PROCEEDINGS OF SCIENCE

HVPS system for $*$ – EUSO detectors

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In the JEM-EUSO focal instrument four multianode photomultipliers (Elementary Cell unit) are powered by one high voltage generator. The HV control system for Photo Detection Module consists of 9 high voltage generators. HV generators are Cockcroft-Walton voltage multipliers with protection system and with 3 level very fast switches for HV at cathodes. Protection systems were made to protect HVPS itself against possible excess of power consumption, but might be as well used as a protection of PMTs in case of unexpected enlighting. Externally controlled switches can reduce 100 times or 10000 times the PMT collection efficiency to enlarge the PMT dynamics up to factor 10^6. The HV control unit provides galvanic insulation of HV system, and allows for input voltage in a range 15-35 V. Control unit provides interface for external voltage setting, control of switches, and emits information about the statuses of 9 HV generators.

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[*] Speaker.
[†] We dedicate this proceeding to Yoshiya Kawasaki and Jacek Karczmarczyk, who passed away in 2016.

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1. Introduction.

The JEM-EUSO Collaboration [1] (JEM - Japanese Experiment Module, EUSO - Extreme Universe Space Observatory) is developing large space detector to measure ultra high energy cosmic rays (UHECR) from space. The main goal is to build a large UV telescope with a very fast camera, pointed from the International Space Station (ISS) towards the Earth's atmosphere along nadir. The telescope will measure electromagnetic radiation in the 330-400 nm range (BG3 filter) at night and record fluorescence flashes of atmospheric N_2 molecules excited by tens of billions of extensive air shower (EAS) particles.

One "frame" of the camera takes 2.5 μs. At the same time, the telescope will have a field of view comparable to the area of Poland and a spatial resolution of about 500 m at sea level. The telescope features 3 large Fresnel lenses (never used in space before). On the focal plane multi-anode photomultipliers are used. The focal plane has a modular construction. Each module has 36 photomultipliers, each photomultiplier is 8x8 multianode (Hamamatsu R11265–M64). The signal of a single photo-electron has the width of about 5 ns.

The measurement consists of counting the signals from single photo-electrons in each of the 2304 pixels in a 2.5 μs window, i.e. at a rate of 400000 frames/sec. The specially designed ASICs allow up to 100 signals to be counted within 2.5 μs individually in each pixel (in the first versions up to 30 signals). All counts are sent to the triggering system which recognizes "interesting" cases by analysing up to the last tens of GTU records.

At the focal plane of the large satellite telescope there will be about 100 Photo Detection Modules (PDMs) – for about 230 thousand of pixels. Fresnel lenses of diameter dose to 2.5 m are planned, and the focal surface would have similar dimensions. The Telescope weight would be about 2 ton.
Several small test telescopes with one PDM have been planned before construction of the large detector.

2. $\ast$ – EUSO family detectors.

To develope, design, and test all measurement method and all subsystems required, a number of test experiments were scheduled. These experiments should prove the feasibility of measurement method, make preliminarly background measurements and the first measurements of extensive air showers (EAS) from the top of the atmosphere. Very important and very interesting scientific targets would be addressed in these measurements. They are:

1. light curve of beginning of lightnings and ionospheric discharges (TLE – Transient Luminous Events),
2. meteor observations,
3. measurements of night UV emission of the atmosphere,
4. bioluminescence of oceans,
5. man made UV light.

So far we have conducted three test experiments using one detection module, and another test experiment is almost ready:

Figure 1: EUSO-Balloon at Timmins airport before the launch

Figure 2: SPB-EUSO at final tests in Palestine TX, USA.

1. **EUSO-Balloon** (Fig.1), a flight lasting one night on August 24, 2014 from a balloon base in Timmins, Ontario, Canada. The flight was organized by the French space agency CNES, and the institute IRAP. The balloon flew at an altitude of about 38 km. The experiment weighed almost 500 kg. The main objective was to test the equipment and demonstrate the detector's ability to record a number of UV light sources travelling at the speed of light (scattered laser light from a helicopter flying in the field of view of the EUSO-Balloon detector) [2], [3];

2. **SPB-EUSO** (Fig. 2) is a balloon experiment that took place from May 26 to April 5, 2017 (SPB - Super Pressure Balloon). The experiment was adapted for several months flight (it was equipped with solar batteries, etc.). It started from the Wanaka base in New Zealand, but NASA ended a flight over the Pacific due to a balloon leakage. The purpose of the experiment was to measure EAS for the first time by observing the atmosphere "from above". Additional scientific targets were UV background measurements, including lightnings, ionospheric discharges (TLE - Transient Luminous Events) and meteors;

3. **EUSO-TA** (TA - Telescope Array, Fig.3) is a test module located in the desert of Utah, USA, near the Black Rock Mesa fluorescence detector of the large detector of the highest energy cosmic rays Telescope Array (coordinates: 39°11'18.46" N, 112°42'43.35" W). The experiment is used for testing measurements of EAS in conjunction with TA, background observations (stars, planes, meteors), tests of trigger, detector components and their firmware (terrestrial tests are much cheaper than balloon tests and they follow laboratory tests);

4. Transport of **Mini-EUSO** on ISS is scheduled from late 2017 to early 2018. The experiment has a similar detection module but a much smaller optical system. The whole device has

Figure 3: EUSO-TA in front of Black Rock Mesa detector of the Telescope Array Experiment.

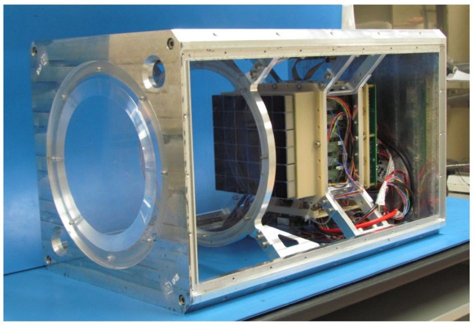

Figure 4: Mini-EUSO EM (Engineering Model) integration. Two circular Fresnel lenses are in front of the PDM (Photo Detection Module) made of 36 multi-anode photomultipliers.

dimensions of 35 cm x 35 cm x 60 cm (see photo in the Fig. 4). It will measure from inside the ISS through a special UV window (in Russian module). The scientific objective is to measure from an altitude of 400 km atmospheric UV background, including lightnings, TLE and meteors. The experiment will enable to create maps of background dependence on latitude and longitude, measure the dynamics of UV emissivity, etc. Knowlege about the UV background at satellite altitude determines the lower limit of EAS size (energy) detectivity, and a trigger algorithm.

3. High voltage power supply system requirements.

The measurement is based on single photo-electron (p-e) counting in each pixel within every GTU (Gate Time Unit = 2.4 μs). HVPS system is optimized for the power consumption by 4 PMTs. There is no voltage divider to minimise energy loss. Therefore the lower level of power is defined by the expected power consumption for the background measurements. This is about 1 photo-electron per pixel per GTU. With a gain of $2{\cdot}10^6$ this corresponds to an anode currentof 0.13 μA in each anode, 8.6 μA per one PMT, or 33 μA per EC (Elementary Cell = 4 PMTs). Since most of power is released on the last dynodes, the minimum power required is about 4 mW per EC (per single HVPS_EC voltage generator).

Hamamatsu set the maximum current limit for long time (>30 s) equal to 100 μs per PMT (this type), and 400 μs per EC. Therefore constant p-e flux of a level above 10 per pixel per GTU is not allowed.

An event with a short pulse of 100 p-e in a few pixels is within this limit. Light from very large EAS generated by UHECR lasts about 30 μs and we expect several p-e per pixel per GTU in pixels corresponding to direction of observation of the event.

However, lightnings, TLEs, and large cities would last longer and would stay in many pixels. Lightning and TLEs might be thousands times brighter than EAS. To meet Hamamatsu requirement and enable to measure those events (counting would be done up to about 100 p-e per GTU, and for higher rate several pulses could be counted as one) a switching system was introduced. HV switches can change the PMT efficiency by 100 or 10000 times. Since the gain is not changed, it

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is still possible to count pulses from individual p-e's, but one pulse is now generated per 100 p-e's emitted from cathode (on average for 100 times reduction). Switching can be done for each EC separately, and it lasts several μs. Since rise time of lightnings or TLEs lasts about millisec, there is enough time to register the increase of light intensity, send a switch command and switch PMT efficiency (all might last less than 10 μs, i.e. much shorter than lightnings rise time). This way the measurement dynamic is from 0 to 10^6 p-e's in the pixel (but switching is per EC, so the statement applies to the brightest pixel in EC) [6].

The HVPS system has several protections against excessive power consumption. These are mainly to avoid over heating of HVPS units. HV generators (HVPS_EC) are powered by 5 V (electronics) and 28 V (for Cockcroft-Walton multiplier for HV generation). 5 V input is protected against too much current consumption, and in such a case HVPS_EC turns off and information about the case is available preceded by the INTerruption signal emission. An overload on 28 V causes high voltage output power reduction (INT signal is emitted and information is available for control subsystems). Full power comes back automatically when HV load returns to normal level. This protection (made for HVPS_EC) is also protecting PMTs in case of too much light received at the cathodes. The HV load level which starts power reduction is 3–4 times above Hamamatsu current limit.

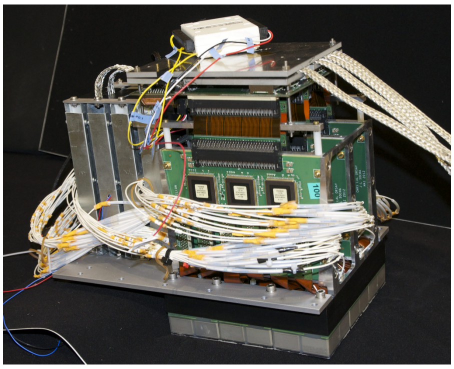

Figure 5: Photo Detection Module (PDM) for EUSO-Balloon. PMTs are at the bottom. HVPS units are inside metal boxes at the left and high voltage to every dynodes and cathodes is transmitted with white cables.

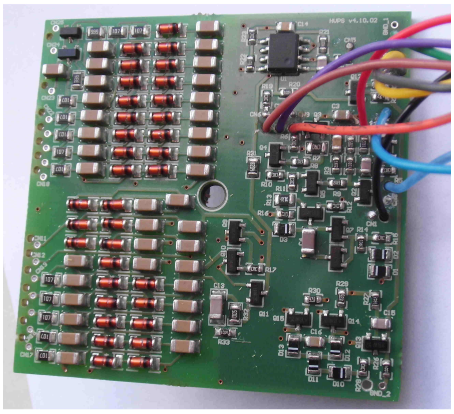

Figure 6: HVPS_EC PCB with Cockcroft-Walton voltage generator and switches for SPB–EUSO and for Mini–EUSO. It provides HV to four 64–anode photomultipliers.

4. High voltage power supply system.

High voltage for PDM photomultipliers are provided individually to each EC. There were 9 HVPS_EC generators, each with individually adjusted high voltage (HV). HV generators were Cockcroft–Walton voltage multipliers which provided voltages to cathode and dynodes of all 4 PMTs (without voltage divider). HV generators were optimised to expected power consumption and have several protections limiting generated power.

The system has evolved. The concept was presented in [4]. EUSO-Balloon [5] and EUSO-TA have HVPS about 20 cm away from PMTs, and HV in conveyed by special (white) cables (see photo in the Fig. 5). Because of HV discharges in low pressure (described by Paschen's law) all HV units have been potted. In SPB-EUSO and Mini-EUSO HVPS generators have been placed in EC, nearby to PMTs and potted. See photo in the Fig. 6 of HVPS_EC generator.

All 9 HVPS_EC generators are controlled by a single HVPS_DC-DC_Ctrl board. This board provided galvanic insulation between HVPS system and the rest of the experiment, and communication between HVPS_EC generators and HouseKeeping unit (HK) and PhotoDetectionModule Board (PDM), which command HV level and switches, receiving a feedback from HVPS_EC generators. Figure 7 shows the command scheme. The new solution in the SPB-EUSO and Mini-EUSO (new respect to EUSO–Balloon and EUSO–TA) has been implemented in lines connecting HVPS_DC-DC_Ctrl board (labelled as DC/DC in the figure) and 9 HVPS_EC generators (labelled as HVPS). The idea is to transmit stable level signals, and not to disturb PMT anode signal transmission to ASICs. These are On/Off bidirectional line, Status line (0/1 level from generator to DC-DC_Ctrl), DAC reference voltage (0, 2.44V) corresponding to 0–1034V at PMT's cathode, switch selection lines SwA, SwB (0/1). Since the HVPS_EC generator required fast switching pulses (pulse width 200 ns, every GTU 2.4 μs), these are sent by symmetric twisted line with amplitude reduced to 10 mV. Oscillator frequency of the Cockcroft–Walton multiplier is 40 kHz, about 10 times slower than data transmission, and it has been tested against potential influence on anode signal transmission.

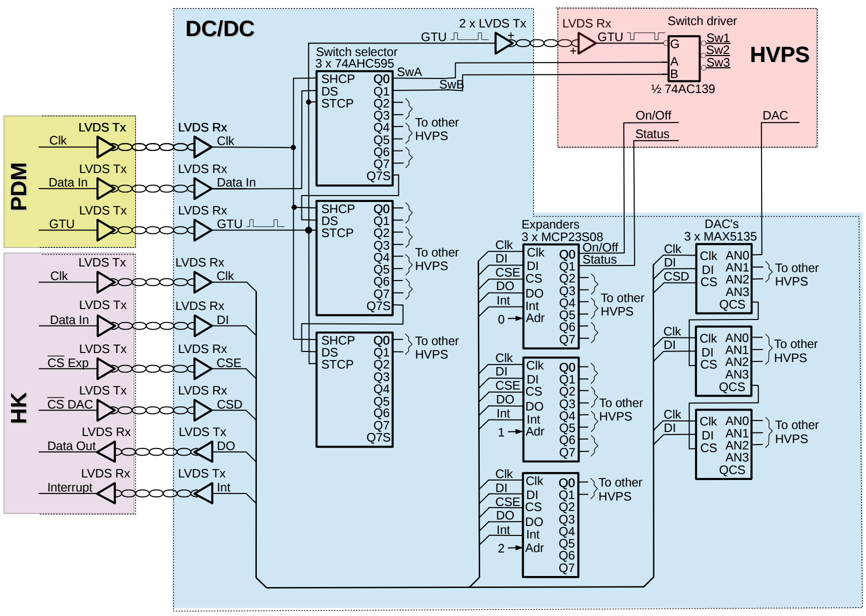

Figure 7: Communication scheme of HVPS system in SPB-EUSO. Different subsystems (PDM – PhotoDetection Module Board, HK – HouseKeeping, DC/DC – HVPS_DC-DC_Ctlr board, HVPS – HVPS_EC generator) have different background colours.

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