The radiative decay width measurement of the η-meson at GlueX

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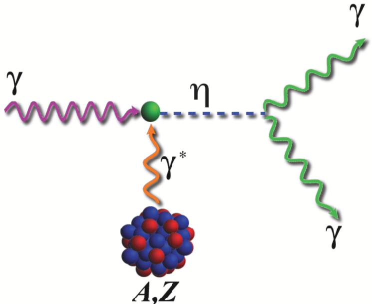
Outline

1. Introduction
2. The GlueX setup
3. Control channel: $\gamma e^- \rightarrow \gamma e^-$
4. $\gamma^4\text{He} \rightarrow \eta^4\text{He}$
5. Conclusions

Introduction

Measuring the partial decay width of $\eta \to \gamma\gamma$:

- Decays mainly through the chiral anomaly
- Will improve other η partial decay width measurements
- Allows for determining fundamental aspects of QCD in a model-independent manner:
  - Light quark mass ratio $\mathcal{Q}^2 = \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}$ (L. Gan and al. arXiv:2007.00664 [hep-ph] (2020))
  - $\eta - \eta'$ mixing angle (L. Goity and al. PRD 66 (2002) 076014)
- Improve theoretical calculation of Hadronic Light-by-Light (HLbL) to g-2

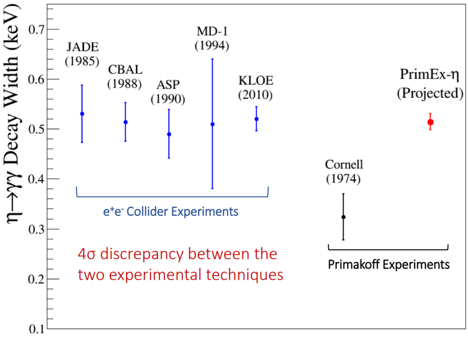


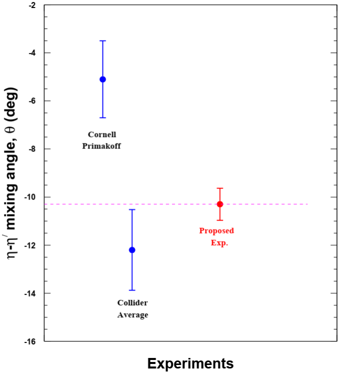
Primakoff photoproduction of an η-meson off a nucleus

Discrepancy between the existing measurements

Between Collider and fixed target experiments

- This discrepancy causes a difference in the calculated $\eta - \eta'$ mixing angle
- The mixing angle discrepancy is $> 6^\circ$
- PrimEx-eta aims for a 3.2% uncertainty on $\Gamma_{\eta\to\gamma\gamma}$, which will yield a 0.45° uncertainty on the mixing angle

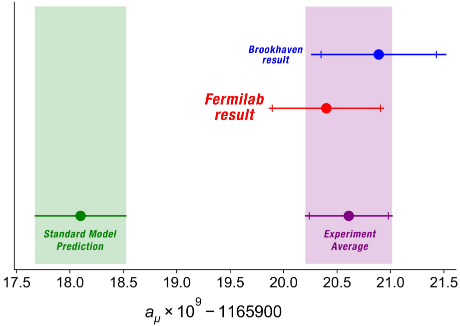




We will show today preliminary results for phase I & II of the PrimEx-eta measurements

Muon magnetic moment from lattice QCD

Combined results from Fermilab and Brookhaven show a difference with theory at a significance of 4.2 sigma



Thoery main source of uncertainties originates from hadronic contributions:
(A. Nyffeler PRD 94 (2016) 5, 053006)
(M. Hoferichter and al. PRL 121 (2018) 11, 112002)

- Vacuum polarization
- Light-by-light scattering (pseudoscalar-photon transition form factor)

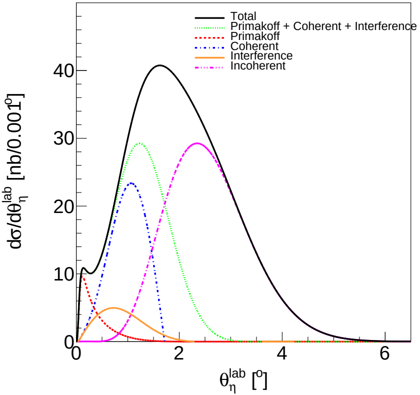
PrimEX-eta as PrimEX-pi0 might reduce the error on the form factor normalisation

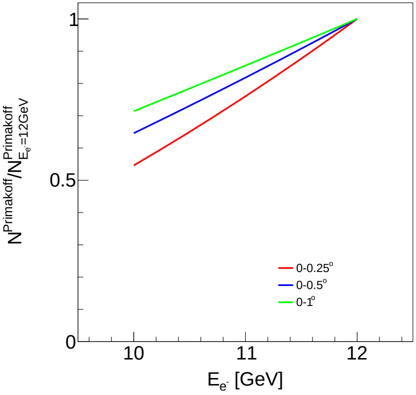
Theoretical differential cross-section

Known for spin-zero nucleus such as ^{4}He, $\gamma + {}^{4}\text{He} \rightarrow \eta + {}^{4}\text{He}$:

- Primakoff contribution is directly proportional to the $\Gamma_{\eta\rightarrow\gamma\gamma}$ decay width
  $$\frac{d\sigma_P}{d\Omega} = \boxed{\Gamma_{\eta\rightarrow\gamma\gamma}} \frac{8\alpha Z^2}{m_\eta^3} \frac{\beta^3 E^4}{Q^4} |F_{e.m.}(Q)|^2 \sin^2(\theta_\eta^{\text{lab}})$$
- Primakoff contribution increases with increasing incident photon-beam energies

- $E_{e^-} = 12$ GeV, $10.5 \leq E_\gamma \leq 11.7$ GeV
- FOM vs. E_{e^-}, $87.5\% \times E_{e^-} \leq E_\gamma \leq 97.5\% \times E_{e^-}$



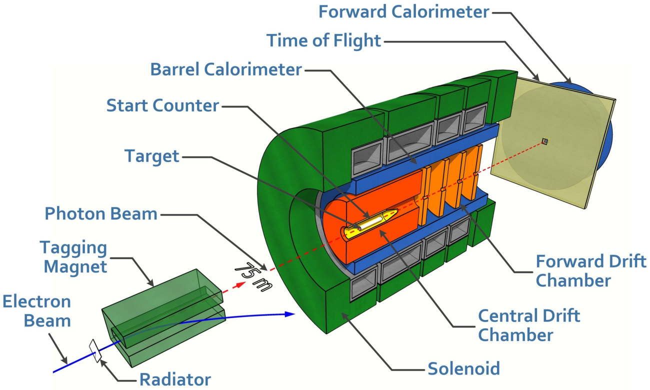


Simultaneously measuring Compton cross-section to control the experimental systematics

The GlueX setup

Photon-beam produced, 75 m upstream from the target center, by bremsstrahlung:
(S. Adhikari and al. NIMA 987 (2021) 164807)

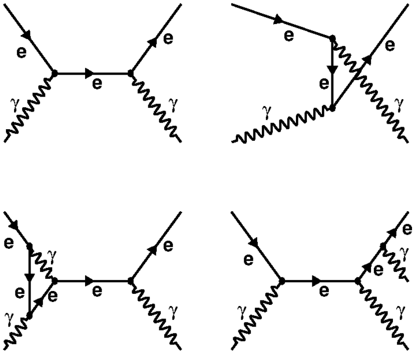
- Electron-beam energy: 10.047 GeV (phase II, 2021) and 11.3 GeV (phase I, 2019)
- Solenoid OFF (no magnetic field) for phase I
- Solenoid ON (1.4T magnetic field) for phase II

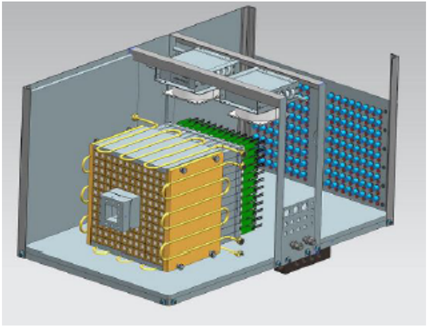


To increase acceptance to Compton events for incident photon-beam energies above 6 GeV, a calorimeter is added 6.5 m downstream from Forward Calorimeter

Compton photoproduction off an atomic electron

- Compton cross-section is a known QED process and is used as a reference process:
  - Verify systematics
  - Monitor luminosity
  - MC simulation validation





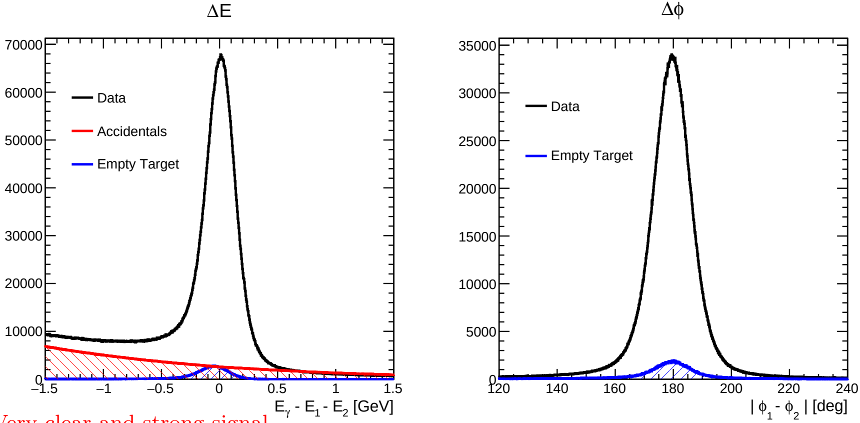
- Compton Calorimeter (right-figure) covers angle between 0.2 and 1^o (A. Assturyan and al. NIM, A 1013 (2021))

Compton detection efficiency varies between 12 and 5 % for E_γ between 6 and 11.3 GeV

Control channel: $\gamma e^- \to \gamma e^-$

Selection criteria:

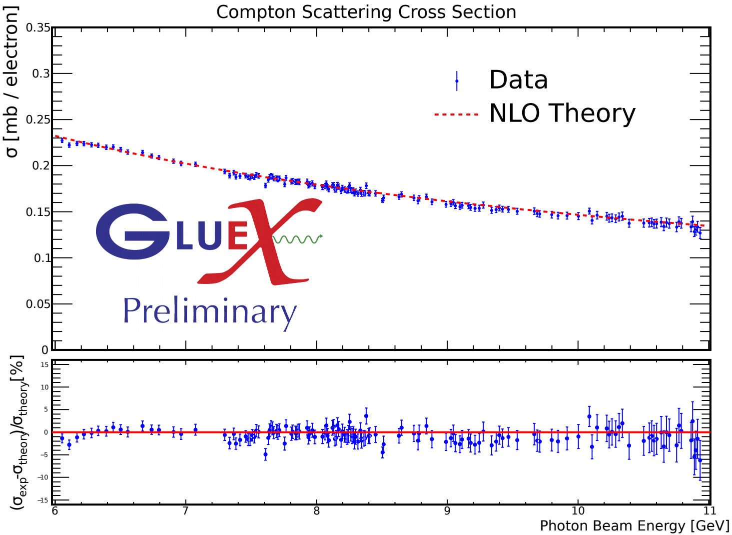
- At least two clusters with one in the Forward and one in the Compton Calorimeters
- Elasticity required
  (energy difference between incident photon-beam and two clusters)
- Coplanarity required



Very clear and strong signal

Preliminary Compton cross-section measurements

First cross-section measurements in this energy range:



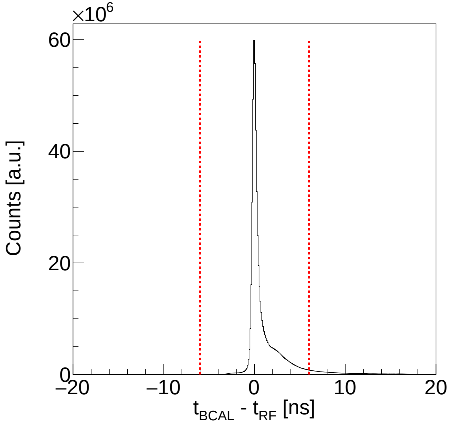
Within 5% from the theoretical cross-section

$\eta \to \gamma\gamma$, selection criteria

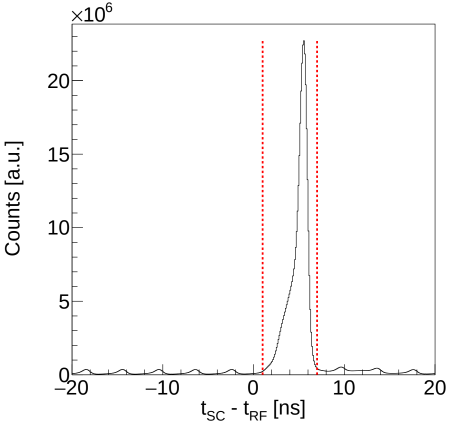
Veto events producing hits in:

- Barrel Calorimeter (BCAL), to veto hadronic backgrounds and/or
- Start Counter (SC), to veto charged particles and/or

- BCAL time against RF time



- SC time against RF time



Veto events in BCAL and/or SC with timing in coincidence with RF time

$\eta \to \gamma\gamma$, selection criteria

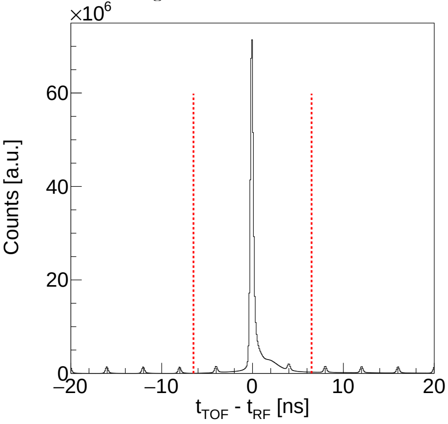
And/or veto events producing hits in:

- Time-Of-Flight (TOF), to veto charged particles

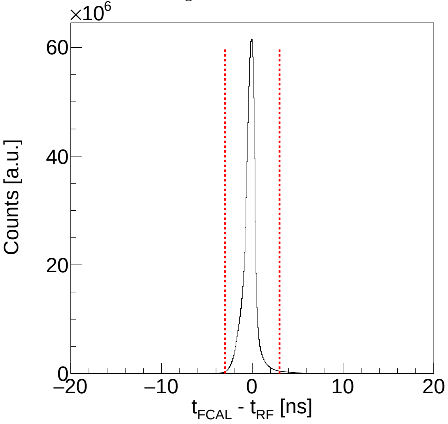
Two Forward Calorimeter (FCAL) clusters (exactly):

- Cluster energy above 500 MeV
- Cluster timing in coincidence with RF time
- Time difference between clusters within 5 ns

- TOF time against RF time



- FCAL time against RF time



$\eta \to \gamma\gamma$, selection criteria

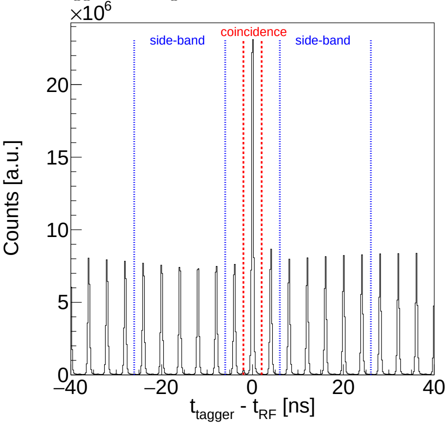
Two clusters in Forward Calorimeter with:

- Clusters energy sum within 1.5 GeV from the incident photon-beam energy (elasticity)

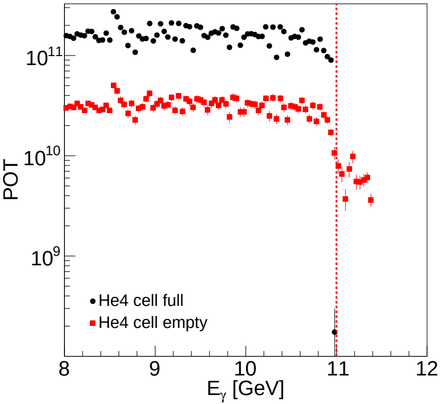
Incident photon-beam energy selected by

- Tagger hit in coincidence with RF time
- Accidental hits removed by side-band substracttion
- $E_\gamma \geq 8$ GeV (well above the 3 GeV energy sum trigger)

- Tagger time against RF time



- Photons On Target (POT)

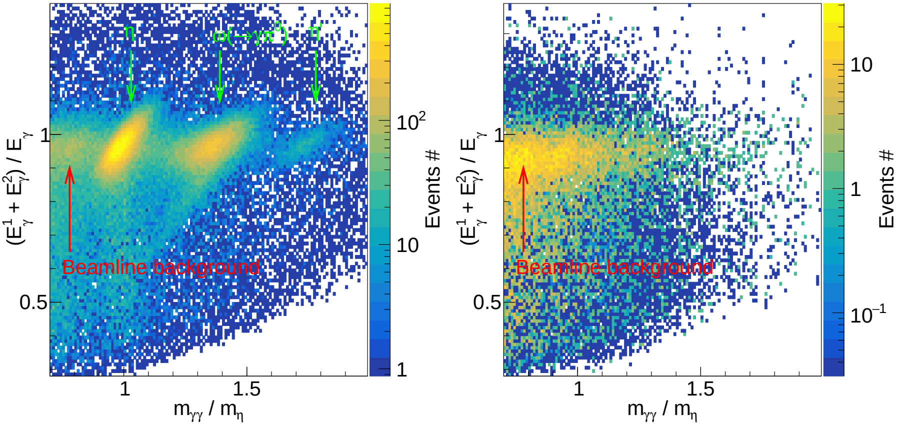


$\eta \to \gamma\gamma$, selection criteria

Two clusters in Forward Calorimeter:

- Barrel Calorimeter used to veto hadronic backgrounds
- Start Counter used to veto charged particles and/or
- Time-Of-Flight wall used to veto charged particles

- He target
- Empty target

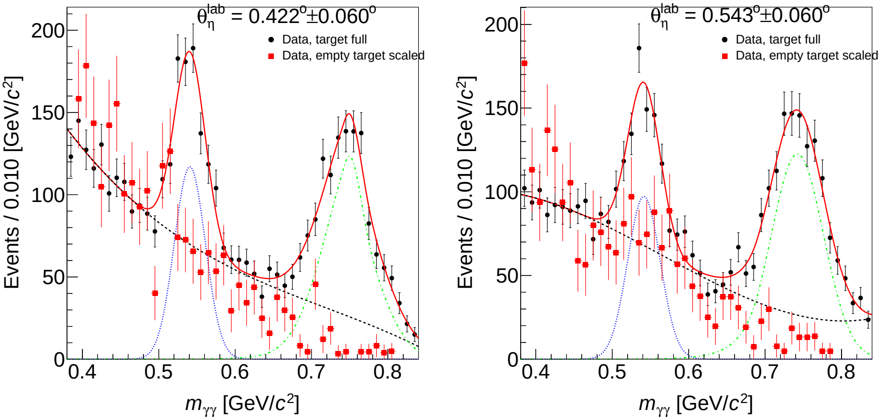


Clear signal but includes Primakoff and (in)coherent events, and non-negligible background beneath η coming from beamline

$\eta \to \gamma\gamma$, preliminary diphoton invariant masses

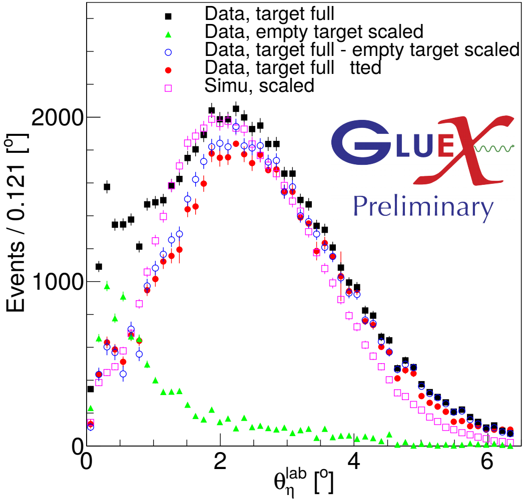
Two clusters in Forward Calorimeter:

- Barrel Calorimeter used to veto hadronic backgrounds
- Time-Of-Flight wall used to veto charged particles
- Elasticity required



- Beamline background not yet understood
- Larger empty target sample is needed

$\eta \to \gamma\gamma$, preliminary polar angle distributions



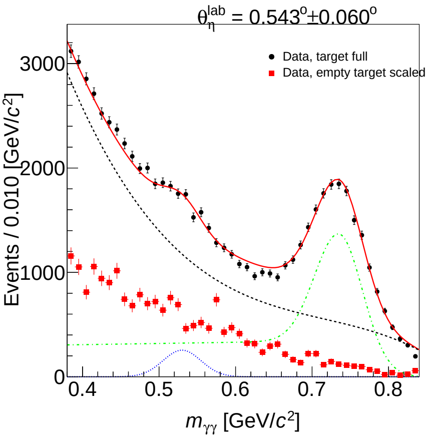
- Integrated luminosity collectd with Helium target in 2019: 6.39 pb^{-1}
- Empty target scaled by POT ratio between target full and empty target
- Simulation scaled by ratio between integrated luminosity simulated (46.5 pb^{-1}) and collected

$\eta \to \gamma\gamma$, preliminary diphoton invariant masses

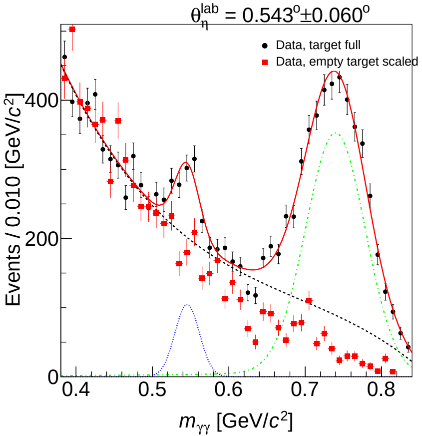
Two clusters in Forward Calorimeter:

- Barrel Calorimeter used to veto hadronic backgrounds
- Start Counter used to veto charged particles
- Elasticity required

- B-field OFF



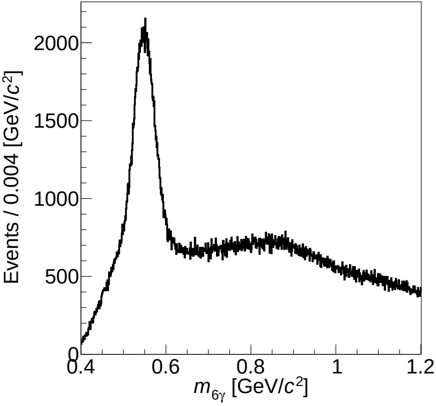
- B-field ON

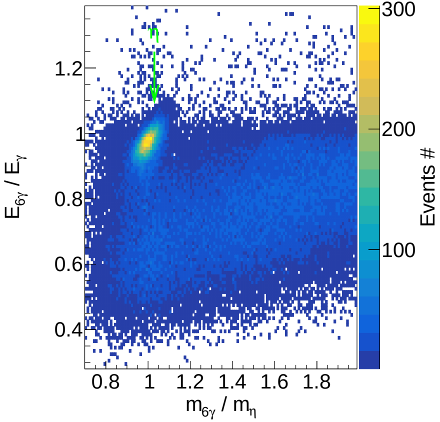


B-field strongly reduced background in forward direction

$\eta \to \pi^0\pi^0\pi^0$, selection criteria

- 6 clusters (Barrel and Forward Calorimeters)
- Time-Of-Flight wall used to veto charge particles
- Elasticity required

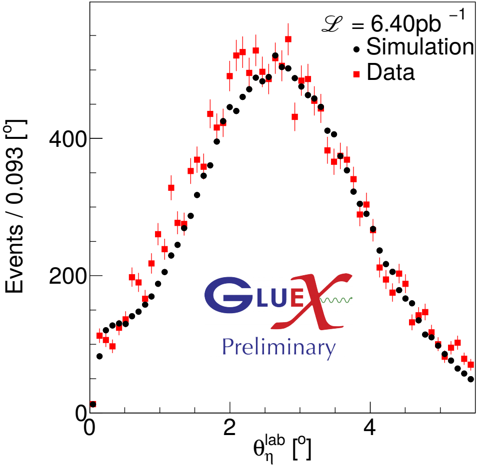




Lower statistic compared to $\eta \to \gamma\gamma$ but cleaner signal

$\eta \to \pi^0\pi^0\pi^0$, preliminary polar angle distributions

Beamline background is not an issue and angular resolution similar to $\eta \to \gamma\gamma$



Fair agreement between data and simulation

Conclusions

Phase I & II data sets of the PrimEx-eta measurements shows promising results for

- Preliminary Compton cross-section measurements in good agreement with theoretical cross-section
- $\eta \rightarrow \gamma\gamma$ but with non-negligible background coming from the beamline
- New B-field data set gives valuable insights on background origins
  Downstream wrt target
- $\eta \rightarrow \pi^0\pi^0\pi^0$ but with lower statistics

Phase III is scheduled at the end of 2022

- Electron-beam energy expected to be 12GeV

GlueX acknowledges the support of several funding agencies and computing facilities:
`http://www.gluex.org/thanks`

Thank you for your attention