Polarization Observables *T* and *F* in the $\gamma p \rightarrow \pi^0 p$ Reaction

Hao Jiang

03-08-2018

CLAS Collaboration Meeting

Newport News, VA

Research Supported by the National Science Foundation NSF PHY-1505615

Polarization Observables

For the single-pion photoproduction reaction, with a polarized photon beam and a polarized target, the available observables are listed.

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}(1 + P_t P_\gamma F \cos\varphi + P_t T \sin\varphi)$$

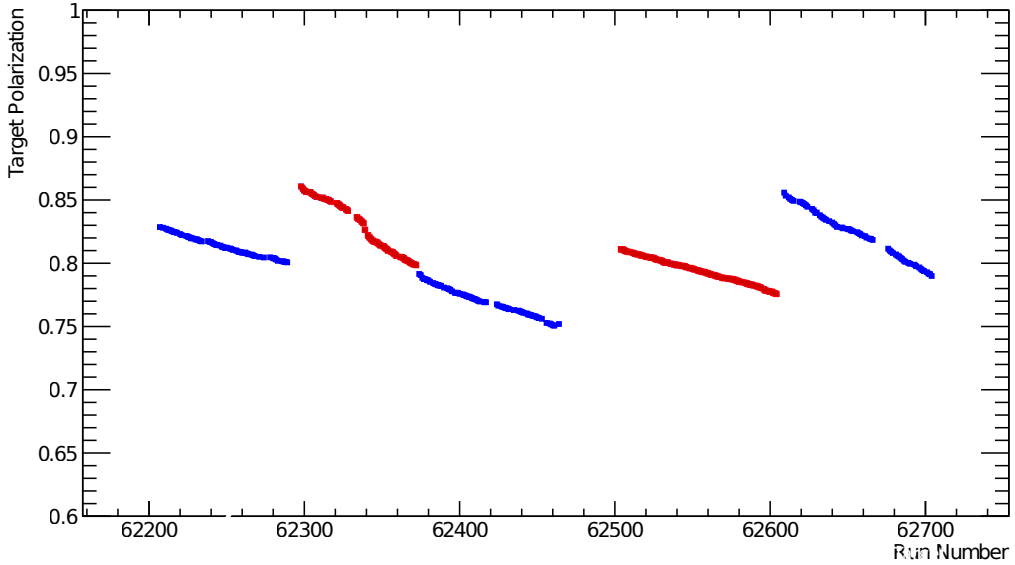
	Photon beam		
	unpolarized	circularly polarized	linearly polarized
Target			
unpolarized	$d\sigma/d\Omega$	—	Σ
longitudinally	—	E	G
transversely	$\boxed{T}$	$\boxed{F}$	H, P

The g9b experiment

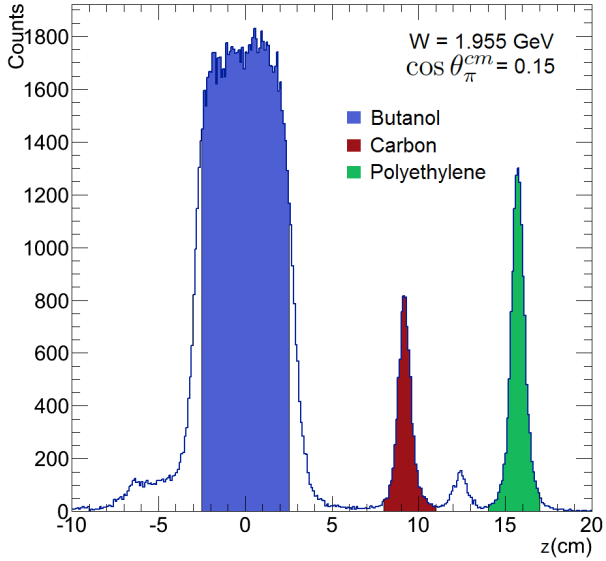
The g9b Experimental data were taken between March 2010 and August 2010 in sets of ten run groups. Only the first five run groups were used In this analysis.

Group	Run range	E_e (GeV)	Events	f (Hz)	Target pol.	Field
1	62207 - 62289	3.082	723.1 M	240	.83 - .80 (+)	(+)
2	62298 - 62372	3.082	894.9 M	240	.86 - .80 (−)	(+)
3	62374 - 62464	3.082	1129.7 M	240 or 30	.79 - .75 (+)	(+)
4	62504 - 62604	3.082	1307.1 M	240	.81 - .76 (−)	(−)
5	62609 - 62704	3.082	972.6 M	240 or 30	.85 - .79 (+)	(−)
runs not used in this analysis						
6	63508 - 63525	2.266	138.2 M	943	.77 - .58 (+)	(+)
7	63529 - 63542	2.266	166.8 M	240 or 943	.56 - .57 (−)	(−)
8	63543 - 63564	2.266	321.7 M	943	.74 - .61 (+)	(+)
9	63566 - 63581	2.266	249.6 M	943	.70 - .64 (−)	(−)
10	63582 - 63598	2.266	242.3 M	240	.48 - .46 (+)	(+)

FROST Target



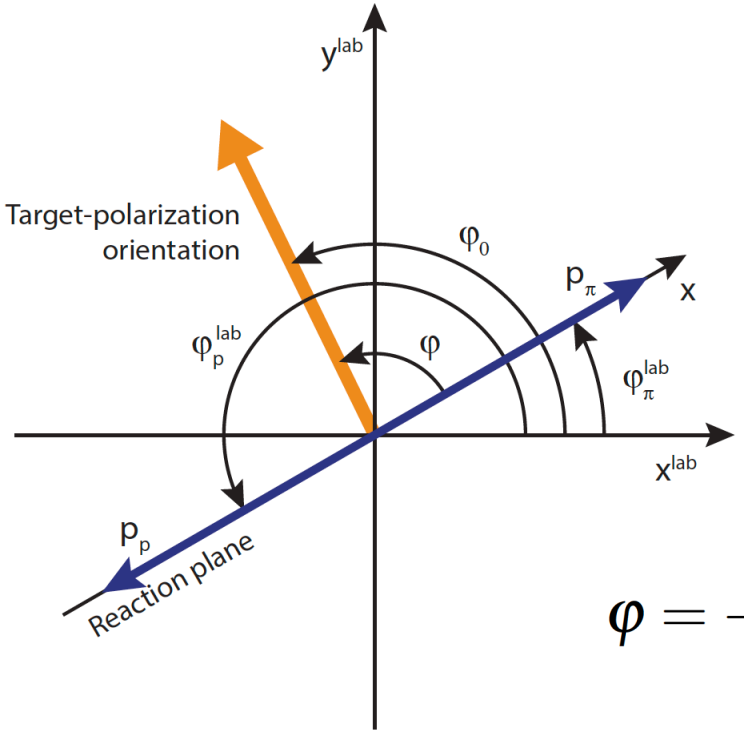
Reconstructed Reaction Vertex



The FROzen Spin Target (FROST) is a polarized target. The free protons from hydrogen atoms in the butanol (C_4H_9OH) target were polarized, $P_t \approx 80\%$. The target-polarization orientations were also flipped regularly.

A Carbon target was placed downstream to provide bound protons to measure the bound-nucleon background of the butanol data.

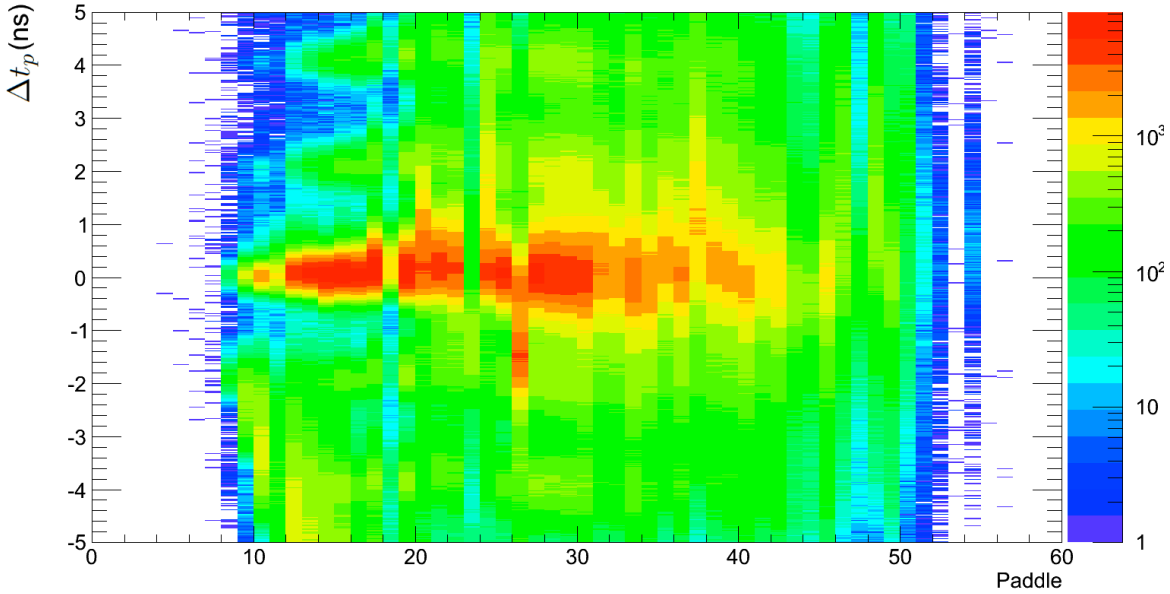
Target Polarization Direction

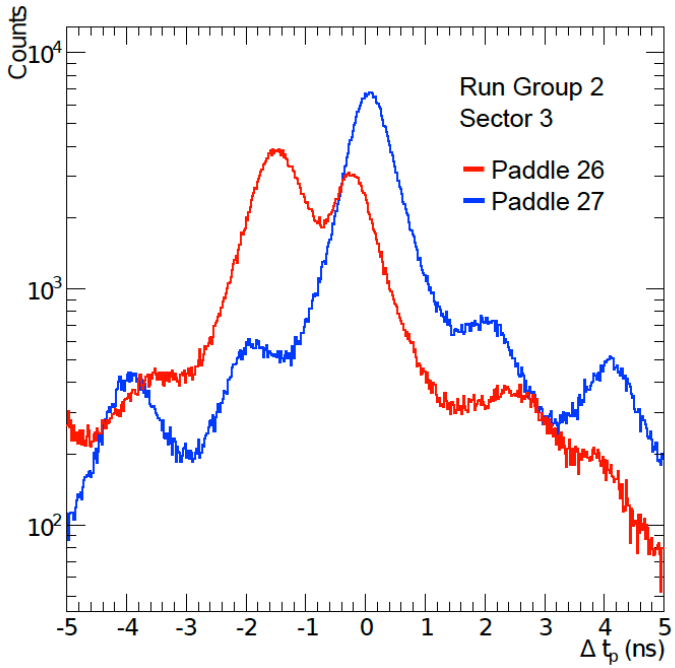


$$\varphi = -\varphi_{\pi}^{\mathrm{lab}} + \varphi_0 = \pi - \varphi_{p}^{\mathrm{lab}} + \varphi_0$$

In this analysis a value of ϕ_0 = 116.3°±1.4° was used which was determined in a moment-method analysis.

CLAS Detector





$$\Delta t_p = t_{exp} - t_{calc} = \frac{\ell_{SC}}{c}\left(\frac{1}{\beta} - \sqrt{\frac{M_p^2 c^2}{p^2} + 1}\right)$$

The performance of all TOF paddles has been examined by checking Δt_p of each paddle for each run group to reduce the probability of particle misidentification. Problematic paddles were removed from the analysis.

Removed Paddles

The paddles listed below have been indentified and removed from this analysis.

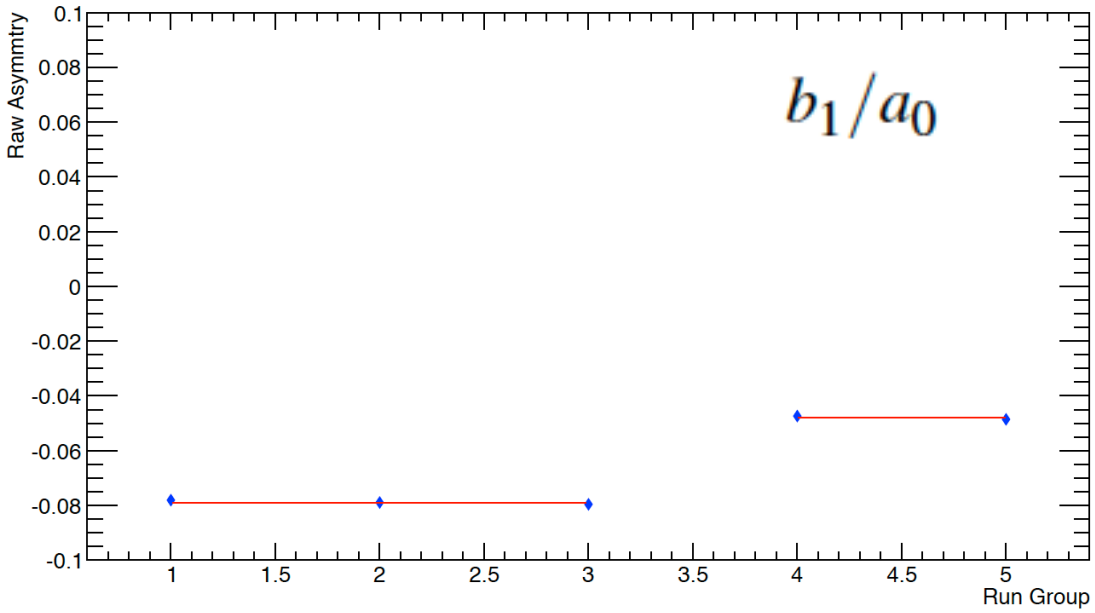
Sector	Paddles
1	24, 40, 42, 43, 44, 52
2	26, 29, 36, 37, 39, 44, 45
3	23, 26, 37
4	33, 39, 40
5	23
6	33

Detector Acceptance

The moments method requires a constant acceptance of the detector. The acceptance can be expanded into Fourier series and extracted from the carbon target.

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}(1 + P_t P_\gamma F \cos\varphi + P_t T \sin\varphi)$$

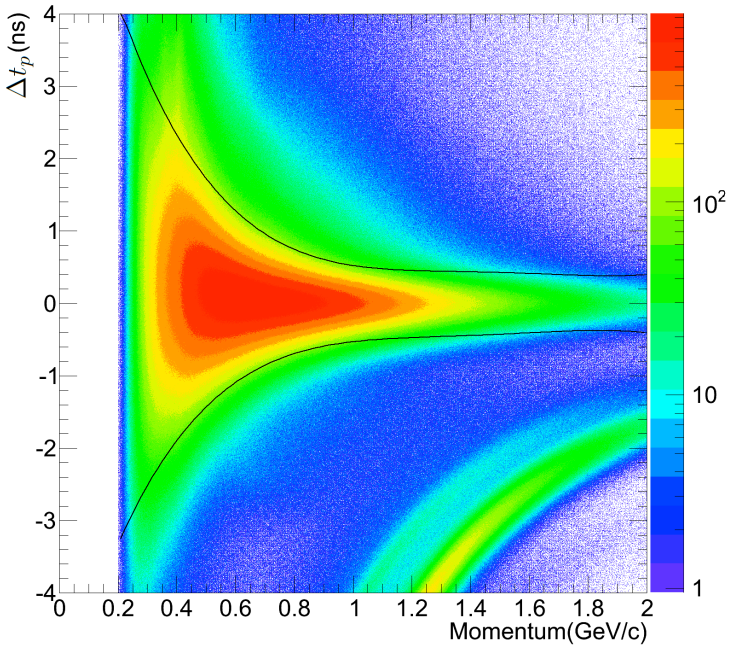
$$A(\varphi) = a_0 + \sum_{n=1}^{+\infty}(a_n \cos n\varphi + b_n \sin n\varphi)$$

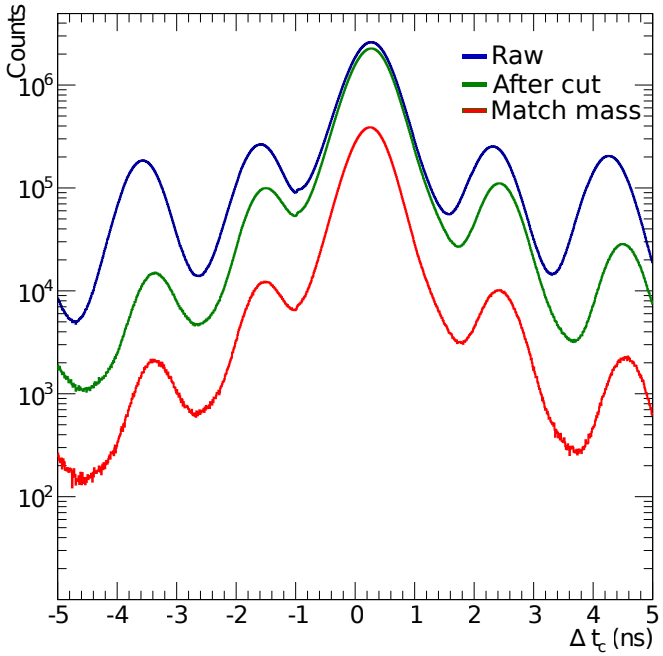


Proton Identification and Photon Selection

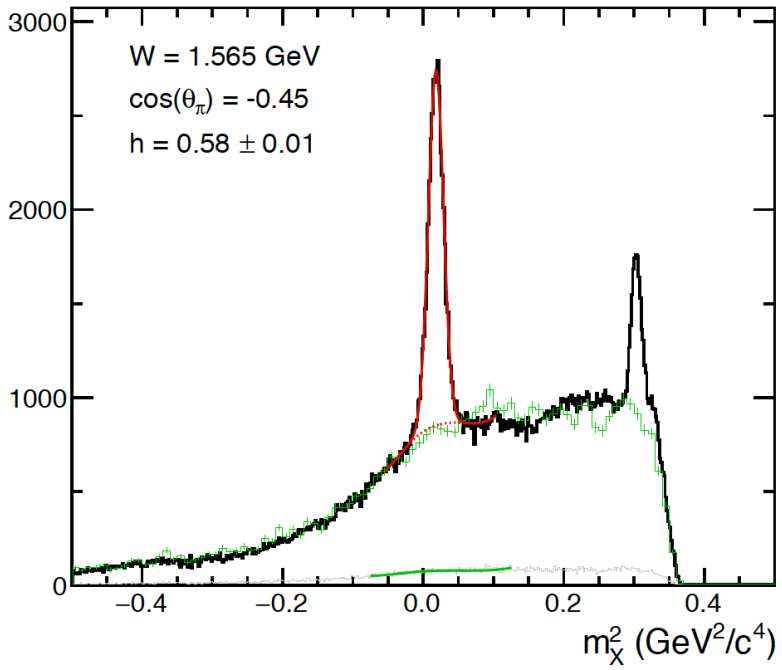
The final-state protons were identified from events with 1 positively charged and 0 negatively charged particles by using the time-of-fight difference.

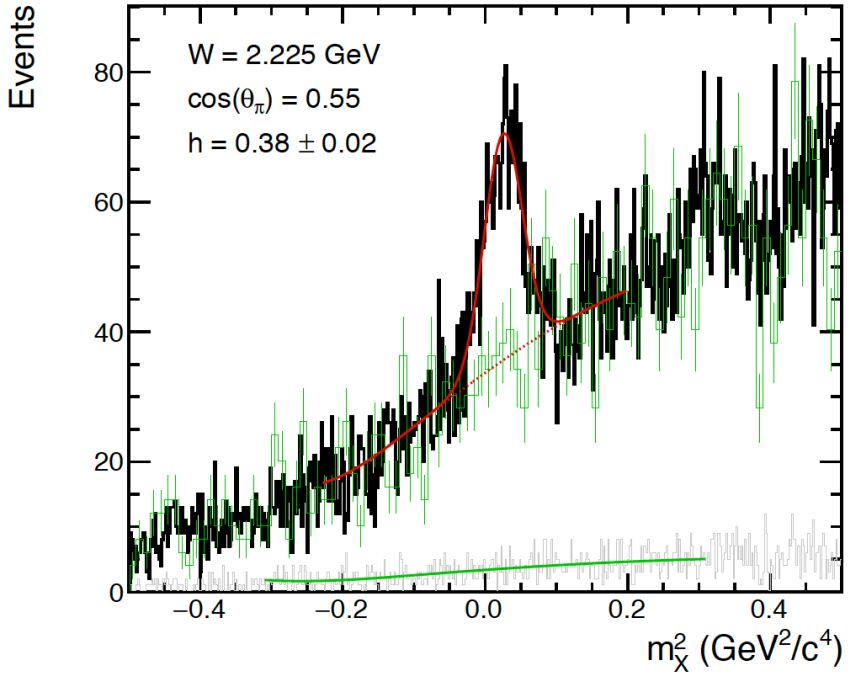
The photon that initiated the reaction and was coincident with the detected proton was selected by using the CLAS-tagger coincidence time.





Determination of Dilution Factors





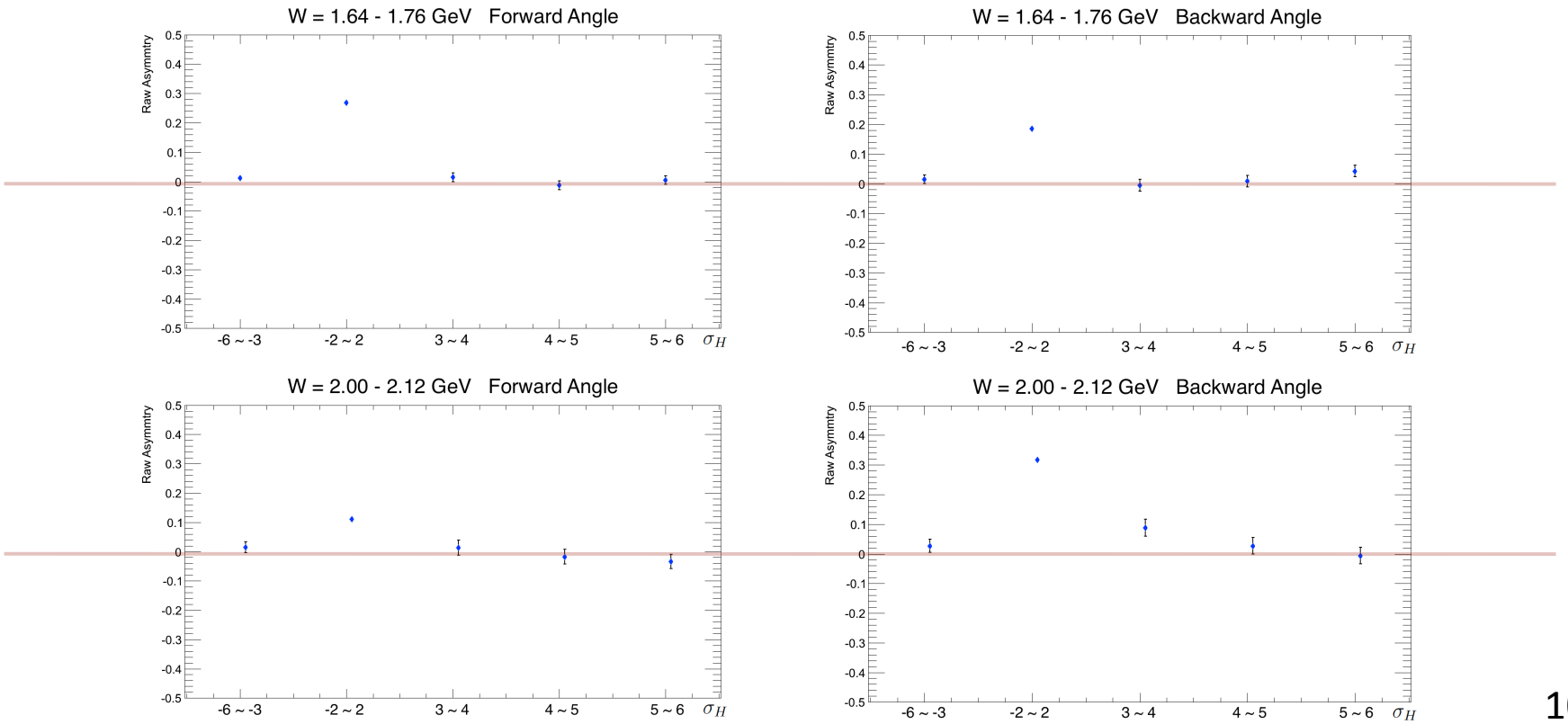
$$|m_X^2 - m_0^2| < n\sigma_H$$

In this analysis $n = 2$

The dilution factors are determined as $h = \dfrac{N^B - \kappa \int C(m^2) dm^2}{N^B}$.

Background Subtraction

The raw asymmetries extracted from various m_x ranges were also studied.



Determination of Target Polarization Direction

$$Y = \frac{1}{2\pi}\int_0^{2\pi} Y_{unpol} A(\varphi)(1 + P_T T \sin\varphi + P_T P_\odot F \cos\varphi) d\varphi \qquad Y = \frac{\sum_i (1)}{N},$$

$$Y_{\sin m\varphi} = \frac{1}{2\pi}\int_0^{2\pi} Y_{unpol} A(\varphi)(1 + P_T T \sin\varphi + P_T P_\odot F \cos\varphi)\sin m\varphi d\varphi \qquad Y_{\sin m\varphi} = \frac{\sum_i (\sin m\varphi_i)}{N}$$

$$Y_{\cos m\varphi} = \frac{1}{2\pi}\int_0^{2\pi} Y_{unpol} A(\varphi)(1 + P_T T \sin\varphi + P_T P_\odot F \cos\varphi)\cos m\varphi d\varphi \qquad Y_{\cos m\varphi} = \frac{\sum_i (\cos m\varphi_i)}{N}$$

$$\tan\varphi_0 = \frac{(P_T^{\rightarrow} Y^{\leftarrow}_{\sin 2\varphi_\pi^{\mathrm{lab}}} + P_T^{\leftarrow} Y^{\rightarrow}_{\sin 2\varphi_\pi^{\mathrm{lab}}})r - P_T^{\rightarrow}(Y^{\leftarrow} + Y^{\leftarrow}_{\cos 2\varphi_\pi^{\mathrm{lab}}})q - P_T^{\leftarrow}(Y^{\rightarrow} + Y^{\rightarrow}_{\cos 2\varphi_\pi^{\mathrm{lab}}})q}{(P_T^{\rightarrow} Y^{\leftarrow}_{\sin 2\varphi_\pi^{\mathrm{lab}}} + P_T^{\leftarrow} Y^{\rightarrow}_{\sin 2\varphi_\pi^{\mathrm{lab}}})q - P_T^{\rightarrow}(Y^{\leftarrow} - Y^{\leftarrow}_{\cos 2\varphi_\pi^{\mathrm{lab}}})r - P_T^{\leftarrow}(Y^{\rightarrow} - Y^{\rightarrow}_{\cos 2\varphi_\pi^{\mathrm{lab}}})r}$$

$$q = Y^{\rightarrow +}_{\sin\varphi_\pi^{\mathrm{lab}}} - Y^{\rightarrow -}_{\sin\varphi_\pi^{\mathrm{lab}}} - Y^{\leftarrow +}_{\sin\varphi_\pi^{\mathrm{lab}}} + Y^{\leftarrow -}_{\sin\varphi_\pi^{\mathrm{lab}}}$$

$$r = Y^{\rightarrow +}_{\cos\varphi_\pi^{\mathrm{lab}}} - Y^{\rightarrow -}_{\cos\varphi_\pi^{\mathrm{lab}}} - Y^{\leftarrow +}_{\cos\varphi_\pi^{\mathrm{lab}}} + Y^{\leftarrow -}_{\cos\varphi_\pi^{\mathrm{lab}}}$$

Determination of Observables T and F

The polarized cross section

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}(1 + P_t P_\gamma F \cos\varphi + P_t T \sin\varphi)$$

By utilizing the moment method, the observables T and F are determined.

$$T = \frac{1}{h}\frac{2(Y^{\rightarrow}_{\sin\varphi} - Y^{\leftarrow}_{\sin\varphi})}{P_T^{\leftarrow}(Y^{\rightarrow} - Y^{\rightarrow}_{\cos 2\varphi}) + P_T^{\rightarrow}(Y^{\leftarrow} - Y^{\leftarrow}_{\cos 2\varphi})}$$

$$F = \frac{1}{h}\frac{2(Y^{\rightarrow +}_{\cos\varphi} - Y^{\rightarrow -}_{\cos\varphi} - Y^{\leftarrow +}_{\cos\varphi} + Y^{\leftarrow -}_{\cos\varphi})}{P_\odot P_T^{\leftarrow}(Y^{\rightarrow} + Y^{\rightarrow}_{\cos 2\varphi}) + P_\odot P_T^{\rightarrow}(Y^{\leftarrow} + Y^{\leftarrow}_{\cos 2\varphi})}$$

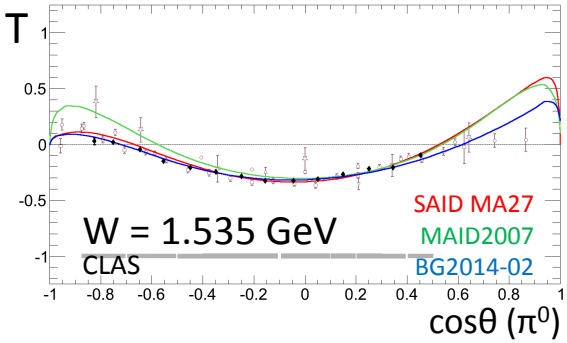
Systematic Uncertainties

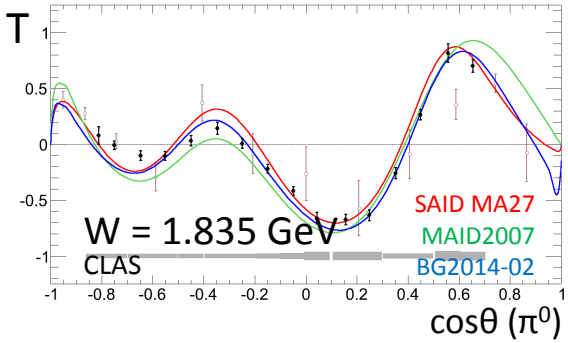
Item	$\sigma(T)$	$\sigma(F)$
Beam-Charge asymmetry	—	0.2%
Degree of beam polarization	—	3%
Degree of target polarization	4%	4%
Target-polarization orientation φ_0	< 0.001	< 0.001
Accidental background	2%	2%
Proton misidentification	2%	2%
Background subtraction	± 0.012	± 0.015
Run-group acceptance changes	± 0.015	—
Total	$4.9\% \pm 0.019$	$5.7\% \pm 0.015$

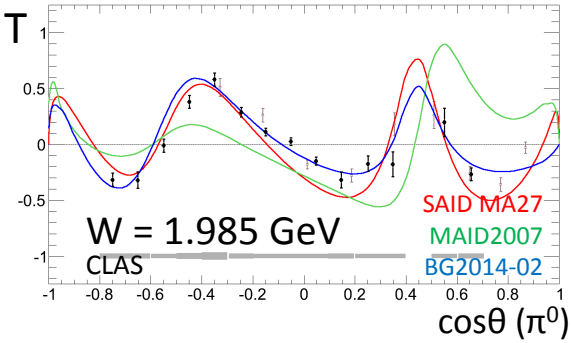
Preliminary

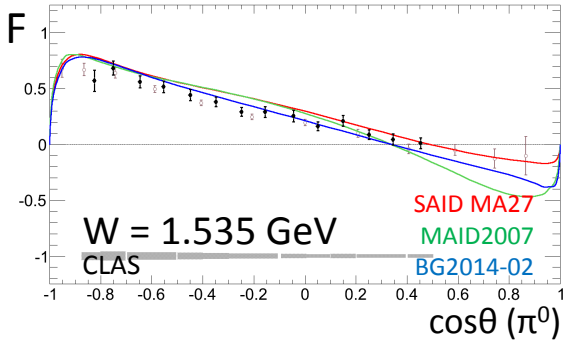
Observables T and F in $\gamma p \rightarrow \pi^0 p$

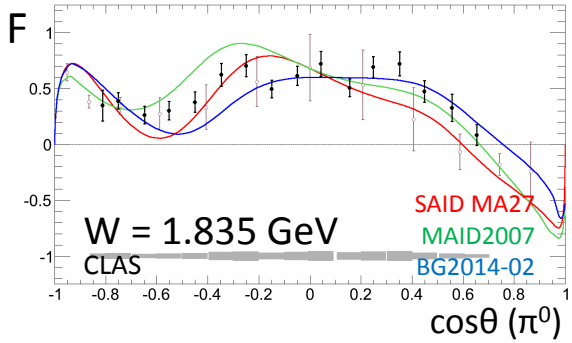
Observables were extracted for 37 bins in W from 1.43 GeV to 2.54 GeV.

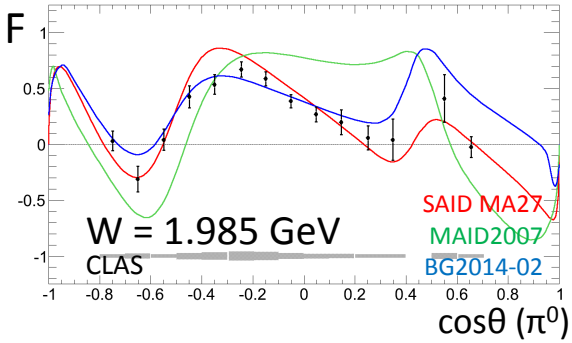










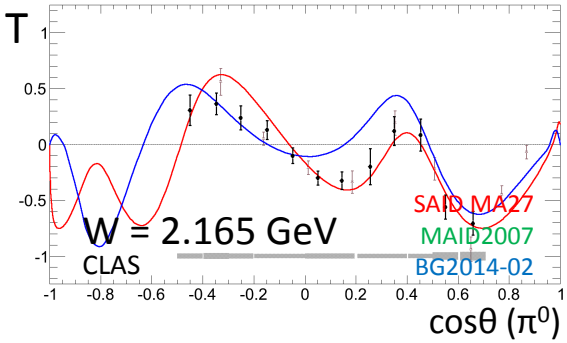


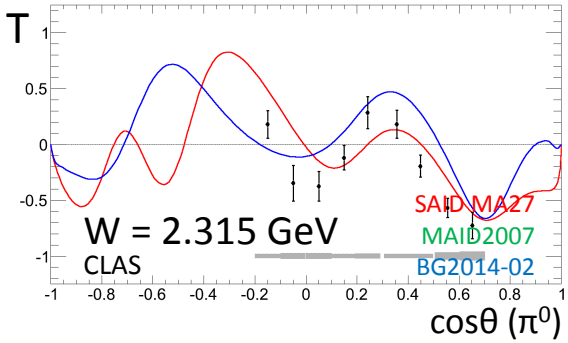
BS(79) DNPL BUSSEY, NPB154, 492(79)
FK(78) TOKY FUKUSHIMA, NPB136, 189(78)
BH(77) DNPL BOOTH, NPB121, 45(77)
FE(76) TOKY FELLER, NPB110, 397(76)
HA(14) BONN HARTMANN, PRL113, 062001(2014)

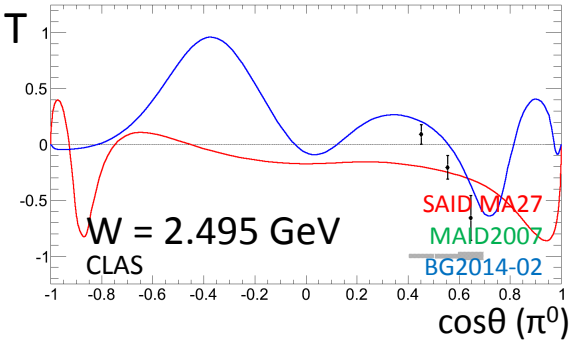
Preliminary

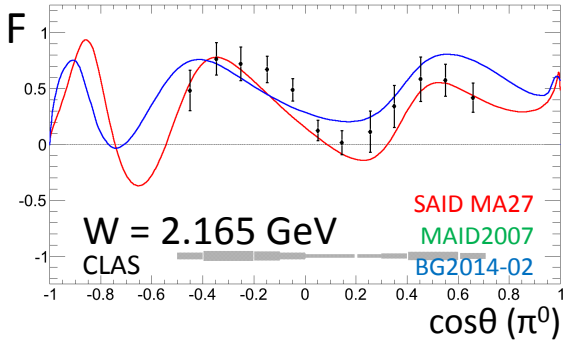
Observables T and F in $\gamma p \rightarrow \pi^0 p$

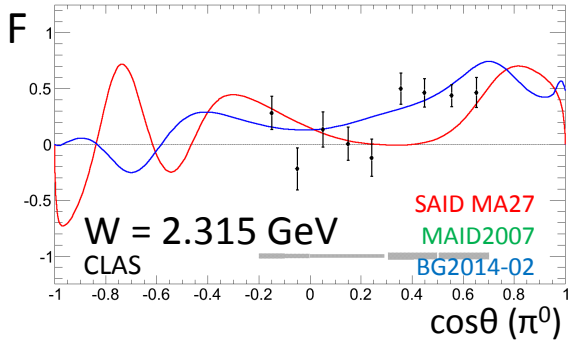
Observables were extracted for 37 bins in W from 1.43 GeV to 2.54 GeV.

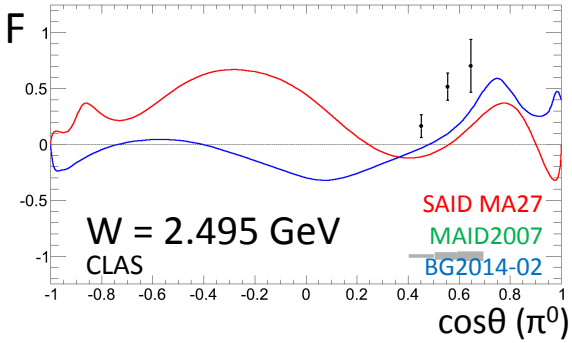




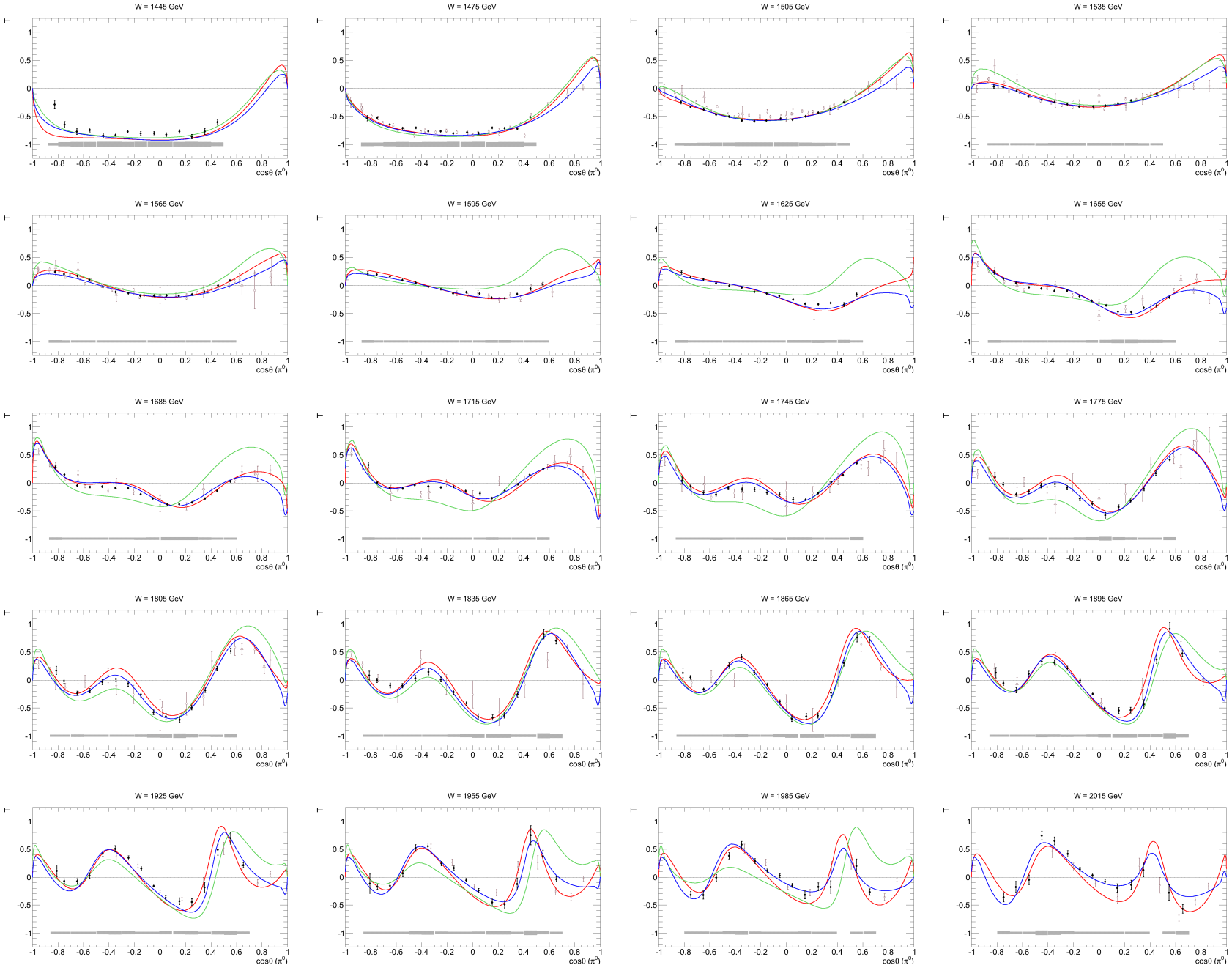




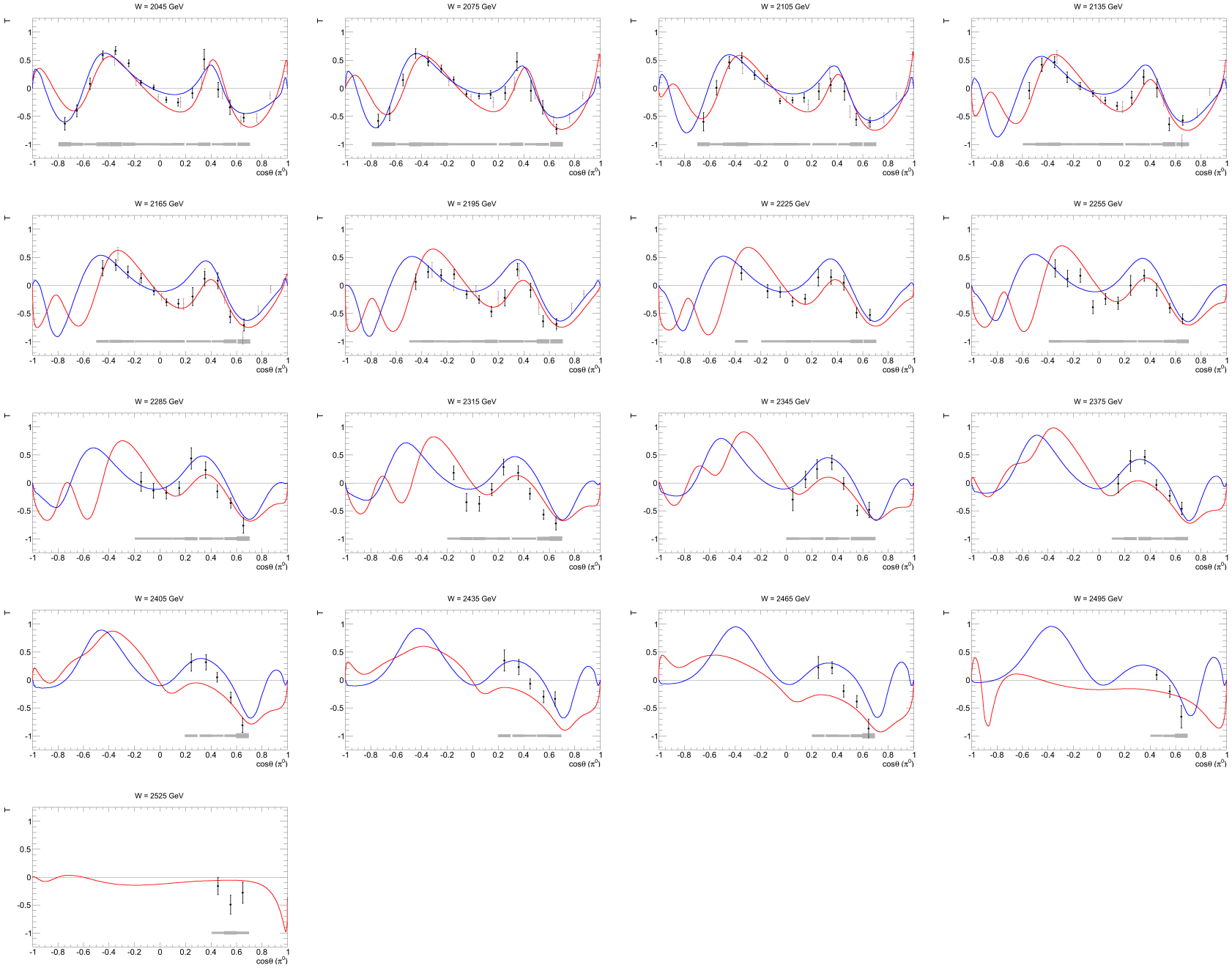




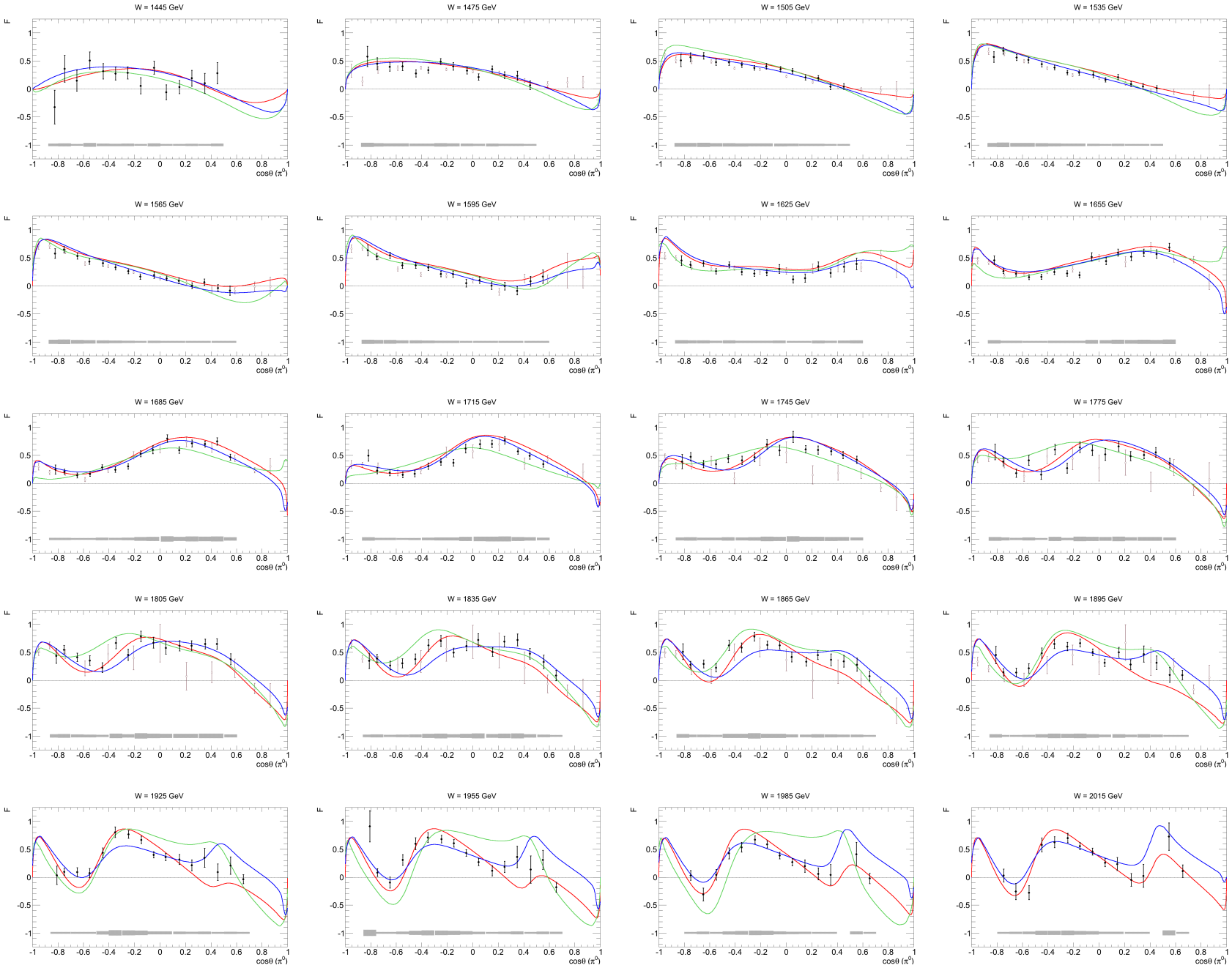
BS(79) DNPL BUSSEY, NPB154, 492(79)
FK(78) TOKY FUKUSHIMA, NPB136, 189(78)
BH(77) DNPL BOOTH, NPB121, 45(77)
FE(76) TOKY FELLER, NPB110, 397(76)
HA(14) BONN HARTMANN, PRL113, 062001(2014)



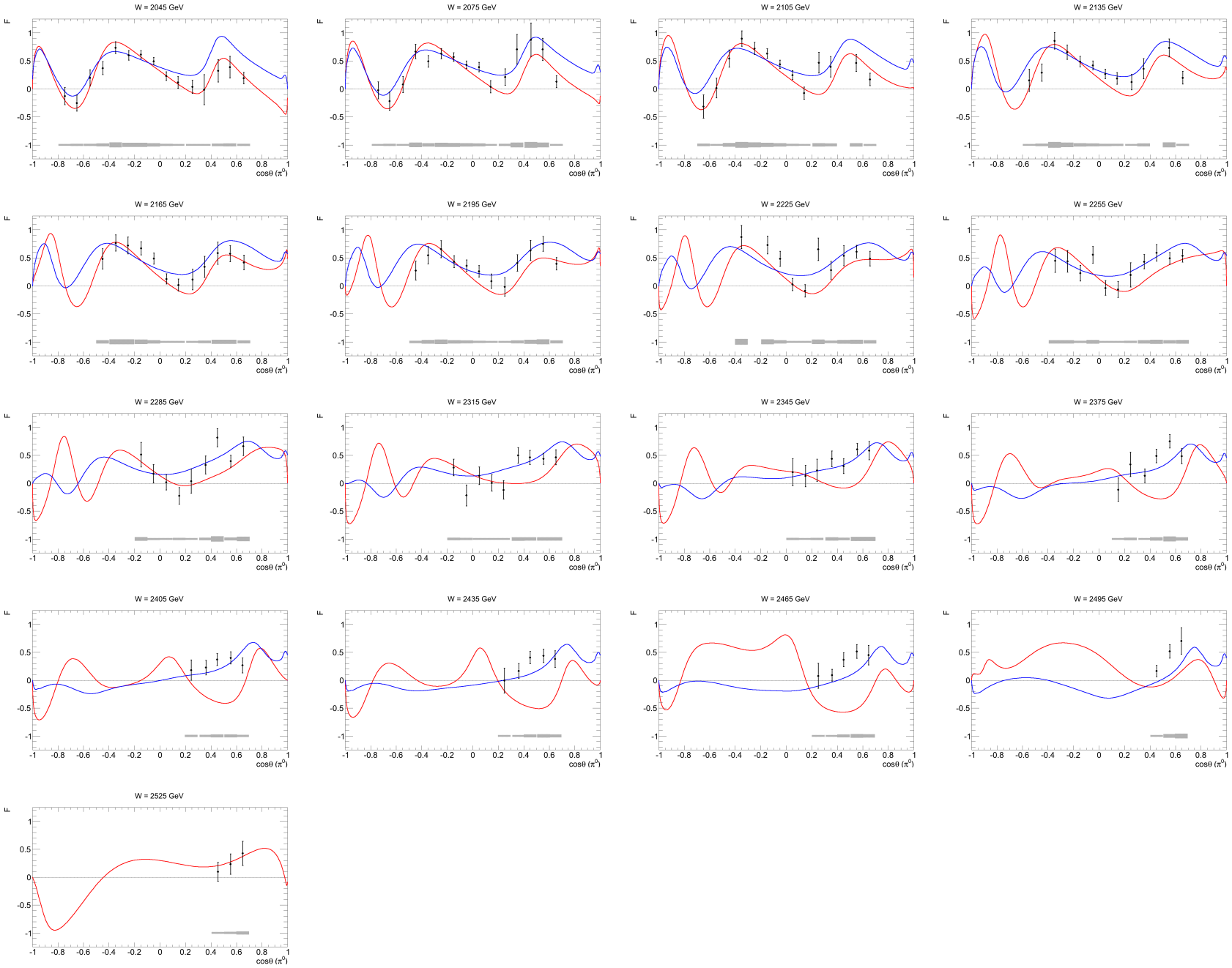
Preliminary



Preliminary



Preliminary



Preliminary

Summary

Polarization observables are sensitive to small amplitudes and phase differences. They provide important constraints to reveal the dynamics and relevant degrees-of-freedom within hadrons.

Preliminary results of polarization observables T and F in the $\gamma p \rightarrow \pi^0 p$ reaction have been extracted for the center-of-mass energy from 1.43 GeV to 2.51 GeV in the FROST experiment at JLab.

The present SAID, BnGa, and MAID model predictions generally agree with the data, but also show marked differences. The data constrain further partial-wave analyses and will improve the extraction of proton-resonance properties. The SAID and JuBo groups have made preliminary fits to the data and a more detailed analysis is ongoing.