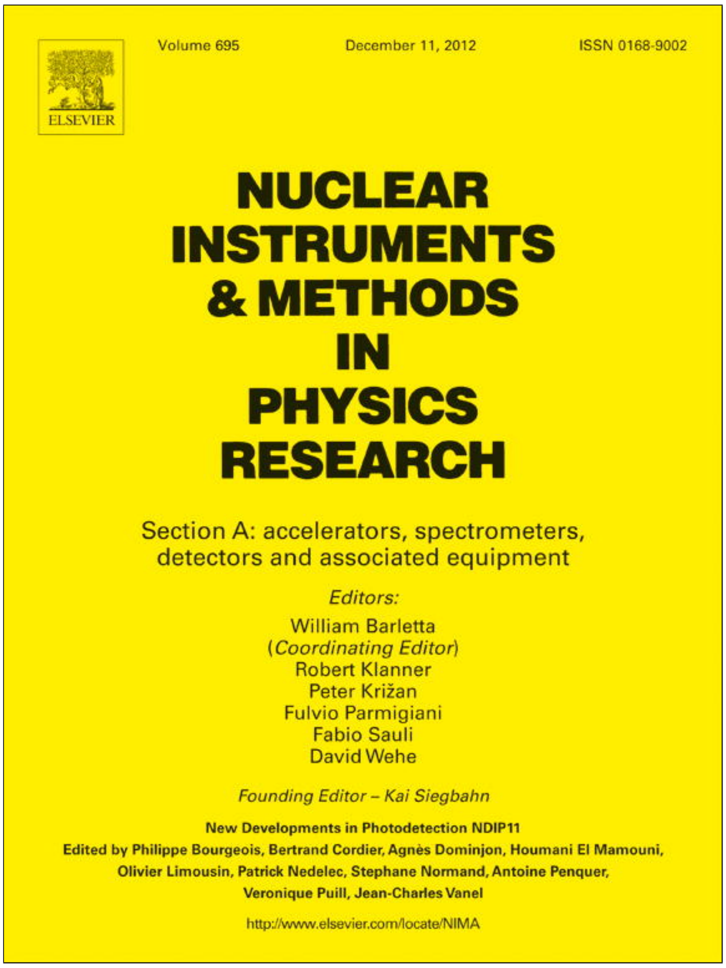
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The PERDaix detector

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ABSTRACT

The PERDaix (Proton Electron Radiation Detector Aix-la-Chapelle) detector is designed to measure charged particles in cosmic rays. It can distinguish particle species up to 5 GV rigidity. PERDaix was flown on the BEXUS-11 balloon on 23rd November 2010.

The detector has the dimensions of $246 \times 400 \times 859$ mm^3, a geometrical acceptance of 32 cm^{2}sr, a low weight of 40 kg and a low power consumption of 60 W. The spectrometer consists of a time-of-flight system, a scintillating fiber tracking detector, a permanent magnet and a transition radiation detector. Silicon photomultipliers are used as photodetectors in the time-of-flight and the tracker system.

1. Introduction

The Proton Electron Radiation Detector Aix-la-Chapelle (PERDaix) presented in this paper was designed, built, tested and conducted by undergraduate and graduate students supported by the Physics AC-Ib department of RWTH Aachen University. The students applied for a balloon flight within the scope of the BEXUS (Balloon-borne Experiments for University Students) programme in late 2009. BEXUS is an outreach programme of the Swedish National Space Board (SNSB) and the German Aerospace Center (DLR) for university students offering flights with balloons which are launched from ESRANGE, Kiruna, Sweden. The balloons have a volume of up to 100.000 m^3, can carry scientific payloads up to 117 kg to altitudes up to 35 km and achieve flight durations up to 5 h.

The goal of PERDaix was to test new detector technologies under stratospheric conditions for future balloon experiments and besides this to measure the fluxes of cosmic protons, electrons and helium in the rigidity range between 0.5 GV and 5 GV [1,2].

The experiment was accepted and approved in early 2010 and launched with the BEXUS-11 balloon flight on 23rd November 2010. The detector measured 177,000 charged particles during the 1.5 h long float phase at 33.4 km altitude.

2. The PERDaix detector

The PERDaix detector consists of a time-of-flight system, a scintillating fiber tracking detector, a permanent magnet and a transition radiation detector (Fig. 1). Due to the limited lifting capacity of the BEXUS-11 balloon and the geometrical dimensions of the gondola, the detector has the dimensions of $246 \times 400 \times 859$ mm^3, a geometrical acceptance of 32 cm^2 sr, a low weight of 40 kg and a low power consumption of 60 W which are provided by battery packs. PERDaix was designed to run on batteries for about 8 h with respect to a maximum flight duration of up to 5 h. The detector components have to withstand temperature changes from $+30\,^{\circ}$C to $-55\,^{\circ}$C and a landing with a 20*g* acceleration. Parts of the detector which use high voltages like the transition radiation detector need to be secured against Corona discharges due to an outside pressure of ≈ 5 mbar during the float phase.

The time-of-flight (ToF) system provides the trigger, measures the velocity β of charged particles and distinguishes downward from upward (Albedo) flying particles. The ToF has a modular design. It consists of four modules, two at the top and two at the bottom of the detector (Fig. 1). Each module has four $6 \times 50 \times 395$ mm^3 scintillator bars (Bicron BC-408) which are arranged in a two by two matrix (Fig. 2). The scintillation light of each bar is detected on both sides by two silicon photomultipliers (SiPM) of type Hamamatsu MPPC S10362-33-100C. The MPPCs have a photon detection efficiency (PDE) of 34% at the wavelength of the maximum of the scintillation light emission of $\lambda_{max} = 430$ nm, a crosstalk probability of 17%, a dark count rate of 12 MHz and a breakdown voltage of ≈ 70 V [3]. The temperature dependence of the breakdown voltage is $0.056(V/K)$. The operation voltage is set for each MPPC individually via DACs (Digital to Analog Converter). Eight MPPCs are mounted on the optical hybrid (HPO board, Fig. 3). The SiPM signals are feed into NINO discriminator chips [4] followed by a HPTDC based digitizing board (MTDC-64 [5]).

The spectrometer consists of a permanent magnet ($B = 0.2$ T) and a scintillating fiber tracker. It measures the track position on

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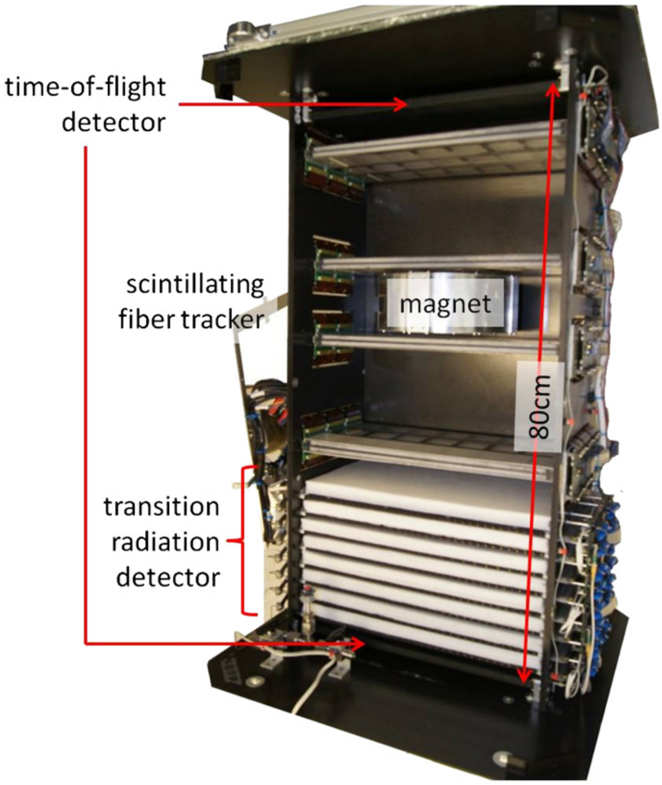

Fig. 1. PERDaix detector.

eight points in four double layers. Each double layer consists of a top and bottom part made of 64 mm wide, 400 mm long and 6 mm thick carbon fiber supported Rohacell foam structures which are glued together and tilted to each other by a relative stereo angle of 1° (Fig. 4). Two ribbons made out of five layers of two hundred fifty-six 250 μm thin scintillating fibers (Kuraray SCSF-78MJ) are glued on each side of a module. The scintillation peak emission wavelength λ_{max} of 450 nm matches the peak sensitivity of the Hamamatsu silicon photomultiplier arrays MPPC 5883 which are used for the readout. The MPPC 5883 arrays have an active area of $8.0 \times 1\ \text{mm}^2$ segmented into 32 individual SiPMs with 80 pixels each. The channels have a readout pitch of 250 μm, matching the fiber diameter. At an overvoltage of 2 V the MPPCs have a photon detection efficiency of 44% at λ_{max}, a crosstalk probability of 23%, a dark count rate of 200 kHz per channel and breakdown voltage of 70 V [6,7]. The temperature dependence of the breakdown voltage is $0.066(V/K)$. A passive compensation circuit using thermistors regulates the operation voltage in dependence of the temperature variations. The same one is used in the ToF-system. Groups of 32 fiber columns are read out by an SiPM array at alternating ends of the module. Two optical hybrids are mounted on each module. Each hybrid holds four MPPC 5883 arrays interleaved with four mirrors. The MPPC arrays are read out with VA-32/75 chips.

A single point resolution of 50 μm was achieved with these scintillating fiber modules in testbeam measurements [6,7]. The particle momentum is measured via the bending angle of the trajectory caused by the permanent magnet with a resolution of $\sigma_p/p = 0.08 \cdot p/\text{GeV} \oplus 0.25/\beta$.

The transition radiation detector (TRD) is based on the design and built out of spare parts of the AMS-02 TRD [8]. Highly relativistic particles with a Lorentz factor $\gamma \geq 500$ produce transition radiation (TR) by passing through the 20 mm fleece material with its multiple irregular boundary crossings. The TR-photons are detected in proportional mode modules filled with a Xe/CO_2

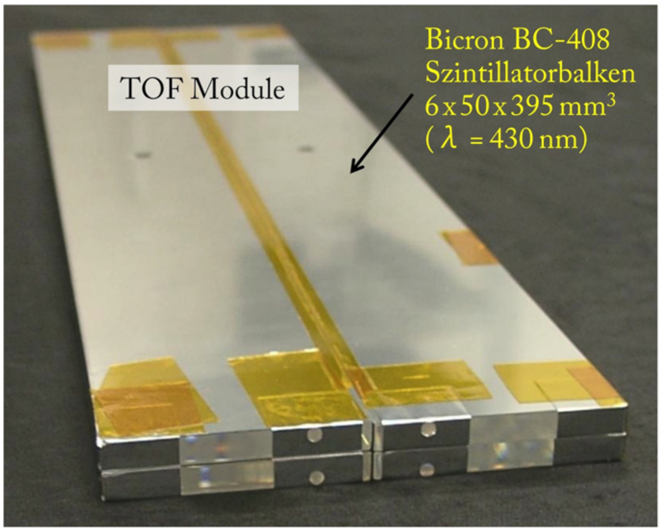

Fig. 2. PERDaix ToF-Module.

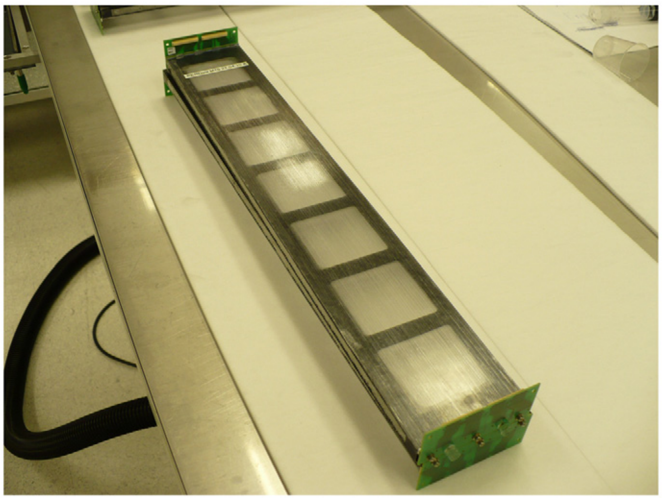

Fig. 4. PERDaix scintillating fiber tracker module.

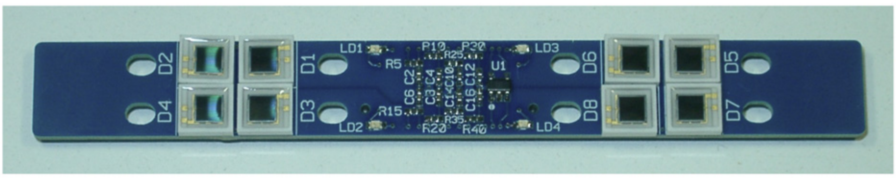

Fig. 3. PERDaix ToF optical hybrid (HPO-board) with eight MPPCs S10362-33-100C.

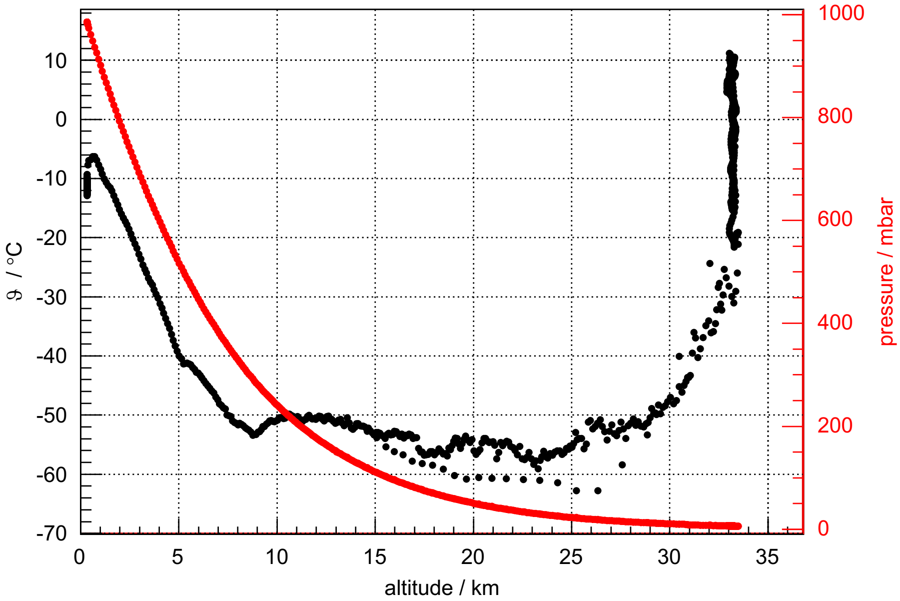

Fig. 5. Temperature and pressure as a function of the altitude for the BEXUS-11 balloon flight from Kiruna in November 2010.

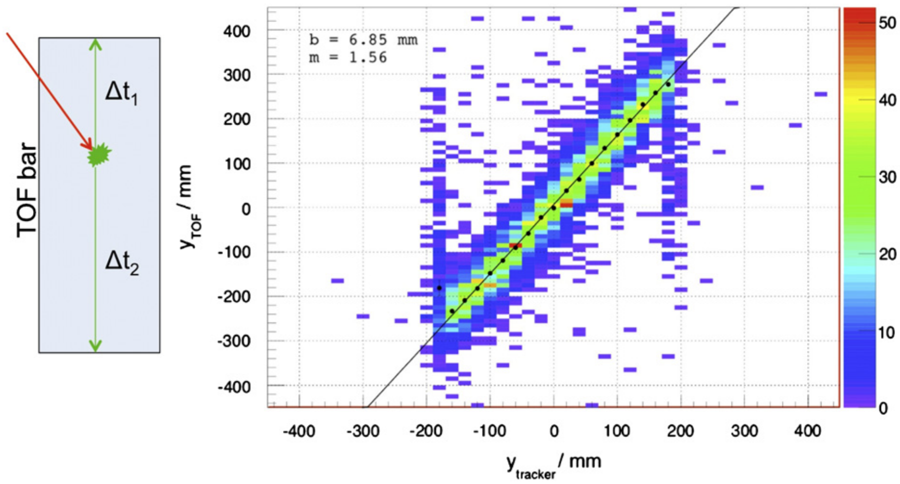

Fig. 6. Correlation between *y*-coordinate measured by PERDaix ToF-system and scintillating fiber tracker.

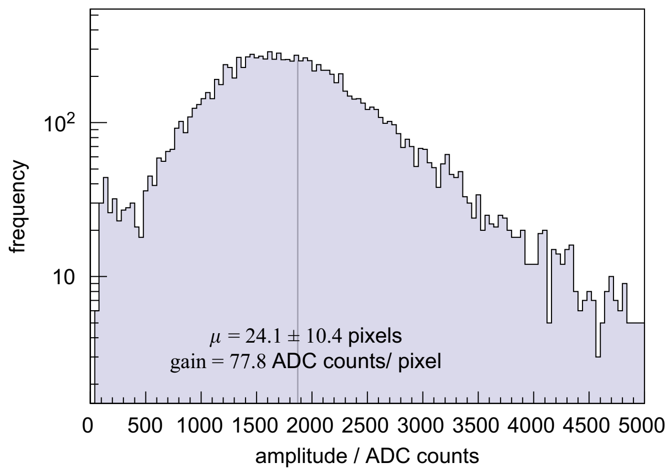

Fig. 7. Measured signal of one SiPM MPPC 5883 array on a track of a minimum ionizing particle passing the corresponding scintillating fibers.

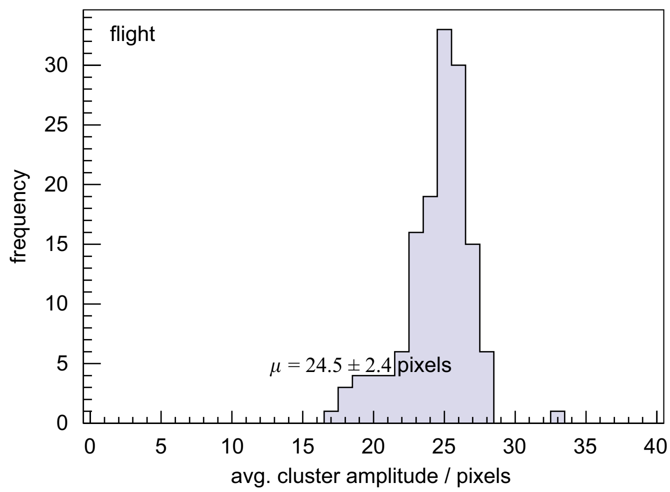

Fig. 8. Measured averaged signals of all MPPC 5883 arrays of the scintillating fiber tracker on tracks of minimum ionizing particles passing the scintillating fibers.

gas mixture (80%/20% at 1.1 bar), each module consisting of 16 straw tubes which are made out of a 72 μm thin double-layer kapton-aluminium foil with a diameter of 6 mm and a length of 400 mm. A 30 μm gold-plated tungsten wire tensioned in the tubes serves as anode operated at 1.5 kV. The TRD consists of eight layers of 20 mm fleece and straw tube modules (Fig. 1) to discriminate electrons which produce TR-photons from protons not producing them.

3. PERDaix performance

The experiment was launched with the BEXUS-11 balloon flight from ESRANGE, Kiruna in Sweden on 23rd November 2010. In point of view of a technical feasibility study the detector withstood successfully the harsh environment during launch and float phase (Fig. 5) and was fully functional even after a landing with a 20g acceleration. The detector measured 177,000 charged particles during the 1.5 h long float phase at 33.4 km altitude.

The time-of-flight for a particle going upward or downward through the PERDaix detector is 2.7 ns. The ToF-system measured it with a resolution of 390 ps. The trigger rate of 1 Hz on ground increased to 35 Hz during float phase. The y-coordinate determined with the ToF-system by a measurement of the difference in photon travel time to each side of the scintillation bar is in good agreement to the measurement of the scintillating fiber tracker (Fig. 6). The measured light yield on a track of a minimum ionizing particle passing through the scintillating fiber ribbon of

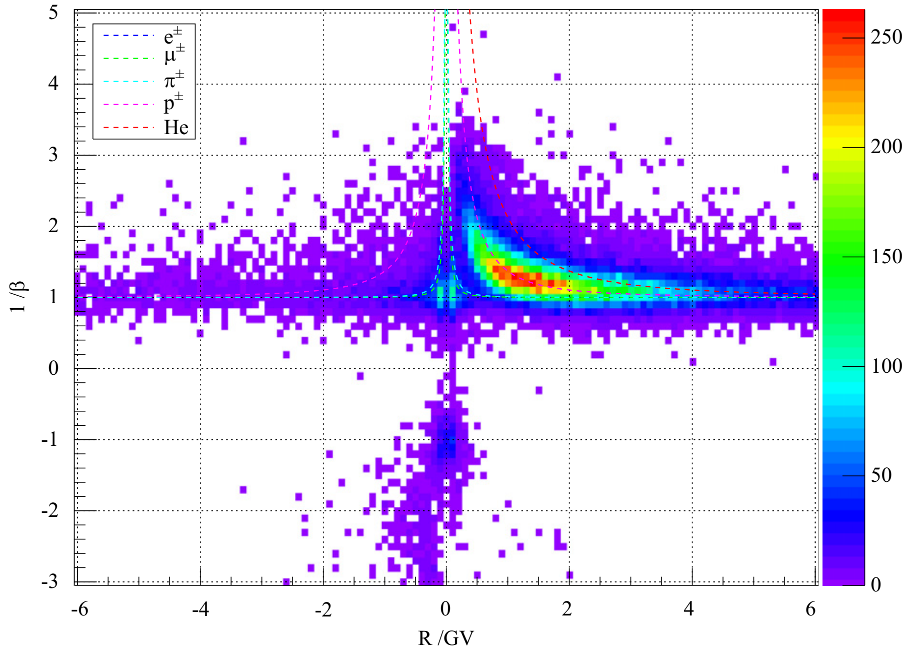

Fig. 9. Correlation between reconstructed inverse velocity $1/\beta$ and reconstructed rigidity R during float phase.

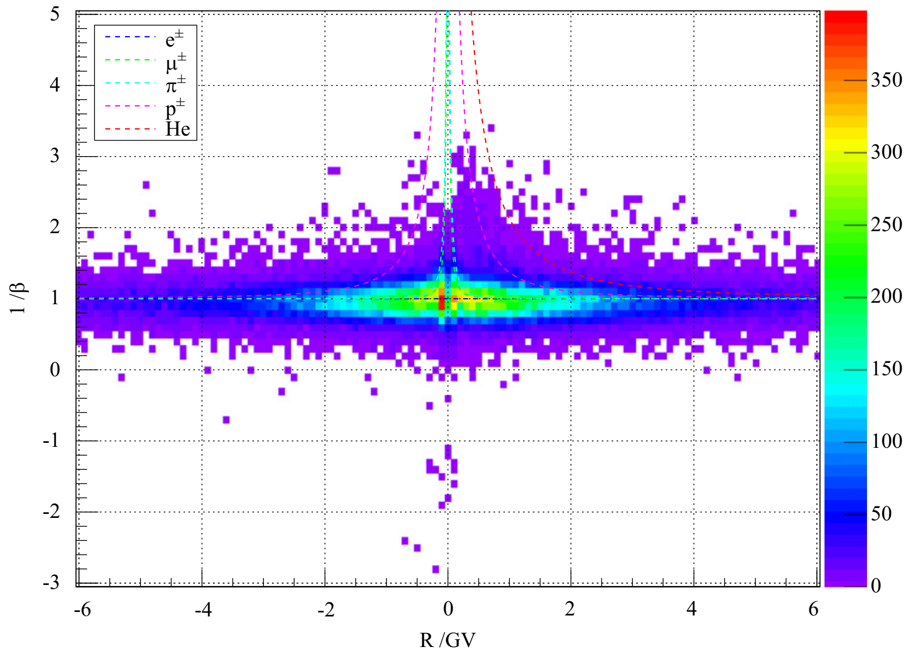

Fig. 10. Correlation between reconstructed inverse velocity $1/\beta$ and reconstructed rigidity R on ground.

the tracker modules during the float phase was around 16–20 photons resulting in a signal-to-noise ratio for all 160 MPPC 5883 arrays of 60 (Figs. 7 and 8).

The correlation between reconstructed inverse velocity β^{-1} and reconstructed rigidity R for the float phase and ground data is shown in Figs. 9 and 10. During flight mostly protons (89% of cosmic ray particles are protons) are reconstructed while on ground mostly muons. 2.1 % of the measured particles during float phase are Albedo particles.

The PERDaix flight data analysis is still ongoing. For the separation of proton from Helium events the time over threshold information of the ToF system will be used. To determine the electron spectrum, the background of protons with misidentified charge-sign need to be suppressed by using the measurements of the TRD and the ToF system. Therefore, also calibration measurements of the detector have been performed in a beam test at the T9 beamline of the CERN Proton Synchrotron (PS) facility. The results still need to be included in the flight data analysis.

4. Conclusion

The PERDaix detector was a successful first application of a scintillating fiber tracker and a time-of-flight system with silicon photomultiplier readout in the harsh environment of the stratosphere. This novel technology can therefore be used in upcoming cosmic ray balloon experiments like PEBS [9]. The ToF-system triggered 177,000 charged particles and the measured time-of-flight resolution was 390 ps. The spectrometer using 250 μm thin scintillating fibers readout with silicon photomultipliers achieved a spatial resolution of 50 μm and a light yield of 16–20 photons per minimum ionizing particle during the float phase. The physics goal to determine the cosmic proton and electron spectra together with the solar modulation parameter will be achieved with further analysis of the flight data and testbeam data.

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