Meson photoproduction experiments at ELPH, Tohoku University

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Contents:

university based facility
1.3 GeV bremsstrahlung photon beam

Introduction for meson photoproduction

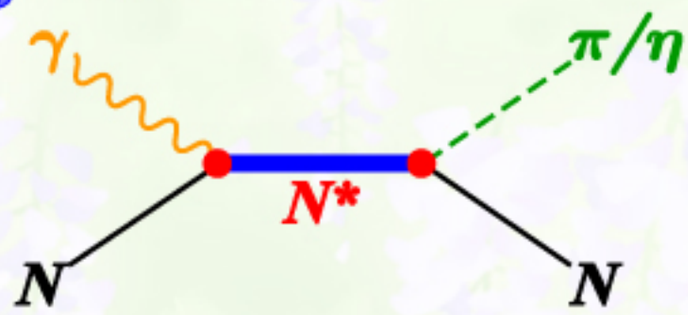
Meson photoproduction is utilized for baryon spectroscopy:
- **testing ground for understanding low energy QCD**
- **to figure out new effective degree of freedom**
  - **describing hadrons:**
    - **diquark correlation, meson-molecule, hybrid, *etc***

At the first stage:

proton channels are intensively investigated

$\gamma p \to \pi^+ n$, $\gamma p \to \pi^0 p$

$\gamma p \to \eta p$ **(isospin filter: 1/2)**



In the second stage for highly excited baryons

1) multi-meson photoproduction

$\gamma p \to \pi^+ \pi^- p$, $\gamma p \to \pi^+ \pi^0 n$, $\gamma p \to \pi^0 \pi^0 p$, $\gamma p \to \pi^0 \eta p$

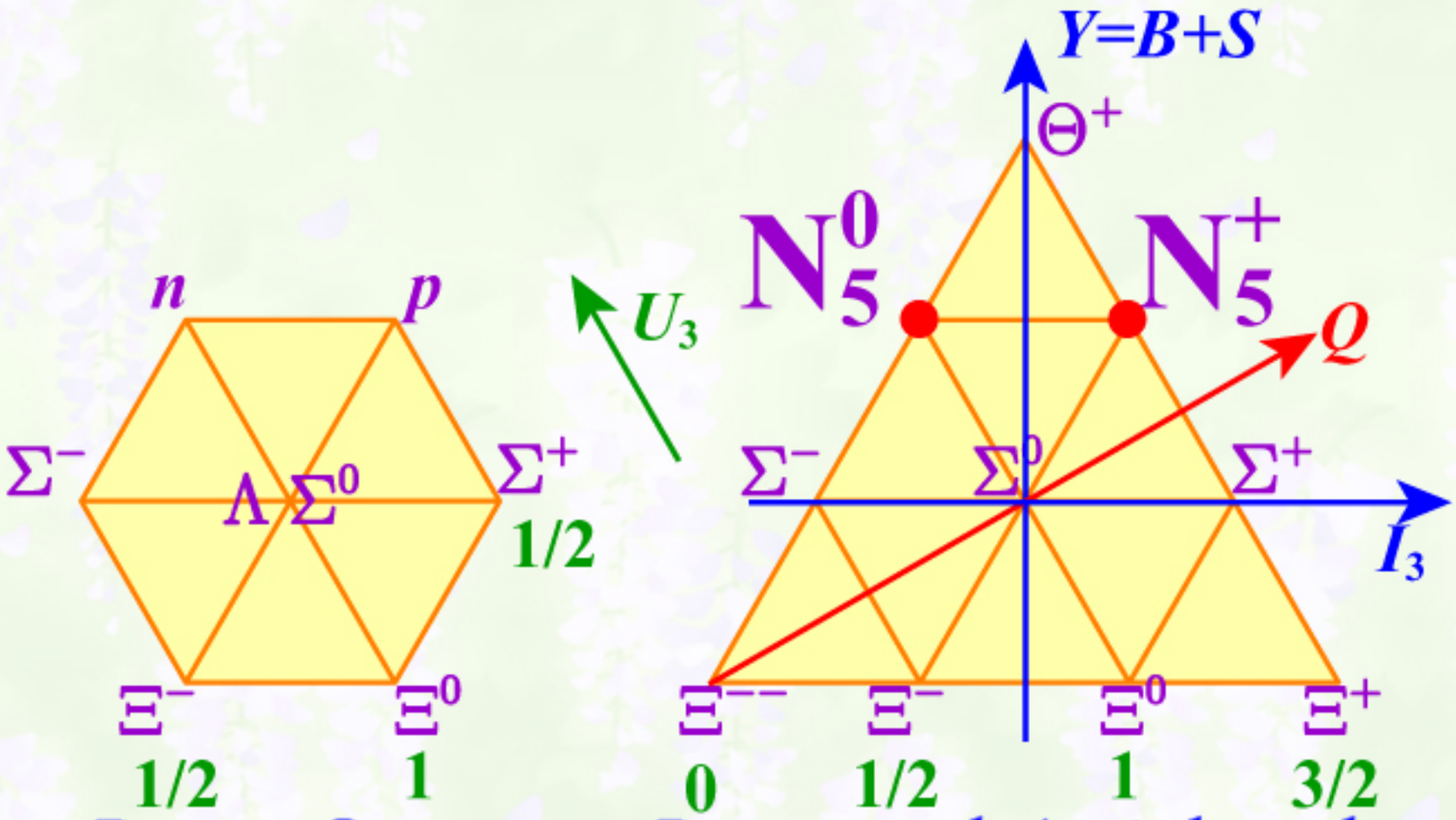
2) neutron target

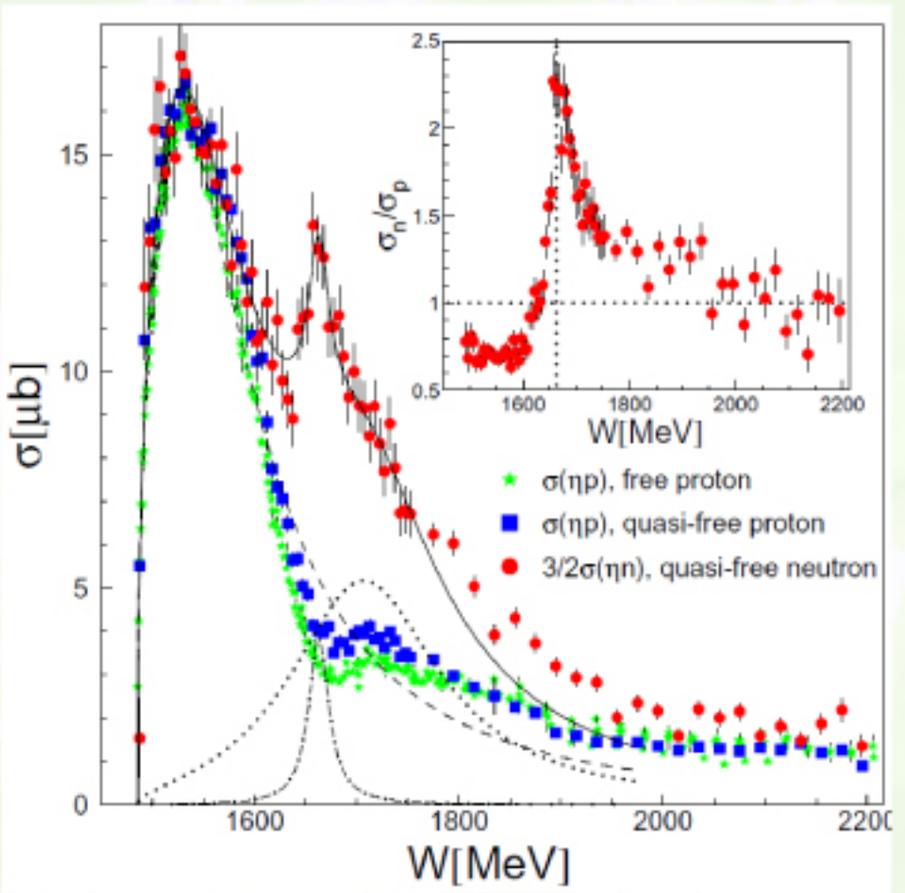
$\gamma n \to \pi^- p$, $\gamma n \to \pi^0 n$, $\gamma n \to \eta n$

Introduction for meson photoproduction

Narrow resonance $N^*(1670)$

A narrow resonance was observed via η photoproduction on the neutron at LNS (ELPH), CB-ELSA, GRAAL.





I. Jaegle, B. Krusche *et al.*, EPJA47, 89 (2011).

$\gamma n \to \pi^0 n$ and $\gamma n \to \eta n$ reactions

Experiments with FOREST ~ accelerator

Electron Beam **after the earthquake**

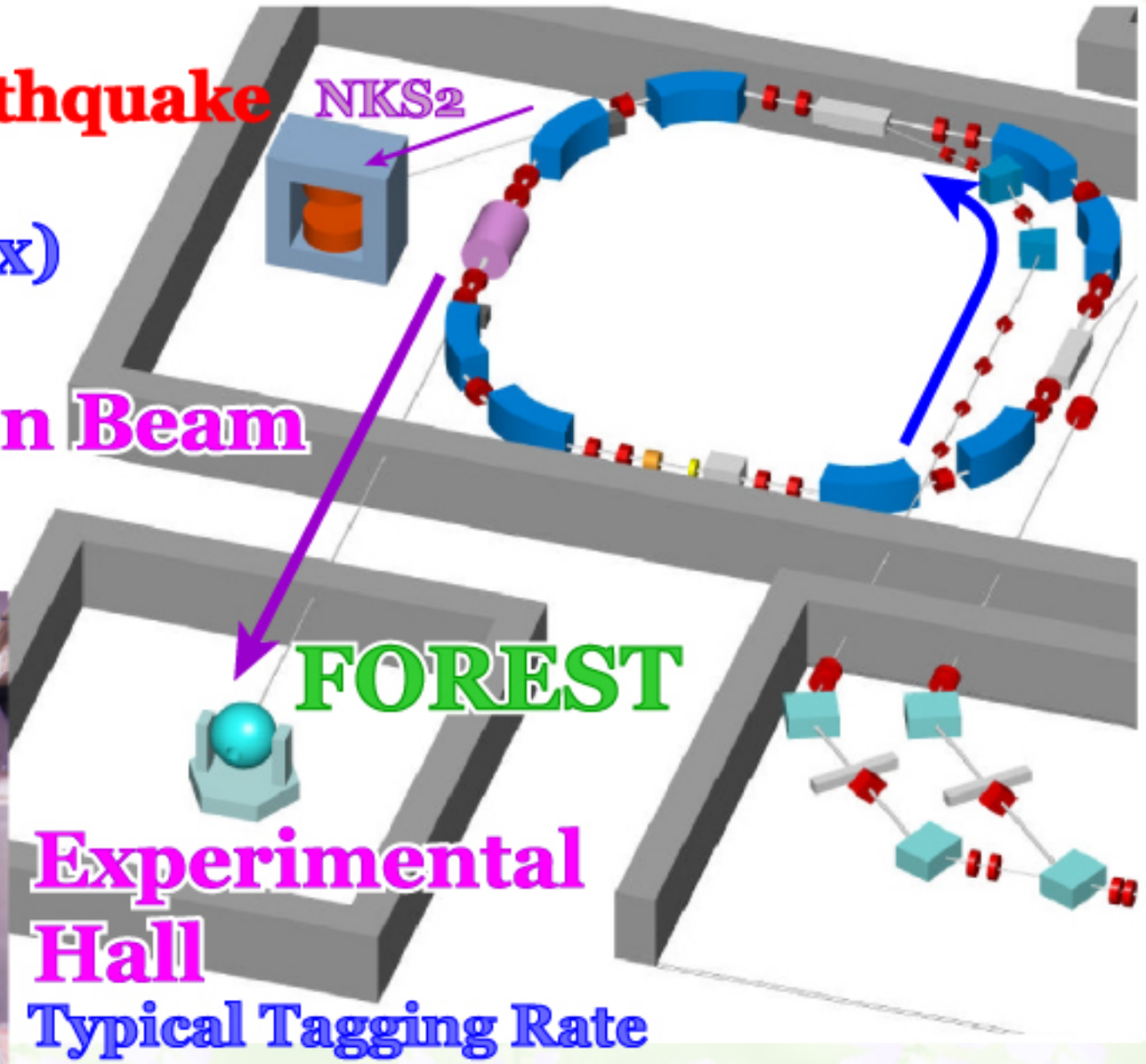
LINAC 150 MeV→93 MeV

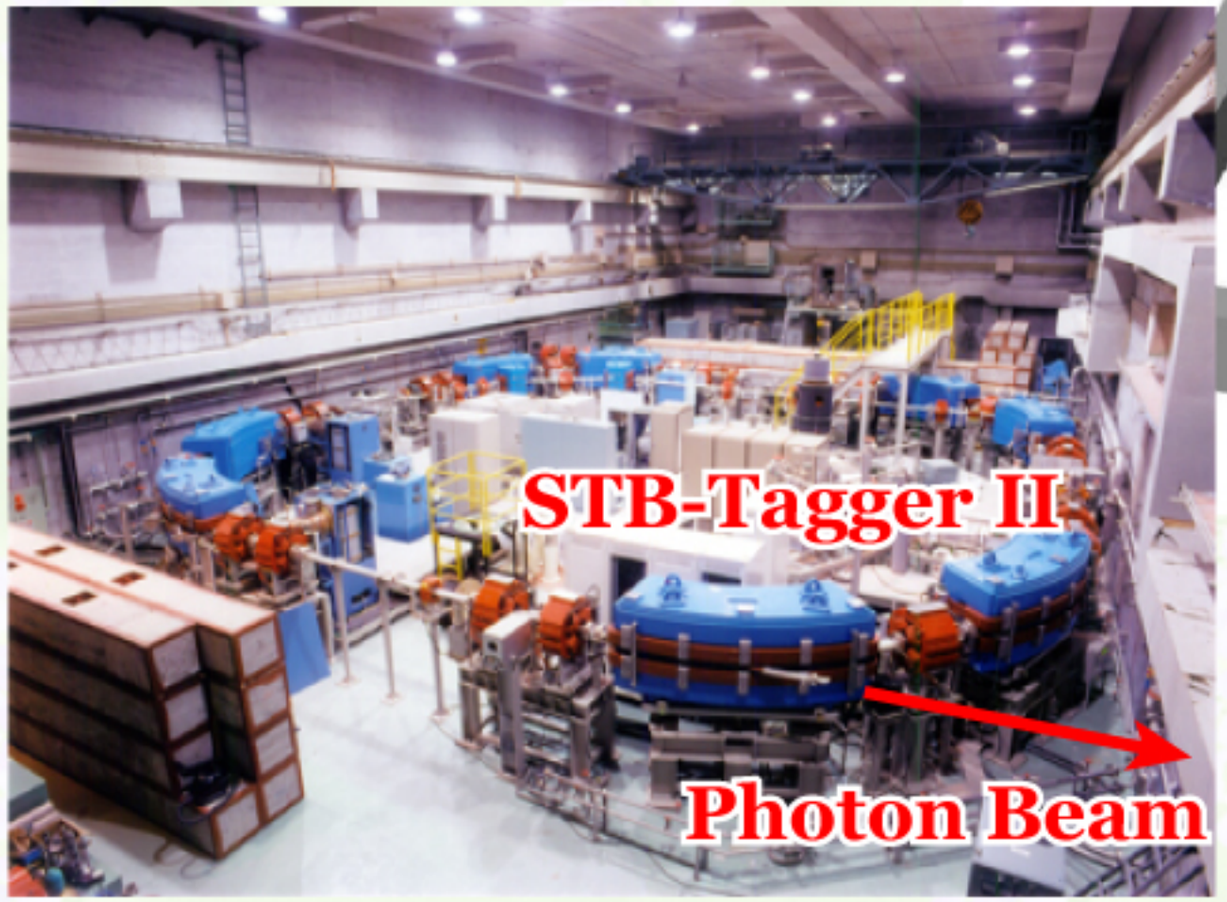
Booster Ring 1200 MeV (max)

Photon Beam →1300 MeV

Bremsstrahlung

Tagged





1.2 GeV Strecher Booster Ring

Typical Tagging Rate

20 MHz (photon: 10 MHz)

Bremsstrahlung Tagged Photon Beam

740~1150 MeV @ 1200 MeV

570~890 MeV @ 930 MeV

δE: 1~2 MeV

T. Ishikawa *et al.*, NIMA622, 1 (2010).

Experiments with FOREST ~ EM calorimeter

LEPS Backward Gamma

SCISSORS III

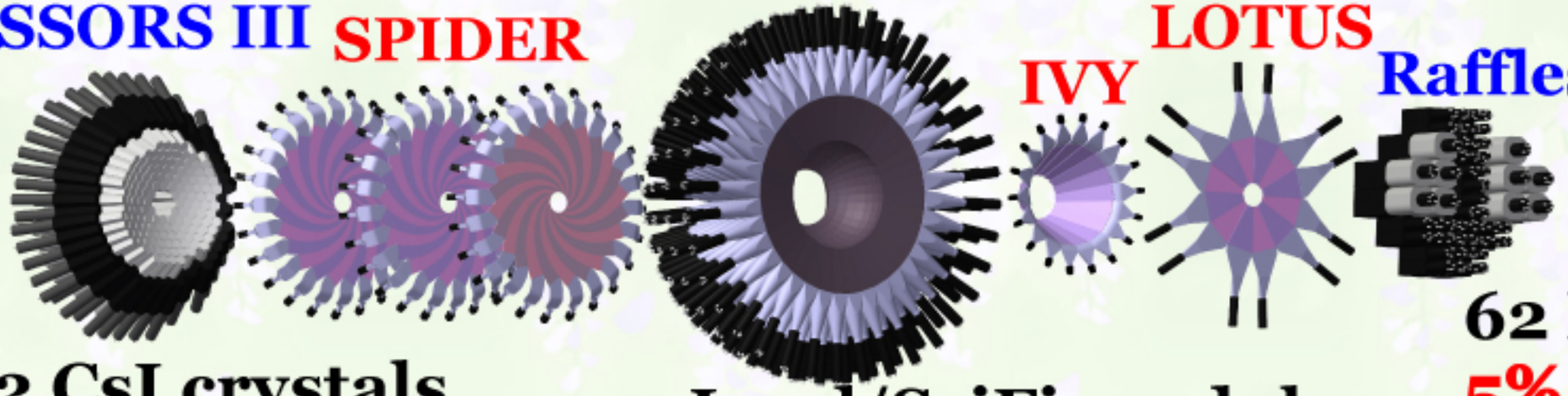
SPIDER

LOTUS

IVY

Rafflesia II

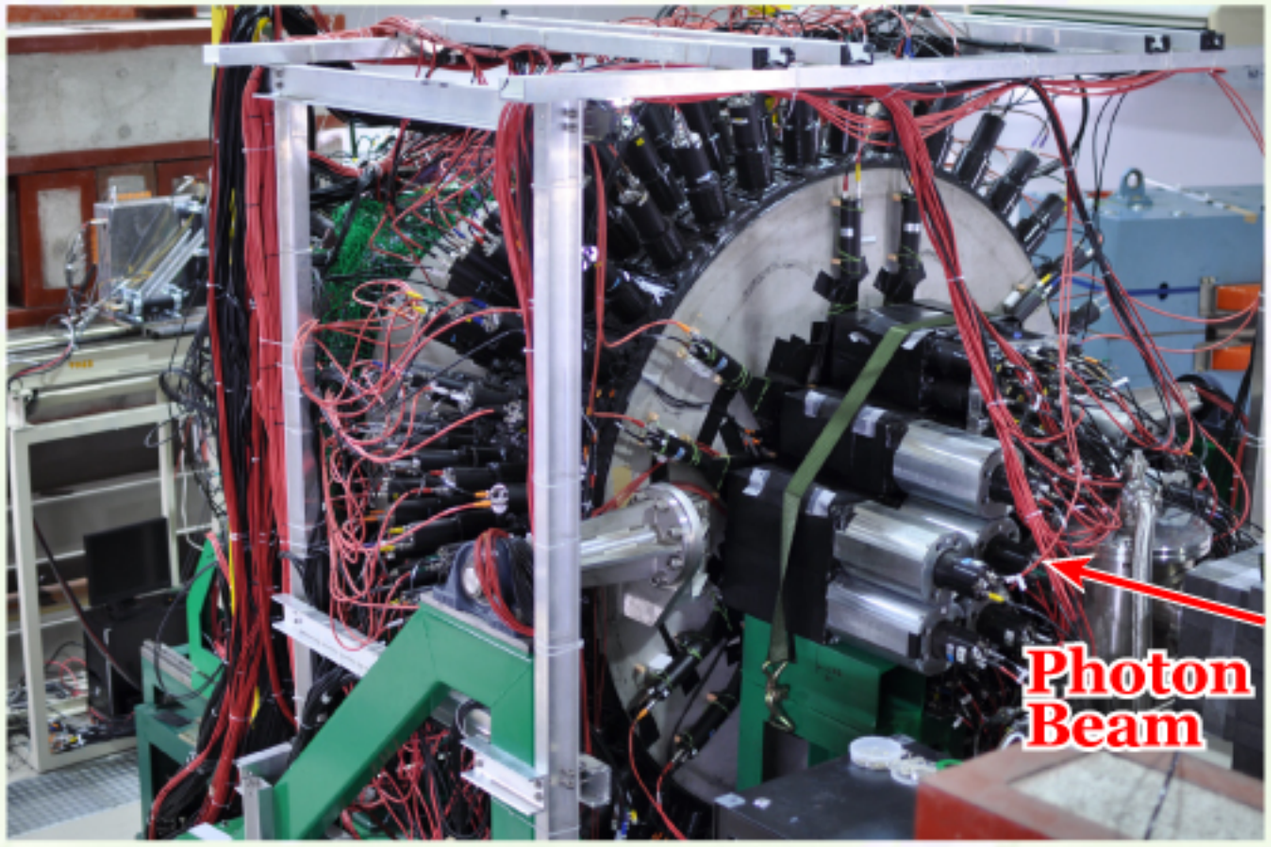
Photon Beam

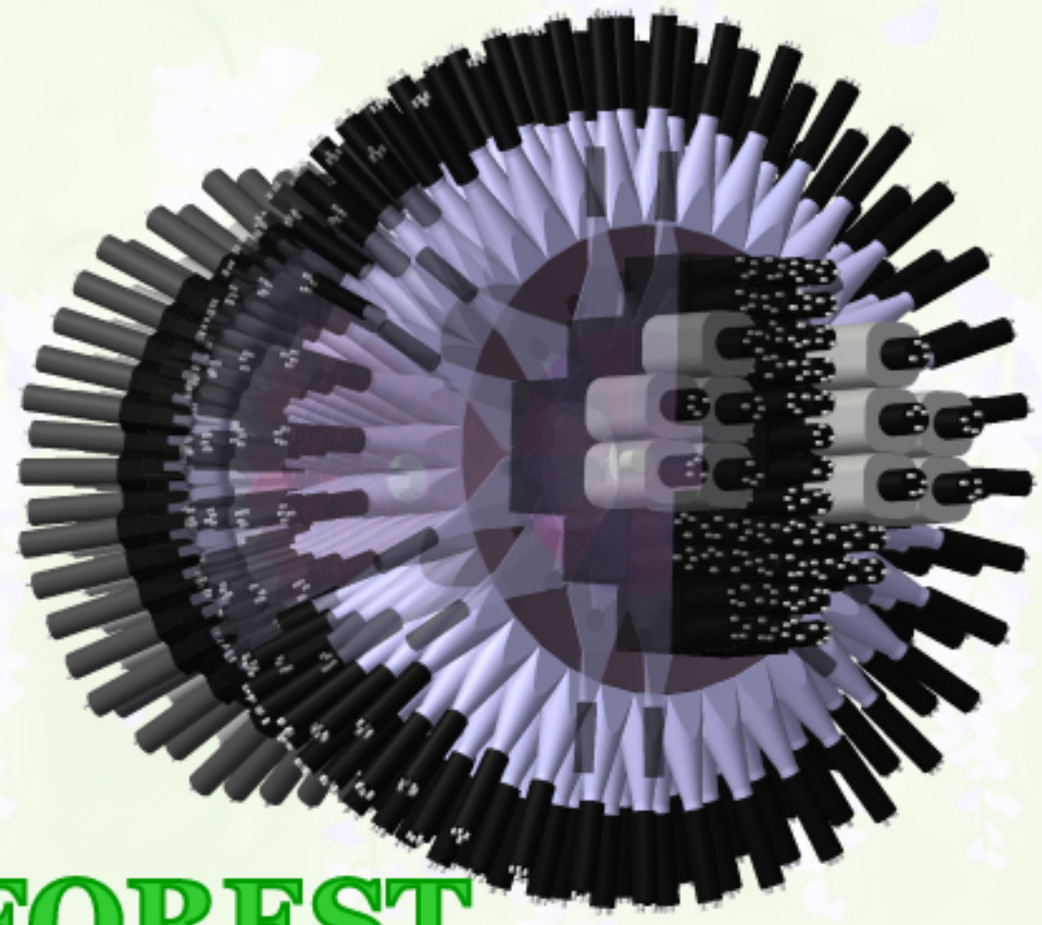


192 CsI crystals
3% @ 1 GeV

252 Lead/SciFi modules
7% @ 1 GeV

62 Lead Glasses
5% @ 1 GeV





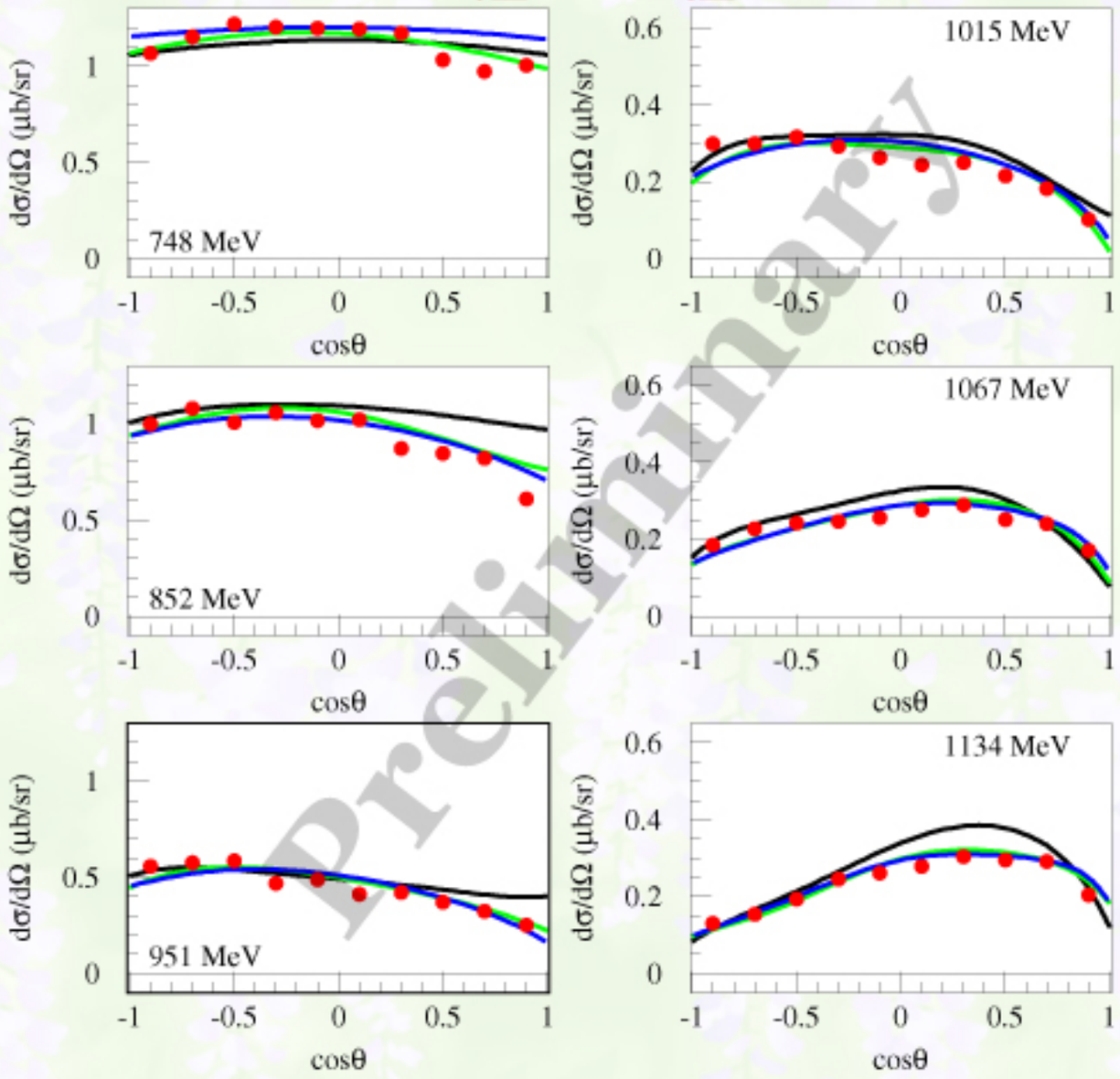
FOREST

Target: 45 mm thick LH2 & LD2

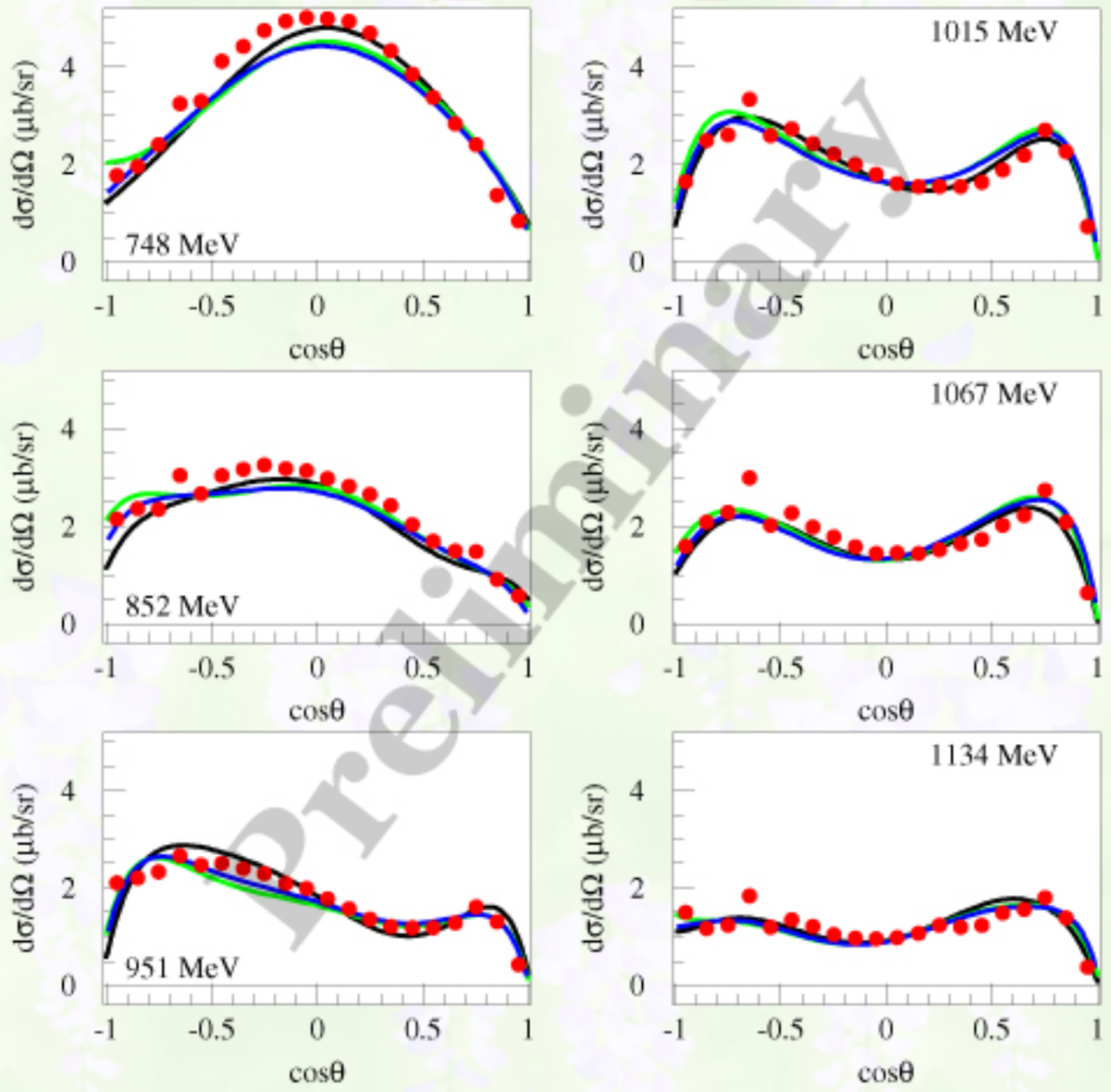
Experiments with FOREST ~ proton target

Differential cross sections as a function of the meson emitting angle

$\gamma p \rightarrow \eta p$



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

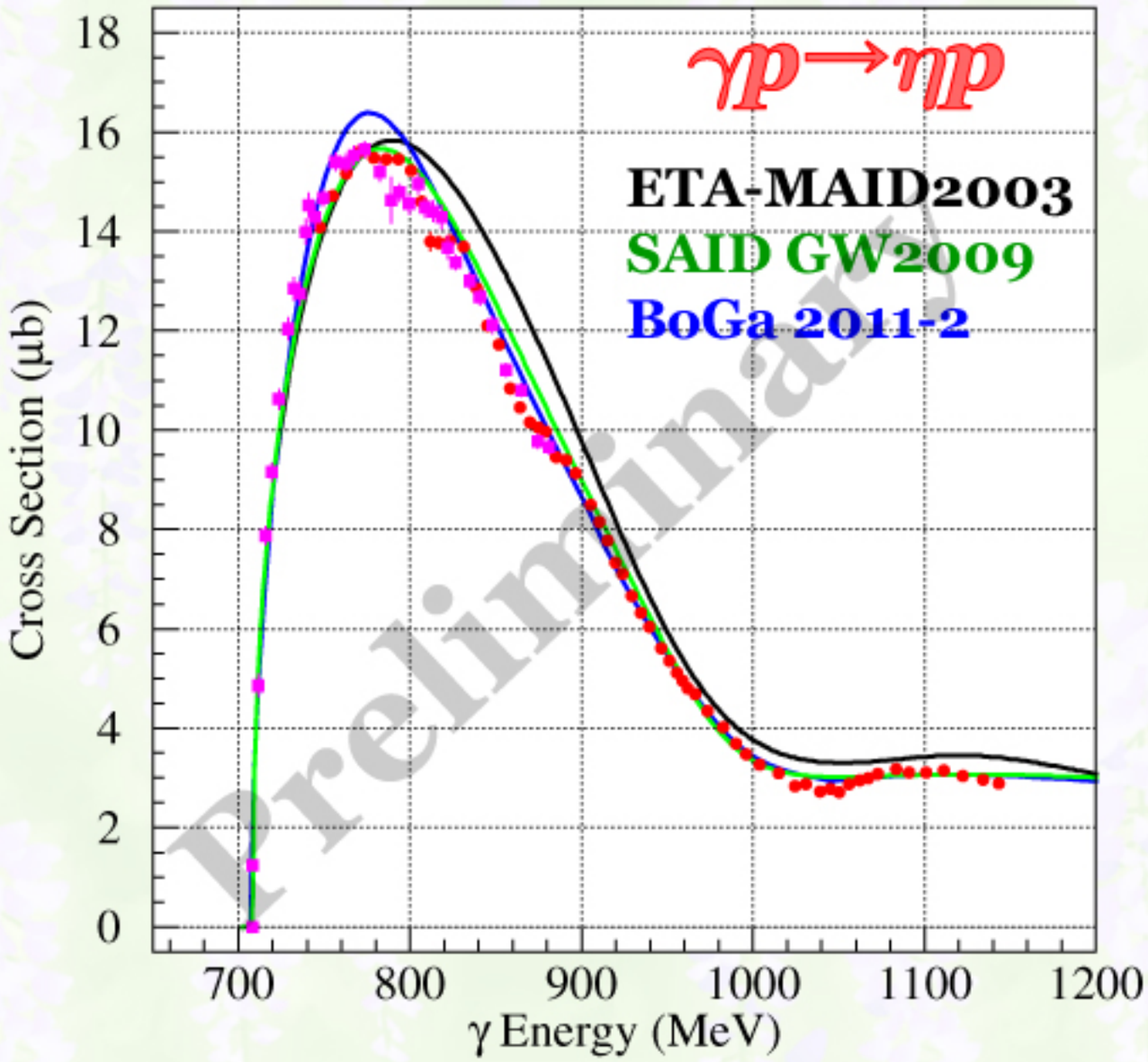


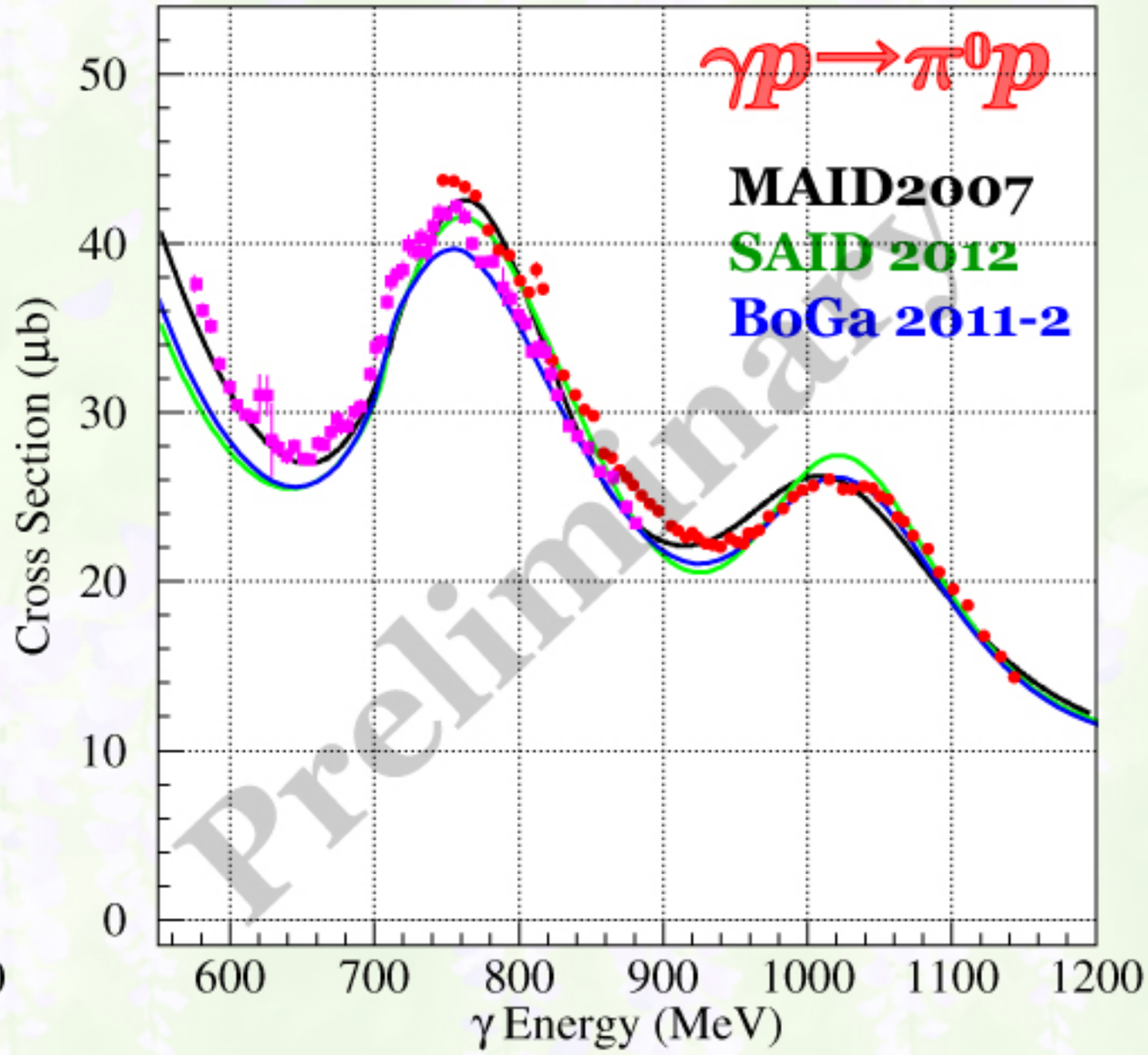
ETA-MAID2003
SAID GW2009
BoGa 2011-2

MAID2007
SAID 2012
BoGa 2011-2

Experiments with FOREST ~ proton target

Exclusive Analysis for $\gamma p \to \eta p$, $\gamma p \to \pi^0 p$
Total cross sections as a function of the incident energy



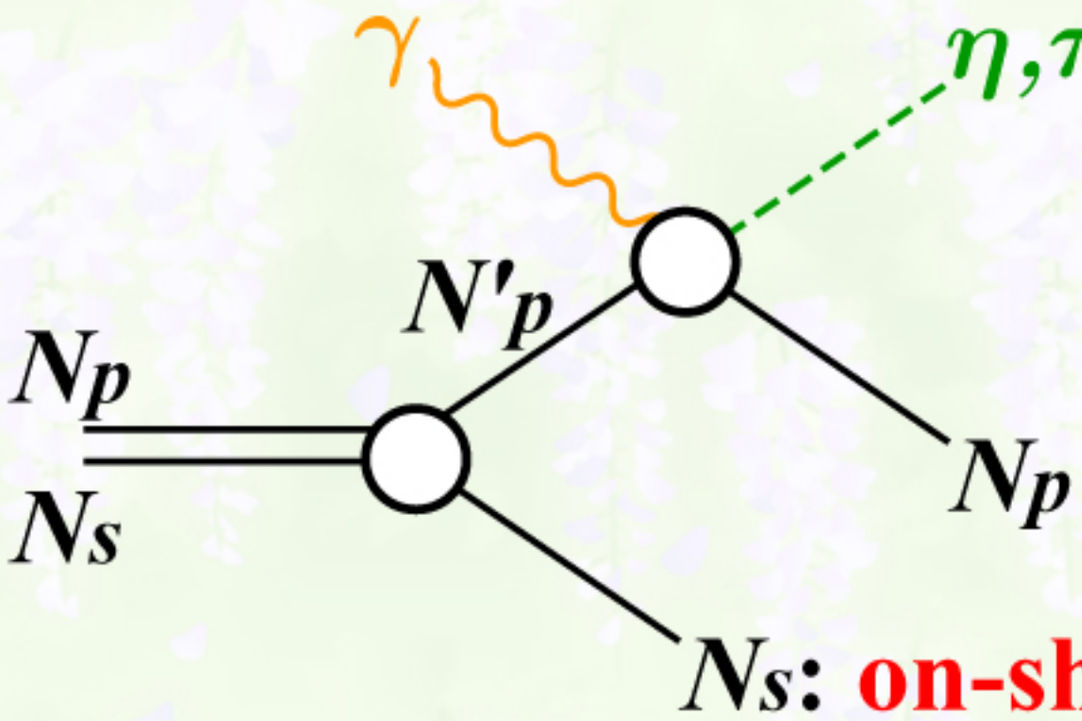


Results from two different 1200 and 930 MeV modes are consistenet.

Experiments with FOREST ~ deuteron target

Exclusive Analysis for $\gamma N' \to \eta N$, $\gamma N' \to \pi^0 N$

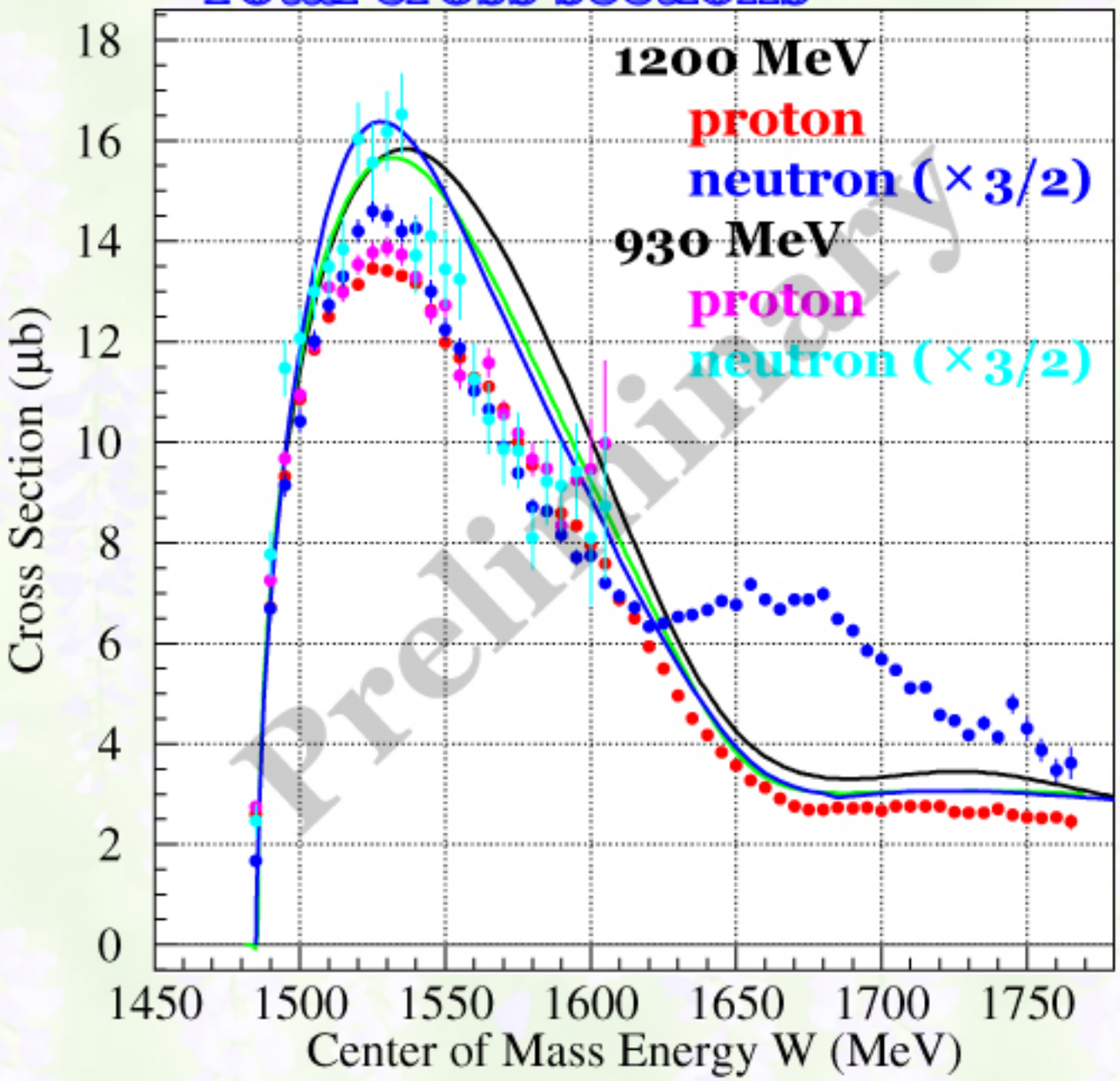
- two photons ($\gamma\gamma$) and a nucleon are detected
- coincidence between STB Tagger II and FOREST
- 5C kinematical fitting
  - energy and momentum conservation (4)
  - two photon invariant mass = η, π mass (1)
  - participant and spectator model
    - Fermi momentum (x, y, z) is assumed to be measured as 0 MeV/c with a resolution of 40 MeV/c



$$E_{N'_p} = m_d - E_{N_s}$$

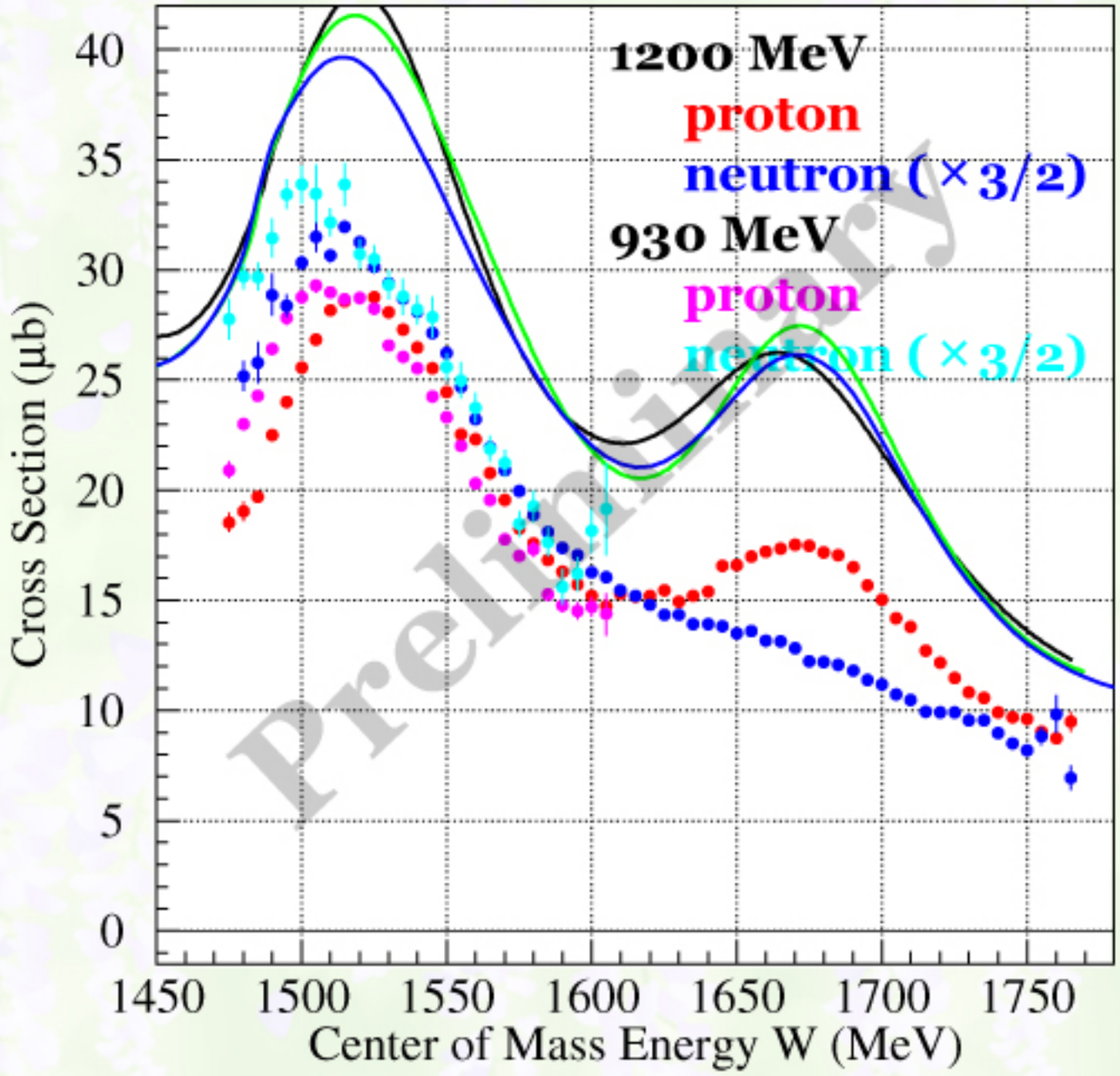
Experiments with FOREST ~ deuteron target

Exclusive Analysis
Total cross sections



$\gamma N' \rightarrow \eta N$

ETA-MAID2003
SAID GW2009
BoGa 2011-2

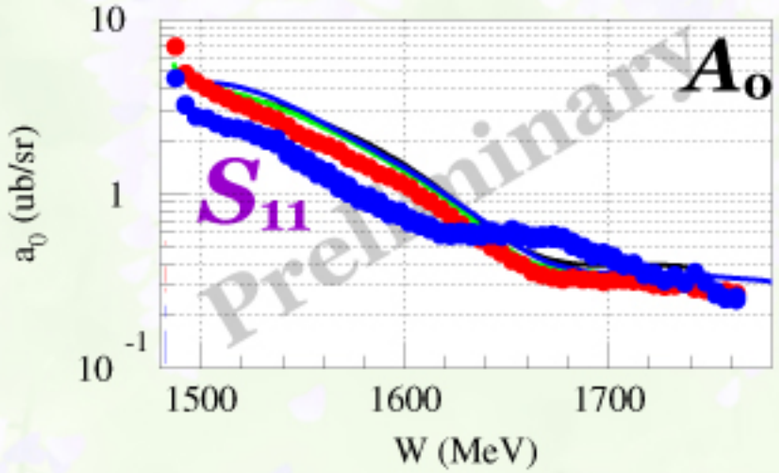


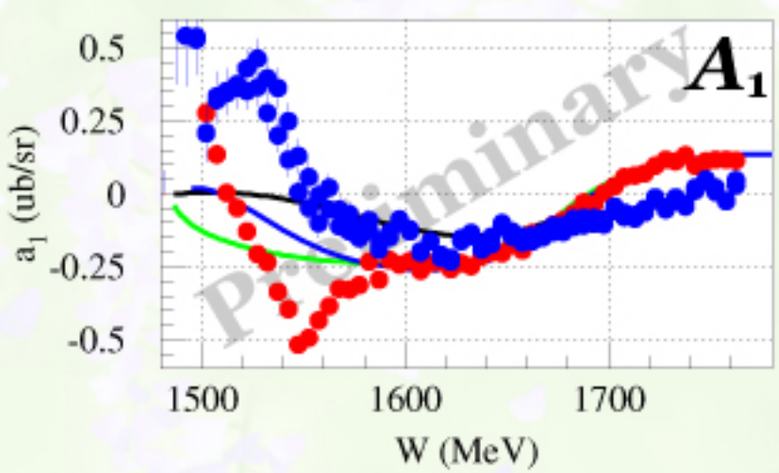
$\gamma N' \rightarrow \pi^0 N$

MAID2007
SAID 2012
BoGa 2011-2

Experiments with FOREST ~ deuteron target

Coefficients of the Legendre series



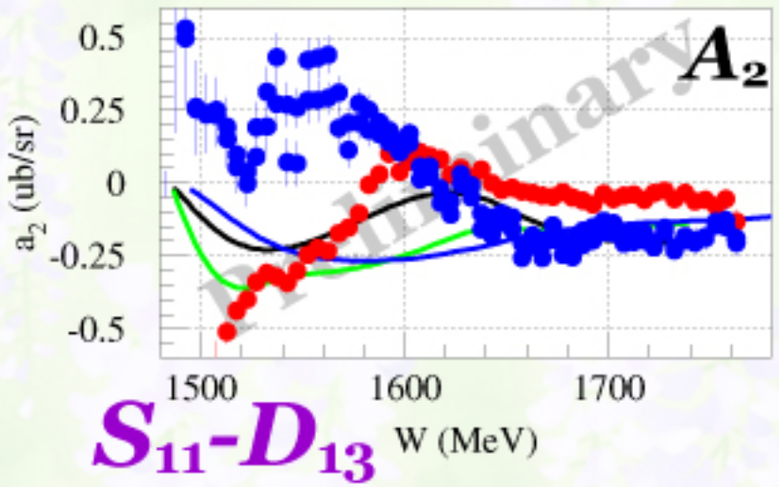


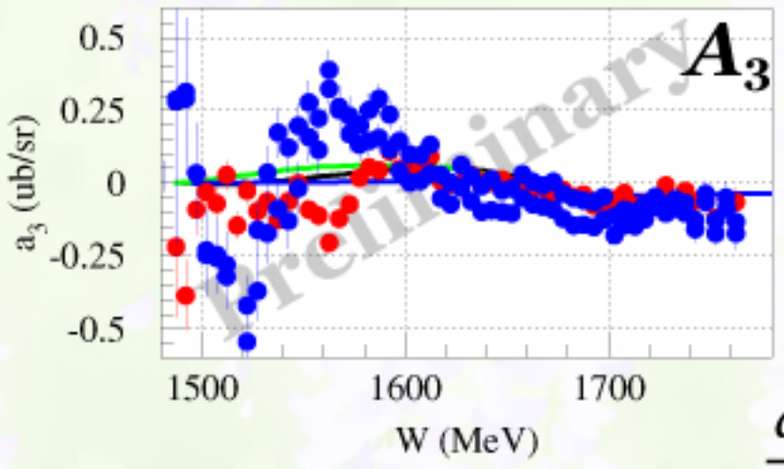
$\gamma N' \rightarrow \eta N$

ETA-MAID2003

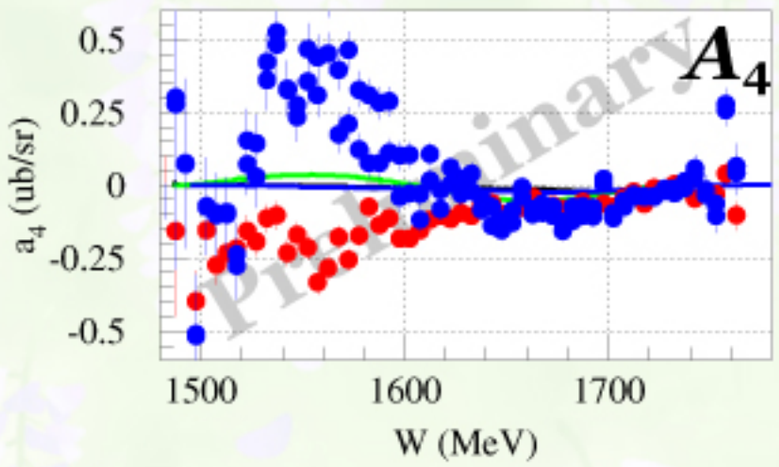
SAID GW2009

BoGa 2011-2





S_{11}-D_{13}



$$\frac{d\sigma}{d\Omega} = \frac{p_\eta^*}{p_\gamma^*} \sum_{i=0}^{4} A_i P_i\left(\cos\theta^*\right)$$

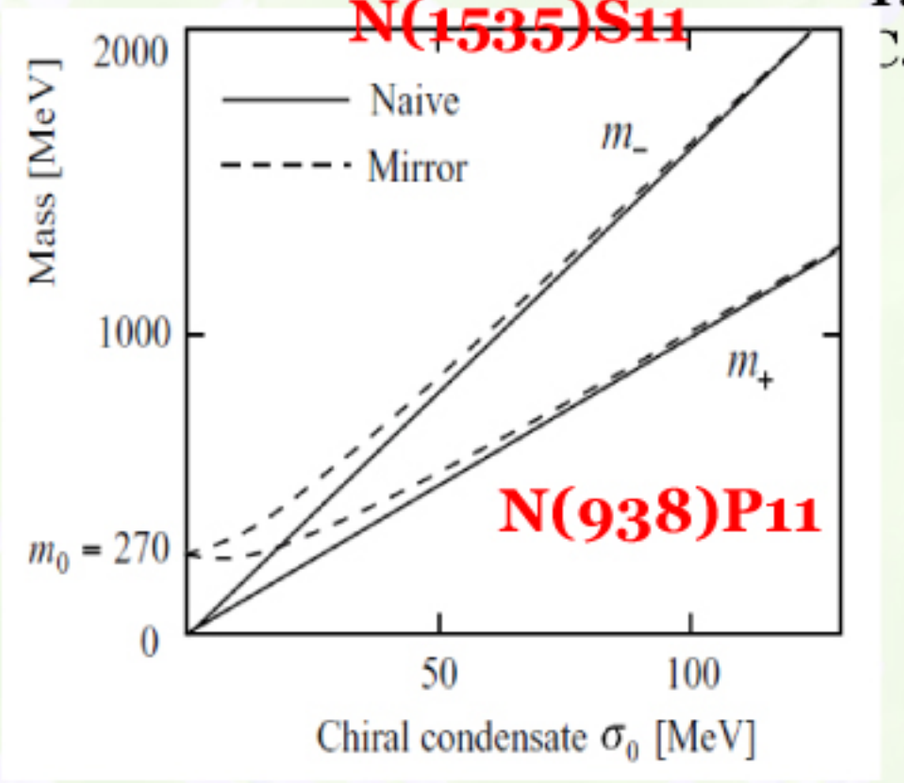
Structure corresponding to the bump at W~1670 MeV is observed only in A_0

η-nucleus bound/resonance state

hadron properties in the nuclear medium
S_{11} is speculated to be the chiral partner of the nucleon

$N(938)P_{11}$ and $N(1535)S_{11}$ degenerate

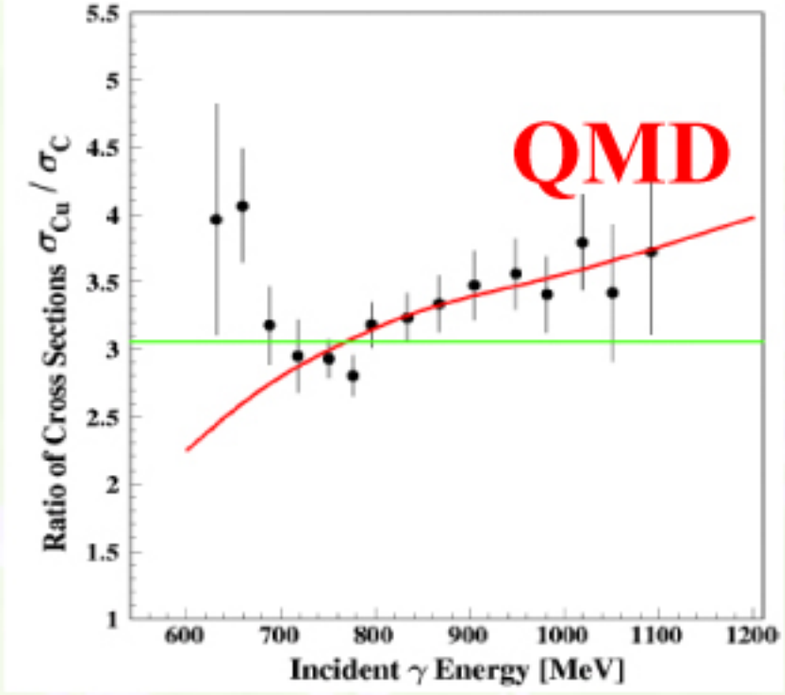
T. Hatsuda and M. Prakash, PLB224, 11 (1989);
C. DeTar and T. Kunihiro, Phys. Rev. D 39, 2805 (1989).

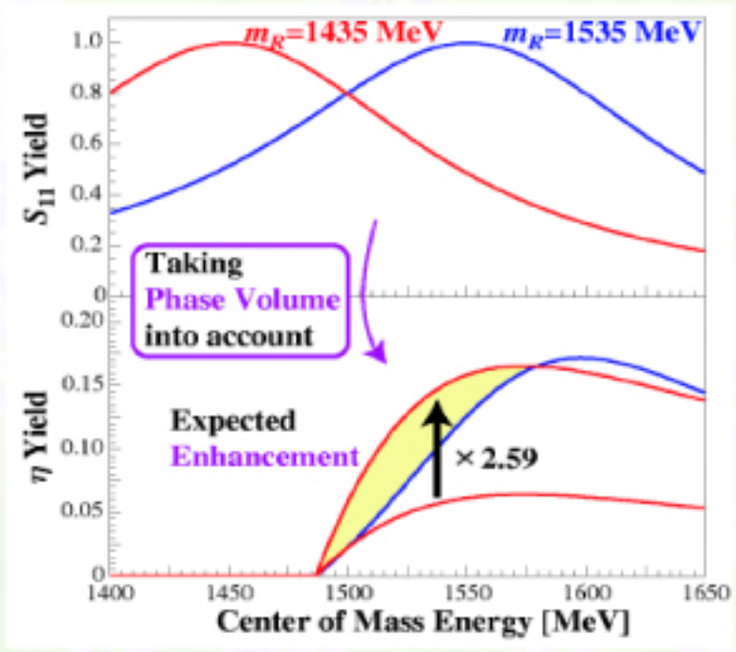


η photoproduction from nuclei

T. Kinoshita et al., PLB639, 429 (2006).

SCISSORS & SCISSORS II





enhancement near the threshold
indication of S_{11} mass decrease ?

$$\sigma(\gamma N \to \eta N) \propto \frac{1}{(W^2 - m_R^2)^2 + m_R^2\Gamma^2}\frac{p_\eta^*}{W}$$

η-nucleus bound/resonance state

η-mesic nucleus:

ηN and $S_{11}(1535)$ in the nuclear medium

η meson in free space

N^*-N

48 MeV

η

attractive

D. Jido et al.,
NPA811, 158 (2008).

η meson in a nucleus

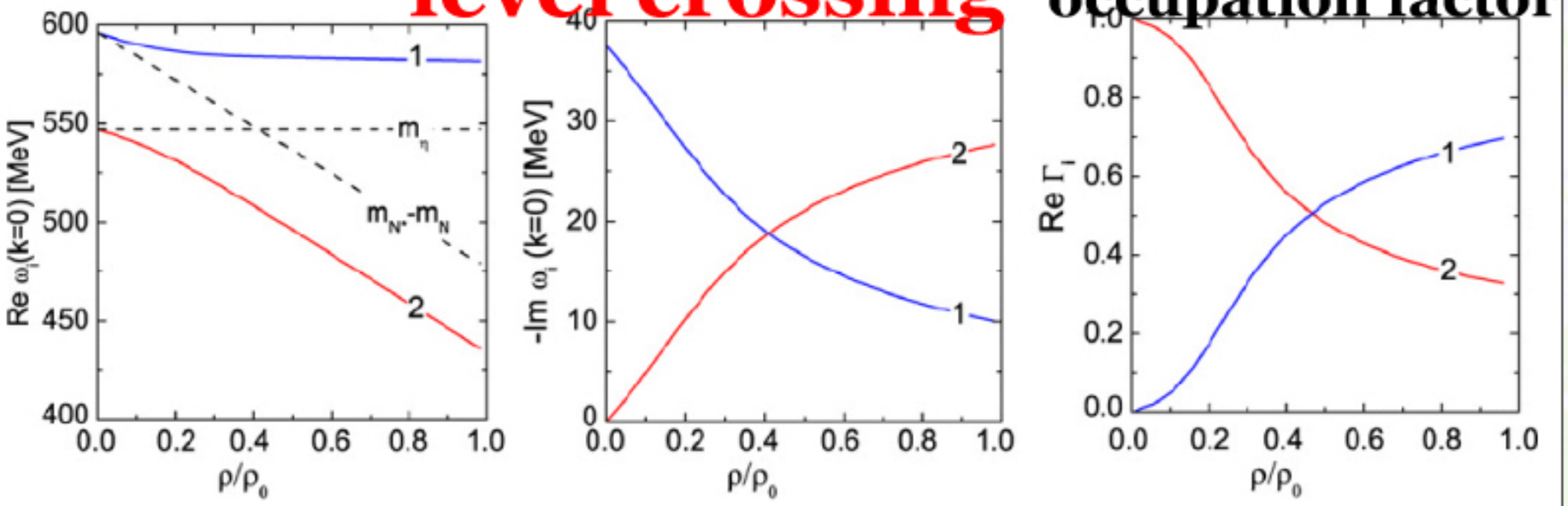
η

N^*-N

repulsive
medium effect

level crossing

occupation factor

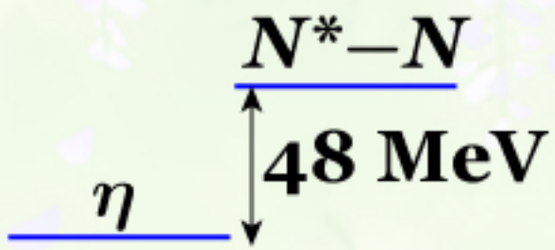


η-nucleus bound/resonance state

η-mesic nucleus:

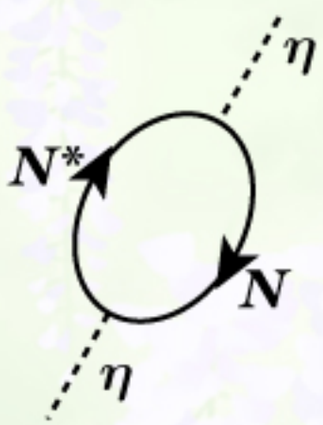
ηN and $S_{11}(1535)$ in the nuclear medium

η meson in free space

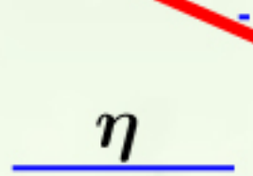


attractive

D. Jido et al.,
NPA811, 158 (2008).



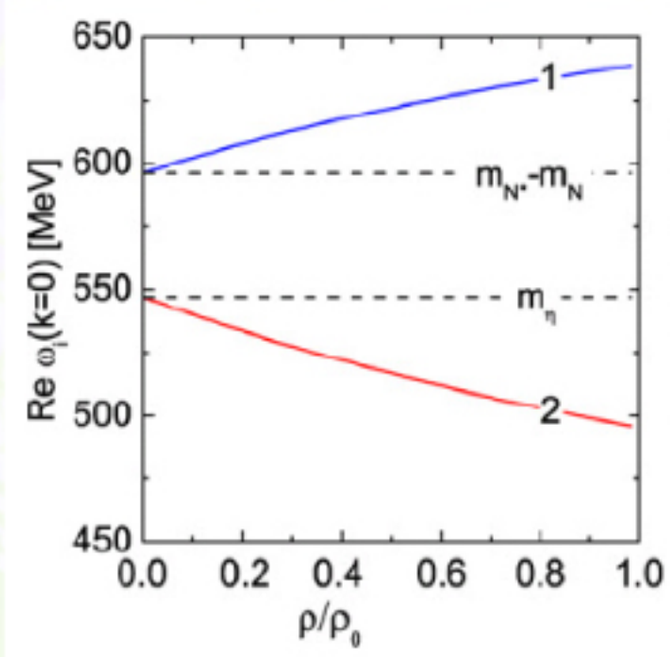
η meson in a nucleus

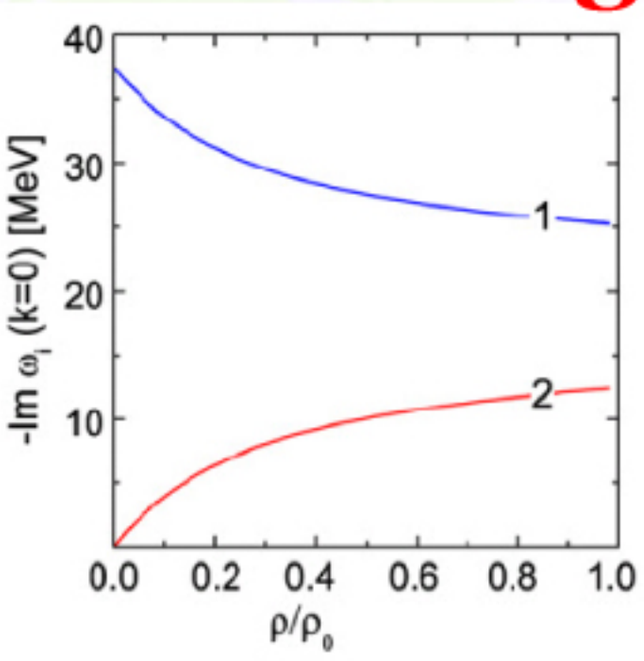


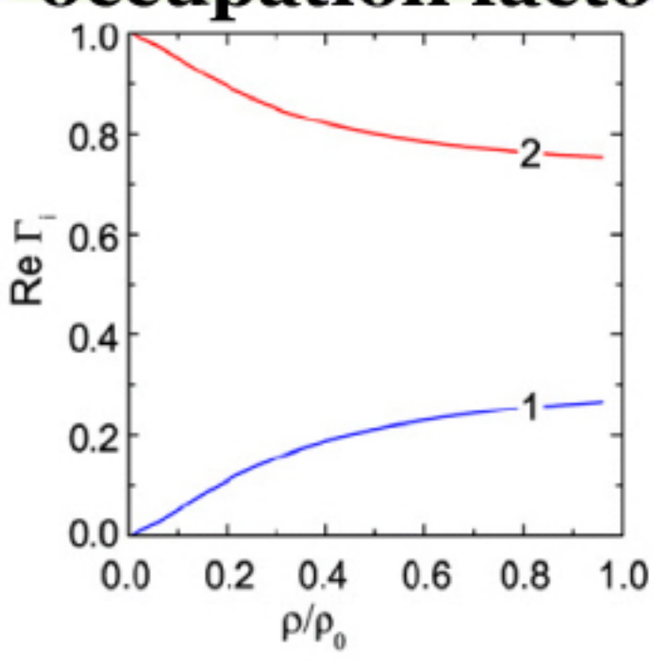
repulsive
medium effect

level crossing

occupation factor



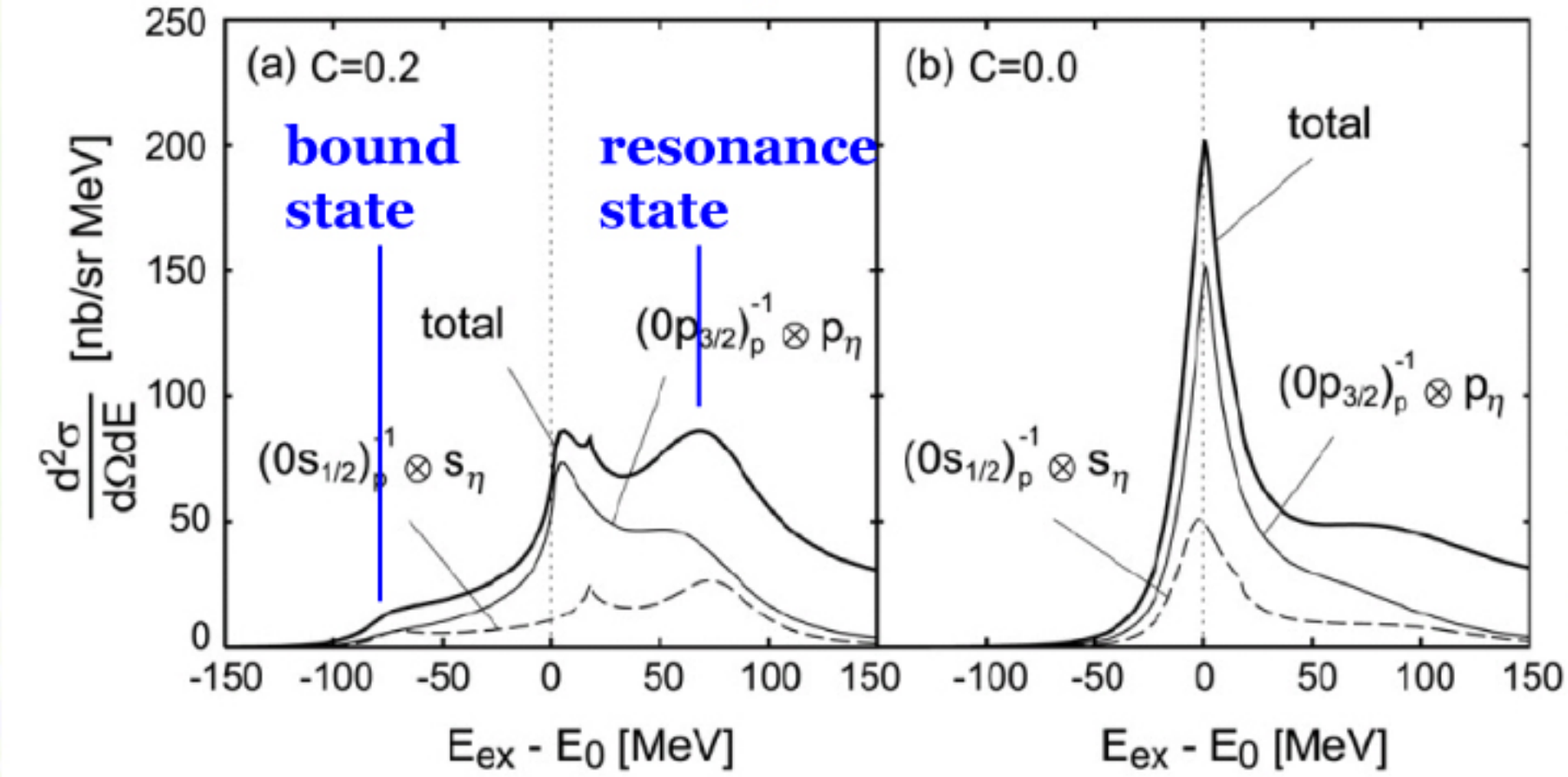




η-nucleus bound/resonance state

Expected spectra

with level crossing without level crossing

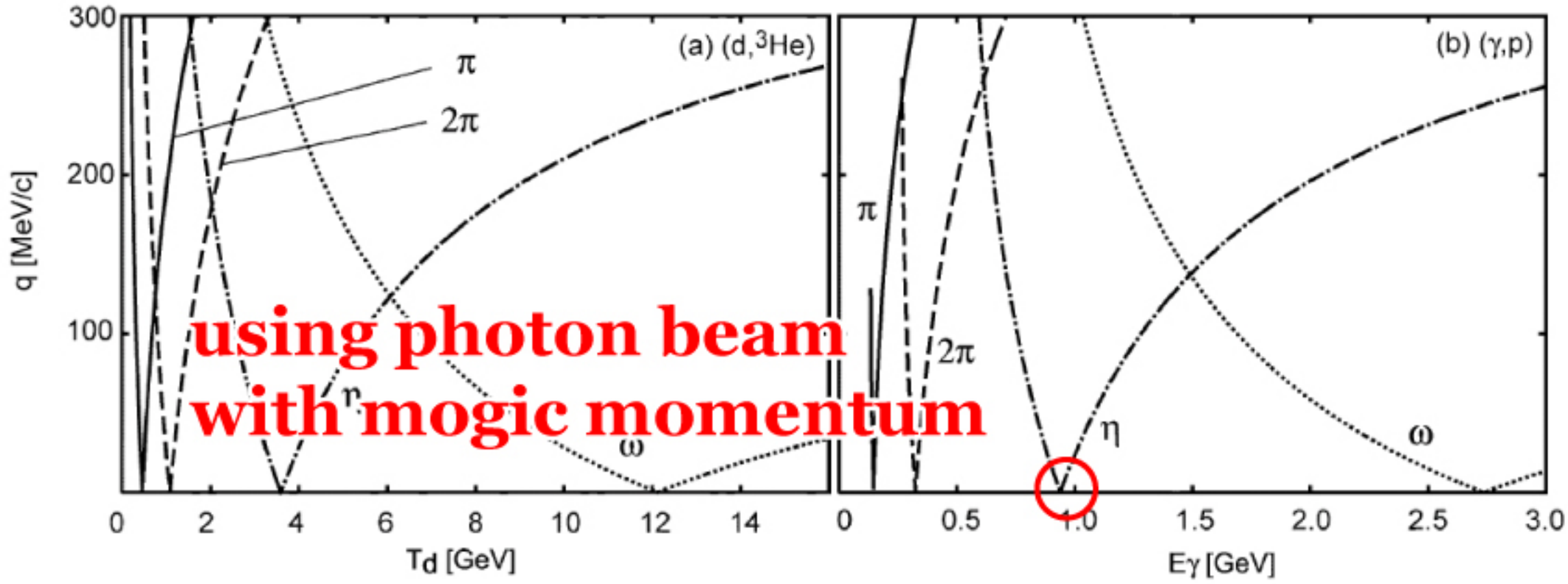


bound state:
difficult to observe
resonance state:
S_{11} properties in the nuclear medium

H. Nagahiro *et al.*, PRC74, 045203 (2006).

η-nucleus bound/resonance state

Missing mass spectra for the $A(\gamma,p)$ reaction



using photon beam with mogic momentum

1) proton is detected at foward angles to minimize the recoil momentum of η mesons

2) back-to-back $\pi^0(\eta)$ and N are detected to suppress background processes

note that $\pi^0 N$ (ηN) invariant mass gives N^* mass

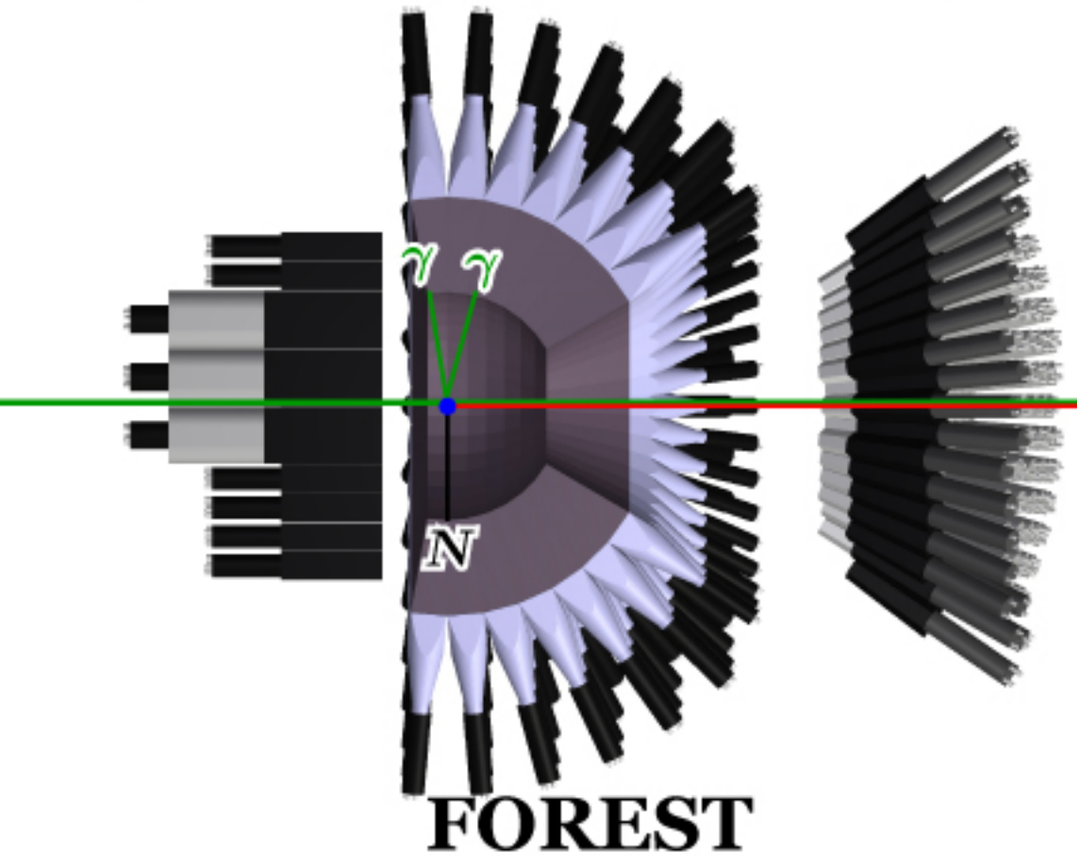
Upgrade of the FOREST experiments

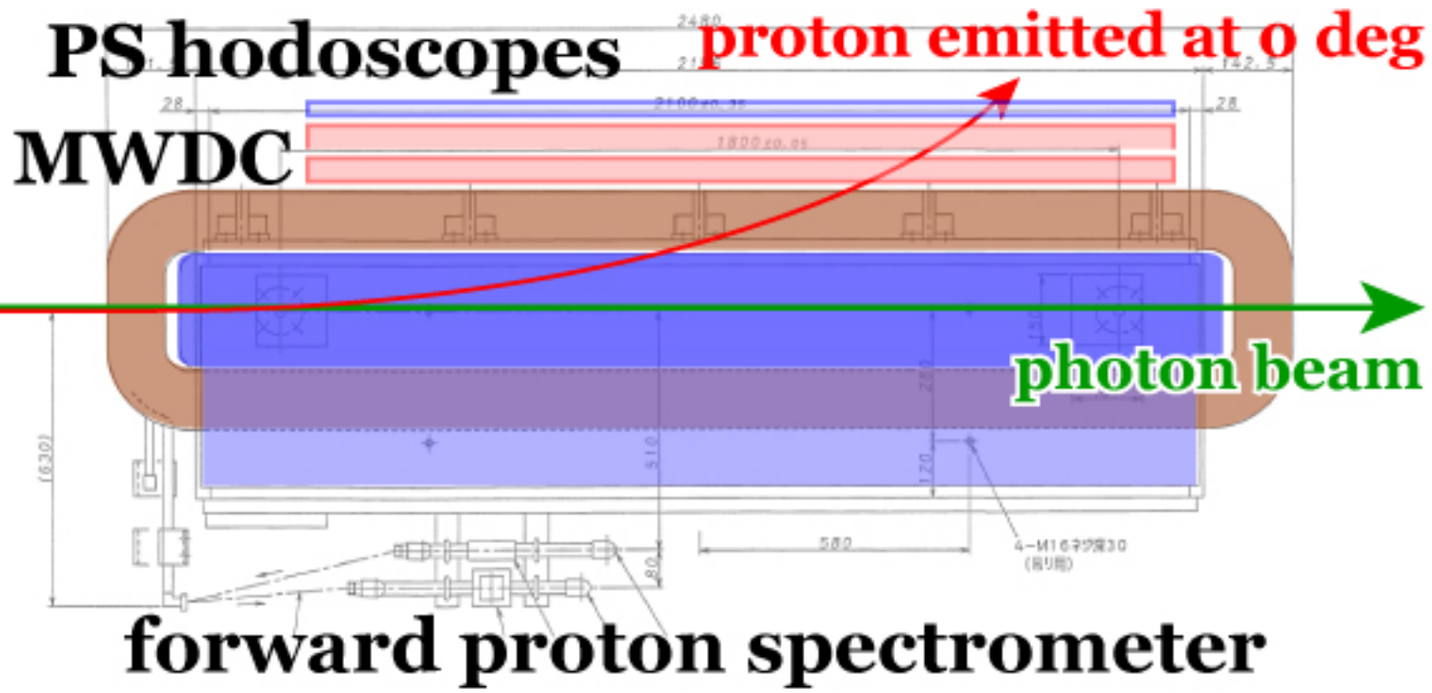
η-nucleus bound/resonance search is planned
to study S_{11} properies in the nuclear medium

to minimize the recoil momentum of produced η mesons
1) tagged photon beam around 950 MeV
tagging system (STB-Tagger II)
2) proton is detected at 0 deg
a bending magnet from KEKB-LER
placed at downstream of the FOREST detector

to suppress background events
3) back-to-back $\pi^0(\eta)$ and N are detected
FOREST detector

Upgrade of the FOREST experiments





Bendin magnet for KEKB-LER
- gap 110 mm

MWDC
- determine the momentum and emitted angle of the proton

PS hodoscopes
- determine the time of flight (TOF) [start: RF signal]
- particle ID and precise determination of the momentum

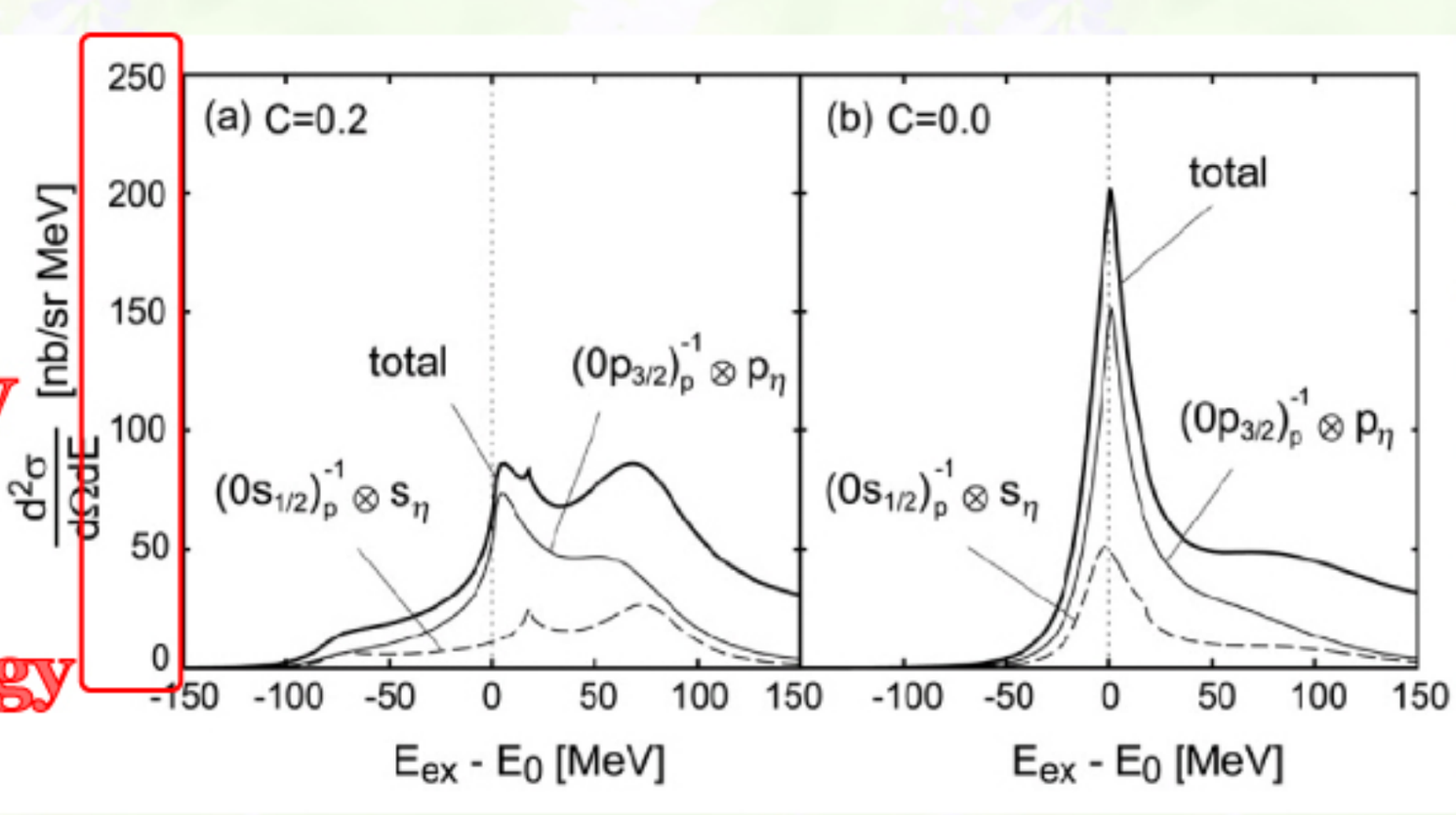
Upgrade of the FOREST experiments

Estimated beamtime

gap of the bending magnet: 110 mm
covered polar angles 0.0-0.6 deg ... 0.38 msr
C target density 1.5 g/cm^3,thickness 20 mm ... 0.15 b^{-1}
beam intensity around 950 MeV... 50 kHz
duty factor 50%

800 days required
10 MeV Ex bin
1 counts for 1 nb/sr MeV

1/10 ?
if we loose the beam energy condition



Upgrade of the FOREST experiments

Expected missing mass resolution: 3.8~ 6.1 MeV

incident photon energy: 0.5~2.5 MeV

emitted protons:

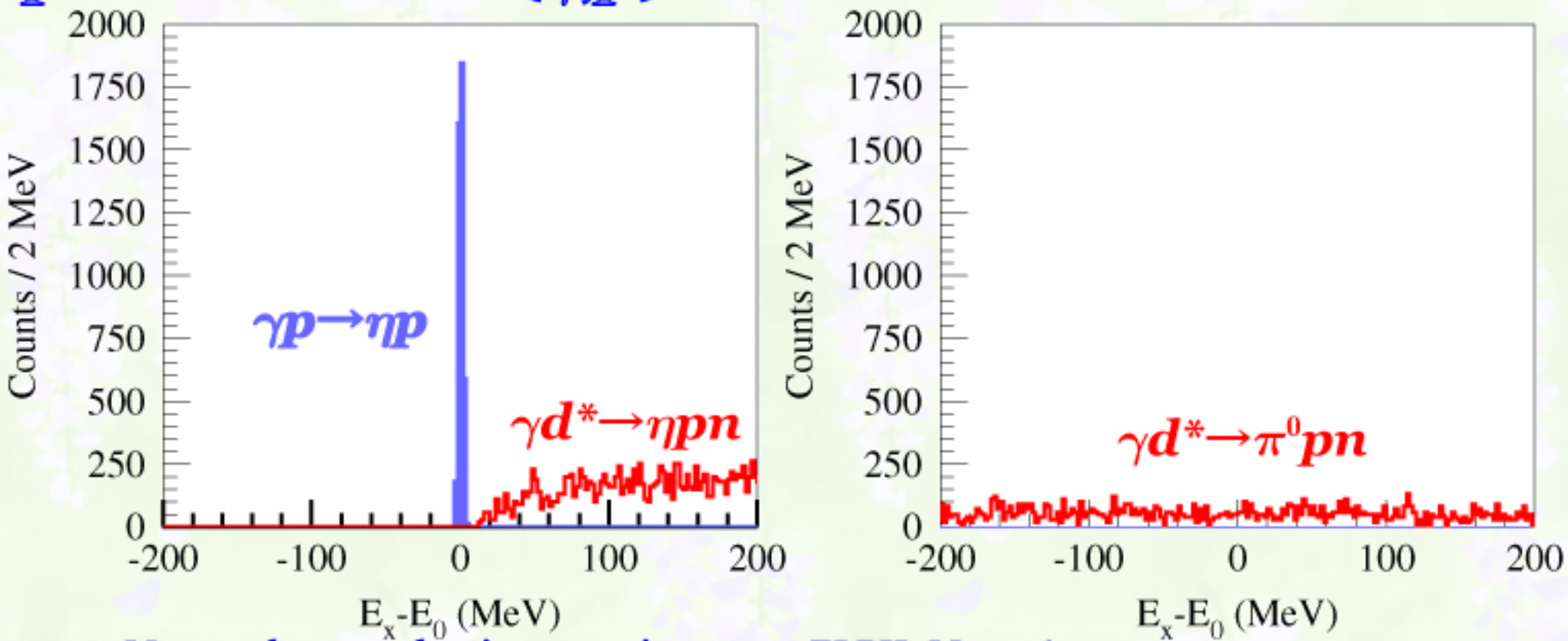
uncertainty of the vertex *z* point

8 ps(σ) for 20 mm target thickness

time resolution of PS hodoscopes 50~100 ps

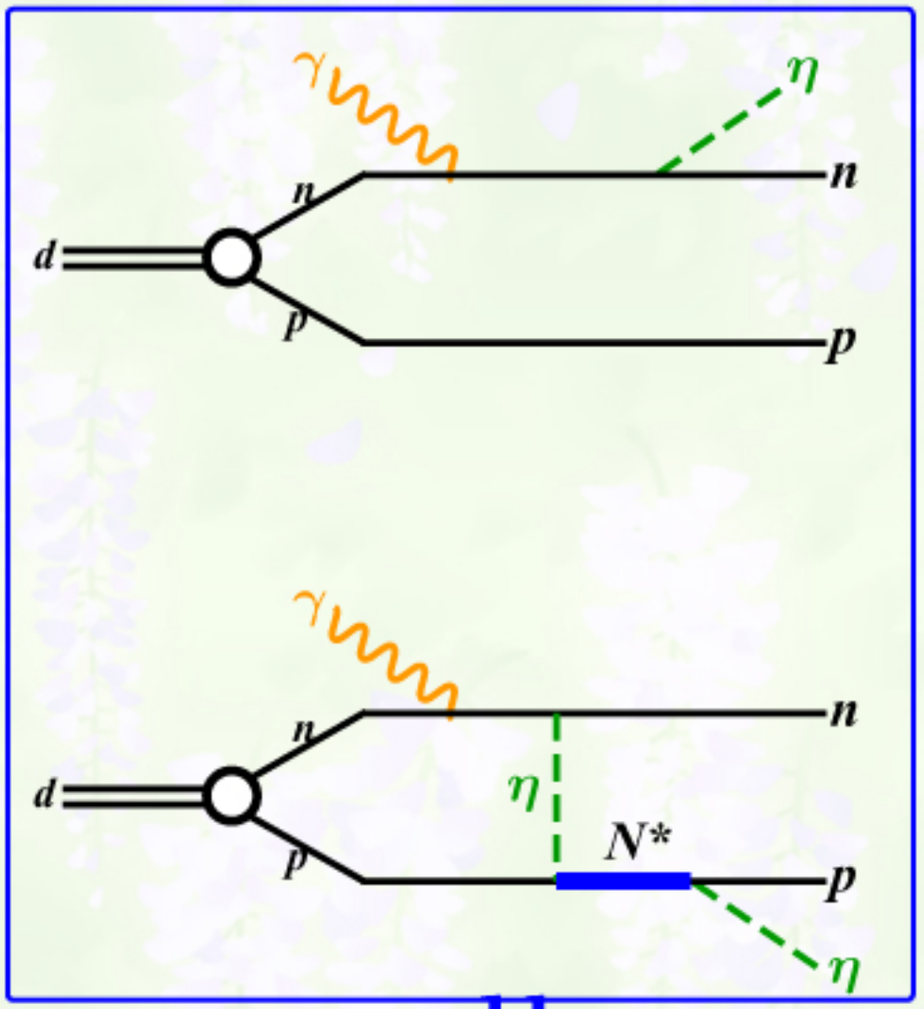
flight length ~5 m giving 4~8 MeV/c

No structure is expected in the missing energy spectra for the $A(\gamma,p)$ reaction

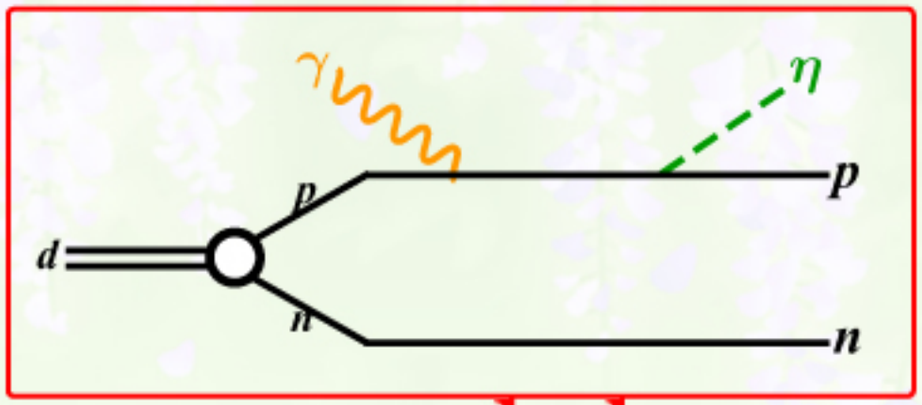


Upgrade of the FOREST experiments

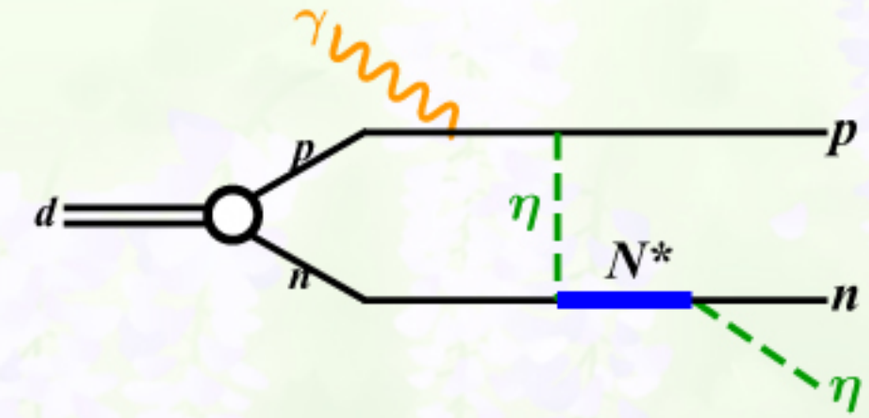
Pilot experiment with the deteron target



suppressed because *p* is detected at 0 deg



suppressed when *p* at 0 deg and back-to-back η-*n* are detected



precise determination of ηn scattering length
quasi-free η photoproduction at backward angles: 0.5~1.0 μb/sr
40 mm thick liquid deterium target: 1, 800/hour

Summary

Baryon spectroscopy by π^0, η, $\pi^0\pi^0$, $\pi^0\pi^+$, K^0,... production
pentaquak candidate $N^*(1670)$ in $\gamma n \to \eta n$
baryon resonance coupling
to σN ($\pi^0\pi^0$), ρN ($\pi^0\pi^+$), KY (K^0)

η-nucleus bound/resonance search is planned
to study S_{11} properies in the nuclear medium

FOREST with a foward proton spectrometer
incident energy of 950 MeV is selected
proton emitted at 0 deg is detected
back-to-back η-N are detected

Pilot experimet with the deuteron target is also planned
to determine ηn scattering length precisely

Schedule of the new experiments

Stable operation of the electron synchrotron was obtained in the end of this April

Energy calibration of the photon tagging system for new operation of the synchrotron

1) utilizing e+e- pair production: on-going from May 21 to May 31

2) confirmation of the $\gamma p \rightarrow \eta p$ threshold : planned from June 13 to June 21

Coverage 0.49~1.26 GeV (0.57~1.15 GeV before earthquake)
0.82~1.26, 0.62~0.96, and 0.49~0.77 GeV tagged photon beams are expected for 1.3, 1.0, and 0.8 GeV ciruclating energies

Transportation of the bending magnet during summer shutdown (this August?)

Commissioning run of the new detector setup starts from this November