Hadron physics

Kanchan Khemchandani
Unifesp

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  - Heavy-ion collisions: we need to understand yields; they can be affected by the formation of resonances.

Hadron physics: coupled channel dynamics

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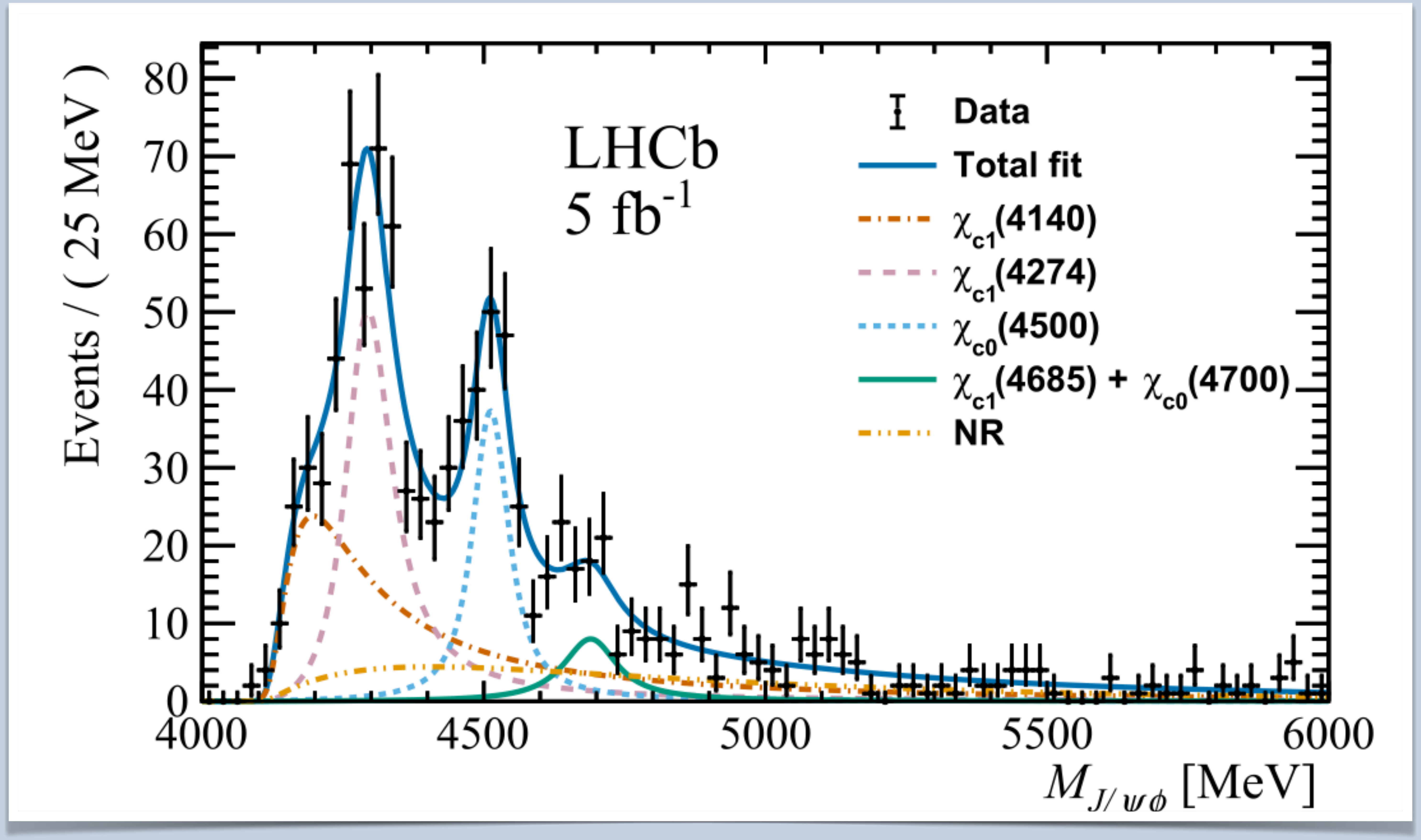
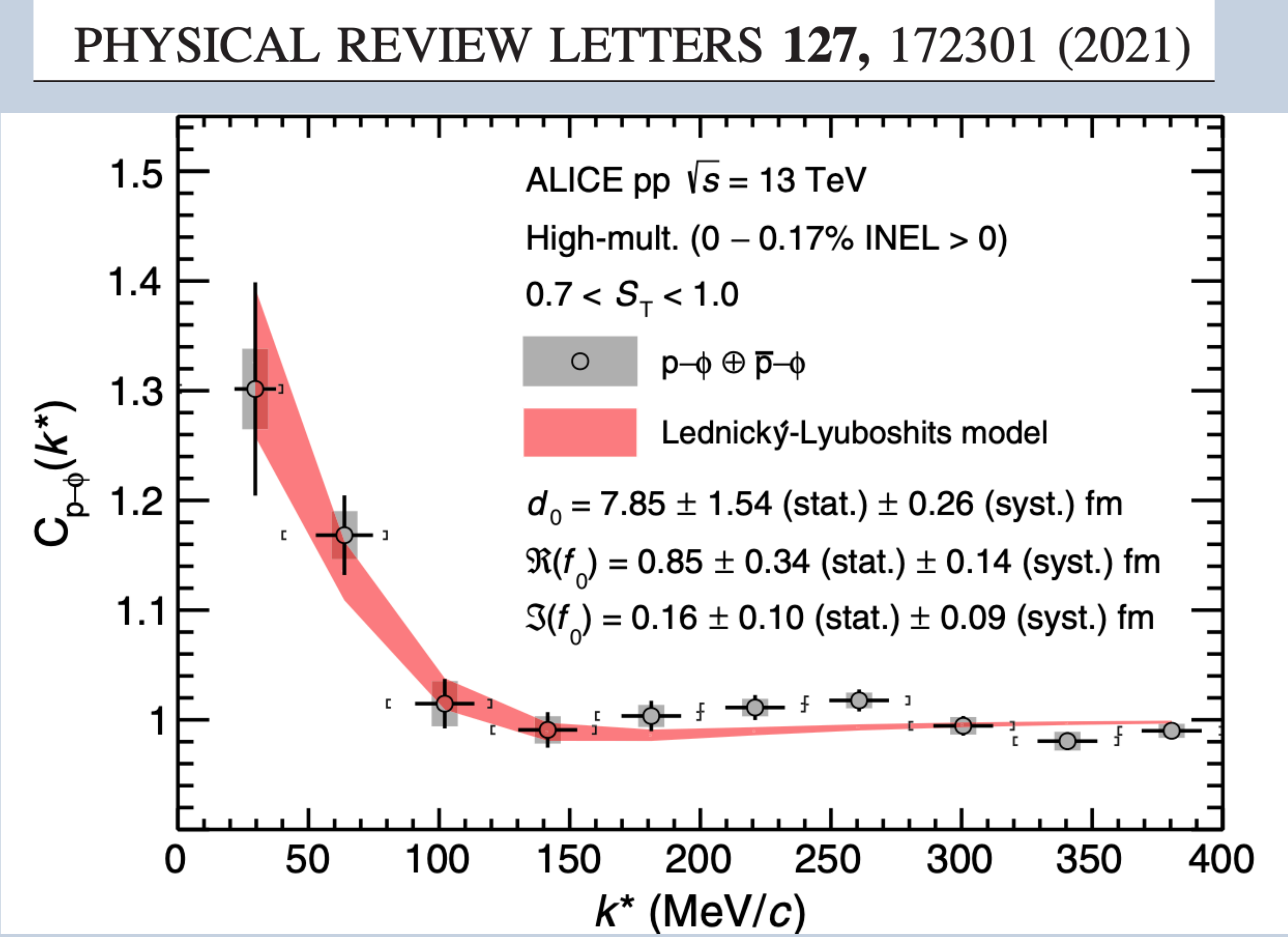
- Structures seen in OZI-suppressed systems



Nuclear and Particle Physics Proceedings Volume 347, December 2024, Pages 90-93

Hadron physics: coupled channel dynamics

- Similar case: ϕN



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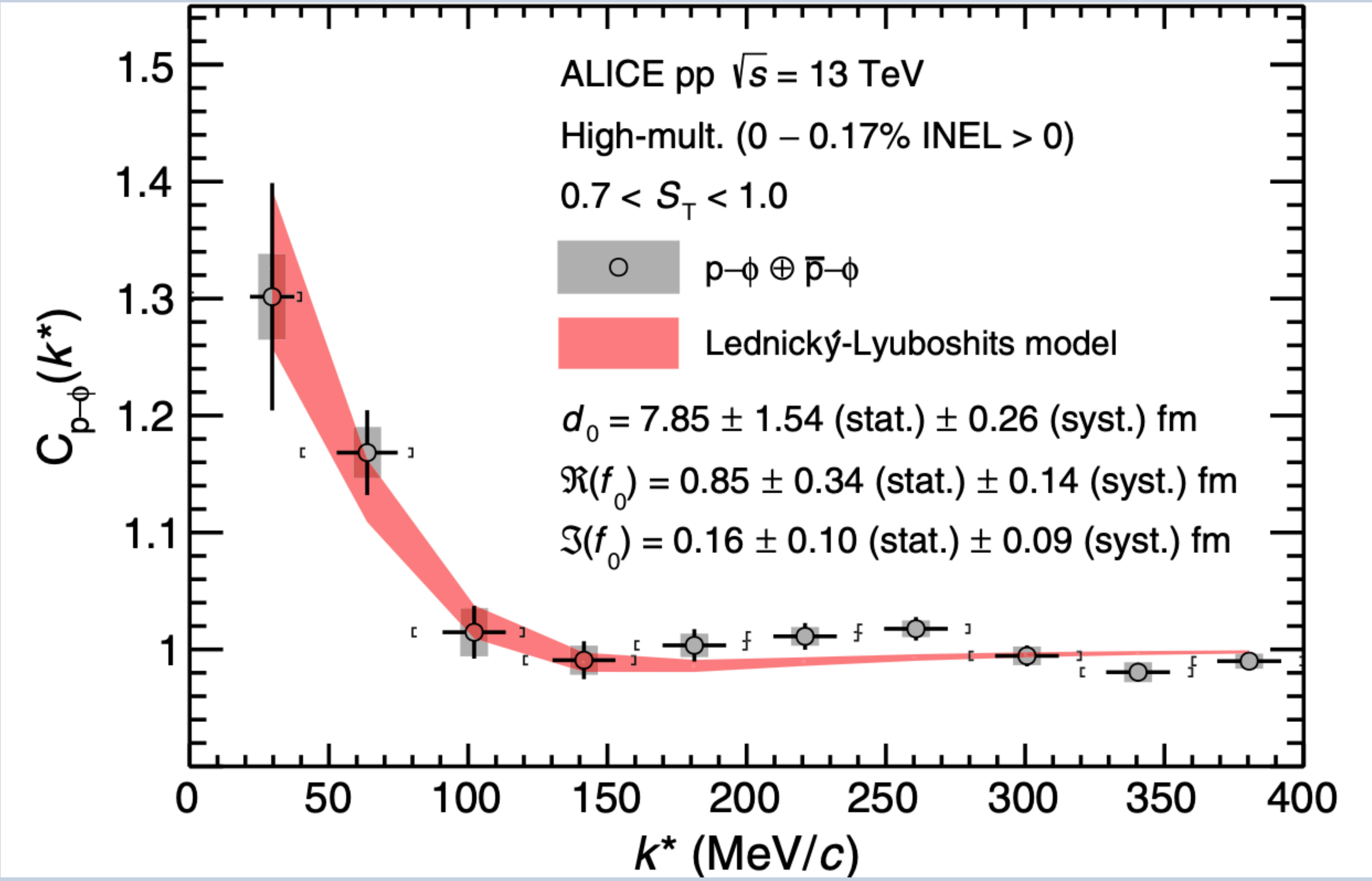
Expt:

PHYSICAL REVIEW LETTERS **127,** 172301 (2021)



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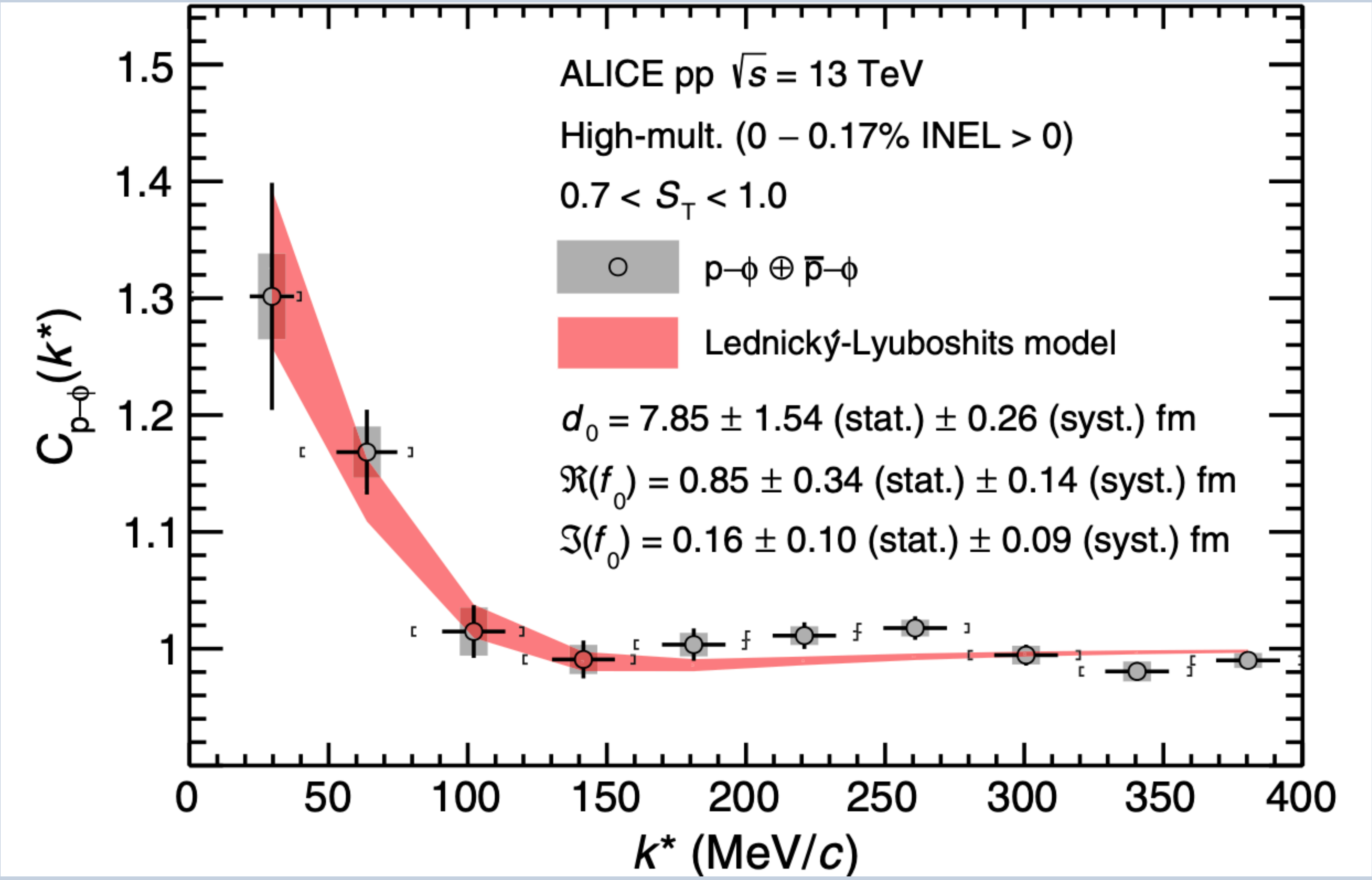

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momentum distribution of a pair in the same event vs pair coming from different events

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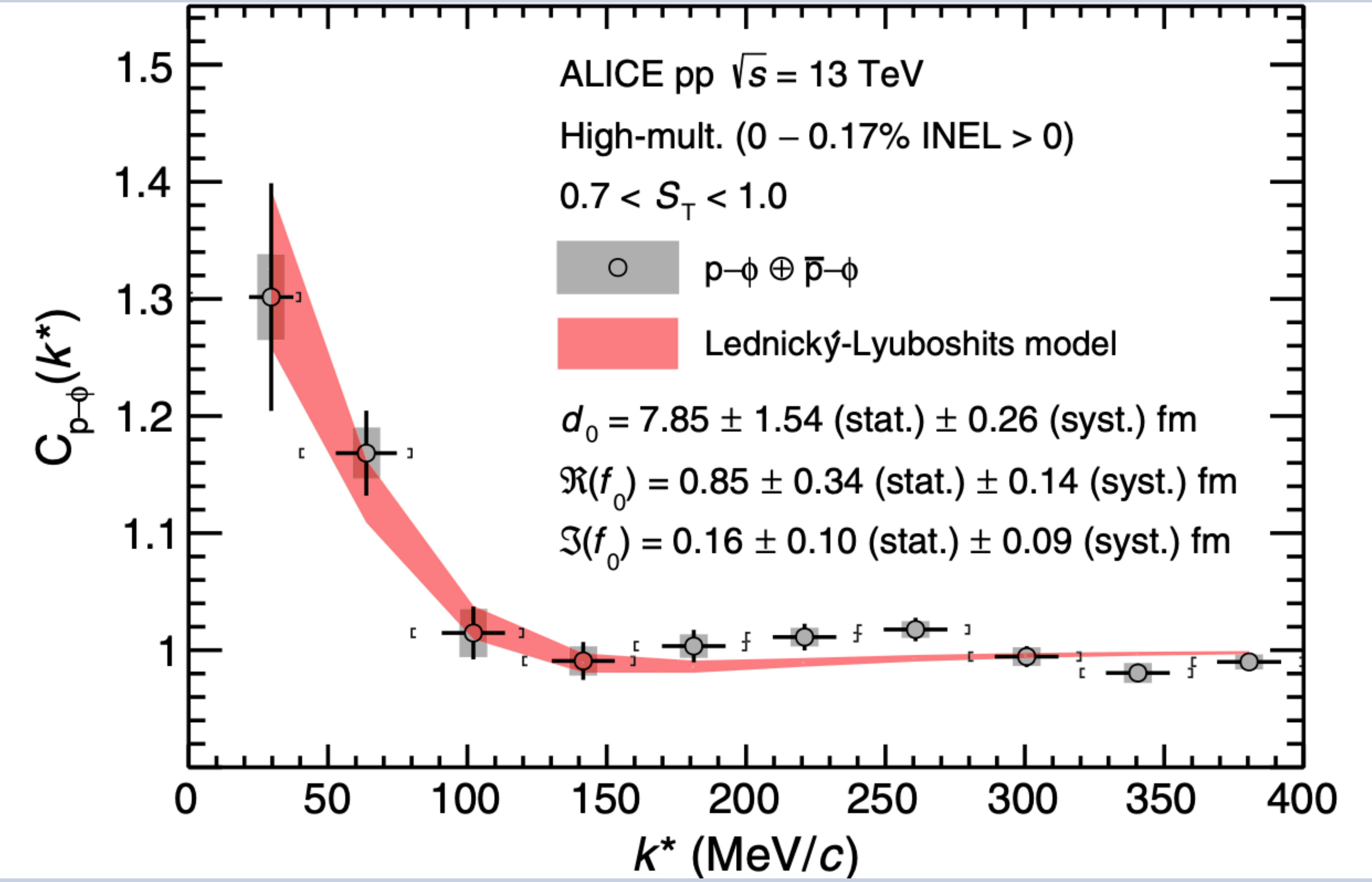

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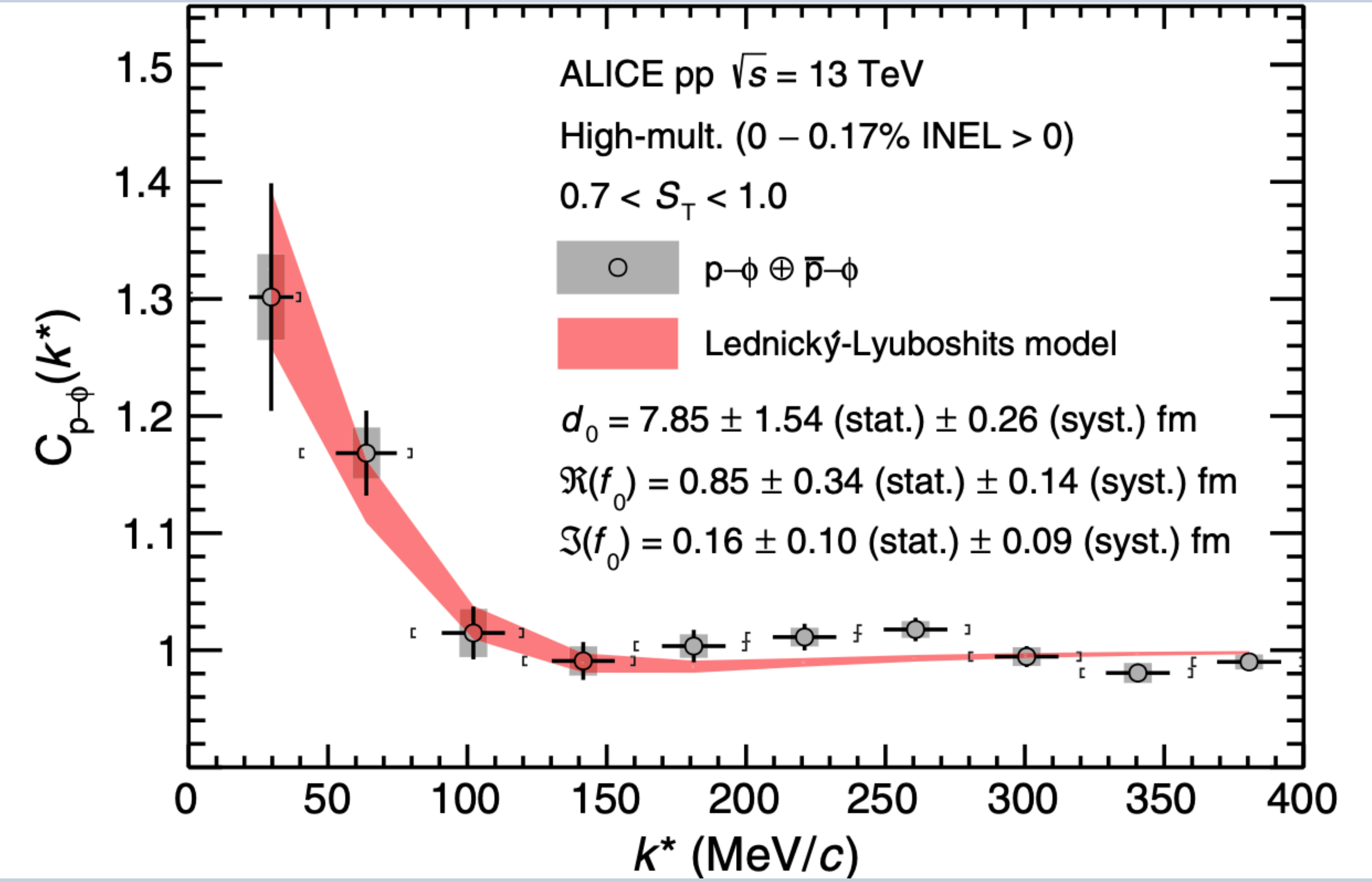

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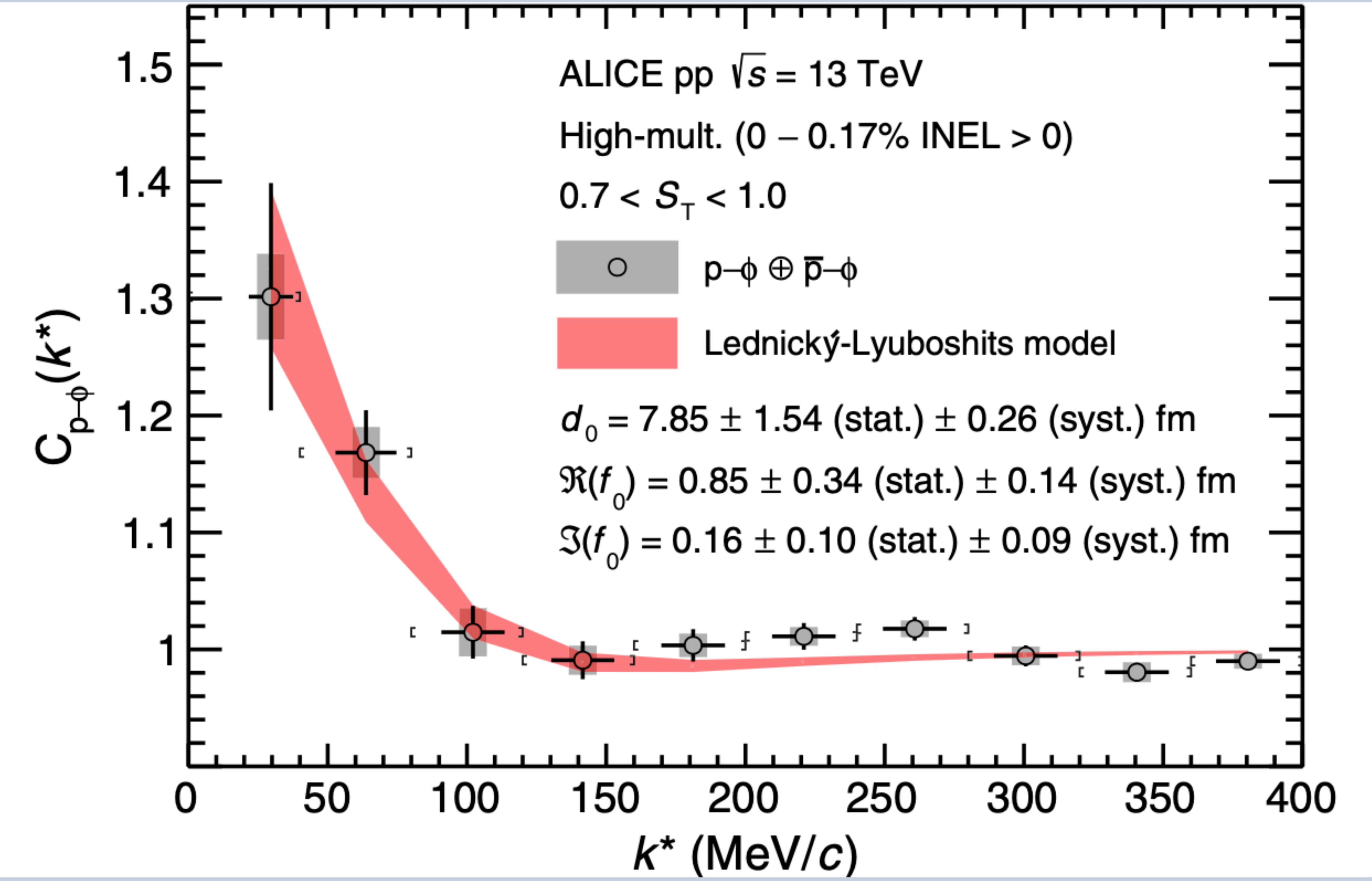

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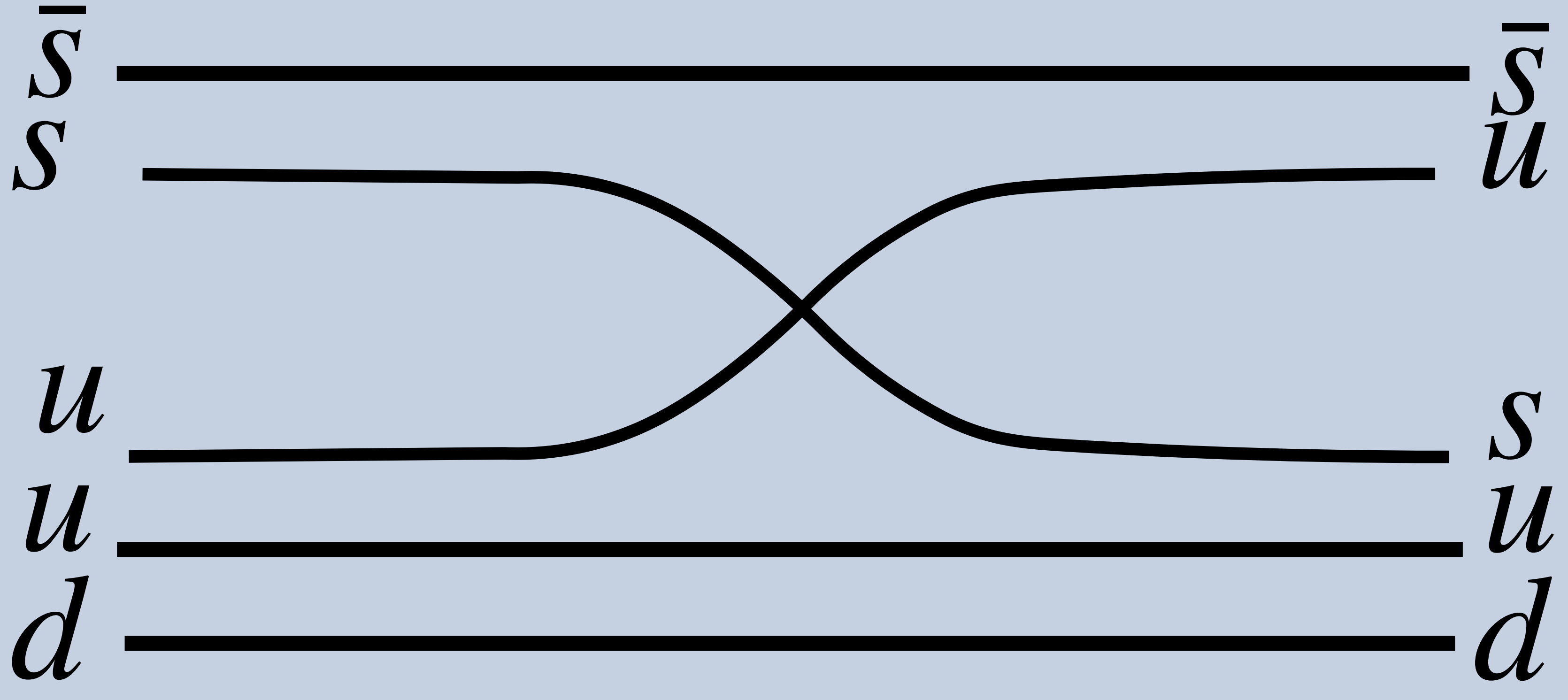
$$\phi N \to \bar{K}^*\Sigma, \bar{K}^*\Lambda, \pi\Xi \ldots$$



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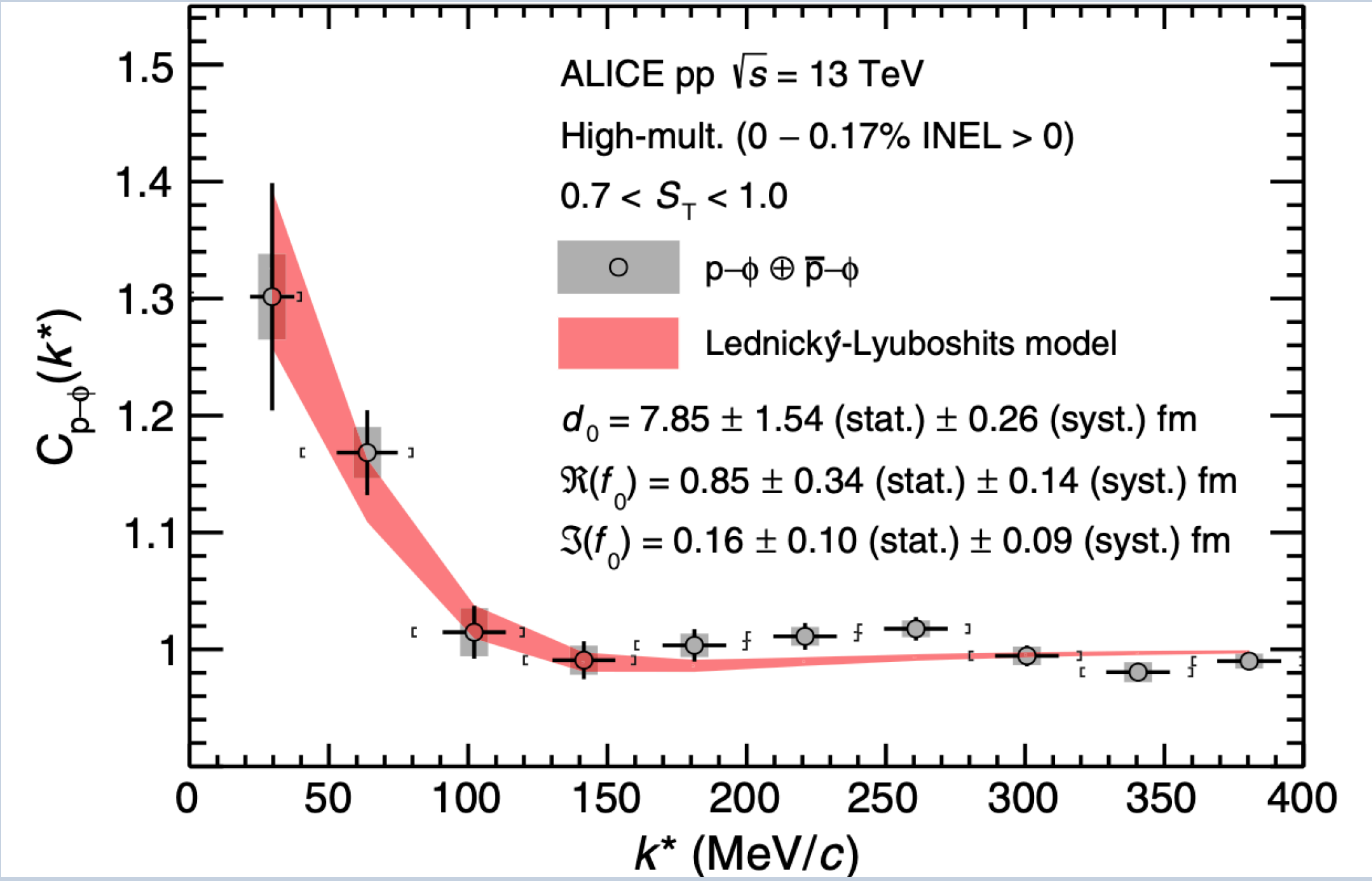
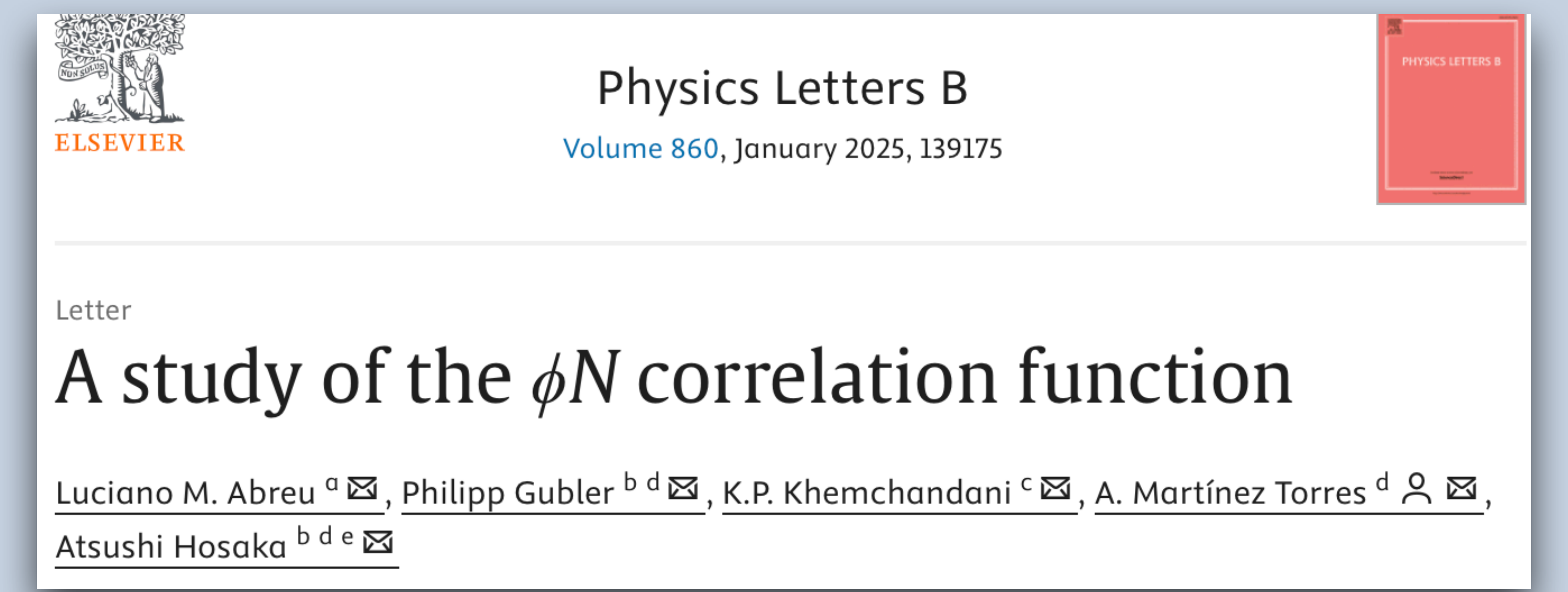


Hadron physics: coupled channel dynamics

- Interactions determined from Lagrangians written with hadrons as effective degrees of freedom, with the relevant degrees of freedom.


ELSEVIER

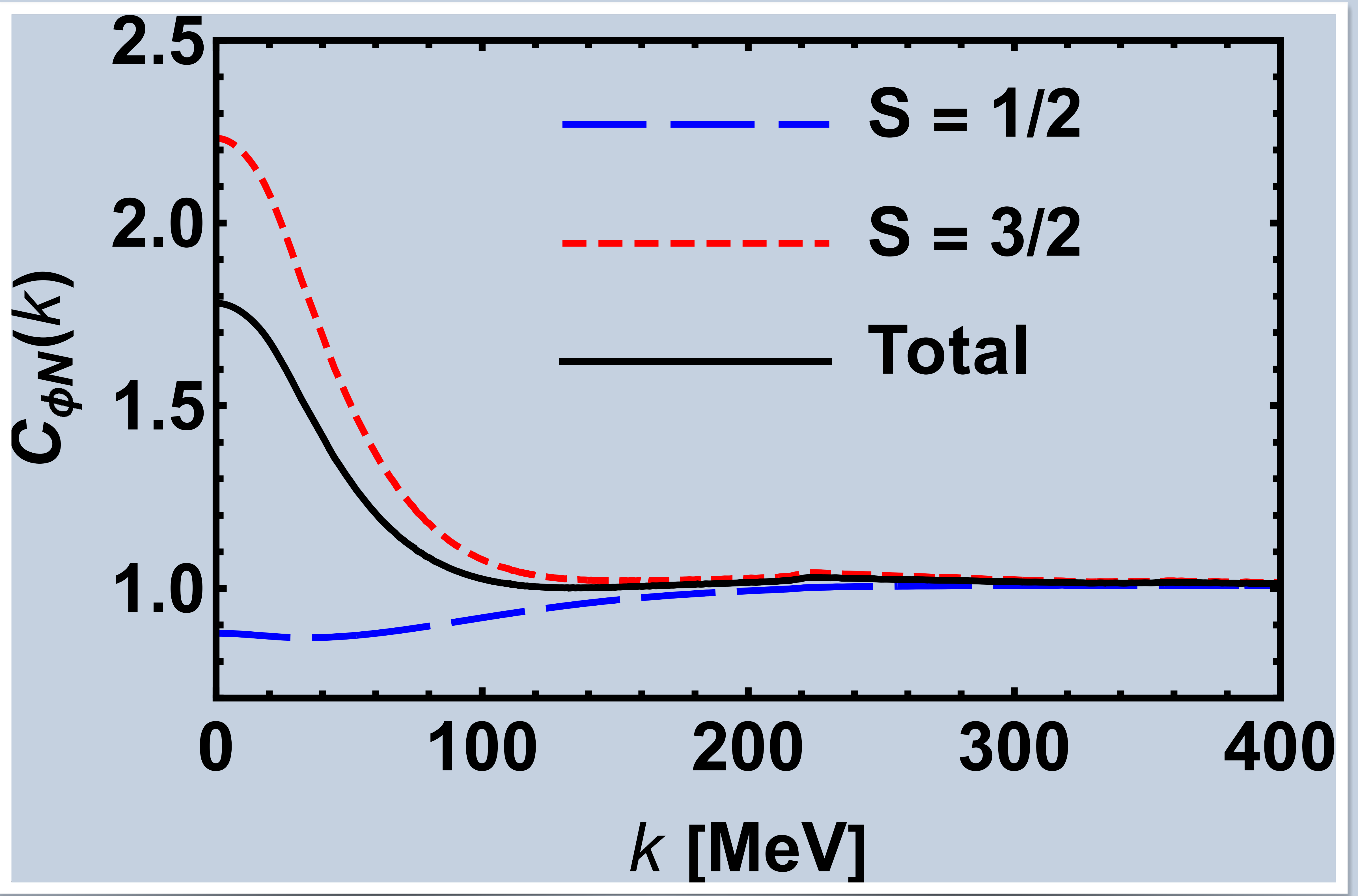
Physics Letters B

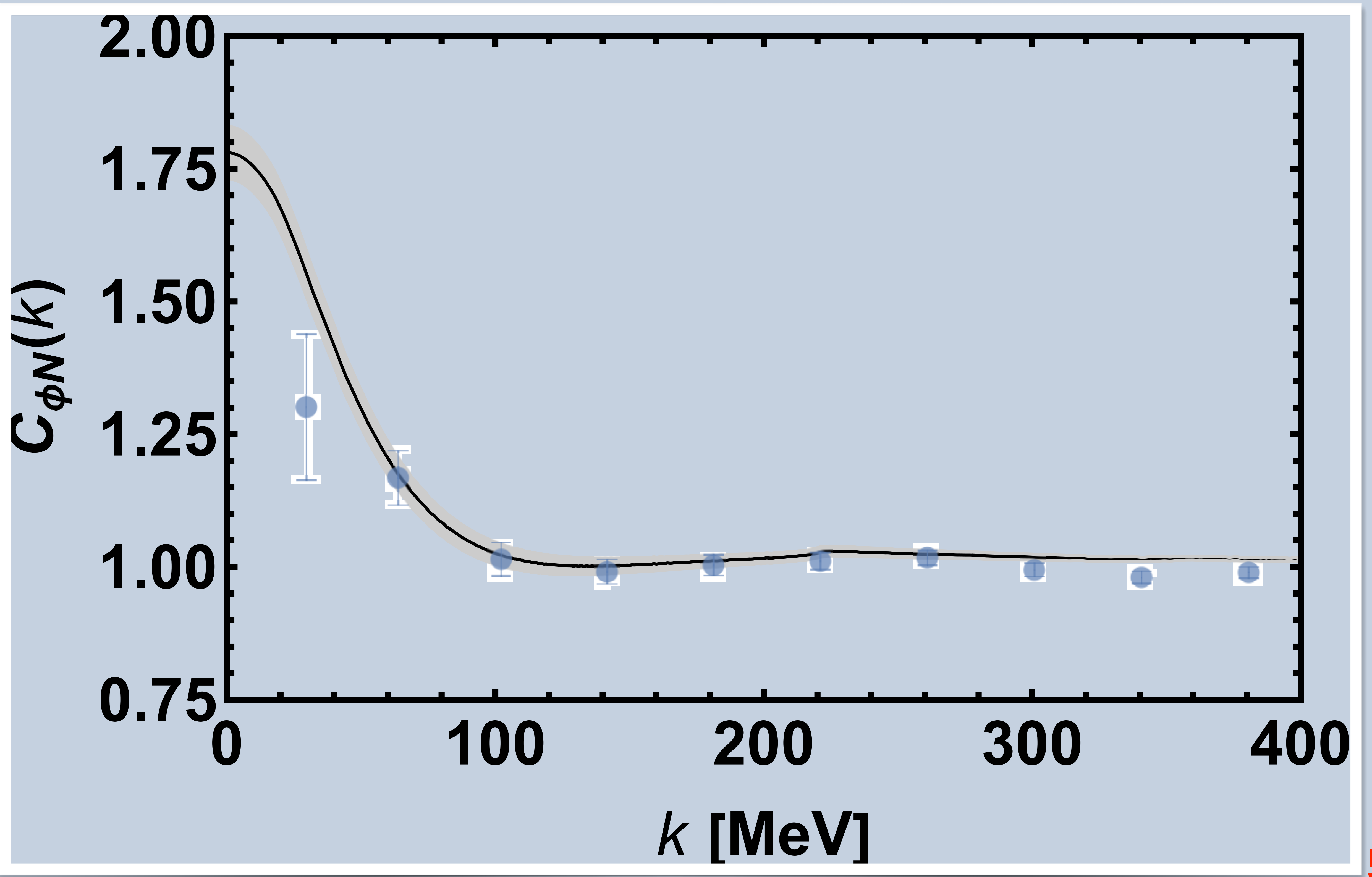
Volume 860, January 2025, 139175

Letter

A study of the ϕN correlation function

Luciano M. Abreu [a], Philipp Gubler [b d], K.P. Khemchandani [c], A. Martínez Torres [d], Atsushi Hosaka [b d e]





Hadron physics: coupled channel dynamics

Vector-baryon interaction:

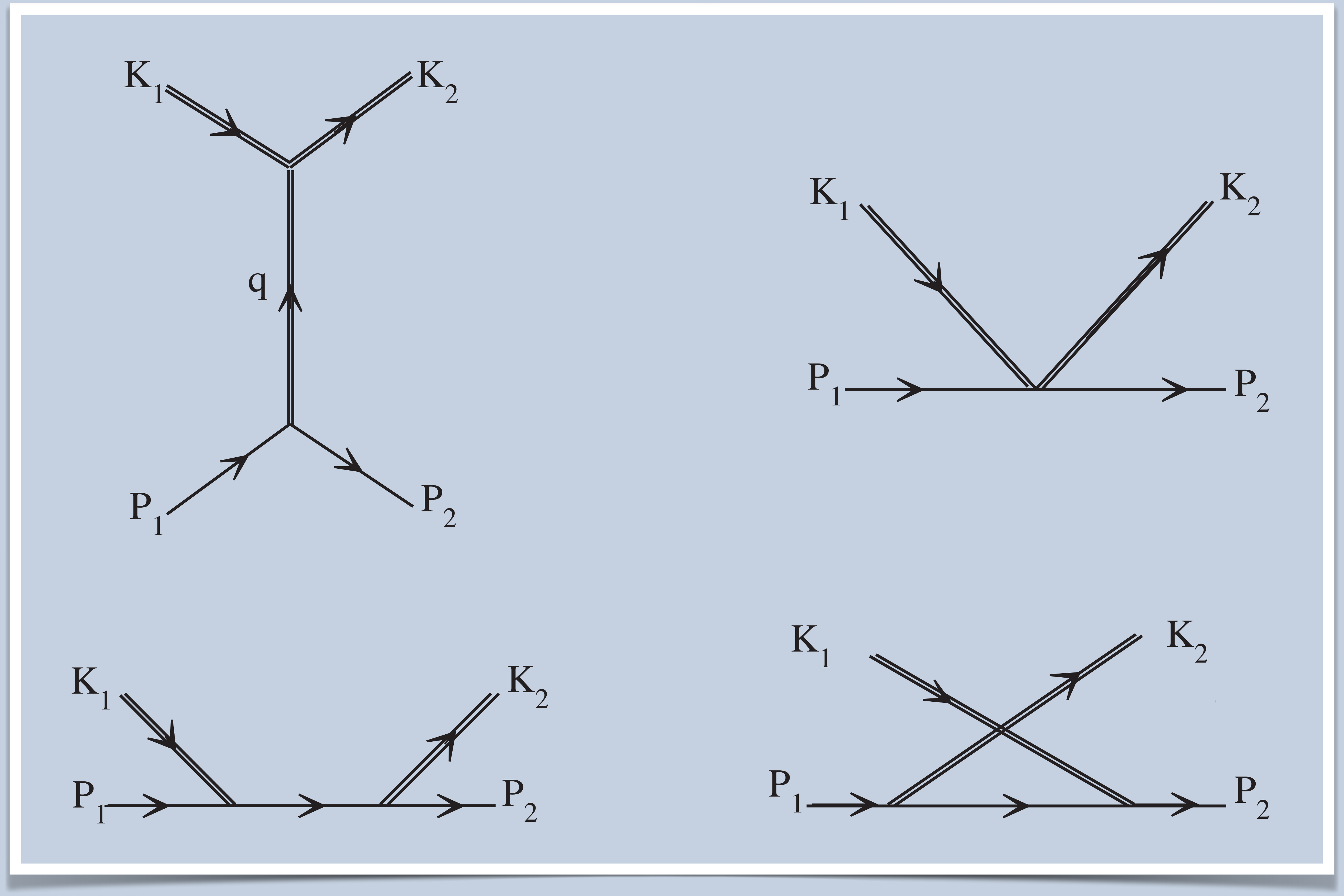
$$\mathscr{L}_{VB} = -g\left\{ \langle \bar{B}\gamma_\mu \left[V_8^\mu, B\right]\rangle + \langle \bar{B}\gamma_\mu B\rangle\langle V_8^\mu\rangle + \frac{1}{4M}\left(F\langle \bar{B}\sigma_{\mu\nu}\left[V_8^{\mu\nu}, B\right]\rangle + D\langle \bar{B}\sigma_{\mu\nu}\left\{V_8^{\mu\nu}, B\right\}\rangle\right) + \langle \bar{B}\gamma_\mu B\rangle\langle V_0^\mu\rangle + \frac{C_0}{4M}\langle \bar{B}\sigma_{\mu\nu}V_0^{\mu\nu}B\rangle \right\};$$

$$D = 2.4,\ F = 0.82,\ C_0 = 3F - D$$

$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig\left[V^\mu, V^\nu\right]$$

Hadron physics: coupled channel dynamics

- **Lowest order amplitude is a sum of:**



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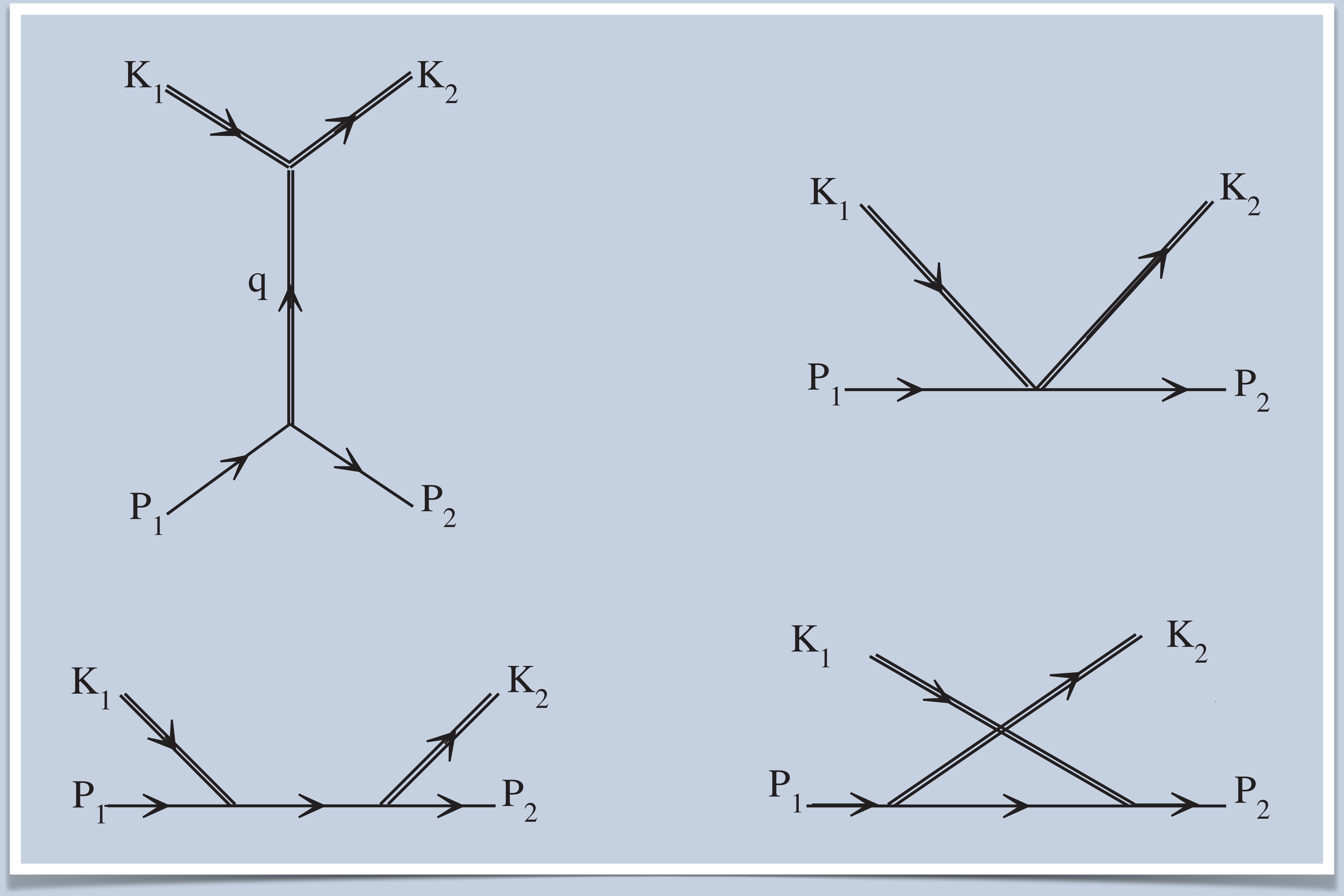

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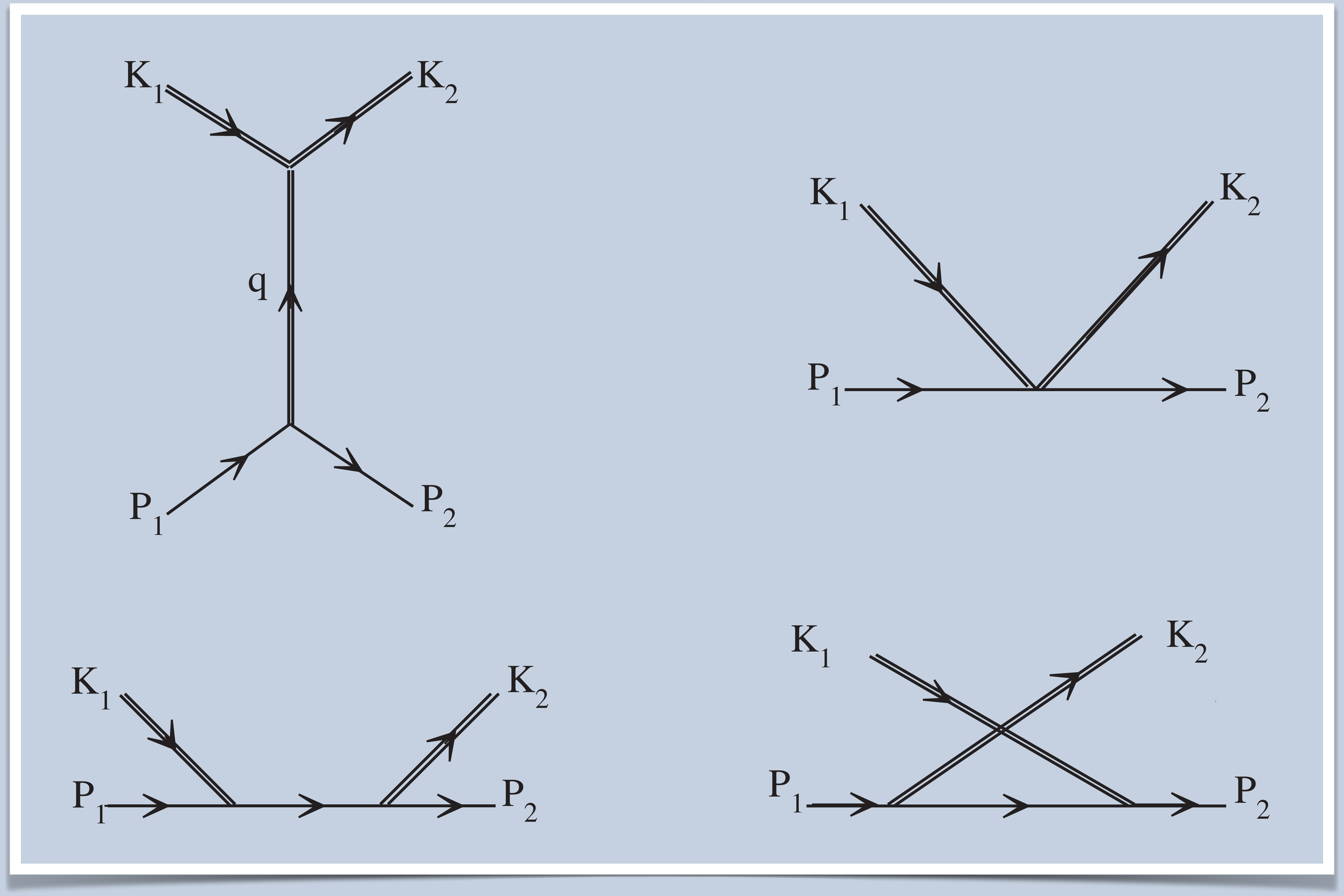

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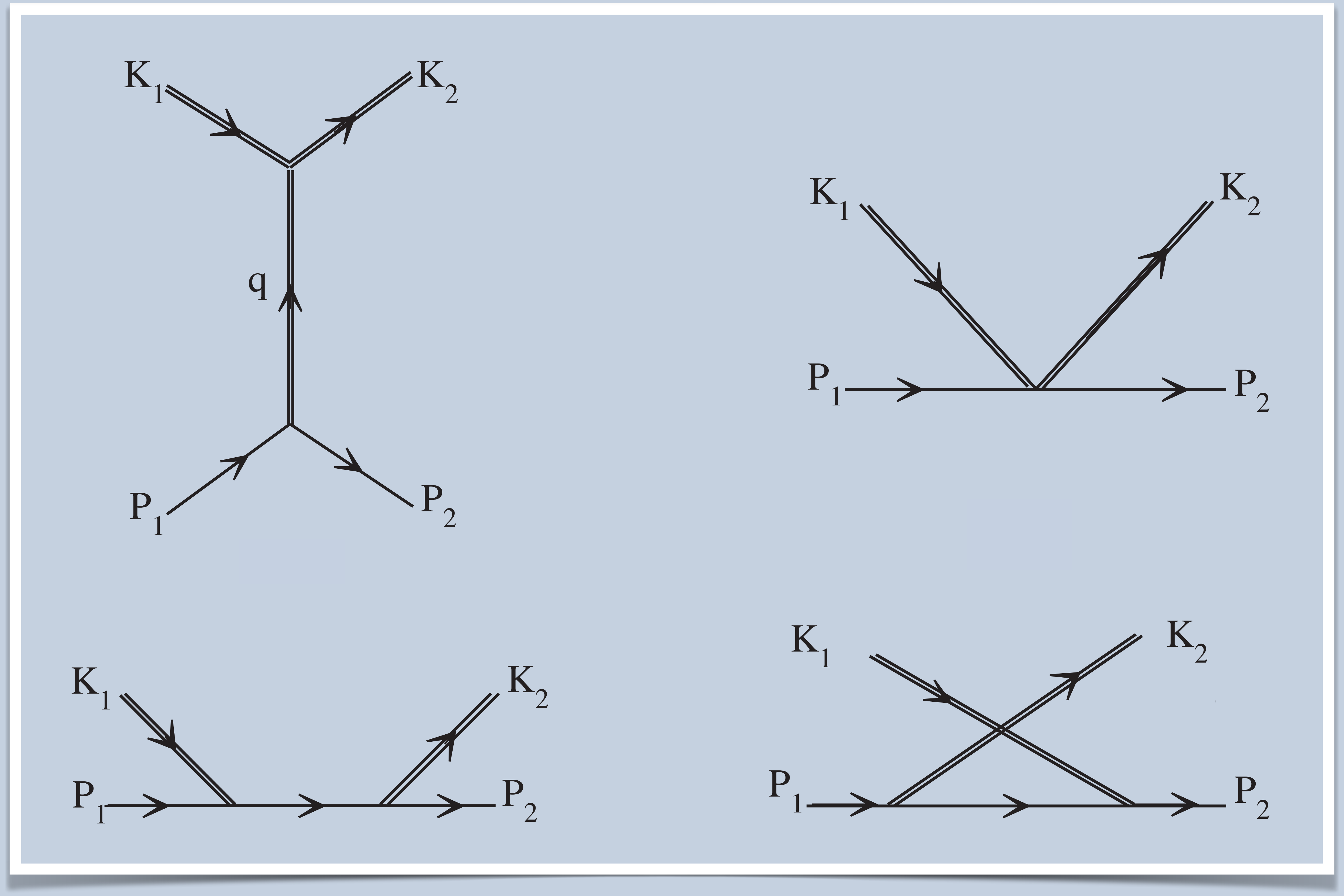


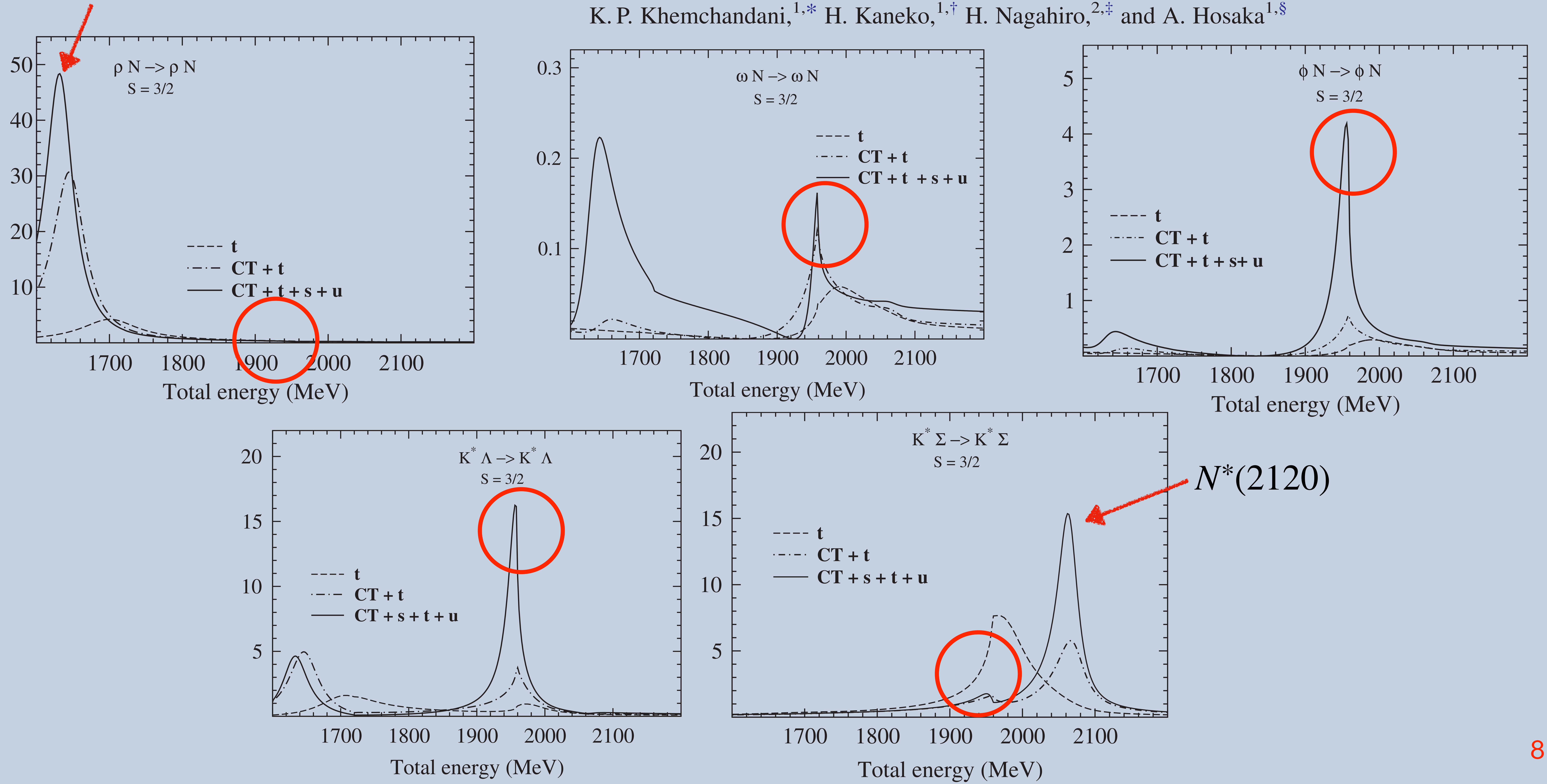
- **With this, we solve the scattering equation in a coupled-channel approach.**
- **We have UV divergences, usually regularized by using a subtraction constant or a cutoff.**
- **Question you may have: does the description of ϕN CF depends on such parameters?**

PHYSICAL REVIEW D **83,** 114041 (2011)

Vector meson-baryon dynamics and generation of resonances

K. P. Khemchandani,[1,*] H. Kaneko,[1,†] H. Nagahiro,[2,‡] and A. Hosaka[1,§]

$N^*(1700)$



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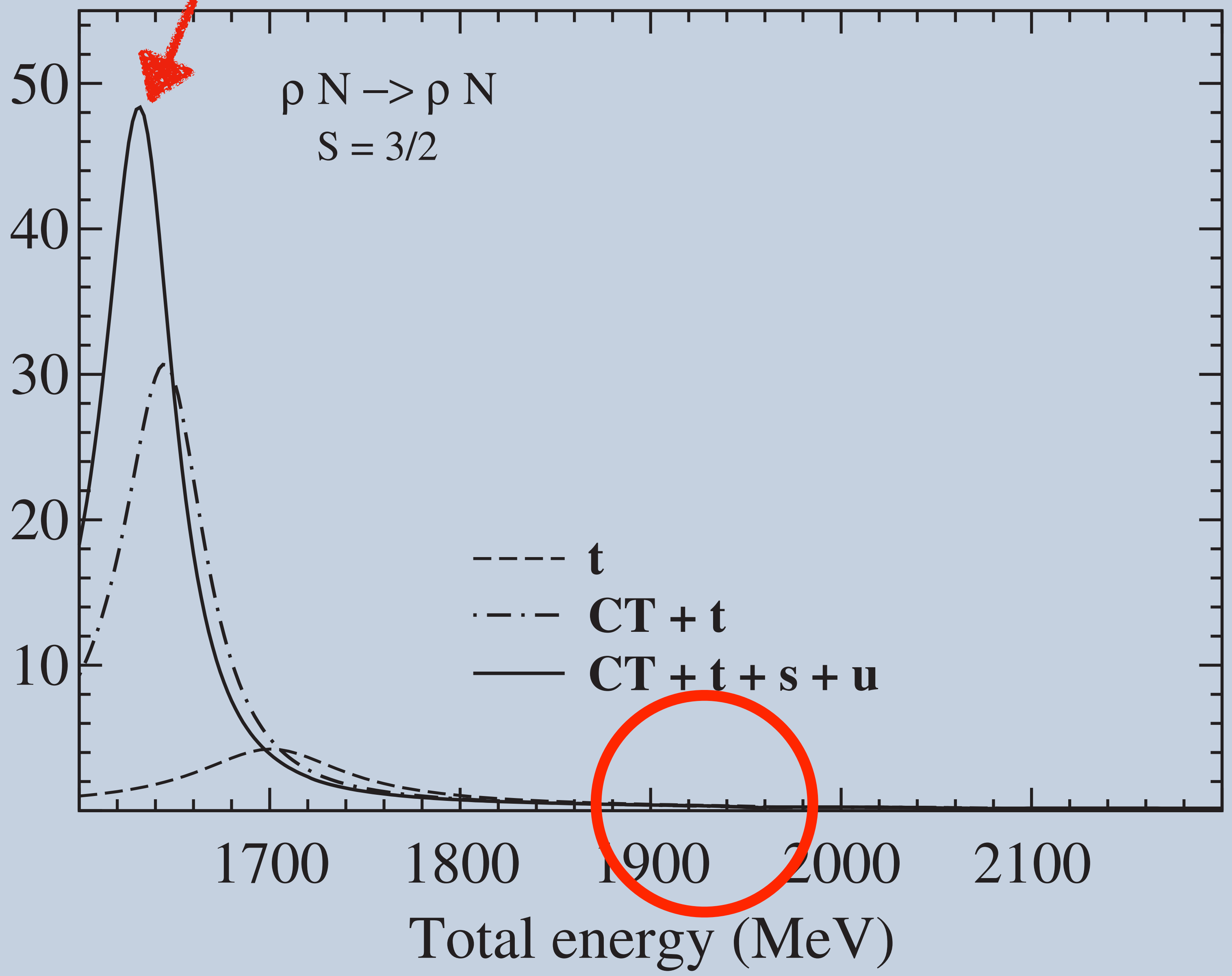

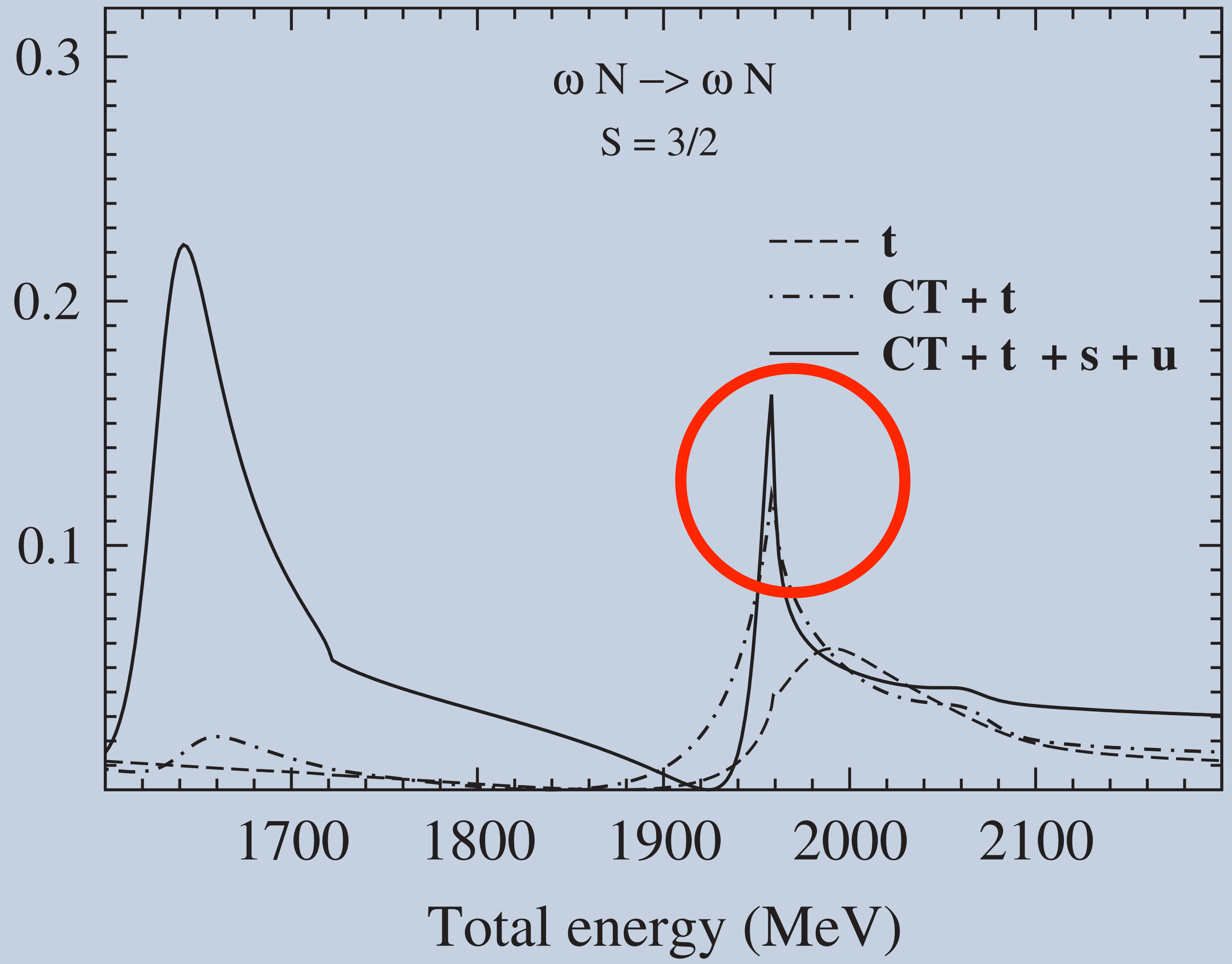

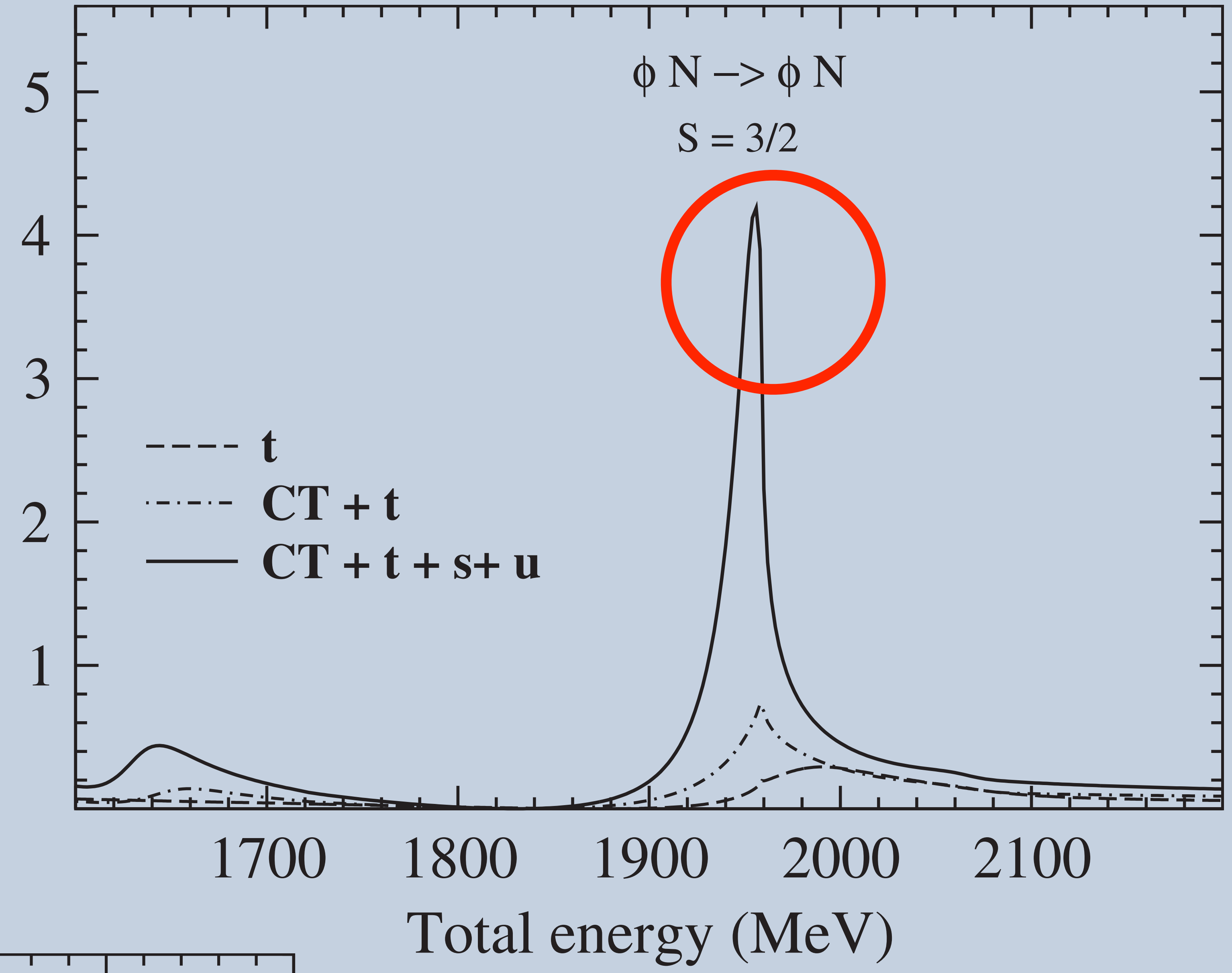

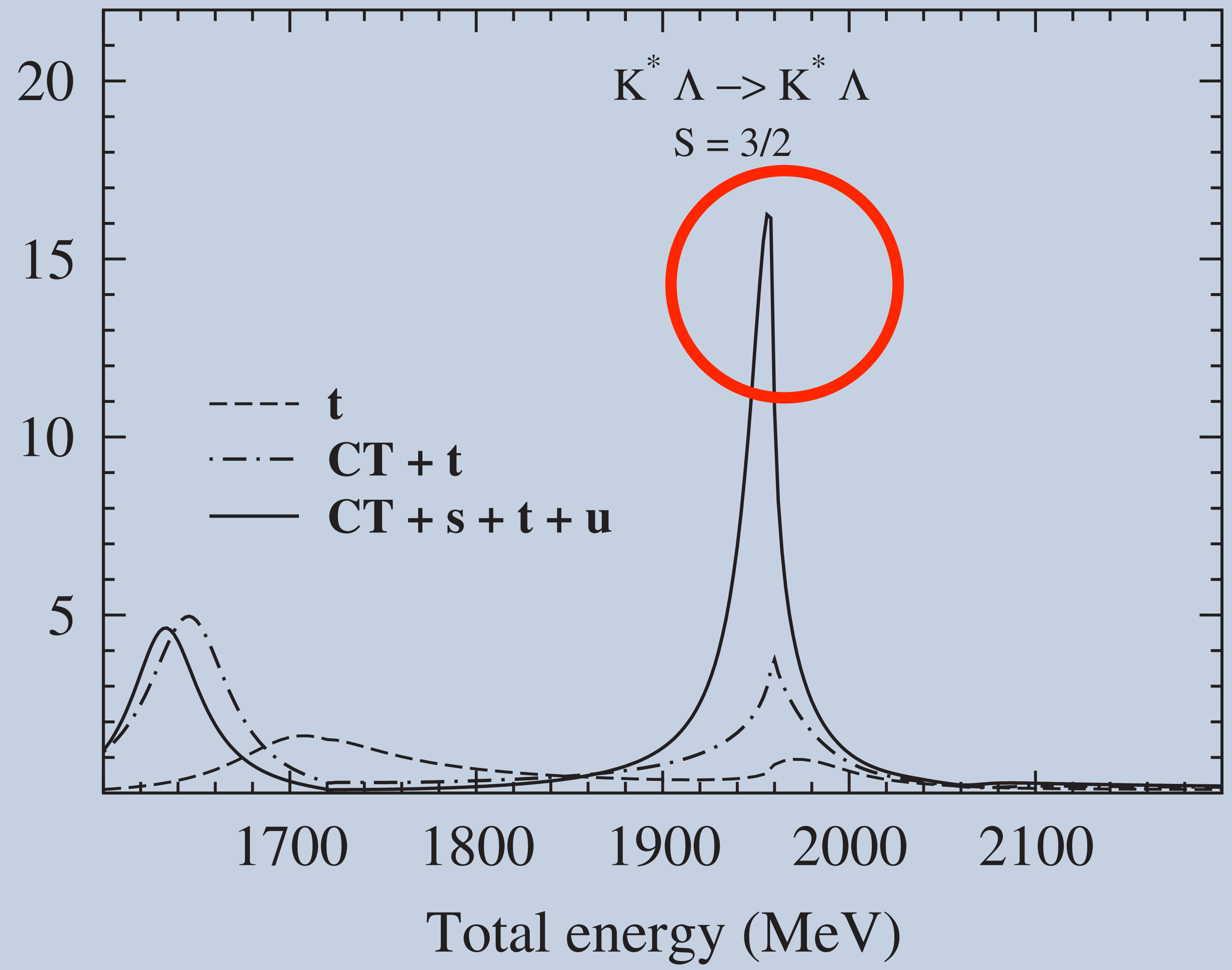

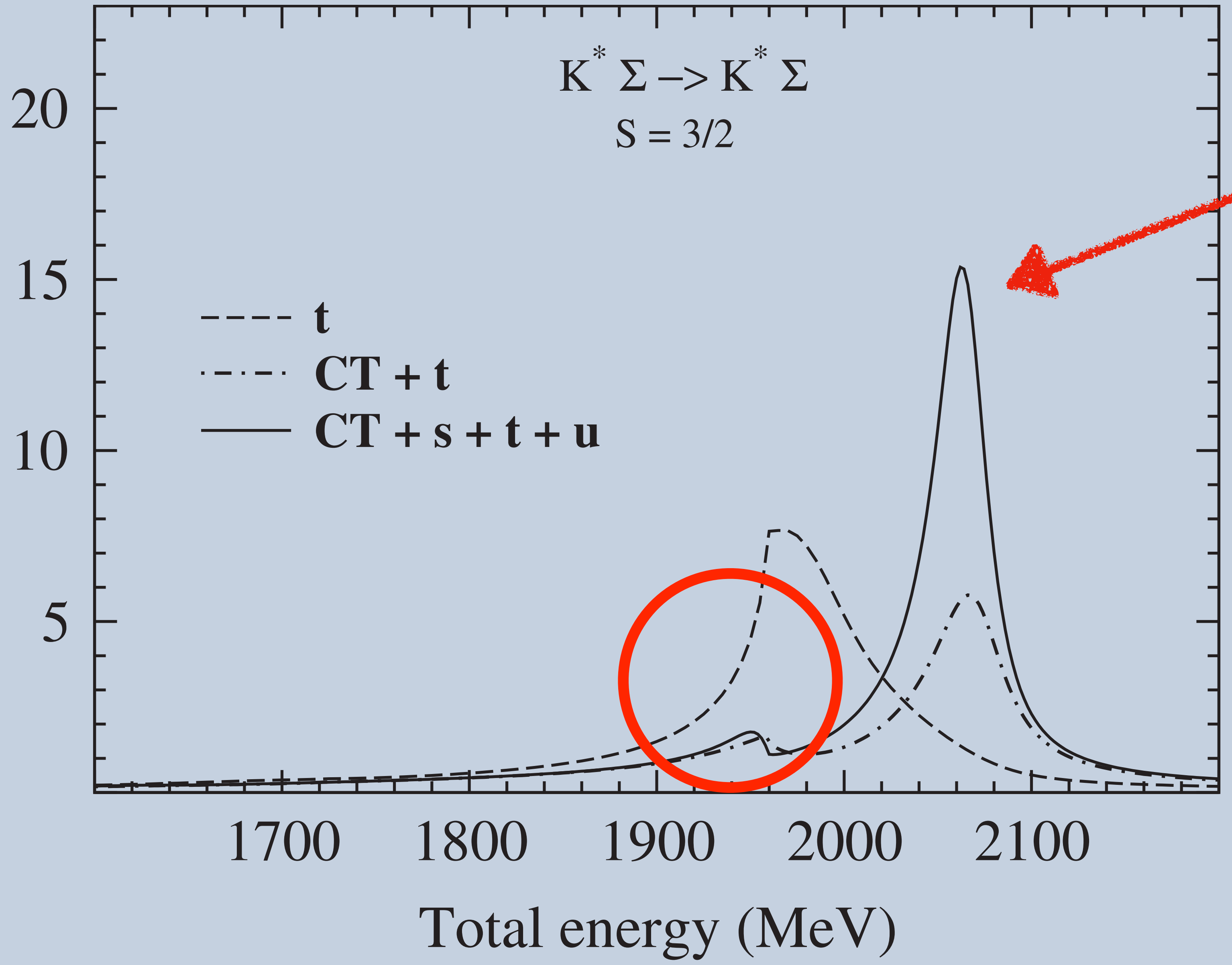

$N^*(2120)$

A new state **Ω(2109)**

arXiv:2606.27572v2

Nature of the newly found $\Omega(2109)$

Taísa Veloso,[1,*] K. P. Khemchandani,[1,†]
A. Martínez Torres,[2,‡] H. Nagahiro,[3,4,§] and A. Hosaka[4,¶]

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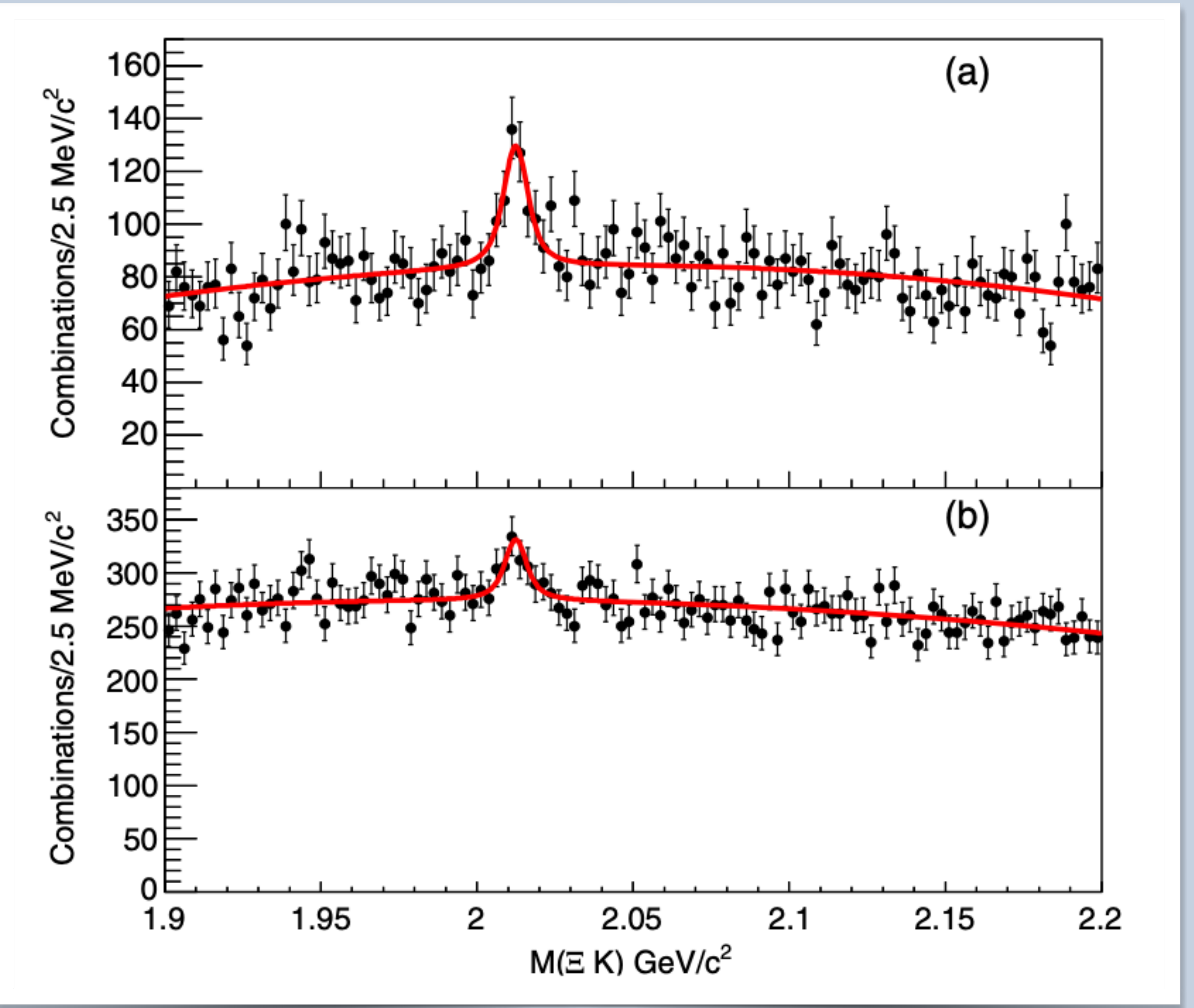

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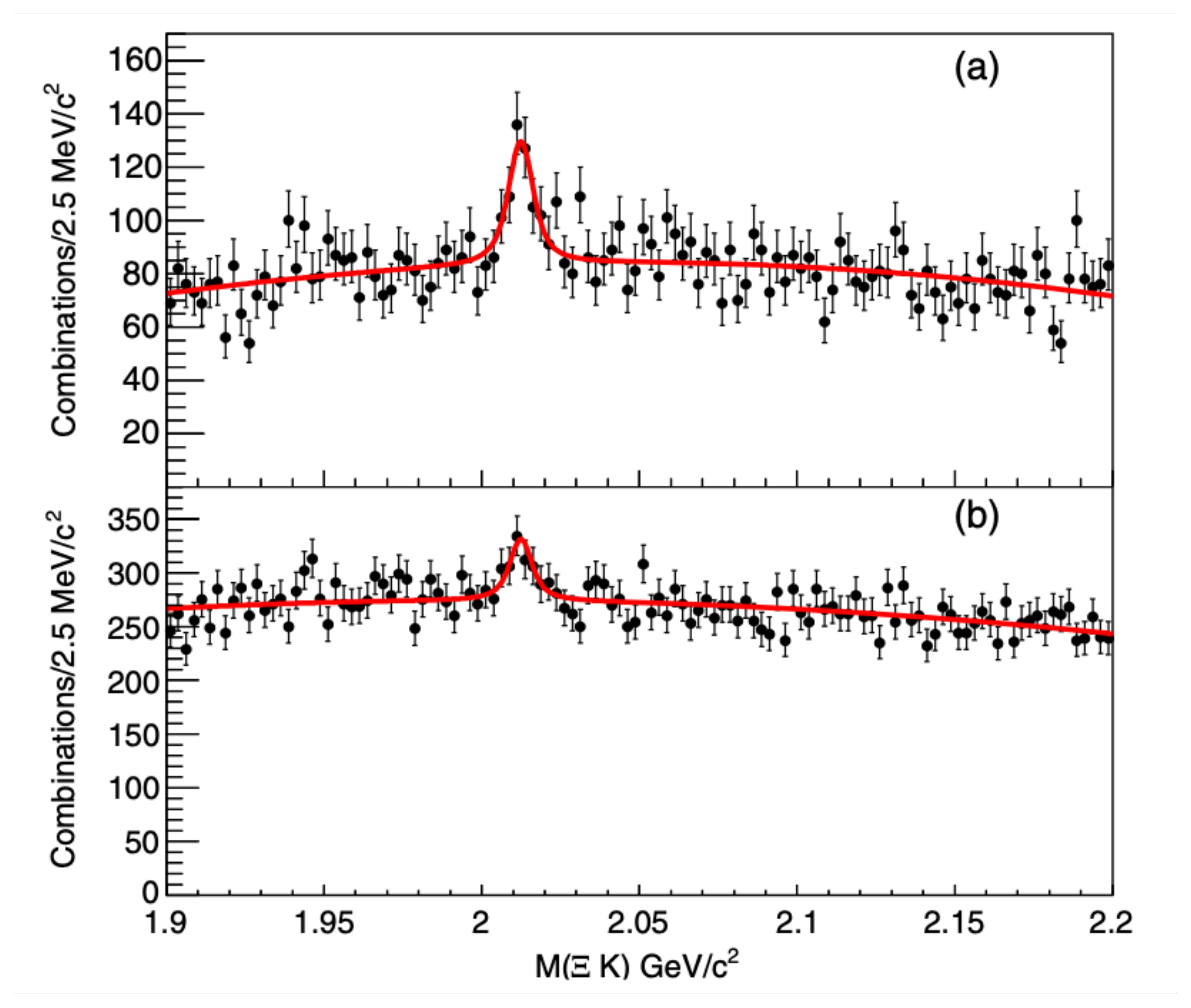

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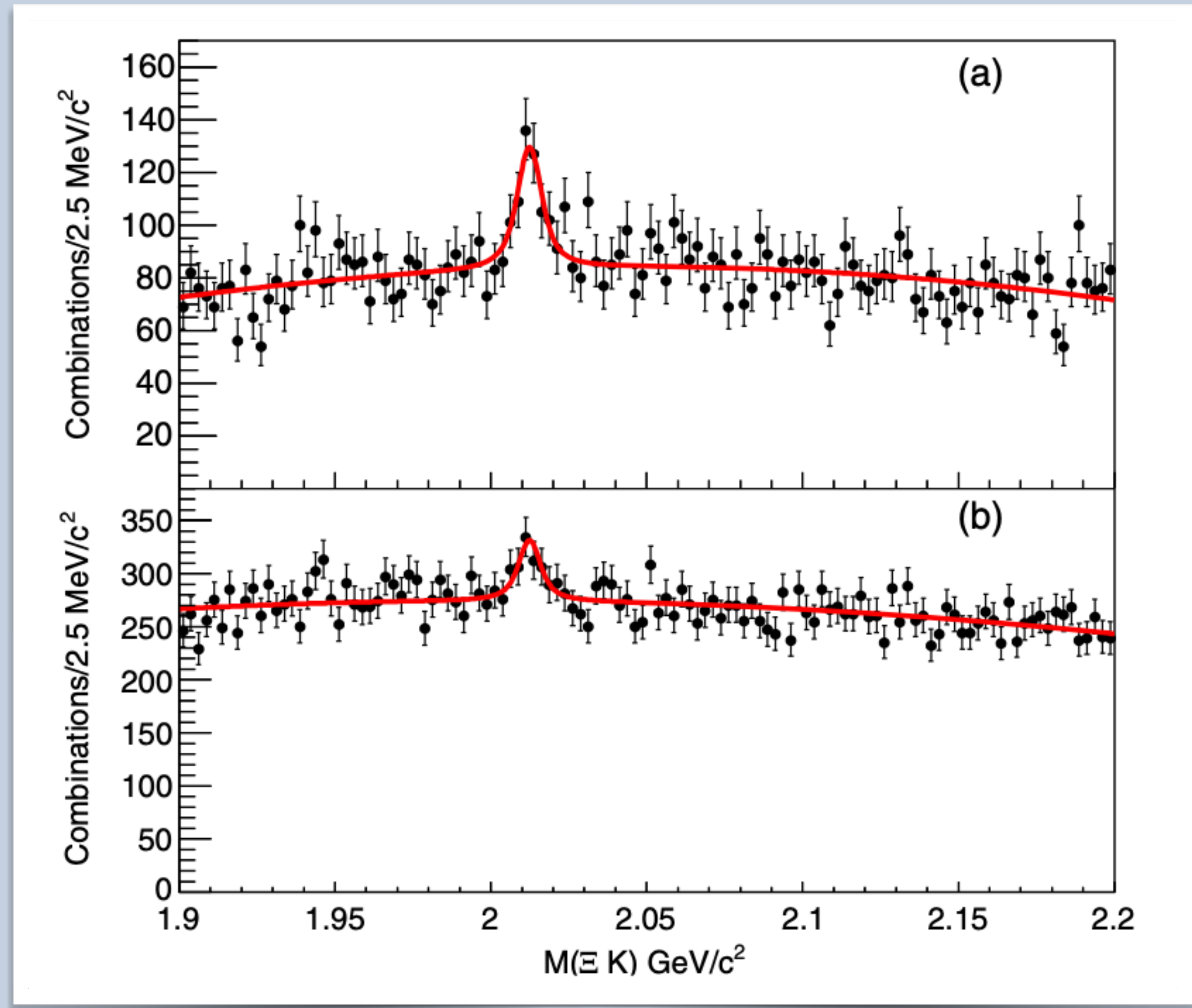

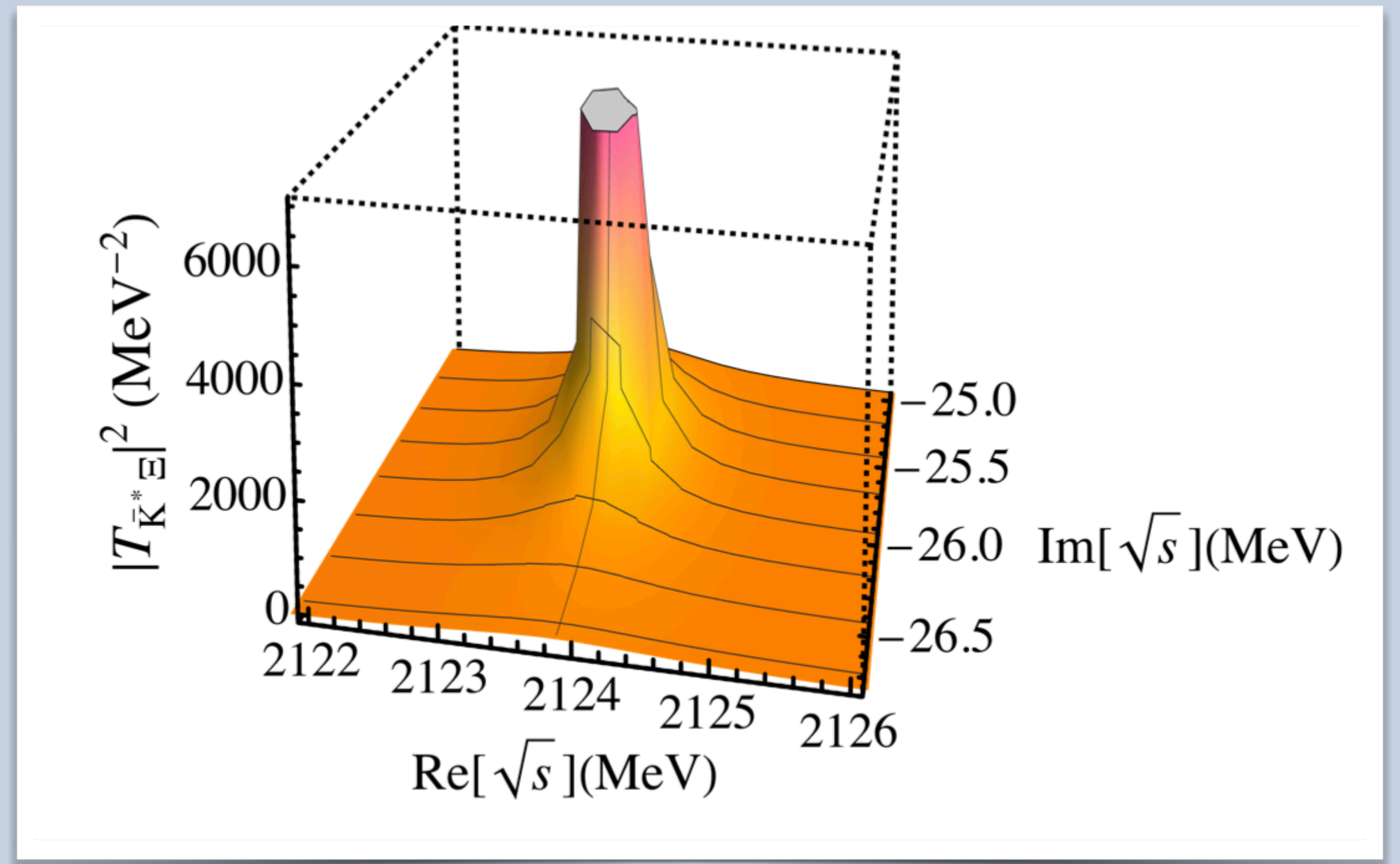

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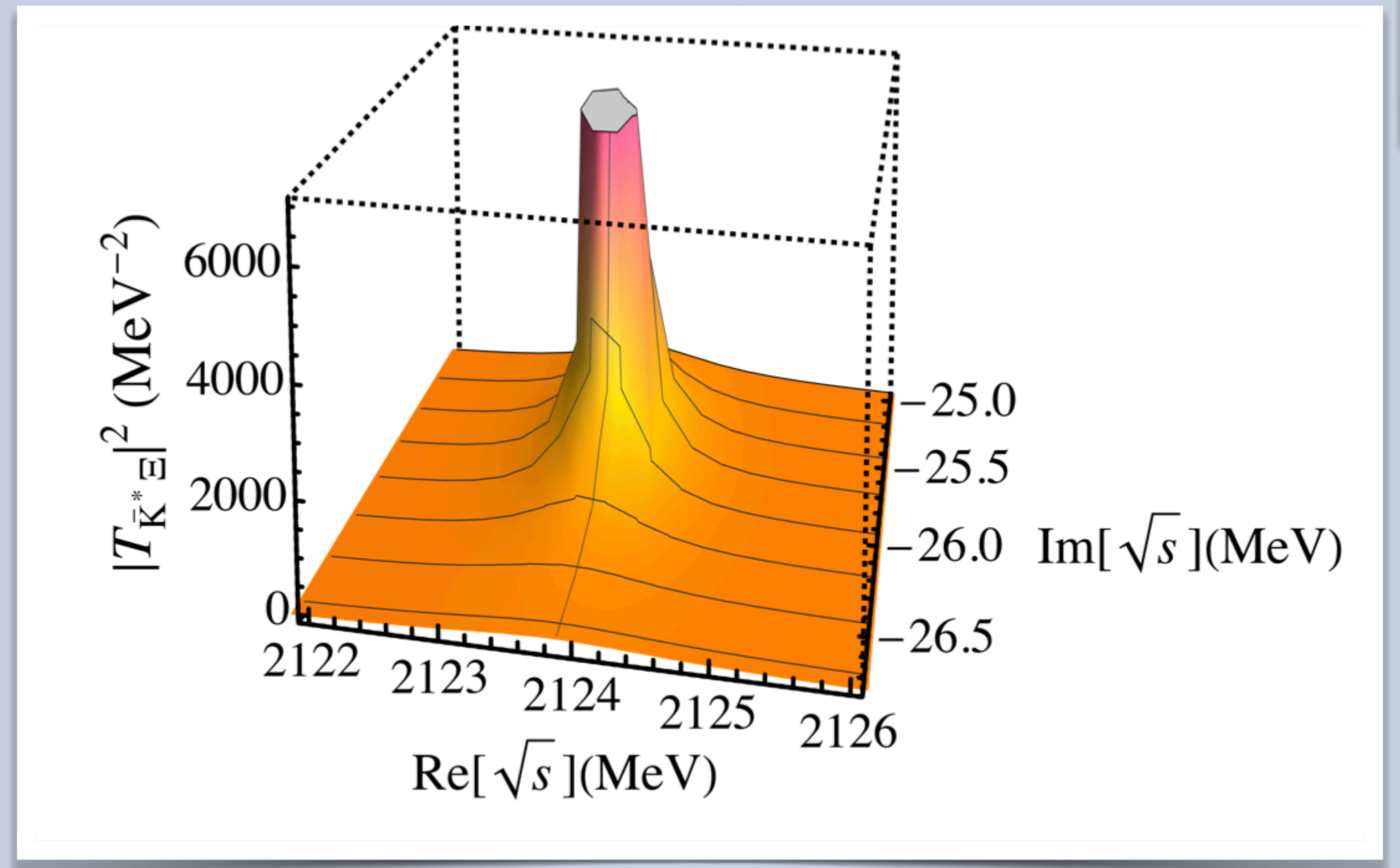

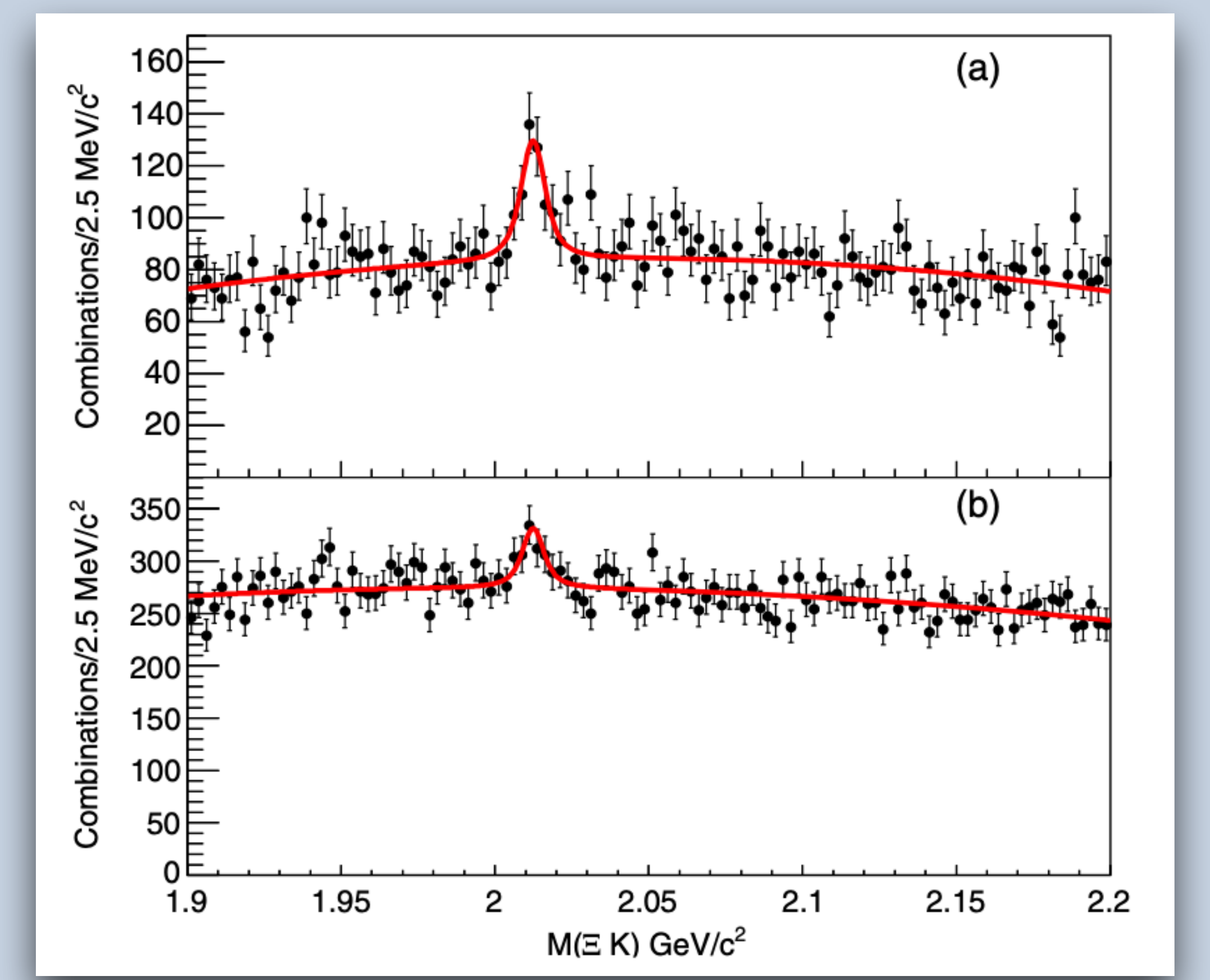

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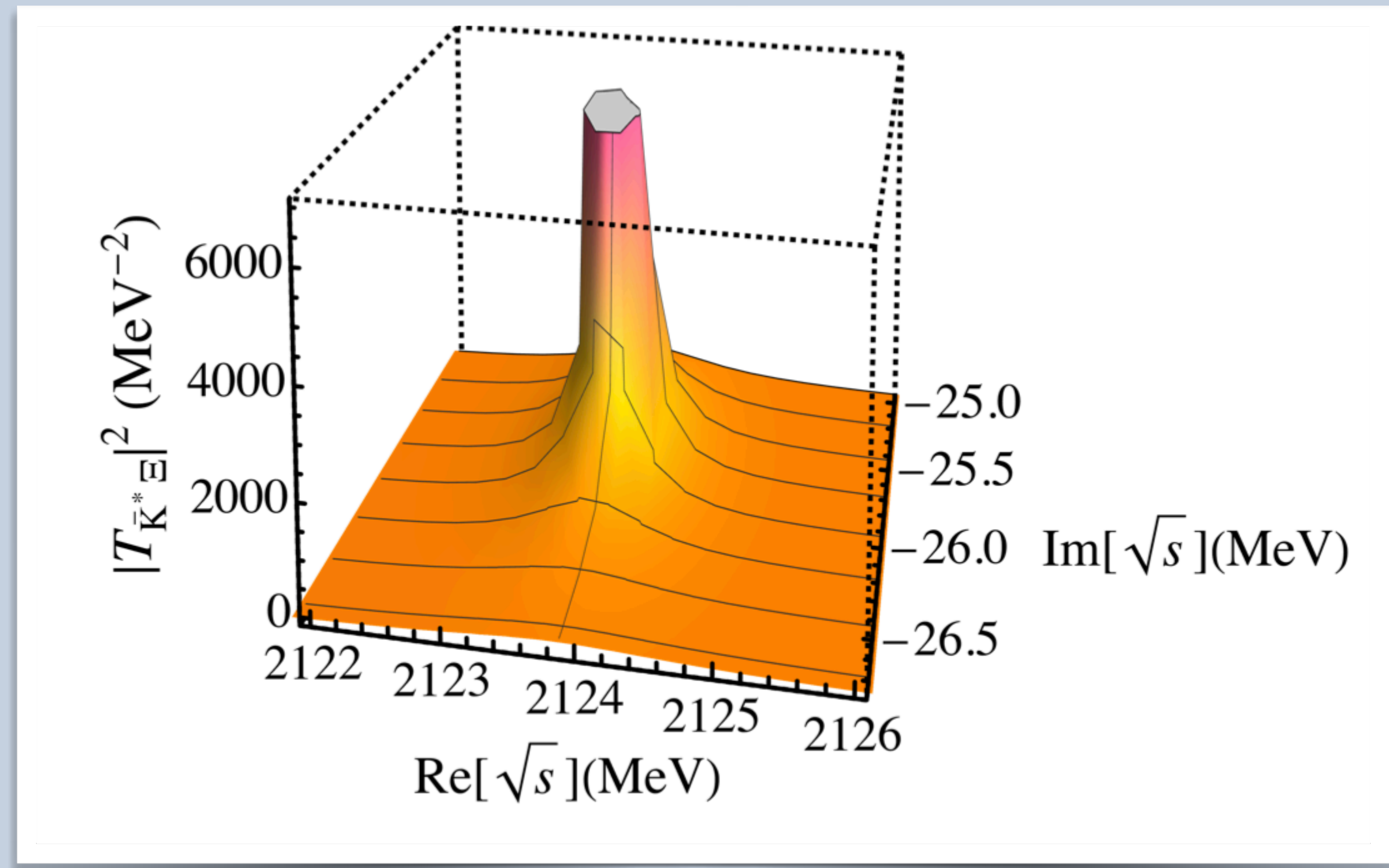

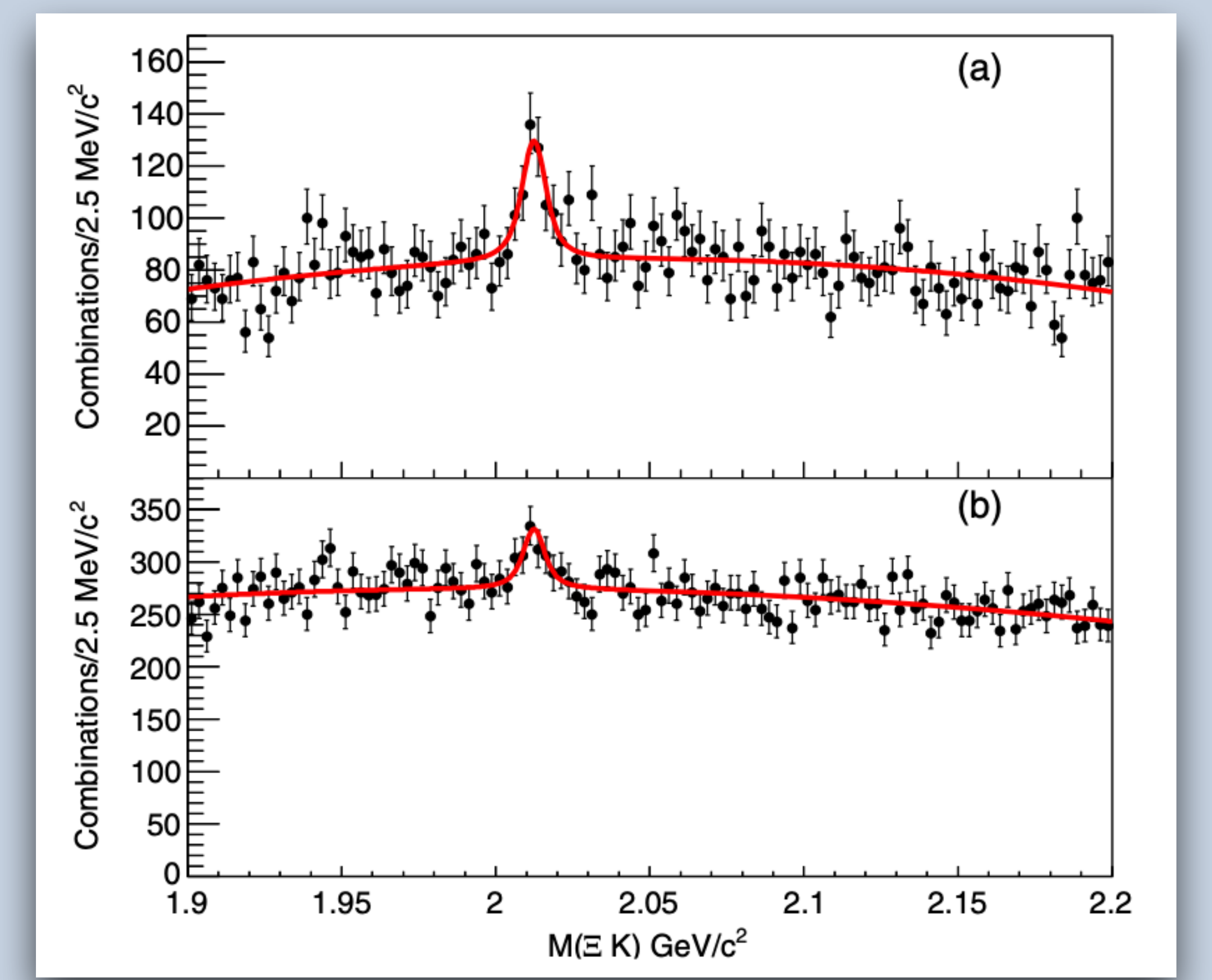

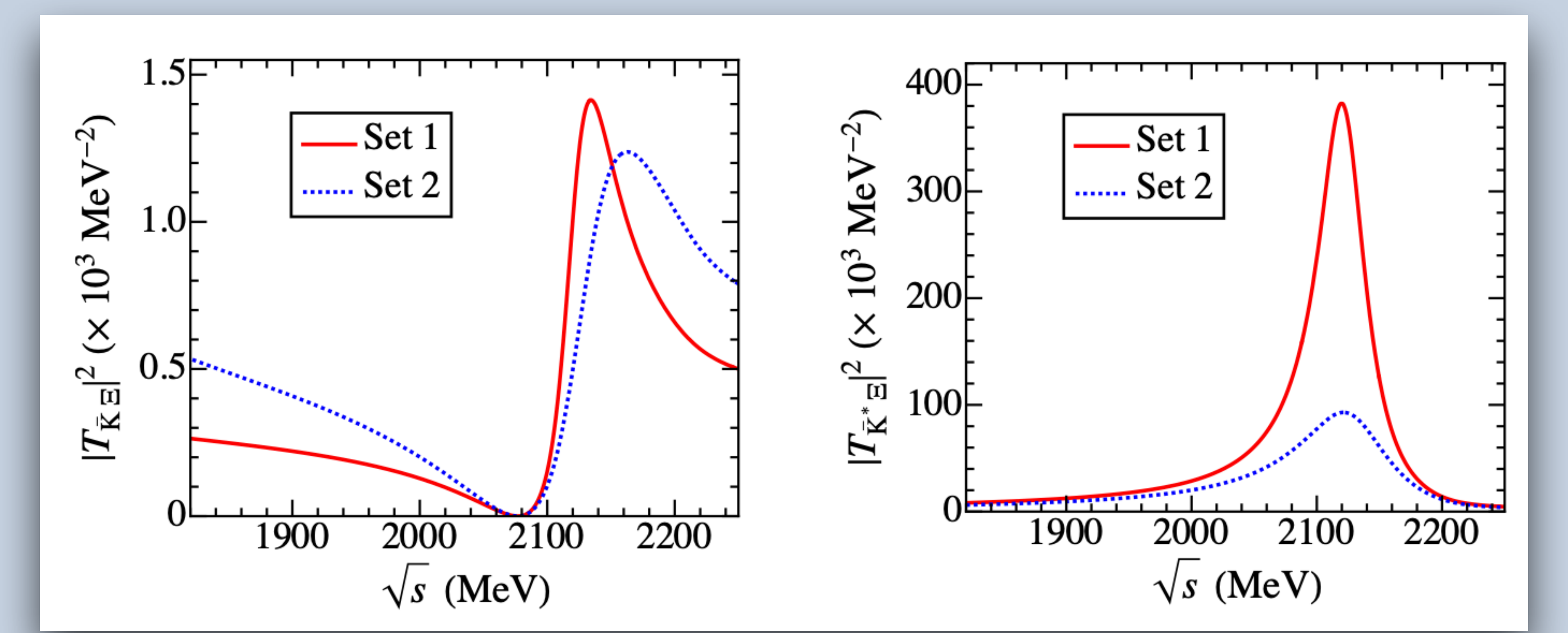

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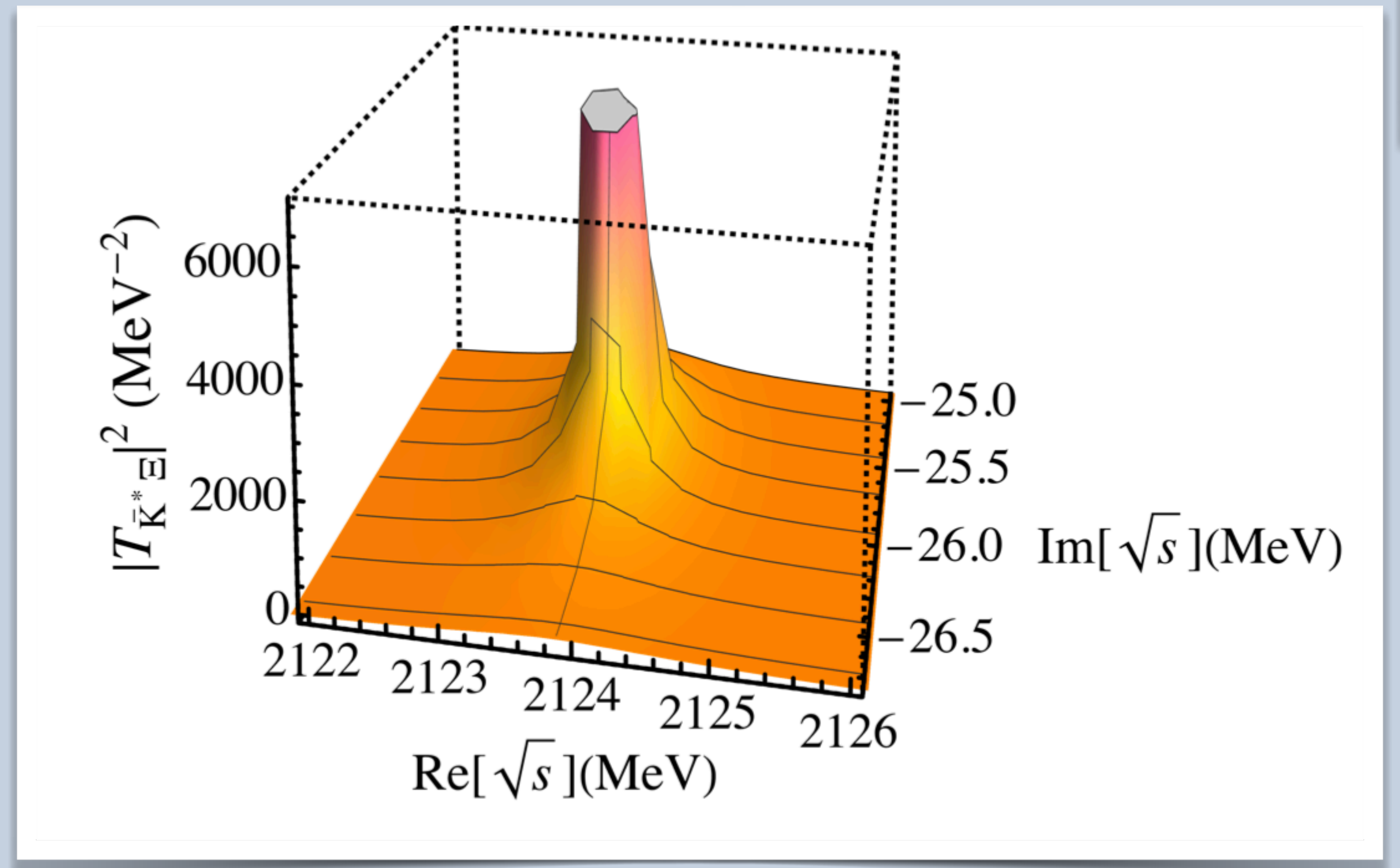

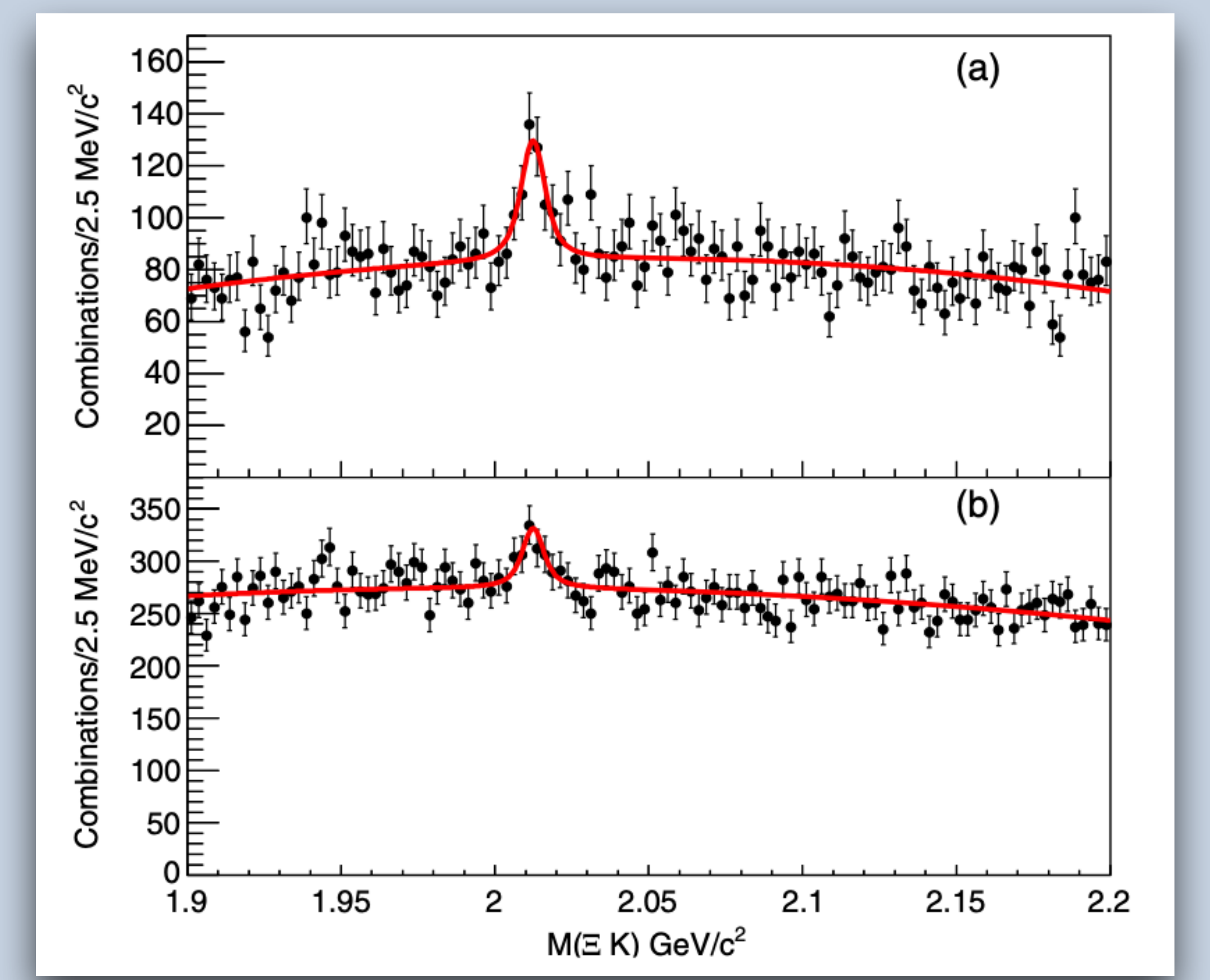

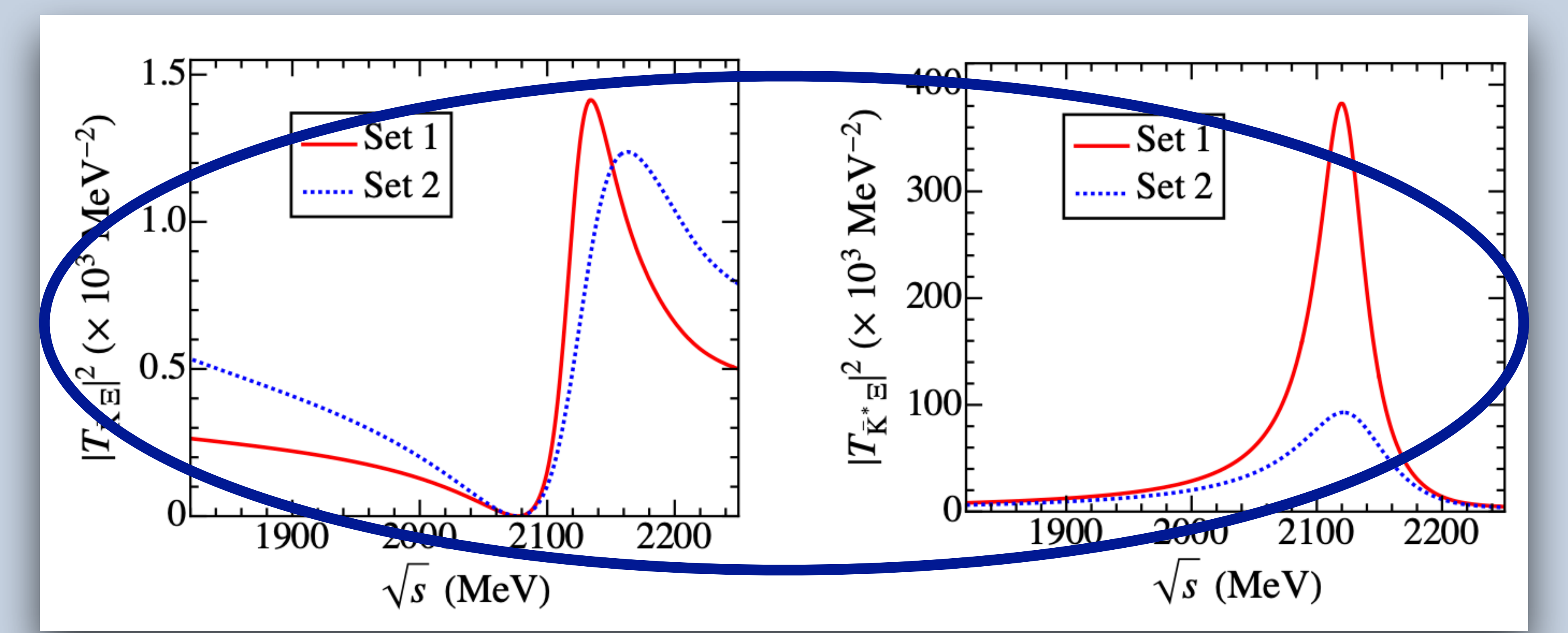

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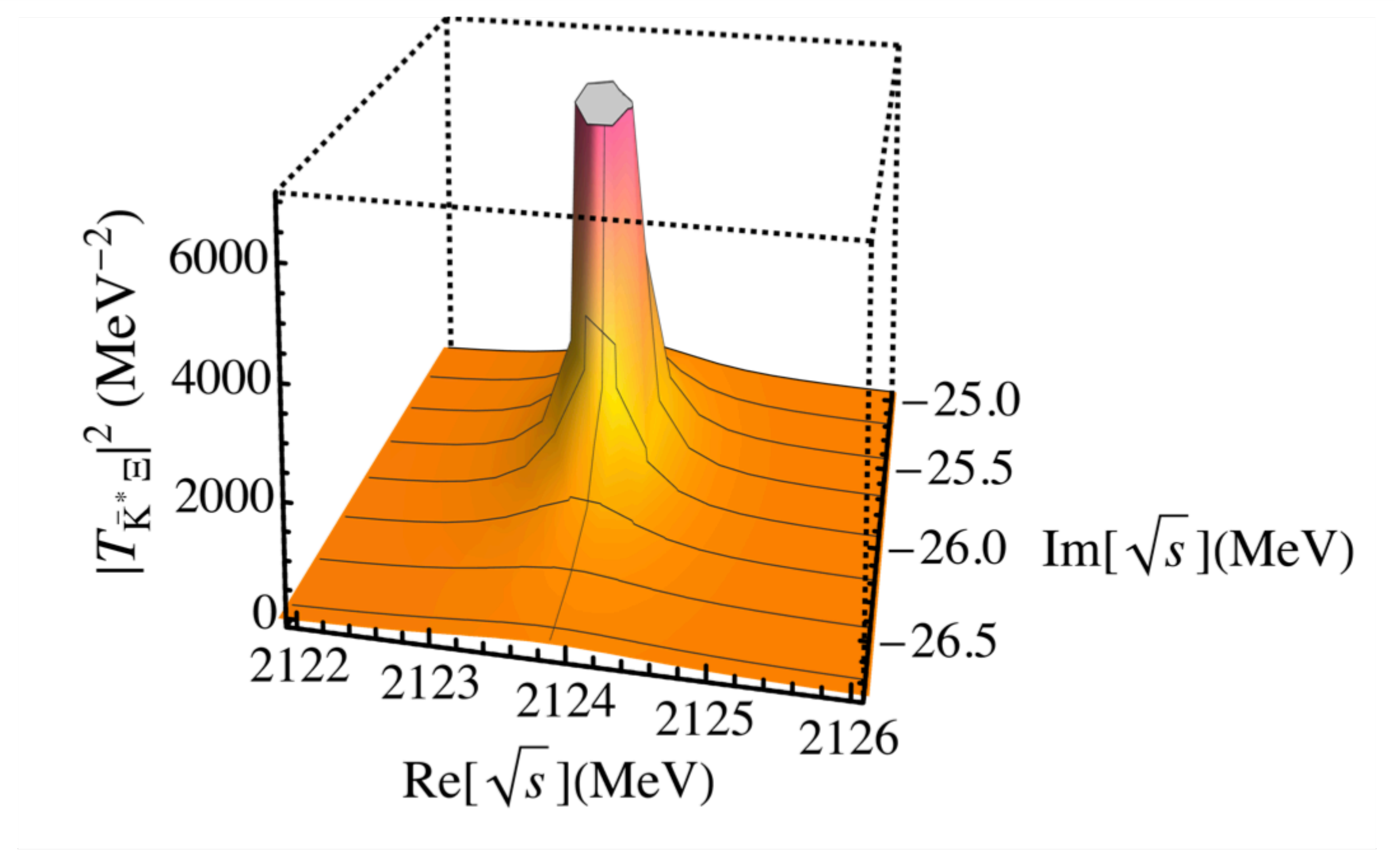

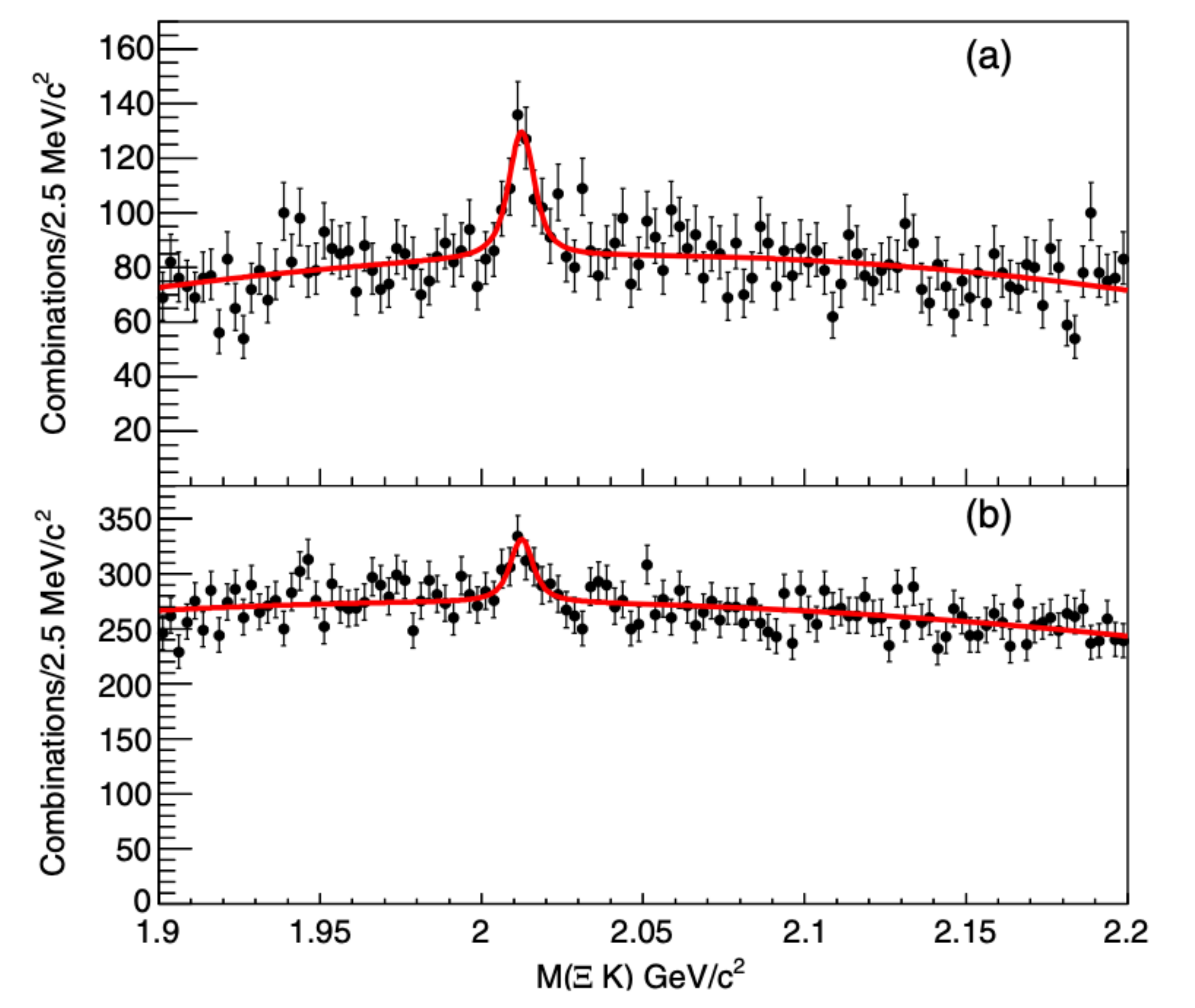

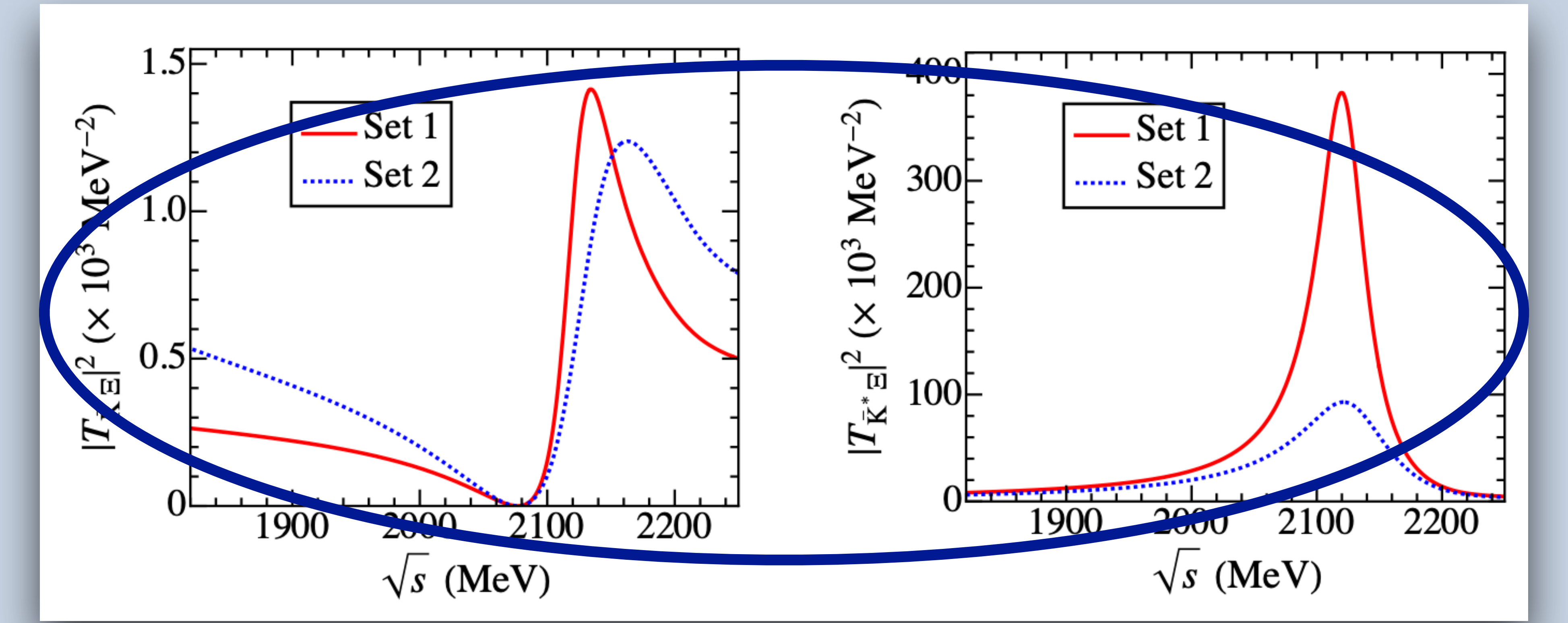

Uncertainties from
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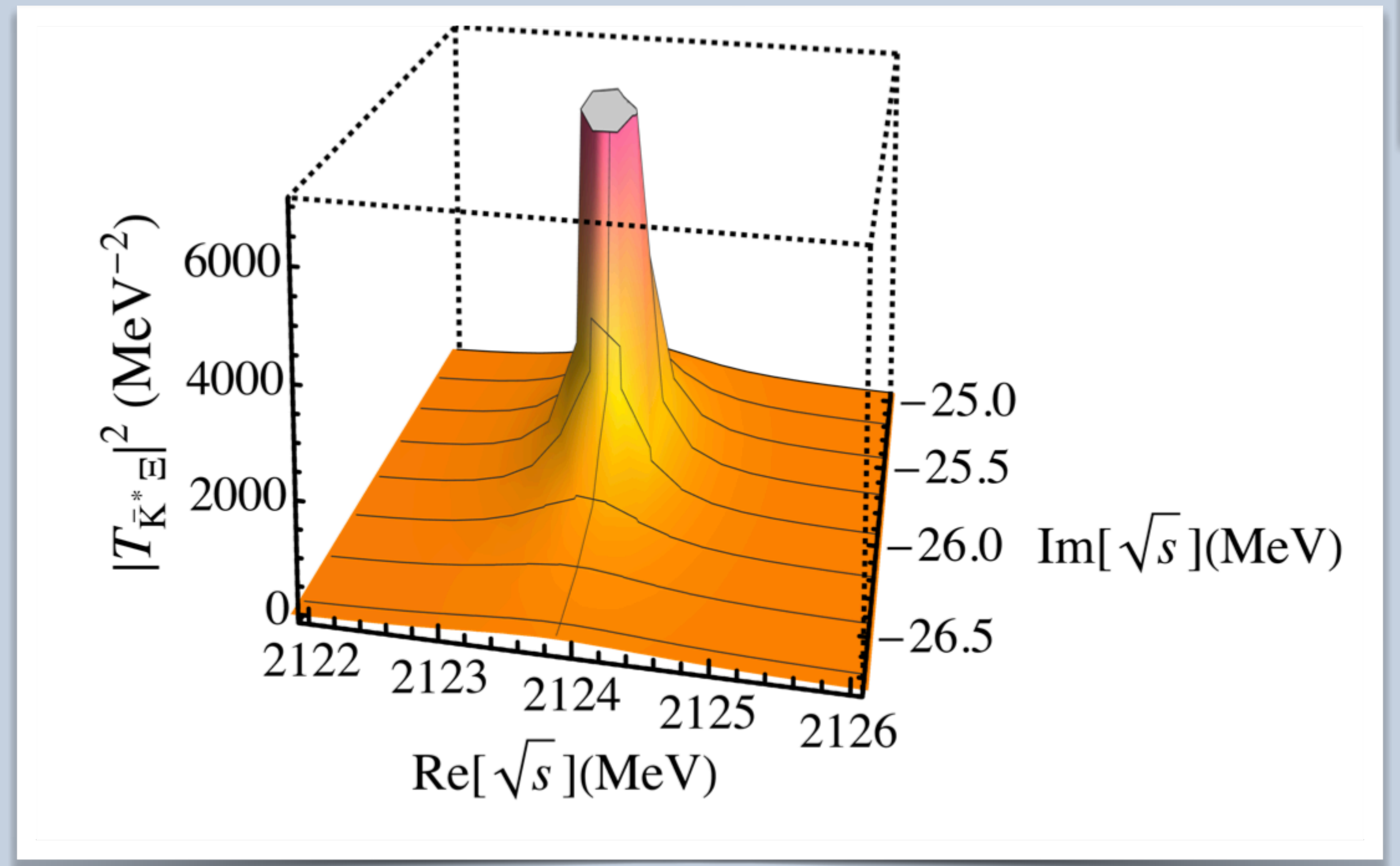

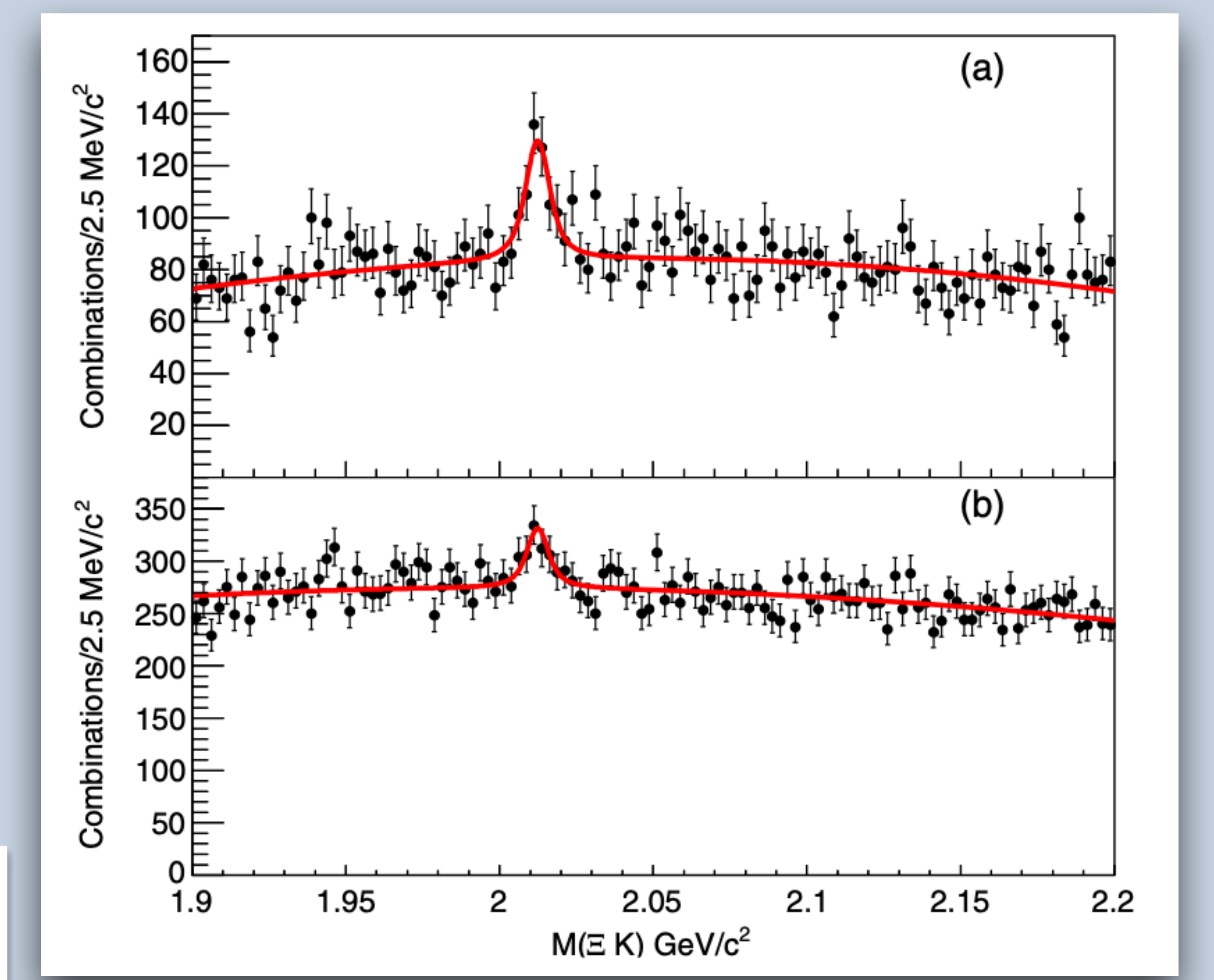

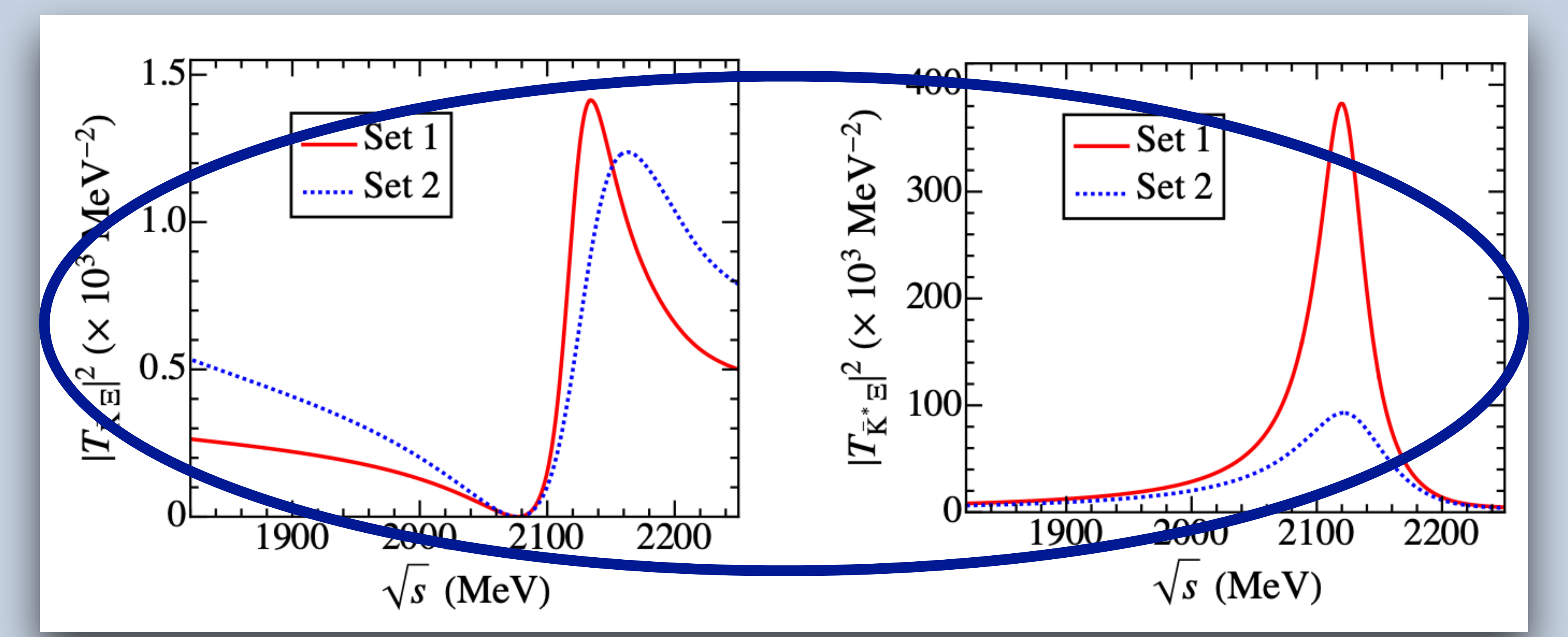

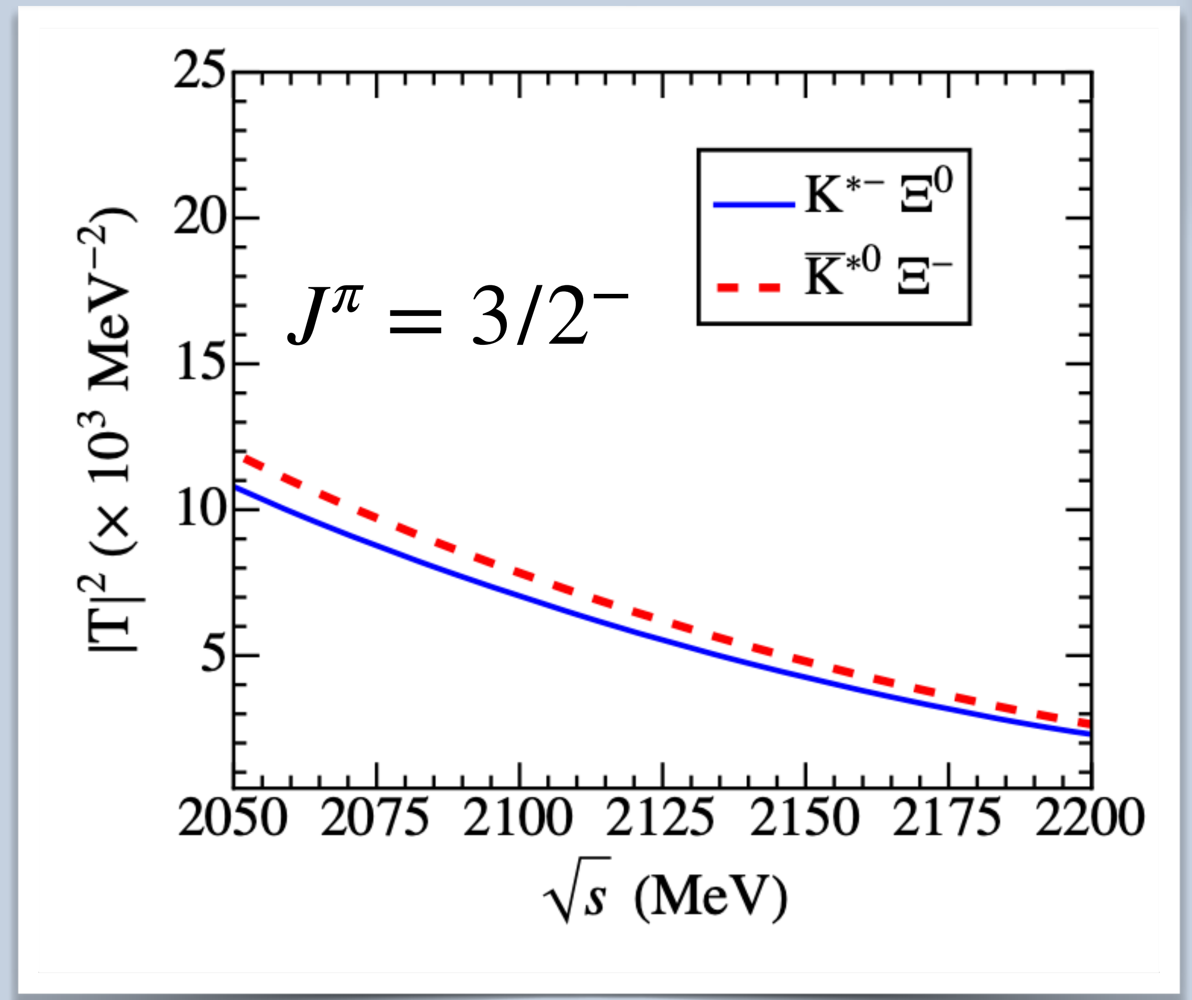

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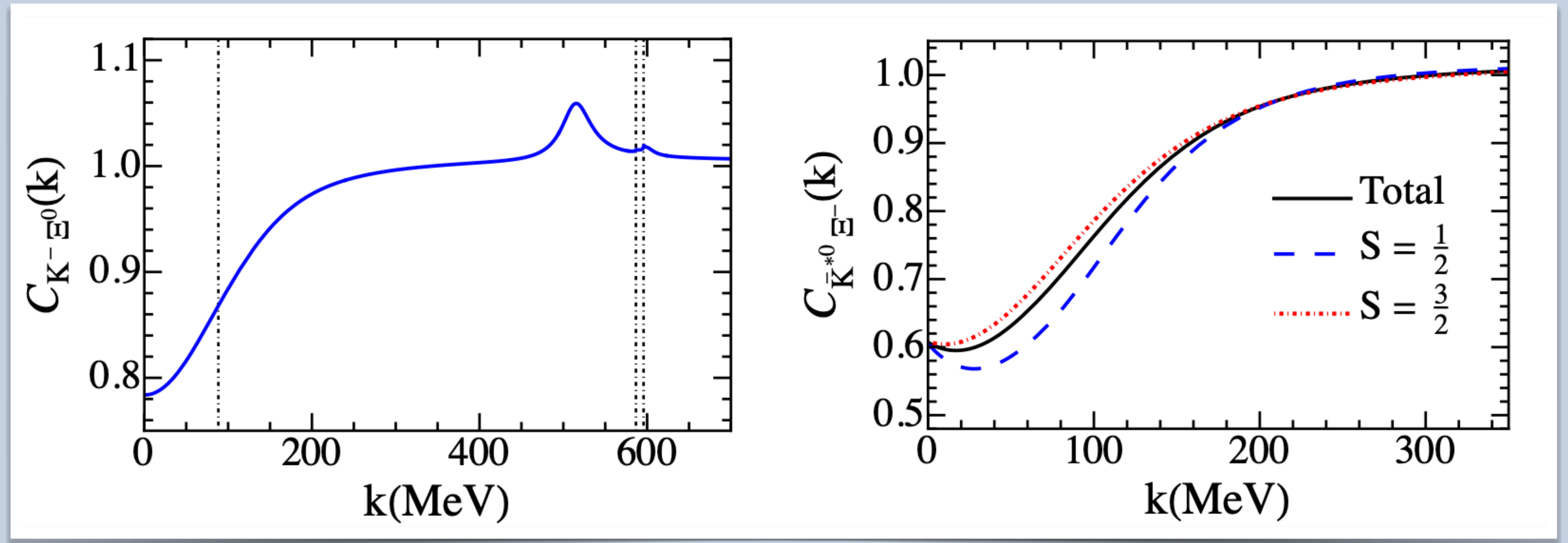
Taísa Veloso,[1,*] K. P. Khemchandani,[1,†]
A. Martínez Torres,[2,‡] H. Nagahiro,[3,4,§] and A. Hosaka[4,¶]



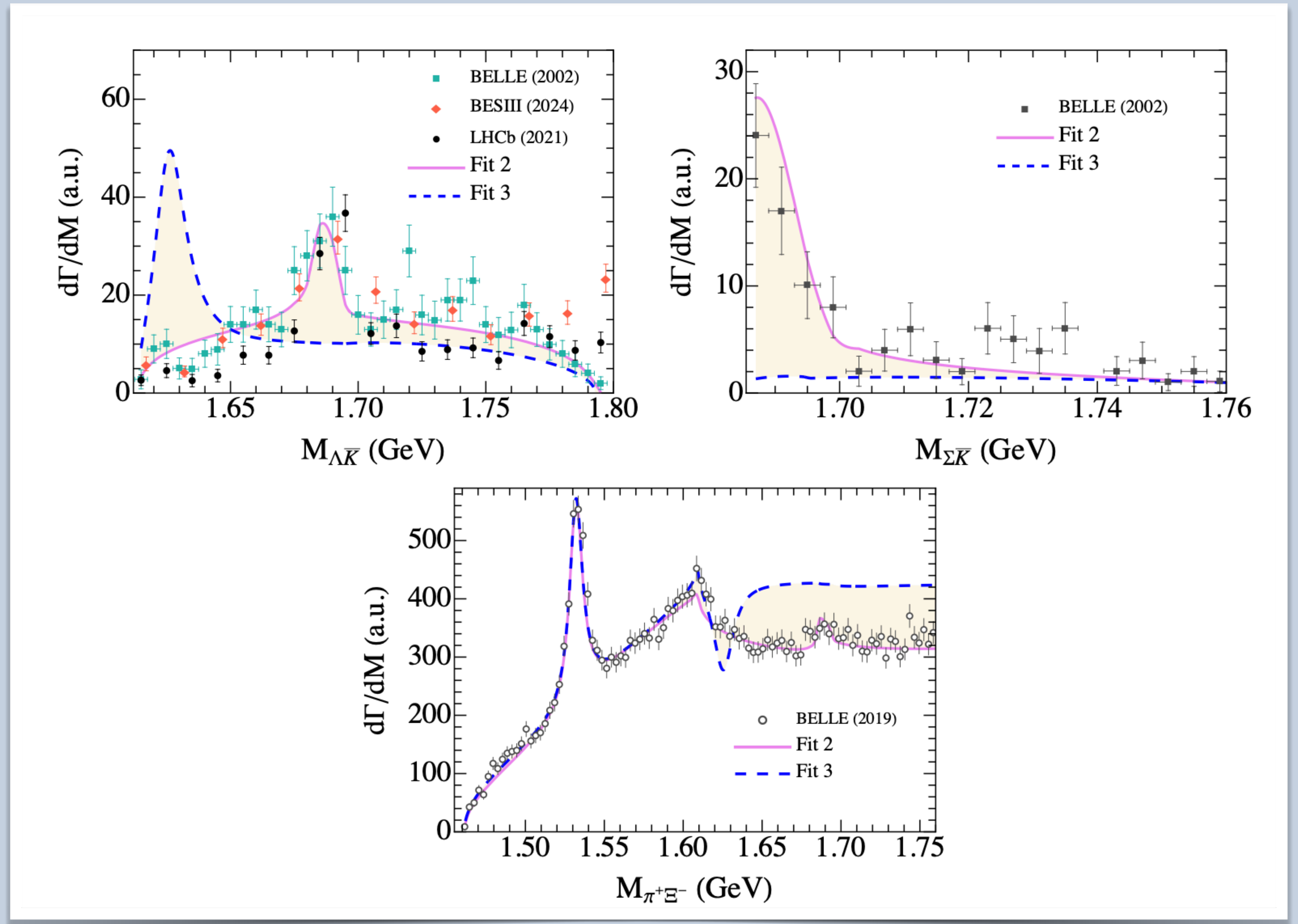
- Prediction for measuring data on Femtoscopic correlation functions

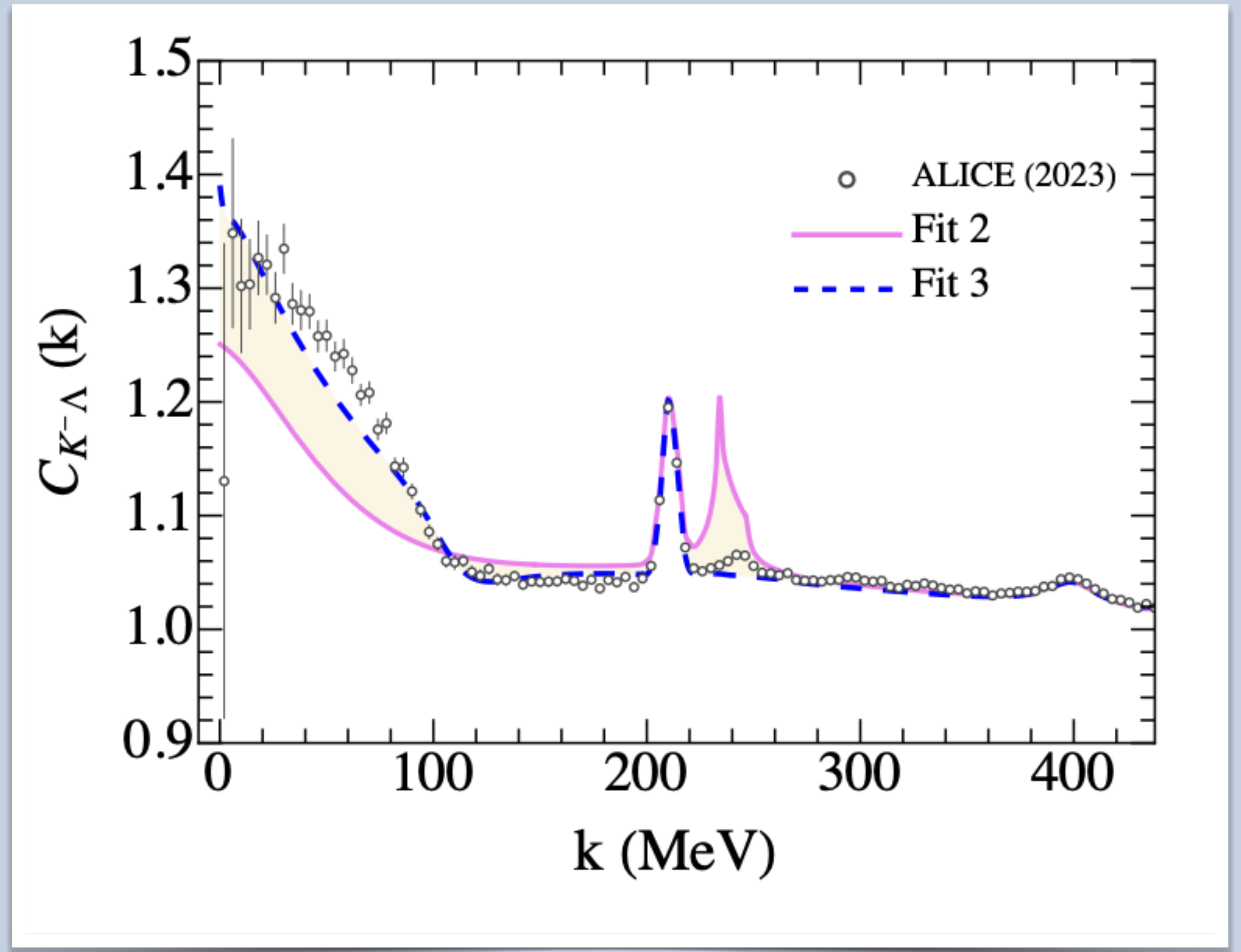
- Test of our model

Model and data disagreements

- Free parameters do not imply that we will always fit the data.

- Example: a study in progress. Coupled dynamics of
$\pi\Xi, \eta\Xi, \bar{K}\Sigma, \bar{K}\Lambda, \rho\Xi, \omega\Xi, \phi\Xi, \bar{K}^*\Sigma$, and $\bar{K}^*\Lambda$.





Strong final state interaction in weak decays

- Recently, data on $B^+ \to D^{*-}D_s^+\pi^+$ [JHEP 08, 165 (2024)]

- $B^- \to D^{*+}\pi^-\pi^-$ 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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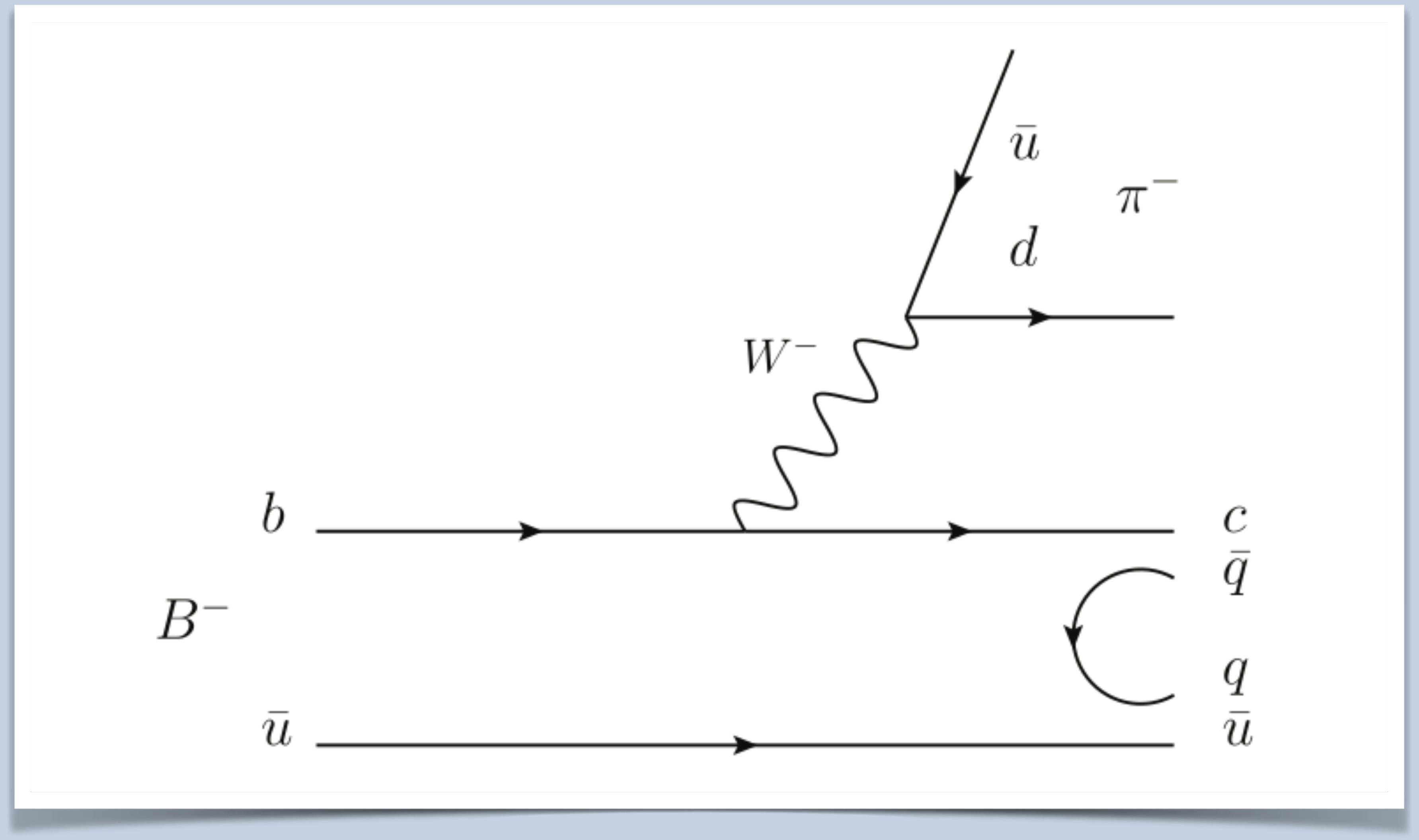

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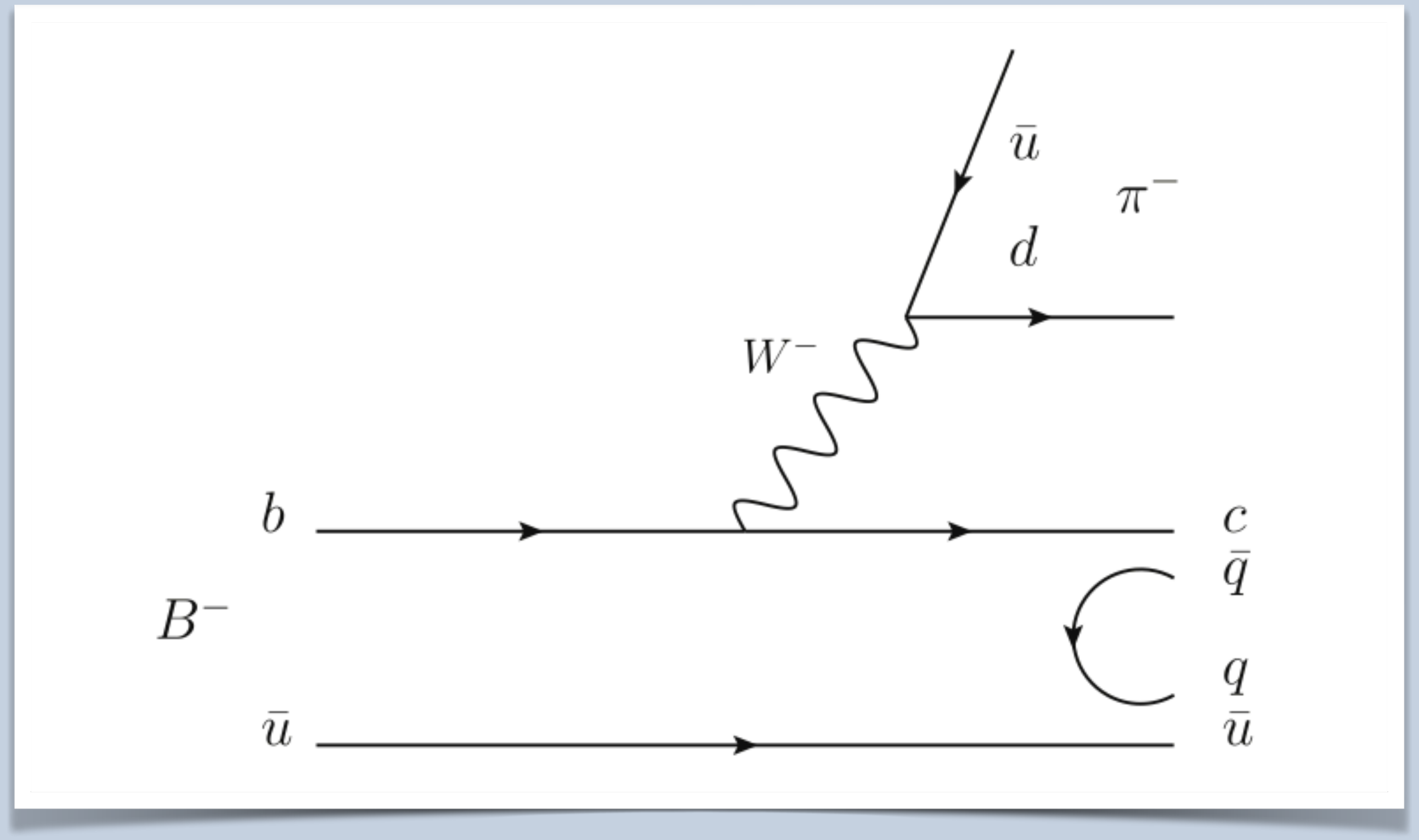

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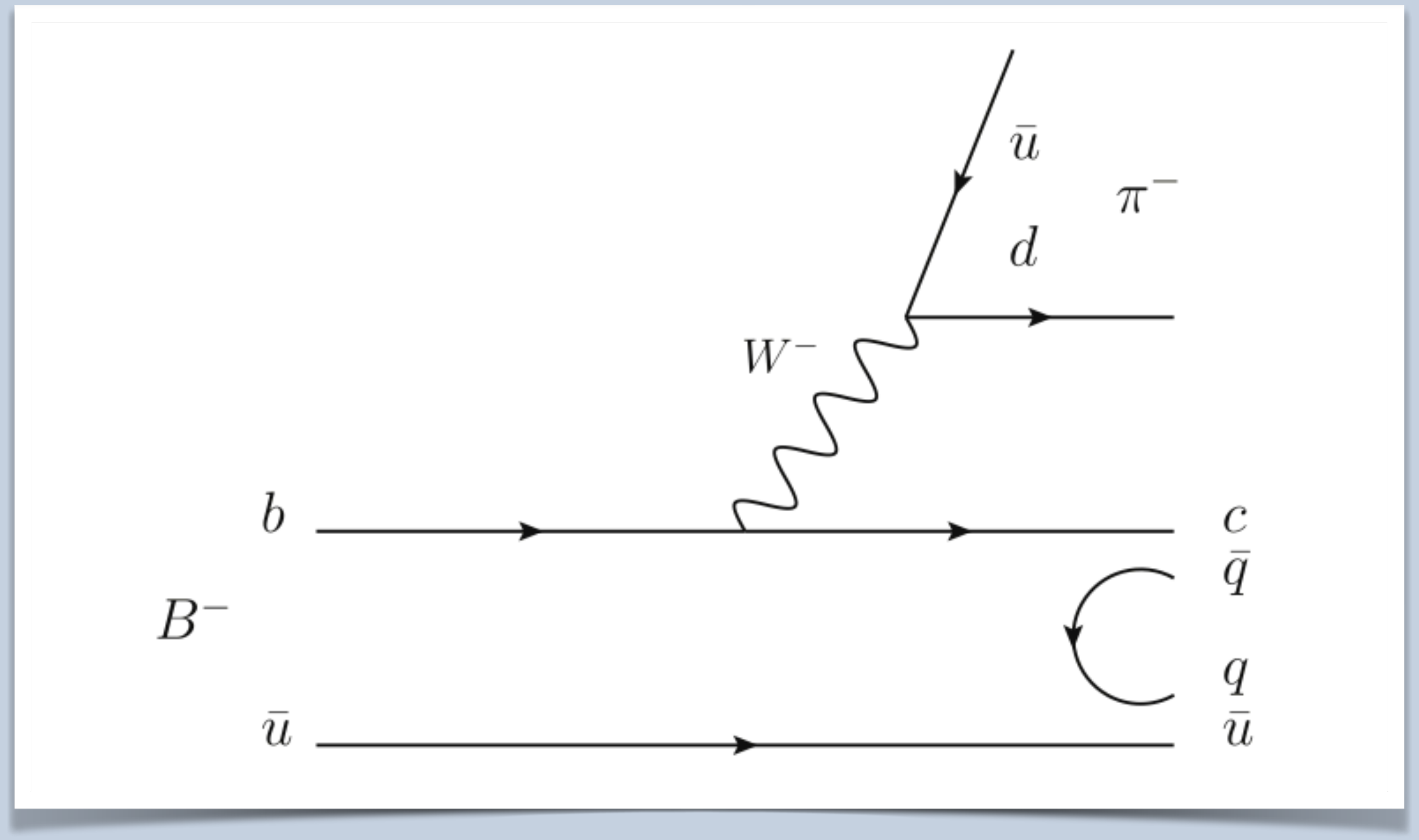
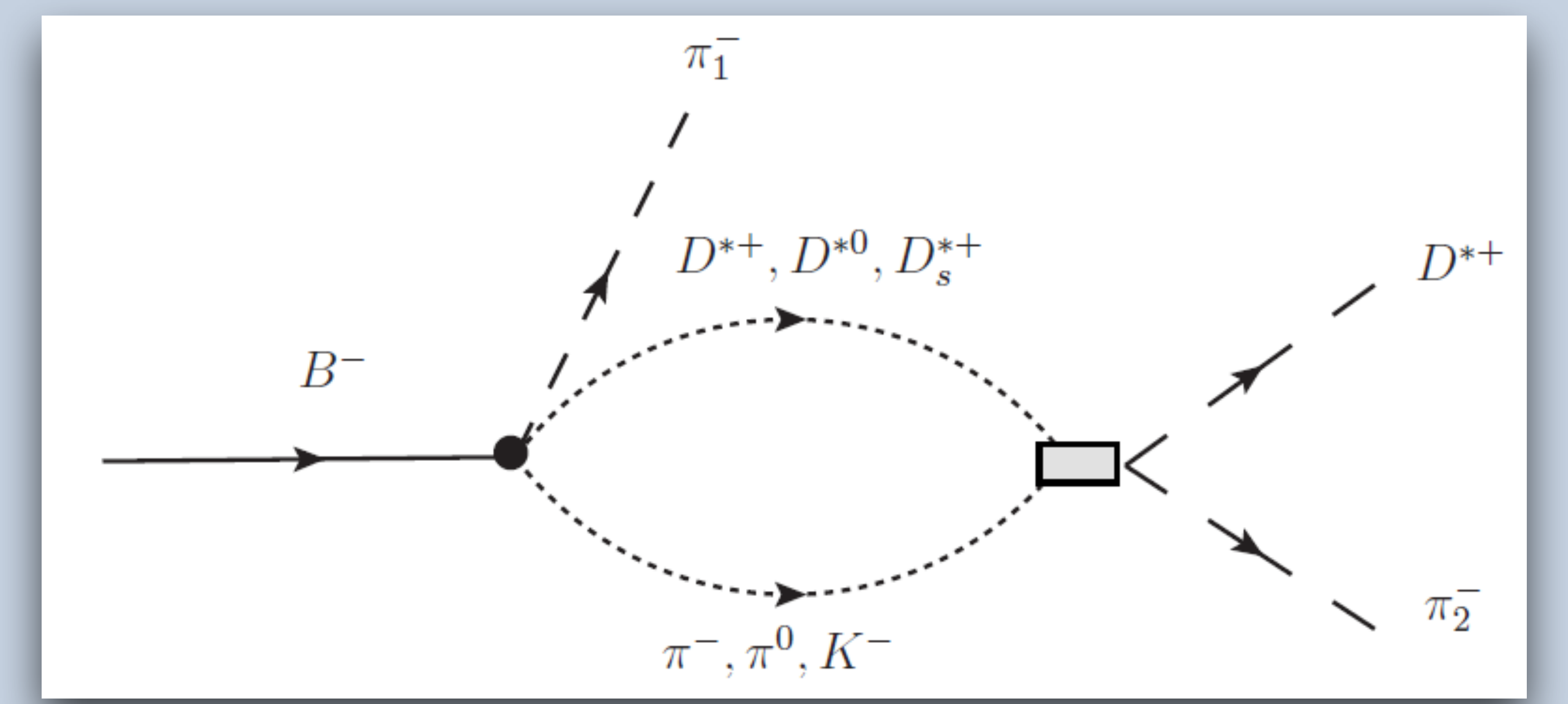
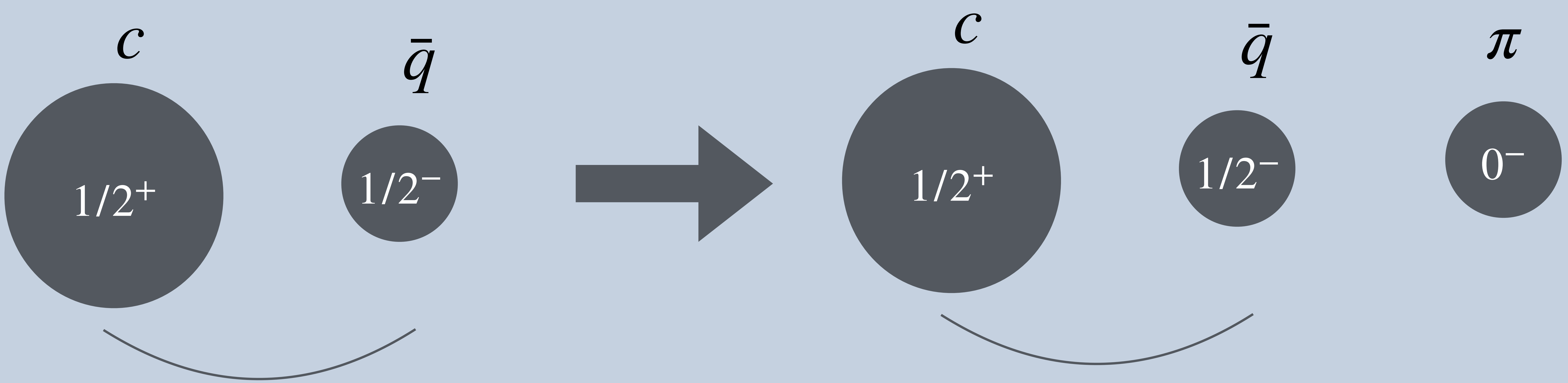




Strong final state interaction in weak decays

- Motivation to study $D^*\pi$ 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.



$L = 1$

$L = 0$

Larger width

$1/2^+ \otimes 1/2^+ \Rightarrow 1/2^+ \otimes (1/2^- \otimes 0^-)$ Decay in $L = 0$

$1/2^+ \otimes 3/2^+ \Rightarrow 1/2^+ \otimes (1/2^- \otimes 0^-)$ $1/2^+ \otimes \left(1/2^- \otimes 0^- \otimes 2^+\right)$

Decay in $L = 2$ smaller width

Strong final state interaction in weak decays

- 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.

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

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

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

Lattice-inspired χFT models

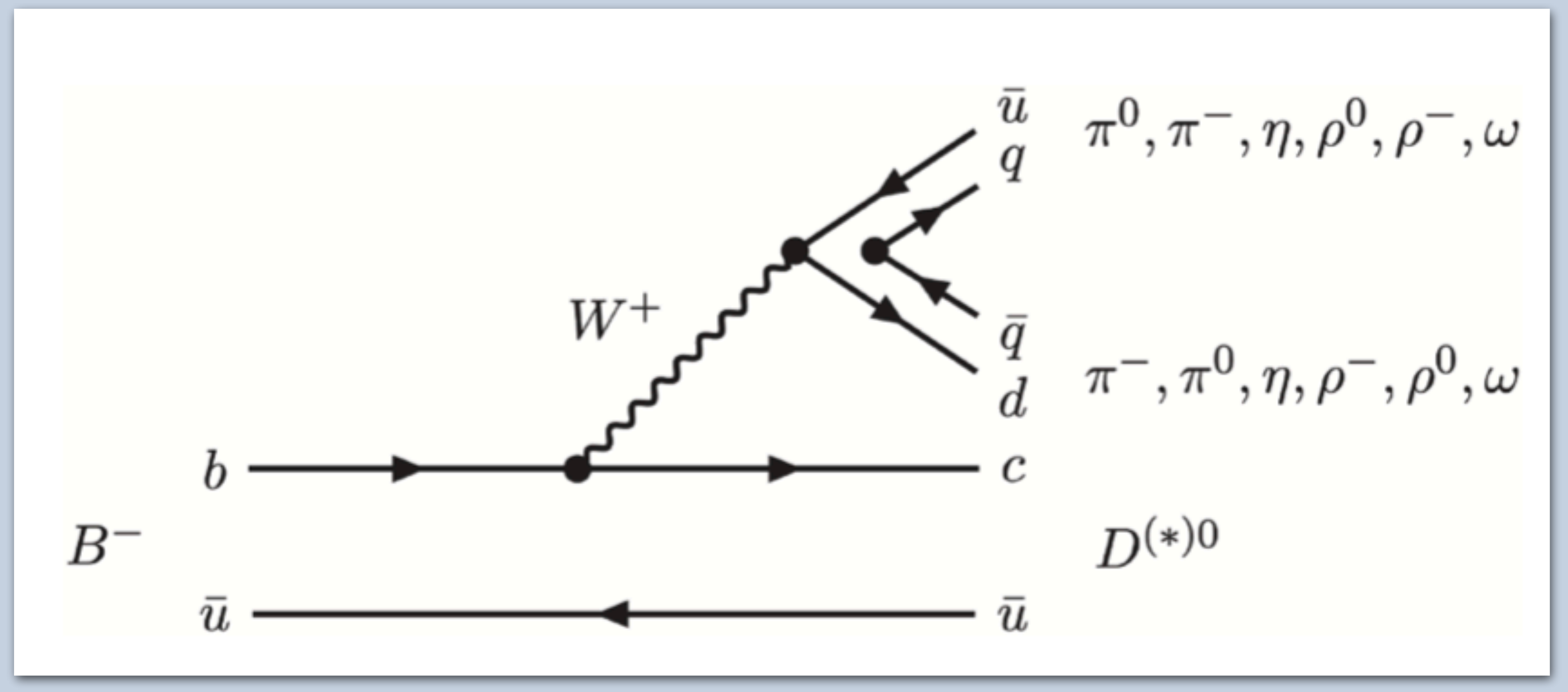
L. M. Abreu, D. Cabrera, F. J. Llanes-Estrada, and J. M. Torres-Rincon, Ann. Phys. (Amsterdam) 326, 2737 (2011).
L. S. Geng, N. Kaiser, J. Martin-Camalich, and W. Weise,Phys. Rev. D 82, 054022 (2010).

Alice

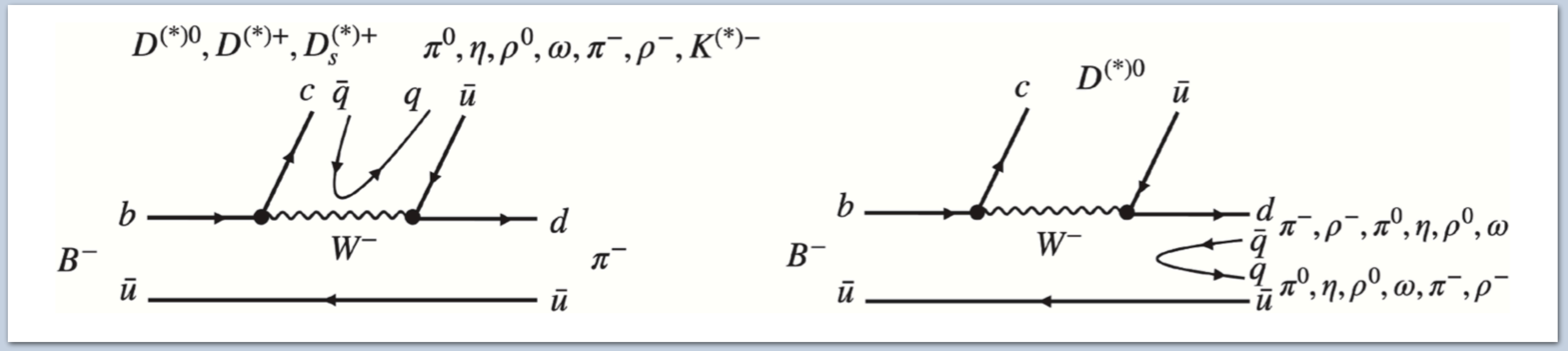
Phys. Rev. D 110 (2024) 032004

Strong final state interaction in weak decays

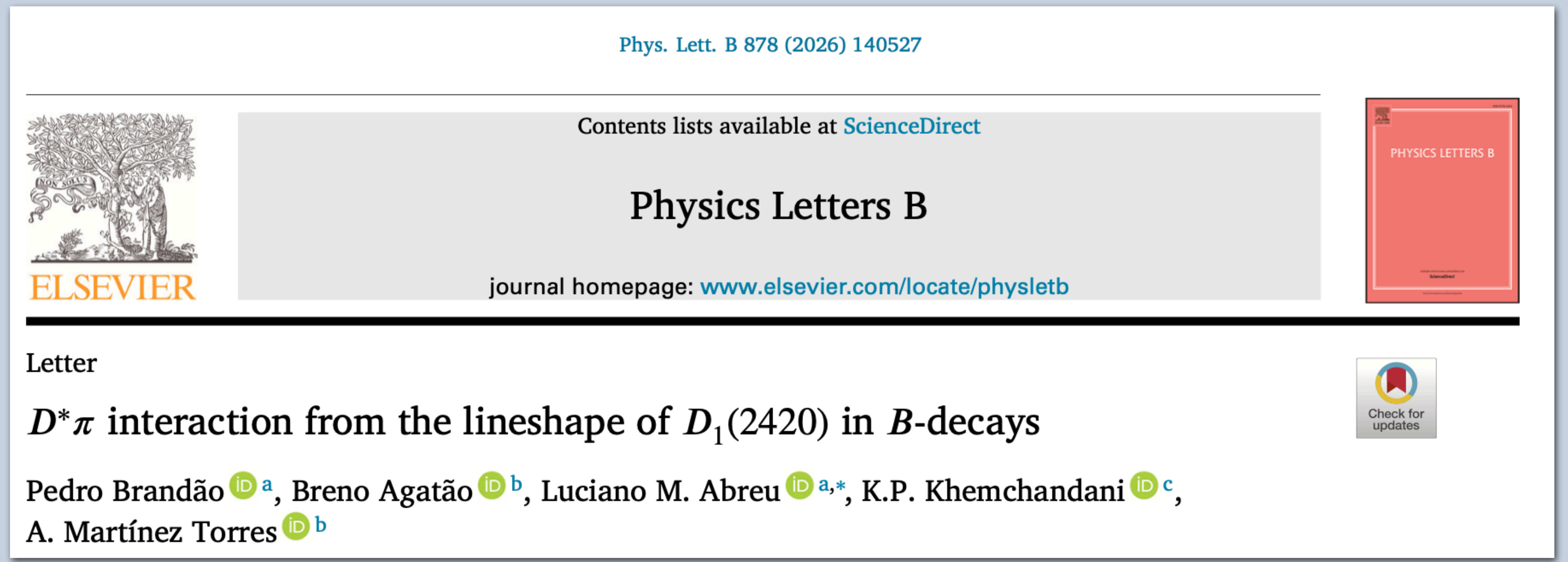
- We consider data on weak decays $B^+ \to D^{*-} D_s^+ \pi^+$, $B^- \to D^{*+} \pi^- \pi^-$ as an alternative source of information



+



+ FSI



Phys. Lett. B 878 (2026) 140527

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Letter

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

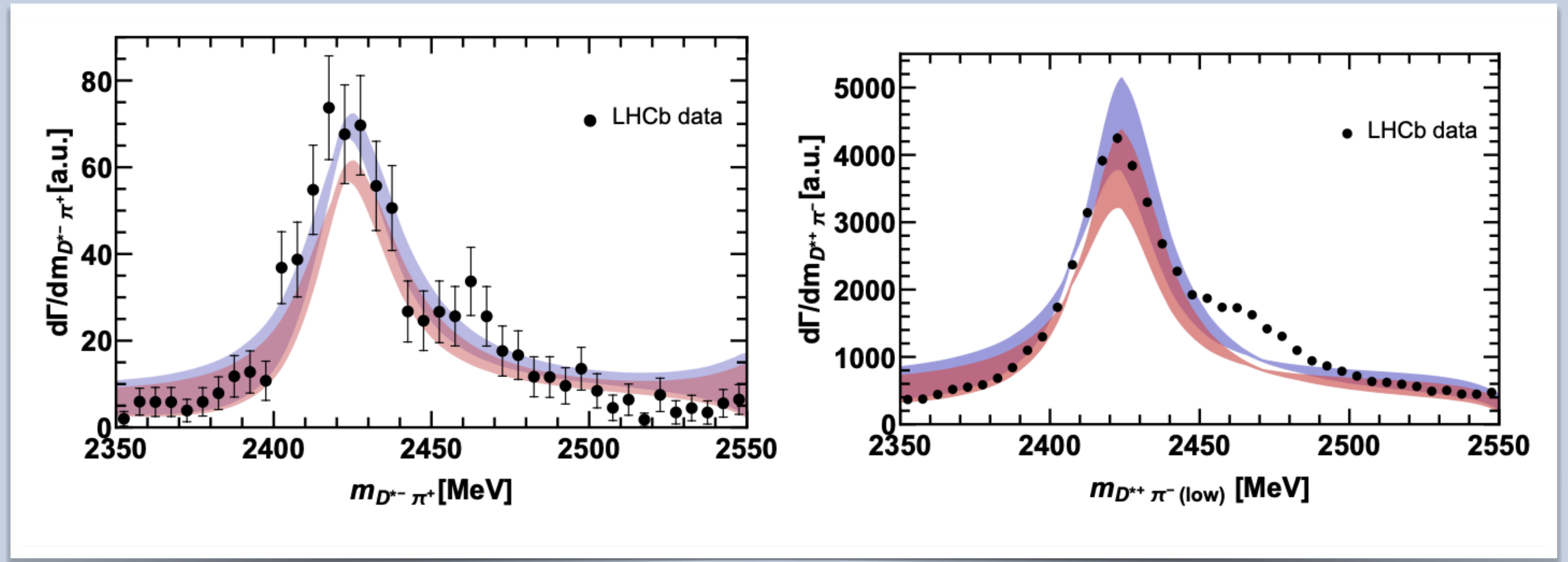
Pedro Brandão [a], Breno Agatão [b], Luciano M. Abreu [a,*], K.P. Khemchandani [c], A. Martínez Torres [b]

Strong final state interaction in weak decays

- 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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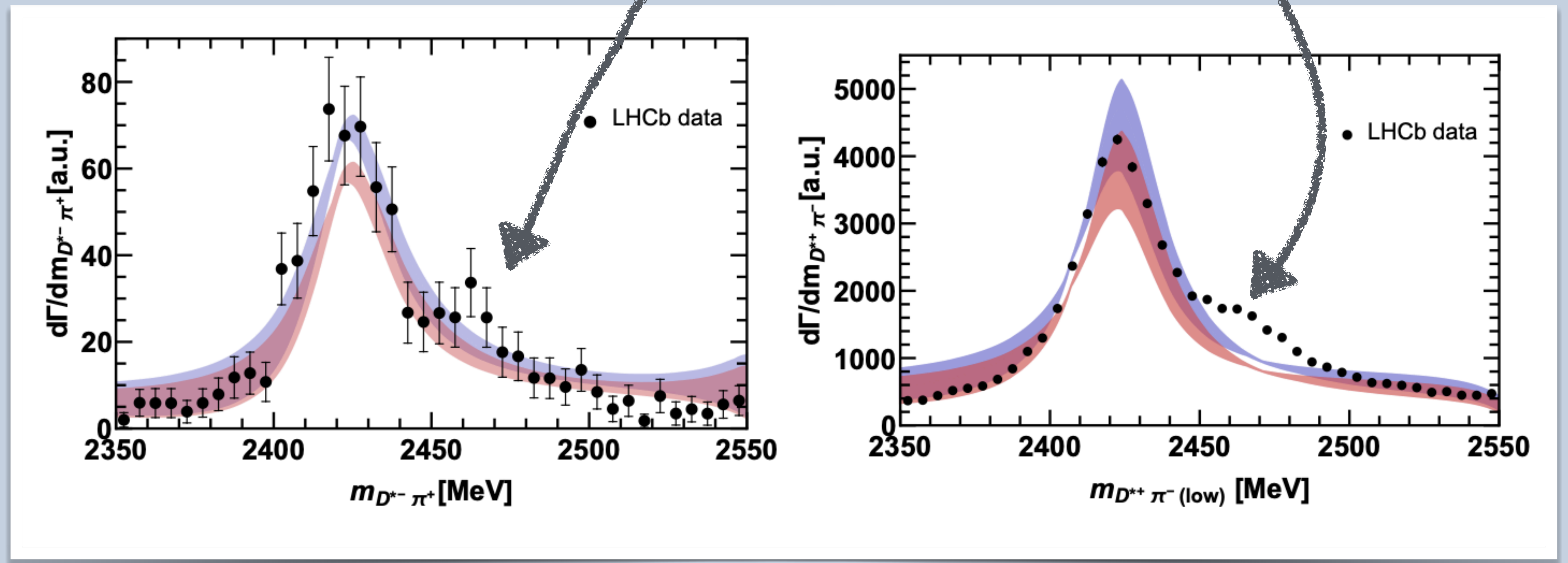
Tensor state, not present in our model



Strong final state interaction in weak decays

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

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

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

Lattice-inspired χFT models

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

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

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Conclusions

- We do not have good precision yet, neither from the experimental side nor from models.

- Several effects appear at the same time: resonances, threshold effects, etc. We cannot isolate them.

- Coupled-channel dynamics is important to interpret experimental data carefully.

- A good description of nonperturbative hadronic interactions is not only important for spectroscopy, but also for deducing reliable information on the weak phase when analysing CP violation and when looking for evidence for new physics.

THANK YOU!