ηn scattering length from the reaction $\gamma d \to p\eta n$ at E_γ~0.9 GeV

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The 14th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon

July 29, 2016.

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1. ηN interaction
2. η-mesic nuclei
3. $\gamma d \to p\eta n$ reaction at E_γ~0.9 GeV
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1.3 GeV bremsstrahlung photon beam

ηN interaction

Interaction between mesons and nucleons
fundamental & important

Neutral mesons:
not precisely determined (except for π^0)

scattering experiments: impossible
life time is very short
no beam is available

X-ray measurements: impossible
no electro-magnetic attraction
no mesic atom

ηn scattering length from the reaction $\gamma d \rightarrow p\eta n$ at E_γ~0.9 GeV

T. Ishikawa, July 29, 2016.

ηN interaction

ηN low-energy scattering parameters

combined theoretical analyses of

differential and total cross sections for

$\pi N \to \eta N$ transition, $\gamma N \to \eta N$ photoproduction

together with

$\pi N \to \pi N$ scattering, $\gamma N \to \pi N$ photoproduction

obtained scattering length $a_{\eta N}$

– Im $a_{\eta N}$: ~0.26 fm (optical theorem)

– Re $a_{\eta N}$: 0.4~1.1 fm

ηn scattering length from the reaction $\gamma d \to p\eta n$ at E_γ~0.9 GeV

T. Ishikawa, July 29, 2016.

ηN interaction

ηN low-energy scattering parameters

three-body treatment of the final state

for $np \to \eta d$ reaction

(WASA/PROMICE at CELCIUS)

H. Garzilazo and M.T. Pena, Eur. Phys. J. A 38, 209 (2008).

obtained scattering length $a_{\eta N}$

$-$Re $a_{\eta N}$: 0.4~1.1 fm$\to$0.4~0.6 fm

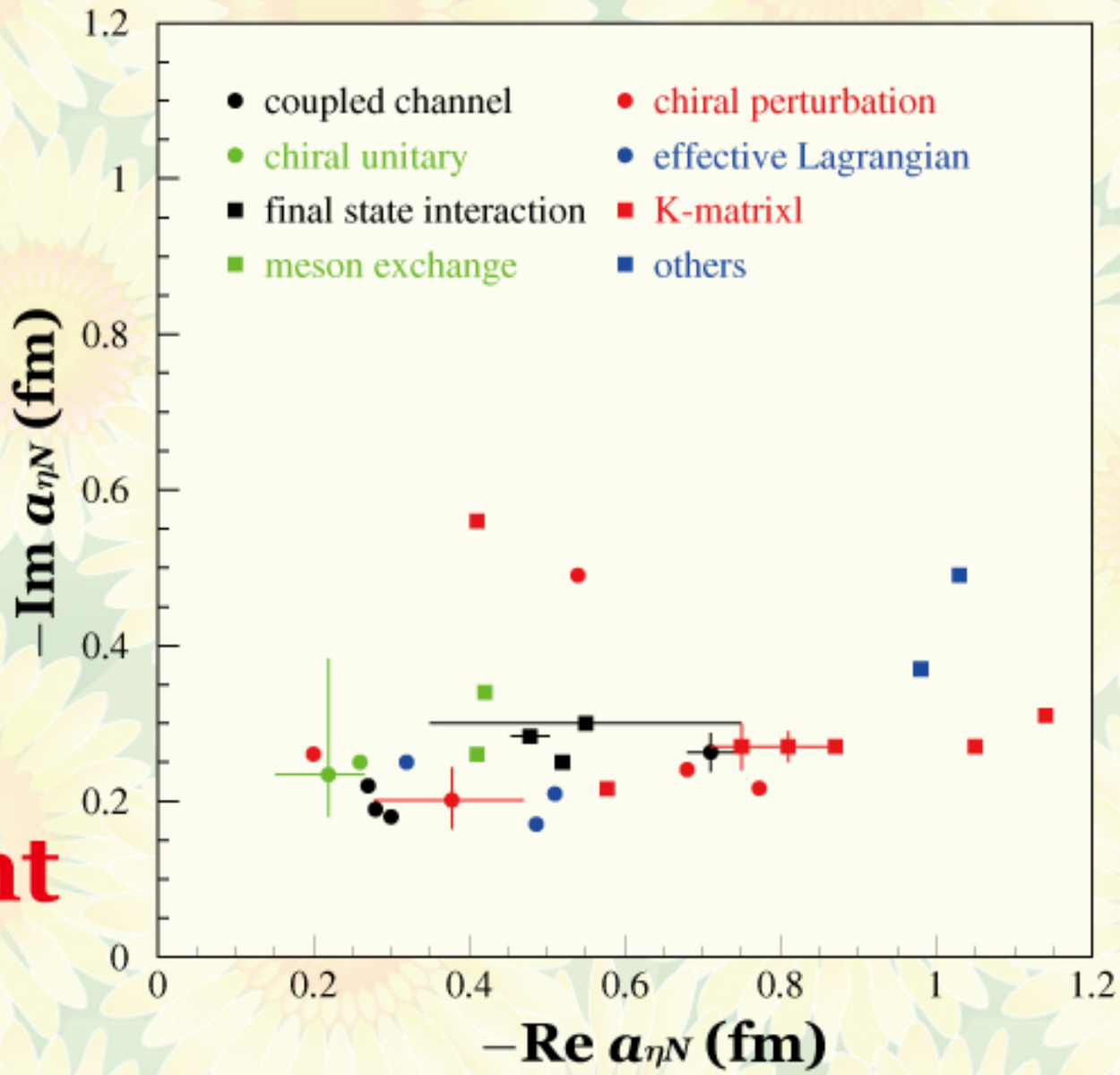
(depending on the treatement of σ)

ηN interaction

scattering length $a_{\eta N}$

indirectly determined

real part is scattered



a direct measurement

of $a_{\eta N}$ is desired

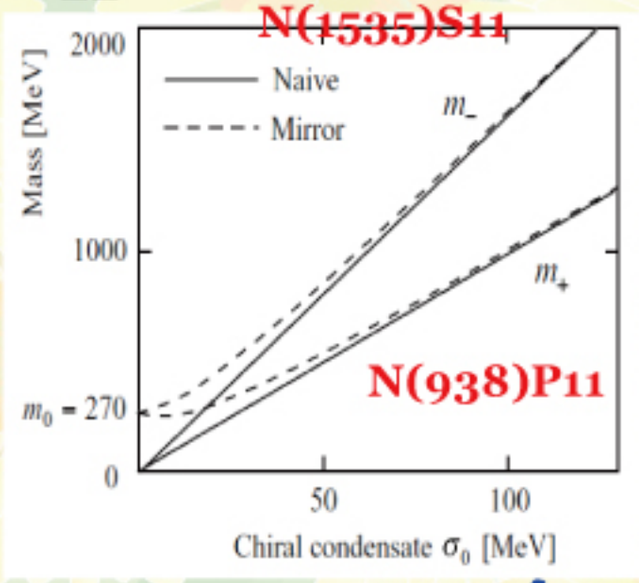
Q. Haider and L.C. Liu,
J. Mod. Phys. E 24, 1530009 (2015).

η-mesic nuclei

Scattering length $a_{\eta N}$ affects
the existence of an exotic nuleus:
η-nucleus bound state (η-mesic nucleus)
pure strong interaction

first prediction Q. Haider and L.C. Liu,
Phys. Lett. B 172 (1986) 257; B 174 (1986) 465E.

search for η-mesic nuclei
in-medium properties of $N(1535)S_{11}$
strongly couples to ηN
chiral partner of the nucleon



T. Hatsuda and M. Prakash, Phys. Lett. B 224, 11 (1989);
C. DeTar and T. Kunihiro, Phys. Rev. D 39, 2805 (1989).

ηn scattering length from the reaction $\gamma d \to p\eta n$ at E_γ~0.9 GeV

T. Ishikawa, July 29, 2016.

η-mesic nuclei

η meson in free space

N^*-N

48 MeV

η

attractive

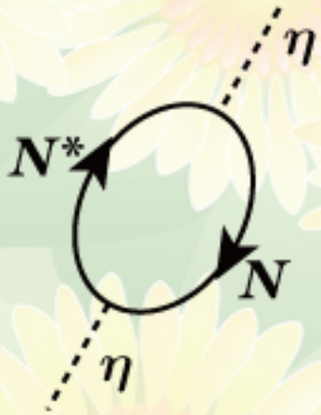
η meson in a nucleus

η

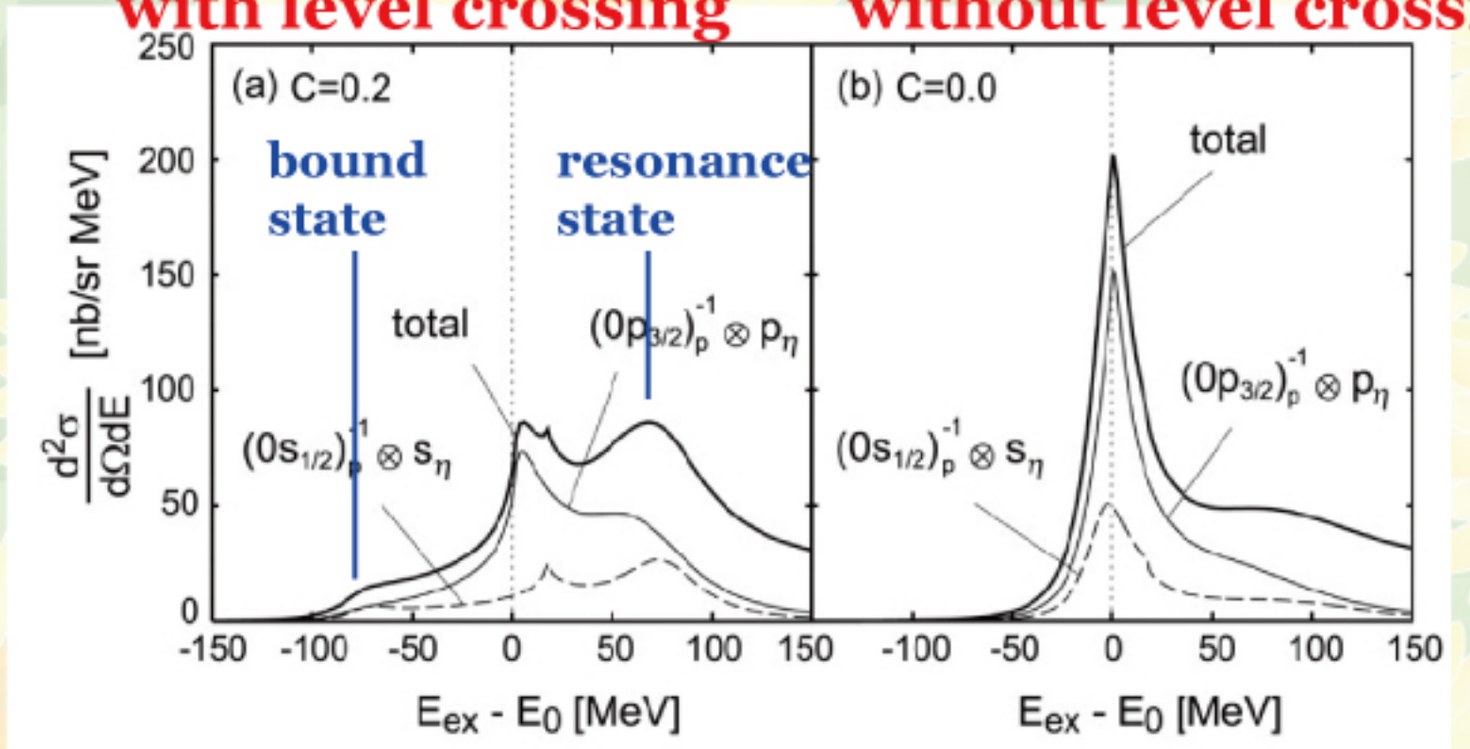
repulsive
medium effect

N^*-N

level crossing



with level crossing **without level crossing**



Expected spectra for the $\gamma^{12}C \to pX$ reaction

$E_0 = m_{^{11}B} + m_\eta$

H. Nagahiro, D. Jido, S. Hirenzaki, Nucl. Phys. A 761, 92 (2005);

D. Jido, E.E. Kolomeitsev, H. Nagahiro, S. Hirenzaki, Nucl. Phys. A 811, 158 (2008).

η-mesic nuclei

Some hints for light η-mesic nuclei (ηN interaction)

$dp \to {}^3\mathrm{He}\eta$, $dd \to {}^4\mathrm{He}\eta$:

SATURNE **attractive** $a_{^3\mathrm{He}\text{-}\eta} \sim -2.3 + i3.2$ fm, $a_{^4\mathrm{He}\text{-}\eta} \sim -2.2 + i1.1$ fm

W. Willis et al., Phys. Lett. B 406, 14 (1997).

COSY-11 $|a_{^3\mathrm{He}\text{-}\eta}| = 4.3 \pm 0.5$ fm

J. Smyrski et al., Phys. Lett. B 649, 258 (2007).

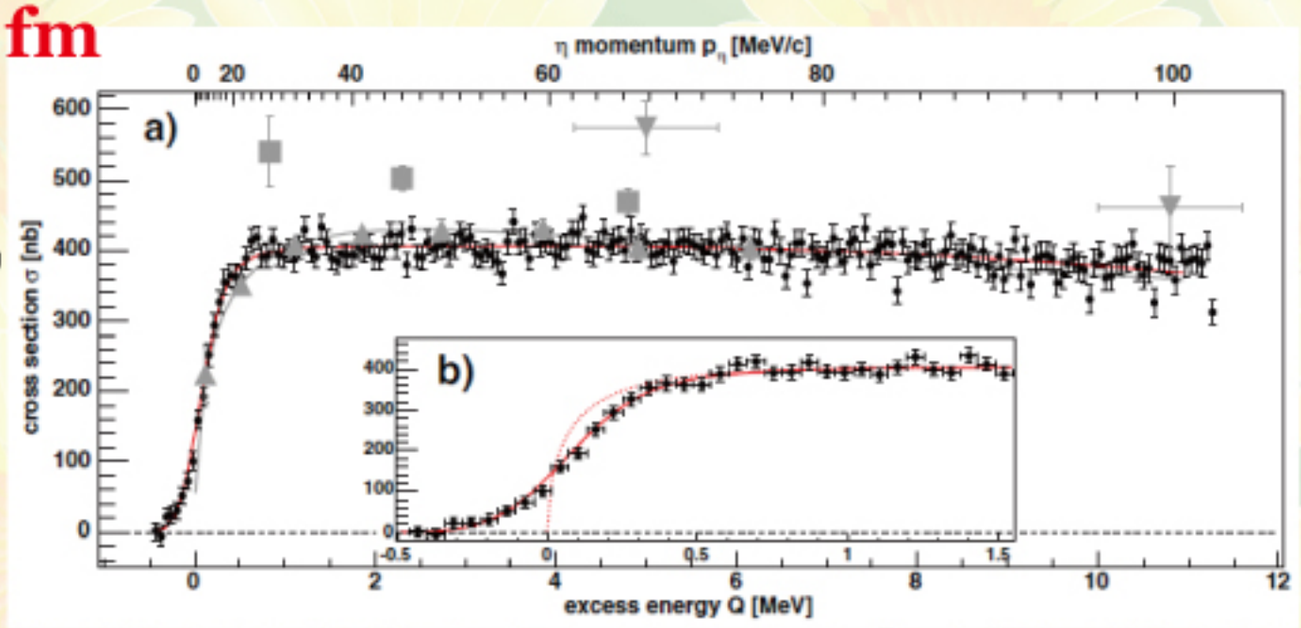
COSY-ANKE $a_{^3\mathrm{He}\text{-}\eta} \sim \pm 10.9 + i1.0$ fm

C. Wilkin et al., Phys. Lett. B 654, 92 (2007);
T. Mersmann et al., Phys. Rev. Lett. 98, 242301 (2007).

$a_{^3\mathrm{He}\text{-}\eta} \sim \pm(10.7 \pm 0.8^{+0.1}_{-0.5}) + i1.5 \pm 2.6^{+0.1}_{-0.5}$ fm

COSY-WASA

P. Moskal, M. Skurzok et al.,
arXiv:1602.06767 (2016).

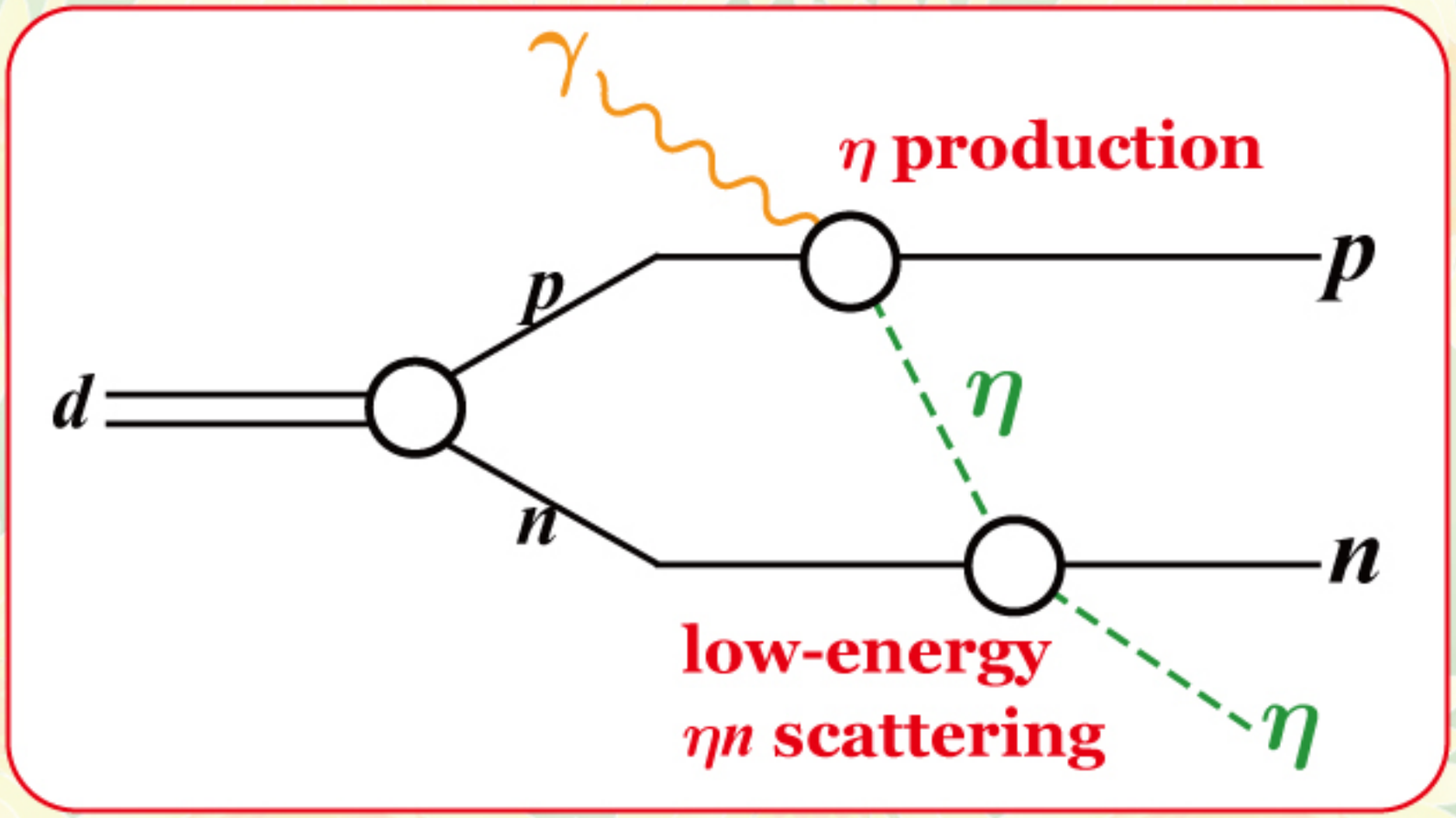


ηn scattering length from the reaction $\gamma d \to p\eta n$ at $E_\gamma \sim 0.9$ GeV

T. Ishikawa, July 29, 2016.

$\gamma d \to p\eta n$ reaction at E_γ~0.9 GeV

Proposed reaction to extract ηn scattering length

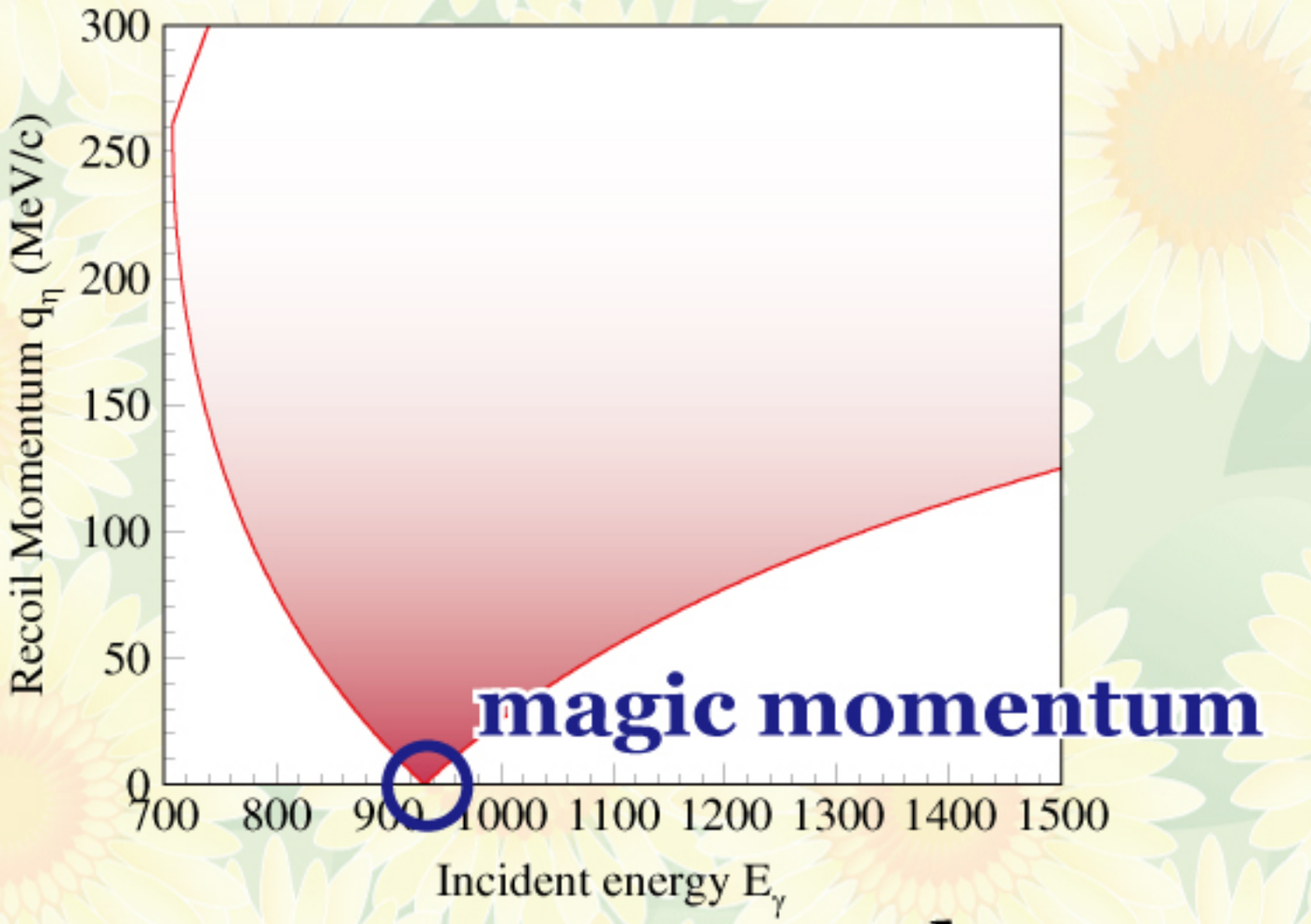


To be considered:

contirbution of the $\eta n \to \eta n$ reaction

$\gamma d \rightarrow p\eta n$ reaction at E_γ~0.9 GeV

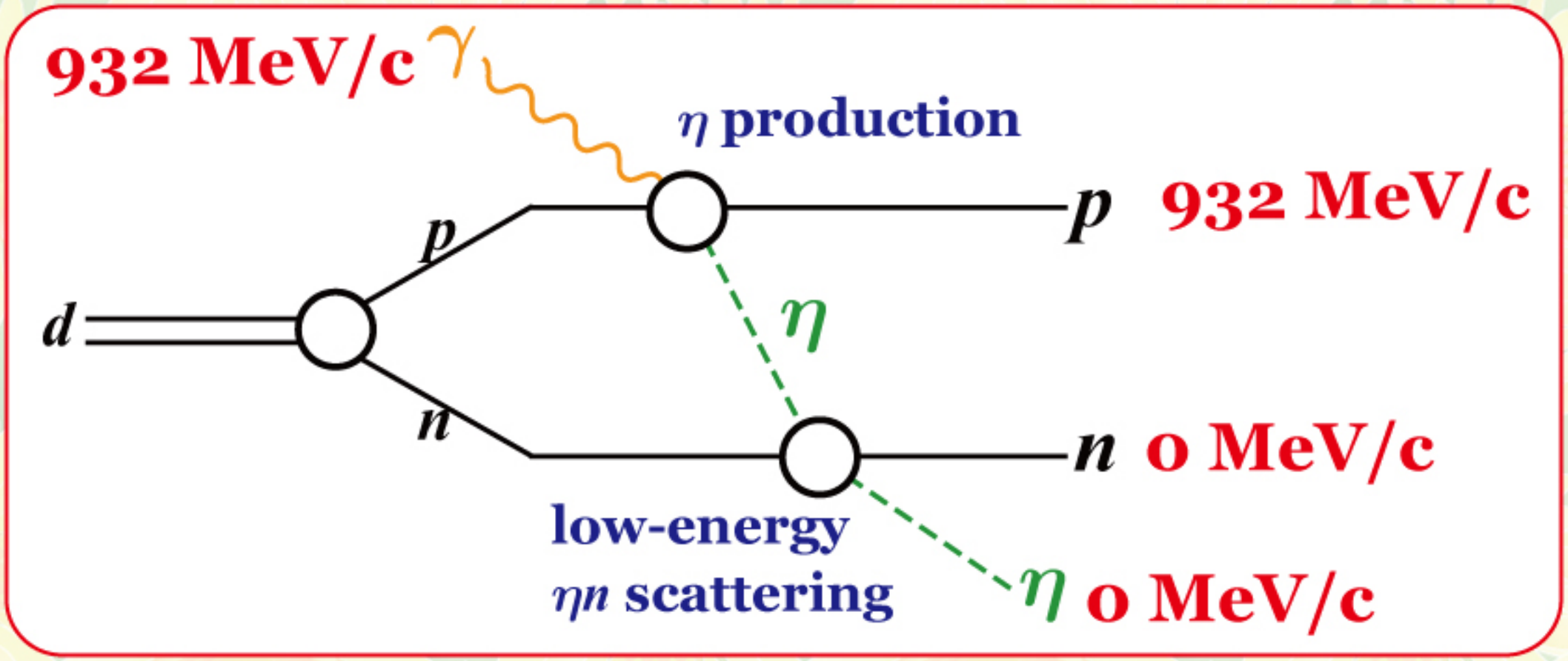
recoil momentum of η for the $\gamma p \rightarrow p\eta$ reaction



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

$\gamma d \to p\eta n$ reaction at E_γ~0.9 GeV

Proposed reaction to extract ηn scattering length



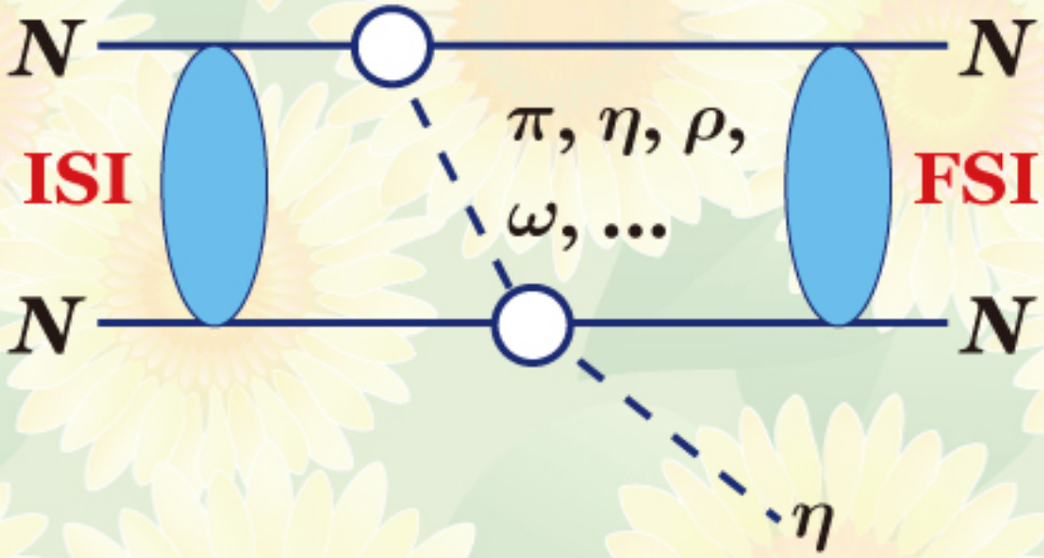
The FSI between ηp and pn is expected to be suppressed.

The Fermi motion should be taken into account though.

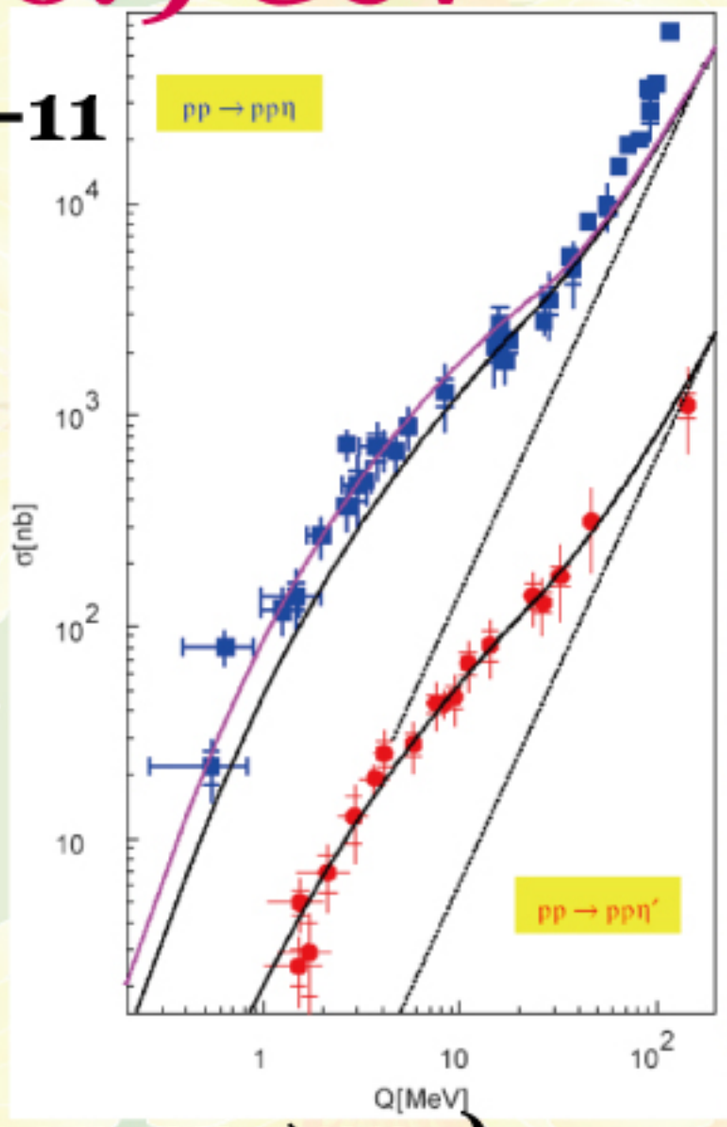
$\gamma d \to p\eta n$ reaction at E_γ~0.9 GeV

How abount $pp \to pp\eta$?

enhancement near the threshold



COSY-11



isospin depedence rejects η, ω exchanges

(cross section for $pn \to pn\eta$ is much larger than $pp \to pp\eta$)

P. Moskal et al., Prog. Part. Nucl. Phys. 49, 1 (2002).

analyzing power as a function of θ_η rejects ρ exchanges

R. Czyzykiewicz et al., Phys. Rev. Lett. 98, 122003 (2007).

$\gamma d \to p\eta n$ reaction at E_γ~0.9 GeV

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.

$\gamma d \to p\eta n$ reaction at E_γ~0.9 GeV

DCC model

coupled channel Lippman-Schwinger equation for meson-baryon scattering

A. Matsuyama, T. Sato, T.-S.H. Lee, Phys. Rept. 439, 193 (2007).

H. Kamano et al., Phys. Rev. C 88, 035209 (2013).

coupled channel

meson-baryon Green function including quasi two-body channels

$$T_{ab} = V_{ab} + \sum_c V_{ac} G_c T_{cb}$$

transition potential

exchange (*s*, *t*, *u*, and contact)

Z-diagrams (transition between quasi two-body channels)

bare N* states

full consideration

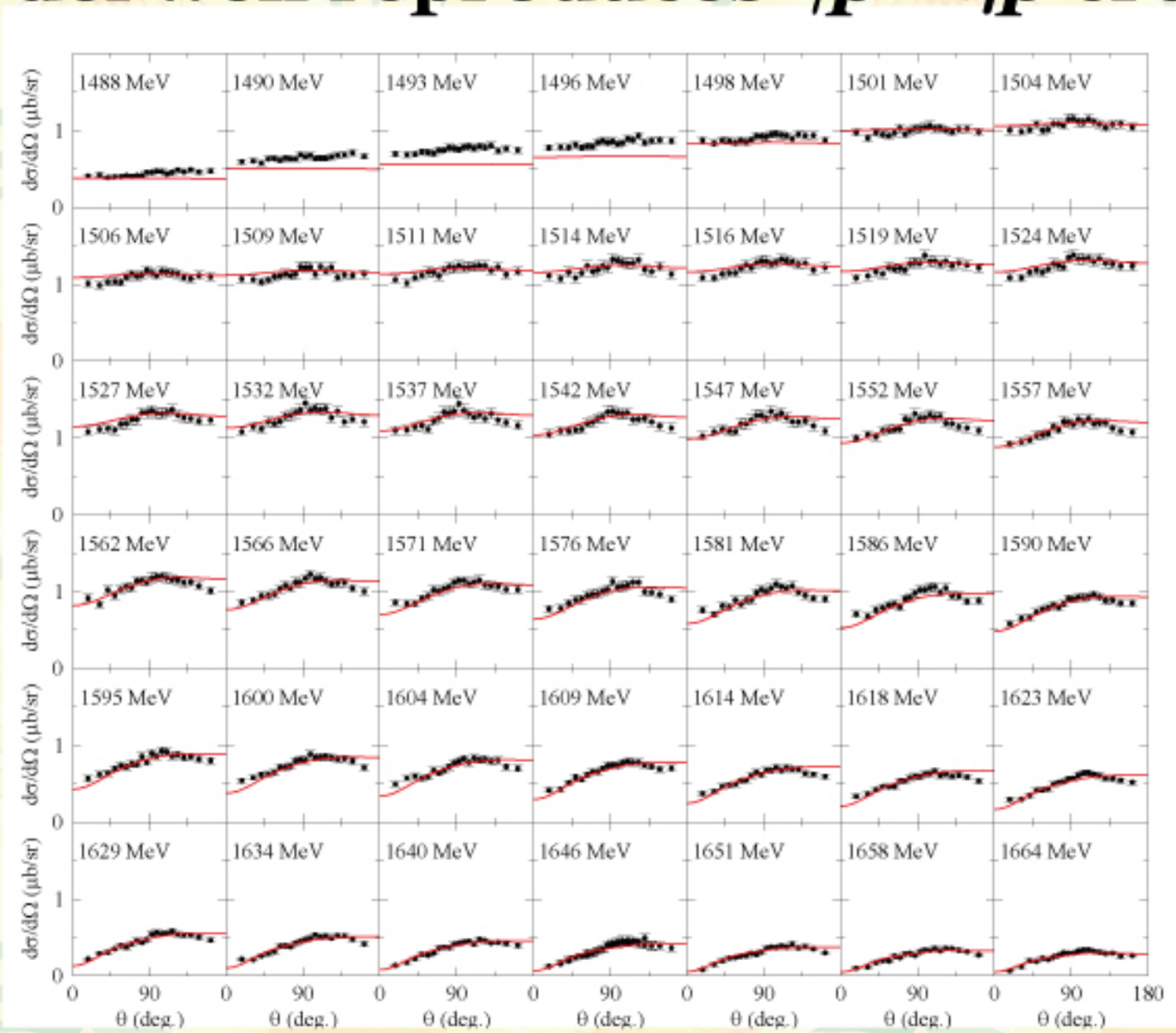
coupled-channel unitarity

on- and off-shell amplitudes

$$\{a,b,c\} = \gamma^{(*)}N, \pi N, \eta N, \underbrace{\pi\Delta, \sigma N, \rho N}_{\pi\pi N}, K\Lambda, K\Sigma, \ldots$$

$\gamma d \to p\eta n$ reaction at E_γ~0.9 GeV

DCC model well reproduces $\gamma p \to \eta p$ cross sections

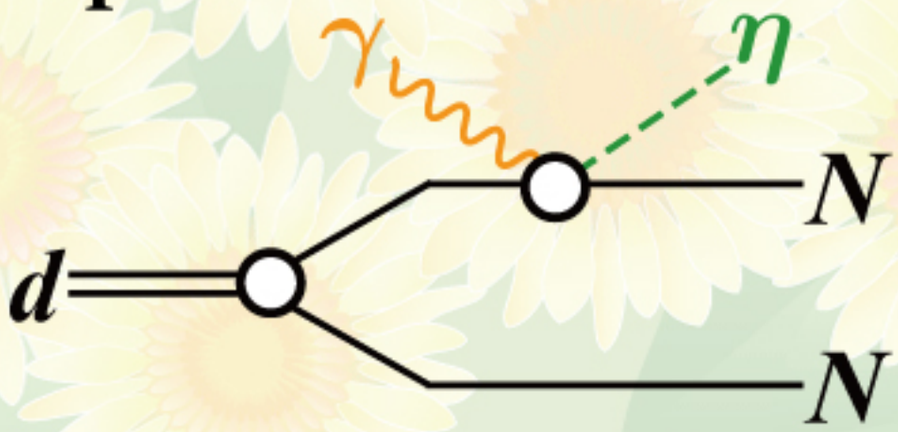


H. Kamano et al., Phys. Rev. C 88, 035209 (2013).

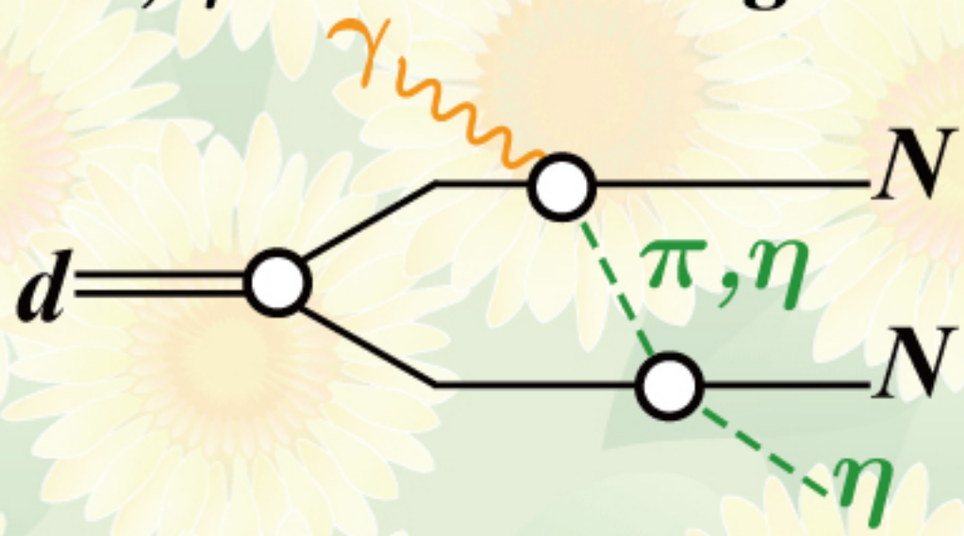
$\gamma d \to p\eta n$ reaction at E_γ~0.9 GeV

Model for $\gamma d \to \eta np$

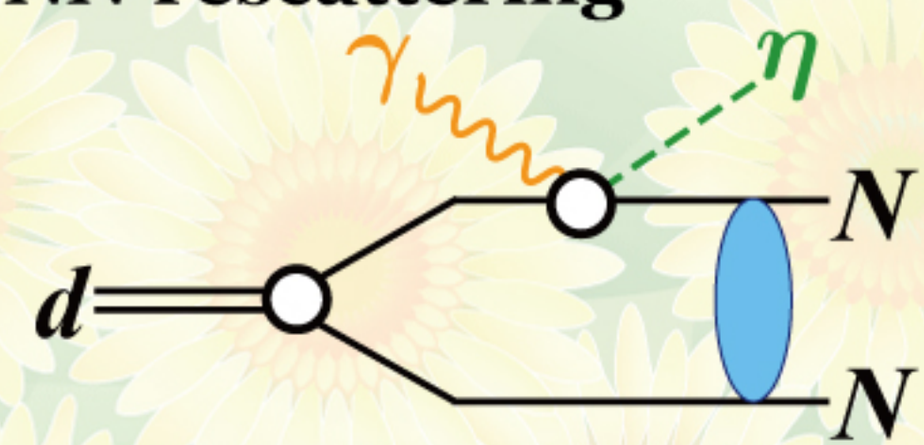
impulse



πN, ηN rescattering



***NN* rescattering**



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

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

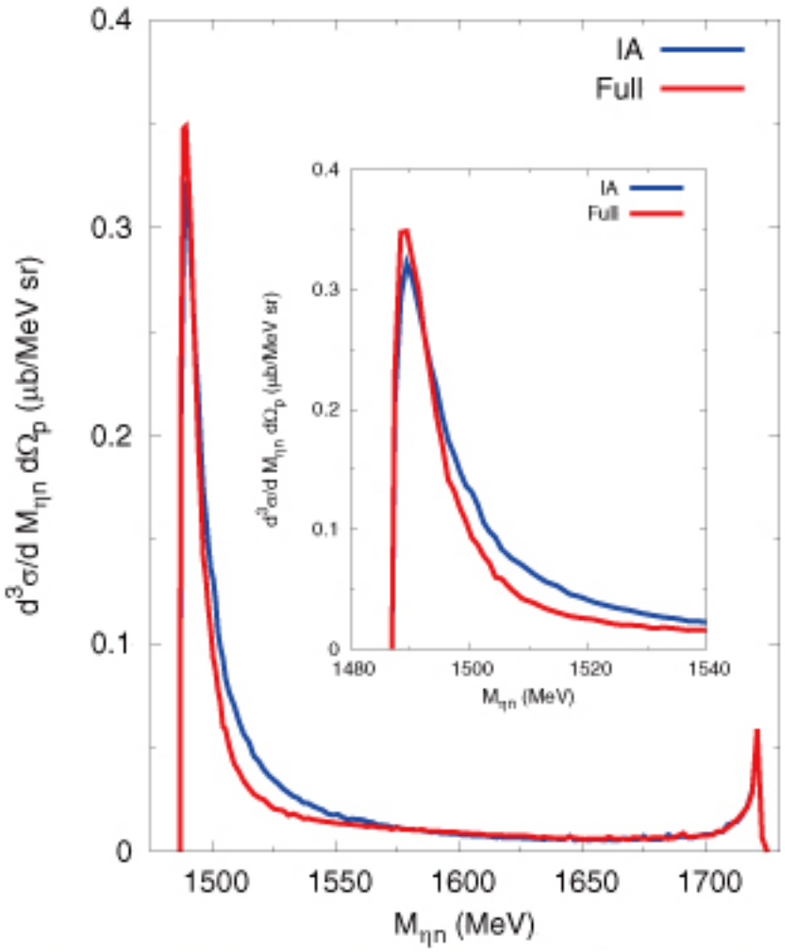
off-shell effects

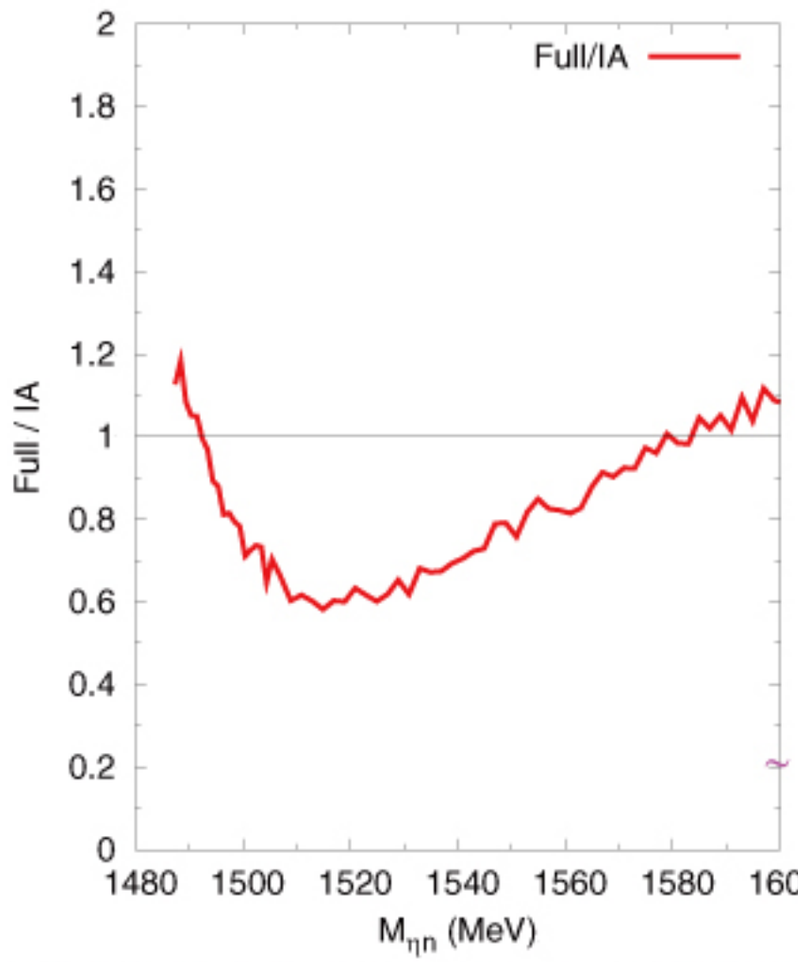
$\gamma d \to p\eta n$ reaction at E_γ~0.9 GeV

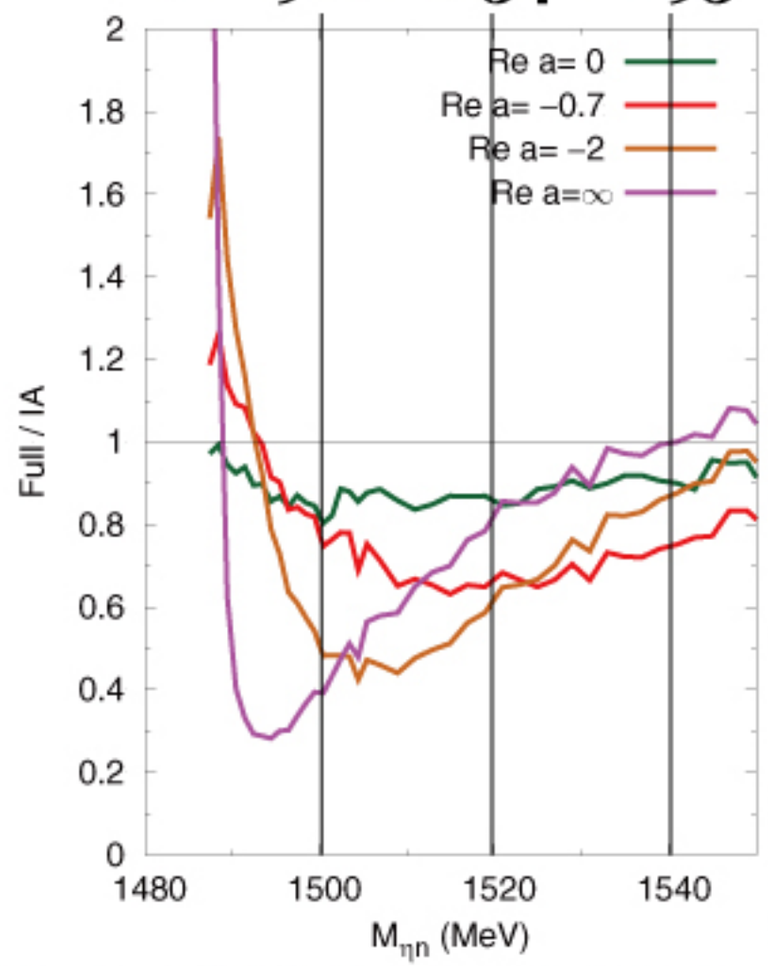
E_γ=950 MeV and θ_p=0°

ηn relative momentum (MeV/c)

98 154 195







$\eta n \to \eta n$ 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

$\pi n \to \eta n$ transition effect is small

NN rescattering effect is small

Experimental setup

Electron Beam **after the earthquake**

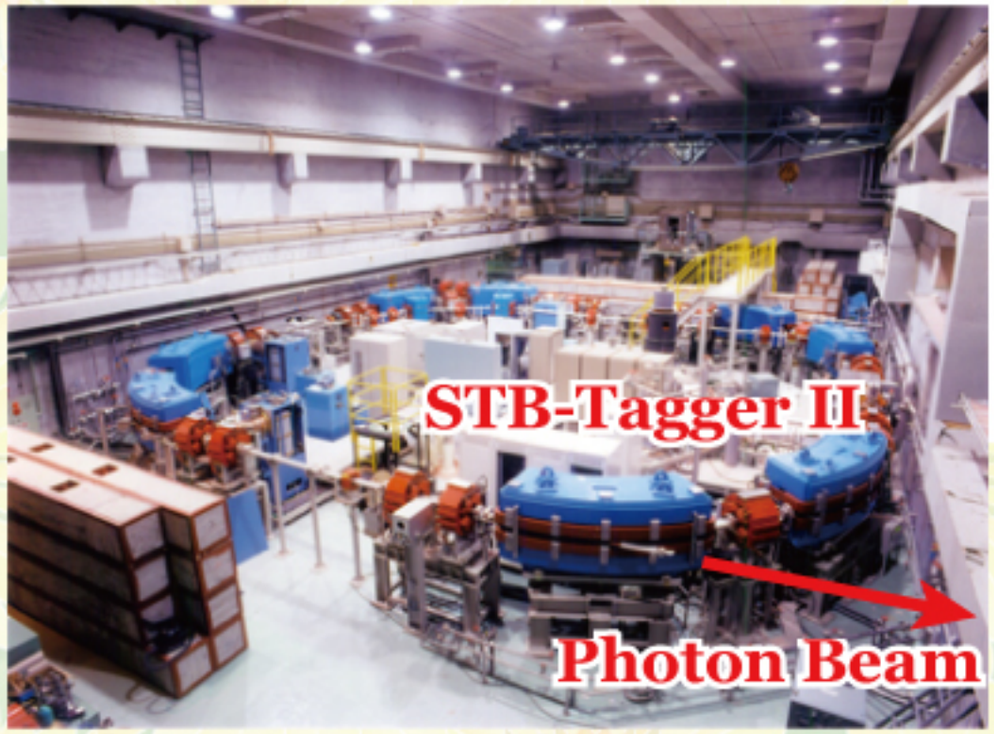
LINAC 150 MeV →93 MeV

Booster Ring 1200 MeV (max) →1300 MeV

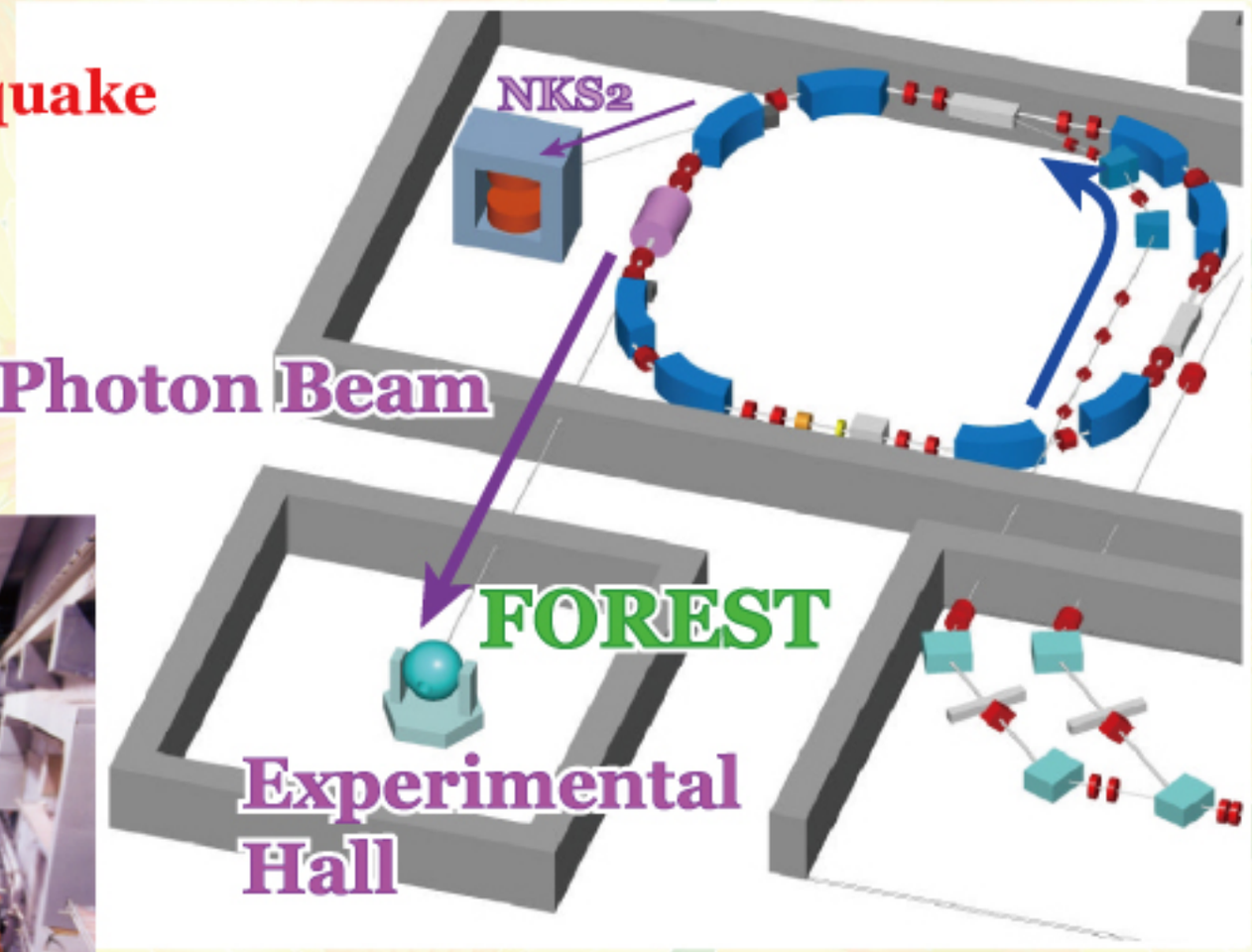
Photon Beam

Bremsstrahlung

Tagged



1.3 GeV Booster STorage Ring



Typical Tagging Rate

20 MHz (photon: 10 MHz)

Bremsstrahlung Tagged Photon Beam

740~1150 MeV @ 1200 MeV

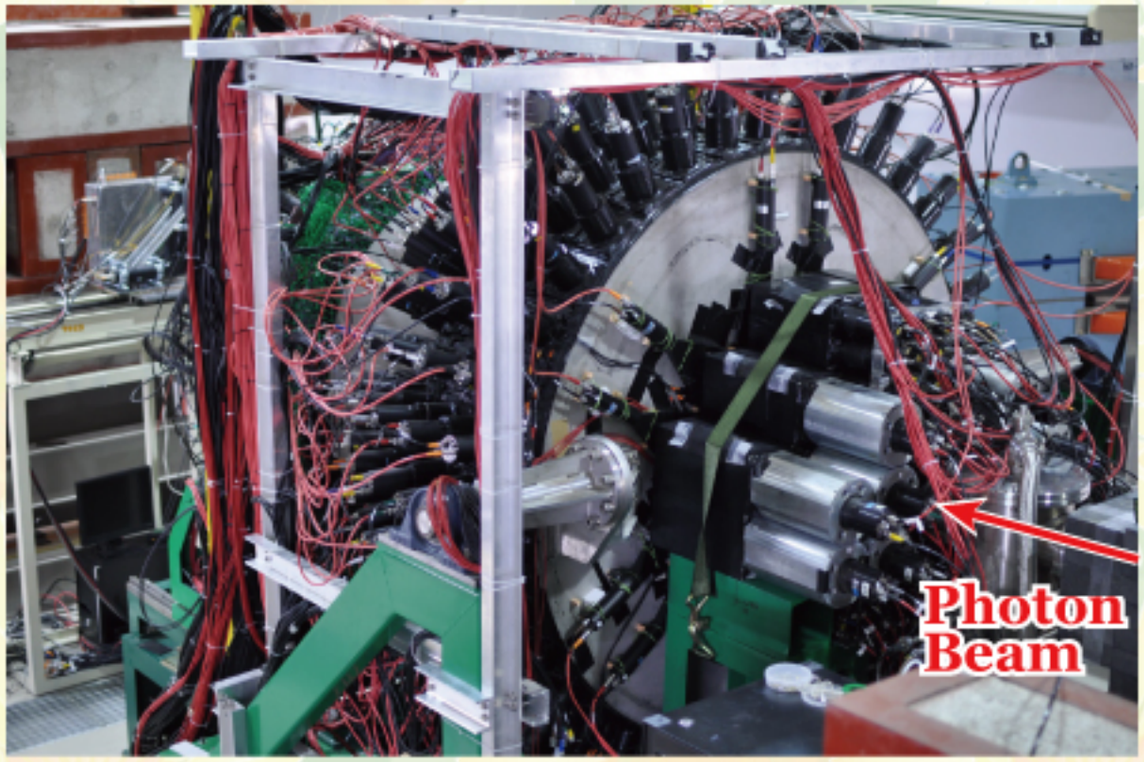
570~890 MeV @ 930 MeV

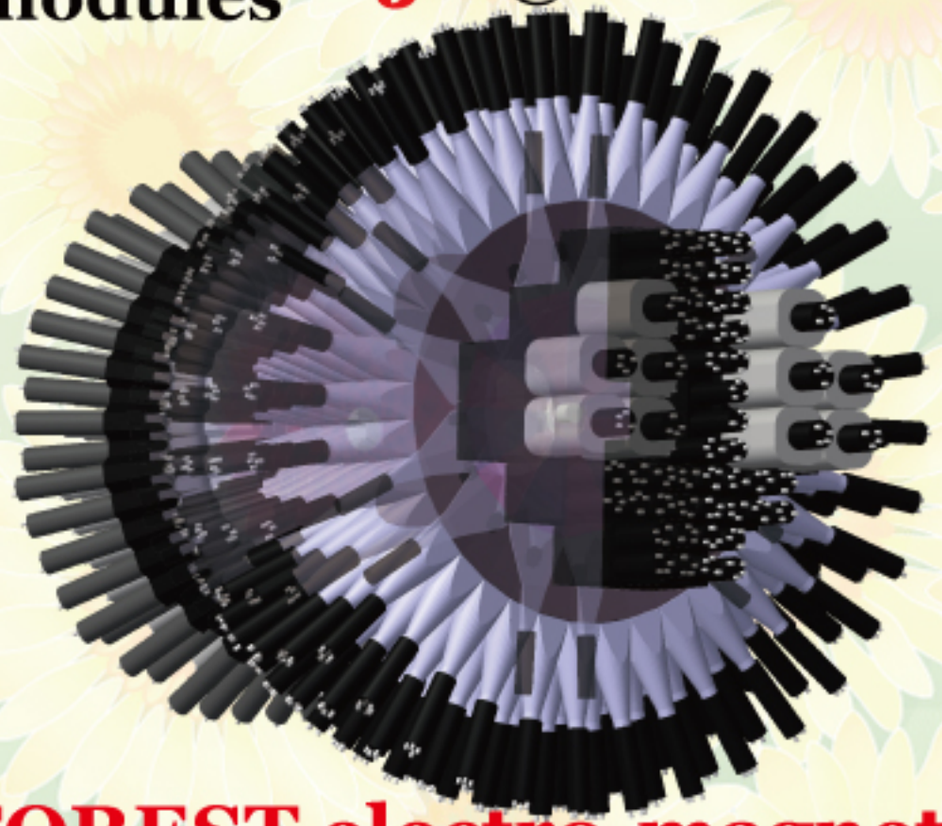
δE: **1~2 MeV**

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

T. Ishikawa et al., Nucl. Instr. Meth. A 811, 124 (2016).

Experimental setup





FOREST electro-magnetic calorimeter

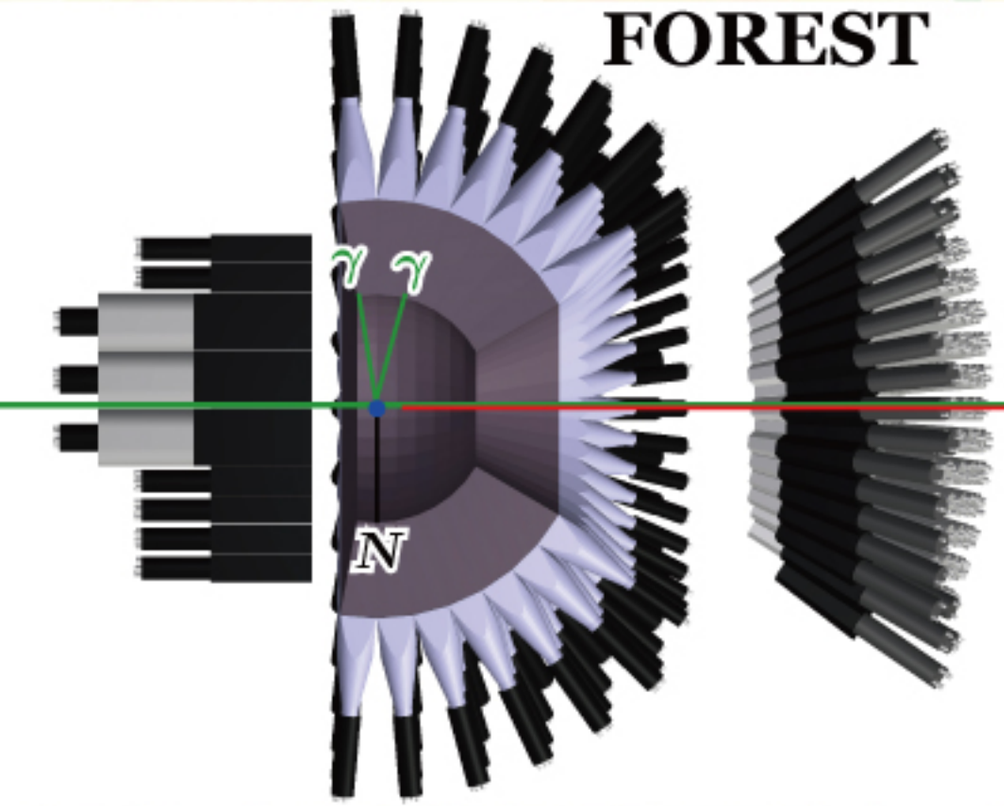
Target: 45 mm thick LH2 & LD2

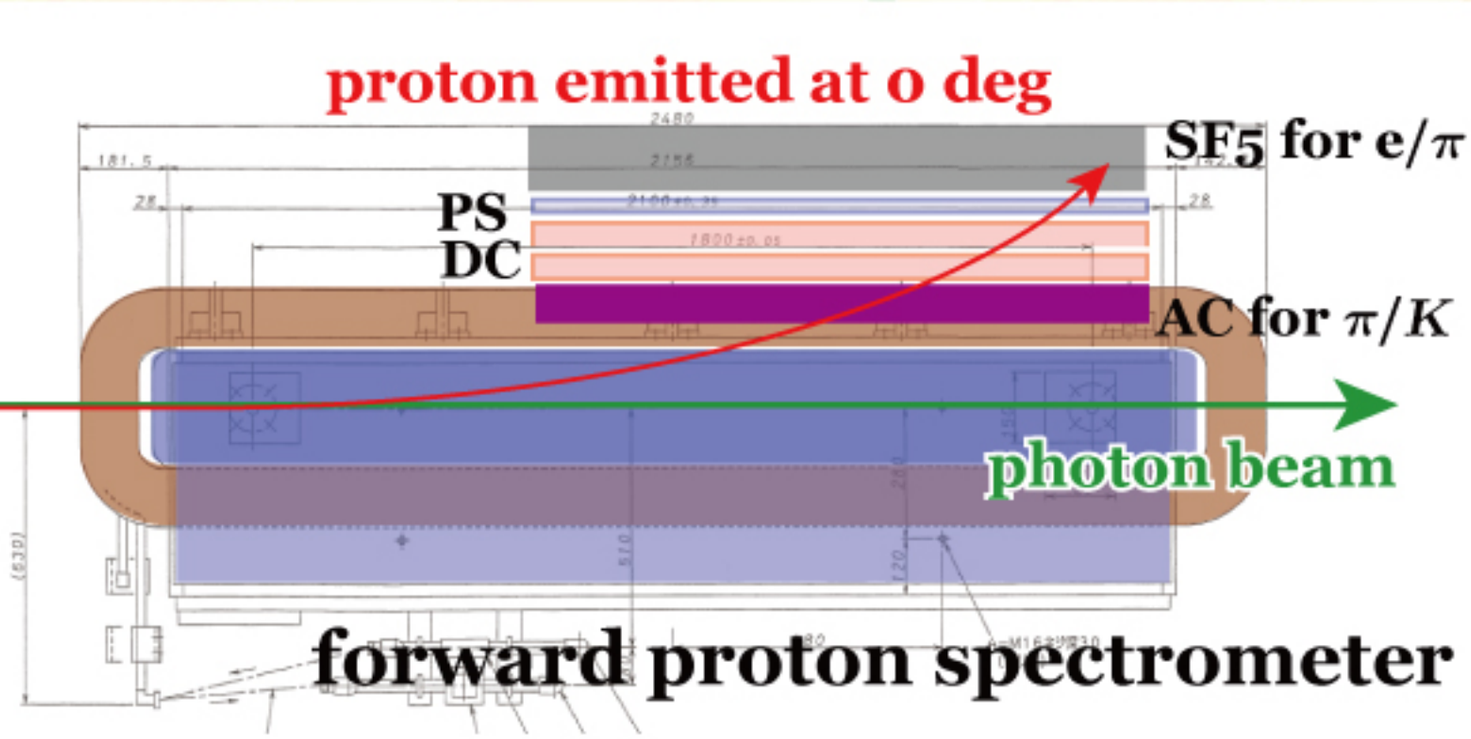
T. Ishikawa et al., Nucl. Instr. Meth. A 832, 108 (2016).

ηn scattering length from the reaction $\gamma d \to p\eta n$ at E_γ~0.9 GeV

T. Ishikawa, July 29, 2016.

Experimental setup





Proton detection at 0°

- beding 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 year

ηn scattering length from the reaction $\gamma d \rightarrow p\eta n$ at E_γ~0.9 GeV

T. Ishikawa, July 29, 2016.

Experimental setup

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

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

TOF start: RF signal of the STB ring

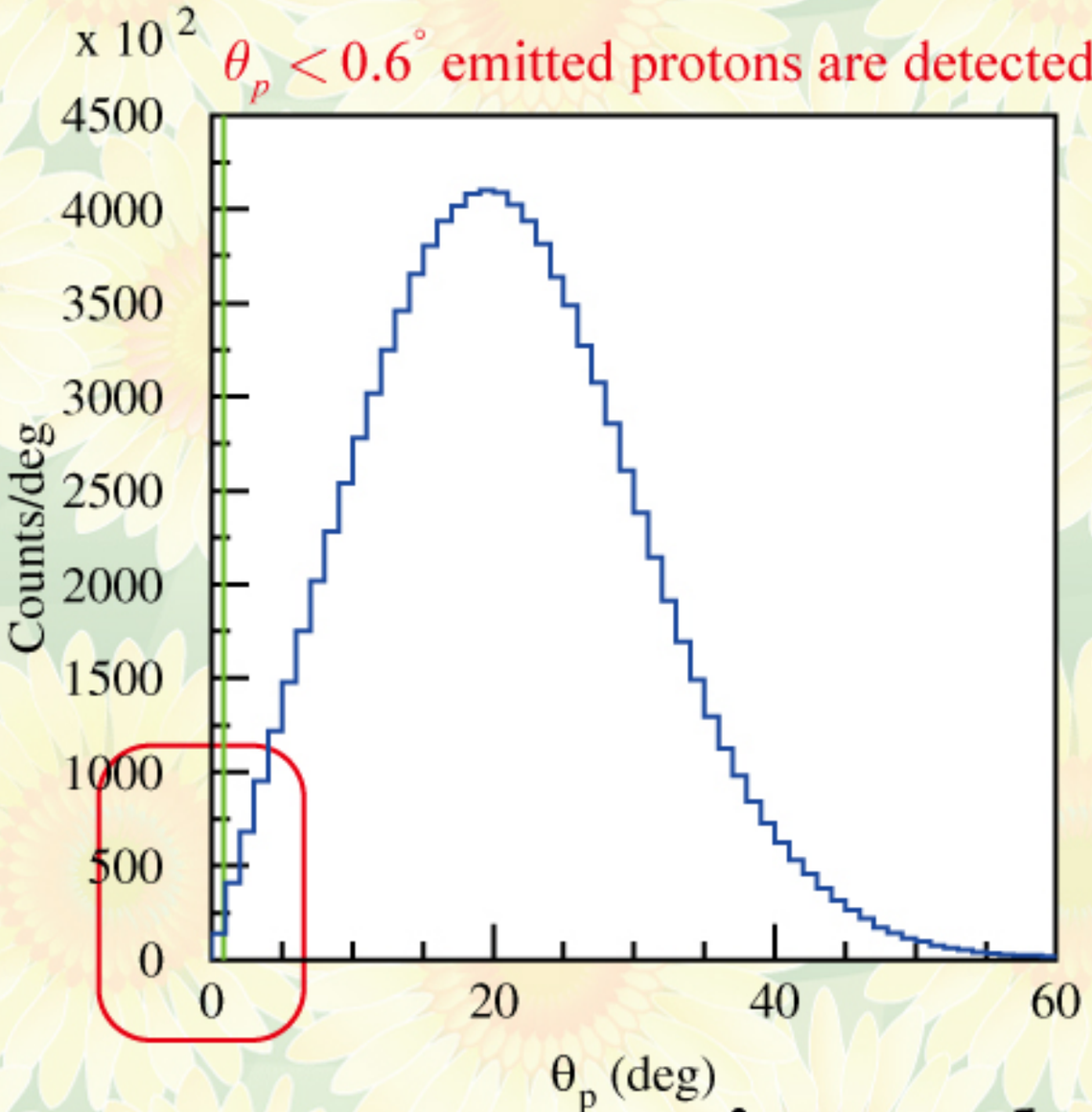
ηN relative momentum:

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

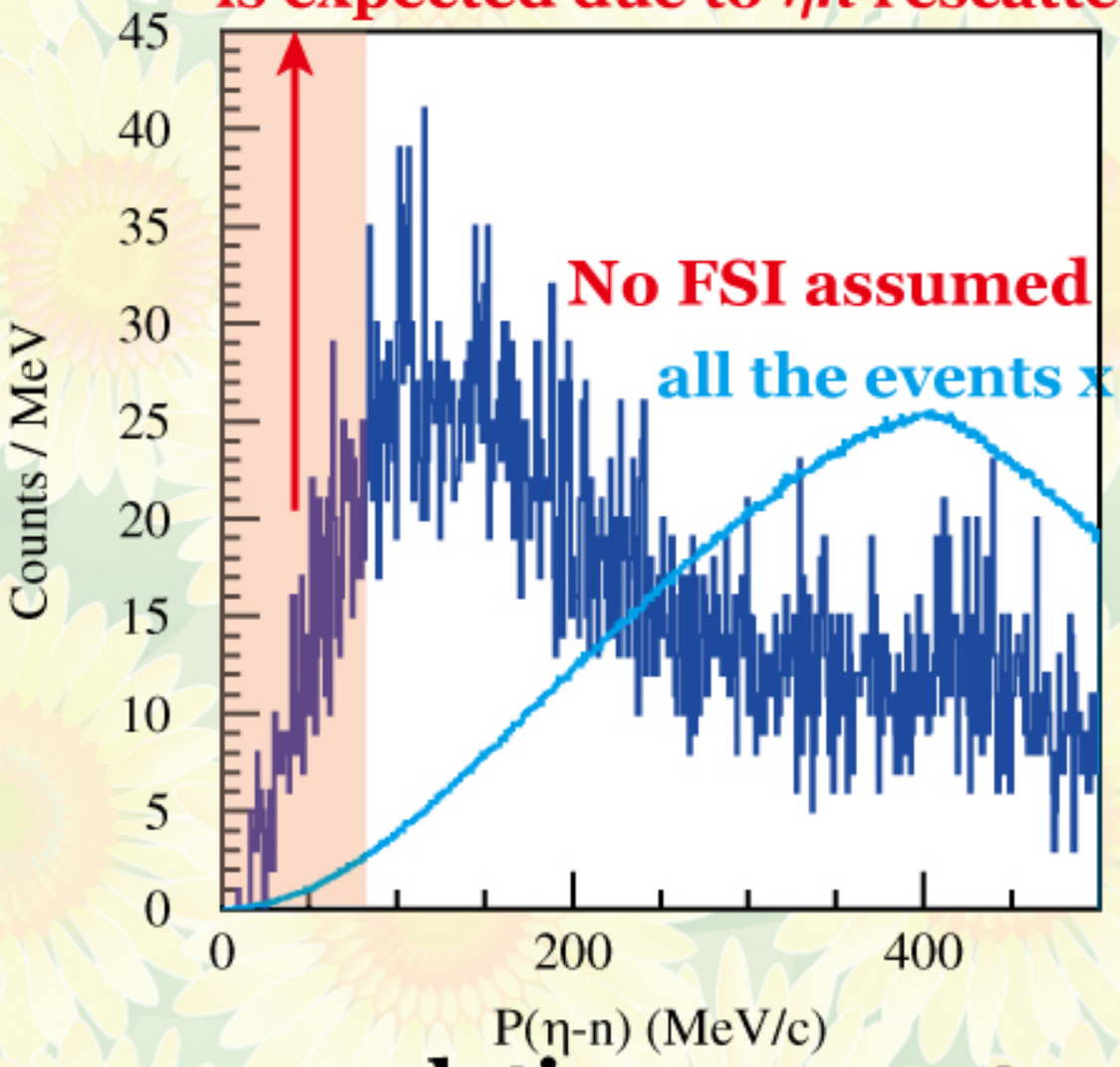
performance of the new detector system is on-going.

Experimental setup



proton scattering angle

enhancement by a factor is expected due to ηn rescattering



ηn relative momentum

Expected yield for a 90-day experiments at ELPH

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ηn scattering length from the reaction $\gamma d \rightarrow p\eta n$ at E_γ~0.9 GeV

T. Ishikawa, July 29, 2016.

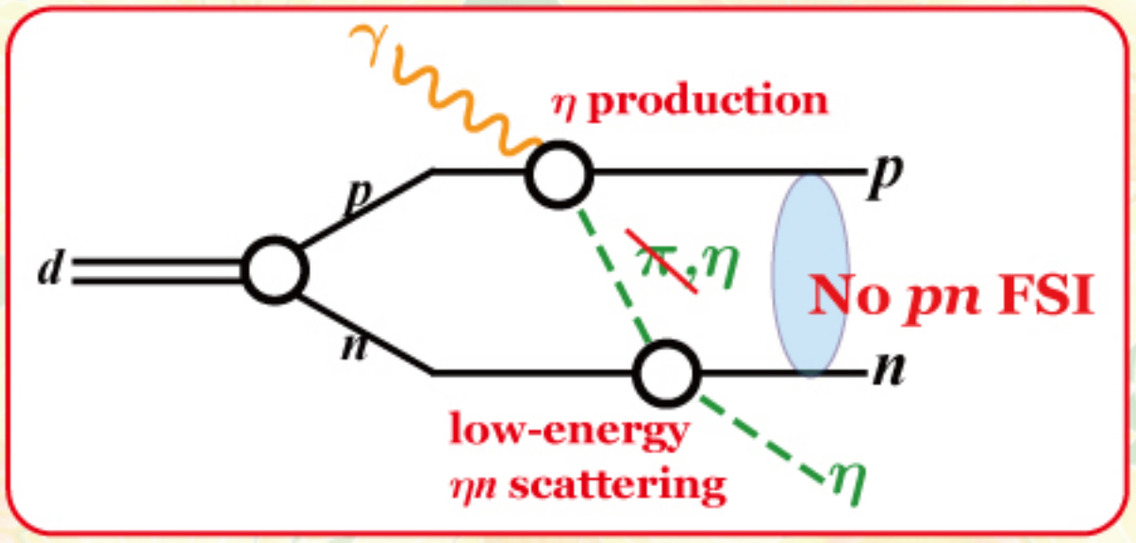
Summary

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

ELPH-2844 (T. Ishikawa *et al.*)

$\gamma p \to p\eta n$ experiment is proposed
using the FOREST detector at ELPH to extract $a_{\eta n}$

E_γ=930 MeV and θ_p=0° is the ideal condition:
minimum ηn relative momentum
***pn* rescattering effect is small**
$\pi n \to \eta n$ transition effect is small



Details of the theoretical calculation:
S.X. Nakamura,
Meson in Nucleus 2016, August 1, 2016.

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ηn scattering length from the reaction $\gamma d \to p\eta n$ at E_γ~0.9 GeV
T. Ishikawa, July 29, 2016.

ELPH-2844 collaborators

T. Ishikawa, **Y. Honda**, **Y. Inoue**, **M. Miyabe**, **Y. Matsumura**,
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Institute of Particle and Nuclear Study, KEK

Y. Tsuchikawa
Department of Physics, Nagoya University

Backup slides

$\gamma d \to p\eta n$ reaction at E_γ~0.9 GeV

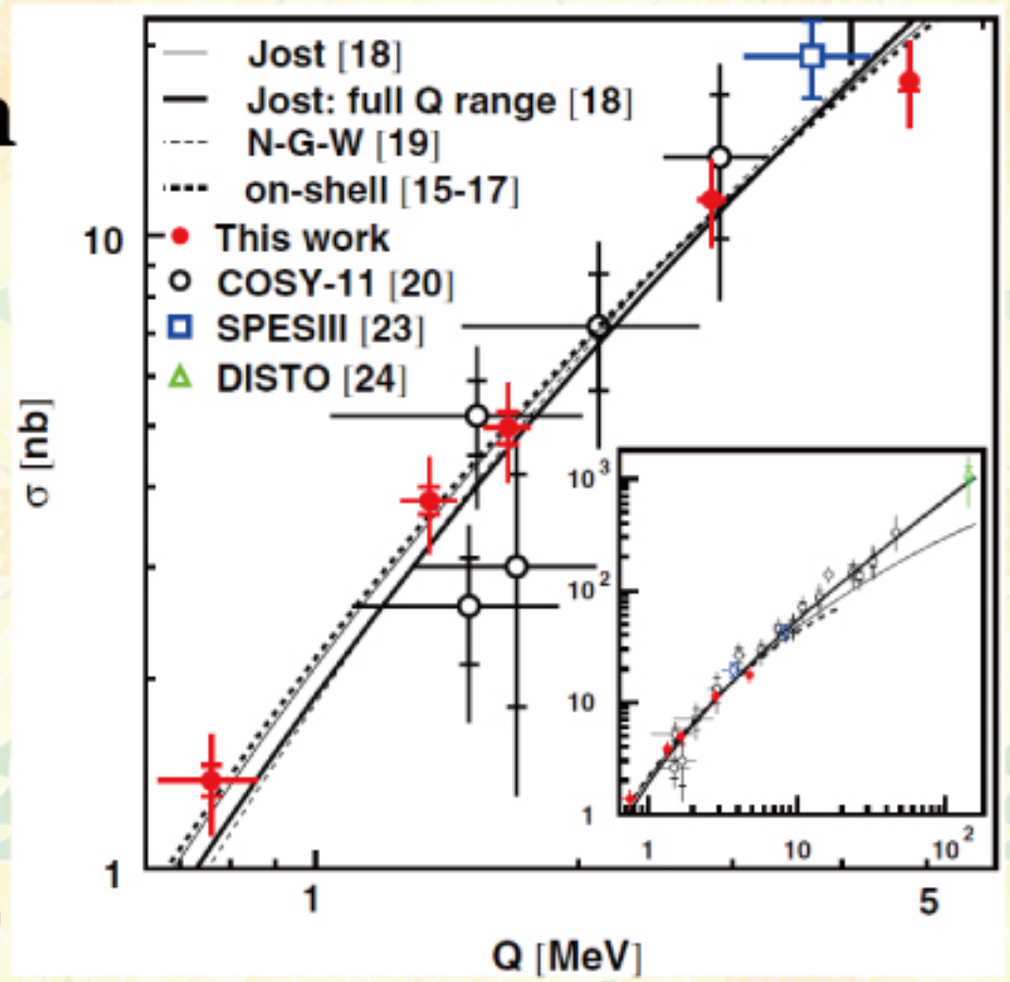
scattering length $a_{\eta' N}$

Im $a_{\eta' N}$: $0.37\ ^{+0.02\ +0.38}_{-0.11\ -0.05}$ fm

Re $a_{\eta' N}$: $0.00 \pm 0.43 \pm 0.00$ fm

by the final state interaction

for $pp \to pp\eta'$ (COSY-11)



How abount $pp \to pp\eta$?

E. Czerwinski, P. Moskal et al.,
Phys. Rev. Lett. 113,062004 (2014).

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ηn scattering length from the reaction $\gamma d \to p\eta n$ at E_γ~0.9 GeV

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