Possibility of the existence of charm exotica

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in collaboration with
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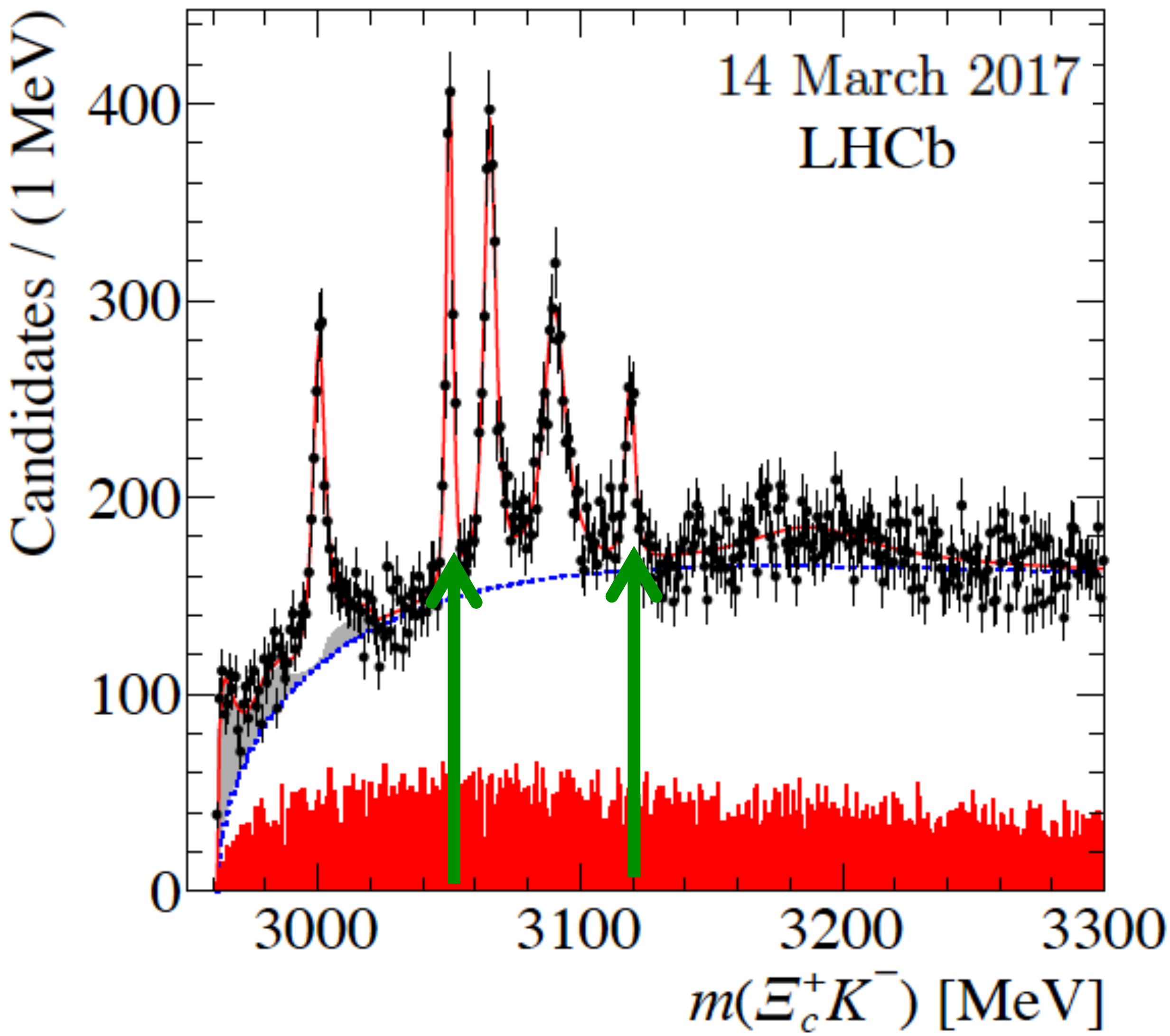
Ω_c^{**} as charmed exotica



Five very narrow resonances, unknown quantum numbers

Resonance	Mass (MeV)	Γ (MeV)
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$
	70 MeV	$< 1.2\,\mathrm{MeV}, 95\%\ \mathrm{CL}$
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$
		$< 2.6\,\mathrm{MeV}, 95\%\ \mathrm{CL}$
$\Omega_c(3188)^0$	$3188 \pm 5 \pm 13$	$60 \pm 15 \pm 11$

- Chiral Quark Soliton Model – intro
- Light sector phenomenology
- Narrow and light pentaquark
- Soliton model for heavy baryons: ground state: 3-bar and 6
- Excitations: regular and exotic
- Test on known ground states and on 3-bar excitations
- Interpretation of the LHCb data
- Consequences and summary

QCD: quarks and gluons

↓ integrate out gluons

many quark nonlocal interactions

Lagrangian chirally symmetric

↓ approximation:

manyq, nonl. ⟶ 4q, local

Nambu Jona Lasinio model

spontaneous chiral symmetry breaking

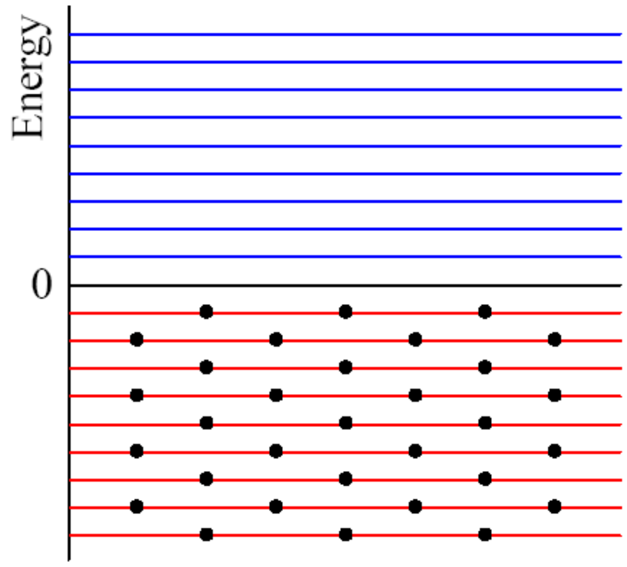
↓ semibosonization:

$q\bar{q}q\bar{q} \longrightarrow q\bar{q}\pi$

Chiral Quark Model

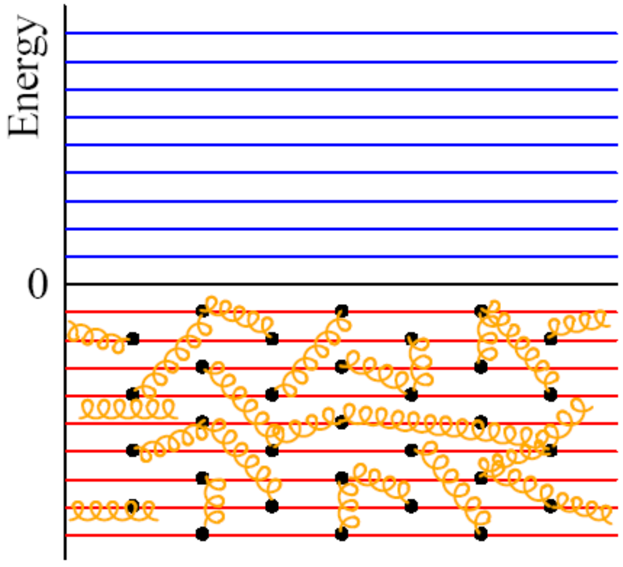
Chiral Quark Soliton Model

QCD vacuum:



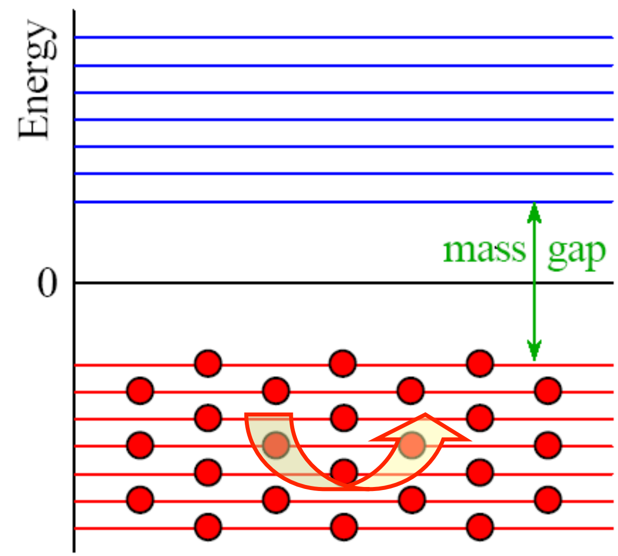
Chiral Quark Soliton Model

QCD vacuum:



Chiral Quark Soliton Model

chiral symmetry breaking:

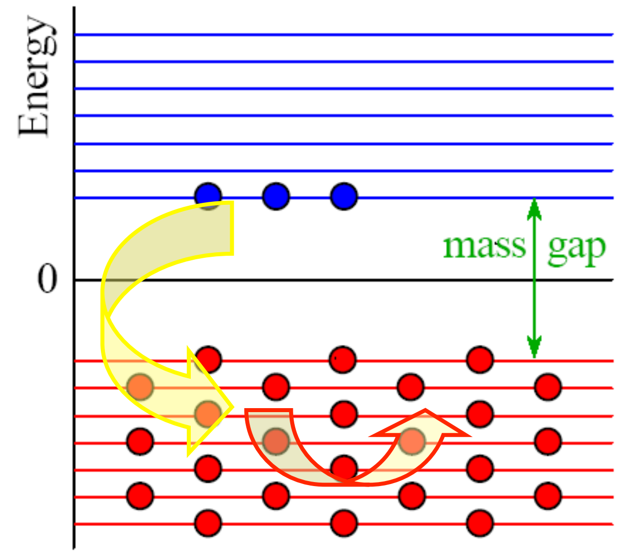


chirally inv. manyquark int.

Chiral Quark Soliton Model

baryon:

adding vlence quarks:

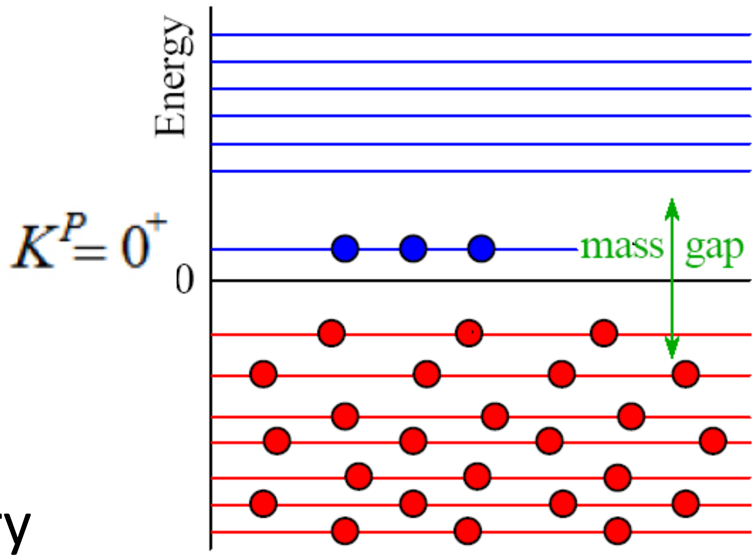


chirally inv. manyquark int.

Chiral Quark Soliton Model

baryon:

"classical" baryon:



due to hedgehog symmetry
of the mean field only
grand spin

$$K = T + S$$

is a *good* quantum number

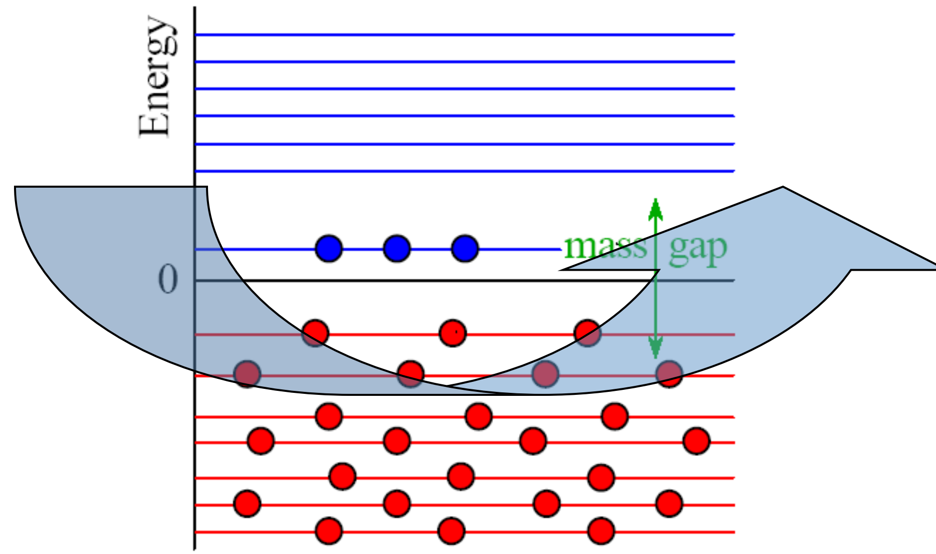
chirally inv. manyquark int.

soliton configuration
no quantum numbers except B

Chiral Quark Soliton Model

baryon:

"quantum" baryon:



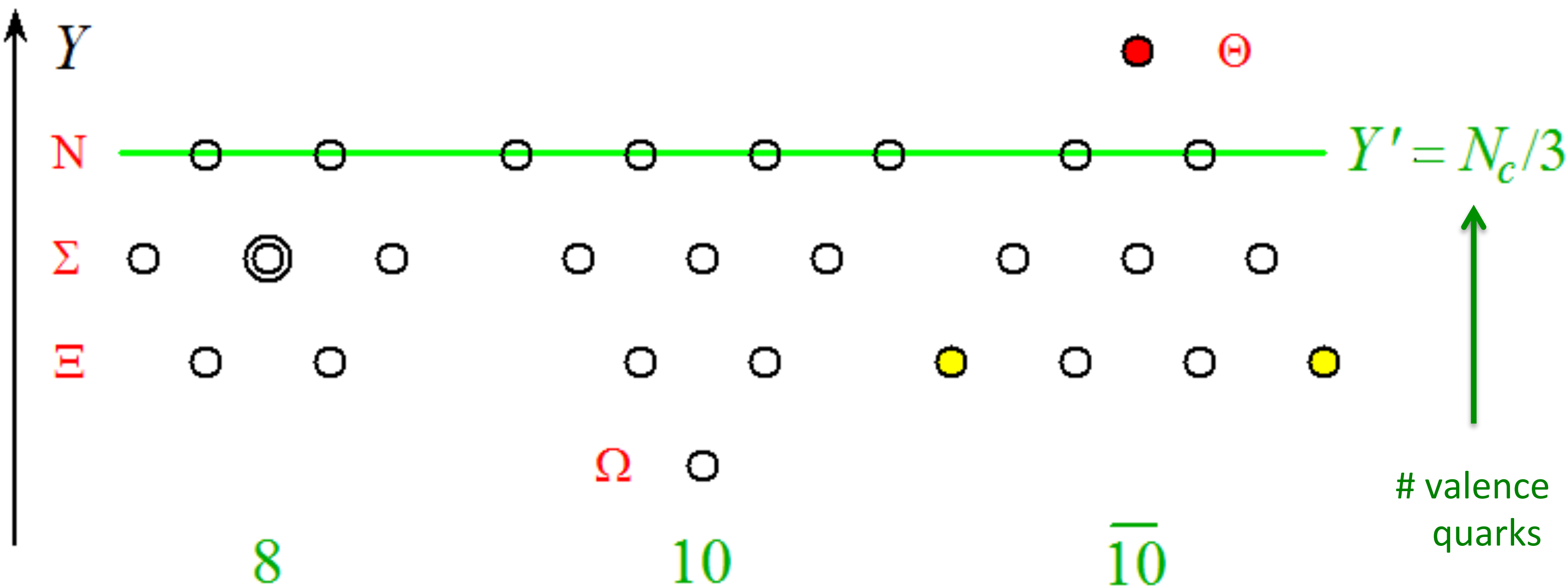
chirally inv. manyquark int.

soliton configuration
no quantum numbers except B

rotation generates flavor and spin

Allowed states

- allowed SU(3) representations must contain states with hypercharge $Y' = N_c/3$,
- the isospin $\boldsymbol{T}'$ of the states with $Y' = N_c/3$ couples with the soliton spin $\boldsymbol{J}$ to a singlet: $\boldsymbol{T}' + \boldsymbol{J} = 0$.



Ch.V. Christov et al. Prog. Part. Nucl. Phys. 37 (1996) 91

Successful Phenomenology

In a ”model independent” approach
one can get good description of the existing data
(including very narrow light pentaquark Θ^+)

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

NRQM limit =
= squeezing the soliton to zero size

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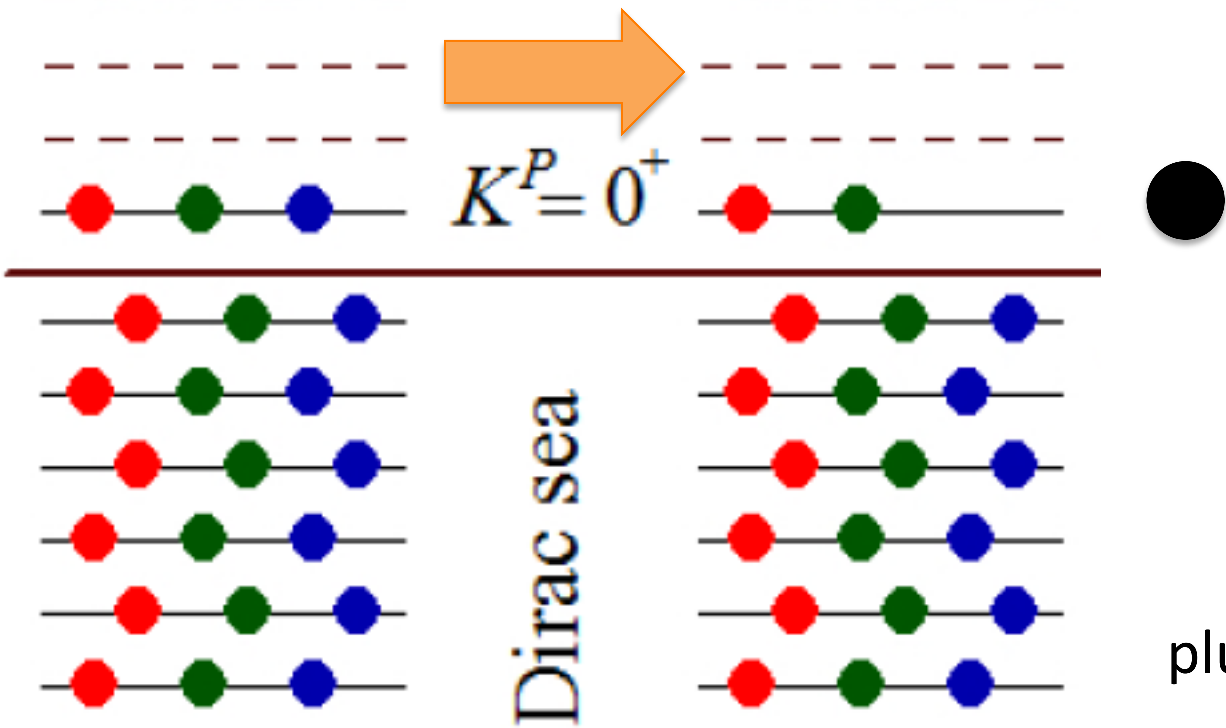
NRQM limit =
= squeezing the soliton to zero size

$$g_A^{(3)} = \frac{5}{3}, \quad \Delta\Sigma = 1, \quad \frac{\mu_p}{\mu_n} = -\frac{3}{2} \qquad G_{\overline{10}} = 0$$

Soliton model for heavy baryons

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



plus one heavy quark

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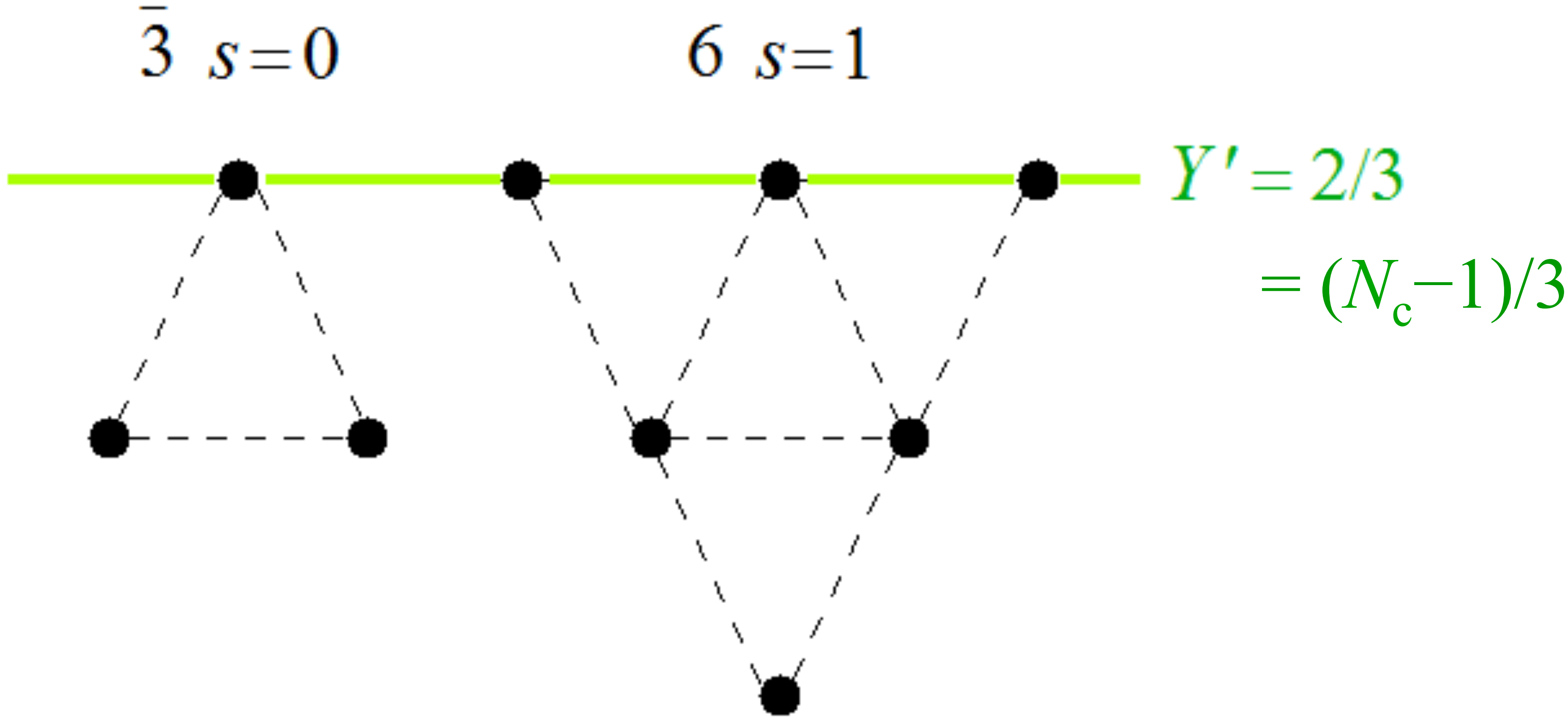
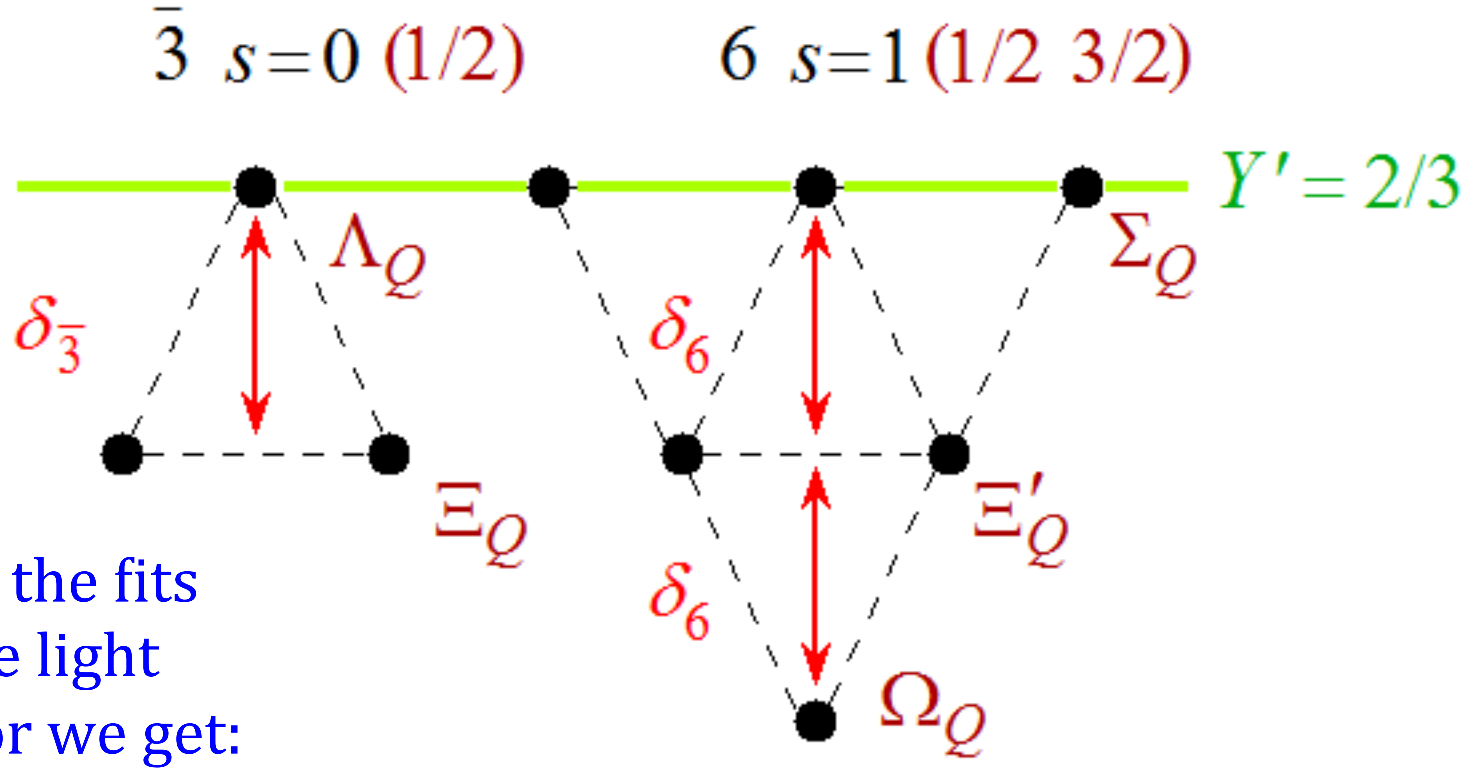
Allowed SU(3) irreps.



Soliton + heavy quark (splittings)



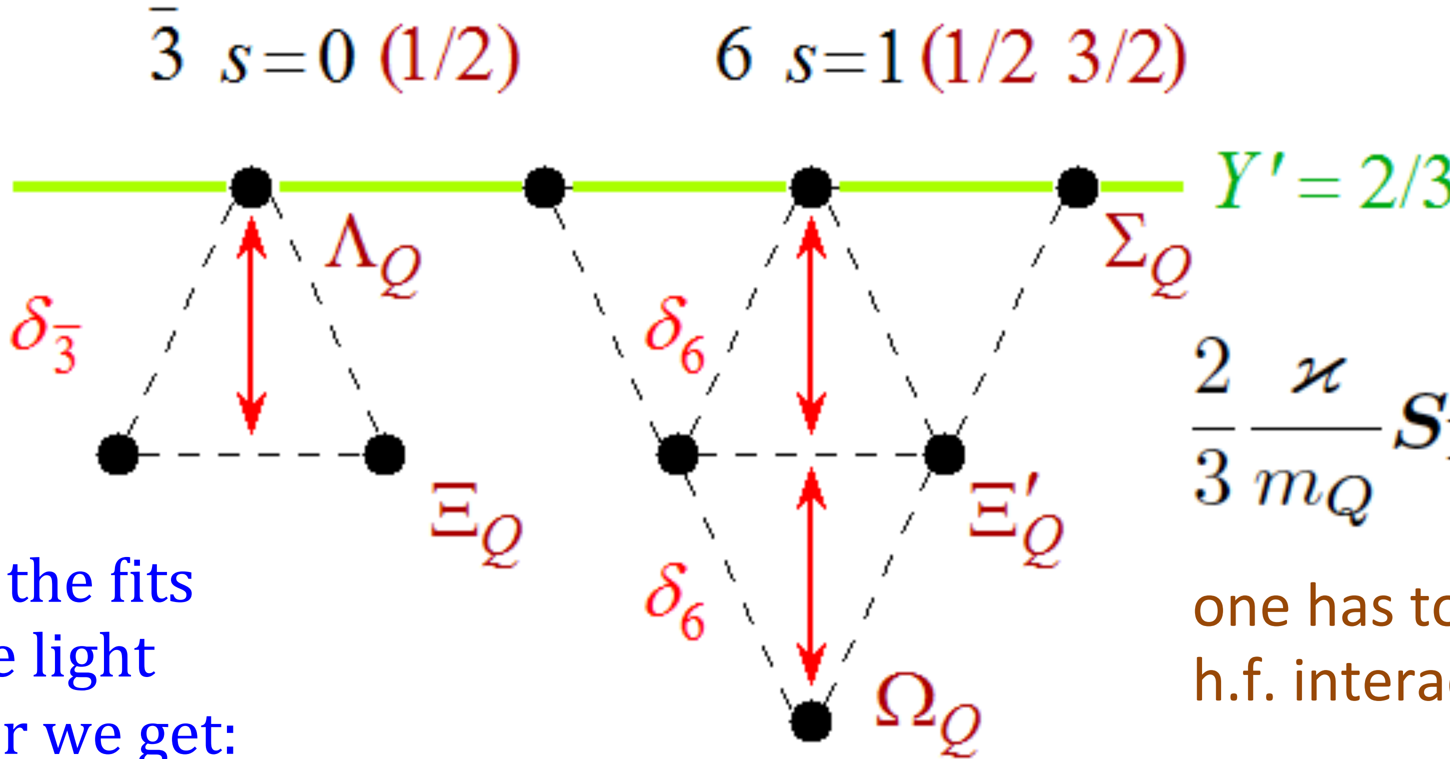
from the fits
to the light
sector we get:

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

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

13%

Soliton + heavy quark (splittings)



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

from the fits to the light sector we get:

one has to add h.f. interaction

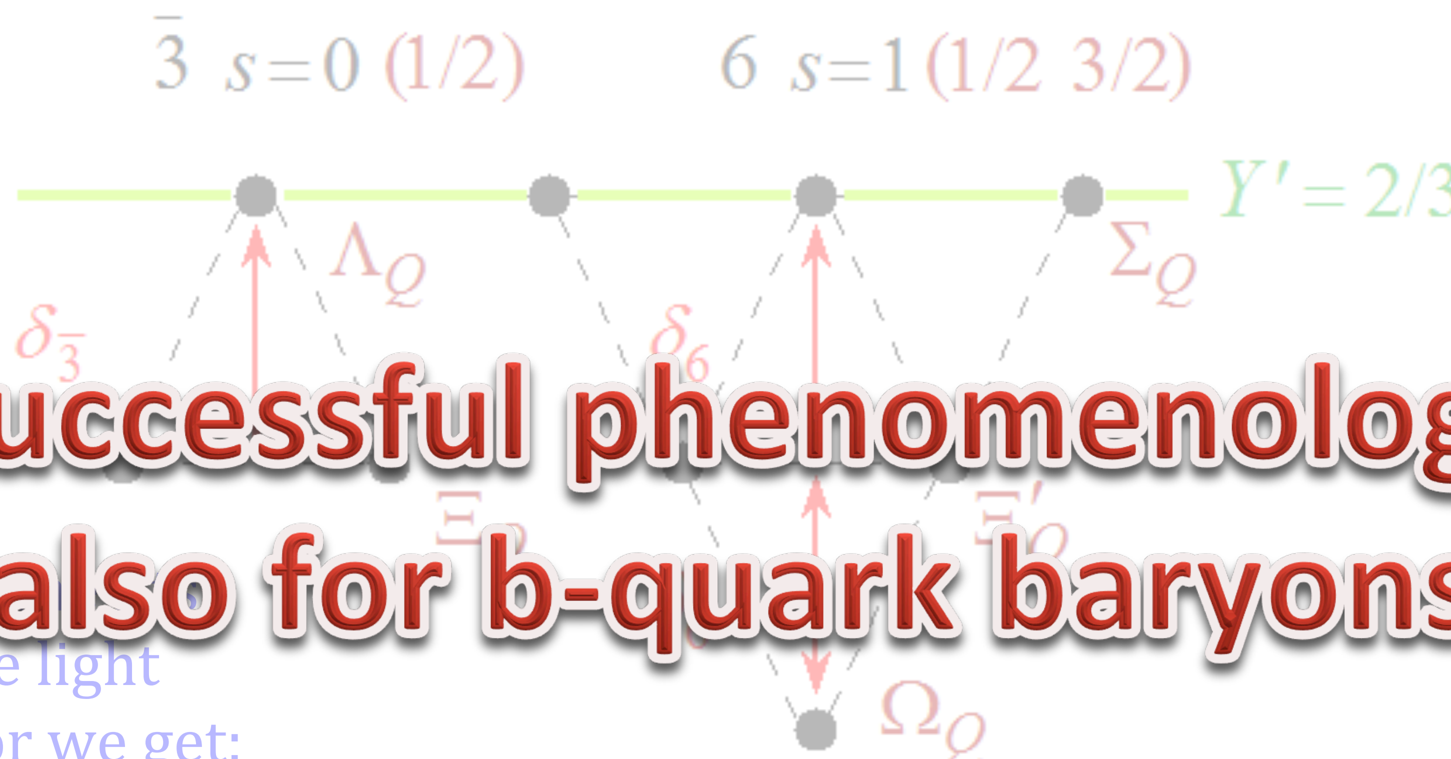
$$\kappa/m_c = 70 \text{ MeV}$$

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

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

13%

Soliton + heavy quark (splittings)



Successful phenomenology (also for b-quark baryons)

fro
to the light
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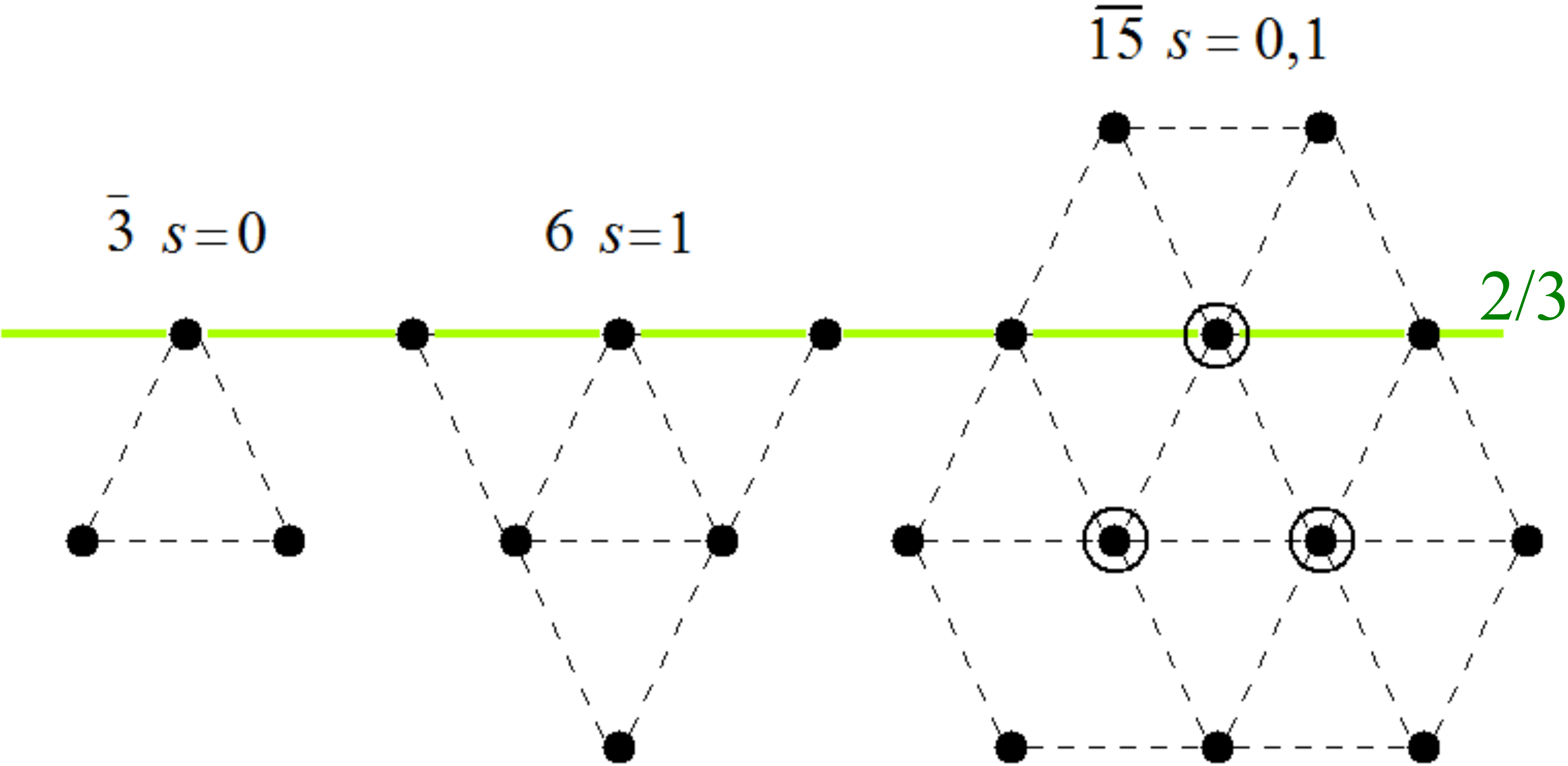
13%

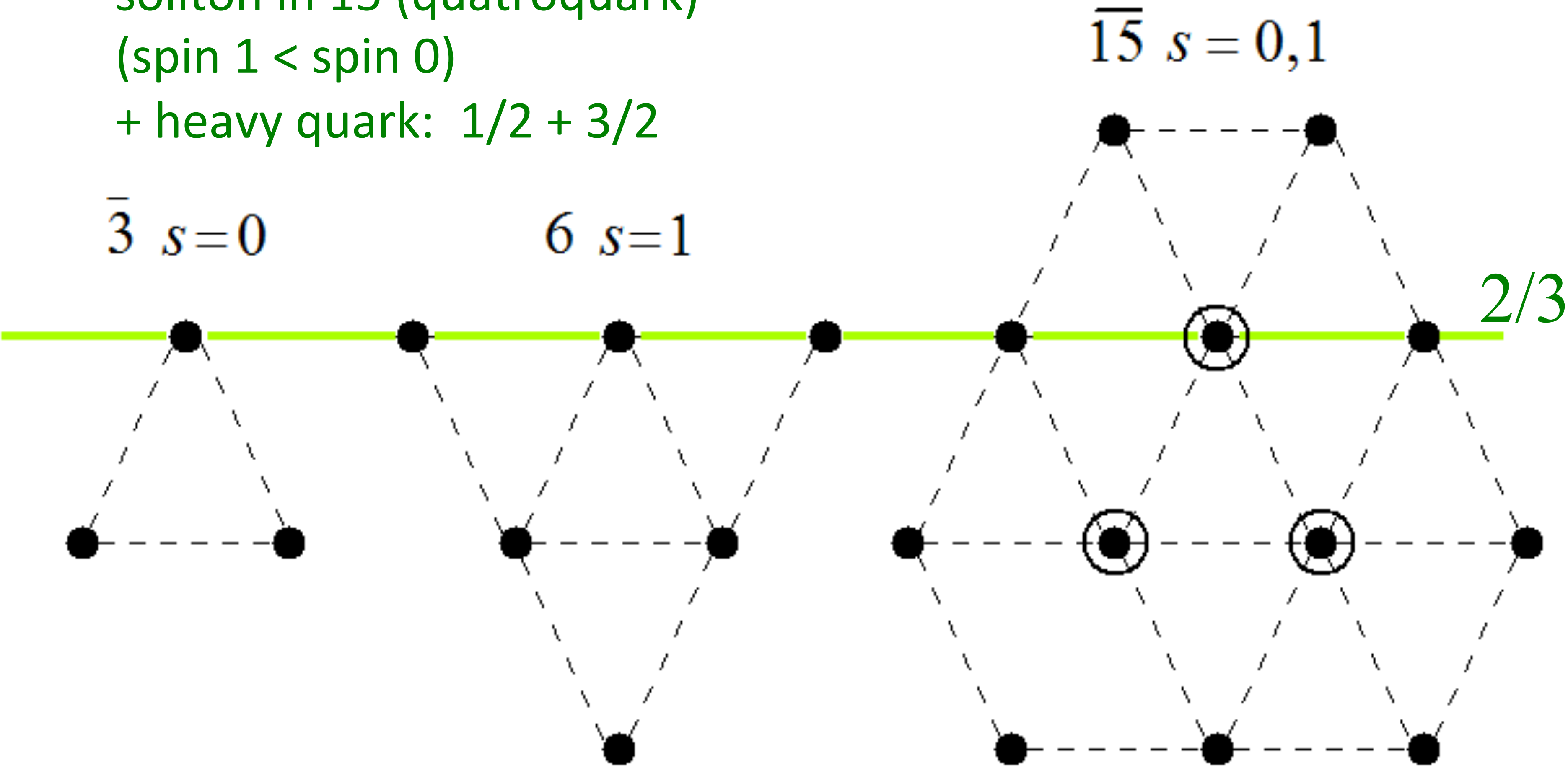
Rotational excitations: heavy pentaquarks



H.C. Kim, M.V. Plyakov, MP arXiv:1704.04082 [hep-ph]

Rotational excitations: heavy pentaquarks

soliton in 15 (quatroquark)
(spin 1 < spin 0)
+ heavy quark: 1/2 + 3/2



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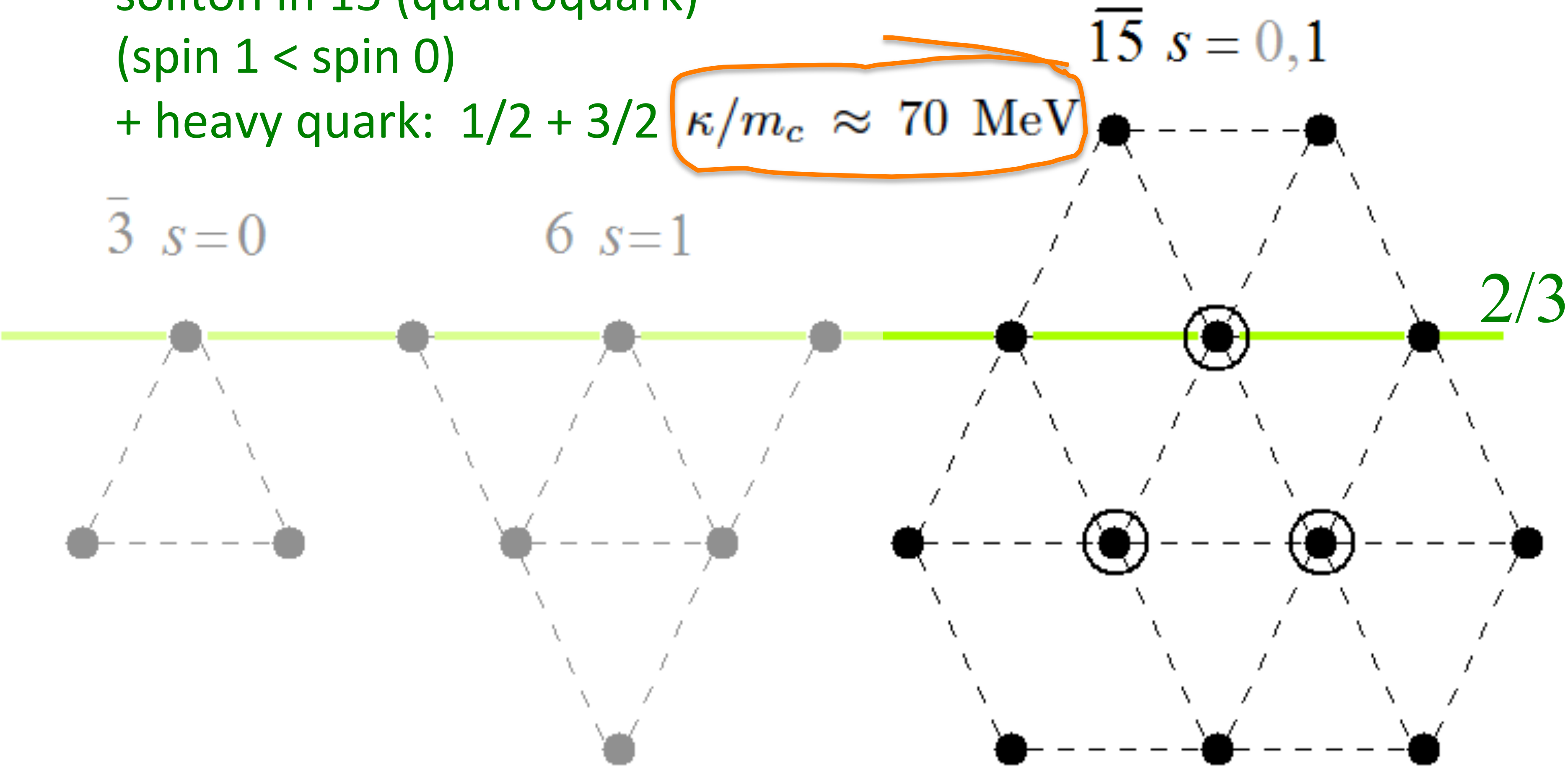
Rotational excitations: heavy pentaquarks

soliton in 15 (quatroquark)
(spin 1 < spin 0)
+ heavy quark: 1/2 + 3/2 $\kappa/m_c \approx 70$ MeV



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Decay constants

$$\overline{\mathbf{15}}_1 \to \overline{\mathbf{3}}_0$$

$$\overline{\mathbf{15}}_1 \to \mathbf{6}_1$$

H.C. Kim, M.V. Plyakov, MP arXiv:1704.04082 [hep-ph]

Decay constants

$$\overline{\mathbf{15}}_1 \to \overline{\mathbf{3}}_0$$

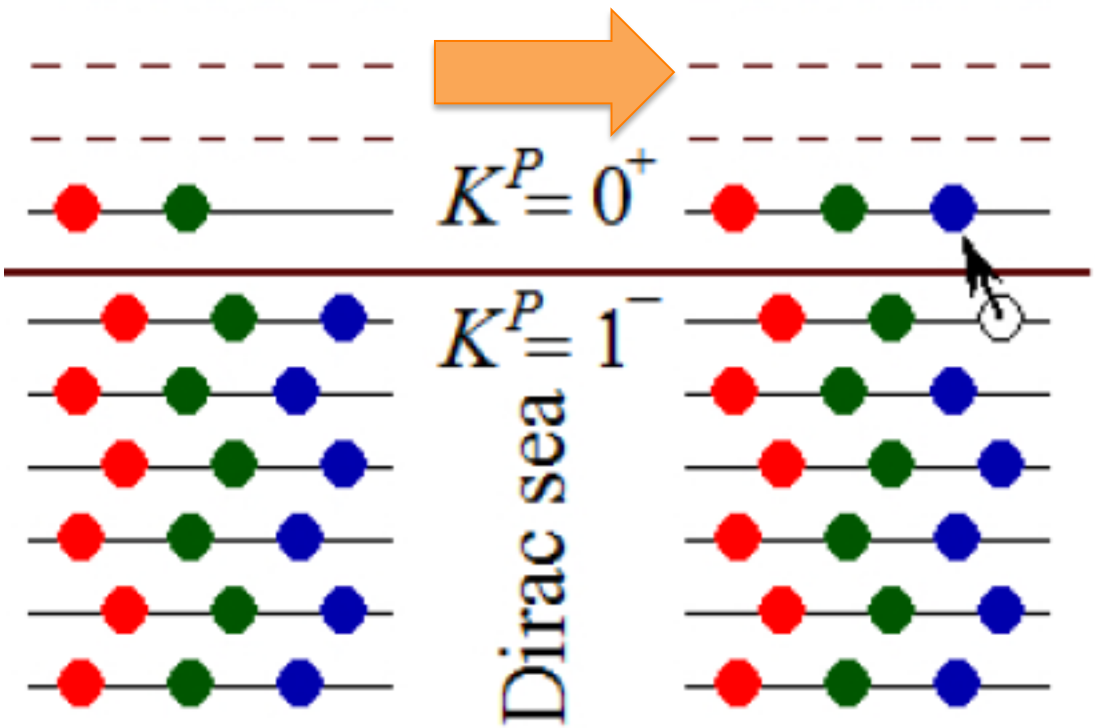
$$\overline{\mathbf{15}}_1 \to \mathbf{6}_1$$

In NRQM limit: $G_{\mathbf{6}} = 0$

Expectations:
some decays will be suppressed

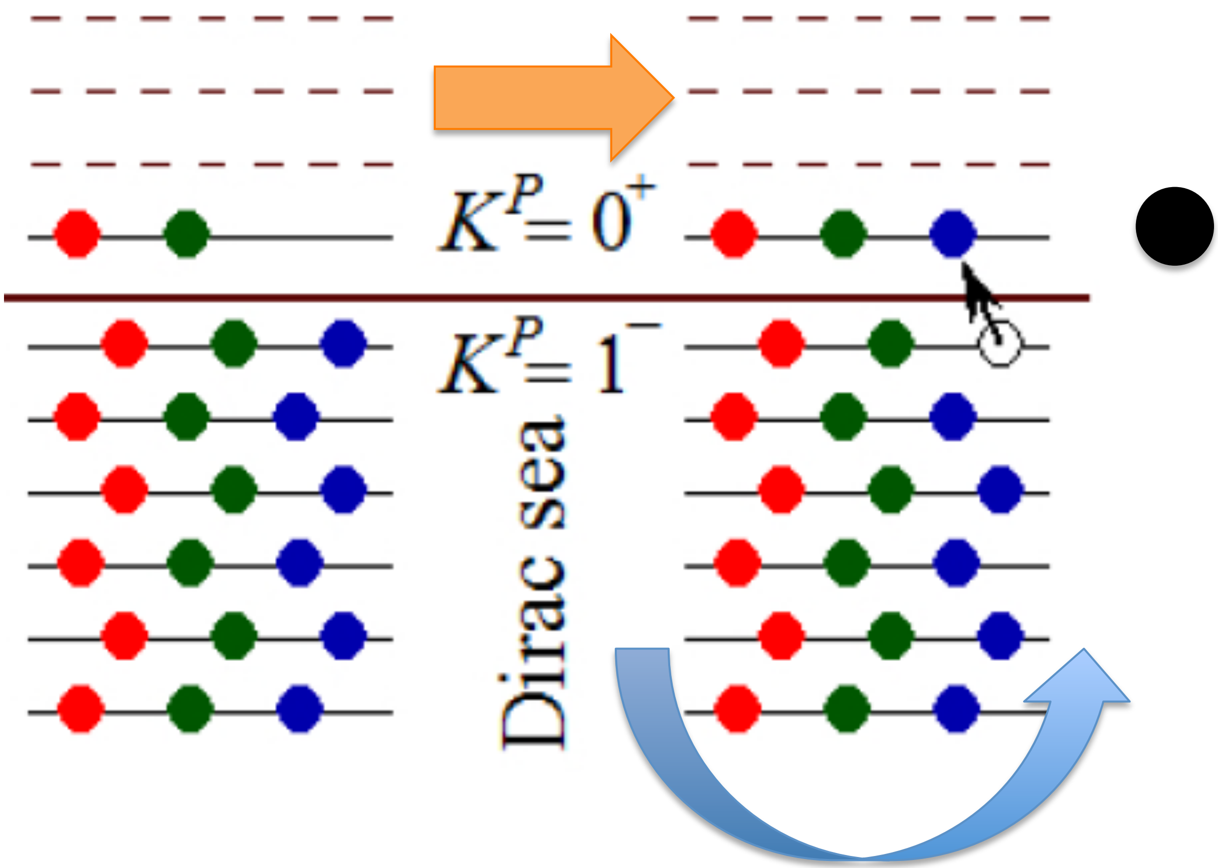
H.C. Kim, M.V. Plyakov, MP arXiv:1704.04082 [hep-ph]

Quark excitations: non-exotic heavy baryons



V. Petrov, Acta Phys. Pol. B47 (2016) 59

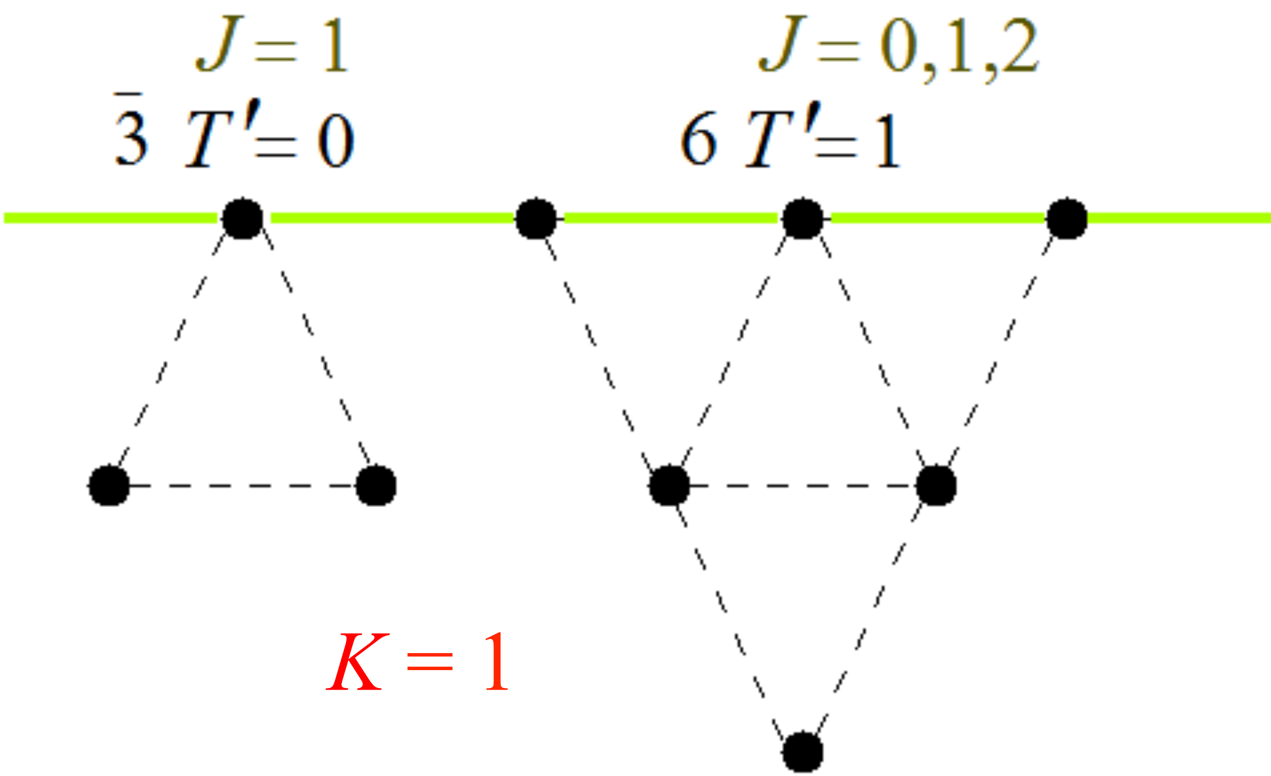
Quark excitations: non-exotic heavy baryons



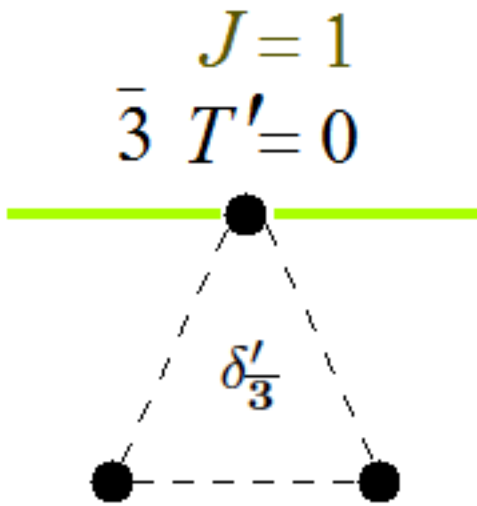
V. Petrov, Acta Phys. Pol. B47 (2016) 59

One K=1 quark excited solitons

- the isospin $\boldsymbol{T'}$ of the states with $Y' = (N_c - 1)/3$ couples with the soliton spin $\boldsymbol{J}$ as follows: $\boldsymbol{T'} + \boldsymbol{J} = \boldsymbol{K}$, where $\boldsymbol{K}$ is the grand spin of the excited level.



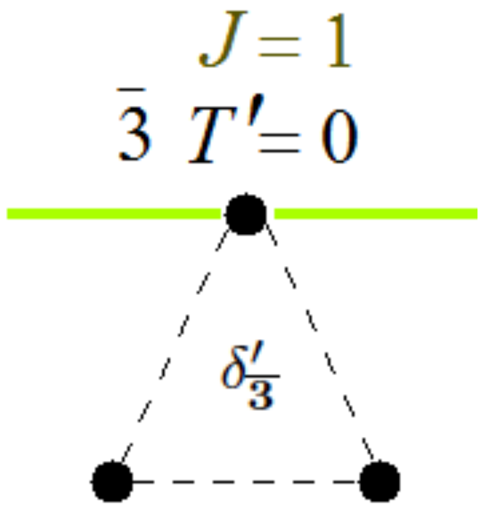
3bar excited heavy baryons



add heavy quark
total spin 1/2 and 3/2

$$\delta'_{\bar{\mathbf{3}}} = \delta_{\bar{\mathbf{3}}} = -180 \text{ MeV}$$

3bar excited heavy baryons



experimentally:

$\Lambda_c(2592)$	$\Lambda_c(2628)$
198 MeV	190 MeV
$\Xi_c(2818)$	$\Xi_c(2790)$
$(1/2)^-$	$(3/2)^-$

add heavy quark
total spin 1/2 and 3/2

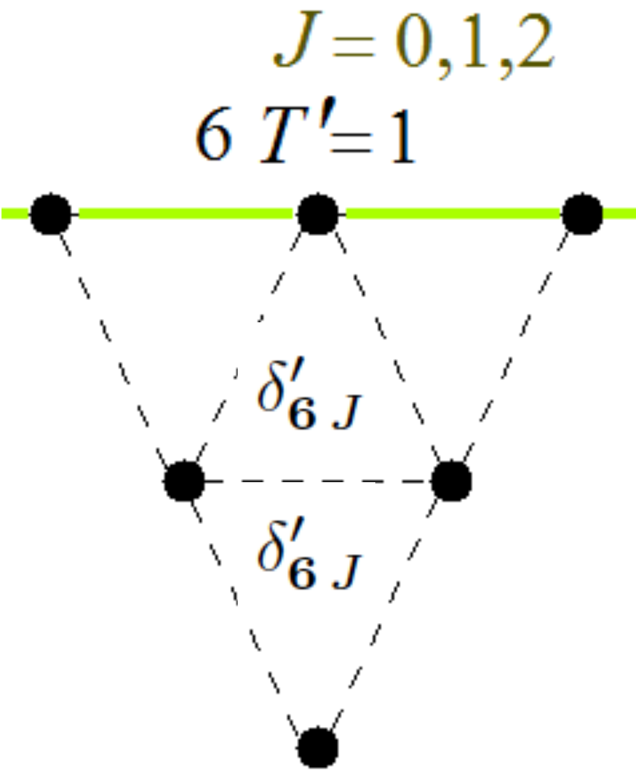
$$\delta'_{\bar{\mathbf{3}}} = \delta_{\bar{\mathbf{3}}} = -180\ \text{MeV}$$

$$\frac{\kappa'}{m_c} = 30\ \text{MeV}$$

$$H_{\rm hf} = \frac{2}{3}\frac{\kappa}{m_Q}\boldsymbol{J}\cdot\boldsymbol{J}_Q$$

hyprfine splitting different from the ground state

sextet excited baryons

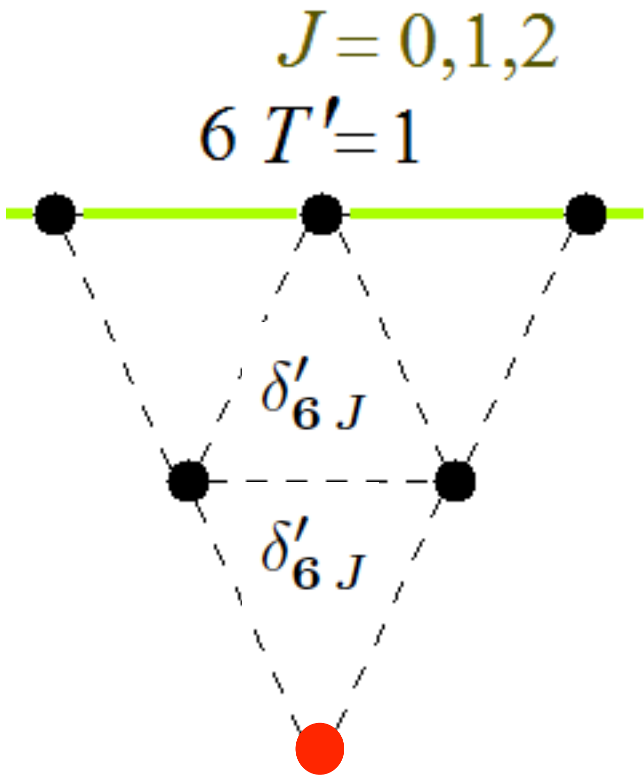


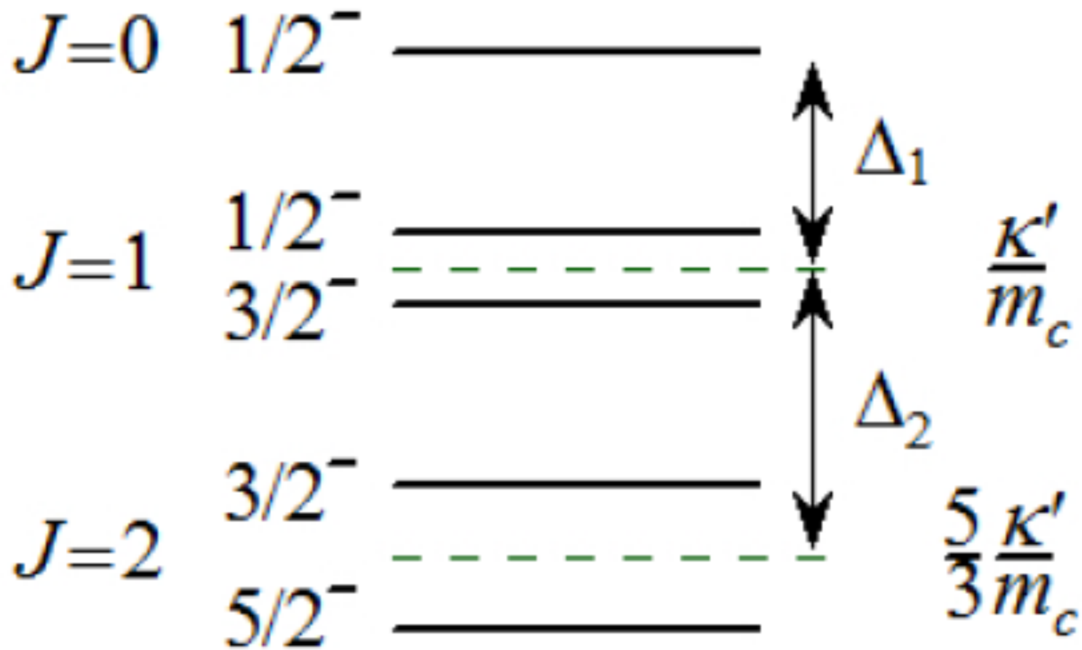
$$\delta'_{\mathbf{6}\,J} = \delta_{\mathbf{6}} - \frac{3}{20}\delta \times \begin{cases} 2 & \text{for} \quad J = 0 \\ 1 & \text{for} \quad J = 1 \\ -1 & \text{for} \quad J = 2 \end{cases}$$

sextet excited baryons

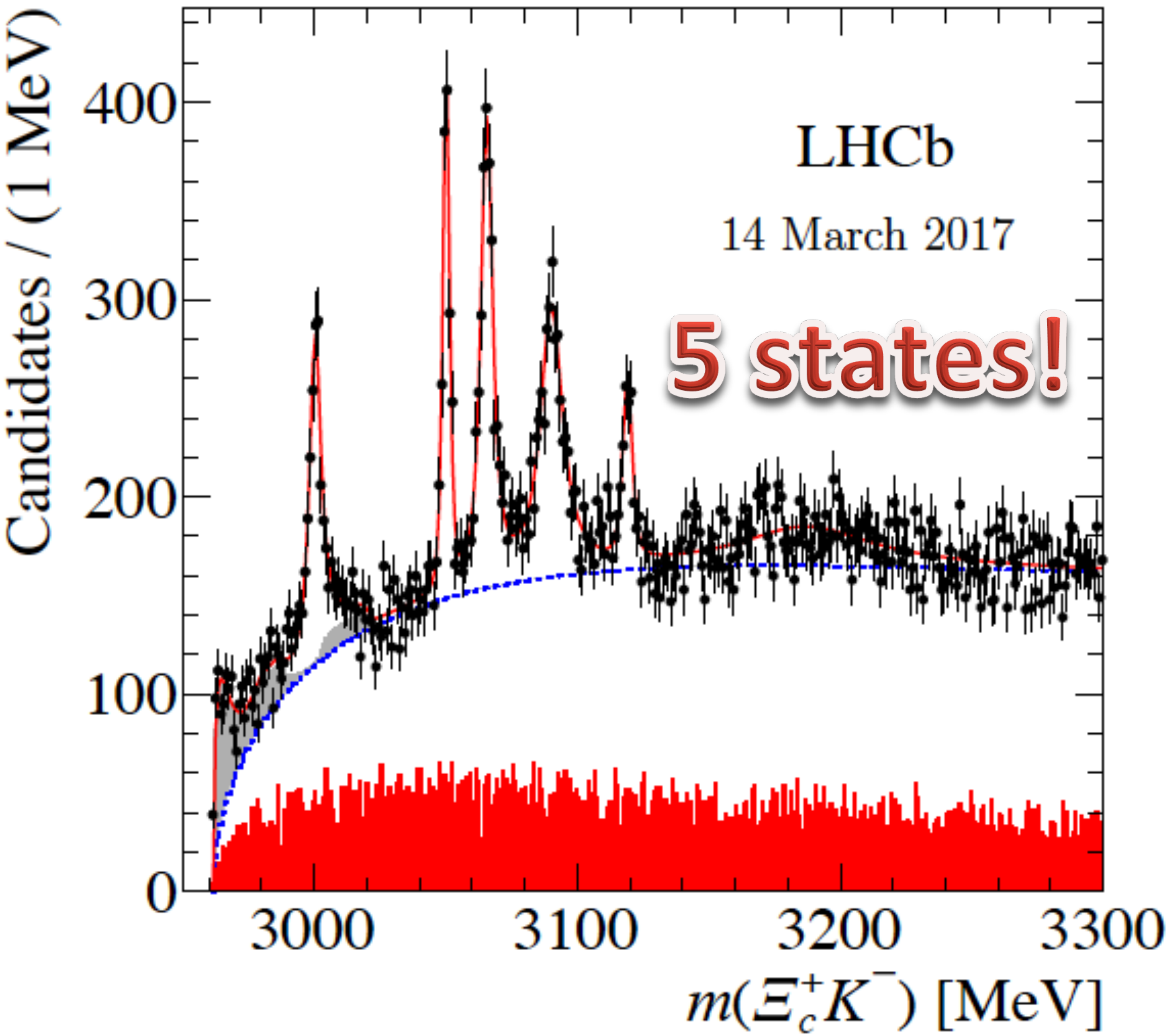
$$\frac{\kappa'}{m_c} = 30\ \mathrm{MeV}$$

$$\Delta_2 = 2\Delta_1$$





excited Omega_Q spectrum,
5 states



LHCb
14 March 2017
5 states!
Candidates / (1 MeV)
0
100
200
300
400
3000
3100
3200
3300
$m(\Xi_c^+ K^-)$ [MeV]

Scenario 1:
all LHCb Omega's are sextet states

J	S^P	M [MeV]	κ'/m_c [MeV]	Δ_J [MeV]
0	$\frac{1}{2}^-$	3000	–	–
1	$\frac{1}{2}^-$	3050	16	61
	$\frac{3}{2}^-$	3066		
2	$\frac{3}{2}^-$	3090	17	47
	$\frac{5}{2}^-$	3119		

violates constraints: $\frac{\kappa'}{m_c} = 30$ MeV $\quad \Delta_2 = 2\Delta_1$

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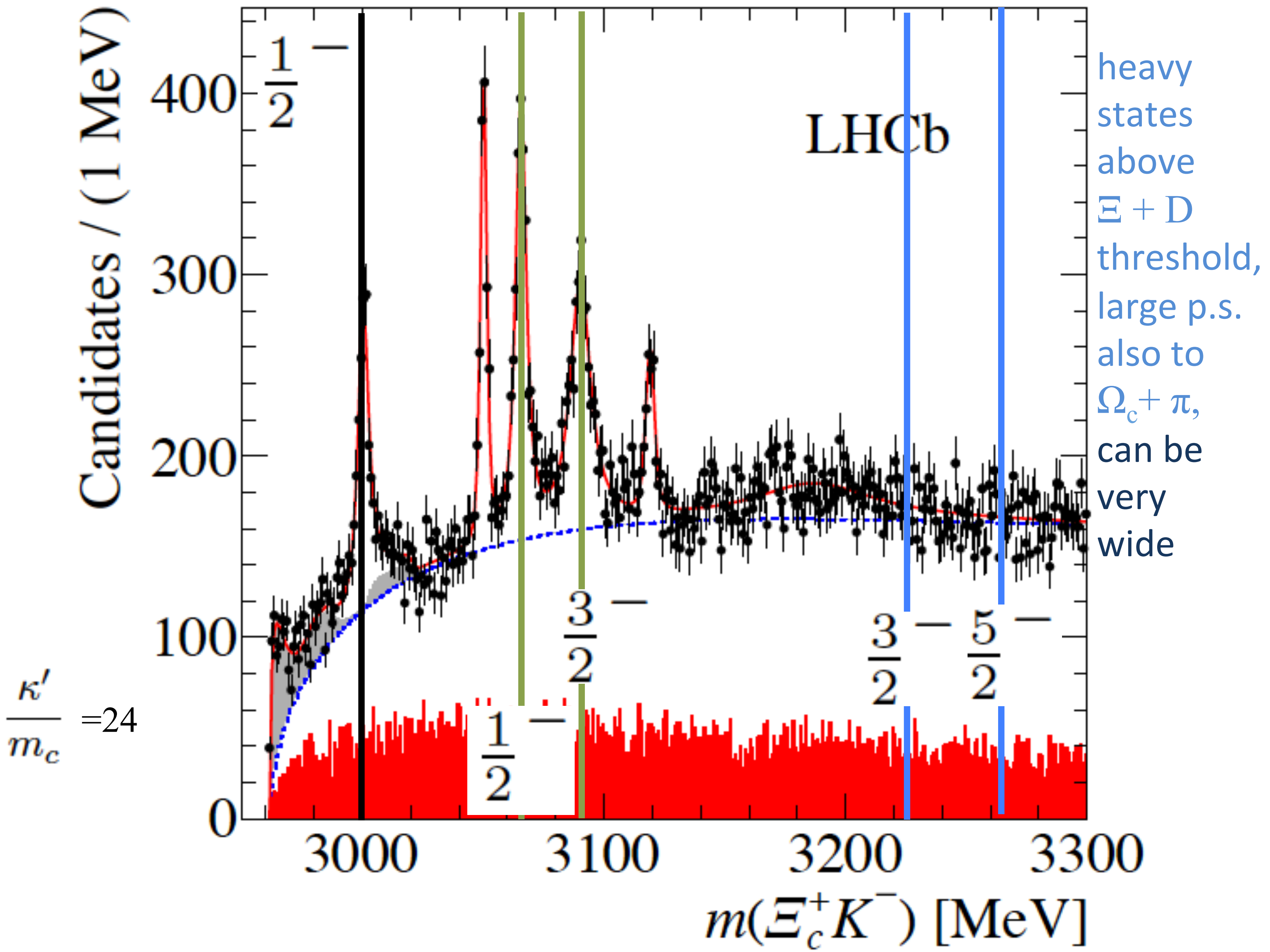
2	$\frac{3}{2}^-$	3090	17	47
	$\frac{5}{2}^-$	3119		

violates constraints: $\frac{\kappa'}{m_c} = 30$ MeV $\quad \Delta_2 = 2\Delta_1$

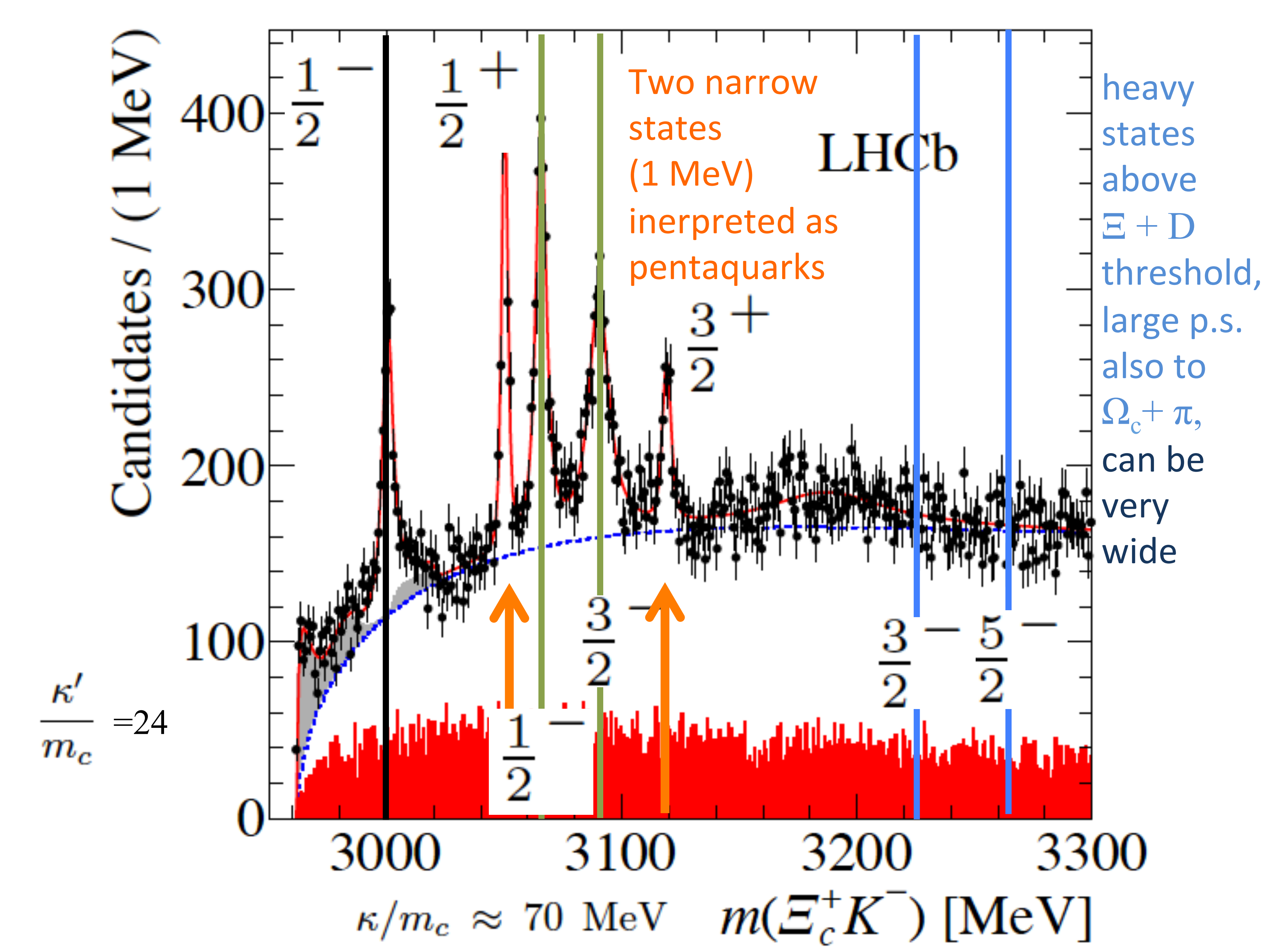
similar problem in the quark models

Scenario 2

force sextet constraints

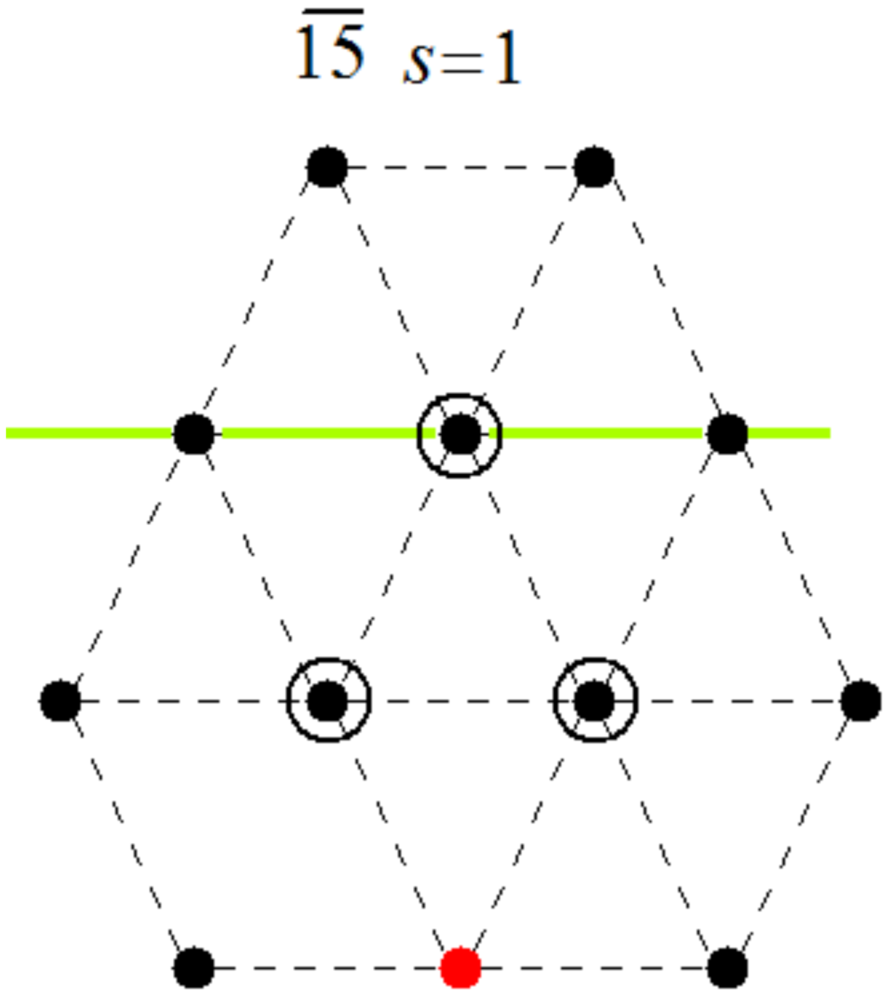


Candidates / (1 MeV)
0
100
200
300
400
3000
3100
3200
3300
$m(\Xi_c^+ K^-)$ [MeV]
LHCb
$\frac{1}{2}^-$
$\frac{1}{2}^-$
$\frac{3}{2}^-$
$\frac{3}{2}^-$
$\frac{5}{2}^-$
$\frac{\kappa'}{m_c}$ =24
heavy states above $\Xi + D$ threshold, large p.s. also to $\Omega_c + \pi$, can be very wide



Candidates / (1 MeV)
LHCb
Two narrow states (1 MeV) inerpreted as pentaquarks
heavy states above $\Xi + D$ threshold, large p.s. also to $\Omega_c + \pi$, can be very wide
$\frac{1}{2}^-$
$\frac{1}{2}^+$
$\frac{3}{2}^+$
$\frac{3}{2}^-$
$\frac{1}{2}^-$
$\frac{3}{2}^-$
$\frac{5}{2}^-$
$\frac{\kappa'}{m_c} = 24$
$\kappa/m_c \approx 70$ MeV
$m(\Xi_c^+ K^-)$ [MeV]
0
100
200
300
400
3000
3100
3200
3300

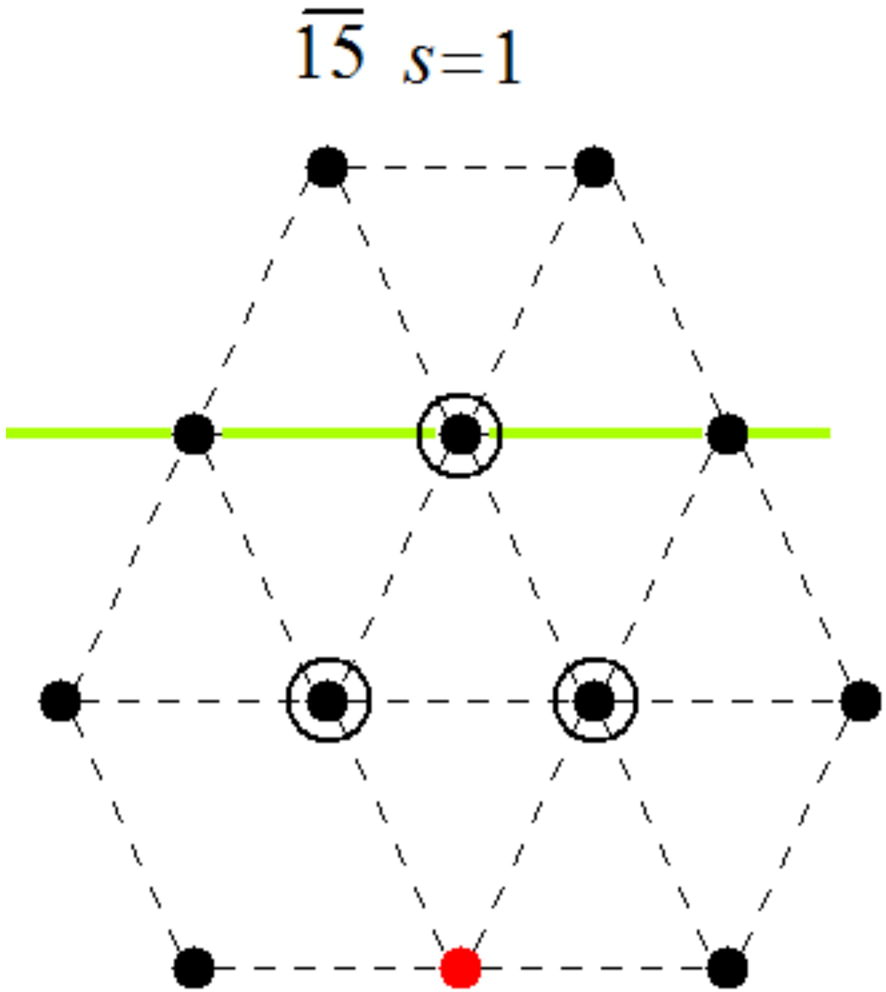
Consequences



$$\Xi_c^0 + K^- \text{ or } \Xi_c^+ + \bar{K}^0$$

Omega's form isospin triplet,
easy to check experimentally

Consequences



rich structure -
- many new states,

also in the case of b baryons

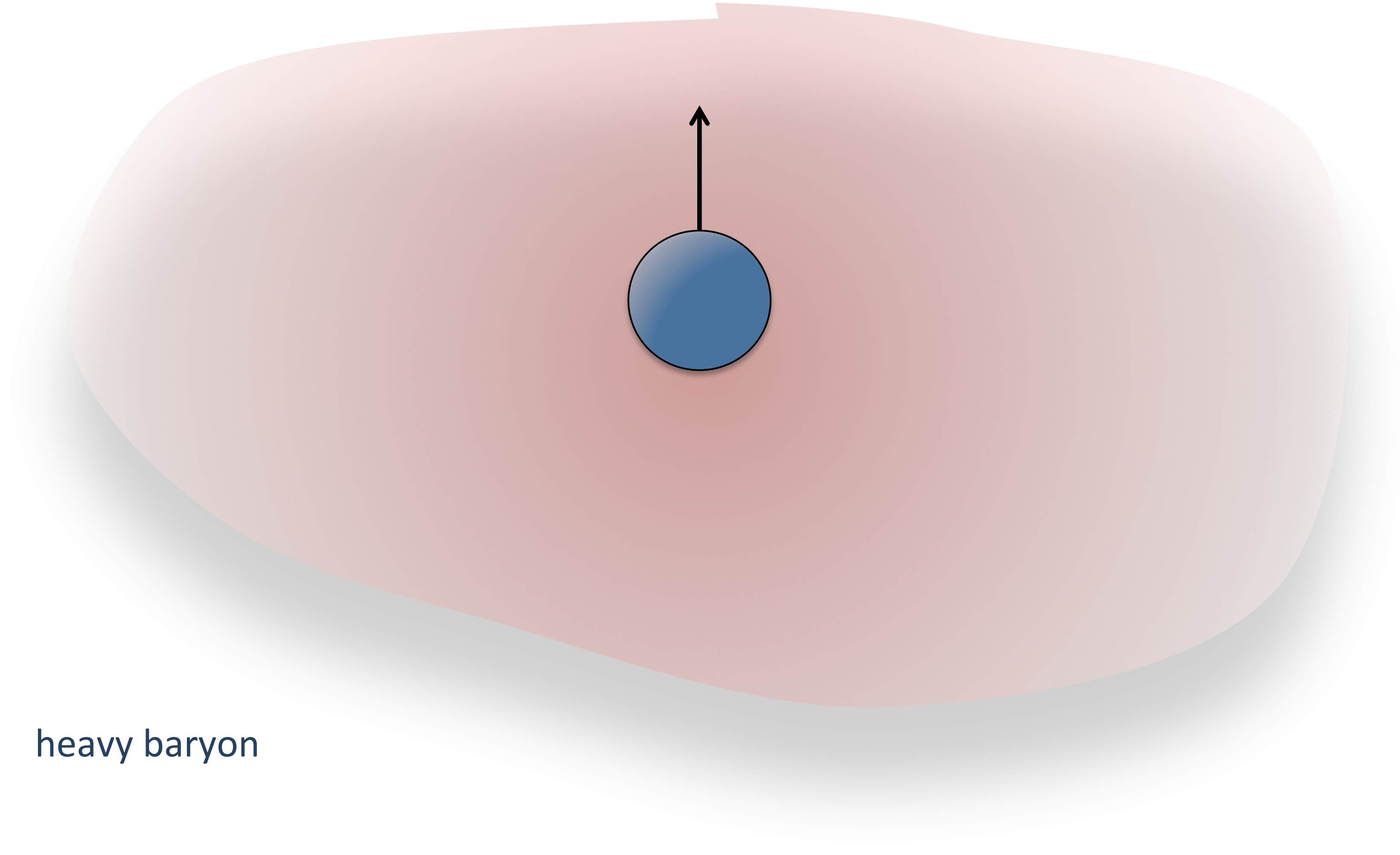
$$\Xi_c^0 + K^- \text{ or } \Xi_c^+ + \bar{K}^0$$

Omega's form isospin triplet, easy to check experimentally

Conclusions

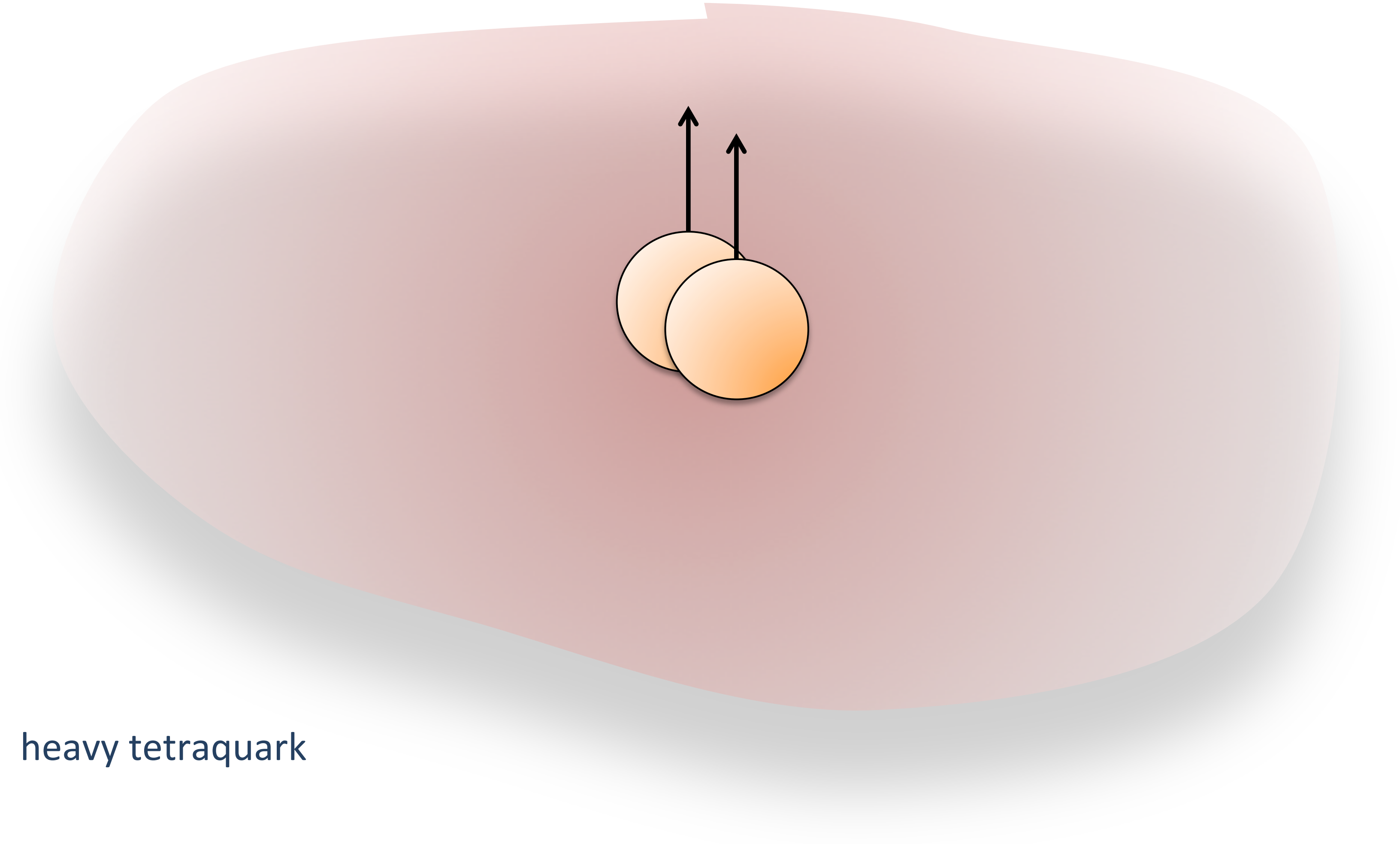
- soliton models **ARE** quark models
- **successful phenomenology** in the light baryon sector
- in soliton models pentaquarks are **naturally light**
- in NR limit **no decay** of antidecuplet to ocet (!)
- heavy baryons can be desribed in terms of N_c**-1 quark soliton**
- two types of excitations:
  - **rotations**: 3-bar, 6 (regular) and 15-bar (exotic)
  - **quark** excitations: 3-bar, 6 (regular)
- **two** of the LHCb Omega_c states may be interpreted as **5q**
- **isospin partners** make the model easy to falsify or to confirm
- similar structure for **bottom**

Further developements



heavy baryon

Further developements



heavy tetraquark