Photoproduction of the scalar mesons $f_0(980)$ and $f_0(500)$ off the nucleon

Jehee Lee
Inha University, Korea

NSTAR2015 @ RCNP

In collaboration with Huiyoung Ryu,
Byung-Geel Yu, and Hyun-Chul Kim

Outline

- Motivation
- Theoretical Framework
  - Effective Lagrangian Approach
  - Coupling Constants
  - Regge Propagators
- Numerical Result
- Summary and Outlook

Motivation

- Scalar mesons
  - $I^G(J^{PC}) = 0^+(0^{++})$
  - Long-standing puzzle
  - Large decay widths
  - Interpretation of structure is not clear
  - Lack of information about the production mechanism

Motivation

Name	Mass [MeV]	Width [MeV]	$I^G(J^{PC})$
$f_0(980)$	990	$40-100$	$0^+(0^{++})$
$f_0(500)$	$400-550$	$400-700$	$0^+(0^{++})$

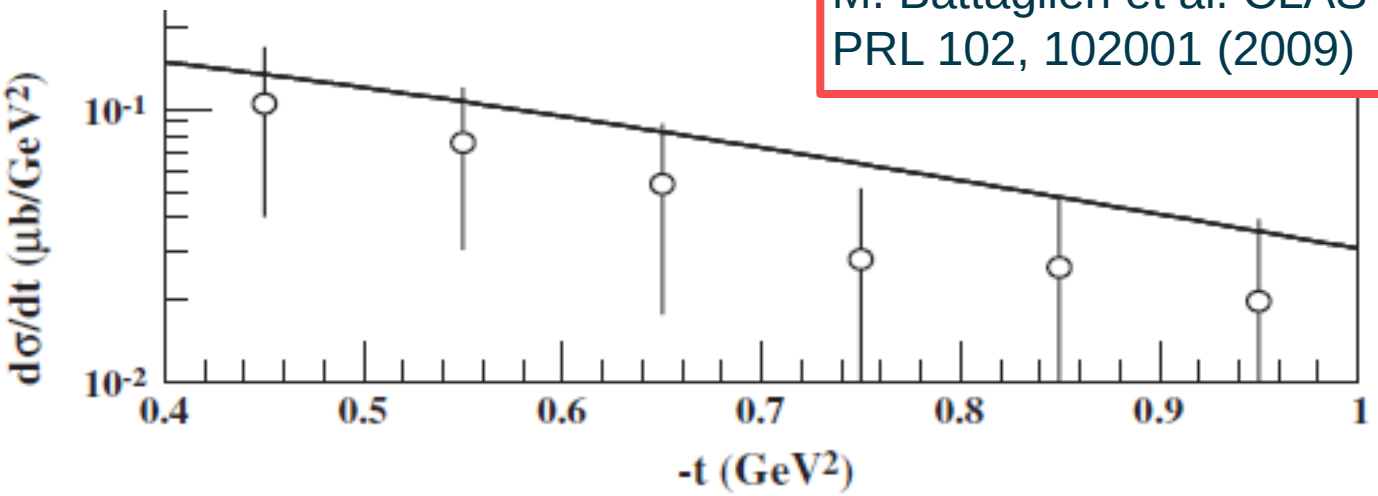
- Both of them exist in $\pi\pi$ scattering

K.A. Olive et al., (Particle Data Group), Chin. Phys. **C 38**, 090001 (2014).

Motivation

- $(\pi\pi)^{I=0}_{s-wave}$ photoproduction has been reported.

M. Battaglieri et al. CLAS Collaboration
PRL 102, 102001 (2009)



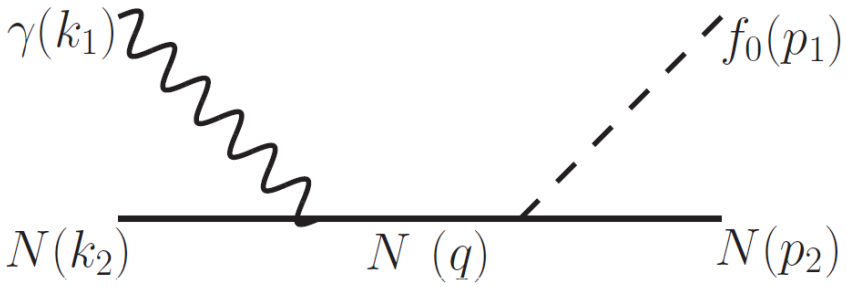
- CLAS collaboration. M. Bellis et al., Proposal to the PAC, E-06-013. at Jefferson Lab.

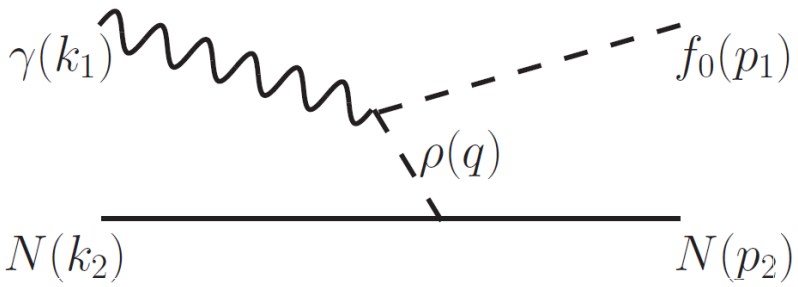
Theoretical Framework

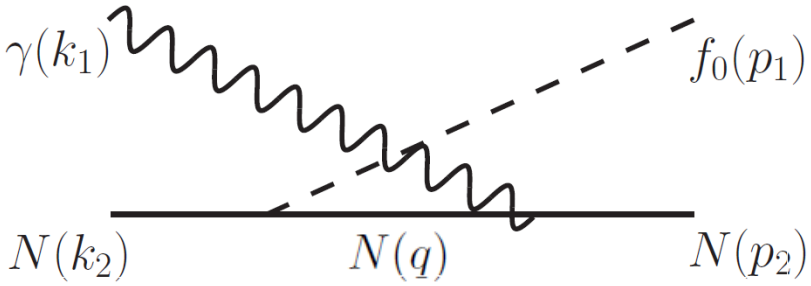
- Effective Lagrangian Approach
- Coupling Constants
- Regge Propagators

Effective Lagrangians Approach

$$\gamma N \rightarrow f_0(980) N$$

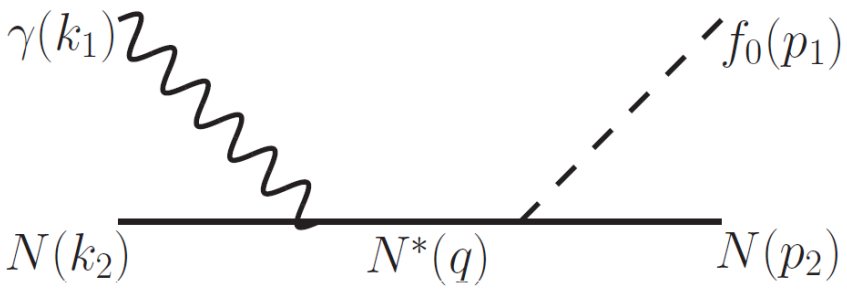






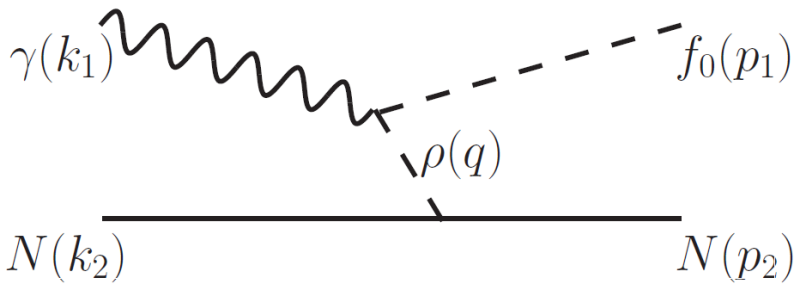
Effective Lagrangians Approach

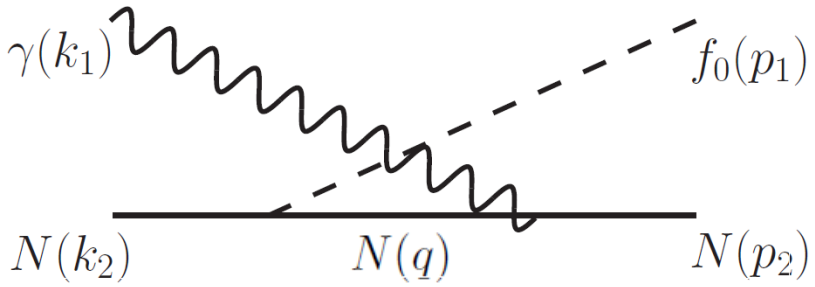
$$\gamma N \to f_0(500) N$$



Resonance	$I(J^P)$	Status
N(1440)	$\frac{1}{2}(\frac{1}{2}^+)$	****
N(1535)	$\frac{1}{2}(\frac{1}{2}^-)$	****
N(1710)	$\frac{1}{2}(\frac{1}{2}^+)$	***

K.A. Olive et al., (Particle Data Group), Chin. Phys. **C 38**, 090001 (2014).

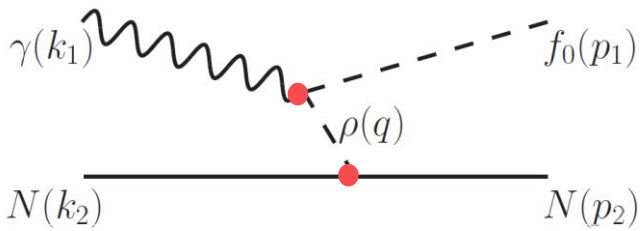




Effective Lagrangians Approach

$\gamma N \rightarrow f_0(980) N$ $\gamma N \rightarrow f_0(500) N$

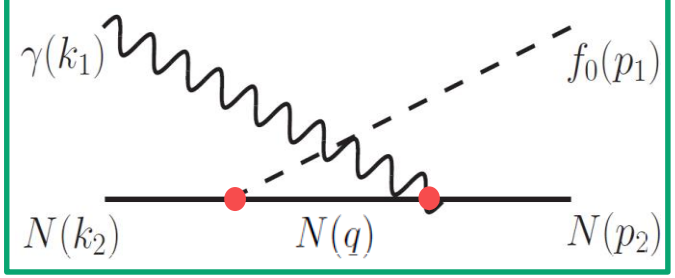
t-channel : ρ



$$\mathcal{L}_{\gamma\rho f_0} = \frac{g_{\gamma\rho f_0}}{m_\rho}\left[\partial_\mu A_\nu \partial^\mu \rho^\nu - \partial_\mu A_\nu \partial^\nu \rho^\mu\right] f_0$$

$$\mathcal{L}_{\rho NN} = -g_{\rho NN}\bar{N}\left[\gamma_\mu \rho^\mu - \frac{\kappa_\rho}{2m_N}\sigma^{\mu\nu}\partial_\nu \rho_\mu\right] N$$

u-channel : N(938)



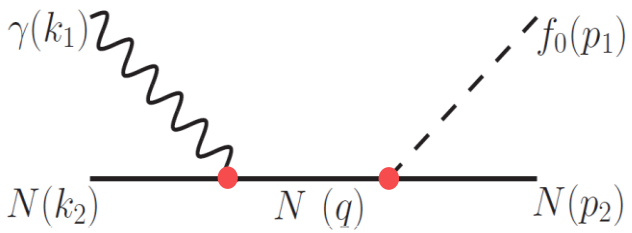
$$\mathcal{L}_{\gamma NN} = -\bar{N}\left(e_N \gamma_\mu A^\mu - \frac{e\kappa_N}{2m_N}\sigma_{\mu\nu}\partial^\nu A^\mu\right) N$$

$$\mathcal{L}_{f_0 NN} = g_{f_0 NN} f_0 \bar{N} N$$

Effective Lagrangians Approach

$\gamma N \rightarrow f_0(980) N$ $\gamma N \rightarrow f_0(500) N$

s-channel : N(938)



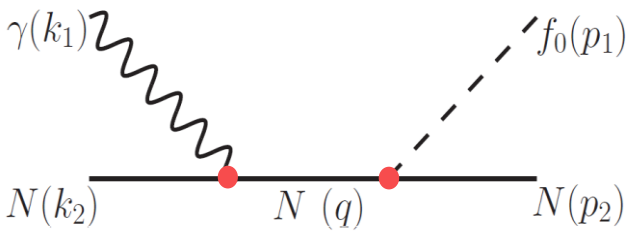
$$\mathcal{L}_{\gamma NN} = -\bar{N}\left(e_N \gamma_\mu A^\mu - \frac{e\kappa_N}{2m_N}\sigma_{\mu\nu}\partial^\nu A^\mu\right) N$$

$$\mathcal{L}_{f_0 NN} = g_{f_0 NN} f_0 \bar{N} N$$

Effective Lagrangians Approach

$$\gamma N \rightarrow f_0(500) N$$

s-channel : N(1440), N(1650), N(1710)



$$\mathcal{L}_{\gamma N N^*}\left(\frac{1}{2}^{\pm}\right) = \pm\frac{e f_1}{2m_N}\bar{N}^*\partial^\nu A^\mu \sigma^{\mu\nu}\Gamma^{(\mp)}N$$

$$\mathcal{L}_{f_0 N N^*}\left(\frac{1}{2}^{\pm}\right) = \pm g_{f_0 N N^*} f_0 \bar{N}\Gamma^{(\mp)}N^*$$

Coupling Constants

Meson vertex

Using the partial decay width

$$\Gamma = \frac{P}{8\pi m_R^2}\frac{1}{2J+1}\sum_{\lambda_\gamma,s,s'}|\mathcal{M}|^2$$

$$\Gamma = \left(\text{the Breit-Wigner width of the meson}\right) X \left(\text{the branching ratio of } (\pi\pi)^{I=0}_{s-wave}\right)$$

Assumption

We only consider $(\pi\pi)^{I=0}_{s-wave}$ decay mode

Coupling Constants

$$\gamma N \rightarrow f_0(980) N$$

s- and *u*- channel

κ_p	$g_{f_0 N N}$
1.79	0.56

t- channel

κ_ρ	$g_{\rho N N}$	$g_{\gamma \rho f_0}$
6.1	3.1	0.22

B. Friman and M. Soyeur, Nucl. Phys. A 600, 477 (1996)

Coupling Constants

$\gamma N \rightarrow f_0(500) N$

s- channel

κ_p	$g_{f_0 NN}$
1.79	5.6

Name	$g_{f_0 NN^*}$
N(1440)	$\pm$ 3.88166
N(1535)	$\pm$ 0.962174
N(1710)	$\pm$ 2.29678

t- channel

κ_ρ	$g_{\rho NN}$	$g_{\gamma \rho f_0}$
6.1	3.1	0.25

u- channel

κ_p	$g_{f_0 NN}$
1.79	5.6

B. Friman and M. Soyeur, Nucl. Phys. A 600, 477 (1996)
Y. s. Oh and T. S. H. Lee, Phys. Rev. C 69, 025201 (2004)

Coupling Constants

$$\gamma N \rightarrow f_0(500) N$$

γNN vertex

Using the $R \rightarrow N\gamma$ helicity amplitude

$$A_{1/2}\left(\frac{1}{2}^{\pm}\right) = \mp \frac{e f_1}{2 m_N} \sqrt{\frac{k_\gamma m_R}{m_N}}$$

Name	f_1
N(1440)	0.47198
N(1535)	0.803571
N(1710)	-0.237518

V. Shklyar, H. Lenske, U. Mosel, and G. Penner, Phys. Rev. C 71, 055206 (2005)

Regge Propagator

t-channel

$$D_{Regge} = \left(\frac{s}{s_0}\right)^{\alpha_\rho(t)-1} \frac{1}{\sin[\pi\alpha_\rho(t)]} \frac{\pi\alpha'_\rho}{\Gamma[\alpha_\rho(t)]}$$

$$= \left(\frac{s}{s_0}\right)^{\alpha_\rho(t)-1} \Gamma[1-\alpha_\rho(t)] \cdot \alpha'_\rho$$

u-channel

$$D_{Regge} = \frac{\left(\frac{s}{s_0}\right)^{\alpha_N(u)-\frac{1}{2}} \pi\alpha'_N}{\Gamma[\alpha_N(u)+\frac{1}{2}]\sin\pi(\alpha_N+\frac{1}{2})}$$

$$= \left(\frac{s}{s_0}\right)^{\alpha_N(u)-\frac{1}{2}} \Gamma[1-(\alpha_N(u)+\frac{1}{2})]\alpha'_N$$

M.Guidal, J.-M Laget, M.Vanderhaeghen, Nucl. Phy. A 627, 645-678 (1997)

Regge Trajectory

t-channel

$$\alpha_\rho(t) = 0.55 + 0.8t$$

u-channel

$$\alpha_N(u) = -0.34 + 0.98u$$

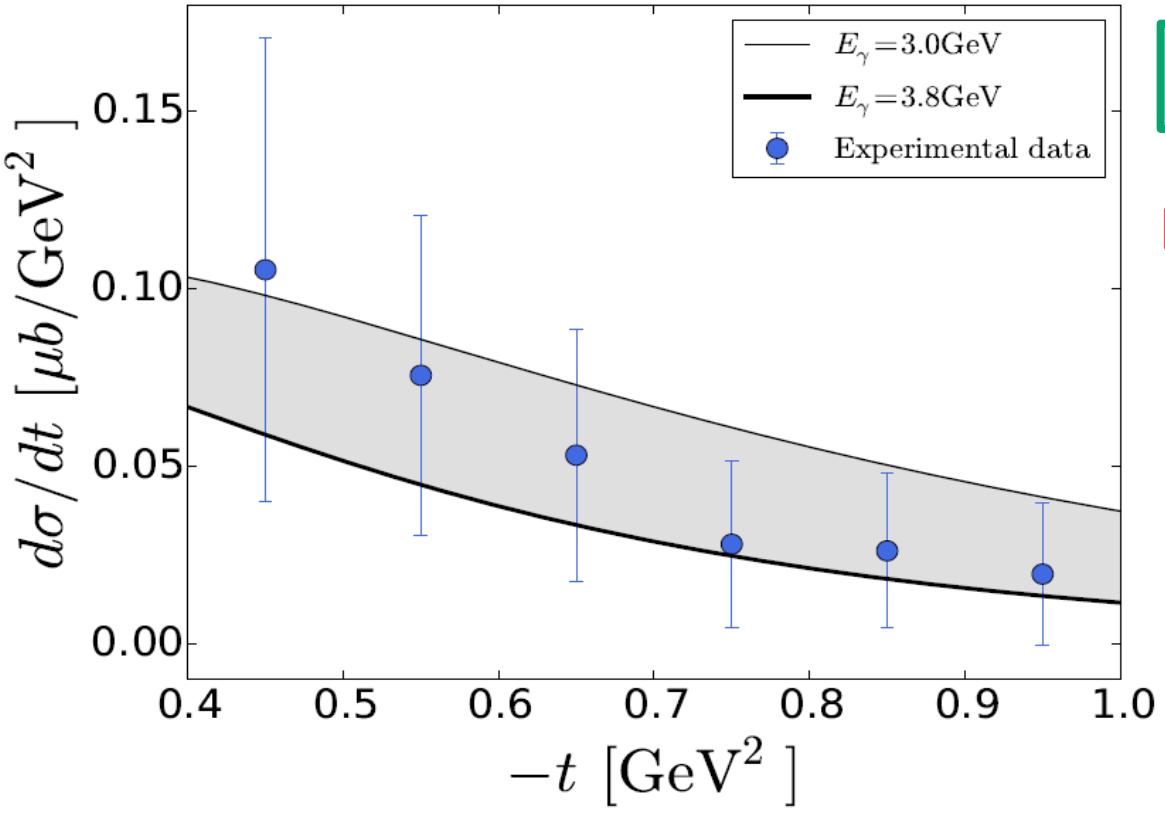
M.Guidal, J.-M Laget, M.Vanderhaeghen, Nucl. Phy. A 627, 645-678 (1997)
L. Sertorio, L.L. Wang, Phys. Rev. 178, 5 (1969)

Numerical Results

- Differential cross section of $\gamma N \rightarrow f_0(980)N$
- Total cross section of $\gamma N \rightarrow f_0(980)N$
- Differential cross section of $\gamma N \rightarrow f_0(500)N$
- Total cross section of $\gamma N \rightarrow f_0(500)N$

Differential cross section of $f_0(980)$

- To determine the cutoff and s_scale



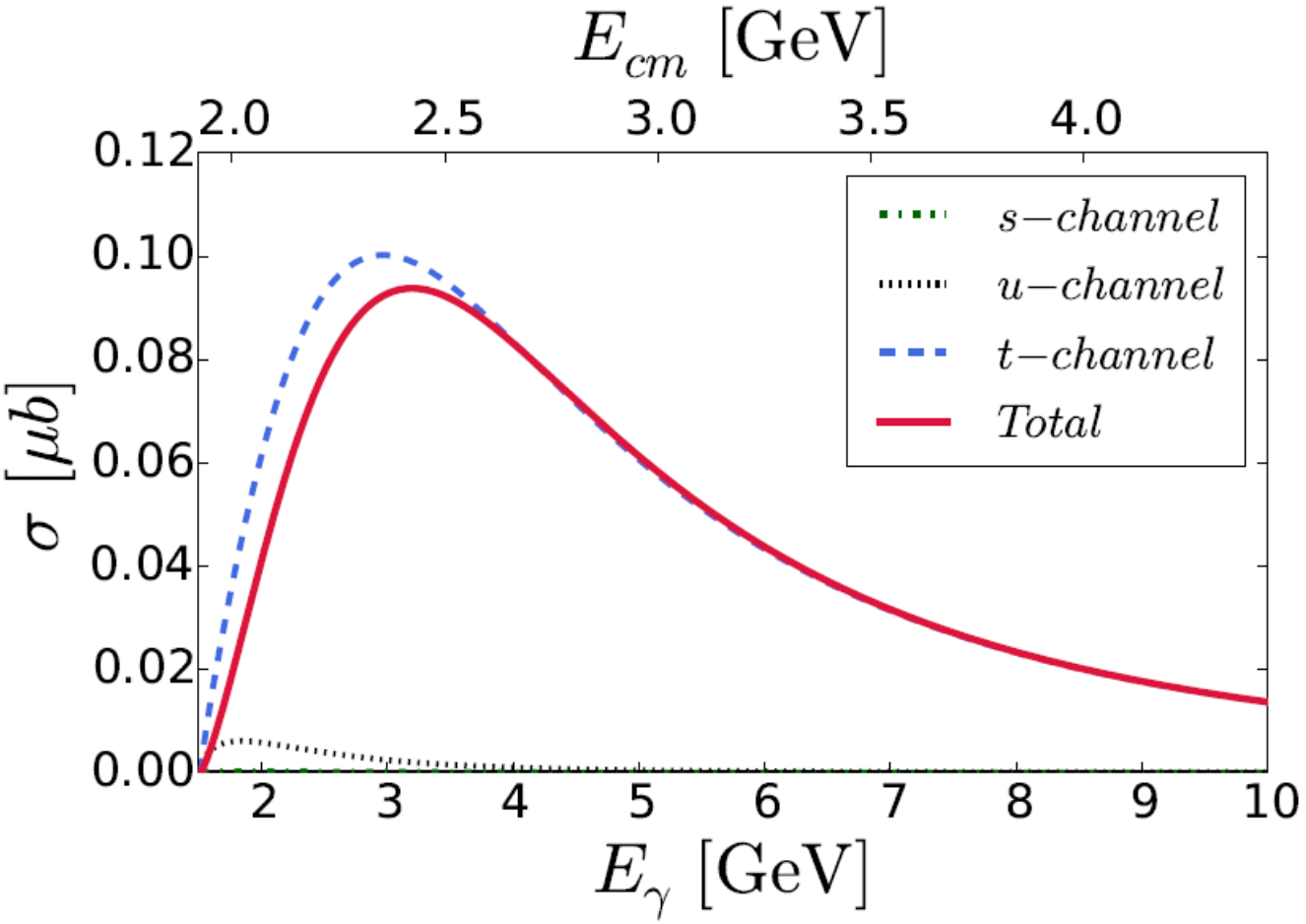
E_γ = 3.0 – 3.8 GeV

Λ = 0.8 GeV
s_0 = 1.2 GeV^2

$$\frac{\Lambda^4}{\Lambda^4 + (p^2 - m_R^2)^2}$$

M. Battaglieri et al. CLAS Collaboration PRL 102, 102001 (2009)

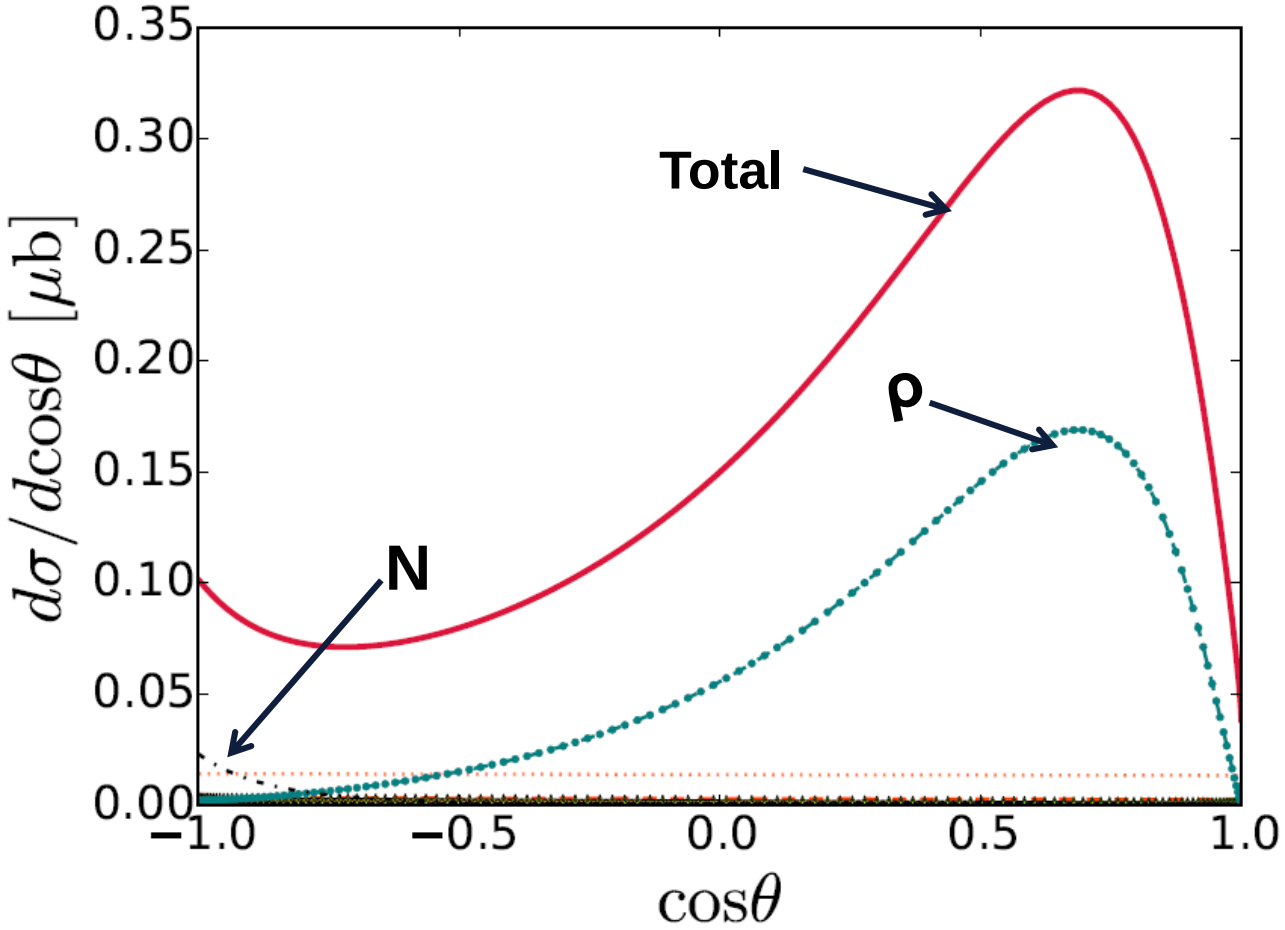
Total cross section of $f_0(980)$



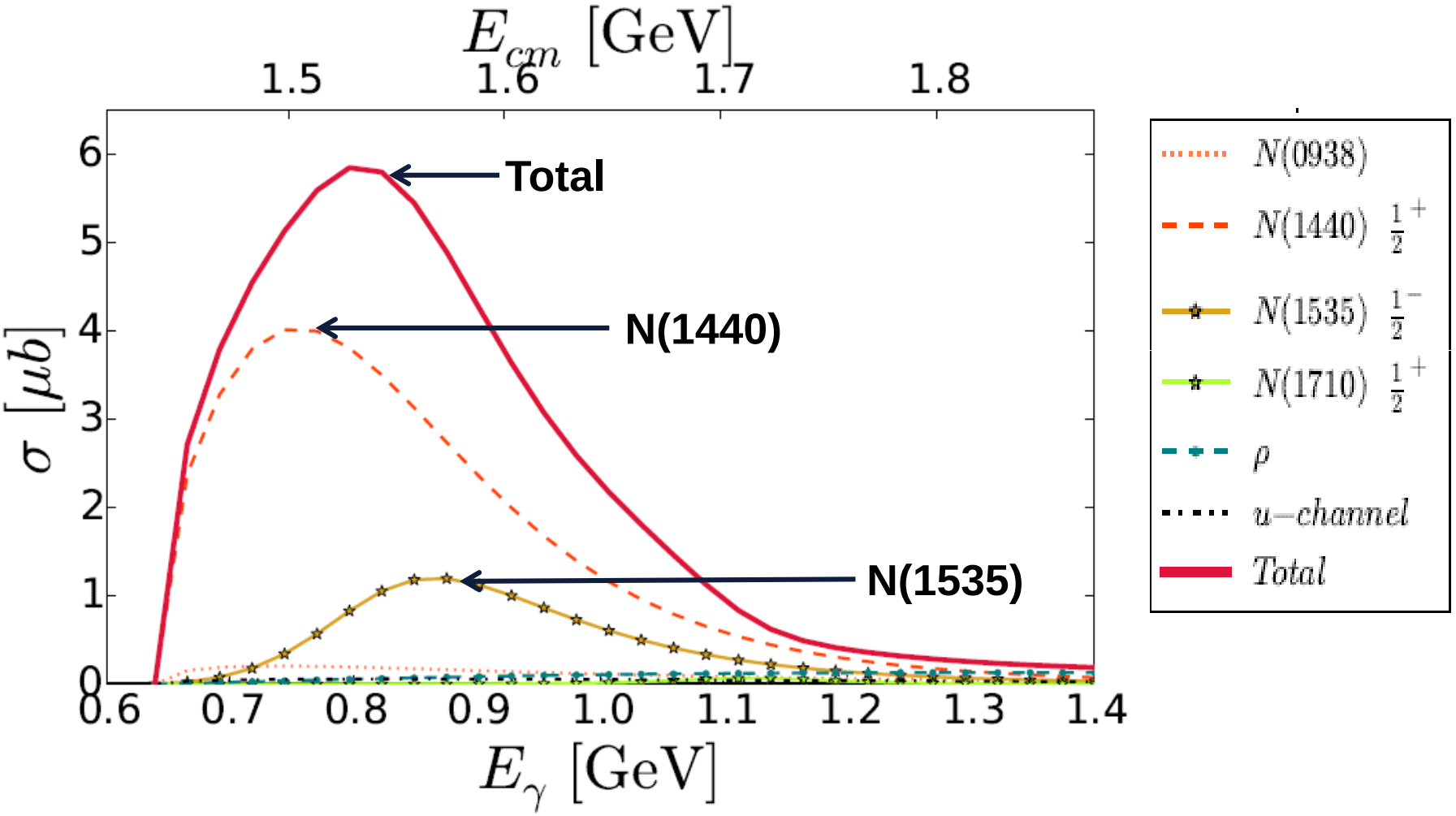
ρ-meson exchange is dominant !

Differential cross section of $f_0(500)$

$E_\gamma = 2.0\ \mathrm{GeV}$



Total cross section of $f_0(500)$

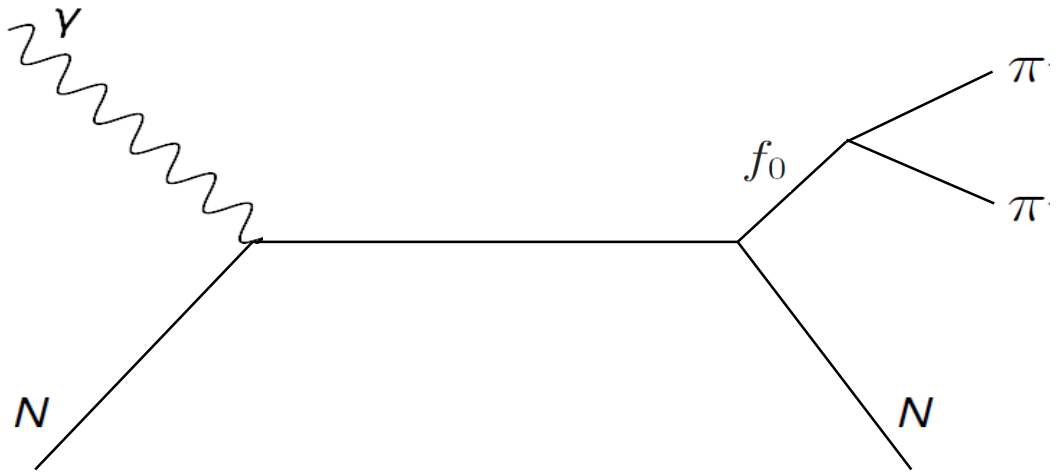


Summary

- We investigated the $f_0(980)N$ and $f_0(500)N$ photoproduction within the effective Lagrangian method.
- We took into account the contributions of nucleon resonances in $f_0(500)N$ photoproduction.
- Using the Regge approach, we consider the rho and nucleon exchange in the *t*- and *u*-channel, respectively.
- We calculated the differential cross section and the total cross section.

Outlook

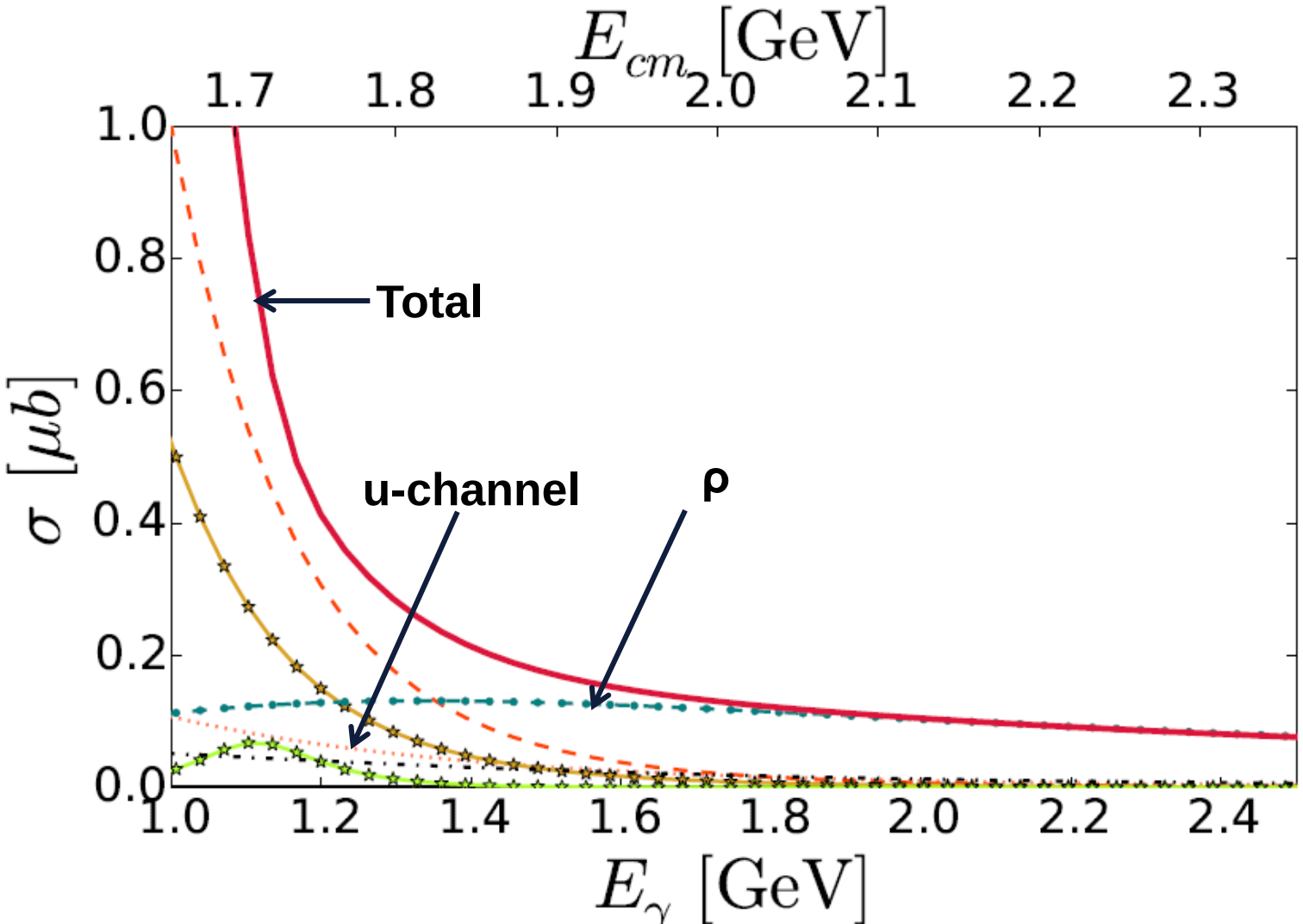
- The $(\pi\pi)^{I=0}_{s-wave}$ photoproduction is under investigation with final-state interactions considered.



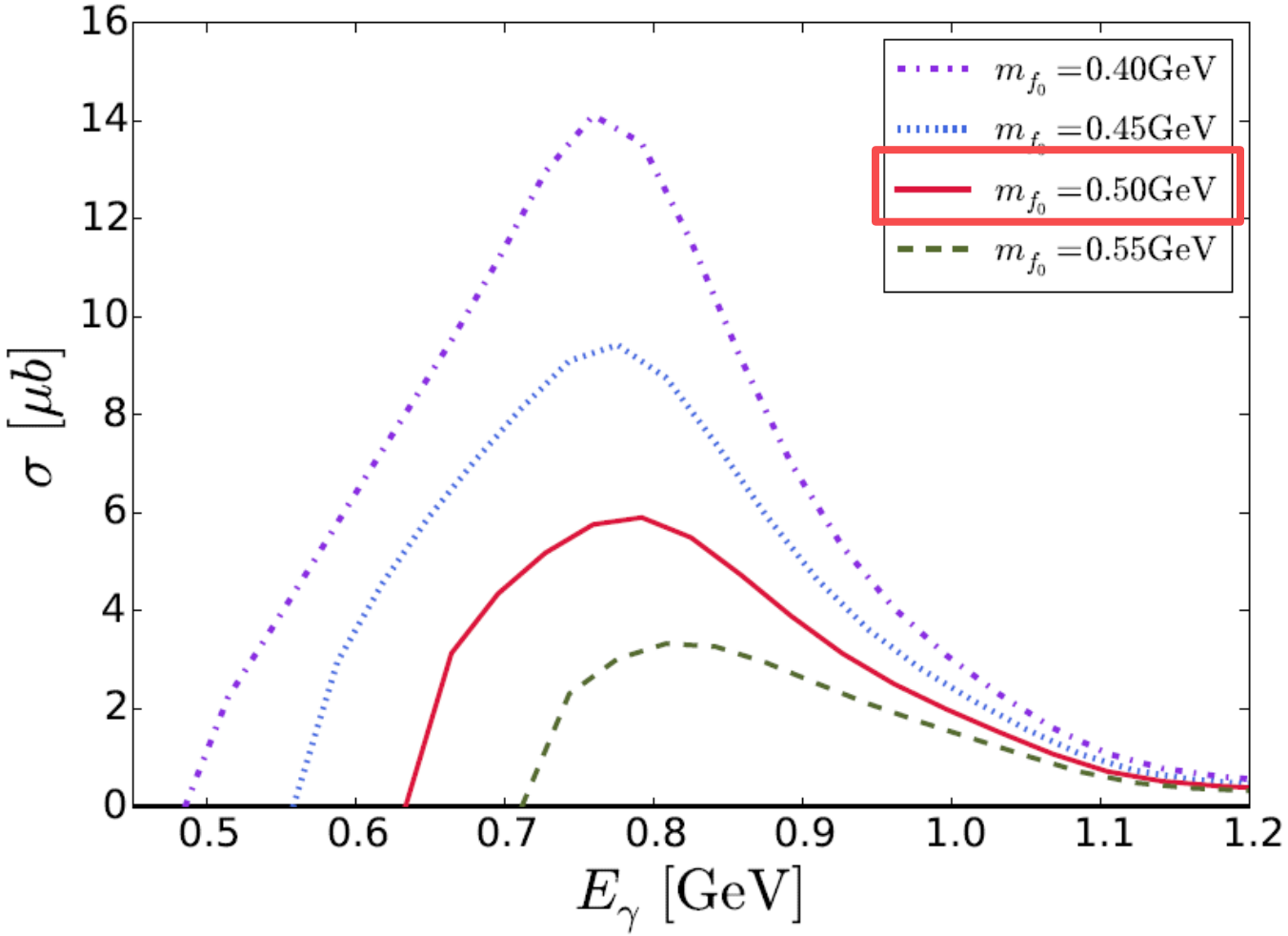
THANK YOU

Backup slides

$\gamma N \to f_0(500) N$: High energy



$\gamma N \to f_0(500) N$: Mass dependence



Resonances

Particle	spin$^{\text{parity}}$	Mass [GeV]	Width [GeV]	Status	Decay mode $N(\pi\pi)^{I=0}_{s-wave}$ [%]
N(1440)	$\frac{1}{2}^+$	1.410-1.450	0.250-0.450	****	10∼20
N(1535)	$\frac{1}{2}^-$	1.520-1.545	0.125-0.175	****	2±1
N(1710)	$\frac{1}{2}^+$	1.680-1.740	0.050-0.250	***	10∼40