

Study of baryon resonances and meson-nucleon interactions using photoproduction reactions at ELPH

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- 1. d*(2380) dibaryon resonance $\gamma d \rightarrow \pi^0 \pi^0 d$ reaction at E_{γ} ~0.57 GeV
- 2. ηN scattering length $\gamma d \rightarrow p \eta n$ reaction at $E_{\gamma} \sim 0.93$ GeV
- 3. Summary

Sendai

1.3 GeV bremsstrahlung photon beam



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d*(2380) dibaryon resonance

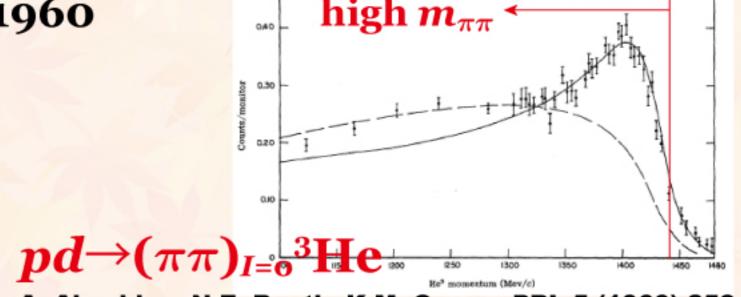
Abashian-Booth-Crowe (ABC) effect

low-mass enhancement in $m_{\pi\pi}$ distribution

first observation in 1960

isoscalar $\pi\pi$ -pair





A. Abashian, N.E. Booth, K.M. Crowe, PRL 5 (1960) 258; N.E. Booth, A. Abashian, K.M. Crowe, PRL 7 (1961) 35.

appearance of the $d^*(2380)$ dibaryon resonance

 $pn \rightarrow \pi^{o}\pi^{o}d$ reaction (only I=0)

first indication by the CELCIUS/WASA collaboration
M. Bashkanov et al., PRL102, 052301 (2009).

observation by the WASA-at-COSY collabration
P. Adlarson et al., PRL106, 242302 (2011).

peak with a mass m=2.37 GeV and width $\Gamma=0.07$ GeV

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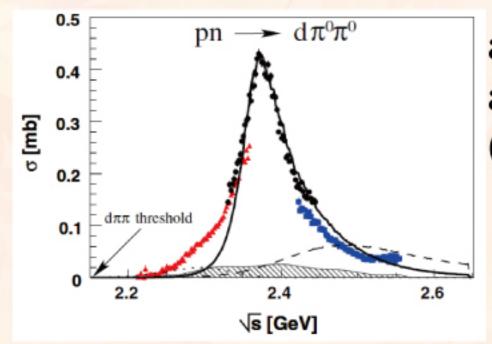
0

d*(2380) dibaryon resonance

 $pn \rightarrow \pi^{0}\pi^{0}d$ reaction (only I=0)

isoscalar $\pi\pi$ -pair

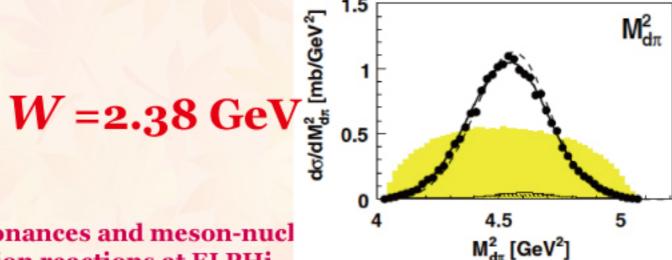
peak with a mass m=2.37 GeV and width $\Gamma=0.07$ GeV



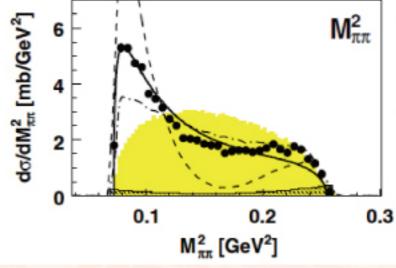
a six-quark state an isoscalar ΔΔ quasi-bound state, \mathcal{D}_{03} (predicted by Dyson and Xuong)

F.J. Dyson and N.-H. Xuong, PRL13, 815 (1964).

low-mass enhancement in $m_{\pi\pi}$ distribution



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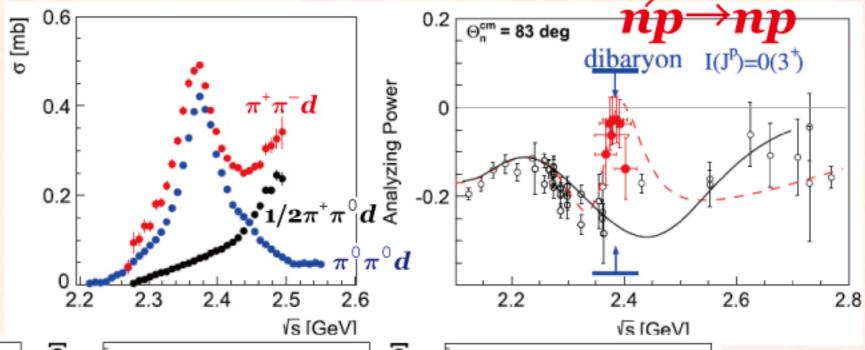


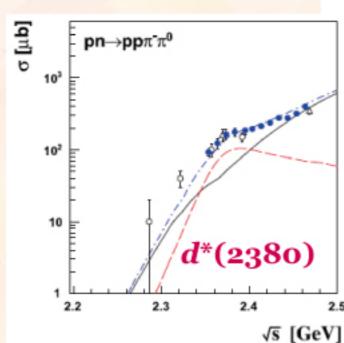
d*(2380) dibaryon resonance

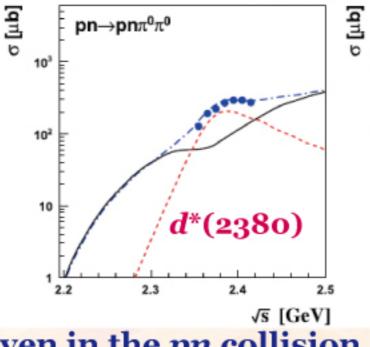
other reactions

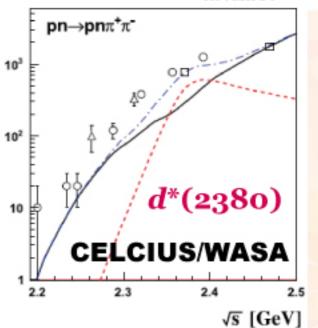
H. Clement et al., Phys. Scr. T 166, 014016 (2015).

$$pn \rightarrow \pi^{+}\pi^{-}d$$
 $\rightarrow \pi^{0}\pi^{-}pp$
 $\rightarrow \pi^{0}\pi^{0}pn$
 $\rightarrow \pi^{+}\pi^{-}pn$
 $\rightarrow pn$









All the evidences were given in the pn collision

Nearly all the observation was made by the WASA-at-COSY collaboration.

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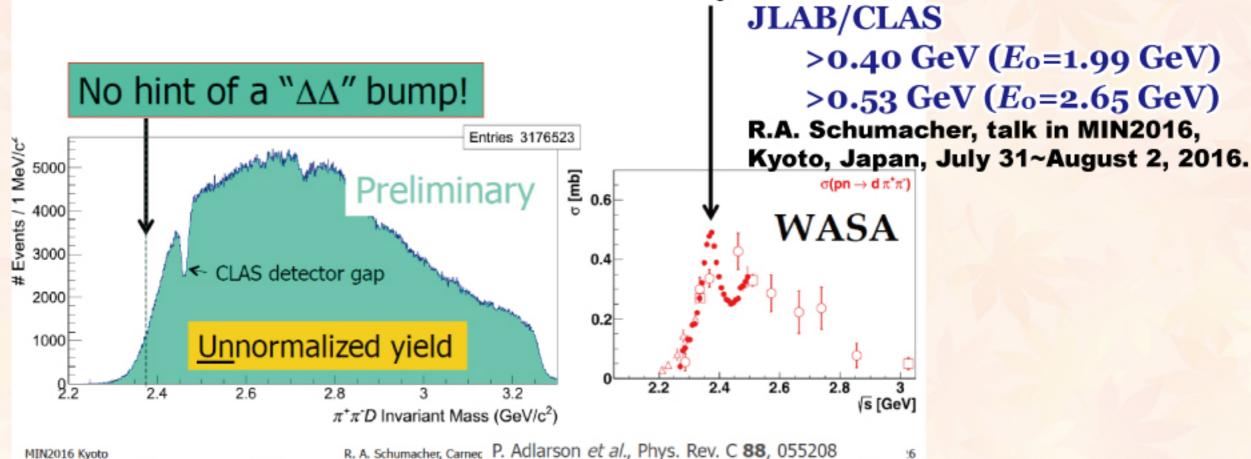
How about photoproduction?

MIN2016 Kyoto

d*(2380) dibaryon resonance

s-channel photoproduction $\gamma d \rightarrow \pi^+ \pi^- d$ and $\gamma d \rightarrow \pi^0 \pi^0 d$ advantageous to study the production mechanism

- Gash at $W = 2.46 \text{ GeV/c}^2$: known gap in CLAS photon energy coverage
- No obvious $\Delta\Delta$ visible in CALS/g13 (maybe PWA, or not formed in γ d)
- Recall WASA@COSY claims $\Delta\Delta$ at W = 2.37 GeV/c² in $pn \rightarrow d \pi^+ \pi^-$



The Kroll-Ruderman contact term can give a larged effect in this channel.

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 $\gamma d \rightarrow \pi^{o} \pi^{o} d$ can be the best!



Experimental setup

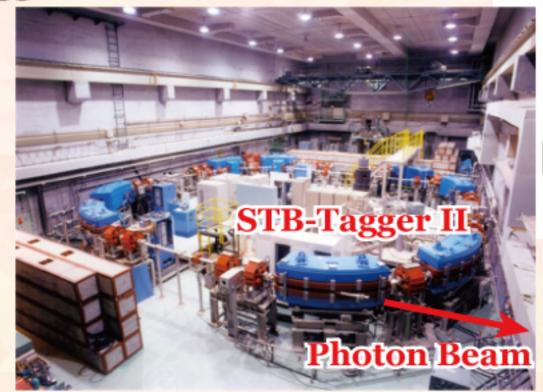
Electron Beam after the earthquake LINAC 150 MeV→93 MeV

Booster Ring 1200 MeV (max)

Photon Beam →1300 MeV

Bremsstrahlung

Tagged



1.3 GeV Booster STorage Ring

- T. Ishikawa et al., Nucl. Instr. Meth. A 622, 1 (2010);
- T. Ishikawa et al., Nucl. Instr. Meth. A 811, 124 (2016).



Bremsstrahlung Tagged Photon Beam 740~1150 MeV @ 1200 MeV

~20 MHz (photon: 10 MHz)

570~890 MeV @ 930 MeV

Photon Beam

~2.8 MHz (photon: 1.2 MHz)

δE: 1~2 MeV

 $W_{\gamma d}$ =2.38~2.61 GeV

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Experimental setup Backward Gamma

252 Lead/SciFi modules

SCISSORS III SPIDER

192 CsI crystals 3% @ 1 GeV

LOTUS Rafflesia II

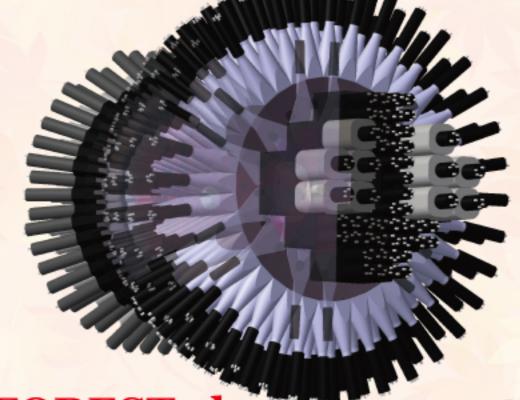
Photon Beam

62 Lead Glasses

5% @ 1 GeV

7% @ 1 GeV

Target: 45 mm thick LH2 & LD2



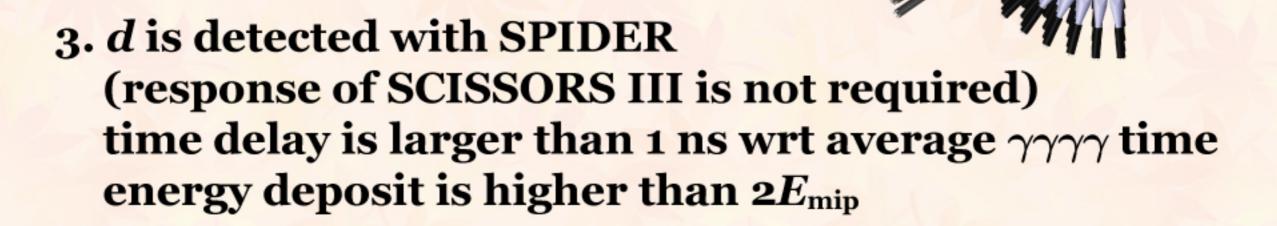
FOREST electro-magnetic calorimeter

T. Ishikawa et al., Nucl. Instr. Meth. A 832, 108 (2016). Study of baryon resonances and meson-nucleon interactions using photoproduction reactions at ELPHi



Event selection for $\gamma d \rightarrow \pi^{o} \pi^{o} d$

- 1. 4 neutral particles and 1 charged particle
- 2. each neutral pion: $\gamma \gamma$ decay time difference is less than $3\sigma_t$ btw every 2 neutral clusters of 4

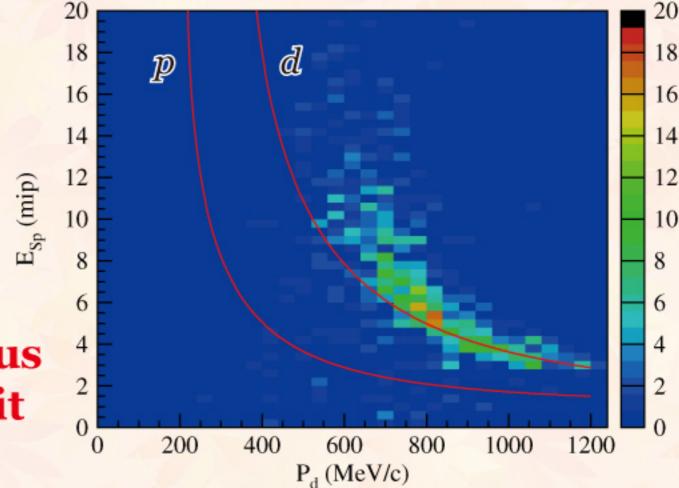


4. sideband background subtraction to remove accidental coincidence effect btw STB-Tagger II and FOREST



Event selection for $\gamma d \rightarrow \pi^{o} \pi^{o} d$

Further event selection:
a kinematic fit with 6 constraints is applied energy and momentum conservation (4) each $\gamma\gamma$ invariant mass is $m_{\pi\pi}$ (2) χ^2 probility is higher than 0.1



Only the deuteron locus is observed after the fit



Total cross section for $\gamma d \rightarrow \pi^{o} \pi^{o} d$

Total cross section:

$$\sigma = rac{N_{\pi^0\pi^0d}}{N_{\gamma'}N_{ au}\eta_{
m acc}\left\{{
m BR}(\pi^0 o\gamma\gamma)
ight\}^2}$$

 N'_{γ} : effective number of incident photons number of tagging signals photon transmittance DAQ efficiency

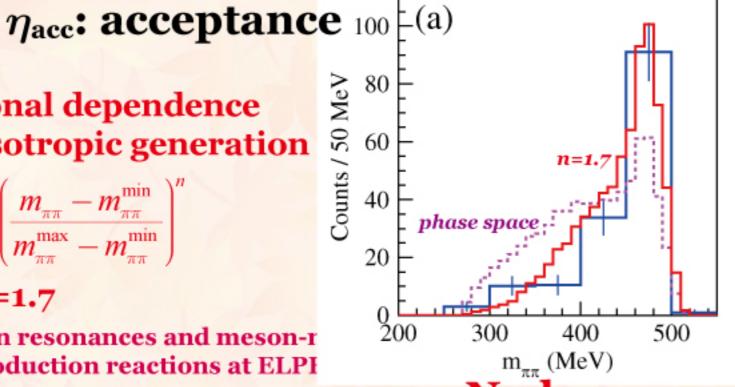
 N_{τ} : number of target deterons in a unit area

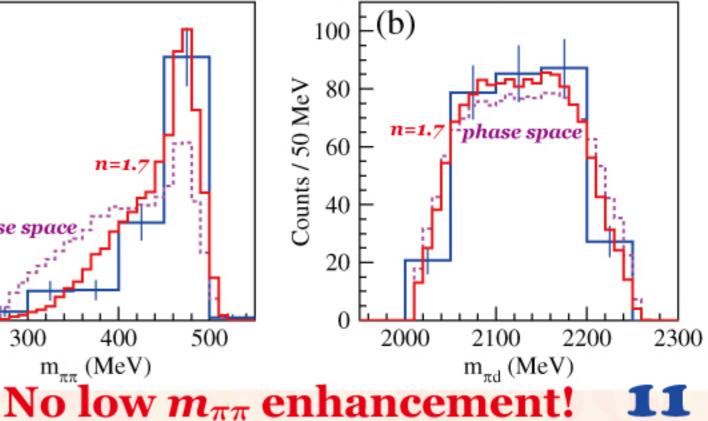
additional dependence from isotropic generation

$$P = \left(\frac{m_{\pi\pi} - m_{\pi\pi}^{\min}}{m_{\pi\pi}^{\max} - m_{\pi\pi}^{\min}}\right)^n$$

with n=1.7

Study of baryon resonances and meson-r using photoproduction reactions at ELPI

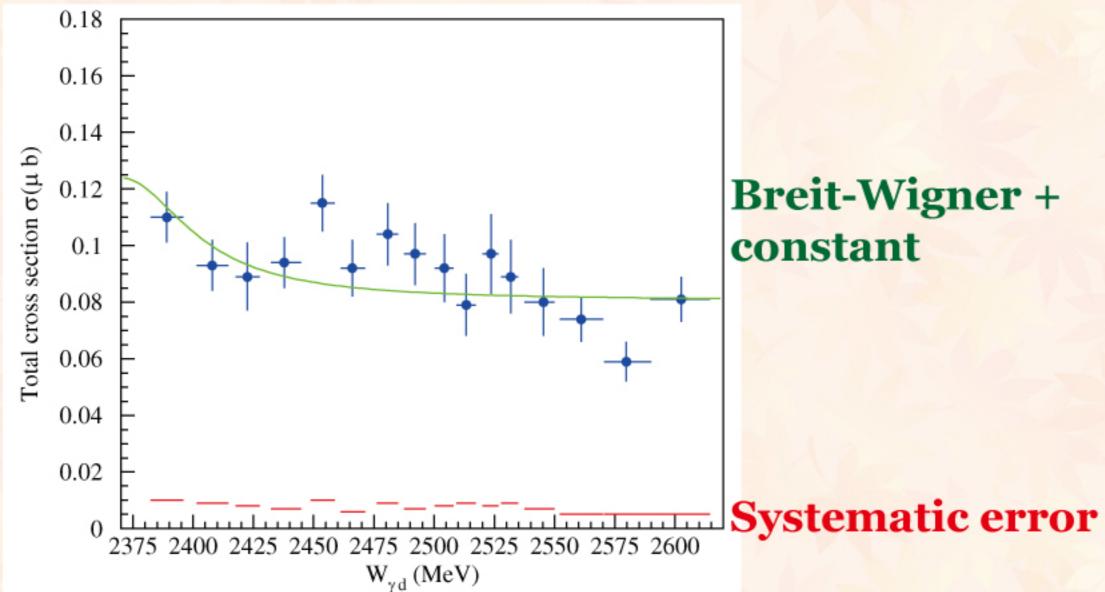






Total cross section for $\gamma d \rightarrow \pi^{o} \pi^{o} d$

Total cross section:

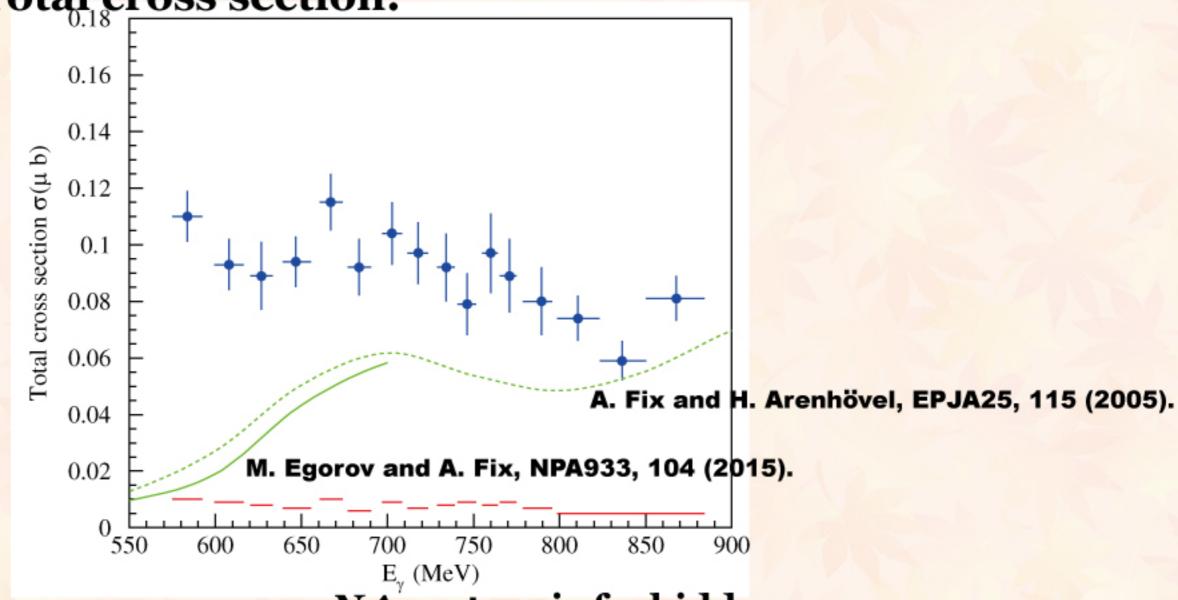


No clear resonance-like behavior at W=2.37 GeV. Upper limit of the cross section: 0.071 ub (90% CL)



Total cross section for $\gamma d \rightarrow \pi^{o} \pi^{o} d$

Total cross section:



 $N\Delta$ system is forbidden

 NN^* system cannot explain at low energies lowest-mass N^* is $P_{11}(1440): E_{\gamma} \sim 0.64$ GeV sequential π^0 emission $\gamma N \rightarrow \pi^0 \Delta \rightarrow \pi^0 \pi^0 N$?

Study of baryon resonances and meson-nucleon interactions using photoproduction reactions at ELPHi

Summary for $\gamma d \rightarrow \pi^0 \pi^0 d$

Total cross section has been measured for $W_{\gamma d}$ =2.38~2.61 GeV for the first time

No clear resonance-like behavior corresponding to d*(2380) is observed.

Upper limit of the d*(2380) contribution is 0.071 ub (90% CL) at $W_{\gamma d}$ =2.37 GeV.

The measured excitation function is rather flat and incosistent with the existing theoretical calculation for this reaction.

A further understanding of the isoscalar part of $\pi^{o}\pi^{o}$ production is required.

Please see arXiv:1610.05532 (T. Ishikawa et al.)



Interaction between mesons and nucleons fundamental & important

Neutral mesons:

not precisely determined (except for π^{o})

scattering experiments: impossible

life time is very short

no beam is available

X-ray measurements: impossible

no electro-magnetic attraction

no mesic atom

Study of baryon resonances and meson-nucleon interactions using photoproduction reactions at ELPHi

T. Ishikawa, October 26, 2016.



 ηN low-energy scattering parameters combined theoretical analyses of differential and total cross sections for $\pi N \rightarrow \eta N$ transition, $\gamma N \rightarrow \eta N$ photoproduction together with

 $\pi N \rightarrow \pi N$ scattering, $\gamma N \rightarrow \pi N$ photoproduction obtained scattering length $a_{\eta N}$

- -Im $a_{\eta N}$: ~0.26 fm (optical theorem)
- -Re $a_{\eta N}$: 0.2~1.1 fm

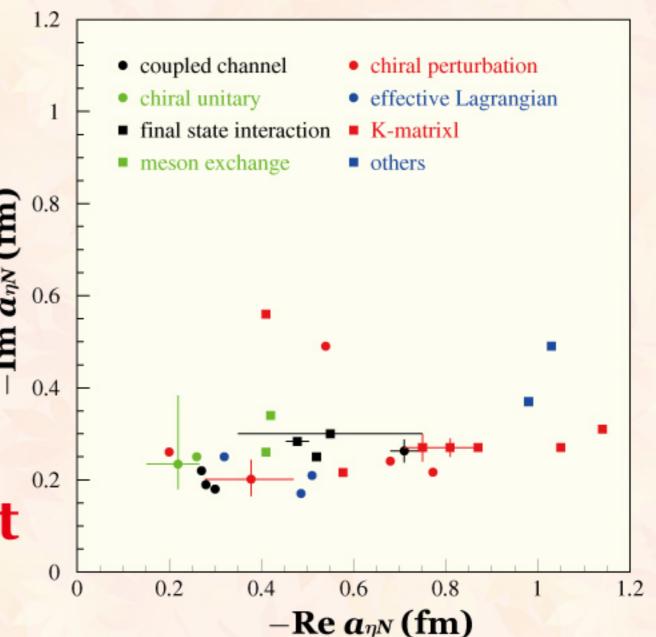
Study of baryon resonances and meson-nucleon interactions using photoproduction reactions at ELPHi

T. Ishikawa, October 26, 2016.



scattering length $a\eta N$ indirectly determined real part is scattered

a direct measurement of $a_{\eta N}$ is desired

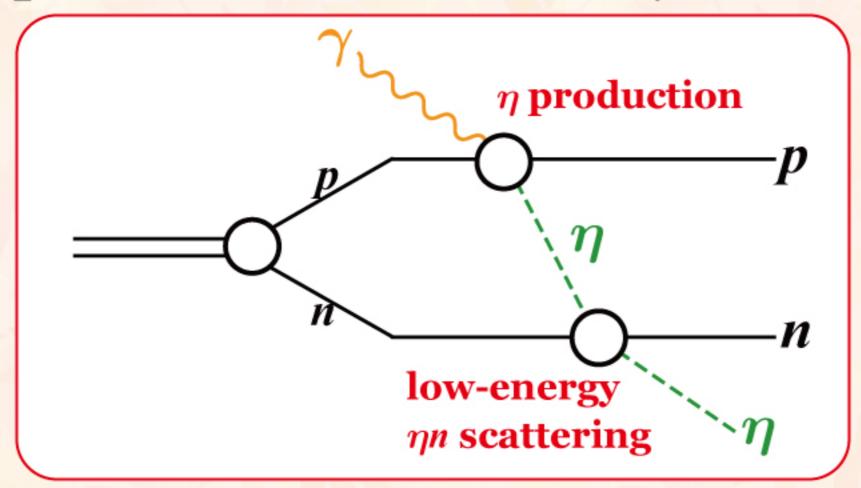


Q. Haider and L.C. Liu,

J. Mod. Phys. E 24, 1530009 (2015).



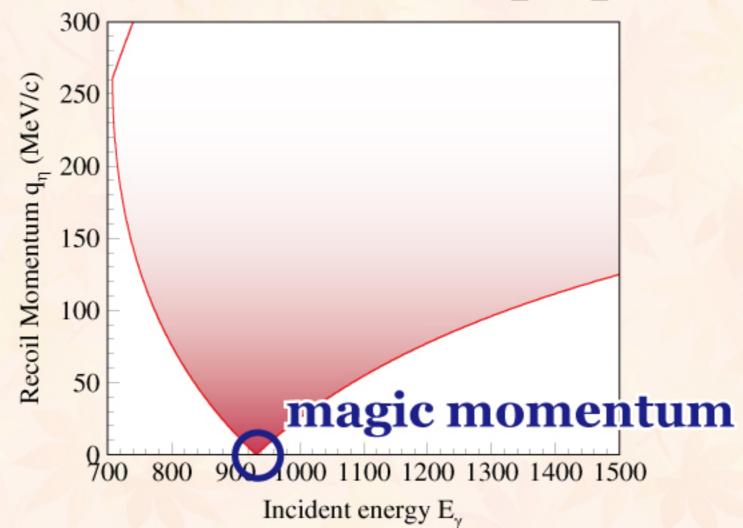
Proposed reaction to extract ηn scattering length



To be considered: contirbution of the $\eta n \rightarrow \eta n$ reaction



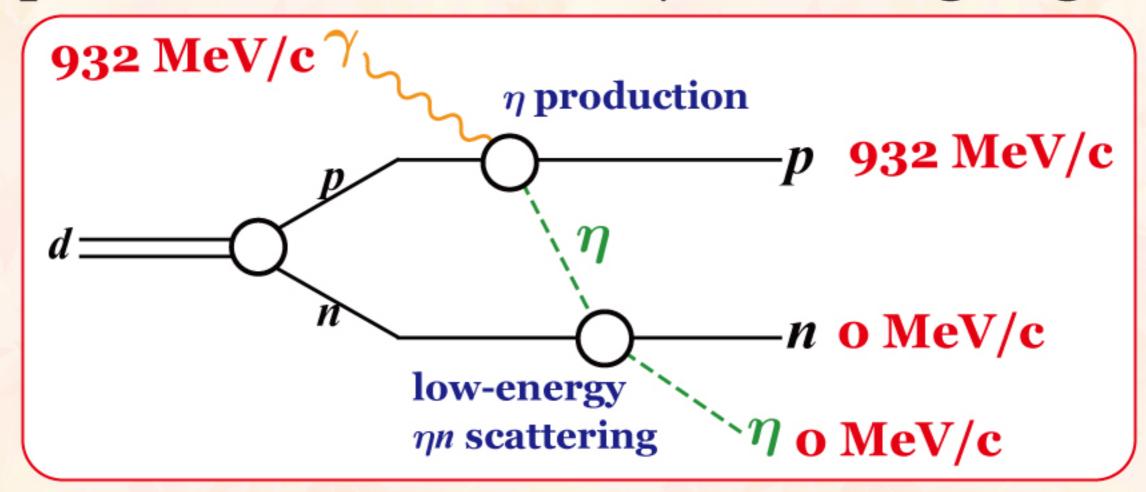
recoil momentum of η for the $\gamma p \rightarrow p \eta$ reaction



The η mesons are at rest when the incident photon energy is 932 MeV, and protons are detected at 0°.



Proposed reaction to extract ηn scattering length



The FSI between ηp and pn is expected to be suppressed.

The Fermi motion should be taken into account though.



Sensitivity to ηn scattering length dynamical coupled channel (DCC) model is applied to γd reactions

S.X. Nakamura, H. Kamano et al., in private communication.

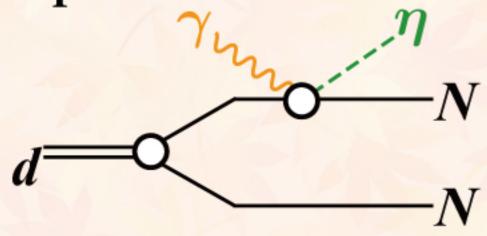
to be checked:

- 1. η exchange is dominant?
- 2. pn FSI is suppressed?
- 3. how is the sensitivity?
 - S.X. Nakamura,

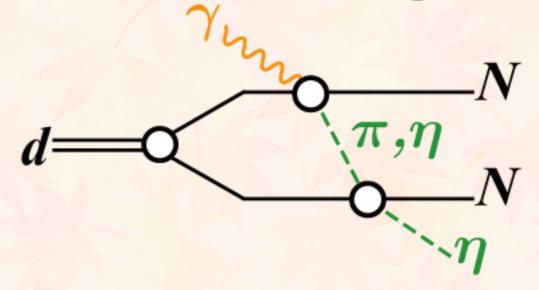
Extracting eta-neutron interaction from gamma d → eta n p data, Meson in Nucleus 2016, August 1, 2016.



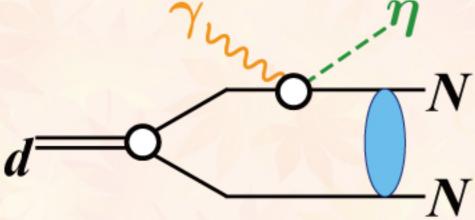
Model for $\gamma d \rightarrow \eta np$ impulse



 πN , ηN rescattering



NN rescattering



 $\gamma N \rightarrow \pi N$, $\gamma N \rightarrow \eta N$, $\pi N \rightarrow \eta N$ amplitudes (DCC model)

NN FSI and deteron wave function (CD-Bonn potenial)

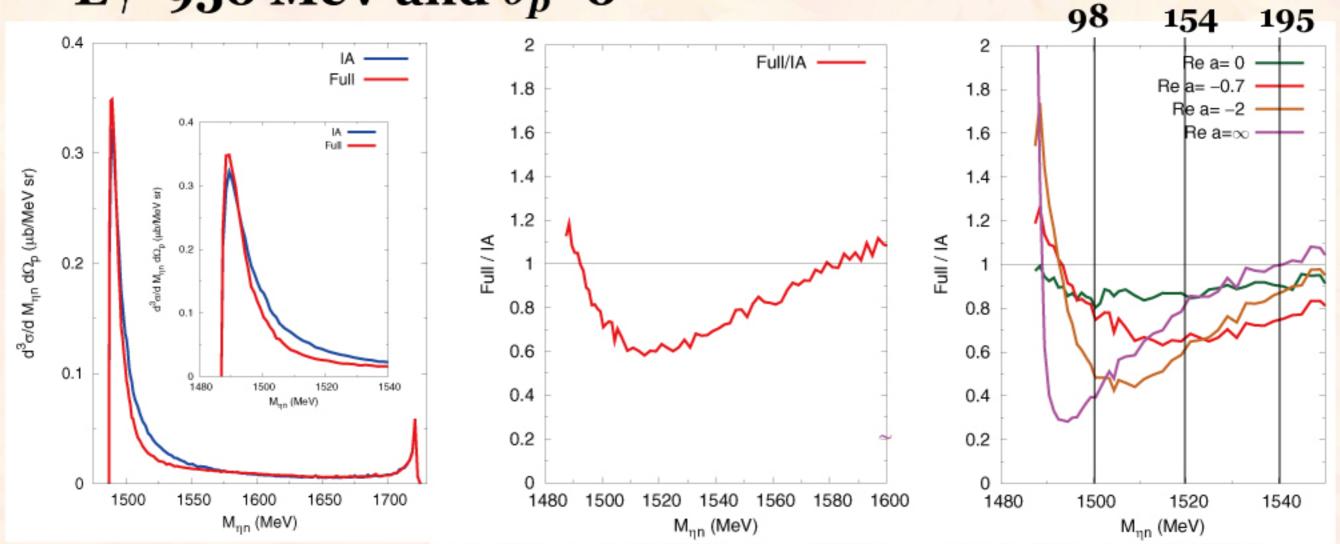
off-shell effects

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 ηn relative momentum (MeV/c)



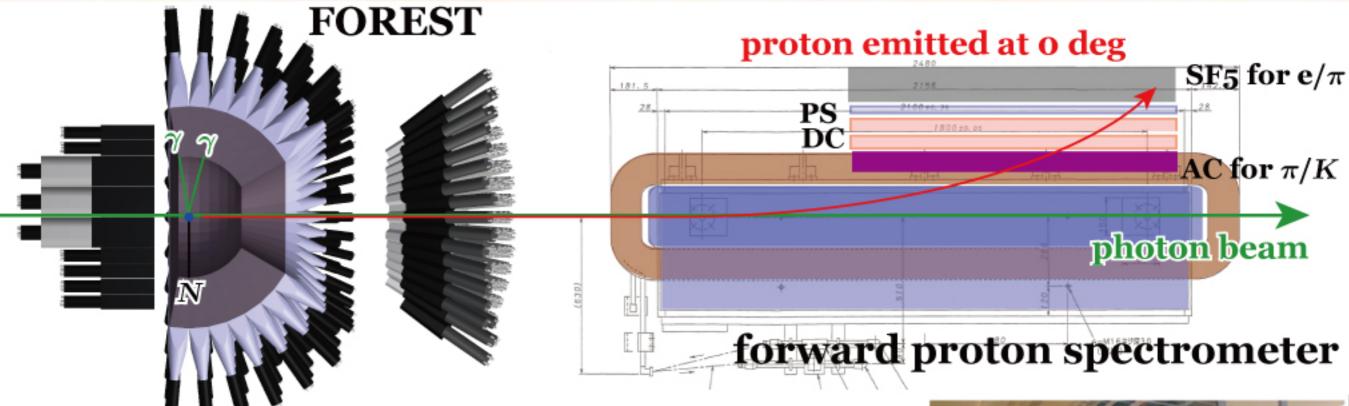
 $\eta n \rightarrow \eta n$ rescattering effect is visible at the small ηn relative momentum DCC model suggests: $a_{\eta n} = -0.7 - i0.3$ fm, $r_{\eta n} = -1.9 - i0.5$ fm $\pi n \rightarrow \eta n$ transition effect is small NN rescattering effect is small

Study of baryon resonances and meson-nucleon interactions using photoproduction reactions at ELPHi

T. Ishikawa, October 26, 2016.



Experimental setup



Proton detection at oo

bending magnet from the KEKB low energy ring plastic hodoscopes for the TOF measurement drift chambers for the momentum measurement aerogel Cherenkov counters for π/K separation SF5 lead glass Counters for e/π separation

New experiments will start in the end

of this fiscal year Study of baryon resonances and meson-nucleon interactions using photoproduction reactions at ELPHi





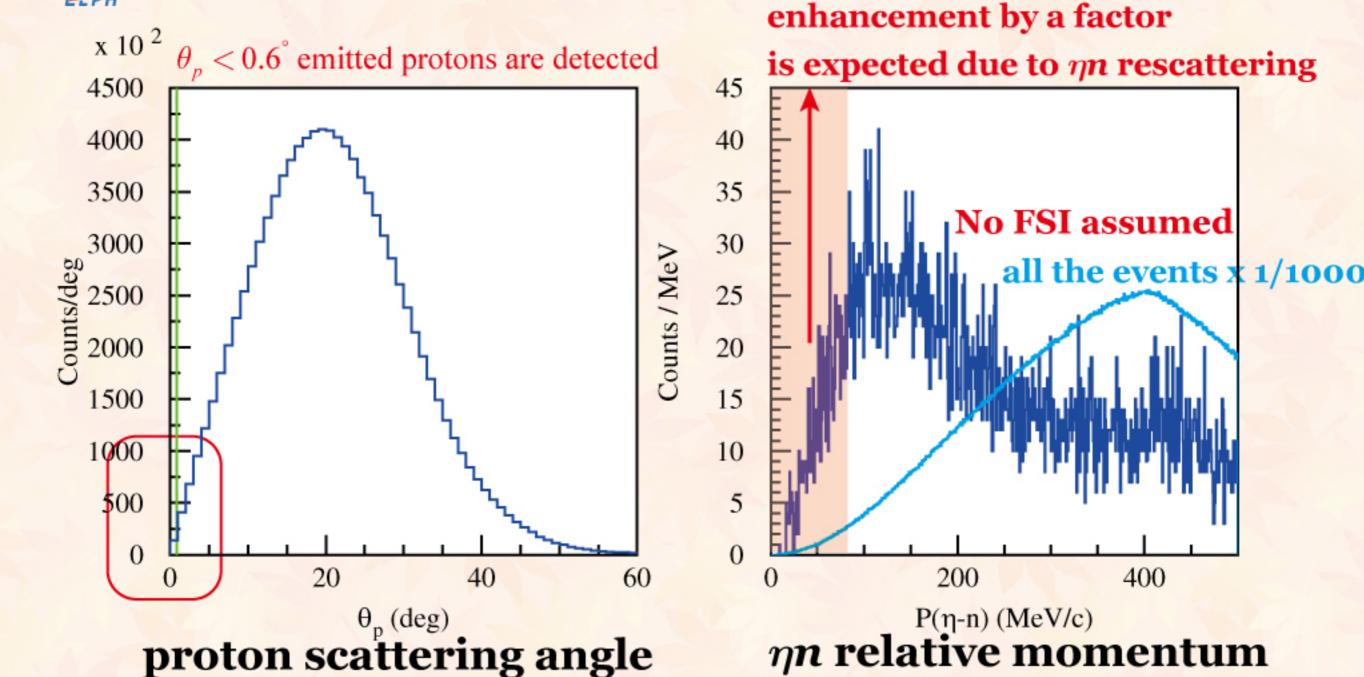
Proton missing mass resolution: 3.8~ 6.1 MeV corresponding to ηn invariant mass resolution photon tagging: 0.5~2.5 MeV emitted proton measurement:

uncertainty of the vertex z point of the STB ring 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

 ηn relative momentum: 8~13 MeV/c for 3.8 MeV $m\eta n$ mass resolution 12~20 MeV/c for 6.1 MeV $m\eta n$ mass resolution performance of the new detector system is on-going.



Experimental setup



Expected yield for a 90-day experiments at ELPH

Study of baryon resonances and meson-nucleon interactions using photoproduction reactions at ELPHi

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Summary for ηN scattering length

Low-energy ηn scattering parameters: fundamental & important little is known

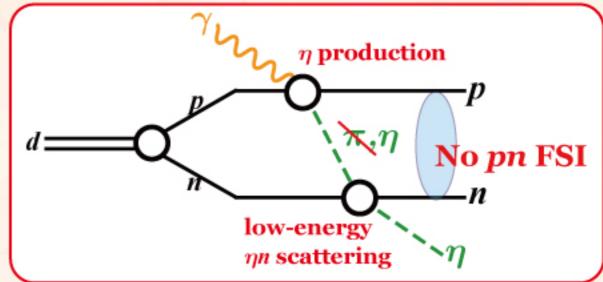
ELPH-2844 (T. Ishikawa et al.)

γd→pηn experiment is proposed using the FOREST detector at ELPH to extract aηn

 E_{γ} =930 MeV and θ_p =0° is the ideal condition:

minimum ηn relative momentum

pn rescattering effect is small $\pi n \rightarrow \eta n$ transition effect is small





Measurement of coherent $\pi^0\pi^0$ production on the deuteron to verify whether $d^*(2380)$ can be photoproduced or not no clear resonance-like behavior is observed upper limit is 0.071 ub at W=2.37 GeV (90% CL) excitation function is rather flat and inconsitent with the existing calculation w/o $d^*(2380)$

arXiv:1610.05532 (T. Ishikawa et al.)

Measurement of $\gamma d \rightarrow p \eta n$ is planned incident energy ~ 930 MeV detecting protons at 0 degrees direct measurement of ηn scattering parameters

ELPH-2844 (T. Ishikawa et al.)