T_{cc} and TS

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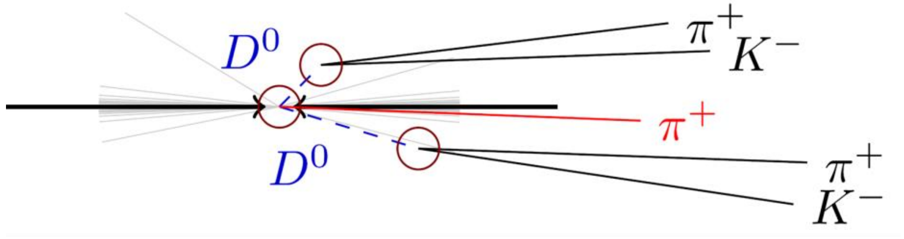
Observation of the doubly-charm tetraquark T_{cc}^{+}



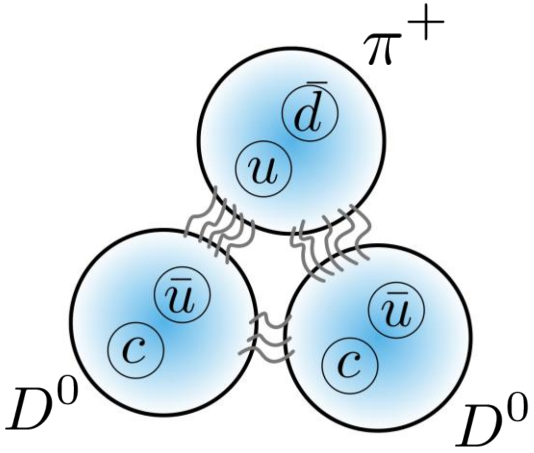
Peak in $D^0 D^0 \pi^+$ just below $D^{*+} D^0$ threshold

Extremely narrow, ~300keV

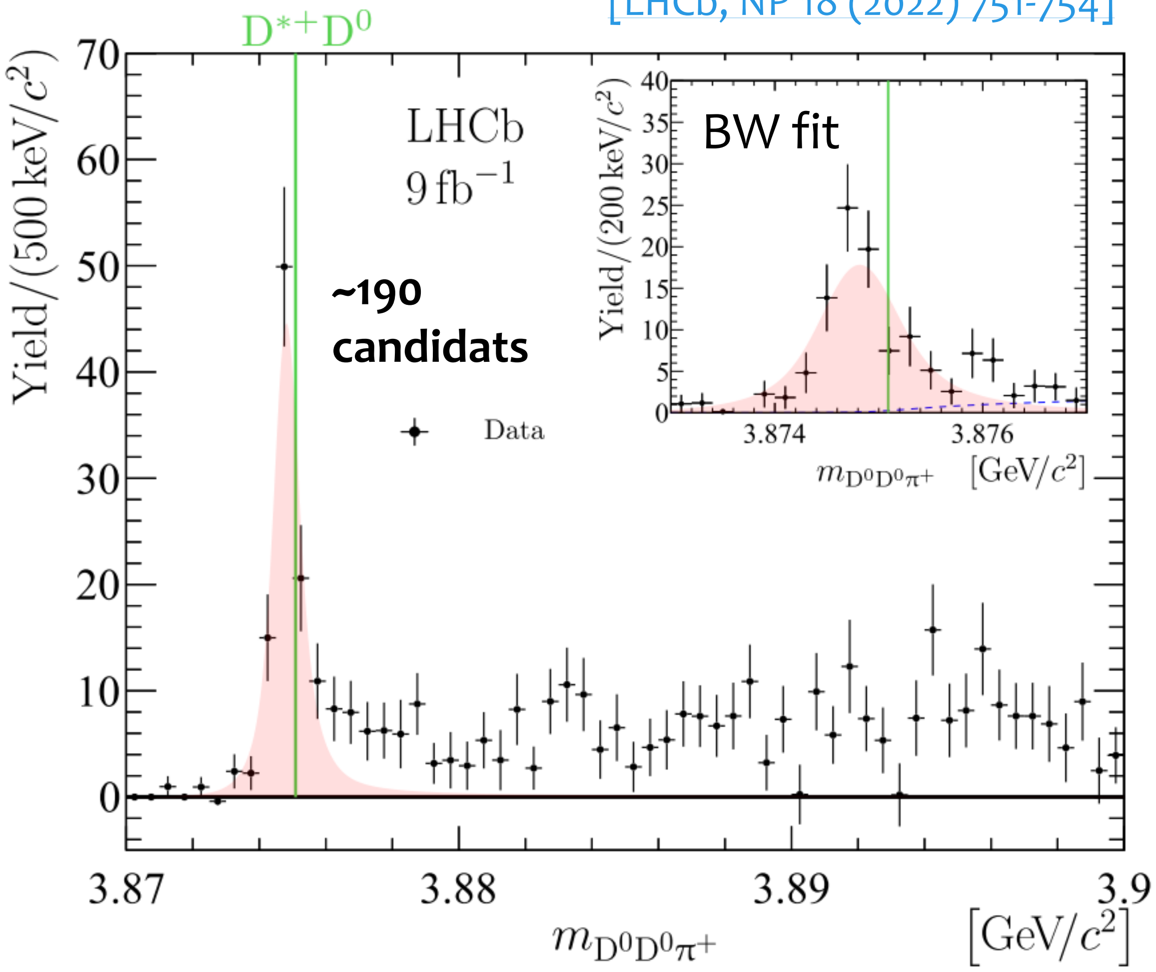
(resolution)

Needs to be treated as

three-body effect

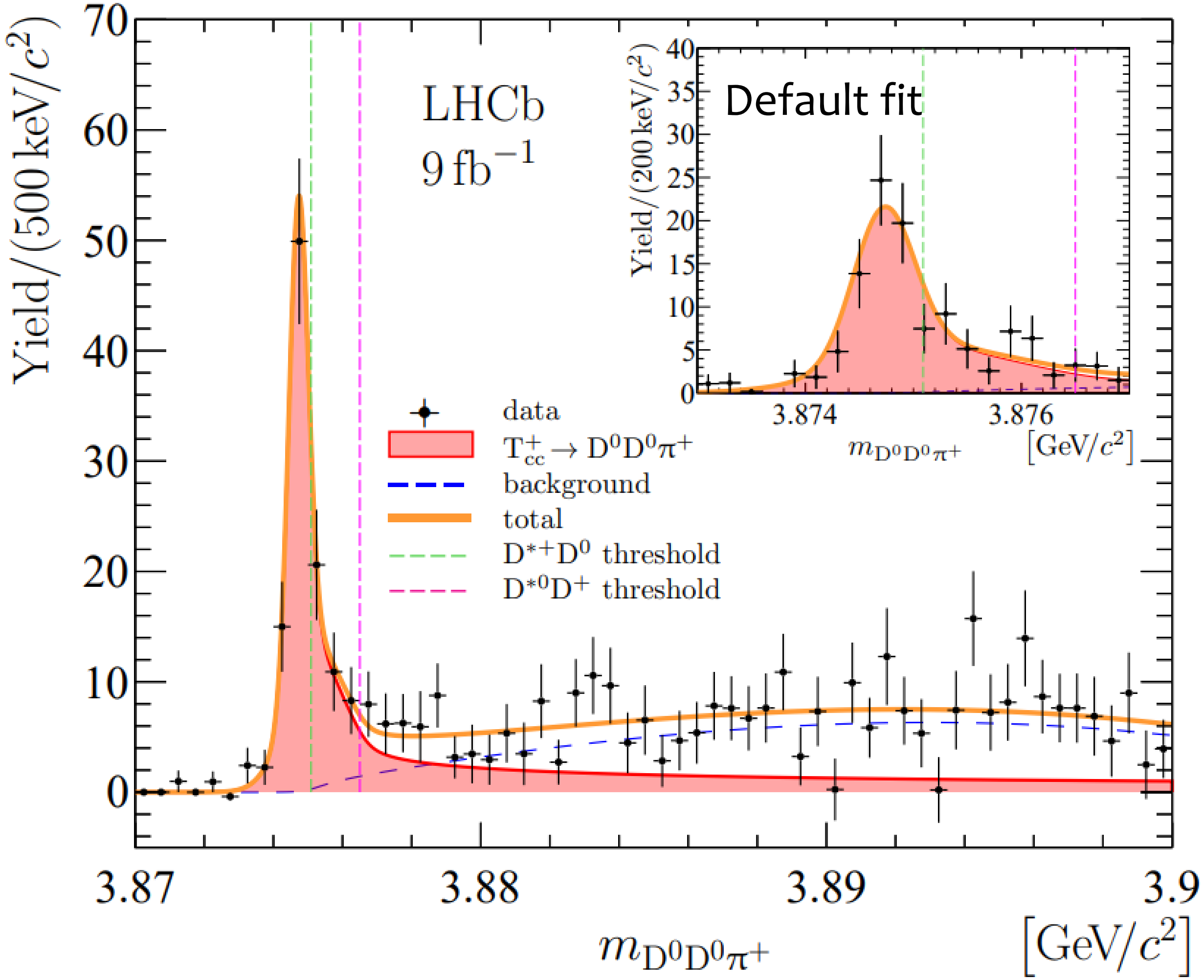


[LHCb, NP 18 (2022) 751-754]



Studies of the doubly-charm tetraquark T_{cc}^{+}

[LHCb, NC 13 (2022) 3351]

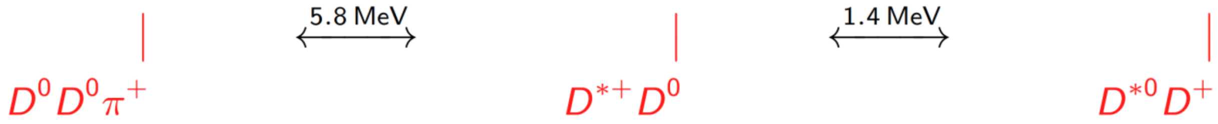


QN: isoscalar ($I = 0$), axial ($J^{PC} = 1^{++}$)

Coupled channel model

$$D^{*+}D^0 + D^{*0}D^+$$

$$\to \{D^0D^0\pi^+, D^0D^+\pi^0, D^0D^+\gamma\}$$



Yields pole parameters:

- **Binding energy:** $-360 \pm 40^{+4}_{-0}$ **keV**
- **Width:** $48 \pm 2^{+0}_{-14}$ **keV**

Prediction of the three-body spectrum

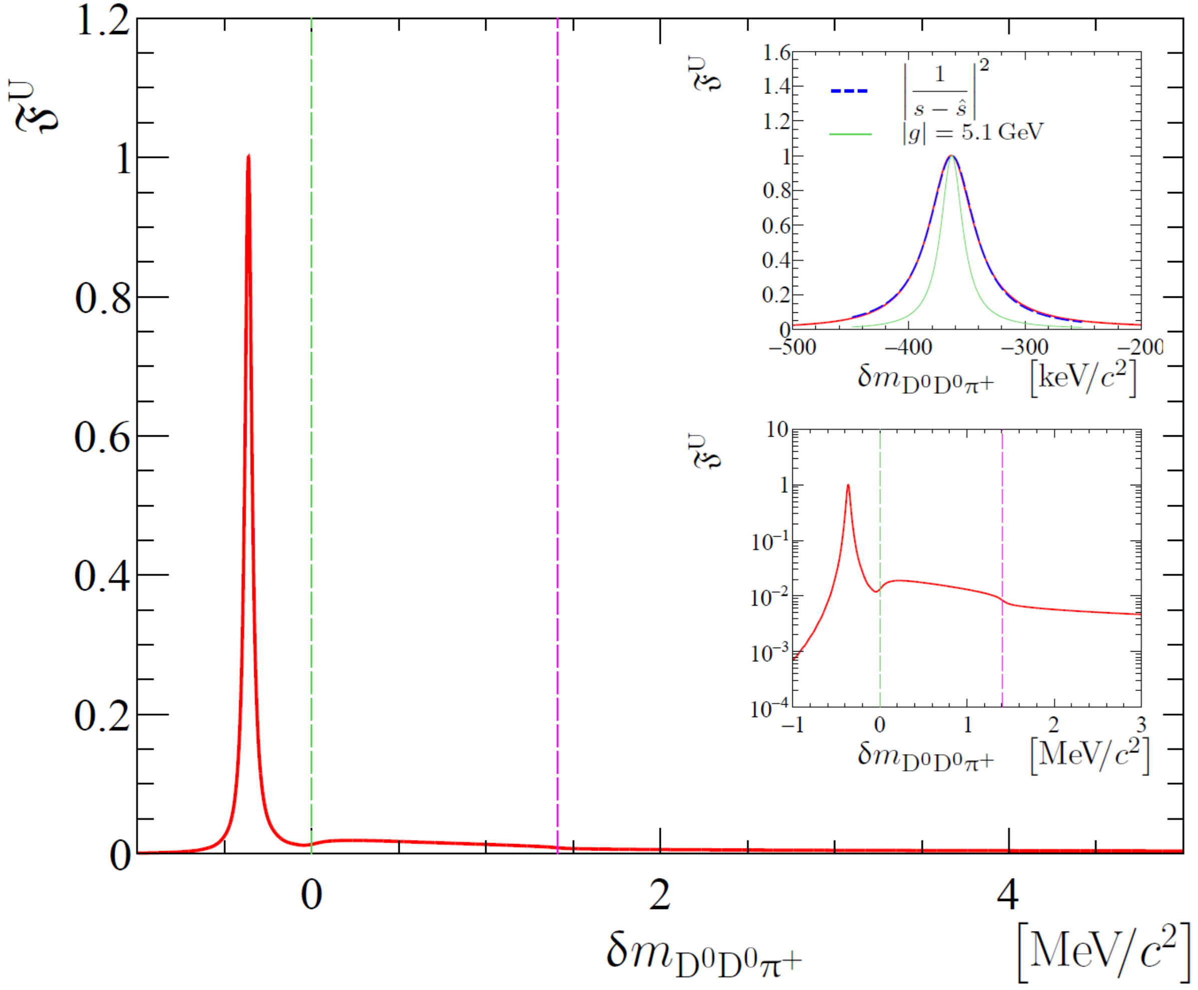
-The narrow peak below the lowest threshold

-Long tail with cusps at the thresholds

$$T(s) = \frac{\text{production}}{\text{rescattering}(s\,|\,\delta m, g)}$$

Analytic solution enables us:

- **Obtain pole mass and width**
- **Compute scattering parameters**



Tcc model and analytic continuation

similar to [MM et al. (JPAC), PRD 98 (2018) 096021]

Dynamic amplitude of $D^*D \to D^*D$ scattering:

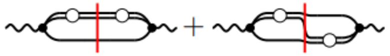
$$T_{2\times2}(s) = \frac{K}{1-\Sigma K} = \frac{K(m^2-s)}{m^2 - s - i\,g^2\left(\rho_{\text{tot}}(s) + i\xi(s)\right)}$$

where K is the isoscalar potential:

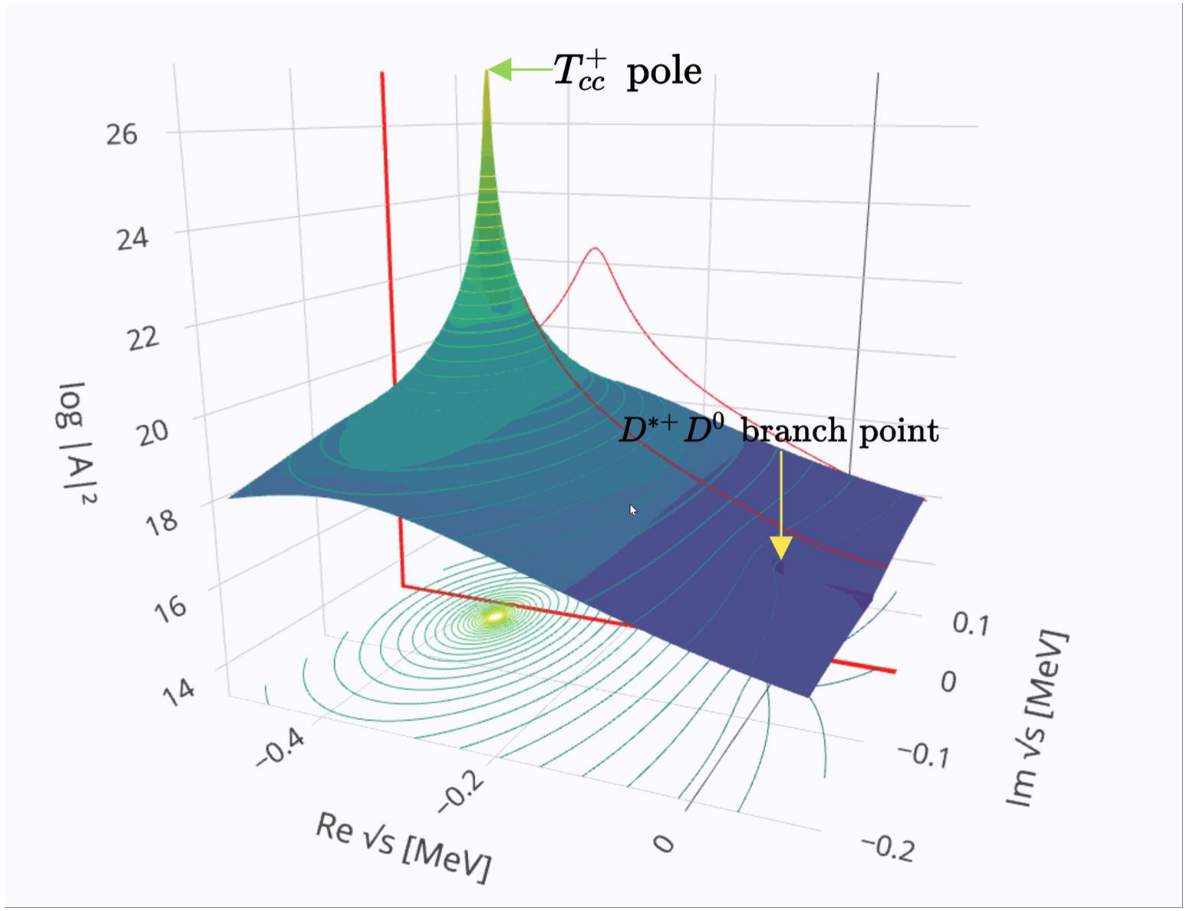
$$K = \frac{1}{m^2-s}\begin{pmatrix} g\cdot g & -g\cdot g \\ -g\cdot g & g\cdot g \end{pmatrix},$$

and Σ is the loop function:

$$\Sigma(s) = [D^*D \to DD\pi(\gamma) \to D^*D]$$

$$= \Big[$$  $$\Big].$$

Model parameters: $|g|^2$ and m^2 – bare



Effective range expansion

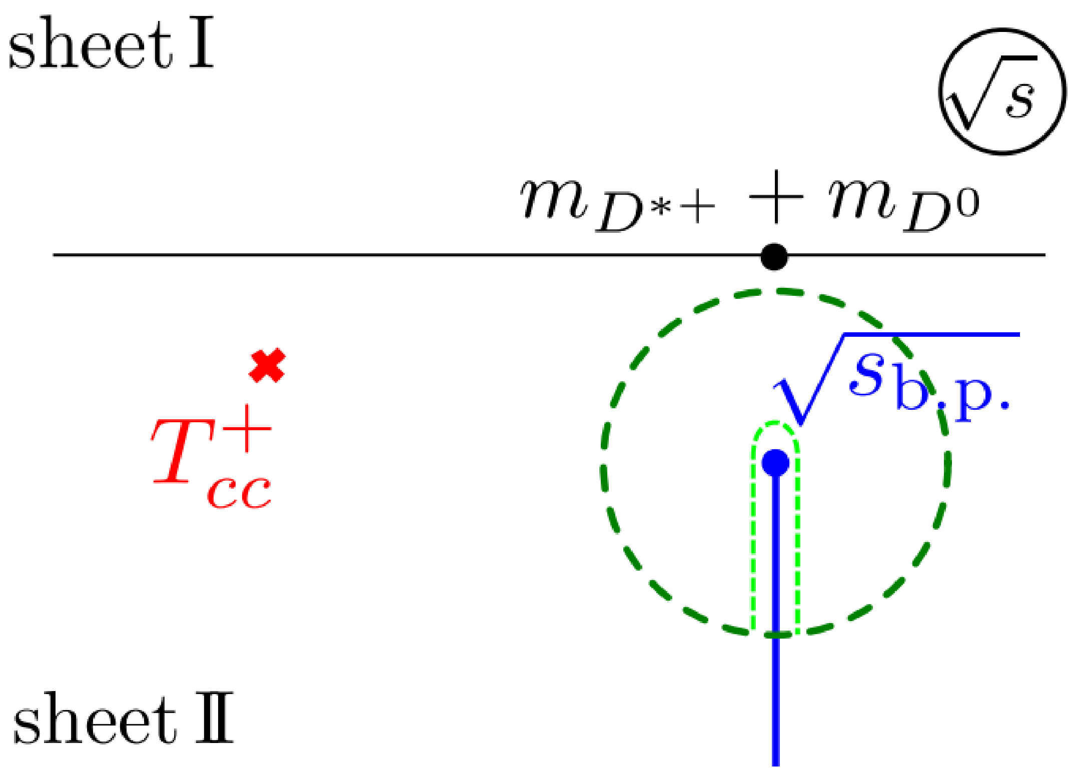
Expansion coefficients

$$k \cot \delta(k) = \frac{1}{a} + r\frac{k^2}{2} + O(a^3 k^4)$$

- k is a break-up momentum
- 1/a, r are coefficient in expansion

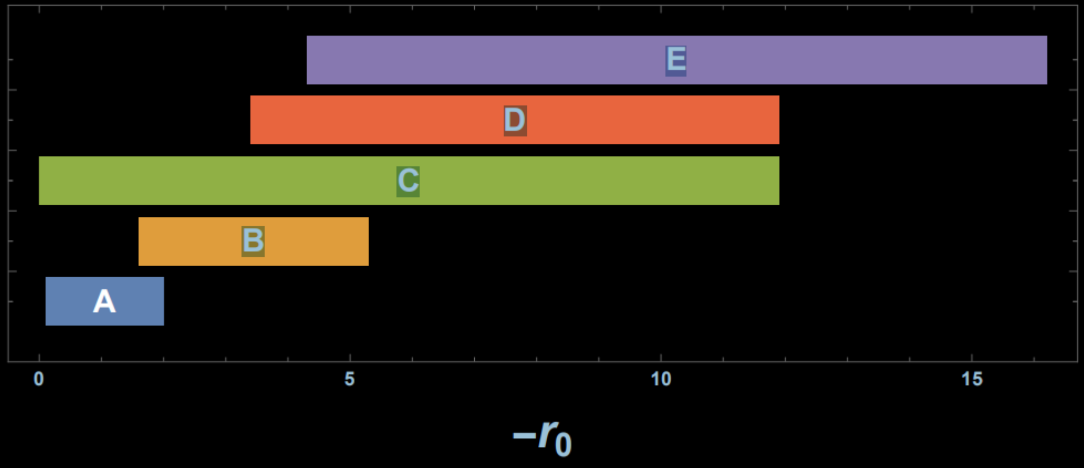
Can be done by computing derivatives of regular (k cot delta)

D* is unstable, complex branch point



Different values on Effective range discussion

[courtesy A.Polosa, HADRON 2023]



A: Baru et al., 2110.07484
B: Esposito et al., 2108.11413
C: LHCb, 2109.01056
D: Maiani & Pilloni GGI-Lects
E: Mikhasenko, 2203.04622

Scattering parameters (a,r) gives simplified description of the amplitude near threshold.

Scattering length is well constrained by the binding energy

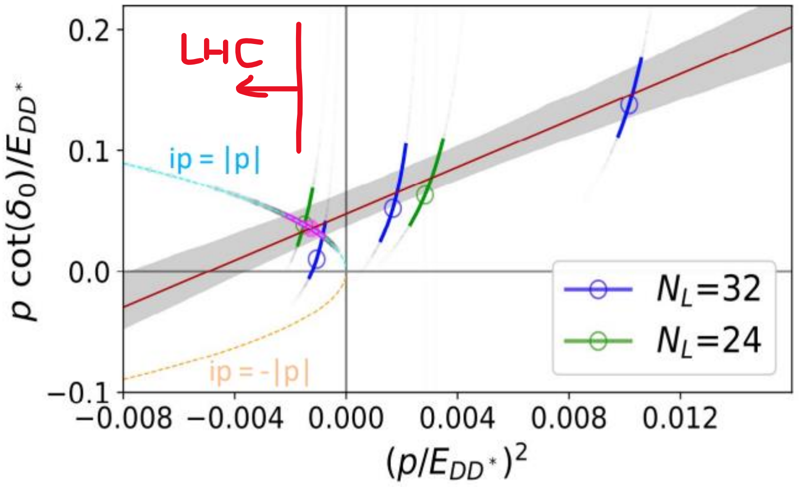
Limit is set in the effective range (related to the width)

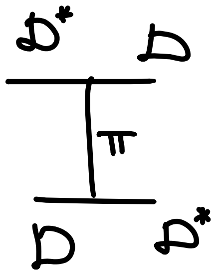
High Weinberg compositeness is obtained

T_{QQ} in Lattice: left hand cut

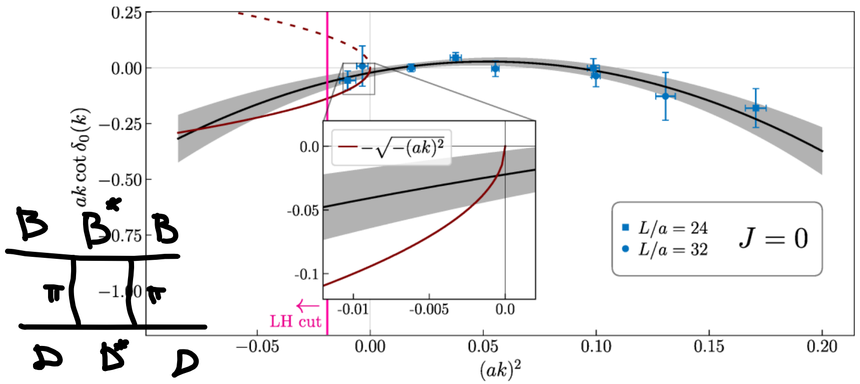
Tbc

Padmanath, SP: 2202.10110, PRL, $m_\pi \approx 280$ MeV

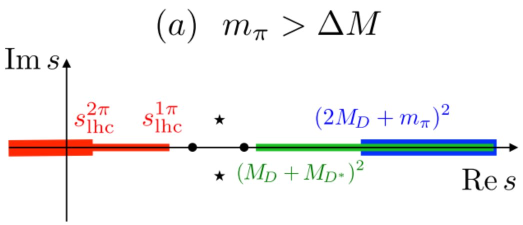


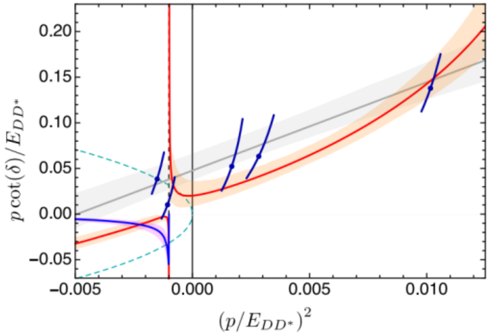


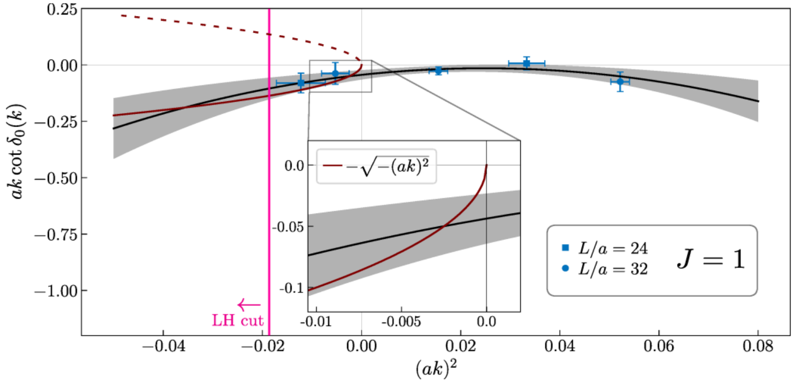
[Mark Wagner 2312.02925]



[Baru et al., 2303.09441]







Effective range expansion

Convergence of the expansion

Effective range expansion

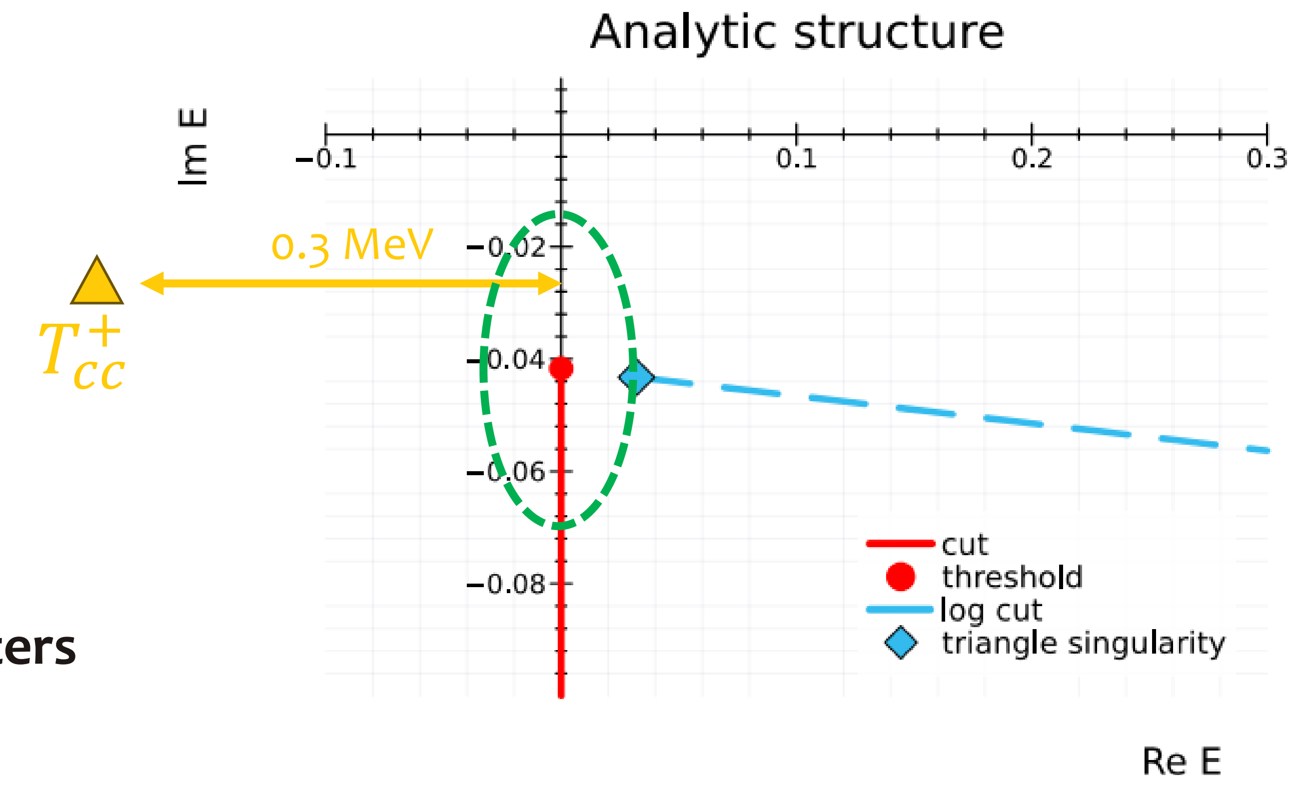
- **First observation:**

dependence of expansion parameters on radius of Cauchy integrals

- **Reason: log branch point nearby**
- **Convergence radius ~20keV**

- **Rethinking of the effective range parameters & Weinberg compositeness is needed**

Small radius of convergence



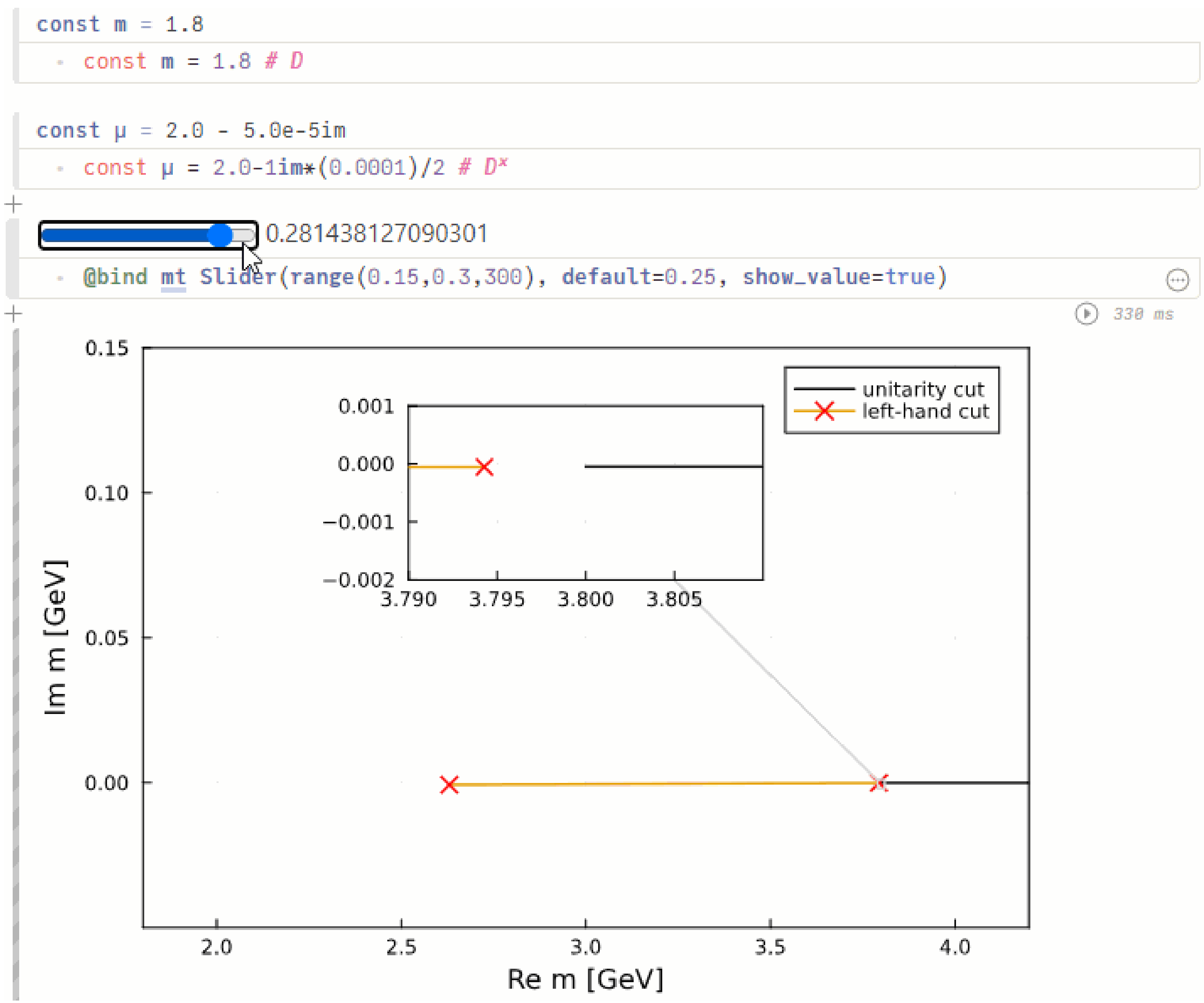
Triangle Singularity & LHC

Simple setup

- mD = 1.8
- mD*=2.0

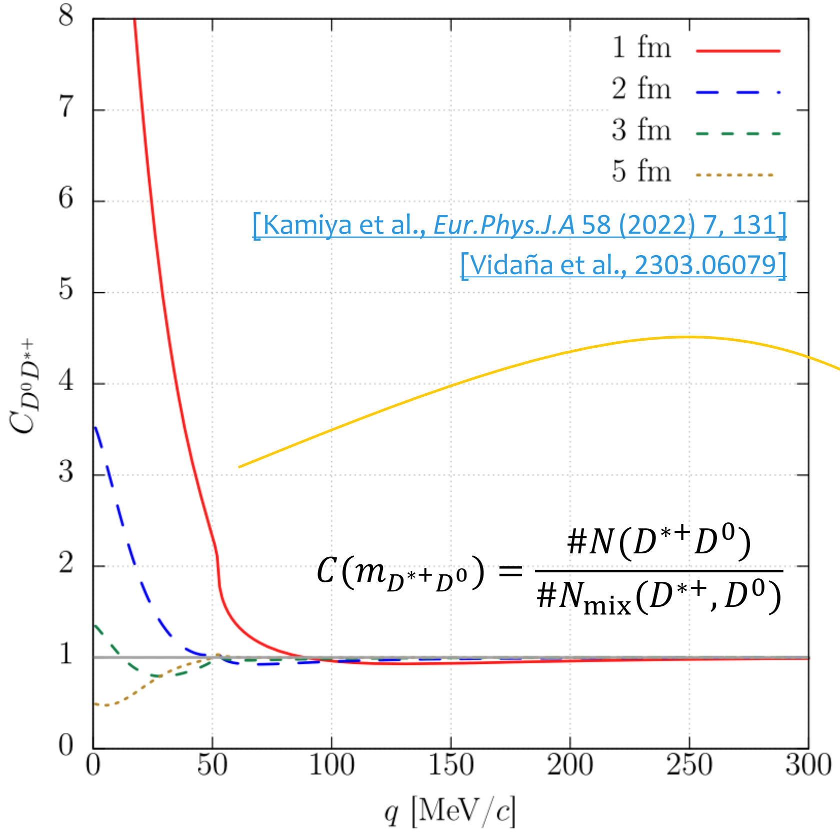
- Mass of pion is varied

- Red crosses – location of log branch points

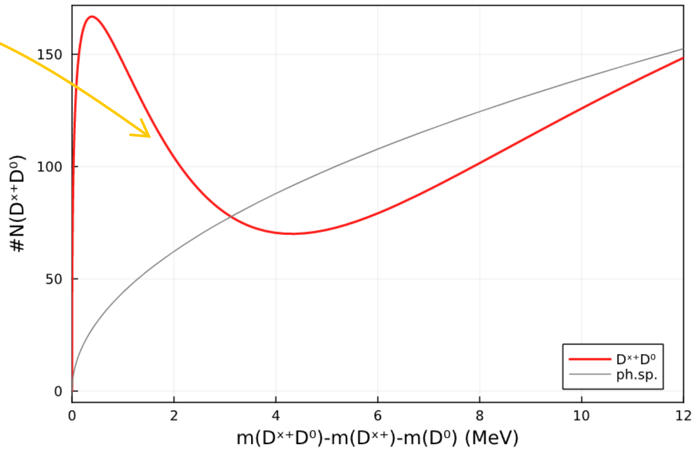


Femtoscopy and Unitarization

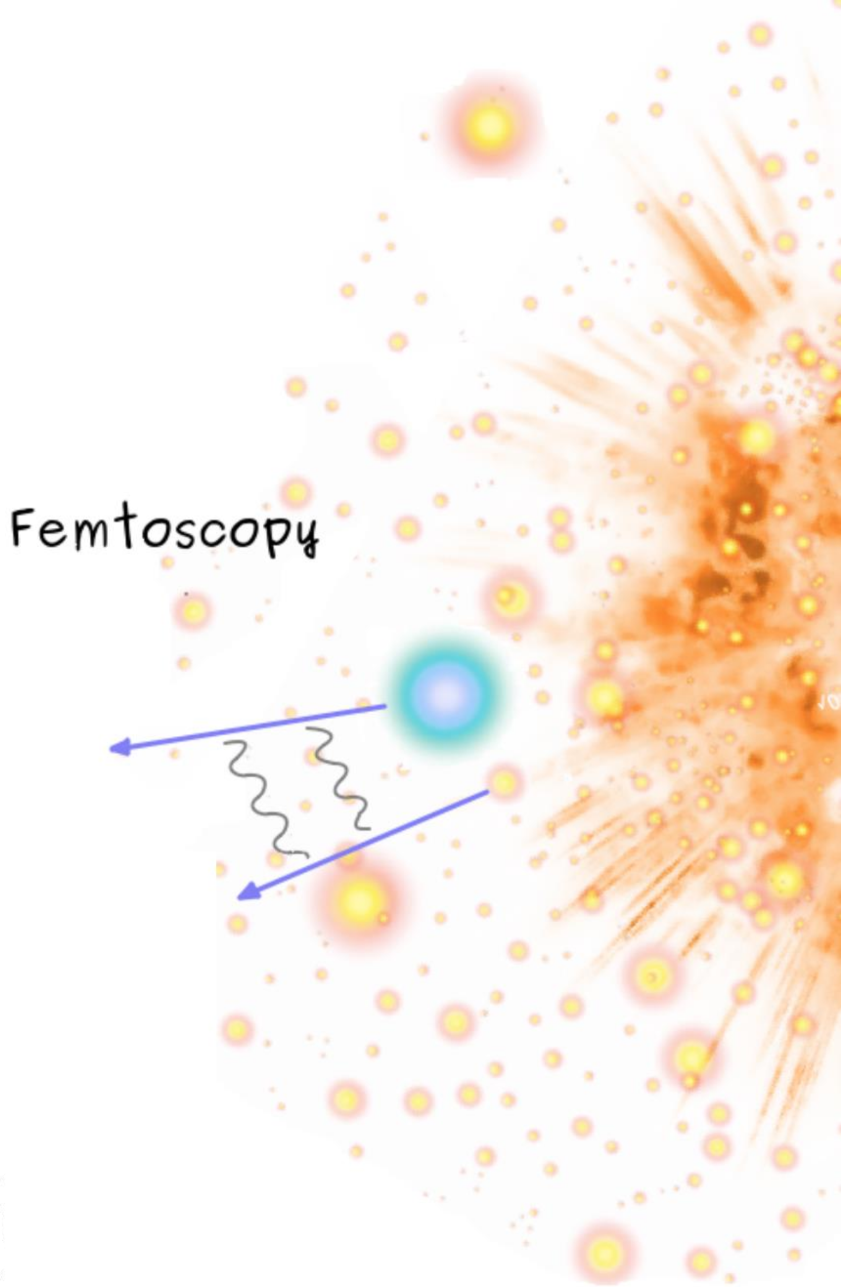
Tcc: discussion on production and femtoscopy



On-shell D^{*+}, D^0 produced independently may experience residual T_{cc}^{+}-interaction



[GitHub/mmikhasenko]



[Image credit Wioleta Rzęsa talk]

Basdevant Unitarization

Unitarization with background

$$T^u_D(M^2) = T_D(M^2) - \frac{1}{2i\pi} D(M^2) \int_{M_R{}^2}^{\infty} ds' \frac{\mathrm{disc}(D^{-1}(s'))T_D(s')}{(s'-M^2)} . \quad (3.5)$$

https://journals.aps.org/prd/pdf/10.1103/PhysRevD.16.657

Interference with spherical wave

$$C_{D^+D^{*0}}(p_{D^+}) = 1 + 4\pi\theta(q_{\max} - p_{D^+})\times \int_0^{+\infty} dr r^2 S_{12}(r)\left\{\left|j_0(p_{D^+}r) + T_{22}(E)\widetilde{G}^{(2)}(r;E)\right|^2 + \left|T_{12}(E)\widetilde{G}^{(1)}(r;E)\right|^2 - j_0^2(p_{D^+}r)\right\}$$

https://arxiv.org/pdf/2303.06079.pdf

Summary

Part1:

Effective range parameters can be mathematically well defined for three-body scattering

The convergence radius is small -- due to one-pion exchange singularity (Triangle singularity)

=> a,r do not reflect properties of T_{cc}

Part2:

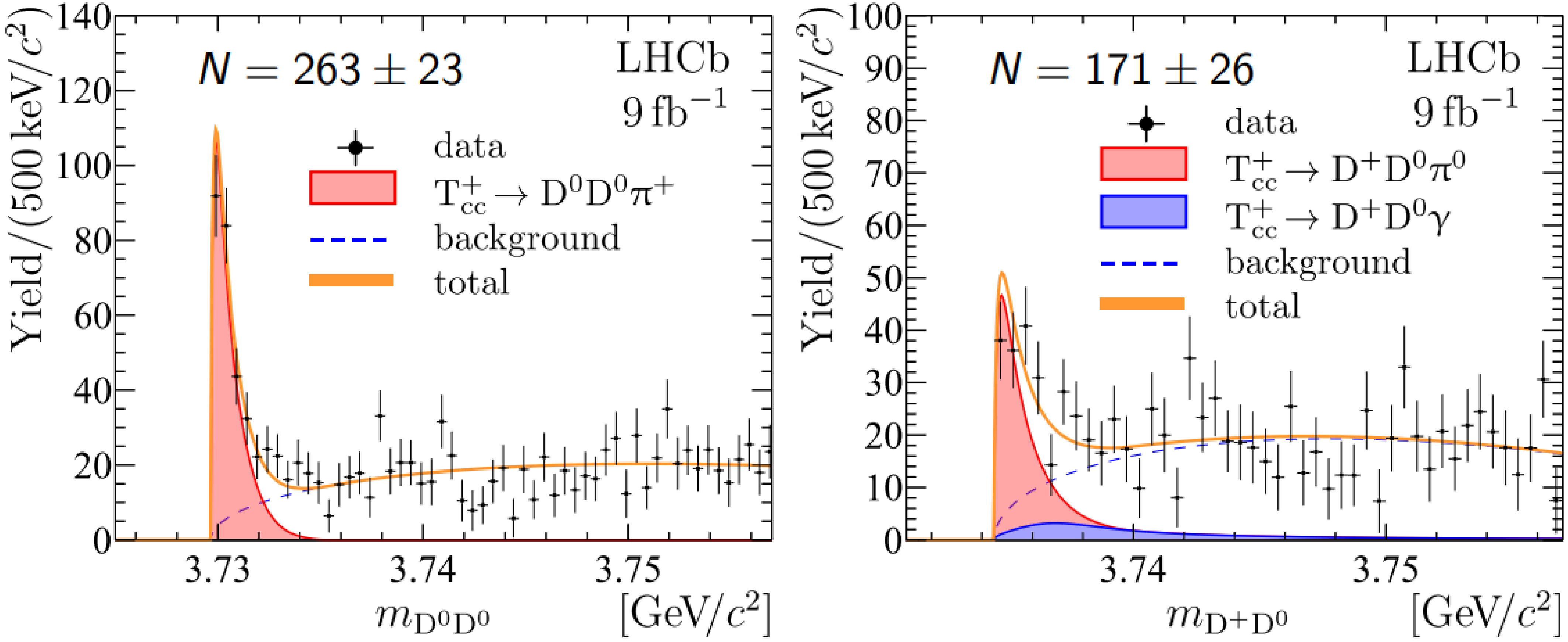
Approach to Femtoscopy & Dispersion Unitarization has similarities in physical picture and mathematical approach. Differences are also prominent:

- Inclusive vs Exclusive,
- Wave-functions vs S-matrix scattering

Clarification is needed.

Backup

Partially reconstructed T_{cc}^{+}



- Lineshape of D^0D^0 and D^0D^+ spectra are predicted well by the model
- Relative yeilds of D^0D^0 and D^0D^+ is in good agreement with the model predictions