MEDIPIX COSMIC RAY TRACKING DEVICE ON BEXUS-7 STRATOSPHERIC BALLOON FLIGHT

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ABSTRACT

The first experiment using a MEDIPIX detector for cosmic ray tracking in stratospheric environment is presented. The detector was used in its tracking mode allowing it to operate as an „active nuclear emulsion“. The actual flight time was over 4 hours, with 2 hours at stable floating altitude of 26km. Experiment was under full remote control and monitoring by custom control hardware built for this purpose. Thousands of cosmic ray tracks were acquired in the stratospheric radiation environment, analyses ongoing. Experiment operated flawlessly, overall performance is evaluated for further design implications

1. INTRODUCTION

This paper describes the performance and reliability of MEDIPIX detector during stratospheric balloon flight. The detecting device is based on hybrid pixel detector of Medipix2-type [1] developed at CERN with USB interface [2] developed at Institute of Experimental and Applied Physics of Czech Technical University in Prague (IEAP CTU in Prague)
The actual flight campaign took place on 8th Oct 2008 from Swedish Space Corporation (SSC) commercial spaceport ESRANGE nearby Kiruna in Sweden. The flight opportunity on BEXUS7 (Balloon EXperiment for University Students) stratospheric balloon project was provided by Education dept. of European Space Agency and Eurolaunch (Collaboration of SSC and DLR).

Whole concept served as original testbed for feasibility study of extended stratospheric flight demonstration of Medipix detectors in near-space environment. Control hardware was custom designed, based on PC/104 platform. The robustness of the design allowed it to operate flawlessly as was expected from the previous extensive vacuum testing.

The scientific motivation was to check height-dependent profiles of ionizing radiation. BEXUS is quite ideal platform for such in-situ measurements. Not only because of the high altitudes reached, but also due to its slow ascent velocity for statistically relevant sampling of the ambient environment.

2. EXPERIMENT DESIGN

2.1. *Conceptual overview*

The Medipix2.1 #48 particle detector with USB interface ver.1.1 (MEDIPIX) is controlled by a single-board embedded PC/ (Fig. 1). Embedded PC has a solid state CompactFlash hard drive (CF2) and additional USB flash disk as on-board backup storage. The computer has an Ethernet connection via radiolink of the BEXUS balloon platform (E-link) to the ground station PC. This wireless connection allows full on-line data monitoring and control. The experiment is powered from primary battery cells. Complete experiment requires only single 5V source that is provided by custom built switching power supply. Experiment included also additional attitude determining hardware (camera with polarizer) as will be discussed later in data analysis section. Total experiment power consumption is very low, approximately 10W.

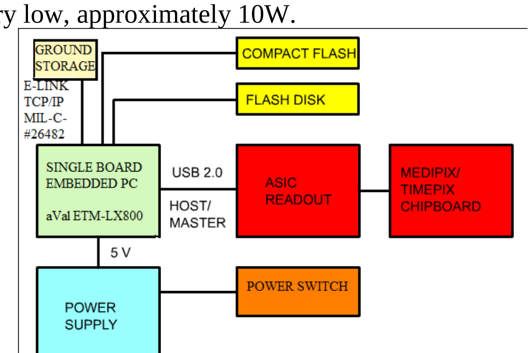

Fig. 1 – Experiment block layout

Detector control and acquisitions (suitable for further cluster analyses using particle track pattern recognition [3]) were handled by used Pixelman software control package [4].

The high level of development of MEDIPIX USB

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readout interface, supported by advanced Pixelman control software, made it possible to realize this task just as student project, being financed solely by own resources below 1000EUR.

2.2. *Testing of Electronics*

The experiment is not pressurized. That design was possible after testing all the electronic subcomponents for the environmental conditions applicable, checking and proving its ability to work in harsh stratospheric environment. Therefore all critical electronics (Fig. 3) was thermally balanced by connecting it to big aluminum passive heat capacitors by thermopaste for proper heat transport and distribution. All subsystems were tested in applicable vacuum conditions (5Pa) for over 3 hours and at -35°C for over 6h running from batteries. All these tests were successful and the experimental design was proven stable.

2.3. *Mechanical Structure*

The experiment is composed of two main boxes (Fig.3), which were mounted together for the flight campaign (Fig.4). To provide the experiment with outer thermally insulating and protective structure, Styrofoam insulation blocks (Fig.4).

The first, aluminum box (Fig. 3: left), contains industrial PC, all electronics and batteries. One side served as the attachment point for thermally modified industrial PC and also high-power diode and transistors, all mounted on additional heat sinks to maintain thermal balance.

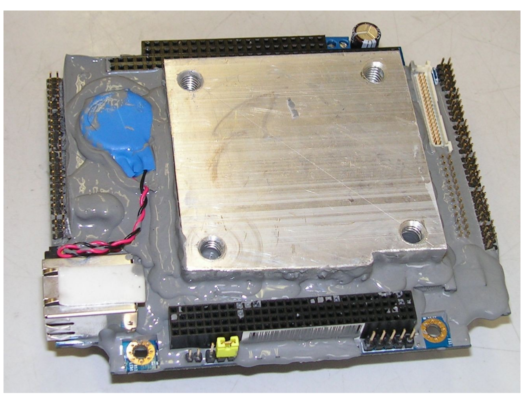

Fig. 2 – Custom thermal modification of PC/104

The other side carries boards with CF2 main system drive unit, custom built power supply PCB and also extension interface USB board with 2 additional USB2.0 ports. These internal USBs are the primary robust interfaces, serving for the essential connection of MEDIPIX detector and redundant SD memory.

Front panel provides access to important interfaces for operating experiment directly as a PC station (Fig. 3), without need to do that remotely through E-link, as was the case of the actual flight campaign. Located there are 2 USB2.0 ports, Video-out, Ethernet and also arm plug with status LED. Experiment can run from the external power source (15~30VDC), or from internal battery pack. Battery pack was mounted on the main box nearby computer heat sink, to maintain proper thermal operating conditions during the flight campaign.

Inside the second small plastic box (Fig. 3: right) is MEDIPIX detector. The MEDIPIX detector is placed there vertically relative to ground and is looking outside the balloon gondola with unobstructed field of view approx. 1π sr. MEDIPIX detector unit was placed into non-metallic box to stress also the actual low energetic environmental effects not hidden by conductive case. That also because of the main design goal was to keep as low as possible attenuation and scattering caused by any material surrounding the detector.

2.4. *Experiment structure attenuation simulations*

To check proper design of the experimental box, enclosing MEDIPIX detector, CERN package Geant4 was used for the simulation of the particle passage through dead and active material of the experiment. Considering the preliminary attenuating configuration of material nearby the detector, simulations with test material properties (3mm PE, 3cm PS) have been undertaken. That determined:

- levels of loss of the particle energy in dead material
- shape of the particle traces in the detector
- fraction of misidentified particles (background)

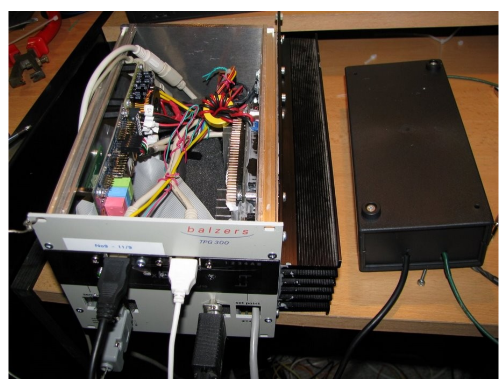

Fig. 3 – Rack with electronics (left), MEDIPIX box (right)

2.4.1 *Simulations for photons*

Photons are absorbed or reflected by box wall (Fig. 5 - 8). At 20 keV, 80% photons will pass through. Threshold on collected charge is applied on every pixel for correction of specific deposited charge effect of e-h pair creation (3.65 eV).

2.4.2. *Simulations for electrons*

Most important difference is that electrons loose much more energy than photons since they have a charge. From this reason about 50% electrons of 2 MeV will be absorbed in the wall as the simulations demonstrate (Fig. 9 - 11). On the other hand, PE box enclosing the main detector enables registration of electrons in the MeV range, while converting them to lower energies they more efficiently leave charge passing the detector. Overall charge deposited by electrons in the sensor is more than 10 times larger compared to photons. These studies made for Medipix2 detector (provided in configuration with 700µm Si chip) inside custom-built case confirmed that it can be used well as a tracking detector for detecting particles above specified energy ranges.

2.5. *Particle identification*

Different particles create distinctive patterns in the detector which can be used for their proper identification. For resolving their energy, backplane pulse amplitude provides information about charge deposited in the whole detector which can be used for determination of deposited energy.

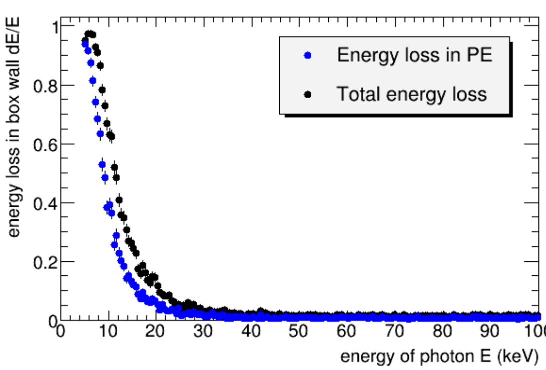

Fig. 5 – Overall energy losses due to Compton scattering

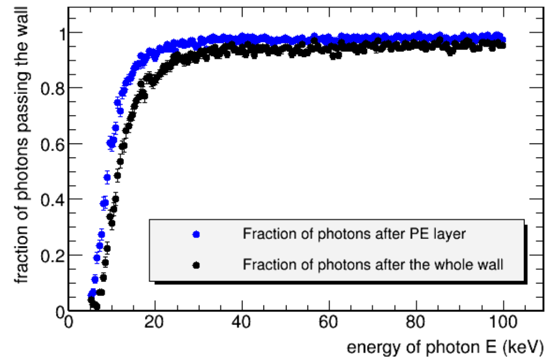

Fig. 6 – Fractions of photons passing test box layers

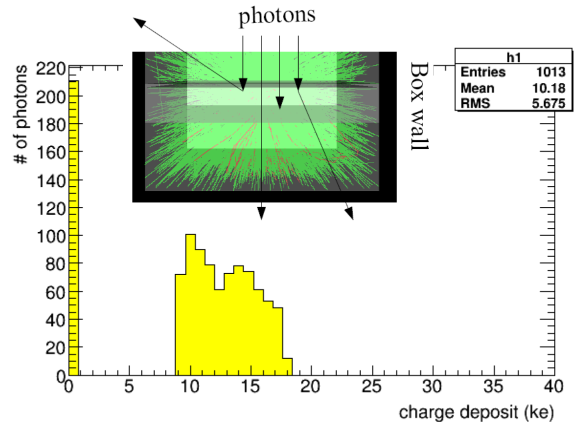

Fig.7 – Mean deposited charge in Si wafer by photons

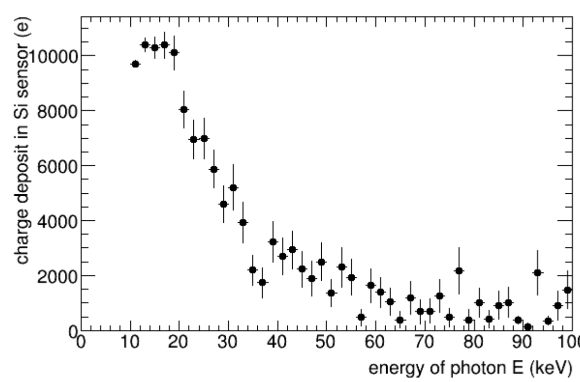

Fig.8 – Deposited charge for photons 10keV<*E*<20keV

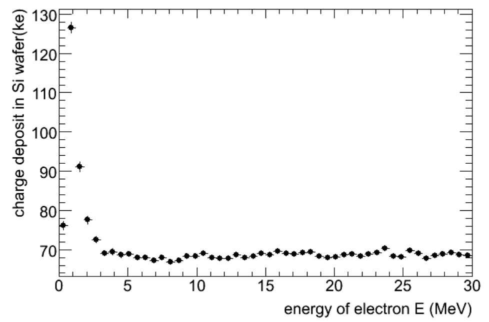

Fig. 9 – Mean deposited charge in Si wafer by electrons

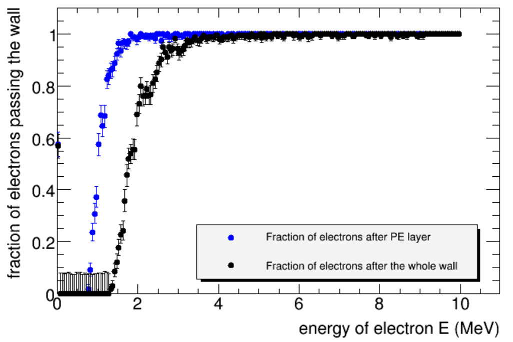

Fig.10 – Resp. fraction of electrons passing the box wall

Monte Carlo software package such as CERN Geant4 simulation can be used to model particles passage through active and dead material. Comparison of measured data and the simulation helps to better identify particles. Therefore improvement in comparison with standard approaches using scintillator intrumentation is that the specific tracks recorded can be associated to distinctive particle types using advanced software techniques.

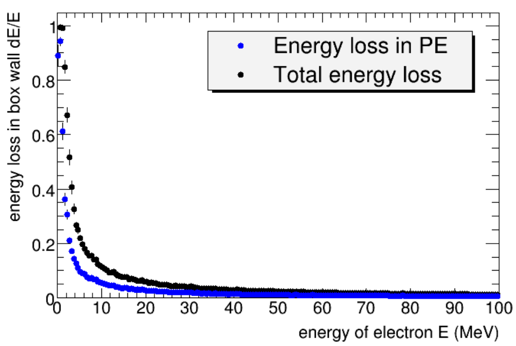

Fig.11 – Energy loss of electrons passing the box wall

The detailed principle of particle recognition and also fully automated method to evaluate these data is readily available and described in [3]. For getting the basic idea its concept is sketchy illustrated here (Fig. 12 - 14).

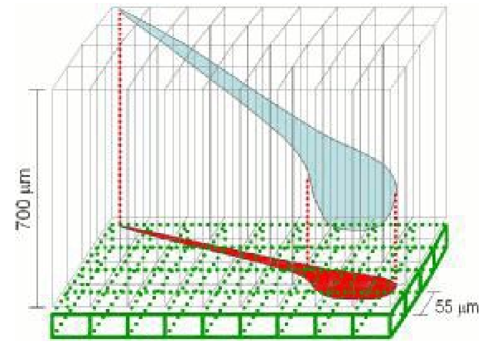

Fig. 13 – Projection of deposited charge, identified as specific particle types (courtesy of C. Granja, IEAP CTU)

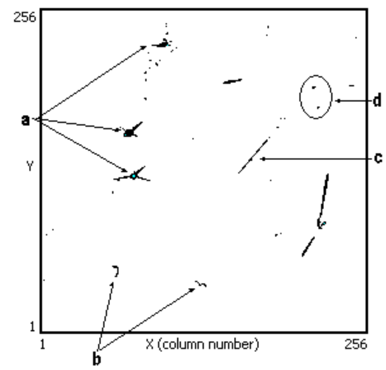

Fig. 14 – Particle pattern identification-by-track concept, a- Heavy charged particles, b- Slow light charged particles, c- Fast light charged particles, d- X-rays, low energy gamma

3. Design Performance in Ambient Environment

Thermal design was successful. Temperature of industrial computer electronics was kept by 15 ÷ 37°C, while outside ambient temperature dropped from 5°C at ground level to lowest -60°C during the flight (Fig.17). In stratosphere, mean ambient temperature was -30°C (stand. atmospheric physics).

Flown Medipix2 detector (in config. with 700µm Si wafer) provided 4436 of 5-second acquisitions. Recording started 50min before take-off and continued 2 hours after landing, making our ground level calibration data sufficient. Therefore the final dataset constitutes of over 7 hours of track images acquired with *fixed* threshold.

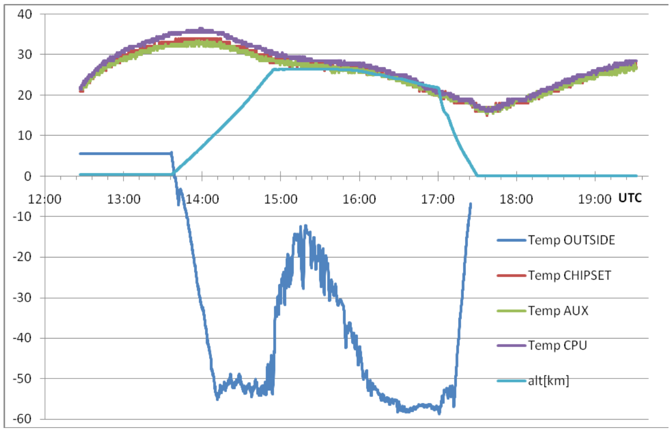

Fig. 17 – Ind. PCs' and ambient temp. along the flight profile

While this threshold was set quite low, 11 (noisy) pixels were masked during whole flight to ensure acquisitions at the highest sensitivity (lowest threshold), while maintaining noise-free data. Energetic calibrations have been done extensively previously and are underway for the actual flight setup. But the main configuration mistake introduced very low bias voltage, meaning that the detector was not set optimally after all, with too low sensitivity, mostly for slow light charged particles. The setup used (Medipix USB interface 1.1. on industrial PC) introduced mean 350ms read-out delay in acquisitions, corresponding to overall detector 90% live time. Medipix USB interface 2.0 is readily available, can be used if required.

4. Data Analysis

Primary goal of the experiment was recording height dependent profiles of ionizing radiation environment travelled. That with additional possible distinction of various particle types which impinged MEDIPIX detector used.

The statistical comparisons and various sanity-checks of effects expected will be done by comparing with classical theory of cosmic ray atmospheric profiles (analytical transport equations) and primarily with numerical CORSIKA [5] Monte Carlo propagation simulations.

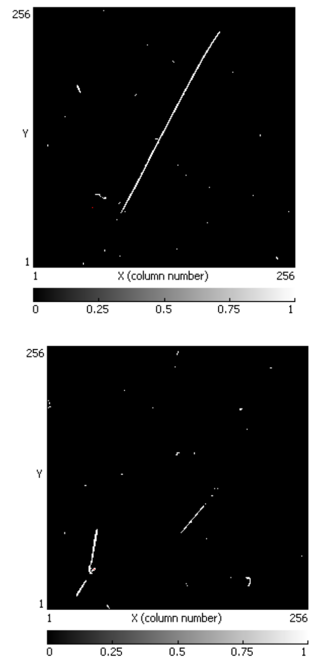

Fig. 18 – Ionizing radiation tracks acquired in stratosphere

Developed analysis scripts are already done and useful for making calculations for conditions, where the actual experiment took place. As one sanity-check, confirming data consistency (Fig. 19), any rise of detected particles cannot be seen during first 5 km of ascent, but followed by huge amplification traversing 5-15km, reaching maximum values already at about 15km of altitude.

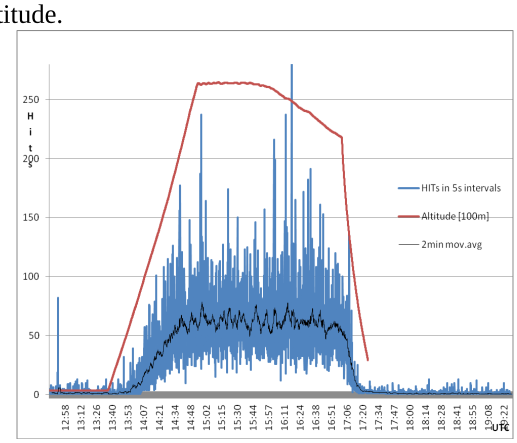

Fig. 19 – Detector pixel hit (5s) counts along flight profile

Along with altitude, we have to consider that the experiment took place in arctic stratosphere, associated with high-geomagnetic latitude, corresponding to geomagnetic cutoff rigidity of 280 MV. That, along with ongoing solar minima, provided measurements of relatively high GCR flux.

Further analyses need to assume time-independent fluxes of cosmic rays, otherwise requires to correlate with other data. All stable geomagnetic indexes, spaceweather data (Fig.21) and geografically close Oulu NM readings (Fig.22) (with similar geomag. cut-off rigidity) prove this assumption right.

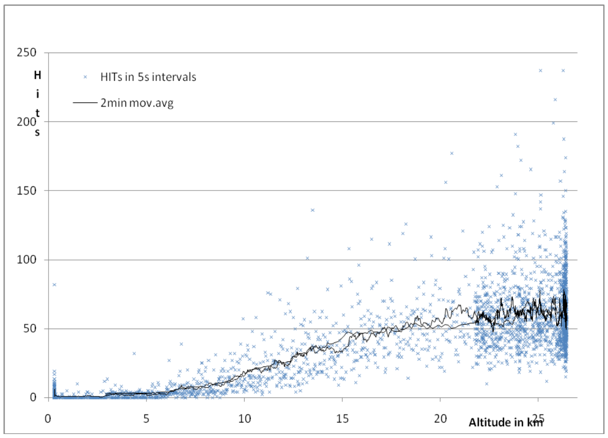

Fig. 20 – Detector pixel hit (5s) counts at respective altitudes

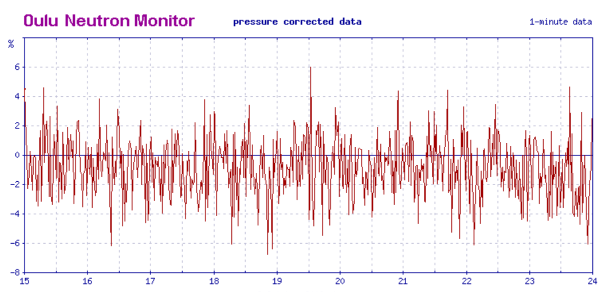

Fig. 22 – Oulu NM detector counts

Assuming statistically stable flux of CRs, further analyses of data from the floating altitude can be done with detector having well-defined FOV of unattenuated radiation (1π sr) in comparison with that interacting with experiment mass, coming from the rest of whole space angle (about 3π sr).

The statistical demonstration of presence of the E-W effect (low-energetic Cosmic Rays directional modulation imposed by Earth's magnetosphere) discernible from just statistical fluctuation noise, (small for low-energetic CRs) is feasible.

On the timescale of gondola oscillations around vertical axis (~4 minutes, 2π angle) there is high coincidence of this harmonic period with modulation of hits. Prelim. findings to be confirmed by correlating with magnetometer data. Further analysis details are not in scope of this instrumentation paper.

5. Conclusion

Medipix2 detector with USB readout interface developed at IEAP CTU in Prague was tested during the BEXUS 7 stratospheric balloon flight, using control computer custom built for this purpose based on PC/104 platform. The robustness of whole design allowed it to operate flawlessly and with low power consumption. This compact control hardware can be used for alternative applications. The high level of development of USB interface for Medipix, supported by Pixelman control software, allowed to realize this seemingly extensive task just as student project, also financed solely by student own resources being still below 1000EUR.

6. References

[1] X. Llopart, M. Campbell, R. Dinapoli, D. San Segundo, E. Pernigotti, "Medipix2 - a 64 k pixel readout chip with 55 mm square elements working in single photon counting mode", Proc. IEEE NSS/MIC, San Diego (2001), IEEE Trans. Nucl. Sci. 49 (2002) 2279-2283

[2] Z. Vykydal, J. Jakubek, M. Platkevic, S. Pospisil: "USB interface for Medipix2 pixel device enabling energy and position detection of heavy charged particles", NUCLEAR INSTRUMENTS AND METHODS A, VOLUME 563 (2006), NIMA 44759, 2006, pp. 112-115

[3] T. Holy, E. Heijne, J. Jakubek, S. Pospisil, J. Uher, Z. Vykydal, „Pattern recognition of tracks induced by individual quanta of ionizing radiation in Medipix2 silicon detector", Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 591, Issue 1, Radiation Imaging Detectors 2007, ISSN 0168-9002

[4] T. Holy, J. Jakubek, S. Pospisil, J. Uher, D. Vavrik, Z. Vykydal, „Data acquisition and processing software package for Medipix2", IWORID, 1 July 2006, ISSN 0168-9002