The Neutral Particle Spectrometer in Hall C

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Neutral Particle Spectrometer (NPS)

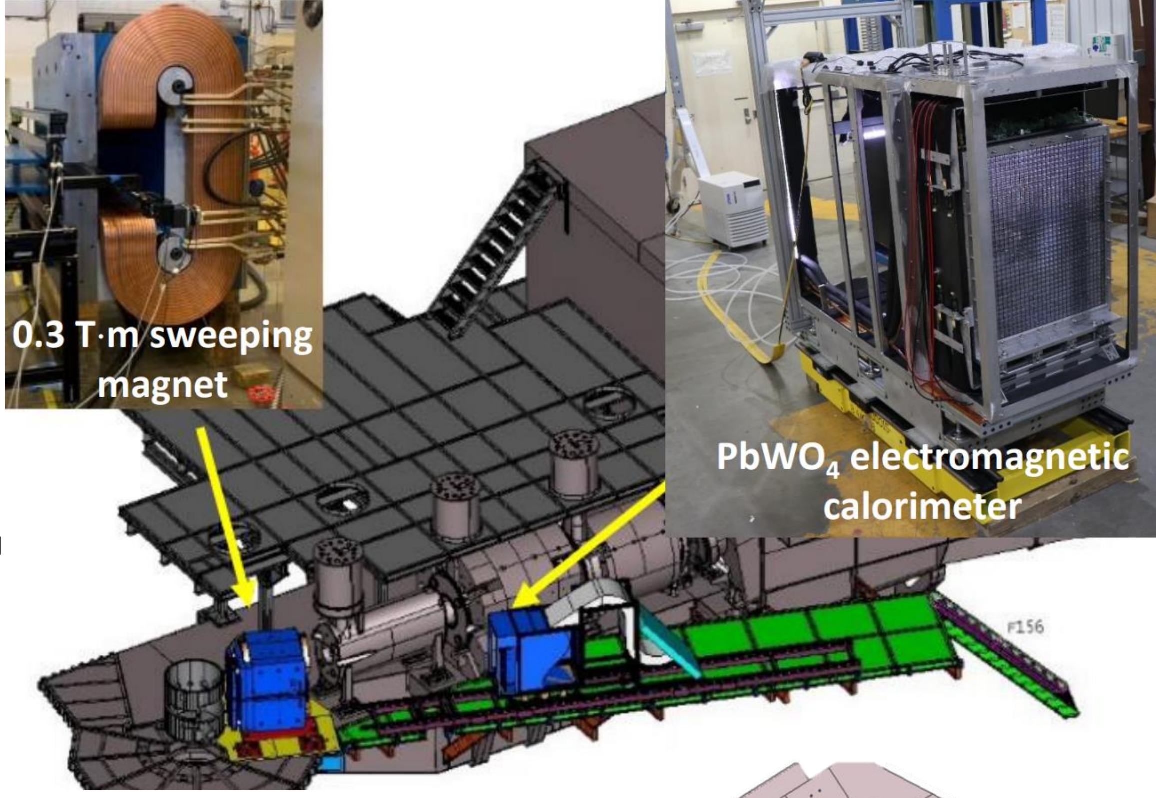
- NPS experiments Ran from September 2023- May 2024:
  - E12-13-010: Exclusive Deeply Virtual Compton and Neutral Pion Cross-Section Measurements in Hall C
  - E12-13-007: Measurement of Semi-Inclusive pi0 Production as Validation of Factorization
  - E12-22-006: Deeply Virtual Compton Scattering off the neutron with the Neutral Particle Spectrometer in Hall
  - E12-23-014: Measurements of the Ratio R = σ_L/σ_T , p/d ratios, P_t dependence, and azimuthal asymmetries in Semi-Inclusive DIS π^0 production using the NPS in Hall C

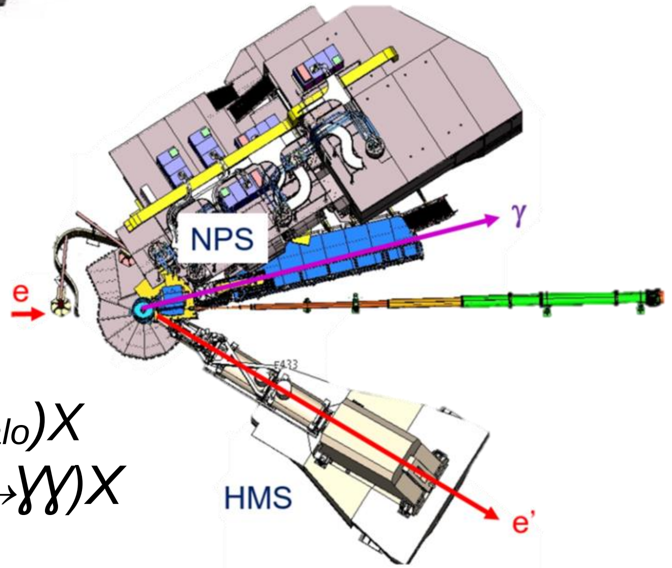
- Scattered electrons are detected in the HMS and high energy photons in the NPS calorimeter

- The calorimeter is installed on a new platform attached to the SHMS carriage to allow remote rotation

- A sweep magnet is installed to reduce charged background. Replacing the SHMS Horizontal Bender

- Enables neutral particle detection with good energy and spatial resolution at high luminosity ($\leq 7.5\times10^{37}$ $cm^{-2}s^{-1}$) for precise cross-section measurements

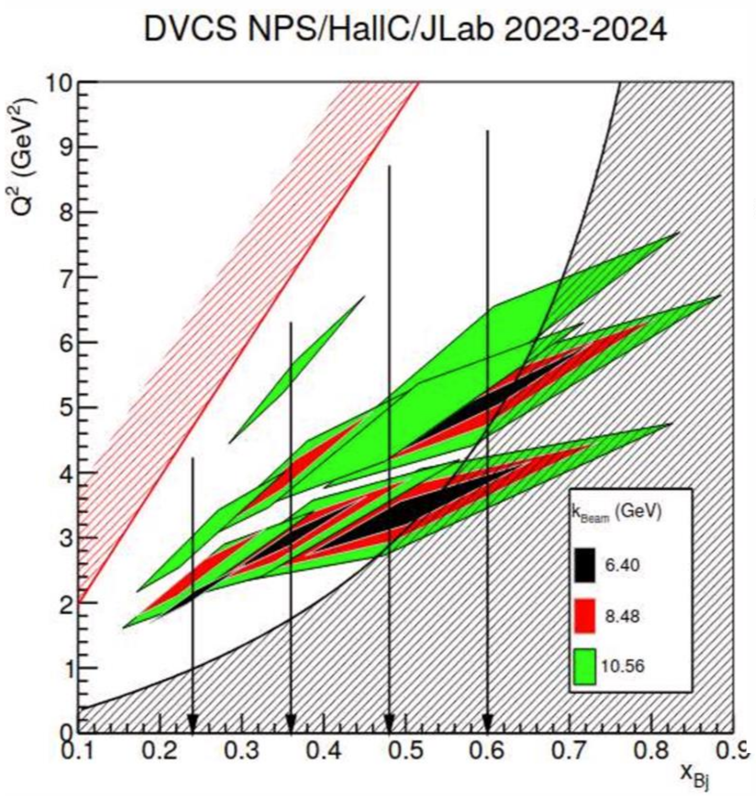




$H(e,e'_{HMS}\,\gamma_{calo})X$
$H(e,e'_{HMS}\,\pi^0\rightarrow\gamma\gamma)X$

NPS Physics

- Exclusive Deeply Virtual Compton Scattering off LH2 and LD2
  - *H(e,e'ɣ)p*
  - *D(e,e'ɣ)pn*
- Exclusive π^0 Production
  - *H(e,e'π^0)p*
  - *D(e,e'π^0)pn*
- Semi-Inclusive π^0 Production
  - *H(e,e'π^0)X*
  - *D(e,e'π^0)X*



- Data taken in 2023

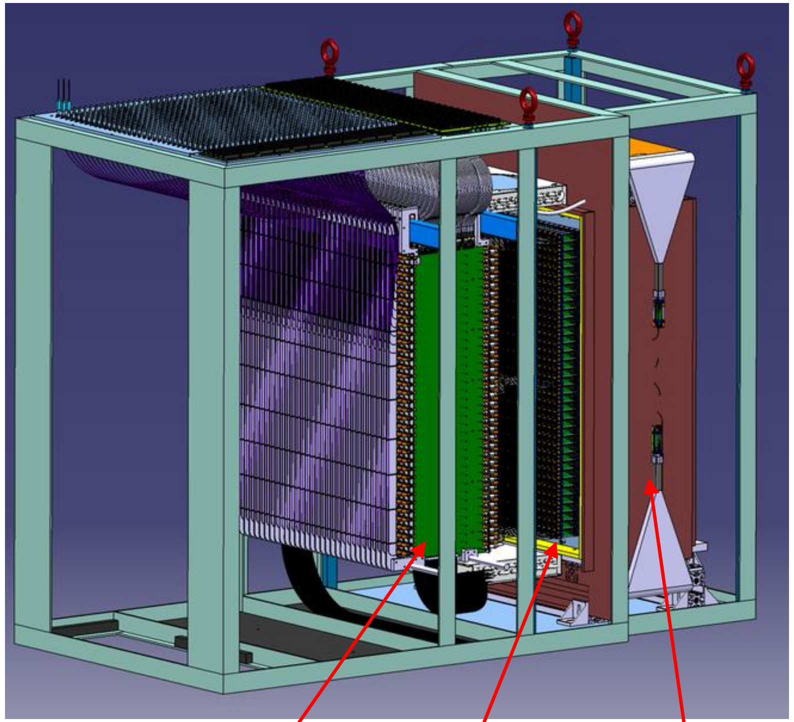
x_Bj	Kinematic Setting	Pass	Q2 (GeV^2)
0.36	KinC_x36_3	5	3.0
	KinC_x36_5	5	4.0
	KinC_x36_2	4	3.0
0.50	KinC_x50_2	5	3.4
	KinC_x50_3	5	4.8
	KinC_x50_1	4	3.4
0.6	KinC_x60_3	5	5.1
	KinC_x60_2	4	5.1

- Data taken in 2024

x_Bj	Kinematic Setting	Pass	Q2 (GeV^2)
0.25	KinC_x25_1	5	2.1
	KinC_x25_2	5	2.4
	KinC_x25_3	4	2.4
	KinC_x25_4	3	3.0
0.36	KinC_x36_6	5	5.5
	KinC_x36_4	4	4.0
	KinC_x36_1	3	3.0
0.5	KinC_x50_0	3	3.4
0.6	KinC_x60_4	5	6.0
	KinC_x60_1	3	5.1

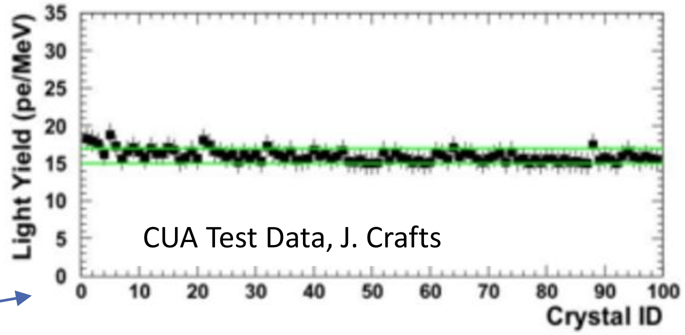
NPS Detector Design

- 1,080 $PbWO_4$ ($2x2cm^2$) blocks in 30x36 array
- 0.5mm carbon fiber grid to hold crystals
- Hamamatsu 4125 PMTs
- Onboard HV divider and amplifier for high rates
- LED system for curing and calibration
- HV, LV, and LED signals distributed to an entire column through distribution board



NPS Crystals

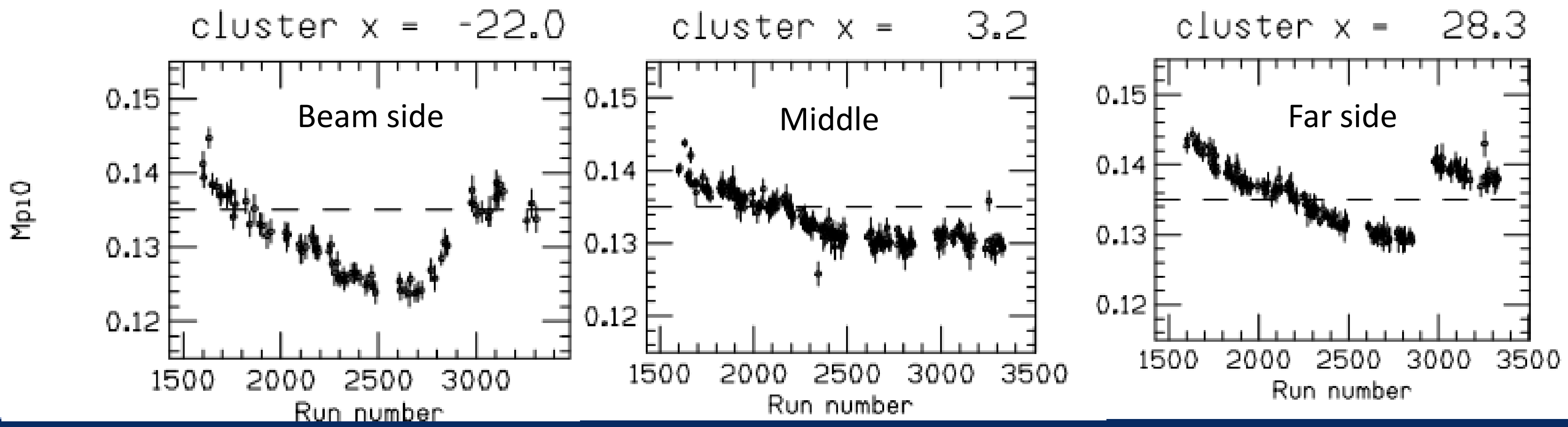
- $PbWO_4$ crystals manufactured by CRYTUR
- Lack of defects led to consistent light yield
- Fast time response (5-14ns)
- High density and lack of self-absorption provides potential high energy resolution



- Radiation causes darkening and discoloring of crystals which reduces the light transmission

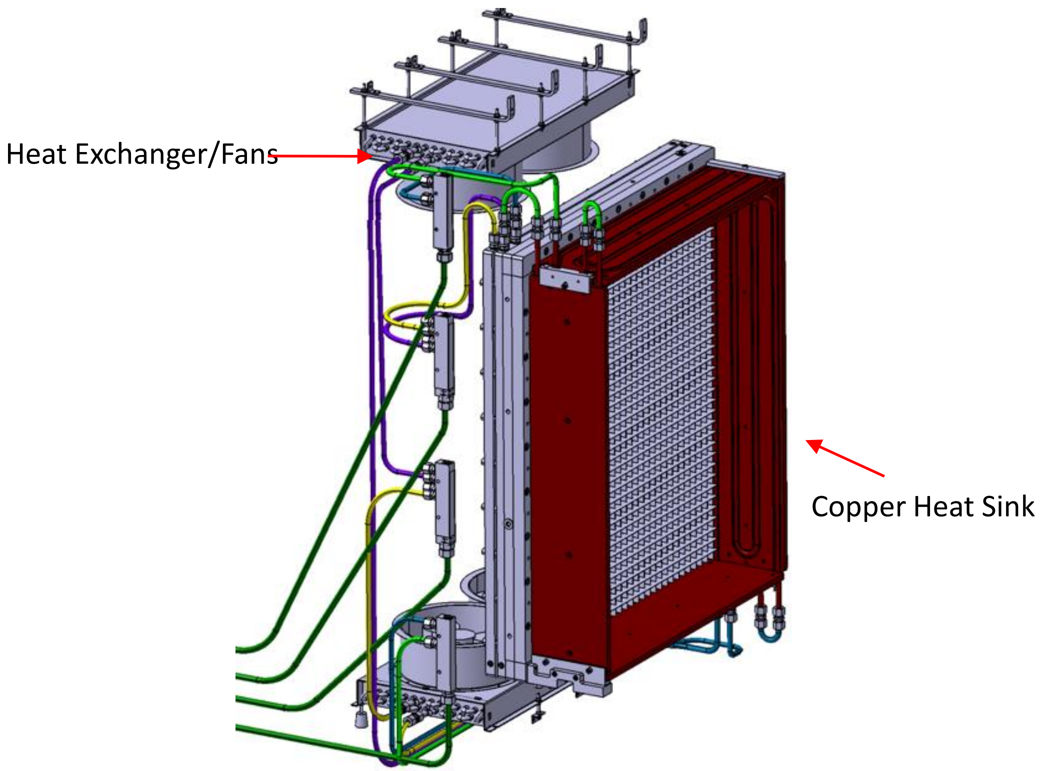
- There was a shift in the raw π^0 mass over time
- Columns on the edges of the calorimeter saw a larger shift in π^0 mass
  - This effect is accounted by re-calibration

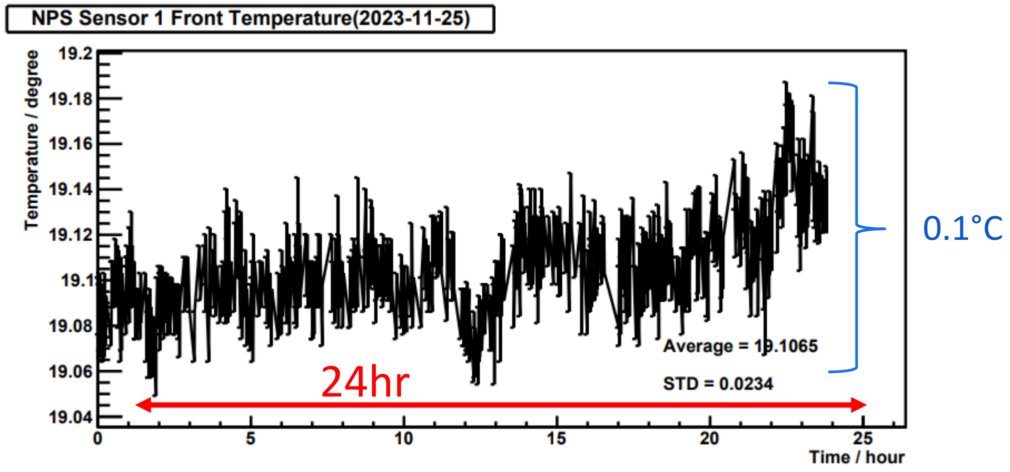
Raw π^0 Mass as a Function of Run# for Different Values of x



Temperature Control

- Light yield from PbWO4 are temperature dependent (-2% / °C at 20°C)
- For 0.5% energy stability need 0.1°C stability
- The high-voltage dividers on the PMTs dissipate several hundred Watts total
- Chilled water circulates around copper heat sink frame
- Fans and heat exchanger
- 56 temperature sensors on both front and back of crystals

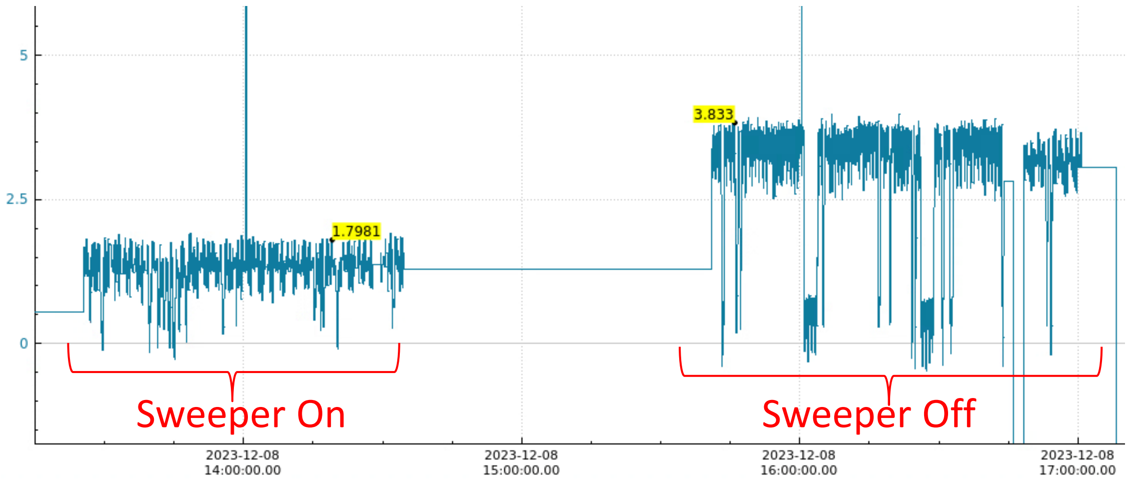


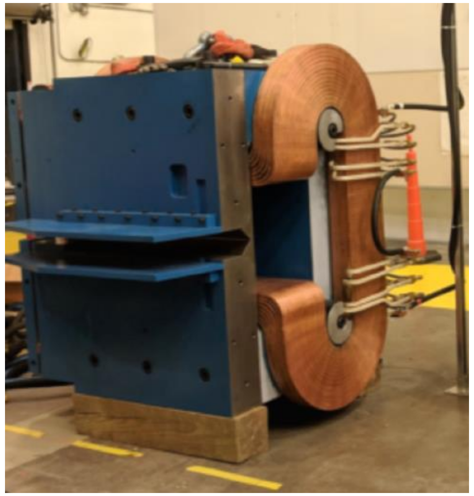


NPS Sweeper Magnet

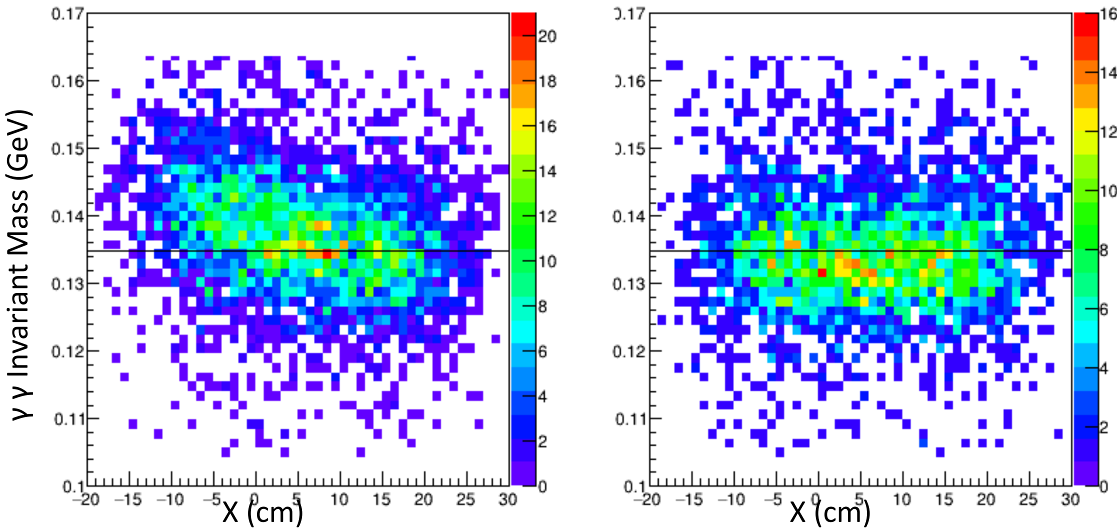
- 0.3 Tm conventional copper coil
- Reduces electromagnetic background for high-rate environment
- With 15uA beam on LD2 the maximum anode current reduced from 9.9uA → 3.7uA with the sweeper off/on
- However, with calorimeter 3m from target, fringe field caused a 0-7% change in PMT gain as a function of the column # (more calibrations!)

Calorimeter PMT Anode Current with Sweeper on/off



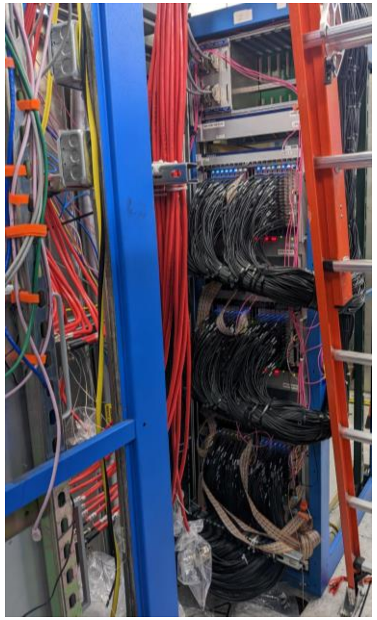


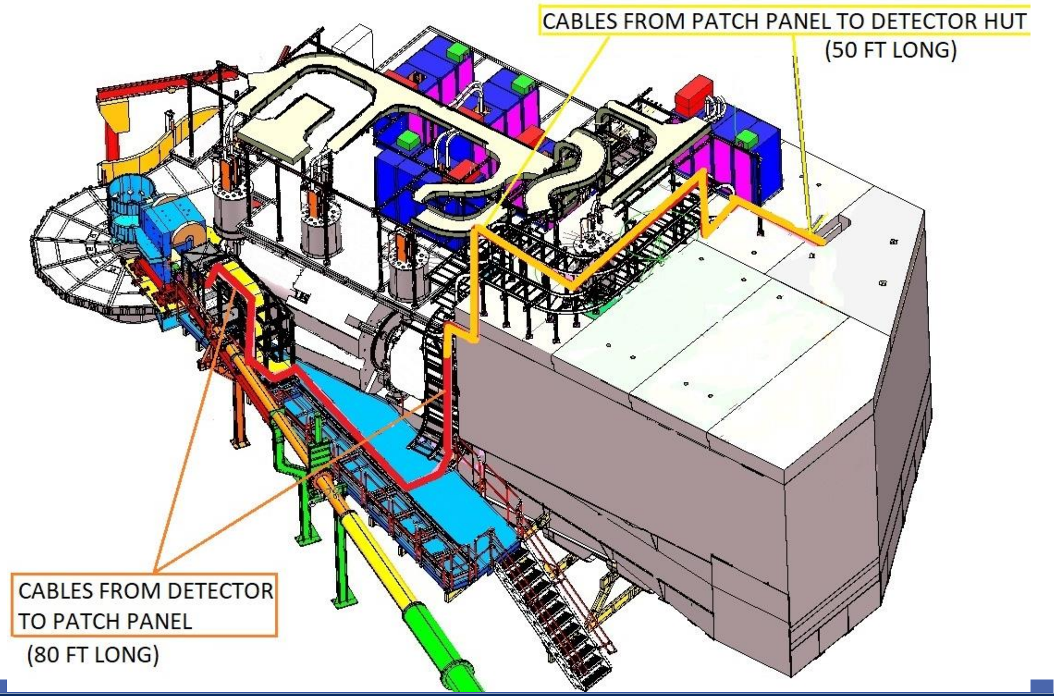
Change in γ γ Invariant Mass



Installation

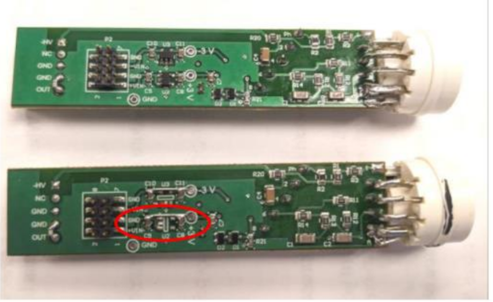
- Installation, cabling, and testing began in April 2023 and finished by September
- Calorimeter installed on sliding rail
- 5 VME crates, 2 HV , and 1 LV power supplies added to SHMS hut
    - 250MHz FADC with streaming ɣ and ɣɣ triggers
- Cables ran through the hut roof down to the NPS platform



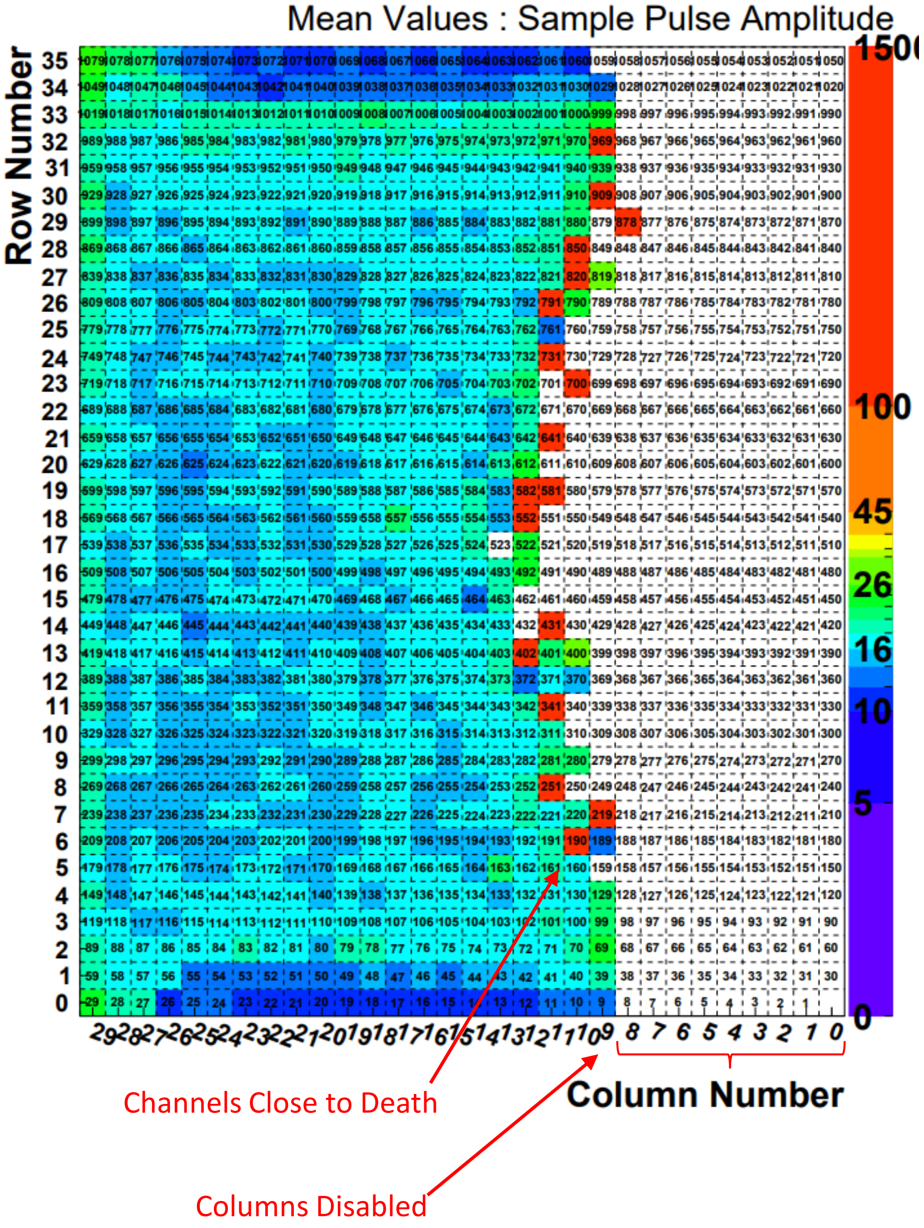


Radiation Damage to PMT Preamp

- Radiation damage seen in the LV regulators on the PMT pre-amps
- Damaged amplifiers cause instability in the LV power supply for all channels in the column
- Dec 15th - Jan 13th work carried out to bypass the regulators in the pre-amps
- Lead and polyethylene shielding added to the side of the calorimeter



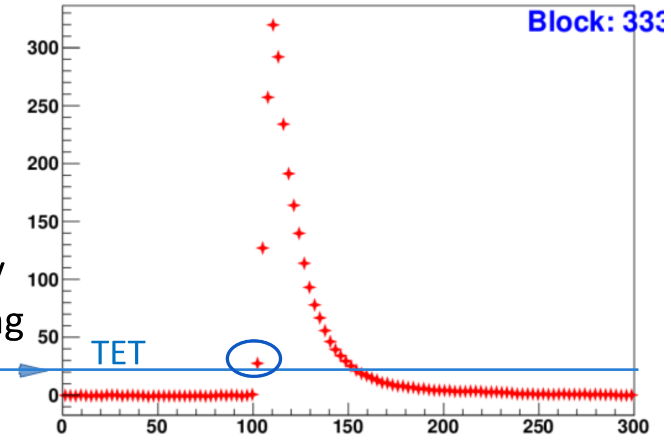
Top:Original Bottom: Bypassed Amplifier



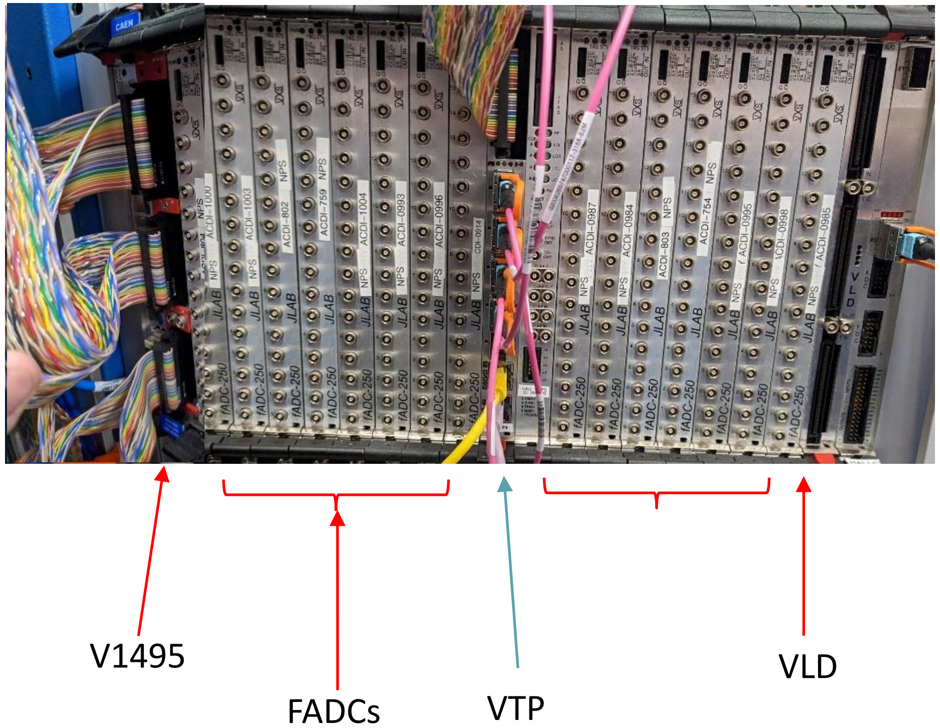
NPS Semi-Streaming Data Acquisition

- Flash analog to digital converter (FADC): digitizes raw waveforms
- FPGA logic in each FADC channel identifies a “hit” as [-12,32]ns integral of every occurrence above threshold (20 adc counts above pedestal)
- Waveform samples are stored in 8μs memory buffer while data is continuously streamed to a VTP every 4ns
  - Data sent to VTP is hit energy(from [pulse integral-pedestal] x gain), time, and position
- The VXS trigger processor(VTP) looks at FADC signals and performs clustering

Sample waveform from FADC

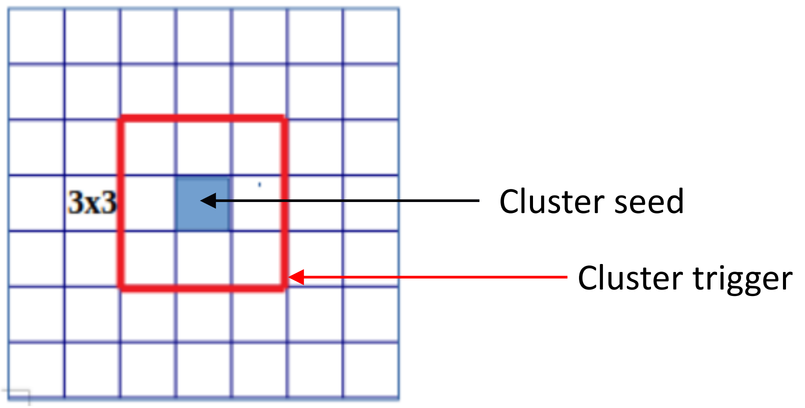


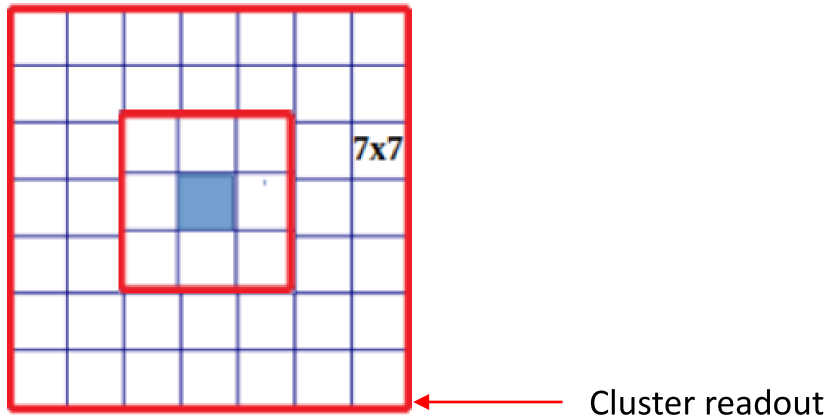
Hit time defined by first sample crossing threshold



VTP Single Cluster Logic

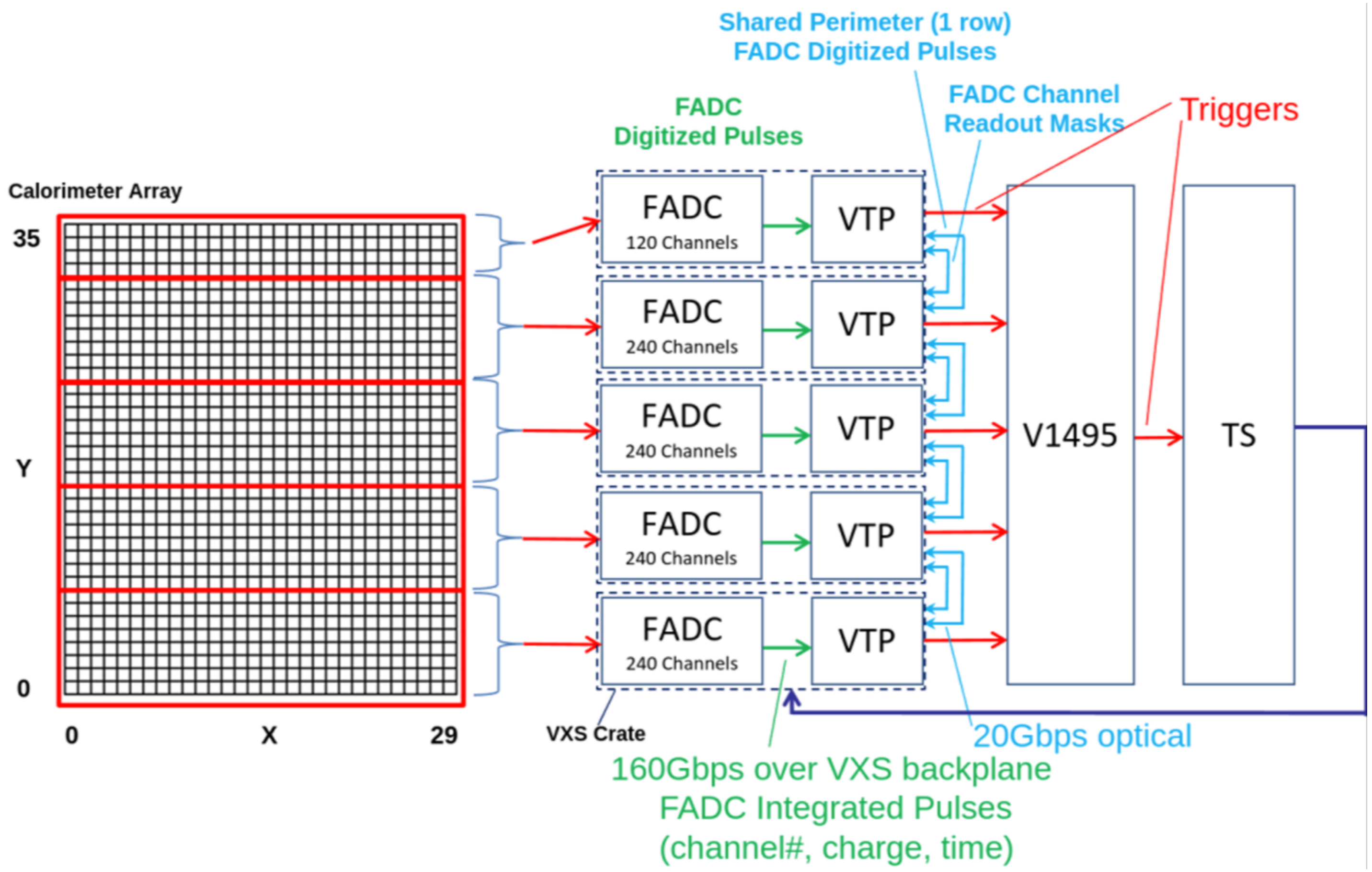
- A hit from FADC is a cluster "seed" if:
  - Energy is above threshold (70MeV)
  - Energy is local maximum of adjacent blocks within 20ns window
- Cluster energy is summed from seed plus any hits in 8 surrounding blocks within +/-10ns window
- Single photon trigger = If cluster energy > single photon trigger threshold (1600MeV)
- All FADC waveforms remain in FPGA memory. If VTP trigger is validated by HMS trigger, then either:
  - FADCs readout waveforms of surrounding 7x7 blocks to get full energy from shower (sparsification); or
  - Entire calorimeter waveforms are readout





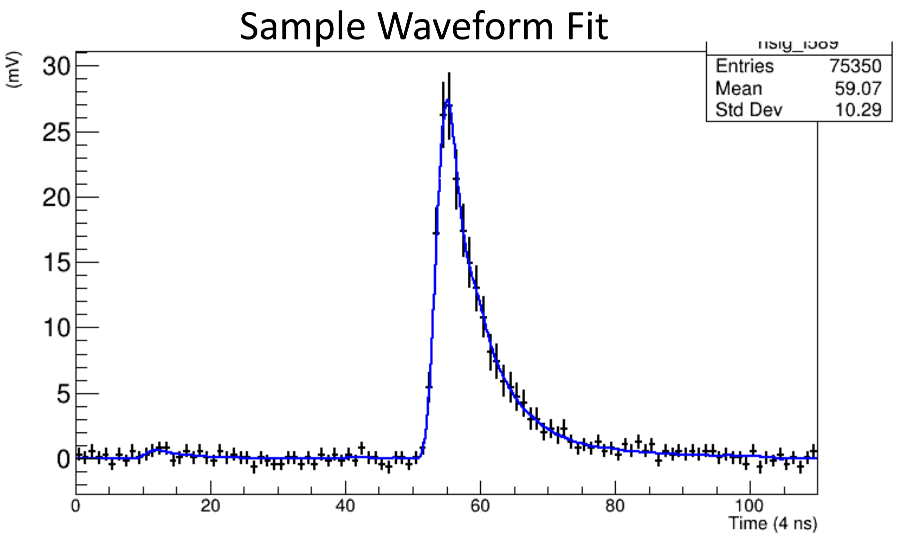
NPS Digital Trigger

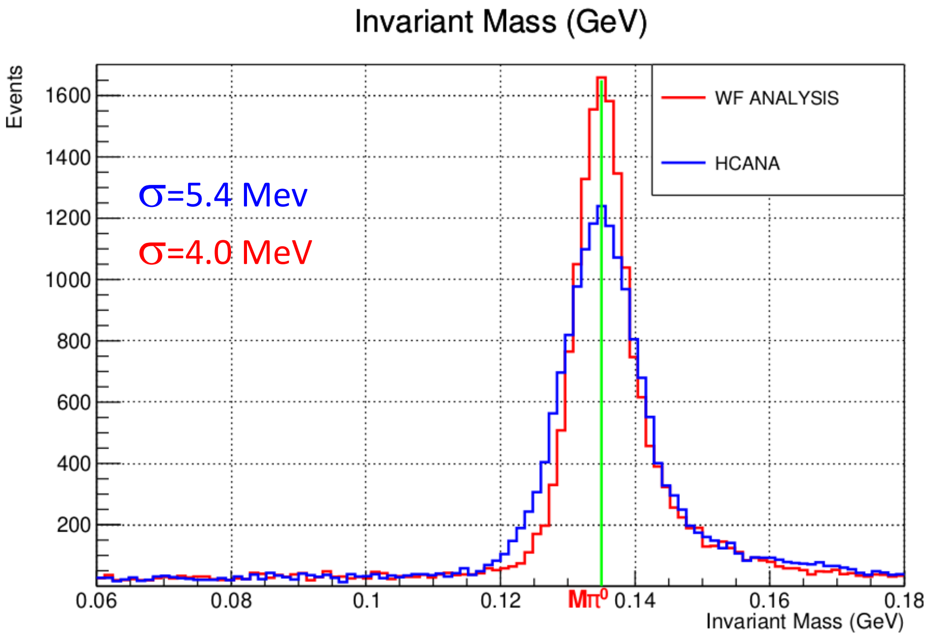
- The calorimeter is segmented across 5 VTPs. VTPs share information via optical connection for clusters on the segment edges
- A CAEN V1495 logic unit consolidates trigger bits from all 5 VTPs and sends trigger to counting house for coincidence with HMS
- A 2 photon trigger is formed by the V1495 when ≥2 clusters within a 20ns window have energy>800MeV threshold in any VTP
- After trigger is formed the VTP sends channel masks to FADCs to readout all channels from the cluster(s)



Waveform Analysis

- Goal: Fit waveforms for a more accurate pulse amplitude compared to just using the max FADC sample(hcana)
- Create a reference pulse shape from elastic H(e,e'$_{calo}$ p_{HMS}) data for each channel
- Create a fit function for each channel with spline interpolation between pulse samples and the reference waveform
- From π^0 calibrations: 26% improvement in invariant mass σ

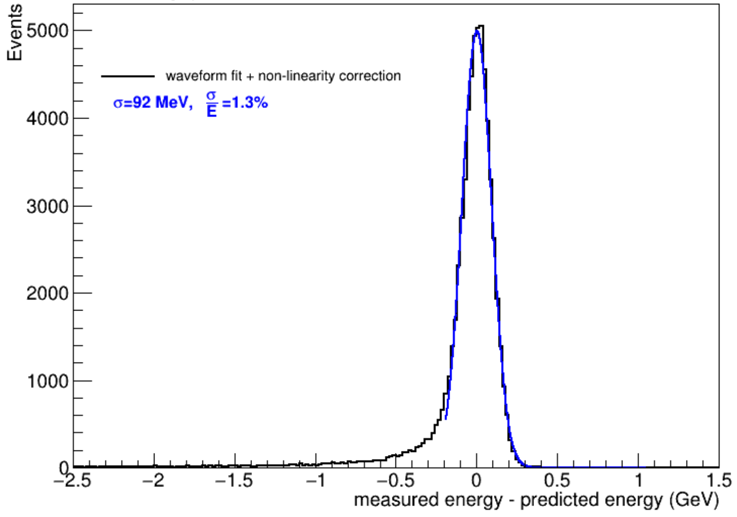


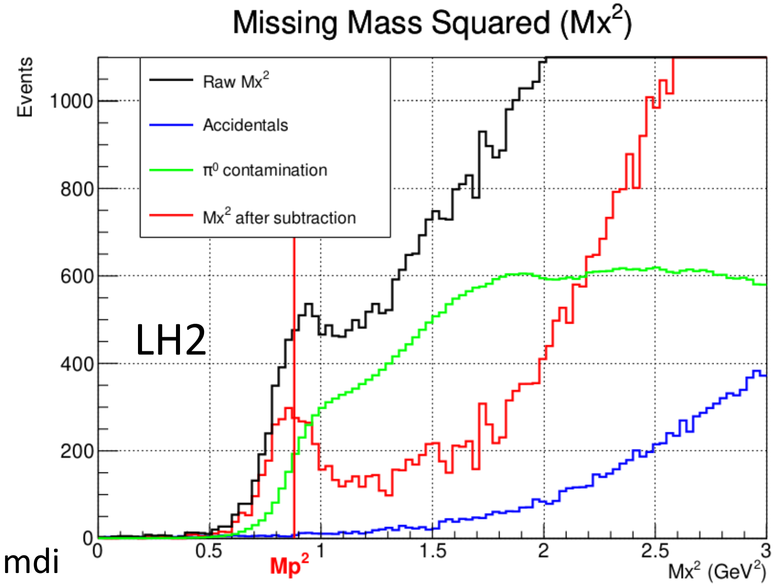


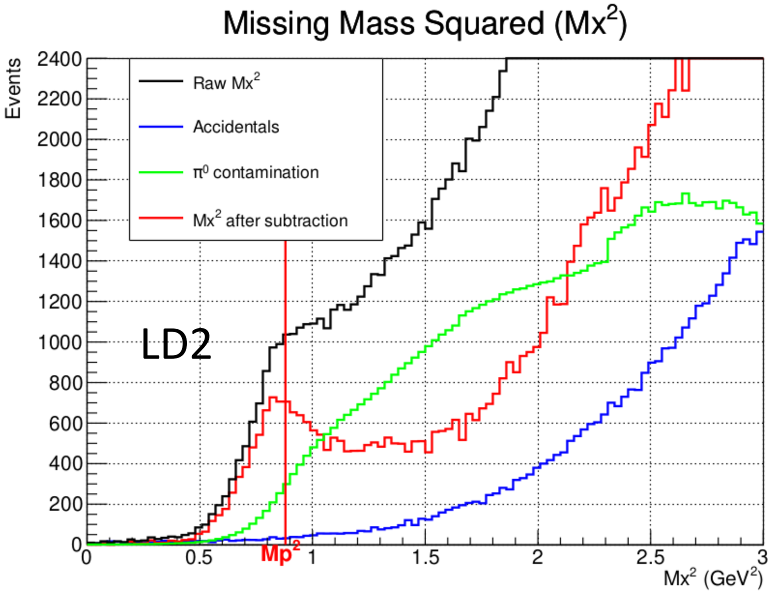
Preliminary Results

- Waveform analysis of elastic signals shows good energy resolution (1.3% at 7.3GeV)
- DVCS missing mass peak clear after π^0 + accidental subtraction. Shows high exclusivity

Energy Resolution from Elastics







Analysis from W. Hamdi

Thank You!

Thanks to the NPS Spokespeople, Graduate Students, JLab Staff, and all our Collaborators

Jefferson Lab