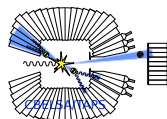


Determination of Polarization Observables in the $\pi^0\eta$ -Photoproduction off the Nucleon

NSTAR 2026 Conference

L. Reschke for the CBELSA/TAPS Collaboration

September 2026

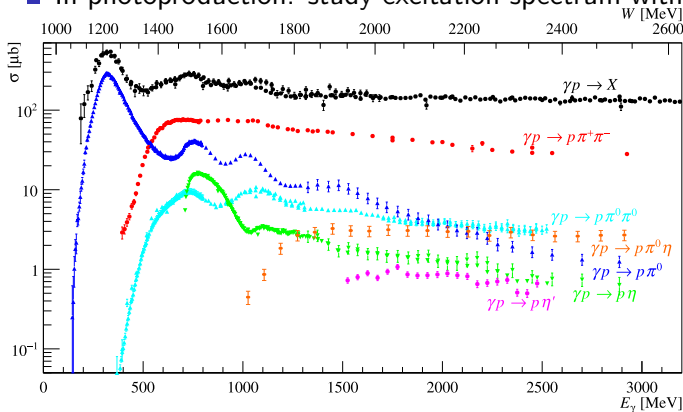


Nucleon Excitation Spectrum

- Nucleons are composite particles

Nucleon Excitation Spectrum

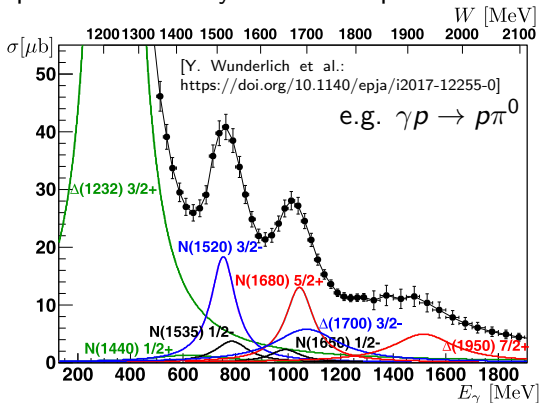
- Nucleons are composite particles
- In photoproduction: study excitation spectrum with γ beam



[A. Thiel, F. Afzal, Y. Wunderlich arXiv:2202.05055v2; I. Horn et al. <https://hdl.handle.net/20.500.11811/2061>]

Nucleon Excitation Spectrum

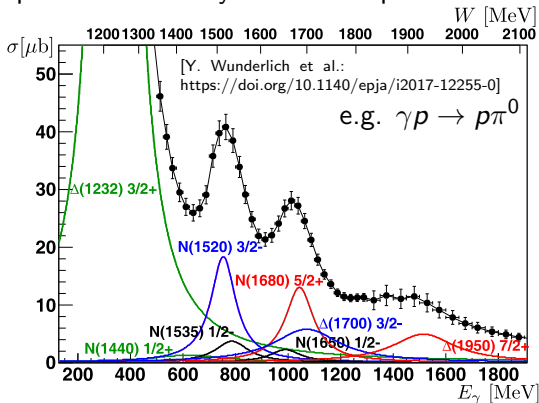
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$$\sigma \propto \sum_{\ell} |\mathcal{A}_{\ell}|^2 + 2 \operatorname{Re} \sum_{\ell < \ell'} \mathcal{A}_{\ell} \mathcal{A}_{\ell'}^*$$

Nucleon Excitation Spectrum

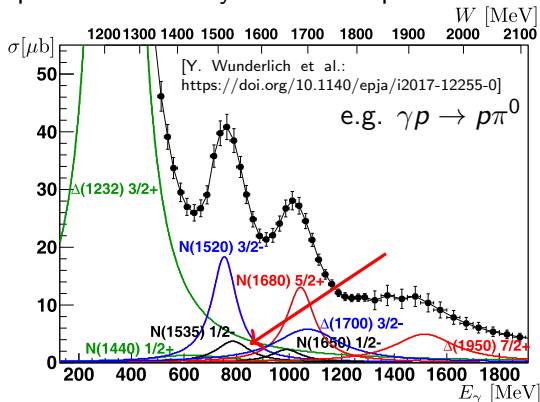
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$$\mathcal{O}_i \propto \text{Re} \sum_{\ell, \ell'} \mathcal{A}_\ell \mathcal{A}_{\ell'}^*$$

Nucleon Excitation Spectrum

- Nucleons are composite particles
- In photoproduction: study excitation spectrum with γ beam



$$\rightarrow \mathcal{T} \propto \underbrace{-2E_{0+}^* E_{1+} - 2E_{0+}^* M_{1+}} + \dots$$

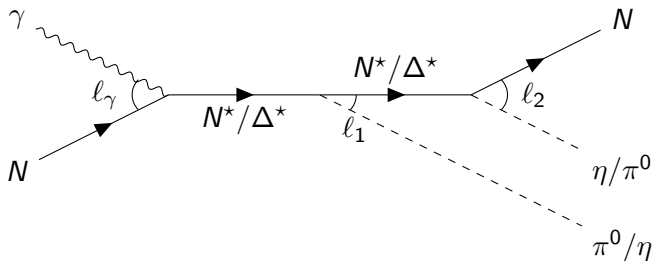
Interference between $\Delta(1232)(P_{33})$ and $N(1535)(S_{11})$

Pion Eta Photoproduction

$$\gamma N \rightarrow N\pi^0\eta \rightarrow N4\gamma \Rightarrow \mathcal{O}_i$$

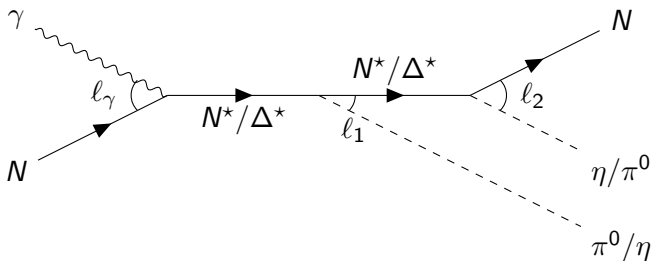
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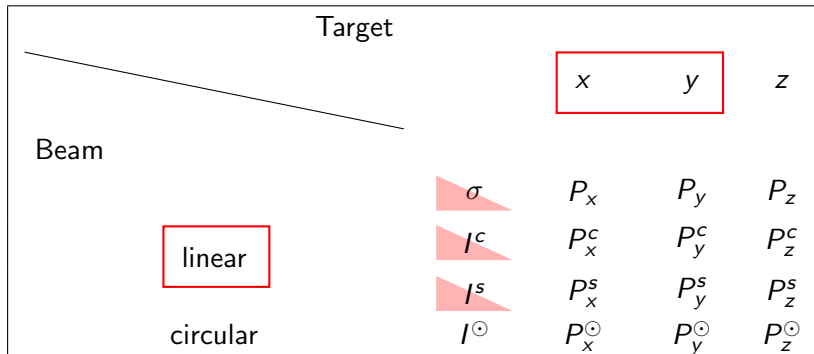
- CBELSA/TAPS well suited for neutral final states
- Two-meson final state $\rightarrow$ rich resonance dynamics
- Combined **n** and **p** measurements $\rightarrow$ complementary

Polarization Observables in $\gamma N \rightarrow N\pi^0\eta$

Target		x	y	z
Beam				
		P_x	P_y	P_z
	linear 	P_x^c	P_y^c	P_z^c
		P_x^s	P_y^s	P_z^s
circular	$I^\odot$	$P_x^\odot$	$P_y^\odot$	$P_z^\odot$

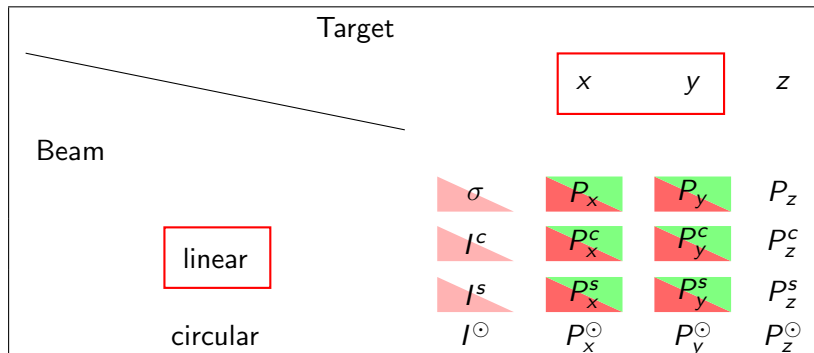
 proton

Polarization Observables in $\gamma N \rightarrow N\pi^0\eta$



proton

Polarization Observables in $\gamma N \rightarrow N\pi^0\eta$

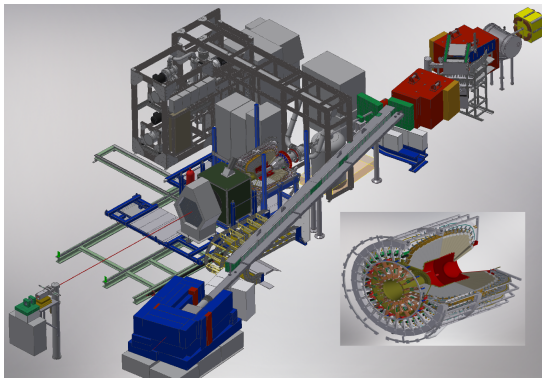


proton

neutron

CBELSA/TAPS Experiment

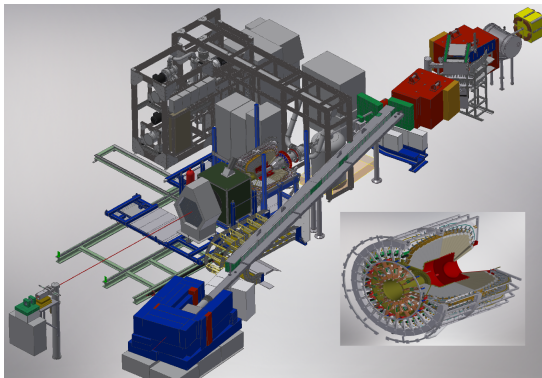
M. Grüner (HISKP)



- Linearly polarized photon beam

CBELSA/TAPS Experiment

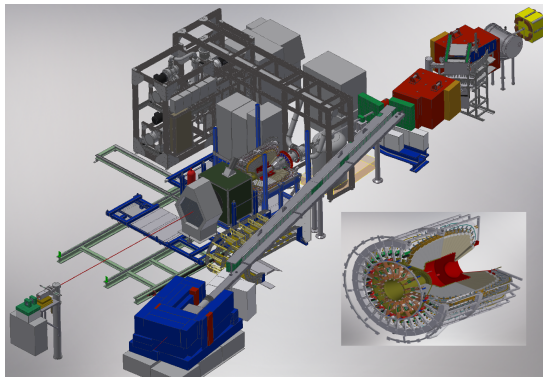
M. Grüner (HISKP)



- Linearly polarized photon beam
- Polarized deuterated butanol target ($\text{C}_4\text{D}_{10}\text{O}$)

CBELSA/TAPS Experiment

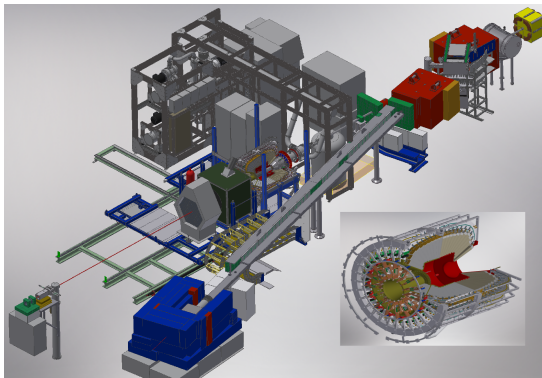
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- $\rightarrow$ measurement with C -target for background subtraction

CBELSA/TAPS Experiment

M. Grüner (HISKP)



- Linearly polarized photon beam
- Polarized deuterated butanol target ($\text{C}_4\text{D}_{10}\text{O}$)
- $\rightarrow$ measurement with C -target for background subtraction
- Nearly 4π e.m. calorimetry + charge sens. detectors

Event Topology and Selection

Selection of $\gamma N \rightarrow N\pi^0\eta \rightarrow N(2\gamma)(2\gamma)$:

Event Topology and Selection

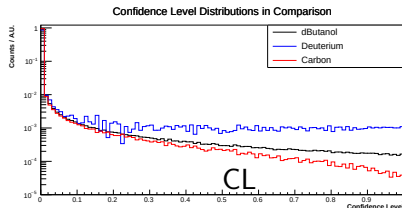
Selection of $\gamma N \rightarrow N\pi^0\eta \rightarrow N(2\gamma)(2\gamma)$:

1 Preselection:

- 4 n. + 1 ch. / 5 n. clusters
- Initial-final state time coincidence

2 Kinematic fit:

- Cut on $CL_{\pi^0\eta} > 0.1$
- Anti-cut on $CL_{2\pi^0} < 0.02$



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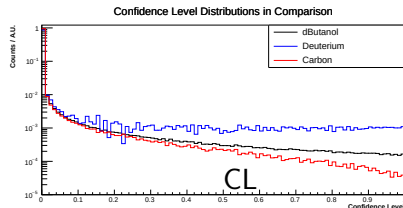
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3 Cut on $p^{\text{Fermi}} < 93 \text{ MeV}$



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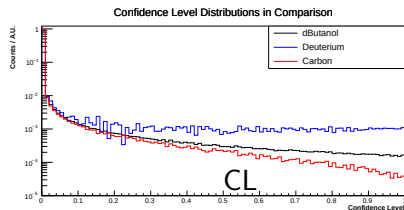
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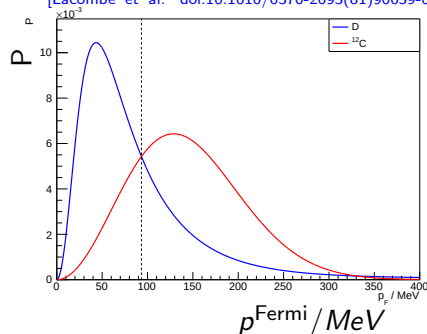
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[Lacombe et al. doi:10.1016/0370-2693(81)90659-6]



Kinematic Fit

$$\text{Bound N} \rightarrow p_N^{\text{Fermi}} \neq \vec{0}$$

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$$\begin{bmatrix} E_{\gamma_b} \\ \rho_{\gamma_b} \\ \theta_{\gamma_b} \\ \phi_{\gamma_b} \end{bmatrix} + \begin{bmatrix} E_n \\ p_x \\ p_y \\ p_z \end{bmatrix} \rightarrow \begin{bmatrix} E_{n'} \\ \rho_{n'} \\ \theta_{n'} \\ \phi_{n'} \end{bmatrix} + \begin{bmatrix} E_{\pi^0} \\ \rho_{\pi} \\ \theta_{\pi} \\ \phi_{\pi} \end{bmatrix} + \begin{bmatrix} E_{\eta} \\ \rho_{\eta} \\ \theta_{\eta} \\ \phi_{\eta} \end{bmatrix}$$

$$\text{with } \vec{p}_i^{\text{Fermi}} = 0 \pm 48 \text{ MeV}$$

Kinematic Fit

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$$\begin{bmatrix} E_{\gamma_b} \\ \rho_{\gamma_b} \\ \theta_{\gamma_b} \\ \phi_{\gamma_b} \end{bmatrix} + \begin{bmatrix} E_n \\ p_x \\ p_y \\ p_z \end{bmatrix} \rightarrow \begin{bmatrix} E_{n'} \\ \rho_{n'} \\ \theta_{n'} \\ \phi_{n'} \end{bmatrix} + \begin{bmatrix} E_{\pi^0} \\ \rho_{\pi} \\ \theta_{\pi} \\ \phi_{\pi} \end{bmatrix} + \begin{bmatrix} E_{\eta} \\ \rho_{\eta} \\ \theta_{\eta} \\ \phi_{\eta} \end{bmatrix}$$

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- Energy-momentum conservation
- Particle mass constraints
- Fermi-momentum distribution

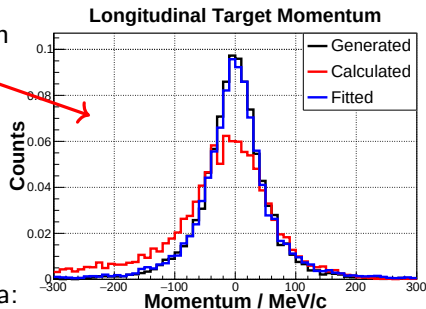
Kinematic Fit

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$$\text{with } \vec{p}_i^{\text{Fermi}} = 0 \pm 48 \text{ MeV}$$

- Energy-momentum conservation
- Particle mass constraints
- Fermi-momentum distribution
- Improved kinematic resolution
- Reduced systematic shifts

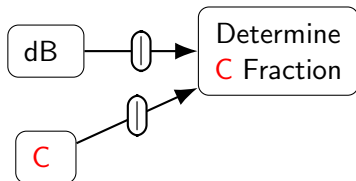


→ N. Kolanus, J. Kohlen, U. Thoma:

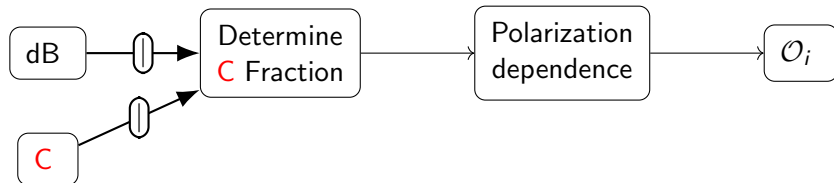
“Kinematic Fitting of Electromagnetic Calorimetry Data – an Improved Method”

eprint: coming soon

Observable Extraction

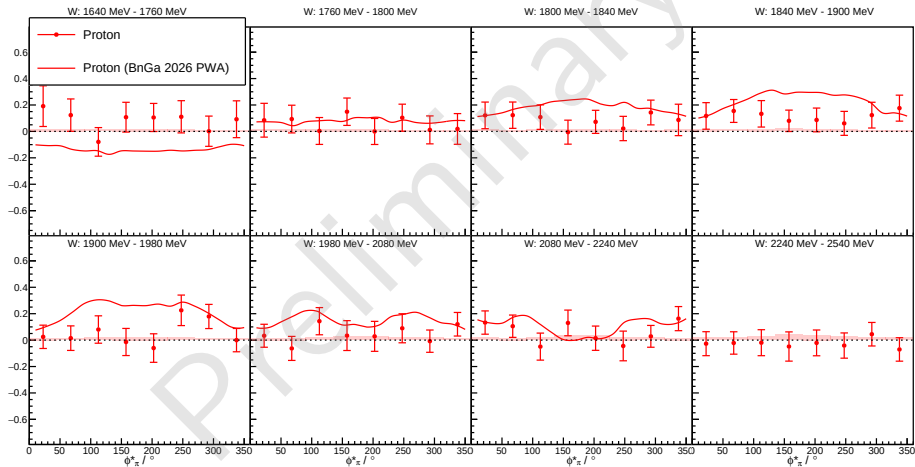


Observable Extraction

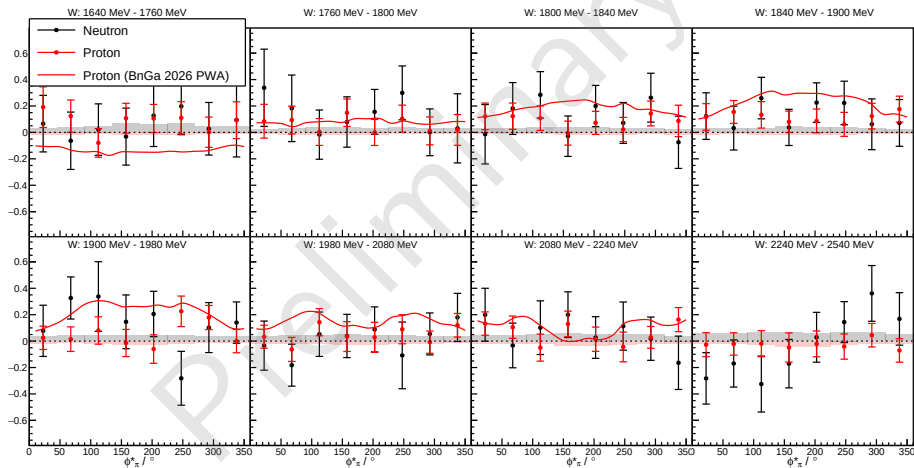


$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} \left\{ 1 + \Lambda \cos(\beta - \varphi) P_x + \Lambda \sin(\beta - \varphi) P_y \right. \\
+ \delta_\ell \sin(2(\alpha - \varphi)) \left[I^s + \Lambda \cos(\beta - \varphi) P_x^s + \Lambda \sin(\beta - \varphi) P_y^s \right] \\
\left. + \delta_\ell \cos(2(\alpha - \varphi)) \left[I^c + \Lambda \cos(\beta - \varphi) P_x^c + \Lambda \sin(\beta - \varphi) P_y^c \right] \right\}$$

Results for P_y in $N\pi^0\eta$

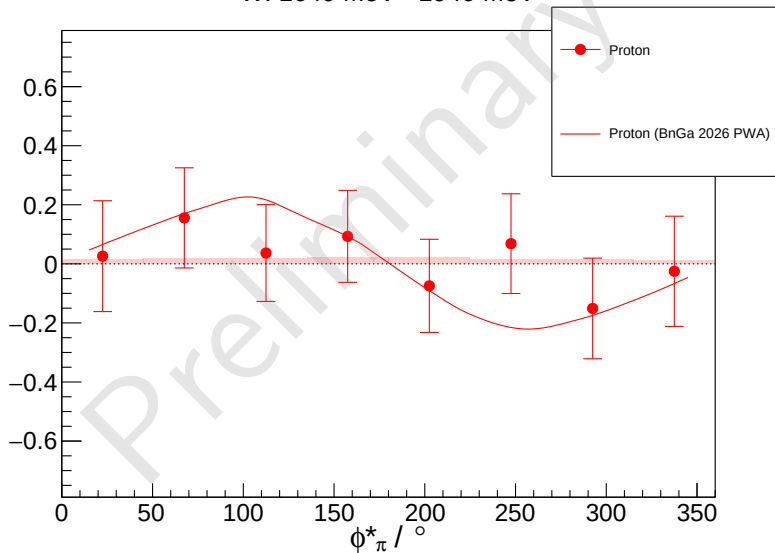


Results for P_y in $N\pi^0\eta$



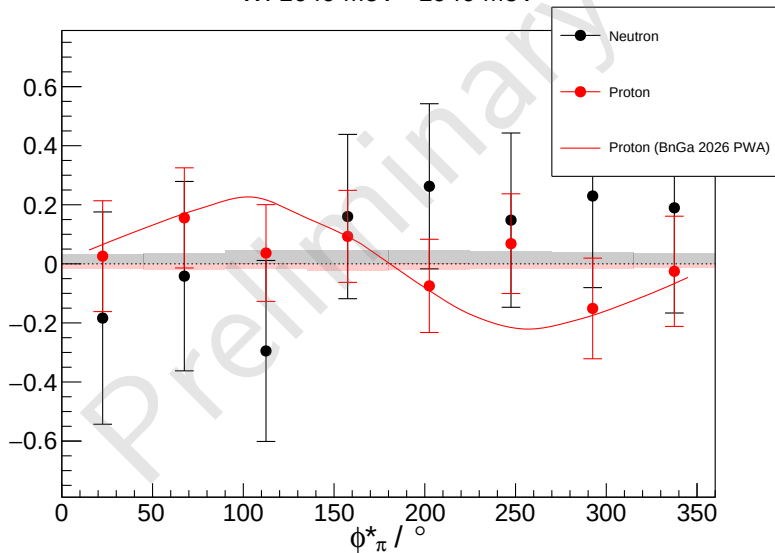
Results for P_y^s in $N\pi^0\eta$

W: 1640 MeV - 1940 MeV



Results for P_y^s in $N\pi^0\eta$

W: 1640 MeV - 1940 MeV



Conclusions

- Event selection using a kinematic fit and carbon subtraction
- First-time extraction of $P_x, P_y, P_x^s, P_x^c, P_y^s, P_y^c$ for $\gamma N \rightarrow N\pi^0\eta$

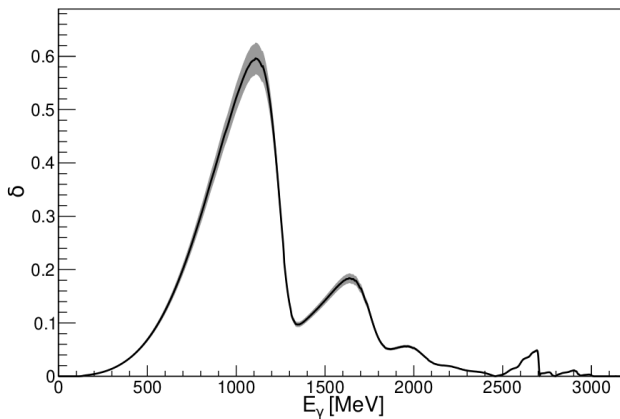
Outlook:

- Quantify systematic uncertainties
- Continuation of measurements of pol. observables with a neutron target at the upcoming INSIGHT experiment

Supported by DFG: 505387544

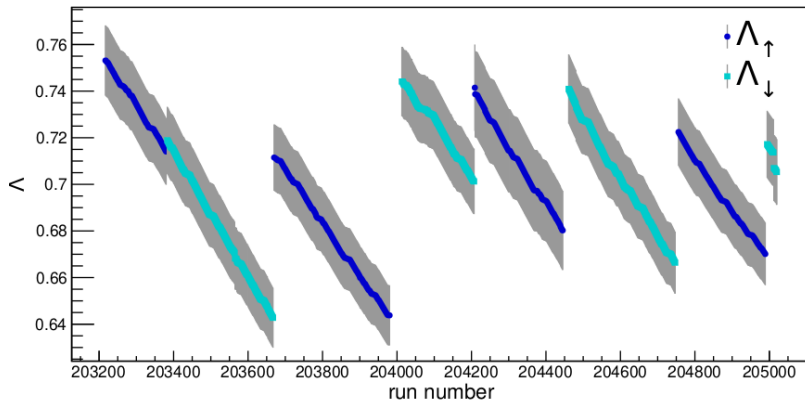
Beam Polarization

[Jermann: eprint:10.5451/unibas-ep94640]



Target Polarization

[Jermann: eprint:10.5451/unibas-ep94640]



Cross Section - Formulas

$$\sigma \propto \sum_{\ell} |\mathcal{A}_{\ell}|^2 + 2 \operatorname{Re} \sum_{\ell < \ell'} \mathcal{A}_{\ell} \mathcal{A}_{\ell'}^*$$

$$\mathcal{A} \propto \sum_{\ell, \pm} (E_{\ell, \pm} + M_{\ell, \pm}) + \mathcal{A}_{bg}$$

$$\rightarrow \sigma \propto |E_{0+}|^2 + |E_{1+}|^2 + |M_{1+}|^2 + |M_{1-}|^2 + \dots$$

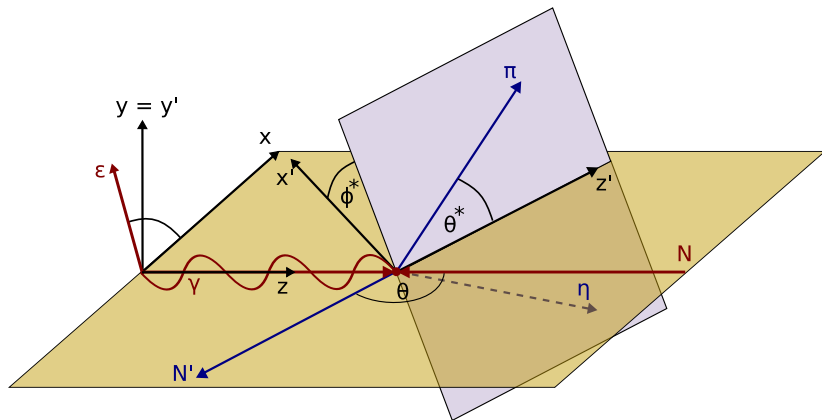
Polarization Observables - Formulas

$$\mathcal{O}_i \propto \text{Re} \sum_{\ell, \ell'} \mathcal{A}_\ell \mathcal{A}_{\ell'}^*$$

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$$\rightarrow \mathcal{T} \propto \underbrace{-2E_{0+}^* E_{1+} - 2E_{0+}^* M_{1+}} + \dots$$

Coordinate System



Caption

Background Subtraction

Pol. **d** bound to unpol. **O/C**:

$$N_d = N_{dB} - c \cdot N_C$$



C measurement



d-free space by m_{inv} , angles, and p_N^{Fermi}

