Fractionally Charged Particles in Cosmic Rays? Reevaluation of the Data

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Abstract

The search for fractionally charged particles has been performed at Aragatz Cosmic Ray Station in 1975. The apparatus consisted of a hadron calorimeter, multilayer proportional counters and a hodoscope. Only single hadrons with energy $>$ 80 GeV were observed. About 10% of their flux had an ionization 1.4 times higher than protons. Supposing di-quarks with a charge $4/3e$ may be registered their mass can be evaluated as about 30 GeV. An average energy calculated for those suspicious events was much higher (355 GeV) than for general proton/pion peak (205 GeV). It may show that their energy spectrum has a slope and/or cutoff, which is different from proton/pion spectrum. Preliminary analysis of the ATIC first flight data has also shown anomalous region in the proton charge distribution, which may indicate that fractionally charged particles with an unusual energy spectrum are present in cosmic rays.

1. Introduction

The Aragatz experiment [1] included rather thick (750 g/cm^2) calorimeter and 24-layer proportional counter for precise primary particle charge/ionization measurements. The calorimeter allows dramatic decrease of charged particle flux and multylayer charge measuring system improves charge resolution. Due to that interesting results have been obtained and presented at 16th ICRC in Kyoto (1979) [2]. It seems to be useful to compare those old results with modern ones obtained beyond the atmosphere. ATIC balloon experiment gives such an opportunity because it also includes calorimeter and charge measuring system.

2. The Aragatz Experiment

The work has been performed on Aragatz mountain in Armenia at 3200 m above see-level. The setup consisted of an iron calorimeter, two 12-layer proportional counters and a 5-layer hodoscope.

The system was triggered by total energy deposited in the calorimeter with 80 GeV threshold. There was an additional muon trigger. Muons with energy 0.6 GeV were registered simultaneously with hadrons for a precise proportional

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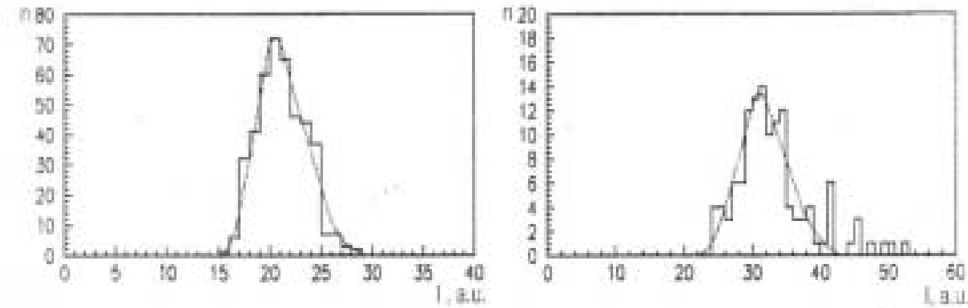

Fig. 1. Ionization spectra for muons (left) and hadrons (right).

counters calibration. Ionization spectra for muons and hadrons are shown in Fig. 1. The statistics is very poor because only pure single hadrons and muons without accompanying air shower particles and without backscatter particles in the proportional counters volumes were selected for off-line analysis.

Using normalized muon spectrum as a reference we can see that about 10% of hadrons are beyond the tail of the normalized curve. The probability to get it accidentally is less than $5{\cdot}10^{-4}$. Very interesting fact is that mean energy for those suspicious events is 355 GeV. The same parameter for regular hadrons is $\bar{E}$ =205 GeV, which is in a good agreement with known energy spectrum and 80 GeV threshold.

Supposing that registered mean energy peak is not an accidental deviation we have to find a logical explanation for it. Because trigger is generated by calorimeter without any involvement of proportional counters there has to be no correlation between energy and charge measurements.

Let's suppose that unusual events are responsible for that group. This case we should come to a conclusion that either they have another slope of energy spectrum or another threshold, which determined not by calorimeter trigger but by another mechanism of their generation. An average ionization for those strange events is $\sim$ 44 a. u. when hadrons have $\sim$ 31 a. u. It is 1.42 times higher than for protons/pions. Neither single charged particle nor pair of them can generate this ionization value. Nearest ionization could be created by di-quarks with $4/3e$ charge. This case ionization should be 1.78 times higher than for single hadrons. But we should take into account relativistic rise of the ionization in gas. It will essentially decrease di-quark ionization if its mass higher than proton one. We can evaluate what mass would correspond to di-quarks with $4/3e$ charge, mean energy 355 GeV and ionization 44 a. u. If relativistic rise of ionization for them has similar shape as for the hadrons their Lorentz factor $\gamma{\simeq}11$. It corresponds to a mass $m_{4/3}$ $\simeq$355 GeV/11$\simeq$32 GeV. This value is a result of very rough estimation but may explain why energy spectrum has different slope and/or cut off.

Table 1. Quantity of particles in various energy regions.

Q,e	<50	50-100	100-150	150-200	200-300	300-500	500-700	700-1000	1000-1500	1500-2000
0.8-1.1	66763	33372	7059	2669	2107	1263	413	243	135	42
0.45-0.7	5531	2948	647	240	209	129	41	30	17	15
0.45-0.7 NORM	5531	2807	594	224	177	106	35	20	11	3.5
DIF	0	141	53.3	15.5	32	23	6	10	6	11.5

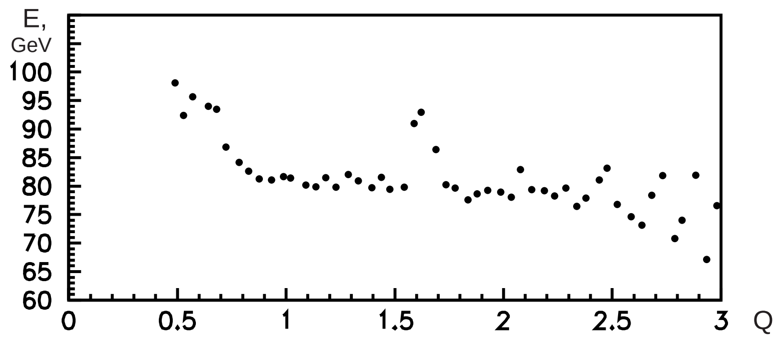

Fig. 2. Average energy versus charge.

3. ATIC Data

The ATIC experiment shows that one layer of silicon detectors does not give good enough charge resolution especially in single hadron region where strong fluctuations of ionization are present. There is no possibility to see something like a peak in charge spectrum even if fractionally charged particles are present. The only way to recognize it is to look for unusual energy spectrum in various regions of charge.

Fig. 2 presents average energy $\bar{E}$ deposited in calorimeter versus charge determined by silicon matrix. One can see a few regions where $\bar{E}$ is much higher (beyond 3σ). As well as in the Aragatz experiment the ATIC trigger was generated by calorimeter and $\bar{E}$ depends on the calorimeter threshold and energy spectrum only. We could not find any reasonable correlation between energy and charge measurement procedures.

More detailed analysis of energy spectra in q=0.5-2 region has been performed. The area with q=1, where pure protons are expected was used as a reference. Table 1 shows the quantity of particles in energy regions for pure protons (q=0.8-1.1) and for the area with high $\bar{E}$ (q=0.45-0.7). Let's assume that in 0.45-0.7 charge region there is a limited amount of unusual particles. Basing on Aragats results and mean energy distribution we may suppose that they appear in

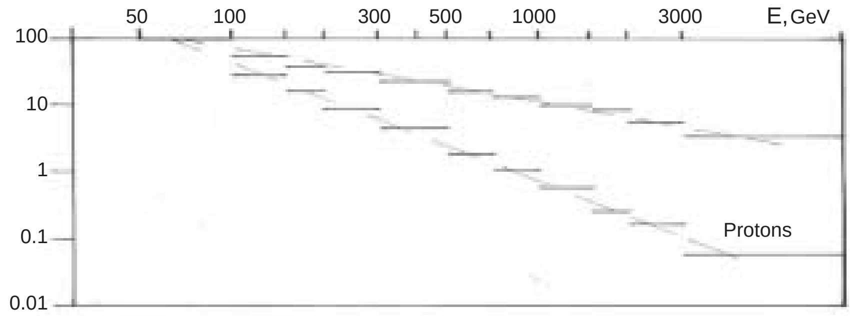

Fig. 3. Energy spectra.

higher energy region only or their percentage is more essential for higher energies. As a starting stage we assumed that in lowest energy region (E≤50 GeV) only protons exist and used this point to normalize energy spectra for all the regions of charge distribution. It is clear that for $q\simeq1$ normalized energy spectrum is identical to the real one. For most other q regions there are only statistical deviations. But for q=0.45-0.7 real spectrum essentially differs from normalized proton one and this difference is considerably greater than statistical errors (the 3^{rd} line in Table 1). Supposing that unusual particle admixture is responsible for that we may subtract them (the 4^{th} line) and to construct an energy spectrum for that addition. It is presented in Fig. 3 together with pure proton spectrum. In both spectra 100% is an amount of particles in 50-100 GeV energy region.

One can see that slopes are very different. The major questions are: 1) Is it a real particle signature? 2) If yes, what kind of particle can be supposed? The easiest answer to the first question is "no" because many kinds of conservative explanations can be (and will be) found. As an answer to the second question we can assume that quarks with $q=2/3e$ are responsible for this effect.

4. Conclusion

Basing on presented results we can suppose but not claim that fractionally charged particles are really present in cosmic ray flux. These results can be an argument to improve charge measuring systems in future cosmic ray experiments. Only an instrument providing energy determination in combination with good charge resolution can confirm or refuse that supposition.

References

1. Bashindzhagyan G.L. et al. 1977, Proc. of the 15th ICRC, v.9, p.185
2. Bashindzhagyan G.L et al. 1979, Proc. of the 16th ICRC, v.6, p.143