On a possibility of baryonic exotica

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in collaboration with
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G.-S. Yang (Soongsil University, Seoul)

and in preparation

Workshop on Standard Model and Beyond, Corfu, Greece, September 4, 2017
Motivation
Motivation: 5 narrow $\Omega_c$’s
Motivation: 5 narrow $\Omega_c$’s

<table>
<thead>
<tr>
<th>Resonance</th>
<th>Mass (MeV)</th>
<th>$\Gamma$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega_c(3000)^0$</td>
<td>$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$</td>
<td>$4.5 \pm 0.6 \pm 0.3$</td>
</tr>
<tr>
<td>$\Omega_c(3050)^0$</td>
<td>$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$</td>
<td>$0.8 \pm 0.2 \pm 0.1$</td>
</tr>
<tr>
<td>$\Omega_c(3066)^0$</td>
<td>$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$</td>
<td>$&lt; 1.2$ MeV, 95% CL</td>
</tr>
<tr>
<td>$\Omega_c(3090)^0$</td>
<td>$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$</td>
<td>$3.5 \pm 0.4 \pm 0.2$</td>
</tr>
<tr>
<td>$\Omega_c(3119)^0$</td>
<td>$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$</td>
<td>$8.7 \pm 1.0 \pm 0.8$</td>
</tr>
<tr>
<td>$\Omega_c(3188)^0$</td>
<td>$3188 \pm 5 \pm 13$</td>
<td>$1.1 \pm 0.8 \pm 0.4$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$&lt; 2.6$ MeV, 95% CL</td>
</tr>
</tbody>
</table>

70 MeV
Motivation: 5 narrow $\Omega_c$'s

14 March 2017

LHCb

Candidates / (1 MeV)

$m(\Xi_c^+K^-) [\text{MeV}]$
Reminder
Heavy baryon ground states

\[ \Lambda_c^+ \text{ (3 } 1/2^+) \quad \Sigma_c^0 \quad \Sigma_c^+ \quad \Sigma_c^{++} \quad \Sigma_c^{*0} \quad \Sigma_c^{*+} \quad \Sigma_c^{*++} \]

\[ \Xi_c^0 \quad \Xi_c^+ \quad \Xi_c^{'0} \quad \Xi_c^{'+} \quad \Omega_c^0 \quad \Omega_c^{*0} \quad \Omega_c^{*+} \]

Masses:
- \( 2409 \text{ MeV} \) for \( \Xi_c^0 \) and \( \Xi_c^+ \)
- \( 2535 \text{ MeV} \) for \( \Omega_c^0 \)
- \( 2580 \text{ MeV} \) for \( \Xi_c^0 \) before \( \text{hf splitting} \)
- \( 2602 \text{ MeV} \) for \( \Omega_c^{*0} \)

Average multiplet masses:
- \( (3 1/2^+) \)
- \( (6 1/2^+) \)
- \( (6 3/2^+) \)

\[ s = 0 \text{ diquark} + s = 1/2 \text{ HQ} \quad s = 1 \text{ diquark} + s = 1/2 \text{ HQ} \]
Heavy baryon ground states

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(3 1/2+)                          (6 1/2+)                                            (6 3/2+)

\[\begin{align*}
\Lambda_c^+ & \quad \Sigma_c^0 & \quad \Sigma_c^+ & \quad \Sigma_c^{++} \\
\Xi_c^0 & \quad \Xi'_c^0 & \quad \Xi_c^+ & \quad \Sigma_c^*0 & \quad \Sigma_c^*+ & \quad \Sigma_c^{*++} \\
2409 \text{ MeV} & \quad 2535 \text{ MeV} & \quad 2580 \text{ MeV} & \quad 2602 \text{ MeV}
\end{align*}\]

average multiplet masses

before hf splitting 70 MeV

\[s = 0 \text{ diquark} + s = 1/2 \text{ HQ} \quad s = 1 \text{ diquark} + s = 1/2 \text{ HQ}\]
Heavy baryon ground states

$|3\ 1/2^+\rangle$

- $\Lambda_c^+$
- $\Xi_c^0$
- $\Xi_c^+$

2409 MeV
5735 MeV
average multiplet masses

$(6\ 1/2^+)$

- $\Sigma_c^0$
- $\Sigma_c^+$
- $\Sigma_c^{++}$

2535 MeV
5893 MeV

$(6\ 3/2^+)$

- $\Sigma_c^{*0}$
- $\Sigma_c^{*+}$
- $\Sigma_c^{*++}$

2580 MeV
5908 MeV
before hf splitting
70 MeV
20 MeV
2602 MeV
5913 MeV

same for the bottom
Heavy baryon ground states

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\begin{itemize}
\item \(\bar{\Lambda}_{c}^{+}\) \(\Sigma_{c}^{0}\) \(\Sigma_{c}^{+}\) \(\Sigma_{c}^{++}\) \(\Sigma_{c}^{*0}\) \(\Sigma_{c}^{*+}\) \(\Sigma_{c}^{*++}\)
\item \(\Xi_{c}^{0}\) \(\Xi_{c}^{+}\) \(\Xi'_{c}^{0}\) \(\Xi'_{c}^{+}\) \(\Omega_{c}^{0}\) \(\Xi_{c}^{*0}\) \(\Xi_{c}^{*+}\)
\end{itemize}

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\item 2409 MeV
\item 5735 MeV
\item average multiplet masses
\item 171 MeV
\item 2535 MeV
\item 5893 MeV
\item 2580 MeV
\item 5908 MeV
\item before hf splitting
\item 70 MeV
\item 20 MeV
\item 2602 MeV
\item 5913 MeV
\end{itemize}

hf splitting ratio \(\sim 0.3 \sim \frac{m_{c}}{m_{b}}\)

same for the bottom
Heavy baryon excited states

\[(\overline{3} \ 1/2^-)\]  
\[\Lambda_c^+ \quad \Xi_c^0 \quad \Xi_c^+ \]  
2724 MeV  
30 MeV

\[(\overline{3} \ 3/2^-)\]  
\[\Lambda_c^+ \quad \Xi_c^0 \quad \Xi_c^+ \]  
2754 MeV

\[s = 0 \text{ diquark} + s = 1/2 \text{ HQ} + L= 1\]
Heavy baryon excited states

\[ (3\, 1/2^-) \quad (3\, 3/2^-) \]

2724 MeV \quad 2754 MeV

5912 MeV \quad 5920 MeV

not much known in the bottom sector
Sextet excitations $1/2^-$ and $3/2^-$?

$s = 1$ diquark + $s = 1/2$ HQ + $L = 1$ → $1/2, 1/2, 3/2, 3/2, 5/2$ → 5 states!
Sextet excitations $1/2^-$ and $3/2^-$?

$$s = 1 \text{ diquark} + s = 1/2 \text{ HQ} + L = 1 \rightarrow 1/2, 1/2, 3/2, 3/2, 5/2 \rightarrow 5 \text{ states!}$$

however:
one has to fit both masses and widths
B. Chen and X. Liu, arXiv:1704.02583 [hep-ph].
different approaches:
quark and quark-diquark models
quarks + resonating group method
chiral quark models
QCD sum rules
lattice
phenomenology
holographic QCD

outcome:
s-wave and p-wave excitations
both positive and negative parity
pentaquarks
Chiral Quark-Soliton Model
Why Chiral Quark-Soliton Model?

• Why not?
Why Chiral Quark-Soliton Model?

• Why not?
• because it predicts small widths for some specific decays
QCD: quarks and gluons
integrate out gluons
many quark nonlocal interactions
Lagrangian chirally symmetric
approximation:
manyq, nonl. $\rightarrow$ 4q, local
Nambu Jona Lasinio model
spontaneous chiral symmetry breaking
semibosonization:
$q\bar{q}q\bar{q} \rightarrow q\bar{q}\pi$
Chiral Quark Model

M. Praszałłowicz
Chiral Quark Soliton Model
Chiral Quark Soliton Model

QCD vacuum:
Chiral Quark Soliton Model

chiral symmetry breaking:

chirally inv. manyquark int.
Chiral Quark Soliton Model

baryon:

adding valence quarks:

chirally inv. manyquark int.
Chiral Quark Soliton Model

**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
Mass formula

\[ \pi_8 = \frac{N_c}{2\sqrt{3}} \]

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

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first order perturbation in the strange quark mass and in \( N_c \):

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

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

Mass formula

\[ \pi_8 = \frac{N_c}{2 \sqrt{3}} \]

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

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

\( \text{octet-decuplet splitting} \)

\( \text{known} \)

\( ? \text{ exotc-nonexotic splittings} \)

\( \text{first order perturbation in the strange quark mass and in } N_c: \)

\[ H_{\text{br}} = \alpha D_{88}^{(8)} + \beta \hat{Y} + \frac{\gamma}{\sqrt{3}} \sum_{i=1}^{3} D_{8i}^{(8)} \hat{J}_i \]

\[ \alpha \sim m_s N_c, \quad \beta, \gamma \sim m_s O(1) \]

Allowed states

- allowed SU(3) representations must contain states with hypercharge $Y' = N_c/3$,

- the isospin $T'$ of the states with $Y' = N_c/3$ couples with the soliton spin $J$ to a singlet: $T' + J = 0$.

\[ Y' = \frac{N_c}{3} \]

\[ Y \]

\[ \Theta \quad (1540 \text{ MeV}) \]

\[ N \quad \Sigma \quad \Xi \quad \Omega \quad \bar{\Omega} \]

\[ 8 \quad 10 \quad \bar{10} \]

# valence quarks
Successful Phenomenology

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

In a ”model independent” approach one can get both good fits to the existing data (including very narrow light pentaquark $\Theta^+$) 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

$$\text{NRQM limit} = \text{squeezing the soliton to zero size}$$

NRQM Limit

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

energy is calculated with respect to the vacuum:
NRQM Limit

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

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NRQM Limit

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

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) 305

energy is calculated with respect to the vacuum:

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

in the NRQM limit only valence level contributes
NRQM Limit

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

energy is calculated with respect to the vacuum:

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

\[ G_{10} = 0 \]

pentaquark width = 0!

in the NRQM limit only valence level contributes
Heavy baryons in the Chiral Quark-Soliton Model
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.

\[ \bar{3} \quad s = 0 \]
\[ 6 \quad s = 1 \]

\[ Y' = \frac{2}{3} \]
\[ = \frac{(N_c - 1)}{3} \]
Heavy Baryons: soliton + heavy Q

\[ \begin{array}{ll}
\bar{3} & s = 0 \ (1/2) \\
6 & s = 1 \ (1/2 \ 3/2)
\end{array} \]

\[ Y' = 2/3 \]
Splittings inside multiplets

\[ \begin{align*}
\bar{3} & \quad s = 0 \quad (1/2) \\
6 & \quad s = 1 \quad (1/2 \ 3/2) = S_L
\end{align*} \]

\[ \begin{align*}
\delta_{\bar{3}} & \quad \Lambda_Q \\
\delta_6 & \quad \Xi_Q \quad \delta_6 \\
\Xi_Q' & \quad \Omega_Q \quad \Xi_Q' \\
\Sigma_Q & \quad Y' = 2/3 \\
\end{align*} \]

\[ \frac{2}{3} \frac{\kappa}{m_Q} S_L \cdot S_Q \]

one has to add h.f. interaction

\[ \kappa/m_c = 70 \text{ MeV} \]
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 follow from Eckhart-Wigner theorem
Splittings inside multiplets

\[ \delta_3 = 203.8 \pm 3.5 \text{ MeV}, \quad \text{(exp.: } 178 \text{ MeV)} \]
\[ \delta_6 = 135.2 \pm 3.3 \text{ MeV}, \quad \text{(exp.: } 121 \text{ MeV)} \]
Splittings inside multiplets

from the fits to the light sector we get:


\[ \delta_3 = 203.8 \pm 3.5 \text{ MeV}, \quad \text{(exp.: 178 MeV)} \]

\[ \delta_6 = 135.2 \pm 3.3 \text{ MeV}, \quad \text{(exp.: 121 MeV)} \]

13%
Rotational excitations: heavy pentaquarks

$\bar{3} \ s = 0$

$6 \ s = 1$

$\bar{15} \ s = 0, 1$

$2/3$
Rotational excitations: heavy pentaquarks

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

Rotational excitations: heavy pentaquarks

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

$\overline{3}$, $s=0$
$6$, $s=1$

$\kappa/m_c \approx 70$ MeV

Decays

axial-vector constants with $X = 3, 8, 0$

\[
g^{(B_1 \to B_2)} = a_1 \langle B_2 | D_{X3}^{(8)} | B_1 \rangle + a_2 d_{pq3} \langle B_2 | D_{Xp}^{(8)} \hat{S}_q | B_1 \rangle + \frac{a_3}{\sqrt{3}} \langle B_2 | D_{X8}^{(8)} \hat{S}_3 | B_1 \rangle
\]

$a_1 \sim N_c, a_2 \sim O(1), a_3 \sim O(1)$ fixed from the data on weak hyperon decays

Goldberger-Treiman relation:
for strong decays $B_1 \to B_2 + \varphi$ use the same operator, but

\[
\{a_1, a_2, a_3\} \to \frac{M_1 + M_2}{2 F_{\varphi}} \{a_1, a_2, a_3\}
\]

\[
\Gamma_{\Sigma(\bar{6}_1) \to \Lambda(\bar{3}_0) + \pi} = \frac{1}{72\pi} \frac{p^3}{F_{\pi}^2} \frac{M_{\Lambda(\bar{3}_0)}}{M_{\Sigma(\bar{6}_1)}} \frac{H_3^2}{8} \quad H_3 = -a_1 + \frac{1}{2} a_2
\]
Decay constants

\[ a_1 \sim N_c \quad \rightarrow \quad a_1 \sim N_c - 1 \]

\[ \overline{15}_1 \quad \rightarrow \quad \overline{3}_0 \]

\[ \overline{15}_1 \quad \rightarrow \quad 6_1 \]
Decay constants

\[ a_1 \sim N_c \quad \rightarrow \quad a_1 \sim N_c - 1 \]

\[ \overline{15}_1 \quad \rightarrow \quad \overline{3}_0 \]

\[ \overline{15}_1 \quad \rightarrow \quad 6_1 \]

In NRQM limit:

\[ G_6 = 0 \]

Expectations:
some decays will be suppressed

Quark excitations: non-exotic heavy baryons

Quark excitations: non-exotic heavy baryons

Rotations generate quantum numbers
One $K=1$ quark excited solitons

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

\[ J = 1 \quad \bar{3} \quad T' = 0 \]

\[ \delta'_{\frac{1}{3}} = \delta_{\frac{1}{3}} = -180 \text{ MeV} \]

add heavy quark

total spin 1/2 and 3/2
3bar excited heavy baryons

Add heavy quark

Total spin 1/2 and 3/2

Experimentally:

\[ \begin{align*} 
\Lambda_c(2592) & : 198 \text{ MeV} \\
\Xi_c(2790) & : (1/2)^- \\
\Lambda_c(2628) & : 190 \text{ MeV} \\
\Xi_c(2818) & : (3/2)^- \\
\end{align*} \]

\[ \frac{\kappa'}{m_c} = 30 \text{ MeV} \]

Hyperfine splitting different from the ground state

\[ H_{hf} = \frac{2}{3} \frac{\kappa}{m_Q} J \cdot J_Q \]
sextet excited baryons

\[ J = 0, 1, 2 \]
\[ 6 \ T' = 1 \]

\[ \delta'_6 J = \delta_6 - \frac{3}{20} \delta \times \begin{cases} 
2 & \text{for } J = 0 \\
1 & \text{for } J = 1 \\
-1 & \text{for } J = 2 
\end{cases} \]
sextet excited baryons

excited Omega_Q spectrum,
5 states
LHCb
14 March 2017
5 states!
Scenario 1: all LHCb Omega’s are sextet states

<table>
<thead>
<tr>
<th>$J$</th>
<th>$S^P$</th>
<th>$M$ [MeV]</th>
<th>$\kappa'/m_c$ [MeV]</th>
<th>$\Delta_J$ [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$\frac{1}{2}^-$</td>
<td>3000</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>1</td>
<td>$\frac{1}{2}^-$</td>
<td>3050</td>
<td>16</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>$\frac{3}{2}^-$</td>
<td>3066</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$\frac{3}{2}^-$</td>
<td>3090</td>
<td>17</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>$\frac{5}{2}^-$</td>
<td>3119</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

violates constraints:

$$\frac{\kappa'}{m_c} = 30 \text{ MeV} \quad \Delta_2 = 2\Delta_1$$
Scenario 1: all LHCb Omega’s are sextet states

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<tr>
<th>$J$</th>
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<tr>
<td>0</td>
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<td>–</td>
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<td>2</td>
<td>$\frac{5}{2}^-$</td>
<td>3119</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

violates constraints:

\[
\frac{\kappa'}{m_c} = 30 \text{ MeV} \quad \Delta_2 = 2\Delta_1
\]

similar problem in the quark models
Scenario 2

force sextet constraints
heavy states above $\Xi + D$ threshold, large p.s. also to $\Omega_c + \pi$, can be very wide

$$\kappa'/m_c = 24$$
Two narrow states (1 MeV) interpreted as pentaquarks heavy states above \( \Xi^+ + D \) threshold, large p.s. also to \( \Omega_c^+ + \pi \), can be very wide.
Charm decay widths

<table>
<thead>
<tr>
<th>Decay</th>
<th>Final State</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\Sigma_c^{++}(6_1, 1/2) \rightarrow \Lambda_c^+(30, 1/2) + \pi^+$</td>
</tr>
<tr>
<td>2</td>
<td>$\Sigma_c^+(6_1, 1/2) \rightarrow \Lambda_c^+(30, 1/2) + \pi^0$</td>
</tr>
<tr>
<td>3</td>
<td>$\Sigma_c^0(6_1, 1/2) \rightarrow \Lambda_c^+(30, 1/2) + \pi^-$</td>
</tr>
<tr>
<td>4</td>
<td>$\Sigma_c^{++}(6_1, 3/2) \rightarrow \Lambda_c^+(30, 1/2) + \pi^+$</td>
</tr>
<tr>
<td>5</td>
<td>$\Sigma_c^+(6_1, 3/2) \rightarrow \Lambda_c^+(30, 1/2) + \pi^0$</td>
</tr>
<tr>
<td>6</td>
<td>$\Sigma_c^0(6_1, 3/2) \rightarrow \Lambda_c^+(30, 1/2) + \pi^-$</td>
</tr>
<tr>
<td>7</td>
<td>$\Xi_c^+(6_1, 3/2) \rightarrow \Xi_c(30, 1/2) + \pi$</td>
</tr>
<tr>
<td>8</td>
<td>$\Xi_c^0(6_1, 3/2) \rightarrow \Xi_c(30, 1/2) + \pi$</td>
</tr>
<tr>
<td>9</td>
<td>$\Omega_c(15_1, 1/2) \rightarrow \Xi_c(30, 1/2) + K$</td>
</tr>
<tr>
<td></td>
<td>$\Omega_c(15_1, 1/2) \rightarrow \Omega_c(6_1, 1/2) + \pi$</td>
</tr>
<tr>
<td></td>
<td>$\Omega_c(15_1, 1/2) \rightarrow \Omega_c(6_1, 3/2) + \pi$</td>
</tr>
<tr>
<td>10</td>
<td>$\Omega_c(15_1, 3/2) \rightarrow \Xi_c(30, 1/2) + K$</td>
</tr>
<tr>
<td></td>
<td>$\Omega_c(15_1, 3/2) \rightarrow \Xi_c(6_1, 1/2) + K$</td>
</tr>
<tr>
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<td>$\Omega_c(15_1, 3/2) \rightarrow \Omega_c(6_1, 1/2) + \pi$</td>
</tr>
<tr>
<td></td>
<td>$\Omega_c(15_1, 3/2) \rightarrow \Omega_c(6_1, 3/2) + \pi$</td>
</tr>
</tbody>
</table>

with one adjustable parameter that takes into account the fact that soliton is built up from $N_c - 1$ quarks. 15% correction to $a_1$
Bottom decay widths

<table>
<thead>
<tr>
<th>decay</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\Sigma_b^+ (6_1, 1/2) \rightarrow \Lambda_b^0 (\bar{3}_0, 1/2) + \pi^+$</td>
</tr>
<tr>
<td>2</td>
<td>$\Sigma_b^- (6_1, 1/2) \rightarrow \Lambda_b^0 (\bar{3}_0, 1/2) + \pi^-$</td>
</tr>
<tr>
<td>3</td>
<td>$\Xi_b^0 (6_1, 1/2) \rightarrow \Xi_c (\bar{3}_0, 1/2) + \pi$</td>
</tr>
<tr>
<td>4</td>
<td>$\Sigma_b^+ (6_1, 3/2) \rightarrow \Lambda_b^0 (\bar{3}_0, 1/2) + \pi^+$</td>
</tr>
<tr>
<td>5</td>
<td>$\Sigma_b^- (6_1, 3/2) \rightarrow \Lambda_b^0 (\bar{3}_0, 1/2) + \pi^-$</td>
</tr>
<tr>
<td>6</td>
<td>$\Xi_b^0 (6_1, 3/2) \rightarrow \Xi_b (\bar{3}_0, 1/2) + \pi$</td>
</tr>
<tr>
<td>7</td>
<td>$\Xi_b^- (6_1, 3/2) \rightarrow \Xi_b (\bar{3}_0, 1/2) + \pi$</td>
</tr>
</tbody>
</table>

Experimental data a little puzzling because of rather strong isospin violation.
Consequences

Omega’s form isospin triplet, easy to check experimentally
Consequences

Omega's form isospin triplet, easy to check experimentally rich structure - many new states, also in the case of b baryons

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 octet (!)
- heavy baryons can be described in terms of $N_c$-1 quark soliton
- two types of excitations:
  - rotations: 15-bar (exotic)
  - quark excitations (regular)
- decay widths agree well with the data with one free parameter
- two of the LHCb Omega_c states may be interpreted as 5q
Backup slides
What is the experimental status of light pentaquarks today?
Status of the $\Theta^+$ analysis at LEPS

T. Nakano, for the LEPS collaboration

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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 $\Theta^+$ 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 $\sigma$, and the differential cross-section for the $\gamma n \rightarrow K^-\Theta^+$ reaction is estimated to be $12 \pm 2$ nb/sr in the LEPS angular range by assuming the isotropic production.

Key words: Penta-quark, Photo-production
Observation of a narrow baryon resonance with positive strangeness formed in $K^+\text{Xe}$ collisions

V. V. Barmin, A. E. Asratyan, V. S. Borisov, C. Curceanu, G. V. Davidenko, A. G. Dolgolenko, C. Guaraldo, M. A. Kubantsev, I. F. Larin, V. A. Matveev, V. A. Shebanov, N. N. Shishov, L. I. Sokolov, V. V. Tarasov, G. K. Tumanov, and V. S. Verebryusov

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The charge-exchange reaction $K^+\text{Xe} \rightarrow K^0p\text{Xe}^\prime$ 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 $K^+\text{Xe}$ collisions, the statistical significance of the signal reaches 5.5$\sigma$. 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 $K^+n \rightarrow K^0p$ on a bound neutron. The mass of the $\Theta^+$ 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.
We report observation of a narrow peak structure at $\sim 1.54$ GeV with a Gaussian width $\sigma = 6$ MeV in the missing mass of $K_S$ in the reaction $\gamma + p \rightarrow pK_SK_L$. The observed structure may be due to the interference between a strange (or antistrange) baryon resonance in the $pK_L$ system and the $\phi(K_SK_L)$ photoproduction leading to the same final state. The statistical significance of the observed excess of events estimated as the log-likelihood ratio of the resonant signal + background hypothesis and the $\phi$-production-based background-only hypothesis corresponds to 5.3$\sigma$. 
PHYSICAL REVIEW C 85, 035209 (2012)

Observation of a narrow structure in $^{1}H(\gamma,K_{S}^{0})X$ via interference with $\phi$-meson production

PHYSICAL REVIEW C 86, 069801 (2012)

Comment on “Observation of a narrow structure in $^{1}H(\gamma,K_{S}^{0})X$ via interference with $\phi$-meson production”

This analysis was reviewed by the CLAS Collaboration, following the established procedures for all CLAS papers, and did not receive approval. The purpose of this Comment is to explain the reasons why that analysis was not approved for publication.

The ratio of the resonant signal + background hypothesis and the $\phi$-production-based background-only hypothesis corresponds to 5.3$\sigma$. 
What is the experimental status of light pentaquarks today?
Evidence for an Exotic $S = -2$, $Q = -2$ Baryon Resonance in Proton-Proton Collisions at the CERN SPS

Results of resonance searches in the $\Xi^-\pi^-$, $\Xi^-\pi^+$, $\Xi^+\pi^-$, and $\Xi^+\pi^+$ invariant mass spectra in proton-proton collisions at $\sqrt{s} = 17.2$ GeV are presented. Evidence is shown for the existence of a narrow $\Xi^-\pi^-$ baryon resonance with mass of $1.862 \pm 0.002$ GeV/$c^2$ and width below the detector resolution of about 0.018 GeV/$c^2$. The significance is estimated to be above 4.2$\sigma$. This state is a candidate for the hypothetical exotic $\Xi_{3/2}^-$ baryon with $S = -2$, $I = \frac{3}{2}$, and a quark content of $(d s d s \bar{u})$. At the same mass, a peak is observed in the $\Xi^-\pi^+$ spectrum which is a candidate for the $\Xi_{3/2}^0$ member of this isospin quartet with a quark content of $(d s u s \bar{d})$. The corresponding antibaryon spectra also show enhancements at the same invariant mass.
What is the experimental status of light pentaquarks today?
Pentanucleon?

D. Werthmuller et al. [A2 Collaboration]
Pentanucleon?

M.V. Polyakov and A. Rathke, 
*On photoexcitation of baryon anti-decuplet*

natural (but not the only one) explanation if N* is a pentaquark
Insight into the Narrow Structure in $\eta$ 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 $\eta$ 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 4$\pi$ detector setup of the Crystal Ball and TAPS is ideally suited to detect the recoil nucleons and the decay photons from $\eta \rightarrow 2\gamma$ and $\eta \rightarrow 3\pi^0$. The results show that the narrow structure previously observed in $\eta$ 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 $\eta$ 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.