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CHERCAM: the Cherenkov imager of the CREAM experiment, results in Z=1 test beams.

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Abstract: The CREAM experiment investigates the high energy spectrum of nuclear elements from H to Fe in the cosmic ray flux up to 10^{15} eV, with an instrument designed to achieve individual elements separation over the whole mass range. A proximity focused Cherenkov imager, CHERCAM (CHERenkov CAMera), will provide both a good topological signature (Cherenkov ring) for downgoing Z=1 particles, and a charge independent individual element separation through the considered range of nuclear charges. It will be implemented in the forthcoming CREAM flight 3. The contribution reports on the CHERCAM main features and on the preliminary results from in-beam tests at CERN.

Introduction

The CREAM experiment investigates the nature and the origin of nuclear cosmic rays (CR) by measuring the high energy CR flux at the statistical limit accessible to the current generation of balloon experiments. The measurement of the CR spectrum of nuclear elements from proton to iron between 10^{1O} eV for Z >2 and 10^{12} eV for H and He particles, up to 10^{15} eV, will provide new data on CR spectral characteristics and abundances, including the first measurements of the B/C secondary to primary ratio in this energy domain. The individual nuclear elements separation will allow to probe the current models of acceleration mechanisms, and will provide clues for the interpretation of the "knee" in the inclusive spectrum, and for the physics of the CR galactic transport. A general presentation of the experiment is given in several papers at this conference, see also [1].

CHERCAM design and architecture

CHERCAM is a proximity focusing imager derived from the solution developed for AMS experiment [2]. The conceptual design is illustrated in Fig. 2. The detector is optimized for charge measurements, with a constant resolution through the range of nuclear charge, from H to Fe.

The Cherenkov radiator consists of a 20.8 mm thick silica aerogel plane, made of two superimposed layers of 10.5×10.5 cm^2 tiles, with a refraction index n=1.05. Since the physical requirements on the detector performances implied an accuracy on the refraction index n of the radiator material of the order of $5{\cdot}10^{-4}$, and since the variations in a given tile turned out to reach up to $\sim 2{\cdot}10^{-3}$, a complete mapping of each tile's index was necessary and a dedicated measurement method had to be developed to this purpose, based on laser beam deviation induced by gradient of index [3].

The radiator plane is separated by a 12 cm deep ring expansion gap, from the photon detector plane. The latter consists of an array of 1600 photomultiplier tubes (PMT, Photonis XP3112), backed with dedicated front-end (FE) electronics, power supply, and read-out (RO) electronics. The PMTs geometrical arrangement is a square pattern (Fig. 3), for technical reasons, close packed as far as mechanically possible with a 27.5 mm pitch (1" tubes). This arrangement provides an fiducial detector area of about 50%.

The mechanical structure of the detector is illustrated in Fig. 2. The counter body consists of two frames. The upper one includes the radiator plane fixed on the top lid, and the (empty) drift space, while the lower frame is housing the PMT array and the first level readout electronics. The

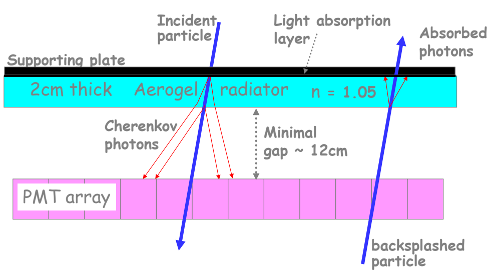

Figure 1: Schematic view of the Cherenkov imager principle.

110×110 cm detector plane is arranged in 5×5 22×22 cm modules of 64 PMTs individually inserted in a 15 mm thick ertalyte housing block. The latter are mounted on a support grid (Fig. 2). Each module is divided into four 4×4-PMT blocks read out by the same 16-channel FE electronics ASIC circuit as developed for the AMS Cherenkov imager [4]. Each block is also powered by one dedicated high voltage (HV) module. The 100 HV modules have been designed at LPSC Grenoble and CESR Toulouse. They are placed on two opposite sides of the lower frame, while the data acquisition (DAQ) boards and housekeeping (HSK) boards are fixed on the other two sides respectively. The detector is equipped with a LED plus optical fiber array test system.

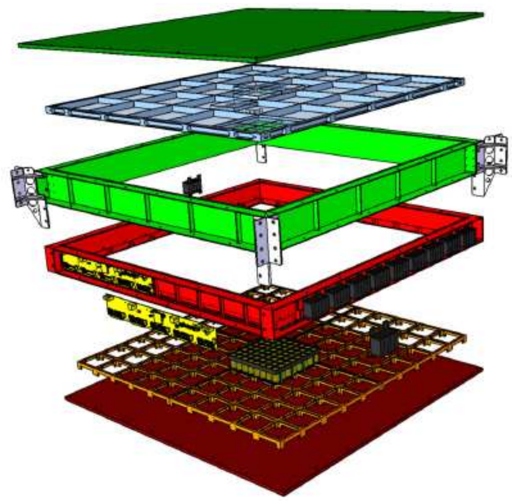

Figure 2: Exploded CAD view of the CHERCAM mechanical structure.

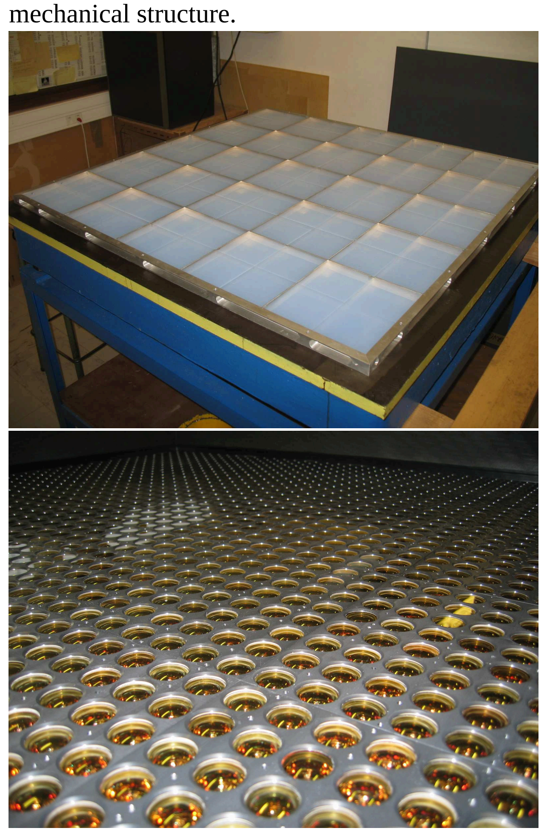

Figure 3: Aerogel radiator plane (top) and PMT detector plane (bottom) of the CHERCAM detector.

CHERCAM simulation

The GEANT4 simulation of the instrument, still in development phase, is used to investigate the detailed features of the detector response [3]. This simulation has allowed to validate the instrumental options and to study the limit of the detector performance. It includes the Cherenkov light generation and propagation, Rayleigh scattering dispersion, and photon detection by modelized photomultipliers. The photocathode quantum efficiency is taken into account according to the data given by the PMT manufacturer. The reconstruction of simulated events samples shows that the expected charge reconstruction accuracy should be of the order of $\Delta Z = 0.3$ charge unit over the considered charge range (see Fig.4).

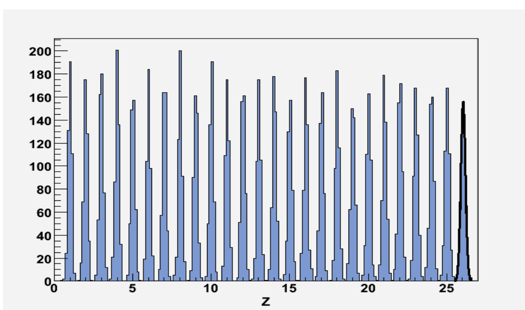

Figure 4: Reconstructed charge spectrum from the simulation of a 11000 events sample with uniform charge distribution.

Test beam results

A detector prototype has been tested in a secondary $Z = 1$ particles beam in the CERN North area, at various incident energies, between 100 GeV/c and 300 GeV/c incident momentum. Z=1 particles provide a sensitive way of testing the background sources since the counter is operated at its lower limit of sensitivity. The tested apparatus consisted of a single 64 PMT module equipped with the flight model RO and DAQ system. A 4-planes silicon strip beam tracker (SBT) [5] was used to measure the incident trajectory coordinates. This was necessary for the Z=1 events reconstruction. The results presented here are preliminary.

Figure 5 shows some typical events measured with the prototype for 100 GeV electrons. A large fraction of the measured events with associated SBT trajectory (∼60% tracking efficiency) displays the expected hit pattern with 6-7 photoelectrons (pe) on the average, distributed along a ring, with (middle left) or without (top two frames) one tube inside the ring being hit by the incident particle with a large response in amplitude of typically 20 equivalent pe (see upper Fig. 6). Some of the PMTs fired along the ring, have a much larger than the expected 1-2 photons amplitude (middle right). This type of response is identified as due to PMT afterpulses induced by ionisation of the residual atmosphere inside the PMT cell (observed in lab tests for XP3112). These amplitudes have been corrected. Some events are affected by a high level of background around the ring as shown in the lower two frames of Fig. 5. This is currently not understood quantitatively. It is speculated that this background might originates from the incident particle hitting the thickest part of the PMT cell, and generating a large number of Cherenkov photons that spread to the nearby tubes. It could also be related

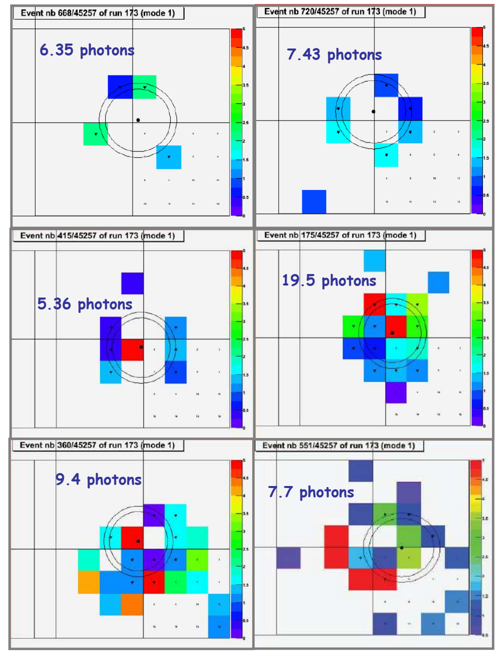

Figure 5: Examples of measured events. See text for comments.

to the beam features. Note that the number of photons detected in a ring, may vary by a factor up to 2, since it depends rather critically on the overlap of the ring with the PMT pattern, and thus on the position of the particle impact. Figure 6 shows

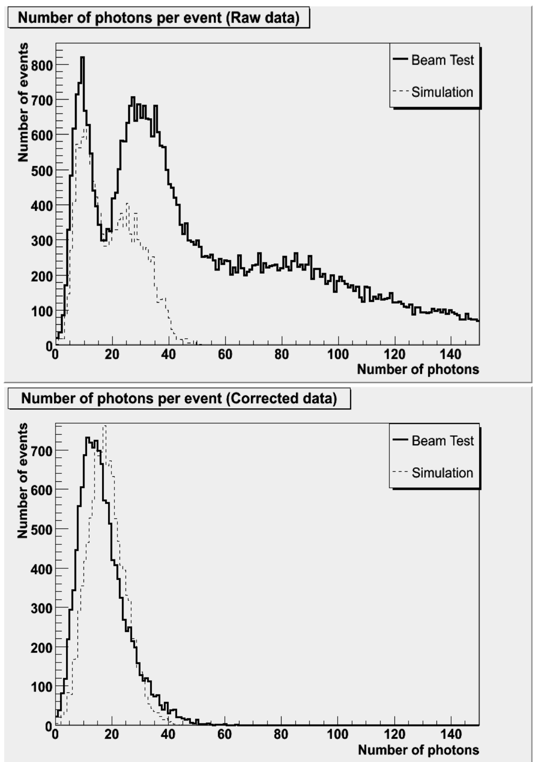

Figure 6: Measured (solid line) and simulated (dashed line) number of photons per event, raw (top) and cut (bottom). See text for details.

the raw distribution of the number of detected photons per event (top) having a SBT track associated, and the number of photons per ring after cuts and corrections (bottom). The latter corresponds to the reconstructed square charge if the mean value is normalized to 1. The cuts consisted in taking into account only the response of the only PMTs which photocathode (PK) overlapped with the expected Cherenkov ring drawn around the particle impact coordinates on the detector plane, obtained from the particle hit trajectory given by the SBT. This is illustrated on Fig. 5, where the width of the ring is determined by the radiator thickness. Since this overlap varies with the impact position, the number of detected photons was corrected from this variable acceptance (as well as from the PK quantum efficiency) to obtain the number of Cherenkov photons in the ring (lower Fig 6.). The Cherenkov photon peak in the upper spectrum has a mean N_{pe} =6.5pe and a variance $\sigma_{pe} = 2.6pe \approx \sqrt{N_{pe}}$. This provides a preliminary estimate of the charge resolution of $\sigma_Z \sim \frac{1}{2}\frac{1}{N_{pe}}$ ~0.2 charge unit. This result is compatible with the expected value and with the simulation results as shown on the figure. The observed difference with the simulation results for the raw distributions is due to the PMT after pulses not modeled yet in the simulation, while for the mean value of the photon distribution it could be due to the absence of absorption in the photon propagation in the simulation, and to some inaccuracy in the PMT calibration. Both assumptions are being investigated. In the forthcoming steps, the complete simulation results will be compared to both these data and the muon CR data which are currently being taken, to investigate what level of knowledge of the detector response has been reached. More details will be available at the conference time.

Conclusion

The Cherenkov imager CHERCAM for cosmic rays charge measurement in CREAM is operational. One module of the flight model has been successfully tested with high energy Z=1 particles. The detector is now integrated in the CREAM payload in preparation of the forthcoming CREAM III flight that should be launched next December 2007 from the McMurdo station in Antarctica. The complete apparatus is currently taking cosmic muon data on the ground at U. Maryland.

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