Beam Spin Asymmetry of Exclusive η Electroproduction at CLAS12

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14 March 2024

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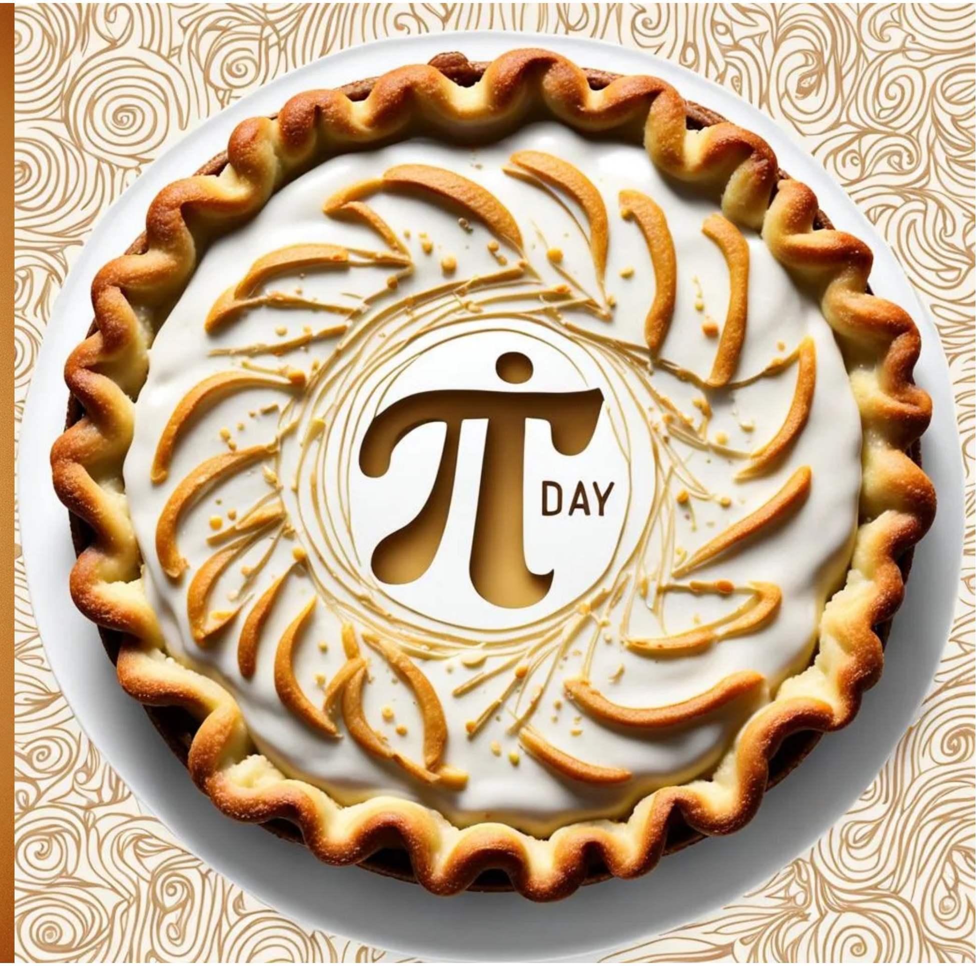
Happy Pi Day!

DALLE3



SDXL 1.0

Motivation

- Why study η electroproduction?
- η acts as "isospin filter":
  - Access nucleon resonances I = ½
- Current world database:
  - Nπ final states
- Extend measurements beyond S11(1535)
  - **Beam spin asymmetry for η electroproduction has not been studied for W in 1.6-2 GeV region before**

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

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

Particle	J^P	Fraction Γ_i/Γ for Decay Modes	
		$N\pi$	$N\eta$
N(1710)	$1/2^+$	5-20 %	10-50 %
N(1895)	$1/2^-$	2-18 %	15-45 %

Tables modified from PDG

Beam Spin Asymmetry (BSA)

- Beam Spin Asymmetry:

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

- Sin φ* Moment:

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

$$A_{LU}^{\sin\phi^*} = \sqrt{2\epsilon(1-\epsilon)}\left(\frac{\sigma_{LT'}}{\sigma_T + \epsilon\sigma_L}\right)$$

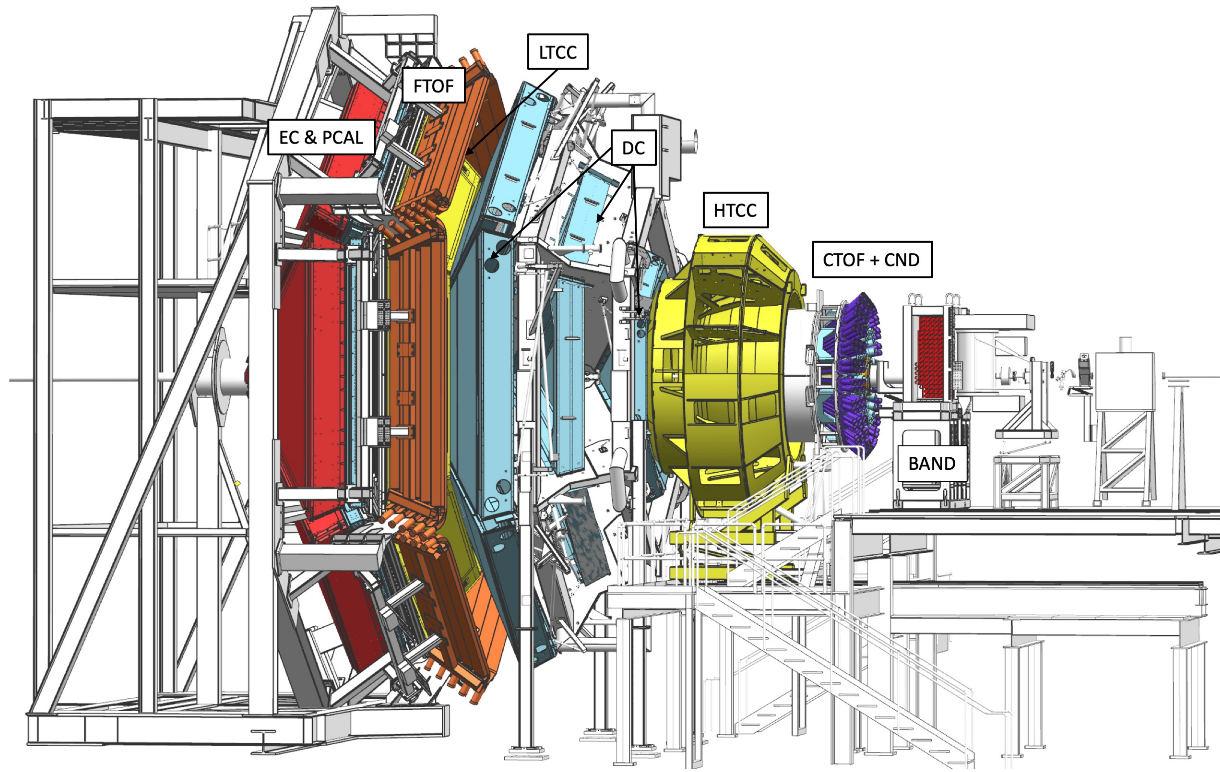
- $N^{\pm}$ = η signal yield for (±1) helicity
- P_b = beam polarization (0.8517)

Objectives and Outline

- Objective:
- **Measure Beam Spin Asymmetry (BSA) and sin moment $A_{LU}^{\sin\varphi^*}$ in η electroproduction**
  - Focus on the nucleon resonance region ($1.6 < W < 2$ GeV)
- Outline of this talk:
  - Discuss the dataset and event selection
  - Outline the kinematics and the kinematic binning procedure
  - Describe the signal extraction and background fitting methods
  - Present the BSA and $A_{LU}^{\sin\varphi^*}$ results across various kinematic bins
  - Illustration of how our findings compare with current theoretical models

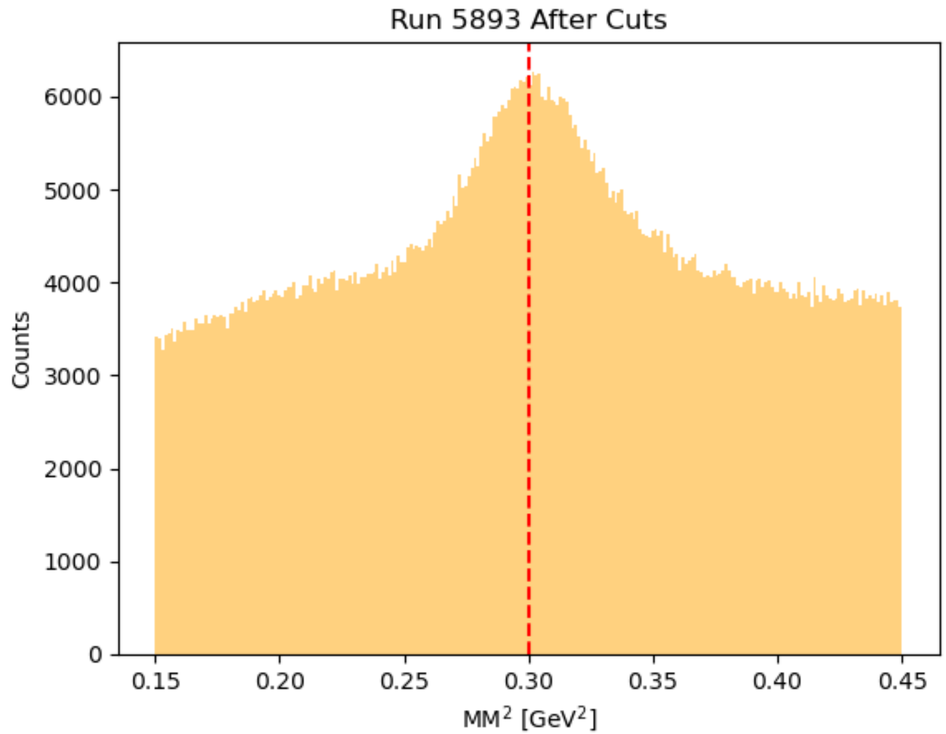
Dataset

- RGK Winter 2018
- Beam energy: 6.5 GeV
- Polarized electron beam
- Unpolarized LH_2 target
- Outbending electrons
- Luminosity: 10^{35} $cm^{-2}s^{-1}$
- Beam current: 60 nA
- Collected events: 7.8G



Event Selection

- Reaction channel:
  - $ep \rightarrow e'p'\eta$
- η identified via missing mass squared technique
- Electron and proton in Forward Detector
- Cuts:
  - $W < 2$ GeV
    - Nucleon resonance region
  - $0.15\ GeV^2 < MM^2 < 0.45\ GeV^2$
    - η peak around $0.3\ GeV^2$
  - Standard RGK analysis & fiducial cuts as outline by Analysis Note
- Version: pass2



Kinematic Parameters

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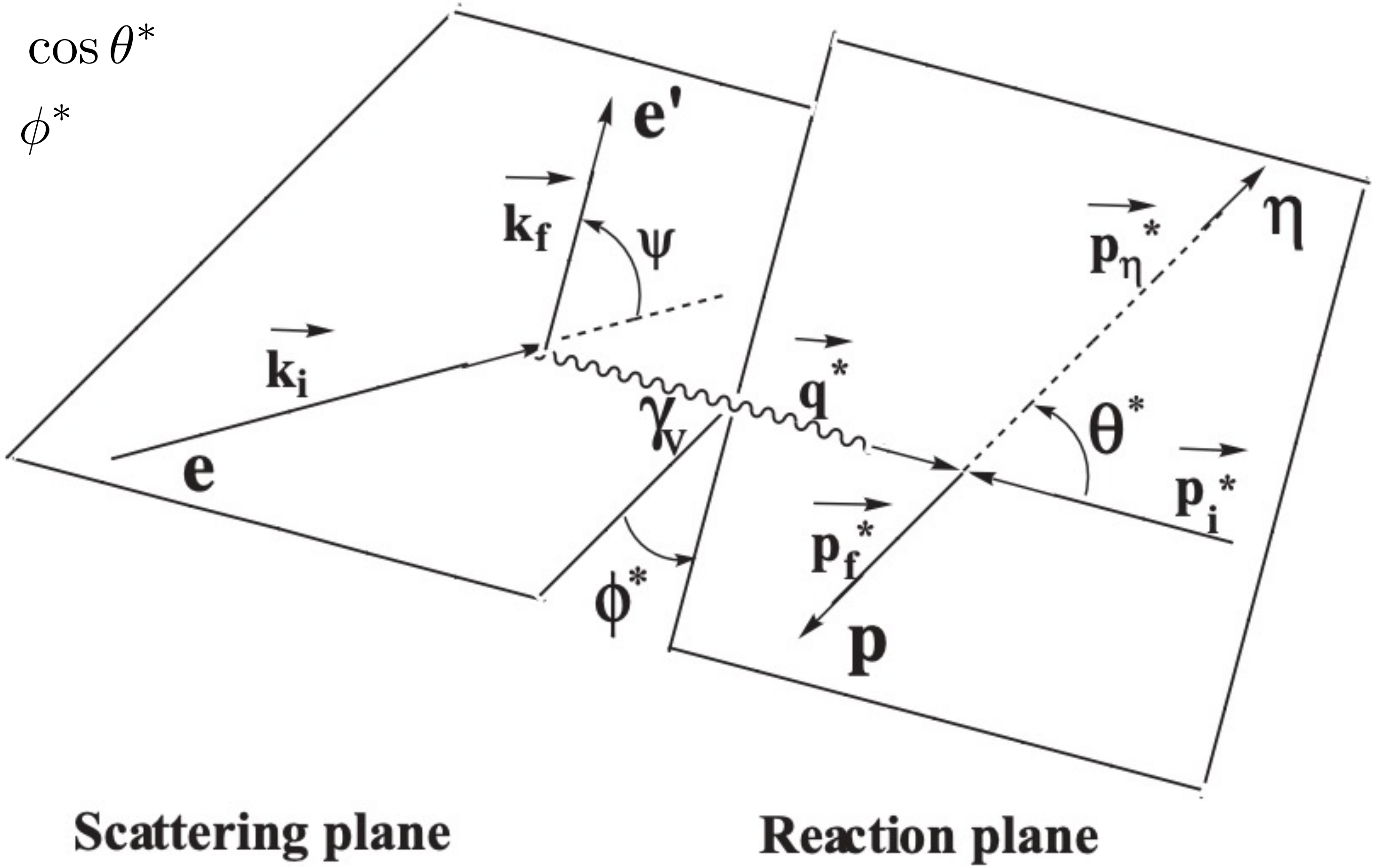
$$W = \sqrt{s} = (P^{\mu}_{\gamma_{\nu}} + P^{\mu}_{\text{target}})$$

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

$$\cos\theta^*$$

$$\phi^*$$



H. Denizli et al., “Q^2 dependence of the S11(1535) photocoupling and evidence for a P-wave resonance in η electroproduction”, Physical Review C **76** (2007).

Kinematic Binning

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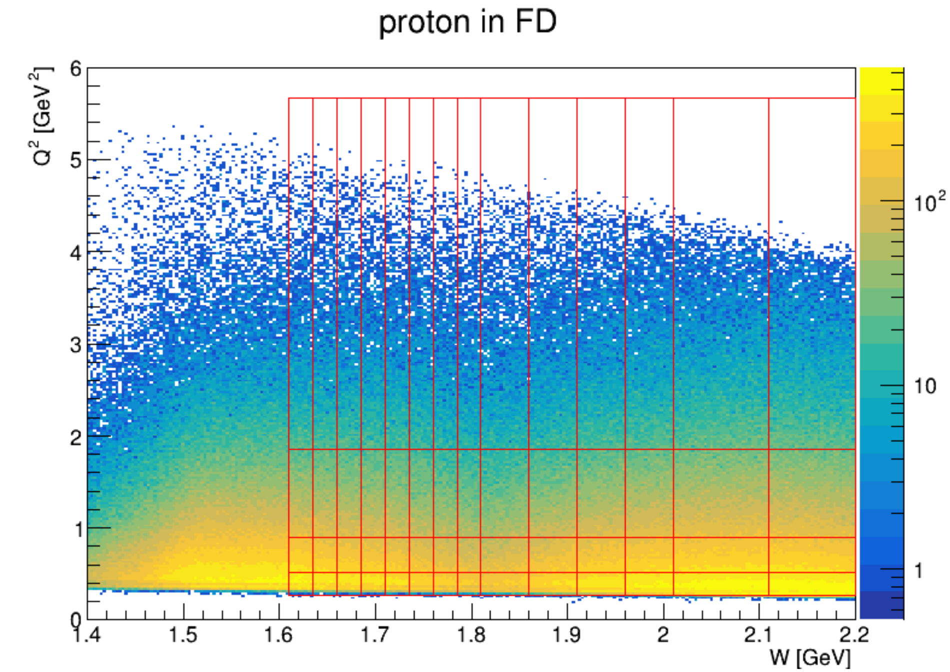
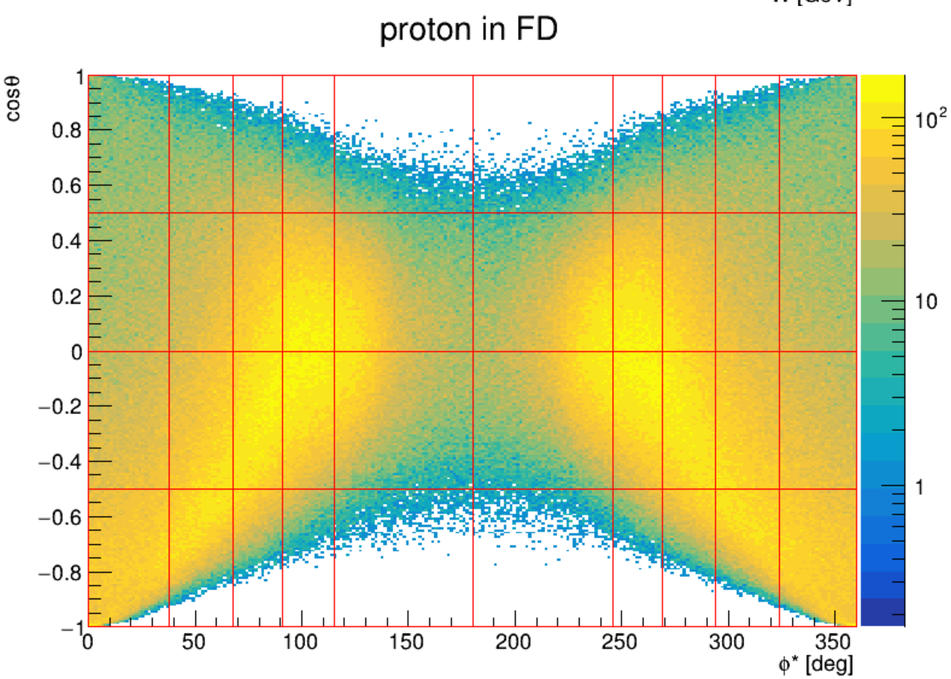
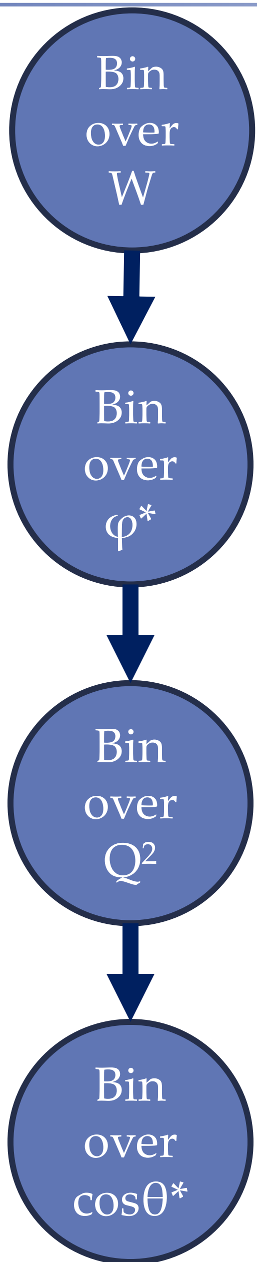




W [GeV]	ϕ* [deg]	Q^2 [GeV2]	cos(θ*)
1.610 to 1.635	0 to 38	0.300 to 0.521	-1.0 to -0.5
1.635 to 1.660	38 to 68	0.521 to 0.896	-0.5 to 0.0
1.660 to 1.685	68 to 91	0.896 to 1.850	0.0 to 0.5
1.685 to 1.710	91 to 115	1.850 to 5.671	0.5 to 1.0
1.710 to 1.735	115 to 180		
1.735 to 1.760	180 to 246		
1.760 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			

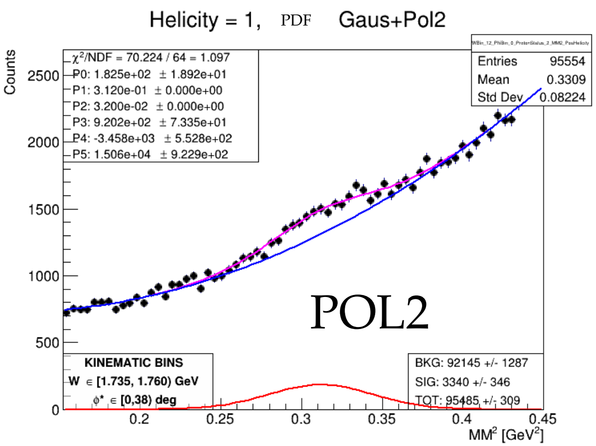
Kinematic Binning: Stepwise Methodology

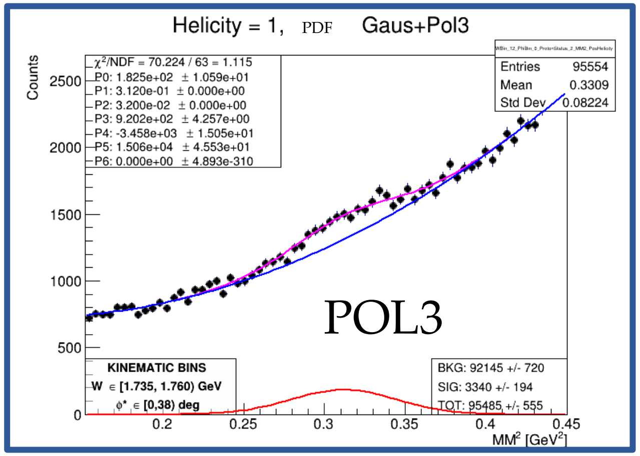


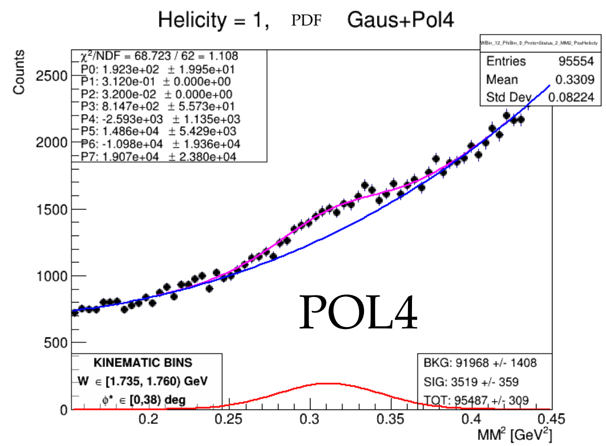
1. Start with binning over W
   - Necessary for identifying nucleon resonances
2. Bin over φ*
   - Necessary for fit to beam spin asymmetry
3. Bin over Q^2
   - Determine variable width of bins of Q^2 with the same number of events
4. Bin over cosθ*
   - Choose relatively wide bins as an exploration of the parameter

Signal Extraction and Background Fit

pol3 as “benchmark”







- Gaussian Signal
- Polynomial Background
- Total Distribution
- Use polynomial functions of various orders to fit the background shape
- Systematic uncertainty due to the choice of background

Bins in W: BSA

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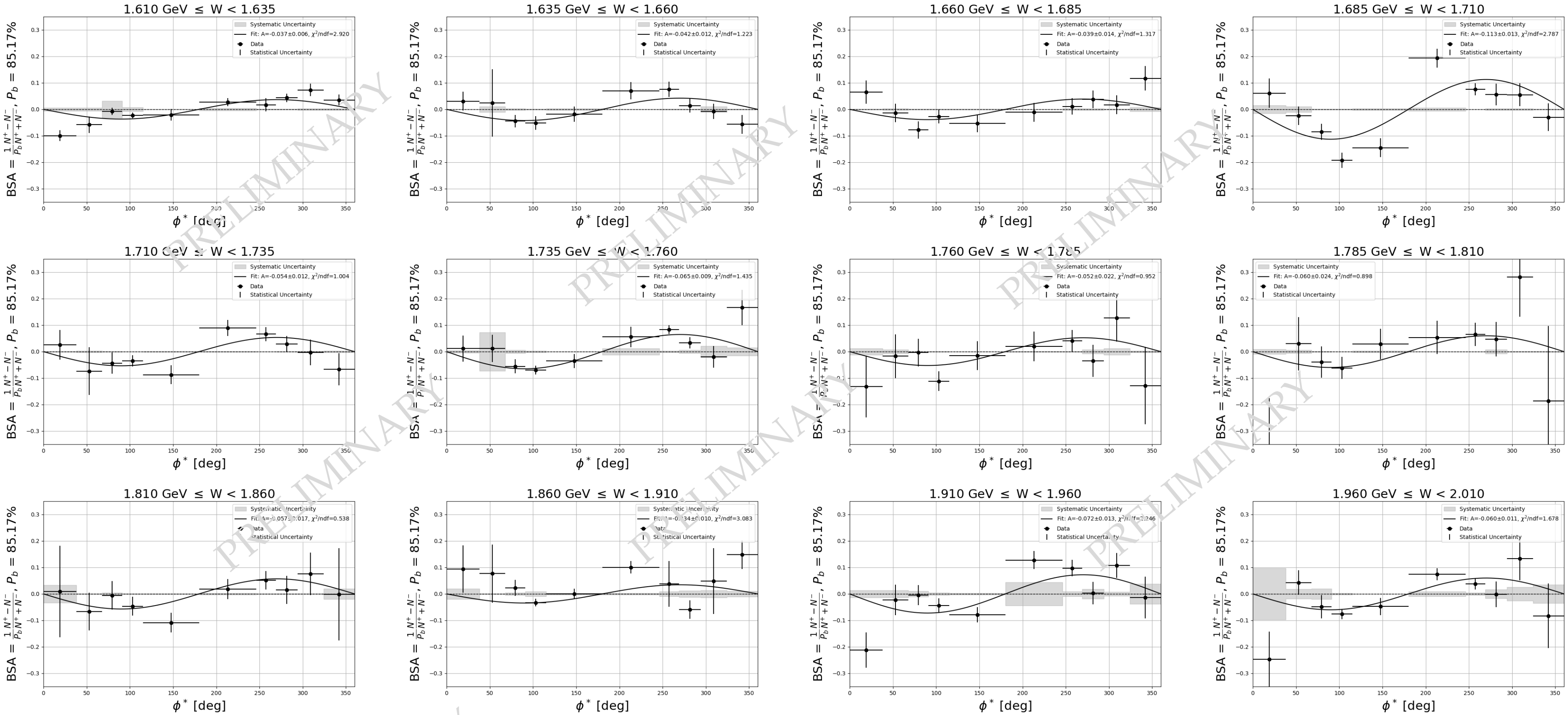
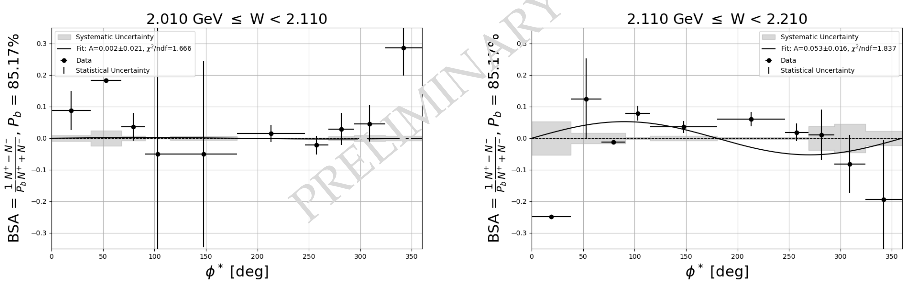


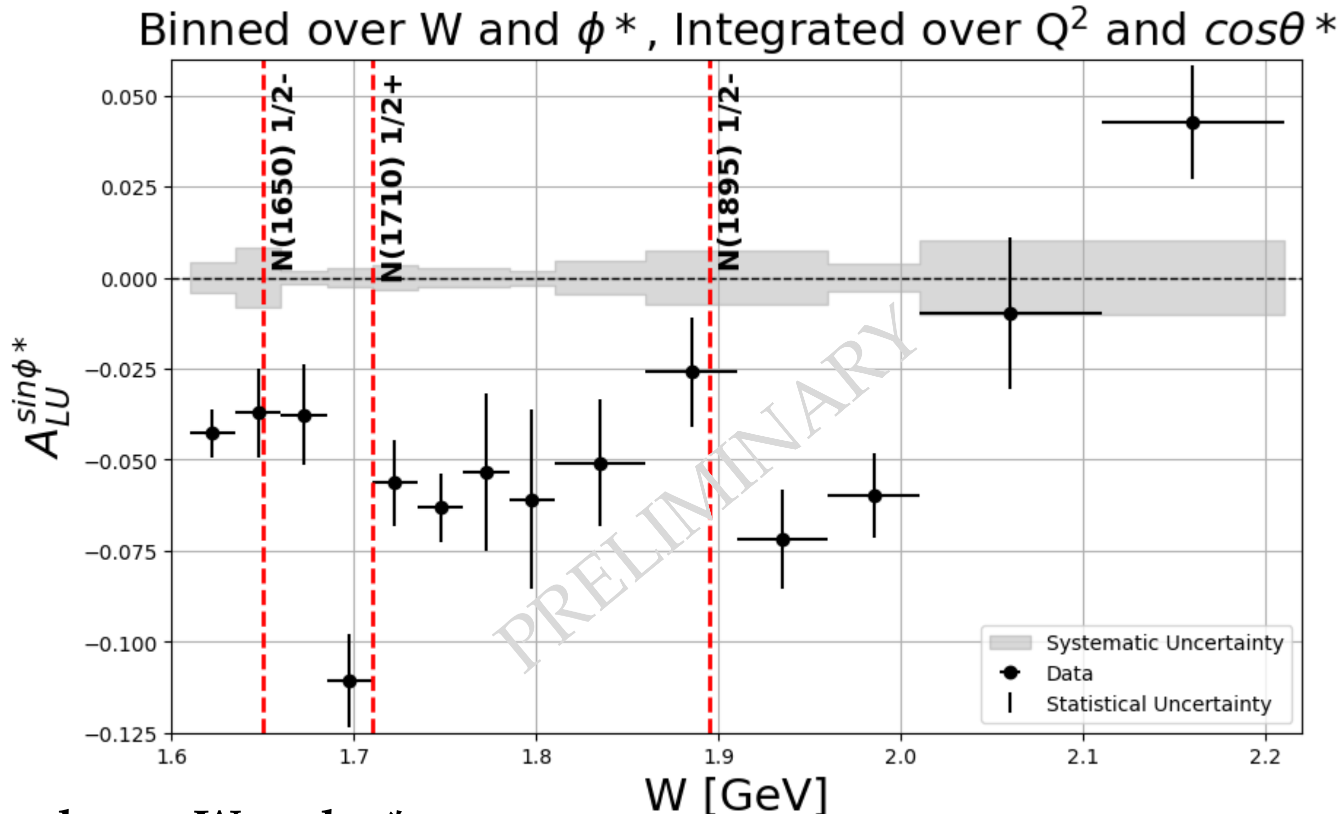


- **Data binned over W and φ***
- **Data integrated over Q^2 and cosθ***
- Error bars: statistical uncertainty
- Grey histograms around zero line: systematic uncertainty
- BSA y range ±0.35
- Asinφ* fit

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

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

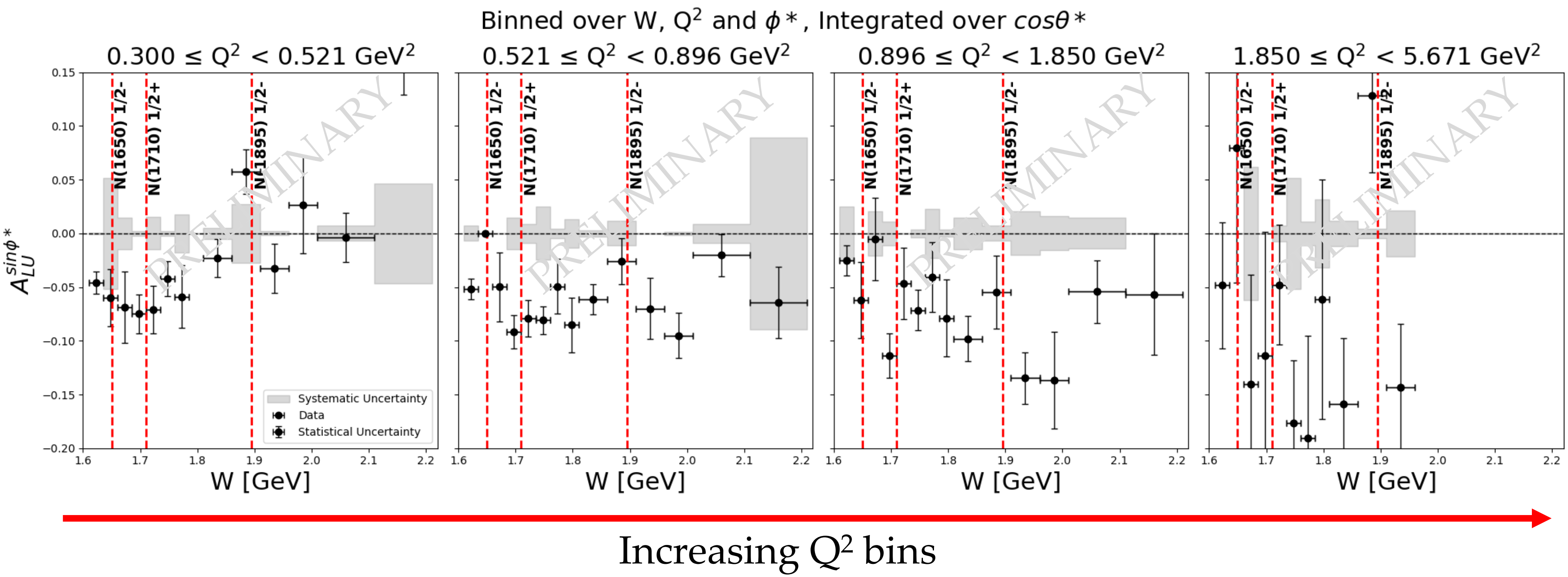
Bins in W: $A_{LU}^{\sin\varphi^*}$



- **Data binned over W and φ***
- **Data integrated over Q² and cosθ***
- Error bars: statistical uncertainty
- Grey histograms around zero line: systematic uncertainty

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

Bins in W and Q^2: $A_{LU}^{\sin\varphi*}$

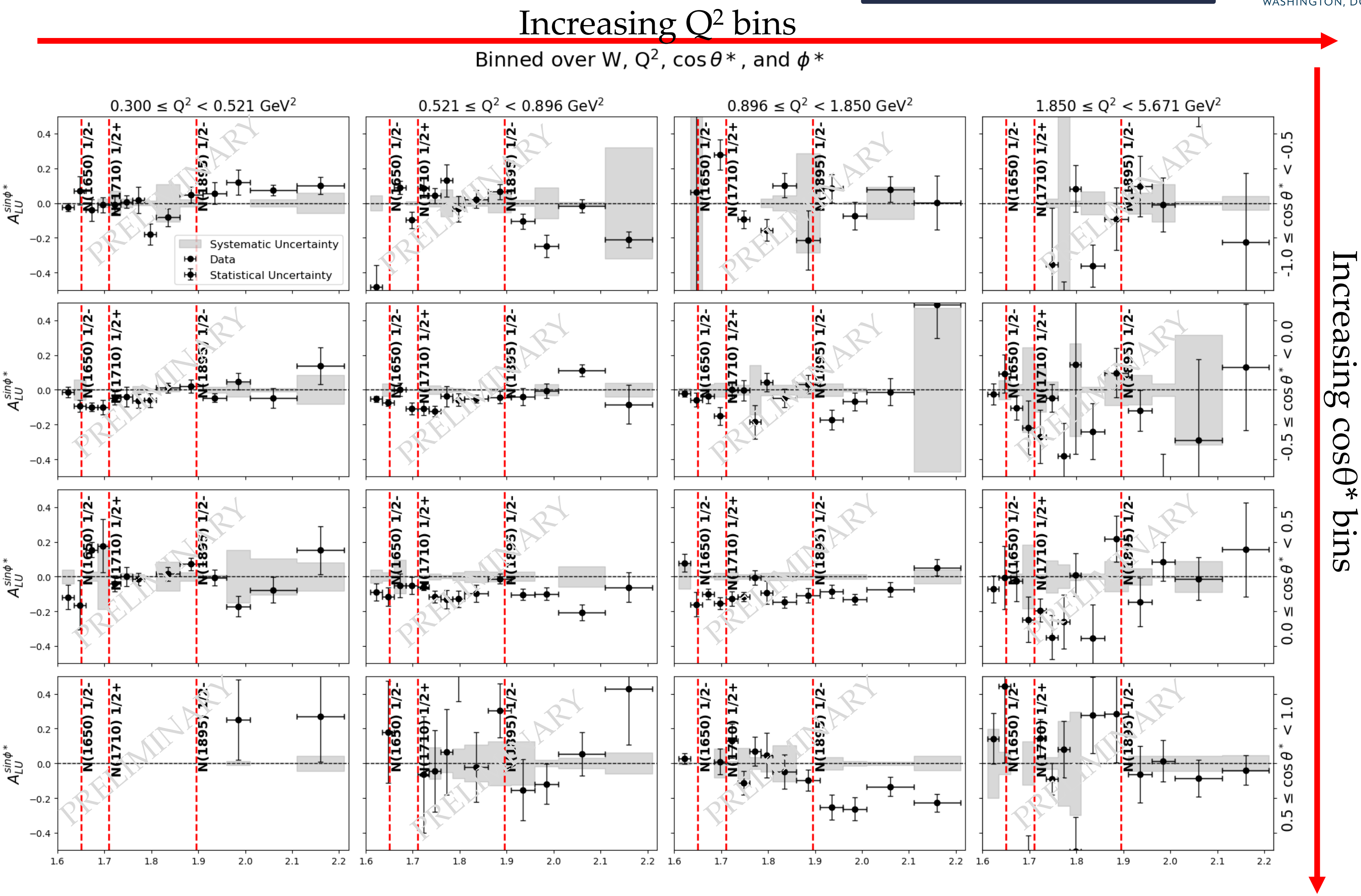


- **Data binned over W, φ*, and Q^2**
- **Data integrated over cosθ***
- Error bars: statistical uncertainty
- Grey histograms around zero line: systematic uncertainty

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

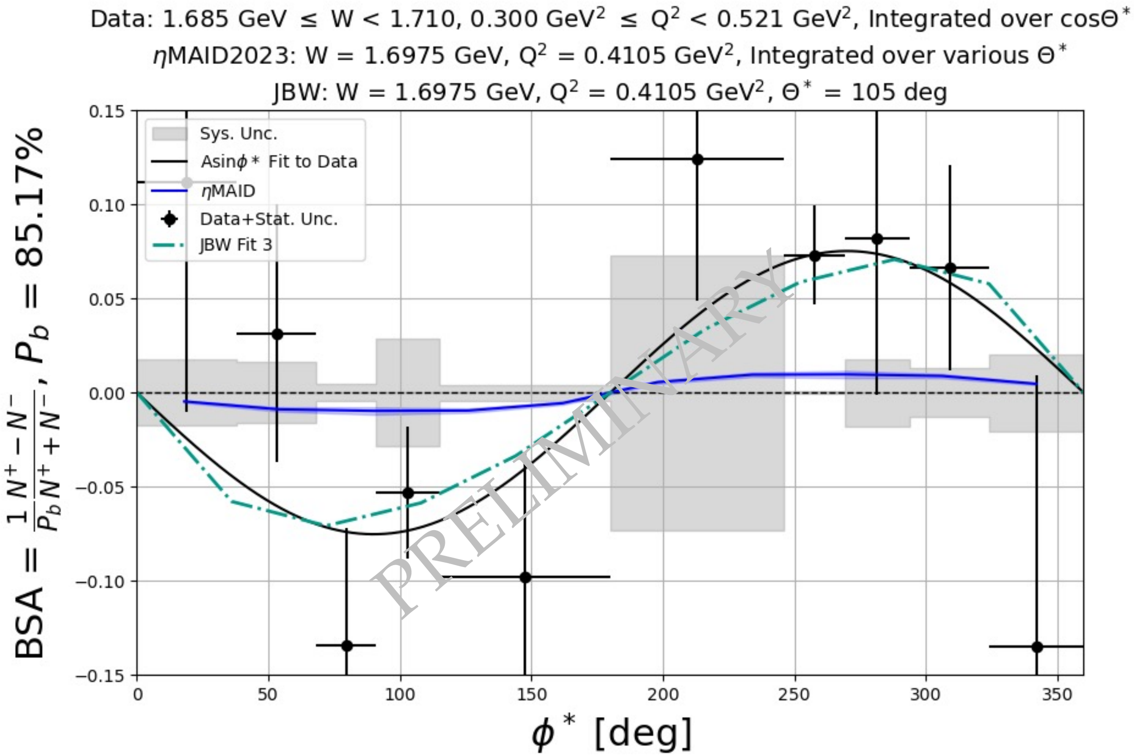
Bins in W, Q^2, and cosθ*: $A_{LU}^{\sin\phi*}$

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



Illustrative Example with Theoretical Models

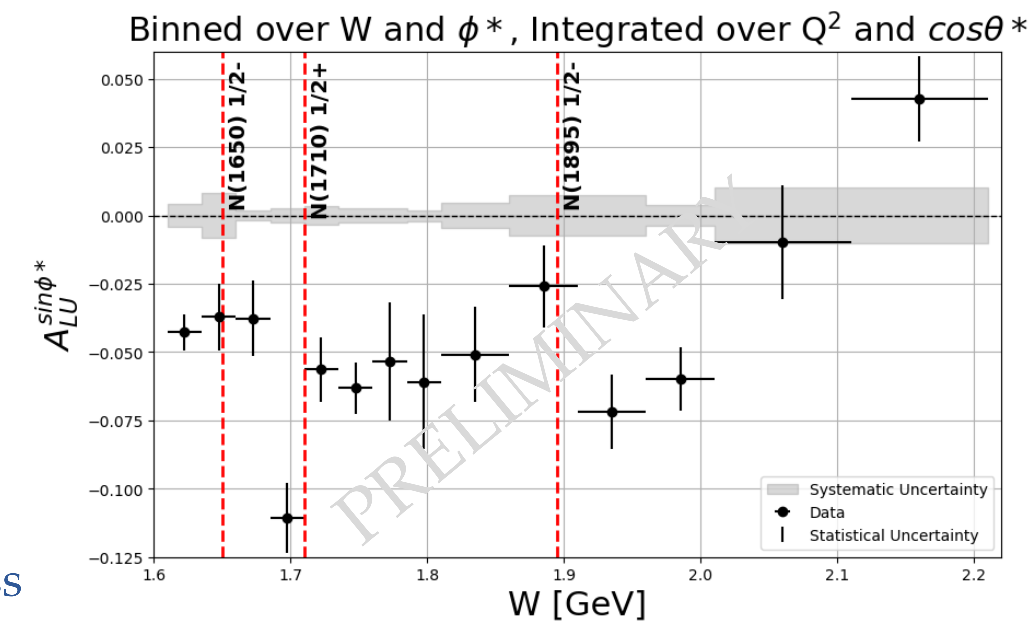
- Data binned over W, φ*, and Q² and integrated over cosθ*
- Jülich-Bonn-Washington (JBW)
- EtaMAID



- 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

- 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



EXTRA SLIDES

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Motivation

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- η acts as "isospin filter":
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- Current world database:
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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

Tables modified from PDG

Data: Run Group K

Experiments

- E12-16-010
  - A Search for Hybrid Baryons in Hall B with CLAS12
  - Annalisa D'Angelo
- E12-16-010
  - A Nucleon Resonance Structure Studies Via Exclusive KY Electroproduction at 6.6 GeV and 8.8 GeV
  - Daniel Carman
- E12-16-010B
  - Deeply Virtual Compton Scattering with CLAS12 at 6.6 GeV and 8.8 GeV
  - Latifa Elouadrhiri

A. D'Angelo, *Run Group K - Confinement and Strong QCD PASS2 Calibration Readiness Review*, Apr. 2022.

Data Status

- 4.0 PAC days
- Eb = 6.5 GeV
- Target: LH2
- Beam current: 60 nA
- Trigger: e in CLAS
- Luminosity: 1035 $cm^{-2}s^{-1}$ @ 6.5 GeV (Full Luminosity)
- Collected Events: 7.8G
- Torus Current: 100% (3375 A) (negative outbending)
- Solenoid -100%
- Polarized e, unpolarized LH2
- Target Center: x,y = 0cm, z = -3cm

What are we measuring? Spin Observables

Experiment

- Beam Spin Asymmetry:

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

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

- Sin φ* Moment:

$$BSA = \frac{A_{LU}^{\sin\phi^*}\sin\phi^*}{1 + A_{UU}^{\cos\phi^*}\cos\phi^* + A_{UU}^{\cos 2\phi^*}\cos 2\phi^*}$$

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

$N^\pm$ = signal yield for ±helicity
P_b = beam polarization (85.17%)

Theorists

- Structure Function:

$$\frac{1}{N_0}\sigma_0 = \sigma_T + \epsilon\sigma_L + \epsilon\cos 2\phi_h\sigma_{TT} + \sqrt{\epsilon(1+\epsilon)/2}\cos\phi_h\sigma_{LT} + h_e\sqrt{\epsilon(1-\epsilon)/2}\sin\phi_h\sigma'_{LT}$$

±1 = longitudinal beam polarization (anti-)parallel

$$N_0 = \frac{W^2 - M^2}{2S^2Q^2(1-\epsilon)}$$

- Beam Spin Asymmetry:

$$BSA = \frac{1}{P_b}\times\frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

$$= \frac{1}{P_b}\times\frac{\sqrt{2\epsilon(1-\epsilon)}\sin(\phi*)\sigma'_{LT}}{2\left(\sigma_T + \epsilon\sigma_L + \sqrt{\epsilon(1+\epsilon)/2}\cos\phi_h\sigma_{LT} + \epsilon\cos 2\phi_h\sigma_{TT}\right)}$$

- Sin φ* Moment:

$$A_{LU}^{\sin\phi^*} = \sqrt{2\epsilon(1-\epsilon)}\frac{\sigma_{LT'}}{\sigma_T + \epsilon\sigma_L}$$

$$\epsilon = \left[1 + 2\left(1 + \frac{\nu^2}{Q^2}\right)\tan^2\frac{\theta_e}{2}\right]^{-1}$$

$$\nu = E_e - E_{e'}$$

A. Afanasev, I. Akushevich, V. Burkert, and K. Joo, "QED radiative corrections in processes of exclusive pion electroproduction", Physical Review D **66**, 10.1103/physrevd.66.074004 (2002).

Extracting η → Event Selection Criteria (e and p)

- Cuts applied to run 5893

Before cuts applied

Particle Type	Location	Count
Electrons	FD	454544
Protons	FD+CD	196189
	FD	59409
	CD	136780

Details of each electron cut

Particle Type	Detector	Cut	Count	% Retained
Electrons	FD	PCAL Fiducial Cuts	454105	99.90%
		DC Fiducial Cuts	431126	94.85%
		chi2pid	451472	99.32%
		momentum	452852	99.63%
		z-vertex	401289	88.28%
		ECAL π contamination	444680	97.83%

After cuts applied

Description	Number	Percentage
Total final states before cuts	515269	100%
Final states after all cuts	141739	27.51%
Final states after all cuts with proton in FD	76298	53.83%
Final states after all cuts with proton in CD	65441	46.17%

Details of each proton cut

Particle Type	Detector	Cut	Count	% Retained
Protons	FD	DC Fiducial Cuts	59543	30.35%
		beta	58869	99.09%
		momentum	59016	99.34%
	CD	beta	136780	100.00%
		momentum	136780	100.00%
	FD+CD	chi2pid	187127	95.38%
		z-vertex	185806	94.71%
		beta	195649	99.72%
		momentum	195796	99.8%

- Analysis cuts: refining particle identification and enhancing sample purity
- Fiducial cuts: define the operational boundaries of the detectors

PCAL

- FX developed PCAL Fiducial Cuts for RGK Analysis Note

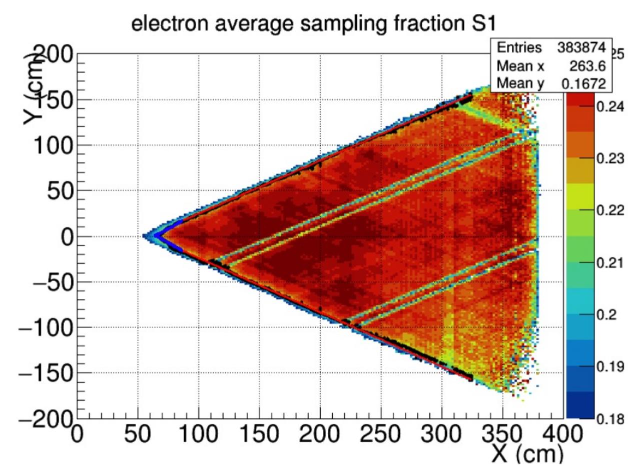
Algorithm 1: ECAL Fiducial cuts procedure

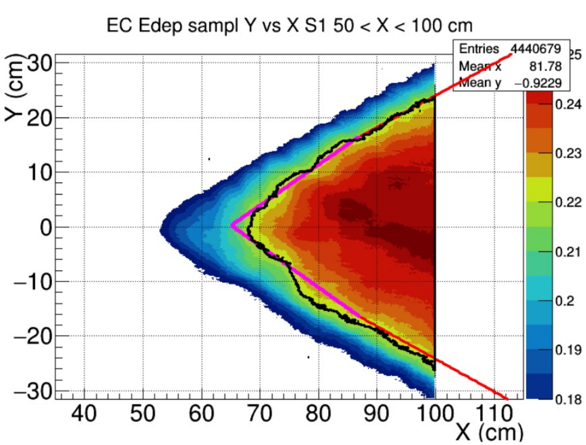
Result: boolean is true if position inside fiducial cuts
res ← false : return value of algorithm;
cX ← PCAL X coordinate of cluster from REC::Calorimeter hipo bank;
cY ← PCAL Y coordinate of cluster from REC::Calorimeter hipo bank;
S ← sector number;
if $cX > p_{split}$ **and** $cY < s_{left} \times (cX - t_{left})$ **and** $cY > s_{right} \times (cX - t_{right})$ **then**
  res ← true;
else if $cX < p_{split}$ **and** $cY < q_{left} \times (cX - r_{left})$ **and** $cY > q_{right} \times (cX - r_{right})$ **then**
  res ← true;

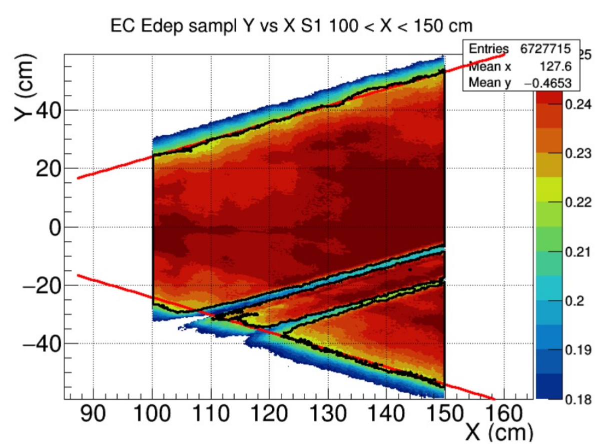
sector	1	2	3	4	5	6
p_{split}	87	82	85	77	78	82
t_{left}	58.7356	62.8204	62.2296	53.7756	58.2888	54.5822
t_{right}	58.7477	51.2589	59.2357	56.2415	60.8219	49.8914
s_{left}	0.582053	0.544976	0.549788	0.56899	0.56414	0.57343
s_{right}	-0.591876	-0.562926	-0.562246	-0.563726	-0.568902	-0.550729
r_{left}	64.9348	64.7541	67.832	55.9324	55.9225	60.0997
r_{right}	65.424	54.6992	63.6628	57.8931	56.5367	56.4641
q_{left}	0.745578	0.606081	0.729202	0.627239	0.503674	0.717899
q_{right}	-0.775022	-0.633863	-0.678901	-0.612458	-0.455319	-0.692481

Table 9: ECAL fiducial cut parameters

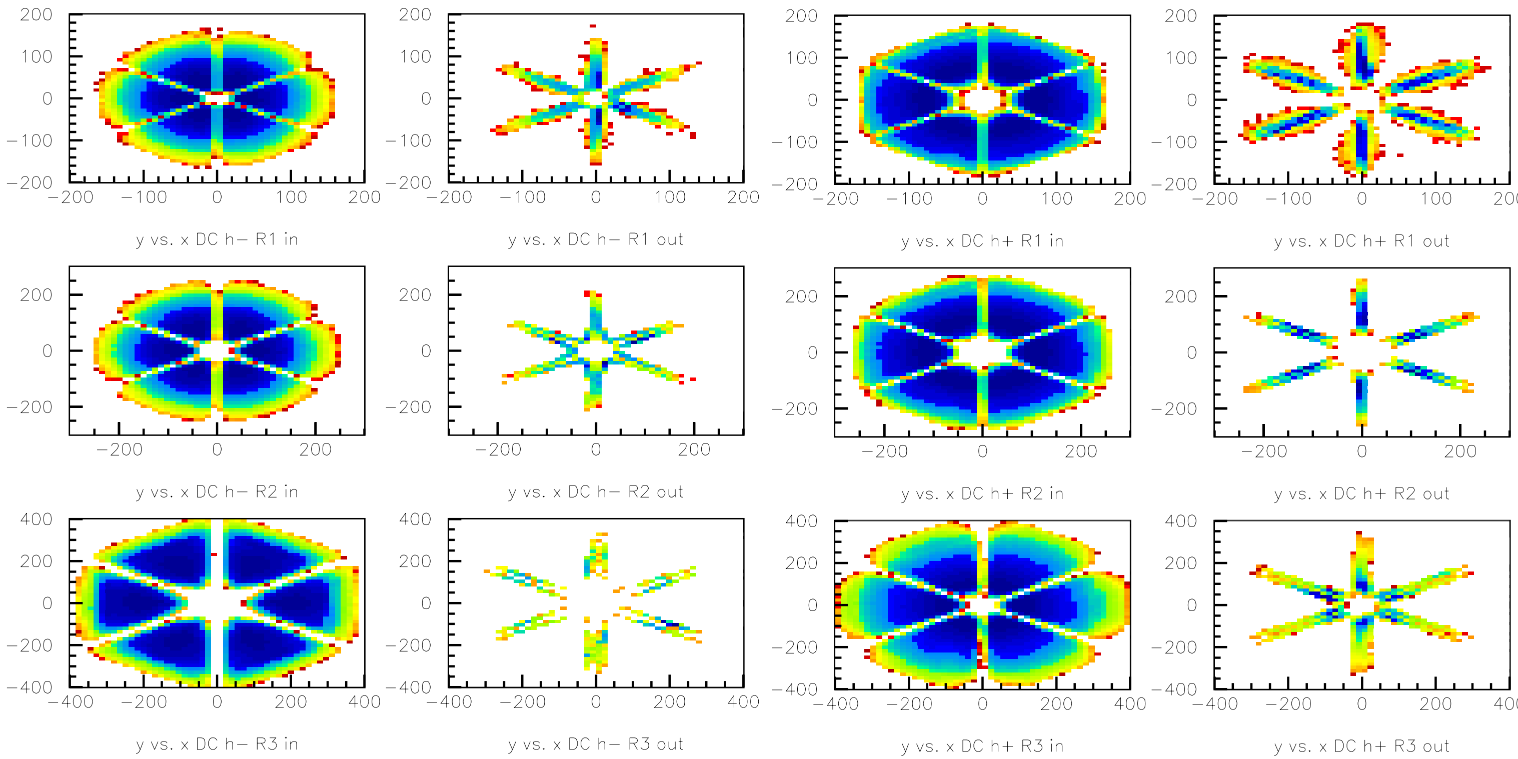
- **Developed using weight of average sampling fraction < Etot / p >**







DC



	h-		h+	
R1	$y \leq$	$0.556 \cdot x - 6.878$	$y \leq$	$0.610 \cdot x - 12.720$
	$y \geq$	$-0.560 \cdot x + 7.482$	$y \geq$	$-0.604 \cdot x + 12.159$
	$x \geq$	24.052	$x \geq$	38.02
R2	$y \leq$	$0.578 \cdot x - 13.898$	$y \leq$	$0.573 \cdot x - 13.949$
	$y \geq$	$-0.577 \cdot x + 14.851$	$y \geq$	$-0.569 \cdot x + 13.891$
	$x \geq$	39.705	$x \geq$	54.88
R3	$y \leq$	$0.591 \cdot x - 27.459$	$y \leq$	$0.527 \cdot x - 11.998$
	$y \geq$	$-0.588 \cdot x + 26.912$	$y \geq$	$-0.530 \cdot x + 13.372$
	$x \geq$	77.755	$x \geq$	49.0

- The plots show events inside and outside of fiducial volume
- Left: positively charged particles
- Right: negatively charged particles

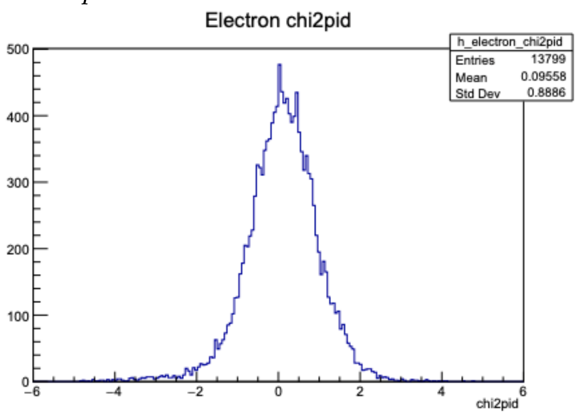
RGK Analysis Note

- Charged hadron & electron fiducial cuts in FD using reconstructed (x, y) point of trajectory in DC
- R1 (layer 6), R2 (layer 18), and R3 (layer 36)
- Uses fiducial cuts algorithm developed by Stefan Diehl for RG-A analysis

chi2pid

- For electrons/positrons: "The electron 'chi2pid' value…is an event builder quality factor that quantifies how closely the expected and calculated sampling fractions are, as shown by the formula below where σ_p is the resolution of the sampling fraction," (Newton 2021)

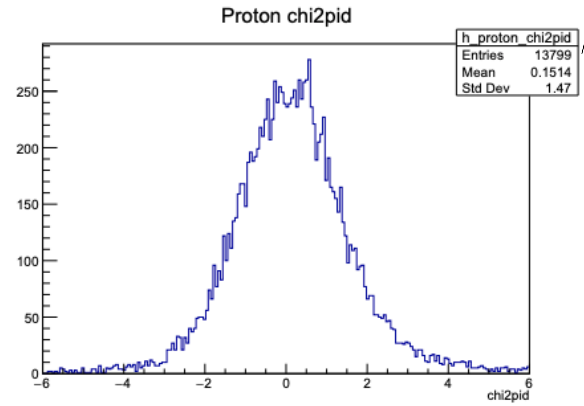
$$\chi^2 = \frac{\mathrm{SF}_{\mathrm{meas}}(E) - \mathrm{SF}_{\mathrm{calc}}(E)}{\sigma_p}$$

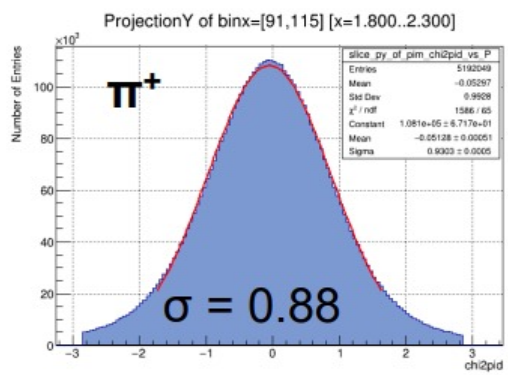


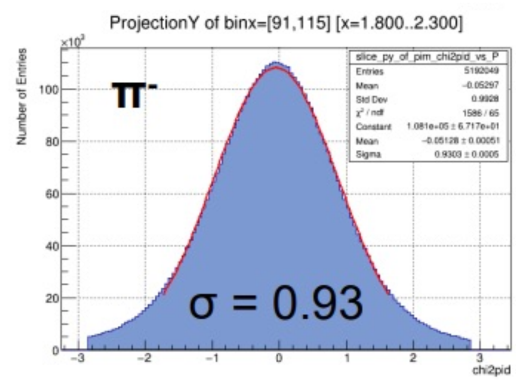
- For hadrons: "…quality factory based off of the difference of the vertex times and the expected timing resolution, which is dependent on the FTOF layer and component." (Newton 2021)

$$\Delta t_i = t_0 - \left[t_{\mathrm{FTOF}} - \frac{L}{\beta_i(p)}\right], \quad i = \pi/K/p/d...$$

$$\beta_i(p) = \frac{p}{\sqrt{p^2 + m_i^2}}$$

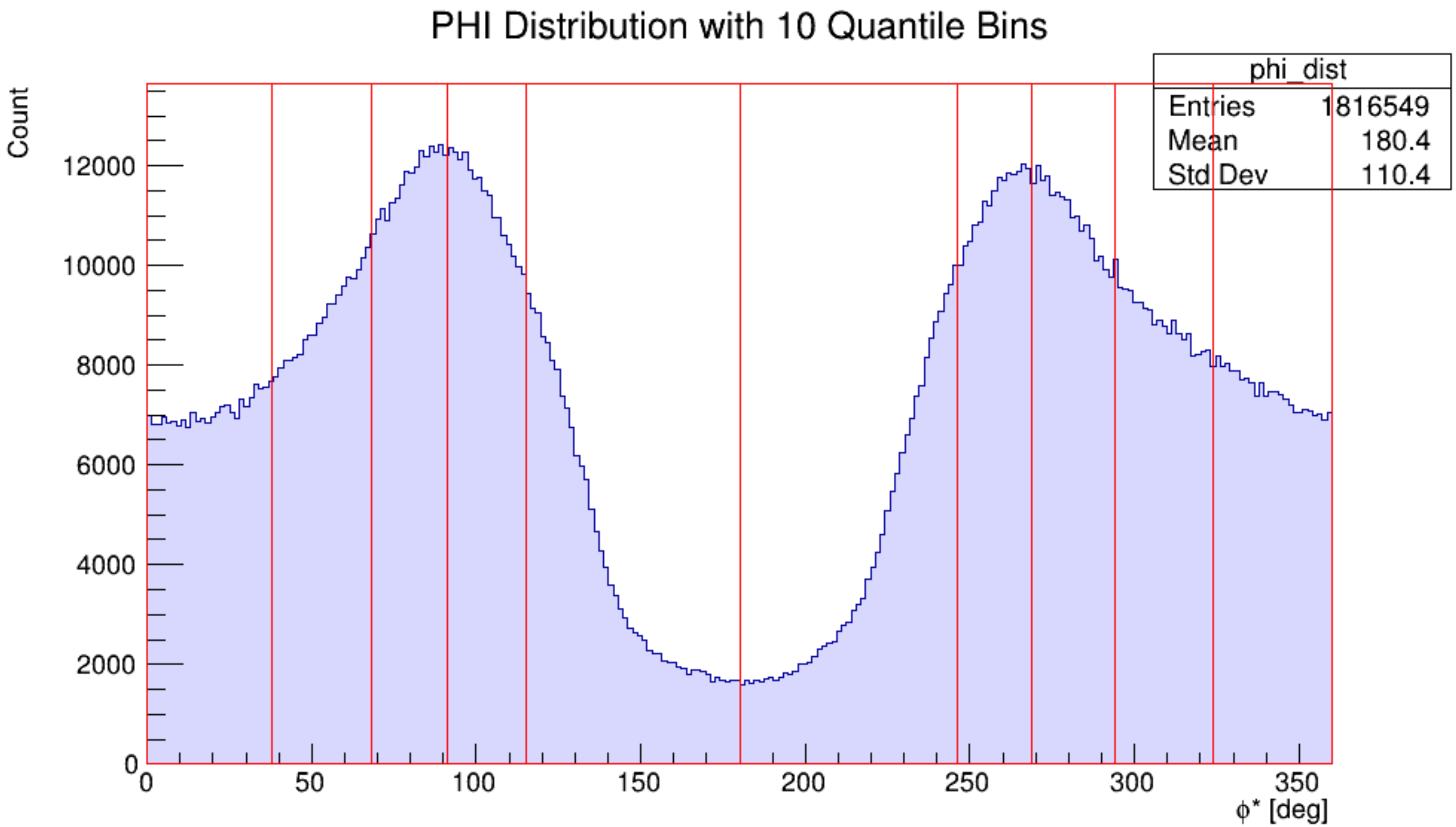






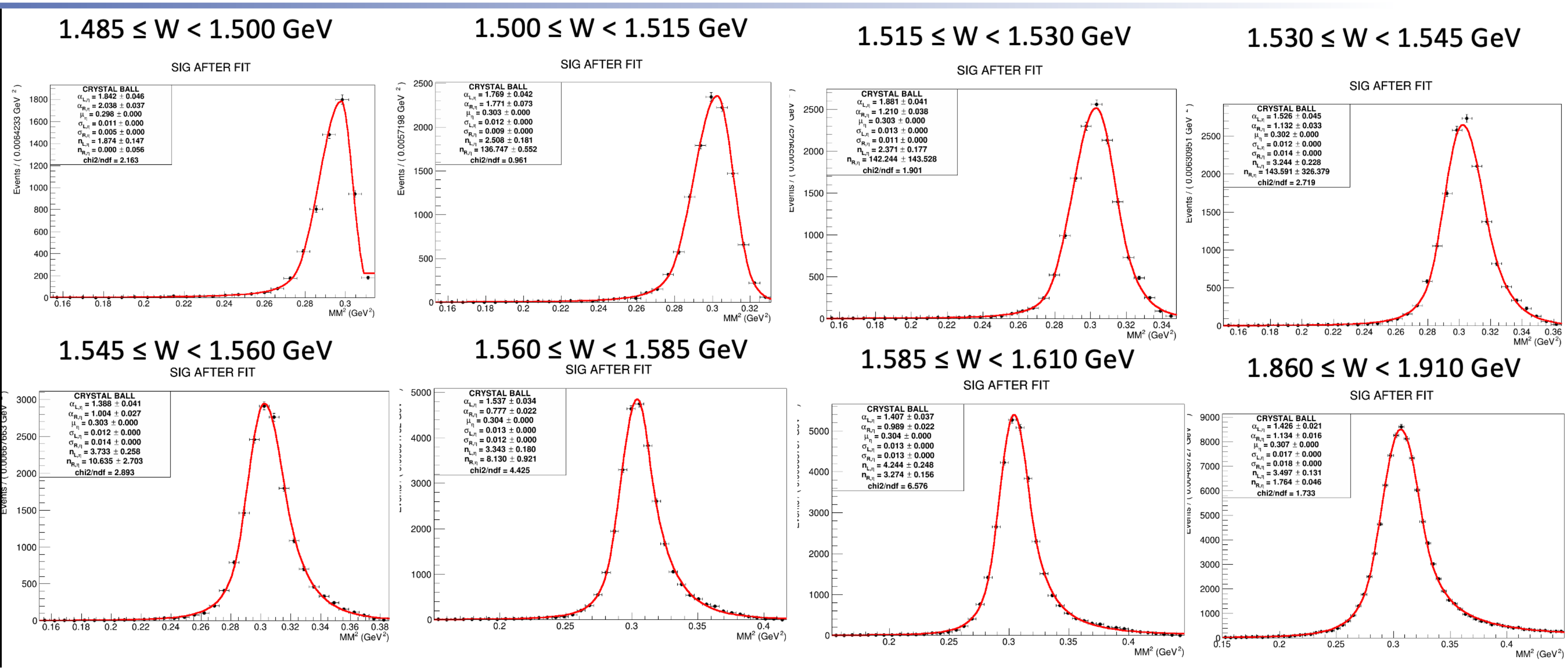
1. N. Baltzell, "Event Builder Status", (CLAS Collaboration, July 2018).
2. S. Diehl, "Particle Identification and Fiducial Volumes for the First SIDIS Publications", (CLAS Collaboration, July 2020).
3. J. Newton, "J/ψ Photoproduction Near Threshold With CLAS12", PhD thesis (Old Dominion University, 2021).

φ* bins



- 10 φ* bins with equal number of events
- Bin edges = 0, 38, 68, 91, 115, 180, 246, 269, 294, 324, 360 degrees

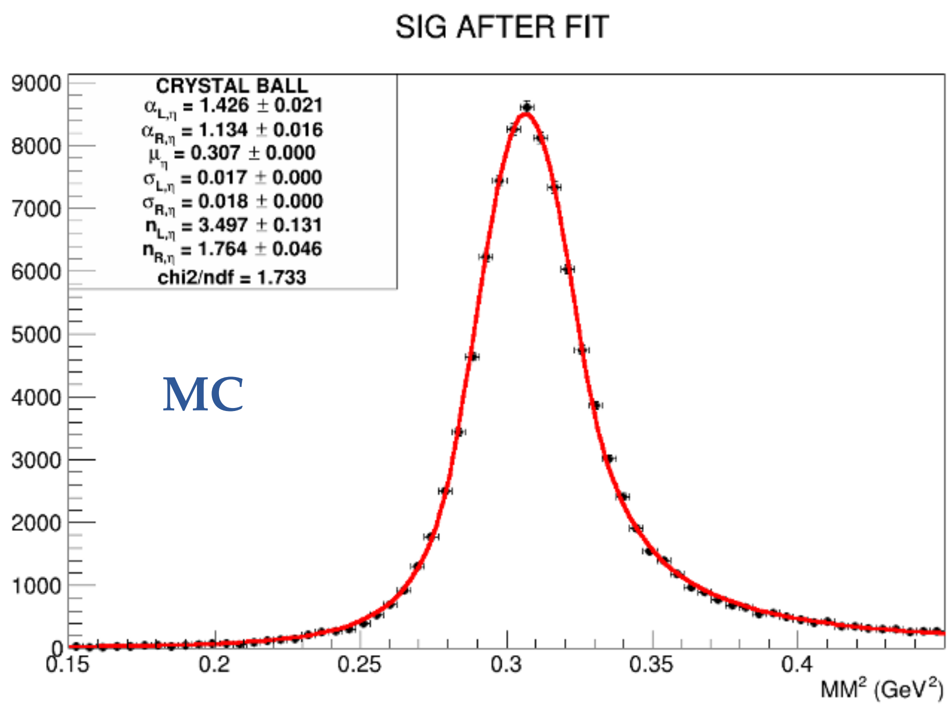
Monte Carlo Simulations: Signal

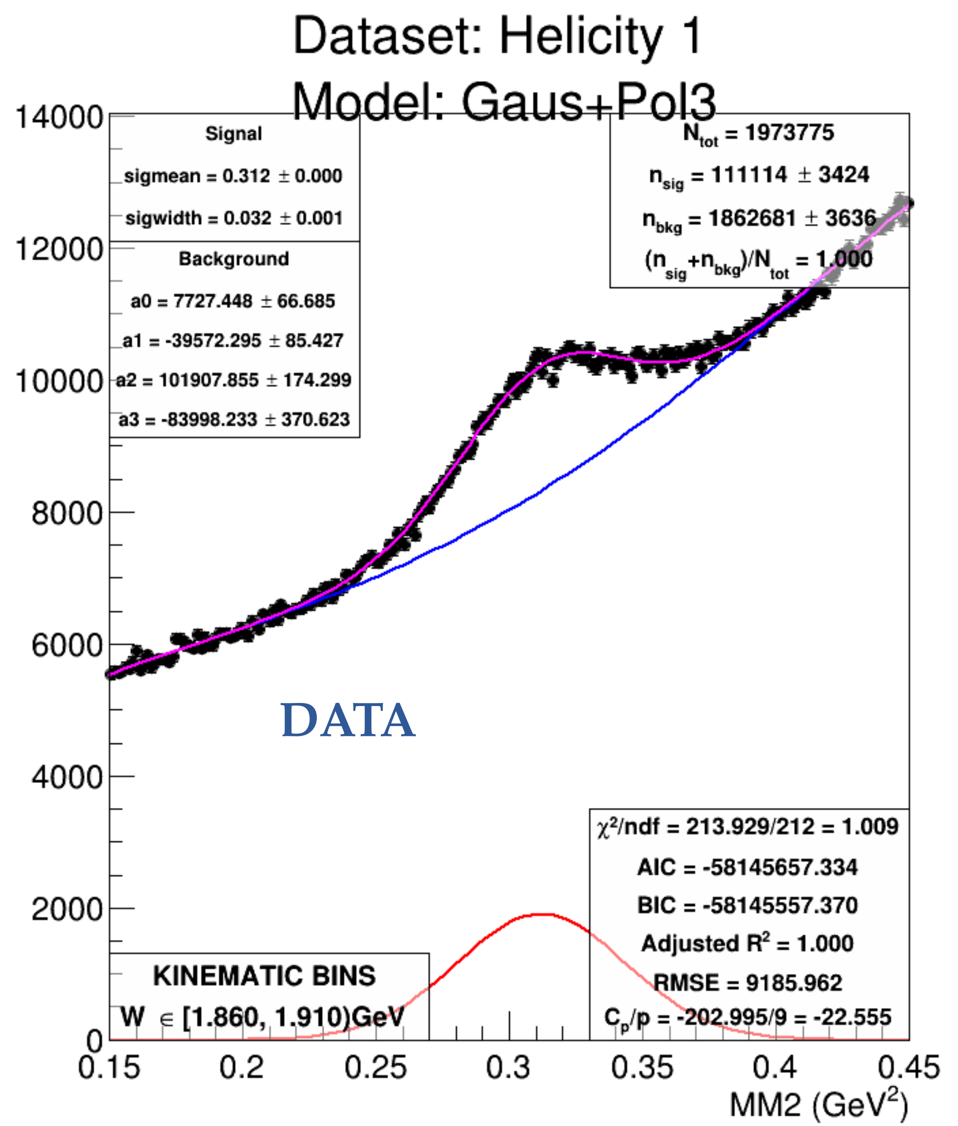


- clas12elspectro
- Reaction channel: ep→e′p′η
- Signal only
- Background Merging included

MC vs Data

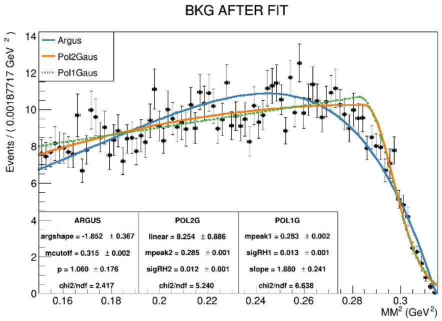
1.860 ≤ W < 1.910 GeV



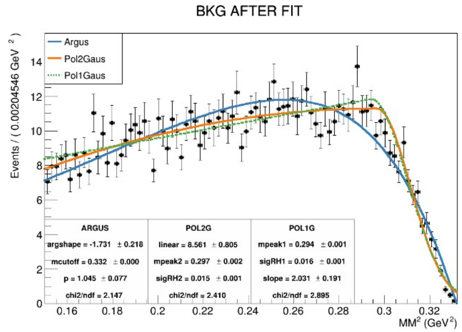


Monte Carlo Simulations: Background

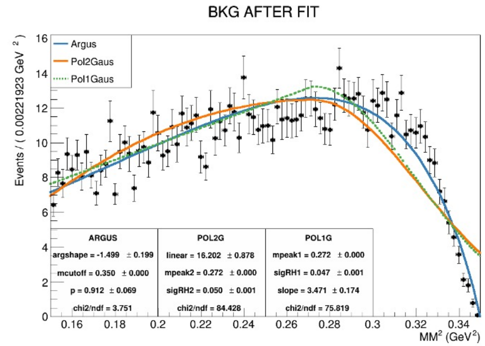
$1.485 \le W < 1.500$ GeV



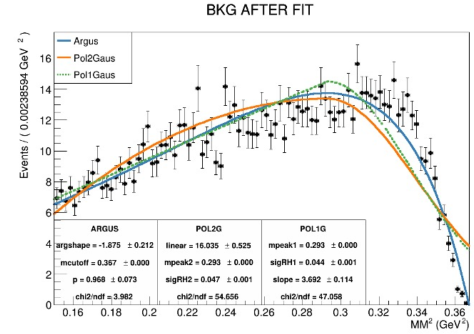
$1.500 \le W < 1.515$ GeV



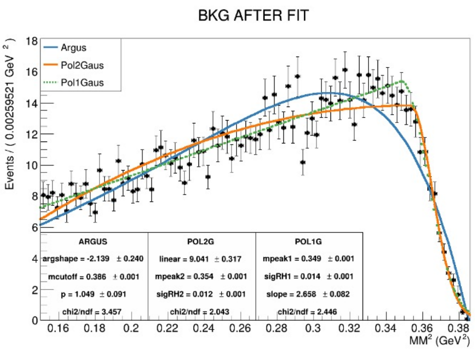
$1.515 \le W < 1.530$ GeV



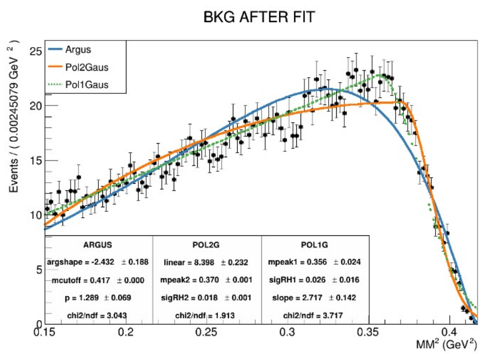
$1.530 \le W < 1.545$ GeV



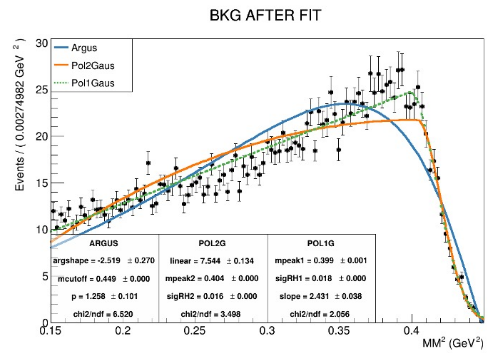
$1.545 \le W < 1.560$ GeV



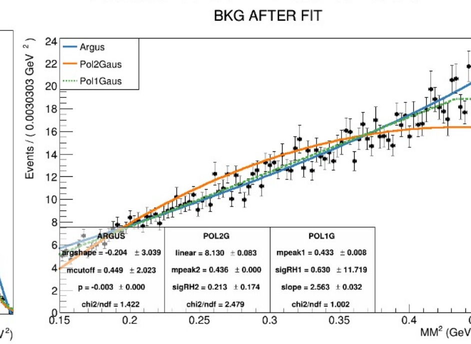
$1.560 \le W < 1.585$ GeV



$1.585 \le W < 1.610$ GeV



$1.860 \le W < 1.910$ GeV

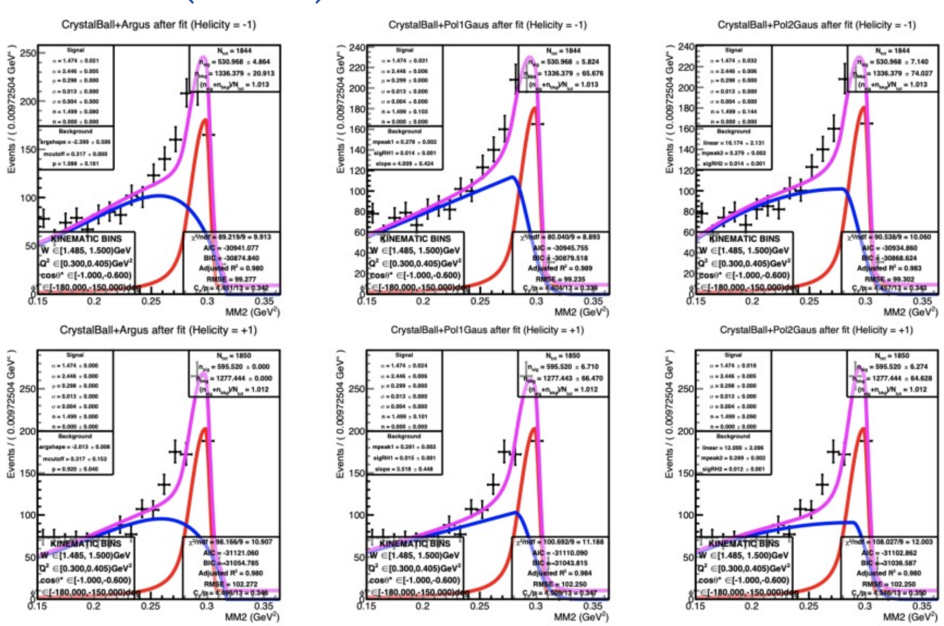


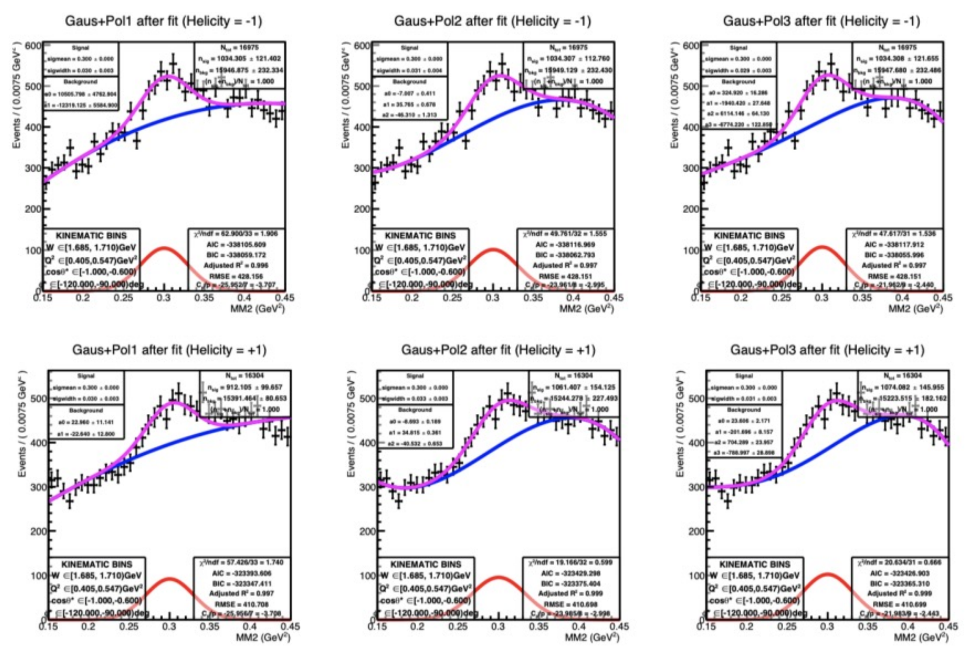
- TWOPEG
- 2pion background
- Background Merging included

Model Fitting: Extracting η Yields

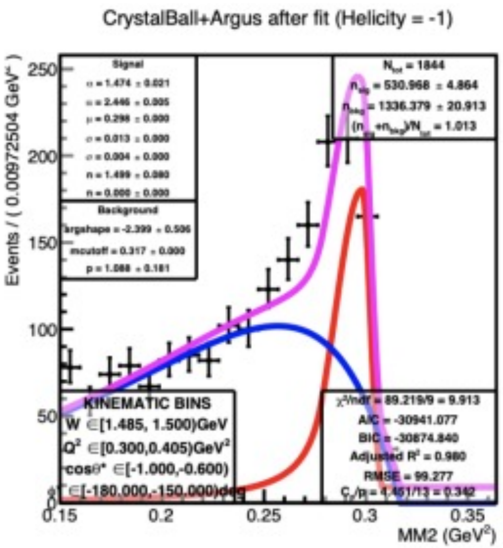
- 1.486 GeV ≤ W < 1.610 GeV
- Asymmetric missing mass2 distribution due to near η production threshold behavior
- Special models developed
- Majority of η data focuses on S11(1535)

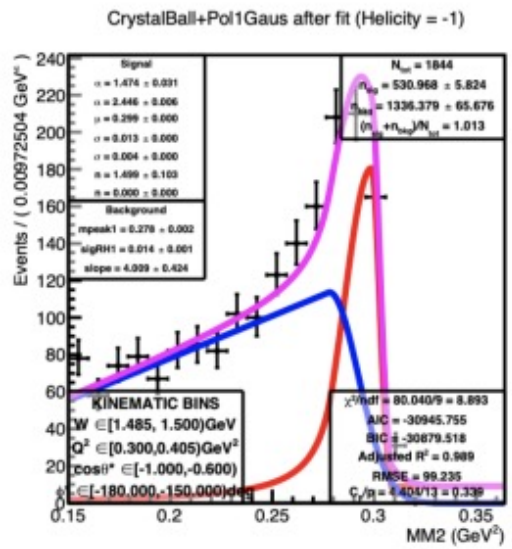
- 1.610 GeV ≤ W < 2.210 GeV
- Background symmetric under the signal
- Can use relatively simple total model of Gaussian signal + polynomial background

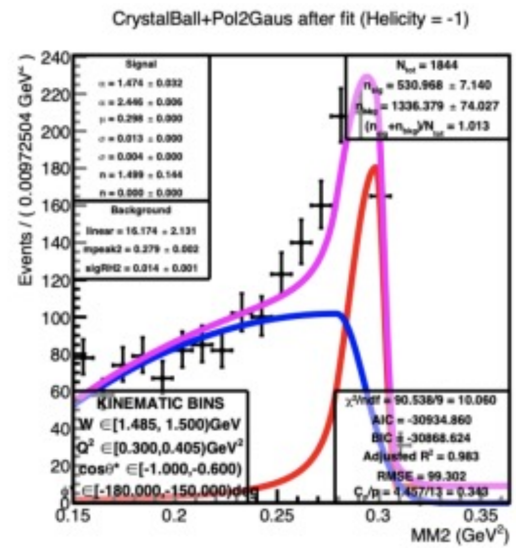


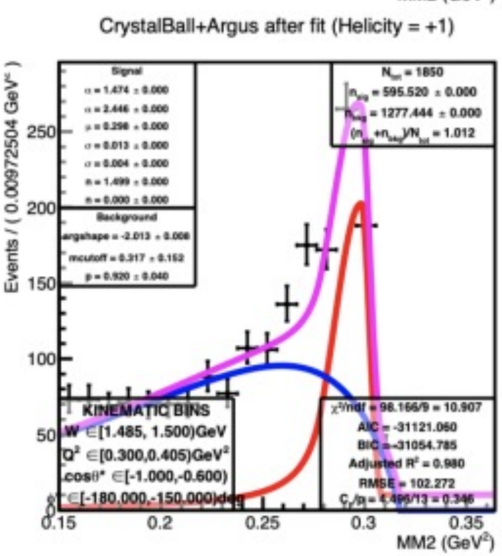


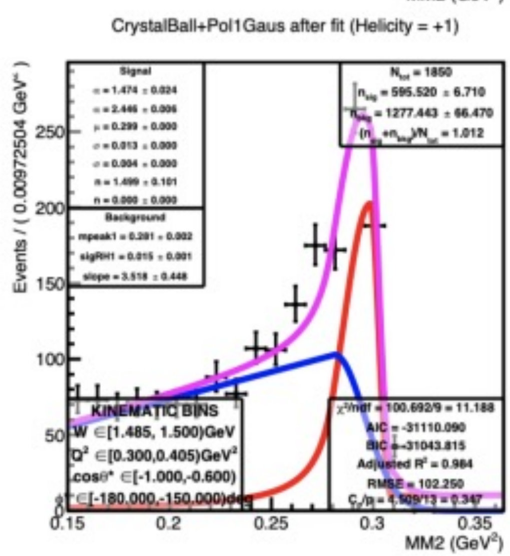
Near production threshold

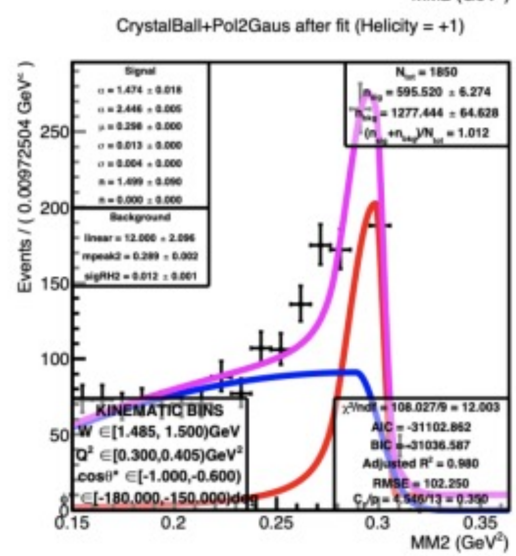












MM2 fit to φ* bins

W in [1.685, 1.710) GeV

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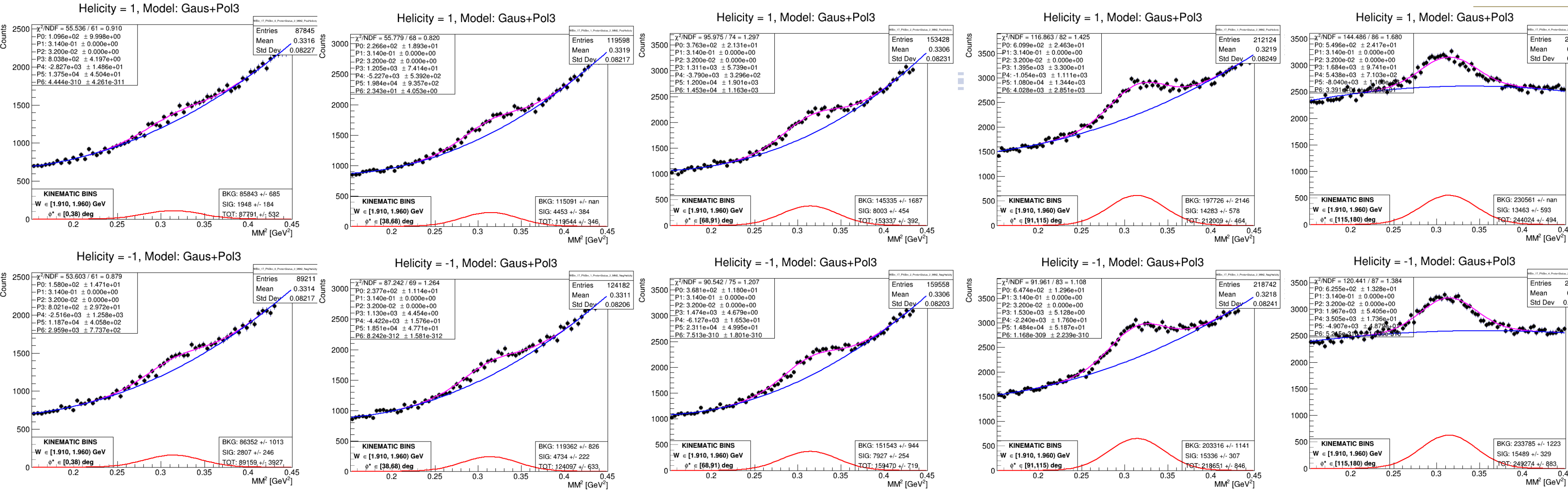
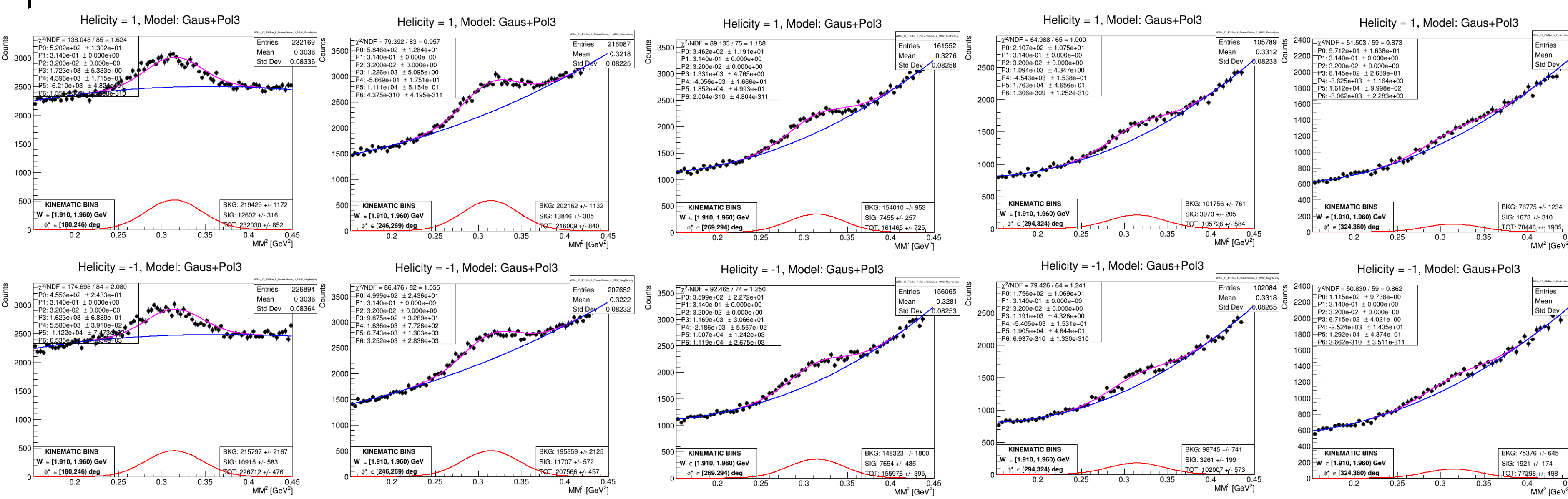


[0, 38) deg [38, 68) deg [68, 91) deg [91, 115) deg [115, 180) deg

φ*

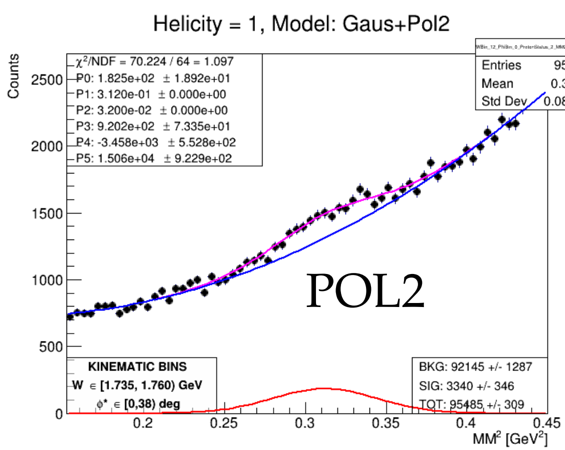


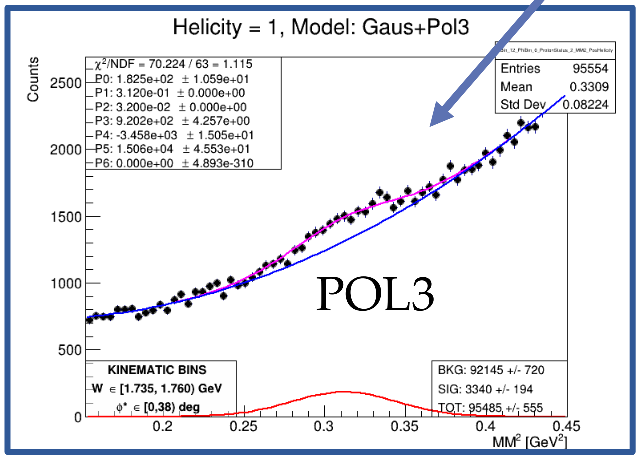
[180, 246) deg [246, 269) deg [269, 294) deg [294, 324) deg [324, 360) deg

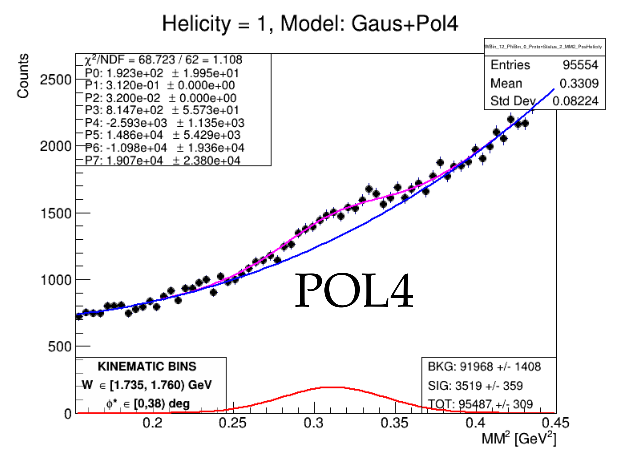
Quality of MM2 Fits

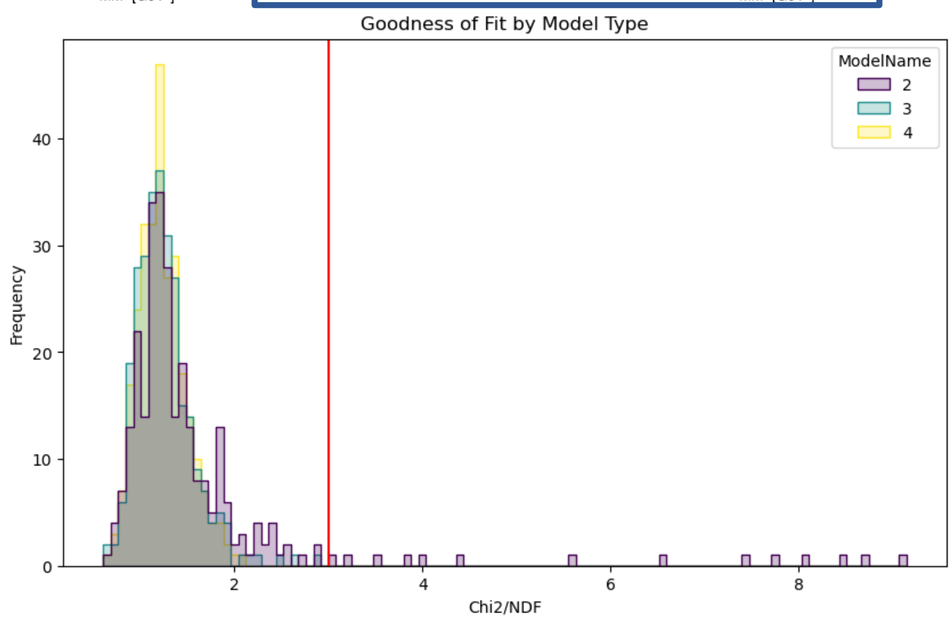
- Going forward: cut fits to MM2 where chi2/ndf > 3

pol3 as benchmark

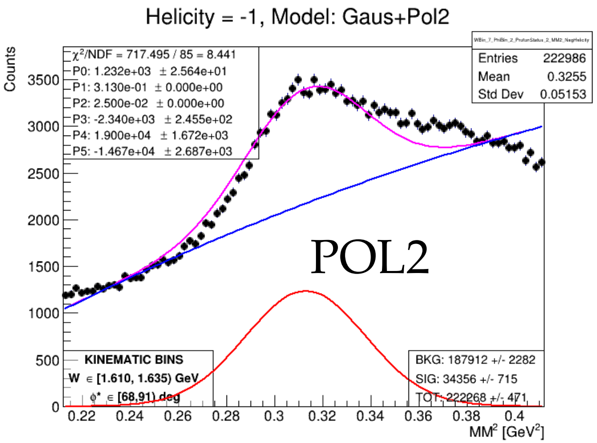


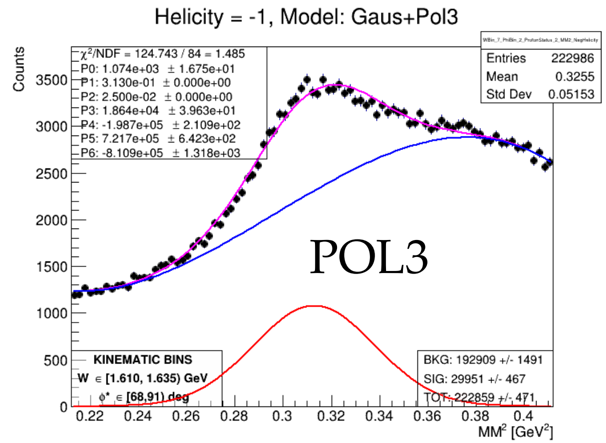


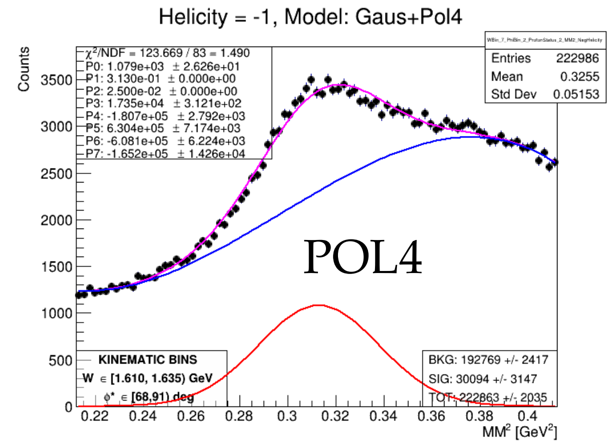


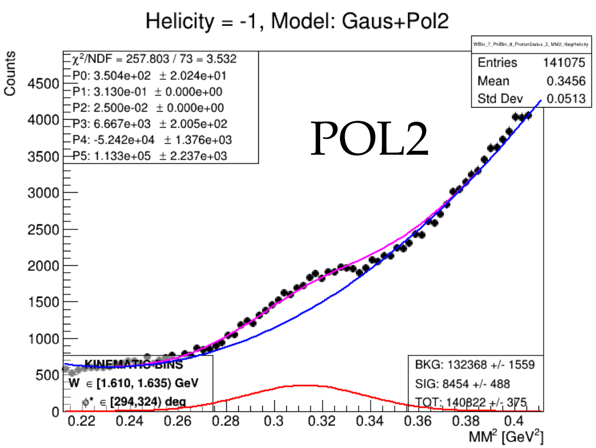


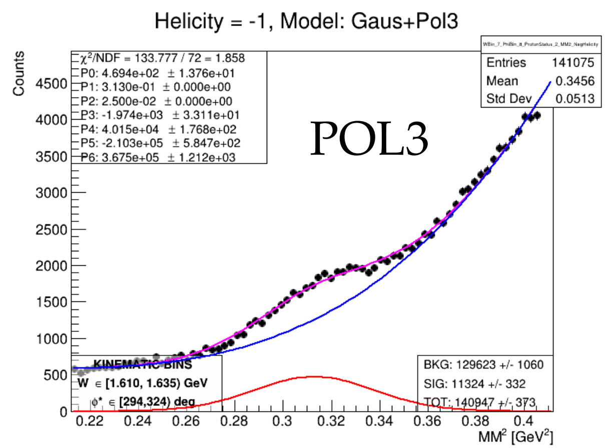
Comparison of pol background fits

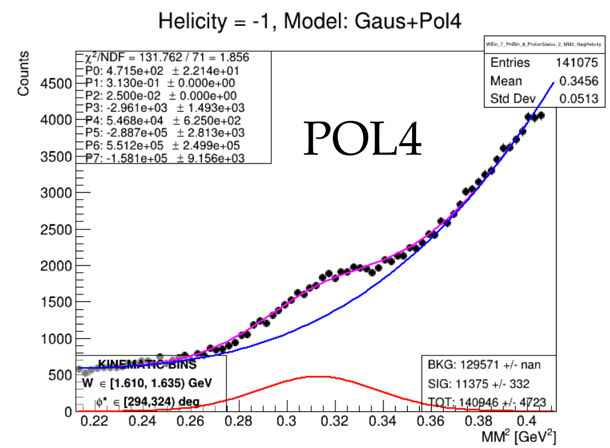












Systematic Uncertainty Calculation

- Use results from pol3 as "benchmark"
- Calculate Mean Absolute Error (MAE)
  - Average absolute difference between predicted and observed values
  - Evaluate the average absolute deviation of data points from different fitting models (pol2, pol3, pol4) against the benchmark model (pol3)
  - Focuses on the average magnitude of errors
  - Less sensitive to outliers than (R)MSE (Root Mean Squared Error)

$$\mathrm{MAE} = \frac{1}{N}\sum_{i=1}^{N} \left|Y_{\mathrm{benchmark}} - Y_{\mathrm{model},i}\right|$$

Beam Spin Asymmetry: η signal

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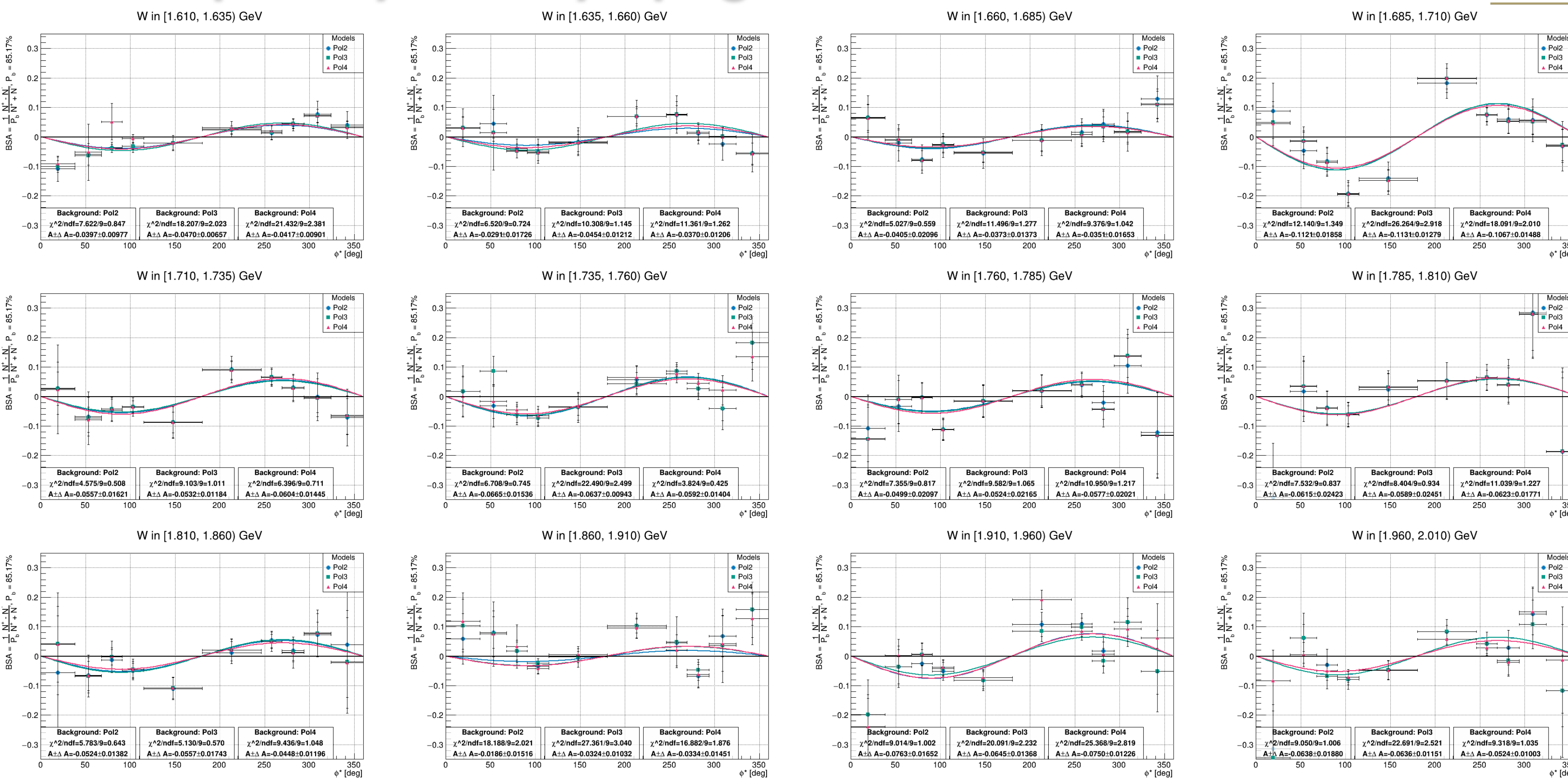
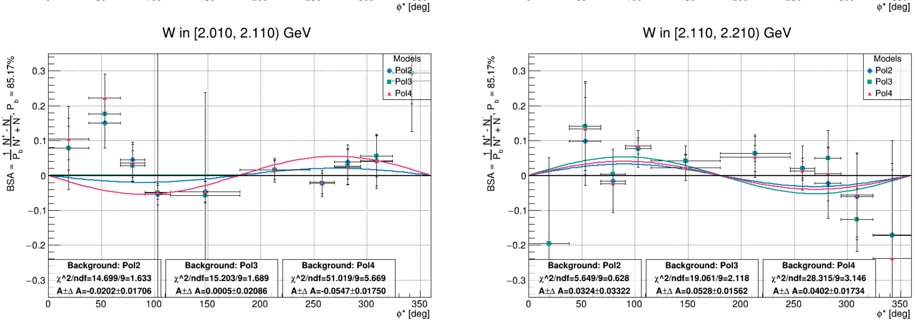
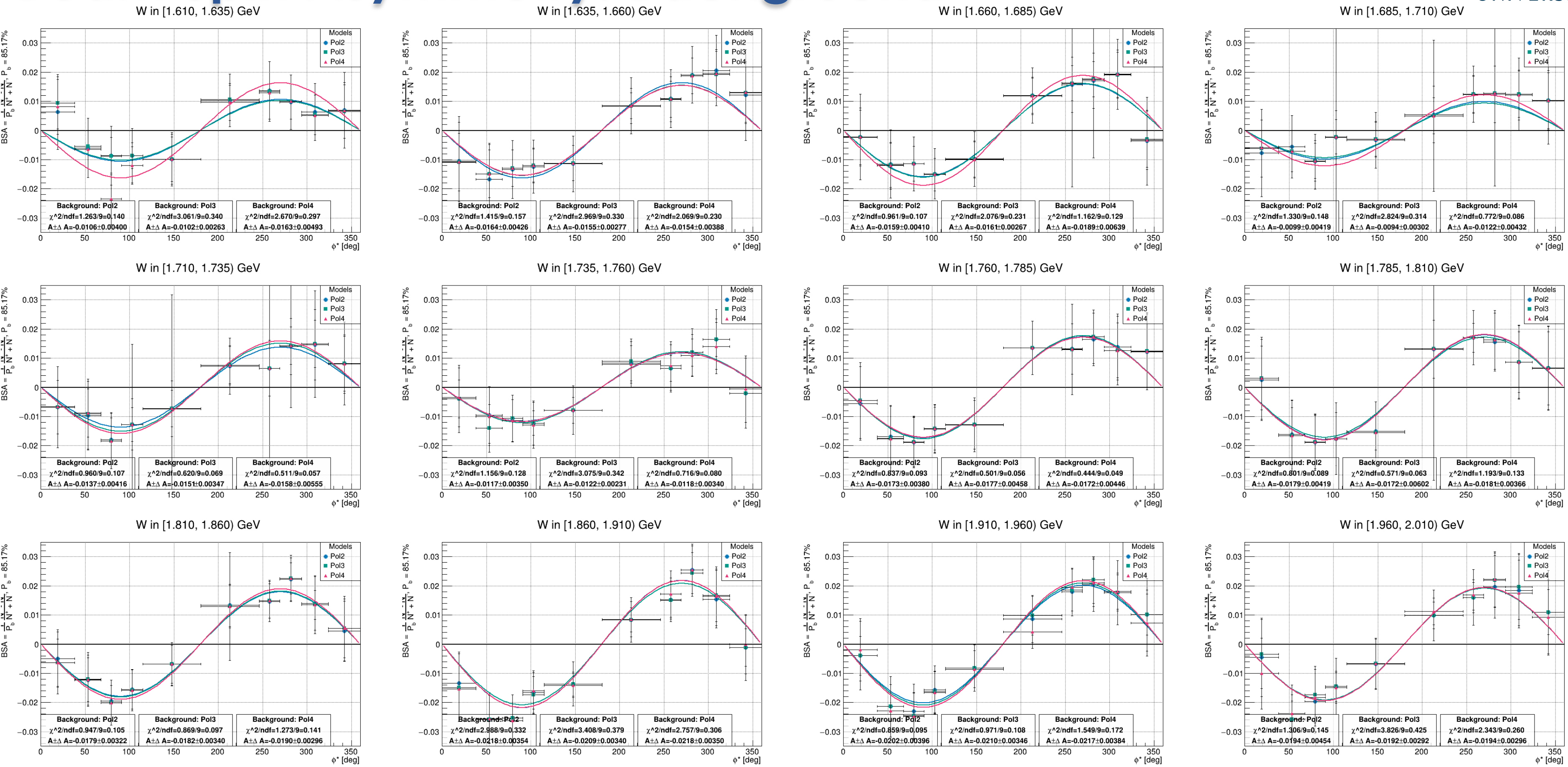
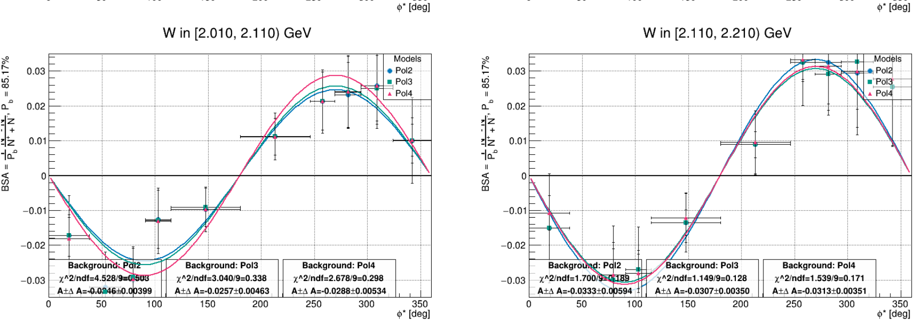




- **Data binned over W and φ***
- **Data integrated over Q² and cosθ***
- Background: pol2 pol3 pol4
- BSA y range ±0.35
- Asinφ* fit

Beam Spin Asymmetry: Background





- Data binned over W and φ*
- Data integrated over Q^2 and cosθ*
- Background: pol2 pol3 pol4
- BSA y range ±0.035
- Asinφ* fit

Beam Spin Asymmetry: Background

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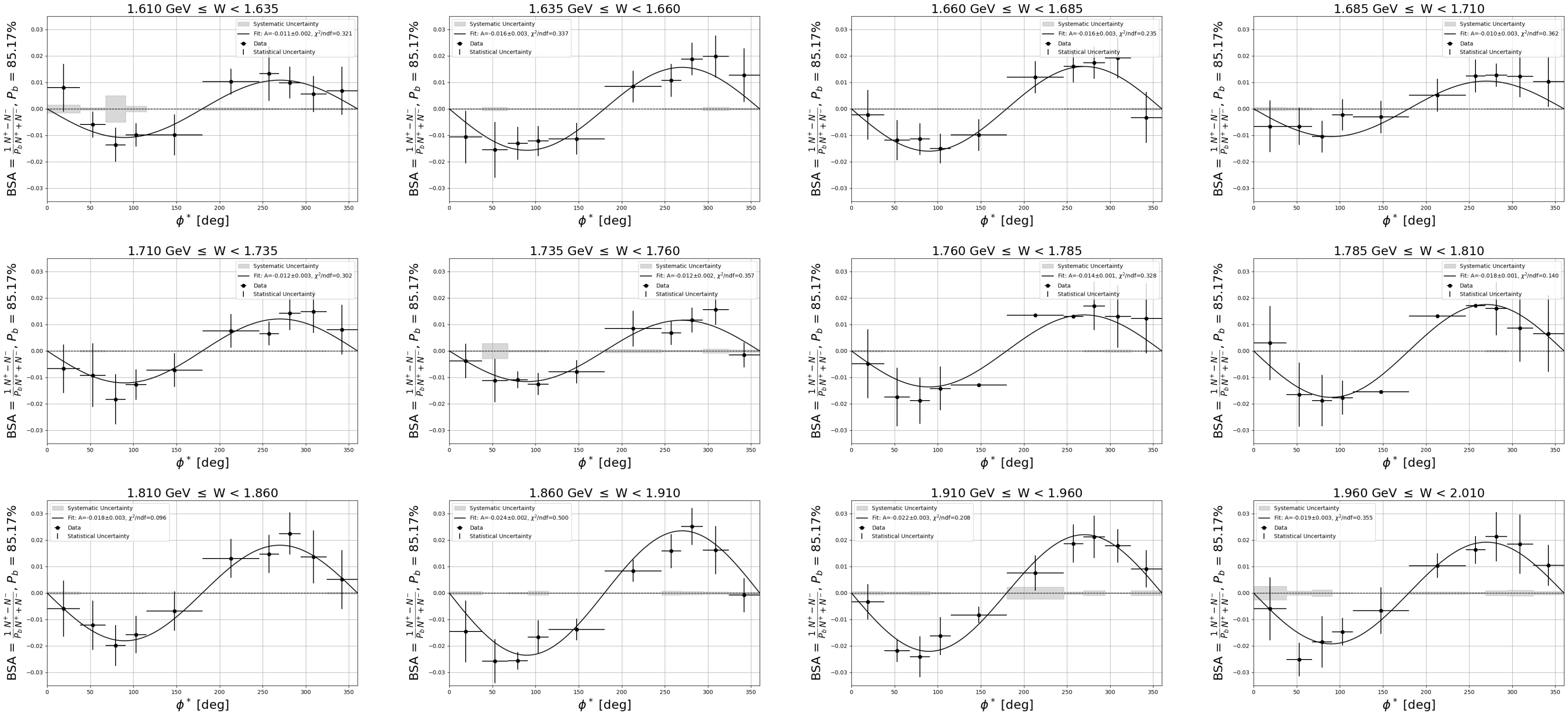
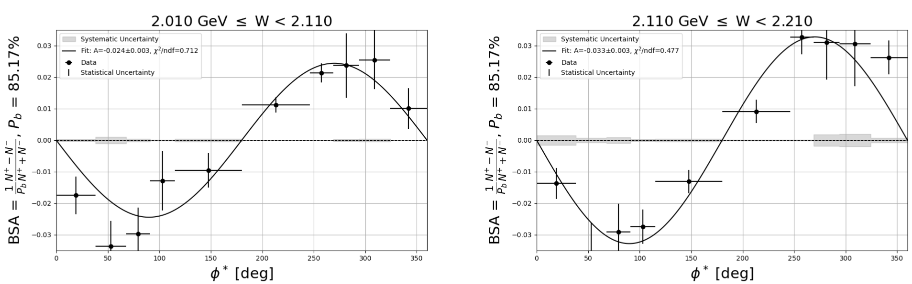
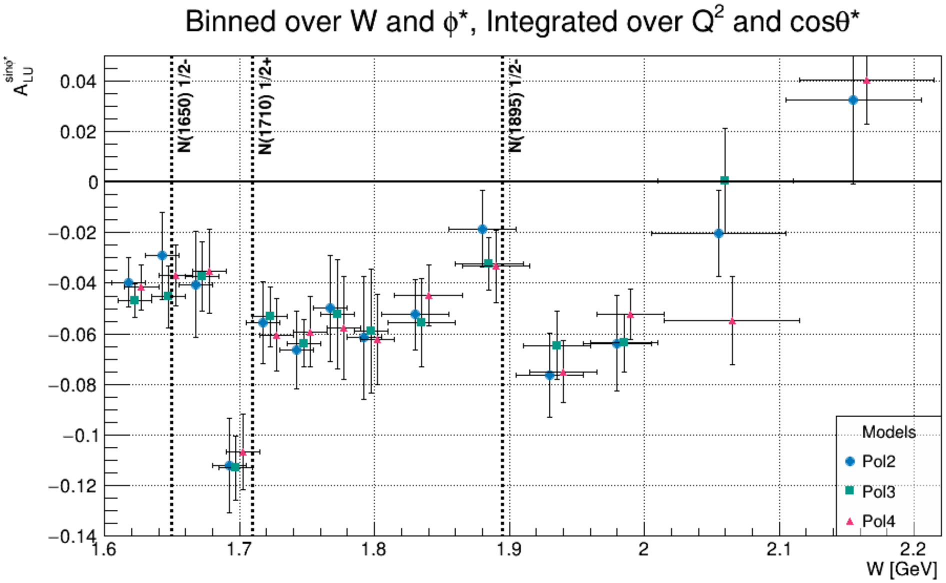


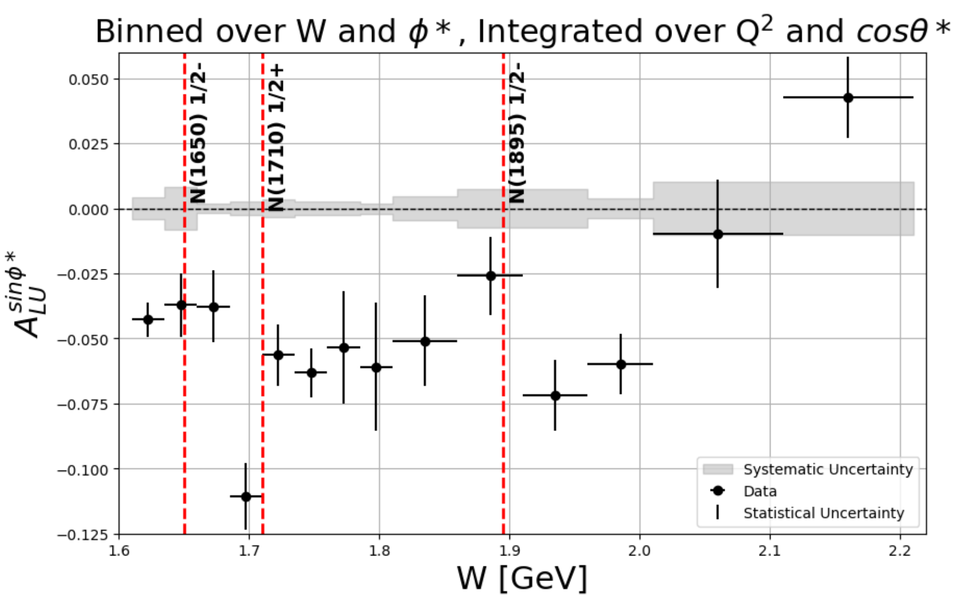


- Data binned over W and φ*
- Data integrated over Q^2 and cosθ*
- Error bars: statistical uncertainty
- Grey histograms around zero line: systematic uncertainty
- BSA y range ±0.035
- Asinφ* fit

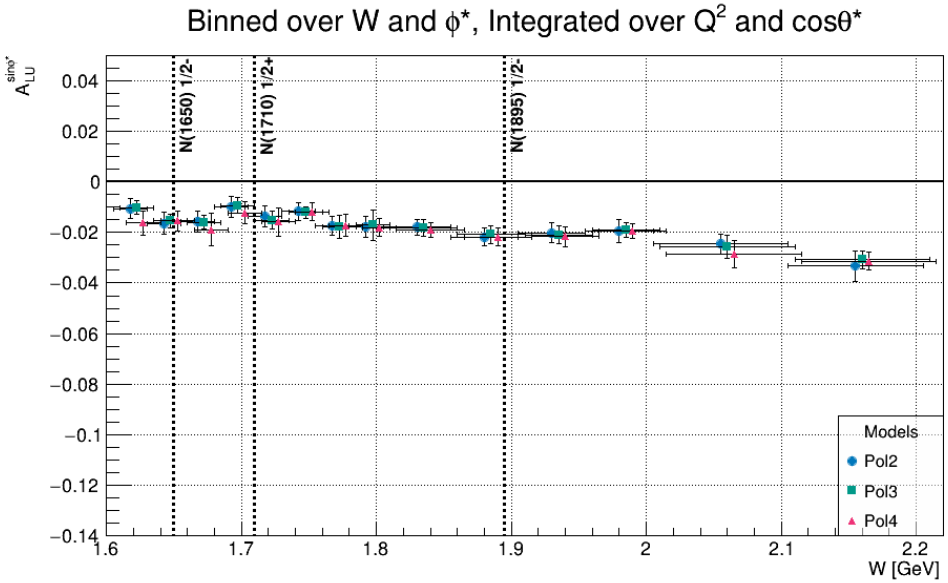
Sin moment of the asymmetry $A_{LU}^{\sin\varphi^*}$: η signal



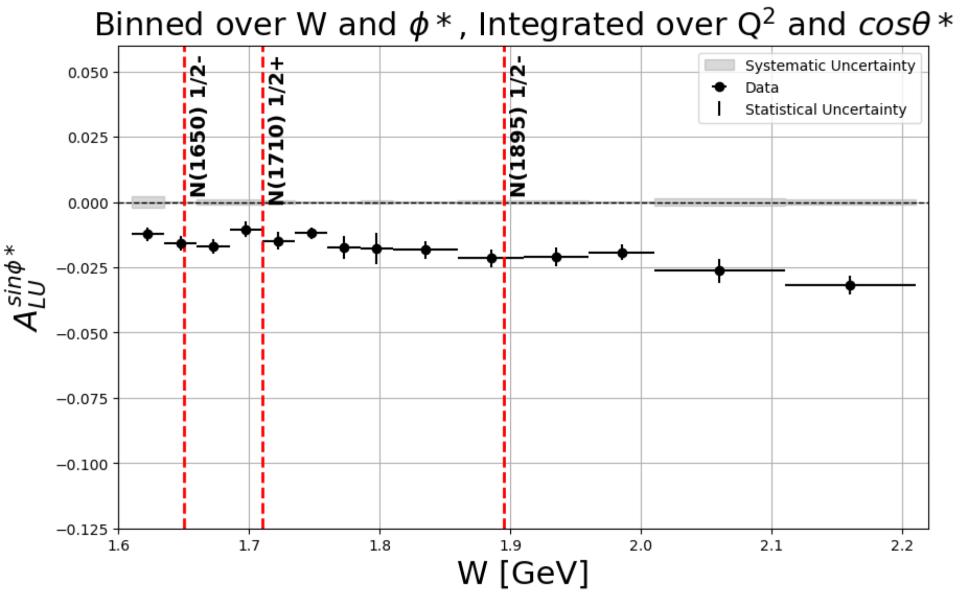
- **Data binned over W and φ***
- **Data integrated over Q² and cosθ***
- Error bars: statistical uncertainty
- Grey histograms around zero line: systematic uncertainty
- Results from Asinφ* fit to BSA



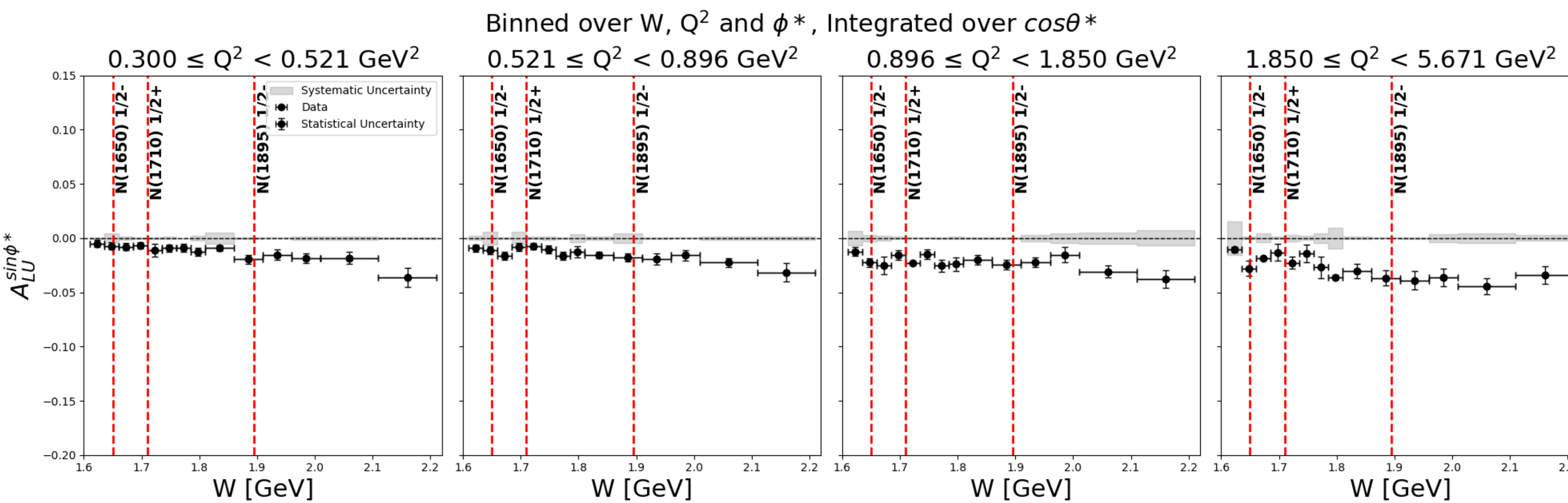
Sin moment of the asymmetry $A_{LU}^{\sin\varphi^*}$: Background



- **Data binned over W and φ***
- **Data integrated over Q² and cosθ***
- Error bars: statistical uncertainty
- Grey histograms around zero line: systematic uncertainty
- Results from Asinφ* fit to BSA



Bins in W and Q²: $A_{LU}^{\sin\varphi^*}$



Increasing Q² bins

- **Data binned over W, φ*, and Q²**
- **Data integrated over cosθ***
- Error bars: statistical uncertainty
- Grey histograms around zero line: systematic uncertainty

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

Comparison to Jülich-Bonn-Washington (JBW) Model

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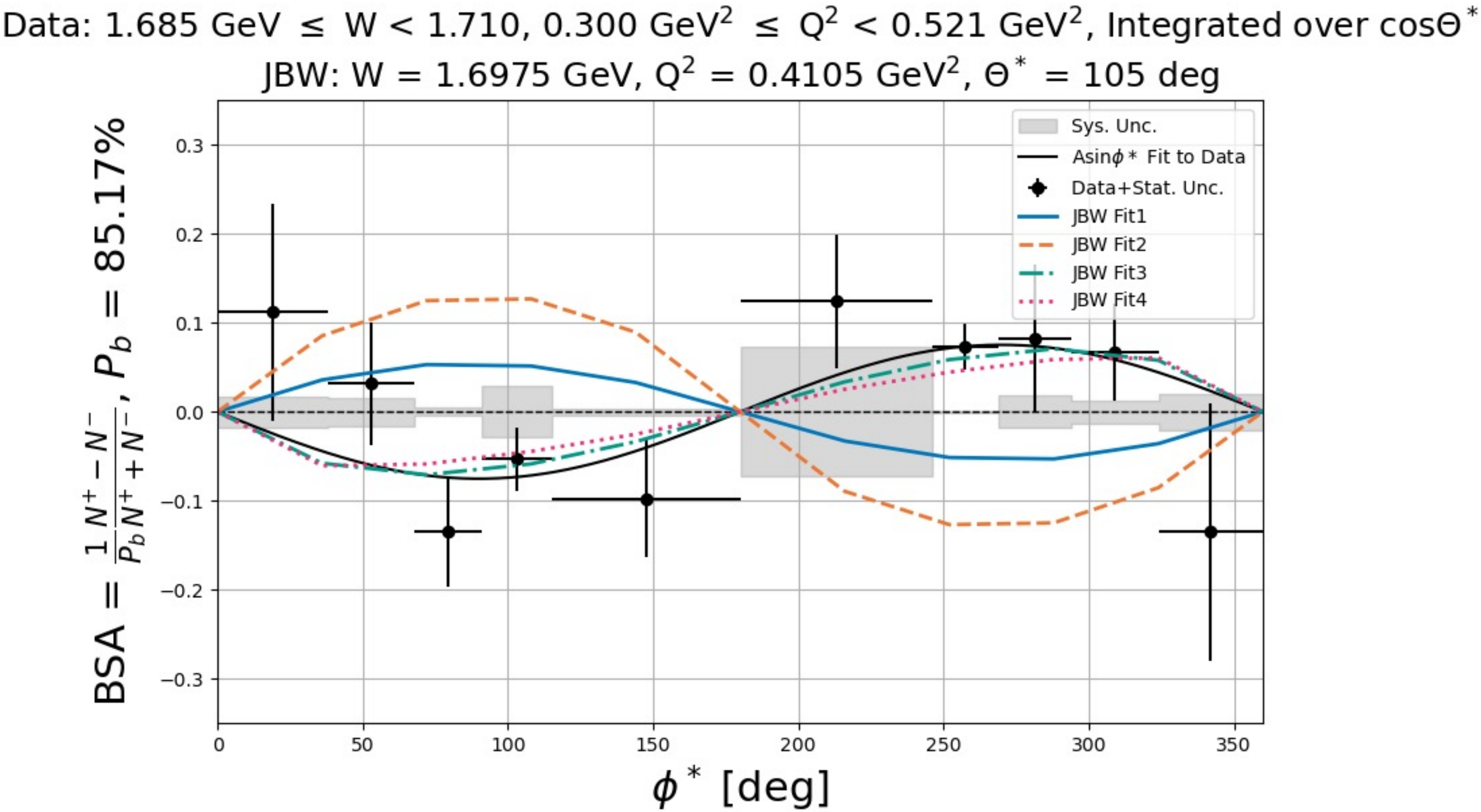
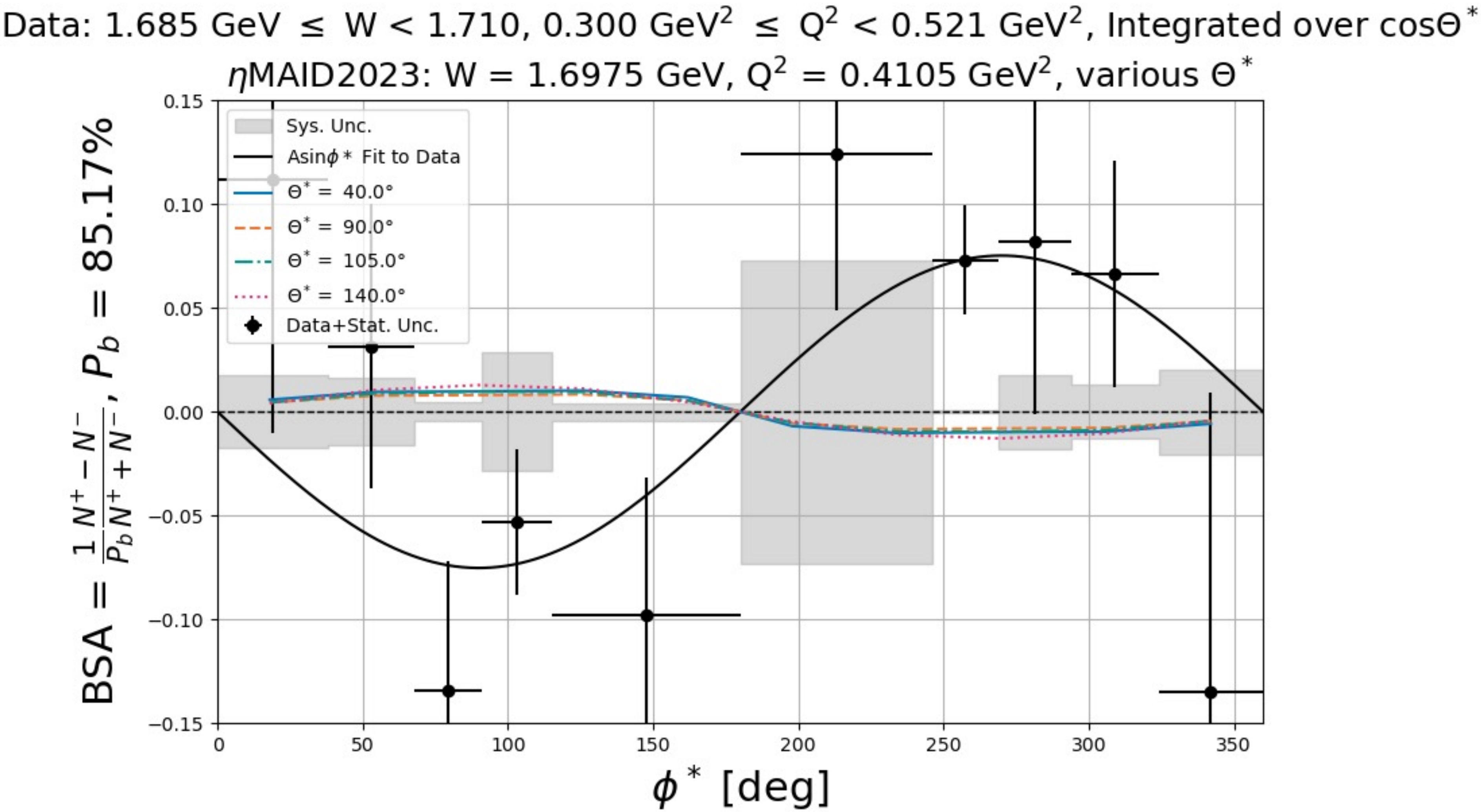


Comparison to EtaMAID Model



What about adding the cosφ* moments?

- So far used Asinφ* fit to BSA
- But what about:

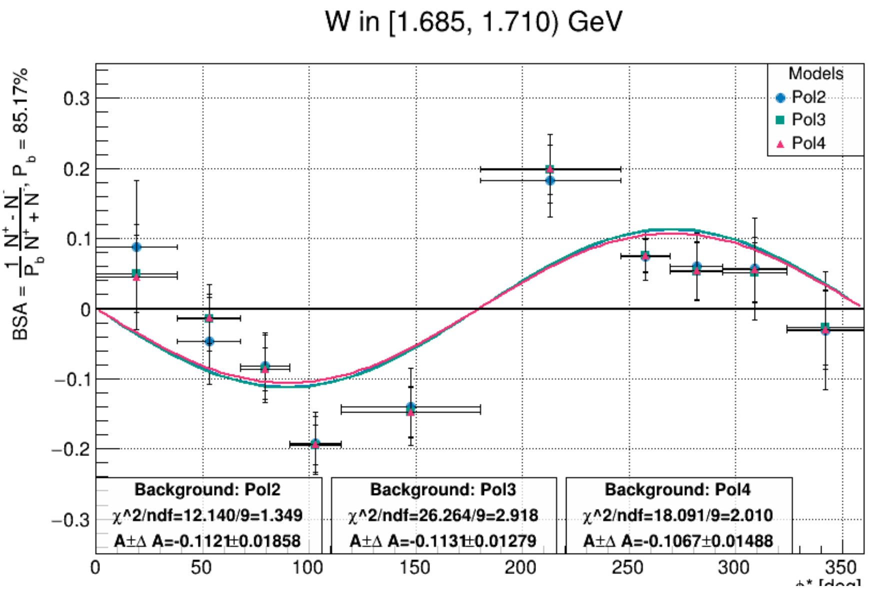
$$\mathrm{BSA}(\phi*) = \frac{A\sin\phi*}{1 + B\cos\phi*}$$

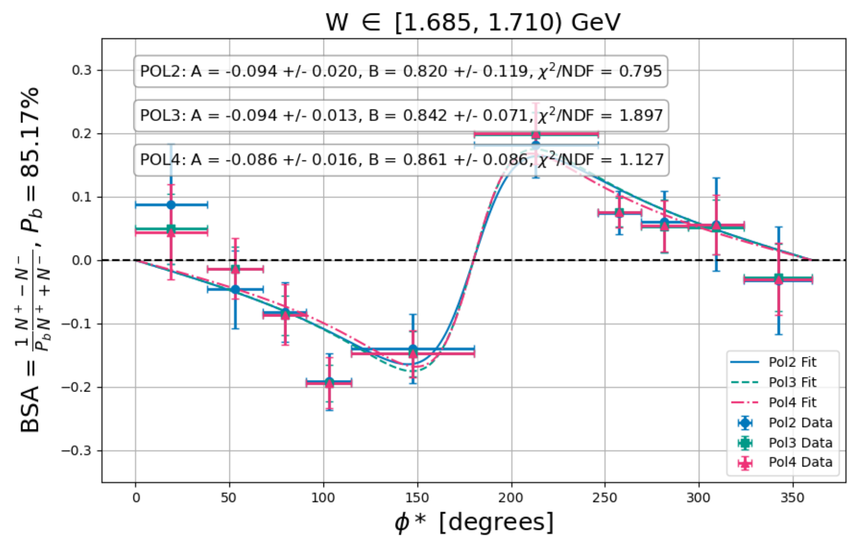
$$\mathrm{BSA}(\phi*) = \frac{A\sin\phi*}{1 + B\cos\phi * + C\cos 2\phi*}$$

Results of adding cosφ* moments

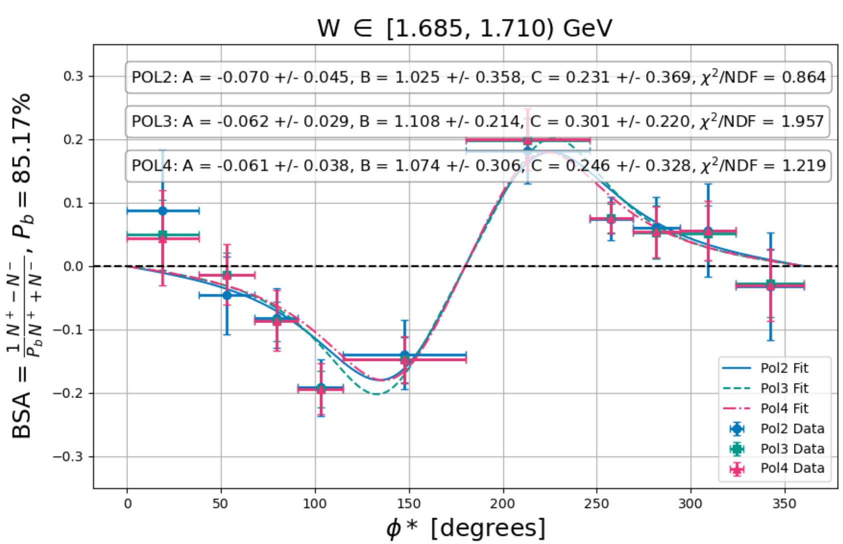
$$\frac{A\sin\phi*}{1+B\cos\phi*}$$

Asinφ* fit





$$\frac{A\sin\phi*}{1+B\cos\phi*+C\cos2\phi*}$$



- Binned over W and φ*
- Integrated over Q2 and cosθ*

Fits to BSA

$$\frac{A \sin \phi*}{1 + B \cos \phi*}$$

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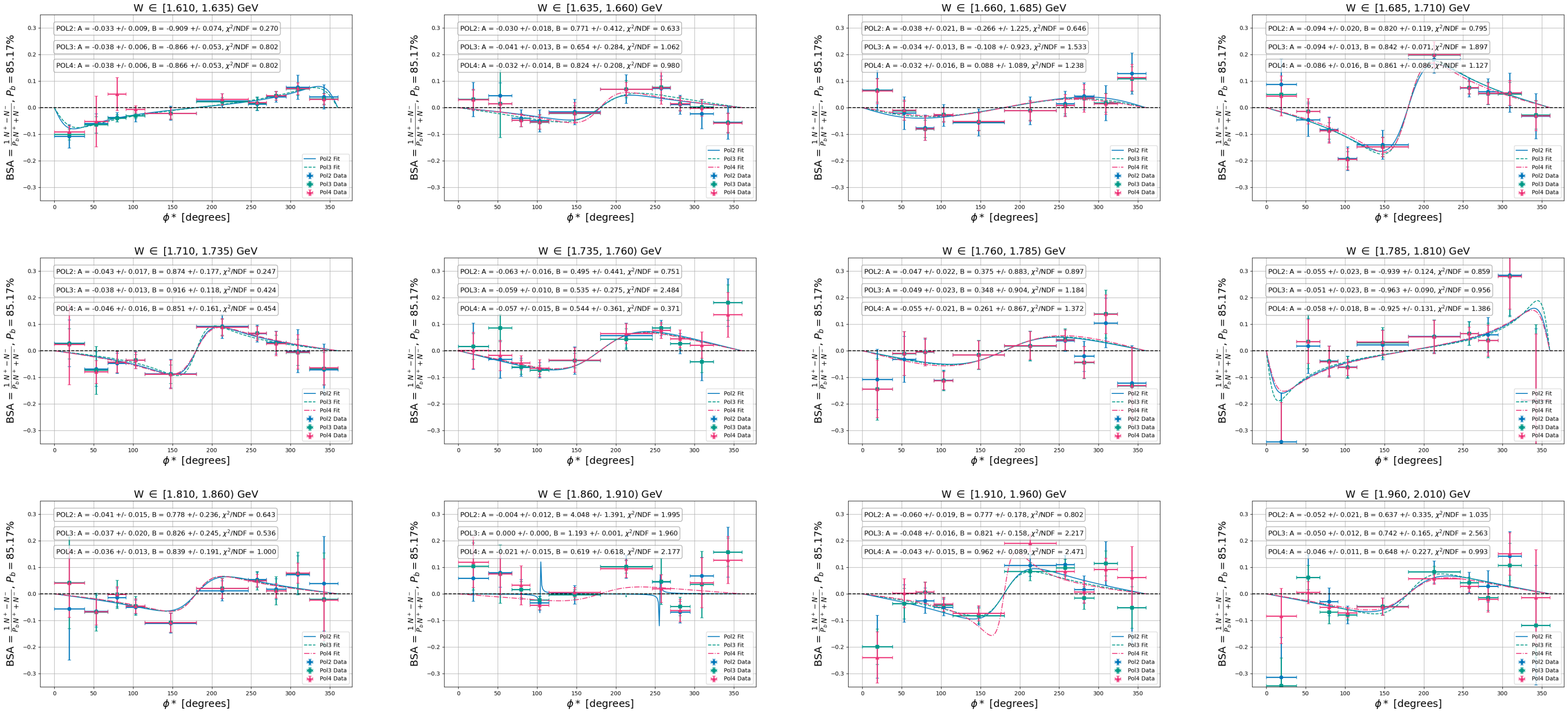

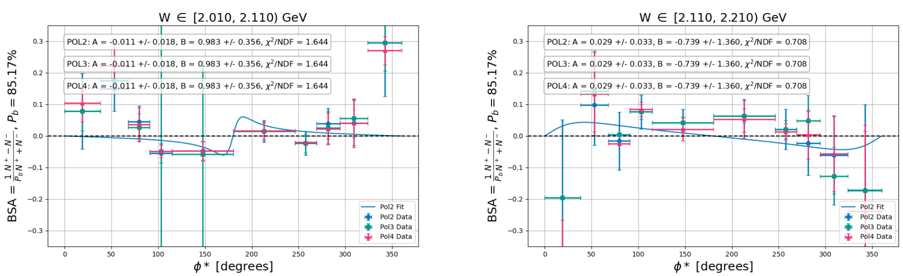

- BSA y range ±0.35
- Binned over W and φ*
- Integrated over Q2 and cosθ*
- Unconstrained B

Fits to BSA

$$\frac{A \sin \phi*}{1 + B \cos \phi * + C \cos 2\phi*}$$

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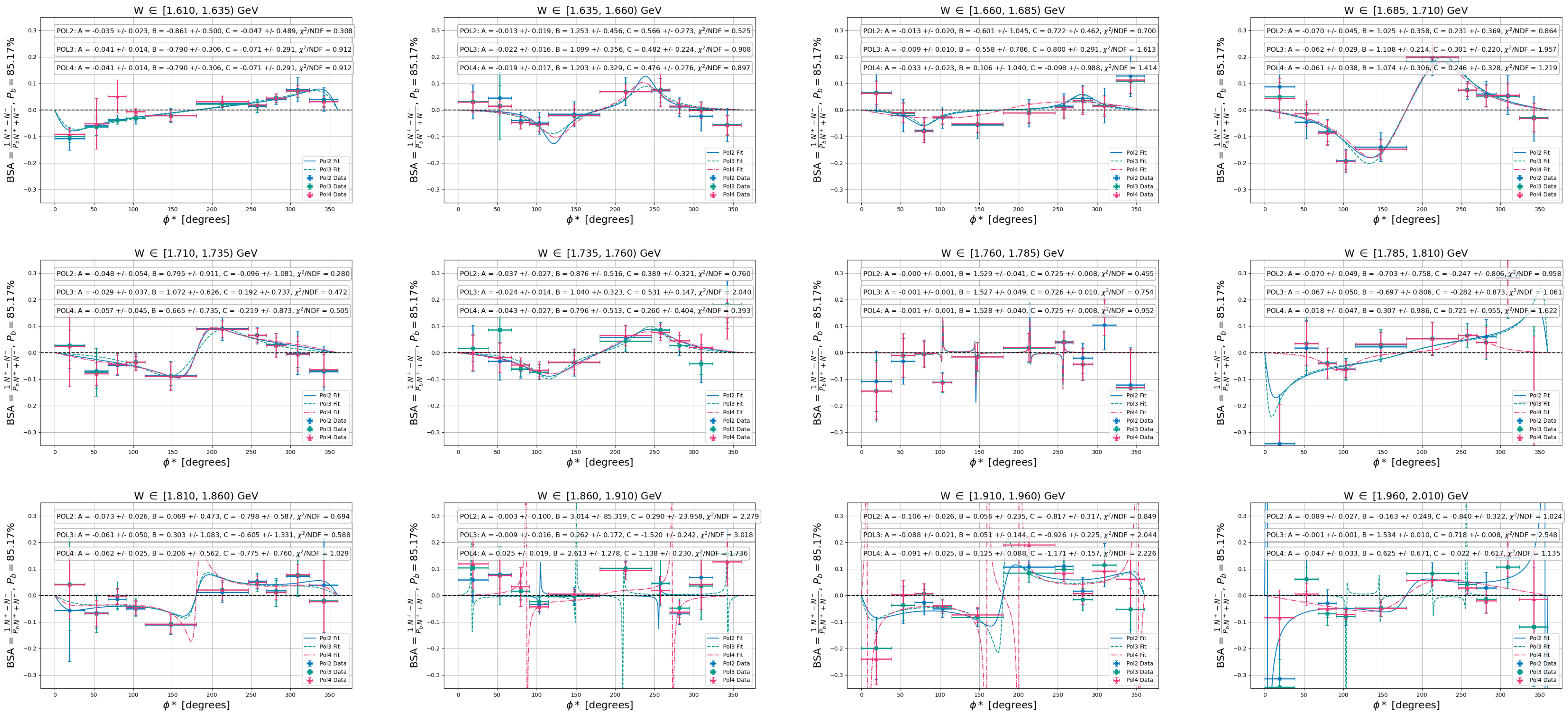

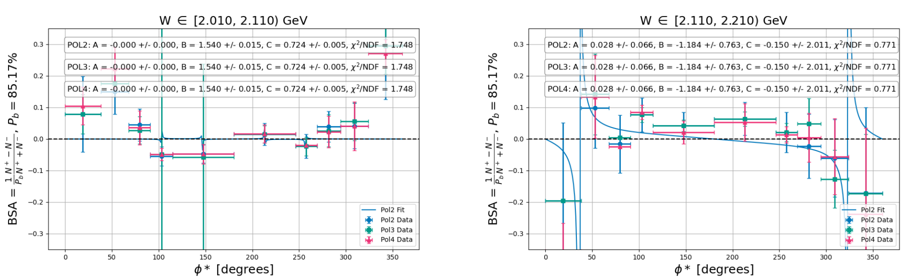

- BSA y range ±0.35
- Binned over W and φ*
- Integrated over Q2 and cosθ*
- Unconstrained B and C

Comparison of sin moment