Correlation function and the inverse problem in the BD interaction

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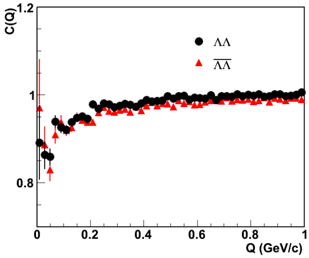
Based on:Chin.Phys.C 48 (2024) 5, 053107

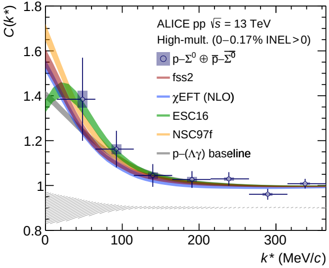
Outline

1. Background and motivation

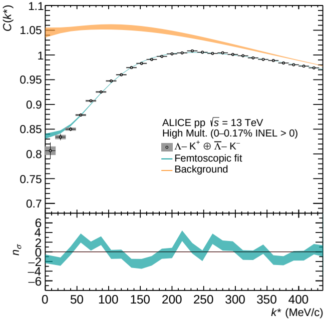
Increasing experimental data on correlation functions.



STAR /PRL 114 (2015)



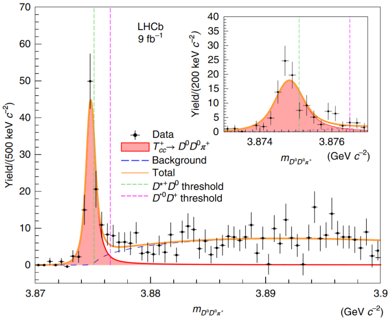
ALICE /PLB 805 (2020)



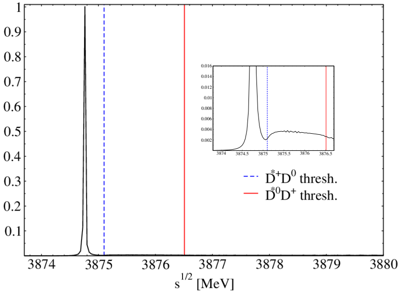
ALICE /PLB 845 (2023)

Studied D^*D and $B(B^*)D(D^*)$ interaction within the chiral unitary approach framework.

LHCb / NP 18 (2022) 7
$T_{cc}^+ \to D^0 D^0 \pi^+$



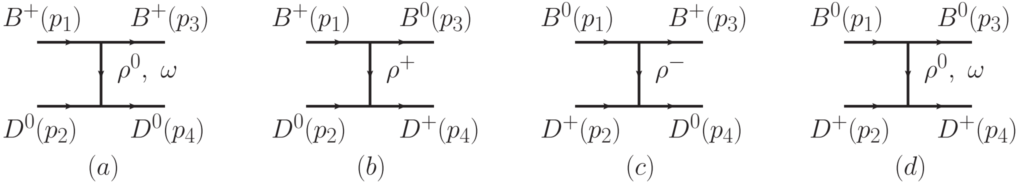
A. Feijoo , W.H. Liang , Eulogio Oset/ PRD 104 (2021)
$\Gamma(T_{cc} \to D^0 D^0 \pi^+)$



S. Sakai , L. Roca , E. Oset/ Phys.Rev.D 96 (2017) 5, 054023

	$I(J^P)$	$\sqrt{s_p}$	B	g	a [fm]
BD	$0(0^+)$	7133|7111	15|38	33484| 49867	-1.78|-1.45
B^*D	$0(1^+)$	7179|7156	15|38	33742| 50243	-1.78|-1.45
BD^*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Two coupled channels: D^0B^+, D^+B^0(without Coulomb interaction).



$$V_{ij} = -\frac{1}{4f^2}\, C_{ij}\, (p_1 + p_3)\cdot(p_2 + p_4); \quad f = 93\ \text{MeV}, \quad C = \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}.$$

This formalism is similar to that used for D^*D interaction.

Amplitude

$$T=[1-VG]^{-1}V,$$

$$G_i(\sqrt{s})=\int_{|\vec{q}|<q_{\rm max}}\frac{{\rm d}^3q}{(2\pi)^3}\,\frac{\omega_1(q)+\omega_2(q)}{2\,\omega_1(q)\,\omega_2(q)}\,\frac{1}{s-[\omega_1(q)+\omega_2(q)]^2+i\varepsilon},$$

$$\omega_1(q)=\sqrt{\vec{q}^{\,2}+m_i^2},\quad \omega_2(q)=\sqrt{\vec{q}^{\,2}+M_i^2}.$$

Only one free parameter $q_{\rm max}$,
used $q_{\rm max}=420$ MeV

Couplings

$$T_{ij}=\frac{g_i\,g_j}{s-s_p},$$

$$g_1^2=\lim_{s\to s_p}(s-s_p)\,T_{11},$$

$$g_1\,g_j=\lim_{s\to s_p}(s-s_p)\,T_{1j},$$

Probabilities and the wave function at the origin

$$\mathcal{P}_i = -g_i^2 \left.\frac{\partial G_i}{\partial s}\right|_{s=s_p} .$$

$$\psi_i(r=0) = g_i \, G_i|_{s=s_p} .$$

If $P_1 + P_2 = 1$,completely molecular

Observables

$$T = -8\pi\sqrt{s}\; f^{QM}$$
$$\simeq -8\pi\sqrt{s}\,\frac{1}{-\frac{1}{a}+\frac{1}{2}r_0k^2-ik},$$

$$-\frac{1}{a_i} = \left.\left(-8\pi\sqrt{s}\;T_{ii}^{-1}\right)\right|_{s_{\mathrm{th},i}} ,$$

$$r_{0,i} = \left[\frac{2\sqrt{s}}{\mu_i}\frac{\partial}{\partial s}\left(-8\pi\sqrt{s}\;T_{ii}^{-1}+ik_i\right)\right]_{s_{\mathrm{th},i}} ,$$

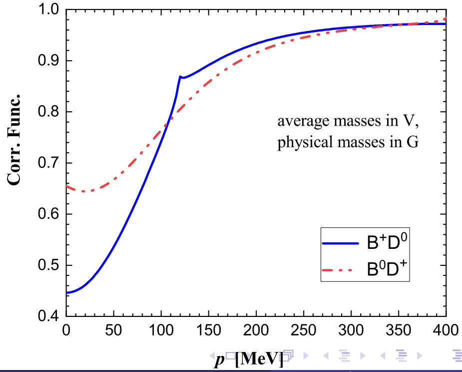
$$C_i(p) = 1 + 4\pi\theta(q_{\text{max}} - p)\int \mathrm{d}r^2 S_{12}(r)\Big\{\Big|j_0(pr) + T_{ii}(E)\tilde{G}^i(r,E)\Big|^2 + \sum_{j\neq i}\Big|T_{ij}(E)\tilde{G}^j(r,E)\Big|^2 - j_0^2(pr)\Big\}$$

$$\tilde{G}^{(i)}(r;E) = \int \frac{\mathrm{d}^3 q}{(2\pi)^3}\,\frac{\omega_1(q)+\omega_2(q)}{2\,\omega_1(q)\,\omega_2(q)}\,\frac{j_0(q\,r)}{s - [\omega_1(q)+\omega_2(q)]^2 + i\varepsilon}, \quad E = \sqrt{s},$$

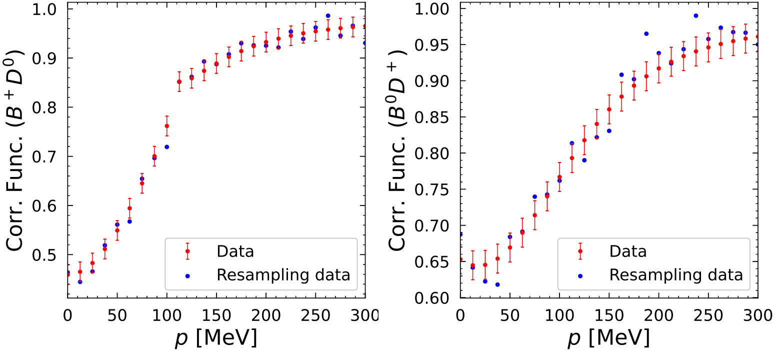
Source function

$$S_{12}(r) = \frac{1}{(\sqrt{4\pi}\,R)^3}\,e^{-(r^2/4R^2)},$$

$R = 1$ fm



Resampling



Resample 25 points for each channel for fitting, and run the process 50 times.

Assuming errors at the order of ± 0.02.

General framework

$$V = \begin{pmatrix} V_{11} & V_{12} \\ V_{12} & V_{22} \end{pmatrix},$$

considering isospin symmetric

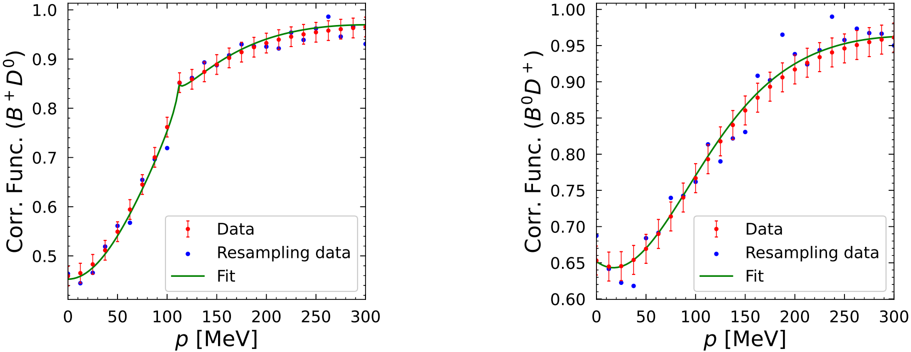
$$\langle BD, I=0|V|BD, I=1\rangle = \frac{1}{2}(V_{11}-V_{22}) = 0, \qquad \Rightarrow \qquad V_{22}=V_{11}.$$

$$V_{11} = V'_{11} + \frac{\alpha}{m_V^2}(s-s_{\mathrm{th},1}), \qquad V_{12} = V'_{12} + \frac{\beta}{m_V^2}(s-s_{\mathrm{th},1}), \qquad M_V = 800 \text{ MeV}$$

6 free parameters: V'_{11}, V'_{23}, α, β, q_{max} and R.

Average values and dispersion for the parameters.

V'_{11}	V'_{12}	α
-1537.54 ± 918.93	-1512.32 ± 913.55	-31.89 ± 10.00
β	$q_{\max}$ (MeV)	R (fm)
-165.16 ± 133.31	407.9 ± 60.8	1.01 ± 0.04



Fitting results: Average values and dispersion of the pole position and couplings. [in units of MeV]

$\sqrt{s_p}$	$g_1(D^0B^+)$	$g_2(D^+B^0)$
7107.84 ± 17.79	34623.08 ± 14300.15	34506.64 ± 14304.57

Theoretical results: Pole position and couplings with $q_{\max} = 420$ MeV. [in units of MeV]

$\sqrt{s_p}$	$g_1(D^0B^+)$	$g_2(D^+B^0)$
$(7110.41 + 0i)$	31636.8	31631.0

Fitting results: Average value and dispersion for the probability $\mathcal{P}_i$ and wave function at the origin $\psi_i(r=0)$ for channel i.

$\mathcal{P}_1(D^0B^+)$	$\mathcal{P}_2(D^+B^0)$	$\psi_1(r=0)$	$\psi_2(r=0)$
0.49 ± 0.03	0.42 ± 0.03	-13.61 ± 2.65	-12.61 ± 2.423

$$\mathcal{P}_1 + \mathcal{P}_2 = 0.91$$

Theoretical results: Probability $\mathcal{P}_i$ and wave function at the origin $\psi_i(r=0)$ for channel i.

$\mathcal{P}_1(D^0B^+)$	$\mathcal{P}_2(D^+B^0)$	$\psi_1(r=0)$	$\psi_2(r=0)$
0.52	0.44	-14.75	-13.61

$$\mathcal{P}_1 + \mathcal{P}_2 = 0.96$$

Fitting results: Average value and dispersion for scattering length a_i and effective range r_i for channel i. [in units of fm]

$a_1(D^0B^+)$	$a_2(D^+B^0)$
0.72 ± 0.03	$(0.51 \pm 0.02) - (0.17 \pm 0.01)i$
r_1	r_2
-0.61 ± 0.19	$(1.41 \pm 0.28) - (1.65 \pm 0.07)i$

Theoretical results: Scattering length a_i and effective range r_i for channel i. [in units of fm]

a_1	a_2	r_1	r_2
0.71	$0.50 - 0.16i$	-0.61	$1.22 - 1.77i$

- Studied BD interaction within the chiral unitary approach framework and obtained a bound state at $7110\ \mathrm{MeV}$, indicating a fully molecular state.
- Studied the inverse problem of obtaining observables from correlation functions. The correlation functions contain information below the threshold and can serve as a useful tool for studying hadron interactions.

Thank You!