Study of the η'N interaction in the η' photoproduction

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Introduction

η'-nucleus system

- Origin of the η' mass
  ←$U_A(1)$ anomaly and **chiral symmetry breaking** (3flavor)
  Pisarski-Wilzek(1984), Kunihiro-Hatsuda(1988), Cohen (1996), Lee-Hatsuda (1996), …
- Chiral restoration in nuclear medium
  (reduction of order parameter of chiral symmetry breaking)
  Drukarev-Levin(1991), Cohen et al.(1991),…

✓ η' mass reduction in nuclear medium

✓ Existence of η'-nucleus bound state

Nagahiro-Hirenzaki(2005)
Nagahiro-Takizawa-Hirenzaki (2006)
Jido-Nagahiro-Hirenzaki (2012)

η'-nucleon interaction = basic information

- Theoretical and Experimental studies

Theory) Borasoy (2000), Bass and Thomas (2006), Oset and Ramos (2011),…

Experiment) Moyssides et al.(1979), Moskal(2000), Czerwinski et al.(2014),…

Theoretical study based on linear sigma model

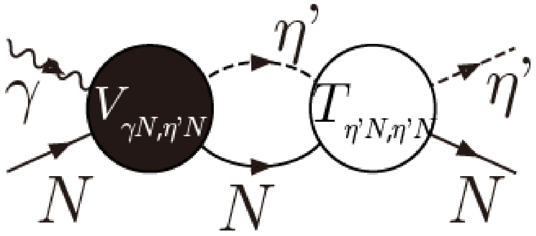
η'N attraction from the scalar meson exchange
➔ Possible existence of η'N bound state

S.S. and Jido (2013)

Investigation of the η’N interaction from the **η’ photoproduction**

(Nakayama et al.(2004,2006),Tryasuchev(2008),Huang et al.(2013))

- η’N interaction appears
  from the final-state interaction



- Rich experimental data in many facilities
  - Energy and angular dependence of cross section
  - Polarization observables

Qualitative discussion for the effect of the η’N interaction on η’ photoproduction process near η’N threshold

- Study based on linear sigma model with vector meson
  ➔ Analysis including **η’ production** and **η’N interaction** in a consistent manner

Model setup

$$\mathcal{L}_{L\sigma M} = \frac{1}{2}\mathrm{tr}(D_\mu M D^\mu M^\dagger) - \frac{\mu^2}{2}\mathrm{tr}(MM^\dagger) - \frac{\lambda}{4}\mathrm{tr}\left[(MM^\dagger)^2\right]$$
$$- \frac{\lambda'}{4}\left[\mathrm{tr}(MM^\dagger)\right]^2 + A\mathrm{tr}\chi M^\dagger + \sqrt{3}B\det M + \mathrm{h.c.}$$
$$+\bar{N}\left[i\left(\partial\!\!\!/ + ig_V V\!\!\!/ + i\frac{t_V}{4m_V}\sigma^{\mu\nu}V_{\mu\nu}\right) - m_N\right.$$
$$\left. -g\left\{\left(\frac{\tilde{\sigma}_0}{\sqrt{3}} + \frac{\tilde{\sigma}_8}{\sqrt{6}}\right) + i\gamma_5\left(\frac{\eta_0}{\sqrt{3}} + \frac{\vec{\pi}\cdot\vec{\tau}}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}}\right)\right\}\right]N$$
$$-\frac{1}{4}V_{\mu\nu}^{a2} + \frac{m_0^2}{2}V_\mu^{a2} + e g_{\gamma V\eta'}\epsilon^{\mu\nu\rho\sigma}\left(\partial_\mu V_\nu\right)\left(\partial_\rho A_\sigma\right)\eta'$$

$$M = \sum_{a=0}^{8}\frac{\sigma_a\lambda_a}{\sqrt{2}} + i\sum_{a=0}^{8}\frac{\pi_a\lambda_a}{\sqrt{2}} \qquad N = \begin{pmatrix} p \\ n \end{pmatrix} \qquad V^a = \rho, \omega \qquad A_\mu : \text{photon field}$$

(λ_a: Gell-Mann matrix)

$$\chi = \mathrm{diag}(m_q, m_q, m_s)$$

$\mathcal{L}_{L\sigma M} \Longrightarrow \mathcal{V}(\sigma_i)$ ➡ $\langle\sigma_i\rangle$ from $\frac{\partial\mathcal{V}}{\partial\sigma_i}(\sigma_i) = 0$ ($\langle\sigma_i\rangle$: chiral order parameter)

tree-level approx. — effective potential — minimum condition

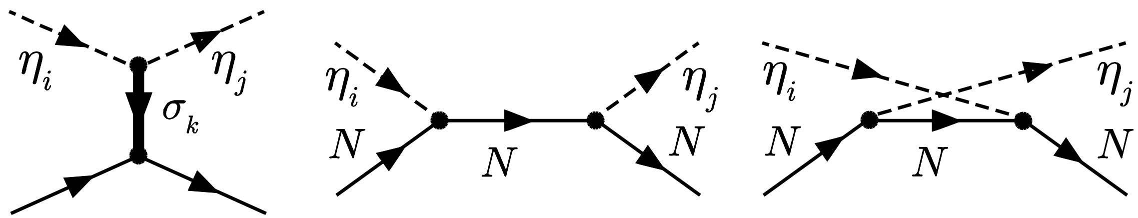
※ Free parameters: reproduce in-vacuum meson properties
and 35% reduction of quark condensate @normal nuclear density.

Suzuki et al.(2004), Friedman et al.(2004)

η’N interaction

S.S. and Jido (2013)

Tree-level approximation



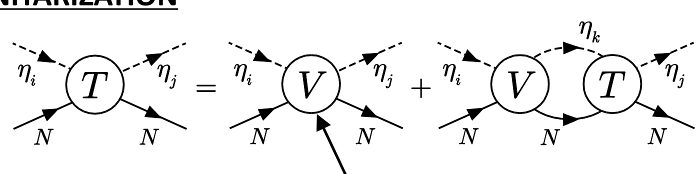
Expansion wrt the hadron momenta & flavor SU(3) limit

$$V_{\eta' N\to\eta' N} = -\frac{6gB}{\sqrt{3}m_{\sigma_0}^2} \quad V_{\eta' N\to\eta N} = \frac{6gB}{\sqrt{6}m_{\sigma_8}^2} \quad V_{\eta N\to\eta N} = 0$$

Attractive interaction from the scalar-meson exchange

➔ Possible η’N bound state (binding energy: ~10MeV)

UNITARIZATION



$$T_{ij} = V_{ij} + V_{ik}G_kT_{kj}$$
$$(i,j,k = \eta N, \eta' N)$$

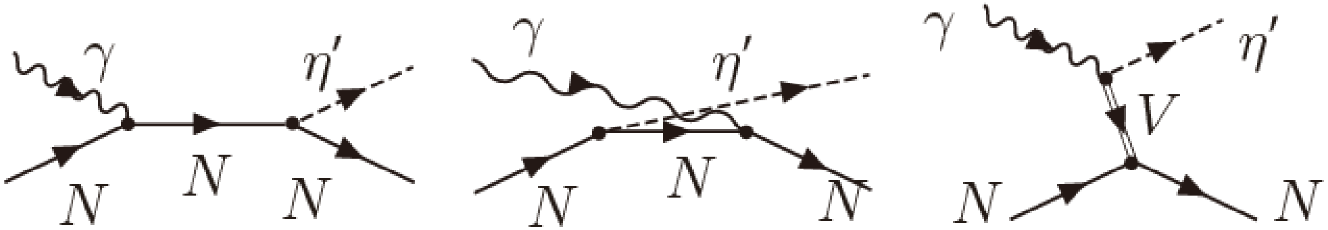
※ Omit the πN channel contribution:

Small production cross section of πN→η’N (Rader et al.(1972))

○ g is varied to check the effect of η’N FSI

η’ photoproduction

tree level $V_{\gamma N \to \eta' N}$



Born terms

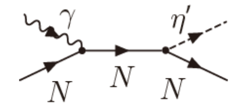
Vector-meson exchange

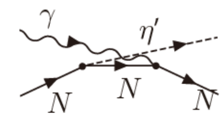
※1. Single channel study in production part:
Expectation of the small energy dependence

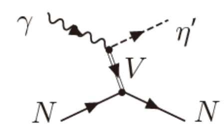
※2. Form factors → additional cutoff parameter
➔ Fixed to reproduce the order of the γp→η’p experimental data

$\gamma N \to \eta' N$ amplitude

$$
\begin{aligned}
-iV_{\gamma N\to\eta' N} = & e\bar{u}(p',s')\Bigg[g_{PN}\left\{\gamma_5 \frac{F_s \not{k} + F_c(\not{p}+m_N)}{(p+k)^2-m_N^2}\not{\epsilon} + \not{\epsilon}\frac{-F_u \not{k}' + F_c(\not{p}+m_N)}{(p-k')^2-m_N^2}\gamma_5 \right.\\
& \left. + \frac{\kappa_p}{4m_N}\left(F_s\gamma_5 \frac{\not{p}+\not{k}+m_N}{(p+k)^2-m_N^2}[\not{k},\not{\epsilon}] + F_u[\not{k},\not{\epsilon}]\frac{\not{p}-\not{k}'+m_N}{(p-k')^2-m_N^2}\gamma_5\right)\right\}\\
& + iF_t \frac{g_V g_{\gamma VP}/2}{t-m_V^2+i\epsilon} g_{\mu\sigma}\epsilon^{\rho\sigma\alpha\beta}k'_\rho k_\alpha \epsilon_\beta \left\{\gamma^\mu + \frac{\kappa_V}{4m_N}[\not{q},\gamma^\mu]\right\}\Bigg] u(p,s),
\end{aligned}
$$







$$F_i = \frac{\Lambda^4}{(i-m^2)^2+\Lambda^4} \quad (i = s,t,u)$$

$$F_c = F_s + F_u - F_s F_u$$

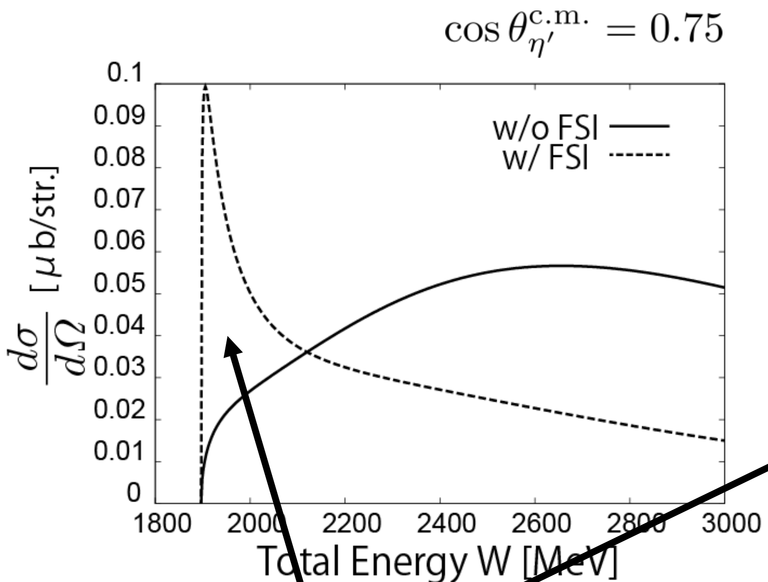
$$T_{\gamma N\to\eta' N} = V_{\gamma N\to\eta' N}\left(1 + G_{\eta' N} T_{\eta' N\to\eta' N}\right)$$

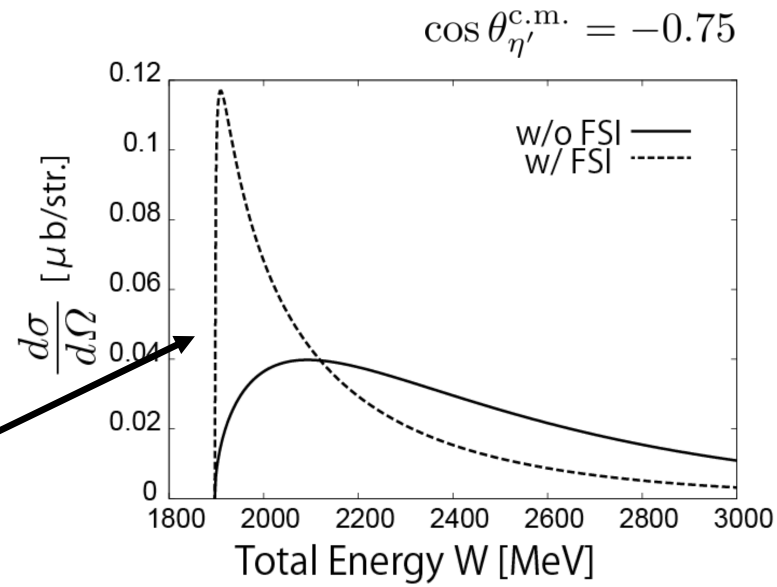
η’N final-state interaction

■ η’N interaction: s wave ← dominant near the η’N threshold

➡ **Focus on the near-threshold energy**

Energy dependence of differential cross section of η’ photoproduction

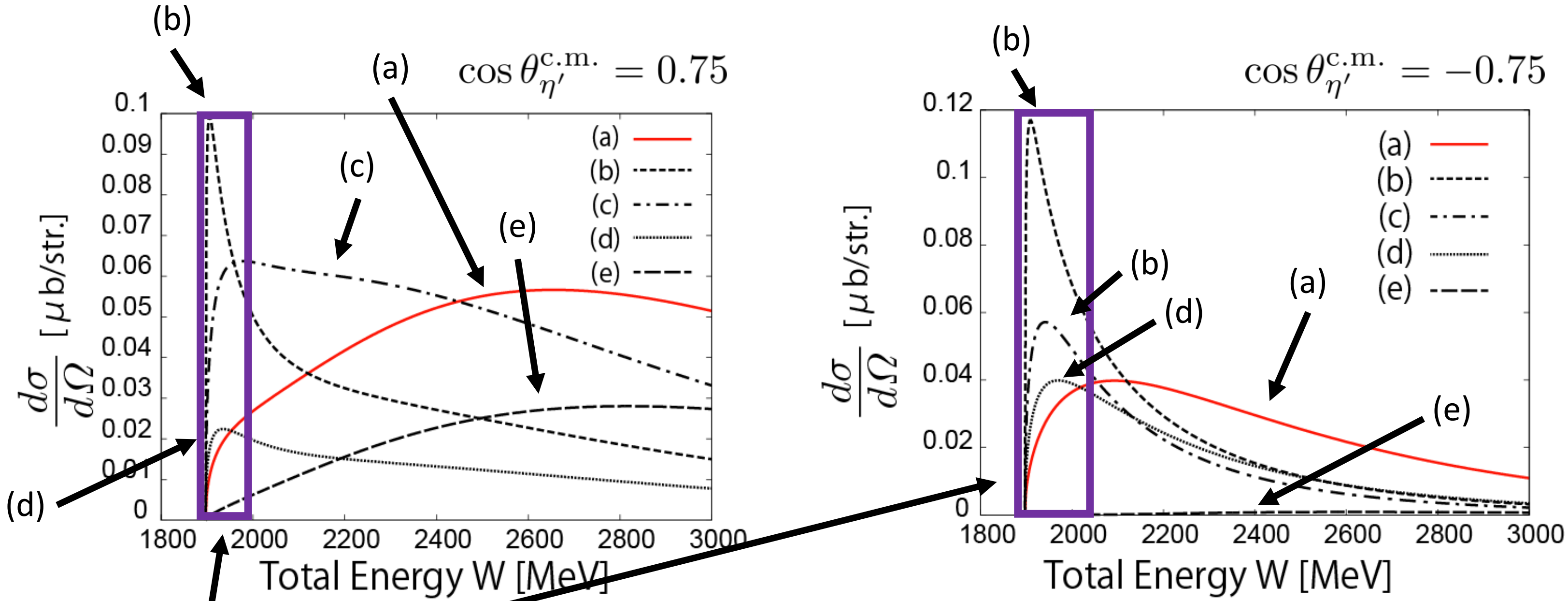




※ Cutoff parameter Λ: same value in every channel and g

Enhancement near η’N threshold

Energy dependence of differential cross section of η’ photoproduction



Enhancement from η’N FSI

※ Cutoff parameter Λ: same value in every channel and g

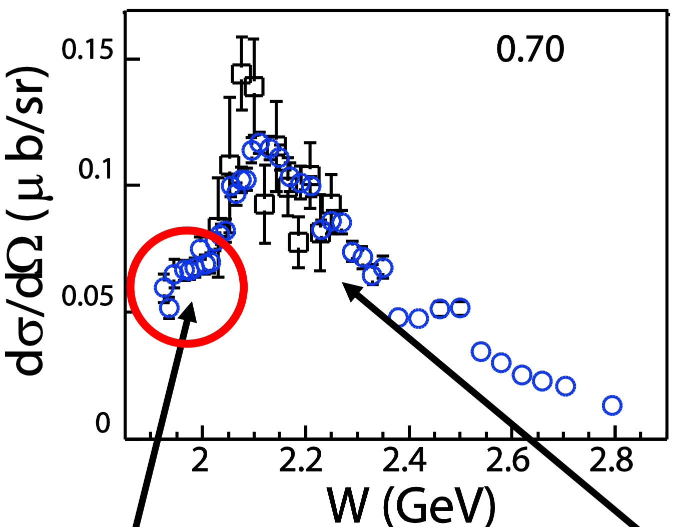
(a)	$g \times 0.0$	:no η’N interaction
(b)	$g \times 1.0$	:attractive (shallow bound state)
(c)	$g \times 0.5$	:attractive (no bound state)
(d)	$g \times 1.5$	:attractive (deep bound state)
(e)	$g \times -0.5$	:repulsive

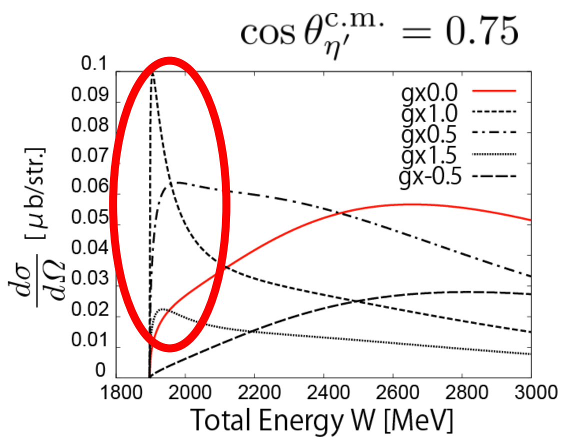
(Interaction kernel $V_{ij} \propto g$)

- Inclusion of η’N FSI ➔ Enhancement of near-threshold η’ production
- Near-threshold bound state: large enhancement

Energy dependence of differential cross section of η' photoproduction $(\cos\theta_{\eta'}^{\text{c.m.}} = 0.75)$

Williams et al.(CLAS Collab.), PRC80(2009)045213.





Enhancement below 2GeV?

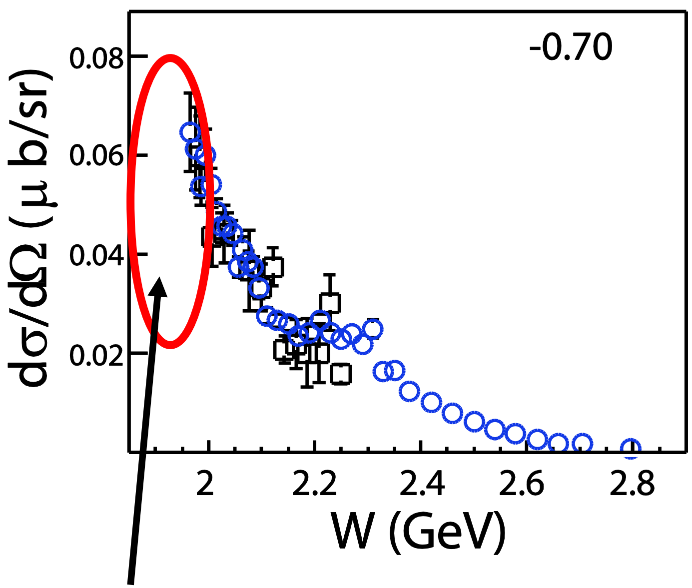
Resonance contribution around 2.1GeV?

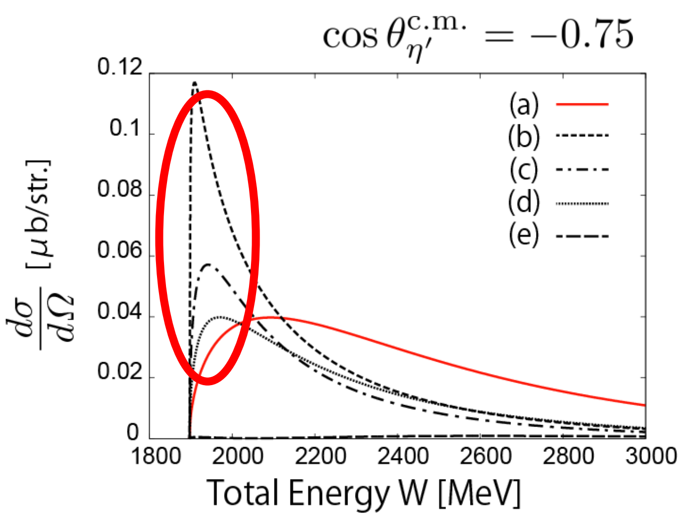
Nakayama and Haberzettl (2006), Kashevarov et al.(2015)

➡ Further study should be done to clarify η'N interaction from the photoproduction process

Energy dependence of differential cross section of η' photoproduction $(\cos\theta_{\eta'}^{c.m.} = -0.75)$

Williams et al.(CLAS Collab.), PRC80(2009)045213.





Lack of the near-threshold data

➡ Near-threshlod data in the backward direction can be a clue to study the η'N interaction

★ Recent A2MAMI data and its analysis (Kashevarov et al.(2015))

➔ Necessity of near-threshold enhancement in η' photoproduction (implemented through $S_{11}(1895)$)

Summary

- Effect of the η'N final-state interaction
  on the η'-photoproduction process
  based on linear sigma model
  - Near-threshold enhancement from η'N attraction
  - Importance of the near-threshold data
    in backward direction

Outlook

Other quantities

- Angular dependence of cross section, polarization observables,…

Development of model including larger energy region and channel coupling

- More detailed study of η'N interaction
  (flavor symmetry breaking, momentum dependence,…)
  S.S. and Jido, arXiv:1607.07116 (2016)
- Application to coupled-channel analysis (πN, ηN, KΛ,…)
- Resonance contribution?,…

Thank you for your attention!!