

Hadron and Charm Physics in São Paulo (city): A Panoramic Perspective

Kanchan P. Khemchandani
Universidade Federal de São Paulo

ETHNP, 05 Sept 2026

Universities in São Paulo with hadron and nuclear theory physics (HNTP) groups

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- Patricia Magalhães (Unicamp), Tobias Fredreico (ITA)

Recent event with several Japanese visitors



Local hadron physics event:



Local hadron physics event:



Please expect international meetings:

Hadrons 2026
(Santos)

Charm 2026 (Rio)

QNP2027 (Bahia)

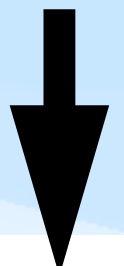
Current topics on which we are working, that got motivated by visiting Valencia

- In 2020, LHCb [*PRL* 125, 242001 (2020), *PRD* 102, 112003 (2020)] discovered two new exotic states in the D^-K^+ invariant mass
- Four different flavors $\Rightarrow$ quark content $\bar{c}d\bar{s}u$
- The states have been confirmed, more recently, in a different process.

PHYSICAL REVIEW LETTERS 133, 131902 (2024)

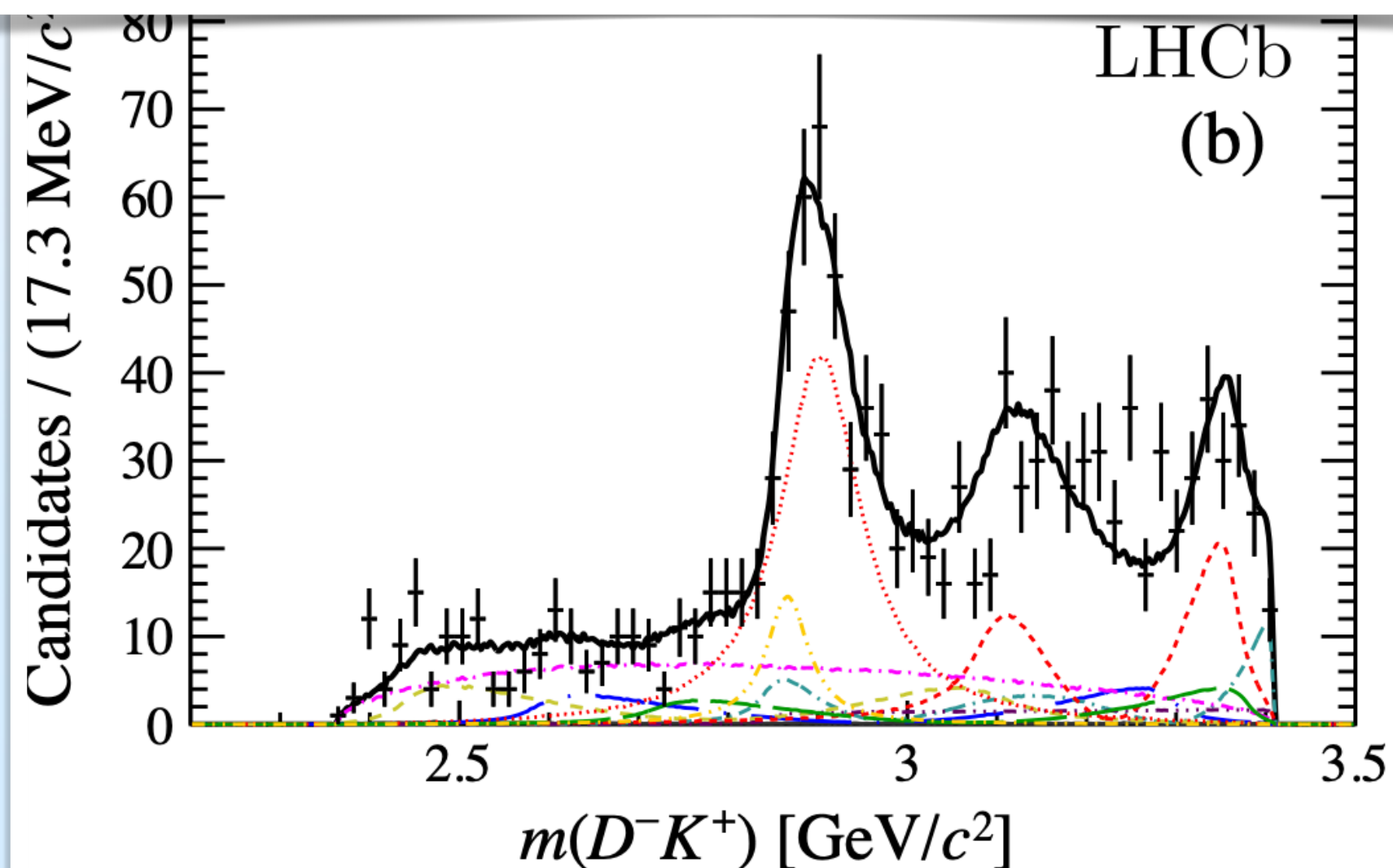
--- $T_{\bar{c}\bar{s}0}^*(2870)^0$

--- $T_{\bar{c}\bar{s}1}^*(2900)^0$

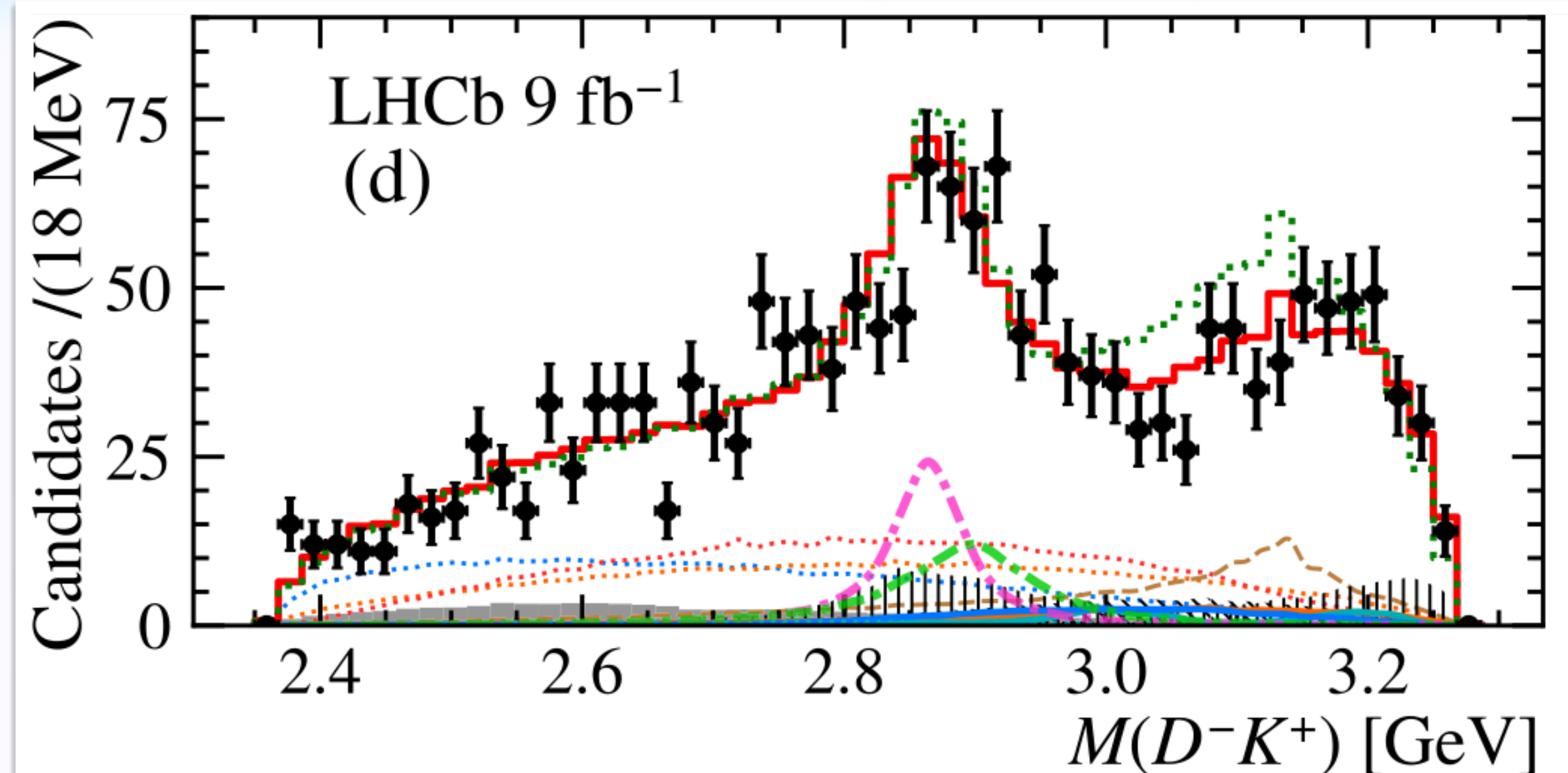


PHYS. REV. D 102, 112003 (2020)

Amplitude analysis of the $B^+ \rightarrow D^+D^-K^+$ decay



Observation of New Charmonium or Charmoniumlike States in $B^+ \rightarrow D^{*\pm}D^\mp K^+$ Decays

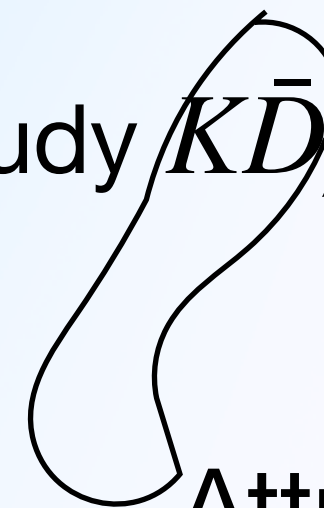


Explicitly exotic mesons with charm

- $T_{\bar{c}\bar{s}0}$ has spin parity 0^+ , $M = 2866 \pm 7$ MeV, $\Gamma = 57 \pm 13$ MeV.
- $T_{\bar{c}\bar{s}1}$ has spin parity 1^- , $M = 2904 \pm 5$ MeV, $\Gamma = 110 \pm 12$ MeV.
- Most agreed upon structure of $T_{\bar{c}\bar{s}0}$ seems to be a molecule of $\bar{D}^* K^*$ (several works by Raquel, Eulogio).
- $T_{\bar{c}\bar{s}1}$ is harder to describe as a molecule of two hadrons.
- Some works have studied interactions in the $K_1 \bar{D}$ and $\bar{D}_1 K$. [Bingsong Zhou et. al., *EPJC* 81, no.7, 639 (2021), *EPJC* 81, no.9, 812 (2021), *Chin. Phys. C* 45, no.6, 063102 (2021),]
- The results are not similar.
- It could be useful to couple $K_1 \bar{D}$ and $\bar{D}_1 K$ instead of studying separately.
- A good solution could be to study $K \bar{D} \rho$.

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Attractive interaction, strongly coupling with $K_1(1270)$

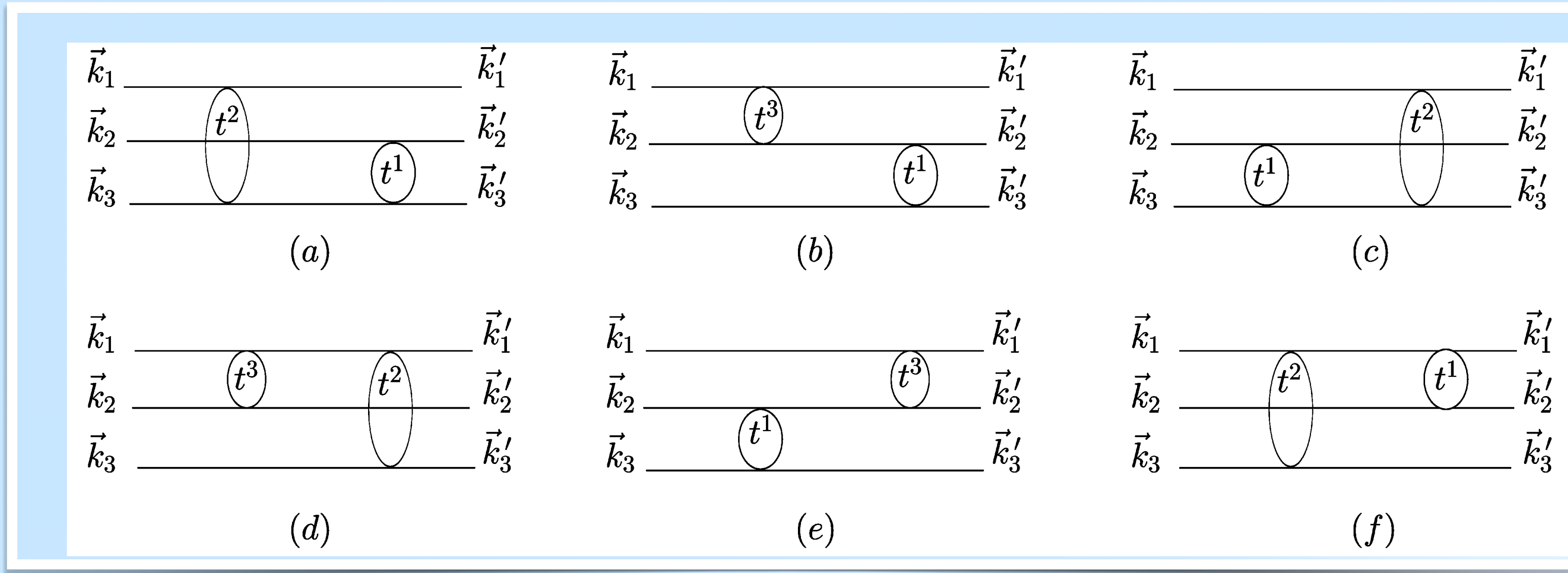
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- The results are not similar.
- It could be useful to couple $K_1 \bar{D}$ and $\bar{D}_1 K$ instead of studying separately.
- A good solution could be to study $K \bar{D} \rho$.  Attractive interaction, strongly coupling with $D_1(2420)$

Three-body interactions:



$$T_1 = t_1 + t_1 G [T_2 + T_3]$$

$$T_2 = t_2 + t_2 G [T_1 + T_3]$$

$$T_3 = t_3 + t_3 G [T_1 + T_2]$$

- We studied several systems, solving these equations in an onshell factorization form (which is based on cancellation of three-body contact terms).
- One result worth mentioning: $N^*(1910)$, possibly confirmed by Bgood Collaboration

Talk by Alberto Martinez Torres in Nstar, on Monday!

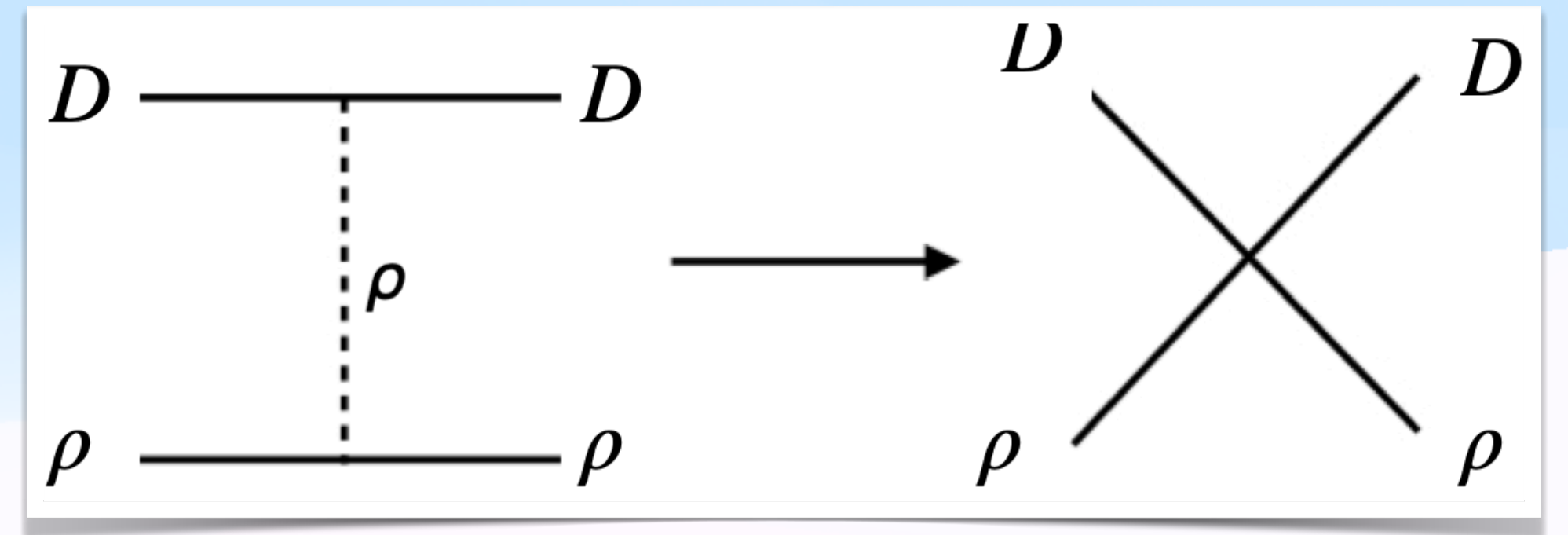
- Further detailed study planned with Michael Doering.
- Going back to our study $K\bar{D}\rho$: it is possible to simplify the formalism in this case.

$D\rho$ and $\bar{D}\rho$ interactions

- We determine the two-body interactions using hidden local symmetry (obtaining the same results as Gamermann-Oset) .
- solve the Bethe-Salpeter equation in a coupled-channel approach for the charm system: $t = v + vgt$
- $D\rho$ and $\bar{D}\rho$ are same.

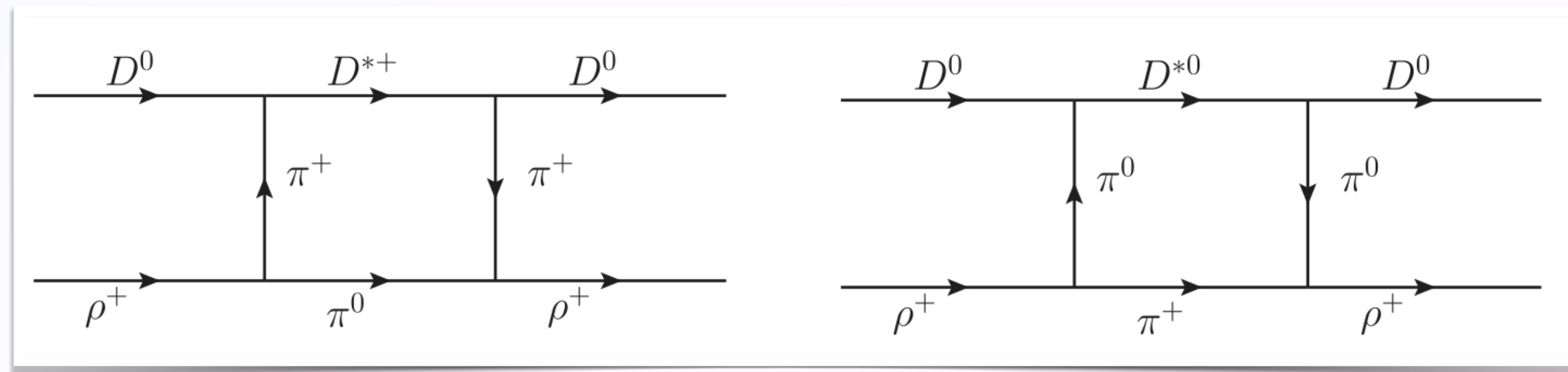
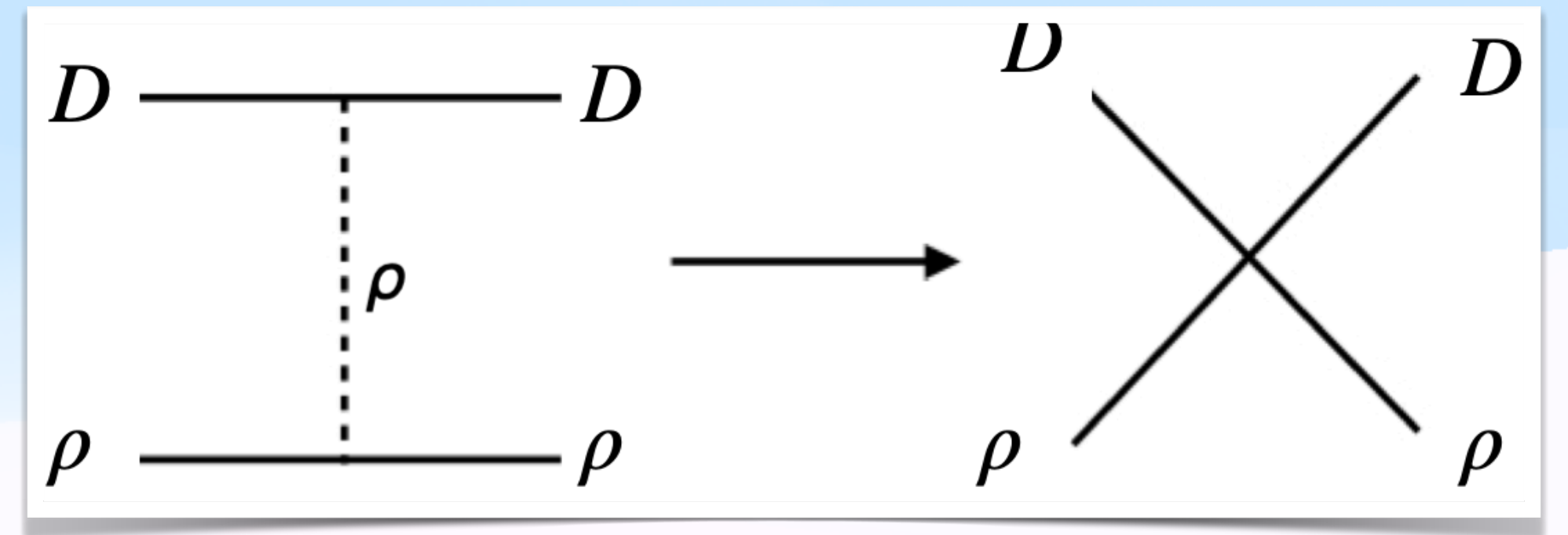
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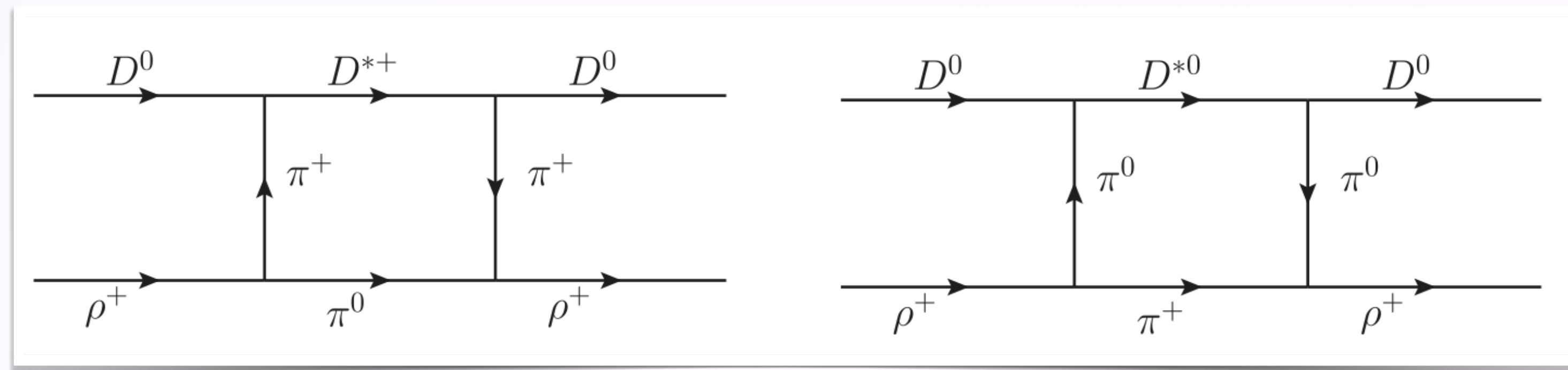
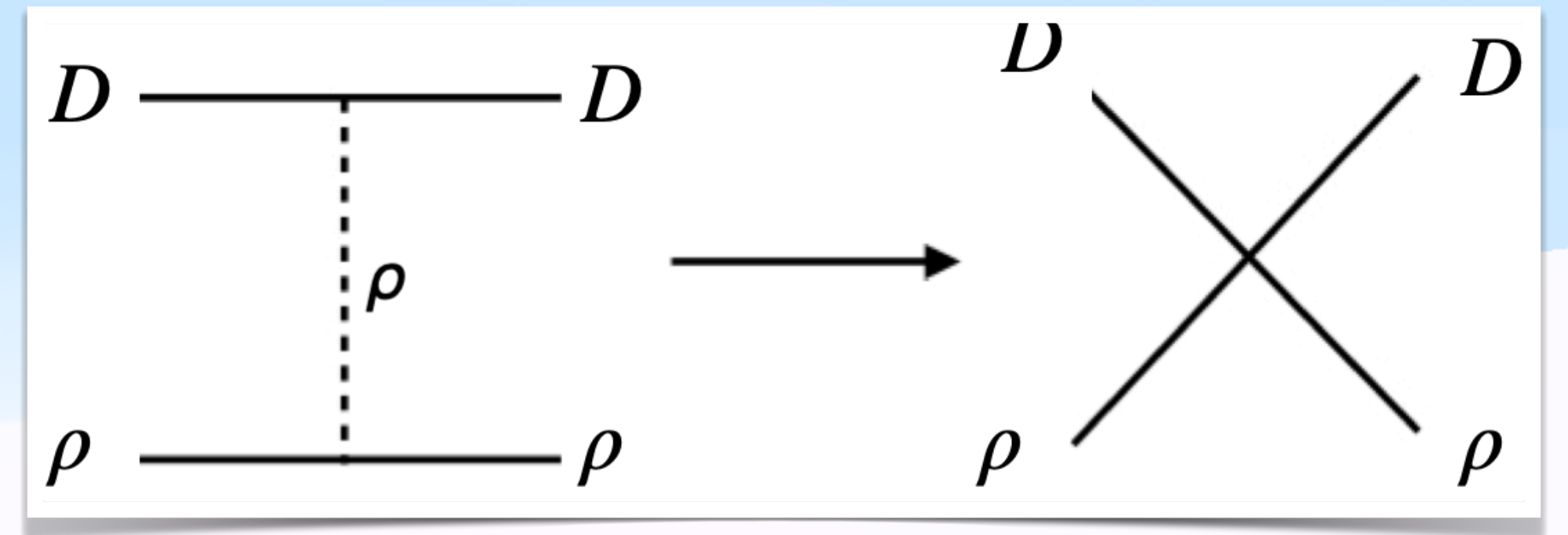
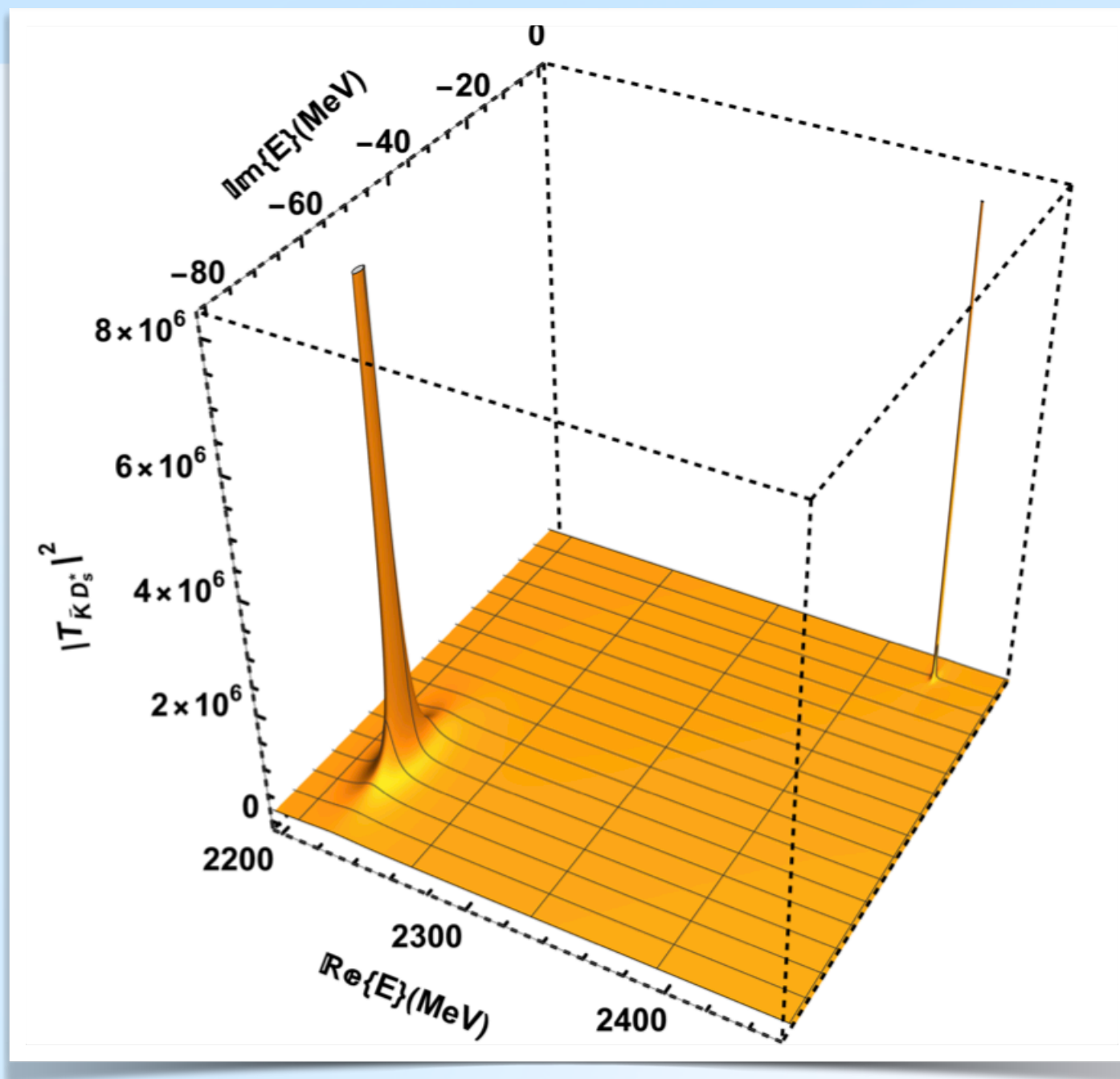
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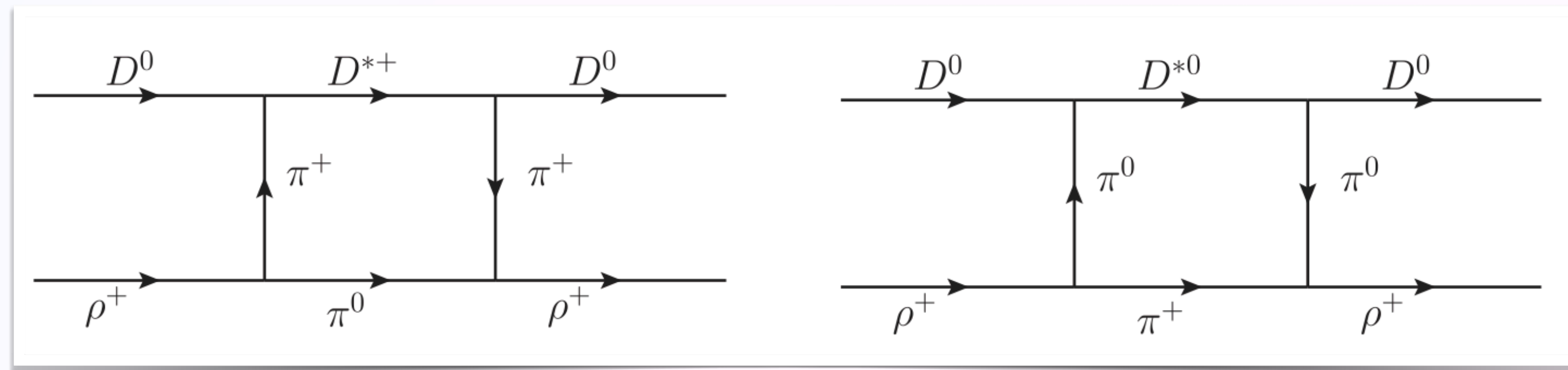
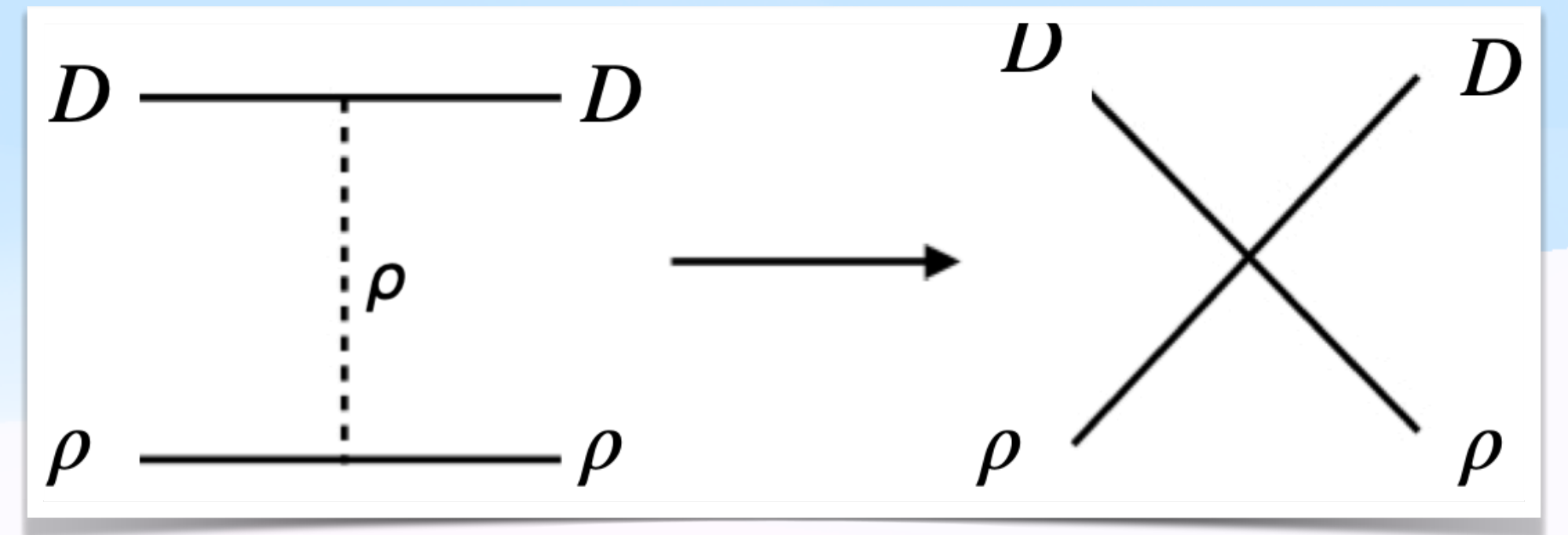
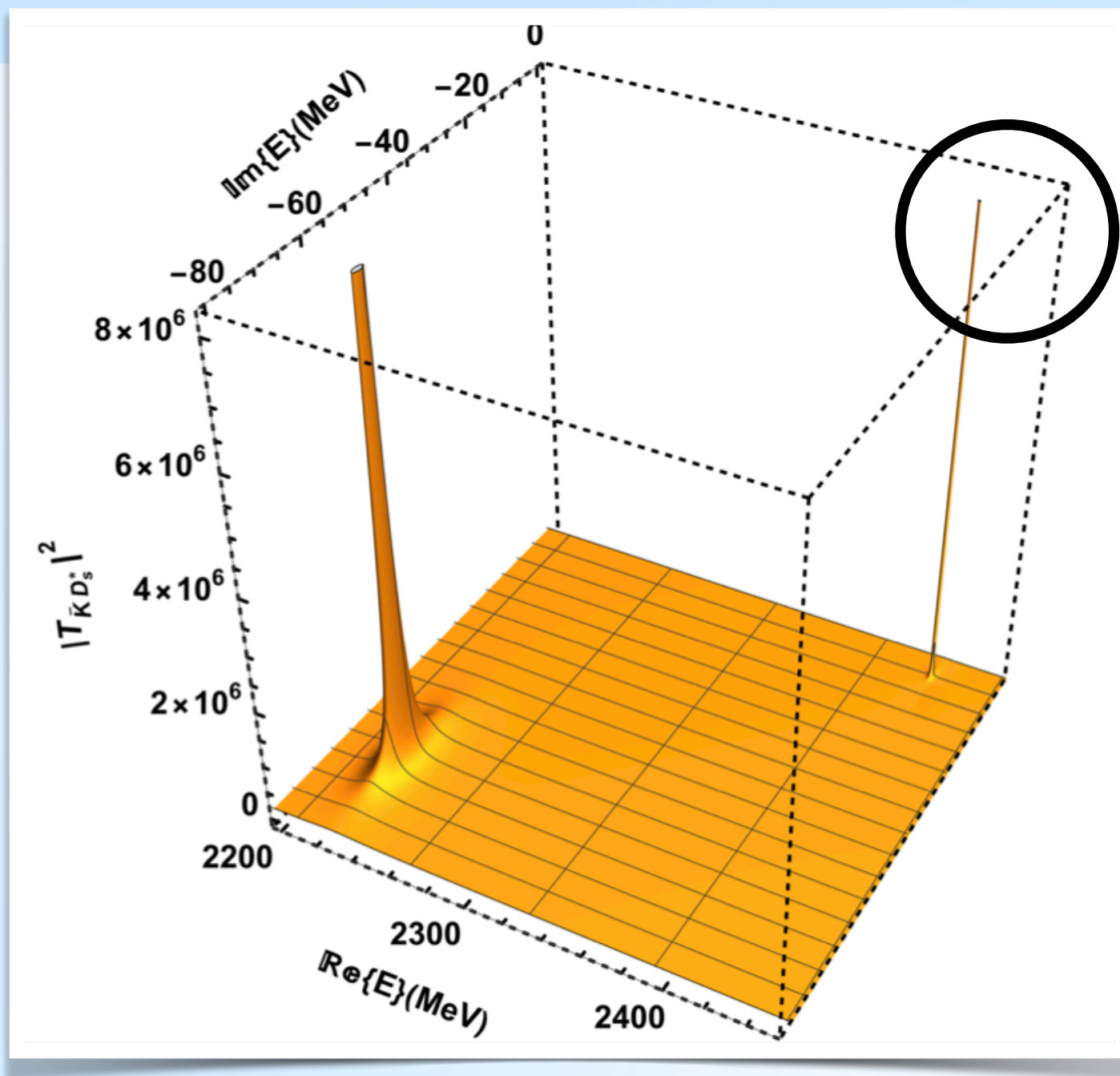
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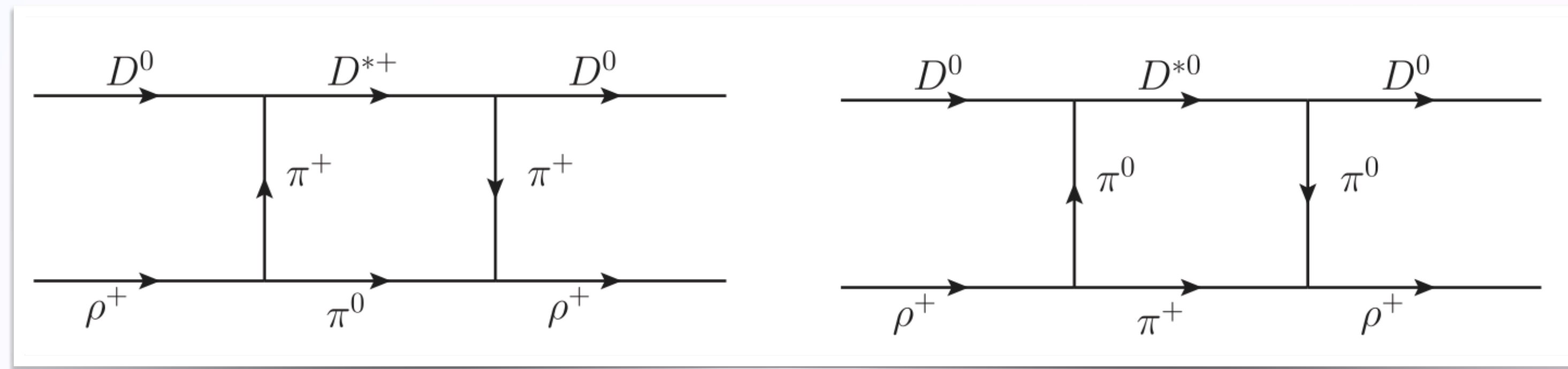
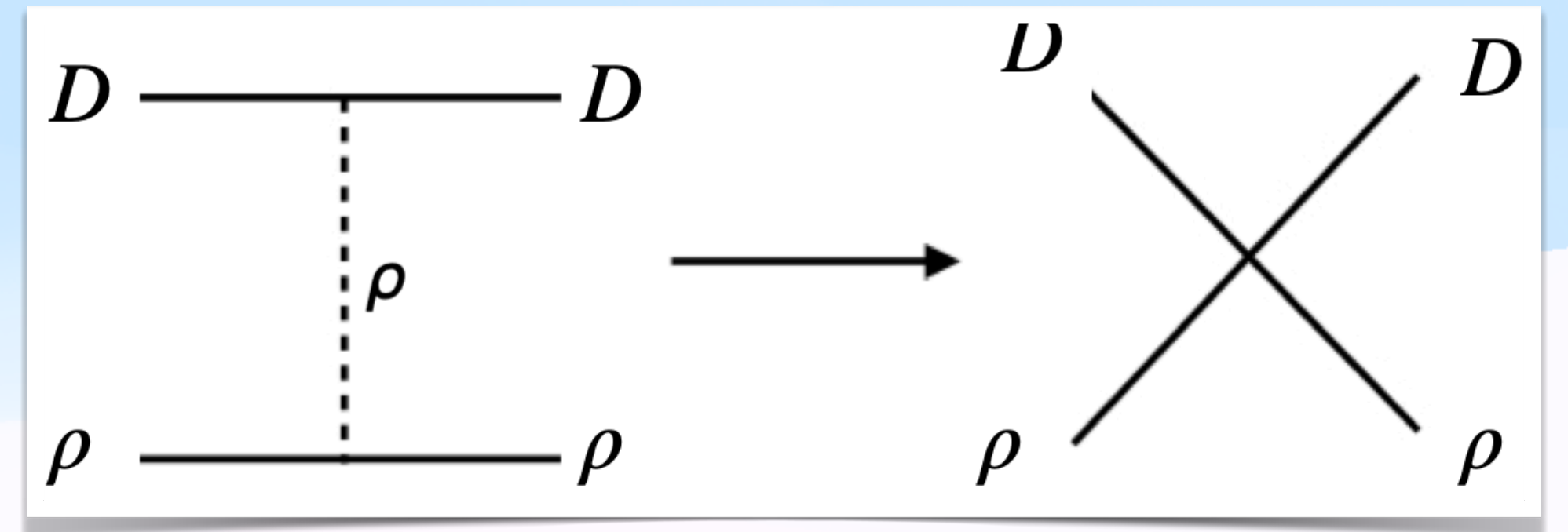
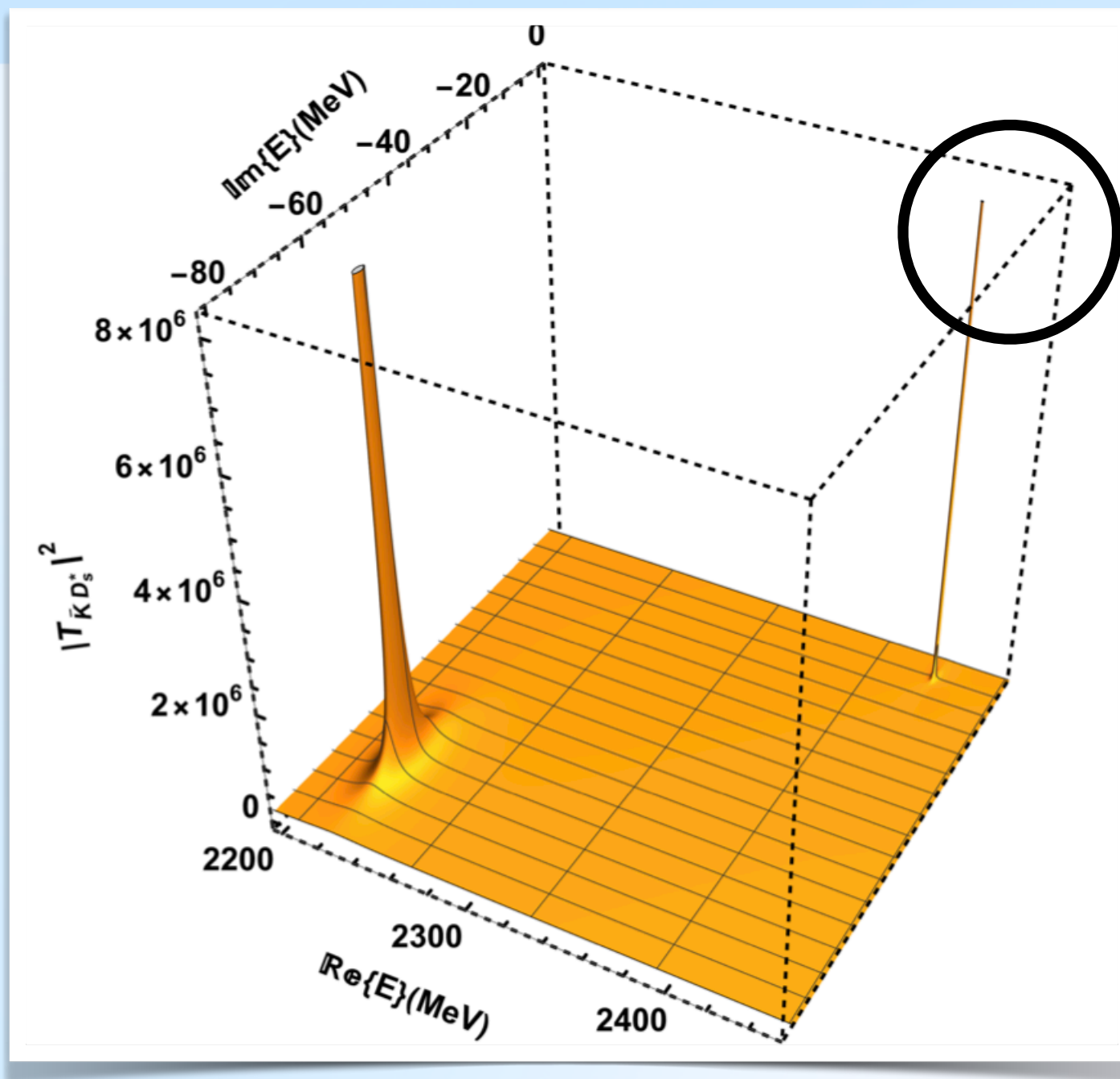
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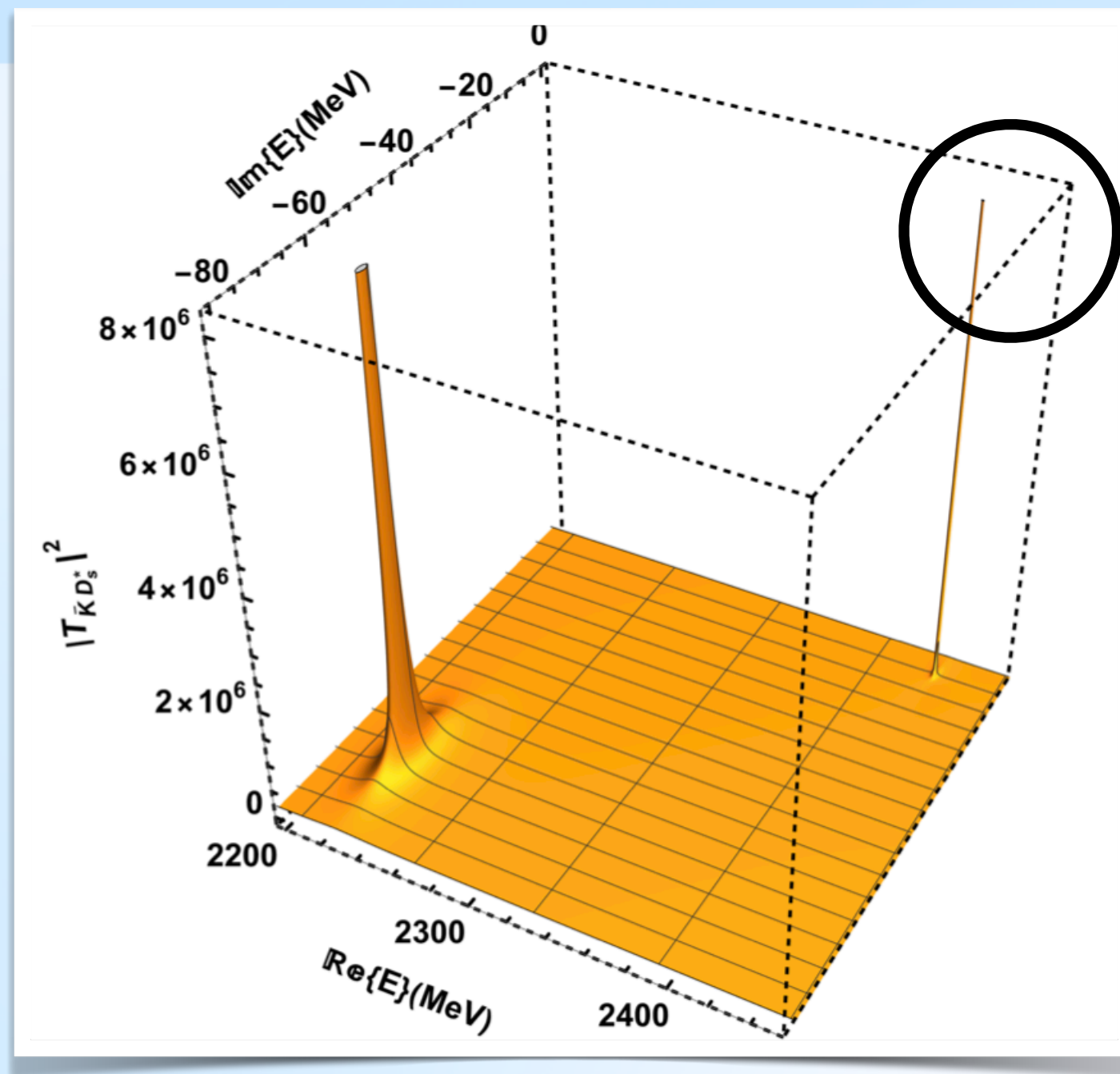
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$D_1(2420)$ is a narrow state,
& much heavier than kaon!



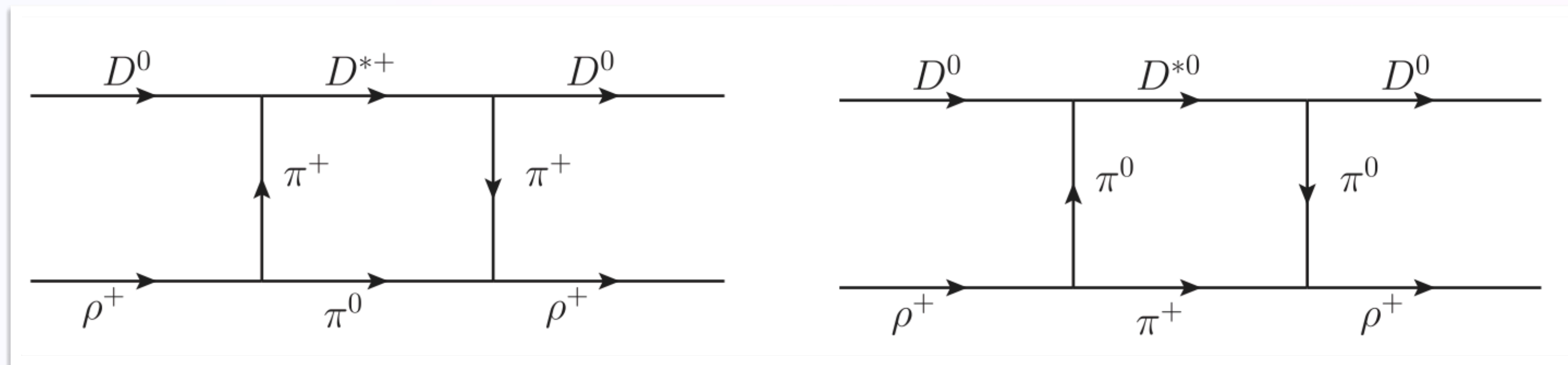
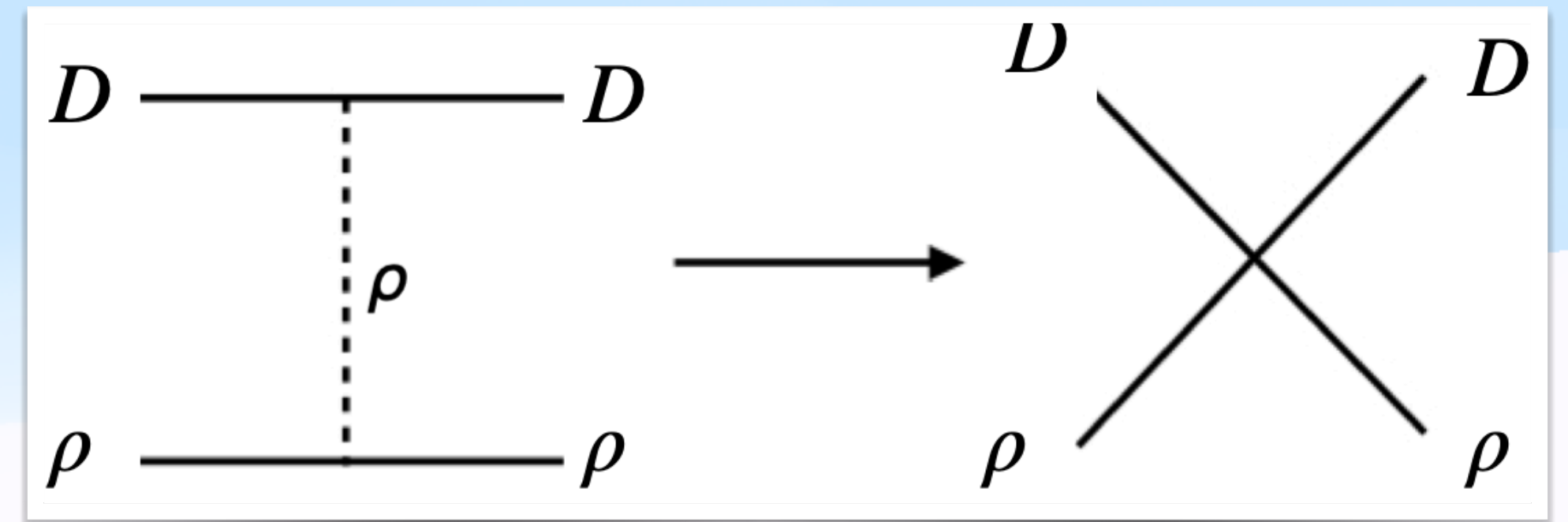
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Simplify the formalism, solve three-body scattering equations where kaon scatters off two fixed "centers"

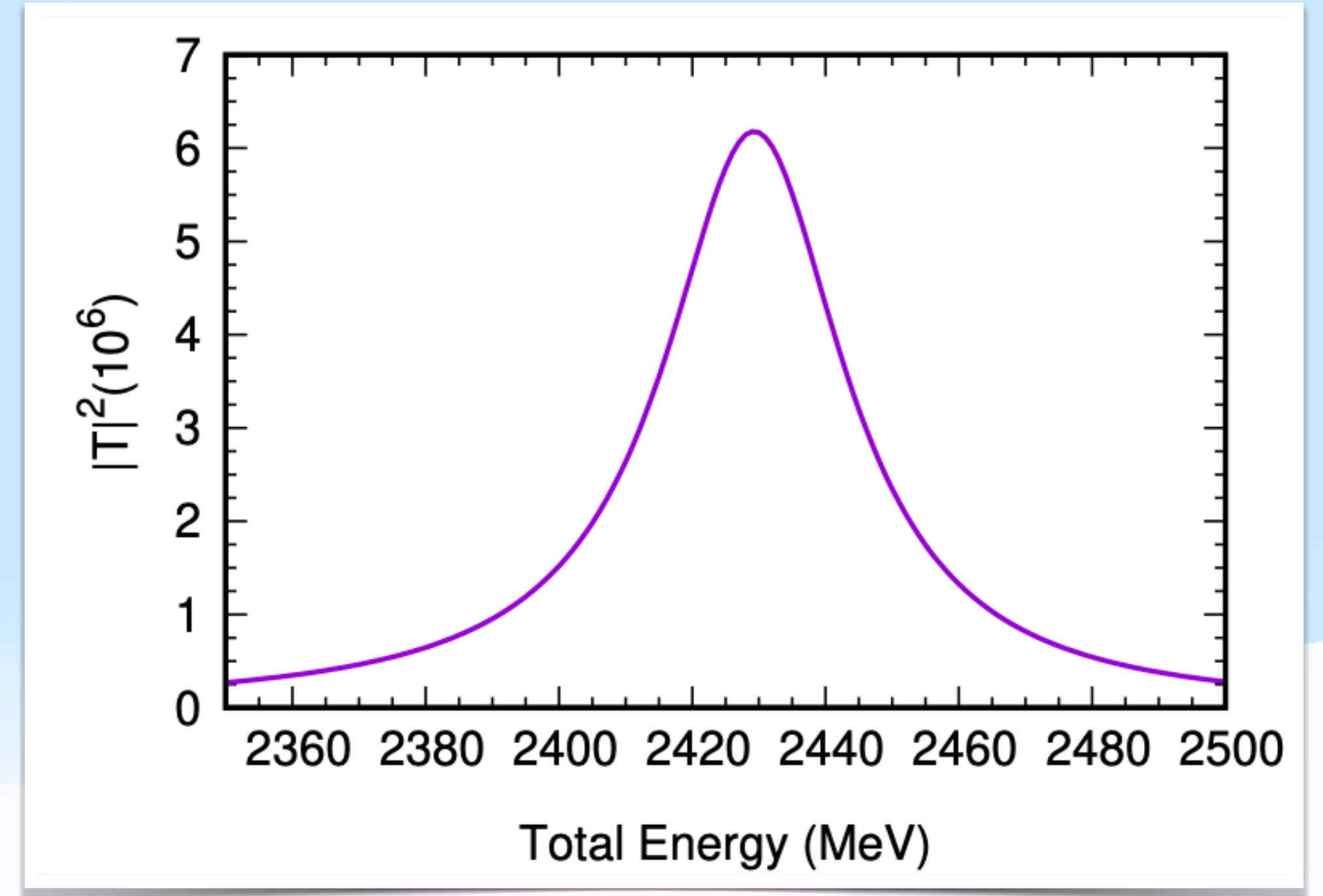


Kaon interaction with $D(\bar{D})$ and ρ

- Interactions among $\bar{D}K$ and coupled channels, as well as ρK coupled channels are studied (*for the latter case we follow L. Roca, E. Oset, and J. Singh, Phys. Rev. D 72, 014002 (2005) and L. S. Geng, E. Oset, L. Roca, and J. A. Oller, Phys. Rev. D 75, 014017 (2007)).*
- The $\bar{D}K$ system is weakly attractive.
- In ρK and coupled channels amplitudes, we find the generation of $K_1(1270)$.

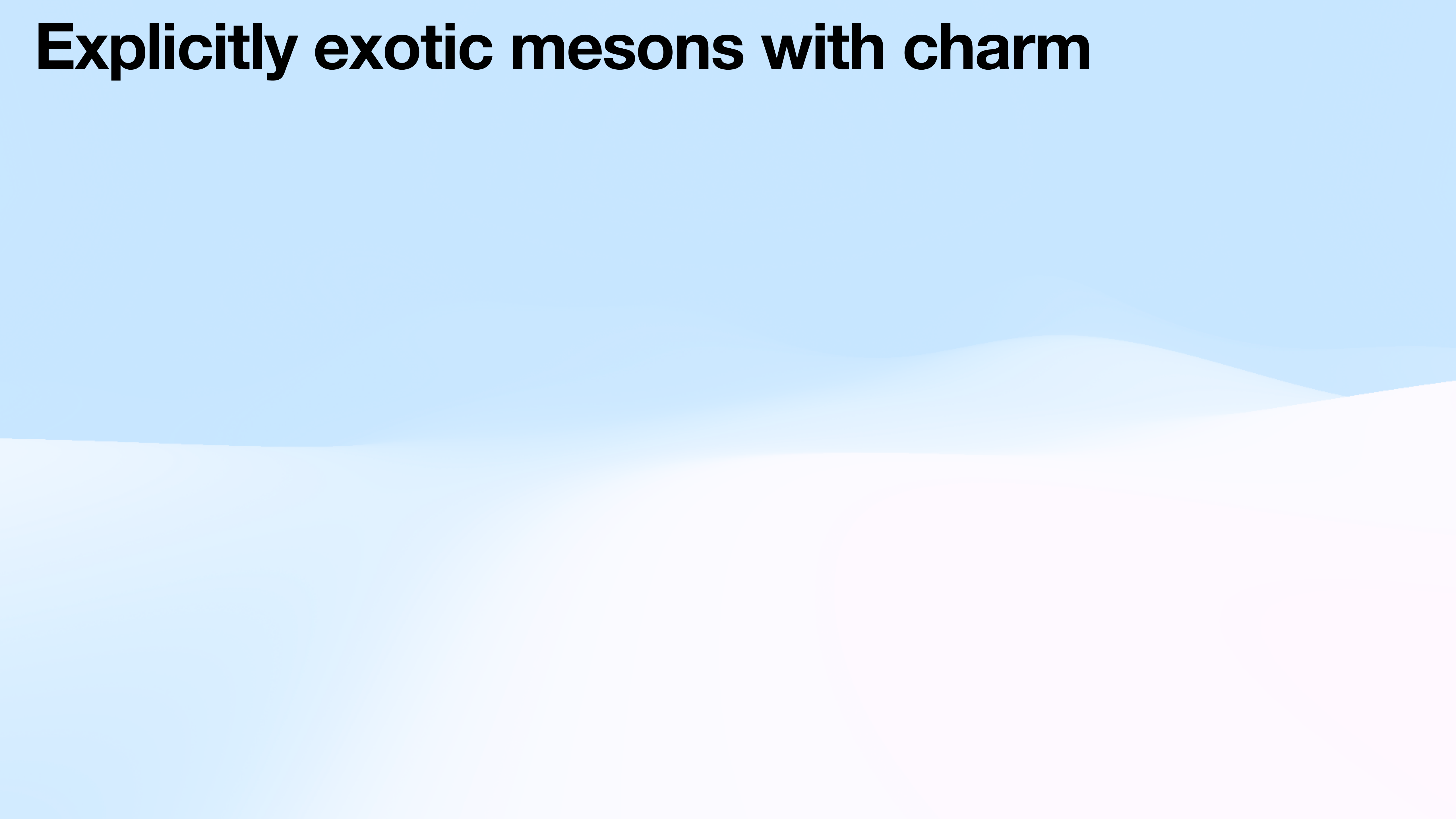
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The $D\rho$ amplitude showing $D_1(2420)$

Explicitly exotic mesons with charm

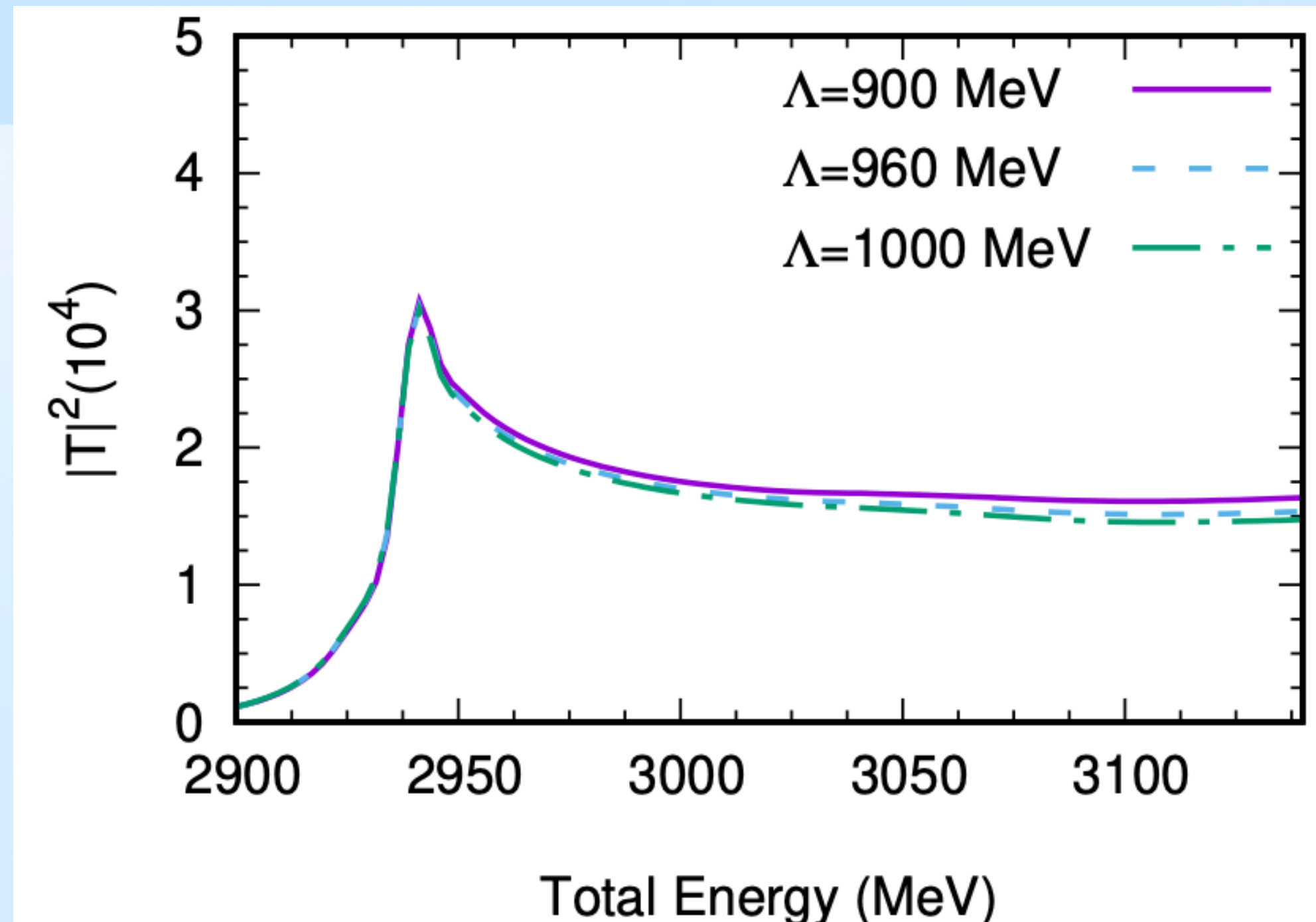


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- We do not find a state formed in the $K\bar{D}\rho$ system.

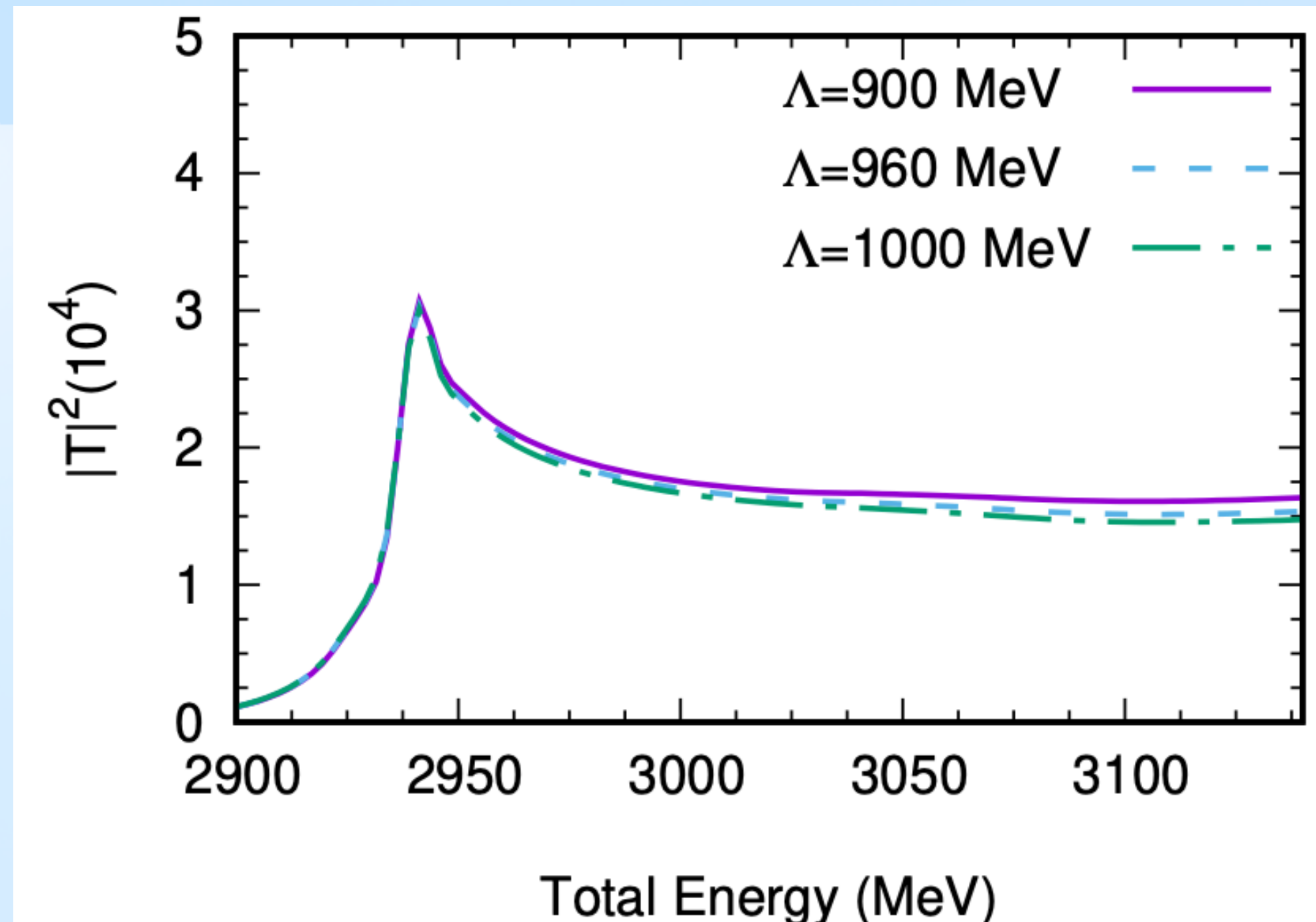
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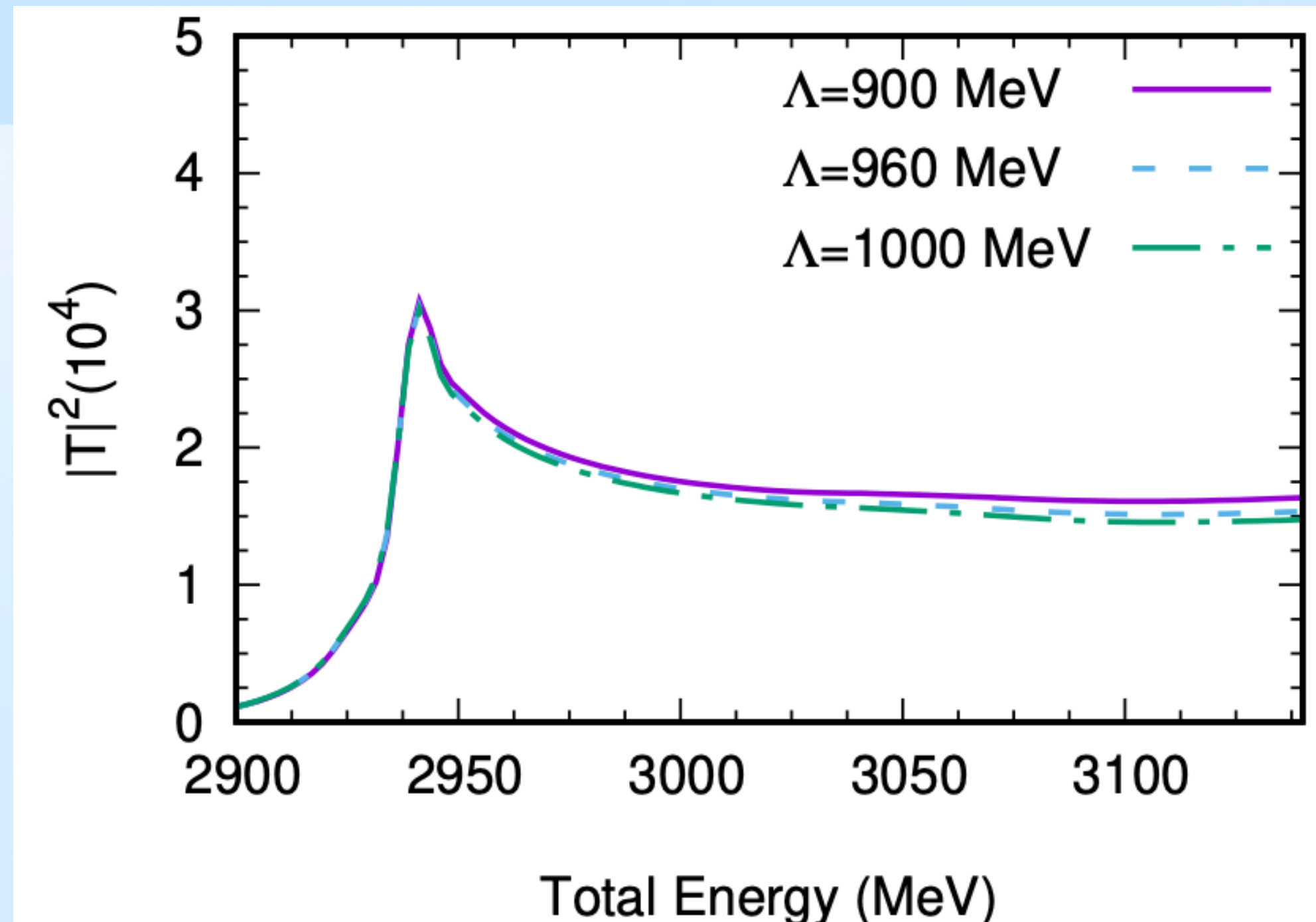
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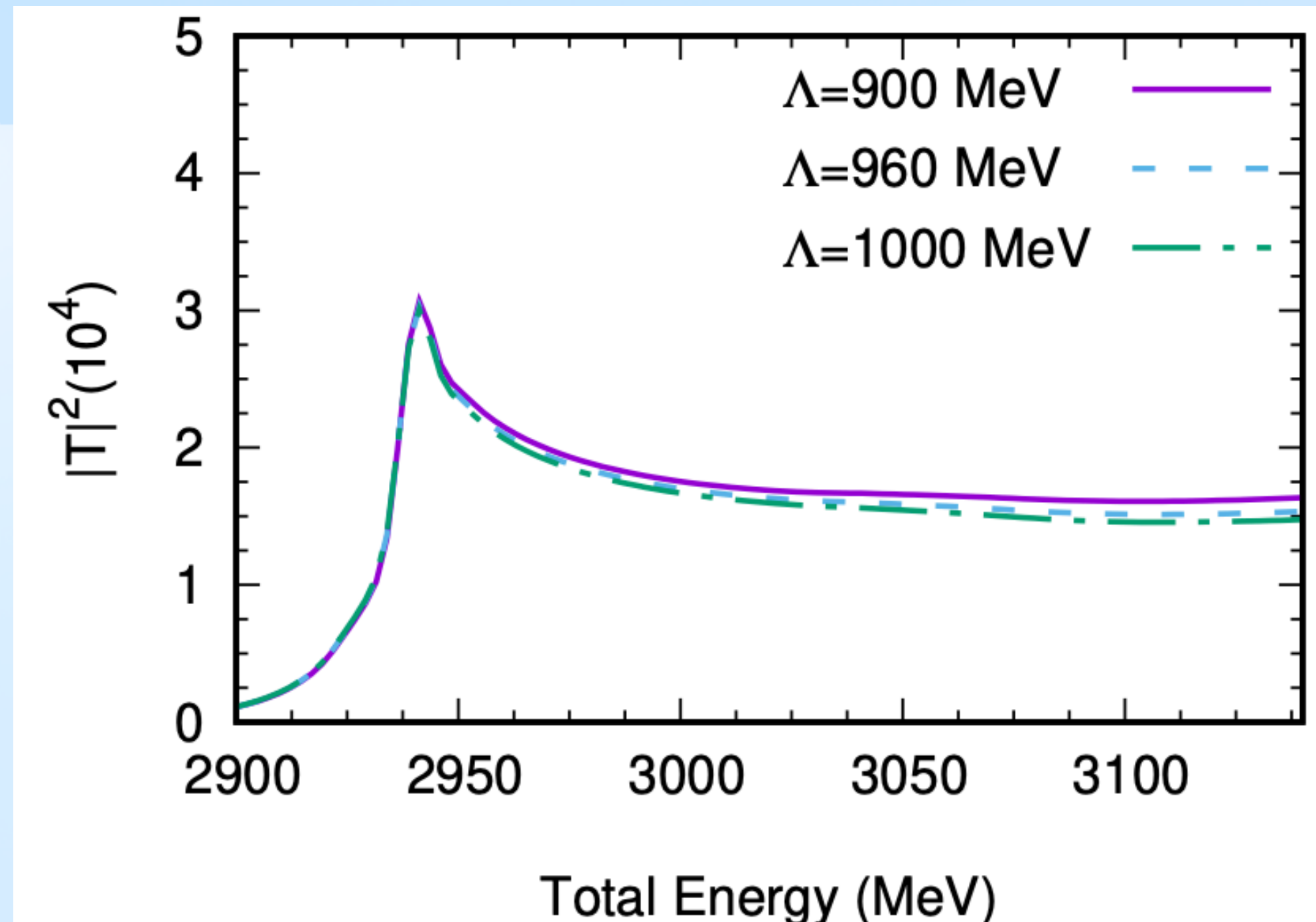
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- However, in the study of the system with $C=+1$, we do find a state in isospin zero as well as 1.



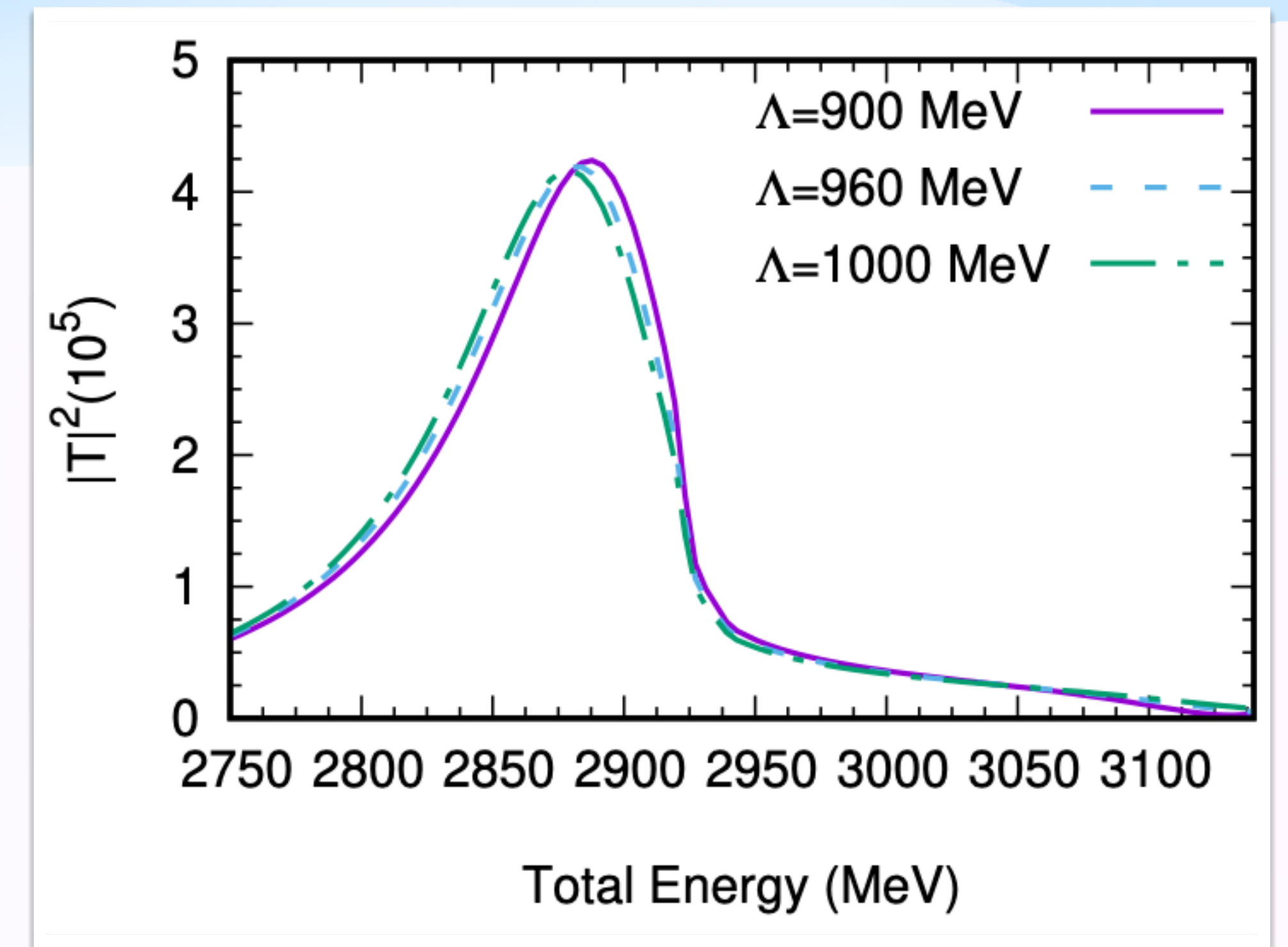
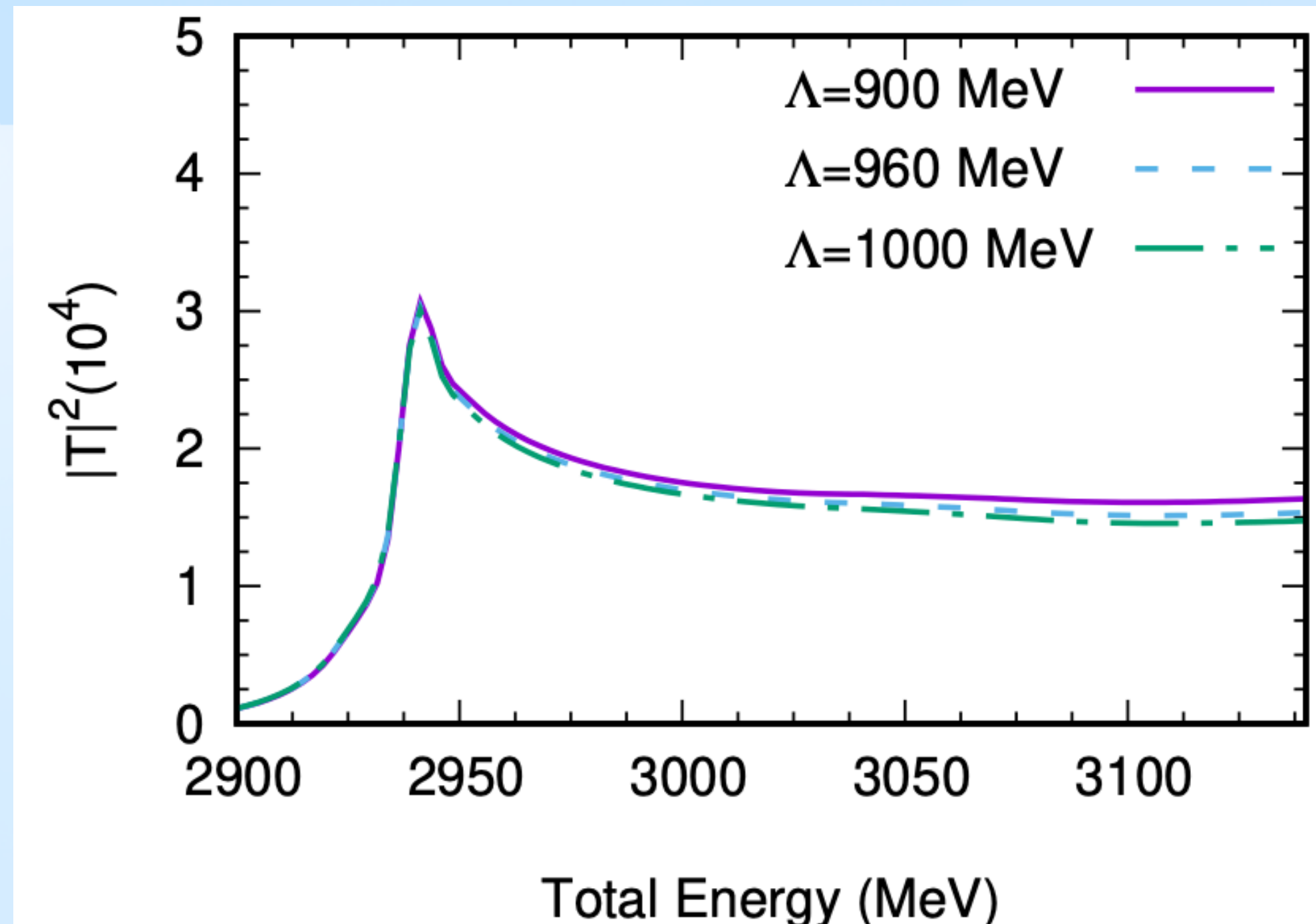
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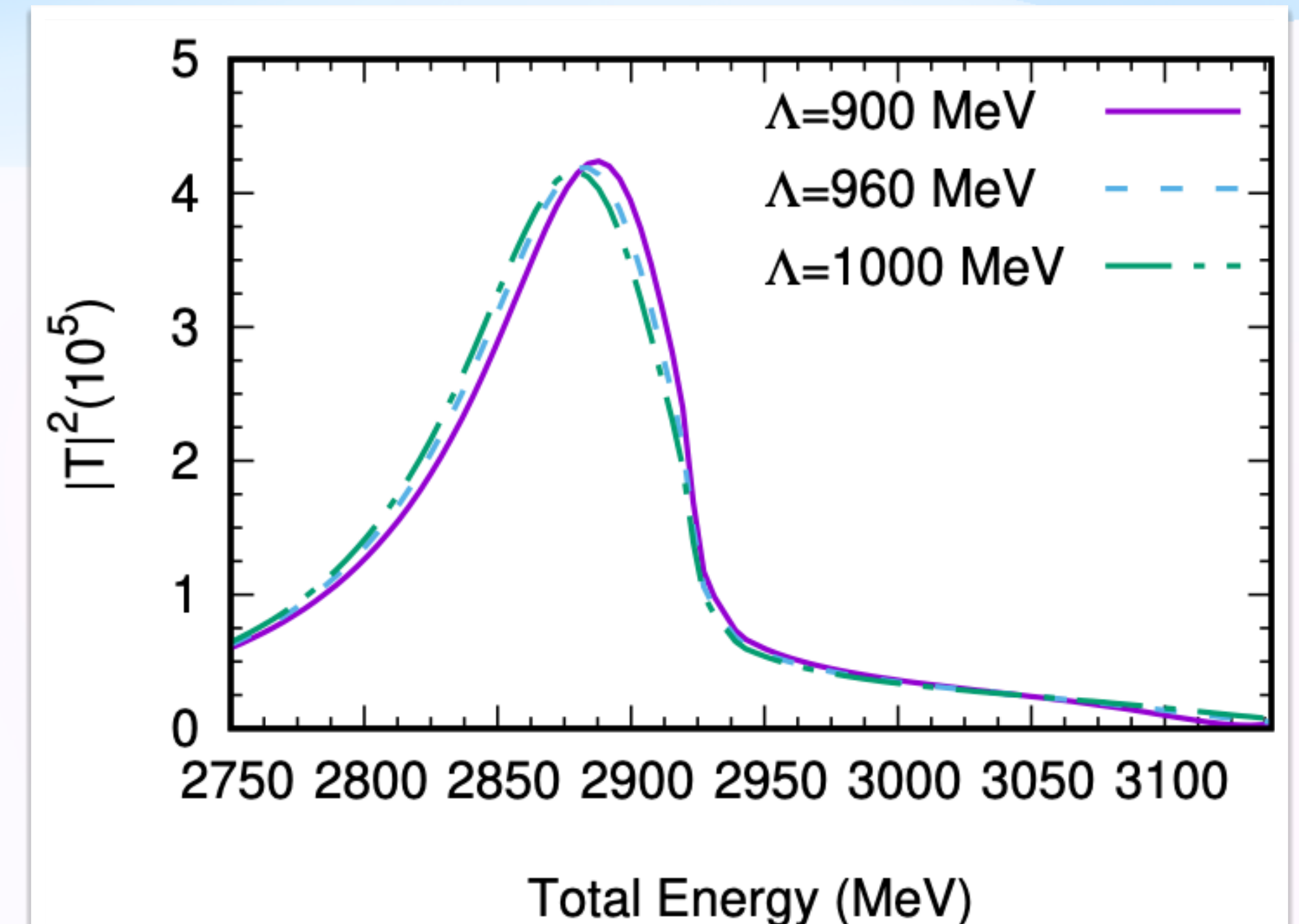
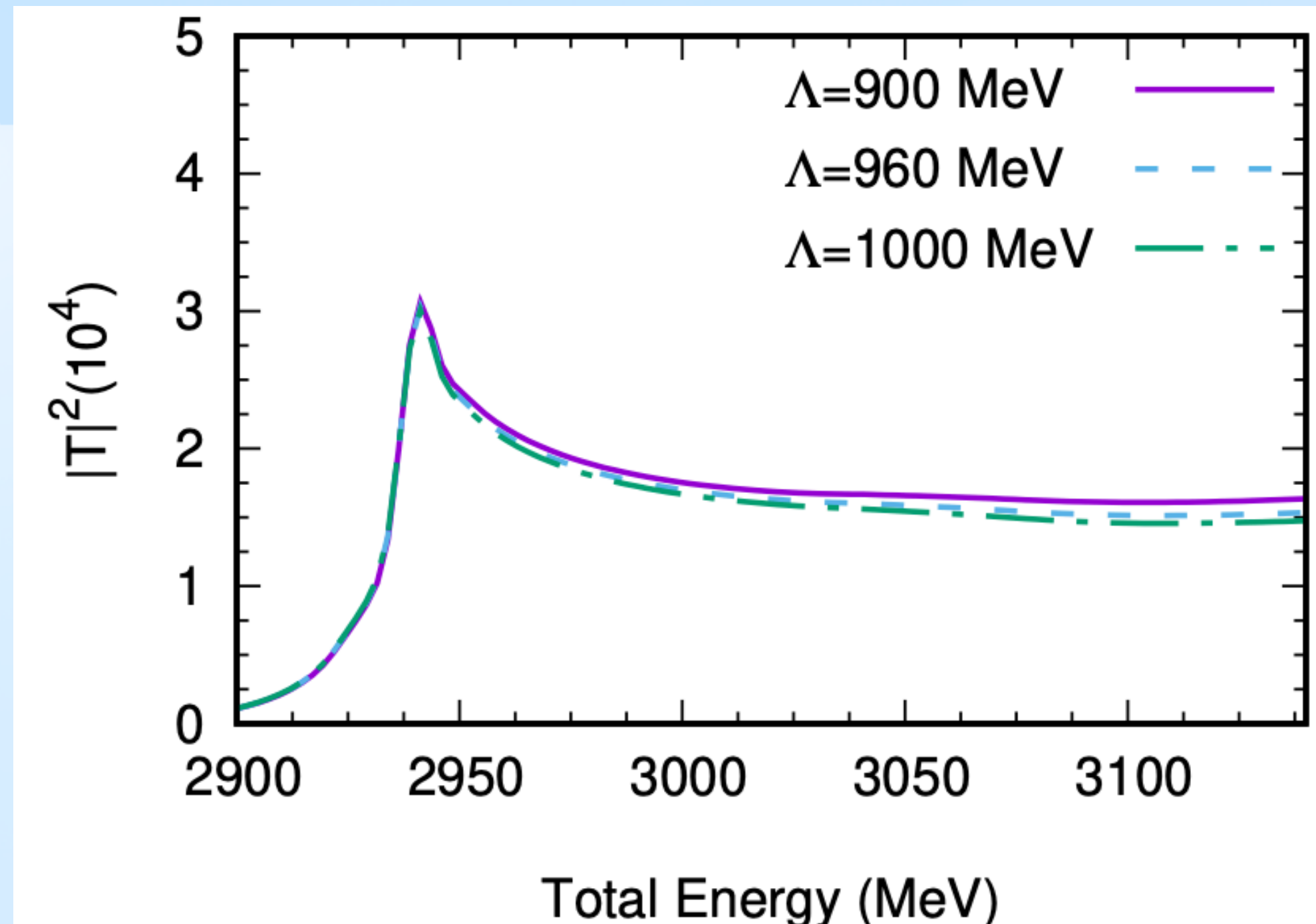
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PHYSICAL REVIEW D **107**, 036016 (2023)

**$D_1(2420)$ and its interactions with a kaon:
Open charm states with strangeness**

Brenda B. Malabarba,^{1,2,*} K. P. Khemchandani,^{3,2,†} A. Martínez Torres,^{1,2,‡} and E. Oset^{2,§}



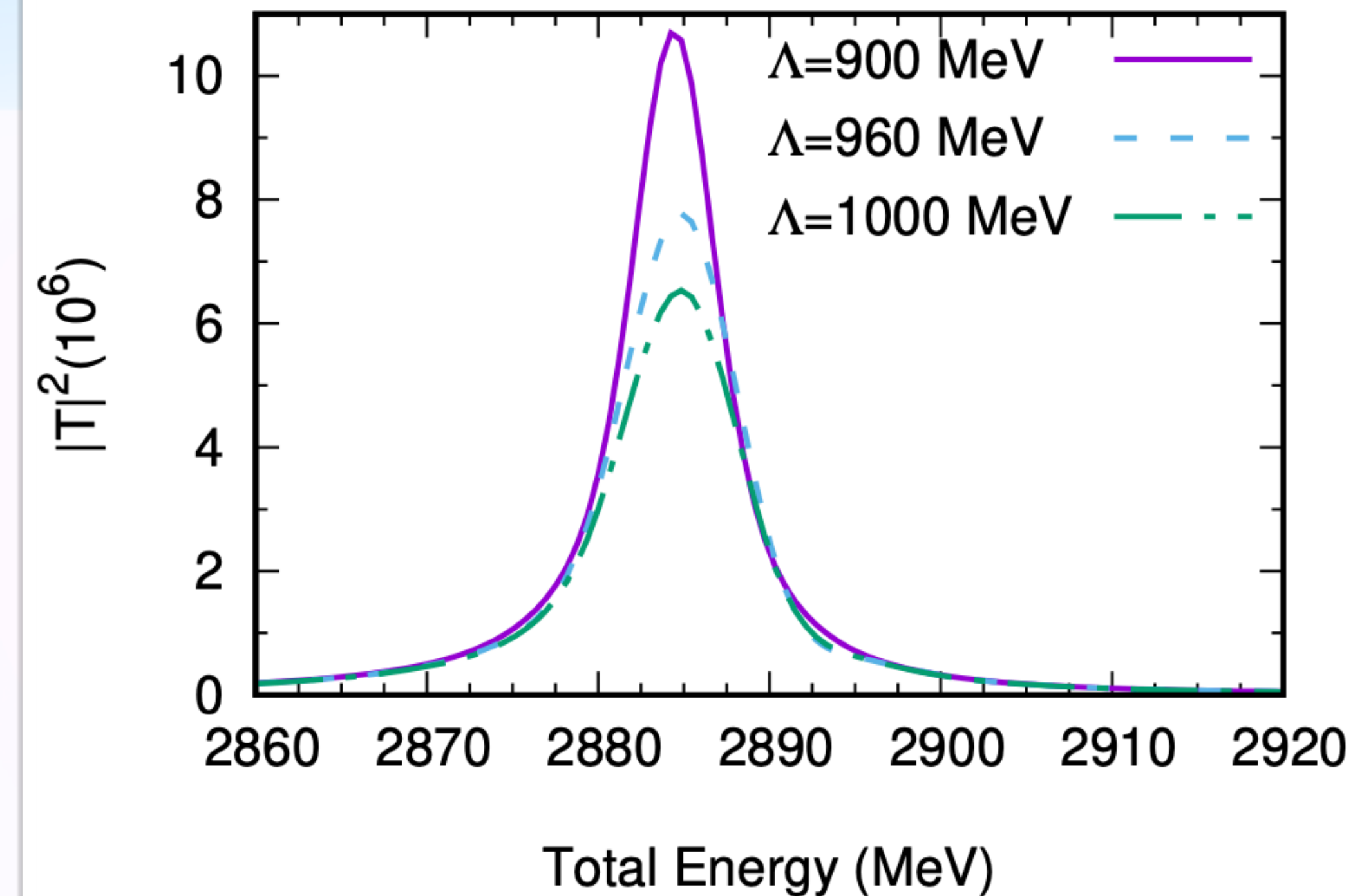
Going back to explicitly exotic mesons with charm

- In the same system with $C=+1$, we do find a state in isospin zero as well as 1.
- The state with isospin 1 can be interpreted as an effective “bound state” of $D_s(2317)\rho$. It is an exotic with minimum quark content: $cd\bar{s}u$ instead of $\bar{c}d\bar{s}u$ for $T_{\bar{c}\bar{s}1}$!
- We call it $T_{c\bar{s}1}$. It should be found in systems like DK^* .

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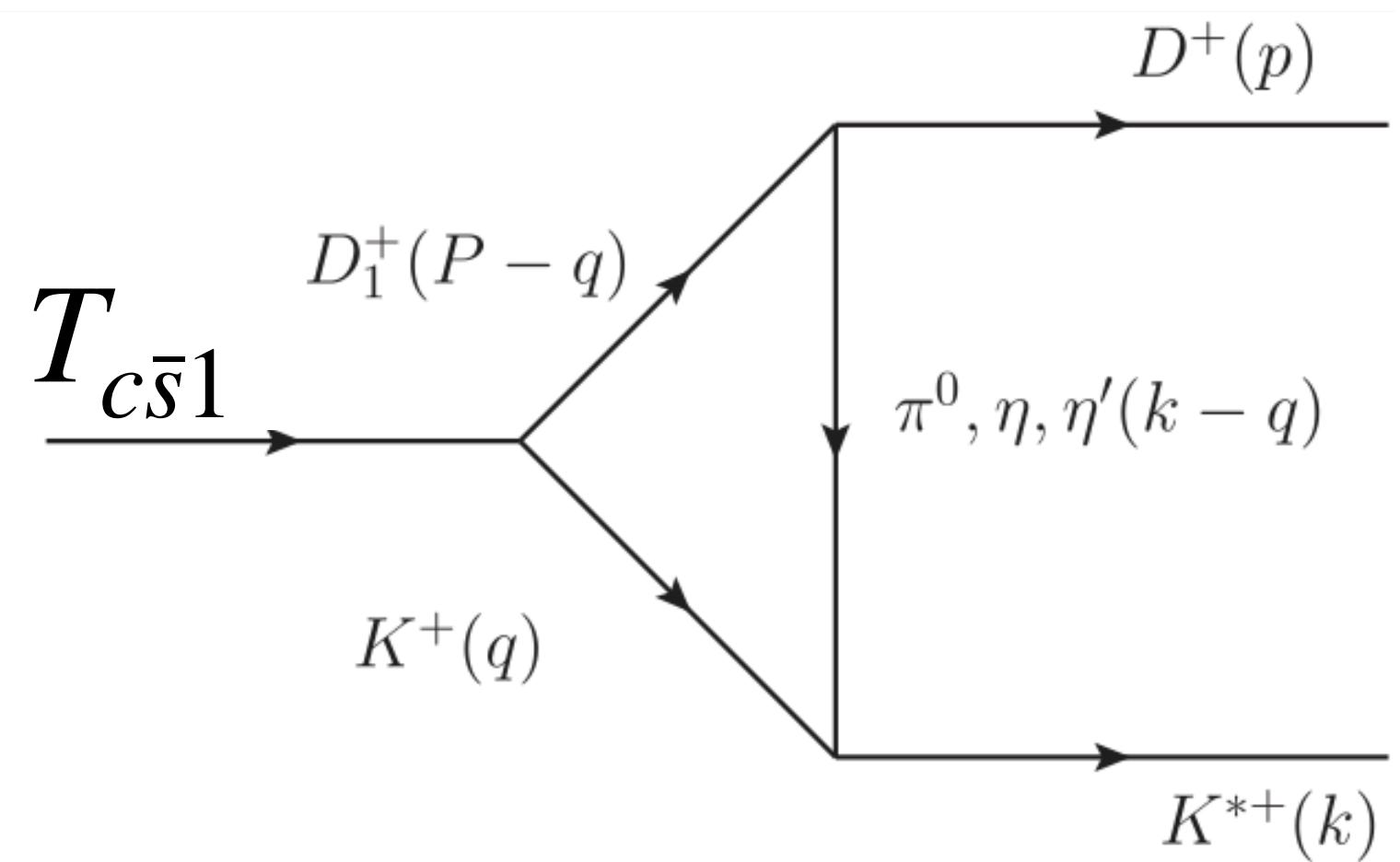


Work in progress (with Alberto's student)

- At present, we are studying which system would be most promising to find these $T_{c\bar{s}1}$.
- To do this, we are studying the coupling of $T_{c\bar{s}1}$ to two-body channels through triangular loops.
- We are also studying the processes for isospin 0 state: related to $D_{s1}(2860)$.

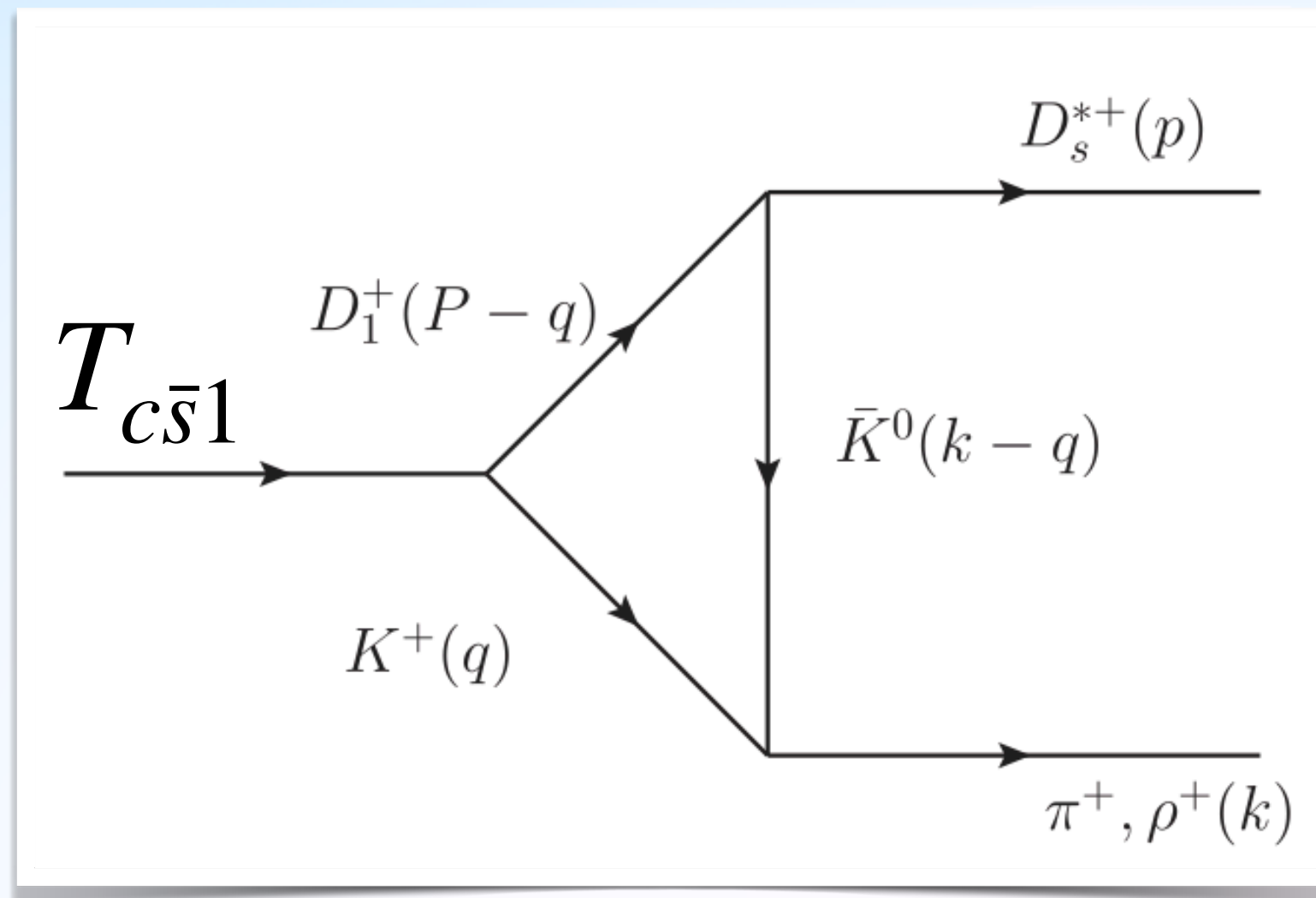
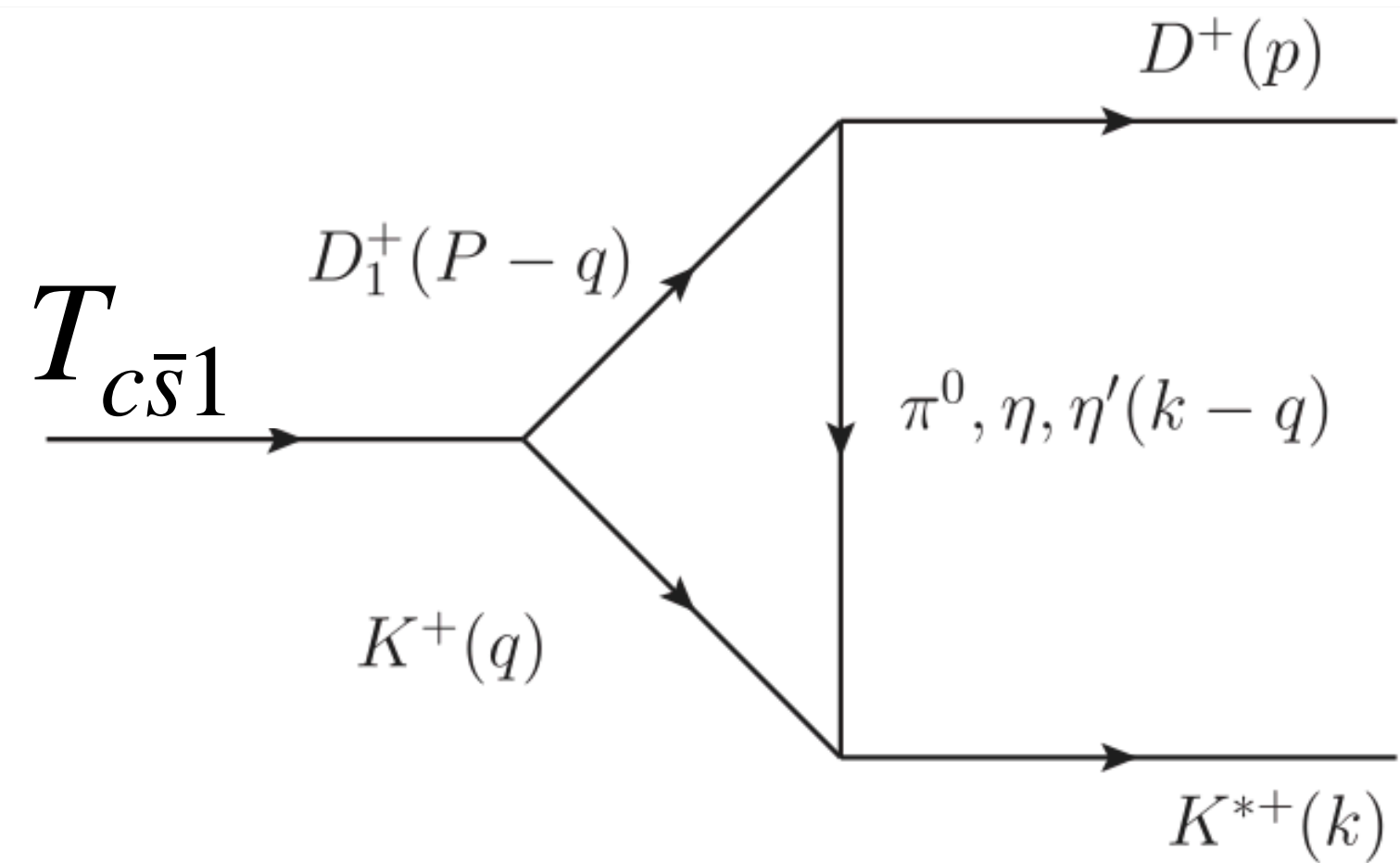
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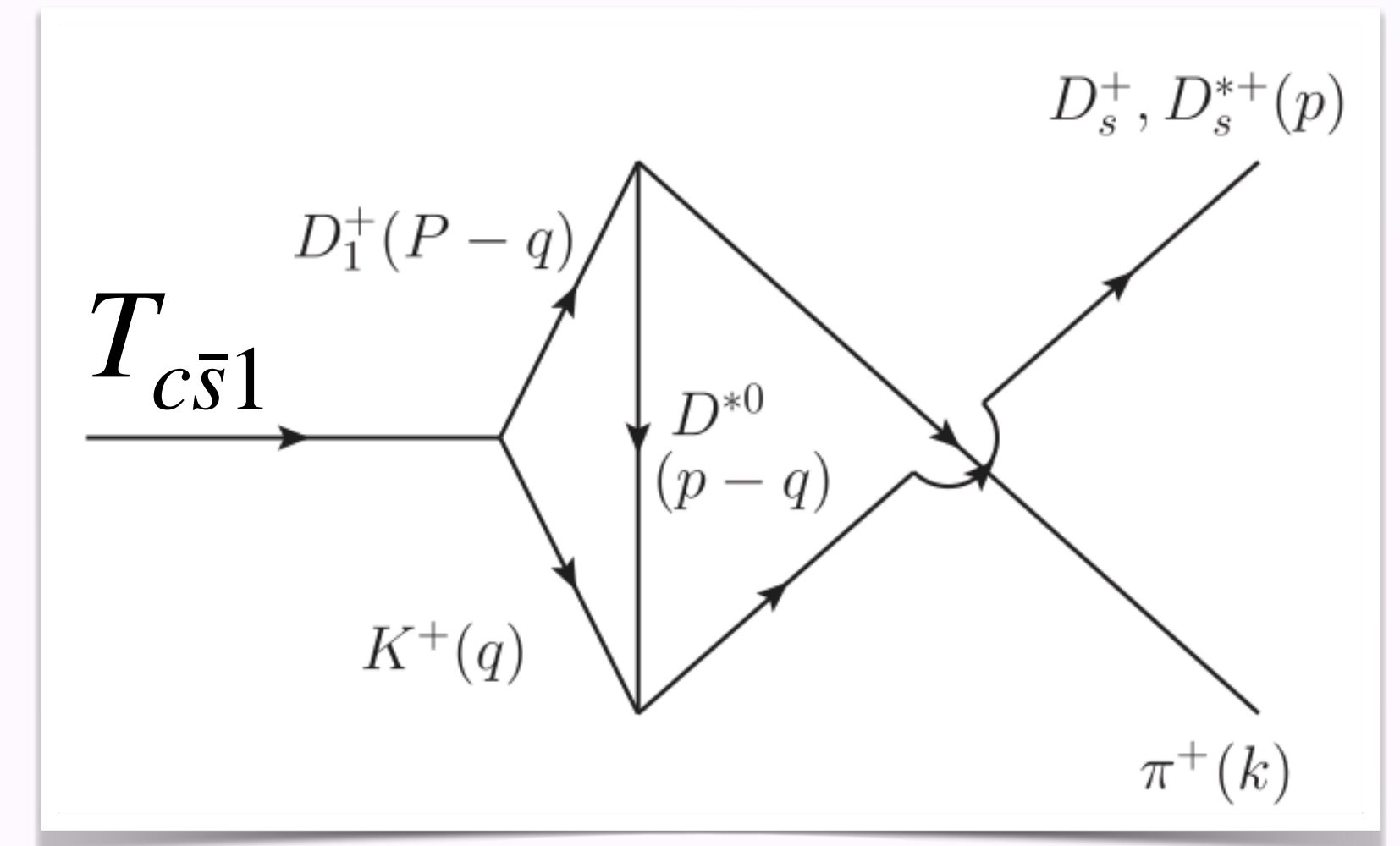
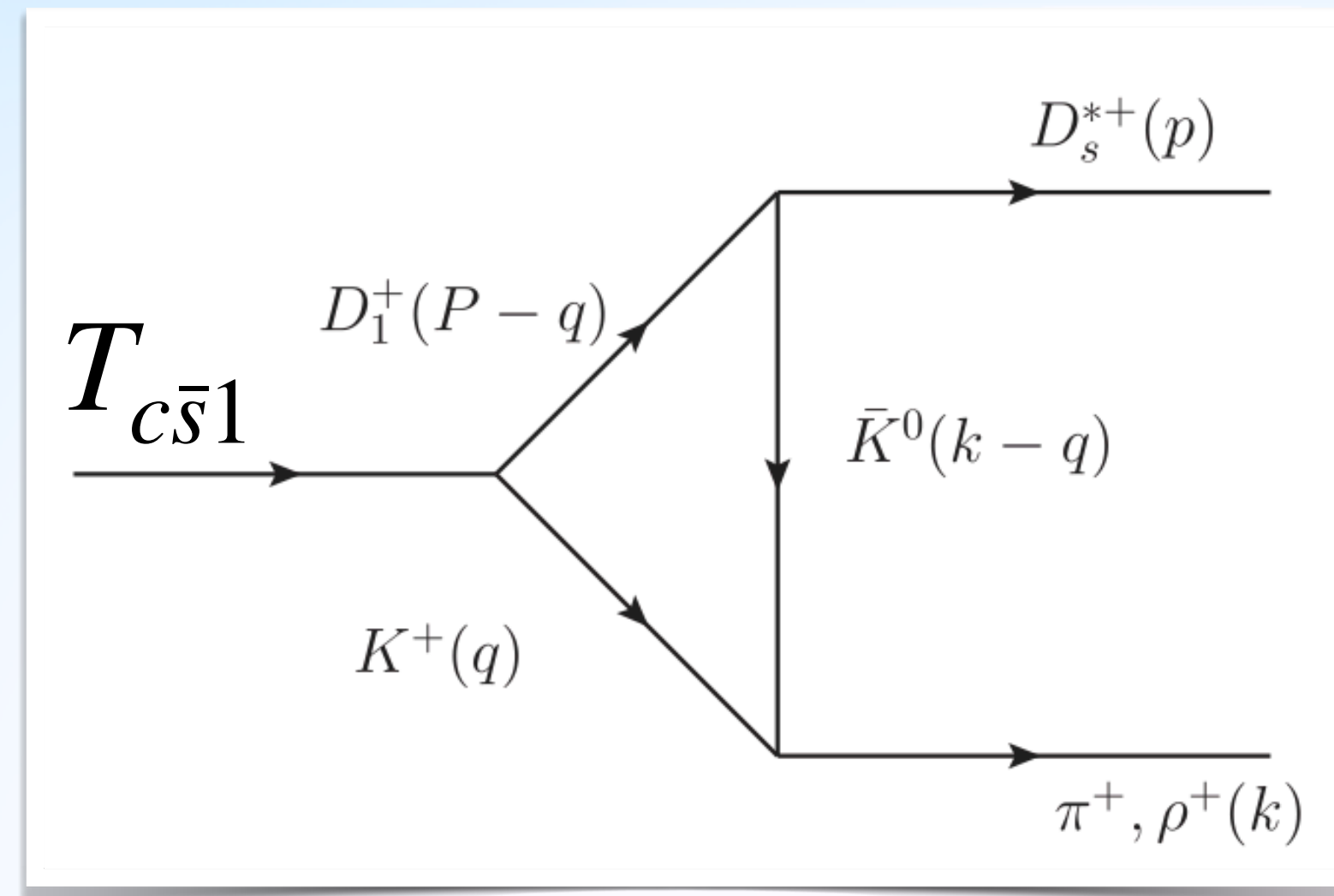
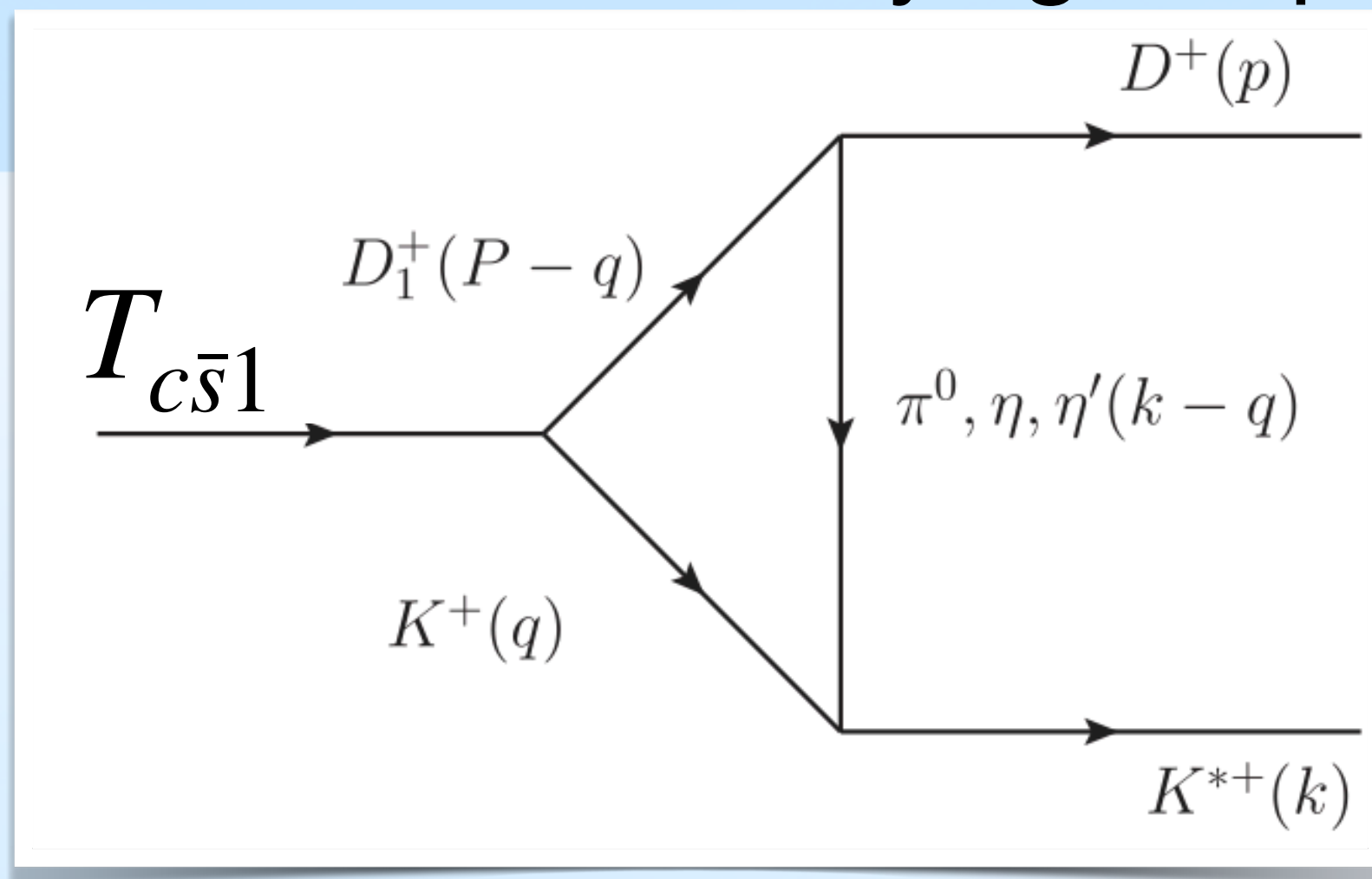
Work in progress (with Alberto's student)

- At present, we are studying which system would be most promising to find these $T_{c\bar{s}1}$.
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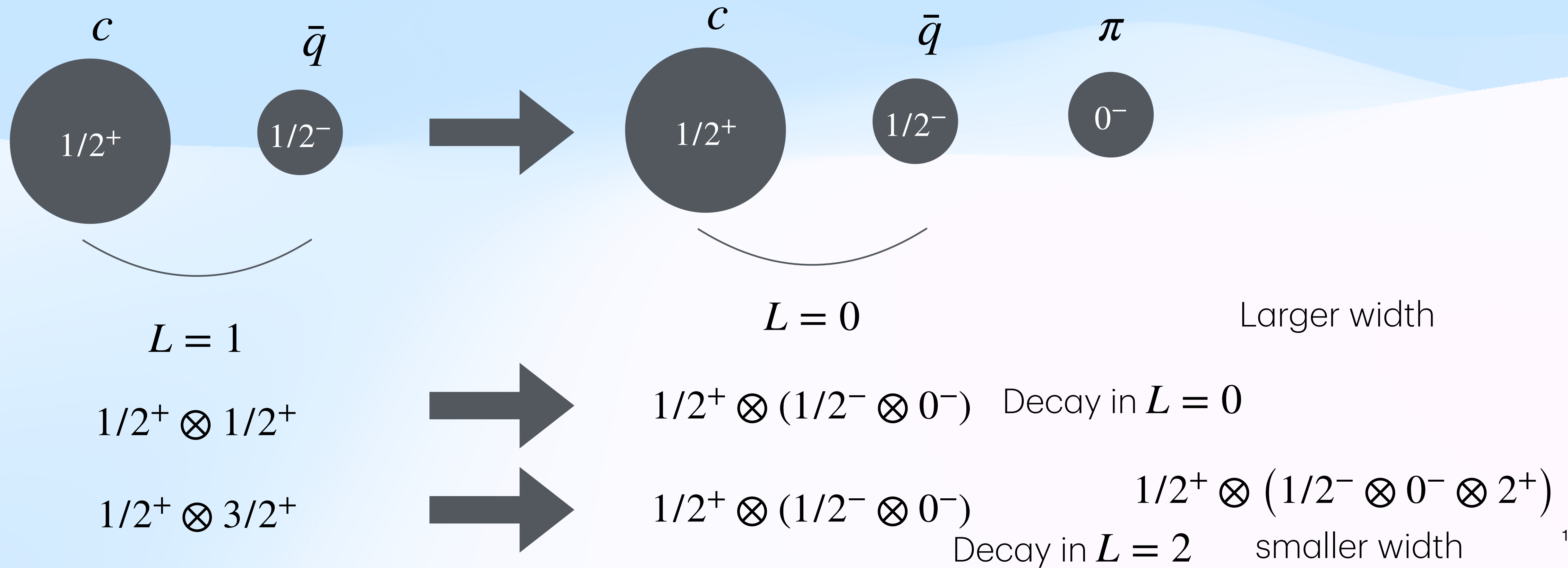
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A bit more on $D_1(2420)$

- Motivation for further study of $D^*\pi$ interactions: the existence of two lightest axial mesons with large uncertainties on their properties.
- $D_1(2420)$, $D_1(2430)$. Similar mass, different widths. We should be able to understand this in heavy quark spin symmetry.



Need for further studies of $D\rho - D^*\pi$ -coupled channels

- In practice, neither effective field theories based on chiral and heavy quark spin symmetry are able to describe the properties of the axial states, even with the presence of large uncertainties.
- The scattering lengths measured from heavy-ion collisions and from lattice do not agree with each other.

$$a_{D\pi}^{1/2} \sim 0.2 \text{ fm}$$

$$a_{D\pi}^{3/2} = -0.100(1) \text{ fm}$$

$$\tilde{a}_{D\pi}^{(1/2)} = 0.02 \pm 0.03 \pm 0.01 \text{ fm},$$

$$\tilde{a}_{D\pi}^{(3/2)} = 0.01 \pm 0.02 \pm 0.01 \text{ fm},$$

$$\tilde{a}_{D^*\pi}^{(1/2)} = -0.03 \pm 0.05 \pm 0.02 \text{ fm},$$

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Lattice-inspired χ FT models

L. M. Abreu, D. Cabrera, F. J. Llanes-Estrada, and J. M. Torres-Rincon, Ann. Phys. (Amsterdam) 326, 2737 (2011).

L. S. Geng, N. Kaiser, J. Martin-Camalich, and W. Weise, Phys. Rev. D 82, 054022 (2010).

Alice

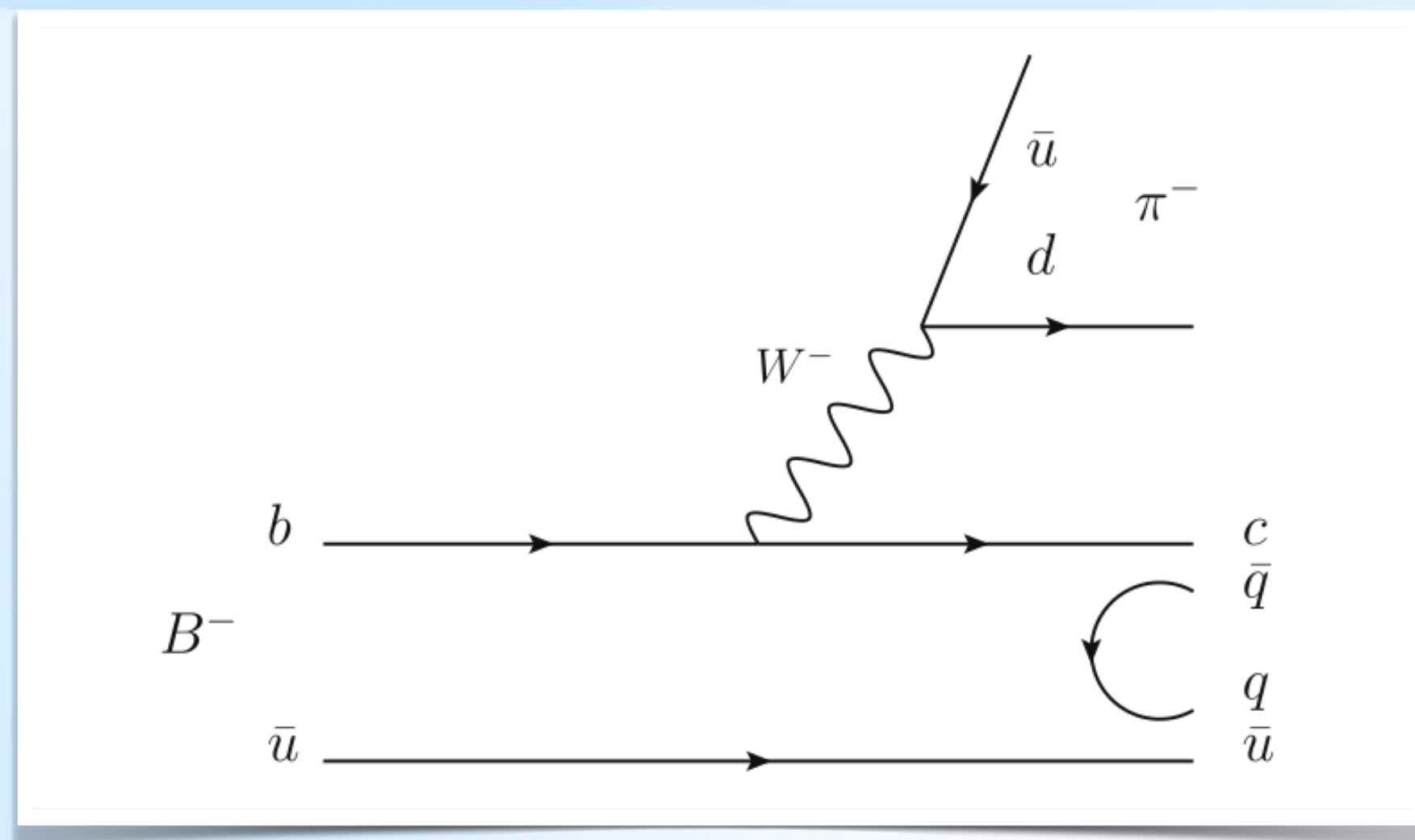
Phys. Rev. D 110 (2024) 032004

Need for further studies of $D\rho - D^*\pi$ -coupled channels

- Recently, data on $B^+ \rightarrow D^{*-} D_s^+ \pi^+$ [JHEP 08, 165 (2024)]
- $B^- \rightarrow D^{*+} \pi^- \pi^-$ has been made available [R. Aaij et al. (LHCb), PRD 101, 032005 (2020)]
- Studying FSI in these processes can bring useful information.

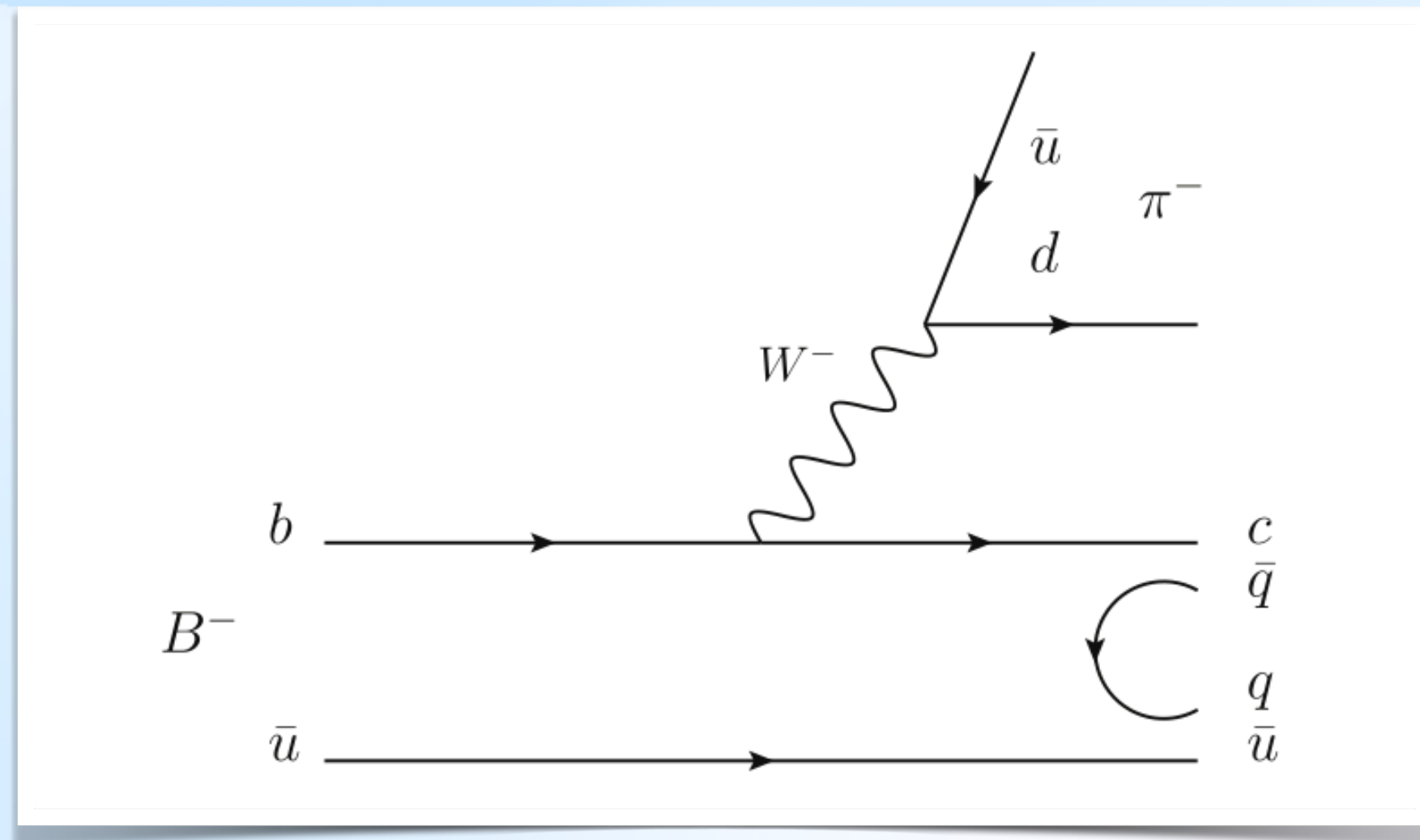
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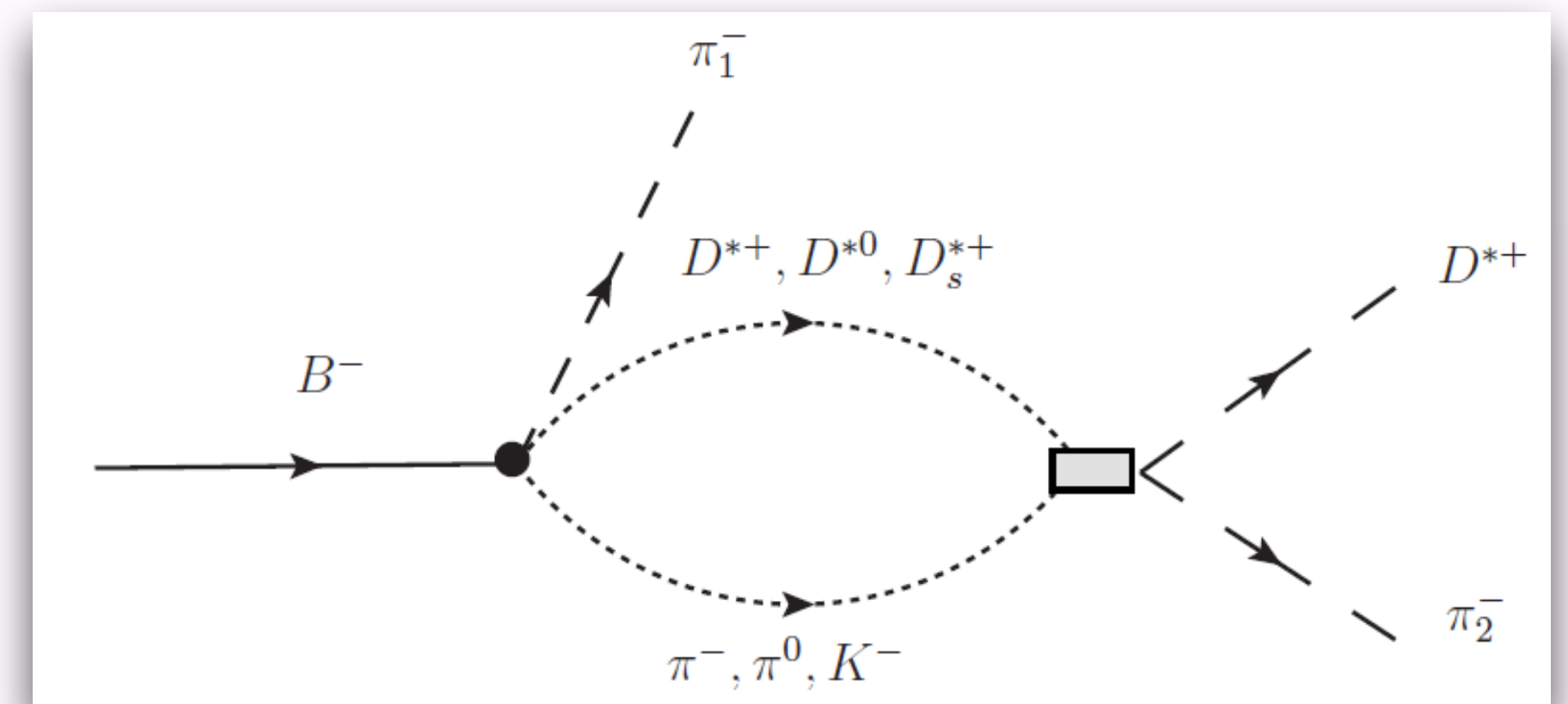
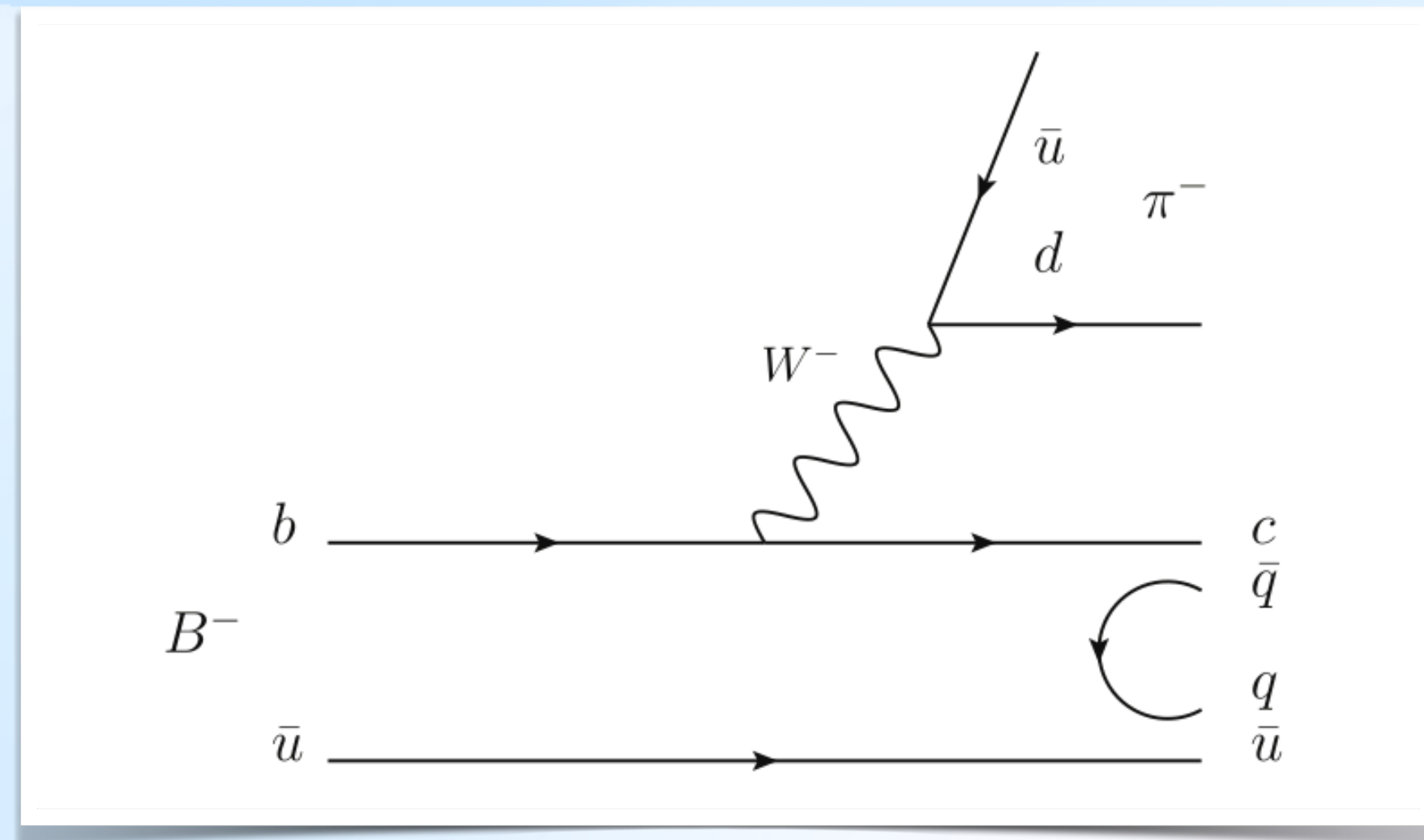
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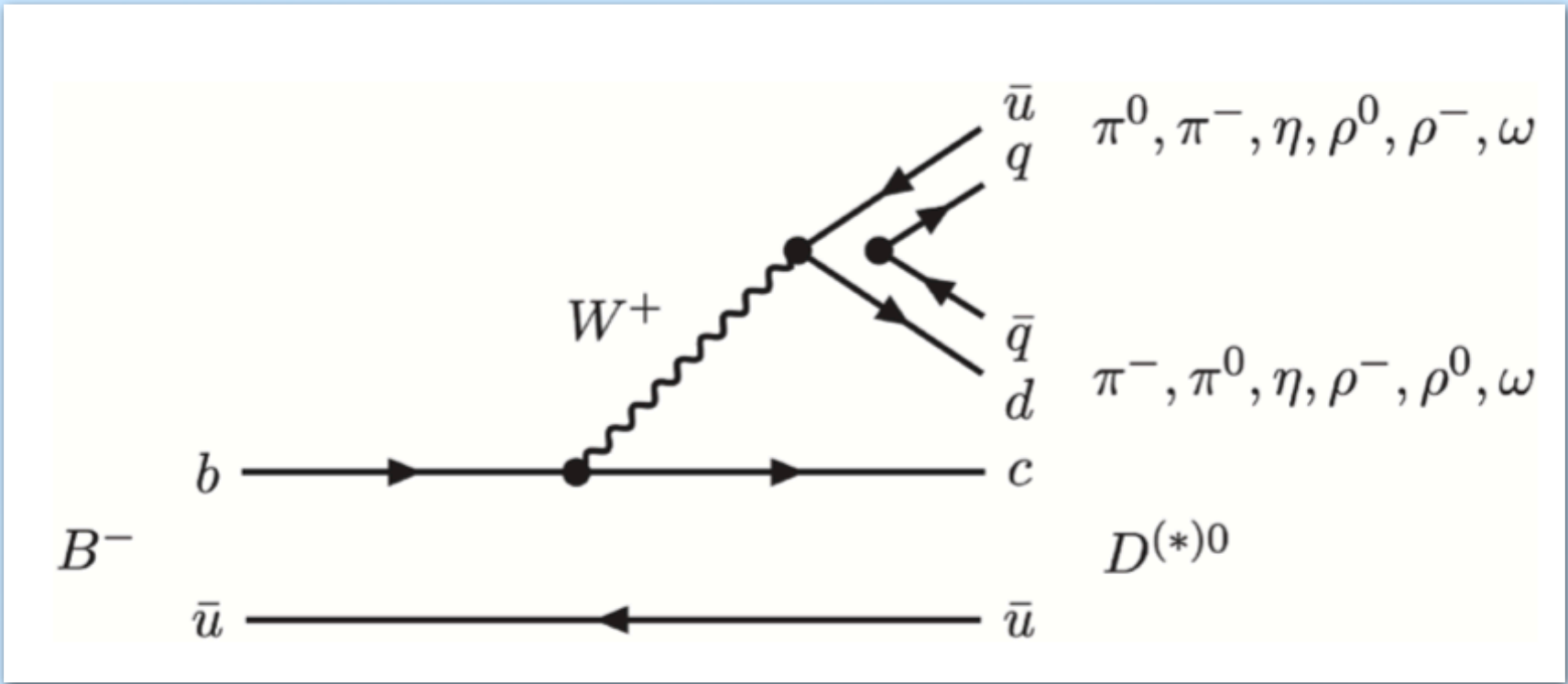


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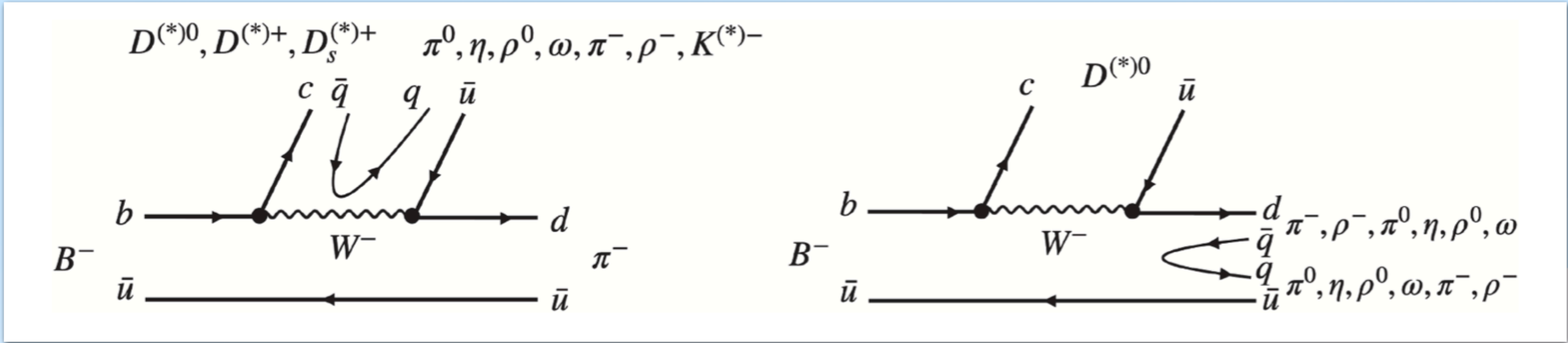
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- Studying FSI in these processes can bring useful information.



- We consider data on weak decays $B^+ \rightarrow D^{*-} D_s^+ \pi^+$, $B^- \rightarrow D^{*+} \pi^- \pi^-$ as an alternative source of information



+



+ FSI

Phys. Lett. B 878 (2026) 140527

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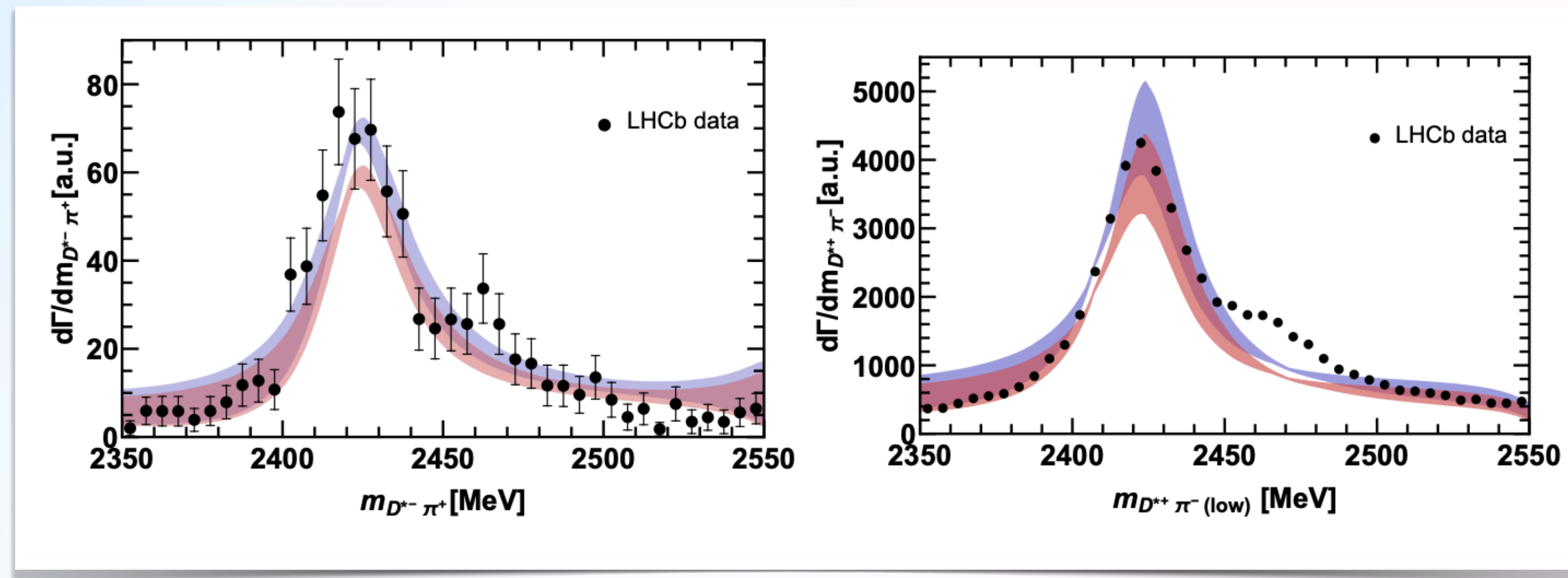
$D^* \pi$ interaction from the lineshape of $D_1(2420)$ in B -decays

Pedro Brandão ^a, Breno Agatão ^b, Luciano M. Abreu ^{a,*}, K.P. Khemchandani ^c,
A. Martínez Torres ^b



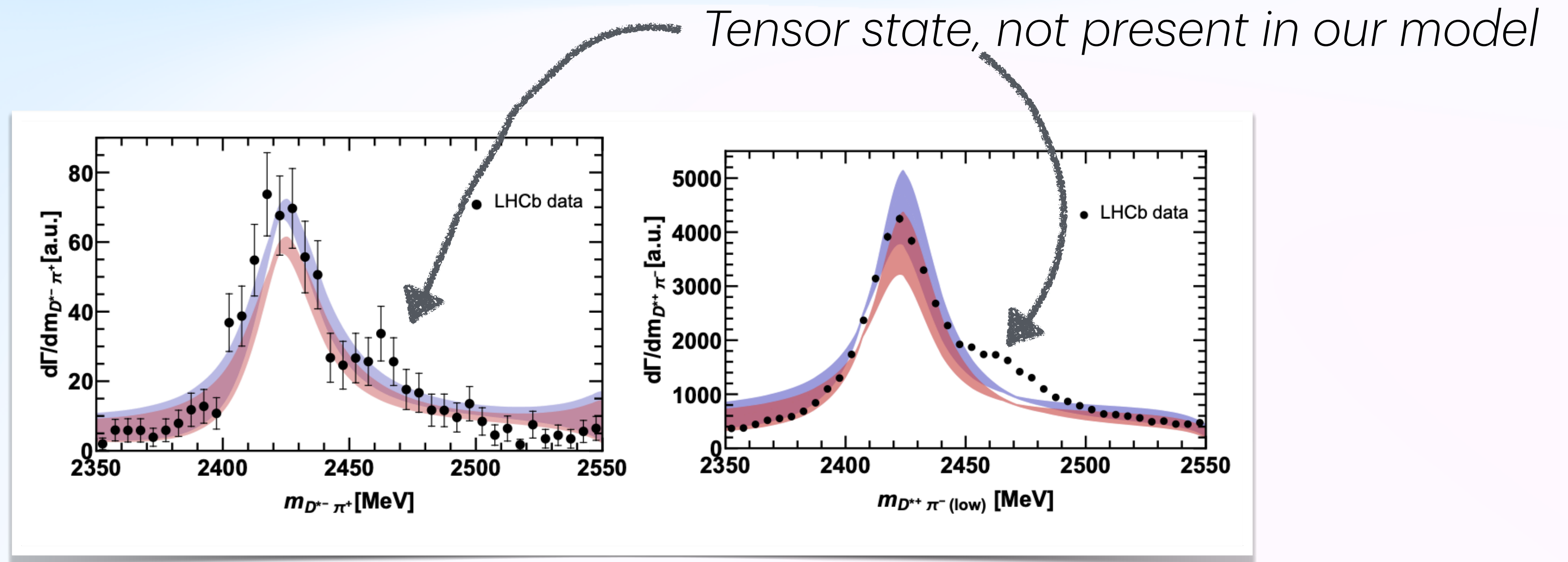
Is $D_1(2420)$ related to $D\rho - D^*\pi$ -coupled channel interactions?

- The data can be described by s-wave interactions alone. In contrast to the 60-80% D-wave + 1-10% S-wave contribution considered in the fit made by the experimental group.
- D-wave interaction may contribute in a smaller proportion. We should implement it in the future.
- Future prospects: the data is dominated by the $D_1(2420)$ signal. A more refined model describing $D_1(2430)$ should be considered.



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$D^*\pi$ scattering length

- We find the scattering length value, $|a_{D^*\pi}^{1/2}| = 0.45$ fm, in agreement with lattice-inspired χ FT models.

$$a_{D^*\pi}^{1/2} = 0.37^{+0.03}_{-0.02} \text{ fm}$$

$$a_{D^*\pi}^{3/2} = -0.100(1) \text{ fm}$$

Lattice-inspired χ FT models

Liuming Liu, Kostas Orginos, Feng-Kun Guo, Christoph Hanhart, Ulf-G. Meissner Phys.Rev.D 87 (2013) 1, 014508

$$\begin{aligned}\tilde{a}_{D\pi}^{(1/2)} &= 0.02 \pm 0.03 \pm 0.01 \text{ fm}, \\ \tilde{a}_{D\pi}^{(3/2)} &= 0.01 \pm 0.02 \pm 0.01 \text{ fm}, \\ \tilde{a}_{D^*\pi}^{(1/2)} &= -0.03 \pm 0.05 \pm 0.02 \text{ fm}, \\ \tilde{a}_{D^*\pi}^{(3/2)} &= 0.05 \pm 0.04 \pm 0.02 \text{ fm}.\end{aligned}$$

Alice

Phys. Rev. D 110 (2024) 032004

Works motivated by Brazilian research on heavy ion collisions

- Yields of different hadrons in heavy ion collisions is sensitive to the nature of hadrons and their interactions
- Heavy ion collisions, even future facilities like EIC can be useful to study properties of exotic hadrons
- Several photons are produced in ultraperipheral collisions.
- These photons have different energies.
- Number of photons with low energies is much larger
- These photons can interact to produce exotic hadrons!
- Raquel and Eulogio studied decays of several exotics to two photons. They are being very used by Brazilian researchers.

Probing the $X(3700)$ through two-photon $D\bar{D}$ production in ultraperipheral collisions
and at the EIC

F.C. Sobrinho,¹ F.S. Navarra,¹ K.P. Khemchandani,² and A. Martínez Torres¹

¹*Instituto de Física, Universidade de São Paulo,
Rua do Matão 1371 - CEP 05508-090, Cidade Universitária, São Paulo, SP, Brazil*

²*Universidade Federal de São Paulo, CEP 01302-907, São Paulo, SP, Brazil*

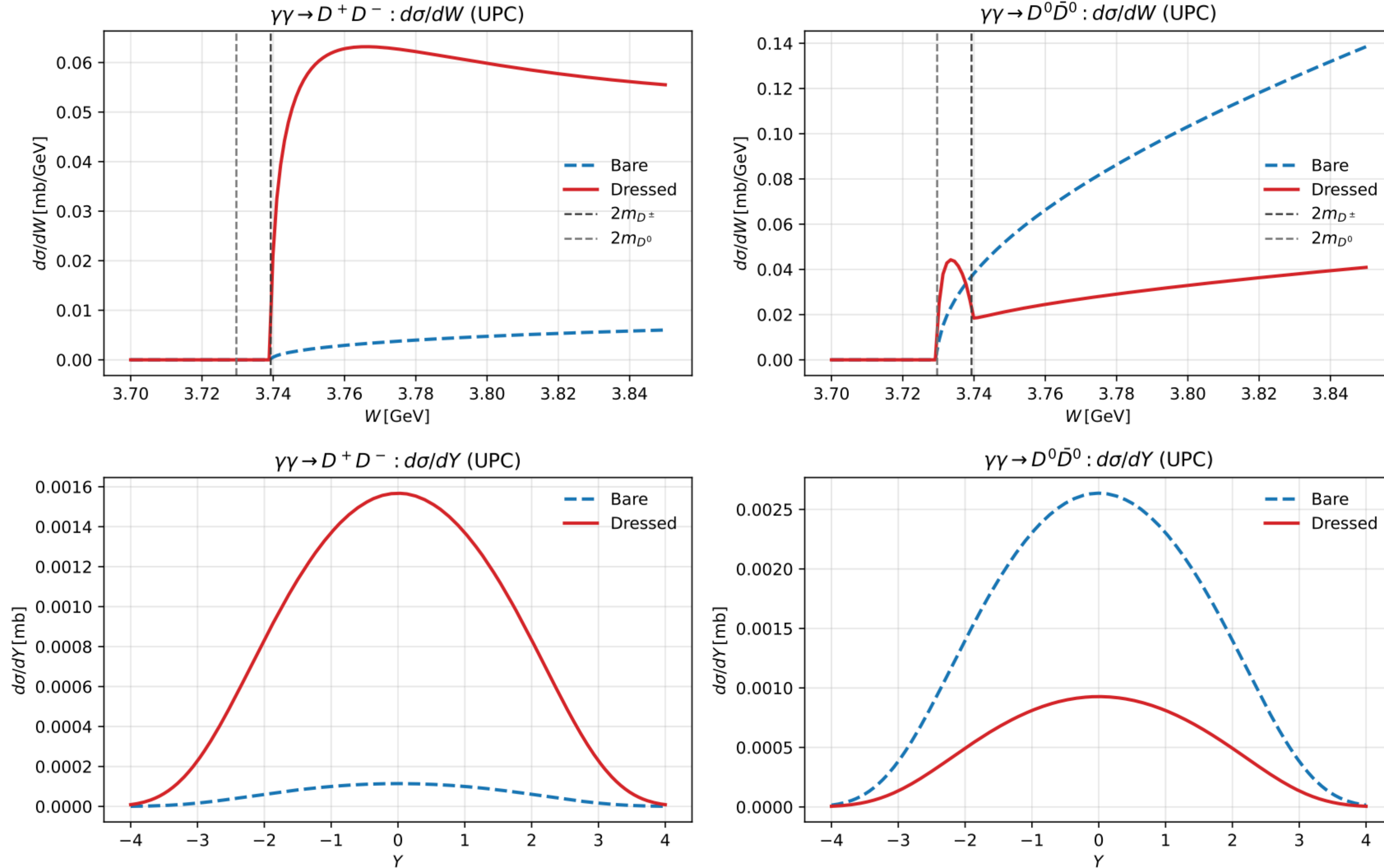
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UPC Observables (Pb-Pb @ LHC, $\gamma\gamma=2750$)



Conclusions

- Interesting problems are being studied in the USP-Unifesp collaborative projects
- Studies of properties of exotic mesons $T_{c\bar{s}1}$ and $D_{s1}(2860)$ are underway and can hopefully motivate new experimental investigations.
- Scattering length values for $D^*\pi$ the system are in disagreement from different sources, and we have studied its production in weak processes; we are able to describe the data with a larger s-wave contribution than proposed by the analysis carried out by the experimental group. Further studies are being carried out.
- Properties of hadrons can be investigated in heavy-ion collisions and at facilities like the EIC.

THANK YOU!