Proceedings of ICRC 2001: 2147 © Copernicus Gesellschaft 2001

ICRC 2001

Polar balloon experiment for astrophysics research (Polar BEAR)

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Abstract. A new balloon experiment is proposed for a long duration flight around the North Pole. The primary objective of the experiment is to measure the elemental energy spectra of high-energy cosmic rays in the region up to 10^{15} eV. The proposed instrument involves the combination of a large collecting area (≈1×1m^2) KLEM (Kinematic Lightweight Energy Meter) device with an ionization calorimeter having a smaller collecting area (≈ 0.5×0.5 m^2) and integrated beneath the KLEM apparatus. This combination has several important advantages. Due to the large aperture (>2 m^2 sr) of the KLEM device a large exposure factor can be achieved with a long duration balloon flight (2−4 weeks). The calorimeter will collect about 10% of the events already registered by KLEM and provide effective cross-calibration for both energy measurement methods. Details of the experiment and its astrophysical significance will be presented.

1 Introduction

Long duration balloon experiments like ATIC (Wefel et al., 2001; Guzik et al., 1999) can compete with satellite experiments in measuring the elemental energy spectra of high-energy cosmic rays. They have many advantages including a much smaller cost per flight and the opportunity to repeat the flight a few times. The weight of an instrument can be relatively high (up to a few metric tons), size can be relatively large (~1×1 m^2) and there will be no obstructions in the geometry factor, which may be expected at the ISS (International Space Station). These advantages may compensate for the much smaller exposure time (2-4 weeks per single flight).

The proposed instrument involves the combination of a large collecting area KLEM device (Adams et al., 2000) with an ionization calorimeter having a smaller collecting area and integrated beneath the KLEM apparatus.

The opportunity to use silicon detectors and electronics developed for the NUCLEON satellite experiment (Podorozhnyi et al., 2001) can significantly decrease R&D cost. Further cost reduction can be achieved due to a simpler internal structure of the KLEM system.

2 Scientific objectives and experimental goals

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. It is very important to accumulate more data in this energy range with elemental CR resolution.

The primary objective of the proposed long duration balloon experiment is to measure the elemental energy spectra of high-energy cosmic rays in the region up to 10^{15} eV.

The Polar BEAR instrument includes a large collecting area (≈1×1 m^2) KLEM device combined with a smaller area (≈0.5×0.5 m^2) ionization calorimeter, which is integrated beneath the final detector layer of the KLEM device. The important advantages of this combination are:

- The KLEM device with 1.0 m^2 collecting area provides a large aperture (> 2 m^2 sr). Thus, with a long duration balloon flight (2-4 weeks), an excellent exposure factor can be achieved.
- The ionization calorimeter measures the primary particle energy for about 10% of the events, which have already been detected by the KLEM device. This allows calibration of the KLEM device by the widely used calorimeter method.
- The flight will provide verification and field testing of a 1.0 m^2 KLEM device for use as a basic module for the future super-large aperture (4-6 m^2 collecting area) modular satellite instrument, which allow

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investigations to be conducted in a very wide energy range from 10^{11} eV/particle up to and beyond 10^{16} eV/particle.

3 Technical description

The schematic layout of the Polar BEAR device is given in Fig. 1.

SD1 is a silicon pad detector layer with completely overlapping pads. About 1 cm^2 size pads allow a primary particle position determination with an accuracy of about 3 mm and the measurement of primary particle charge. Another task is to distinguish a primary particle from backscatter particles. CR-1 16-channel VLSI chips can be used to readout the SD1 pads. This chip (Adams et al., 1999) has been developed for the ATIC and PAMELA experiments. Its main advantage is high dynamic range (up to 2500 mips), which allows a primary particle charge up to Z=30 or even more to be measured. The chip and similar silicon pad structures have been successfully used during the first ATIC two-week flight in Antarctica in 2000-2001.

Comparing the Polar BEAR structure with the KLEM device in the NUCLEON mission (Bashindzhagyan et al., 2001) one can see that two layers of microstrip detectors under the pad layer have been removed. It is assumed that 3 mm space resolution obtained with pads is still acceptable but saving 2 m^2 of silicon will dramatically decrease the total cost of the KLEM system.

The gap (about 15 cm) between the target and the detecting plane SD2 is to get secondaries separated after an interaction in the target. The size of a spot created by secondaries in SD2 has to be large enough to determine the shape of their distribution around the primary particle trajectory.

Four layers of carbon target T1-T4 (each is 2 cm thick) interleaved with four layers of scintillator strips SC1-SC4. Scintillator layers are intended to determine where in the target the interaction occurred and to generate a first level trigger. Knowledge of the interaction point in the Z direction helps to achieve better energy resolution in the KLEM system. Each scintillator strip is 1 m long, about 1.6 cm wide and 0.5 cm thick. It helps to determine primary particle trajectory detecting secondary particle jet in X and Y directions after an interaction in the target. It is assumed that scintillator strips are relatively cheap and will be read out with a 64-channel HAMAMATSU photomultiplier tube (one PMT per layer). Therefore dividing the target into four

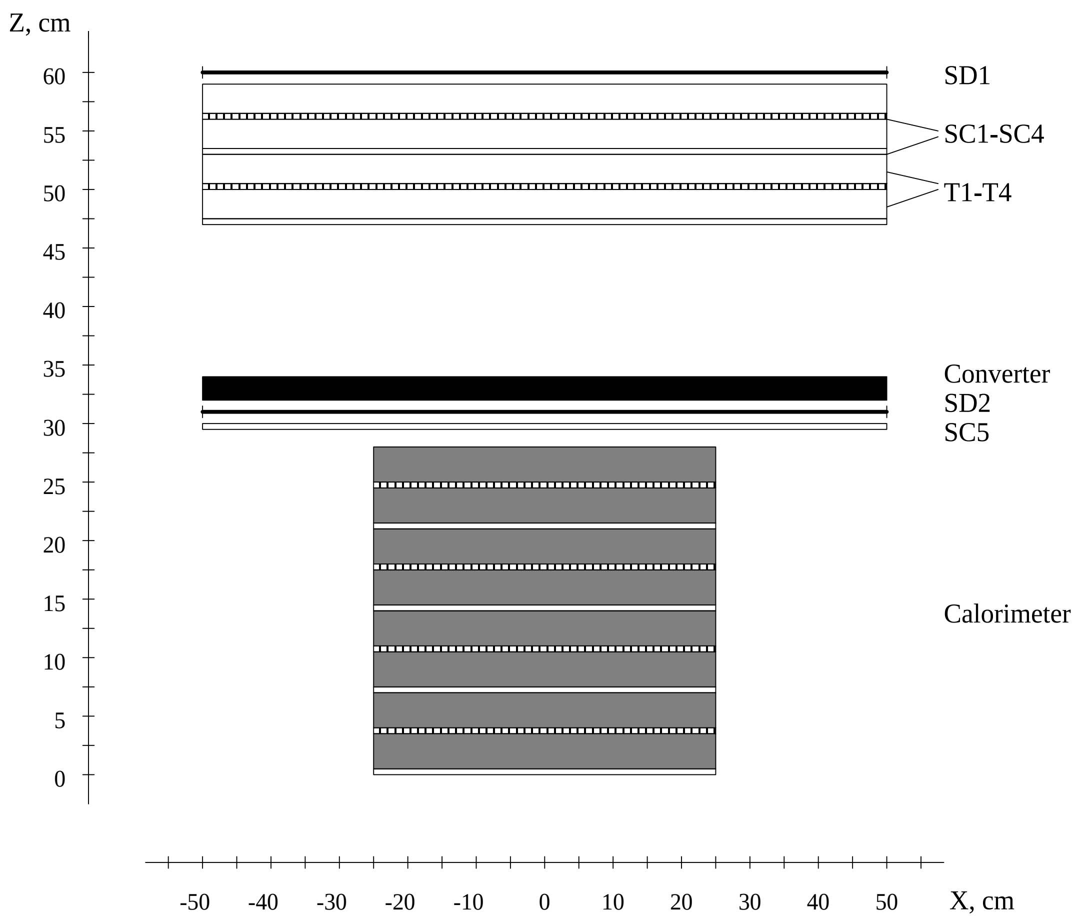

Fig. 1. The schematic layout of the Polar BEAR device.

layers can improve the system without significantly increasing the cost.

A tungsten 3-4 X_0 (10-14 mm) thick gamma-ray converter allows registration of π^0 generated in the target in addition to π^+ and π^-. It considerably increases the total number of secondaries and improves energy resolution. This hard rigid converter is planned to be either solid 1 m^2 tungsten plate or 1 m long tungsten bars and should be an important part of the mechanical structure, which supports the whole KLEM system.

Under the converter there is one layer of silicon microstrip detectors SD2 (in Fig. 1 strips are parallel to the *Y* axis). This is the main part of the KLEM system. Its purpose is to determine:

- The *X*-coordinate of primary particle trajectory.
- The secondary particle distribution along the *X*-axis near the primary particle trajectory. The number of secondaries registered by every strip in this area is used for energy measuring by the KLEM method.
- An average angle in the *XZ* plane for the secondaries. Angular information is important to recalculate the energy deposition in silicon into a number of secondaries.
- It also may be used as a part of the calorimeter.

The SD2 layer consists of 400 silicon microstrip detectors about 6×6 cm^2 each. Strip pitch is about 50 μm. Ten detectors are placed on one 50 cm long Mother Board (MB) with complete overlapping. All the detectors on one MB are wire bonded creating 1024 strips. Each strip is 50 cm long and connected to individual readout channels on the end of the MB. A total of 40 MBs are slid into the supporting structure from two opposite sides. Neighbor MBs overlap each other so the SD2 layer has no leak, as was the case with SD1. As a first approach it is intended to use VA32 hdr2 type electronic chips with the highest available dynamic range.

One can see that for Polar BEAR only one layer of strips is planned instead of the two proposed for the NUCLEON mission. It certainly will decrease energy resolution about 1.2 - 1.3 times. The only reason is cost reduction. It should be remembered that two layers in NUCLEON is only 1/4 of one Polar BEAR layer.

Scintillator strip layer SC5 consists of 128 strips, which are parallel to the *X* direction. Each strip is 0.8 cm wide, 0.5 cm thick and 1m long. They are read out by two 64-channel HAMAMATSU PMTs.

SC5 tasks are:

- To determine the position of the secondary particle spot in the *Y* direction.
- To determine an average angle in the *YZ* plane.
- To generate the first level trigger for KLEM together with SC1-SC4.

A calorimeter of 50×50×28 cm^3 approximate size can be build with eight 3 cm thick iron absorber layers followed by 8 layers of scintillator strips. It is supposed that one of the already existed calorimeters can be used.

4 Summary

The proposed Polar BEAR experiment could make a major contribution to the accumulation of data concerning the elemental energy spectra of high-energy cosmic rays. Furthermore it could be a significant step towards the future super large aperture satellite instrument, which would allow investigations to be conducted over a very wide energy range, up to and through the “knee” region.

Owing to the comparatively simple structure and low total cost of the instrument the Polar BEAR flight could be successfully implemented during 2004-2005.

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