BLED WORKSHOPS
IN PHYSICS
VOL. 19, NO. 1
*p. 41*

*Proceedings of the Mini-Workshop*
***Double-charm baryons and dimesons***
Bled, Slovenia, June 17 - 23, 2018

# Double charm baryons and dimesons

Mitja Rosina

Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, P.O. Box 2964, 1001 Ljubljana, Slovenia
and J. Stefan Institute, 1000 Ljubljana, Slovenia

**Abstract.** Several constituent quark models more or less agree in the descripton of baryons and mesons. They may, however, largely disagree in their predictions for dimesons (tetraquarks). The cleanest systems may be ccud = DD* and bbud = (bb)ud. In view of Belle II experiments (at KEK, Japan) in near future, it is of interest to study the DD* dimeson, in order to gain some understanding of the production and detection mechanism and to give some guidance to experimentalists.

## 1 Introduction

There is a strong motivation to verify whether we are capable to extrapolate our experience in QCD from baryons and mesons to many-quark systems. At the level of model-making, it is of interest to look at dimesons (tetraquarks), pentaquarks and dibaryons (hexaquarks). It is important to check whether we may use the same effective quark-quark interaction (apart from the colour factor and the mass-dependent spin-spin term) Vuu = Vcu = Vcc = $V c\bar{c}$ = Vbu = Vbb = $V b\bar{b}$.

The obvious system worth studying is the DD* system which is expected to be either a weakly bound "molecule" or a low-lying resonance. It is relatively long-lived since it decays only electromagnetically ($D^* \to D\gamma$) or strongly with extremely small phase space ($D^* \to D\pi$). Note that the DD system is a bad candidate since D+D repel each other and no bound state forms.

After the discovery of the $\Xi_{cc}^{++} = ccu$ baryon at LHCb, there is a revived interest for the search of the double charm dimesons. The production mechanism might be similar, but the detection of dimesons is more difficult. For the double charm baryon, they analysed the resonant decay $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi + \pi +$ where the $\Lambda$ baryon was reconstructed in the decay mode $\Lambda_c^+ \to p K^- \pi^+$. There is no such clear production and detection process available for the DD* intermediate state and it is a great challenge to find a mesurable signature for this dimeson.

## 2 The binding energy of the $\Xi_{cc}^{++}$ baryon

There is a controversy regarding the mass of the double charm baryon. The better documented value of $\Xi_{cc}^{++}$ from LHCb is 3621 MeV while the SELEX value 3519

MeV of $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi +$ is met with some scepticism. It would be good to find out whether these are two different states, or SELEX is wrong.

We made a phenomenological estimate using a diquark-quark model and the analogy with mesons (fig.1). Regarding colour quantum number, the diquark in an antisymmetric colour state behaves just as an antiquark. We took a nonrelativistic potential model with a one-gluon-exchange + confining potential with the "Grenoble parameters AL1" [1] which reproduce rather well most baryons and mesons, in particular also $J/\psi$, the analogon of cc. We get for the mass of the cc diquark 3500 MeV.

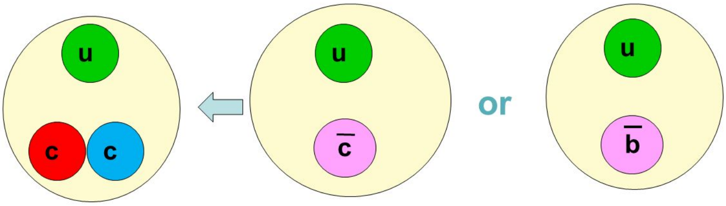

**Fig. 1.** The comparison of the $\Xi_{cc}^{++}$ baryon with the $\bar{D}^0$ and $B^+$ mesons

Using $m(c)$=1870 MeV, $m(\bar{D}^0)$=1865 MeV, $m(b))$ = 5259 MeV and $m(B^+)$=5279 MeV we get

$$m(\Xi_{cc}^{++}) = m(\bar{D}^0) - m(c) + m(cc) = 3495 \text{ MeV}$$

or

$$m(\Xi_{cc}^{++}) = m(B^+) - m(b) + m(cc) = 3520 \text{ MeV} .$$

At face value, the latter estimate is very close to the SELEX value. However, the finite size of the diquark and the extra Coulomb repulsion will raise the mass, possibly close to the LHCb value.

Let me quote also other results.

Plessas - the Graz group [2] - obtained with the "Universal constituent quark model for all baryons" (relativistic kinetic energy and a one-Goldston-boson-exchange interaction for the 24-plet + singlet with 5 flavours) the $\Xi_{cc}^{++}$ mass 3642 MeV.

The Lattice QCD result [3] is also around 3600 MeV.

## 3 The binding energy of the D+D* dimeson

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 $\bar{d}$ the energy is also above the D+D* threshold. Only combining both spaces brings the energy below the threshold.

In the nonrelativistic calculation of Janc and Rosina [4] the one-gluon exchange potential (including the chromomagnetic term) + the linear confining potential was used. The model parameters (Grenoble AL1) [1] fitted all relevant mesons and baryons.

A rich 4-body space was used (an s-state Gaussian expansion at optimized distances, with 3 types of Jacobi coordinates in order to mimic also the p-states. The binding energy (DD*) - (D + D*) = - 2.7 MeV was obtained. This is encouraging, but we have to explore in future, what happens with other interactions and whether the pion cloud between the u and d antiquarks can increase binding, in analogy with the deuteron.

## 4 The formation and decay of the DD* dimeson

There are two possible mechanism for the formation of the dimeson:

1. In the first step the cc-diquark is formed and later automatically dressed by $\bar{u} + \bar{d}$ (or u or d or s in the case of $\Xi_{cc}$ and $\Omega_{cc}$). We have estimated the relative probability of forming ccu or ccd or ccs or the "atomic" configuration $cc\bar{u}\bar{d}$ by analogy with the dressing of the b quark into $B^+$, $B^0$, $B_s^0$ and the $\Lambda_b$ baryon determined experimentally in ref. [5]. Initially the relative probability of forming $(cc)\bar{u}\bar{d}$ is about 9% which is about 1/4 probability with respect to $\Xi_{cc}^{++}$ (table 1). Quite a lot! However, this percentage is further reduced by the evolution of the "atomic" configuration $(cc)\bar{u}\bar{d}$ into the "molecular" configuration of DD*. Mind that the atomic configuration is almost 100 MeV above the D + D* threshold and would decay mostly into two free mesons. The question remains, whether it will decay copiously enough through the DD* bound state or resonance which we are searching for.

**Table 1.** The estimated probability of formation of the tetraquark configuration $cc\,\bar{u}\bar{d}$

| | | | | | |
|---|---|---|---|---|---|
| b → | $B^- = b\bar{u}$ | 0.375±0.015 | cc → | $\Xi_{cc}^{++}$ = ccu | 37% |
| | $B^0 = b\bar{d}$ | 0.375±0.015 | | $\Xi_{cc}^{+}$ = ccd | 37% |
| | $B_s = b\bar{s}$ | 0.160±0.025 | | $\Omega_{cc}^{+}$ = ccs | 16% |
| | $\Lambda_b$ = bud | 0.090±0.028 | | $T_{cc}^{+} = cc\,\bar{u}\bar{d}$ | 9% |

2. In the first step two separate mesons D and D* are formed and then they merge into the DD* dimeson. This process might profit from resonance formation, but due to the dense environement there is a danger that the D + D* system would dissociate before forming the dimeson. The question remains how to distinguish these two mechanisms by analysing the decay products.

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+$\pi$, or electromagnetically in D+D+$\gamma$, 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.

One possibility of detection related to the small phase space of the pionic decay has been proposed by Janc [4, 6]. The ratio between the pionic and gamma decay will strongly depend on the binding or resonance energy of the dimeson. For binding energy more than about 5 MeV there will be only $\gamma$ decay. But there will be a strong background due to the decay of free B* and some kinematical analysis is needed to distinguish it.

## 5 Conclusion

More work is needed to predict theoretically the mechanism of formation of the DD* dimeson and to suggest to experimentalists a reliable signature or tagging.

## References

1. B. Silvestre-Brac, Few-Body Systems **20** (1996) 11.
2. W.Plessas, these Proceedings.
3. Padmanath Madanagopalan et al., Phys.Rev.D **91** (2015) 094502.
4. D. Janc and M. Rosina, Few-Body Systems **35** (2004) 175-196; also available at arXiv:hep-ph/0405208v2.
5. T. Affolder et al. (CDF Collaboration), Phys. Rev. Lett. **84** (2000) 1663.
6. M. Rosina and D. Janc, Bled Workshops in Physics **5**, No. 1 (2004) 74; also available at http://www-f1.ijs.si/BledPub.
7. M. Rosina, Bled Workshops in Physics **18**, No. 1 (2017) 82; also available at http://www-f1.ijs.si/BledPub.