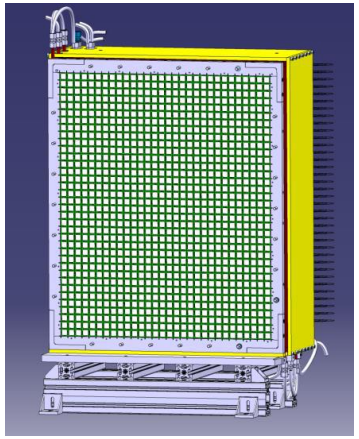
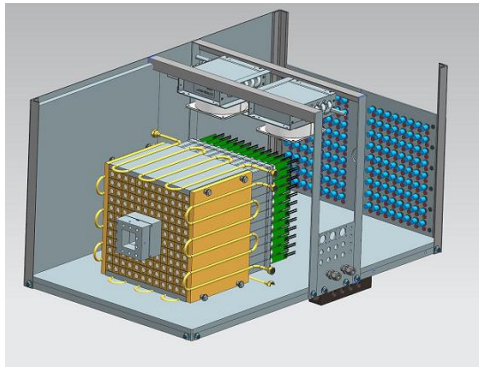
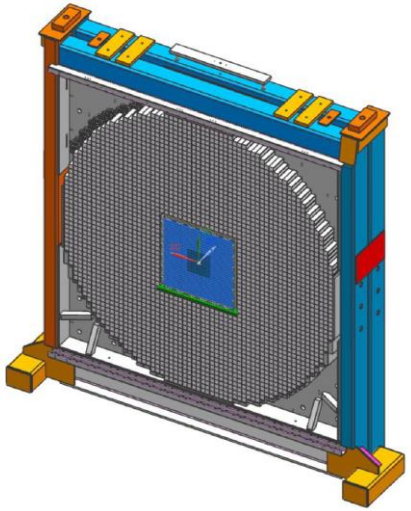






Beam Tests of $PbWO_4$ Crystals and Calorimeter Modules using Hall D Pair Spectrometer

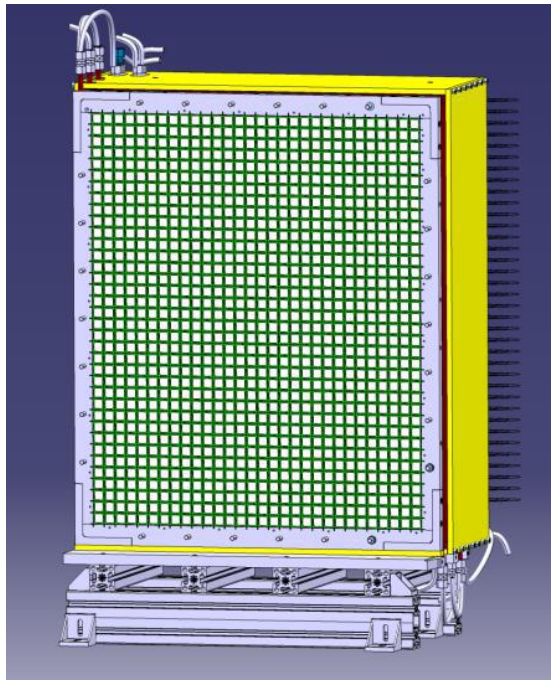
JLab EIC meeting, January 28

A. Somov, V. Berdnikov, T. Horn, J. Crafts, and A. Asaturyan

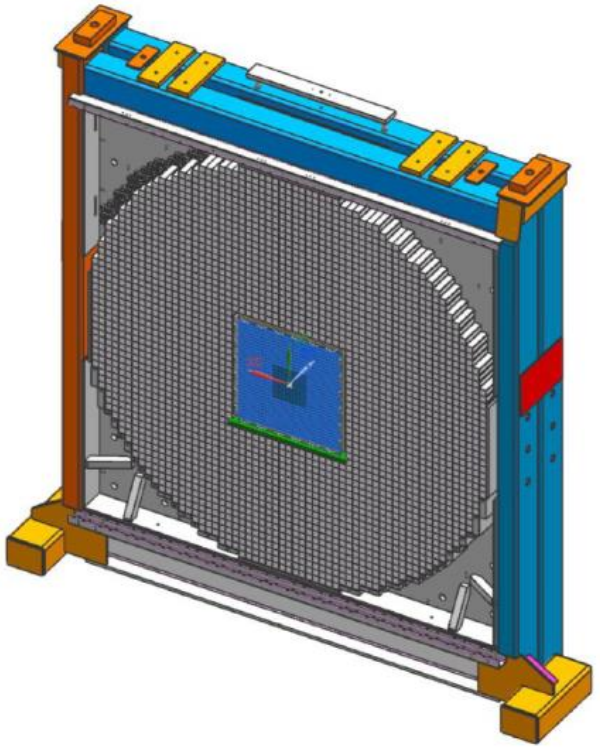
Introduction

Two $PbWO_4$-based calorimeters are currently under construction at Jefferson Lab

NPS (Hall C)



FCAL 2 (Hall D)



- Crystal size:

  2.05 cm x 2.05 cm x 20 cm

- Procured from two vendors:

  - SICCAS (China)

  - Crytur (the Czech republic)

- Crystals of the same size are considered for EIC

Beam Tests

- Crystal characterization for JLAB and future EIC
- Optimization of readout electronics
- Optimization of the module design (FCAL 2)
- Study detector properties

- Use leptons provided by Hall D pair spectrometer to check / study crystals and small prototypes
- Build a large scale prototype (140 modules). Used to reconstruct Compton scattering events in the PrimEx - η experiment during runs in 2019 and 2021

Timeline

April 2018 - First test of the 3 x 3 prototype using PS test setup
Study read out electronics, operation conditions (some features observed)

October 2018 - Construction of Compton Calorimeter (140 modules). Installed in Hall D
for the PrimEx-η experiment. Study electronics, detector resolution, performance at high rate

Spring 2019 - first tests of crystals using PS setup. Continue with the PS beam tests since then

Fall 2019 - new tests of 3 x 3 prototypes using PS test setup (new electronics). Good agreement
of the energy resolution with CCAL. Some results added to Nucl. Inst. Meth. A956 (2020) 163375

Fall 2019 - optimize design of the FCAL 2 module. Study light guides. Nucl. Inst. Meth. A 1013 (2021) 165683

Fall 2021 - CCAL 2 in the new PrimEx-η run (new electronics, updated LMS system)

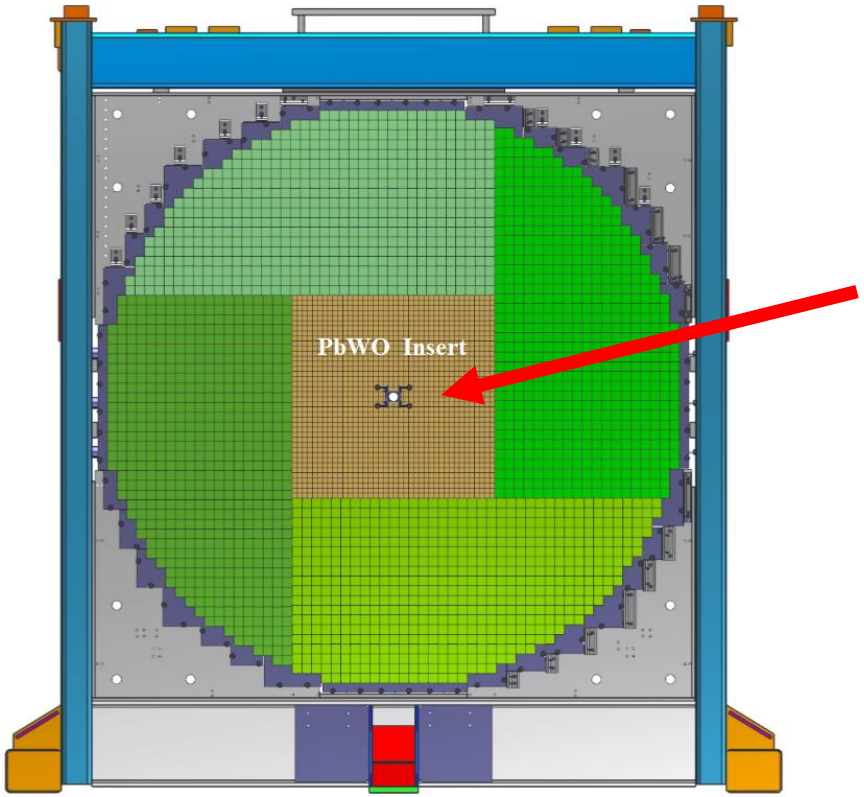
Fall 2021 - test fabricated FCAL 2 modules using the PS setup

Fall 2021 - various tests of calorimeter prototypes (PMT and SiPM readout), test scintillator
glass modules using the PS setup

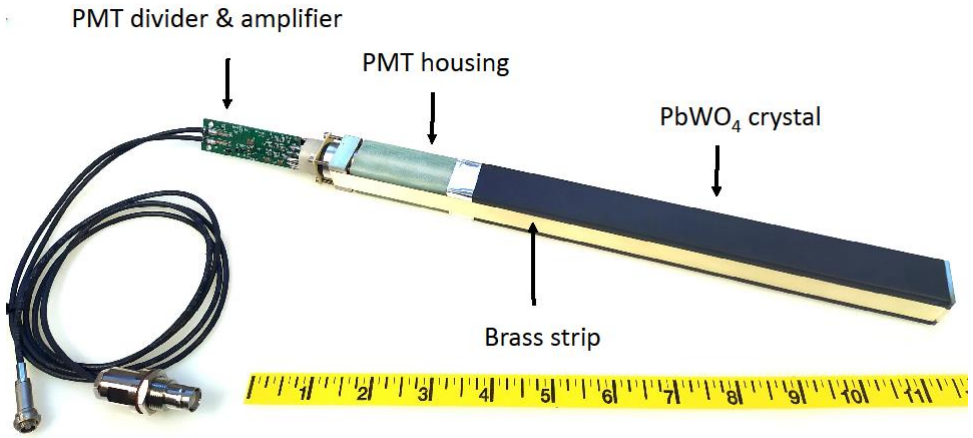
A lot of details about testing of prototypes are in Vlad's talk

Hall D Calorimeter Upgrade (FCAL 2)

Forward Calorimeter



$PbWO_4$ module



- Install an array of 40 x 40 $PbWO_4$ modules in the inner part of the FCAL (replace lead glass modules)

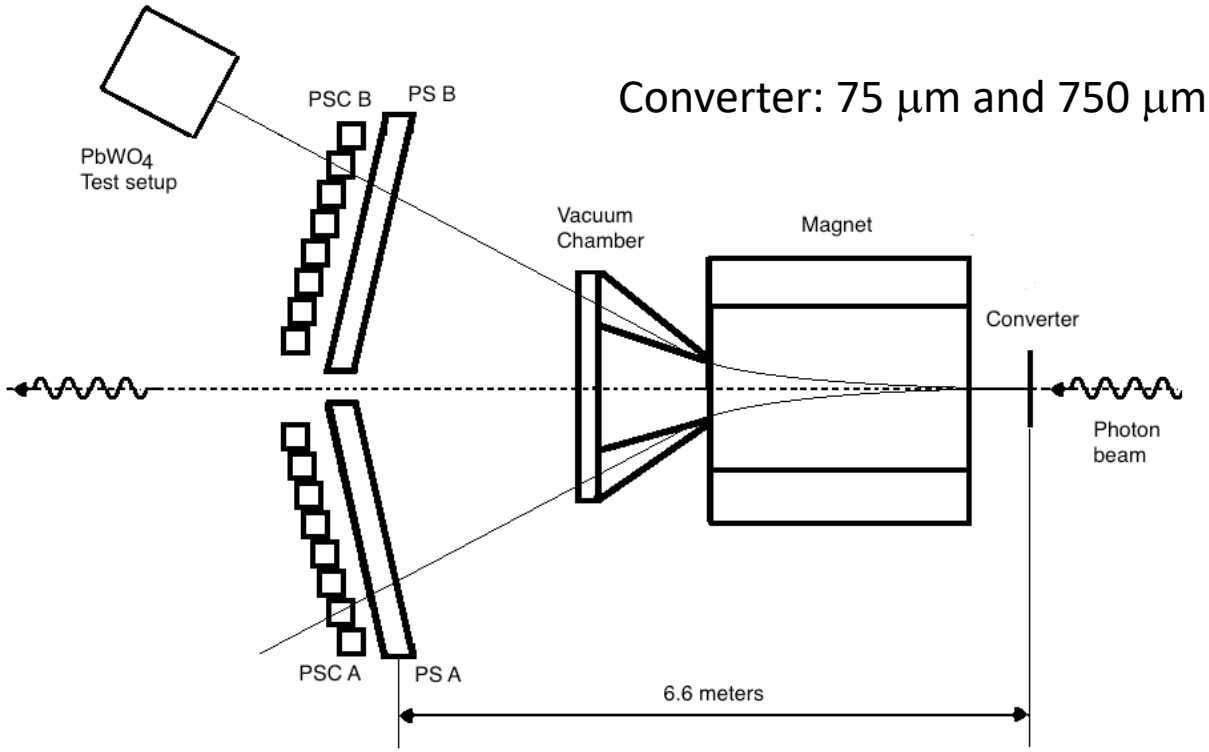
  - 2 cm x 2 cm x 20 cm $PbWO_4$
  - 4 cm x 4 cm x 45 cm lead glass

- A factor of 4 better detector granularity
  - significantly improve shower separation

- Improves the energy and position resolution by about a factor of 2

Hall *D* Pair Spectrometer and Test Stand

Nucl. Inst. Meth. A795 (2015) 376
new paper in preparation



Converter: 75 μm and 750 μm Be

Note, the energy range can be changed by changing the magnetic field (special runs)

Pair Spectrometer Scintillator Counters:

PSC coarse counters, trigger, time

PS high-granularity, energy measurement
145 counters per PS arm

- energy range: 3 GeV – 6.25 GeV
- size of the counters: 1 mm and 2 mm (at 6 GeV)

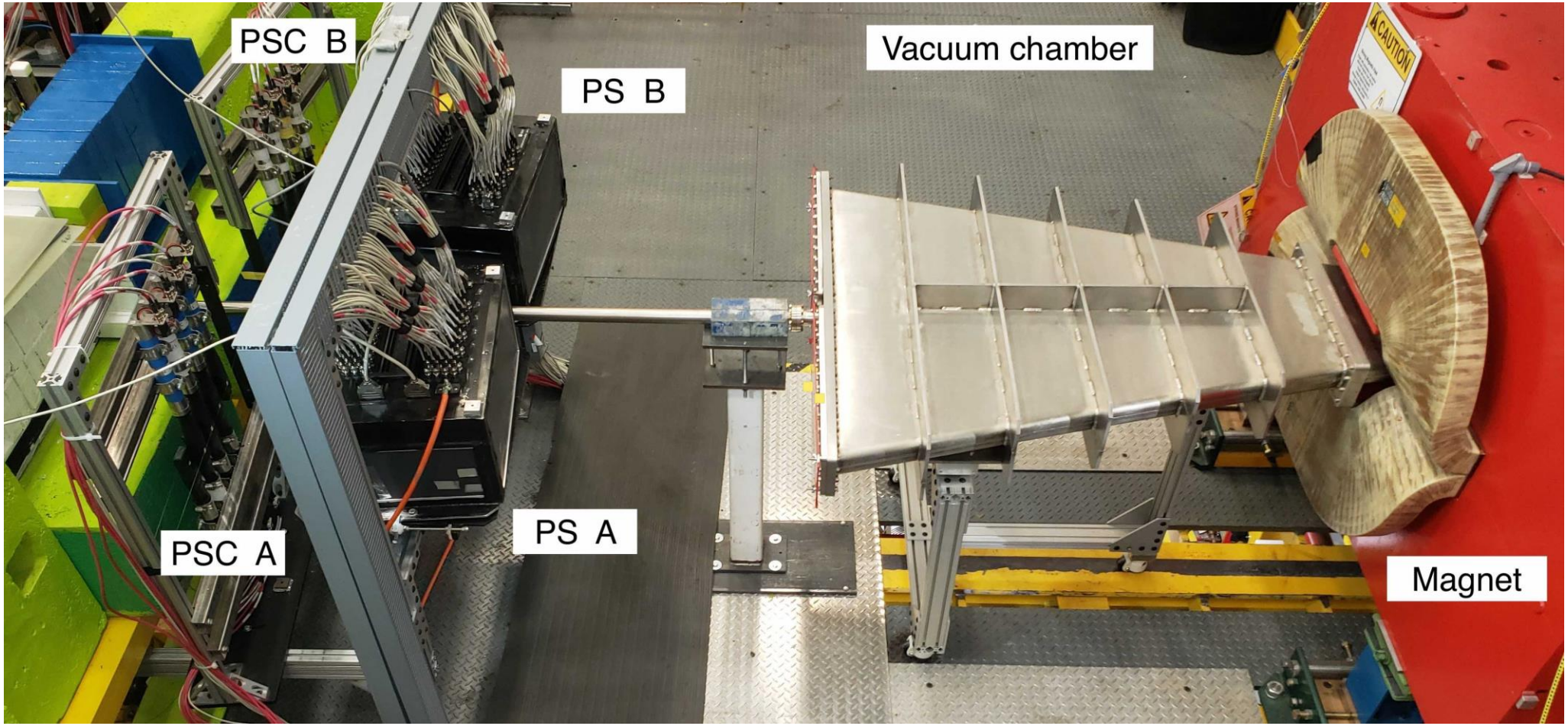
Beam collimator size:
- 5 mm (GlueX production), 3.4 mm, and 1 mm

Typical energy resolution:
0.5 % - 0.8 % for 3 GeV and 6 GeV leptons
(0.4 % is 1 mm collimator is used)

Rate (coincidence of arms) during production runs: ~6 kHz

Time resolution: ~100 ps

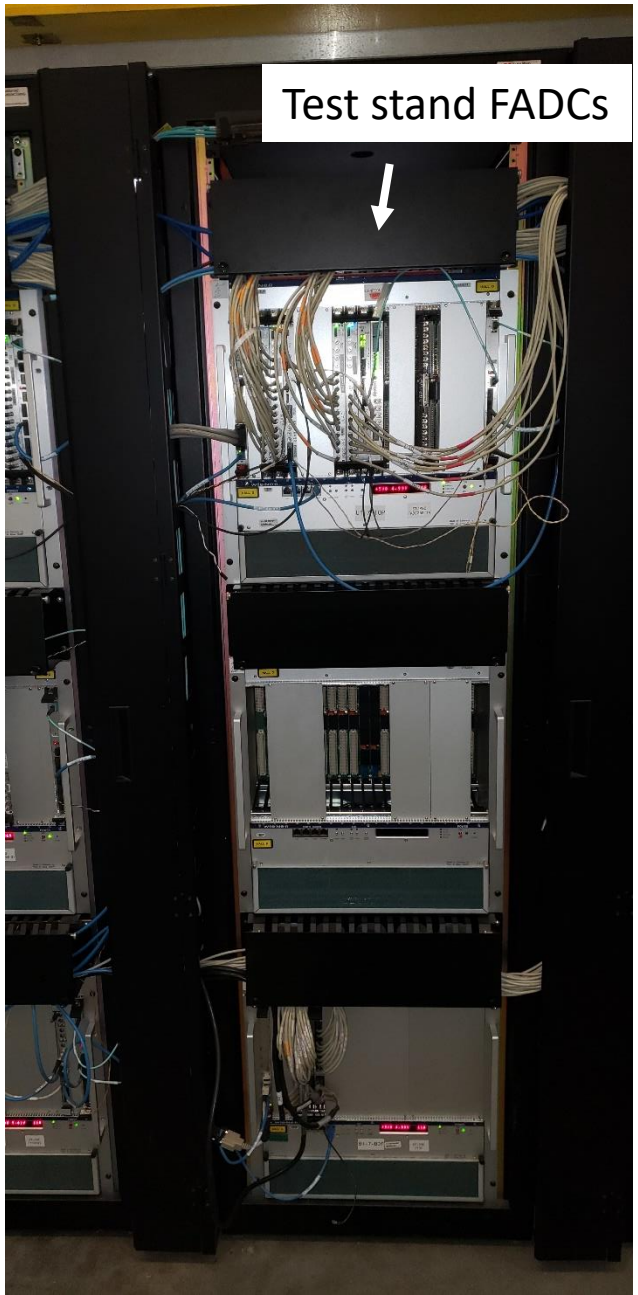
Hall *D* Pair Spectrometer



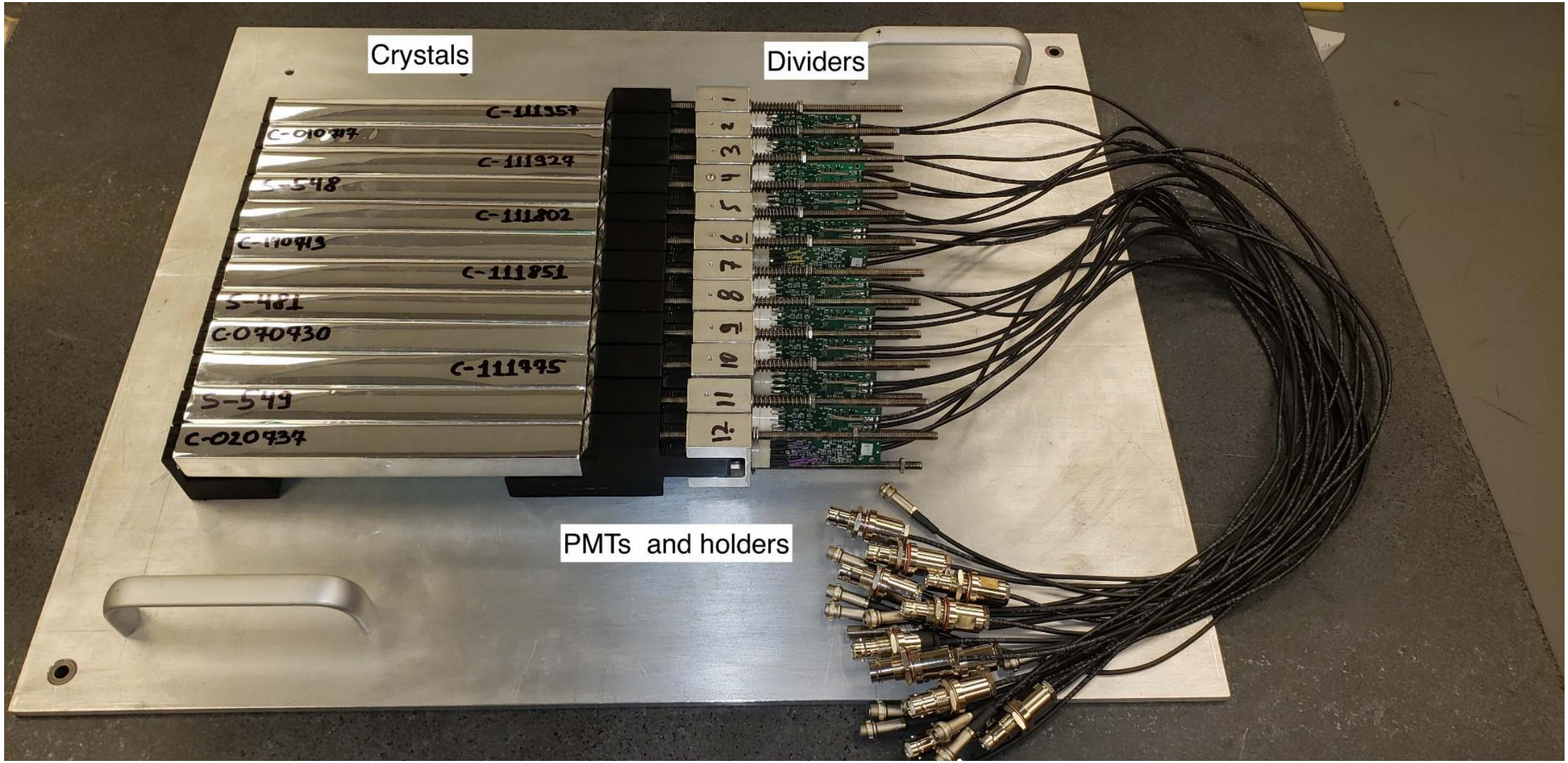
Electronics and Trigger

- 12 channels of the crystal tests stand
- 10 channels for the calorimeter prototype
  - HV and signal cables
- Read out using FADC 250
  - two FADC modules placed in one of the Hall D VXS crate
- Integrated to the GlueX DAQ / trigger system
  - readout using Pair Spectrometer trigger
  - independent configuration of test stand FADCs (change thresholds, readout mode, …)

Perform tests in parallel with the GlueX data taking

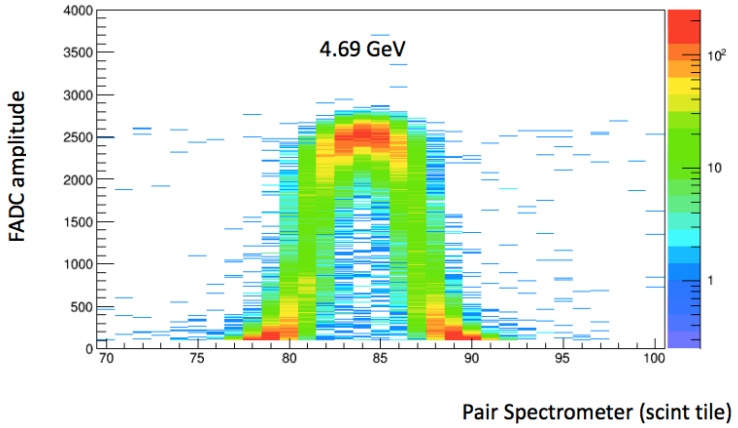


Test Setup for Crystals



PS Test Setup in Hall D

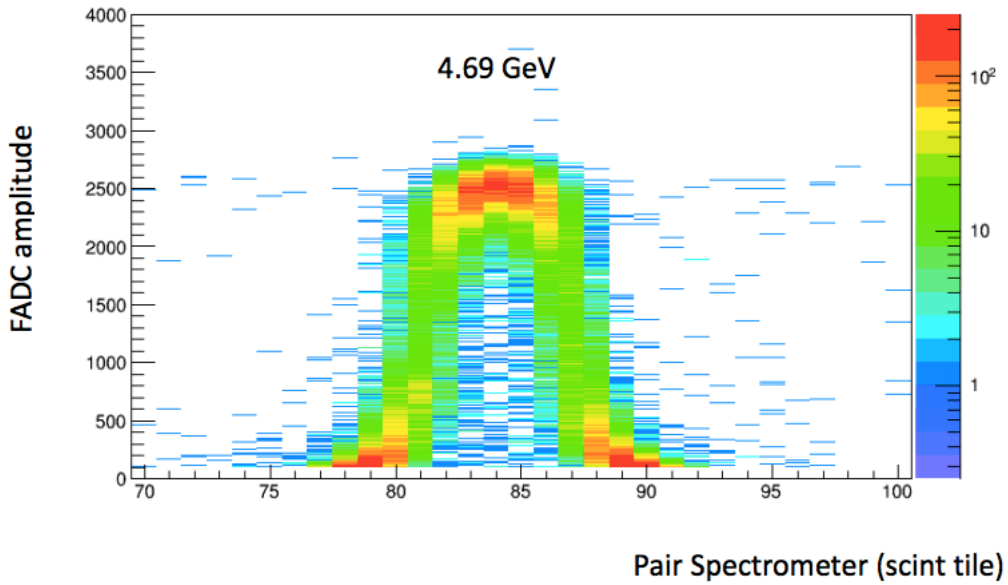
‘Projection’ of the crystal to the PS hodoscope



GlueX-doc-3590,
V. Berdnikov, A.Somov, J. Crafts

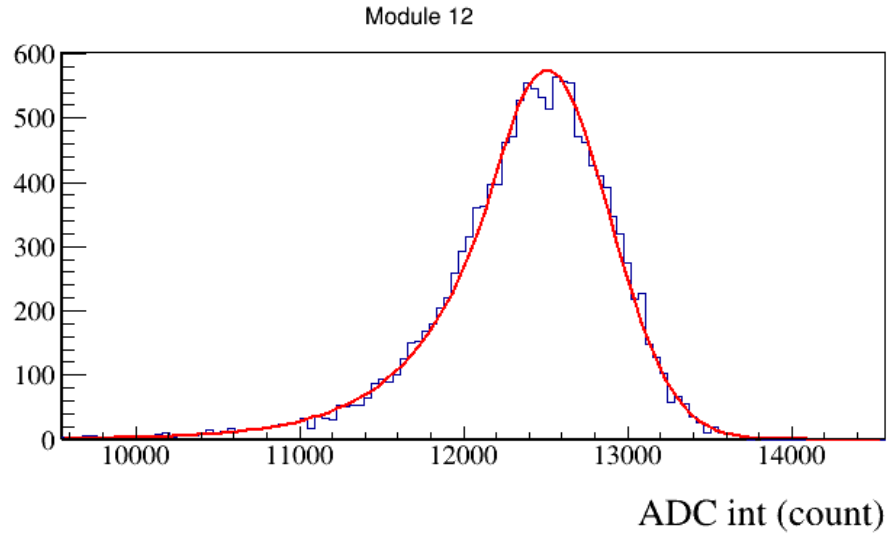
- Measure light yield of 12 crystals
- Crystals can be easily installed during opportunistic access to the hall
  (install crystals on the plate and bring the setup to the hall)
- Perform measurements in parallel with GlueX data taking

Crystal Testing Using Pair Spectrometer



Leptons going through the middle of the crystal

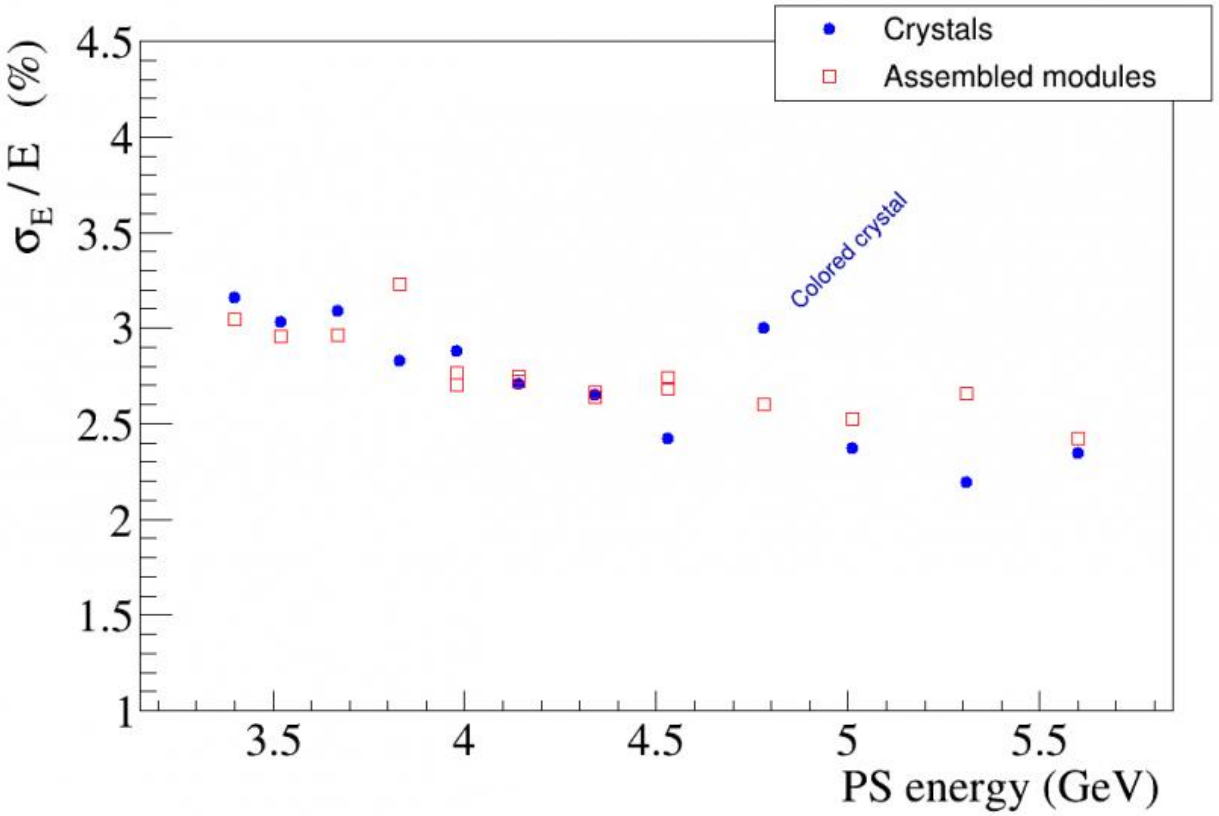
Energy distribution (pulse integral)



- Couple different crystals to the same PMTs
- Estimate light yields
- Estimate relative energy resolution of a single crystal

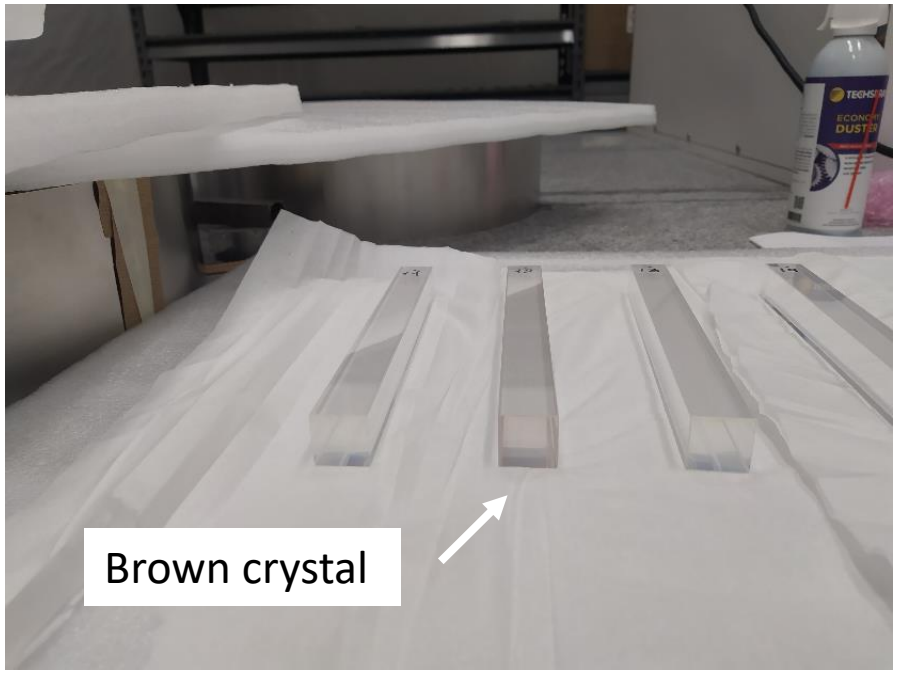
Test Results

Energy resolution of a single crystal



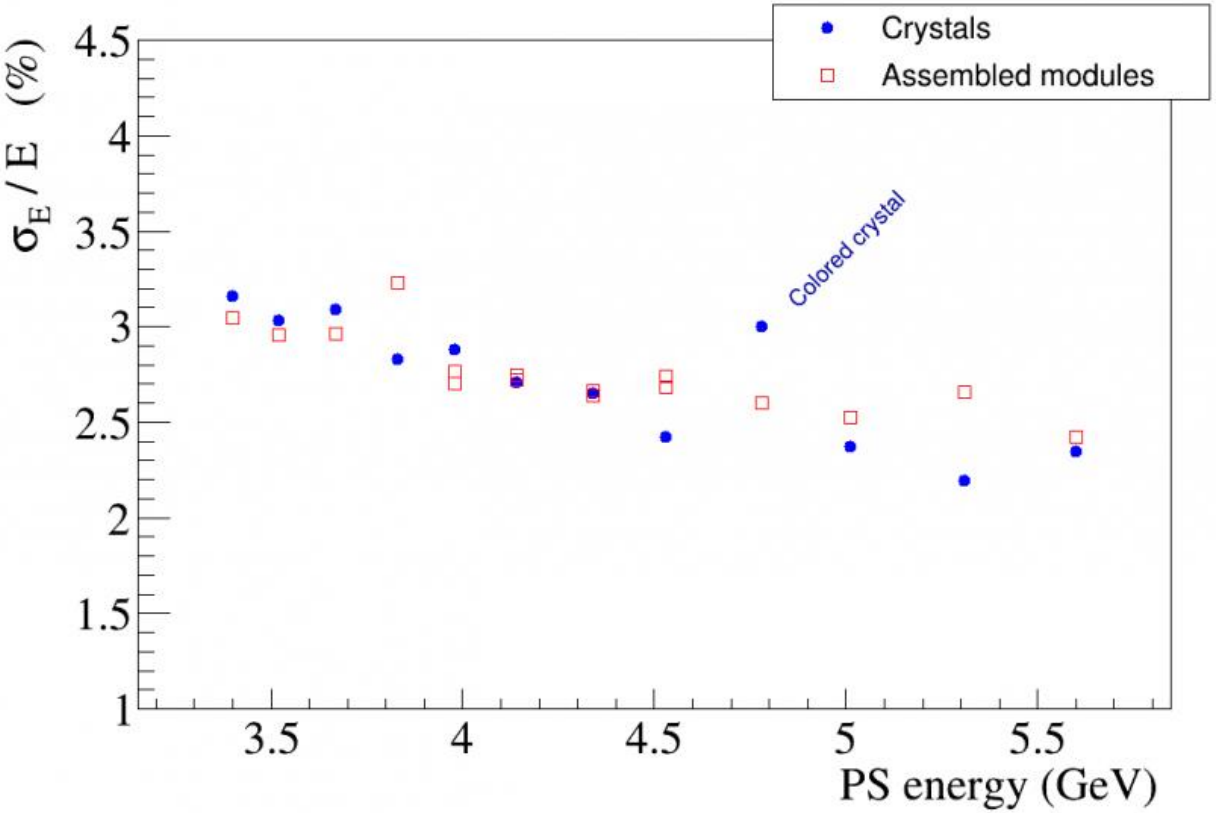
Test crystals (more than 100 SICCAS and CRYTUR) and FCAL 2 fabricated modules

Test ‘suspicious’ SICCAS crystals



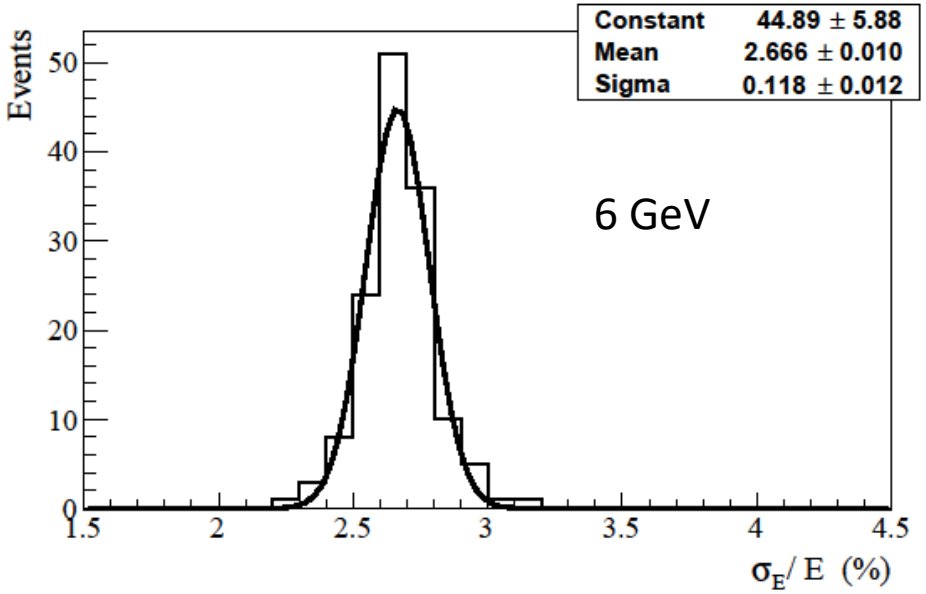
Test Results

PS test setup



CCAL

Energy resolution 140 modules installed on CCAL.
Measurements during CCAL beam calibration



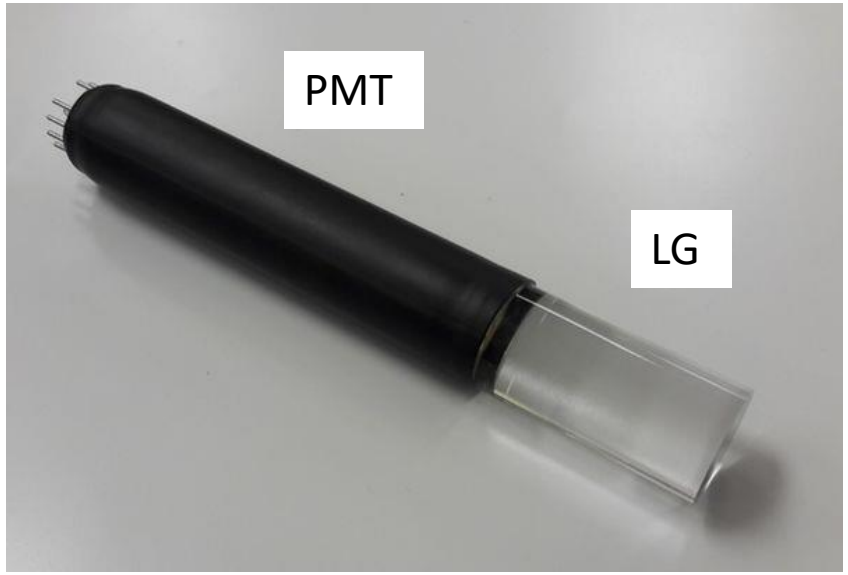
Spread of the distribution ~ 5 %

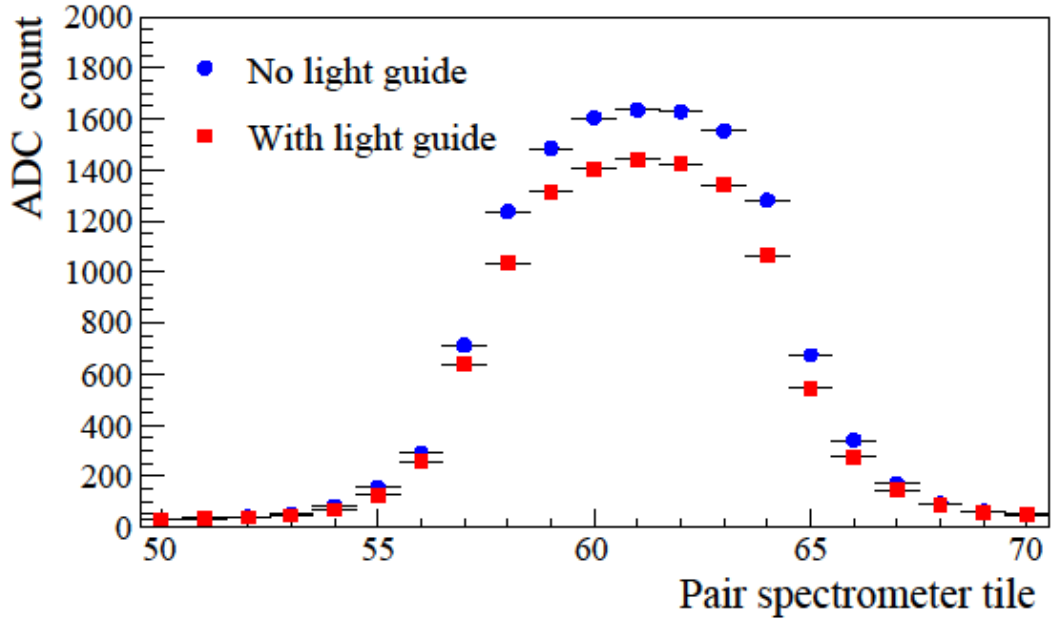
Design Optimization of FCAL 2 Modules

FCAL2 will be positioned in the fringe field of the Solenoid magnet (B ~ 50 Gauss)

- light guides are required to shield PMTs (TOSCA calculation & measurements with Helmholz coils)

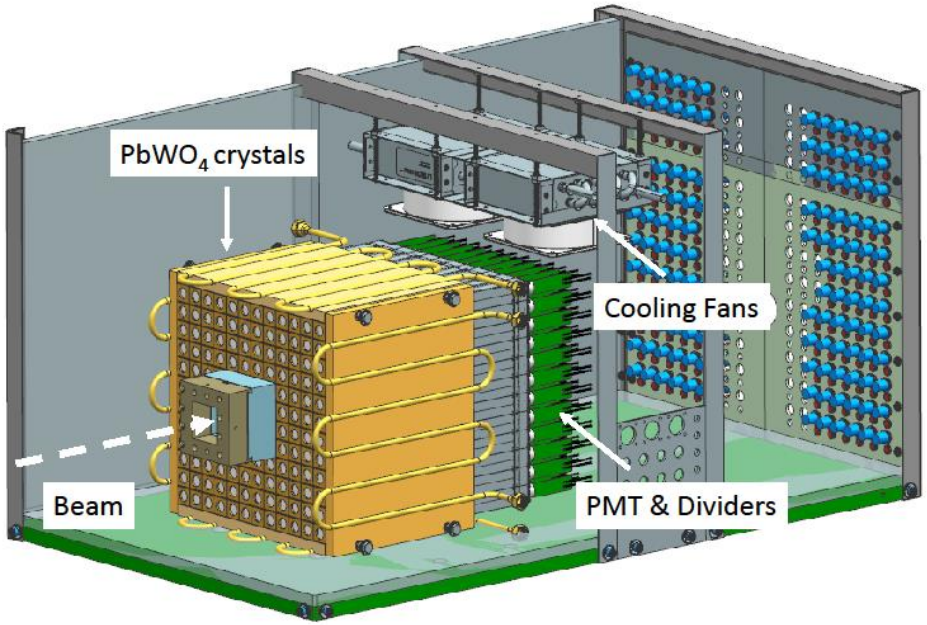
- PS setup was used to study different light guide configurations
- size, wrapping, coupling to the crystal





Large Scale Prototype: CCAL in PrimEx - η

Nucl. Inst. Meth. A 1013 (2021) 165683



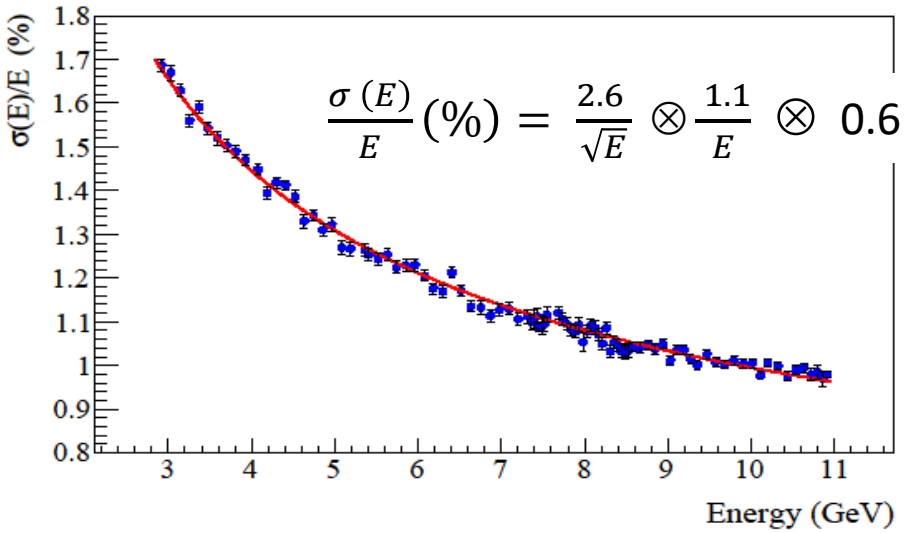
- 12 x 12 modules (SICCAS crystals)
- Used as a Compton calorimeter in PrimEx in 2019 and 2021
- Positioned in a movable platform (inserted into the beam for energy calibration)

  - initial calibration with respect to Hall D tagger (energy resolution 0.1 %)

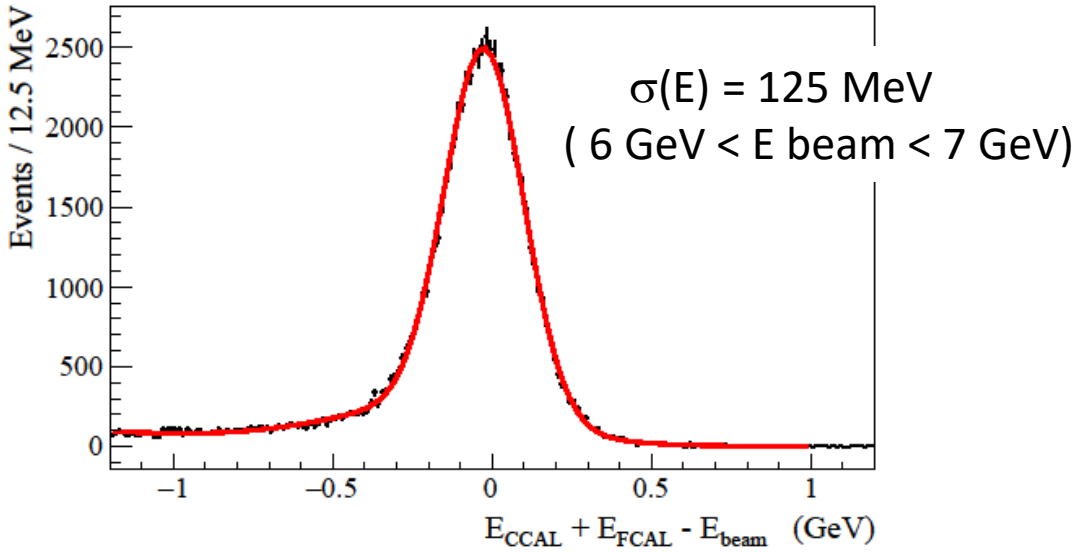
- Temperature stabilization ($17° \pm 0.2°$ during run)

CCAL in PrimEx - η

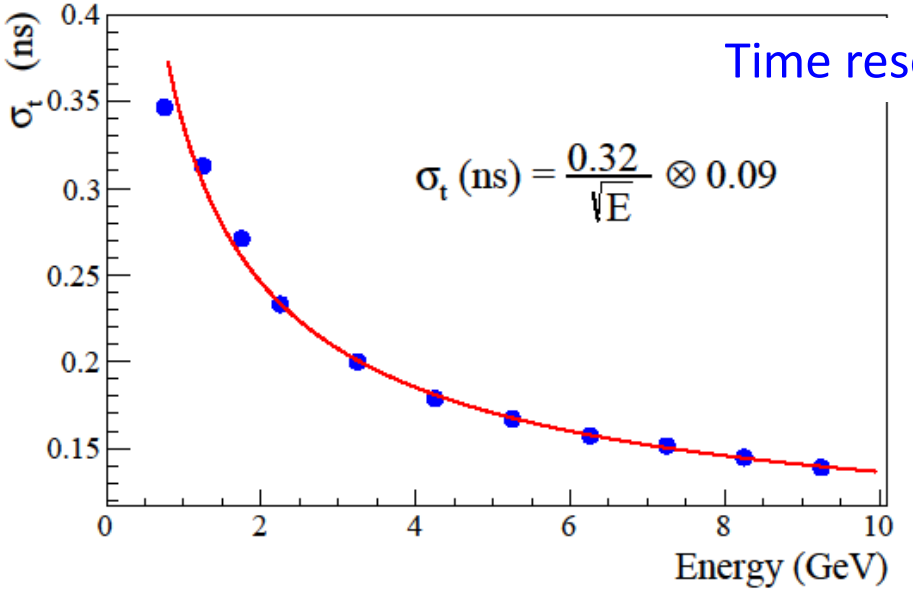
Energy resolution



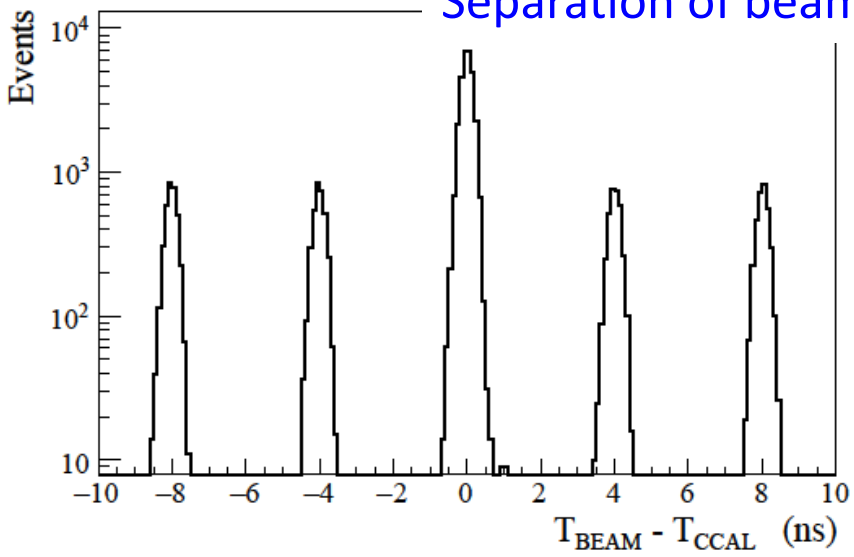
Elasticity distribution (Compton Candidates)



Time resolution



Separation of beam bunches



Next Steps

- Continue with tests of $PbWO_4$ crystals (mostly SICCAS) and FCAL 2 fabricated modules (test crystals for EIC if needed)

- Study prototypes with SiPM readout and glass scintillator modules (see Vlad's talk)