Exclusive η Electroproduction Beam Spin Asymmetry Measurements using CLAS12 at Jefferson Lab

IZZY ILLARI

PWA13/ATHOS8

29 May 2024

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

Unique Opportunity of ηN Final States

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

- **Key Idea:** ηN final states provide a cleaner probe of nucleon resonances compared to πN final states
- η is an isospin singlet (I = 0)
- "Isospin filter": ηN final states access only I = 1/2 nucleon resonances
- Simplifies the analysis by reducing the number of contributing resonances
- Enables cleaner extraction of resonance properties

Particle	J^P	Overall	$N\gamma$	$N\pi$	$N\eta$
$N(1440)$	$1/2^+$	****	****	****	
$N(1520)$	$3/2^-$	****	****	****	****
$N(1535)$	$1/2^-$	****	****	****	****
$N(1650)$	$1/2^-$	****	****	****	****
$N(1675)$	$5/2^-$	****	****	****	*
$N(1680)$	$5/2^+$	****	****	****	*
$N(1700)$	$3/2^-$	***	**	***	*
$N(1710)$	$1/2^+$	****	****	****	***
$N(1720)$	$3/2^+$	****	****	****	*
$N(1860)$	$5/2^+$	**	*	**	*
$N(1875)$	$3/2^-$	***	**	**	*
$N(1880)$	$1/2^+$	***	**	*	*
$N(1895)$	$1/2^-$	****	****	*	****

Particle	J^P	Fraction Γ_i/Γ for Decay Modes	
		$N\pi$	$N\eta$
N(1440)	$1/2^+$	55-75 %	<1 %
N(1520)	$3/2^-$	55-65 %	0.07-0.09 %
N(1535)	$1/2^-$	32-52 %	30-55 %
N(1650)	$1/2^-$	50-70 %	15-35 %
N(1675)	$5/2^-$	38-42 %	<1 %
N(1680)	$5/2^+$	60-70 %	<1 %
N(1700)	$3/2^-$	7-17 %	1-2 %
N(1710)	$1/2^+$	5-20 %	10-50 %
N(1720)	$3/2^+$	8-14 %	1-5 %
N(1875)	$3/2^-$	3-11 %	3-16 %
N(1880)	$1/2^+$	3-31 %	1-55 %
N(1895)	$1/2^-$	2-18 %	15-45 %
N(1900)	$3/2^+$	1-20 %	2-14 %
N(2060)	$5/2^-$	7-12 %	2-38 %
N(2100)	$1/2^+$	8-32 %	5-45 %
N(2120)	$3/2^-$	5-15 %	1-5 %
N(2190)	$7/2^-$	10-20 %	1-5 %
N(2220)	$9/2^-$	15-30 %	N/A

****	Existence is certain.
***	Existence is very likely.
**	Evidence of existence is fair.
*	Evidence of existence is poor.

Objective: Measuring Beam Spin Asymmetry (BSA/A_{LU}) in η Electroproduction

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

- **Key Idea:** First ever measurement of the beam spin asymmetry (BSA) in exclusive η electroproduction in a previously unexplored kinematic region.
- Unexplored kinematic region: $1.6 \leq W \leq 2.2$ GeV
- Complements existing cross section and polarization observable measurements

Beam Spin Asymmetry A_{LU} (BSA):

$$A_{LU} = \frac{1}{P_b}\frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

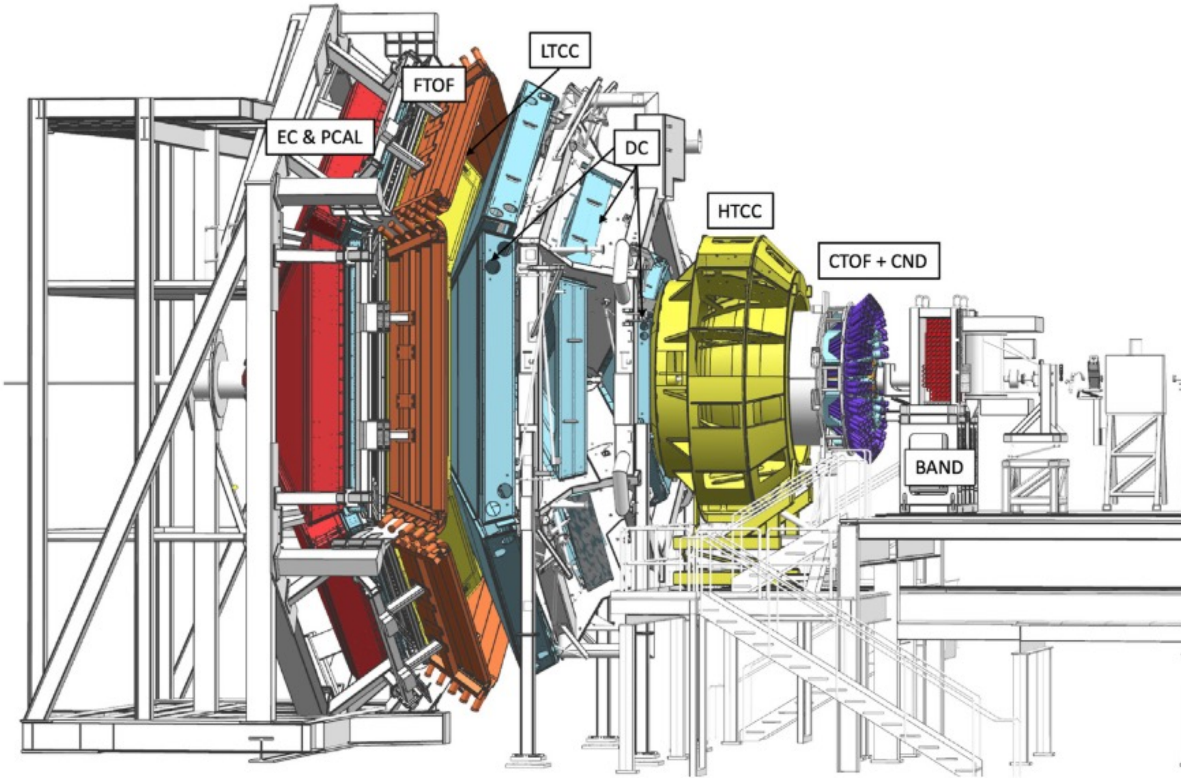
$$= \boxed{\frac{1}{P_b}\frac{N^+ - N^-}{N^+ + N^-}}$$

Sin φ* Moment:

$$A_{LU} \approx \boxed{A_{LU}^{\sin\phi^*}} \sin\phi^*$$

$N^{\pm}$ = η signal yield for (±1) helicity
P_b = beam polarization (0.8517)

CEBAF and CLAS12 at Jefferson Lab



- **Key Idea:** The 12 GeV upgrade of the Continuous Electron Beam Accelerator Facility (CEBAF) and the CLAS12 spectrometer enable high-precision studies of nucleon structure and resonances.

Analysis Roadmap

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

- **Key Idea:** A systematic approach to extract the beam spin asymmetry (BSA or A_{LU}) and the sin φ* moment of the asymmetry ($A_{LU}^{\sin\varphi^*}$) from the data.

Step 1:
- **Event Selection:**
- Skim data for relevant final states and apply fiducial and analysis cuts

Step 2
- **Kinematic Binning:**
- Determine the physics of the final state

Step 3:
- **Signal Extraction:**
- Fit data to extract the η signal yield

Step 4:
- **Determine Polarization Observables:**
- Beam Spin Asymmetry (BSA/A_{LU}) and sine moment ($A_{LU}^{\sin\varphi^*}$)

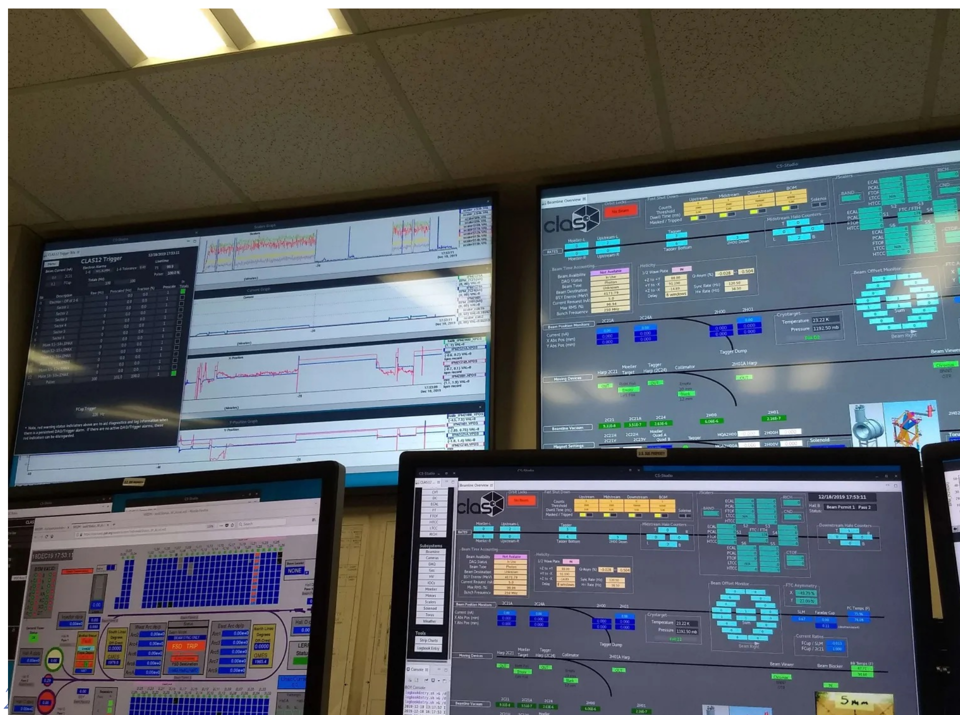
Step 5:
- **Uncertainties:**
- Statistical and Systematic

Step 6:
- **Present Results**

CLAS12 Run Group K Dataset

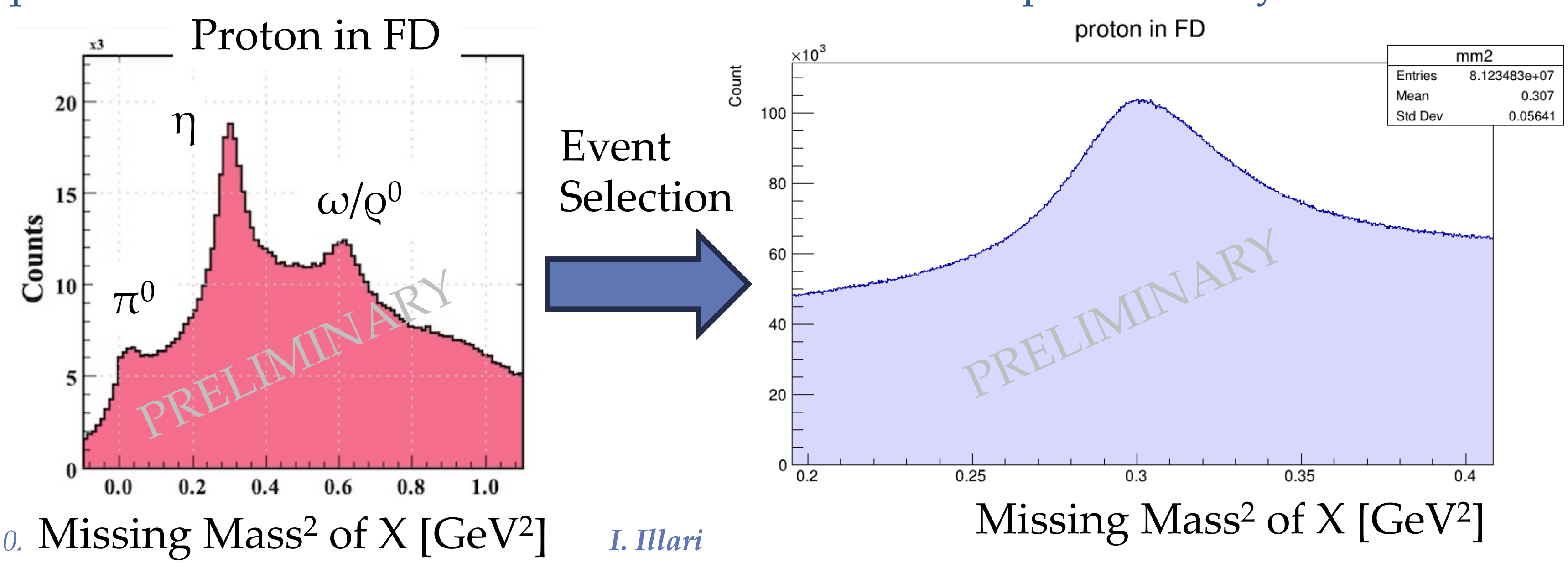
THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

- **Key Idea:** This work utilizes a subset of the RG-K dataset
- Data collected from Nov. 28 to Dec. 20, 2018
- Beam energy: 6.5 GeV
- Polarized electron beam ($P_b \geq 85\%$) on unpolarized liquid hydrogen (LH_2) target
- High luminosity: 10^{35} cm^{-2} s^{-1}
- Total events collected: 7.8 billion



Event Selection and η Identification

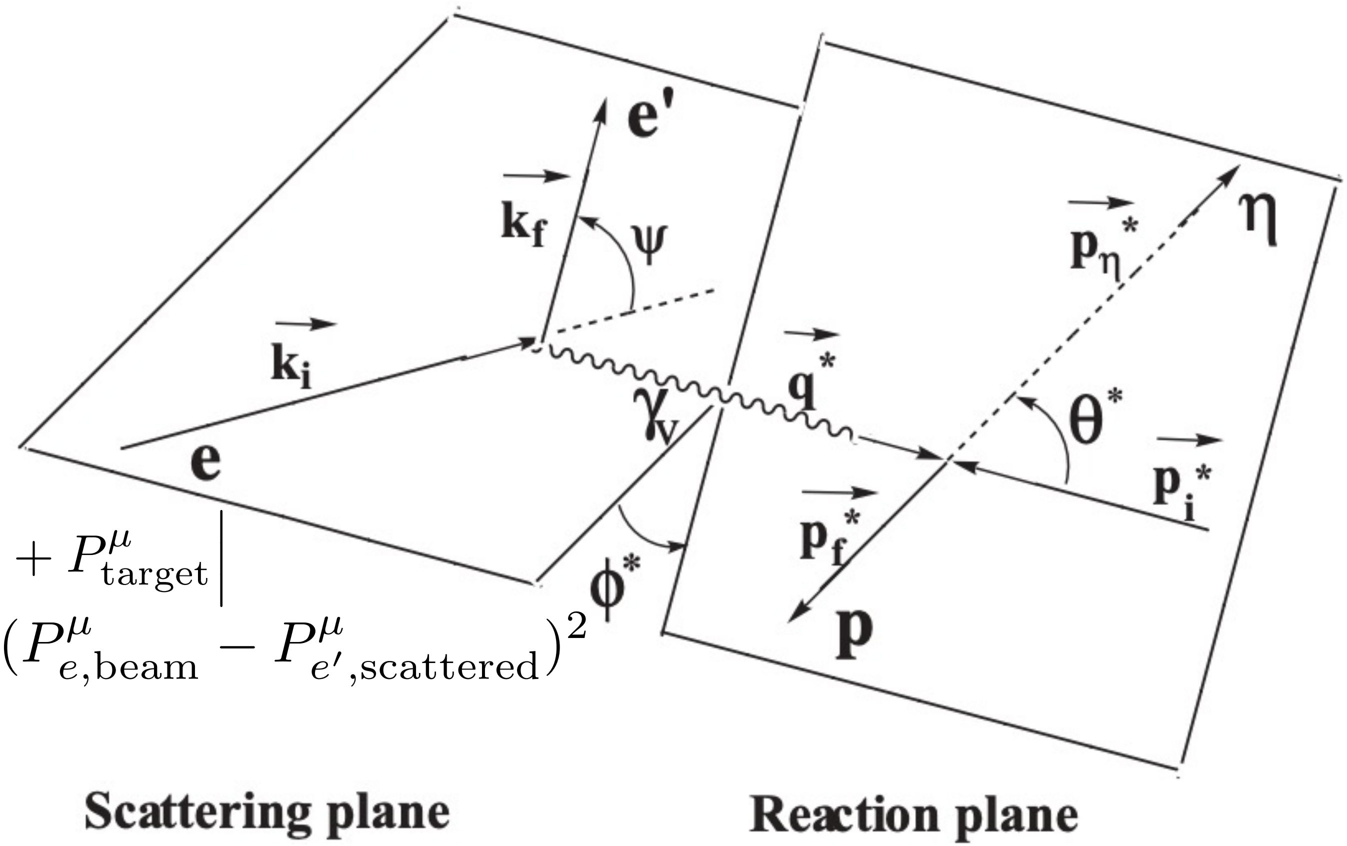
- **Key Idea:** η mesons are identified using the missing mass technique in the ep → e'p'X reaction.
- Detect scattered electron and proton in the Forward Detector
- Reconstruct the missing mass squared (MM^2) of the undetected particle X
- η signal appears as a peak around $MM^2 = 0.3$ GeV^2
- Apply analysis cuts:
  - W < 2 GeV (nucleon resonance region)
  - 0.15 GeV^2 < MM^2 < 0.45 GeV^2 (η peak region)
- Implement standard RGK fiducial cuts and cuts developed for analysis



η Electroproduction Kinematics

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

- **Key Idea:** The η electroproduction reaction is studied in the center-of-mass frame, with key kinematic variables W, Q^2, cos(θ*), and φ*.
- Reaction: ep → e'p'η
- Center-of-mass frame: resonance is at rest



$$W = \sqrt{s} = \left| P^{\mu}_{\gamma_\mu} + P^{\mu}_{\text{target}} \right|$$

$$Q^2 = -q^2 = -(P^{\mu}_{e,\text{beam}} - P^{\mu}_{e',\text{scattered}})^2$$

$$\cos\theta^*$$

$$\phi^*$$

Kinematic Binning: Stepwise Methodology

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

- **Key Idea:** A strategic, adaptive approach to binning is employed to balance kinematic resolution and statistical power.

Step 1
- Begin with binning over W
- Identify nucleon resonances

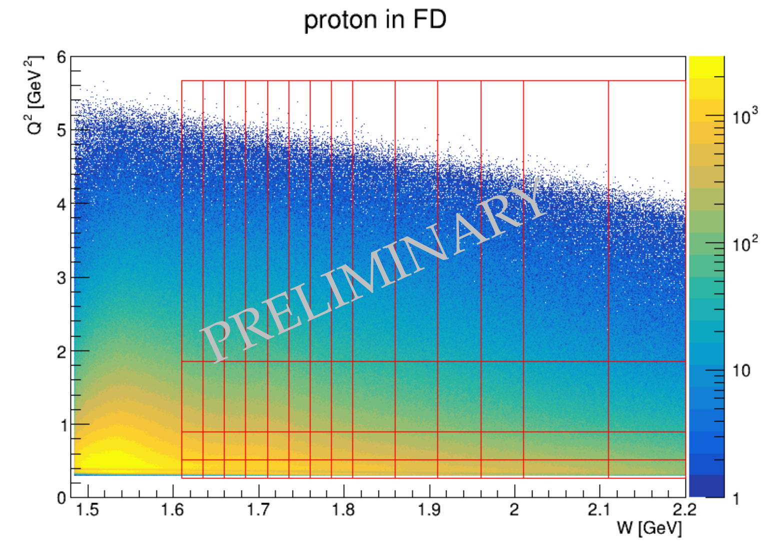
Step 2
- Bin over φ^*
- Enable fitting of the BSA

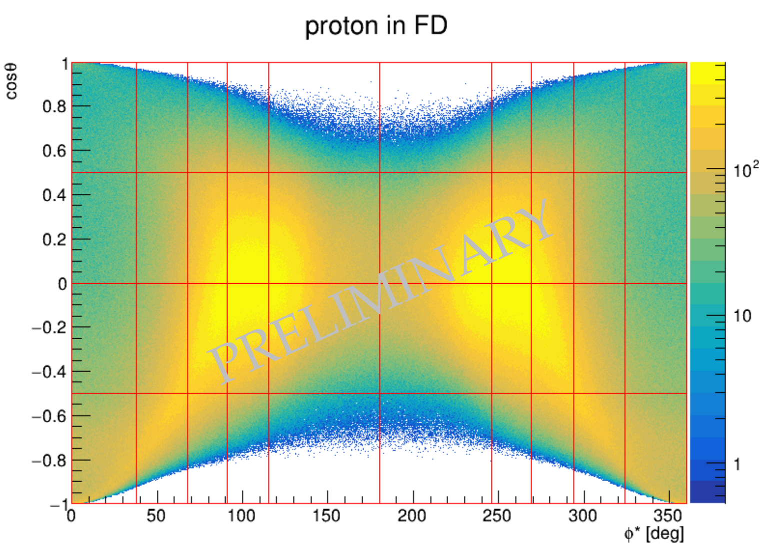
Step 3
- Bin over Q^2
- Variable bin widths → equal Nevent per bin

Step 4
- Bin over $\cos\theta^*$
- Wide bins to explore this parameter space

Kinematic Binning: Phase Space Coverage

- **Key Idea:** The multi-dimensional kinematic phase space is partitioned into discrete bins for detailed analysis.



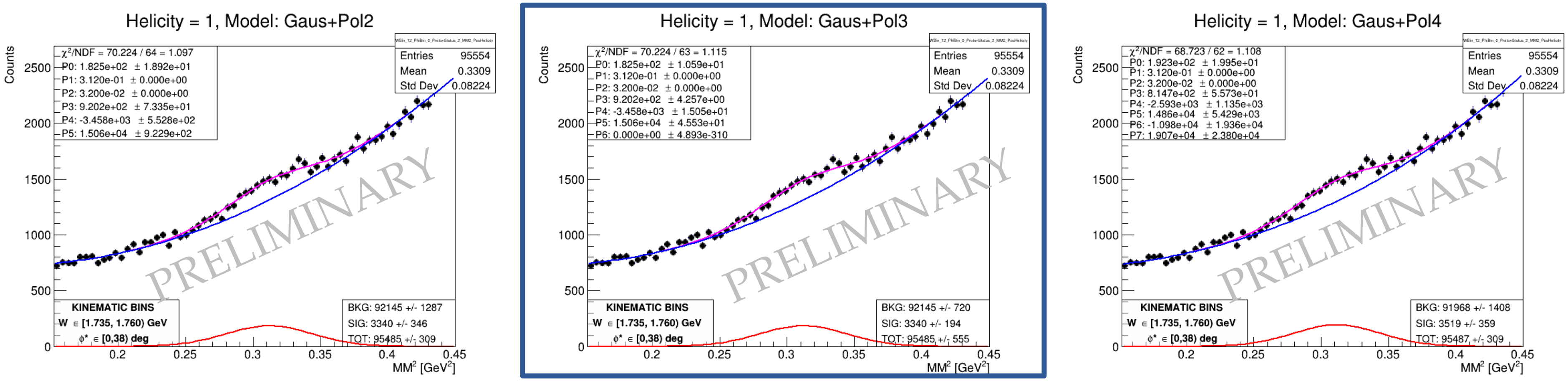


W [GeV]	ϕ^* [deg]	Q^2 [GeV²]	cos(θ^*)
1.610 to 1.635	0 to 38	0.300 to 0.521	-1.0 to -0.5
1.635 to 1.660	38 to 68	0.521 to 0.896	-0.5 to 0.0
1.660 to 1.685	68 to 91	0.896 to 1.850	0.0 to 0.5
1.685 to 1.710	91 to 115	1.850 to 5.671	0.5 to 1.0
1.710 to 1.735	115 to 180		
1.735 to 1.760	180 to 246		
1.760 to 1.785	246 to 269		
1.785 to 1.810	269 to 294		
1.810 to 1.860	294 to 324		
1.860 to 1.910	324 to 360		
1.910 to 1.960			
1.960 to 2.010			
2.010 to 2.110			
2.110 to 2.210			

Signal Extraction and Background Fit

- Key Idea: Extracting the η signal yield requires fitting the missing mass squared distribution with a combination of signal and background models.

pol3 as "benchmark"

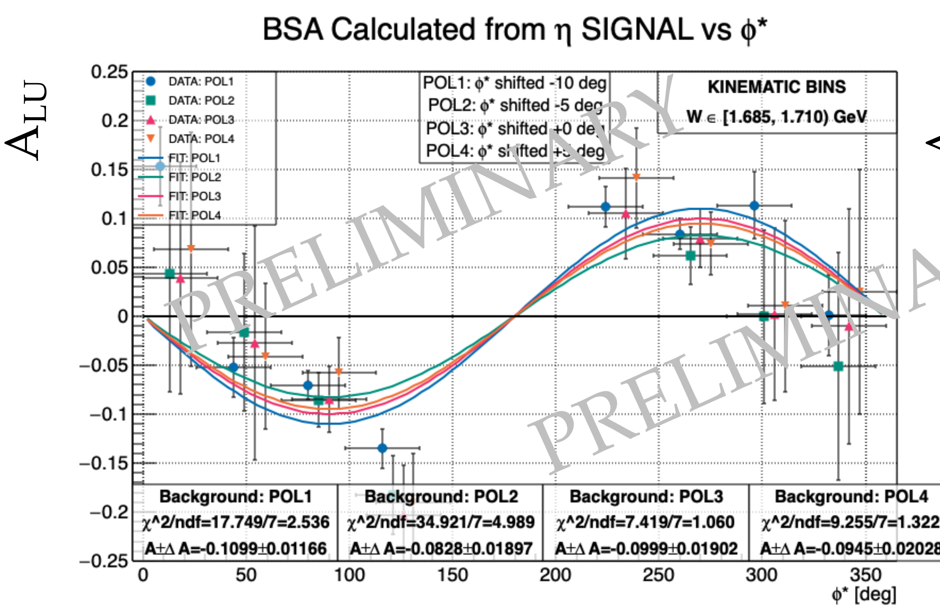


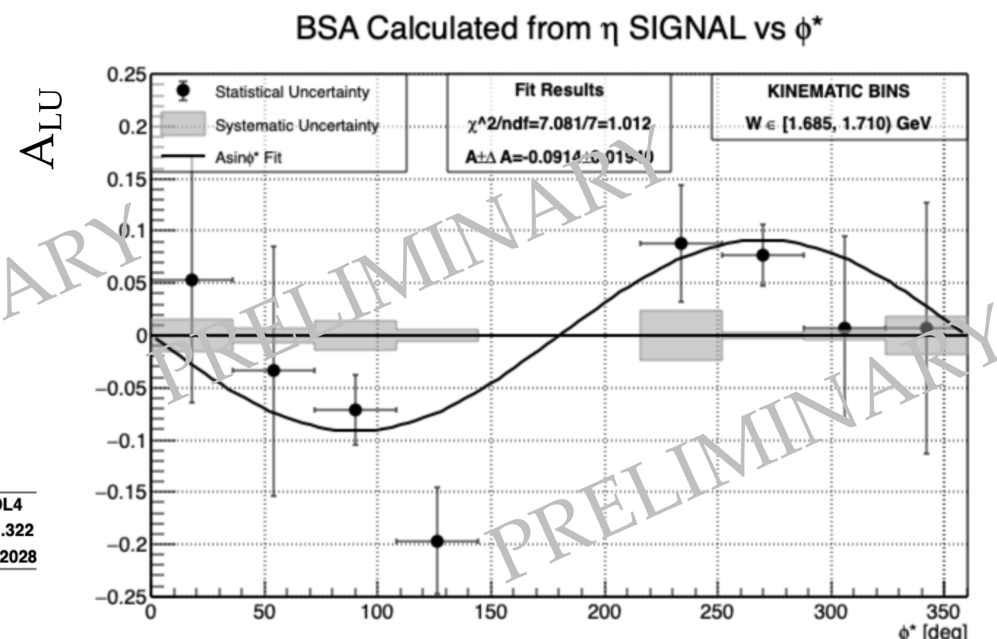
- Signal: Modeled using a Gaussian function
- Background: Modeled using polynomial functions of various orders (pol2, pol3, pol4)
- pol3 chosen as the "benchmark" model, balancing bias and variance
- Systematic uncertainty calculated by comparing different background models

Representative Fit to Beam Spin Asymmetry

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

- **Key Idea:** The BSA is extracted by fitting the asymmetry as a function of φ* with a sine function.
- Data binned over W and φ*, integrated over Q^2 and cosθ*





$$A_{LU} = \frac{1}{P_b}\frac{N^+ - N^-}{N^+ + N^-}$$

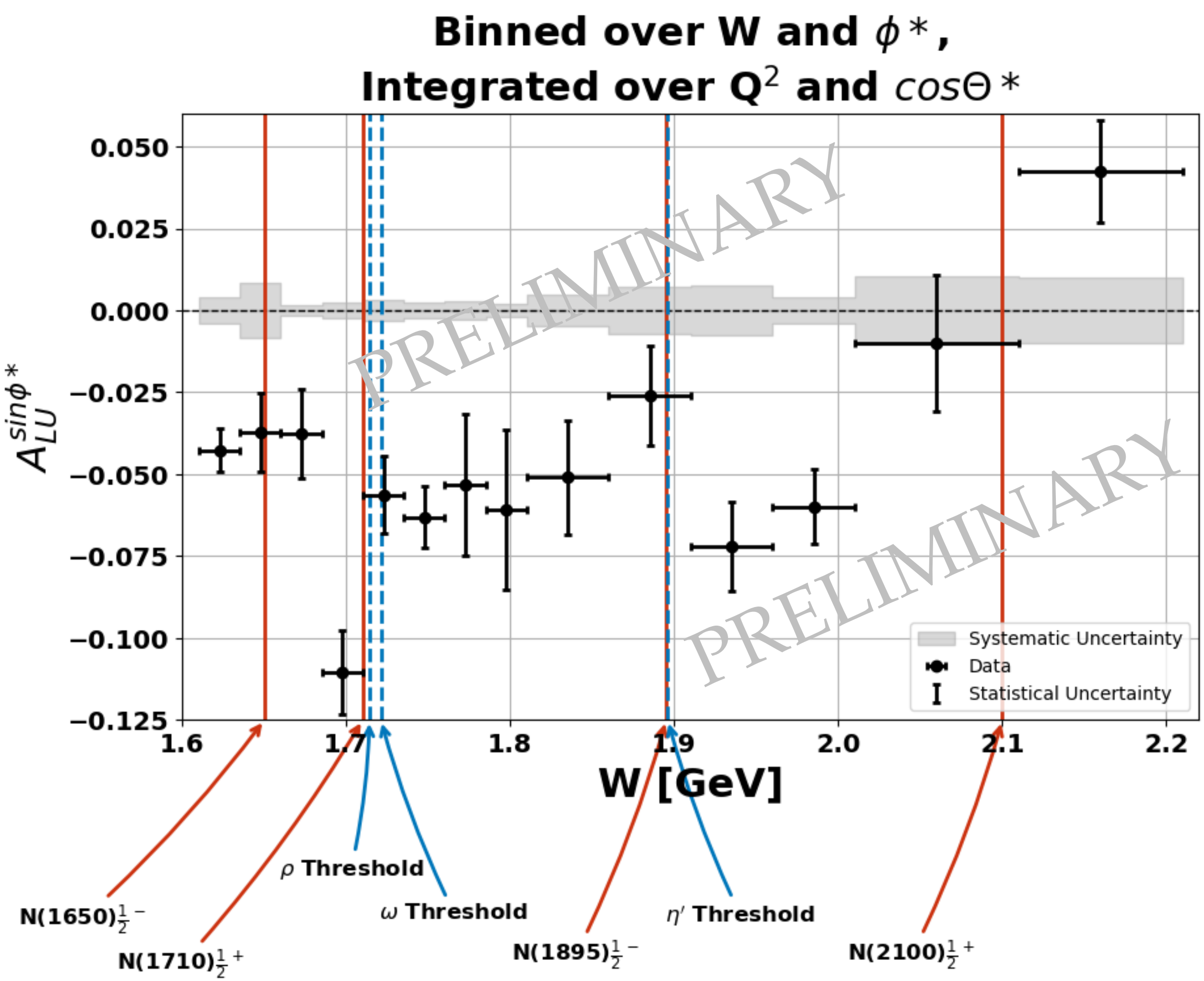
$$A_{LU} \approx A_{LU}^{\sin\phi*} \sin\phi*$$

Sine Moment of the Beam Spin Asymmetry ($A_{LU}^{\sin\varphi^*}$)

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

- **Key Idea:** The sine moment of the asymmetry, $A_{LU}^{\sin\varphi^*}$, is extracted to study the dependence on the center-of-mass energy W.

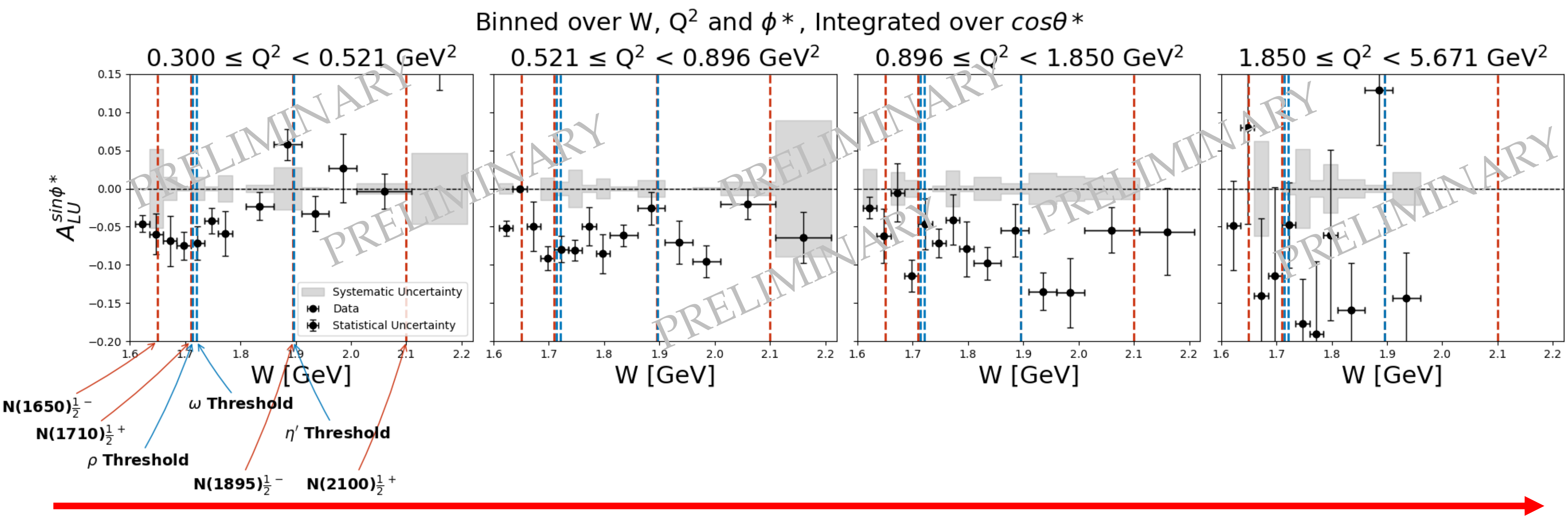
- Data binned over W and φ*, integrated over Q2 and cosθ*
- Error bars represent statistical uncertainties
- Grey histograms around zero line indicate systematic uncertainties
- Selected nucleon resonances
- Selected meson production thresholds



Q^2 Dependence of the Sine Moment ($A_{LU}^{\sin\varphi^*}$)

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

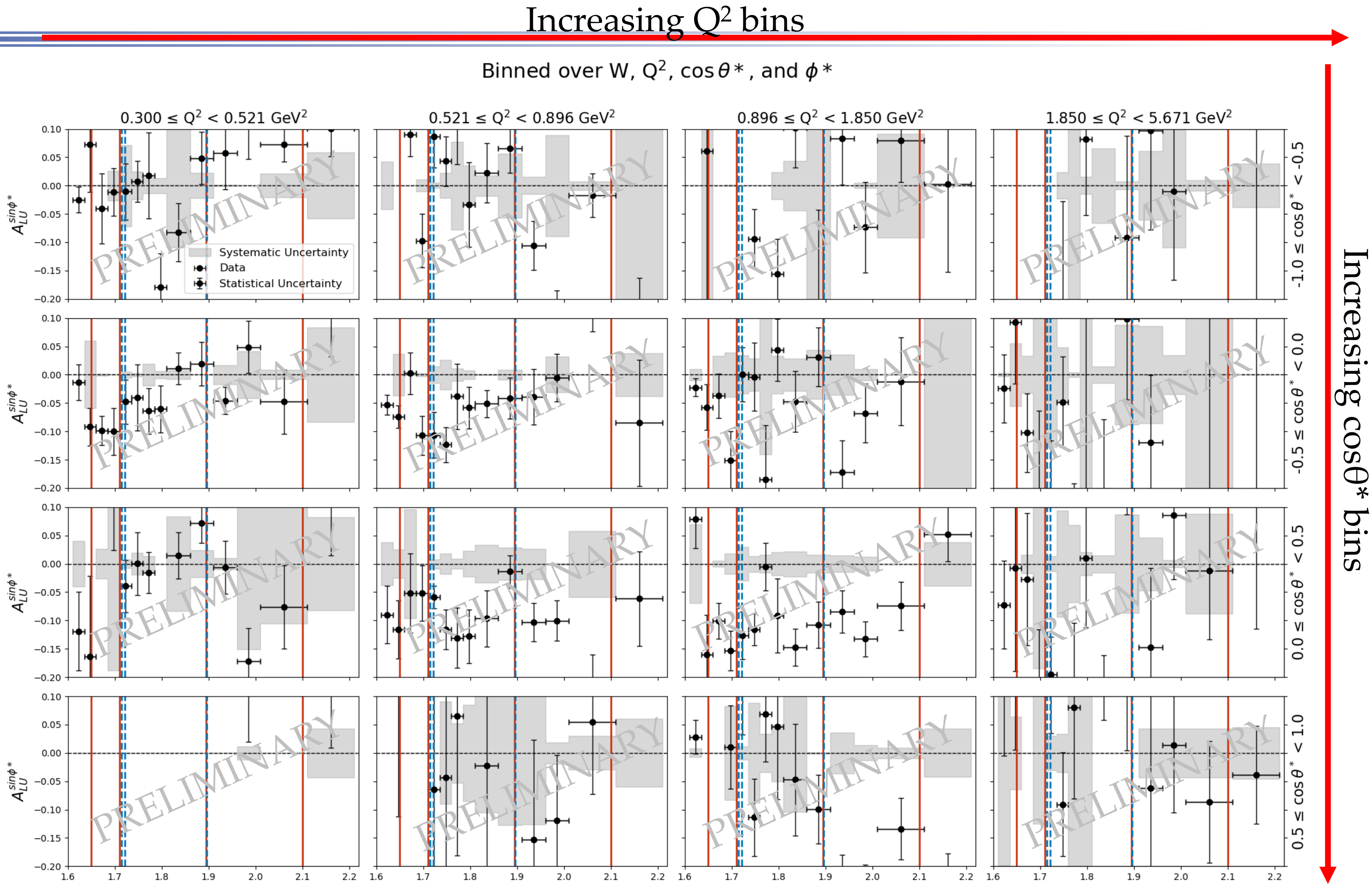
- **Key Idea:** Binning the data over Q^2 allows for investigating the dependence of $A_{LU}^{\sin\varphi^*}$ on the four-momentum transfer squared.



Increasing Q^2 bins

Full Kinematic Dependence of the Sine Moment

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC



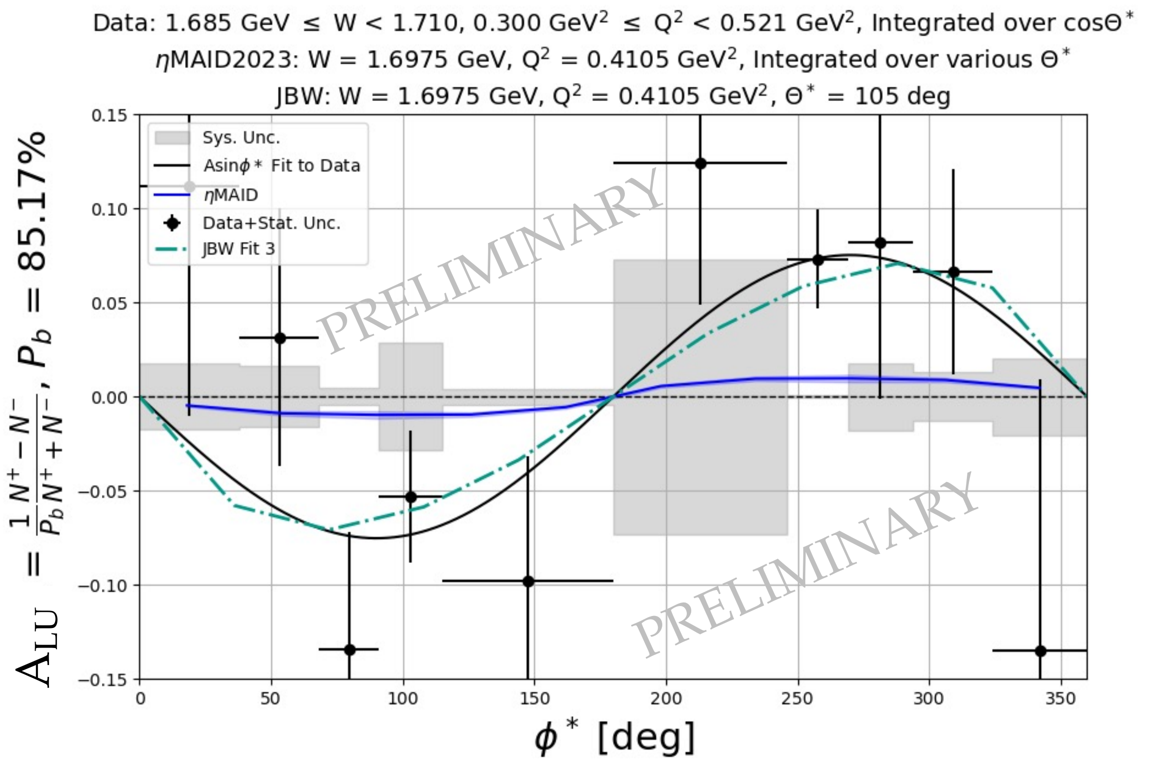
Key Idea: A comprehensive study of the sine moment's dependence on the kinematic phase space.

Comparison with Theoretical Models: An Illustrative Example

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

- **Key Idea:** The beam spin asymmetry data has the potential to constrain and improve theoretical models of η electroproduction.

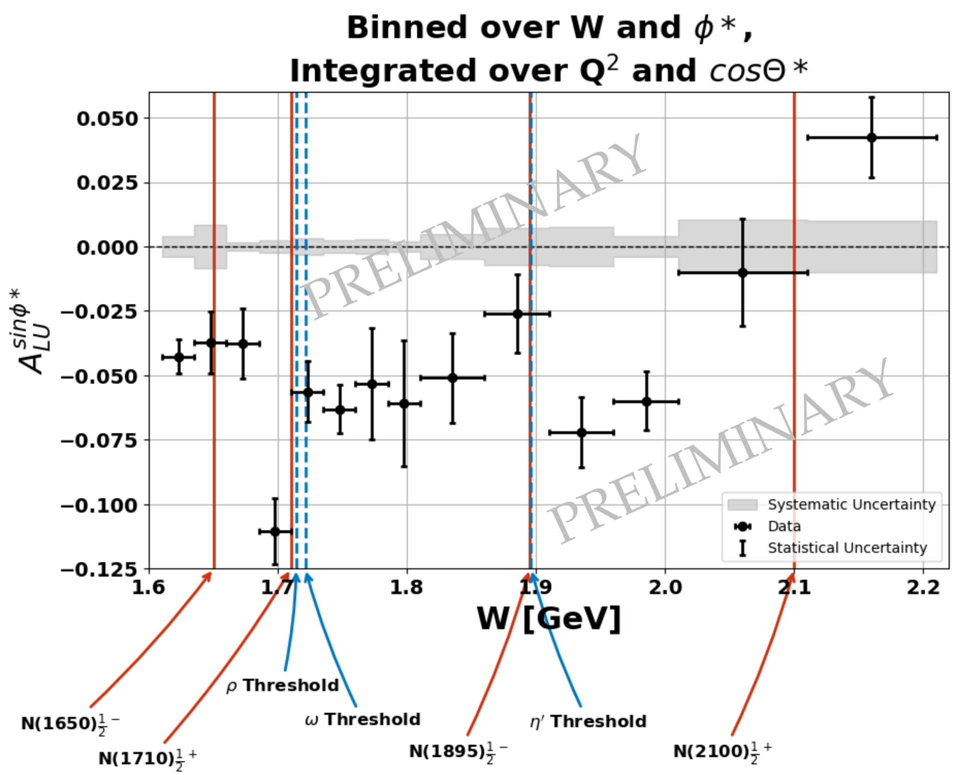
- Data binned over W, φ*, and Q^2 and integrated over cosθ*
- Jülich-Bonn-Washington (JBW)
- EtaMAID
- Illustrative example of the potential for this data to constrain and improve theoretical models
- Limitations in the models (small Nη datasets, lack of polarization observables) prevent definitive conclusions at this stage



Summary of Key Findings and Impact

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

- **Key Idea:** The beam spin asymmetry measurements in η electroproduction offer valuable data for theoretical models and could be provide new insights into nucleon resonances.
- Key Findings:
  - Consistently negative $A_{LU}^{\sin\varphi^*}$ values across the W range
  - Dip-like structure near N(1710)
  - Cusp-like behavior near N(1895)
- Impact:
  - Expands kinematic reach in η electroproduction BSA measurements
  - Bridges the gap between well-studied S11(1535) and higher mass states
  - Provides new data to evaluate and constrain theoretical models



Any Questions?

• • •