Test of the CRASH experiment counters at GSI (*)(**)

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Summary. — The CRASH (Cosmic RAys and Strange Hadronic matter) balloon-borne experiment is specifically designed for the detection of the Strange Quark Matter, which according to theory is probably present in the cosmic-ray radiation at the top of the atmosphere. The detection technique is based on the measure of the A/Z ratio of the nuclei crossing the detector. The charge, the velocity and the mass of the incoming nuclei are determined using both active and passive detectors. First results of the tests of the Čerenkov and scintillation counters performed at GSI Darmstadt with heavy ions (Ar and Ni) of different energies are reported.

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1. – Introduction

Two events with $Z = 14$ and mass of about 370 a.m.u. have been reported [1] by the analysis of a cosmic-ray balloon-borne experiment.

The Strange Quark Matter (SQM) was the best explanation for those two events with high baryon-to-charge number ($A/Z = 26$). Other events from cosmic rays

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experiments [2, 3] could be interpreted as the interaction of nuclei with an anomalous baryon-to-charge ratio. In order to study these anomalous events and, possibly, to confirm the presence of SQM in the primary cosmic rays, a new balloon-borne hybrid detector has been built with a sensitivity ten times higher than any previous experiment. This new instrument will give an estimation of the mass of the anomalous nuclei and perform particle identification.

The candidates selection criteria [4] are based on the comparison between Čerenkov and scintillation signals in order to detect nuclei moving slowly because of their anomalous greater masses. If the nuclei are moving slower than the Čerenkov threshold (320 MeV / n), we determine their energy / nucleon observing the change in dE/dx in different scintillation detectors at different depths of material.

Series of tests have been performed at the GSI heavy-ions accelerator in order to calibrate the whole counting system. We used Ar and Ni ions beams with energies ranging from 500 MeV / n to 1200 MeV / n. Passive-detector samples of different type have also been tested.

In this paper the first results of the analysis of the counters data are reported, resolutions are calculated and the selection strategy is tested.

2. – Instrument description

The main characteristics of the instrument are shown in fig. 1 and summarized in table I. S_1 and S_2 are diffusion-box–type scintillation counters; they are used to measure the charge of incident particles with high accuracy. The discrimination threshold of the scintillators S_1 and S_2 will be set during the flight at 7 minimum ionizing particle (MIP) in order to avoid protons and helium nuclei which are the most

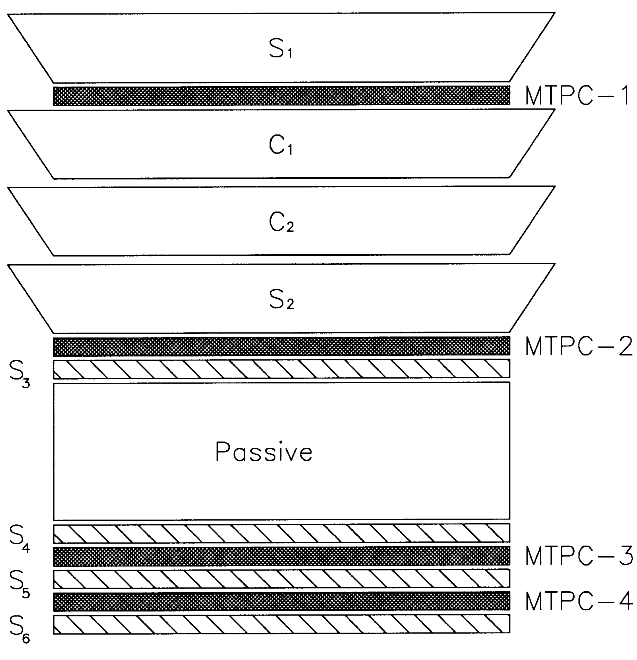

Fig. 1. – SQM telescope.

TABLE I. – *Scintillators and Čerenkov counters characteristics.*

C_1	Čerenkov (diffusion)	(100×100) cm$^2 \times 2$ cm acrylate $[5'' \text{ PMT} \times 8] \times 2$ channel
C_2	Čerenkov (diffusion)	(100×100) cm$^2 \times 2$ cm acrylate with wavelength shifter $[5'' \text{ PMT} \times 8] \times 2$ channel
S_1S_2	Scintillator (diffusion)	(100×100) cm$^2 \times 1$ cm plastic $[5'' \text{ PMT} \times 4] \times 2$ channel
S_3-S_6	Scintillator (light guide)	(100×100) cm$^2 \times 1$ cm plastic $[2'' \text{ PMT} \times 4] \times 2$ channel

aboundant species in cosmic rays. C_1 and C_2 are diffusion-box–type Čerenkov counters; they are used to measure the velocity (*i.e.* energy/nucleon) of incident particles. The discrimination levels of the Čerenkov counters will be set at 0.5 MIP in order to detect massive nuclei with $Z = 2$. S_3, S_4, S_5 and S_6 are light-guide–type scintillation counters; they are used to measure changes in ionization energy loss of primary nuclei at different depths in the detector. Four double layers of MTPCs [5] (multi-tube proportional counters) are distributed along the detector in order to determine the trajectories of both primary and secondary particles with an accuracy of about 0.5 cm.

The trigger is made using the threefold coincidence of scintillators S_1, S_2 and S_3.

The passive detector is composed of three sections: *a*) a strack of sandwiches of CR-39 plates and nuclear emulsion plates to measure the Z/β ratio and the particle position, *b*) a stack of emulsion and polyethylene plates for multiple-scattering observation (rigidity estimation) and *c*) plates of Pb, tracking, emulsion and X-ray film to observe cascade development (3 radiation lengths).

The events are selected using the counter system located at the top of the instrument and then traced in the passive detector, where interactions of the primary particles are also observed in the passive detector.

The total weight of the SQM telescope is about 1500 kg including the supporting structure, its acceptance is 8300 cm$^2\cdot$sr (for $S_1 \times S_2 \times S_3$ trigger); and it is planned to fly across the Mediterranean Sea from Italy (Milo, Sicily) to Spain at an altitude of about 36 km (4 g/cm^2).

3. – Experimental set-up

The tests have been performed at GSI in the Cave B. The instrument was located on the beam line ten meters far from the vacuum pipe and rotated by 90° with the scintillator S_1 ahead. The beam was not centered in the middle of the top plane due to the presence of an aluminium cross belonging to the mechanical structure. Therefore the beam resulted to be positioned roughly in the center of one quarter. Argon ions with energy ranging from 500 to 800 MeV/n and nichel ions with energies from 500 to 1200 MeV/n were used for the test. Different experimental configurations were used for all the different exploited energies and ions. During the test, samples of passive-detector sandwiches were located in front of the telescope. The presence of the passive detector between S_3 and S_4 was simulated by an absorber of about 30 g/cm^2. An external plastic scintillator was positioned on the beam line in front of the instrument for triggering purposes; a multiwire chamber was also installed to determine the position of the incoming ions as well as to monitor the beam shape.

In order to test the instrument in the real working conditions the on-board electronic was used. Since this electronic is low power consuming, it is not fast enough for beam test. Besides, the data read out is designed for serial transmission, therefore, taking into account the difficulty of separating the electronic from our detector, we interfaced it to the CAMAC for fast parallel read out. CAMAC was also used to read out and control the external fast electronic and the trigger system. We designed the trigger system in order to avoid problems due to the high-frequency rate of the ion events. The trigger was generated by the external fast scintillator and the data were read out only after the slow internal trigger was set. Some logic was dedicated to avoid the pile-up of different events on ADC's input. We read out only those events without a second pulse within 100 μs.

4. – Data analysis

A preliminary study was performed on single counters to verify the consistency of the data at different energies and charges.

In addition we also used the nuclei produced by fragmentation since they are well resolved down to $Z = 10$ were the fragmentation secondary-particles background overcomes the signal due to fragments. The analysis was satisfactory and the individual detector responses agree with the predicted ones both for Čerenkov and scintillation counters. The resolution of different detectors was calculated for various ion charges and energies. Results are reported in table II.

The data collected during the test were analized using the same technique that will be used on those collected during the balloon flight as a test of the discriminating power of the whole detector. The distribution of the ratio of the two ADC channels of each Čerenkov and scintillation detector was obtained and all the events beyond 4σ were removed in order to avoid non-uniformities due to background and not to the beam ions. The same selection process was then applied on the distributions of the S_1/S_2 and C_1/C_2 ratios, to eliminate the effects of the background and of the

TABLE II. – *Scintillator and Čerenkov counters percentual resolutions* (FWHM).

Ion	Ar	Ar	Ni	Ni
E/n (MeV/n)	650	800	1000	1200
C_1 (%)	3.7	3.2	6.0	5.3
C_2 (%)	3.4	2.3	5.0	3.9
S_1 (%)	3.7	4.3	4.9	5.6
S_2 (%)	3.0	4.1	5.4	5.2

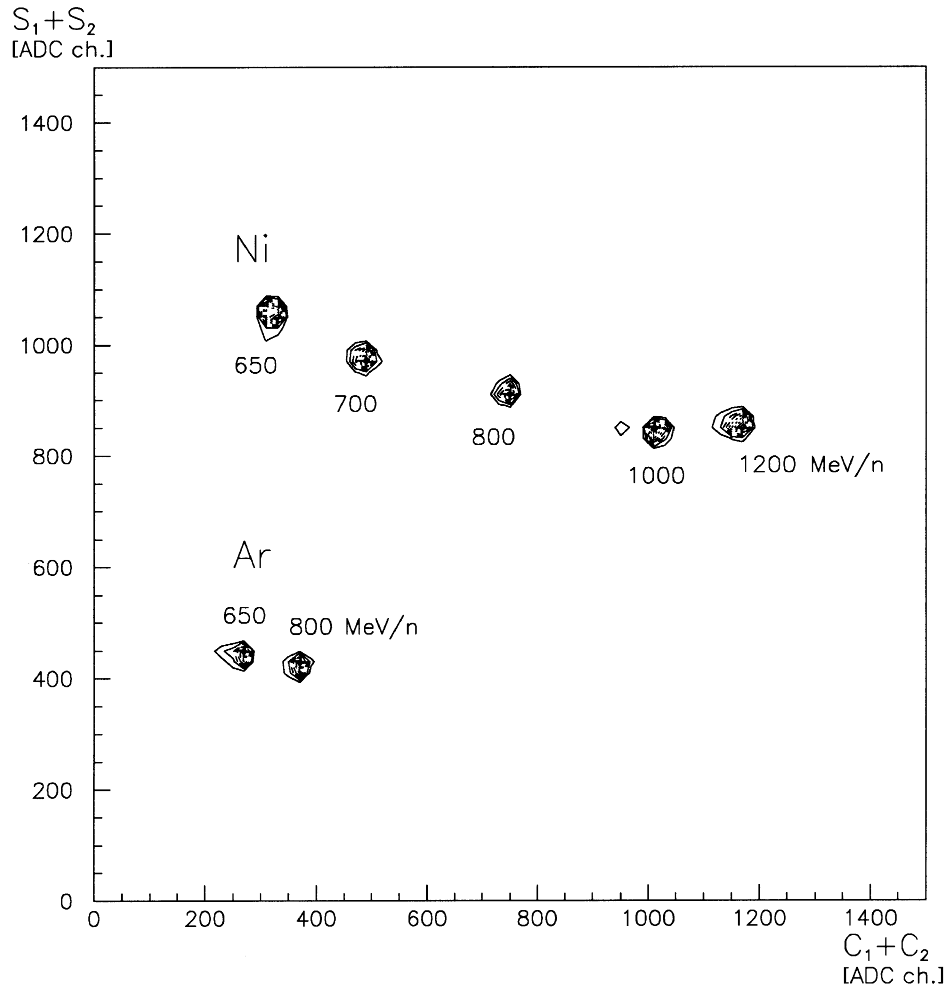

Fig. 2. – Scatter plot of Čerenkov counters signal ($C_1 + C_2$) *vs.* scintillators signal ($S_1 + S_2$). The correlation peaks are represented using 10 equidistant isolevel curves.

interactions inside the detector. Finally the $C_1 + C_2$ and $S_1 + S_2$ signals were correlated. The sum of all the scatter plots for both Ar and Ni ions of different energy/nucleon (*i.e.* velocity) is shown in fig. 2 where one can see how the correlation peaks are resolved.

More than 50% of the total events were removed by the previous analysis, mainly because of the fragmentation of the ions in the instrument. The interaction probability on the path between S_1 and S_2 for Ni ions of 1200 MeV/n is about 40%.

5. – Conclusion

The preliminary analysis of the data collected during the test on the CRASH SQM telescope confirms the expected resolutions for the active counters. They are good enough to use these counters to select the candidate events to be analyzed in the passive detector. Analysis of the passive-detector sample data collected during the test and further analysis of the counting system data are in progress.

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