Multiquarks and molecules

Jean-Marc Richard

Institut de Physique Nucléaire de Lyon
Université Claude Bernard (Lyon 1)–IN2P3-CNRS
Villeurbanne, France

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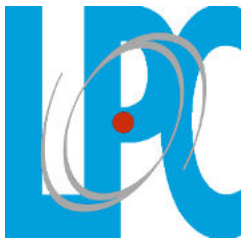


Table of contents

Content

Work done in collaboration with Qiang Zhao (IHEP) and Qian Wang (Juelich),
and Emi Kou et al. for the first part.

Isospin partner of $X(3872)$ -1

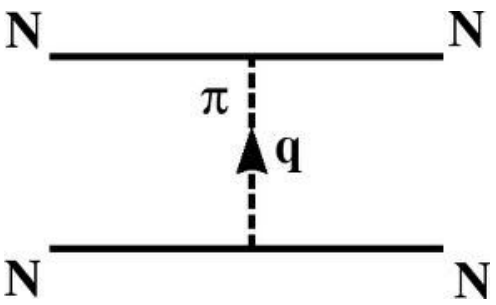
$X(3872)$

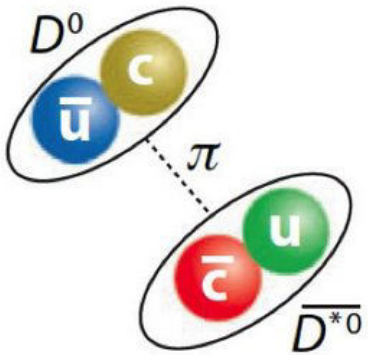
- $X(3872)$ seen in several experiments
- BELLE, BABAR, CDF, D0
- More recently at LHC
- Firmly established, $J^{PC} = 1^{++}$
- $M = 3871.68 \pm .17\,\text{MeV}$ (PDG) $\quad \Gamma = 3.9^{+2.8+0.2}_{-1.4-1.1}\,\text{MeV}$
- Decay mostly into $D\bar{D} + \text{c.c.}$, $D\bar{D}\pi$

$X(3872)$ Theory

- Predicted in a molecular model (Törnqvist, Voloshin, . . .)
- Also studied in a diquark model (Maiani et al.)
- Several studies with QCD SR (Nielsen, Narison, S.-L. Zhu et al.,Z.-G. Wang,. . .)
- Firmly established
- Chromomagnetic model (Høgassen et al.)

Isospin partner of $X(3872)$ -2





- Favours one isospin
- Due to $\tau_1.\tau_2$ factor
- Historically, this was a problem in "bootstrap" theory, where mesons were mostly baryon-antibaryon

- Factor 3 better for $I = 0$
- Again, due to $\tau_1.\tau_2$ factor
- Favours $I = 0$ vs. $I = 1$

Isospin partner of $X(3872)$ -3

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Chromomagnetic mechanism for the X(3872) resonance

H. Høgaasen,[1,*] J.-M. Richard,[2,†] and P. Sorba[3,‡]

[1]*Department of Physics, University of Oslo, Box 1048 NO-0316 Oslo Norway*
[2]*Laboratoire de Physique Subatomique et Cosmologie, Université Joseph Fourier–IN2P3-CNRS 53, avenue des Martyrs, 38026 Grenoble cedex, France*
[3]*Laboratoire d'Annecy-le-Vieux de Physique Théorique (LAPTH) 9 chemin de Bellevue, B.P. 110, 74941 Annecy-le-Vieux Cedex, France*

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The chromomagnetic interaction, with proper account for flavor-symmetry breaking, is shown to explain the mass and coupling properties of the X(3872) resonance as a $J^{PC} = 1^{++}$ state consisting of a heavy quark-antiquark pair and a light one. It is crucial to introduce all the spin-color configurations compatible with these quantum numbers and diagonalize the chromomagnetic interaction in this basis. This approach thus differs from the molecular picture $D\bar{D}^*$ and from the diquark–anti-diquark picture.

- annihilation term and $m_d - m_u = 3.5$ MeV, the "mostly $I = 1$" state lies 31 MeV above the "mostly $I = 0$" state.
- symmetry dimensions of particle physics

Chinese collider expands particle zoo

China's Beijing Electron-Positron Collider seems to be hosting a reunion; members of a poorly understood family of particles keep popping up in their data, which may help clarify the properties of this reclusive family.

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Isospin partner of $X(3872)$ -4

Observation of a Charged Charmoniumlike Structure in $e^+e^- \to \pi^+\pi^-$ J/ψ at $\sqrt{s}$ =4.26 GeV

BESIII Collaboration (M. Ablikim (Beijing, Inst. High Energy Phys.) *et al.*) *Afficher les 354 auteurs*

Mar 24, 2013 - 7 pages

- to charmonium. A fit to the π±J/ψ invariant mass spectrum, neglecting interference, results in a mass
- of (3899.0±3.6±4.9) MeV/c2 and a width of (46±10±20) MeV. Its production ratio is measured to be

Study of $e^+e^- \to \pi^+\pi^- J/\psi$ and Observation of a Charged Charmoniumlike State at Belle

Belle Collaboration (Z.Q. Liu (Beijing, Inst. High Energy Phys.) *et al.*) *Afficher les 187 auteurs*

- Mar 30, 2013 - 7 pages

Isospin partner of $X(3872)$ -5

Chromomagnetic model

$$H = M + H_{\rm CM} = \sum_i m_i - \sum_{i,j} C_{ij}\, \tilde{\lambda}_i \cdot \tilde{\lambda}_j\, \sigma_i . \sigma_j \ ,$$

- Gives $X(3872)$ with right mass and decay properties
- $I = 0$ and $I = 1$ degenerate
- Annihilation term predicted the right splitting
- X is mainly $(c\bar{c})_8 (q\bar{q})_8$

Beauty partners of $X(3872)$ and $Z_c(3900)$

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Isovector and hidden-beauty partners of the $X(3872)$

Hallstein Høgaasen [a], Emi Kou [b], Jean-Marc Richard [c,*], Paul Sorba [d]

[a] Department of Physics, University of Oslo, Box 1048, NO-0316 Oslo, Norway
[b] Laboratoire de l'Accélérateur Linéaire, Université Paris-Sud, IN2P3-CNRS, Centre Scientifique d'Orsay, 91898 Orsay Cedex, France
[c] Université de Lyon, Institut de Physique Nucléaire de Lyon, UCBL–IN2P3-CNRS, 4, rue Enrico Fermi, 69622 Villeurbanne Cedex, France
[d] LAPTh, Laboratoire d'Annecy-le-Vieux de Physique Théorique, CNRS, Université de Savoie, BP 110, 74941 Annecy-le-Vieux Cedex, France

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$$H = M + H_{\rm CM} + H_{\rm CE} = \sum_i m_i - \sum_{i,j} C_{ij}\, \tilde{\lambda}_i \cdot \tilde{\lambda}_j\, \boldsymbol{\sigma}_i . \boldsymbol{\sigma}_j - \sum_{i,j} A_{ij}\, \tilde{\lambda}_i \cdot \tilde{\lambda}_j \ ,$$

- One quadruplet near 10.62 GeV
- No possibility of two charged triplets with $J^{PC} = 1^{++}$ at about the same mass

Summary Part 1

- For a review of other approaches, see Q. Zhao at Beijing Chiral Workshop
- Near degeneracy of $I = 0$ and $I = 1$ natural in a quark picture
- Molecular model predicts a difference between $I = 0$ and $I = 1$
- Radiative decay seems crucial, in particular

$$\frac{X(3872) \to \psi(2s) + \gamma}{X(3872) \to J/psi + \gamma} \gg 1$$

- See, the recent review by S.L. Zhu et al.
- See the recent better measurement by LHCb

Summary Part 1

X 3900 is a local speciality

L'autorail X 3900

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Part 2: New light hypernuclei

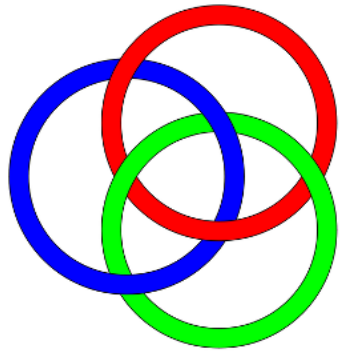
- Much activity in the “molecular’ model,
- meson-meson, baryon–baryon, baryon–antibaryon, etc.
- stimulated by $X(3872)$ and other states in the heavy-quark sector
- also for nucleon-hyperon systems = light hypernuclei
- Qiang Zhao (IHEP) Qian Wang (Jülich) and JMR, to be posted and submitted next week
- and presented next month at the Conference on Nuclear Clusters (Yokohama)

Light hypernuclei: survey

- $N\Lambda$ not bound
- $\Lambda\Lambda$ not bound, but might be attractive at short distances
- See, speculations on H dibaryon (Jaffe, . . .)
- ${}^{3}_{\Lambda}\mathrm{H} = (n, p, \Lambda)$ bound slightly below ${}^{2}\mathrm{H} + \Lambda$
- This probes the ΛN interaction of the Nijmegen + Japan group fitting the (rare) scattering data and constrained from NN by $\mathrm{SU(3)_F}$
- ${}^{5}_{\Lambda}\mathrm{He} = (\alpha, \Lambda)$ bound, another example (More in Sakaguchi, 2009)
- Double hypernuclei also seen
- "Nagara" event ${}^{6}_{\Lambda\Lambda}\mathrm{He}$ seen
- Indicates a weak attraction for $\Lambda\Lambda$ in medium
- Suppression of $\Lambda\Lambda \leftrightarrow N\Xi \leftrightarrow \Lambda\Lambda$ due to Pauli principle

Borromean binding

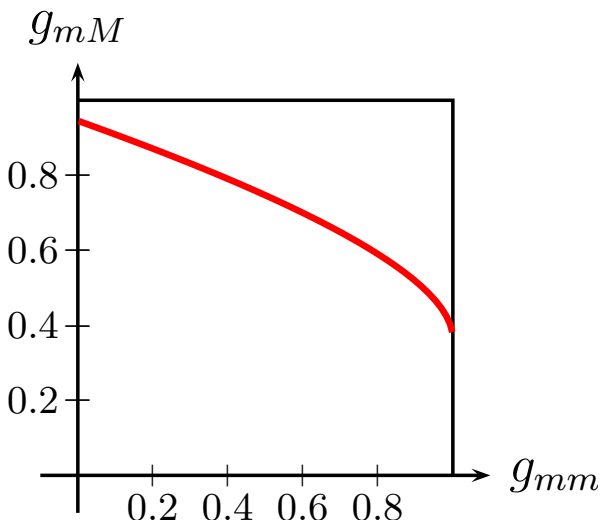
- Thomas (1935), Zhukov et al. (1993) milestones to stress the possibility of Borromean binding
- Bound state whose subsystems are unbound

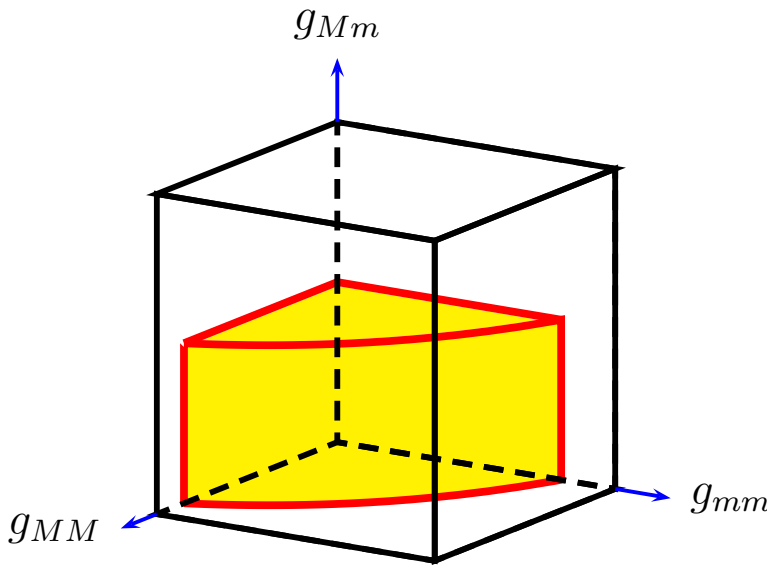


- In quantum mechanics for bosons, a short-range attractive potential $g\,V(r)$
- Needs $g > g_2$ to bind (m, m)
- Needs $g > g_3$ to bind (m, m, m)
- With $g_3 < g_2$ $\quad [g_3, g_2]$ Booromean windows

Borromean binding

- Example $^6\mathrm{He} = (\alpha, n, n)$ is stable
- while neither (α, n) nor (n, n) are bound
- Rigorous limit $2\,g_2/3 < g_3$ can be established
- And generalized to unequal masses and coupling, and to $N > 3$ body systems

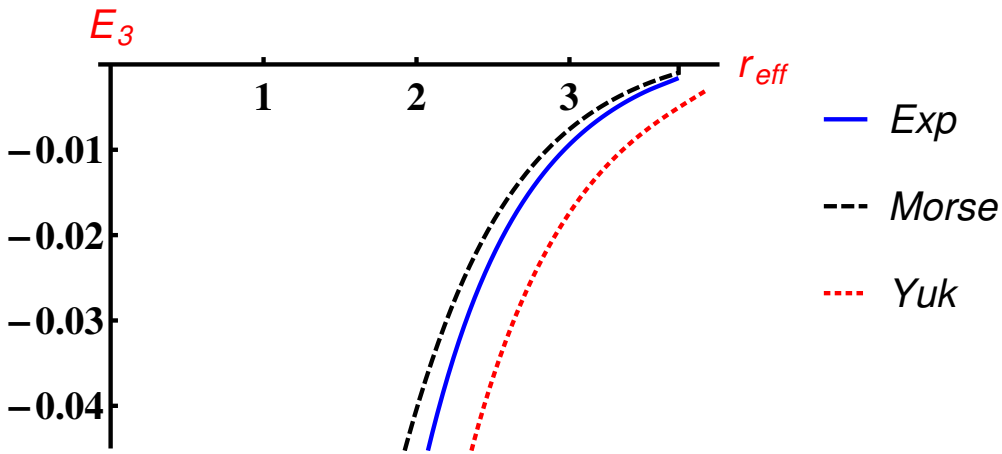




So, some hope is permitted

Borromean binding

The amount of Borromean binding, for given scattering length, depends on the effective range a point sometimes overlooked.

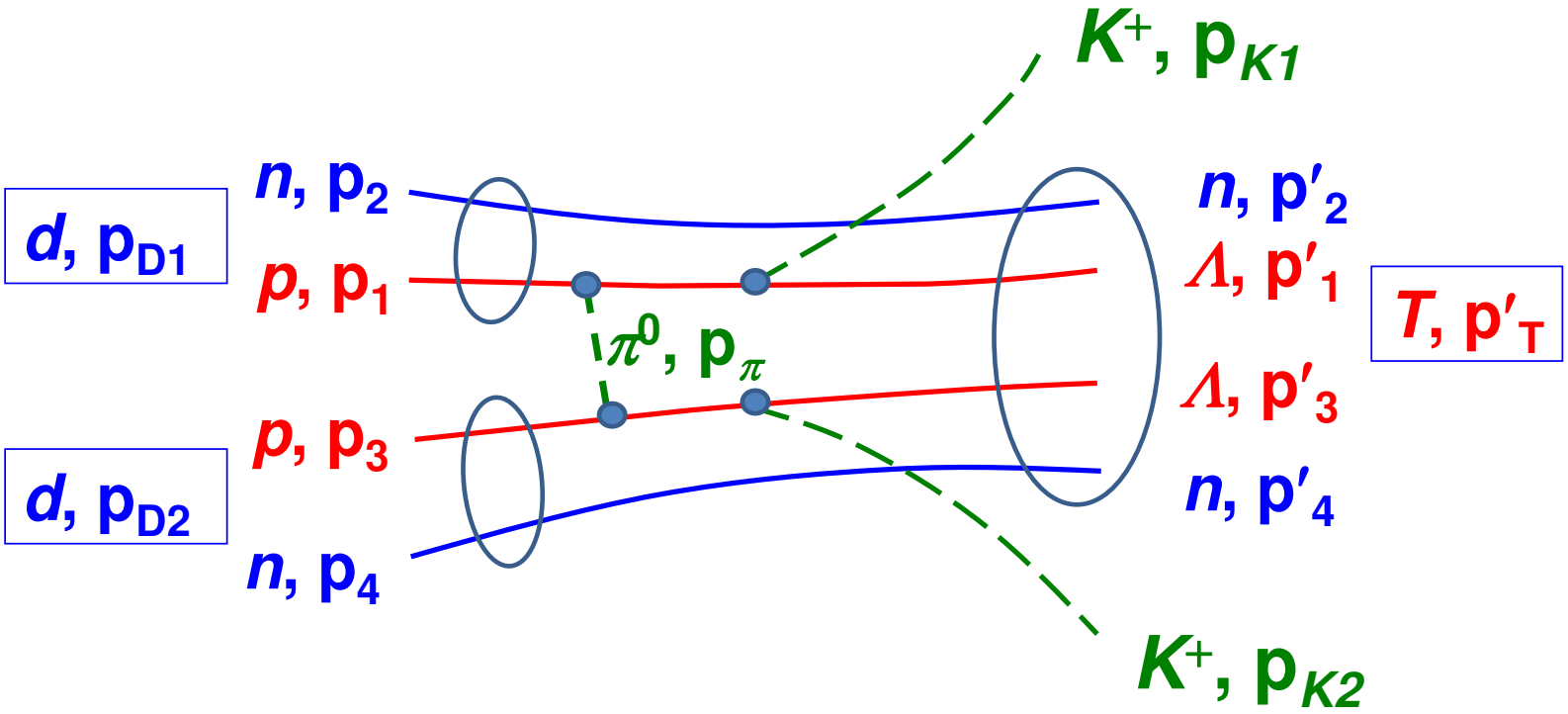


Results

- Very delicate 3-body and 4-body calculations
- With $V = -g_{ij}\ \exp(-r)$, r in GeV, tuned to reproduce the scattering lengths (n,p), (n,p,Λ) OK, (n,n,Λ) unbound, (n,p,Λ,Λ) and (n,n,Λ,Λ) stable, but effective range too small
- With $V = -g_{ij}\ \exp(-0.2\,r)$, r in GeV, (n,p), (n,p,Λ) OK, (n,n,Λ) unbound, (n,p,Λ,Λ) bound and (n,n,Λ,Λ) unstable, but effective range too large,
- With $V = g_{ij}\ \exp[-2\alpha_{ij}(r-R)] - 2\,g_{ij}\ \exp[-\alpha_{ij}(r-R)]$ (Morse), and a reasonable R, one can adjust g_{ij} and α_{ij} to reproduce the scattering length and effective range for each pair, then (n,p), (n,p,Λ) OK, (n,n,Λ) unbound, (n,p,Λ,Λ) bound and (n,n,Λ,Λ) very weakly bound
- First indication for this neutral configuration
- Which is fully Borromean

Production mechanism

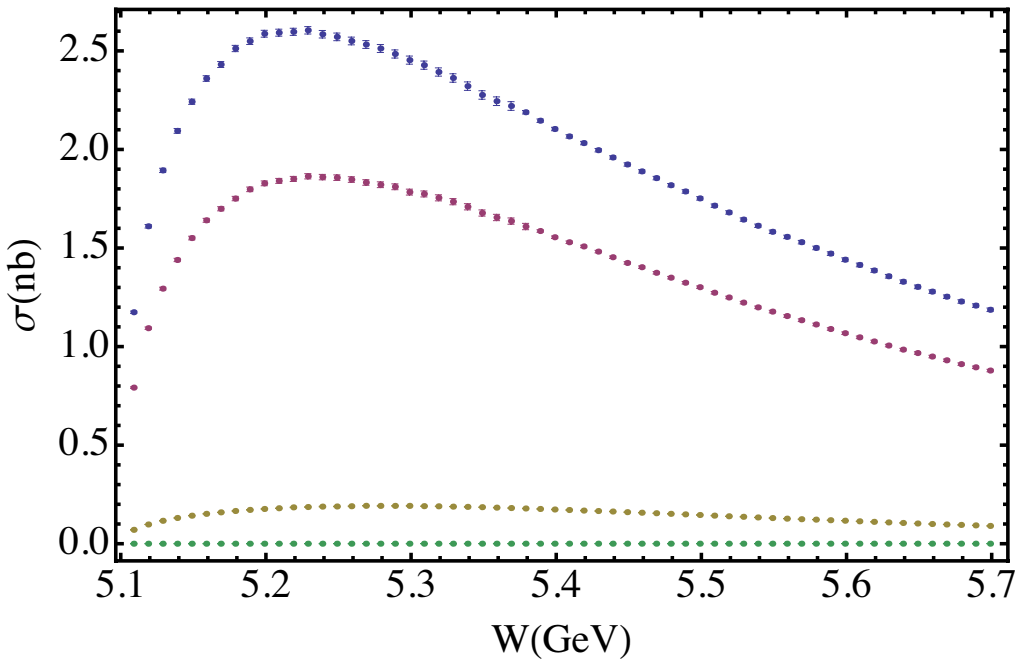
Production mechanism for the tetra-baryon state ($\Lambda\Lambda nn$) in deuteron-deuteron collision



- The two K^+ production is via the elementary process, $pp \rightarrow \Lambda\Lambda K^+K^+$.
- The intermediate S11(1535) excitations dominate the threshold production.

Production mechanism

- Preliminary estimate (still under checking)
- Total, and Born term, double $N(1530)$, single $N(1530)$ contributions



Conclusions

$Z_c(3900)$

- $Z_c(3900)$ expected in models based on quark dynamics
- Predictions for hidden beauty

Neutral tetrabaryon

- New light hypernuclei expected such as (n, n, Λ, Λ)
- In a regime of extreme Borromean binding