GAMMA-HADRON FAMILIES AND SCALING VIOLATION

T.K.Gaisser(*), T.Stanev(**) and J.A.Wrotniak(***)

Bartol Research Foundation of the Franklin Institute,
University of Delaware,
Newark, DE 19816, U.S.A.

For three different interaction models we have simulated gamma-hadron families, including the detector (Pamir emulsion chamber) response. We compare with experiment rates of gamma families, of hadrons, and hadron-gamma ratios.

The Monte Carlo data on families in large emulsion chambers indicate, that simulations made for primary vertical protons are sufficient for the interpretation of observed gamma families (except of their intensity rates). However, for gamma-hadron families the increase in air thickness and the presence of heavier primaries may be important, as the hadron component has different penetrating power than the electromagnetic one.

Therefore we used our three different nuclear interaction models embedded in the same simulation framework, including heavy primaries and zenithal angles from 0 to 45 degrees.

Summary of models used in simulation

@ FF-Y00 - scaling extrapolation of ISR data, constant AA and pA cross-sections.

@ RR-F00 - energy dissipation increasing with energy; at 1.5 TeV as FF-Y00, at 150 TeV y-distributions reflect the SPS $p\bar{p}$ data (what by itself does not say much about the x-distributions, decisive for the family features), with fraction of neutral pions increasing with energy, rapidly rising AA and pA cross-sections.

@ ST - based on a parametrization of hadron-nuclear collisions at accelerator energies, tuned to fit the balloon data in the TeV region. Scaling holds in the fragmentation region, while the central rapidity density increases as log E. Leading hadron energy is skewed towards smaller values and energy-dependent cross-sections correspond to $\log^2 E$ rise of the pp one.

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(***) On leave from the Łódź University, Poland.

First two models are described in detail by Wrotniak [4] (see also [7] in this volume), the third one - by Gaisser et al.[8]. Simulations were done in frames of the SHOWERSIM/84 standard [4], with Nikolskii [11] primary mass/energy spectrum; sampling threshold effects were avoided.

Simulation of the chamber response

The chamber [1,2] consisted of a 5 cm lead layer (gamma block), 60 cm (66 g/cm^2) of carbon and another 5 cm of lead (hadron block), with increase at non-zero zenithal angles.

Mean free path for nuclear interaction in carbon was 70, 91 and 102 g/cm^2 (nucleons, pions and kaons, respectively), and in lead - 168, 218 and 245 g/cm^2.

The effective gamma inelasticity of interacting hadrons was distributed as in [5] with mean value of .24 (nucleons) or .29 (mesons). Particles in the gamma block (including few interacting hadrons) were processed as in [9] (energy distortion, resolving power and a 15 cm cut-off).

Results

We compare our results with the Pamir Experiment data from Bangalore [1,2]. Both these papers refer to basically the same experimental results from a 250 m^2y exposure [1], expanded to 308 m^2y in [2].

Table 1 The ratio of gamma families with $\Sigma E_\gamma > 100$ TeV to primary flux above 1000 TeV/nucleus.

Primary	FF-Y00	RR-F00	ST	Exp [1]
p	.077(4)	.0153(11)	.039(5)	.
Alpha	.028(3)	.0051(9)	.016(5)	.
M	.007(2)	.0021(5)	.003(2)	.
LH	.011(3)	.0013(6)	.002(2)	.
VH	.0075(23)	.0011(2)	-	.
Total	.037(2)	.0073(5)	.018(2)	.0056(5)

Obviously, one can adjust the overall rate just by assuming different primary composition (cf Amenomori et al.[10]). However, at $\Sigma E_\gamma > 100$ TeV there were 133 gamma families in experiment, versus 874 (FF-Y00), 173 (RR-F00) or 430 (ST) predicted by us for this exposure. Assuming the spectrum used by Gaisser (cf [3]) will reduce these numbers by about 6%; the spectra used by Kasahara et al. or M.Shibata (compared in [3]) - by 30-40%.

The experimental rates for hadron families (>100 TeV in total detected energy, at least 1 hadron) have not been published, but this should be not too difficult [6]:

Table 2 The ratio of hadron families with $\sum E$[detected] > 100 TeV to primary flux above 1000 TeV/nucleus.

Primary	FF-Y00	RR-F00	ST
p	.020(2)	.0017(4)	.0034(15)
Alpha	.013(2)	.0017(2)	.0012(7)
M	.004(1)	.0008(3)	.0022(16)
LH	.007(2)	.0005(4)	-
VH	.005(2)	.0006(1)	-
Total	.012(1)	.0013(2)	.0024(8)

The 308 m^2y exposure [2] gave 144 hadrons above 50 TeV (electromagnetic component energy in the chamber) and 41 hadrons above 100 TeV. We can compare these figures with ours:

Table 3 The ratio of hadrons with E > 50 TeV and E > 100 TeV to primary flux above 1000 TeV/nucleus.

Model:	FF-Y00	RR-F00	ST	Exp [2]
E > 50 TeV	.0164(11)	.0024(3)	.0051(11)	.0049(4)
E > 100 TeV	.0049(6)	.0006(1)	.0017(6)	.0014(2)

The hadron to gamma-family ratio is often quoted for the experimental data, being independent on the absolute primary flux: H = N[hadrons >100TeV]/N[gamma families >100TeV] .

Table 4 The hadron/gamma family ratio, H (as defined above)

Model:	FF-Y00	RR-F00	ST	Exp [1]
H	.13(2)	.08(2)	.09(4)	.27(5)!

The pattern emerging from Tables 1-3 is lost here! Also, simulations presented in [1] indicate, that H decreases with rising cross-section and increases with energy dissipation in nuclear interaction. This makes the experiment harder to explain with a quasi-scaling model with rising cross-section (needed to account for absolute rates); the rise assumed for non-scaling models should be much slower than ours.

Of course, higher effective gamma inelasticity and/or shorter interaction paths in the chamber would also bring simulations closer to experiment. However, more than 2/3 of hadrons interact in the sensitive volume of our chamber, so the mean free paths will not give us even a 50% increase in H, and an approximate argument shows, that we need a much higher effective inelasticity to bring our results into agreement with experiment (the average of .4 for FF-Y00 or .5 for two other models).

Finally, let us compare the data on the accompaniment of high-energy hadrons:

S - the ratio of hadrons with neither gamma nor hadron accompaniment (above visible 2 TeV) to all hadrons above 50 or 100 TeV,
S' - the ratio as above, but no hadron accompaniment only,
S" - as above, but no gamma accompaniment only.

Table 5 The percentage of 50 and 100 TeV hadrons with no accompaniment at all, with no other hadrons and without gamma accompaniment.

	E > 50 TeV				E > 100 TeV			
	FF-Y00	RR-F00	ST	Exp[2]	FF-Y00	RR-F00	ST	Exp[2]
S	11(2)	25(5)	25(10)	45(4)	07(3)	10(7)	29(17)	41(8)
S'	23(3)	47(6)	40(11)	49(4)	14(5)	30(9)	43(19)	49(8)
S"	15(3)	26(5)	25(10)	71(4)	09(4)	10(7)	29(17)	61(8)

Once again, the discrepancy lies in the hadron/gamma ratio, as the S' values fit two of our models. One possible explanation is, that there are more hadrons produced than we assume (though there are no Centauros in Pamir), another - serious underestimation of gamma-ray energy or (perhaps more probable) overestimation of energy in the hadron block.

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