The Neutral Particle Spectrometer (NPS) at JLab : RG-1a

Mongi Dlamini,
on behalf of the NPS collaboration

UNIVERSITY OF ESWATINI

NPS Collaboration and Sponsors

Talented graduate students (alphabetical order):

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W. Hamdi (U. of Tunisia)
H. Huang (U. Paris-Saclay)
M. Keryer (ODU)
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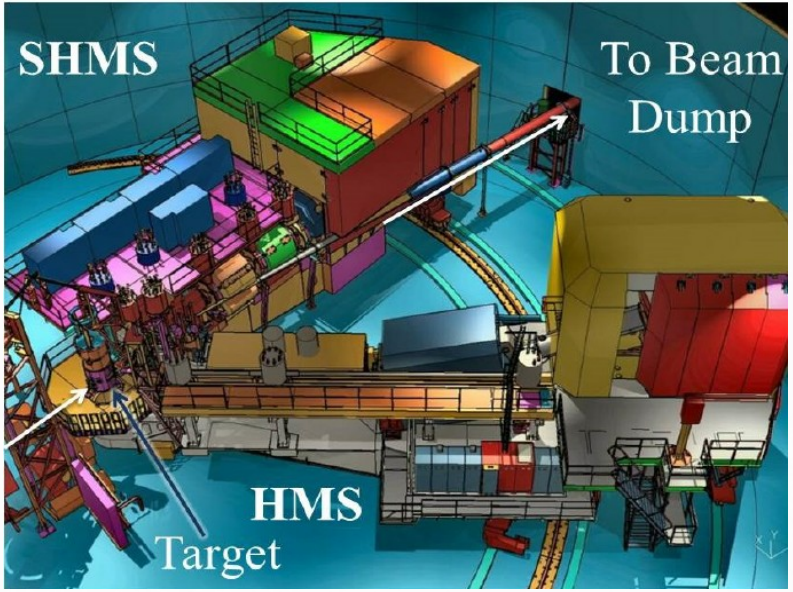
C. Ploen (ODU)
A. Singh (CUA)
T.H Song (Kyungpook Nat. U.)
Y. Zhang (Tsinghua U.)

Hall C and the Neutral Particle Spectrometer

- **HALL C:**
  - Is for precision measurements
  - High luminosity ~ 8 x 10^{37}/(cm^2s)
  - Small angle, precision cross-sections, L/T separation

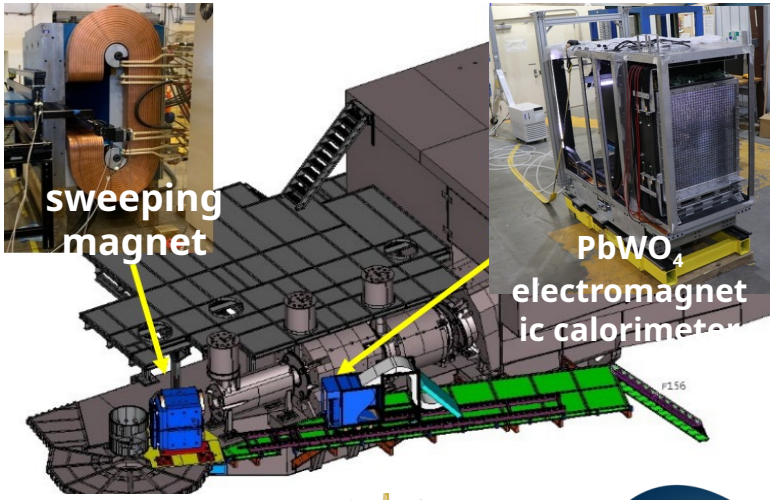
- **NPS:**
  - Electromagnetic calorimeter installed on SHMS rail in Hall C
  - NPS designed for precision cross-section measurements of neutral particles (π^0 and γ) in coincidence with the well understood HMS infrastructure
  - Angular range (production): 9.0 – 20.6 degrees

Targets:
- LH2
- LD2



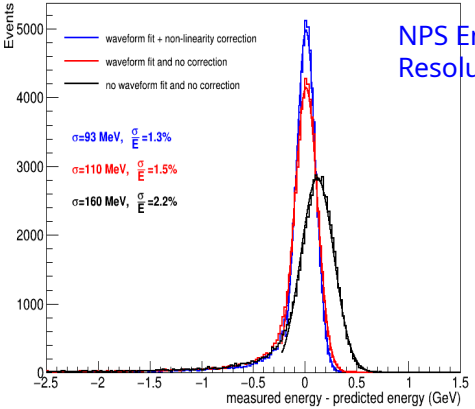
HMS:
- Detection of scattered e^- (or proton – during NPS calibration)
- Excellent momentum resolution ~0.1%
- Wide momentum range: 0.5 – 7.5 GeV/c

Performance of The Neutral Particle Spectrometer



- NPS is a new instrument at JLab Hall C built with support from NSF MRI PHY1530874
- The NPS calorimeter consists of 1080 PbWO4 crystals, the preferred material for high-resolution calorimetry, also at EIC – NPS has the largest set of PbWO4 crystals in an operating calorimeter in the US
- The NPS Science Program consists of ten approved experiments
- **4** experiments have been running in parallel from Sept 2023 to May 2024 (training 12 grad/undergrad students)

- 1080 $PbWO_4$ crystals
- 0.6 Tm sweeping magnet
- F250ADC sampling electronics
- Large opening angle beam pipe
- SHMS as a carriage for rotation



All channels perform well at very high luminosity on LH2 and LD2(≈ $8x10^{37}$ cm^2/s).

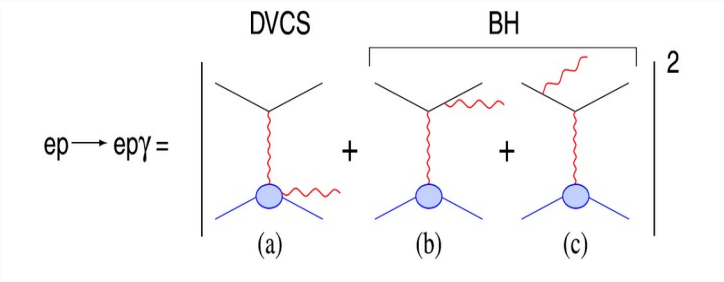
The expected resolution energy resolution was achieved (1.3% at 7.3 GeV).

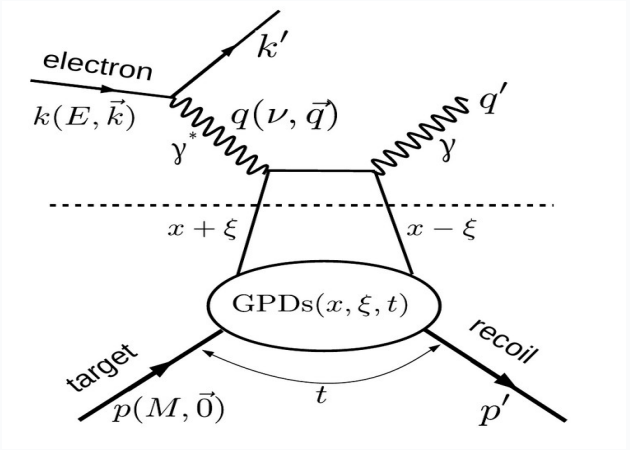
Small Angle Program of NPS : September 2023 – May 2024 (RG-1a)

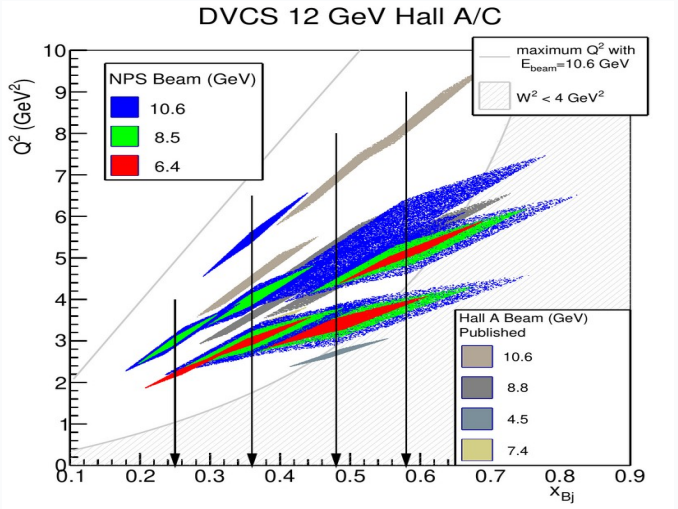
- Deeply Virtual Compton Scattering (DVCS) off the proton
- DVCS off the neutron
- Deeply Virtual Meson Production (DVMP) with π^0
- Semi-Inclusive Deep Inelastic Scattering (SIDIS) with π^0

E12-13-010: DVCS/DVMP & Nucleon Structure

- **DVCS Cross-Sections**
- E12-13-010 DVCS measurements complementary to DVCS in Hall A - extension of phase space
- Scaling of Compton Form Factor
- Measurement at different beam energies for Rosenbluth separation of DVCS cross-section:
  - $\sigma(ep \to ep\gamma) = |BH|^2 + Re[DVCS^{\dagger} BH] + |DVCS|^2$

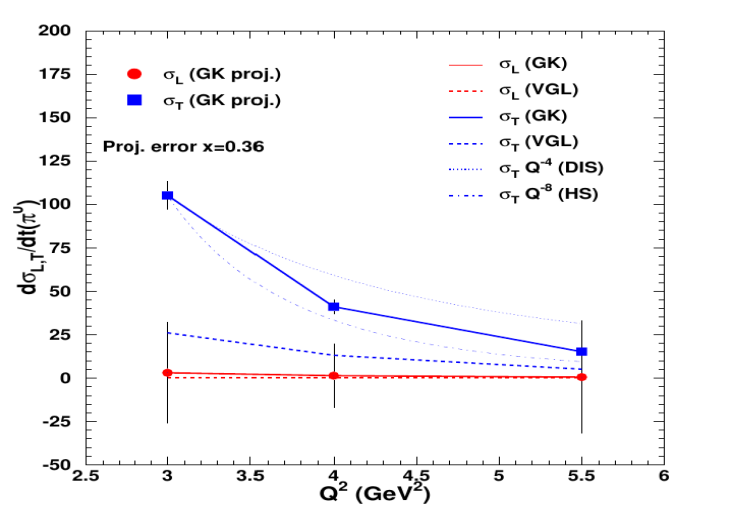


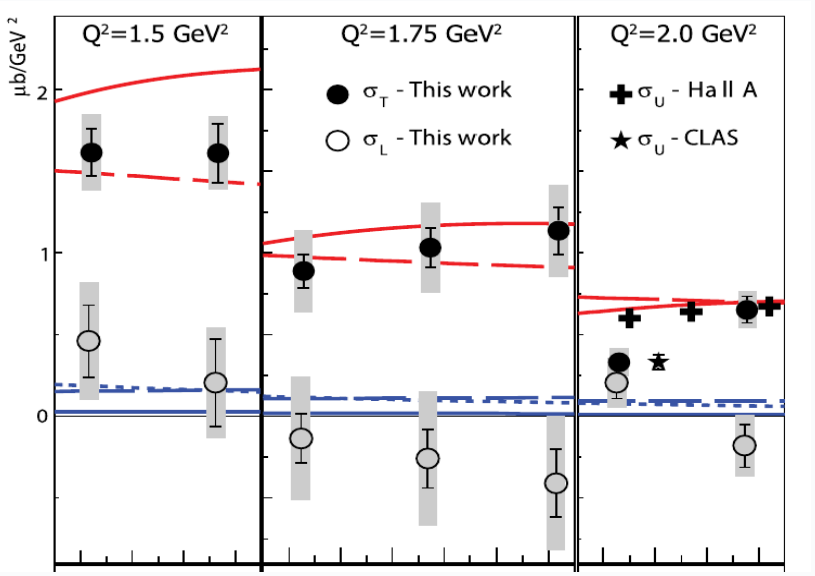




E12-13-010/E12-22-006: DVCS/DVMP & Nucleon Structure

- **π^0 Exclusive Cross-Sections:**
- 6 GeV results from Hall A suggest a non-zero σ_T up to $Q^2 \sim 2GeV^2$ => perturbative QCD regime hasn't been reached
- L/T contribution to π^0 cross-section important to access transversity GPDs
- Need to also test 12 GeV projections which confirm the Q^2 – σ_T dependence

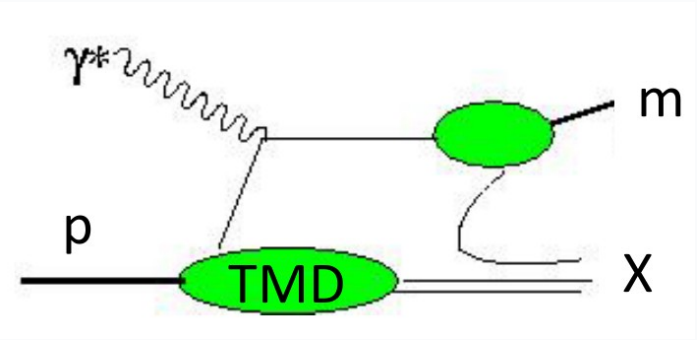




M. Defurne et al, PRL 117 (2016)

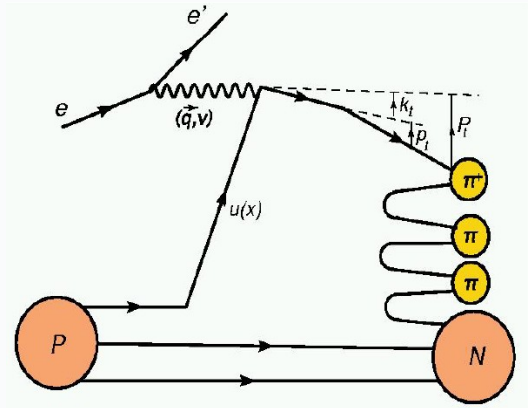
- **DVCS off the Neutron:**
- To probe flavor dependence of GPDs with precision DVCS off the neutron measurements by using an LD_2 target
- Azimuthal, beam, and helicity dependence of cross-section
- Improved separation of nDVCS and dDVCS

E12-13-007: SIDIS Basic (e,e',π^0) cross sections



- SIDIS cross sections depend on the transverse momentum of the hadron, hence linked to the Transverse Momentum Dependent Parton Distributions framework
- Arises from intrinsic transverse momentum of struck parton (k_t) and the transverse momentum (P_t) of fragmentation process

- π^0's are a good test for validation of factorization theorem



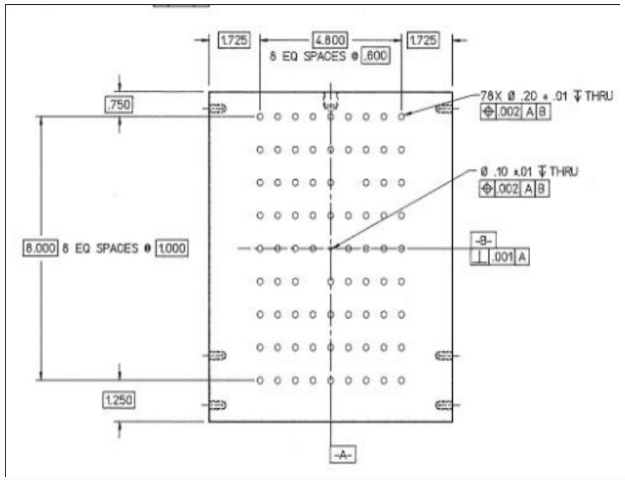
E12-13-007 goal: Measure SIDIS cross sections of π^0 production the proton & Map P_T dependence to validate flavor decomposition and the K_T dependence of up and down quarks.

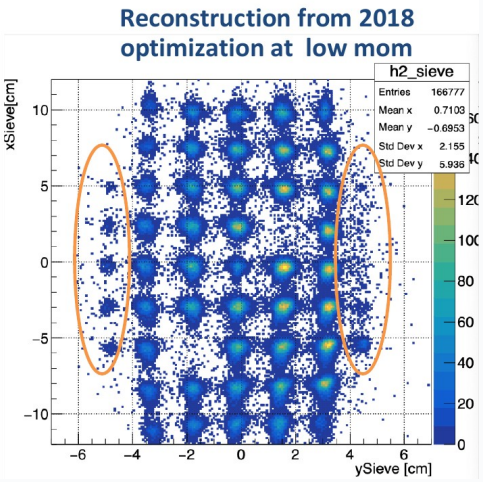
Why π^0 channel instead of $\pi^{+/-}$?:

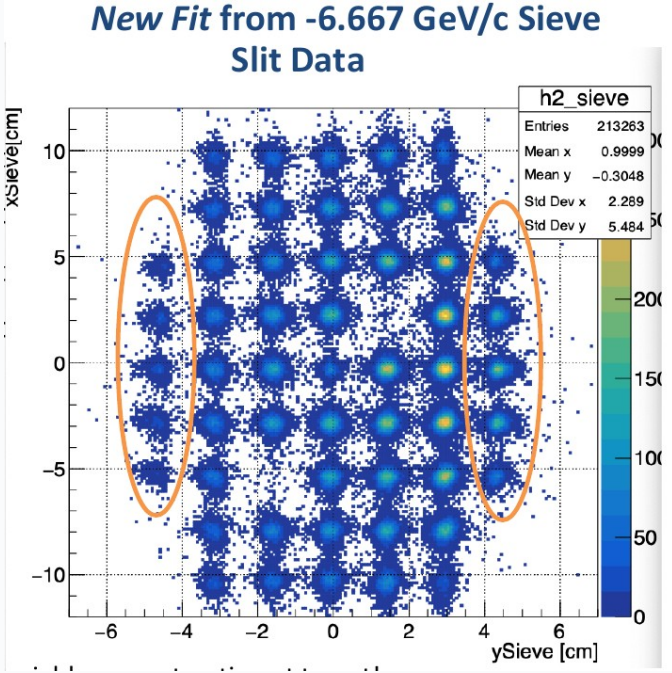
- No diffractive ρ and pole contributions
- Reduced resonance contributions
- Proportional to fragmentation function D

HMS Optics Reconstruction

- For high HMS momentum (>5.6 GeV) we need to accurately reconstruct position variables at the target from the focal plane variables: $(x_{fp}, x'_{fp}, y_{fp}, y'_{fp}) \rightarrow (x'_{targ}, y_{targ}, y'_{targ})$





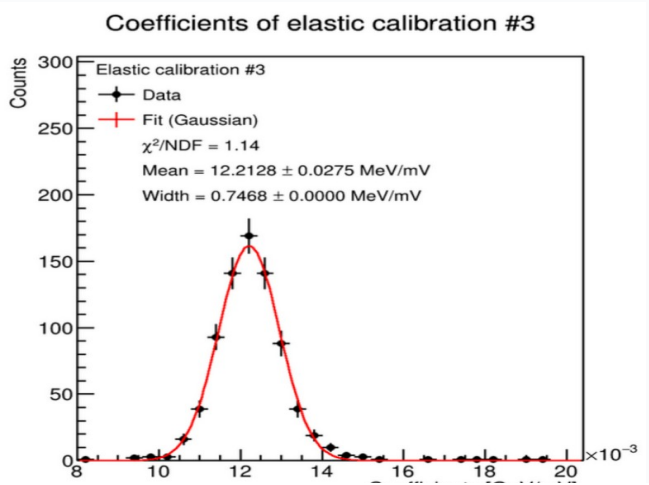


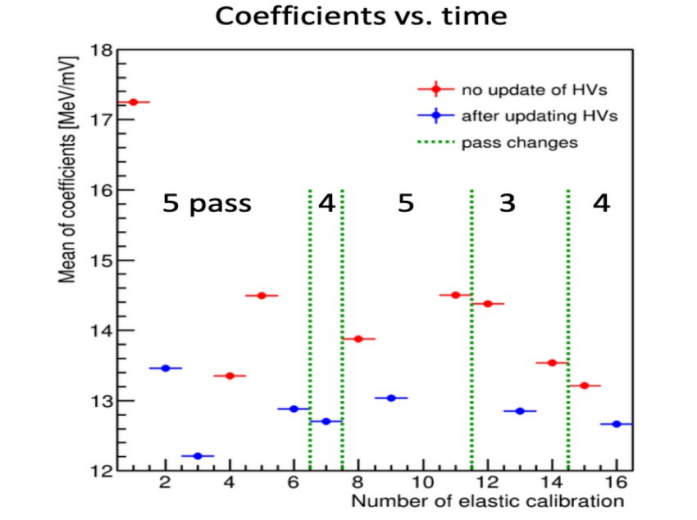
Credit: C. Ploen

NPS Elastic Calibrations

- HMS polarity switch to detect elastic protons
- NPS detects electrons – NPS sweep magnet off
- 3 NPS to cover the whole calorimeter at calibration
- PMT High Voltages adjusted based on coefficients obtained via χ^2 minimization

- 16 elastic calibrations performed
- Uniform in each PMT is important for better trigger on DVCS
- Elastic data also useful for optimizing waveforms … see waveform analysis slide

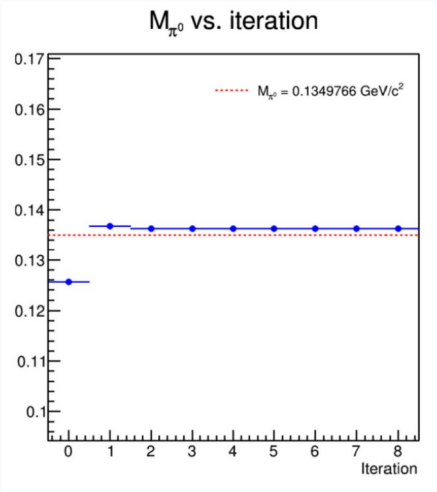


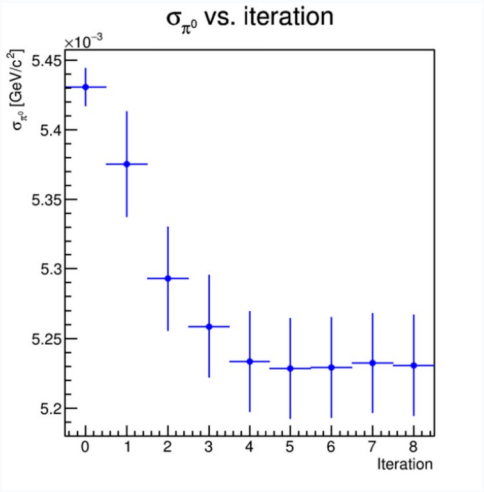


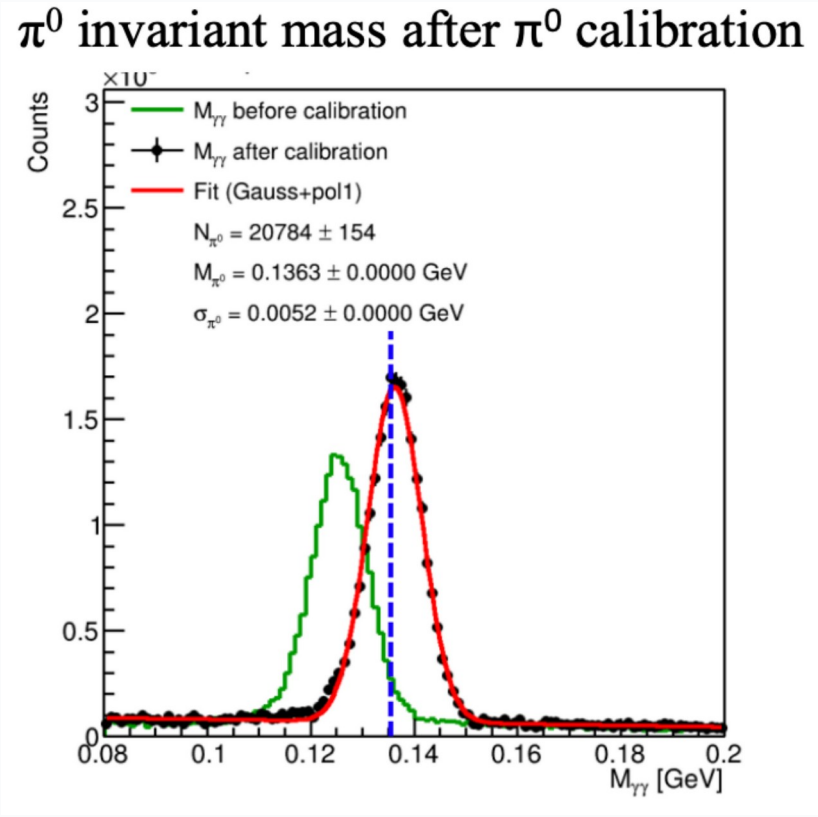
Credit: H. Huang

NPS Calibrations with π^0 Mass Measurement

- Reconstruction of π^0 mass via $\pi^0 \rightarrow \gamma\gamma$ channel
- Adjust gains for each crystal block after run period
- Analysis takes abou 5 iterations to stabilize

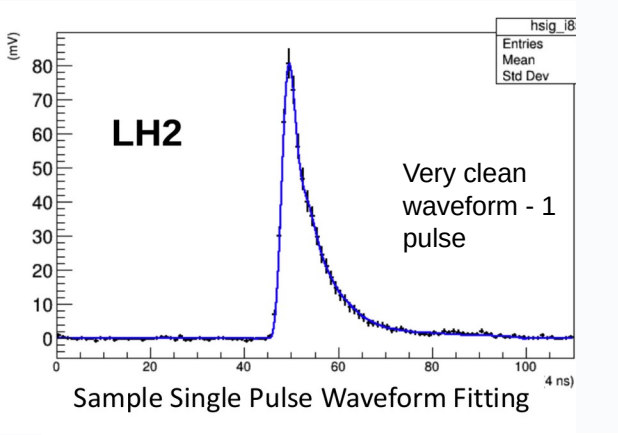




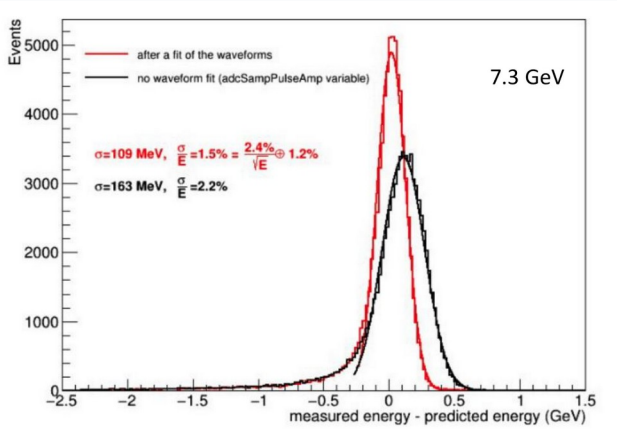


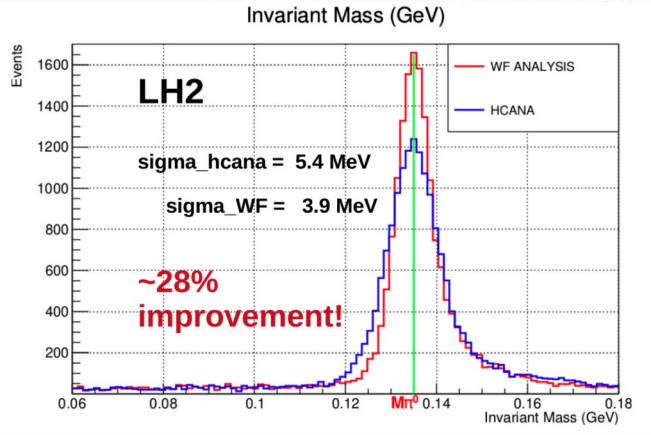
Credit: H. Huang

Preliminary Waveform Analysis

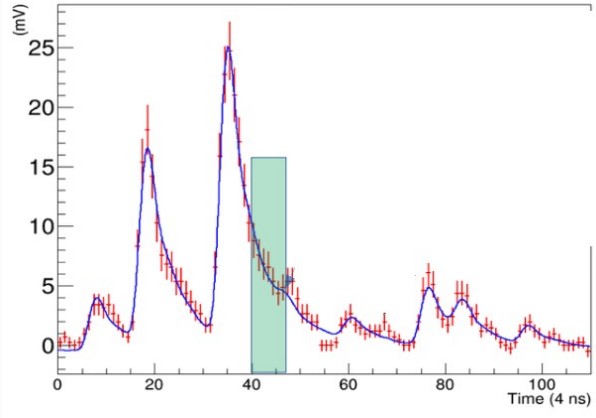


Sample Single Pulse Waveform Fitting





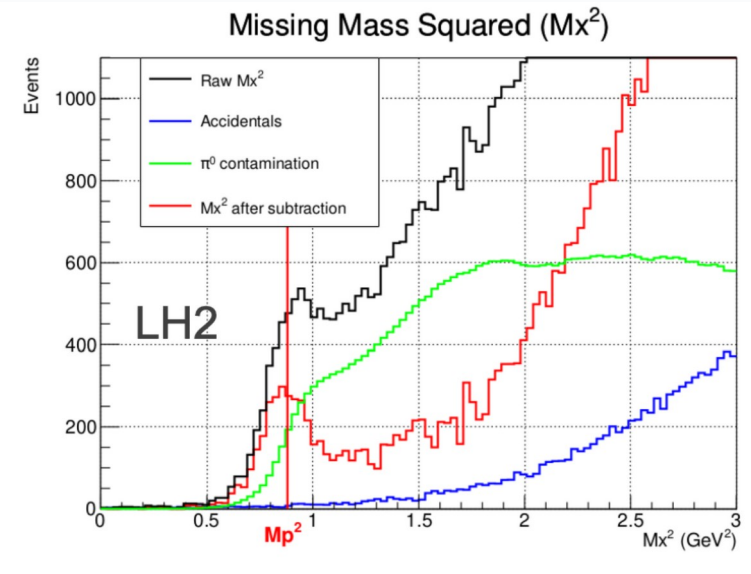
Credit: W. Hamdi

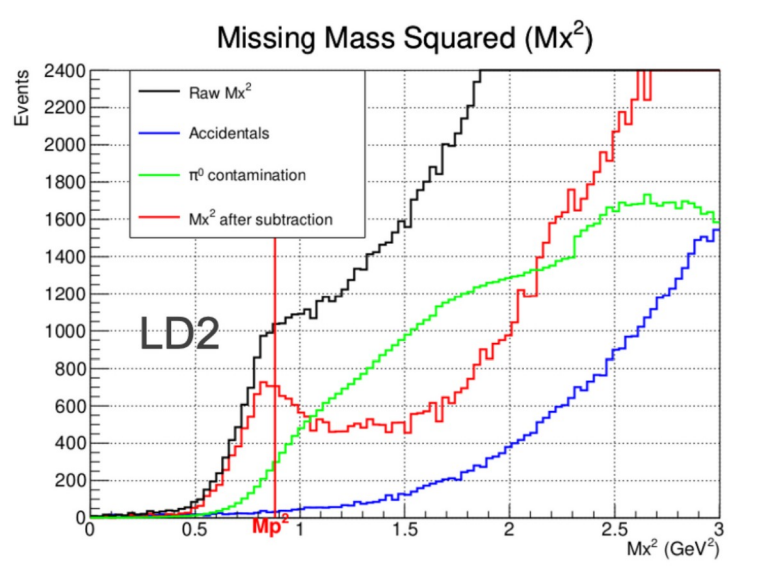


very busy waveform: 7 pulses

- Waveform analysis is vital for optimal calorimeter resolution
- Waveform fits extract pulse time and amplitude more accurately
- Reference pulses are created for each crystal, from elastic data
- Spline interpolation used between pulse samples and their reference shape to create fit function
- Waveform fitting of all data still work in progress

Preliminary Exclusivity Results - DVCS

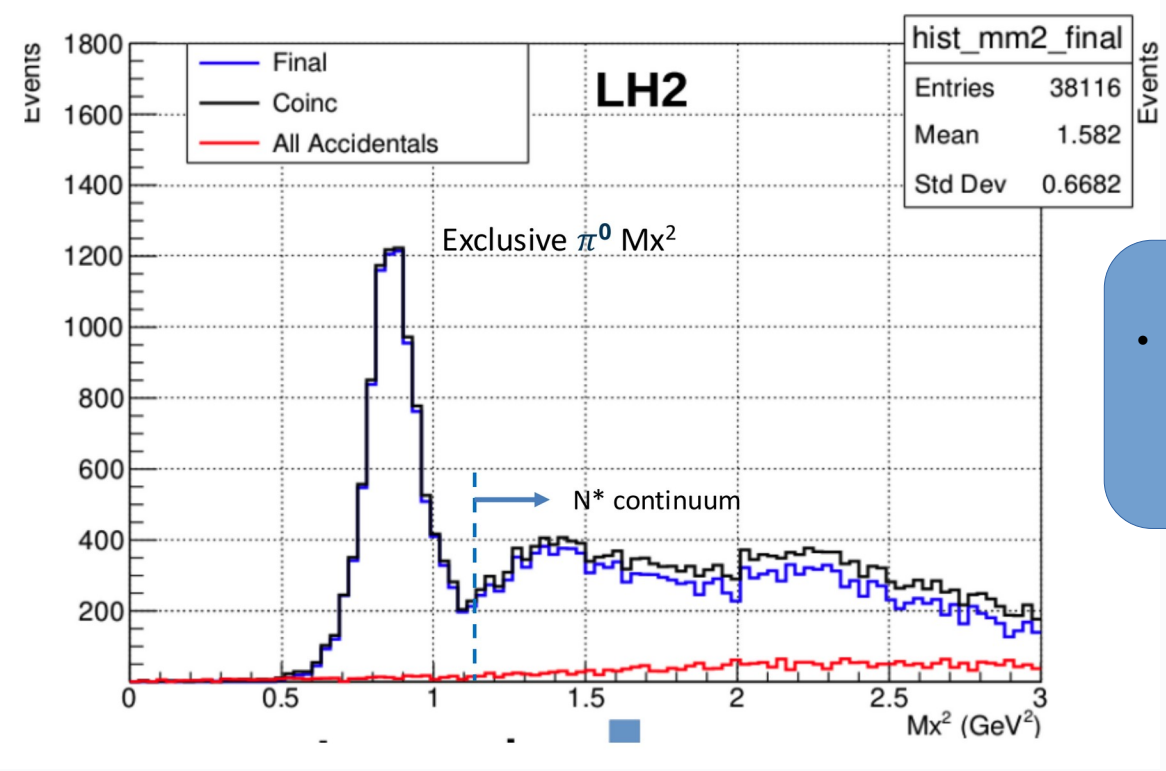




Credit: W. Hamdi

- DVCS events extracted from missing mass technique:
  - $M^2_x = (k+P-k'-q_\gamma)^2$
- Subtraction of contamination : π^0 and accidentals makes DVCS signal cleaner

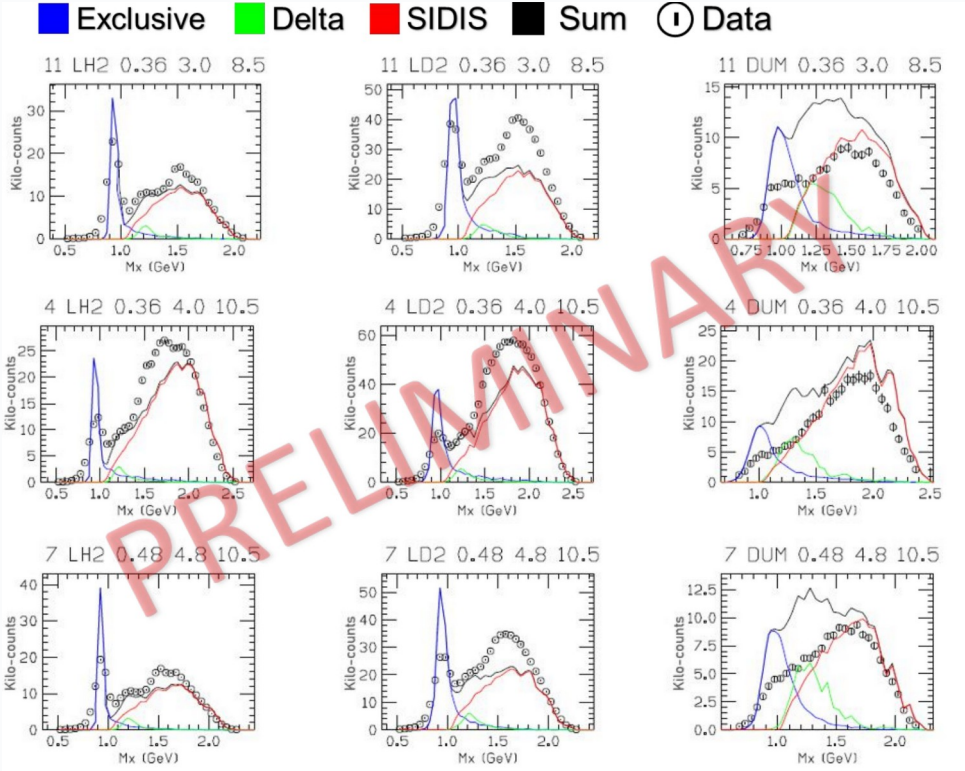
Preliminary Exclusivity Results - π^0



- *H(e,e'π⁰)p* exclusive channel extracted using missing mass technique:
  - $M^2_x = (k+P-k'-q_{\gamma\gamma})^2$

Credit: W. Hamdi

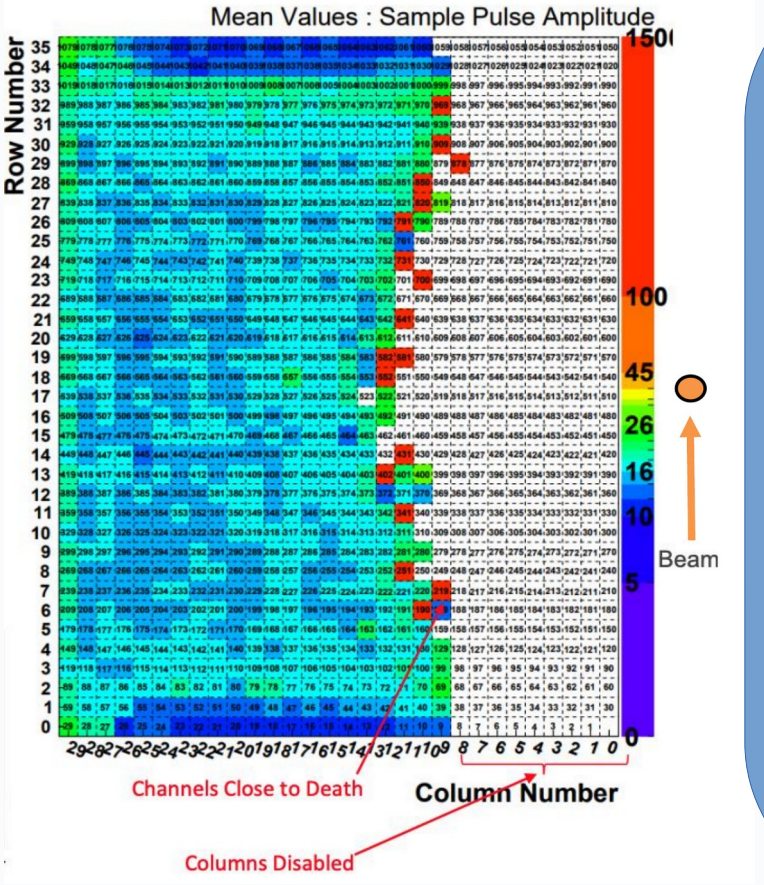
Preliminary π^0 Missing Mass – All Channels
Preliminary Exclusivity Results - π^0



- Sample π^0 missing mass statistics from 3 of 56 kinematics from the Pass-1 data analysis
- LH2, LD2, and dummy target
- Colored curves represent SIMC predictions with black curve representing the SIMC sum
- NPS Fiducial cuts were applied to both SIMC and data

Credit: P. Bosted

Run Period Challenges – Radiation Damage of Preamplifiers



Problem:

- Calorimeter channels became unstable and failed, especially starting with those closest to the beam
- Radiation damage in LV regulators on the pre-amplifier bases led to unstable LV power supply for the whole column

Solutions:

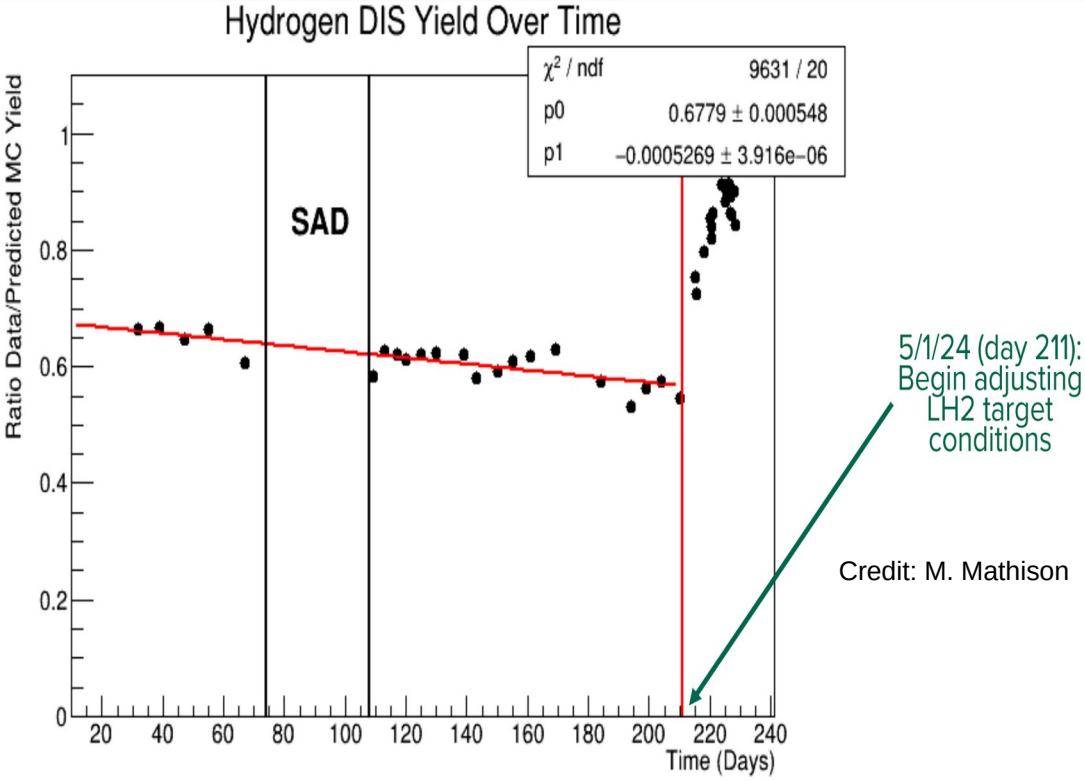
- Columns were disabled as they became unstable
- Bypassed the regulators in the pre-amps to refurbish the bases

Run Period Challenges - Problems with LH2 Target

- Validation of luminosity and HMS acceptance using the analysis of DIS yield shows huge discrepancy between simulation and data for LH2 target
  - **Hypotheses:**
- Unusual fan speed created bubbles?
- Helium (coolant) contamination

Interventions:

- Fan speed adjusted (from 58Hz to 42Hz)
- Replaced fan cooler
- Moved LH2 from loop 2 to loop 3
- Increased pressure in target loop (from 25psia to 40 psia)



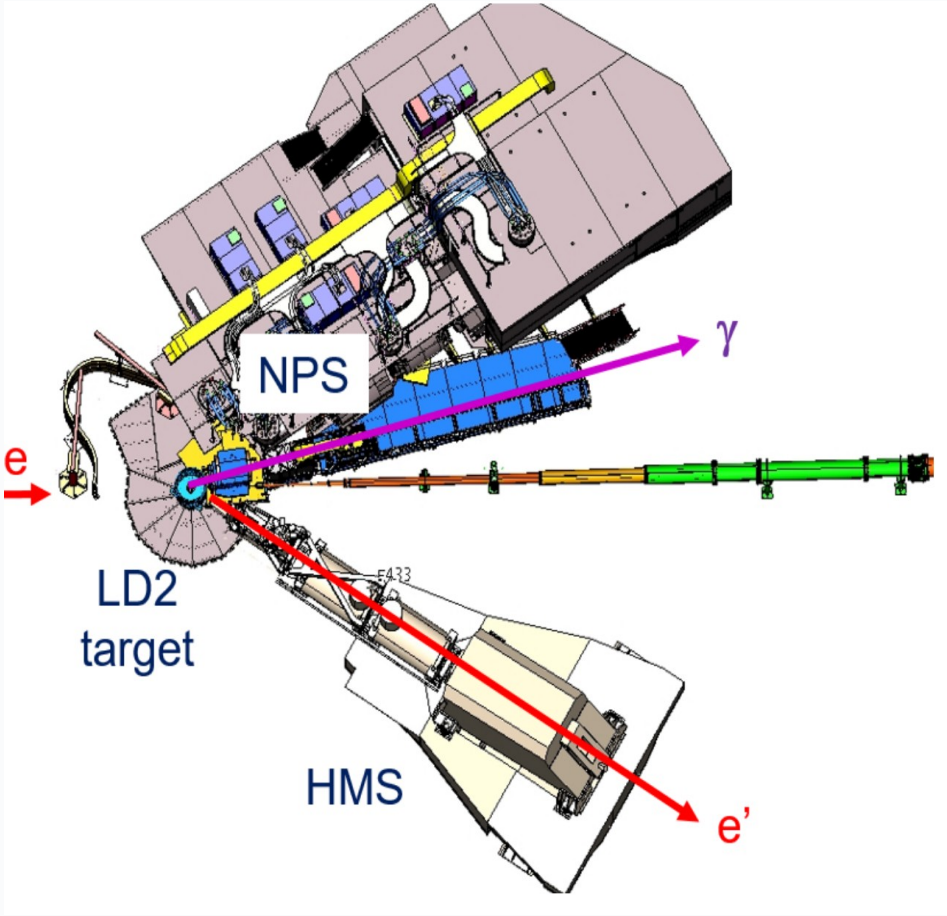
Simulations in development to help pin down and correct for the discrepancy in LH2 yield

Conclusion:

- NPS RG-1a experiments (September 2023 – May 2024) ran in Hall C of Jlab using NPS detector in coincidence with the hall's HMS to detect photons corresponding to both DVCS and π^0 electroproduction
- 16 elastic calibrations were performed and further calibration using π^0 measurement still ongoing
- Preliminary exclusive (missing mass) peaks have been extracted
- Currently starting to perform waveform fitting on the overall data
- NPS will return to the floor in future for more data and more experiments on studying nucleon structure

Thank you for your attention !!

DVCS off the Neutron : Recent Work



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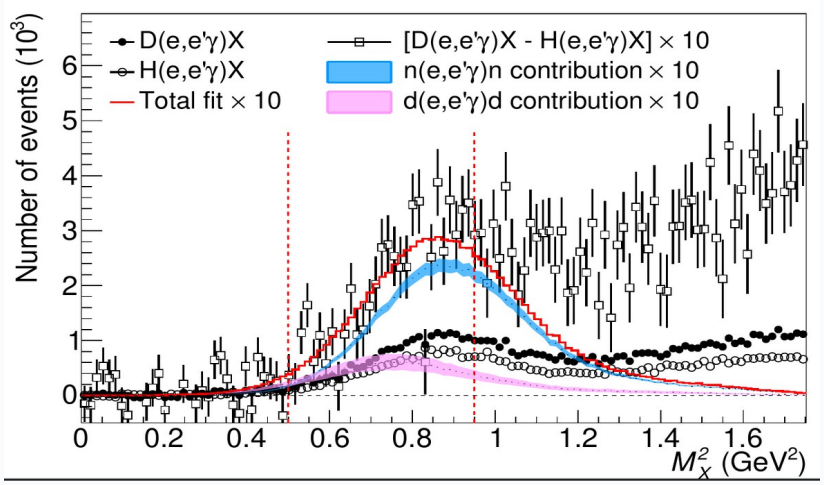

M. Benali et. al. Nature Phys. 16 (2020)