THE CATHOLIC UNIVERSITY of AMERICA

Jefferson Lab

# The workplan for EIC ECAL @ JLAB

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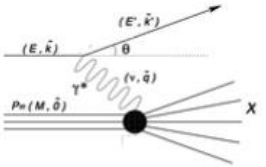
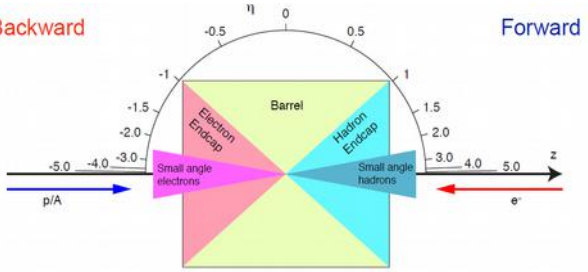
Streaming Readout VI Workshop; May 13 2020

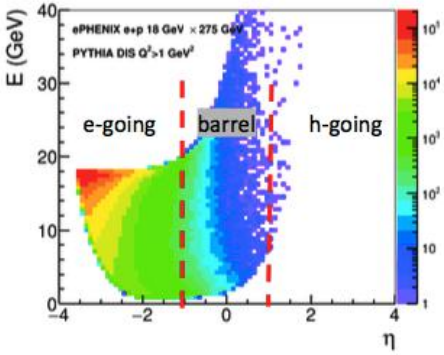
# EIC Electromagnetic Calorimetry

## Inclusive DIS: scattered electron

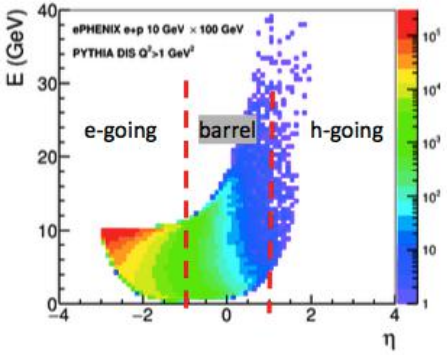





e+p 18x275 GeV

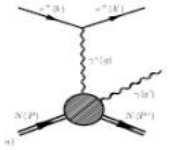



e+p 10x100 GeV



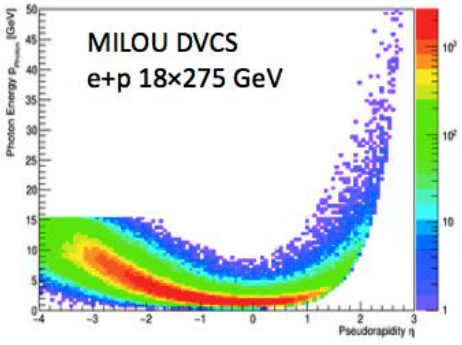

- **Electrons mostly scattered in backward (e-going) and barrel**
- **Electrons energy varies from 0 to e-beam energy in backward**
- **Higher electron energies in barrel and forward (h-going) region**

## Exclusive DIS: DVCS and DVMP

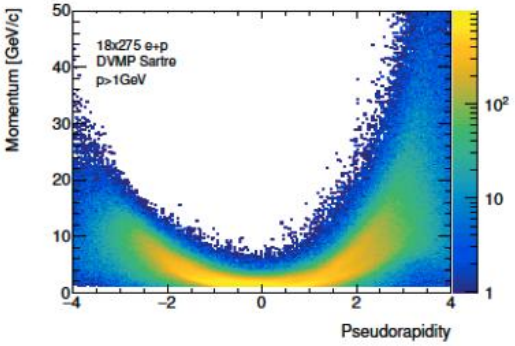


- **Good resolution needed at η < -2**
- **Wide rapidity coverage is crucial**

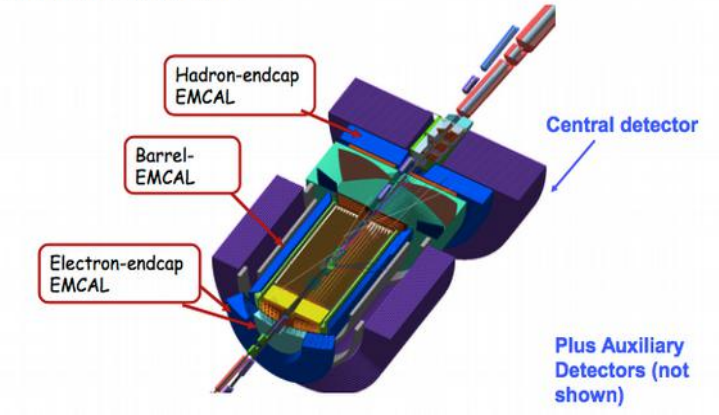
DVCS photon kinematics




J/ψ→ee kinematics



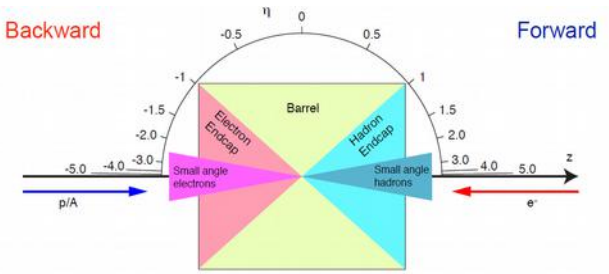

Several options including crystals, glass, W/SciFi, Shashlyk, Pb/Sc, PbGl, etc.




*EIC White paper; EIC R&D Handbook;*
*A. Bazilevsky talk Initial Considerations for the EMCal of the EIC detector*

# Electron endcap EmCal detector requirements

| | | | | Electrons | | | | |
|---|---|---|---|---|---|---|---|---|
| η | Nomenclature | | | Resolution σE/E | Spatial resolution | Granularity | Minimum photon energy | PID |
| -6.9 to -5.8 | | | low-Q2 tagger | | | | | |
| ... | | | | | | | | |
| -4.5 to -4.0 | | Auxiliary | | | | | | |
| -4.0 to -3.5 | ↓ p/A | Detectors | Instrumentation | | | | | |
| -3.5 to -3.0 | | | | | | | | |
| -3.0 to -2.5 | | | | 2%/√E+1% | 3mm/√E +1mm | 2x2 cm^2 | 50 MeV | |
| -2.5 to -2.0 | | | | 2%/√E+1% | 3mm/√E +1mm | 2x2 cm^2 | 50 MeV | |
| -2.0 to -1.5 | | | | 7%/√E+1.5% | 3mm(6mm)/√E +1mm | 2.5x2.5(4x4) cm^2 | 100 MeV | |
| -1.5 to -1.0 | | | Backward Dete | 7%/√E+1.5% | 3mm(6mm)/√E +1mm | 2.5x2.5(4x4) cm^2 | 100 MeV | |
| -1.0 to -0.5 | | | | | | | | |
| -0.5 to 0.0 | | | | | | | | |
| 0.0 to 0.5 | | | | | | | | |
| 0.5 to 1.0 | | | Barrel | | | | | π suppression u |
| 1.0 to 1.5 | | | | | | | | |
| 1.5 to 2.0 | | | | | | | | |
| 2.0 to 2.5 | | | | | | | | |
| 2.5 to 3.0 | | Central | | | | | | |
| 3.0 to 3.5 | | Detector | Forward Detect | | | | | |
| 3.5 to 4.0 | | | | | | | | |
| 4.0 to 4.5 | | | Instrumentation | (10-12)%/√E+2% | 3mm/√E +1mm | 2.5x2.5 cm^2 | 100 MeV | |
| ... | | Auxiliary | Neutron Detecti | | | | | |
| > 6.2 | ↑ e | Detectors | Proton Spectror | | | | | |

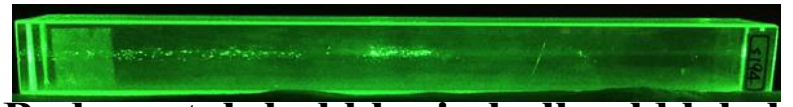



- **Homogeneous calorimetry with high resolution inner part and more relaxed requirements at larger angles (eRD1)**
  - **PWO crystals provide high resolution, radiation hard material and meet inner part requirements**
  - **Scintillating glass (DSB:Ce) provides a cost effective option in regions where resolution requirements are less stringent**
- **Benefits from synergies with other projects: Neutral Particle Spectrometer (NPS) and FCAL at JLab, PANDA**
  - **Resources, prototypes, software development**

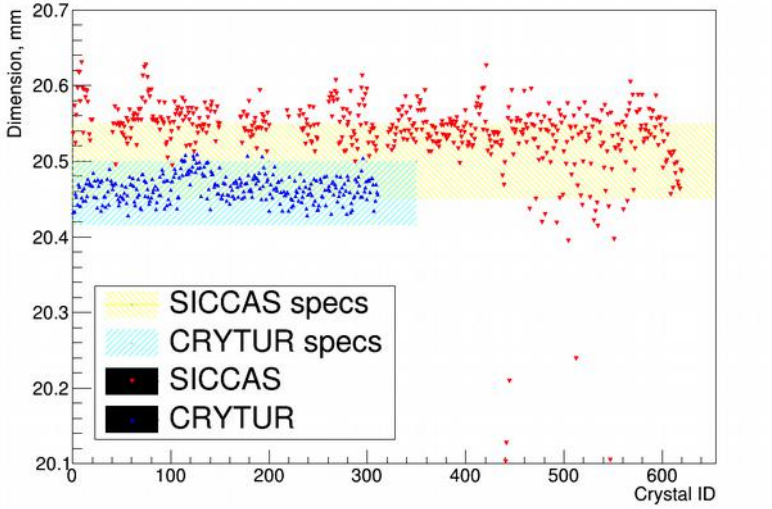
# Electron endcap EmCal PbWO4 crystals

- **Crystal dimensions 20.5x20.5x200 mm3**
- **Vendors exist, but only two vendors of PbWO4 crystals available worldwide**
- **Still some R&D related to raw crystal material powder**
- **SICCAS/China: failure rate ~30% of crystals produced in 2014-19 due to major mechanical defects**
- **CRYTUR/Czech Republic: Strict quality control procedures – so far 100% of crystals accepted**

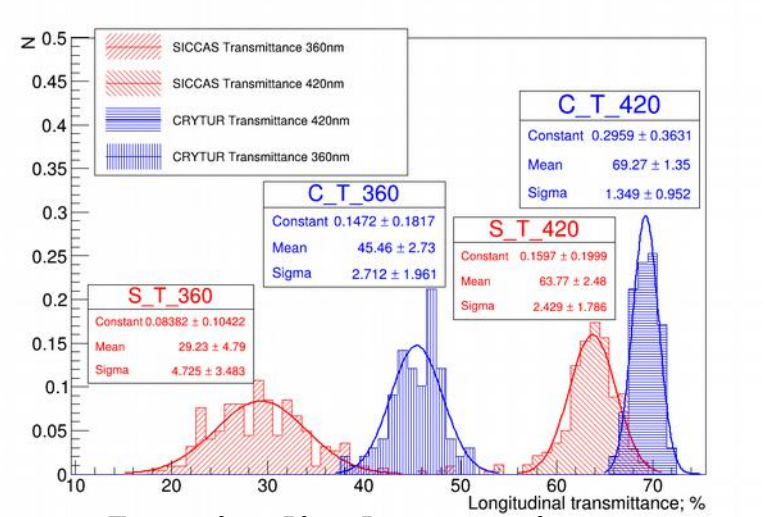
**Good crystal**



**Bad crystal: bubbles in bulk, old labels ...**




**Quality check: dimension uniformity**




**Longitudinal transmittance**

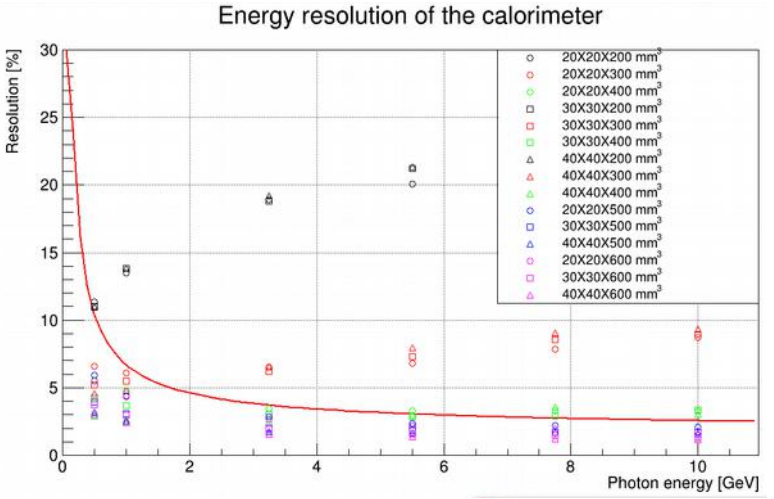
# Electron endcap EmCal DSB:Ce glass

- **Ongoing EIC R&D program (eRD1)**
- **Simulation suggests a resolution comparable to PbWO4**

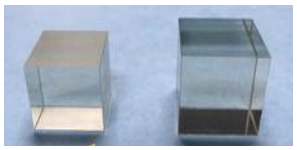
$$\frac{\sigma_E}{E} = \frac{2.5\%}{\sqrt{E}} \oplus \frac{2.7\%}{E} \oplus 1.5\%$$

**Assumes that 40cm long glass bars with these properties will be available**

- **Scintilex has developed the scale-up and can now fabricate 20cm long glass bars – further scale up optimization ongoing. Within one year achieved scale-up to 20cm and improving manufacturing. Goal: 40x40x400 cm3**
- **Ongoing preparation for beam tests: bars need to be polished (flatness, rectangularity etc.), quality assurance, testing with gamma sources, cosmic**




SCINTILEX



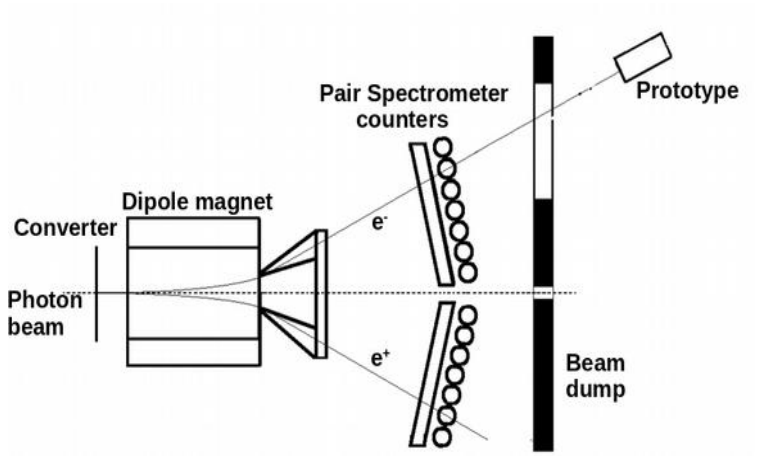
1cm x 1cm x 0.5cm — 2019

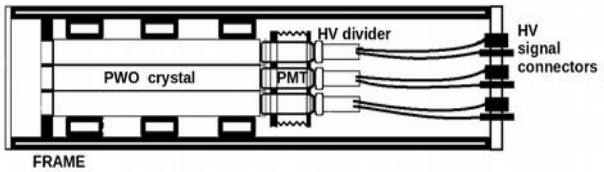
2cm x 2cm x (2-4)cm — 2020

2.0cm x 2.0cm x 20.0cm — 2020

4.0cm x 4.0cm x 40.0 cm — 2021

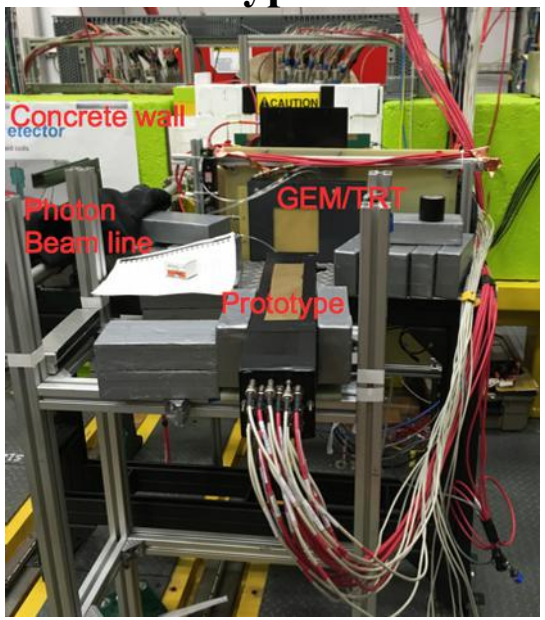
# EmCal 3x3 prototype measurements with Pair Spectrometer



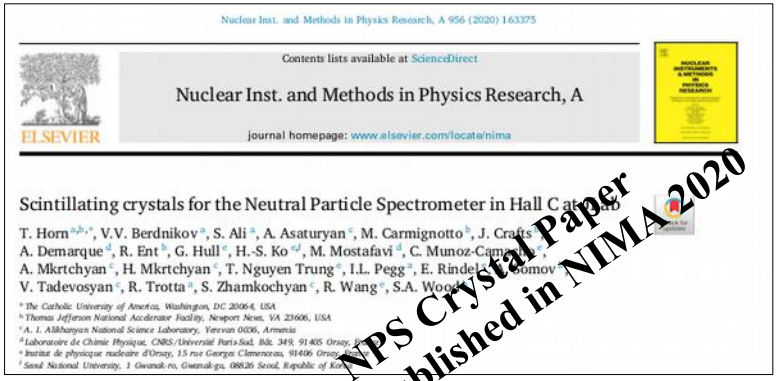




- **Crystal/glass beam test program in HallD:**
  - **Installed the 3x3 PMT based prototype behind the PS (2018,2019,2020)**
  - **Energy resolution measurement**
  - **Readout chain optimization**
  - **Glass-ceramic scintillator tests**
  - **SRO preferable option**
- **Crystal test stand 12 crystal measured at the same time (2020)**
- **Studies of crystal defects, light guides, cookies and etc.**
- **SRO optional**

**3x3 Prototype**




**Crystal test stand**


Nuclear Inst. and Methods in Physics Research, A 956 (2020) 163375

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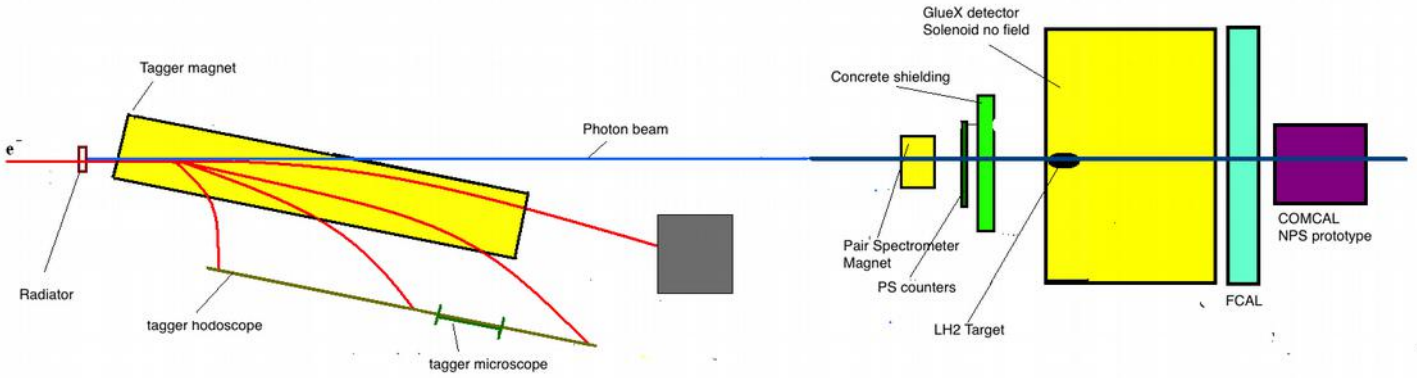
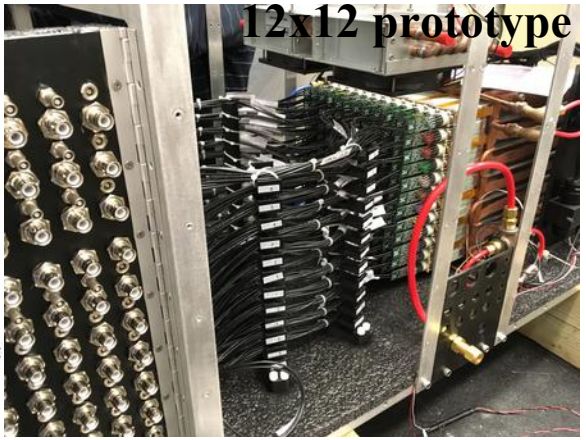
Scintillating crystals for the Neutral Particle Spectrometer in Hall C at JLab

T. Horn, V.V. Berdnikov, S. Ali, A. Asaturyan, M. Carmignotto, J. Crafts, A. Demarque, R. Ent, G. Hull, H.-S. Ko, M. Mostafavi, C. Munoz-Camacho, A. Mkrtchyan, H. Mkrtchyan, T. Nguyen Trung, I.L. Pegg, E. Rindel, A. Somov, V. Tadevosyan, R. Trotta, S. Zhamkochyan, R. Wang, S.A. Wood

NPS Crystal Paper Published in NIMA 2020

# Additional SRO opportunities with 12x12 prototype



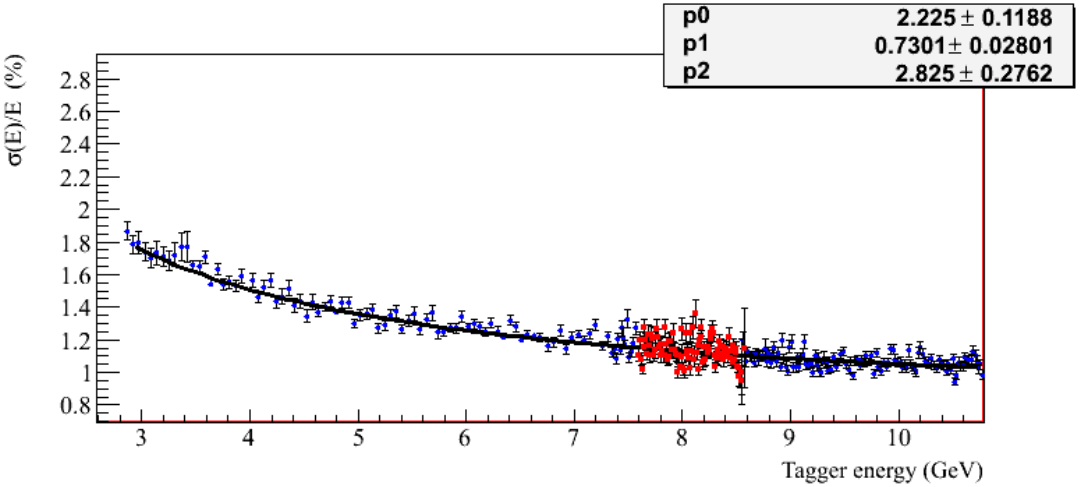




- **12x12 ch PMT based detector for more detailed studies compared to quick checks with the 3x3 prototype**
  - **Allows for studies of energy resolution in wide energy range, stability, rate dependence, etc.**
  - **But, not as flexible as 3x3 since cannot run in parasitic mode and has to be installed in the beamline - requires scheduling, crane installation, alignment, slow controls, integration to data stream...**

**Detector design major components:**

- 12x12 Matrix (140 crystals)
- NPS HV divider
- **250 fADC readout**
- Environment control:
  - Temperature, humidity, light sensors
- Monitoring system consisting of LED and α-source
- Moving platform

- Beam test program completed in 2019
  - Initial results show **energy resolution: ~2.83%/E+2.23%/√E+0.73%**
  - Ongoing studies to improve linearity
  - Preparing publication on beam test results – to be submitted to NIMA in next few months



# EmCal 3x3 prototype tests 2020 plan with SRO

- **Instrument two 3x3 SiPM and PMT based prototypes to test scintillator materials and test/optimize the entire readout: preamps, fADC and streaming DAQ system**

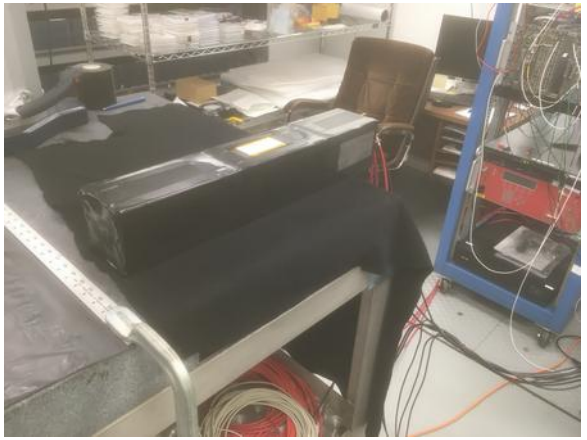
- **Establish baseline performance with PMT based PWO prototype and standard RO**

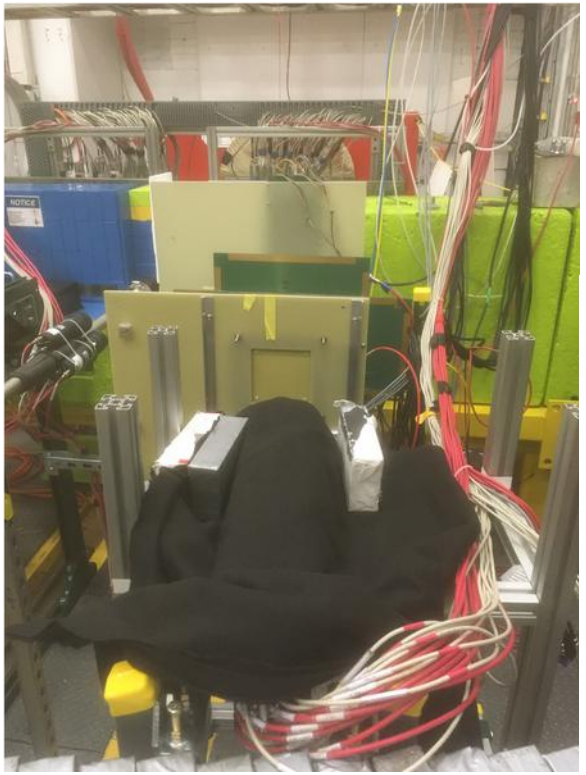
- **Planned tests in HallD will have up to 8 configurations**

  - **PWO proto-PMT + fADC250+VTP**
  - **PWO proto-PMT + WB**
  - **PWO proto-SiPM+BIAS board/Preamp+fADC250+VTP**
  - **PWO proto-SiPM+WB**

  - **Glass proto-PMT + fADC250+VTP**
  - **Glass proto-PMT + WB**
  - **Glass proto-SiPM+BIAS board/Preamp+fADC250+VTP**
  - **Glass proto-SiPM+WB**

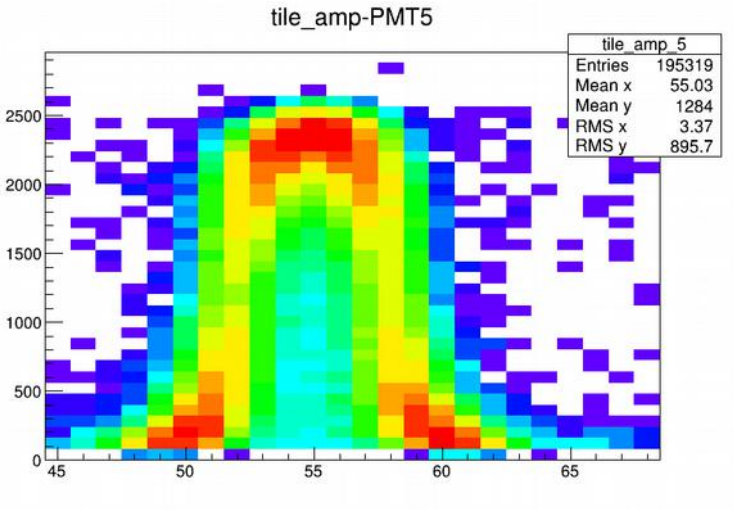
# Baseline measurements with PMT based 3x3 prototype

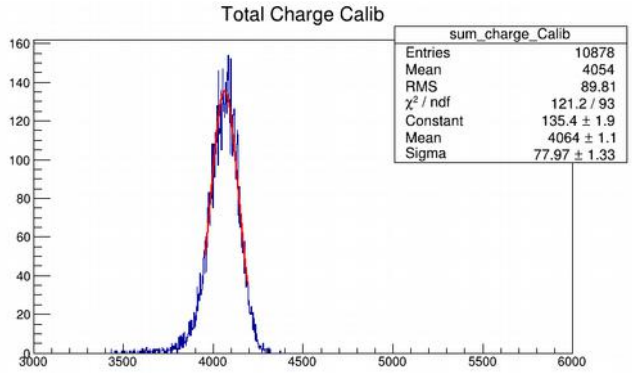




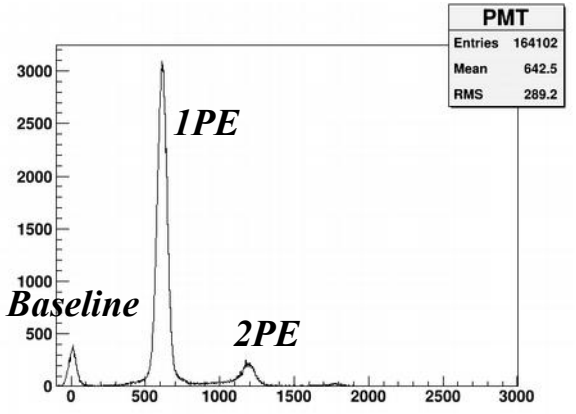
- **Baseline measurement with 3x3 PMT based PWO prototype**
- **Prototype installed, surveyed and aligned**
- **HV connected, tested (remote control)**
- **FADC250 RO channels, PS trigger bit**
- **Readout with GlueX data stream (parasitic)**
- **Energy resolution ~1.9% for ~4GeV lepton**
- **Calibration made by regression algorithm**

$$\begin{bmatrix} \sum_{events} A_1 A_1 & \sum_{events} A_i A_1 & \sum_{events} A_{Nseg} A_1 \\ \sum_{events} A_1 A_j & \sum_{events} A_i A_j & \sum_{events} A_{Nseg} A_j \\ \sum_{events} A_1 A_{Nseg} & \sum_{events} A_i A_{Nseg} & \sum_{events} A_{Nseg} A_{Nseg} \end{bmatrix} * \begin{bmatrix} k_1 \\ k_j \\ k_{Nseg} \end{bmatrix} = \begin{bmatrix} \sum_{events} E_{ps} A_1 \\ \sum_{events} E_{ps} A_j \\ \sum_{events} E_{ps} A_{Nseg} \end{bmatrix}$$

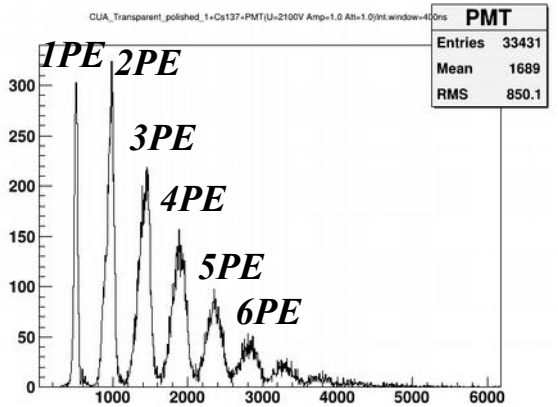


# SiPM and SiPM+PWO performance tests in the darkbox




LED OFF



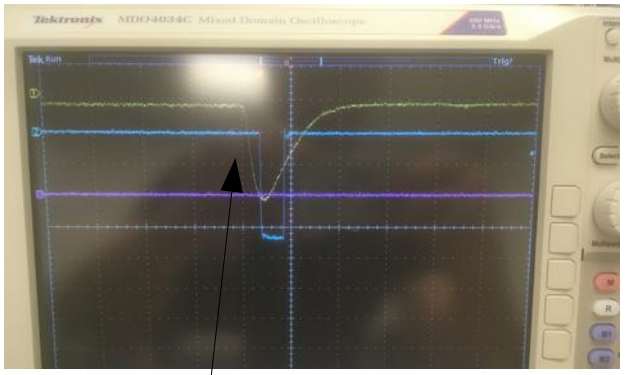

LED ON

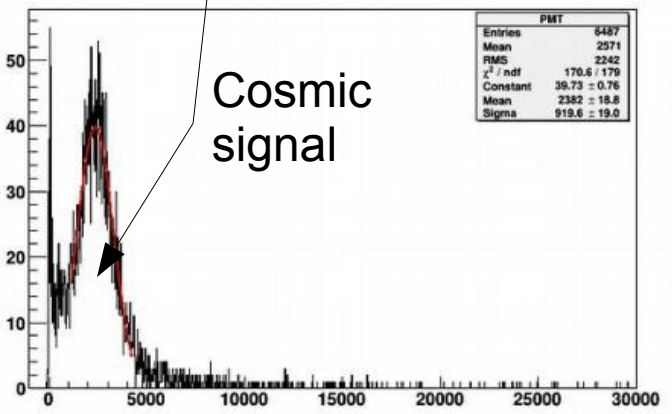
- 25um and 75um 6x6 mm^2 SiPM Hamamatsu S13360
- Performed tests with LED ON/OFF
- BiAS board + Preamp board
- FADC250 self trigger, threshold level under baseline
- CODA based DAQ

- SiPM coupled with PWO crystal (ESR wrapped)
- Cosmic tests
- BiAS board + Preamp board

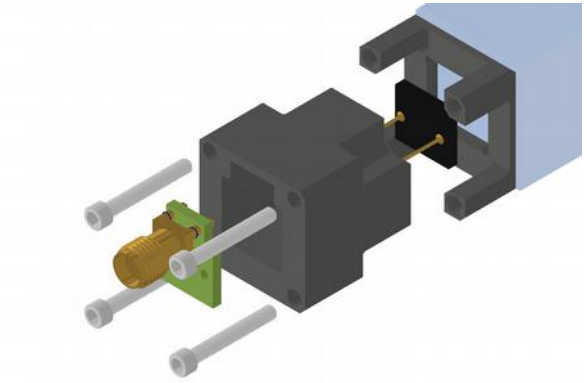
- FADC250, trigger coincidence between two plastic scintillator pads with SiPM readout
- CODA based DAQ

- ~50Photoelectrons for ~15MeV energy deposit mean ~3.3 PE/MeV

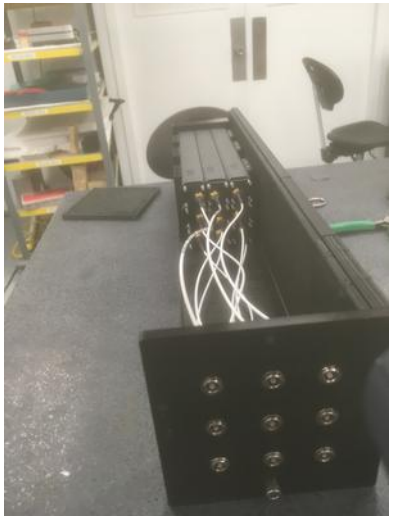




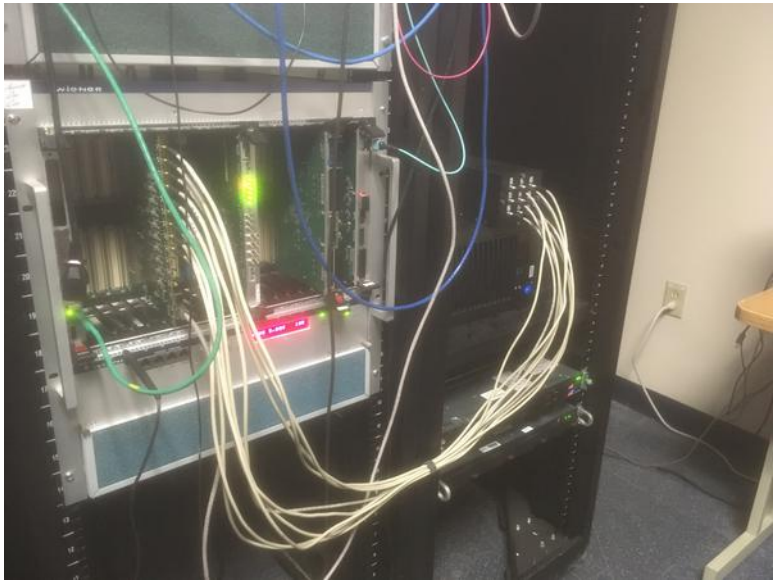
# SiPM based 3x3 PWO prototype assembly



- Improved prototype with new SiPM based assembly
- Same size 3D printed frame as PMT based version
- Two peace SiPM holder concept developed
- Holders are 3D printed (PLA plastic)
- PEEK plastic will be used in real detector
- Silicon based glue for frame, no SiPM glueing to crystal
- SiPM soldered to circuit board with SMA connector
- 25um cell SiPM for beam tests installed (75um second option)
- LEMO output at the detector patch panel (BIAS/Preamp or Waveboard application)
- Assembled and sanity checked
- Ready for beam tests

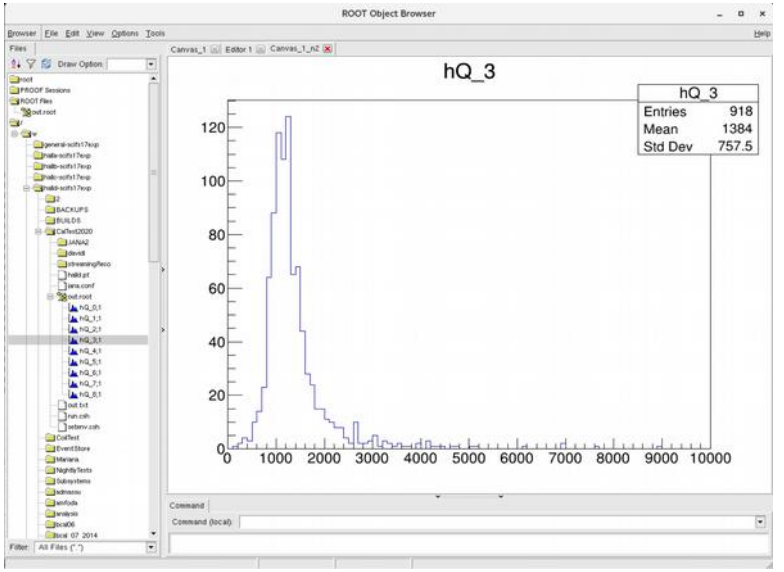


# SiPM prototype tests with Waveboard in INDRA lab



- **Prototype moved to INDRA lab and connected to Waveboard, interaction via INDRAlab machine**
- **The parameters for Waveboard set to perform cosmic measurements (HV calibrated, gain value, thresholds and etc.)**
- **First quick tests, data streamed to host machine, pulses make sense, analyzed via DbgParser code**
- **Full readout chain tested SiPM+Waveboard+TRIDAS, data analyzed via JANA-2+SRO plugin**
- **Calorimeter calibration is ongoing**
- **Full Readout chain+analyzer is working**

```
 0x00   0x00     9     0x0209B0C3              0      0x10CC        0x10CC        0x000F        0x0008        0x0000   0x0007
 0x00   0x00    10     0x0201B5D5A             0      0x0000        0x0000        0x0000        0x0000        0x0000   0x0007
 0x00   0x00    11     0x0201B34E9             0      0x0000        0x0000        0x0000        0x0000        0x0000   0x0007
root@wvb_daq_axis:~# ./ReadParam
CRATE#  SLOT#   CHAN#   PEDESTAL*4096  RATE MON (Hz)   START THR     STOP THR      LEAD LENGTH   TAIL LENGTH   CONTROL  STATUS
 0x00   0x00     0     0x010E75BA              700      0x10CA        0x10CA        0x000F        0x0008        0x000A   0x0004
 0x00   0x00     1     0x0201B4B7D             0      0x10CC        0x10CC        0x000F        0x0008        0x000A   0x0007
 0x00   0x00     2     0x02101660              0      0x10CC        0x10CC        0x000F        0x0008        0x000A   0x0007
 0x00   0x00     3     0x02097806              0      0x10CC        0x10CC        0x000F        0x0008        0x000A   0x0007
 0x00   0x00     4     0x0201AB5B4             0      0x10CC        0x10CC        0x000F        0x0008        0x000A   0x0007
 0x00   0x00     5     0x0201AEFF6             0      0x10CC        0x10CC        0x000F        0x0008        0x000A   0x0007
 0x00   0x00     6     0x0201B8D01             0      0x10CC        0x10CC        0x000F        0x0008        0x000A   0x0007
 0x00   0x00     7     0x0201CB3D2             0      0x10CC        0x10CC        0x000F        0x0008        0x000A   0x0007
 0x00   0x00     8     0x0201BE940             0      0x10CC        0x10CC        0x000F        0x0008        0x000A   0x0007
 0x00   0x00     9     0x0209B038              0      0x10CC        0x10CC        0x000F        0x0008        0x0000   0x0007
 0x00   0x00    10     0x02015726              0      0x0000        0x0000        0x0000        0x0000        0x0000   0x0007
 0x00   0x00    11     0x0201B295F             0      0x0000        0x0000        0x0000        0x0000        0x0000   0x0007
root@wvb_daq_axis:~#
```



# Summary

- **Beam test with prototypes crucial for EIC EmCal development**
- **Crystal/glass material performance beam test method with PS in HallD established**
- **Good opportunities for testing SRO with different calorimeter prototype versions**
- **SiPM and PMT based prototypes assembled**
- **Baseline for PMT based PWO prototype performance have determined**
- **Full streaming readout chain tested**
- **Ready for the beam tests and streaming**