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A storage ring EDM polarimeter

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Abstract. The search for electric dipole moments (EDM) of elementary particles is one of the hot topic in contemporary particle physics. The method to measure charged particle EDMs (p,d) is to observe the time development of a polarized beam in a dedicated storage ring (srEDM). This requires a new polarimeter with a special target system which is under development at COSY-Juelich.

The particle detector consists of the two layers: a plastic scintillator for ΔE and an inorganic LYSO crystal as a calorimeter. Both systems are readout by multi-pixel SiPM (silicon photo multiplier) arrays. SiPMs operate at significantly lower supply voltages compared to the traditional multi-stage vacuum tubes, simplifying detector construction and operation. The developed calorimeter modules operate at voltages up to 30 Volt. For this purpose a modular, high precision voltage supply has been developed together with slow control and voltage monitoring systems. The fully assembled calorimeter part of the polarimeter has been successfully tested together with its high speed and high-resolution sampling ADC-based readout. All test have been carried out using solid block target. However, the final polarimeter will include a ballistic target system which will be shooting point-like diamond pellet through the beam. The movement of the pellet will be precisely tracked in three dimensions and synchronized with the data acquisition system. This will allow us to reconstruct the polarization profile of the beam. Currently, the mechanical and electrical systems for the pellet target are under development.

Recent achievements and experimental results of this project are summarized and discussed in this paper.

1. Introduction

Nowadays there is a huge number of experiments in the field of fundamental physics trying to find out the basic principles of evolution of the universe. Still, set of questions remain that are not yet answered, such as observed mater-antimatter asymmetry in the universe. According to present understanding, at the beginning of universe there should have been equal number of particles and antiparticles, i.e. matter and antimatter. But somehow, after particle-antiparticle annihilation process more particles survived. CP-violation in early stages of the universe development is one of the required ingredients to explain the leftover of matter. The level of the CP-violation, allowed within the Standard model (SM), is not enough to quantitatively explain such an asymmetry.

Today there are two main directions to search processes beyond the standard model: research at higher energies, for example experiments on the Large Hadron Collider, and its alternatives - precision measurements - the use of advanced technologies and methods in relatively low energy

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environments, that enable to significantly increase the accuracy of the experiments in expense of rational resources. Such a direction is the search for electric dipole moments of charged particles (EDM). A finite EDM would indicate a violation of time-reversal (T-) invariance and equivalent CP-(charge-parity) invariance. This can lead to a new physics.

A new idea, promoted at Forschungszentrum Jülich (Germany), is to search for EDMs of charged particles (protons, deuterons) in novel precision storage rings. This method exploits stored polarized beams and observes a minuscule rotation of the polarization axis due to the interaction of a finite EDM with large electric fields. The task is to track the spin axis of the beam particles, circulating in a storage ring, as a function of time with utmost accuracy. In order to achive this goal, a new precision polarimeter is being developed in the framework of the JEDI (Juelich Electric Dipole moment Investigation) collaboration [1]. The JEDI collaboration is conducting a set of experiments at the COSY accelerator and storage ring [2], to develop precise equipment and experimental techniques for measuring EDMs of protons and deuterons at an unprecedented sensitivity.

2. JEDI Polarimeter

One of the key elements of the JEDI experiment is the new modular polarimeter (JePo). JePo is a two layer detector consisting of ΔE scintillators and inorganic LYSO crystals. Produced light is detected by SiPM arrays. The main requirements for calorimeter development are simplicity, interchangeability, long term stability and high resolution. All of the calorimeter modules are designed identically, so that thay can be easily exchanged. Each module uses minimal number of parts for simplicity. This makes the assembly process easier and faster. Each module consists of the following parts: a LYSO (Lutetium-yttrium oxyorthosilicate) crystal, a SensL-s J series SiPM (silicon photo-multiplier) [3], a SiPM holder PCB, an aluminum holder, a specially designed spring and some other 3D-printed supporting parts, as shown in Figure 1. SiPMs are manufactured in arrays of different sizes, where each element represents thousands of avalanche photo-diodes, operating in Geiger mode, connected in parallel. These devices are relatively new and are still considered innovative. Due to the unique features of the SiPM, such as high gain, high time resolution and ability to work in strong magnetic fields, these light-sensitive detectors are successfully replacing classical photo-multiplier tubes in many areas of research and industry. The main application areas of SiPMs are PET (Positron Emission Tomography) and hybrid MRI-PET system manufacturers. The energy interval and the number of detected photons in the JEDI experiment are almost three orders of magnitude higher than in case of PET applications leading to much higher currents through the SiPMs during the particle detection, while the steady (dark) current remains the same. Due to these circumstances special multi-channel power supply had to be developed for SiPM bias supply.

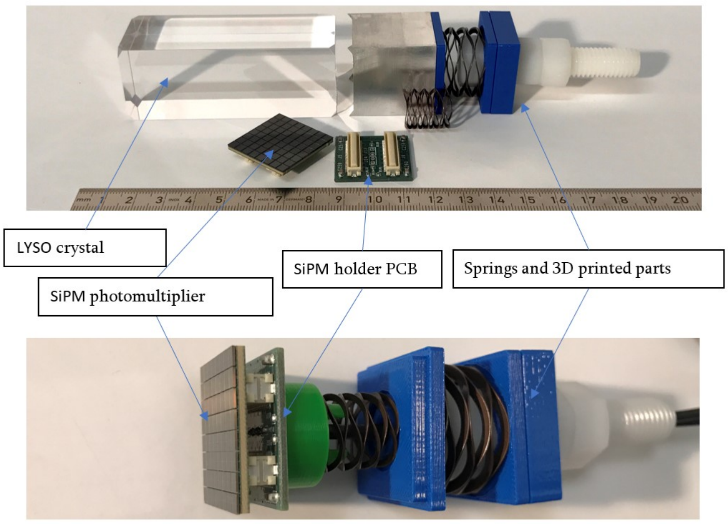

Figure 1. A picture of the single calorimeter module before assembly.

Power supply used in polarimeter has low output noise level, can handle fast dynamic loads, it has high short and long-term voltage stability, also it has voltage monitoring system and remote on/off functions incorporating EPICS platform [4]. The main requirements for the power supply were determined based on SiPM load characteristics and lab tests. Since SiPMs operate at voltages exceeding their breakdown voltage, the gain is very sensitive to the supply voltage, as was also identified experimentally. During the laboratory tests, the gain dependency on the bias voltage was measured also at high over-voltage values.

As it becomes clear from Figure 2 the gain factor of our SiPM arrays strongly depends on the biasing reverse voltage. With higher voltage we can achieve higher gains that will benefit in increased SiPM resolution, leading to higher energy resolution of the calorimeter modules, but higher voltage will also increase dark current. The energy resolution of the LYSO crystals used in the calorimeter is also limited at the level of 0.5-1 % and there is no more benefit from increasing the SiPM gain too much. As an optimal working voltage range we chose 29 V up to 31 V interval. In this range 1 mV change in the supply voltage will induce about 0.05 % change in the SiPM gain. Therefore, the overall instability plus noise of the power supply output voltage must be less than 10 mV. In this case the overall energy resolution of the calorimeter will not be degraded noticeably due to voltage variations. The stability of one channel of power supply, measured during experiment can be seen on Figure 3

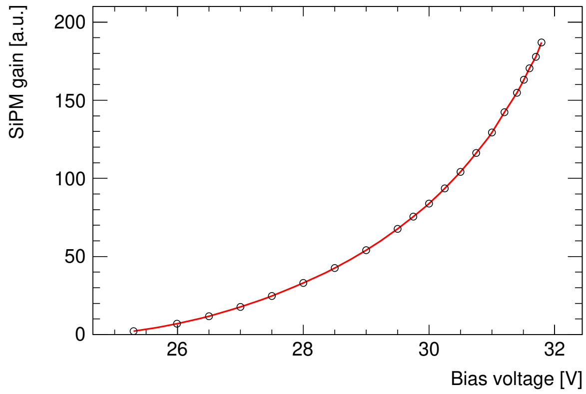

Figure 2. The gain factor dependency of SiPM on bias voltage

One of the crucial parts of the polarimeter is the target system. There are lots of target types used in experiments, such as solid, liquid, gas and pellet targets. In srEDM measurements the requirements for the target are following: minimal influence on the beam particles and on the vacuum system of the storage ring. Most of the traditional target systems are not suitable for srEDM experiment as far as some of the targets either can not use carbon, or they significantly worsen vacuum conditions, or they have too high density.

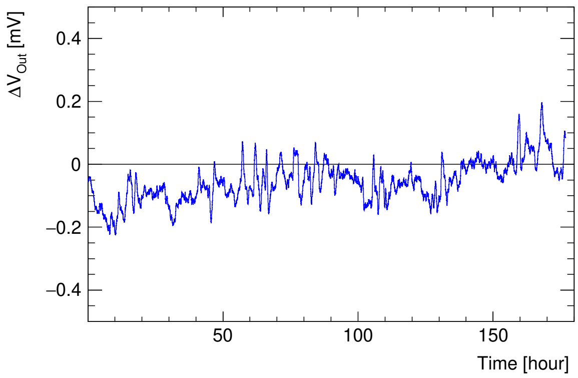

Figure 3. The voltage change of one channel of power supply, measured during 180 hours experiment

As an example, in the current configuration horizontal and vertical carbon block targets are used in JePo. They are mounted on linear stepper actuators. The slow control system of the target is based on EPICS. Therefore, it can be accessed from a remote computer, running dedicated GUI software, via a network. EPICS integration in our system allows us to set optimal target position manually or automatically by monitoring different variables from the DAQ and the accelerator and accordingly adjusting the target position. There are software and hardware interlock systems implemented for safety reasons, which cut power to the motors and avoids accidental collision of the two block targets if both motors start moving simultaneously inside the beam pipe.

This type of target requires additional beam excitation with white noise to make the small part of the beam particles hit the target. Although a wire target with very thin carbon wire could be employed, but the density of the wire will be still way too high, leading to high beam losses.

Concerning all the drawbacks of different types of targets we developed new concept of ballistic carbon pellet target. The idea is to shoot a small carbon pellet through the beam Figure 4. It will consist of shooter and catcher mechanisms to oscillate the pellet and make it to cross the beam. By controlling the movement of the pellet it will be possible to even scan the beam profile at desired position if the data acquisition system (DAQ) will be synchronized with the pellet movement. In this way the target system will have the least interaction with the beam. Anything, using electrical and magnetic fields must be avoided to be employed in the system to not disturb the beam. Frequency and speed of the oscillation must be variable to achieve desired effective target density. Proper monitoring system must be developed, including precise triggering, track reconstruction and data synchronisation units which will allow us to synchronize the target tracking data with other polarimeter systems. The triggering and time-of-flight (TOF) measurement unit consists of two laser and two fast pin photo diodes. The output of the pin diode is amplified and then converted to a digital signal which is then fed into the FPGA. It performs TOF measurement and also triggers the CMOS camera. By processing images, the FPGA extracts tracking information from frames such as flight trajectory. A fast camera is required for the tracking system to get as much frames as possible during the flight of the pellet. The used FPGA incorporates dedicated ARM core, which can be used to communicate with the target system from a remote computer, using local network.

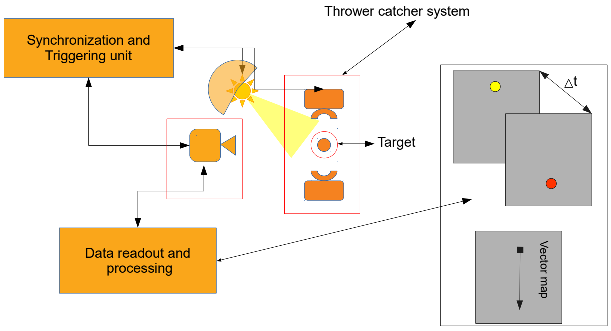

Figure 4. Block diagram of pellet target system

Besides, the target system must be able to read and write data from other parts of the detector and the accelerator using the EPICS control system. This can be also easily achieved with ARM CPU. The triggering system is already ready. It was tested with 0.4 mm metal ball. The output signal is very clean as it is shown on Figure 5. These tests will continue to examine pellets of different sizes, further adjust optics and tune amplifier parameters.

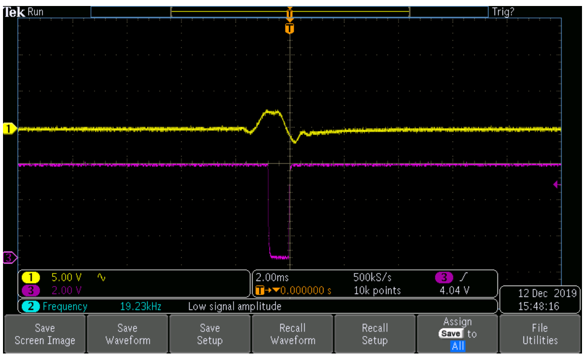

Figure 5. The trigger unit test with 0.4 mm pellet. The yellow line is analog signal from amplifier, the purple line is digital signal pulse which goes in FPGA

3. Summary

A modular detector system has been developed which is simple in use and easy to maintain. In case of failure the modular structure makes it easier to exchange damaged modules. The 54 calorimeter modules has been assembled so far.

A precision power supply system has been developed including EPICS-based and user-friendly GUI for controlling and monitoring the power supply modules. Two axis block target system has been developed with remote control software and several safety features. Development of a new type of the pellet target is in progress. Current activities are focused on image processing techniques and methods which can be achieved using FPGA/ARM combined system. The existing image processing techniques need to be adopted to our needs and integrated into the TOF triggering system.

4. Acknowledgement
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