Can we describe heavy baryons in terms of a pion mean field?

Michał Praszałowicz
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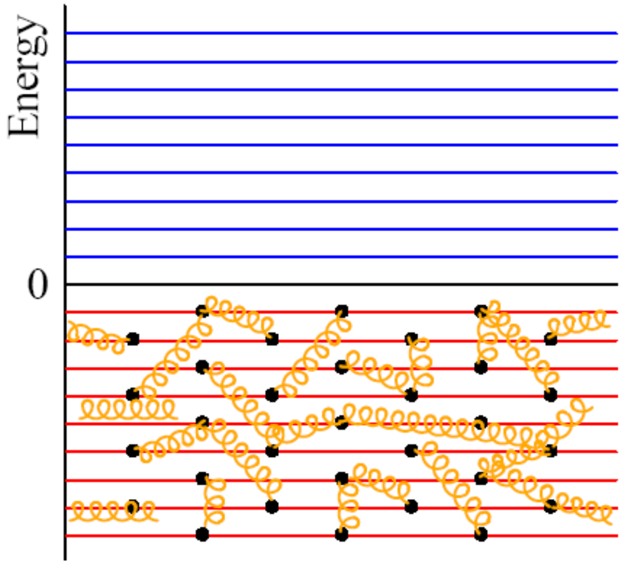
Soliton models are quark models

Soliton Models:



Soliton models are quark models

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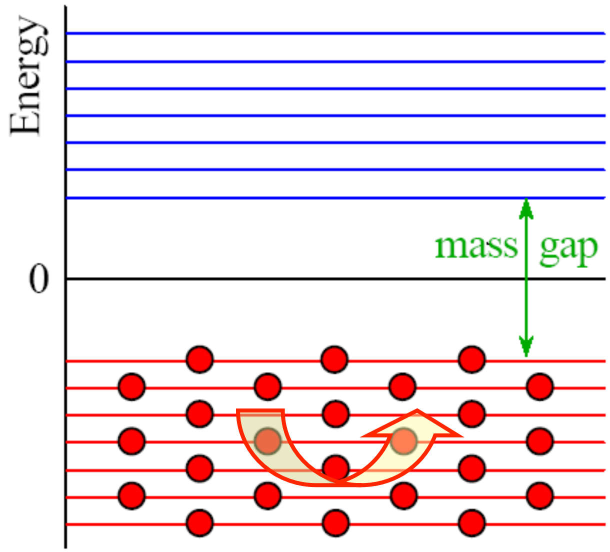

chiral symmetry breaking

chirally inv. manyquark int.

Soliton models are quark models

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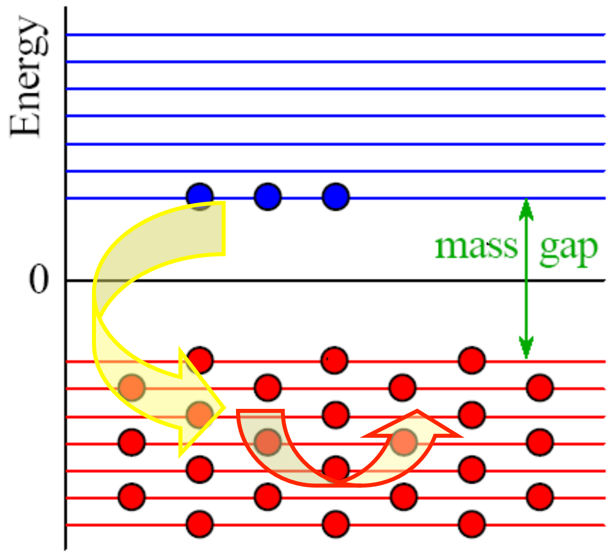

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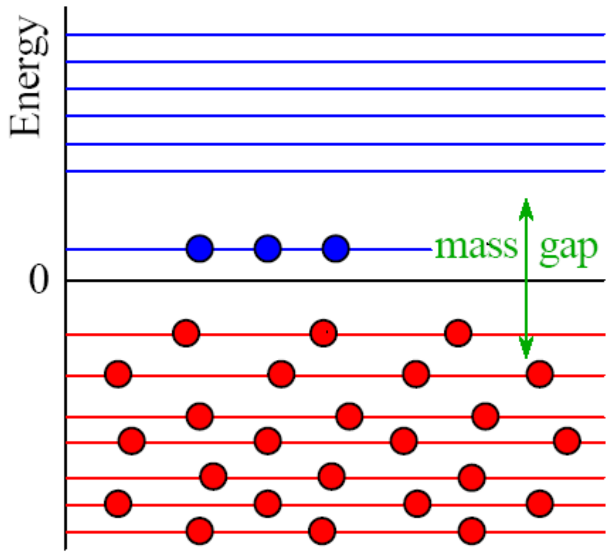

chiral symmetry breaking

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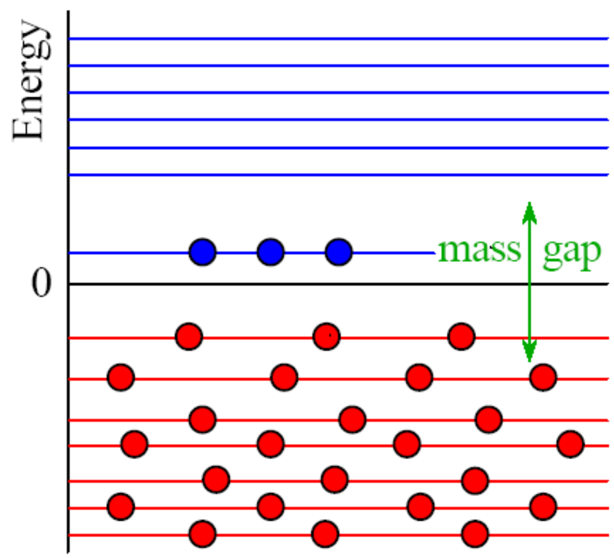
soliton configuration

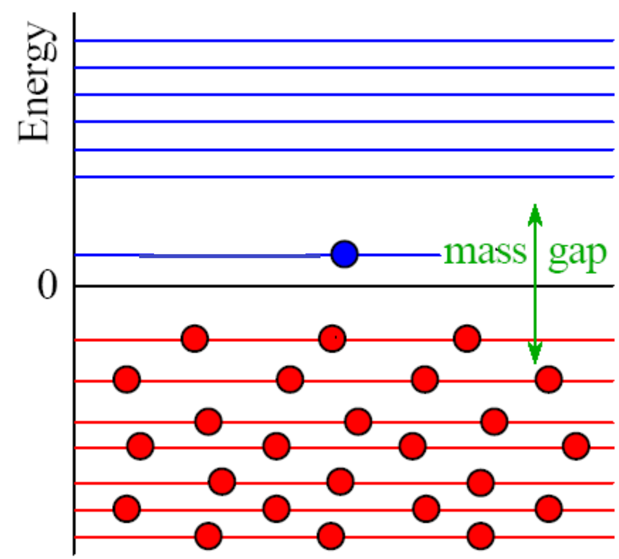
no quantum numbers except B

Soliton models are quark models



$= N_c \times$

Soliton Models:



chiral symmetry breaking

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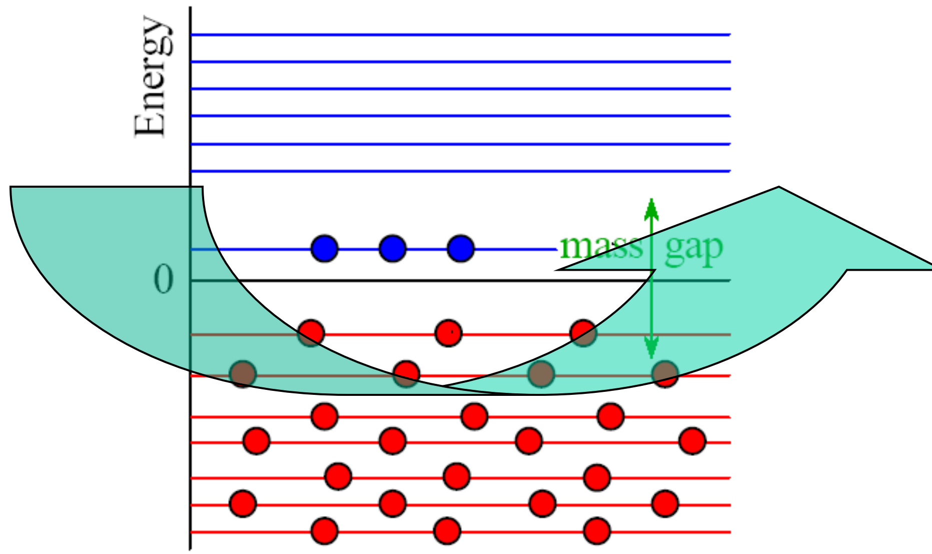
soliton configuration

no quantum numbers except B

color factorizes!

Soliton models are quark models

Soliton Models:



chiral symmetry breaking

chirally inv. manyquark int.

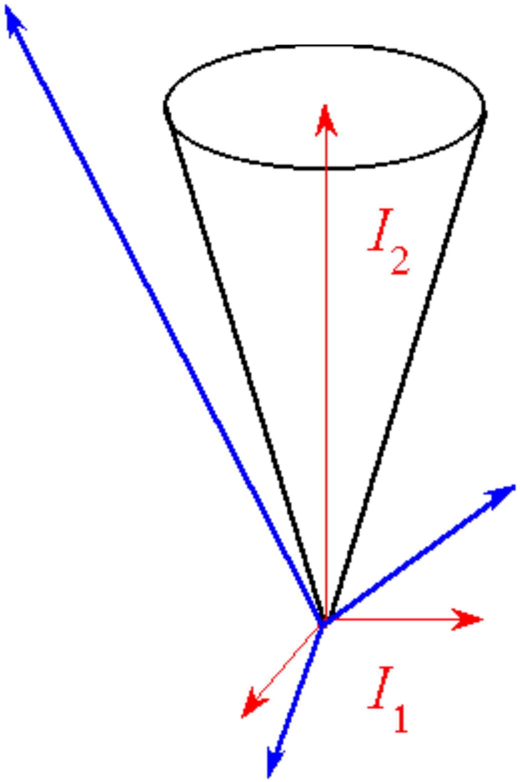
soliton configuration

no quantum numbers except B

rotation generates flavor and spin

Collective quantiztion → symmetric top

$$L_0 = -M_{\rm cl} + \frac{I_1}{2}\sum_{a=1}^{3}\Omega_a^2 + \frac{I_2}{2}\sum_{a=4}^{7}\Omega_a^2 + \frac{N_c}{2\sqrt{3}}\Omega_8$$



There is no kinetic term for 8-th angular velocity
→ conjugated momentum is constant and produces constraint:

$$\pi_8 = N_c/2\sqrt{3}$$

Mass formula

O(1) corrections to M_{cl} do not allow for absolute mass predictions

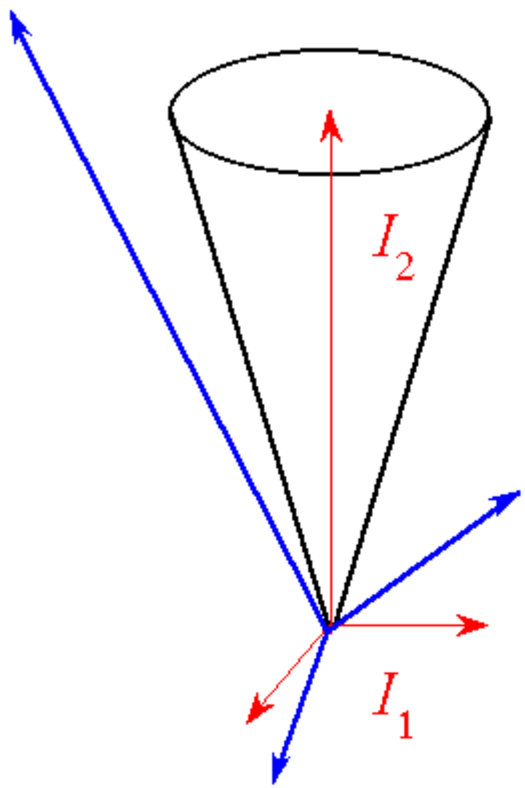
$$H_0 = M_{\rm cl} + \frac{1}{2I_1} S(S+1) + \frac{1}{2I_2}\left(C_2(\mathcal{R}) - S(S+1) - \frac{N_c^2}{12} \right)$$

octet-decuplet splitting

known

?

exotic-nonexotic splittings



$$I_1 = \frac{N_c}{6} \sum_{m,n} \sum_{A=1}^{3} \frac{\langle m|\lambda_A|n\rangle \langle n|\lambda_A|m\rangle}{\varepsilon_n - \varepsilon_m}$$

Mass formula

O(1) corrections to M_{cl} do not allow for absolute mass predictions

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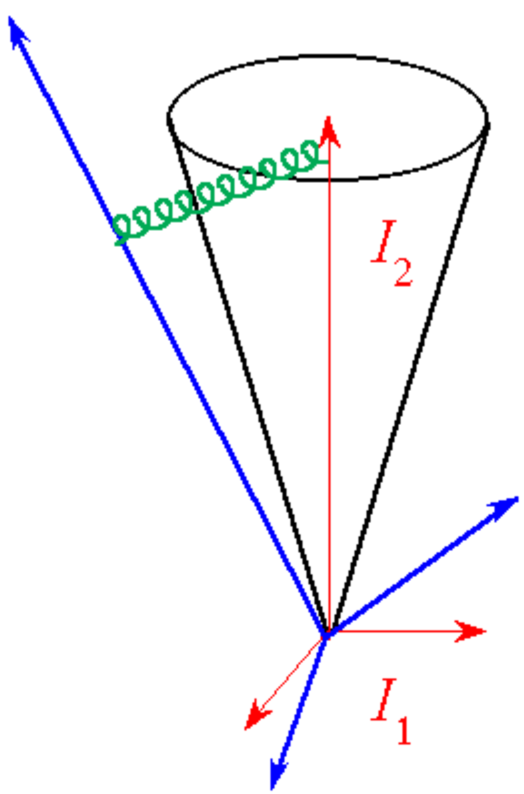
? — exotic-nonexotic splittings



first order perturbation in the strange quark mass and in N_c:

$$H_{\rm br} = \alpha\, D^{(8)}_{88} + \beta\, \hat{Y} + \frac{\gamma}{\sqrt{3}} \sum_{i=1}^{3} D^{(8)}_{8i}\, \hat{J}_i$$

$$\alpha \sim m_s N_c, \quad \beta, \gamma \sim m_s \mathcal{O}(1)$$

Mass formula

O(1) corrections to M_{cl} do not allow for absolute mass predictions

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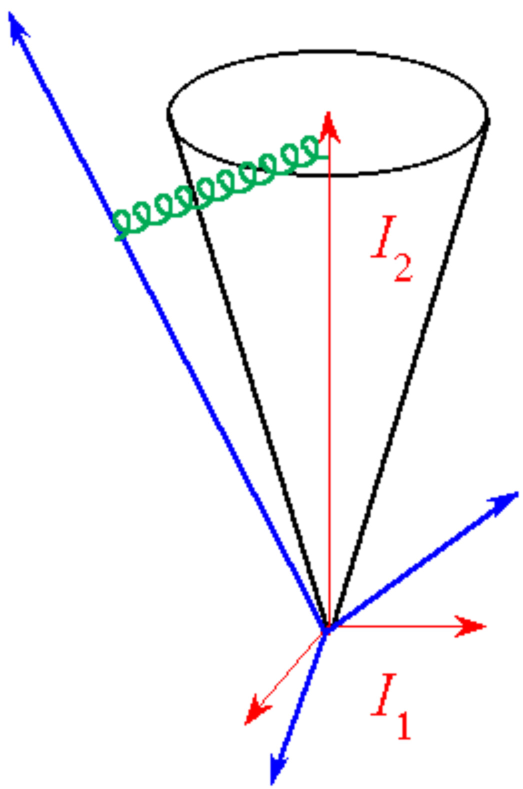

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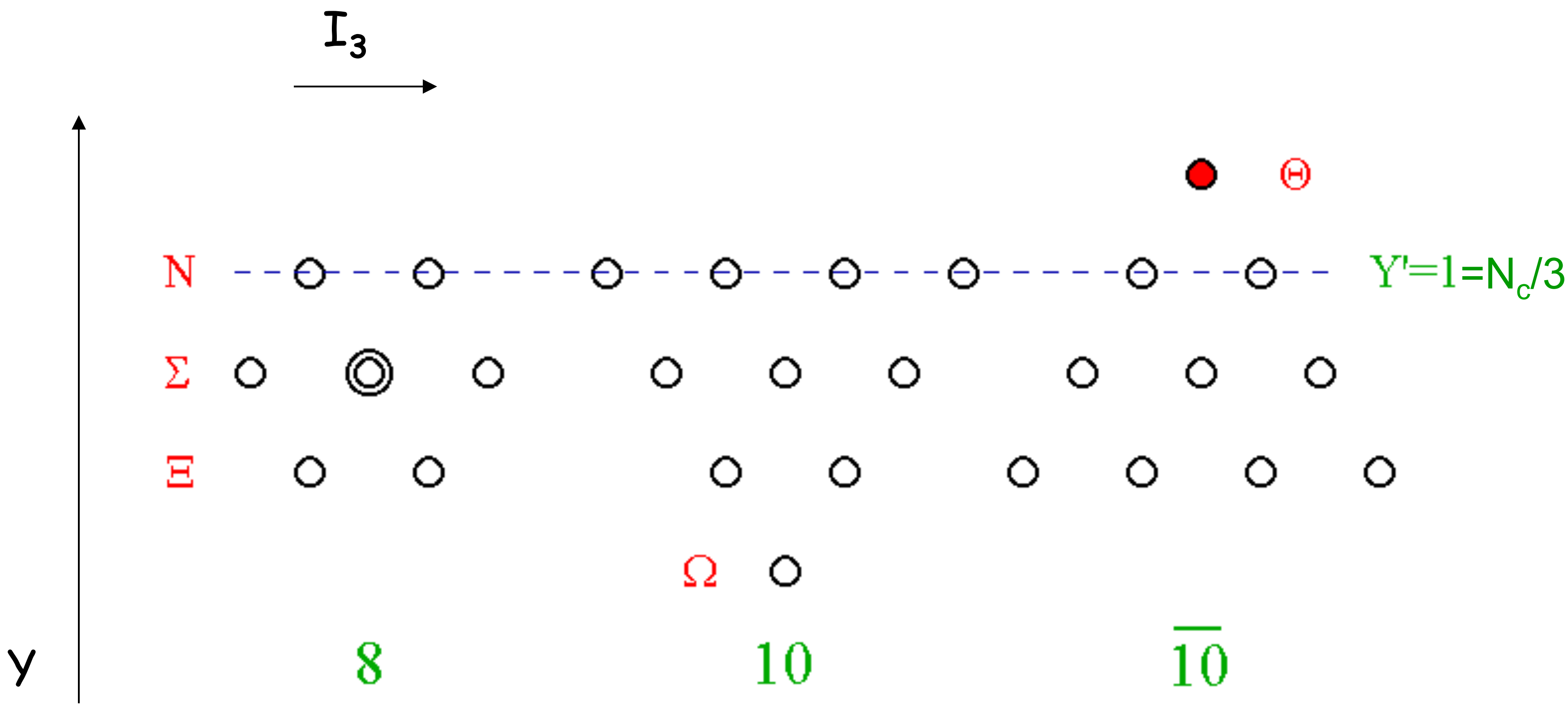
$$\alpha \sim m_s N_c, \quad \beta, \gamma \sim m_s \mathcal{O}(1)$$

$$M_{\rm cl} \sim N_c \times M_{\rm const}$$

expected accuracy: $\frac{1}{N_c} \times \frac{m_s}{M_{\rm const}} \sim 10\%$

Wave functions and allowed states

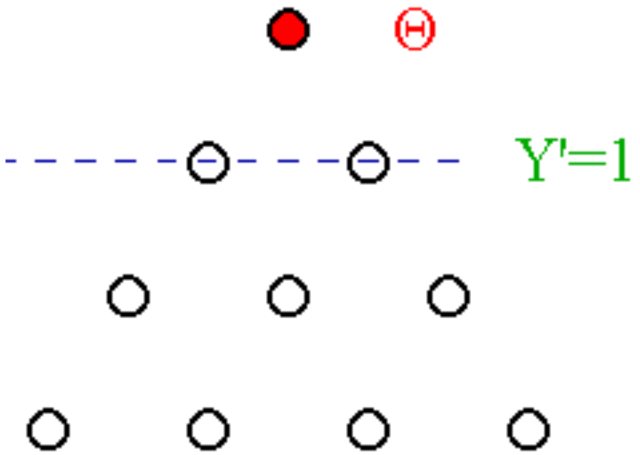
$$|R,B,S\rangle = \sqrt{R}\, D^{(\mathcal{R})\,*}_{\underbrace{Y I I_3}_{B}\ \underbrace{Y' J J_3}_{S}}(A) \qquad J_3 = -S_3$$



Successful Phenomenology

In a "model independent" approach
one can get both good fits to the existing data
(including very narrow light pentaquark Θ^+)
one can fix all necessary model parameters:
M, I_1, I_2, α, β, γ

A comment on light pentaquarks



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NUCLEAR PHYSICS A
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Status of the Θ^+ analysis at LEPS

T. Nakano, for the LEPS collaboration

Research Center for Nuclear Physics, Osaka University, Ibaraki 567-0047, Japan

Abstract

We report recent results on the $Theta^+$ study from LEPS. The $\gamma d \rightarrow K^+K^- pn$ reaction has been studied to search for the evidence of the Θ^+ by detecting K^+K^- pairs at forward angles. The Fermi-motion corrected nK^+ invariant mass distribution shows a narrow peak at 1.53 GeV/c^2. The statistical significance of the peak calculated from a shape analysis is 5 σ, and the differential cross-section for the $\gamma n \rightarrow K^-\Theta^+$ reaction is estimated to be 12 ± 2 nb/sr in the LEPS angular range by assuming the isotropic production.

Key words: Penta-quark, Photo-production

PHYSICAL REVIEW C **89**, 045204 (2014)

Observation of a narrow baryon resonance with positive strangeness formed in K^+Xe collisions

V. V. Barmin,[1] A. E. Asratyan,[1,*] V. S. Borisov,[1] C. Curceanu,[2] G. V. Davidenko,[1] A. G. Dolgolenko,[1] C. Guaraldo,[2] M. A. Kubantsev,[1] I. F. Larin,[1] V. A. Matveev,[1] V. A. Shebanov,[1] N. N. Shishov,[1] L. I. Sokolov,[1] V. V. Tarasov,[1] G. K. Tumanov,[1] and V. S. Verebryusov[1]
(DIANA Collaboration)
[1]*Institute of Theoretical and Experimental Physics, Moscow 117218, Russia*
[2]*Laboratori Nazionali di Frascati dell' INFN, C.P. 13, I-00044 Frascati, Italy*

(Received 9 February 2014; published 14 April 2014)

The charge-exchange reaction $K^+\mathrm{Xe} \to K^0 p \mathrm{Xe}'$ is investigated using the data of the DIANA experiment. The distribution of the pK^0 effective mass shows a prominent enhancement near 1538 MeV formed by nearly 80 events above the background, whose width is consistent with being entirely due to the experimental resolution. Under the selections based on a simulation of K^+Xe collisions, the statistical significance of the signal reaches 5.5σ. We interpret this observation as strong evidence for formation of a pentaquark baryon with positive strangeness, $\Theta^+(uudd\bar{s})$, in the charge-exchange reaction $K^+n \to K^0 p$ on a bound neutron. The mass of the Θ^+ baryon is measured as $m(\Theta^+) = 1538 \pm 2$ MeV. Using the ratio between the numbers of resonant and nonresonant charge-exchange events in the peak region, the intrinsic width of this baryon resonance is determined as $\Gamma(\Theta^+) = 0.34 \pm 0.10$ MeV.

Successful Phenomenology

In a "model independent" approach
one can get both good fits to the existing data
(including very narrow light pentaquark Θ^+)
one can fix all necessary model parameters:
$M, I_1, I_2, \alpha, \beta, \gamma$

but also one can recover the NRQM result
in a special limit

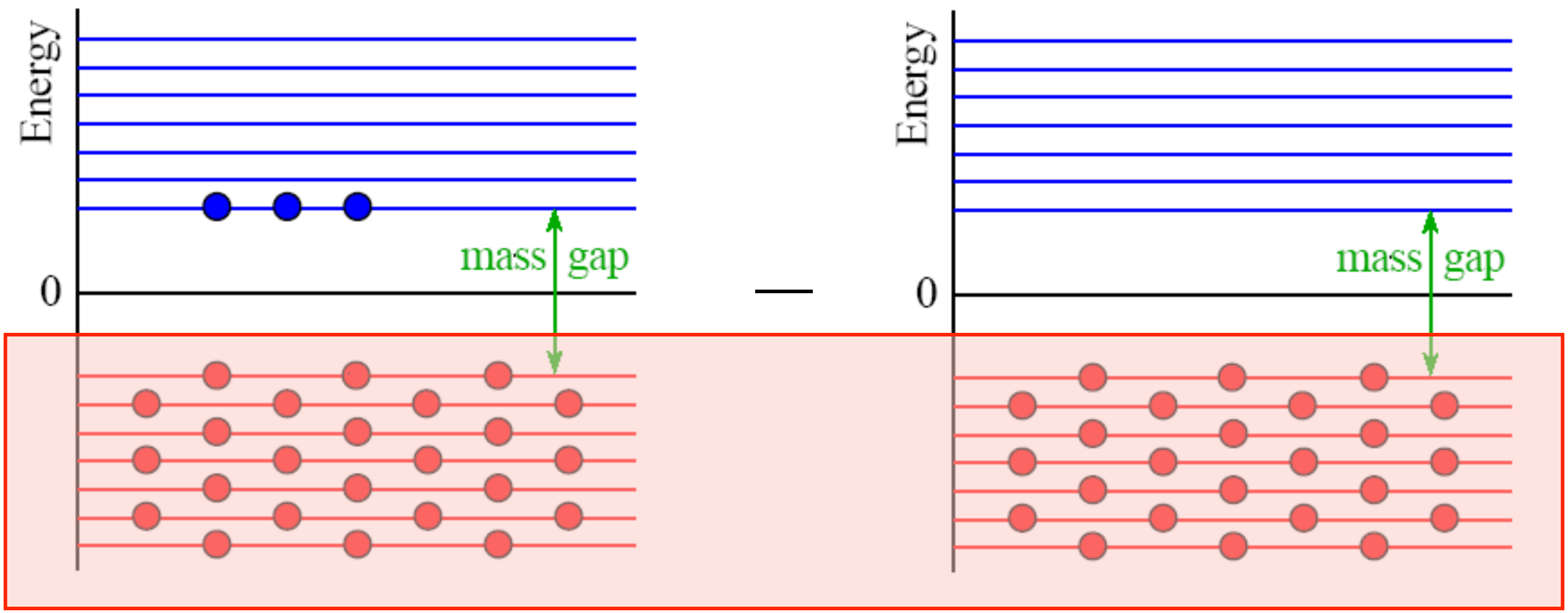
NRQM limit =
= squeezing the soliton to zero size

NRQM Limit

Diakonov, Petrov, Polyakov, Z.Phys **A359** (97) 305

MP, A.Blotz K.Goeke, Phys.Lett.**B354**:415-422,1995

energy is calculated
with respect to the vacuum:



in the NRQM limit only valence level contributes

NRQM Limit

Diakonov, Petrov, Polyakov, Z.Phys **A359** (97)

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$$g_A^{(3)} = \frac{5}{3}, \quad \Delta\Sigma = 1, \quad \frac{\mu_p}{\mu_n} = -\frac{3}{2}$$

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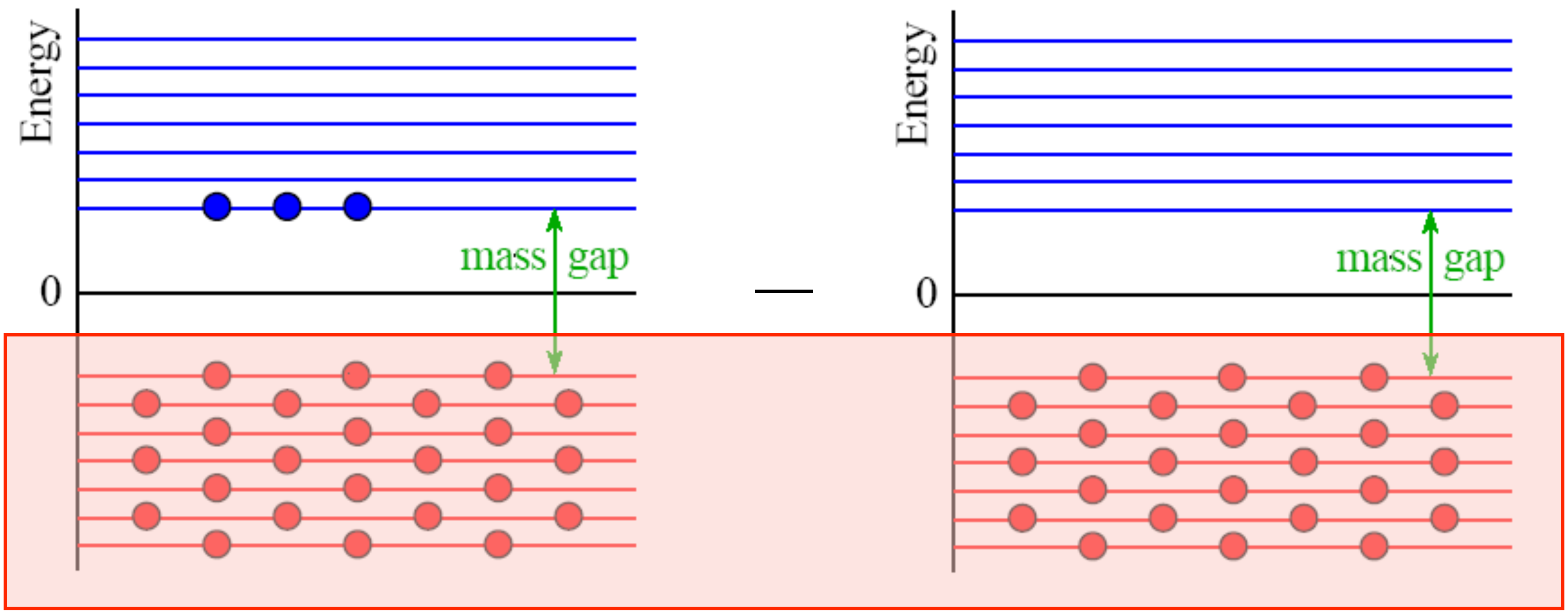

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NRQM Limit

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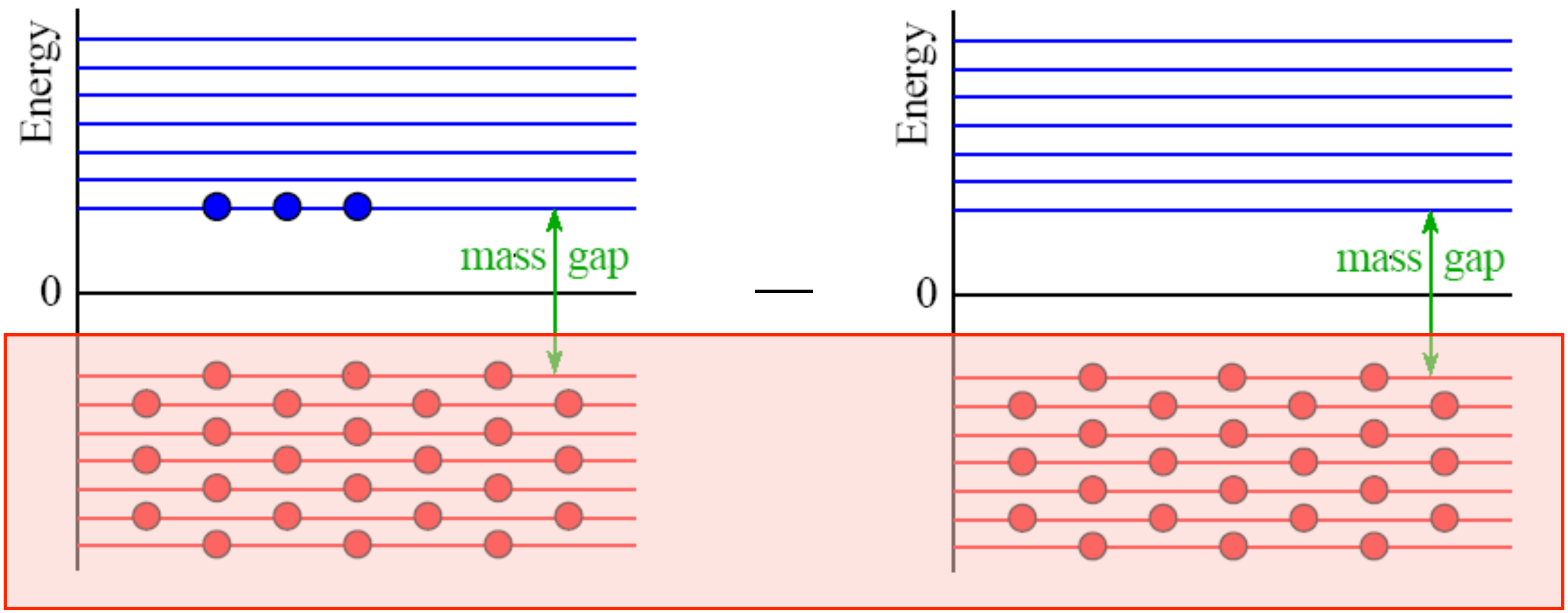
$$g_A^{(3)} = \frac{5}{3}, \quad \Delta\Sigma = 1, \quad \frac{\mu_p}{\mu_n} = -\frac{3}{2}$$

$$G_{\overline{10}} = 0$$

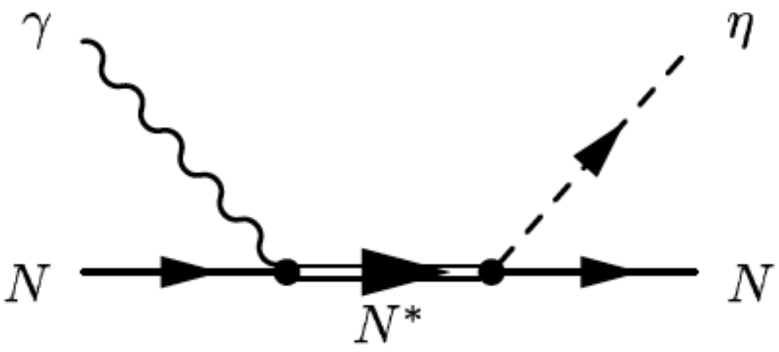
energy is calculated
with respect to the vacuum:

pentaquark width = 0 !

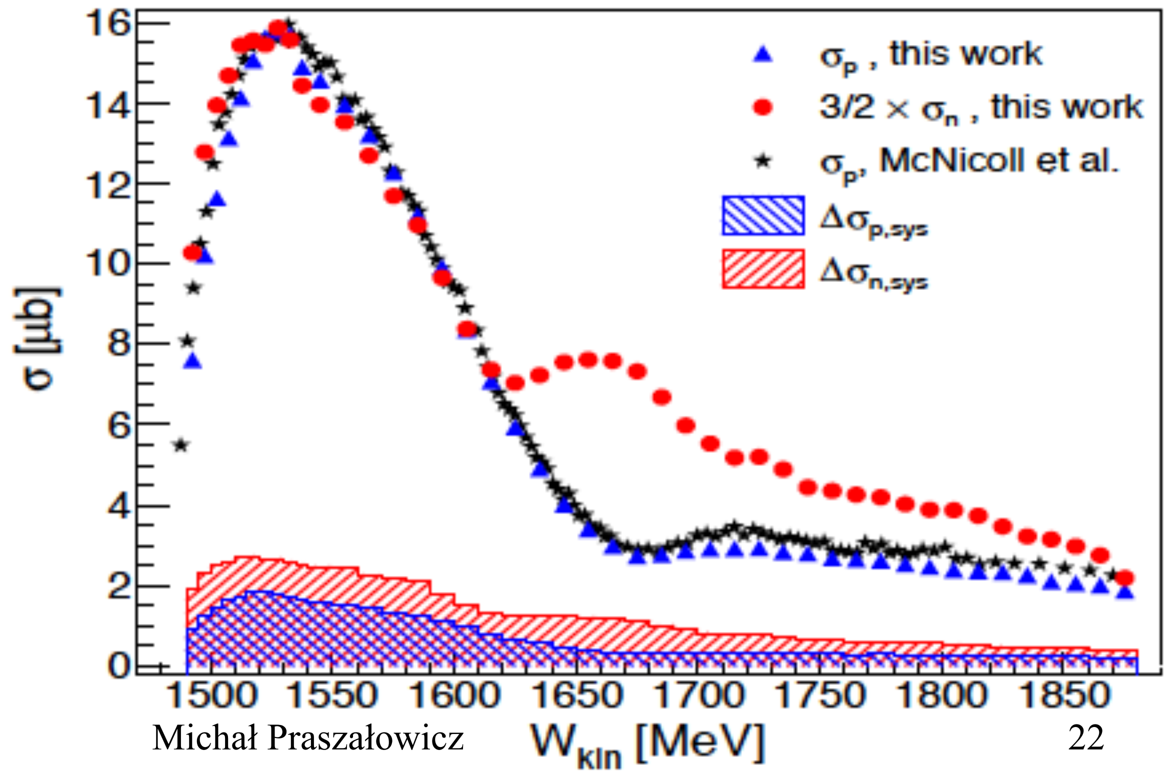


in the NRQM limit only valence level contributes

Pentanucleon?



D. Werthmuller et al. [A2 Collaboration]
Phys. Rev. Lett. 111 (2013) 23, 232001
Eur. Phys. J. A 49 (2013) 154
Phys. Rev. Rev. C 90 (2014) 015205



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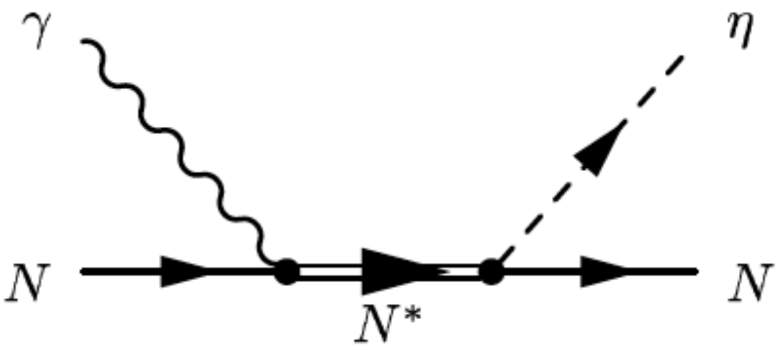
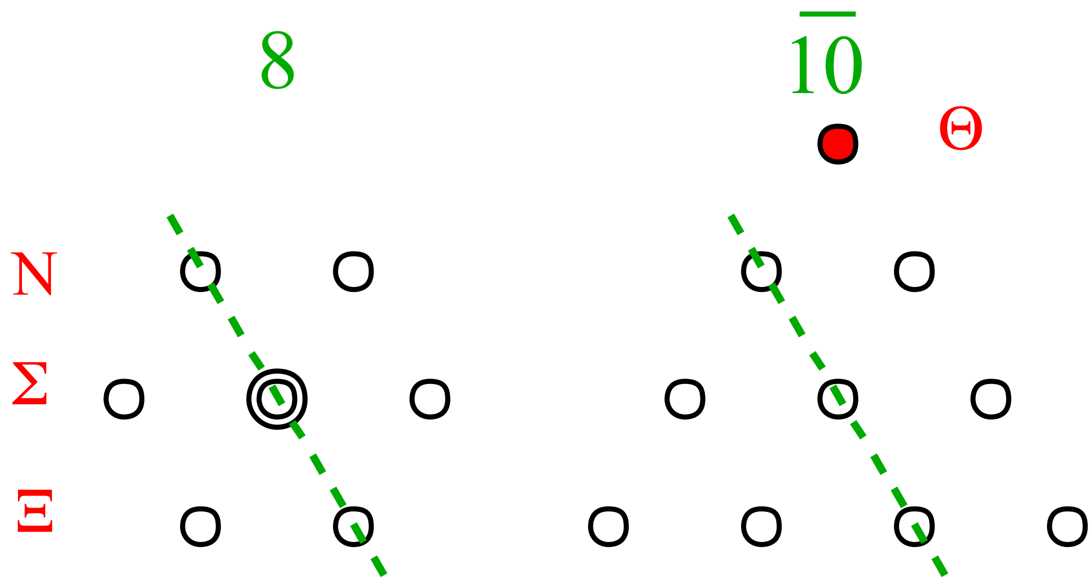


M.V. Polyakov and A. Rathke,
On photoexcitation of baryon anti-decuplet
Eur. Phys. J. A 18 (2003) 691



natural (but not the only one) explanation if N^* is a pentaquark

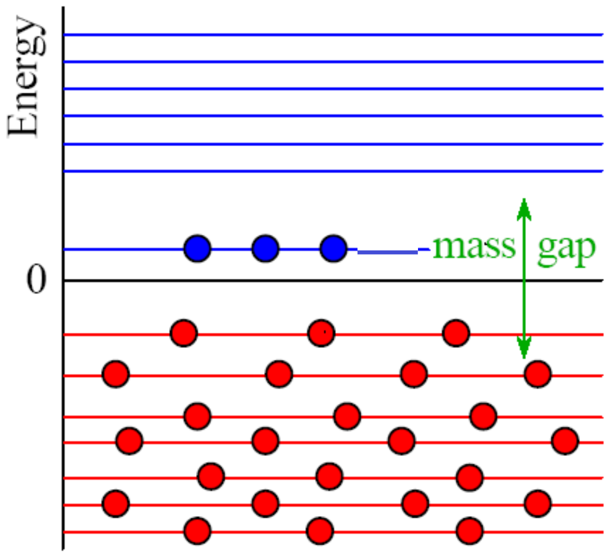
Insight into the Narrow Structure in η Photoproduction on the Neutron from Helicity-Dependent Cross Sections

(A2 Collaboration at MAMI)

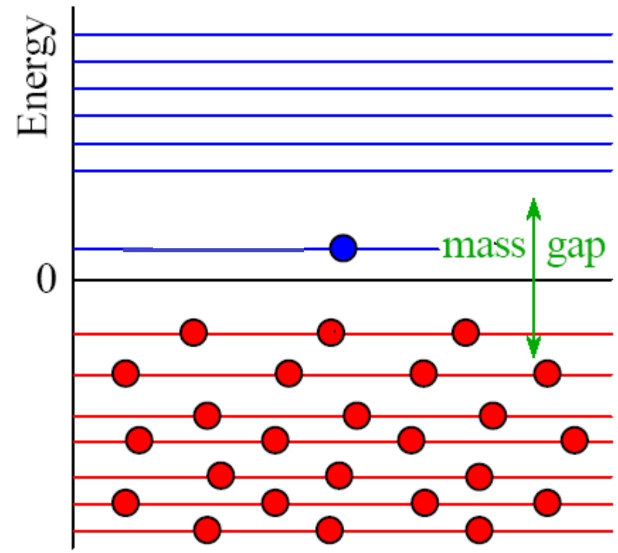
The double polarization observable E and the helicity dependent cross sections $\sigma_{1/2}$ and $\sigma_{3/2}$ were measured for η photoproduction from quasifree protons and neutrons. The circularly polarized tagged photon beam of the A2 experiment at the Mainz MAMI accelerator was used in combination with a longitudinally polarized deuterated butanol target. The almost 4π detector setup of the Crystal Ball and TAPS is ideally suited to detect the recoil nucleons and the decay photons from $\eta \to 2\gamma$ and $\eta \to 3\pi^0$. The results show that the narrow structure previously observed in η photoproduction from the neutron is only apparent in $\sigma_{1/2}$ and hence, most likely related to a spin-$1/2$ amplitude. Nucleon resonances that contribute to this partial wave in η production are only $N1/2^-$ (S_{11}) and $N1/2^+$ (P_{11}). Furthermore, the extracted Legendre coefficients of the angular distributions for $\sigma_{1/2}$ are in good agreement with recent reaction model predictions assuming a narrow resonance in the P_{11} wave as the origin of this structure.

Soliton with $N_c - 1$ quarks

if N_c is large, $N_c - 1$ is also large and one can use the same mean field arguments

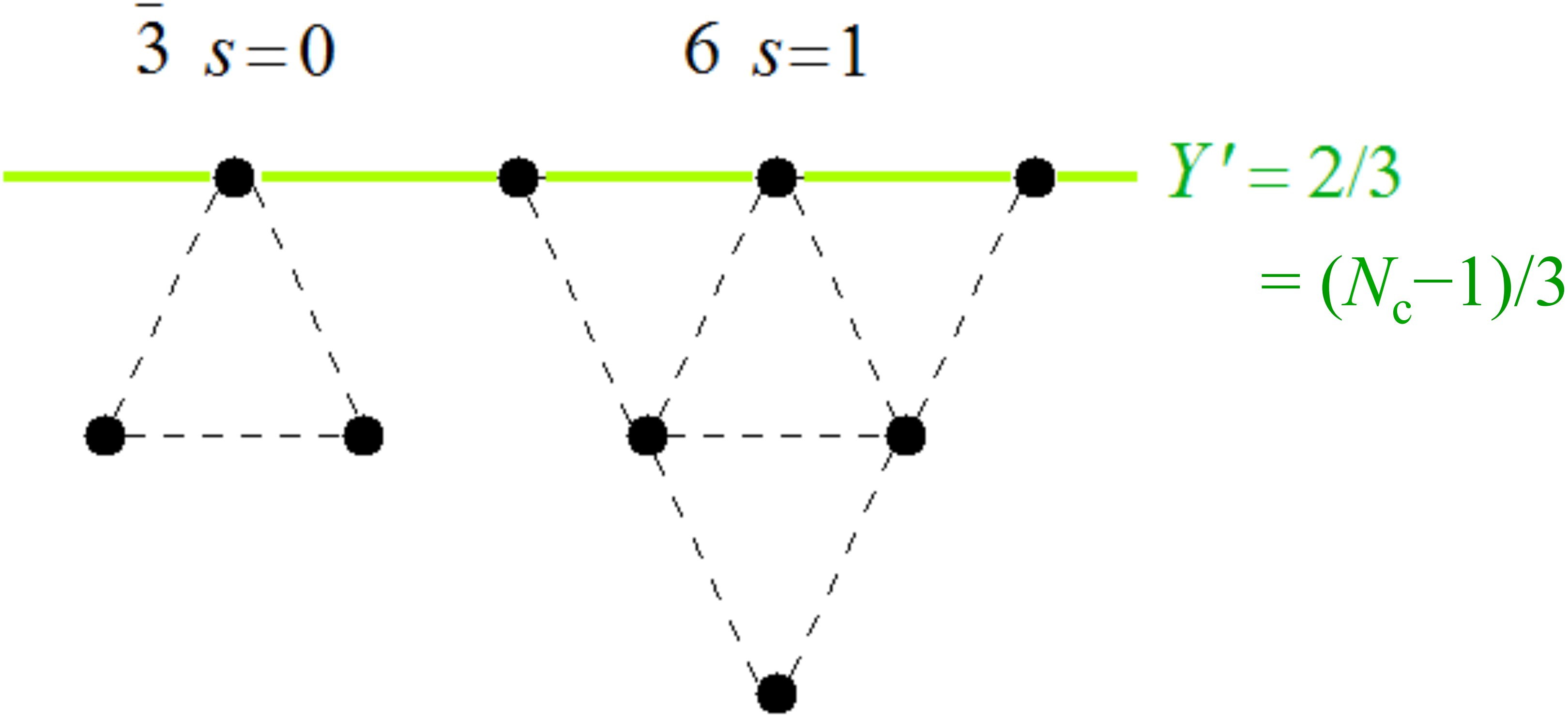


$$= (N_c - 1) \times$$

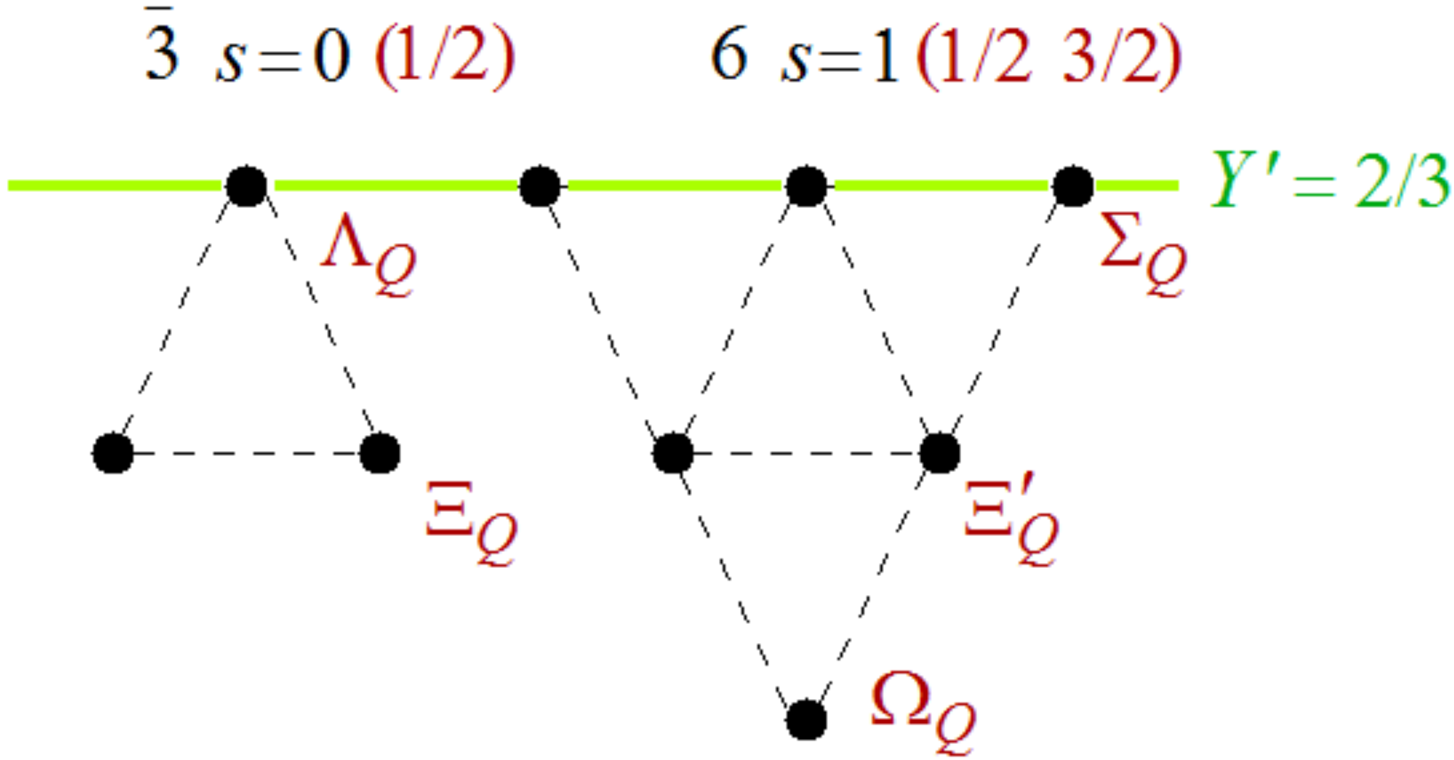


color factorizes!

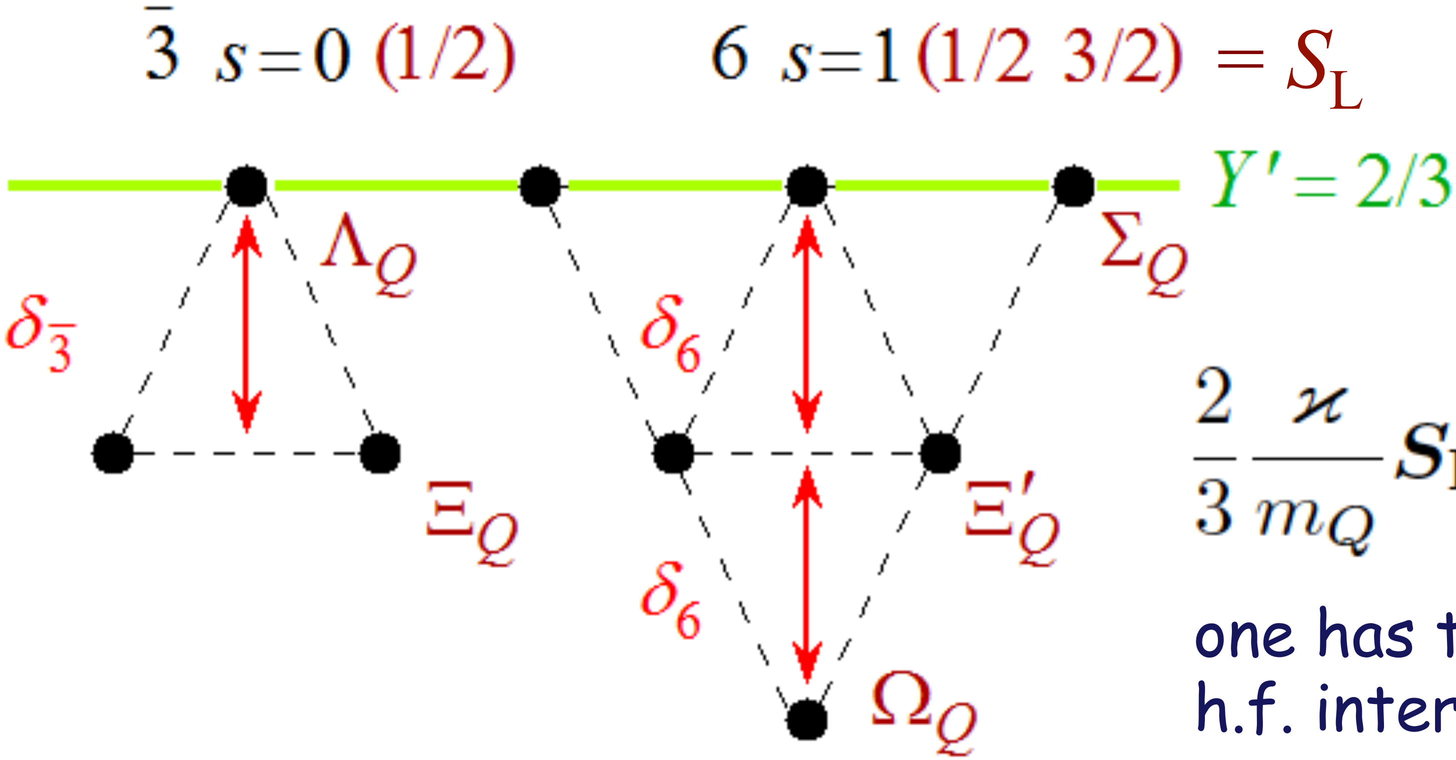
Allowed SU(3) irreps.



Heavy Baryons: soliton + heavy Q



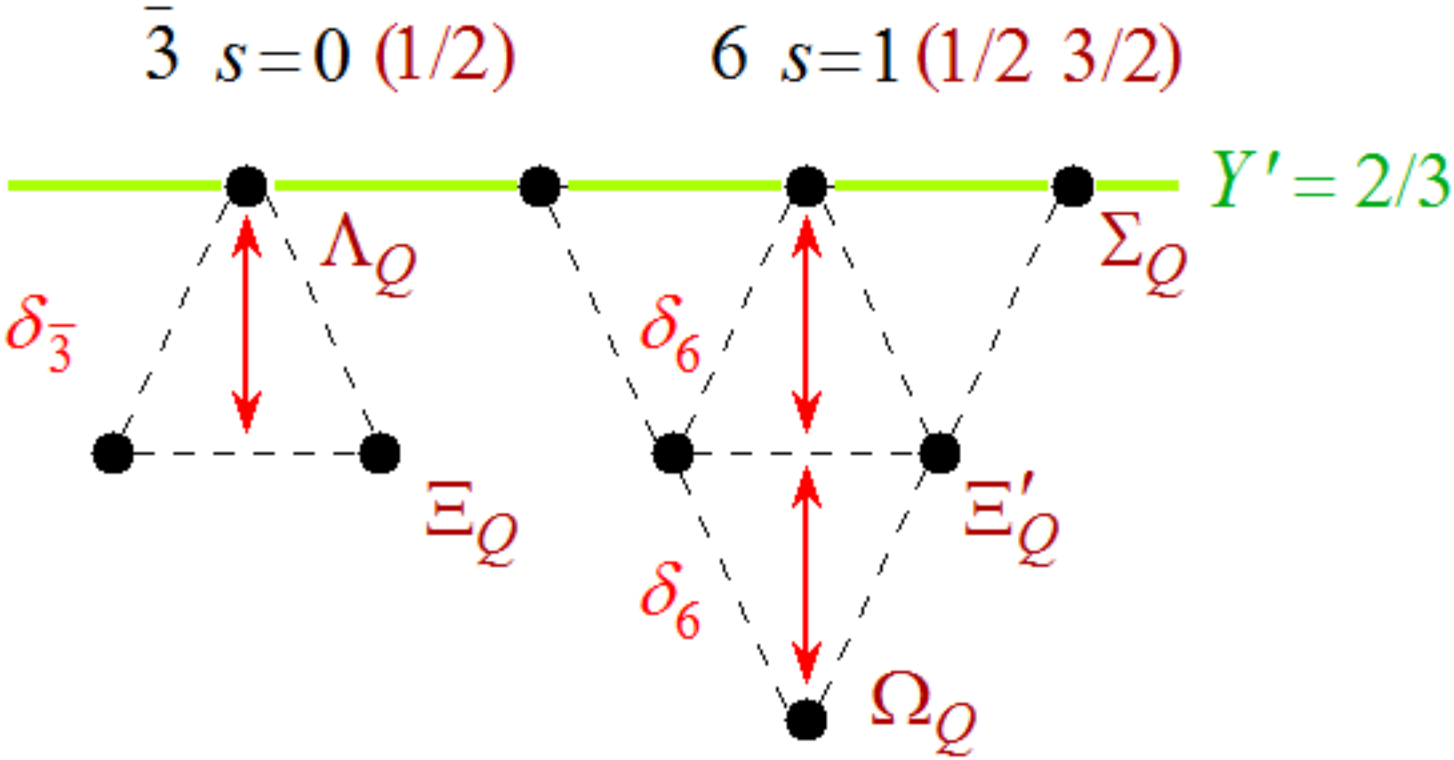
Splittings inside multiplets



$$\frac{2}{3}\frac{\varkappa}{m_Q}\boldsymbol{S}_\mathrm{L}\cdot\boldsymbol{S}_Q$$

one has to add h.f. interaction

Splittings inside multiplets



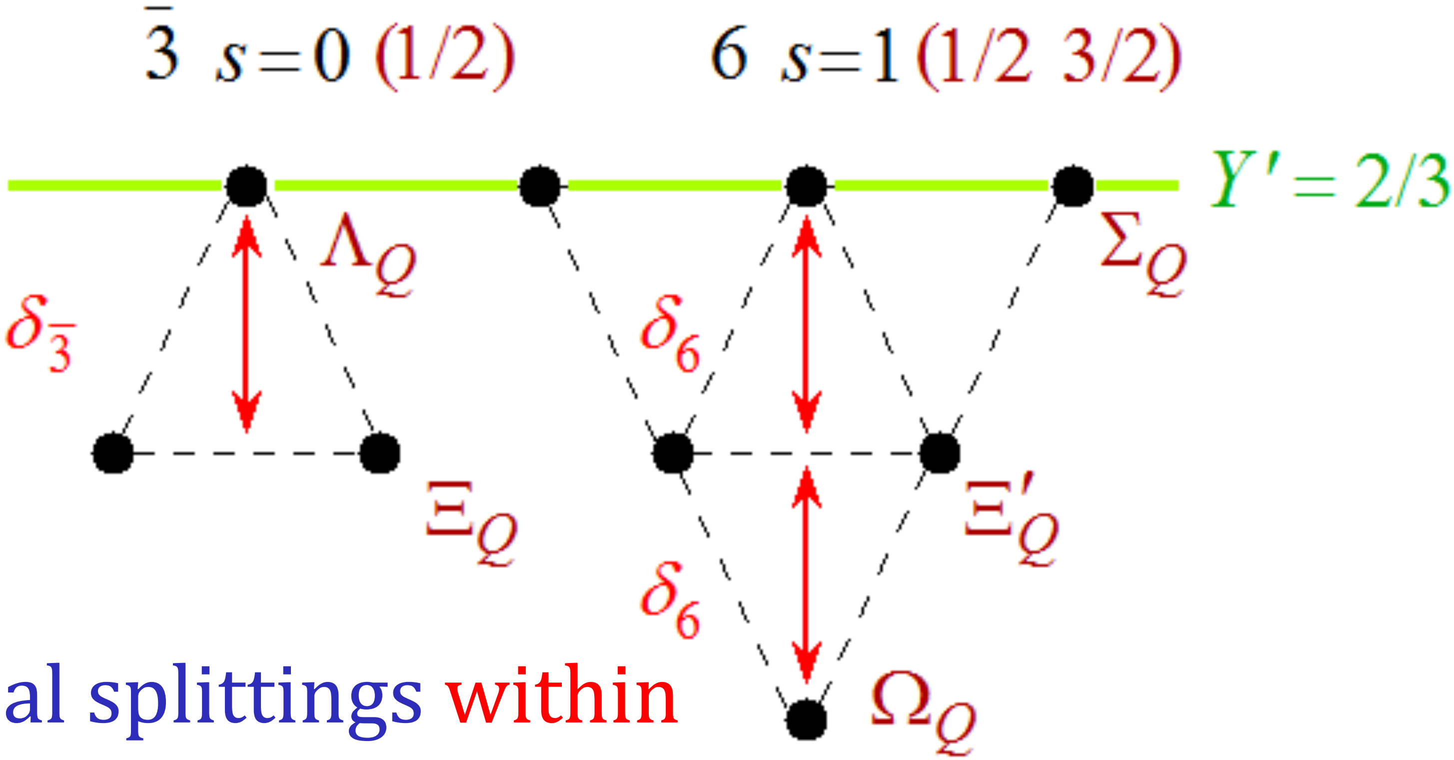
$$\delta_{\bar{\mathbf{3}}} = 182.9 \pm 0.3|_{\Xi_c - \Lambda_c} = 173.6 \pm 0.7|_{\Xi_b - \Lambda_b}$$

Splittings inside multiplets

6 $s=1$ (1/2 3/2)

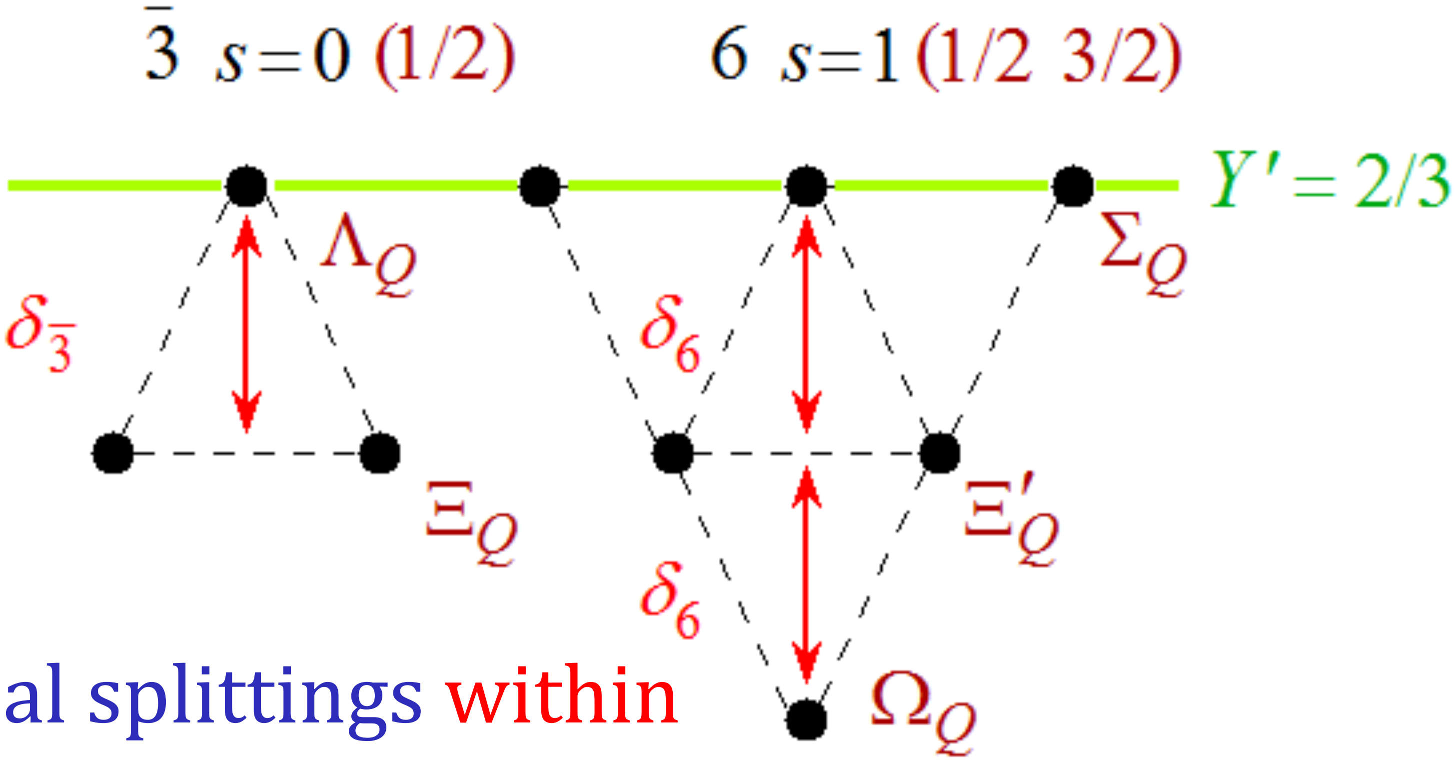
$$
\begin{aligned}
\delta_{\mathbf{6}} &= 123.3 \pm 2.1|_{\Xi_c'-\Sigma_c} = 118.4 \pm 2.7|_{\Omega_c-\Xi_c'} \\
&= 127.8 \pm 0.8|_{\Xi_c^*-\Sigma_c^*} = 120.0 \pm 2.0|_{\Omega_c^*-\Xi_c^*} \\
&= 121.6 \pm 1.3|_{\Xi_b'-\Sigma_b} = 113.0 \pm 1.9|_{\Omega_b-\Xi_b'} \\
&= 121.7 \pm 1.3|_{\Xi_b^*-\Sigma_b^*} .
\end{aligned}
$$

Splittings inside multiplets



Equal splittings within multiplets follow from Eckhart-Wigner theorem (GMO relations)

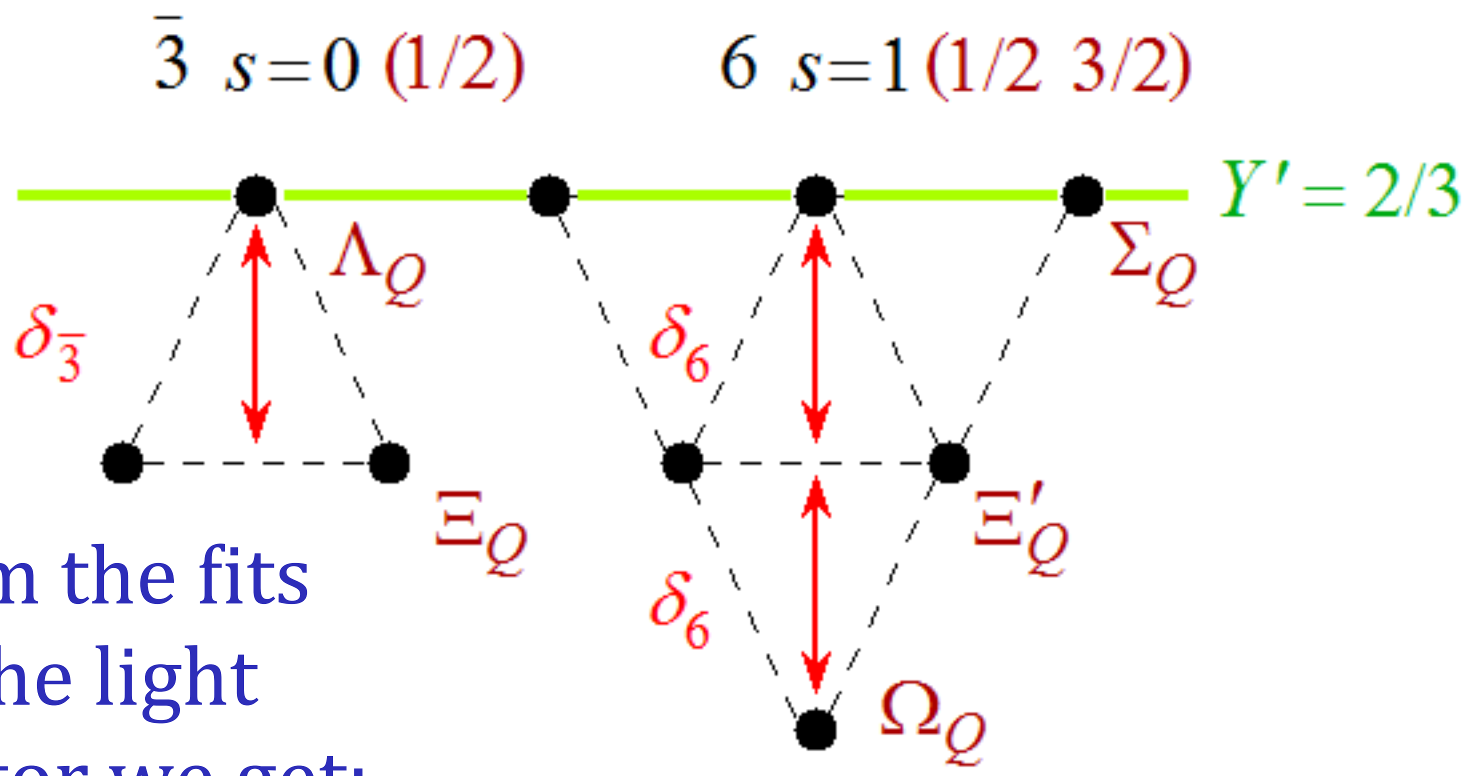
Splittings inside multiplets



Equal splittings within multiplets follow from Eckhart-Wigner theorem (GMO relations)

however the relation between the deltas does not

Splittings inside multiplets



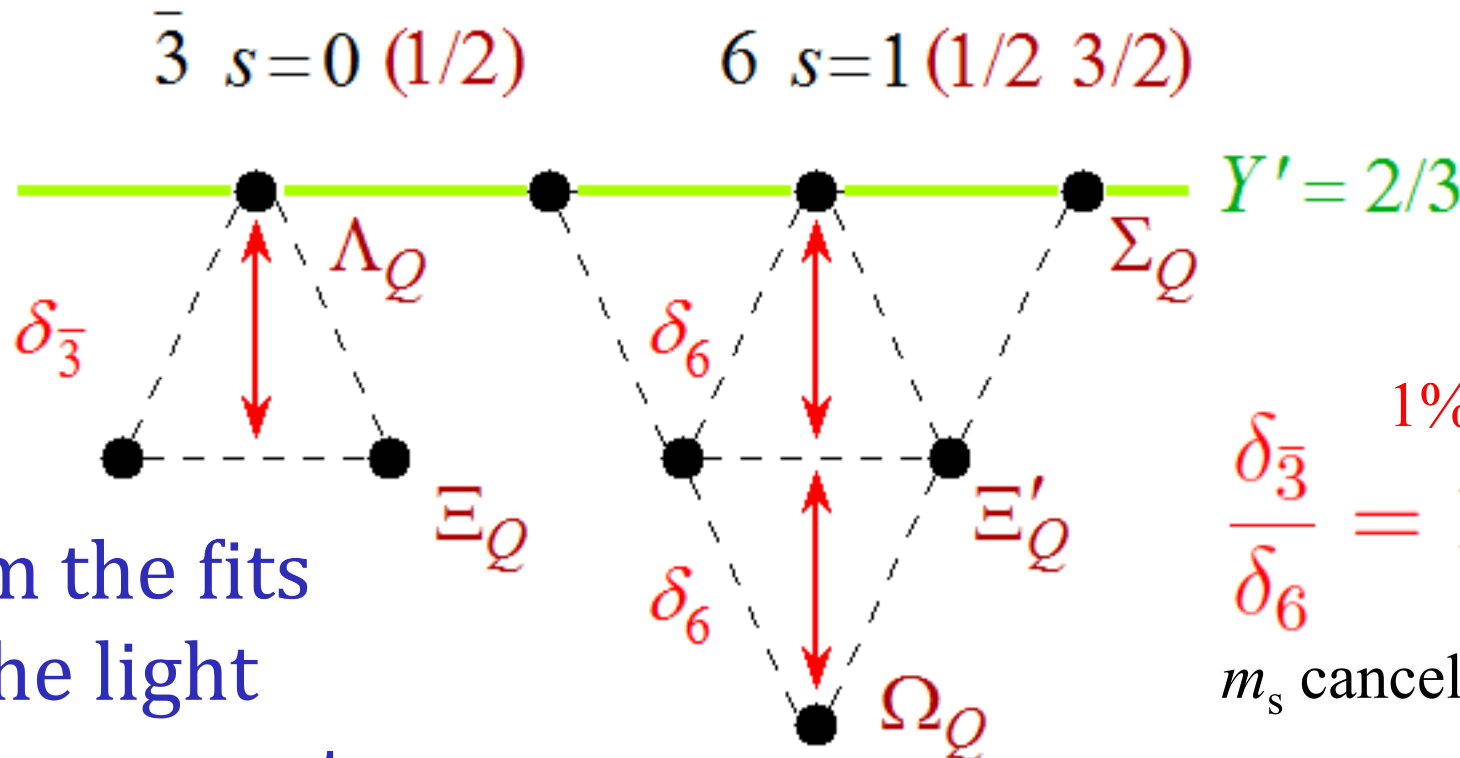
from the fits
to the light
sector we get:

$$\delta_{\mathbf{\bar{3}}} = 203.8 \pm 3.5 \text{ MeV}, \quad (\text{exp.: } 178 \text{ MeV})$$

$$\delta_{\mathbf{6}} = 135.2 \pm 3.3 \text{ MeV}, \quad (\text{exp.: } 121 \text{ MeV})$$

13%

Splittings inside multiplets



1%

$$\frac{\delta_{\bar{3}}}{\delta_6} = 1.5$$

m_s cancels out

from the fits to the light sector we get:

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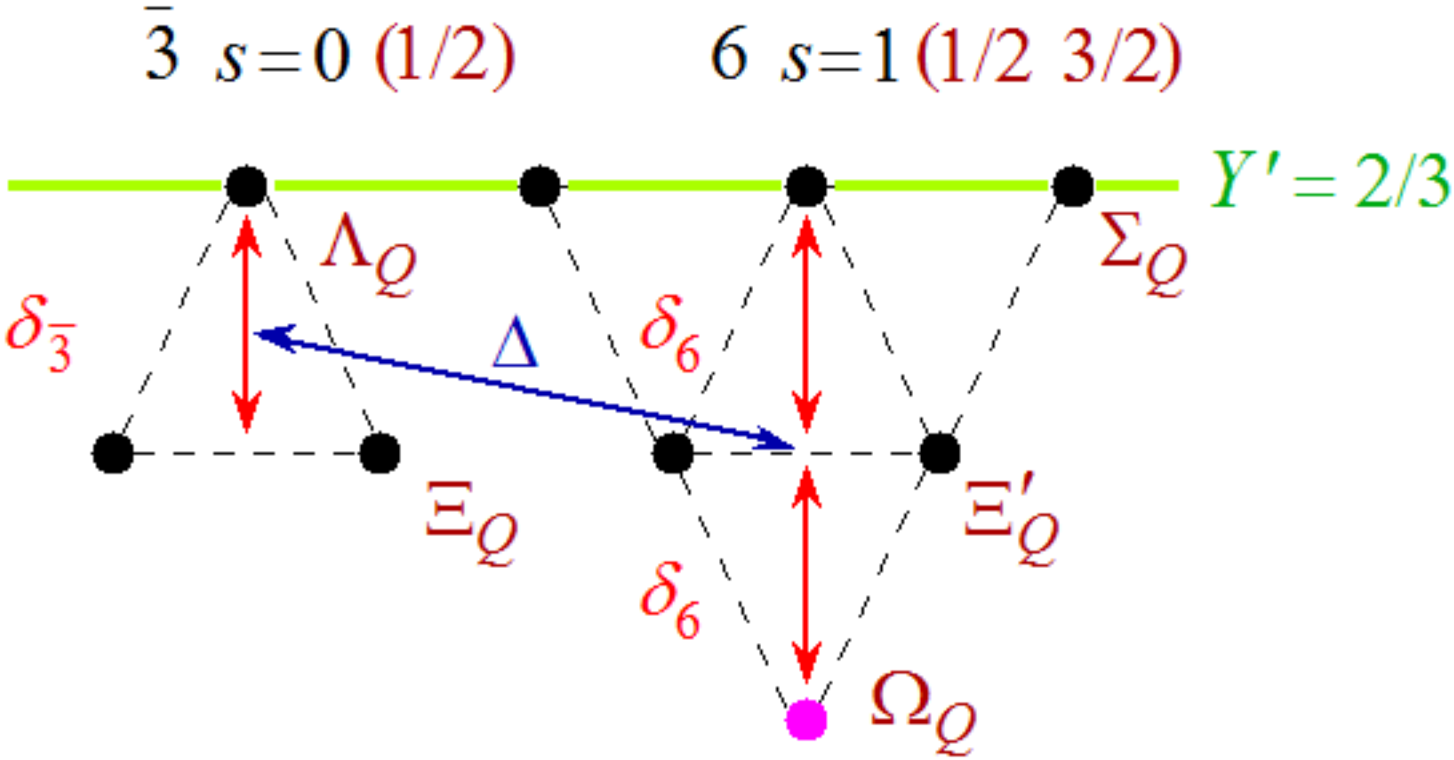
$$\delta_{\mathbf{6}} = 135.2 \pm 3.3 \text{ MeV}, \quad \text{(exp.: 121 MeV)}$$

13%

Splittings between multiplets



$$\Delta \sim \frac{1}{I_1} = \frac{2}{3}(M_{\mathbf{6}}^Q - M_{\bar{\mathbf{3}}}^Q) = 114.7|_c = 115.2|_b$$

Prediction for Ω^*_b

model – independent relation:

$$M_{\Omega^*_Q} = 2M_{\Xi'_Q} + M_{\Sigma^*_Q} - 2M_{\Sigma_Q}$$

satisfied for charm:

$$\Omega^*_c = 2764.5 \pm 3.1 \text{ MeV } (2765.9 \pm 2.0)$$

Prediction for Ω^*_b

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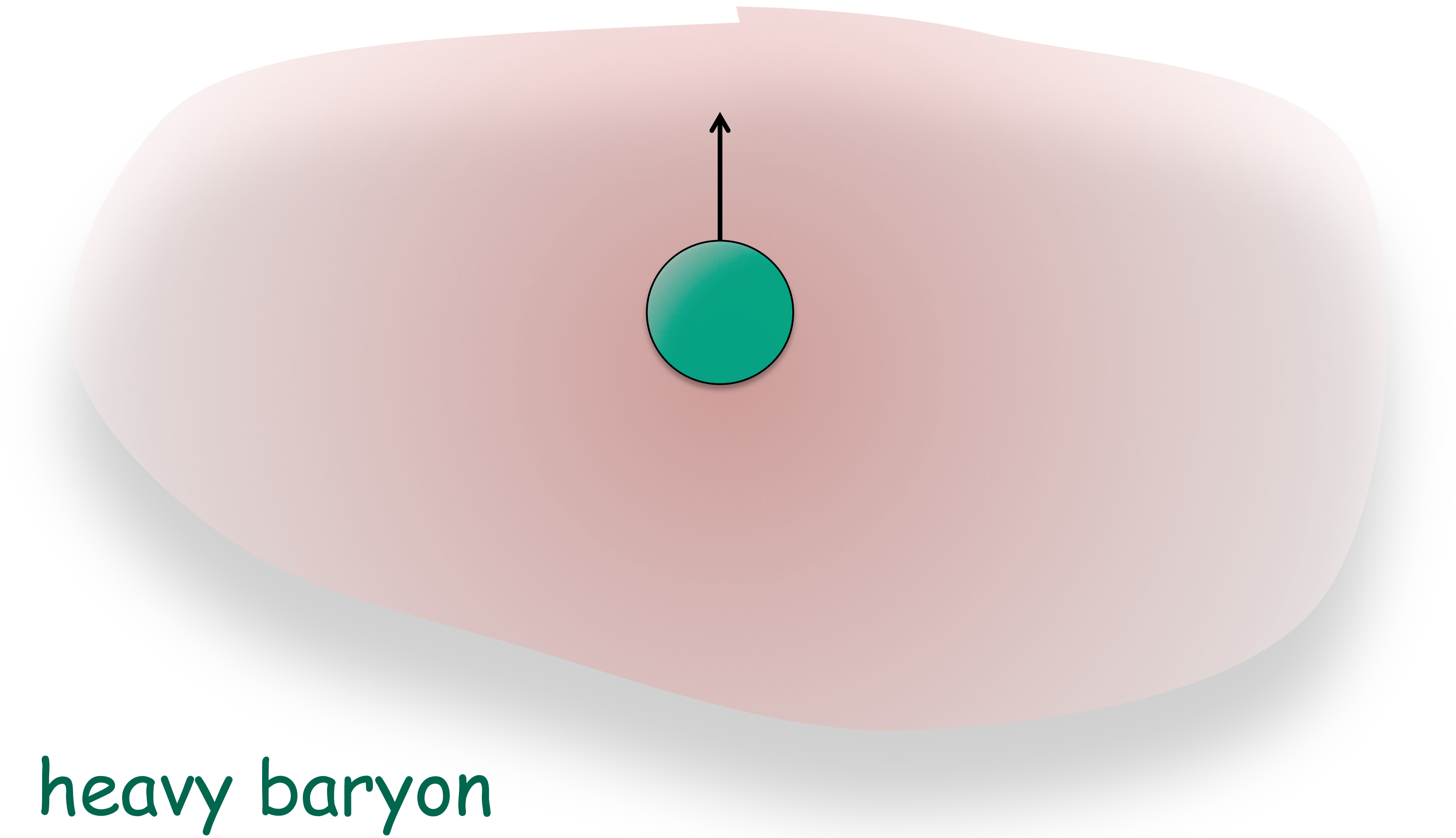
$\Omega^*_b = 6079.8 \pm 2.3$ MeV

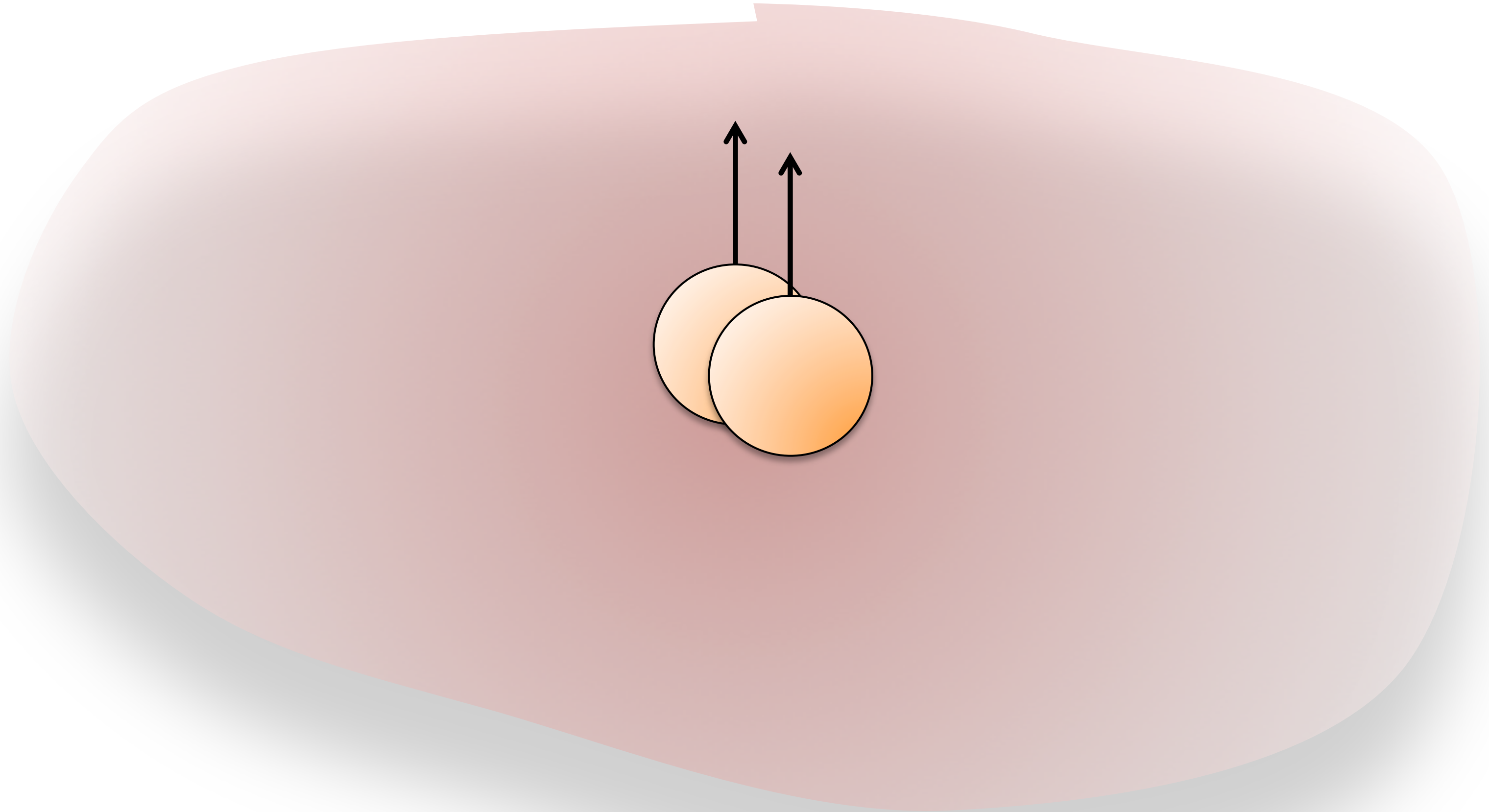
compatible with Karliner and Rosner:

6082.8 ± 5.6 MeV Annals Phys. 324 (2009) 2-15

Further developements

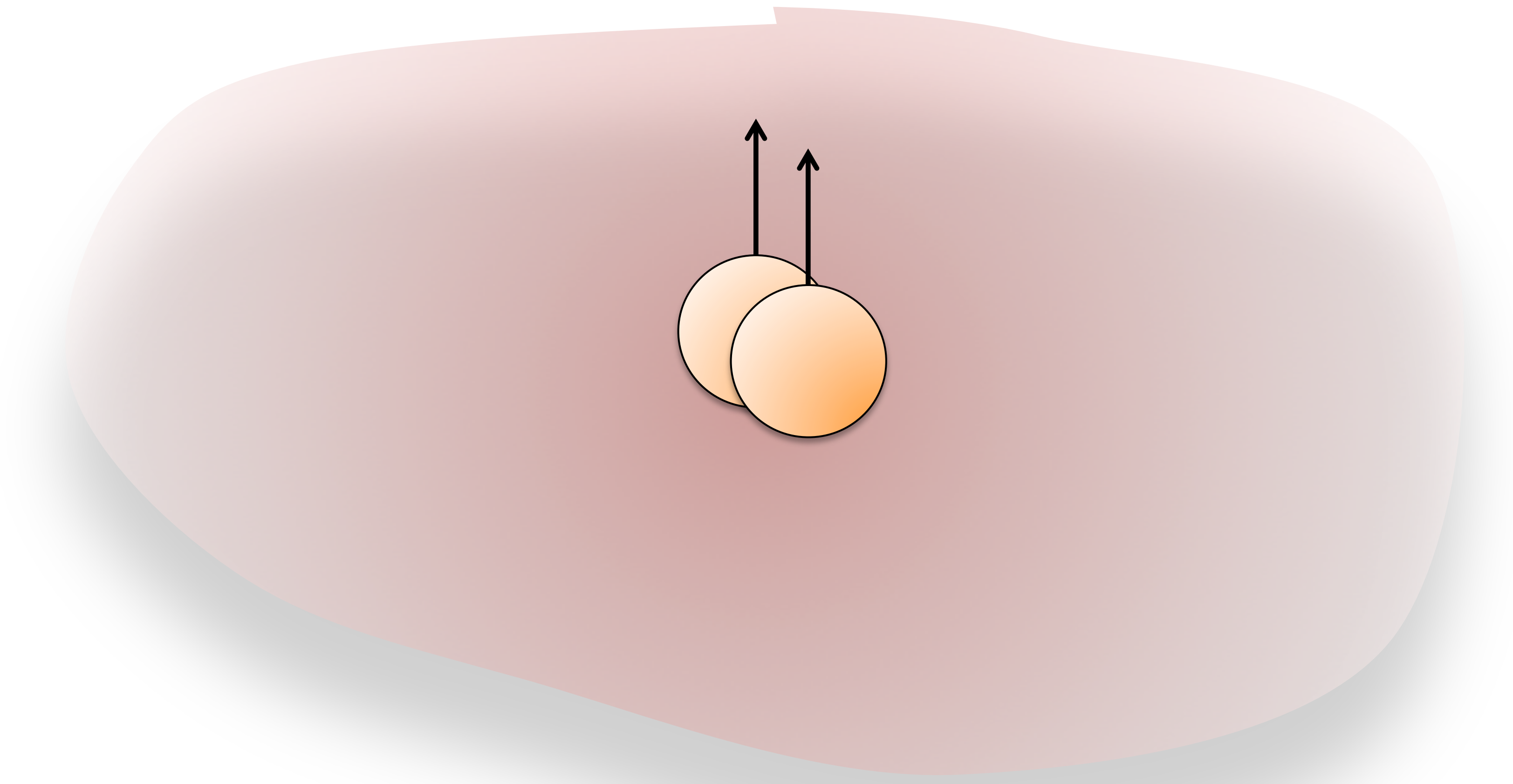


Further developements



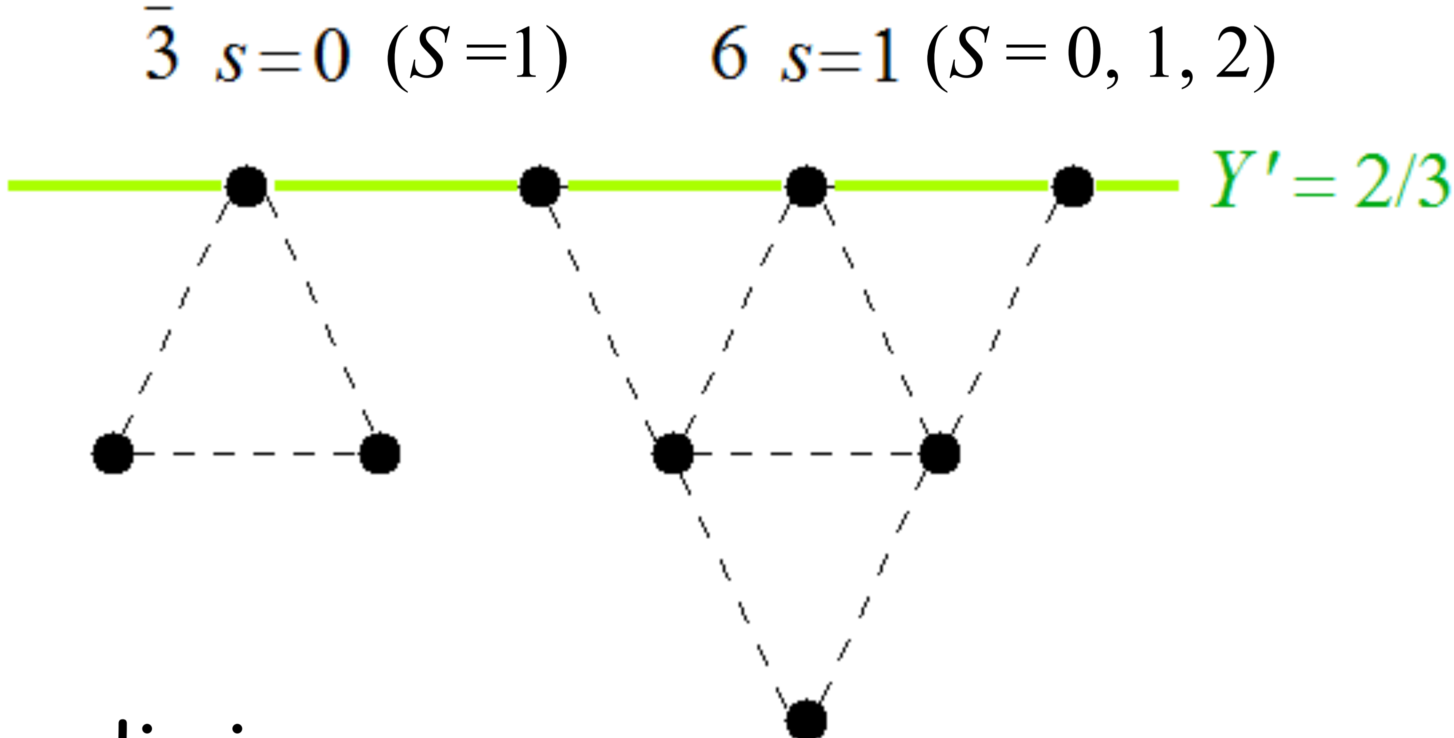
heavy tetraquark

Further developements



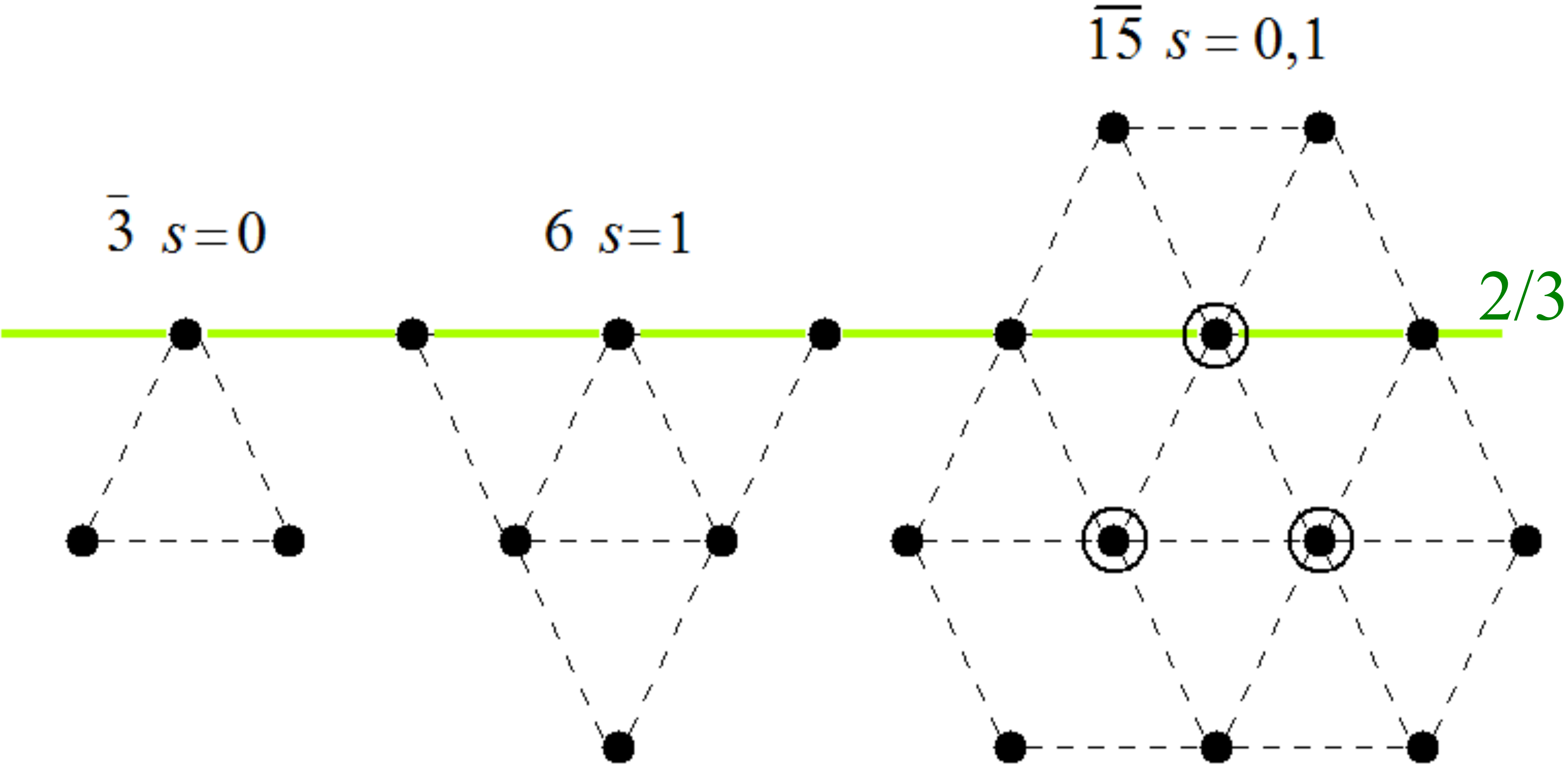
heavy tetraquark
= soliton + spin 1 di(anty)quark in color 3

Doubly heavy tetraquarks



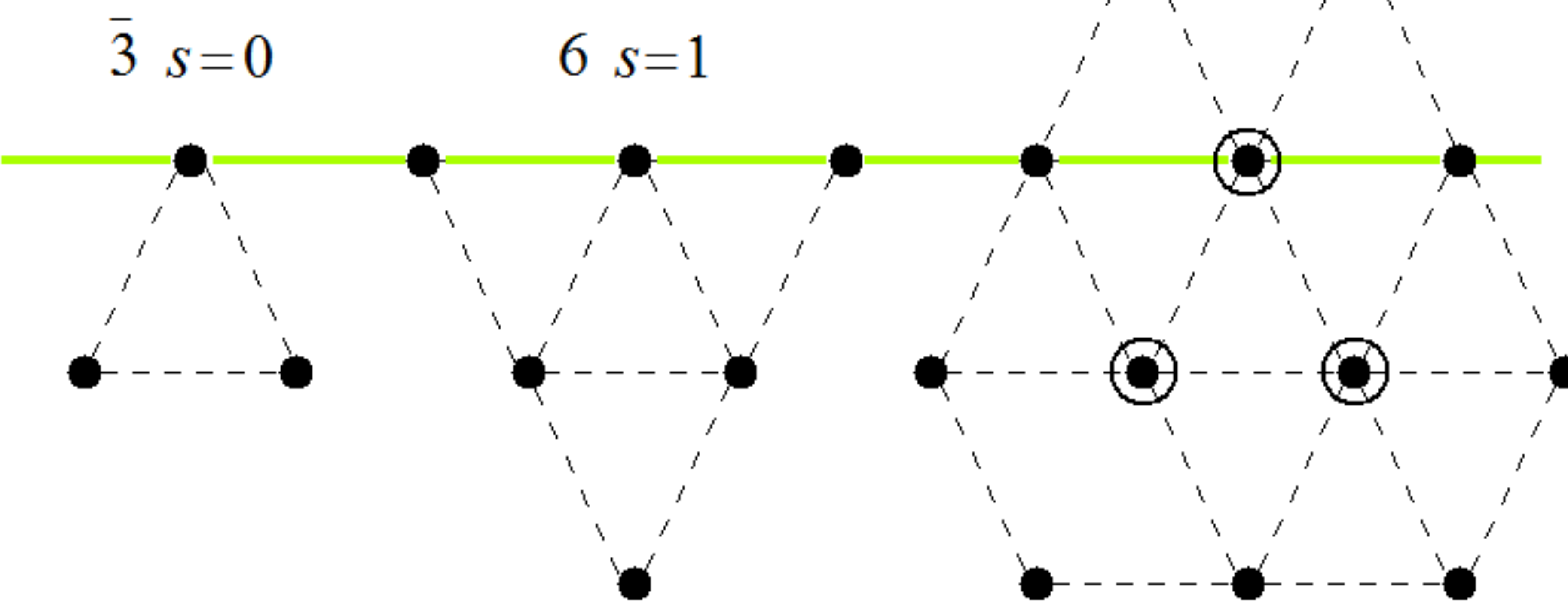
preliminary
studies show that such states maybe stable against strong decays

Further developements: heavy pentaquarks



Further developements: heavy pentaquarks

soliton in $\overline{15}$ (quatroquark)
+ heavy quark: 2 × 1/2 + 3/2



Thank you !

Thank you !

you are welcome