ηN scattering parameters and possible $\eta' d$ bound state from η photoproduction on the deuteron

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Contents

FOREST/BLC experiments

ELPH is a university-based accelerator facility in Japan

1.3 GeV bremsstrahlung photon beam

FOREST/BLC exp

1. high-intensity photon beam bremsstrahlung

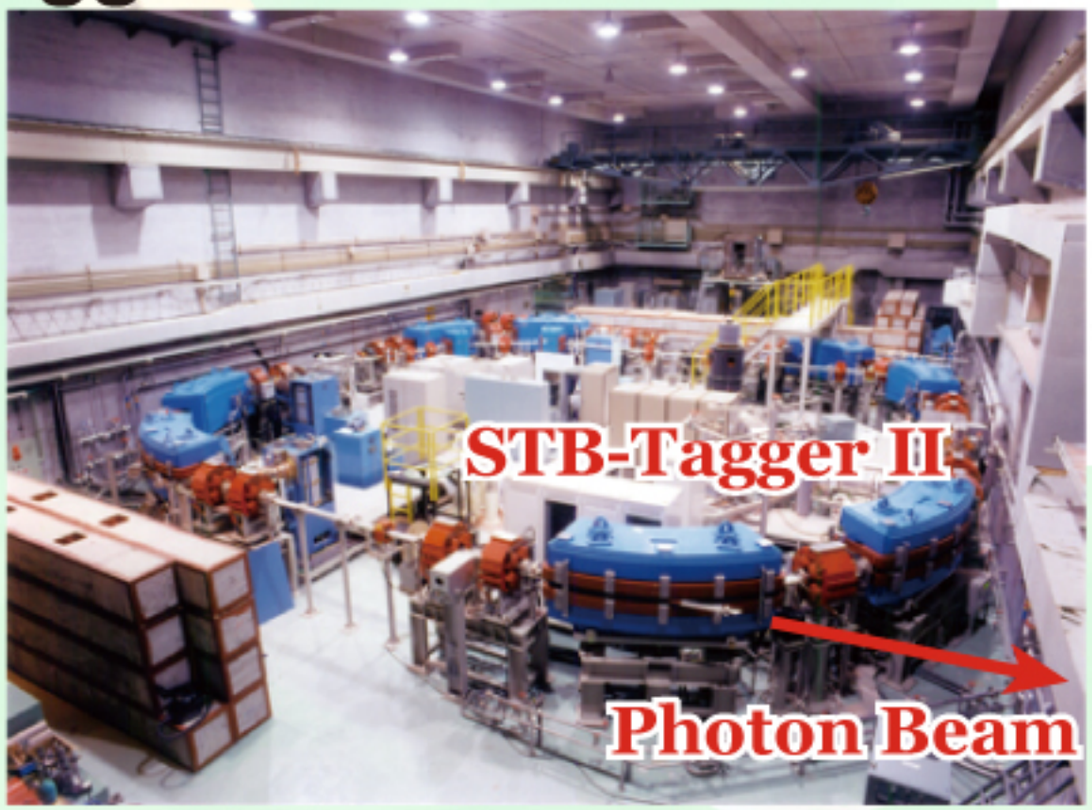
2. electro-magnetic (EM) calorimeter with a large solid-angle coverage
   FOREST

3. charged-particle spectrometer at extremely forward angles
   BLC

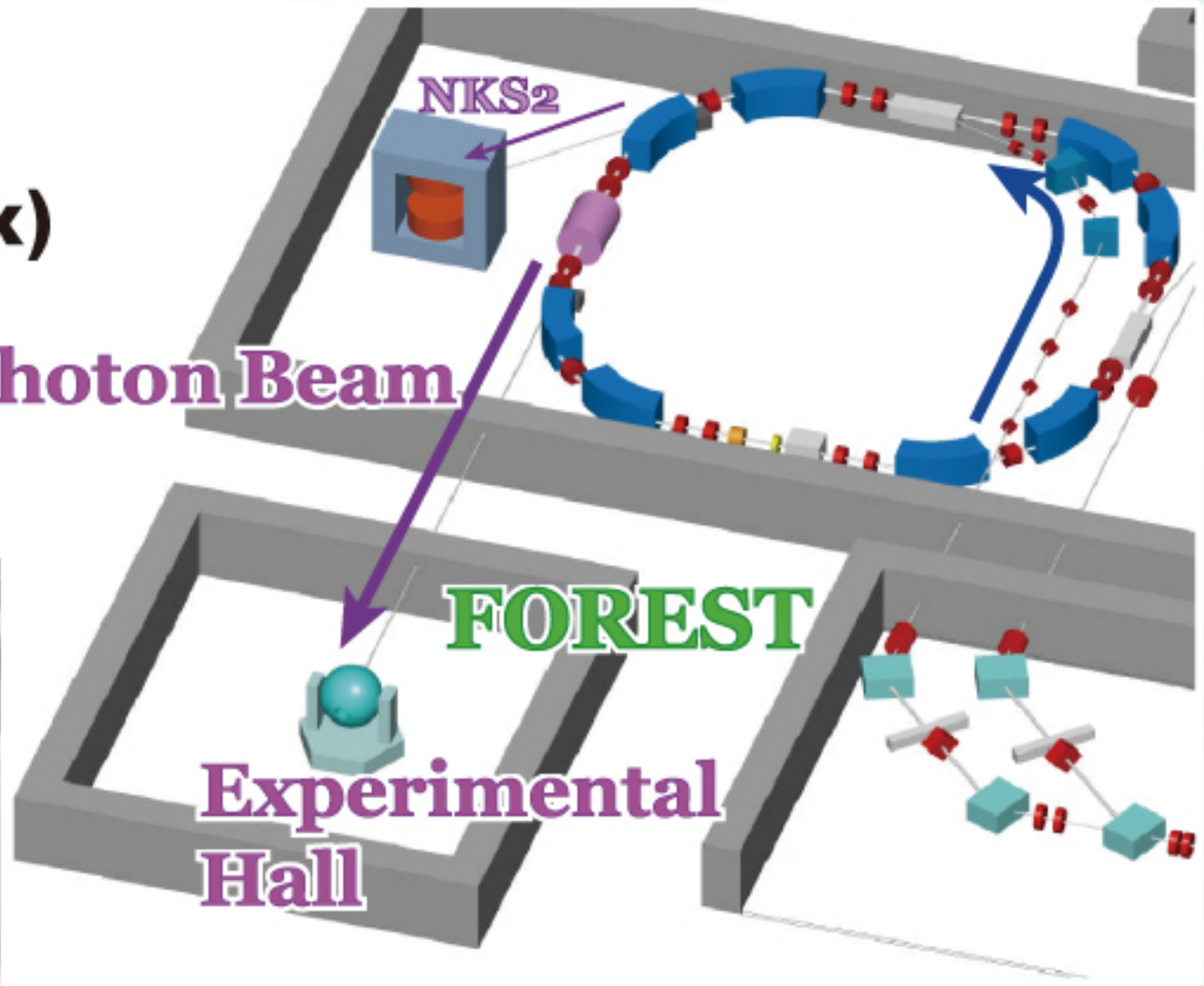
Accelerator

Electron Beam
- **LINAC 150 MeV**
- **Booster Ring 1.3 GeV (max)**

Photon Beam
- **Bremsstrahlung**
- **Tagged**



1.3 GeV Booster STorage Ring



0.80~1.25 GeV @ 1.3 GeV

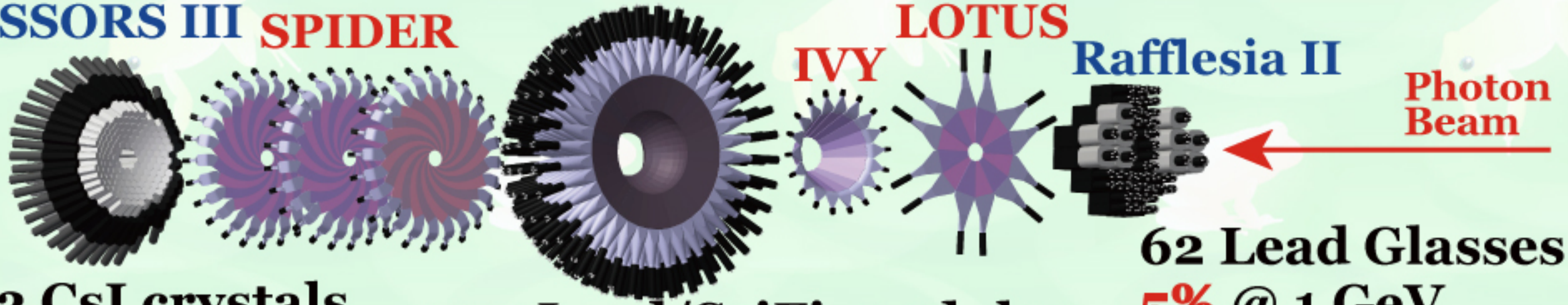
~20 MHz (photon: 10 MHz)

$W_{\gamma N}$=1.54~1.80 GeV

T. Ishikawa et al., NIMA 622, 1 (2010); T. Ishikawa et al., NIMA 811, 124 (2016);
Y. Matsumura et al., NIMA 902, 103 (2018); Y. Obara et al., NIMA 922, 108 (2019).

EM calorimeter

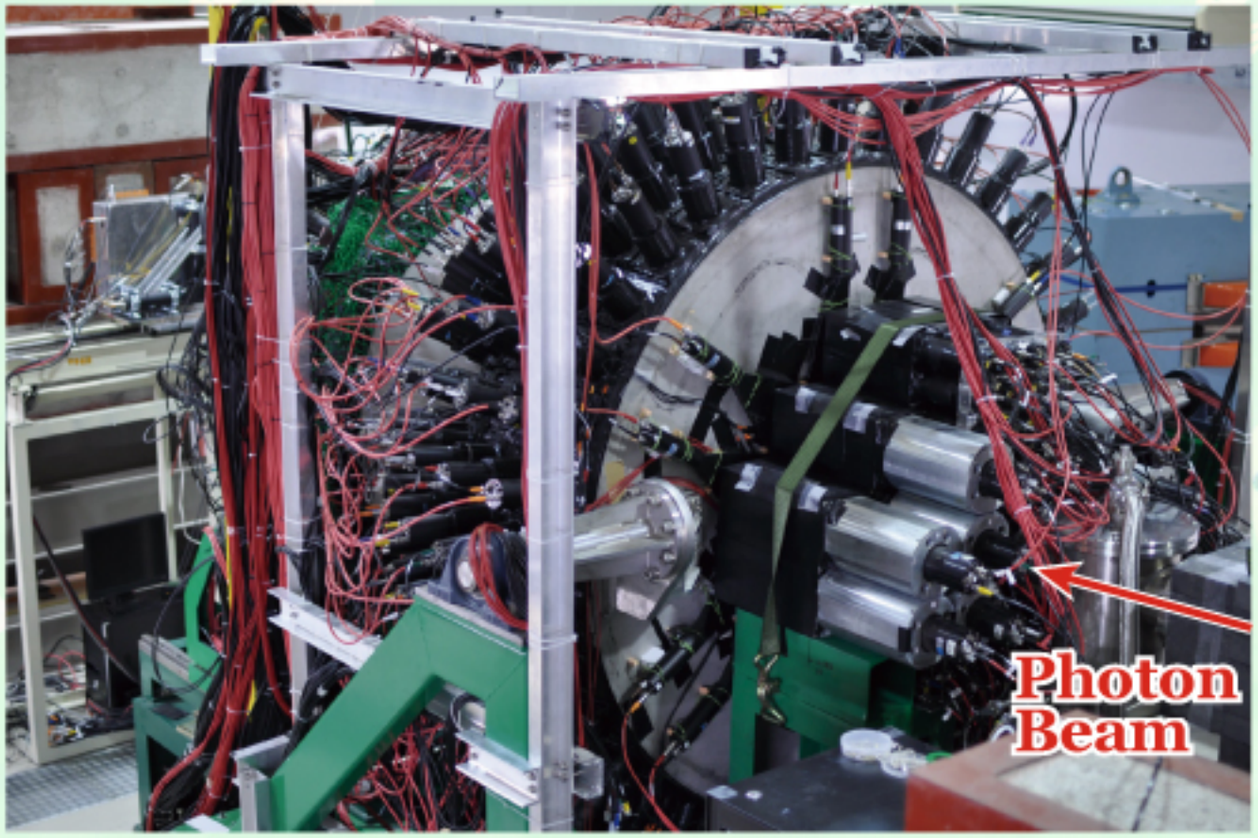
Backward Gamma

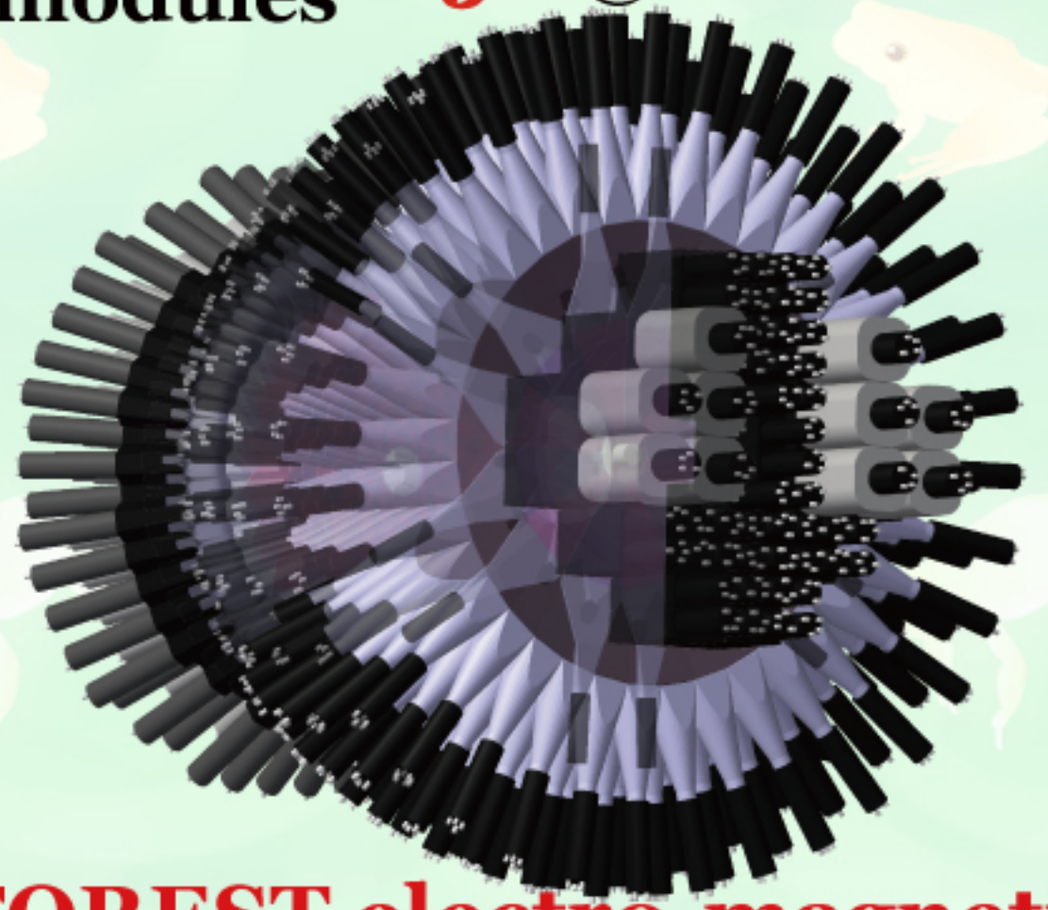


192 CsI crystals
3% @ 1 GeV

252 Lead/SciFi modules
7% @ 1 GeV

62 Lead Glasses
5% @ 1 GeV





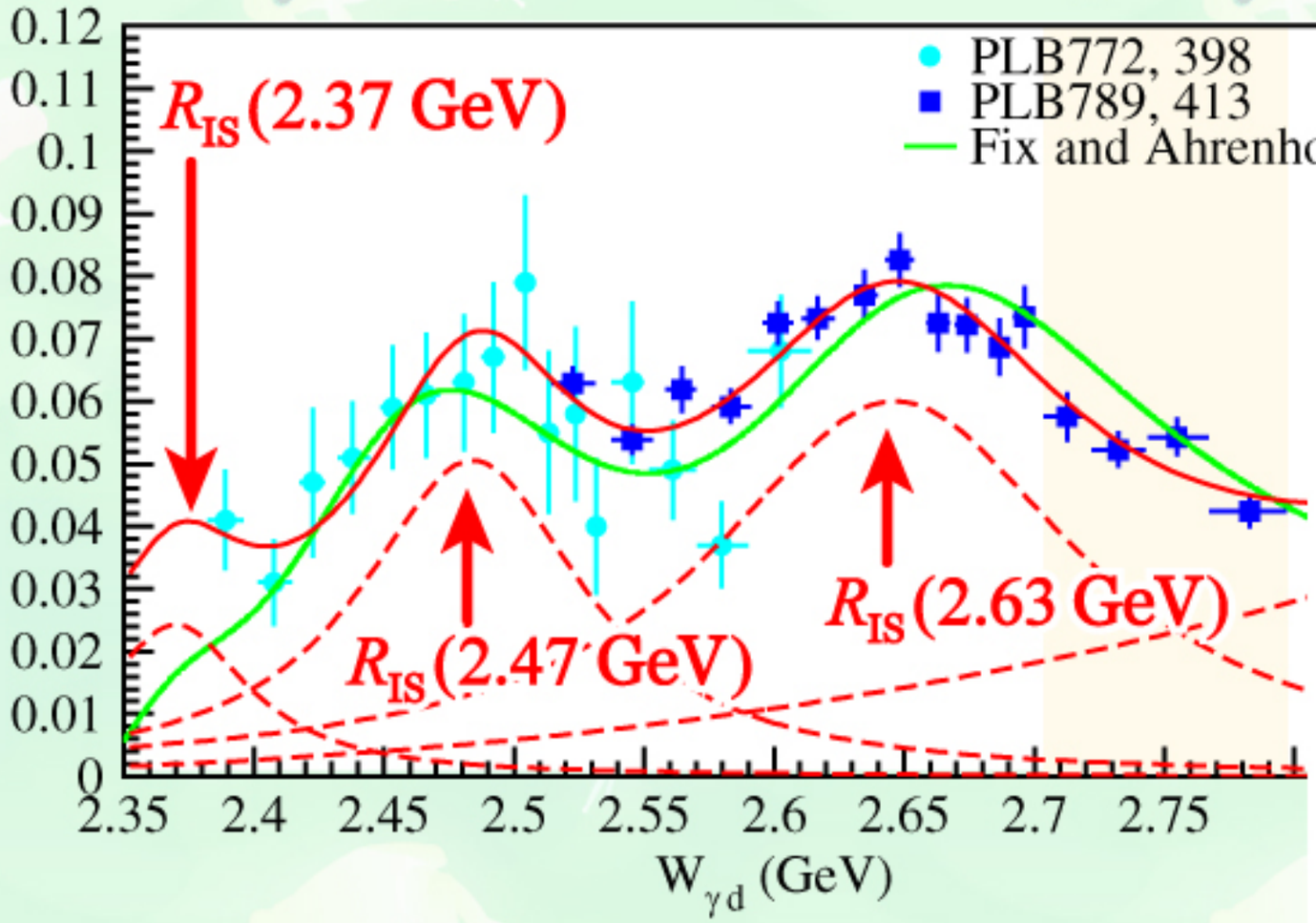
FOREST electro-magnetic calorimeter

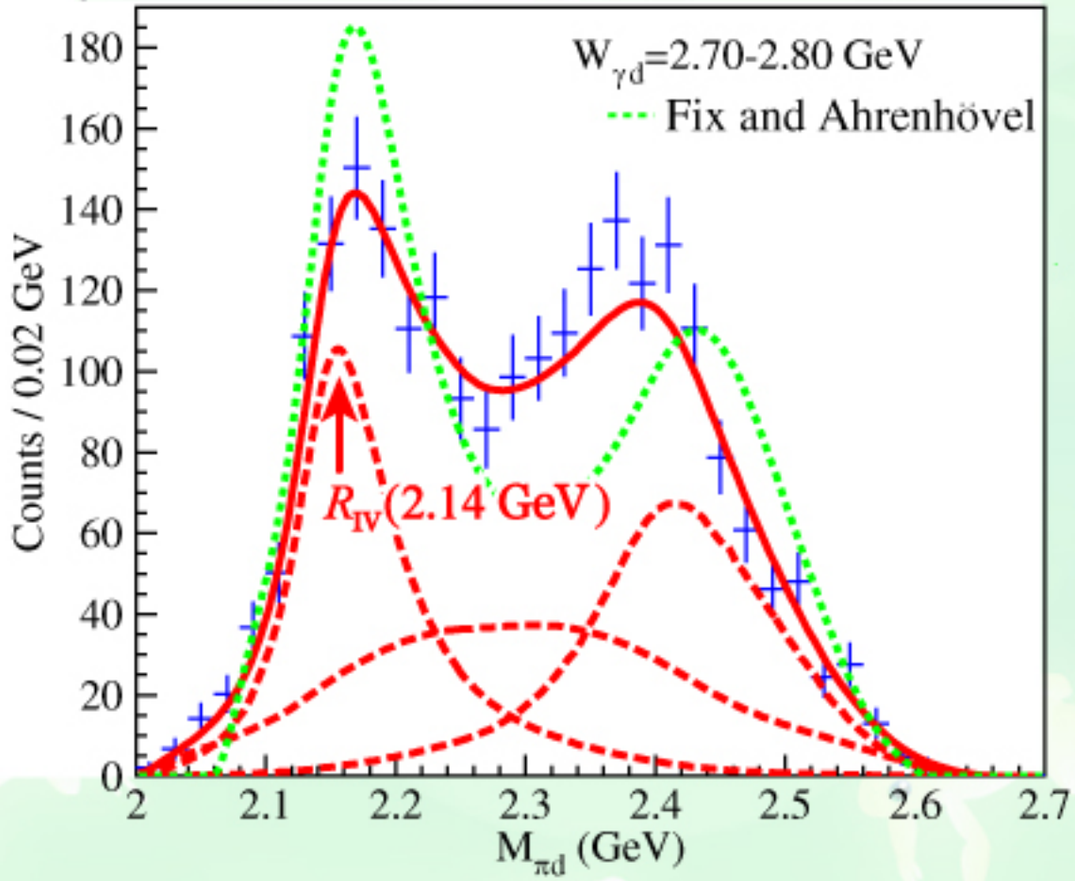
Target: 45 mm thick LH2 & LD2

T. Ishikawa et al., NIMA 832, 108 (2016).

Dibaryons

Recent results using FOREST: $\gamma d \to \pi^0\pi^0 d$





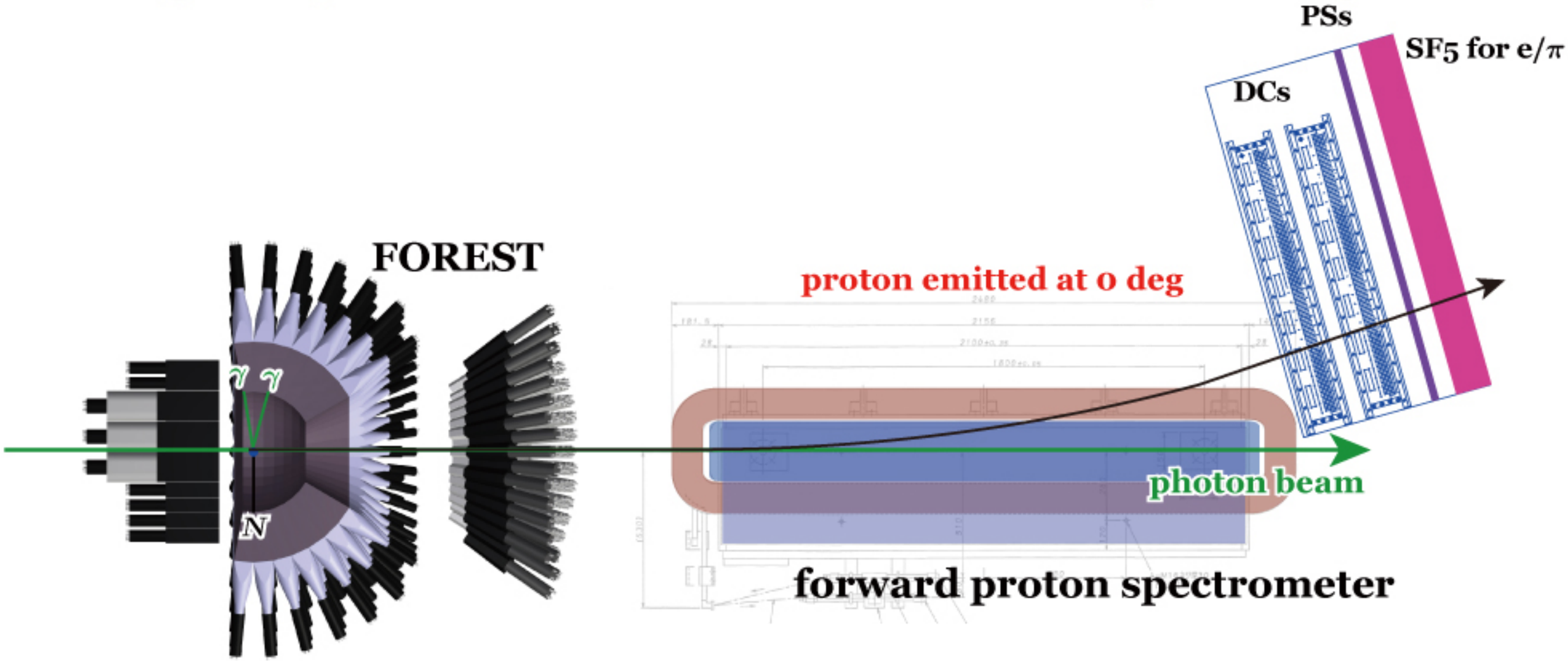
sequential process:

$$\gamma d \to R_{\mathrm{IS}} \to \pi^0 R_{\mathrm{IV}} \to \pi^0\pi^0 d$$

poster session (tommorow)

BLC spectrometer

Charged particles emitted at 0° (<0.5°)



beding magnet from the KEKB low energy ring
plastic hodoscopes (PSs) for the TOF measurement
drift chambers (DCs) for the momentum measurement
SF5 lead glass Counters for e/π separation

ηN scattering length from the $\gamma d \to \eta p p n$ reaction

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 is of particular importance:
chiral partner candidate $S_{11}(1535)$

ηN interaction

low-energy scattering is characterized with the *S*-wave phase shift $\delta(p)$:

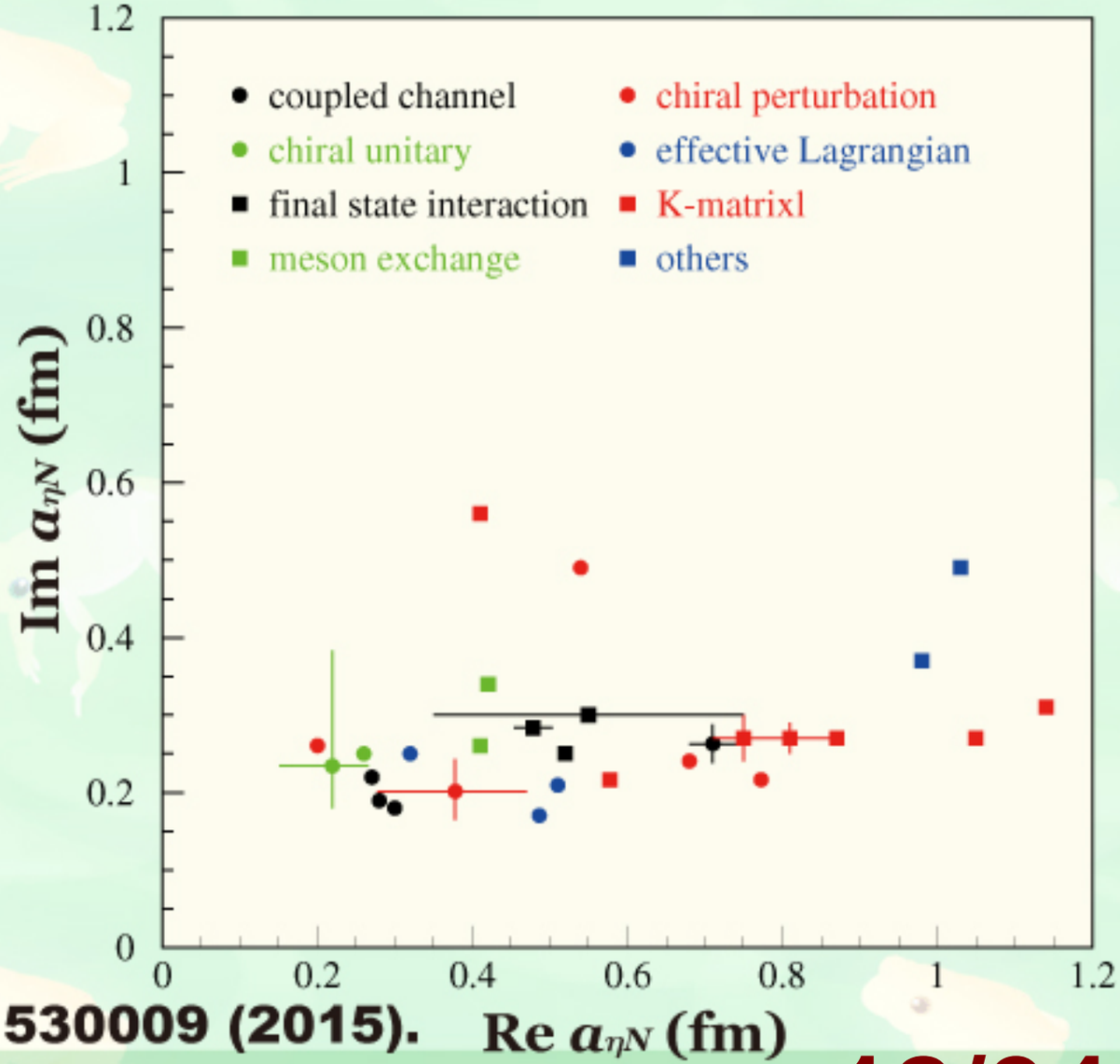
$$p\cot\delta(p) = \frac{1}{a_{\eta N}} + \frac{1}{2} r_{\eta N} p^2 + O(p^4)$$

$a_{\eta N}$: **scattering length**

$r_{\eta N}$: **effective range**

indirectly determined

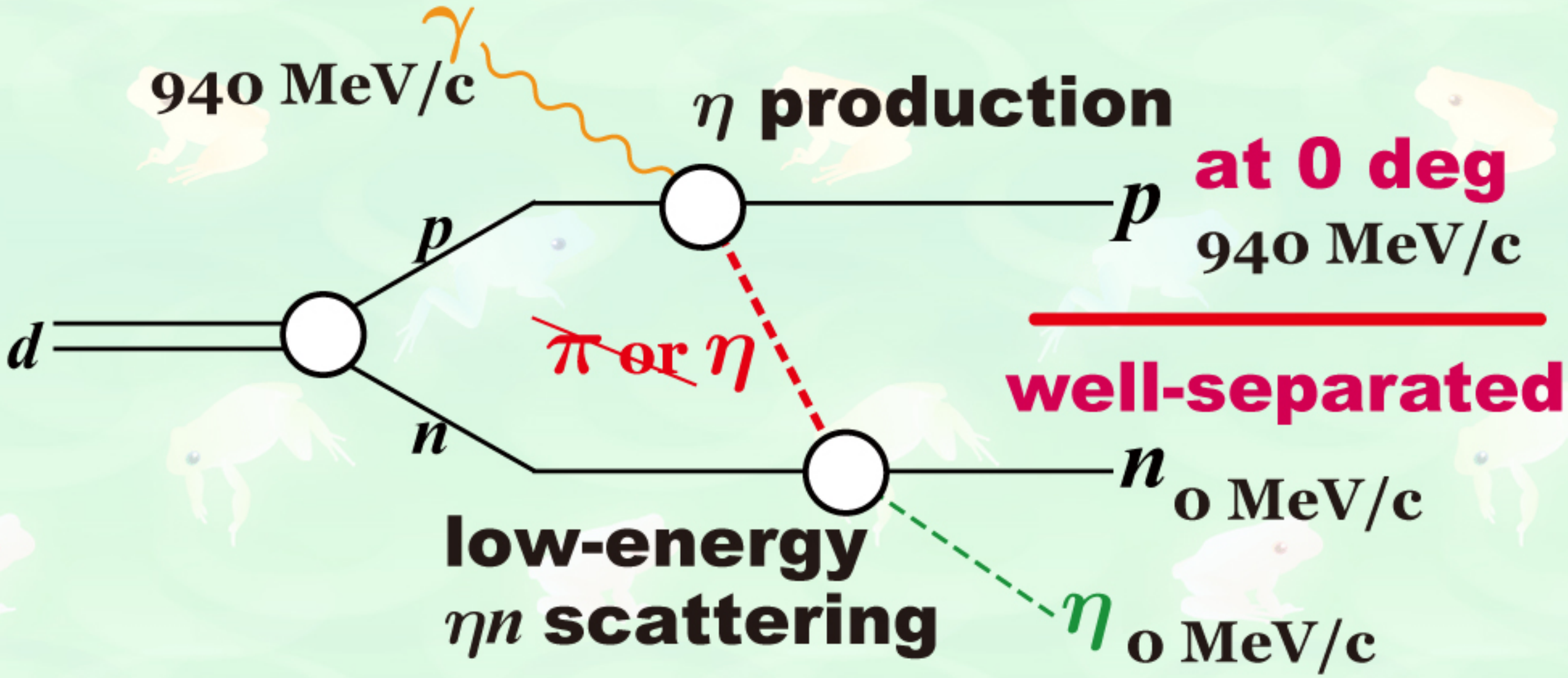
real part is scattered



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

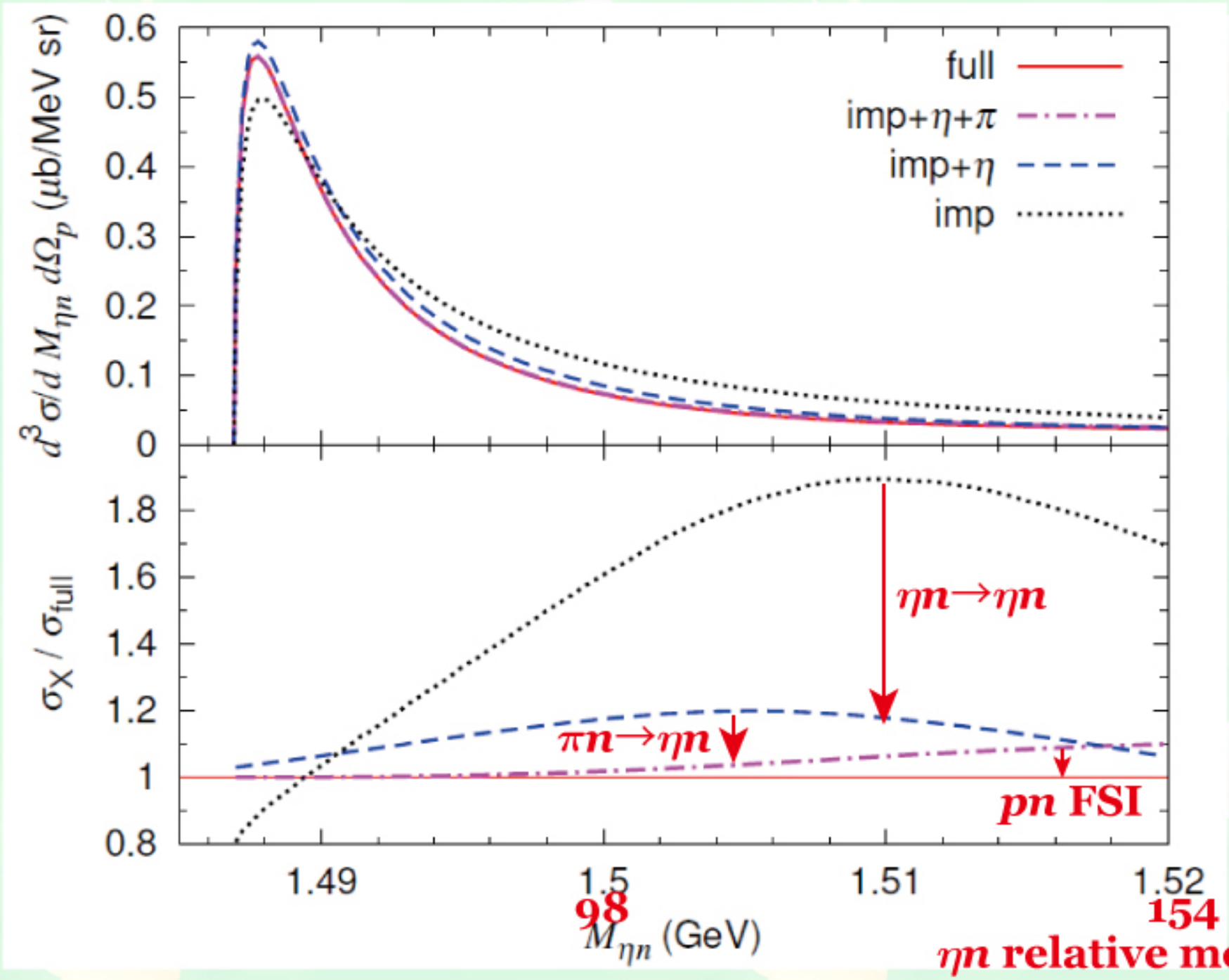
ηN interaction

proposed kinematics for $a_{\eta N}$ determination using $\gamma d \to \eta p n$

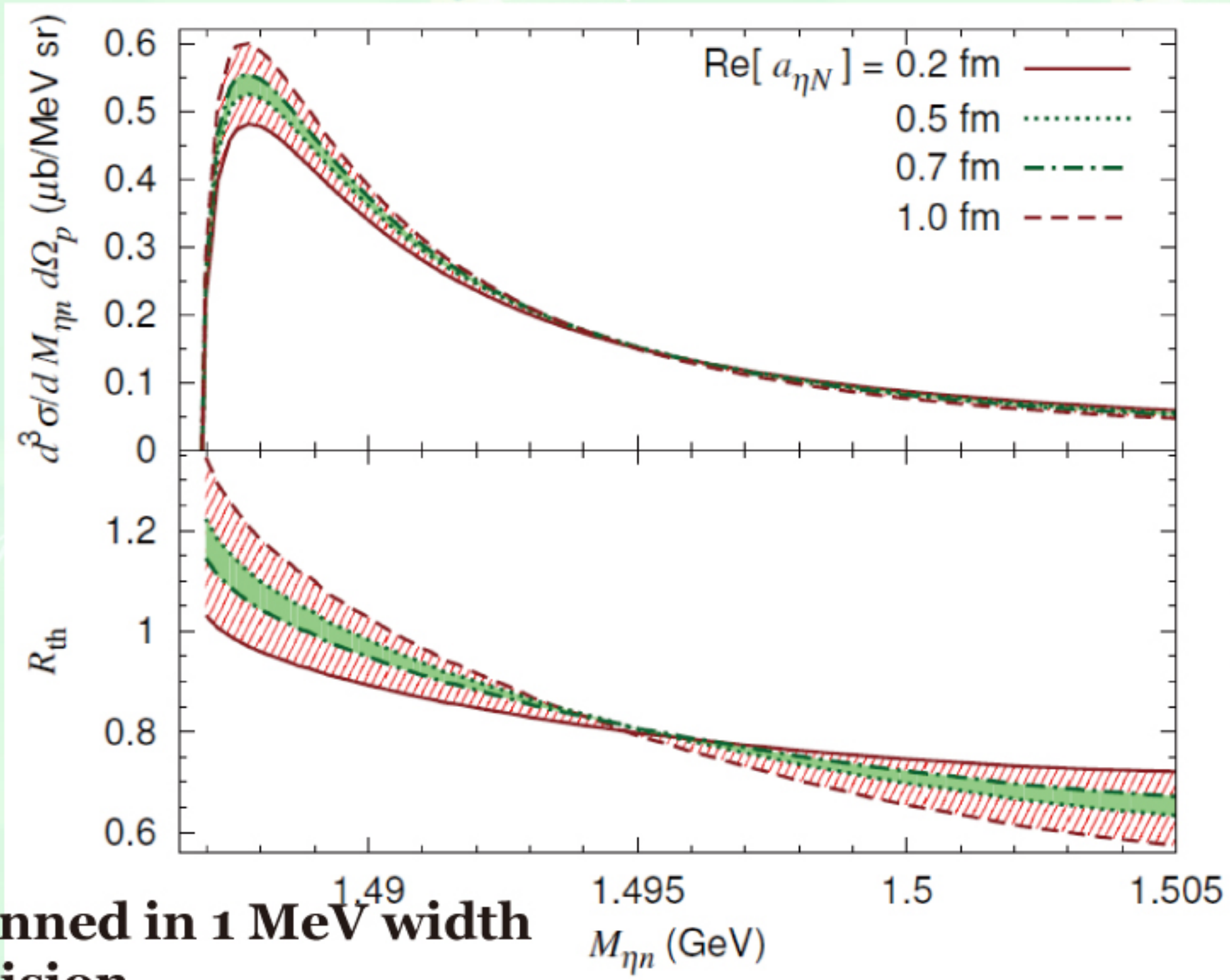


$\gamma d \to p\eta n$ reaction

differential cross section for $\gamma d \to \eta p n$ as a function of the ηn invariant mass



Sensitivity to the real part of the scattering length



5% yield error binned in 1 MeV width gives 0.1 fm precision

ηn invariant mass

$\gamma d \to \eta p n$ reaction

η is identified using the $\gamma\gamma$ decay

FOREST

p is detected at 0 deg.

BLC

ηn invariant mass is precisely available using the missing mass method: $\gamma d \to \eta p n$

$\gamma d \to p\eta n$ reaction

Proton detection at 0°

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.
required beamtime estimation is also on-going
(approximately 100 days)

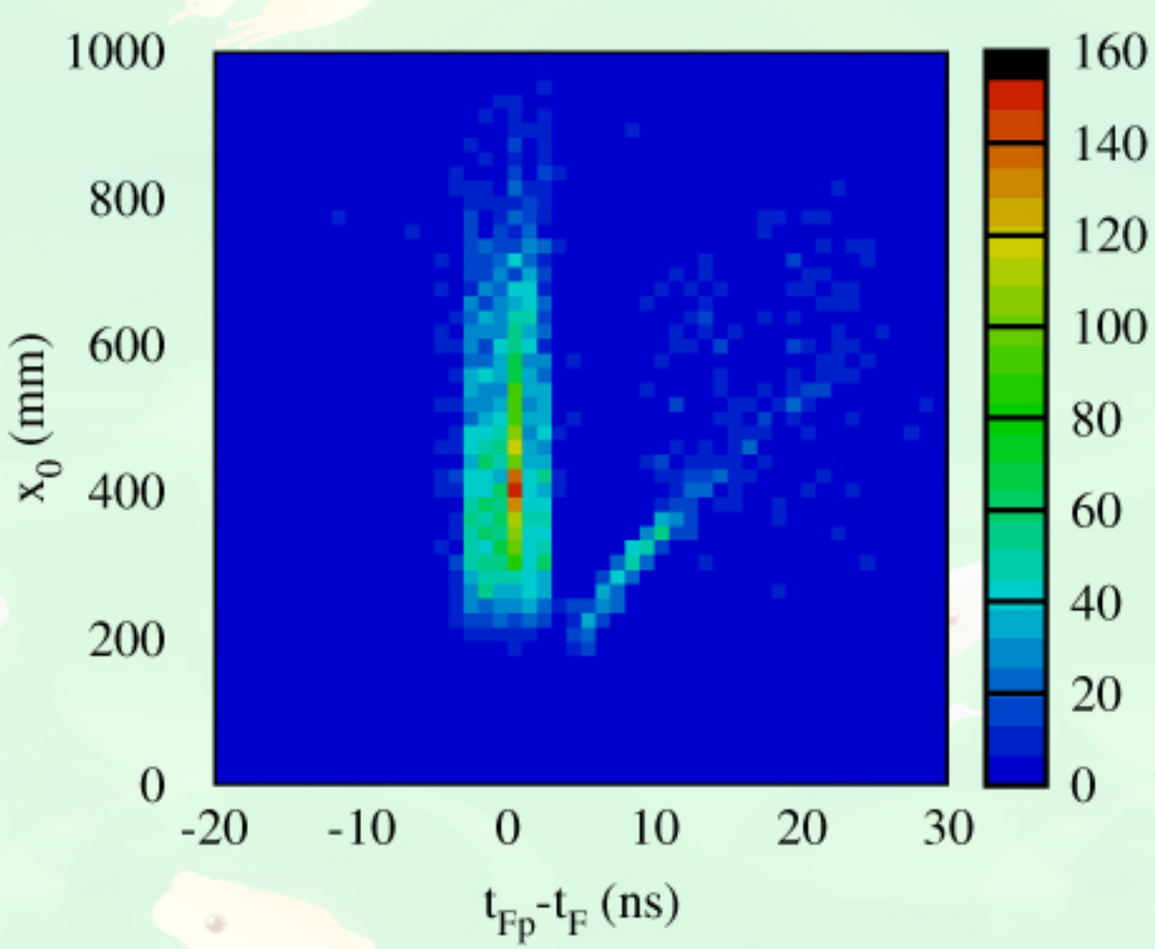
Data collection

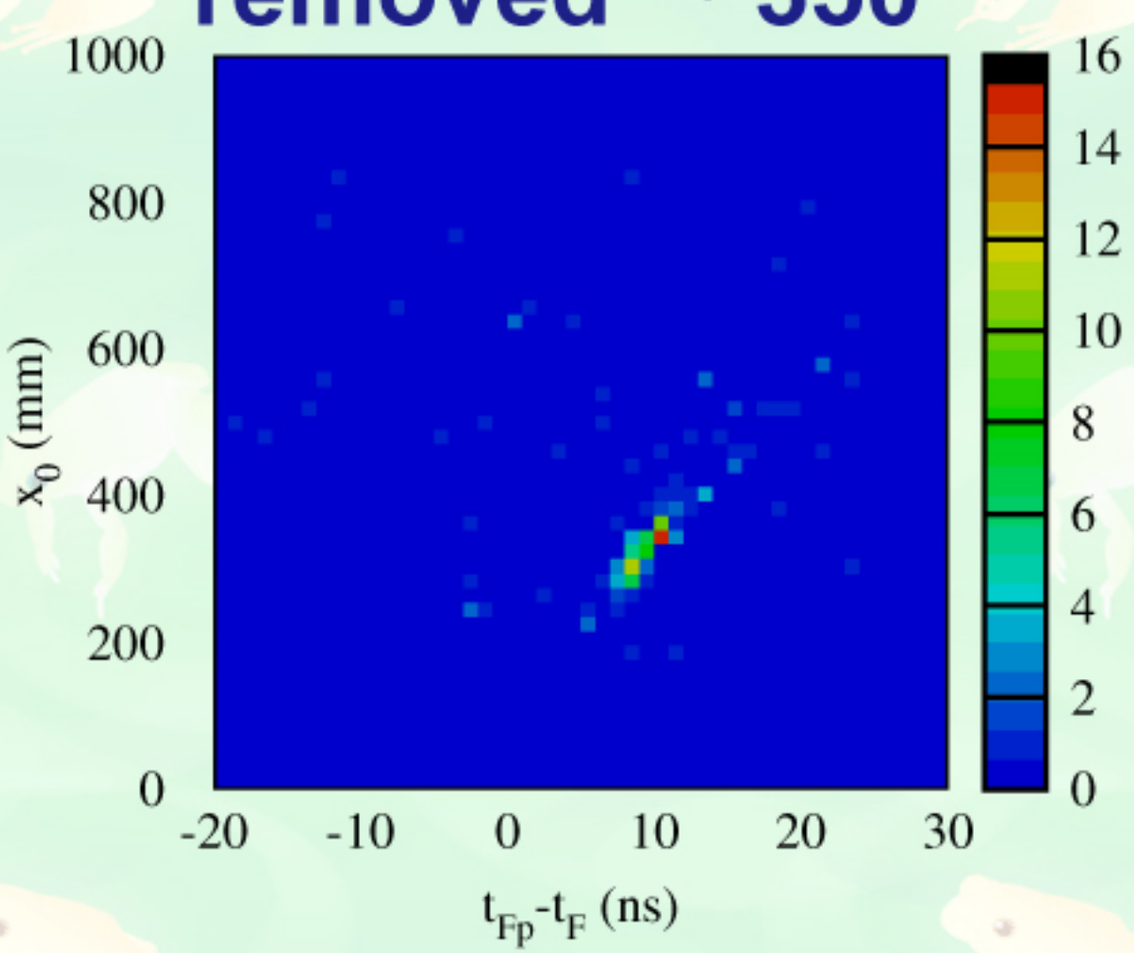
Statistics: 1/4~1/3

acclerator troubles & increse of electricity fee

$\gamma p \to \eta p$ LH2

accidentan coin. of photon-tagging removed ~ 350





Data collection

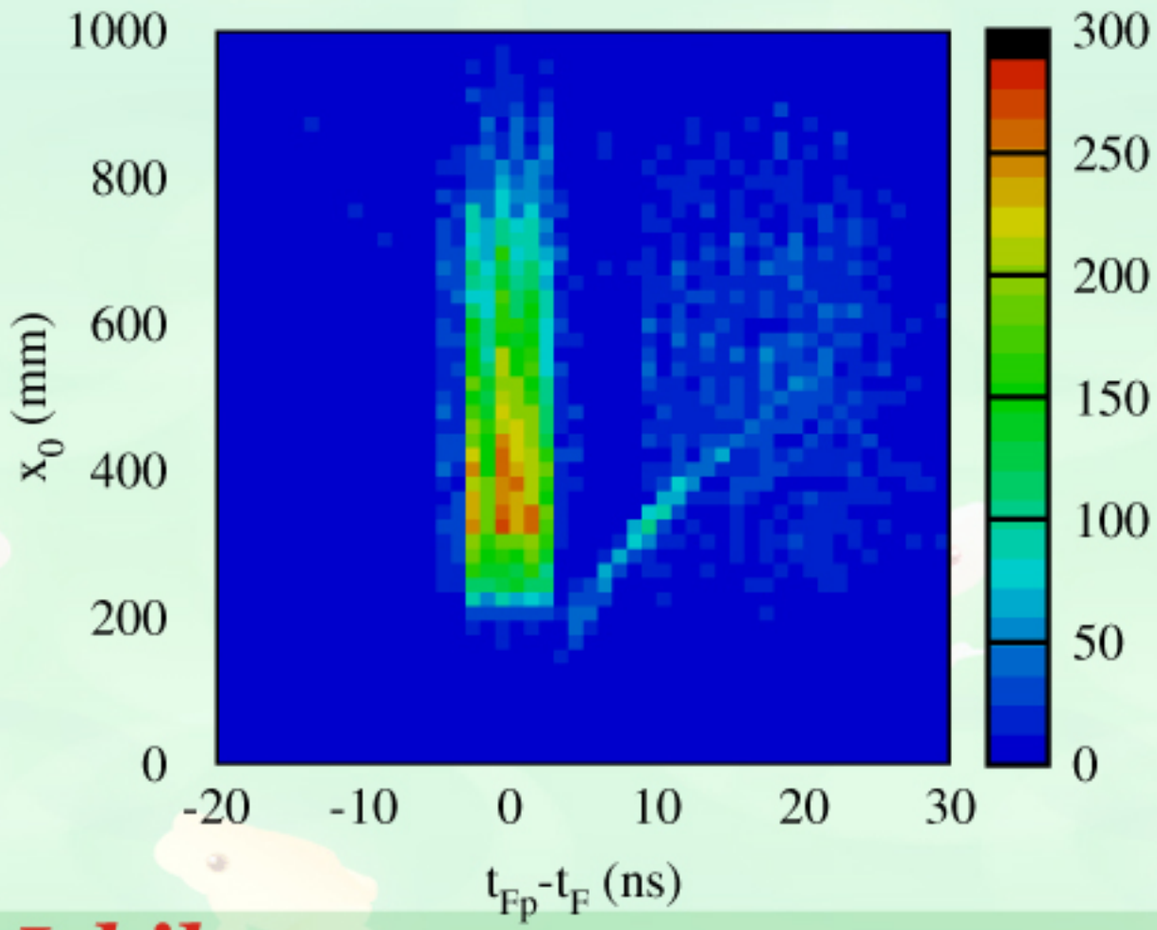
Statistics: 1/4~1/3

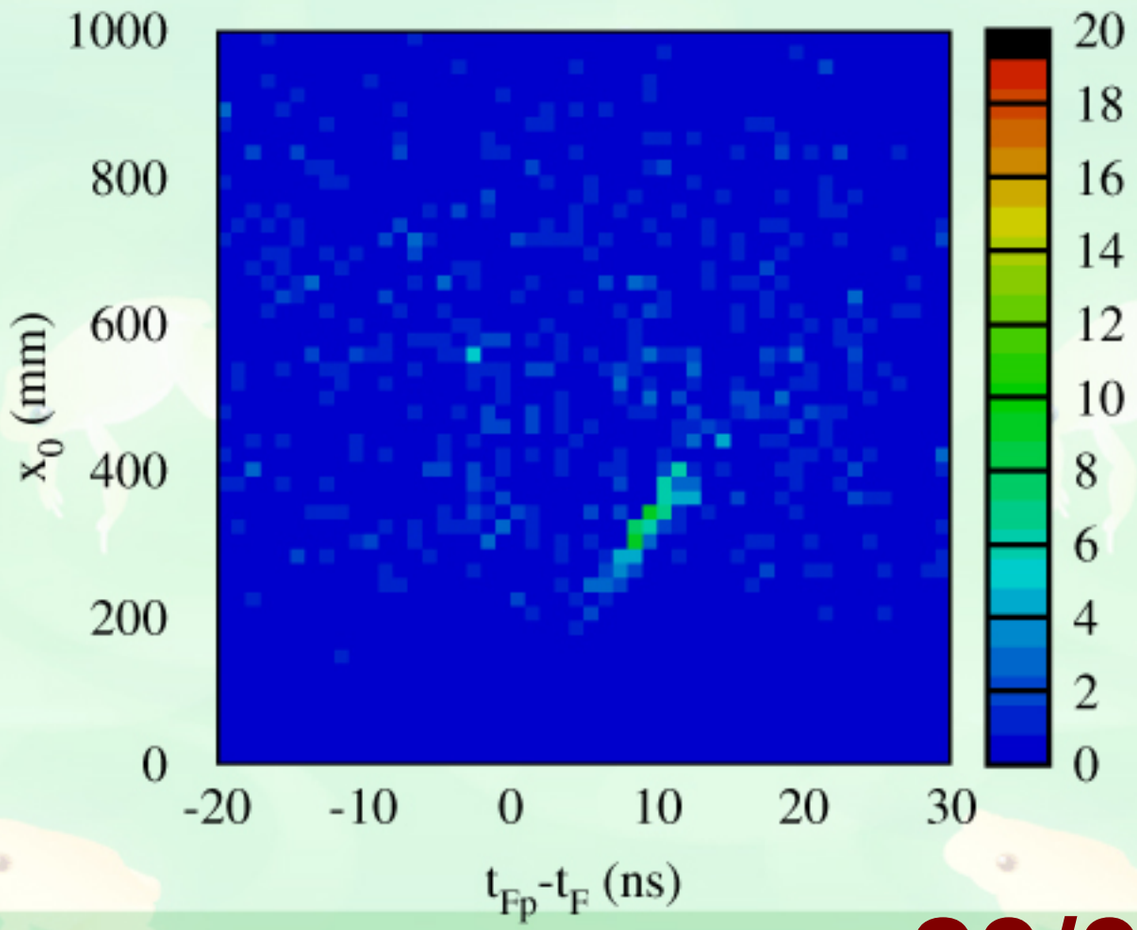
acclerator troubles & increse of electricity fee

QF $\gamma p' \rightarrow \eta p$

LD2

accidentan coin. of photon-tagging removed ~1500





possible $\eta' d$ bound state from the $\gamma d \to \eta d$ reaction

η' meson

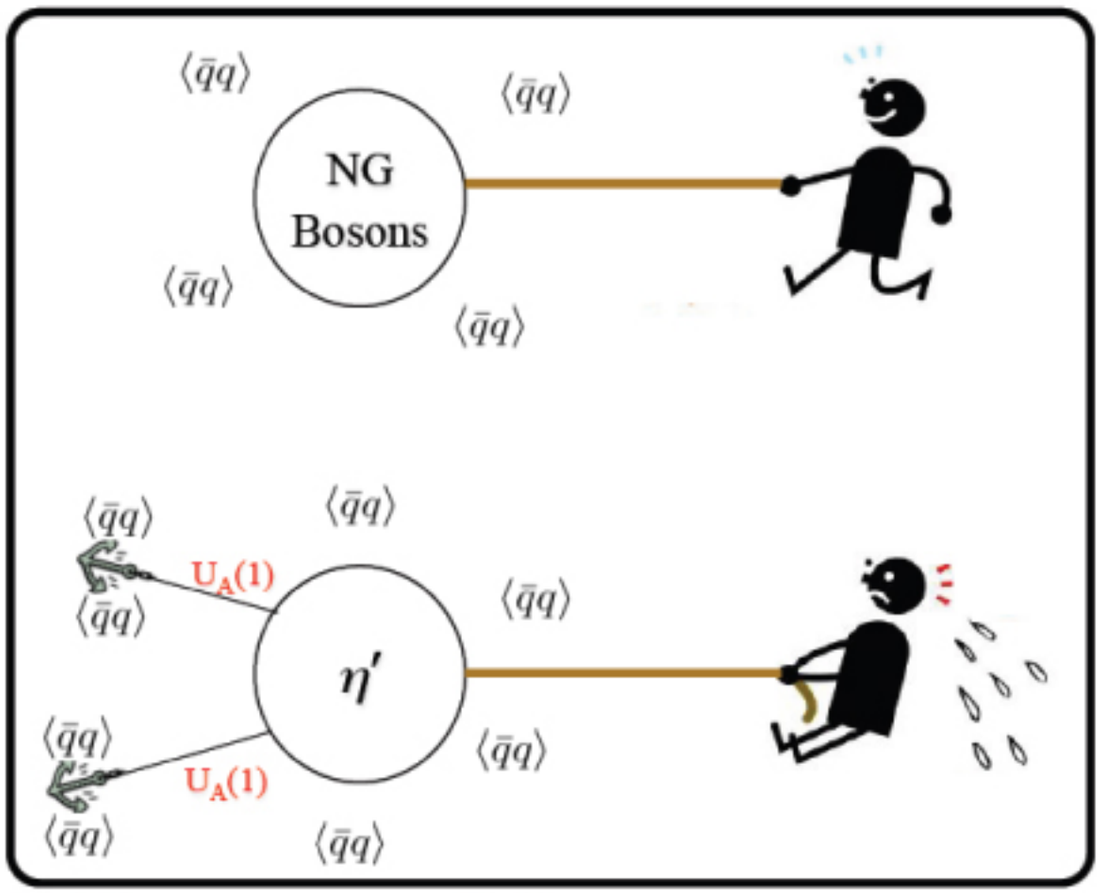
exceptionaly large mass among pseudo-scalar mesons

interplay of quark symmetry and gluon dynamics

mass is expressed by $U_A(1)$ and $\langle\bar{q}q\rangle$

mass decreasae in the nuclear medium

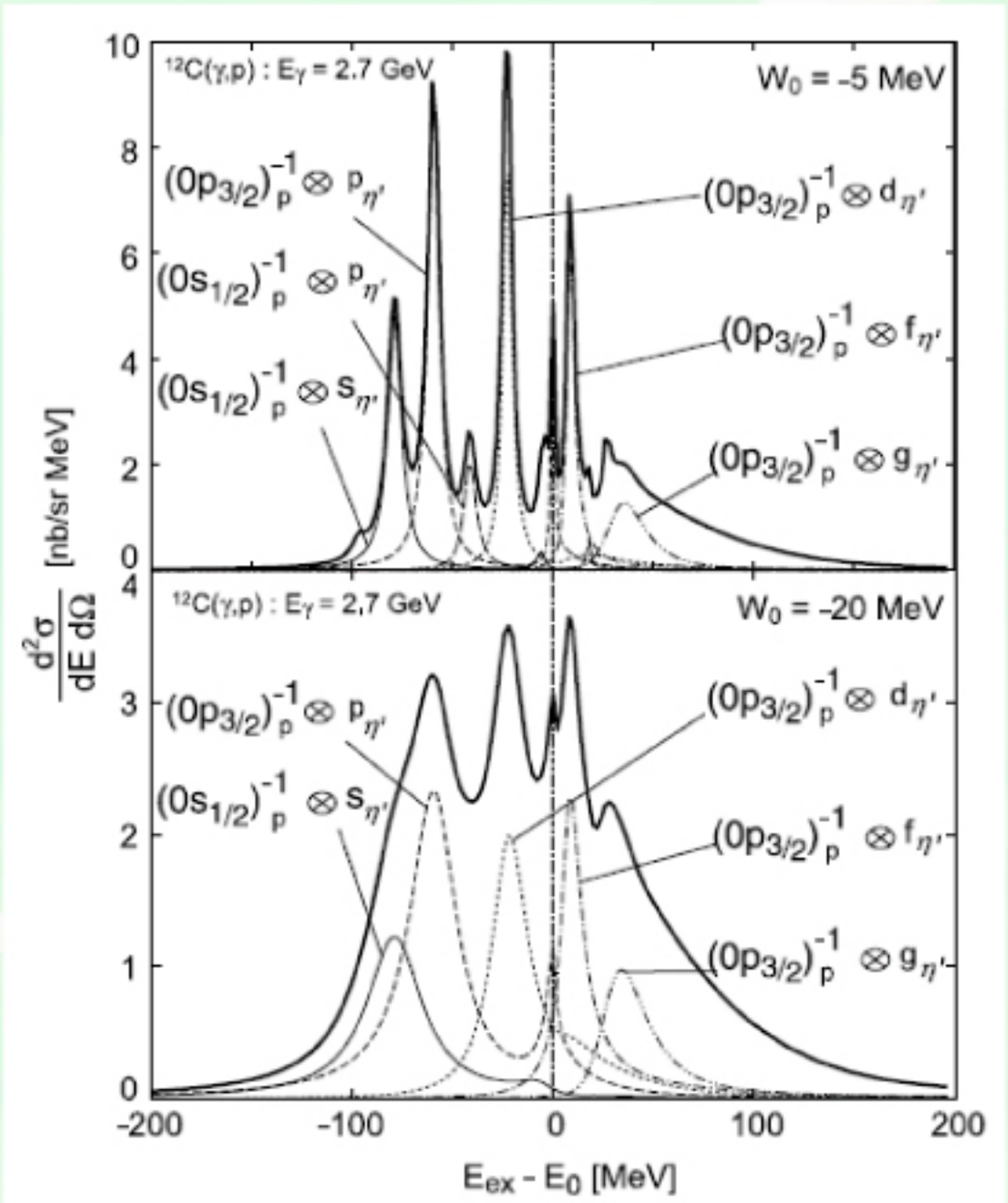
- **Nambu-Jona-Lassino model**
- **linear σ model**



Hirenzaki

$\eta'A$ & $\eta'N$ bound sys.

if mass reduction in association with $\langle\bar{q}q\rangle$ exists $\eta'A$ bound system (η' mesic nucleus) is available



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

^{12}C$(\gamma,p)^{11}_{\eta'}$B spectra

strong attraction

- 200-MeV mass reduction from Bose-Einstein condensation
  - T. Csorgo et al., PRL105, 182301 (2010).

weak absorption

- A-dep. of transparency ratio
- width of 15~25 MeV
  - M. Nanova et al., PLB710, 600 (2012).

$\eta' A$ & $\eta' N$ bound sys.

experimental efforts to study $\eta' A$

(p,d)@ GSI ... Itahashi, Tanaka, ...

(γ,p)@ SPring-8/LEPS2 ... Muramatsu

short scattering length

E. Czerwinski et al., PRL113, 062004 (2012).

$pp \to pp\eta'$ **near the threshold**

$$\mathrm{Re}\, a_{\eta' N} = 0.00 \pm 0.43 \pm 0.00 \ \mathrm{fm}$$

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

basic interaction & chiral symmetry breaking effect can be different issues

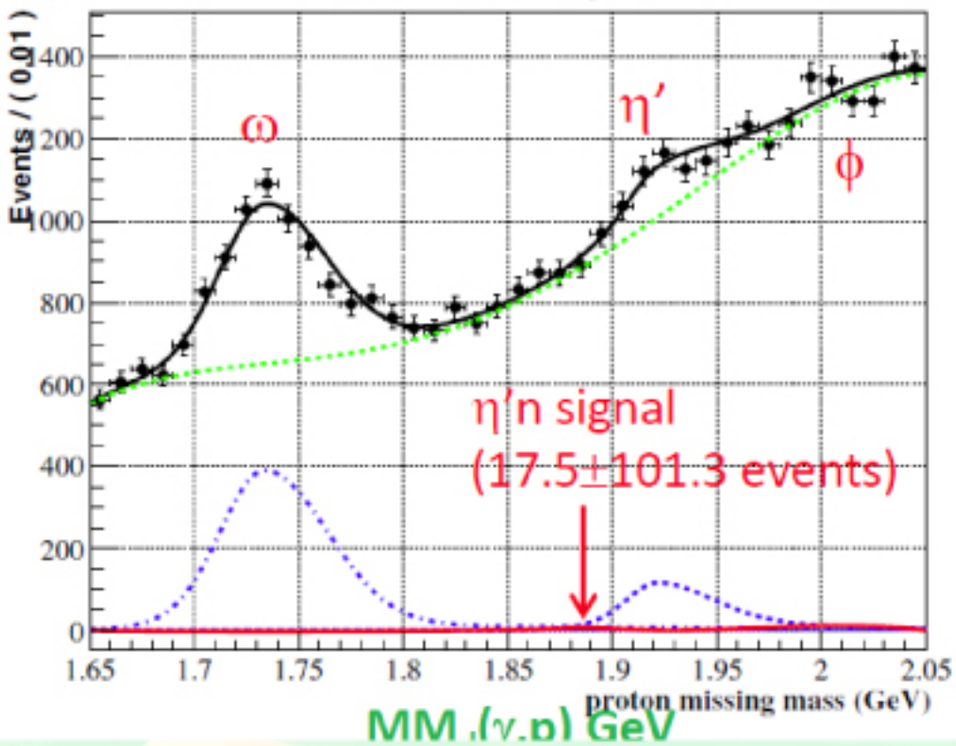
$\eta' A$ & $\eta' N$ bound sys.

if mass reduction in association with $\langle \bar{q}q \rangle$ exists
$\eta' N$ bound system is also available

binding energy ~ 6 MeV
S. Sakai and D. Jido, PRC88, 064906 (2016).

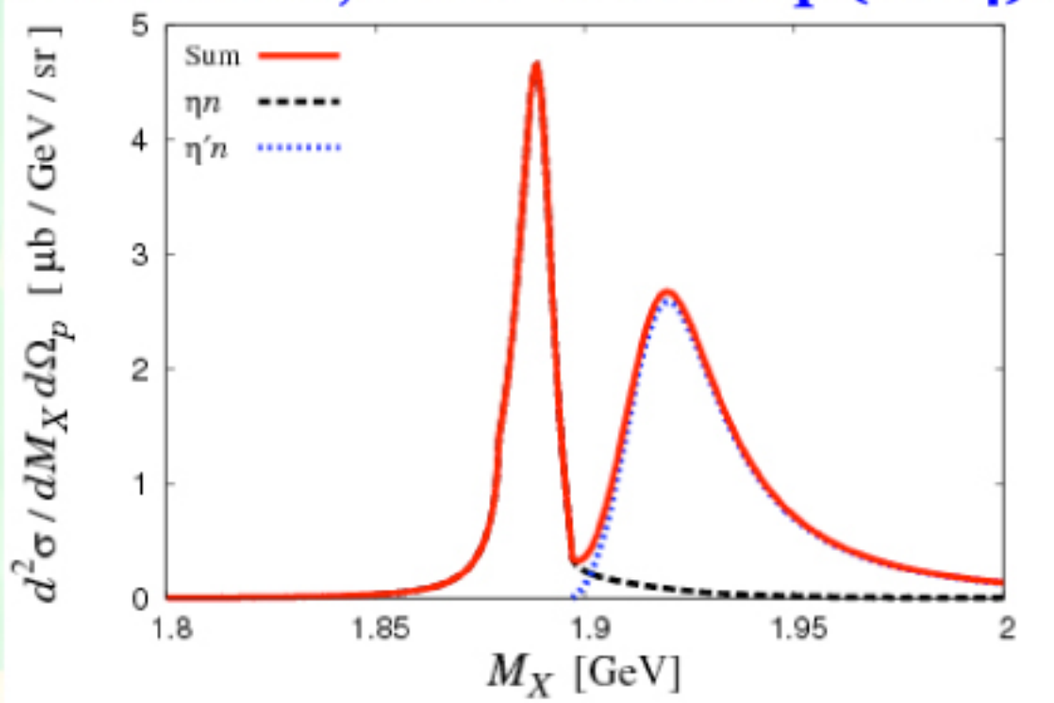
search for $\eta' N$ bound sys. using $d(\gamma, p)$

A fit with the signal @ M(η'n)=1.887 GeV/c²



Muramatsu (LEPS)

T. Sekihara, ELPH workshop (2014).



$\eta'A$ & $\eta'N$ bound sys.

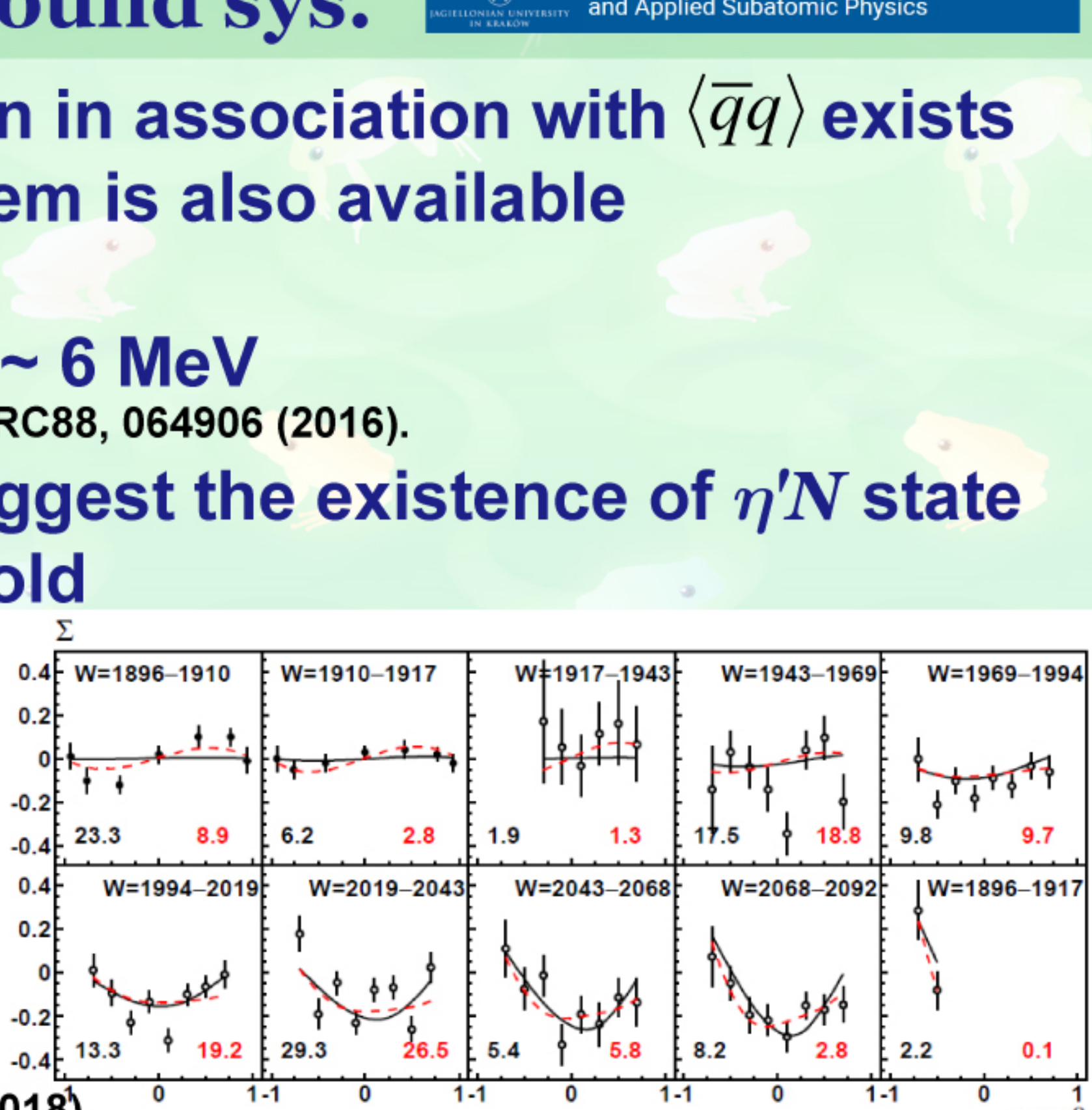
if mass reduction in association with $\langle \overline{q}q \rangle$ exists

$\eta'N$ bound system is also available

binding energy ~ 6 MeV

S. Sakai and D. Jido, PRC88, 064906 (2016).

GRAAL data suggest the existence of $\eta'N$ state near the threshold



BnGa PWA, PLB785, 626 (2018).

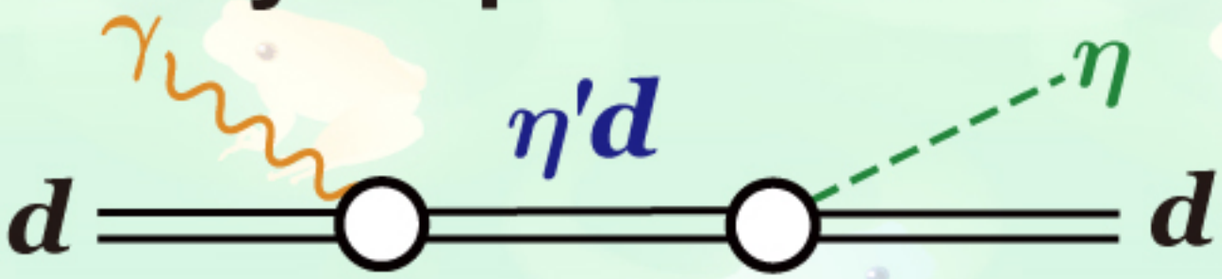
$\eta' d$ bound system

$\eta' d$ bound system can be observed in $\gamma d \to \eta d$

binding energy: 25 MeV

width: 19 MeV

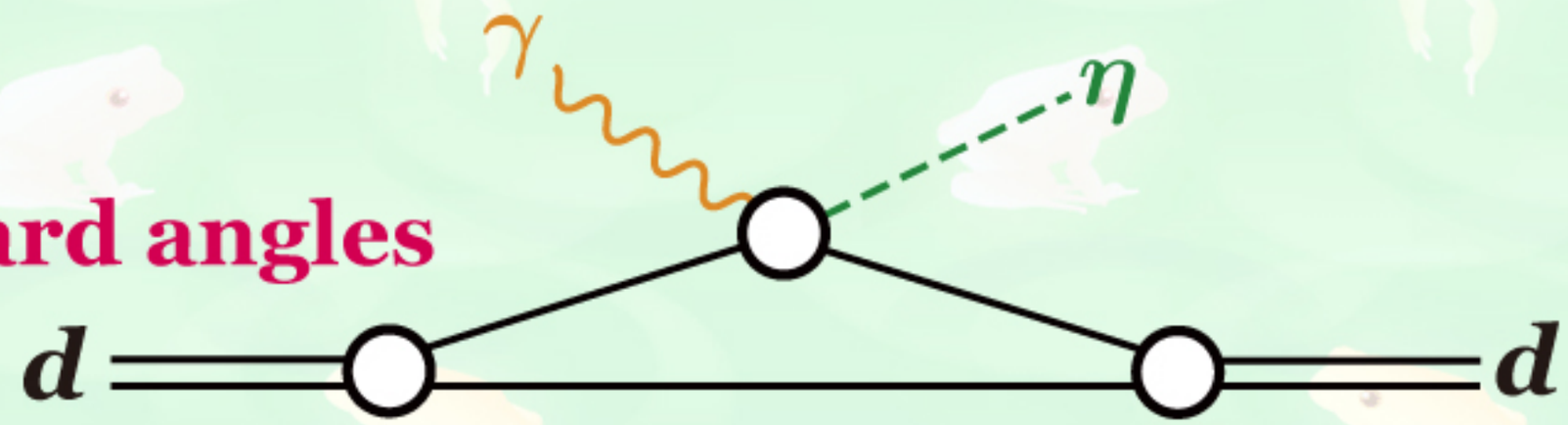
dibaryon production



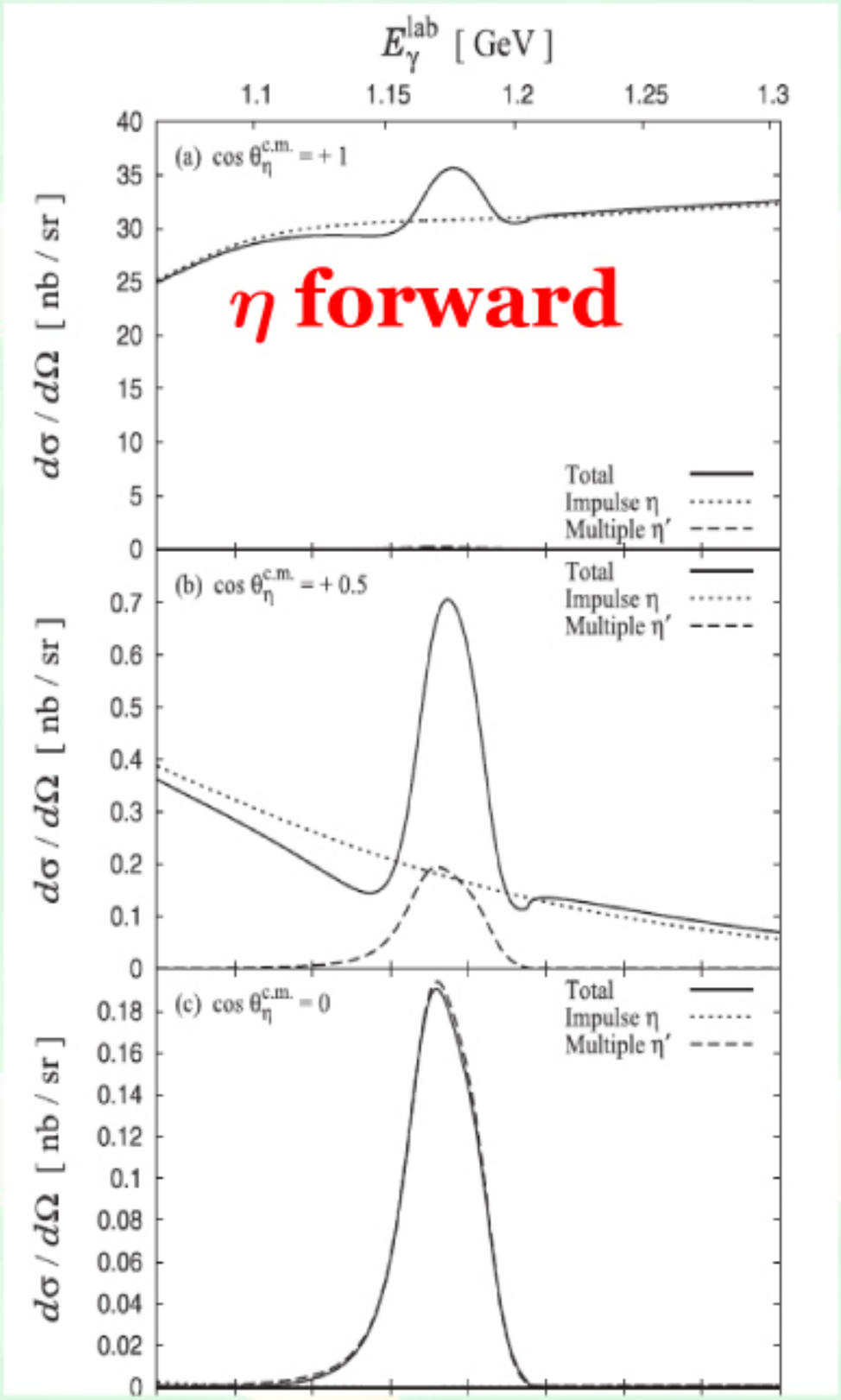
η is emitted isotropically

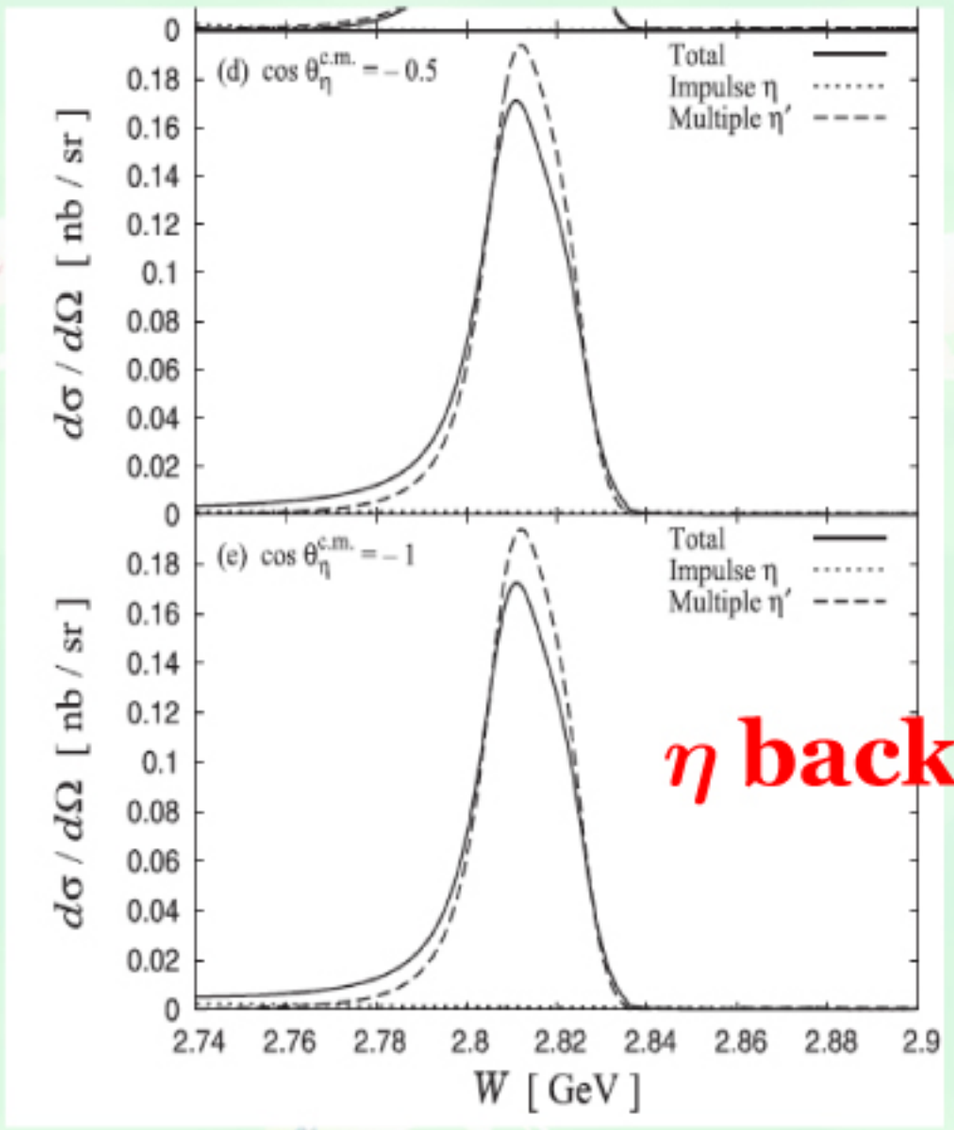
quasi-free (QF) η production followed by deuteron coalescence

η is emitted at extremely forward angles



$\eta' d$ bound system





$\eta' d$ bound system search in $\gamma d \to \eta d$ in the FORET/BLC experiments

H. Fujioka et al., ELPH-LOI

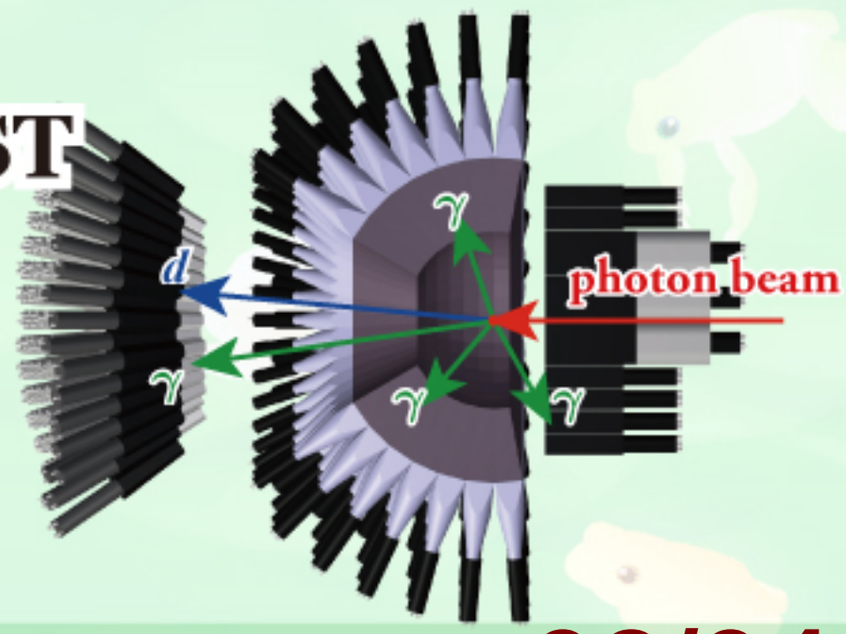
Event selection

1. 2 neutral particles and 1 charged particle

2. each neutral pion: $\gamma\gamma$ decay
   time difference is less than $3\sigma_t$

3. *d* is detected with SPIDER and SCISSORS III
   identified by ΔE-E correlation

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



Event selection

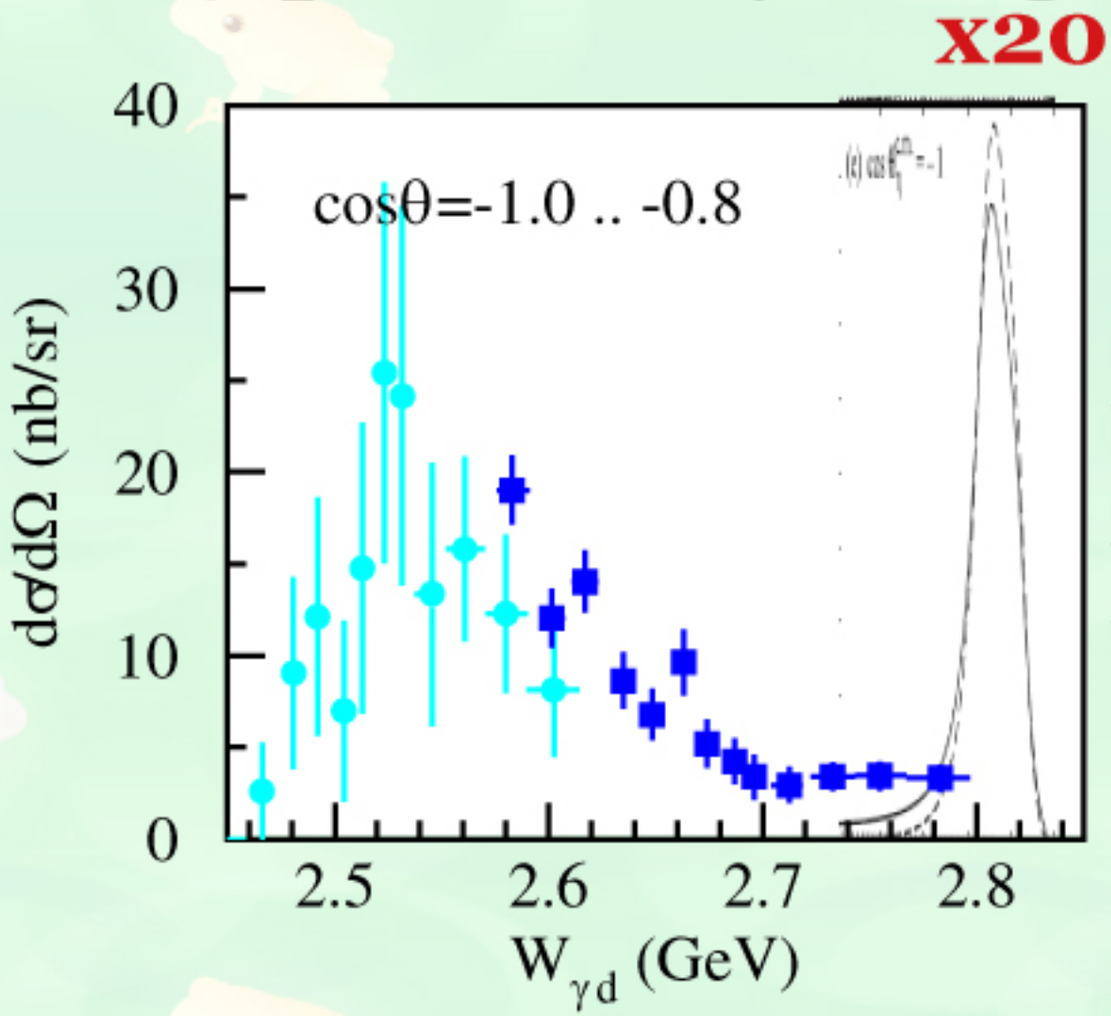
Further event selection:

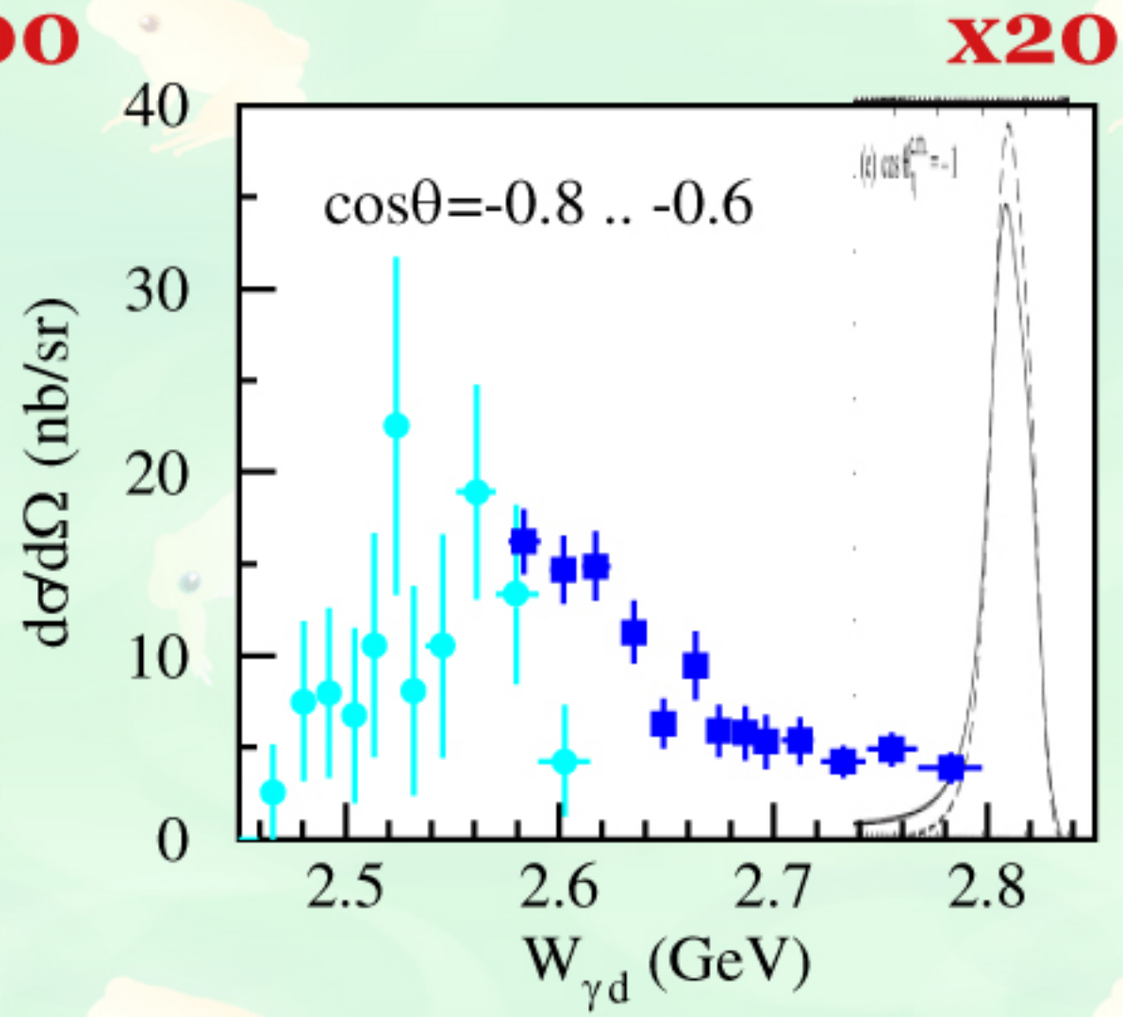
a kinematic fit with 5 constraints is applied

energy and momentum conservation (4)

$\gamma\gamma$ invariant mass is m_η (1)

χ^2 probability is higher than 0.4





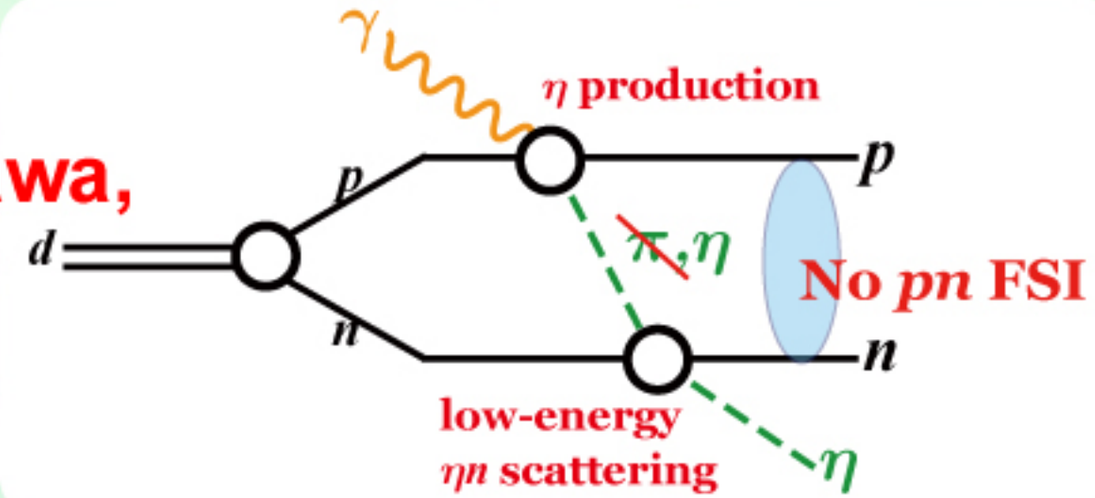
Summary

$\gamma p \to p\eta n$ is measured to extract $a_{\eta n}$

E_γ=940 MeV and θ_p=0° is the ideal condition

current statics: 1/4~1/3

S.X. Nakamura, H. Kamano, T. Ishikawa,
PRC96, 042201 (R) (2017).



$\eta' d$ bound state search using $\gamma d \to \eta d$

new data give an answer

understanding quasi-free production is necessary

T. Sekihara, H. Fujioka, T. Ishikawa, PRC97, 045202 (2018).

ηN interaction

determination of $a_{\eta N}$ using $\gamma d \to \eta pn$

A. Sibirtsev et al., PRC65, 044007 (2002).
possible with near-threshold data
A. Fix and H. Arenhovel, EPJA 19, 275 (2004).
realistically impossible

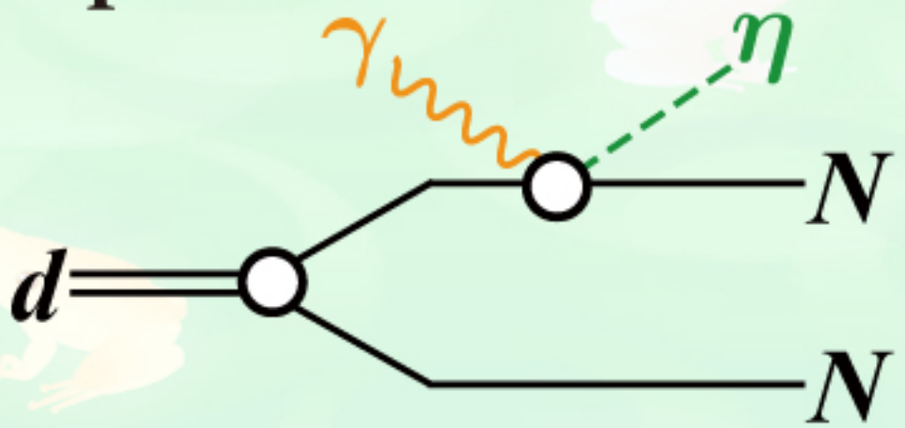
problems using near-threshold data (<0.7 GeV)
separation between ηp and ηn interactions
separation between ηN and NN interactions

special kinematics for determining $a_{\eta N}$

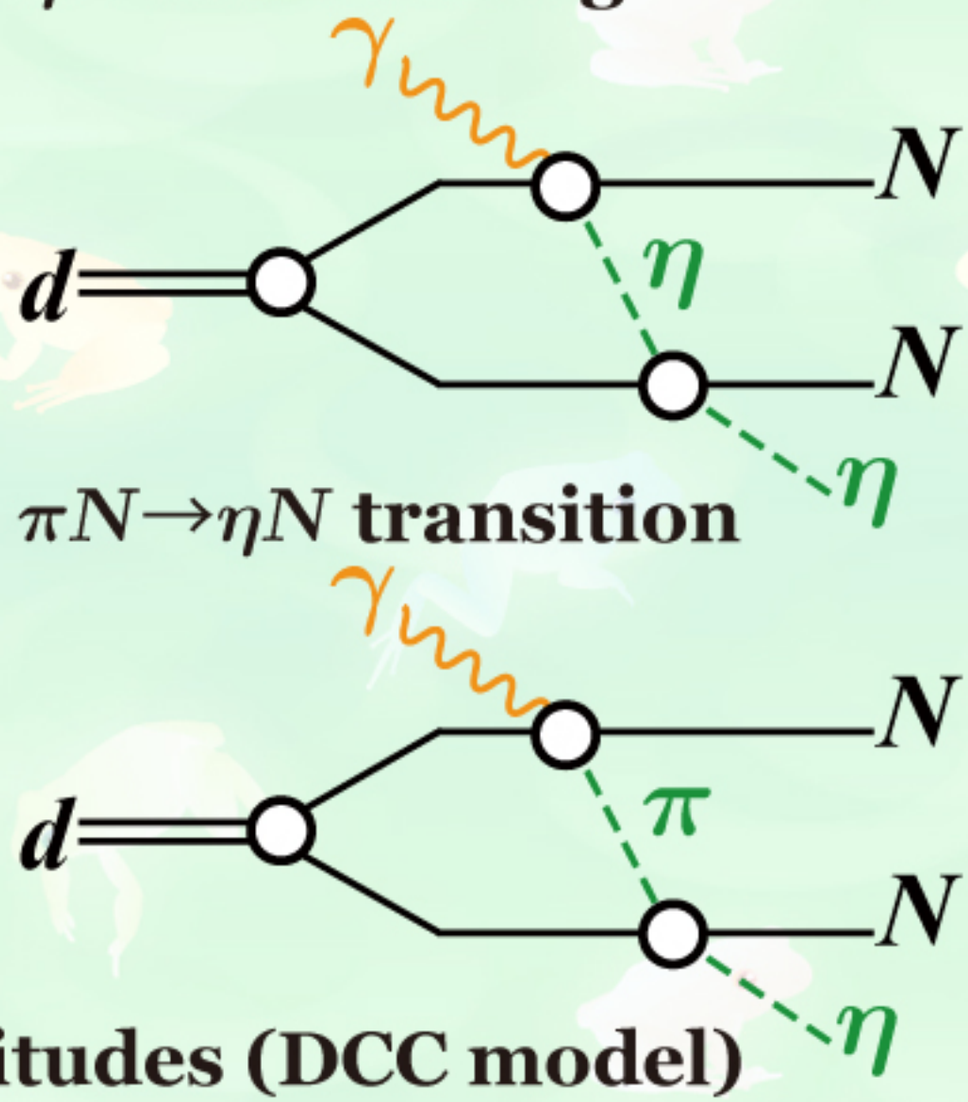
$\gamma d \to p\eta n$ reaction

Sensitivity: dynamical coupled channel (DCC) model is applied to γd reactions

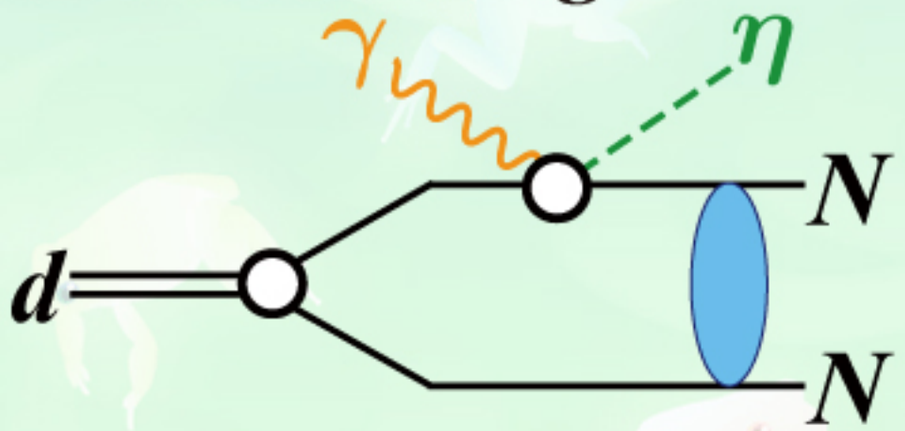
impulse



ηN rescattering



NN rescattering



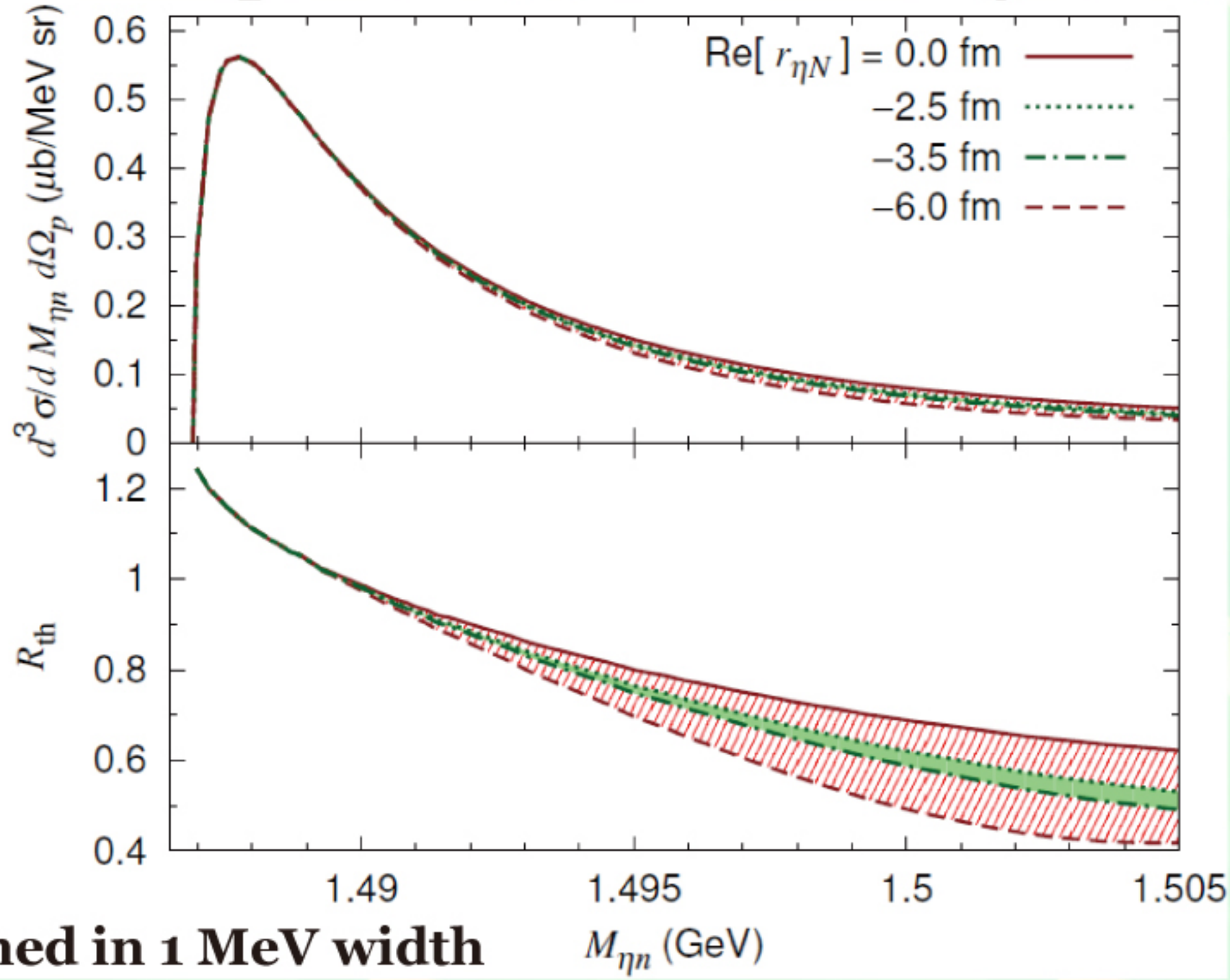
$\pi N \to \eta N$ transition

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

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

off-shell effects

Sensitivity to the real part of the effective range

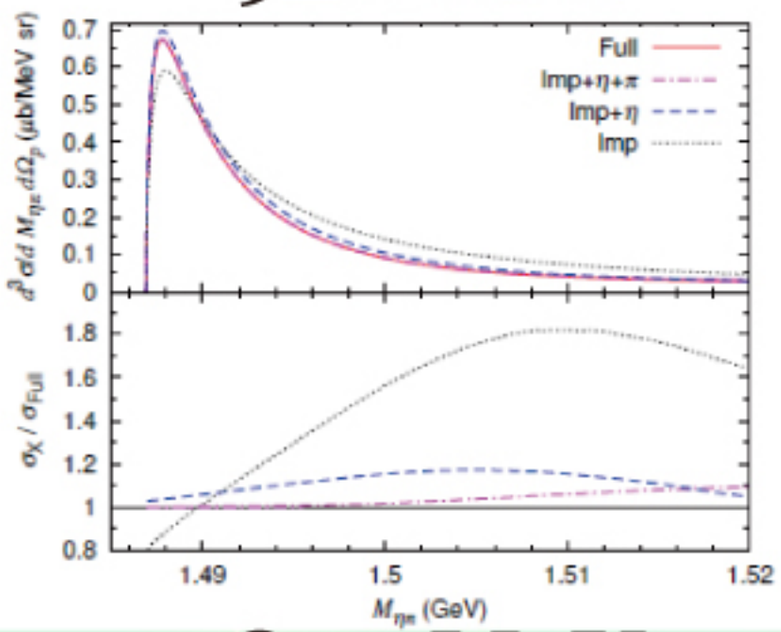


5% yield error binned in 1 MeV width gives 0.5 fm precision

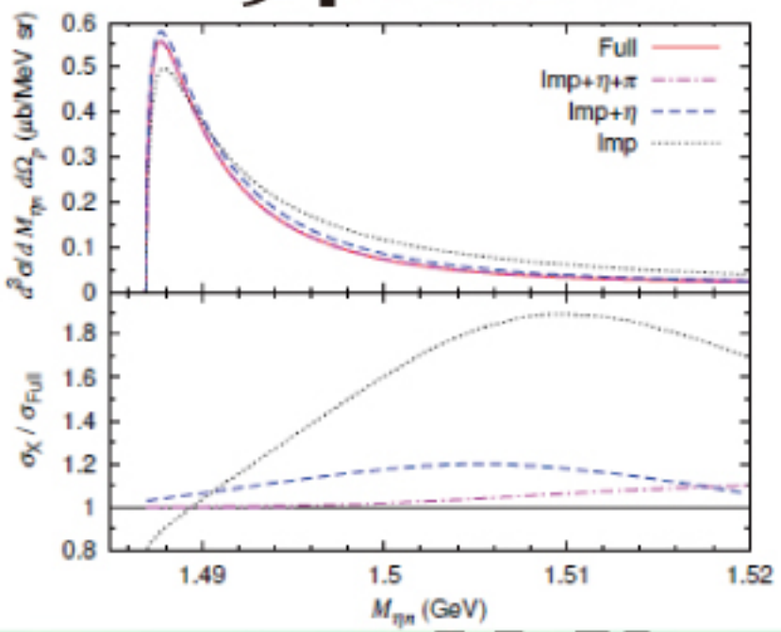
T. Ishikawa, 24 Jun. 2019 (3rd J. Sympo.)

$\gamma d \to p\eta n$ reaction

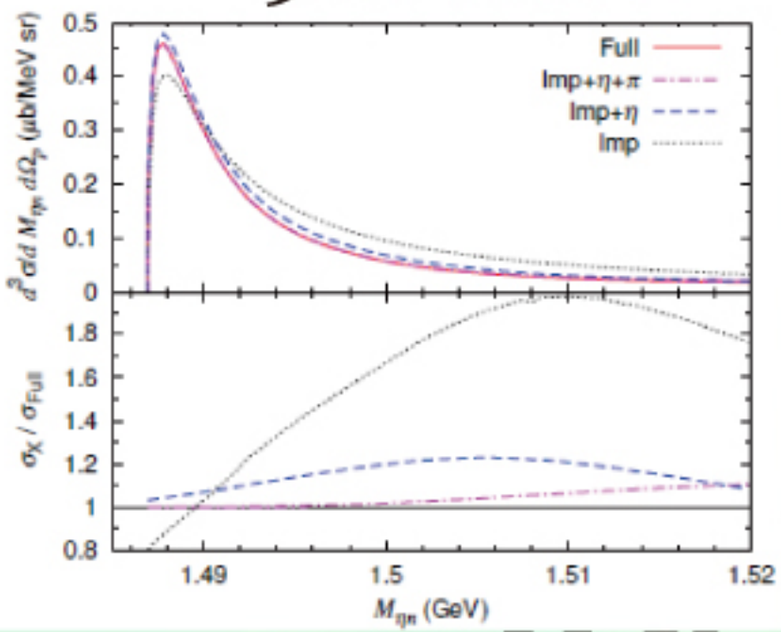
920 MeV



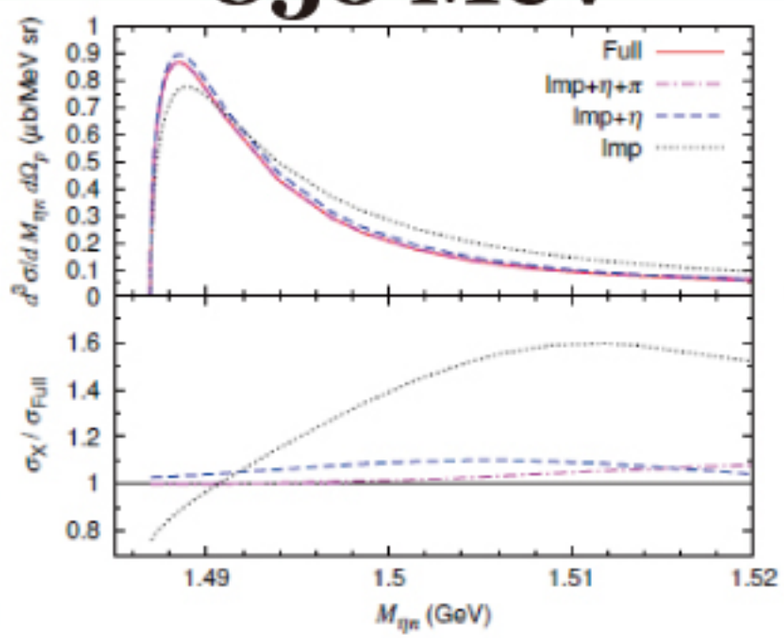
940 MeV



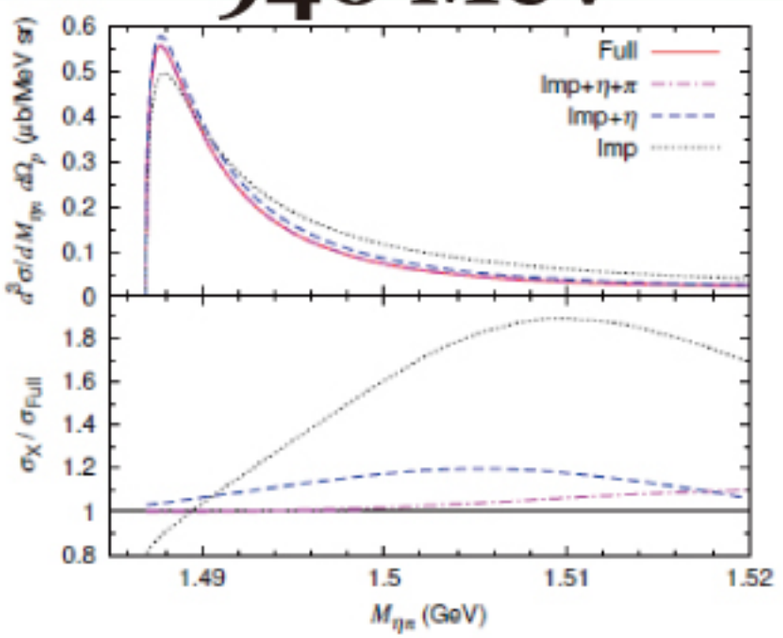
960 MeV



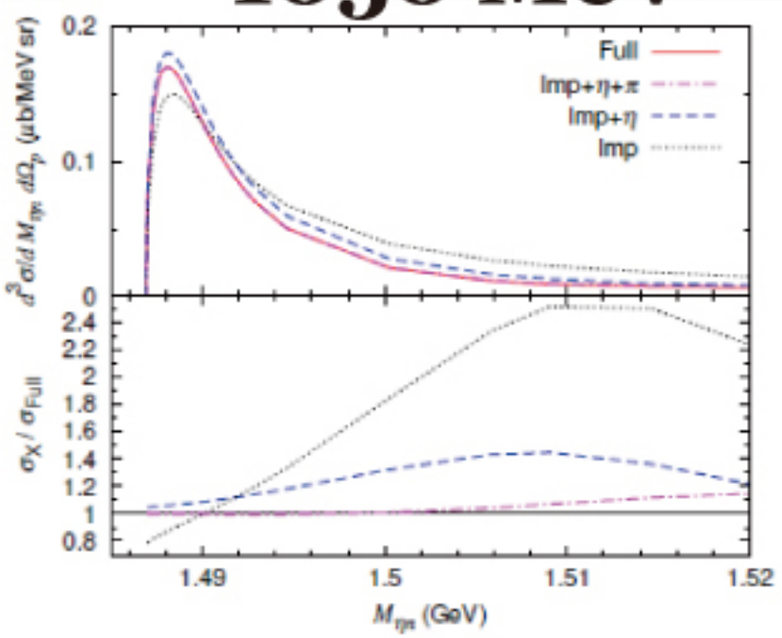
850 MeV



940 MeV



1050 MeV



similar behaviors for different incident energies

→we can use a photon beam with a finite energy range.