Differential $\eta$ photoproduction cross sections off the proton from the GlueX experiment

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On behalf of the GlueX Collaboration
Outline

• Introduction
• GlueX detector and data selection
  • $\eta$ Differential cross section in low t-range
  • $\eta$ Differential cross section in low u-range
  • $\eta$ Differential cross section in the intermediate region (Large t and u)
• Summary
GlueX studies the light meson spectrum and searches for exotic and hybrid mesons. The production of the lightest multiplet of exotic mesons involves the same Regge exchanges that occur in the pseudoscalar mesons production like $\eta^{(')}$ (Mathieu et al., *Physics Letters B, 774* (2017) 362-367).

The chosen reaction is one of the simplest final states in the GlueX experiment to test the Regge theory for $s$ and $t$ dependence.

The forward cross section peak is due to mesons exchange $(S^2\alpha(t) - 2)$, while the backward cross section peak is due to baryons exchange $(S^2\alpha(u) - 2)$, where $\alpha(t)$ and $\alpha(u)$ are the exchanged Regge trajectories (M. Guidal, J.M. Laget and M. Vanderhaeghen: *Nucl.Phys.A 627* (1997) 645-678).

Previous cross section measurements are scarce for beam energies above 4.5 GeV. GlueX will provide the most extensive high statistics measurements currently available.
GlueX data tests many theoretical models in the full t-range such as:

  - 21 N* nucleon resonance states and Regge background
  - Handbag model studies the patron distribution functions and its cross section predictions valid for large s, t, and u >> conventional hadron scale 1 GeV^2
- GlueX detector located at Hall-D in Jefferson lab.
- Designed to detect charged particles and neutrals that are byproducts of possible exotic states.
- Linearly polarized photon beam interacts with a 30 cm liquid Hydrogen target in the middle of the GlueX detector.
Data Selection
\[ \gamma + p \rightarrow \eta + p \]

- 39.41% ± 0.20 \( \eta \rightarrow \gamma \gamma \) neutral mode
- OR
- 22.92% ± 0.28 \( \eta \rightarrow \pi^+ \pi^- \pi^0 \) charged mode
- Most of the differential cross section results that will be shown today are from the neutral mode.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Run period</th>
<th>Raw Data(PB)</th>
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<tbody>
<tr>
<td>GlueX I</td>
<td>Spring 2017</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Spring 2018</td>
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</tr>
<tr>
<td></td>
<td>Fall 2018</td>
<td>1.1</td>
</tr>
<tr>
<td>GlueX II</td>
<td>Spring 2020</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>Summer 2020</td>
<td>1.7</td>
</tr>
</tbody>
</table>

- The GlueX beam energy \((6.0 < E_\gamma < 11.5 \text{ GeV})\).

- 50% of GlueX-I data were used in the \( \eta \) photoproduction differential cross section measurements. The luminosity in the bin of \( E_\gamma = 8.25 \pm 0.25 \text{ GeV} \) is 44 pb\(^{-1}\).

- Short dedicated run for low energy data \((3 < E_\gamma < 5.5 \text{ GeV})\) during the Fall 2018 run period.
Differential cross section comparisons with previous measurements

- Short dedicated run for low energy data $3 < E_\gamma < 5.5$ GeV.
- GlueX has better coverage than CLAS in low $t$, and $u$ kinematic regions.
- At higher energies, the statistics are not limited in the GlueX compared to CLAS2020 results.

Hu et al., arXiv:2006.01361, 2020
Tiator et al., arXiv:1806.04525, 2018
Nys et al., PhysRevD.95.034014, 2017
http://cgl.soic.indiana.edu/jpac/EtaPhot.php,
GlueX-I data
Yield Extraction

\[ E_\gamma = 8.25 \pm 0.25 \text{ GeV} \]

- Good fits and agreement between data and simulation
Differential Cross Section Results for the $t$-range $[0, 3.0]$ GeV$^2$

**$W = 3550$ MeV**

$E_\gamma = 6.25 \pm 0.25$ GeV

Errors are statistical

**$W = 3680$ MeV**

$E_\gamma = 6.75 \pm 0.25$ GeV

**$W = 4044$ MeV**

$E_\gamma = 8.25 \pm 0.25$ GeV

**$W = 4588$ MeV**

$E_\gamma = 10.75 \pm 0.25$ GeV
Differential Cross Section Results for the t-range [0, 3.0] GeV^2

- EtaMAID2018 has similar pattern as data at |t| < 1.5 GeV^2, while Laget model has similar pattern as the data at |t| > 1.5 GeV^2.

- EtaMAID2018 has better agreement with the data at low energies.
Differential Cross Section Results for the t-range [0, 3.0] GeV²

Compare to charged decay mode

\[ E_\gamma = 7.75 \pm 0.25 \text{ GeV} \]

- Good agreement with the PDG branching fraction of the two decay-branching ratios

\[ 0.58 \pm 0.01 \]
Zoom In Differential Cross Section Results for the t-range [0, 1.0] GeV^2

- Linear Fit for $\ln\left(\frac{d\sigma}{dt}\right)$ for $|t| < 1$ GeV^2
- Determine Regge parameters

- The slope from the data is very similar to the EtaMAID2018
A Regge trajectory can be expressed as

\[ \alpha(t) = \alpha' t + \alpha_0 , \]

where the differential cross section in the t-channel exchange is proportional to:

\[ \frac{d\sigma}{dt} \propto \left( \frac{s}{s_0} \right)^{2(\alpha' t + \alpha_0) - 2} \]

\[ s_0 = 1 \text{ GeV}^2 \quad (\text{Conventional hadronic scale}) \]

\[ \ln \left( \frac{d\sigma}{dt} \right) \propto C_0 + C_1 \alpha' t , \]

where

\[ C_1 = 2 \ln \left( \frac{s}{s_0} \right) \]

\[ C_0 = C_1 (\alpha_0 - 1) + \ln \Lambda , \]

Where \( \Lambda \) is the proportionality constant.
Extracted Regge Trajectories

\[ \alpha' = \frac{|\text{slope}|}{C_1} \]

\[ \alpha' = 0.513 \pm 0.003 \]
Differential cross section in the low \( u \)-range

- GlueX has a very good acceptance to measure the differential cross section in both \( t \)-channel, and \( u \)-channel exchanges.

Gaussian fit + Linear background to extract the yield from each \( t \)-bin.

\[
t = 14.1 \text{ GeV}^2
\]
Differential cross section in the low u-range

\[ E_\gamma = 8.25 \pm 0.25 \text{ GeV} \]

- Differential cross section peak in u-channel exchange.
Intermediate region (large t and u)

- Hard reactions, very small cross sections
- Low statistics, peak shape constrained by simulation

\[ t = 10.5 \text{ GeV}^2 \]
Differential cross section results for the intermediate region

\[ E_\gamma = 8.25 \pm 0.25 \text{ GeV} \]

The general data trend is generally reproduced by the handbag model in this region.

P. Kroll and P. Passek, PhysRevD.97.074023, 2018

Errors are statistical
Summary

\( E_y = 8.25 \pm 0.25 \ \text{GeV} \)

- EtaMIAD2018 and Laget models reproduce data trend for \(|t| < 2-3 \ \text{GeV}^2\).
- For the transition region (4 < \(|t| < 11 \ \text{GeV}^2\)), the handbag model seems to be valid.
- For \(|t| > 12 \ \text{GeV}\), no current model is describing the data.

- GlueX provides \( \eta \) photo-production cross section in the full t-range over a very wide range of beam energies up to 11.5 GeV, that covers several physics topics and production mechanisms.
- All the \( \eta \) differential cross section work will be published after systematic uncertainties are calculated.

GlueX acknowledges the support of several funding agencies and computing facilities [gluex.org/thanks/](http://gluex.org/thanks/)

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Backup
Differential Cross Section Results for the t-range [0.1, 3.0] GeV$^2$

**W = 3550 MeV**

BE = 6.25 ± 0.25 GeV

**W = 3680 MeV**

BE = 6.75 ± 0.25 GeV

**W = 3805 MeV**

BE = 7.25 ± 0.25 GeV

Errors are statistical