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A Cherenkov imager for charge measurements of Nuclear Cosmic Rays in the CREAM II instrument

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A proximity focusing Cherenkov imager for the charge measurement of nuclear cosmic rays in the CREAM II instrument, called CHERCAM, is under construction. This imager consists of a silica aerogel radiator plane facing a detector plane equipped with standard photomultipliers. The two planes are separated by a minimal ring expansion gap. The Cherenkov light yield is proportional to the squared charge of the detected particle. The expected relative light collection accuracy is in the few percents range. It should lead to single element separation over the range of nuclear charge Z of main interest $1 \leq Z < \approx 26$.

1. Introduction

The CREAM II instrument is planned to fly alternately with the CREAM I instrument to observe cosmic rays at ultra high energies [1]. The first CREAM II flight is scheduled for December 2005. One of the main scientific objectives of CREAM is to search for an upper energy cutoff in the proton spectrum, which would provide a signature for cosmic-ray acceleration in shock waves. A good Z=1 measurement is required to meet this goal, in particular a good discrimination against both backsplashed particles produced in the calorimeter of the instrument and albedo particles. Moreover, the identification capabilities of the apparatus are a key to successful physics results, in particular in the upper part of the nucleosynthesis mass range around the Fe element. Accurate measurement of the nuclear charge with individual element separation over this range is important since it will make possible the study the subFe(Sc,V,Ti)/Fe ratio of secondary over primary products for larger Z nuclei, in complementarity with the B/C measurements and with a similar data quality.

Both requirements can be met by a proximity focused type of Cherenkov imager, which would provide both a good signature of downgoing Z=1 particles and good single element separation through the whole range of nuclear charges [2]. Such a detector has been designed and is being built with a view toward the forthcoming CREAM II flights.

2. Counter architecture

The counter architecture is derived from the solution developed for the AMS imager [2]. The principle is illustrated on Fig. 1. The radiator consists of a plane of silica aerogel equipped with $11 \times 11 cm^2$ tiles, 2 cm thick, with refractive index n=1.08. Charge one particles will produce about 200 photons, leading to approximately

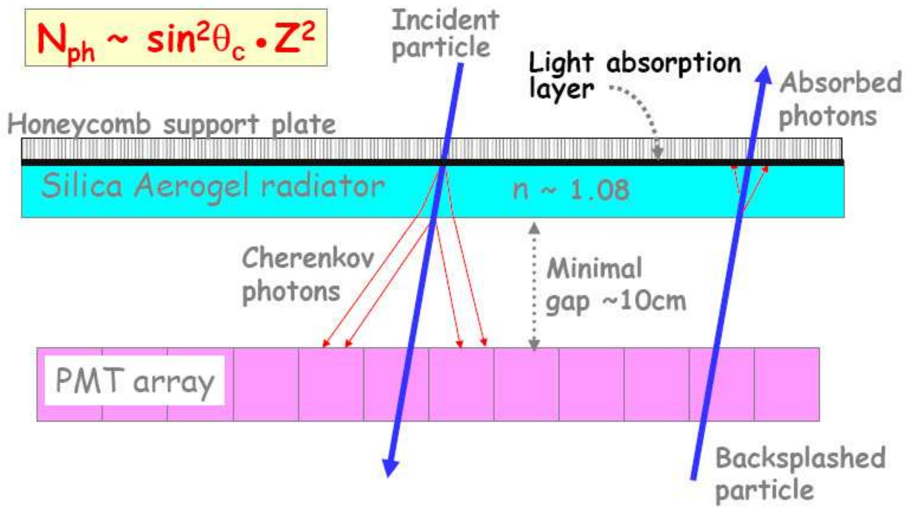

Figure 1. Schematics of the principle of operation of the Cherenkov imager.

5 photoelectrons per photomultiplier. For this value of the refraction index, the Cherenkov emission threshold energy is around 2.3 GeV/nucleon and the Cherenkov angle over the CREAM energy range (1-1000 TeV) is to good accuracy the asymptotic value $\theta_\infty \approx$22 deg, leaving the nuclear charge Z as the only particle dependent variable of the light yield.

The detector plane is an array of 1600 1-inch diameter Photonis XP3112 photomultiplier tubes (PMT) in a square arrangement (i.e., not closely packed) with a 27.5 mm pitch. The Cherenkov ring expansion gap between radiator and detector plane is 10 cm. This distance, for the chosen index of refraction, ensures that most Cherenkov photons are collected on the 8 tubes surrounding the tube hit by the incident particle. This provides the very selective event signature of an 8-fold hit PMT multiplicity with a circular pattern for particle incidence angles not too large with respect to the detector axis. The Cherenkov light yield from upward travelling backsplash and albedo particles will be absorbed in the radiator support. The only significant signal left by these particles should be in the crossed PMT.

The geometrical arrangement used has about a 50% active area. It would suffer a significant dependence of the light collection on the XY particle impact coordinates. With the simple geometry used, the correction of this dependence can be easily performed provided the hit coordinates are known with an accuracy on the scale of a mm. An alternative option to improve the light collection uniformity is to have each tube of the array coupled to a short, about 15-20 mm in length, light guide covering a square photon collection area (Fig.2 right), to ensure that light collection across the fiducial detector surface is as uniform as possible. In this case, however, upward going particles would generate a large number of photons, a significant fraction of which would be Rayleigh (back-)scattered, generating a background in the detector which must be evaluated. See the Monte-Carlo discussion below.

Mechanical structure: The 110x110 cm^2 detector plane is arranged in 5x5 blocks of 64 PMTs. Each block (see Fig2 right) is divided into 4 modules of 16(4x4) units, each being read out by a single 16-channel FE electronics circuit. The mechanical structure of the device is illustrated in Fig. 2. The Cherenkov radiator is glued onto the honeycomb top lid. The body of the counter is divided into two frames for reasons related to the mechanical properties of the structure. The upper frame is empty, only defining the photon expansion gap.

The lower frame contains the whole detector plane. The bottom lid should also be used as a thermal radiator. The thermal model of the detector is in progress.

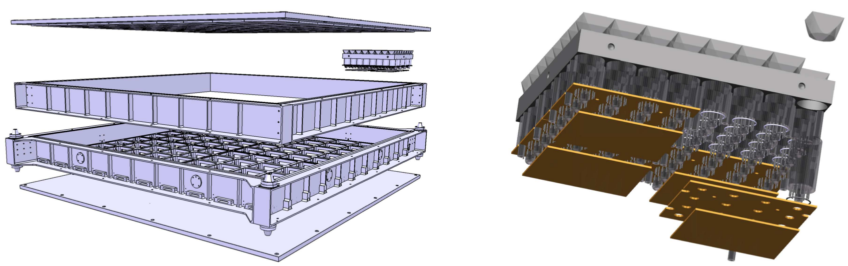

Figure 2. Left : Exploded CAD view of the mechanical architecture of the 120x120 cm^2 counter. Right : CAD view of a 22x22 cm^2 module of 64 PMTs.

3. Readout electronics and DAQ

The front-end readout (RO) electronics employs the same 16-channel ASIC circuit as used for the AMS Cherenkov imager [3]. This circuit performs the multiplexing of the 16 input channels using the track and hold technique. Featuring two gains, x1 and x5, it provides a close to 10^3 dynamic range. In the present application, it is used for reading the 16 PMTs of a module. The dynamic range to be covered in amplitude matches the physics requirements (similar to those of AMS): it is at least of 10^3, so that the charge measurement range extends conveniently from charge one particles through the Fe-Zn nuclei region. In addition to the multiplexed preamplifier ASIC, the CHERCAM FE electronics boards also include a FPGA for providing the readout control sequence of the ASIC and storing the data in a buffer memory before transfer to the merger level, from where the data are transferred to the sparsification board via LVDS protocol.

The event data collection proceeds physically via 10 RO lines of 10 modules per line by two merger boards. The RO lines consist of flat flexible kapton-supported conductors. A dedicated high voltage (HV) power unit delivering adjustable 900-1400 V HV values, has been developed to supply the 16 PMTs of a module, with 100 such units to be implemented in the whole detector.

Most of the RO electronics boards will be fixed along the periphery of the main frame, and lodged inside the U shape of the frame profile. The merger board, located on one side, is connected to the 10 RO lines through dedicated feed-throughs across the frame. The (100) HV supply units are fixed along the two adjacent sides, while the two HV control boards and the housekeeping board are located along the fourth side.

4. Monte-Carlo simulation

A Monte-Carlo simulation is currently being developed to investigate the detailed features and the limits of the detector performances for the charge measurement of particles in the two options considered for the light collection. At the current stage of the work, the geometry of the light collectors has been optimized. The next step, in progress, will cover the complete charge reconstruction in realistic physical and experimental conditions. The critical points to be adressed in priority concern, first, the evaluation of the photon background induced by backsplashed and Albedo particles in the light collectors, Rayleigh scattered by the aerogel radiator back to the detector, and, next, the expected accuracy on the charge reconstruction of the particles over the nuclear charge range considered for CREAM.

Figure 3 shows some results obtained from the simulations. The ray tracing (left) illustrates the light ray paths obtained from the simulation for a uniform generation of incident photons over the light guide surface under 50 deg incidence angle. The curves (right) show the difference in uniformity of the light collection efficiency obtained with and without a light guide for 0 deg incidence angle. For incident photons, the uniformity difference is similar although the overall collection efficiency with and without light guide decreases with the increasing incident angle.

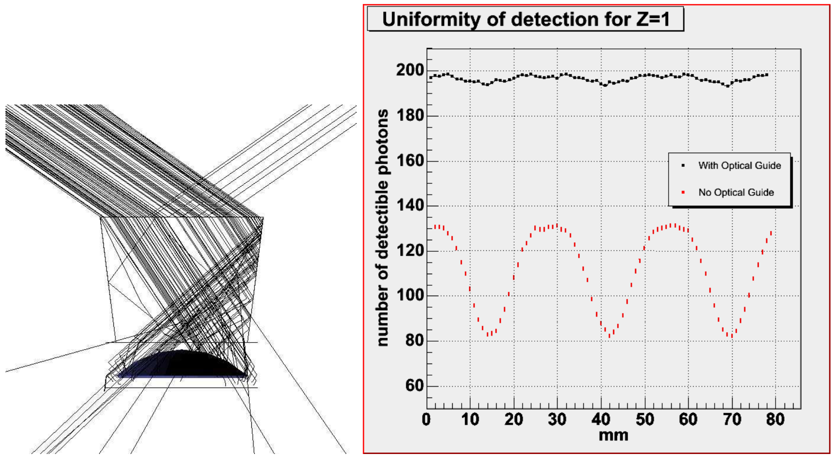

Figure 3. Left : Ray tracing results under 50 deg incidence through the light guides in the simulation for the light transmission evaluation. Right : Results of the photon collection efficiency dependence on the particle hit coordinates along the direction of largest variations. The non uniformity is found at the level ot ±25% without light guide (bottom) and ±2.5% with light guide (top).

5. Conclusions

The engineering model of the Cherenkov imager CHERCAM for the CREAM II project is under construction. The simulation of the counter under the main optical options is in progress, which results will determine the final optical configuration. The flight model is expected to be available by the end of year 2006.

References

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