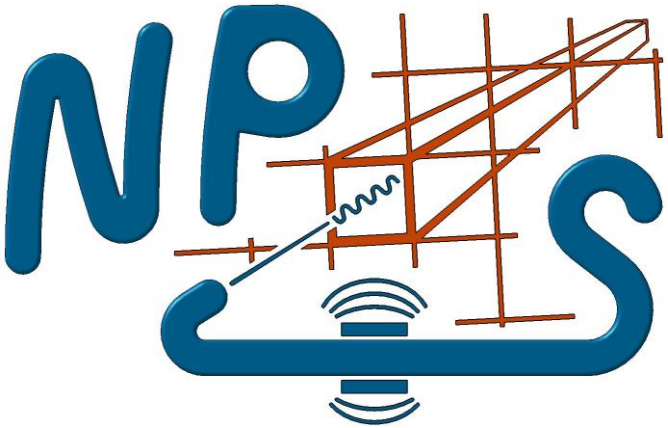
Neutral Particle Spectrometer



Tanja Horn

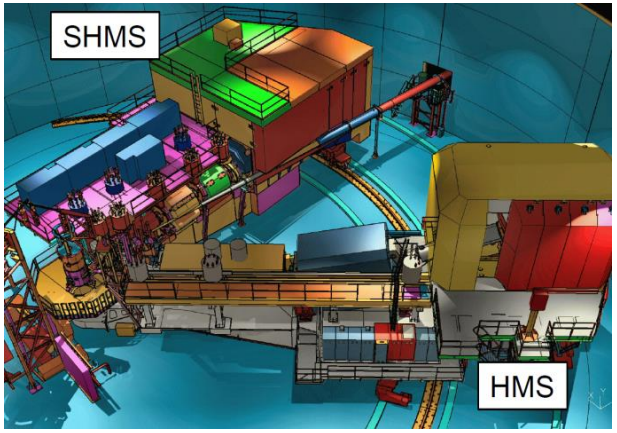
(for the NPS Collaboration)

Credits: V. Berdnikov, A. Brown, P. Medeiros, C. Munoz-Camacho, B. Sawatzky, and C. Yero for slides; DSG, FEG, Hall A/C, and all NPS project collaborators

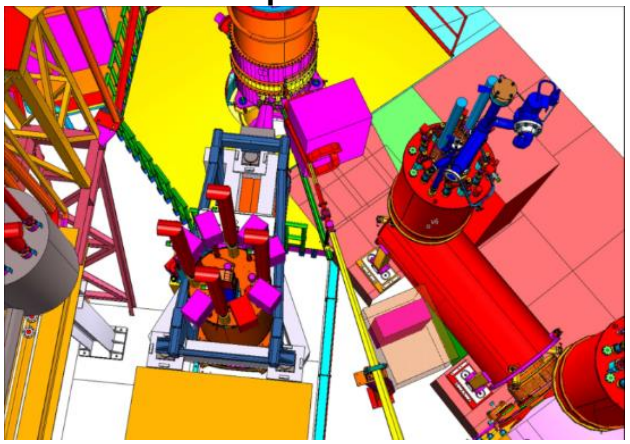
Neutral Particle Spectrometer Overview

- Neutral Particle Spectrometer replaces one of the Hall C focusing spectrometers in the experiments
  - Angle reach between 5.5 and 60 degrees
  - allows for precision (coincidence) cross section measurements of neutral particles (γ and π^0).
- HMS (existing 6 GeV era)
  - Has been recommissioned for 12 GeV
- Beam line and beam line instrumentation
- Cryogenic liquid hydrogen and solid targets
- Data acquisition, counting house, computing

Hall C focusing spectrometers



Neutral Particle Spectrometer



Overview Scientific Program

- Approved experiments to date

NPS ERR 2019

Run group 1

- E12-13-010 – Exclusive Deeply Virtual Compton and π^0 Cross Section Measurements in Hall C
- E12-13-007: Measurement of Semi-inclusive π^0 production as Validation of Factorization
- E12-06-114 – DVCS – days moved from Hall A

Run group 2

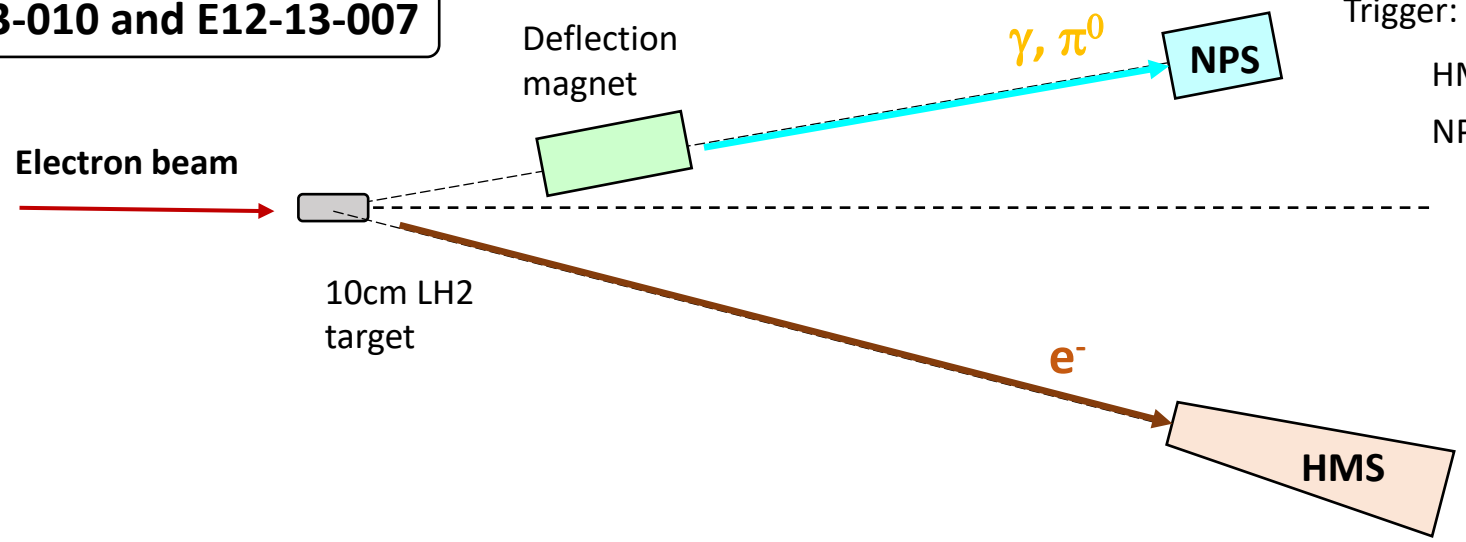
- E12-14-003 – Wide-angle Compton Scattering at 8 and 10 GeV Photon Energies
- E12-14-005 – Wide Angle Exclusive Photoproduction of π^0 Mesons

- E12-17-008 – Polarization Observables in Wide-Angle Compton Scattering

- Conditionally approved experiments: TCS with transverse target

Experimental Techniques

E12-13-010 and E12-13-007

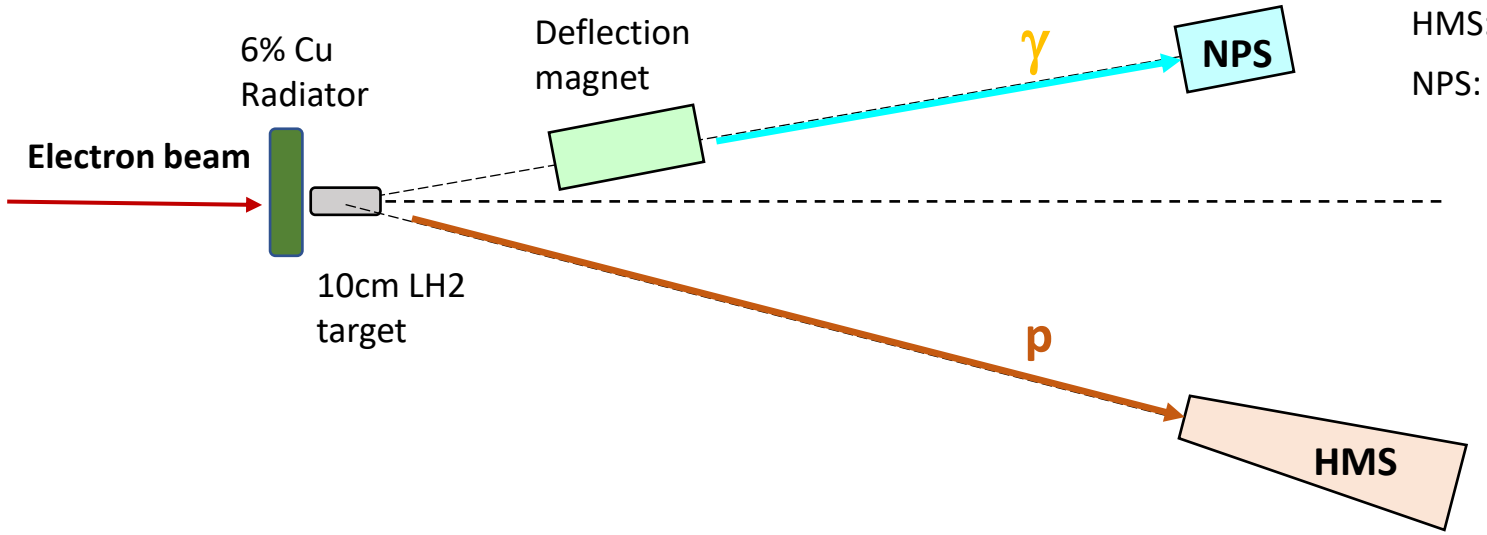


Trigger: HMS, HMS+NPS

HMS: 1 MHz (max)

NPS: 86 MHz (max)

E12-14-003 and E12-14-005



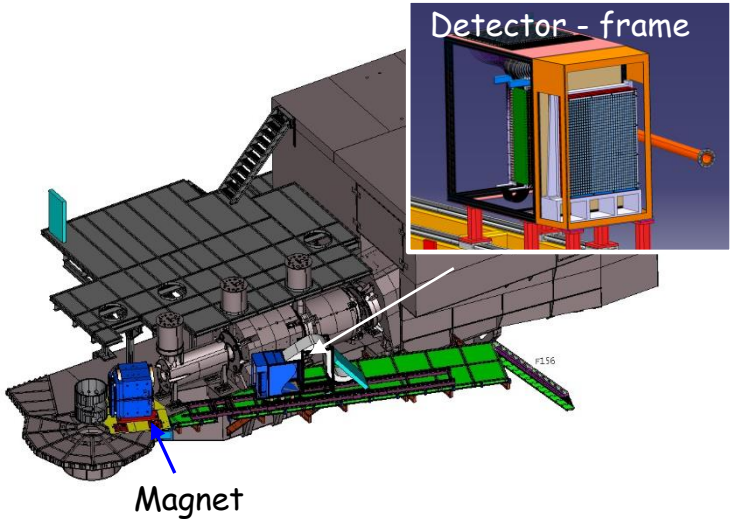
Trigger: HMS

HMS: ~47 kHz (max)

NPS: ~1MHz (max)

Equipment to achieve science goals

- ~25 msr neutral particle detector consisting of ~1080 **$PbWO_4$ crystals** in a temperature-controlled frame including gain monitoring and curing systems – outer layers of 30x36 crystal matrix only to catch showers
- HV distribution bases with built-in amplifiers for operation in a high-rate environment
- Essentially deadtime-less digitizing electronics to independently sample the entire pulse form for each crystal – JLab-developed Flash ADCs
- 0.3Tm sweeping magnet allowing for small-angle and large angle operation at 0.6 Tm. The magnet is compatible with existing JLab power supplies.
- Cantelevered platforms off the SHMS carriage to allow for remote rotation (in the small angle range), and platforms to be on the SHMS carriage (in the large angle range)
- A beam pipe with as large critical angle as possible to reduce beamline-associated backgrounds – only a small section needs modification



Item List

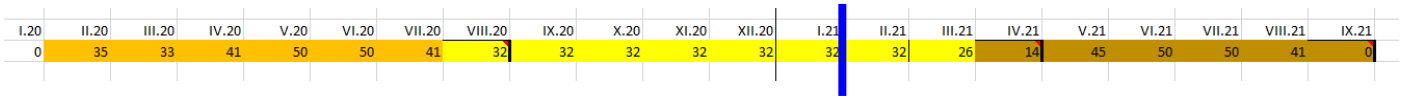
Magnet

Detector

Electronics, DAQ

Mechanical structures, installation

Software, analysis



NPS Crystal Status

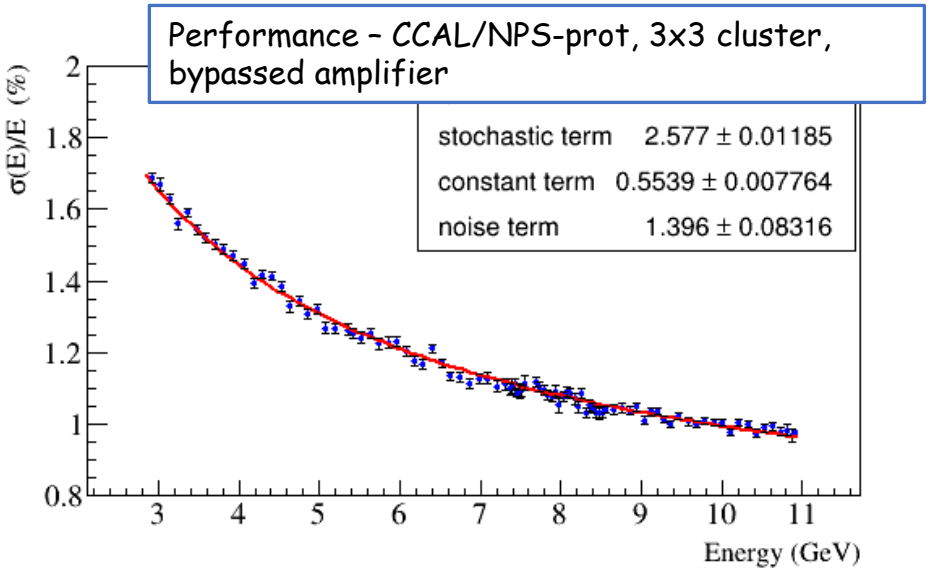
- Goal: all Crytur crystals (~1100) – suitable quality and uniformity

Vendor	Crystals tested	Manufactured
SICCAS	460*	2017
CRYTUR	827+100	2018-present

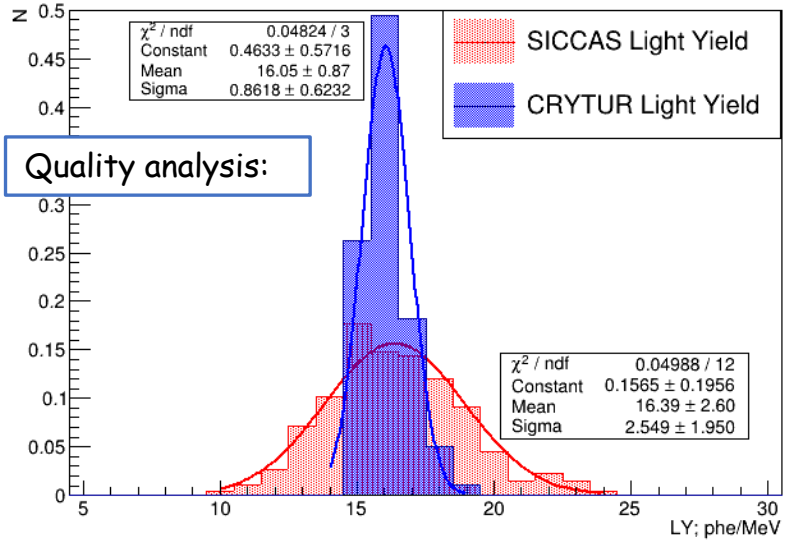
*Rejection rate ~30-50%

- Crytur production rate: ~20-50 crystals/month
  - By the end of August 2021: 1150 Crytur crystals
  - By end of 2021: 150 more Crytur crystals

Measurement	CRYTUR	SICCAS
Visual Inspection	✓	✓
Dimensions	✓	✓
Transmittance	✓	✓
Light Yield	✓	✓
Radiation resistance	✓	X

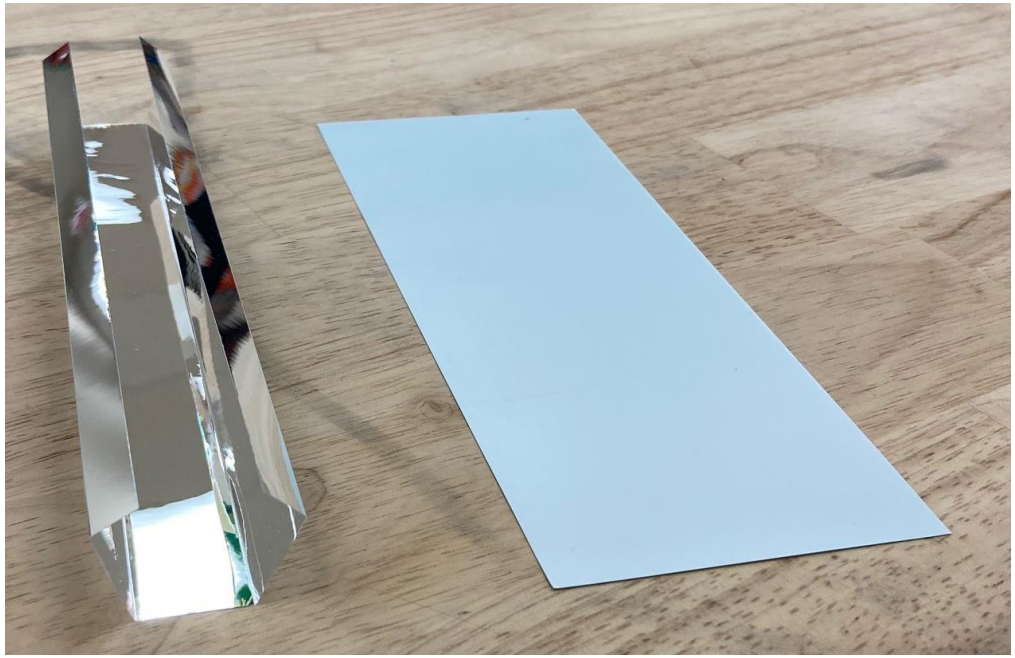


https://halldweb.jlab.org/DocDB/0047/004784/003/ccal_nps.pdf



NPS Crystal Wrapping

Vladimir Berdnikov (CUA), Josh Crafts (CUA), Carlos Yero (Jlab)

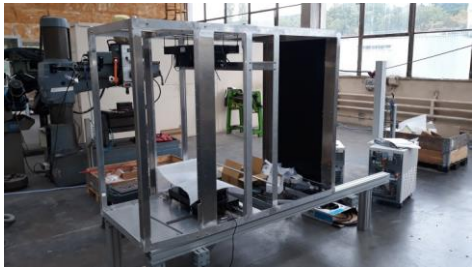


- ESR (used to be VM2000) reflectivity superior to other reflectors – requires pre-shaping
- 10 shaping tools constructed (Hall C tech team)
- Pre-shaping: batches of 10 at the time, production rate: 20/day

https://wiki.jlab.org/cuawiki/index.php/NPS_reflector_(ESR)_preshaping_procedure

NPS Frame Construction at IJCLab-Orsay

Outer frame construction

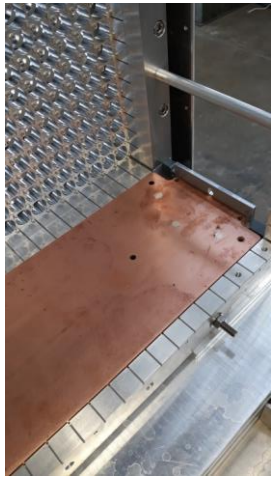


PMT support plate and temp. sensors assembly

Crystals frame

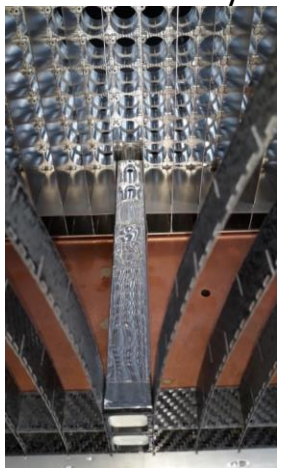
PMT holders

Cooling plates



Mu-metal shielding

Carbon support structure for crystals



- Temperature-controlled frame for 1080 $PbWO_4$ crystals
- PMT readout + LED calibration/curing system

NPS frame construction completed during 2020 in Orsay

NPS Frame Construction at IJCLab-Orsay

Recent view of the inside

Orsay NPS engineering team

https://wiki.jlab.org/cuawiki/index.php/Cooling_system

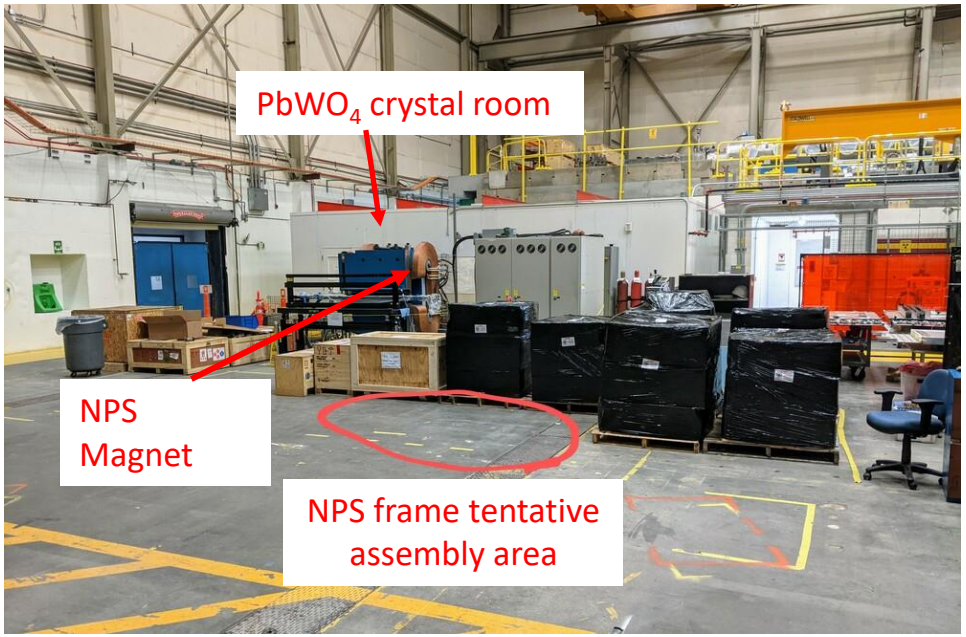
https://wiki.jlab.org/cuawiki/index.php/Cables

Shipped to JLab on Jan 6, 2021 (received Jan 19)

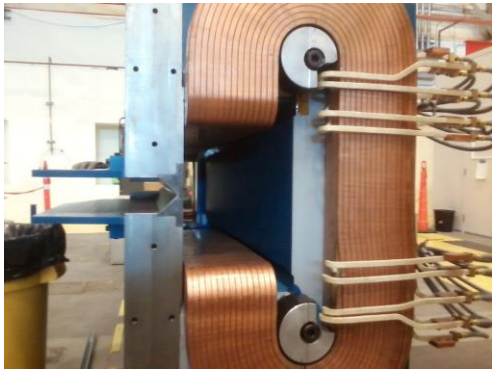
NPS Assembly at JLab

- Plans to start final assembly and tests at JLab as soon as COVID-19 allows
- Pre-shaping of the crystals reflective wrapping already started (see previous slides)

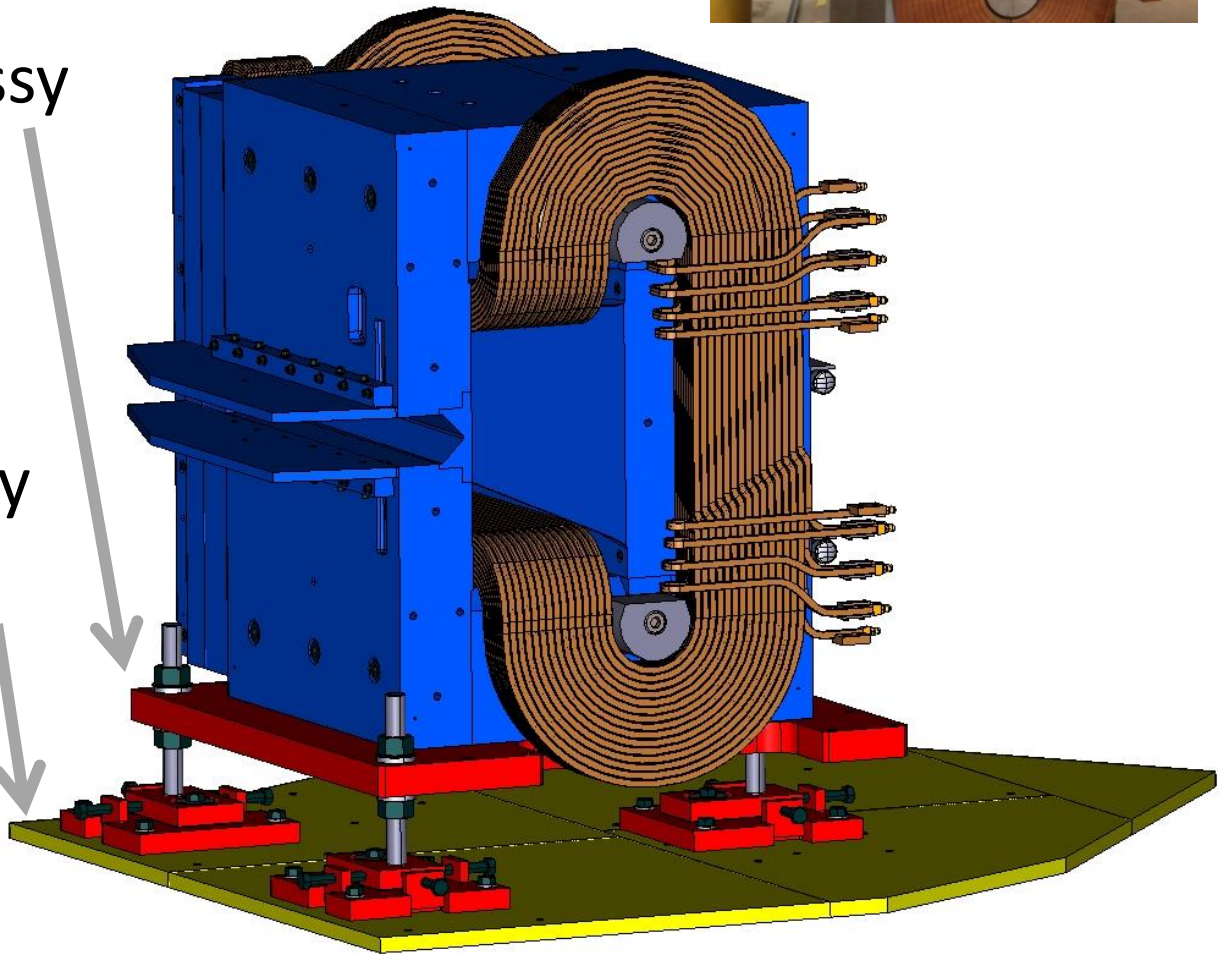
Test Lab High Bay area



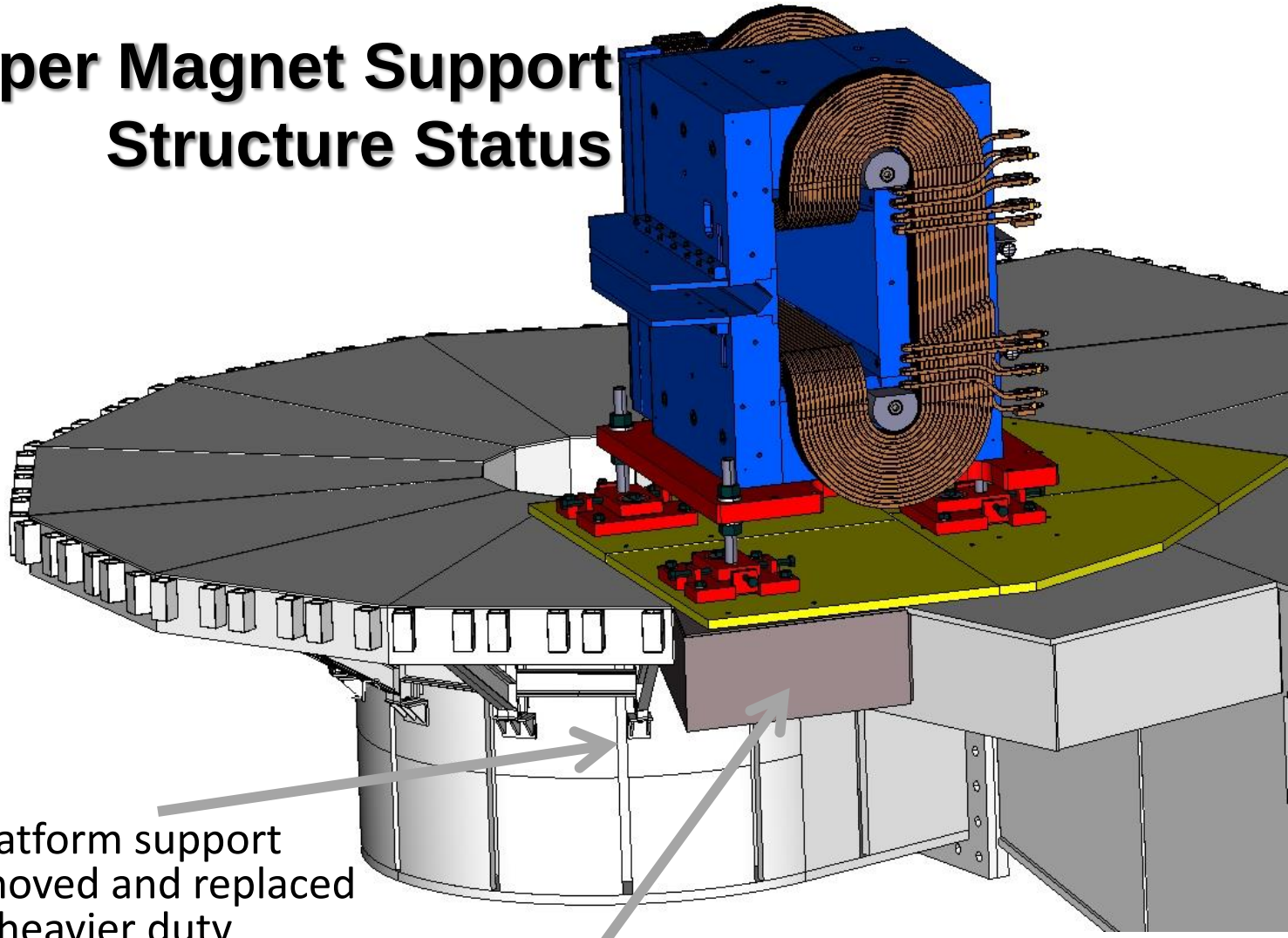
Sweeper Magnet Support Structure Status



- Sweeper support assy delivered.
- Base/slide plate assy in design phase (80% completion).



Sweeper Magnet Support Structure Status



- Target access platform support needs to be removed and replaced with larger and heavier duty section or reinforce existing. In design phase (10% completion).

- Target access platform section needs to be removed and replaced with larger and heavier duty section. New section delivered.

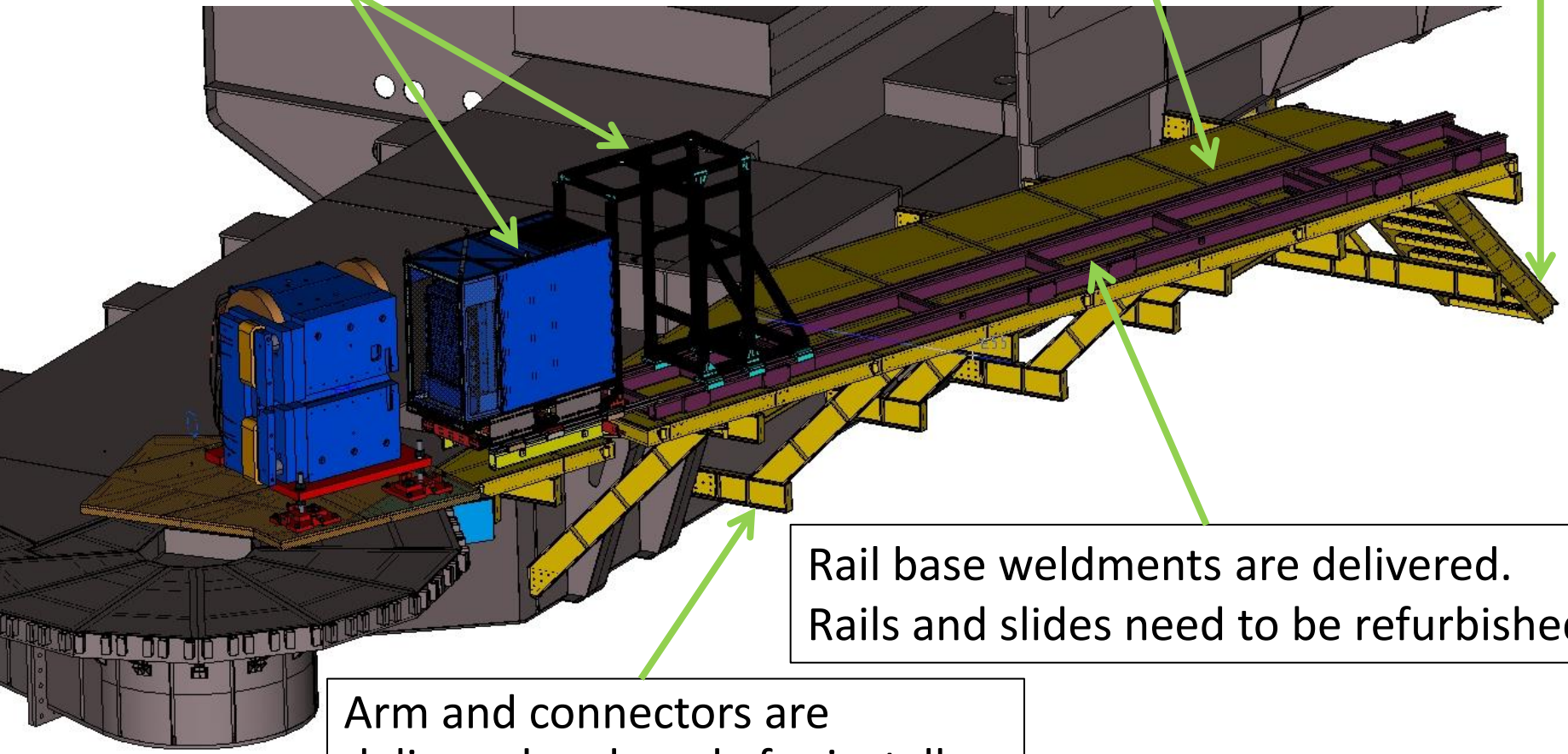
Detector Support Structure Status

Detector slide cart is in design phase (75% completion).

Cable slide cart is in design phase (50% completion).

Platform weldments are delivered and ready for install.

Staircase in design phase (50% completion).



Rail base weldments are delivered.
Rails and slides need to be refurbished.

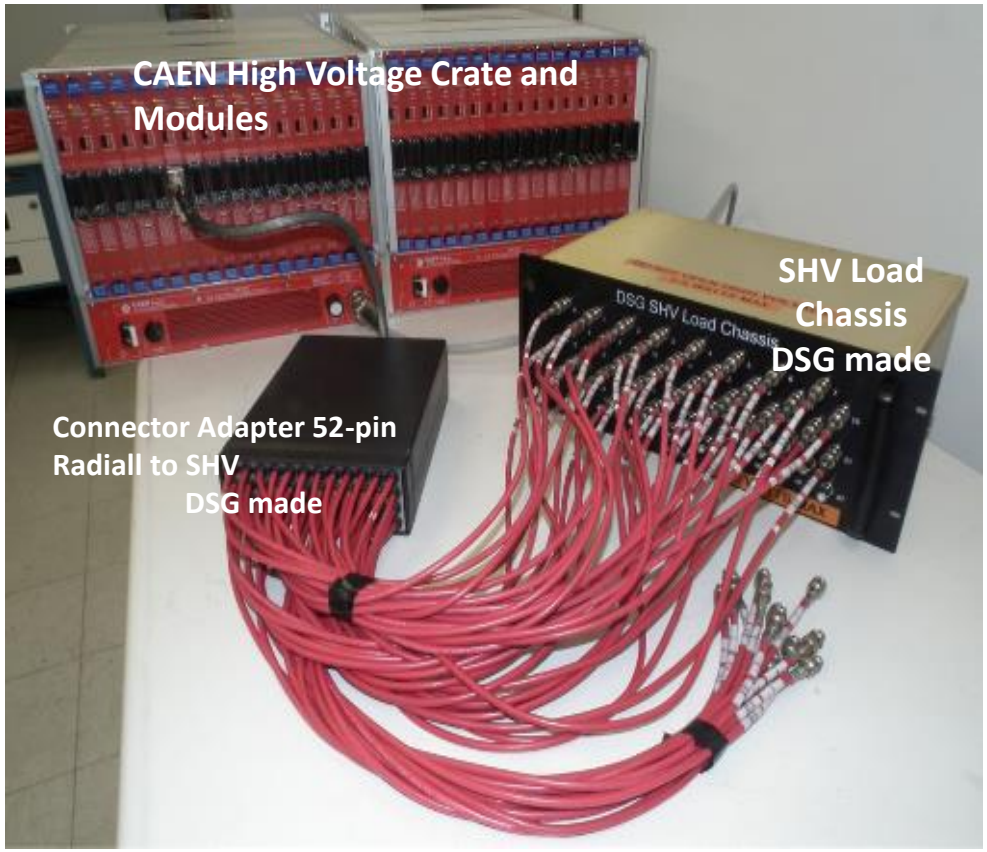
Arm and connectors are delivered and ready for install.

Outstanding Design Tasks

- Sweeper base/slide plate in design phase (80%).
- Target access platform reinforcement in design phase (10%).
- Platform access staircase in design phase (50%).
- Detector slide cart in design phase (75%).
- Cable slide cart in design phase (50%).
- Beam line (both setups) need to be reviewed and design complete (50%).
- Corrector in design phase (40%).
- Cable layout and support structure in design phase (20%).

Detector Support Group: Completed Tasks

- High voltage divider cables
  - 1100(!) high voltage divider cables fabricated
- CAEN high voltage system tested
  - Voltage and current stability
  - Current trip
  - Voltage ramp
- CSS-BOY Control & Monitoring screens developed
  - NPS Overview
  - NPS Voltage/Current Readback

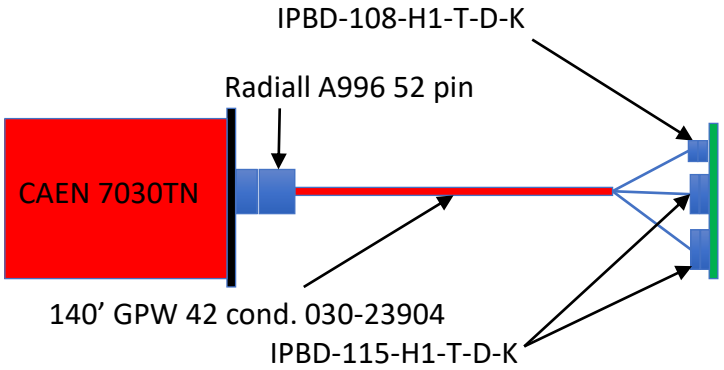


CAEN HV system test stand

https://www.jlab.org/physics/dsg/technical_documentation/hall_c/NPS

Detector Support Group: Current Tasks

- CAEN Radiall 52-pin to SAMTEC cable
  - Fabricating 140’ multi-conductor HV cables (40 total)



- Additional CSS-BOY Controls & Monitoring Screens
  - PMT settings screen
  - NPS Expert screen

- NPS Hardware Interlock System

https://www.jlab.org/physics/dsg/technical_documentation/hall_c/NPS

DAQ Hardware for NPS

- **NPS: 1080 $PbWO_4$ blocks**
  - → Readout consists of JLab F250 FADCs
    - » Full waveform for crystals of interest
    - » < 1ns timing res. is provided by F250s
  - → NPS trigger generated by JLab VTP modules in NPS F250 VXS crates
- **Hardware needed for NPS** **(All hardware in-hand except where noted)**
  - → 67x FADCs (Note: 51 modules to be provided by Physics Div / FE group pool)
  - → 5x VXS crates
  - → 5x SD + TI + Linux SBC / ROC
  - → 5x VTP modules (Order placed in May 2020)
  - → HV supplies (2x SY4527 crates + 64 HV modules: 1152 HV channels)
- **Firmware development**
  - → VTP firmware
    - » provide required summing trigger, and 'sparsification mask' to F250
  - → F250 FADC firmware updated to emit waveform data based on channel mask from VTP
  - → TI/TM firmware must support full complement of 5 NPS crates + 3 HMS crates
- **LED System Driver boards**
  - → Each NPS block has a UV LED attached; can be run in two modes
    - » Bleaching (extended UV exposure used to 'heal' accumulated radiation damage)
    - » Pulse mode (used to test trigger and individual block responses)
  - → FE Group board design nearly complete

VTP / F250 / TM Firmware / Trigger

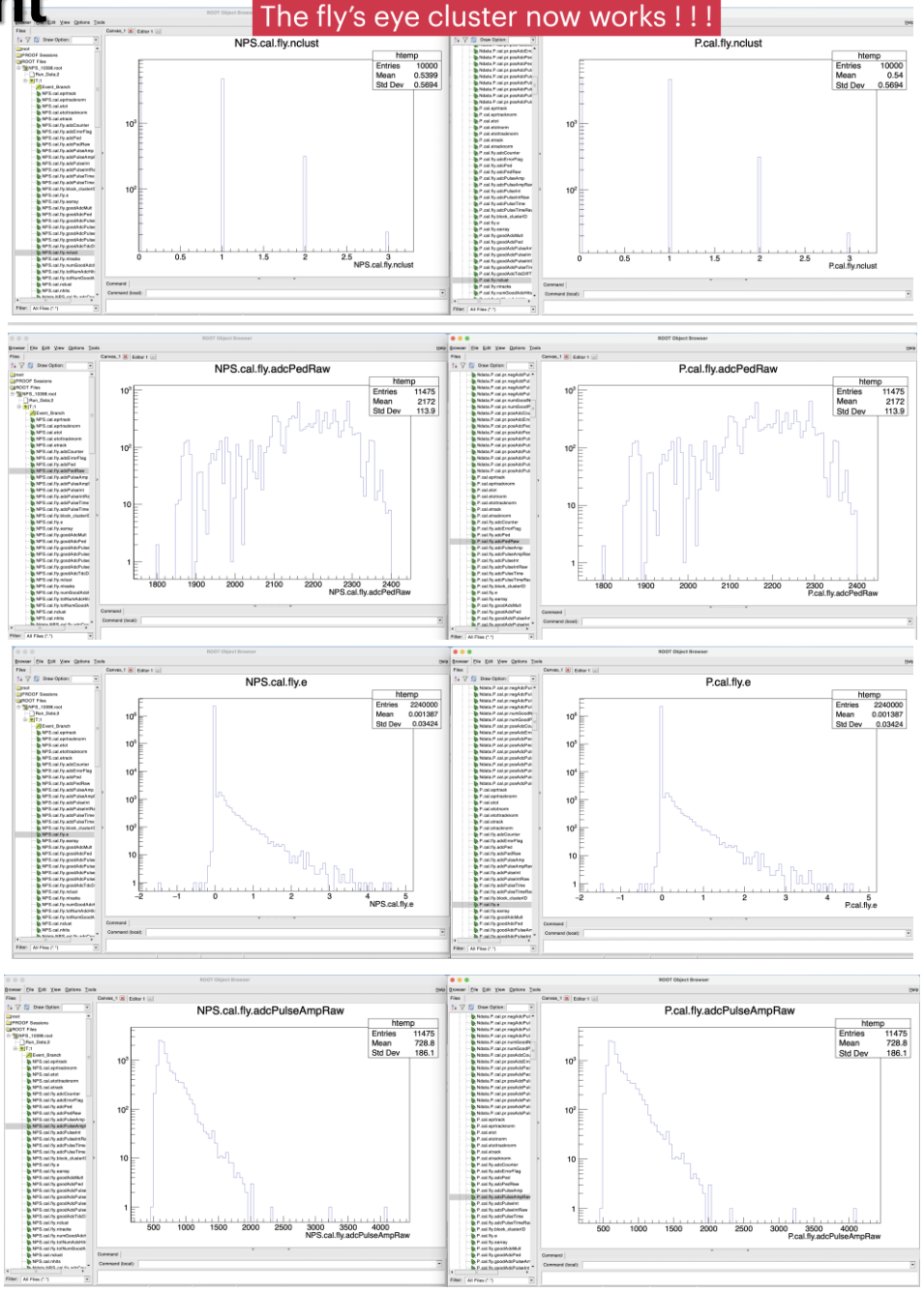
- VTP (5+1 modules ordered May 2020)
  - → Cluster trigger based on 3x3 groups, with 1 row shared between crates
  - → Logic signals emitted by each VTP will be OR'd in NIM to form NPS trigger
    - » CODA trig: HMS .AND. (.OR. of NPS)
    - » Timing latency on VTP triggers deterministic to <12ns
  - → Define/update VTP data payload
    - » cluster charge, timing?
    - » cluster crystal list to be used to sparsify F250 waveform readout
- F250 FADC (51 modules from FE/PD pool)
  - → Hi-res timing required (< 1ns)
    - » Preserve multi-hit/ch output
  - → QDC data, Scaler data
  - → Full waveforms (25 samples)
    - » Compressed?
  - → VTP info used to sparsify F250 readout channels to those in a 5x5 cluster(s) centered on the 3x3 'trigger' cluster(s)
- TI/TM modifications (if needed)
  - → must support 5 NPS crates + 3 HMS crates
  - → maintain six L1 trigger inputs on primary TM
- CODA / HMS trigger assumptions
  - → 'Standard HMS' NIM triggers will be available
    - » ¾, EL_{real}, EL_{clean}, ...
  - → NPS + HMS trigger made in NIM
    - » NPS + HMS {¾, EL_{foo}}
    - » NPS VTP latency is NOT a problem
- NPS detector assembly and full DAQ chain readout tests to be done in TestLab highbay space this year

FE/DAQ group actively working on firmware

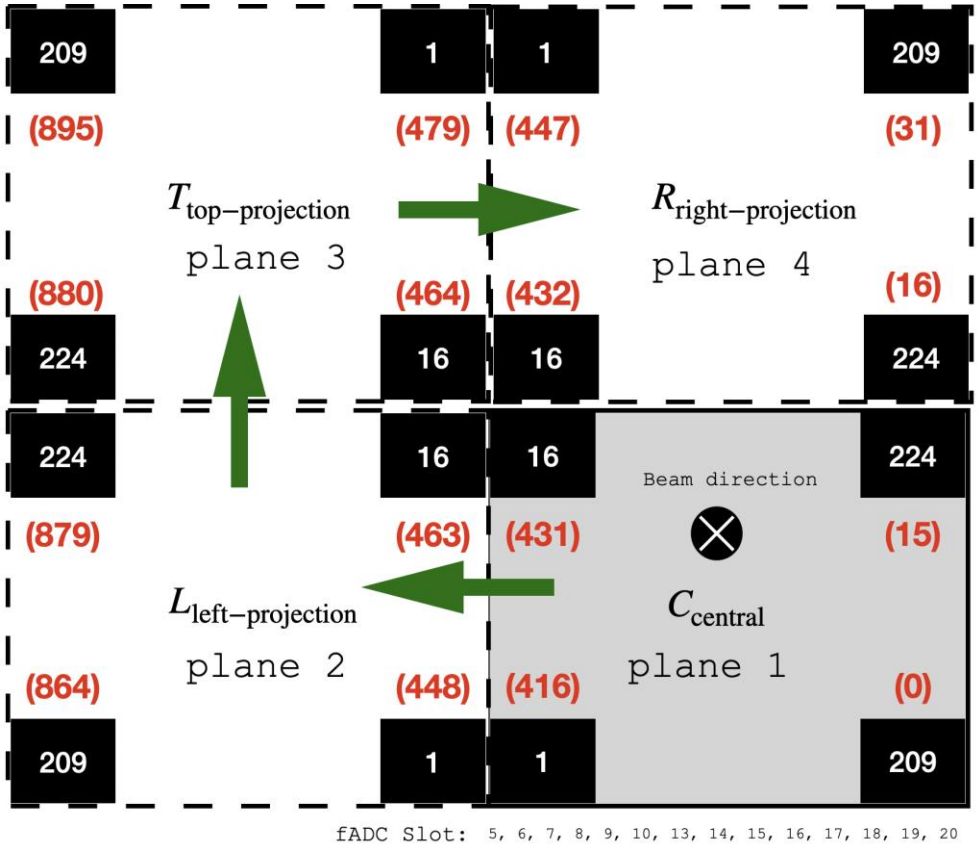
Software Development

- NPS Software is currently under development (e.g., using GitHub repository for version control)
- Existing NPS C++ classes have been adapted from `HCANA` to the `NPSApp` development repo, e.g., the classes are: `THcNPSApparatus`, `THcNPSCalorimeter`, `THcNPSArray` which represent the general NPS spectrometer apparatus, A generic calorimeter detector and a specialized sub-detector, respectively.
- The NPS replay script has been adapted from the `hallc_replay` structure, with re-named parameters and a simplified test stand replay script
- Since NPS does not have tracking detector, tracking information has been removed and the NPS code has been tested under these conditions using actual SHMS data. e.g., these tests show agreement between NPS and SHMS software codes for variables which do NOT depend on tracking
- Currently, the clustering algorithm in SHMS and the existing Hall A DVCS code are being studied and compared to determine which are fundamental differences, and which parts of the DVCS code must be adapted to NPS.

The fly's eye cluster now works ! ! !



Future Plans for NPS Software Development



- Project SHMS "fly's eye" calorimeter on four planes to mimic NPS block density e.g., the corresponding map has already been developed
- The calorimeter projection tests will serve as additional checks/tests of the NPS software currently being developed
- Actual SHMS calorimeter block hits will be projected onto each of the other 3 planes (e.g., the advantage of doing this projection is that hits at the edges will form a mirror image once projected to form additional clusters of hits)
- Will use time information as well as x-y coordinates of blocks) in cluster identification. (3D clustering)

Legend:

SHMS block

(NPS block)

- Using SHMS data taken in sample mode (mode 10) to simulate NPS data format
- Mixing data from several SHMS events together to simulate high rates and accidentals. e.g., This can be done with the scheme of replicating the SHMS calorimeter. Instead of copy the event 3 times, one could take each quadrant from a different event. So a run of 16000 events would be 4000 NPS-like events.

Summary and Outlook

- Neutral Particle Spectrometer and Compact Photon Source (next talk) enables a science program of precision cross section measurements with neutral final states
  - Validation of QCD factorisation in exclusive processes - key for accessing GPDs
  - Progress towards flavour separation made possible through measurements of meson production – L/T separations are crucial for pions and kaons
- Passed ERR in 2019 – beam time requests submitted
- Final assembly as soon as Covid-19 allows – some tasks already ongoing

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- Many opportunities – if interested in joining please email: hornt@cua.edu
- NPS Wiki: https://wiki.jlab.org/cuawiki/index.php/Main_Page
- NPS Collaboration Meeting: 1-2 February (remote); agenda available at: https://wiki.jlab.org/cuawiki/index.php/NPS_Collaboration_Meeting_(online,_2/1-2/2_2021)