J/ψ-meson photoproduction off the nucleon in a dynamical model

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Contents based on
S.H.Kim, et al, PRC. 104.045202 (2021)
S.H.Kim, PLB. 868. 139725 (2025)

XXXVII International Workshop on High Energy Physics
22 -24/July, 2025, Logunov Institute for High Energy Physics, Russia

Contents

$\gamma\, p \to J/\psi\, p$

- QCD, the field theory of quark and gluon interactions,
  > is expected to describe the strong force between hadrons.
  > is a successful theory in the limit of short distances (perturbative QCD).

- Many of the scattering processes of hadrons are dominated by long-range forces ("soft interactions").

- A large fraction of these soft interactions is mediated by vacuum quantum number ($J^{PC} = 0^{++}$) exchange and is termed "diffractive".

- In hadronic interactions, diffraction is well described by Regge theory.

- Examples of diffractive scattering processes
  > $\bar{p}\,p \to \bar{p}\,p$, $\pi^{\pm} p \to \pi^{\pm} p$, $\gamma\, p \to (\rho, \omega, \varphi, J/\psi)\, p$ ...

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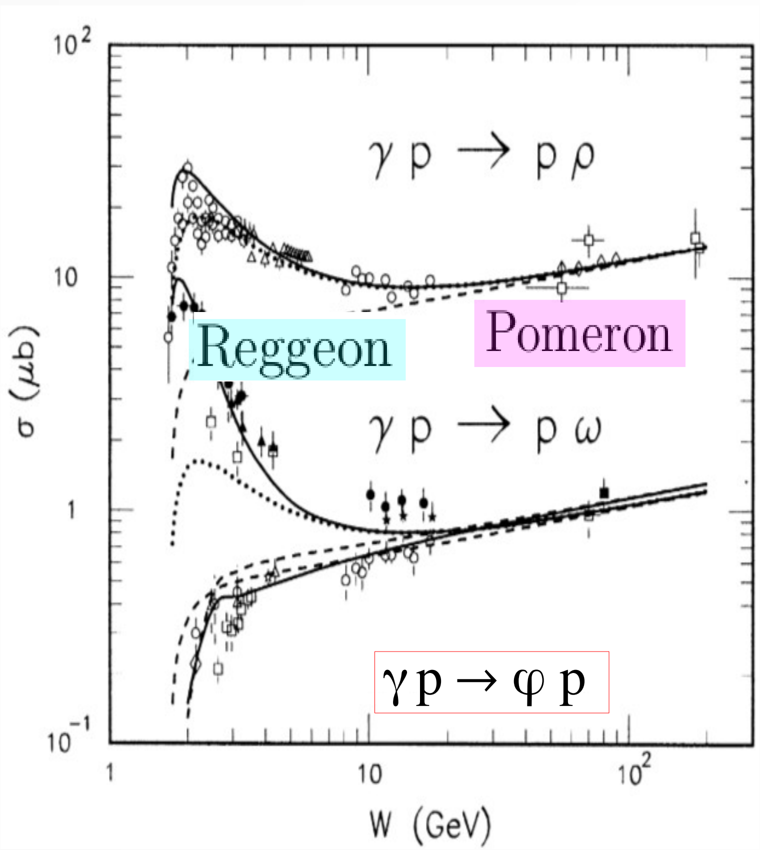
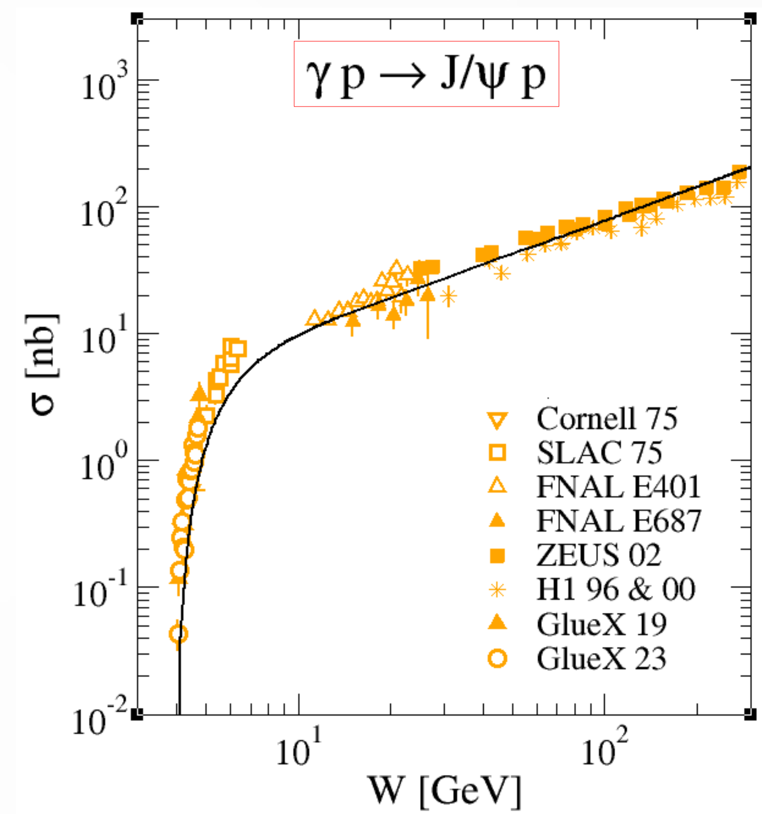
- ❑ Many of the scattering processes of hadrons are dominated by long-range forces ("soft interactions").
- ❑ A large fraction of these soft interactions is mediated by vacuum quantum number ($J^{PC} = 0^{++}$) exchange and is termed "diffractive".
- ❑ In hadronic interactions, diffraction is well described by Regge theory.
- ❑ Examples of diffractive scattering processes
  - > $\bar{p}\,p \to \bar{p}\,p$, $\pi^{\pm} p \to \pi^{\pm} p$, $\gamma\, p \to (\rho, \omega, \varphi, J/\psi)\, p$ ...

□ Pomeron exchange is responsible for describing slow rising total cross section.
□ At low energies, φ & J/ψ photoproduction is far more suppressed because of the OZI rule.
□ The production mechanism at low energies should be investigated with the recent experimental data.



low energy : data [Dey, CLAS, PRC.89. 055208 (2014)
Seraydaryan, CLAS, PRC.89.055206 (2014)
Mizutani, LEPS, PRC.96.062201 (2017)]



low energy : data [Pentchev, GlueX, PRL.123.072001 (2019)
Duran, JLab, Nature.615.813 (2023)
Pentchev, GlueX, PRC.108.025201 (2023)]

❑ high energy:

The two-gluon exchange is simplified by the Donnachie-Landshoff (DL) model which suggests that the Pomeron couples to the nucleon like a C = +1 isoscalar photon and its coupling is described in terms of $F_N(t)$.

[Pomeron Physics and QCD (Cambridge University, 2002)]

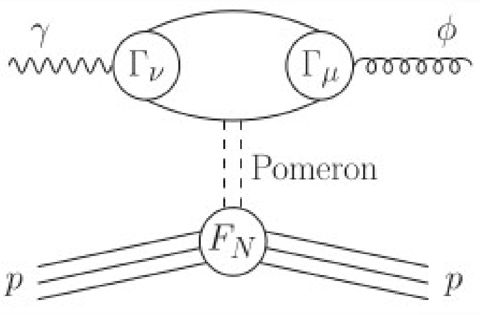
❑ low energy:

We need to clarify the reaction mechanism.

[Exp: Dey, CLAS, PRC.89. 055208 (2014)
Seraydaryan, CLAS, PRC.89.055206 (2014)
Mizutani, LEPS, PRC.96.062201 (2017)]

❑ We focus on $\gamma\, p \to J/\psi\, p$.

❑ high energy



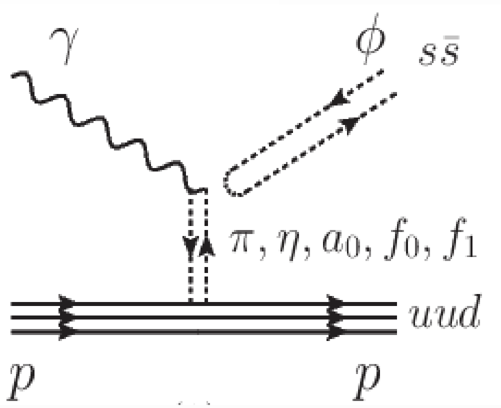
□ σ [γp → φp] ≈ σ [γp → ωp]

□ F_N: isoscalar EM form factor of the nucleon

$$F_N(t) = \frac{4M_N^2 - a_N^2 t}{(4M_N^2 - t)(1 - t/t_0)^2}$$

□ $\alpha_P(t) = 1.08 + 0.25t$

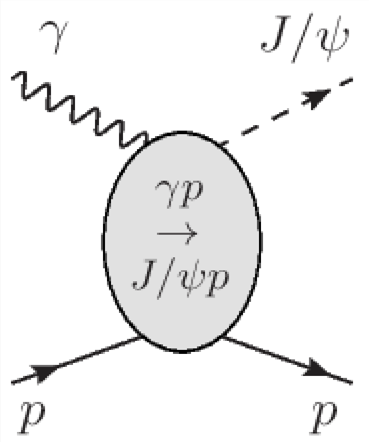
❑ low energy



□ σ[γp → φp] << σ[γp → (ρ,ω)p] due to the OZI rule

Born term

❑ Scattering amplitude: $T_{J/\psi N,\gamma N}(E) = \boxed{B_{J/\psi N,\gamma N}} + T^{\mathrm{FSI}}_{J/\psi N,\gamma N}(E)$



□ Some *t*-channel light mesons [π^0(135), η(548), a_0(980), f_0(980), f_1(1285)] play a crucial role in $\gamma\, p \longrightarrow \varphi\, p$.

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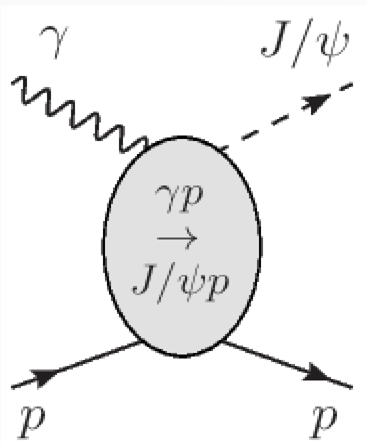
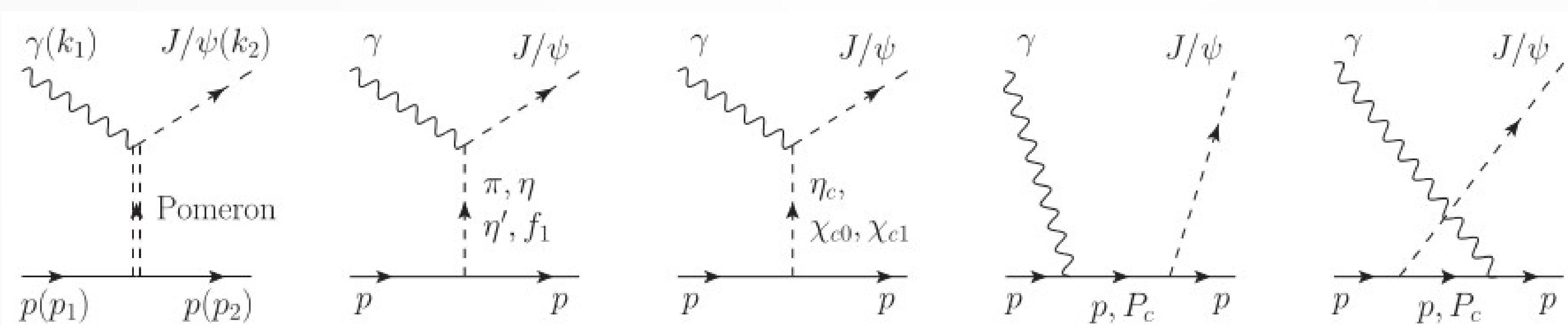
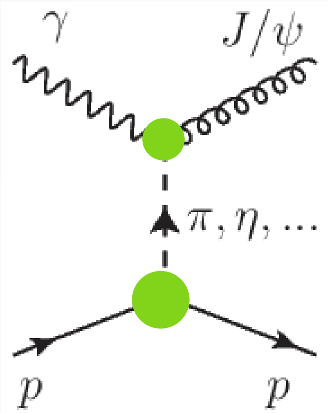


- □ Some *t*-channel light mesons [π^0(135), η(548), a_0(980), f_0(980), f_1(1285)] play a crucial role in γ p ⟶ φ p.
- □ In case of γ p ⟶ J/ψ p, the radiative decays of J/ψ meson mostly proceed by producing multi-mesonic resonant or non-resonant states.
- □ We need to investigate the role of meson exchanges rigorously, i.e., the relative contributions between light mesons and charmonium mesons.



light mesons $c\bar{c}$ mesons

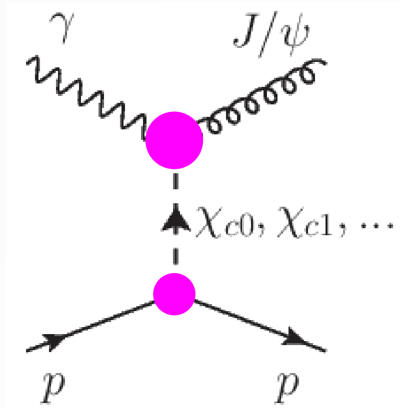
Born term



light mesons

<<

>>



$c\bar{c}$ mesons

- □ There are many $c\bar{c}$ mesons above J/ψ meson.
- □ Their contributions may not be negligible compared to those of light mesons.
- □ Which mechanism is more dominant?

light mesons

Mesons (M)	Mass (J^P)	$\mathrm{Br}_{J/\psi\to M\gamma}$ [%]	$\lvert g_{\gamma MJ/\psi}\rvert$	g_{MNN}
π	134 (0^-)	$(3.39 \pm 0.08)\cdot 10^{-3}$	$1.83 \cdot 10^{-3}$	13.0
η	548 (0^-)	$(1.090 \pm 0.013)\cdot 10^{-1}$	$1.09 \cdot 10^{-2}$	6.34
η'	958 (0^-)	$(5.28 \pm 0.06)\cdot 10^{-1}$	$2.65 \cdot 10^{-2}$	6.87
f_1	1285 (1^+)	$(6.1 \pm 0.8)\cdot 10^{-2}$	$3.93 \cdot 10^{-3}$	2.5
$\eta_c(1S)$	2984 (0^-)	1.41 ± 0.14	1.95	-

$c\bar{c}$ mesons

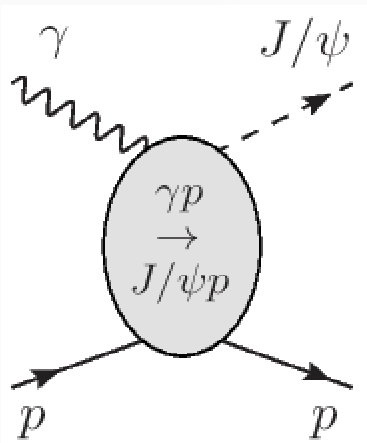
Mesons (M)	Mass (J^P)	$\mathrm{Br}_{M\to J/\psi\gamma}$ [%]	$\lvert g_{\gamma MJ/\psi}\rvert$	$\mathrm{Br}_{M\to p\bar{p}}$ [%]	$\lvert g_{Mpp}\rvert$
$\eta_c(1S)$	2984 (0^-)	-	-	$(1.33 \pm 0.11)\cdot 10^{-1}$	$2.70 \cdot 10^{-2}$
$\chi_{c0}(1P)$	3414 (0^+)	1.41 ± 0.09	1.33	$(2.21 \pm 0.14)\cdot 10^{-2}$	$4.56 \cdot 10^{-3}$
$\chi_{c1}(1P)$	3511 (1^+)	34.3 ± 1.3	3.29	$(7.6 \pm 0.4)\cdot 10^{-3}$	$8.42 \cdot 10^{-4}$
$\eta_c(2S)$	3638 (0^-)	< 1.4	< 1.32	$< 2.0 \cdot 10^{-1}$	$< 1.61 \cdot 10^{-2}$
$\chi_{c1}(3872)$	3872 (1^+)	0.78 ± 0.29	0.257	$< 2.2 \cdot 10^{-3}$	$< 5.11 \cdot 10^{-4}$

$c\bar{c}$ mesons
(including non-$q\bar{q}$ states)

- $\eta_c(1S)$ — $0^+(0^{-+})$
- $J/\psi(1S)$ — $0^-(1^{--})$
- $\chi_{c0}(1P)$ — $0^+(0^{++})$
- $\chi_{c1}(1P)$ — $0^+(1^{++})$
- $h_c(1P)$ — $0^-(1^{+-})$
- $\chi_{c2}(1P)$ — $0^+(2^{++})$
- $\eta_c(2S)$ — $0^+(0^{-+})$
- $\psi(2S)$ — $0^-(1^{--})$
- $\psi(3770)$ — $0^-(1^{--})$
- $\psi_2(3823)$ — $0^-(2^{--})$ was $\psi(3823)$, $X(3823)$
- $\psi_3(3842)$ — $0^-(3^{--})$

Born term

❑ Scattering amplitude: $T_{J/\psi N,\gamma N}(E) = \boxed{B_{J/\psi N,\gamma N}}$



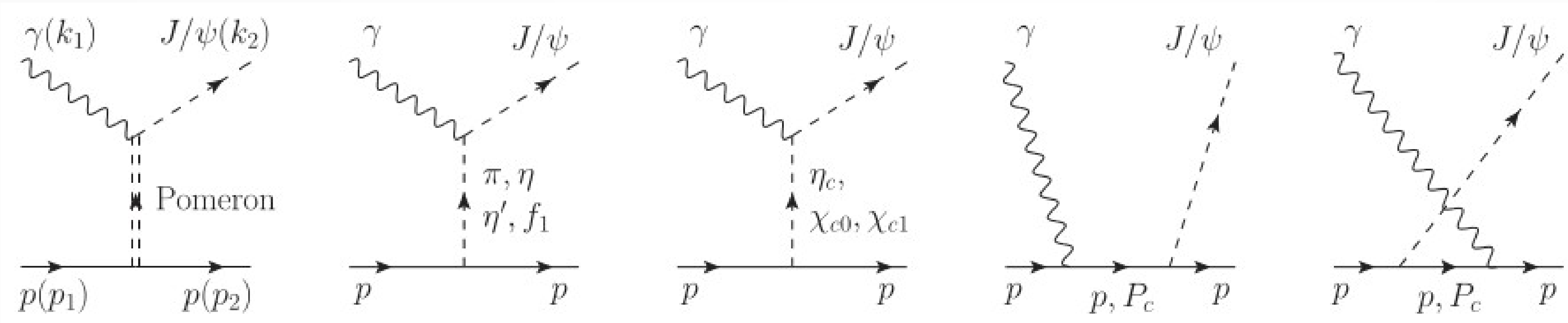
□ We employ a dynamical approach based on a Hamiltonian.

$$H = H_0 + B_{J/\psi N,\gamma N} + \Gamma_{N^*,\gamma N} + \Gamma_{N^*,J/\psi N}$$

□ Ward-Takahashi identity

$$\mathcal{M}(k) = \epsilon_\mu(k)\mathcal{M}^\mu(k)$$

if we replace ϵ_μ with k_μ: $k_\mu \mathcal{M}^\mu(k) = 0$



light mesons $c\bar{c}$ mesons

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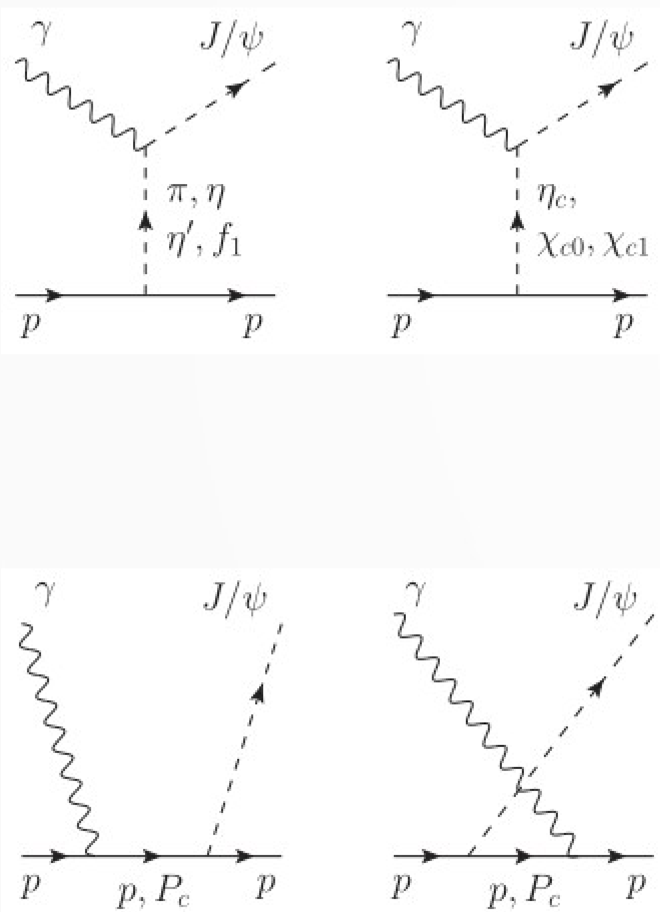

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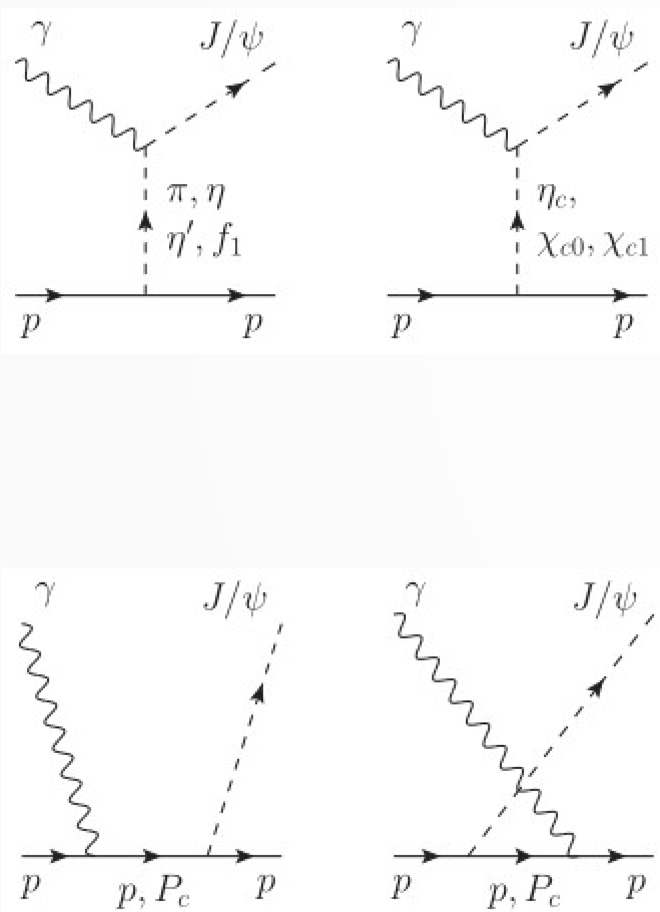

❑ Effective Lagrangians

□ EM vertex

$$\mathcal{L}_{\gamma\phi f_1} = g_{\gamma\phi f_1}\epsilon^{\mu\nu\alpha\beta}\partial_\mu A_\nu \partial^\lambda \partial_\lambda \phi_\alpha f_{1\beta}$$

$$\mathcal{L}_{\gamma\Phi\phi} = \frac{e g_{\gamma\Phi\phi}}{M_\phi}\epsilon^{\mu\nu\alpha\beta}\partial_\mu A_\nu \partial_\alpha \phi_\beta \Phi$$

$$\mathcal{L}_{\gamma S\phi} = \frac{e g_{\gamma S\phi}}{M_\phi} F^{\mu\nu}\phi_{\mu\nu} S$$

□ strong vertex

$$\mathcal{L}_{f_1 NN} = -g_{f_1 NN}\bar{N}\left[\gamma_\mu - i\frac{\kappa_{f_1 NN}}{2M_N}\gamma_\nu\gamma_\mu\partial^\nu\right] f_1^\mu \gamma_5 N$$

$$\mathcal{L}_{\Phi NN} = -\, i g_{\Phi NN}\bar{N}\Phi\gamma_5 N$$

$$\mathcal{L}_{SNN} = -\, g_{SNN}\bar{N}SN$$

$$\mathcal{L}_{\gamma NN} = -\, e\bar{N}\left[\gamma_\mu - \frac{\kappa_N}{2M_N}\sigma_{\mu\nu}\partial^\nu\right] N A^\mu$$

$$\mathcal{L}_{\phi NN} = -\, g_{\phi NN}\bar{N}\left[\gamma_\mu - \frac{\kappa_{\phi NN}}{2M_N}\sigma_{\mu\nu}\partial^\nu\right] N \phi^\mu$$

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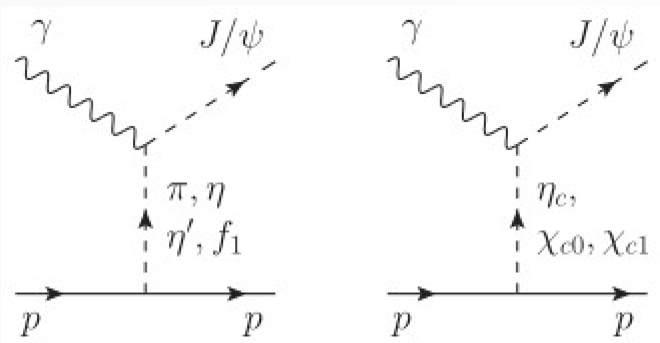
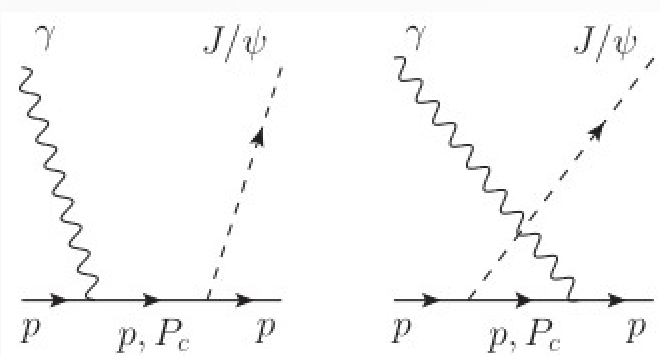


$$\mathcal{M} = \varepsilon_\nu^* \bar{u}_{N'} \mathcal{M}^{\mu\nu} u_N \epsilon_\mu$$

$$\mathcal{M}_{f_1}^{\mu\nu} = i\frac{M_\phi^2 g_{\gamma f_1 \phi} g_{f_1 NN}}{t - M_{f_1}^2} \epsilon^{\mu\nu\alpha\beta} \left[-g_{\alpha\lambda} + \frac{q_{t\alpha} q_{t\lambda}}{M_{f_1}^2} \right] \times \left[\gamma^\lambda + \frac{\kappa_{f_1 NN}}{2M_N} \gamma^\sigma \gamma^\lambda q_{t\sigma} \right] \gamma_5 k_{1\beta},$$

$$\mathcal{M}_\Phi^{\mu\nu} = i\frac{e}{M_\phi} \frac{g_{\gamma\Phi\phi} g_{\Phi NN}}{t - M_\Phi^2} \epsilon^{\mu\nu\alpha\beta} k_{1\alpha} k_{2\beta} \gamma_5,$$

$$\mathcal{M}_S^{\mu\nu} = \frac{e}{M_\phi} \frac{2 g_{\gamma S\phi} g_{SNN}}{t - M_S^2 + i\Gamma_S M_S} (k_1 k_2 g^{\mu\nu} - k_1^\mu k_2^\nu),$$



$$\mathcal{M}_{\phi\,\mathrm{rad},s}^{\mu\nu} = \frac{e g_{\phi NN}}{s - M_N^2} \left(\gamma^\nu - i\frac{\kappa_{\phi NN}}{2M_N} \sigma^{\nu\alpha} k_{2\alpha} \right) (\not{q}_s + M_N) \times \left(\gamma^\mu + i\frac{\kappa_N}{2M_N} \sigma^{\mu\beta} k_{1\beta} \right),$$

$$\mathcal{M}_{\phi\,\mathrm{rad},u}^{\mu\nu} = \frac{e g_{\phi NN}}{u - M_N^2} \left(\gamma^\mu + i\frac{\kappa_N}{2M_N} \sigma^{\mu\alpha} k_{1\alpha} \right) (\not{q}_u + M_N) \times \left(\gamma^\nu - i\frac{\kappa_{\phi NN}}{2M_N} \sigma^{\nu\beta} k_{2\beta} \right),$$

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$$\mathcal{L}_{\Phi NN} = -i g_{\Phi NN} \bar{N} \Phi \gamma_5 N$$

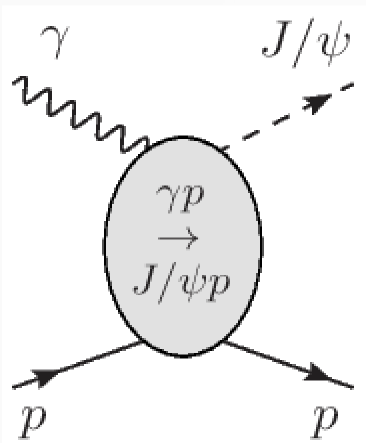
$$\mathcal{L}_{SNN} = -g_{SNN} \bar{N} S N$$

$$\mathcal{L}_{\gamma NN} = -e\bar{N} \left[\gamma_\mu - \frac{\kappa_N}{2M_N} \sigma_{\mu\nu} \partial^\nu \right] N A^\mu$$

$$\mathcal{L}_{\phi NN} = -g_{\phi NN} \bar{N} \left[\gamma_\mu - \frac{\kappa_{\phi NN}}{2M_N} \sigma_{\mu\nu} \partial^\nu \right] N \phi^\mu$$

final state interaction (FSI)

❑ Scattering amplitude: $T_{J/\psi N,\gamma N}(E) = B_{J/\psi N,\gamma N} + \boxed{T^{\mathrm{FSI}}_{J/\psi N,\gamma N}(E)}$



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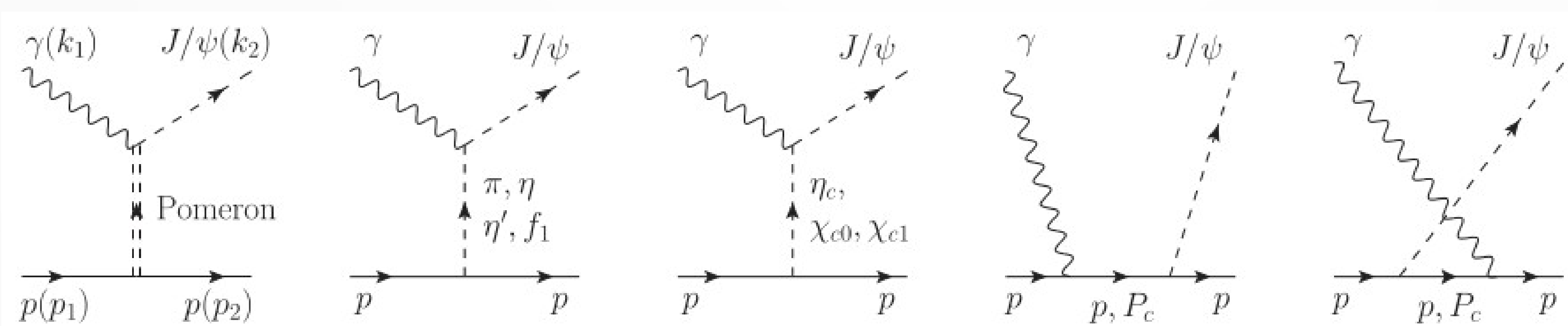

light mesons $c\bar{c}$ mesons

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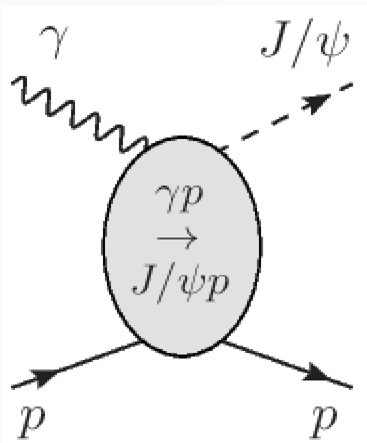

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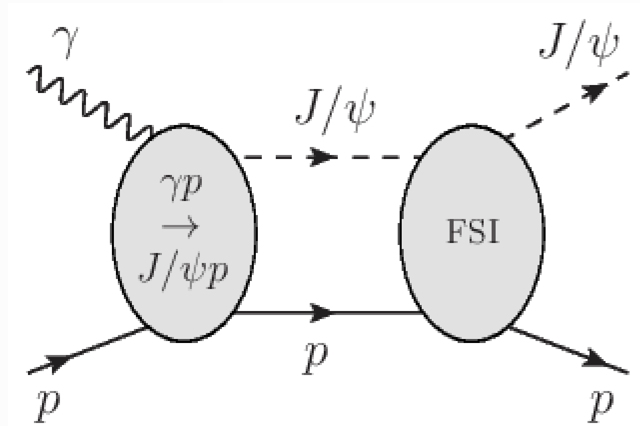
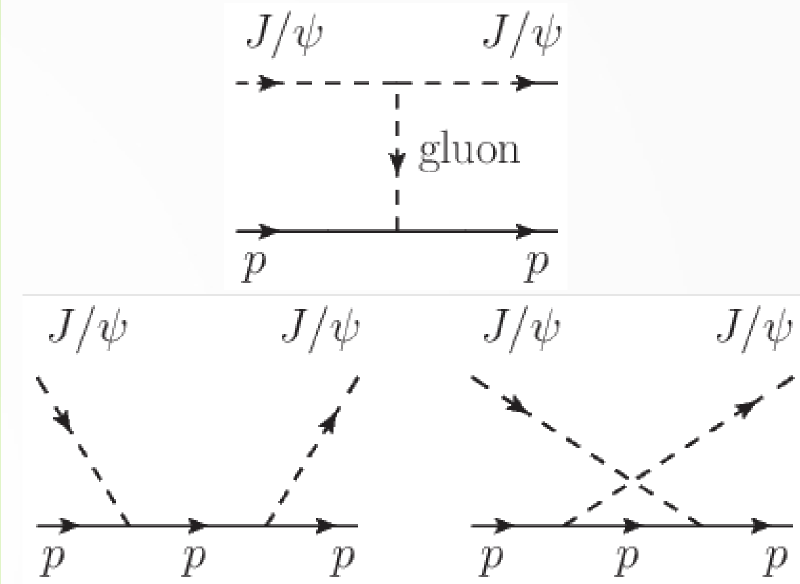
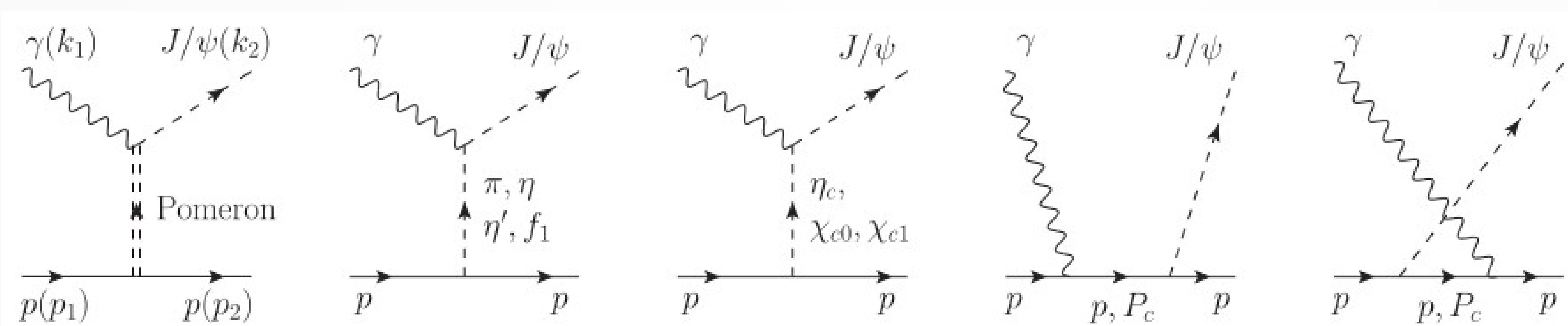
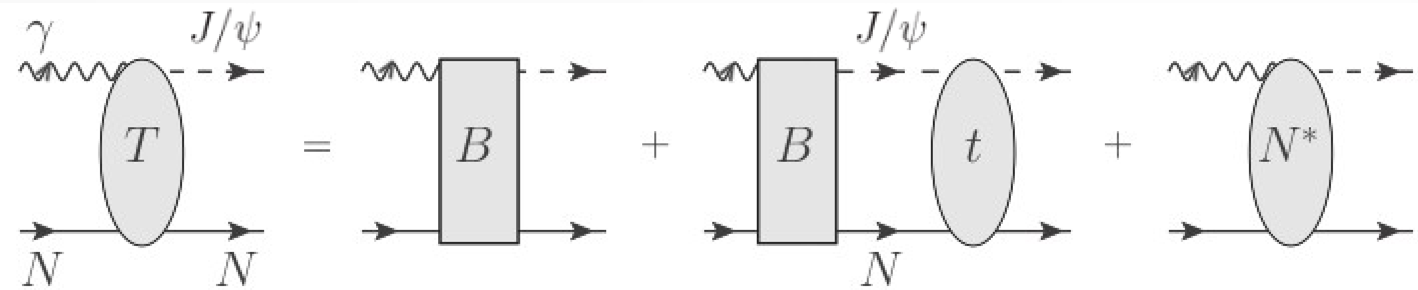






light mesons $c\bar{c}$ mesons

final state interaction (FSI)



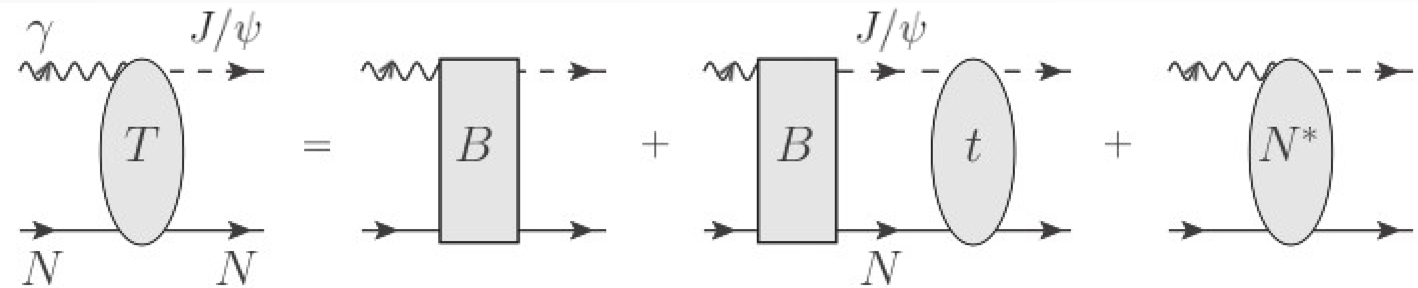
$$T_{J/\psi N,\gamma N}(E) = B_{J/\psi N,\gamma N} + \underline{T^{\mathrm{FSI}}_{J/\psi N,\gamma N}(E)}$$

$$t_{J/\psi N,J/\psi N}(E)\, G_{J/\psi N}(E)\, B_{J/\psi N,\gamma N}$$

$$G_{MB}(E) = \frac{|MB\rangle \langle MB|}{E - H_0 + i\epsilon}$$: meson-baryon propagator

$$t_{J/\psi N,J/\psi N}(E)$$
$$= V_{J/\psi N,J/\psi N}(E) + V_{J/\psi N,J/\psi N}(E)\, G_{J/\psi N}(E)\, t_{J/\psi N,J/\psi N}(E)$$

final state interaction (FSI)



$$T_{J/\psi N,\gamma N}(E) = B_{J/\psi N,\gamma N} + T^{\mathrm{FSI}}_{J/\psi N,\gamma N}(E)$$

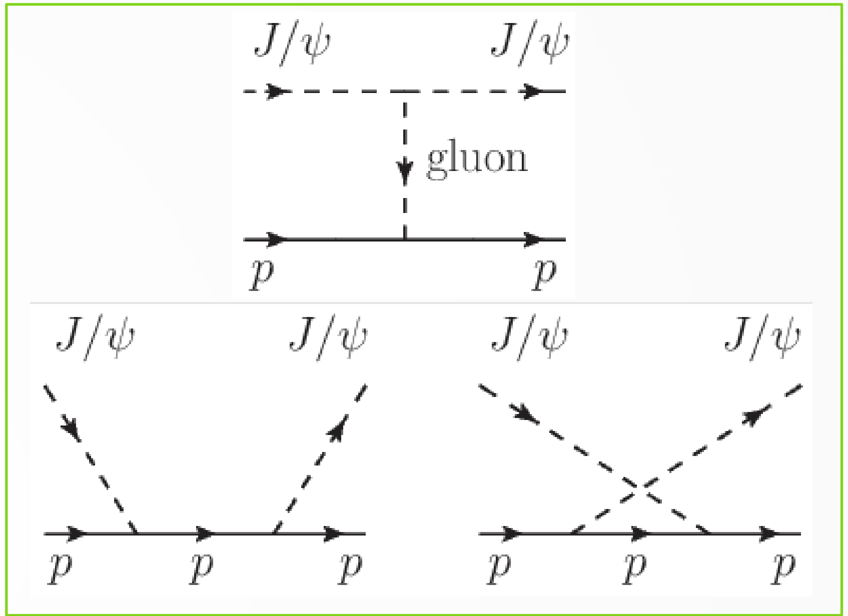
$$T^{\mathrm{FSI}}_{J/\psi N,\gamma N}(E) = t_{J/\psi N,J/\psi N}(E)\, G_{J/\psi N}(E)\, B_{J/\psi N,\gamma N}$$

$$G_{MB}(E) = \frac{|MB\rangle\,\langle MB|}{E - H_0 + i\epsilon}$$: meson-baryon propagator

$$t_{J/\psi N,J/\psi N}(E) = V_{J/\psi N,J/\psi N}(E) + V_{J/\psi N,J/\psi N}(E)\, G_{J/\psi N}(E)\, t_{J/\psi N,J/\psi N}(E)$$

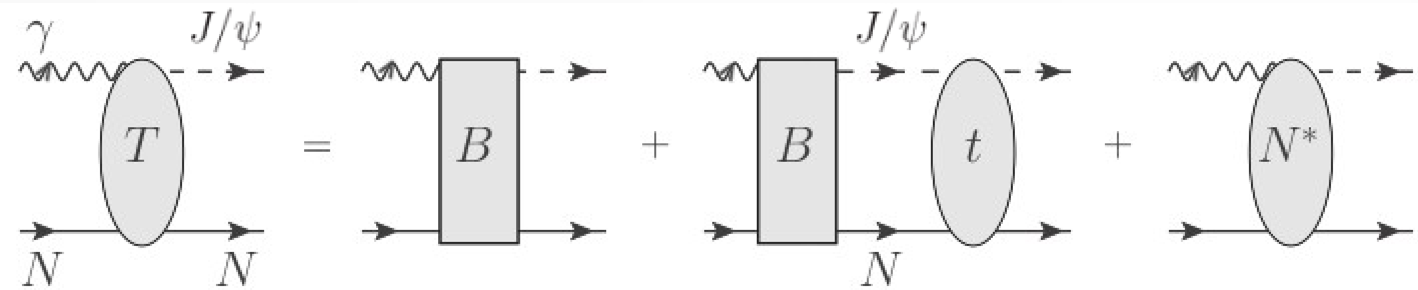
$$V_{J/\psi N,J/\psi N}(E) = v^{\mathrm{Gluon}}_{J/\psi N,J/\psi N}(E) + v^{\mathrm{Direct}}_{J/\psi N,J/\psi N}(E)$$

$t_{J/\psi N,J/\psi N}(E)$



□ To leading order, we obtain these FSI diagrams.

final state interaction (FSI)



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$$t_{J/\psi N,J/\psi N}(E)\, G_{J/\psi N}(E)\, B_{J/\psi N,\gamma N}$$

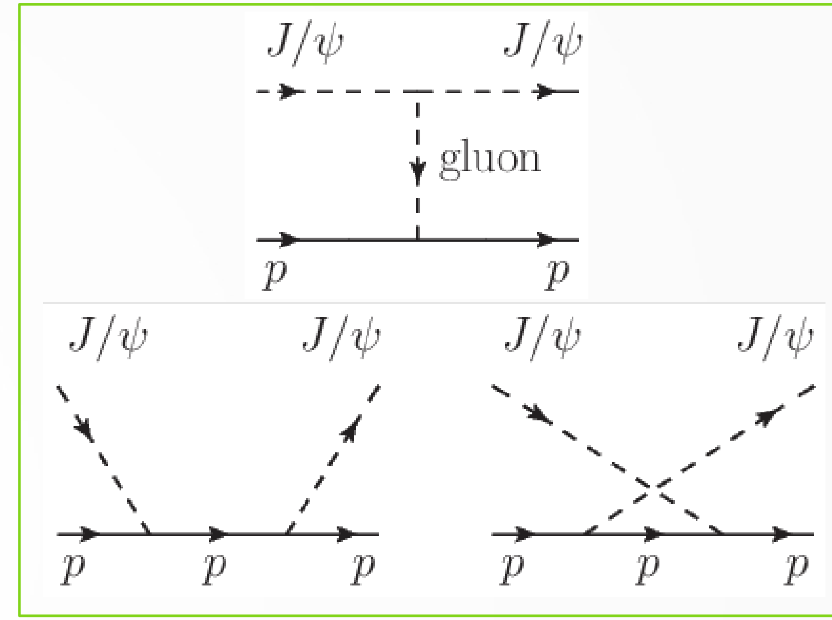
$$G_{MB}(E) = \frac{|MB\rangle\langle MB|}{E - H_0 + i\epsilon}$$: meson-baryon propagator

$$t_{J/\psi N,J/\psi N}(E)$$

$$= V_{J/\psi N,J/\psi N}(E) + V_{J/\psi N,J/\psi N}(E)\, G_{J/\psi N}(E)\, t_{J/\psi N,J/\psi N}(E)$$

$$v^{\rm Gluon}_{J/\psi N,J/\psi N}(E) + v^{\rm Direct}_{J/\psi N,J/\psi N}(E)$$

$$t_{J/\psi N,J/\psi N}(E)$$

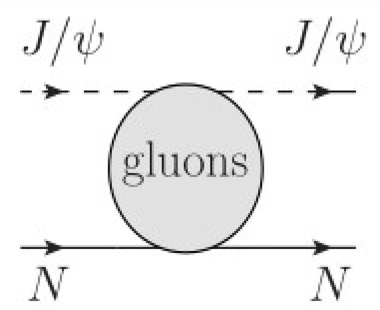


□ To leading order,
we obtain these FSI diagrams.

$$\frac{1}{E - H_0 + i\epsilon} = P\frac{1}{E - H_0} - i\pi\delta(E - H_0)$$

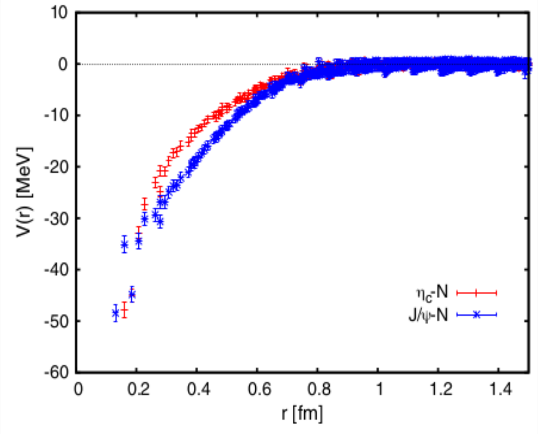
□ We consider both parts numerically.

final state interaction (FSI)



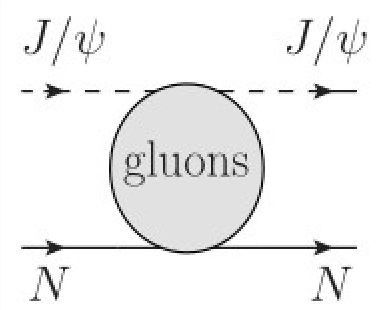
❑ J/ψ-N potential is of the Yukawa form

$$\mathcal{V}_{\text{gluon}} = -v_0 \frac{e^{-\alpha r}}{r}$$



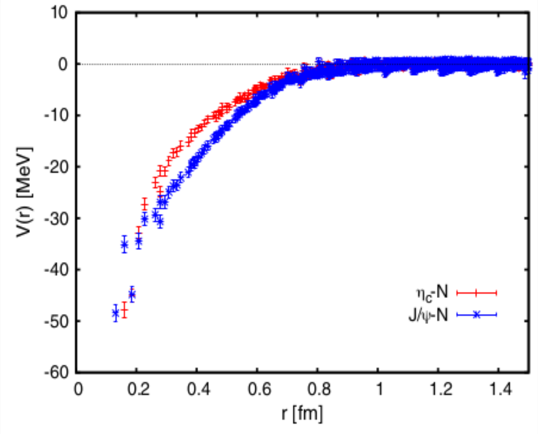
- □ LQCD data ~ (υ_0 = 0.10, α = 0.6 GeV)
  [Kawanai, Sasaki, PRD.82.091501(R) (2010)]
- □ Phenomenological model ~ (υ_0 = 0.42, α = 0.6 GeV)
  [Brodsky, et al, PRL.66.1011 (1990)]

final state interaction (FSI)



❑ J/ψ-N potential is of the Yukawa form

$$\mathcal{V}_{\text{gluon}} = -v_0 \frac{e^{-\alpha r}}{r}$$



□ LQCD data ~ ($\upsilon_0 = 0.10$, $\alpha = 0.6$ GeV)
[Kawanai, Sasaki, PRD.82.091501(R) (2010)]

□ Phenomenological model ~ ($\upsilon_0 = 0.42$, $\alpha = 0.6$ GeV)
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→ We attempt to use both of them and compare the results with each other.

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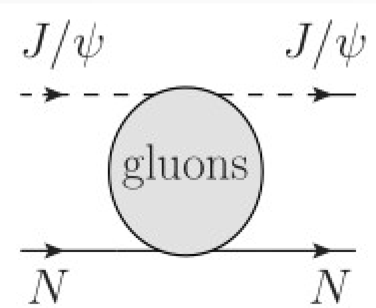

❑ J/ψ-N potential is of the Yukawa form

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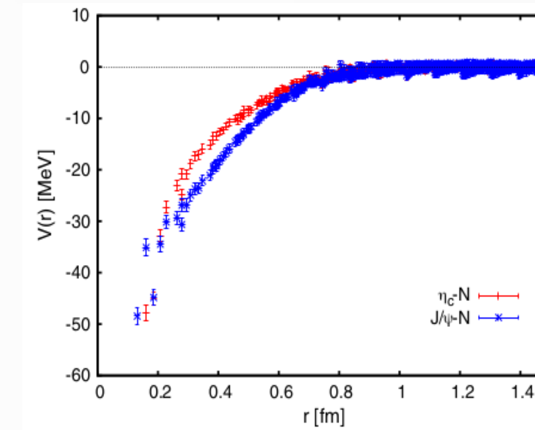

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⟶ We attempt to use both of them and compare the results with each other.

□ The potential is obtained by taking the nonrelativistic limit of the scalar-meson exchange amplitude calculated from the Lagrangian:

$$\mathscr{L}_\sigma = V_0(\bar{\psi}_N \psi_N \Phi_\sigma + \phi^\mu \phi_\mu \Phi_\sigma)$$

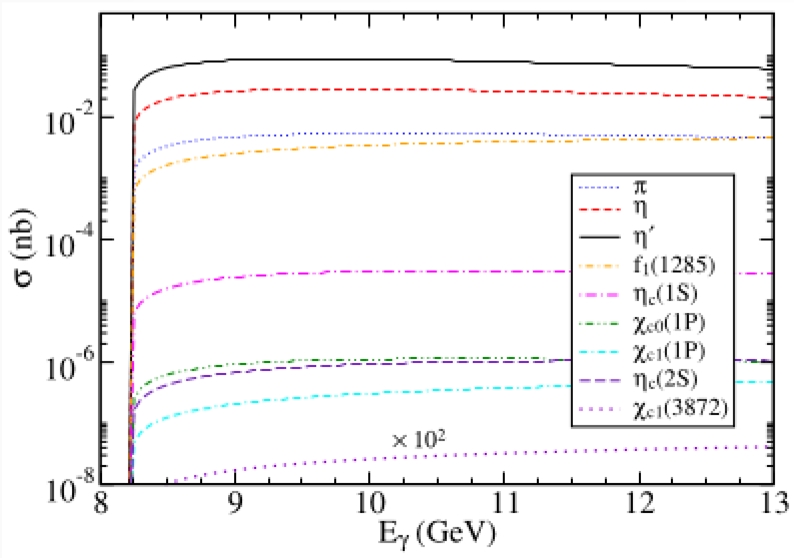
Φ_σ is a scalar field with mass α ($V_0 = -8\upsilon_0 \pi M_\varphi$).

□ $$\mathcal{V}_{\rm gluon}(k\lambda_\phi, pm_s; k'\lambda'_\phi, p'm'_s) = \frac{V_0}{(p-p')^2 - \alpha^2}[\bar{u}_N(p, m_s) u_N(p', m'_s)][\epsilon^*_\mu(k, \lambda_\phi)\epsilon^\mu(k', \lambda'_\phi)]$$

Born term

$\gamma\, p \to J/\psi\, p$

meson contributions



- □ η′(958) and η(548) light mesons give the most significant contributions.
- □ Charmonium mesons give small contributions.
- □ Light mesons are indeed essential for describing the JLab data.

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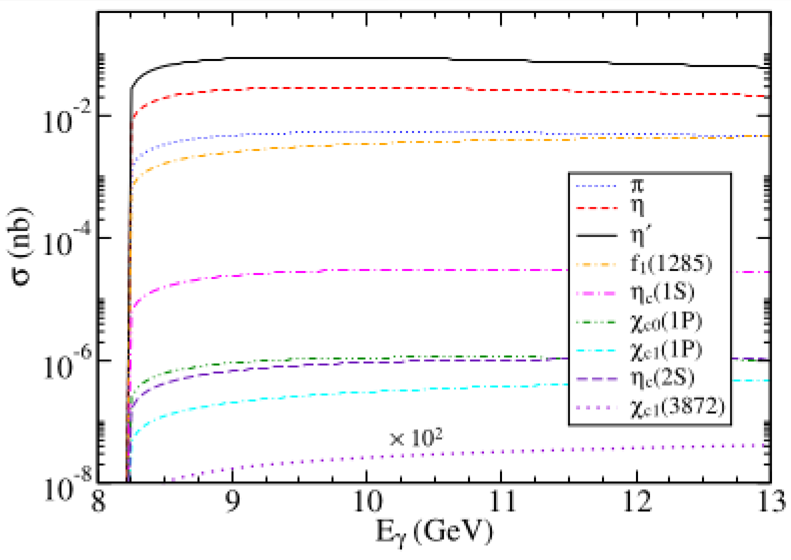

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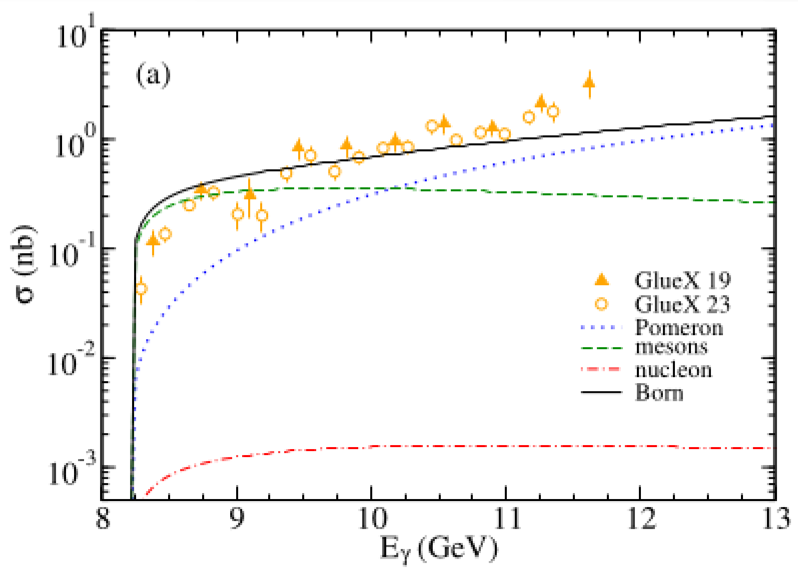
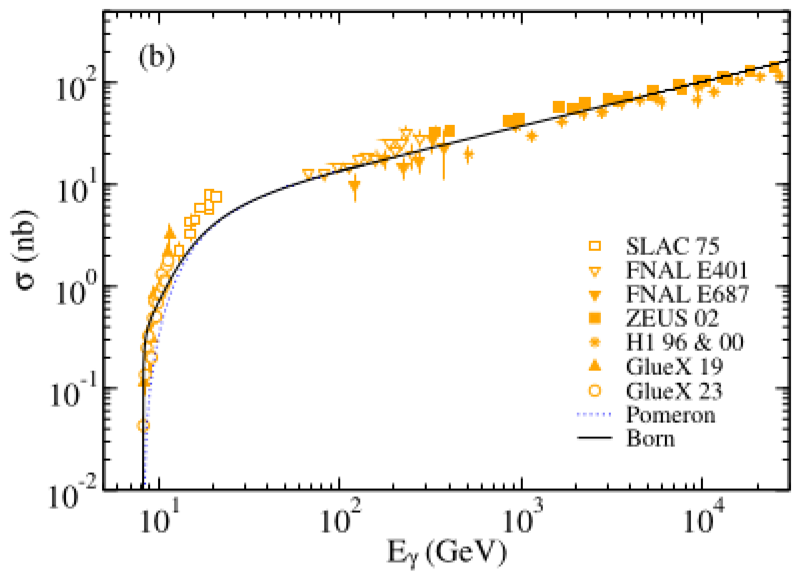
total cross section

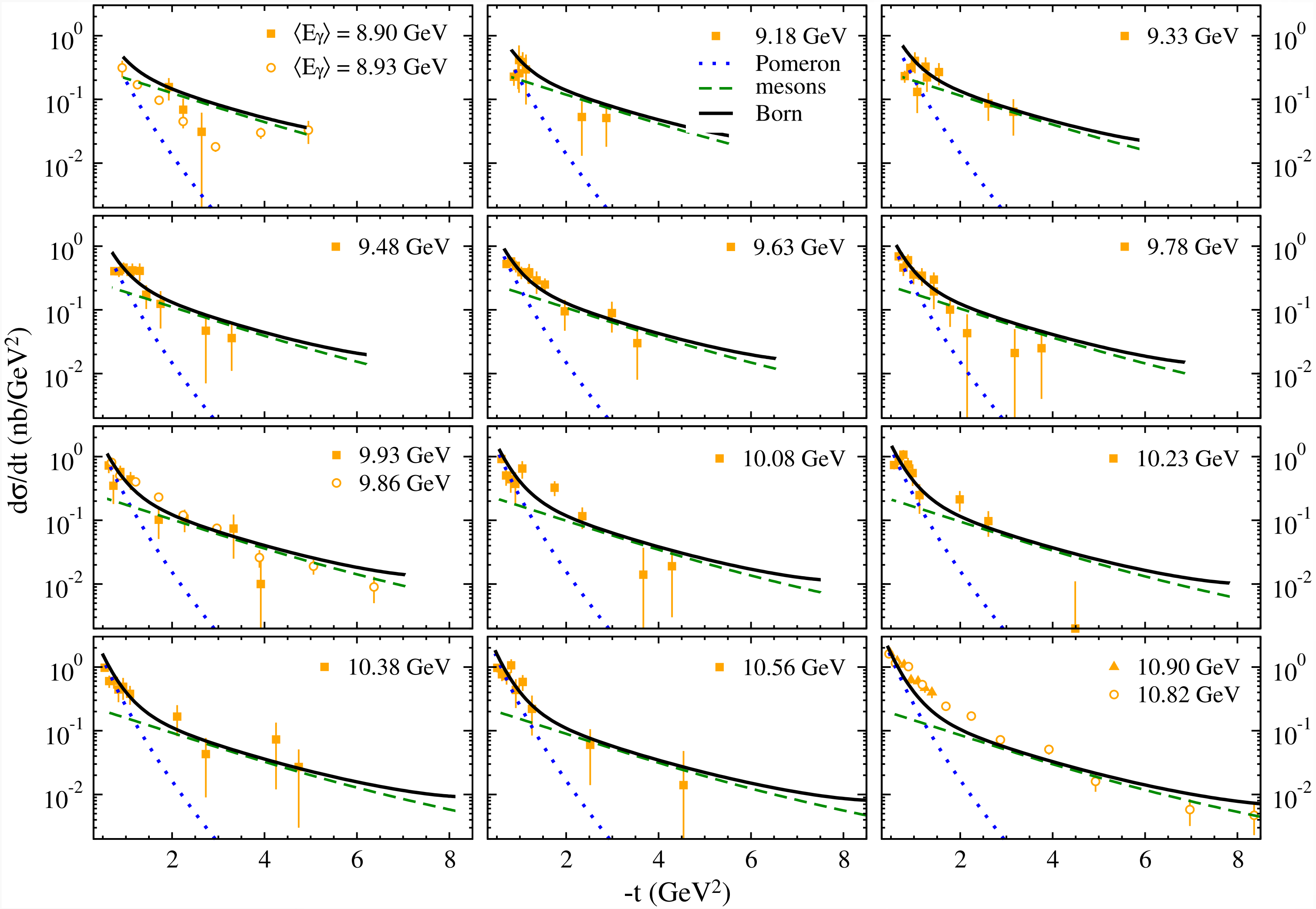




Born term

differential cross sections

[γ p → J/ψ p]



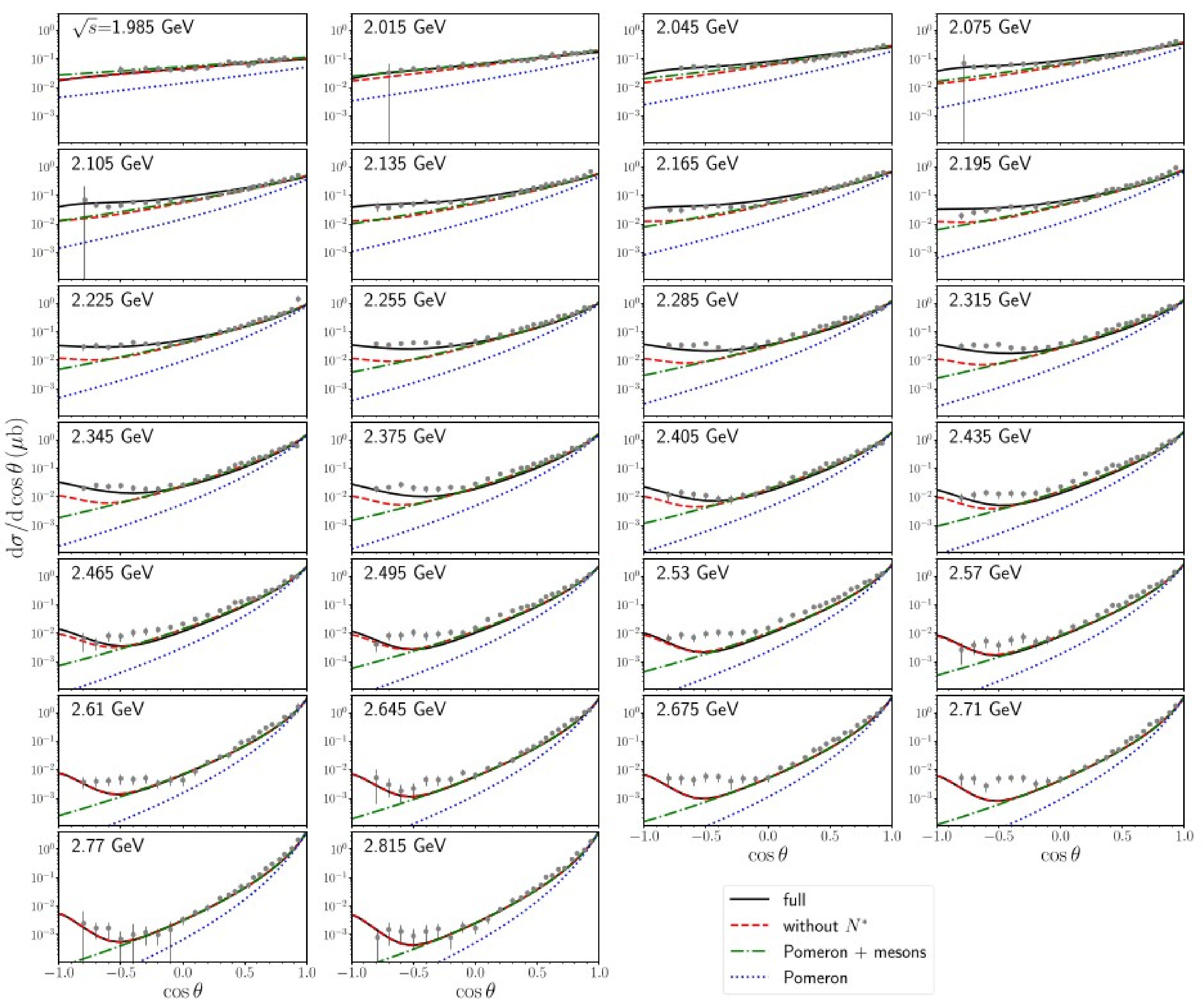
□ Forward: Pomeron exchange

□ Backward: mesons, nucleon exchanges

□ Some *t*-channel light mesons play a crucial role in γ p → J/ψ p.

□ The GlueX23 data (o) cover the whole scattering angles and thus place constraint on the nucleon-exchange contribution.

[Exp: GlueX, PRL.123.072001 (2019)
J/ψ-007, Nature.615.813 (2023)
GlueX, PRC.108.025201 (2023)]



differential cross sections
[γ p → φ p]

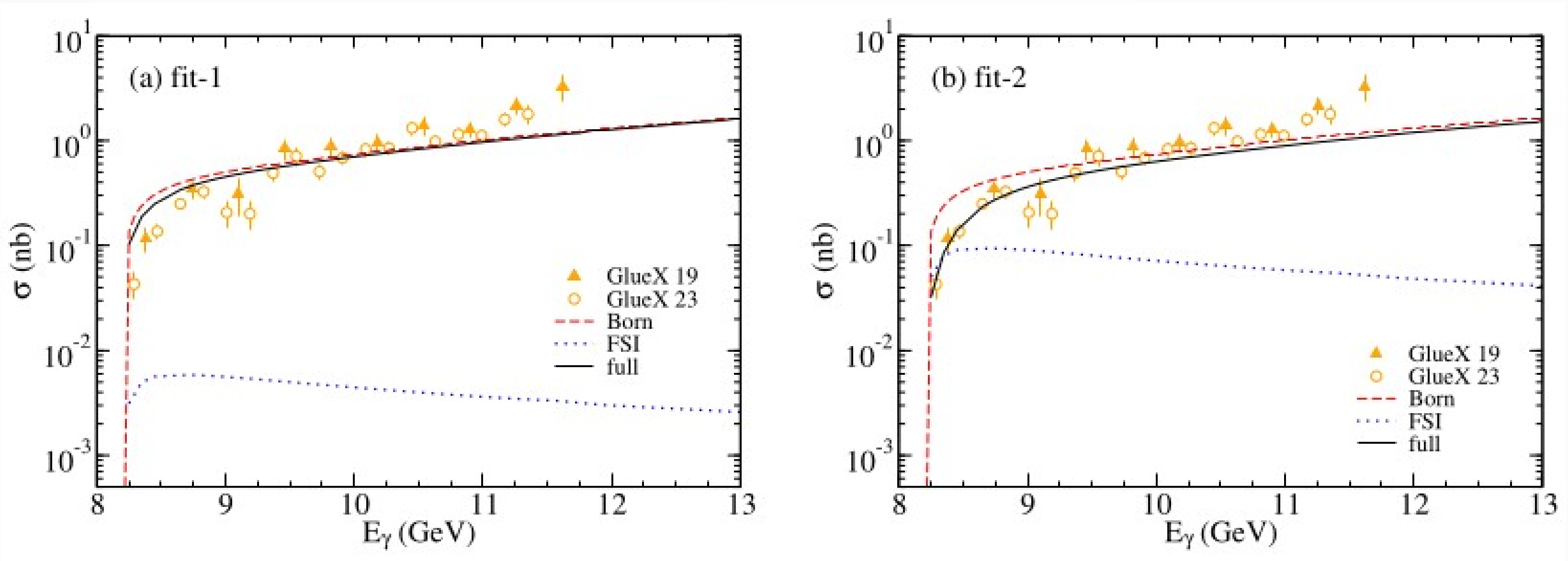
Born term

- □ Forward: Pomeron exchange
- □ Backward: mesons, nucleon, N^* exchanges

- □ Some *t*-channel light mesons play a crucial role in γ p → φ p.

[Exp: CLAS, PRC.89.055208 (2014)]

final state interaction (FSI) total cross section



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$$\mathcal{V}_{\rm gluon} = -v_0 \frac{e^{-\alpha r}}{r}$$

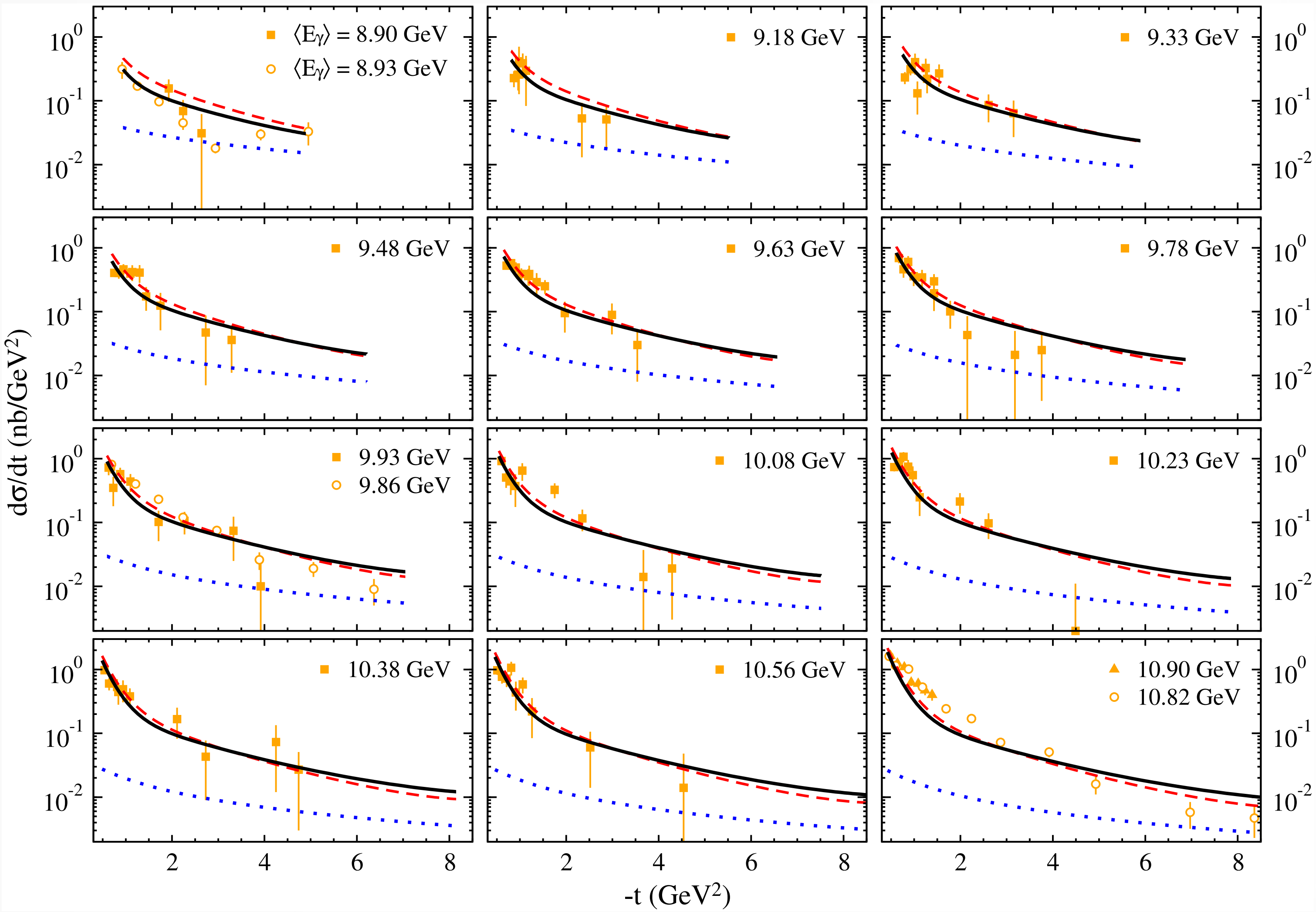
□ The results are sensitive to the parameters in the Yukawa potential.
□ We find a noticeable improvement with fit-2 model near threshold.

[Exp: GlueX, PRL.123.072001 (2019)
GlueX, PRC.108.025201 (2023)]

final state interaction (FSI)

differential cross sections

[$\gamma\, p \rightarrow J/\psi\, p$]



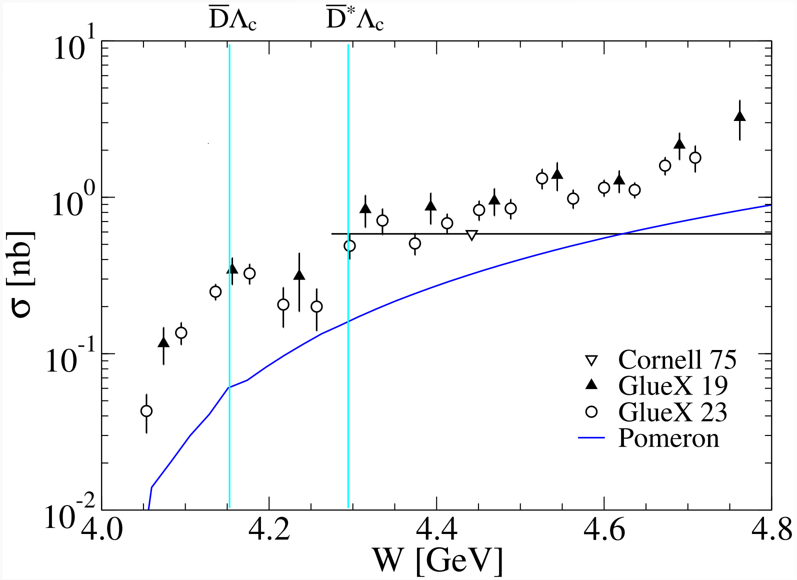
[Exp: GlueX, PRL.123.072001 (2019)
J/ψ-007, Nature.615.813 (2023)
GlueX, PRC.108.025201 (2023)]

□ The FSI term makes the result better near threshold.

□ More data near very threshold ($E_\gamma \leq 8.9$ GeV) are strongly desired to clarify the role of FSI term.

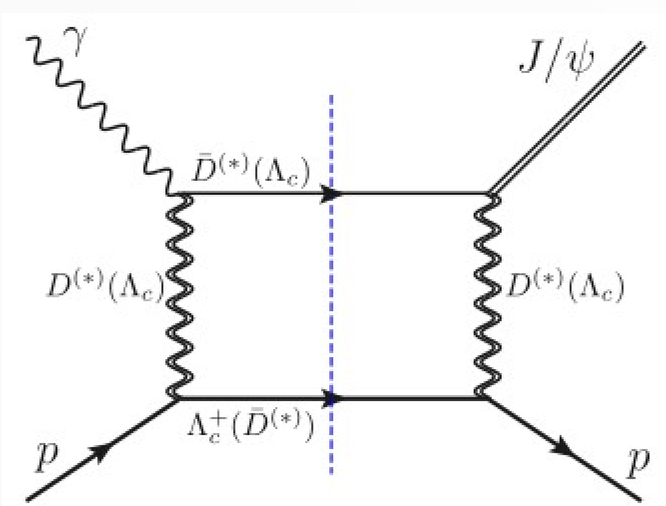
□ Two pronounced cusp structures are located at the $\overline{D}_c$ and $\overline{D}^*{}_c$ thresholds.

Rescattering diagram
[$\gamma\, p \to J/\psi\, p$]



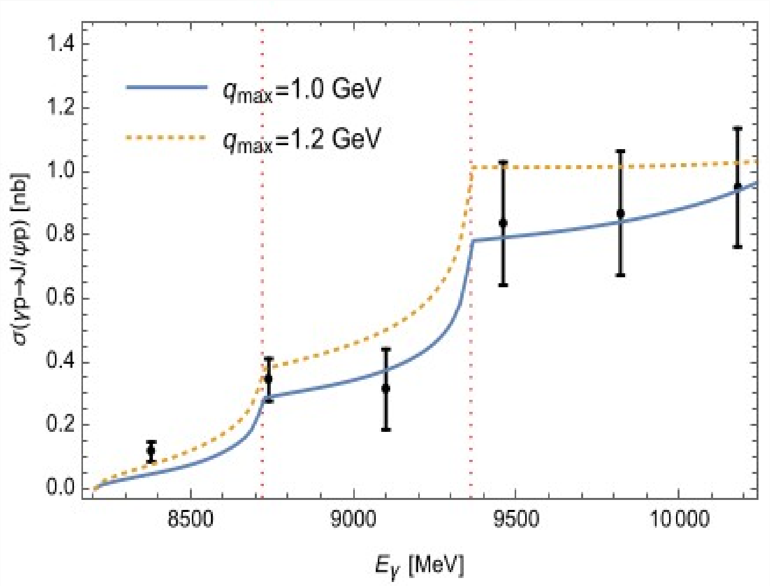
$$\mathcal{L}_{\Lambda_c DN} = -g_{D^*N\Lambda_c}\bar{\Lambda}_c\gamma_\mu N D^{*\mu} - i g_{DN\Lambda_c}\bar{\Lambda}_c\gamma_5 N D$$
$$-g_{D^*N\Lambda_c}\bar{N}\gamma_\mu \Lambda_c D^{*\mu\dagger} - i g_{DN\Lambda_c}\bar{N}\gamma_5\Lambda_c D^\dagger,$$

$$\mathcal{L}_\psi = -g_{\psi DD^*}\psi_\mu\epsilon_{\mu\nu\alpha\beta}(\partial_\nu D^*_\alpha\partial_\beta D^\dagger - \partial_\nu D\partial_\beta D^{*\dagger}_\alpha)$$
$$+ i g_{\psi D^*D^*}\psi^\mu(D^{*\nu}\partial_\nu D^{*\dagger}_\mu - \partial_\nu D^*_\mu D^{*\nu\dagger}$$
$$- D^{*\nu}\overleftrightarrow{\partial}_\mu D^{*\dagger}_\nu) - i g_{\psi DD} D^\dagger\overleftrightarrow{\partial}_\mu D\psi^\mu$$
$$+ g_{\psi\Lambda_c\Lambda_c}\bar{\Lambda}_c\gamma_\mu\psi^\mu\Lambda_c,$$
$$\mathcal{L}_\gamma = -g_{\gamma DD^*}F_{\mu\nu}\epsilon^{\mu\nu\alpha\beta}(D^*_\alpha\overleftrightarrow{\partial}_\beta D^\dagger - D\overleftrightarrow{\partial}_\beta D^{*\dagger}_\alpha)$$
$$- i g_{\gamma D^*D^*}F^{\mu\nu}D^{*\dagger}_\mu D^*_\nu - e\bar{\Lambda}_c\gamma_\mu A^\mu\Lambda,$$



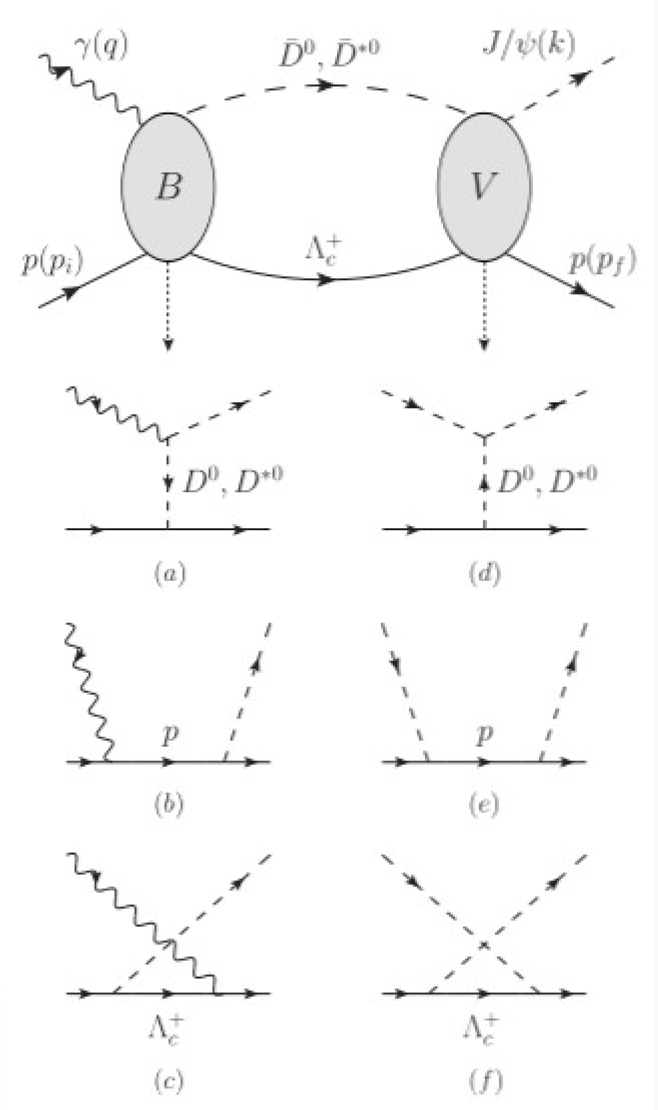
Coupling	$g_{\gamma DD^*}$	$g_{\gamma D^*D^*}$	$g_{DN\Lambda_c}$	$g_{D^*N\Lambda_c}$	$g_{\psi\Lambda_c\Lambda_c}$	$g_{\psi DD}$
Value	0.134 GeV^{-1}	0.641	−4.3	−13.2	−1.4	7.44
Source	Experimental data [46]		SU(4) [47,48]			VMD [47,48]

□ The presence of such cusps can be a clear indication of the importance of the charm loops.



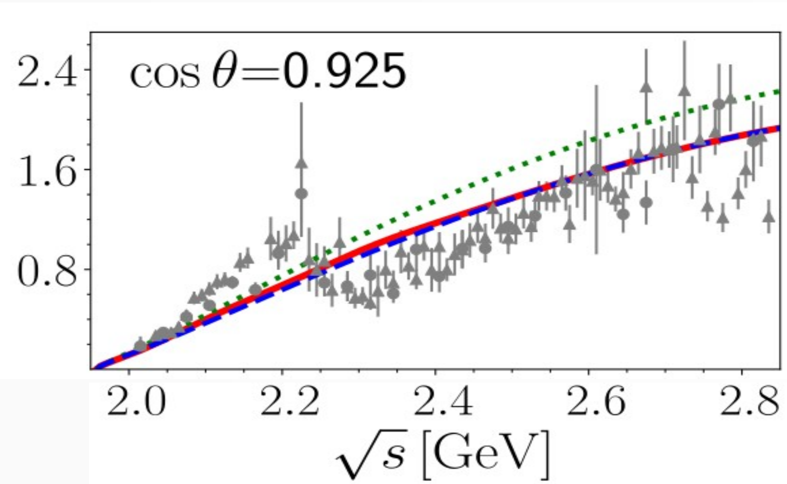
[Du, EPJC.80.1053 (2020)]

Rescattering diagram
[γ p → J/ψ p]



□ We are trying to calculate this region by using the 3-dimensional reduction of the integral equation for both principal and singular parts.

$$T_{MB}(p,p') = \sum_i \int \frac{d^3\mathbf{q}}{(2\pi)^3}\frac{m_{B_i}}{E_{B_i}} T_{\gamma p\to M_iB_i}(p,q)\frac{1}{s-(E_{M_i}+E_{B_i})^2+i\epsilon}T_{M_iB_i\to J/\psi p}(q,p')$$
$$= -i\sum_i \frac{q_{\text{c.m.}}}{16\pi^2}\frac{m_{B_i}}{\sqrt{s}}\int d\Omega\,[T_{\gamma p\to M_iB_i}(p,q)T_{M_iB_i\to J/\psi p}(q,p')] + \mathcal{P}$$



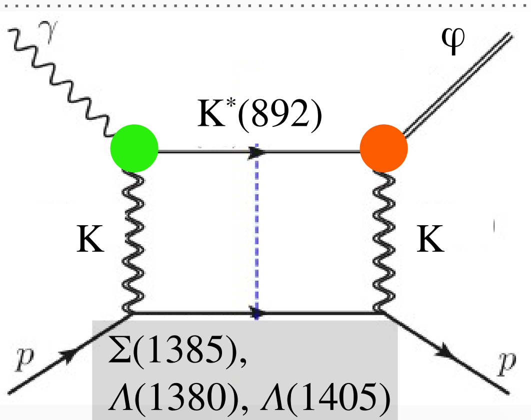
Rescattering diagram

[$\gamma\, p \to \varphi\, p$]

	Γ [$Y^* \to \bar{K}N$]
φ(1020) + N(938, $1/2^+$, ****) = 1.96	
K^*(892) + Λ(1116, $1/2^+$, ****) = 2.01	
K^*(892) + Σ(1385, $3/2^+$, ****) = 2.28	
K^*(892) + Λ(1380, $1/2^-$, ****) = 2.27	
K^*(892) + Λ(1405, $1/2^-$, ****) = 2.30	
K(494) + Λ(1520, $3/2^-$, ****) = 2.01	(45 ±1) %
K(494) + Λ(1600, $1/2^+$, ****) = 2.09	(15-30) %
K(494) + Λ(1670, $1/2^-$, ****) = 2.16	(20-30) %
K(494) + Λ(1690, $3/2^-$, ****) = 2.18	(20-30) %
K(494) + Λ(1800, $1/2^-$, ***) = 2.29	(25-40) %
K(494) + Σ(1660, $1/2^+$, ***) = 2.15	(05-15) %
K(494) + Σ(1670, $3/2^-$, ****) = 2.16	(06-12) %
K(494) + Σ(1750, $1/2^-$, ***) = 2.24	(06-12) %
K(494) + Σ(1775, $5/2^-$, ****) = 2.27	(37-43) %

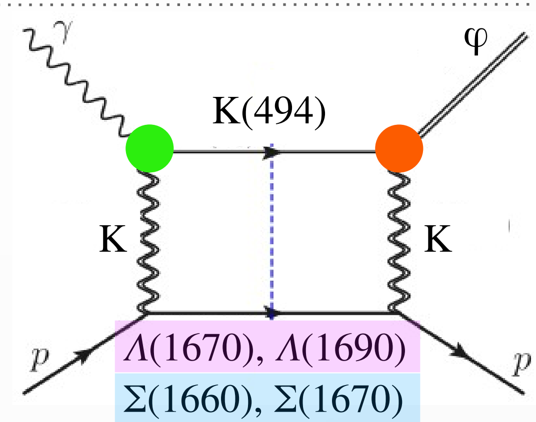
- □ It is quite plausible that the presence of such cusp can be a clear indication of the importance of the strange loops.
- □ KΛ(1670) and KΛ(1690) loops are the most strong candidates.

σ [KΛ(1670), KΛ(1690)] ≃ 6 · σ [KΣ(1660), KΣ(1670)]



- Γ [$K^{*\pm} \to K^\pm\gamma$] = 9.8 · 10^{-2} %
- Γ [$K^{*0} \to K^0\gamma$] = 2.46 · 10^{-1} %
- SU(3) flavor symmetry

$$g_{\phi K^* K} = g_{\rho\omega\pi}/\sqrt{2},$$
$$g_{\rho\omega\pi} = 14.4\,\mathrm{GeV}^{-1}$$

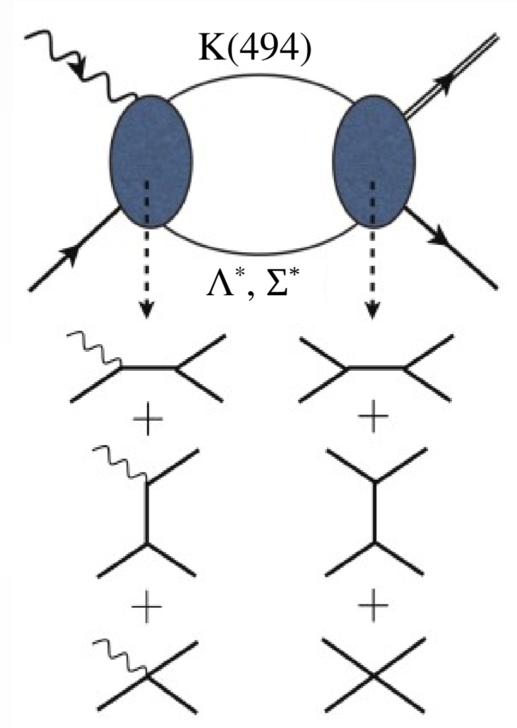


- electric charge
- Γ [$\varphi \to K^+K^-$] = 49.1 %

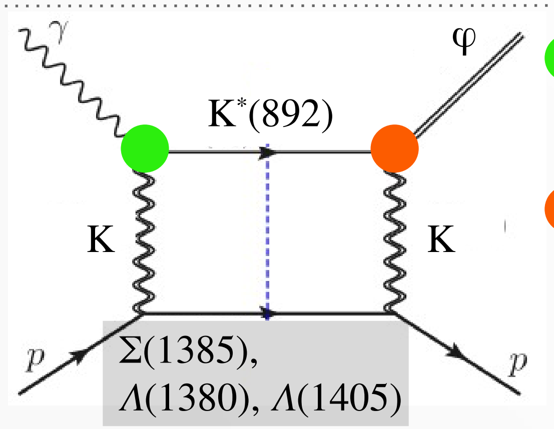
Rescattering diagram

[$\gamma\, p \rightarrow \varphi\, p$]

□ It satisfies the gauge invariance by itself.



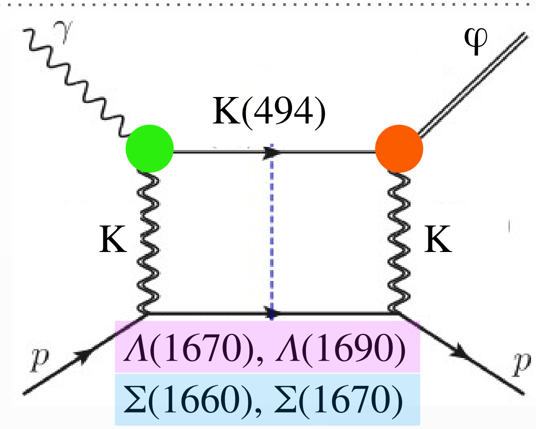
□ To satisfy the gauge invariance, we should include the t-, s-channels, and contact terms simultaneously.



- (green) $\Gamma\,[K^{*\pm} \rightarrow K^{\pm}\gamma] = 9.8 \cdot 10^{-2}\ \%$
  $\Gamma\,[K^{*0} \rightarrow K^{0}\gamma] = 2.46 \cdot 10^{-1}\ \%$
- (orange) SU(3) flavor symmetry

$$g_{\phi K^* K} = g_{\rho\omega\pi}/\sqrt{2}$$

$$g_{\rho\omega\pi} = 14.4\,\mathrm{GeV}^{-1}$$



- (green) electric charge
- (orange) $\Gamma\,[\varphi \rightarrow K^{+}K^{-}] = 49.1\ \%$

▷ For $\gamma\, p \to J/\psi\, p$, we studied relative contributions between the Pomeson and meson exchanges.

> Light-meson [π, η, a_0, f_0, $f_1(1285)$] contribution is more important than charmonium-meson [$\eta_c(1S)$, $\chi_{c0}(1P)$, $\chi_{c1}(1P)$, $\eta_c(2S)$, $\chi_{c1}(3872)$] contribution to describe the JLab data at low energies.

▷ The final J/ψ N interactions are described by the "gluon-exchange" and "direct J/ψ N couplings".

> The "gluon-exchange term" is much more important.

> The results are sensitive to the parameters in the Yukawa potential.

> The inclusion of the FSI term improves the total & differential cross sections near threshold.

> The angle-dependent data near the very threshold ($E_\gamma \leq 8.9$ GeV) are strongly desirable to clarify the role of the FSI term.

▷ For $\varphi\, p$ and $J/\psi\, p$ photoproduction, the meson-baryon loops should be studied more systematically, the pentaquark (P_s, P_c) in the *s*-channel diagram as well.

▷ For J/ψ photoproduction on nuclear targets, we refer to "PRC.112.015206 (2015) " for more details.

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Thank you very much for your attention