η Meson Photoproduction with the GlueX Experiment

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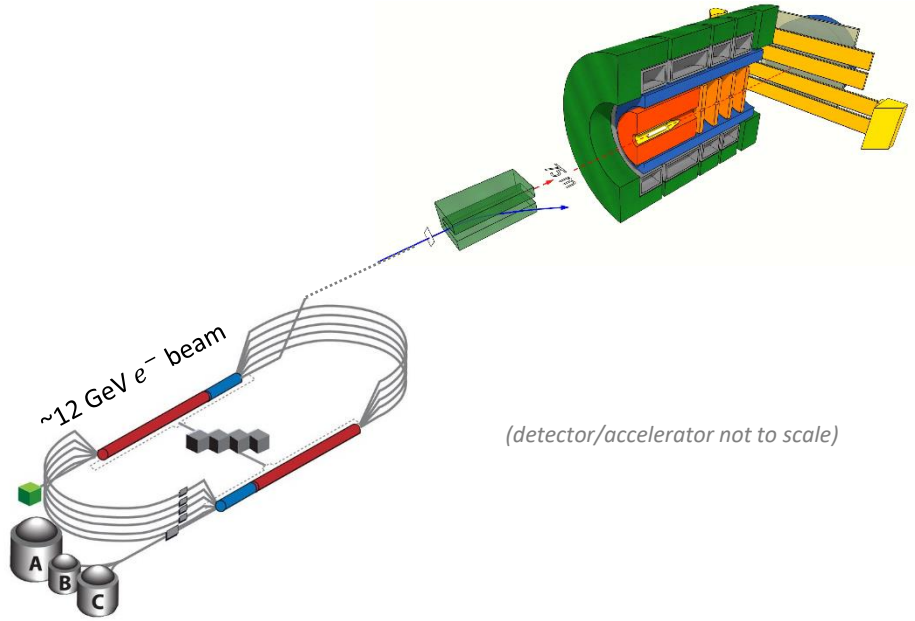
Jon Zarling

The GlueX Experiment

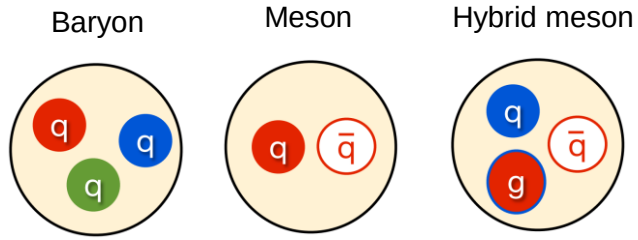
- Photon beam
- Proton target (LH2)
- Map light mesons in search of "exotic hybrid" mesons

  but also much more!

- Production mechanisms complicated
  - Requires detailed study
  - Well known pseudoscalars (π^0, η, η') ideal starting point



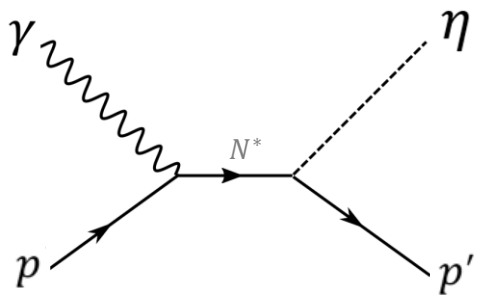
(detector/accelerator not to scale)



Exclusive η Photoproduction

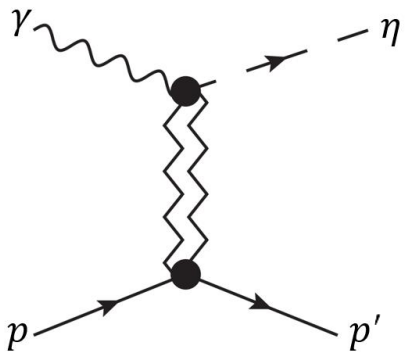
Reaction: $\gamma p \rightarrow \eta p$

- Lower energies (CLAS, MAMI, LEPS,…)
  - few hundred MeV to ~ 4 GeV
  - Nuclear excitation (s-channel)



s-channel

- Higher energies (GlueX, CLAS12)
  - ~ 4-12 GeV
  - Quasi-particle exchanges (Regge, t-channel)
  - **Similar mechanism as potential exotic states**



t-channel

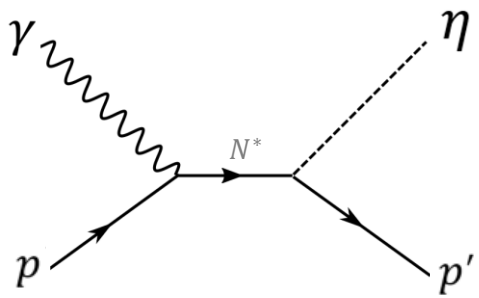
Exclusive η Photoproduction

Reaction: $\gamma p \rightarrow \eta p$

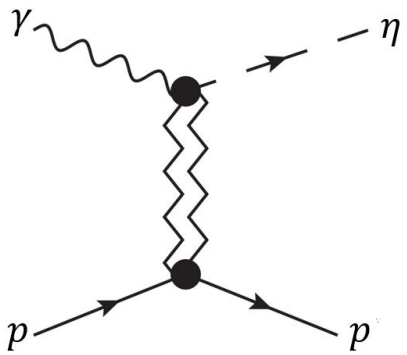
Measuring differential cross section at GlueX:

- Constrain models for exotic hybrid production
- Constrain backgrounds in lower E_γ data
  $\Rightarrow$ aid in excited baryon (N^*) extraction
- Deep, parton interactions?
- u-channel enhancement

$$t = (p_\gamma - p_\eta)^2$$
$$u = (p_\gamma - p_{p'})^2$$

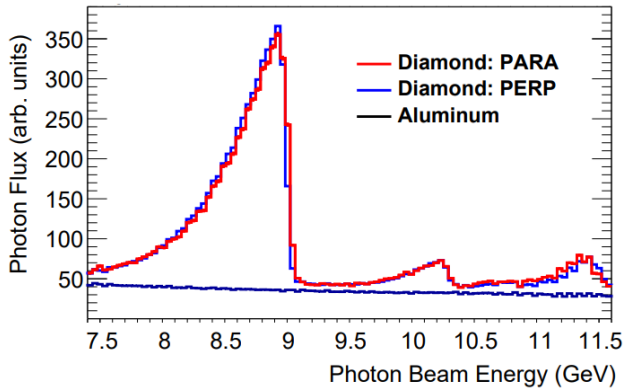


s-channel



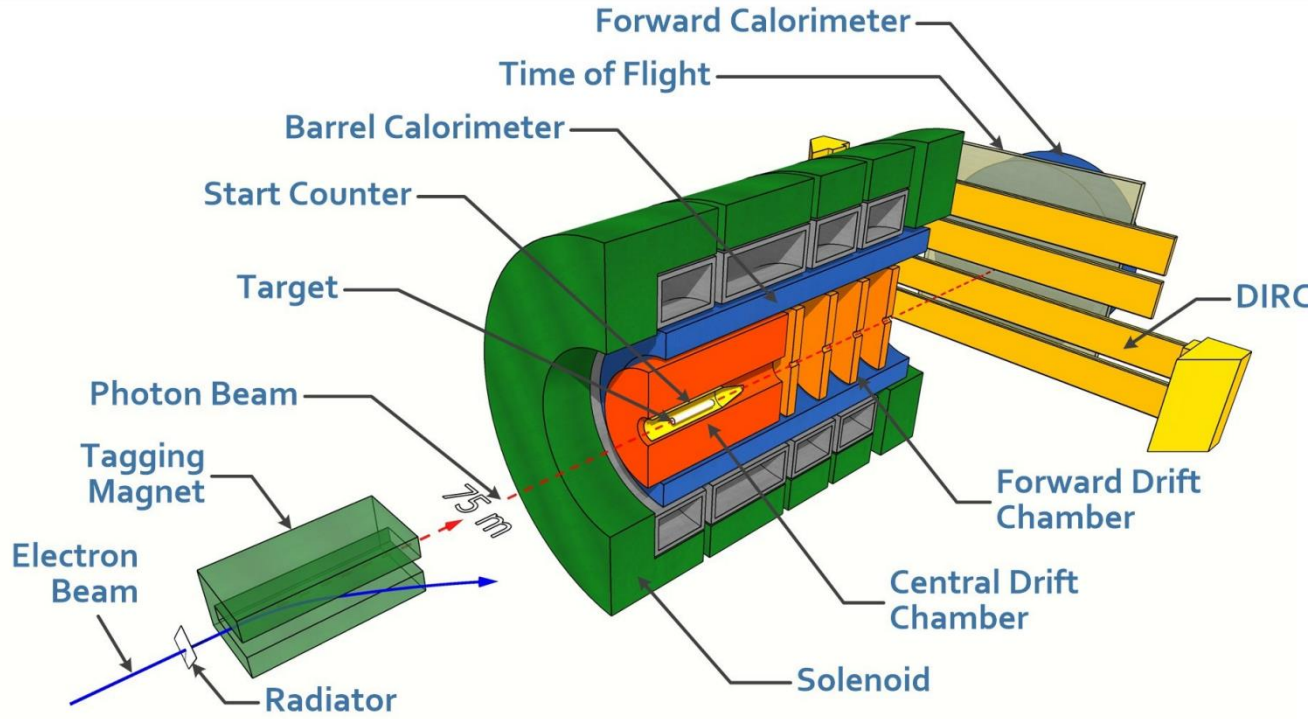
t-channel

GlueX @ Jefferson Lab



Key features:

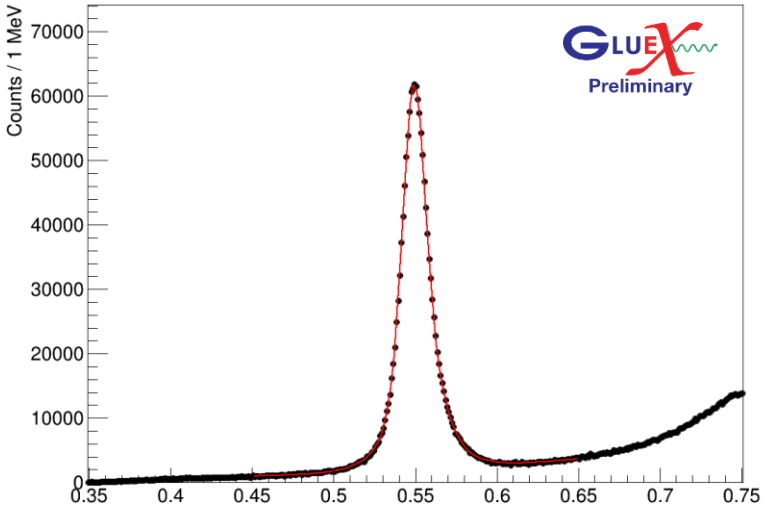
- 6-11 GeV photon beam
  - Enhanced, linearly polarized ~8.8 GeV
- Proton (LH_2) target
- Wide acceptance
- High statistics
  - Over 300 pb^{-1} (≈4 PB) GlueX-I dataset (2016-2018)
  - GlueX-II ongoing (2019-present)



η Reconstruction

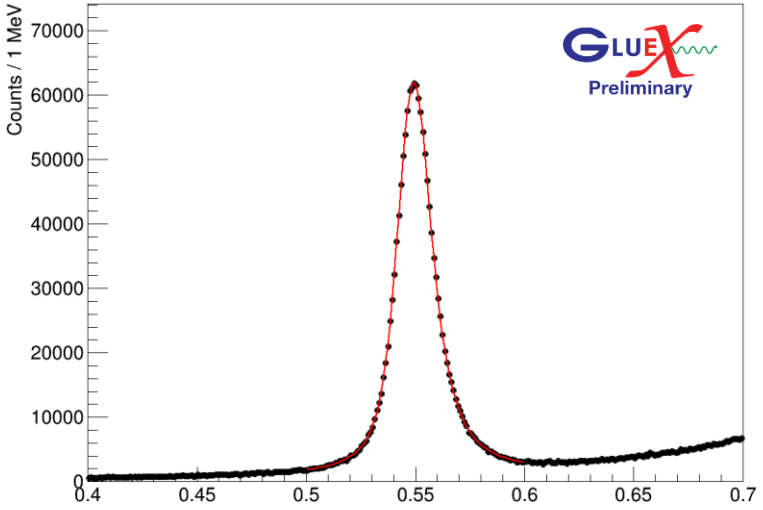
- Three decay modes offer high statistics at GlueX
- Kinematic fitting for exclusivity, resolution $(\chi^2_{\mathrm{kf}}/\mathrm{NDF}<10)$

$\eta \to \gamma\gamma$
$\mathcal{B}$=0.39



$\gamma\gamma$ inv. mass (GeV)

$\eta \to \pi^+\pi^-\pi^0$
$\mathcal{B}$=0.23



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$\eta \to \pi^0\pi^0\pi^0$
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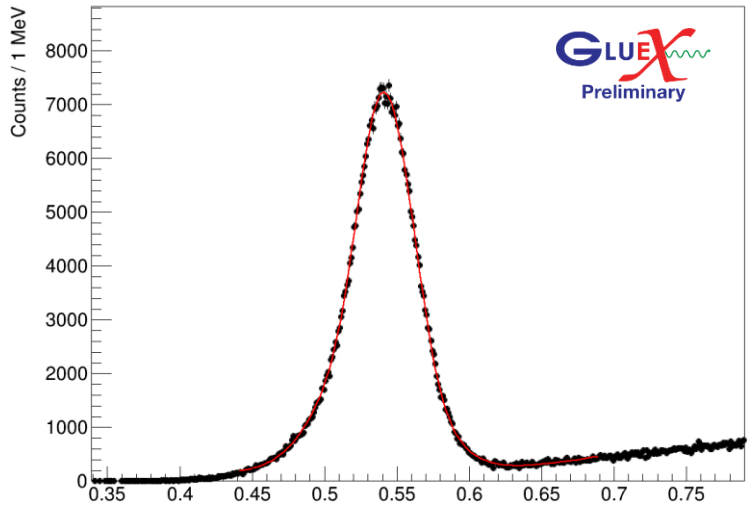
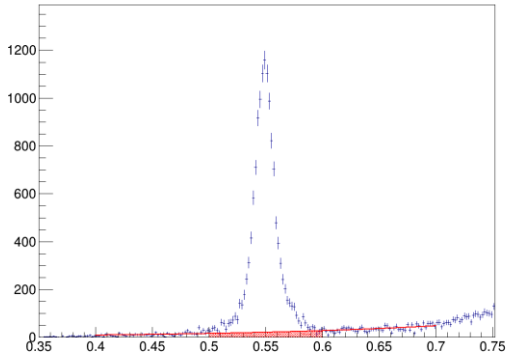


$\pi^0\pi^0\pi^0$ inv. mass (GeV)

Yield Determination

- Exponential background shape
  - Primarily from ω meson
  - Note $\omega \nrightarrow \pi^0\pi^0\pi^0$
- η yield:
  - Excess yield in fit range
  - Or double gaussian
  - Any difference ⇒ taken as systematic

$\eta \to \gamma\gamma$



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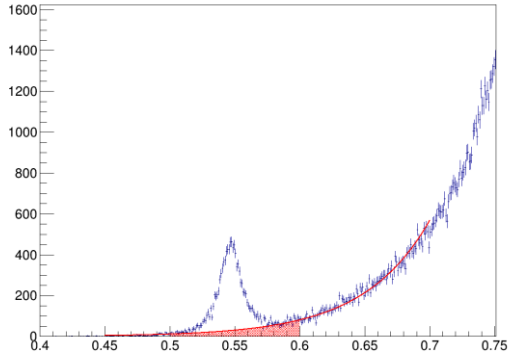

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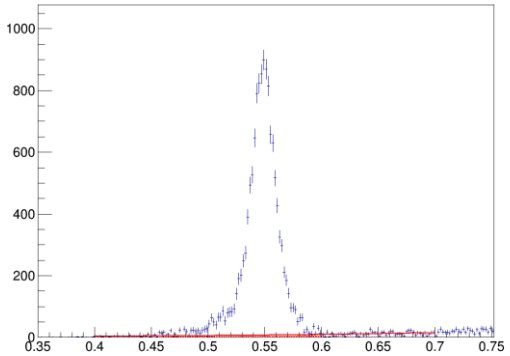
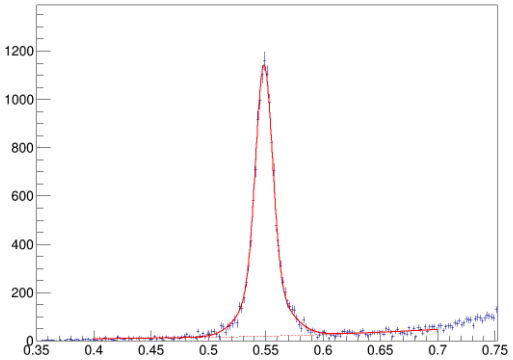
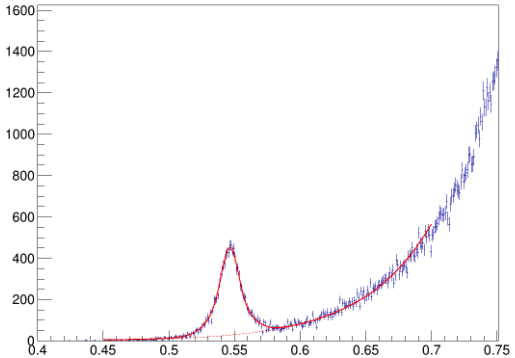


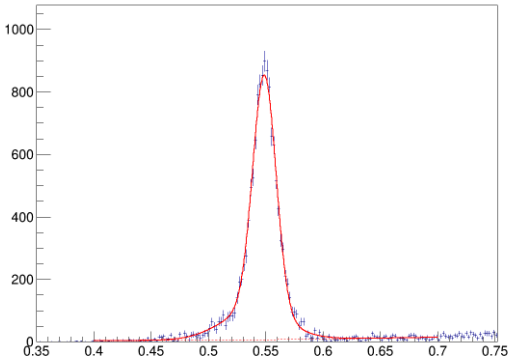
$\pi^0\pi^0\pi^0$ inv. mass (GeV)



$\gamma\gamma$ inv. mass (GeV)



$\pi^+\pi^-\pi^0$ inv. mass (GeV)



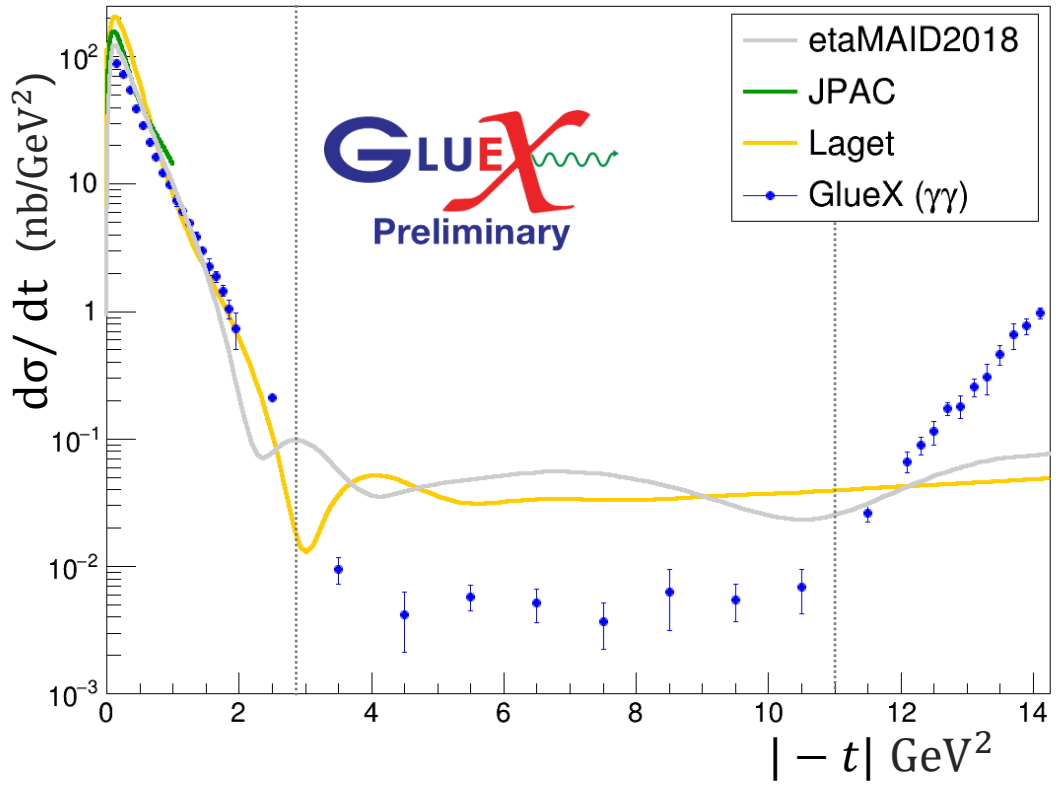
$\pi^0\pi^0\pi^0$ inv. mass (GeV)

Differential Cross Sections

- **Today**: focus on beam energy: 8.0 < E_γ< 8.5 GeV

  (good statistics for E_γ 6-11 GeV, also analyzing)

- Wide acceptance
- Three distinct kinematic regions
  - Small |-t| (large |-u|)
  - Intermediate |-t| and |-u|
  - Large |-t| (small |-u|)



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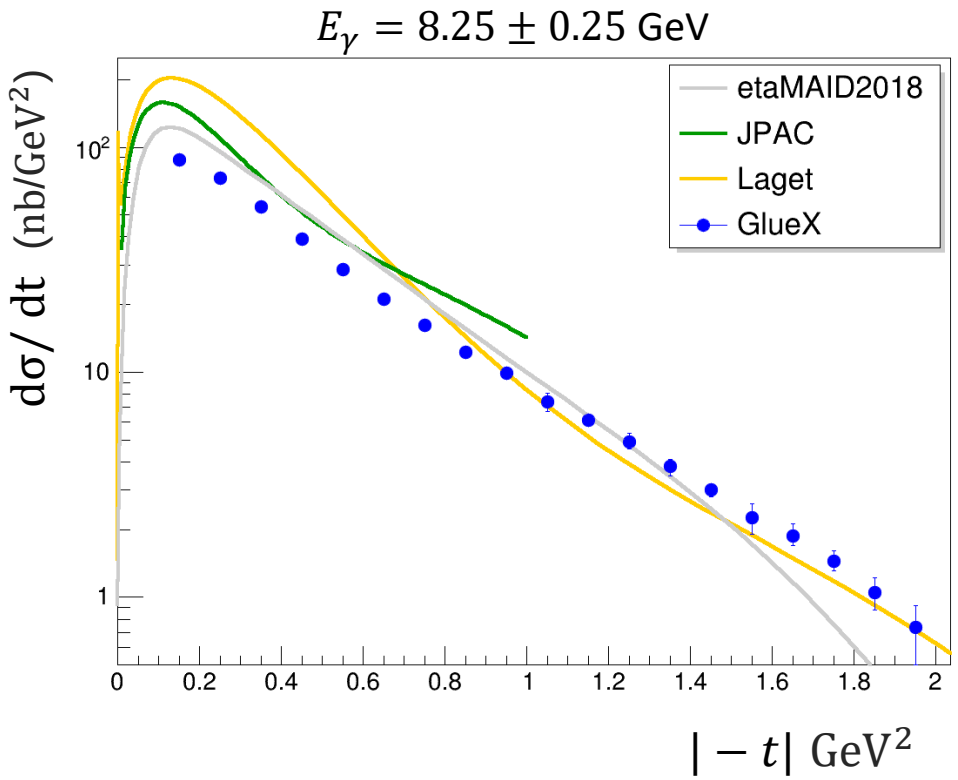


Theory models

etaMAID2018

- 21 N* resonances + Born + Regge
- L. Tiator *et al.* Eur. Phys. A **54**, 210 (2018)

JPAC

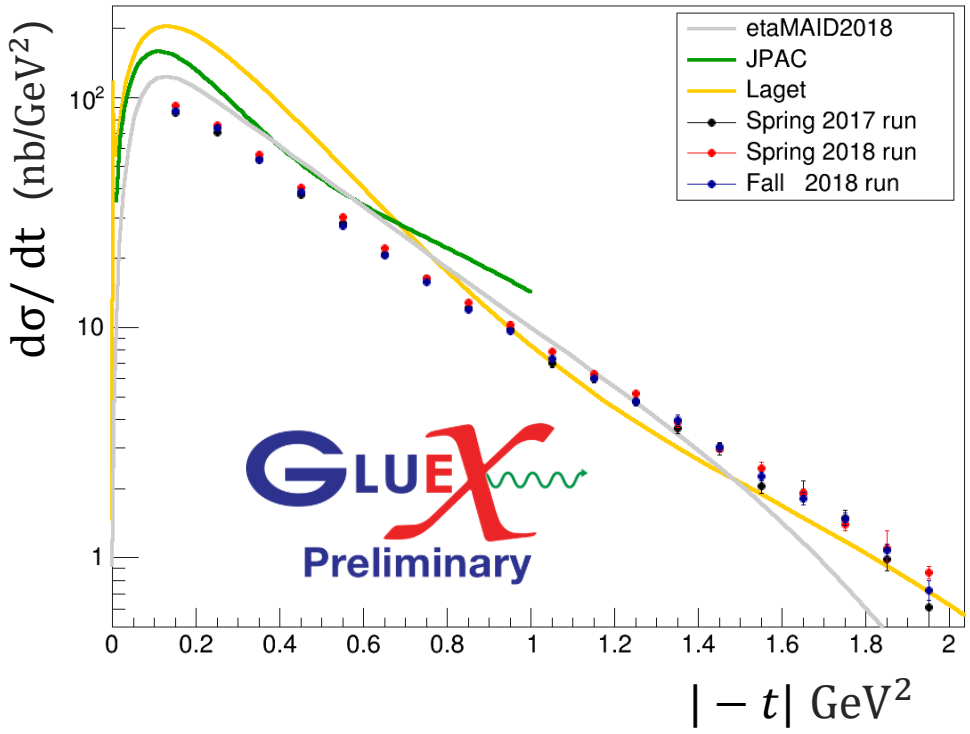
- t-channel Regge w/ FESR
- J. Nys *et al.* (Joint Physics Analysis Center) PRD **95**, 034014 (2017)

J.M. Laget

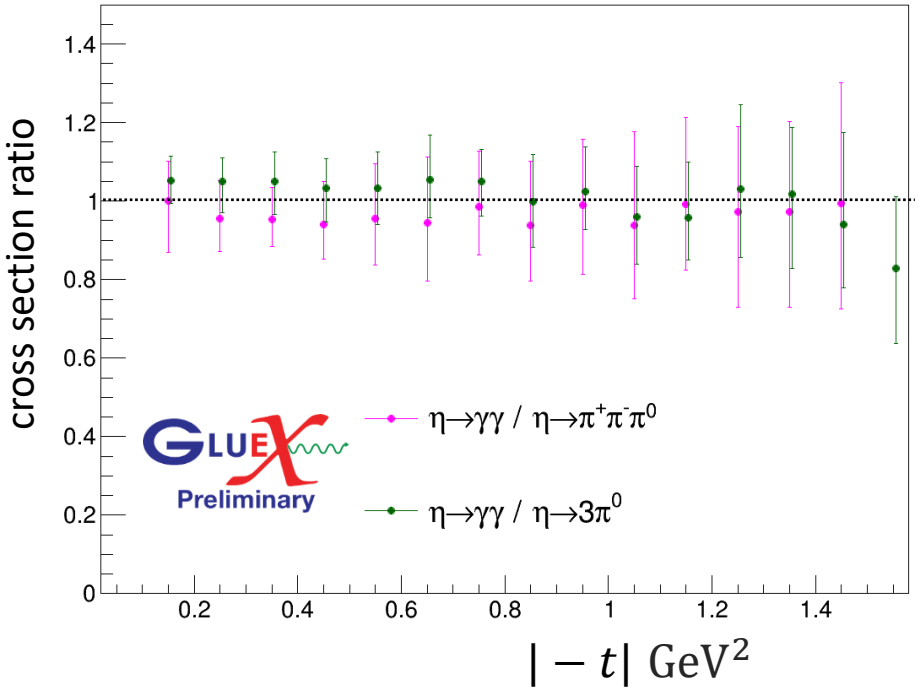
- t-channel Regge + Primakoff
- PRC **72**, 022202(R) (2005)

Validation Checks

Comparing data periods



Comparing decay modes

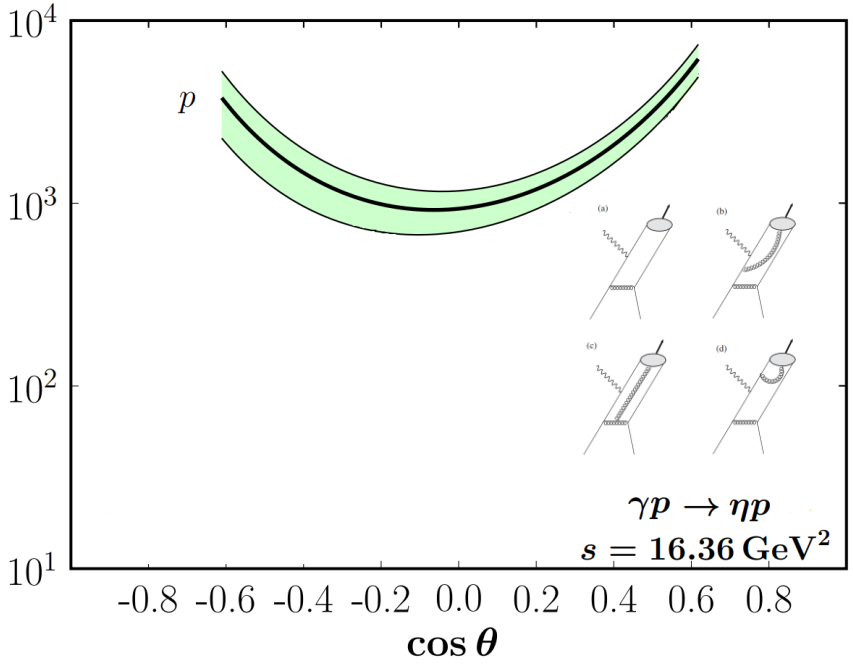


[any normalization uncertainty (flux, target) under study, not quantified here]

Wide-angle Cross Sections

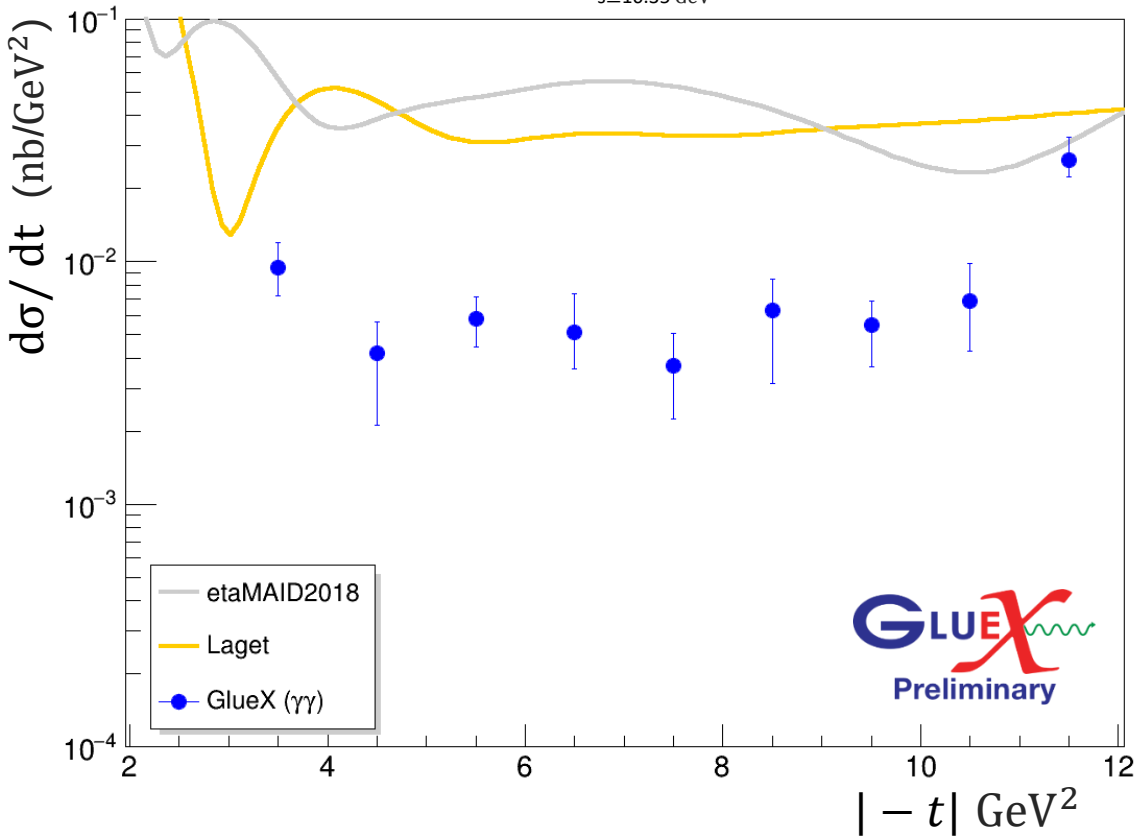
Handbag model

- P. Kroll and K. Passek-Kumerički
- Deep photon-parton interactions
- PRD **105**, 034005 (2022)



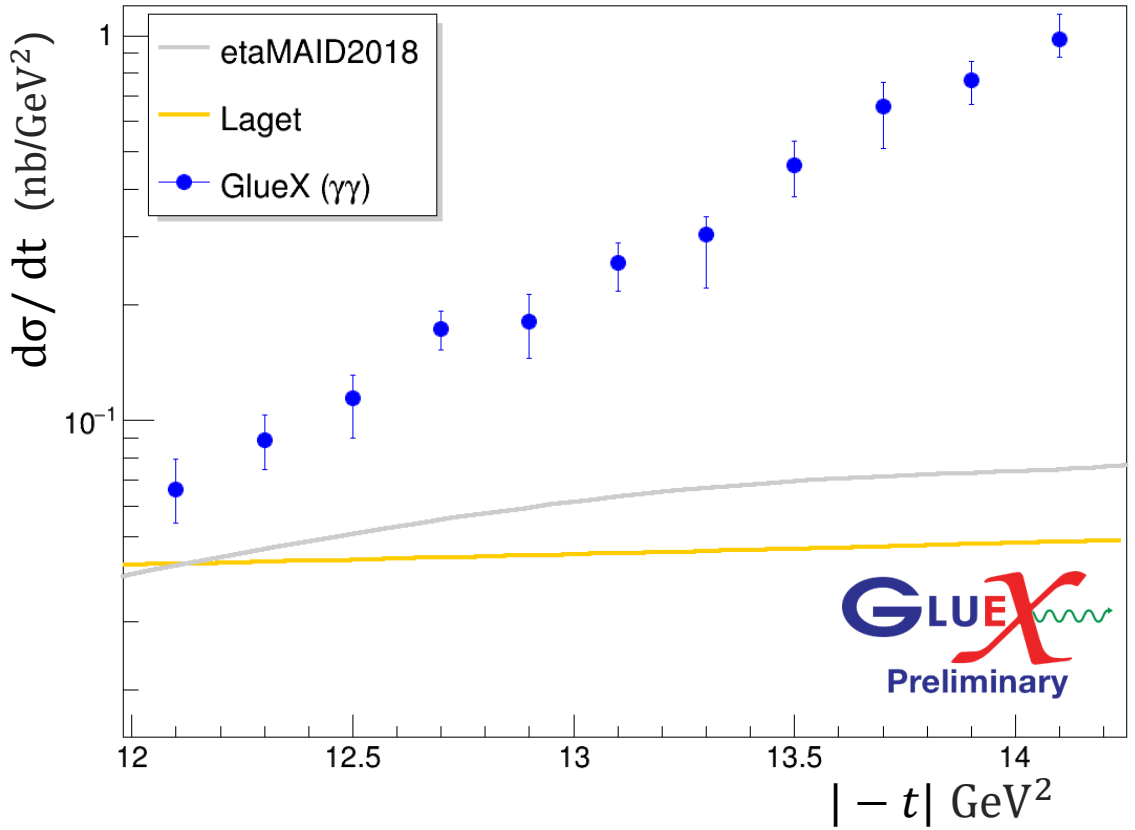
$8.0 < E_\gamma < 8.5$ GeV

$s \cong 16.35\ \mathrm{GeV}^2$



η Production in u-channel

- Secondary enhancement at backward angles (high |t|, low |u|)
- Extrapolation of theory models
  - Not aware of models that explicitly attempt to describe |u|-channel
- Growing interest in backward-angle meson production
  - https://www.jlab.org/indico/event/375/

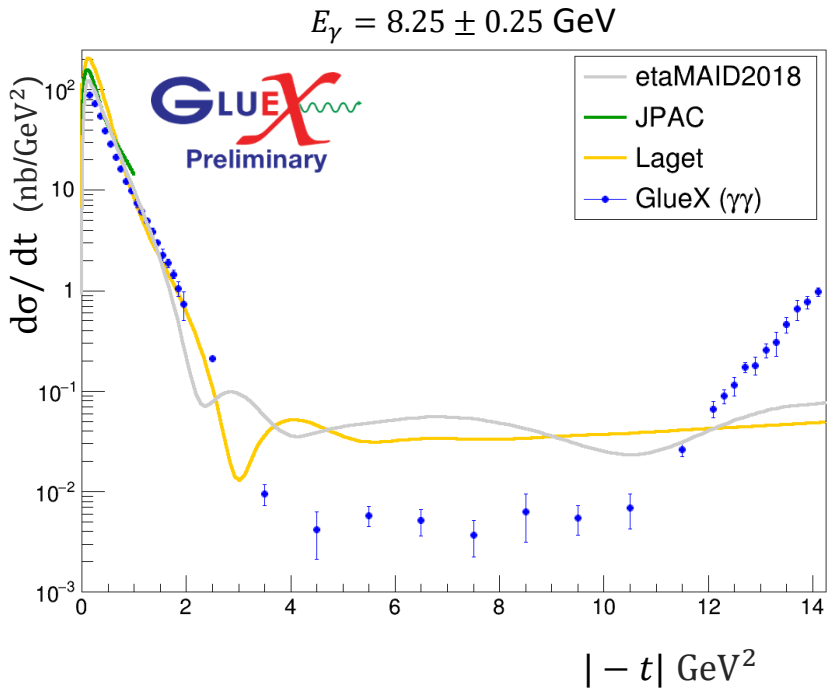


Summary

- η production at GlueX offers portal to:
  - Photoproduction mechanisms
  - Aid lower E_γ extraction of N^* states
  - Higher $|t|$: probe nucleon structure

- Differential cross section analysis:
  - Well underway, planned for publication

- Benchmark for η factory (JEF)
  - Planned upgrade for 2023



http://gluex.org/thanks/

Backup Event Selection

- Data collected in 2017, spring 2018, fall 2018
- PID timing cuts on all particles
- Proton:
  - z,r vertex within target
  - momentum > 350 MeV
- Kinematic fit
  - $\chi^2/NDF < 10$
- $0.09 < m_{\pi^0} < 0.16$ GeV

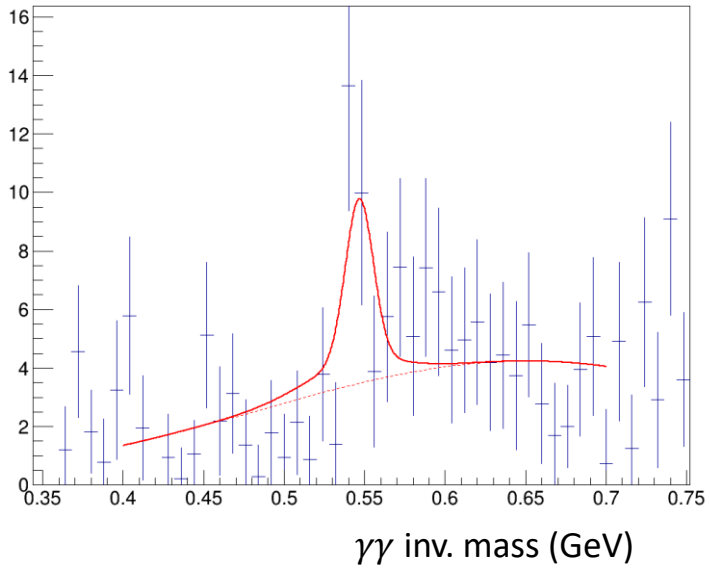
Backup: Fitting Variations

- To estimate systematic uncertainty of fitting, modify the following and refit:
  - Binning
  - Fit minimization
  - Add 2nd, 3rd order exponential functions
  - Reduce fitting window in 5 MeV steps on either low or high sides

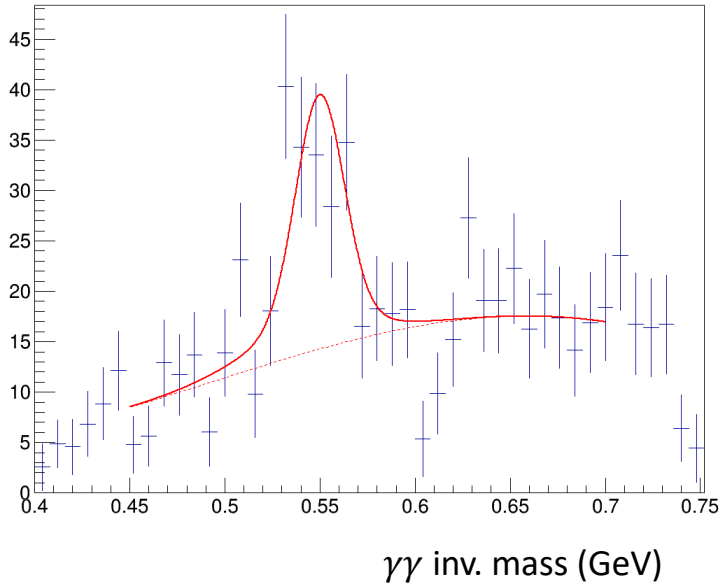
Backup: Wide Angle Fits

Signal shape fixed from MC

$6 < |t| < 7\ \mathrm{GeV}^2$

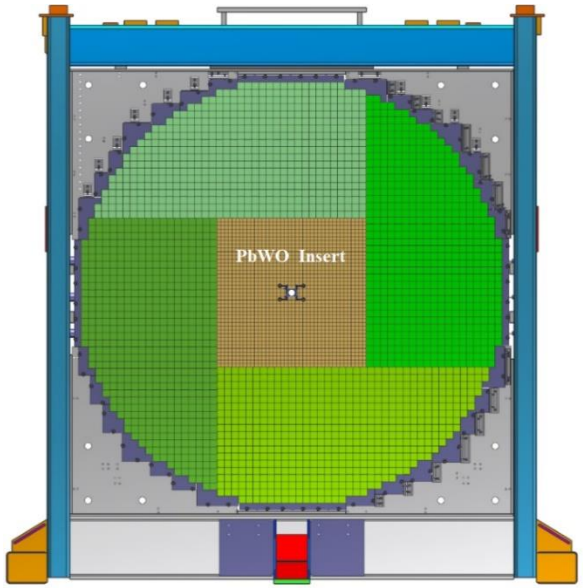


$12.4 < |t| < 12.6\ \mathrm{GeV}^2$



Towards Jefferson Lab Eta Factory JEF D

- Upgraded inner forward calorimeter
- Planned installation 2023
- This work: benchmark to future analyses

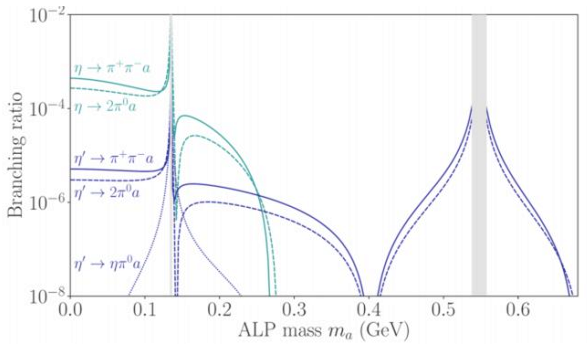


Dark Sector searches

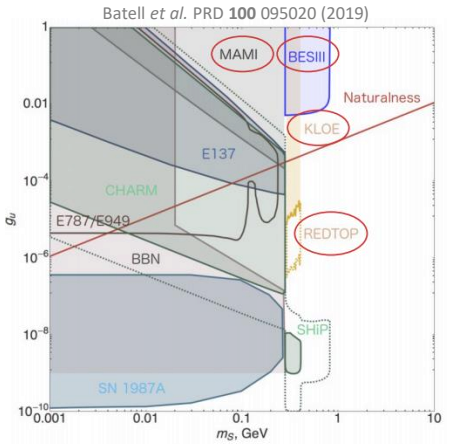
Fundamental symmetry tests
- C, P, CP violation
- Lepton flavor

SM measurements
- Quark mass ratio (strange-to-light)
- Light-by-light input to $(g-2)_\mu$
- QCD dynamics

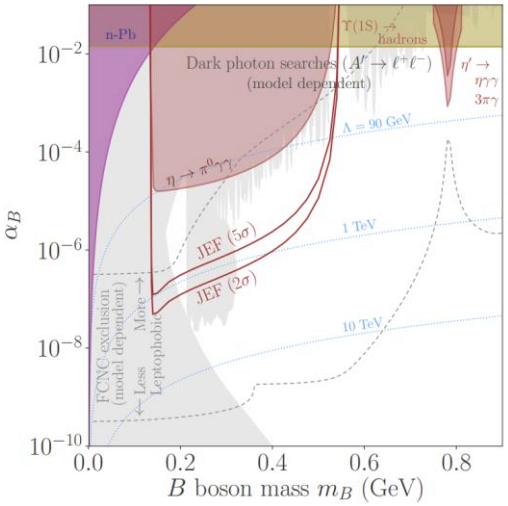
$\eta \to ALP + \cdots$



$\eta \to \pi^0 S \to \pi^0\gamma\gamma$



$\eta \to B\gamma \to \pi^0\gamma\gamma$



$\eta \to X(17)\gamma \to e^+e^-\gamma$