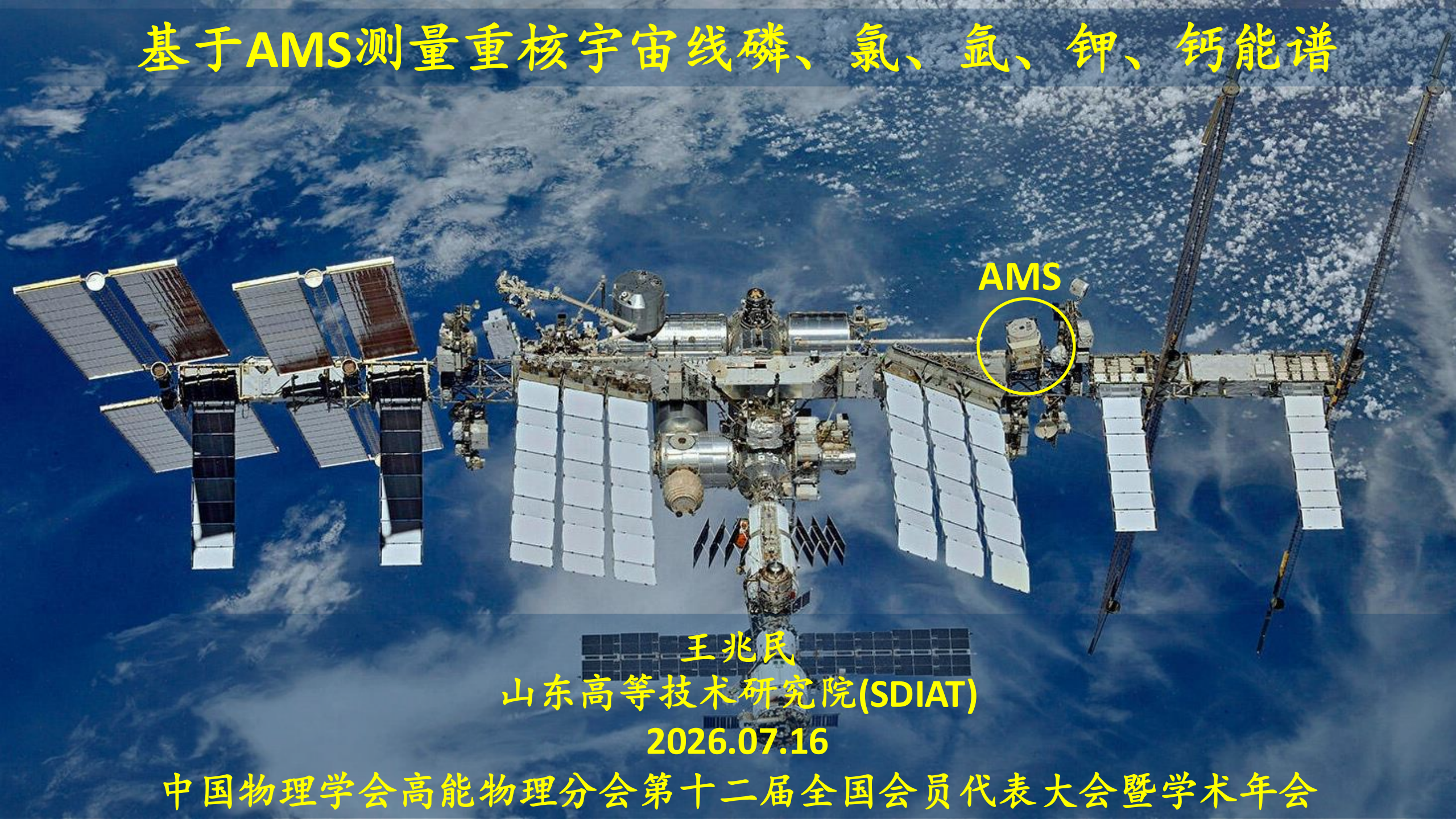


基于AMS测量重核宇宙线磷、氯、氩、钾、钙能谱

AMS



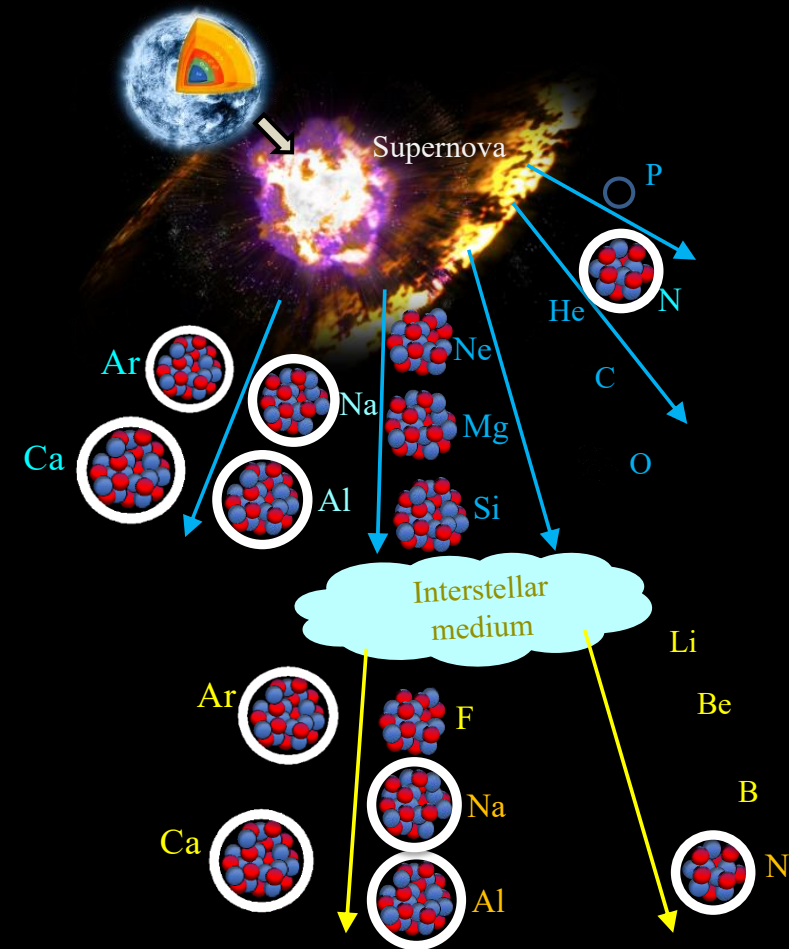
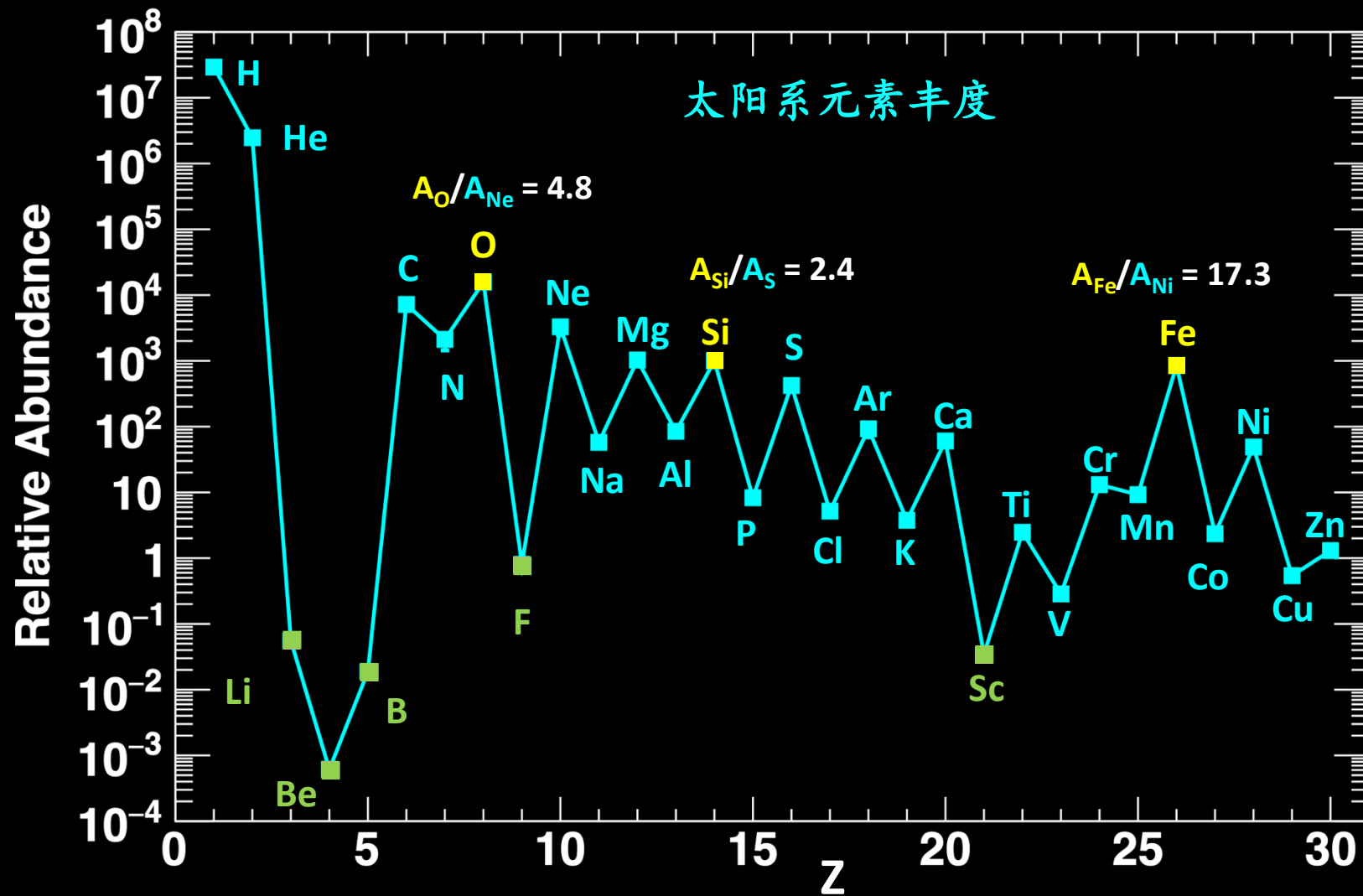
王兆民

山东高等技术研究院(SDIAT)

2026.07.16

中国物理学会高能物理分会第十二届全国会员代表大会暨学术年会

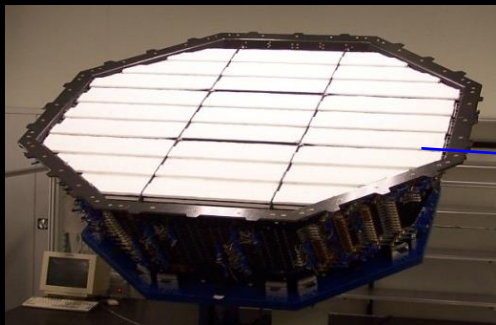
初级与次级宇宙线



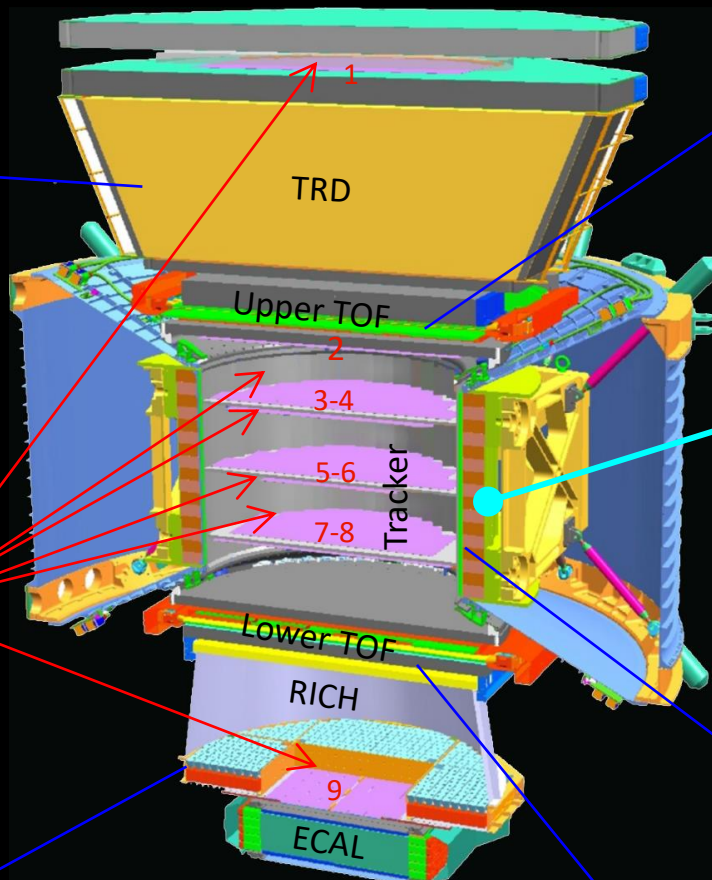
更多的宇宙线原子核同时
包含初级与次级两种成分

在太空运行的粒子物理实验 AMS

穿越辐射探测器 TRD



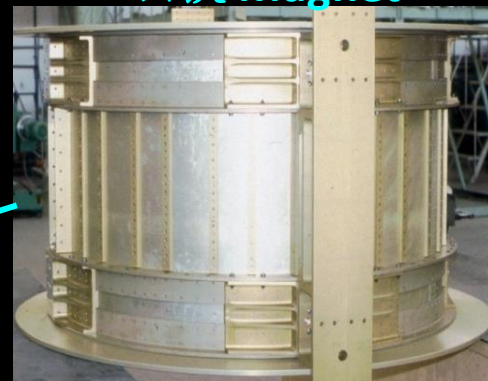
重7.5吨, 30万路信号



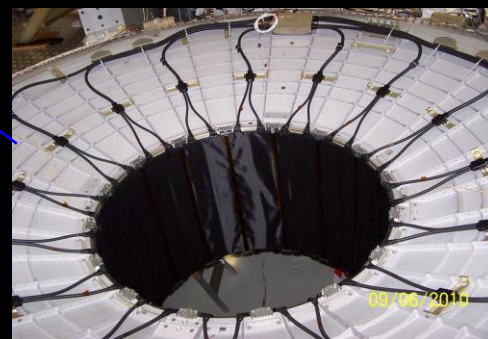
上层飞行时间探测器 UTOF



磁铁 Magnet



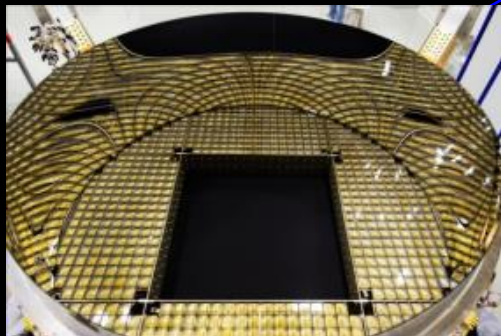
反符合计数器 ACC



硅探测器 Tracker



切伦科夫探测器 RICH



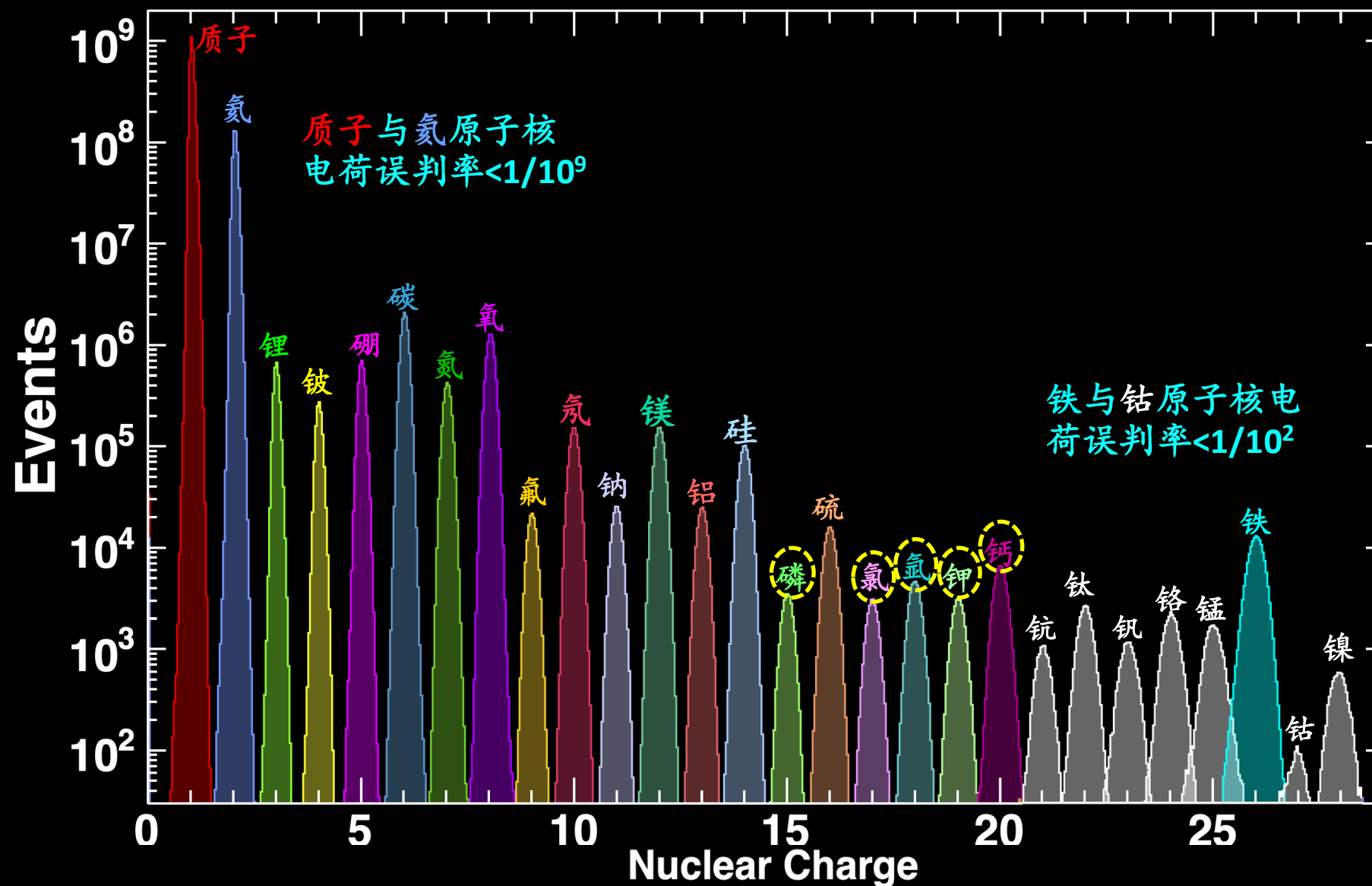
电磁量能器 ECAL



下层飞行时间探测器 LTOF

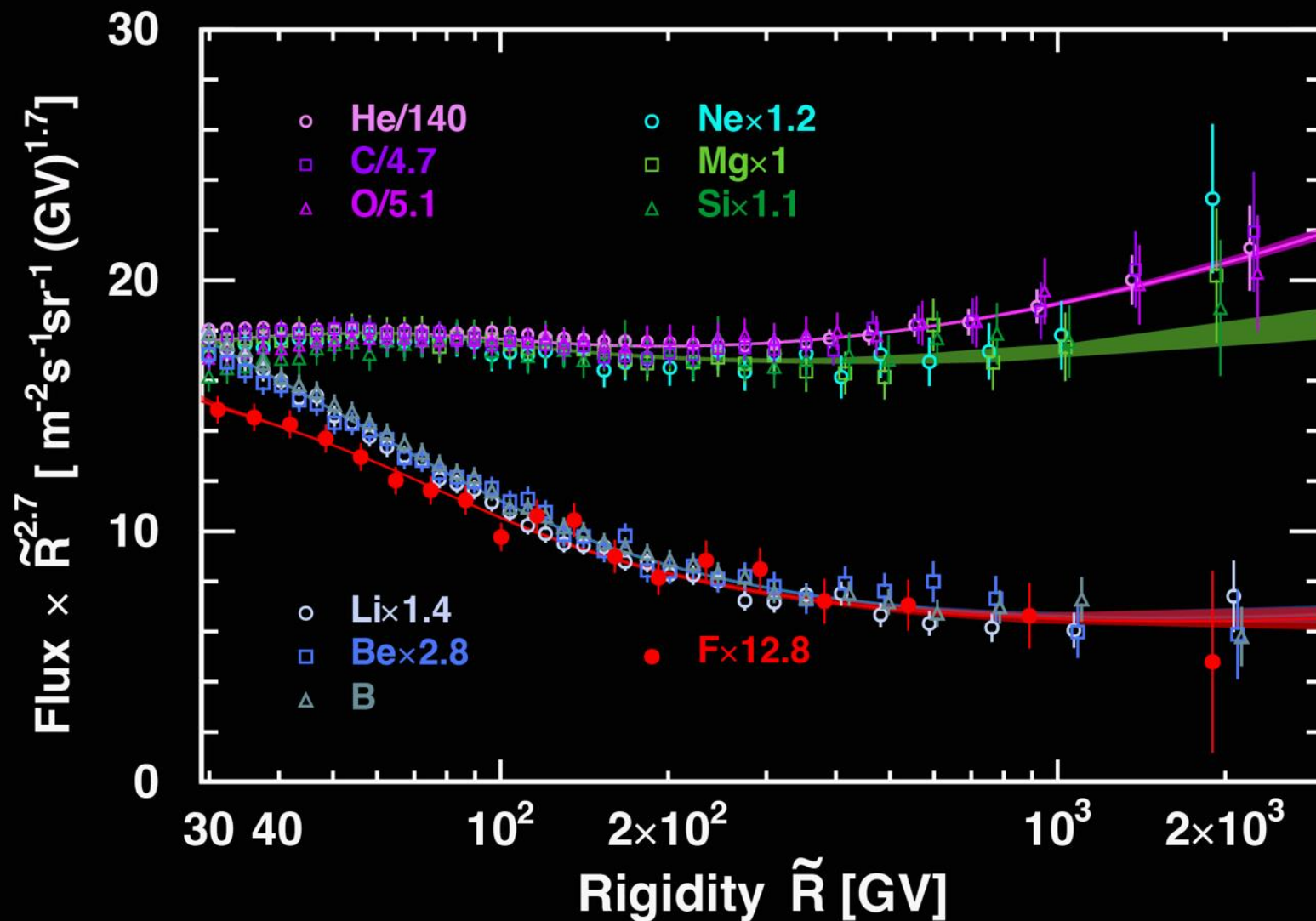


AMS 对宇宙线原子核电荷的测量



本报告将介绍AMS关于磷、氯、氩、钾、钙能谱的最新测量结果

两类初级宇宙线与两类次级宇宙线

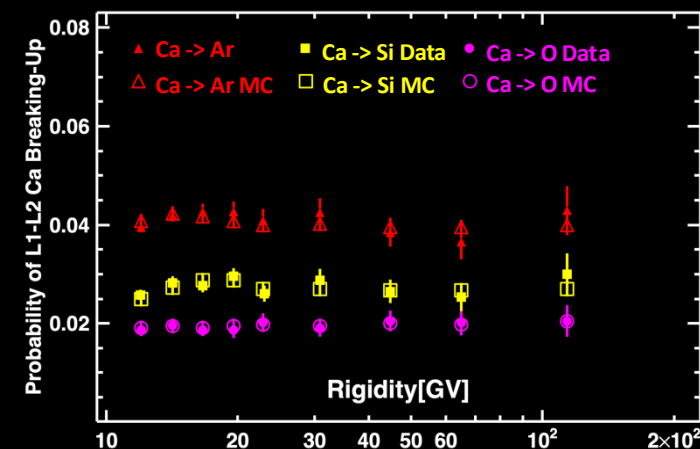
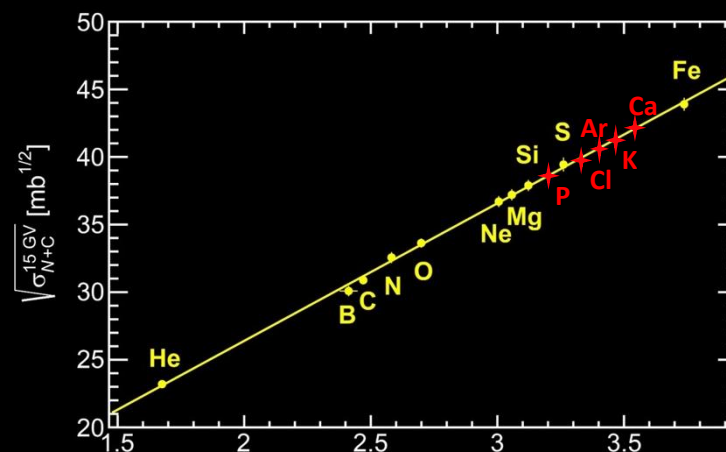
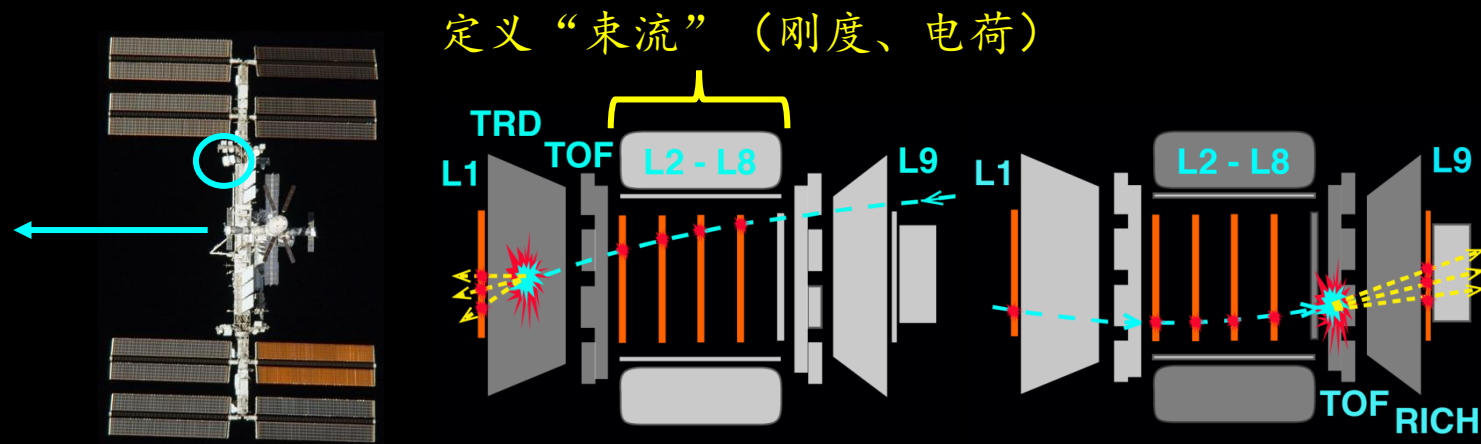


AMS的测量结果显示：宇宙中存在两类初级宇宙线以及两类次级宇宙线

AMS对宇宙线能谱的测量

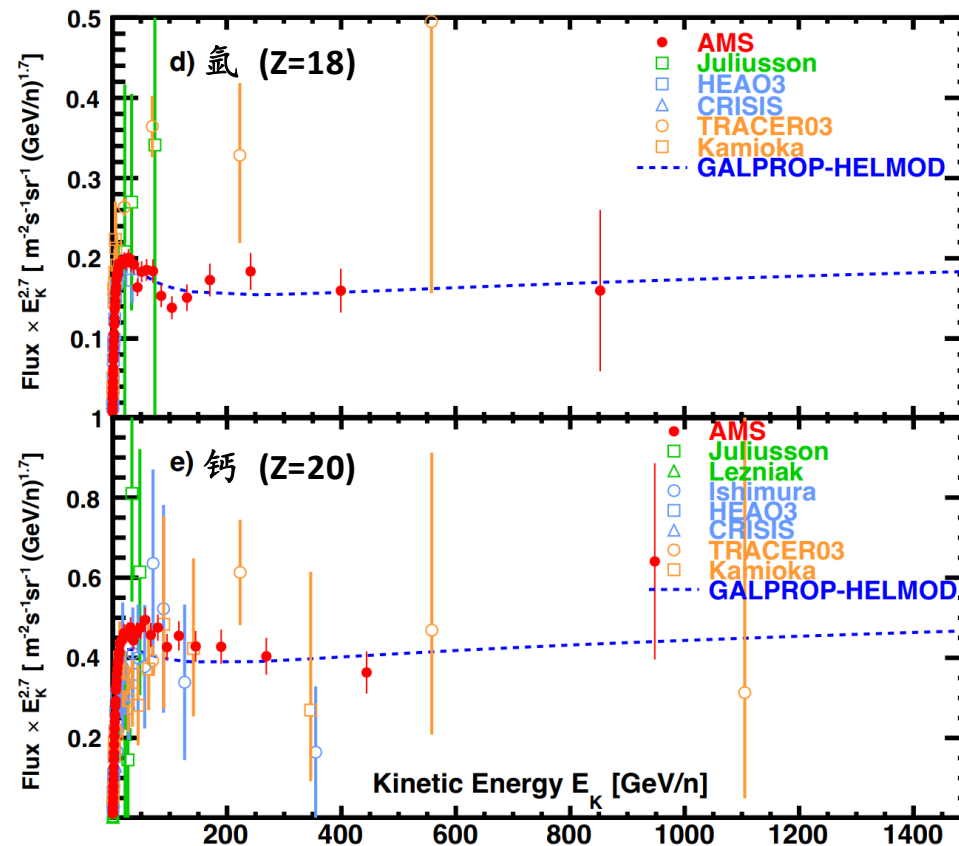
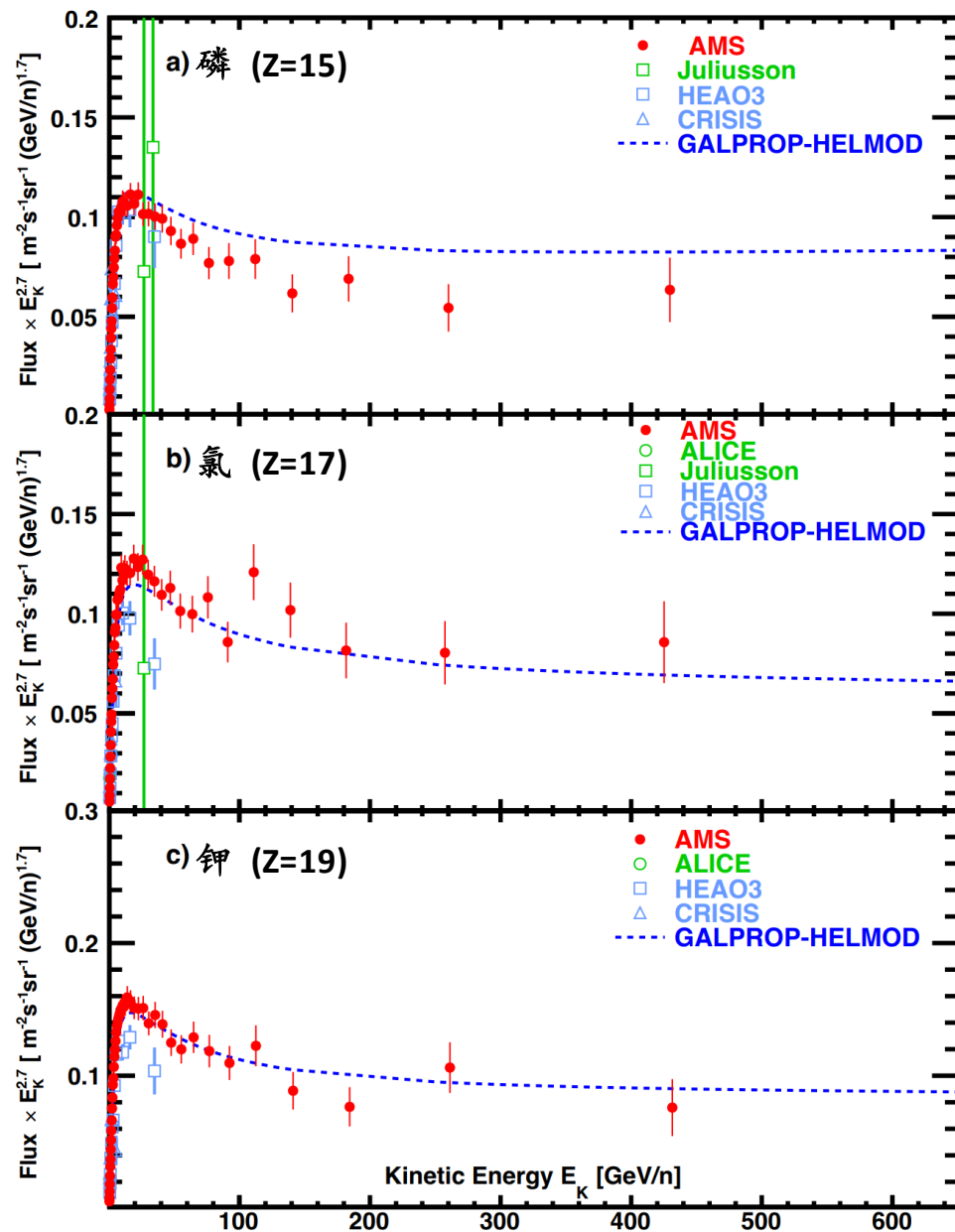
$$\Phi_i = \frac{N_i}{T_i A_i \varepsilon_i \Delta R_i}$$

AMS基于蒙特卡洛工具，模拟了宇宙线在探测器内的具体物理过程，修正模拟数据与真实数据的差异，并基于模拟数据获取了探测器的有效接受度、刚度分辨率函数等关键数据



根据截面测量结果，AMS修正了MC模拟的核相互作用模型，以确保能谱测量的精确性

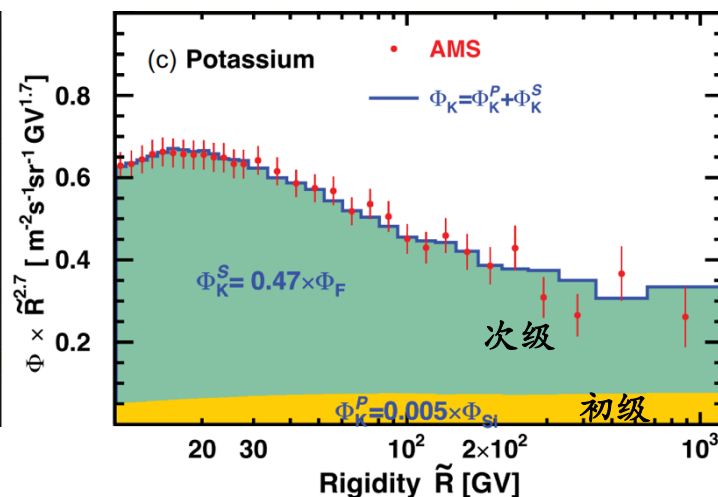
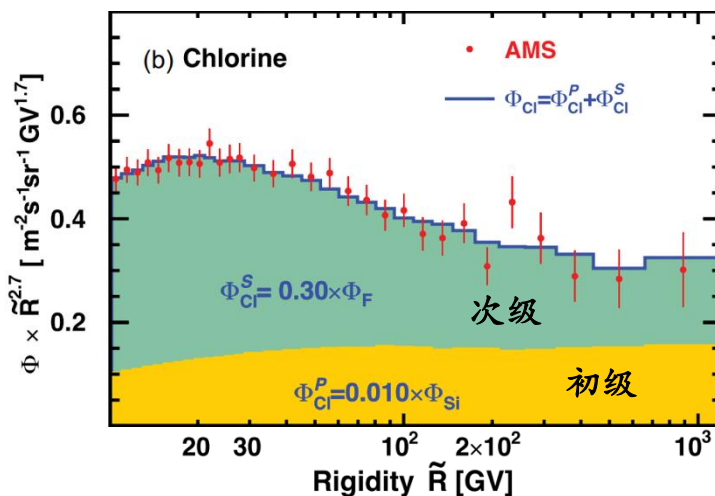
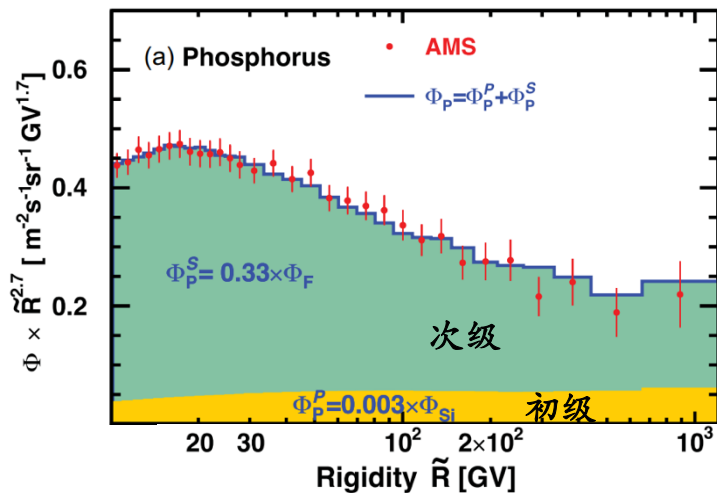
磷、氯、氩、钾、钙流强



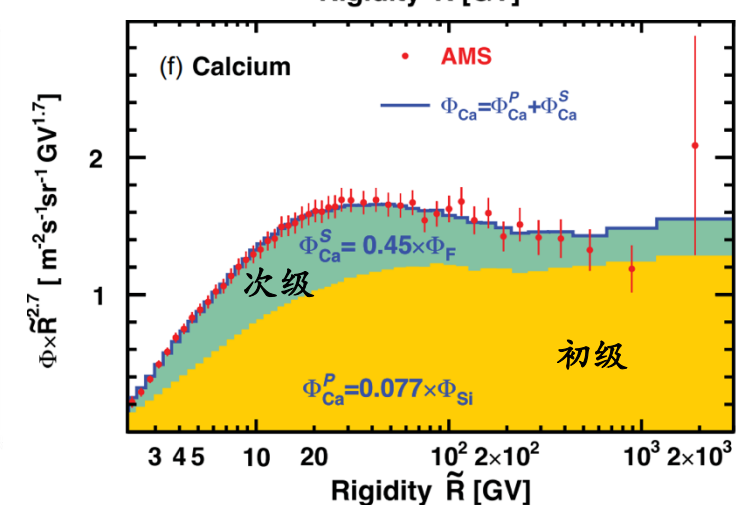
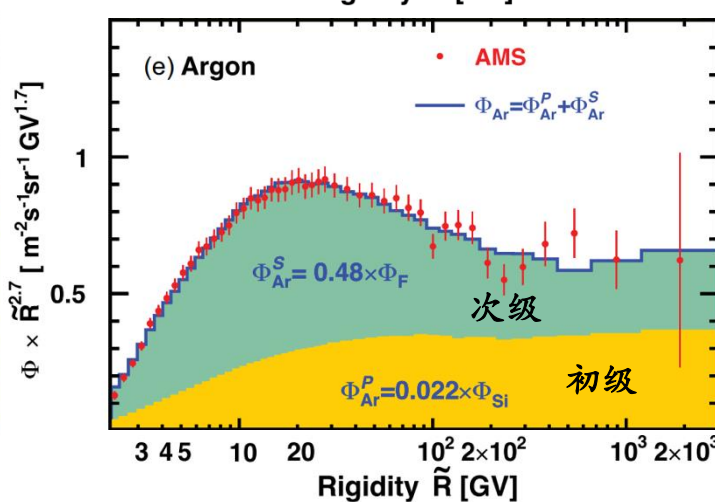
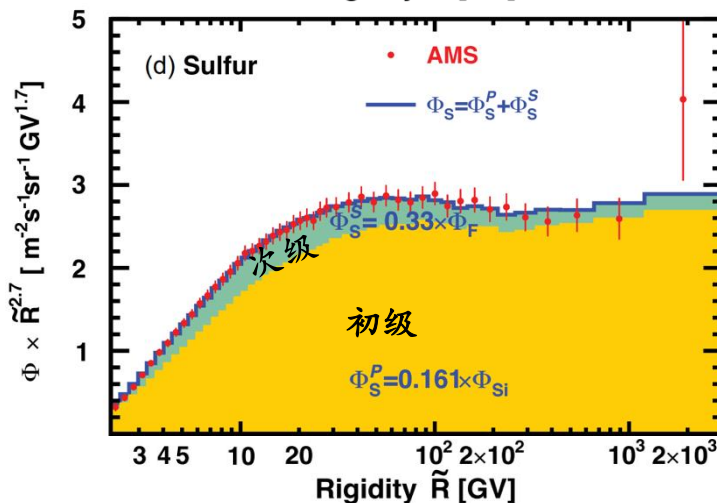
AMS以前所未有的精度测量了宇宙线磷、氯、钾(2.15 GV-1.2 TV, 约0.5 GeV/n-600 GeV/n)以及氩、钙(2.15 GV-3 TV, 约0.5 GeV/n-1.2 TeV/n)原子核能谱

宇宙线磷、硫、氯、氩、钾、钙初级与次级成分

奇电荷
原子核

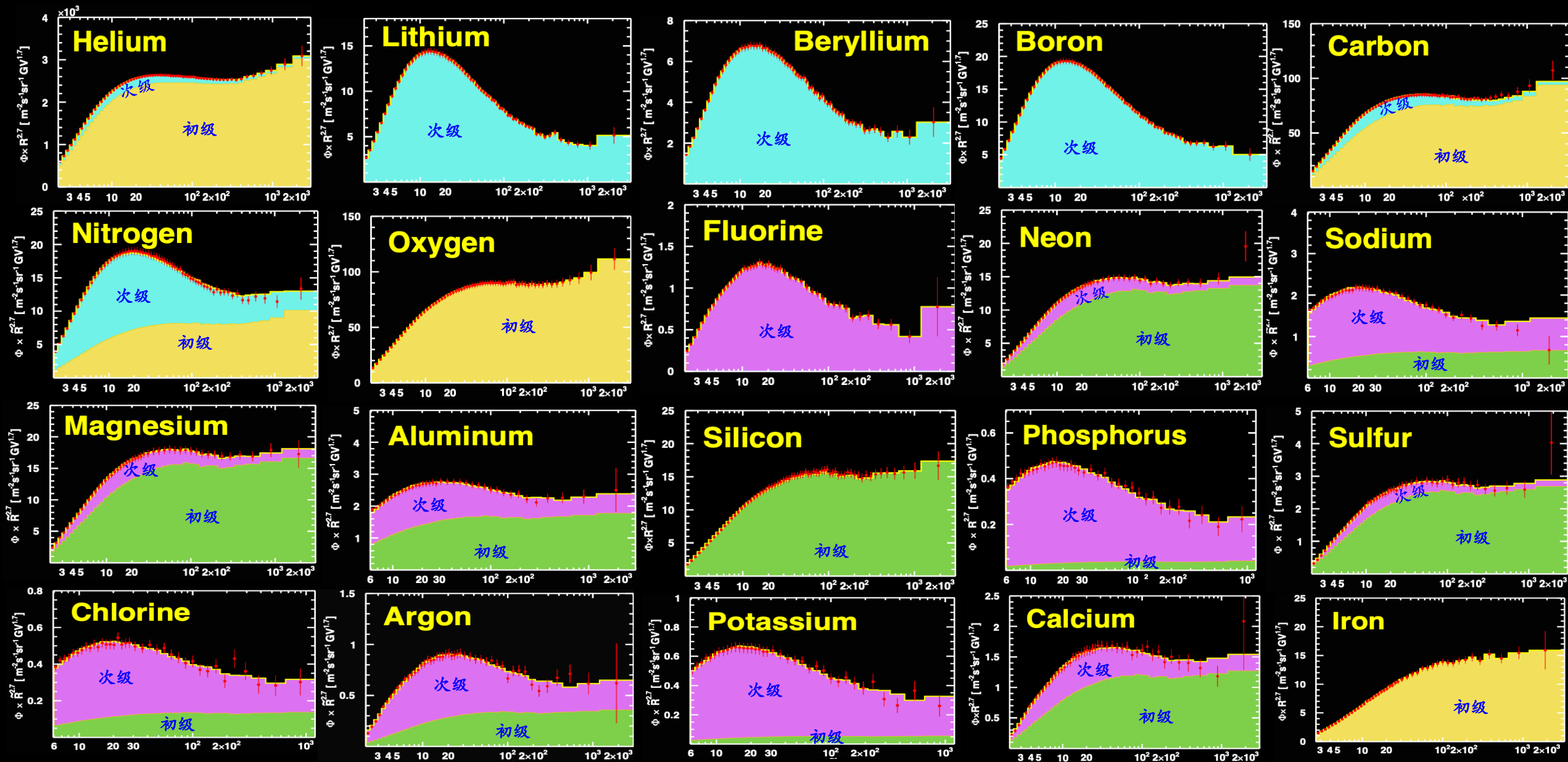


偶电荷
原子核



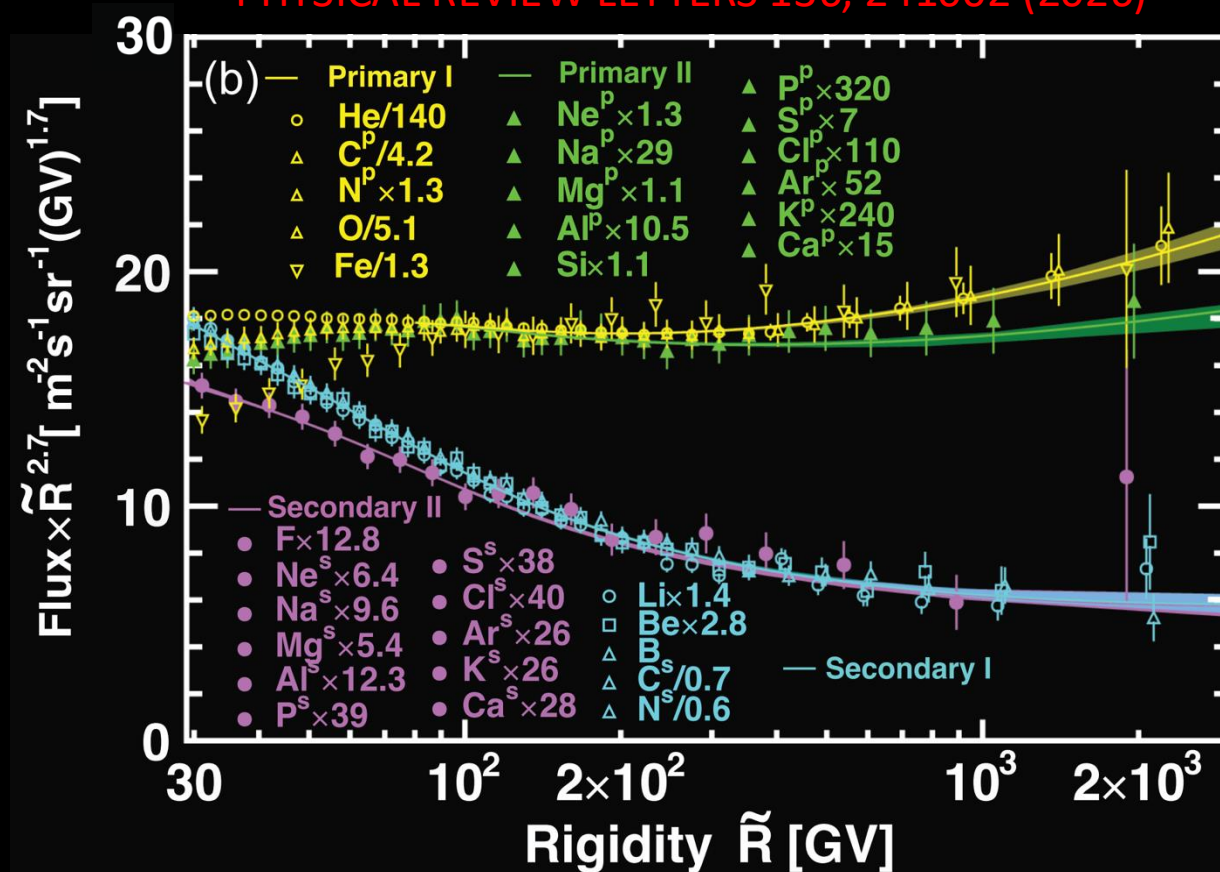
- 磷、氯、氩、钾、钙流强的刚度依赖性可以很好地由初级宇宙线成分与次级宇宙线成分之和来描述
- 偶电荷数原子核氩、钙的初级成分显著大于奇电荷数原子核磷、氯、钾的初级成分

各宇宙线原子核的初级与次级成分



最新发现：宇宙线原子核的四大类

PHYSICAL REVIEW LETTERS 136, 241002 (2026)

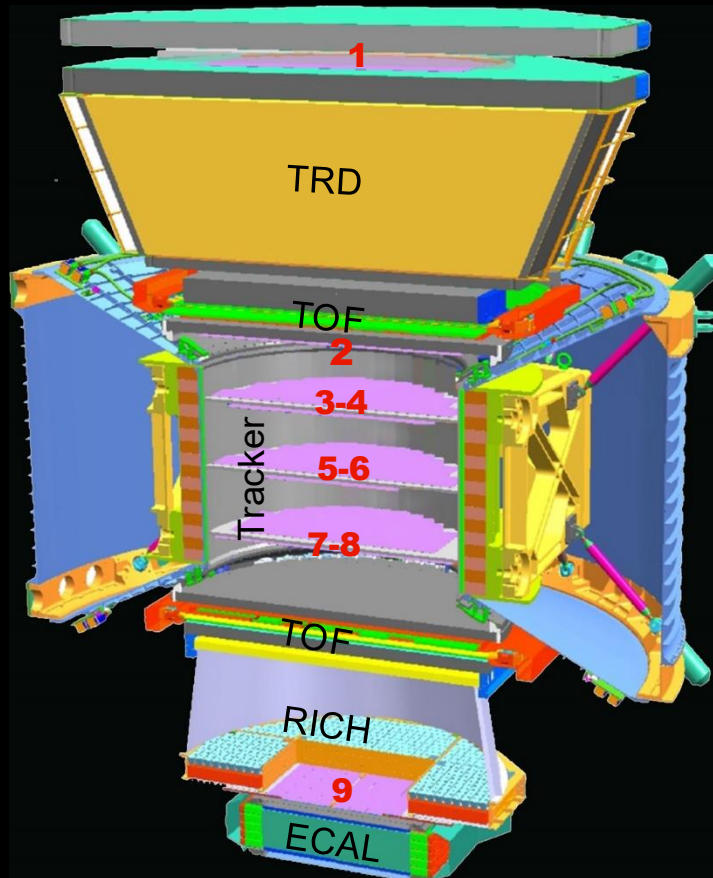


- 结合氦至钙(电荷Z=2-20)以及 Fe(Z=26)的流强测量结果，AMS发现：初级宇宙线占主导的原子核可分为以**氦-碳-氧-铁**以及以**氦-镁-硅-硫**为代表的两大类；次级宇宙线也可分为以**锂-铍-硼**以及以**氟-磷-钾**为代表的两大类。其他元素则由初级和次级宇宙线共同组成
- 根据刚度依赖性，AMS测量的从氦到钙(Z=2-20)以及铁(Z=26)等 20 种原子核实际仅包含4大类

谢 谢

Back-Up

AMS detectors provide independent information of cosmic rays



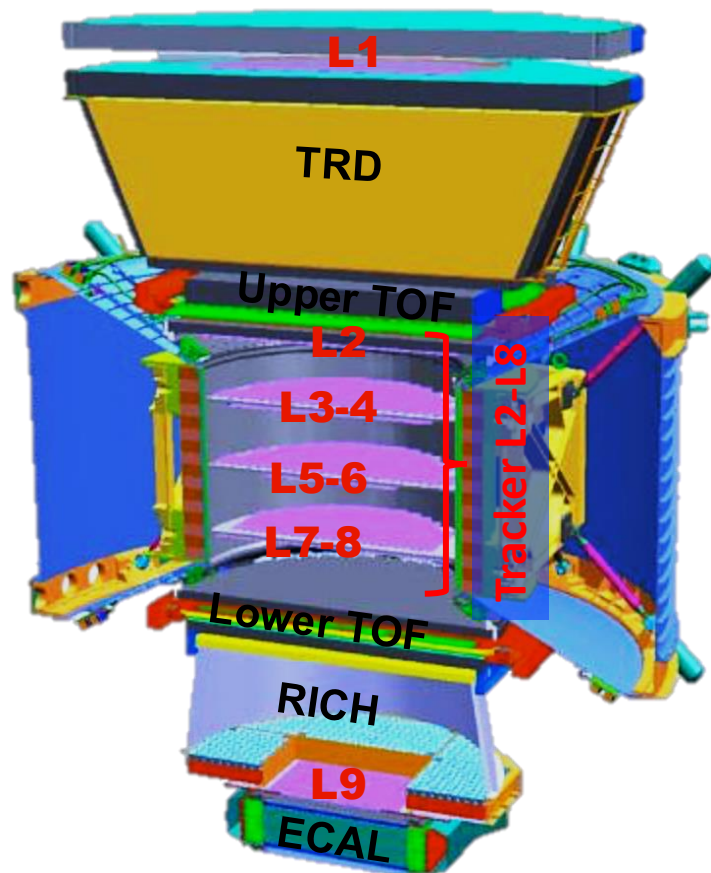
	e^-	P	Fe	e^+	$\bar{P}$	$\overline{He}$
TRD						
TOF						
Tracker + Magnet						
RICH						
ECAL						

AMS measures :

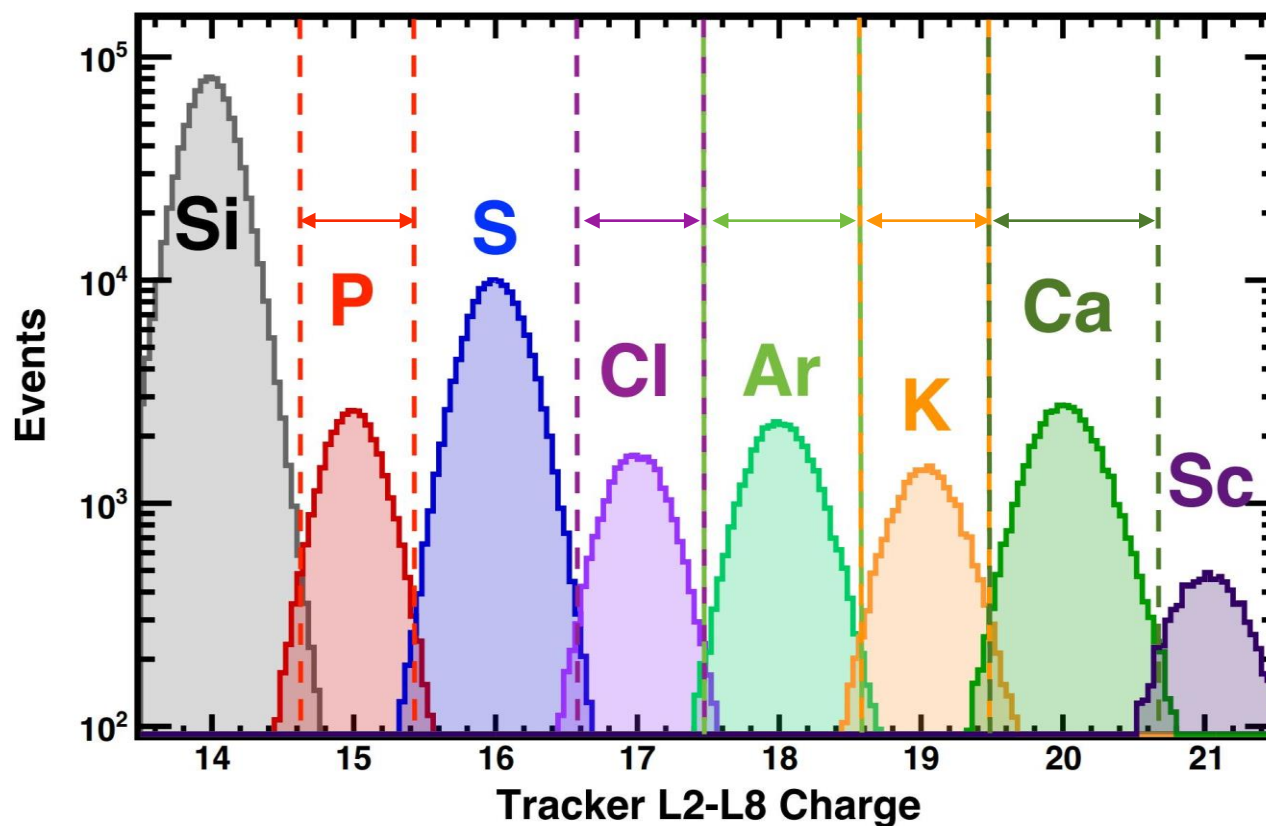
- Momentum (P , GeV/c)
- Charge (Z)
- Rigidity ($R=P/Z$, GV)
- Energy (E , GeV/A)
- Flux (signals/(s sr m² GeV))

1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.933	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.09	35 Br Bromine 79.904	36 Kr Krypton 84.80
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209.982]	85 At Astatine [209.987]	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium [278]	114 Fl Flerovium [289]	115 Uup Ununpentium [288]	116 Lv Livermorium [293]	117 Uus Ununseptium [294]	118 Uuo Ununoctium [294]

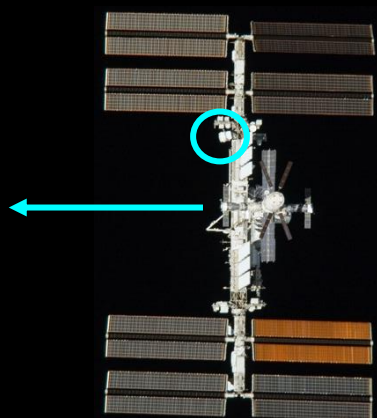
目标原子核的筛选



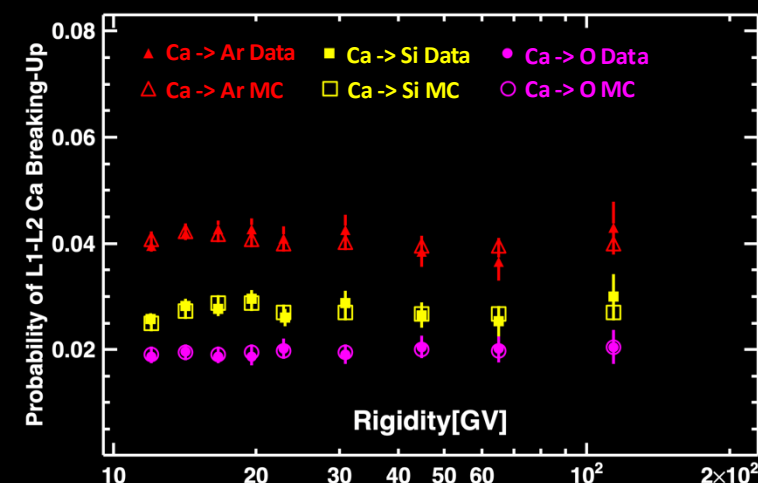
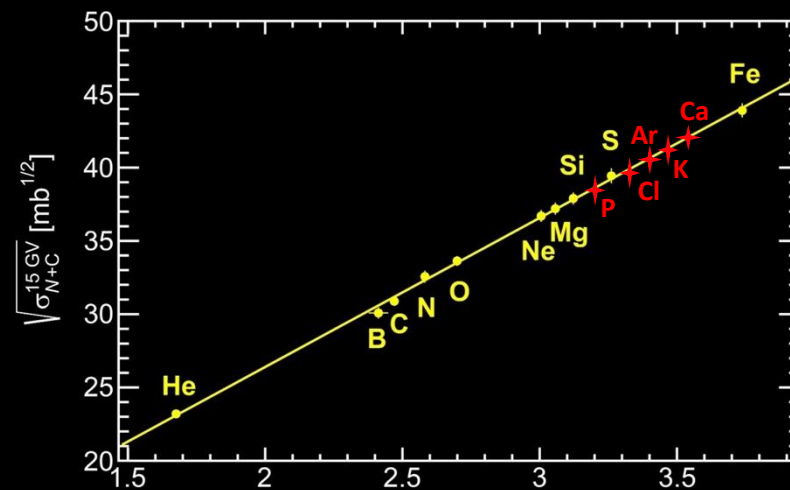
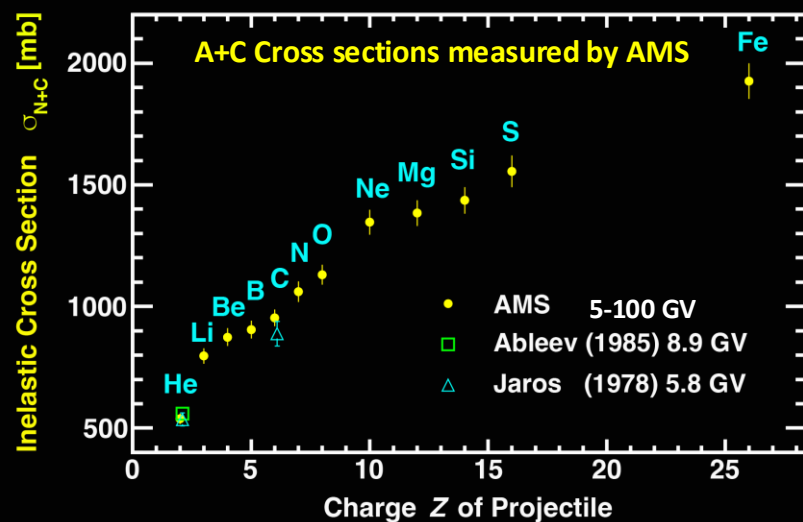
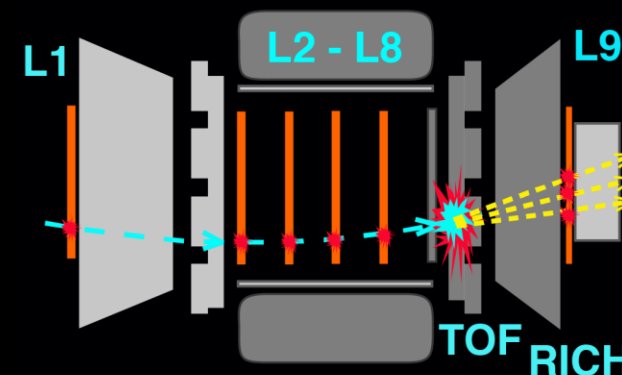
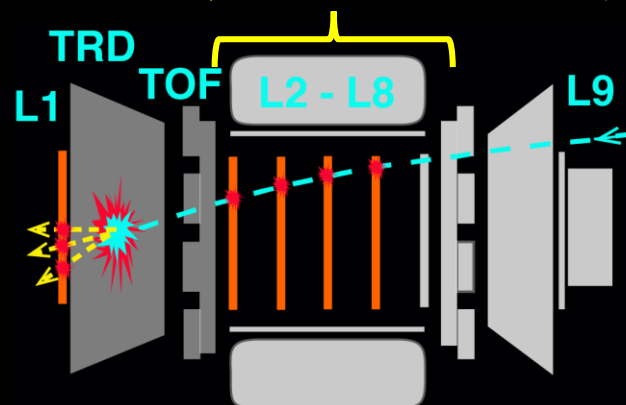
得益于强大的电荷分辨率能力，AMS 能够高精度地识别 P、Cl、Ar、K 和 Ca 原子核，在整个刚度范围内，由电荷误识别造成的本底对 P 小于 2%，对 Cl、Ar、K 和 Ca 小于 1%。



AMS对原子核碎裂截面的测量

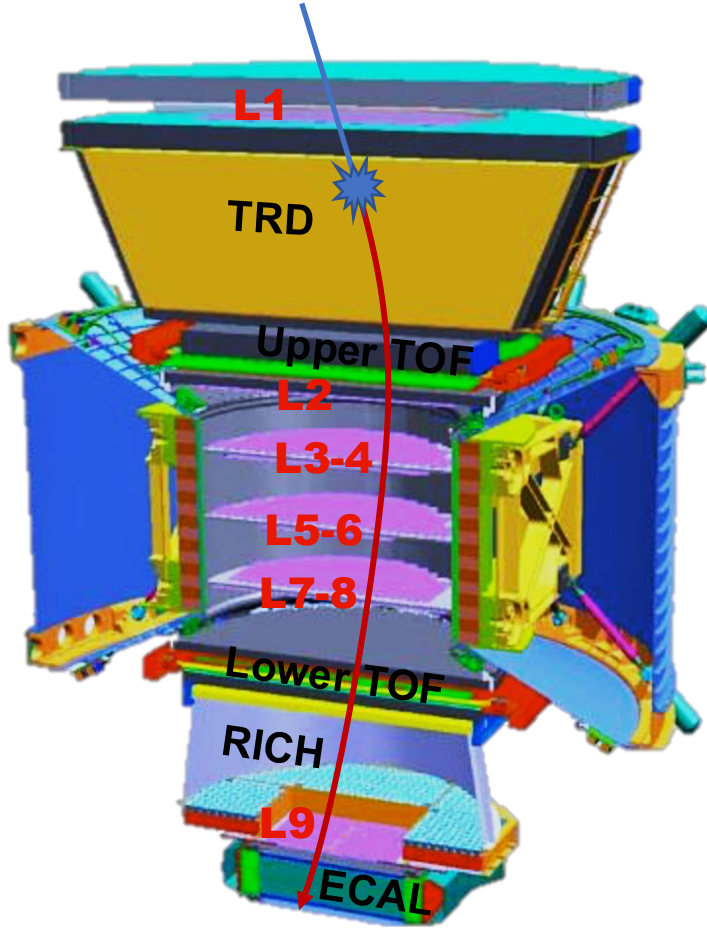


定义“束流”（刚度、电荷）



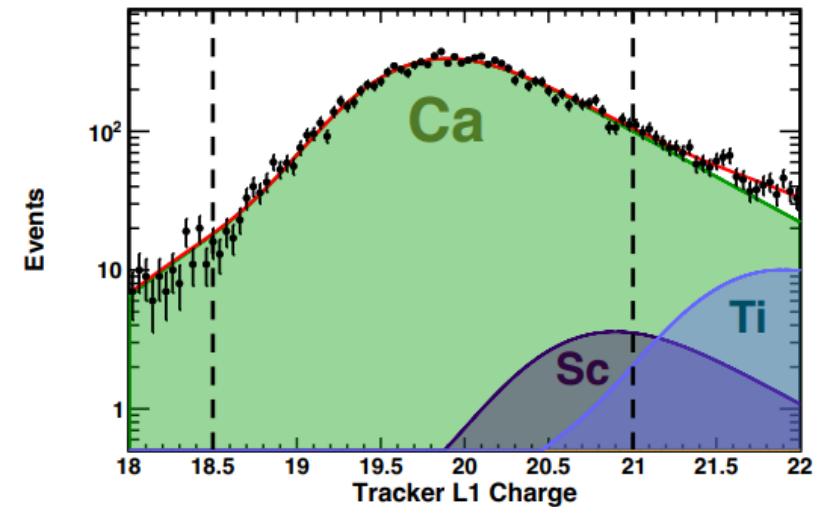
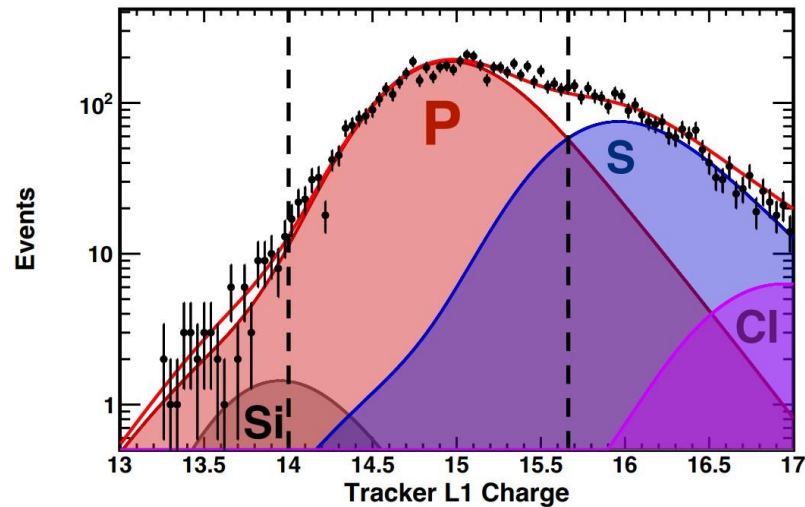
根据测量结果，AMS调整了模拟数据中核相互作用模型的关键参数，以确保能谱测量的精确性

Background from Nuclei Interaction in AMS Materials



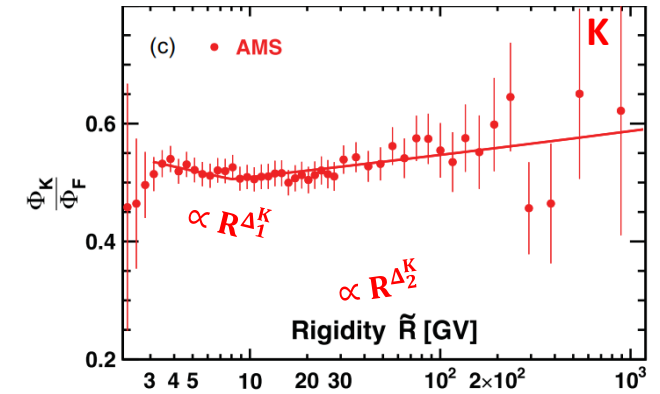
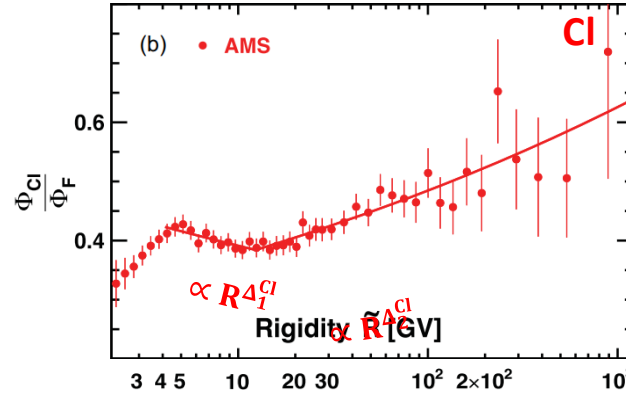
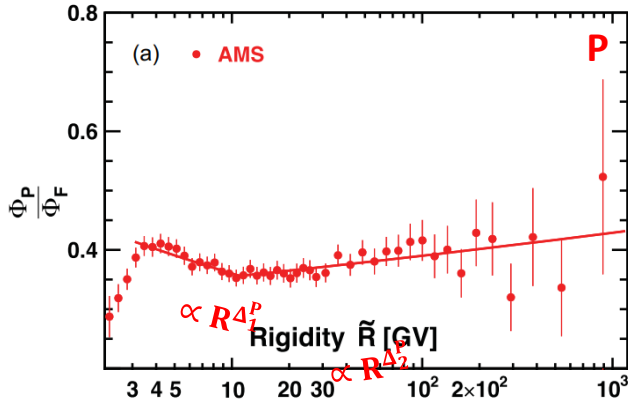
The background mainly comes from heavier nuclei interaction with AMS material, the background is accurately estimated, then a clean sample is obtained by subtracting the background from measured event numbers.

Example of the measurements of the background arising from the interaction with TRD and Upper ToF material for P and Ca:

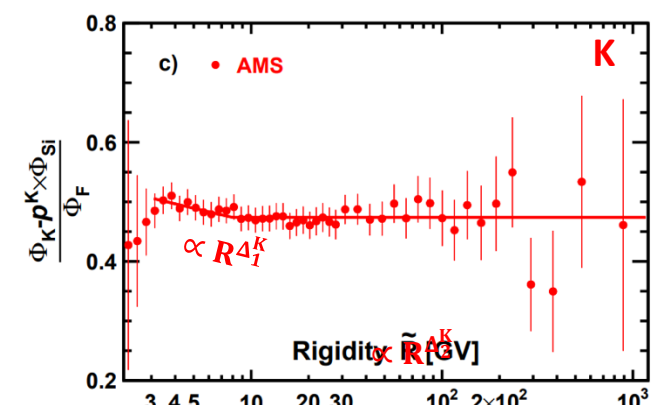
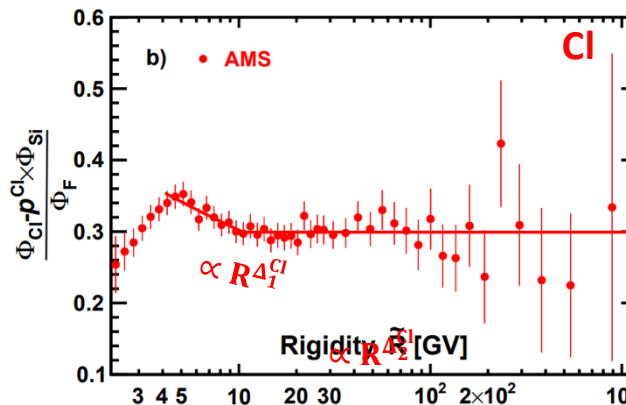
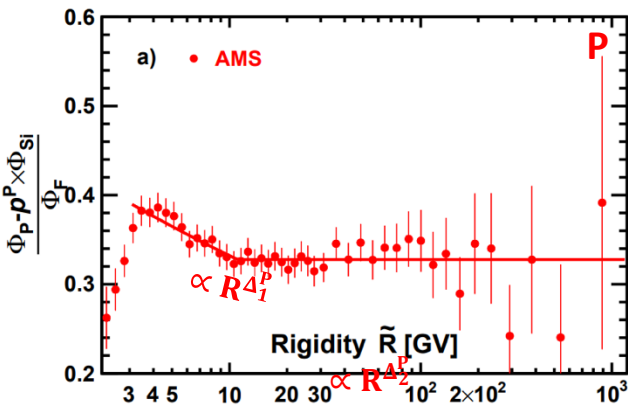


New Proprieties of P Cl and K Fluxes

The Flux ratios of Φ_P/Φ_F , Φ_{Cl}/Φ_F , and Φ_K/Φ_F Can be fitted with:

$$\frac{\Phi_X}{\Phi_F} = \begin{cases} k^X (R/R_0^X)^{\Delta_1^X}, & R \leq R_0^X \text{ GV} \\ k^X (R/R_0^X)^{\Delta_2^X}, & R > R_0^X \text{ GV} \end{cases}$$


After subtracting the scaled Si flux (characteristic primary cosmic ray), the Φ_P/Φ_F , Φ_{Cl}/Φ_F , and Φ_K/Φ_F flux ratios above 10 GV can be well described by a constant ($\Delta_2^X = 0$), this indicates potential primary contribution to P flux



总结

- 本报告展示了AMS关于宇宙线磷、氯、钾(2.15GV-1.2TV)，以及氩、钙(2.15GV-3TV)能谱的最新测量结果
- 磷、氯、氩、钾、钙流强的刚度依赖性均可以很好地由初级宇宙线成分和次级宇宙线成分之和来描述
- 偶电荷数原子核氩、钙流强中的初级成分显著大于奇电荷数原子核磷、氯、氩、钾流强中的初级成分
- 宇宙线中存在两类初级宇宙线，以及两类次级宇宙线，其他宇宙线则由初级和次级宇宙线成分共同组成
- 根据其刚度依赖性，AMS测量的从氦到钙 ($Z=2-20$) 以及铁 ($Z=26$) 等 20 种原子核实际仅包含4大类