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Double-charm baryons : Possible multiquarks states containing heavy quarks

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Multicharm and multiquark states

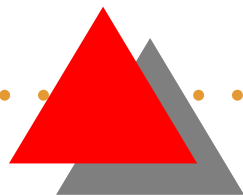
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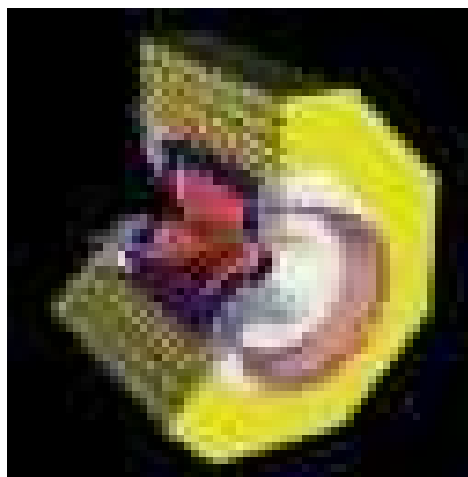
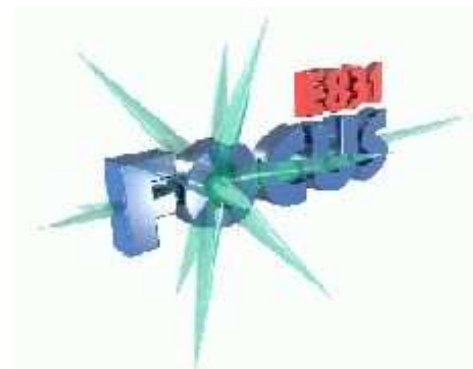
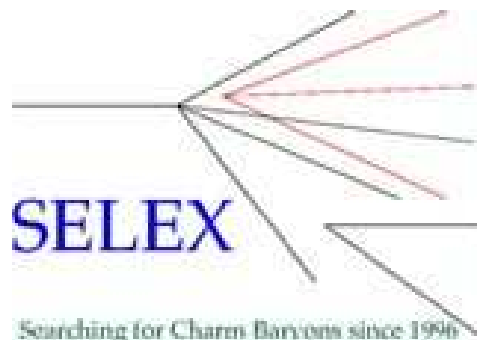
53, avenue des Martyrs, F-38026 Grenoble Cedex, France



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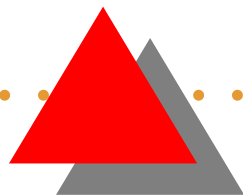
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Outline

- Double-charm baryons
- Brief survey of multiquark candidates
- Tetraquarks with hidden or naked charm
- not covered here: weak decays of double charm



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Single-charm baryons (as quark-diquark?)

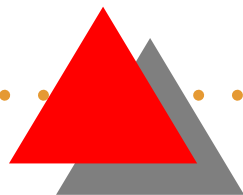


Single-charm baryons-2

Qqq states tentatively described in a variety of models:
potential, bags, etc.

Many data in recent years on ground and excited states with
 $S = 0$, $S = -1$ and $S = -2$. Minor problems, e.g., isospin
splittings.

Note: Hierarchy of lifetimes OK
but the spread of values is larger than expected.



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Spectroscopy of QQq baryons

Probably the **most interesting** among **ordinary** hadrons to study confinement dynamics.

It combines:

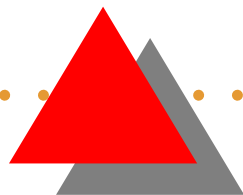
the slow $Q - Q$ relative motion, as in quarkonia

the relativistic q motion, as in D 's and B 's.

Two main strategies:

- diquark–quark
- Born– Oppenheimer

The **first** excitations are mainly in $Q - Q$.



Diquark–quark picture

For sure $Q - Q$ clustering inside QQq .

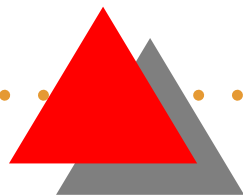
Two steps strategy:

1. Calculate QQ
2. Calculate $[QQ] - q$

Step #2 is O.K. But in step #1, care that $V(QQ)$ is effective.

In the H.O. model, $V = K(r_{12}^2 + r_{23}^2 + r_{31}^2)$ is **exactly**
 $V = 3/2 K r_{QQ}^2 + 2K r_{q-[QQ]}^2$. So 1/3 of QQQ interaction
comes from the q field.

Similarly, in H_2^+ , the $p - p$ force comes from the electron.

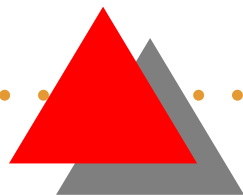


Born–Oppenheimer

Theorem: *The Born–Oppenheimer approximation works always **better** than expected.*

See, e.g., Fleck and R. (PTP, 1989). Two steps:

1. **Freeze out** r_{QQ} . Calculate the “electronic energy”, i.e. the energy of q in the 2-centre problem.
2. $V_{\text{eff}}(QQ) = \text{this energy} + \text{direct } Q - Q$.
Then **solve the** $Q - Q$ problem



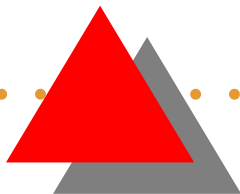
Results

Variants of the **bag model** also tried. Not very stable v.s. parameter changes.

Results of **potential models** rather **stable** vs. choice of potential

Typically:

- ccq ground-state near 3.6 GeV
- hyperfine splitting about 80 MeV
- orbital excitation about 300 MeV
- flavour excitation (ccs) – (ccd) near 90 MeV.





Inequalities

Under reasonable assumptions, (See Lieb, Martin et al.,
Nussinov)

flavour independence implies

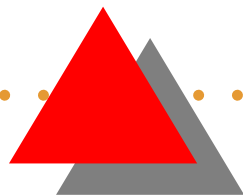
$$\mathcal{M}(M, M, m) \leq 2\mathcal{M}(M, m, m) - \mathcal{M}(m, m, m) ,$$

relating ccq to cqq and qqq , leading to a potential-independent

$$\mathcal{M}(ccq) \leq 3.7 \text{ GeV}$$

for the average of the hyperfine multiplet. Can be refined. Also

$q \rightarrow s$.





Towards a better calculation

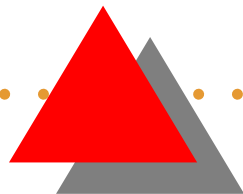
Stancu (Liege) + R. (project). Help welcome.

Use the **Born–Oppenheimer approximation**,
with a **better** treatment of light quark dynamics for fixed r_{QQ} ,
e.g.,

- lattice QCD a
- relativistic equation probed for D mesons

Progress expected.

^aA direct lattice study (without Born–Oppenheimer) recently published by Flynn et al., UKQCD



Multiquarks: 1. Possibly related to our discussion

- many scalar mesons $\rightarrow qq\bar{q}\bar{q}$?
- including perhaps $I = 2$ exotics
- Light pentaquark $S = +1$ seen in several experiments
- $D_{s,J}^*$ possibly a kind of multiquark

17) **HINTS FOR A $I = 2$ $\pi\pi$ RESONANT STATE IN THE ANTI- $n p \rightarrow \pi^+ \pi^+ \pi^-$ ANNIHILATION REACTION.**

By OBELIX Collaboration (A. Filippi *for the collaboration*). 2001.

Prepared for Biennial Conference on Low-Energy Antiproton Physics (LEAP 2000), Venice, Italy, 26 Aug 2000.

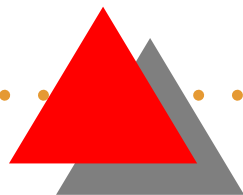
Published in **Nucl.Phys.A692:287-294,2001**

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Multiquarks: 2. H

Jaffe: H ($uuddss$) 150 MeV below $\Lambda\Lambda$ threshold

Due to chromomagnetic forces (or bag model analogue)

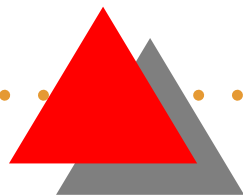
$$-g \sum_{i < j} \frac{\tilde{\lambda}_i \cdot \tilde{\lambda}_j \sigma_i \cdot \sigma_j}{m_i m_j} \delta^{(3)}(\mathbf{r}_{ij})$$

$SU(3)_F$ breaking

Hardly survives: Other terms in the Hamiltonian

A realistic $\langle \delta^{(3)}(\mathbf{r}_{ij}) \rangle$

H search in many exp., e.g., ${}_{\Lambda\Lambda}^6\text{He} \rightarrow H + \alpha$ not seen.



Multiquarks: 3. Heavy pentaquark P

P Proposed by Gignoux et al. and by Lipkin (1987)

$P = \bar{Q}qqqq$ with $qqqq = uud s, udds$ or $udss$.

150 MeV below $D + \Lambda$ threshold?

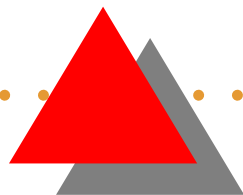
Also due to chromomagnetic forces

$$M(Q) < \infty$$

Binding suffers from:

- $SU(3)_F$ breaking
- Other terms in Hamiltonian
- A realistic $\langle \delta^{(3)}(r_{ij}) \rangle$

P search at Fermilab (Ashery et al.). Next: Compass



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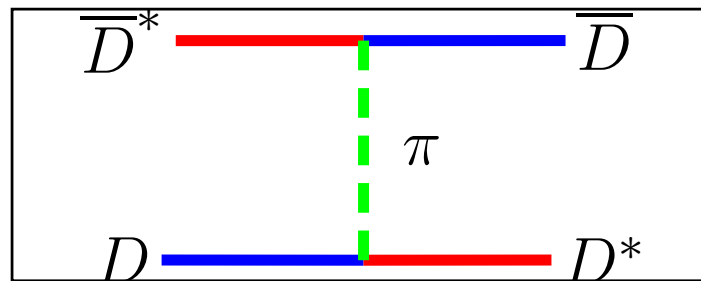


4. Hidden-charm tetraquarks $Q\bar{Q}q\bar{q}$

Cf. Belle state at 3.8 GeV

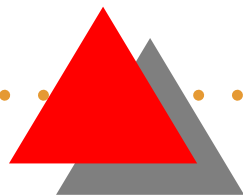
Already proposed for $\Psi(4.03)$, which turned out to be $c\bar{c}$

A long history, see Okun, Voloshin, De Rujula et al.,
Törnqvist, Manohar and Wise, Ericson and Karl, etc.



Yukawa potential $V = -g \exp(-\mu r)/r$, g weaker than for NN , but mg OK. $D\bar{D}^*$ nearly bound. $B\bar{B}^*$ probably.

Short range interaction? (repulsive?)



5. Double-charm tetraquarks $QQ\bar{q}\bar{q}$

$QQ\bar{q}\bar{q}$ studied in **quark model** or **lattice** by Ader et al. (then at CERN), Heller et al. (Los Alamos), Zouzou et al. (Grenoble), Lipkin (Argonne), Silvestre-Brac et al. (Grenoble), Brink and Stancu (ECT*, Trento), Rosina et al. (Slovenia), Michael et al. (UKQCD), etc., See, also, T. Barnes.(Oak Ridge), Nussinov

All agree! **stable**, i.e., below the threshold $(Q\bar{q}) + (Q\bar{q})$, if M/m large enough.



$QQ\bar{q}\bar{q}$ (Cont.)

This is a chromoelectric effect. In a flavour-independent potential, heavy particles enjoy more binding.

If flavour independence is taken seriously, even for light quarks, then close analogy with

$\text{Ps}_2(e^+, e^+, e^-, e^-)$ weakly b.

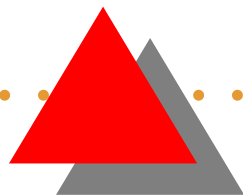
atomic physics: $\text{H}_2(p, p, e^-, e^-)$ more deeply b.

$\text{H}\bar{\text{H}}(p, e^+, \bar{p}, e^-)$ unstable

$(qq\bar{q}\bar{q})$ unbound

In simple quark models: $(QQ\bar{q}\bar{q})$ stable if $Q \gg q$

$(Qq\bar{Q}\bar{q})$ unbound without LR



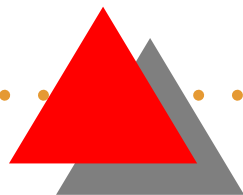
$QQ\bar{q}\bar{q}$ (Cont.)

In the limit of large M/m , remarkable structure

- $Q + Q \rightarrow (Q, Q)$ with colour $\bar{3}$ as in baryons.
- $(Q, Q)_{\bar{3}} + \bar{q} + \bar{q} \rightarrow$ colour singlet like in every antibaryon.

So **well known** colour structures and wave functions, unlike the more speculative colour chemistry of Chan H.M. et al.

Charmed quark c perhaps not heavy enough, BUT



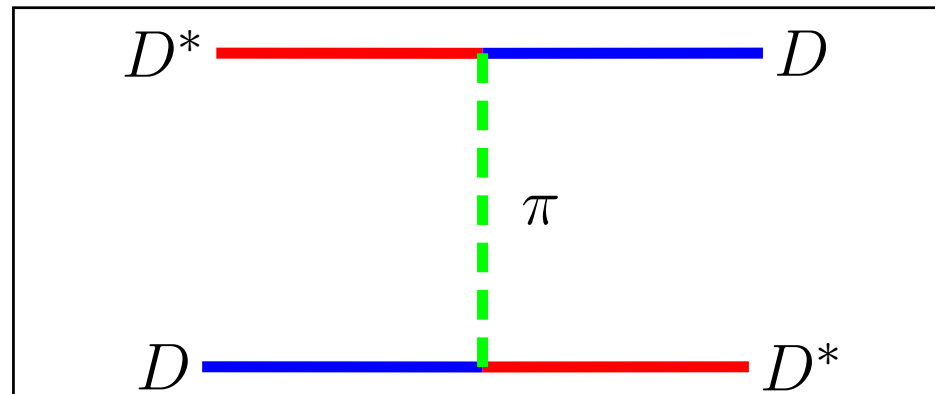
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$QQ\bar{q}\bar{q}$ (Cont.)

Other approach by Törnqvist (Helsinki), Manohar and Wise, Ericson and Karl



Yukawa potential $V = -g \exp(-\mu r)/r$ between D and D^* .

Coupling g **weaker** than for NN , but $m(D) > m(N)$.

What matters is mg .

π - exchange a little marginal to bind DD^* .



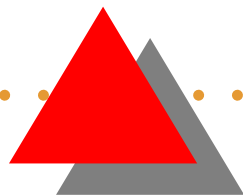
$QQ\bar{q}\bar{q}$ (end)

A proper combination of

short-range attraction, as given by UKQCD or quark models

long-range attraction, due to π -exchange

could well give **a stable tetraquark with charm = 2**



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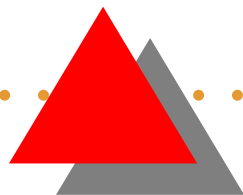
Conclusion: double charm

Interesting weak decay

ccq: laboratory for confinement, in particular

Aspects of light quark dynamics enhanced

Possibility of exotics with heavy flavour



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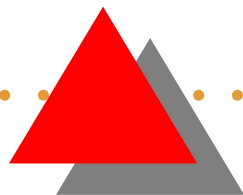
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Lessons from recent findings

Light quark dynamics might be more subtle than the simple chromomagnetic interaction of Jaffe, Lipkin, etc.

$QQ\bar{q}\bar{q}$ Arguments based on flavour independence, analogy with atomic physics probably OK. However, the role of meson–meson long-range interaction is crucial.

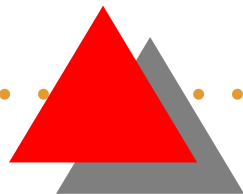


Beyond double charm

TRIPLE CHARM

ccc

Ultime goal
of baryon
spectroscopy
(Bjorken)



LPSC
Grenoble

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QwG