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Possibilities of detecting the DD* dimesons at Belle2

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Abstract. The double charm dimeson DD* represents a very interesting four-body problem since it is a delicate superposition of a molecular (dimeson) and an atomic (tetraquark) configuration. It is expected to be either weakly bound or a low resonance, depending on the model. Therefore it is a sensitive test how similar are the effective quark-quark interactions between heavy quarks and light quarks.

After the discovery of the $\Xi_{cc}^{+} =$ ccd baryon at LHCb, there is a revived interest for the search of the double charm dimesons. There is, however, no such clear production and decay process available as it was for Ξ_{cc}^{+}. Therefore we argue that it is, compared to LHCb, a better chance for the discovery of the DD* dimeson at the upgraded Belle-2 at KEK (Tsukuba, Japan) after 2019.

1 Introduction

While the BB* dimeson (tetraquark) is expected to be strongly bound (>100 MeV) due to the smaller kinetic energy of the heavy quarks, the DD* dimeson is expected to be weakly bound (possibly at ~2 MeV) or a low resonance, depending on the model. Therefore it is a sensitive test of the effective quark-quark and quark-antiquark interactions. For example, can we assume Vuu = Vcu = Vcc = Vc$\bar{u}$ (apart from mass dependence of spin-dependent terms)?

There is no such clear production and detection process available for the DD* intermediate state as it was for Ξ_{cc}^{+} which was recently discovered at LHCb analysing the resonant decay to $\Lambda_c^+ K^- \pi + \pi +$ where the Λ_c^+ baryon was reconstructed in the decay mode $pK^-\pi^+$.

Therefore we have started a study which production mechanism could enable the discovery of the DD* dimeson at the upgraded Belle-2 at KEK (Tsukuba, Japan) after 2019. For the time being, we summarize our old calculations of the DD* binding energy [1] and explain several tricky features of this interesting four-body system.

2 Comparison of charmed dimesons with the hydrogen molecule

It is interesting to compare the molecule of two heavy (charmed) mesons with the hydrogen molecule. At short distance, the two protons in the hydrogen molecule are repelled by the electrostatic interaction, while the two heavy (charm) quarks in the mesonic molecule are attracted by the chromodynamic interaction because they can recouple their colour charges.

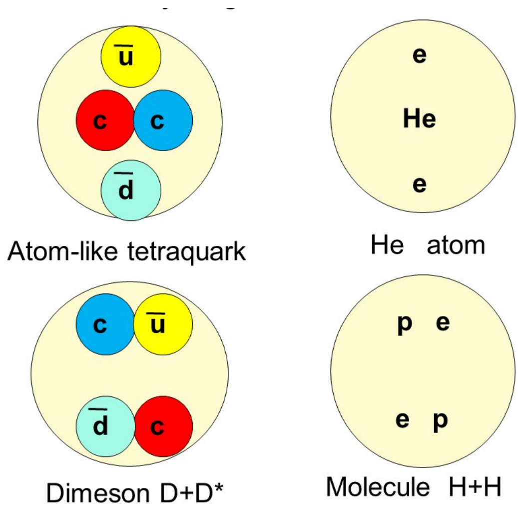

Fig. 1. Difference between atom-like and molecular configurations

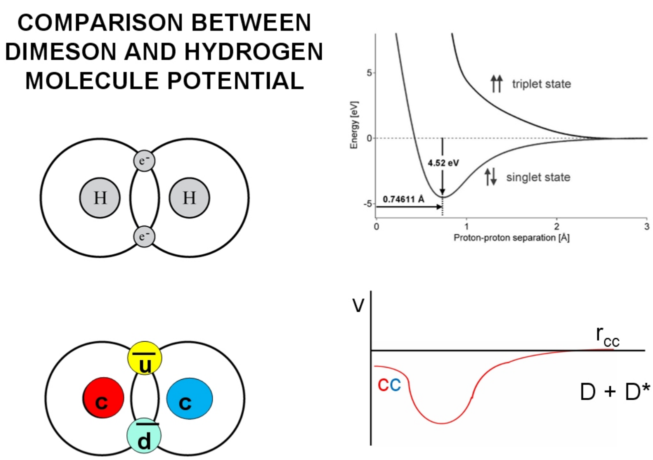

Fig. 2.

3 Is the D+D* dimeson bound?

In the restricted 4-body space assuming ”cc” in a bound diquark state and the u and d quarks in a general wavefunction, the energy is above the D+D* threshold. In the restricted ”molecular” 4-body space with the two c quarks far apart and a general wavefunction of $\bar{u}$ and $\bar{d}$ (as assumed by several authors), the energy is also above the D+D* threshold. Only combining both spaces (we took a rich 4-body space) brings the energy below the threshold. We should verify whether it happens also for other interactions (we have used the one-gluon exchange+linear confinement [1]).

We failed to calculate the energy of the hidden charm (charmonium-like) meson X(3872) using the same method and interaction as for DD* [2]. The reason is that a perfect variational calculation in a rather complete 4-body space finds the absolute minimum of energy which corresponds to J/psi+eta rather than $D\bar{D}*$. A demanding coupled channel calculation would be needed for a reliable result, and we have postponed it.

It is an interesting question whether in the first step ”cc” diquark is formed and later automatically dressed by u or d or $\bar{u}$ and $\bar{d}$, or is the first step to form D + D* which merge into DD*. The later choice can profit from resonance formation, but due to the dense environment it is a danger that the D + D* system would again dissociate before really forming the dimeson. We intend to see which formalism would be appropriate for this.

The dressing (fragmentation) of the **b** quark

b ⟶	B^-	= $b\bar{u}$	.....	0.375±0.015
	B^0	= $b\bar{d}$	.....	0.375±0.015
	B_s	= $b\bar{s}$	.....	0.160±0.025
	Λ_b	= bud	.....	0.090±0.028

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The dressing (fragmentation) of the **cc** diquark

cc ⟶	Ξ_{cc}^{++}	= ccu	.....	37 %
	Ξ_{cc}^{+}	= ccd	.....	37 %
	Ω_{cc}^{+}	= ccs	.....	16 %
	T_{cc}^{+}	=$cc\bar{u}\bar{d}$	.....	9 %

Fig. 3. The estimated probability of formation of the atomic tetraquark configuration compared to the Ξ_{cc} production

Once the ”cc” diquark is formed, it is probably dressed with one light quark into the Ξ_{cc} baryon and only with about 9% probability into the ”atomic” $(cc)\bar{u}\bar{d}$ configuration. We have estimated this probability by analogy with the dressing of the b quark [3] into the Λ_b baryon compared to the production of B mesons (fig. 3). This percentage is further reduced by the evolution of the ”atomic” configuration $(cc)\bar{u}\bar{d}$ into the ”molecular” configuration of DD*.

4 The decay of the DD* dimeson

The DD* dimeson is stable against a two-body decay into D+D due to its quantum numbers I=0, J=1. It can decay, however, strongly in D+D+π, or electromagnetically in D+D+γ, via the decay of D*. The strong decay is very slow (comparable to the electromagnetic decay) due to the extremely small phase space for the pion. Therefore, the DD* dimeson is "almost stable" and very suitable for detection.

We are looking for convenient methods of detection. One possibility is related to the small phase space of the pionic decay [1] (fig. 4). The ratio between the pionic and gamma decay will strongly depend on the binding or resonance energy of the dimeson.

Alternative suggestions are needed in order to have a reliable signature or tagging. We encourage the reader to come forth with new ideas!

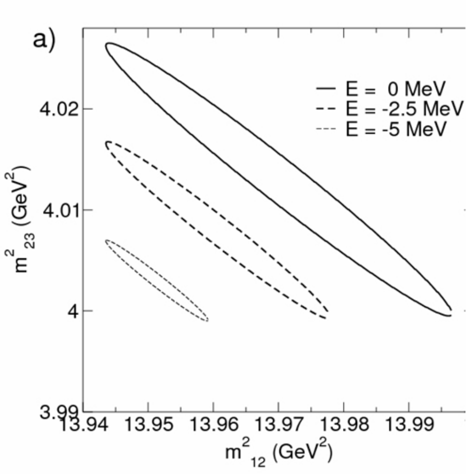

Fig. 4. Dalitz plot for the DD* decay depending on the binding or resonance energy; the area of the contours is proportional to the decay probability into pion

5 Conclusion

Considering a rather large production cross section of double $c\bar{c}$ pairs at Belle, we expect a sufficient production rate of **cc** diquarks which get dressed by a light quark into a Ξ_{cc} baryon. Once this expectation is verified, it is promising to search for the DD* dimesons, especially if they proceed via $cc + \bar{u} + \bar{d} \to (c\bar{u})(c\bar{d})$.

The motivation is twofold.

- Since the DD* dimeson is a delicate system, it is barely bound or barely unbound, it would distinguish between different models.
- Its production rate might help to understand the mechanism of the high production rate of double $c\bar{c}$ pairs at Belle.

Work is in progress to study different production and decay mechanisms in order to find a tell-tale signature in the decay products.

References

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