Observation of the Identical Rigidity Dependence of He, C, and O Cosmic Rays at High Rigidities by the Alpha Magnetic Spectrometer on the International Space Station
- SUPPLEMENTAL MATERIAL -

(AMS Collaboration)

For references see the main text.

Detector.— Two of the TOF planes are located above the magnet (upper TOF) and two planes are below the magnet (lower TOF). The overall velocity ($\beta = v/c$) resolution has been measured to be $\Delta\beta/\beta^2 = 0.02$ for helium and $\Delta\beta/\beta^2 = 0.01$ for carbon and oxygen nuclei. This discriminates between upward- and downward-going particles. The pulse heights of the two upper planes are combined to provide an independent measurement of the charge with an accuracy $\Delta Z/Z = 4\%$ for helium, 3% for carbon, and 2% for oxygen. The pulse heights from the two lower planes are combined to provide another independent charge measurement with the same accuracy.

Event Selection.— The impurities in carbon and oxygen event samples have two sources. First, a residual background to carbon and oxygen events comes from the interactions of heavy nuclei such as N, O, F, and Ne in the material between $L1$ and $L2$ (the TRD and upper TOF). It has been evaluated by fitting the charge distribution from $L1$ with charge distribution templates of C, N, O, F, and Ne as shown in Fig. SM 2. The charge distribution templates are obtained from a selection of non-interacting samples at $L2$ by the use of the charge measurements with $L1$ and $L3$-$L8$. This residual background is <0.5% for carbon and negligible for oxygen over the entire rigidity range. Second, the background from N, O, F, and Ne interacting in materials above $L1$ (thin support structures made of carbon fiber and aluminum honeycomb). It has been estimated from simulation using MC samples generated according to AMS flux measurements in Table SM III and Ref. [24] to be <0.5% for carbon and negligible for oxygen over the entire rigidity range.

Data Analysis.— The corresponding inelastic cross sections for C+C and C+Al have only been measured below 10 GV and for O+C below 1 GV [25]. To verify the MC predictions, the carbon and oxygen events that traverse materials between $L8$ and $L9$ (lower TOF and RICH) without interacting were measured in data and compared with simulations with the inelastic cross sections varied within ±10%. The resulting cross sections with the best agreement to data were chosen. Figure SM 3 shows the measured carbon and oxygen survival probabilities between $L8$ and $L9$ compared with the simulation. The survival probability between $L1$ and $L2$ has been calculated using data collected when AMS was horizontal, i.e. $\sim 90^\circ$ with respect to the zenith [2]. This independently verifies the inelastic cross sections. The systematic error on the fluxes due to uncertainties of inelastic cross sections is evaluated to be <2.2% for carbon and <2.7% for oxygen up to 100 GV. At higher rigidities, the small rigidity dependence of the cross sections from the Glauber-Gribov model was treated as an uncertainty and added in quadrature to the uncertainties from the measured interaction probabilities. The resulting systematic errors on the fluxes were evaluated to be 3% for carbon and 3.5% for oxygen at 3 TV.

TABLE SM I: The helium flux Φ as a function of rigidity at the top of AMS in units of $[\mathrm{m}^2 \cdot \mathrm{sr} \cdot \mathrm{s} \cdot \mathrm{GV}]^{-1}$ including errors due to statistics (stat.); contributions to the systematic error from the trigger and acceptance (acc.); the rigidity resolution function and unfolding (unf.); the absolute rigidity scale (scale); and the total systematic error (syst.). The contribution of individual sources to the systematic error are added in quadrature to arrive at the total systematic error. The Monte Carlo event samples have sufficient statistics such that they do not contribute to the errors.

Rigidity [GV]	Φ	$\sigma_{\text{stat.}}$	$\sigma_{\text{acc.}}$	$\sigma_{\text{unf.}}$	σ_{scale}	$\sigma_{\text{syst.}}$	
1.92 – 2.15	(5.968	0.005	0.094	0.096	0.016	0.136)	$\times 10^{1}$
2.15 – 2.40	(5.572	0.004	0.078	0.042	0.008	0.089)	$\times 10^{1}$
2.40 – 2.67	(5.050	0.003	0.065	0.030	0.003	0.071)	$\times 10^{1}$
2.67 – 2.97	(4.561	0.003	0.057	0.024	0.000	0.061)	$\times 10^{1}$
2.97 – 3.29	(4.066	0.003	0.051	0.019	0.002	0.055)	$\times 10^{1}$
3.29 – 3.64	(3.565	0.002	0.046	0.014	0.004	0.048)	$\times 10^{1}$
3.64 – 4.02	(3.085	0.002	0.041	0.011	0.004	0.043)	$\times 10^{1}$
4.02 – 4.43	(2.640	0.002	0.036	0.008	0.004	0.037)	$\times 10^{1}$
4.43 – 4.88	(2.233	0.001	0.031	0.006	0.004	0.032)	$\times 10^{1}$
4.88 – 5.37	(1.870	0.001	0.026	0.005	0.004	0.026)	$\times 10^{1}$
5.37 – 5.90	(1.552	0.001	0.021	0.004	0.004	0.022)	$\times 10^{1}$
5.90 – 6.47	(1.282	0.001	0.017	0.003	0.003	0.018)	$\times 10^{1}$
6.47 – 7.09	(1.054	0.001	0.014	0.002	0.003	0.014)	$\times 10^{1}$
7.09 – 7.76	(8.633	0.005	0.113	0.018	0.025	0.117)	$\times 10^{0}$
7.76 – 8.48	(7.068	0.004	0.091	0.014	0.022	0.095)	$\times 10^{0}$
8.48 – 9.26	(5.770	0.003	0.073	0.012	0.019	0.077)	$\times 10^{0}$
9.26 – 10.1	(4.716	0.003	0.059	0.010	0.016	0.062)	$\times 10^{0}$
10.1 – 11.0	(3.842	0.002	0.048	0.008	0.013	0.050)	$\times 10^{0}$
11.0 – 12.0	(3.121	0.002	0.039	0.007	0.011	0.041)	$\times 10^{0}$
12.0 – 13.0	(2.550	0.002	0.031	0.006	0.009	0.033)	$\times 10^{0}$
13.0 – 14.1	(2.086	0.002	0.026	0.005	0.008	0.027)	$\times 10^{0}$
14.1 – 15.3	(1.701	0.001	0.021	0.004	0.006	0.022)	$\times 10^{0}$
15.3 – 16.6	(1.386	0.001	0.017	0.004	0.005	0.018)	$\times 10^{0}$
16.6 – 18.0	(1.125	0.001	0.014	0.003	0.004	0.015)	$\times 10^{0}$
18.0 – 19.5	(9.151	0.008	0.112	0.026	0.036	0.121)	$\times 10^{-1}$
19.5 – 21.1	(7.423	0.007	0.091	0.022	0.029	0.098)	$\times 10^{-1}$
21.1 – 22.8	(6.047	0.006	0.074	0.019	0.024	0.080)	$\times 10^{-1}$
22.8 – 24.7	(4.925	0.005	0.060	0.016	0.020	0.066)	$\times 10^{-1}$
24.7 – 26.7	(3.996	0.004	0.049	0.014	0.016	0.053)	$\times 10^{-1}$
26.7 – 28.8	(3.263	0.003	0.040	0.012	0.013	0.044)	$\times 10^{-1}$
28.8 – 31.1	(2.662	0.003	0.033	0.010	0.011	0.036)	$\times 10^{-1}$
31.1 – 33.5	(2.174	0.002	0.027	0.009	0.009	0.029)	$\times 10^{-1}$
33.5 – 36.1	(1.780	0.002	0.022	0.007	0.007	0.024)	$\times 10^{-1}$

Table continued

TABLE SM I – *(Continued)*.

Rigidity [GV]	Φ	$\sigma_{\text{stat.}}$	$\sigma_{\text{acc.}}$	$\sigma_{\text{unf.}}$	σ_{scale}	$\sigma_{\text{syst.}}$	
36.1 – 38.9	(1.457	0.002	0.018	0.006	0.006	0.020)	$\times10^{-1}$
38.9 – 41.9	(1.189	0.002	0.015	0.005	0.005	0.016)	$\times10^{-1}$
41.9 – 45.1	(9.732	0.013	0.120	0.044	0.040	0.133)	$\times10^{-2}$
45.1 – 48.5	(8.010	0.012	0.098	0.037	0.033	0.110)	$\times10^{-2}$
48.5 – 52.2	(6.536	0.010	0.080	0.031	0.027	0.090)	$\times10^{-2}$
52.2 – 56.1	(5.380	0.009	0.066	0.026	0.023	0.074)	$\times10^{-2}$
56.1 – 60.3	(4.423	0.008	0.054	0.021	0.019	0.061)	$\times10^{-2}$
60.3 – 64.8	(3.633	0.007	0.045	0.018	0.016	0.051)	$\times10^{-2}$
64.8 – 69.7	(2.986	0.006	0.037	0.015	0.013	0.042)	$\times10^{-2}$
69.7 – 74.9	(2.458	0.005	0.030	0.012	0.011	0.034)	$\times10^{-2}$
74.9 – 80.5	(2.020	0.004	0.025	0.010	0.009	0.028)	$\times10^{-2}$
80.5 – 86.5	(1.656	0.004	0.020	0.008	0.007	0.023)	$\times10^{-2}$
86.5 – 93.0	(1.362	0.003	0.017	0.007	0.006	0.019)	$\times10^{-2}$
93.0 – 100	(1.125	0.003	0.014	0.006	0.005	0.016)	$\times10^{-2}$
100 – 108	(9.169	0.025	0.114	0.045	0.044	0.130)	$\times10^{-3}$
108 – 116	(7.470	0.023	0.093	0.036	0.037	0.107)	$\times10^{-3}$
116 – 125	(6.092	0.019	0.077	0.029	0.031	0.087)	$\times10^{-3}$
125 – 135	(4.957	0.016	0.063	0.023	0.026	0.072)	$\times10^{-3}$
135 – 147	(3.961	0.013	0.050	0.019	0.021	0.058)	$\times10^{-3}$
147 – 160	(3.146	0.011	0.040	0.015	0.017	0.046)	$\times10^{-3}$
160 – 175	(2.489	0.009	0.032	0.012	0.014	0.037)	$\times10^{-3}$
175 – 192	(1.929	0.008	0.025	0.009	0.012	0.029)	$\times10^{-3}$
192 – 211	(1.504	0.006	0.020	0.007	0.009	0.023)	$\times10^{-3}$
211 – 233	(1.146	0.005	0.016	0.006	0.008	0.018)	$\times10^{-3}$
233 – 259	(8.721	0.042	0.122	0.044	0.061	0.143)	$\times10^{-4}$
259 – 291	(6.453	0.032	0.092	0.034	0.048	0.109)	$\times10^{-4}$
291 – 330	(4.673	0.025	0.069	0.027	0.037	0.083)	$\times10^{-4}$
330 – 379	(3.299	0.019	0.050	0.021	0.029	0.062)	$\times10^{-4}$
379 – 441	(2.221	0.013	0.035	0.016	0.022	0.045)	$\times10^{-4}$
441 – 525	(1.445	0.009	0.024	0.012	0.017	0.032)	$\times10^{-4}$
525 – 643	(8.890	0.062	0.155	0.091	0.123	0.218)	$\times10^{-5}$
643 – 822	(4.856	0.037	0.089	0.062	0.085	0.138)	$\times10^{-5}$
822 – 1130	(2.368	0.020	0.046	0.039	0.056	0.083)	$\times10^{-5}$
1130 – 1800	(8.542	0.080	0.178	0.209	0.315	0.418)	$\times10^{-6}$
1800 – 3000	(2.463	0.032	0.054	0.099	0.159	0.195)	$\times10^{-6}$

TABLE SM II: The carbon flux Φ as a function of rigidity at the top of AMS in units of $[\mathrm{m}^2 \cdot \mathrm{sr} \cdot \mathrm{s} \cdot \mathrm{GV}]^{-1}$ including errors due to statistics (stat.); contributions to the systematic error from the trigger, acceptance, and background (acc.); the rigidity resolution function and unfolding (unf.); the absolute rigidity scale (scale); and the total systematic error (syst.). The contribution of individual sources to the systematic error are added in quadrature to arrive at the total systematic error. The Monte Carlo event samples have sufficient statistics such that they do not contribute to the errors.

Rigidity [GV]	Φ	$\sigma_{\mathrm{stat.}}$	$\sigma_{\mathrm{acc.}}$	$\sigma_{\mathrm{unf.}}$	σ_{scale}	$\sigma_{\mathrm{syst.}}$	
1.92 – 2.15	(1.434	0.004	0.039	0.029	0.007	0.050)	$\times 10^{0}$
2.15 – 2.40	(1.443	0.003	0.038	0.016	0.005	0.042)	$\times 10^{0}$
2.40 – 2.67	(1.392	0.003	0.036	0.012	0.003	0.038)	$\times 10^{0}$
2.67 – 2.97	(1.275	0.003	0.032	0.010	0.001	0.033)	$\times 10^{0}$
2.97 – 3.29	(1.125	0.002	0.027	0.007	0.000	0.028)	$\times 10^{0}$
3.29 – 3.64	(9.826	0.018	0.236	0.053	0.003	0.241)	$\times 10^{-1}$
3.64 – 4.02	(8.480	0.015	0.201	0.039	0.006	0.204)	$\times 10^{-1}$
4.02 – 4.43	(7.338	0.013	0.172	0.029	0.008	0.174)	$\times 10^{-1}$
4.43 – 4.88	(6.286	0.011	0.146	0.021	0.009	0.148)	$\times 10^{-1}$
4.88 – 5.37	(5.360	0.009	0.123	0.015	0.009	0.125)	$\times 10^{-1}$
5.37 – 5.90	(4.505	0.007	0.103	0.011	0.009	0.104)	$\times 10^{-1}$
5.90 – 6.47	(3.774	0.006	0.086	0.008	0.008	0.087)	$\times 10^{-1}$
6.47 – 7.09	(3.142	0.005	0.071	0.006	0.008	0.072)	$\times 10^{-1}$
7.09 – 7.76	(2.590	0.004	0.059	0.005	0.007	0.059)	$\times 10^{-1}$
7.76 – 8.48	(2.139	0.003	0.048	0.004	0.006	0.049)	$\times 10^{-1}$
8.48 – 9.26	(1.752	0.003	0.040	0.003	0.005	0.040)	$\times 10^{-1}$
9.26 – 10.1	(1.431	0.002	0.032	0.002	0.004	0.033)	$\times 10^{-1}$
10.1 – 11.0	(1.168	0.002	0.026	0.002	0.004	0.027)	$\times 10^{-1}$
11.0 – 12.0	(9.484	0.018	0.215	0.017	0.032	0.218)	$\times 10^{-2}$
12.0 – 13.0	(7.770	0.016	0.176	0.014	0.027	0.178)	$\times 10^{-2}$
13.0 – 14.1	(6.377	0.014	0.144	0.012	0.022	0.147)	$\times 10^{-2}$
14.1 – 15.3	(5.211	0.012	0.118	0.011	0.018	0.120)	$\times 10^{-2}$
15.3 – 16.6	(4.273	0.010	0.097	0.009	0.015	0.098)	$\times 10^{-2}$
16.6 – 18.0	(3.479	0.008	0.079	0.008	0.013	0.080)	$\times 10^{-2}$
18.0 – 19.5	(2.848	0.007	0.065	0.007	0.011	0.066)	$\times 10^{-2}$
19.5 – 21.1	(2.344	0.006	0.053	0.006	0.009	0.054)	$\times 10^{-2}$
21.1 – 22.8	(1.915	0.005	0.044	0.005	0.007	0.045)	$\times 10^{-2}$
22.8 – 24.7	(1.564	0.004	0.036	0.005	0.006	0.036)	$\times 10^{-2}$
24.7 – 26.7	(1.273	0.004	0.029	0.004	0.005	0.030)	$\times 10^{-2}$
26.7 – 28.8	(1.041	0.003	0.024	0.003	0.004	0.024)	$\times 10^{-2}$
28.8 – 31.1	(8.510	0.025	0.195	0.029	0.034	0.200)	$\times 10^{-3}$
31.1 – 33.5	(6.981	0.022	0.160	0.025	0.028	0.165)	$\times 10^{-3}$
33.5 – 36.1	(5.744	0.019	0.132	0.022	0.024	0.136)	$\times 10^{-3}$

Table continued

TABLE SM II – *(Continued)*.

Rigidity [GV]	Φ	$\sigma_{\text{stat.}}$	$\sigma_{\text{acc.}}$	$\sigma_{\text{unf.}}$	σ_{scale}	$\sigma_{\text{syst.}}$	
36.1 – 38.9	(4.716	0.016	0.109	0.019	0.020	0.112)	$\times 10^{-3}$
38.9 – 41.9	(3.886	0.014	0.090	0.016	0.016	0.093)	$\times 10^{-3}$
41.9 – 45.1	(3.156	0.013	0.073	0.014	0.013	0.076)	$\times 10^{-3}$
45.1 – 48.5	(2.591	0.011	0.060	0.012	0.011	0.062)	$\times 10^{-3}$
48.5 – 52.2	(2.167	0.010	0.050	0.010	0.009	0.052)	$\times 10^{-3}$
52.2 – 56.1	(1.765	0.009	0.041	0.009	0.008	0.043)	$\times 10^{-3}$
56.1 – 60.3	(1.458	0.007	0.034	0.007	0.007	0.035)	$\times 10^{-3}$
60.3 – 64.8	(1.195	0.007	0.028	0.006	0.005	0.029)	$\times 10^{-3}$
64.8 – 69.7	(9.726	0.056	0.228	0.052	0.046	0.238)	$\times 10^{-4}$
69.7 – 74.9	(8.003	0.050	0.188	0.044	0.038	0.197)	$\times 10^{-4}$
74.9 – 80.5	(6.631	0.043	0.156	0.037	0.032	0.164)	$\times 10^{-4}$
80.5 – 86.5	(5.391	0.038	0.127	0.031	0.027	0.133)	$\times 10^{-4}$
86.5 – 93.0	(4.478	0.033	0.106	0.026	0.023	0.111)	$\times 10^{-4}$
93.0 – 100	(3.629	0.029	0.086	0.022	0.019	0.091)	$\times 10^{-4}$
100 – 108	(2.989	0.024	0.071	0.018	0.016	0.075)	$\times 10^{-4}$
108 – 116	(2.412	0.022	0.057	0.015	0.013	0.061)	$\times 10^{-4}$
116 – 125	(2.005	0.019	0.048	0.013	0.011	0.051)	$\times 10^{-4}$
125 – 135	(1.602	0.016	0.038	0.010	0.009	0.041)	$\times 10^{-4}$
135 – 147	(1.287	0.013	0.031	0.008	0.008	0.033)	$\times 10^{-4}$
147 – 160	(1.003	0.011	0.024	0.007	0.006	0.026)	$\times 10^{-4}$
160 – 175	(7.964	0.091	0.190	0.054	0.051	0.204)	$\times 10^{-5}$
175 – 192	(6.260	0.076	0.150	0.044	0.042	0.162)	$\times 10^{-5}$
192 – 211	(4.763	0.063	0.114	0.035	0.034	0.124)	$\times 10^{-5}$
211 – 233	(3.749	0.052	0.090	0.029	0.028	0.099)	$\times 10^{-5}$
233 – 259	(2.866	0.041	0.069	0.024	0.023	0.077)	$\times 10^{-5}$
259 – 291	(2.177	0.033	0.053	0.020	0.019	0.060)	$\times 10^{-5}$
291 – 330	(1.536	0.025	0.037	0.015	0.015	0.043)	$\times 10^{-5}$
330 – 379	(1.109	0.019	0.027	0.013	0.013	0.033)	$\times 10^{-5}$
379 – 441	(7.146	0.134	0.176	0.095	0.099	0.223)	$\times 10^{-6}$
441 – 525	(4.886	0.095	0.121	0.077	0.084	0.166)	$\times 10^{-6}$
525 – 643	(2.951	0.062	0.074	0.057	0.065	0.114)	$\times 10^{-6}$
643 – 822	(1.623	0.038	0.042	0.039	0.048	0.075)	$\times 10^{-6}$
822 – 1130	(7.558	0.196	0.200	0.240	0.306	0.437)	$\times 10^{-7}$
1130 – 1800	(2.783	0.188	0.092	0.066	0.122	0.167)	$\times 10^{-7}$
1800 – 3000	(8.660	0.787	0.311	0.333	0.633	0.780)	$\times 10^{-8}$

TABLE SM III: The oxygen flux Φ as a function of rigidity at the top of AMS in units of $[\mathrm{m}^2 \cdot \mathrm{sr} \cdot \mathrm{s} \cdot \mathrm{GV}]^{-1}$ including errors due to statistics (stat.); contributions to the systematic error from the trigger, acceptance, and background (acc.); the rigidity resolution function and unfolding (unf.); the absolute rigidity scale (scale); and the total systematic error (syst.). The contribution of individual sources to the systematic error are added in quadrature to arrive at the total systematic error. The Monte Carlo event samples have sufficient statistics such that they do not contribute to the errors.

Rigidity [GV]	Φ	$\sigma_{\mathrm{stat.}}$	$\sigma_{\mathrm{acc.}}$	$\sigma_{\mathrm{unf.}}$	σ_{scale}	$\sigma_{\mathrm{syst.}}$	
2.15 – 2.40	(1.385	0.004	0.044	0.017	0.007	0.047)	$\times 10^{0}$
2.40 – 2.67	(1.295	0.003	0.039	0.013	0.004	0.041)	$\times 10^{0}$
2.67 – 2.97	(1.185	0.003	0.034	0.010	0.002	0.036)	$\times 10^{0}$
2.97 – 3.29	(1.065	0.002	0.030	0.008	0.001	0.031)	$\times 10^{0}$
3.29 – 3.64	(9.367	0.019	0.259	0.059	0.001	0.266)	$\times 10^{-1}$
3.64 – 4.02	(8.148	0.016	0.222	0.043	0.004	0.226)	$\times 10^{-1}$
4.02 – 4.43	(7.004	0.014	0.189	0.032	0.007	0.192)	$\times 10^{-1}$
4.43 – 4.88	(5.989	0.011	0.161	0.023	0.008	0.163)	$\times 10^{-1}$
4.88 – 5.37	(5.076	0.009	0.136	0.017	0.008	0.137)	$\times 10^{-1}$
5.37 – 5.90	(4.268	0.008	0.114	0.012	0.008	0.115)	$\times 10^{-1}$
5.90 – 6.47	(3.570	0.006	0.095	0.009	0.007	0.096)	$\times 10^{-1}$
6.47 – 7.09	(2.967	0.005	0.079	0.007	0.007	0.080)	$\times 10^{-1}$
7.09 – 7.76	(2.451	0.004	0.065	0.005	0.006	0.066)	$\times 10^{-1}$
7.76 – 8.48	(2.032	0.004	0.054	0.004	0.005	0.055)	$\times 10^{-1}$
8.48 – 9.26	(1.677	0.003	0.045	0.003	0.005	0.045)	$\times 10^{-1}$
9.26 – 10.1	(1.380	0.003	0.037	0.003	0.004	0.037)	$\times 10^{-1}$
10.1 – 11.0	(1.131	0.002	0.030	0.002	0.003	0.031)	$\times 10^{-1}$
11.0 – 12.0	(9.285	0.019	0.249	0.018	0.028	0.251)	$\times 10^{-2}$
12.0 – 13.0	(7.670	0.017	0.206	0.015	0.024	0.208)	$\times 10^{-2}$
13.0 – 14.1	(6.336	0.015	0.170	0.013	0.020	0.172)	$\times 10^{-2}$
14.1 – 15.3	(5.179	0.012	0.139	0.011	0.017	0.141)	$\times 10^{-2}$
15.3 – 16.6	(4.288	0.011	0.116	0.009	0.014	0.117)	$\times 10^{-2}$
16.6 – 18.0	(3.518	0.009	0.095	0.008	0.012	0.096)	$\times 10^{-2}$
18.0 – 19.5	(2.896	0.008	0.078	0.007	0.010	0.079)	$\times 10^{-2}$
19.5 – 21.1	(2.381	0.007	0.064	0.006	0.008	0.065)	$\times 10^{-2}$
21.1 – 22.8	(1.955	0.006	0.053	0.005	0.007	0.054)	$\times 10^{-2}$
22.8 – 24.7	(1.613	0.005	0.044	0.004	0.006	0.044)	$\times 10^{-2}$
24.7 – 26.7	(1.319	0.004	0.036	0.004	0.005	0.036)	$\times 10^{-2}$
26.7 – 28.8	(1.081	0.003	0.029	0.003	0.004	0.030)	$\times 10^{-2}$
28.8 – 31.1	(8.927	0.028	0.244	0.028	0.034	0.248)	$\times 10^{-3}$
31.1 – 33.5	(7.364	0.024	0.202	0.024	0.029	0.205)	$\times 10^{-3}$
33.5 – 36.1	(6.068	0.021	0.167	0.021	0.024	0.170)	$\times 10^{-3}$
36.1 – 38.9	(4.990	0.018	0.137	0.018	0.020	0.140)	$\times 10^{-3}$

Table continued

TABLE SM III – *(Continued)*.

Rigidity [GV]	Φ	$\sigma_{\text{stat.}}$	$\sigma_{\text{acc.}}$	$\sigma_{\text{unf.}}$	σ_{scale}	$\sigma_{\text{syst.}}$	
38.9 – 41.9	(4.079	0.016	0.113	0.015	0.017	0.115)	$\times 10^{-3}$
41.9 – 45.1	(3.373	0.014	0.093	0.013	0.014	0.095)	$\times 10^{-3}$
45.1 – 48.5	(2.783	0.012	0.077	0.011	0.012	0.079)	$\times 10^{-3}$
48.5 – 52.2	(2.314	0.011	0.065	0.010	0.010	0.066)	$\times 10^{-3}$
52.2 – 56.1	(1.909	0.010	0.053	0.008	0.008	0.055)	$\times 10^{-3}$
56.1 – 60.3	(1.557	0.008	0.044	0.007	0.007	0.045)	$\times 10^{-3}$
60.3 – 64.8	(1.290	0.007	0.036	0.006	0.006	0.037)	$\times 10^{-3}$
64.8 – 69.7	(1.064	0.006	0.030	0.005	0.005	0.031)	$\times 10^{-3}$
69.7 – 74.9	(8.611	0.055	0.246	0.042	0.040	0.252)	$\times 10^{-4}$
74.9 – 80.5	(7.160	0.049	0.205	0.036	0.034	0.211)	$\times 10^{-4}$
80.5 – 86.5	(5.933	0.043	0.171	0.030	0.029	0.176)	$\times 10^{-4}$
86.5 – 93.0	(4.822	0.037	0.140	0.025	0.024	0.144)	$\times 10^{-4}$
93.0 – 100	(3.942	0.032	0.115	0.021	0.020	0.118)	$\times 10^{-4}$
100 – 108	(3.241	0.027	0.095	0.018	0.017	0.098)	$\times 10^{-4}$
108 – 116	(2.676	0.025	0.079	0.015	0.015	0.082)	$\times 10^{-4}$
116 – 125	(2.182	0.021	0.065	0.012	0.012	0.067)	$\times 10^{-4}$
125 – 135	(1.781	0.018	0.053	0.010	0.010	0.055)	$\times 10^{-4}$
135 – 147	(1.449	0.015	0.044	0.008	0.009	0.045)	$\times 10^{-4}$
147 – 160	(1.122	0.013	0.034	0.007	0.007	0.035)	$\times 10^{-4}$
160 – 175	(8.904	0.105	0.272	0.055	0.059	0.284)	$\times 10^{-5}$
175 – 192	(7.036	0.087	0.217	0.045	0.050	0.227)	$\times 10^{-5}$
192 – 211	(5.580	0.074	0.173	0.038	0.042	0.182)	$\times 10^{-5}$
211 – 233	(4.189	0.059	0.132	0.030	0.034	0.139)	$\times 10^{-5}$
233 – 259	(3.170	0.047	0.101	0.025	0.028	0.107)	$\times 10^{-5}$
259 – 291	(2.370	0.037	0.076	0.020	0.023	0.082)	$\times 10^{-5}$
291 – 330	(1.704	0.028	0.056	0.017	0.019	0.061)	$\times 10^{-5}$
330 – 379	(1.223	0.021	0.041	0.014	0.015	0.045)	$\times 10^{-5}$
379 – 441	(8.224	0.156	0.278	0.109	0.121	0.322)	$\times 10^{-6}$
441 – 525	(5.256	0.107	0.181	0.085	0.094	0.221)	$\times 10^{-6}$
525 – 643	(3.122	0.070	0.111	0.063	0.070	0.145)	$\times 10^{-6}$
643 – 822	(1.750	0.043	0.064	0.046	0.050	0.094)	$\times 10^{-6}$
822 – 1130	(8.675	0.229	0.331	0.313	0.331	0.563)	$\times 10^{-7}$
1130 – 1800	(3.294	0.231	0.151	0.079	0.131	0.215)	$\times 10^{-7}$
1800 – 3000	(9.659	0.939	0.473	0.406	0.635	0.889)	$\times 10^{-8}$

TABLE SM IV: The helium to oxygen flux ratio He/O as a function of rigidity including errors due to statistics (stat.); contributions to the systematic error from the trigger, acceptance, and background (acc.); the rigidity resolution function and unfolding (unf.); the absolute rigidity scale (scale); and the total systematic error (syst.). The statistical errors are the sum in quadrature of the relative statistical errors of the helium and oxygen fluxes multiplied by the He/O ratio. The systematic errors from the background subtraction, the trigger, and the event reconstruction and selection are likewise added in quadrature. The correlations in the systematic errors from the uncertainty in nuclear interaction cross sections, the unfolding and the absolute rigidity scale between the helium and oxygen fluxes have been taken into account in calculating the corresponding systematic errors of the He/O ratio. The contribution of individual sources to the systematic error are added in quadrature to arrive at the total systematic uncertainty.

Rigidity [GV]	He/O	$\sigma_{\text{stat.}}$	$\sigma_{\text{acc.}}$	$\sigma_{\text{unf.}}$	σ_{scale}	$\sigma_{\text{syst.}}$
2.15 – 2.40	40.223	0.106	1.099	0.433	0.136	1.189
2.40 – 2.67	38.999	0.096	1.050	0.344	0.093	1.109
2.67 – 2.97	38.486	0.088	1.027	0.291	0.063	1.069
2.97 – 3.29	38.174	0.084	1.013	0.246	0.006	1.043
3.29 – 3.64	38.062	0.079	1.007	0.209	0.037	1.029
3.64 – 4.02	37.859	0.078	1.000	0.178	0.032	1.016
4.02 – 4.43	37.693	0.076	0.994	0.152	0.028	1.006
4.43 – 4.88	37.288	0.072	0.983	0.130	0.024	0.992
4.88 – 5.37	36.840	0.068	0.972	0.112	0.020	0.979
5.37 – 5.90	36.354	0.067	0.960	0.099	0.018	0.965
5.90 – 6.47	35.902	0.067	0.949	0.088	0.017	0.953
6.47 – 7.09	35.523	0.066	0.940	0.080	0.017	0.944
7.09 – 7.76	35.222	0.066	0.933	0.075	0.017	0.937
7.76 – 8.48	34.789	0.065	0.923	0.071	0.018	0.926
8.48 – 9.26	34.411	0.065	0.915	0.069	0.018	0.917
9.26 – 10.1	34.182	0.067	0.910	0.068	0.019	0.912
10.1 – 11.0	33.967	0.070	0.905	0.068	0.019	0.908
11.0 – 12.0	33.615	0.072	0.897	0.069	0.019	0.900
12.0 – 13.0	33.245	0.077	0.888	0.070	0.018	0.891
13.0 – 14.1	32.922	0.079	0.881	0.072	0.018	0.884
14.1 – 15.3	32.851	0.082	0.880	0.075	0.017	0.883
15.3 – 16.6	32.320	0.084	0.867	0.077	0.016	0.870
16.6 – 18.0	31.974	0.087	0.859	0.080	0.014	0.863
18.0 – 19.5	31.597	0.089	0.850	0.083	0.013	0.854
19.5 – 21.1	31.171	0.091	0.840	0.087	0.012	0.844

Table continued

TABLE SM IV – *(Continued).*

Rigidity [GV]	He/O	$\sigma_{\text{stat.}}$	$\sigma_{\text{acc.}}$	$\sigma_{\text{unf.}}$	σ_{scale}	$\sigma_{\text{syst.}}$
21.1 – 22.8	30.936	0.092	0.835	0.090	0.011	0.840
22.8 – 24.7	30.529	0.091	0.825	0.093	0.009	0.831
24.7 – 26.7	30.305	0.093	0.821	0.097	0.008	0.827
26.7 – 28.8	30.172	0.096	0.819	0.101	0.007	0.825
28.8 – 31.1	29.826	0.098	0.811	0.105	0.007	0.818
31.1 – 33.5	29.514	0.103	0.805	0.108	0.006	0.812
33.5 – 36.1	29.339	0.107	0.802	0.111	0.006	0.810
36.1 – 38.9	29.190	0.112	0.800	0.115	0.007	0.809
38.9 – 41.9	29.148	0.120	0.802	0.119	0.007	0.810
41.9 – 45.1	28.852	0.126	0.796	0.122	0.008	0.805
45.1 – 48.5	28.777	0.135	0.797	0.125	0.009	0.807
48.5 – 52.2	28.243	0.139	0.785	0.126	0.010	0.795
52.2 – 56.1	28.187	0.149	0.787	0.129	0.011	0.797
56.1 – 60.3	28.397	0.160	0.796	0.133	0.012	0.807
60.3 – 64.8	28.156	0.168	0.792	0.134	0.013	0.804
64.8 – 69.7	28.074	0.177	0.794	0.137	0.014	0.806
69.7 – 74.9	28.542	0.193	0.811	0.141	0.015	0.823
74.9 – 80.5	28.211	0.202	0.806	0.141	0.016	0.818
80.5 – 86.5	27.907	0.212	0.801	0.141	0.016	0.814
86.5 – 93.0	28.251	0.229	0.815	0.144	0.017	0.828
93.0 – 100	28.537	0.246	0.828	0.147	0.018	0.841
100 – 108	28.292	0.251	0.826	0.147	0.018	0.839
108 – 116	27.915	0.273	0.820	0.146	0.019	0.833
116 – 125	27.916	0.285	0.826	0.146	0.019	0.839
125 – 135	27.824	0.298	0.829	0.147	0.020	0.842
135 – 147	27.327	0.296	0.820	0.146	0.021	0.833
147 – 160	28.046	0.331	0.849	0.152	0.024	0.863
160 – 175	27.956	0.345	0.853	0.156	0.027	0.868
175 – 192	27.415	0.358	0.845	0.158	0.031	0.860
192 – 211	26.962	0.374	0.839	0.162	0.037	0.856
211 – 233	27.357	0.406	0.861	0.174	0.046	0.879
233 – 259	27.512	0.431	0.876	0.189	0.057	0.898
259 – 291	27.228	0.445	0.878	0.205	0.069	0.904
291 – 330	27.418	0.478	0.897	0.232	0.086	0.931
330 – 379	26.980	0.496	0.898	0.263	0.105	0.941
379 – 441	27.010	0.538	0.916	0.311	0.135	0.977
441 – 525	27.492	0.588	0.953	0.384	0.181	1.043
525 – 643	28.476	0.667	1.013	0.498	0.248	1.155
643 – 822	27.748	0.706	1.016	0.633	0.317	1.238
822 – 1130	27.302	0.755	1.031	0.855	0.396	1.397
1130 – 1800	25.930	1.834	1.158	0.628	0.074	1.319
1800 – 3000	25.500	2.502	1.180	1.049	0.034	1.579

TABLE SM V: The carbon to oxygen flux ratio C/O as a function of rigidity including errors due to statistics (stat.); contributions to the systematic error from the trigger, acceptance, and background (acc.); the rigidity resolution function and unfolding (unf.); the absolute rigidity scale (scale); and the total systematic error (syst.). The statistical errors are the sum in quadrature of the relative statistical errors of the carbon and oxygen fluxes multiplied by the C/O ratio. The systematic errors from the background subtraction, the trigger, and the event reconstruction and selection are likewise added in quadrature. The correlations in the systematic errors from the uncertainty in nuclear interaction cross sections, the unfolding and the absolute rigidity scale between the carbon and oxygen fluxes have been taken into account in calculating the corresponding systematic errors of the C/O ratio. The contribution of individual sources to the systematic error are added in quadrature to arrive at the total systematic uncertainty.

Rigidity [GV]	C/O	$\sigma_{\text{stat.}}$	$\sigma_{\text{acc.}}$	$\sigma_{\text{unf.}}$	σ_{scale}	$\sigma_{\text{syst.}}$
2.15 – 2.40	1.042	0.004	0.023	0.012	0.002	0.027
2.40 – 2.67	1.075	0.003	0.023	0.010	0.001	0.025
2.67 – 2.97	1.076	0.003	0.022	0.009	0.001	0.023
2.97 – 3.29	1.056	0.003	0.021	0.007	0.000	0.022
3.29 – 3.64	1.049	0.003	0.020	0.006	0.000	0.021
3.64 – 4.02	1.041	0.003	0.019	0.005	0.000	0.020
4.02 – 4.43	1.048	0.003	0.019	0.004	0.000	0.020
4.43 – 4.88	1.050	0.003	0.019	0.004	0.000	0.020
4.88 – 5.37	1.056	0.003	0.019	0.003	0.000	0.019
5.37 – 5.90	1.056	0.003	0.019	0.003	0.000	0.019
5.90 – 6.47	1.057	0.003	0.019	0.003	0.000	0.019
6.47 – 7.09	1.059	0.003	0.019	0.002	0.000	0.019
7.09 – 7.76	1.057	0.003	0.019	0.002	0.000	0.019
7.76 – 8.48	1.053	0.003	0.019	0.002	0.000	0.019
8.48 – 9.26	1.045	0.003	0.019	0.002	0.000	0.019
9.26 – 10.1	1.037	0.003	0.019	0.002	0.000	0.019
10.1 – 11.0	1.032	0.003	0.019	0.002	0.000	0.019
11.0 – 12.0	1.021	0.003	0.019	0.002	0.000	0.019
12.0 – 13.0	1.013	0.003	0.019	0.002	0.000	0.019
13.0 – 14.1	1.006	0.003	0.019	0.002	0.000	0.019
14.1 – 15.3	1.006	0.003	0.019	0.002	0.000	0.019
15.3 – 16.6	0.996	0.003	0.019	0.002	0.000	0.019
16.6 – 18.0	0.989	0.004	0.018	0.002	0.000	0.019
18.0 – 19.5	0.984	0.004	0.018	0.002	0.000	0.019
19.5 – 21.1	0.984	0.004	0.019	0.002	0.000	0.019

Table continued

TABLE SM V – *(Continued)*.

Rigidity [GV]	C/O	$\sigma_{\text{stat.}}$	$\sigma_{\text{acc.}}$	$\sigma_{\text{unf.}}$	σ_{scale}	$\sigma_{\text{syst.}}$
21.1 – 22.8	0.980	0.004	0.019	0.003	0.000	0.019
22.8 – 24.7	0.969	0.004	0.018	0.003	0.000	0.019
24.7 – 26.7	0.966	0.004	0.019	0.003	0.000	0.019
26.7 – 28.8	0.962	0.004	0.019	0.003	0.000	0.019
28.8 – 31.1	0.953	0.004	0.019	0.003	0.000	0.019
31.1 – 33.5	0.948	0.004	0.019	0.003	0.000	0.019
33.5 – 36.1	0.947	0.005	0.019	0.003	0.000	0.019
36.1 – 38.9	0.945	0.005	0.019	0.004	0.000	0.019
38.9 – 41.9	0.952	0.005	0.019	0.004	0.000	0.019
41.9 – 45.1	0.935	0.005	0.019	0.004	0.000	0.019
45.1 – 48.5	0.931	0.006	0.019	0.004	0.000	0.019
48.5 – 52.2	0.936	0.006	0.019	0.004	0.000	0.020
52.2 – 56.1	0.925	0.006	0.019	0.004	0.000	0.020
56.1 – 60.3	0.936	0.007	0.020	0.004	0.000	0.020
60.3 – 64.8	0.926	0.007	0.020	0.005	0.000	0.020
64.8 – 69.7	0.914	0.008	0.020	0.005	0.000	0.020
69.7 – 74.9	0.929	0.008	0.020	0.005	0.000	0.021
74.9 – 80.5	0.926	0.009	0.020	0.005	0.000	0.021
80.5 – 86.5	0.909	0.009	0.020	0.005	0.000	0.021
86.5 – 93.0	0.929	0.010	0.021	0.005	0.000	0.021
93.0 – 100	0.921	0.010	0.021	0.005	0.000	0.021
100 – 108	0.922	0.011	0.021	0.005	0.000	0.022
108 – 116	0.901	0.012	0.021	0.005	0.000	0.022
116 – 125	0.919	0.012	0.022	0.005	0.000	0.022
125 – 135	0.899	0.013	0.021	0.005	0.000	0.022
135 – 147	0.888	0.013	0.021	0.005	0.000	0.022
147 – 160	0.894	0.014	0.022	0.006	0.000	0.022
160 – 175	0.894	0.015	0.022	0.006	0.000	0.023
175 – 192	0.890	0.015	0.022	0.006	0.000	0.023
192 – 211	0.854	0.016	0.022	0.006	0.000	0.023
211 – 233	0.895	0.018	0.023	0.007	0.001	0.024
233 – 259	0.904	0.019	0.024	0.007	0.001	0.025
259 – 291	0.919	0.020	0.025	0.008	0.001	0.026
291 – 330	0.901	0.021	0.025	0.009	0.001	0.026
330 – 379	0.907	0.022	0.025	0.010	0.001	0.027
379 – 441	0.869	0.023	0.025	0.012	0.001	0.028
441 – 525	0.930	0.026	0.028	0.015	0.001	0.031
525 – 643	0.945	0.029	0.029	0.019	0.000	0.035
643 – 822	0.927	0.031	0.030	0.024	0.001	0.038
822 – 1130	0.871	0.032	0.029	0.030	0.002	0.042
1130 – 1800	0.845	0.082	0.037	0.020	0.004	0.043
1800 – 3000	0.897	0.119	0.042	0.036	0.007	0.056

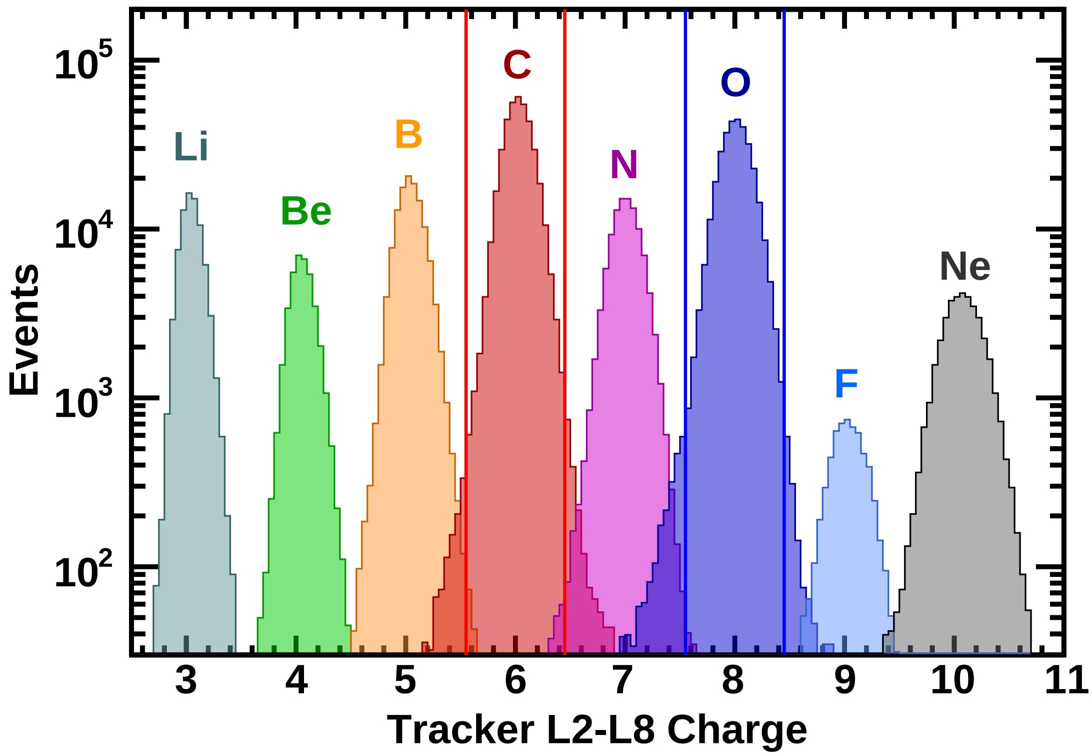

FIG. SM 1. Distribution of the charge measured with the inner tracker ($L2$-$L8$) for samples from $Z = 3$ to $Z = 10$ selected by the combined charge measured with $L1$, the upper TOF, and the lower TOF over the rigidities above 4 GV. The colored vertical lines correspond to the charge selection in the inner tracker for carbon (red) and oxygen (blue).

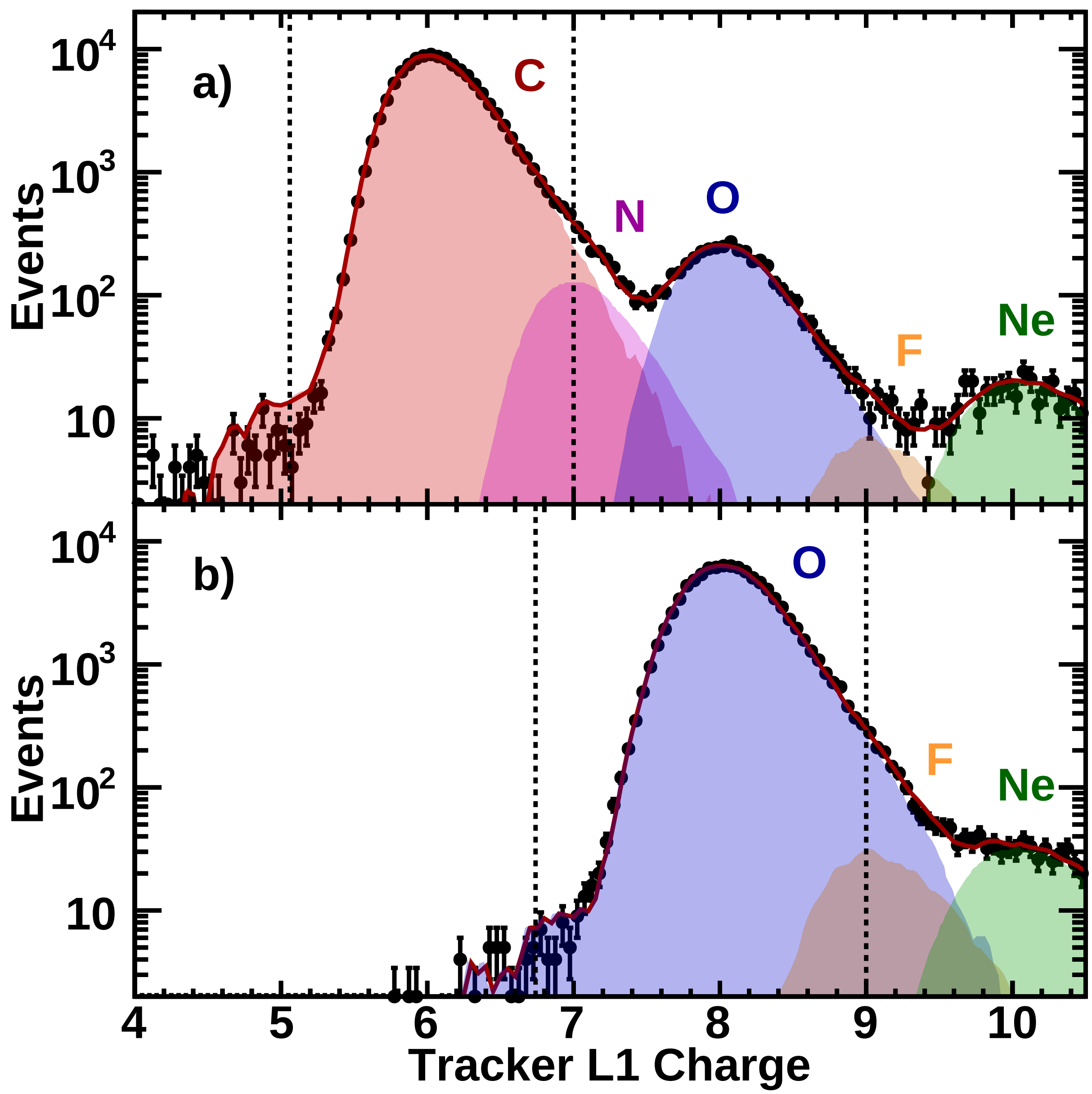

FIG. SM 2. Charge distributions measured by tracker $L1$ for (a) carbon and (b) oxygen events selected by the inner tracker in the rigidity range between 9 and 11 GV (black dots). The solid red curves show the fit to the data of the C, N, O, F, and Ne charge distribution templates. The templates are obtained from samples selected to be non-interacting samples at $L2$ by the use of the charge measurement with $L1$ and $L3$-$L8$. The charge selections applied on tracker $L1$ are shown as vertical dashed lines. The residual backgrounds to the carbon and oxygen samples are calculated by integrating the charge template distributions over the selection range, and found to be $<0.5\%$ for carbon and negligible for oxygen over the entire rigidity range.

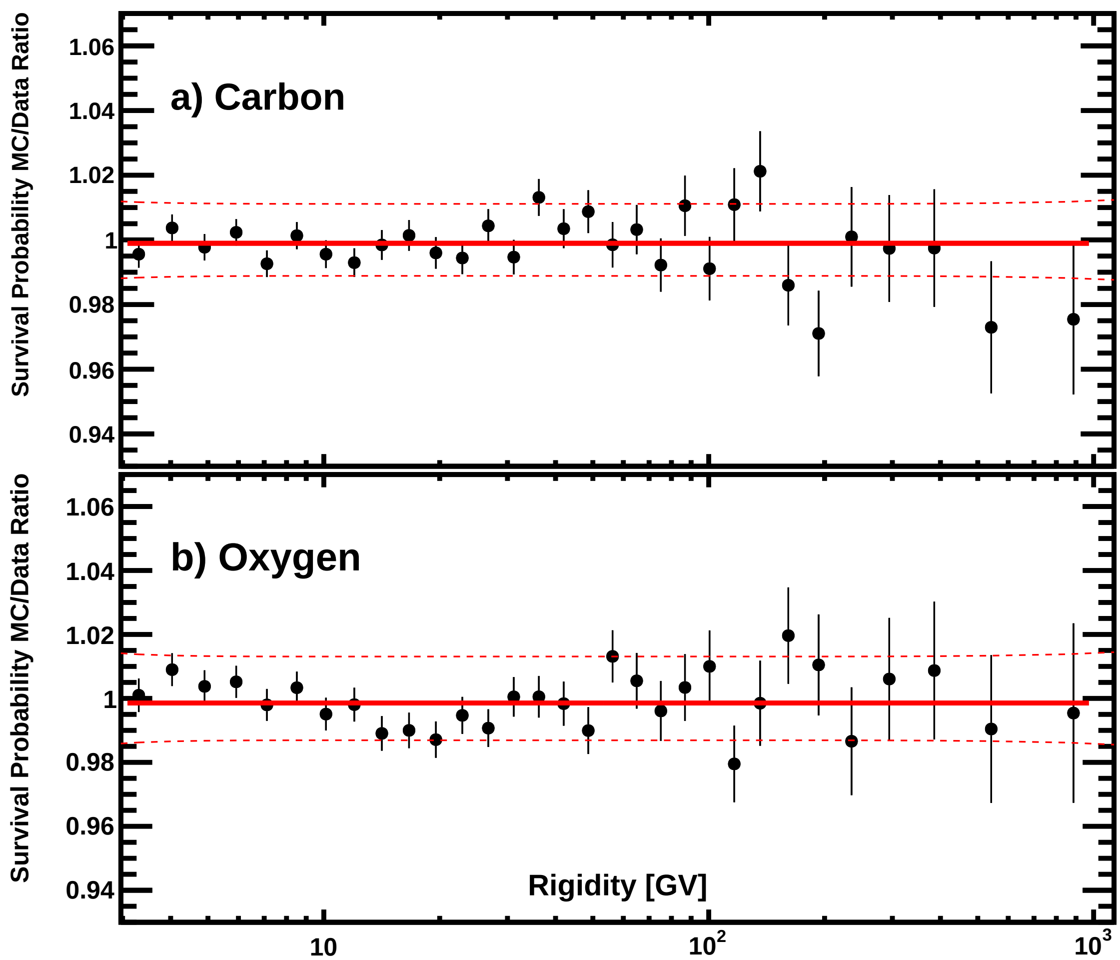

FIG. SM 3. The MC to data ratio of the (a) carbon and (b) oxygen survival probabilities between $L8$ and $L9$. The solid lines show fits to the data points and the dashed lines indicate the estimated systematic errors ranges (68% CL).

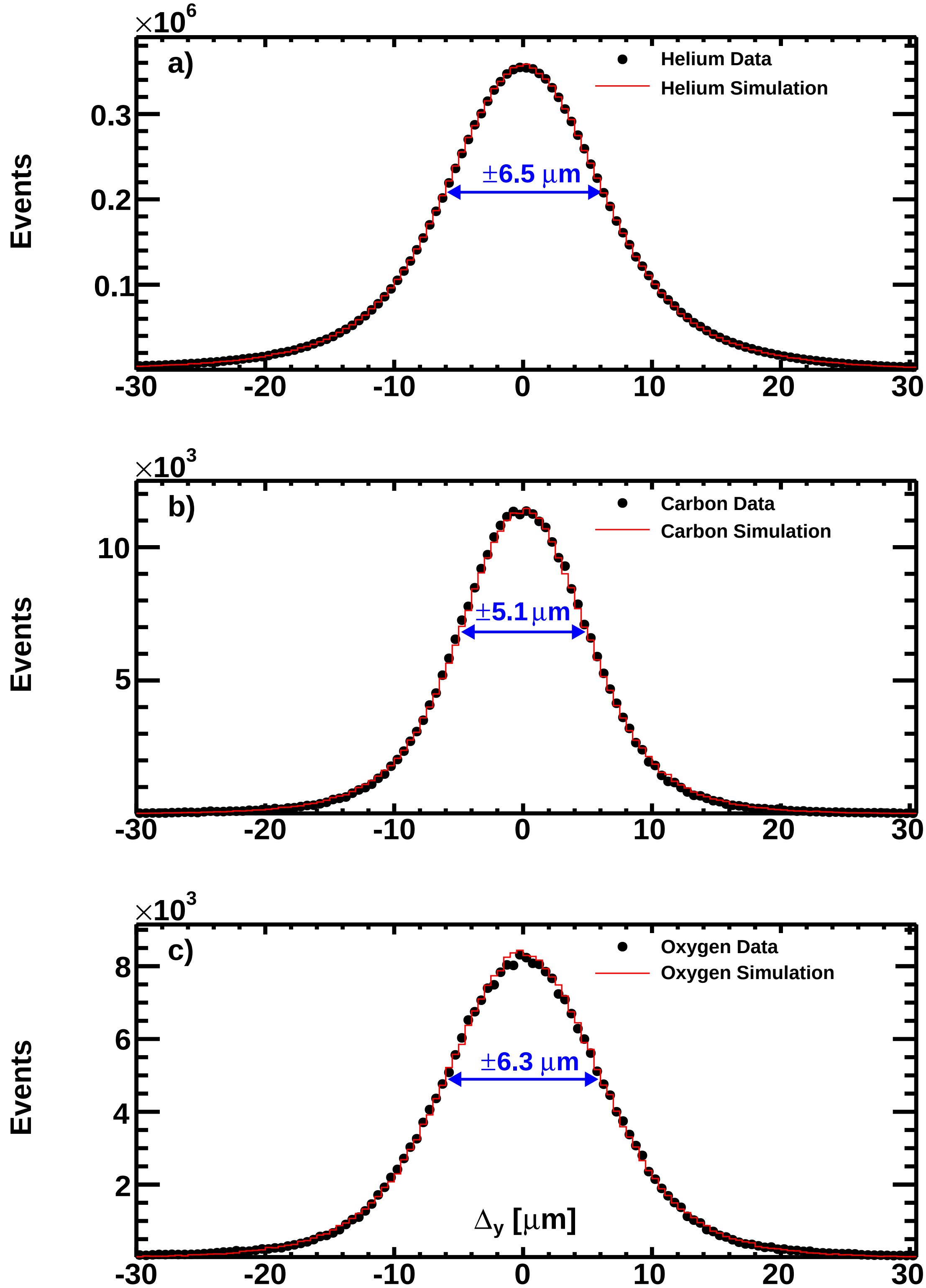

FIG. SM 4. Comparison of the differences of the coordinates measured in $L3$ or $L5$ to those obtained from the track fit using the measurements from $L1$, $L2$, $L4$, $L6$, $L7$, and $L8$ between data and simulation in the rigidity range $R > 50$ GV for (a) helium, (b) carbon, and (c) oxygen samples. The observed bending coordinate accuracy is 6.5 μm for helium, 5.1 μm for carbon, and 6.3 μm for oxygen.

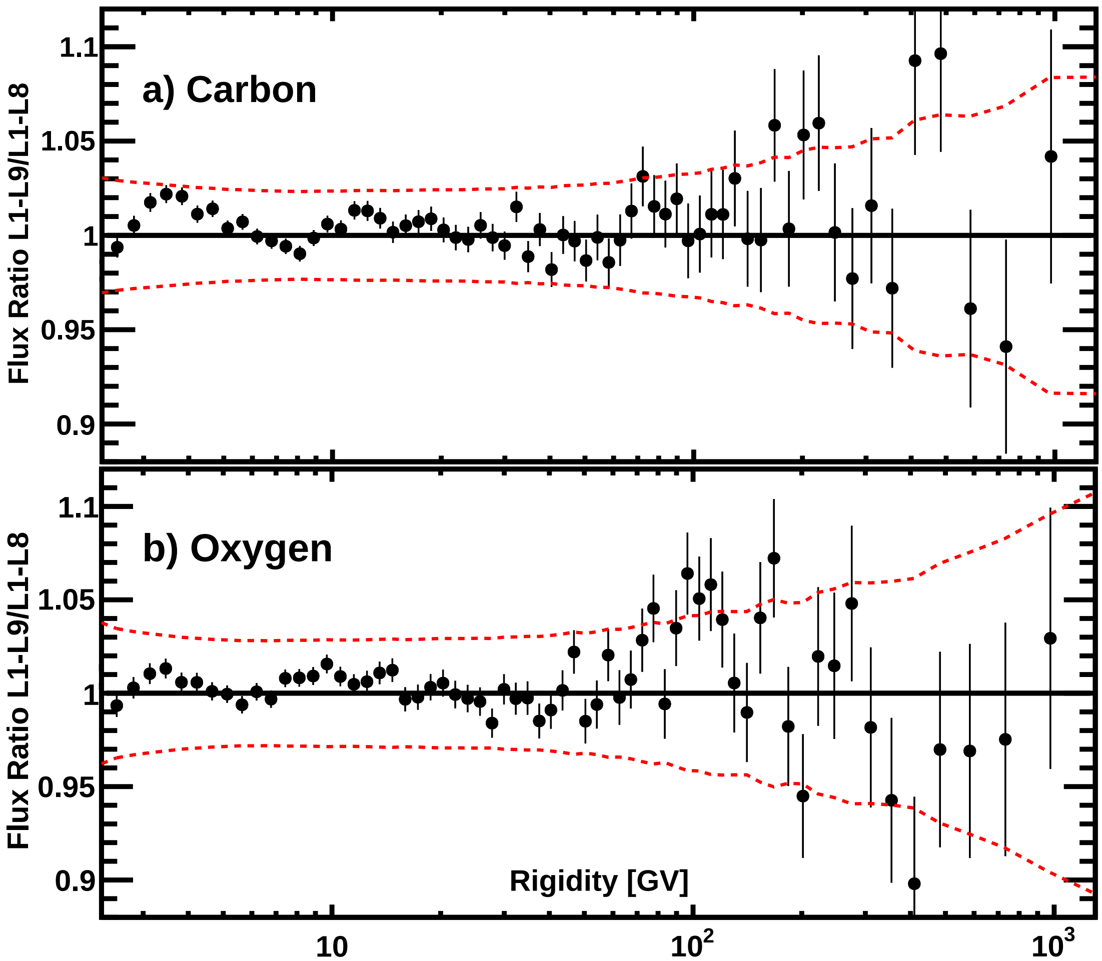

FIG. SM 5. The ratio of the (a) carbon and (b) oxygen fluxes measured with events passing through $L1$ to $L9$ over the events passing through $L1$ to $L8$. The red dashed lines indicate the total errors. The black lines, set at one, are drawn to guide the eye.

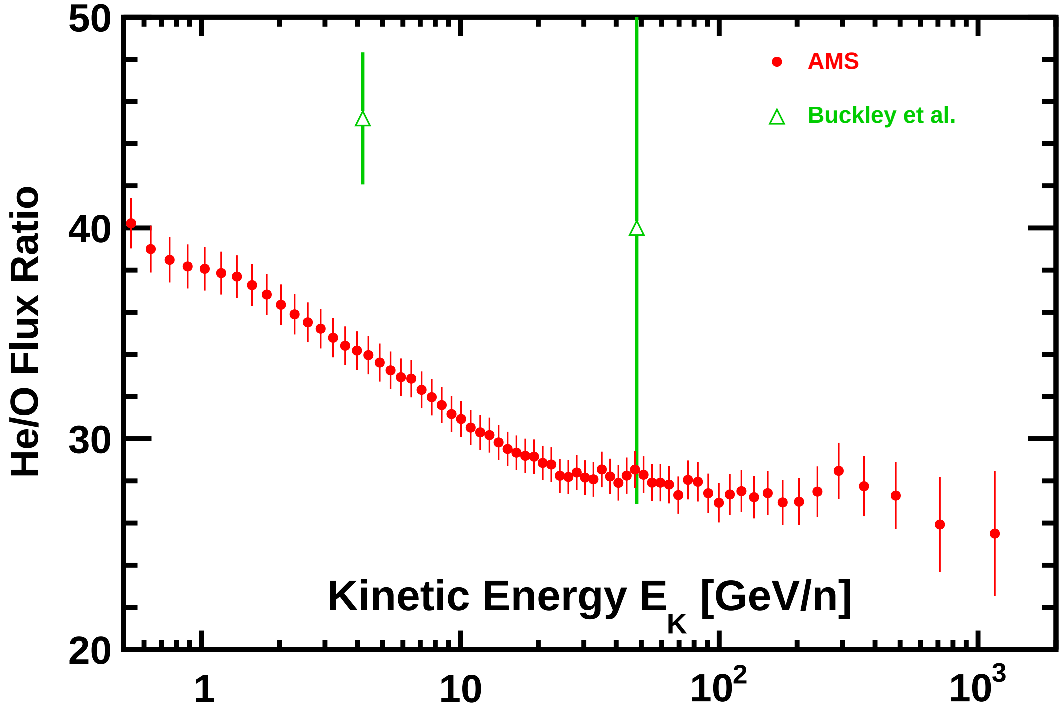

FIG. SM 6. The AMS helium to oxygen flux ratio as a function of kinetic energy per nucleon E_K together with the previous measurement [6]. For the AMS measurement $E_K = \left(\sqrt{Z^2\tilde{R}^2 + M^2} - M\right)/A$ where M, Z, and A are the ^{4}He or ^{16}O mass, charge, and atomic mass number, respectively.

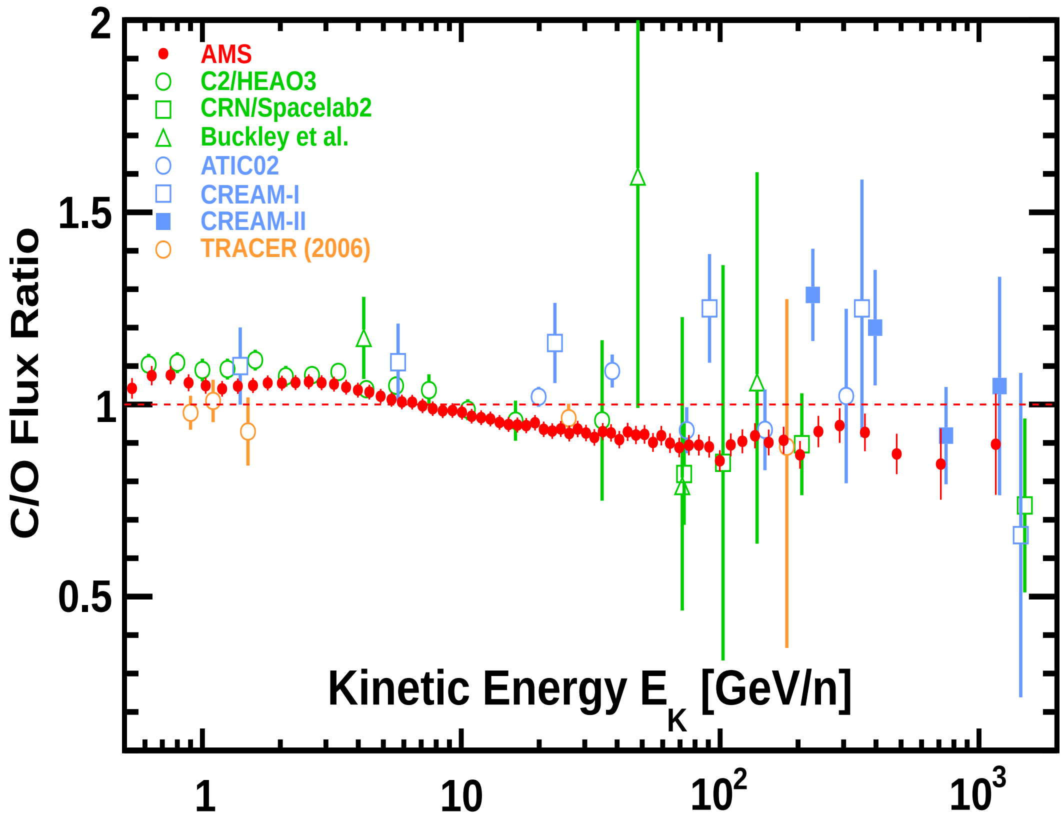

FIG. SM 7. The AMS carbon to oxygen flux ratio as a function of kinetic energy per nucleon E_K together with the previous measurements. For the AMS measurement $E_K = \left(\sqrt{Z^2\tilde{R}^2 + M^2} - M\right)/A$ where M, Z, and A are the ^{12}C or ^{16}O mass, charge, and atomic mass number, respectively. As seen, the C/O ratio measured by AMS is within 10% of unity (dashed red line).