Multi-meson photoproduction on the proton in BGOegg Phase-II experiment

2024/11/20
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LEPS2/BGOegg Collaboration

- Physics motivation
- LEPS2/BGOegg experiment(Phase-I / Phase-II)
- Phase-II experimental status and plan
- Multi-meson photoproduction on the proton

Physics motivation

Meson photoproduction experiment

- **Spectroscopy of light baryon resonance**
  - single meson photoproduction
  $\gamma p \rightarrow \pi^0 p$ / ηp / ωp / $\eta' p$
  - double meson photoproduction
  $\gamma p \rightarrow \pi^0 \pi^0 p$ / $\pi^0 \eta p$ / $\pi^0 \omega p$ / $\pi^0 \eta' p$ / $\eta \eta p$

- **Search for evidence of exotic hadron structures**
  - photoproduction of scaler mesons
  $\gamma p \rightarrow f_0(980) p$ /$a_0(980) p$

- **Study of hadron properties in nuclear medium**
  - Search for η' mesic nuclei
  - Direct measurement of in-medium η' mass spectrum

Physics motivation

Achievements in Phase-I experiment

- **Spectroscopy of light baryon resonance**
  - single meson photoproduction
  $\gamma p \rightarrow \pi^0 p$ / ηp / ωp / $\eta' p$
  - double meson photoproduction
  $\gamma p \rightarrow \pi^0\pi^0 p$ / $\pi^0\eta p$ / $\pi^0\omega p$ / $\pi^0\eta' p$ / $\eta\eta p$

  PRC 100, 055202(2019)
  PRC 102, 025201(2020)
  PRC 106, 035201(2022)

- **Search for evidence of exotic hadron structures**
  - photoproduction of scaler mesons
  $\gamma p \rightarrow f_0(980)p$ /$a_0(980)p$

  PRC 107, L042201(2023)

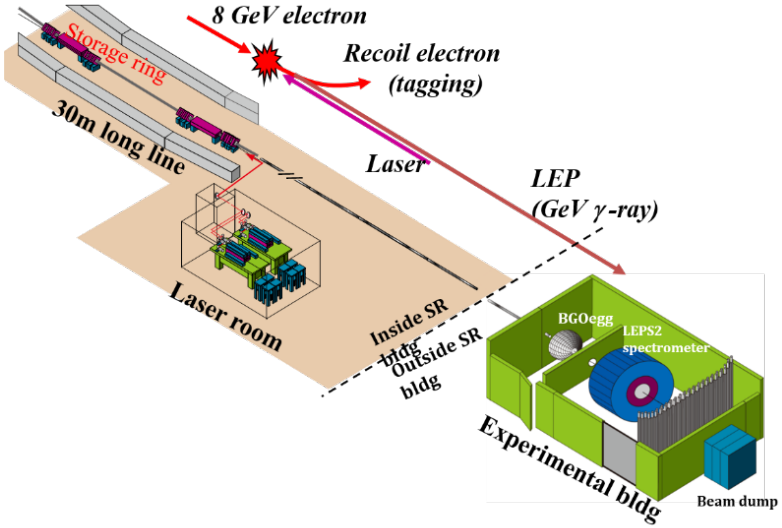
- **Study of hadron properties in nuclear medium**
  - Search for η' mesic nuclei
  - Direct measurement of in-medium η' mass spectrum

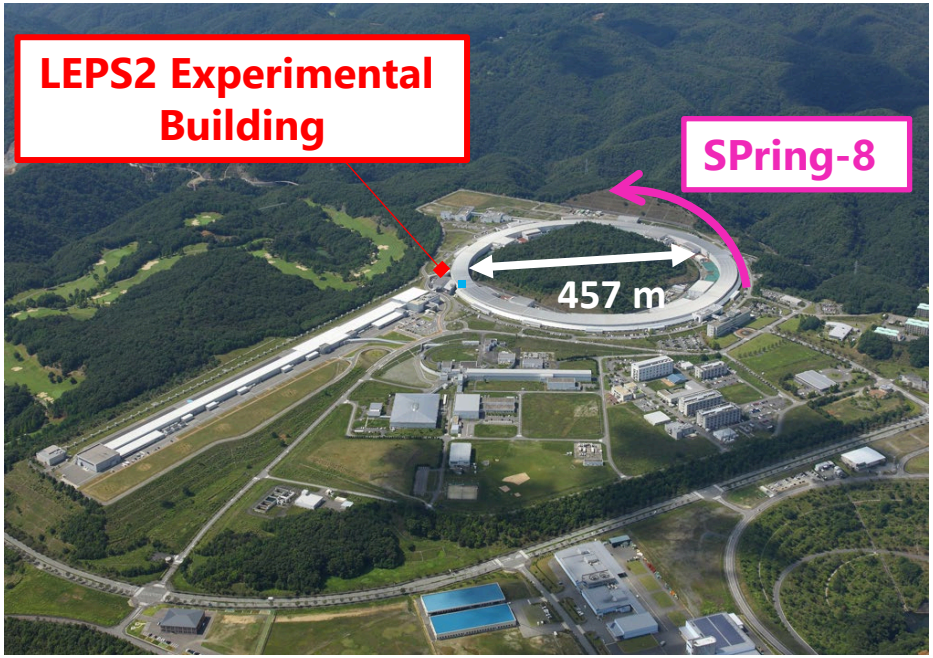
  PRL 124, 202501(2020)

A hint of η' mass shift in carbon nuclei -> Upgrade experiment(Phase-II)
In detail, Matsumura-san's talk at tomorrow's plenary session.

SPring-8/LEPS2 beamline

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





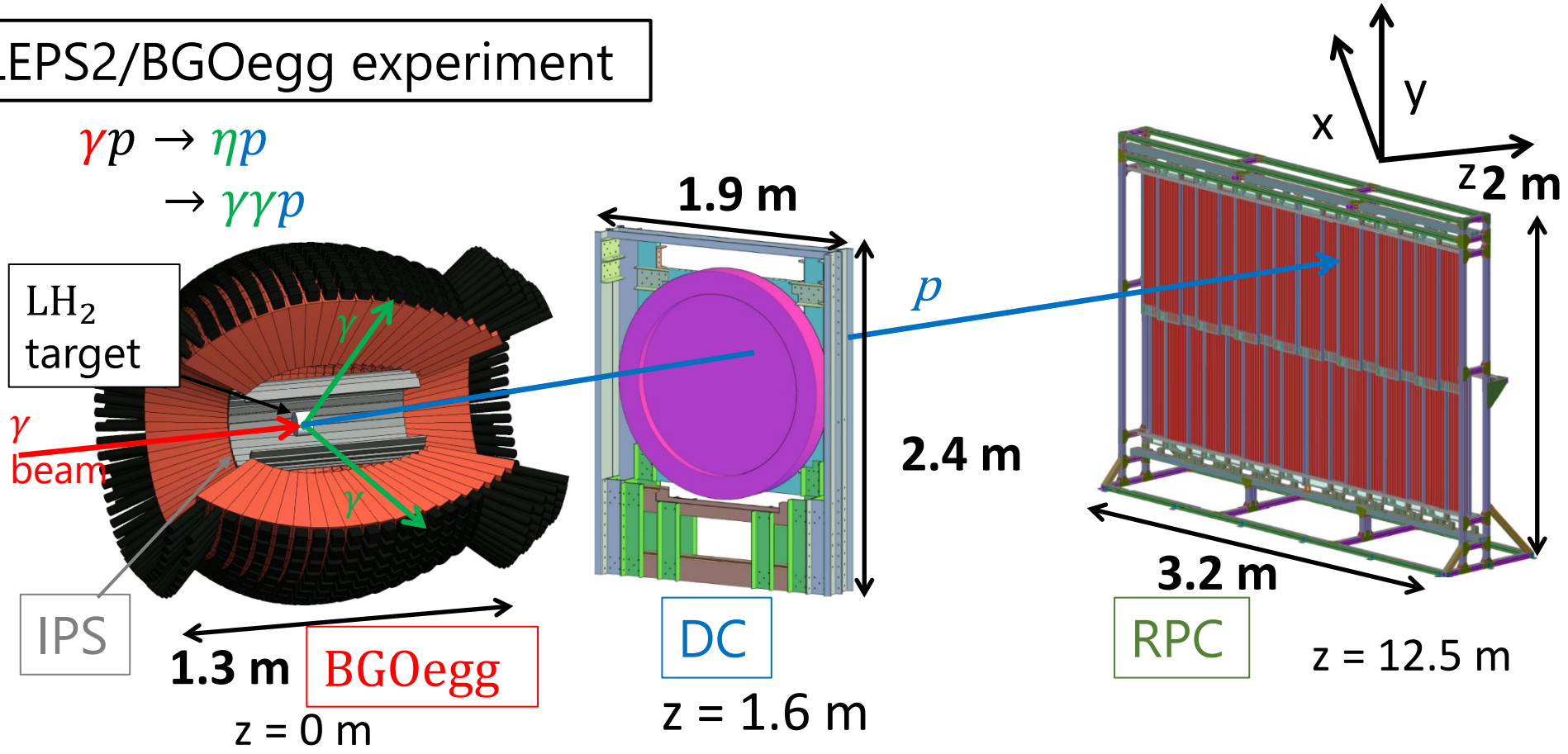
Backward compton scattering with 355nm UV laser and 8 GeV electron

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

LEPS2/BGOegg experiment



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 °**

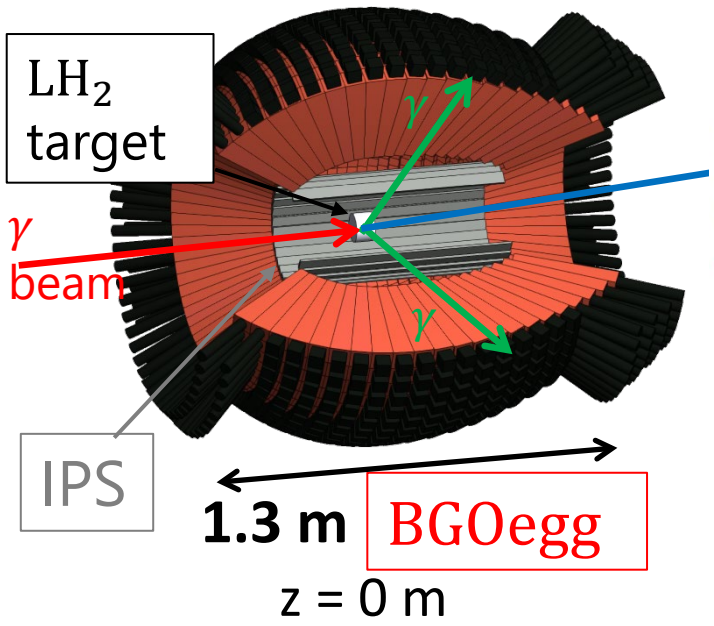
RPC: Gas chamber for TOF measurement

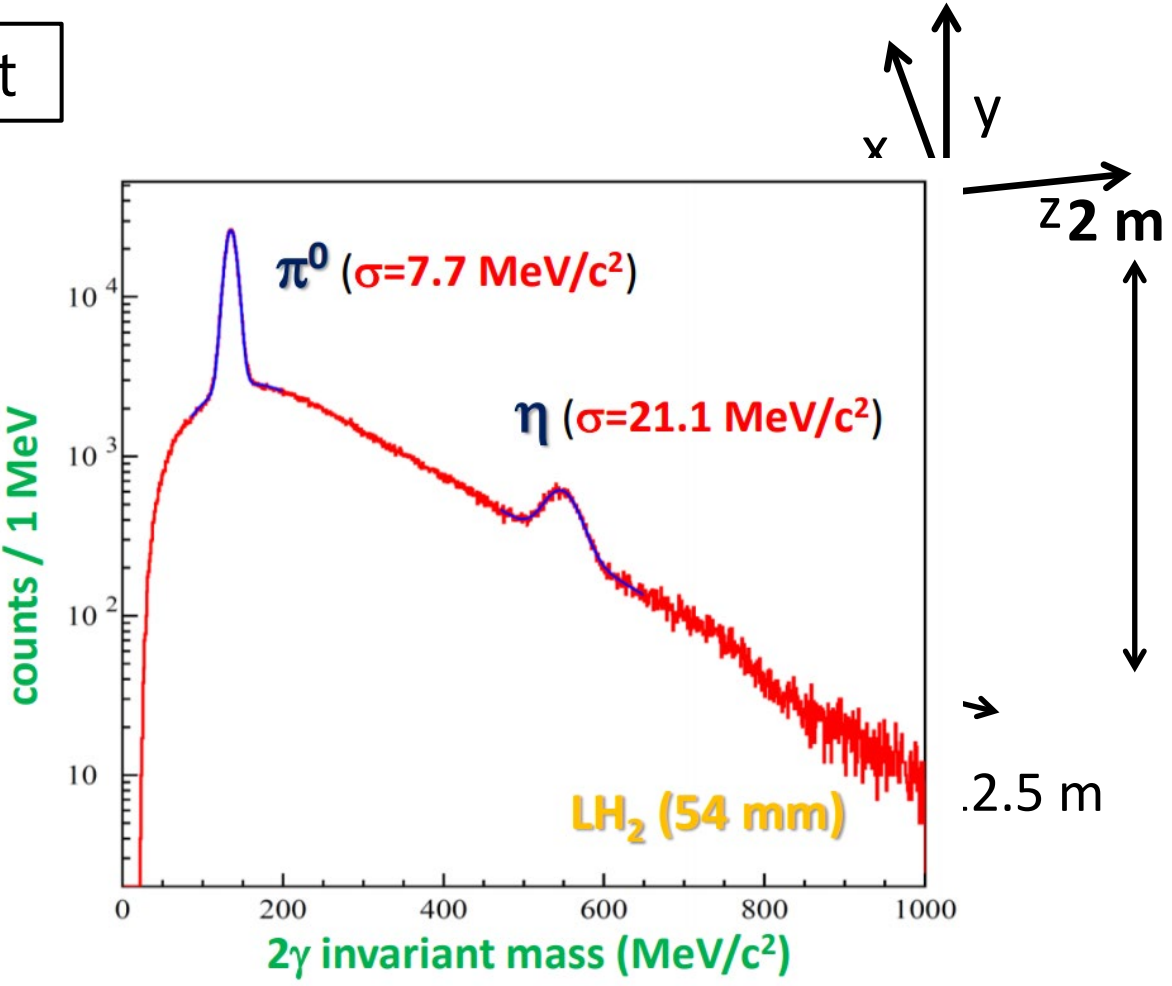
σ_{TOF} = 80 ps ⇒σ_p = 1 % @ 2 GeV proton, covering θ<6.8 °

LEPS2/BGOegg experiment

$\gamma p \rightarrow \eta p$

$\rightarrow \gamma\gamma p$





BGOegg: EM calorimeter c

σ_E = 1.3% @ 1 GeV, c

IPS: Plastic scintillator b

DC: Charged particle tr

RPC: Gas chamber for T

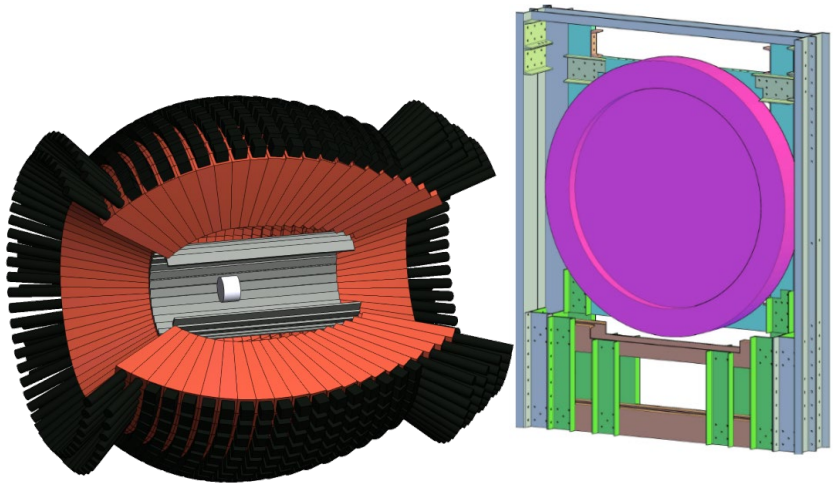
σ_{TOF} = 80 ps $\Rightarrow \sigma_p$ = 1 % @ 2 GeV proton, covering θ<0.8

Experiment	$\sigma_\pi(\mathrm{MeV}/c^2)$
BGOegg	7.7
Crystall Barrel [NIM A, **321**, 69 (1992)]	9.9
BGO-OD [EPJA, **56**, 104 (2020)]	12

Upgrade to Phase-II

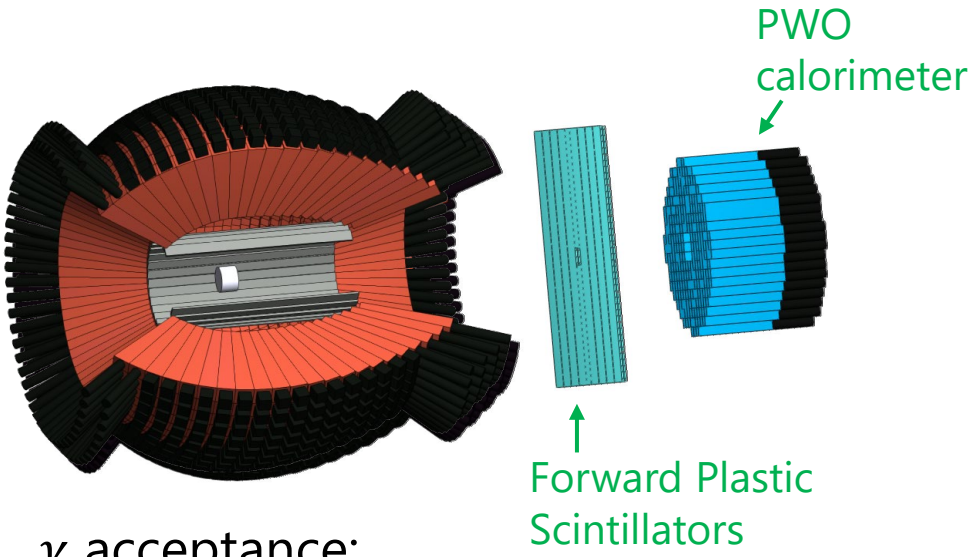
We changed the forward detectors to a new electromagnetic calorimeter.

Phase-I



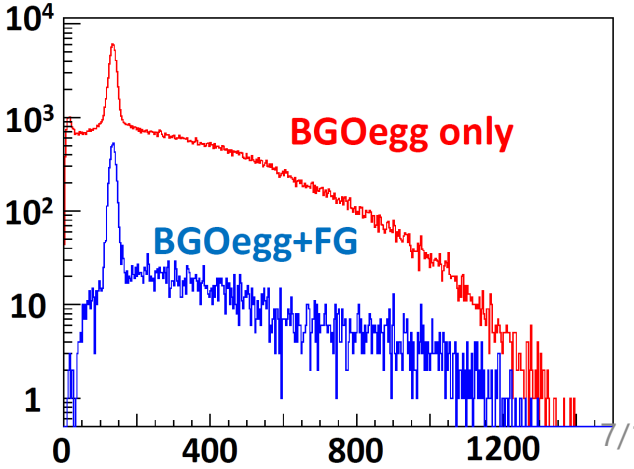
γ acceptance:
$24° < \theta < 144°$

Phase-II



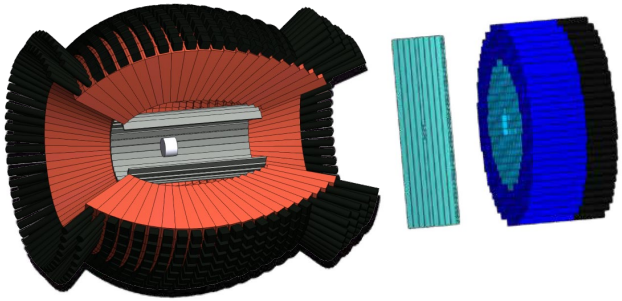
γ acceptance:
$6° < \theta < 16°, 24° < \theta < 144°$

Forward γ can be detected.
-> It is easier to identify multi-meson photoproduction reactions.
ex) Muliti-meson BG($\gamma p \to \pi^0\pi^0 p$) ~ 1/8 in η' analysis.
Target: Cu, Increase beam intensity (5Mcps).
28σ significance in a few months.



Phase-II status and future plane

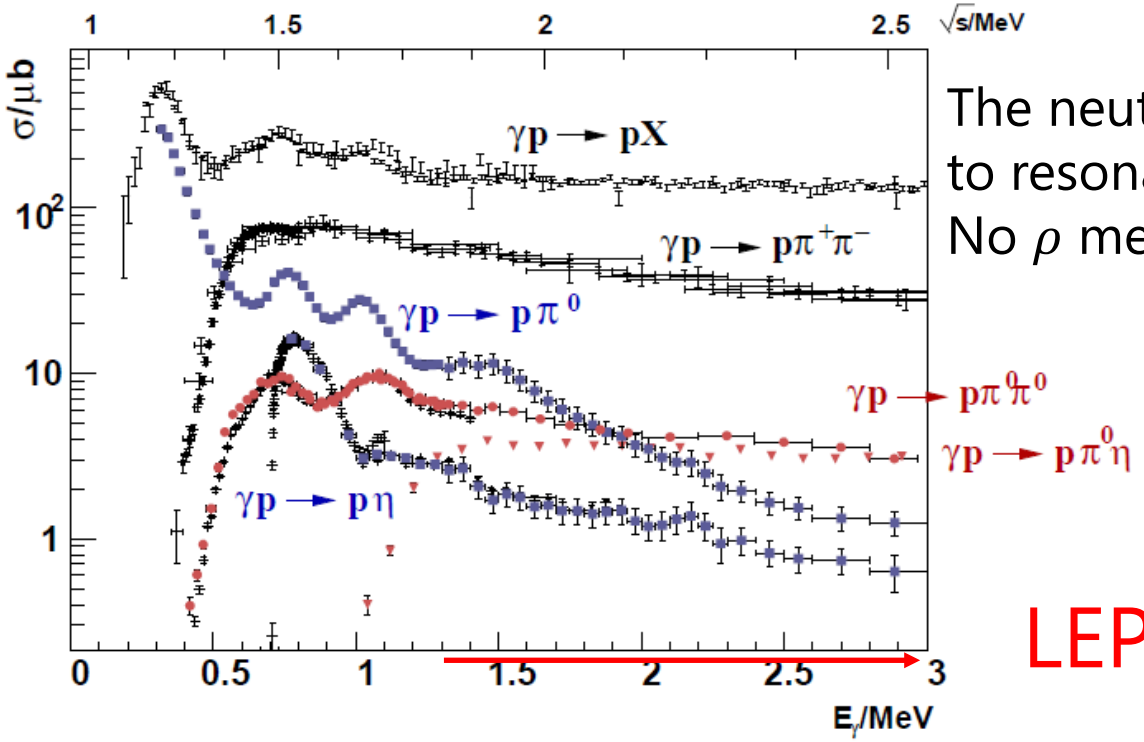
- Detector upgrade in progress from FY2021.
- DAQ preparation and pilot run were done in FY2023.
- We took physics data on copper target(7.5 mm) from May to July 2024.
  Obtained 5 G events, equivalent to about 80% of the phase-I carbon target data.
  Calibration in progress.
- Future plan
  Copper target: additional data acquisition
  Liquid hydrogen target: The target system is not yet ready...
- Second stage plan
  Improve forward acceptance. $6° < \theta < 144°$
  Additional 150 PWO crystals
  Already bought
  The beam test was done on Nov.



Multi-meson photoproduction on the proton

- 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)



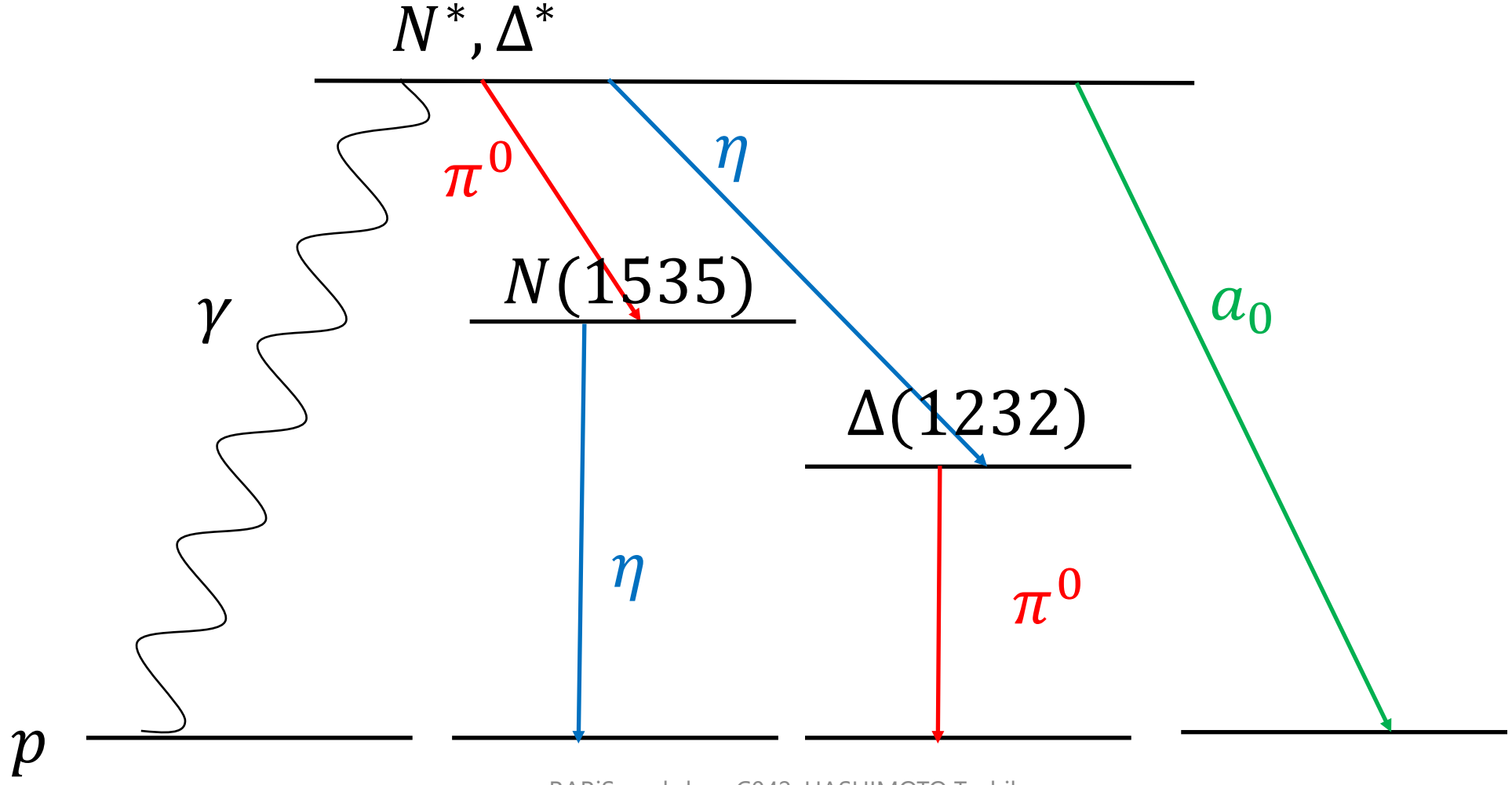
The neutral channel must be very sensitive to resonance contributions.
No ρ meson contribution

$\gamma p \rightarrow \pi^0\pi^0 p$
$\pi^0\eta p$
$\pi^0\omega p$
$\pi^0\eta' p$
$\eta\eta p$

LEPS2 coverage

Sequential decay for $\gamma p \to \pi^0 \eta p$ reaction

- Access to baryon resonances at higher energies.
- Access to the internal structure of baryon resonances.
  partial wave analysis, decay branching ratio, di-quark information??

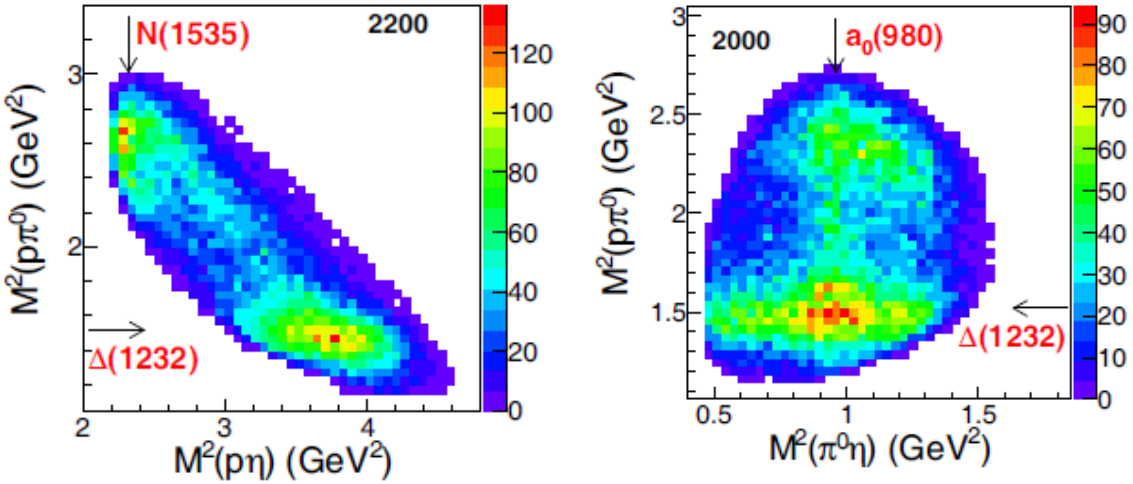


$\gamma p \to \pi^0 \eta p$ @CBELSA/TAPS

Eur. Phys. J. A (2014) **50** 74

Linearly polarized photon beam
$0.6 < E_\gamma < 2.5$ (GeV)

$N(1535)\, 1/2^-\, \pi^0 \to \pi^0 \eta p$
$\Delta(1232)\, 3/2^+\, \eta \to \pi^0 \eta p$
$a_0(980) p \to \pi^0 \eta p$
were seen clearly.



- Photon beam asymmetries $\Sigma, I^s,$ and I^c were measured, and the partial wave analysis was done.
- They determined the branching ratio of many resonances for their decays into $\pi^0 \eta p$ via several intermediate states.
- A parity doublet ($\Delta(1920)\, 3/2^+$ and $\Delta(1940)\, 3/2^-$) , which is not expected in quark models, was observed.

$\gamma p \to \pi^0 \eta p$ @CBELSA/TAPS

Resonance	πN	$N(1535)\pi$	$\Delta(1232)\eta$
$N(1710)1/2^+$	$5 \pm 3\%$	$15 \pm 6\%$	–
$N(1880)1/2^+$	$6 \pm 3\%$	$8 \pm 4\%$	–
$N(1900)3/2^+$	$3 \pm 3\%$	$7 \pm 3\%$	–
$N(2100)1/2^+$	$3 \pm 2\%$	$22 \pm 8\%$	–
$N(2120)3/2^-$	$5 \pm 3\%$	$15 \pm 8\%$	–

For all N^*s, the decay branching ratios to $N(1535)\pi$ is larger than that to πN.

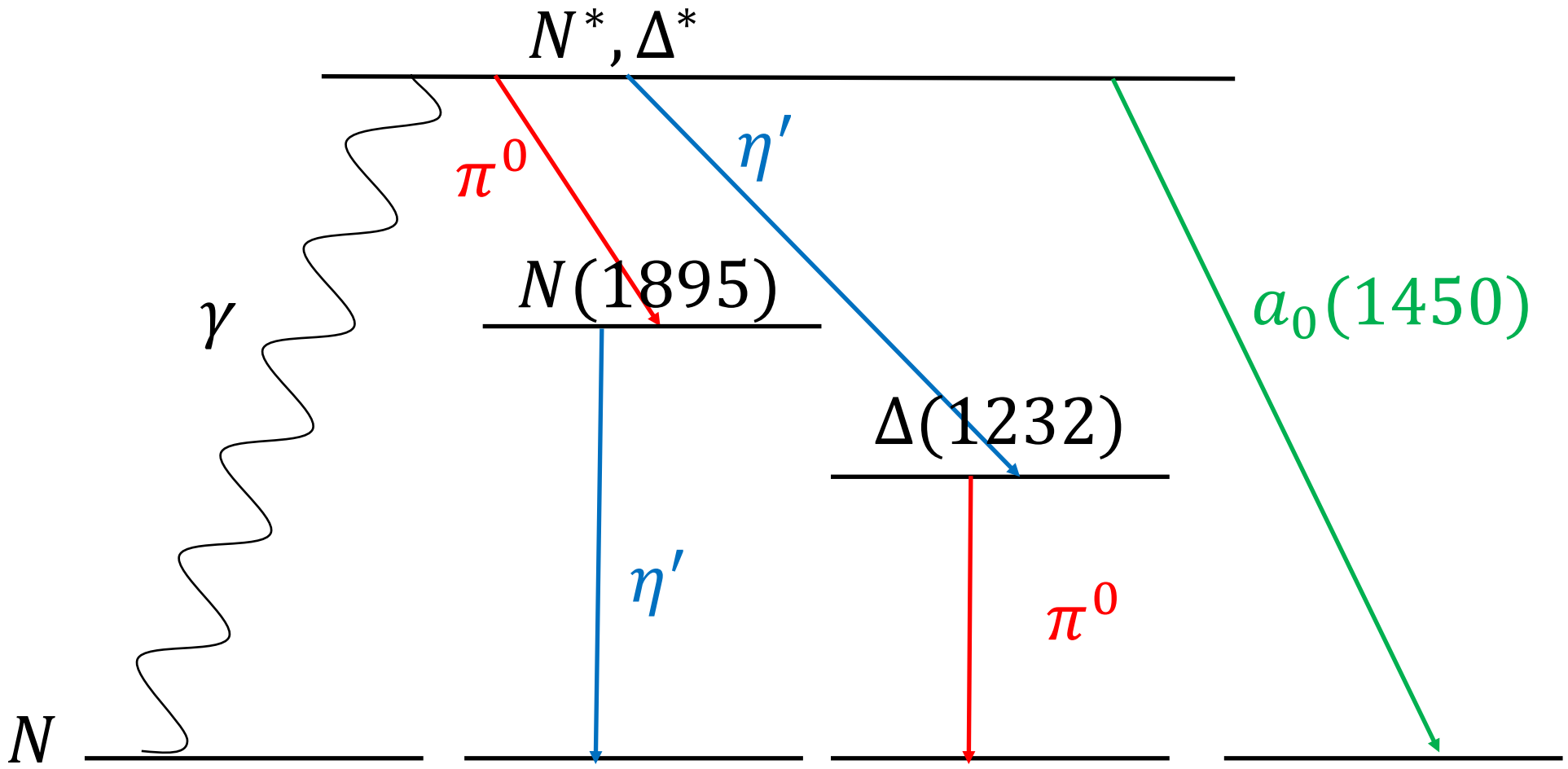
Resonance	πN	$N(1535)\pi$	$\Delta(1232)\eta$
$\Delta(1700)3/2^-$	$22 \pm 4\%$	$1 \pm 0.5\%$	$5 \pm 2\%$
$\Delta(1900)1/2^-$	$7 \pm 2\%$	–	$1 \pm 1\%$
$\Delta(1905)5/2^+$	$13 \pm 2\%$	$\leq 1\%$	$4 \pm 2\%$
$\Delta(1910)1/2^+$	$12 \pm 3\%$	$5 \pm 3\%$	$9 \pm 4\%$
$\Delta(1920)3/2^+$	$8 \pm 4\%$	$\leq 2\%$	$11 \pm 6\%$
$\Delta(1940)3/2^-$	$2 \pm 1\%$	$8 \pm 6\%$	$10 \pm 6\%$
$\Delta(1950)7/2^+$	$46 \pm 2\%$		$\leq 1\%$

For some Δ^*s, the decay branching ratios to $N(1535)\pi$ and $\Delta(1232)\eta$ is smaller/larger than that to πN.

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

$N(1895)\,1/2^-\,\pi^0$ (W_{thr}=2.03 GeV)
$\Delta(1232)\,3/2^+\,\eta'$ (W_{thr}=2.19 GeV)
$a_0(1450)p$ (W_{thr}=2.39 GeV)

No data exist.
Search for high-mass resonances, especially around W=2.3 GeV



Rough yield estimation

Rough estimation of $\sigma(\gamma p \to \pi^0 \eta' p\ )$ from $\sigma(\gamma p \to \pi^0 \eta p\ )$

$\sigma \propto \mathrm{PS} \times f^2$

$$\frac{\sigma(\gamma p \to \eta' p)}{\sigma(\gamma p \to \eta p)} \cong \frac{\mathrm{PS}(\gamma p \to \eta' p)}{\mathrm{PS}(\gamma p \to \eta p)}$$

$$\frac{\mathrm{PS}(\gamma p \to \pi^0 \eta' p)}{\mathrm{PS}(\gamma p \to \pi^0 \eta p)} \sim \frac{1}{3}$$

$$\sigma(\gamma p \to \pi^0 \eta' p\ ) \cong \frac{1}{3}\sigma(\gamma p \to \pi^0 \eta p\ ) \cong 1\ \mu\mathrm{b}$$

2×10^5 events @LEPS2

assuming 5 MHz beam, 50 days

Considering acceptance and decay branching ratio, -> 2×10^4 events@Phase-II

<1000 events@Phase-I

Summary

- BGOegg experiment has studied the following:
  spectroscopy of light baryon resonances
  exotic hadron structures
  hadron properties in nuclear medium

- Phase-II experiment improved γ-acceptance to forward, thereby reducing background in single-meson reactions and allowing measurement of multi-meson reactions.

- Phase-II experiment has started this year for in-medium η' mass study.
  We plan to take data on liquid hydrogen target in the future.

- Multi-meson photoproduction reactions increase importance in the higher energy regions.
  We are interested in $\gamma p \to \pi^0 \eta' p$ reaction.