XYZ charmonium-like states — paper highlights (INSPIRE recids)

Generated on 2026-02-06.

This note summarizes the main takeaways and collects a few slide-ready figures from the following INSPIRE records:
`2741866, 2764766, 2774582, 2755412, 2670504, 2972902, 2827674, 2871943, 2714203, 2798380, 2842813, 2898337, 2734668`.

It also appends a curated **lattice-QCD-since-2021** mini-survey with figures from:
`1828477, 2702490, 2702489, 2760743, 2035594, 2094767, 2789957, 2670791, 2917805`.

Figure thumbnails are embedded as clickable HTML tables (to keep sizing consistent across renderers): 2-up images use `width="420"`, and 3-up images use `width="300"`. If you want a different balance, global search/replace those width values.

Table of contents (by slide blocks)

    - 2972902
    - 2827674
    - 2871943
- Production / STCF prospects
    - 2734668
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- Appendices
    - Color decomposition for X(3872) molecule
    - Repro / regeneration notes

Suggested slide flow (optional)

- **Global fits / poles / line shapes:** 2741866, 2755412, 2774582, 2714203
- **Threshold dynamics (OBE / coupled channels):** 2764766, 2670504
- **Lattice QCD (2021→) status:** 1828477, 2702490/2702489, 2760743, 2035594, 2094767, 2789957, 2670791, 2917805
- **Lattice + EFT near threshold:** 2798380, 2842813
- **Born–Oppenheimer / BO(E)FT viewpoints:** 2972902, 2827674, 2871943
- **Production / STCF prospects:** 2734668, 2898337

Vector 1^{--} states — two papers, same question, different answers (2741866 vs 2755412)

Both papers try to answer a very practical question: *are the "Y" structures in e^+e^- data in the 4.2–4.35 GeV region evidence for one vector pole or multiple?* They agree that **thresholds + coupled channels** matter and that **pole extractions** are more meaningful than single-channel Breit–Wigner fits.

What they have in common

- **Data-driven**: both confront multiple e^+e^- final states (open-charm and hidden-charm) and emphasize line-shape distortions from nearby thresholds.
- **Coupled-channel mindset**: both treat "Y" features as emerging from **unitarity + channel coupling** rather than isolated Breit–Wigner bumps.
- **Pole language**: both quote/interpret **pole positions** (mass + width) instead of "fit masses" on the real axis.

Key differences (slide-ready)

Topic	2741866 (Nakamura et al.; global DCC)	2755412 (von Detten et al.; focused molecular fit)
Energy range	Broad: $\sqrt{s} = 3.75$–4.7 GeV	Focused: $\sqrt{s} = 4.2$–4.35 GeV
Channels included	“Global” set of quasi-2-body channels in $J^{PC} = 1^{--}$, including $D^{(*)}\bar{D}^{(*)}$, $D_{1,2}\bar{D}^{(*)}$, $D_s^{(*)}\bar{D}_s^{(*)}$, $J/\psi\,\eta^{(\prime)}$, $\omega\chi_{c0}$, $\Lambda_c\bar{\Lambda}_c$, plus effective channels like $f_0 J/\psi$, $Z_c\pi$, ...	Exactly **8** production channels in 4.2–4.35: $D^0 D^{*-}\pi$, $J/\psi\pi\pi$, $J/\psi KK$, $h_c\pi\pi$, $\mu^+\mu^-$, $\chi_{c0}\omega$, $J/\psi\eta$, $X(3872)\gamma$
Dynamical picture	Dynamical coupled-channel (DCC) model with **bare** ψ states + **short-range open-charm interactions** that can generate hadron-molecule poles; approximate 3-body unitarity	Start from the hypothesis $Y(4230) \sim D_1\bar{D}$ molecule; enforce unitarity constraints in the production/FSI machinery and include $\pi\pi/\bar{K}K$ FSI; needs interference with $\psi(4160)$
What is “one Y?”	In practice: multiple nearby poles can interfere differently in different channels → process-dependent “Y” line shapes	In 4.2–4.35 GeV: **one exotic pole** (plus $\psi(4160)$ as a known charmonium) can describe all channels consistently
Pole counting around 4.2–4.4	Reports **multiple** poles; they explicitly state “4 poles with $M \sim 4.23$ GeV, and 2 poles with $M \sim 4.38$ GeV” (Table III entries cluster as $M =$ 4192, 4216, 4229, 4308 MeV and $M =$ 4346, 4390 MeV)	Extracts a single $Y(4230)$ pole $\sqrt{s_{\text{pole}}} = (4227 \pm 4) - \frac{i}{2}(50^{+8}_{-2})$ MeV (in that window) and does not require an additional $Y(4320)$-like pole

Practical takeaway for slides: **2741866** is a “global, many-channel DCC” view that naturally produces **multiple poles** and emphasizes process dependence; **2755412** is a “targeted multi-channel EFT/FSI” view arguing that in 4.2–4.35 GeV the data are already consistent with **one** exotic vector pole (plus $\psi(4160)$) once interference and FSI are treated carefully.

Extra pages — detailed comparison (2741866 vs 2755412)

Page 1 — What is the shared physics question?

- **Observable:** energy-dependent $e^+e^- \to$ hadrons cross sections (and, in 2741866, also subsystem invariant-mass distributions).

- **Core issue:** in the 4.2–4.35 GeV region, do the observed "Y" line shapes require **multiple vector poles**, or can they be captured by **one exotic pole** once thresholds + interference are treated properly?
- **Common starting point: thresholds + coupled channels** can deform line shapes strongly, so pole extractions are preferred over single-channel BW peak parameters.

Page 2 — Data scope and channel coverage (what is actually constrained)

Topic	2741866	2755412
Fitted energy range	$\sqrt{s} = 3.75$–4.7 GeV (global)	$\sqrt{s} = 4.2$–4.35 GeV (focused window)
How much data	Fits **20 final states** (10 two-body, 9 three-body, 1 four-body) and includes **subsystem invariant-mass distributions**	Fits **8 total cross sections** in the window; **does not include** $\psi(2S)\pi\pi$ because the subsystem distributions show unusual energy dependence there
Channel "basis"	Built from many **quasi-two-body** Rc channels in $J^{PC} = 1^{--}$; explicitly includes $D^{(*)}\bar{D}^{(*)}$, $D_{1,2}\bar{D}^{(*)}$, $D_s^{(*)}\bar{D}_s^{(*)}$, $J/\psi\,\eta^{(\prime)}$, $\omega\chi_{c0}$, $\Lambda_c\bar{\Lambda}_c$, and effective channels like $f_0 J/\psi$, $Z_c\pi$, ...	Uses a **production + FSI** model for these 8 channels: $D^0 D^{*-}\pi$, $J/\psi\pi\pi$, $J/\psi K\bar{K}$, $h_c\pi\pi$, $\mu^+\mu^-$, $\omega\chi_{c0}$, $J/\psi\eta$, $X(3872)\gamma$

Page 3 — Model architecture and approximations (why the answers can differ)

Topic	2741866 (global DCC)	2755412 (focused molecular fit)
Primary hypothesis	Many-channel dynamics with **bare** ψ excitations + hadronic continua; near-threshold poles can be molecule-dominated	$Y(4230)$ is predominantly a $D_1(2420)\bar{D}$ hadronic molecule
Dynamics included	Dozens of coupled quasi-2-body channels with **particle exchange + short-range interactions**; **approximate 3-body unitarity**; analytic continuation of the global amplitude	One-window, channel-by-channel **production amplitude** with explicit $D_1\bar{D}$ threshold dynamics; includes $\pi\pi/K\bar{K}$ FSI (in simplified form) where needed
HQSS multiplets	Coupled-channel framework includes $D_1\bar{D}^{(*)}$, $D_2^*\bar{D}^{(*)}$, ... as part of the global channel set	Notes that HQSS suggests coupled channels like $D_1\bar{D}^*$, $D_2\bar{D}^*$, but **largely ignores** them in the chosen energy window (explicitly stated as a main limitation)
Treatment of $\psi(4160)$	Emerges as a pole in the global coupled-channel amplitude	Included explicitly and its **interference** with $Y(4230)$ is essential to fit all channels; the paper notes this simplified interference treatment can violate strict unitarity across all channels

Page 4 — Pole content: "multiple poles" vs "one pole" (and what each implies)

What 2741866 emphasizes

- After analytic continuation of the **global** amplitude, they extract many vector poles (14 in their main list) and explicitly state that there are **clusters**: "4 poles with $M \sim 4.23$ GeV, and 2 poles with $M \sim 4.38$ GeV" (Table III: $M =$ 4192, 4216, 4229, 4308 MeV and $M =$ 4346, 4390 MeV).
- Interpretation: overlapping poles can **interfere differently across processes**, so a "Y" feature is intrinsically **process dependent** in a many-channel world.
- In their pole table they also list a $\psi(4230)$-like pole and a $Y(4320)$-like pole, but the broader message is that the spectrum is richer once many channels + thresholds are constrained simultaneously.

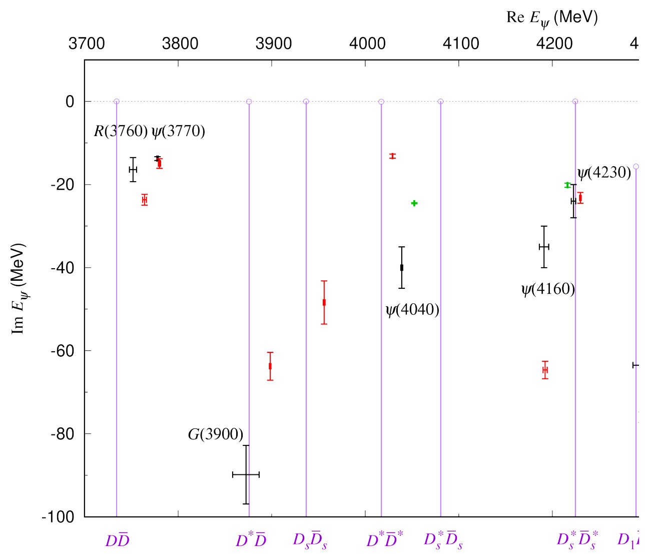
What 2755412 emphasizes

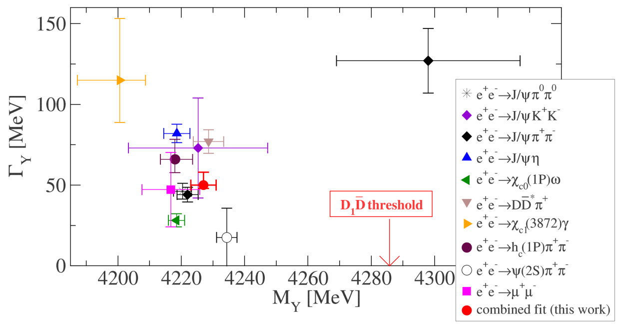
- In the restricted 4.2–4.35 GeV window, they find that a **single exotic** $Y(4230)$ pole plus the established $\psi(4160)$ (with interference) can describe all 8 channels; no additional $Y(4320)$-

like pole is required in that window.

- Their fit yields $\sqrt{s_{\text{pole}}^{Y(4230)}} = (4227 \pm 4) - \frac{i}{2}(50^{+8}_{-2})$ MeV and interprets the $J/\psi\pi\pi$ vs $J/\psi K\bar{K}$ asymmetry as the **same physics** (approximate SU(3) $_f$).
- They explicitly remark that a contemporaneous global analysis (2741866) finds an additional **very broad** pole near 4.32 GeV, but argue that such a contribution is **absent/unused** in their fits and that its dynamical origin is unclear from the information available there.

Page 5 — One-slide figure pair (global poles vs one-pole fit)





2741866 — Global coupled-channel analysis of $e^+e^- \to c\,\bar{c}$ (3.75–4.7 GeV)

Citation / links

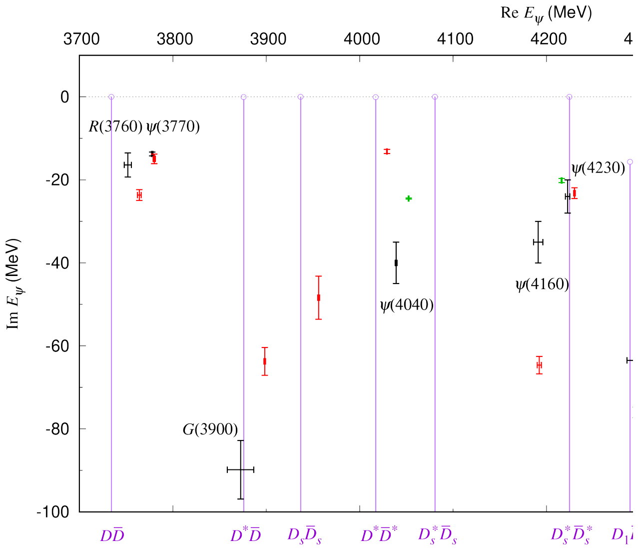
- Authors: S.X. Nakamura, X.-H. Li, H.-P. Peng, Z.-T. Sun, X.-R. Zhou
- Publication: Phys. Rev. D 112 (2025) 054027
- INSPIRE: https://inspirehep.net/literature/2741866
- arXiv: https://arxiv.org/abs/2312.17658 (PDF: https://arxiv.org/pdf/2312.17658.pdf)

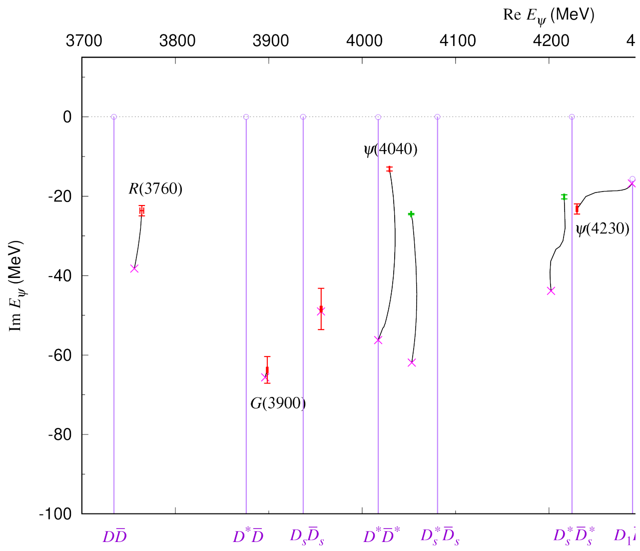
Key points

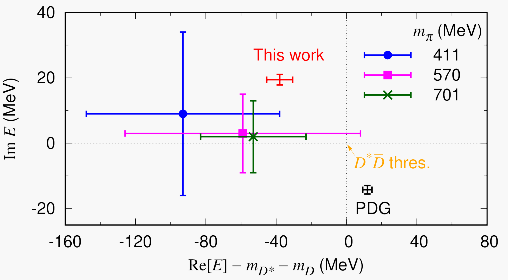
- Global coupled-channel fit to a large set of BESIII/Belle $e^+e^- \to c\,\bar{c}$ data (multiple 2/3/4-body final states) in √s = 3.75–4.7 GeV, including fits to invariant-mass distributions.

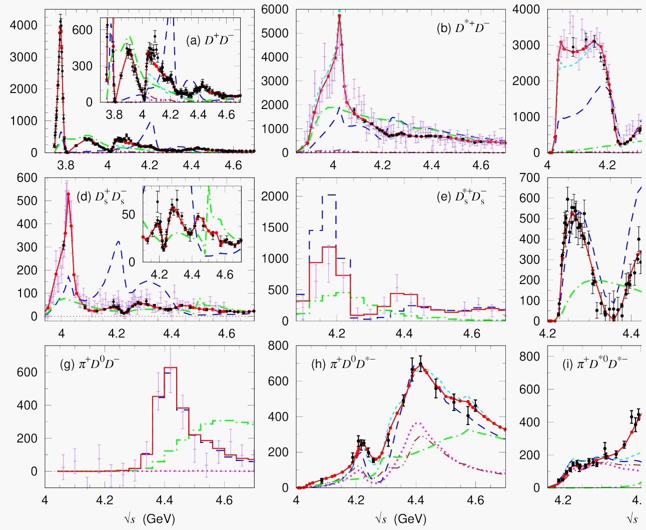
- Analytic continuation to extract vector charmonium poles and *Zc* poles; near-threshold pole trajectories/compositeness suggest sizable hadron-molecule components for some states.
- Finds *Zc* poles as virtual states below the $D^{(*)}\bar{D}^{(*)}$ thresholds (qualitatively consistent with lattice-QCD-informed expectations in the same energy region).

Figures (click to open full-resolution PNGs)









2755412 — How many vector charmoniumlike states in 4.2–4.35 GeV?

Citation / links

- Authors: Leon von Detten, Vadim Baru, Christoph Hanhart, Qian Wang, Daniel Winney, Qiang Zhao
- Publication: Phys. Rev. D 109 (2024) 116002
- INSPIRE: https://inspirehep.net/literature/2755412
- arXiv: https://arxiv.org/abs/2402.03057 (PDF: https://arxiv.org/pdf/2402.03057.pdf)

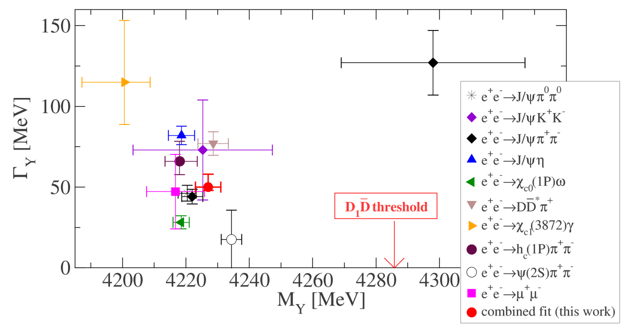
Key points

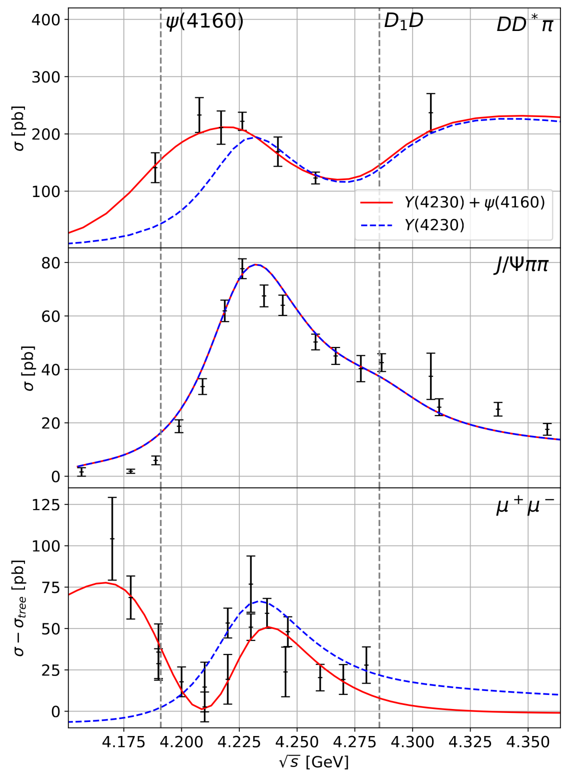
- Combined analysis of **eight** e^+e^- final states in 4.2–4.35 GeV, highlighting that single-channel BW fits can be misleading once thresholds/interference are treated consistently.
- Concludes that **one** vector charmoniumlike state can describe the data in this window, compatible with a $D_1\bar{D}$ molecular interpretation, with a pole location

$$\sqrt{s_{\text{pole}}^{Y(4230)}} = (4227 \pm 4) - \tfrac{i}{2}\,(50^{+8}_{-2})\ \text{MeV}. \tag{1}$$

- The asymmetric $J/\psi\pi\pi$ and $J/\psi K\bar{K}$ total cross sections near 4.23 GeV are argued to share the same origin (approximate SU(3)$_f$).

Figures (click to open full-resolution PNGs)





2774582 — Poles and poltergeists in $e^+e^- \to D\bar{D}$ data

Citation / links

- Authors: Nils Hüsken, Richard F. Lebed, Ryan E. Mitchell, Eric S. Swanson, Ya-Qian Wang, Chang-Zheng Yuan
- Publication: Phys. Rev. D 109 (2024) 114010
- INSPIRE: https://inspirehep.net/literature/2774582
- arXiv: https://arxiv.org/abs/2404.03896 (PDF: https://arxiv.org/pdf/2404.03896.pdf)

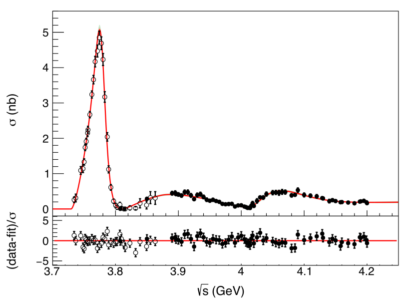
Key points

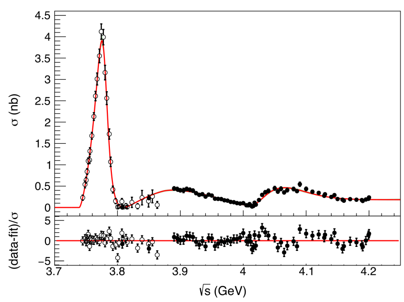
- Motivated by the BESIII claim of an $R(3900)$ structure in $e^+e^- \to D\bar{D}$, argues that the historical $G(3900)$ enhancement can be a **threshold / coupled-channel effect** rather than a new $c\bar{c}$ resonance.
- Performs a unitary coupled-channel K**-matrix** analysis (Chew–Mandelstam function + P-vector production) in the window $\sqrt{s} = 3.7$–4.2 GeV, with only two bare charmonium poles:

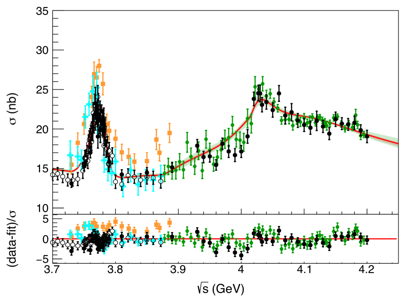
$\psi(3770)$ and $\psi(4040)$.

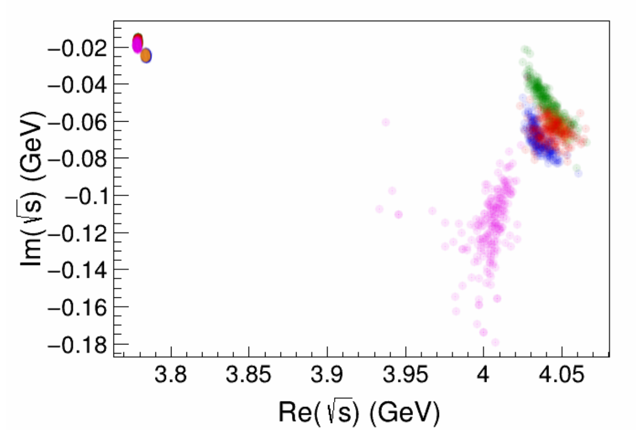
- Fit channels: $D^0\bar{D}^0$, D^+D^-, $D\bar{D}^* + \bar{D}D^*$, $D^*\bar{D}^*$, and an inclusive $e^+e^- \to c\bar{c}$ constraint; introduces a **dummy channel** (either $[J/\psi(\pi\pi)]$ or $[D_s^+ D_s^-]$) to absorb the missing inclusive strength.
- Main mechanism: the opening of $D^*\bar{D}$ (and rescattering / interference with nearby vectors) naturally produces a “poltergeist” structure near 3.9 GeV in $D\bar{D}$, consistent with the classic Cornell coupled-channel picture; a node in $\psi(4040)$ decay amplitudes is **not required**, but can improve fit quality.
- Extracts pole parameters by analytic continuation; their “fit summary” values (model spread treated as a systematic) include
  - $\psi(3770)$: $M = 3778.7(7)(50)$ MeV, $\Gamma = 34(4)(15)$ MeV, $\Gamma_{ee} = 205(25)(70)$ eV,
  - $\psi(4040)$: $M = 4044(15)(36)$ MeV, $\Gamma = 130(30)(125)$ MeV, $\Gamma_{ee} = 180(100)(170)$ eV,
    and emphasizes that $\Gamma_{ee}[\psi(4040)]$ comes out **substantially smaller** than PDG extractions that assume the inclusive hadronic structure is purely resonant.
- Contrast point for slides: compared to 2764766 (which interprets $G(3900)$ as a P-wave dimeson resonance), this work argues the same structure can emerge **without** an extra pole once coupled-channel unitarity + thresholds are enforced.

Figures (click to open full-resolution PNGs)









2714203 — Precise pole position of the exotic $Z_c(3900)$

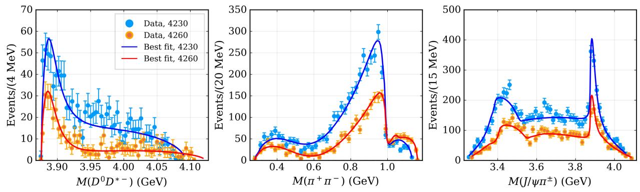
Citation / links

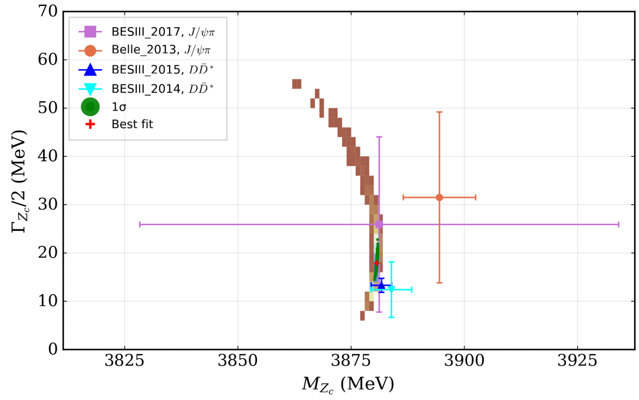
- Authors: Yun-Hua Chen, Meng-Lin Du, Feng-Kun Guo
- Publication: Sci. China Phys. Mech. Astron. 67 (2024) 291011
- INSPIRE: https://inspirehep.net/literature/2714203
- arXiv: https://arxiv.org/abs/2310.15965 (PDF: https://arxiv.org/pdf/2310.15965.pdf)

Key points

- Unified description of $e^+e^- \to J/\psi\pi^+\pi^-$ (at 4.23, 4.26 GeV) and $e^+e^- \to D^0 D^{*-}\pi^+$ including: triangle singularities from open-charm loops, unitarized $J/\psi\pi$-$D\bar{D}^*$ coupled channels, and $\pi\pi$-$K\bar{K}$ FSI via dispersion relations.
- Extracts a $Z_c(3900)$ pole with (quoted) pole mass and width:
  - $M_{\text{pole}} = (3880.7 \pm 1.7_{\text{stat}} \pm 22.4_{\text{syst}})$ MeV
  - $\Gamma_{\text{pole}} = (35.9 \pm 1.4_{\text{stat}} \pm 15.3_{\text{syst}})$ MeV
- Suggests molecular and non-molecular components are both relevant in forming the observed structure.

Figures (click to open full-resolution PNGs)





2764766 — Identification of the G(3900) as a P-wave dimeson resonance

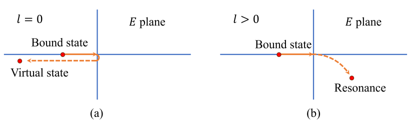
Citation / links

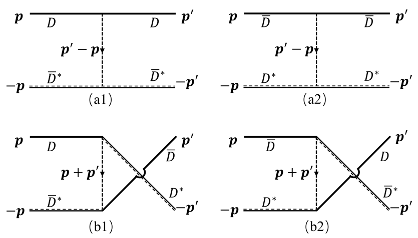
- Authors: Zi-Yang Lin, Jun-Zhang Wang, Jian-Bo Cheng, Lu Meng, Shi-Lin Zhu
- Publication: Phys. Rev. Lett. 133 (2024) 241903
- INSPIRE: https://inspirehep.net/literature/2764766
- arXiv: https://arxiv.org/abs/2403.01727 (PDF: https://arxiv.org/pdf/2403.01727.pdf)

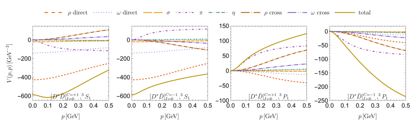
Key points

- Interprets the $G(3900)$ structure as a **P-wave** molecular resonance in $D\bar{D}^*/\bar{D}D^*$, within a unified meson-exchange framework that also addresses $\chi_{c1}(3872)$, $Z_c(3900)$, and $T_{cc}(3875)$.
- Emphasizes that long-range pion exchange dominantly drives the P-wave interaction; suggests experimental tests via $e^+e^- \to D\bar{D}^*/\bar{D}D^*$ near threshold.
- Predicts a richer spectrum of DD and $D\bar{D}$ states in various quantum numbers up to P-wave.

Figures (click to open full-resolution PNGs)







2670504 — Constraints on $D\bar{D}^*$ exotics from T_{cc}^+

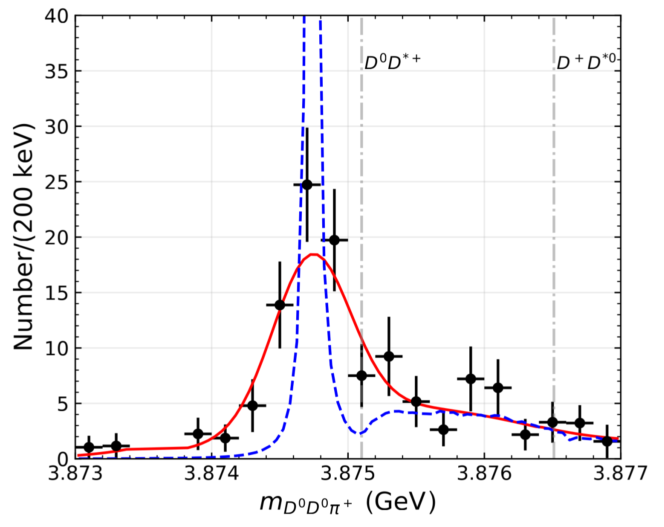
Citation / links

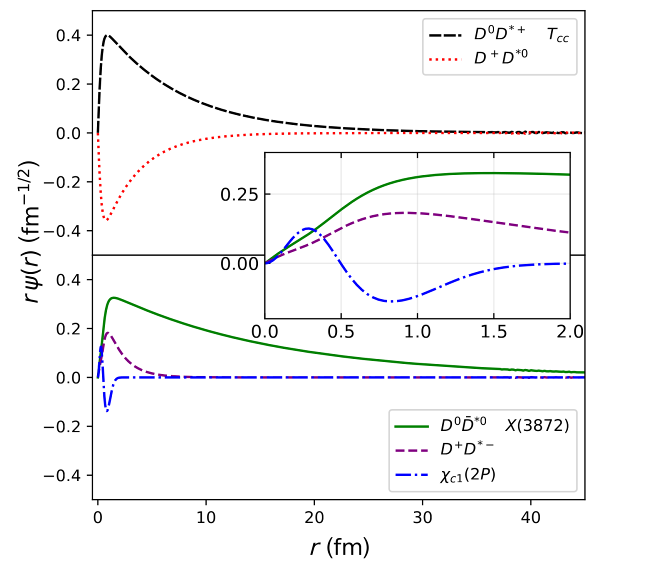
- Authors: Guang-Juan Wang, Zhi Yang, Jia-Jun Wu, Makoto Oka, Shi-Lin Zhu
- Publication: Sci. Bull. 69 (2024) 2855
- INSPIRE: https://inspirehep.net/literature/2670504
- arXiv: https://arxiv.org/abs/2306.12406 (PDF: https://arxiv.org/pdf/2306.12406.pdf)

Key points

- Fits the T_{cc}^+ line shape to constrain the DD^* interaction; uses charge conjugation to infer the $D\bar{D}^*$ interaction.
- Finds the $D\bar{D}^*$ force is attractive but **insufficient** to bind $X(3872)$ without coupled-channel effects; in their framework the $c\bar{c}$ component is small (order percent) but crucial.
- Also reports a higher structure near 3.96 GeV (width ∼O(10 MeV)) as a candidate in the $X(3940)$ region, and discusses related states in other J^{PC} sectors.

Figures (click to open full-resolution PNGs)





Lattice QCD (since 2021) — selected highlights for charmonium-like spectroscopy

Most results below are at **unphysical** pion masses and/or with an **incomplete** set of coupled channels; interpret pole locations as *qualitative* until physical-point, multi-channel (and eventually 3-body) effects are under control.

1828477 — Coupled-channel $D\bar{D}$–$D_s\bar{D}_s$ scattering in $J^{PC} = 0^{++}, 2^{++}$

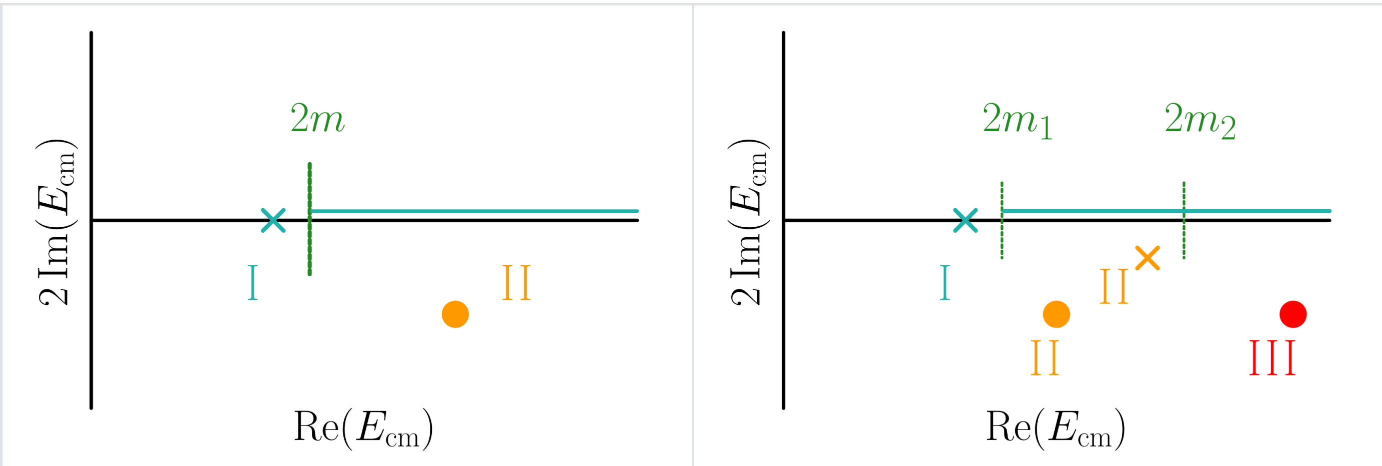
Citation / links

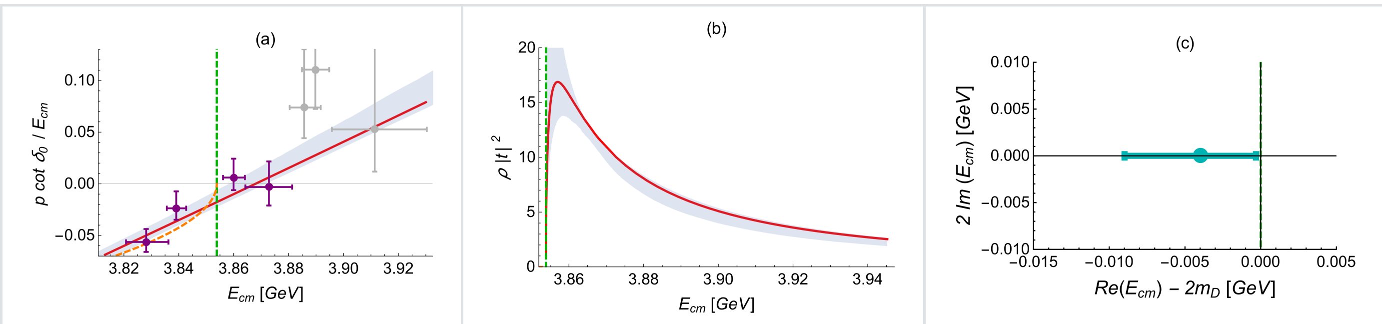
- Authors: Sasa Prelovsek, Sara Collins, Daniel Mohler, M. Padmanath, Stefano Piemonte
- Publication: JHEP 06 (2021) 035
- INSPIRE: https://inspirehep.net/literature/1828477
- arXiv: https://arxiv.org/abs/2011.02542 (PDF: https://arxiv.org/pdf/2011.02542.pdf)

Key points

- First lattice study of coupled-channel $D\bar{D}$ and $D_s\bar{D}_s$ scattering in charmoniumlike $J^{PC} = 0^{++}$ and 2^{++} (isospin 0), extracting the $l = 0, 2$ scattering matrix via Lüscher's formalism using multiple volumes/frames (CLS, $m_\pi \simeq 280$ MeV, $a \simeq 0.09$ fm).
- Reports evidence for **three** 0^{++} states between slightly below $2m_D$ and ~ 4.13 GeV: a $D\bar{D}$ bound state just below threshold, a $D\bar{D}$ resonance likely related to $\chi_{c0}(3860)$ (often identified with $\chi_{c0}(2P)$), and a narrow state just below $D_s\bar{D}_s$ threshold with large coupling to $D_s\bar{D}_s$ but tiny coupling to $D\bar{D}$ (discussed as potentially related to X(3915)/$\chi_{c0}(3930)$).
- Finds an $l = 2$ resonance likely related to $\chi_{c2}(3930)$ and stresses key systematics (omitted $J/\psi\,\omega$, $\eta_c\eta$, and 3-body channels; only statistical uncertainties quoted).

Figures (click to open full-resolution PNGs)





2702490 (+2702489 companion) — Coupled-channel χ_{c0}, χ_{c2} above open-charm thresholds

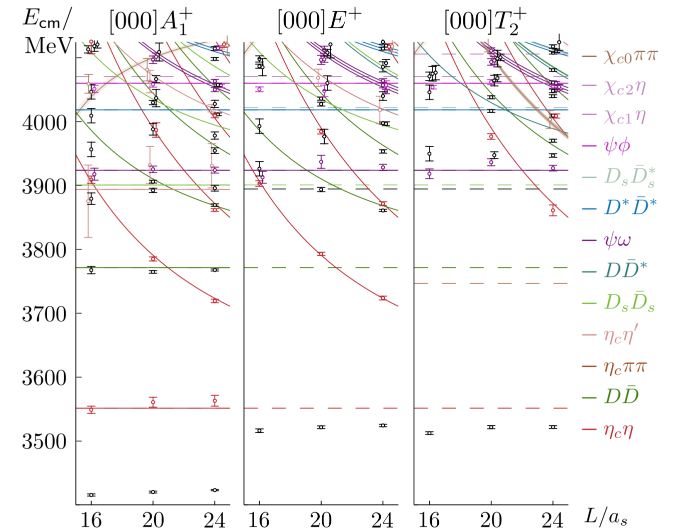
Citation / links

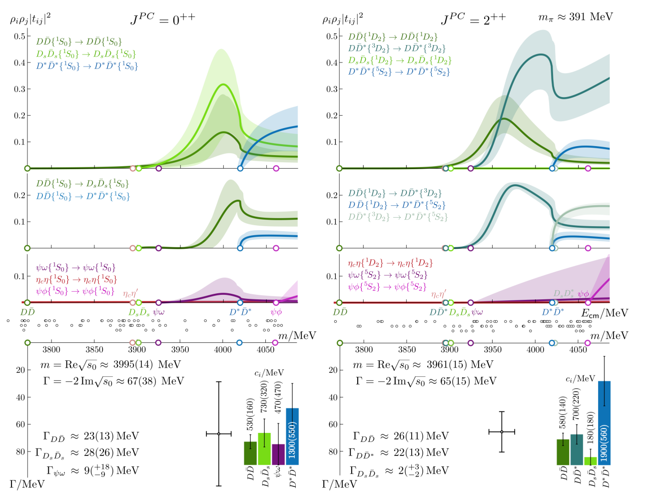
- Authors: David J. Wilson, Christopher E. Thomas, Jozef J. Dudek, Robert G. Edwards (Hadron Spectrum Collaboration)
- Publication: Phys. Rev. Lett. 132 (2024) 241901; companion Phys. Rev. D 109 (2024) 114503
- INSPIRE: https://inspirehep.net/literature/2702490 (companion: https://inspirehep.net/literature/2702489)
- arXiv: https://arxiv.org/abs/2309.14070 (companion: https://arxiv.org/abs/2309.14071)

Key points

- Hadron Spectrum Collaboration: extract coupled-channel scattering amplitudes in $J^{PC} = 0^{++}$ and 2^{++} up to ~ 4.1 GeV from a large finite-volume spectrum ($m_\pi \simeq 391$ MeV).
- Find **one** isolated scalar and **one** isolated tensor resonance (pole singularities on nearby unphysical sheets) with sizable couplings to multiple open-charm channels; no extra near-threshold scalar structure is seen between $\chi_{c0}(1P)$ and the ~ 4.0 GeV resonance in this setup.

Figures (click to open full-resolution PNGs)





2760743 — $D\bar{D}^*$ (I=0) scattering and X(3872)-relevant near-threshold physics

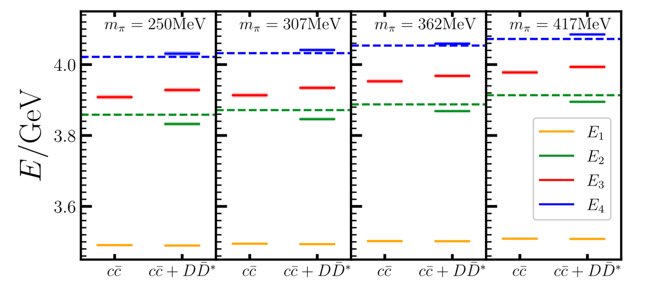
Citation / links

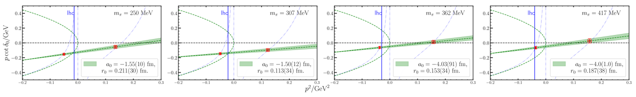
- Authors: Haozheng Li, Chunjiang Shi, Ying Chen, Ming Gong, Juzheng Liang, Zhaofeng Liu, Wei Sun
- Publication: preprint [arXiv:2402.14541]
- INSPIRE: https://inspirehep.net/literature/2760743
- arXiv: https://arxiv.org/abs/2402.14541 (PDF: https://arxiv.org/pdf/2402.14541.pdf)

Key points

- $N_f = 2$ lattice study of S-wave $D\bar{D}^*(I=0)$ at four pion masses $m_\pi \sim 250$–417 MeV; extracts three energy levels per m_π.
- ERE and K-matrix analyses both support a **shallow bound state** below the $D\bar{D}^*$ threshold; phase shifts at higher energies suggest a possible **resonance near 4.0 GeV** with width $\mathcal{O}(40$–$60)$ MeV (discussed in connection with $\chi_{c1}(4010)$).

Figures (click to open full-resolution PNGs)





2035594 — DD^* scattering signature of the T_{cc} pole (lattice)

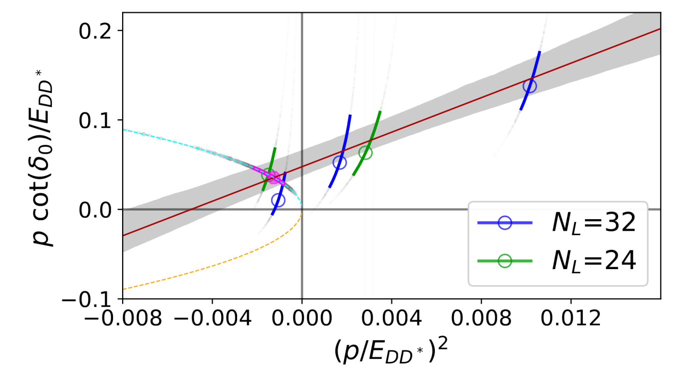
Citation / links

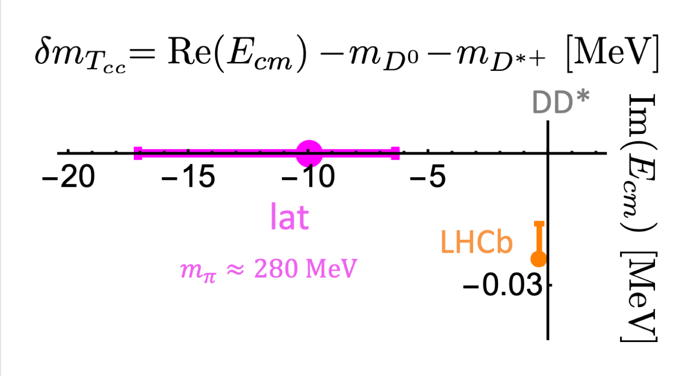
- Authors: M. Padmanath, S. Prelovsek
- Publication: Phys. Rev. Lett. 129 (2022) 032002
- INSPIRE: https://inspirehep.net/literature/2035594
- arXiv: https://arxiv.org/abs/2202.10110 (PDF: https://arxiv.org/pdf/2202.10110.pdf)

Key points

- Lüscher analysis on CLS $N_f = 2+1$ ensembles ($m_\pi \simeq 280$ MeV): extract $l = 0, 1$ DD^* amplitudes close to threshold (two volumes, multiple total momenta).
- Find a **virtual bound-state pole** in S-wave DD^* below threshold for the charm mass close to physical, plausibly related to LHCb's T_{cc}^+ (noting remaining systematics from lattice spacing/quark masses).

Figures (click to open full-resolution PNGs)





2094767 — DD^* scattering (I=0,1) and the isospin structure relevant to T_{cc}

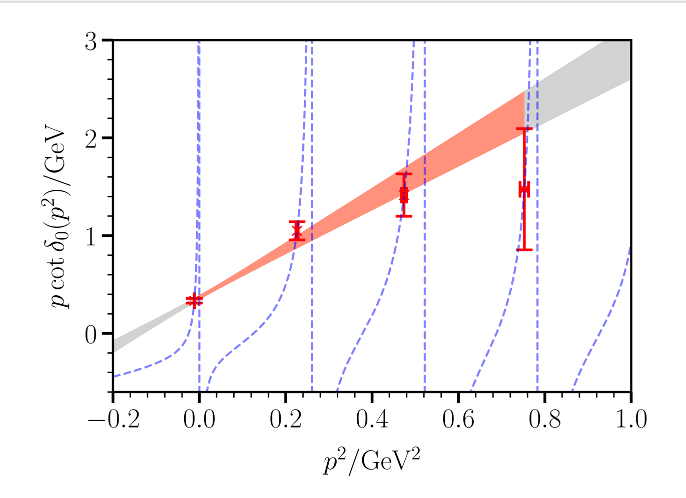
Citation / links

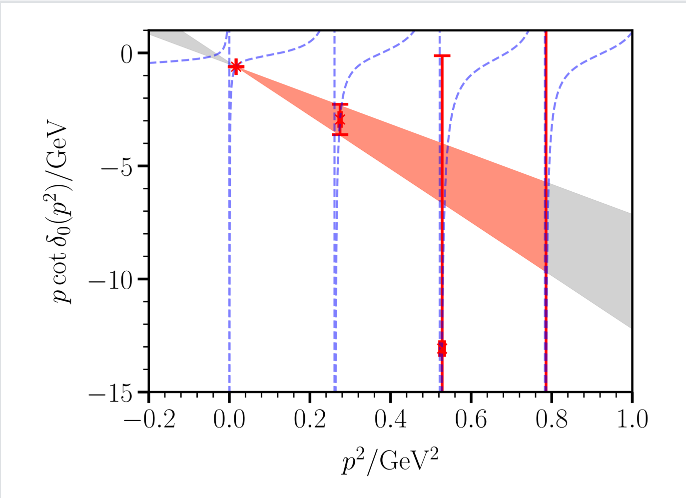
- Authors: Siyang Chen, Chunjiang Shi, Ying Chen, Ming Gong, Zhaofeng Liu, Wei Sun, Renqiang Zhang
- Publication: Phys. Lett. B 833 (2022) 137391
- INSPIRE: https://inspirehep.net/literature/2094767
- arXiv: https://arxiv.org/abs/2206.06185 (PDF: https://arxiv.org/pdf/2206.06185.pdf)

Key points

- $N_f = 2$ lattice study at $m_\pi \sim 350$ MeV: S-wave DD^* scattering in both $I = 0$ and $I = 1$.
- Finds **attraction** in $I = 0$ over a wide energy window and **repulsion** near threshold in $I = 1$, consistent with assigning $I = 0$ to $T_{cc}^+(3875)$ and suggesting an intuitive origin in quark-diagram contributions (interpreted as a $\rho^\pm$ exchange effect).

Figures (click to open full-resolution PNGs)





2789957 — Coupled DD^*–D^*D^* scattering: T_{cc} virtual state + additional pole

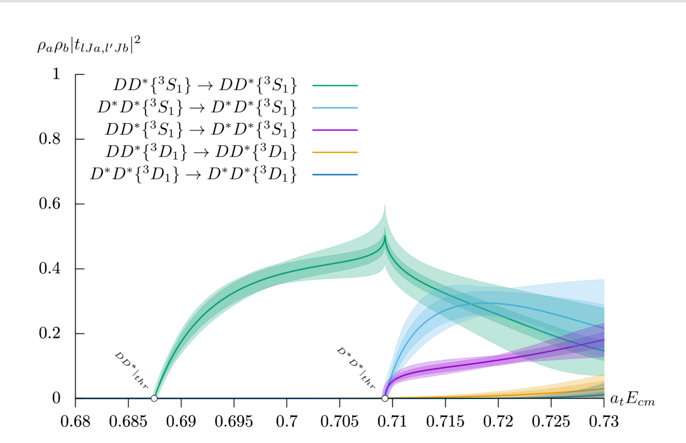
Citation / links

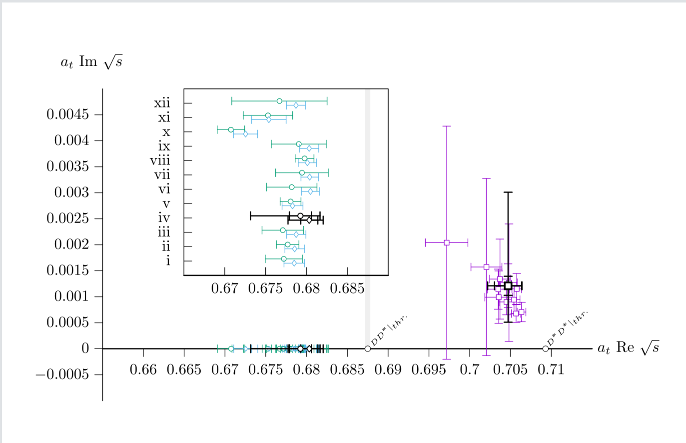
- Authors: Travis Whyte, David J. Wilson, Christopher E. Thomas (Hadron Spectrum Collaboration)
- Publication: Phys. Rev. D 111 (2025) 034511
- INSPIRE: https://inspirehep.net/literature/2789957
- arXiv: https://arxiv.org/abs/2405.15741 (PDF: https://arxiv.org/pdf/2405.15741.pdf)

Key points

- Hadron Spectrum Collaboration: first coupled-channel $I = 0$ DD^*–D^*D^* amplitudes in $J^P = 1^+$ ($m_\pi \simeq 391$ MeV, three volumes), using analytic continuation to extract pole content.
- Finds a **virtual bound-state** pole below DD^* threshold (identified with T_{cc}) and a second pole (T'_{cc}) behaving like a **resonance** below the kinematically closed D^*D^* channel, with a visible cusp at the D^*D^* threshold due to nonzero inter-channel coupling.

Figures (click to open full-resolution PNGs)





2670791 — Lattice prediction of decay widths for a 1^{-+} charmoniumlike hybrid

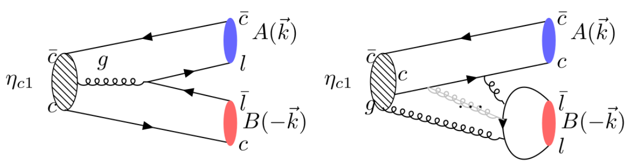
Citation / links

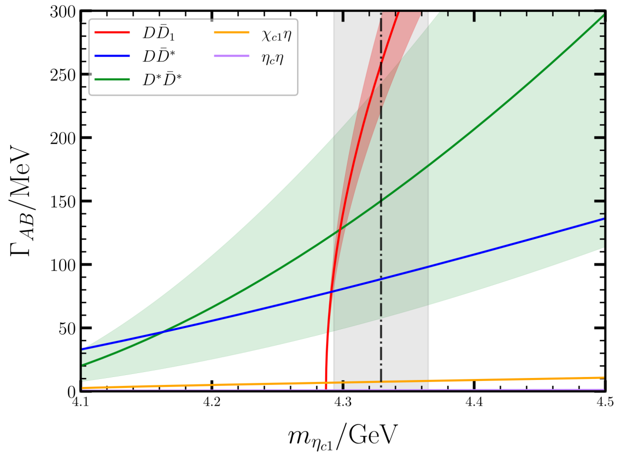
- Authors: Chunjiang Shi, Ying Chen, Ming Gong, Xiangyu Jiang, Zhaofeng Liu, Wei Sun
- Publication: Phys. Rev. D 109 (2024) 094513
- INSPIRE: https://inspirehep.net/literature/2670791
- arXiv: https://arxiv.org/abs/2306.12884 (PDF: https://arxiv.org/pdf/2306.12884.pdf)

Key points

- Computes transition amplitudes and reports (claimed first) lattice-QCD predictions for two-body partial widths of the 1^{-+} charmoniumlike hybrid η_{c1}.
- Using their lattice mass $m_{\eta_{c1}} = 4.329(36)$ GeV, finds open-charm modes dominate (notably $D_1\bar{D}$, $D^*\bar{D}$, $D^*\bar{D}^*$), with a small $\eta_c\eta'$ width at the ~MeV level (and $\chi_{c1}\eta$ suppressed by η–η' mixing).

Figures (click to open full-resolution PNGs)





2917805 — Isospin-1 coupled DD, DD^*, D^*D^*: baseline amplitudes (no poles found)

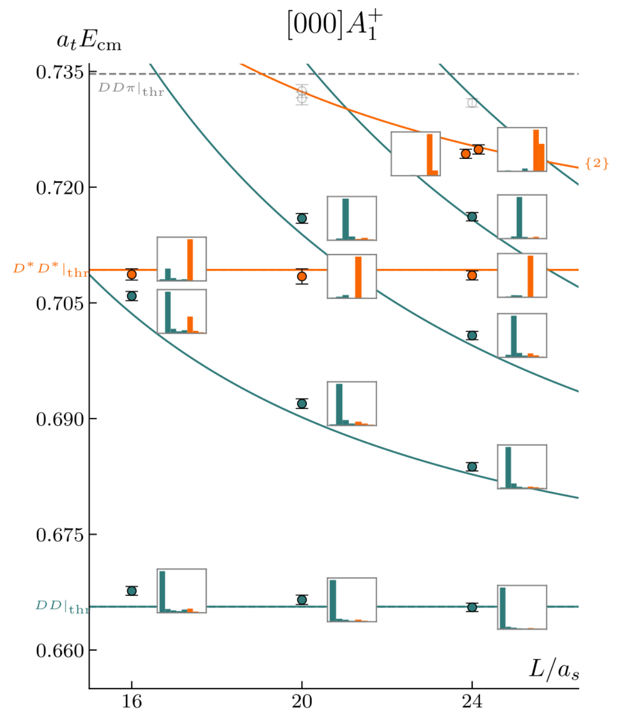
Citation / links

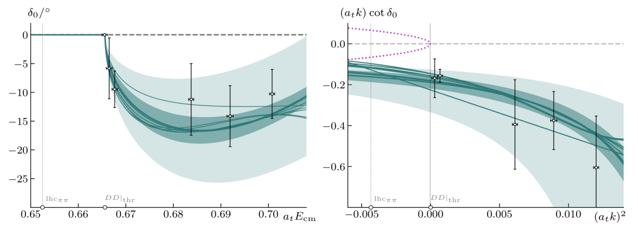
- Authors: Nelson Pitanga Lachini, Christopher E. Thomas, David J. Wilson (Hadron Spectrum Collaboration)
- Publication: Phys. Rev. D 112 (2025) 114511
- INSPIRE: https://inspirehep.net/literature/2917805
- arXiv: https://arxiv.org/abs/2505.01363 (PDF: https://arxiv.org/pdf/2505.01363.pdf)

Key points

- Hadron Spectrum Collaboration: first $I = 1$ coupled-channel amplitudes for DD, DD^*, D^*D^* in several J^P channels ($m_\pi \simeq 391$ MeV).
- Reports mostly weakly repulsive S-wave interactions and finds **no** amplitude singularities corresponding to physical states in this setup; provides an ingredient for future analyses that include 3-body and left-hand-cut effects.

Figures (click to open full-resolution PNGs)





2798380 — $I = 1$, $J^{PC} = 1^{+\pm}$ charmoniumlike channels from lattice + EFT

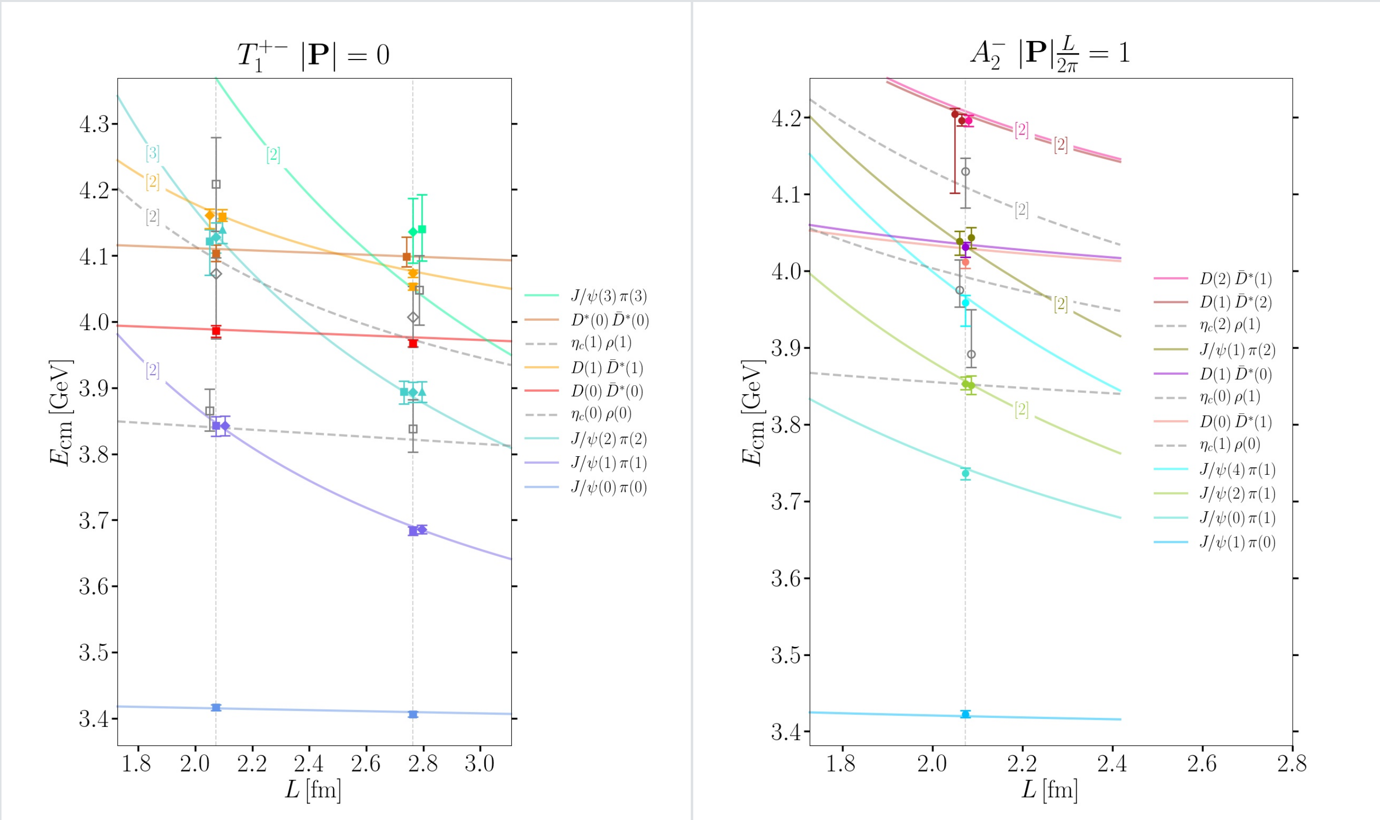
Citation / links

- Authors: Mitja Sadl, Sara Collins, Zhi-Hui Guo, M. Padmanath, Sasa Prelovsek, Lin-Wan Yan
- Publication: Phys. Rev. D 111 (2025) 054513
- INSPIRE: https://inspirehep.net/literature/2798380
- arXiv: https://arxiv.org/abs/2406.09842 (PDF: https://arxiv.org/pdf/2406.09842.pdf)

Key points

- Lattice-QCD study of $I = 1$ $\bar{c}c\bar{q}q$ ($q = u, d$) channels with $J^{PC} = 1^{+\pm}$, using multiple volumes and moving frames (CLS, $N_f = 2 + 1$, $m_\pi \simeq 280$ MeV; qualitative due to unphysical masses / missing 3-body channels).
- Eigenenergies are mostly near non-interacting levels, with the strongest shifts in some $D\bar{D}^*$ levels.
- EFT coupled-channel analysis ($J/\psi\pi$ and $D\bar{D}^*$) fits BESIII invariant-mass spectra and finite-volume energies simultaneously, yielding pole structures near the $D\bar{D}^*$ threshold reproducing the observed peaks.

Figures (click to open full-resolution PNGs)



2842813 — P-wave charmonium effects in reanalysis of lattice hidden-charm channels

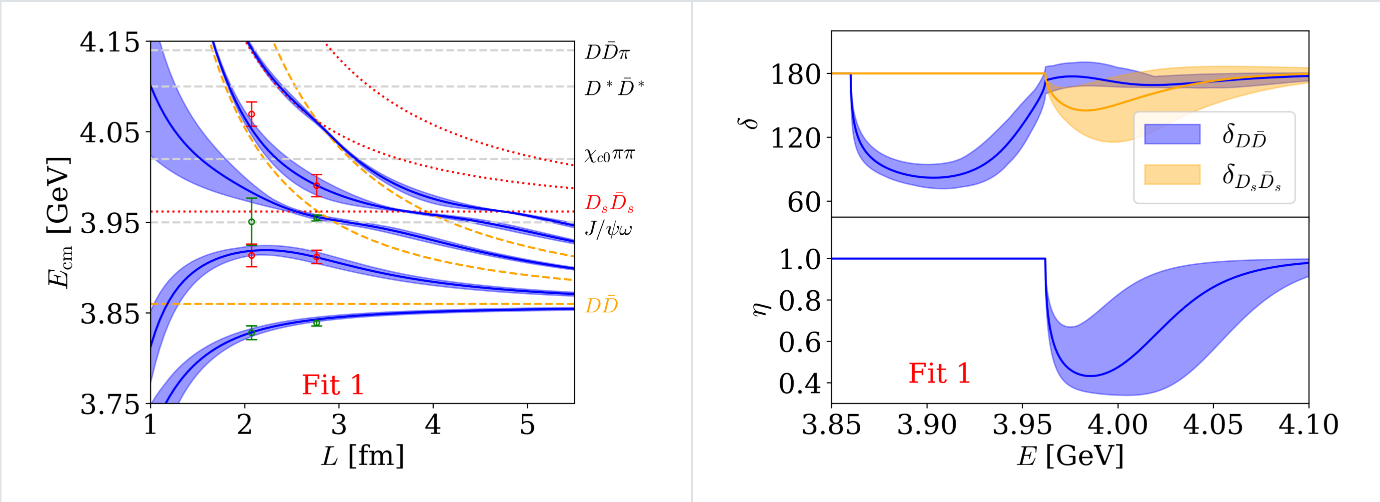
Citation / links

- Authors: Pan-Pan Shi, Miguel Albaladejo, Meng-Lin Du, Feng-Kun Guo, Juan Nieves
- Publication: Phys. Rev. D 111 (2025) 074043
- INSPIRE: https://inspirehep.net/literature/2842813
- arXiv: https://arxiv.org/abs/2410.19563 (PDF: https://arxiv.org/pdf/2410.19563.pdf)

Key points

- Reanalysis of lattice coupled-channel data including explicit P-wave charmonium contributions, searching for $J^{PC} = 0^{++}, 1^{++}, 2^{++}$ hidden-charm poles.
- Reports multiple poles in the analyzed channels; in particular for 1^{++} finds a mostly-molecular pole associated with $X(3872)$ (compositeness $> 90\%$) and a second pole related to dressed $\chi_{c1}(2P)$, discussed in connection with $\chi_{c1}(4010)$.
- Emphasizes the fits are underconstrained; more lattice information would sharpen conclusions.

Figures (click to open full-resolution PNGs)



BO / BOEFT papers — similarities and differences (quick comparison)

Common ground (all three)

- Use a Born–Oppenheimer separation of scales: heavy degrees of freedom are slow, while light degrees of freedom generate (adiabatic) potentials.
- Near-threshold phenomena enter naturally when BO potentials connect to, or mix with, heavy-hadron-pair thresholds at large distances.

Key differences (what you should say on a slide)

INSPIRE	"BO" object	Inputs (how potentials are fixed)	Threshold / mixing treatment	What you get out
2972902	**BOEFT** for $Q\bar{Q}q\bar{q}$ and $QQ\bar{q}\bar{q}$	QCD-motivated BO potentials (lattice parametrizations where available, short-distance multipole constraints, modeled long-distance behavior)	Explicit coupled Schrödinger equations with potential mixing (short-distance degeneracies + avoided crossings)	Composition statements for $X(3872), T_{cc}$ + bottom-sector predictions
2827674	BO **potential taxonomy** in QCD with light quarks	General continuity constraints + (ultimately) lattice input for the spectrum of $\mathbf{8}$-hadrons (adjoint mesons/gluelumps)	Exotics as bound states/resonances in adjoint-hadron potentials that dip below a heavy-hadron-pair threshold	"Where to look": explains threshold clustering + identifies which channels can plausibly host exotics
2871943	BO **model** for compact tetraquarks	Phenomenological constituent-quark + Cornell-like potentials + variational modeling	Thresholds enter indirectly; emphasis is on compact wavefunctions, spectra, and radiative transitions	Full $J = 0, 1, 2$ tetraquark spectrum + radiative ratio $\mathcal{R}$ consistency check

2972902 — Nature of $\chi_{c1}(3872)$ and $T_{cc}^{+}(3875)$ in BOEFT

Citation / links

- Authors: Nora Brambilla, Abhishek Mohapatra, Tommaso Scirpa, Antonio Vairo
- Publication: Phys. Rev. Lett. 135 (2025) 131902
- INSPIRE: https://inspirehep.net/literature/2972902
- arXiv: https://arxiv.org/abs/2411.14306 (PDF: https://arxiv.org/pdf/2411.14306.pdf)

Key points

- Uses Born–Oppenheimer effective field theory (BOEFT) to address the composition of $\chi_{c1}(3872)$ and T_{cc}^{+}, aiming for a QCD-grounded description via adiabatic potentials and mixing.
- Provides an interpretation of near-threshold binding and discusses implications/predictions for the bottom sector.

How the potentials are obtained in this paper (detailed, slide-friendly)

1) What "the potential" means in BOEFT

- In BOEFT the relevant objects are **QCD static energies** of the light degrees of freedom in the presence of static heavy sources separated by r. These static energies (labeled by BO quantum numbers like Σ_g^+, $\Sigma_g^{+\prime}$, Π_g) enter coupled Schrödinger equations for the heavy degrees of freedom.
- In full QCD these static energies can be computed from gauge-invariant generalized Wilson loops, but available lattice data are **incomplete** across r and channels. This paper therefore uses a **QCD-constrained interpolation**: lattice where available + short-distance multipole/pNRQCD constraints + a controlled long-distance tail.

2) $\chi_{c1}(3872)$: the $Q\bar{Q}q\bar{q}$ potentials and mixing

The coupled-channel problem uses three diabatic potentials $V_{\Sigma_g^+}(r)$, $V_{\Sigma_g^{+\prime}}(r)$, $V_{\Pi_g}(r)$ and a mixing term $V_{\Sigma_g^+-\Sigma_g^{+\prime}}(r)$ (see the Supplemental Material for the Schrödinger equation / potential matrix).

- **Quarkonium channel $V_{\Sigma_g^+}(r)$**:
  - Taken in a Cornell-like form $V_0 + \gamma/r + \sigma r$ with parameters fixed by the lattice-based string-breaking analysis they cite (Bulava et al.).
  - Numbers used: $V_0 = -1.142$ GeV, $\gamma = -0.434$, $\sigma = 0.198$ GeV^2.
- **Tetraquark channels $V_{\Sigma_g^{+\prime}}(r)$ and $V_{\Pi_g}(r)$**:
  - **Short distance** ($r < R_\Lambda$): use BOEFT multipole-expansion logic: the heavy pair is in a **color-octet** configuration (repulsive Coulomb), plus a constant shift given by the

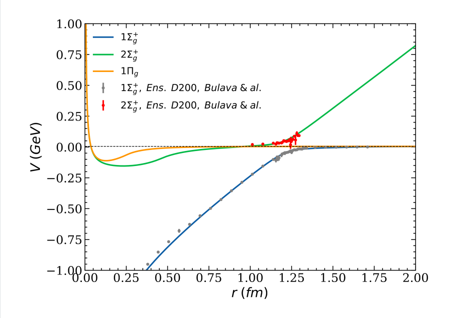
adjoint-meson mass $\Lambda_{1^{--}}$, plus higher-order terms in r.

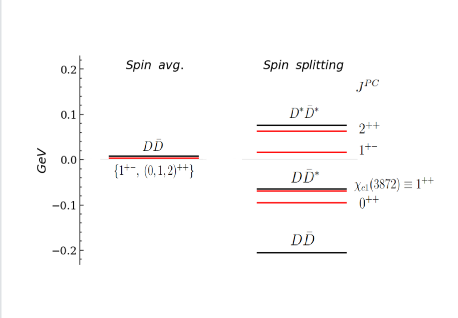
    - Implemented as $\kappa_8/r + \Lambda_{1^{--}} + A_\Lambda r^2 + B_\Lambda r^4$ with coefficients taken from a **quenched** parametrization (Alasiri et al.) because full-QCD data are missing at small r.
    - Numbers used: $\kappa_8 = 0.037$; $A_{\Sigma_g^{+\prime}} = 0.0065$ GeV^3, $B_{\Sigma_g^{+\prime}} = 0.0018$ GeV^5; $A_{\Pi_g} = 0.0726$ GeV^3, $B_{\Pi_g} = -0.0051$ GeV^5.
  - **Long distance** ($r > R_\Lambda$): enforce that BO quantum numbers evolve into the appropriate heavy-meson-pair threshold. They model the tail with a **two-pion-exchange** form (Lyu et al.) behaving like $F_\Lambda e^{-r/d}/r^2$ plus a threshold offset E_1.
    - Numbers used: $d \sim 1/(2m_\pi) \approx 0.66$ fm, $E_1 = 0.005$ GeV.
  - The matching radii R_Λ and strengths F_Λ are fixed by demanding **continuity of the potential and its first derivative** at $r = R_\Lambda$.
- **String-breaking / avoided-crossing mixing** $V_{\Sigma_g^+ - \Sigma_g^{+\prime}}(r)$:
  - Constrained to vanish as $r \to 0$ (pNRQCD) and as $r \to \infty$, with a peak in the string-breaking region.
  - Parameterized as a simple piecewise function: linear rise to a plateau of height g, then exponential fall with scale r_0.
  - Numbers used: $r_0 = 0.5$ fm (Sommer scale), $g = 0.05$ GeV, $r_1 = 0.95$ fm, $r_2 = 1.51$ fm, fixed to the cited lattice data and continuity.
- **What is tuned vs predicted**:
  - The key unknown short-distance constant is $\Lambda_{1^{--}}$ (adjoint-meson mass). They treat it as a **fit parameter** and tune it to reproduce the $\chi_{c1}(3872)$ binding, obtaining $\Lambda^*_{1^{--}} = 919$ MeV.
  - Once $\Lambda_{1^{--}}$ is fixed, the coupled Schrödinger problem predicts the near-threshold state and its wavefunction decomposition (including a nonzero quarkonium admixture induced by the avoided crossing).

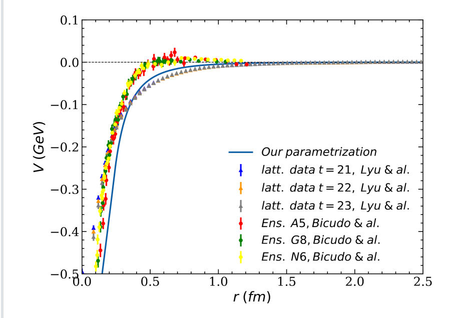
3) $T_{cc}^+(3875)$: the $QQ\bar{q}\bar{q}$ potential

- For the doubly-heavy case the BOEFT prediction is **single-channel** for the lowest Σ_g^+ potential: at short distance the QQ pair is in a **color antitriplet** (attractive Coulomb) shifted by the **triplet-meson mass** Λ_{0^+}; at long distance it must approach the DD threshold.
- They use a short-distance form $\kappa_3/r + \Lambda_{0^+} + Ar^2$ with $\kappa_3 = -0.120$, $A_{\Sigma_g^+} = 0.197$ GeV^3 (again taken from the quenched parametrization they cite), and the same two-pion-exchange tail $Fe^{-r/d}/r^2$ at large r, with matching fixed by continuity of the potential and its derivative.
- The free constant Λ_{0^+} is tuned to the T_{cc} binding, giving $\Lambda^*_{0^+} = 664$ MeV; the resulting potential is checked against available lattice data they cite (Bicudo et al., Lyu et al.).

Figures (click to open full-resolution PNGs)







2827674 — Exotic hidden-heavy hadrons and “where to find them”

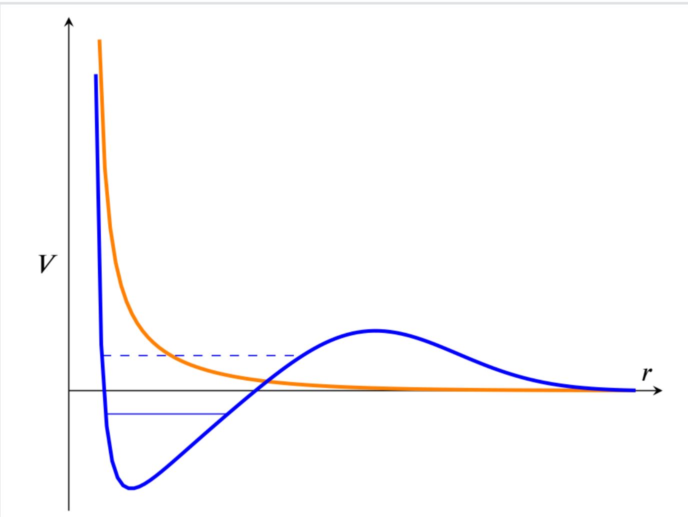
Citation / links

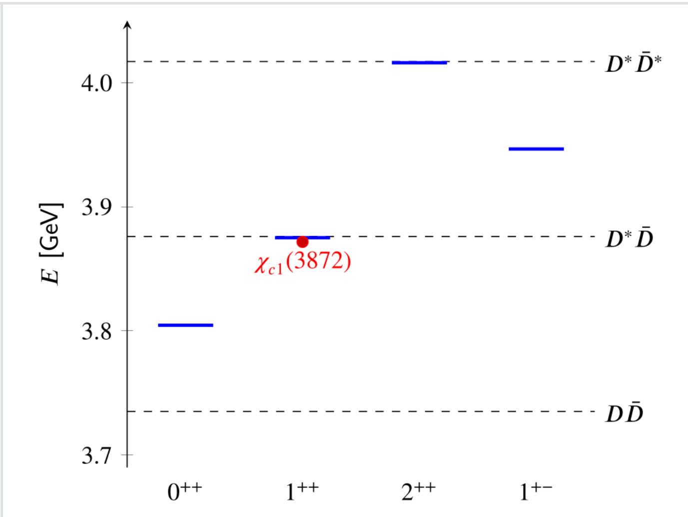
- Authors: Eric Braaten, Roberto Bruschini
- Publication: Phys. Lett. B 863 (2025) 139386
- INSPIRE: https://inspirehep.net/literature/2827674
- arXiv: https://arxiv.org/abs/2409.08002 (PDF: https://arxiv.org/pdf/2409.08002.pdf)

Key points

- Born–Oppenheimer viewpoint: adjoint-hadron potentials (repulsive at short distances) must smoothly connect to heavy-hadron-pair potentials approaching thresholds at large distances.
- Proposes that many exotic hidden-heavy hadrons appear as bound states/resonances in adjoint-hadron potentials that cross below heavy-hadron-pair thresholds, explaining the empirical clustering near thresholds.
- Highlights possible fine-tuning mechanisms controlling “exceptional” properties of some exotics.

Figures (click to open full-resolution PNGs)





2871943 — Tetraquarks in the Born–Oppenheimer approximation

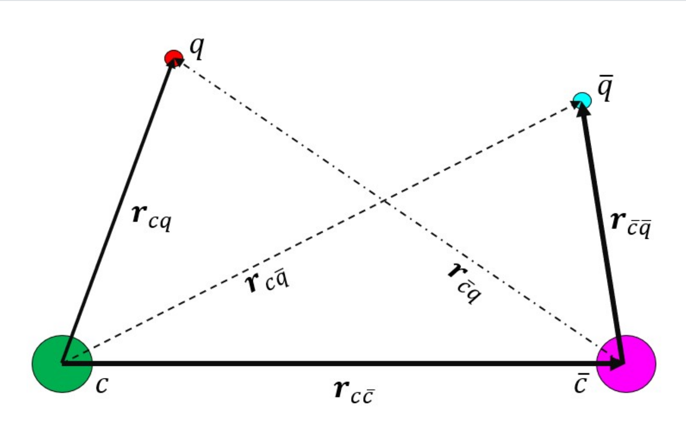
Citation / links

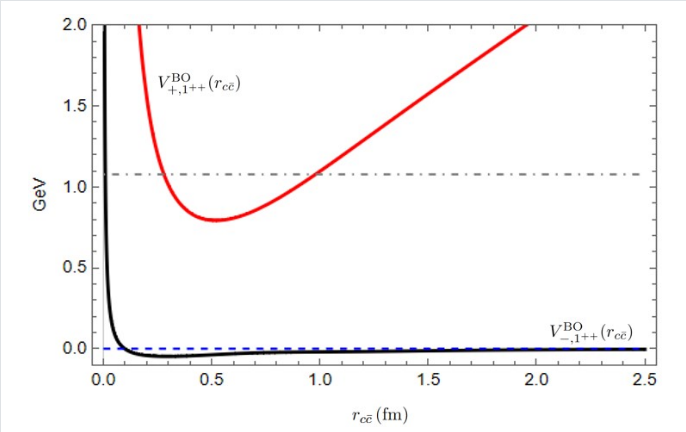
- Authors: Davide Germani, Benjamin Grinstein, Antonio Davide Polosa
- Publication: JHEP 04 (2025) 004
- INSPIRE: https://inspirehep.net/literature/2871943
- arXiv: https://arxiv.org/abs/2501.13249 (PDF: https://arxiv.org/pdf/2501.13249.pdf)

Key points

- Motivates a compact-tetraquark BO description of $X(3872)$, discussing tension between a purely “loose molecule” picture and radiative branching data (notably $\mathcal{R} = \mathrm{Br}(X \to \psi'\gamma)/\mathrm{Br}(X \to \psi\gamma)$).
- Determines BO tetraquark spectra for $J = 0, 1, 2$ and refines the estimate of $\mathcal{R}$ within that framework.
- Extends the diquark–antidiquark basis to include linear superpositions of open-charm singlets and color octets.

Figures (click to open full-resolution PNGs)





2734668 — Production of $X(4014)$ (spin-2 partner of $X(3872)$) in e^+e^-

Citation / links

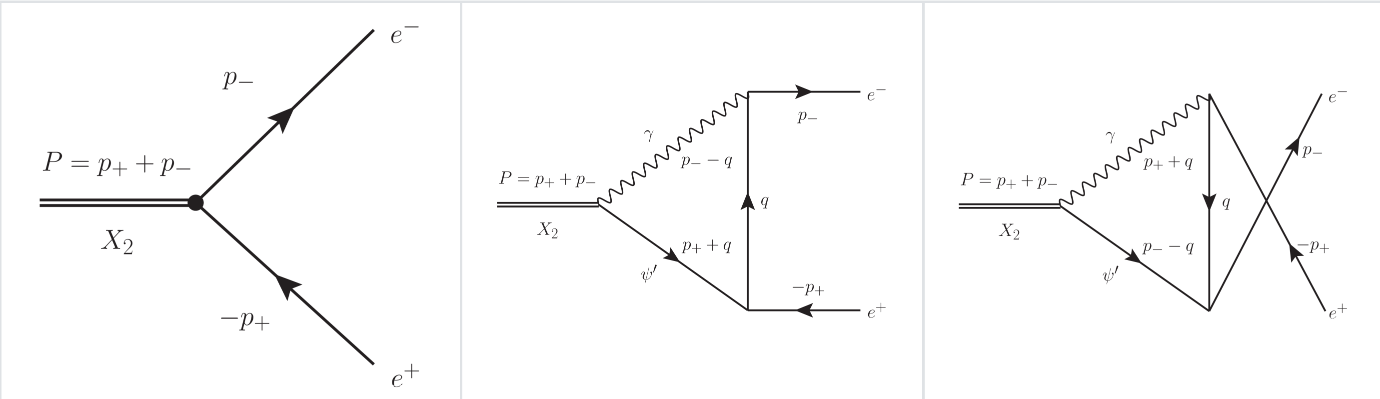
- Authors: Pan-Pan Shi, Vadim Baru, Feng-Kun Guo, Christoph Hanhart, Alexey Nefediev
- Publication: Chin. Phys. Lett. 41 (2024) 031301
- INSPIRE: https://inspirehep.net/literature/2734668
- arXiv: https://arxiv.org/abs/2312.05389 (PDF: https://arxiv.org/pdf/2312.05389.pdf)

Key points

- Motivated by Belle's reported structure near the $D^{*0}\bar{D}^{*0}$ threshold in the $\psi(2S)\gamma$ final state, interpretable as a 2^{++} HQSS partner of $X(3872)$ (often denoted X_2 / $X(4014)$).
- Estimates the electronic width of this state and argues sensitivity to its total width; suggests searches at STCF in $J/\psi\gamma$ and $\psi(2S)\gamma$ invariant-mass distributions.

Figures (click to open full-resolution PNGs)

- Contributions to $X_2 \to e^+e^-$ amplitude (three diagrams):



2898337 — Production of 1^{-+} exotic charmonium-like molecules in e^+e^-

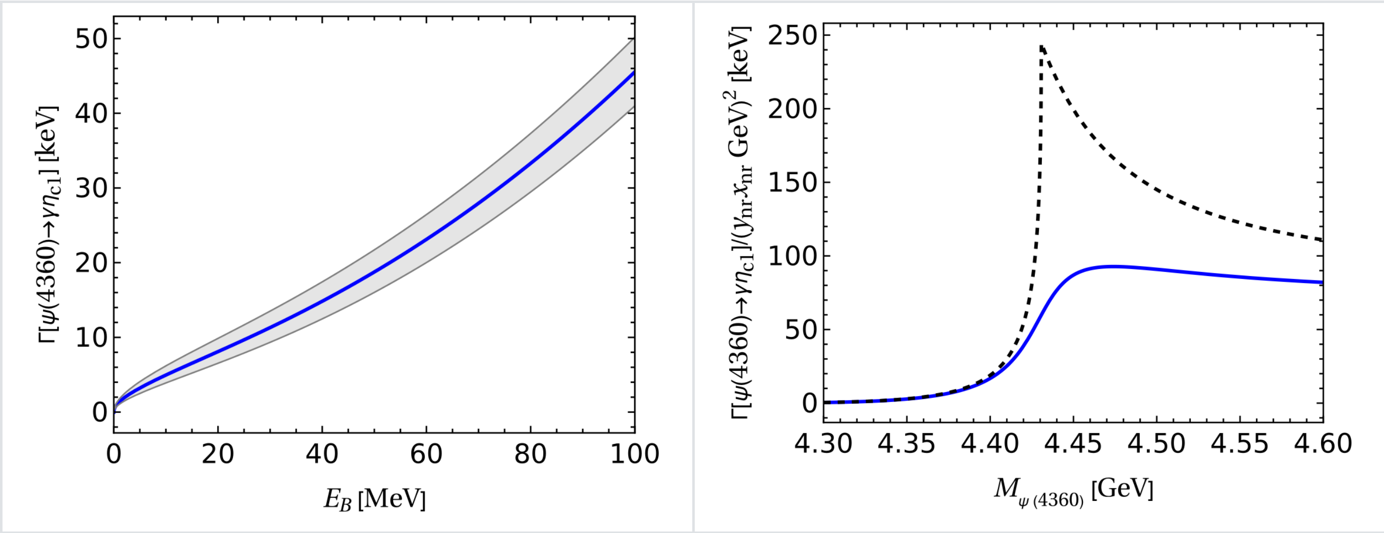
Citation / links

- Authors: Xiao-Yu Zhang, Pan-Pan Shi, Feng-Kun Guo
- Publication: Phys. Lett. B 867 (2025) 139603
- INSPIRE: https://inspirehep.net/literature/2898337
- arXiv: https://arxiv.org/abs/2503.06259 (PDF: https://arxiv.org/pdf/2503.06259.pdf)

Key points

- Studies 1^{-+} hadronic molecules built from $D\bar{D}_1(2420)$ and $D^*\bar{D}_1(2420)$ (denoted η_{c1} and η'_{c1}) and their production prospects in e^+e^- collisions.
- Under the assumption that $\psi(4360)$ and $\psi(4415)$ are hadronic molecules, computes radiative widths and translates them into production cross sections/event yields at a future Super τ-Charm Facility (STCF).
- Finds an optimal energy region for observation around 4.44–4.50 GeV (just above the relevant thresholds).

Figures (click to open full-resolution PNGs)



Appendix — color decomposition of the 1^{++} hadronic molecule (X(3872))

In the standard molecular picture,

$$X(3872) \sim \frac{1}{\sqrt{2}}\Big(|D^0\bar{D}^{*0}\rangle + |D^{*0}\bar{D}^0\rangle\Big) \quad (I=0,\ J^{PC}=1^{++}), \tag{2}$$

where the color structure of each meson is a **color singlet**. The decomposition below is purely in **color space** (independent of the spin/flavor wavefunction that enforces 1^{++}).

Step 1: write the meson–meson color wavefunction with indices

Let the color indices be
c_i (fundamental), $\bar{c}_k$ (anti-fundamental), q_l (fundamental), $\bar{q}_j$ (anti-fundamental).
The color-singlet mesons are

$$|(c\bar{q})_{\mathbf{1}}\rangle = \frac{1}{\sqrt{3}}\,\delta_{ij}\,|c_i\bar{q}_j\rangle, \qquad |(\bar{c}q)_{\mathbf{1}}\rangle = \frac{1}{\sqrt{3}}\,\delta_{kl}\,|\bar{c}_k q_l\rangle. \tag{3}$$

Therefore the color wavefunction of a color-singlet meson pair is

$$|(c\bar{q})_{\mathbf{1}}(\bar{c}q)_{\mathbf{1}}\rangle = \frac{1}{3}\,\delta_{ij}\delta_{kl}\,|c_i\bar{q}_j\,\bar{c}_k q_l\rangle. \tag{4}$$

Step 2: Fierz-rearrange to the $(c\bar{c})$ $(q\bar{q})$ basis

Use the SU(3) completeness/Fierz identity (with T^a normalized by $\mathrm{Tr}(T^aT^b) = \delta^{ab}/2$):

$$\delta_{ij}\delta_{kl} = \frac{1}{3}\,\delta_{ik}\delta_{lj} + 2\,(T^a)_{ik}(T^a)_{lj}, \tag{5}$$

which regroups the color contractions into a heavy pair $(c\bar{c})$ and a light pair $(q\bar{q})$.

Step 3: define normalized singlet and octet pair states

Color-singlet pair states:

$$|(c\bar{c})_{\mathbf{1}}\rangle = \frac{1}{\sqrt{3}}\delta_{ik}|c_i\bar{c}_k\rangle, \qquad |(q\bar{q})_{\mathbf{1}}\rangle = \frac{1}{\sqrt{3}}\delta_{lj}|q_l\bar{q}_j\rangle. \tag{6}$$

Color-octet pair states:

$$|(c\bar{c})^a_{\mathbf{8}}\rangle = \sqrt{2}\,(T^a)_{ik}|c_i\bar{c}_k\rangle, \qquad |(q\bar{q})^a_{\mathbf{8}}\rangle = \sqrt{2}\,(T^a)_{lj}|q_l\bar{q}_j\rangle. \tag{7}$$

The overall-color-singlet combination built from two octets is

$$|(c\bar{c})_{\mathbf{8}}(q\bar{q})_{\mathbf{8}}\rangle_{\mathbf{1}} \equiv \frac{1}{\sqrt{8}}\sum_{a=1}^{8}|(c\bar{c})^a_{\mathbf{8}}\rangle\,|(q\bar{q})^a_{\mathbf{8}}\rangle. \tag{8}$$

Final result: singlet–singlet + octet–octet decomposition

Putting everything together (and keeping normalized basis states), the color wavefunction of a two-meson molecule satisfies

$$|(c\bar{q})_{\mathbf{1}}(\bar{c}q)_{\mathbf{1}}\rangle = \frac{1}{3}\,|(c\bar{c})_{\mathbf{1}}(q\bar{q})_{\mathbf{1}}\rangle \;+\; \frac{2\sqrt{2}}{3}\,|(c\bar{c})_{\mathbf{8}}(q\bar{q})_{\mathbf{8}}\rangle_{\mathbf{1}}. \tag{9}$$

Equivalently, the weights are

$$P\big[(c\bar{c})_{\mathbf{1}}\big] = \frac{1}{9}, \qquad P\big[(c\bar{c})_{\mathbf{8}}\big] = \frac{8}{9}, \tag{10}$$

meaning that a hadronic molecule built from two color-singlet mesons is dominantly **color-octet** $c\bar{c}$ once you regroup the colors into a heavy pair and a light pair (the overall state is still a total color singlet because the light pair is simultaneously in an octet).

Repro / regeneration notes

- arXiv sources live under `papers/arxiv_src/<arxiv_id>/src/`.
- Extracted PNGs live under `assets/papers/<recid>/`.
- Re-extract a paper's key figures (adjust `--max-figures` as needed):
  - `python3 scripts/extract_paper_figures.py --recid <RECID> --arxiv-id <ARXIV_ID> --src-dir papers/arxiv_src/<ARXIV_ID>/src --out-dir assets/papers --max-figures 3`