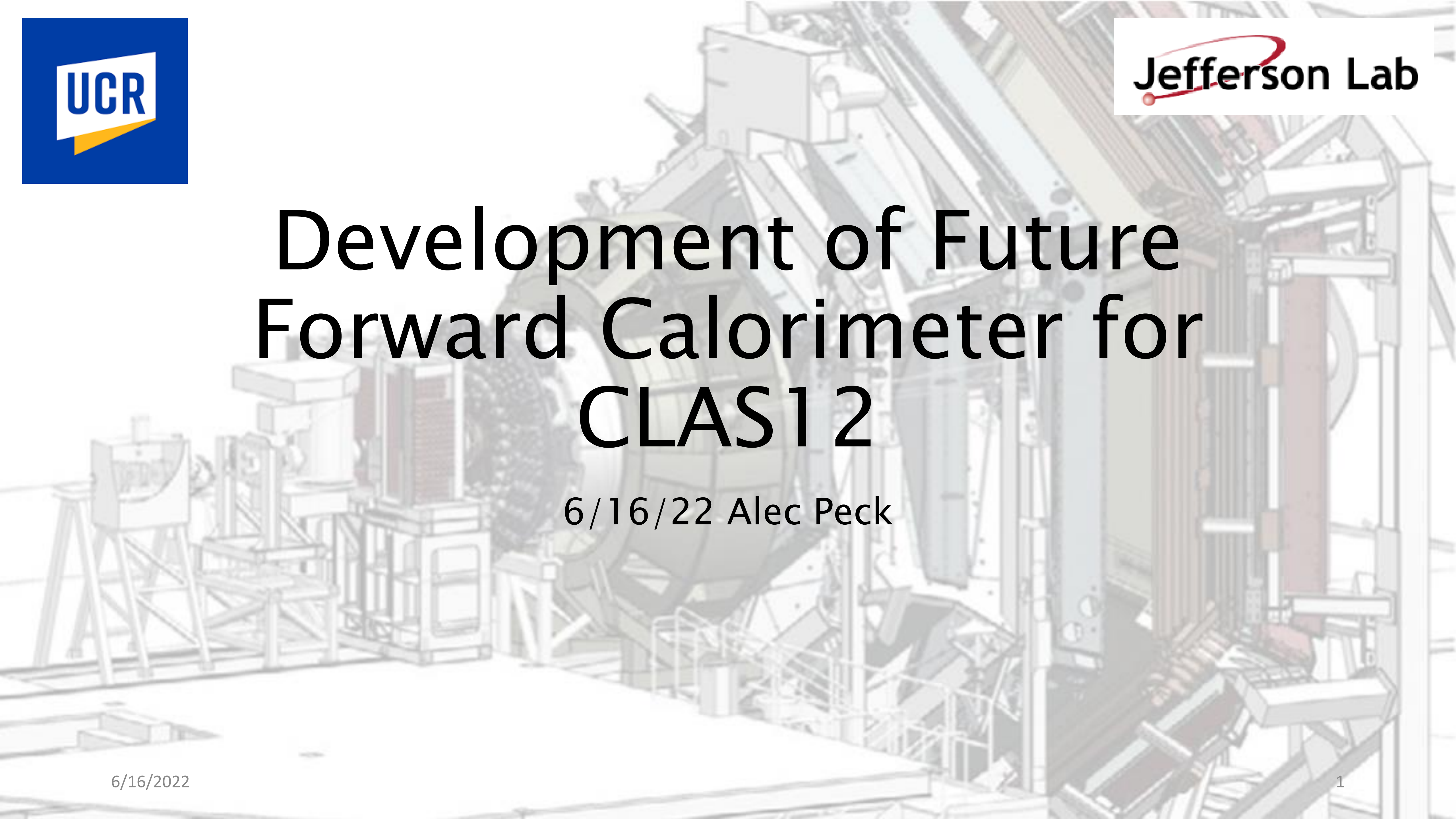
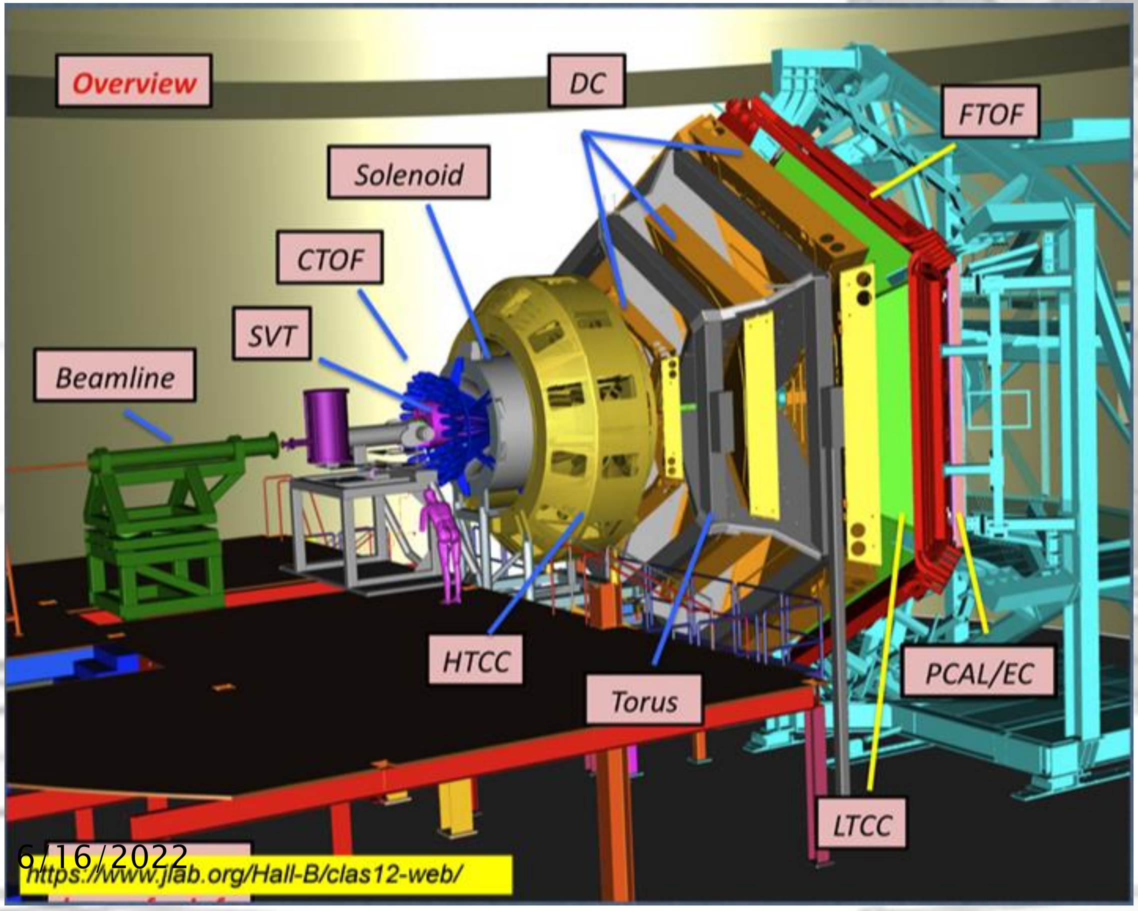


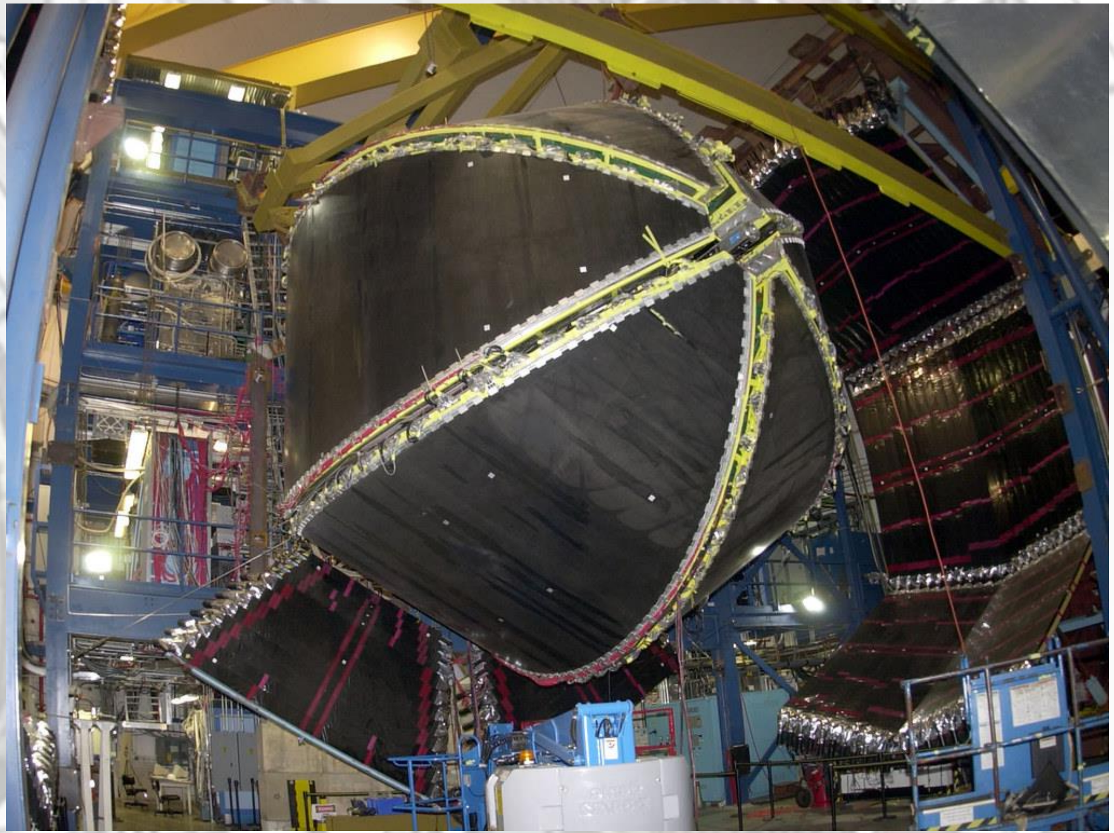
Development of Future Forward Calorimeter for CLAS12

6/16/22 Alec Peck

Hall B & the CLAS

Purpose: 3D tomography, form factors, TDPs, GPDs



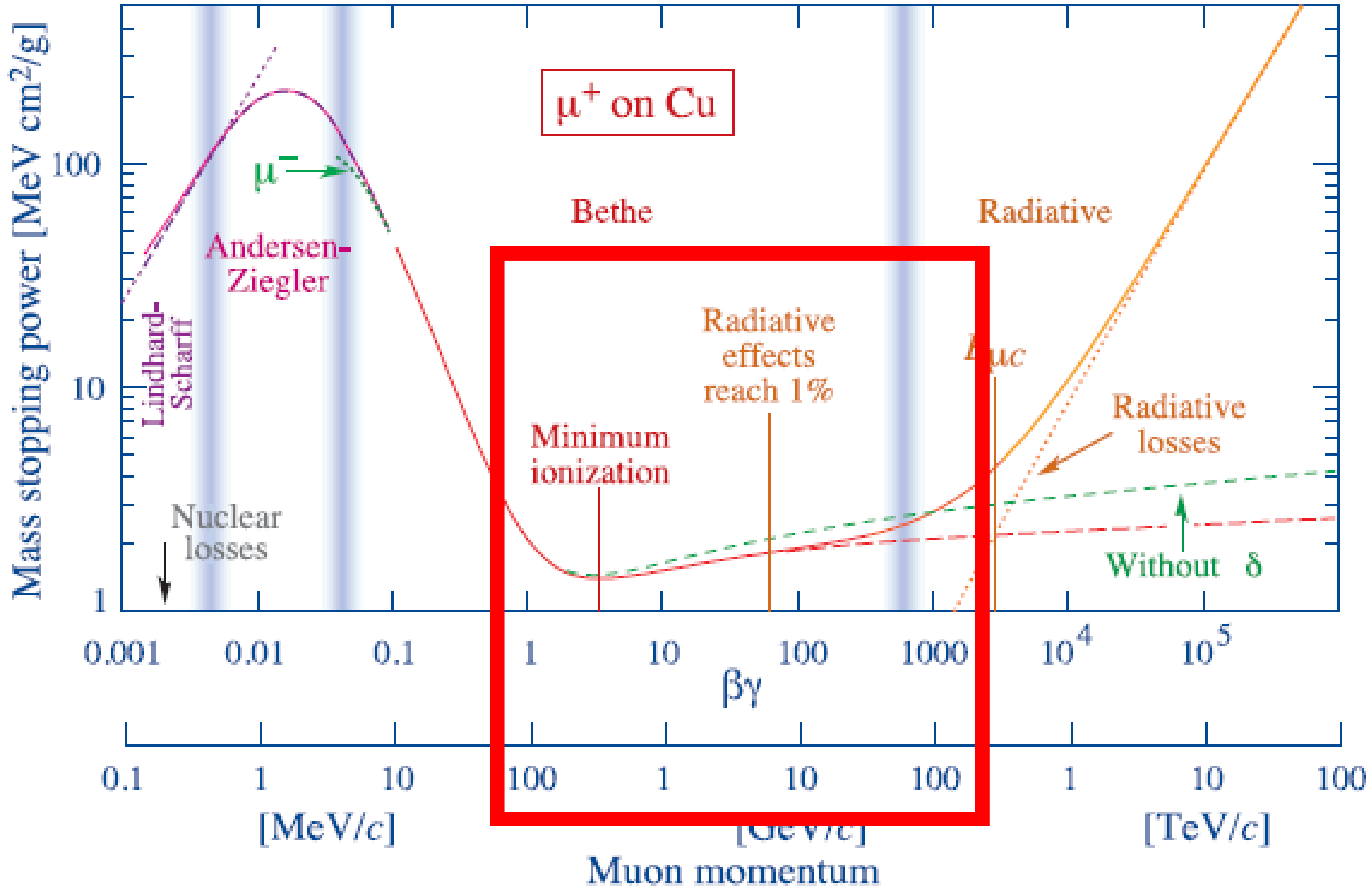


- Pre-shower, Electromagnetic, and forward tagger Calorimeters
- Central barrel: neutron detector

Minimum Ionizing Particle (MIP) Calorimetry

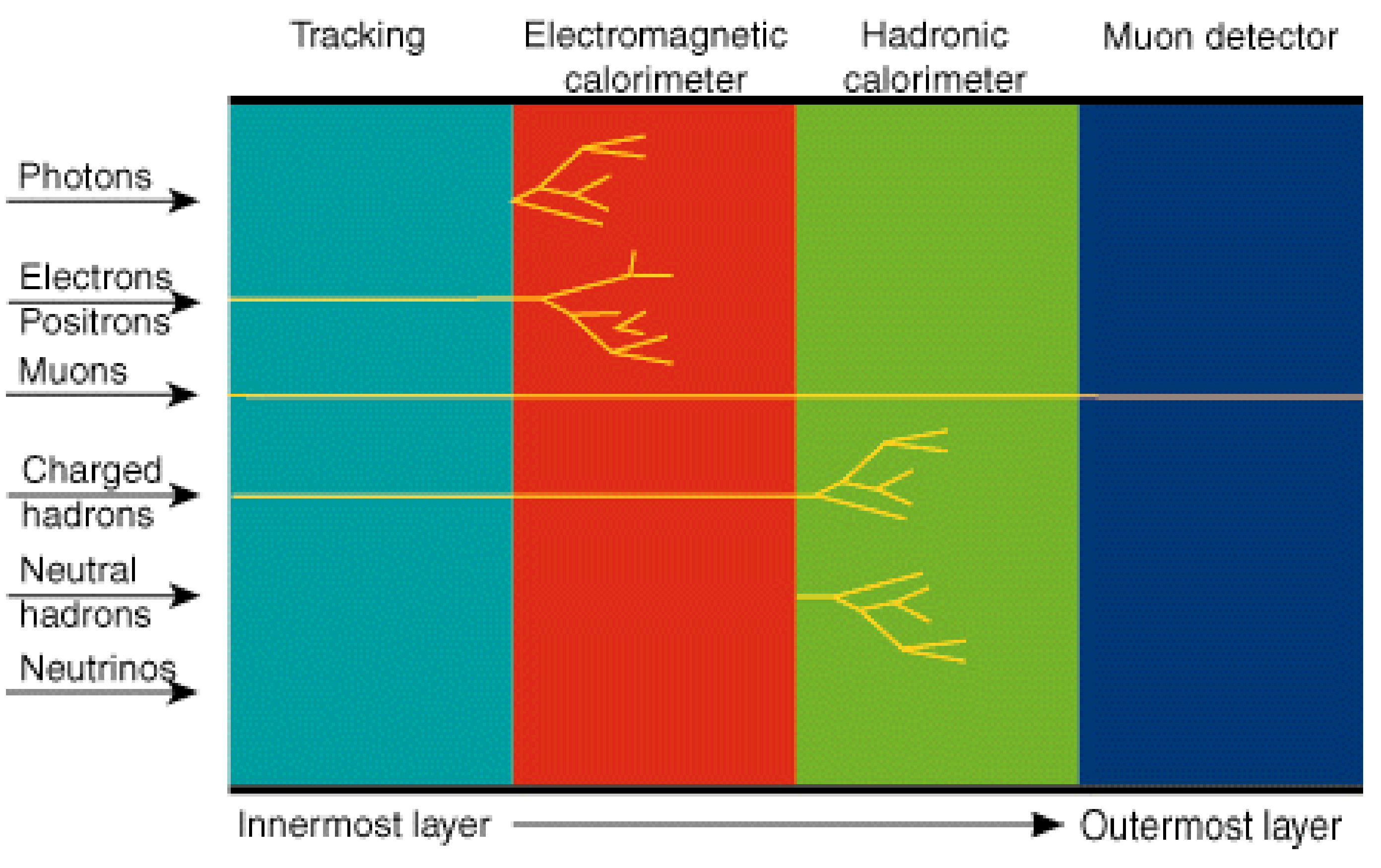
- Energy loss in matter: Bethe–Bloch formula, radiative corrections

- Large kinematic range of minimal Ionization

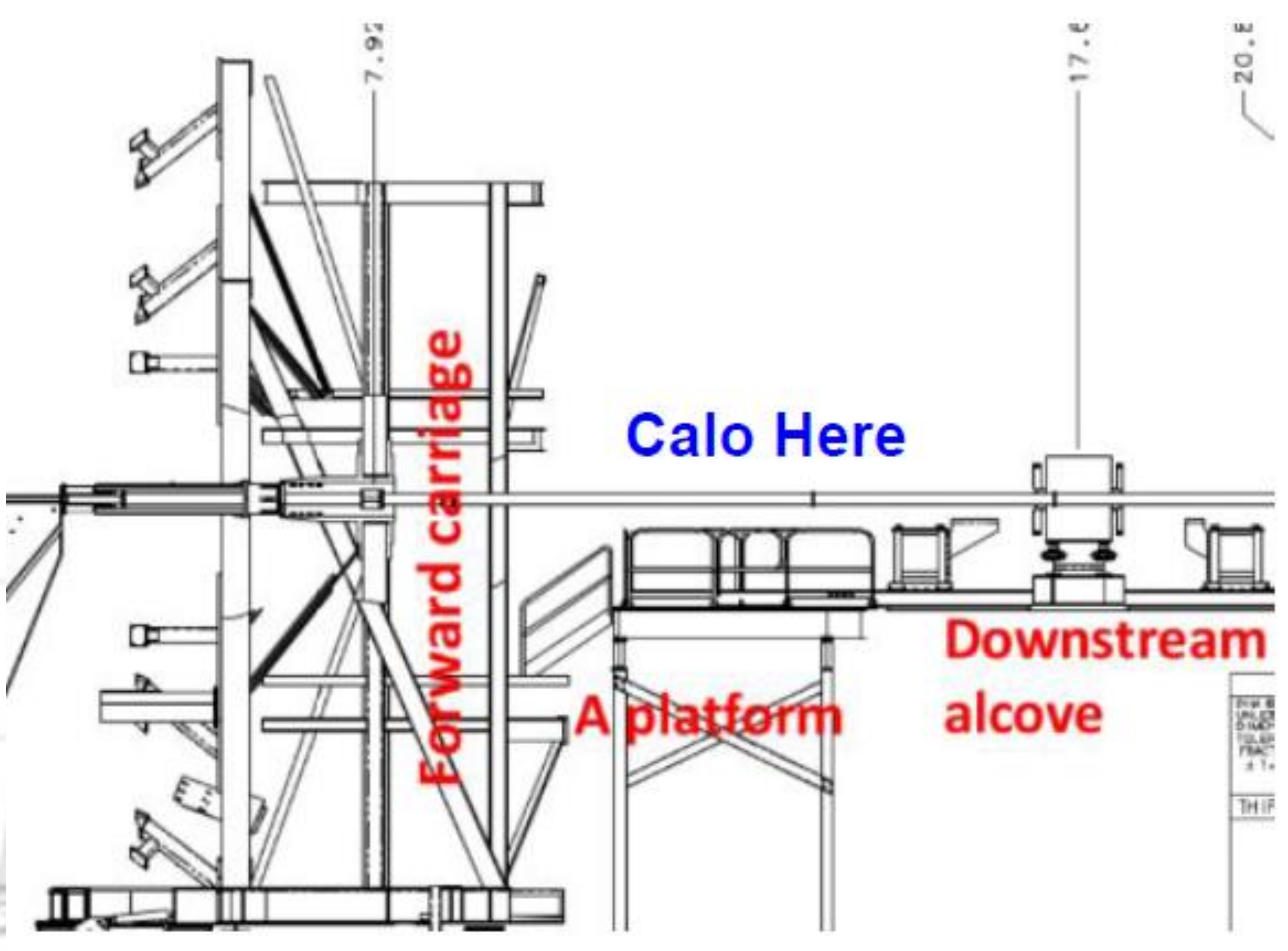


Minimum Ionizing Particle (MIP) Calorimetry

- Energy loss in matter: Bethe-Bloch formula, radiative corrections
- Large kinematic range of minimum Ionization
- Muons, other neutral hadrons



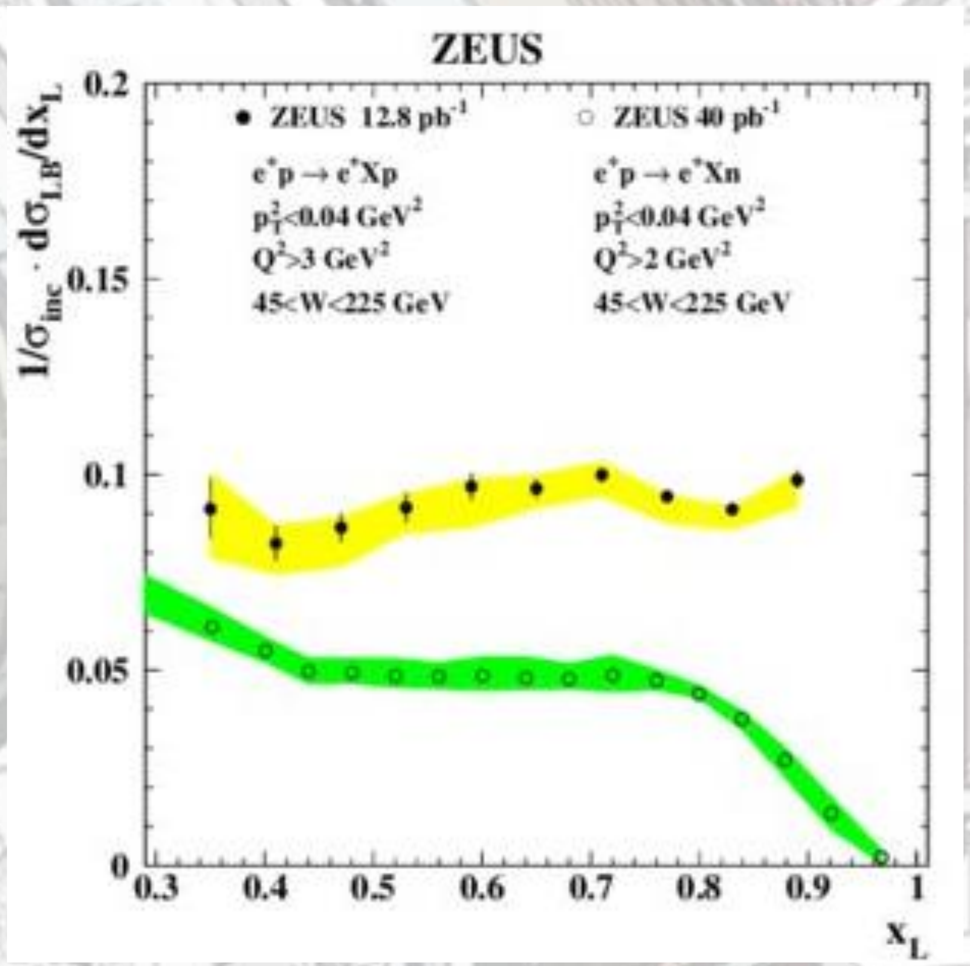
MIP Calorimeter at the CLAS



- Far forward ($\theta < 11°$) region
- Energy deposition and spatial tracking
- Neutrons, K_L, and Muon detection
- Currently at prototype stage
- Applications for Hall B and GlueX

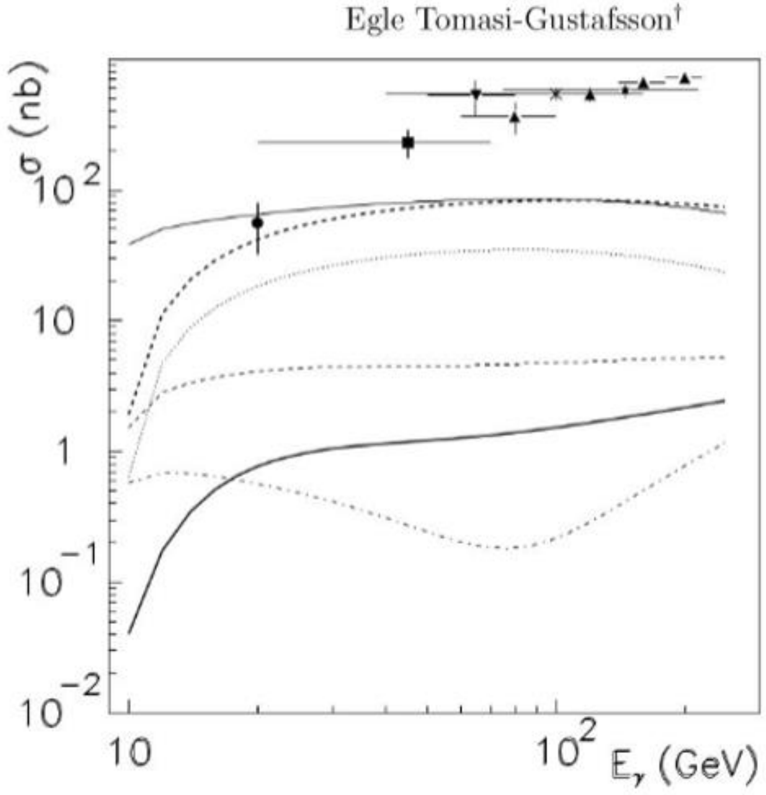
Neutron Detection

- High-x neutron emission
- SRC pair detection
- Hadronization model dependence
- Leading Neutron production, neutron spin asymmetries, isospin asymmetries

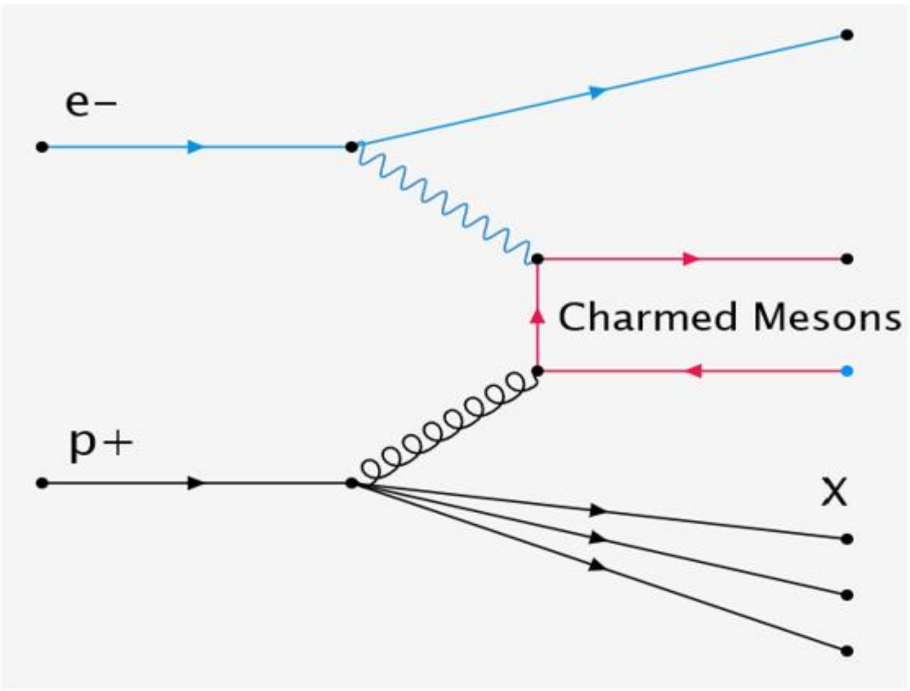


Muon Detection

- Muon tagging in open charm production
- Sensitive to GPDs
- Cross sections poorly constrained at low energy
- Relatively high decay to muons

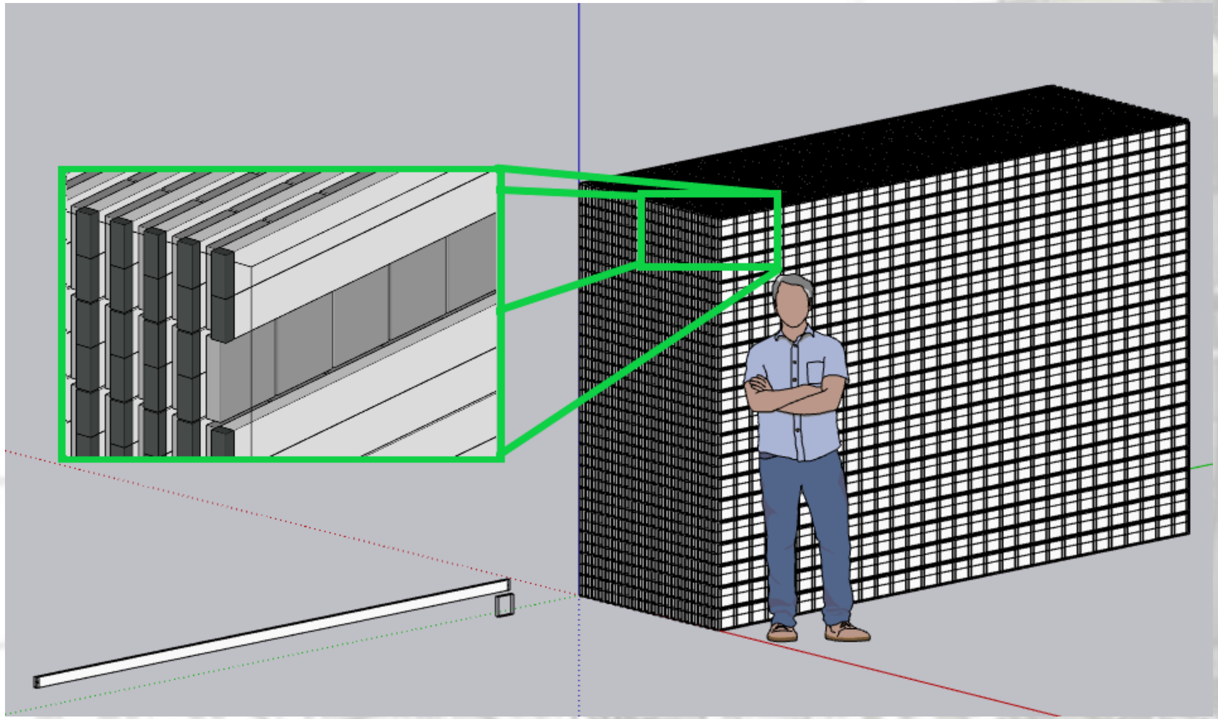


$\gamma + p \rightarrow \Lambda_c^+ + \bar{D}^0$ (solid line)
$\gamma + p \rightarrow \Sigma_c^{++} + D^-$ (dashed line)
$\gamma + p \rightarrow \Sigma_c^+ + \bar{D}^0$ (dotted line)
$\gamma + p \rightarrow \Sigma_c^+ + D^-$(thick solid line)
$\gamma + p \rightarrow \Sigma_c^0 + \bar{D}^0$ (thick dashed line)



Decay	BR
$D^+ \rightarrow \mu^+$ anything	(17.6 ±3.2) %
$D^+ \rightarrow K^-$ anything	(25.7 ±1.4) %
$D^+ \rightarrow \overline{K}^0$ anything + K^0 any-	(61 ±5) %

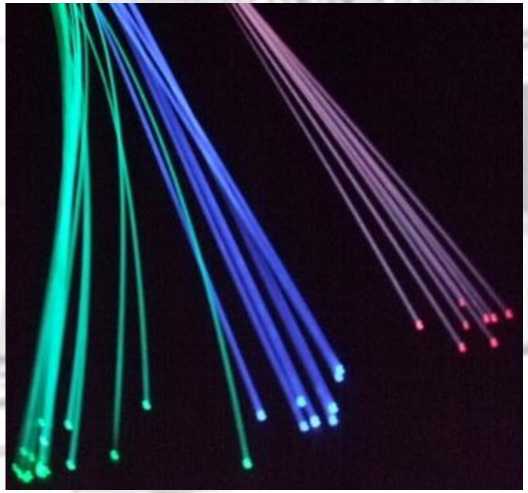
MIP Calorimeter Design

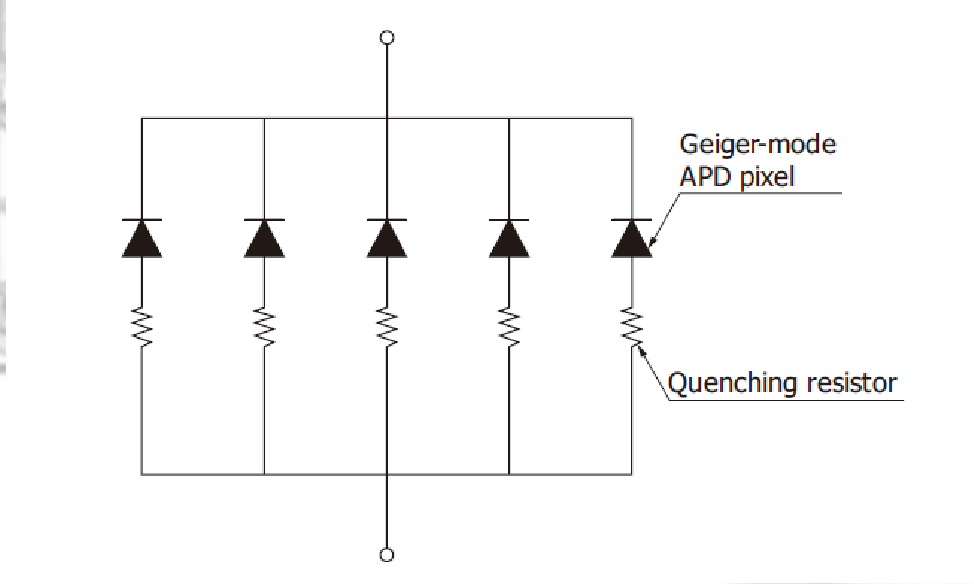


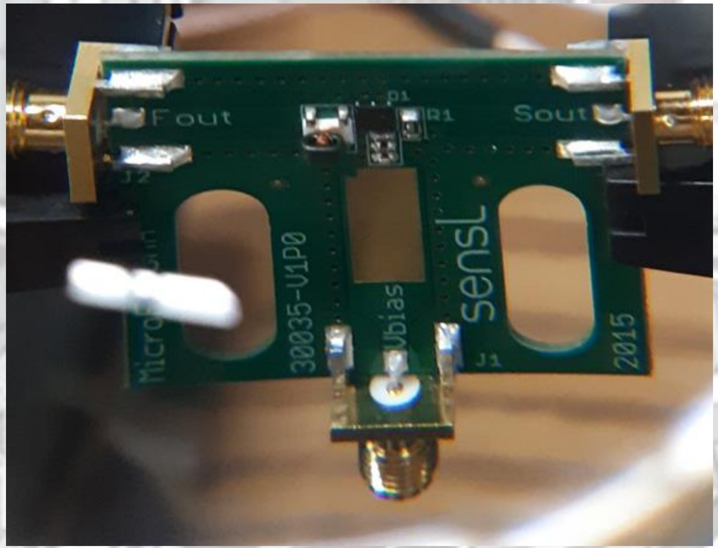
- Array of scintillating material
- Fast, high gain readout electronics
- Signal amplitude, timing correlate to energy deposition and location
- Based on previous designs used for muon tomography, muon telescopes

MIP Calorimeter Design

- Diphenyloxazole (PPO) doped plastic scintillator
- Wavelength shifting fiber
- Silicon Photomultiplier (SiPM), "multi-pixel photon counter"

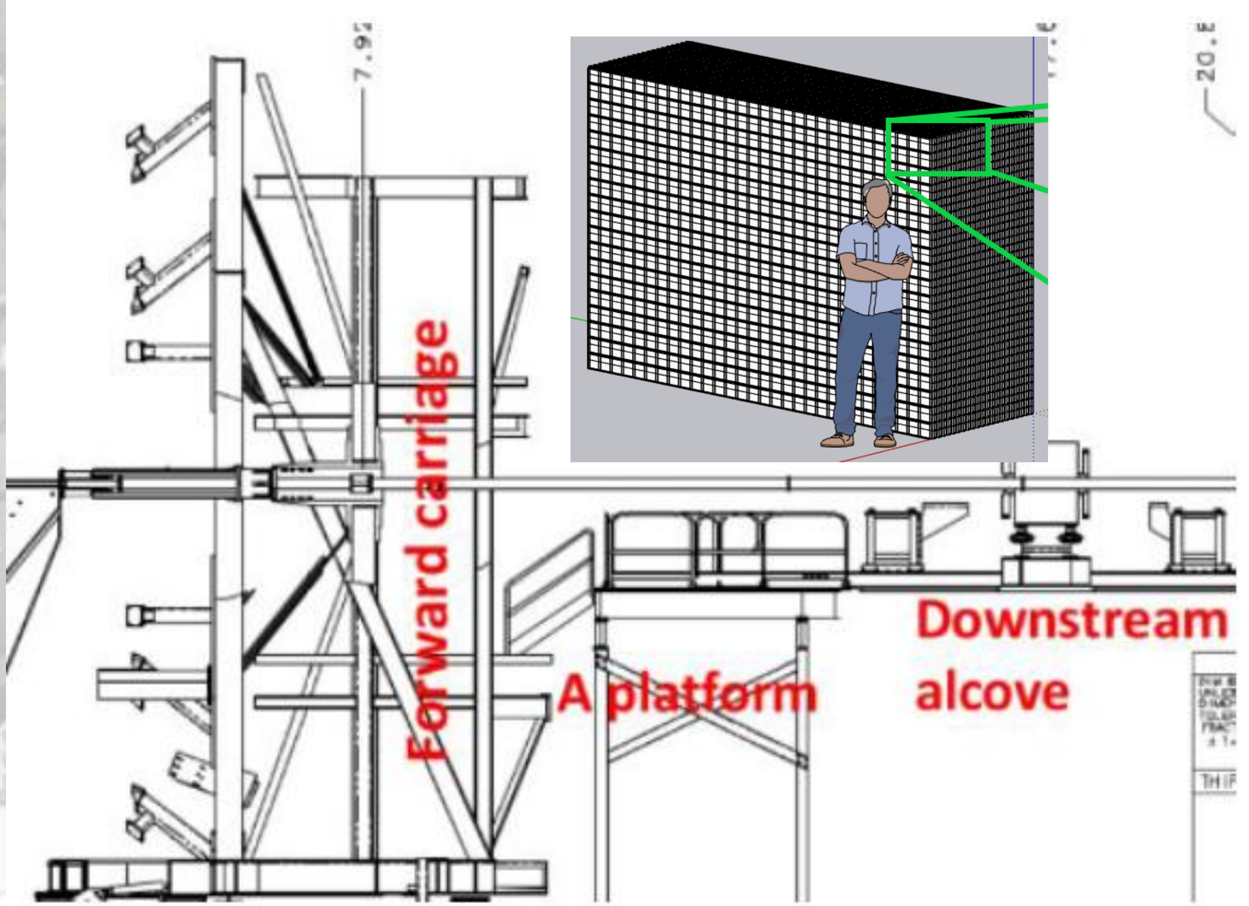




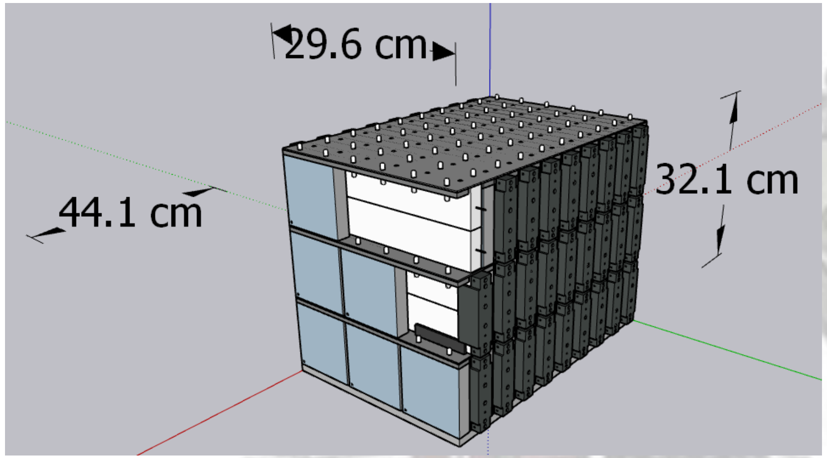


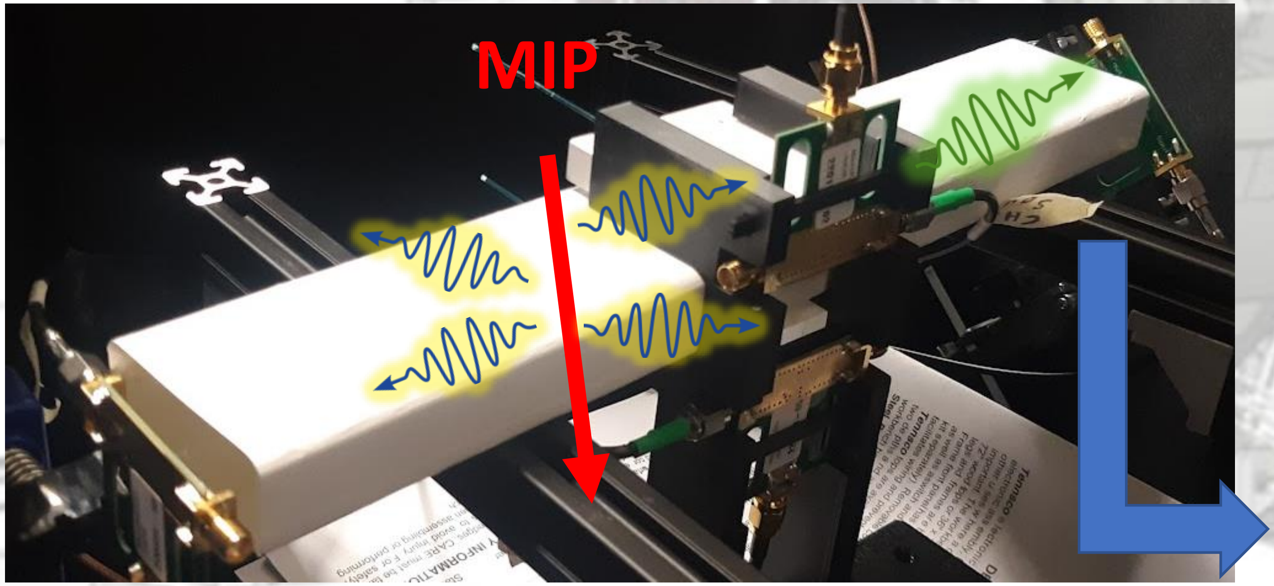
Implementation at the CLAS

- Placement behind EM cal.
- Relatively inexpensive, ~$0.5M
  - Plastic: ~$10/bar
  - Electronics: ~$100/channel
- Operationally simple: readout alternative to PMTs
- LOI within next year

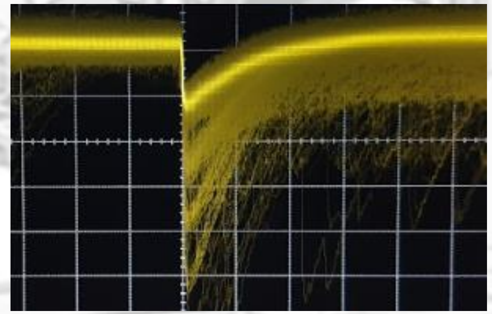


Benchtop Prototype



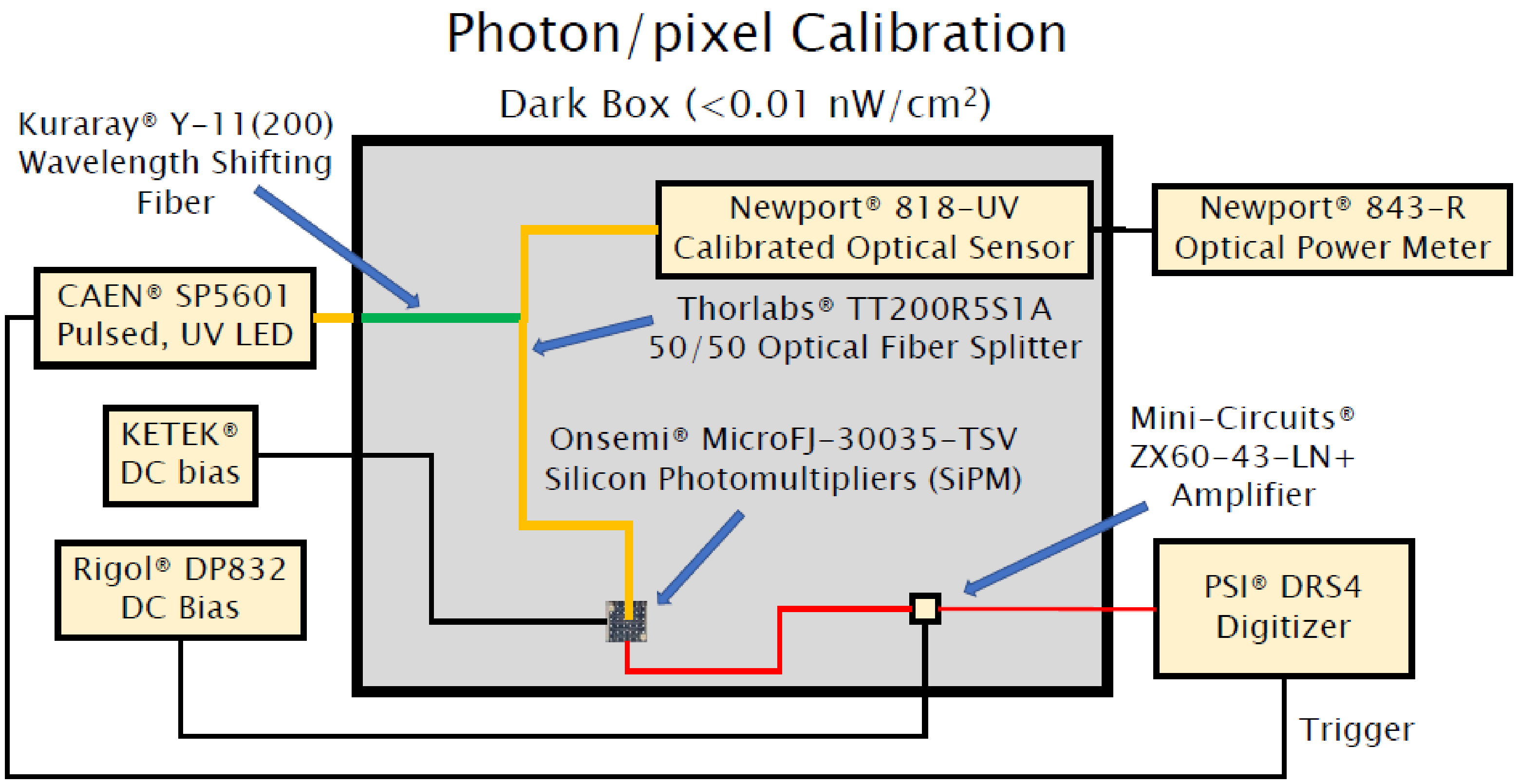


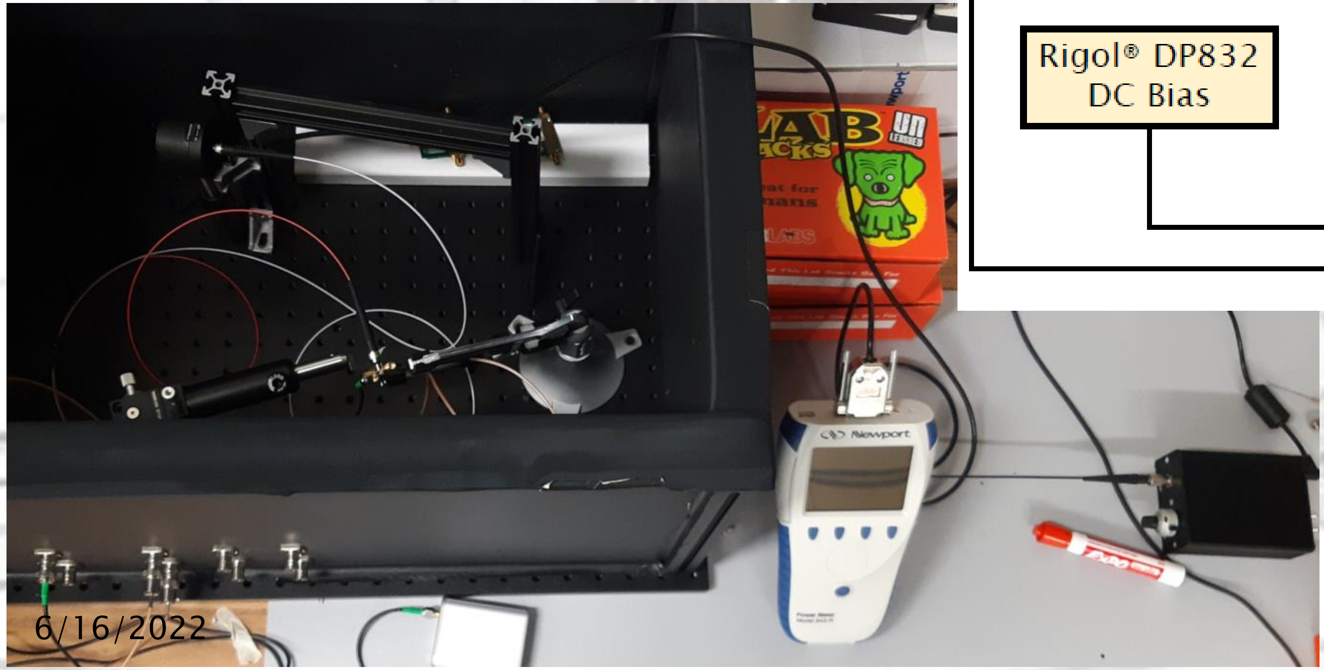
- Test unit comprised of single, scintillating bar and small scintillating tiles for triggering
  - MIP passes through bar
  - Bar scintillates in UV
  - Photons captured, wavelength shifted in fiber
  - Photons activate discrete pixels in SiPM



Benchtop Prototype

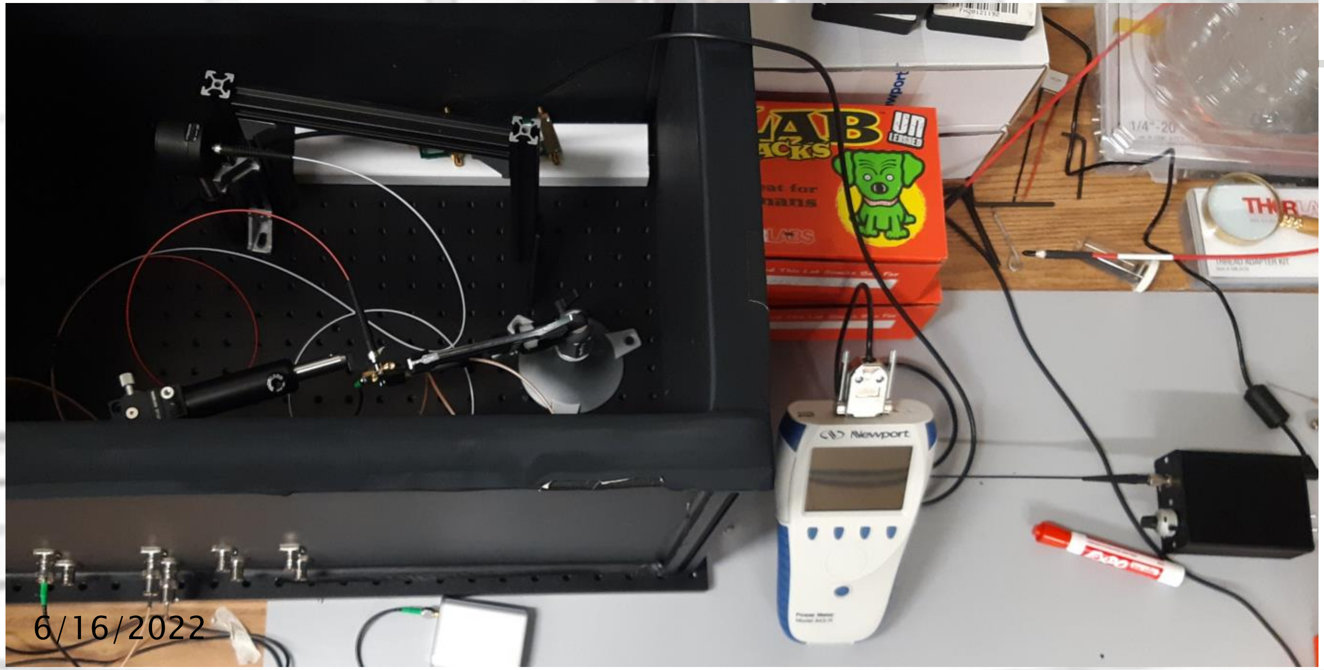
- LED simulates UV signal from MIP
- Calibrated photodiode determines photon flux

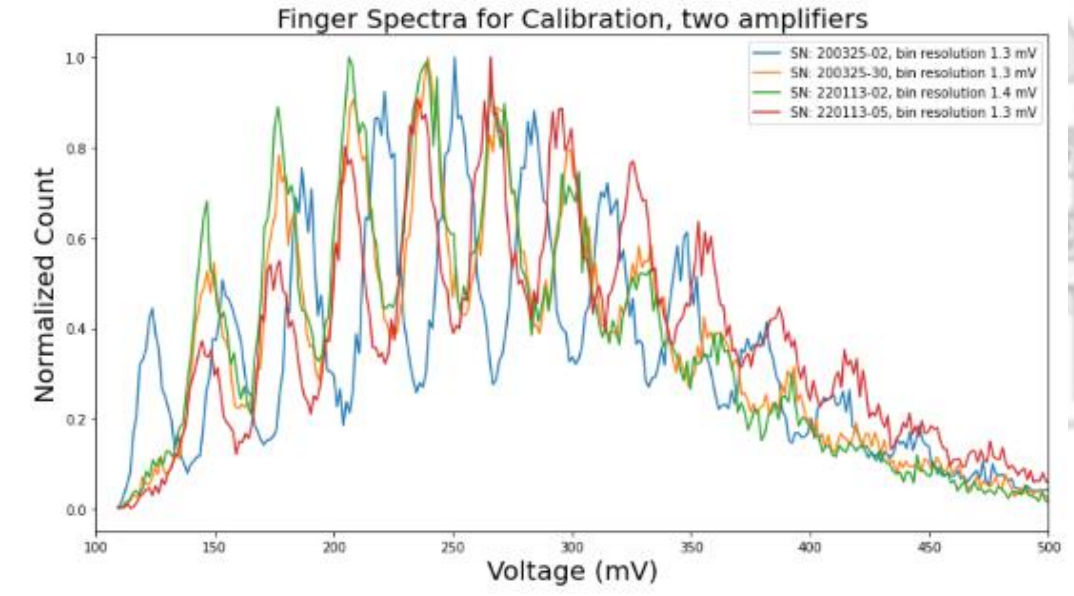


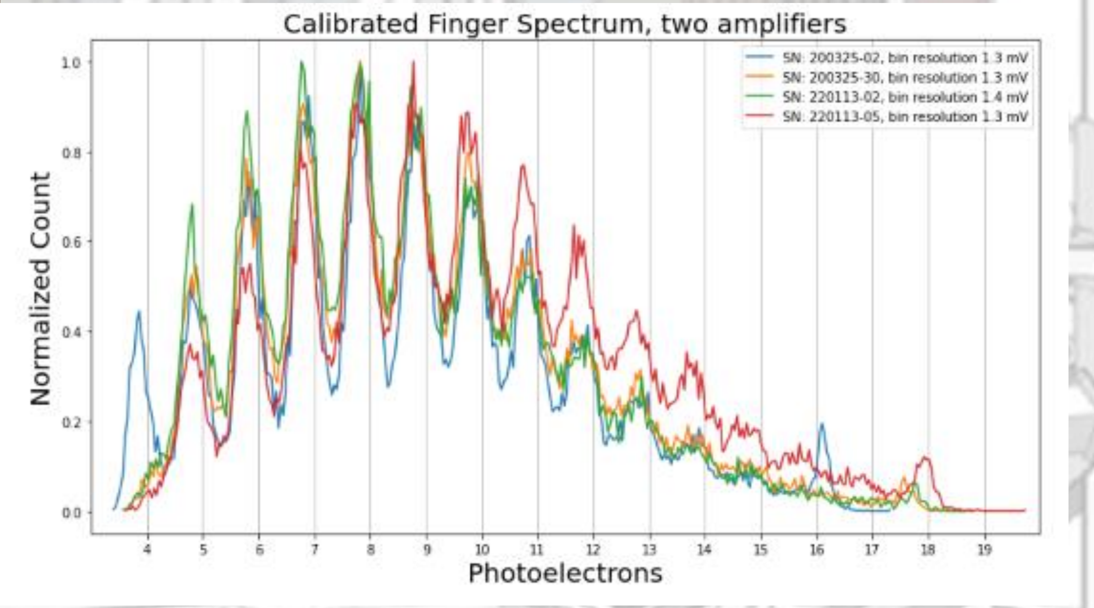


Benchtop Prototype

- SiPM pulse amplitudes produce "Finger spectrum"
- After calibration, ADC voltage converts to photon flux

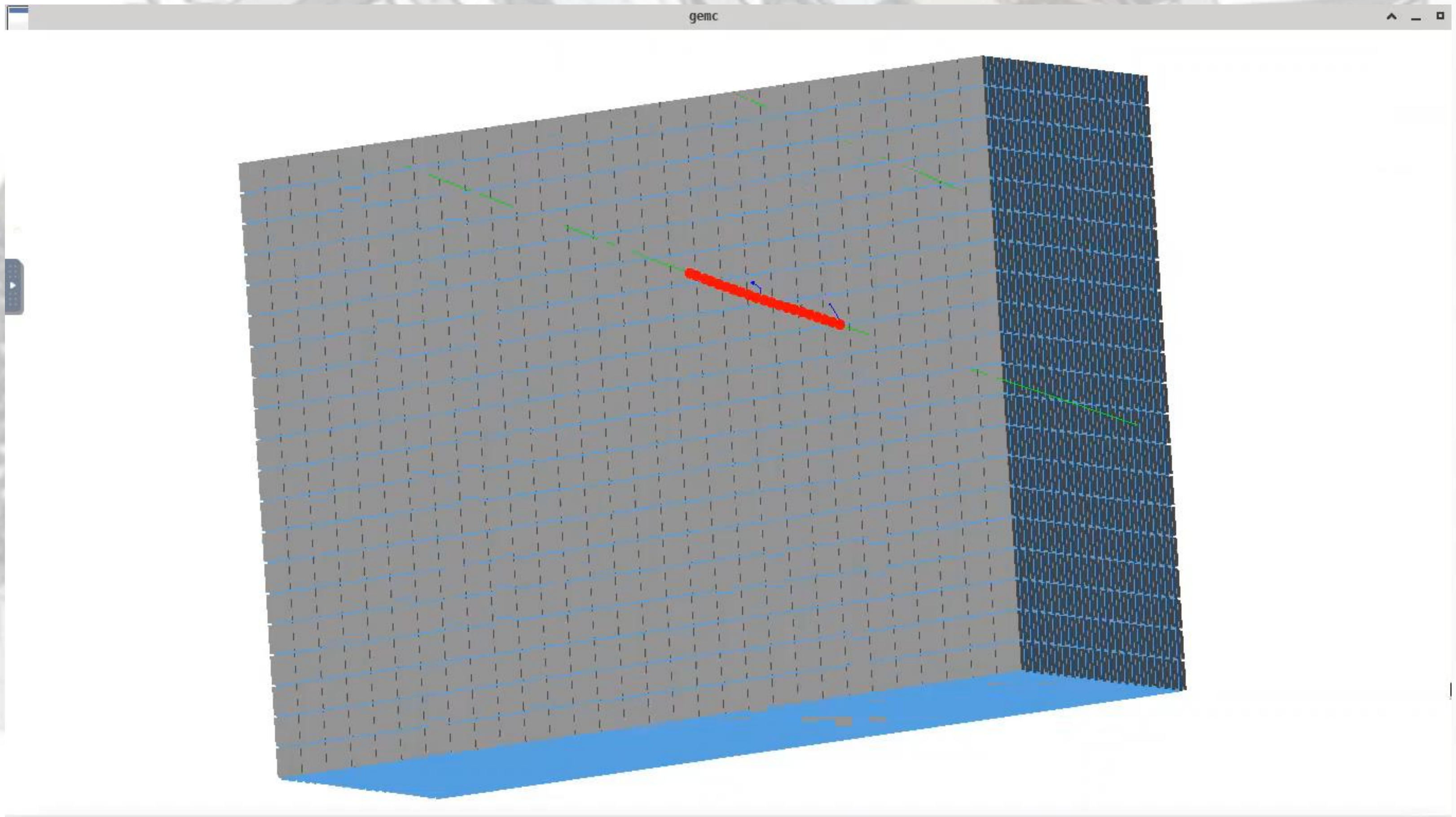






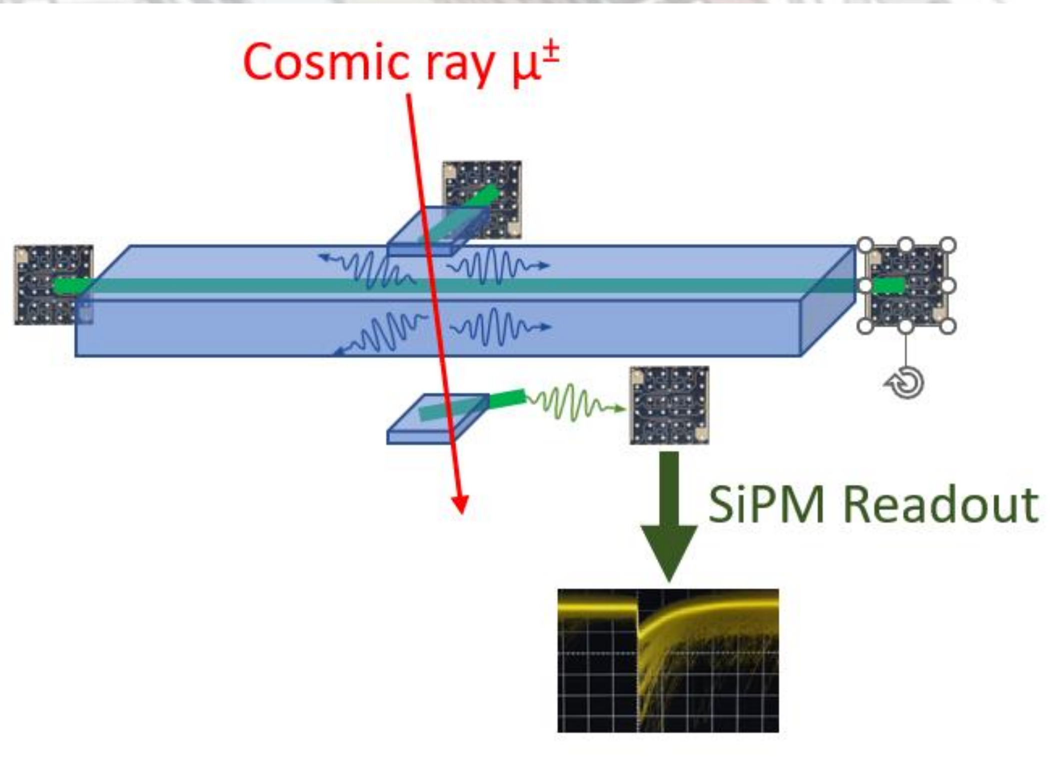
GEant4 Monte Carlo (GEMC) simulations

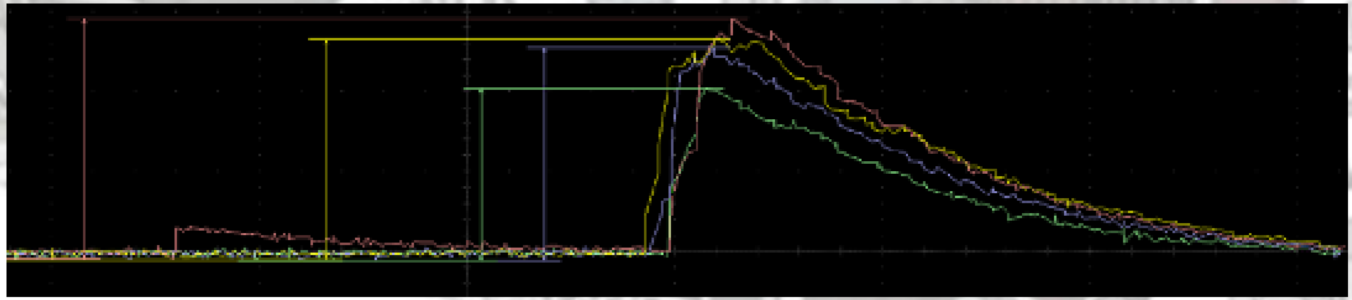
- Simulate expected performance; energy resolution, spatial resolution
- Good responsivity to incident muons
- Known radiation source can be used to calibrate simulated SiPM response



Cosmic Ray Test

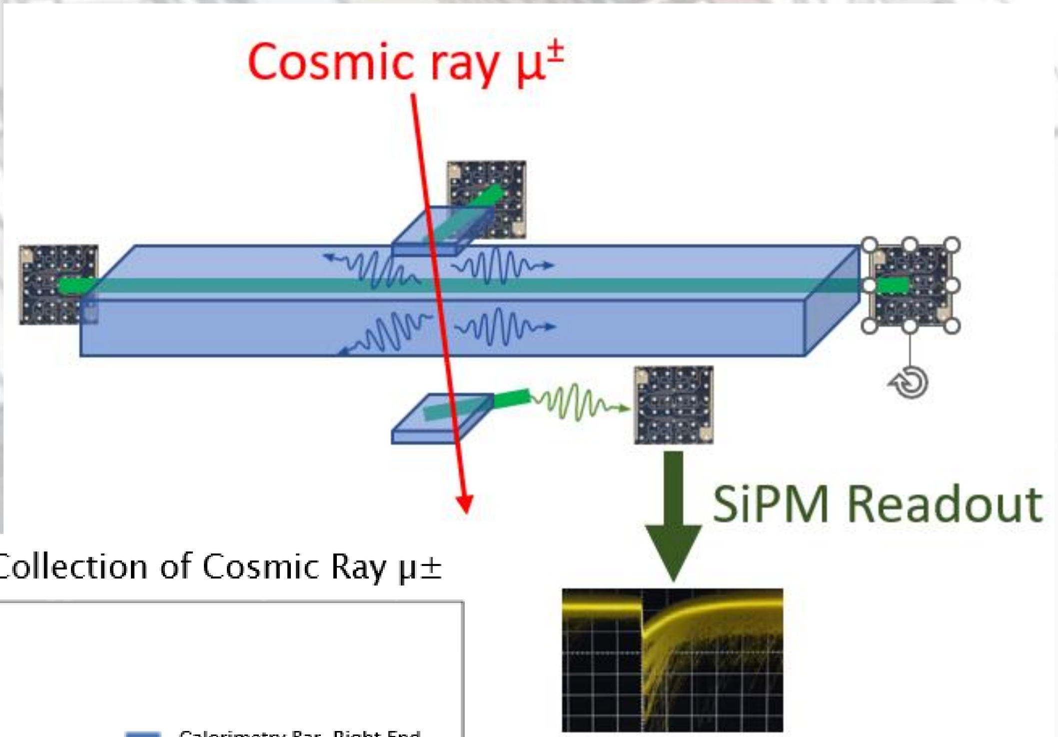
- We can test cosmic ray muons for free!
- Trigger by coincident detection at small tile above and below
- Signal collected from both ends of the bar

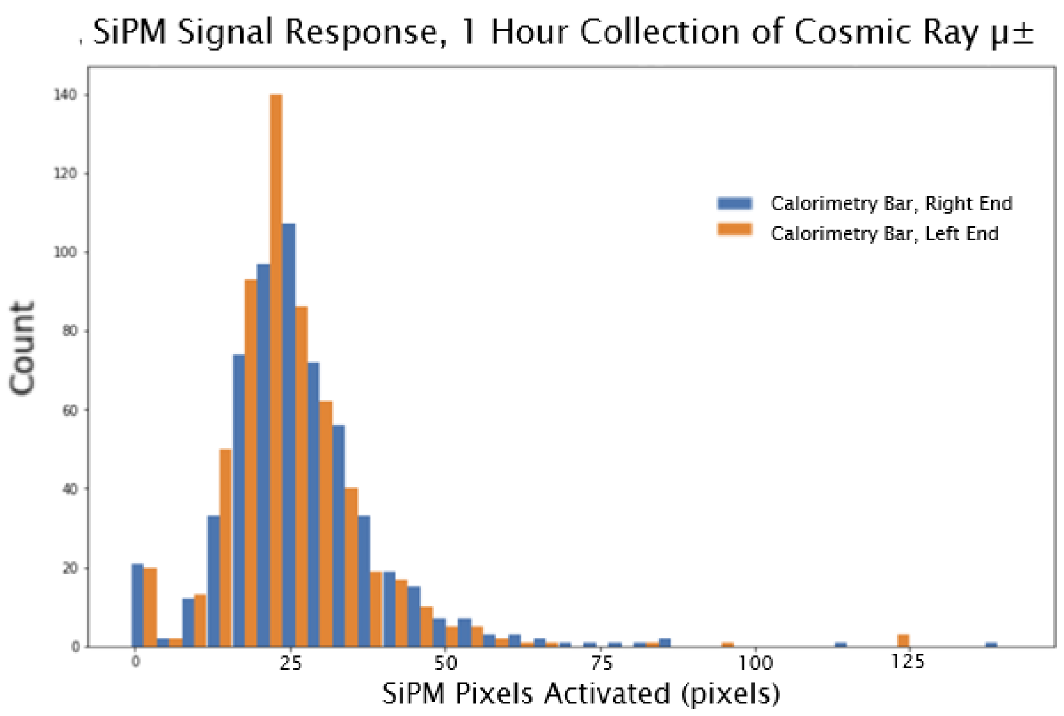




Cosmic Ray Test

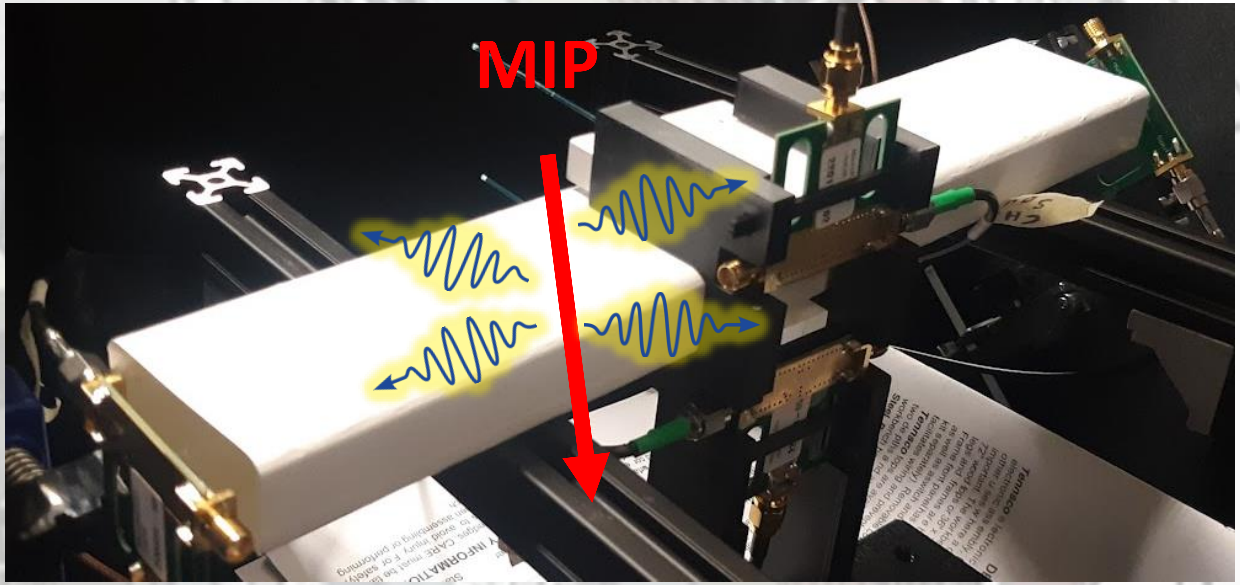
- Pulse amplitude spectrum is a Landau distribution – what we expect for cosmic rays!
- ~87% trigger efficiency
- Good correlation between ends of the bar

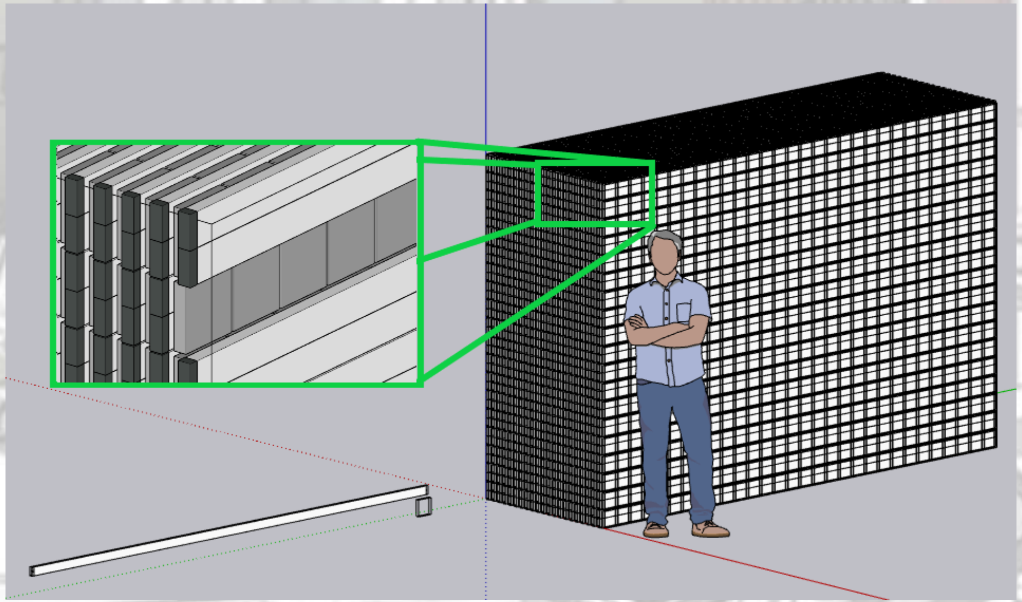




Next Steps

- Characterize responsivity of scintillating bars
- Complete GEMC simulations of SiPM response
- Scale benchtop model (and electronics) to full size
- Propose!





References

M. Battaglieri, “*Present and future of JLab CLAS12 physics program*” (2020)

A. Buniatyan, “*Leading Hadron Production at HERA*”, EPJ Web of Conferences (2013)

M. Arratia *“About a forward “KLM” calorimeter for CLAS12”*, (2022)

PDG Reviews *“33. Passage of Particles Through Matter”* (2018)

Image Sources

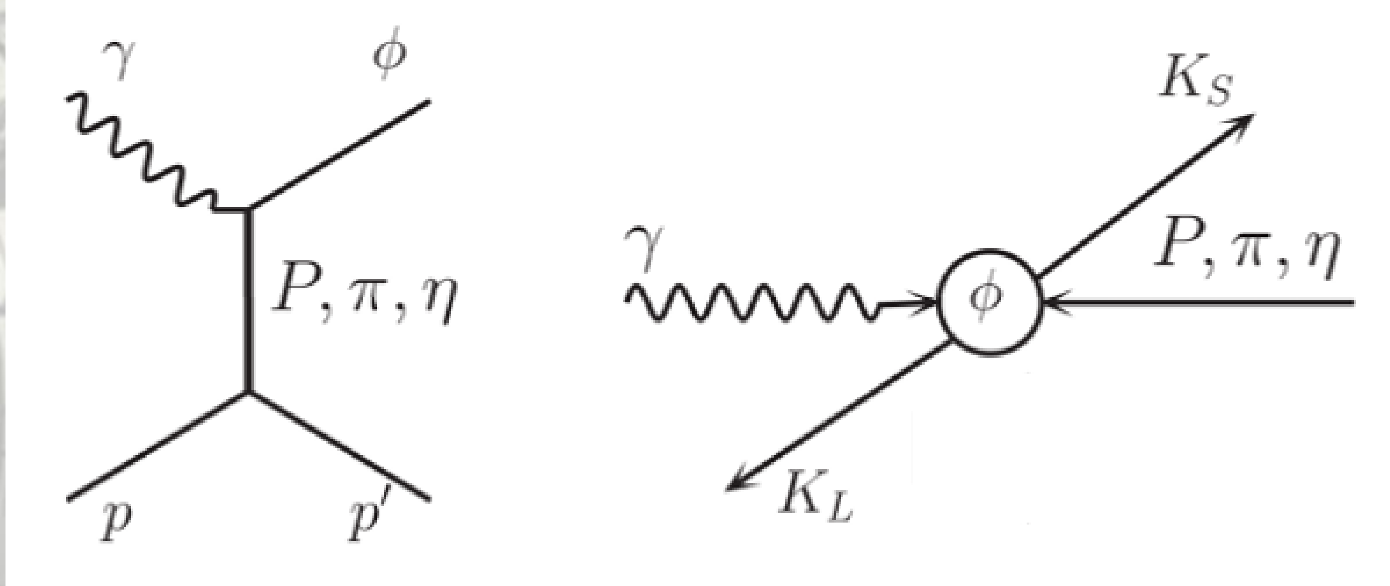
Jefferson Lab, https://www.jlab.org/physics/hall-b/clas12

Kuraray, http://kuraraypsf.jp/

Thank you to the Department of Energy for funding this research!

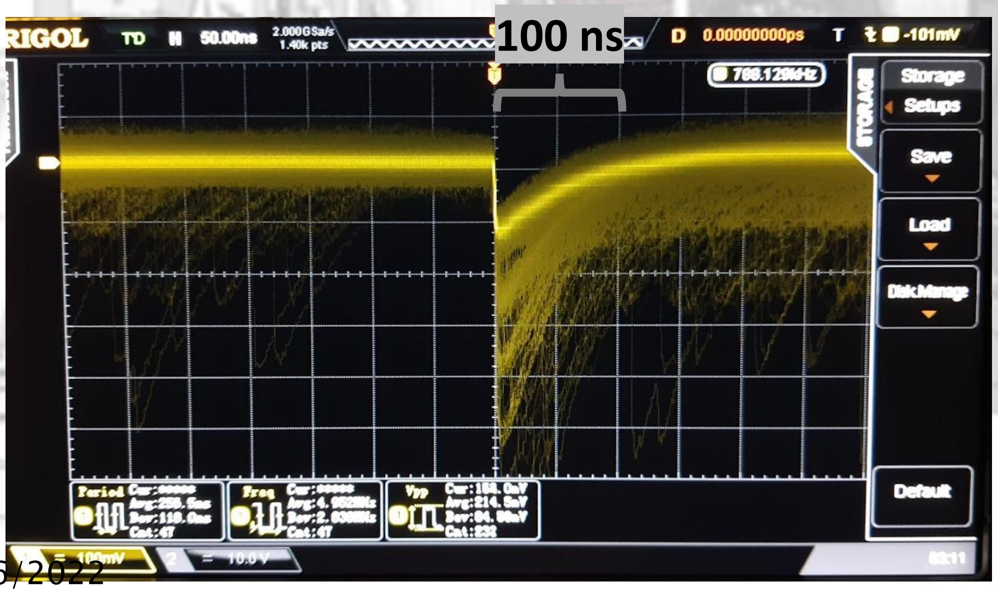
K_L Detection

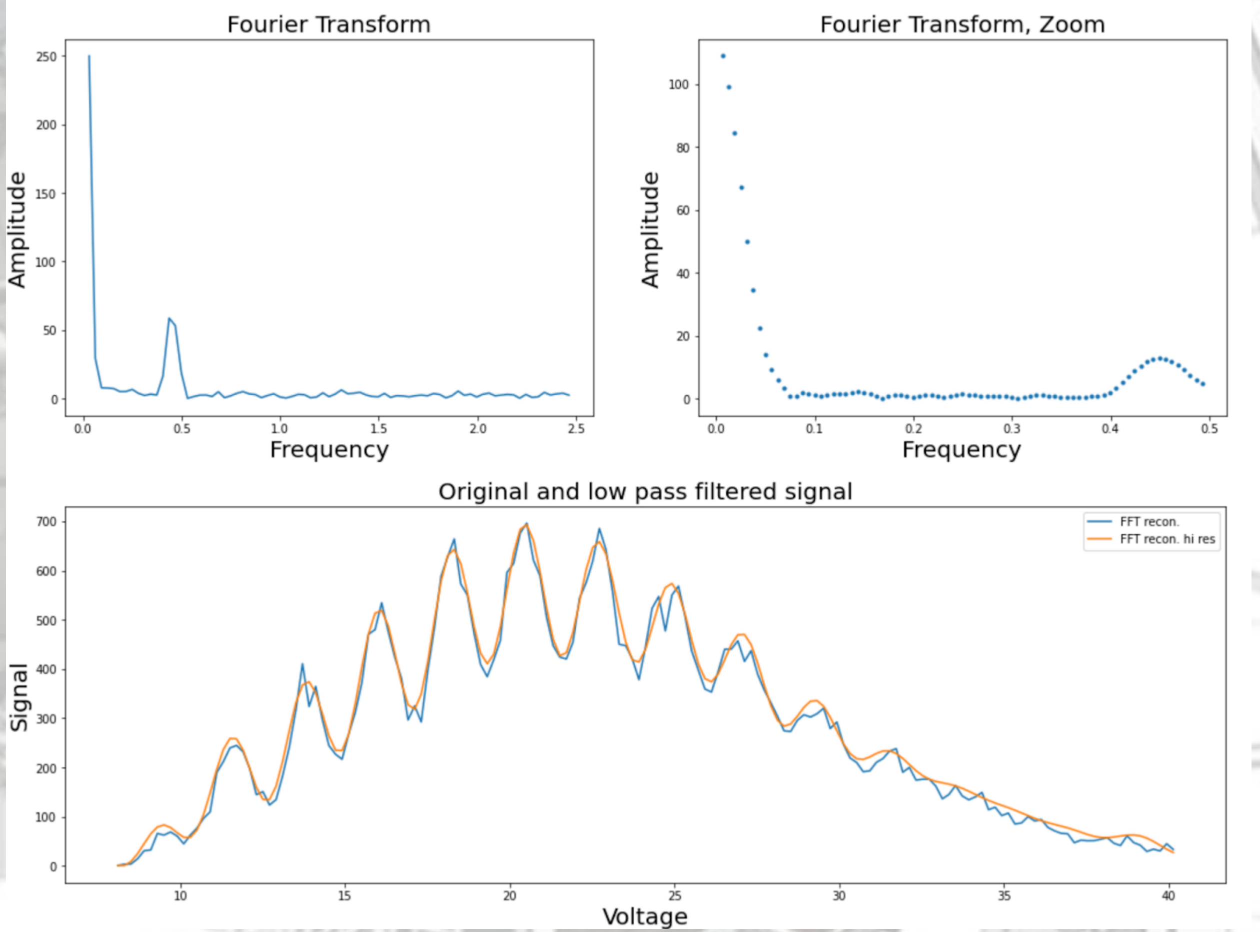
- Neutral kaon decay channels in vector mesons
- K_L decay length typically 10–100m
- Investigate CP violation



SiPM Signal Calibration

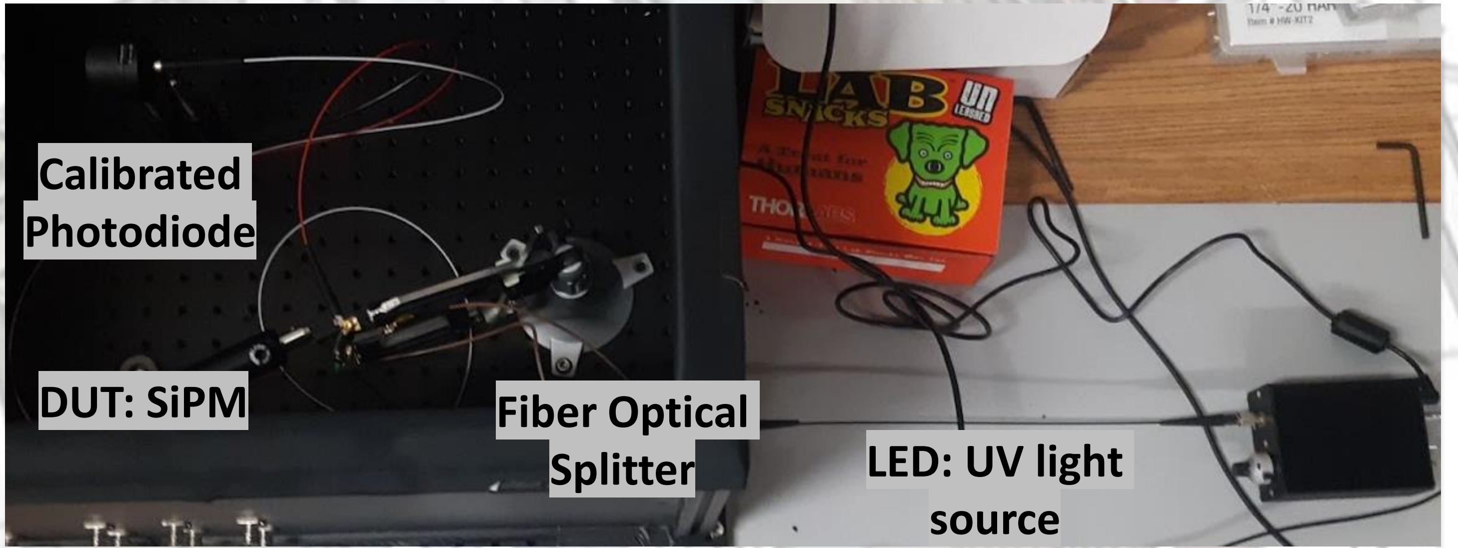
- Pixel count determined from low-intensity “finger spectrum”
- Gaussian noise floor and ~sinusoidal fingers separated by Fourier Transform

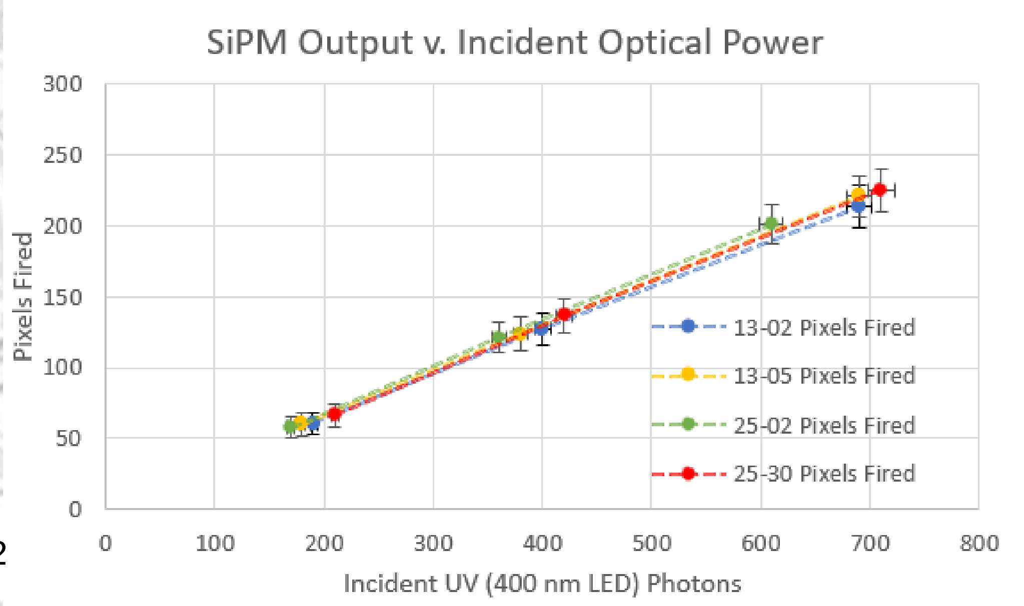


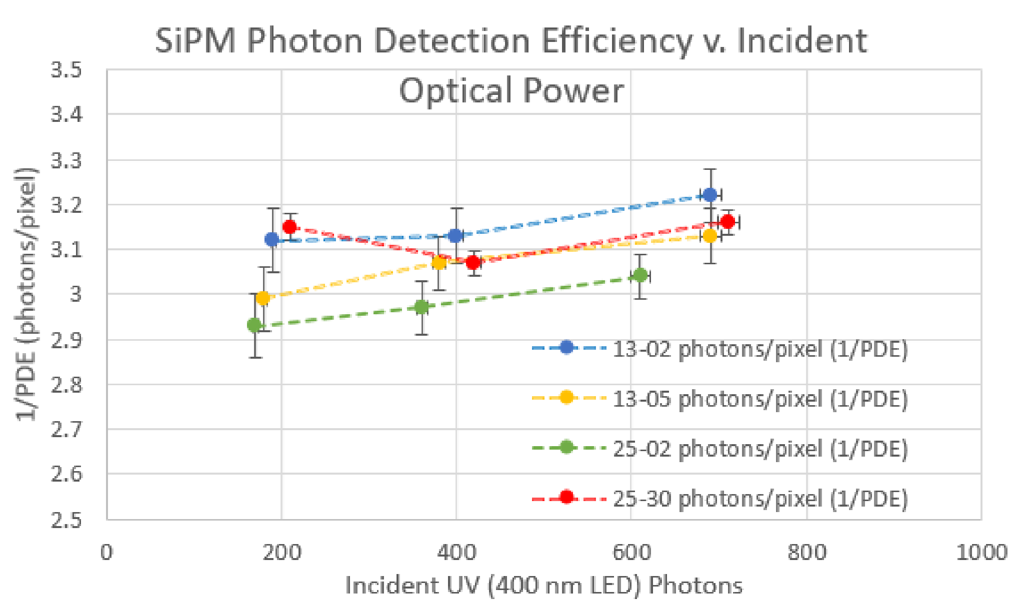


SiPM Signal Calibration

- Incident photon count determined from Newport calibrated photodiode
  - Constant splitter ratio
  - Calibrated diode measures average power from LED
  - SiPM pixel count “measures” photons/pulse







Calorimeter Trigger

- Smaller tiles of scintillating plastic above and below bar trigger data collection
- Trigger occurs if both SiPM are above the 3.3 pixel threshold
  - Requiring coincidence between tiles removes background noise
  - With scintillator material added, high energy coincident spectrum appears – not Landau