Decays of the heavy-quark-spin molecular partner of T_{cc}^{+}

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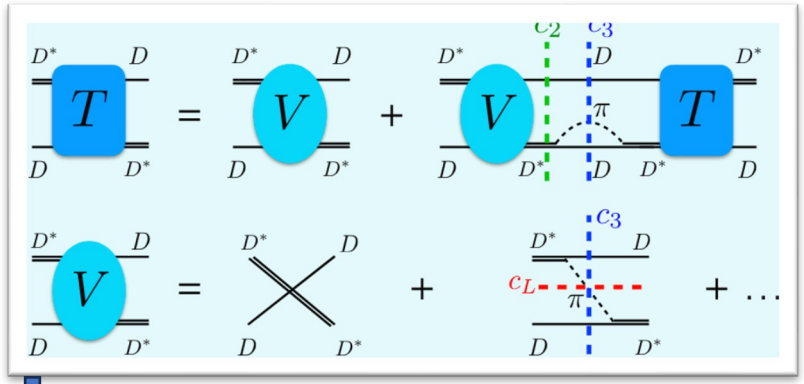
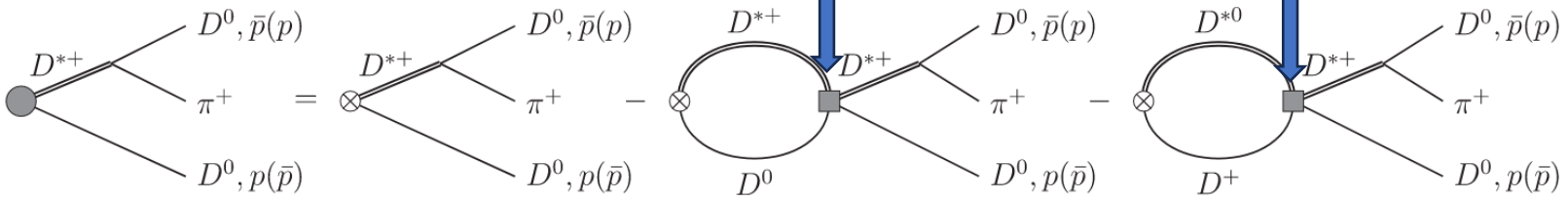
Based on PRD 107 (2023) 074029; PRD 108 (2023) 094038
In collaboration with Z.-S. Jia, Z.-H. Zhang, G. Li , P.-P. Shi, M.-J. Yan

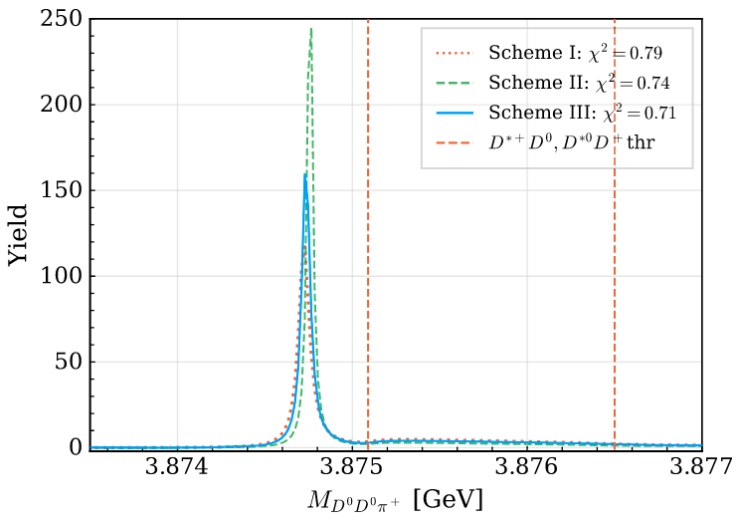
$T_{cc}(3875)$ as DD^* hadronic molecule

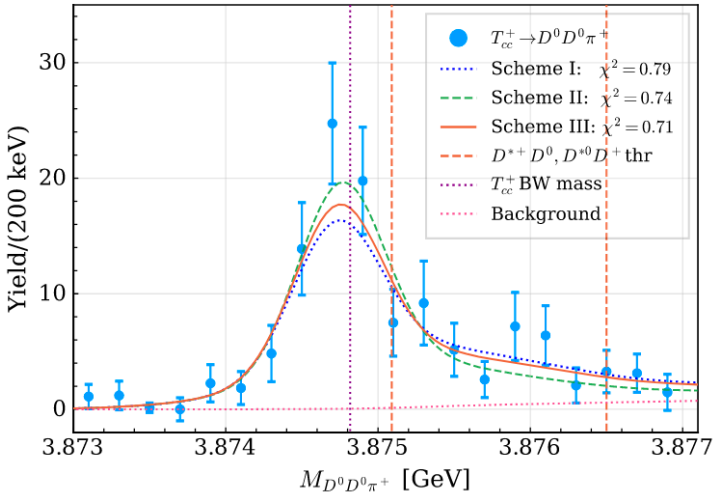
M.-L. Du et al., PRD 105 (2022) 014024

- EFT description of the T_{cc}
  - channels: $D^{*+}D^0, D^{*0}D^+$
  - contact term + one-pion exchange
  - three-body effects









Convolved with energy resolution

Pole w.r.t. the $D^{*+}D^0$ th:

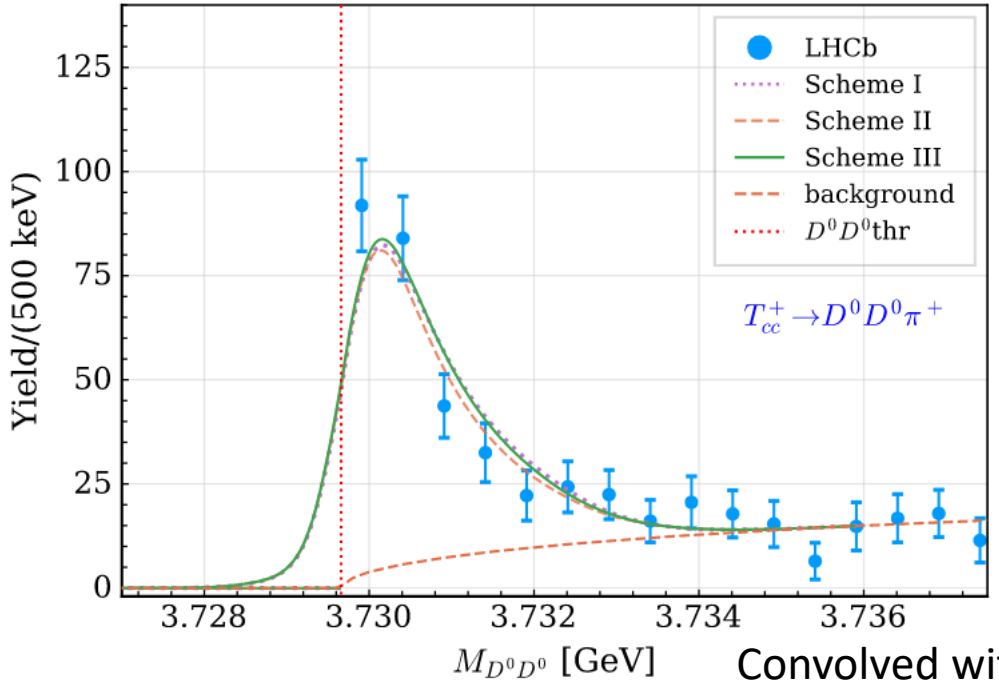
Scheme I	Scheme II	Scheme III
Contact only, const. Γ_{D^*}	Contact + D^* self-energy	Full 3-body
$-368^{+43}_{-42} - i(37 \pm 0)$ keV	$-333^{+41}_{-36} - i(18 \pm 1)$ keV	$-356^{+39}_{-38} - i(28 \pm 1)$ keV

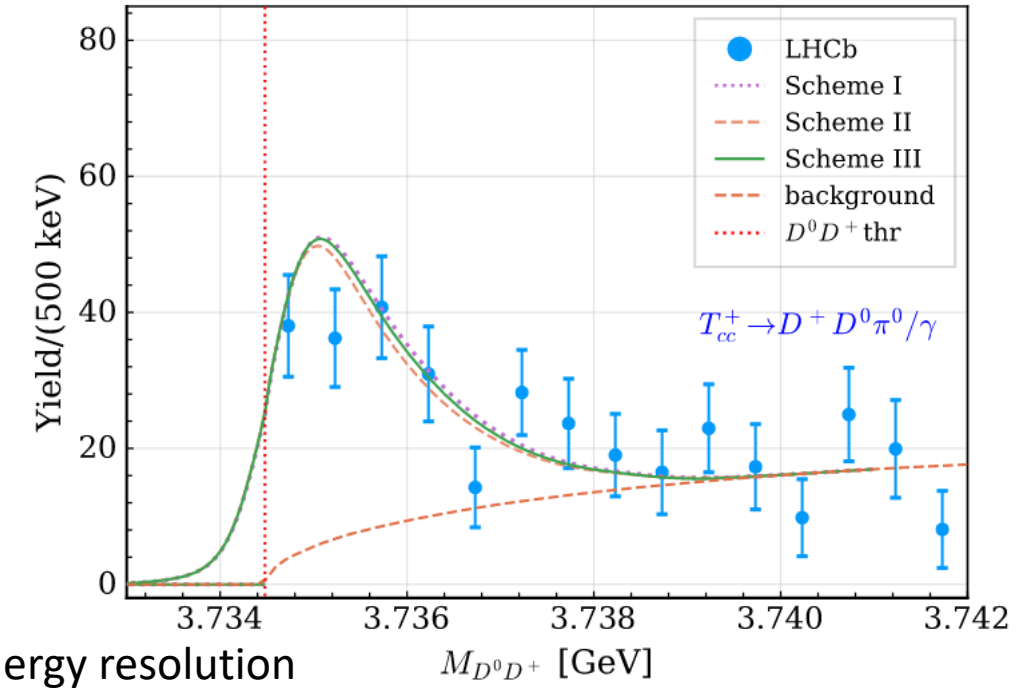
$\Gamma_{T_{cc}} = (56 \pm 2)$ keV

$T_{cc}(3875)$ as DD^* hadronic molecule

M.-L. Du et al., PRD 105 (2022) 014024

- Predictions of DD invariant mass distributions v.s. LHCb measurements





Convolved with energy resolution

- Compositeness:

$X\,[D^{*+}D^0]$	$X\,[D^{*0}D^+]$
0.73 ± 0.11	0.27 ± 0.02

For decays of T_{cc} in the XEFT, see talk by Tom Mehen

→ $T_{cc}(3875)$ is DD^* hadronic molecule

- Heavy quark spin partner: D^*D^* bound state with $J^P = 1^+, I = 0$

  Binding energy: $\delta_{cc}^{*+} = -503(40)$ keV

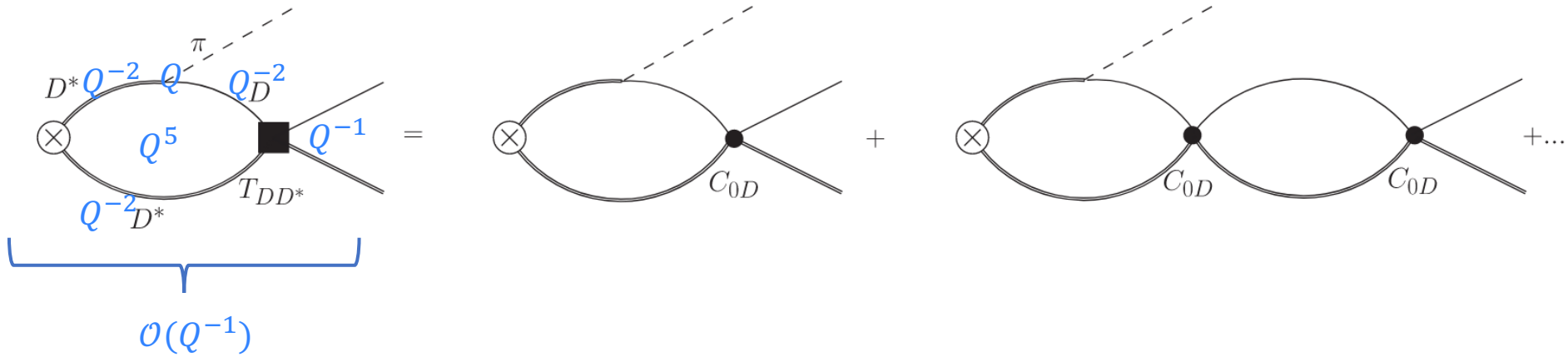
  - For LO contact term: $V^{I=0}(D^*D^* \to D^*D^*, 1^+) = V^{I=0}(D^*D \to D^*D, 1^+)$

See also M. Albaladejo PLB 829 (2022) 137052; …

Hadronic decays of T_{cc}^*

Z.-S. Jia et al., PRD 107 (2023) 074029

- Hadronic decay modes:
  - 3-body modes: $D^{*+}D^0\pi^0, D^{*0}D^+\pi^0, D^{*0}D^0\pi^+$; they interfere since D^* needs to be reconstructed from $D\pi, D\gamma$
  - 4-body modes: $D^0D^+\pi^0\pi^0,\ D^0D^0\pi^0\pi^+$
- Isospin breaking contribution from $T_{cc}(3875)$ through DD^* rescattering

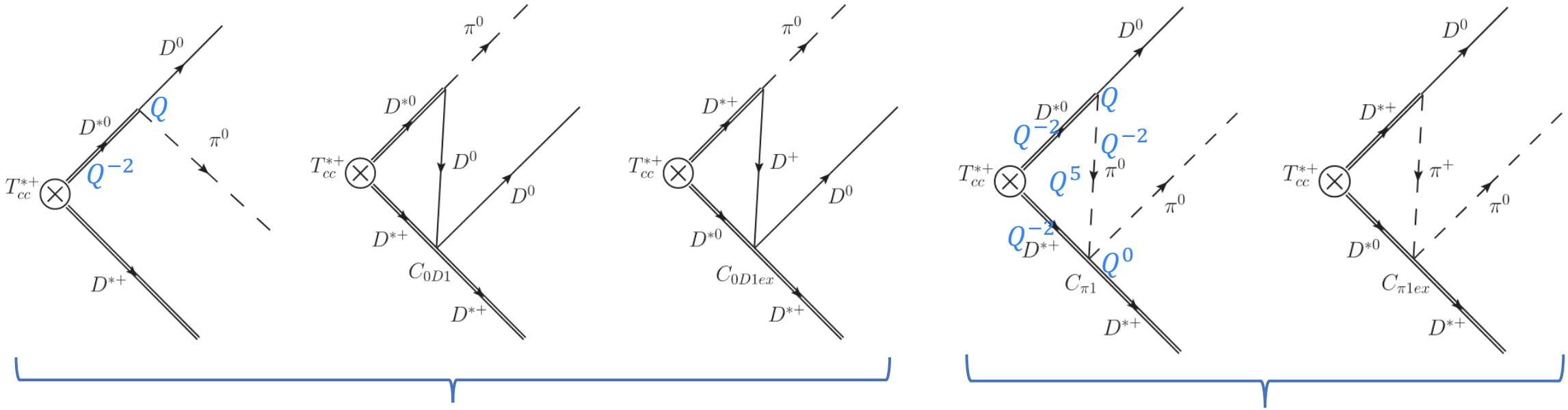


  - power counting: binding momentum $\gamma \sim 30$ MeV, small momentum scale $Q \sim \gamma \sim p_D \sim p_{D^*} \sim p_\pi$
  - From previous analysis: $\frac{g_{TD^{*+}D^0}}{g_{TD^{*0}D^+}} = -1.04$
- The isovector DD^* rescattering is neglected as no isovector double-charm state observed

Hadronic decays of T_{cc}^*

Z.-S. Jia et al., PRD 107 (2023) 074029

- Diagrams for $T_{cc}^{*+} \to D^{*+}D^0\pi^0$



LO: $\mathcal{O}(Q^{-1})$

NLO: $\mathcal{O}(Q^0)$

Γ[keV]	Tree	LO	Up to NLO
$\Gamma[T_{cc}^{*+} \to D^{*+}D^0\pi^0]$	$12.8^{+0.6}_{-0.5}$	17.4 ± 0.7	$15.3^{+0.7}_{-0.6}$
$\Gamma[T_{cc}^{*+} \to D^{*0}D^+\pi^0]$	8.0 ± 0.4	9.2 ± 0.5	$8.3^{+0.5}_{-0.4}$
$\Gamma[T_{cc}^{*+} \to D^{*0}D^0\pi^+]$	18.2 ± 0.9	18.2 ± 0.9	17.6 ± 0.9

Sizable corrections due to T_{cc} (isospin breaking)

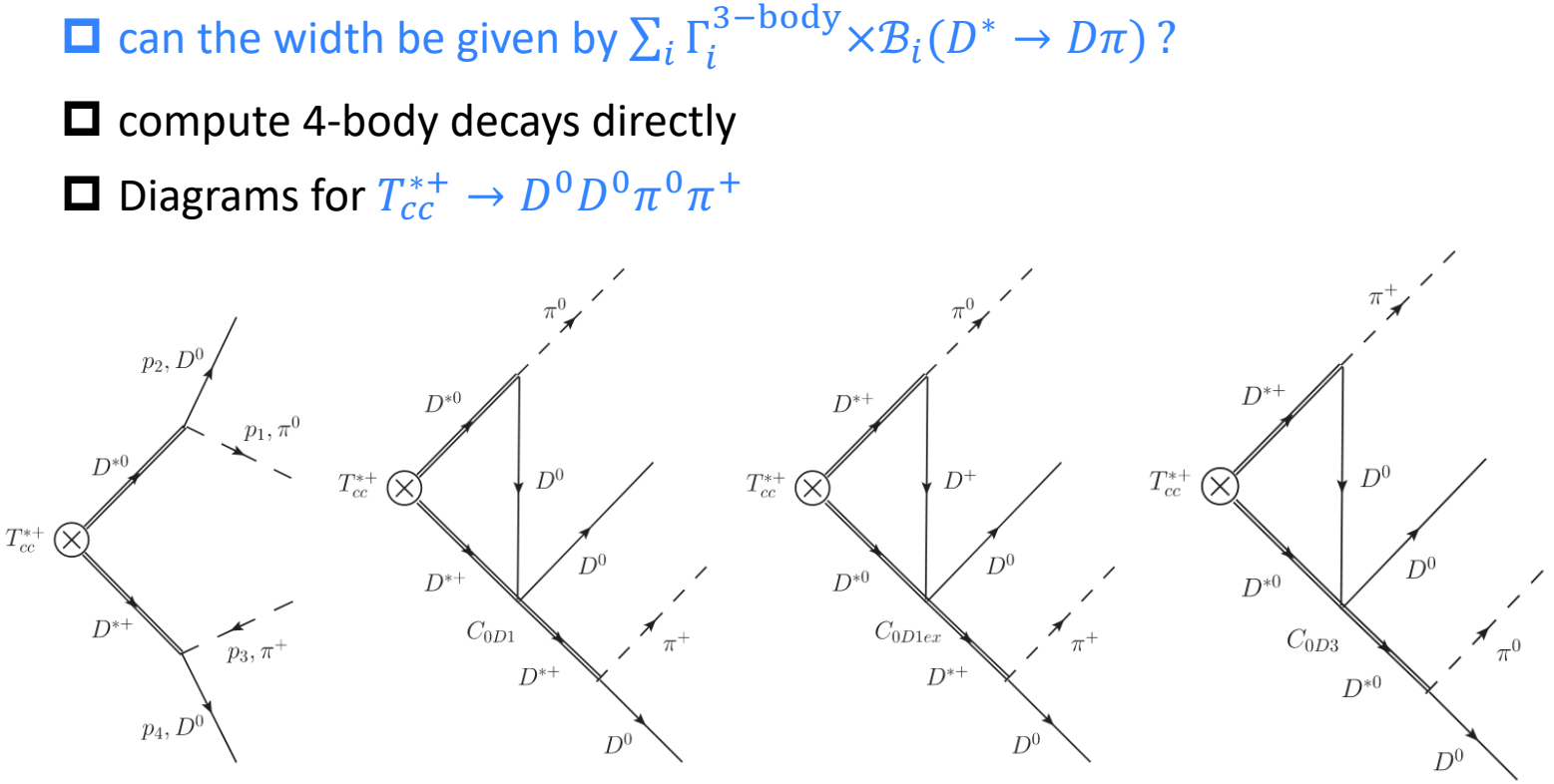
Significant isospin breaking

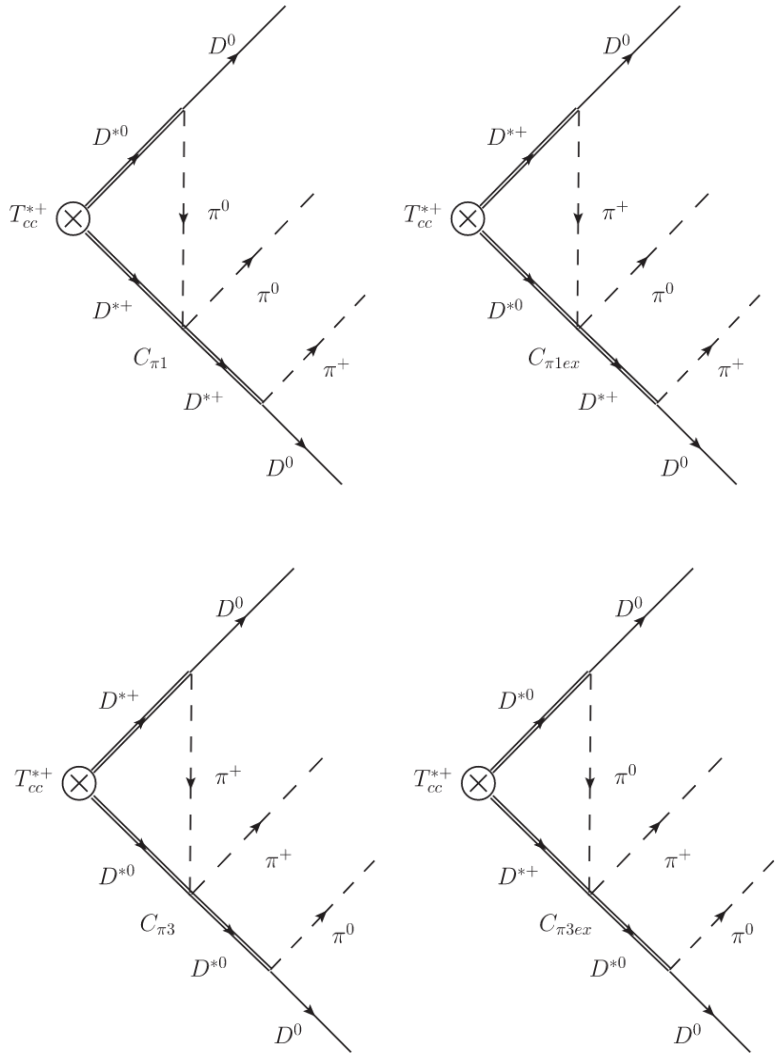
isovector DD^* rescattering neglected

Hadronic decays of T_{cc}^*

Z.-S. Jia et al., PRD 107 (2023) 074029

- Three-body partial width: $\Gamma(D^{*+}D^0\pi^0 + D^{*0}D^+\pi^0 + D^{*0}D^0\pi^+) = (41 \pm 2)\ \text{keV}$
- But these modes interfer to give four-body modes: $D^0D^+\pi^0\pi^0,\ D^0D^0\pi^0\pi^+$
  - can the width be given by $\sum_i \Gamma_i^{3-\text{body}} \times \mathcal{B}_i(D^* \to D\pi)$?
  - compute 4-body decays directly
  - Diagrams for $T_{cc}^{*+} \to D^0D^0\pi^0\pi^+$





A graphic method for easily deriving n-body phase space:
H.-J. Jing, C.-W. Shen, FKG, Sci.Bull. 66 (2020) 653 [arXiv:2005.01942]

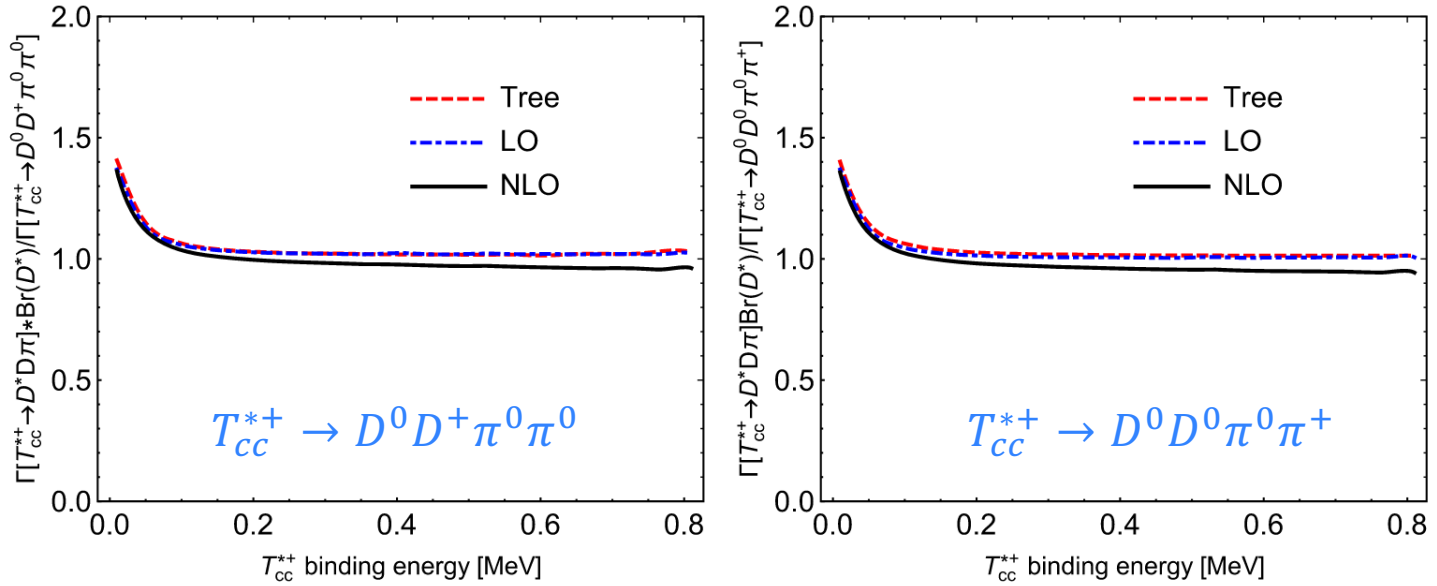
Hadronic decays of T_{cc}^*

Z.-S. Jia et al., PRD 107 (2023) 074029

- 4-body hadronic widths: Interference does have effects, but marginal

Γ[keV]	Tree	LO	NLO
$\Gamma[T_{cc}^{*+} \to D^0 D^+ \pi^0 \pi^0]$	$8.3^{+0.6}_{-0.3}$	$10.5^{+0.8}_{-0.4}$	$9.8^{+0.8}_{-0.4}$
$\Gamma[T_{cc}^{*+} \to D^{*+} \pi D] \times \mathcal{B}(D^{*+} \to \pi^0 D^+) + \Gamma[T_{cc}^{*+} \to D^* \pi D^+] \times \mathcal{B}(D^{*0} \to \pi^0 D^0)$	9.1 ± 0.4	11.3 ± 0.5	$10.1^{+0.5}_{-0.4}$
$\Gamma[T_{cc}^{*+} \to D^0 D^0 \pi^0 \pi^+]$	$19.5^{+1.3}_{-1.8}$	$23.9^{+0.1}_{-1.7}$	$23.2^{+0.1}_{-1.7}$
$\Gamma[T_{cc}^{*+} \to D^{*+} \pi D] \times \mathcal{B}(D^{*+} \to \pi^+ D^0) + \Gamma[T_{cc}^{*+} \to D^* \pi^+ D] \times \mathcal{B}(D^{*0} \to \pi^0 D^0)$	20.4 ± 0.9	23.6 ± 1.1	21.7 ± 1.0

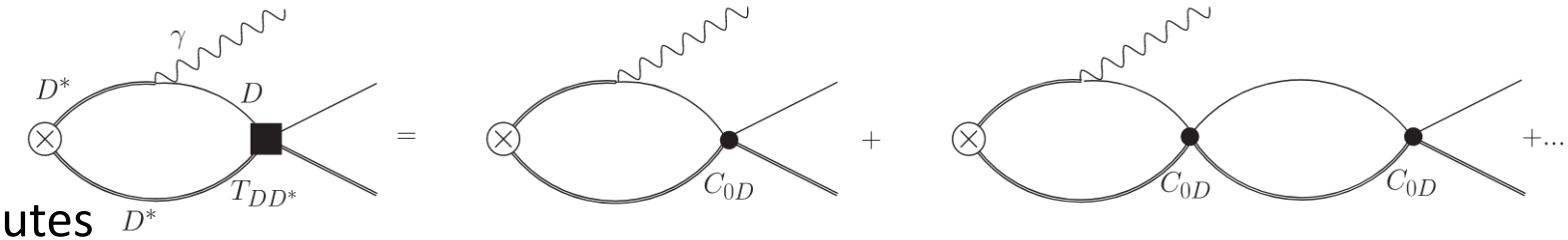
Ratios:



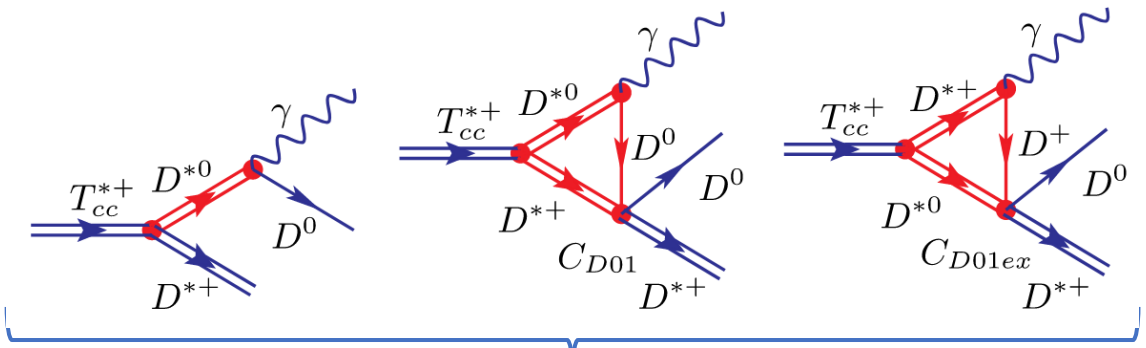
Radiative decays of T_{cc}^*

Z.-S. Jia et al., PRD 108 (2023) 094038

- Radiative decay modes:
  - 3-body modes: $D^{*+}D^0\gamma, D^{*0}D^+\gamma$
  - Similar to hadronic decays, T_{cc} contributes

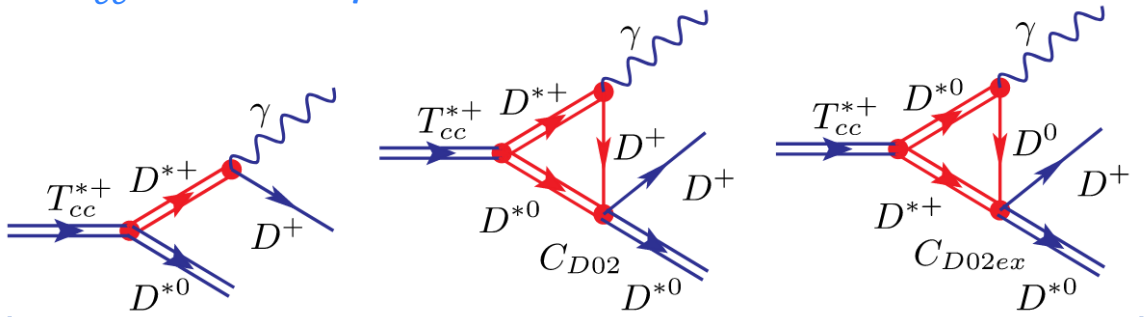


➢ $T_{cc}^{*+} \to D^{*+}D^0\gamma$



LO: $\mathcal{O}(Q^{-1})$

➢ $T_{cc}^{*+} \to D^{*0}D^+\gamma$



LO: $\mathcal{O}(Q^{-1})$

- Consider only LO contributions
  - neglect isovector DD^* rescattering
  - Isoscalar DD^* rescattering (T_{cc}) is important

Γ[keV]	Tree level	LO
$\Gamma[T_{cc}^{*+} \to D^{*+}D^0\gamma]$	15.6 ± 0.2	23.4 ± 0.1
$\Gamma[T_{cc}^{*+} \to D^{*0}D^+\gamma]$	1.0 ± 0.1	0.4 ± 0.0
$\Gamma[T_{cc}^{*+} \to T_{cc}^+\gamma]$	...	6.1 ± 0.1

Radiative decays of T_{cc}^*

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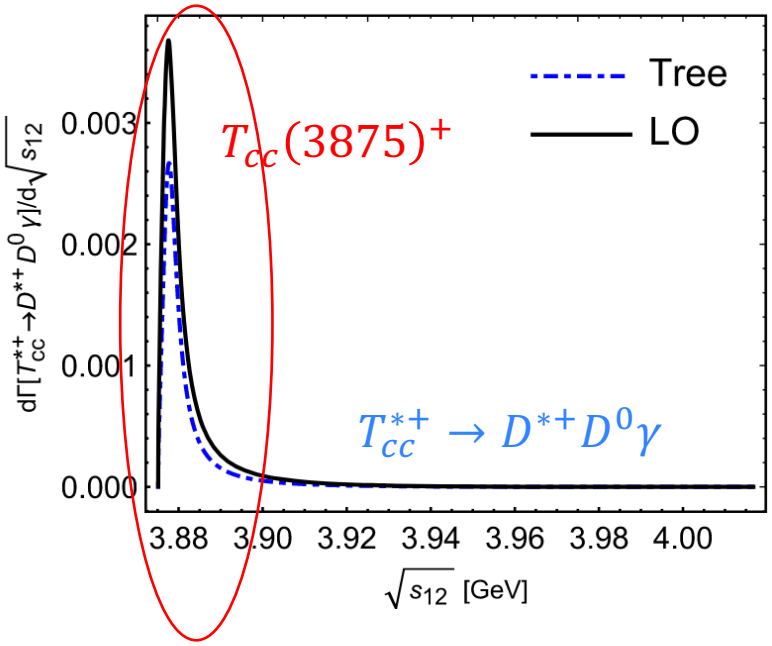
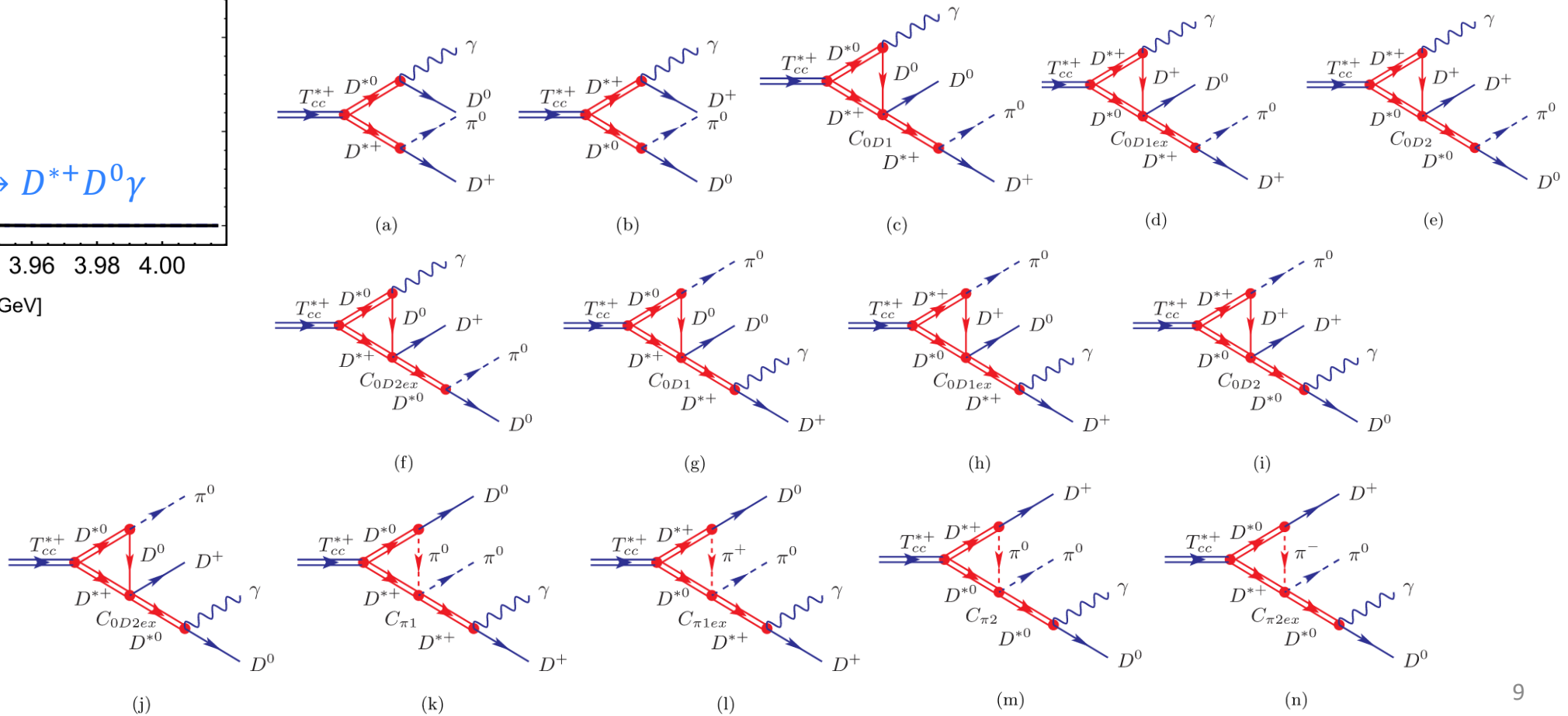
- Differential decay width



- Similar to hadronic decays: $D^{*+}D^0\gamma, D^{*0}D^+\gamma, D^{*0}D^+\pi^0, D^{*+}D^0\pi^0$ interfere to give 4-body radiative modes $D^0D^0\gamma\pi^+, D^+D^0\gamma\pi^0, D^+D^0\gamma\gamma$
  - For $T_{cc}^{*+} \to D^+D^0\gamma\pi^0$: (10.7 ± 0.2) keV [w/ interference]
    (10.6 ± 0.2) keV [w/o interf., $\sum_i \Gamma_i^{3-\text{body}} \times \mathcal{B}_i$]



Summary

- Hadronic and radiative decays of the T_{cc}^* calculated; interference effects among D^* modes found marginal
- $\Gamma(T_{cc}^*) \simeq \Gamma(T_{cc}^* \to DD^*\pi) + \Gamma(T_{cc}^* \to DD^*\gamma) = (65 \pm 2)\,\mathrm{keV}$

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