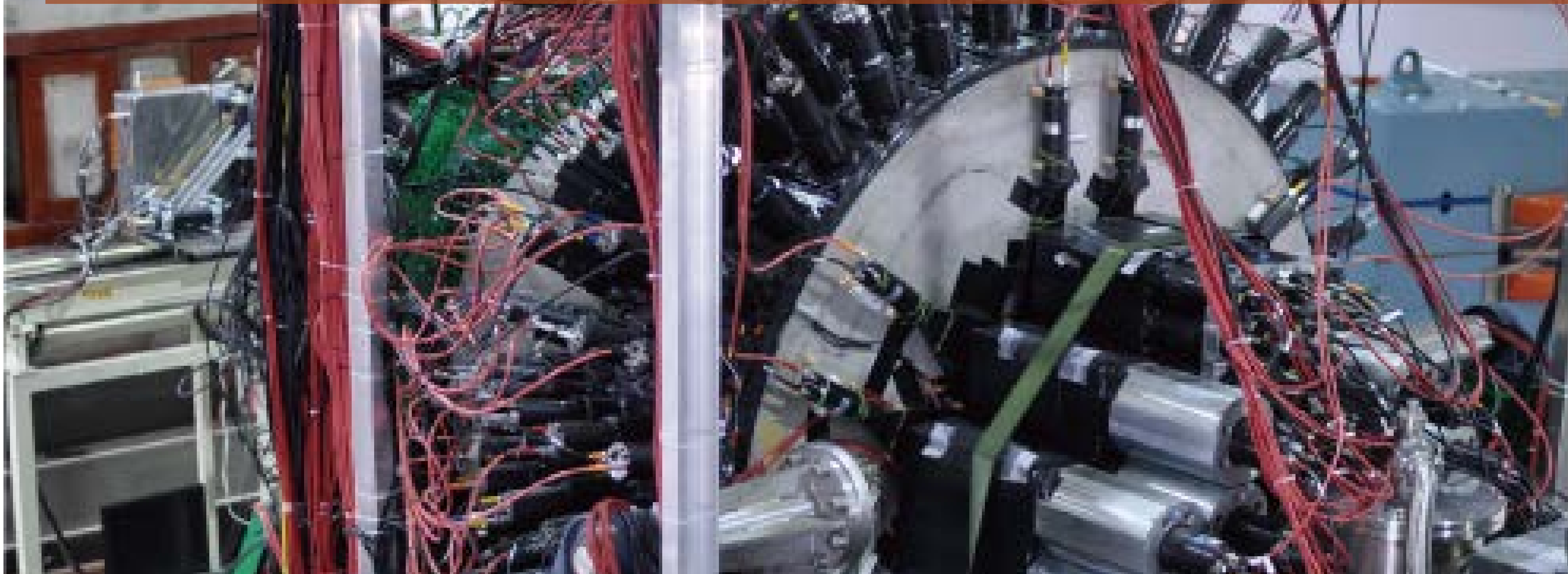
ηN scattering length from **coherent $\pi^0\eta$** photoproduction on the deuteron



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- 5th Symposium on Clustering as a window on the hierarchical structure of quantum systems, Sep. 24~25, 2020

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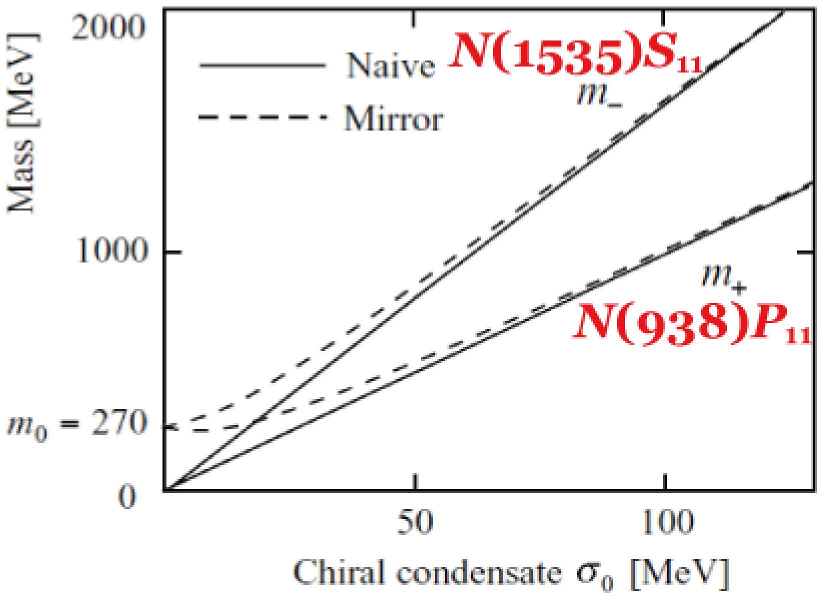
N(1535) with J^{π}=1/2⁻

chiral partner of the nucleon N(940) ?
N(940) and N(1535) degenerate
at high density and/or high temperature

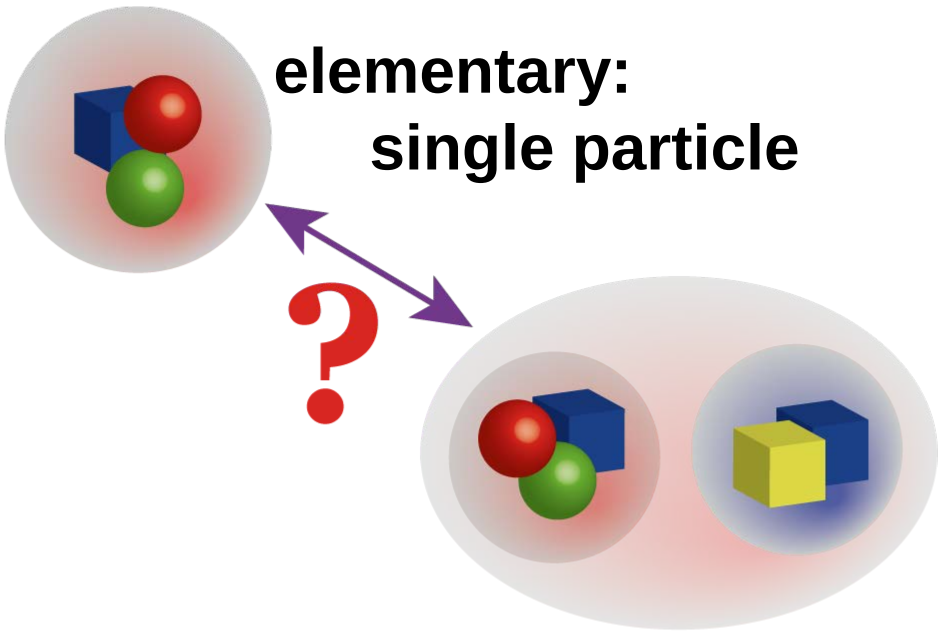


C. DeTar and T. Kunihiro, PRD 39, 2805 (1989);
T. Hatsuda and M. Prakash, PLB 224, 11 (1989);
D. Jido, M. Oka, and A. Hosaka, PTP106, 873 (2001).

strongly couples to the eta meson (η) and nucleon (N)

N(1535) with J^{π}=1/2^{-}

chiral partner of the nucleon *N*(940) ?
***N*(940) and *N*(1535) degenerate**
at high density and/or high temperature



strongly couples to the eta meson (η)
and nucleon (N)

compositeness X:
overlap with the two-body scattering state

X is directly given by the scattering length a and effective range r

$$a=\frac{2X}{X+1}R,\quad r=\frac{X-1}{X}R,\quad R=\left(2\mu B\right)^{-1/2}$$

S. Weinberg, PR137, B672 (1965).

X can be also used for the near threshold resonances

T. Hyodo, PRL111, 132002 (2013).

compositeness for $N(1535)S_{11}$

$$X_{\eta N}=0.04+i0.37$$

T. Sekihara *et al.*, PRC 93, 035204 (2016).

scattering length

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

$$p\cot\delta(p) = \frac{1}{a} + \frac{1}{2}rp^2 + O(p^4)$$

a **: scattering length**

r **: effective range**

positive (negative) a **provides attraction (repulsion)**

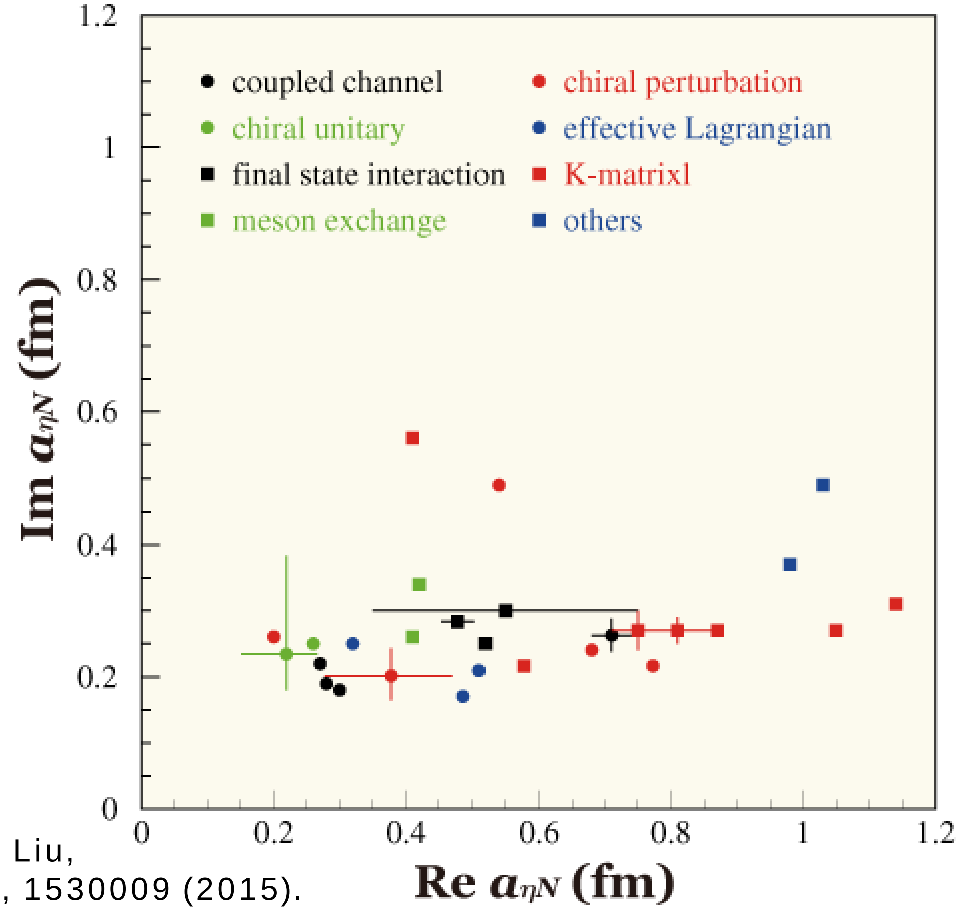
a **is negative if a bound state is available**

scattering length

fundamental and important

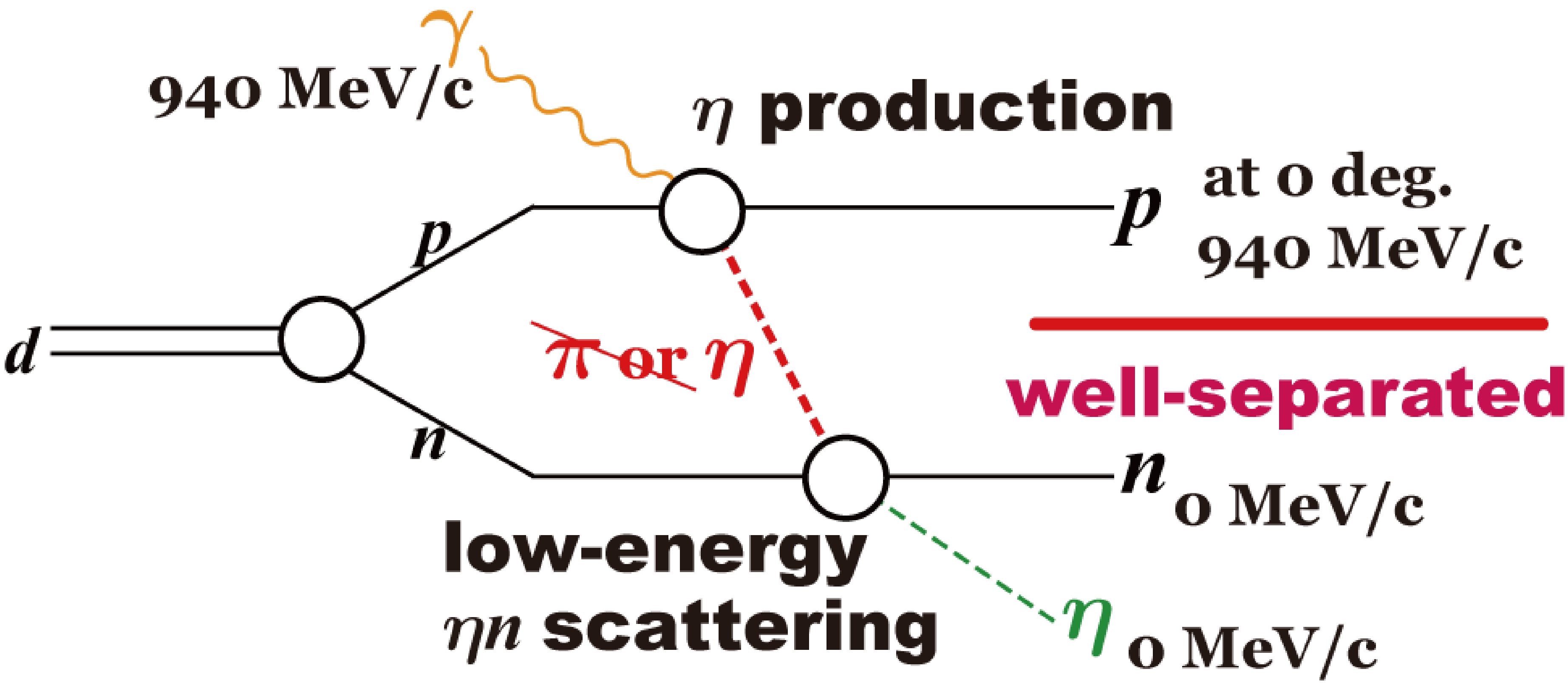
difficult to determine the scattering length between neutral hadrons

eta-nucleon scattering
Im: ~ 0.25 fm
Re: scattered



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

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



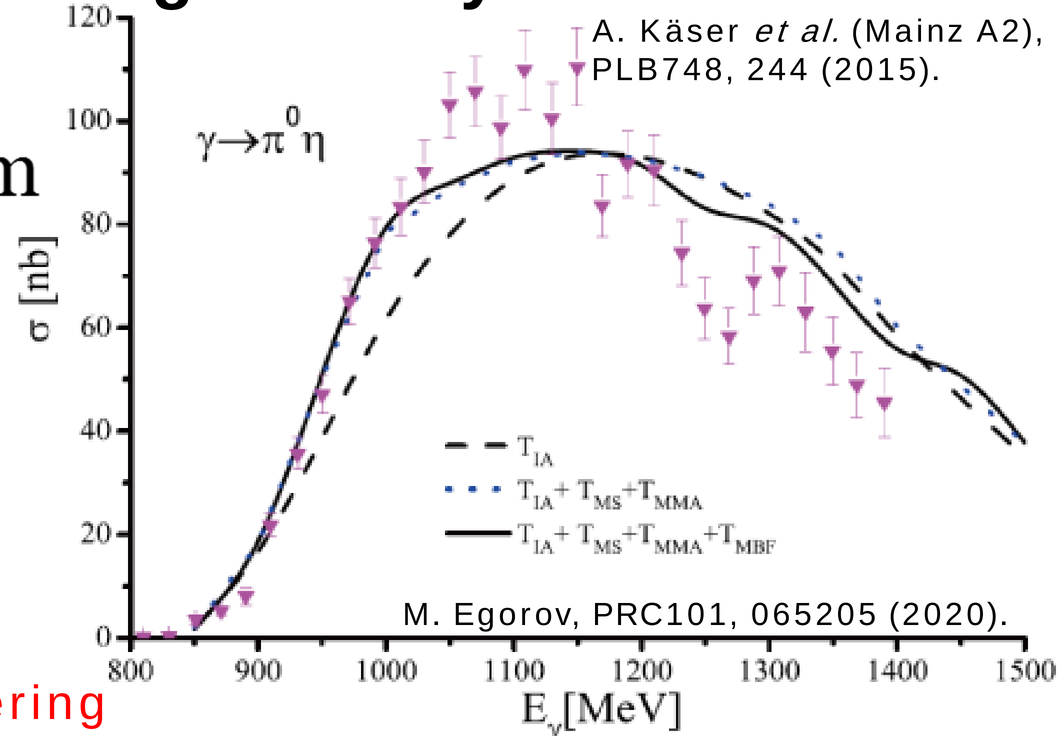
S.X. Nakamura, H. Kamano, T. Ishikawa, Phys. Rev. C 96, 042201 (R) (2017);
T. Ishikawa *et al.*, Acta Phys. Pol. B 51, 27 (2020).

alternative method

coherent $\pi^0\eta$ photoproduction on the deuteron ($\gamma d \to \pi^0 \eta d$)

1. **no *Δ*-Kroll-Ruderman or meson-pole Born term**
2. **final-state interaction is significantly enhanced**

$$a_{\eta N} = 0.70 + i0.29 \text{ fm}$$



IA: impulse
MS: meson-nucleon scattering
MMA: absorption of an additionally produced meson
MBF: meson-deuteron scattering

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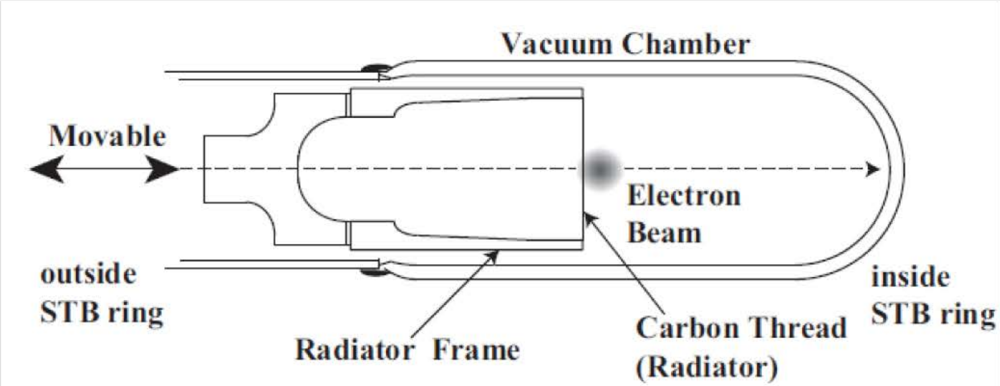
experiment ~ photo beam



the energy of each produced photon: determined by detecting the corresponding post-bremsstrahlung electron

$$E_\gamma = 0.74 \sim 1.15\,\mathrm{GeV} \;\; (E_\gamma^{\mathrm{thr}} \simeq 0.81\,\mathrm{GeV})$$

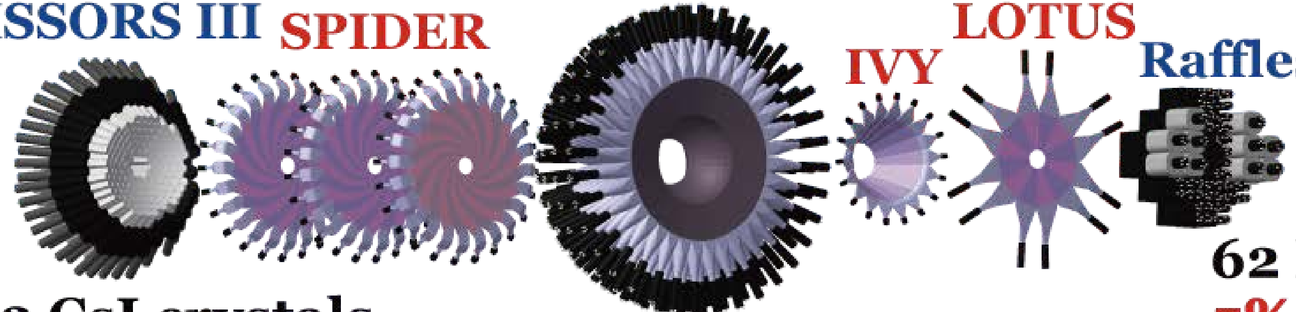
tagging intensity ~ 20 MHz
(photon intensity ~ 10 MHz)

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).

Backward Gamma

SCISSORS III SPIDER IVY LOTUS Rafflesia II

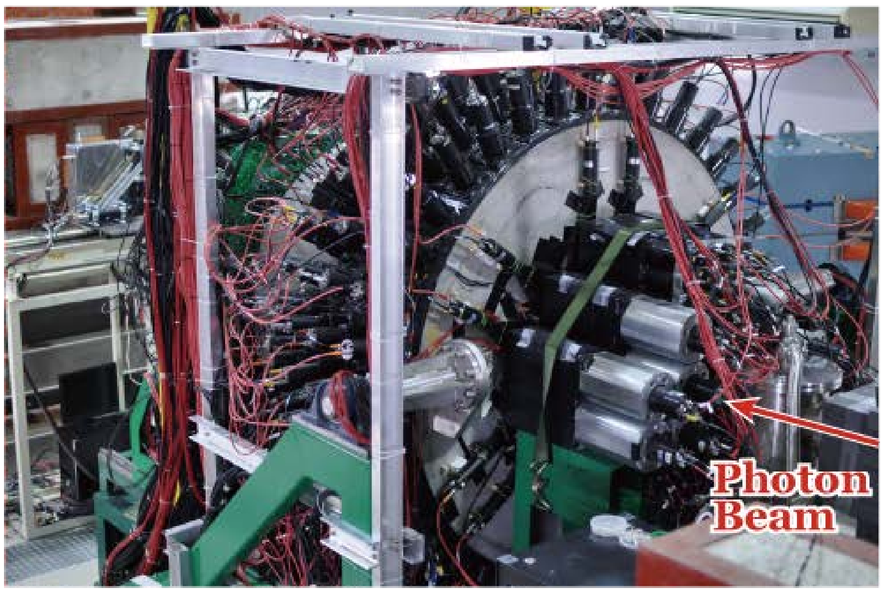
Photon Beam



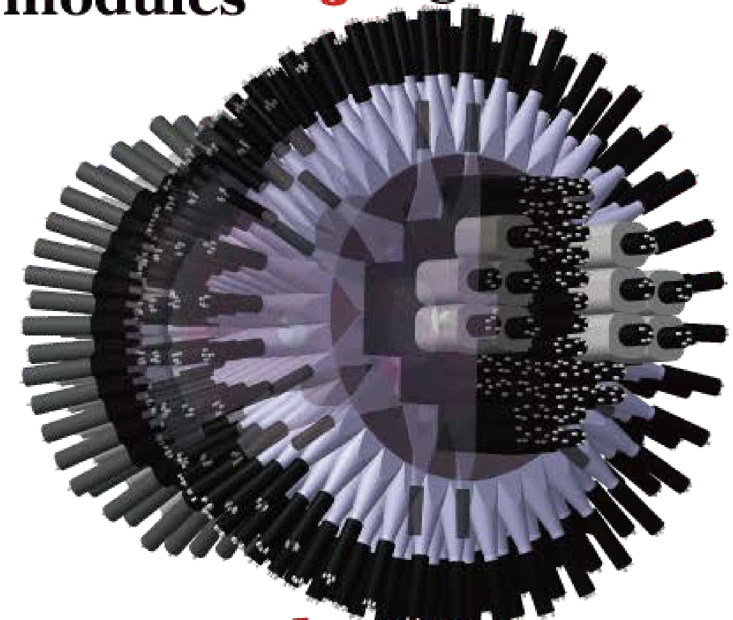
192 CsI crystals
3% @ 1 GeV

252 Lead/SciFi modules
7% @ 1 GeV

62 Lead Glasses
5% @ 1 GeV



Target: 45 mm thick LH2 & LD2



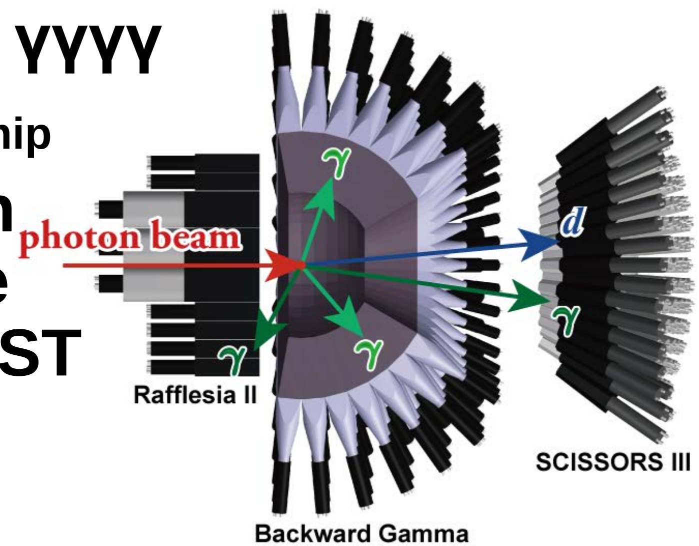
FOREST electro-magnetic calorimeter

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

analysis

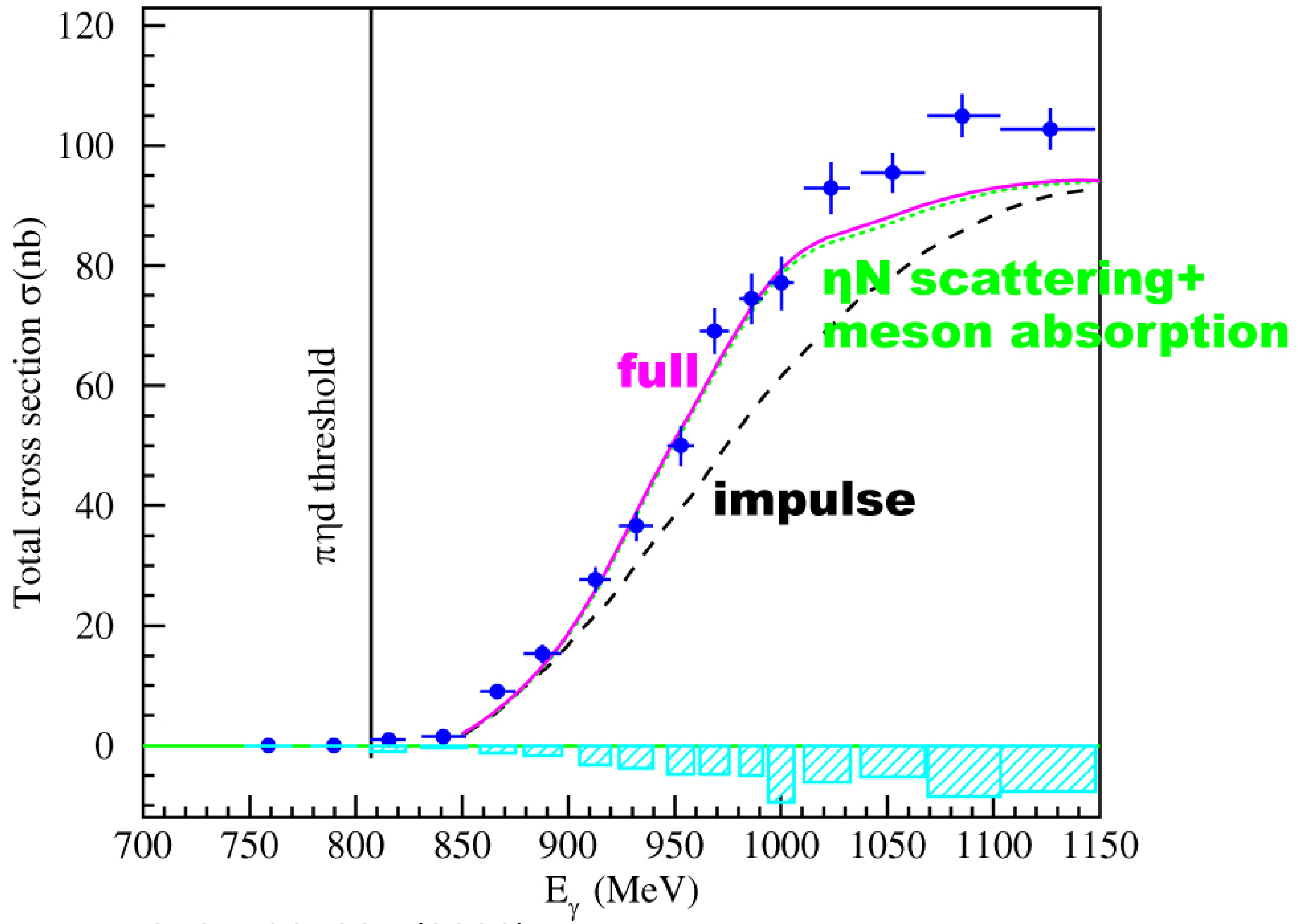
event selection for $\gamma d \to \pi^0 \eta d$

1. **4 neutral particles and 1 charged particle**
2. **π^0: $\gamma\gamma$ decay**
3. **η: $\gamma\gamma$ decay**
4. **time difference is less than $3\sigma_t$ between every two neutral clusters out of 4**
5. **d is detected with SPIDER**
   time delay is longer than 1 ns wrt $\gamma\gamma\gamma\gamma$
   energy deposit is higher than $2E_{\mathrm{mip}}$
6. **sideband background subtraction to remove accidental coincidence between STB-Tagger II and FOREST**



total cross section

excitation function below 1 GeV is well-reproduced by the theoretical calculation with the final-state interaction



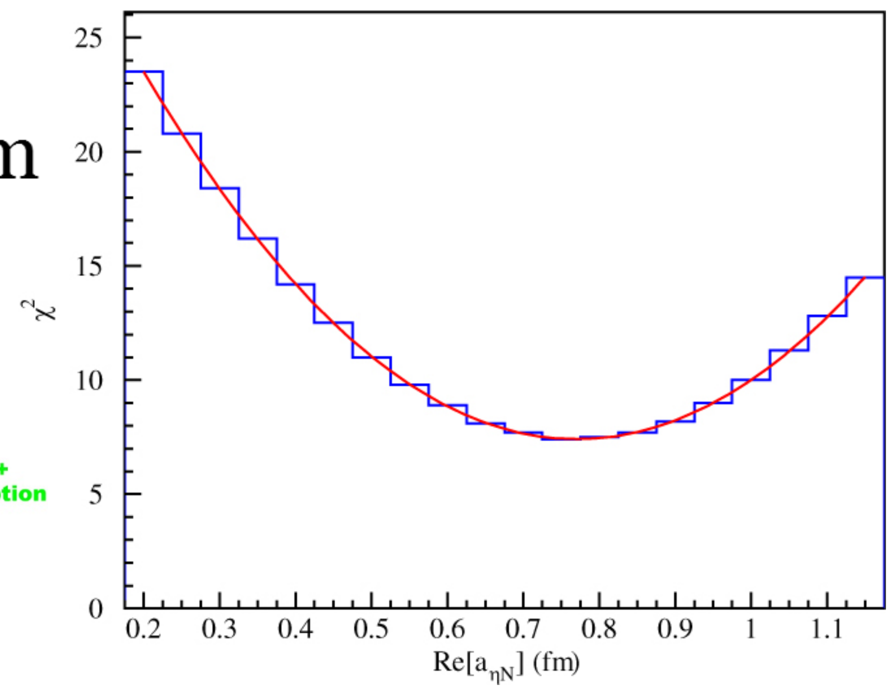
calculation: M. Egorov, PRC101, 065205 (2020).

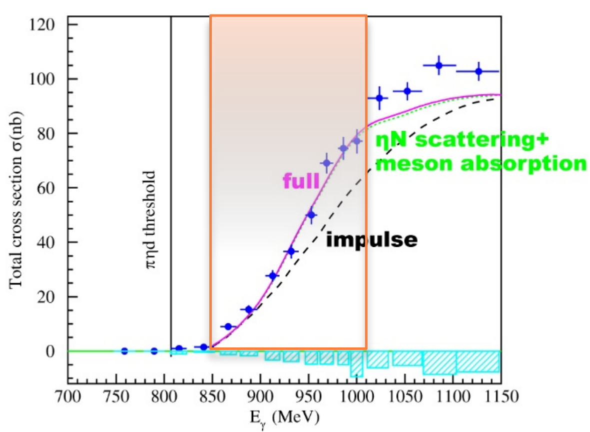
extraction of $a_{\eta n}$

ηn scattering is dominant in distortion from the impulse approximation

real part of the ηn scattering length is determined to reproduce the experimentally obtained excitation function below 1 GeV

$$a_{\eta N} = (0.77 \pm 0.04) + i0.29 \text{ fm}$$





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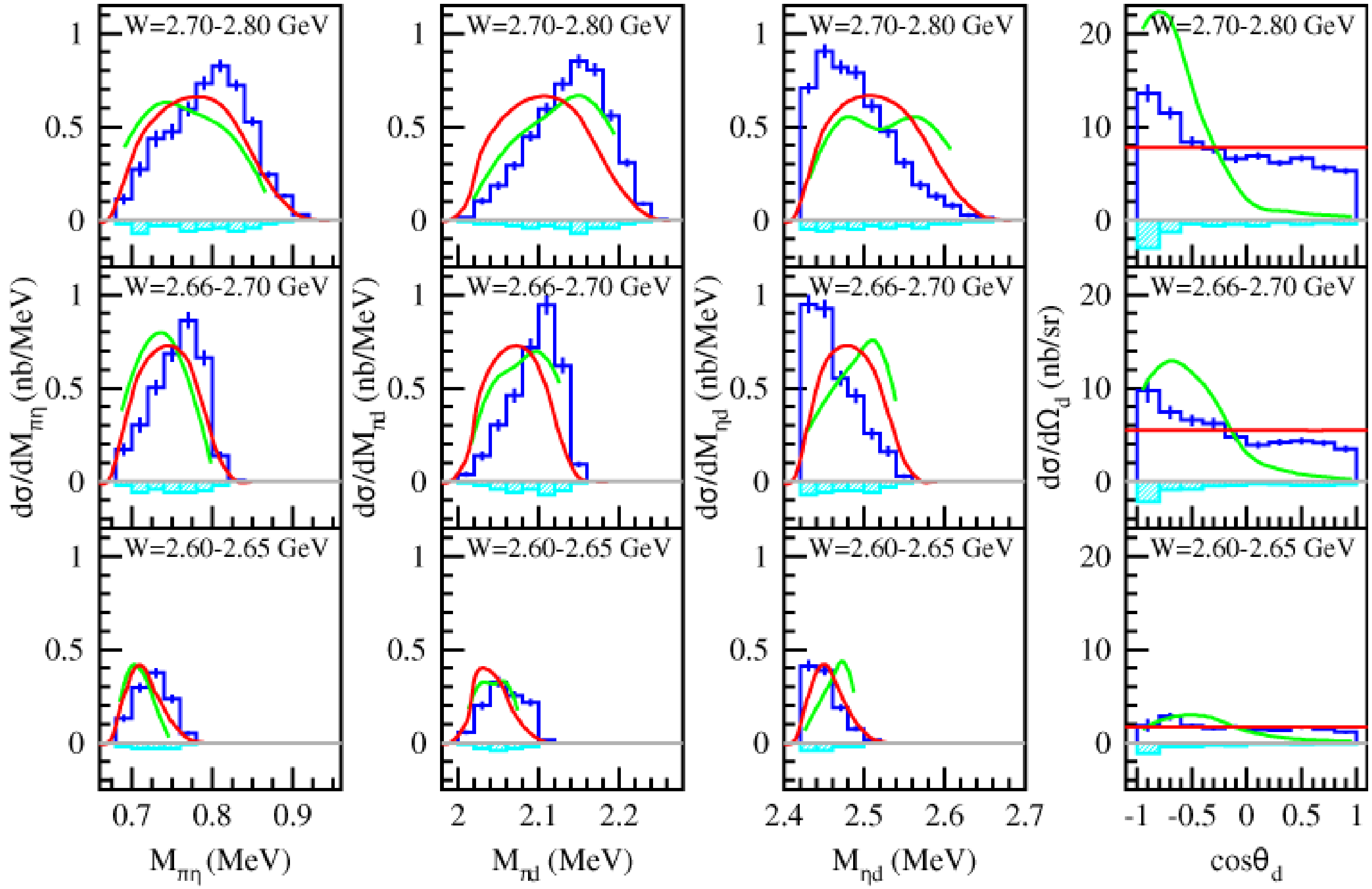
differential cross section

angular distribution of deuteron emission is not reproduced, suggesting a sequential process:

$$\gamma d \to \mathcal{D}_{IV} \to \pi^0 \mathcal{D}_{IS} / \eta \mathcal{D}_{IV} \to \pi^0 \eta d$$



phase space calculation: M. Egorov, PRC101, 065205 (2020).

summary

coherent $\pi^0\eta$ photoproduction on the deuteron ($\gamma d \to \pi^0 \eta d$) has been measured to determine the ηN scattering length $a_{\eta N}$

$a_{\eta N}$ is found to be $a_{\eta N} = (0.77 \pm 0.04) + i0.29\ \mathrm{fm}$
(imaginary part is fixed) from the excitation function of the total cross section below 1.2 GeV

angular distribution of deuteron emission is not reproduced, suggesting a sequential process:
$\gamma d \to \mathcal{D}_{IV} \to \pi^0 \mathcal{D}_{IS} / \eta \mathcal{D}_{IV} \to \pi^0 \eta d$

ηn invariant mass distribution