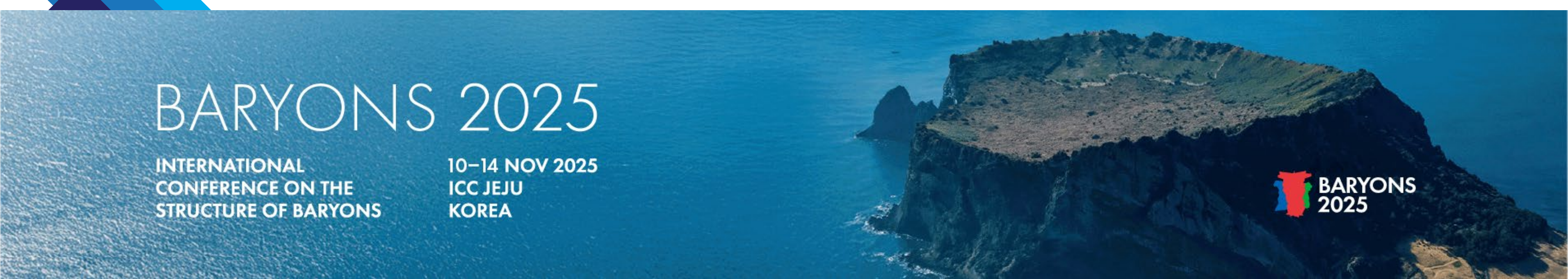
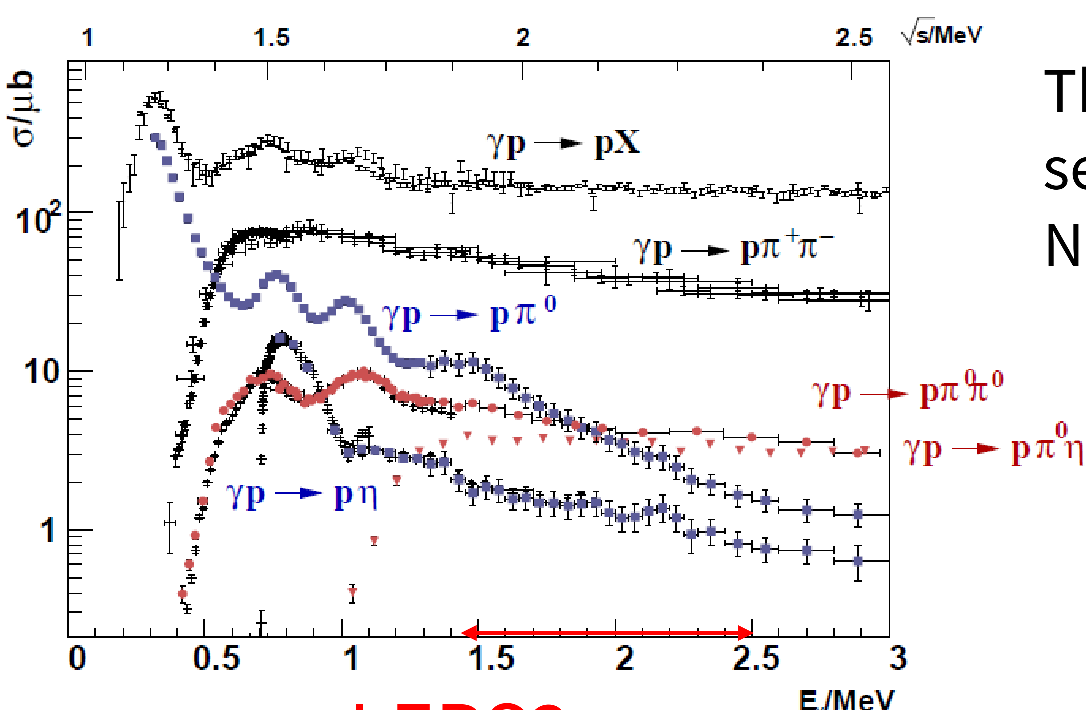
Baryon resonance study via photon beam asymmetries in the reaction $\gamma p \rightarrow \pi^0 \eta p$

HASHIMOTO, Toshikazu and LEPS2/BGOegg collaboration
RCNP, The University of Osaka
BARYONS2025@Jeju



1 Multi-meson photoproduction

- In the higher energy regions, multi-meson final states are of increasing importance in photoproduction experiments.
- The charged channel has large non-resonant contributions including $\Delta\pi$ production. (Kroll-Ruderman term)



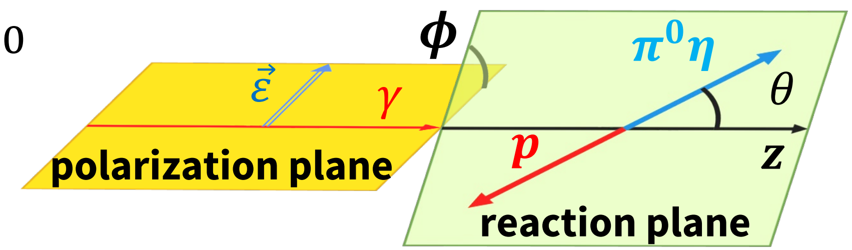
LEPS2 coverage

The neutral channel must be very sensitive to resonance contributions. No ρ meson contribution.

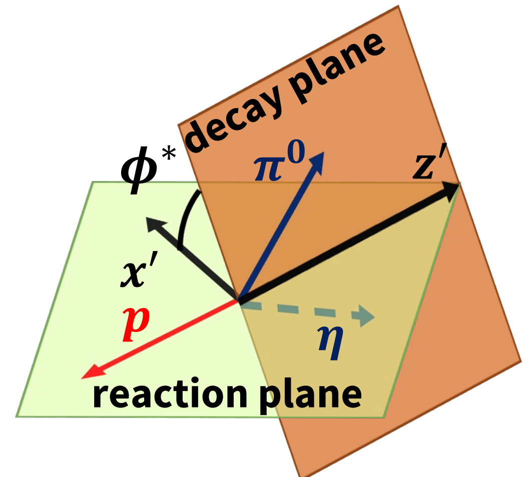
The N^*s & Δ^*s have broad widths overlapping with each other. Measurement of spin observables($d\sigma/d\Omega$, Σ ... .)

2 Quasi-two body and three body asymmetry

$\gamma p \to \pi^0 \eta p$: cascade decay
$\gamma p \to \Delta^* \to \Delta(1232)\eta$
$\gamma p \to N^* \to N(1535)\pi^0$



Quasi two-body



three-body

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \{1 - P_\gamma \Sigma(\theta)\cos(2\phi)\}$$

$$= \left(\frac{d\sigma}{d\Omega}\right)_0 \{1 - P_\gamma (I^c(\phi^*)\cos(2\phi) + I^s(\phi^*)\sin(2\phi))\}$$

Σ is more sensitive to J^P of resonances(Δ^*, N^*) than dσ/dΩ.

I^c is like Σ, and I^s reflects the dynamics of reaction.

$|I^s| \sim 0$: two-body like

$|I^s| \sim 1$: large spin alignment

sign of I^s: interference phase

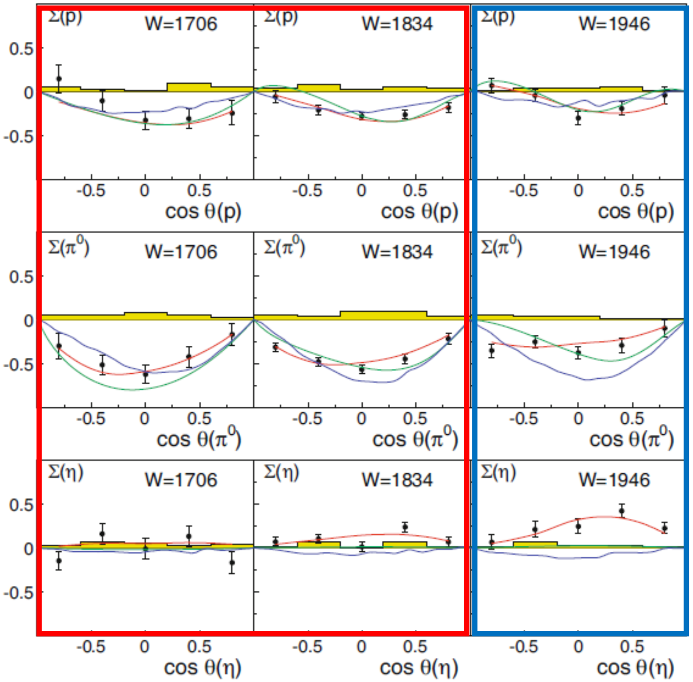
3 Previous experiment

CBELSA/TAPS Collaboration measured photoproduction off protons of the $p\pi^0\eta$ three-body final state. Eur. Phys. J. A (2014) **50**: 74, E. Gutz *et al.*

Beam asymmetries were measured in $E_\gamma < 1.65$ GeV regions.

Partial wave analyses including three-body asymmetries demonstrate the importance of $J^P = \frac{3}{2}^-$ resonances($\Delta(1700)$ and $\Delta(1940)$).

$E_\gamma = 1.08$ $E_\gamma = 1.32$ $E_\gamma = 1.55$



- $E_\gamma < 1.44$ GeV regions,
  Σ_p, and Σ_{π^0} are similar, but Σ_η is zero.
  $\rightarrow \Delta(1700) \rightarrow \Delta\eta$ S-wave dominance
- $E_\gamma > 1.44$ GeV regions,
  Σ_η is also non-zero.
  $\rightarrow \Delta(1940)$ contribution

Previous experiment

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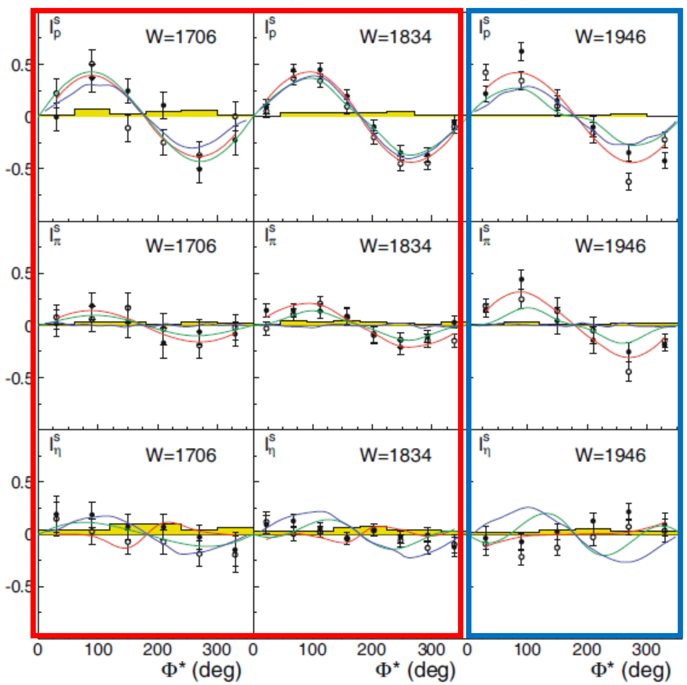
$E_\gamma = 1.09$ $E_\gamma = 1.33$ $E_\gamma = 1.55$

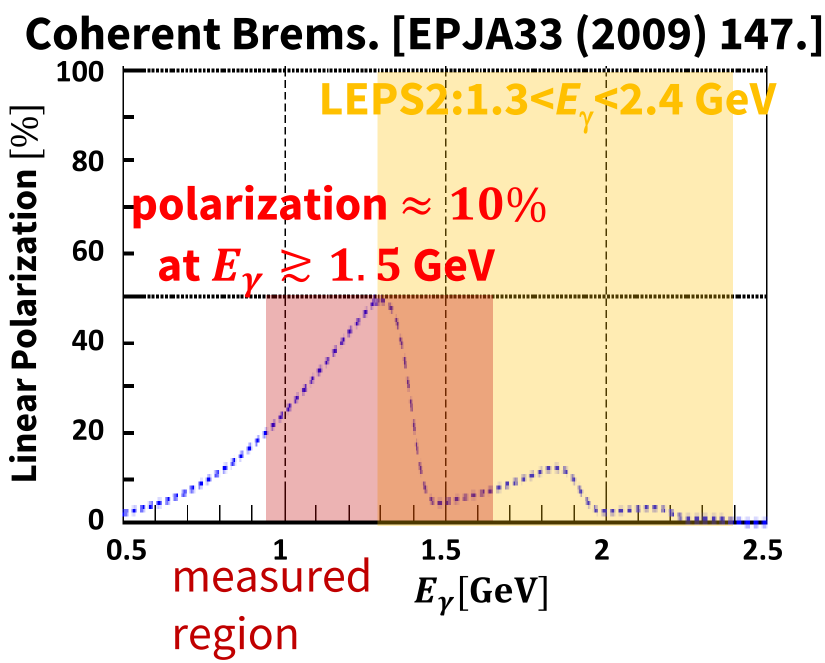


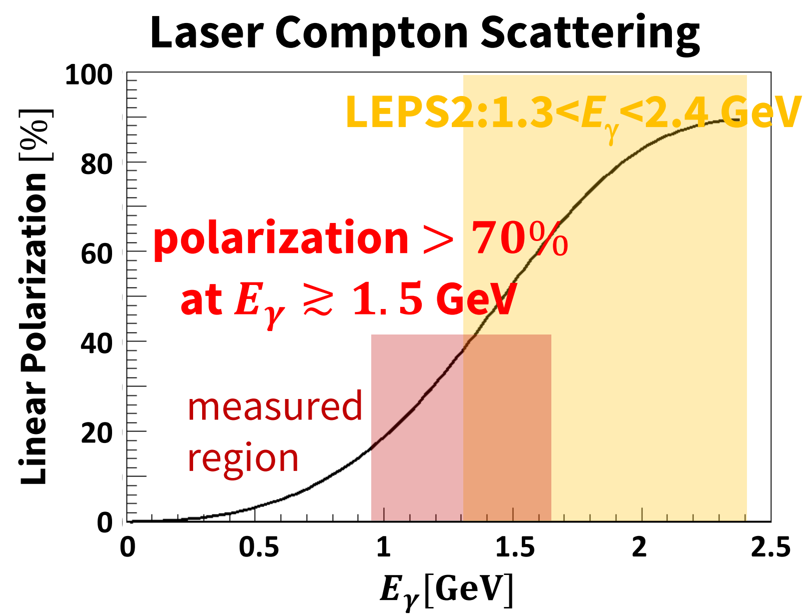
- $|I_p^s|$ is large.
  → spin alignment of $\Delta(1232)$.
- I_p^s is oscillated.
  → interference existed. ex) $N(1535)$
- $I_{\pi^0}^s$ and I_η^s are also oscillated in $E_\gamma > 1.45$ GeV.
  → interference of heavier resonances
  $\Delta(1920), \Delta(1940)$ ...

→ measure in higher energy region ($E_\gamma < 2.4$ GeV).

5 Linearly polarized photon beam

- LEPS2 beam is generated via laser Compton scattering.
- Other experimental facilities(CLAS, ELSA…) use coherent bremsstrahlung as a photon beam.

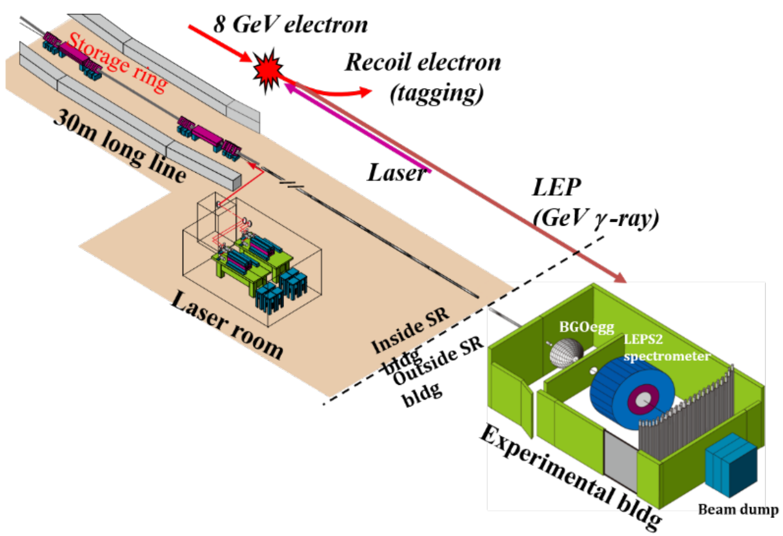


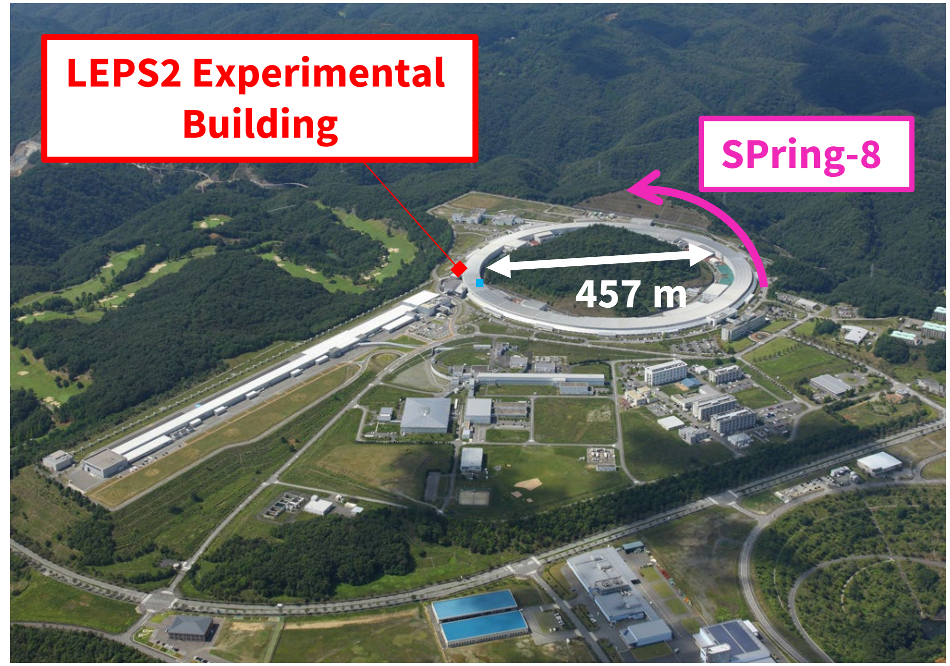


- LEPS2 beam polarization is **greater** than other experimental facilities at higher energies($E_\gamma \gtrsim 1.5$ **GeV**).

SPring-8 LEPS2 beamline

SPring-8 (Electron storage ring: 8 GeV and100 mA)





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

Beam tagging is performed by detecting recoil electrons.

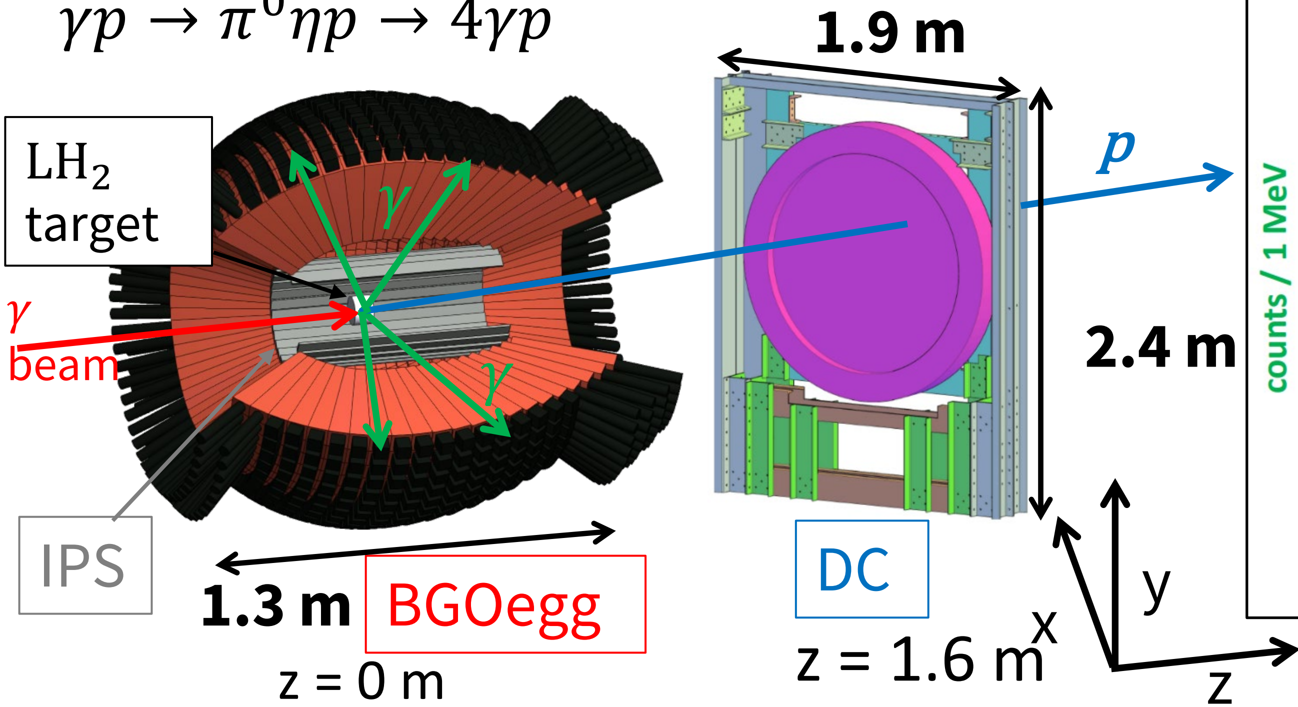
E_γ 1.3〜2.4 GeV (W 1.8~2.3 GeV@proton tagert)

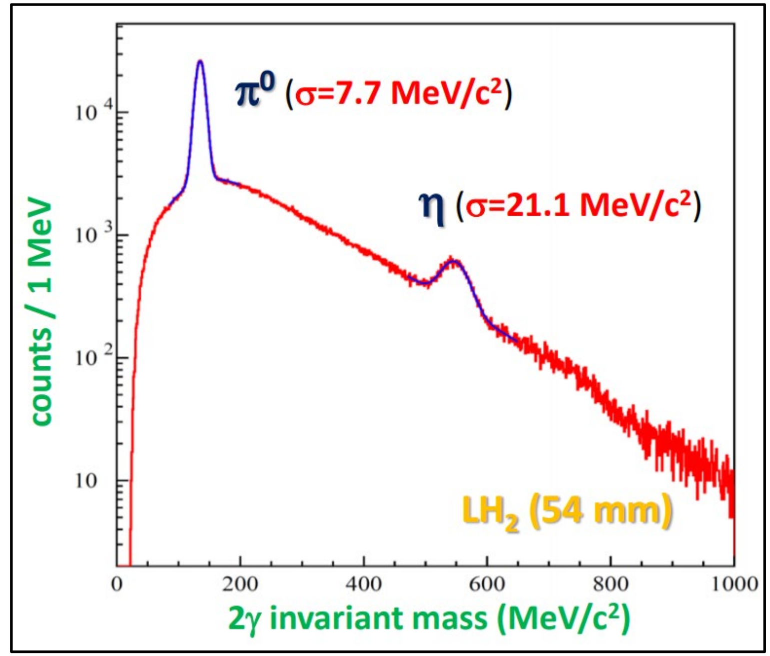
beam intensity 〜2 Mcps

T. Hashimoto
thashi@rcnp.osaka-u.ac.jp

BGOegg experiment

$$\gamma p \rightarrow \pi^0 \eta p \rightarrow 4\gamma p$$





Experiment	σ_π
BGOegg	**7.7**
Crystall Barrel [NIM A, **321**, 69 (1992)]	9.9
BGO-OD [EPJA, **56**, 104 (2020)]	12

BGOegg: EM calorimeter consisting of BGO crystals

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

The world-leading performance

IPS: Plastic scintillator bars for charge identification

DC: Charged particle tracker

$\sigma_{position}$ = 300 µm, covering θ<21 °

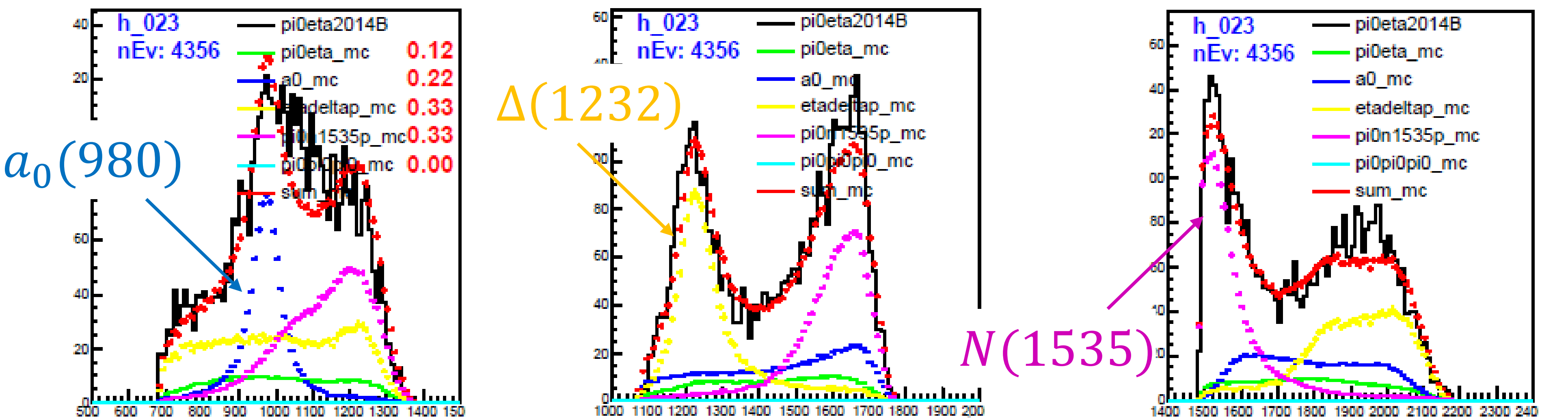
Analysis procedure

$\gamma p \to \pi^0 \eta p \to 4\gamma p$

- 4γ's were detected by using BGOegg.
- A proton was detected by using BGOegg or DC.
  Momentum could not be measured, but polar and azimuthal angles could.
- Event selection:
  4 neutral clusters and 1 charged particle were required.
  Combination of 2γ which invariant mass closest to nomial π^0/η mass were selected.
- A kinematic fit was applied.
  17 kinematic variables and 6 constraints:
  3 momentum x 5 particles, beam energy, and vertex of z.
  4-momentum conservation and nominal masses of π^0 and η.
  * proton momentum was unmeasured.
  We required the probability of χ^2 is larger than 0.01.

9 Background subtraction

- To estimate the background, MC samples for signal and background were prepared as templates and fitted to the real data.
- As signals, non-resonant $\pi^0\eta p$, $a_0(980)p$, $\eta\Delta(1232)$, $\pi^0N(1535)$ are considered and as a background, $\pi^0\pi^0\pi^0p$ is considered.
- Fitted histograms were invariant masses of $\pi^0\eta$, π^0p, and ηp.
- E_γ: 1.3 - 2.4 GeV 3 bins, $\cos\theta$: -1.0 - 0.6 6 bins, ϕ^*: 0 - 360 ° 6 bins, ϕ: 0 - 360 ° 8 bins
- Background amount is 1~15%.

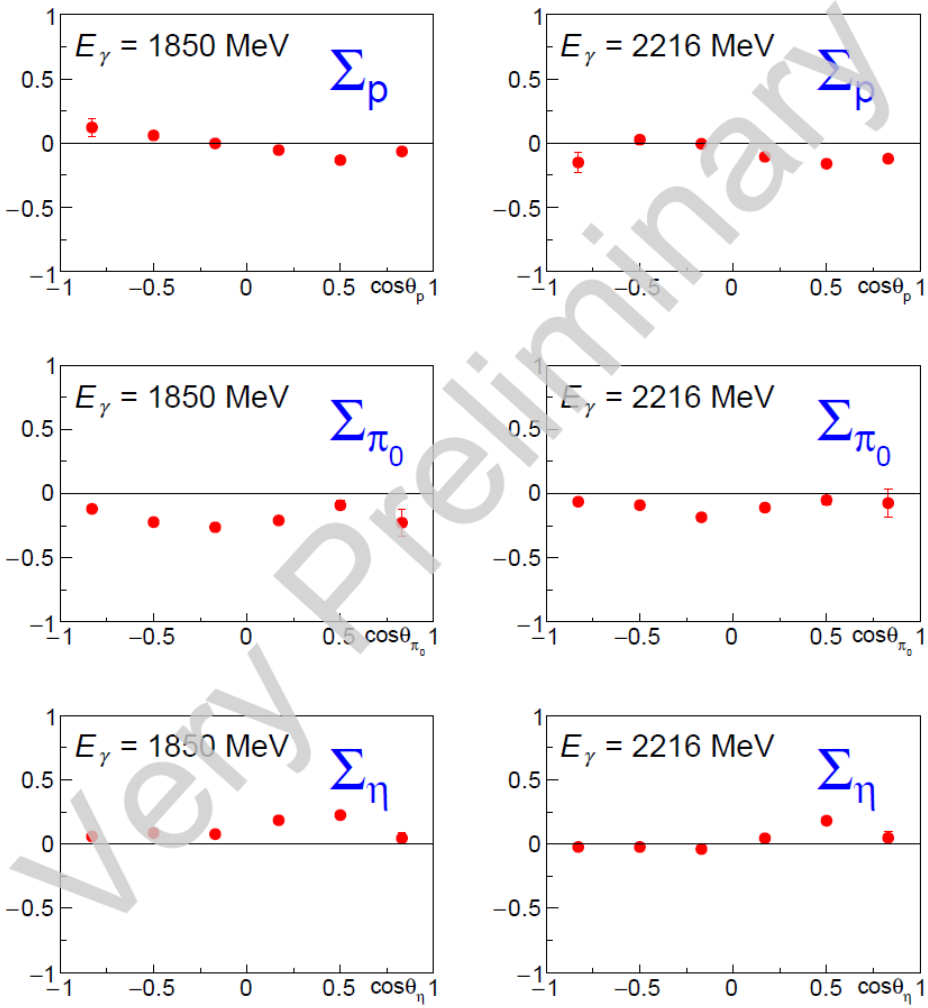


T. Ha… thasl…

$\pi^0\eta$ invariant mass[MeV/c^2] π^0p invariant mass[MeV/c^2] ηp invariant mass[MeV/c^2]

NEW Result of quasi two-body asymmetry

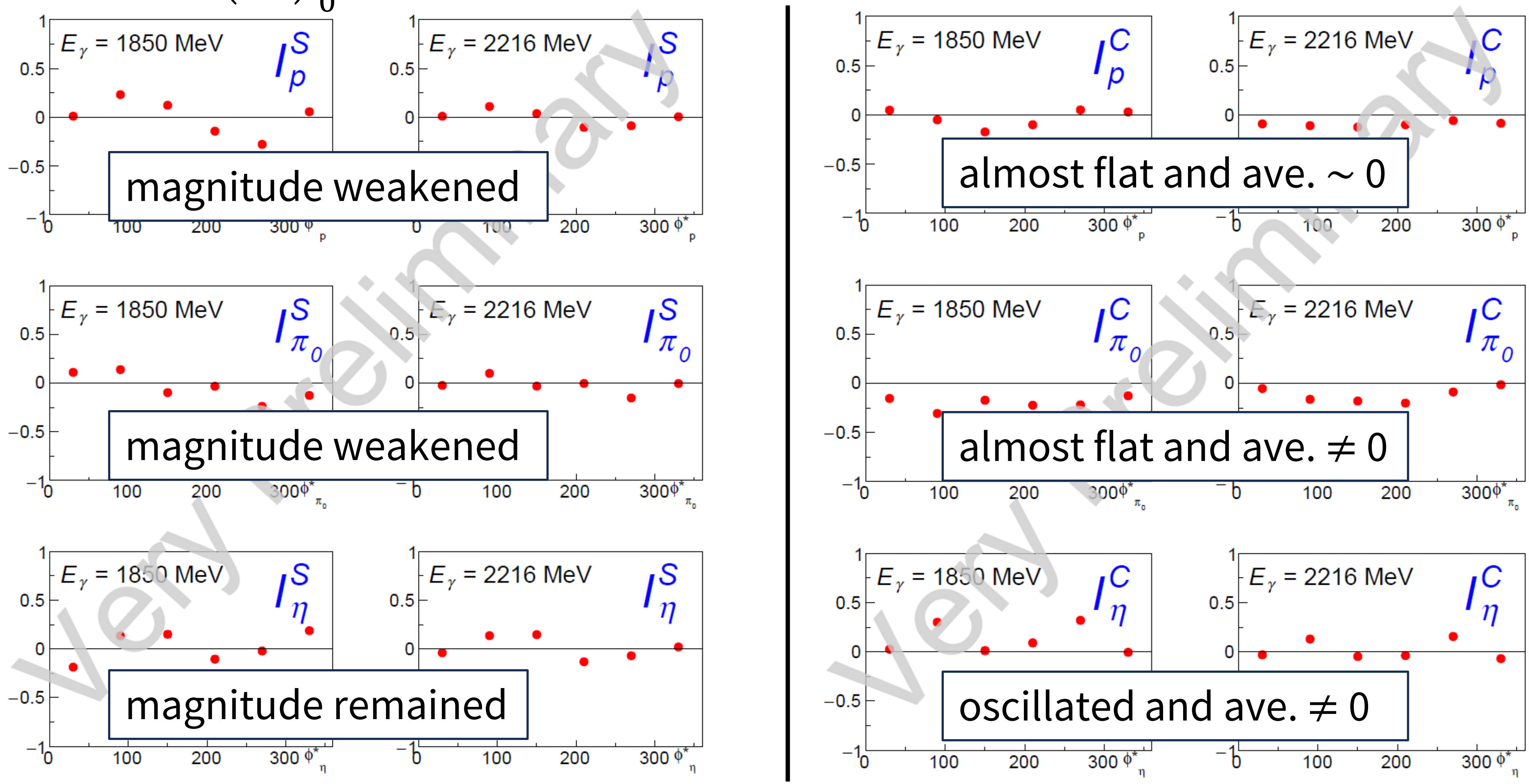
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \{1 - P_\gamma \Sigma(\theta)\cos(2\phi)\}$$



- The magnitude of Σ become smaller.
- Σ_p :
  almost unchanged
- Σ_{π^0} :
  negative values in whole region
  $N(1535)\pi^0$ contribution?
- Σ_η :
  slightly enhanced at $\cos\theta \sim 0.5$
  Is $\Delta(1940)$ contribution not strong?

NEW Result of three-body asymmetry

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \{1 - P_\gamma(I^c(\phi^*)\cos(2\phi) + I^s(\phi^*)\sin(2\phi))\}$$

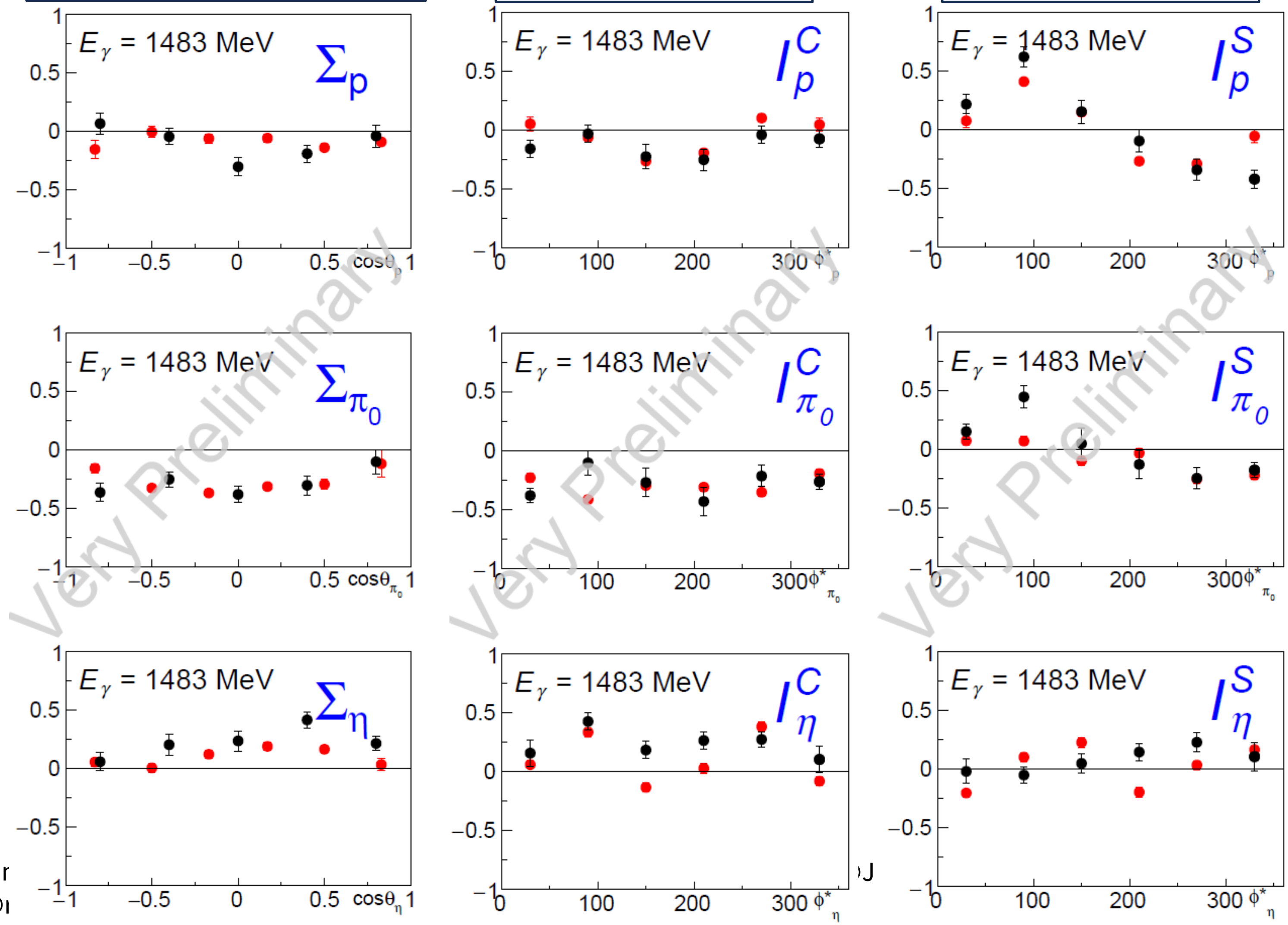


Detailed interpretation requires partial wave analyses.

Comparison with CBELSA results

Our data is consistent with the previous results.

Quasi two-body Σ	Three-body I^C	Three-body I^S



- CBELSA/TAPS
- LEPS2/BGOegg

Summary

- **Multi-meson** photoproduction is a useful tool for baryon spectroscopy.
- We measured quasi two-body and three-body beam asymmetries in the reaction $\boldsymbol{\gamma p \to \pi^0 \eta p}$ for photon energies ranging from 1.3 to 2.4 GeV
- In $\boldsymbol{E_\gamma \gtrsim 1.65}$ regions, the beam asymmetries were measured **for the first time**.
- As a further study, we perform the partial wave analysis.