New Hadrons

available at *http://lpsc.in2p3.fr/theorie/Richard/SemConf/Talks.html*

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Introduction

Encouraging recent results

- new states seen in high-energy experiments,
- for instance, $D_{s,J}$, $X(3872)$, $\eta_c(2S)$
- while low-energy experiments sometimes gave misleading results (pentaquarks)
- even complex and fragile structures, such as antideuterium produced at high energy

Less encouraging

- spectroscopy and flavour program also foreseen at heavy-ion facilities (RHIC)
- see, e.g., BNL Workshop, May 2002
- but never given enough priority in detector tuning and in analysis

New baryons

Single-charm baryons

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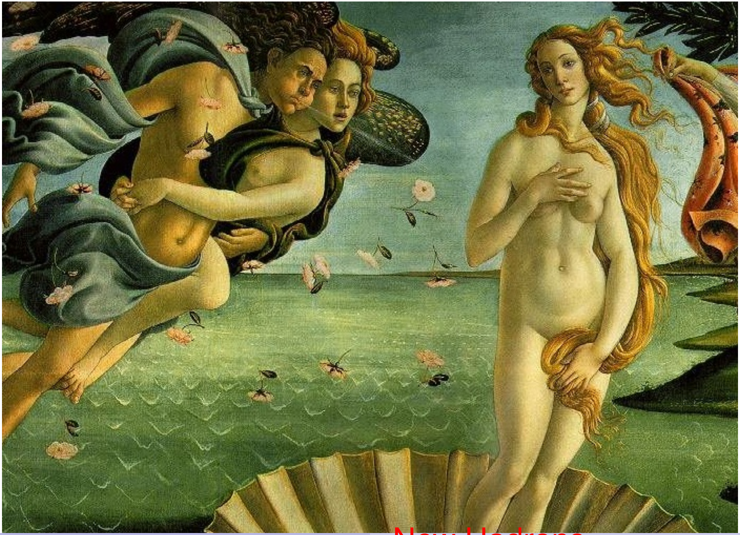

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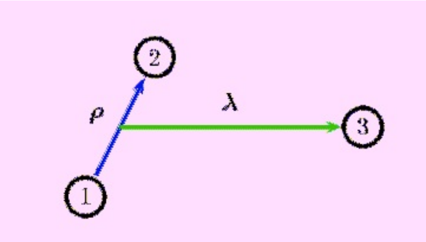
- Perspective of a detailed spectroscopy, and perhaps, evidence for 3-body degrees of freedom in baryons
- Remember: states with excitation in both Jacobi coordinates are absent in the quark-diquark models and weakly coupled to formation channels,



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- Combine the charmonium-like dynamics (non-relativistic limit of QCD)
- With the *D*-like dynamics (ultra-relativistic regime)
- Very suited for a Born–Oppenheimer treatment à la ${H_2}^+$
- Quark-diquark, if properly done, also works for the ground state
- In a single hadron, with also interesting weak-decay properties

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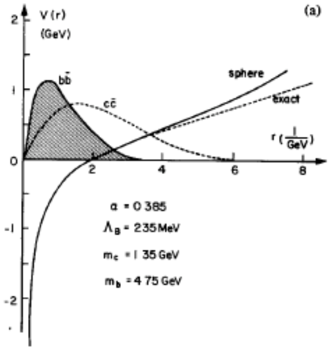
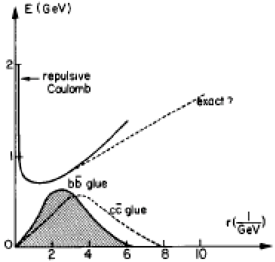
- Possibility of exotic J^{PC}
- Already some speculations for $X(3872)$, $X(3940)$ or $Y(4260)$

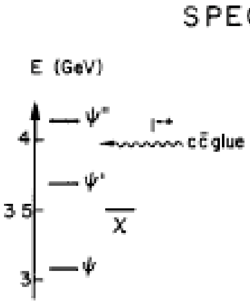
Hybrids of heavy quarkonia

1980 Born–Oppenheimer estimate with classical treatment of gluons





Hybrids 1980 predictions



$c\bar{c}g \sim 4$ GeV $\quad$ $b\bar{b}g \sim 10.4$ GeV

Mass and some properties of X(3940) makes it a possible candidate for hybrid.

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- Same mechanism by which in atomic physics (ppe^-e^-) is more stable than $(e^+e^+e^-e^-)$: the 4-body compound benefits of the heavy-heavy binding, and this effect is not active in the threshold.

The role of symmetry breaking

- Any symmetry breaking benefits to the ground state

$$H = H_0(\text{even}) + H_1(\text{odd}) \Longrightarrow E(H) < E(H_0)\ ,$$

- (use the variational principle),e.g., parity:

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- an example (permutation symmetry) is (M^+, M^-, m^-, m^-), stable for $M = m$ (PS_2 molecule), unstable if $M/m > 2.2$.
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- Coulomb irrelevant here, what matter is flavour independence, thus the mechanism applies to heavy quark systems.

Difficulties with multiquark calculations -1-

- Potential models. Much activity. Good account of correlation and anticorrelation effects.
- But non-relativistic or semi-relavistic wave equations,
- Simple-minded extrapolation from quarkonium phenomenology,

$$V_{Q\overline{Q}} = v(r) \longrightarrow V(QQ\overline{QQ}) = -\frac{3}{16}\sum_{i<j} \tilde{\lambda}_i^{(c)}.\tilde{\lambda}_j^{(c)} v(r_{ij}) \ ,$$

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- More elaborate approaches to multiquarks
  - QCD sum rules, Narison et al., X(3872), etc.
  - Lattice QCD: Markum et al., Michael & Green, Negele et al., etc.
- Still difficulties to distinguish clearly a genuine resonance from a state in the discretised continuum

Difficulties with multiquark calculations -2-

- though techniques exist, which could perhaps be extended to field theory,
- for instance complex scaling,
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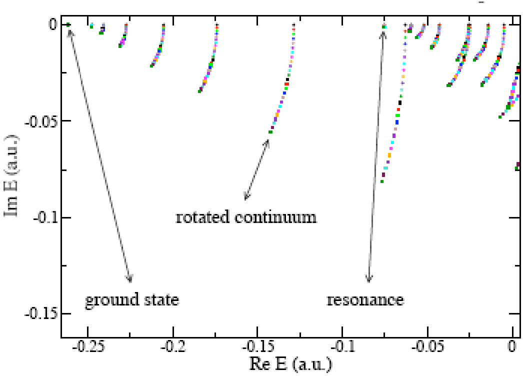
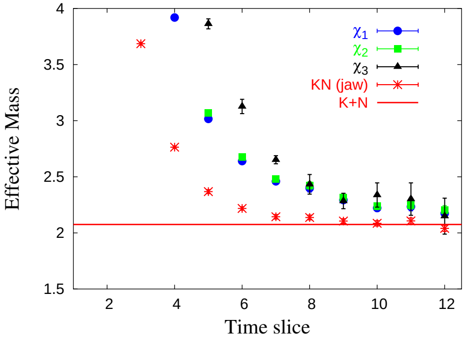
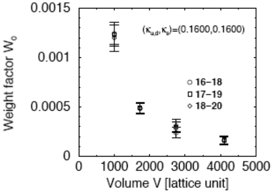
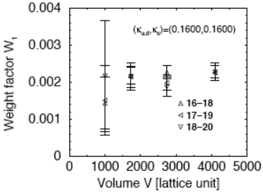
The bound state and the genuine resonance are clearly singled out from a bunch of continuum states.



To be compared with lattice calculations







Further exotics

- Four-quark mesons sometimes described as meson–meson molecules
- Bound by nuclear forces (Törnqvist, Swanson, Ericson & Karl, Manohar, etc
- Other states predicted in this approach, in particular bound states of charmed baryons
- For instance $(ccq) - (ccq)$ (Riska & Julia-Diaz)
- Unlike nuclear physics, no short-range repulsion to prevent collapse of the two hadrons.

Conclusion-1

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