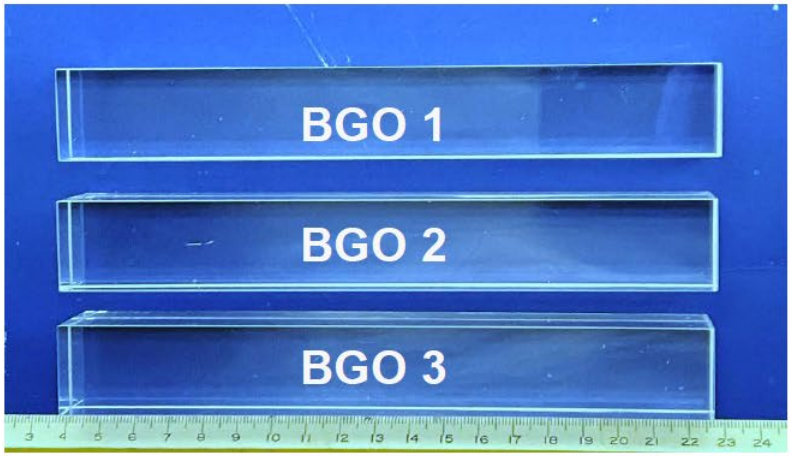
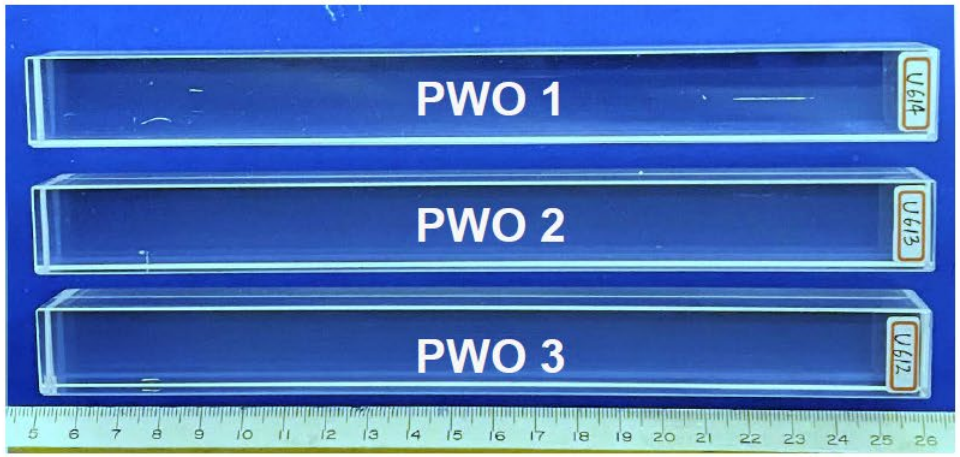
BGO and PWO crystals





ID	Dimension (mm^3)	#	Polishing
BGO-1,2,3	25×25×180	3	All faces
PWO-1,2,3	20×20×200	3	All faces

Plus another BGO crystal with a dimension of 25×25×60 mm^3

Crystal test results (done by R.Y. Zhu and C. Hu)

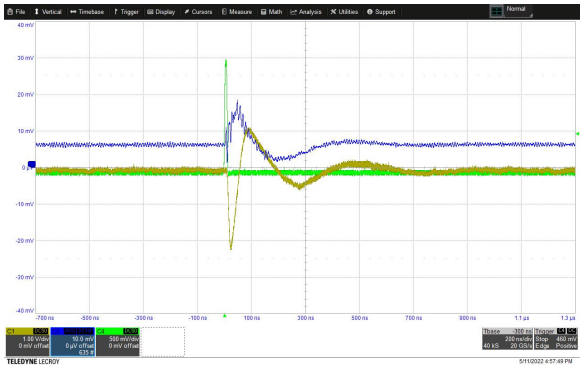
BGO	EWLT (%)	Light Output (p.e./MeV)	Energy Resolution (%)	Light Response Uniformity (%)
BGO-1	72.2	733	17.0	2.2
BGO-2	73.8	739	16.9	2.4
BGO-3	74.6	722	17.0	2.9
Ave	73.5	731	17.0	2.5
rms/Ave (%)	1.4	1.0	0.2	12

PWO	EWLT (%)	Light Output (p.e./MeV)	Energy Resolution (%)	Light Response Uniformity (%)
PWO-1	59.9	31	101.4	5.1
PWO-2	63.0	28	107.2	4.5
PWO-3	61.7	29	103.2	2.6
Ave	61.5	29	103.9	4.1
rms/Ave (%)	2.1	3.6	2.4	26

Plus other measurements: X-ray excited luminescence, Longitudinal/Transverse transmittance, Pulse Height Spectra, Light Output, Decay time

Readout setup

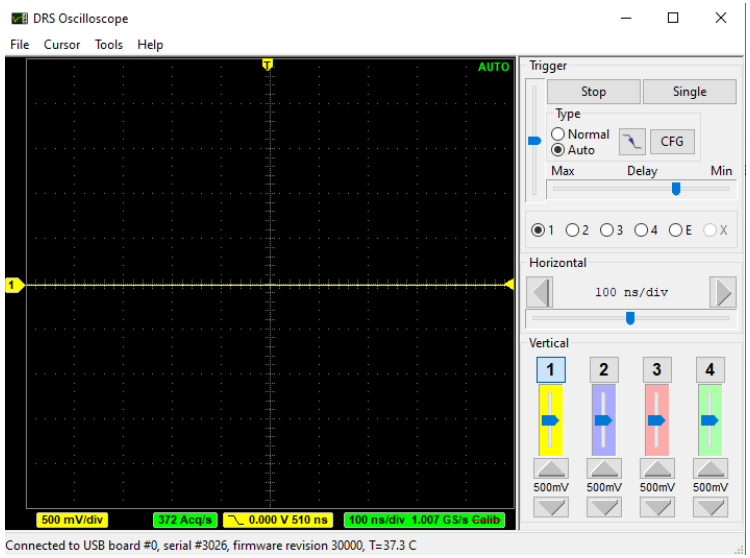
Oscilloscope: Lecroy waverunner 8404m

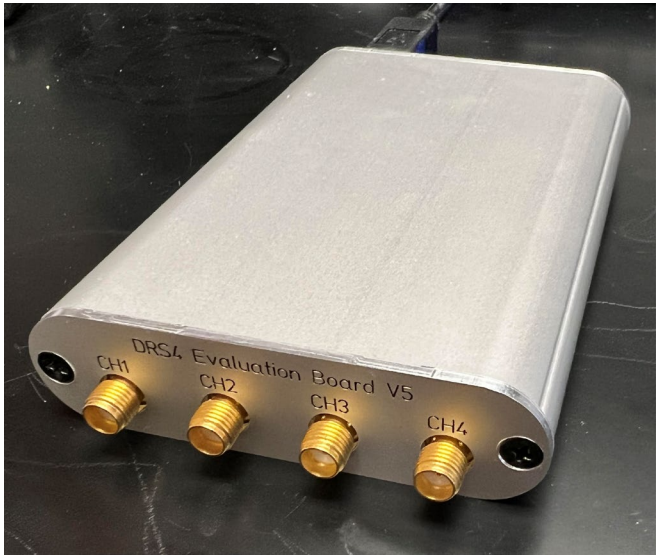


- Python script readout from Ethernet port (modified from https://www.tlatorre.com/cgit/lecrunch/)
- 4 channel sampling, with an extra external trigger channel
- 4 GHz, up to 40 Gbps
- Code developed to analyze the output data

DRS4 evaluation board

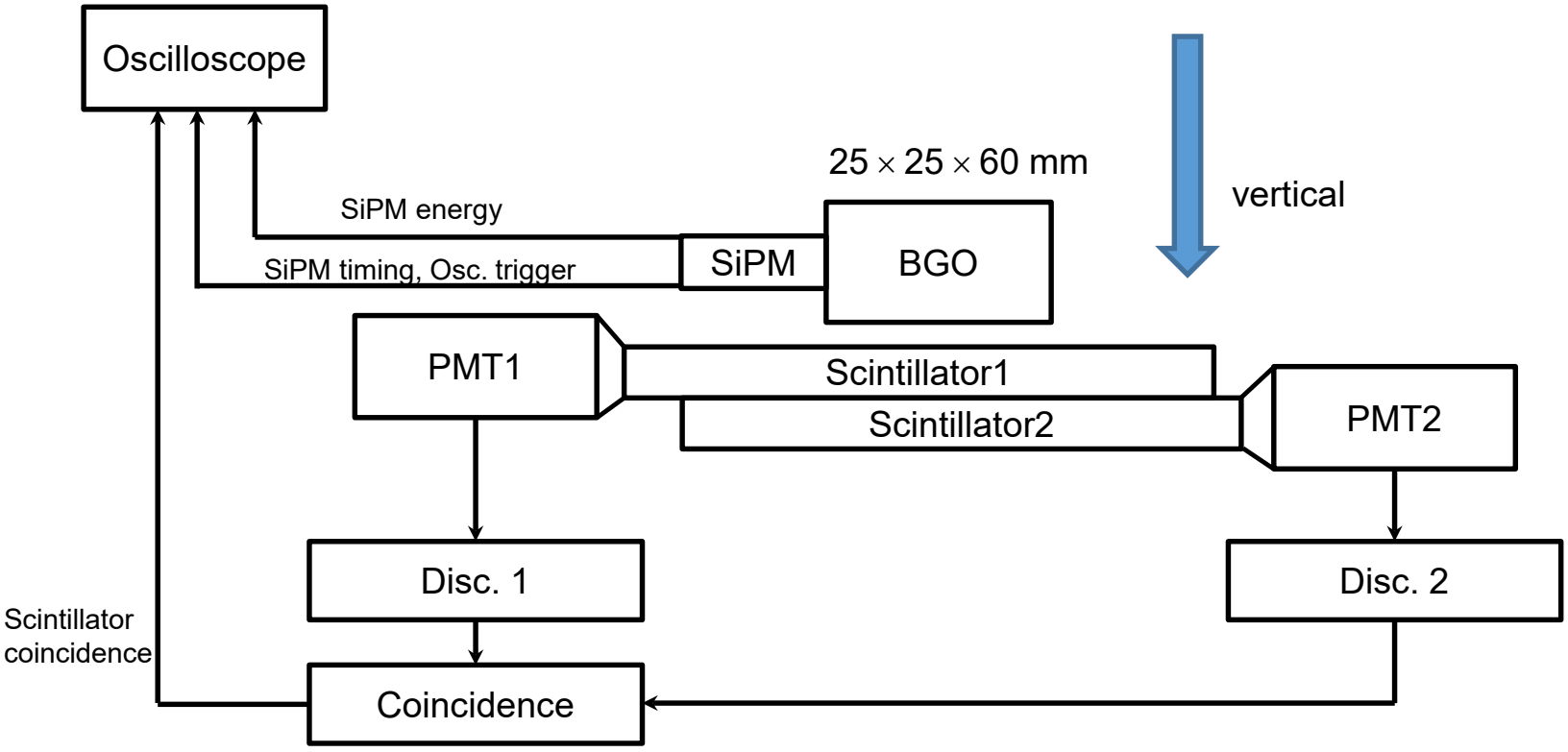
- 4 channel sampling, with an extra external trigger channel
- 1V peak-to-peak input. 1024 points per sampling. Up to 5 Gbps.
- Readout GUI available (similar to an oscilloscope), readout via USB2.0
- Code developed to analyze the output data





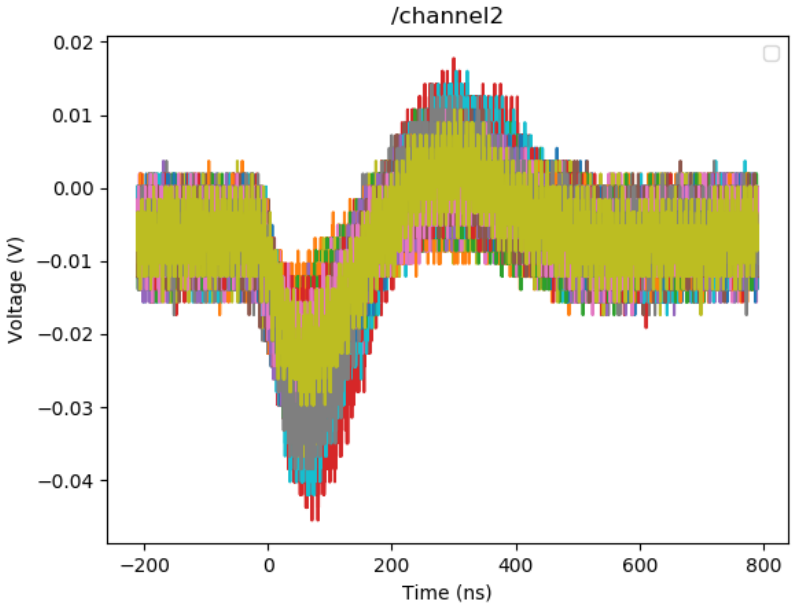
Cosmic ray test setup

- SiPM S14160-3015PS, 3x3 mm^2, pixel pitch: 15 um
- Vbr=38 V, Vop=42 V
- Scintillator overlapping area = 14×15 cm^2
- Direct trigger with the SiPM timing signal
- Scintillator coincident signal recorded to confirm cosmic muons
- Read out scintillation light (no SiPM output observed if not attached to the crystal)

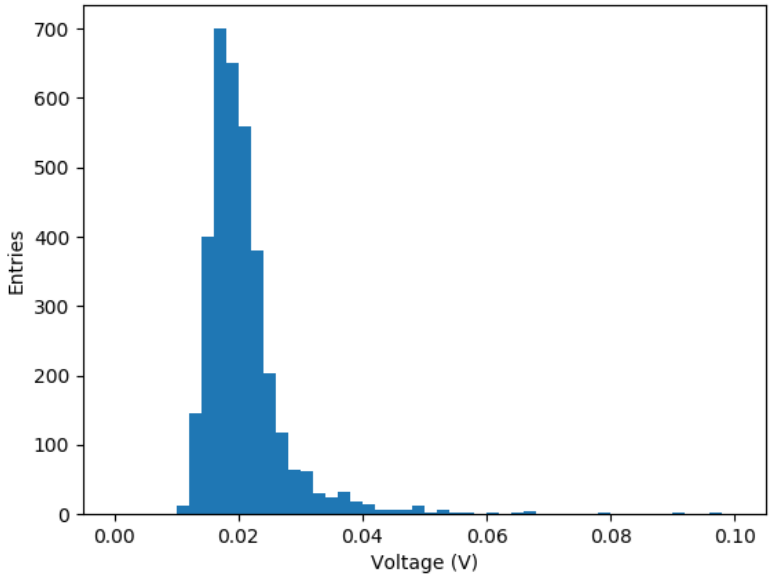


Cosmic ray result

- 6110 SiPM direct triggers in 12.5 h, average rate = 0.14 Hz
- Among all SiPM triggers, 3500 events have scintillator coincidence.



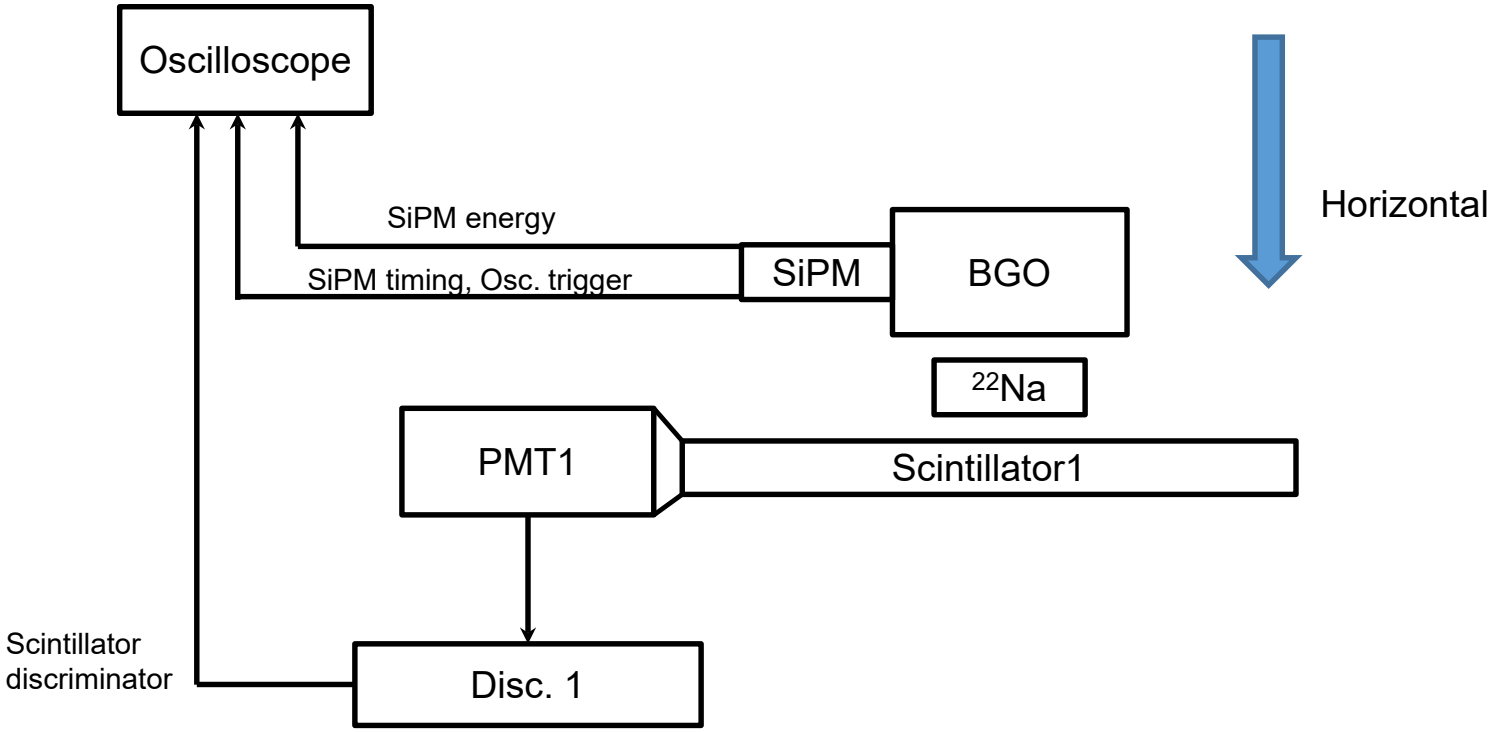
SiPM energy waveform 50 samples with scintillator coincidence. A 200 MHz 10 mV peak-to-peak sine-wave noise is found for this output (mainly due to the HV power supply we used)



SiPM energy amplitude histogram with scintillator coincidence (rare large signals excluded).

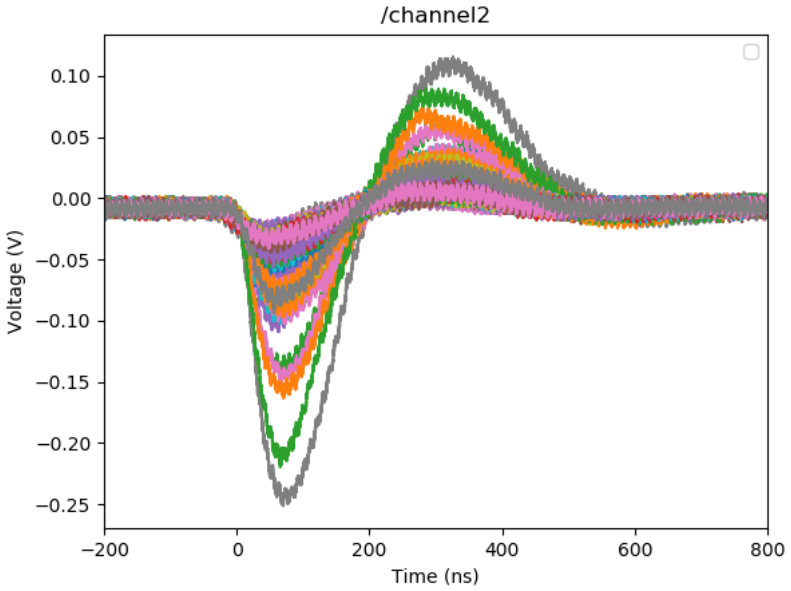
^{22}Na test setup

- SiPM Vbr=38 V, Vop=43 V (at the time we did not realize the HV supply shows a wrong voltage reading so it is different from the cosmic ray setup)
- ^{22}Na source (e^+ source →$\gamma\gamma$, 1 uCi, purchased two years ago) placed in between BGO and scintillator1 (horizontal back-to-back setup)
- Direct trigger with the SiPM timing signal
- Scintillator coincident signal recorded to confirm cosmic muons

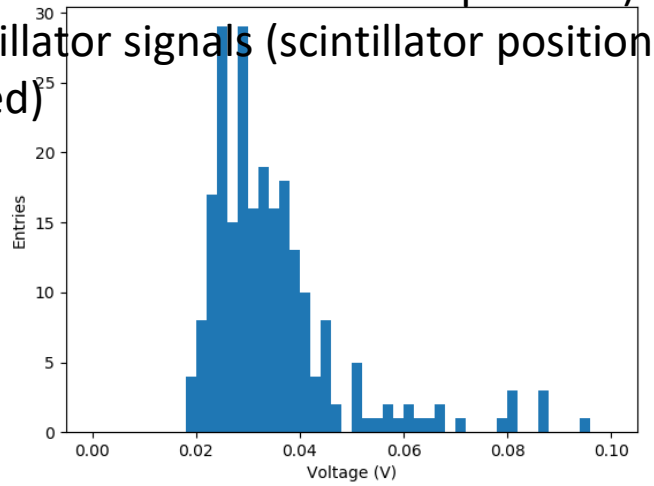


^{22}Na test setup

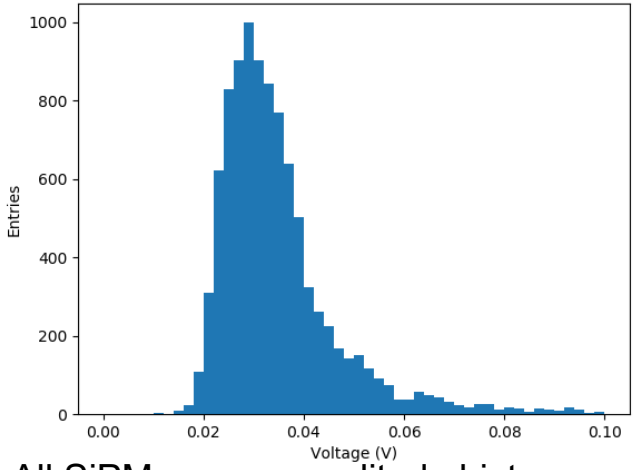
- 9668 SiPM direct triggers in 11.5 h, average rate = 0.22 Hz (small acceptance for the SiPM, and no scintillation photons detected due to the incident of 511 keV photons)
- Among all SiPM triggers, only 238 events have scintillator signals (scintillator positioned differently this time and less cosmic muons expected)



SiPM energy waveforms with scintillator signals (238 events).



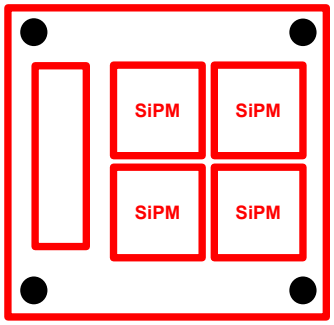
SiPM energy amplitude histogram with scintillator signals (rare large signals excluded)

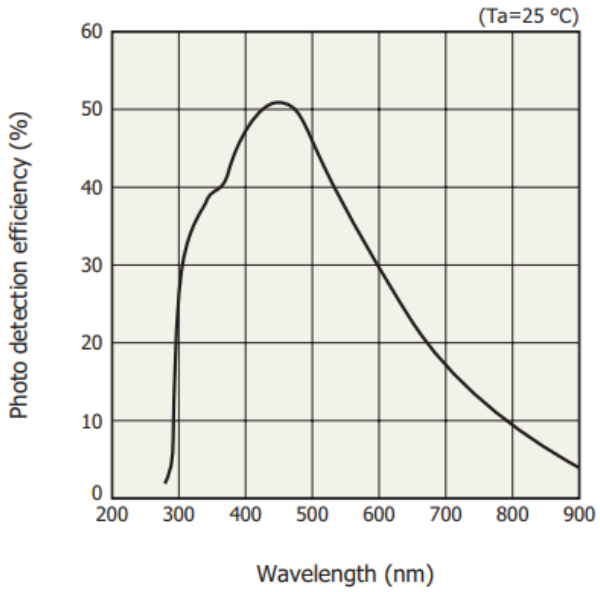


All SiPM energy amplitude histogram (rare large signals excluded)

Larger-area SiPMs

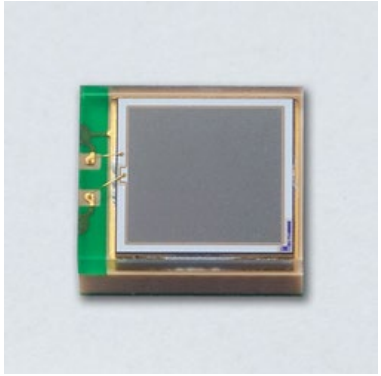
S14160-6050HS 6x6 mm^2
Pixel pitch: 50 um

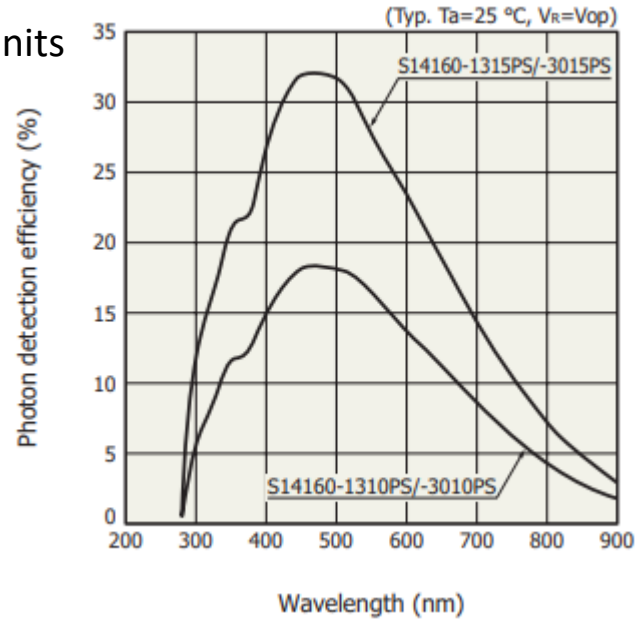




Checked with Hamamatsu and was told that they can ship 8 units to me in one week ($90 per unit) → $67 per unit if we purchase 50 units

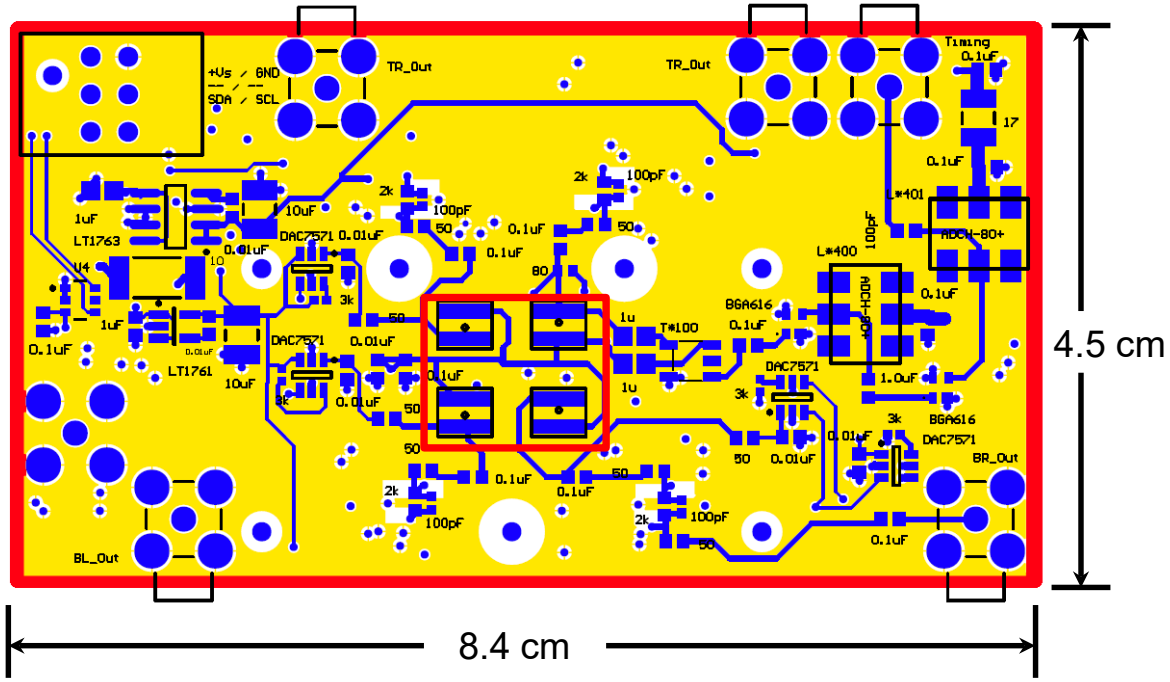
The one we have now: S14160-3015PS 3x3 mm^2
Pixel pitch: 15 um





4-channel SiPM readout board (From B. Hirosky and T. Anderson)

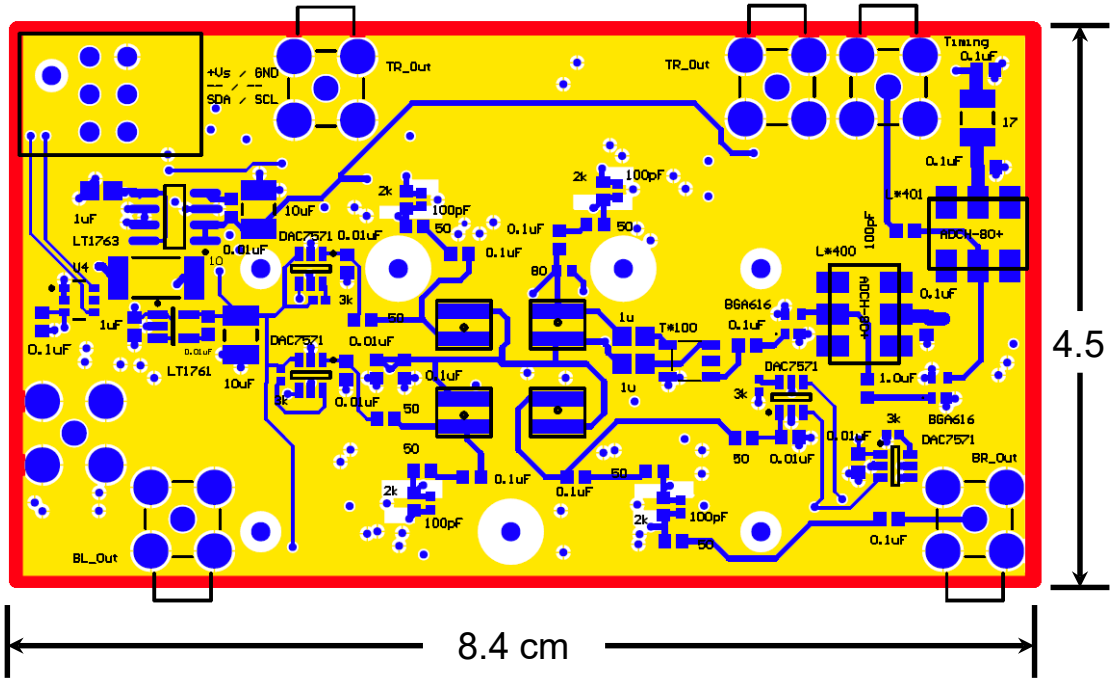
- 4-channel readout board is pretty small (footprint 3.85*4.35mm for 3*3mm SiPM)
- 1 timing readout, 4 energy readout

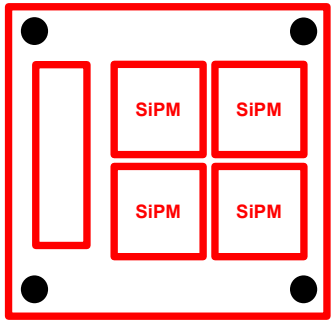


4-channel SiPM readout board (From B. Hirosky and T. Anderson)

Modification thoughts:

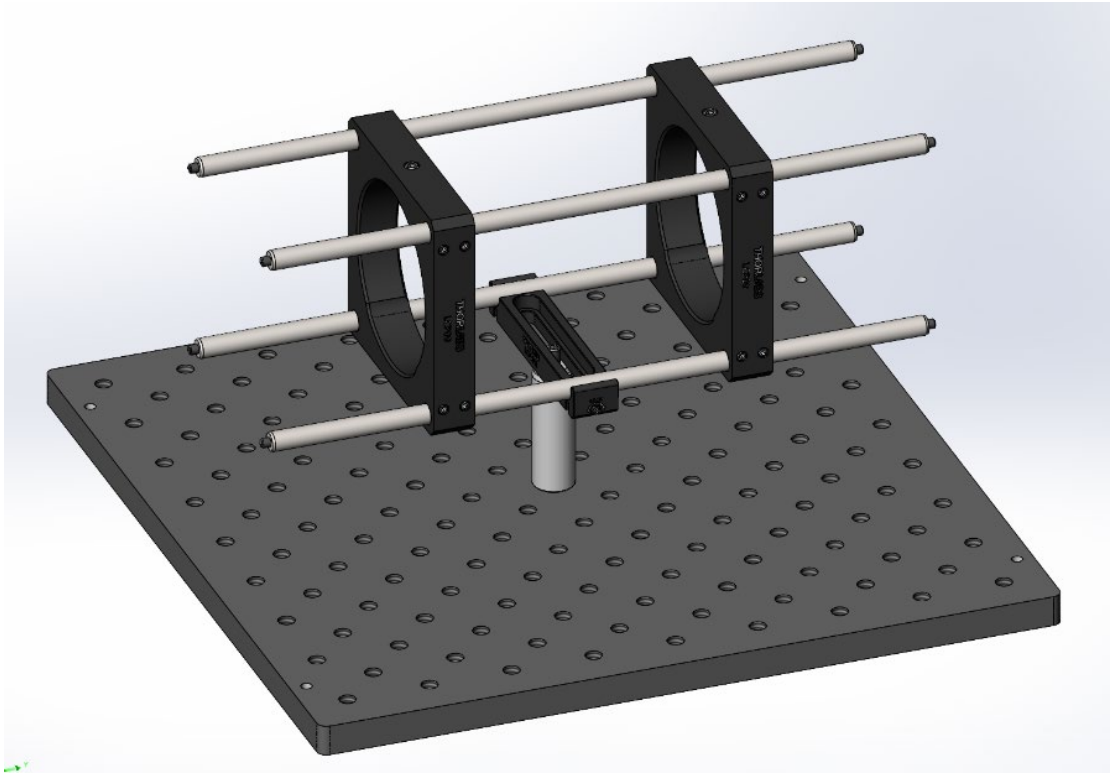
- Bigger foot print for 6*6mm SiPM (6.4*6.4mm for S14160-6050HS, or 6.85*7.35mm for S13360-6050PE)
- Daughterboard holding 4 SiPMs, with connector at one edge and standoffs at four corners



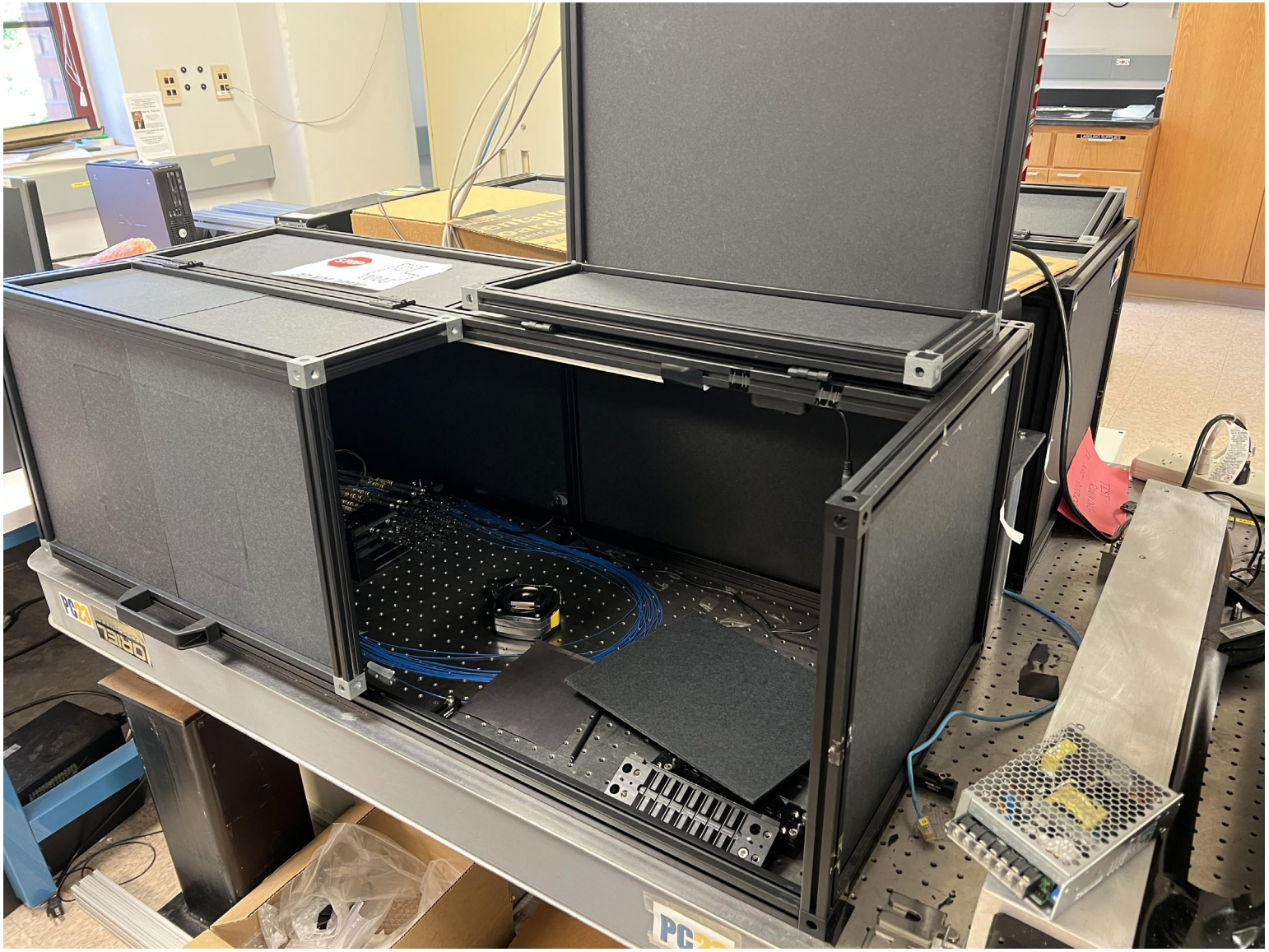


Planned supporting platform in the dark box

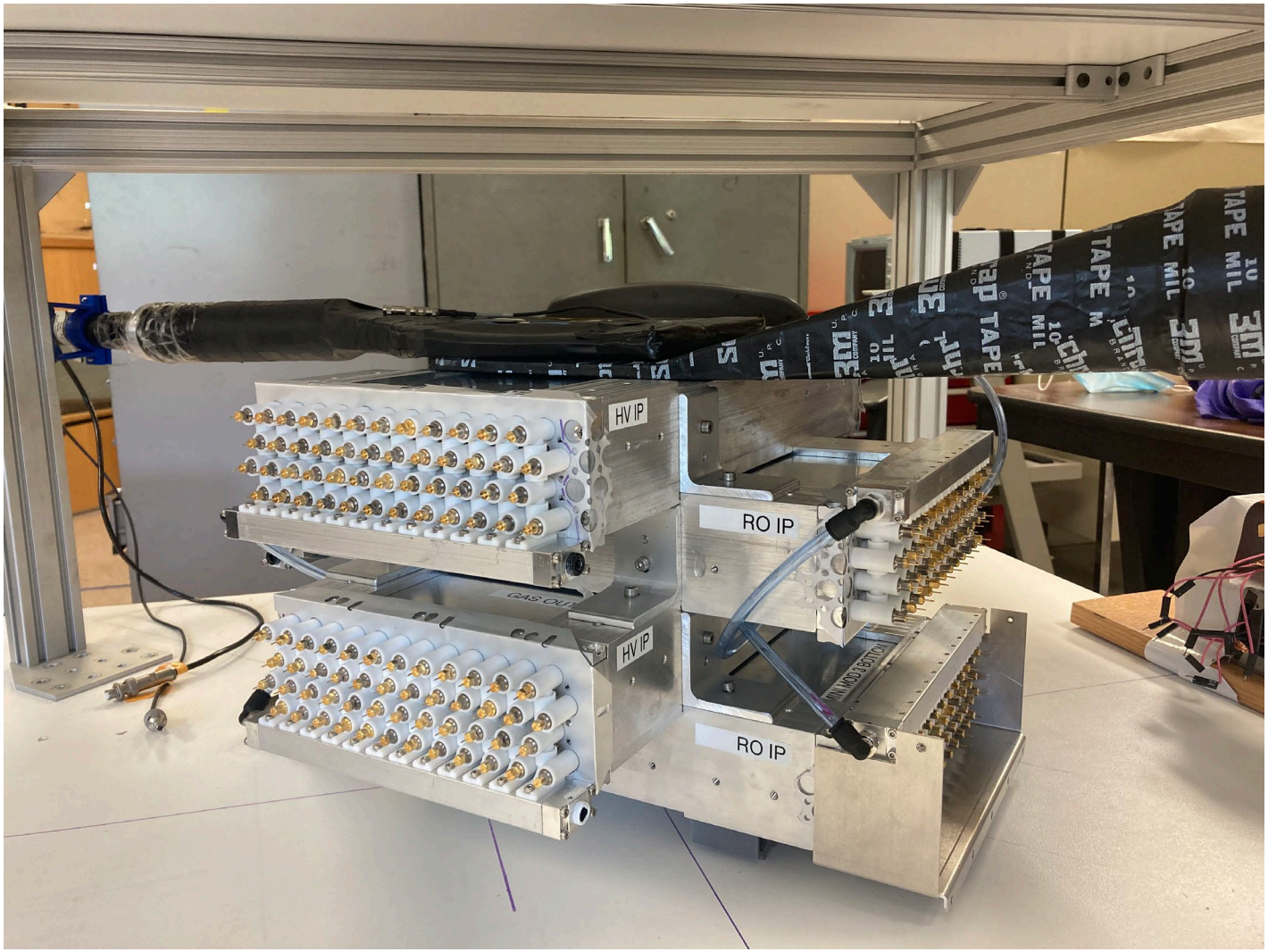
- Optical cage system from ThorLabs
- Horizontal rods: 6mm diameter and 60 mm spacing
- Crystal in the center, filter lens and PCBs attached to the 2 sides
- Can replace the two cage ends with two plastic boards to hold up rods
- The readout board can then be attached to the plastic boards
- The whole supporting platform may be placed vertically.



Blackbox



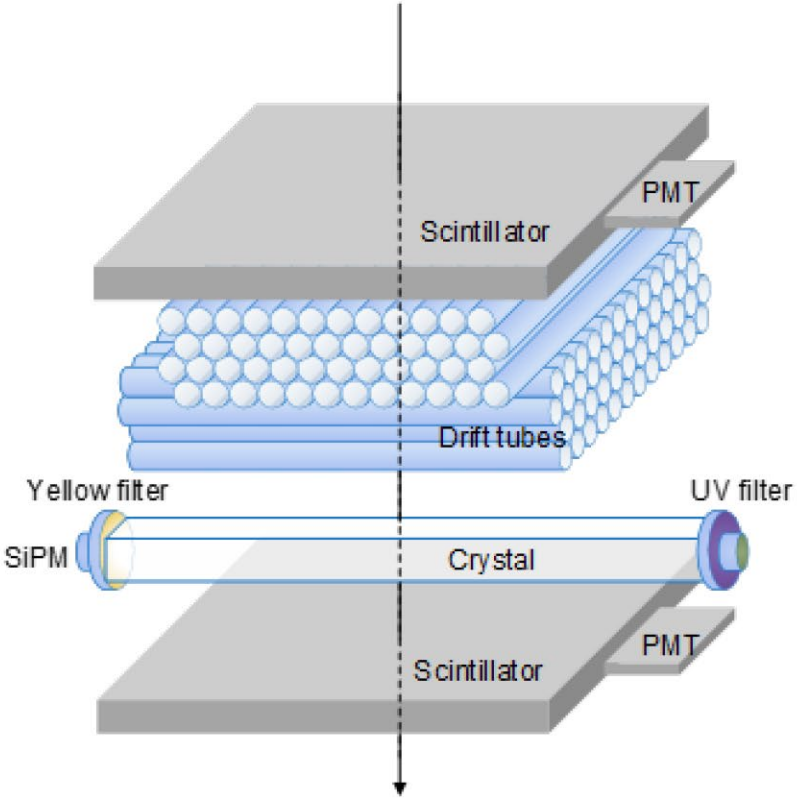
Small-diameter Monitored Drift Tube

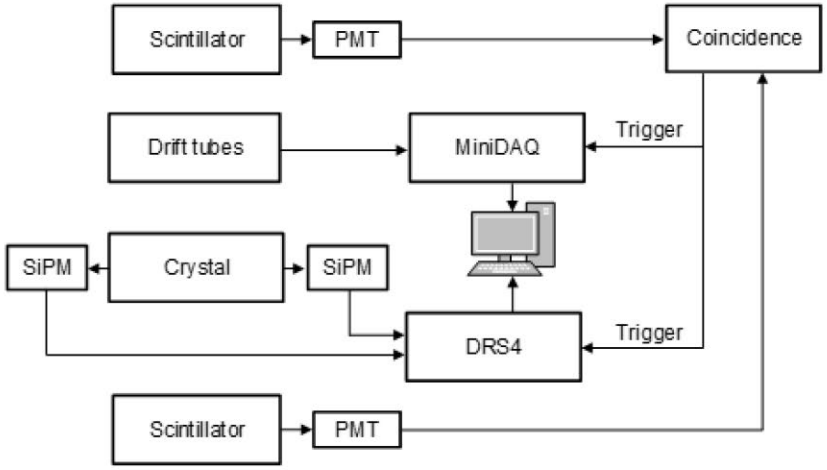


- Built 6 sMDT chambers (4 shown here), to be used to determine the muon position and direction
- Collecting frontend mezzanine cards (chips designed at Michigan and MPI, boards produced by MPI) and producing more miniDAQ boards

Next plan

Important to have large-area SiPMs





- For the first step, will not use the sMDT detector and will put the crystal vertically
- Use the SiPM timing signal as the trigger and use the scintillator signals for validation