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EM Calorimeters for SoLID at Jefferson Lab

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Abstract. Several approved experiments at Jefferson Lab for the 12 GeV era will use the proposed Solenoid Large Intensity Device (SoLID) spectrometer. Two EM calorimeters with a total area of 15 square meters are required for electron identification and electron-pion separation. The challenge is to build calorimeters that can withstand high radiation doses in high magnetic field region and bring photon signals to low field region for readout. Several types of calorimeters were considered and we are favoring Shashlyk type as a result of balancing performance and cost. Our preliminary design and simulation of SoLID EM calorimeters are presented.

1. Introduction

The Solenoidal Large Intensity Device (SoLID) is a versatile spectrometer based on a large solenoid magnet. Presently, there are two distinct series of measurement that have been proposed for this spectrometer at Jefferson Lab in the 12 GeV era. In one configuration, the spectrometer will be used to measure parity violating deep inelastic scattering (PVDIS) [1]. The experiment will study lepton-quark neutral current interactions by recording collisions of polarized electrons with cryogenic hydrogen and deuterium targets. Measuring the polarization asymmetry due to the interference of the photon and the Z boson over a wide range of kinematics will determine of the axial-quark, vector-electron couplings while at the same time providing a measurement of charge symmetry violation at the quark level. Measurement of PVDIS with a hydrogen target can provide a determination of the d/u ratio in the proton without the need for nuclear corrections. The second configuration will be used for studies of semi-inclusive deep inelastic scattering (SIDIS) [2] with nearly 2π azimuthal-angle coverage and momentum transfers up to 9 GeV^2. The SIDIS experiment will measure semi-inclusive electroproduction of charged pions from transversely/longitudinally polarized ^{3}He and from transversely polarized proton. With the SoLID spectrometer, the single target spin and double beam-target spin azimuthal asymmetries can be measured with high precision and within a large 4-dimension (x,Q^2,z,P_T) kinematic space, which will lead to a more comprehensive understanding of

Transverse Momentum dependent parton Distribution functions (TMD) for the neutron and proton in the valence quark region.

The PVDIS and SIDIS setups will share the same magnet yoke and many of the same detector elements, but configured in different ways. The magnet will be a large bore solenoid of 2-3 meter diameter and 1.5T field. Re-use of an existing large superconducting solenoidal magnet (such as BaBar [3] and CLEO-II [4]) is being pursued. For PVDIS setup, the detection system requires excellent electron identification that is achieved by a gas Cerenkov counters and an electromagnetic calorimeter at forward angles. Gas Electron Multiplier (GEM) chambers are used for tracking at high rates. A series of baffles would be deployed to block soft electrons and line of sight photons' trajectories. For SIDIS setup, the electron-hadron separation would be accomplished with a light gas Cerenkov and an electromagnetic calorimeter at forward angles. At large angles, the electron-hadron separation will be accomplished by an electromagnetic calorimeter alone. A heavy gas Cerenkov and a layer of multi-gap resistant plate chamber (MRPC) as time of flight will be used for pion identification. GEMs will be also used for tracking. Both setups (with the CLEO-II magnet) are shown in Figure 1.

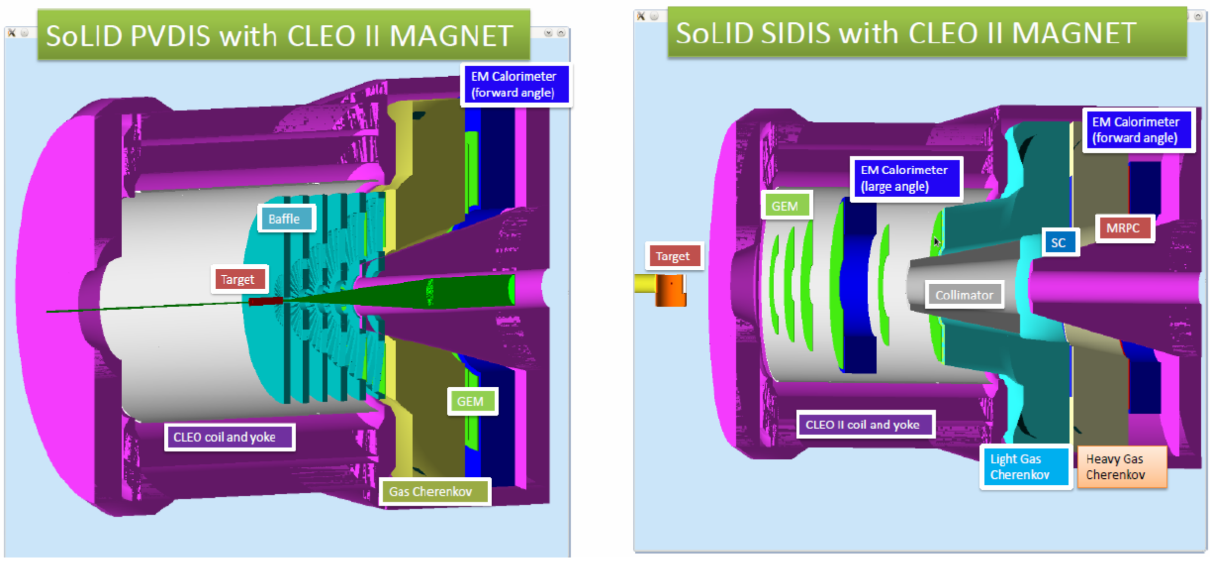

Figure 1. SoLID PVDIS setup (left) and SIDIS setup (right).

SoLID Electromagnetic Calorimeter (EC) is a key detector, used in both PVDIS and SIDIS experiments to provide electron-hadron separation. The EC modules need to be designed to fit the needs of both PVDIS and SIDIS experiments and be able to be reconfigured for the different setups. The challenge is to build the calorimeters that can withstand high radiation dose in high magnetic field region and bring photon signals to low field region for readout. The EC's main characteristics are determined by both the physics goals and the designed running conditions of the experiments. We are favoring Shashlyk type calorimeters [5] as a result of balancing the performance and cost.

2. Prelimnary Design

A Shashlyk calorimeter is a sampling calorimeter constructed from alternating layers of scintillator and heavy absorber e.g. lead. Scintillation light is absorbed, re-emitted and transported to the photon detector by wavelength shifting (WLS) optical fibers penetrating through the calorimeter modules longitudinally.

Our Shashlyk calorimeter module design is based on the COMPASS module [6] as shown in Figure 2. A Geant4 simulation was used to study the key specifications for optimal physics results and to lower the cost.

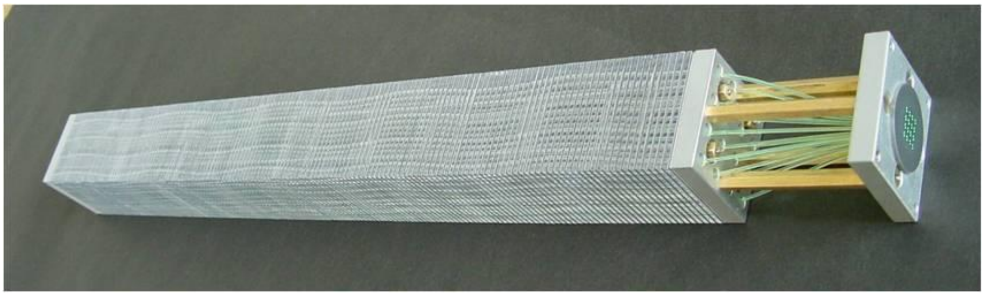

Figure 2. A Shashlyk calorimeter module produced by IHEP for the COMPASS experiment.

The main features of our current design are the following

- Scintillator and absorber ratio:

Each layer consists of a 1.5 mm-thick scintillator plate and an absorber plate made of lead. The Pb absorber thickness of 0.6 mm or less is favored to provide a fine sampling, and therefore an energy resolution of 5%. For the 0.6 mm Pb configuration, effective radiation length is about 21 mm.

- Longitudinal size:

A total length about 20 radiation length is sufficient to contain to 95% of the electromagnetic shower and short enough to maximize the difference in energy deposition between electrons and pions. A calorimeter module of 20 radiation length us approximately 42 cm composed of 183 layers.

- Longitudinal segmentation:

Having both preshower and shower segments in EC is essential to reach the required pion rejection factor of between 10 and 100 depending on the particle's momentum. The preshower thickness of 3-5 radiation lengths can maximize the difference in energy deposition between electrons and pions at the momentum ranges of 2-7 GeV for SoLID. The proposed design is to build the Shashlyk calorimeter in one unified structure, but separating the preshower and shower parts by different readout fibers. The preshower fibers must be optically isolated from shower part.

- Lateral size:

The lateral size of each module determines the position resolution and the background level of the reconstructed shower hits. It is also the most relevant factor to the overall cost of the calorimeter. The Monte Carlo study showed that a lateral size of about 10 cm would provide a good balance between position resolution and cost as shown in Figure 3.

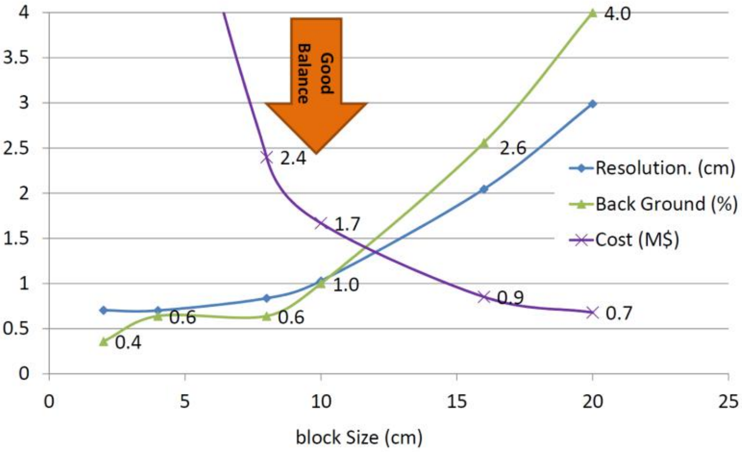

Figure 3. Lateral size dependence of the position resolution, background level from simulation and the nominal cost of the SoLID calorimeter if using COMPASS type module.

- Radiation hardness:

At the designed luminosity of 10^{39}/cm^2/s for PVDIS and 10^{36}/cm^2/s for SIDIS, the radiation level at EC reaches 60 krad/year in the PVDIS configuration and 400krad/year in the SIDIS configuration (the difference comes from luminosities, targets, acceptance angles and the use of baffles for PVDIS). The COMPASS module has been tested up to 500 krad. Increasing the thickness of the first lead layer and using more radiation resistant scintillator and fibers can further improve the radiation hardness.

- Fiber connection:

Because the high rate and high magnetic field environment, the photon sensors need to stay outside of the SoLID yoke structure. We plan to combine and connect the WSL fibers into clear fibers and lead them outside of the yoke to where the photon sensors will be located.

- Module layout:

The modules need to be easily swapped between PVDIS and SIDIS settings. And the layout needs to preserve the reflection symmetry in the spectrometer. Modules with a square cross section can be stacked in the layout shown in Figure 4 to meet this criteria.

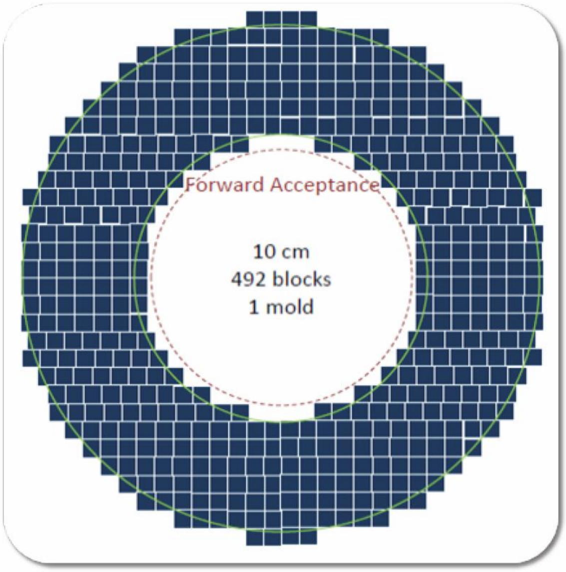

Figure 4. The layout of SIDIS large angle calorimeter with square modules.

3. Summary

SoLID at Jefferson lab will open doors to exciting physics through precise measurements of PVDIS and SIDIS. EC is one of key detectors of SoLID. Its primary role is the identification and separation of pions and electrons. This must be done at the trigger level for the proposed PVDIS measurements. The required features of the EC system were outlined, and these features appear to be available in Shashlyk-type calorimeter modules, similar to those used in COMPASS.

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