Recent results and future plan of LEPS2/BGOegg experiment

HASHIMOTO, Toshikazu
Research Center for Nuclear Physics (RCNP),
Osaka University

- Physics motivation
- Recent results
- Upgrade plan (Phase-II)

Physics motivation

- The studies of excited baryon resonances are essential for understanding the hadron structure since the non-perturbative properties of QCD make analytical calculations impossible in the low energy regions.
- Meson photoproduction from the nucleon is a powerful tool for clarifying the nucleon excitation spectra.
- The N^*s & Δ^*s have broad widths overlapping with each other.
  The measurement of the photon beam asymmetry (Σ) in addition to the $d\sigma/d\Omega$ helps to decompose the resonances with the interferences of spin dependent amplitudes.
- Baryon resonance studies via meson photoproduction

➢ Single meson ($\pi^0/\eta/\omega$) photoproduction

N. Muramatsu *et al*. Phys. Rev. C **100**, 055202 (2019)
N. Muramatsu *et al*. Phys. Rev. C **102**, 025201 (2020)
T. Hashimoto *et al*. Phys. Rev. C **106**, 035201 (2022)

π^0 : Isospin I is 1. ⇒ Both N^* and Δ^* contribute at s-channel.
η / ω : Isospin I is 0. ⇒ Only N^* contributes at s-channel.
η meson couple to N^* with $s\bar{s}$ component.
ω meson couple to N^* with the different spin state

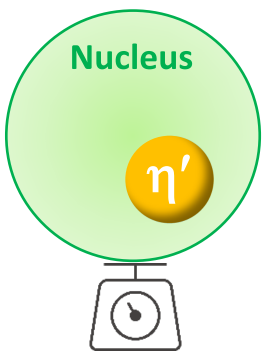
Physics motivation

- We want to get evidence for partial restoration of spontaneous breaking of chiral symmetry.
- An $\eta'(958)$ meson is expected to have large mass reduction in nuclei.
- The η' meson provides an attractive way to explore the relation between chiral symmetry and UA(1) anomaly.
- Studies of η' mass in nuclei
  - η'- nucleus bound search
  - Direct measurement of η' mass in nuclei

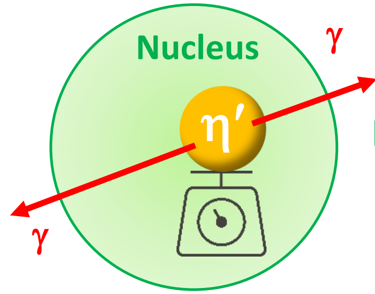
N. Tomida *et al*. Phys. Rev. Lett. **124**, 202501 (2020)
Y. Matsumura, Doctoral Thesis.

Indirect measurement ($m_{\eta'} + M_A$)
Need to know bound levels.

Direct measurement by $M(\gamma\gamma)$
Need high-resolution calorimeter.

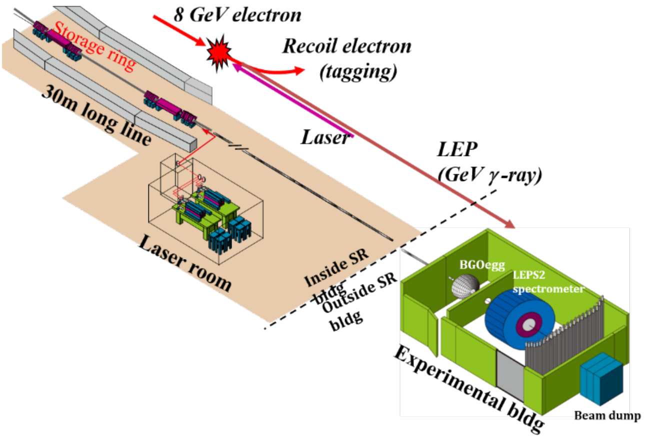


η-PRiME/Super-FRS **(GSI)**
BGOegg phase-1 **(SPring-8)**



BGOegg phase-1 **(SPring-8)**

LEPS2/BGOegg experiment

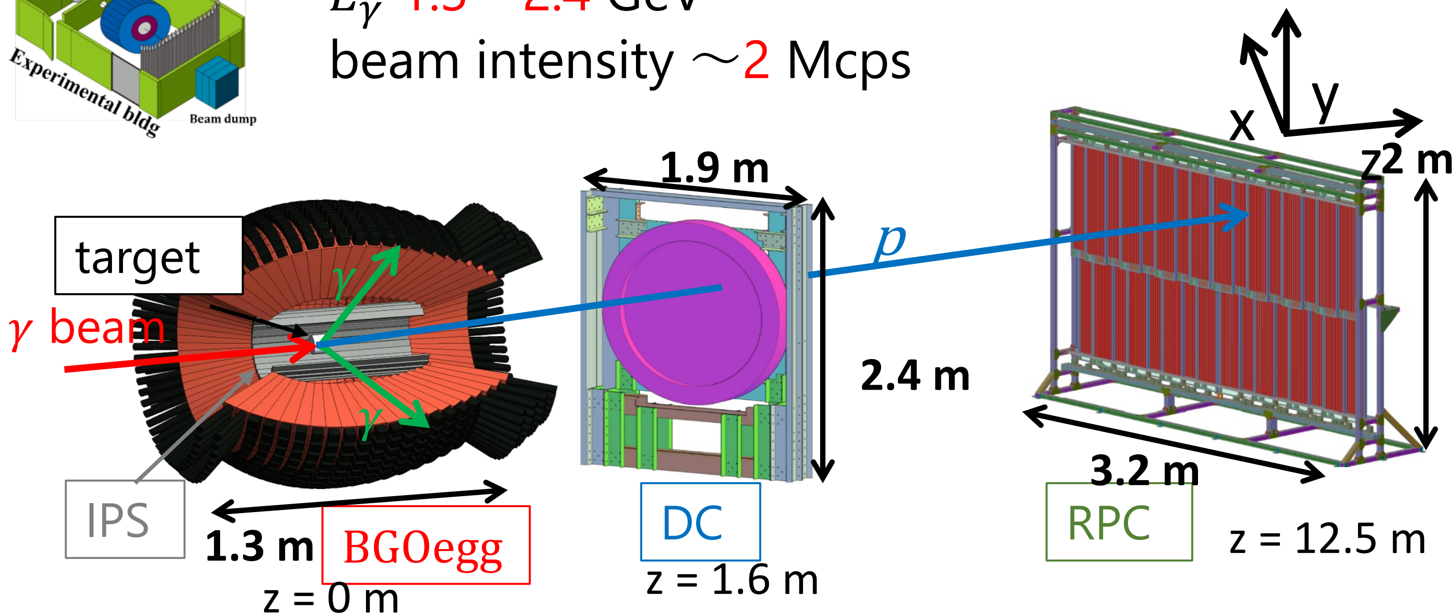


Backward Compton scattering with 355nm UV laser and 8 GeV electron

Beam tagging is performed by detecting recoil electrons.

E_γ 1.3～2.4 GeV

beam intensity ～2 Mcps



BGOegg: EM calorimeter consisting of BGO crystals

σ_E = 1.3% @ 1 GeV, covering θ = 24° –144°

IPS: Plastic scintillator bars for charge identification

DC: Charged particle tracker **$\sigma_{position}$ = 300 μm, covering θ<21°**

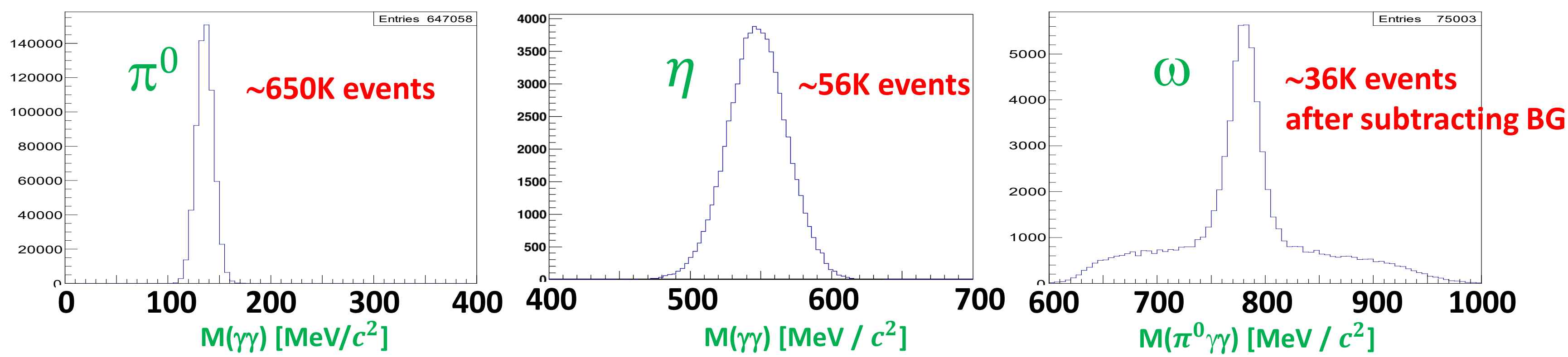
RPC: Gas chamber for TOF measurement **σ_{TOF} = 80 ps ⇒ σ_p = 1 % @ 2 GeV proton, covering θ<6.8°**

Single meson photoproduction

We measure all particles in final state and use a kinematic fit.

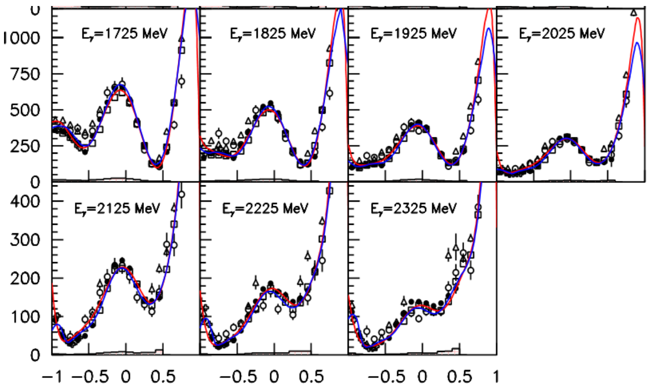
$$\gamma p \rightarrow \pi^0 p \rightarrow \gamma\gamma p (\text{Br: } 98.8\ \%)$$
$$\rightarrow \eta p \quad \rightarrow \gamma\gamma p (\text{Br: } 39.4\ \%)$$
$$\rightarrow \omega p \quad \rightarrow \pi^0 \gamma p \rightarrow \gamma\gamma\gamma p (\text{Br: } 8.40\ \%)$$

- γ detection at BGOegg
- Proton detection at BGOegg or DC(and RPC)
- Beam energy measurement at the photon tagging counter.
- require 4-momentum conservation and meson mass(π^0/ η mass)
- magnitude of proton momentum is treated as an unmeasured variable.

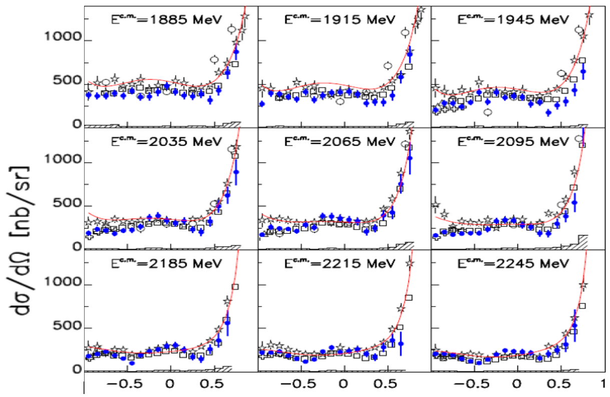


Differential cross section

$d\sigma/d\Omega\ (\pi^0)$

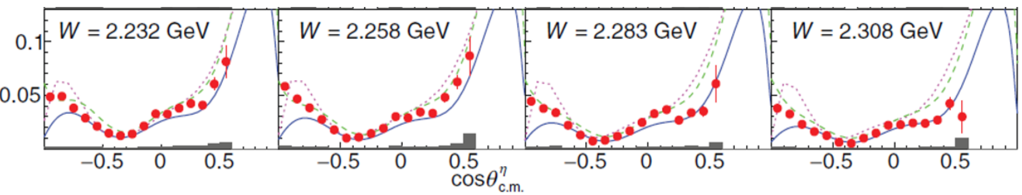


$d\sigma/d\Omega\ (\omega)$

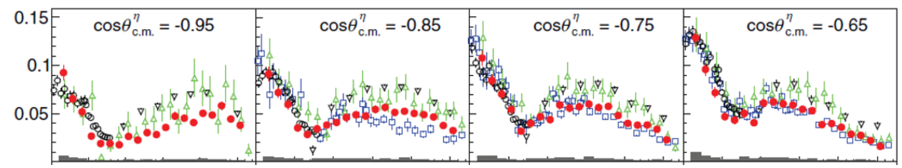


Our data are consistent with other experimental results and PWA model calculations.

Polar angle dependence of $d\sigma/d\Omega\ (\eta)$

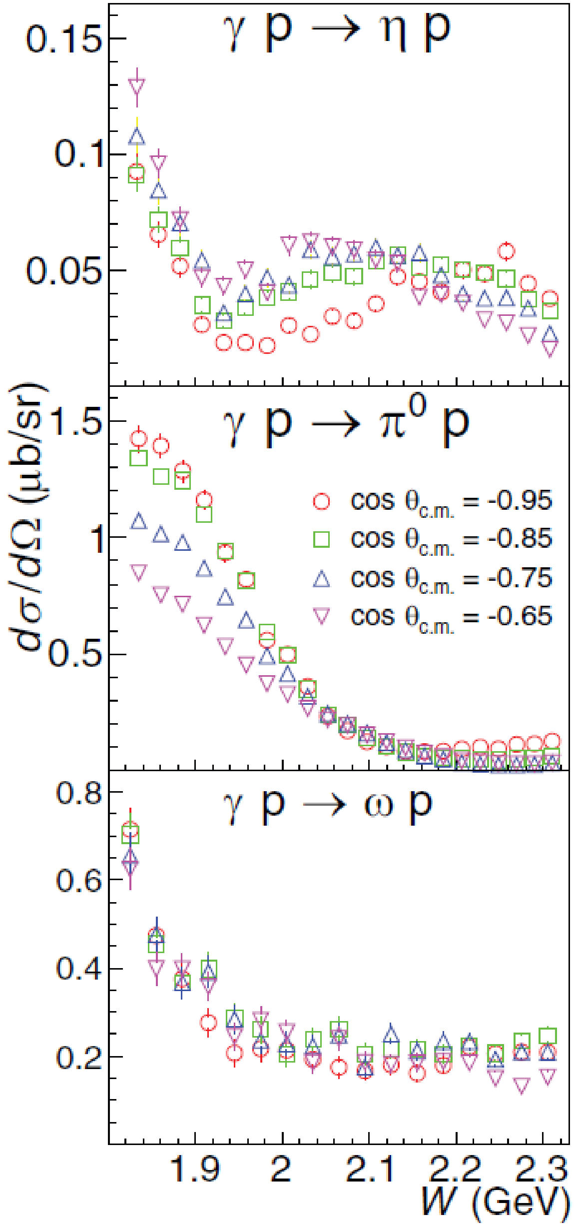


C.M. energy dependence of $d\sigma/d\Omega\ (\eta)$



- The peaking behavior at backward angles and high energies can be seen.
  ⇒ Naively thinking, u-channel contribution.
  ⇒ If so, smooth energy dependence should be seen, but …
- A clear bump structure was seen at the backward angles.
  ⇒ The above behavior can not be explained with only u-channel contribution.
- This structure was not seen at other angles.
  ⇒ high-spin resonances which strongly decay to forward/backward angles.
- The position of this structure shifts over $\cos\theta^{\eta}_{\mathrm{c.m.}}$.
  ⇒ Multi-resonance contributions?

Comparison with η, π^0, and ω differential cross sections

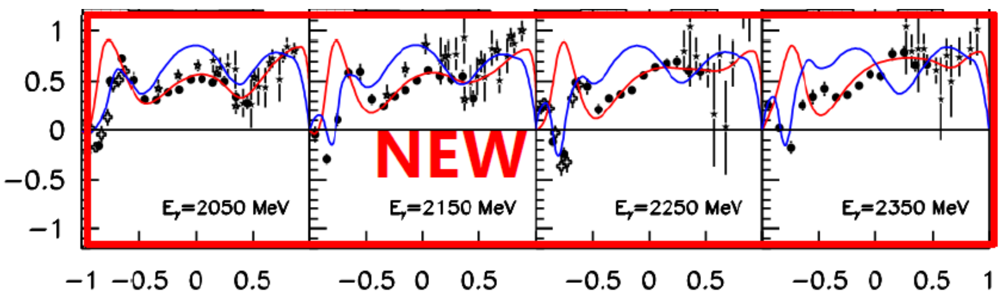


Phys. Rev. C **106**, 035201 (2022)

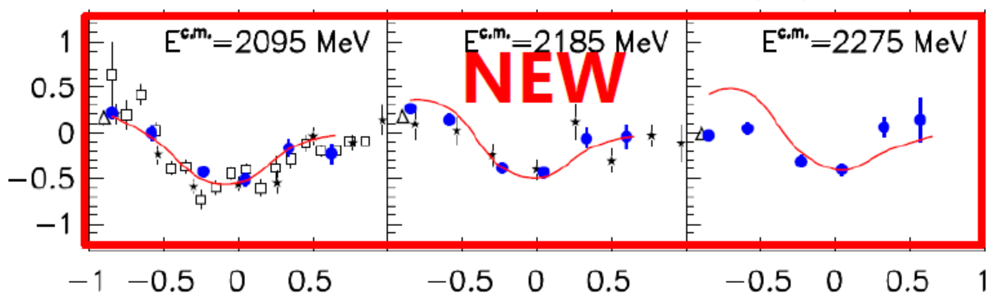
- A bump-like enhancement of differential cross sections can only be seen at backward angles in the η photoproduction reaction.
- This bump structure is likely to be associated with the nucleon resonances that have a large $s\bar{s}$ component and strongly couple to the ηN channel.
- Candidates such as $N(2120)\frac{3}{2}^-$, $N(2190)\frac{7}{2}^-$, $N(2220)\frac{9}{2}^+$, $N(2250)\frac{9}{2}^-$.

Photon beam asymmetry

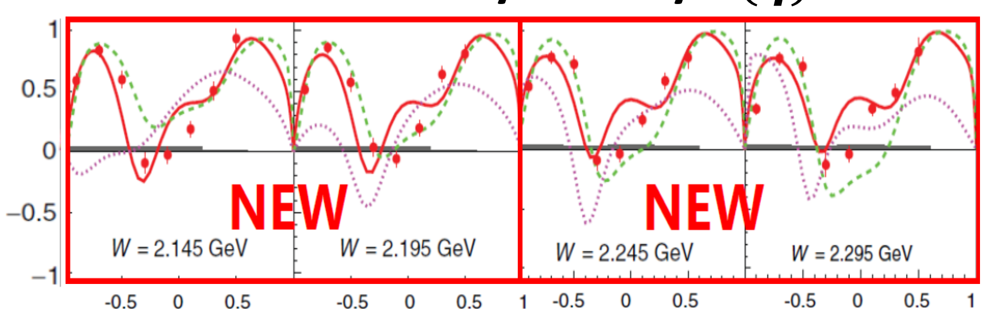
Photon beam asymmetry $\Sigma(\pi^0)$



Photon beam asymmetry $\Sigma(\omega)$



Photon beam asymmetry $\Sigma(\eta)$



- We measured photon beam asymmetries of each meson $1.8 < W < 2.3$ GeV.
- Our data are similar to other experimental results at lower energies.
- A wide angle measurement at $E_\gamma > 2$ GeV is new. (π^0)
- Precise values in a wide angular range were obtained for the first time above c.m. energies around 2.1 GeV. (ω)
- Our data above 2.1 GeV is new. (η)
- The discrepancy between PWA model calculations exists.
- A re-fit to the new data can improve the current understanding of resonance and Born-term contributions.

η' nucleus bound search

$$\gamma + {}^{12}\mathrm{C} \rightarrow \underline{p_f} + \underline{\eta' \otimes {}^{11}\mathrm{B}}$$

High momentum proton detection at extremely forward angles.
⇒ TOF measurement at **RPC**

Search for the bound state in the **missing mass spectrum**.
&
Nuclear absorption signal for **a better S/N ratio**.
⇒ **η'p → ηp** (**back-to-back**) at **BGOegg**

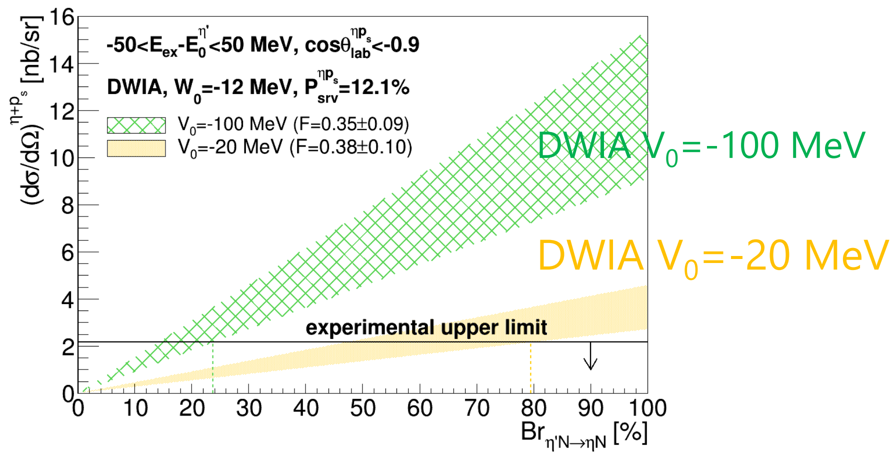
$$\gamma + {}^{12}\mathrm{C} \rightarrow p_f + \eta' \otimes {}^{11}\mathrm{B}$$
$$\hookrightarrow \eta' + p \rightarrow \eta + p_s$$

Absorption of η' **at rest**
⇒ **Isotropic & back-to-back** angular distribution. The kinetic energy of **η** & **p** is **monochromatic**.

- No $(\eta + p_s)$ signals from η' bound state in $-50 < E_{ex} - E_0 < 50$ MeV

Upper limit : **2.2 nb/sr** @ $\cos(\eta p_s) < -0.9$
(E_γ=1.3-2.4 GeV average)
⇒ Compare with the DWIA calculation to discuss η'-nucleus potential.

- Indicate small potential V_0 or small η'N->ηN branch

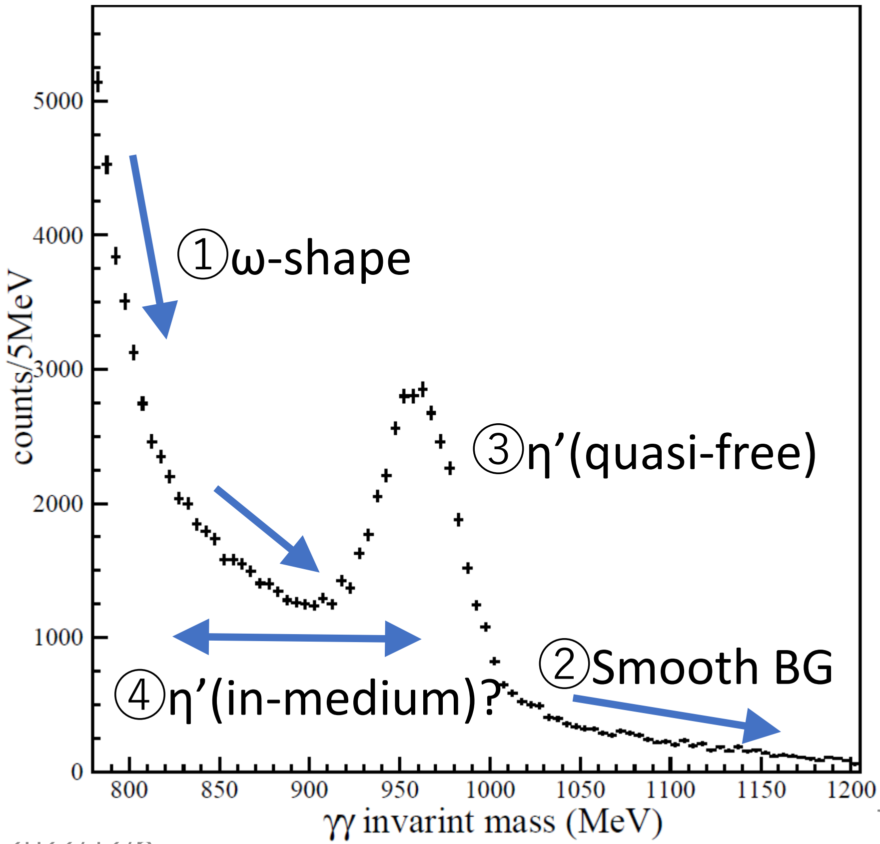


Direct measurement of η' mass in nuclei

$$\gamma + {}^{12}\mathrm{C} \rightarrow \eta' + \mathrm{X}, \eta' \rightarrow \gamma\gamma\ (2.2\ \%)$$

- Measurement of **spectral function** (line-shape) of η' meson.
- No experimental data for η'.

Line shape analysis



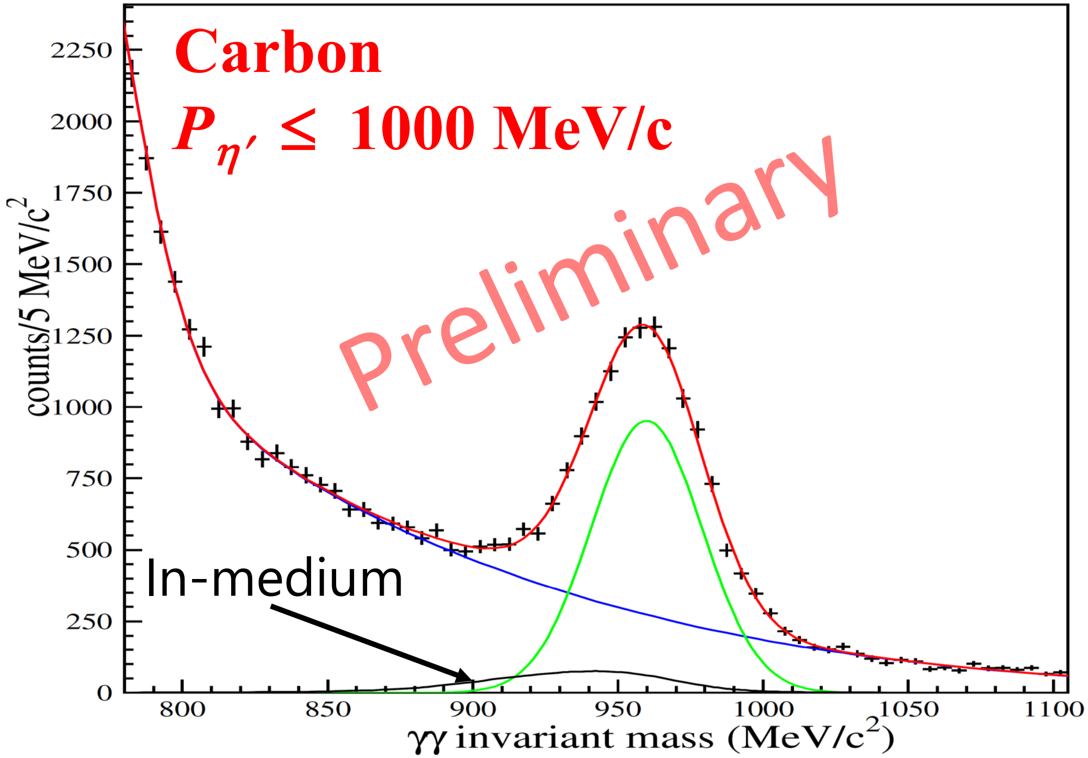
- Structure of background
  - tail from $\omega \rightarrow \pi^0\gamma$ with $\gamma\gamma$ detection
  - smooth BG around η' mass

- Following function is fitted to the $\gamma\gamma$ spectrum:

  <u>ω-shape</u> + <u>smooth BG</u>
  ①(MC) ②$\exp(p_0 + p_1 x + p_2 x^2 + p_3 x^3)$
  + <u>η'(quasi-free)</u> + <u>η'(in-medium)</u>
  ③(gaussian) ④(MC)

- The difference of the fitness(χ^2) between with and without in-medium signal ④ is used to discuss in-medium effect on the spectrum.

Result of the direct measurement



- Introduced the phenomenological parameters for mass and width of η' inside the nucleus.
- The maximum significance of 3.7 σ was obtained for the parameter corresponding to the mass reduction.
  - $\Delta m_{\eta'} = 40 - 70$ MeV/ c^2
  - $\Delta\Gamma_{\mathrm{tot}} < 60$ MeV

- This result is obtained from 2015A Carbon data.
- More carbon data exists (2016A). -> Increase statistics x2.
- We will publish the merged 2015A and 2016A results.

Upgrade plan for BGOegg experiment

Forward DC & RPC were removed for the LEPS2Solenoid experiment.
Instead, **Forward Gamma detector** & **Forward Plastic Scintillators** have been installed.
⇒ A new experiment to search for the **η′ mass medium modification** with **a Cu target**.

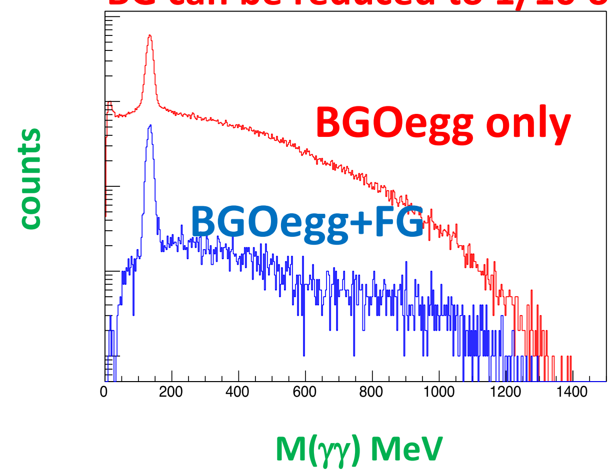
(1) **Upgrade the detector setup.**
⇒ Multi-meson BG ($\gamma p \to \pi^0\pi^0 p$) **×1/40**

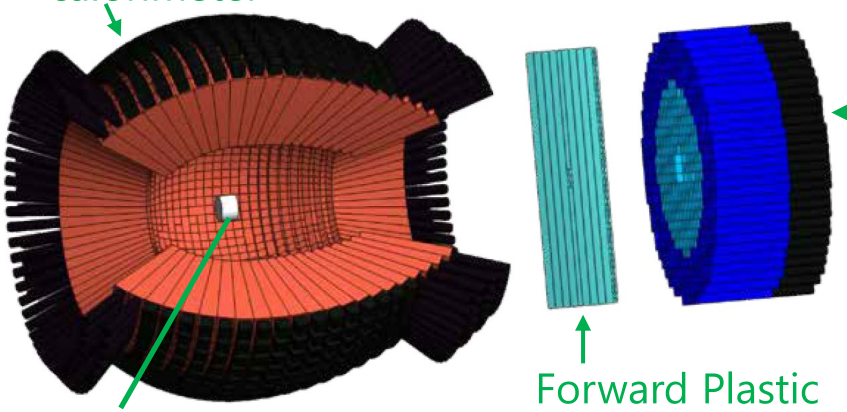
(2) Change a target **from C [20 mm] to Cu [7 mm]**.
⇒ $R_{nucleus}$ **×1.8**, # of nucleons **×1.8**, $\sigma(M_{\gamma\gamma})$ **×0.6**

(3) Increase **a photon beam intensity**.
24W pulse laser + existing 3 lasers ⇒ **~5M cps**

⇒28σ in a few months
if the Phase-I result is assumed.

MC simulation for **$\gamma p \to \pi^0\pi^0 p$** .
BG can be reduced to 1/10 or less.



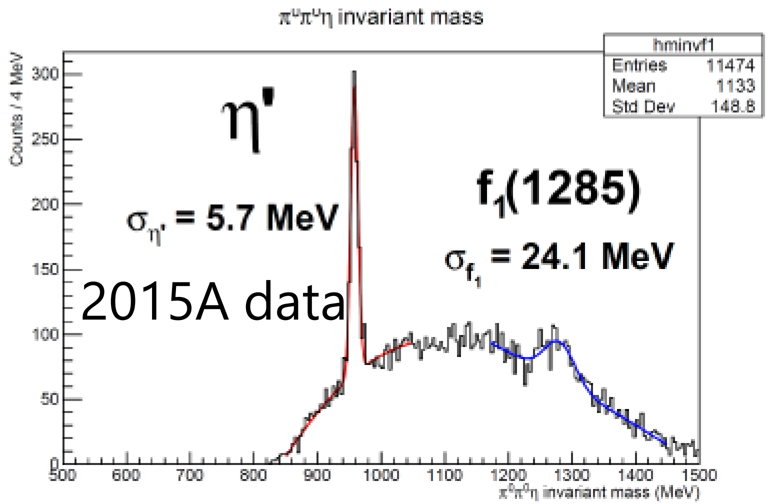


Preparation & test data-taking in FY2022.
Physics runs with a Cu target in FY2023.
Reference data with LH_2 target in FY2024.

Other studies at BGOegg experiment

Phase-II

- ➢ Measurement of the mass shift and width broadening of the $f_1(1285)$ meson
- A QCD sum rule analysis for the $f1(1285)$ meson mass predicts about 100 MeV attraction at the normal nuclear density
- Spectral analysis of $f_1(1285)$
  $\eta'/f_1 \to \pi^0\pi^0\eta \to 6\gamma$
- The BGOegg calorimeter has already achieved a good mass resolution.



Phase-I

- ➢ Single η' photoproduction
- ➢ Double meson photoproduction ($\pi^0\pi^0$/ $\pi^0\eta$/ $\pi^0\omega$)
- ➢ Search for η' bound nuclei with 2-nucleon absorption tag($\eta' NN \to NN$)

Summary

We summarized the recent results in LEPS2/BGOegg experiment.

- Baryon resonance studies via single meson photoproduction
- The bump structure in η backward angle region above 2 GeV can be seen.

⇒ Indicate resonances with high-spin and large $s\bar{s}$ component.

- New photon beam asymmetries at higher energies are measured.
- η' mass reduction in nuclei with carbon target
- No signal event from η' nucleus bound state

⇒ Indicate small V_0 or η'N->ηN branch

- An enhancement in the low-mass region of the η' mass is obtained.
- This significance is 3.7 σ.

⇒ Not enough to exclude statistical fluctuations.

- BGOegg Phase-II experiment
- Additional acceptance for forwarding γ
- Heavier nuclear target (Cu)
- Physics run will start in the next fiscal year.