Baryon resonance studies at the LEPS2 BGOegg experiment

Tran Nam

Research Center for Nuclear Physics, Osaka University

(LEPS & BGOegg collaboration)

Motivation

- Establishing excitation spectra in the high-mass region from the experimental side via photon-induced reactions.
- π^0 photoproduction
  - π^0 data have been well established => Excellent candidate as reference.
  - I=1 , both N^* and Δ^* contributions appear in the s-channel intermediate state maybe an disadvantage.
  - Our data can contribute to enriching the existing database.
- single ω and η photoproduction
  - I=0 , only couple to N^*.
  - η meson, couples with $s\bar{s}$, is likely the key to solve missing resonance problem.
- Simultaneous measurement of $d\sigma/d\omega$ and photon beam asymmetry (Σ) in a wide angle and wide energy range helps to decompose the resonance spectrum.

Contents

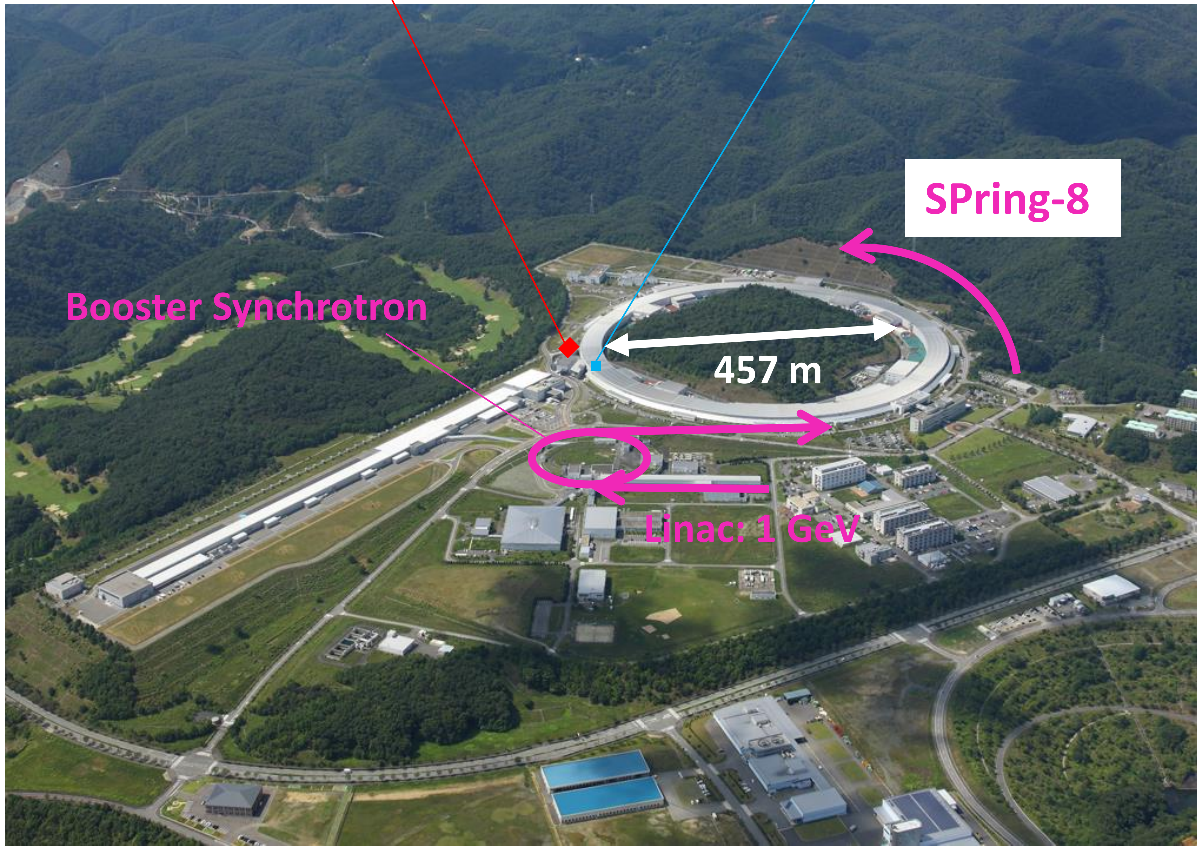
- Introduction to LEPS2 BGOegg experiment at SPring-8 research facility
  - Photoproduction experiments by a Laser Compton Scattering (LCS) beam.
- Baryon resonance studies via single π^0, ω and η photoproduction off the proton:
  - Differential cross section data in a wide angle region, $-1 < \cos\theta^{cm} < 0.5$
  - Photon beam asymmetry data for 1.3 GeV $< E_\gamma < 2.4$ GeV, especially data above 2 GeV are new.
- Summary of the N* program at BGOegg experiment
- Other studies on the η' bound nuclei and in-medium decay of η'
- Upgrade plan for BGOegg experiment

LEPS2 BGOegg experiment at SPring-8, Japan

SPring-8 (Storage ring of 8 GeV e^- w/ 100 mA)

LEPS2 Experimental Building (2013 ~)

LEPS Experimental Hutch (1999 ~)



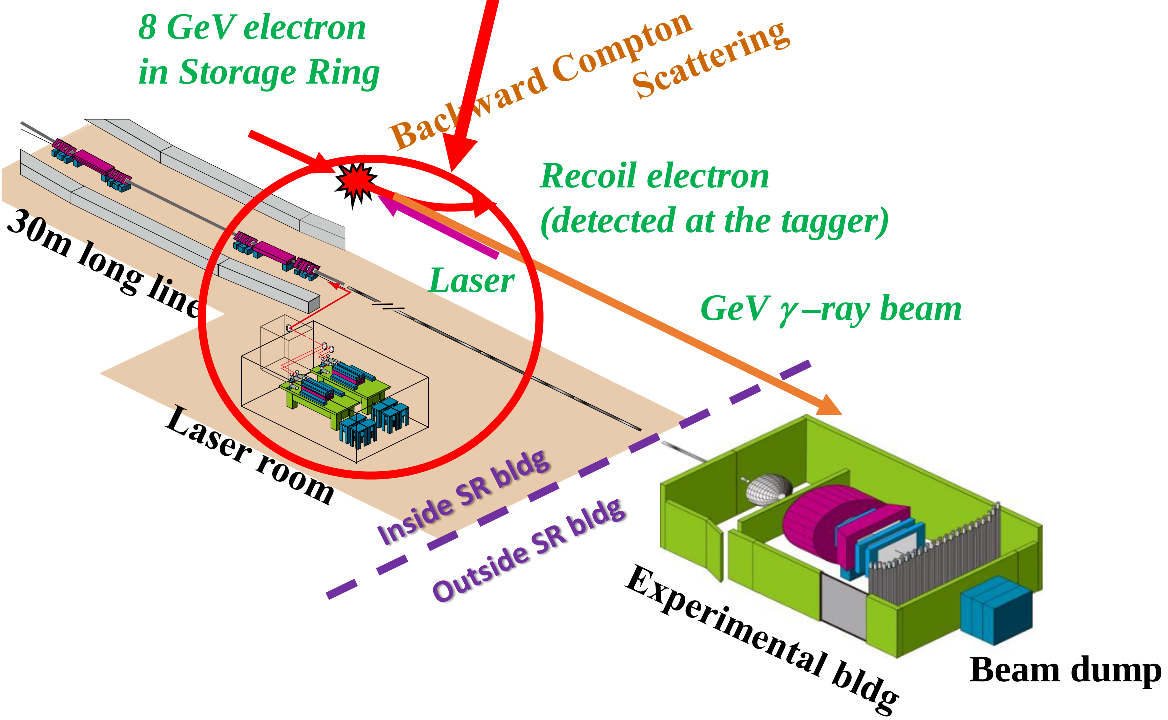
LEPS2 BGOegg experiment at SPring-8, Japan

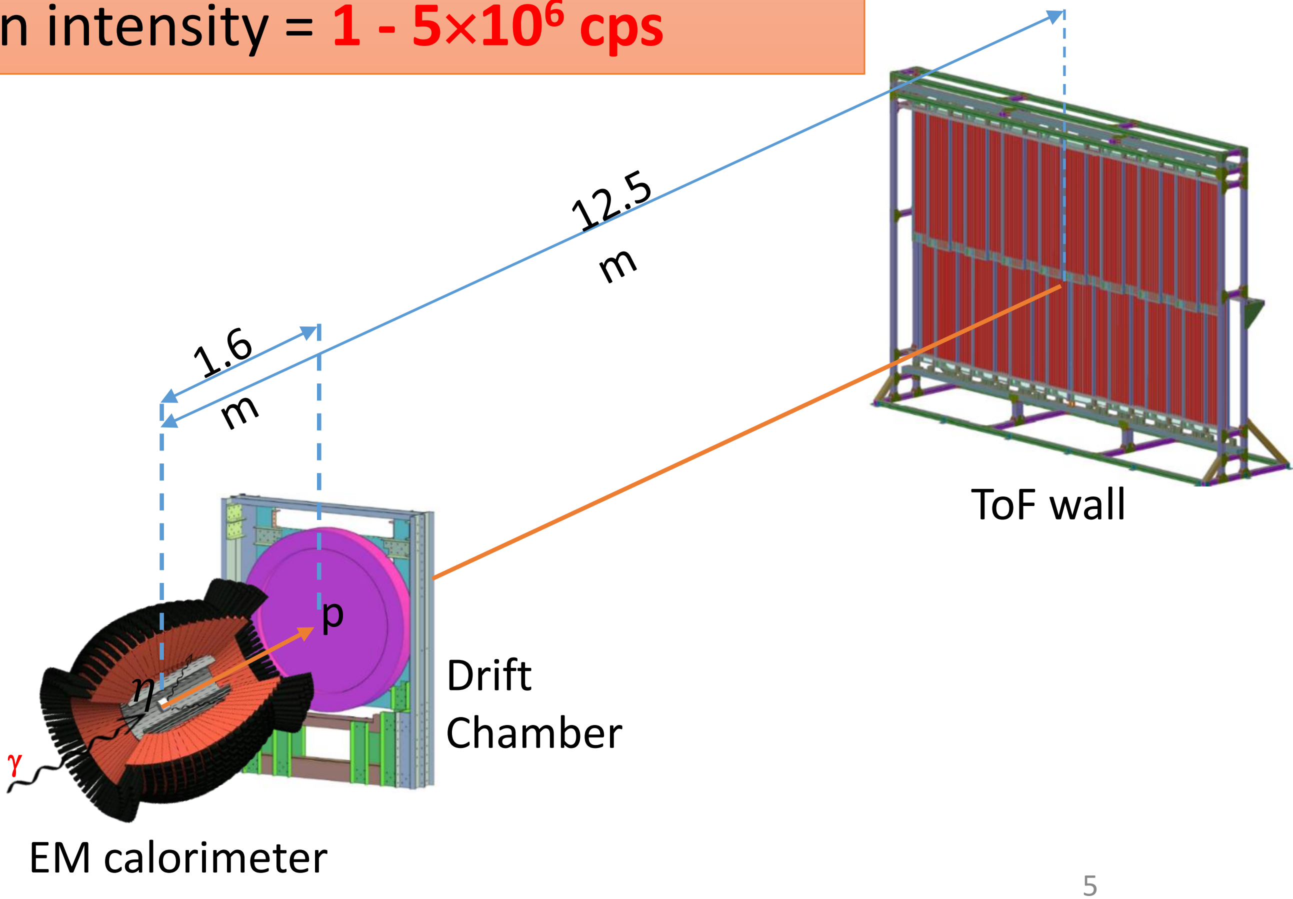
Simultaneous injection of 4 Lasers at maximum

355 nm UV laser ⇒ **$E_\gamma \leq 2.4$ GeV**

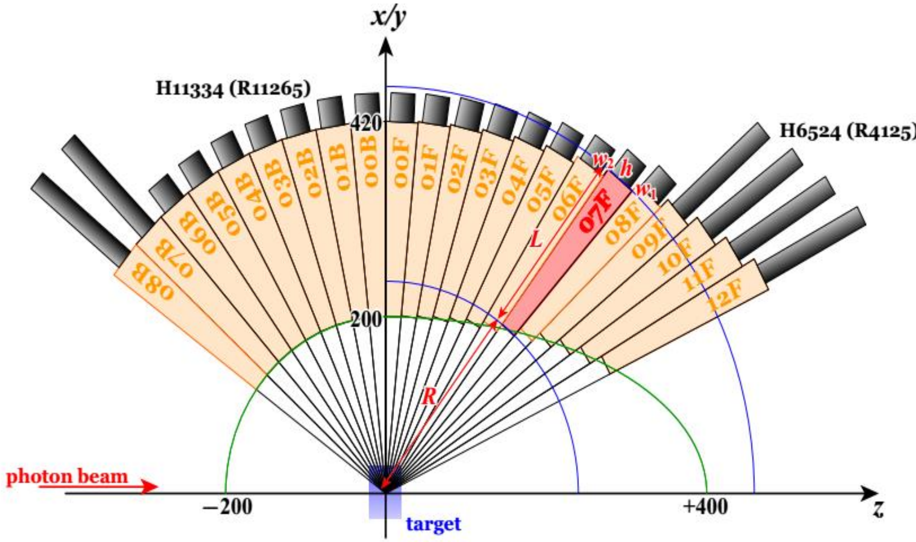
E_γ measurement by tagging recoil electron

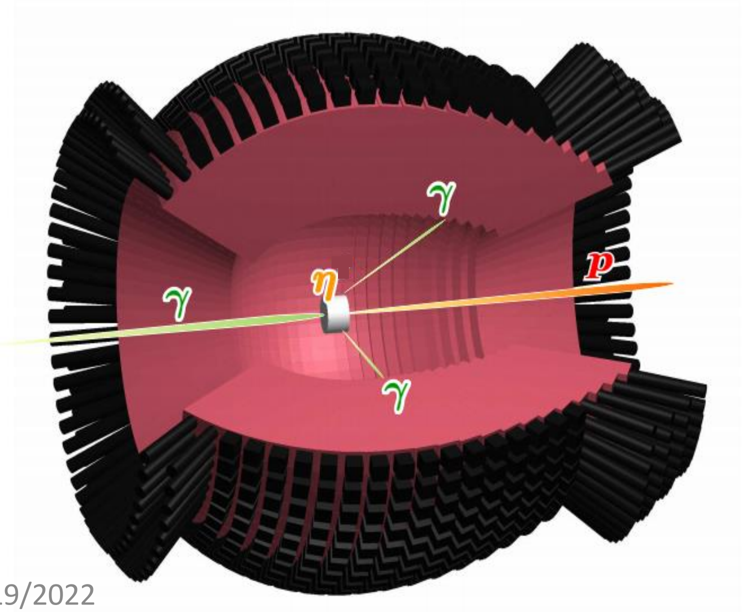
Tagged photon intensity = **1 - 5×10^6 cps**



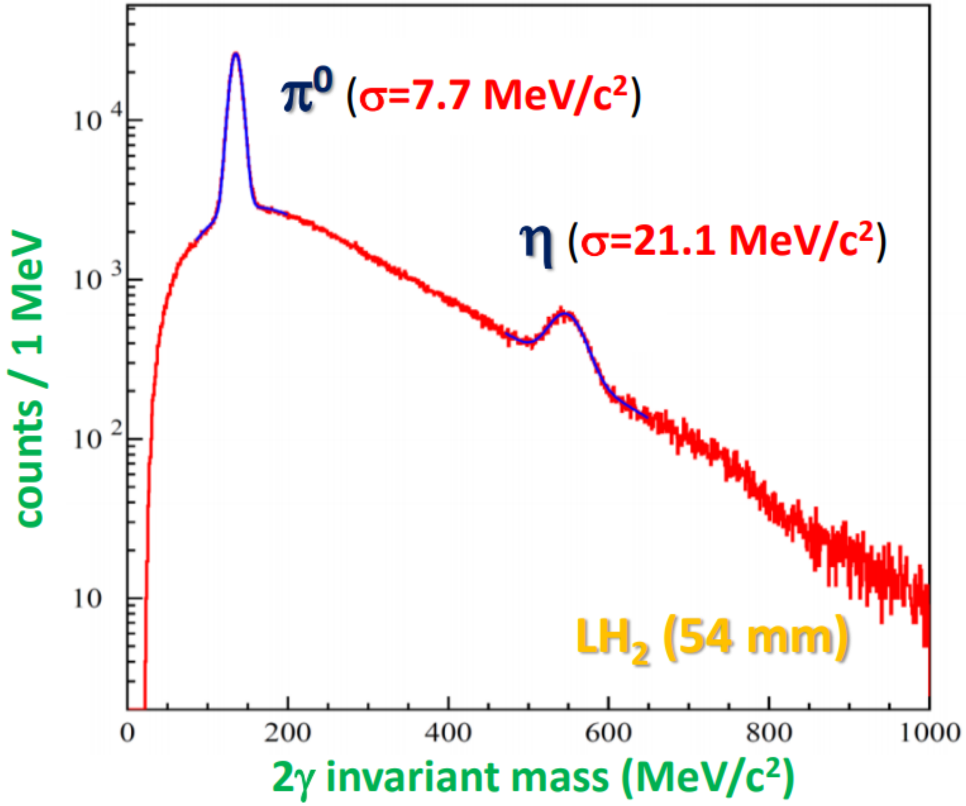


Large acceptance EM calorimeter BGOegg



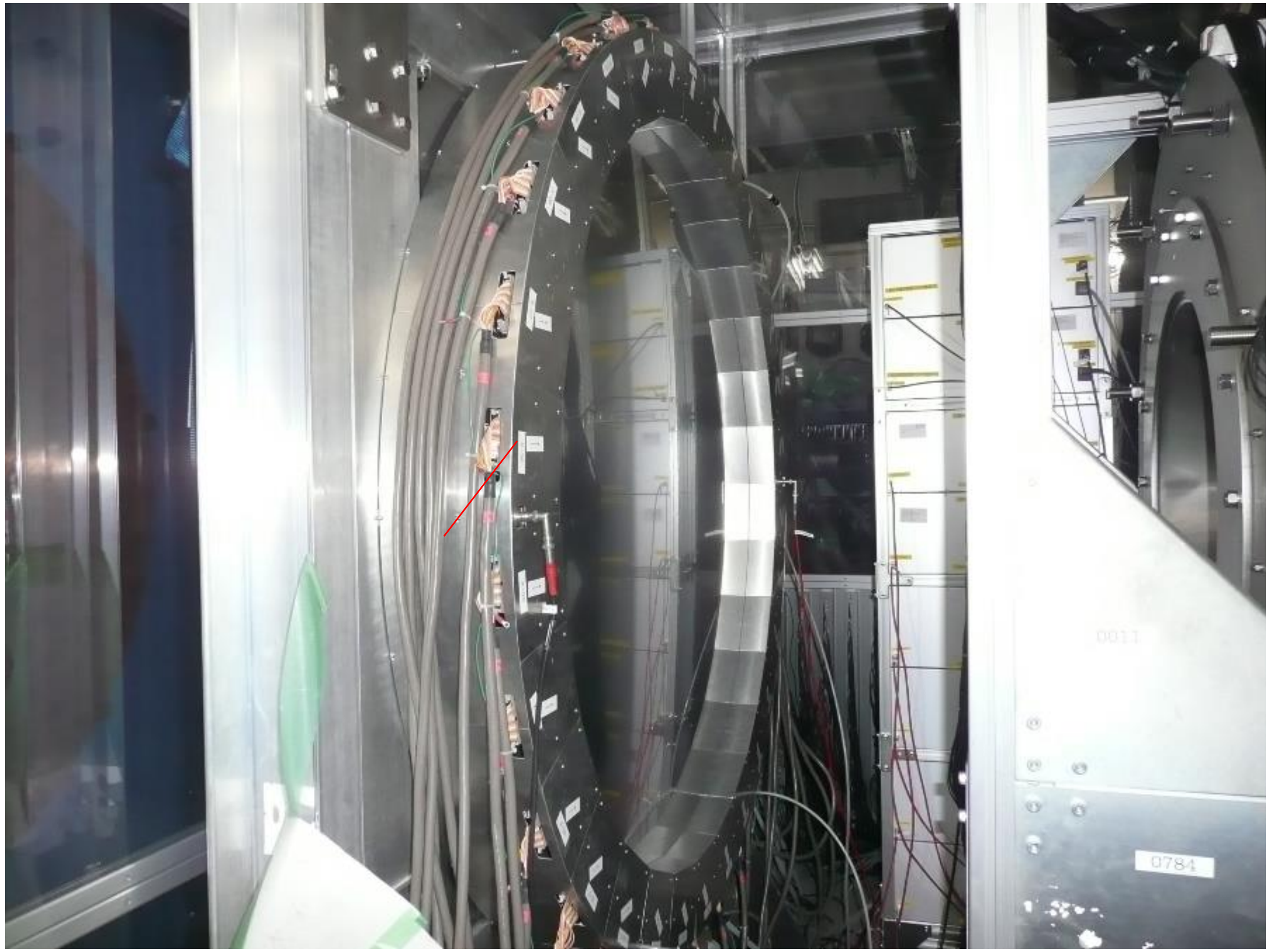


60 $Bi_4Ge_3O_{12}$ crystals x 22 layers covering $24^0 \sim 144^0$, $\boldsymbol{\sigma_E = 1.3\%}$ **@ 1 GeV**
Each BGO crystal cover 6^0in (θ, ϕ) with $L_{crystal} = 220$ mm$= 20X_0$



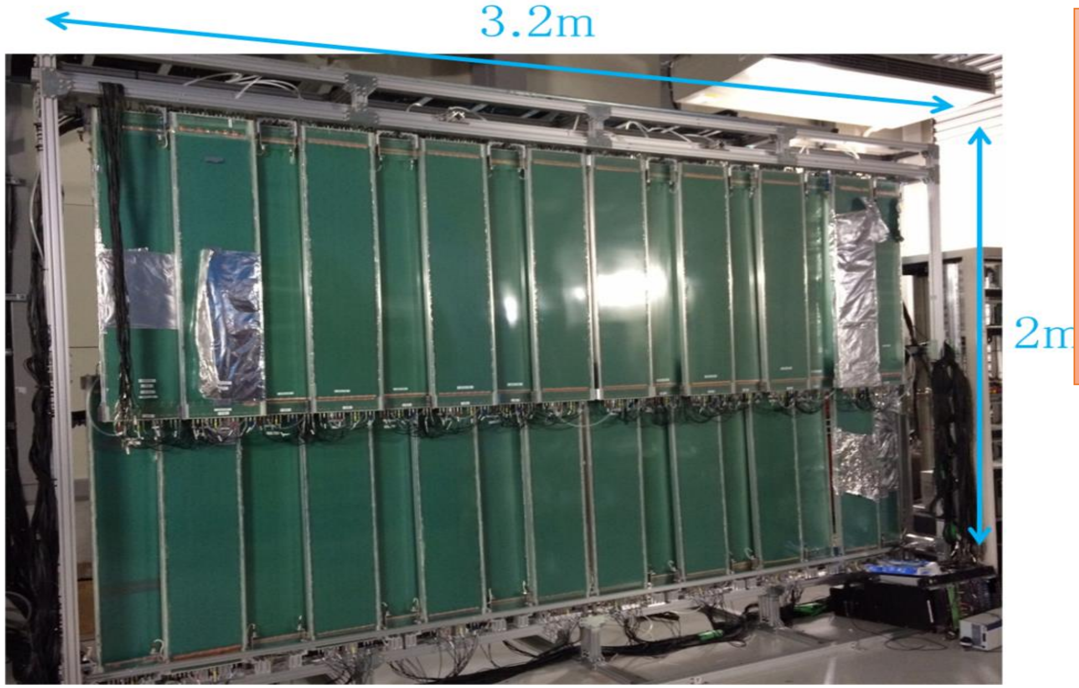
NIM A 837 (2016) 109–122

Drift Chamber (DC)



- The distance from DC to target is $z = 1.6$ m
- the covering angle $\theta < 21^0$
- Resolution $\sim 300\mu m$

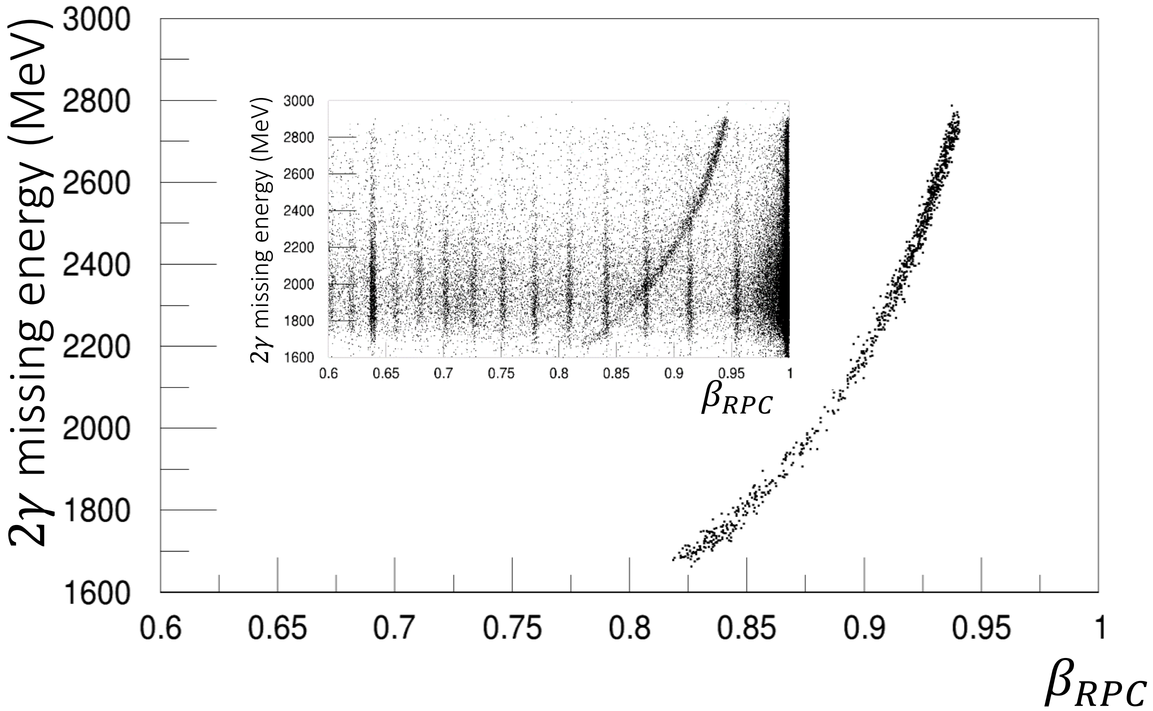
Resistive Plate Chamber(RPC)



- $\theta^{lab} < 6^o$=> Targeting the extreme angles
- 12.5m distance from the target => only long-live charged particles (proton, electron…) can be measured
- Using ToF method with time resolution is 50-120ps
- Complete 4-momentum conservation => minimum BG

$$\gamma + p \rightarrow \eta + X \rightarrow 2\gamma + X$$

Where X was expected to be a proton



Analysis procedure

Event Selection

E_γ meas. (1.3—2.4 GeV) at tagger.

2 or 3 neutral clusters at BGOegg.

$\pi^0 \rightarrow \gamma\gamma$ (Br=98.8%)

$\eta \rightarrow \gamma\gamma$ (Br=39.4%)

$\omega \rightarrow \pi^0\gamma \rightarrow \gamma\gamma\gamma$ (Br=8.40%)

Proton detection at DC, RPC or BGOegg.

χ^2 probability cut with Kinematic Fit

Required **4-momentum conservation**

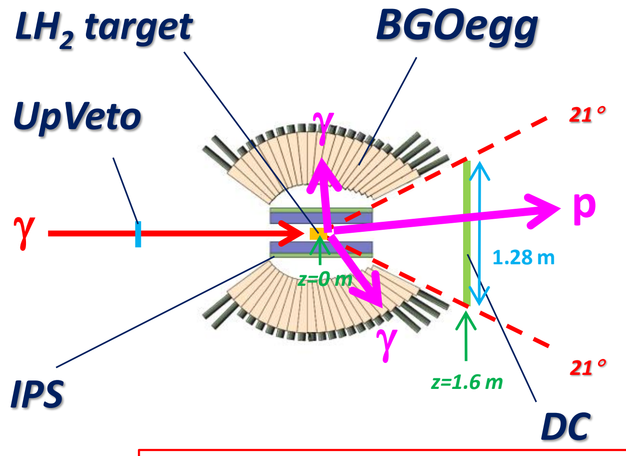
& **π^0 / η mass** (PDG value).

Better S/N ratio & resolutions are expected.

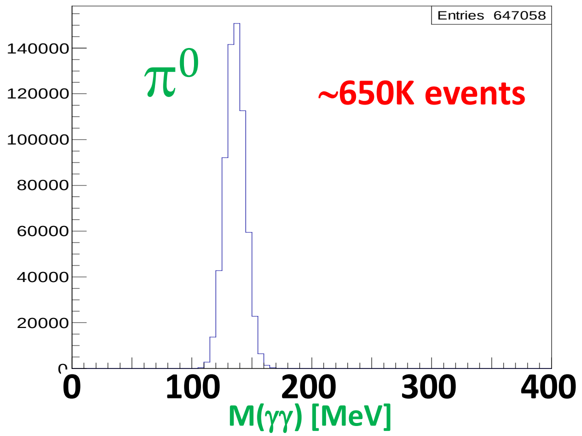
Vertex is assumed to be variable on z-axis.

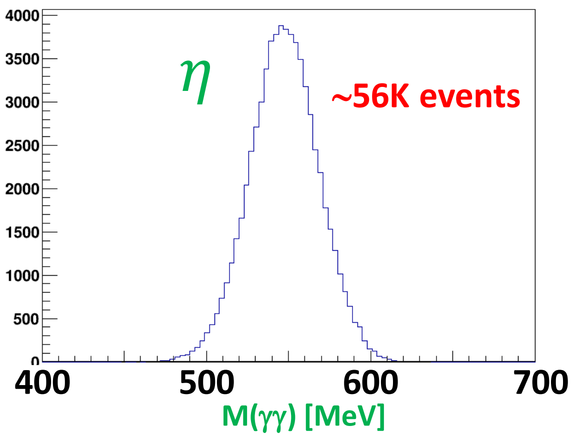
2 or 3 neutral clusters $\Rightarrow$ 4-momenta of each γ

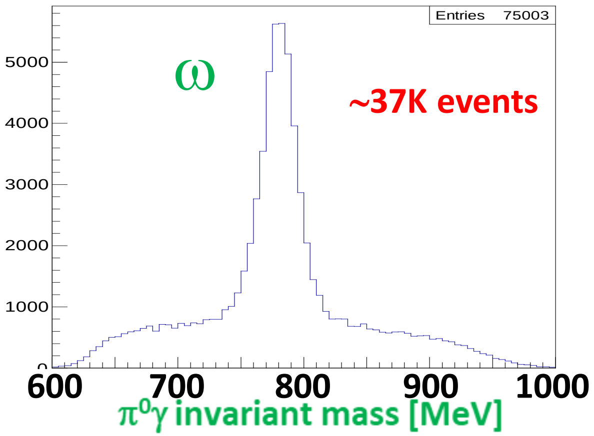
Beam energy comes from tagger.



Only the proton direction is measured at DC or BGOegg.



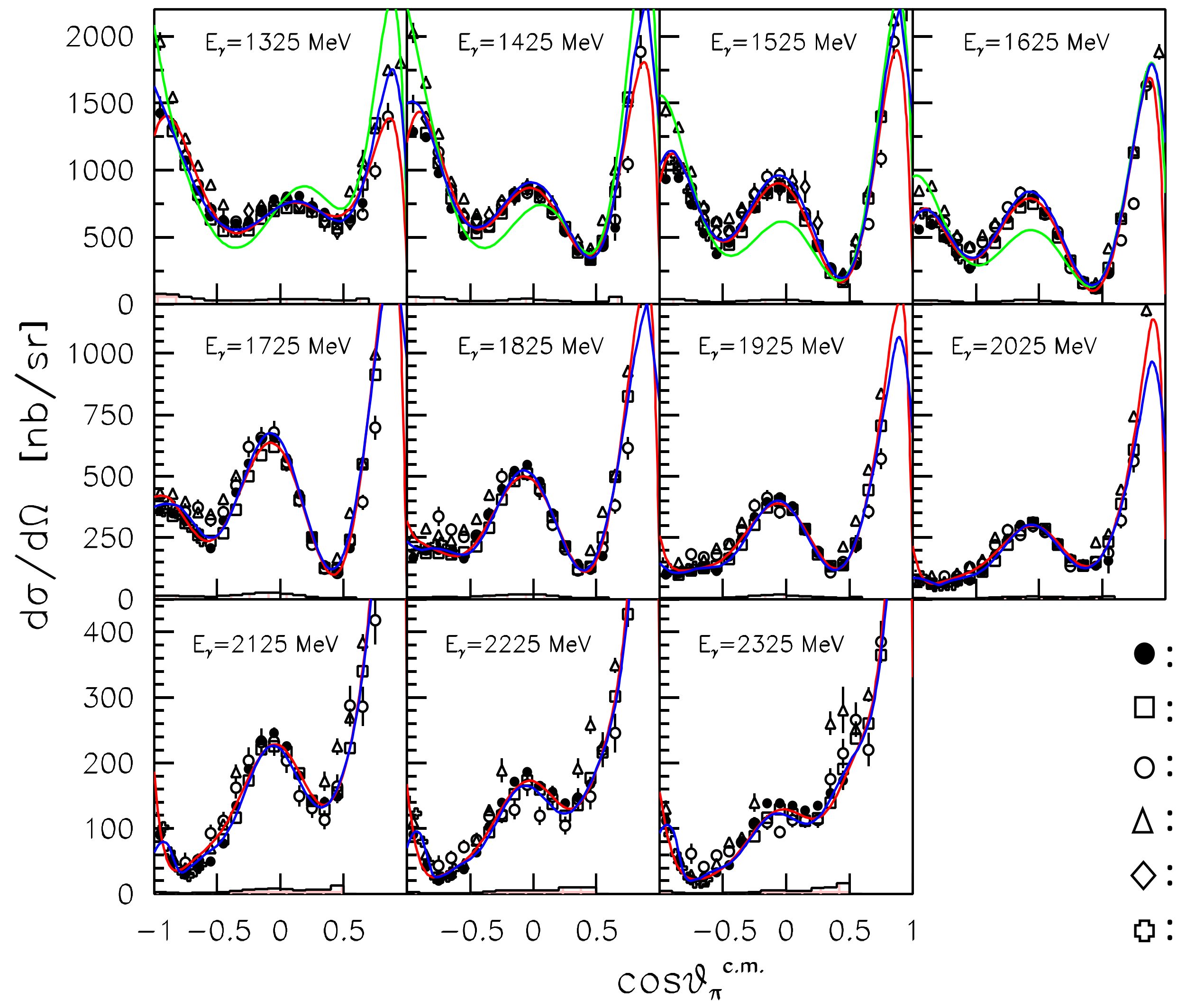




PHYSICAL REVIEW C **100**, 055202 (2019)

Differential cross section of $\gamma p \rightarrow \pi^0 p$

22 energy bins for 1300<E_γ<2400 MeV & **17 polar angle bins** for -1.0<$\cos\theta_\pi^{CM}$<0.7



- ***Our $d\sigma/d\Omega$ data are consistent with the existing PWA model calculations. What about photon beam asymmetry?***

—— : **Bonn-Gatchina** [https://pwa.hiskp.uni-bonn.de/BG2014_02_obs_int.htm]

—— : **GWU SAID** [http://gwdac.phys.gwu.edu/analysis/pr_analysis.html]

—— : **ANL-Osaka** [Private communication with Prof. Sato (Osaka Univ.)]

●: BGOegg experiment

□: CLAS [PRC76, 025211 (2007)]

○: CB-ELSA [PRC94, 012003 (2005)]

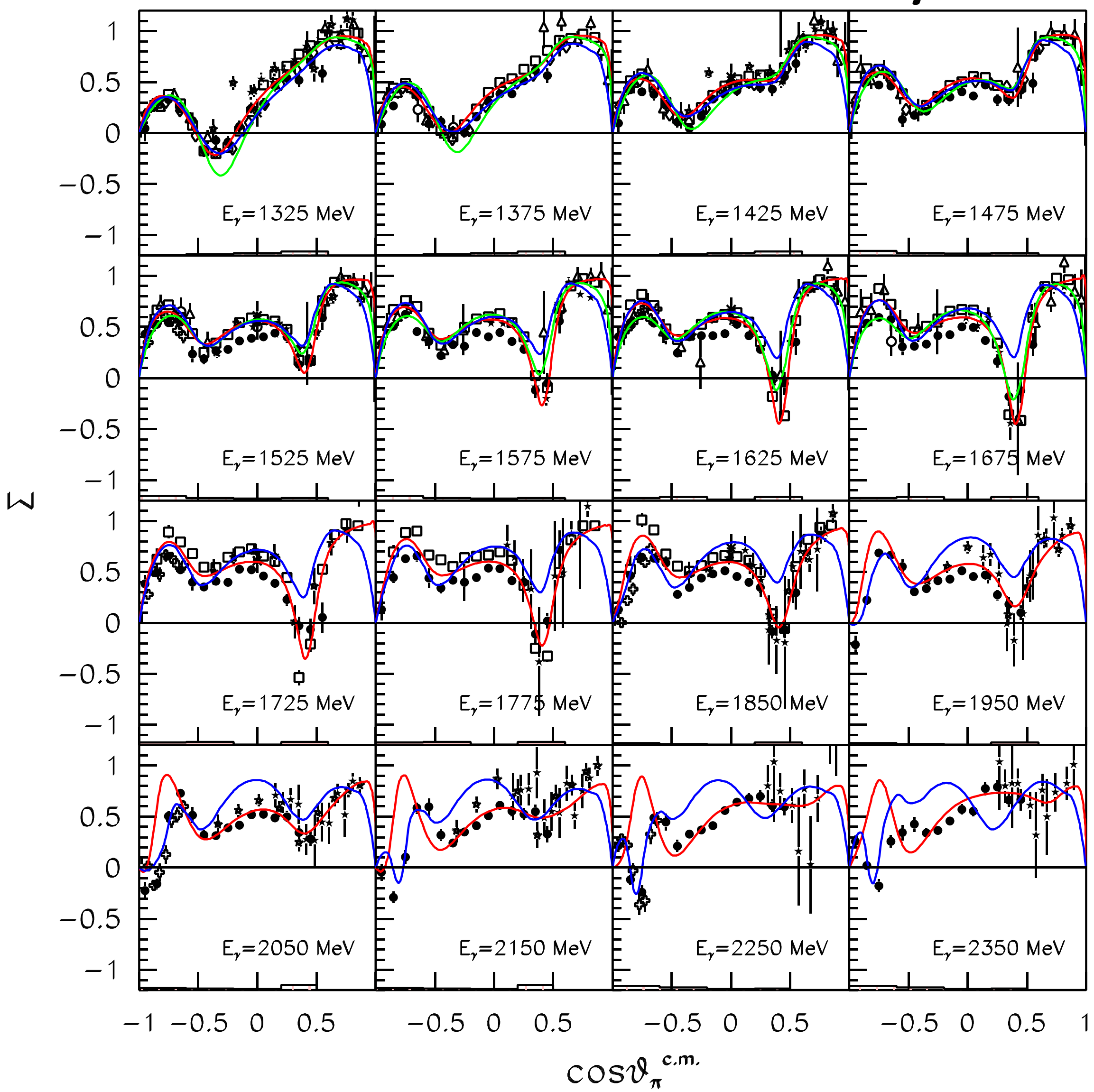
△: CBELSA/TAP [PRC84, 055203 (2011)]

◇: GRAAL [EPJA26, 399 (2005)]

✧: LEPS [PLB657, 32 (2007)]

Typical systematic error ~ 4%-5% (hist)

Photon beam asymmetry of $\gamma p \rightarrow \pi^0 p$

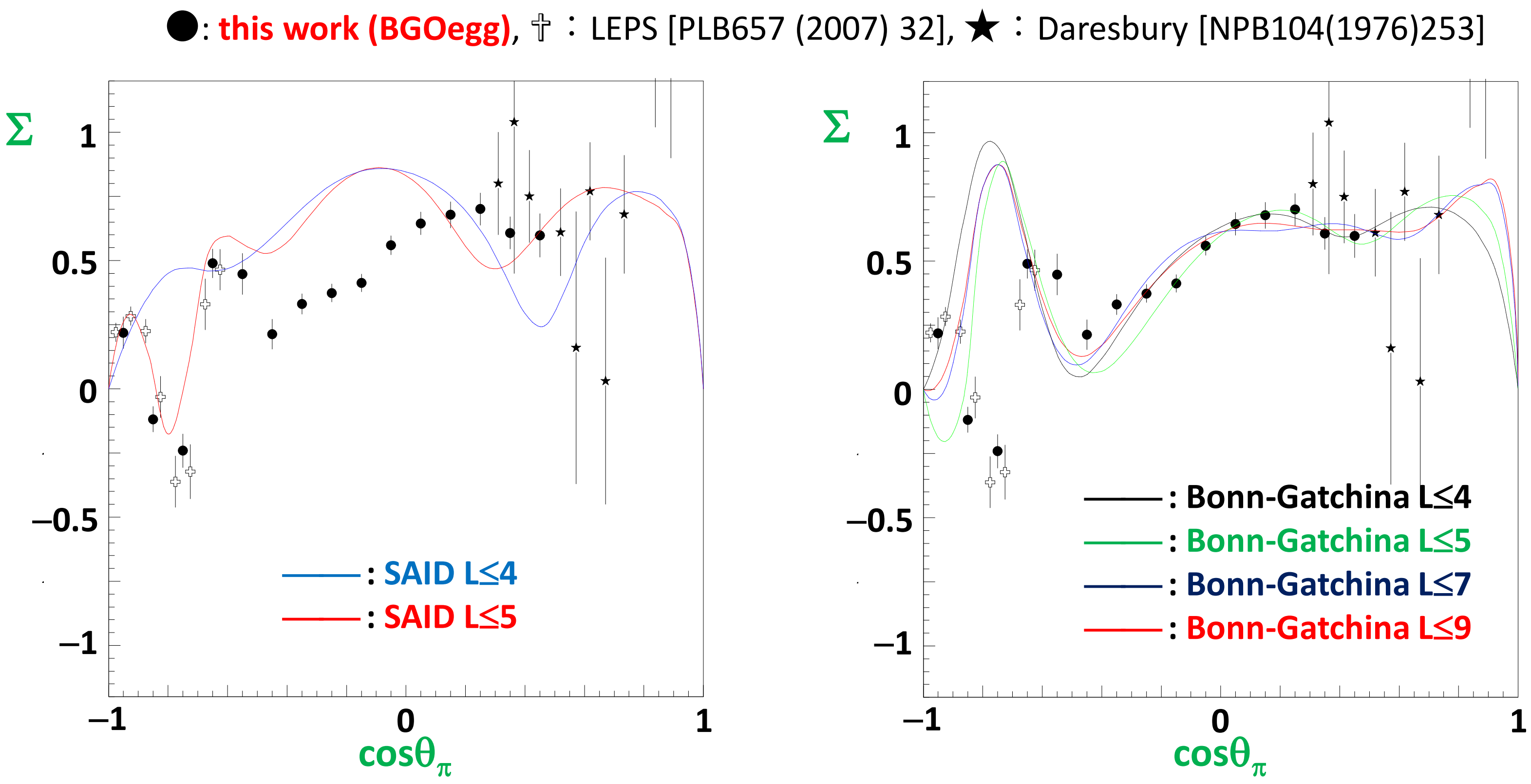


●: **BGOegg experiment**
□: CLAS [PRC88 (2013) 065203]
○: CBELSA [PRC81 (2010) 065210]
◇: GRAAL [EPJA26 (2005) 399]
✞ : LEPS [PLB657 (2007) 32]
★ : Daresbury [NPB104(1976)253]
☆ : Daresbury [NPB154(1979)492]
∗ : CEA [PRL28(1972)1403]
△ : Yerevan [PLB48(1974)463]
Syst. error (hist) : **0.006 – 0.050**

—— : **Bonn-Gatchina** [https://pwa.hiskp.uni-bonn.de/BG2014_02_obs_int.htm]
—— : **GWU SAID** [http://gwdac.phys.gwu.edu/analysis/pr_analysis.html]
—— : **ANL-Osaka** [Private communication with Prof. Sato (Osaka Univ.)]

- ***Data at $E_\gamma \gtrsim$ 2 GeV were scarce, big discrepancy between PWAs, which suggest a large ambiguity in the amplitude solution.***
- ***good agree at $E_\gamma < 1.7$ GeV***
- ***At 1.7 GeV $< E_\gamma <$ 2 GeV, bonn-Gatchina moderately reproduce our data.***

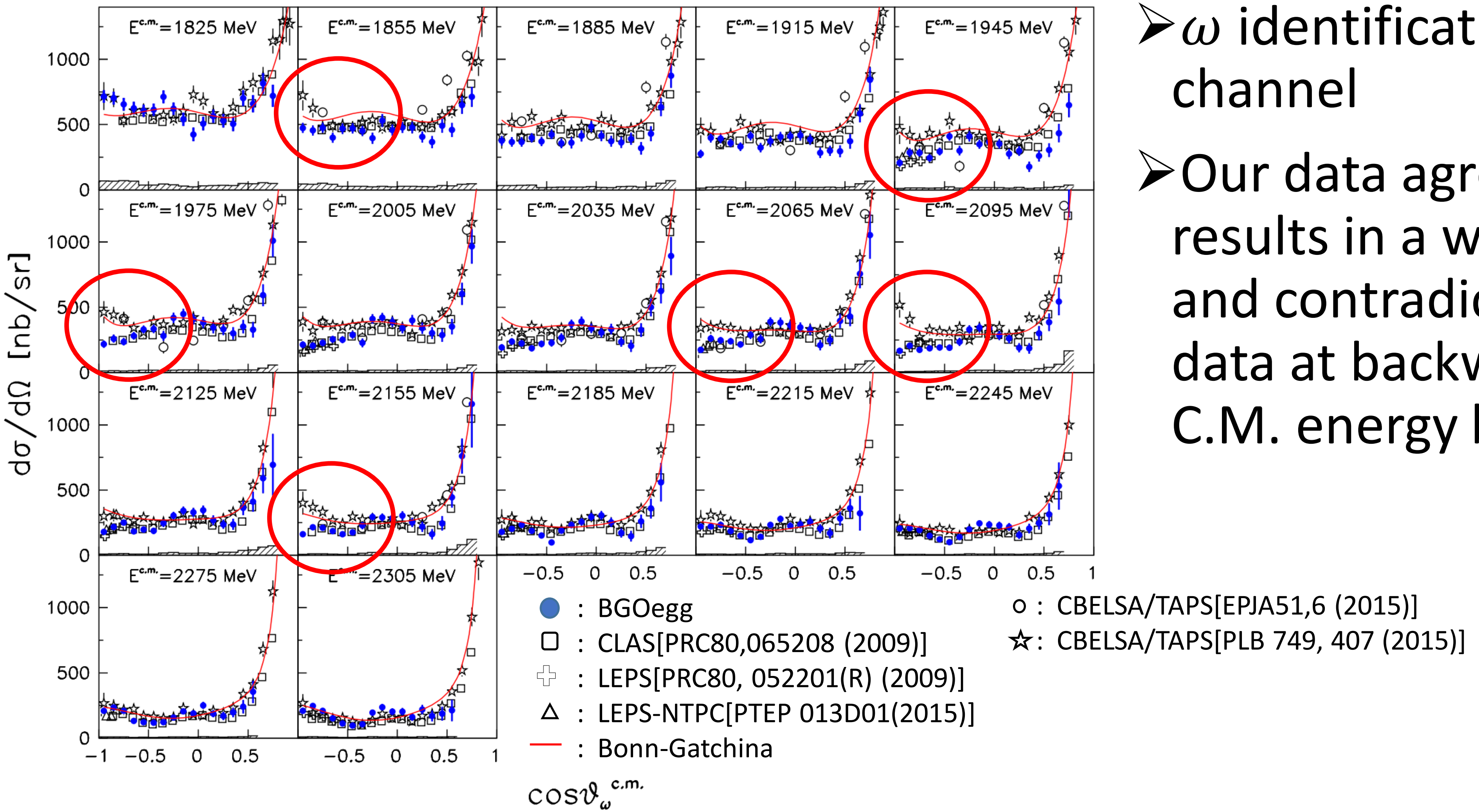
Comparison with PWA results at high energy



Photon Beam Asymmetry (Σ) at 2200 < E_γ < 2300 GeV

- SAID solution shows a big difference between $L \leq 4$ and $L \leq 5$ at reproducing the backward dip structure, corresponding to H_{19} (N(2220))and H_{39}(Δ(2300)) with $J^P = \frac{9}{2}^+$.
- Bonn-Gatchina shows no significant different when restricting L from 9 to 4. The middle range can be reproduced but not backward dip structure.
- **The inconsistency of two PWA models tells a large ambiguity in the amplitude solutions at E_γ > 2 GeV**

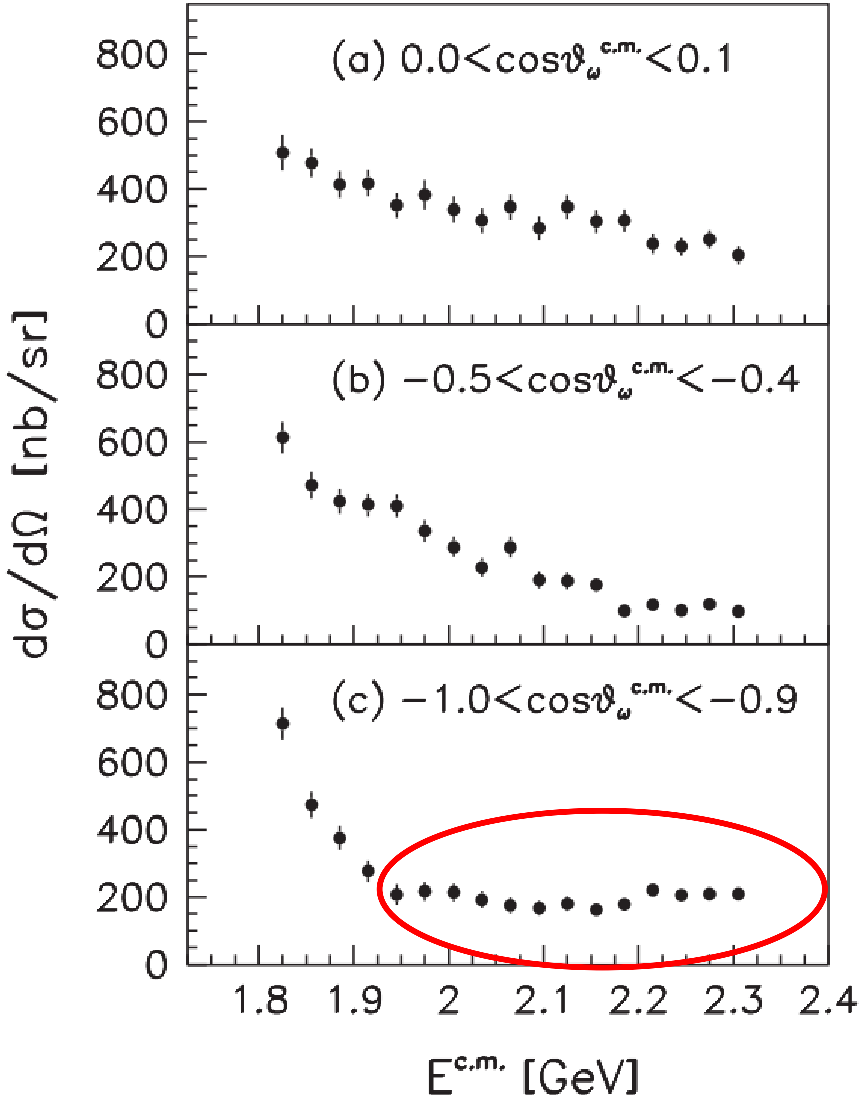
Differential cross section of $\gamma p \to \omega p$



- ω identification via $\pi^0\gamma$ channel
- Our data agree with CLAS results in a whole C.M. region and contradict CBELSA/TAPS data at backward angle in the C.M. energy below 2.1 GeV.

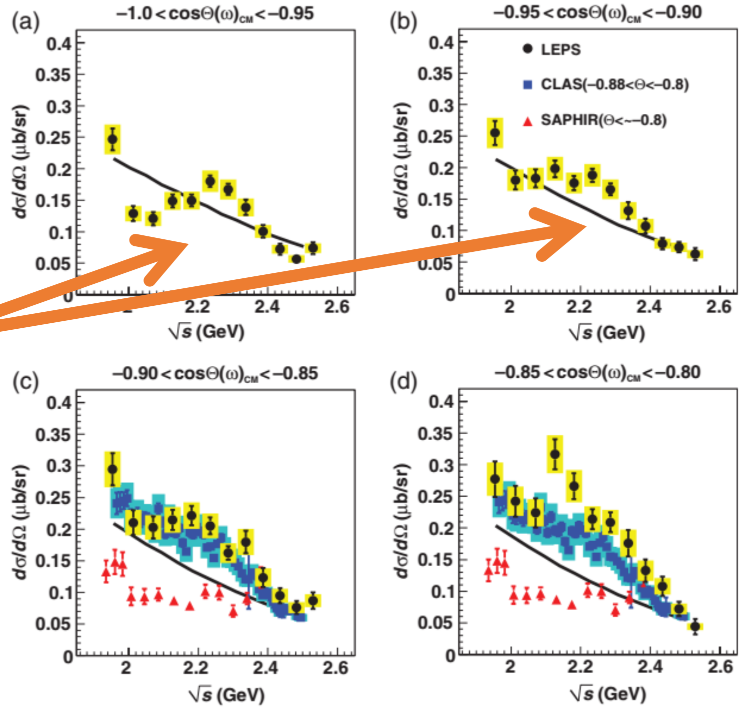
PHYSICAL REVIEW C **102**, 025201 (2020)

Differential cross section of $\gamma p \rightarrow \omega p$



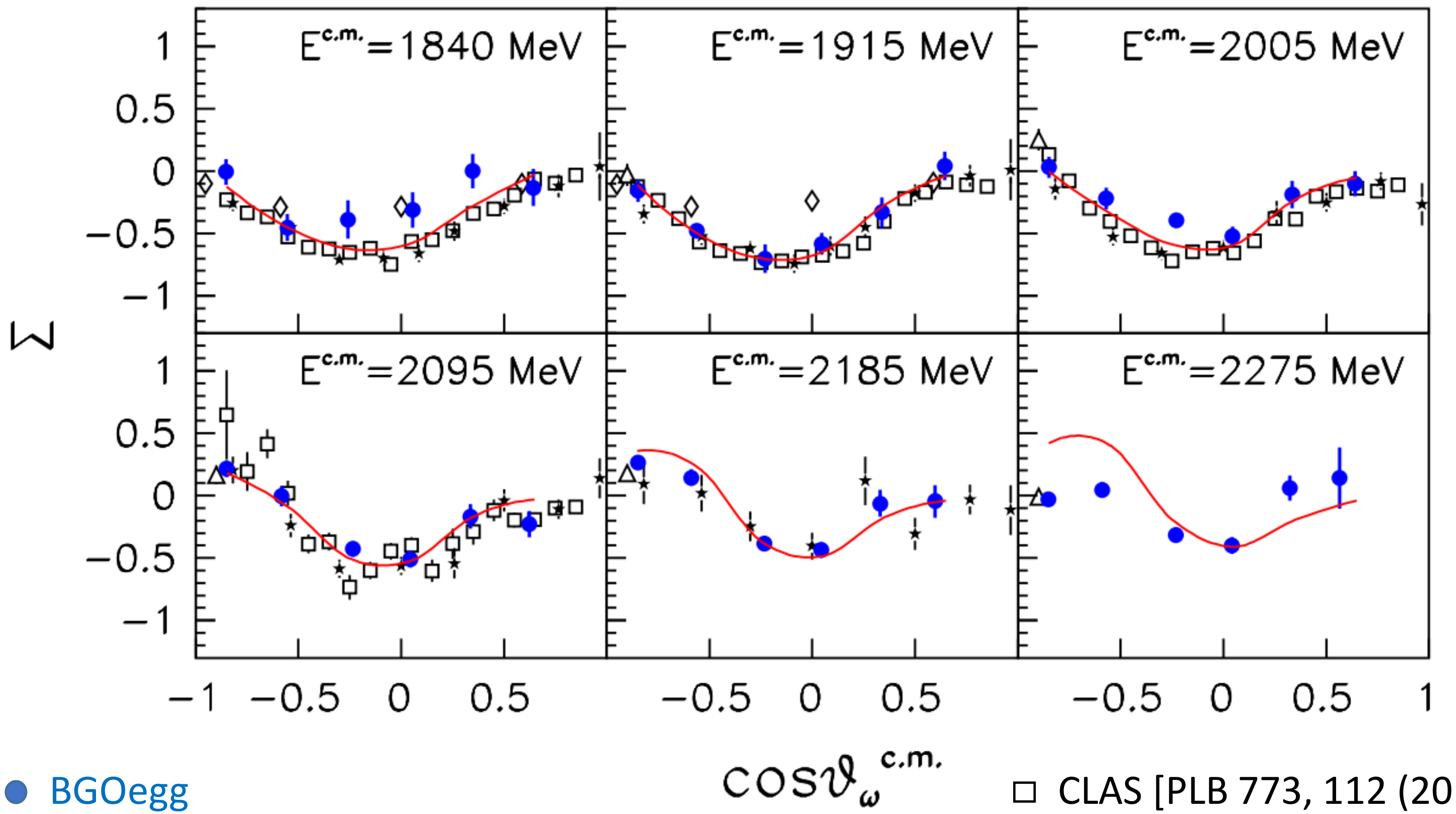
- $d\sigma/d\Omega$ at extremely backward angles became flat at $W > 1.95\ GeV$
- Possible of multi high-spin resonance contributions at backward angles such as $G_{17}(2190)$ and "missing state" around with $J^P = \frac{5}{2}^+$ **[Phys. Rev. C 80, 065209]**

Prog. Theor. Exp. Phys. **2015**, 013D01 (2015)



Not seen in our results

Photon beam asymmetry of $\gamma p \rightarrow \omega p$

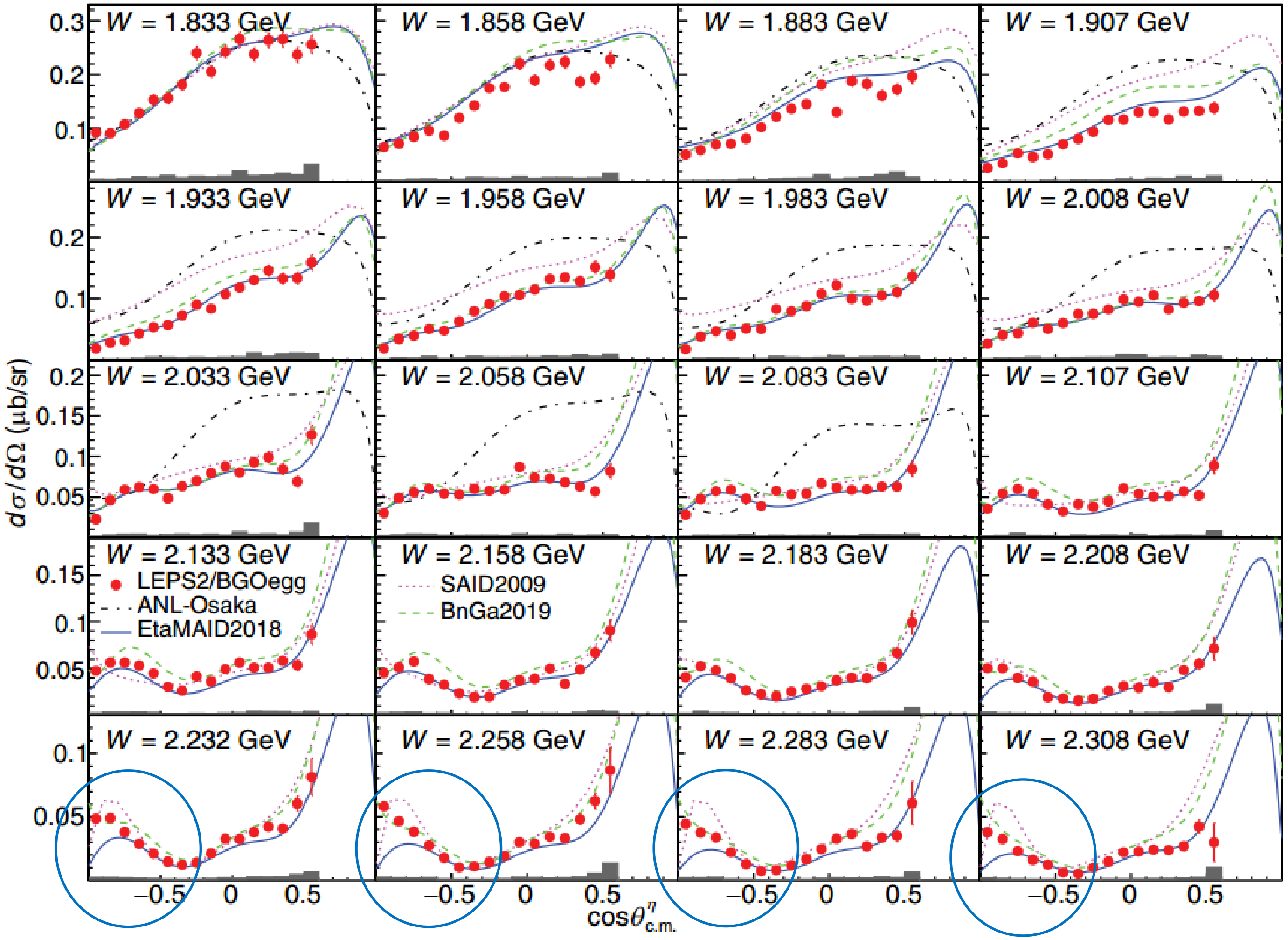


- Precise Σ values in a wide angular range were obtained for the first time above c.m. energy of about 2.1 GeV.
- Bonn-Gatchina reproduced data except for the highest energy bin
- The polarized spin density matrix element which represent the decay asymmetry of $\omega \rightarrow \pi^0\gamma$ relatives to photon beam polarization is available.

● BGOegg
◇ GRAAL [PRC91, 065207 (2015).]
△ LEPS-NTPC [PTEP, 013D01(2015).]
□ CLAS [PLB 773, 112 (2017)]
★ CLAS-FROST [PRC97, 055202 (2018)]
— Bonn-Gatchina

PHYSICAL REVIEW C **106**, 035201 (2022)

Differential cross section of $\gamma p \to \eta p$

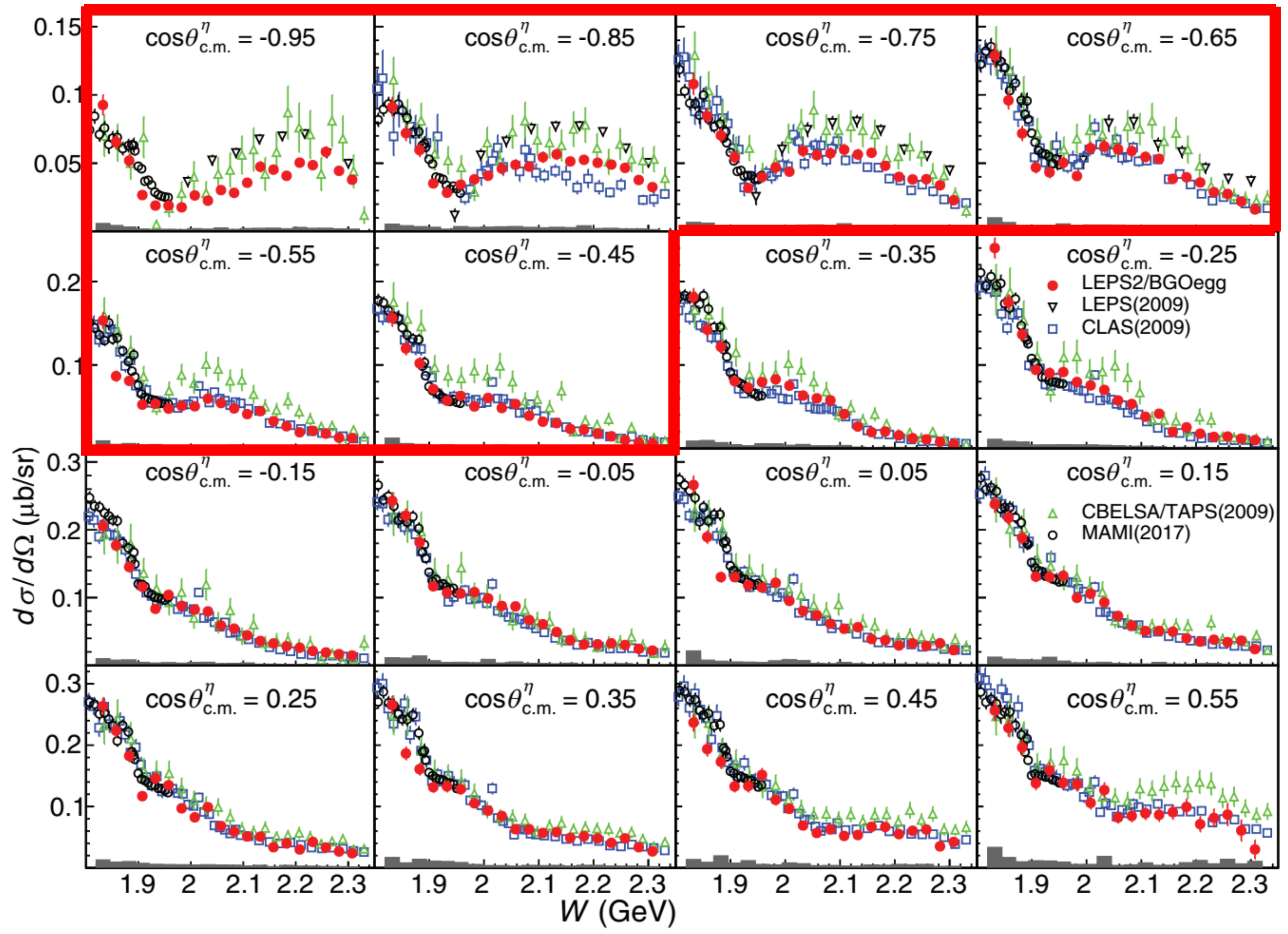


- ➢PWA solutions, such as MAID and BnGa, well describe data at $W < 2.2\ GeV$.
- ➢The peaking behavior at backward angles and at higher energies can not be explained with only u-channel contributions.

: etaMAID2018
: SAID2009
: Bonn-Gatchina2019
: ANL-Osaka2016

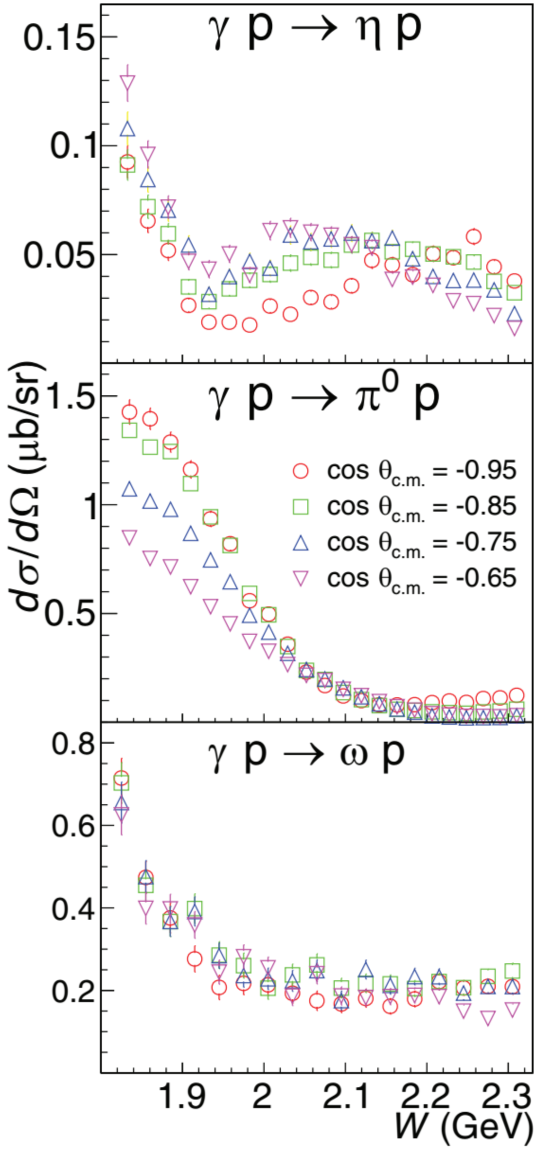
Differential cross section of $\gamma p \rightarrow \eta p$

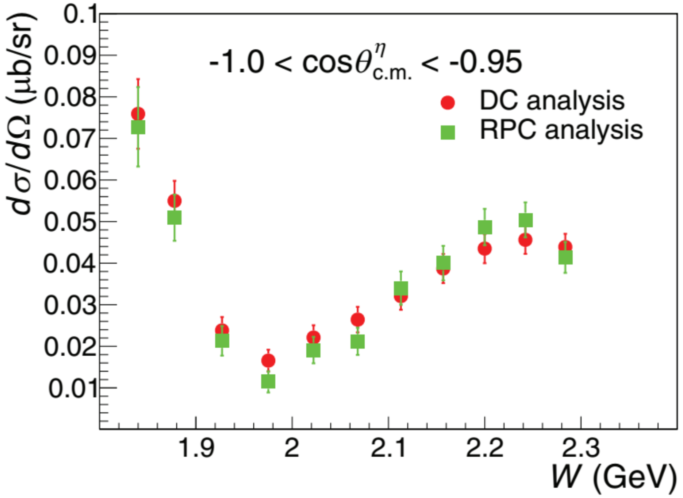
Backward angles



- Existing data at the backward angles are inconsistent => variation in PWA results.
- A clear bump structure was seen at the backward angles.
- Shift in the position of the bump structure over the decay angles indicate possibility of multi-resonance contributions at $E_{\gamma} > 2GeV$.
- This bump structure was not seen in the other angles besides backward angles => high-spin resonances which decay strongly to the backward/forward angles.

Differential cross section of $\gamma p \rightarrow \eta p$



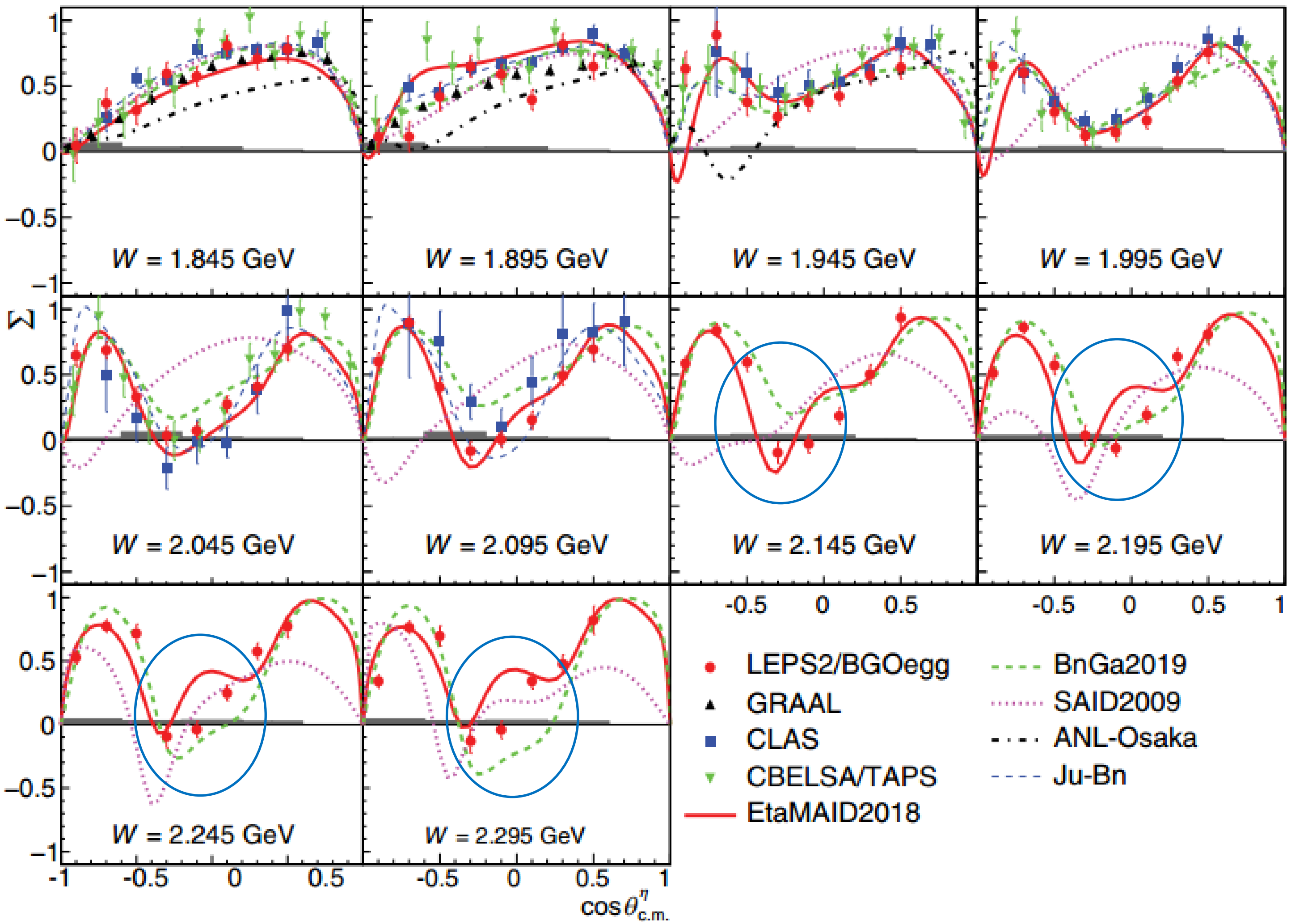


- ✓ The bump structure was double checked at the most backward angle with a full four-momentum conservation measurement.

- ➢ likely associated with the nucleon resonances that have a large $s\bar{s}$ component and strongly couple to the ηN channel.
- ➢ Candidates such as $N(2120)\frac{3}{2}^{-}, N(2190)\frac{7}{2}^{-}, N(2220)\frac{9}{2}^{+}, N(2250)\frac{9}{2}^{-}$

Which the current information in the ηN decay channel are limited

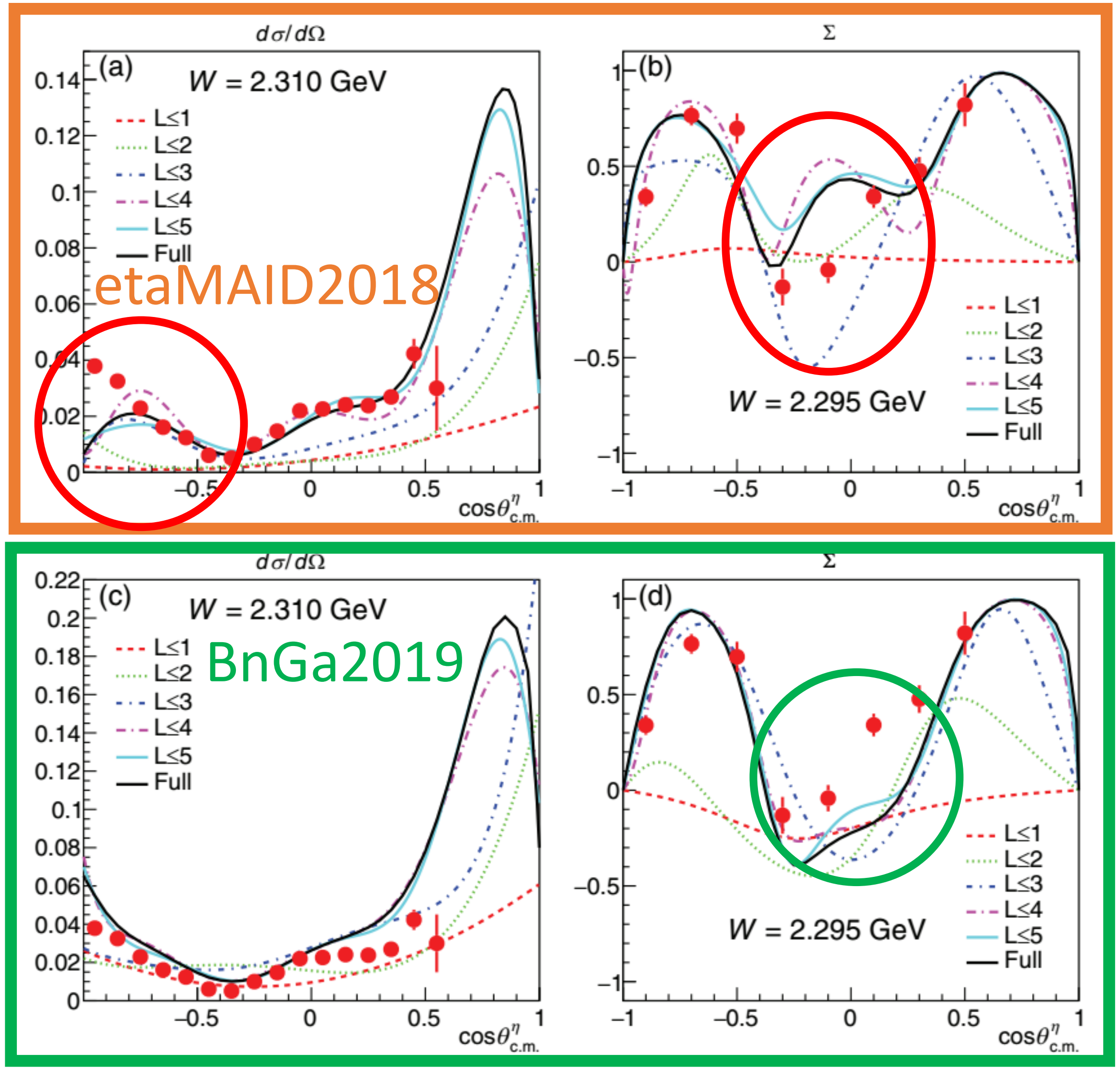
Photon beam asymmetry of $\gamma p \rightarrow \eta p$



- Data above 2 GeV is new => large discrepancy between PWA calculations.
- etaMAID2018 and BnGa2019 can reproduce the new data to some extend except the middle range.

PHYSICAL REVIEW C **106**, 035201 (2022)

Differential cross section and Photon beam asymmetry of $\gamma p \rightarrow \eta p$



➢The multipole amplitudes of existing PWA solutions are inconsistent even at lower orbital momentum L.

=> A re-fit to the new data can improve the current understanding of resonance and Born-term contributions

Summary for the N* program at BGOegg experiment

- N* physics with single π^0, ω and η photoproduction off the proton.
- A wide angular measurement $(-1 < \cos\theta^{CM} < 0.5)$ of differential cross sections and photon beam asymmetries were presented for photon beam energy $1.3\ GeV < E_\gamma < 2.4\ GeV$.
- A bump structure was found in η DCS distribution which is unique
  - The main contribution should come from high-spin resonances instead of u-channel.
  - No similar structure was found in π^0 and ω => the resonances should contain $s\bar{s}$ which strongly couple to ηN channel.
  - Possible candidates such as $N(2120)\frac{3}{2}^-, N(2190)\frac{7}{2}^-, N(2220)\frac{9}{2}^+, N(2250)\frac{9}{2}^-$ were poorly established in ηN decay channel => our data may help to improve the status of them.
- Photon beam asymmetry at higher energies are new and reveal inconsistences between PWA calculations, in addition, non of the existing PWAs can reproduce new data above $\mathrm{E}_\gamma > 2.1\ GeV$.=> a re-fit that including our data is welcome.

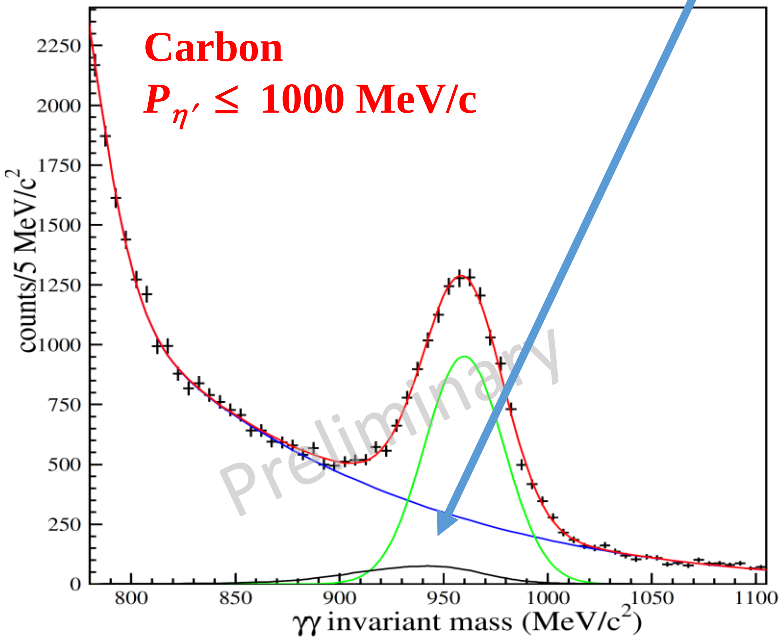
Other studies at BGOegg experiment

- We performed **two analysis procedures** using Carbon-target data:

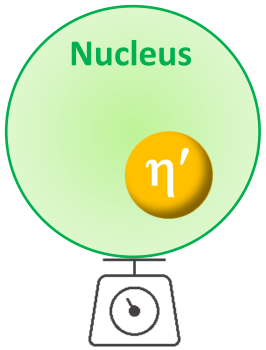
➢ **Search for η′ bound nuclei**
  - **N. Tomida et al., PRL 124 (2020) 202501.**
    - **Upper limit : 2.2 nb/sr for $\cos\theta^{\eta p_s}_{lab} < -0.9$**

➢ **Direct measurement of in-medium η′ mass spectrum**
  - **Y. Matsumura, Doctoral Thesis (Tohoku Univ., 2021).**

This small enhancement is **not enough** for a conclusion => we are in the middle of analyzing more data and update this figure

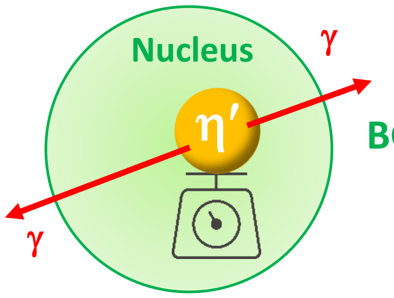


Indirect measurement ($m_{\eta'} + M_A$)
Need to know bound levels.



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

Direct measurement by M(γγ)
Need high-resolution calorimeter.



BGOegg phase-1 (SPring-8)

Upgrade plan for BGOegg experiment

(1) **Upgrade the detector setup.**

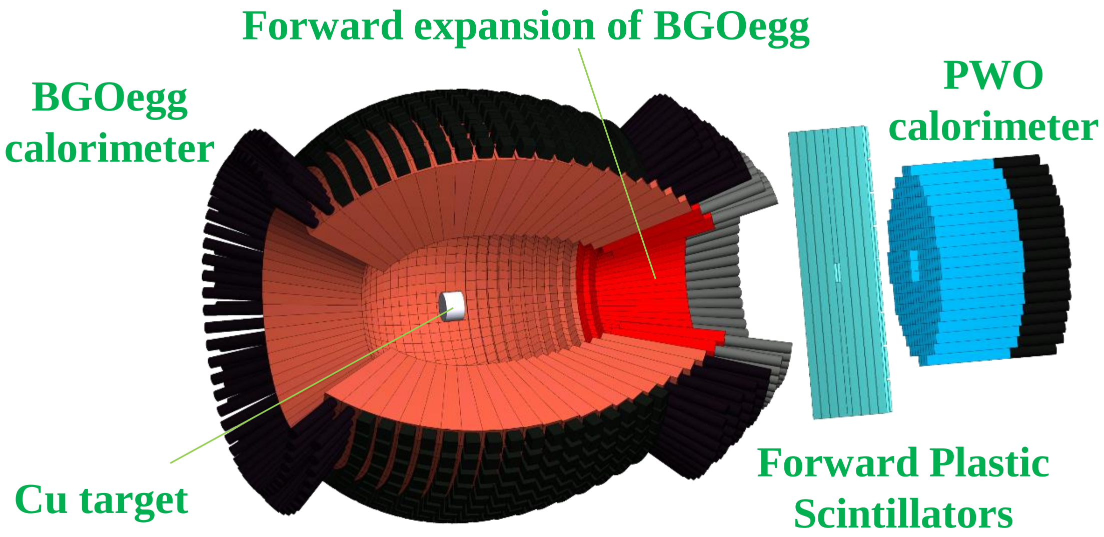
$\Rightarrow$ Multi-meson BG ($\gamma p \to \pi^0 \pi^0 p$) **×1/40**

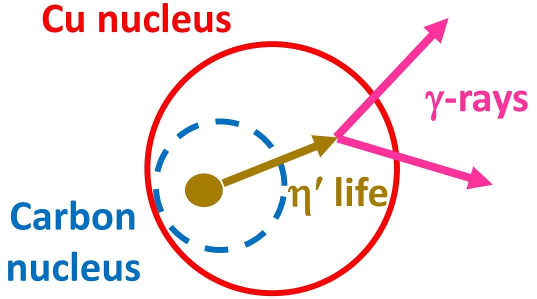
(2) Change a target **from C [20 mm] to Cu [7 mm]**.

$\Rightarrow$ $R_{nucleus}$ **×1.8**, # of nucleons **×1.8**, $\sigma(M_{\gamma\gamma})$ **×0.6**

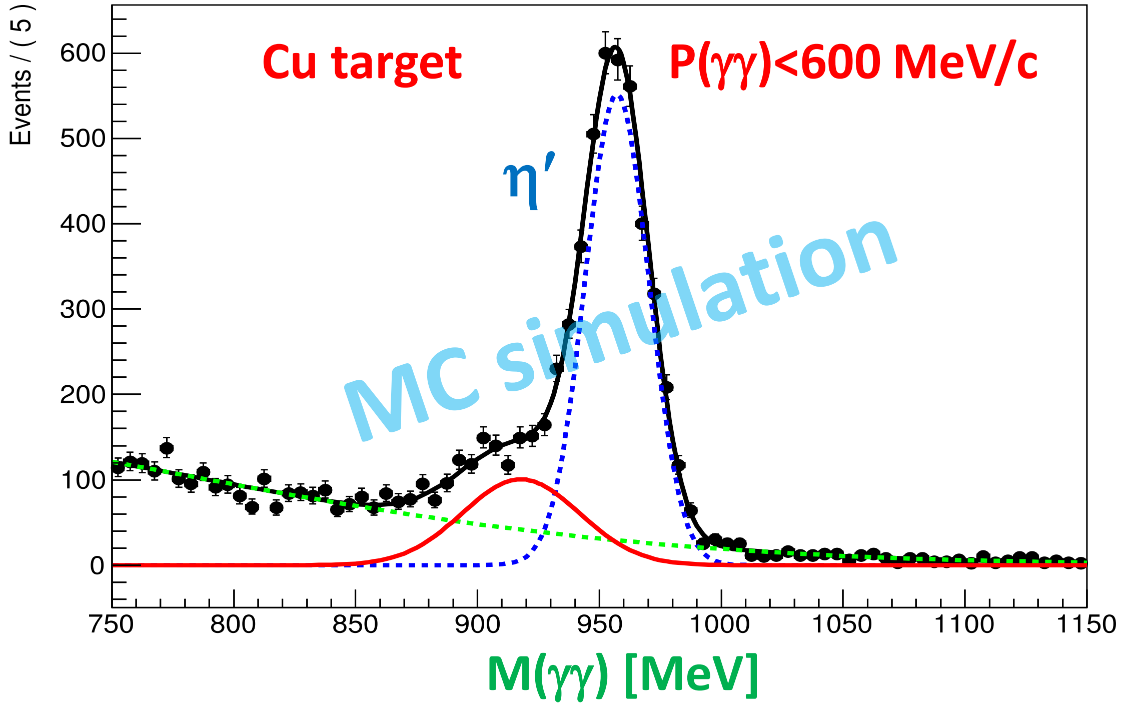
(3) Increase **a photon beam intensity**.

24W pulse laser + existing 3 lasers $\Rightarrow$ **~5M cps**





Upgrade plan for BGOegg experiment



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