SBS Collaboration Meeting 2023

Research Update

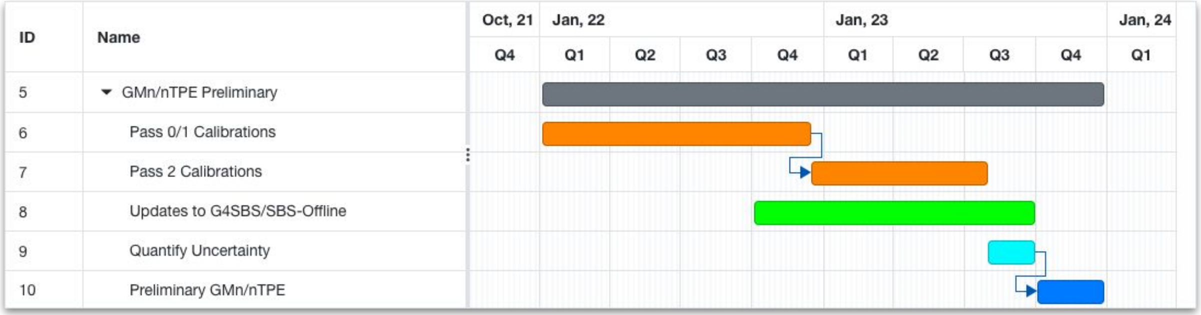
Sebastian Seeds

July 12, 2023
Jefferson Lab

Jefferson Lab UCONN

Topics

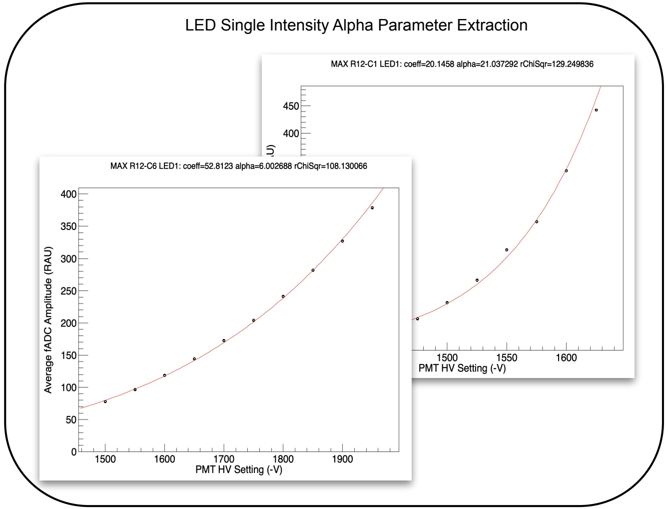
- Pass 2 Calibrations
  - Software
  - Status
- Utility
  - Data parsing
  - HCal
- HCal GMn Performance
  - Resolution
  - TDCs and Timing
- HCal Detection Efficiency
  - Anticut method
  - dx direct method
- Current Work
  - GMn/nTPE
  - Documentation

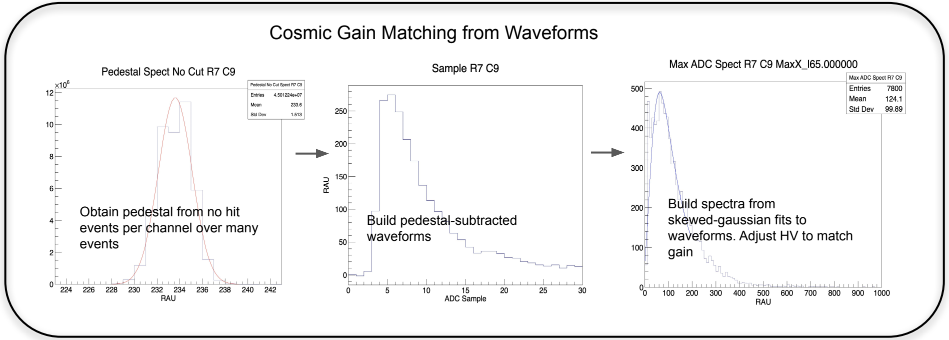


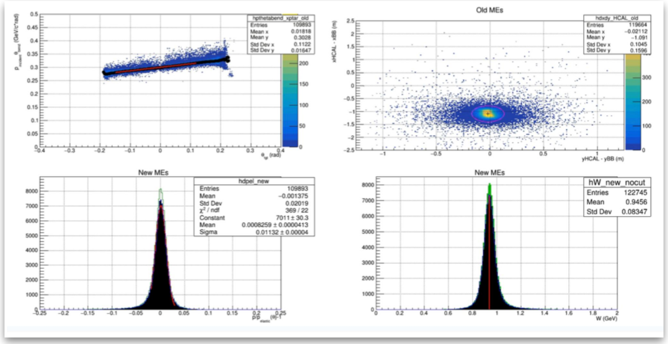
**Estimated, simplified timeline*

Pass 2 Calibrations - Software

- HCal - *written and configured*
  - Alpha Parameters
  - Cosmic Gain and HV
  - HCal energy (discussed later)
  - HCal timing (discussed later)
  - SBS-Offline - timewalk (*sbs.hcal.tdc.tw*) and cluster block dt max (*sbs.hcal.tmax*)
- Monte Carlo - *configured*
  - e’ momentum
  - Electron arm optics



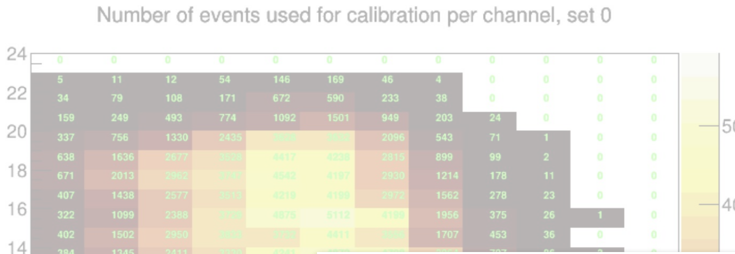




**SBS 8 MC calibration progress courtesy JBoyd and APuckett*

Pass 2 Calibrations - Status

- HCal
  - Energy - 83% complete (all but SBS4)
    - Resolving SBS4 multiple-calibration-set bugs
  - Timing - 100% complete
- Documentation - 70% complete



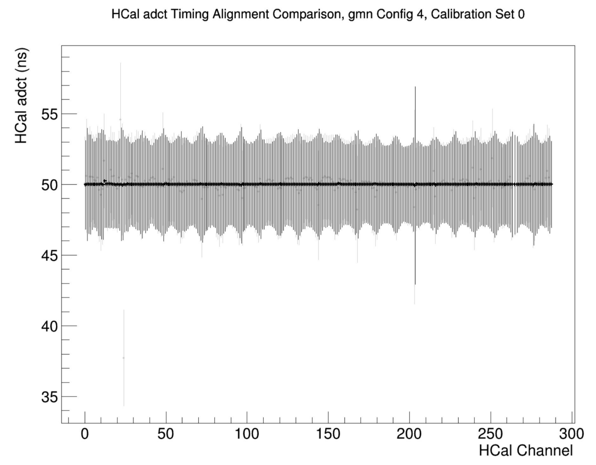


Figure 3: ADCt Fit Comparison, Post-Cal in Black

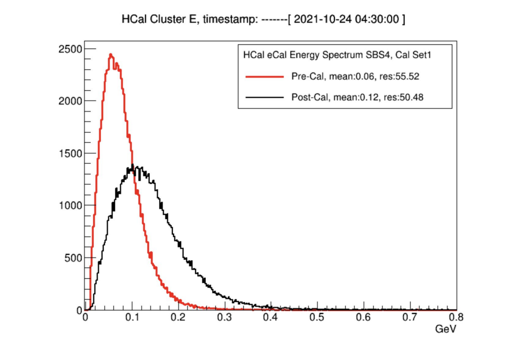


Figure 13: HCal Cluster E, Before Calibration vs After Calibration

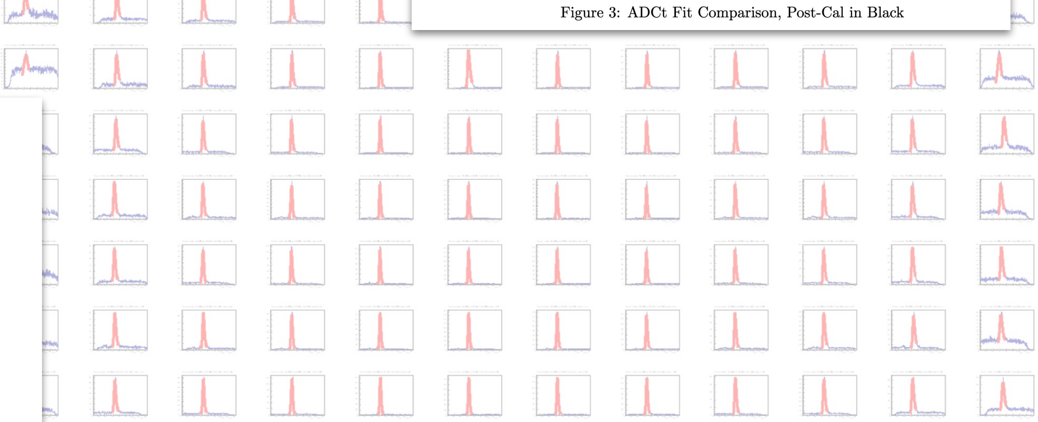


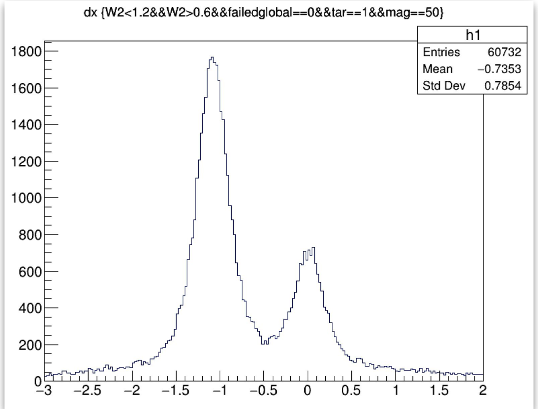
Figure 4: TDC Spectra Fits vs. Channel, Top Half

Data Parsing

- Runs over all GMn data from a given kinematic with wide elastic cut effects
- Produces output tree with far fewer branches, same total events, single root file
- Can be found here: https://github.com/sebastianseeds/SBS-ana/blob/main/analysis/gana/parse_sh.C
    - Wide elastic cuts can be found here: https://github.com/sebastianseeds/SBS-ana/blob/main/src/etune.C
- Word of caution: elastic selection requires judicious HCal cluster selection not included in this analysis (primary cluster only here) - *prior to completion of pass 2 (at least), this tool is best used as a diagnostic*

BRANCH	DESCRIPTION
dx	HCal expected vertical position - HCal detected vertical position
dy	HCal expected horizontal position - HCal detected horizontal position
W2	Invariant mass squared (GeV)^2
Q2	Inverse four-momentum transfer squared (GeV)^2
nu	Energy transfer or KE of scattered nucleon
hcale	Measured primary cluster energy in HCal
pse	Measured preshower energy
she	Measured shower energy
ep	Reconstructed e' momentum
eoverp	e' energy over e' momentum
hcalatime	HCal ADC time, primary block, primary cluster
hodotmean	Hodoscope TDC cluster mean time
thetapq_p	Proton scattering angle
thetapq_n	Neutron scattering angle
mag	SBS magnetic field setting
run	Run number
tar	Target
failedglobal	Indicates if global cuts would have cut the event
failedaccmatch	Indicates acceptance matching between e-arm and h-arm
failedcoin	Indicates HCal ADC time cut

Example - dx from the tree with wide elastic cuts selecting deuterium at SBS field 50%

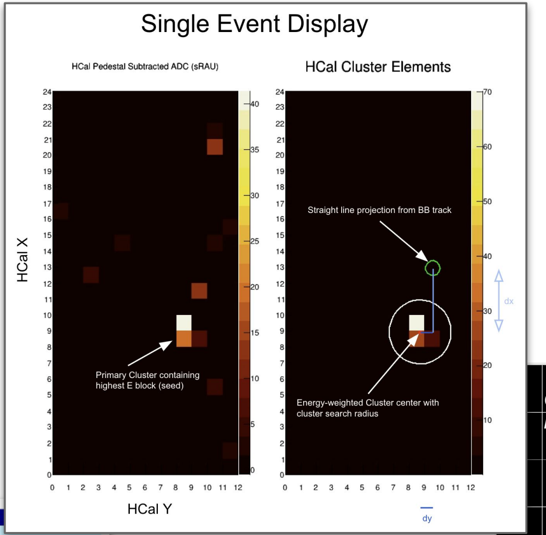


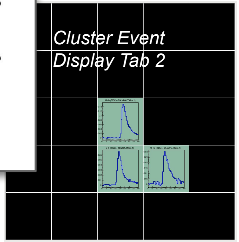
HCal Utility

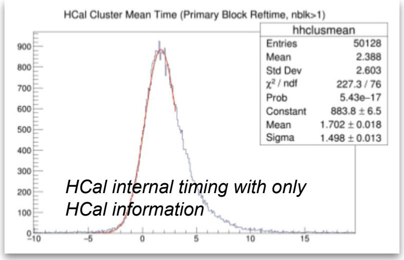
- Event Displays
  - Full waveform - all channels
  - Cluster elements only - added analysis utility
- Proton Spot - timing only for commissioning
- TDC Efficiency - Calculates TDC signal efficiency with various reconstruction schema
- Internal timing - Estimates timing resolution

General Software Map with Locations

Analysis	Script(s)	Description	Location
Alpha Extraction	alpha_extraction.C LED_spectral_analysis.C	Builds spectra from single LED intensity over many channels and several HV to extract alpha gain parameter per PMT	On CH: adaqfs/home/a-onl/sbs/hcal_devel
Cosmic Gain Matching	cosmic_gain_match.C	Via waveforms and alphas, extracts pedestal, pedestal subtracts, builds PMT spectra, gives target HV and maps to .set rpi format	On CH: adaqfs/home/a-onl/sbs/hcal_devel
Energy Calibrations	ecal.C	Gives gain parameters for database from in-beam event clusters in HCal and expected elastic energies from e-arm	On git: github.com/sebastianseeds/HCal_replay/tree/main/hcal/hcalCalibration/SBS
Timing Calibrations	adct_align.C tdc_align.C tdc_tw.C	Aligns HCal TDC/ADC time signals with loose elastic cut spectra. Also extracts timewalk corrections for TDC spectra. Gives params for database	On git: github.com/sebastianseeds/HCal_replay/tree/main/hcal/hcalCalibration/SBS
Other HCal Analysis	sfracMC.C simTOF.C hcaltdc_eff_chainC.C elas.C htres.C	- Obtains expected sampling fraction from MC - Obtains time of flight corrections as a function of scattered elastic/quasi-elastic nucleon momentum - Calculates TDC efficiency given loss of HCal TDC signals in GMn - Uses only timing to resolve elastic protons in HCal - Uses cluster members to estimate best possible HCal TDC resolution	On git: github.com/sebastianseeds/HCal_replay/tree/main/hcal/hcalCalibration/GMn github.com/sebastianseeds/HCal_replay/tree/main/hcal/analysis/TOF github.com/sebastianseeds/HCal_replay/tree/main/hcal/analysis/TDCsigloss github.com/sebastianseeds/HCal_replay/tree/main/hcal/analysis/protonDisplay github.com/sebastianseeds/SBS-ana/tree/master/analysis/hta
HCal Utility	replay_hcal_SAS_general.C display_v2.C clusDisplay_HCal.C	- General HCal replay with all branches enabled (full waveforms) - Event by event full waveform display with GUI - Event by event cluster waveform display including expected nucleon location and cluster search region	On git: github.com/sebastianseeds/HCal_replay/tree/main/hcal/replay github.com/sebastianseeds/HCal_replay/tree/main/hcal/displays







GMn Performance - Energy

- Calibrations (nearly complete for current pass)
  - Integrated ADC (pC) ➡ E (GeV) via χ^2 minimization on linear system
  - Relate total hadron E (from BB) to cluster elements with sampling fraction (MC)

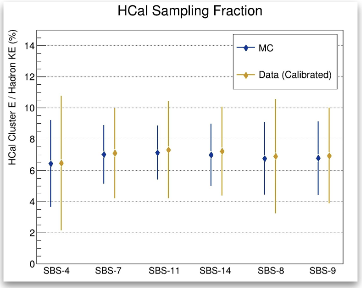
$$\chi^2 = \sum_{i=1}^{n} \left(E_i - \sum_j c_j A_j^i \right)^2 / \sigma_E^2$$

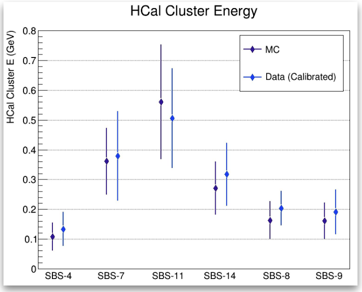
$$\sigma_E^2 \approx E_i$$

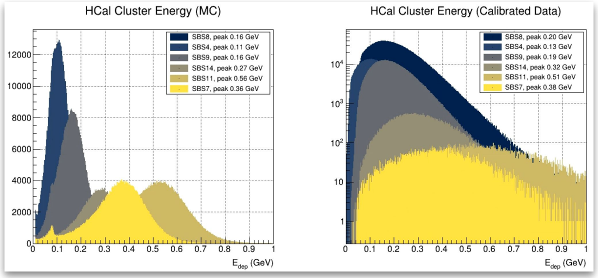
$$\frac{d\chi^2}{dc_k} = 2 \sum_{i=1}^{n} \frac{1}{E_i} \left(E_i - \sum_j c_j A_j \right) A_k = 0$$

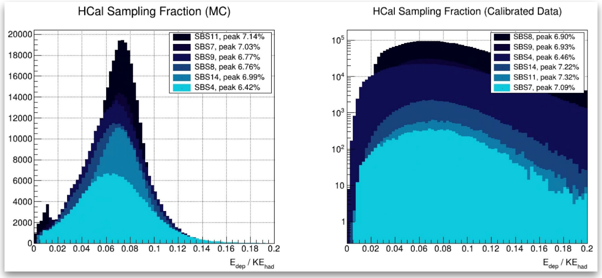
Minimize

- Post-calibration
  - MC and data agree well over all kinematics
  - Energy resolution trends towards better resolution at higher Q^2







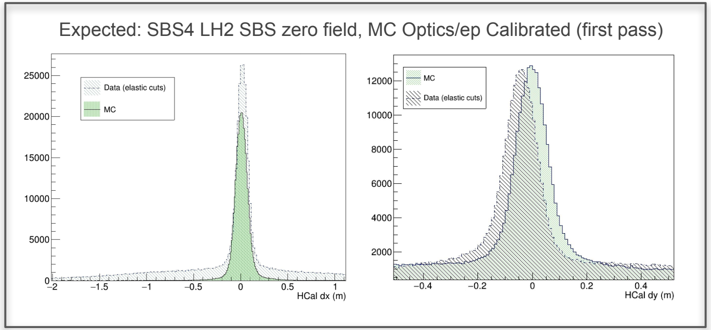


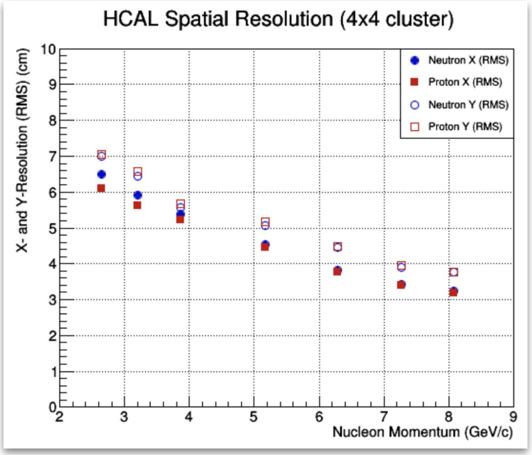
KINEMATIC	4	7	11	14	8	9
Beam Energy (GeV)	3.739	7.931	9.889	5.983	5.983	4.027
HCal Angle (deg)	31.9	16.1	13.3	17.3	29.4	22.0
Recoil Nucleon Central KE (GeV)	1.62	5.26	7.22	3.98	2.40	2.40
HCal Energy Resolution (%)	**67**	**42**	**41**	**41**	**55**	**45**

GMn Performance - Position

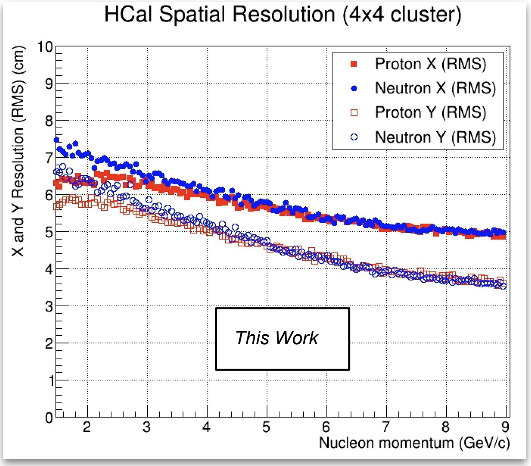
- Delta plots
  - Difference between cluster centroid and expected nucleon location in dispersive (vertical, X) and non-dispersive (horizontal, Y)
  - dx/dy RMS: HCal spatial resolution
- Simulated (no target)
  - PAC expected: proton / neutron generator with 4x4 clusters
  - This work: proton / neutron generator with 4x4 clusters, data digitization, and replay
- Expected / Data (preliminary)
  - Position will be impacted by nucleon momentum and SBS field

Kinematic	X res	Y Res	MC X Res	MC Y Res
SBS 4	5.94	6.46	6.10	6.27
SBS 8	5.34	6.12	5.93	7.50



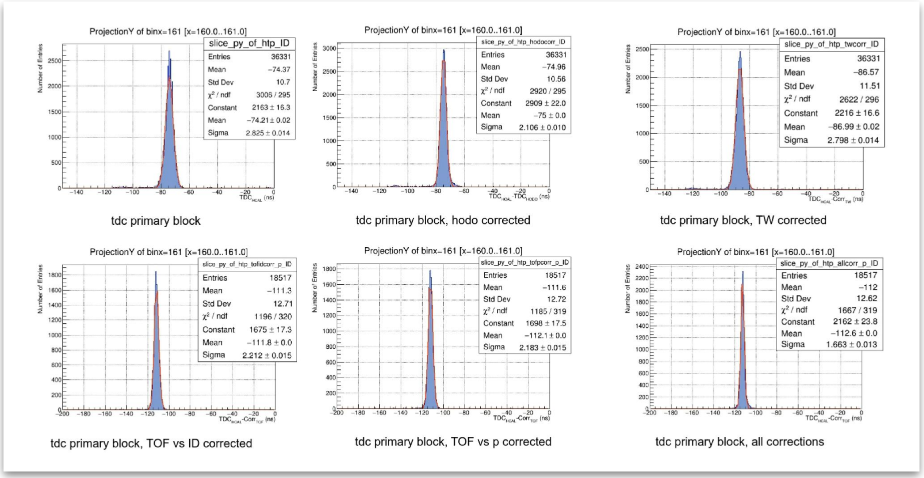


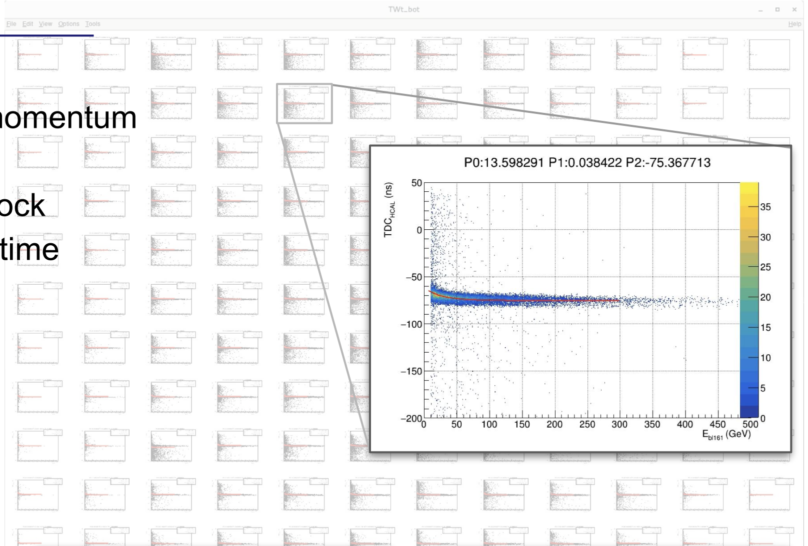
PAC35, Juan-Carlos Cornejo

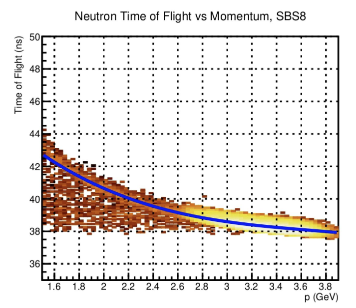


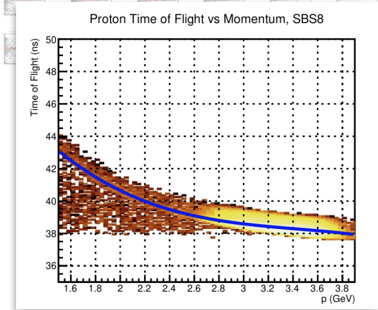
GMn Performance - Timing

- Corrections passed per event (*channel 161 shown, SBS4*)
  - Time-of-flight (TOF): order-3 polynomial fit to nucleon momentum from MC
  - Timewalk (TW): exponential fit to integrated ADC per block
  - Trigger: difference with e-arm hodoscope cluster mean time
  - All channel TDC RMS (HCal active area): *1.7 ns*







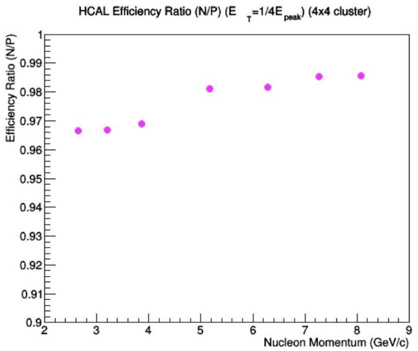


GMn/nTPE Physics Deliverables

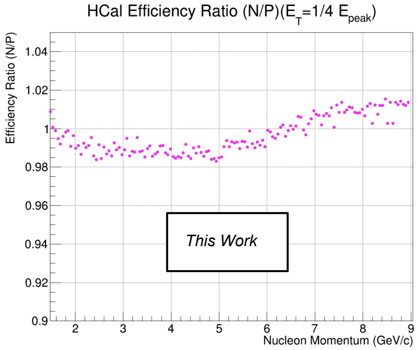
- *R”* is the experimental observable and the form factor ratio (FFR) on deuterium
  - Requires simultaneous measurement of protons and neutrons with known detection efficiency
  - Durand technique or “ratio” technique cancels systematic error, but in HCal we need:
    - *Uniformity in detection efficiency*
    - *Proton / neutron efficiency ratio near unity*
- With nuclear corrections, get *R’*, then extract GMn!

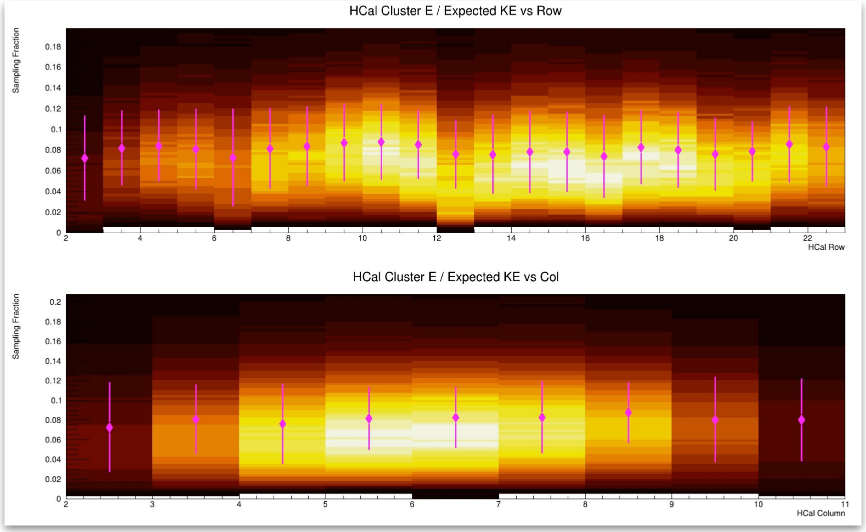
$$R'' = \frac{\frac{d\sigma}{d\Omega}\big|_{d(e,e'n)}}{\frac{d\sigma}{d\Omega}\big|_{d(e,e'p)}} \;\Rightarrow\; R' = \frac{\frac{d\sigma}{d\Omega}\big|_{n(e,e')}}{\frac{d\sigma}{d\Omega}\big|_{p(e,e')}} \equiv \frac{\frac{\sigma_{Mott}}{1+\tau}\left({G_E^n}^2 + \frac{\tau}{\epsilon}{G_M^n}^2\right)}{\frac{d\sigma}{d\Omega}\big|_{p(e,e')}}$$

$$\Rightarrow\; G_M^n = -\sqrt{\frac{1}{\tau}\frac{d\sigma}{d\Omega}\Big|_{p(e,e')}R' - \frac{\epsilon}{\tau}{G_E^n}^2}$$



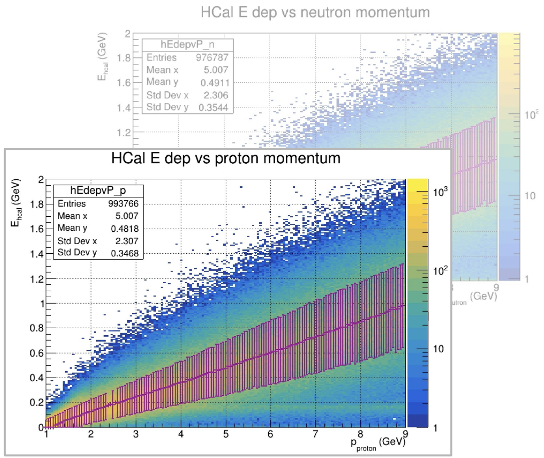
*PAC35, Juan-Carlos Cornejo



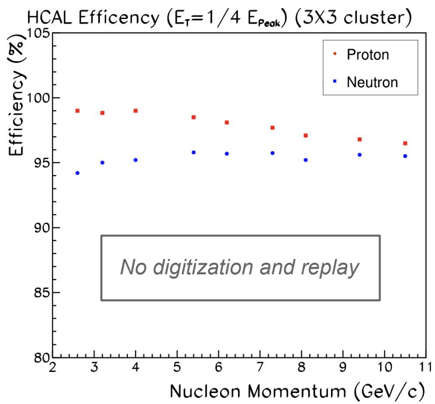


*SBS4 Data, all

Detection Efficiency (MC)



- Extraction of expected detection efficiency from MC
  - Simulate protons and neutrons with momentum 1-9 GeV, throw flat, populate 1000 ev/ch
  - Get energy spectra v nucleon momentum, fit peaks to extract mean E per bin p
  - Sum events per bin passing E_{mean} / 4 threshold (*pass*)
  - Sum all events per bin (*total*)
  - Efficiency: (*pass*) / (*total*) *100
- *Digitized and replayed simulations are consistent with proposal*



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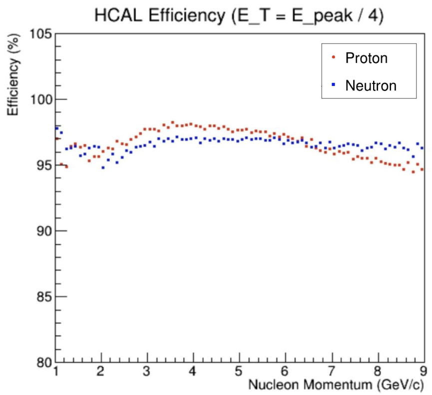
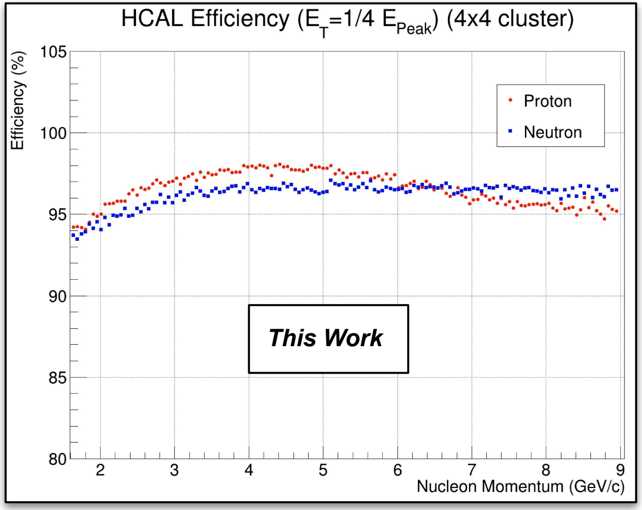
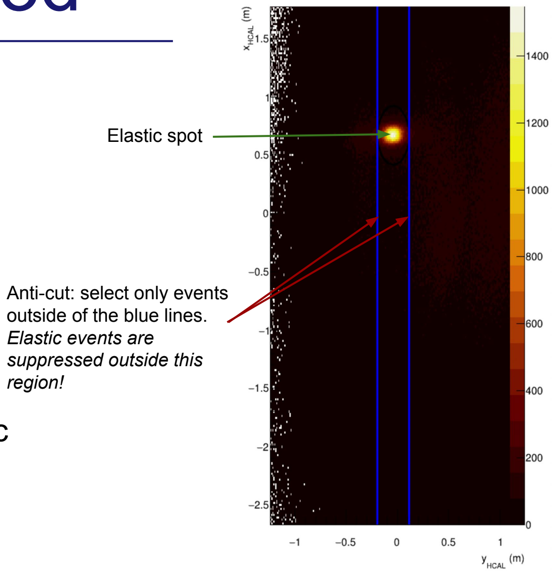


*GMn Analysis, Provakar Datta



Detection Efficiency: dy Anti-cut Method

- Methodology
  - Focus on protons from liquid hydrogen (*LH2*) with high signal to noise (*SBS 4, high elastic yield / C, relatively low Q^2*)
  - Account for best clusters
    - Per event, select hcal cluster which minimizes Θ_{pq} of elastic hadron with loose coin cut
  - Expected number of elastics from W^2
    - Populate *"full"* histogram with acceptance matching cut only
    - Get *"pure"* elastic sample from cuts on both arms (shape only, elastic cuts)
    - Fit *"total"* histogram to scaled elastic sample and polynomial for background
    - Subtract background from *"full"* histogram to obtain *expected* elastics
  - Detected elastics from W^2 with harm anticut
    - Populate *"anticut"* histogram with acceptance matching cut and HCal dx/dy anticuts
    - Follow red steps above to extract *missed* elastics
    - Detected elastics: *expected* - *missed*
  - **HCal Detection Efficiency: Detected / Expected**

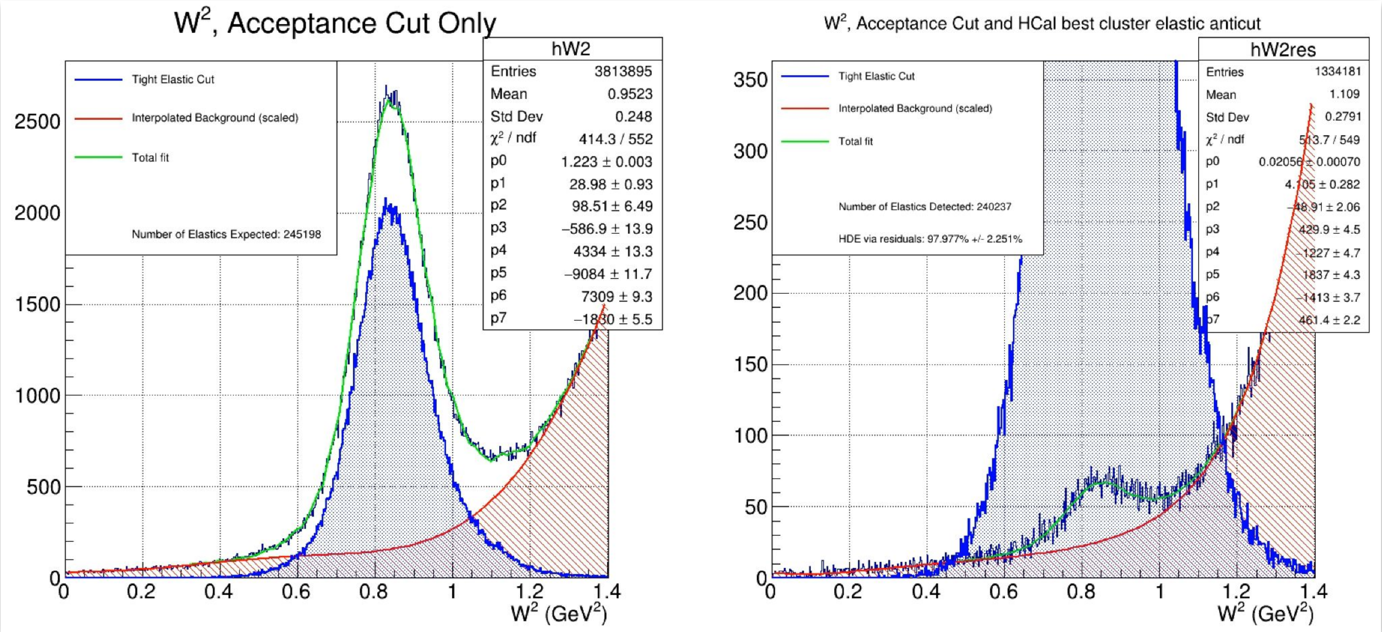


Shape Elastic Cuts

Subsystem	Type	Cut
BigBite	Acceptance	x/y expected HCal active area
BBCal	Preshower Energy	>200 MeV
Tracking	Number Tracks	1
GEMs	Hits	>3 planes
BBCal	Total E	>1.7 GeV
HCal	ADC Time	$<5\sigma$
Physics	θ_{pq}	<0.4 rad
HCal	dy	$<3\sigma$

Proton Detection Efficiency

- HCal Detection Efficiency (HDE) with anti-cut method: 98%
- MC expected: 94%



Detection Efficiency: dx Direct Method

- Methodology
  - Consider again LH2, SBS 4
  - Account for best HCal clusters
    - Per event, select hcal cluster which minimizes Θ_{pq} of elastic hadron with loose coin cut
  - Expected number of elastics from W^2
    - Populate *"full"* histogram with acceptance matching cut only
    - Get *"pure"* elastic sample from cuts on both arms (shape only, elastic cuts)
    - Fit *"total"* histogram to scaled elastic sample and polynomial for background
    - Subtract background from *"full"* histogram to obtain *expected* elastics
  - Detected elastics from dx with elastic cuts
    - Populate *dx* histogram with same elastic cuts, minimum HCal energy cut, and cluster selection
    - Follow red steps above with dx histogram to extract *detected* elastics
  - **HCal Detection Efficiency: Detected / Expected**

Shape Elastic Cuts

Subsystem	Type	Cut
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BBCal	Preshower Energy	>200 MeV
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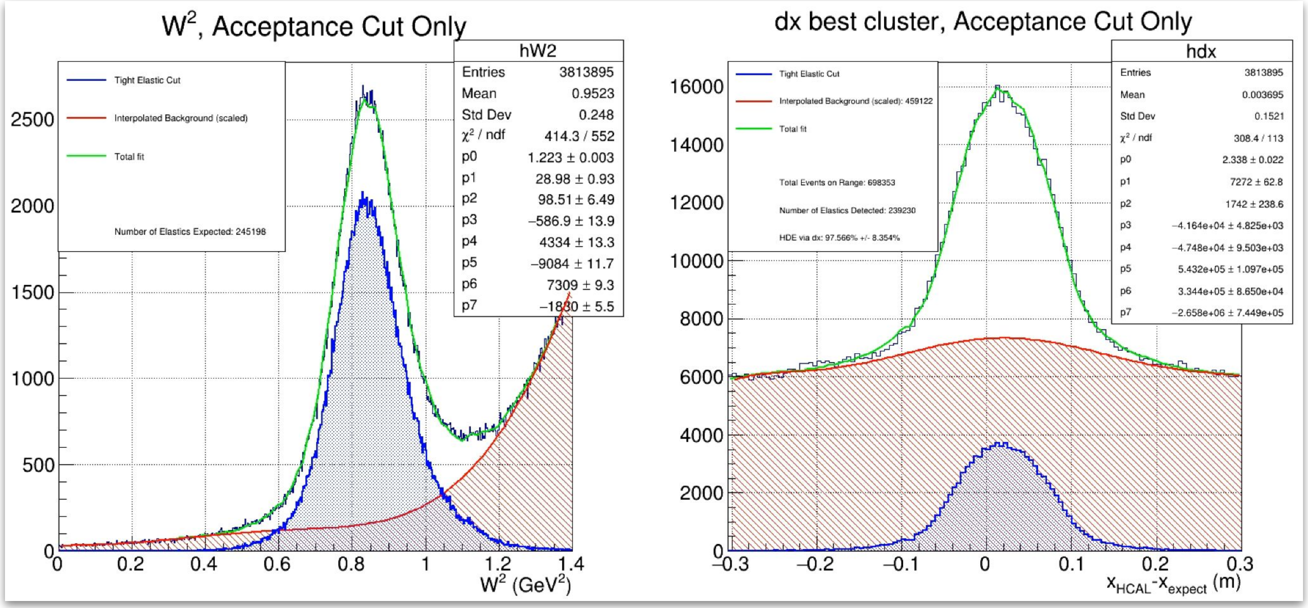
BBCal	Total E	>1.7 GeV
HCal	ADC Time	$<5\sigma$
Physics	θ_{pq}	<0.4 rad
HCal	dy	$<3\sigma$

Proton Detection Efficiency

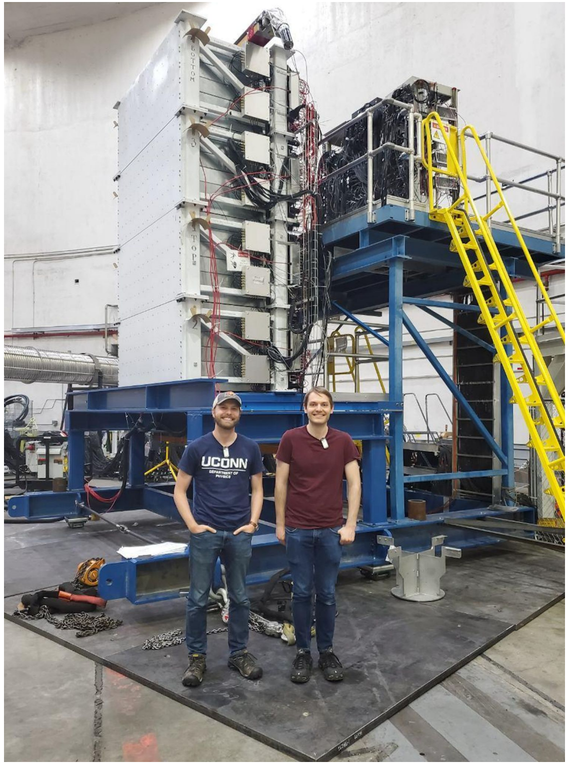
- HCal Detection Efficiency (HDE) with dx-direct method: 98%
- MC expected: 94%
- *Testing robustness of result with other analyses, other kinematics, and systematic studies on cluster selection*



Current Work

- GMn extraction
  - Implementation of new SBS field corrections and RC
  - Systematic studies on cut variables
- nTPE extraction and uncertainty estimation
- HCal Documentation / NIM paper
- Thesis!
  - Aim to graduate in *December 2023*

Document	Description	Estimate
HCal NIM	Research paper detailing the design, construction, commissioning, calibration, and performance of HCal	50%
HCal Instructions	General HCal document containing technical software and hardware information	-
HCal Calibration Instructions	Documentation of current calibration software, calibration theory, and use instructions	90%
HCal Calibration Results	Pass 2 calibration results and quality checks	80%
HCal GMn Change Record	Record of all hardware changes during GMn commissioning and experiment	100%
HCal GEn Change Record	Record of all hardware changes between GMn and GEn and during GEn commissioning and experiment	10%
Thesis Proposal	Proposed thesis topic, theory, milestones, and timeline	100%
Thesis	Dissertation including HCal commissioning/calibration, MC results/expectations, and preliminary GMn/nTPE results	30%



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Current Work

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- HCal Documentation / NIM paper
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Questions?

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HCal Calibration Instructions	Documentation of current calibration software, calibration theory, and use instructions	90%
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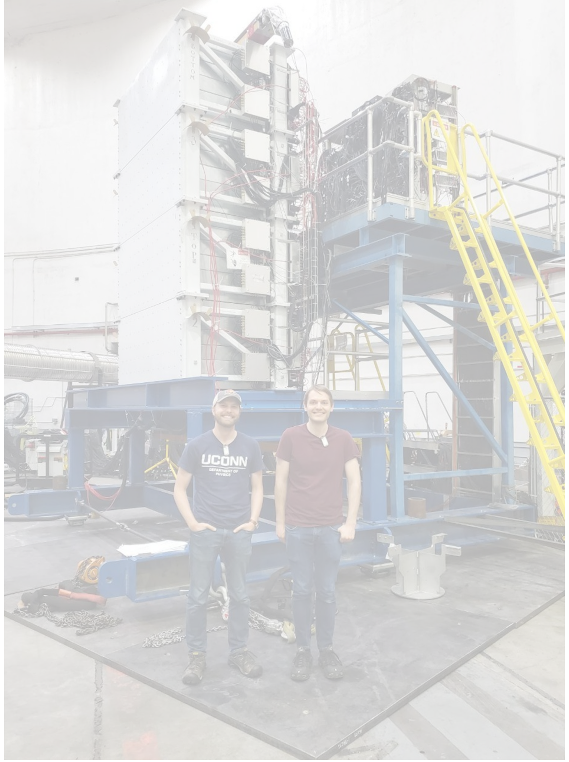

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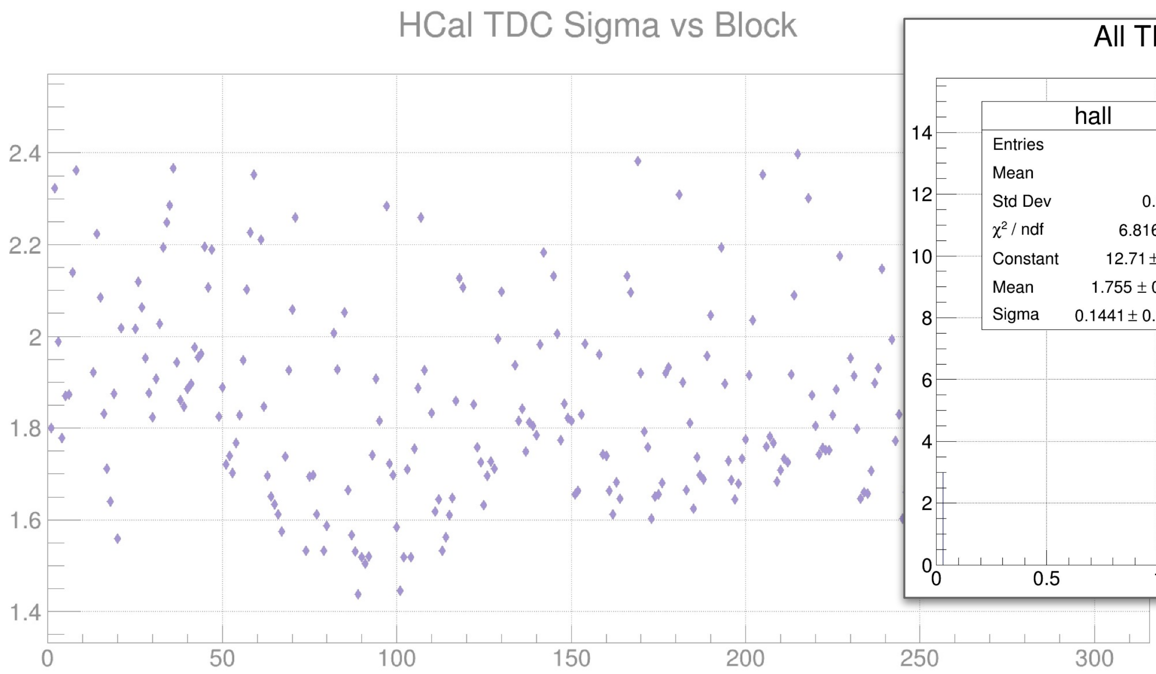
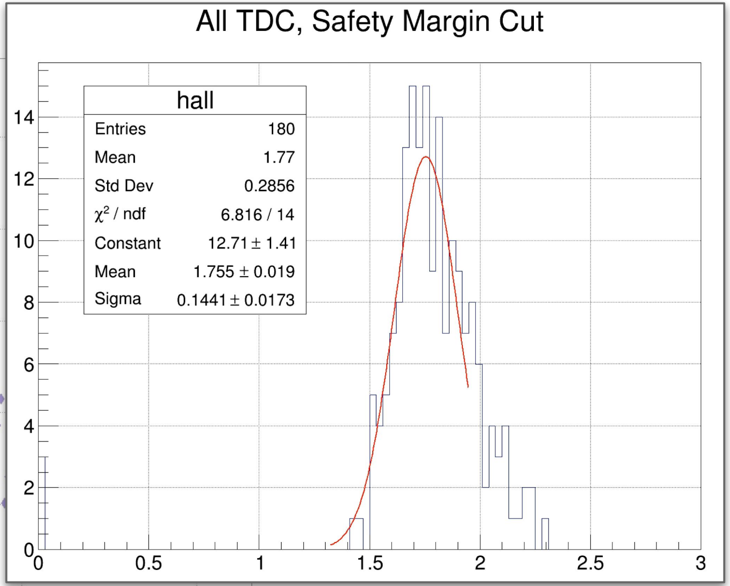
Backup - TDC over all blocks

- All data from SBS8, primary block in cluster, block 161 (center of acceptance)



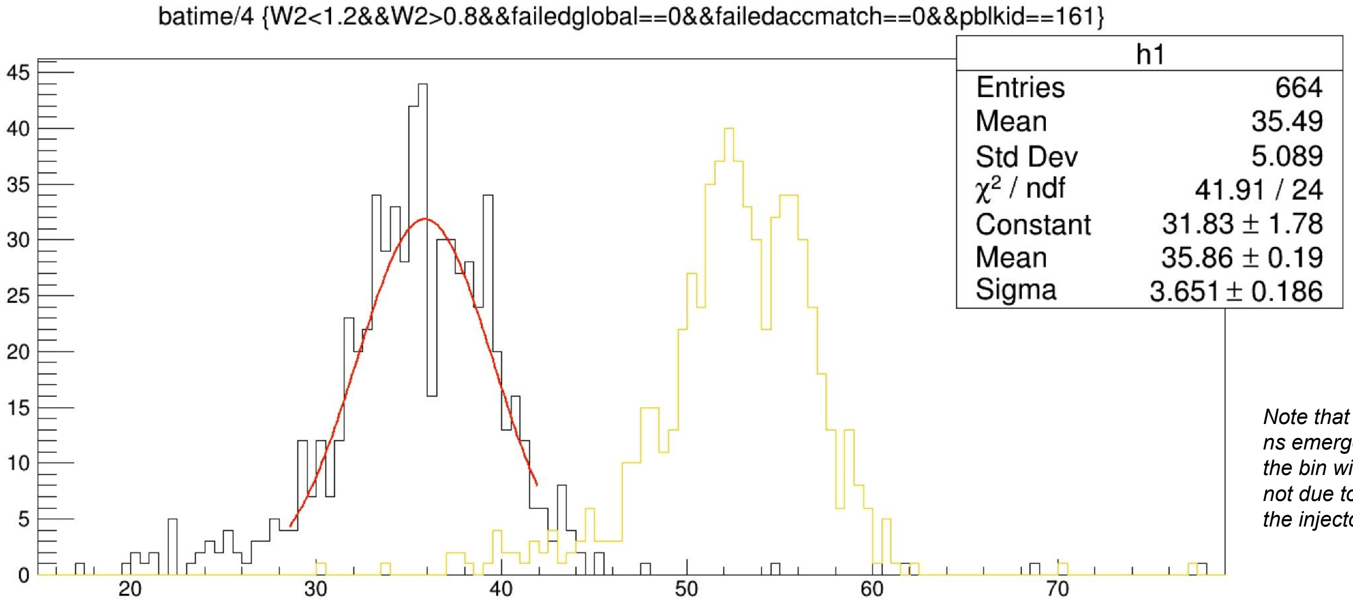


HCal ADC time: Performance of various fits to waveforms (continued)

From these results, the following steps were taken:

- Gaussian Landau convolution fits are removed. After tuning FFT points with SetNofPointsFFT() to attempt to improve processing time, no acceptable limit is possible with sufficient data. Other, more efficient methods to return a convolution fit may exist.
- Threshold methods to obtain rising edge are effective and should be more accurate than methods that rely on the spread in the data and are thus dependent on the amplitude of the signal.
- Where both landau (L) and skewed gaussian (SG) rising edge values exist, alternative atime (AAt) over analyzed data is the rising edge from either L or SG is added to output tree for comparison with current tree atime.
- If neither L or SG rising edge can be obtained, AAt defaults to current tree atime (with **batime** in black).

The following plots are over three runs (11589, 11590, 11592) from SBS4 LH2 data (block 161, wide elastic cuts) with no further corrections (hodo, ToF, etc.) applied. The fit is applied to **batime**. No substantial improvement is observed on **batime** (or independent landau and skewed gaussian distributions as compared to atime).



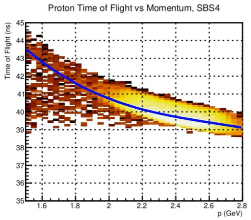
Note that the appearance of a 4 ns emergent structure is due to the bin width of ADC waveforms, not due to the RF structure from the injector.

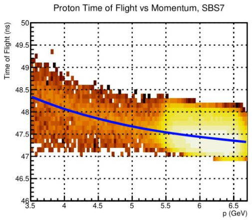
Backup - HCal Specifications

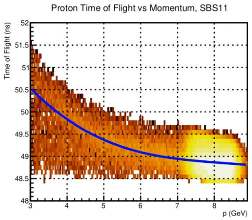
Hardware	Purpose	Specification
Module	Facilitate hadron showers, provide segmentation for position	40 layers alternating steel/scintillator, 1 WLS, 1 custom light guide, 1 PMT (15cm x 15cm x 1m)
Scintillator	Transduce hadron KE to gamma	PPO 2,5-Diphenyloxazole: fluor, peak 385nm
Wavelength Shifter (WLS)	Shift gamma to PMT peak detection efficiency	St. Gobain BC-484: 3ns decay; peak abs. 375nm; peak emi. 484nm
PMT	Transduce gamma to signal	192 12-stage "CMU" Photonis XP2262, 96 8-stage "JLAB" Photonis XP2282 (center third columns)
ADC	Analog-to-digital conversion (per module)	fADC250: 2V dynamic range; 250 MHz (4 ns bins)
TDC	Time-to-digital conversion (per module)	F1TDC: Multi-hit; 800 ns dynamic range

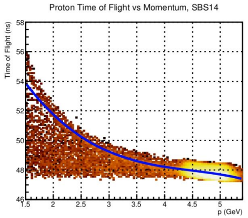
Backup - TOF fits over all kinematics

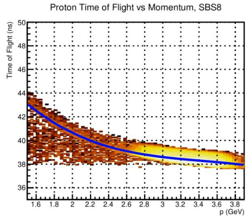
- Polynomial order 3 fits to MC time-of-flight vs nucleon momentum

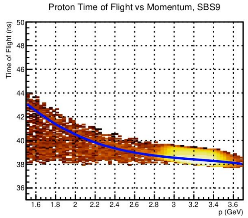


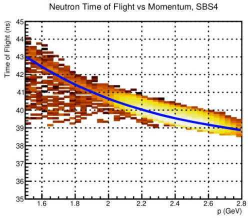


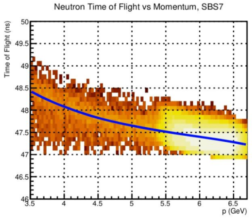


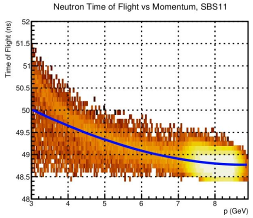


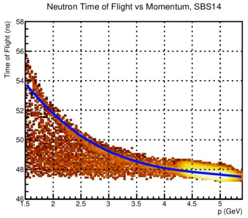


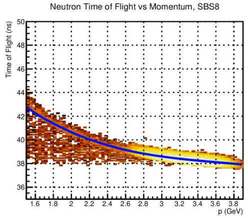


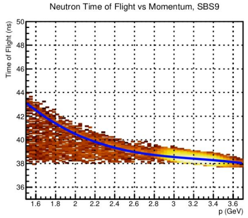








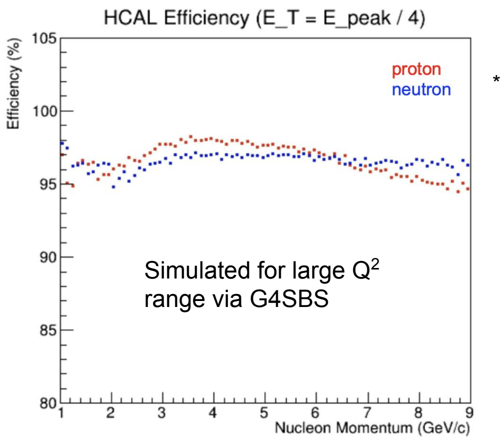


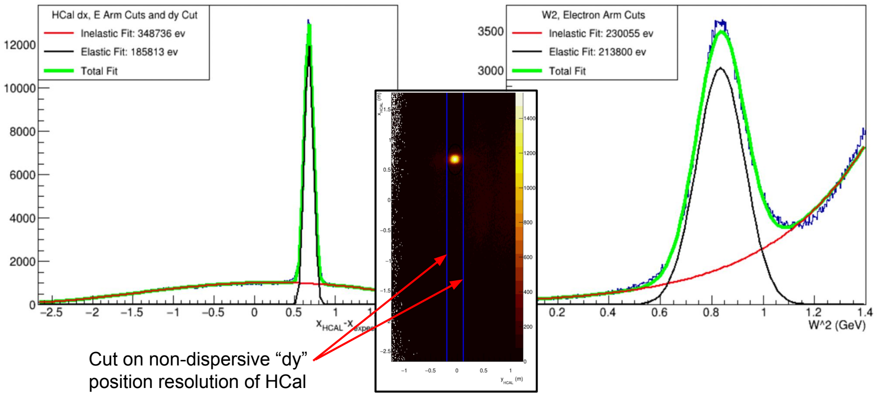


Backup - HDE simple fits

- Simulate *expected* efficiencies
  - Threshold: E_peak/4
  - Complete for all kinematics
- Proton (LH2 target)
  - Extract expected elastics using e' track cuts and HCal active area cuts only
  - Extract detected elastics from HCal dispersive delta plot "dx" fits
  - Ratio detected/expected is *observed* eff.
    - 95.3%
- We will check these results against the MC detection efficiencies for $f_{corrected}$

$$eff. = \frac{N_{ev\_over\_threshold}}{N_{ev}}$$





*plot credit: Provakar Datta, GMn Analysis Meeting Slides 11.18.22