The Discussion of P_c states and the prediction of J/ψ Photo-production

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Outline

- Motivation
- The discussion of P_c
- γ p → J/ψ p background mechanism
- γ p → P_c → J/ψ p
- How to extract information of P_c ?
- Summary

Motivation

- In 2010, from this paper, it was the first propose N*, Λ* with hidden-charm exist around 4 GeV in theory.

PRL **105**, 232001 (2010) PHYSICAL REVIEW LETTERS week ending 3 DECEMBER 2010

Prediction of Narrow N^* and Λ^* Resonances with Hidden Charm above 4 GeV

Jia-Jun Wu,[1,2] R. Molina,[2,3] E. Oset,[2,3] and B. S. Zou[1,3]
[1]*Institute of High Energy Physics, CAS, Beijing 100049, China*
[2]*Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC, Institutos de Investigación de Paterna, Apartado 22085, 46071 Valencia, Spain*
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(Received 5 July 2010; published 29 November 2010)

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PRL 115, 072001 (2015) PHYSICAL REVIEW LETTERS week ending 14 AUGUST 2015

Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays

R. Aaij *et al.*[*]
(LHCb Collaboration)
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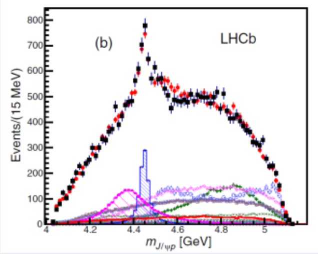

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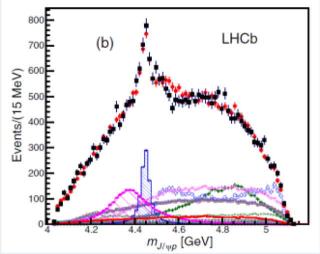

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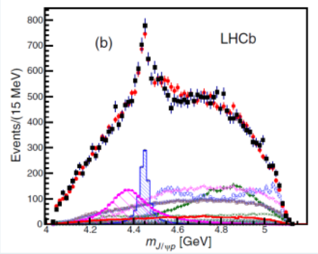
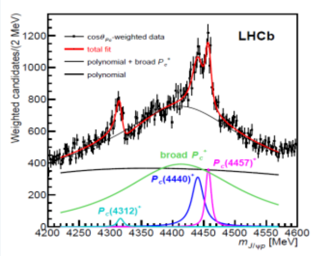


- Two months ago, LHCb group updated the new results.

Observation of a narrow pentaquark state, $P_c(4312)^+$, and of two-peak structure of the $P_c(4450)^+$

arXiv:1904.03947v1 [hep-ex] 8 Apr 2019



Motivation

- Why " $\bar{c}cqqq$ " is important to search five quark states ?

How ?

- Why is it important to confirm P_c in photo-production reaction ?

How ?

First Question

- Why “ $\bar{c}cqqq$ ” is important to search five quark states ?

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Possible Five quark state is studied in many years.

1. $\bar{q}'qqqq$： **Never Confirmed** θ^{+} state ??
2. $\bar{q}'q'qqq$: **Always Argued** Roper, $\Lambda^{*}(1405)$

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u,d,s ⇒ **Five-quark state** / **Three-quark excited states** ⇒ Indistinguishable

Close mass

Parameters

Question ?

First Question

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Close mass / Parameters ⇨ Indistinguishable

Question ?

Solution !

N*($\bar{c}c$) = uud + $\bar{c}c$ → $\bar{D}\Sigma_c$ - $\bar{D}\Lambda_c$; **[ud][uc] $\bar{c}$**

- Before LHCb first announce their results in 2015, there are several theoretical papers about Pc as follows
- Valencia Model：

Wu, Molina, Oset and Zou, PRL 105, 232001， PRC 84, 015202

Wu, Zhao and Zou, PLB 709, 70

Oset, etal, IJMP. E21, 1230011 (2012).

Garcia-Recio, Nieves, Romanets, Salcedo, and Tolos, PRD87, 074034(2013)

Xiao, Nieves, and Oset, PRD88, 056012(2013)

Uchino, Liang, and Oset, EPJA 52, 43(2016)

- EBAC Model： Wu, Lee and Zou, PRC **85**, 044002
- Chiral constituent quark model & a resonating group method equation

  Wang, Huang, Zhang, Zou, PRC 84,015203(2011).
- Schrödinger Equation & One boson exchange：

  Yang, Sun, He, Liu, Zhu, Chin.Phys. C36 (2012) 6-13
- Pentaquark Model： Yuan, Wei, He, Xu and Zou, EPJA 48, 61(2012)

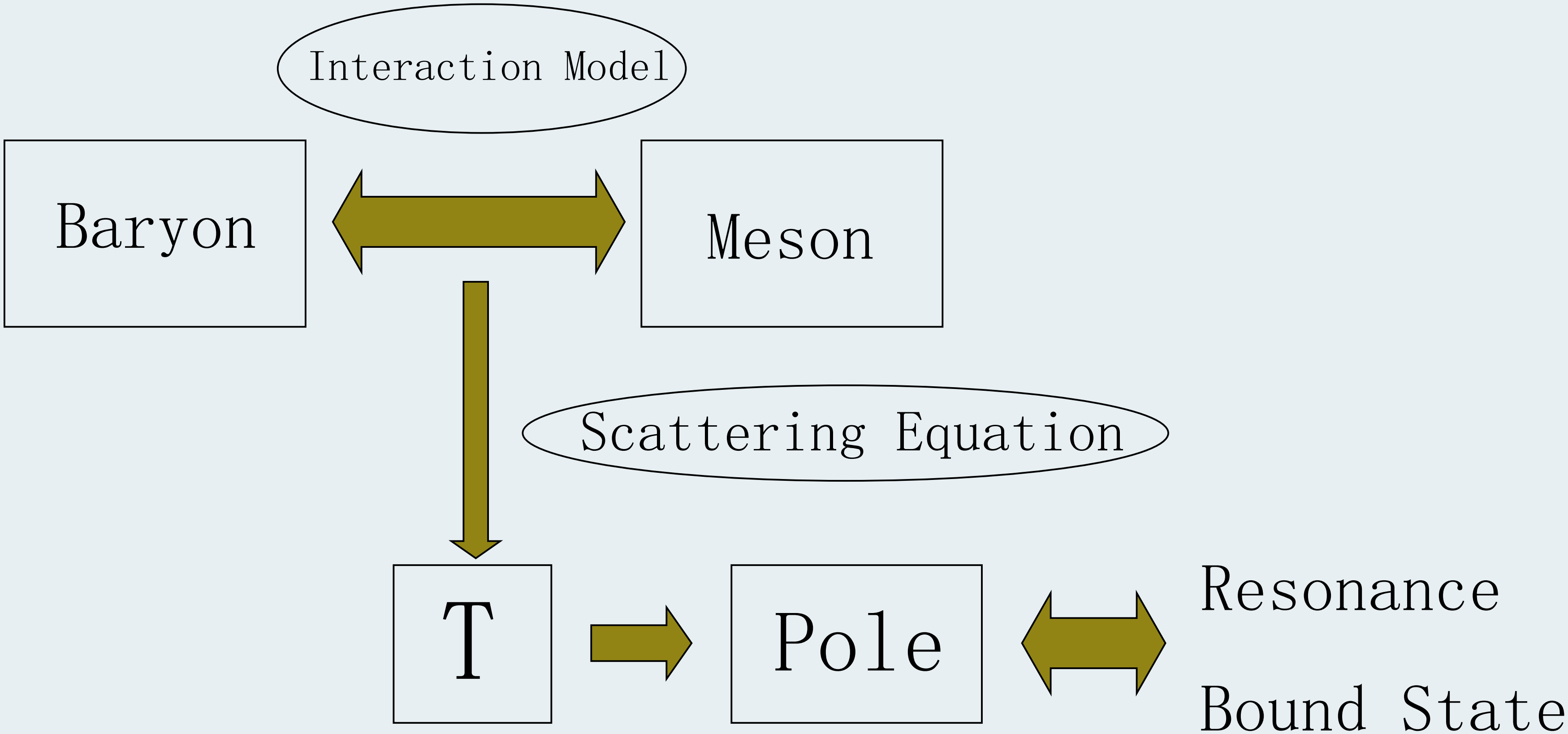
$\bar{D}\Sigma_c - h_c N - hN$ coupled channel state ~ 3.5 GeV

J. Hofmann, M.F.M. Lutz, Nucl. Phys. A 763 (2005) 90

$\bar{c}c$-N bound states in topological soliton model **~ 3.9 GeV**

C. Gobbi, D.O. Riska, N.N. Scoccola, Phys. Lett. B 296 (1992) 166

The Prediction of P_c



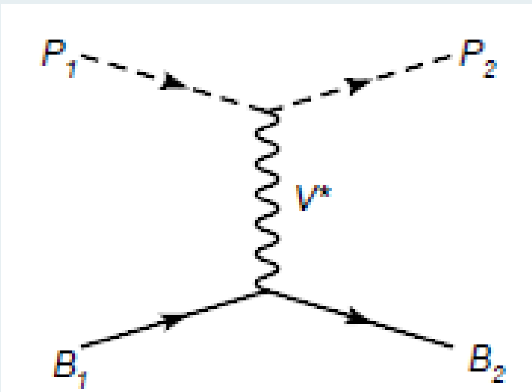
Interaction Model, Chiral Lagrangians

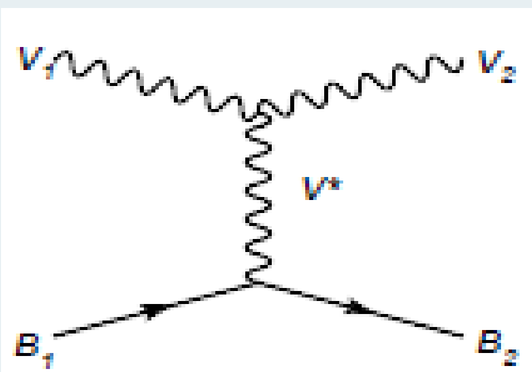
Local Hidden Symmetry and SU(4) Symmetry

Scattering Equation: Valencia and EBAC

$\bar{D}\Sigma_c$, $\bar{D}_s\Lambda_c$ bound states

J. J. Wu, R. Molina, E. Oset, B. S. Zou, PRL 105 (2010) 232001





$$
\begin{aligned}
\mathcal{L}_{VVV} &= ig\langle V^\mu[V^\nu, \partial_\mu V_\nu]\rangle \\
\mathcal{L}_{PPV} &= -ig\langle V^\mu[P, \partial_\mu P]\rangle \\
\mathcal{L}_{BBV} &= g(\langle \bar{B}\gamma_\mu[V^\mu, B]\rangle + \langle \bar{B}\gamma_\mu B\rangle\langle V^\mu\rangle)
\end{aligned}
$$

$$
\begin{aligned}
V_{ab(P_1B_1\to P_2B_2)} &= \frac{C_{ab}}{4f^2}(E_{P_1} + E_{P_2}), \\
V_{ab(V_1B_1\to V_2B_2)} &= \frac{C_{ab}}{4f^2}(E_{V_1} + E_{V_2})\vec{\epsilon}_1 \cdot \vec{\epsilon}_2,
\end{aligned}
$$

$$T = [1 - VG]^{-1}V$$

$$T_{ab} = \frac{g_a g_b}{\sqrt{s} - z_R}$$

	(I,S)	M	Γ	Γ_i						g_a		
N*	$(1/2,0)$			πN	ηN	$\eta' N$	$K\Sigma$		$\eta_c N$	$\bar{D}\Sigma_c$	$\bar{D}\Lambda_c^+$	
		4261	56.9	3.8	8.1	3.9	17.0		23.4	2.85	0	
Λ*	$(0,-1)$			$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$	$\eta_c\Lambda$	$\bar{D}_s\Lambda_c^+$	$\bar{D}\Xi_c$	$\bar{D}\Xi'_c$
		4209	32.4	15.8	2.9	3.2	1.7	2.4	5.8	1.37	3.25	0
		4394	43.3	0	10.6	7.1	3.3	5.8	16.3	0	0	2.64

The states from $PB \to PB$, with units in MeV

	(I,S)	M	Γ	Γ_i						g_a		
N*	$(1/2,0)$			ρN	ωN	$K^*\Sigma$			$J/\psi N$	$\bar{D}^*\Sigma_c$	$\bar{D}^*\Lambda_c^+$	
		4412	47.3	3.2	10.4	13.7			19.2	2.75	0	
Λ*	$(0,-1)$			$\bar{K}^*N$	$\rho\Sigma$	$\omega\Lambda$	$\phi\Lambda$	$K^*\Xi$	$J/\psi\Lambda$	$\bar{D}_s^*\Lambda_c^+$	$\bar{D}^*\Xi_c$	$\bar{D}^*\Xi'_c$
		4368	28.0	13.9	3.1	0.3	4.0	1.8	5.4	1.23	3.14	0
		4544	36.6	0	8.8	9.1	0	5.0	13.8	0	0	2.53

The states from $VB \to VB$, with units in MeV

Valencia &&&& EBAC

$\bar{D}\Sigma_c$ 4269MeV 4301−4318MeV

$$T = V + V G^{Valencia} T$$

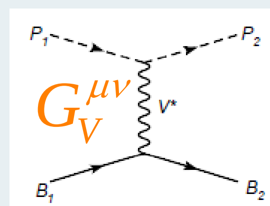
$$T(q_1,q_2) = V + \int q_3^2 dq_3\, V(q_1,q_3) \times G(q_3) T(q_3,q_2)$$

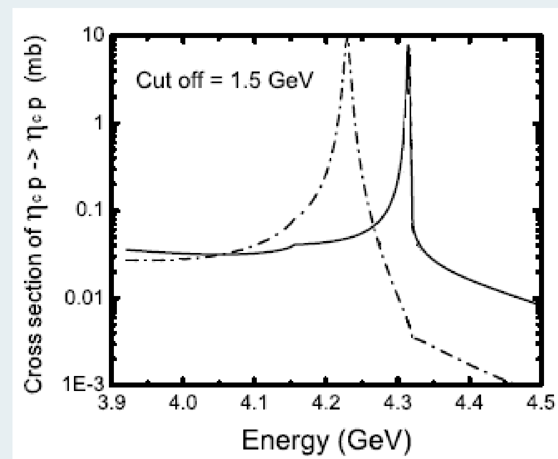
$$G^{Valencia} = \int \frac{dp^4}{(2\pi)^4} \frac{2m_B}{(p^2 - m_B^2)((P-p)^2 - m_M^2)}$$

$$G(q_3) = \frac{1}{\sqrt{S} - E_M - E_B},$$

$$G_V^{\mu\nu} = \frac{p_V^\mu p_V^\nu / m_V^2 - g^{\mu\nu}}{p_V^2 - m_V^2}$$

$$\sim \frac{p_V^\mu p_V^\nu / m_V^2 - g^{\mu\nu}}{-m_V^2} \sim \frac{-g^{\mu\nu}}{-m_V^2}$$

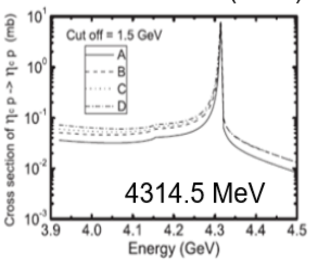




Comparison to numerical predictions

- Many theoretical predictions for $\Sigma_c^+ \bar{D}^{(*)0}$ published before 2015, **some in quantitative agreement with the LHCb data**
  - Wu,Molina,Oset,Zou, PRL105, 232001 (2010),
  - **Wang,Huang,Zhang,Zou, PR C84, 015203 (2011),**
  - **Yang,Sun,He,Liu,Zhu, Chin. Phys. C36, 6 (2012),**
  - **Wu,Lee,Zou, PR C85 044002 (2012),**
  - Karliner,Rosner, PRL 115, 122001 (2015)

PR C85 044002 (2012)



ΔE – binding energy

Example:

Nucleon resonances with hidden charm in coupled-channels models

Jia-Jun Wu, T.-S. H. Lee, and B. S. Zou
Phys. Rev. C **85**, 044002 – Published 17 April 2012

arXiv:1202.1036

TABLE III: The pole position ($M - i\Gamma/2$) and "binding energy" ($\Delta E = E_{thr} - M$) for different cut-off parameter Λ and spin-parity J^P. The threshold E_{thr} is 4320.79 MeV of $\bar{D}\Sigma_c$ in PB system and 4462.18 MeV of $\bar{D}^*\Sigma_c$ in VB system. The unit for the listed numbers is MeV.

		PB System		VB System	
$J^p = \frac{1}{2}^-$	Λ	$M - i\Gamma/2$	ΔE	$M - i\Gamma/2$	ΔE
	650	-	-	-	[illegible]
	800	-	-	$4462.178 - 0.002i$	0.002
	1200	$4318.964 - 0.362i$	1.826	$4459.513 - 0.417i$	2.667
	1500	$4314.531 - 1.448i$	6.259	$4454.088 - 1.662i$	8.092
	2000	$4301.115 - 5.835i$	19.68	$4438.277 - 7.115i$	23.90
$J^p = \frac{3}{2}^-$					
	650	-	-	-	-
	800	-	-	$4462.178 - 0.002i$	0.002
	1200	-	-	$4459.507 - 0.420i$	2.673
	1500	-	-	$4454.057 - 1.681i$	8.123
	2000	-	-	$4438.039 - 7.268i$	23.14

$\Delta E(4312) = 5.8^{+1.0}_{-6.8}$ MeV

$\Delta E(4457) = 2.5^{+4.3}_{-4.1}$ MeV

$\Delta E(4440) = 19.5^{+4.9}_{-4.3}$ MeV

Λ - cut off on exchanged meson mass.

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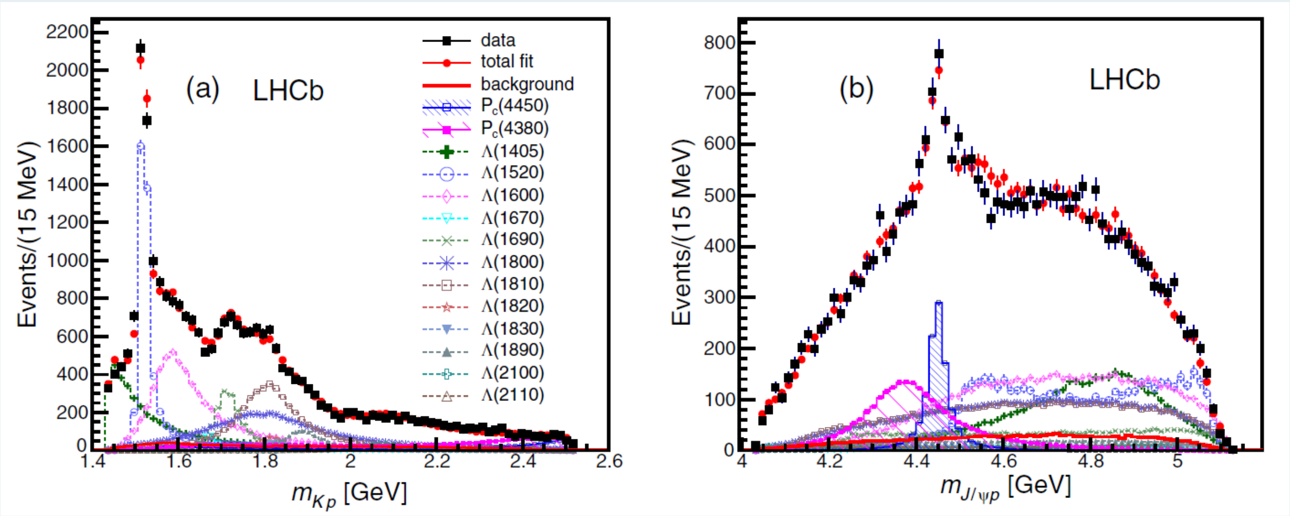

$$P_c(4380)\ :\ (m,\,\Gamma) = (4380 \pm 8 \pm 29,\ 205 \pm 18 \pm 86)\mathrm{MeV}$$
$$P_c(4450)\ :\ (m,\,\Gamma) = (4449.8 \pm 1.7 \pm 2.5,\ 39 \pm 5 \pm 19)\mathrm{MeV}$$

[1] Chen, Chen, Liu, and Zhu, PR **639**, 1 (2016), 1601.02092.
[2] Zhao, AAPPS Bull. **26**, 8 (2016).
[3] Dong, Faessler, and Lyubovitskij, PPNP **94**, 282 (2017).
[4] Guo, Hanhart, Meissner, Wang, Zhao, and Zou, RMP **90**, 015004 (2018), 1705.00141.
[5] Ali, Lange, and Stone, PPNP **97**, 123 (2017), 1706.00610.

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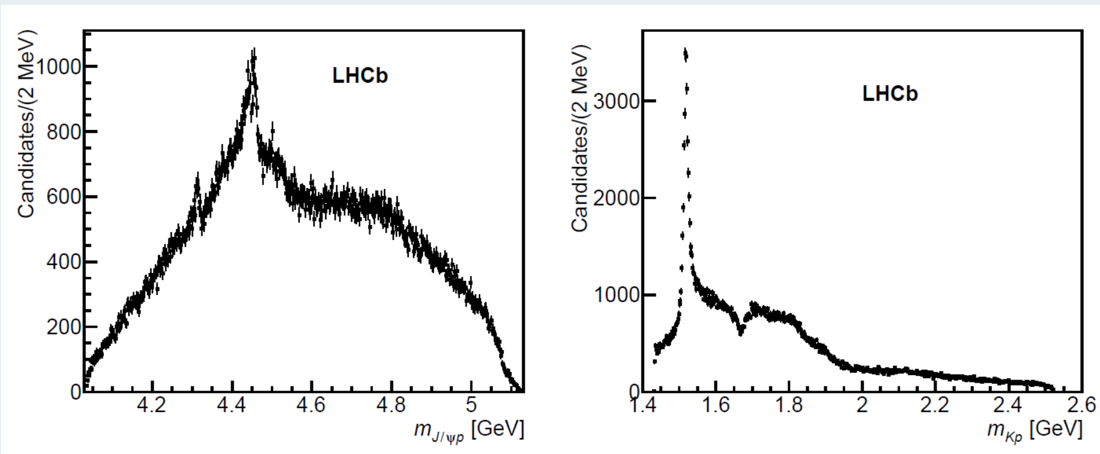
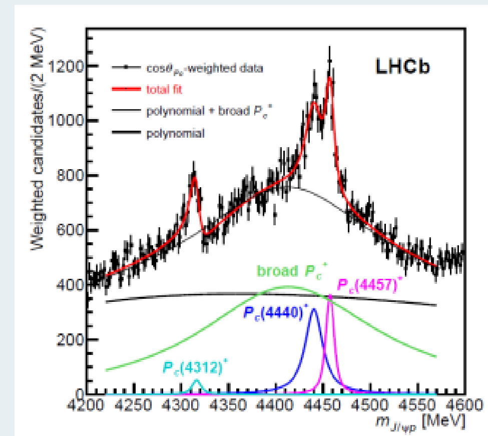
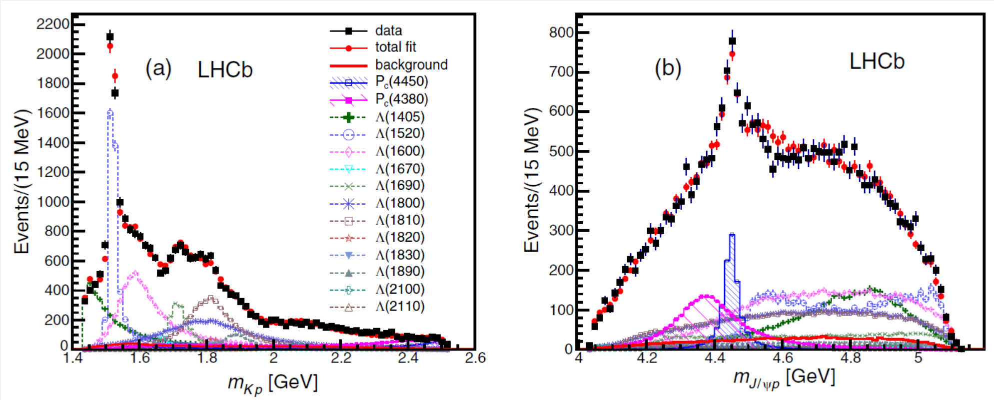
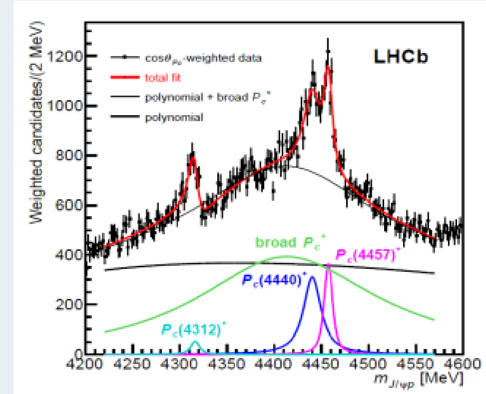


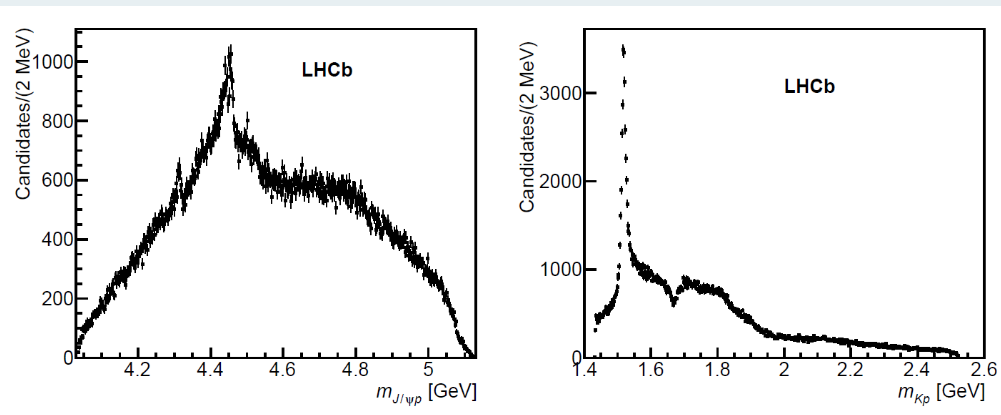


State	M [MeV]	Γ [MeV]	(95% CL)	$\mathcal{R}$ [%]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$	(< 27)	$0.30 \pm 0.07^{+0.34}_{-0.09}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$	(< 49)	$1.11 \pm 0.33^{+0.22}_{-0.10}$
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$	(< 20)	$0.53 \pm 0.16^{+0.15}_{-0.13}$

Comparison







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Where is Pc(4380) ?
What are spin and parity of them ?

[1] R. Chen, Z.-F. Sun, X. Liu, and S.-L. Zhu (2019), 1903.11013.
[2] H.-X. Chen, W. Chen, and S.-L. Zhu (2019), 1903.11001.
[3] M.-Z. Liu, Y.-W. Pan, F.-Z. Peng, M. Sanchez Sanchez, L.-S. Geng, A. Hosaka, and M. Pavon Valderrama (2019), 1903.11560.
[4] F.-K. Guo, H.-J. Jing, U.-G. Meissner, and S. Sakai (2019), 1903.11503.
[5] J. He (2019), 1903.11872.
[6] Y.-R. Liu, H.-X. Chen, W. Chen, X. Liu, and S.-L. Zhu (2019), 1903.11976.
[7] H. Huang, J. He, and J. Ping (2019), 1904.00221.
[8] A. Ali and A. Ya. Parkhomenko (2019), 1904.00446.
[9] C.-J. Xiao, Y. Huang, Y.-B. Dong, L.-S. Geng, and D.-Y. Chen (2019), 1904.00872.
[10] Y. Shimizu, Y. Yamaguchi, and M. Harada (2019), 1904.00587.
[11] Z.-H. Guo and J. A. Oller (2019), 1904.00851.

Photo-Production

- Why is it important to confirm P_c in photo-production reaction ?
- Three peaks of $J/\psi p$ invariant mass spectrum

1. Resonances? or Kinematics effects (Threshold & TS)?

2. If Resonances confirmed, what is the internal structure ?
Meson-Baryon molecule or 5 quark configuration state ?

3. What the spin and parity (J^p) ?

=> We need more experimental input !

Photo-Production

- Why is it important to confirm P_c in photo-production reaction ?
- γ p → P_c → J/ψ p VS Λ_b → J/ψK p

1. Resonances? or Kinematics effects (Threshold & TS)?

   No Threshold & TS effect because two bodies final state.

2. If Resonances confirmed, what is the internal structure ?

Meson-Baryon molecule or 5 quark configuration state ?

   Decay width of channels

3. What the spin and parity (J^p) ?

   Angular differential cross section, Two body vs Three body

=> We need more experimental input !

Definitely, it will provide fruitful information of P_c from γ p reaction.

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

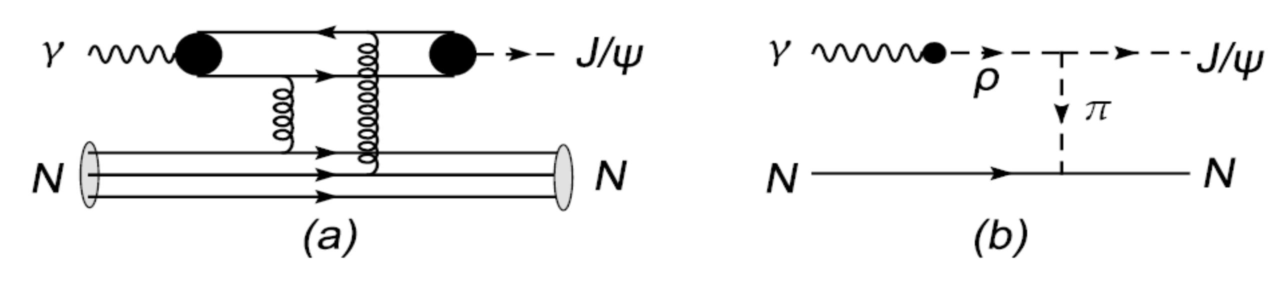
- In our 2010 paper, we have mentioned to search Pc in e p → e J /ψ p after update 12 GeV in Jlab experiment, but we did not calculate it in detail at that time.

- [1] Y. Huang, J. He, H.-F. Zhang, and X.-R. Chen, JPG **41**, 115004 (2014), 1305.4434.
- [2] Q. Wang, X.-H. Liu, and Q. Zhao, PR**D92**, 034022 (2015), 1508.00339.
- [3] V. Kubarovsky and M. B. Voloshin, PR**D92**, 031502 (2015), 1508.00888.
- [4] M. Karliner and J. L. Rosner, PL**B752**, 329 (2016), 1508.01496.
- [5] A. N. Hiller Blin, C. Fernandez-Ramirez, A. Jackura, V. Mathieu, V. I. Mokeev, A. Pilloni, and A. P. Szczepaniak, PR**D94**, 034002 (2016), 1606.08912.
- [6] E. Ya. Paryev and Yu. T. Kiselev, NP**A978**, 201 (2018), 1810.01715.
- [7] X.-Y. Wang, X.-R. Chen, J. He, arXiv:1904.11706

- Last year, Prof. Harry Lee was suggested by the experimentalist in Argonne National Lab who also collaborates with Jlab. We restart to research this reaction, and provide estimations of production. The paper is soon …

γ p → J/ψ p background mechanism

- **Feynman Diagram**



- **Formulas**

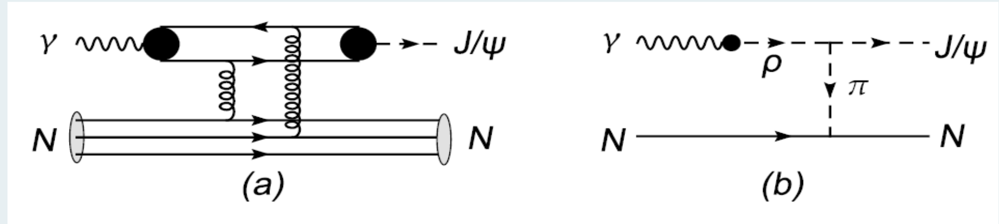
$$\frac{d\sigma}{d\Omega} = \frac{1}{(2\pi)^2}\frac{m_N m_B}{4W^2}\frac{1}{4}\sum_{\lambda_\gamma,\lambda_M}\sum_{m_s,m_s'}\left|\bar{u}_p(p',m_s')\epsilon^*_\mu(q',\lambda'_{J/\Psi})\mathcal{M}^{\mu\nu}(q,p,q',p')u_p(p,m_s)\epsilon_\nu(q,\lambda_\gamma)\right|^2$$

$$\mathcal{M}^{\mu\nu}_P(q,p,q',p') = \left(\frac{s}{s_0}\right)^{\alpha_P(t)-1}\exp\left\{-\frac{i\pi}{2}\left[\alpha_P(t)-1\right]\right\} i12e\frac{M_V^2\beta_q\beta_{q'}}{f_V}\frac{1}{M_V^2-t}\left(\frac{2\mu_0^2}{2\mu_0^2+M_V^2-t}\right)\frac{4M_N^2-2.8t}{(4M_N^2-t)(1-t/0.71)^2}\{\gamma.qg^{\mu\nu}-q^\mu\gamma^\nu\}$$

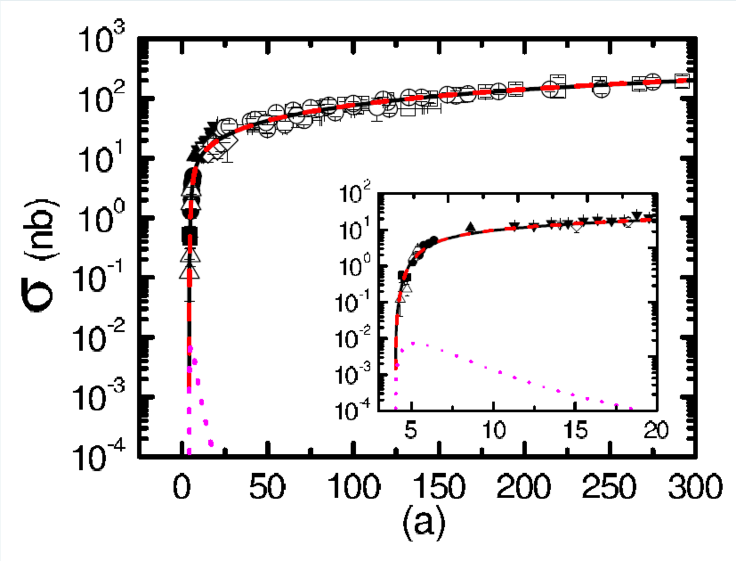
$$\mathcal{M}^{\mu\nu}_\pi(q,q',p,p') = \frac{e}{f_\rho}\frac{g_{J/\Psi,\rho^0\pi^0}}{m_{J/\Psi}}\frac{f_\pi}{m_\pi}\frac{-m_\rho^2}{q^2-m_\rho^2+i\Gamma_\rho m_\rho}\frac{\Lambda_\rho^4}{\Lambda_\rho^4+(q^2-m_\rho^2)^2}\frac{1}{t-m_\pi^2}\left(\frac{\Lambda_\pi^2-m_\pi^2}{\Lambda_\pi^2-t}\right)^4\epsilon^{\mu\nu\alpha\beta}q'_\alpha q_\beta\left(\gamma.(p'-p)\right)\gamma^5$$

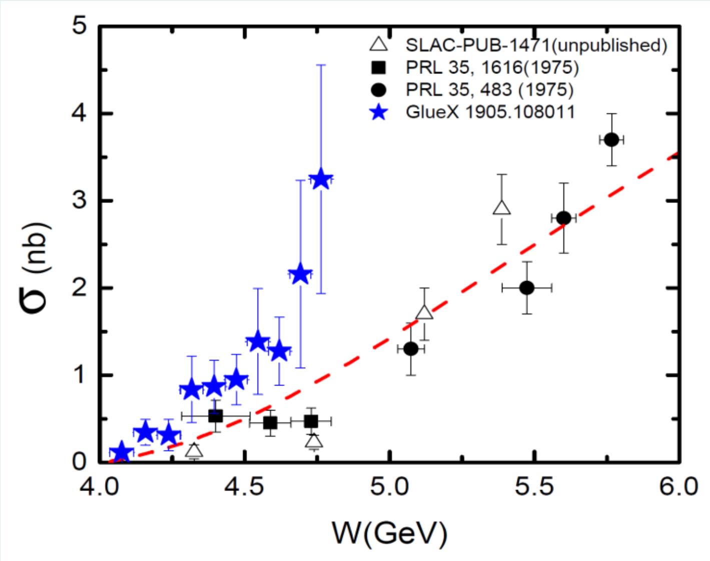
γ p → J/ψ p background mechanism

- **Feynman Diagram**



- **Result**

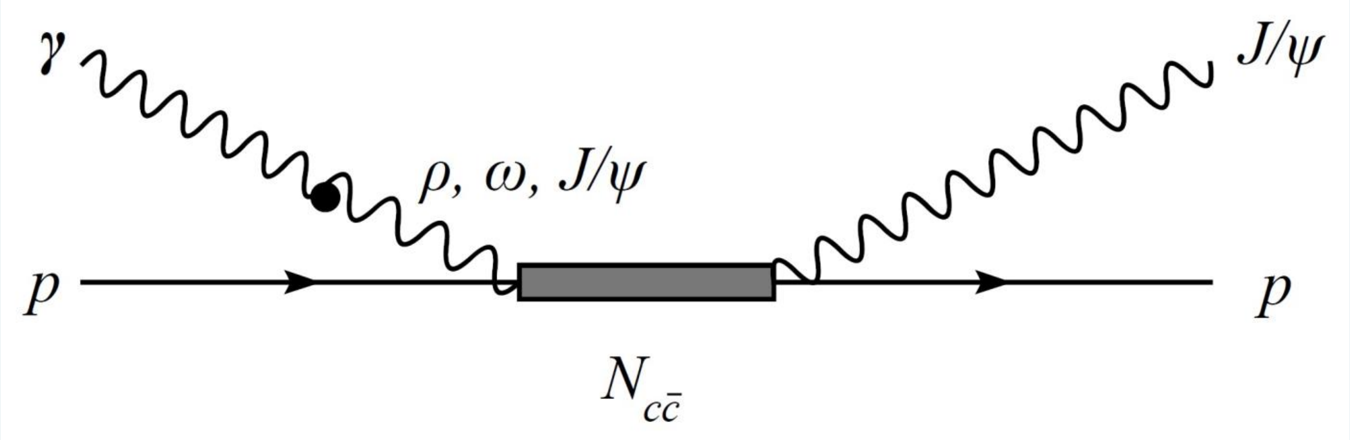




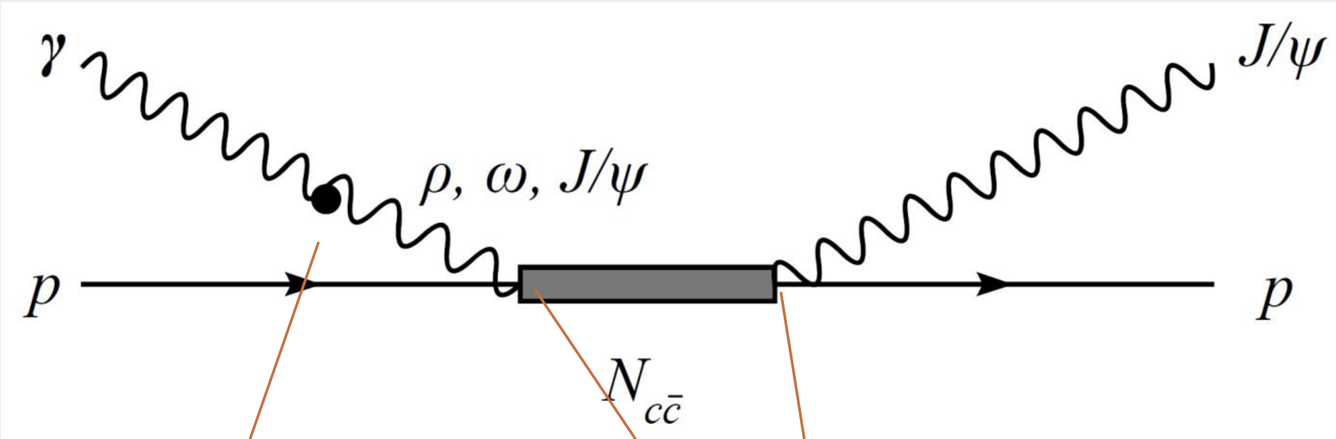
$$\mathcal{M}_P^{\mu\nu}(q,p,q',p') = \left(\frac{s}{s_0}\right)^{\alpha_P(t)-1} \exp\left\{-\frac{i\pi}{2}\left[\alpha_P(t)-1\right]\right\} i12e\frac{M_V^2\beta_q\beta_{q'}}{f_V}\frac{1}{M_V^2-t}\left(\frac{2\mu_0^2}{2\mu_0^2+M_V^2-t}\right)\frac{4M_N^2-2.8t}{(4M_N^2-t)(1-t/0.71)^2}\{\gamma.qg^{\mu\nu}-q^\mu\gamma^\nu\}$$

$\alpha_P(t) = \alpha_0 + \alpha_p' t$ $\alpha_0 = 1.08$ $\alpha_0 = 1.25$

$\gamma\, p \rightarrow P_c \rightarrow J/\psi\, p$



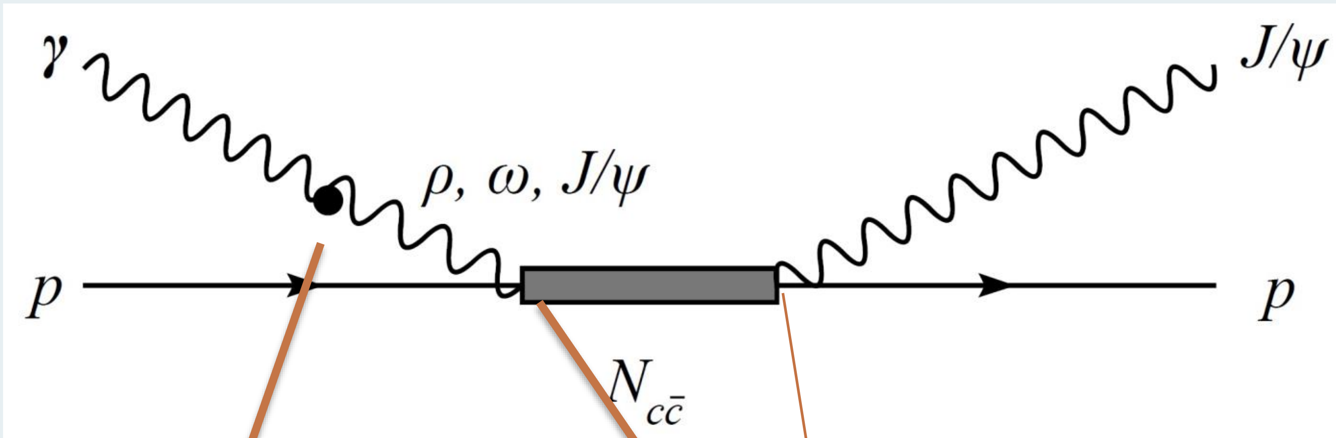
$\gamma\, p \rightarrow P_c \rightarrow J/\psi\, p$



VMD vertex

PcVP vertex

$\gamma\, p \rightarrow P_c \rightarrow J/\psi\, p$



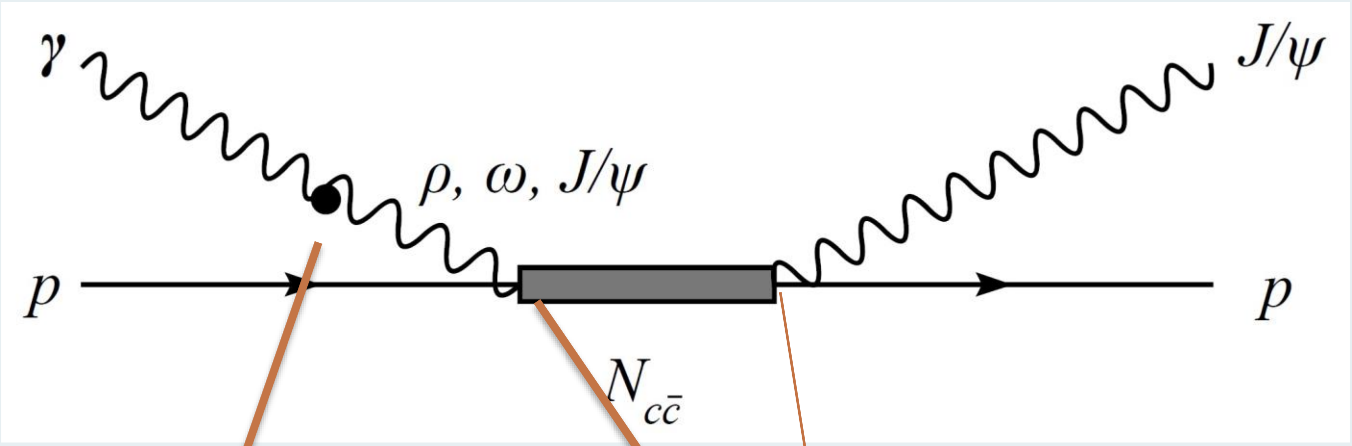
Off shell

On shell

VMD vertex

PcVP vertex

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



Off shell

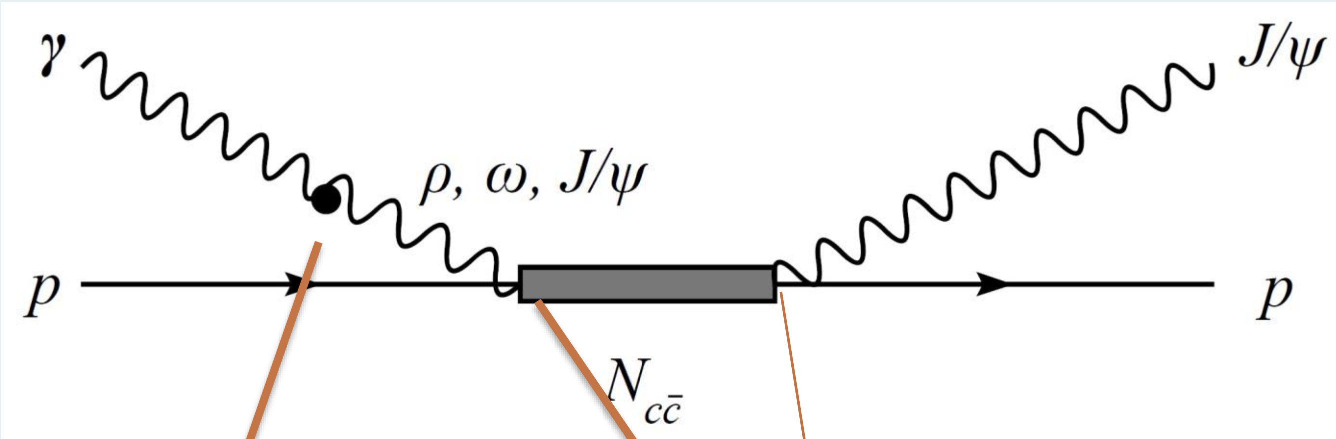
On shell

VMD vertex

PcVP vertex

PcγP vertex

$\gamma\, p \rightarrow P_c \rightarrow J/\psi\, p$



Off shell

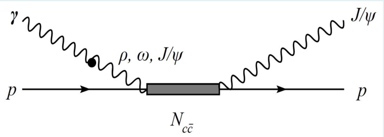
On shell

VMD vertex

PcVP vertex

PcγP vertex

$\gamma\, p \rightarrow P_c \rightarrow J/\psi\, p$



- **Various Models for** $P_c \rightarrow$ VB

No.	J^P	m	Γ	$\Gamma_{J/\psi N}$	$\Gamma_{\rho N}$	$\Gamma_{\omega N}$	$\Gamma_{\bar{D}\Lambda_c}$	$\Gamma_{\bar{D}^*\Lambda_c}$	Main Channel	Ref.
1	$\frac{1}{2}^-$	4262	35.6	10.3	–	–	0.01	–	$\bar{D}\Sigma_c$	[6]
2		4308	–	1.2	–	–	0.02	1.4	$\bar{D}\Sigma_c$	[7]
3		4412	47.3	19.2	3.2	10.4	–	–	$\bar{D}^*\Sigma_c$	[8, 9]
4		4410	58.9	52.5	–	–	0.8	0.7	$\bar{D}^*\Sigma_c$	[6]
5		4460	–	3.9	–	–	1.0	0.3	$\bar{D}^*\Sigma_c$	[7]
6		4481	57.8	14.3	–	–	1.02	0.3	$\bar{D}^*\Sigma_c^*$	[6]
7	$\frac{3}{2}^-$	4334	38.8	38.0	–	–	–	0.8	$\bar{D}\Sigma_c^*$	[6]
8		4375	–	1.5	–	–	–	0.9	$\bar{D}\Sigma_c^*$	[7]
9		4380	144.3	3.8	1.4	5.3	1.2	131.3	$\bar{D}\Sigma_c^*$	[5]
10		4380	69.9	16.6	0.15	0.6	17.0	35.3	$\bar{D}^*\Sigma_c$	[5]
11		4412	47.3	19.2	3.2	10.4	–	–	$\bar{D}^*\Sigma_c$	[8, 9]
12		4417	8.2	4.6	–	–	–	3.1	$\bar{D}^*\Sigma_c$	[6]
13		4450	139.8	16.3	0.14	0.5	41.4	72.3	$\bar{D}^*\Sigma_c$	[5]
14		4450	21.7	0.03	–	–	1.4	6.8	$\bar{D}^*\Sigma_c$	[10]
15		4450	16.2	11	–	–	0.6	4.2	$\Psi' N$	[10]
16		4453	–	1.5	–	–	–	0.3	$\bar{D}\Sigma_c^*$	[7]
17		4481	34.7	32.8	–	–	–	1.2	$\bar{D}^*\Sigma_c^*$	[6]
18	$\frac{5}{2}^+$	4450	46.4	4.0	0.3	0.3	18.8	20.5	$\bar{D}^*\Sigma_c$	[5]
19	$\frac{3}{2}^-$ / $\frac{5}{2}^+$	$4380^{\pm 8}_{\pm 29}$	$205^{\pm 18}_{\pm 86}$	–	–	–	–	–	Exp	[1, 2]
20		$4450^{\pm 2}_{\pm 3}$	$39^{\pm 5}_{\pm 19}$	–	–	–	–	–	Exp	[1, 2]

[5] Lin, Shen, Guo, Zou, PRD95 114017
[6] Xiao, Nieves, Oset, PRD88 056012
[7] Huang, Ping, 1811.04260
[8, 9] Wu, Molina, Oset, Zou, PRL 105 232001, PRC 84 015202
[10] Eides, Petrov, 1811.01691

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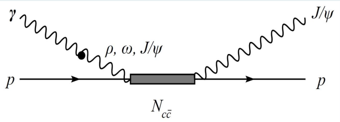
$\gamma\, p \rightarrow P_c \rightarrow J/\psi\, p$



- $P_c \rightarrow$ VB interaction: Lorentz structure

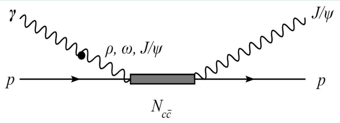
$$\mathcal{M}_{N^*(\frac{1}{2}^-)NV} = \bar{u}_N \gamma_5 \tilde{\gamma}_\mu u_{N^*} \epsilon^*_{V\ \nu} \left(g_{1V} g^{\mu\nu} + f_{1V} \left(\frac{3}{2} \frac{\tilde{r}^\mu \tilde{r}^\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}^{\mu\nu}_{N^*} \right) \right)$$

$$\begin{aligned}\mathcal{M}_{N^*(\frac{3}{2}^-)NV} = {} & \bar{u}_N u_{N^*\ \mu} \epsilon^*_{V\ \nu} \left(g_{3V} g^{\mu\nu} + f_{3V} \left(\frac{3}{2} \frac{\tilde{r}^\mu \tilde{r}^\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}^{\mu\nu}_{N^*} \right) \right) \\ & + h_{3V} \epsilon_{\mu\nu\lambda\delta} \bar{u}_N \gamma_5 (\tilde{\gamma}^\mu g^\beta_\alpha + \tilde{\gamma}_\alpha g^{\mu\beta}) u_{N^*\ \beta} \epsilon^*_{V\ \nu} \left(\frac{\tilde{r}^\alpha \tilde{r}^\lambda}{\tilde{r}^2} - \frac{1}{3} \tilde{g}^{\alpha\lambda}_{N^*} \right) \hat{P}^\delta\end{aligned}$$

$$\begin{aligned}\mathcal{M}_{N^*(\frac{5}{2}^+)NV} = {} & \bar{u}_N u_{N^*\ \mu\nu} \epsilon^*_{V\ \alpha} \left(\frac{g_{5V}}{m_N} g^{\alpha\mu} \tilde{r}^\nu + \frac{f_{5V}}{m_N} \left(\frac{3}{5} \frac{\tilde{r}^\mu \tilde{r}^\nu \tilde{r}^\alpha}{\tilde{r}^2} - \frac{1}{5} (\tilde{g}^{\mu\nu}_{N^*} \tilde{r}^\alpha + \tilde{g}^{\nu\alpha}_{N^*} \tilde{r}^\mu + \tilde{g}^{\alpha\mu}_{N^*} \tilde{r}^\nu) \right) \right) \\ & + \frac{h_{5V}}{m_N} \epsilon_{\mu\nu\lambda\delta} \bar{u}_N \gamma_5 \left(\tilde{\gamma}^\mu g_{\xi\alpha} g_{\sigma\beta} + \tilde{\gamma}_\xi g_{\sigma\beta} g_{\mu\beta} + \tilde{\gamma}_\sigma g_{\mu\beta} g_{\xi\beta} \right) u^{\alpha\beta}_{N^*} \epsilon^{*\ \mu}_V \\ & \times \left(\frac{\tilde{r}^\xi \tilde{r}^\lambda \tilde{r}^\sigma}{\tilde{r}^2} - \frac{1}{3} \left(\tilde{g}^{\xi\sigma}_{N^*} \tilde{r}^\lambda + \tilde{g}^{\sigma\lambda}_{N^*} \tilde{r}^\xi + \tilde{g}^{\lambda\xi}_{N^*} \tilde{r}^\sigma \right) \right) \hat{P}^\delta\end{aligned}$$

$\gamma\, p \rightarrow P_c \rightarrow J/\psi\, p$

- $P_c \rightarrow VB$ interaction: Lorentz structure



$$\mathcal{M}_{N^*(\frac{1}{2}^-)NV} = \bar{u}_N \gamma_5 \tilde{\gamma}_\mu u_{N^*} \epsilon^*_{V\ \nu} \Big(g_{1V} g^{\mu\nu} + \cdots$$

$$\mathcal{M}_{N^*(\frac{3}{2}^-)NV} = \bar{u}_N u_{N^*\ \mu} \epsilon^*_{V\ \nu} \Big(g_{3V} g^{\mu\nu} + f_3 \cdots$$

$$+ h_{3V} \epsilon_{\mu\nu\lambda\delta} \bar{u}_N \gamma_5 (\tilde{\gamma}^\mu g \cdots \cdots \frac{1}{3} \tilde{g}^{\alpha\lambda}_{N^*} \Big) \hat{P}^\delta$$

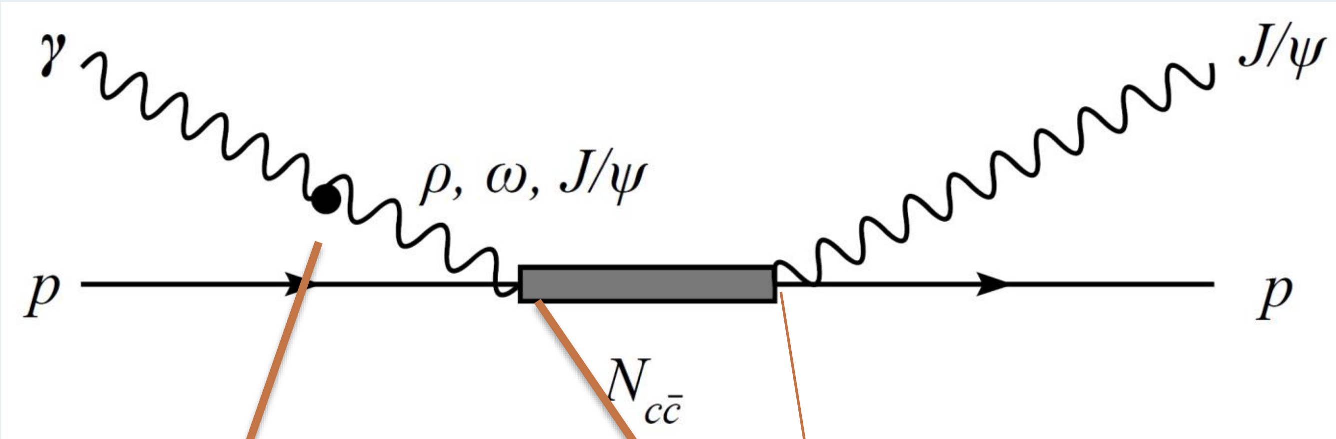
$$\mathcal{M}_{N^*(\frac{5}{2}^+)NV} = \bar{u}_N u_{N^*\ \mu\nu} \epsilon^*_{V\ \alpha} \Big(\frac{g_{5V}}{m_N} g^{\alpha\mu} \tilde{r}^\nu + \cdots \tilde{r}^\mu + \tilde{g}^{\alpha\mu}_{N^*} \tilde{r}^\nu) \Big) \Big)$$

$$+ \frac{h_{5V}}{m_N} \epsilon_{\mu\nu\lambda\delta} \bar{u}_N \gamma_5 \left(\tilde{\gamma}^\mu g_{\xi\alpha} g_\sigma \cdots \right. \cdots \epsilon^{*\ \mu}_V$$

$$\times \left(\frac{\tilde{r}^\xi \tilde{r}^\lambda \tilde{r}^\sigma}{\tilde{r}^2} - \frac{1}{3} \left(\tilde{g}^{\xi\sigma}_{N^*} \tilde{r}^\lambda + \cdots \right. \right.$$

No.	J^P	m	Γ_{tot}	g_V $J/\Psi p$
1	$\frac{1}{2}^-$	4262	35.6	0.39
2		4308	—	0.13
3		4412	47.3	0.46
4		4410	58.9	0.75
5		4460	—	0.20
6		4481	57.8	0.37
7	$\frac{3}{2}^-$	4334	38.8	1.19
8		4375	—	0.23
9		4380	144.3	0.36
10		4380	69.9	0.75
11		4412	47.3	0.79
12		4417	8.2	0.39
13		4450	139.8	0.71
14		4450	21.7	0.030
15		4450	16.2	0.58
16		4453	—	0.21
17		4481	34.7	0.98
18	$\frac{5}{2}^+$	4450	46.4	0.35

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



Off shell

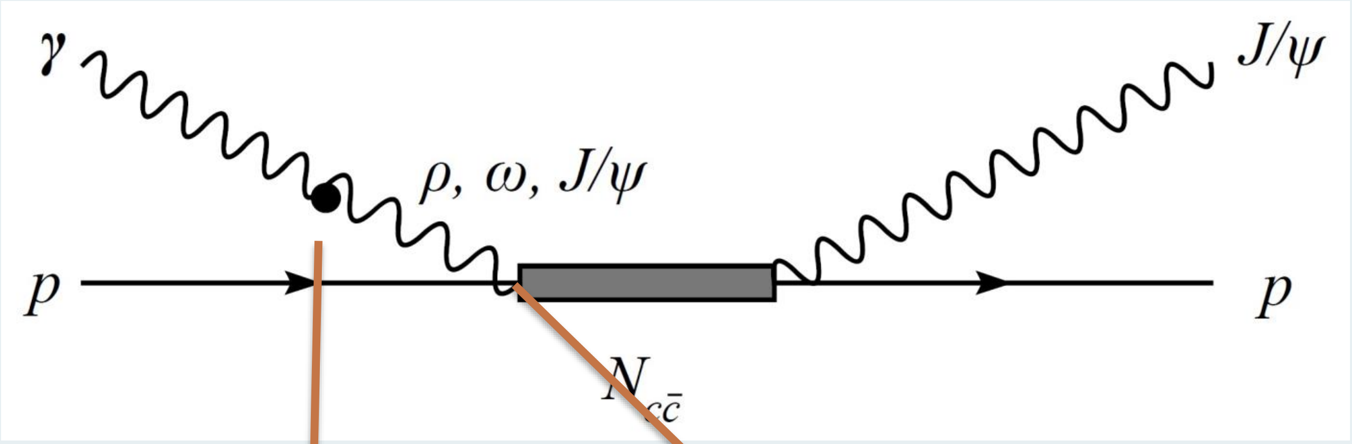
On shell

VMD vertex

PcVP vertex

PcγP vertex

$\gamma\, p \to P_c \to J/\psi\, p$: $\gamma\, p \to P_c$ vertex



Off shell

VMD vertex

$$\mathcal{L}_{VMD} = \frac{iem_V^2}{f_V} A_\mu V^\mu$$

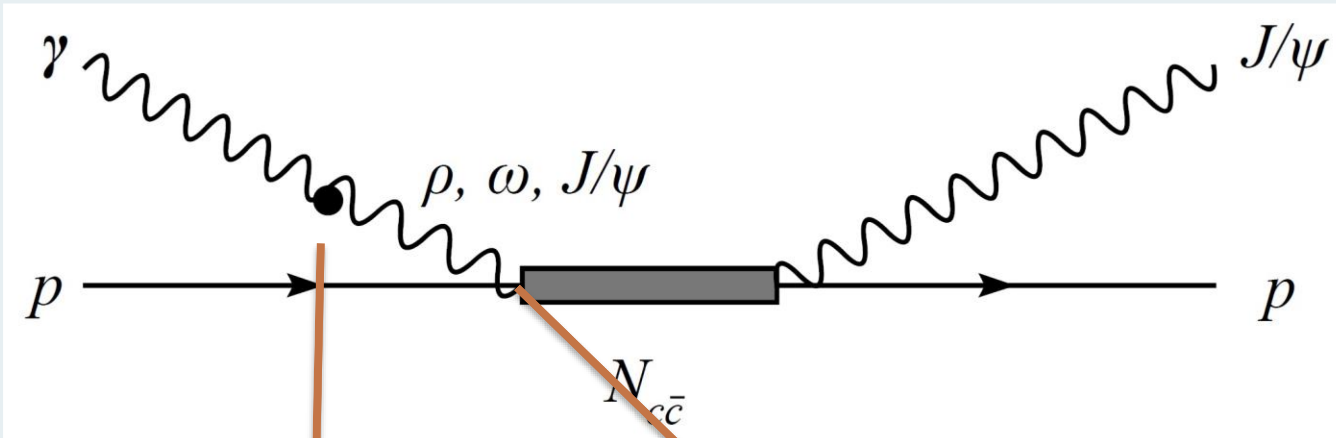
PcVP vertex

$$\mathcal{L}_{N^*(\frac{1}{2}^-)NV} = \overline{N}^* \gamma_5 \tilde{\gamma}_\mu N V_\nu \left(g_{1V} g^{\mu\nu} + f_{1V} \left(\frac{3}{2} \frac{\tilde{r}^\mu \tilde{r}^\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}^{\mu\nu}_{N^*} \right) \right) + h.c.$$

1. Gauge invariance

PcγP vertex

$\gamma\, p \rightarrow P_c \rightarrow J/\psi\, p$: $\gamma\, p \rightarrow P_c$ vertex



Off shell

2. The effect of off-shell

$$F_V(q^2) = \frac{\Lambda^4}{\Lambda^4 + (q^2 - m_V^2)^2}$$

VMD vertex

$$\mathcal{L}_{VMD} = \frac{iem_V^2}{f_V} A_\mu V^\mu$$

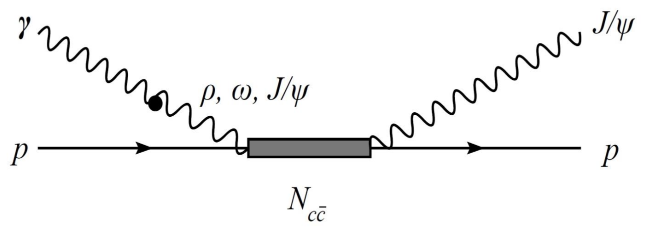
PcVP vertex

$$\mathcal{L}_{N^*(\frac{1}{2}^-)NV} = \overline{N}^* \gamma_5 \tilde{\gamma}_\mu N V_\nu \left(g_{1V} g^{\mu\nu} + f_{1V} \left(\frac{3}{2} \frac{\tilde{r}^\mu \tilde{r}^\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}^{\mu\nu}_{N^*} \right) \right) + h.c.$$

1. Gauge invariance

$\boxed{\text{Pc}\gamma\text{P vertex}}$

$\gamma p \to P_c \to J/\psi\, p$: $\gamma p \to P_c$ vertex



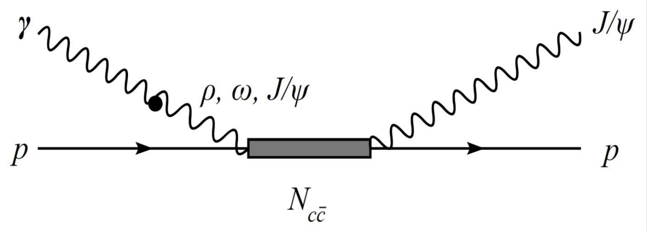
- $\gamma p \to P_c$: **Gauge invariance**

$$\mathcal{L}_{VMD} = \frac{iem_V^2}{f_V} A_\mu V^\mu$$

$$\mathcal{L}_{N^*(\frac{1}{2}^-)NV} = \overline{N}^* \gamma_5 \tilde{\gamma}_\mu N V_\nu \left(g_{1V} g^{\mu\nu} - f_{1V} \left(\frac{3}{2} \frac{\tilde{r}^\mu \tilde{r}^\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}^{\mu\nu}_{N^*} \right) \right) + h.c.$$

$$\mathcal{T}_{N*(\frac{1}{2}^-)\to NV \to N\gamma} = \overline{u}_N \mathcal{M}^\nu u_{N^*} \epsilon^*_\nu,$$

$\gamma\, p \to P_c \to J/\psi\, p$: $\gamma\, p \to P_c$ vertex



- $\gamma\, p \to P_c$: **Gauge invariance**

$$\mathcal{L}_{VMD} = \frac{iem_V^2}{f_V} A_\mu V^\mu$$

$$\mathcal{L}_{N^*(\frac{1}{2}^-)NV} = \overline{N}^* \gamma_5 \tilde{\gamma}_\mu N V_\nu \left(g_{1V} g^{\mu\nu} - f_{1V} \left(\frac{3}{2} \frac{\tilde{r}^\mu \tilde{r}^\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}_{N^*}^{\mu\nu} \right) \right) + h.c.$$

$$\mathcal{T}_{N*(\frac{1}{2}^-) \to NV \to N\gamma} = \overline{u}_N \mathcal{M}^\nu u_{N^*} \epsilon_\nu^*,$$

$$\mathcal{M}^\nu = \frac{ie}{f_V} \frac{-m_V^2}{q^2 - m_V^2 + i\Gamma_V m_V} \gamma_5 \tilde{\gamma}_\mu \left(g_{1V} g_{\mu\nu'} - f_{1V} \left(\frac{3}{2} \frac{\tilde{r}_\mu \tilde{r}_\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}_{N^*\ \mu\nu'} \right) \right) \tilde{g}_V^{\nu'\nu}(q) \times F_V(q^2)$$

$\mathcal{M}^\nu q_\nu \sim (g_{1V} - f_{1V}) \neq 0$ Destroy **Gauge invariance**

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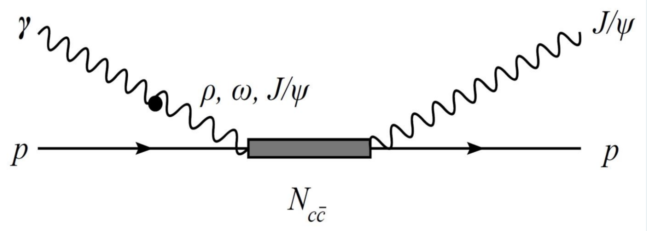
γ p → P_c → J/ψ p： γ p → P_c vertex



- γ p → P_c： **Gauge invariance**

$$\mathcal{L}_{VMD} = \frac{iem_V^2}{f_V} A_\mu V^\mu$$

$$\mathcal{L}_{N^*(\frac{1}{2}^-)NV} = \overline{N}^* \gamma_5 \tilde{\gamma}_\mu N V_\nu \left(g_{1V} g^{\mu\nu} - f_{1V} \left(\frac{3}{2} \frac{\tilde{r}^\mu \tilde{r}^\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}^{\mu\nu}_{N^*} \right) \right) + h.c.$$

$$\mathcal{T}_{N*(\frac{1}{2}^-) \to NV \to N\gamma} = \overline{u}_N \mathcal{M}^\nu u_{N^*} \epsilon^*_\nu,$$

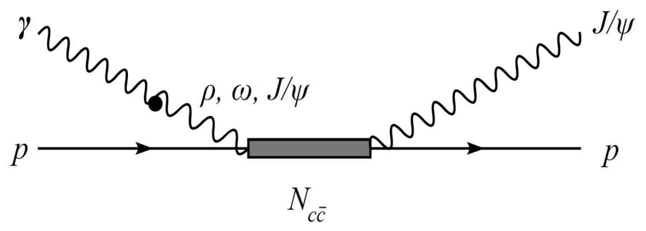
$$\mathcal{M}^\nu = \frac{ie}{f_V} \frac{-m_V^2}{q^2 - m_V^2 + i\Gamma_V m_V} \gamma_5 \tilde{\gamma}_\mu \left(g_{1V} g_{\mu\nu'} - f_{1V} \left(\frac{3}{2} \frac{\tilde{r}_\mu \tilde{r}_\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}_{N^*\ \mu\nu'} \right) \right) \tilde{g}_V^{\nu'\nu}(q) \times F_V(q^2)$$

$\mathcal{M}^\nu q_\nu \sim (g_{1V} - f_{1V}) \neq 0$ Destroy **Gauge invariance**

$$\mathcal{L}_{N^*(\frac{1}{2}^-)N\gamma} = \overline{N}^* \gamma_5 \tilde{\gamma}_\mu N A_\nu \left(g_{1\gamma} g^{\mu\nu} - g_{1\gamma} \left(\frac{3}{2} \frac{\tilde{r}^\mu \tilde{r}^\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}^{\mu\nu}_{N^*} \right) \right) + h.c.$$

Dulat, Wu, Zou, PRD83, 094032 J/ψ -> $\bar{B}$B γ

γ p → P_c → J/ψ p : γ p → P_c vertex



- γ p → P_c : **Gauge invariance**

$$\mathcal{L}_{VMD} = \frac{iem_V^2}{f_V} A_\mu V^\mu$$

$$\mathcal{L}_{N^*(\frac{1}{2}^-)NV} = \overline{N}^* \gamma_5 \tilde{\gamma}_\mu N V_\nu \left(g_{1V} g^{\mu\nu} - f_{1V} \left(\frac{3}{2} \frac{\tilde{r}^\mu \tilde{r}^\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}^{\mu\nu}_{N^*} \right) \right) + h.c.$$

$$\mathcal{T}_{N*(\frac{1}{2}^-) \to NV \to N\gamma} = \overline{u}_N \mathcal{M}^\nu u_{N^*} \epsilon^*_\nu,$$

$$\mathcal{M}^\nu = \frac{ie}{f_V} \frac{-m_V^2}{q^2 - m_V^2 + i\Gamma_V m_V} \gamma_5 \tilde{\gamma}_\mu \left(g_{1V} g_{\mu\nu'} - f_{1V} \left(\frac{3}{2} \frac{\tilde{r}_\mu \tilde{r}_\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}_{N^*\ \mu\nu'} \right) \right) \tilde{g}_V^{\nu'\nu}(q) \times F_V(q^2)$$

$\mathcal{M}^\nu q_\nu \sim (g_{1V} - f_{1V}) \neq 0$ Destroy **Gauge invariance**

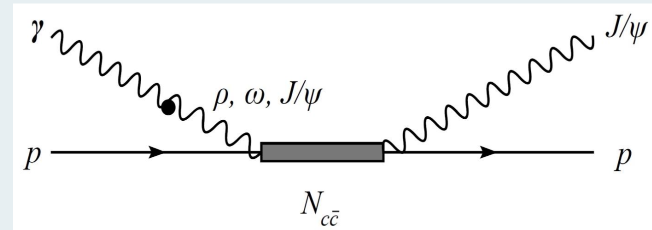
$$\mathcal{L}_{N^*(\frac{1}{2}^-)N\gamma} = \overline{N}^* \gamma_5 \tilde{\gamma}_\mu N A_\nu \left(g_{1\gamma} g^{\mu\nu} - g_{1\gamma} \left(\frac{3}{2} \frac{\tilde{r}^\mu \tilde{r}^\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}^{\mu\nu}_{N^*} \right) \right) + h.c.$$

Dulat, Wu, Zou, PRD83, 094032   J/ψ -> $\overline{B}$B γ

One possible prescription:

$$\mathcal{L}_{N^*(\frac{1}{2}^-)NV} = \overline{N}^* \gamma_5 \tilde{\gamma}_\mu N V_\nu \left(\tilde{g}_{1V} g^{\mu\nu} - \tilde{g}_{1V} \left(\frac{3}{2} \frac{\tilde{r}^\mu \tilde{r}^\nu}{\tilde{r}^2} - \frac{1}{2} \tilde{g}^{\mu\nu}_{N^*} \right) \right) + h.c.$$

$\gamma p \to P_c \to J/\psi\, p$: $\gamma p \to P_c$ vertex



- $\gamma p \to P_c$: **Gauge invariance**

$\mathcal{L}_{VMD} =$

$\mathcal{L}_{N^*(\frac{1}{2}^-)NV} =$ … $\frac{1}{2}\tilde{g}^{\mu\nu}_{N^*}\Big)\Big) + h.c.$

$\mathcal{T}_{N*(\frac{1}{2}^-)}$

$\mathcal{M}^\nu = \frac{ie}{f_V}\frac{-m}{q^2 - m_V^2}$ … $- \frac{1}{2}\tilde{g}_{N^*\ \mu\nu'}\Big)\Big)\tilde{g}_V^{\nu'\nu}(q)\times F_V(q^2)$

$\mathcal{M}^\nu q_\nu \sim ($ … invariance

No.	J^P	m	Γ_{tot}	g_V $J/\Psi p$	$\tilde{g}_V$ $J/\Psi p$	$\tilde{g}_V$ ρp	$\tilde{g}_V$ ωp
1	$\frac{1}{2}^-$	4262	35.6	0.39	0.32	–	–
2		4308	–	0.13	0.11	–	–
3		4412	47.3	0.46	0.38	0.078	0.14
4		4410	58.9	0.75	0.62	–	–
5		4460	–	0.20	0.16	–	–
6		4481	57.8	0.37	0.31	–	–
7	$\frac{3}{2}^-$	4334	38.8	1.19	0.98	–	–
8		4375	–	0.23	0.19	–	–
9		4380	144.3	0.36	0.30	0.090	0.17
10		4380	69.9	0.75	0.62	0.039	0.059
11		4412	47.3	0.79	0.65	0.14	0.24
12		4417	8.2	0.39	0.32	–	–
13		4450	139.8	0.71	0.58	0.028	0.053
14		4450	21.7	0.030	0.025	–	–
15		4450	16.2	0.58	0.48	–	–
16		4453	–	0.21	0.18	–	–
17		4481	34.7	0.98	0.81	–	–
18	$\frac{5}{2}^+$	4450	46.4	0.35	0.27	0.016	0.016

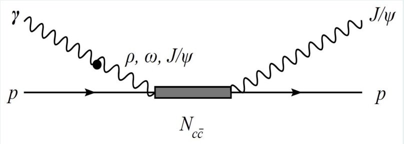
$\mathcal{L}_{N^*(\frac{1}{2}^-)N\gamma} = \bar{N}$ … $\frac{1}{2}\tilde{g}^{\mu\nu}_{N^*}\Big)\Big) + h.c.$

Dulat, W … -> $\overline{B}B\ \gamma$

One possible pre

$\mathcal{L}_{N^*(\frac{1}{2}^-)NV} =$ … $\Big(\frac{}{2}\ \tilde{r}^2$ … $- \frac{1}{2}\tilde{g}^{\mu\nu}_{N^*}\Big)\Big) + h.c.$

$\gamma\, p \to P_c \to J/\psi\, p$: $\gamma\, p \to P_c$ vertex



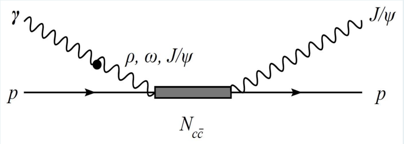
- $\gamma\, p \to P_c$: **The effect of off-shell vector**

$$\mathcal{T}_{N*(\frac{1}{2}^-)\to NV\to N\gamma} = \overline{u}_N \mathcal{M}^\nu u_{N^*} \epsilon^*_\nu,$$

$$\mathcal{M}^\nu = \frac{ie}{f_V}\frac{-m_V^2 \tilde{g}_{1V}}{q^2 - m_V^2 + i\Gamma_V m_V}\gamma_5\tilde{\gamma}_\mu \left(g_{\mu\nu'} - \left(\frac{3}{2}\frac{\tilde{r}_\mu \tilde{r}_\nu}{\tilde{r}^2} - \frac{1}{2}\tilde{g}_{N^*\ \mu\nu'}\right)\right)\tilde{g}_V^{\nu'\nu}(q)\times F_V(q^2)$$

$$F_V(q^2) = \frac{\Lambda^4}{\Lambda^4 + (q^2 - m_V^2)^2} = \frac{\Lambda^4}{\Lambda^4 + m_V^4}$$

$\gamma\, p \to P_c \to J/\psi\, p$: $\gamma\, p \to P_c$ vertex



- $\gamma\, p \to P_c$: **The effect of off-shell vector**

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$$\mathcal{M}^\nu = \frac{ie}{f_V}\frac{-m_V^2 \tilde{g}_{1V}}{q^2 - m_V^2 + i\Gamma_V m_V}\gamma_5 \tilde{\gamma}_\mu \left(g_{\mu\nu'} - \left(\frac{3}{2}\frac{\tilde{r}_\mu \tilde{r}_\nu}{\tilde{r}^2} - \frac{1}{2}\tilde{g}_{N^*\ \mu\nu'}\right)\right)\tilde{g}_V^{\nu'\nu}(q)\times F_V(q^2)$$

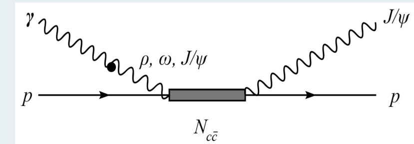
$$F_V(q^2) = \frac{\Lambda^4}{\Lambda^4 + (q^2 - m_V^2)^2} = \frac{\Lambda^4}{\Lambda^4 + m_V^4}$$

It is just a suppress factor, we have no idea how large it is. In other word, in model, the strength of N*Nγ is not determined. To compare with existed experimental data, we take a small cut: $\Lambda = 550$ MeV 。

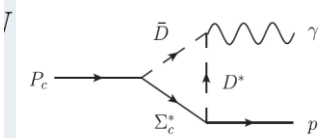
$\gamma p \to P_c \to J/\psi\, p$: $\gamma p \to P_c$ vertex

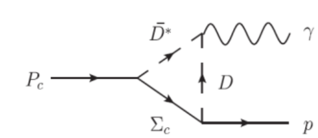
No.	J^P	m	Γ_{tot}	g_V $J/\Psi p$	$\tilde{g}_V$ $J/\Psi p$	$\tilde{g}_V$ ρp	$\tilde{g}_V$ ωp	$\Gamma_{p\gamma}$ (kev)
1	$\frac{1}{2}^-$	4262	35.6	0.39	0.32	–	–	3.9×10^{-5}
2		4308	–	0.13	0.11	–	–	4.5×10^{-6}
3		4412	47.3	0.46	0.38	0.078	0.14	1.14
4		4410	58.9	0.75	0.62	–	–	1.5×10^{-4}
5		4460	–	0.20	0.16	–	–	1.1×10^{-5}
6		4481	57.8	0.37	0.31	–	–	3.8×10^{-5}
7	$\frac{3}{2}^-$	4334	38.8	1.19	0.98	–	–	1.3×10^{-4}
8		4375	–	0.23	0.19	–	–	4.6×10^{-6}
9		4380	144.3	0.36	0.30	0.090	0.17	0.53
10		4380	69.9	0.75	0.62	0.039	0.059	0.060
11		4412	47.3	0.79	0.65	0.14	0.24	1.1
12		4417	8.2	0.39	0.32	–	–	1.4×10^{-5}
13		4450	139.8	0.71	0.58	0.028	0.053	0.054
14		4450	21.7	0.030	0.025	–	–	8.4×10^{-8}
15		4450	16.2	0.58	0.48	–	–	3.1×10^{-5}
16		4453	–	0.21	0.18	–	–	4.2×10^{-6}
17		4481	34.7	0.98	0.81	–	–	8.8×10^{-5}
18	$\frac{5}{2}^+$	4450	46.4	0.35	0.27	0.016	0.016	8.3×10^{-2}

l vector



No.	J^P	m	Γ_{tot}	$\Gamma_{J/\Psi p}$	$\Gamma_{p\gamma}$ (kev)	$\sigma^{(tot)}$(nb)	Ref.
9	$\frac{3}{2}^-$	4380	144.3	3.8	0.53	0.11	This work
		4380	144,3	3.8	0.70	0.15	[19]
18	$\frac{5}{2}^+$	4450	46.4	4.0	0.083	0.25	This work
		4450	46.4	4.0	1.13	3.4	[19]



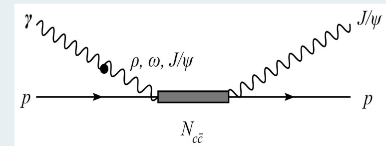


[19] Lin, Shen, Guo, Zou, PRD95 114017

idea how large it is.
h of N*Nγ is not
imental data, we

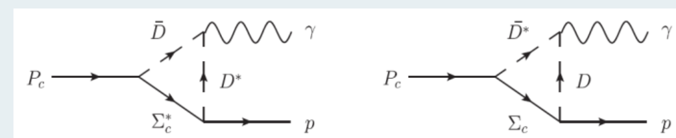
$\gamma\, p \to P_c \to J/\psi\, p$

$$\sigma^{(tot)}(W=M_R)=\frac{2J+1}{4}\frac{4\pi}{q_R^2}\frac{\Gamma_{N^*_{c\bar c}J/\psi p}\Gamma_{N^*_{c\bar c}\gamma p}}{\left[\Gamma^{(tot)}_{N^*_{c\bar c}}\right]^2}$$



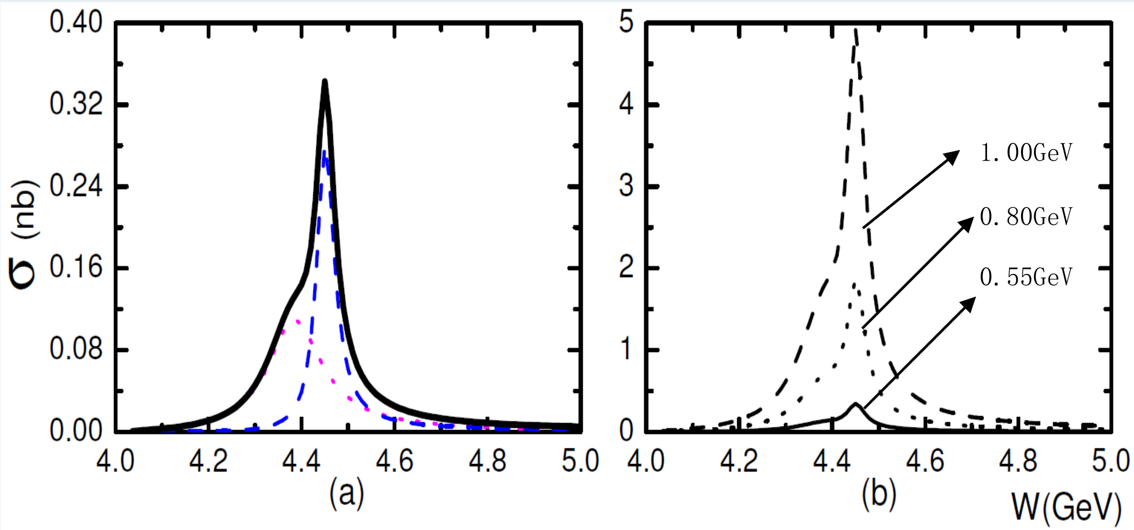
No.	J^P	m	Γ_{tot}	g_V $J/\Psi p$	$\tilde g_V$ $J/\Psi p$	$\tilde g_V$ ρp	$\tilde g_V$ ωp	$\Gamma_{p\gamma}$ (kev)	$\sigma^{(tot)}$(nb)
1	$\frac{1}{2}^-$	4262	35.6	0.39	0.32	–	–	3.9×10^{-5}	1.9×10^{-4}
2		4308	–	0.13	0.11	–	–	4.5×10^{-6}	–
3		4412	47.3	0.46	0.38	0.078	0.14	1.14	5.4
4		4410	58.9	0.75	0.62	–	–	1.5×10^{-4}	1.3×10^{-3}
5		4460	–	0.20	0.16	–	–	1.1×10^{-5}	–
6		4481	57.8	0.37	0.31	–	–	3.8×10^{-5}	8.8×10^{-5}
7	$\frac{3}{2}^-$	4334	38.8	1.19	0.98	–	–	1.3×10^{-4}	3.7×10^{-3}
8		4375	–	0.23	0.19	–	–	4.6×10^{-6}	–
9		4380	144.3	0.36	0.30	0.090	0.17	0.53	0.11
10		4380	69.9	0.75	0.62	0.039	0.059	0.060	0.23
11		4412	47.3	0.79	0.65	0.14	0.24	1.1	10.8
12		4417	8.2	0.39	0.32	–	–	1.4×10^{-5}	1.0×10^{-3}
13		4450	139.8	0.71	0.58	0.028	0.053	0.054	0.048
14		4450	21.7	0.030	0.025	–	–	8.4×10^{-8}	5.8×10^{-9}
15		4450	16.2	0.58	0.48	–	–	3.1×10^{-5}	1.4×10^{-3}
16		4453	–	0.21	0.18	–	–	4.2×10^{-6}	–
17		4481	34.7	0.98	0.81	–	–	8.8×10^{-5}	0.0026
18	$\frac{5}{2}^+$	4450	46.4	0.35	0.27	0.016	0.016	8.3×10^{-2}	0.25

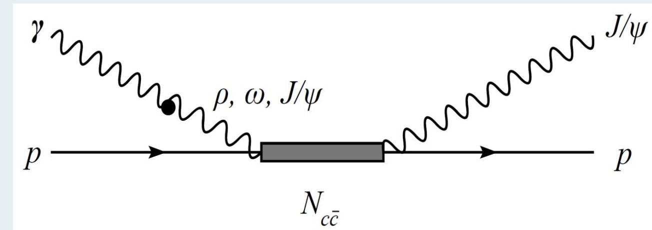
No.	J^P	m	Γ_{tot}	$\Gamma_{J/\Psi p}$	$\Gamma_{p\gamma}$ (kev)	$\sigma^{(tot)}$(nb)	Ref.
9	$\frac{3}{2}^-$	4380	144.3	3.8	0.53	0.11	This work
		4380	144, 3	3.8	0.70	0.15	[19]
18	$\frac{5}{2}^+$	4450	46.4	4.0	0.083	0.25	This work
		4450	46.4	4.0	1.13	3.4	[19]

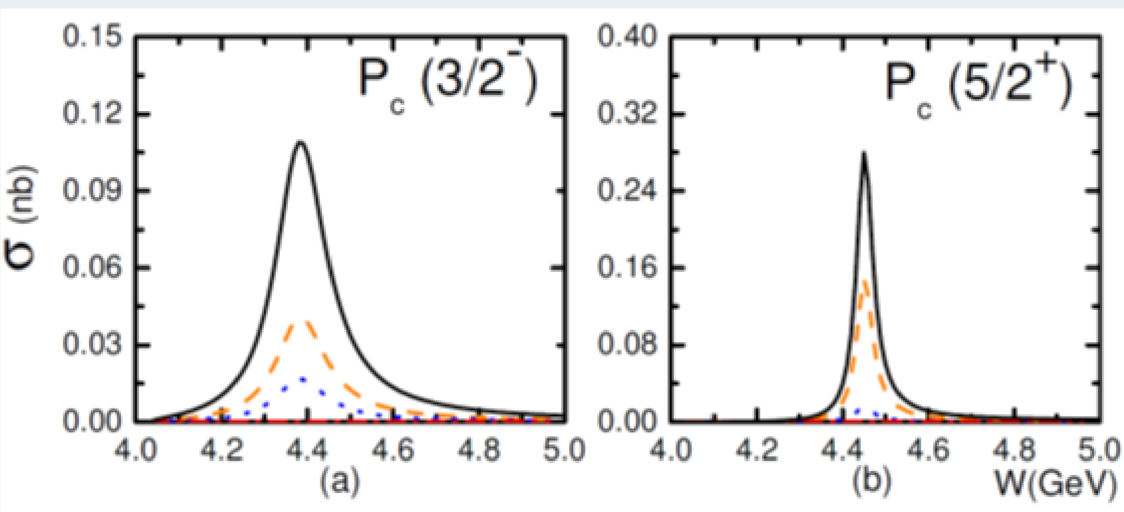


[19] Lin, Shen, Guo, Zou, PRD95 114017

$\gamma\, p \rightarrow P_c \rightarrow J/\psi\, p$

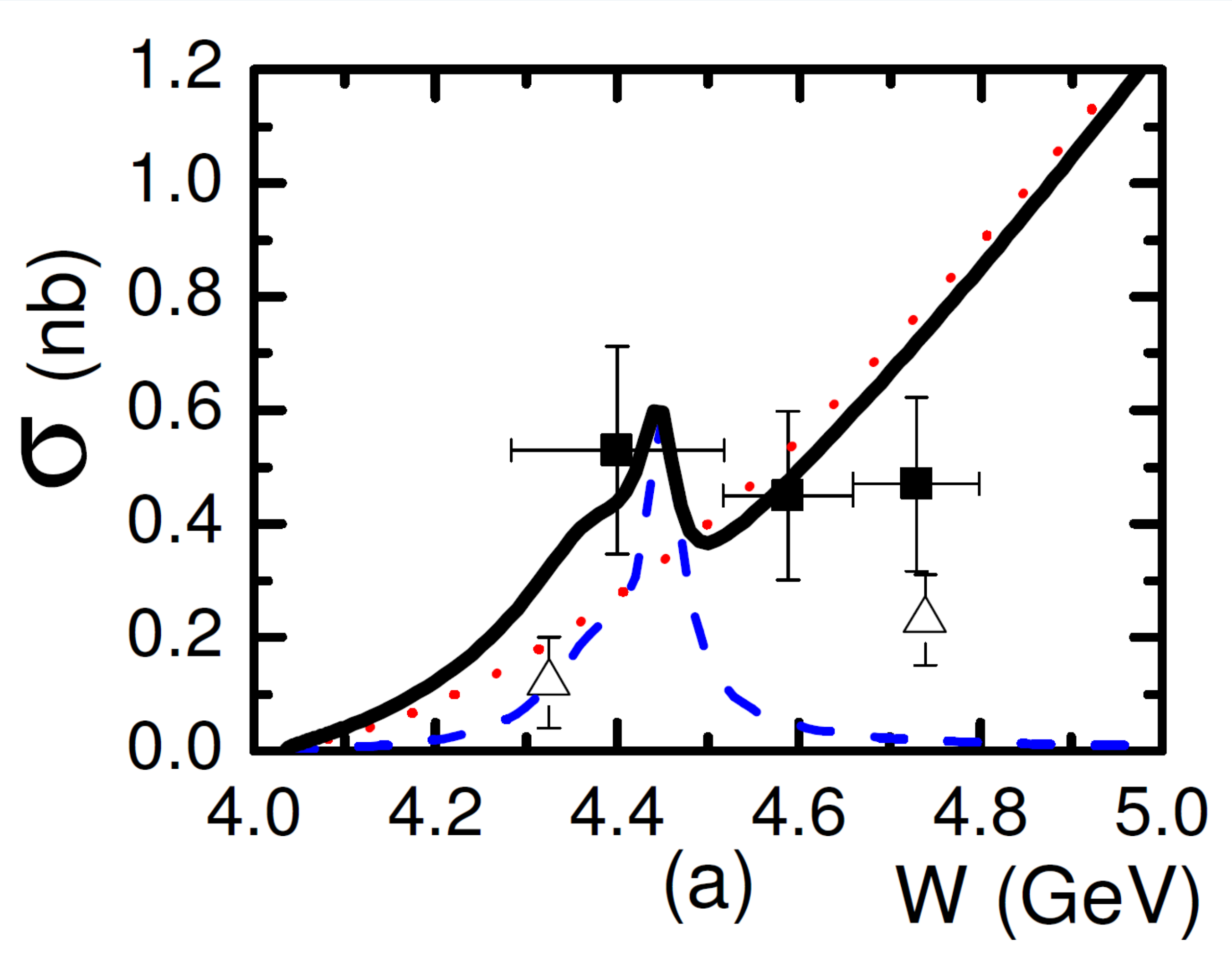




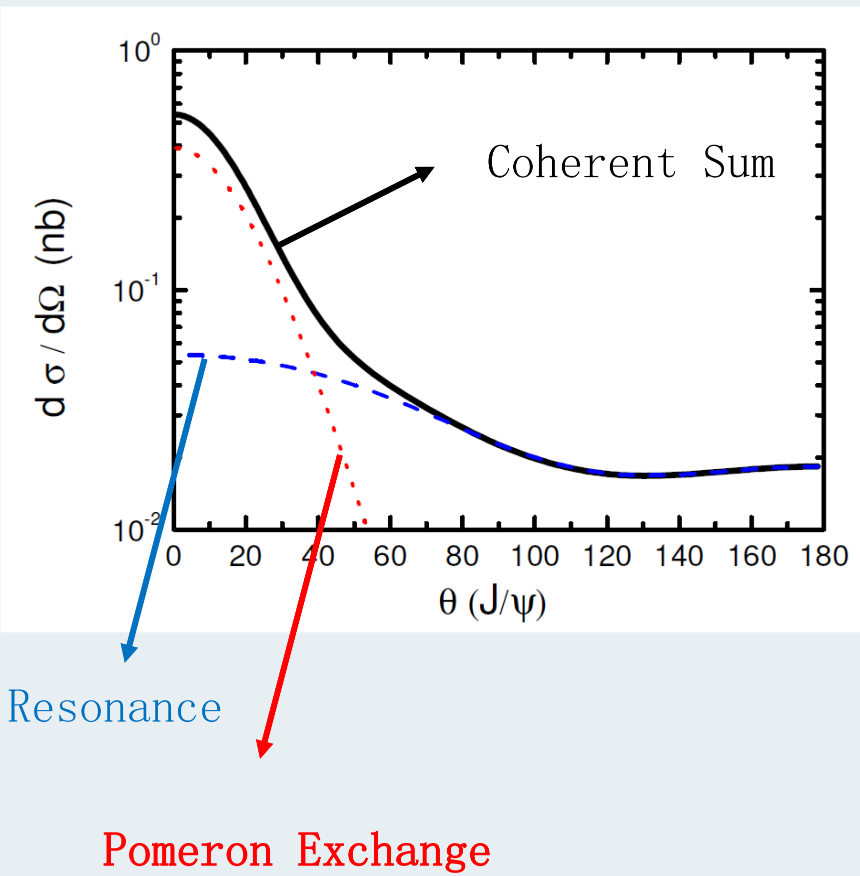


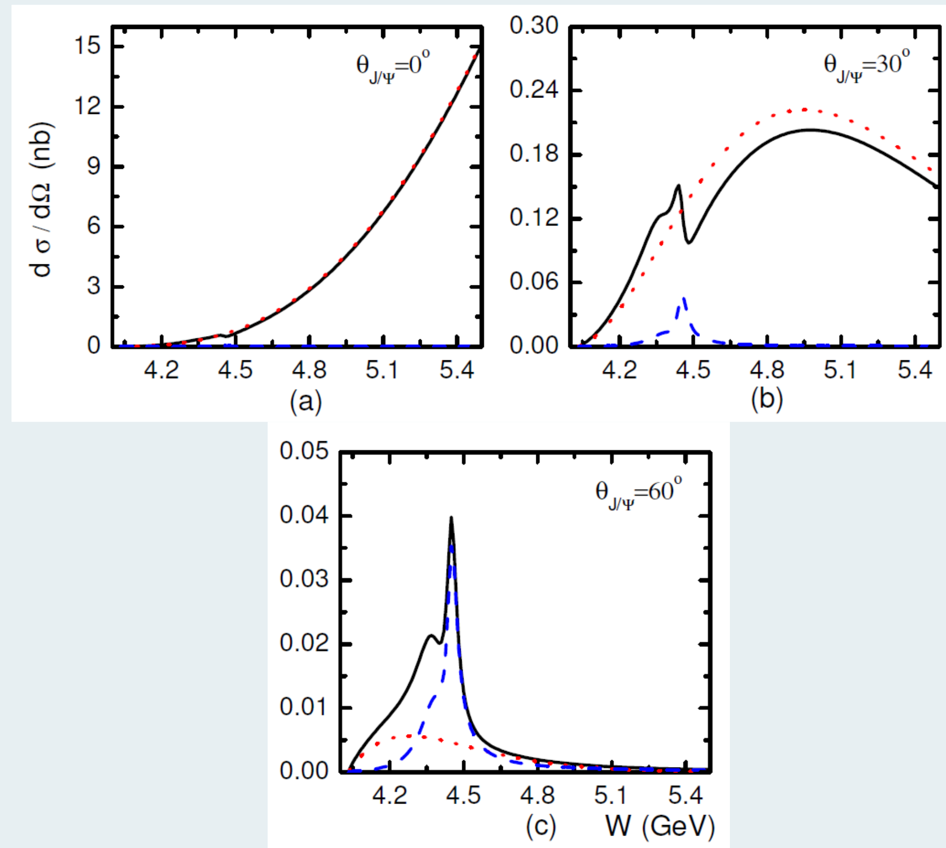
After using a form factor for off shell vector, we will find the main contribution of VMD is just from ρ/ω meson, and J/ψ contribution is negligible.

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



How to extract information of P_c ?





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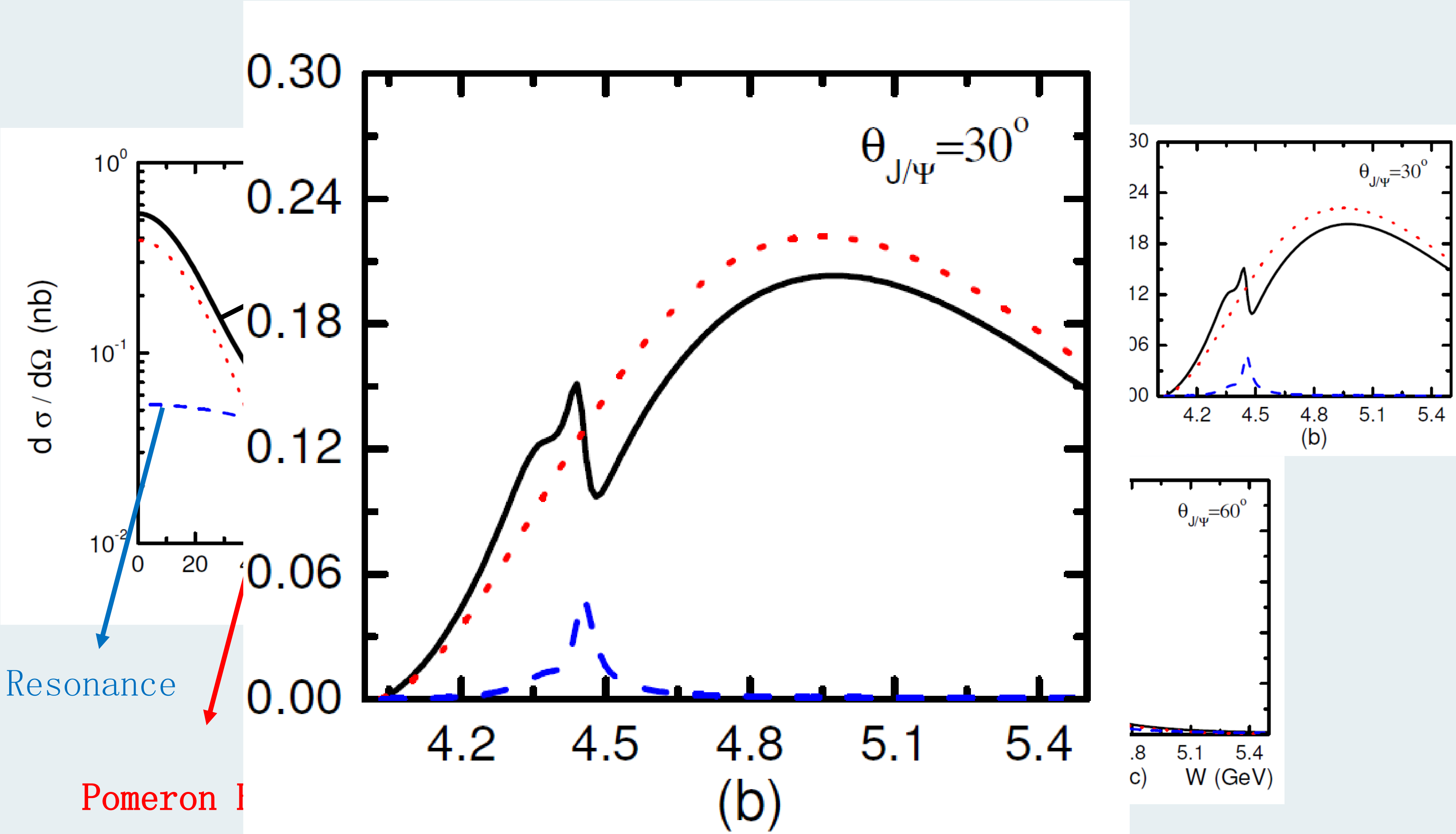
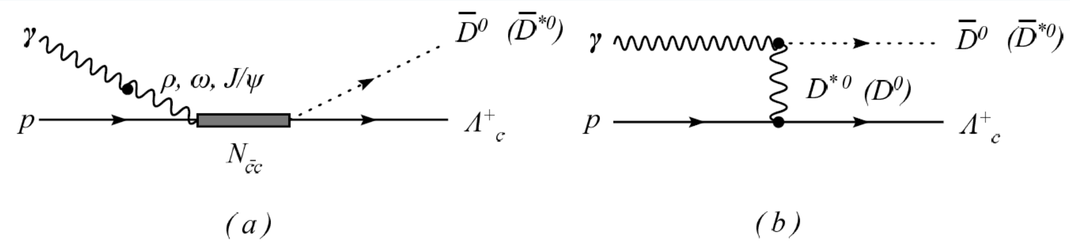
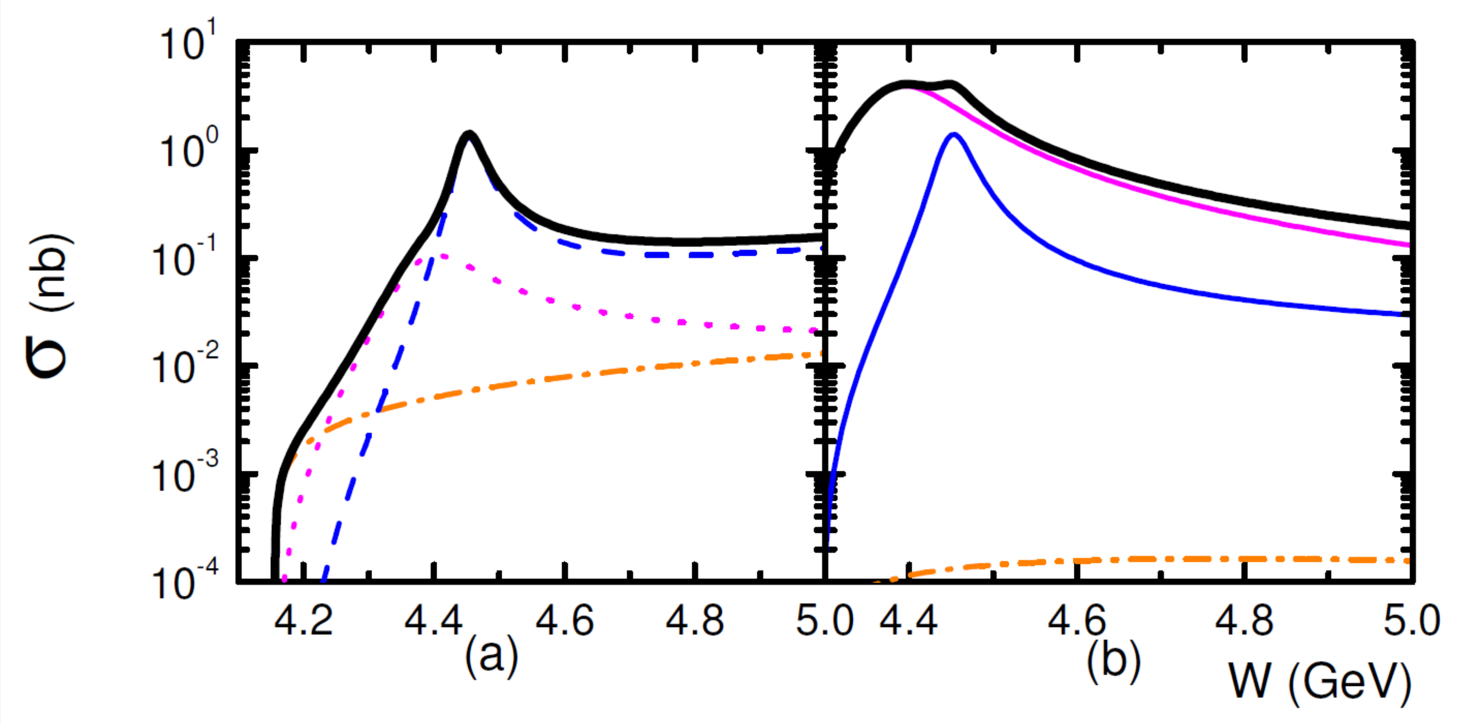
How to extract information of P_c ?



γ p → other final states

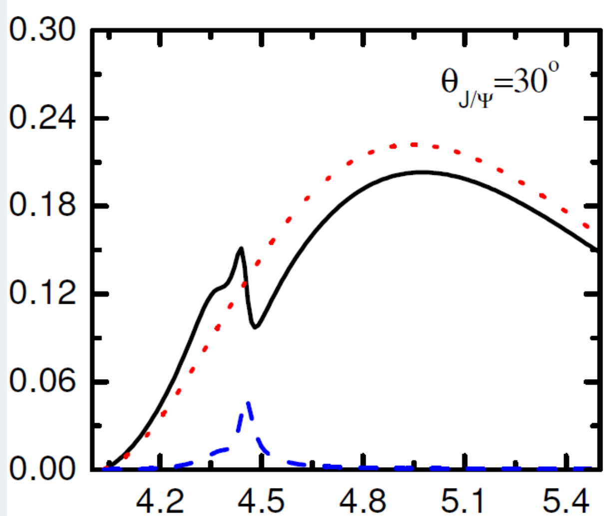
- $\gamma p \rightarrow \Lambda^+_c \bar{D}^0 (\bar{D}^{*0})$





Summary

- We discuss the Pc states
- We calculated the cross section of γ p → J/ψ p reaction through background and resonance with hidden-charm.
- Discuss how to extract the γ p → P_c → J/ψ p signal from the background.



(b)

Thank very much！