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The KLEM high-energy cosmic ray collector for the NUCLEON satellite mission

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Abstract. The basic objective of the KLEM (Kinematic Lightweight Energy Meter) Project is to directly measure the elemental energy spectra of very high-energy (10^{11}–10^{16} eV) cosmic rays by determining the angular distribution of secondaries produced in a target layer. A small-scale version of a KLEM device has been designed for inclusion in the NUCLEON Russian satellite mission. Despite its relatively small size of 36×36×30 cm^3, this instrument has an aperture of about 0.12 m^2 sr and can thus make an important contribution to data concerning the elemental energy spectra of cosmic rays up to 10^{15} eV. Details of the experiment and the astrophysical significance of the mission will be presented.

1 Introduction

The NUCLEON Russian satellite program (Podorozhnyi [1] et al., 2001) consists of two parts: 1) the KLEM project (Adams et al., 2000) concerned with high-energy cosmic ray (CR) direct measurements; and 2) the UHIS (Ultra Heavy Isotope Spectrometer) project (Hasebe et al., 1998) concerned with ultra heavy CR nuclei fluxes registration. The first stage of the NUCLEON program is scheduled for 2001-2005. It includes development, construction and launch of the first small version of the instrument with the following parameters:

- maximum size 36×36×30 cm ,
- weight of scientific equipment < 60 kg ,
- power consumption < 95 W.

It is planed that the NUCLEON will be launched in one of the regular Russian satellites in 2004–2005.

The basic objective of the KLEM project is to directly measure the elemental energy spectra of very high-energy (10^{11}–10^{16} eV) cosmic rays by determining the angular distribution of secondaries produced in a target layer. The essence of the proposed device is the combination of a kinematic method of energy measurement and advanced silicon microstrip detector technology for the measurement of emission angles of secondary particles. Due to its light weight and large aperture the newly developed KLEM instrument will allow a dramatically increased exposure factor and extend the energy range in direct CR experiments beyond 10^{15} eV. This is extremely important for CR investigations on satellites because the high weight and small aperture inherent to ionization calorimeters seriously limit their application to higher energies.

A small-scale version of a KLEM device has been designed for inclusion in the NUCLEON mission. Despite its relatively small size of 36×36×30 cm^3, the instrument has an aperture of about 0.12 m^2 sr and can thus make an important contribution to data concerning the elemental energy spectra of cosmic rays up to 10^{15} eV.

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2 Astrophysical significance of the KLEM project

Direct CR spectral measurements beyond the Earth's atmosphere in an extremely wide energy and charge range will contribute to solving the most fundamental astrophysical problems: the quest for the origin, acceleration and propagation of cosmic rays in our Galaxy. In this regard the energy range 10^{12}–10^{16} eV is a crucial region for CR astrophysics.

During the last 25 years several major experiments (PROTON, SOKOL, JACEE, MUBEE, RUNJOB (Apanasenko et al., 1999), ATIC (Wefel et al., 2001; Guzik et al., 1999) and others) on the direct study of high-energy ($E<10^{15}$ eV) cosmic rays have been done and yielded unique scientific results. But yet no direct observations have been made in the energy range $E>10^{15}$ eV, where practically all investigators have detected a “knee” in the CR energy spectrum at $E\approx3\times10^{15}$ eV. Information on the CR spectrum in this region has been obtained by indirect measurements, essentially by the EAS (Extensive Air Shower) technique.

The main difficulty in the direct study of high-energy CRs to date is the fact that among the wide variety of modern experimental methods for energy measurement by a single technique for all types of nuclei (Z=1-30) simultaneously (which is very important for determination of their intensity ratios), only the ionization calorimeter (IC) method and nuclear emulsion kinematic method may be applied over a wide energy range (over several orders of magnitude). But extension of the IC calorimeter method to provide useful elemental measurements in the high energy region ($E>10^{15}$ eV) would require the deployment of a very heavy mass of flight qualified absorber beyond the atmosphere for a few years which would be extremely expensive. The emulsion technique does not require a thick absorber of released energy. But development of this method to higher energies ($E>5\times10^{14}$ eV) is restricted because it is difficult to obtain a larger exposure factor due to the impossibility of prolonged (> 250 hours) exposure of nuclear emulsions in orbit and also due to the very labour-intensive processing and handling of these materials.

These are the main restraints on wide-scale investigations in the energy region beyond 10^{15} eV. However it is also very important to obtain more experimental data in the energy range $E>10^{14}$ eV for light CR nuclei (protons and helium nuclei) and even $E>10^{12}$ eV for heavy nuclei, where the largest discrepancies between the results of different experiments are observed.

3 The KLEM method for direct cosmic ray spectral measurements

An instrument based on this method would have several important advantages, which allow investigations to be conducted in a very wide energy range from 10^{11} eV/particle up to and beyond 10^{16} eV/particle:

- It is very lightweight because it does not need a thick absorber. This is an extremely advantageous feature for application in satellite and balloon experiments where the weight is one of the main constraints.
- It is a large aperture device, allowing a dramatically increased geometrical factor (an order of magnitude or more) in comparison with a regular IC of the same weight.
- It will have the ability to measure the individual energy spectra of CRs for all types of nuclei (Z=1-30) simultaneously with a single technique over a very wide energy range (10^{11}–10^{16} eV/particle). That is essential for determination of their partial intensities.
- The employment of advanced technology silicon microstrip detectors ensures the precision determination of primary particle charge and coordinates and secondary particle density and provides easy readout of information.
- The employment of silicon detectors will allow long-duration exposures (1-3 years in orbit) to be undertaken. Such extended exposures are necessary to gather adequate statistics at higher energies.

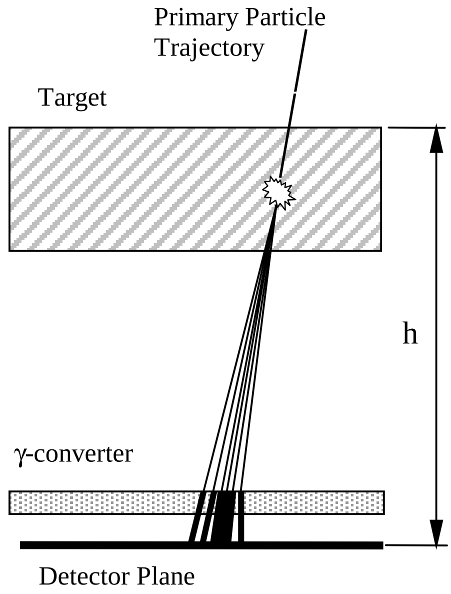

Fig. 1. Illustration of the proposed method.

A schematic illustration of the proposed instrument is given in Fig. 1. A primary particle with energy E interacts in the target where secondary gammas and charged particles are produced. The γ-converter, a thin layer (3–4 X_0) located at some distance from the target and just in front of the detector plane (DP), converts almost all secondary gammas to charged particles. The employment of advanced technology silicon microstrip detectors with modern low power electronic chips ensures the precision determination of primary particle charge and coordinates and secondary particle density. Charge resolution of about 0.1 charge units and spatial resolution of about 30 microns are expected.

The Monte-Carlo simulations (Podorozhnyi [2] et al., 2001) performed at Moscow State University in 1999-2000 show that for an individual event energy resolution of about 60% can be achieved. It is expected that the optimization of an algorithm will improve these preliminary results.

4 Technical description of the KLEM device for the NUCLEON mission

The KLEM device, which is the main part of the NUCLEON instrument (assuming that the second device, UHIS, will be a part of the KLEM target), has the following technical parameters:

- size of active detecting device – 36×36×30 cm ,
- weight of scientific device ~ 60 kg ,
- power consumption ≤ 60 W ,
- number of 6×6 cm^2 silicon detectors (including pad and microstrip detectors) – 180 ,
- number of scintillator strips 0.6×0.6×36 cm^3 – 256 ,
- total number of readout channels ~ 20000.

The schematic layout of the KLEM device is given in Fig. 2.

SD1 is the first layer of silicon detectors. It consists of pads about 1 cm^2 each. Its main task is to measure precisely the primary particle charge. Therefore, it has to be used with high dynamic range electronic channels (up to 2000 mips) to cover at least Z=26 (iron). As a possible solution CR-1 chips (Adams et al., 1999) can be used. The second important task of SD1 is to identify a primary particle within backscatter particles coming back from the targets.

SD2 and SD3 are microstrip detector layers with X and Y strip direction respectively. Although strip pitch is about 50 μm, readout pitch of 300 μm will be used to save readout channels. About 30 μm space resolution is expected due to a charge division method of readout. The main task of SD2 and SD3 is to determine precisely a primary particle position. An additional task is to measure the primary particle charge, confirming SD1 information. It is currently planned to use VA32 hdr2 type chips with SD2-SD3. Therefore, dynamic range is expected to be about 900 mips.

The UHIS low energy metering system consists of many layers of silicon with total thickness 2-2.5 cm. Within the KLEM system it works as an active target giving about 30% of the total matter of the whole target.

Carbon targets CT1 and CT2 are about 4 cm thick each. Both are followed by layers of scintillator strips SC1 and SC2.

The tasks of SC1 and SC2 are: to determine an interaction point within the carbon targets in the X, Y and Z directions; to generate a first level trigger for KLEM together with bottom scintillators SC3, SC4. The scintillator strips are about 0.6×0.6 cm^2 and 36 cm long. Every layer of strips is read out with one 64-channel HAMAMATSU photomultiplier tube (PMT).

CONV is a gamma-ray converter with thickness of 3-4 X_0. It is intended to make the converter with 10-14 mm thick tungsten plate or bars. An advantage of tungsten is its rigidity. Therefore, the converter can be used as a part of the mechanical supporting structure.

SD4 and SD5 are two silicon microstrip layers. Strip pitch is also 50 μm, but every strip has its own readout channel. This is necessary because the task of the layers is not to determine a position of a single particle but to give a cross section of the secondary particle cloud in the X and Y directions. The density of the secondaries near the primary particle trajectory is the basic information for energy determination with the KLEM technique. VA32 hdr2 type chips can be used together with the SD4, SD5 strip layers.

Finally, SC3 and SC4 are the bottom scintillating layers. Their tasks are: to generate the first level KLEM trigger together with SC1, SC2; to confirm the position of the secondary particle cloud in the X and Y directions, determined by SD4 and SD5.

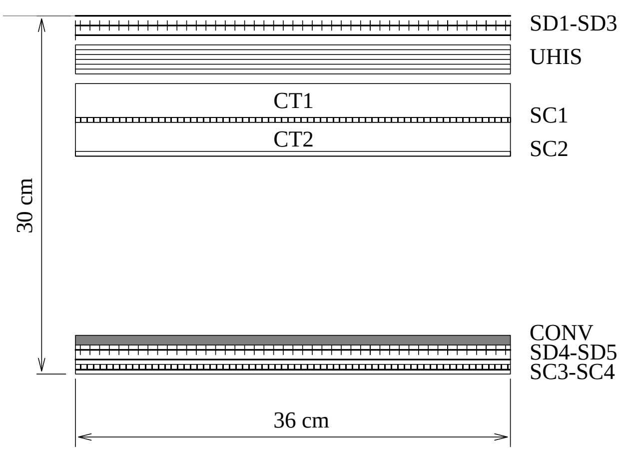

Fig. 2. The schematic layout of the KLEM device for the NUCLEON mission.

5 Summary

A small-scale version (36×36×30 cm) of a KLEM device has been designed for the NUCLEON mission, which is scheduled for 2004-2005. It will allow directly measurement of the elemental energy spectra of high-energy (10^{11}–10^{15} eV) CRs for all types of nuclei (Z=1–30) with an individual event energy resolution of about 60%.

References

Adams, J., et al., A new approach to cosmic ray spectral measurements in the energy range 10^{10}-10^{16} eV. Proc. of the *STAIF*-2000 (Albuquerque, New Mexico), v. 504, p. 175, 2000.

Adams, J., et al., The CR-1 Chip: Custom VLSI Circuitry for Cosmic Rays. Proc. of the *26th International Cosmic Ray Conf.* (Salt Lake City, Utah), v. 5, p. 69, 1999.

Apanasenko, A., et al., Energy determination for RUNJOB Experiment. Proc. of the *26th ICRC* (Salt Lake City, Utah), v. 3, p. 231, 1999.

Guzik, T., et al., The Advanced Thin Ionization Calorimeter (ATIC) for Studies of high-energy Cosmic Rays. Proc. *26th ICRC* (Salt Lake City, Utah), v.5, p. 9-12, 1999.

Hasebe N., et al., Ultra Heavy Isotope Spectrometer. Proposal of RISE WU, 1998.

[1] Podorozhnyi, D. M., et al., The NUCLEON mission for cosmic ray investigation. This Conference, 27th *ICRC*, *OG* 1.6, 2001.

[2] Podorozhnyi, D. M., et al., Recent results of the KLEM method simulations. This Conference, 27th *ICRC*, *OG* 1.6, 2001.

Wefel, J. P., et al., The ATIC Experiment: First Flight. This Conference, 27th *ICRC OG* 1.1, 2001.