Development of Future Muon Calorimeter for the CLAS

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Overview/Goal

The CEBAF Large Acceptance Spectrometer (CLAS), here at Jefferson Lab, is capable of observing high energy DIS events which probe the inner structure of the proton at high-x, the hadronization process, and the production of charmed mesons. The reconstruction of such processes requires the ability to detect neutrons, muons, and other minimum ionizing particles with calorimetry data at high forward angles, a capability which the CLAS currently lacks.

We are designing and testing a forward calorimeter for use in the CLAS which will utilize new technologies to achieve previously unattainable performance levels. Here, we present the motivation, design plan, and prototype performance for a forward calorimeter, using plastic scintillating bars, coupled optically to single-photon counting silicon photomultipliers.

Background

Motivation

- Goal: Detect muons, neutrons, and other MIPs from DIS processes
- Muon calorimetry data at forward angles allows for reconstruction charmed meson production
- Neutron calorimetry allows for high-x, neutron spin asymmetry, leading neutron DIS measurements

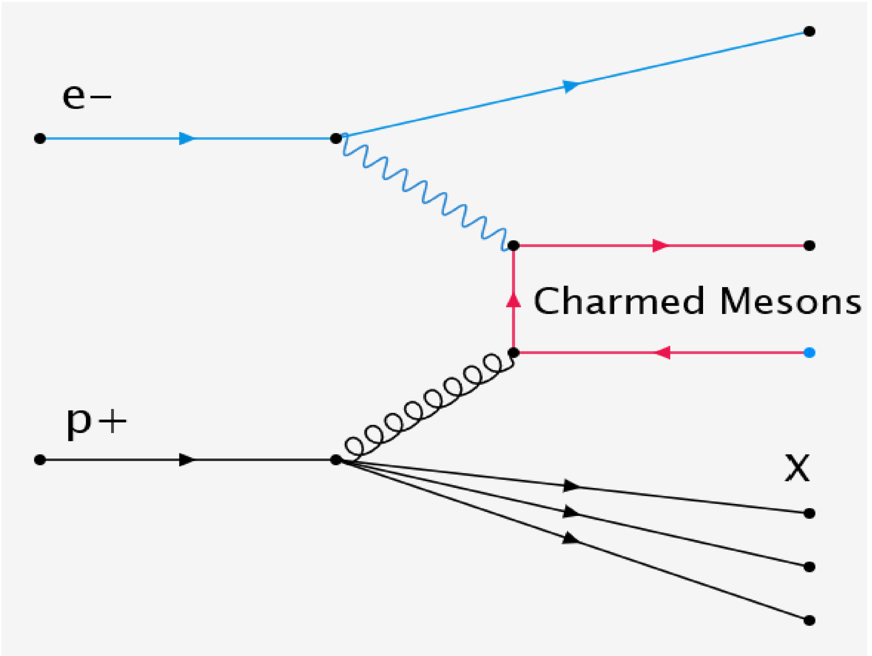

Fig 1. Charmed meson production in DIS

- Highly sensitive to Gluon Distribution Functions
- Rare processes are difficult to detect, but are highly sensitive to GDF
- Leptonic decay modes can be accessed with a MIP calorimeter; lepton tagging for rare events reduces background

The CLAS

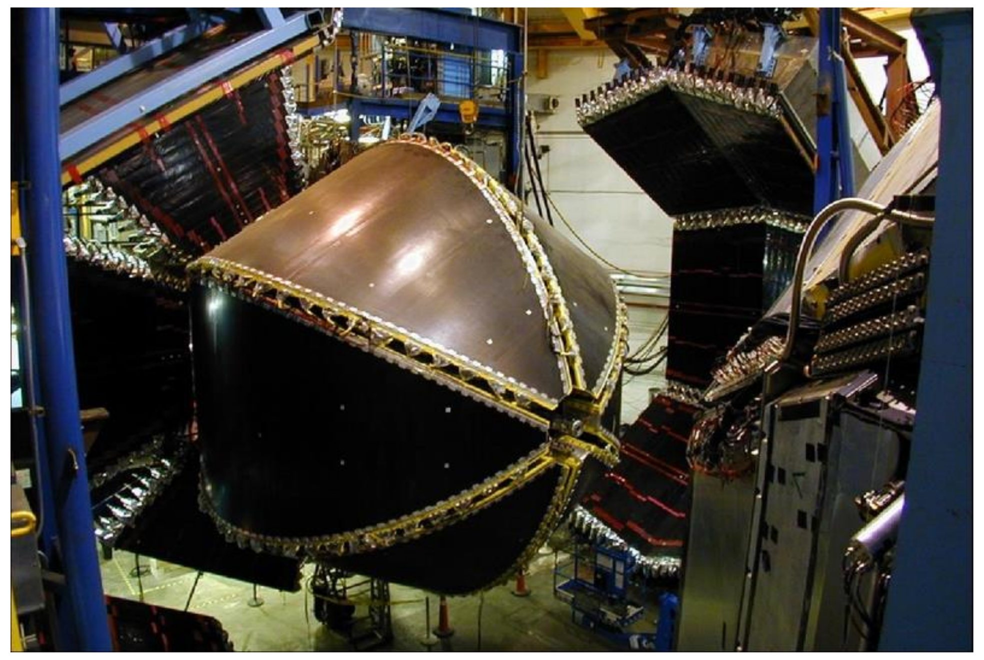

Fig 2. A view of the back side of the CLAS. The future forward calorimeter will be located behind the outer electromagnetic calorimeters

- Current CLAS12 and GlueX experiments can be augmented by neutron, muon calorimetry
- Scintillator-based calorimeter will provide energy and positional measurements in the far forward region

Calorimeter Design

- Provides calorimetry data for muons and other minimum ionizing particles
- Angular coverage in the $0.2° < \theta < 11°$ range
- Array of plastic scintillator bars ionize in the UV from passing muons
- Photons are delivered to SiPM for readout by Wavelength Shifting Fiber

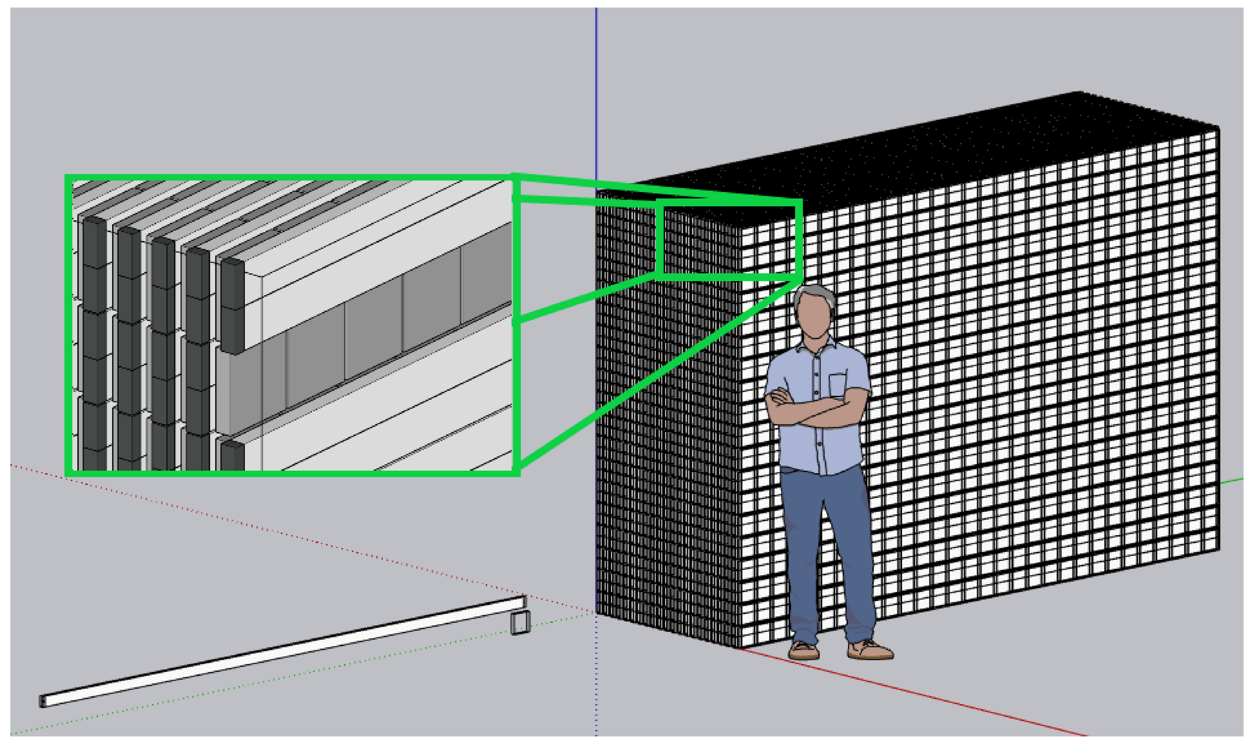

Fig 3. Left: A cutaway view of scintillating bars, assembled in the forward calorimeter, and a single, scintillating bar and shielding plate components; Right: 3D model of forward calorimeter internal assembly, Sketchup's Niraj for scale.

Expected Performance

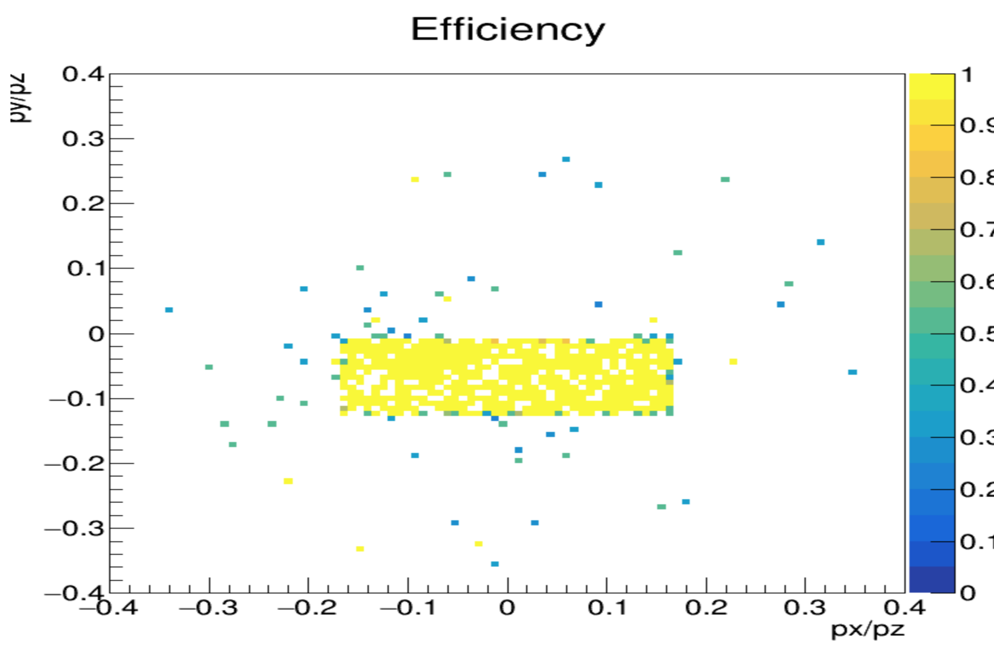

Fig 4. GEMC simulation of muon detection, produced in the 1 GeV range; doped, scintillating plastic provides consistent

- Simulation of muon radiation detected with high efficiency
- Energy resolution to be determined from Signal Characterization and further GEMC simulations

Cosmic Ray Signal

- Calorimeter prototype (single, long bar) is tested using passing cosmic rays
- Trigger by coincident detection at top and bottom tiles, data collection done at the ends of the long, scintillating bar which will make the body of the calorimeter

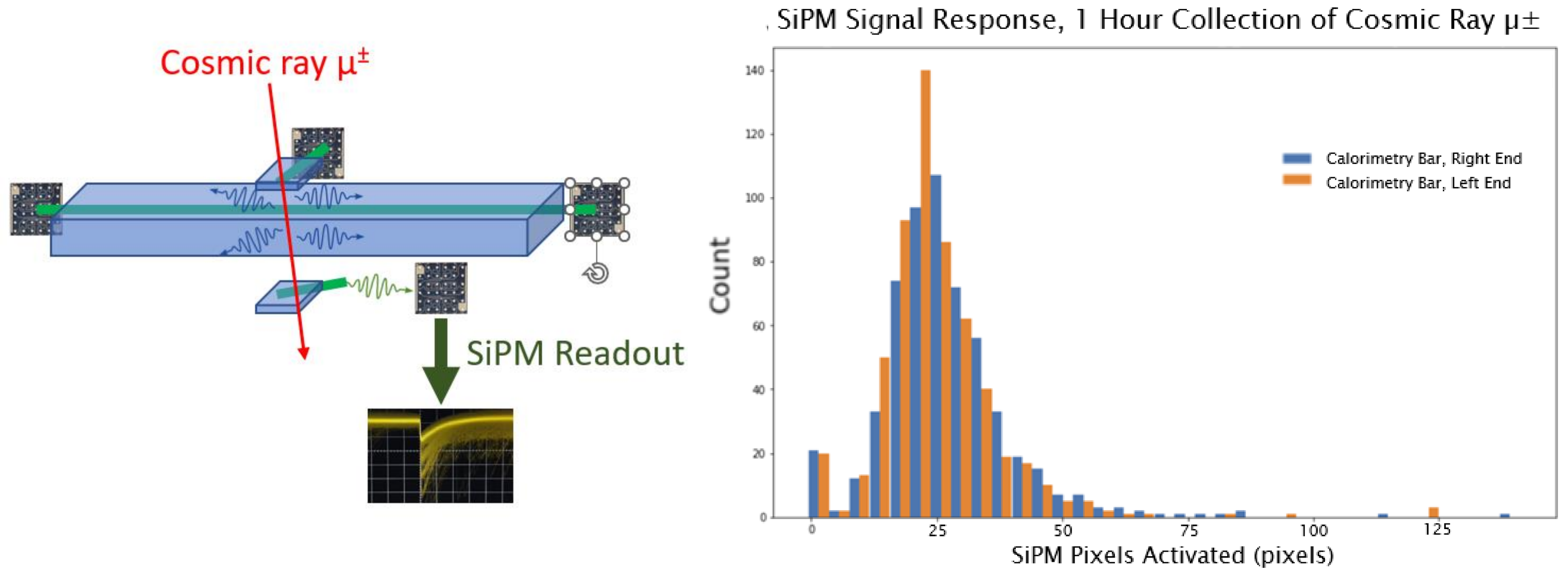

Fig 5. The energy distribution of passing cosmic rays used in prototype testing, measured over one hour. 87% of the triggered measurements showed a pixel count from the bar above the noise level which appear as a Landau distribution, peaking at 25 simultaneous pixel activations. This is the distribution expected for the energy of passing cosmic rays.

Signal Characterization

- Silicon Photomultiplier (SiPM) acts as a multi-pixel single photon counter
- SiPM pixel array produces quantized output proportional energy of a passing ionizing particle in the calorimeter
- Two trigger signals from small tiles and two energy deposition signals for full 4-fold coincidence reading
- Scintillating bar doped with PPO ionizes from passing muons, neutrons, and minimum ionizing particles

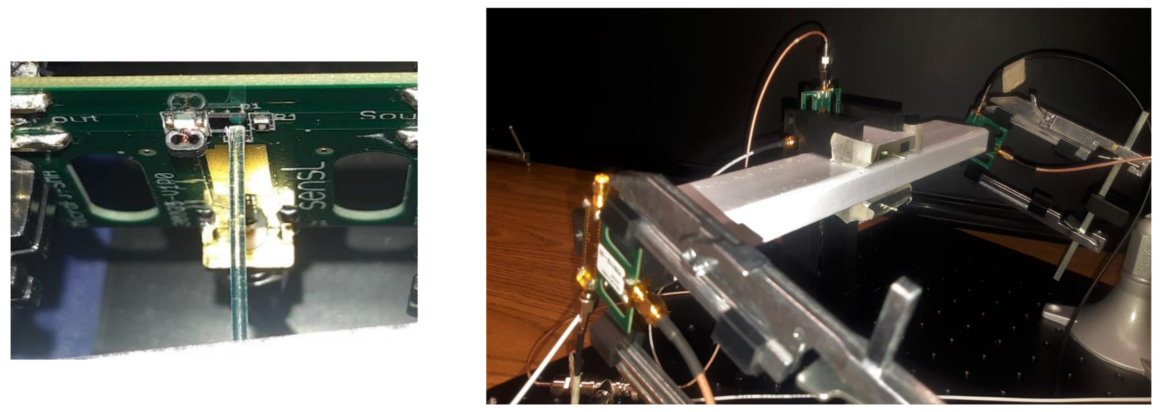

Fig 6. Left: Close-up of a test wavelength shifting fiber, coupling optical signal from passing ionizing particle to SiPM; Right: Test setup for single, scintillating bar with signal readout on both ends and smaller scintillating tiles above and below

- Passing Muon excites doping sites in scintillating plastic
- Some UV photon deexcitations are captured by wavelength-shifting fiber
- Green, wavelength-shifted photons are optically coupled to SiPM pixel array
- Discrete pixel count can be correlated to original muon energy deposition

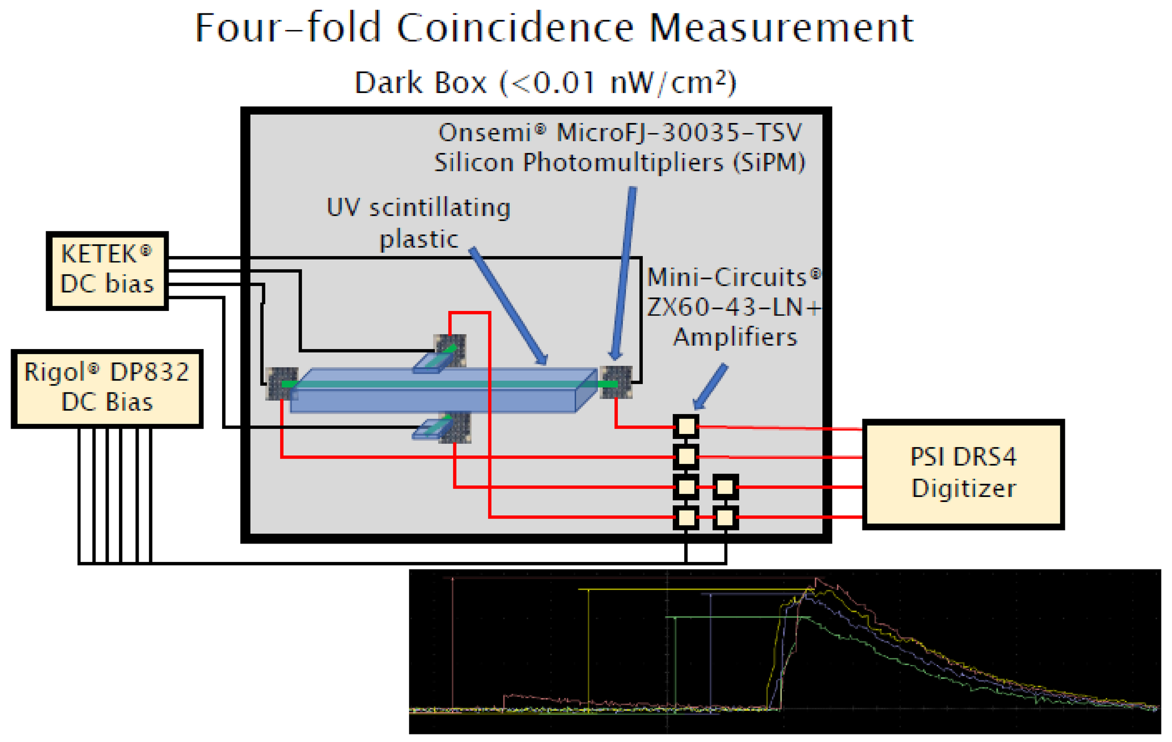

Fig 7: Block diagram of the test setup for a single, scintillating bar, detecting passing cosmic ray muons. When a cosmic ray passes through the smaller, triggering tiles, a large pulse is detected simultaneously on all four channels of the digitizer.

SiPM Signal Calibration

- Discrete pixels activate, correlated to number of incident photons, and crate voltage "finger spectrum"
- SiPM gain (voltage/pixel) and photon detection efficiency (photon/pixel), and system conversion efficiency (incident photons/MIP energy deposition) must be individually calibrated
- SiPM gain and PDE calibration was successful; voltage readout converted to incident photons

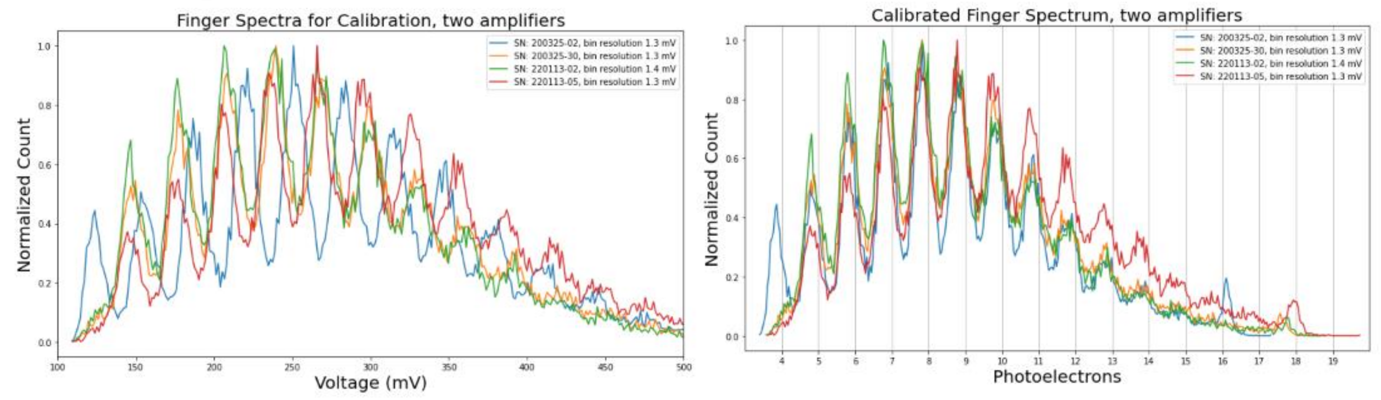

Fig 8. Left: An uncalibrated finger spectrum. Each unit has a slightly different responsivity; Right: The same finger spectrum after calibration. Photon flux at each unit can now be directly compared.

Acknowledgements/References

Advisor: Dr. Miguel Arratia
CLAS photography courtesy of Jefferson Lab: https://www.jlab.org/Hall-B/general/clas_thesis.html
"*About a forward "KLM" calorimeter for CLAS12*"; M. Arratia (2022)

Thank you, Jefferson Lab, for hosting and supporting the CLAS