Imaging the Proton

Investigating Proton Structure with Electron Scattering

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CLAS12 Collaboration

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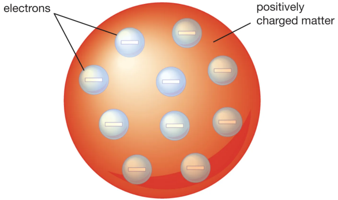
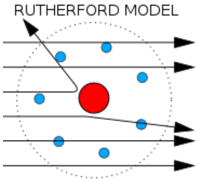
- ∼ **500 BCE: *Atomism***: From Greek *átomos* [uncuttable]: philosophical belief that the universe consists of indivisible units of matters (also present in ancient Indian philosophy) [Wikipedia:Atomism,Leucippus]
- ∼**1800s: Law of Multiple Proportions**: John Dalton: discovered that elements react and combine in small, integer ratios [Wikipedia:Atom]
- **1897: Plum Pudding Model**: J.J. Thomson: discovered *sub*atomic particles (originally called corpuscles, renamed to electrons) [Wikipedia:Plum Pudding Model]



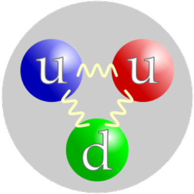
Thomson model of atom, with negatively charged electrons embedded in positively charged ball

[Britannica:Thomson Atomic Model]

- $\sim$ **1911: Discovery of the Nucleus** - Scattering α particles off gold foil yielded significant backscatter, indicating small, dense nucleus [Wikipedia:Geiger-Marsden]
- $\sim$ **1919: Discovery of the Proton** - Proposed by Rutherford after α particle scattering experiments off atoms [E. Rutherford doi:10.1080/14786431003659230]
- $\sim$**1961: Discovery of Quarks** - Electron scattering experiments provided evidence consistent with the proton being a composite object of point-like constituents



[Wikimedia:Geiger-Marsden Exp.]

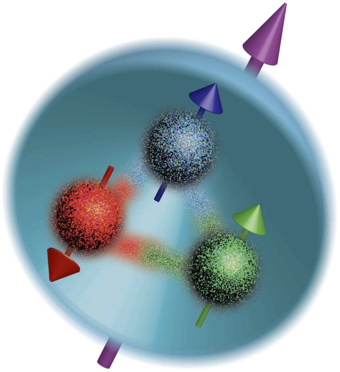


[Wikimedia:Proton Quark Structure]

Protons are:

- **Spin 1/2**
- **Stable**: mean lifetime $>$ 1E34 years
- **Lightweight**: 938.272088 MeV; lightest baryon

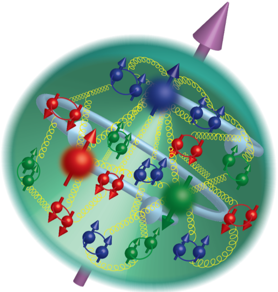
  [n.b. 1 eV = 1.8E-36 kg]
- **Small**: radius $\sim$ 0.85 fm
  - If protons were scaled to the size of pingpong balls, atoms would be $\sim$ 4 football fields across, humans would be $\sim$ diameter of the inner solar system



[EIC Whitepaper]

The Proton is **NOT** well-understood - Testbed for Physics

Macroscopic features are well measured, but many properties remain to be understood



[Argonne National Lab]

- **Proton Spin Crisis**: Where does the proton's spin come from? 1987 measurement showed valence quarks only contribute a small percent to overall proton spin
- **Proton Decay**: Popular Beyond-Standard-Model theories predict the proton to decay, but never has been observed
- **Proton Radius Puzzle**: (possibly resolved) discrepancy in proton charge radius between experimental methods

[Proton Puzzles, Nat Rev Phys, 2021]

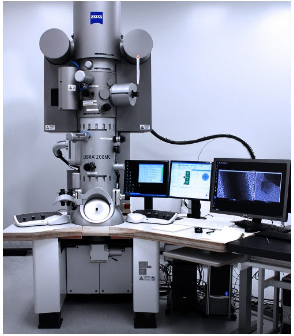
Imaging limited by diffraction ($\sim \frac{\lambda}{2}$) $\rightarrow$ scale set by $\lambda = \frac{hc}{pc}$ with hc = 1200 eV nm

Optical Microscope

3 eV $\rightarrow \lambda \sim$ 400 nm

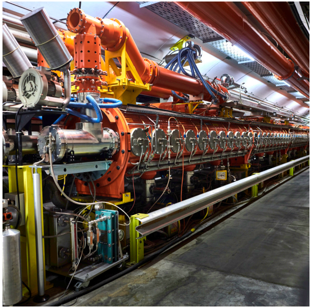
`[n.b. ex. mic for bio]`

Electron Microscope



10 keV $\rightarrow \lambda \sim$ 0.01 nm

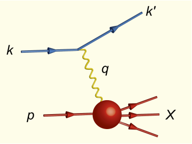
Electron Accelerator



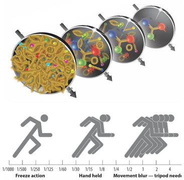
10 GeV $\rightarrow \lambda \sim$ 0.1 fm

Proton Structure must be Indirectly Imaged

Unlike optical imaging, must infer structure from reaction rates (cross sections) $\rightarrow$ structure encoded in various form factors and distribution functions

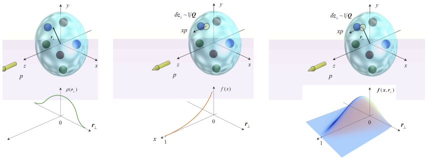


Shutter Speed



[R.G. Milner and R. Ent, Visualzing the Proton (2022)]

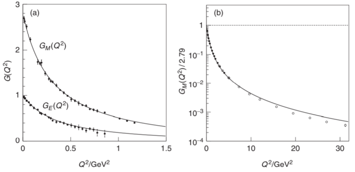
- Reactions of the form e + p $\rightarrow$ e + X
  - X = p: elastic scattering
  - X = X: inclusive scattering
  - X = p + π: DVπP (in proper kinematic regime)
- $\frac{1}{q}$ determines the spatial resolution
- $\frac{1}{x_B}$ determines the shutter speed



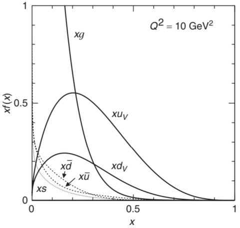
[A.V. Belitsky A.V. Radyushkin 2005]

GPDs Encode Proton 3D Structural Information

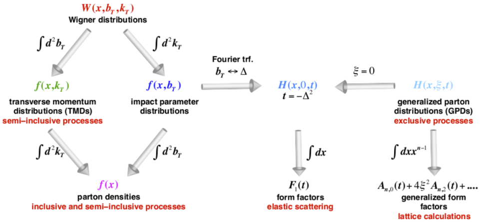
Proton Form Factors



Parton Distribution Functions



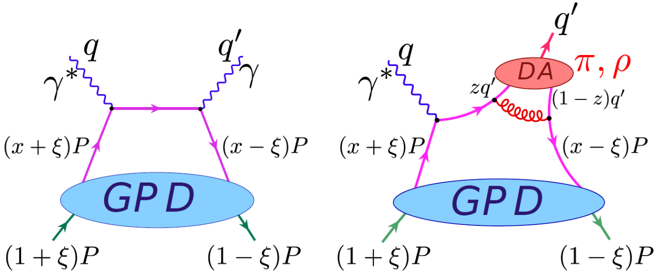
- All distribution functions related through limiting cases of Wigner distributions
- Quark and gluon Wigner distributions have no known direct physical observable
- Can experimentally access TMDs and GPDs



Relationships between different distribution functions

[EIC Whitepaper]

- Deeply Virtual Processe (DVCS, DVMP)s: target nucleon remains intact, DIS regime
- Relies on factorization between hard scattering and soft QCD vertices
- Factorization proved rigorously for DVCS in Bjorken limit, for DVMP with longitudinally polarized photons (sufficient if dominates)



DVCS (left) and DVMP Feynman Handbag diagrams

[V. Kubarovsky Nuc Phys B 2011]

GPD Encoding in $DV\pi^0P$ Cross Section is Nontrivial

The cross section for DVπ^0P can be expressed in terms of structure functions, which can be expressed as convolutions of GPDs:

$$\frac{d^4\sigma_{\gamma^* p\to p'\pi^0}}{dQ^2 dx_B dt d\phi_\pi} = \Gamma(Q^2, x_B, E)\frac{1}{2\pi}\left\{\left(\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt}\right) + \epsilon cos(2\phi)\frac{d\sigma_{TT}}{dt} + \sqrt{2\epsilon(1+\epsilon)}cos(\phi)\frac{d\sigma_{LT}}{dt}\right\} \quad | \quad \Gamma(Q^2, x_B, E) = \frac{\alpha}{8\pi}\frac{Q^2}{m_p^2 E^2}\frac{1-x_B}{x_B^3}\frac{1}{1-\epsilon}$$

The structure functions can be expressed in terms of GPDs:

$$\frac{d\sigma_L}{dt} = \frac{4\pi\alpha}{kQ^2}\left\{(1-\xi^2)\,|\langle\tilde{H}\rangle|^2 - 2\xi^2\Re\left[\langle\tilde{H}\rangle^*\langle\tilde{E}\rangle\right] - \frac{t'}{4m^2}\xi^2|\langle\tilde{E}\rangle|^2\right\}$$

$$\frac{d\sigma_T}{dt} = \frac{2\pi\alpha\mu_\pi^2}{kQ^4}\left\{(1-\xi^2)\,|\langle H_T\rangle|^2 - \frac{t'}{8m^2}|\langle\bar{E}_T\rangle|^2\right\}$$

$$\frac{d\sigma_{LT}}{dt} = \frac{4\pi\alpha\mu_\pi}{\sqrt{2}kQ^3}\xi\sqrt{1-\xi^2}\frac{\sqrt{-t'}}{2m}\Re\left\{\langle H_T\rangle^*\langle\tilde{E}\rangle\right\}$$

$$\frac{d\sigma_{TT}}{dt} = \frac{4\pi\alpha\mu_\pi^2}{kQ^4}\frac{-t'}{16m^2}\langle\bar{E}_T\rangle^2$$

GPD Classification:

Nucleon Polarization	Quark Polarization: U	L	T
U	H		$\bar{E}_T$
L		$\tilde{H}$	
T	E		H_T, $\tilde{H}_T$

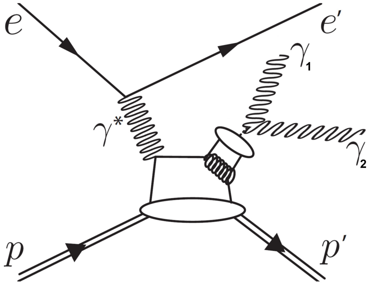
$\bar{E}_T = 2*\tilde{H}_T + E_T$

In contrast to DVCS, DVπ^0P allows access to chiral-odd GPDs, making it a distinct and valuable probe

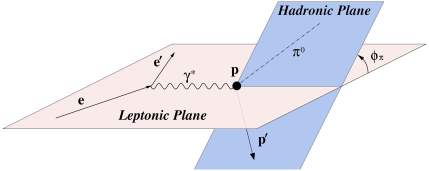
DVπ^0P: 4 particle final state, 4 Degrees of Freedom

Deeply Virtual π^0 Production
(DVπ^0P)

$$e + p \to$$
$$e' + p' + \pi^0 \to$$
$$e' + p' + \gamma_1 + \gamma_2$$



- 4-fold differential cross section $\frac{d\sigma}{dQ^2 dx_B dt d\phi}$ expressed in terms of:
  - Virtual photon 4-momentum: $Q^2 \equiv -(p_e - p_{e'})^2$
  - Bjorken x: $x_B \equiv \frac{Q^2}{2p_p \cdot (p_e - p_{e'})}$
  - Momentum transfer: -t $\equiv -(p_{p'} - p_p)^2$
  - Angle between lepton & hadron planes: ϕ = $\cos^{-1}\left(\frac{(p_e \times p_{e'}) \cdot (p_{p'} \times p_{\gamma*})}{\|p_e \times p_{e'}\| \, \|p_{p'} \times p_{\gamma*}\|}\right)$

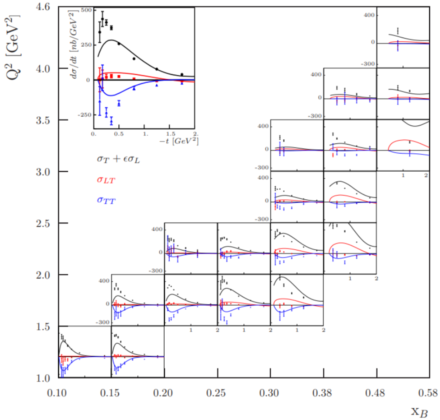


Images from S. Lee, A. Kim

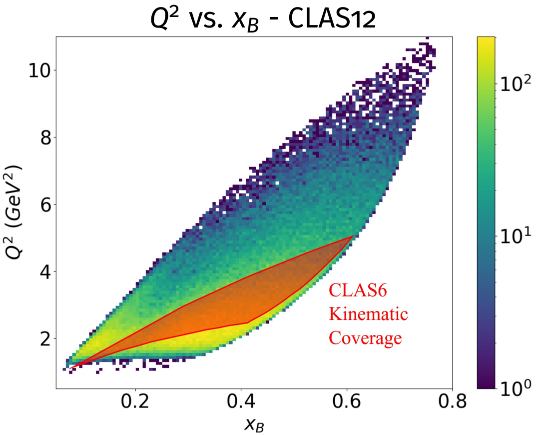
- In DIS regime: W$>$ 2GeV, Q^2> 1GeV^2

Analysis Goal: Extract DVπ^0P Cross Section

Extracting the cross section for the process will extend the CLAS6 work to a larger kinematic range with higher statistics



[I. Bedlinskiy et al., PRC, 90, 025205 (2014)]



The Path to Measurement has Many Steps

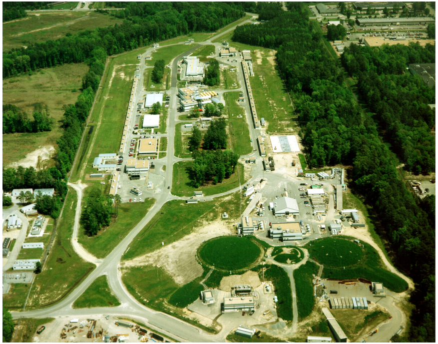
- **Design and Build Detectors**: 2006-2018
- **Take Data**: 2018 start, continuing
- **Process Data**: Reconstruct particle paths from detector signals
- **Analyze Data**: Event selection to find raw process rates
- **Correct Data**: Run simulations and apply correction factors
- **Extract Physics**: Calculate structure functions, deconvolve GPDS,

Detector construction - wire chamber stringing

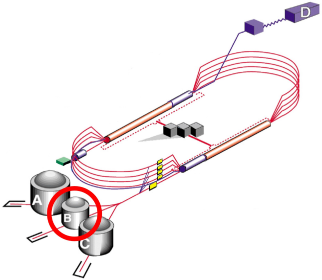
[V. Burkert et al., NIMA, 959, 163419 (2020)]

Jefferson Lab 10.6 GeV CEBAF Accelerator

Thomas Jefferson National Accelerator Facility - Newport News, VA



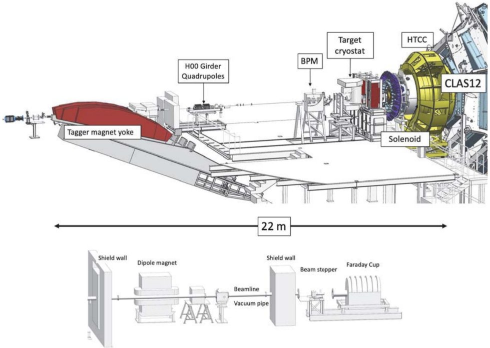
- Jefferson Lab aerial view [jlab.org]

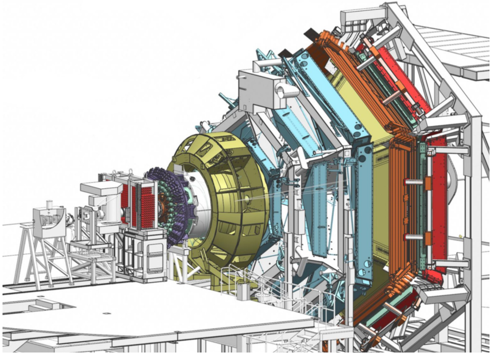


- CEBAF 1,400 m racetrack, 50 RF cryomodules
- 10.6 GeV, $\sim$ 50 nA electron beam

[V. Burkert et al., NIMA, 959, 163419 (2020)]

CLAS12 Detector at Jefferson Lab Hall B





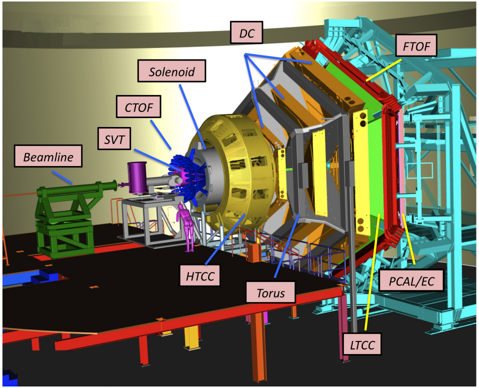
- Top: Beamline into unpolarized LH_2 target (cryostat)
- Bottom: Downstream beamline to Faraday Cup (current monitor)

- CEBAF Large Acceptance Spectrometer:
  - $\sim 2\pi$ coverage in ϕ
  - 5° - 125° coverage in θ
  - Full 4 particle final state reconstruction for this process

[V. Burkert et al., NIMA, 959, 163419 (2020)]

Experiment Layout And Particle Detection

- 6-fold symmetric Forward Detector ($\theta <\sim 40^\circ$) with torodial field
  - Cherenkov Counters
  - Drift Chambers
  - Time-of-Flight Detectors
  - EM Calorimeters
- Central Detector ($\sim 40^\circ < \theta <\sim 125^\circ$) inside solenoid
  - Silicon Vertex Tracker
  - Micromegas
  - ToF Detector
- Forward Tagger, Backward Angle Neutron Detector
- Faraday Cup for luminosity measurement



- This analysis examines data taken in Fall 2018

[V. Burkert et al., NIMA, 959, 163419 (2020)]

CROSS SECTION: COUNT EVENT RATE, INCLUDE CORRECTION FACTORS

Number of DVπ⁰P Events in Bin:

- Particle ID: CLAS common analysis
- Proton Momentum corrections from S. Lee
- Fall 2018 Outbending Dataset
- Exclusivity cuts applied to all candidate events (one proton, one electron, at least two photons)

$$\frac{d^4\sigma_{\gamma^* p \to p' \pi^0}}{dQ^2 dx_B dt d\phi_\pi} = \frac{N(Q^2, x_B, t, \phi_\pi)}{\mathcal{L}_{int} \Delta Q^2 \Delta x_B \Delta t \Delta \phi} \frac{1}{\epsilon_{ACC} \delta_{RC} \delta_{Norm} Br(\pi^0 \to \gamma\gamma)}$$

Integrated Luminosity:

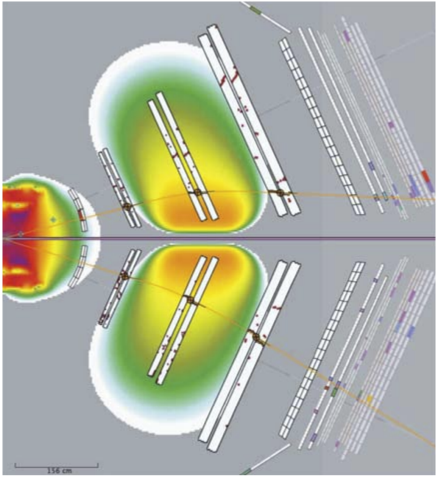
- Measured from Faraday Cup beam charge
- 5.5×10^{40} cm^{-1} from fall 2018 inbending dataset
- 4.6×10^{40} cm^{-1} from fall 2018 outbending dataset

Bin Widths

Correction Factors:

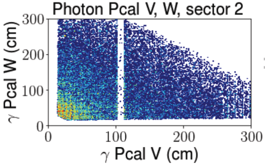
ε_{ACC} : acceptance correction
δ_{RC} : radiative correction
δ_{Norm} : overall normalization
$Br(\pi^0 \to \gamma\gamma)$: branching ratio of neutral pions to two photons
Others : binning corrections

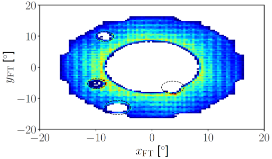
Events and Preliminary Particle Identification



Sample Recon. Event with Detector Hits

- Reconstruction conducted at collaboration level
- Provides particle features (momentum, charge, mass)
- Additional fiducial cuts, momentum corrections applied afterwards





[S. Lee]

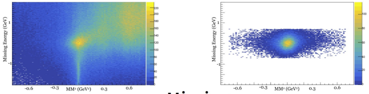
Particle Kinematics

- Electron
  - Cherenkov Counter (PID)
  - Drift Chamber (momentum)
  - Time-of-flight (PID)
  - EM Calorimeter (energy)
- Proton
  - Time-of-flights (PID)
  - Micromegas, SVT, DCs (momentum)
- Neutral Pion
  - EM Calorimeter (γ_1, γ_2)
  - $|M_{\pi^0} - M_{\gamma\gamma}| < 40$ MeV

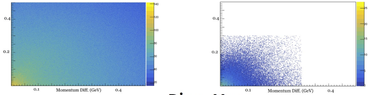
Event Cuts

- DIS Cuts
  - $Q^2 > 1$ GeV^2
  - $W^2 > 4$ GeV^2
- Exclusivity Cuts
  - $MM^2_{epX} < 0.7$ GeV^2
  - $ME_{ep\gamma\gamma} < 0.7$ GeV
  - $\theta_{X\pi} < 2°$
  - $\Delta p_{x,y} < 0.3$ GeV

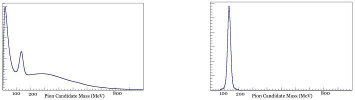
$E_{ep\gamma\gamma}$ vs. MM^2_{epX}



Missing p_T



Pion Mass



Simulations Needed to Determine Correction Factors

- High computational demands: 5 hours to simulate 10K events
- Need $\mathcal{O}(2B)$ events $\rightarrow$ need 1M core-hours for this analysis alone
- Built service to connect research collaboration with HTC nodes worldwide

Open Science Grid

HTCondor High Throughput Computing

Home About OSG Stats Monitors

CLAS12 Monte-Carlo Job Submission Portal

Summary of current jobs

user	submission	total	done	run	idle
lanza	1	2000	819	1181	0
jsalvg	1	10000	9998	0	0
robertej	1	10000	9996	0	0
total	3	22000	20813	1181	0

Click to submit to OSG

Generator

- clas12-mcgen or gemc internal generator
- Arbitrary number of jobs
- Arbitrary number of events for each job (max 10,000)

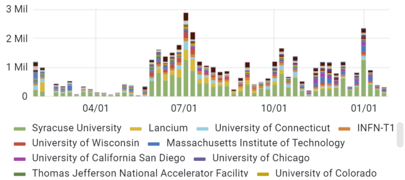
LUND Files

- LUND files (.txt) from a web location
- One job per LUND file
- File define number of events for each job (max 10,000)

Total CPU Hours

35.6 Mil

Core Hours by Site per 7d

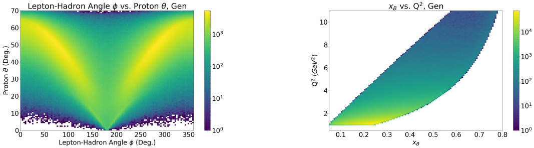


Usage facilitated in 2022

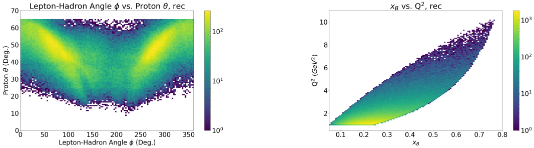
Event Generator and Simulation Details

- Event Generator - aao_(no)rad
  - *DVMP* generator validated on CLAS6 and COMPASS data, origin 1990s
- Simulation - GEMC
  - GEANT4 based simulation developed by CLAS collaboration
- Computing Power
  - Through OSG pipeline, CLAS has access to supercomputing clusters around the world, including dedicated nodes at MIT Tier 2, UConn, INFN, GRIDPP, new groups still joining

Generated



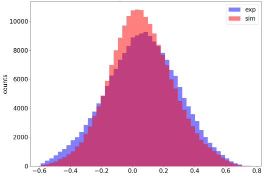
Reconstructed



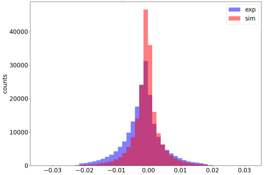
Simulation Needs to be Adjusted to Match Experimental Data

GEANT4 simulation results in reconstructed tracks that are overly optimistic - resolution is better in simulation than in real data

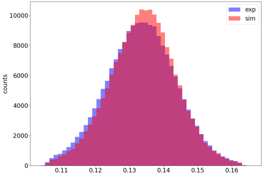
$ME_{ep\gamma\gamma}$



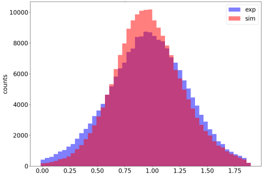
$MM^2_{ep\gamma\gamma}$



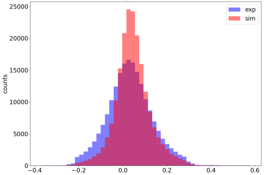
$M_{\gamma\gamma}$



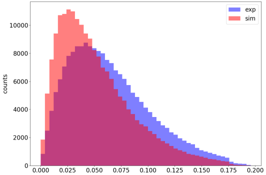
$MM^2_{e\gamma\gamma}$



MM^2_{ep}



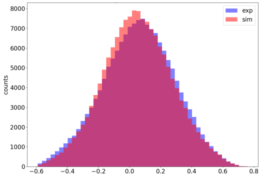
Δp_t



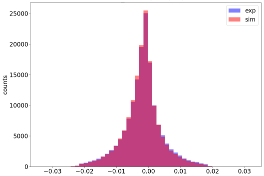
Smearing Factors makes Simulation More Realistic

With the addition of smearing factors to simulated particle reconstruction values, the simulation matches experimental distributions well. `[Collaborator S. Lee]`

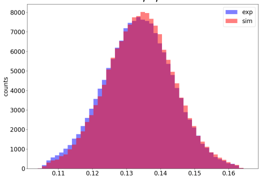
$ME_{ep\gamma\gamma}$



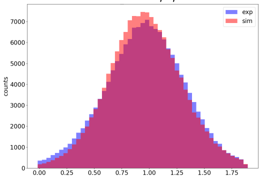
$MM^2_{ep\gamma\gamma}$



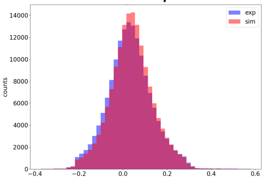
$M_{\gamma\gamma}$



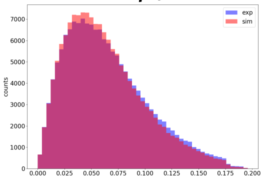
$MM^2_{e\gamma\gamma}$



MM^2_{ep}



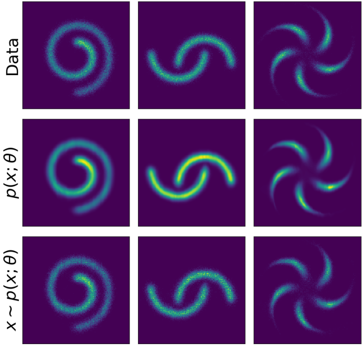
Δp_t



Decrease Computational Needs with Normalizing Flows

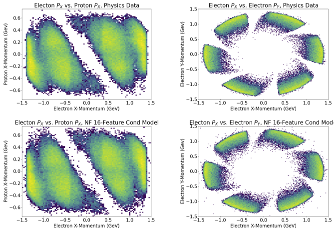
- **Normalizing Flows**: generative model, uses series of invertible transforms to map simple prior distributions into (very complex) target distributions

- **Idea**: Pass only a small percent of generated events through GEANT4 micro physics and reconstruction algorithms (∼90% of comp. load), use to train a NF model to quickly generate the rest



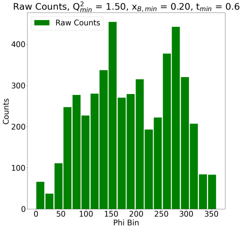
[arxiv:1908.05164]

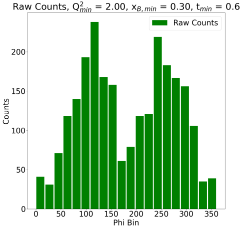
- **Result**: Worked well, but needs additional mechanism for lost particles; unused



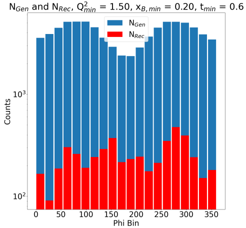
Acceptance Correction - Bin by Bin Calculation

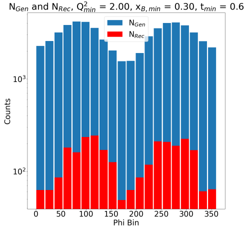
Raw Counts



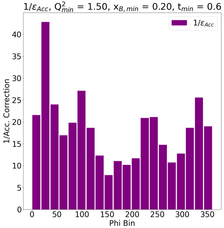


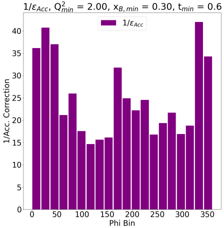
Simulated N_{Gen}, N_{Rec}



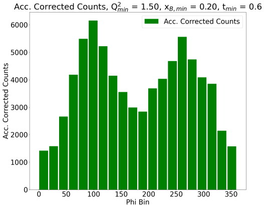


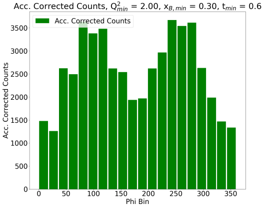
Acc. Correction





Acc. Corr. Counts

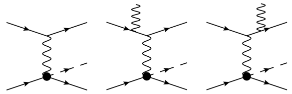




The acceptance dominates the correction factors, but others must be included for a finalized cross section.

Radiative Corrections

- Finalizing results with radiative generator, $\sim$5% correction



Binning Corrections

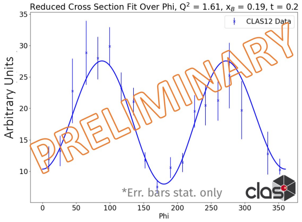
- Finite bin size - average, not differential cross sections
- Bin volume effects
- Bin migration effects
- Preliminary work indicates $\sim$ 10% correction in most bins

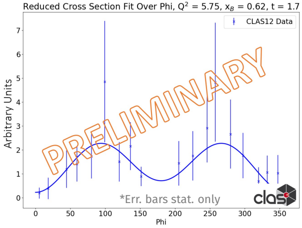
Overall Normalization

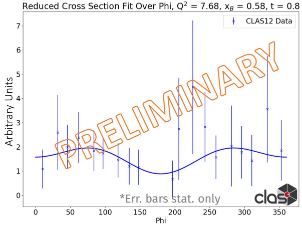
- Simulation detector efficiencies need to be corrected to true efficiencies
- Comparing with well known processes
- Similar processes report $\sim$ 10 % effect

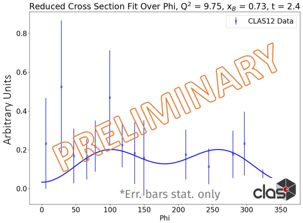
Preliminary Cross Section Results

- Acceptance corrected data follows functional form expected from structure function decomposition
- Binning is currently being improved, along with larger simulation runs to decrease statistical uncertainties









- Goloskokov-Kroll (GK) model predicts exclusive π electroproduction cross sections using handbag approach

  [S.V. Goloskokov & P. Kroll, EPJC, 65,137 (2010)]

- Model parameters chosen to best describe recent CLAS π^+ BSA result

  [S. Diehl et al., PRL 125 182001 (2020)]

- Software implementation from K. Tezgin / PARTONS Framework

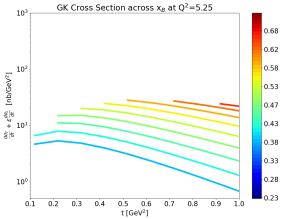
  [B. Berthou et al., EPJC, 78, 478 (2018)]

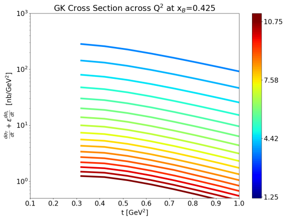
Note:

$$W > 2\text{ GeV} \implies \frac{Q^2(1-x_B)}{x_B} > 3.12\text{ GeV}^2$$

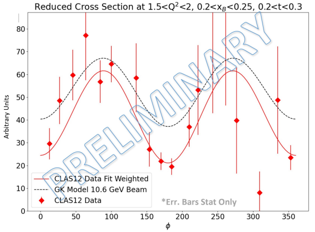
$$t > t_{min} \implies t > \frac{m_p^2 x_B^2}{1-x_B}$$

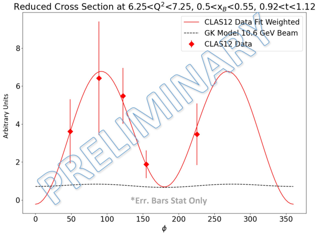
Model Predictions





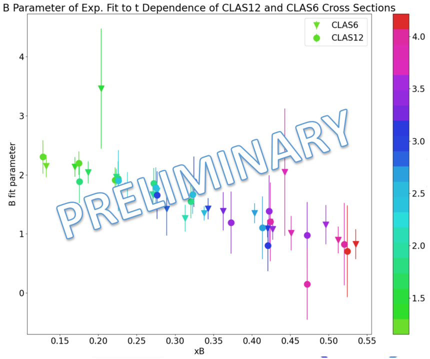
GK and CLAS12 Data





Extracting Physics - B Parameter

- Cross section expected to decrease across increasing **t** as $e^{B\mathbf{t}}$
- The parameter B is related to the distance between the struck quark and the rest of the nucleon
- Preliminary CLAS12 results agree with CLAS6 published results, and are in line with expectations from the above interpretation



CLAS12 (this work) and CLAS6 B slope parameter across x_B and Q^2

[I. Bedlinskiy et al., PRC, 90, 025205 (2014)]

- Cross section measurement does not give a separation on σ_T and σ_L terms:

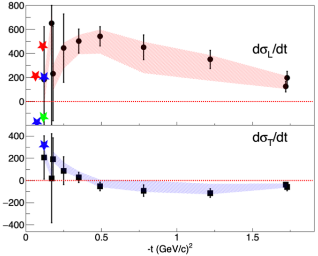
$$\frac{d^4\sigma_{\gamma^* p \to p' \pi^0}}{dQ^2 dx_B dt d\phi_\pi} = \Gamma(Q^2, x_B, E)\frac{1}{2\pi}\left\{\left(\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt}\right) + \ldots\right\}$$

Rosenbluth separation of $d\sigma_L/dt$ and $d\sigma_T/dt$ in π^0 deeply virtual electroproduction from the proton

I. Korover[1,*] and R.G. Milner[1]
[1] Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA 02139.
(Dated: March 2, 2021)

We report on a Rosenbluth separation using previously published data by the CLAS collaboration in Hall B, Jefferson Lab for exclusive π^0 deeply virtual electroproduction (DVEP) from the proton at a mean Q^2 of ≈ 2 (GeV/c)^2. The central question we address is the applicability of factorization in π^0 DVEP at these kinematics. The results of our Rosenbluth separation clearly demonstrate the dominance of the longitudinal contribution to the cross section. The extracted longitudinal and transverse contributions are in agreement with previous data from Hall A at Jefferson Lab, but over a much wider $-t$ range (0.12 - 1.8 (GeV/c)^2). The measured dominance of the longitudinal contribution at $Q^2 \approx 2$ (GeV/c)^2 is consistent with the expectation of the handbag factorization theorem. We find that $\sigma_L(t) \sim 1/(-t)$ for $-t > 0.5$ (GeV/c)^2. Determination of both longitudinal and transverse contributions to the deeply virtual π^0 electroproduction cross section allows extraction of additional GPDs.

- However, can leverage different beam energies between CLAS12 and CLAS6 data to perform Rosenbluth separation
- Will extend prior results and further constrain GPDs



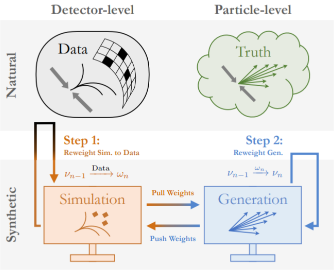
Extracting Physics Directly with OmniFold

OmniFold: A Method to Simultaneously Unfold All Observables

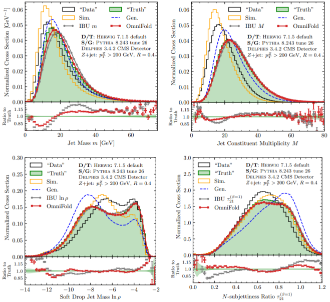
Anders Andreassen,[1,2,3,*] Patrick T. Komiske,[4,†] Eric M. Metodiev,[4,‡] Benjamin Nachman,[2,§] and Jesse Thaler[4,¶]

[1]*Department of Physics, University of California, Berkeley, CA 94720, USA*
[2]*Physics Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*
[3]*Google, Mountain View, CA 94043, USA*
[4]*Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

Collider data must be corrected for detector effects ("unfolded") to be compared with many theoretical calculations and measurements from other experiments. Unfolding is traditionally done for individual, binned observables without including all information relevant for characterizing the detector response. We introduce OmniFold, an unfolding method that iteratively reweights a simulated dataset, using machine learning to capitalize on all available information. Our approach is unbinned, works for arbitrarily high-dimensional data, and naturally incorporates information from the full phase space. We illustrate this technique on a realistic jet substructure example from the Large Hadron Collider and compare it to standard binned unfolding methods. This new paradigm enables the simultaneous measurement of all observables, including those not yet invented at the time of the analysis.



[arxiv:1911.09107]



Presenting Unbinned Differential Cross Section Results

Miguel Arratia,[a,b] Anja Butter,[c] Mario Campanelli,[d] Vincent Croft,[e] Dag Gillberg,[f] Kristin Lohwasser,[g] Bogdan Malaescu,[h] Vinicius Mikuni,[i] Benjamin Nachman,[j,k] Juan Rojo,[l,m] Jesse Thaler,[n,o] Ramon Winterhalder[p]

[a]*Department of Physics and Astronomy, University of California, Riverside, CA 92521, USA*
[b]*Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA*

Conclusion - Towards a Full Cross Section

Preliminary efforts on event selection, simulations, and corrections yield promising results but more work is needed to extract a complete cross section measurement:

- Complete remaining correction factors - radiative, binning, and absolute normalization, and systematic uncertainties
- Quantitative comparisons between data and theory model will be meaningful when uncertainties and binning are more understood
- Pursue extraction of physics, and investigate Omnifold as an alternative analysis methodology

Acknowledgements

MIT Milner Hadronic Physics Research Group: Richard Milner, Doug Hasell, Sangbaek Lee, Igor Korover, Xiaqing Li, Patrick Moran
CLAS Collaboration, Bates Engineering, MIT Tier 2 Computing Group

Backup slides

Backup Slides

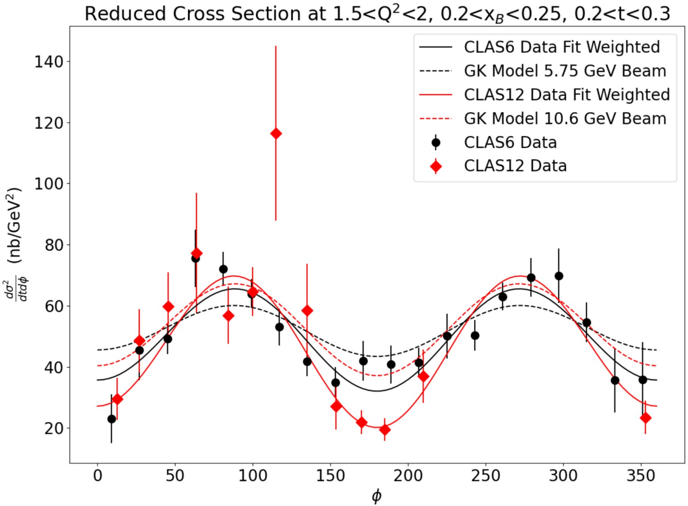
Luminosity Determination

$$\mathcal{L} = \frac{N_A l \rho Q_{FCUP}}{e}$$

Quantity		CLAS12 Value
Avogadro's Number	N_A	$6x10^{23}$
Electron Charge	e	$1.6x10^{-19}$
Target Length	l	5 cm
Target Density	ρ	0.07 g/cm^3 (LH2)
Charge on Faraday Cup	Q_{FCUP}	In data

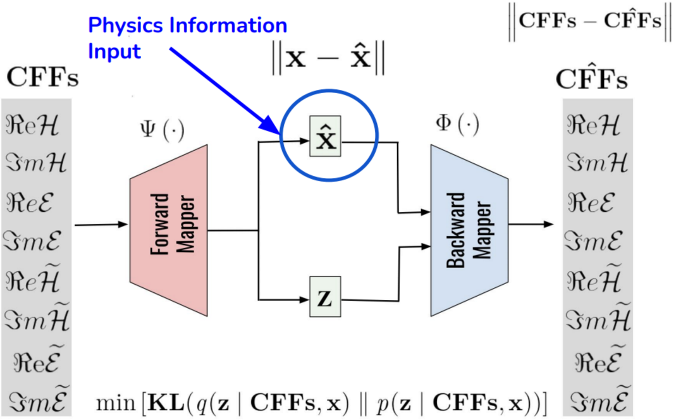
Calculated Integrated Luminosity from Fall 2018 inbending dataset: 5.512 e+40 cm^{-2}

Comparision with CLAS6



Autoencoder approach to GPDs

VAIM-CFF Framework



M. Almaeen, J. Hoskins, BK, Y. Li, H-W. Lin, S. Liuti (**in progress**)

Autoencoder approach to GPDs

Reframing the Extraction of Compton Form Factors

Standard

8 CFFs / 8 polarization configurations.

All observables have to match at the exact kinematics, with controllable uncertainties and systematics from each experiment.

Amazing statistics needed

Nobody has gotten all 8 CFFs before.

FemtoNet

Extraction of 8 CFFs from a single polarization observable treated as an "inverse problem" of extracting 8 unknowns from a single equation.

Quantification of **information that is possible to extract** from certain experiments.

Informed high impact measurements.

M. Almaeen, J. Hoskins, BK, Y. Li, H-W. Lin, S. Liuti (**in progress**)

Backup slides

All data bins
removed

Concrete Abstract

The structure of the proton has been studied extensively since its discovery a century ago. Electron scattering experiments have been utilized as a clean probe into the dynamics of the nucleon, and the past several decades of work investigating structure functions have yielded information on the proton Parton Distribution Functions, which describe the proton's physical inner workings along one dimension. Presently, in specific kinematic regimes nuclear reactions can be theoretically linked to the 3D substructure of the nucleon. This presentation will discuss work towards measuring the properties of one such reaction - Deeply Virtual Neutral Pion Production - from analyzing the data of a 10.6 GeV electron scattering experiment at the CLAS12 detector in Jefferson Lab Hall B.

Find this online at:
https://github.com/robertej19/Thesis-Offense/blob/main/presentation.pdf