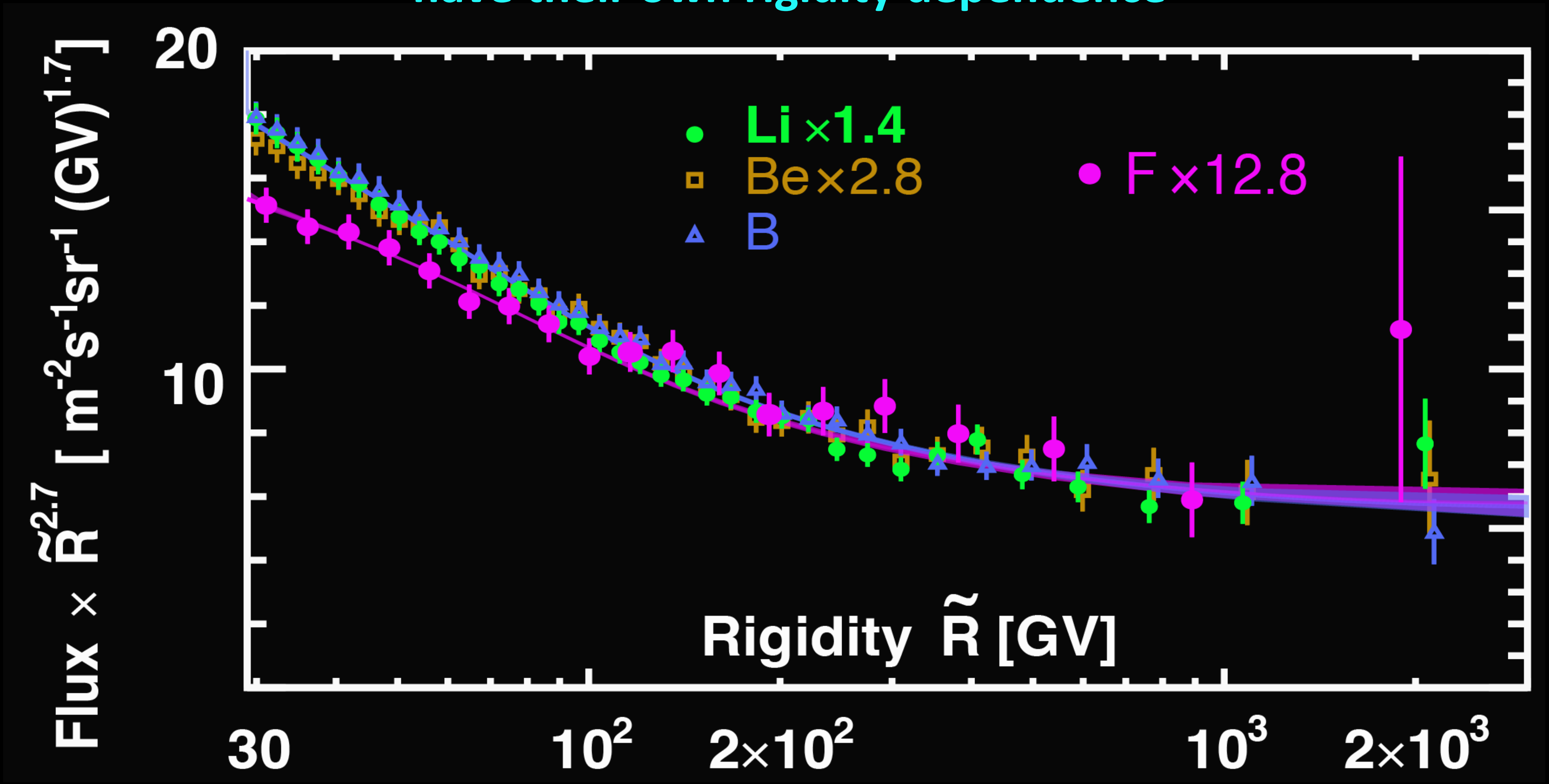
C, O, … + ISM → Li
C, O, … + ISM → Be
C, O, … + ISM → B

Ne, Mg, Si, … + ISM → F + X

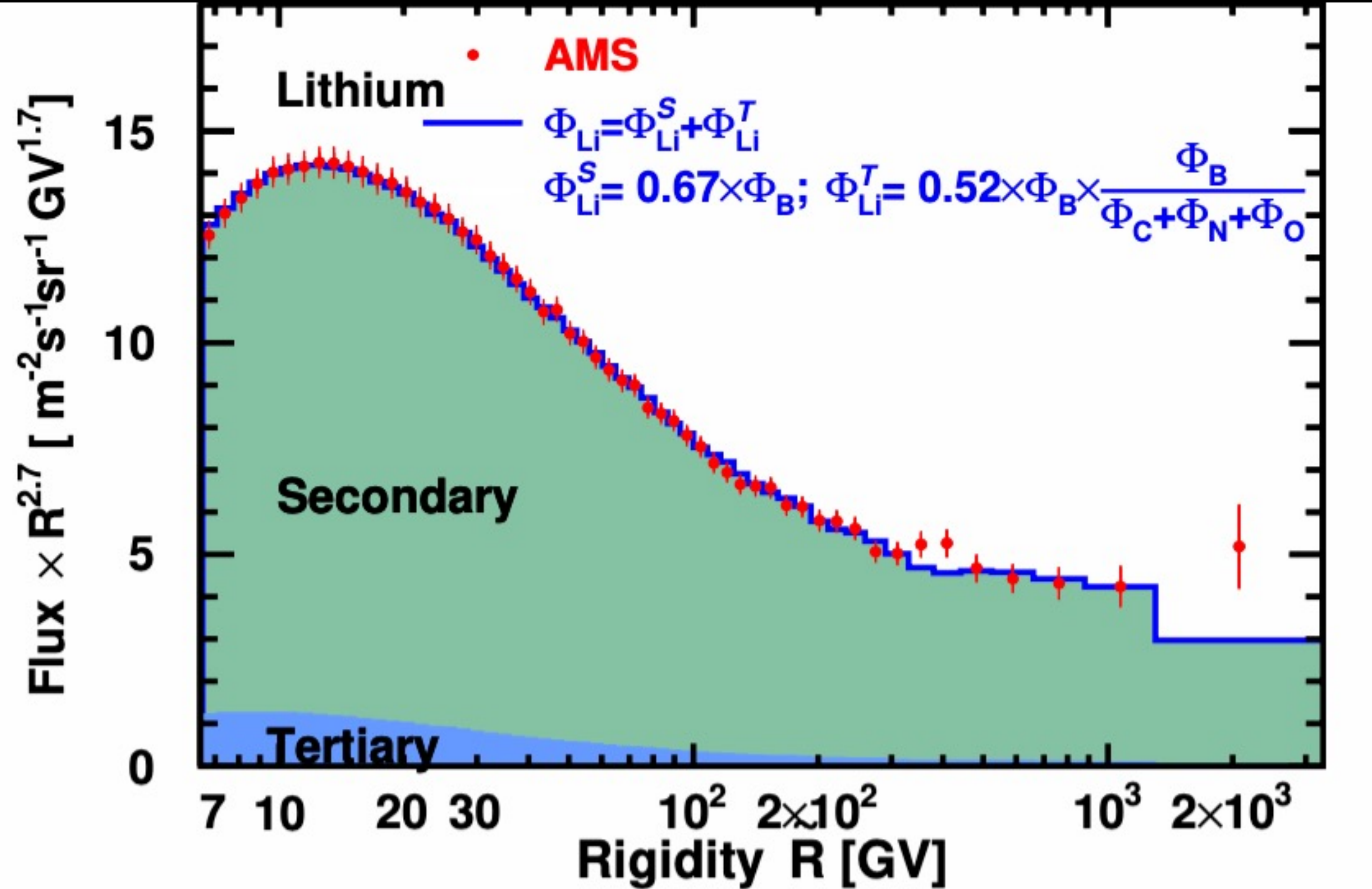
Fe, … + ISM → Sc, … ,Mn

will be presented by Zhaomin Wang

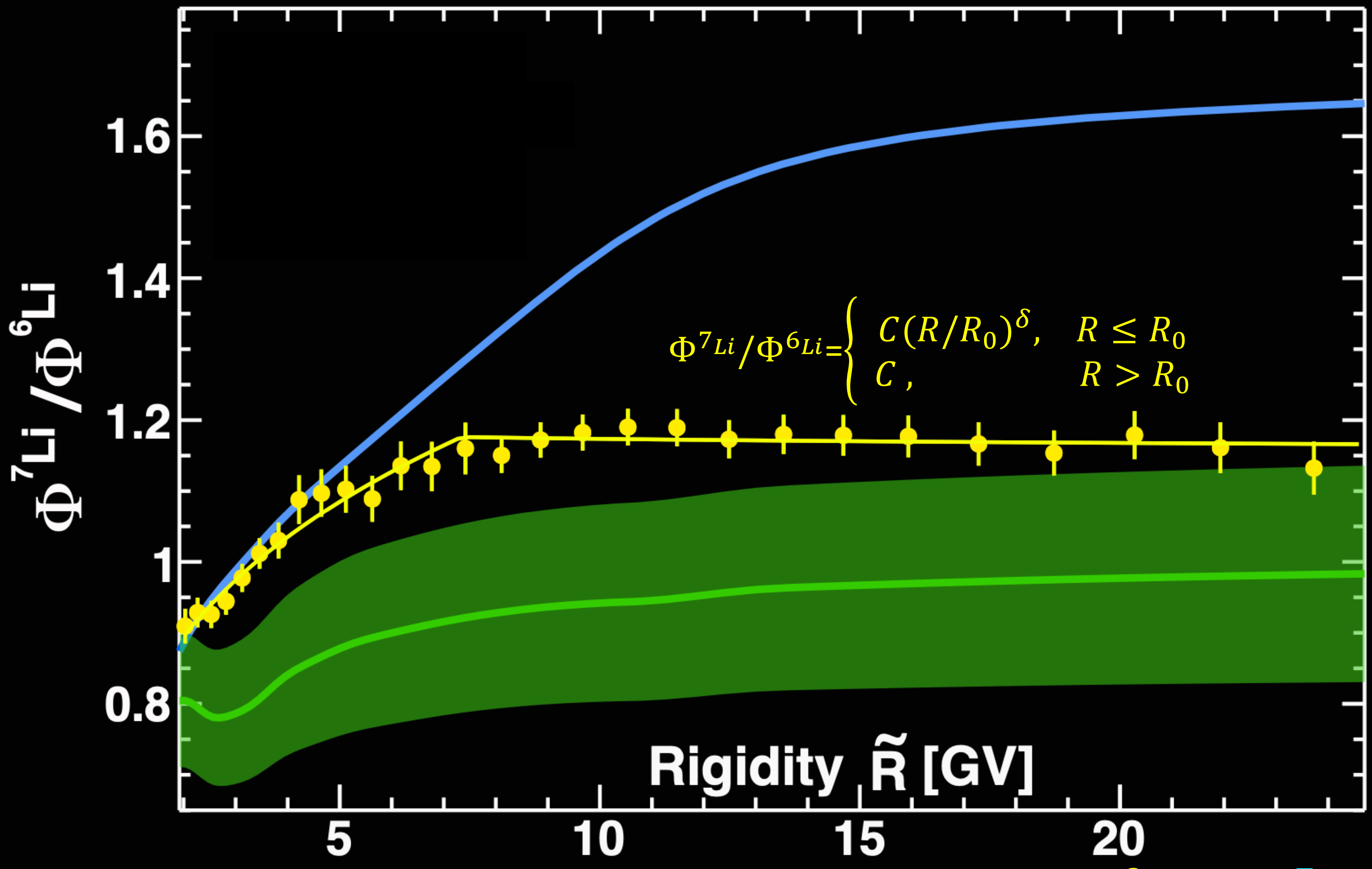
Secondary cosmic rays have two classes Li-Be-B and F have their own rigidity dependence



With more statistics we can study the differences between Li and B fluxes rigidity dependence at low rigidities. One can expect that some part of Li flux has a tertiary nature, i.e. produced by the interaction of B and Be with interstellar medium. To obtain the secondary and the tertiary components of the Li flux we fit $\Phi_{\mathrm{Li}} = \Phi^{S}_{\mathrm{Li}} + \Phi^{T}_{\mathrm{Li}}$ to the weighted sum of a secondary cosmic ray flux, namely boron Φ_{B}, and of a tertiary cosmic ray flux, namely $\Phi_{\mathrm{B}} \times \frac{\Phi_{\mathrm{B}}}{\Phi_{\mathrm{C}}+\Phi_{\mathrm{N}}+\Phi_{\mathrm{O}}}$ above 6 GV. The fit yields $\Phi^{S}_{\mathrm{Li}} = (0.67 \pm 0.02) \times \Phi_{\mathrm{B}}$ and $\Phi^{T}_{\mathrm{Li}} = (0.52 \pm 0.08) \times \Phi_{\mathrm{B}} \times \frac{\Phi_{\mathrm{B}}}{\Phi_{\mathrm{C}}+\Phi_{\mathrm{N}}+\Phi_{\mathrm{O}}}$ with a χ^2/d.o.f. = 28/53.



Results on Lithium Isotopes



GALPROP Model assuming a primary component in the ^{7}Li flux

AMS data and fit, R_0 = 7GV

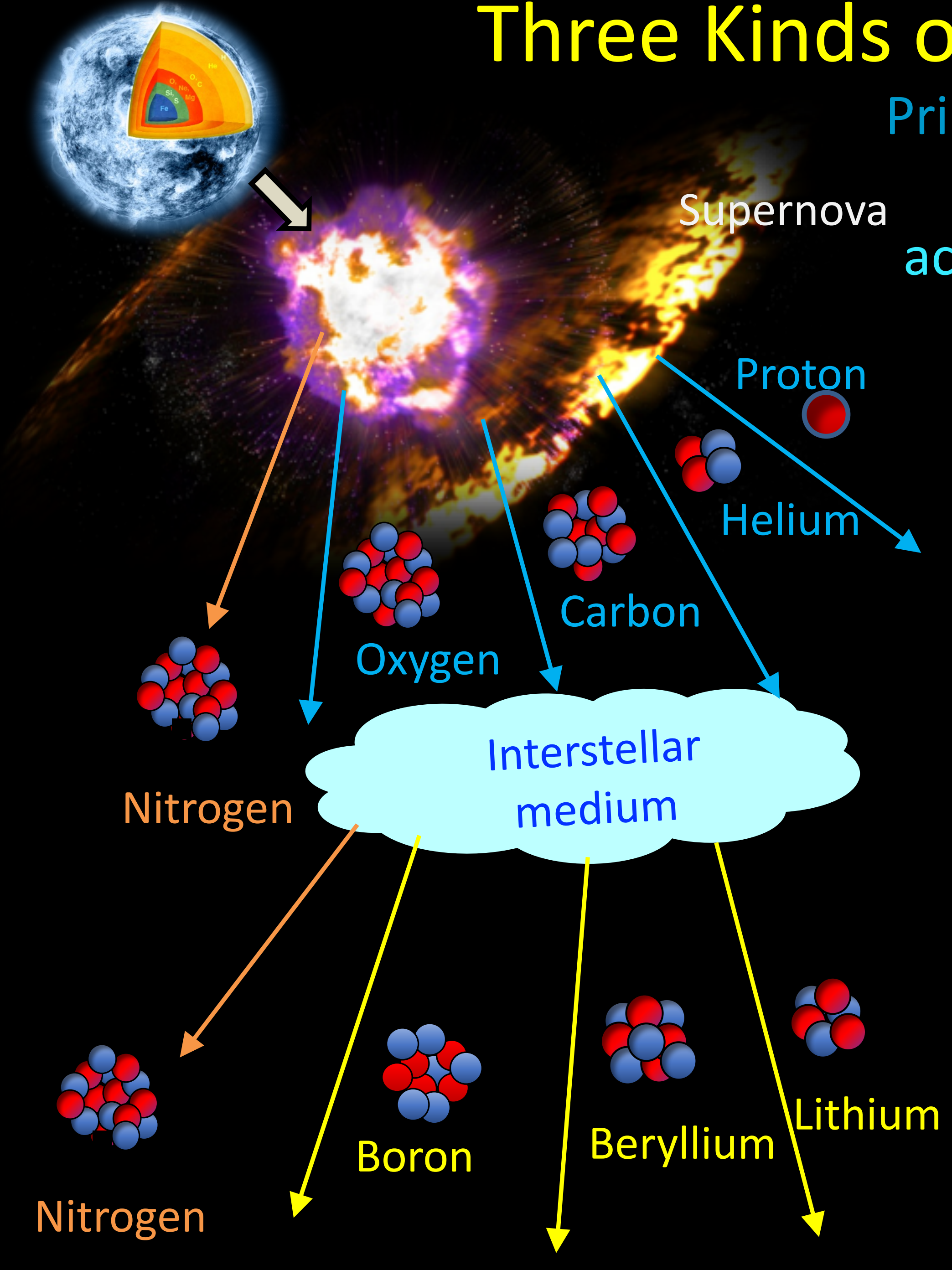
USINE Model assuming secondary origin of ^{6}Li and ^{7}Li

Above ~7 GV, the rigidity dependence of ^{6}Li and ^{7}Li fluxes are identical

Excludes the existence of a sizable primary component in the ^{7}Li flux

will be presented by Hai Chen

Three Kinds of Charged Cosmic Rays



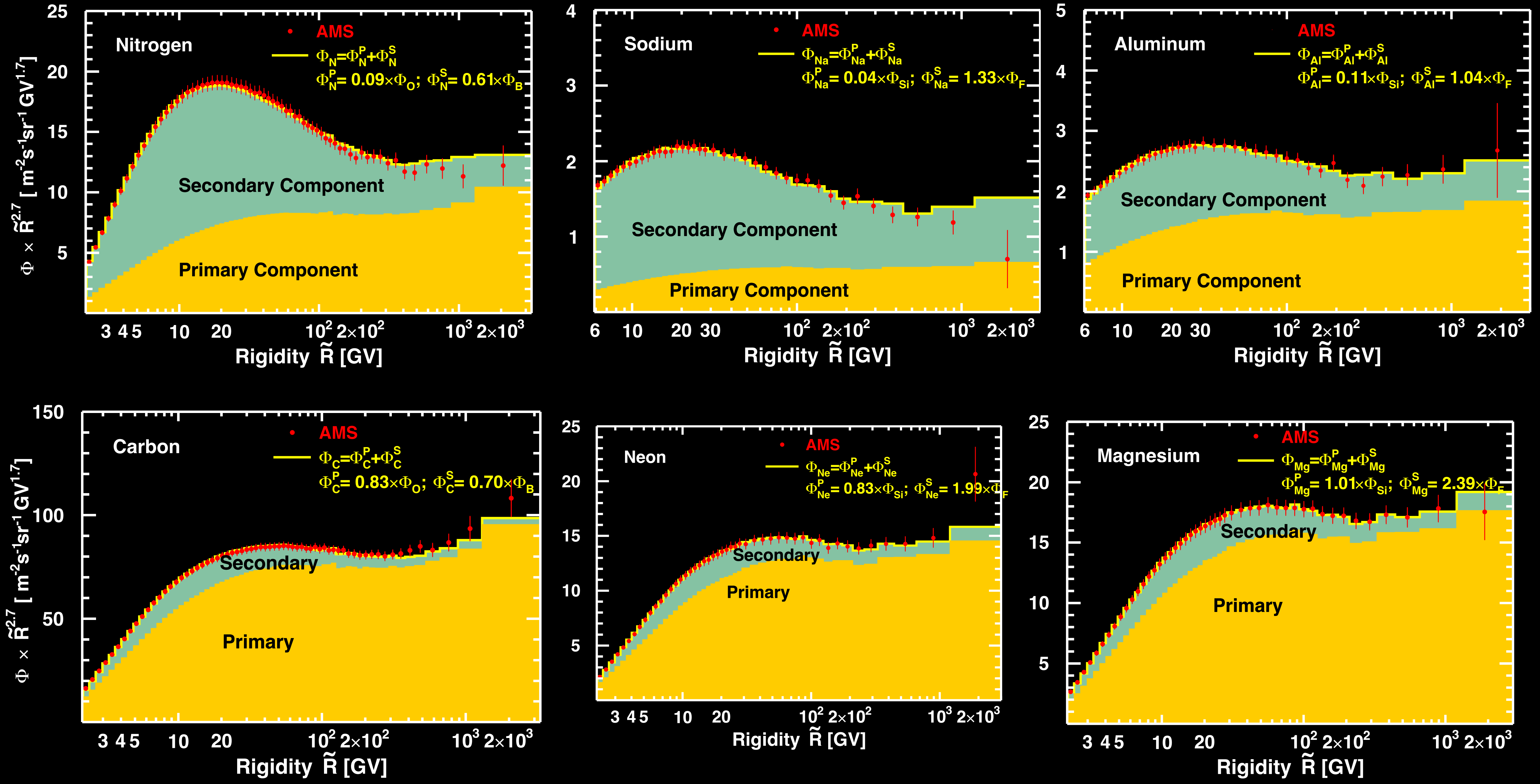
will be presented by Cheng Zhang

Primary cosmic rays (p, He, C, O, Ne, Mg, S ,Ar, ..., Fe) are mostly produced during the lifetime of stars and are accelerated in supernovae shocks, whose explosion rate is about 2-3 per century in our Galaxy.

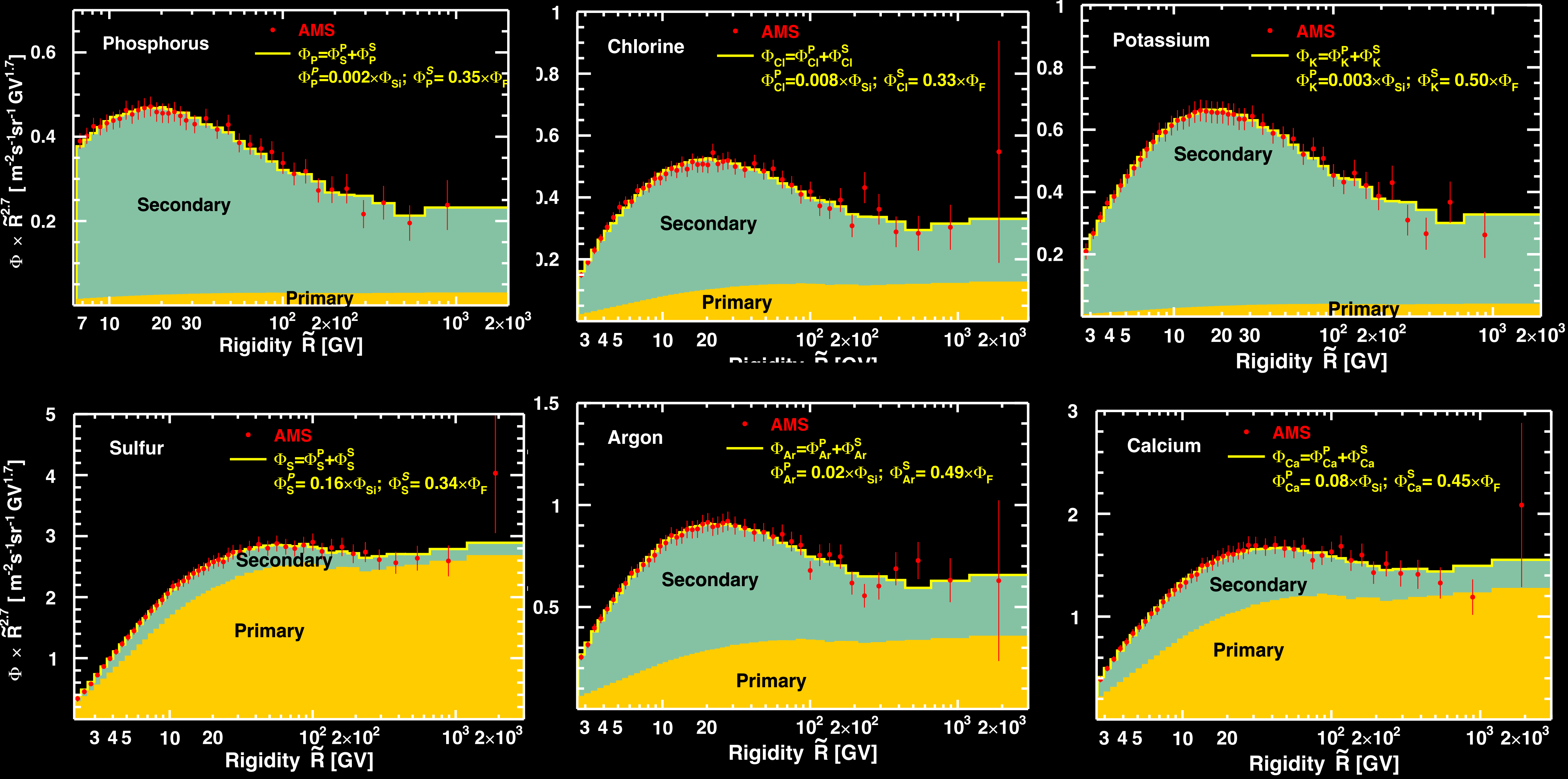
Secondary cosmic nuclei (Li, Be, B, F, …) are produced by the collisions of primary cosmic rays and interstellar medium.

Cosmic nuclei with both Primary and Secondary Components (N, Na, Al, Cl,…) . Many primary cosmic rays C, Ne, Mg, S are also expected to have sizeable secondary component.

AMS found that all such fluxes can be presented as a weighted sums of the characteristic primary flux (O, Si) and a charecteristic secondary flux (B, F)



Nitrogen
AMS
$\Phi_N=\Phi_N^P+\Phi_N^S$
$\Phi_N^P= 0.09\times\Phi_O$; $\Phi_N^S= 0.61\times\Phi_B$
Secondary Component
Primary Component
$\Phi \times \tilde{R}^{2.7}$ [$m^{-2}s^{-1}sr^{-1}$ $GV^{1.7}$]
Rigidity $\tilde{R}$ [GV]
Sodium
AMS
$\Phi_{Na}=\Phi_{Na}^P+\Phi_{Na}^S$
$\Phi_{Na}^P= 0.04\times\Phi_{Si}$; $\Phi_{Na}^S= 1.33\times\Phi_F$
Secondary Component
Primary Component
Rigidity $\tilde{R}$ [GV]
Aluminum
AMS
$\Phi_{Al}=\Phi_{Al}^P+\Phi_{Al}^S$
$\Phi_{Al}^P= 0.11\times\Phi_{Si}$; $\Phi_{Al}^S= 1.04\times\Phi_F$
Secondary Component
Primary Component
Rigidity $\tilde{R}$ [GV]
Carbon
AMS
$\Phi_C=\Phi_C^P+\Phi_C^S$
$\Phi_C^P= 0.83\times\Phi_O$; $\Phi_C^S= 0.70\times\Phi_B$
Secondary
Primary
$\Phi \times \tilde{R}^{2.7}$ [$m^{-2}s^{-1}sr^{-1}$ $GV^{1.7}$]
Rigidity $\tilde{R}$ [GV]
Neon
AMS
$\Phi_{Ne}=\Phi_{Ne}^P+\Phi_{Ne}^S$
$\Phi_{Ne}^P= 0.83\times\Phi_{Si}$; $\Phi_{Ne}^S= 1.99\times\Phi_F$
Secondary
Primary
Rigidity $\tilde{R}$ [GV]
Magnesium
AMS
$\Phi_{Mg}=\Phi_{Mg}^P+\Phi_{Mg}^S$
$\Phi_{Mg}^P= 1.01\times\Phi_{Si}$; $\Phi_{Mg}^S= 2.39\times\Phi_F$
Secondary
Primary
Rigidity $\tilde{R}$ [GV]



Preliminary results, please refer to fututre AMS publication

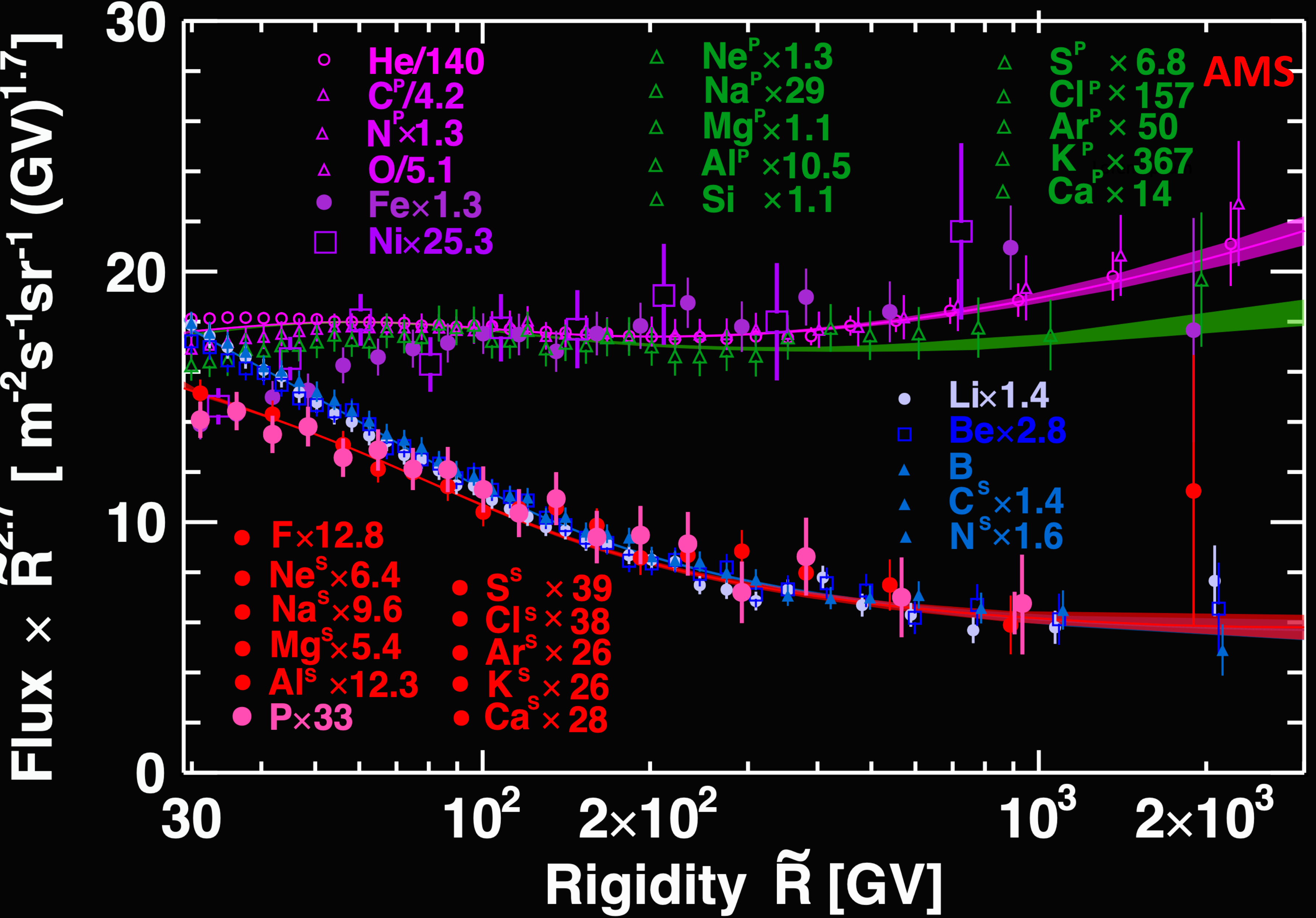
Summary Primary and Secondary Components

Nuclei Flux	Primary	Secondary	Secondary Fr,% 6 GV	Secondary Fr,% 2 TV
Φ_C	$(0.835 \pm 0.025) \times \Phi_O$	$(0.70 \pm 0.03) \times \Phi_B$	20±1	4±0.5
Φ_N	$(0.091 \pm 0.002) \times \Phi_O$	$(0.61 \pm 0.02) \times \Phi_B$	69±1	23±2
Φ_{Ne}	$(0.831 \pm 0.025) \times \Phi_{Si}$	$(1.99 \pm 0.14) \times \Phi_F$	24±1	5±0.5
Φ_{Na}	$(0.038 \pm 0.003) \times \Phi_{Si}$	$(1.33 \pm 0.04) \times \Phi_F$	81±2	38±12
Φ_{Mg}	$(1.008 \pm 0.025) \times \Phi_{Si}$	$(2.39 \pm 0.17) \times \Phi_F$	25±1	5±0.5
Φ_{Al}	$(0.105 \pm 0.004) \times \Phi_{Si}$	$(1.04 \pm 0.03) \times \Phi_F$	57±2	22±8
Φ_P	$(0.002^{+0.002}_{-0.001}) \times \Phi_{Si}$	$(0.35 \pm 0.02) \times \Phi_F$	98±2	92±2
Φ_S	$(0.162 \pm 0.005) \times \Phi_{Si}$	$(0.33 \pm 0.04) \times \Phi_F$	18±3	3±1
Φ_{Cl}	$(0.008 \pm 0.001) \times \Phi_{Si}$	$(0.33 \pm 0.01) \times \Phi_F$	86±3	63±4
Φ_{Ar}	$(0.021 \pm 0.002) \times \Phi_{Si}$	$(0.49 \pm 0.02) \times \Phi_F$	74±4	44±4
Φ_K	$(0.003 \pm 0.001) \times \Phi_{Si}$	$(0.50 \pm 0.02) \times \Phi_F$	96±3	87±3
Φ_{Ca}	$(0.076 \pm 0.003) \times \Phi_{Si}$	$(0.45 \pm 0.03) \times \Phi_F$	44±2	18±1

The C (Z=6) to Ca (Z=20) cosmic ray nuclei primary and secondary components derived as fractions of O(Si) and B(F) fluxes, respectively, and their secondary fractions at 6 GV and 2 TV.

This allows to measure relative cosmic ray abundances of C/O, N/O, Ne/Si, Na/Si, Mg/Si, Al/Si, S/Si, Cl/Si, Ar/si, K/Si, and Ca/Si at the source independently of cosmic ray propagation.

Primary and Secondary Decomposition for All Cosmic Ray Fluxes of 2≤Z≤20, Z=26, Z=28

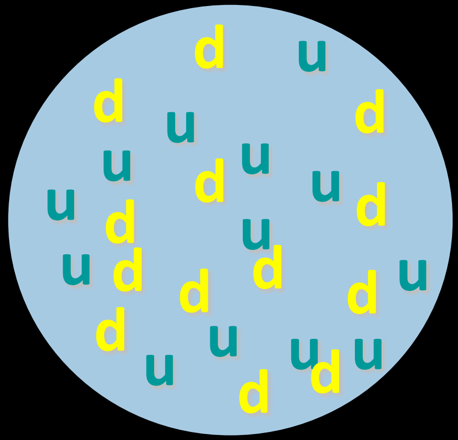


Strange Quark Matter – "Strangelets"

E. Witten, Phys. Rev. D,272-285 (1984

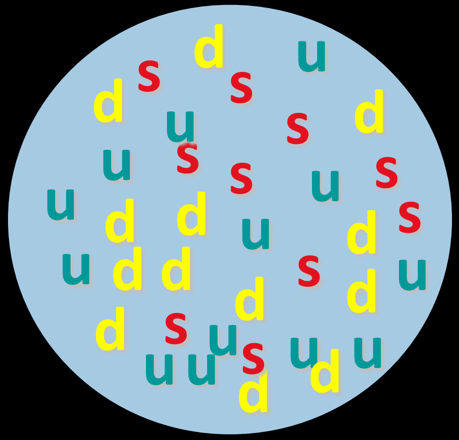
There are six quarks – u, d, s, c, b, and t.

All the material on Earth is made out of u and d quarks

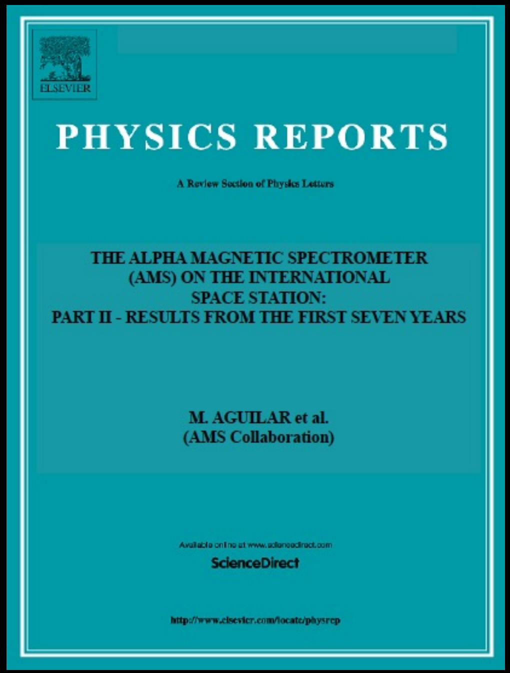


Diamond (Z/A ~ 0.5)

Is there material in the universe made up of u, d, & s quarks?

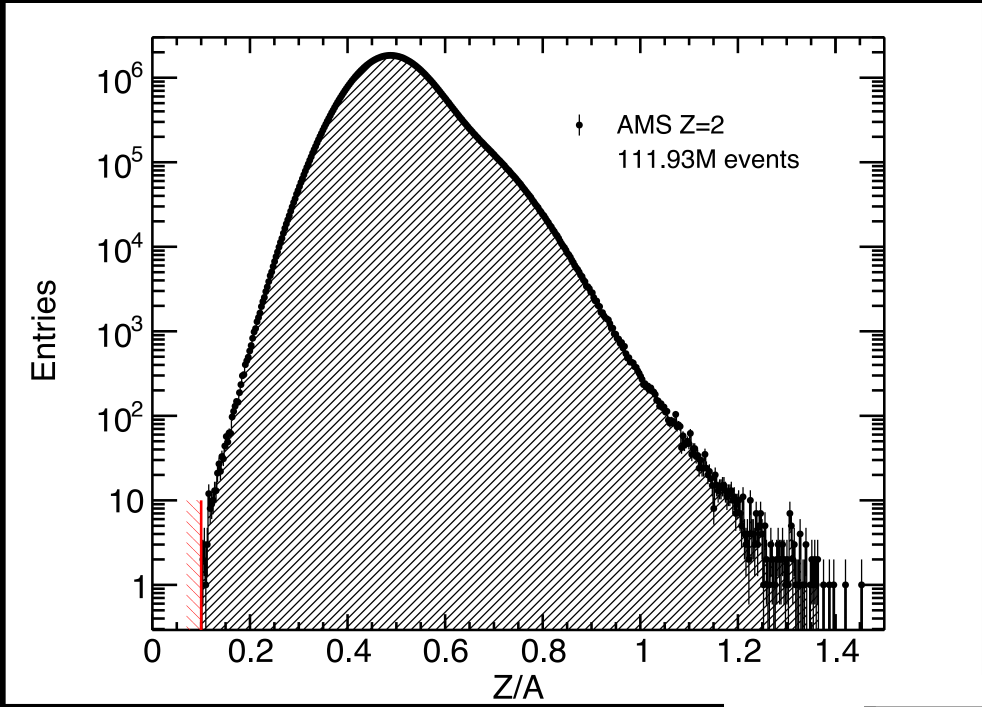


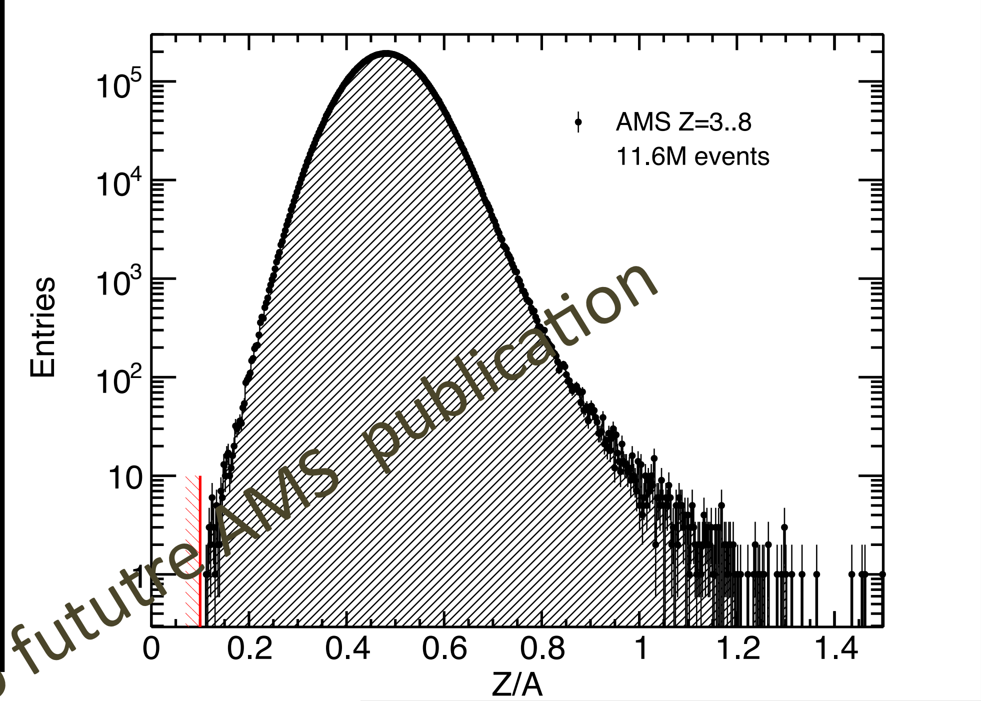
Strangelet (Z/A < 0.1)

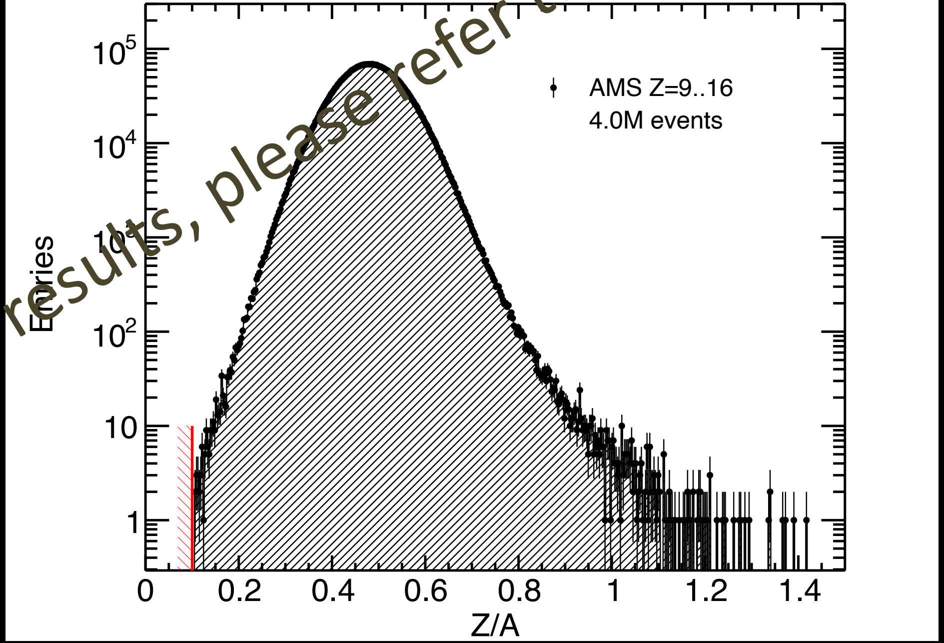


This is being answered by AMS.

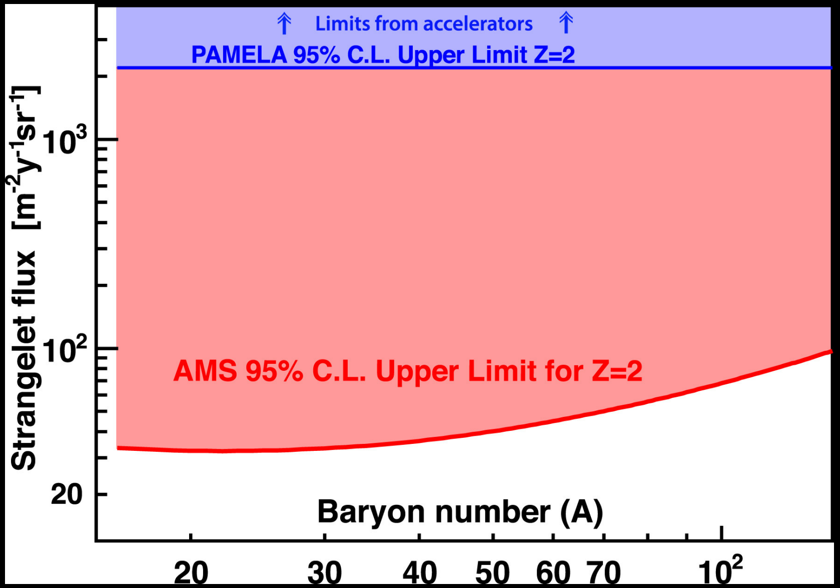
Search for Strangelets Z =2…16

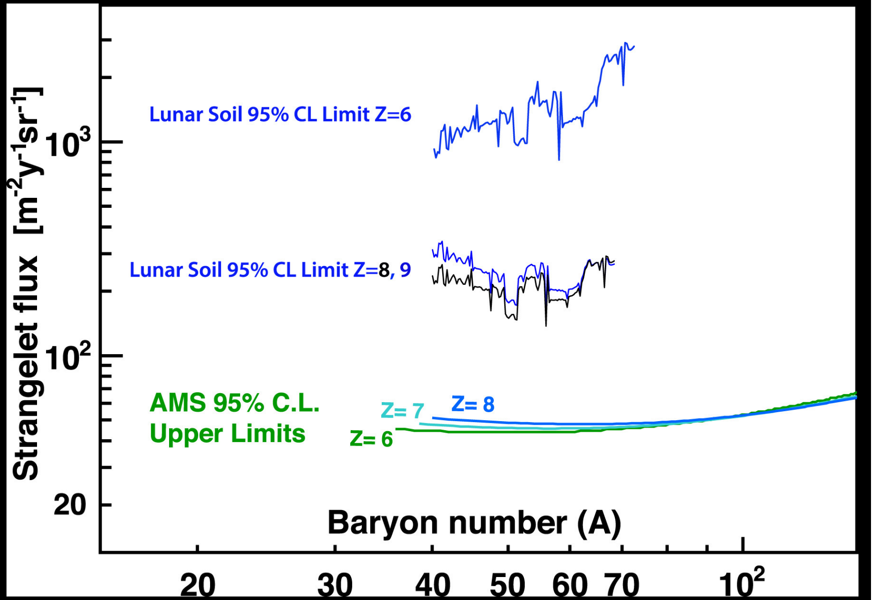


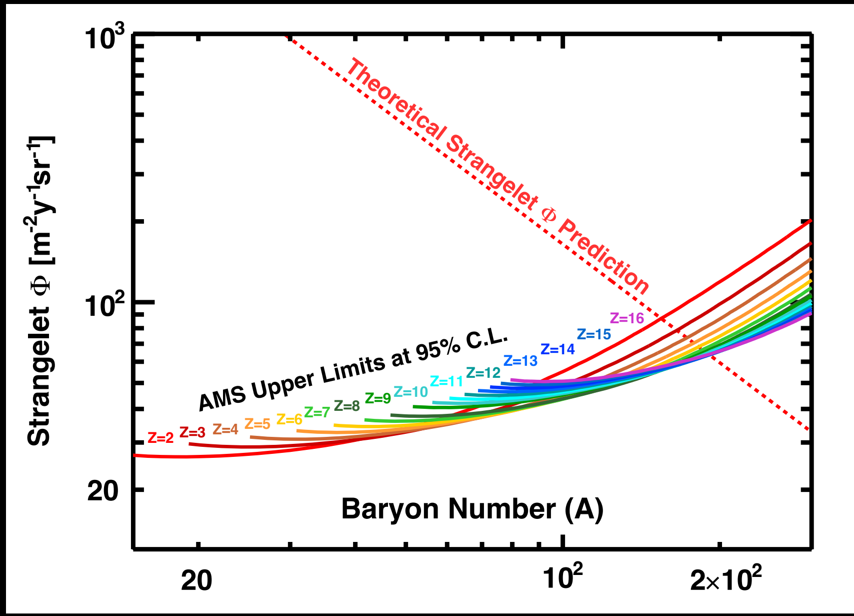




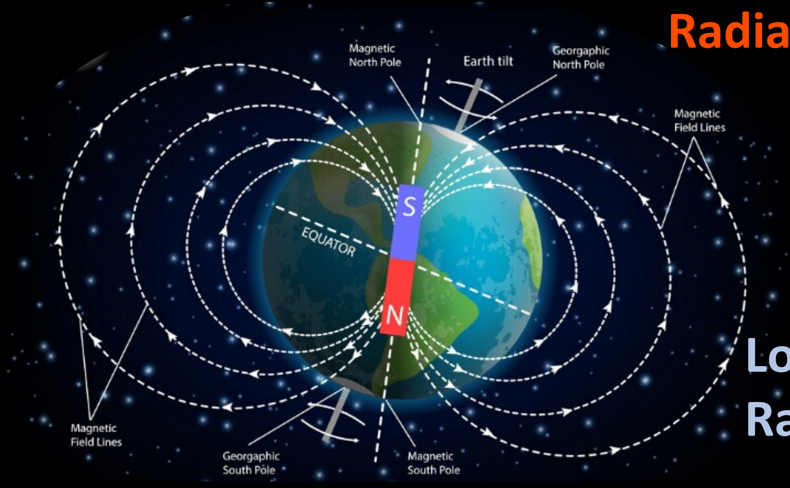
Strangelets with Z = 2 to 16 are ruled out by AMS

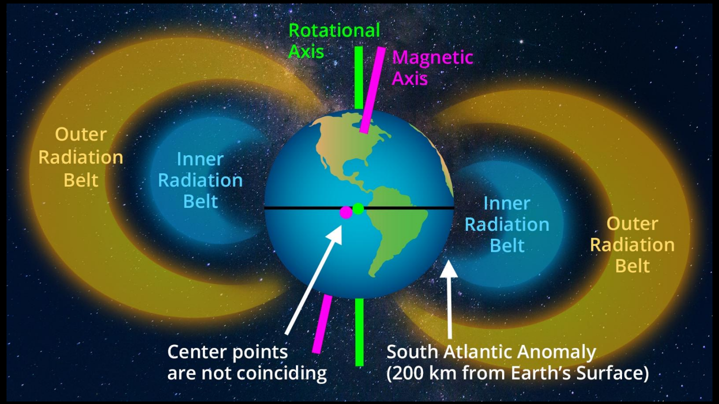


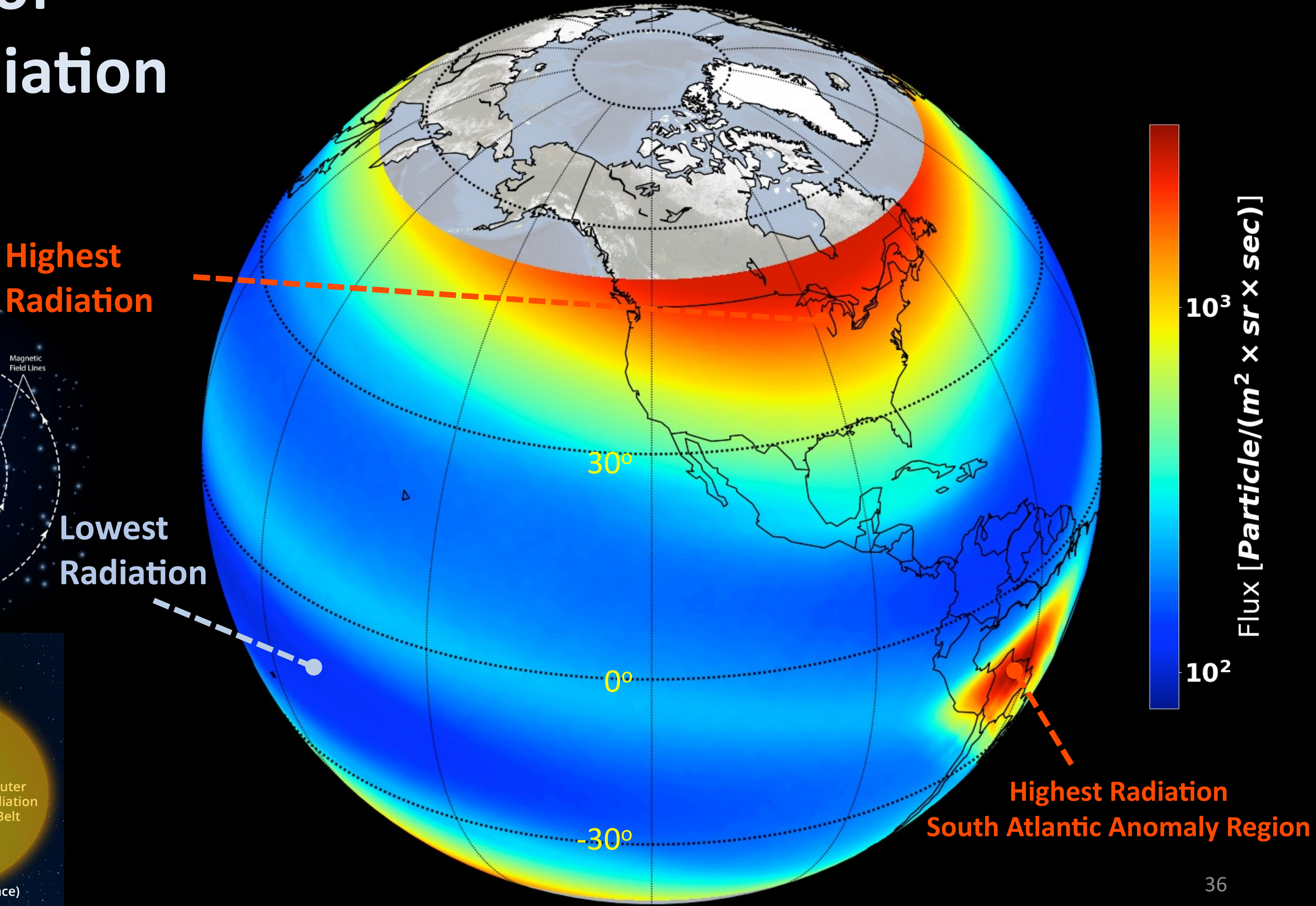




Measurement of near-Earth Radiation

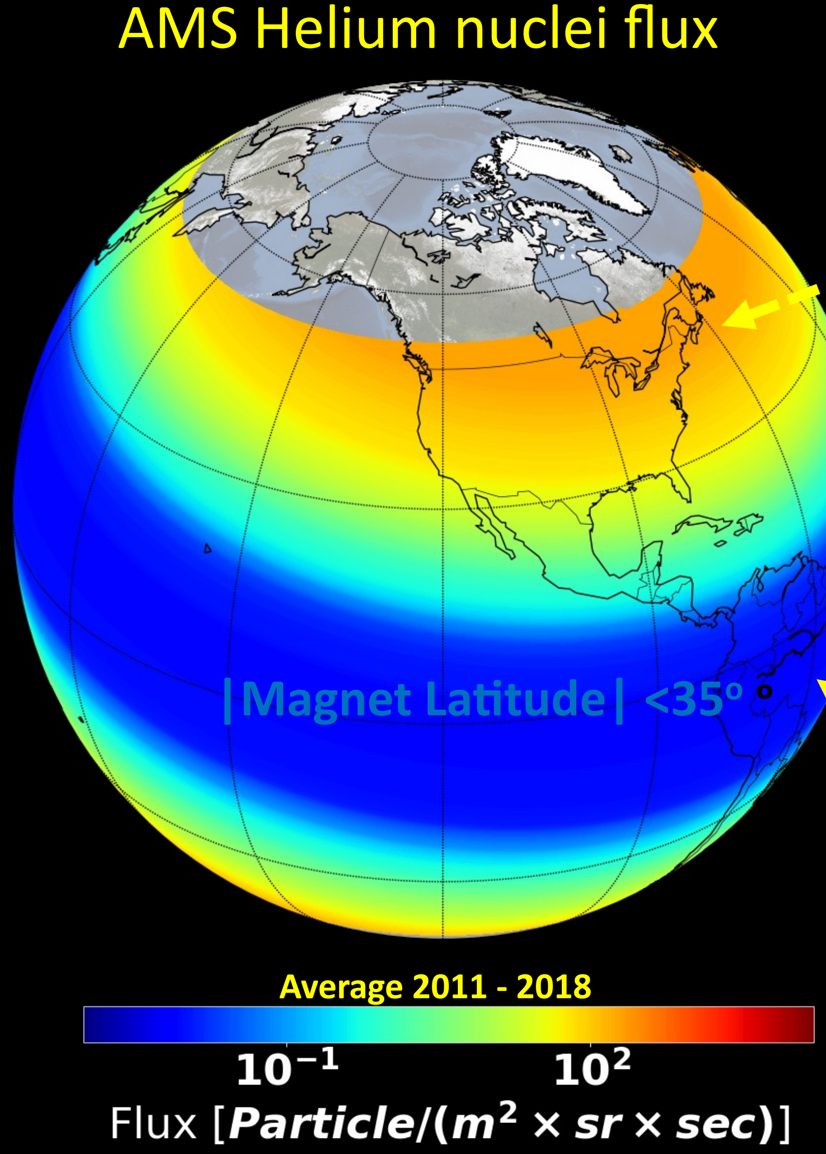


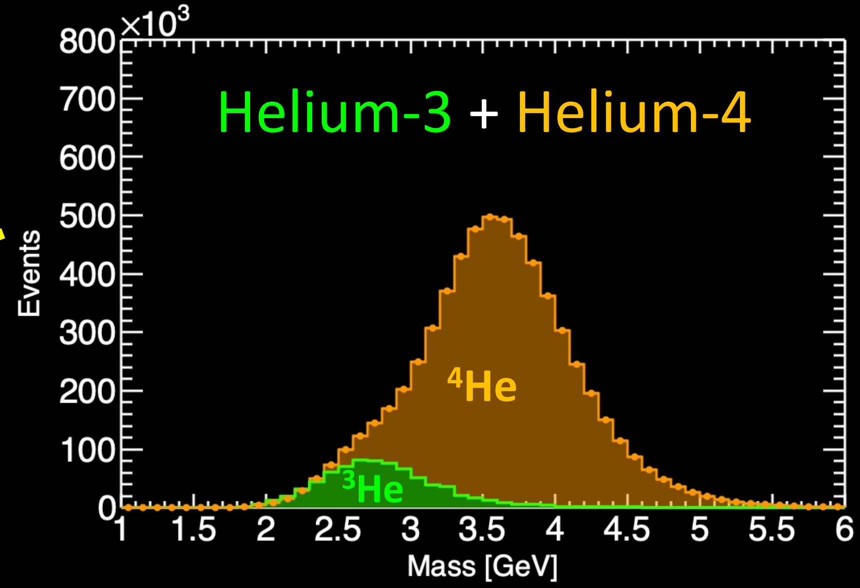


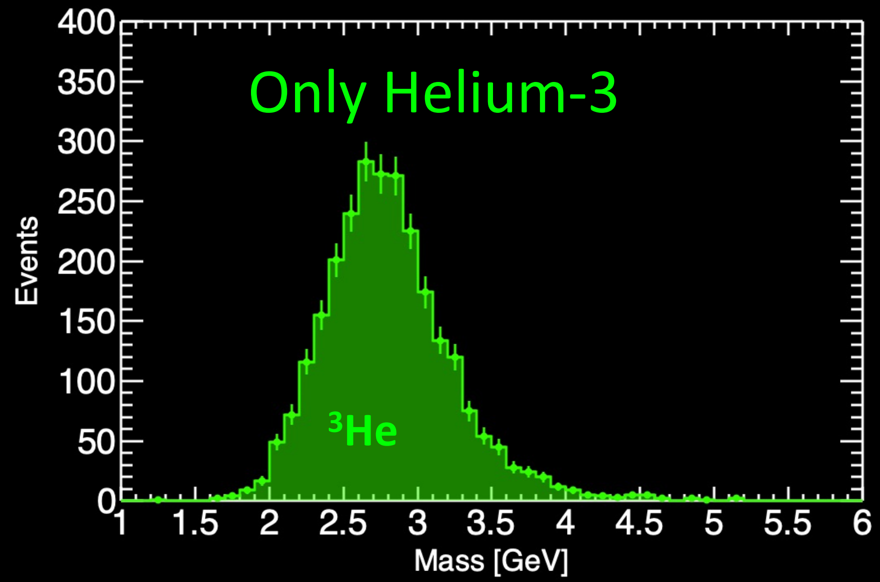


Measurement of near-Earth radiation

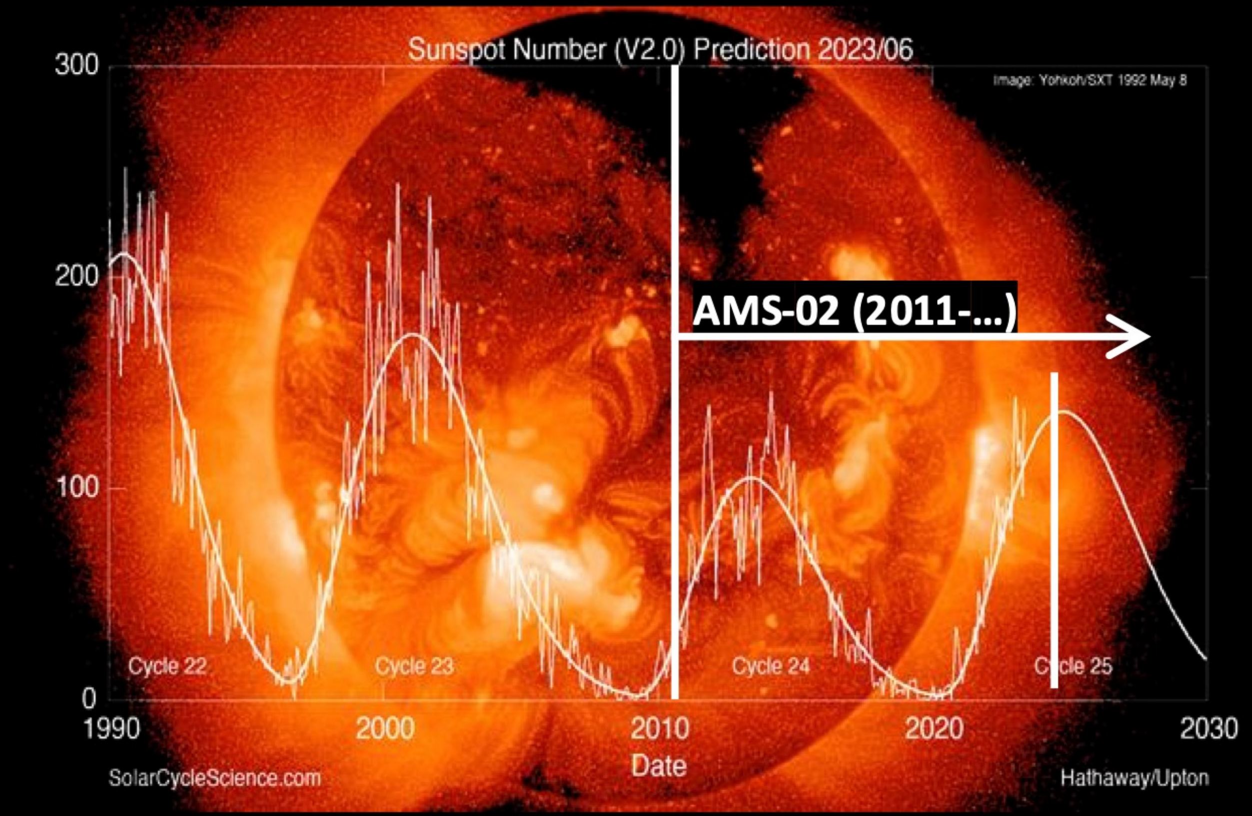
In the energy range 100 MeV to 4000 MeV over a large region, -35°< Θ_M < +35°, only ^{3}He isotope exists.

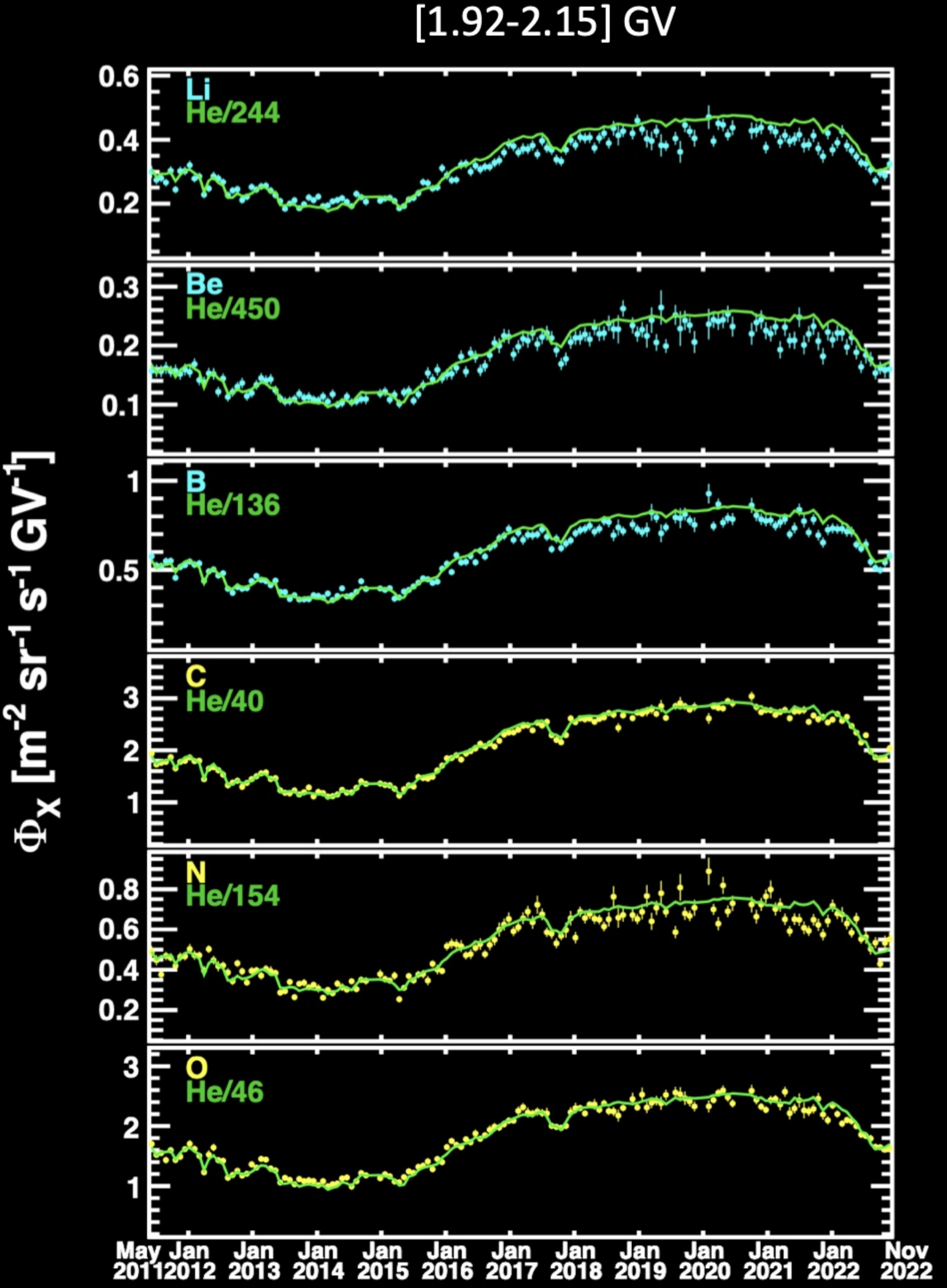






Time Variation of Cosmic Light Nuclei





All nuclei exhibit similar long-term and short-term time dependences.

Fluxes are anti-correlated with solar activity, (a) being lower during epoch of high solar activity and (b) higher during epoch of low solar activity.

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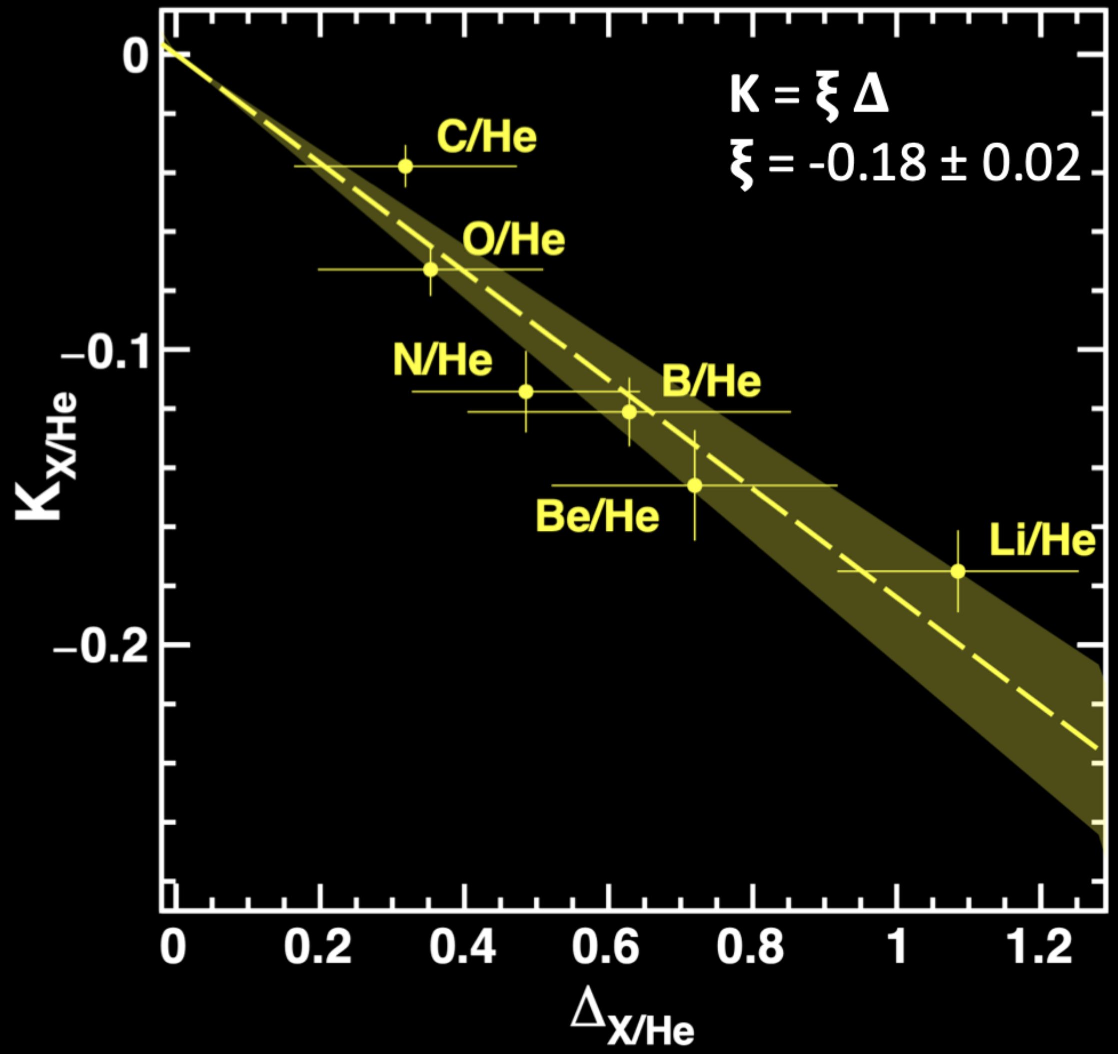
K-parameter as function of rigidity

$$\frac{\Phi^i_X/\Phi^i_{\rm He} - \langle \Phi^i_X/\Phi^i_{\rm He} \rangle}{\langle \Phi^i_X/\Phi^i_{\rm He} \rangle} = K^i_{X/{\rm He}} \frac{\Phi^i_{\rm He} - \langle \Phi^i_{\rm He} \rangle}{\langle \Phi^i_{\rm He} \rangle}$$

- **Li, Be and B are significantly less modulated than He up to 3.6 GV.**
- **C, N and O are significantly less modulated than He up to 2.15 GV.**

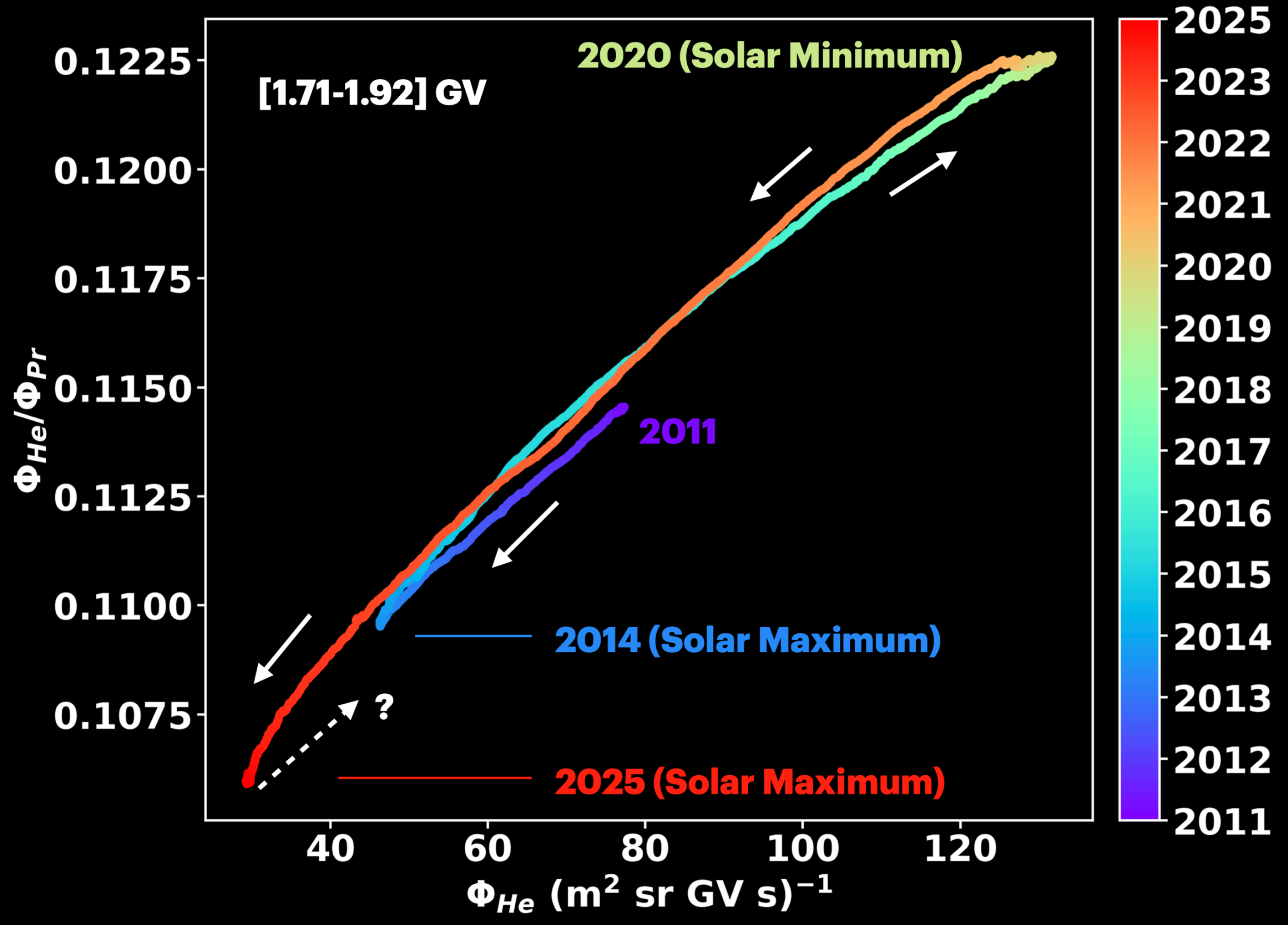
[1.92-2.15] GV



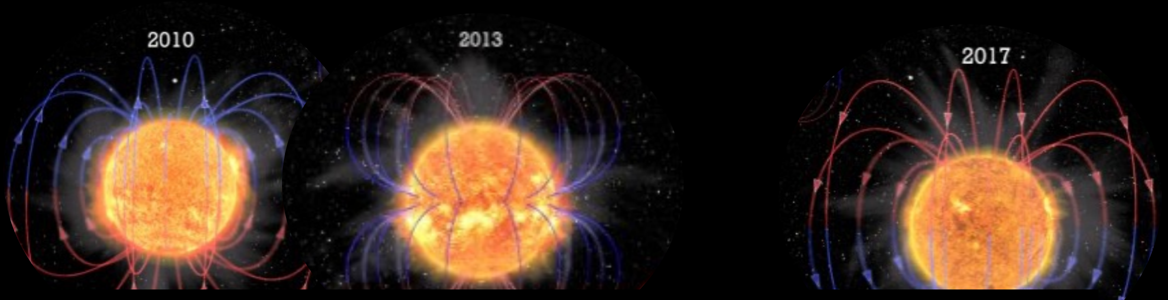
AMS observed that these differences in solar modulation are linearly correlated with the differences in the spectral indices Δ of the cosmic nuclei fluxes. This shows, in a model-independent way, that solar modulation of galactic cosmic nuclei depends on their spectral shape.

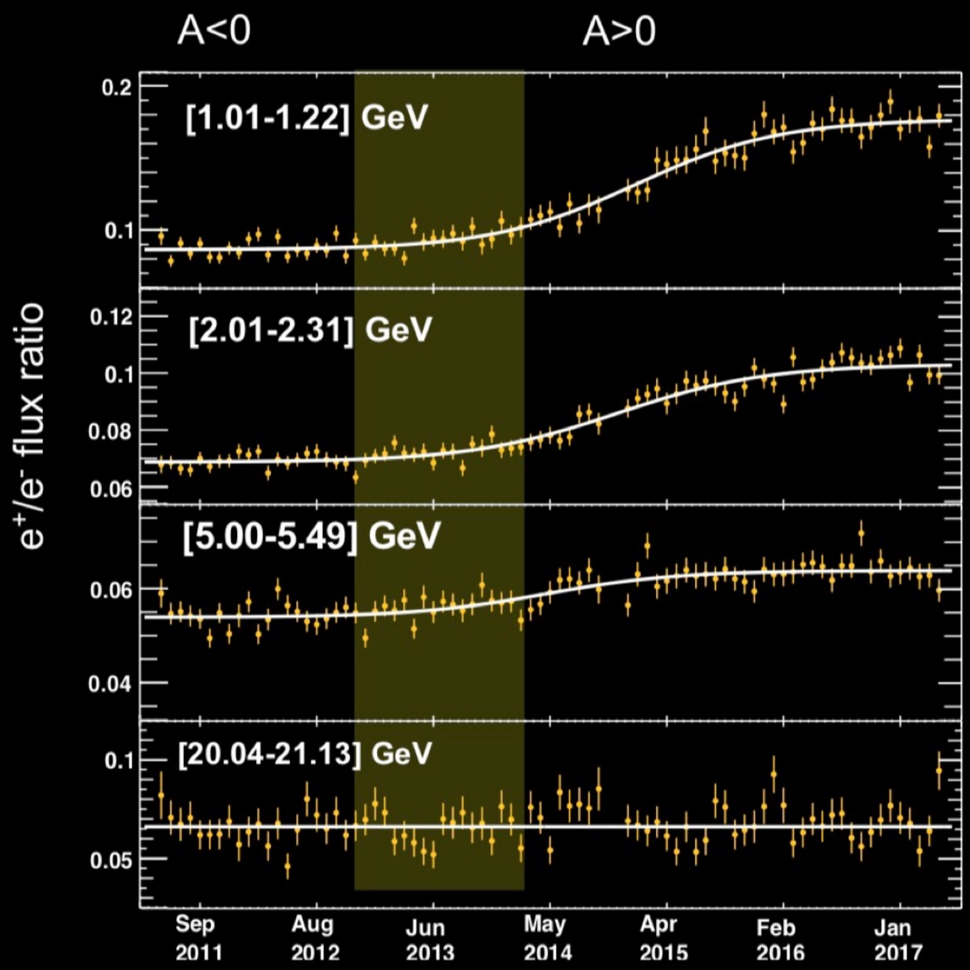
He/Pr Hysteresis

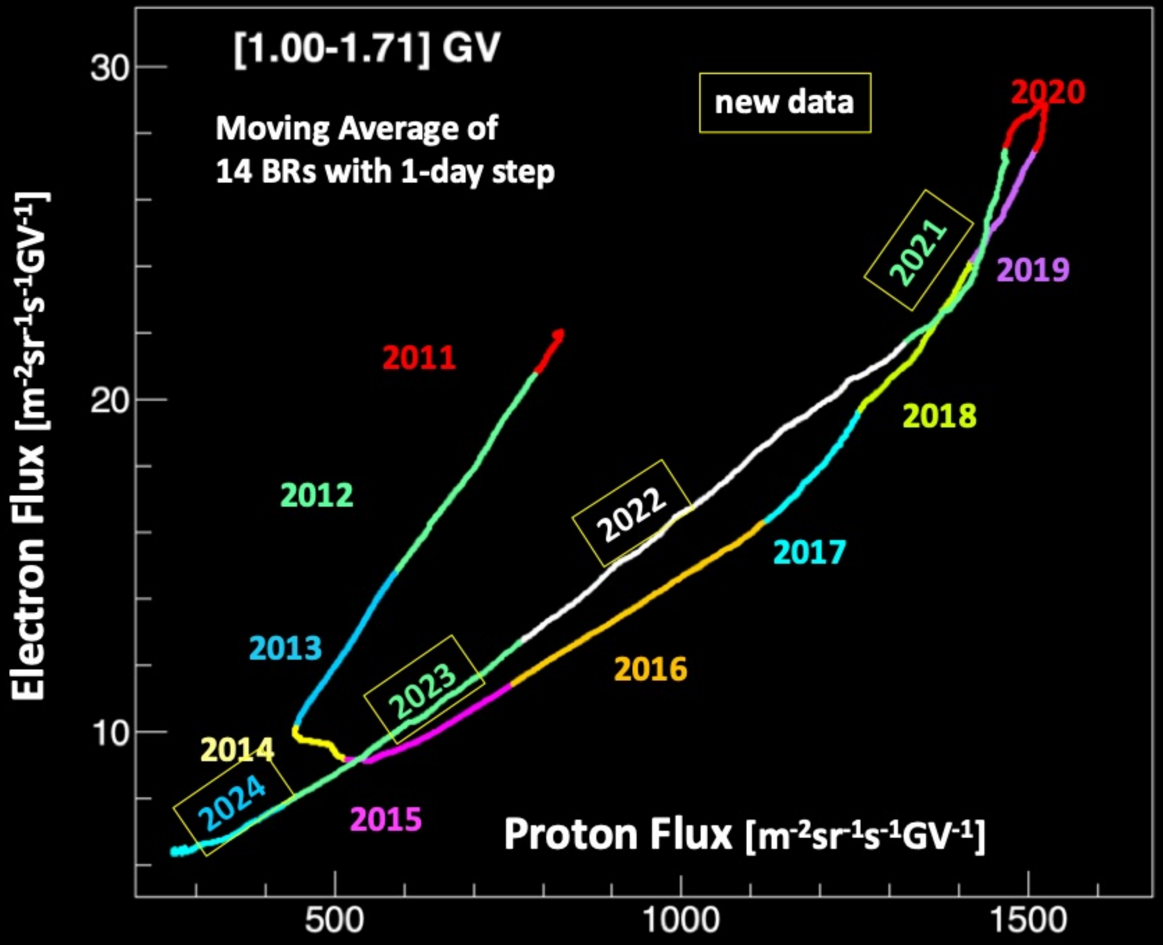
- **Correlation** between He flux and He/Pr ratio (moving average).
- At low rigidity, an **hysteresis** between proton and helium fluxes is observed around the **2014** solar maximum.
- During **2025** solar maximum, both **fluxes** are showing a **lower minimum** compared to 2014.



Long Term(> 1 Solar Cycle) Studies of Charge Sign Effect



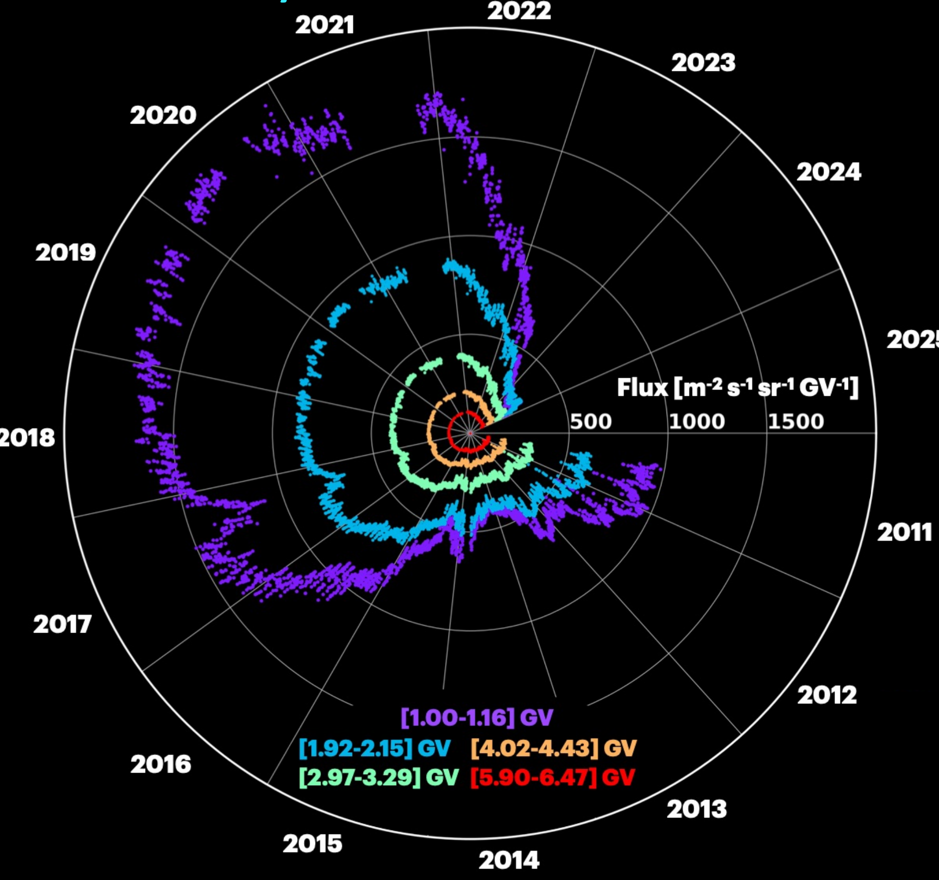




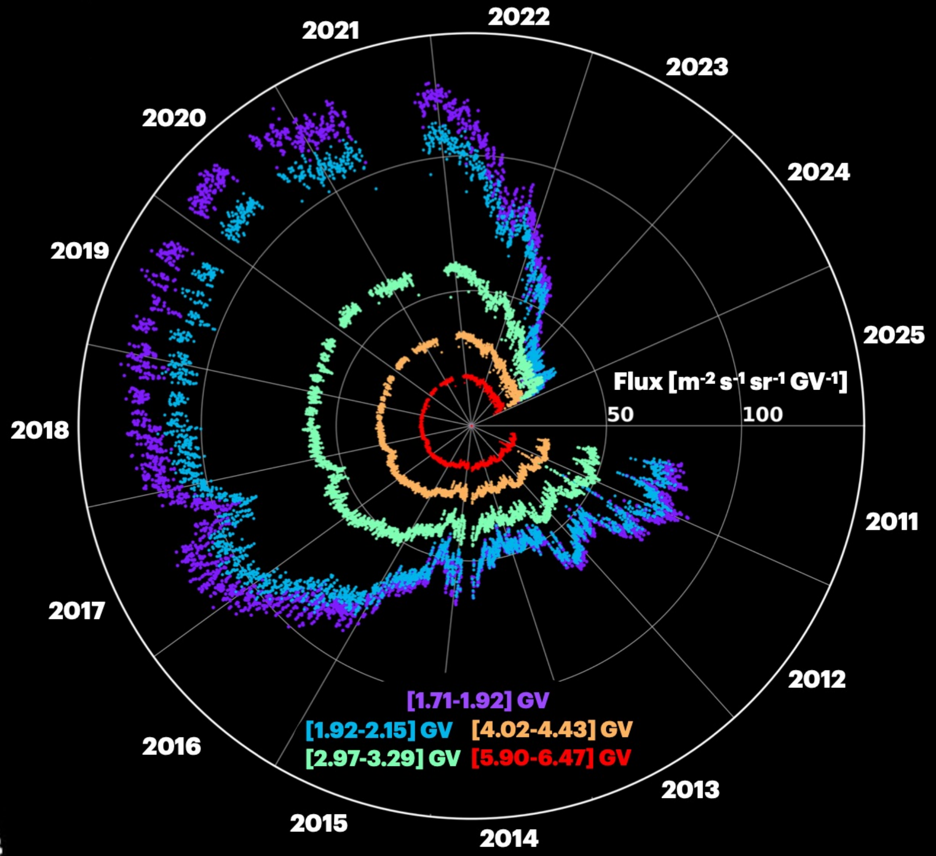
will be presented by Zhetong Sun

Long Term Studies (> 1 Solar Cycle) Daily Variations of Elementary Particles and light Nuclei

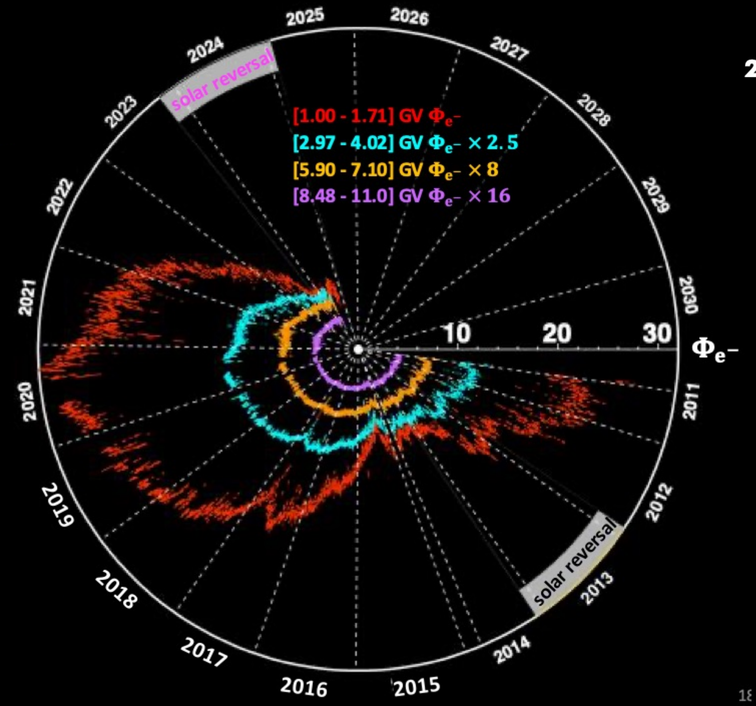
Daily Variations in the Proton Flux



Daily Variations in the Helium Flux



Daily Variations in the Electron Flux



AMS is the only magnetic spectrometer in space.

The results from AMS are unlocking the secrets of the cosmos.

AMS will continue to take data for the ISS lifetime.