DK and $D\bar{K}$ scattering and the $D_{s0}^*(2317)$ from lattice QCD

Christopher Thomas, University of Cambridge

c.e.thomas@damtp.cam.ac.uk

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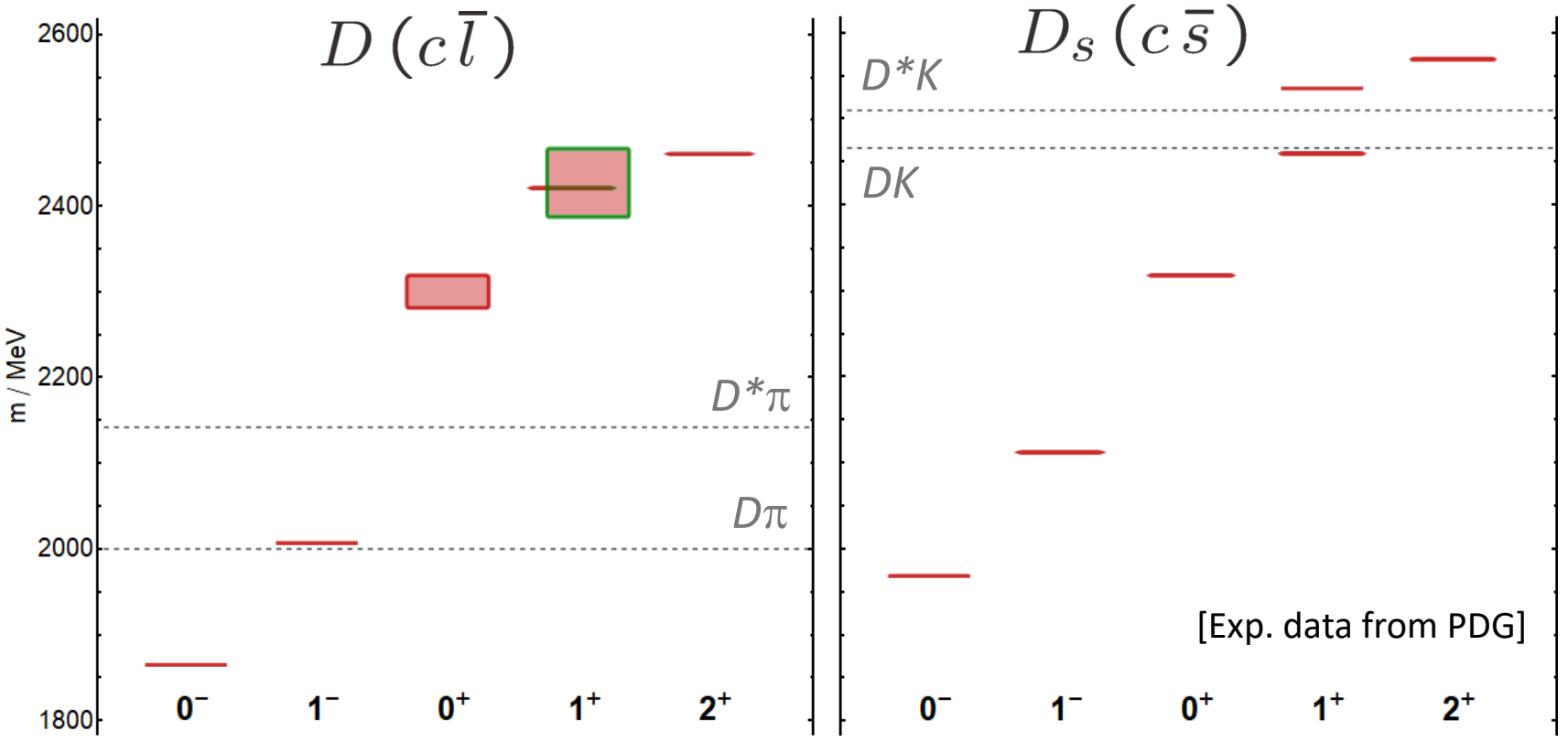
13 April 2021

UNIVERSITY OF CAMBRIDGE

hadspec

Charm-anti-light (D) and charm-anti-strange (D_s) mesons



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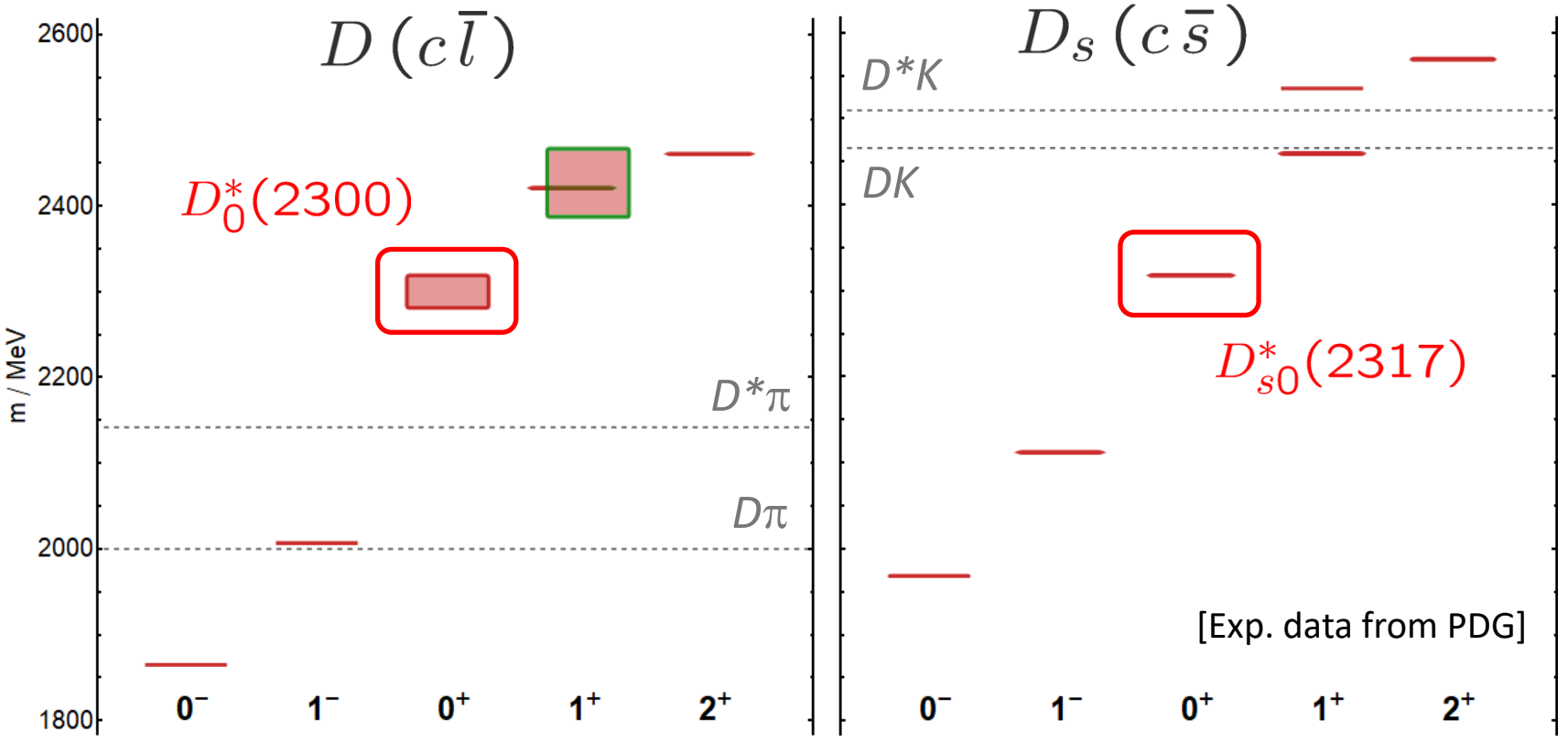

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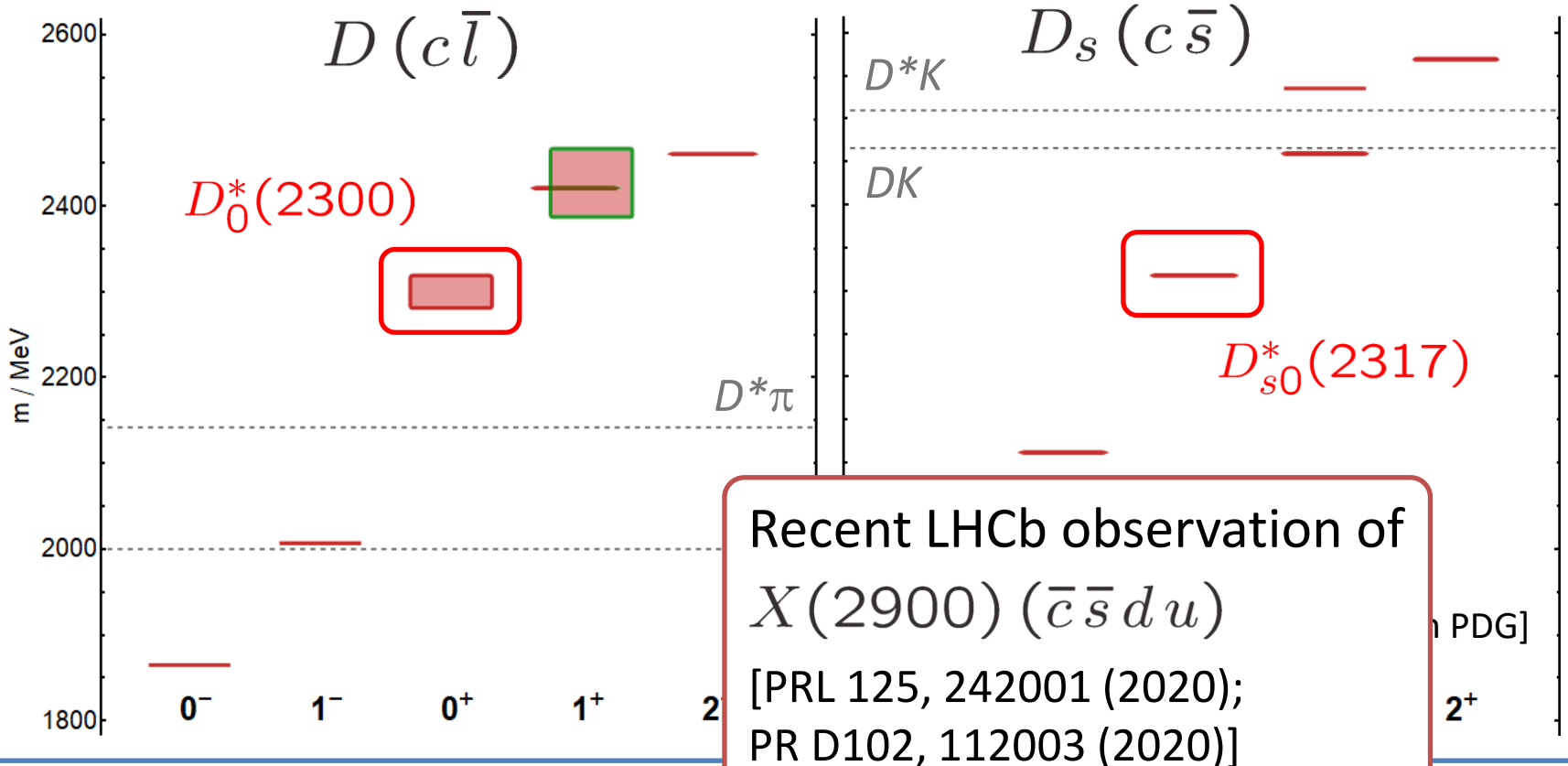
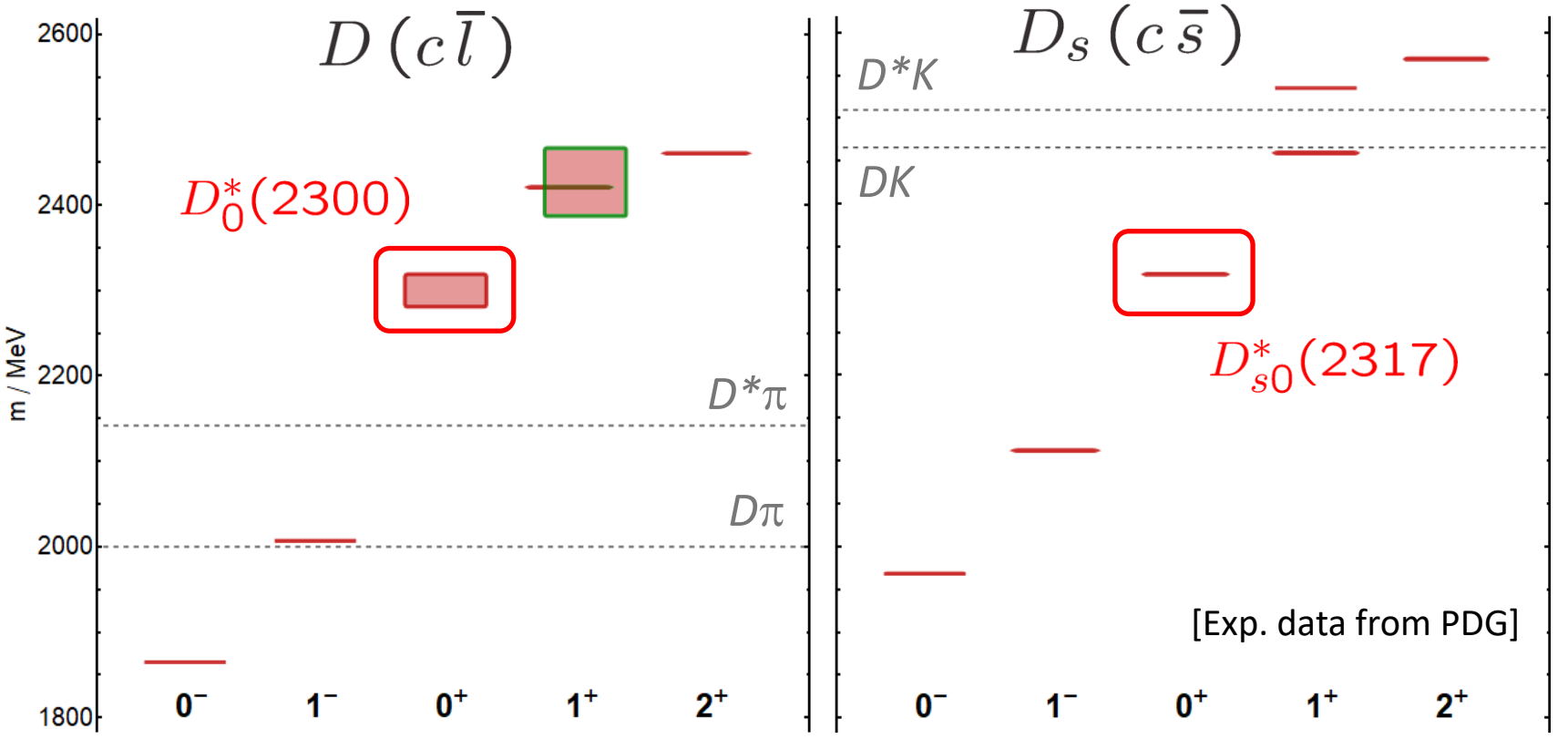


Recent LHCb observation of

$X(2900)\ (\bar{c}\,\bar{s}\,d\,u)$

[PRL 125, 242001 (2020);
PR D102, 112003 (2020)]

Charm-anti-light (D) and charm-anti-strange (D_s) mesons

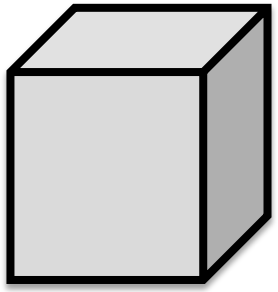


Some other LQCD studies: Mohler *et al* [PR D87, 034501 (2013)], Liu *et al* [PR D87, 014508 (2013)], Mohler *et al* [PRL 111, 222001 (2013)], Lang *et al* [PR D90, 034510 (2014)], Bali *et al* (RQCD) [PR D96, 074501 (2017)], Alexandrou *et al* (ETM) [PR D101 034502 (2020)]

Lattice QCD spectroscopy

Finite-volume energy eigenstates from:

$$C_{ij}(t) = \left\langle 0 \left| \mathcal{O}_i(t) \mathcal{O}_j^\dagger(0) \right| 0 \right\rangle$$



Large bases of interpolating operators
(with appropriate structures)

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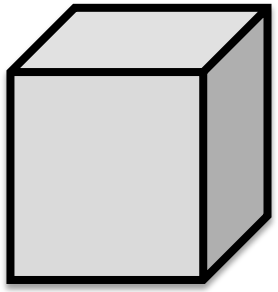

Large bases of interpolating operators
(with appropriate structures)

Lüscher method (and extensions): relate **finite-volume energy levels** to **infinite-volume scattering *t*-matrix**.

Elastic scattering: one-to-one mapping $E_{\text{cm}} \leftrightarrow t(E_{\text{cm}})$

Param. $t(E_{\text{cm}})$ using various *K*-matrix forms, effective range, …

DK (isospin=0)

[Cheung, CT, Wilson, Moir, Peardon, Ryan (HadSpec), JHEP 02 (2021) 100, arXiv:2008.06432]

Use many different fermion-bilinear

$$\sim \bar{\psi}\Gamma D \ldots \psi$$

and *DK*, ... operators

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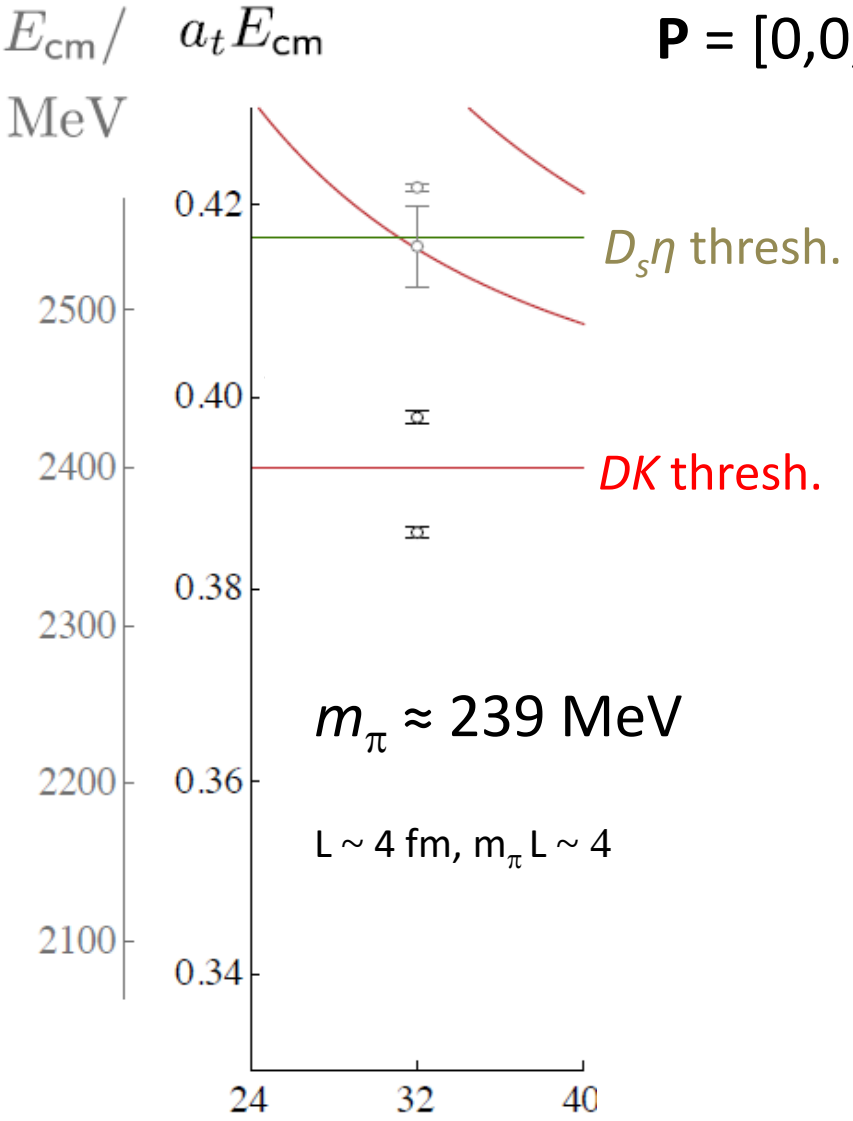
P = [0,0,0] $J^P = 0^+, (4^+, \ldots)$



$m_\pi \approx 239$ MeV

L ~ 4 fm, m_π L ~ 4

Use many different fermion-bilinear

$$\sim \bar{\psi}\Gamma D \ldots \psi$$

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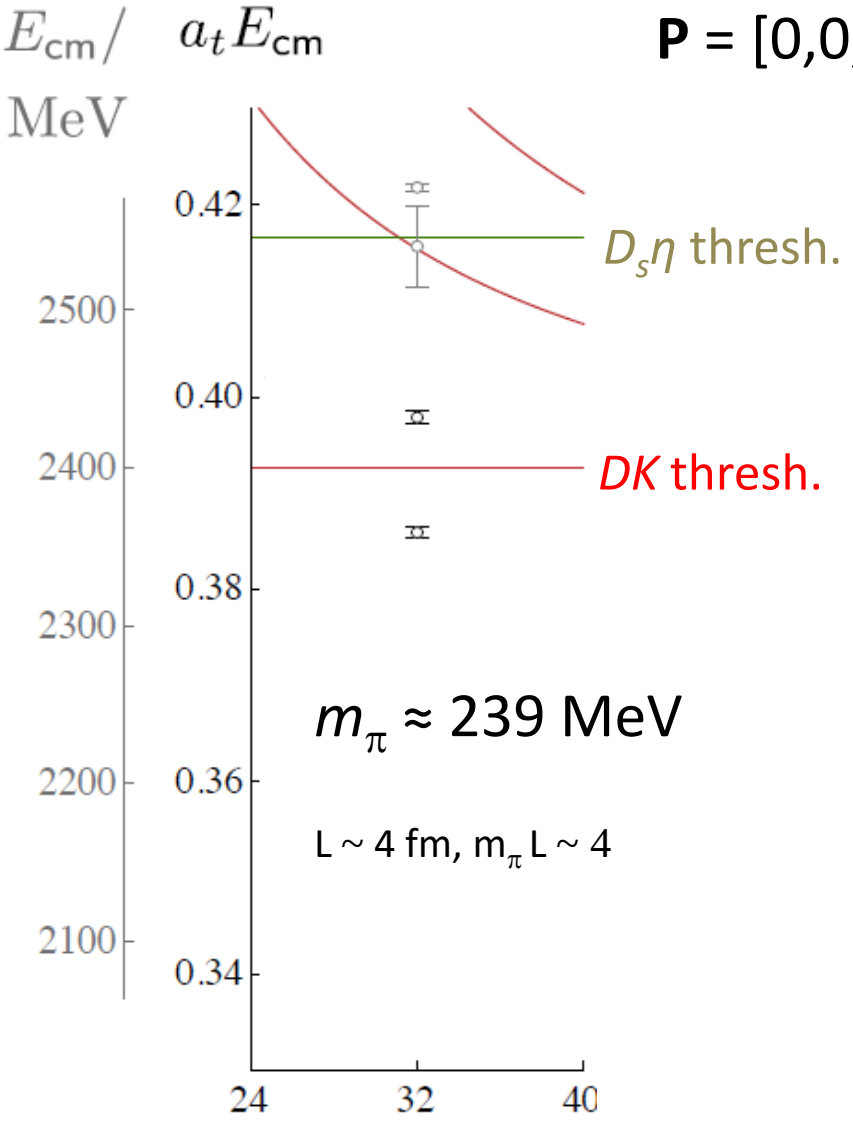

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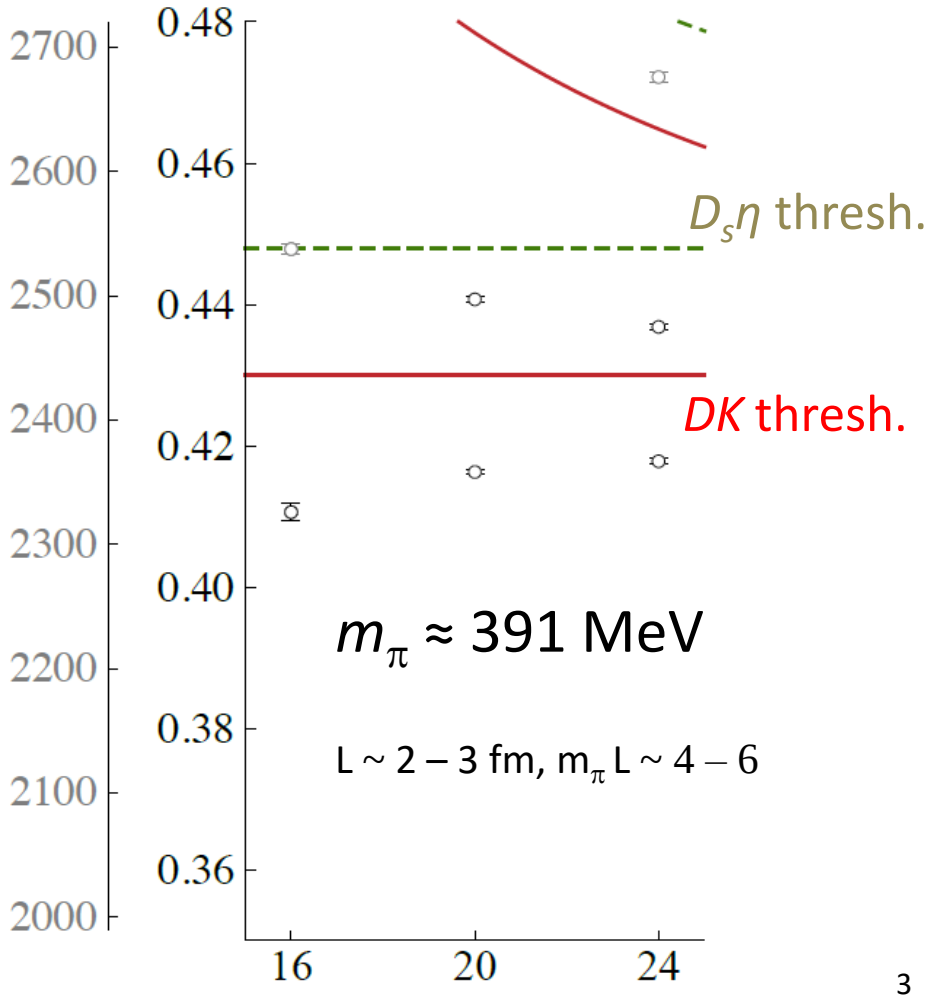
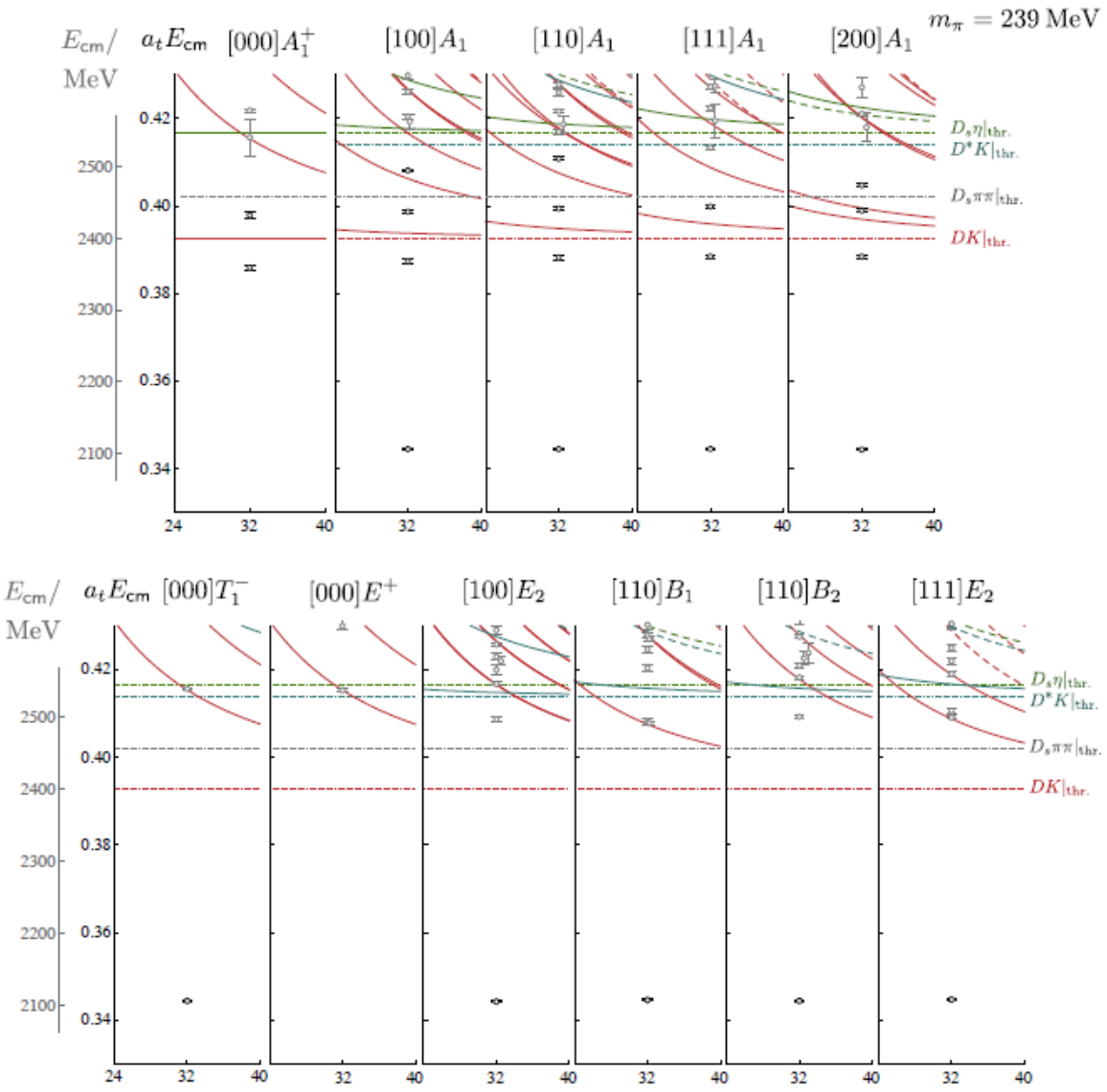


$m_\pi \approx 391$ MeV

L ~ 2 – 3 fm, m_π L ~ 4 – 6

DK (isospin=0) – spectra

[JHEP 02 (2021) 100]

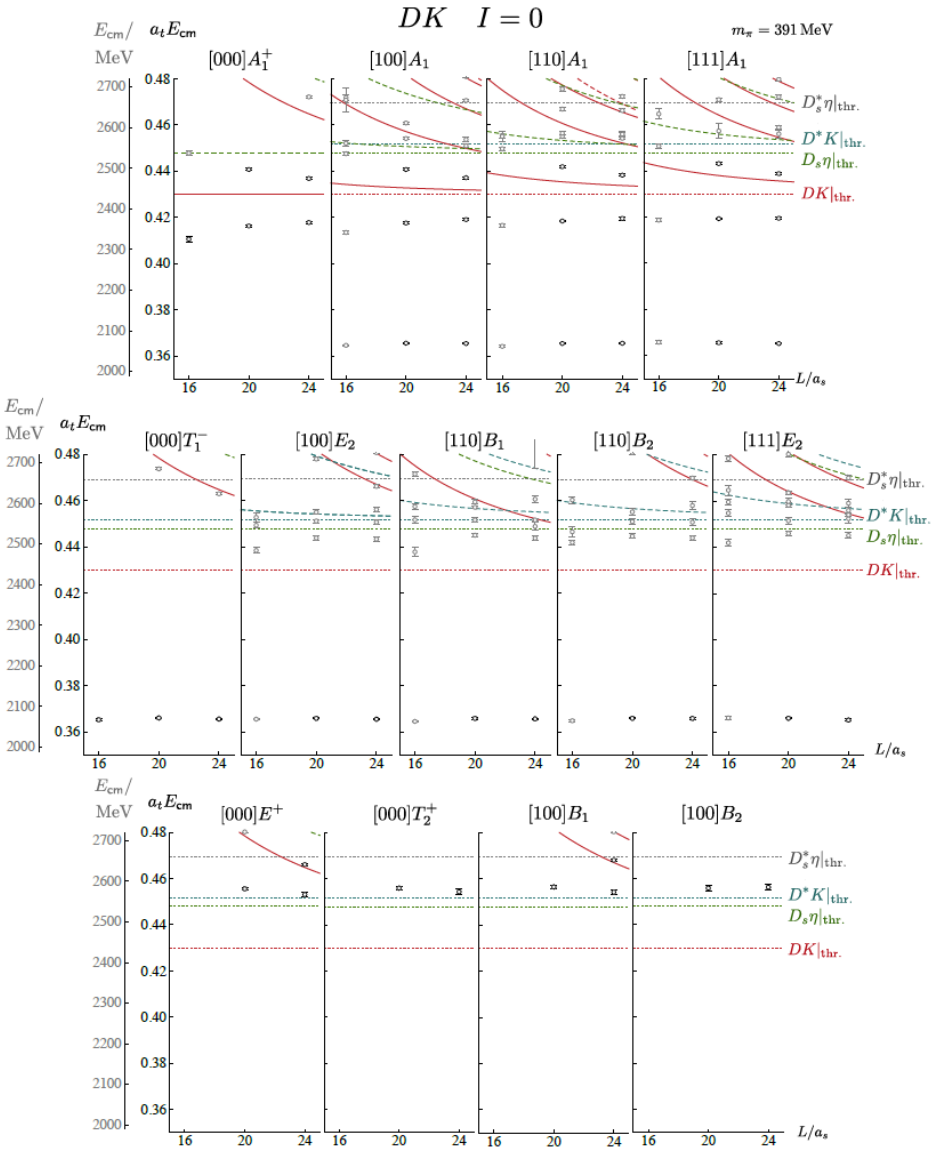


$m_\pi \approx 239$ MeV

Use 22 energy levels for $\ell = 0, 1$

DK (isospin=0) – spectra

[JHEP 02 (2021) 100]



$m_\pi \approx 391$ MeV

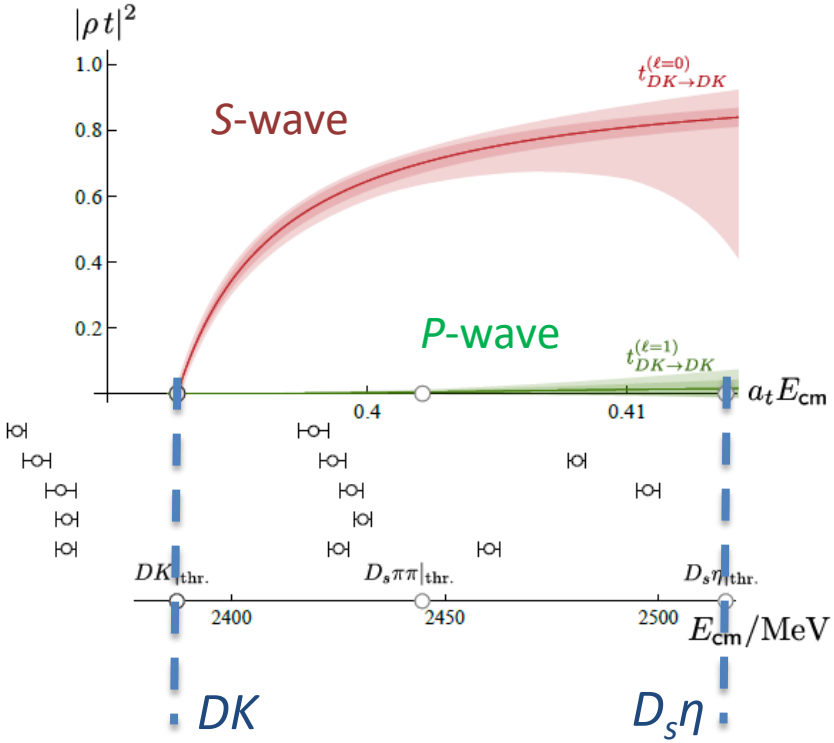
Use 34 energy levels for $\ell = 0, 1$

DK (isospin=0) – amplitudes

[JHEP 02 (2021) 100]

$m_\pi \approx 239$ MeV

$\sim |\text{amp}|^2$



Elastic DK scattering in S and P-wave

Sharp turn-on in S-wave at threshold

DK (isospin=0) – amplitudes

[JHEP 02 (2021) 100]

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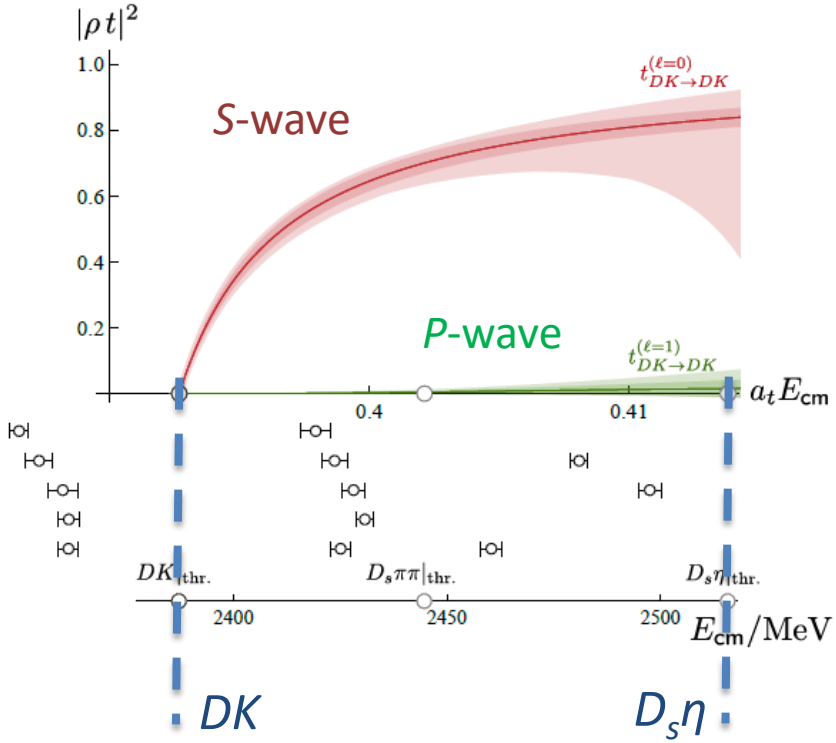
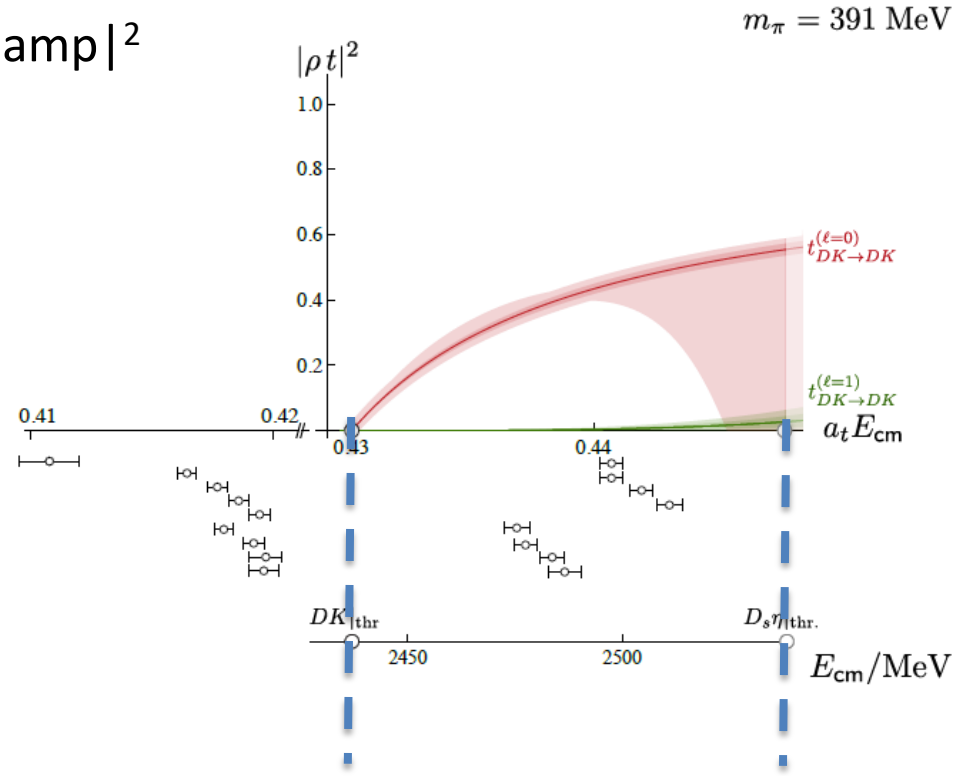


~ |amp|^2



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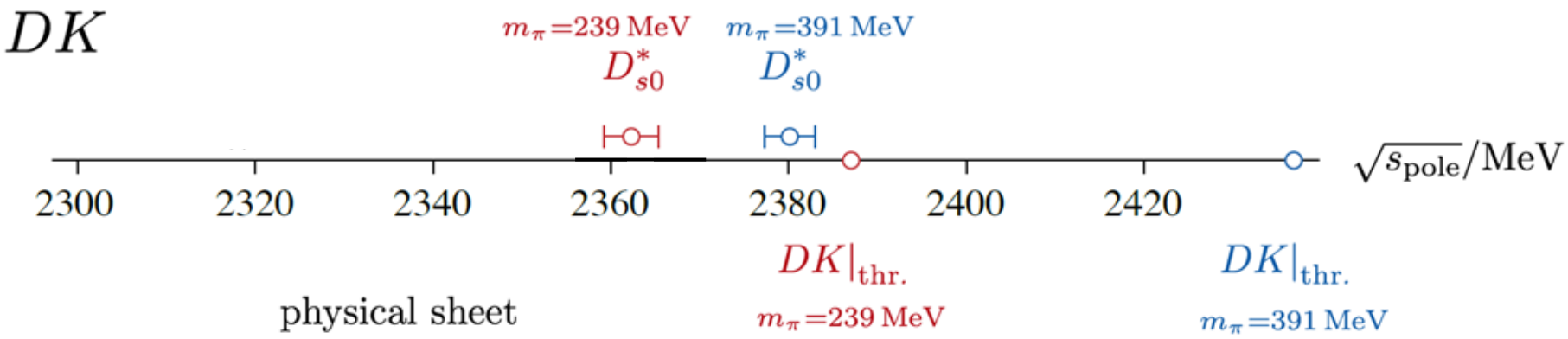
DK (isospin=0) – *S*-wave poles

[JHEP 02 (2021) 100]



Bound-state pole in *S*-wave

ΔE = 25(3) MeV for $m_\pi \approx 239$ MeV

ΔE = 57(3) MeV for $m_\pi \approx 391$ MeV

DK (isospin=0) – *S*-wave poles

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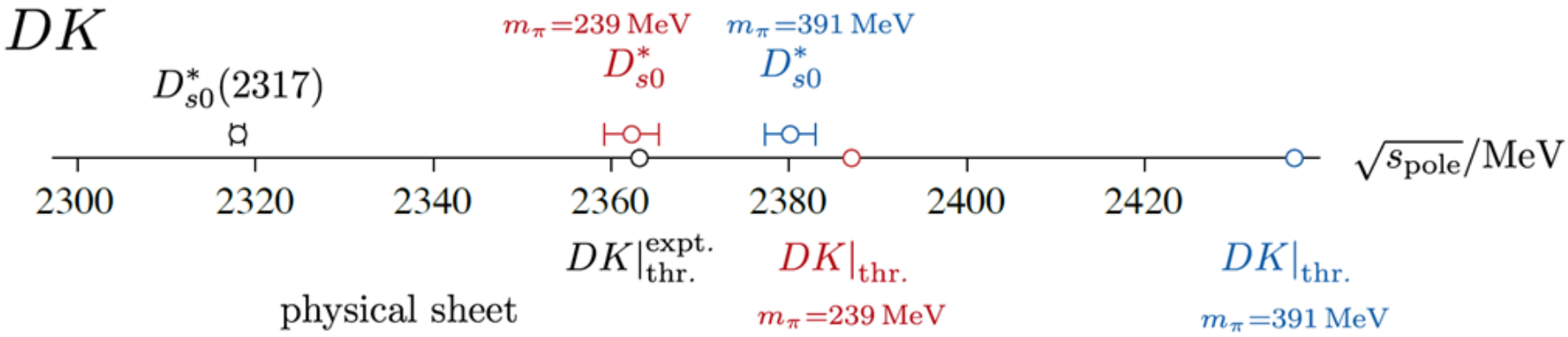

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c.f. experiment ΔE ≈ 45 MeV (decays to $D_s\pi^0$)

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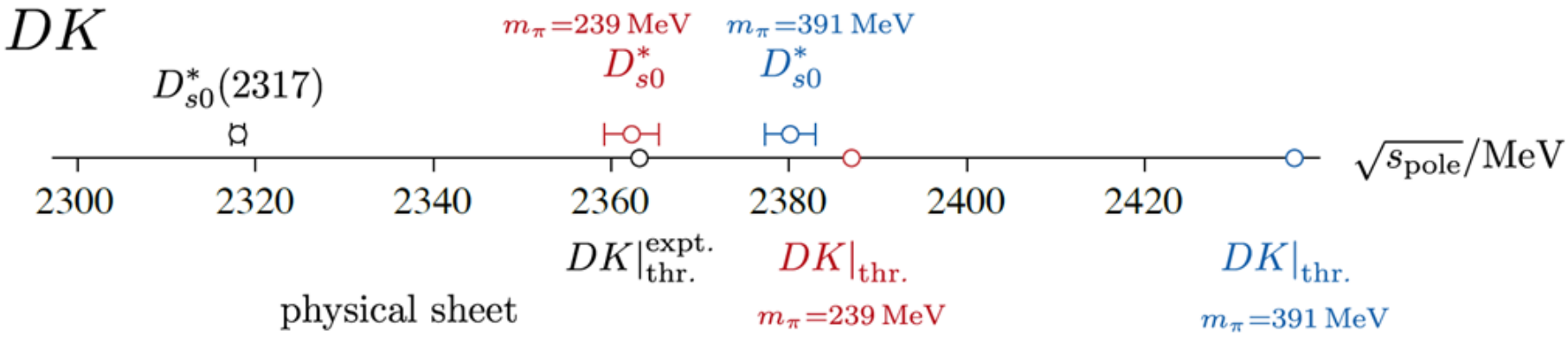

Bound-state pole in *S*-wave

ΔE = 25(3) MeV for $m_\pi \approx 239$ MeV $Z \lesssim 0.11$

ΔE = 57(3) MeV for $m_\pi \approx 391$ MeV $Z \approx 0.13(6)$

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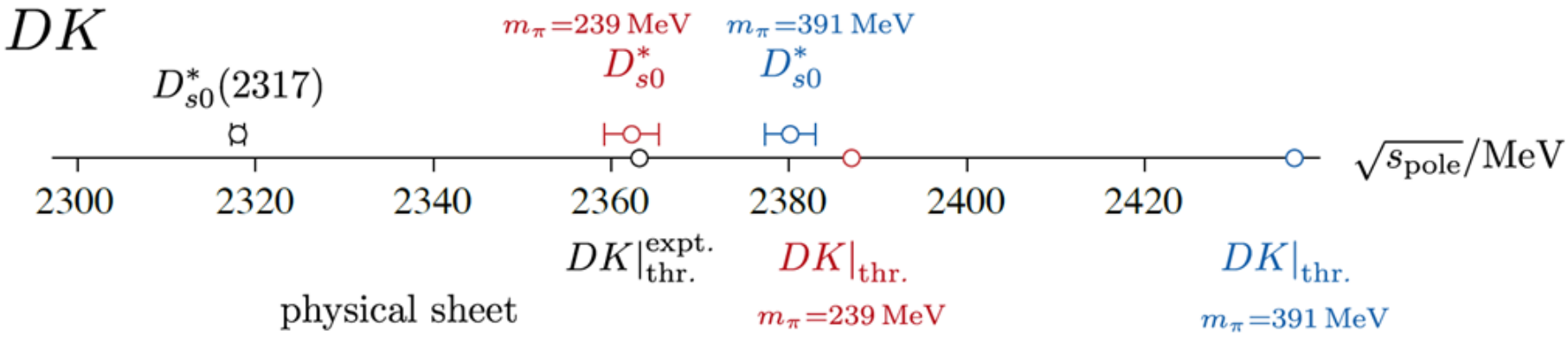
Weinberg [PR 137, B672 (1965)] compositeness, $0 \le Z \le 1$
(assuming binding is sufficiently weak)

DK (isospin=0) – *S*-wave poles

[JHEP 02 (2021) 100]



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c.f. experiment ΔE ≈ 45 MeV (decays to $D_s\pi^0$)

Also deeply bound state in *P*-wave, but doesn't strongly influence *DK* scattering at these energies

$D\bar{K}$ (isospin=0,1)

Exotic flavour $(\bar{l}\bar{l}\,c\,s)$

[JHEP 02 (2021) 100]

Use many operators,

$\sim D\bar{K}$

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[0,0,0] $J^P = 0^+$ (, 4^+, ...)

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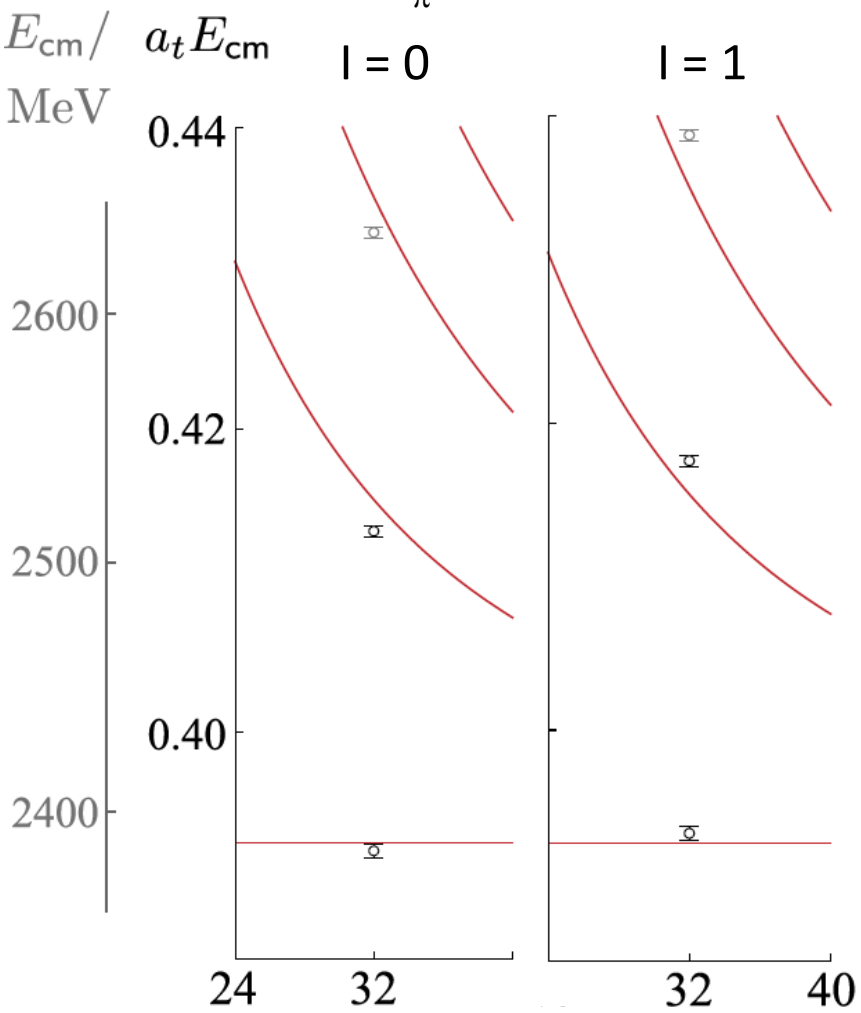

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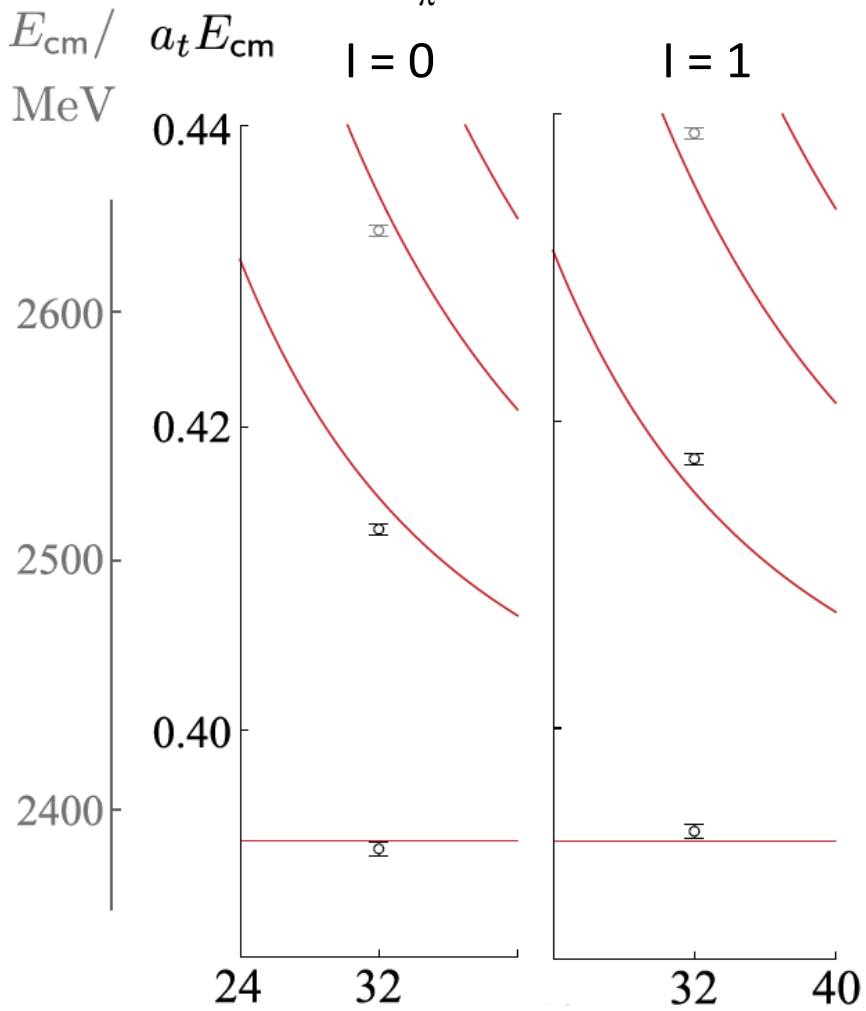

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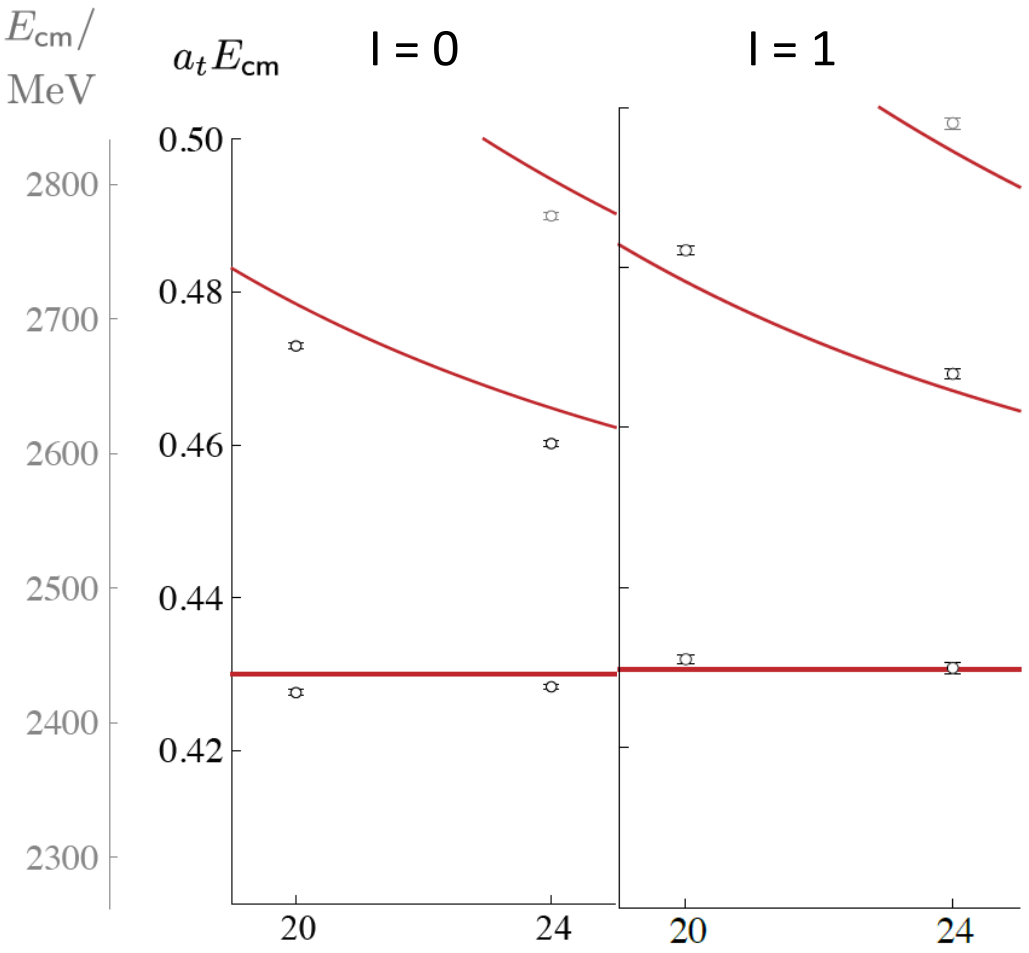
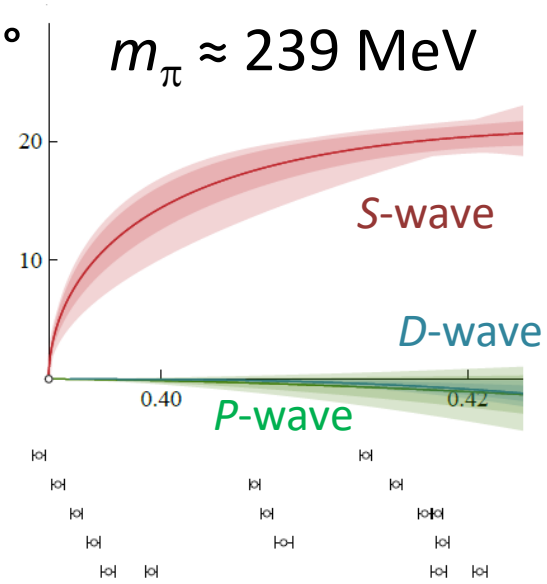


$D\bar{K}$ (isospin=0,1) – amplitudes

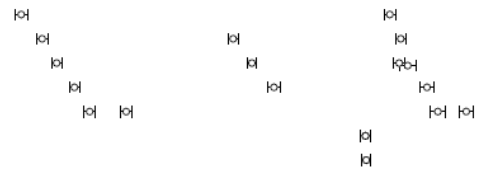
[JHEP 02 (2021) 100]

δ / ° $m_\pi \approx 239$ MeV

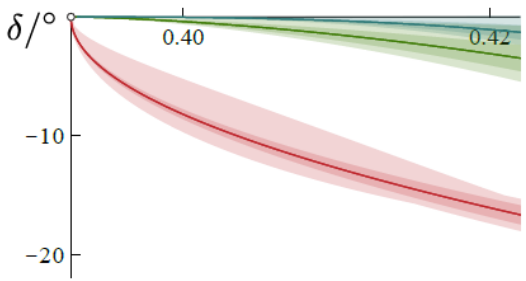
I = 0



(18, 18 levels for I=0,1)



I = 1



Elastic scattering in *S*, *P*, *D*-wave

Weak attraction in *S*-wave I=0

Weak repulsion in *S*-wave I=1

$D\bar{K}$ (isospin=0,1) – amplitudes

[JHEP 02 (2021) 100]

δ / °

$m_\pi \approx 239$ MeV

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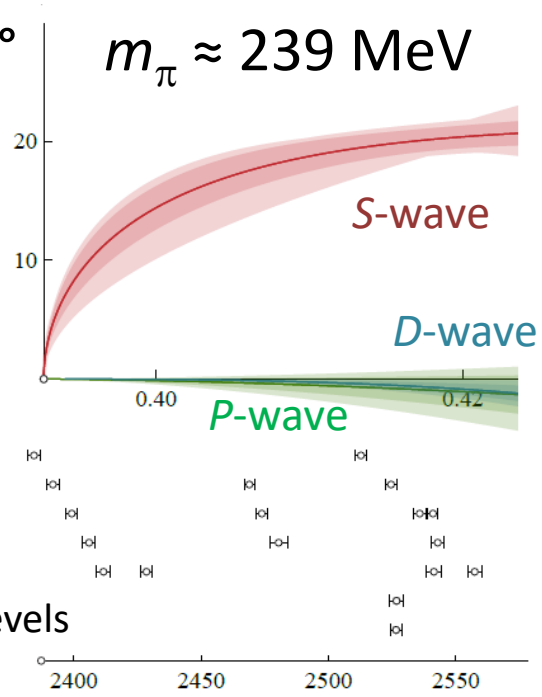

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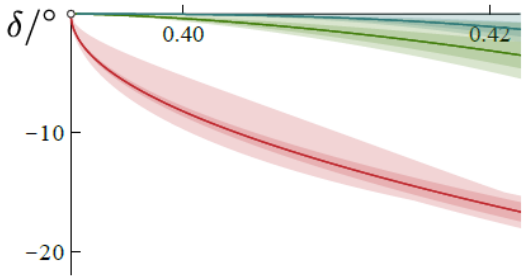

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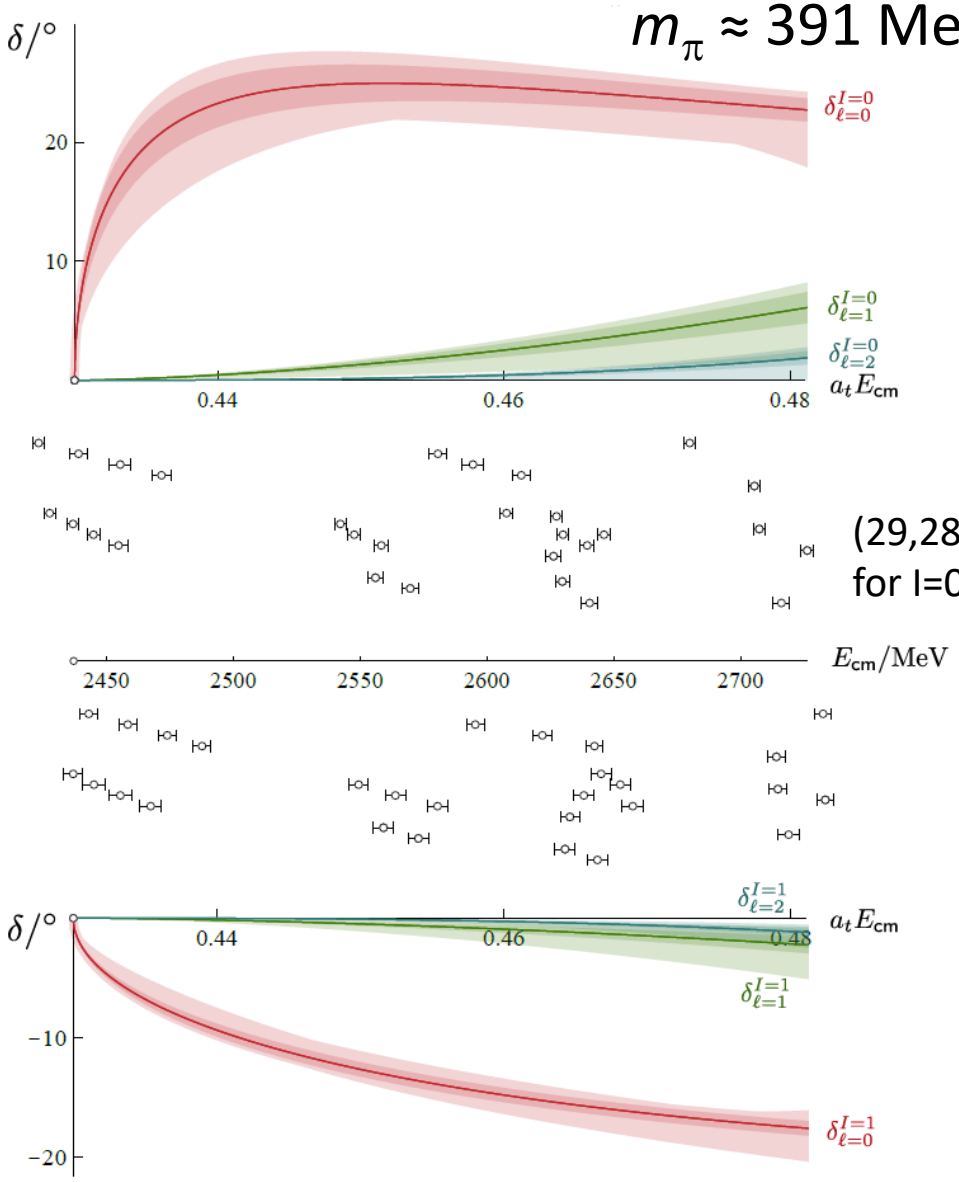
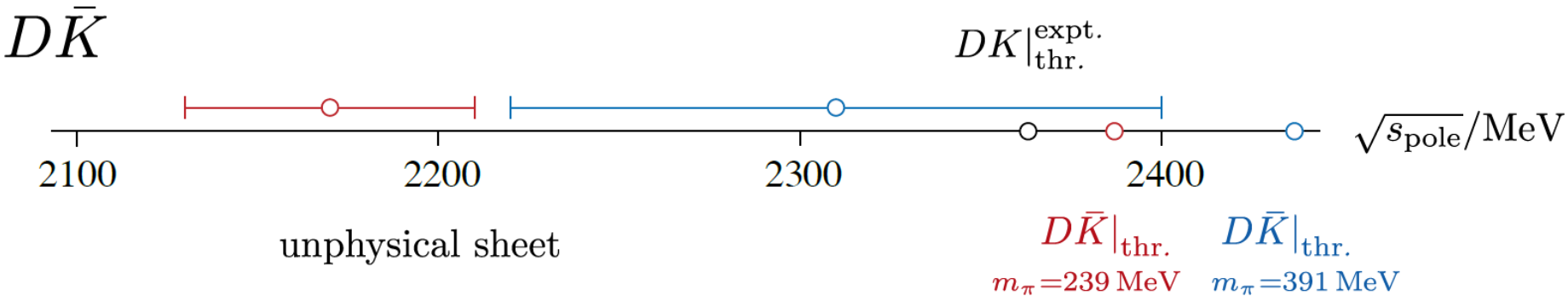


(29,28 levels for I=0,1)

$D\bar{K}$ (isospin=0) – poles

[JHEP 02 (2021) 100]



Suggestion of a **virtual bound-state** pole in *S*-wave I=0 (**exotic flavour**)

SU(3) flavour symmetry

[JHEP 02 (2021) 100]

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SU(3) multiplets:

$D_{(s)}$ $\overline{\mathbf{3}}$ Light/strange meson $\mathbf{8}$ or $\mathbf{1}$

$$\overline{\mathbf{3}} \otimes \mathbf{8} \to \overline{\mathbf{3}} \oplus \mathbf{6} \oplus \overline{\mathbf{15}}, \quad \overline{\mathbf{3}} \otimes \mathbf{1} \to \overline{\mathbf{3}}$$

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$(I=0)$ DK-$D_s\eta$: $\overline{\mathbf{3}} \oplus \overline{\mathbf{15}}$ $(I=\frac{1}{2})$ $D\pi$-$D\eta$-$D_s\bar{K}$: $\overline{\mathbf{3}} \oplus \mathbf{6} \oplus \overline{\mathbf{15}}$

$(I=1)$ DK-$D_s\pi$: $\mathbf{6} \oplus \overline{\mathbf{15}}$ $(I=0)$ $D\bar{K}$: $\mathbf{6}$

$(I=\frac{1}{2})$ D_sK, $(I=1)$ $D\bar{K}$, $(I=\frac{3}{2})$ $D\pi$: $\overline{\mathbf{15}}$

SU(3) flavour symmetry

[JHEP 02 (2021) 100]

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$(I=1)$ DK-$D_s\pi$: $\mathbf{6} \oplus \overline{\mathbf{15}}$

$(I=0)$ $D\bar{K}$: $\mathbf{6}$

$(I=\frac{1}{2})$ D_sK, $(I=1)$ $D\bar{K}$, $(I=\frac{3}{2})$ $D\pi$: $\overline{\mathbf{15}}$

S-wave results [broken SU(3)] suggest:

$\overline{\mathbf{3}}$ bound state

$\mathbf{6}$ virtual bound state

$\overline{\mathbf{15}}$ weak repulsion

[See also PR D87, 014508 (2013) (1208.4535); PL B767, 465 (2017) (1610.06727); PR D98, 094018 (2018) (1712.07957); *EPJ C79, 13 (2019)* (1811.05585)]

Summary

- First principles lattice-QCD calculations
- Isospin-0 *DK* :
  - Bound state in *S*-wave, $D_{s0}^*(2317)$
  - Deeply bound state in *P*-wave, D_s^*
- Exotic-flavour isospin-0, 1 $D\bar{K}$:
  - Suggestion of virtual bound state in *S*-wave isospin-0
- Light quark dependence, comparison with SU(3) flavour symmetry

- See Nicolas Lang's talk (next) for *D*π scattering and the D_0^* , and comparison between *D*π and *DK*.

Acknowledgements

Hadron Spectrum Collaboration

[*www.hadspec.org*]

Jefferson Lab and surroundings, USA:

JLab: Robert Edwards, Jie Chen, Frank Winter; ORNL: Bálint Joó

W&M: Jozef Dudek[1], Arkaitz Rodas, *Christopher Johnson*, *Archana Radhakrishnan, Felipe Ortega* ([1] and Jefferson Lab)

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University of Cambridge, UK:

CT, Bipasha Chakraborty, David Wilson, *James Delaney*

Edinburgh, UK: Max Hansen; Tata Institute, India: Nilmani Mathur