

On a possibility of baryonic exotica

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in collaboration with

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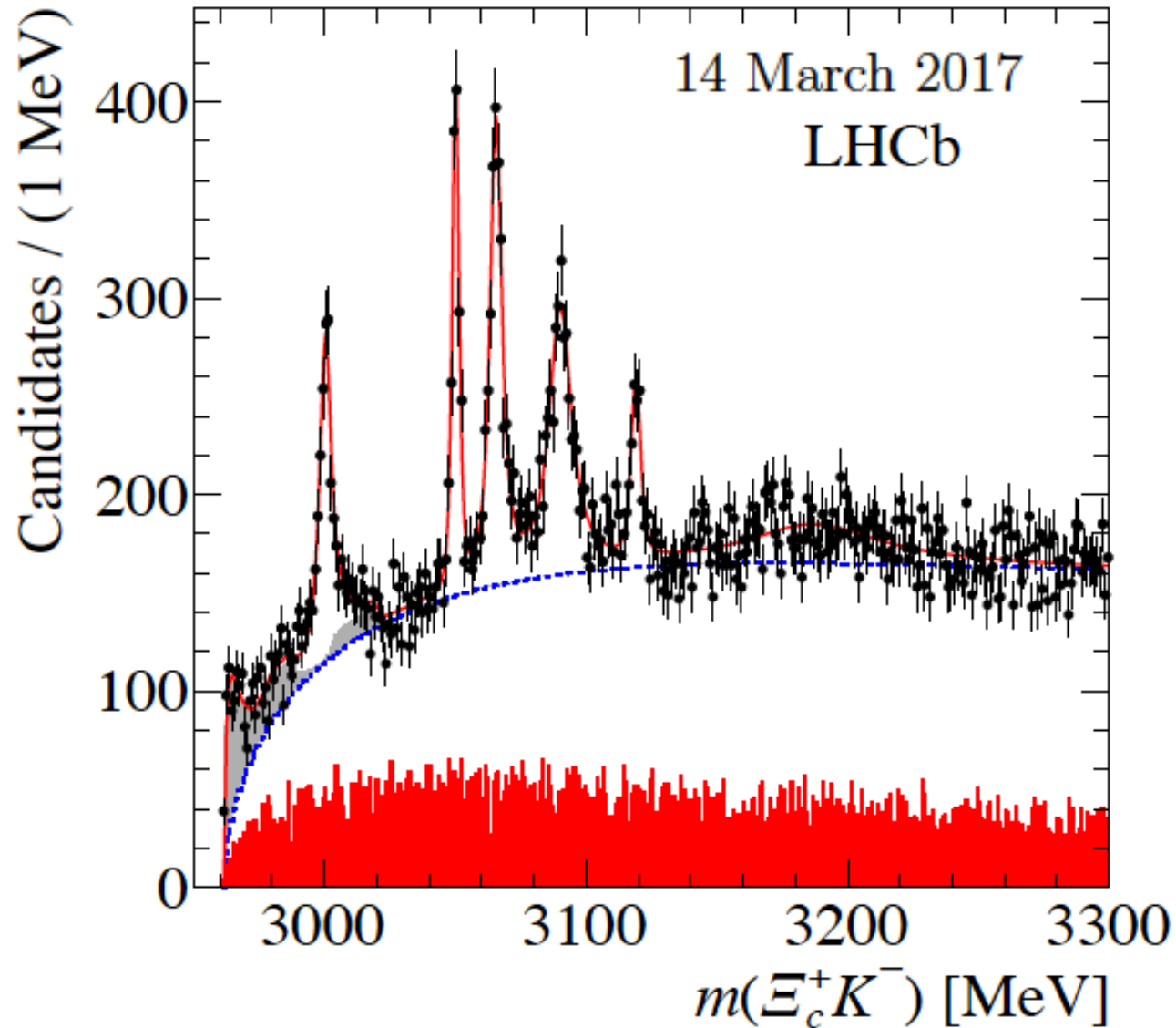
Phys.Rev. D94 (2016) 071502

Phys.Rev. D96 (2017) 014009

and in preparation

Motivation

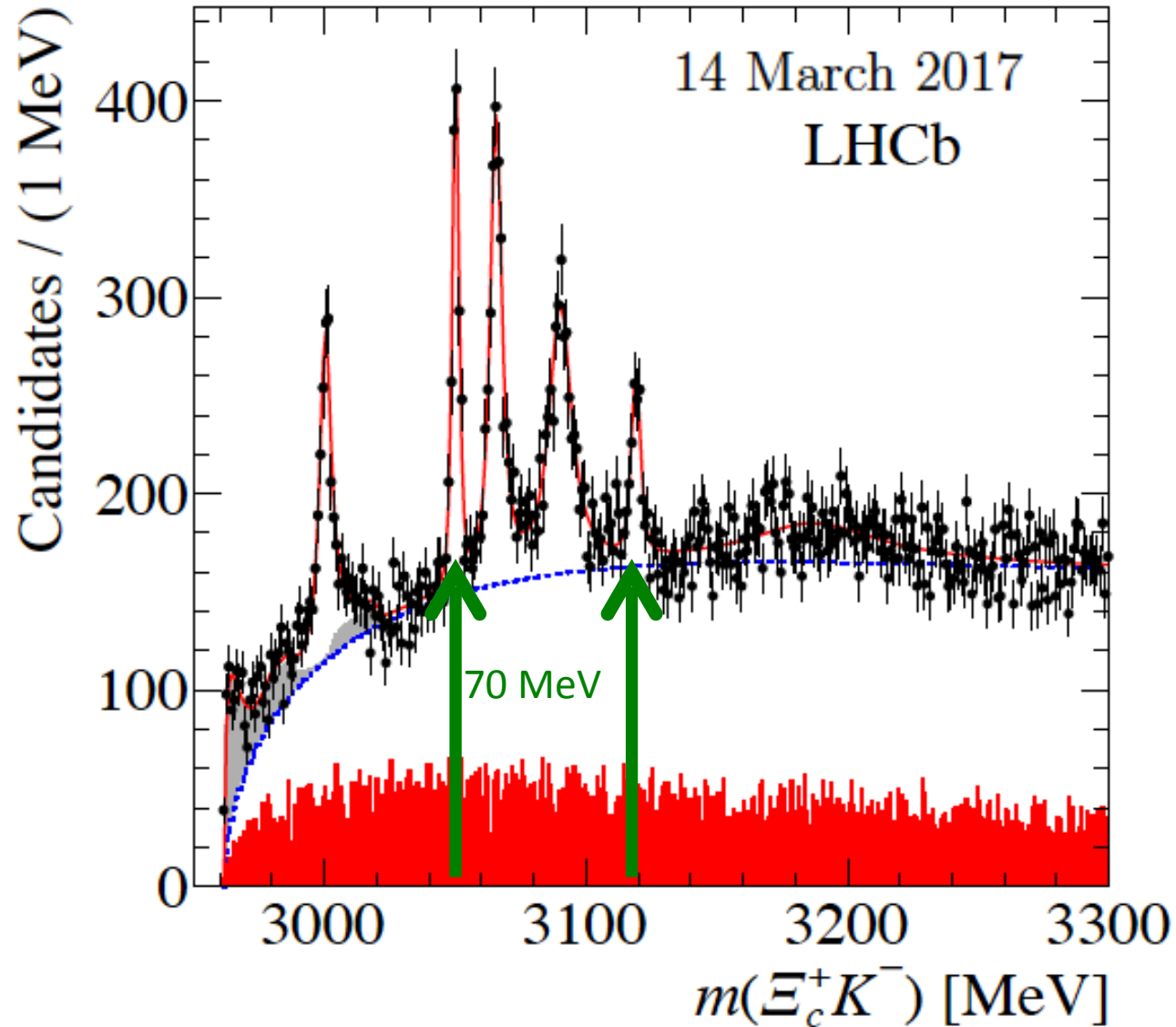
Motivation: 5 narrow Ω_c 's



Motivation: 5 narrow Ω_c 's

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

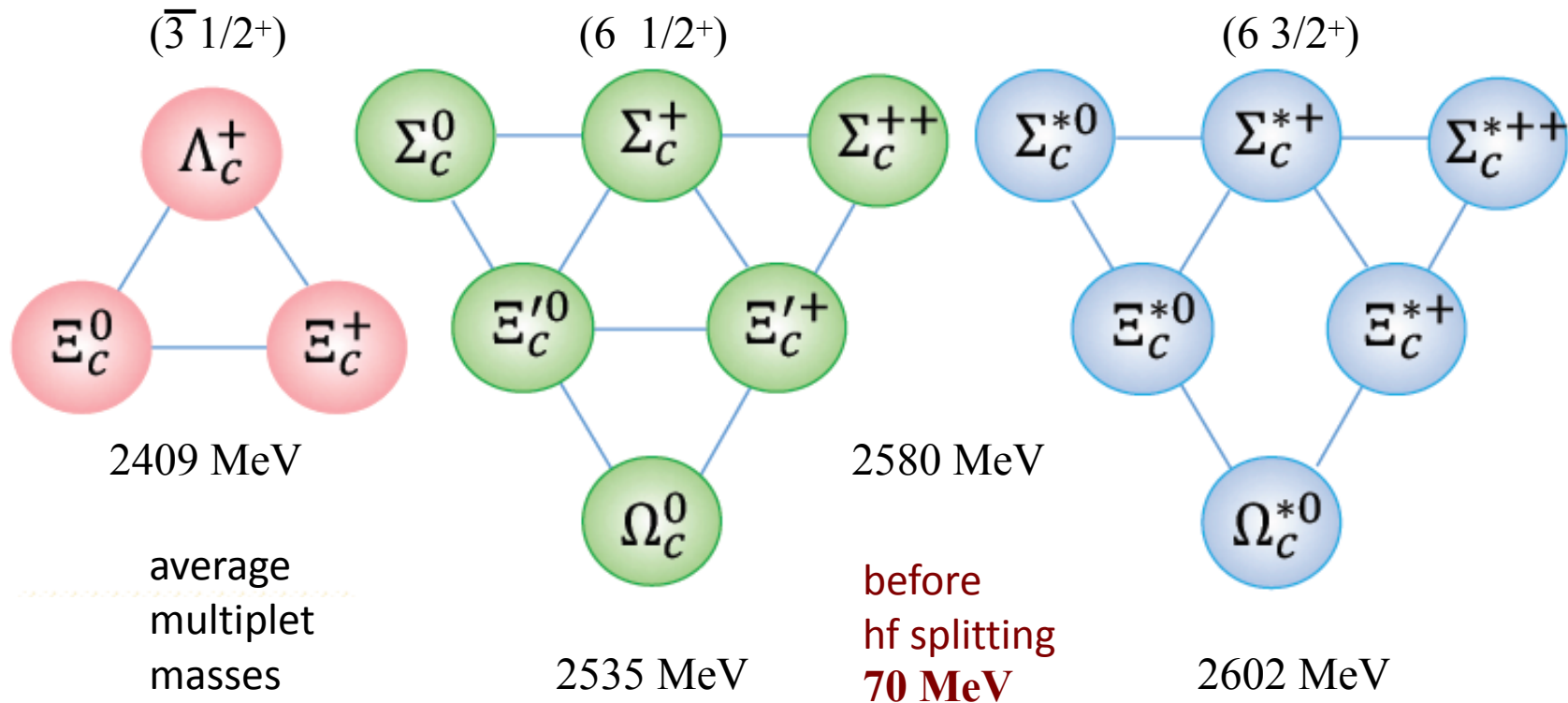
Motivation: 5 narrow Ω_c 's



Reminder

Heavy baryon ground states

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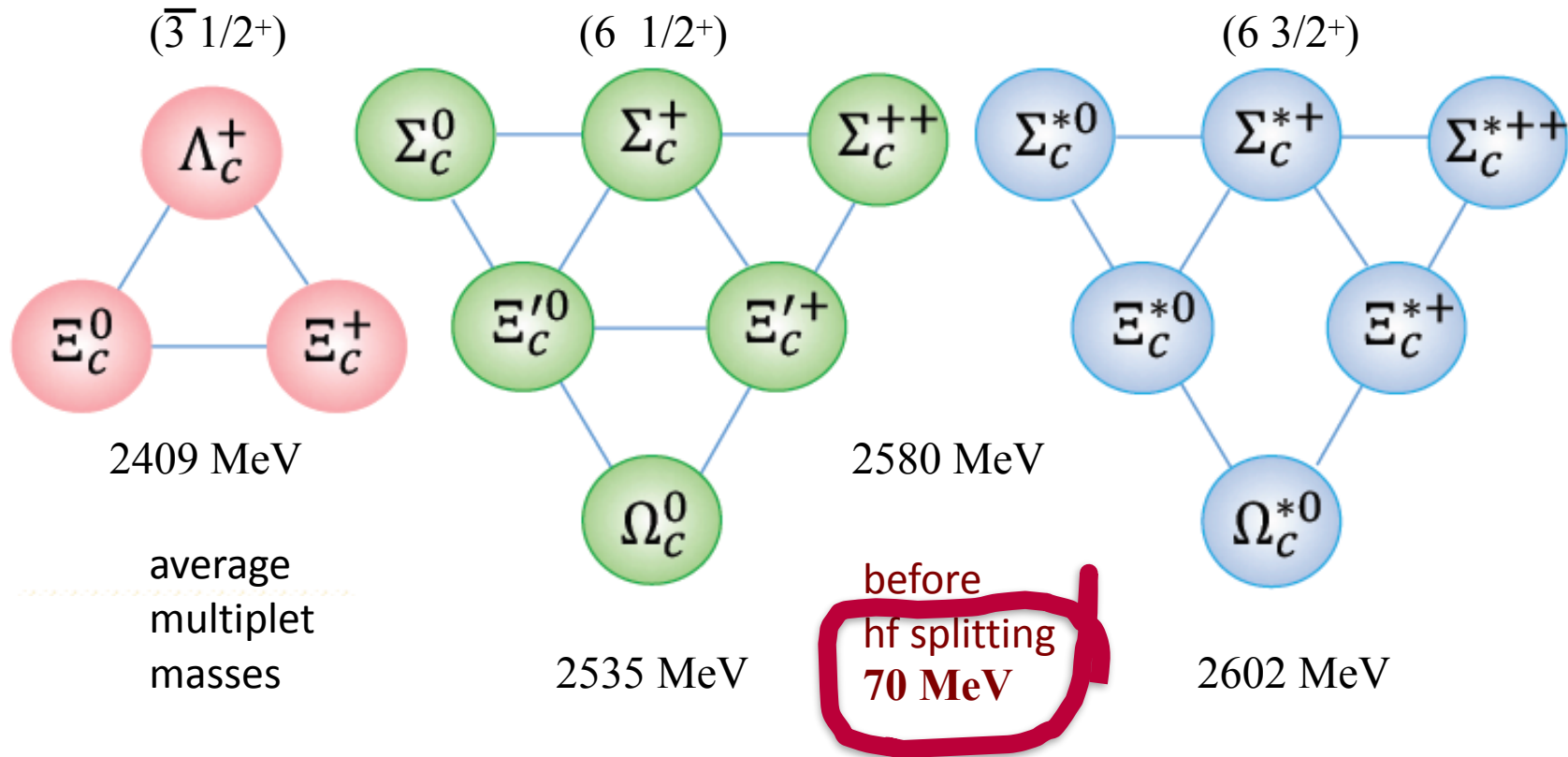


$s = 0$ diquark + $s = 1/2$ HQ

$s = 1$ diquark + $s = 1/2$ HQ

Heavy baryon ground states

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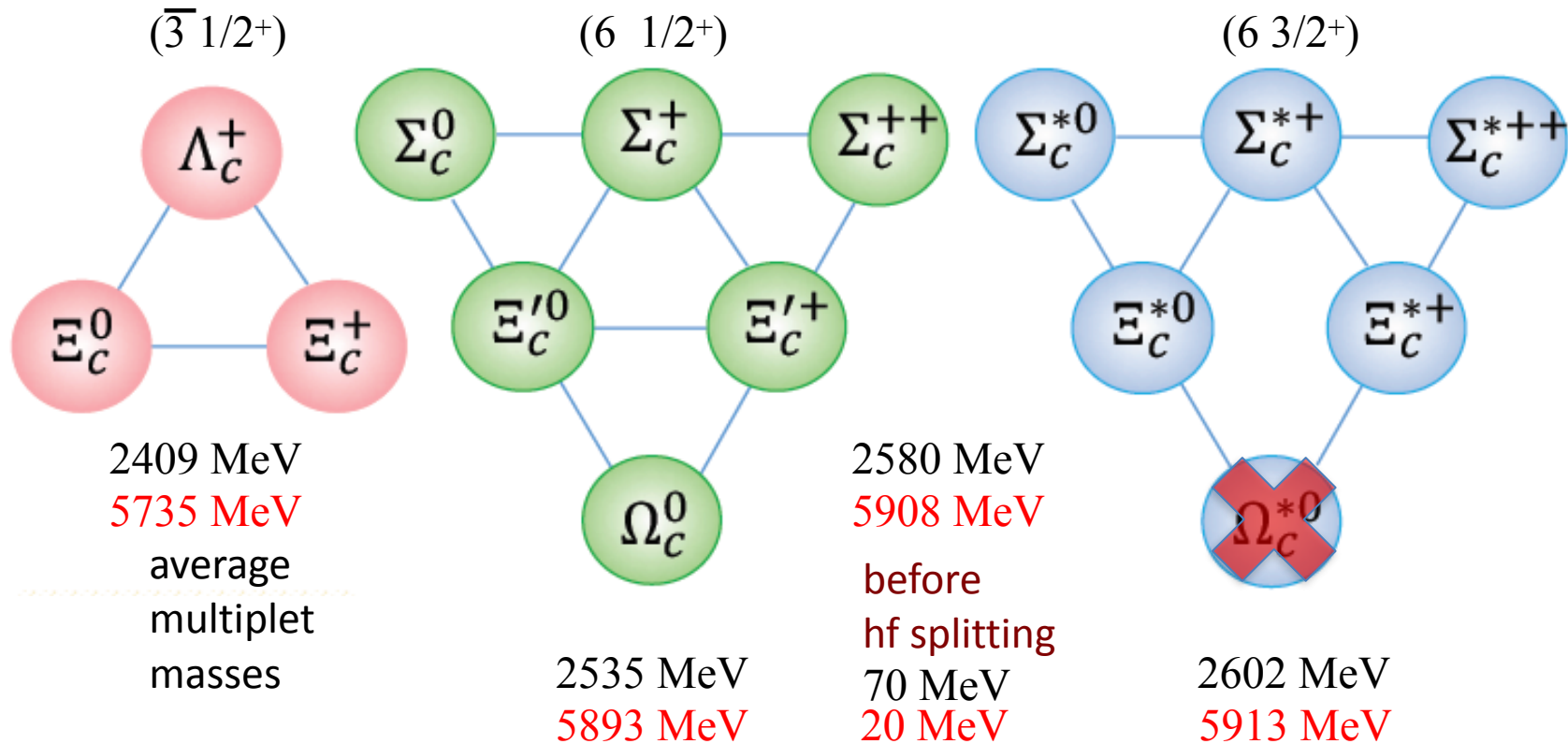


$s = 0$ diquark + $s = 1/2$ HQ

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Heavy baryon ground states

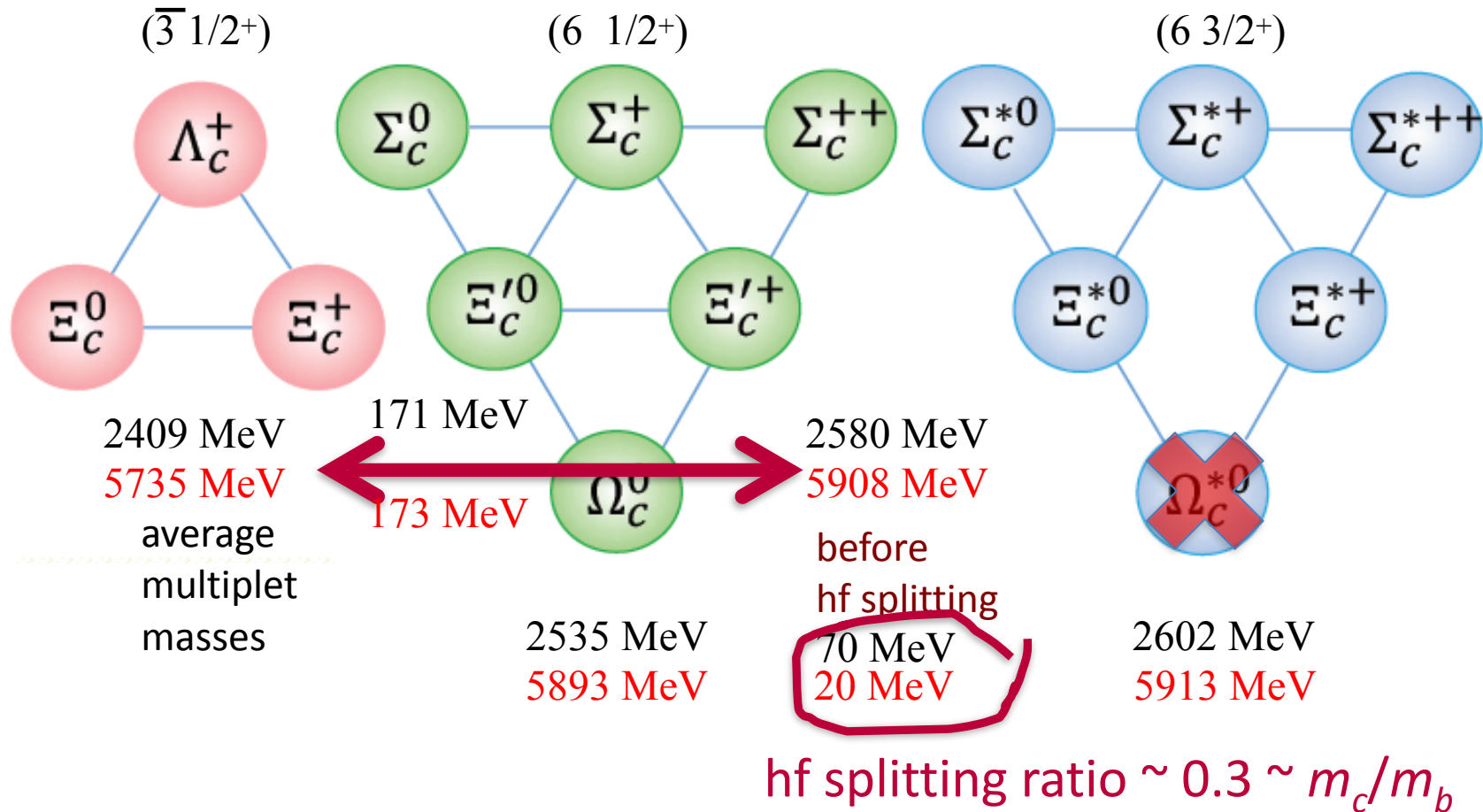
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same for the bottom

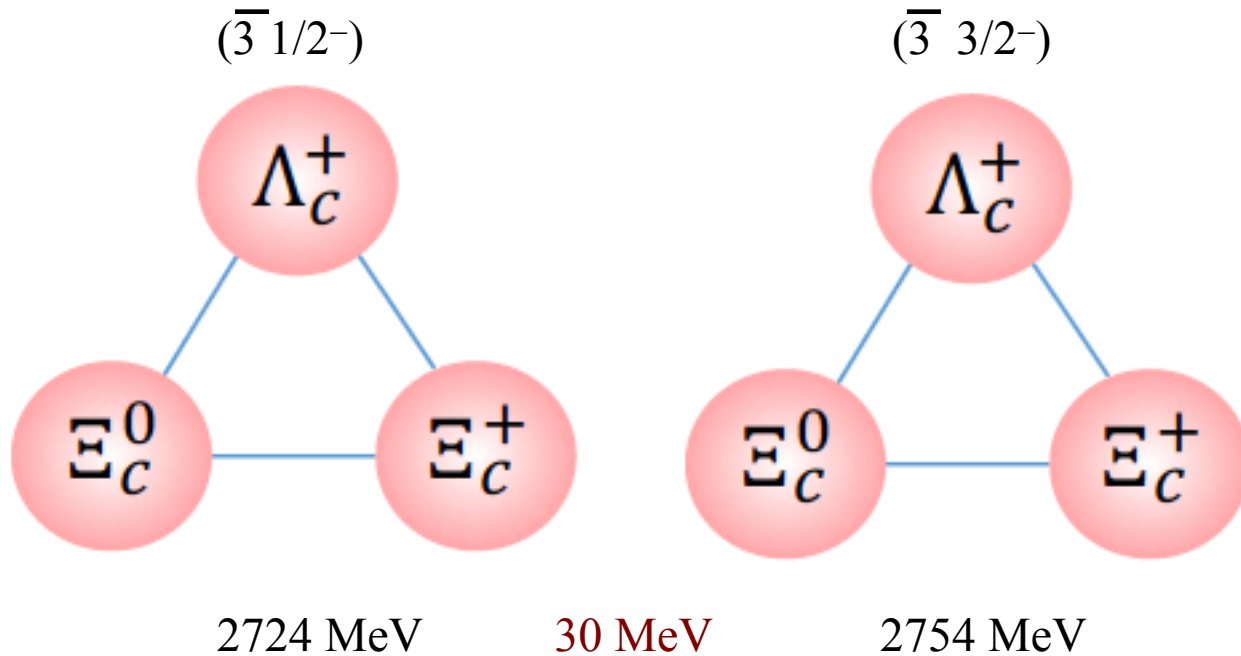
Heavy baryon ground states

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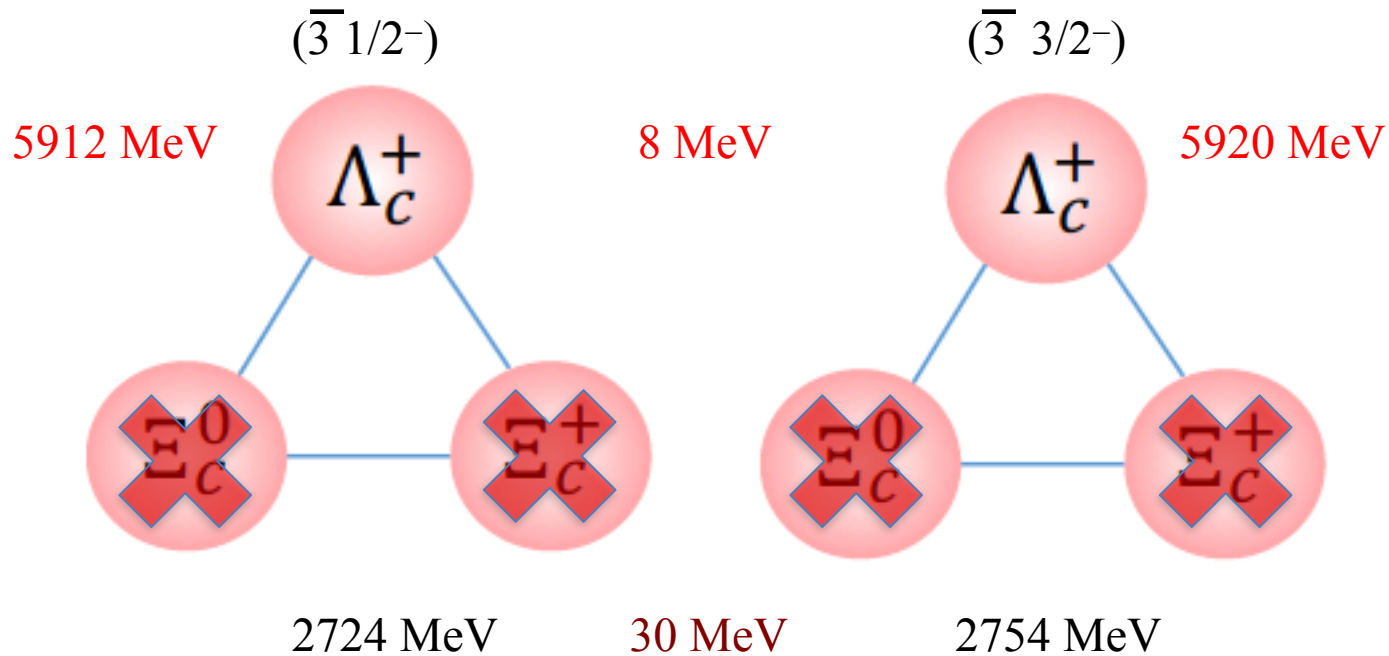
same for the bottom

Heavy baryon excited states



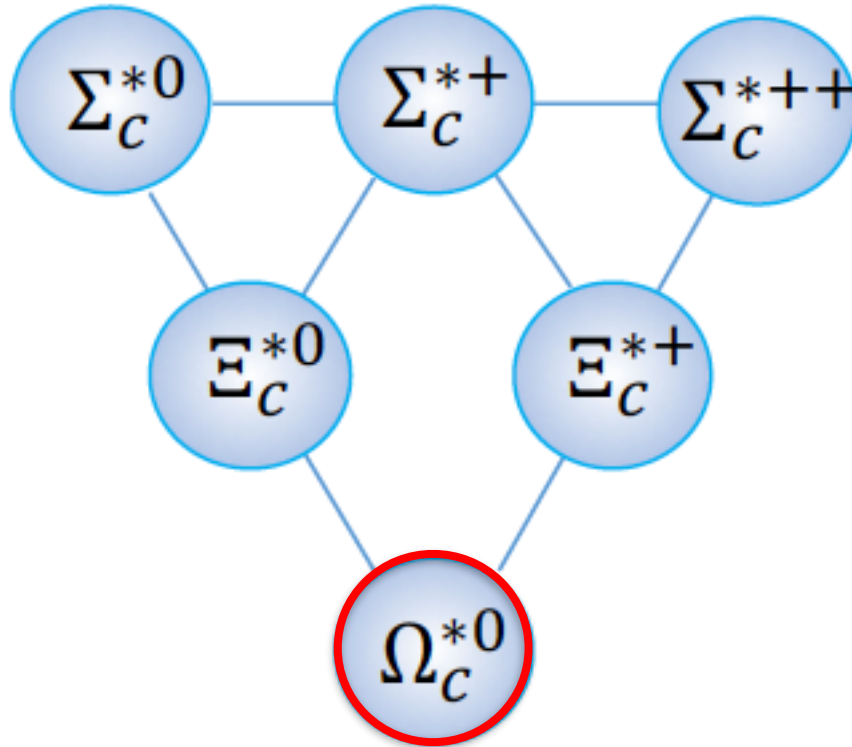
$s = 0$ diquark + $s = 1/2$ HQ + $L = 1$

Heavy baryon excited states



not much known in the bottom sector

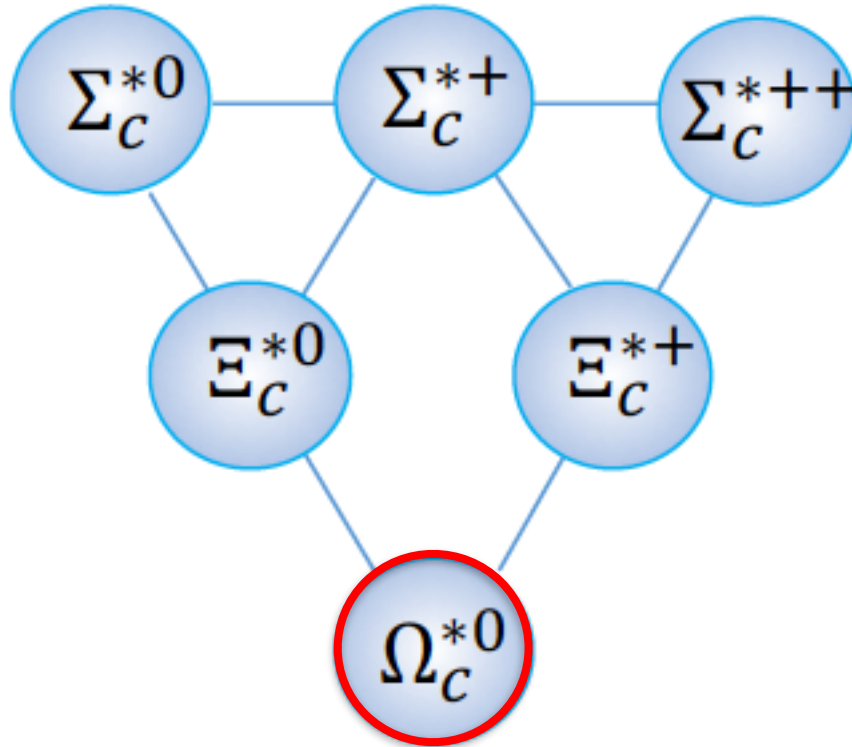
Sextet excitations $1/2^-$ and $3/2^-$?



$s = 1$ diquark + $s = 1/2$ HQ + $L = 1$

$\rightarrow 1/2, 1/2, 3/2, 3/2, 5/2 \rightarrow 5$ states!

Sextet excitations 1/2- and 3/2-?



however:
one has to fit both
masses
and
widths

$$s = 1 \text{ diquark} + s = 1/2 \text{ HQ} + L = 1$$

→ 1/2, 1/2, 3/2, 3/2, 5/2 → 5 states!

G. Yang and J. Ping, arXiv:1703.08845 [hep-ph].

H. Huang, J. Ping and F. Wang, arXiv:1704.01421 [hep-ph].

C. S. An and H. Chen, Phys. Rev. D **96**, no. 3, 034012 (2017) doi:10.1103/PhysRevD.96.034012 [arXiv:1705.08571 [hep-ph]].

V. V. Anisovich, M. A. Matveev, J. Nyiri and A. N. Semenova, Mod. Phys. Lett. A **32**, 1750154 (2017) doi:10.1142/S0217732317501541 [arXiv:1706.01336 [hep-ph]].

M. Karliner and J. L. Rosner, Phys. Rev. D **95**, no. 11, 114012 (2017) doi:10.1103/PhysRevD.95.114012 [arXiv:1703.07774 [hep-ph]].

K. L. Wang, L. Y. Xiao, X. H. Zhong and Q. Zhao, Phys. Rev. D **95**, no. 11, 116010 (2017) doi:10.1103/PhysRevD.95.116010 [arXiv:1703.09130 [hep-ph]].

W. Wang and R. L. Zhu, Phys. Rev. D **96**, no. 1, 014024 (2017) doi:10.1103/PhysRevD.96.014024 [arXiv:1704.00179 [hep-ph]].

H. Y. Cheng and C. W. Chiang, Phys. Rev. D **95**, no. 9, 094018 (2017) doi:10.1103/PhysRevD.95.094018 [arXiv:1704.00396 [hep-ph]].

B. Chen and X. Liu, arXiv:1704.02583 [hep-ph].

A. Ali, L. Maiani, A. V. Borisov, I. Ahmed, M. J. Aslam, A. Y. Parkhomenko, A. D. Polosa and A. Rehman, arXiv:1708.04650 [hep-ph].

S. S. Agaev, K. Azizi and H. Sundu, EPL **118**, no. 6, 61001 (2017) doi:10.1209/0295-5075/118/61001 [arXiv:1703.07091 [hep-ph]] and Eur. Phys. J. C **77**, no. 6, 395 (2017) doi:10.1140/epjc/s10052-017-4953-z [arXiv:1704.04928 [hep-ph]].

H. X. Chen, Q. Mao, W. Chen, A. Hosaka, X. Liu and S. L. Zhu, Phys. Rev. D **95**, no. 9, 094008 (2017) doi:10.1103/PhysRevD.95.094008 [arXiv:1703.07703 [hep-ph]].

Z. G. Wang, Eur. Phys. J. C **77**, no. 5, 325 (2017) doi:10.1140/epjc/s10052-017-4895-5 [arXiv:1704.01854 [hep-ph]].

T. M. Aliev, S. Bilmis and M. Savci, arXiv:1704.03439 [hep-ph].

K. Azizi, Y. Sarac and H. Sundu, arXiv:1707.01248 [hep-ph].

Z. Zhao, D. D. Ye and A. Zhang, Phys. Rev. D **95**, no. 11, 114024 (2017) doi:10.1103/PhysRevD.95.114024 [arXiv:1704.02688 [hep-ph]].

M. Padmanath and N. Mathur, Phys. Rev. Lett. **119**, no. 4, 042001 (2017) doi:10.1103/PhysRevLett.119.042001 [arXiv:1704.00259 [hep-ph]].

Y. Liu and I. Zahed, Phys. Rev. D **95**, no. 11, 116012 (2017) doi:10.1103/PhysRevD.95.116012 [arXiv:1704.03412 [hep-ph]] and arXiv:1705.01397 [hep-ph].

G. Yang and J. Ping, arXiv:1703.08845 [hep-ph].
H. Huang, J. Ping and F. Wang, arXiv:1704.01421 [hep-ph].
C. S. An and H. Chen, Phys. Rev. D **96**, no. 3, 034012 (2017) doi:10.1103/PhysRevD.96.034012 [arXiv:1705.08571 [hep-ph]].
V. V. Anisimov, M. A. Matrosov, I. Niyozov and A. N. Semenova, Mod. Phys. Lett. A **32**, 1750154 (2017) doi:10.1142/S0217732317501541 [arXiv:1706.01336 [hep-ph]].
M. Karliner and R. J. Doss, Phys. Rev. D **95**, no. 11, 114012 (2017) doi:10.1103/PhysRevD.95.114012 [arXiv:1703.07774 [hep-ph]].
K. L. Wang, S. M. Zeppenfeld and C. S. An, Phys. Rev. D **95**, no. 11, 116010 (2017) doi:10.1103/PhysRevD.95.116010 [arXiv:1703.09130 [hep-ph]].
W. Wang and R. J. Zhu, Phys. Rev. D **96**, no. 1, 014024 (2017) doi:10.1103/PhysRevD.96.014024 [arXiv:1704.06150 [hep-ph]].
H. Y. Cheng and C. W. Chiang, Phys. Rev. D **95**, no. 9, 094018 (2017) doi:10.1103/PhysRevD.95.094018 [arXiv:1704.01166 [hep-ph]].
B. Chen and X. Liu, arXiv:1704.02583 [hep-ph].
A. Ali, L. Malik, M. A. Shabir, M. Ahmed, M. J. Aslam, A. Y. Parkhomenko, A. D. Polosa and A. Rehman, arXiv:1708.04650 [hep-ph].
S. S. Agaev, K. Azizi and H. Sundu, EPL **118**, no. 6, 61001 (2017) doi:10.1209/0295-5075/118/61001 [arXiv:1703.07091 [hep-ph]] and Eur. Phys. J. C **77**, no. 6, 395 (2017) doi:10.1140/epjc/s10052-017-4953-z [arXiv:1704.04928 [hep-ph]].
H. X. Chen, C. M. Chen, W. Chen, A. Hosaka, X. Liu and S. L. Zhu, Phys. Rev. D **95**, no. 9, 094008 (2017) doi:10.1103/PhysRevD.95.094008 [arXiv:1703.07703 [hep-ph]].
Z. G. Wang, Eur. Phys. J. C **77**, no. 6, 395 (2017) doi:10.1140/epjc/s10052-017-4895-5 [arXiv:1704.01854 [hep-ph]].
T. M. Aliev, S. Bilmisli and M. Shabir, arXiv:1711.05007 [hep-ph].
K. Azizi, Y. Sarac and H. Sundu, arXiv:1707.01248 [hep-ph].
Z. Zhao, D. D. Ye and A. Zhang, Phys. Rev. D **95**, no. 11, 114024 (2017) doi:10.1103/PhysRevD.95.114024 [arXiv:1704.02688 [hep-ph]].
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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



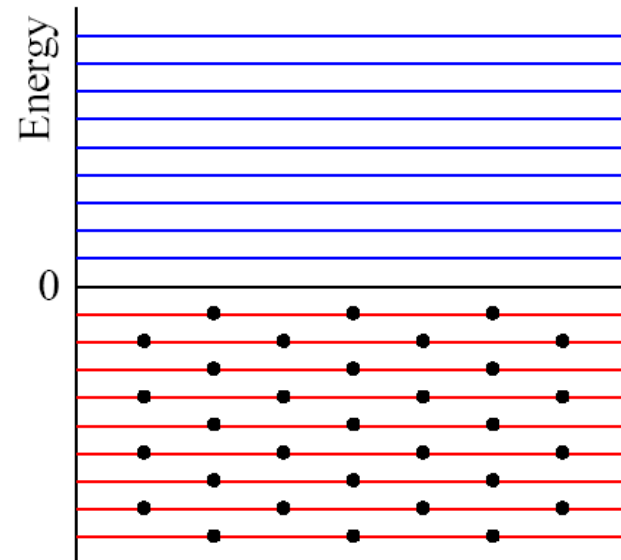
semibosonization:

$q\bar{q}q\bar{q} \rightarrow q\bar{q}\pi$

Chiral Quark Model

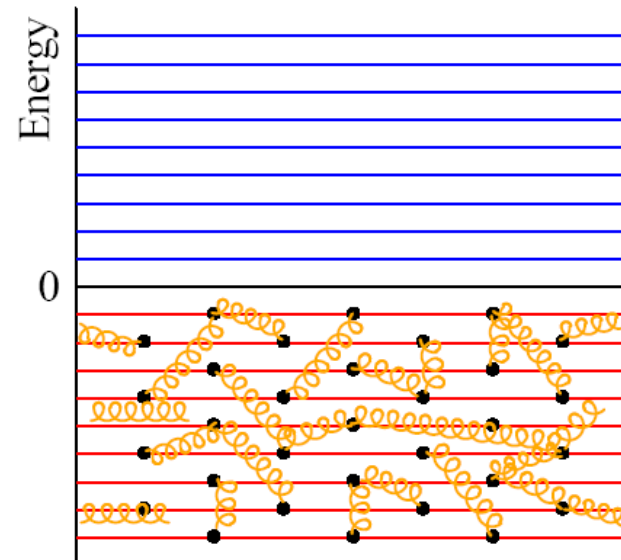
Chiral Quark Soliton Model

QCD vacuum:



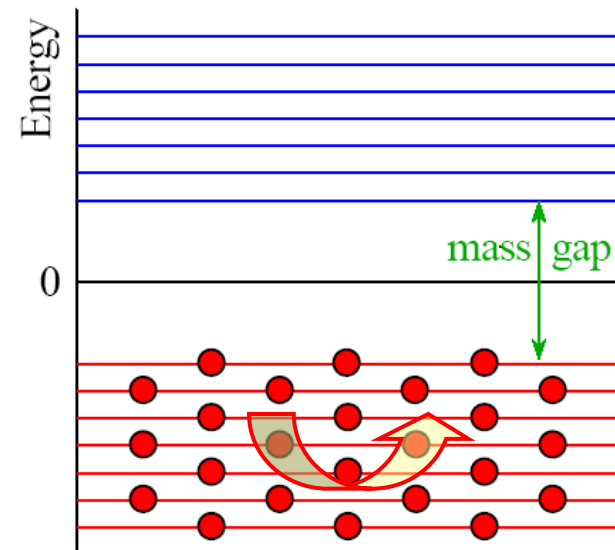
Chiral Quark Soliton Model

QCD vacuum:



Chiral Quark Soliton Model

chiral symmetry breaking:

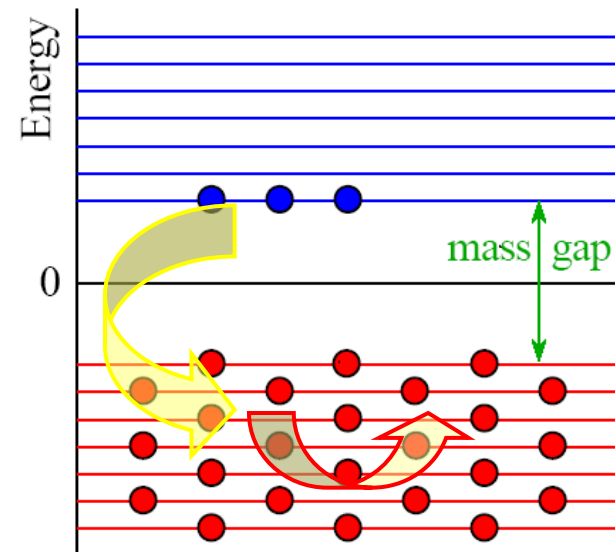


chirally inv. manyquark int.

Chiral Quark Soliton Model

baryon:

adding valence quarks:

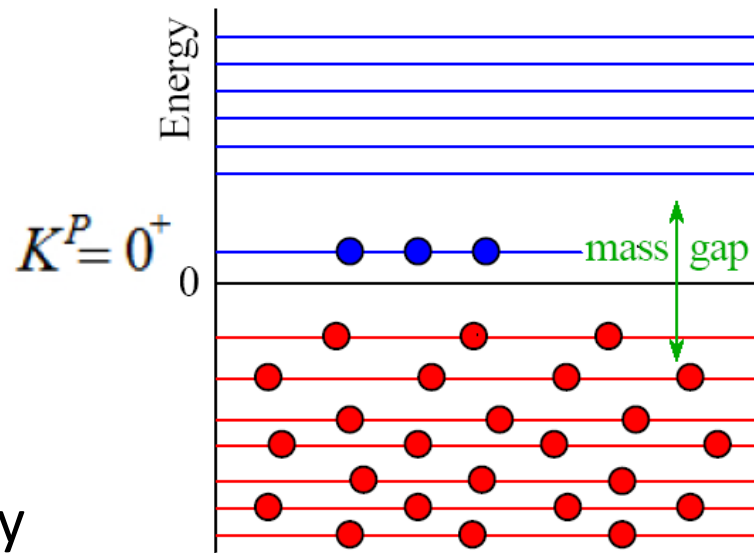


chirally inv. manyquark int.

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.

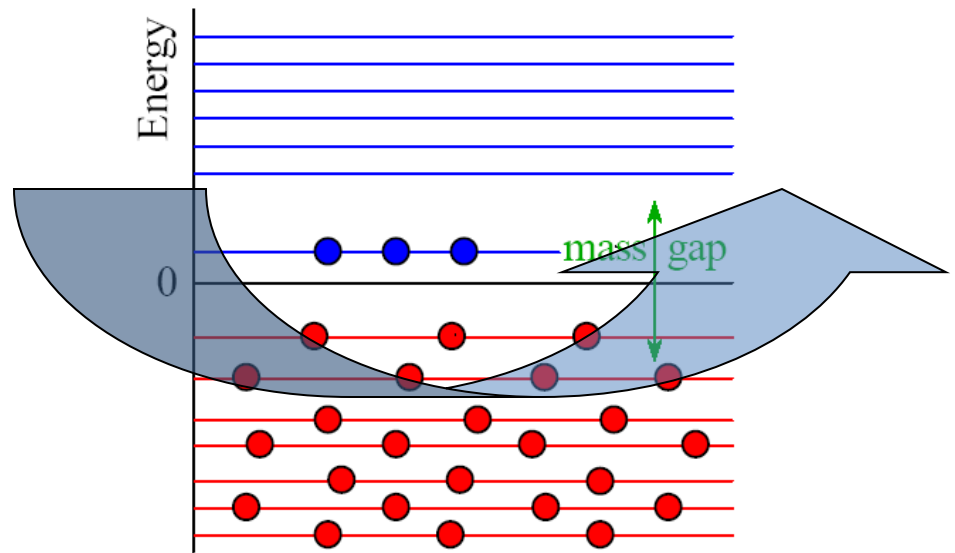
soliton configuration

no quantum numbers except B

Chiral Quark Soliton Model

baryon:

"quantum" baryon:



chirally inv. manyquark int.

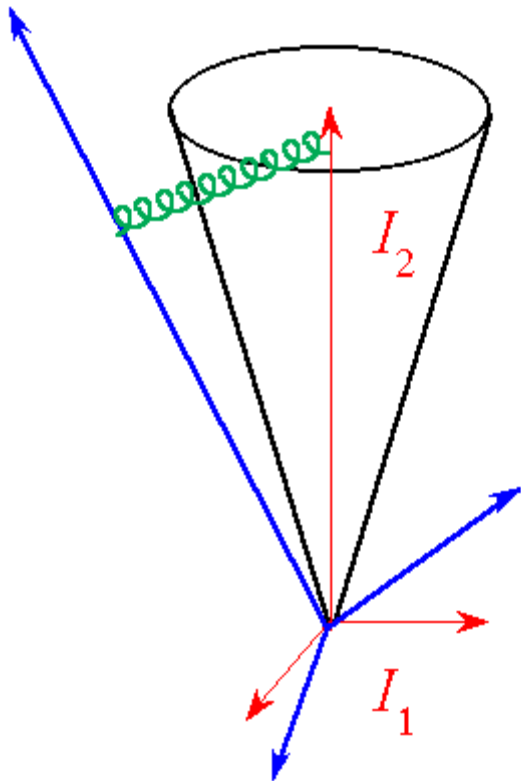
soliton configuration

no quantum numbers except B

rotation generates flavor and spin

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

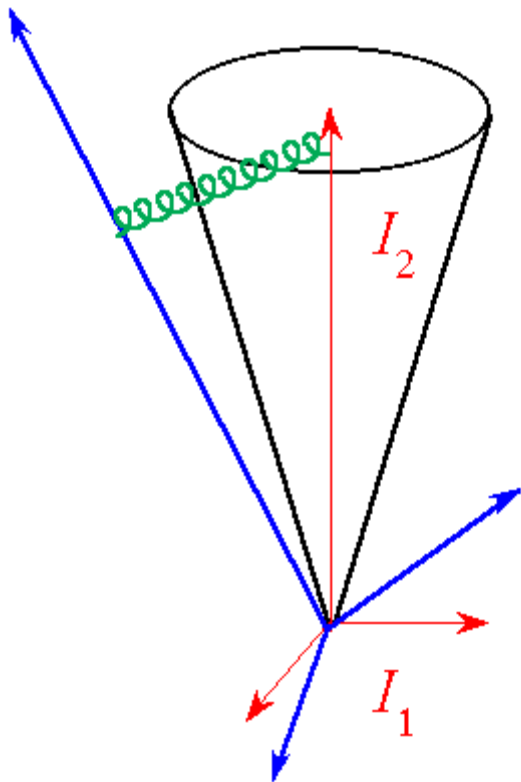
$$H_0 = M_{\text{cl}} + \frac{1}{2I_1}S(S+1) + \frac{1}{2I_2} \left(C_2(\mathcal{R}) - S(S+1) - \frac{N_c^2}{12} \right)$$



P.O. Mazur, M.A. Nowak, MP, Phys. Lett. 147B (1984) 137
E. Guadagnini, Nucl. Phys. B236 (1984) 35
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first order perturbation
in the strange quark mass
and in N_c .

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

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

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S. Jain, S.R. Wadia, Nucl. Phys. B258 (1985) 713

$O(1)$ corrections
to M_{cl} do not allow

for absolute mass predictions

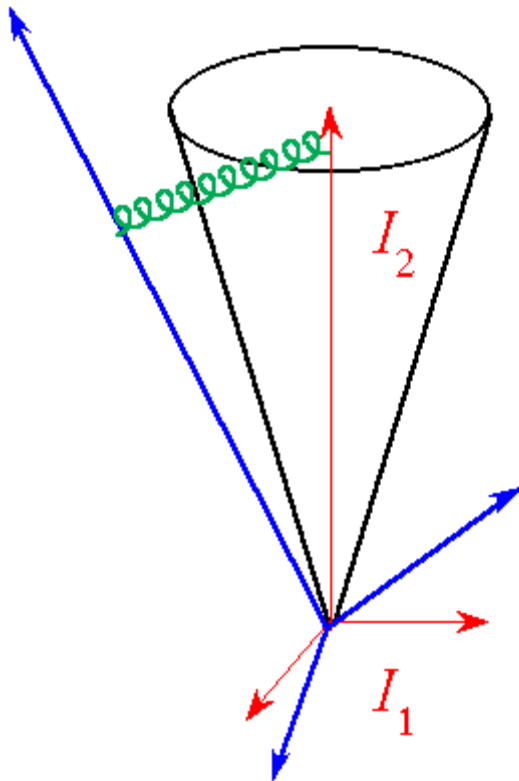
Mass formula

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

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

octet-decuplet
splitting \uparrow known

? \uparrow exotic-nonexotic splittings



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

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

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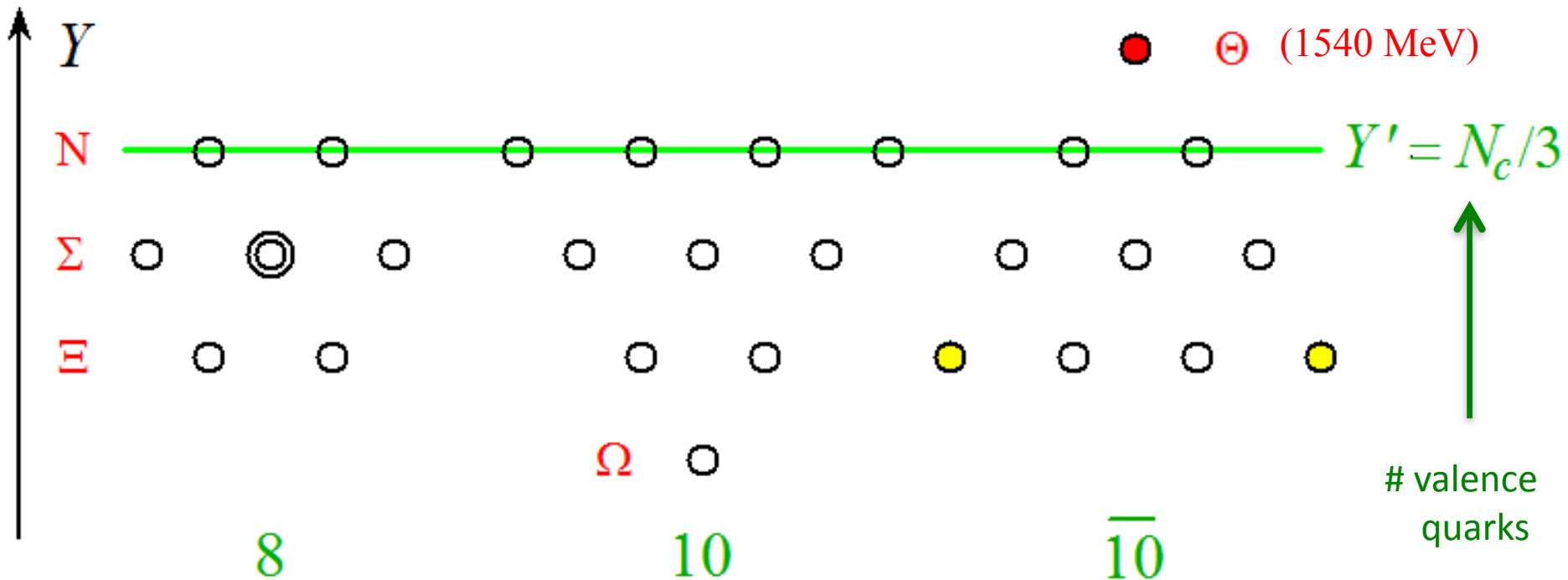
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S. Jain, S.R. Wadia, Nucl. Phys. B258 (1985) 713

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: $T' + J = 0$.



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:

$M, I_1, I_2, \alpha, \beta, \gamma$

Successful Phenomenology

In a "model independent" approach
one can get both good fits to the existing data
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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

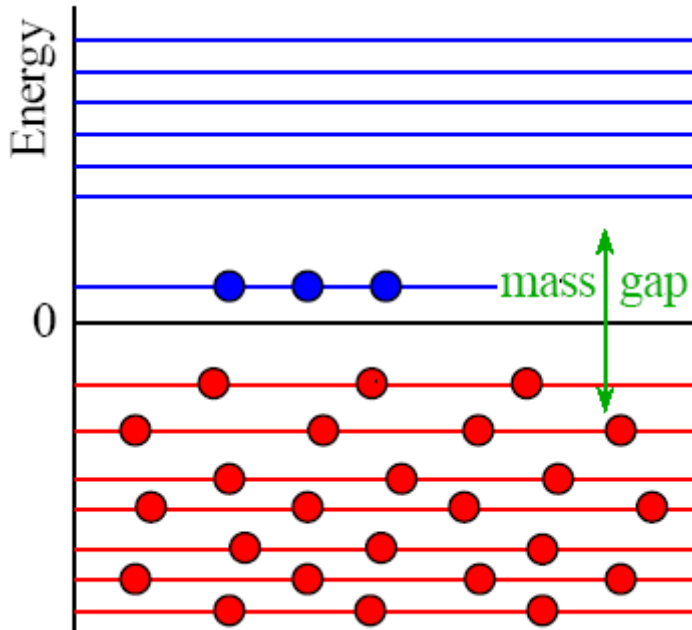
NRQM limit =

= squeezing the soliton to zero size

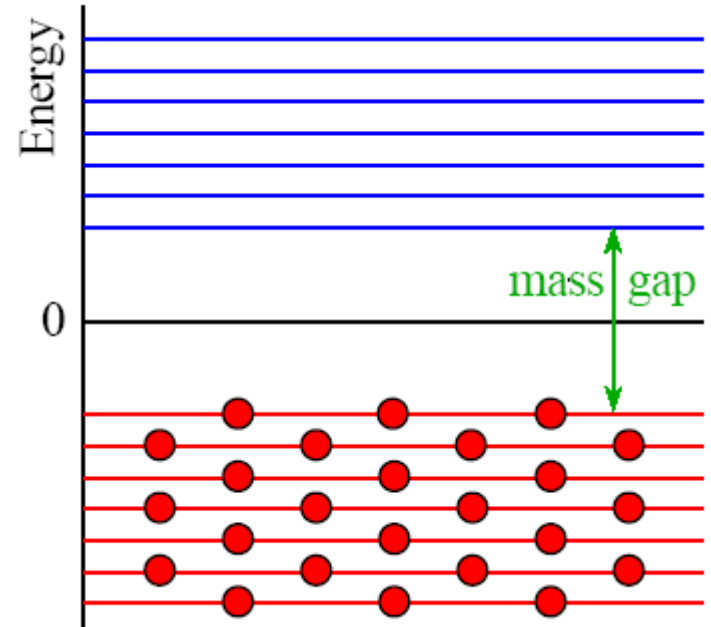
NRQM Limit

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:



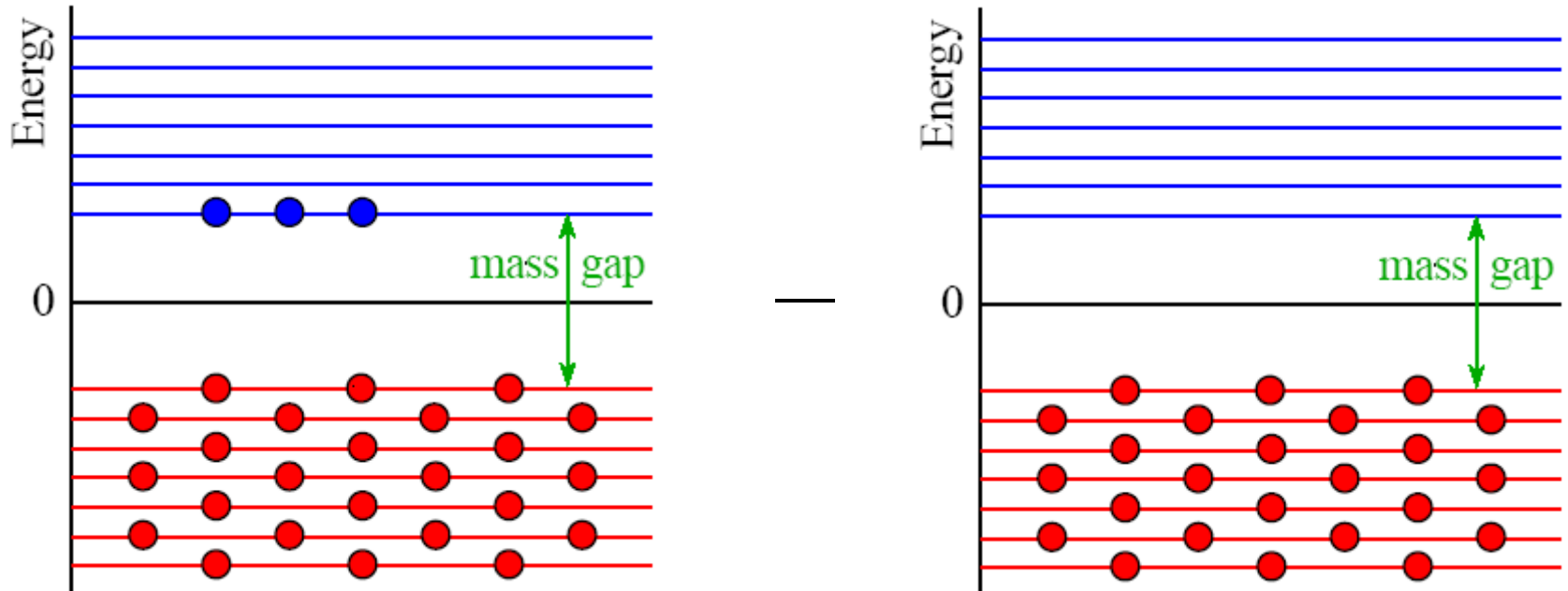
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NRQM Limit

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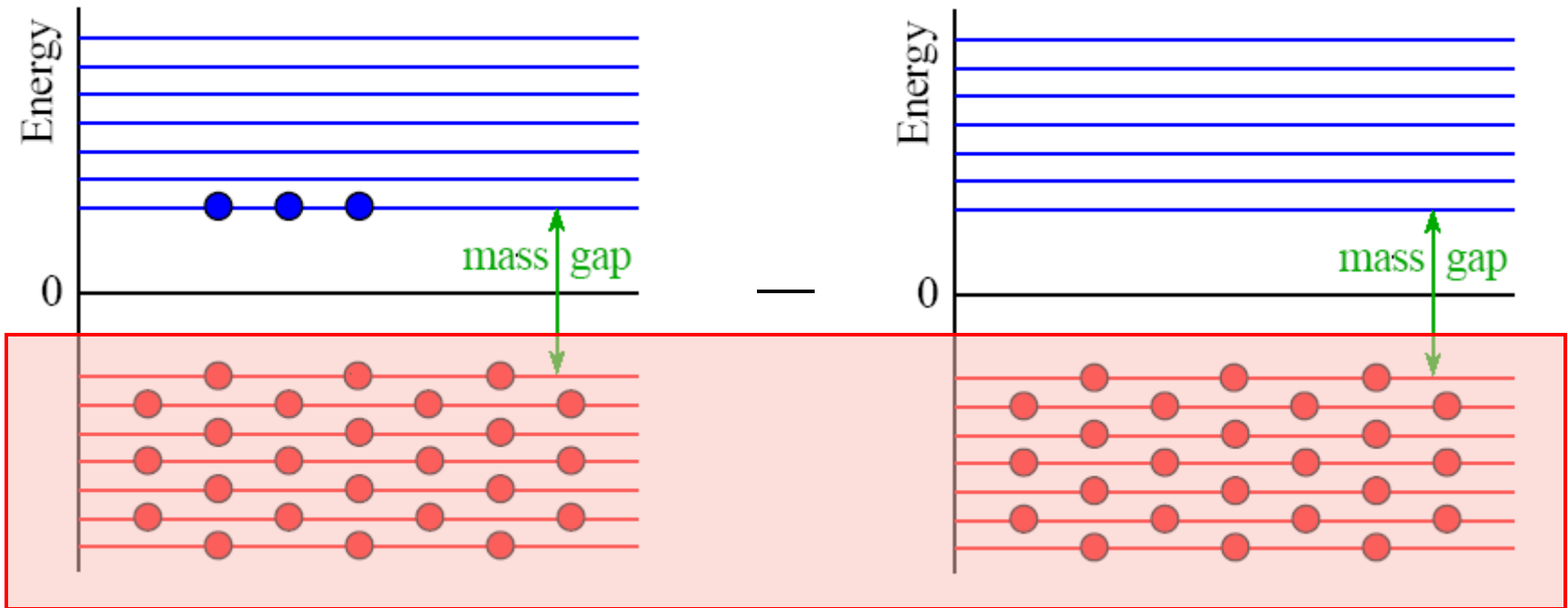
energy is calculated
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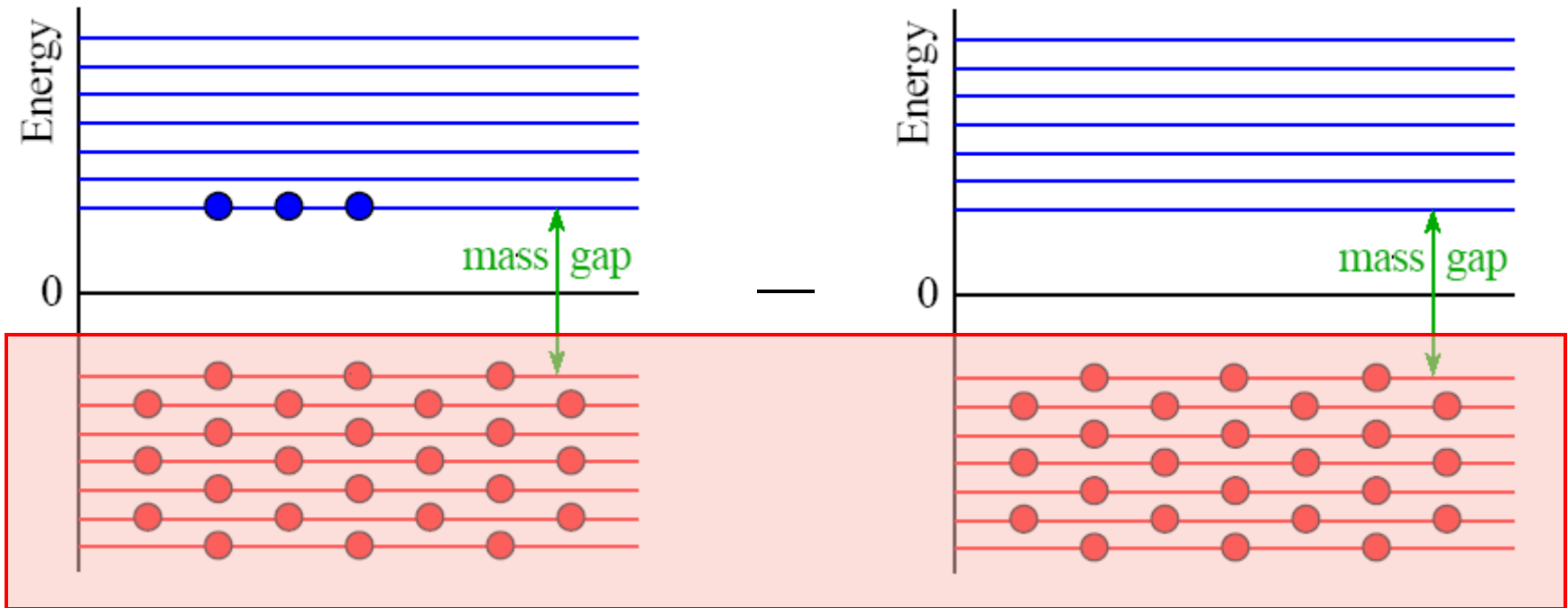
in the NRQM limit only valence level contributes

NRQM Limit

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

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energy is calculated
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in the NRQM limit only valence level contributes

NRQM Limit

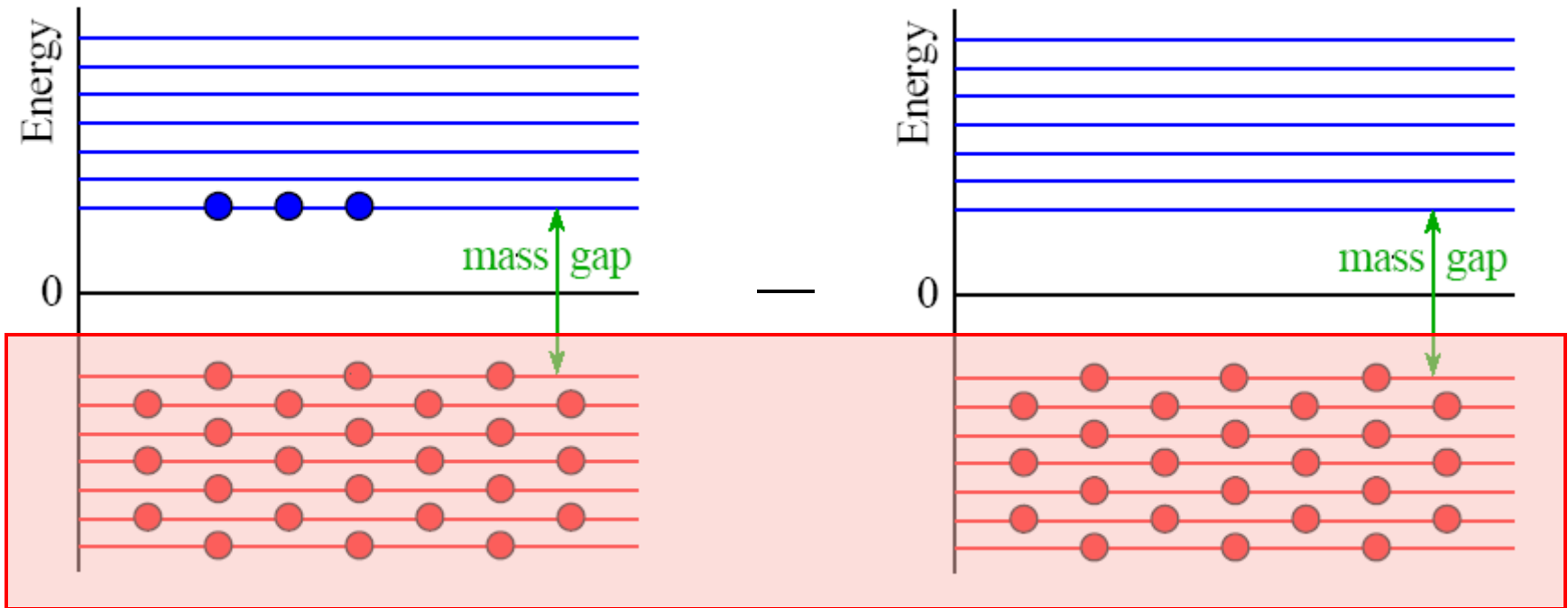
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 MP, A.Blotz K.Goeke, Phys.Lett.**B354**:415-422,1995

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

$$G_{10} = 0$$

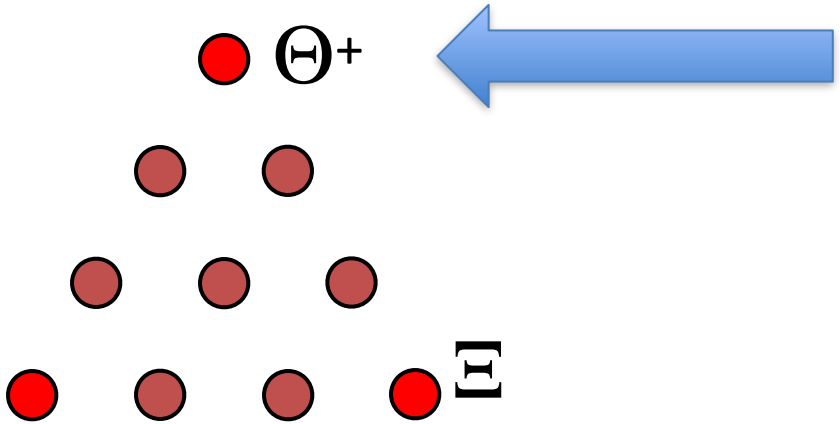
energy is calculated
 with respect to the vacuum:

pentaquark width = 0 !



in the NRQM limit only valence level contributes

What is the experimental status of light pentaquarks today?





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Nuclear Physics A 835 (2010) 254–260

www.elsevier.com/locate/nuclphysa

LEPS

Status of the Θ^+ analysis at LEPS

and various conference
proceedings

e.g. T. Nakano

MENU 2016

T. Nakano, for the LEPS collaboration

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

Abstract

We report recent results on the Θ^+ 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 $1.53 \text{ GeV}/c^2$. The statistical significance of the peak calculated from a shape analysis is 5σ , and the differential cross-section for the $\gamma n \rightarrow K^- \Theta^+$ reaction is estimated to be $12 \pm 2 \text{ nb/sr}$ in the LEPS angular range by assuming the isotropic production.

Key words: Penta-quark, Photo-production

DIANA

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
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(Received 9 February 2014; published 14 April 2014)

The charge-exchange reaction $K^+Xe \rightarrow K^0 pXe'$ 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 $K^+n \rightarrow K^0p$ 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.

dissidents from CLAS

PHYSICAL REVIEW C 85, 035209 (2012)

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

M. J. Amarian,^{1,*} G. Gavalian,¹ C. Nepali,¹ M. V. Polyakov,^{2,3} Ya. Azimov,³ W. J. Briscoe,⁴ G. E. Dodge,¹ C. E. Hyde,¹ F. Klein,⁵ V. Kuznetsov,^{6,7} I. Strakovsky,⁴ and J. Zhang⁸

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We report observation of a narrow peak structure at ~ 1.54 GeV with a Gaussian width $\sigma = 6$ MeV in the missing mass of K_S in the reaction $\gamma + p \rightarrow p K_S K_L$. The observed structure may be due to the interference between a strange (or antistrange) baryon resonance in the $p K_L$ system and the $\phi(K_S K_L)$ 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 ϕ -production-based background-only hypothesis corresponds to 5.3σ .

disclaimer from CLAS

PHYSICAL REVIEW C 85, 035209 (2012)

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

PHYSICAL REVIEW C 86, 069801 (2012)

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

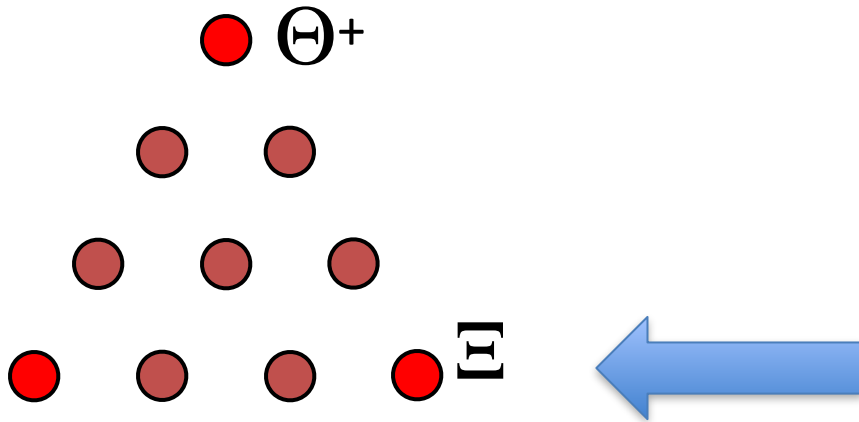
Lyngby National University, 102-101, Lyngby, Republic of Korea

¹Institute for Nuclear Research, 117312, Moscow, Russia

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.

ratio of the resonant signal + background hypothesis and the ϕ -production-based background-only hypothesis corresponds to 5.3σ .

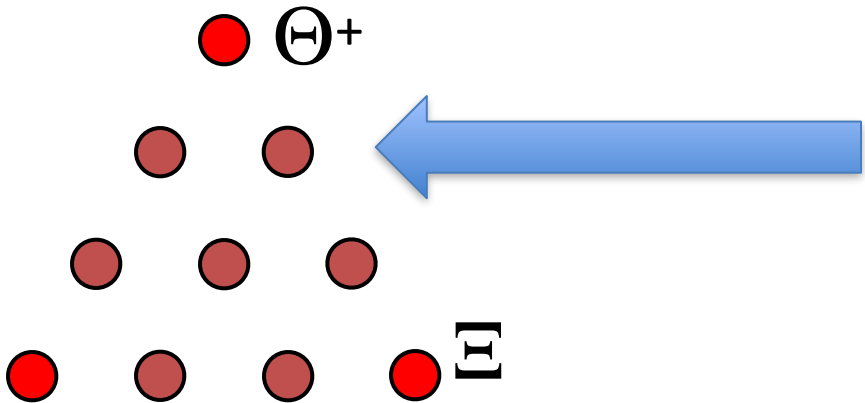
What is the experimental status
of light pentaquarks today?



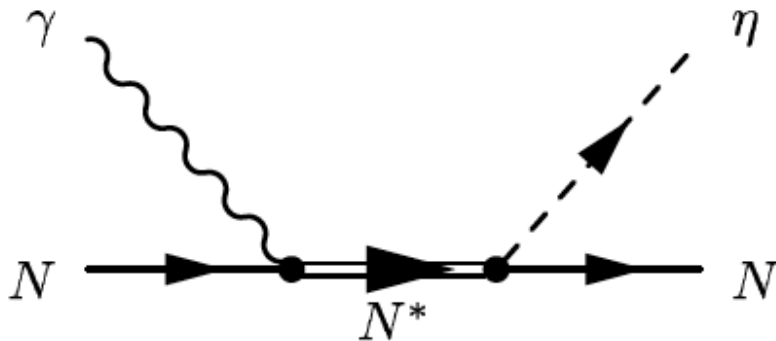
Evidence for an Exotic $S = -2$, $Q = -2$ Baryon Resonance in Proton-Proton Collisions at the CERN SPS

Results of resonance searches in the $\Xi^- \pi^-$, $\Xi^- \pi^+$, $\bar{\Xi}^+ \pi^-$, and $\bar{\Xi}^+ \pi^+$ 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 ± 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 4.2σ . 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 $(dsds\bar{u})$. 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 $(dsus\bar{d})$. The corresponding antibaryon spectra also show enhancements at the same invariant mass.

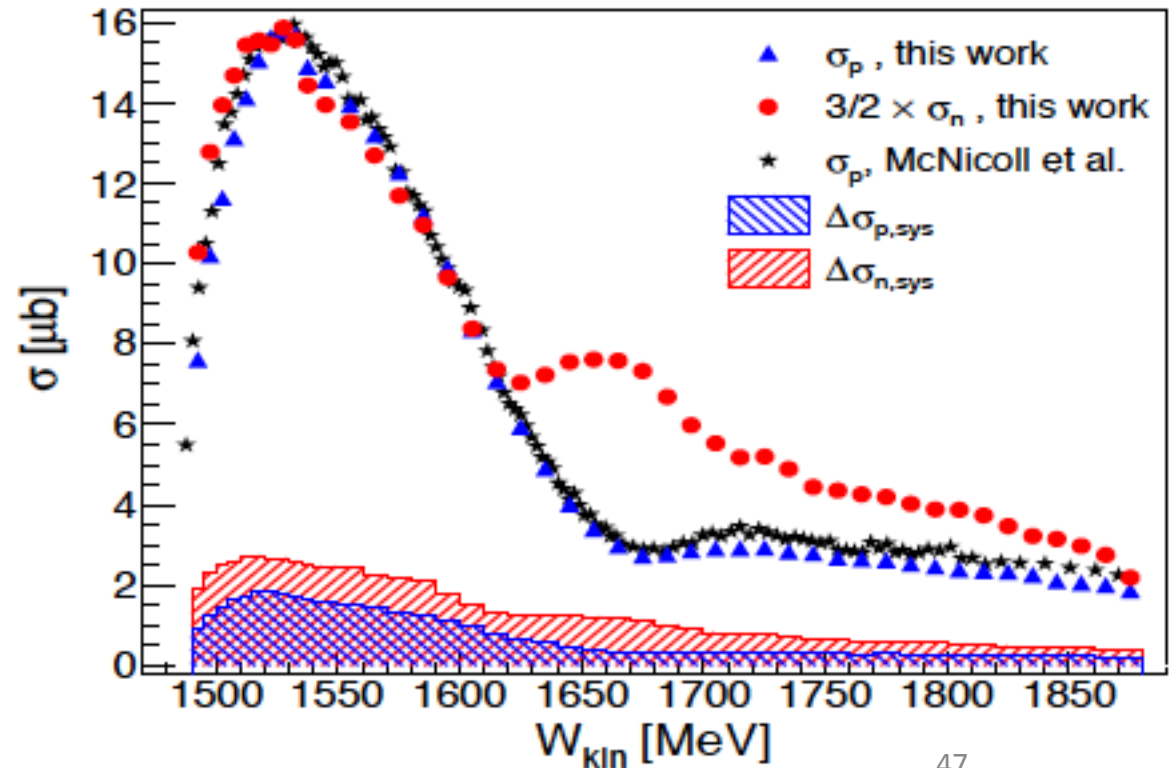
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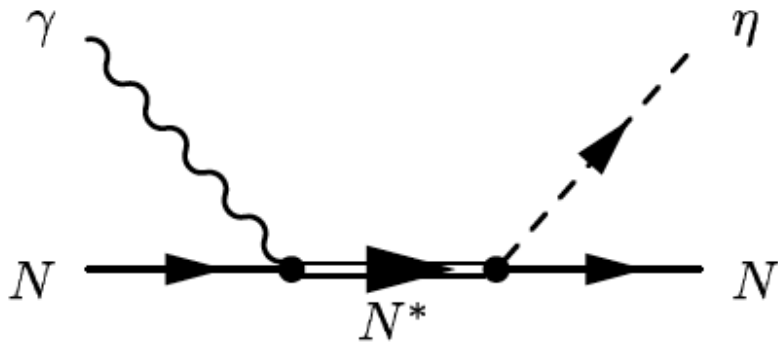
Pentanucleon?



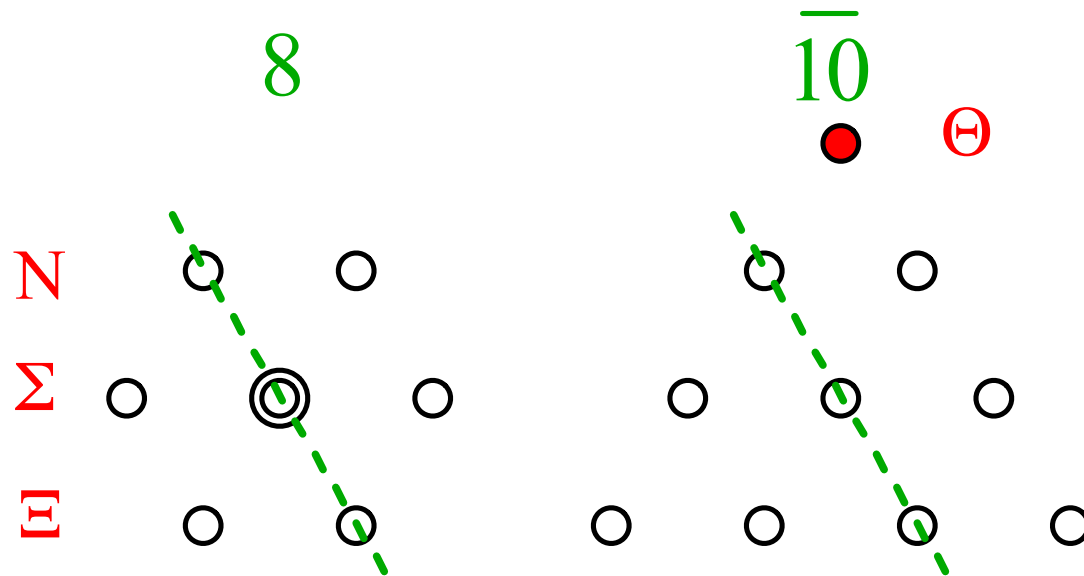
D. Werthmuller et al. [A2 Collaboration]
 Phys. Rev. Lett. 111 (2013) 23, 232001
 Eur. Phys. J. A 49 (2013) 154
 Phys. Rev. Rev. C 90 (2014) 015205



Pentanucleon?



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

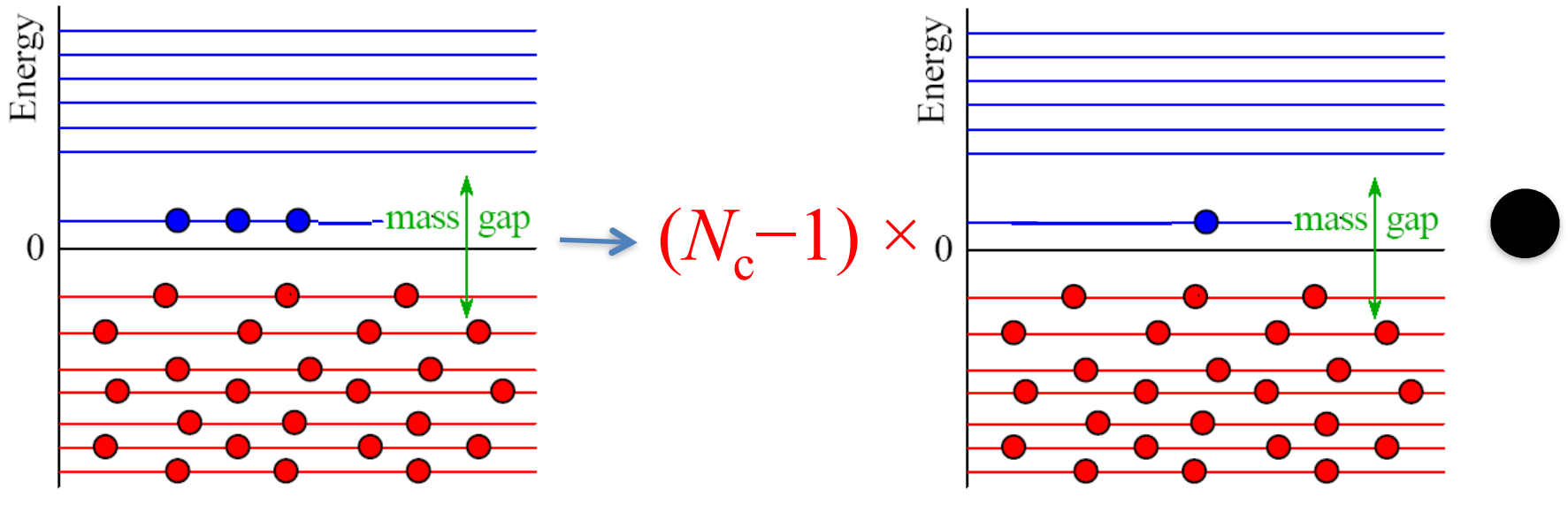
(A2 Collaboration at MAMI)

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 $\eta \rightarrow 2\gamma$ and $\eta \rightarrow 3\pi^0$. 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.

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

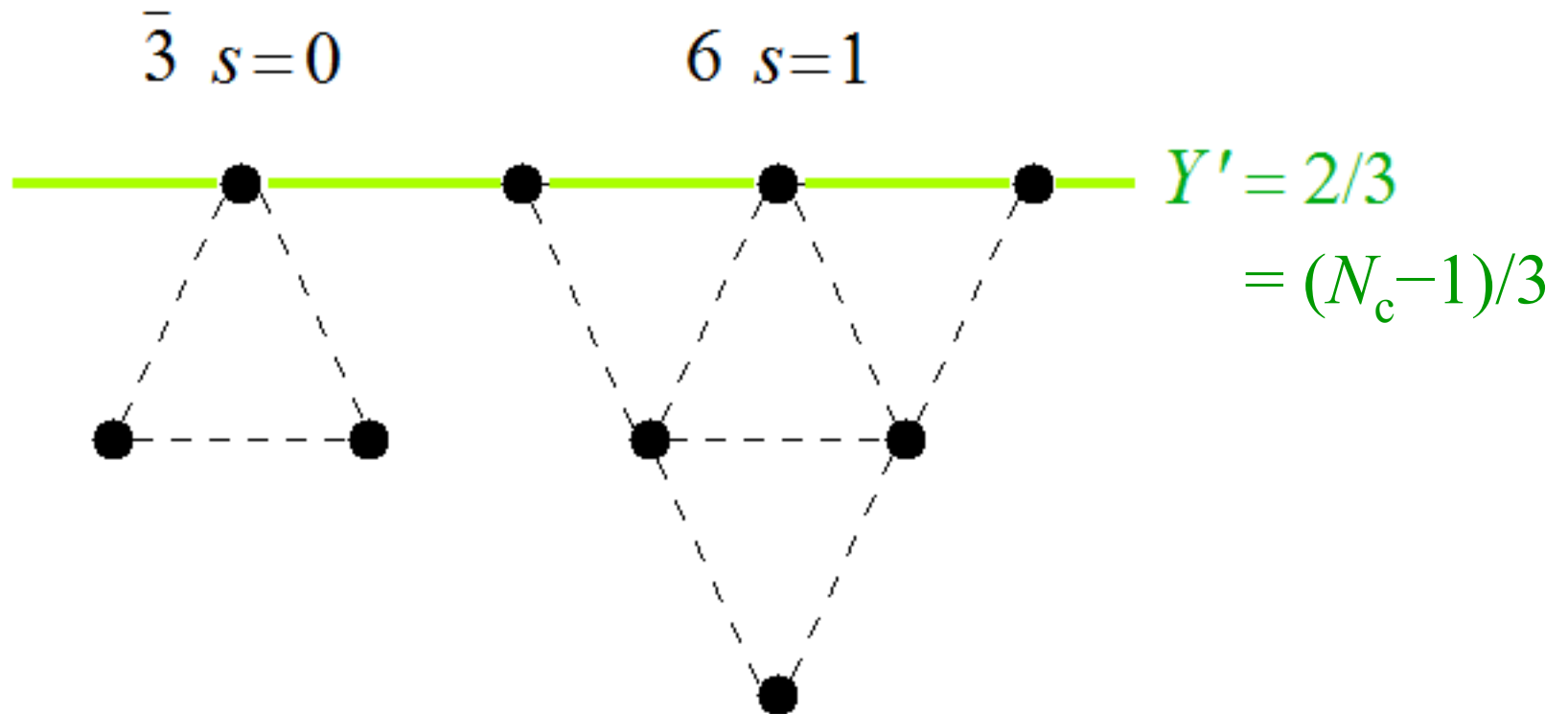


$$(N_c - 1) \times$$

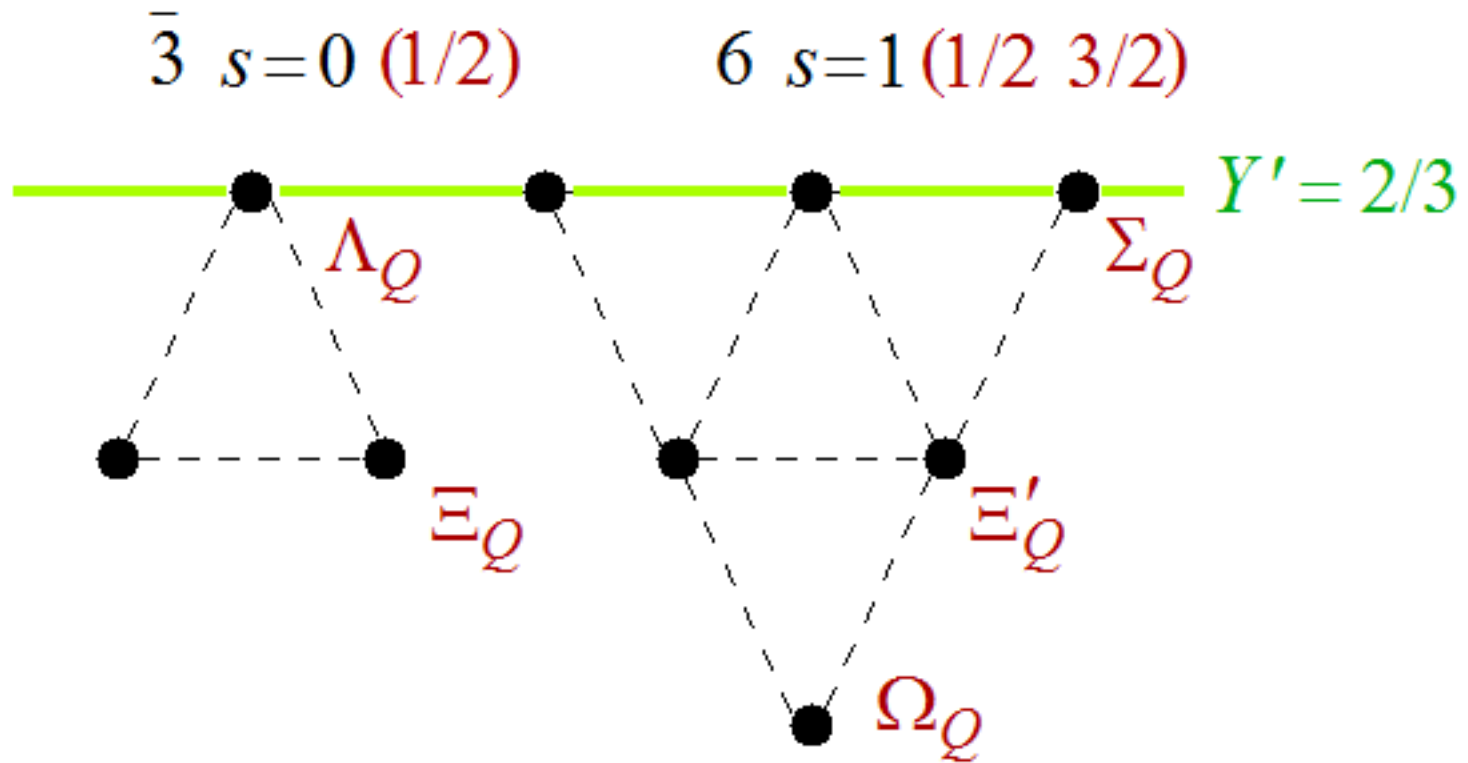
color factorizes!

plus one heavy quark

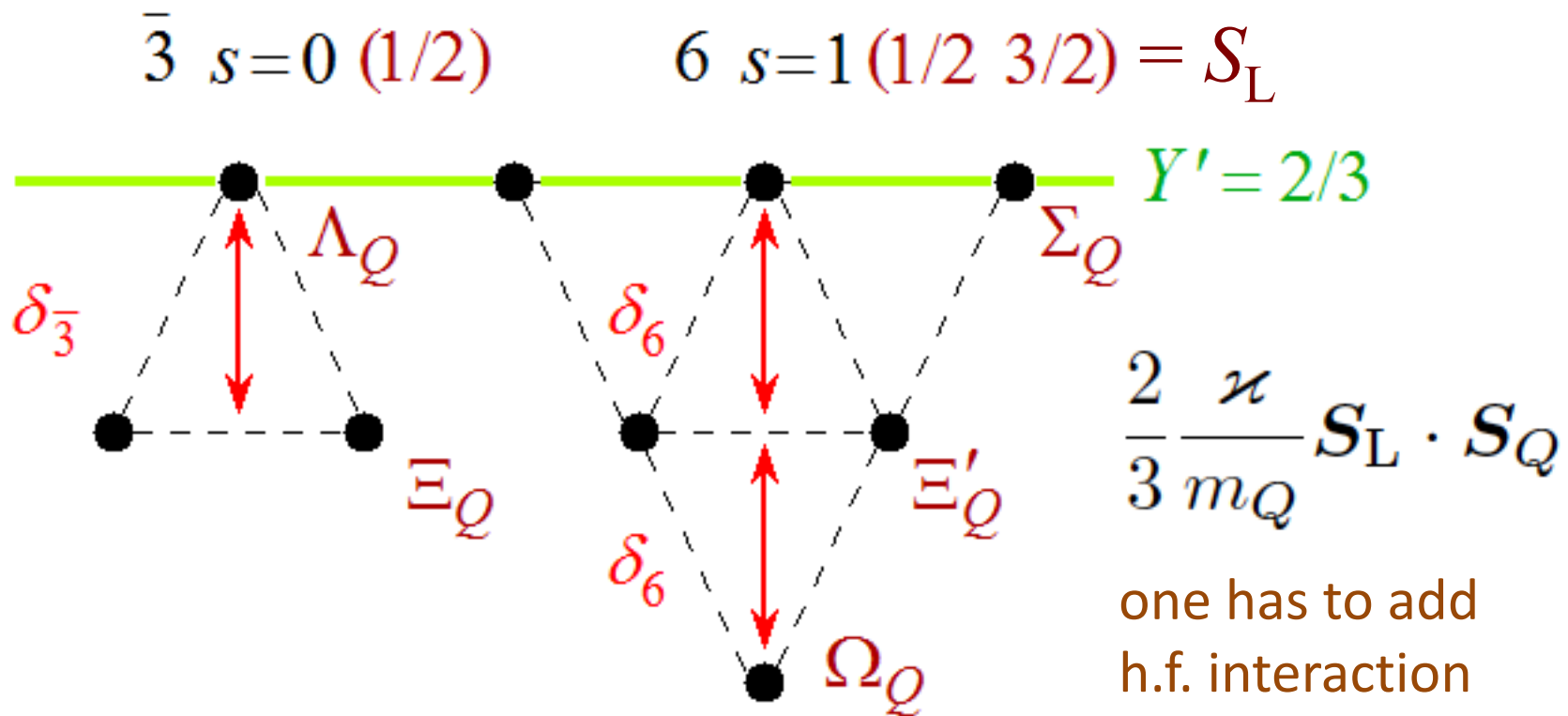
Allowed SU(3) irreps.



Heavy Baryons: soliton + heavy Q

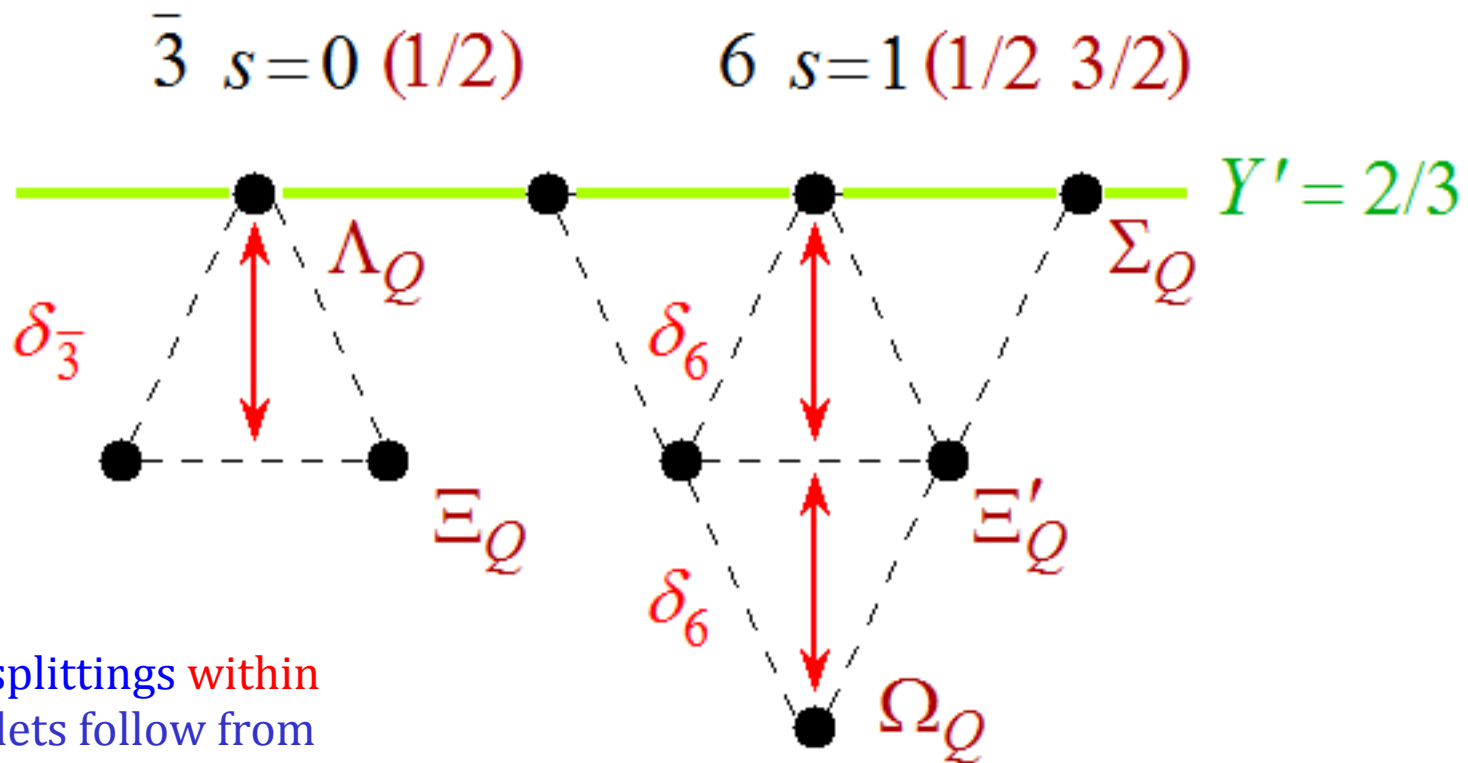


Splittings inside multiplets



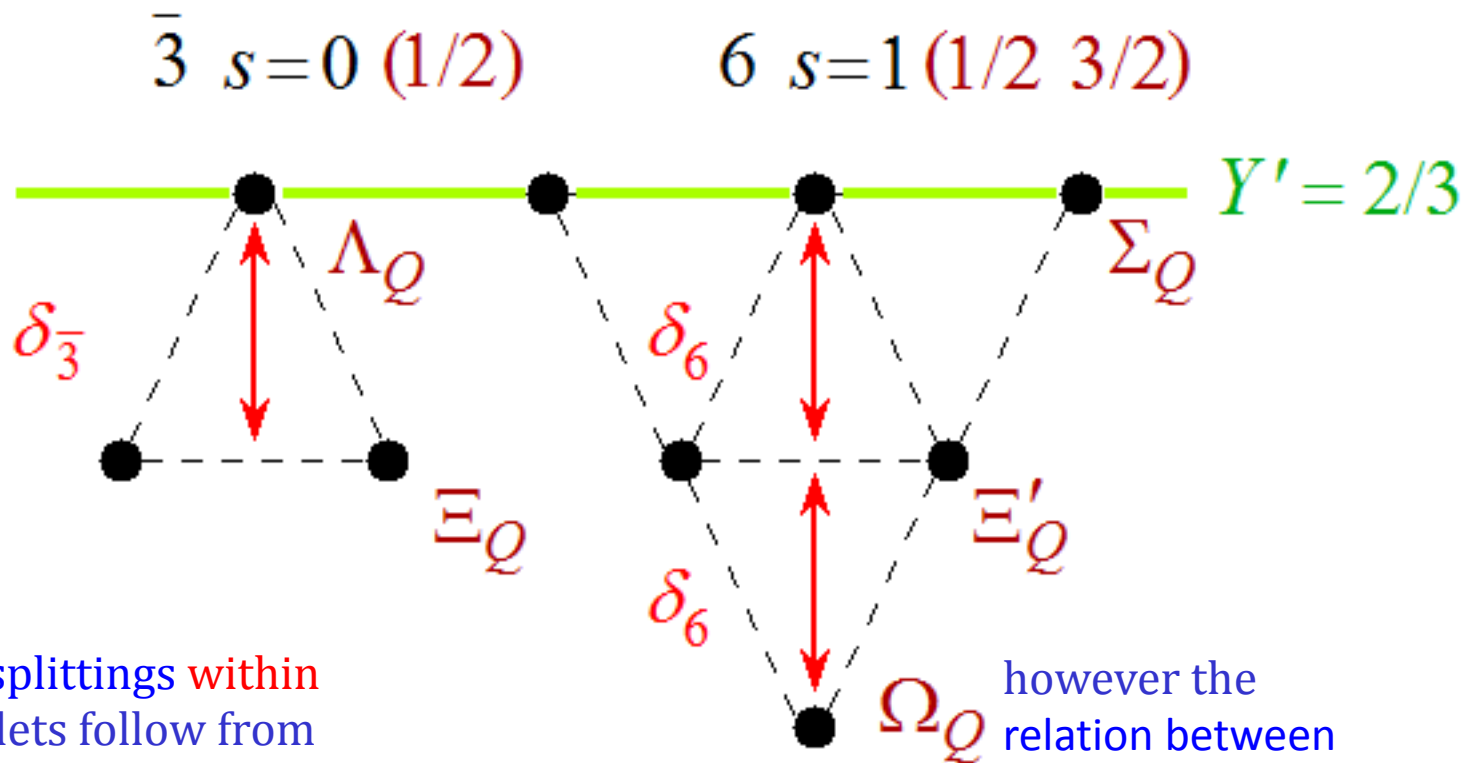
$$\kappa/m_c = 70 \text{ MeV}$$

Splittings inside multiplets



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

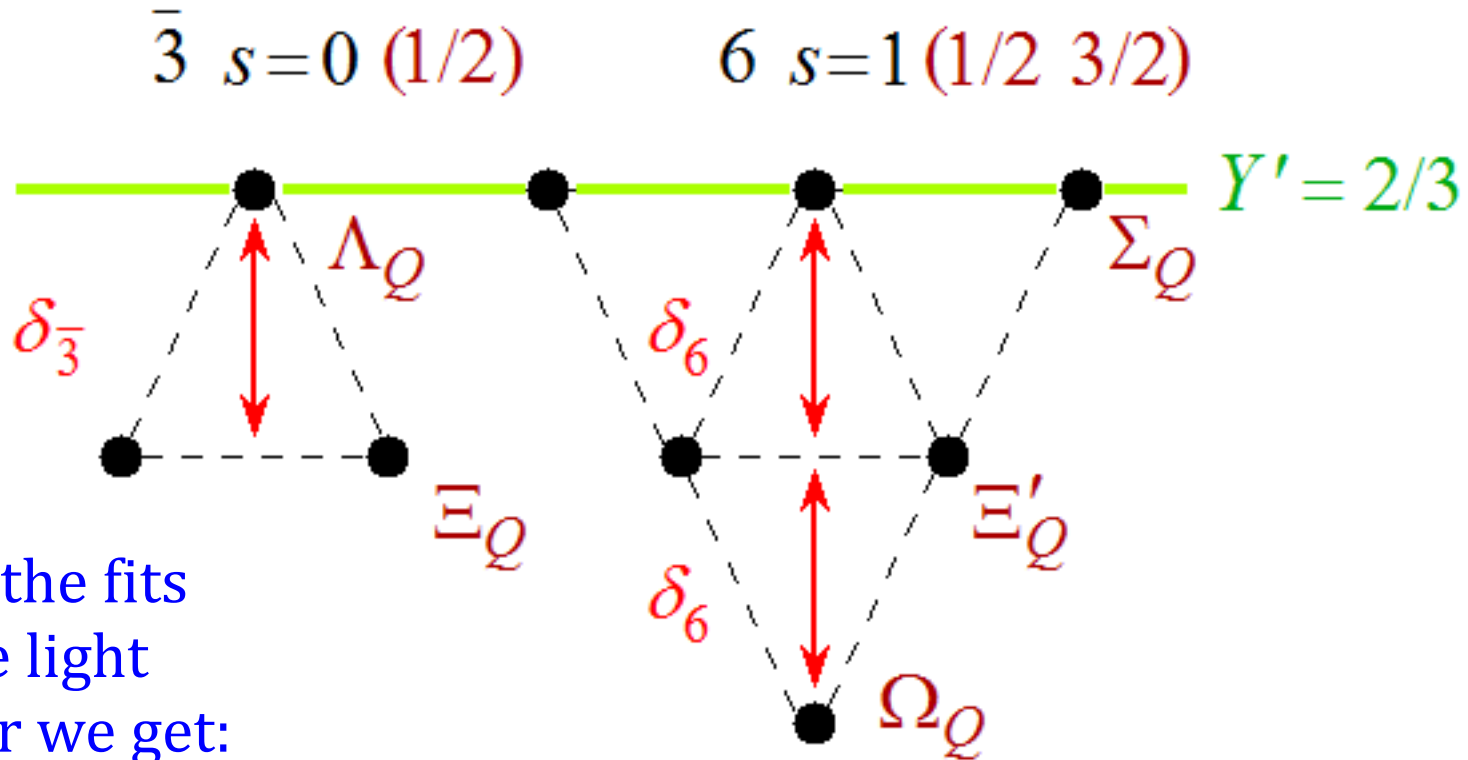
Splittings inside multiplets



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



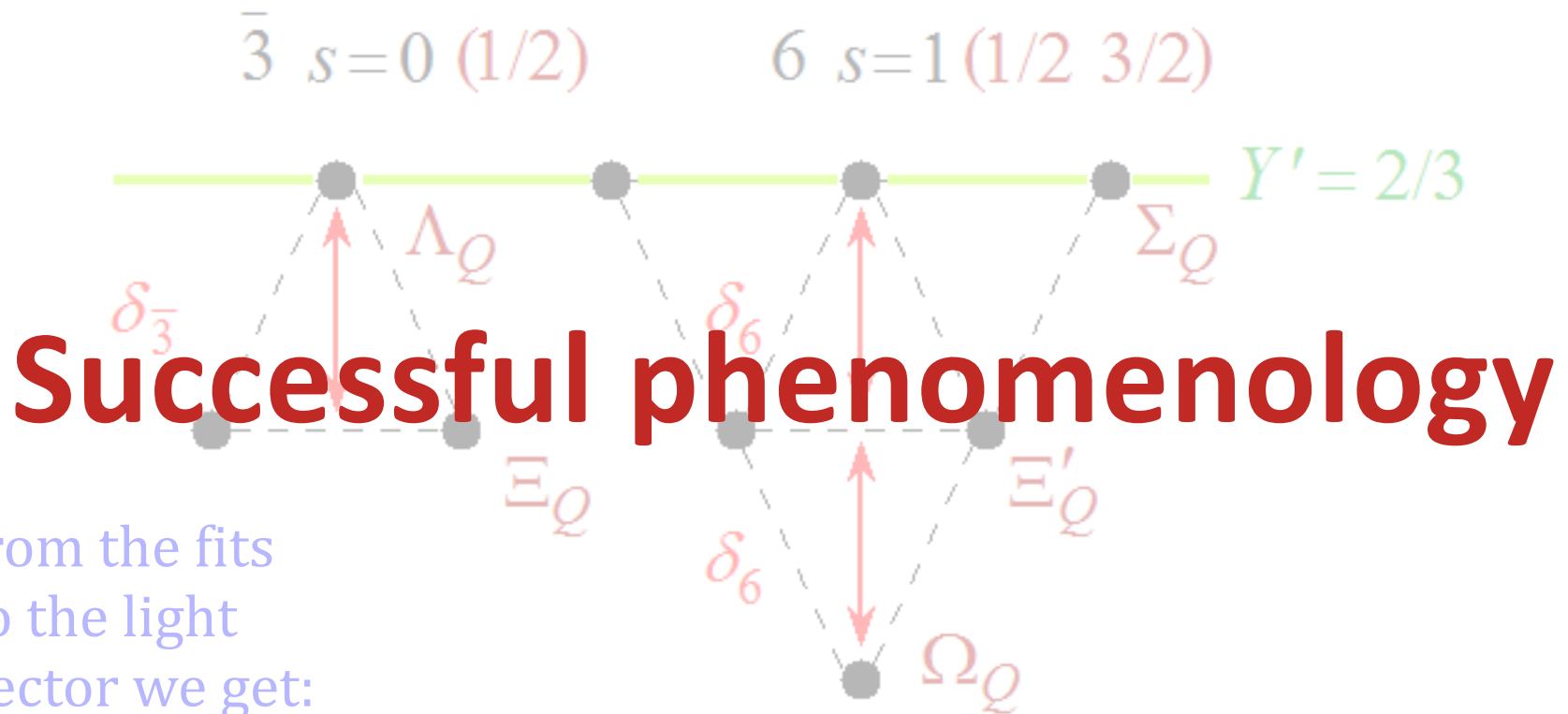
from the fits
to the light
sector we get:

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

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

13%

Splittings inside multiplets



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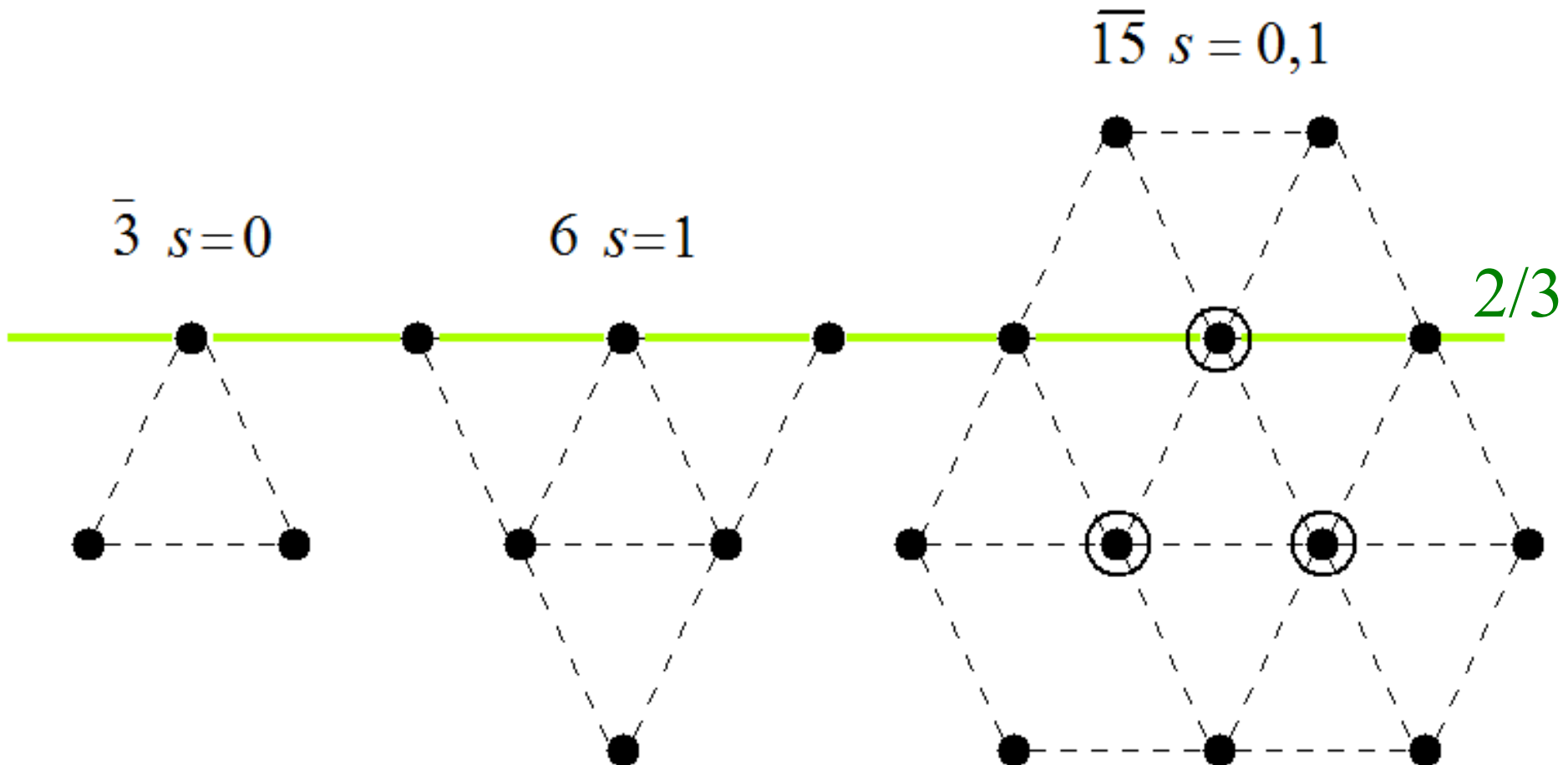
G.S. Yang, H.C. Kim, M.V. Polyakov, MP Phys. Rev. D94 (2016) 071502

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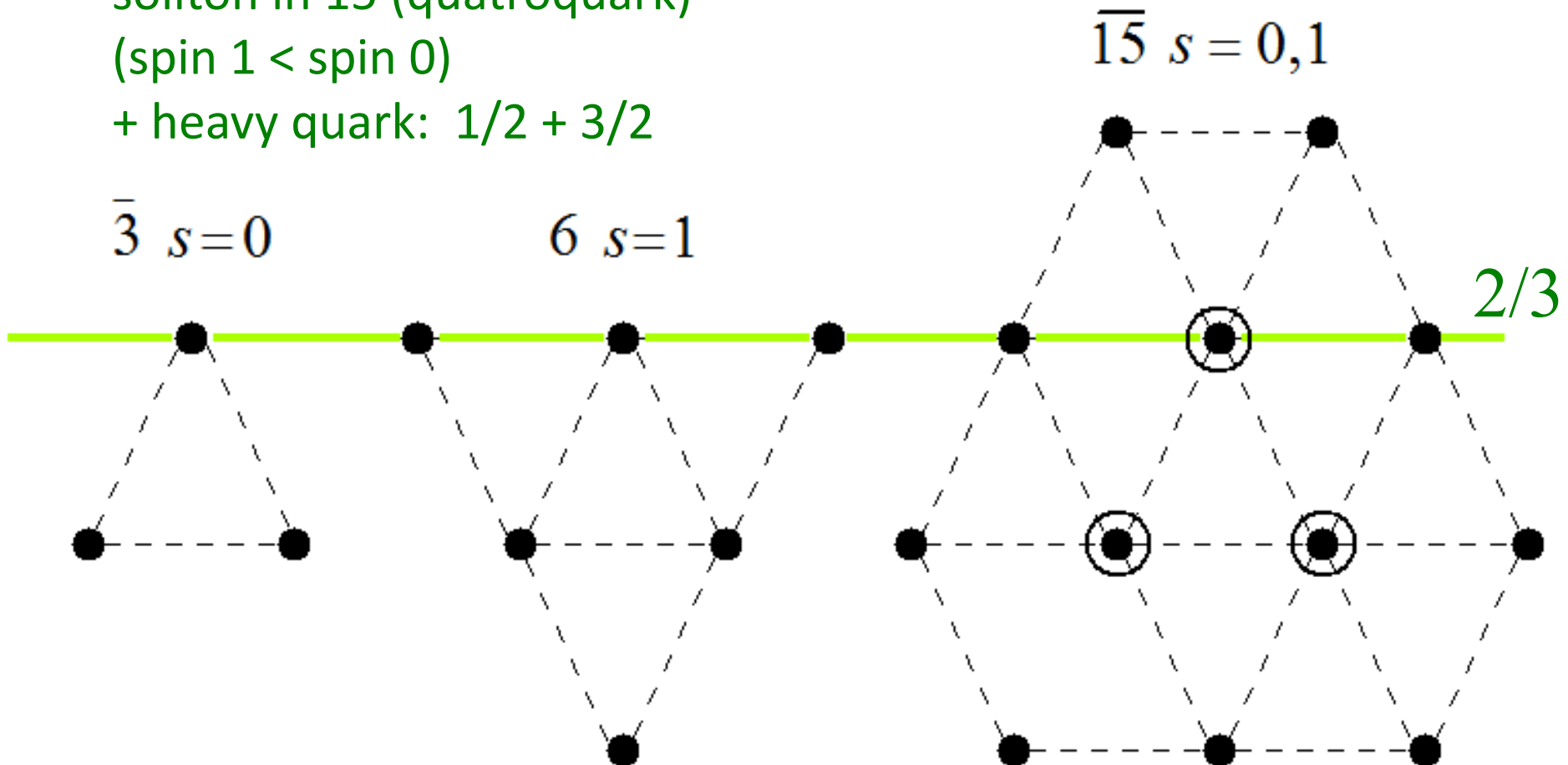
13%

Rotational excitations: heavy pentaquarks



Rotational excitations: heavy pentaquarks

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

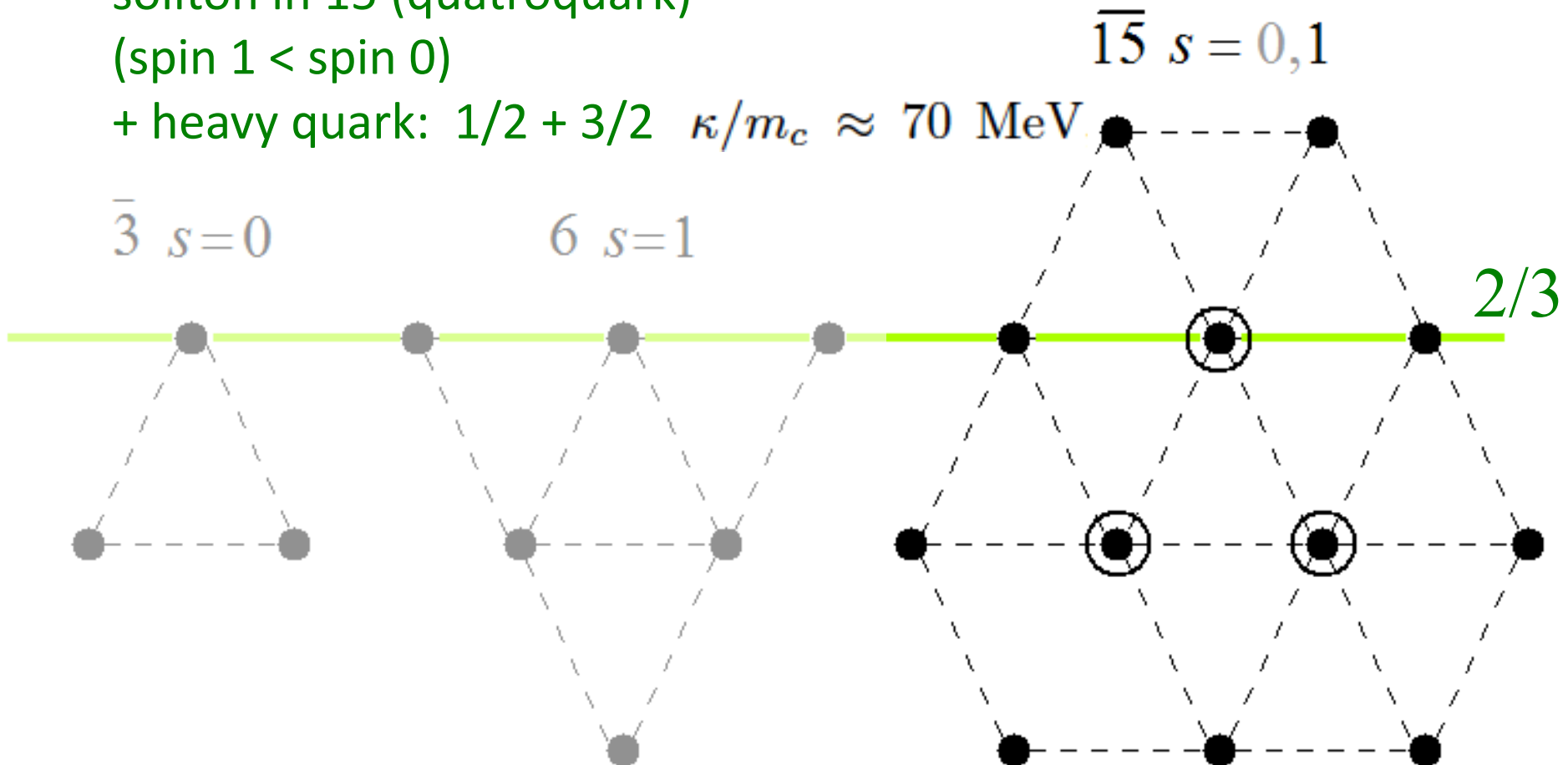


Rotational excitations: heavy pentaquarks

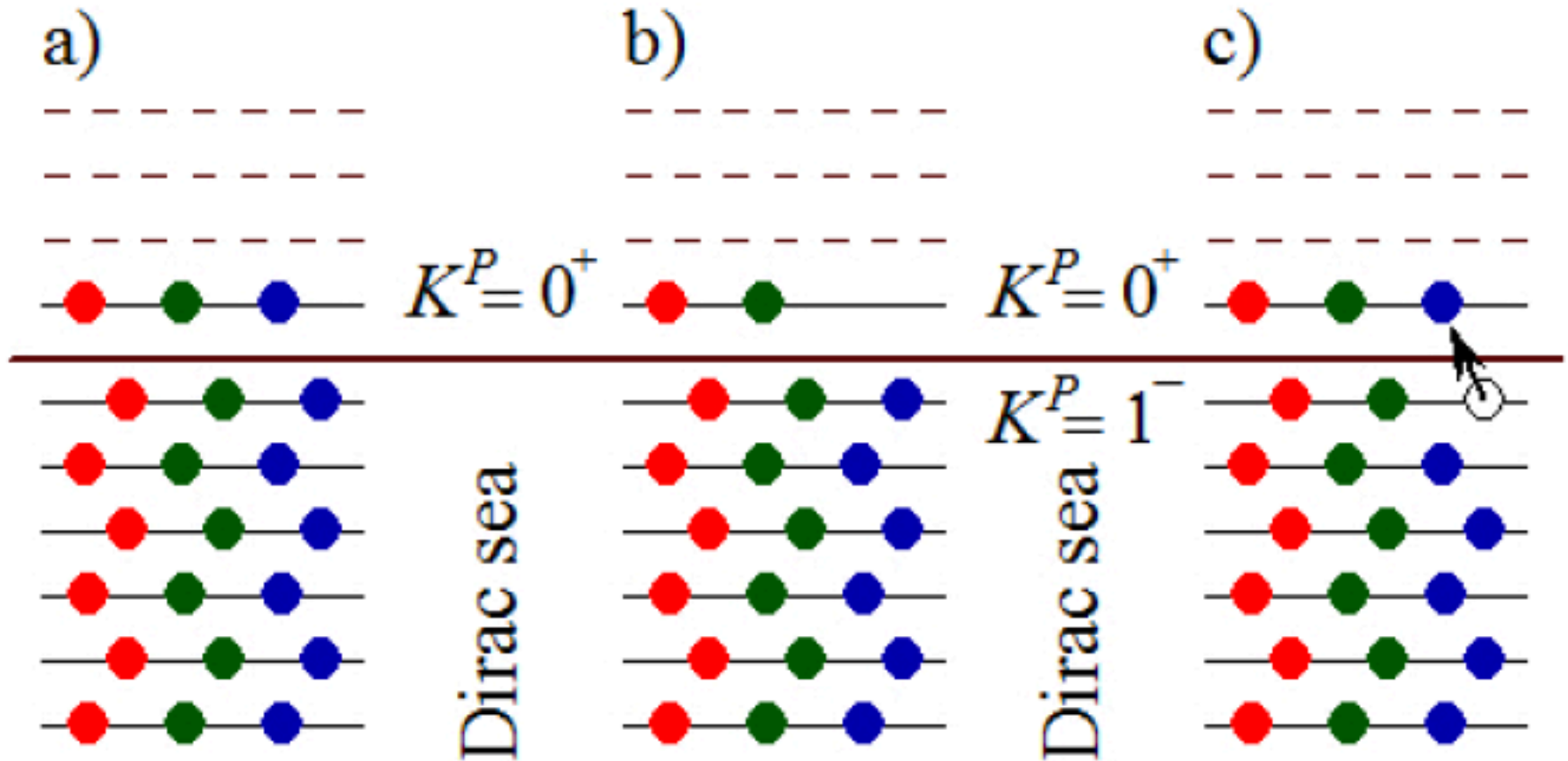
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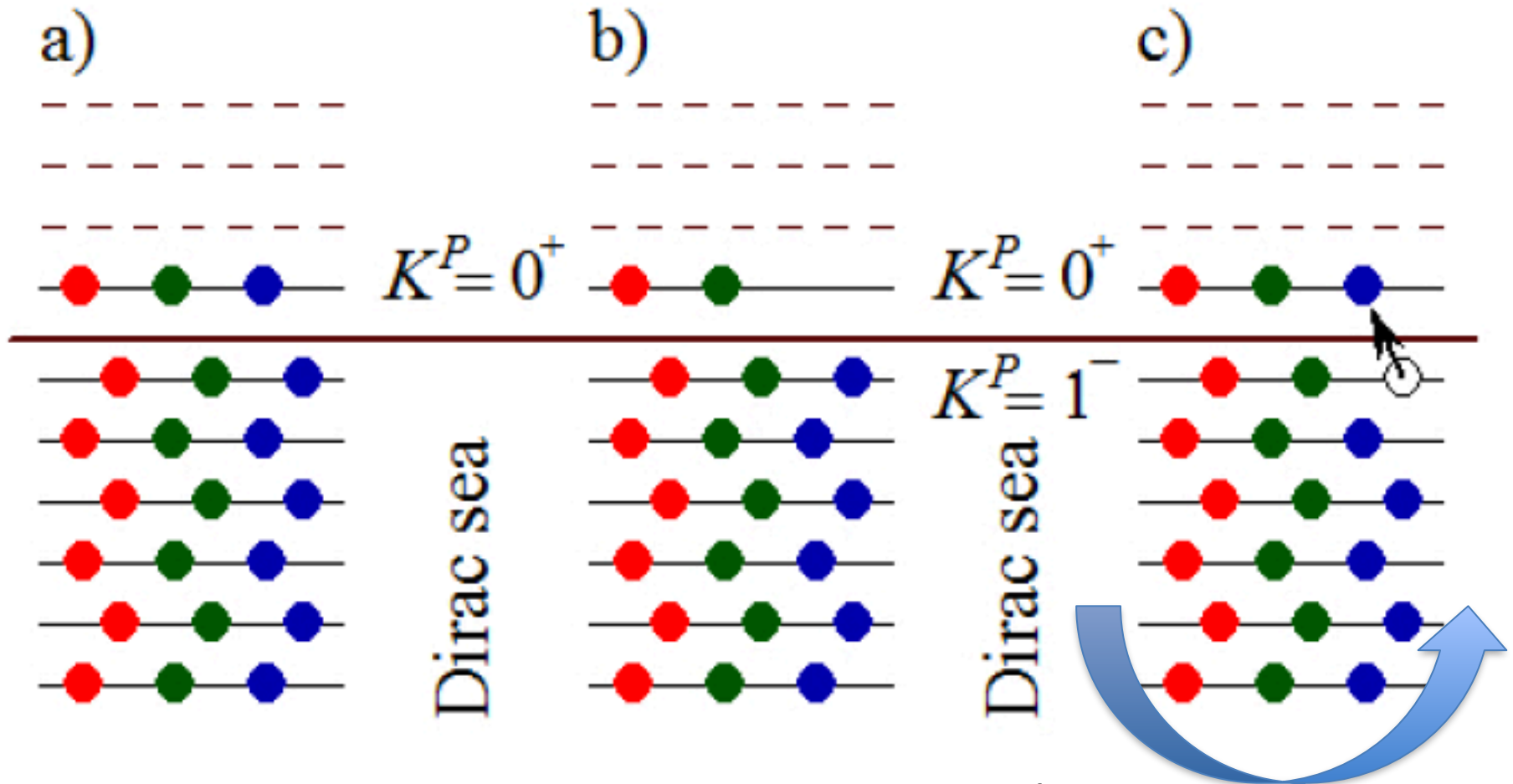
+ heavy quark: $1/2 + 3/2$ $\kappa/m_c \approx 70$ MeV.



Quark excitations: non-exotic heavy baryons

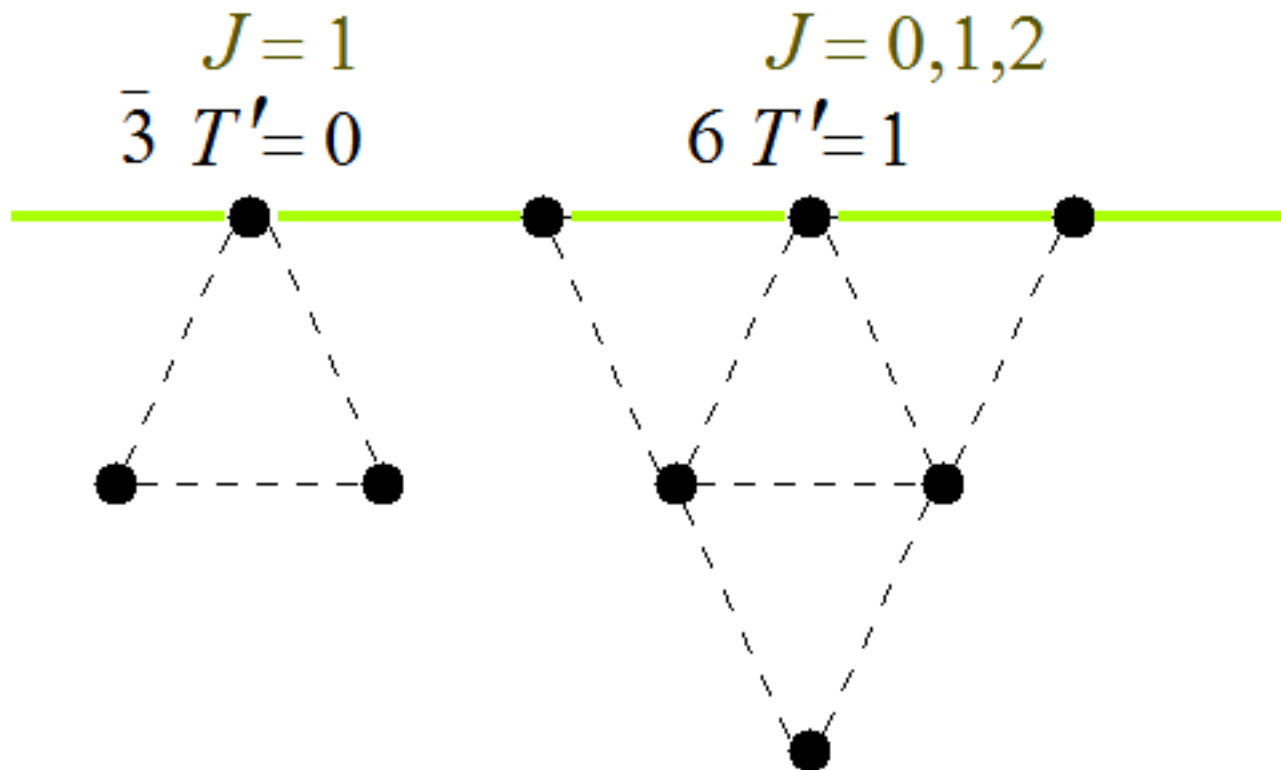


Quark excitations: non-exotic heavy baryons

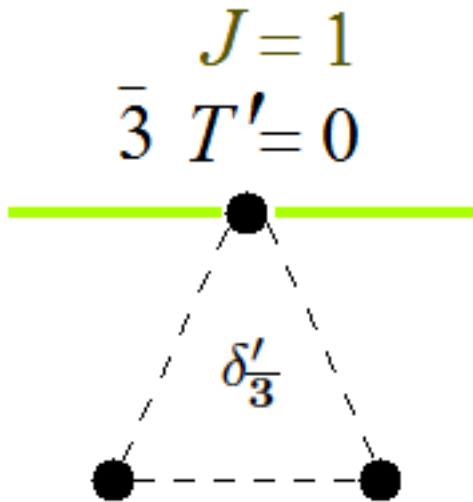


One $K=1$ quark excited solitons

- 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

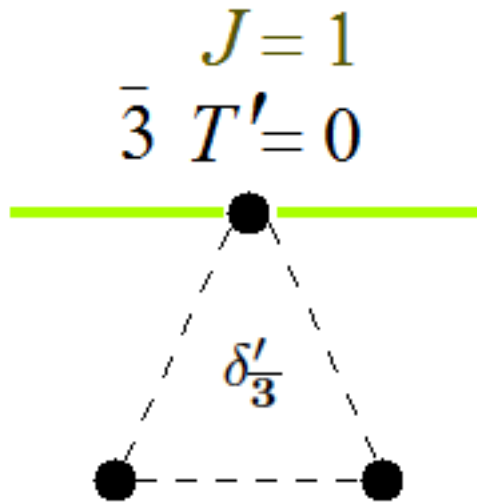


add heavy quark

total spin 1/2 and 3/2

$$\delta'_3 = \delta_3 = -180 \text{ MeV}$$

3bar excited heavy baryons



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

$$\delta'_3 = \delta_3 = -180 \text{ MeV}$$

experimentally:

$\Lambda_c(2592)$	$\Lambda_c(2628)$
-------------------	-------------------

198 MeV	190 MeV
---------	---------

$\Xi_c(2790)$	$\Xi_c(2818)$
---------------	---------------

$$(1/2)^-$$

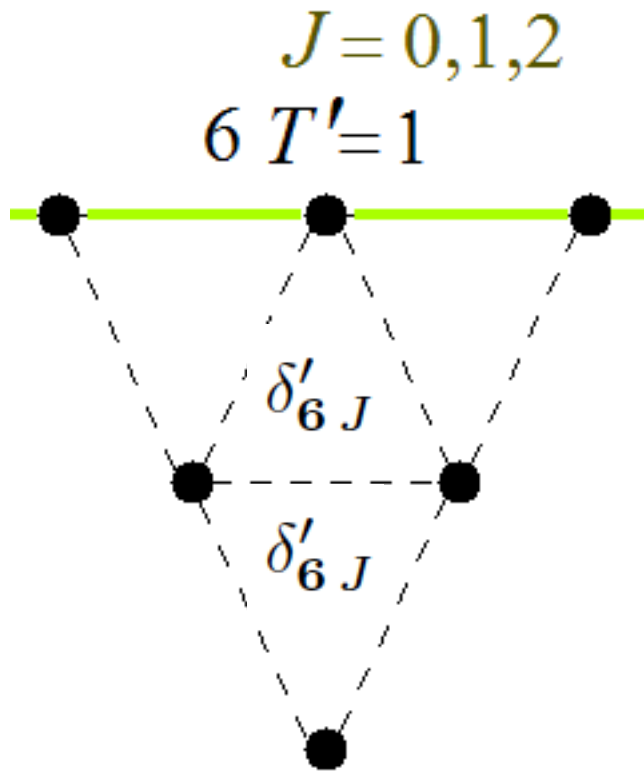
$$(3/2)^-$$

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

$$H_{\text{hf}} = \frac{2}{3} \frac{\kappa}{m_Q} \mathbf{J} \cdot \mathbf{J}_Q$$

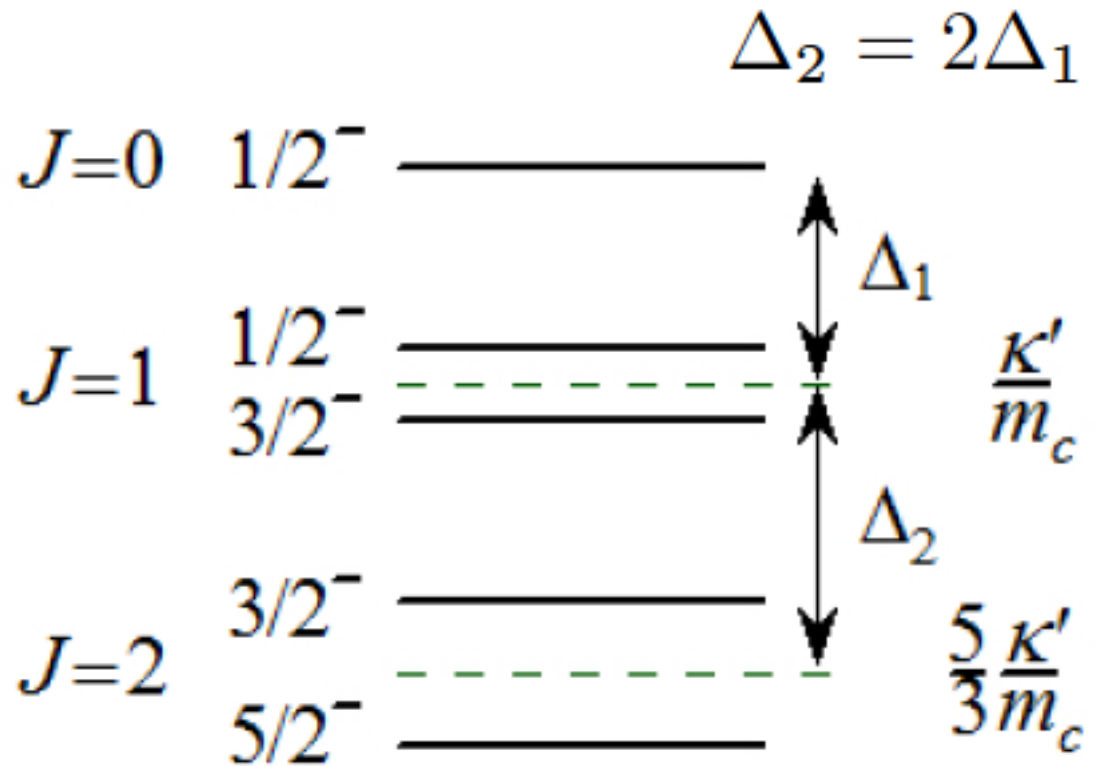
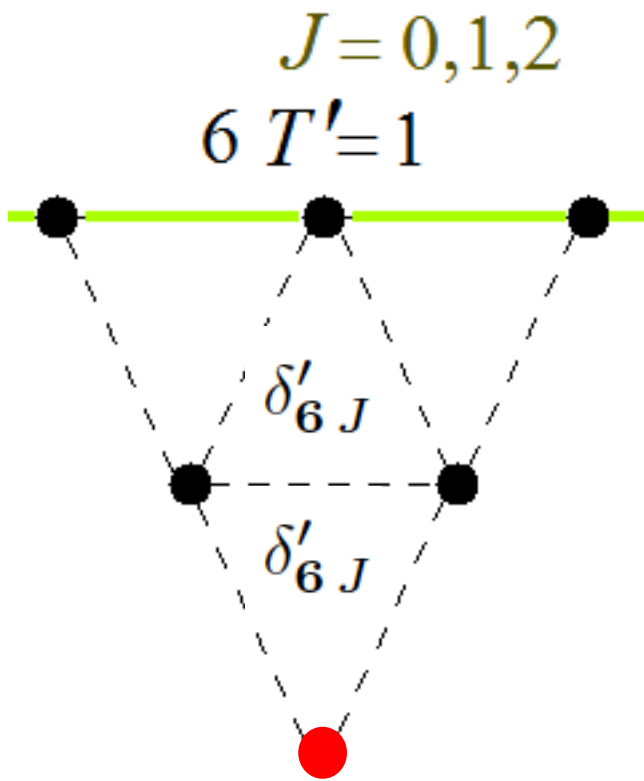
hyprfine
splitting
different
from the
ground
state

sextet excited baryons

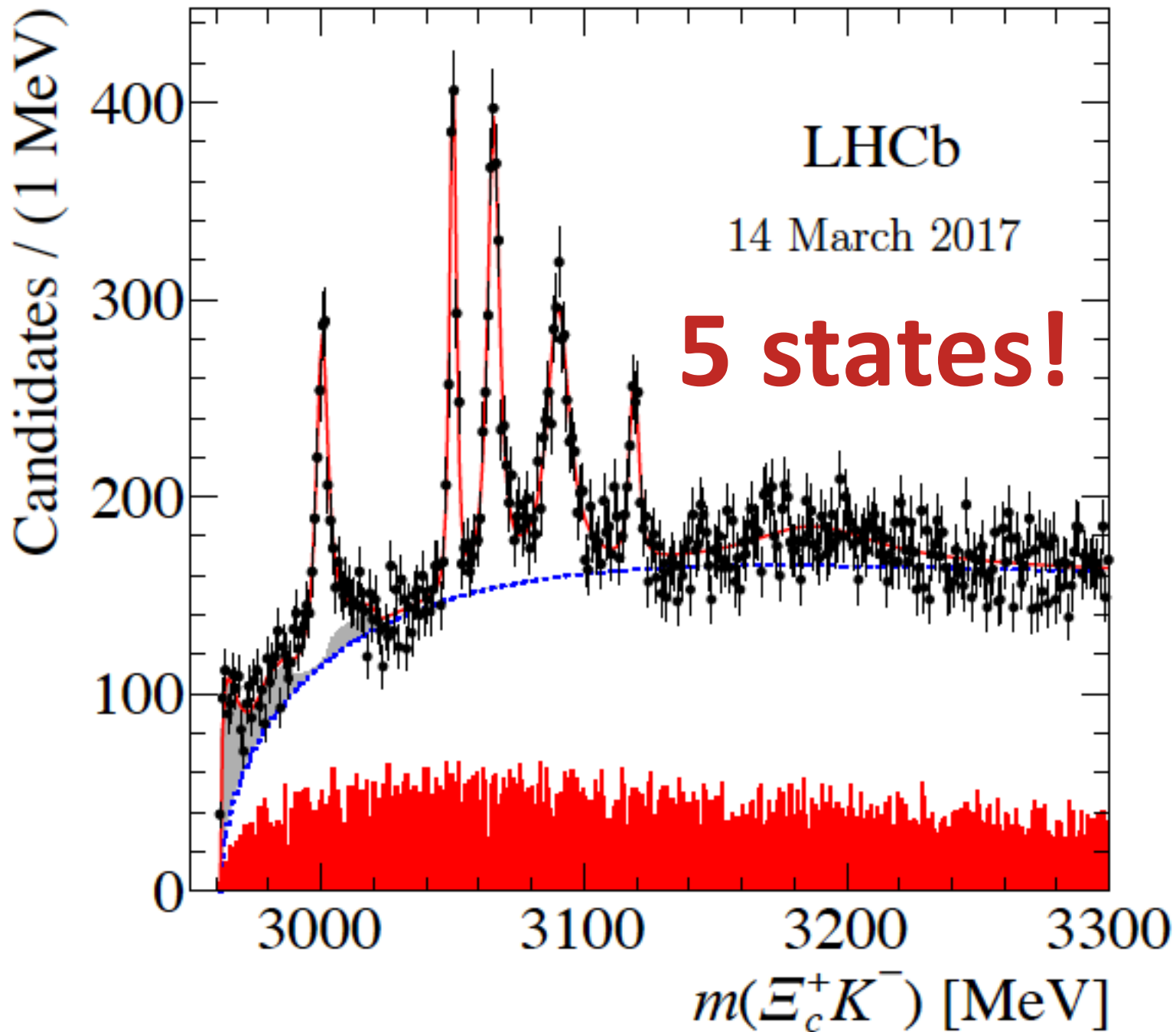


$$\delta'_{6J} = \delta_6 - \frac{3}{20}\delta \times \begin{cases} 2 & \text{for } J = 0 \\ 1 & \text{for } J = 1 \\ -1 & \text{for } J = 2 \end{cases}$$

sextet excited baryons



excited Omega_Q spectrum,
 5 states



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: $\frac{\kappa'}{m_c} = 30 \text{ MeV}$ $\Delta_2 = 2\Delta_1$

Scenario 1:
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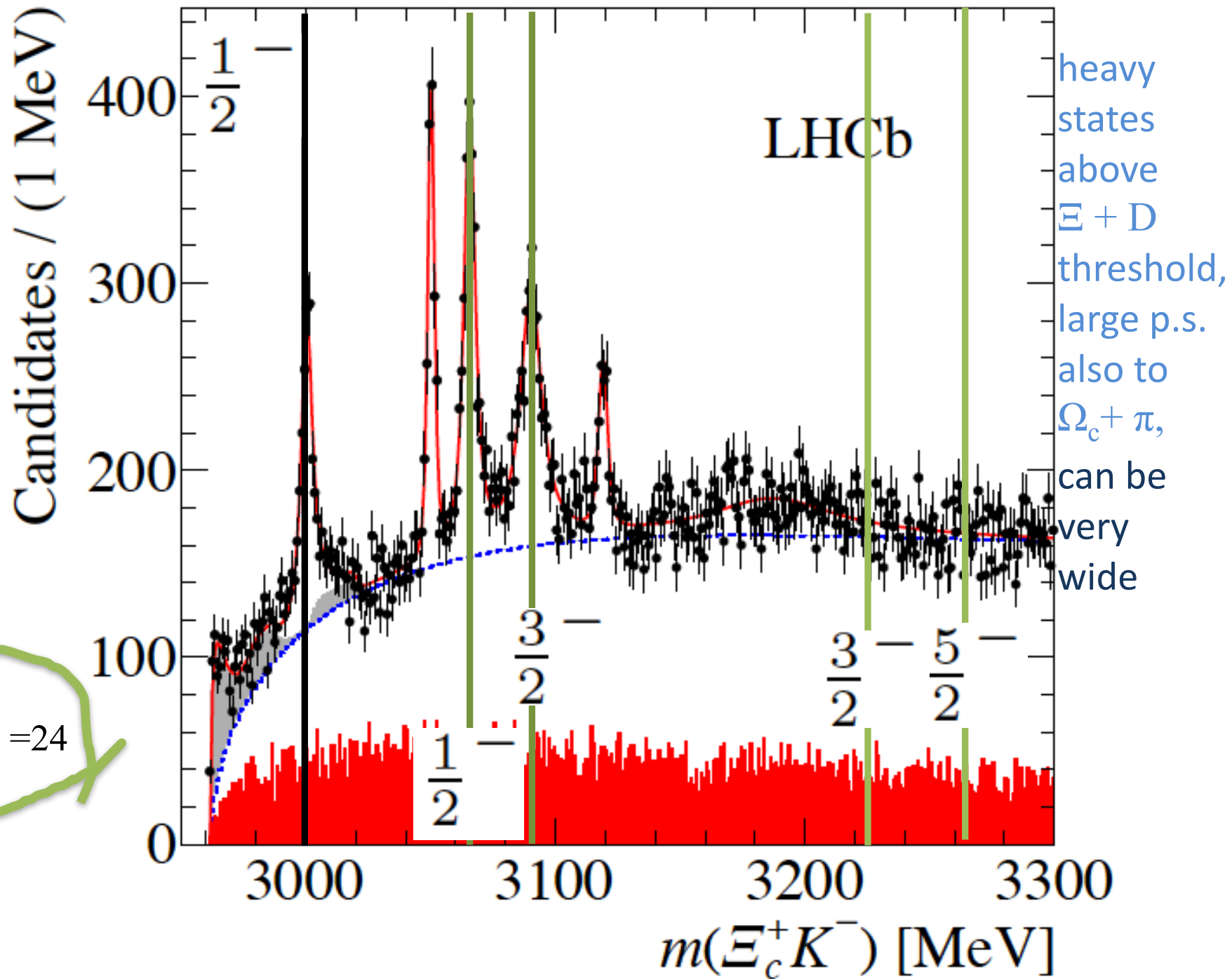
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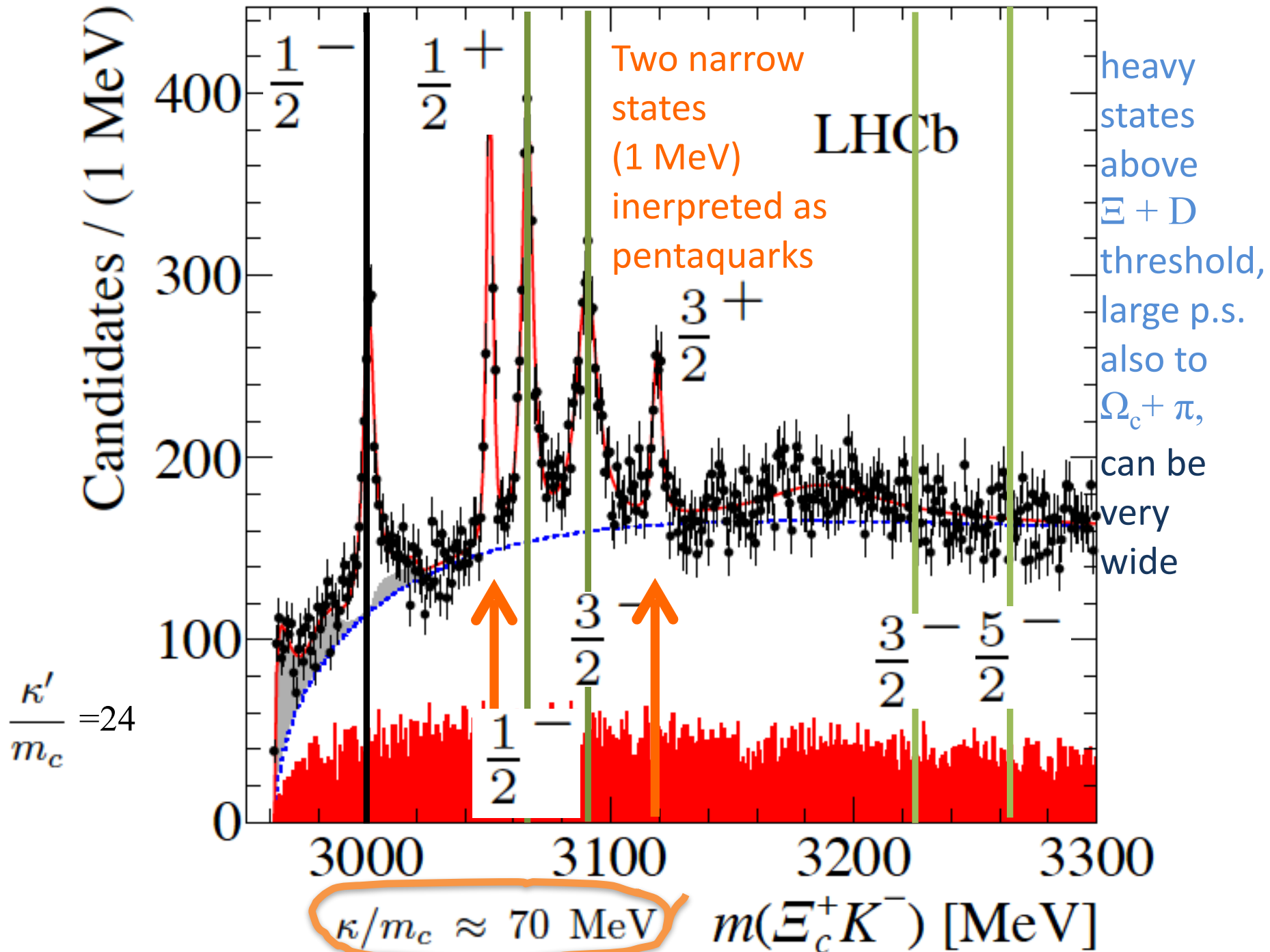
violates constraints: $\frac{\kappa'}{m_c} = 30 \text{ MeV}$ $\Delta_2 = 2\Delta_1$

similar problem in the quark models

Scenario 2

force sextet constraints





Decays of positive parity states

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

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

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

Goldberger-Treiman relation:

for strong decays $B_1 \rightarrow B_2 + \varphi$ use the same operator

H. Y. Cheng and C. K. Chua, Phys. Rev. D 75 (2007) 014006

H. Y. Cheng and C. K. Chua, Phys. Rev. D 92 (2015) 074014

example

$$\Gamma_{\Sigma(\mathbf{6}_1) \rightarrow \Lambda(\bar{\mathbf{3}}_0) + \pi} = \frac{1}{72\pi} \frac{p^3}{F_\pi^2} \frac{M_{\Lambda(\bar{\mathbf{3}}_0)}}{M_{\Sigma(\mathbf{6}_1)}} H_{\bar{\mathbf{3}}}^2 \frac{3}{8} \quad H_{\bar{\mathbf{3}}} = -a_1 + \frac{1}{2}a_2$$

Decay constants

$$a_1 \sim N_c \longrightarrow a_1 \sim N_c - 1$$

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

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

Decay constants

$$a_1 \sim N_c \longrightarrow a_1 \sim N_c - 1$$

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

$$\overline{\mathbf{15}}_1 \longrightarrow \mathbf{6}_1 \quad \text{In NRQM limit:} \quad G_{\mathbf{6}} = 0$$

Expectations:

some decays will be suppressed

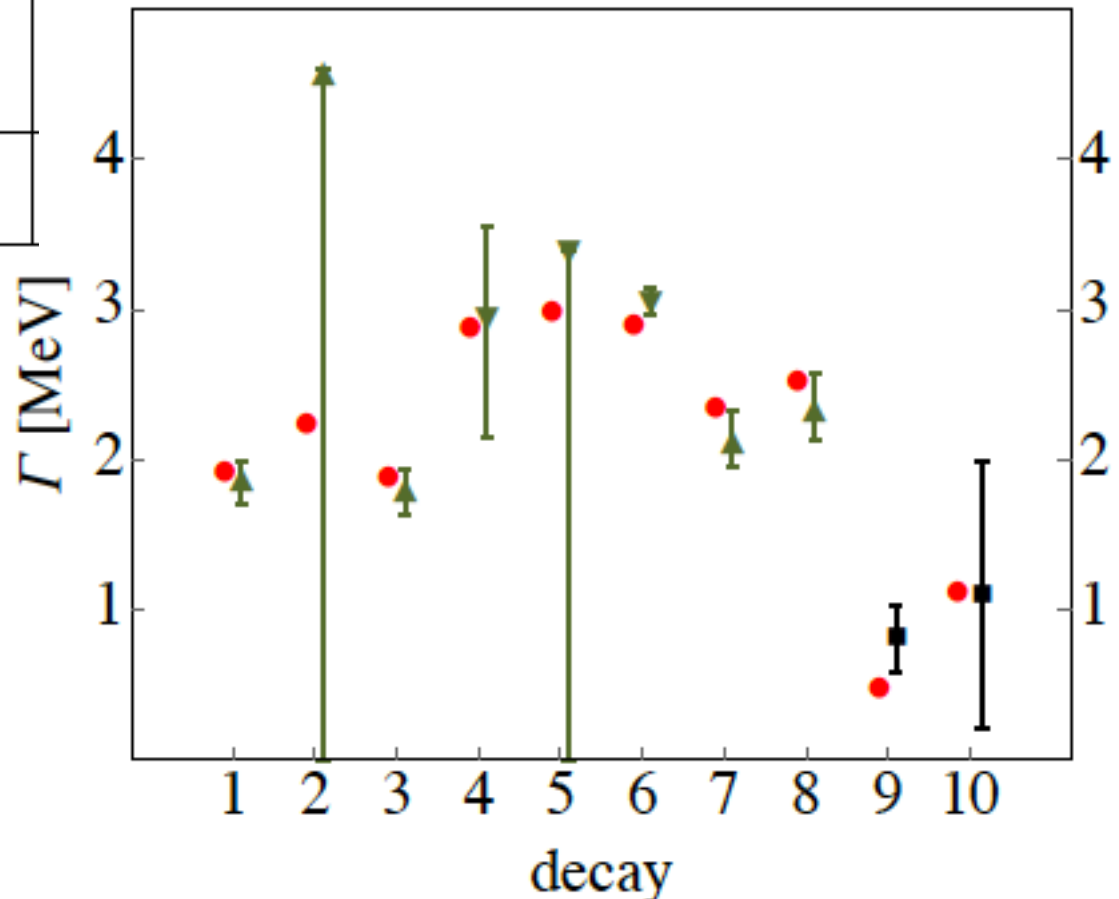
Charm decay widths

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

1	$\Sigma_c^{++}(\mathbf{6}_1, 1/2) \rightarrow \Lambda_c^+(\bar{\mathbf{3}}_0, 1/2) + \pi^+$
2	$\Sigma_c^+(\mathbf{6}_1, 1/2) \rightarrow \Lambda_c^+(\bar{\mathbf{3}}_0, 1/2) + \pi^0$
3	$\Sigma_c^0(\mathbf{6}_1, 1/2) \rightarrow \Lambda_c^+(\bar{\mathbf{3}}_0, 1/2) + \pi^-$
4	$\Sigma_c^{++}(\mathbf{6}_1, 3/2) \rightarrow \Lambda_c^+(\bar{\mathbf{3}}_0, 1/2) + \pi^+$
5	$\Sigma_c^+(\mathbf{6}_1, 3/2) \rightarrow \Lambda_c^+(\bar{\mathbf{3}}_0, 1/2) + \pi^0$
6	$\Sigma_c^0(\mathbf{6}_1, 3/2) \rightarrow \Lambda_c^+(\bar{\mathbf{3}}_0, 1/2) + \pi^-$
7	$\Xi_c^+(\mathbf{6}_1, 3/2) \rightarrow \Xi_c(\bar{\mathbf{3}}_0, 1/2) + \pi$
8	$\Xi_c^0(\mathbf{6}_1, 3/2) \rightarrow \Xi_c(\bar{\mathbf{3}}_0, 1/2) + \pi$

9	$\Omega_c(\bar{\mathbf{15}}_1, 1/2) \rightarrow \Xi_c(\bar{\mathbf{3}}_0, 1/2) + K$
	$\Omega_c(\bar{\mathbf{15}}_1, 1/2) \rightarrow \Omega_c(\mathbf{6}_1, 1/2) + \pi$
	$\Omega_c(\bar{\mathbf{15}}_1, 1/2) \rightarrow \Omega_c(\mathbf{6}_1, 3/2) + \pi$

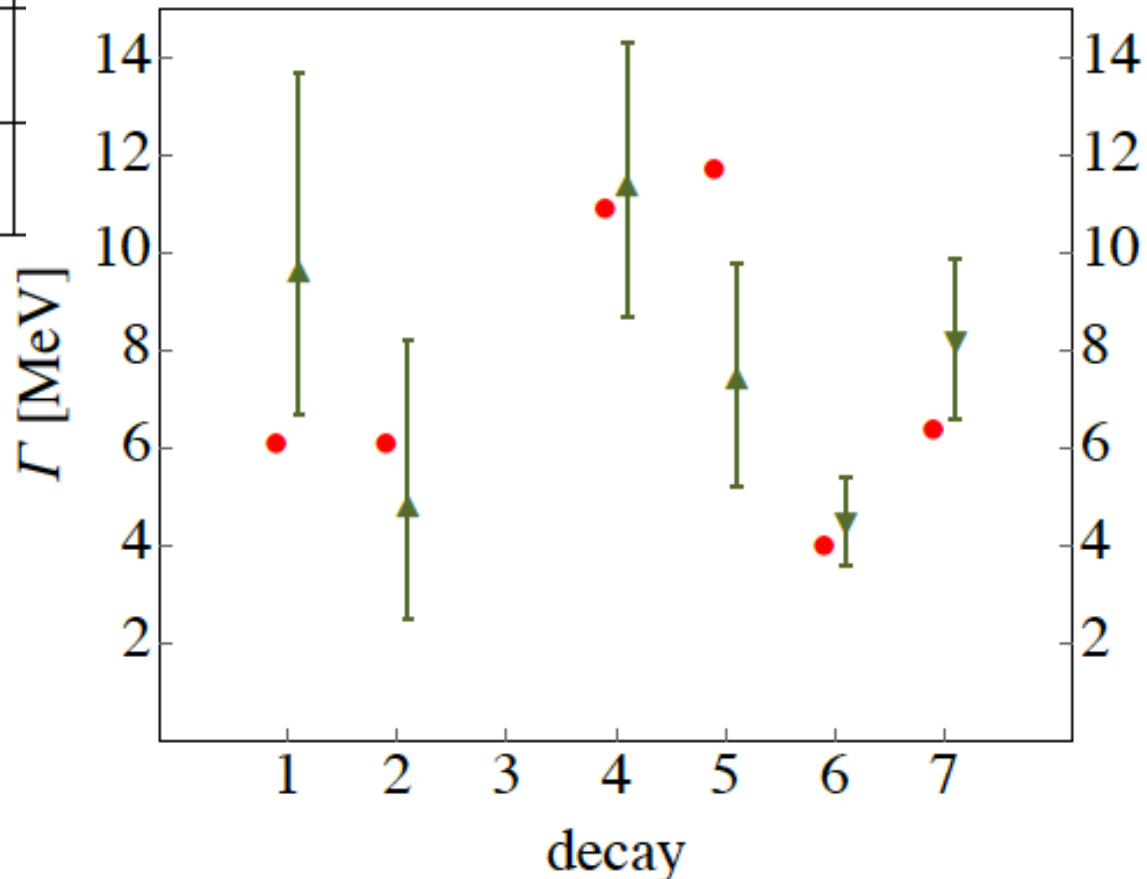
10	$\Omega_c(\bar{\mathbf{15}}_1, 3/2) \rightarrow \Xi_c(\bar{\mathbf{3}}_0, 1/2) + K$
	$\Omega_c(\bar{\mathbf{15}}_1, 3/2) \rightarrow \Xi_c(\mathbf{6}_1, 1/2) + K$
	$\Omega_c(\bar{\mathbf{15}}_1, 3/2) \rightarrow \Omega_c(\mathbf{6}_1, 1/2) + \pi$
	$\Omega_c(\bar{\mathbf{15}}_1, 3/2) \rightarrow \Omega_c(\mathbf{6}_1, 3/2) + \pi$



Bottom decay widths

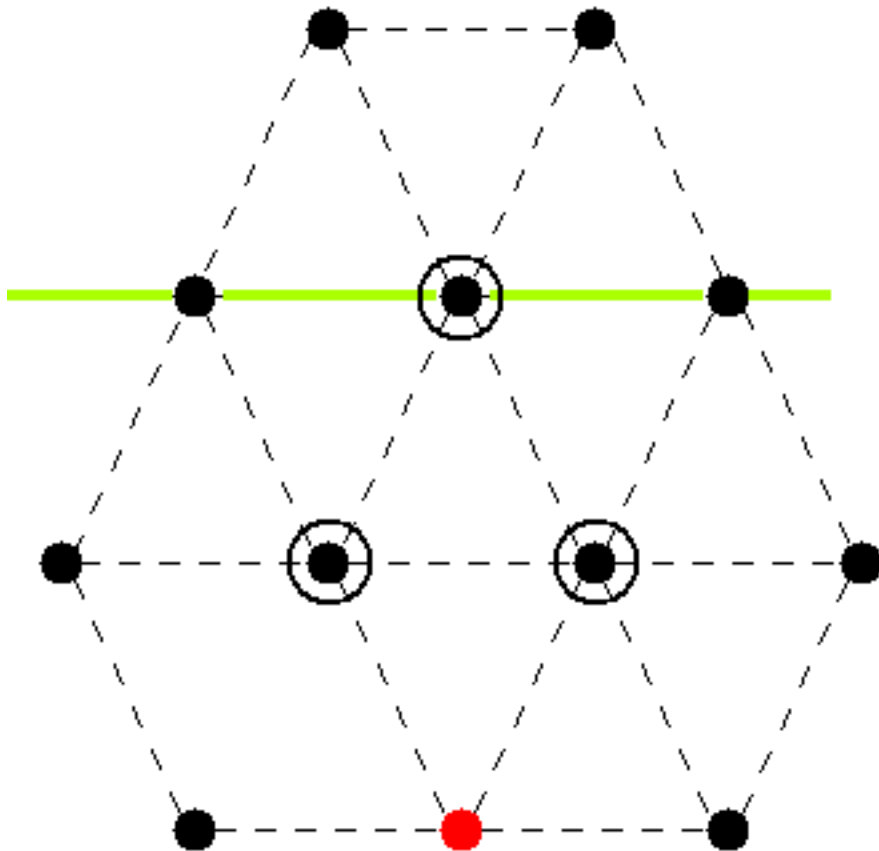
1	$\Sigma_b^+(\mathbf{6}_1, 1/2) \rightarrow \Lambda_b^0(\bar{\mathbf{3}}_0, 1/2) + \pi^+$
2	$\Sigma_b^-(\mathbf{6}_1, 1/2) \rightarrow \Lambda_b^0(\bar{\mathbf{3}}_0, 1/2) + \pi^-$
3	$\Xi_b'(\mathbf{6}_1, 1/2) \rightarrow \Xi_c(\bar{\mathbf{3}}_0, 1/2) + \pi$
4	$\Sigma_b^+(\mathbf{6}_1, 3/2) \rightarrow \Lambda_b^0(\bar{\mathbf{3}}_0, 1/2) + \pi^+$
5	$\Sigma_b^-(\mathbf{6}_1, 3/2) \rightarrow \Lambda_c^0(\bar{\mathbf{3}}_0, 1/2) + \pi^-$
6	$\Xi_b^0(\mathbf{6}_1, 3/2) \rightarrow \Xi_b(\bar{\mathbf{3}}_0, 1/2) + \pi$
7	$\Xi_b^-(\mathbf{6}_1, 3/2) \rightarrow \Xi_b(\bar{\mathbf{3}}_0, 1/2) + \pi$

experimental data
 a little puzzling
 because of rather strong
 isospin
 violation



Consequences

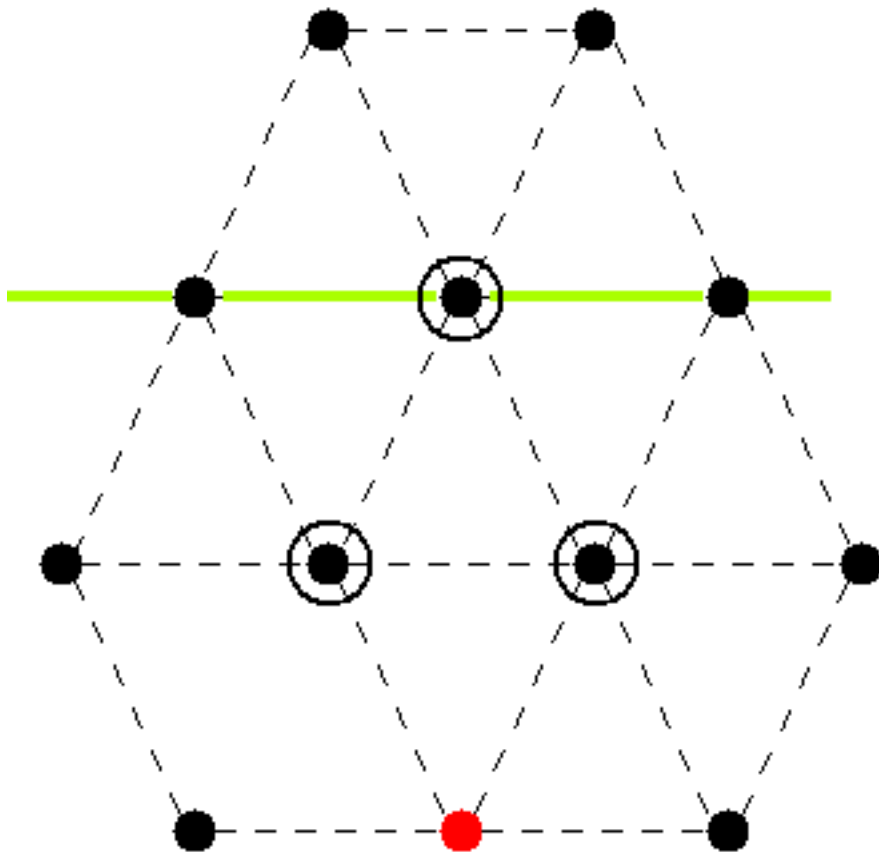
$\overline{15} \quad s=1$



Omega's form isospin triplet,
easy to check experimentally

Consequences

$\overline{15} \quad s=1$



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**