Unquenched Quark Model

Hugo García Tecocoatzi
Roelof Bijker
Elena Santopinto
Jacopo Ferretti

Instituto de Ciencias Nucleares UNAM, INFN sezione di Genova

May 26, 2015

Table of contents

Introduction

Hadron physics, challenge at low energies

One of the main goals of hadron physics is to understand the structure of the baryons and mesons. However, at low energies, no solution of QCD is known. Then we can use the effective degrees of freedom theories that replace part of unknown interactions by physically approximations.

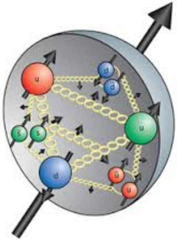
Open problems in hadrons

- Missing resonances
- Electromagnetic Decays of baryon.
- Strong decays
- etc

Quark models

Effective degrees of freedom

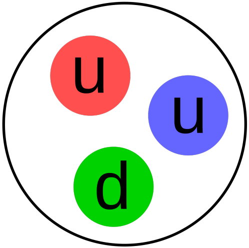
The developed effective models of hadrons, such as bag models, chiral quark models, soliton models, instanton liquid model and the constituent quark model. Each of these approaches are constructed in order to mimic some selected properties of the strong interaction, but obviously none of them are QCD.



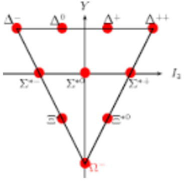
constituent quark models (CQM)

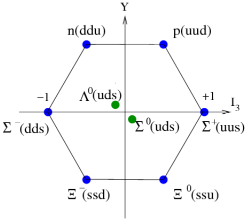
constituent quark models (CQM)

An important class is provided by CQM which are based on constituent (effective) quark degrees of freedoms. There exists a large variety of CQM's. The main features: the effective degrees of freedom of three constituent quarks (qqq configurations), the $SU(3) \otimes SU(2)$ flavor-spin symmetry and a long-range confining potential.

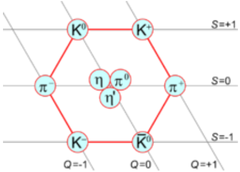


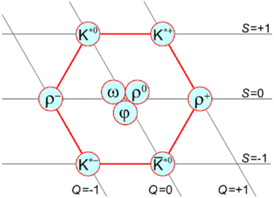
Baryons





Mesons





Exotic Degrees of freedom

Why?

QM reproduces quite well many hadronic observables:
magnetic moments
baryon and meson spectra (lower part)
strong couplings
Some observables only give rise when the coupling to the continuum (loop effects) is taken into account:
strangeness content of the nucleon
Flavor asymmetry
baryon and meson self energies

Unquenched Quark Model

The baryon/meson wave function

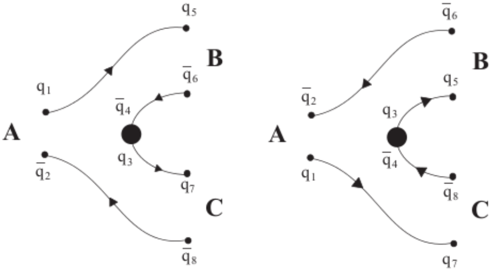
The baryon/meson wave function consists of a zeroth order three-quark(quark-antiquark) configuration $|A\rangle$ plus a sum over all possible higher Fock components due to the creation of ${}^3P_0$ quark-antiquark pairs

$$|\psi_A\rangle = \mathcal{N}\left[|A\rangle + \sum_{BCl}\int dk\ k^2 |BCklJ\rangle \frac{\langle BCklJ|T^\dagger|A\rangle}{M_A - E_B - E_C}\right]$$

The ${}^3P_0$ operator

$$T^\dagger = -3\gamma\sum_{i,j}\int d\vec{p}_i d\vec{p}_j \delta(\vec{p}_i + \vec{p}_j) C_{ij} F_{ij} e^{-\alpha_d^2(p_i - p_j)^2} \times [\chi_{ij} \times \mathcal{Y}_1(\vec{p}_i - \vec{p}_j)]_0^{(0)}\, b_i^\dagger(\vec{p}_i) d_j^\dagger(\vec{p}_j)$$

UQM Mesons



(a) (b)

Figure: Two diagrams can contribute to the process $A \to BC$. q_i and q_i stand for the various initial (i = 1 - 4) and final (i = 5- 8) quarks or antiquarks, respectively.

UQM baryons

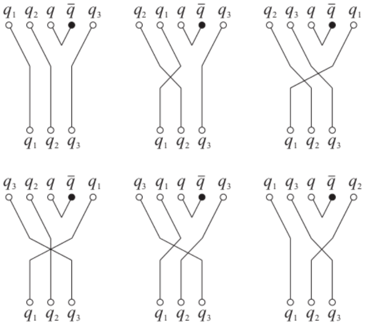


Figure: Quark line diagrams for $A \to BC$ with $q\bar{q} = s\bar{s}$ and $q_1 q_2 q_3 = uud$

UQM

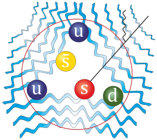
Studies with UQM

- The flavor asymmetry of the proton Santopinto and Bijker, PRC82,062202(2010)
- Strangeness content of nucleon e.m. form factors Bijker, Ferretti and Santopinto, PRC85,035204(2012).
- Meson Self Energies
  Charmonium spectrum Ferretti, Galata' and Santopinto, PRC88,015207(2013).
  Bottomonium spectrum Ferretti et al., PRD90,094022(2014).

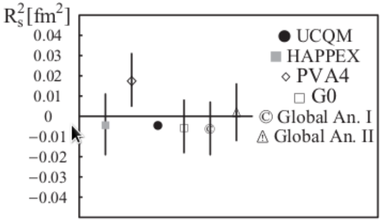
strangeness in the proton

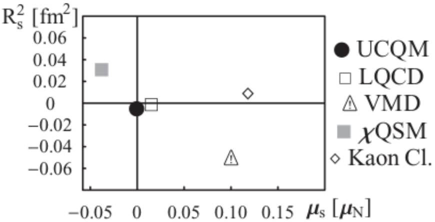
Proton wave function, pseudoscalar mesons

$$
\begin{aligned}
|p_{tot}\rangle = N_n \Bigg[|p\rangle - \int k_0^2\, dk_0\, a_3 \frac{5}{54\sqrt{2}} \left(\sqrt{\tfrac{1}{3}} \left| p\pi^0 \right\rangle - \sqrt{\tfrac{2}{3}} \left| n\pi^+ \right\rangle \right) \\
- \int k_0^2\, dk_0\, a_4 \frac{2}{27} \left(\sqrt{\tfrac{1}{2}} \left| \Delta^{++}\pi^- \right\rangle - \sqrt{\tfrac{1}{3}} \left| \Delta^{+}\pi^0 \right\rangle + \sqrt{\tfrac{1}{6}} \left| \Delta^{0}\pi^+ \right\rangle \right) \\
- \int k_0^2\, dk_0\, a_5 \frac{2}{27\sqrt{2}} \left(\sqrt{\tfrac{1}{3}} \left| \Sigma^{*0} K^+ \right\rangle - \sqrt{\tfrac{2}{3}} \left| \Sigma^{*+} K^0 \right\rangle \right) \\
- \int k_0^2\, dk_0\, a_6 \frac{1}{54\sqrt{2}} \left(\sqrt{\tfrac{1}{3}} \left| \Sigma^{0} K^+ \right\rangle - \sqrt{\tfrac{2}{3}} \left| \Sigma^{+} K^0 \right\rangle \right) \\
+ \int k_0^2\, dk_0 \left(a_7\, SF |p\eta\rangle + a_8 \frac{1}{3\sqrt{6}} \left| \Lambda^0 K^+ \right\rangle + a_9\, SF' |p\eta'\rangle \right) \Bigg].
\end{aligned}
$$



Strangeness in proton





Magnetic moments of octet baryons

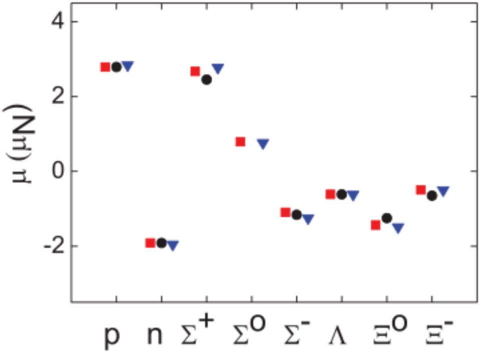


Figure: Bijker and Santopinto PRC80,065210(2009), Experimental data from the PDG (circles), CQM (squares), and unquenched quark model (triangles)

Proton asymmetry

Violation of the Gottfried sum rule.

$$S_G = \int_0^1 \frac{F_2^p(x) - F_2^n(x)}{x}\,\mathrm{d}x = \frac{1}{3} - \frac{2}{3}\int_0^1 [\bar{d}_p(x) - \bar{u}_p(x)]\,\mathrm{d}x = \frac{1}{3}[1 - 2\mathcal{A}(p)] = 0.24 \pm 0.016$$

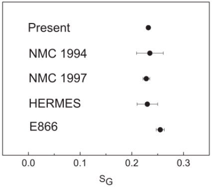


Figure: Bijker and Santopinto PRC80,065210(2009), Comparison between calculated S_G and the experimental data from NMC 1994, NMC 1997, HERMES, and E866

Meson Self Energies

In the UQM, the physical mass of a meson,

$$M_a = E_a + \Sigma(E_a) \ ,$$

is given by the sum of two terms: a bare energy, E_a, and a self energy correction,

$$\Sigma(E_a) = \sum_{BC\ell J} \int_0^\infty q^2 dq \ \frac{\left| \langle BC\vec{q}\,\ell J | T^\dagger | A \rangle \right|^2}{E_a - E_{bc}} \ ,$$

computed within the UQM formalism.

Charmonium spectrum

$X(3872)$ meson

- Several interpretations
- Results used to study the problem of the X(3872) mass, meson with $JPC = 1^{++}$, 23P1
- Experimental mass: $3871.68 \pm 0.17 MeV$ [PDG]
- Larger QM predictions for $X(3872)$'s mass (relativized QM $3.95 GeV$)
- $X(3872)$ very close to $D\bar{D}$ decay threshold

Charmonium spectrum

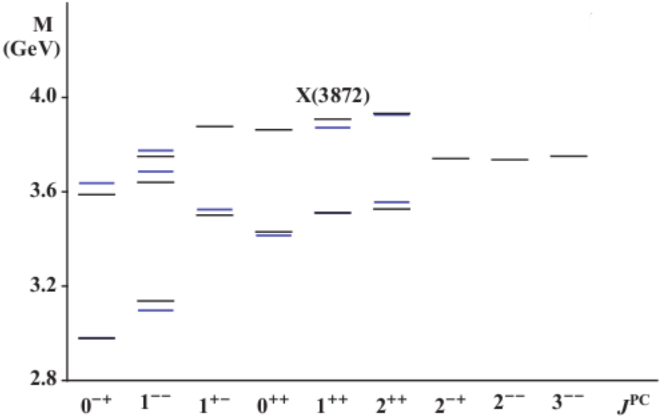


Figure: Ferretti, Galata' and Santopinto, PRC88,015207(2013)

Bottomonium spectrum

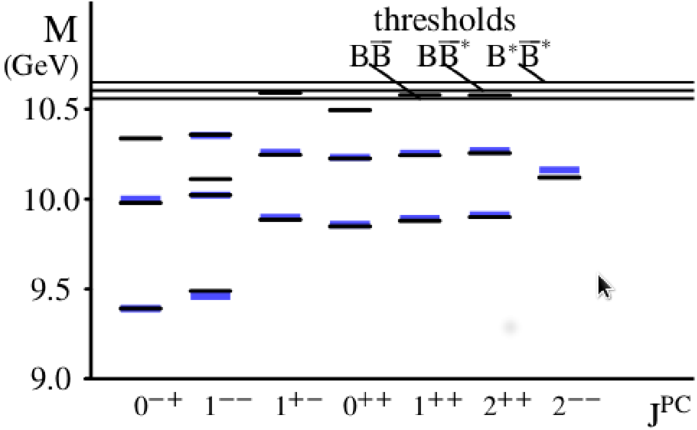


Figure: Ferretti and Santopinto PRD90 094022(2014)

Conclusions

Conclusions

- There are deviations for many observables that can be explained through include sea-quark ($q\bar{q}$) configurations.
- The UQM has only one parameter.

Work in progress

- Self energies for baryons
- Electromagnetic decays of baryons

Thank you!