Polarization Observables T and F in Single π^0 and η-Photoproduction off Quasi-Free Nucleons

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MAINZER MIKROTRON

Outline

Motivation

Problem

- Nucleons' excitation spectrum is a complicated overlap of many short lived, broad resonances
- Cannot be understood from differential cross sections alone

Polarization observables from meson photoproduction

- Probing spin degrees of freedom
- Need 8 carefully chosen observables for complete experiment
- Need high precision measurements

Proton and neutron channel

- Probe isospin degree of freedom
- Isospin decomposition into A^{V3}, A^{IV}, A^{IS} for π photoproduction

$$A(\gamma p \to \pi^+ n) = -\sqrt{\frac{1}{3}} A^{V3} + \sqrt{\frac{2}{3}} \left(A^{IV} - A^{IS}\right) \qquad A(\gamma p \to \pi^0 p) = +\sqrt{\frac{2}{3}} A^{V3} + \sqrt{\frac{1}{3}} \left(A^{IV} - A^{IS}\right)$$

$$A(\gamma n \to \pi^0 n) = +\sqrt{\frac{1}{3}} A^{V3} - \sqrt{\frac{2}{3}} \left(A^{IV} + A^{IS}\right) \qquad A(\gamma n \to \pi^- p) = +\sqrt{\frac{2}{3}} A^{V3} + \sqrt{\frac{1}{3}} \left(A^{IV} + A^{IS}\right)$$

- At least one measurement off the neutron needed.

Motivation

Special case η

- Isospin $I = I_z = 0$.
- No isospin changing current ($A^{V3} = 0$)

$$A(\gamma p \to \eta p) = A^{IS} + A^{IV}$$

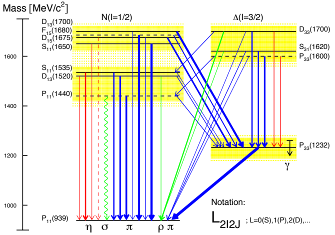
$$A(\gamma n \to \eta n) = A^{IS} - A^{IV}$$

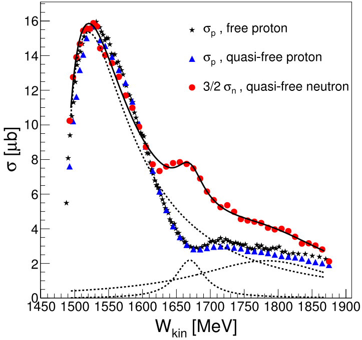
$\Longrightarrow$ only N^* resonances contribute

- Recent results show a narrow structure arround 1670 MeV

Photoproduction off the neutron

- Neutron bound in nucleus
  $\Longrightarrow$ quasi free neutron
- Correct treatment of Fermi motion
- Comparision of free and quasi free proton data





Experimental Setup

Experimental Setup

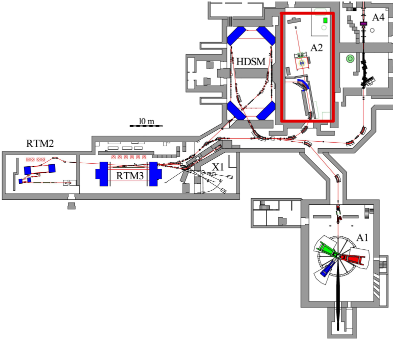
MAinzer MIcrotron

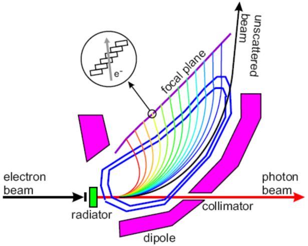
High quality electron beam

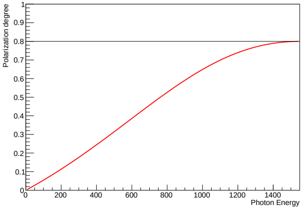
- Energy up to 1.5 GeV
- Intensity up to 100 μA
- Polarization $\approx 80\%$

Bremsstrahlungs photons

- $1/E_\gamma$ distribution
- Photon polarization: Olsen maximum function







Crystal Ball/TAPS @ MAMI

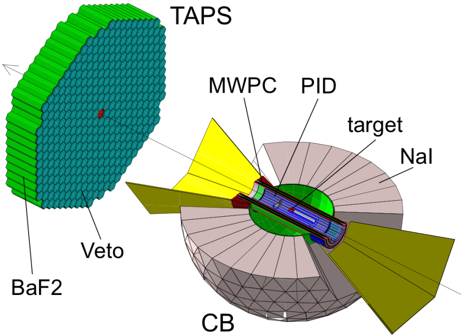
CB

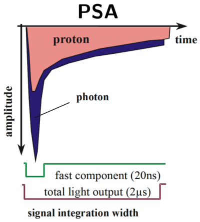
- PID
- MPWC
- NaI crystals

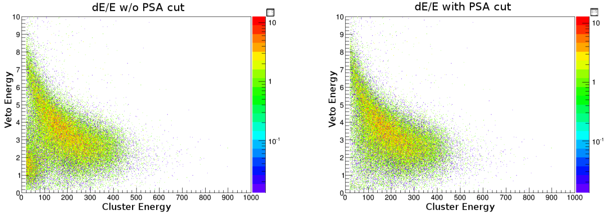
TAPS

- BaF2/PWO crystals
- Veto wall

$\Longrightarrow$ Almost 4π acceptance







Polarization Observables

Polarization Observables

Definition of T and F (experimental approach)

T and F are defined by

$$T\cos(\phi') = \frac{1}{P^T P^\gamma} \frac{d\sigma^\uparrow(\phi') - d\sigma^\downarrow(\phi')}{d\sigma^\uparrow(\phi') + d\sigma^\downarrow(\phi')},$$

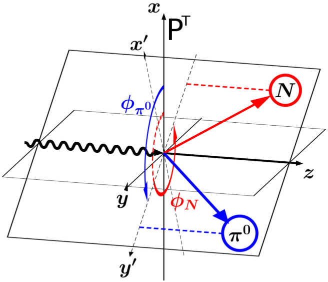
where $(\uparrow, \downarrow)$ denotes the target polarization state,

$$F\cos(\phi) = \frac{1}{P^T P^\gamma} \frac{d\sigma^-(\phi) - d\sigma^+(\phi)}{d\sigma^-(\phi) + d\sigma^+(\phi)},$$

where $(+, -)$ denotes the photon helicity state.

Here, $F = F(E,\theta)$, $T = T(E,\theta)$, $P^T = P^T(t)$ and $P^\gamma = P^\gamma(E^\gamma, P_B(t))$

- Symmetric contributions cancel in the numerator
- Denominator equals unpolarized $d\sigma$



- ϕ = Angle between target polarization vector and production plane
- ϕ' = Angle between target polarization vector and normal to production plane

Methods to extract T and F

- Target: D-butanol (C_4D_9OD), only deuterons are polarized.
- Carbon/oxygen contribution vanish in numerator
- Two methods can be used:
  - 1. Normalize with deuterium target

$$A\cos(\phi) = \frac{1}{P_T P_\gamma} \frac{d\sigma^-_{DB}(\phi) - d\sigma^+_{DB}(\phi)}{d\sigma^-_D(\phi) + d\sigma^+_D(\phi)}$$

$\Longrightarrow$ Needs flux and efficiency correction of count rates.

  - 2. Normalize with D-butanol target

$$A\cos(\phi) = \frac{1}{P_T P_\gamma} \frac{dN^-_{DB}(\phi) - dN^+_{DB}(\phi)}{dN^-_{DB}(\phi) + dN^+_{DB}(\phi)} \cdot d$$

$\Longrightarrow$ No need for flux and efficiency correction, but dilution factor d, i.e.,

$$d = 1 + \frac{d\sigma^0_C}{d\sigma^0_{DB}}$$

Analysis Methods

Analysis Methods

Event selection

- Event selection
  - Full exclusive on proton (neutron as spectator)

$\gamma + d \longrightarrow \pi^0 + p(n)$	$\longrightarrow 2\gamma + p(n)$	2 neutral, 1 charged
$\gamma + d \longrightarrow \eta + p(n)$	$\longrightarrow 2\gamma + p(n)$	2 neutral, 1 charged
$\gamma + d \longrightarrow \eta + p(n) \longrightarrow 3\pi^0 + p(n)$	$\longrightarrow 6\gamma + p(n)$	6 neutral, 1 charged

  - Full exclusive on neutron (proton as spectator)

$\gamma + d \longrightarrow \pi^0 + n(p)$	$\longrightarrow 2\gamma + n(p)$	3 neutral, 0 charged
$\gamma + d \longrightarrow \eta + n(p)$	$\longrightarrow 2\gamma + n(p)$	3 neutral, 0 charged
$\gamma + d \longrightarrow \eta + n(p) \longrightarrow 3\pi^0 + p(n)$	$\longrightarrow 6\gamma + n(p)$	7 neutral, 0 charged

- Determination of the neutron candidate by χ^2-test.
- Invariant mass cut on all 3 π^0 from $\eta \rightarrow 6\gamma$ decay.

Applied Cuts

All cuts are determined from LD_2 target for all θ and energy bins.

- Coplanarity cut

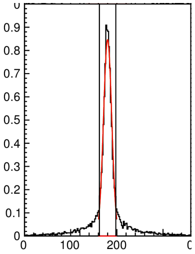
$$\Delta\phi = 180^\circ - |\phi_{\text{meson}} - \phi_{\text{recoil}}|$$

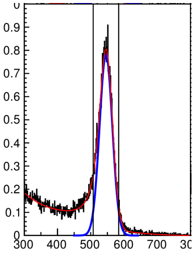
- Invariant mass cut

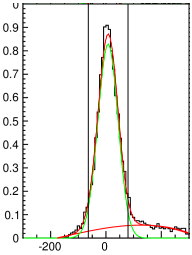
$$\Delta m_{\text{meson}} = |P^{\mu}_{\text{meson}}| - m^{\text{theo.}}_{\text{meson}}$$

- Missing mass cut

$$\Delta MM = |P^{\mu}_{\gamma} + P^{\mu}_{\text{nucleon}} - P^{\mu}_{\text{meson}}| - m^{\text{theo}}_{\text{nucleon}}$$







Reconstruction of Kinematics

Transfer kinematics into CM frame

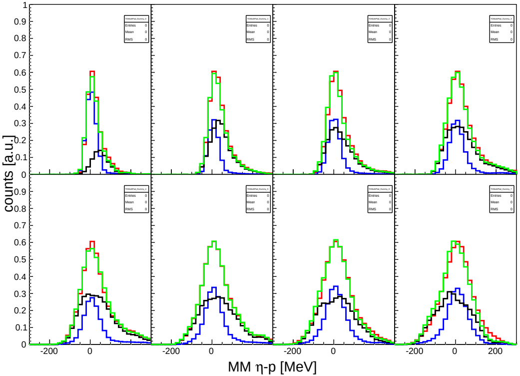
- Fermi momentmum from deuterium (carbon/oxygen) targed
  $\Longrightarrow$ Initial state not determined
- Reconstruction of nucleons fermi momentum from final state, i.e., solve

$$P^{\mu}_{\gamma} + P^{\mu}_{\text{nucleon}} = P^{\mu}_{\text{meson}} + P^{\mu}_{\text{recoil}}$$

  for P^{μ}_{nucleon}.
- Have enough information to reconstruct Fermi momentum of nucleon.

Dilution Factor

- Determination of the dilution factor from missing mass spectra

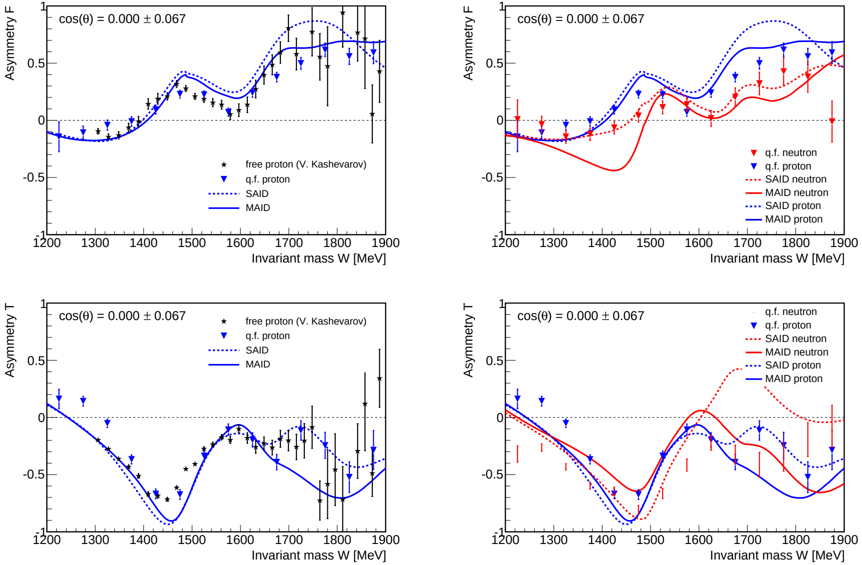


- Carbon + x Deuterium = Sum ≈ D-butanol
- Dilution factor $d = 1 + \int_{MMcut} \Delta MM_{\text{carbon}} / \int_{MMcut} \Delta MM_{\text{deuterium}}$

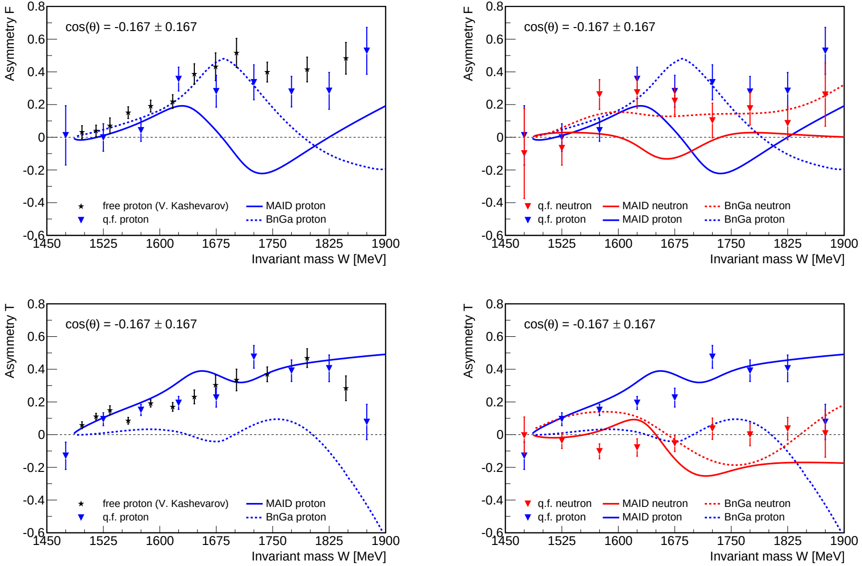
Selected Results

Selected Results (preliminary)

T and F for Single π^0 Photoproduction



T and F for η Photoproduction



Conclusion

Conclusion

- First preliminary results for T and F for single π^0- and η photoproduction off quasi free nucleons
- Very good agreement with free proton
- Models fail for higher energies, for the neutron and η channel

Outlook

- Main goal (η): double energy and theta bins w/o increasing errors
- Kinematic fit (energy and angular resolution)
- Expected impact on models
- Observables from double meson photoproduction.

Thanks

Thank you for your attention.

Definition of T and F

- General decomposition of $d\sigma$ into 16 polarization observables reads

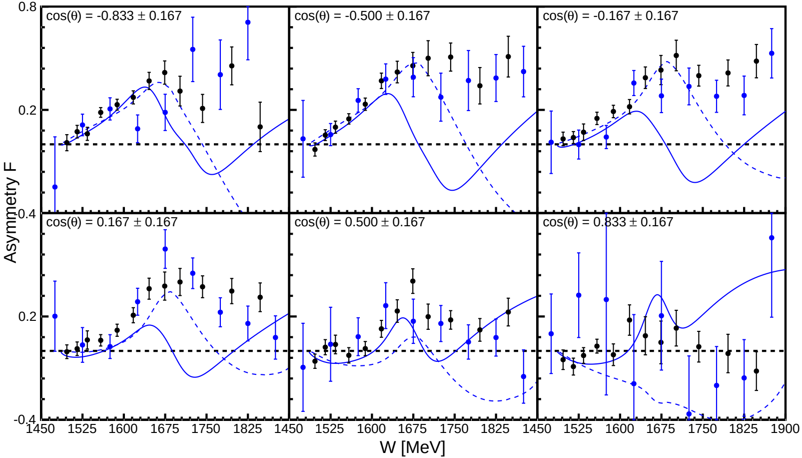
$$\begin{aligned} d\sigma(P^\gamma, P^T, P^R) = \frac{1}{2} d\sigma_0 \{ 1 + \ldots \\ &+ T\, [P_y^T - P_L^\gamma P_{y'}^R \cos()] \\ &+ F\, [P_c^T P_x^T - P_L^\gamma P_z^T P_{y'}^R \sin(2\phi_\gamma)] \\ &+ \ldots \}. \end{aligned}$$

- For $P^R = 0$ (unpolarized recoil), $P^\gamma = P_c^\gamma$ (circular photon polarization) and $P^T = P_y, P_z = 0$ (transversal target polarization) it reduceses to

$$\begin{aligned} d\sigma(P^\gamma, P^T) &= d\sigma_0 \left\{ 1 + T P_y^T + F P_c^\gamma P_x^T \right\} \\ &= d\sigma_0 \left\{ 1 + T |P^T| \cos(\phi') + F |P^\gamma||P^T| \cos(\phi) \right\}. \end{aligned}$$

- Observables T and F manifest themself by a cosine-modulated unpolarized cross-section

F: ηp



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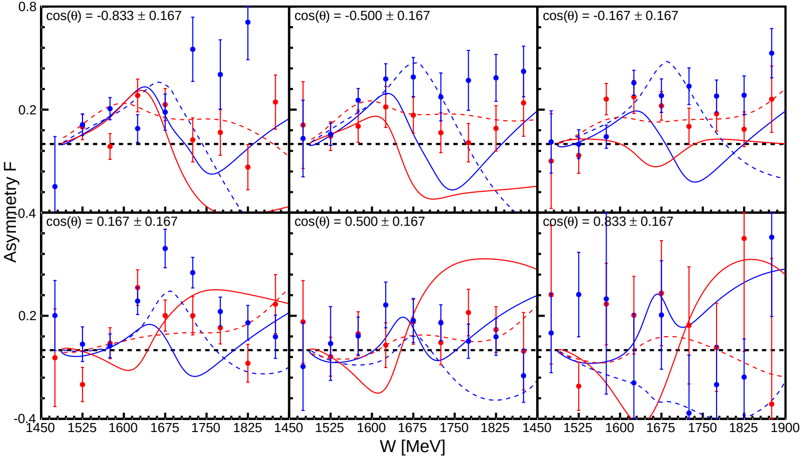
cos(θ) = 0.833 ± 0.167
Asymmetry F
0.8
0.2
-0.4
1450
1525
1600
1675
1750
1825
1900
W [MeV]

F: ηn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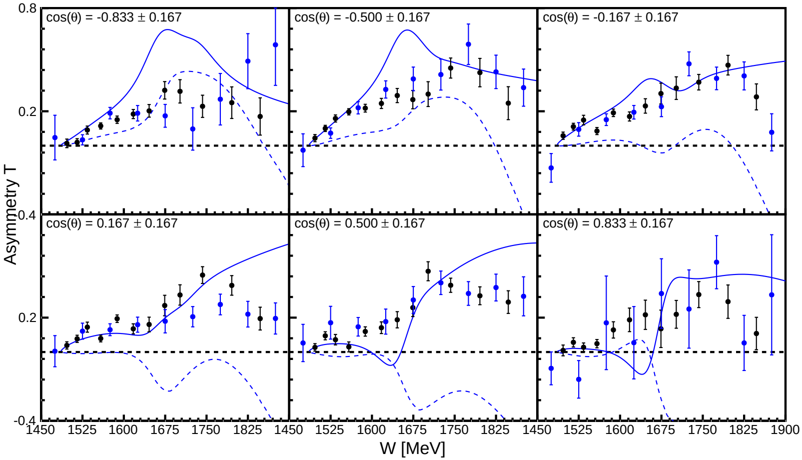
T: ηp



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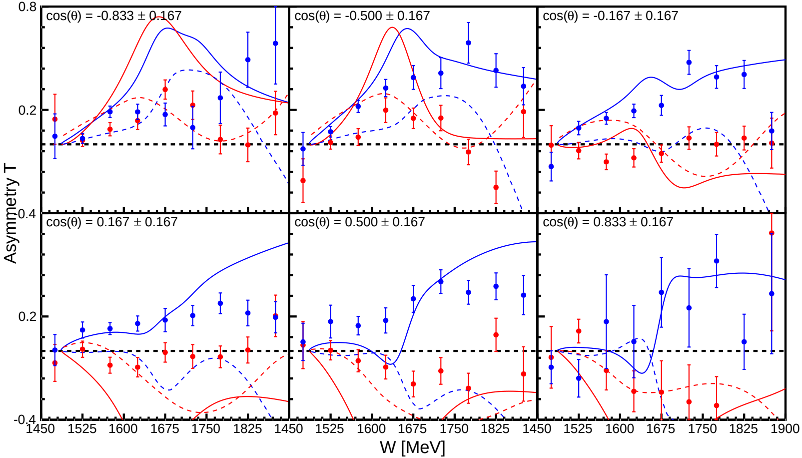
T: ηn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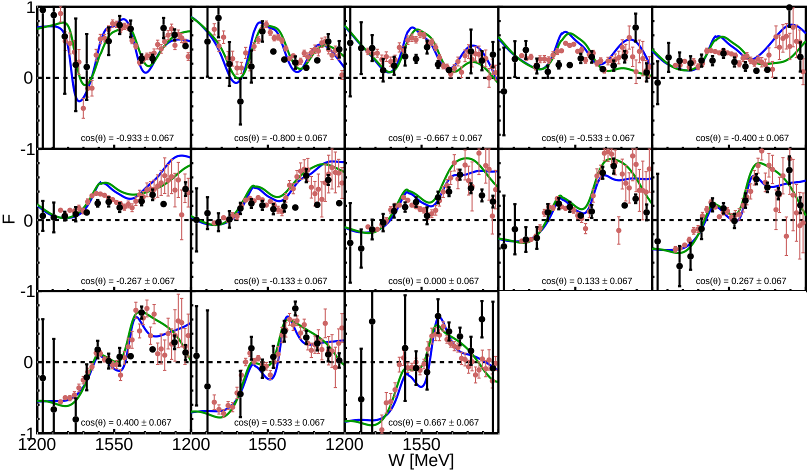
F: $\pi^0 p$



1
0
-1
F
cos(θ) = -0.933 ± 0.067
cos(θ) = -0.800 ± 0.067
cos(θ) = -0.667 ± 0.067
cos(θ) = -0.533 ± 0.067
cos(θ) = -0.400 ± 0.067
cos(θ) = -0.267 ± 0.067
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cos(θ) = 0.000 ± 0.067
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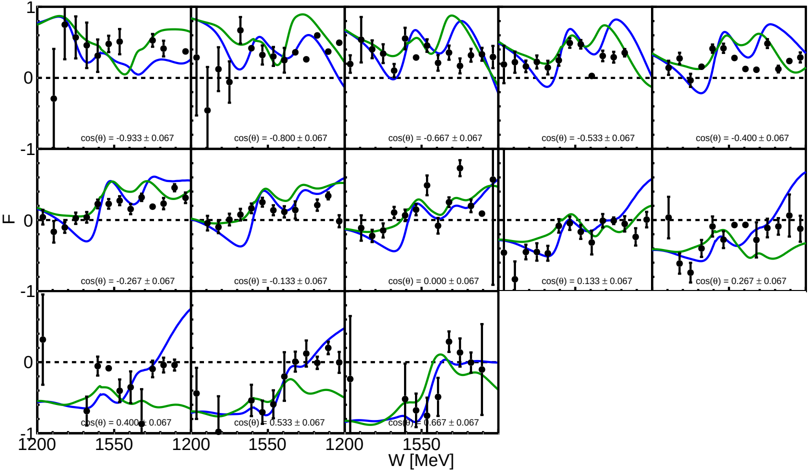
1200
1550
W [MeV]

F: $\pi^0 n$



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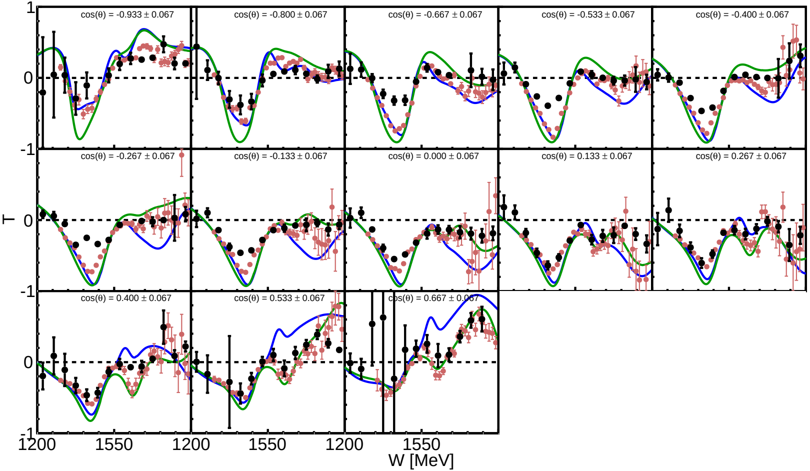
T: $\pi^0 p$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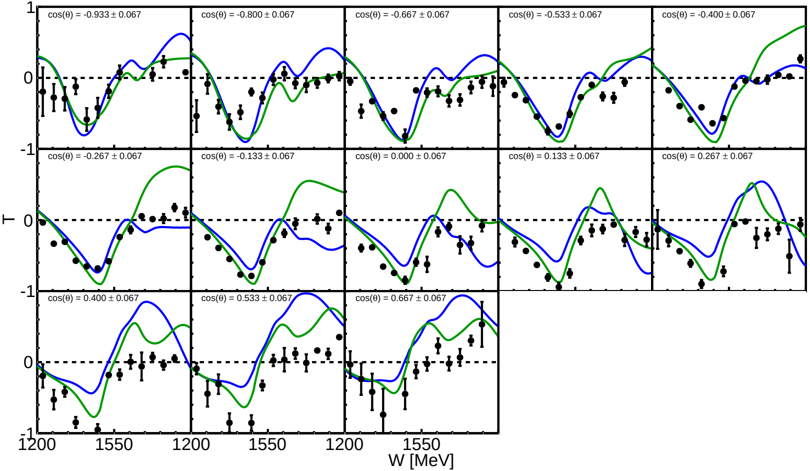

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