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

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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

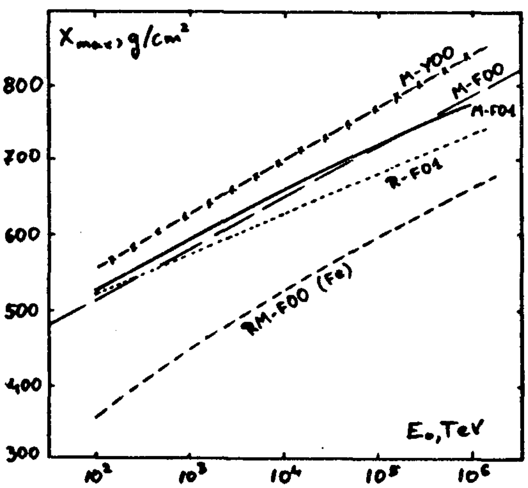

Fig.1. The depth of maximum for some of our models.

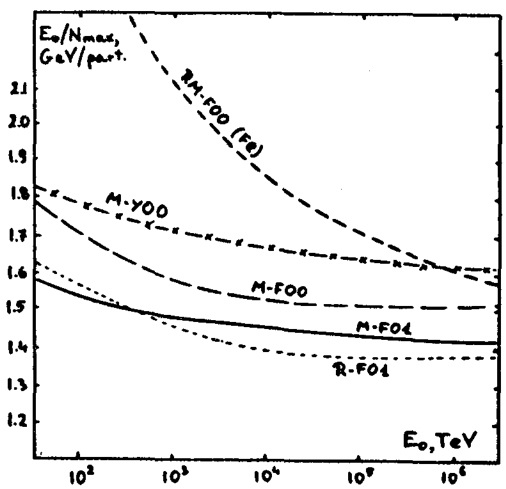

Fig.2. Energy per electron at the shower maximum.

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/cm^2.

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

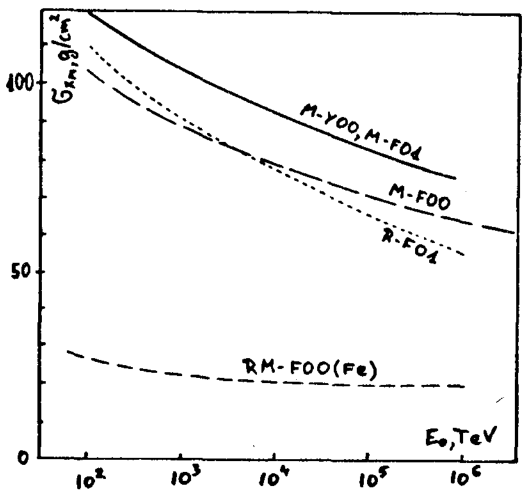

Fig.3. Fluctuations in the depth of maximum.

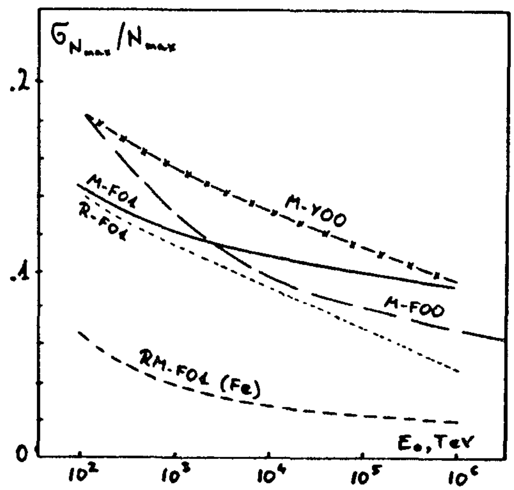

Fig.4. Relative fluctuations of the shower size at maximum.

[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.