Main Detectors for PREX-II/CREX

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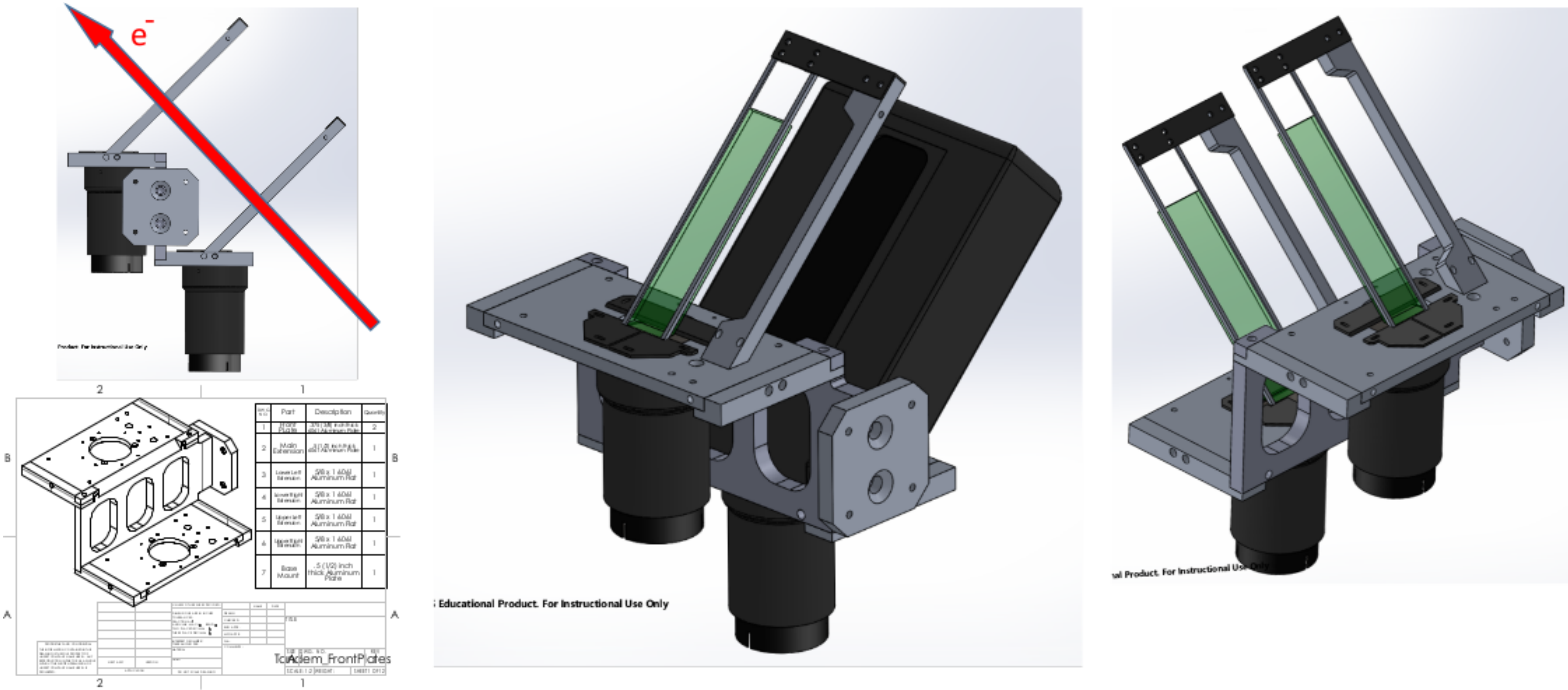
July 25 - 26, 2018

Main Detectors for PREX-II/CREX

Talk Outline:

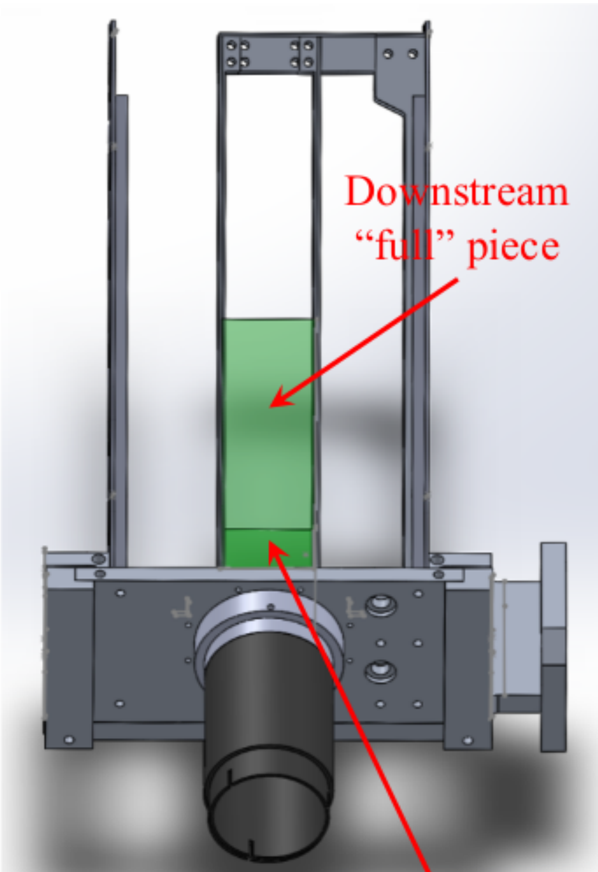
- Main Detector Design
- Motion Control System
- GEM Stand with Tandem Mount
- HRS Detector Package
- PMT Linearity and Gain
- Summary and Future Work

Main Integrating Tandem Detector Design

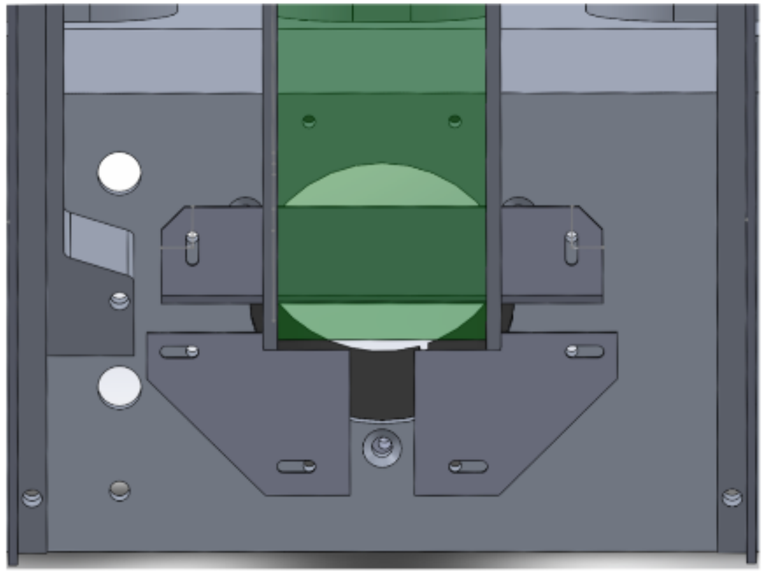


- PREX-II/CREX main detector design based on UMass Design-3
- Rotatable tandem mount designed, prototyped, and final version constructed
- Final design has shorter quartz rails and incorporates mu-metal shields and 3D printed ABS-plastic enclosure with Kapton windows

Quartz Geometry Plans (Preliminary)



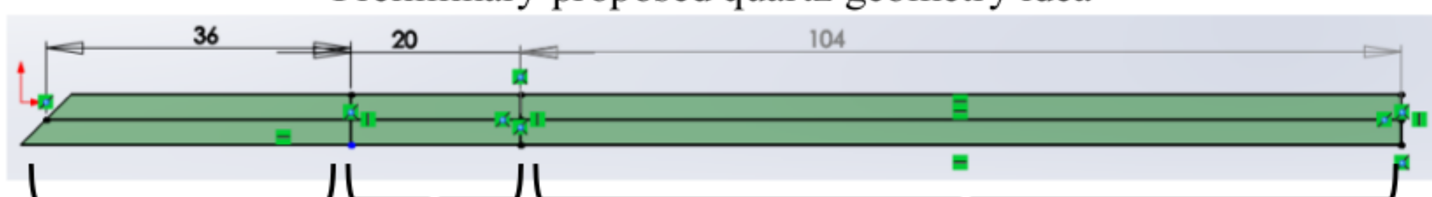
Beam’s view. Note ”stubby” quartz installed upstream, “full” quartz downstream – for illustrative purposes



Top view showing quartz-rail supports (at PMT end). No light guides or wrapping will be used.

- PREX-I quartz was 3.5 cm wide by 16 cm long by 6 mm/10 mm thick
- PREX-II and CREX quartz footprint will be similar to PREX-I
- Design can accommodate up to 4.8 cm wide quartz piece
- May need thinner quartz for PREX-II due to higher 1.8 GHz rate; possibly 4 mm thick…

Preliminary proposed quartz geometry idea



“Light Guide” 3.6cm

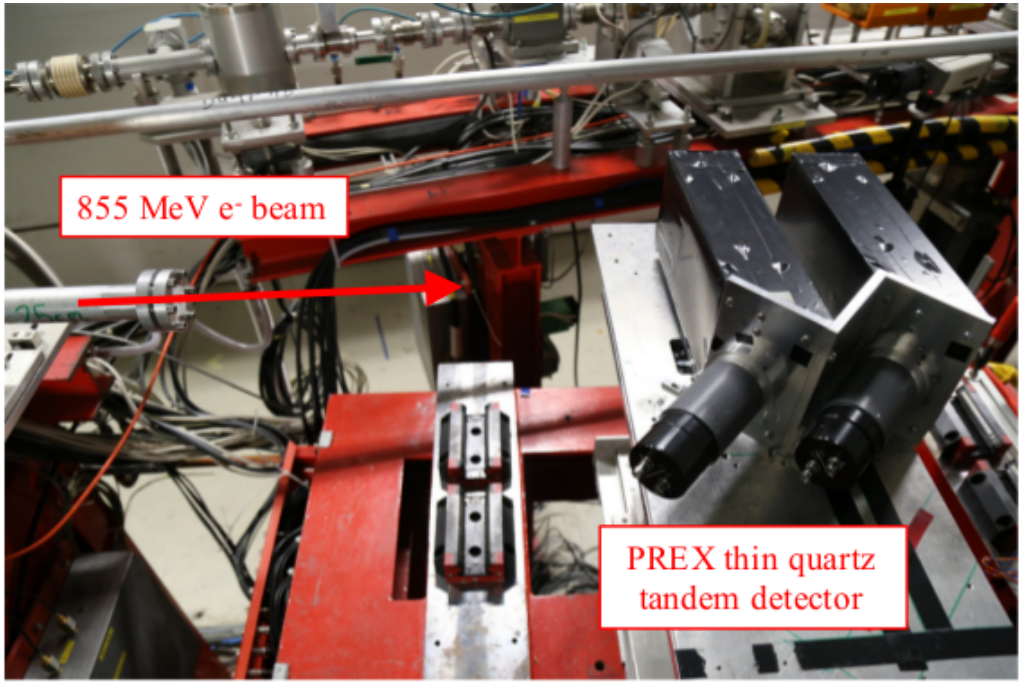
“Buffer” 2.0cm

“Active Region” 10.4cm (PREX)

Total length 16cm

“Stubby” piece 5.6cm

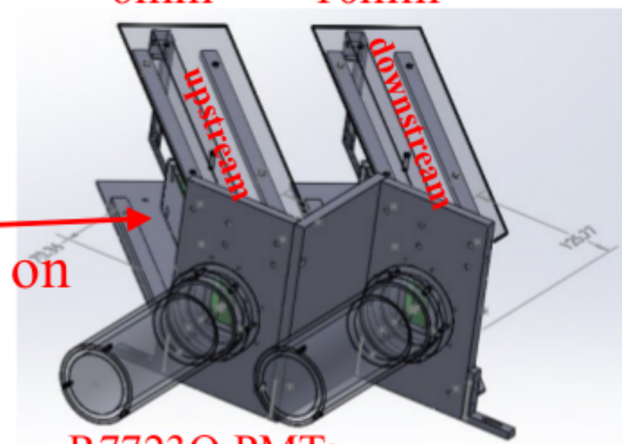
PREX/CREX Tandem mount testbeam (2016)



Spectrosil2000 thicknesses: 6mm 10mm

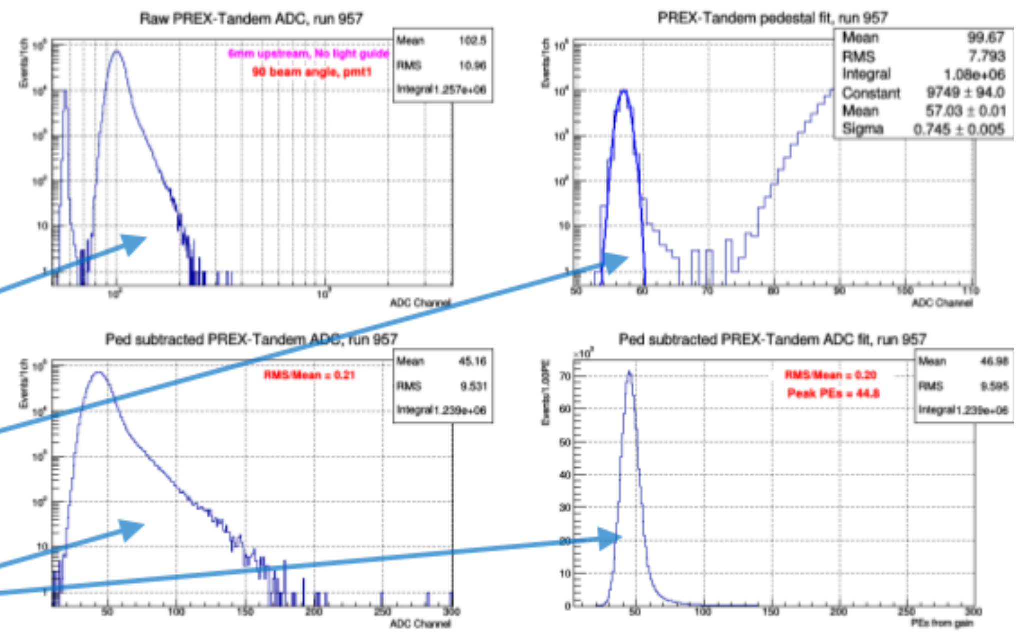
e- beam

Centered on quartz at ~90°

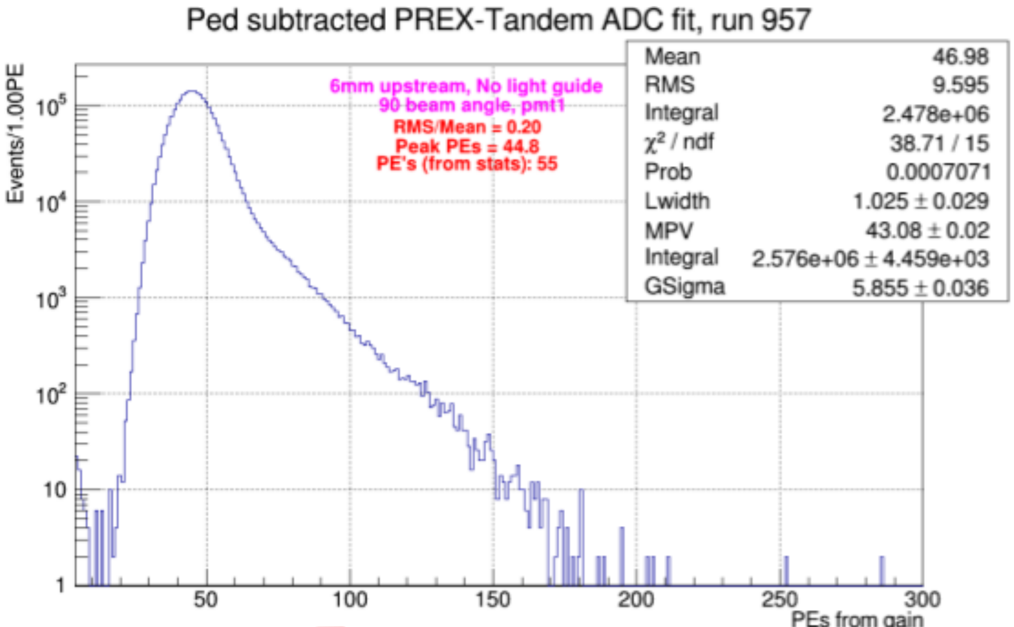


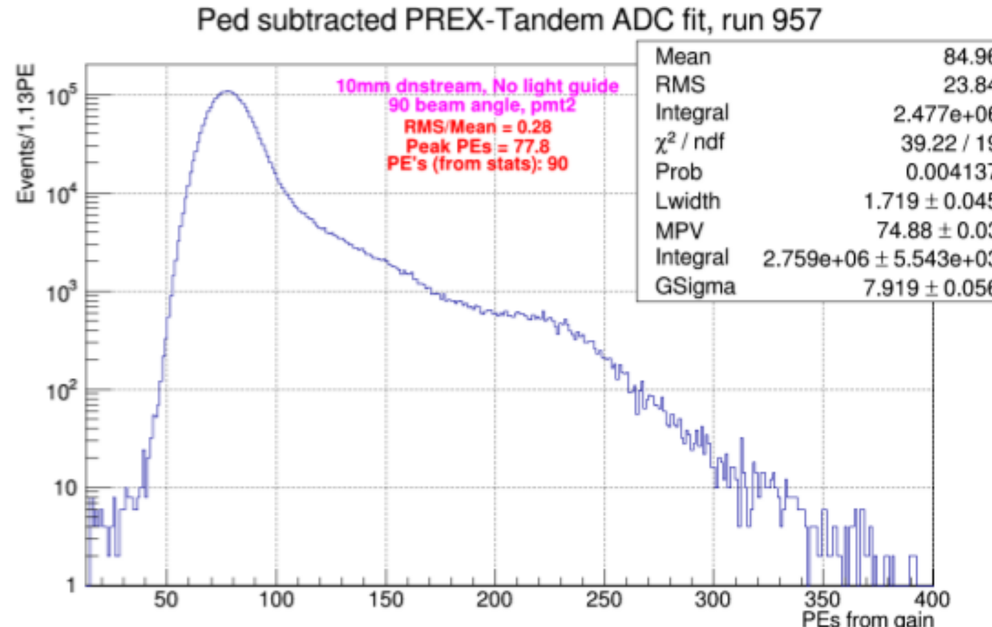
R7723Q PMTs

- Quartz spacing same as for rotary tandem mount (~16 cm)
- Used two Hamamatsu R7723Q pmts
- Quartz is wrapped with 1 mil Al. Mylar
- Took runs for each quartz thickness upstream and downstream
- Example raw data, pedestal fit, and ped-corrected ADC and PE dists



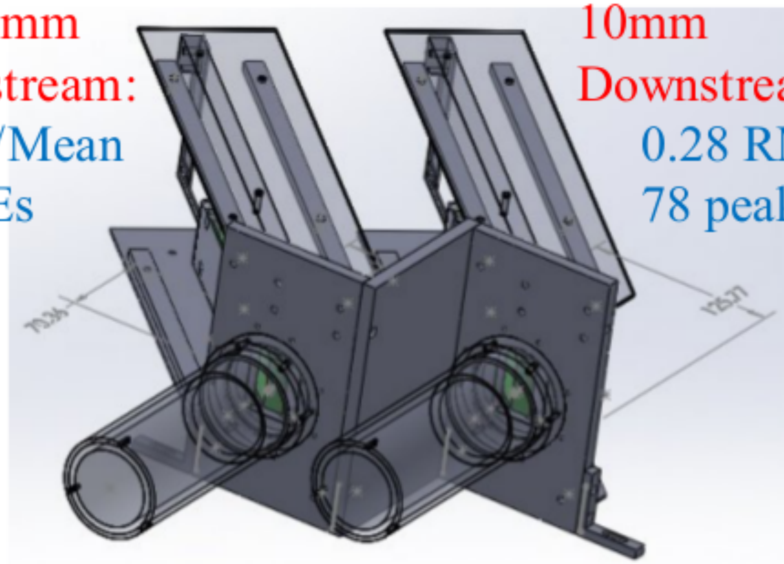
PREX/CREX Tandem mount testbeam





- PEs converted from ADC units using PMT gains
- Peak PE's from Langau fit parameters did not agree with PE's from gain; fits were poor and very sensitive to fit domain around peak

6mm Upstream:
0.20 RMS/Mean
45 peak PEs



10mm Downstream:
0.28 RMS/Mean
78 peak PEs

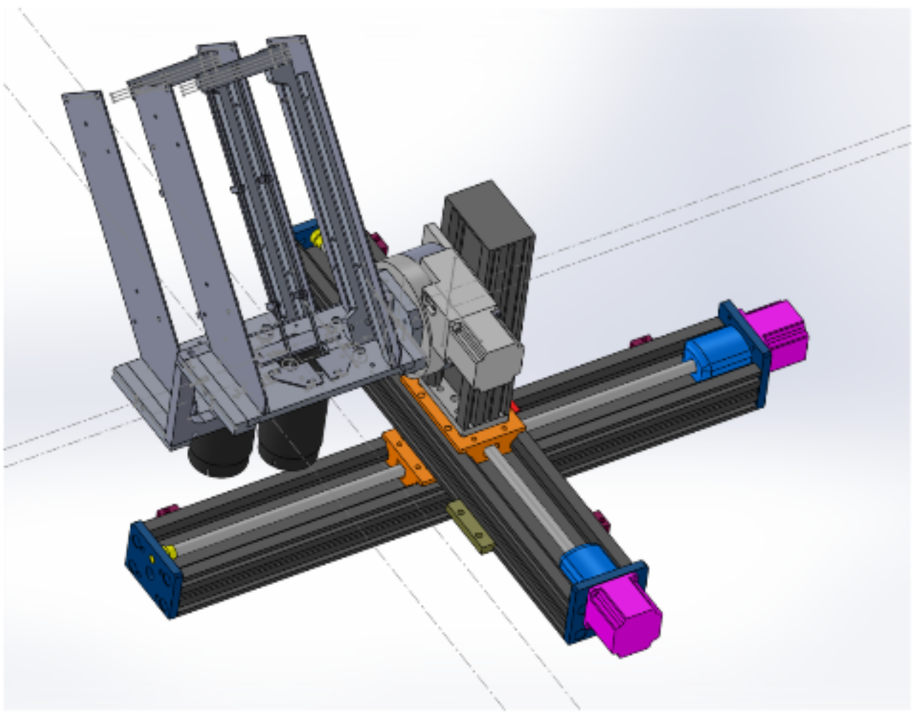
- Uncertainty in PMT gains between ~5%

Main Detector Components List: What we have & what is needed

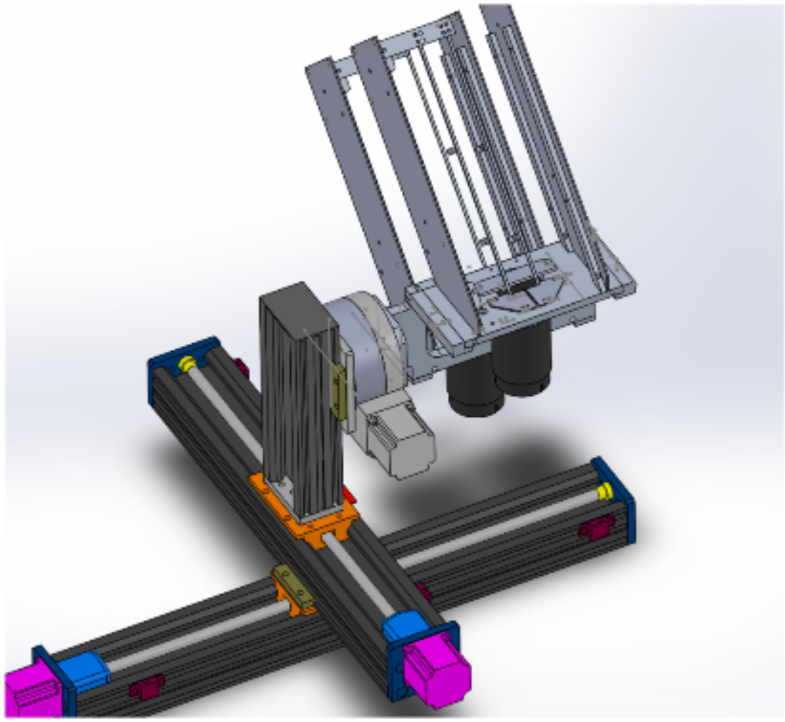
- Left arm tandem mount complete
- Right arm tandem mount under construction (ready in a couple weeks)
- Have 4 R7723Q PMTs with characterized gain and linearity; would like at least 4 to 6 more for A_T detectors and spares ($2k each -- $8 – $12k total).
- Have 2 mu-metal shields in hand; purchased 2 more last month; may want 4 more for A_T detectors ($500 each – total cost is $2k)
- Have 10 mm and 6 mm thick PREX-I quartz; need to finalize geometry and purchase main detector quartz. Can likely use same pieces for PREX and CREX (Cost is expected to be roughly $1k per piece for total of $4k - $5k)
- We also need to purchase the "stubby" quartz pieces (if we want these for alignment validation studies during commissioning). Need at least 2 of these (total ~$1.5k)
- Total cost of main detector and A_T components still to purchase: PMTs, bases and shields -- $10k - $14k; quartz $5.5k - $6.5k. Total: $15k - $20k

Tandem Mount motion system (Prototype shown)

RHRS



LHRS

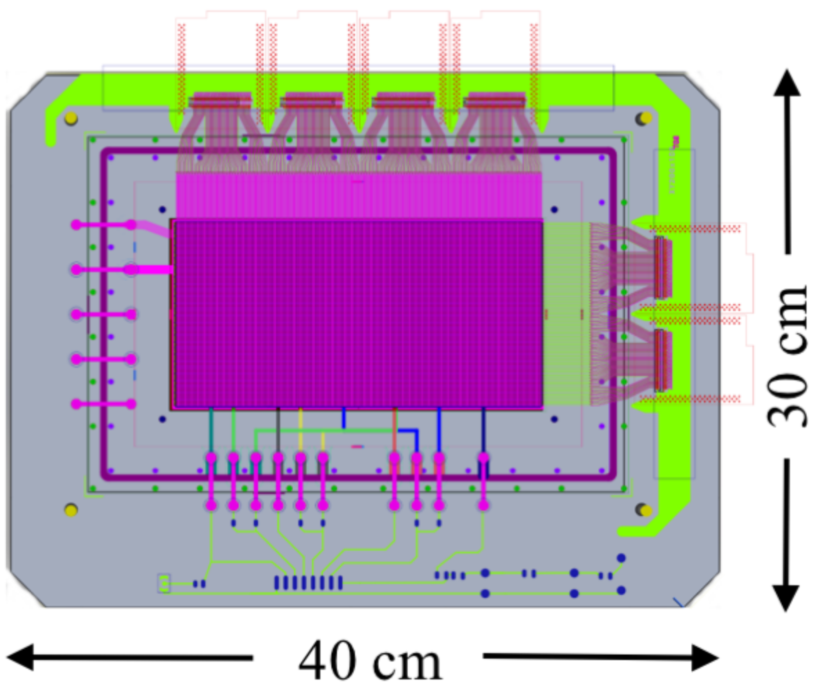


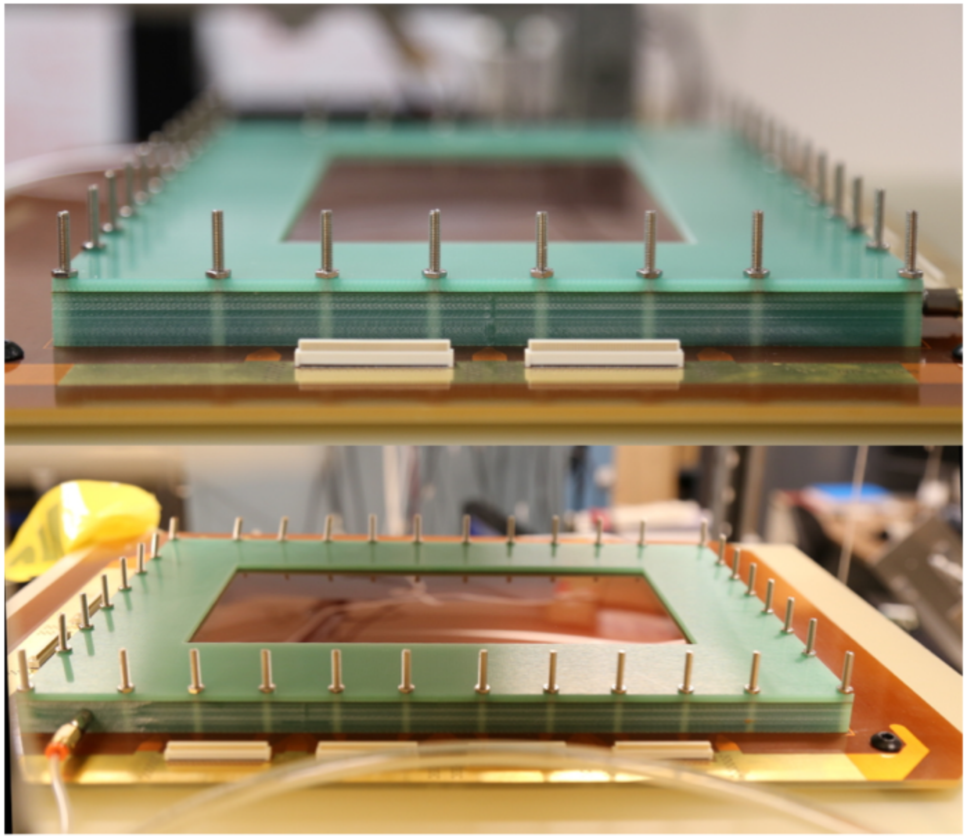
- *X*, *Y*, and θ degrees of freedom for main detectors
- Velmex 5 and 15" Bi-slides for X and Y motion, respectively (from PREX-I, we've found 15" sliders but not 5" and no controllers or cables yet…)
- Velmex rotary stages (have one, *need another*)
- Transducers for position feedback (have 8 from PREX-I)
- A_T dets will use 2 – 4 Velmex X-slides per arm (have 4 from PREX-I)

Motion system Needs

- Stepper motor controllers: ~$400 per channel. Need up to 7 channels per arm. Could purchase four 4-channel controllers (VXM-4) for total cost ~$3200
- Need two 5" Bi-slides with motor: ~$900 each for total cost of ~$1800
- Need one rotary stage with motor and encoder: ~$2150
- Need 4 more X-slides, 2"(?) travel with motor for A_T's: ~$500 each for total of ~$2000
- May need cable extension kits (from controllers to computer): $200 each. Total cost of $800
- Total needed is ~$10k for motion system

PREX/CREX “small” 10x20 cm^2 GEM trackers

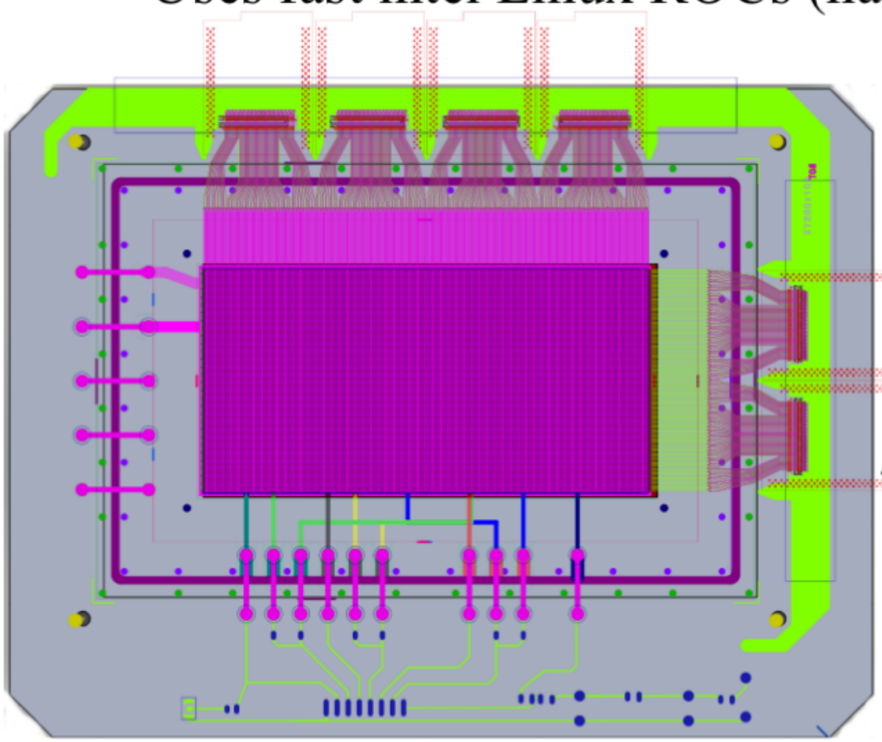


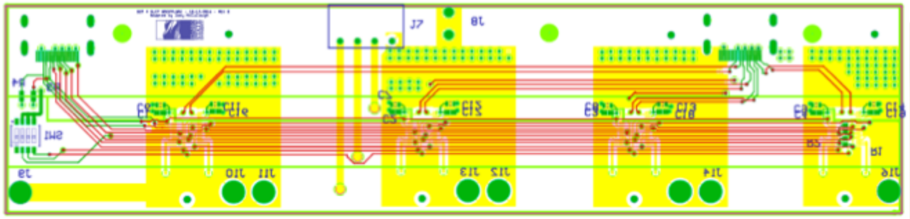


- Custom CERN 10 cm by 20 cm active area triple GEM chambers
  - ➢ 400μm pitch x/y, 4 + 2 Panasonic 130pin Readout connectors
  - ➢ Standard GEM spacing D-3mm-G1-2mm-G2-2mm-G3-2mm-RO
  - ➢ Standard HV filter circuit: uses CERN ceramic resistor
- Readout scheme based on INFN/UVA SBS rear-tracker:
  APV25FE ➟ backplane PCB ➟ VME MPD

GEM Readout Plans

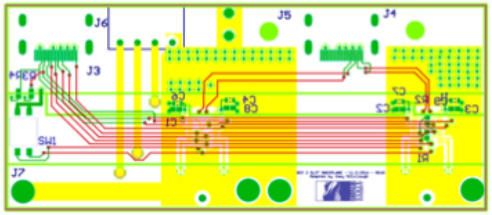
- GEM readout scheme based on INFN/UVA SBS rear-tracker system:
  - Uses APV25FE rev4.1 cards (have 55 in-hand); each chamber requires 6 APVs
  - Requires new 4-slot and 2-slot "backplane" PCBs (have 36 in-hand)
  - Backplanes buss analog-out signals to MPD and pass digital ctrl signals to APVs
  - Have 6 VME MPDs (Multi-Purpose Digitizers); require 2 for each arm
  - Uses fast intel Linux ROCs (have 3 in-hand: GE XVB601); require 1 for each arm





4-slot backplane

APV rev4.1



2-slot backplane

APVs mount directly to Panasonics on GEM readout board—amplifies and multiplexes output

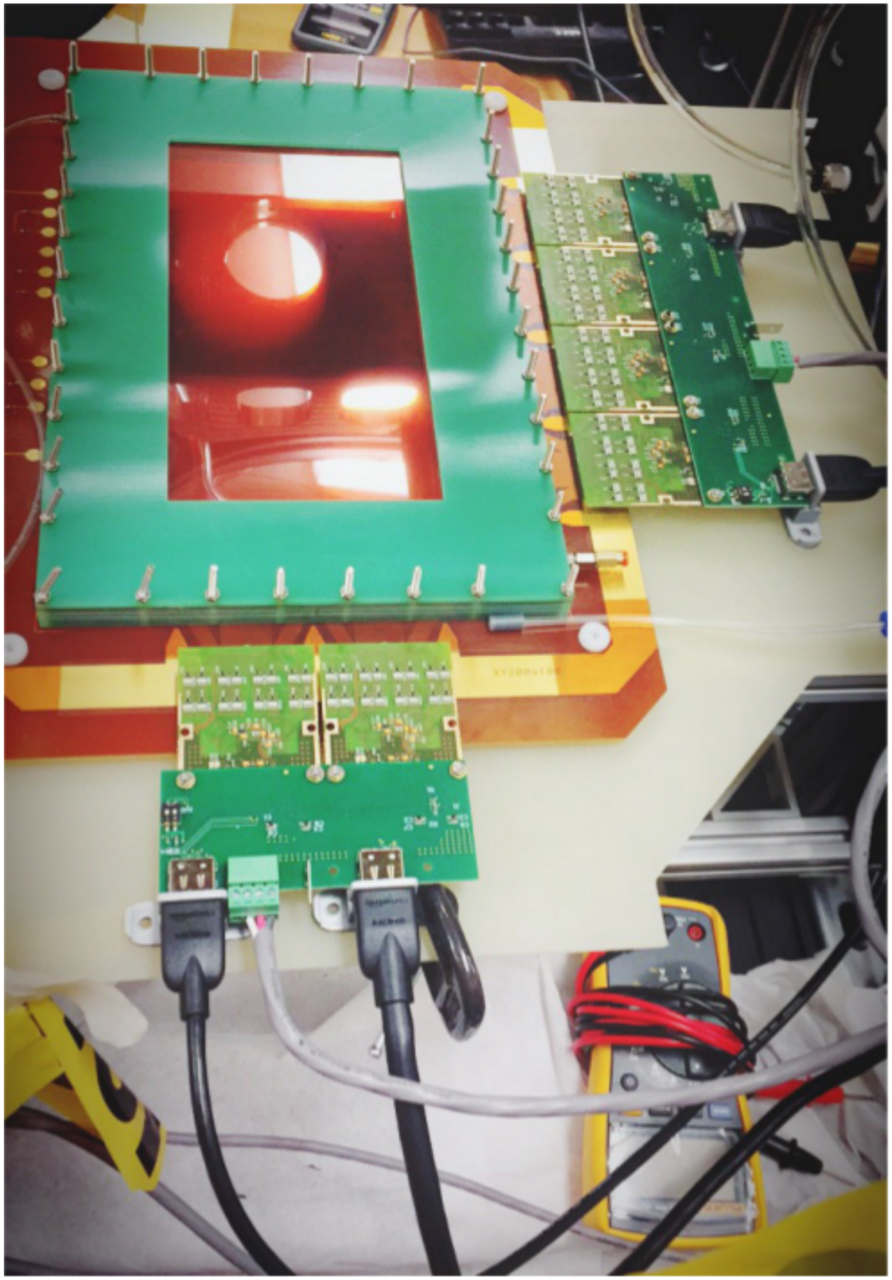
MPD rev4: Handles 16 APVs

❖ Getting much advice and help from Paolo Musico and INFN group, Kondo Gnanvo, Chris Cuevas, Nilanga Liyanage, and Alexandre Camsonne

GEM DAQ Plans

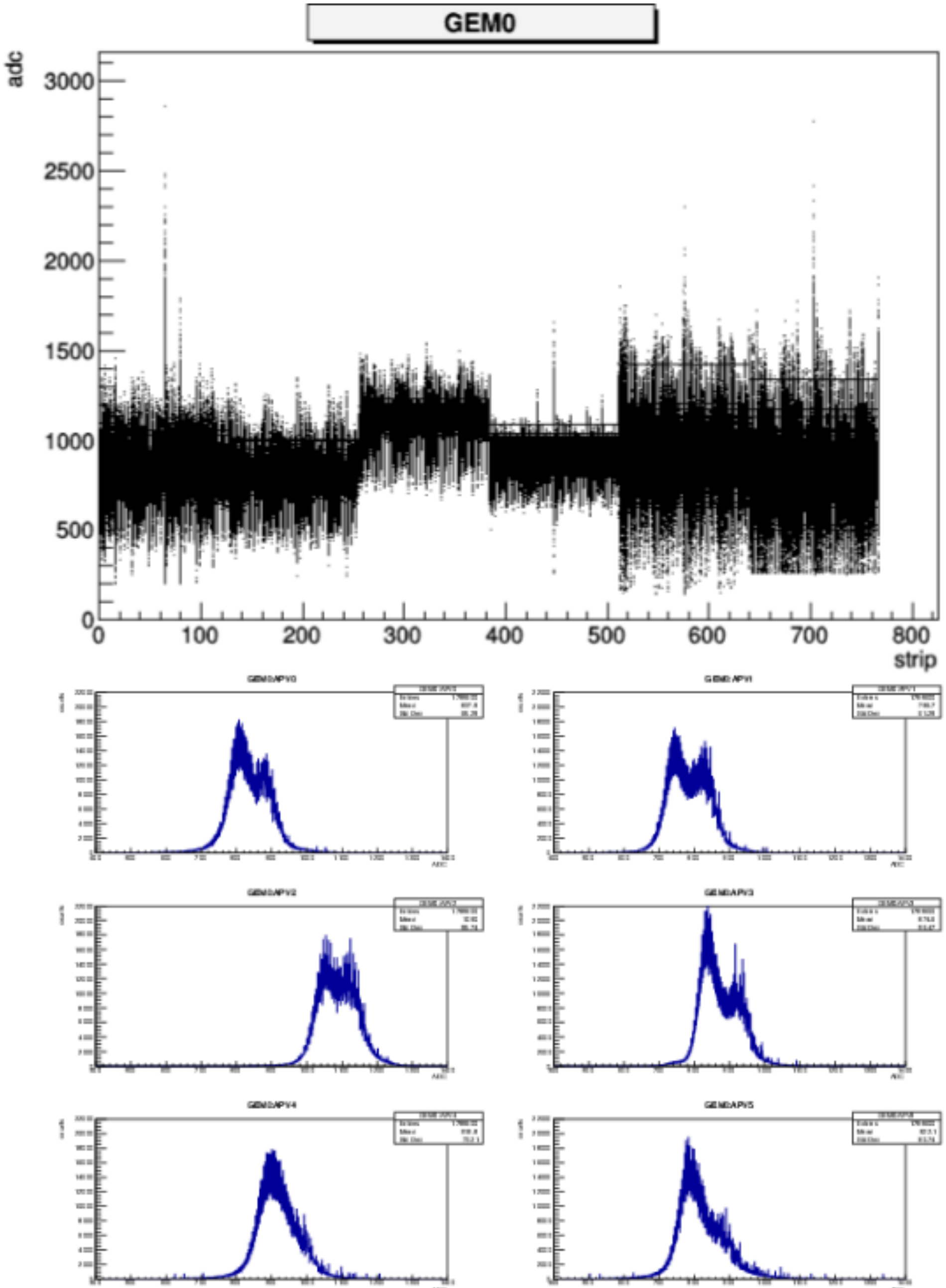
- Each arm requires one VME crate with fast linux ROC and at least three other available slots; I am currently using two Dawn 4-slot VME crates
- Each arm will need a trigger interrupt module and 2 MPDs; currently using a CEAN V965 QDC and v1720 digitizer for triggering interrupts (*we will likely want JLab TIs for this—but needs to be old Tis if use CODA 2*)
- Using CODA 2.6.2 with MPD drivers and support from JLab DAQ group
- Planning to use 6 – 10 meter long high speed HDMI cables for analog and digital signals (have all cables in hand)
- Each arm will need a CAEN N1470 HV NIM module (or equivalent) with 3 available channels (-4000 V); I currently have one HV module. *We will need an HV supply for the other arm*
- Each arm will need LV power supply with 5.0, 2.5 and 1.25 V; I have one already built and plan to build another (note that 5.0 V is for PMT preAmps)

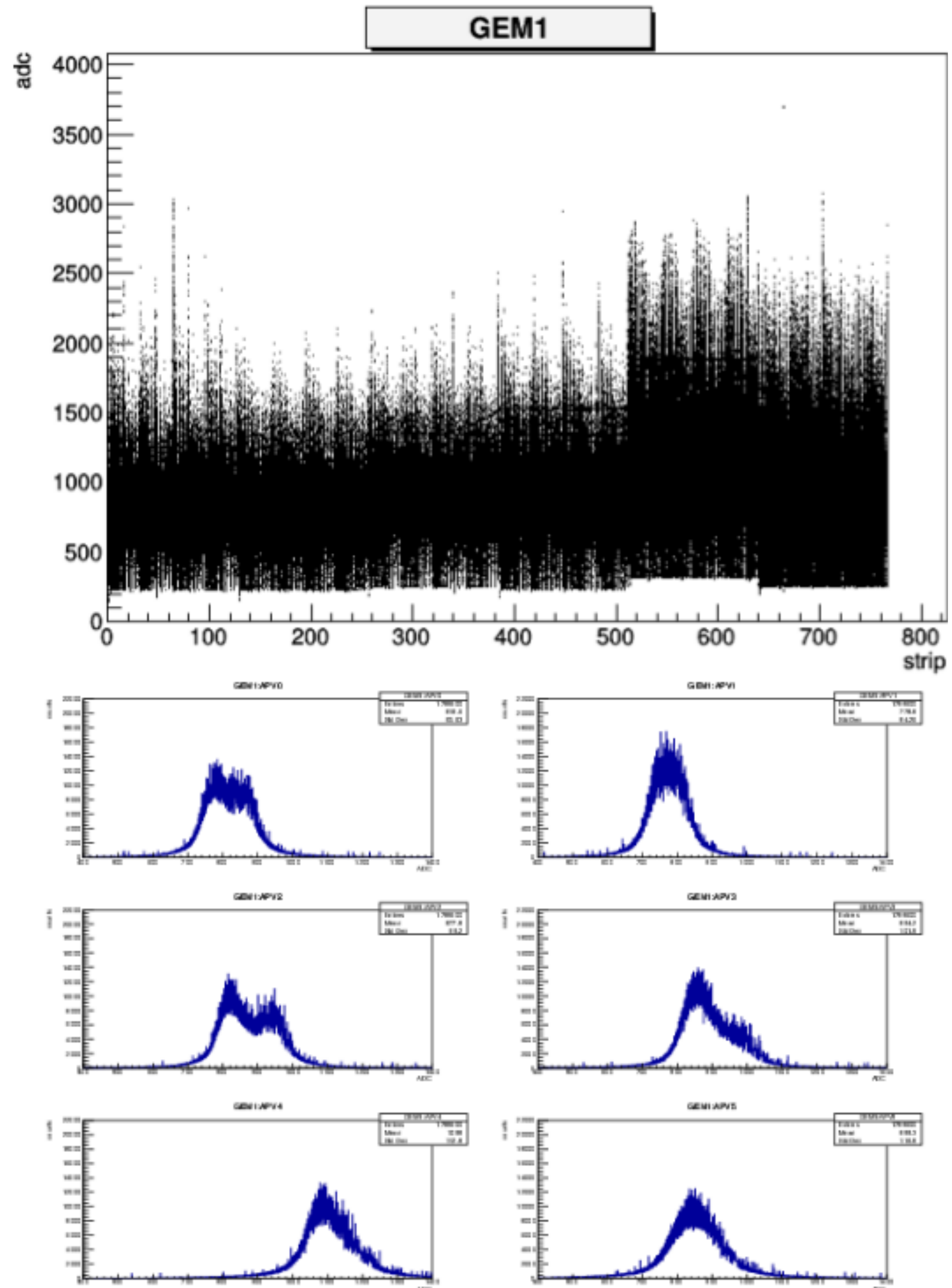
GEM DAQ Progress



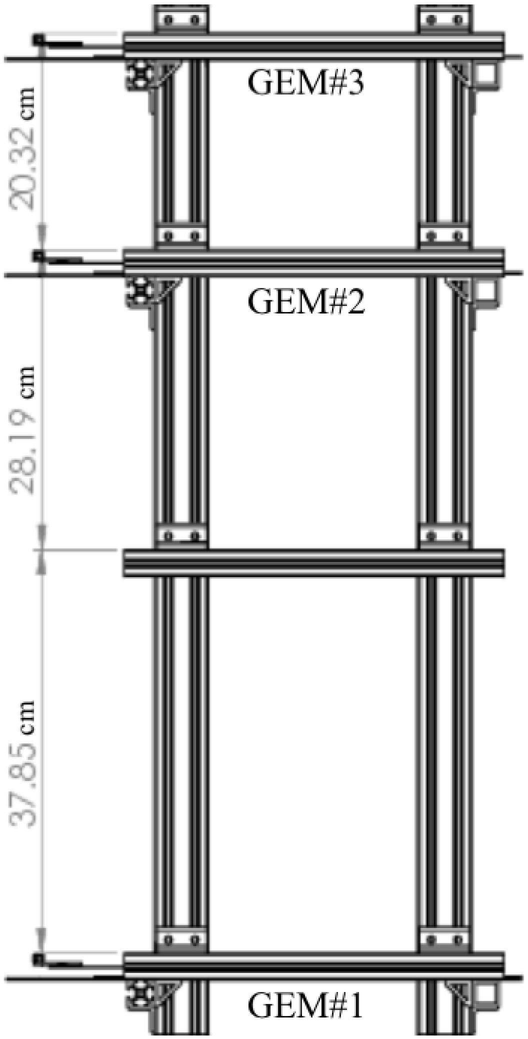
- Two GEMs complete with readout electronics chain: APV ⟷ backplanes (HDMI) ⟷ MPD
- Discovered I^{2}C addressing problem with backplanes; fixed with small jumper-wires
- Working with B. Moffit on CODA VME drivers specific for our setup – using v965 QDC or v1720 for triggering backplane interrupts
- CODA MPD (v3 firmware) system is up and running with two GEMs (so far); can take pedestal data; have working decoder; developing rudimentary analyzer, but have signal timing issues…
- Found out at SBS meeting last winter that there is a VME readout firmware problem with the factory MPDs. Paolo has fixed and given instructions on how to update MPD firmware
- Working wit Bryan Moffit and INFN group to get VME MPD4 DAQ acquiring signals

Sample GEM Pedestals (very preliminary)





GEM Chamber Mounting Concept



Aluminum ladder-frame

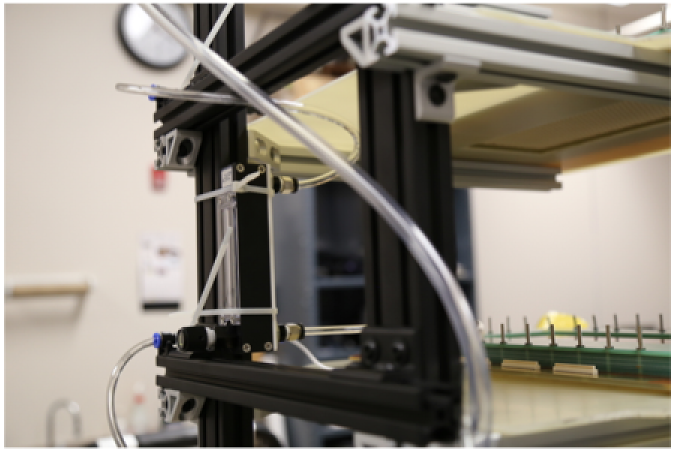
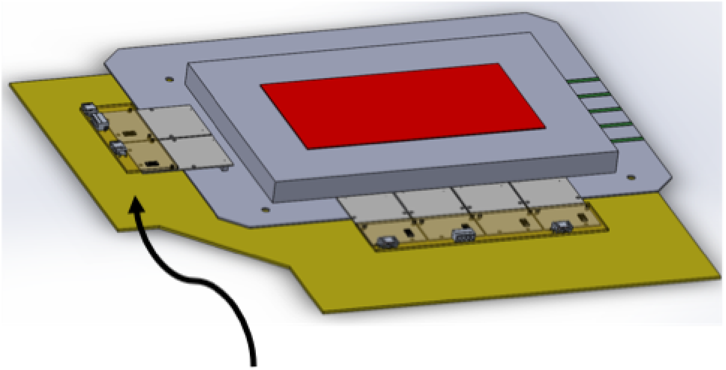
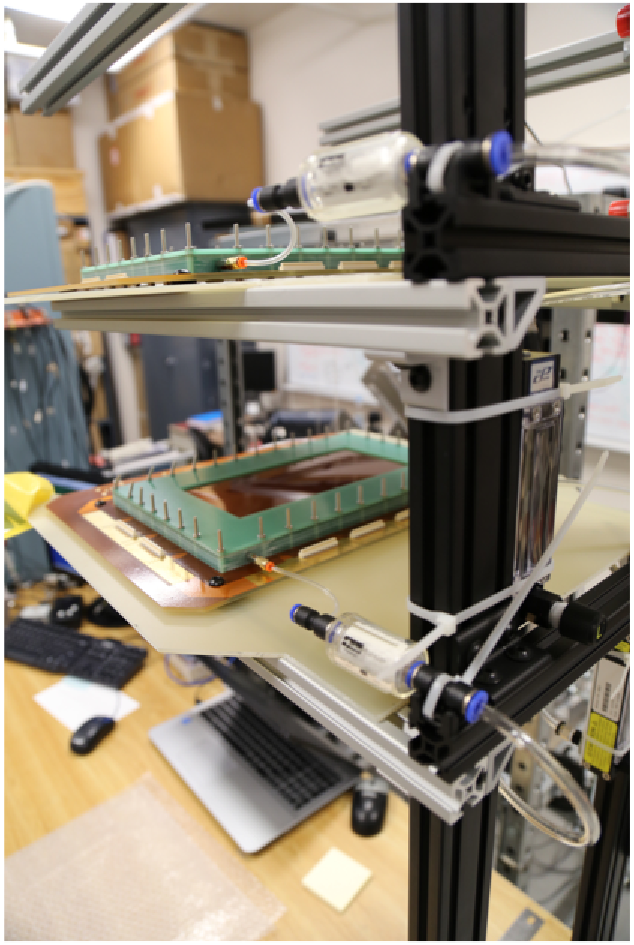


Photo showing rail support brackets



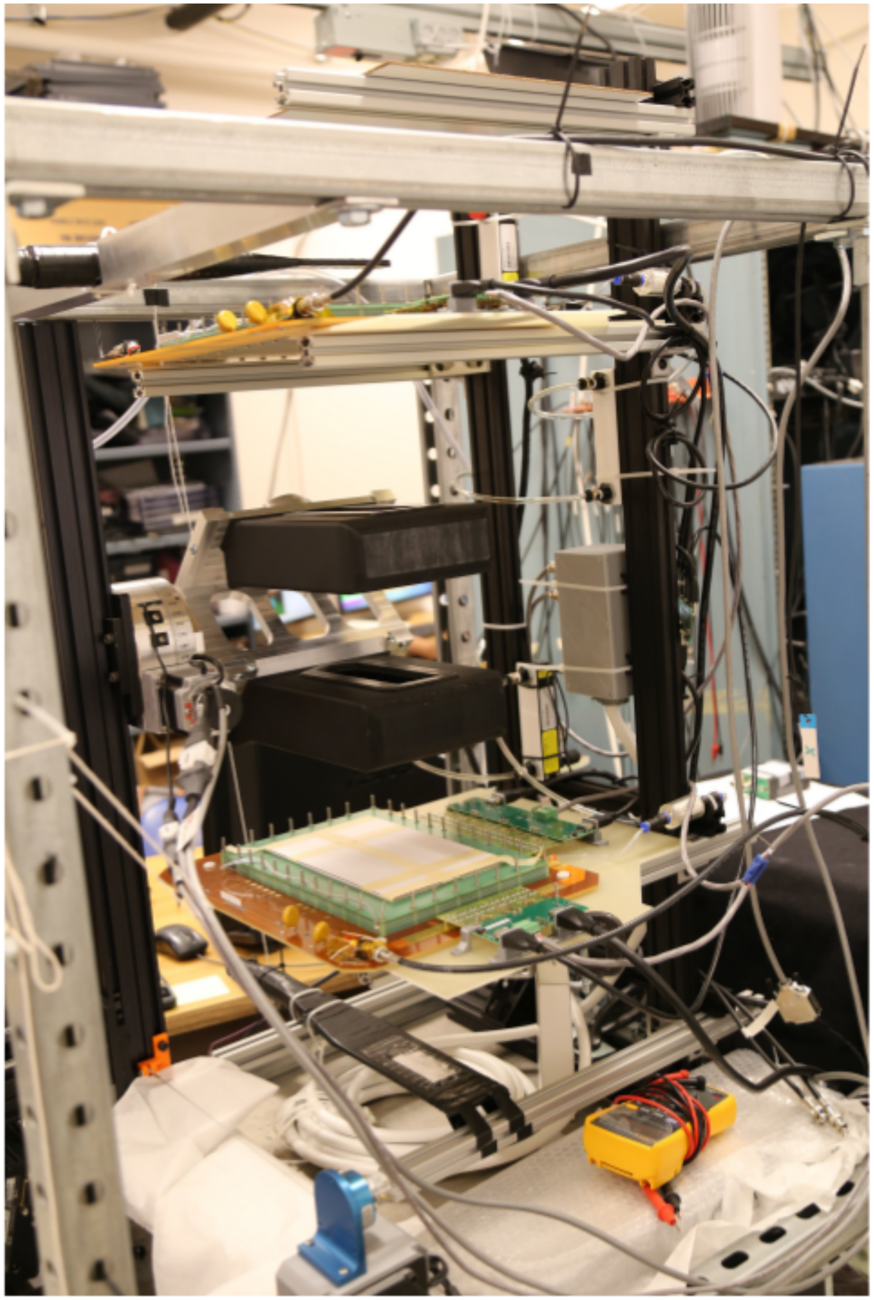
G10 platforms (1/16 in. thick) for GEMs: supports readout electronics

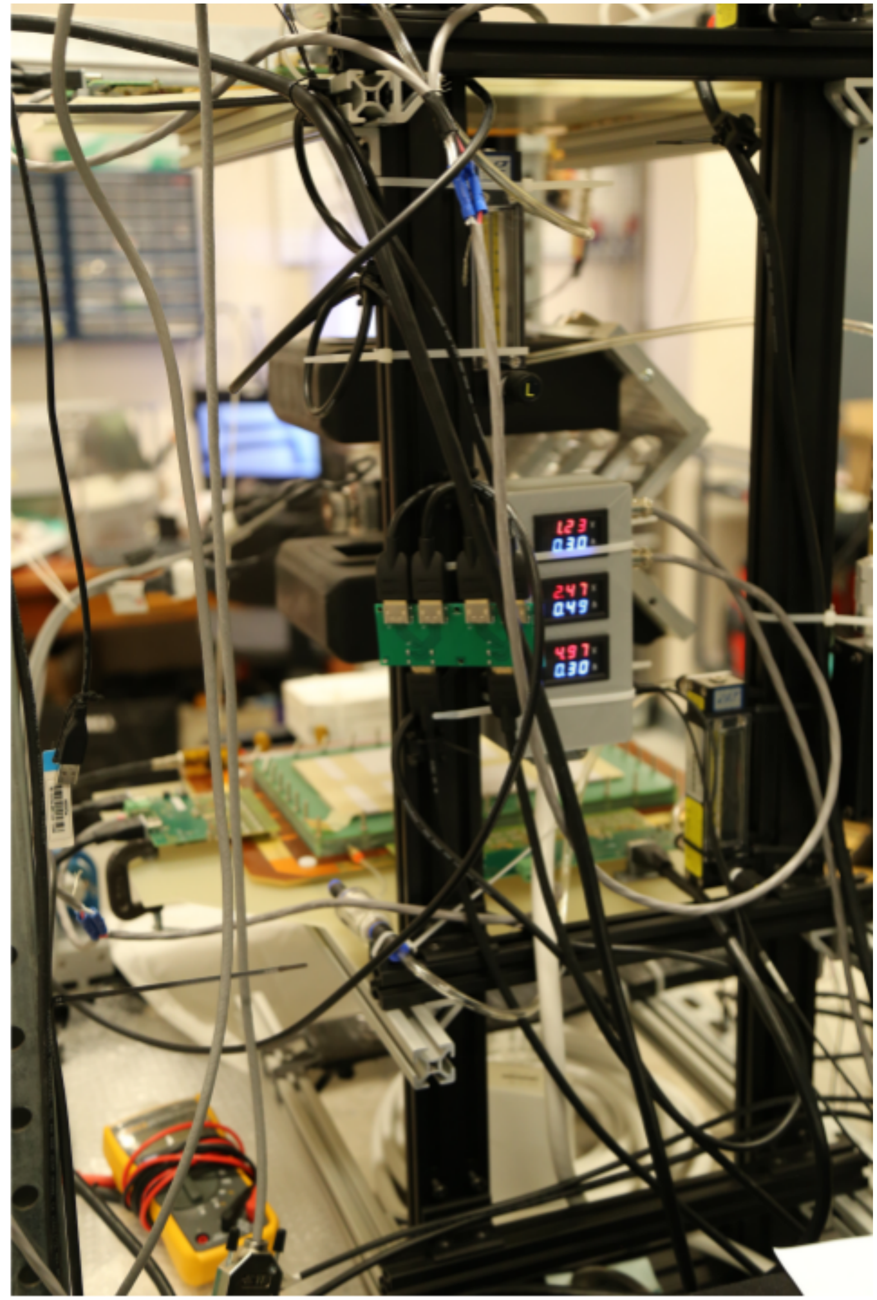


Two Chambers installed; gas flowing

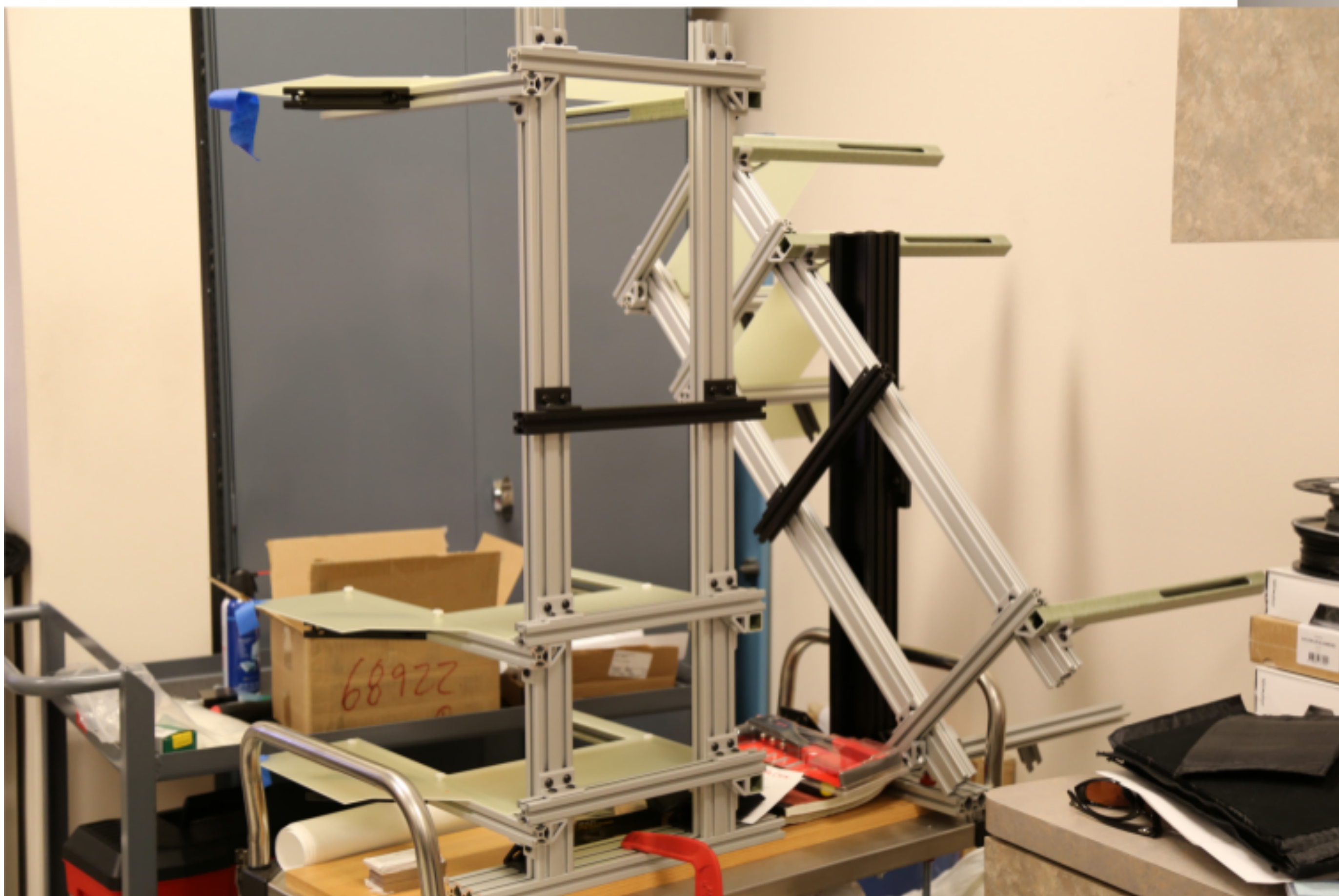
- 1" Extruded aluminum framing system for GEM mount
- Each arm will use three GEM chambers: one upstream and two downstream of quartz
- GEM ladder-frame mounts to Velmex slider post using cleats

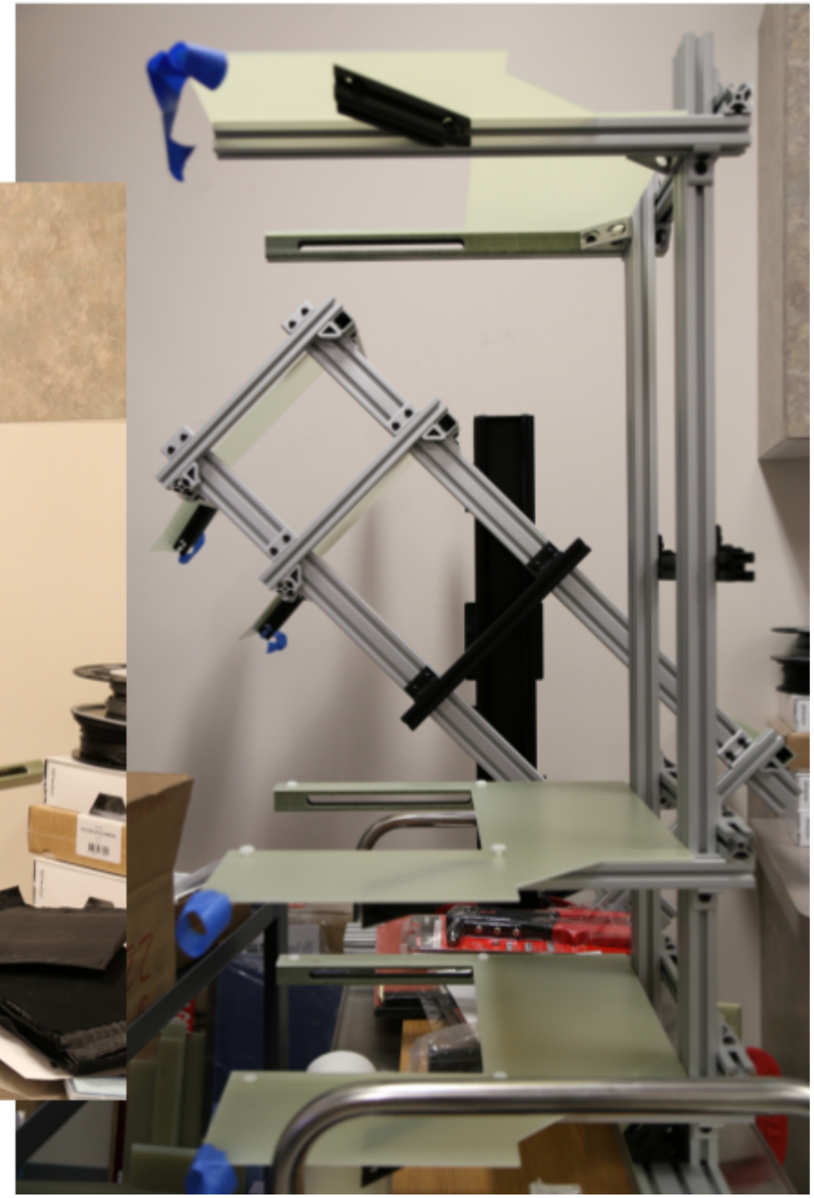
Cosmic Stand (with Rarm Tandem Det & GEMs)



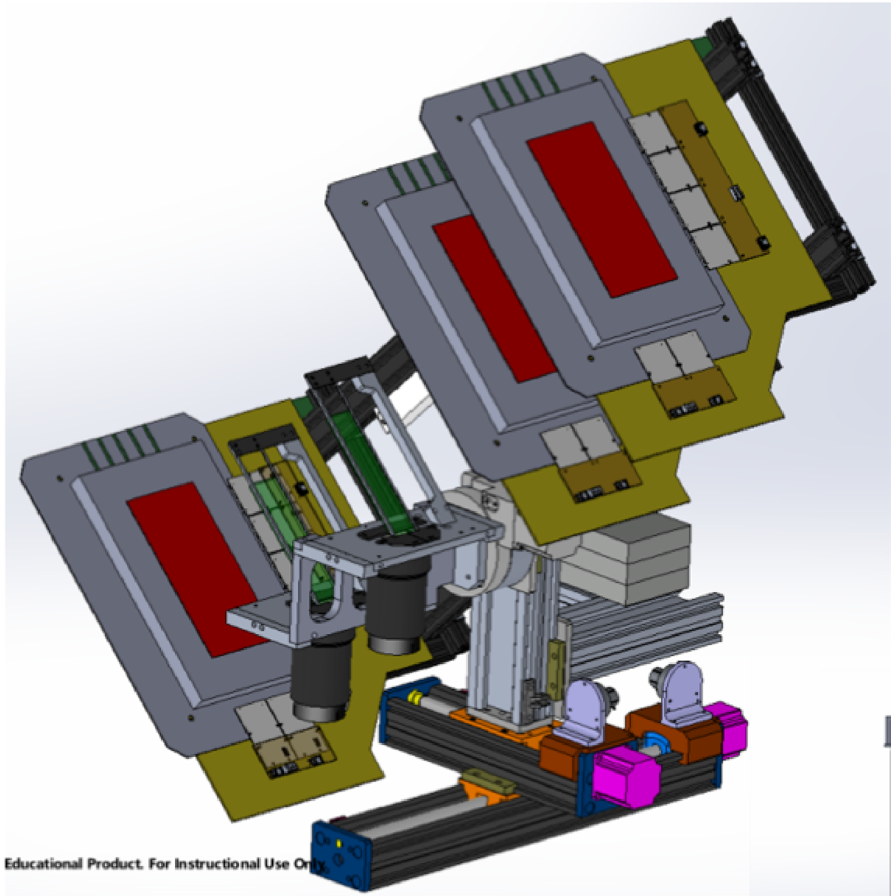


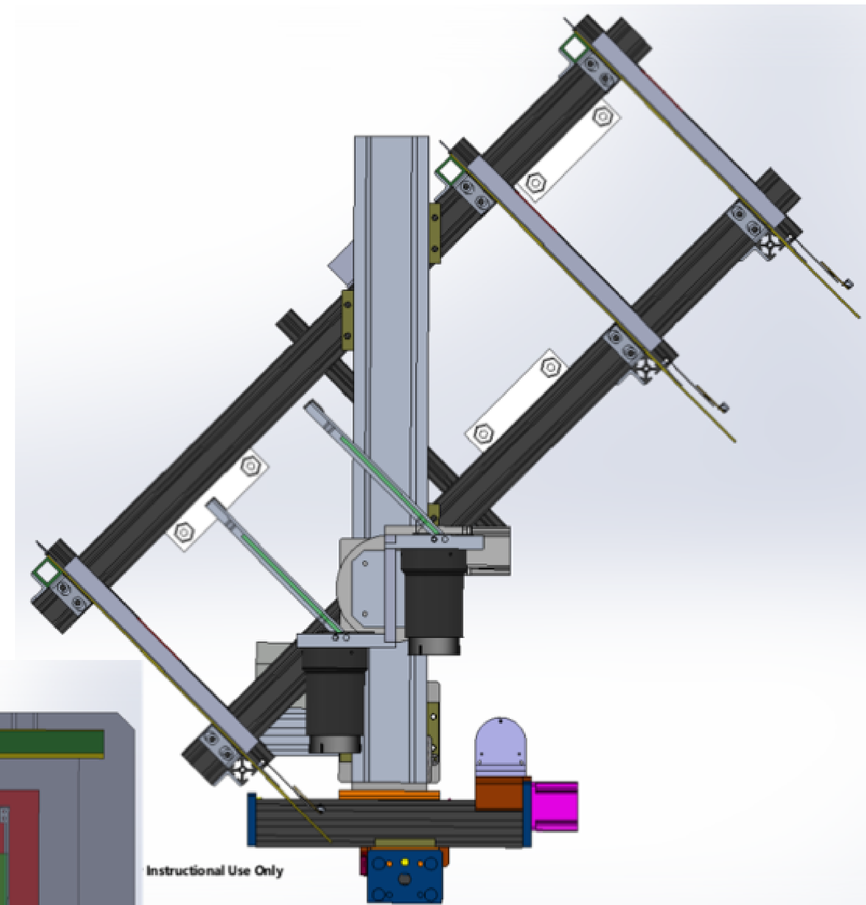
Main Detector Stands

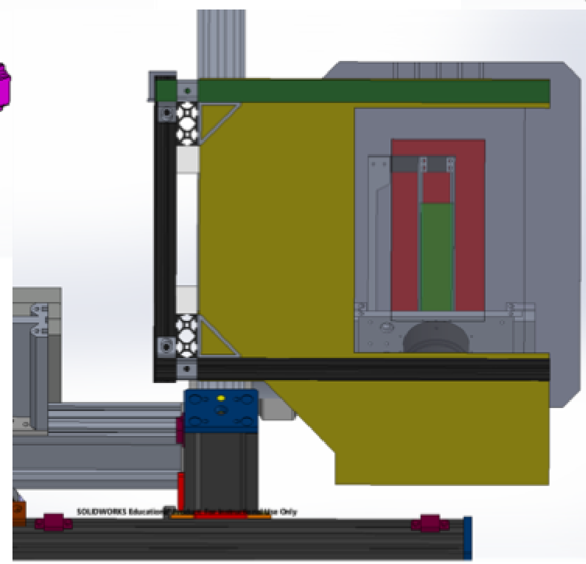




RHRS Tandem Quartz Mount with GEMs

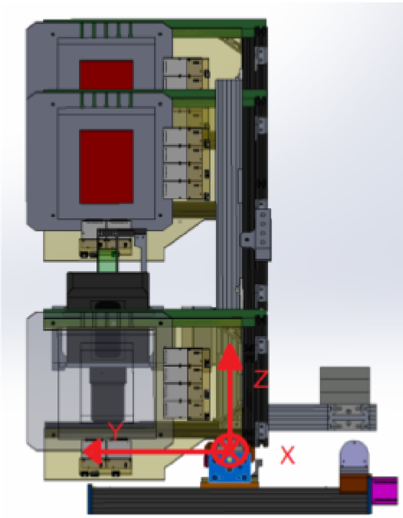






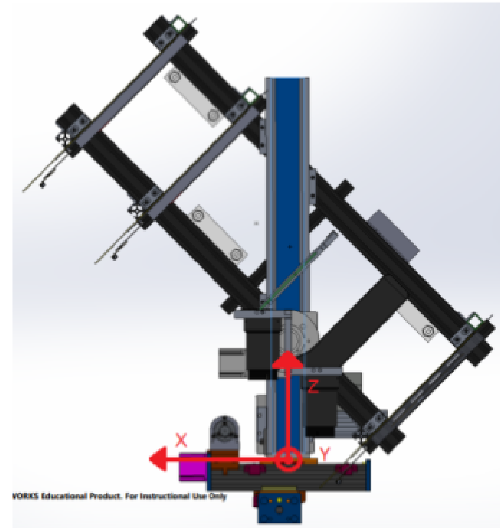
Electron's view (from below)

HRS Detector Package Torque Analysis

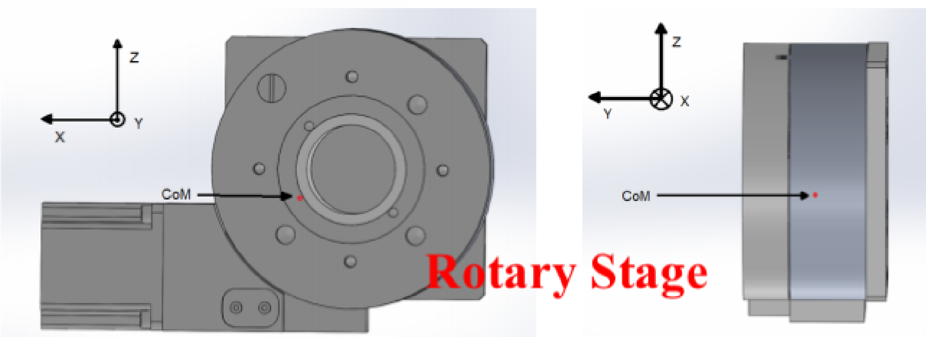


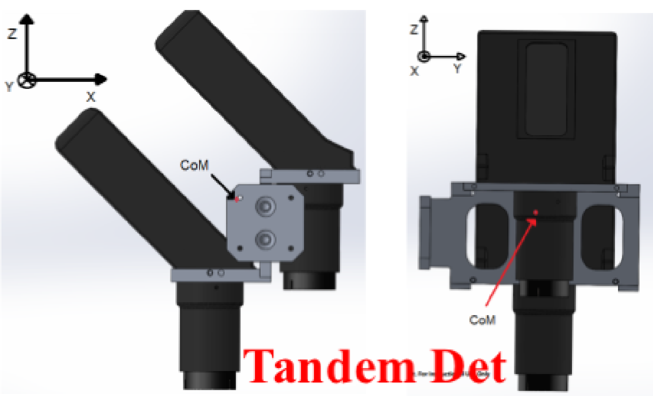
Using HRS hut coordinate system

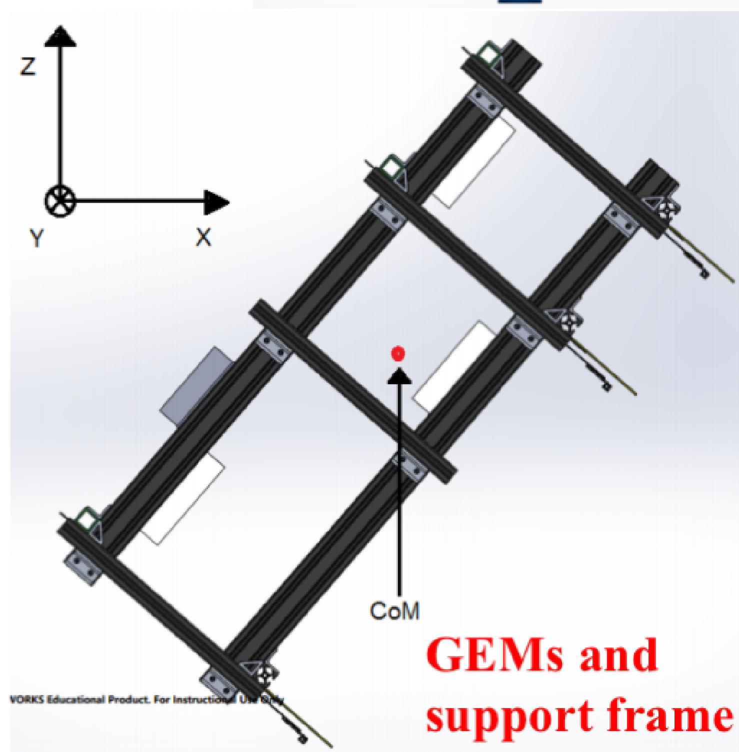
- Origin defined at the center of the 5-inch travel (top) slider platform.



Center of Mass Analysis







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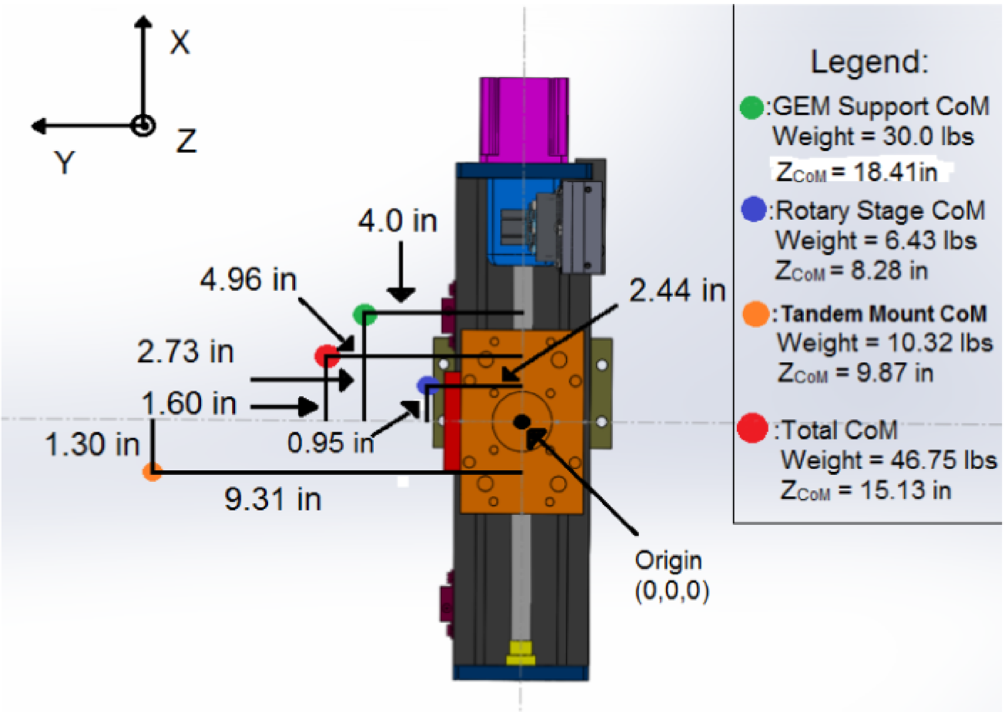
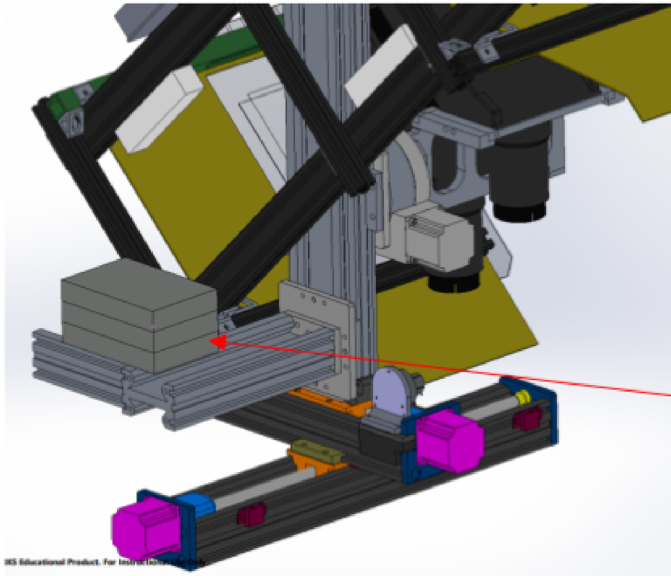
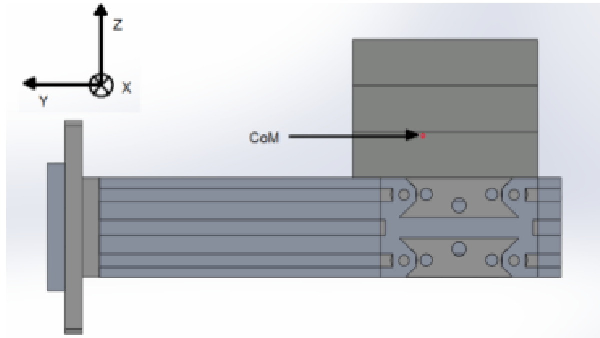
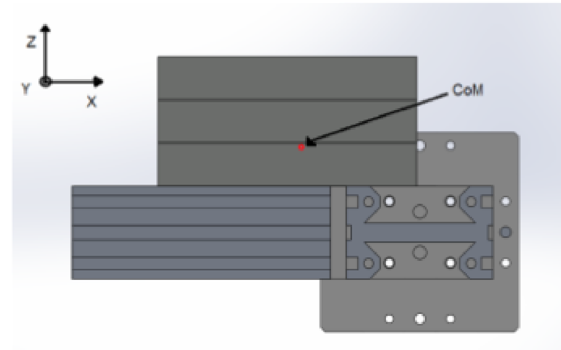


Dot Color	Assembly	Weight (lbs)	Torque around y-axis (in-lbs)	Torque around x-axis (in-lbs)
Green	GEM Support Frame	30.0	81.90	-120.0
Blue	Rotary Stage	6.43	6.11	-15.69
Orange	Tandem Quartz Mount	10.32	-13.42	-96.08
Red	**Total Detector Package**	**46.75**	**74.59**	**-231.77**

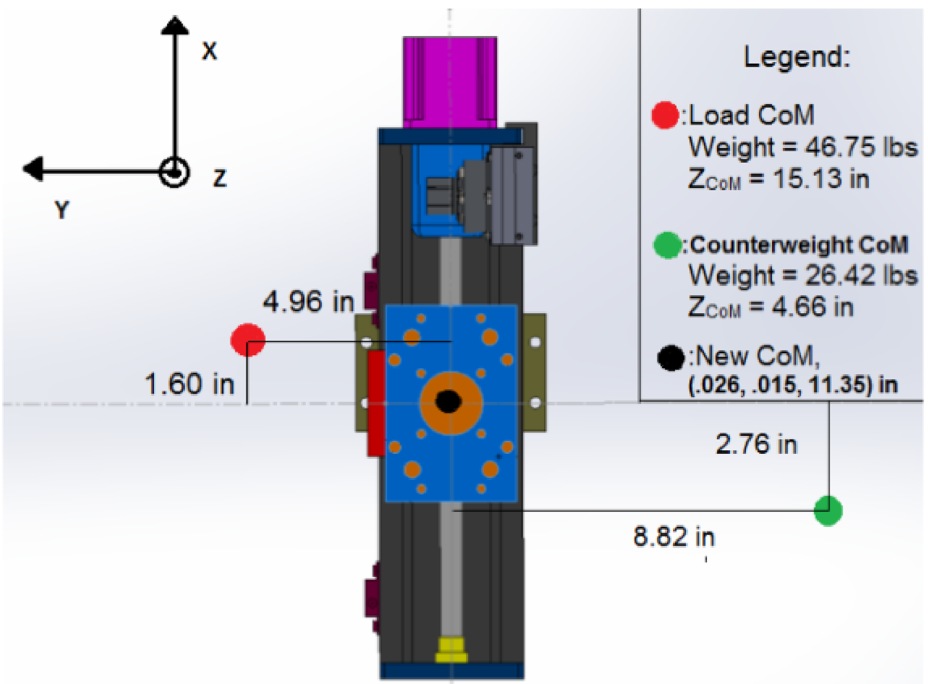
HRS Detector Package Torque Analysis







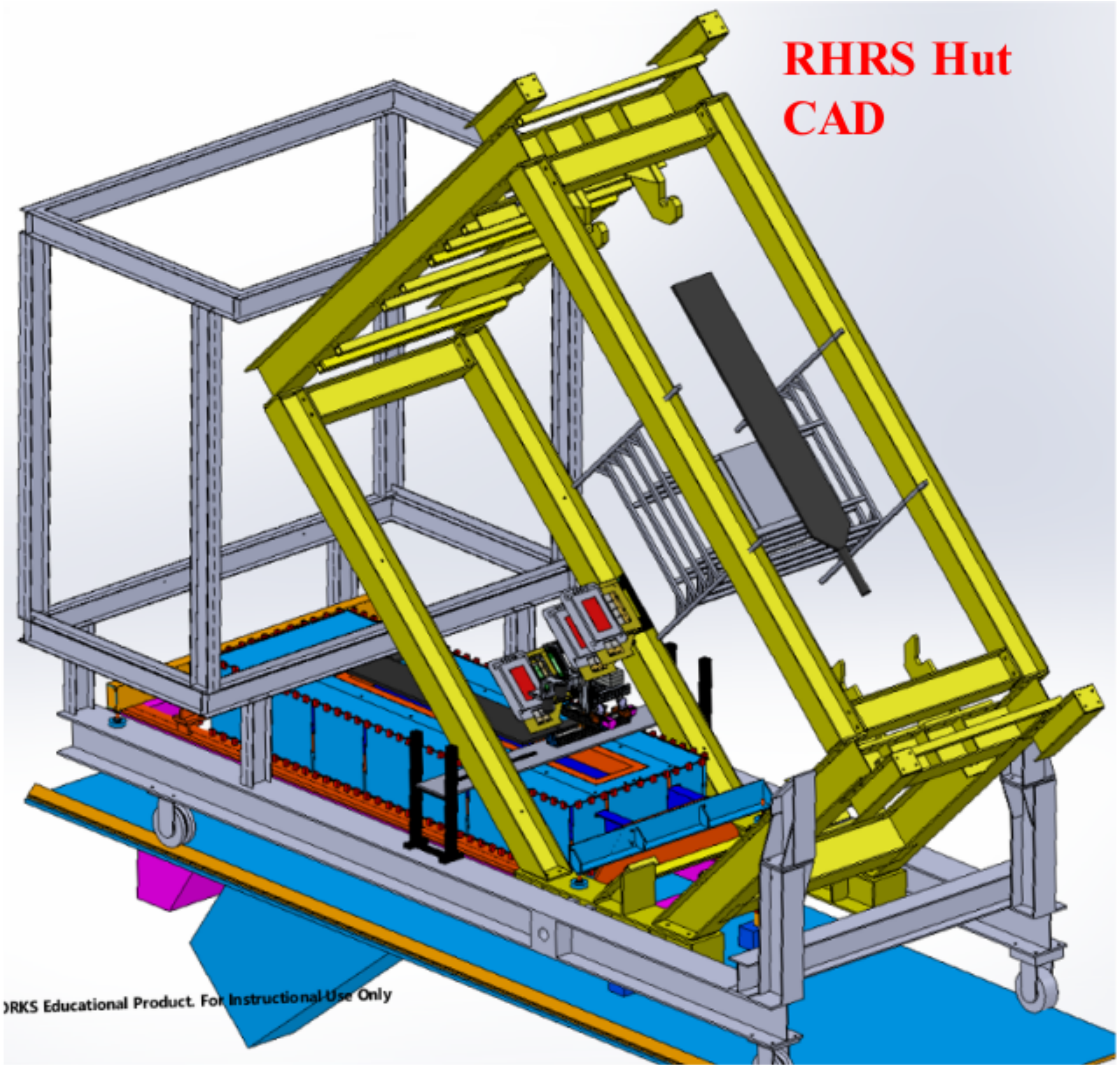
Counter weight (+ supports): 26.4 lbs



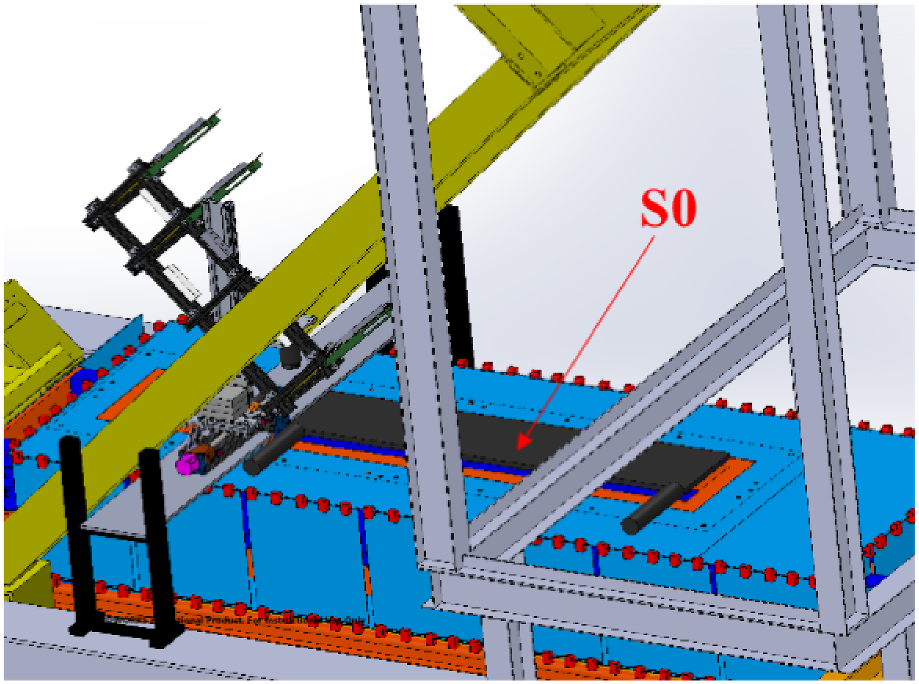
- Using the new center of mass location and new load (old load + counterweight) of **73.17 lbs**, net torques were calculated.
- Net Torque about X-axis: (0.015 in)*(73.17 lbs) = **1.10 in-lbs**
- Net Torque about Y-axis: (0.026 in)*(73.17 lbs) = **1.90 in-lbs**
- Net Total Torque: $((1.10)^2+(1.90)^2)^{1/2}$ = **2.19 in-lbs**

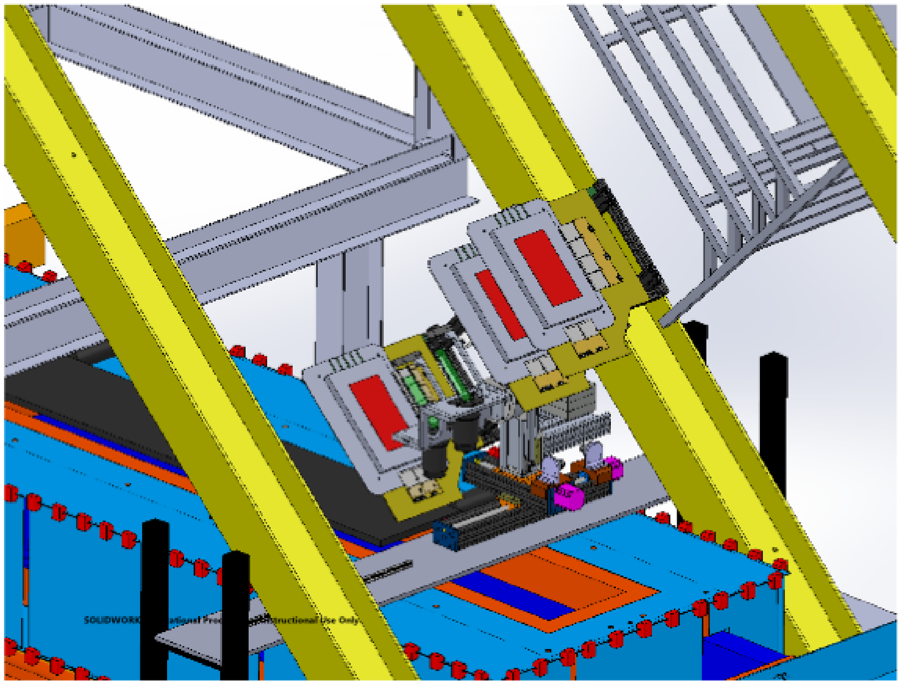
HRS Detector Package for PREX-II/CREX

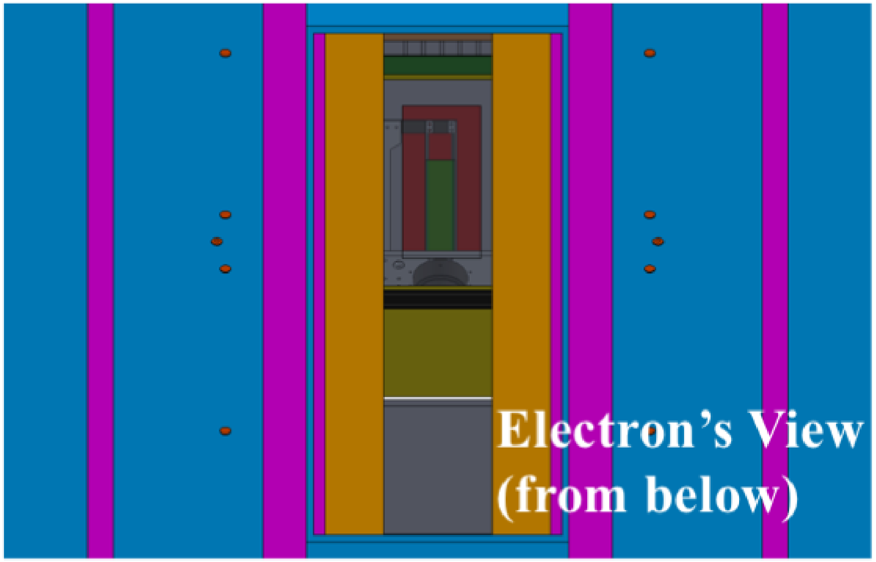
- All HRS standard detector packages removed except for VDCs: No S1, S2, Cerenkov, or Calorimeter
- For event-mode operation: Use S3 (or S0) for triggering
- Additional array of large GEMs from UVA group to be installed above PREX detector package
- A_T detector not shown: will mount just above small GEMs
- Plan to use same hardware and mounting/installation concept developed for PREX-I

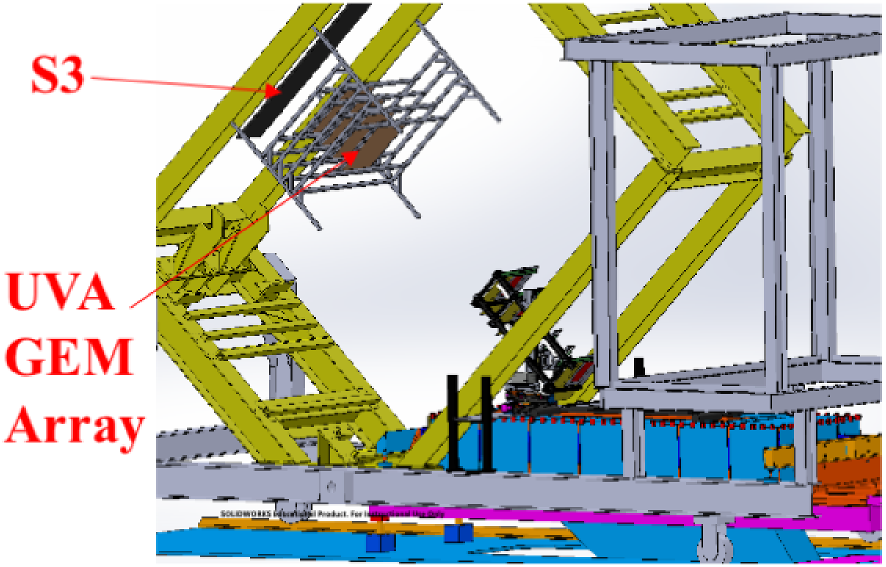


HRS Detector Package for PREX-II/CREX









PMT Linearity Studies: Apparatus)

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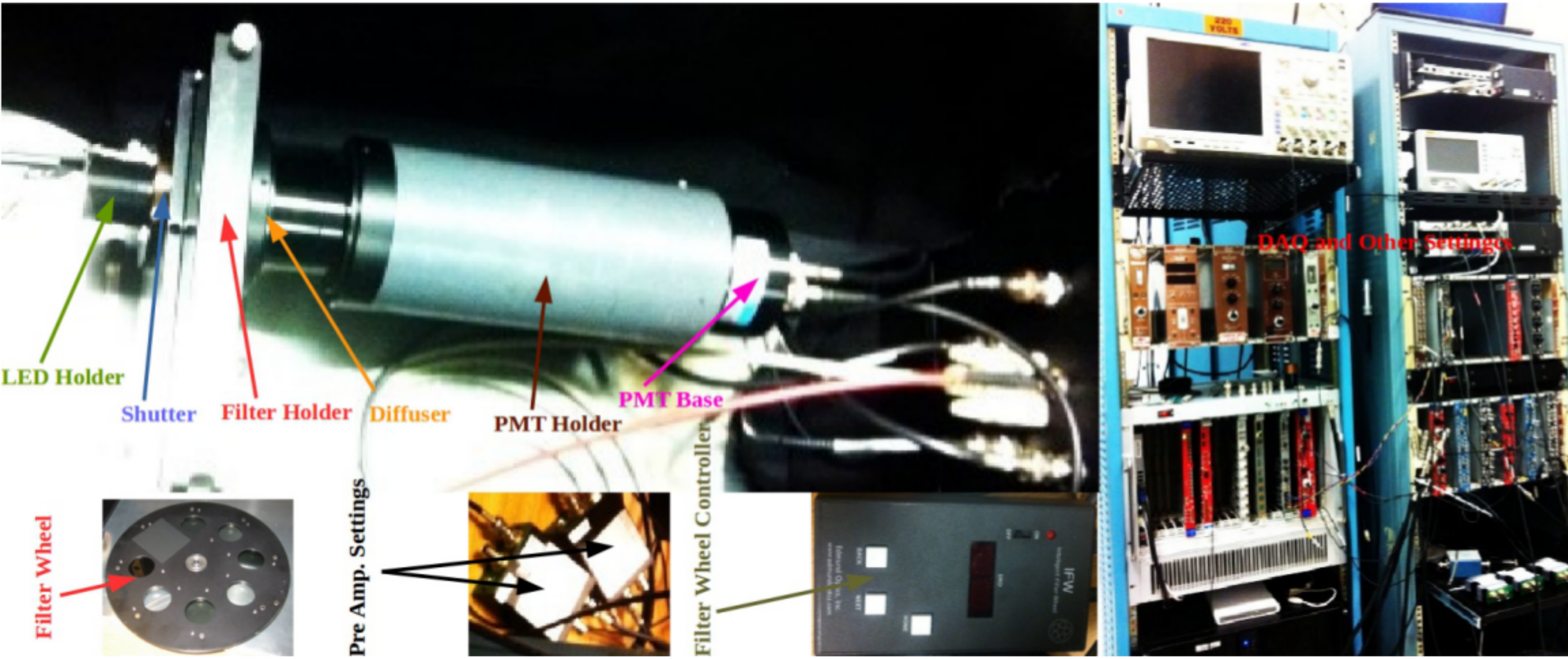
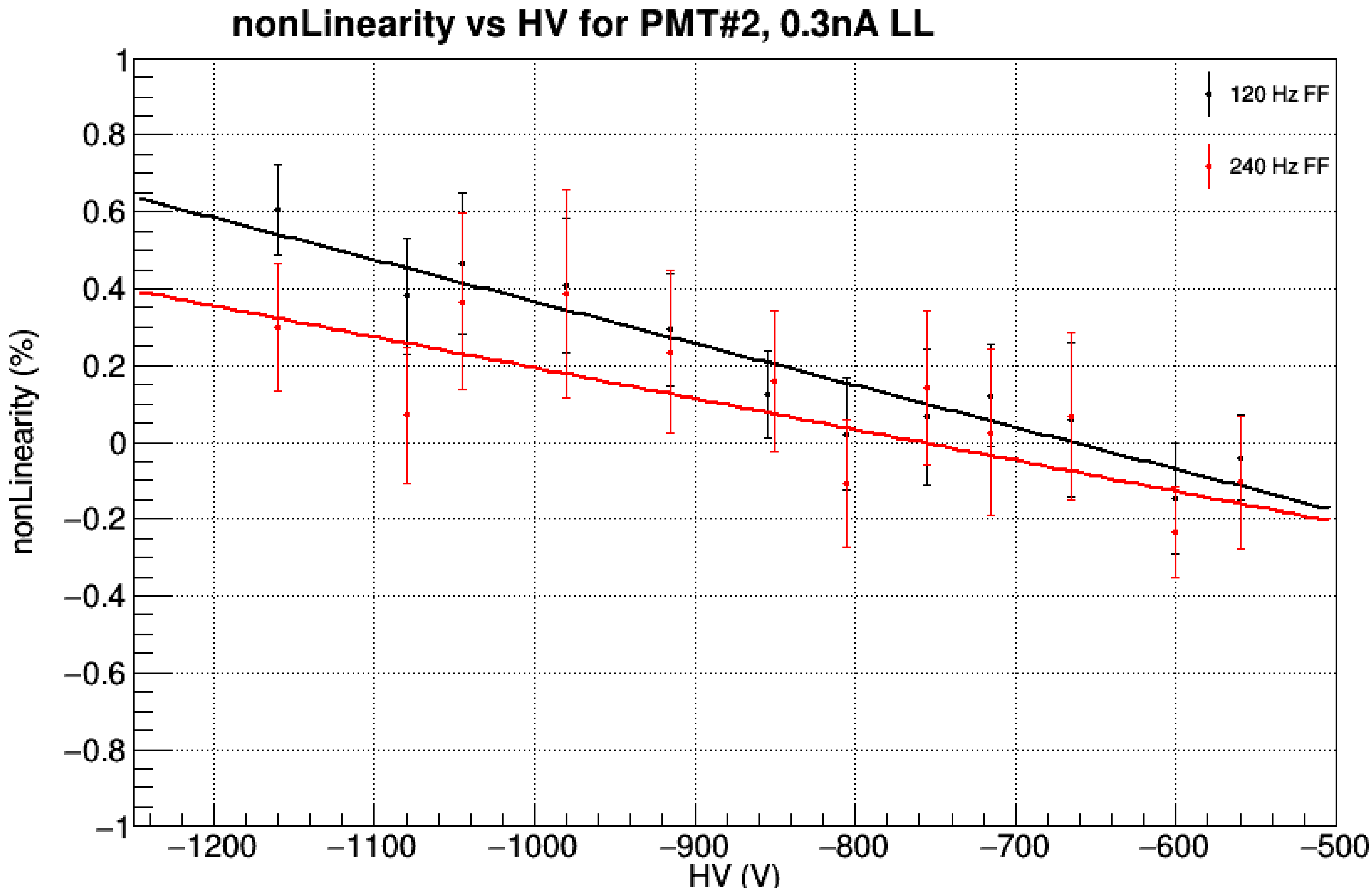
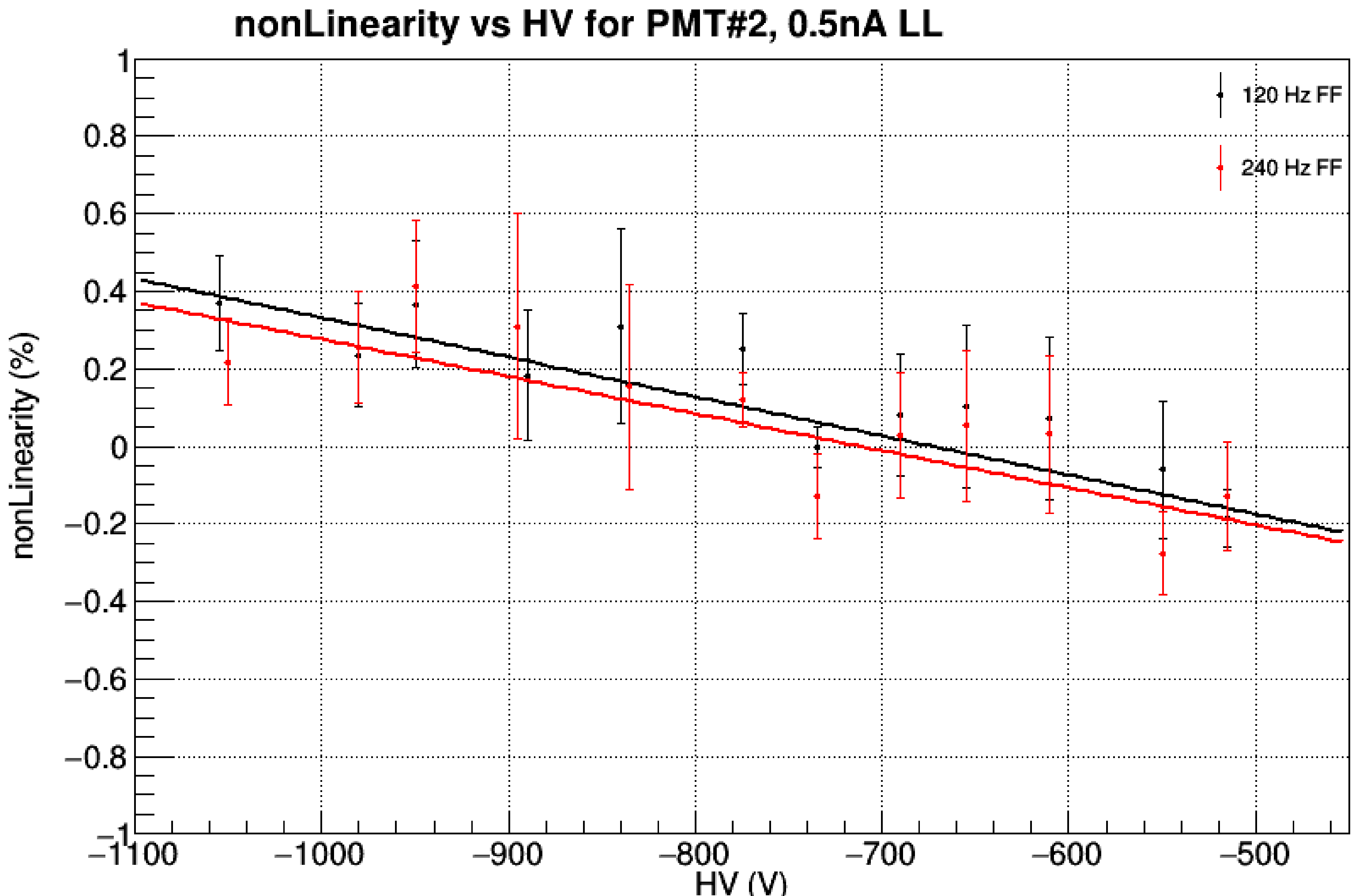


PMT#2 (ZK5365 R7723Q) at 0.3 nA



PMT#2 (ZK5365 R7723Q) at 0.5 nA



PMT#2 (ZK5365 R7723Q) at 0.3 nA

120 Hz Flipping Frequency

Run	HV	PreAmp	non-Lin	Error	$\chi^2/6$df
2505	-1160	0.3	0.605	0.119	7.365
2504	-1080	0.3	0.382	0.151	16.47
2502	-1045	0.5	0.466	0.183	26.16
2501	-980.0	0.5	0.408	0.175	28.09
2503	-915.0	1.0	0.294	0.147	19.07
2499	-855.0	1.0	0.126	0.114	2.584
2497	-805.0	2.0	0.021	0.147	17.43
2496	-755.0	2.0	0.066	0.177	20.95
2508	-715.0	4.0	0.122	0.132	12.55
2507	-665.0	4.0	0.059	0.201	27.86
2491	-600.0	10.0	-0.145	0.145	12.96
2490	-560.0	10.0	-0.040	0.110	4.177

240 Hz Flipping Frequency

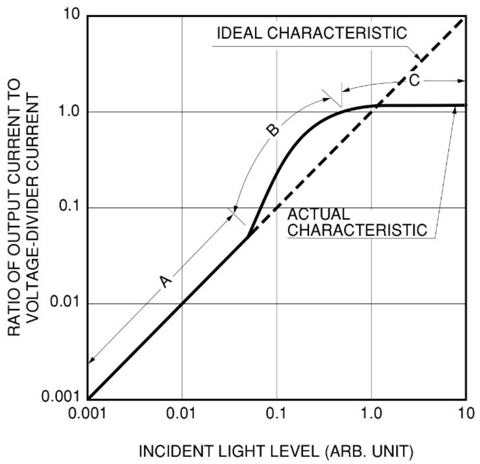
Run	HV	PreAmp	non-Lin	Error	$\chi^2/6$df
2533	-1160	0.3	0.301	0.166	16.49
2530	-1080	0.3	0.071	0.176	15.60
2528	-1045	0.5	0.367	0.229	22.85
2527	-980.0	0.5	0.388	0.271	30.19
2526	-915.0	1.0	0.236	0.211	24.16
2525	-850.0	1.0	0.158	0.184	22.17
2524	-805.0	2.0	-0.109	0.166	14.20
2523	-755.0	2.0	0.140	0.201	22.47
2516	-715.0	4.0	0.026	0.218	30.14
2515	-665.0	4.0	0.067	0.219	35.07
2514	-600.0	10.0	-0.235	0.117	6.974
2512	-560.0	10.0	-0.104	0.173	18.00

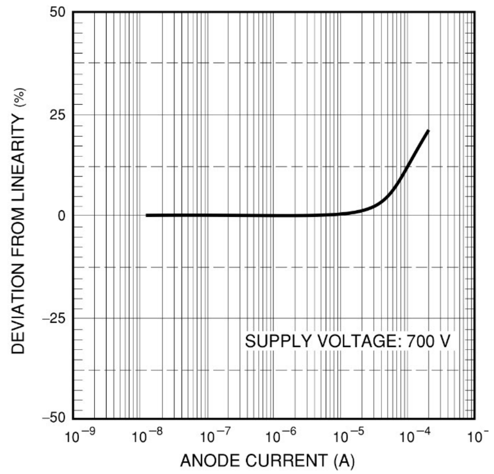
Note: The entries between double lines are acceptable.

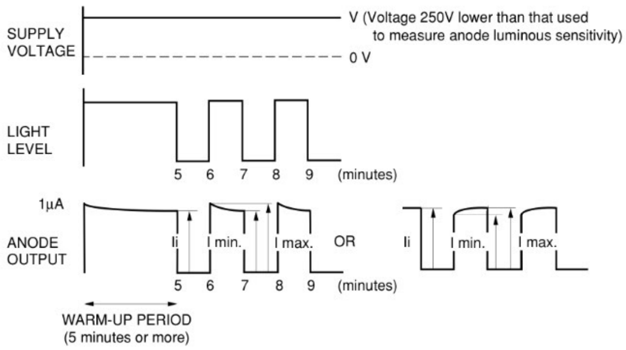
Sign of non-linearity

- Low work function of dynode coatings
- Probability of thermal electrons from dynode coatings and photocathode
- At high currents, space charge can influence the electron trajectories causing collection losses
- At still higher currents, space charge can cause some electrons to return to the surface from which they originate
- Below certain HV, the space charge effect causes collection loss at higher LLs resulting negative non-linearity
- Above certain HV, the HV between the dynodes and between the last dynode and the anode is sufficient enough to overcome the space charge effect
- At higher HV, even the space charge gets dragged towards the anode increasing the collection at higher LLs resulting positive non-linearity

PMT Characteristics from Hamatsu Handbook



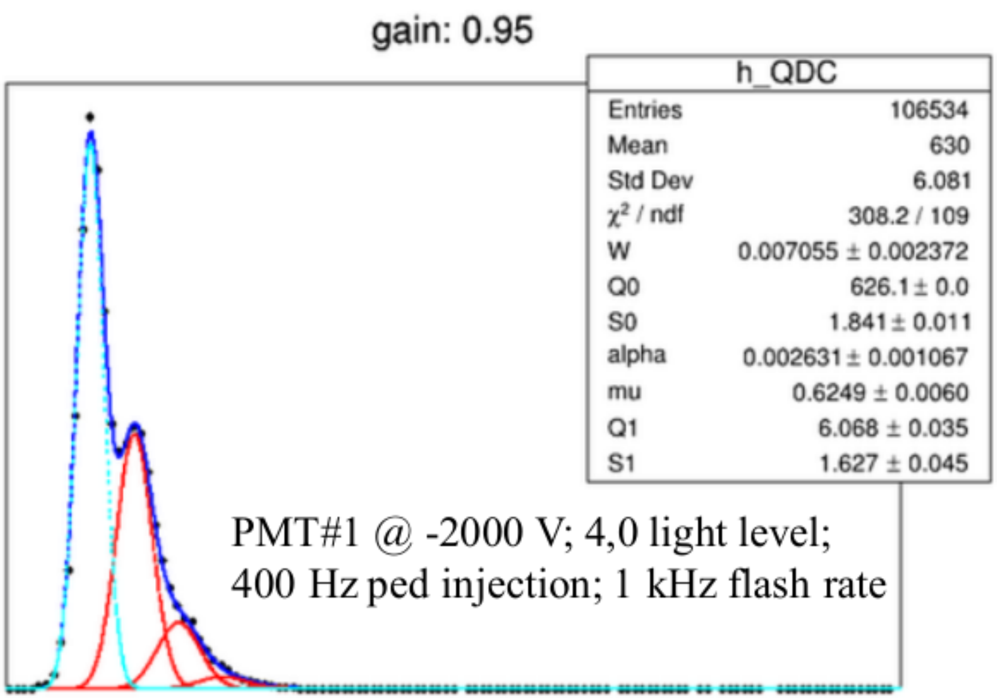


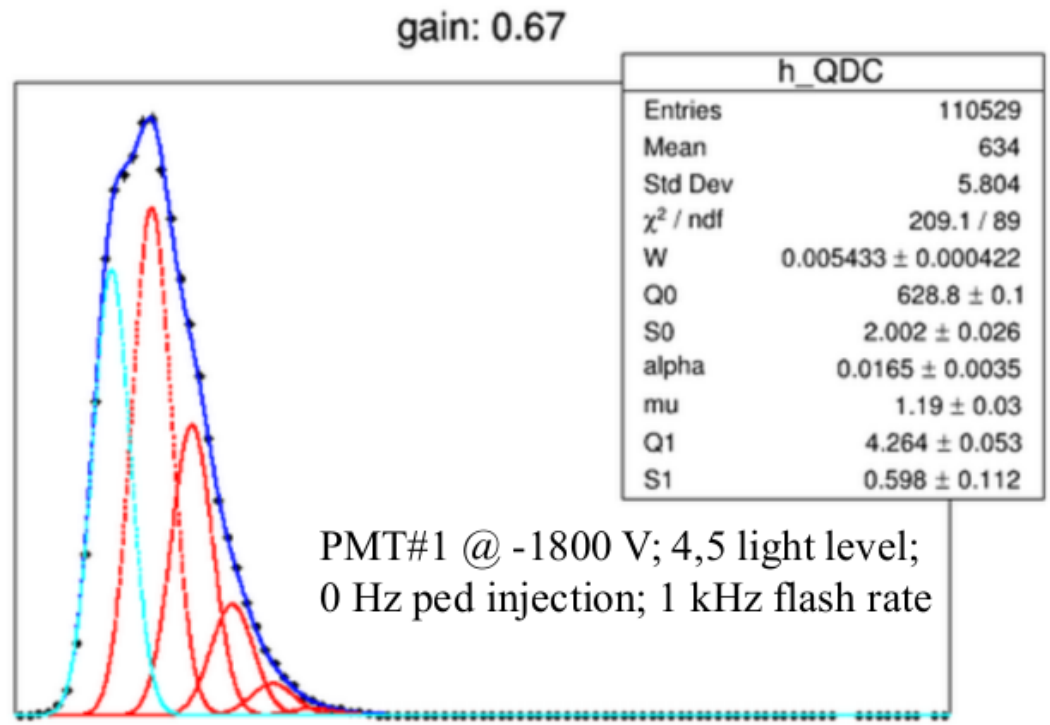


- At high currents, space charge can influence the electron trajectory, causing collection losses.
- Light level > certain level – PMT output becomes saturated and is no longer proportional to the light level.
- Light hysteresis and voltage hysteresis of the PMT.
- Signal to noise ratio of the PMT.
- Drift (time stability) – warm up helps minimize.
- PMT operation stability depends on the total stability of the power supply characteristics (drift, ripple, temperature, input regulation, load regulation).

PMT Gains (Work by Brady Lowe)

- Constructed second dark box (identical to linearity box) for dedicated PMT gain measurements
- Will measure gains of all PMTs from 2000 V down to as low as we can go; anticipated precision at sub 5% level
- This project is fairly advanced and is now in full production mode





PMT Linearity and Gain Summary

- So far we're able to find zero non-linearity crossings for specific HV and preAmp settings for all light levels tested so far (10 nA, 6 nA, 0.5 nA, and 0.3 nA). All these results can be found here: http://daq3.physics.isu.edu/linearity/PMT.html
- The above tested light levels were based on PE yields and 1 GHz/ 50 MHz focal plane rates for PREX/CREX
- Will reassess light levels given new focal plane rates (1.8 GHz for PREX and 30 MHz for CREX; planning to do optical simulations to explore different quartz thicknesses and ND filters for PREX-II main detectors
- There is no significant difference between 120 and 240 Hz FF
- PMT gain calibrations are in full-swing and will be completed by this winter

GEM Summary

- "Small" GEM tracking system development well underway
  - 5 assembled and tested GEM chambers at ISU + 1 at SBU
  - All readout electronics in hand: 55 APVs, 6 MPDs, 20 two-slot and 16 four-slot backplanes; SBU has 18 APVs, 2 MPDs, 5 two-slot and 2 four-slot backplanes
  - GEM mounting concept developed and constructed
  - HV circuits assembled and burn-in procedure completed; but will likely change the divider for lower current
  - CODA DAQ with MPD drivers established; communicating with APVs and acquiring ped data; we have working decoder and rudementary analyzer; exploring basic functionality with source tests; hope to start cosmic tests soon

Main Detector Summary

- PREX-II/CREX main detector design essentially complete
  - Waiting for *final* PREX-II and CREX focal-plane footprints before finalizing quartz geometry
  - Will use bare, unwrapped quartz and no light guide
  - Rotary tandem mount concept vetted: Left arm tandem detector constructed and in cosmic test-stand
- Main detector PE yields and relative widths measured at MAMI for 6mm and 10mm thick tandem configuration
  - For unwrapped quartz, 6mm gives 37 peak PEs with 20% RMS/Mean; 10mm (downstream) gives 65 peak PEs with 28% RMS/Mean
  - Expected focal plane rates times these peak PE calibrations give PMT photocathode light levels–so we can prepare each PMT for optimal linearity–Devi working on this

Extra Slides

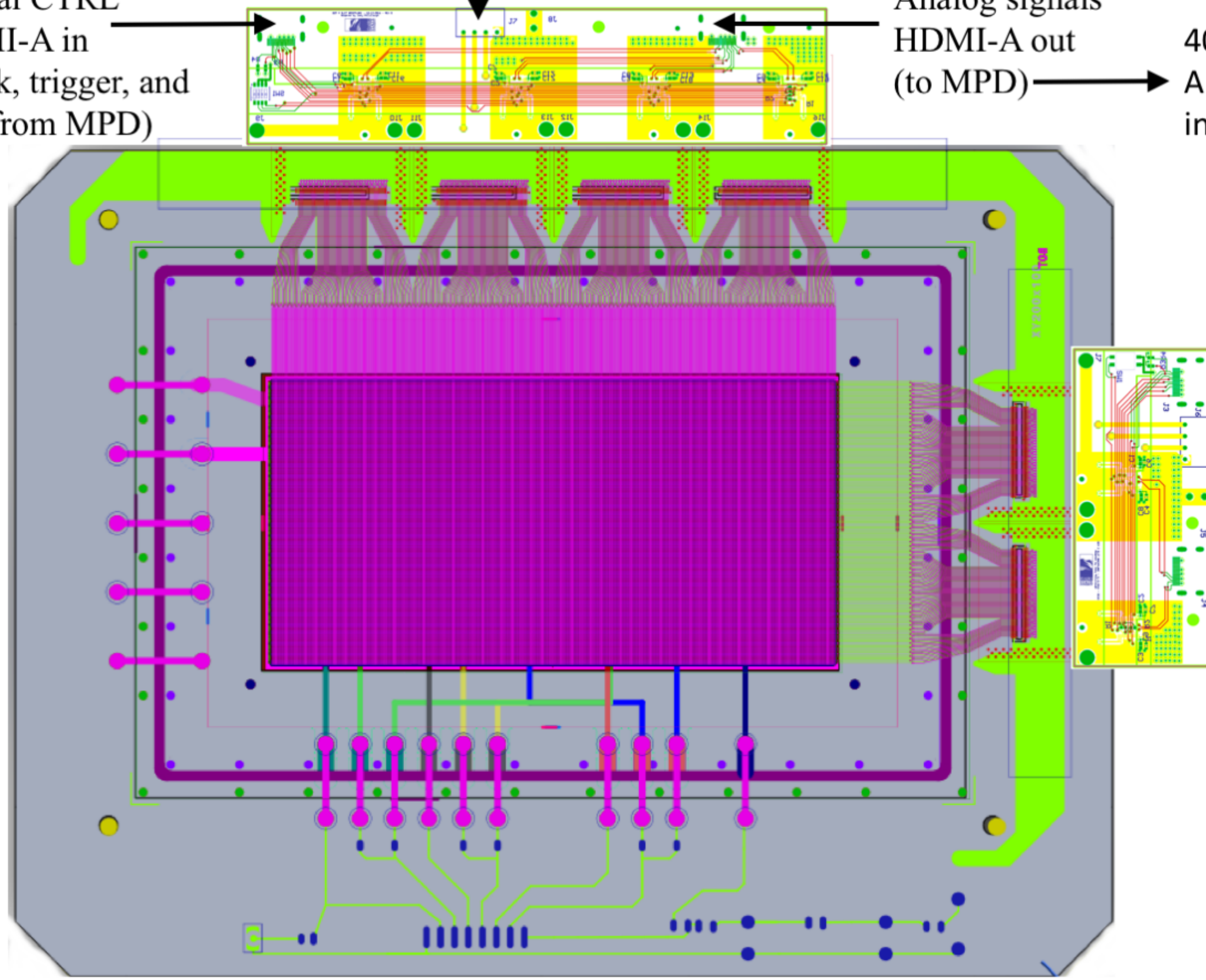
GEM Readout

LV in

Digital CTRL
HDMI-A in
(clock, trigger, and
I²C from MPD)

Analog signals
HDMI-A out
(to MPD)

40 MHz, 12 bit
ADC, differential
inputs, 2 Vpp



125 x 4 = 500
channels for
dispersive (x)
direction

750 x/y channels
per chamber
gives 3000
channels per arm

Each MPD can
handle up to
2000 channels;
Jlab DAQ group
support for
CODA drivers
and readout list

125 x 2 = 250
channels for
transverse (y)
direction

Use analog
patch panels
to combine
signals from
two 2-slot
backplanes –
allows for
efficient use
of MPD
inputs

Detector Configuration in HRS (Top View)