Photoproduction of X(3872) in the near-threshold region

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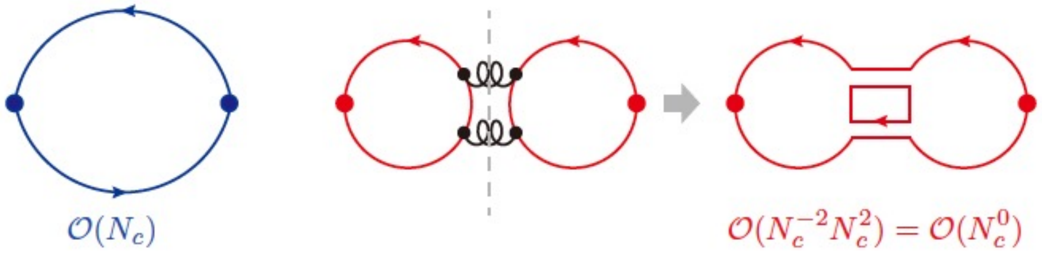
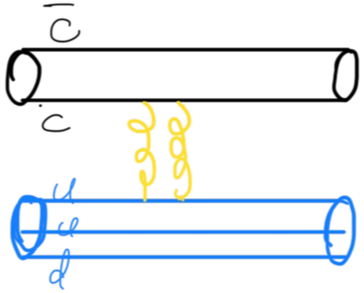
Xiong-Hui Cao, Meng-Lin Du, FKG, arXiv:2401.16112

J/ψ-nucleon scattering and photoproduction

- OZI suppressed scattering
  - ☐ Relatively suppressed by $O(1/N_c)$
  - ☐ General mechanisms (take $J/\psi - N$ as an example)



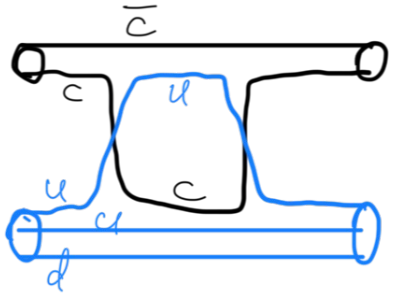
➢ Gluon exchanges



Gluonic matrix elements

- ☐ $\langle J/\psi|GG|J/\psi\rangle$ ~Chromopolarizabilities
- ☐ $\langle N|GG|N\rangle$: trace anomaly contribution to the nucleon mass

➢ Coupled-channel: $J/\psi N - \Lambda_c \bar{D}^{(*)}/\Sigma_c^{(*)}\bar{D}^{(*)} - J/\psi N$



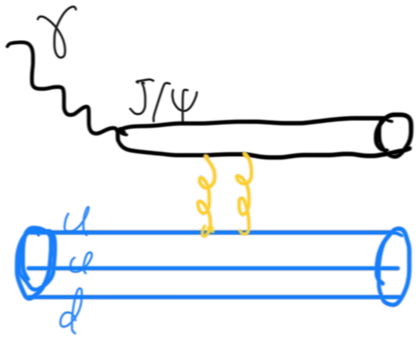
Importance of coupled-channel mechanism in evading OZI suppression in mesonic sector: H. Lipkin, B.-S. Zou, PRD 53 (1996) 6693

J/ψ-nucleon scattering and photoproduction

- The J/ψ photoproduction probes the gluonic contribution to the nucleon mass
  - ☐ if the mechanism of gluon exchanges is dominant

  - ☐ if the J/ψ photoproduction can be modeled by vector-meson dominance

D. Kharzeev, H. Satz, A. Syamtomov, G. Zinovjev, EPJC 9 (1999) 459



$$\frac{d\sigma_{\gamma N\to\psi N}}{dt}(s,t=0)=\frac{3\Gamma(\psi\to e^+e^-)}{\alpha m_\psi}\left(\frac{k_{\psi N}}{k_{\gamma N}}\right)^2 \times\frac{d\sigma_{\psi N\to\psi N}}{dt}(s,t=0)$$

- ➢ Scattering length from VMD and photoproduction: $3-25$ am — L. Pentchev, I. Strakovsky, EPJA 57 (2021) 56

  21.3 ± 8.2 am — GlueX, PRC 108 (2023) 025201
- ➢ Nucleon gluonic gravitational form factor, mass radius measured with this assumption

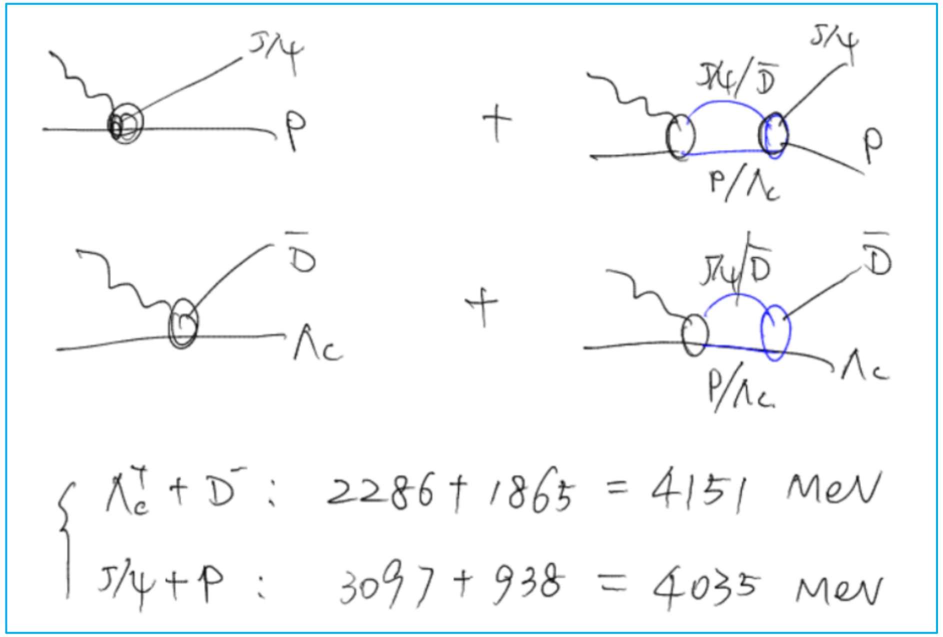
Duran et al. [J/ψ-007], Nature 615 (2023) 813

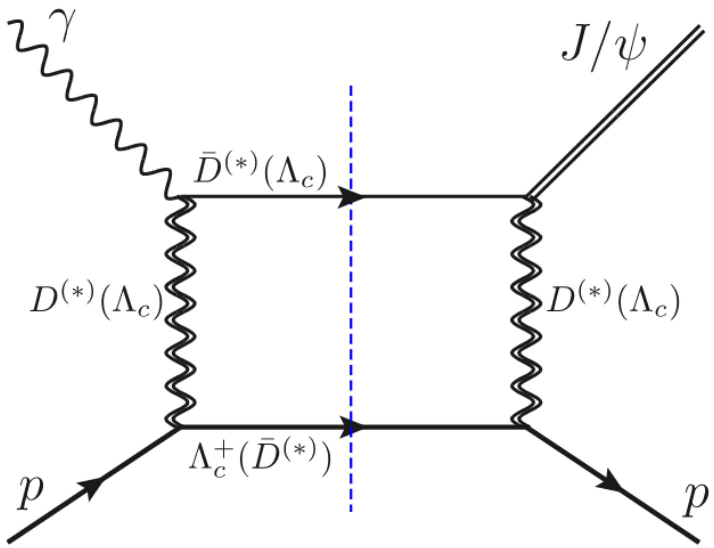
- For the search for hidden-charm P_c pentaquarks

J/ψ in the VMD model would be highly off-shell, but the scattering length and cross section are defined for real J/ψ

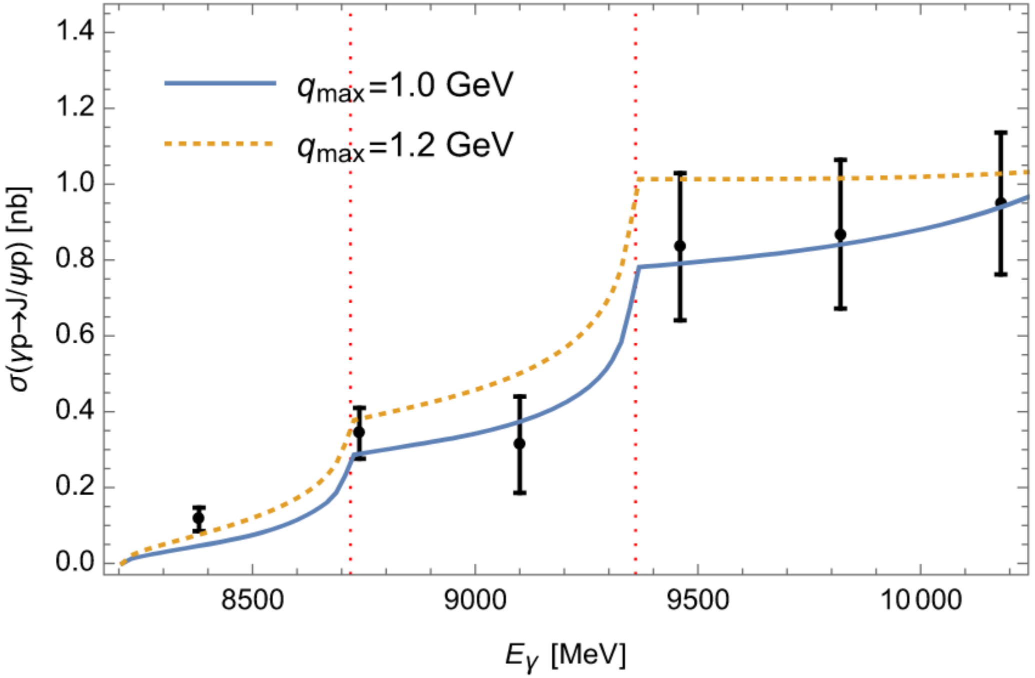
J/ψ photoproduction

- Coupled-channel mechanism
  - Consider $\Lambda_c \bar{D}^{(*)}$ channels: M.-L. Du et al., EPJC 80 (2020) 1053





  - Unique feature: threshold cusps

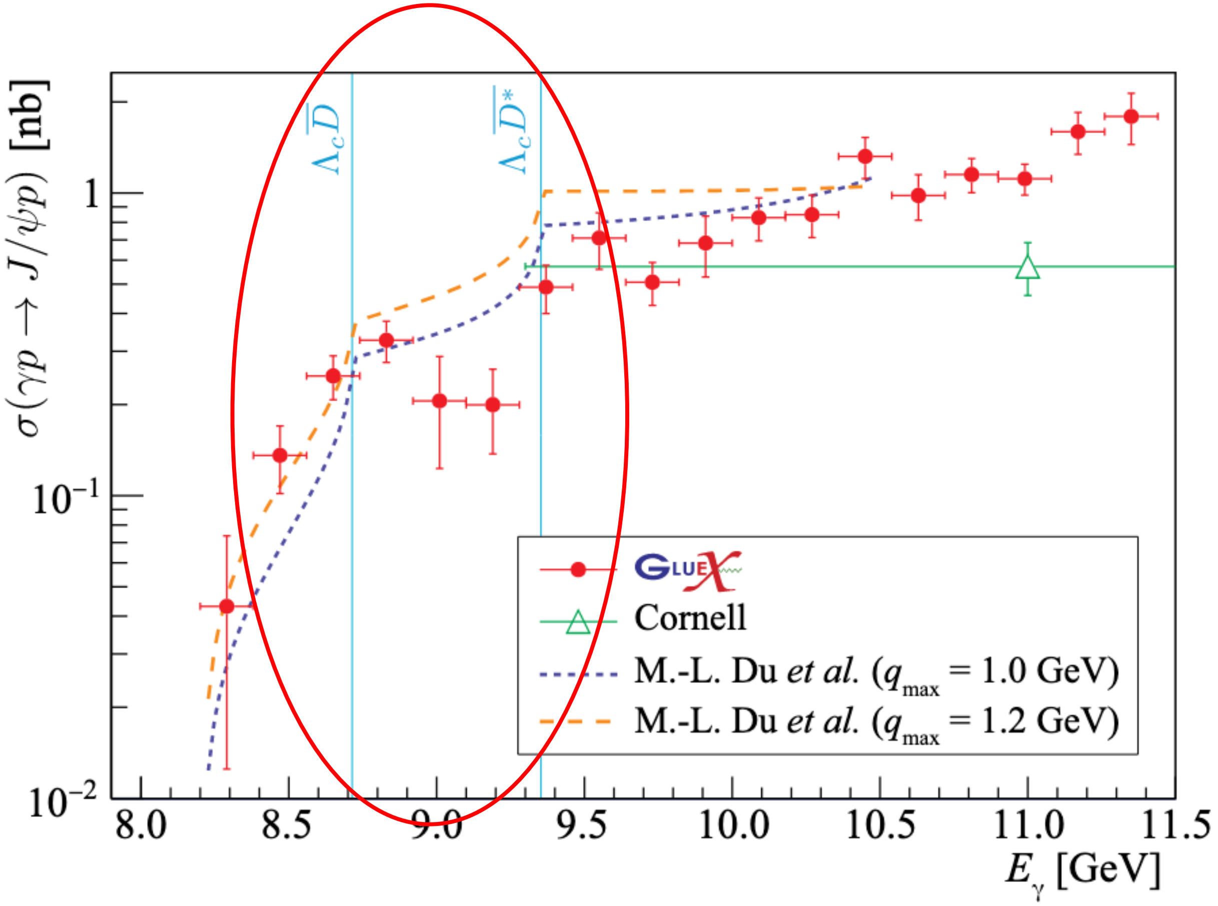


With phenomenological couplings, not a fit.

Data: GlueX, PRL 123 (2019) 072001

J/ψ photoproduction

- Coupled-channel mechanism
  - Hint of threshold cusps in the latest data, but still not conclusive



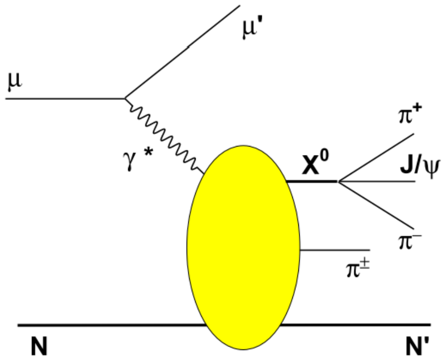
GlueX, PRC 108 (2023) 025201

See also JPAC analysis in D. Winney et al., PRD 108 (2023) 054018

X(3872) photoproduction

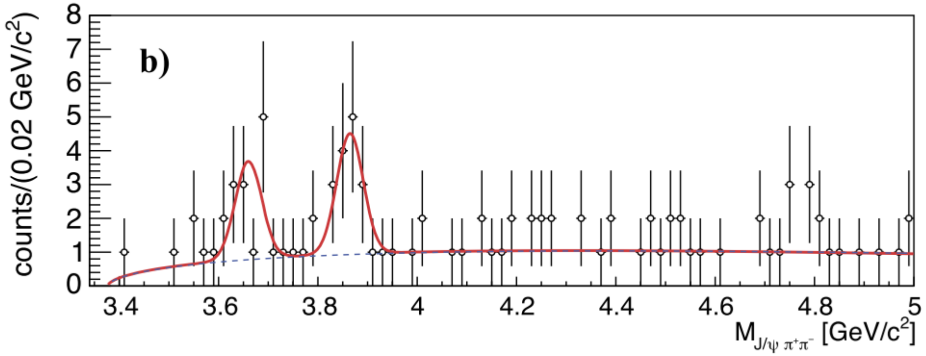
- Searched for at COMPASS, but not seen
  - ☐ Evidence of $\tilde{X}(3872)$ in $\gamma^* N \to X^0 \pi^\pm N'$ with 4.1σ

COMPASS, PLB783(2018)334

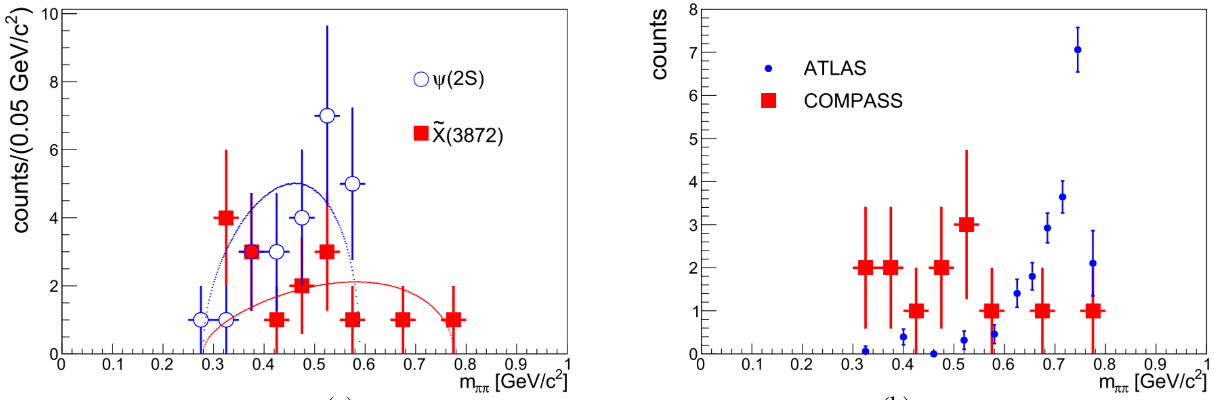


$\sqrt{s_{\gamma N}} \in [8, 18]$ GeV

$M_{\tilde{X}} = (3860.4 \pm 10.0)$ MeV



  - ☐ The $\pi\pi$ invariant mass suggests $C(\tilde{X}) = -1$



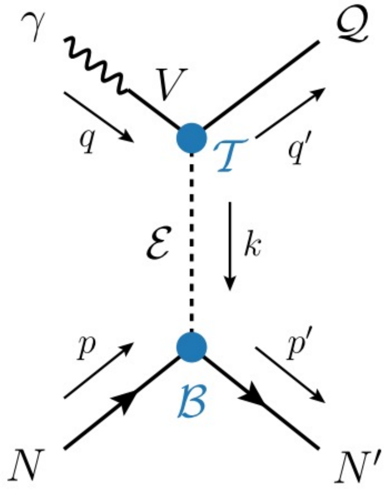
(a) (b)

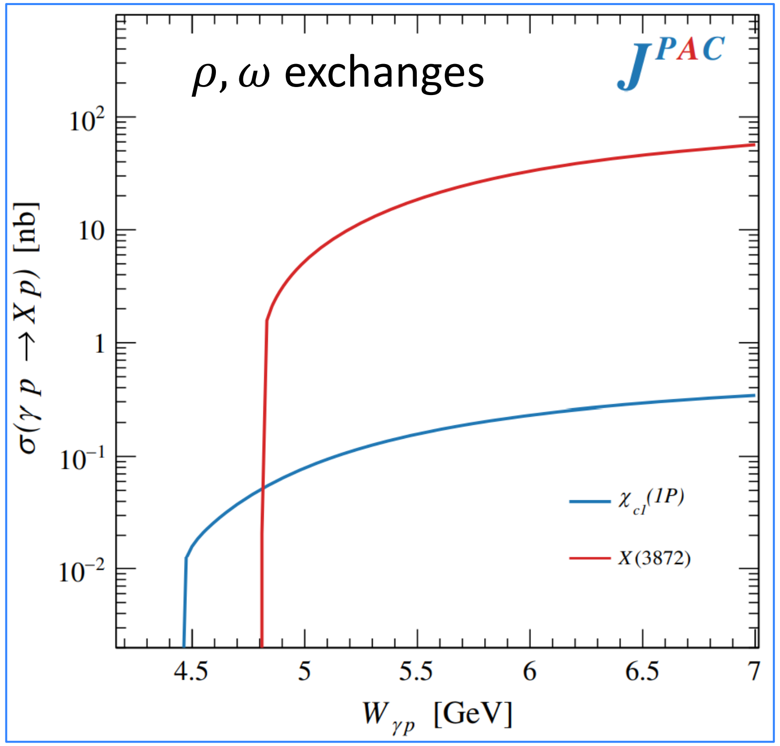
  - ☐ Cross sections at $\sqrt{s_{\gamma N}} = 13.7$ GeV : $\sigma(\gamma N \to \tilde{X}\pi N') \times \mathcal{B}(\tilde{X} \to J/\psi\pi^+\pi^-) = (71 \pm 28 \pm 39)$ pb

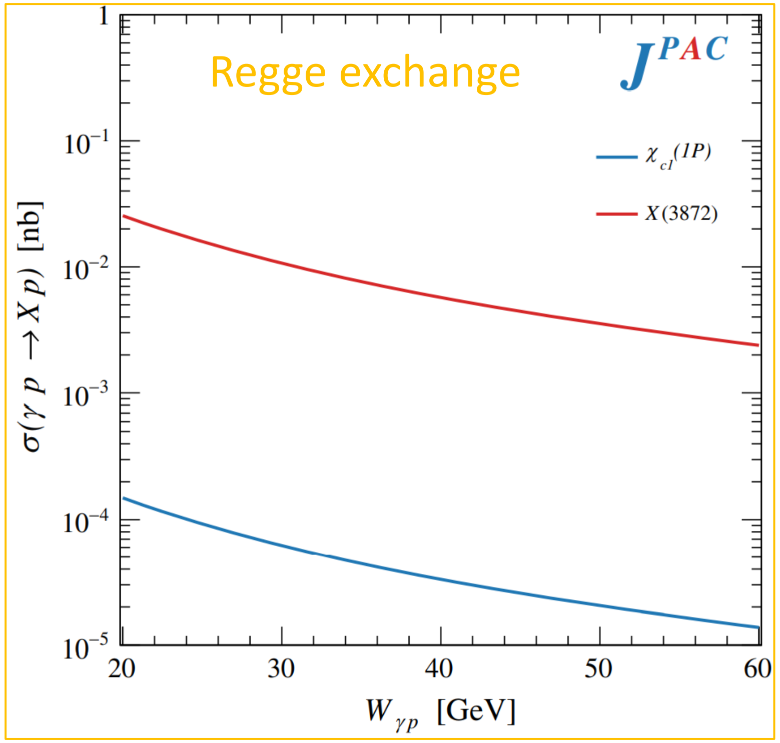
$\sigma(\gamma N \to X(3872)N') \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) < 2.9$ pb (CL = 90%)

X(3872) photoproduction with VMD

- Existing estimate for the X(3872) photoproduction
  - Vector-meson-dominance (VMD) model: $\gamma^* \to J/\psi$ JPAC, PRD102(2020)114010
  - Low energy: ρ, ω exchanges, $\mathcal{O}(10\text{ nb})$
  - High energy: Regge exchange





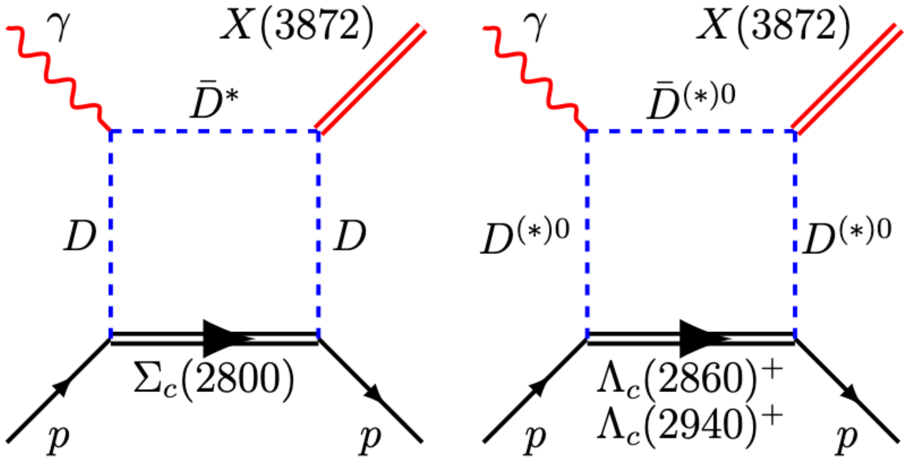


X(3872) photoproduction with coupled channels

- Coupled-channel mechanism for the X(3872) photoproduction in the near-threshold region
  - X(3872) couples strongly to $D\bar{D}^*$
  - Nearby open-charm thresholds:

$m_p + m_X = 4810$ MeV

$\bar{D}^0\Lambda_c(2940)^+: 4804^{+2}_{-1}$ MeV
$\bar{D}^{*0}\Sigma_c(2800)^+: 4799^{+14}_{-5}$ MeV
$D^{*-}\Sigma_c(2800)^{++}: 4811^{+4}_{-6}$ MeV
$\bar{D}^{*0}\Lambda_c(2860)^+: 4863^{+2}_{-6}$ MeV
$\bar{D}^{*0}\Lambda_c(2940)^+: 4946^{+1}_{-1}$ MeV.

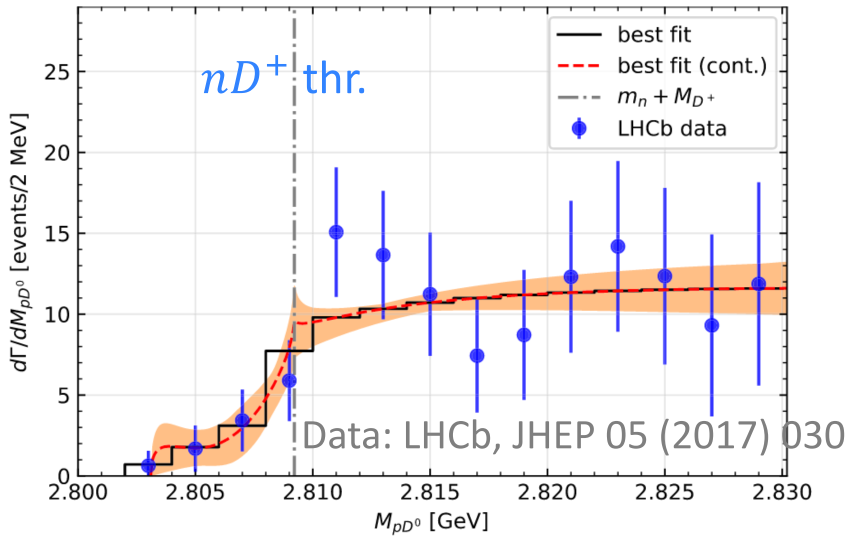


$\Lambda_c(2860)$ $[3/2^+]$
$\Lambda_c(2940)$ $[3/2^-]$
$\Sigma_c(2800)$: ½$^-$ from the analysis of $\Lambda_b \to \pi^- p D^0$

S. Sakai, FKG, B. Kubis, PLB 808 (2020) 135623

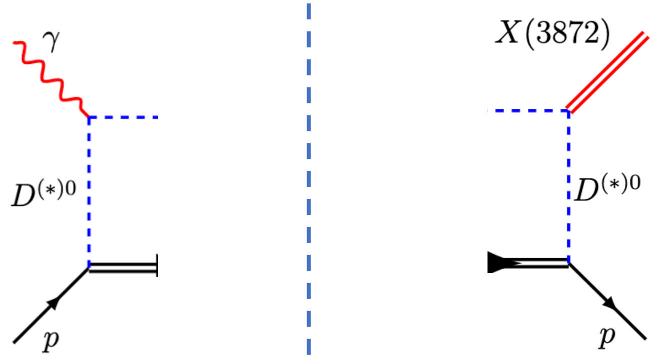
Coupling constants

- Measured widths
- Heavy quark spin symmetry
- $XD\bar{D}^*$ coupling consistent with hadronic molecular picture



X(3872) photoproduction with coupled channels

- Evaluate the box diagrams with a dispersive approach:



$$\mathcal{A}^{(J)}_{\ell S;\bar{\ell}\bar{S}(\gamma p\to\chi_{c1}p)}(s) = \sum_{\ell',S'} \frac{1}{\pi}\int_{s_{\rm th}}^{s_{\rm cut}} ds' \frac{\mathcal{A}^{(J)}_{\ell' S';\bar{\ell}\bar{S}(\gamma p\to\bar{D}^*\Sigma_c/\Lambda_c)}(s')\rho(s')\mathcal{A}^{(J)}_{\ell' S';\ell S(\chi_{c1}p\to\bar{D}^*\Sigma_c/\Lambda_c)}(s')}{s'-s}$$

consider S-wave for open-charm channels, S-, P- and D-waves for $\gamma p, Xp$

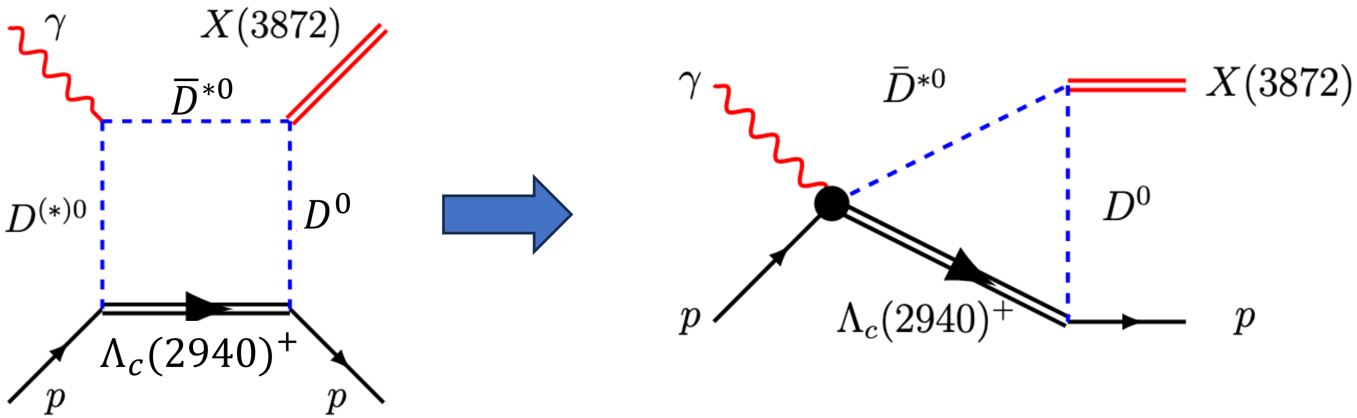
- Only limited channels, hard cutoff: $s_{\rm cut} = \sqrt{q_{\rm max}^2 + m_{\Sigma_c/\Lambda_c}^2} + \sqrt{q_{\rm max}^2 + m_{D^{(*)}}^2}$ with $q_{\rm max} = 1$ GeV
- Monopole form factor for exchanged particles with $\Lambda = m_{\rm ex} + \eta\Lambda_{\rm QCD}$

$$F(t) = \frac{\Lambda^2 - m_{\rm ex}^2}{\Lambda^2 - t}$$

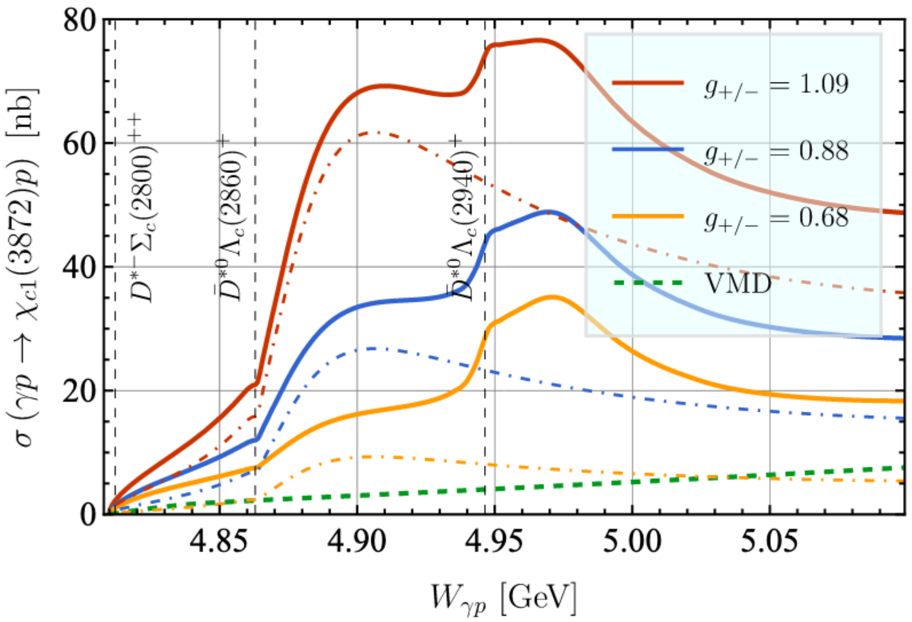
X(3872) photoproduction with coupled channels

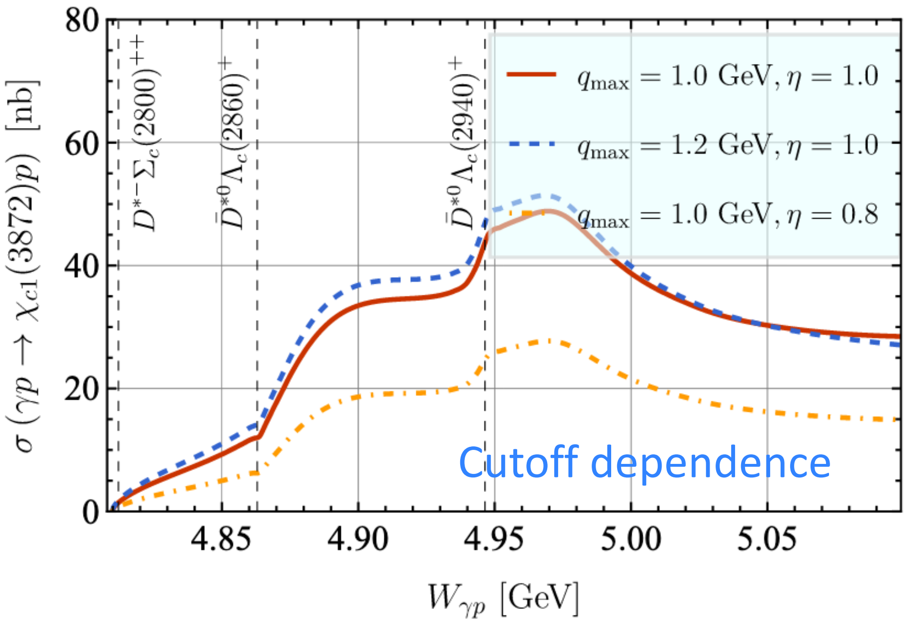
For review on TS: FKG, X.-H.Liu, S.Sakai, PPNP 112 (2020) 103757

- Triangle singularity: subleading Landau singularity of the box diagram



- Total cross section



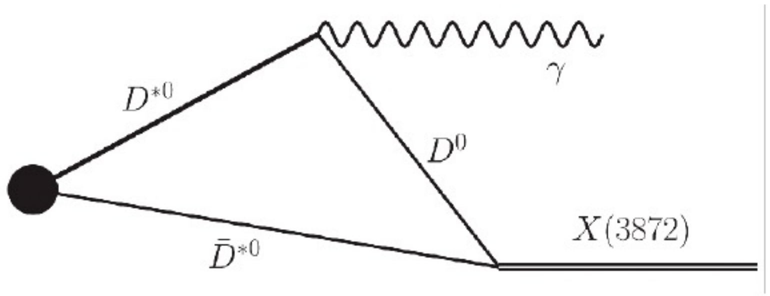


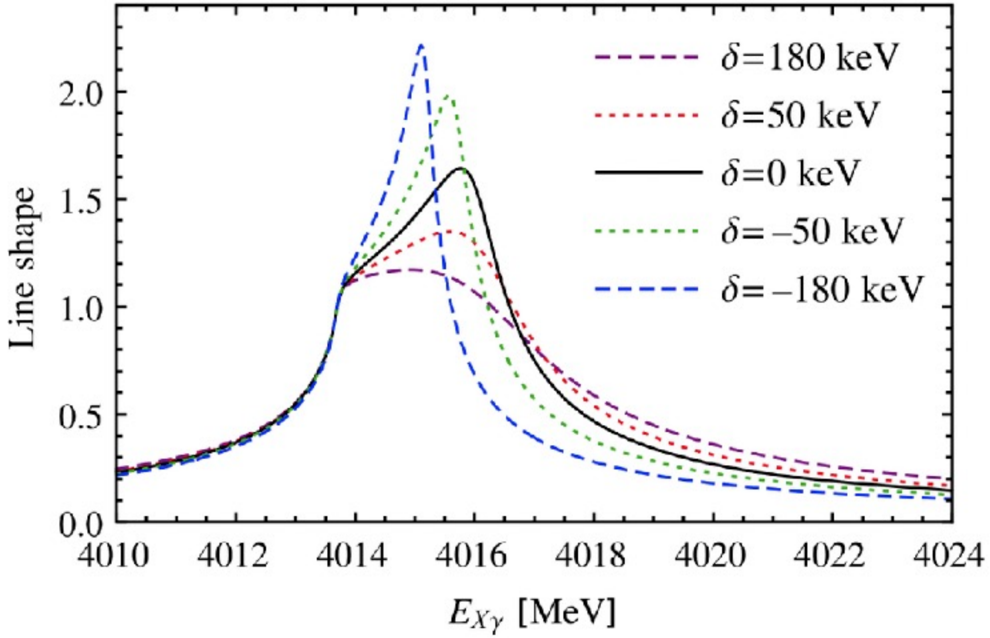
Here $g_{+/-}$ is the ratio of the $\Lambda(2860)D^{(*)}p$ and $\Lambda(2940)D^{(*)}p$ coupling constants constrained by the measured widths

X(3872) photoproduction with coupled channels

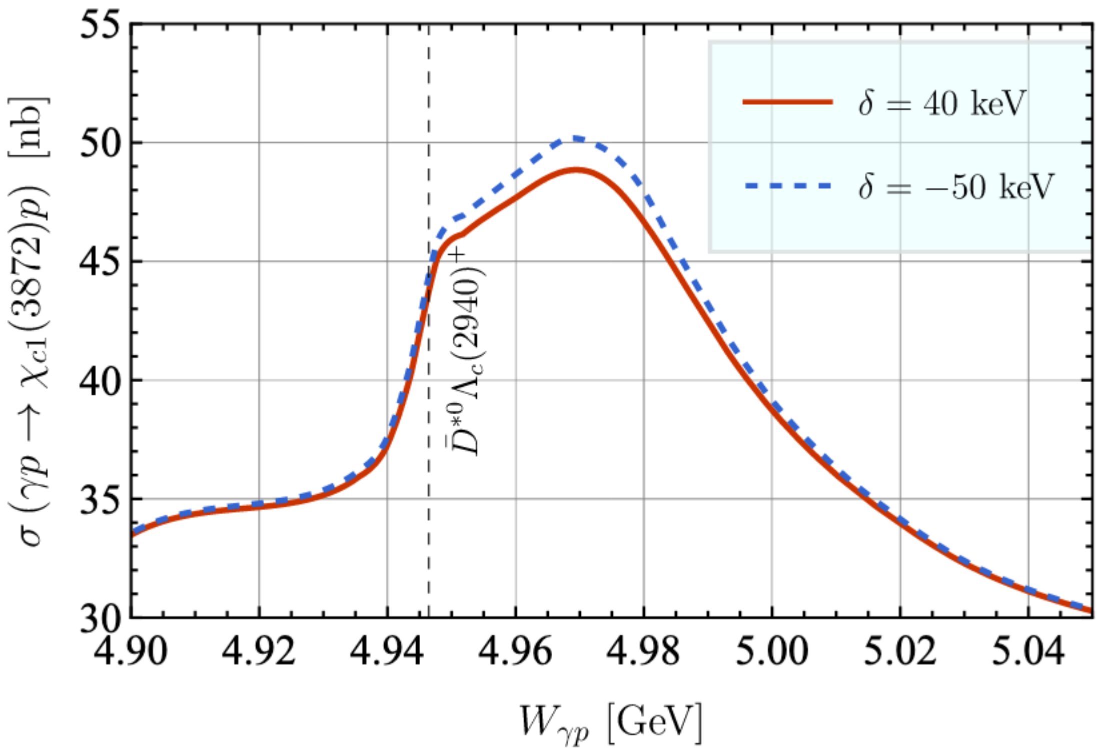
- Triangle singularity induced structure may be used to measure the X(3872) binding energy (δ)

FKG, PRL 122 (2019) 202002





- However, here the sensitivity is smeared out by the $\Lambda(2940)$ width (~ 20 MeV)



Summary

- Nontrivial structures in the energy dependence of the total cross section: probe of the mechanism of the near-threshold production of hidden-charm mesons
- $\sigma(\gamma p \to X(3872)p) = \mathcal{O}(30\ \mathrm{nb})$ at $\sqrt{s_{\gamma p}} \sim 5\ \mathrm{GeV} \Rightarrow\ \mathcal{O}(0.3\ \mathrm{nb})$ for electroproduction
  - Plenty of $X(3872)$ events will be collected with $50\ \mathrm{fb}^{-1}$ for EicC, $300\ \mathrm{fb}^{-1}$ for EIC