ELECTRONS, MUONS AND HADRONS IN EXTENSIVE AIR SHOWERS AND HOW DO THEY DEPEND ON NUCLEAR INTERACTION MODEL (Part II)

J.A.Wrotniak and G.B.Yodh

Department of Physics and Astronomy
University of Maryland
College Park, MD 20742, U.S.A.

Here we present some of the results of Monte Carlo simulations of extensive air showers for nuclear interaction models as outlined in our contribution HE 4.1-7 to this Conference.

In the notation used below, numbers in brackets () denote mean square errors in last decimal digit units. k, M, G, T and E stand for appropriate powers of 10. For the scarcity of place, the radial data on showers are not included.

Table 1. Average shower size at 1000 g/cm²

E[eV]	Primary protons					Primary iron	
	F-Y00	M-Y00	M-F00	M-F01	R-F01	FF-Y00	RM-F00
20 T	1.09(6)k		1.17(5)k			.25(1)k	.31(1)k
100 T	10.8(5)k	11.6(5)k	8.5(4)k	10.7(4)k	10.2(6)k	2.12(4)k	2.41(4)k
500 T	88(3)k		64(3)k			22.3(6)k	21.8(3)k
2 P	539(20)k		331(14)k			165(4)k	139(3)k
10 P	3.21(6)M	2.99(7)M	2.28(6)M	2.69(8)M	2.21(7)M	1.47(5)M	1.08(2)M
50 P	20.2(4)M		15.2(4)M			10.9(1)M	7.7(2)M
200 P	92(1)M		69(2)M			58(1)M	40(1)M
1 E	507(7)M	519(5)M	411(10)M	451(7)M	391(6)M	378(4)M	261(4)M

Table 2. Fluctuations of the shower size at 1000 g/cm² (s.d.of Log{base 10} Ne)

E[eV]	Primary protons					Primary iron	
	F-Y00	M-Y00	M-F00	M-F01	R-F01	FF-Y00	RM-F00
20 T	.42		.44			.13	.12
100 T	.33	.33	.34	.35	.34	.13	.13
500 T	.22		.26			.12	.10
2 P	.18		.19			.08	.07
10 P	.13	.14	.17	.19	.17	.07	.07
50 P	.10		.15			.05	.05
200 P	.07		.11			.04	.05
1 E	.06	.05	.09	.09	.09	.03	.04

Table 3. Average depth of shower maximum (g/cm^2)

E[eV]	Primary protons					Primary iron	
	F-Y00	M-Y00	M-F00	M-F01	R-F01	FF-Y00	RM-F00
20 T	486(6)		481(5)			307(2)	306(2)
100 T	557(7)	562(7)	521(6)	537(7)	532(8)	377(2)	368(2)
500 T	621(7)		570(6)			447(3)	433(2)
2 P	698(10)		602(7)			509(3)	481(3)
10 P	735(6)	712(6)	653(5)	671(6)	639(7)	583(4)	535(3)
50 P	801(8)		708(7)			643(3)	587(3)
200 P	> 865(8)		729(6)			701(4)	622(4)
1 E	> 920(8)	> 872(7)	777(10)	784(6)	742(4)	773(5)	669(4)

Table 4. Average shower size at maximum (exactly: geometric mean values)

E[eV]	Primary protons					Primary iron	
	F-Y00	M-Y00	M-F00	M-F01	R-F01	FF-Y00	RM-F00
20 T	10.6(1)k		10.9(1)k			7.82(4)k	7.50(3)k
100 T	56.9(7)k	56.0(7)k	58.3(6)k	65.2(7)k	63.7(8)k	40.9(2)k	39.6(2)k
500 T	289(3)k		310(3)k			225(1)k	223(1)k
2 P	1.15(2)M		1.26(2)M			957(4)M	982(4)k
10 P	5.74(5)M	6.01(6)M	6.55(4)M	6.95(5)M	7.18(6)M	5.12(2)M	5.38(2)M
50 P	28.8(3)M		33.3(3)M			26.2(1)M	28.8(2)M
200 P	111(2)M		134(1)M			106(1)M	118(1)M
1 E	552(9)M	614(5)M	662(7)M	703(5)M	726(3)M	530(3)M	610(2)M

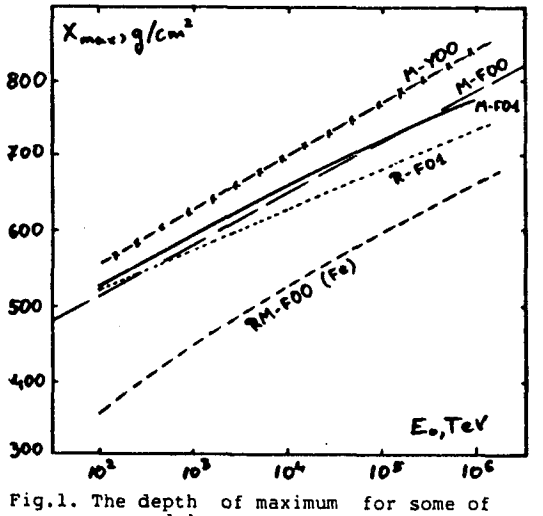

Fig.1. The depth of maximum for some of our models.

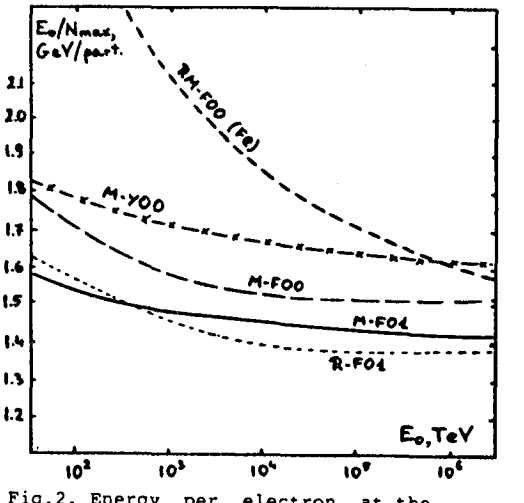

Fig.2. Energy per electron at the shower maximum.

Table 5. Fluctuations in shower size at maximum (s.d.of Log {base 10} Ne[max])

E[eV]	Primary protons					Primary iron	
	F-Y00	M-Y00	M-F00	M-F01	R-F01	FF-Y00	RM-F00
20 T	.10		.09			.032	.033
100 T	.08	.08	.08	.07	.07	.027	.029
500 T	.07		.06			.021	.022
2 P	.06		.05			.017	.014
10 P	.06	.06	.04	.05	.04	.015	.015
50 P	.06		.04			.014	.011
200 P	.07		.04			.009	.014
1 E	.07	.04	.04	.04	.02	.013	.008

Model M-F00 was also run at primary proton energy of 100 EeV (or 10^{20} eV); 151 showers at 1000 g/cm^2 and 64 at 1400 g/cm^2 were simulated. Number of electrons at 1000 g/cm^2 was 59.5(5) G, its fluctuations .04, at maximum (average depth 906(5) g/cm^2): 66.1(5) G and .024, respectively.

Table 6. The average muon number at 1000 g/cm^2.

(a) at E > 2 GeV

E[eV]	Primary protons					Primary iron	
	F-Y00	M-Y00	M-F00	M-F01	R-F01	FF-Y00	RM-F00
20 T	.36(1)k		.34(1)k			.64(1)k	.64(1)k
100 T	1.55(3)k	1.53(2)k	1.43(3)k	1.09(2)k	1.06(2)k	2.32(2)k	2.30(2)k
500 T	6.6(1)k		6.1(1)k			9.57(6)k	9.24(4)k
2 P	22.4(5)k		21.0(3)k			34.2(2)k	32.3(3)k
10 P	90(2)k	91(2)k	82(1)k	52.9(6)k	51.9(8)k	147.6(6)k	136.1(6)k
50 P	337(6)k		334(4)k			612(2)k	567(3)k
200 P	1.03(3)M		1.08(2)M			2.03(2)M	1.90(1)M
1 E	3.71(14)M	4.54(9)M	4.14(7)M	2.33(4)M	2.38(3)M	7.87(5)M	7.60(3)M

(b) at E > 200 GeV

E[eV]	Primary protons					Primary iron	
	F-Y00	M-Y00	M-F00	M-F01	R-F01	FF-Y00	RM-F00
20 T	3.1		2.9			<.1	<.1
100 T	8.4	8.5	8.7	8.5	8.6	7.8	7.5
500 T	29		32			73	77
2 P	83		97			207	223
10 P	299	330	342	254	279	692	773
50 P	1.03 k		1.24 k			2.43 k	2.71 k
200 P	2.88 k		3.96 k			7.11 k	8.25 k
1 E	10.5 k	13.6 k	13.8 k	9.3 k	10.7 k	24.5 k	30.1 k

Table 7. The average hadron number above 2 GeV at 1000 g/cm².

E[eV]	Primary protons					Primary iron	
	F-Y00	M-Y00	M-F00	M-F01	R-F01	FF-Y00	RM-F00
20 T	4.3(3)		4.8(3)			2.0(2)	4.2(3)
100 T	34(3)	38(3)	27(2)	17(2)	19(2)	11(1)	17(1)
500 T	244(11)		168(8)			88(3)	96(2)
2 P	1.33(6)k		701(32)			554(15)	500(13)
10 P	6.7(2)k	5.9(2)k	3.7(2)k	1.95(9)k	1.65(9)k	4.41(9)k	3.19(6)k
50 P	34(2)k		18.3(7)k			28.8(4)k	18.0(5)k
200 P	131(4)k		65(3)k			131(3)k	78(2)k
1 E	566(19)k	550(15)k	293(12)k	130(6)k	106(5)k	711(10)k	388(8)k

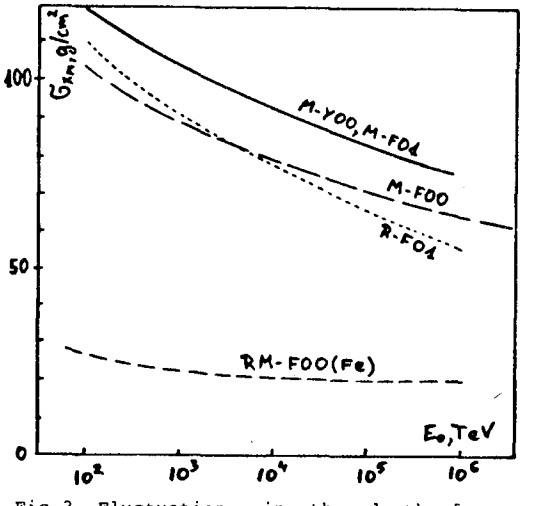

Fig.3. Fluctuations in the depth of maximum.

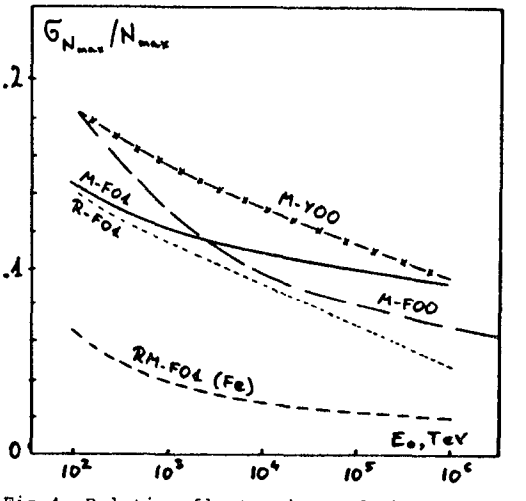

Fig.4. Relative fluctuations of the shower size at maximum.

[One more model was used for EAS generation: M-F10, with all features exactly like M-F00, but with quite different multiplicity distributions. All shower characteristics checked by us were in statistically good agreement between these models].

In principle, the data shown here should speak for themselves. We would like, however, conclude with three remarks:

* The most significant part of scaling violation effect is generated by the inclusion of rising cross-section.
* Among the models considered the lowest value for Eo/N[max] is obtained when rapidly rising cross-section and charge exchange are both included (model R-F01). The value is still 1.38 GeV/electron.
* Except at the highest energies, the sensitivity to atomic mass of the primary is greater than to specific assumptions about multiple production.