Excited QCD 2017

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A NOVEL MULTIQUARK APPROACH TO HADRON RESONANCES

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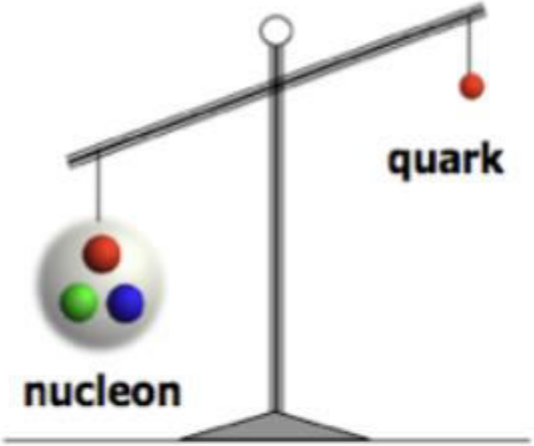
Strong interactions: almost 99% of mass of visible universe



Analytical description - ?

Mass generation mechanism - ? — **Encoded in the hadron spectrum!**

Lattice: O'k for numbers
but no physical picture of resonance formation

Many models in the last 50 years — **Success was partial**

Non-relativistic picture for light hadrons – O'k for classification.

It predicts correctly the observed quantum numbers. Except π_1

Relativistic descriptions – too many variants for (*P*,*C*)-parities

New ideas - ?

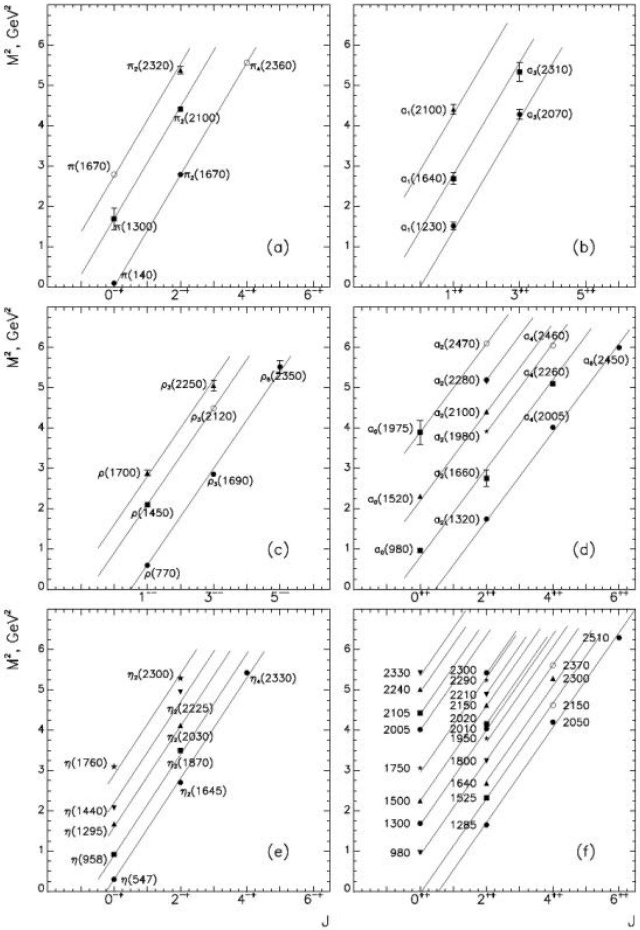
The light hadrons are ultrarelativistic systems.

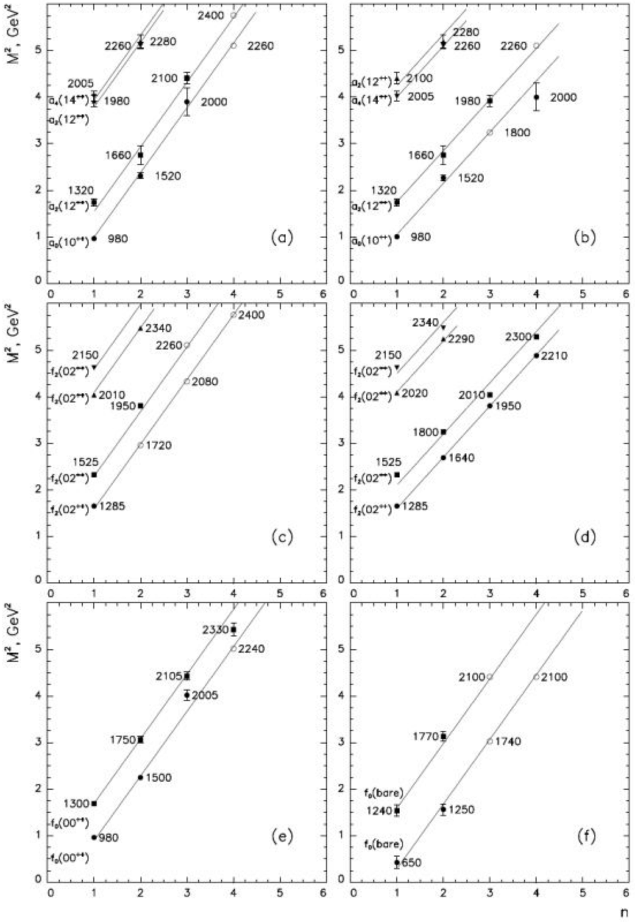
The orbital angular momentum ***L*** of hadron constituents is not relativistic.

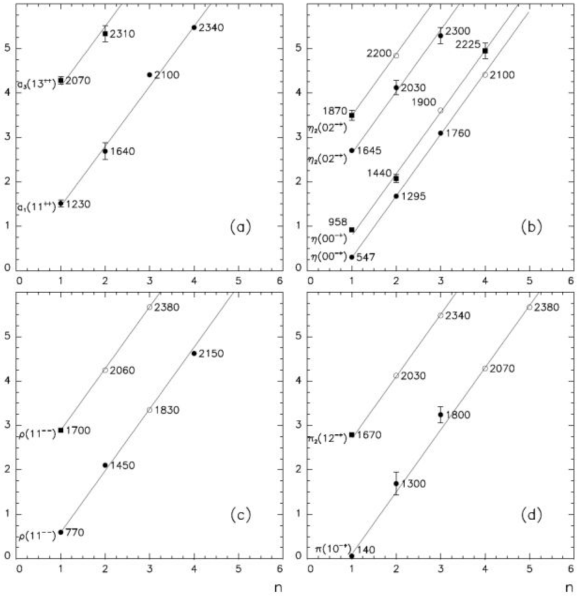
How to explain the appearance of Regge trajectories without ***L***?

Examples

(Anisovich et al. 2000)







HADRON MASS: THE CENTRAL PROBLEM

Mass of resonance →

***Re*-part of *S*-matrix pole**

gravitational mass

related with ↓

Energy-momentum tensor in QCD:

$$T^{\mu\nu} = \tfrac{1}{2}\,\overline{\psi} i \overleftrightarrow{D}^{(\mu}\gamma^{\nu)}\psi + \tfrac{1}{4}\, g^{\mu\nu} F^2 - F^{\mu\alpha} F^{\nu}{}_{\alpha}$$

Its trace:

QCD trace anomaly

anomalous dimension of quark mass

$$T^{\alpha}_{\alpha} = \frac{\beta(g)}{2g} F^{\mu\nu,a} F^{a}_{\mu\nu} + \sum_{q=u,d,s} m_q (1+\gamma_m) \overline{\psi}_q \psi_q$$

$$\beta(g) = -(11 - 2n_f/3)\, g^3/(4\pi)^2 + \ldots$$

$$M = \frac{\langle P|H_{\rm QCD}|P\rangle}{\langle P|P\rangle}|_{\rm rest\ \ frame} \qquad H_{\rm QCD} = \int d^3\vec{x}\, T^{00}(0,\vec{x})$$

$\langle P|P\rangle = 1$ — non-relativistic normalization

$\langle P|P\rangle = 2E$ — relativistic normalization

Hadron mass in relativistic case: $\boxed{2m_h^2 = \langle h|T_\alpha^\alpha|h\rangle}$ renorminvariant!

A consequence of the Ward identity $2p_\mu p_\nu = \langle h|T_{\mu\nu}|h\rangle$

Our ansatz:

$$\boxed{m_h^2 = \Lambda(E_h + 2m_q) = \Lambda E_h + m_\pi^2}$$

where $E_h \sim \langle h|G_{\mu\nu}^2|h\rangle \neq 0$ $\qquad m_u = m_d \doteq m_q$

Λ is universal for light hadrons and fixed by GOR relation

$$m_\pi^2 = -\frac{\langle\bar{q}q\rangle}{f_\pi^2}(m_u + m_d) = \Lambda \cdot 2m_q \qquad \boxed{\Lambda \doteq -\frac{\langle\bar{q}q\rangle}{f_\pi^2}}$$

One must specify E_h **- interpretations?**

$$m_h^2 = \Lambda E_h + m_\pi^2$$

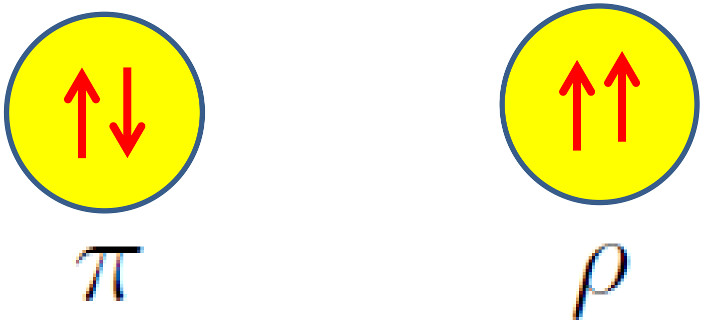
By assumption $E_h \sim \langle G_{\mu\nu}^2 \rangle$

ΛE_h renorminvariant!

Let us fix $\langle \bar{q} q \rangle = -(250\,\mathrm{MeV})^3,\ m_u + m_d = 11\ \mathrm{MeV},\ f_\pi = 92.4\ \mathrm{MeV}$

This yields $\Lambda = 1830\ \mathrm{MeV}$

Consider the rho-meson



$E_\rho \approx 310\ \mathrm{MeV}$ - the energy cost for the given spin flip (looks like a constituent mass!)

The non-renorminvariant logic does not work! $m_\rho \neq E_\rho + m_\pi$

$$m_h^2 = \Lambda E_h + m_\pi^2$$

Higher spin and radial excitations with correct quantum numbers?

A proposal: Let us assume that gluodynamics leads to formation of gluon analogues of positronium inside hadrons

We will call them **UNDERQUARKONIA**

↑↓ $J^{PC} = 0^{-+}$ — A_0

↑↑ $J^{PC} = 1^{--}$ — A_1

notations

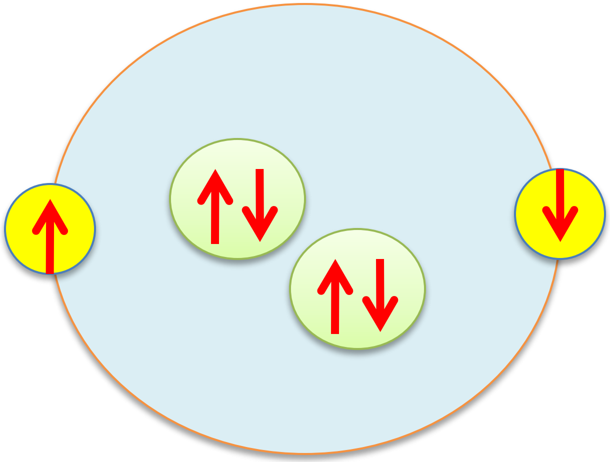
$$\boxed{{}^J\pi_{A_0^n A_1^l}} \quad (P,C) = \left((-1)^{n+l+1}, (-1)^l\right) \quad \boxed{m^2_{\pi_{A_0^n A_1^l}} = \Lambda(nE_0 + lE_1) + m_\pi^2}$$

Light non-strange mesons

$$\boxed{{}^J\rho_{A_0^n A_1^l}} \quad (P,C) = \left((-1)^{n+l+1}, (-1)^{l+1}\right) \quad \boxed{m^2_{\rho_{A_0^n A_1^l}} = \Lambda(E_\rho + nE_0 + lE_1) + m_\pi^2}$$

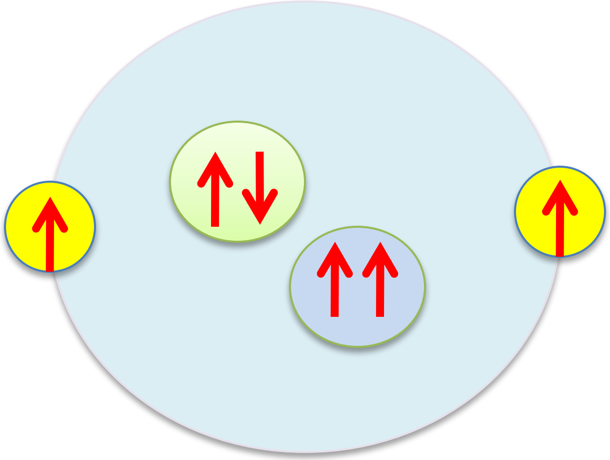
Examples

$^{0}\pi_{A_0^2} \Longrightarrow$



$\pi(1300)$

$^{J}\rho_{A_0 A_1} \Longrightarrow$



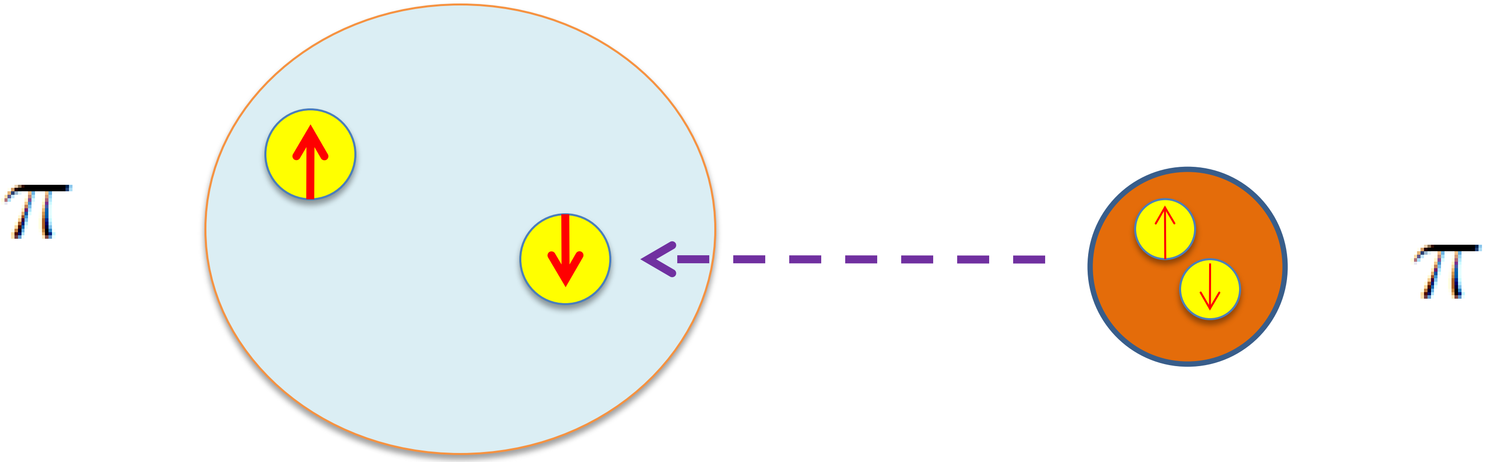
$\pi,\ \pi_1\ \text{and}\ \pi_2$

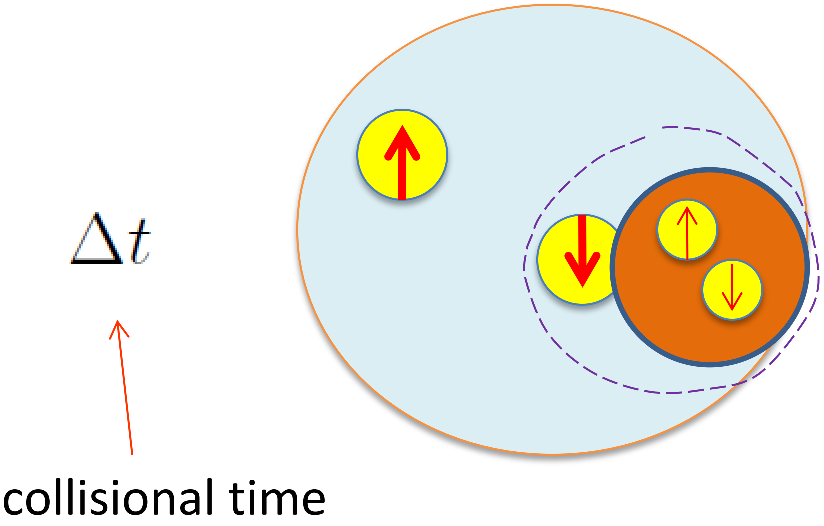
$\uparrow$

Not exotic!

Phenomenologically: $E_0 \approx 450 \quad E_1 \approx 570 \quad \text{MeV}$

Collisional excitations





$$m_h^2 = \Lambda(E_h + 2m_q) = \Lambda E_h + m_\pi^2$$

$$m_q \to m_q + m_\pi$$

$$\Downarrow$$

$$\boxed{m_\sigma^2 = \Lambda m_\pi + m_\pi^2}$$

For our inputs: $m_\sigma \approx 525 \text{ MeV}$.

General principle: $m^2_{\pi_h} = \Lambda m_h + m^2_{\pi}$

Examples

$\boxed{\pi_\rho}$	$m_{h_1} \approx 1190\ \mathrm{MeV}$	$h_1 \rightarrow \rho\pi$	$\boxed{h_1(1170)}$
$\boxed{\pi_\eta}$	$m_{\pi_\eta} \approx 1010\ \mathrm{MeV}$	$\pi_\eta \rightarrow \eta\pi$	$\boxed{a_0(980)}$
$\boxed{\pi_K}$	$m_{\pi_K} \approx 970\ \mathrm{MeV}$	$\pi_K \rightarrow \pi\pi$	$\boxed{f_0(980)}$
$\boxed{K_\pi}$	$m_{K_\pi} \approx 710\ \mathrm{MeV}$		$\boxed{K_0^*(800)}$

PDG: $682 \pm 29\ \mathrm{MeV}$

In conclusion…

The proposed approach is broader than "just another one model" as it gives a new language for discussion of hadron resonances, for interpretation of data in the hadroproduction and formation experiments, and a possible starting point for construction of essentially new dynamical models.