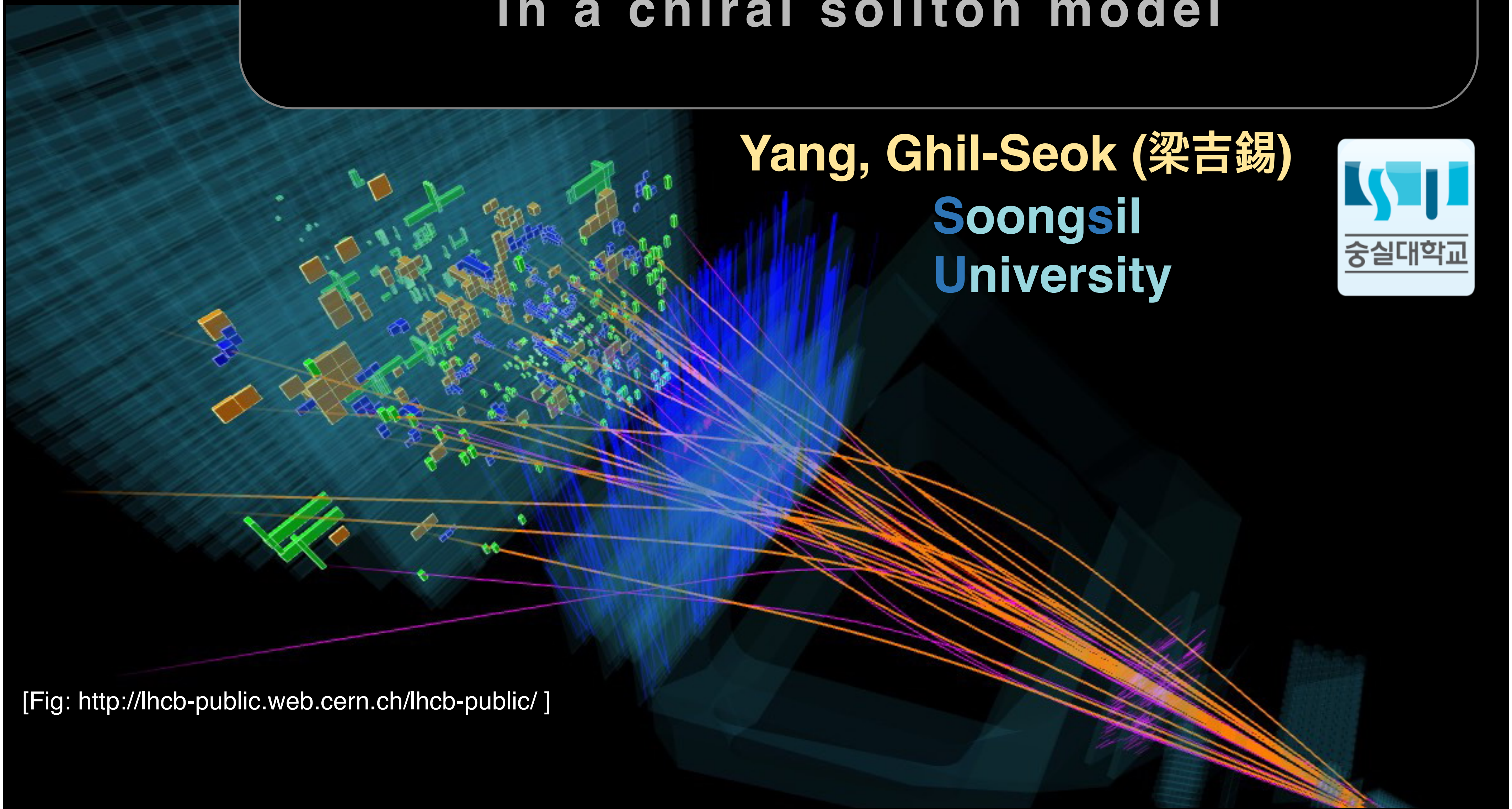
Static Properties of strange and non-strange members of exotic baryons in a chiral soliton model

Yang, Ghil-Seok (梁吉錫)
Soongsil University



[Fig: http://lhcb-public.web.cern.ch/lhcb-public/]

2019 Korea-Japan Joint Workshop on the Present and the Future Hadron Physics at J-PARC March 05, 2019 Pukyong Univ. Pusan

CONTENTS

Collaborators:
Hyun-Chul Kim (Inha Univ., Incheon, South Korea),
Maxim Polyakov (Ruhr-Uni. Bochum, Germany),
Michal Praszalowicz (Jagiellonian Univ., Krakow, Poland)

MOTIVATION I

Light Pentaquarks : Did we put a period at ?

1987, **M. Praszalowicz** (Skyrme Model) presented the first estimate of the mass of

1997, **DPP** (Chiral Soliton Model) showed the small decay width and the mass of .

2002, **T. Nakano (LEPS collaboration)** announced the first measurement of

After 2002, positive evidences **VS** negative evidences of experiments (2006~2008)
From 2011, pentaquark section in PDG disappeared.

New positive experiments (2005 - 2010)

For Θ^+

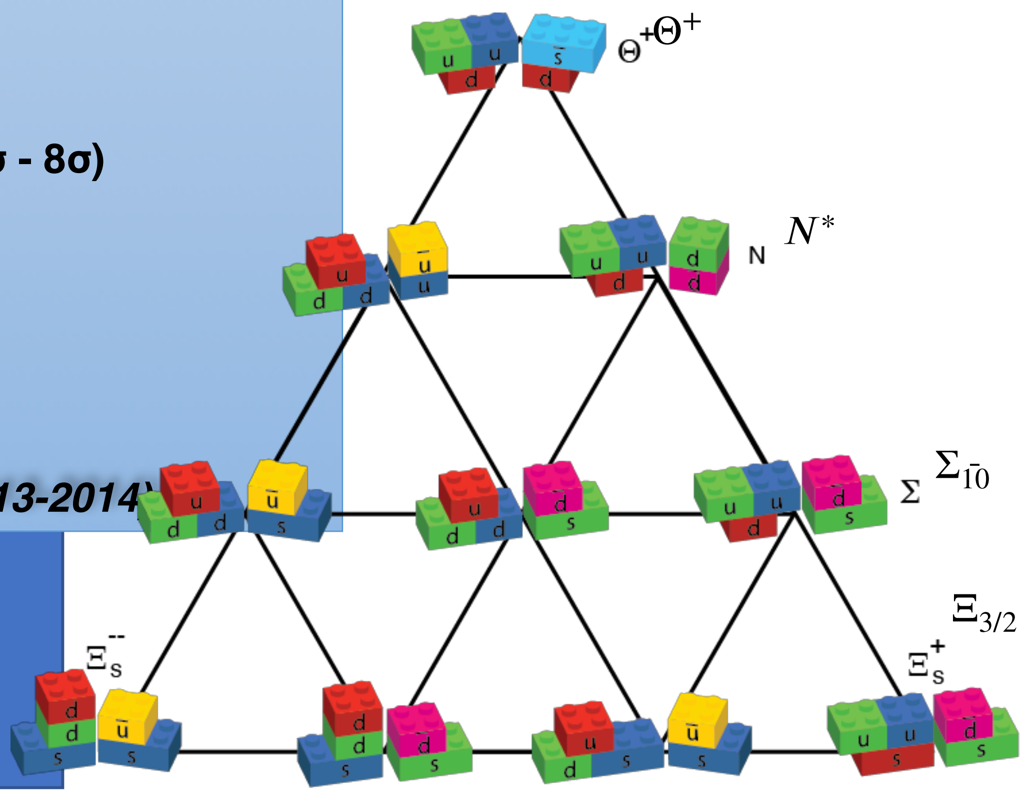
- *DIANA* (2010) : M = 1538±2, = 0.39±0.10 MeV
  ($K^+n \to K^0p$, higher statistical significance : 6σ - 8σ)
- Amaryan et al. (2012, CLAS data) :
  a narrow peak structure at ~1.54 GeV, ~6σ

For N^*

- *GRAAL* (*N**) : M = 1685±0.012 MeV,
  confirmed by *CBELSA/TAPS(2008-2011), A2 (2013-2014)*

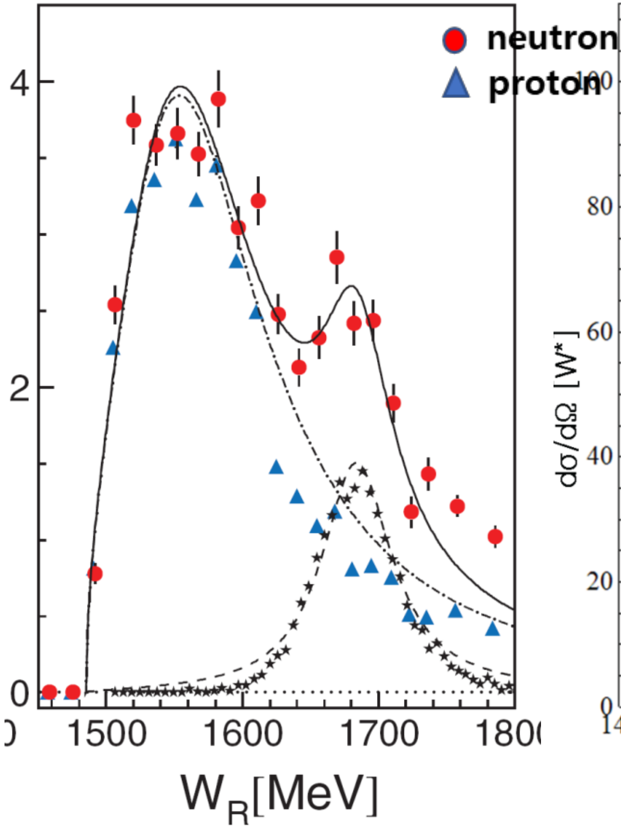
Various experimental data for Θ^+ and N^*

- Mass of Θ^+ : 1525 – 1565 MeV
- Mass of N^* : 1665 – 1695 MeV

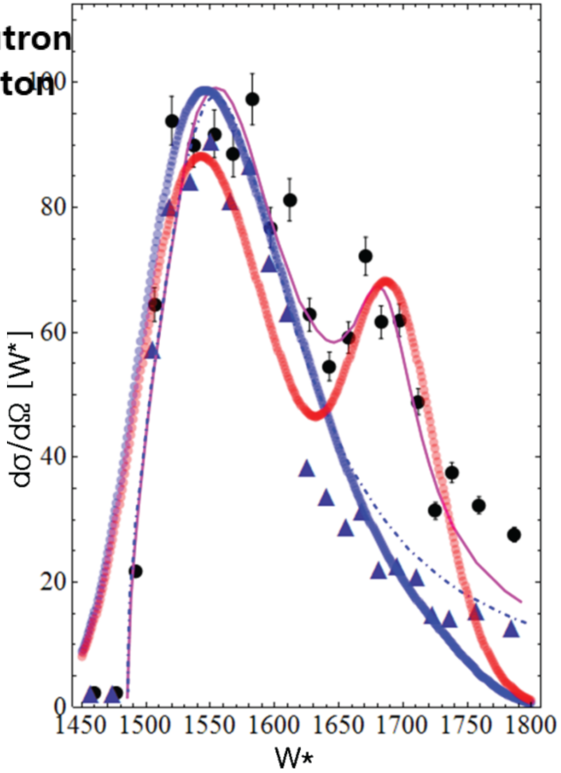


MOTIVATION II New narrow structures and •

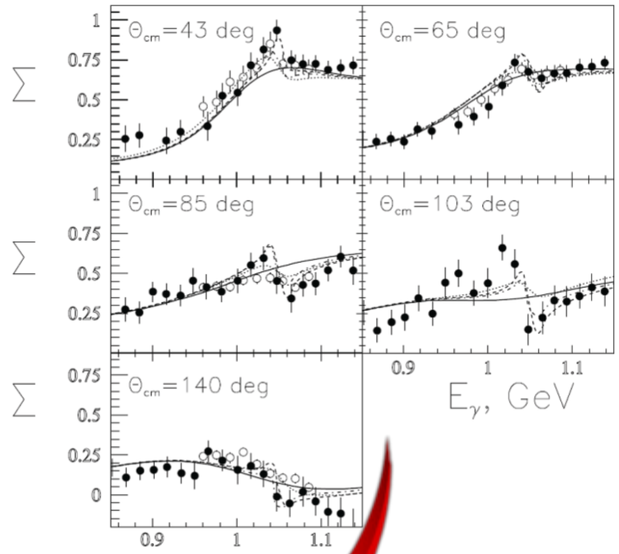
New narrow structure from
(GRAAL 2007, CBELSA/TAPS 2008, A2@MAMI 2013-2017)



CBELSA/TAPS 2008



Acta Physica Polonica B39,1949(2008) based on **GS Yang's PhD diss.**



GRAAL 2007

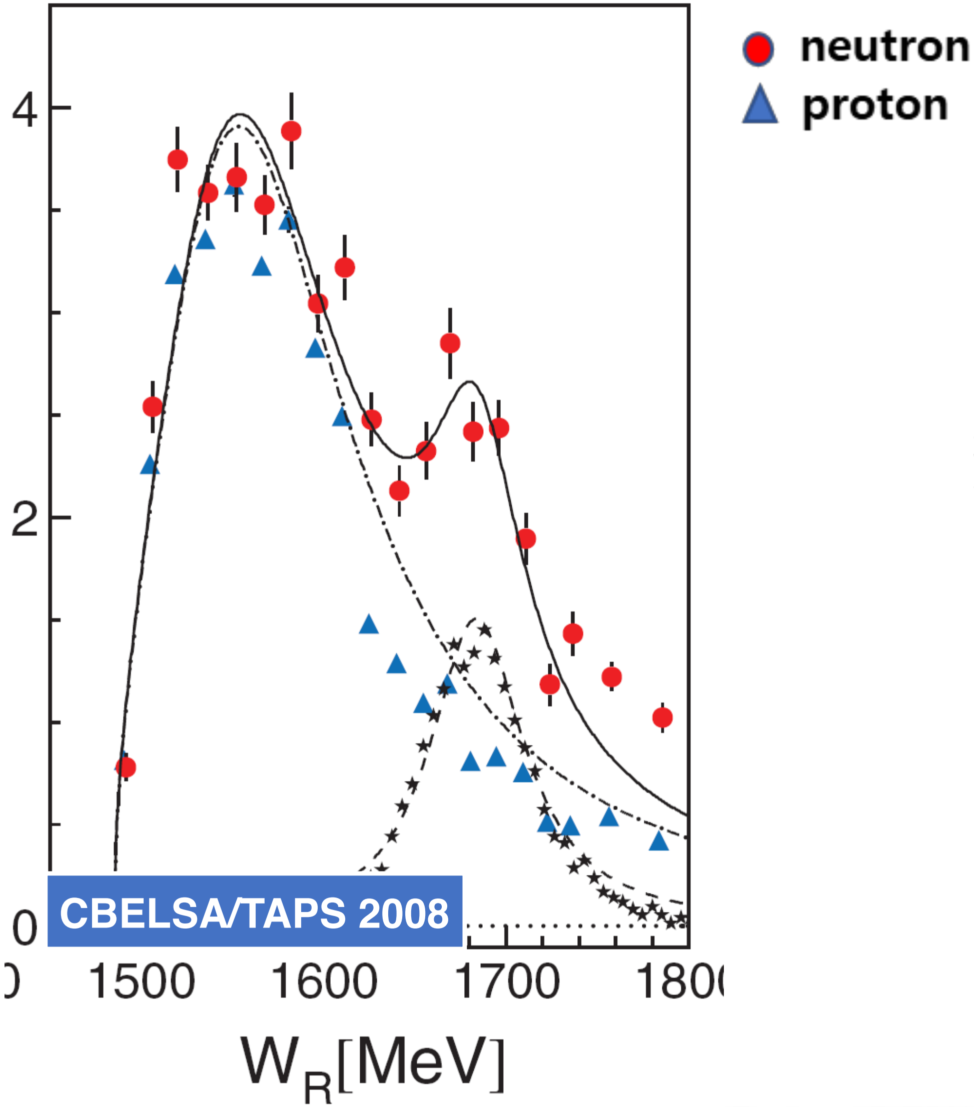
Strong suppression of photoexcitation of this resonance off proton
~ , consistent with the results from Chiral Soliton model

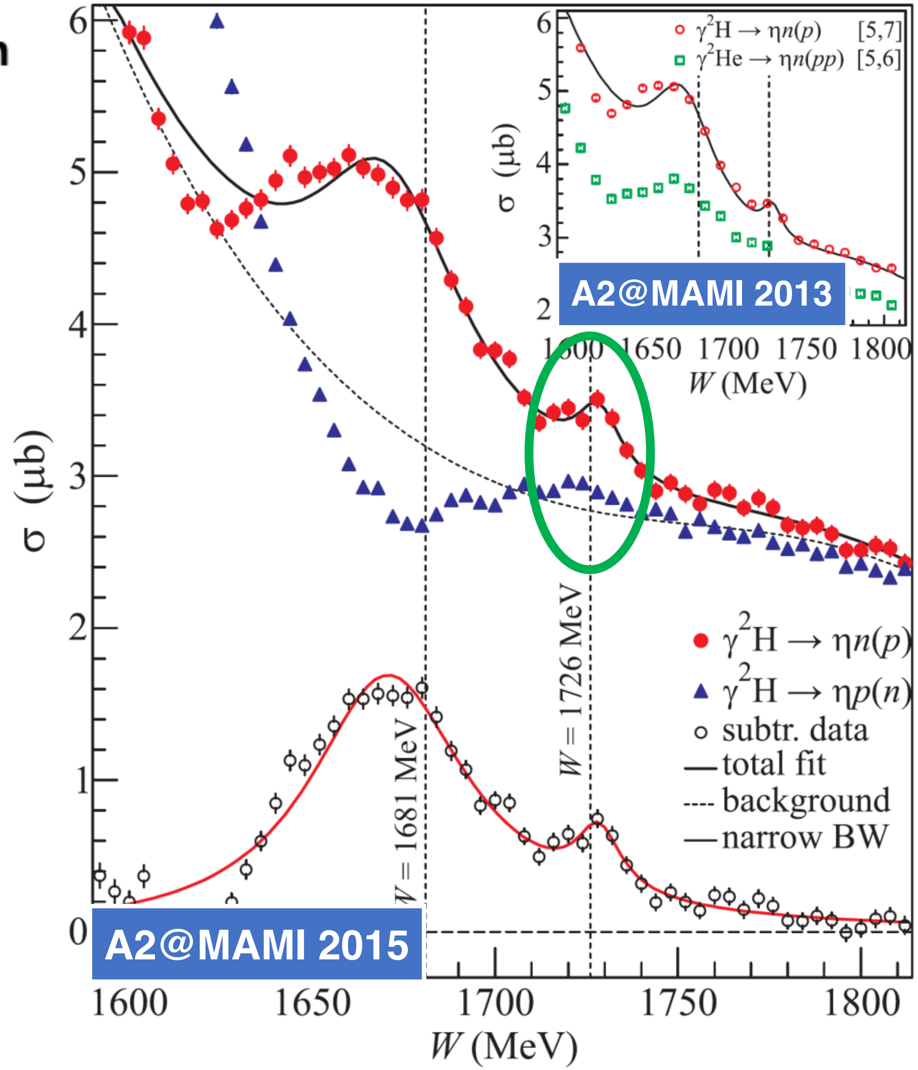
GS Yang et al., **PRD 71, 094023 (2005), arXiv:1809.07489**

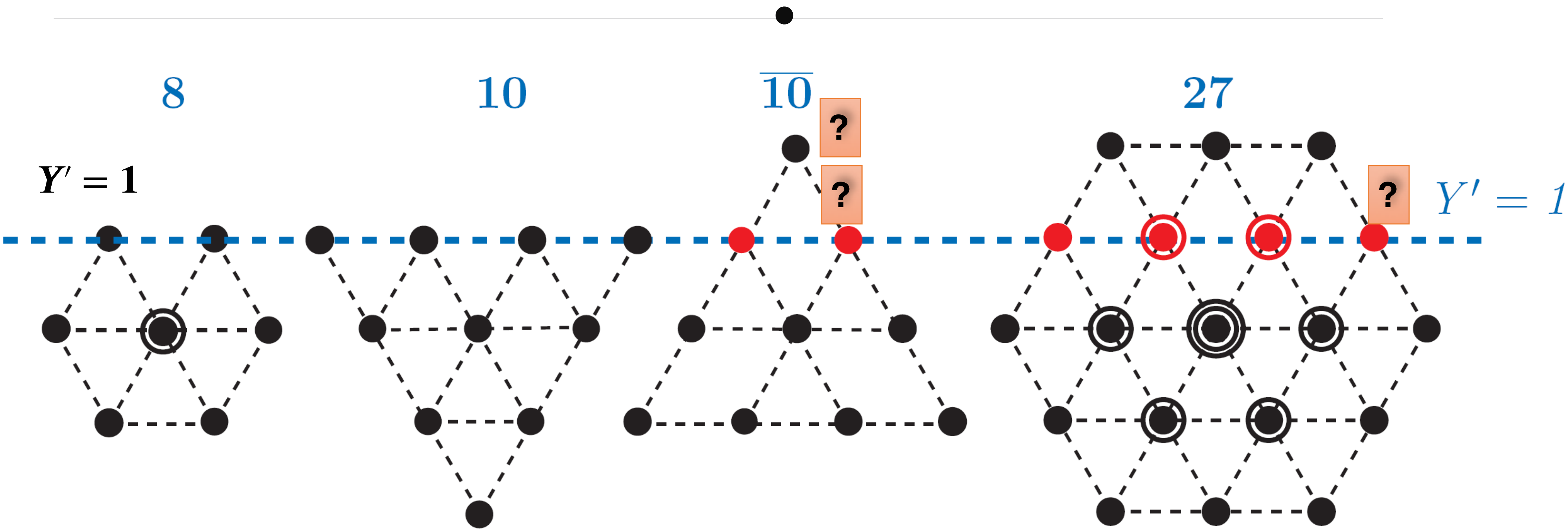
New narrow structures and

New narrow structure from (GRAAL 2007, CBELSA/TAPS 2008, A2@MaMiC 2013)

New narrow structure from (A2@MaMiC 2015, GRAAL 2017)







Assuming as the lightest member,
as the non-strange member of anti-decuplet baryons
and as the non-strange member of eikosiheptaplet baryons,
the mass spectrum, radiative decays, strong decays are strictly investigated
in the framework of chiral soliton model.

Large arguments allows us to consider a classical pion mean field (Witten): Relativistic Mean Field Approximation

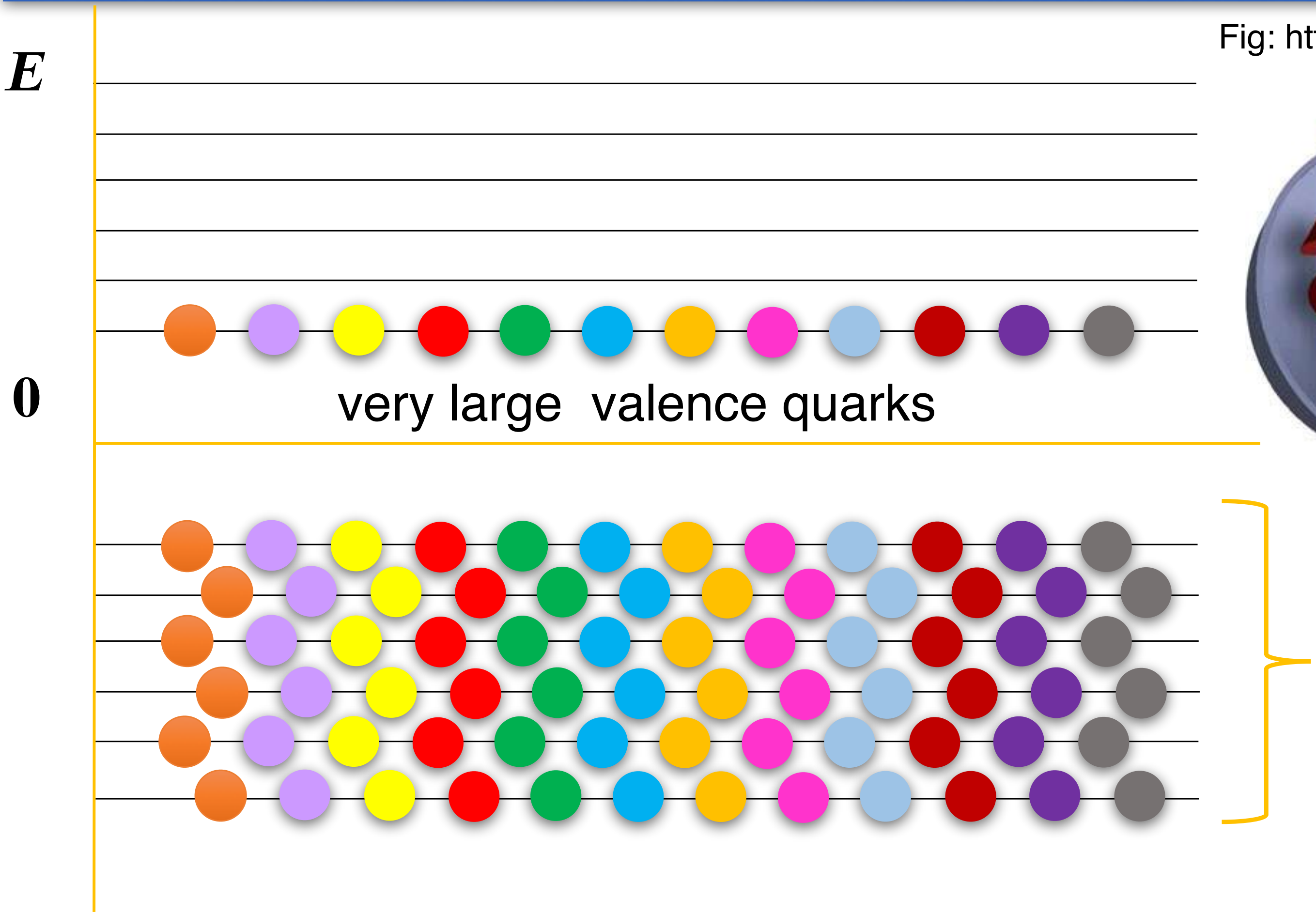
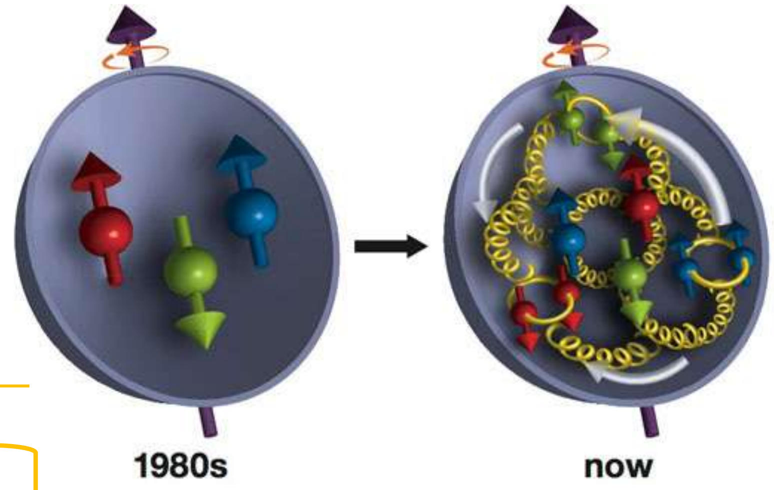


Fig: https://phys.org/news/2017-03-proton.html



The presence **valence quarks** creates the **pion mean fields** and valence quarks are **self-consistently bound** by it in the **large limit**.

One can put **to real-world value** at the end of the calculation.

hedgehog

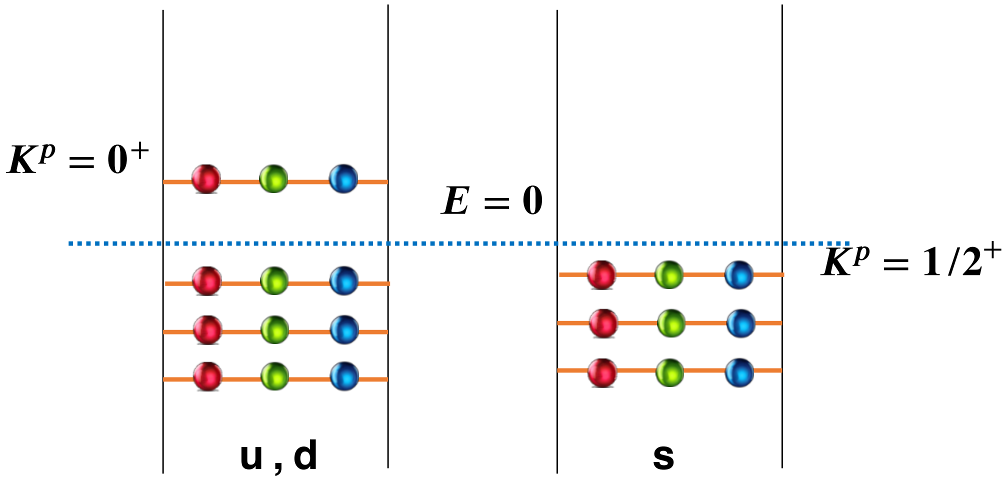
: Effective and relativistic low energy theory

: **Large limit : meson fields**
  → **Soliton (No quark degree of freedom)**

: Quantizing SU(3) meson fields rotated in flavor and spin space
  → Collective Hamiltonian, model baryon states

Hedgehog Ansatz:

$$U_0 = \begin{bmatrix} e^{i\boldsymbol{n}\cdot\boldsymbol{\tau}\, P(r)} & 0 \\ 0 & 1 \end{bmatrix}$$



SU(2) Witten imbedding

into **SU(3)**: SU(2) X U(1)

Model baryon state

$$|B\rangle = \sqrt{\dim(\mathcal{R})}(-1)^{J_3+Y'/2}D^{(\mathcal{R})*}_{(Y,T,T_3)(-Y',J,-J_3)}$$

Constraint for the collective quantization : $Y' = -\frac{N_c B}{3}$

Mixings of baryon states

SU(3) flavor symmetry breakings

$$|B_8\rangle = |8_{1/2}, B\rangle + c^B_{\overline{10}}|\overline{10}_{1/2}, B\rangle + c^B_{27}|27_{1/2}, B\rangle ,$$
$$|B_{10}\rangle = |10_{3/2}, B\rangle + a^B_{27}|27_{3/2}, B\rangle + a^B_{35}|35_{3/2}, B\rangle ,$$
$$|B_{\overline{10}}\rangle = |\overline{10}_{1/2}, B\rangle + d^B_8|8_{1/2}, B\rangle + d^B_{27}|27_{1/2}, B\rangle + d^B_{\overline{35}}|\overline{35}_{1/2}, B\rangle$$

Collective wave functions are no more in pure states
but are given as the linear combinations with higher representations.

Mixing coefficients

$$c_{\overline{10}}^{B} = c_{\overline{10}} \begin{bmatrix} \sqrt{5} \\ 0 \\ \sqrt{5} \\ 0 \end{bmatrix}, \quad c_{27}^{B} = c_{27} \begin{bmatrix} \sqrt{6} \\ 3 \\ 2 \\ \sqrt{6} \end{bmatrix}, \quad a_{27}^{B} = a_{27} \begin{bmatrix} \sqrt{15/2} \\ 2 \\ \sqrt{3/2} \\ 0 \end{bmatrix}, \quad a_{35}^{B} = a_{35} \begin{bmatrix} 5/\sqrt{14} \\ 2\sqrt{5/7} \\ 3\sqrt{5/14} \\ 2\sqrt{5/7} \end{bmatrix},$$

$$d_{8}^{B} = d_{8} \begin{bmatrix} 0 \\ \sqrt{5} \\ \sqrt{5} \\ 0 \end{bmatrix}, \quad d_{27}^{B} = d_{27} \begin{bmatrix} 0 \\ \sqrt{3/10} \\ 2/\sqrt{5} \\ \sqrt{3/2} \end{bmatrix}, \quad d_{\overline{35}}^{B} = d_{\overline{35}} \begin{bmatrix} 1/\sqrt{7} \\ 3/(2\sqrt{14}) \\ 1/\sqrt{7} \\ \sqrt{5/56} \end{bmatrix}$$

$$\Delta M_{10-8} = \frac{3}{2\, I_1}$$

$$\Delta M_{\overline{10}-8} = \frac{3}{2\, I_2}$$

$$c_{\overline{10}} = -\frac{I_2}{15}(m_s - \hat{m})\left(\alpha + \frac{1}{2}\gamma\right), \quad c_{27} = -\frac{I_2}{25}(m_s - \hat{m})\left(\alpha - \frac{1}{6}\gamma\right),$$

$$a_{27} = -\frac{I_2}{8}(m_s - \hat{m})\left(\alpha + \frac{5}{6}\gamma\right), \quad a_{35} = -\frac{I_2}{24}(m_s - \hat{m})\left(\alpha - \frac{1}{2}\gamma\right),$$

$$d_{8} = \frac{I_2}{15}(m_s - \hat{m})\left(\alpha + \frac{1}{2}\gamma\right), \quad d_{27} = -\frac{I_2}{8}(m_s - \hat{m})\left(\alpha - \frac{7}{6}\gamma\right),$$

$$d_{\overline{35}} = -\frac{I_2}{4}(m_s - \hat{m})\left(\alpha + \frac{1}{6}\gamma\right)$$

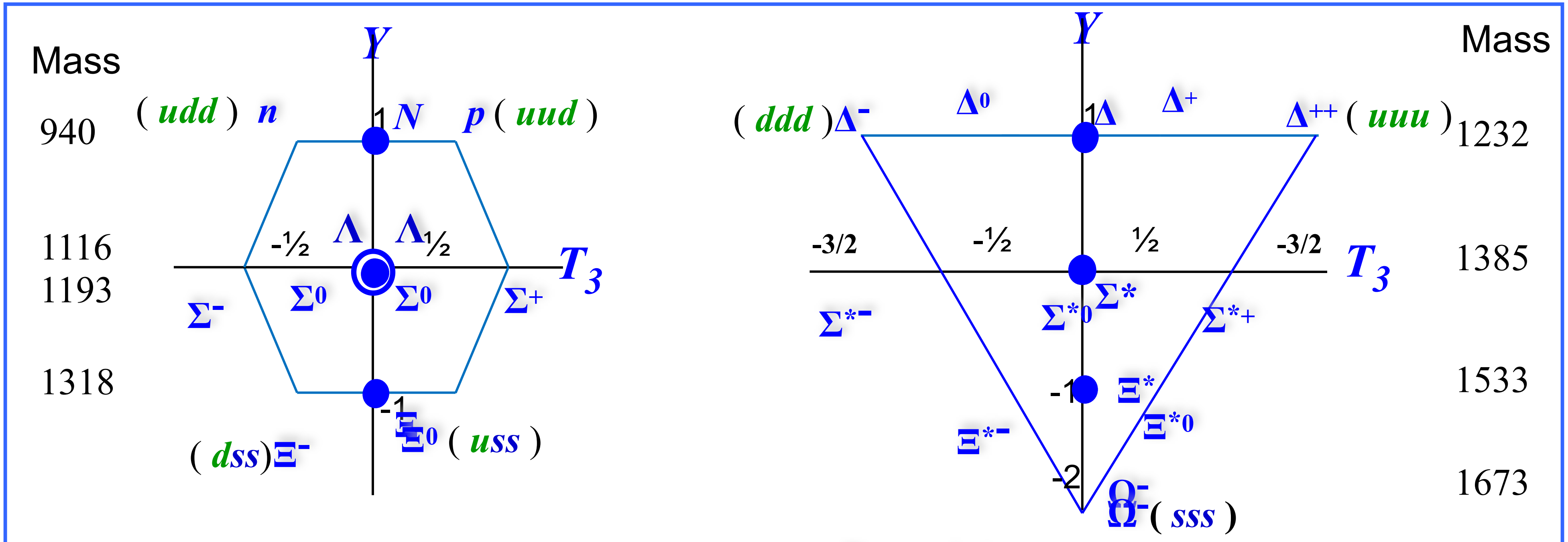
: moments of inertia
~ Isospin transitions

: moments of inertia
~ SU(3) flavor transitions

is very important for describing the effects of SU(3) flavor symmetry breaking.

Collective Hamiltonian for flavor symmetry breakings

$$H_{\rm sb} = (m_s - \hat{m})\left(\alpha D_{88}^{(8)}(\mathcal{R}) + \beta \hat{Y} + \frac{1}{\sqrt{3}}\gamma\sum_{i=1}^{3} D_{8i}^{(8)}(\mathcal{R})\,\hat{J}_i\right)$$
$$+ (m_d - m_u)\left(\frac{\sqrt{3}}{2}\alpha D_{38}^{(8)}(\mathcal{R}) + \beta \hat{T}_3 + \frac{1}{2}\gamma\sum_{i=1}^{3} D_{3i}^{(8)}(\mathcal{R})\,\hat{J}_i\right)$$



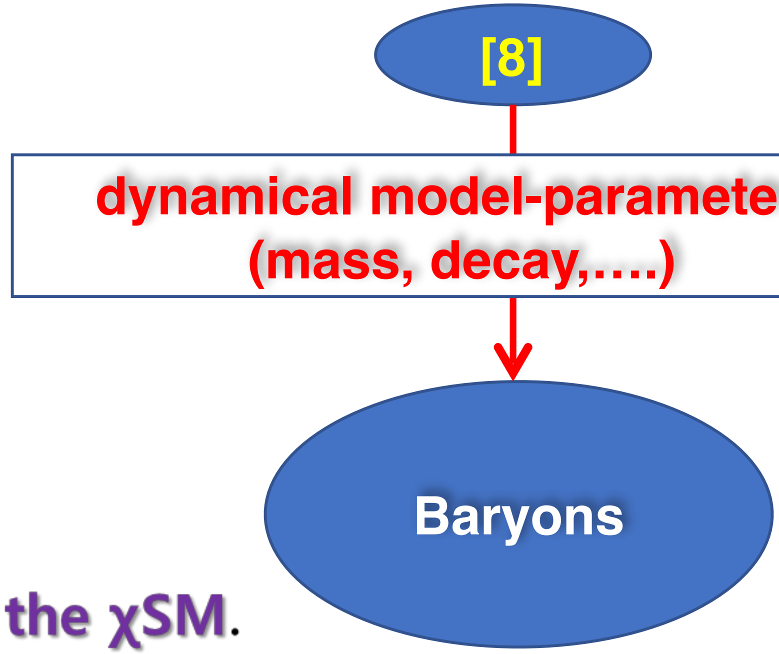
Octet (8) : $J^P = 1/2^+$ Decuplet (10) : $J^P = 3/2^+$

SU(3) flavor symmetry breaking + Isospin symmetry breaking

Self-consistent approach

	Octet	Decuplet
N/Δ	996 (939)	1313 (1232)
Σ	$(\Sigma+\Lambda)/2 = \text{input} = 1151.5$	1430 (1385)
Ξ	1279 (1315)	1544 (1530)
Ω	–	1654 (1672)

Model-independent approach



Two advantages offered by the model-independent approach in the χSM.

1. the very **same set** of dynamical **model-parameters** allows us to calculate the physical observables of all SU(3) baryons regardless of different SU(3) flavor representations of baryons, namely **octet**, **decuplet, antidecuplet**, and so on.

2. these dynamical **model-parameters** can be adjusted to the experimental data of the baryon octet which are well established with high precisions.

Expressions of baryon masses

- **[8]**

$$M_N = \overline{M}_{\mathbf{8}} + c^{(1)} + \frac{1}{5}\left(c^{(8)} + \frac{4}{9}c^{(27)}\right)T_3 + \frac{3}{5}\left(c^{(8)} + \frac{2}{27}c^{(27)}\right)\left(T_3^2 + \frac{1}{4}\right) \quad (\Delta M)_{EM}$$

$$- (m_d - m_u)(\delta_1 - \delta_2)T_3 - (m_s - \hat{m})(\delta_1 + \delta_2), \quad (\Delta M)_H$$

$\sim \alpha,\ \beta, \gamma$

where
$$\delta_1 = -\frac{1}{5}\alpha - \beta + \frac{1}{5}\gamma,$$
$$\delta_2 = -\frac{1}{10}\alpha - \frac{3}{20}\gamma.$$

$\sim 1/I_1$

[10]

$$M_{\Omega^-} = \overline{M}_{\mathbf{10}} + c^{(1)} - \frac{1}{4}\left(c^{(8)} - \frac{4}{21}c^{(27)}\right) + 2(m_s - \hat{m})\left(\delta_1 - \frac{3}{4}\delta_2\right)$$

$\sim \alpha,\ \beta, \gamma$

$\sim 1/I_2$

[$\overline{10}$]

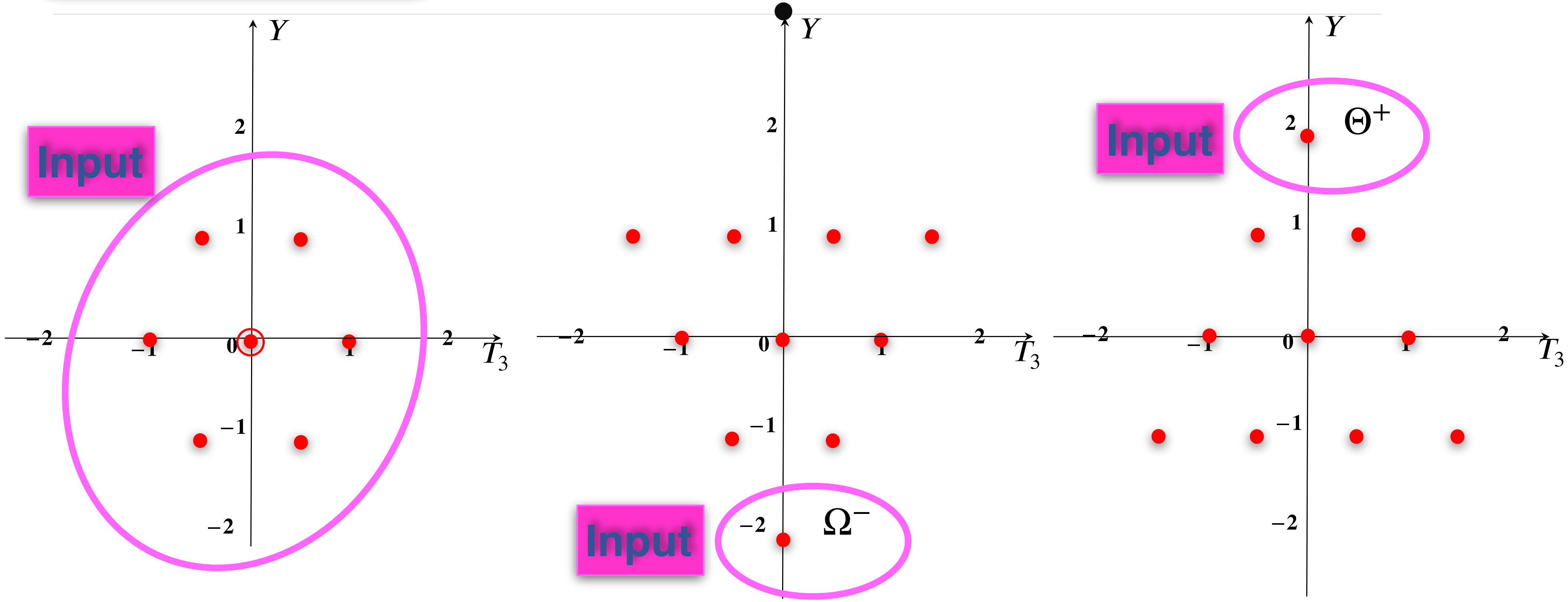
$$M_{\Theta^+} = \overline{M}_{\overline{\mathbf{10}}} + c^{(1)} + \frac{1}{4}\left(c^{(8)} - \frac{4}{21}c^{(27)}\right) - 2(m_s - \hat{m})\delta_3,$$

$$M_{N^*} = \overline{M}_{\overline{\mathbf{10}}} + c^{(1)} + \frac{1}{4}\left(c^{(8)} - \frac{32}{63}c^{(27)}\right)T_3 + \frac{1}{4}\left(c^{(8)} + \frac{8}{63}c^{(27)}\right)\left(T_3^2 + \frac{1}{4}\right)$$
$$- (m_d - m_u)\delta_3 T_3 - (m_s - \hat{m})\delta_3,$$

where
$$\delta_3 = -\frac{1}{8}\alpha - \beta + \frac{1}{16}\gamma.$$

$\sim \alpha,\ \beta, \gamma$

Chiral soliton model & Mean field approach



$[\,\mathbf{8}\,] = D(1,1)$ $[\,\mathbf{10}\,] = D(3,0)$ $[\ \ ]$

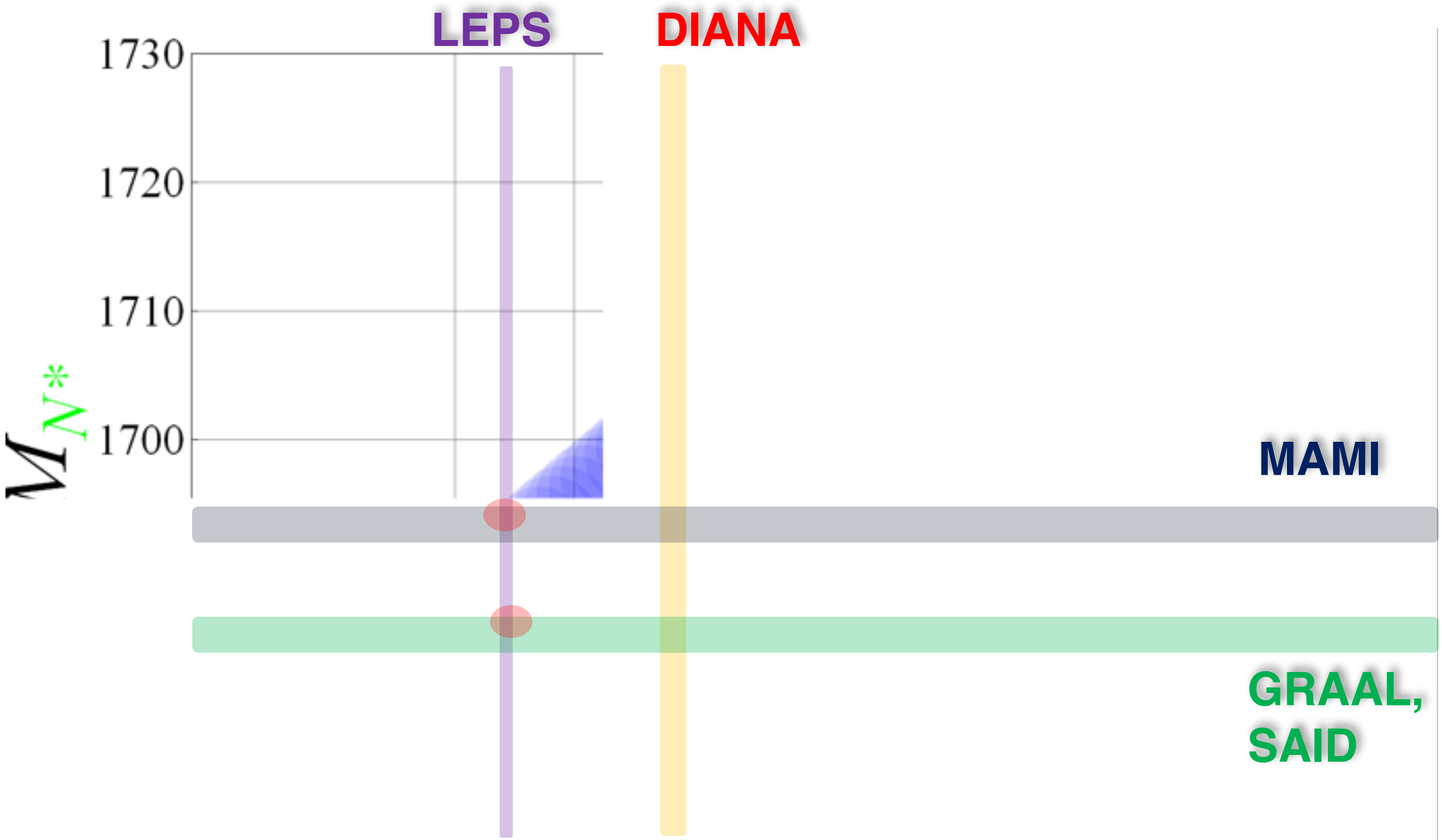
$\alpha,\ \beta,\ \gamma$ I_1 I_2

$$\Delta \overline{M}_{10-8} = \frac{3}{2\,I_1}$$

$$\Delta \overline{M}_{\overline{10}-8} = \frac{3}{2\,I_2}$$

In order to obtain and values,
we use the masses of and as inputs, respectively.

mass as a function of mass

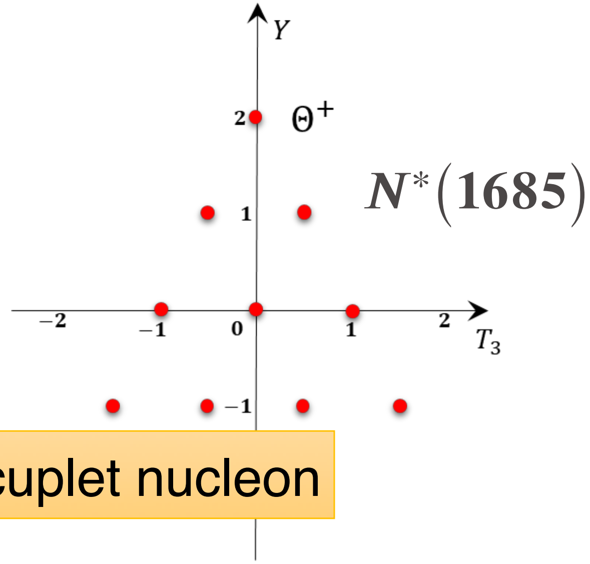


G.S.Yang et al., New Physics (Kor. Journal) 62, 243 (2012)

Within the framework of SM,
mass from LEPS (not from DIANA) is consistent with mass.

Baryon antidecuplet masses

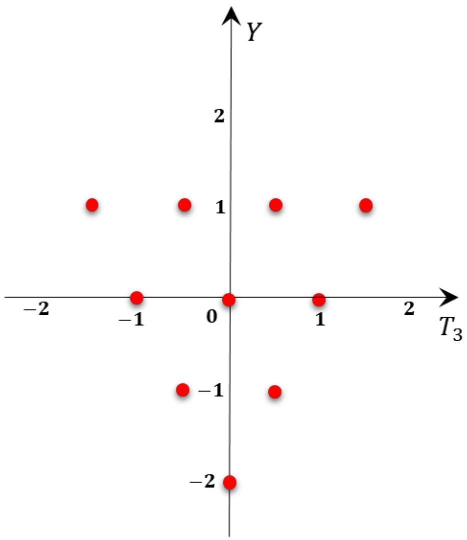
Mass		T_3	Y	Experiment	Predictions
M_{Θ^+}	Θ^+	0	2	1524 ± 5 [15]	Input
M_{N^*}	p^*	$1/2$	1	1686 ± 12 [28]	1688.18 ± 10.53
	n^*	$-1/2$			1692.16 ± 10.53
$M_{\Sigma_{\overline{10}}}$	$\Sigma^+_{\overline{10}}$	1	0		1852.35 ± 10.00
	$\Sigma^0_{\overline{10}}$	0			1856.33 ± 10.00
	$\Sigma^-_{\overline{10}}$	-1			1858.95 ± 10.00
	$\Xi^+_{3/2}$	$3/2$			2016.53 ± 10.53
	$\Xi^{--}_{3/2}$	$-3/2$			2024.37 ± 10.53



Mass of new narrow structure can be described by antidecuplet nucleon

Baryon decuplet masses

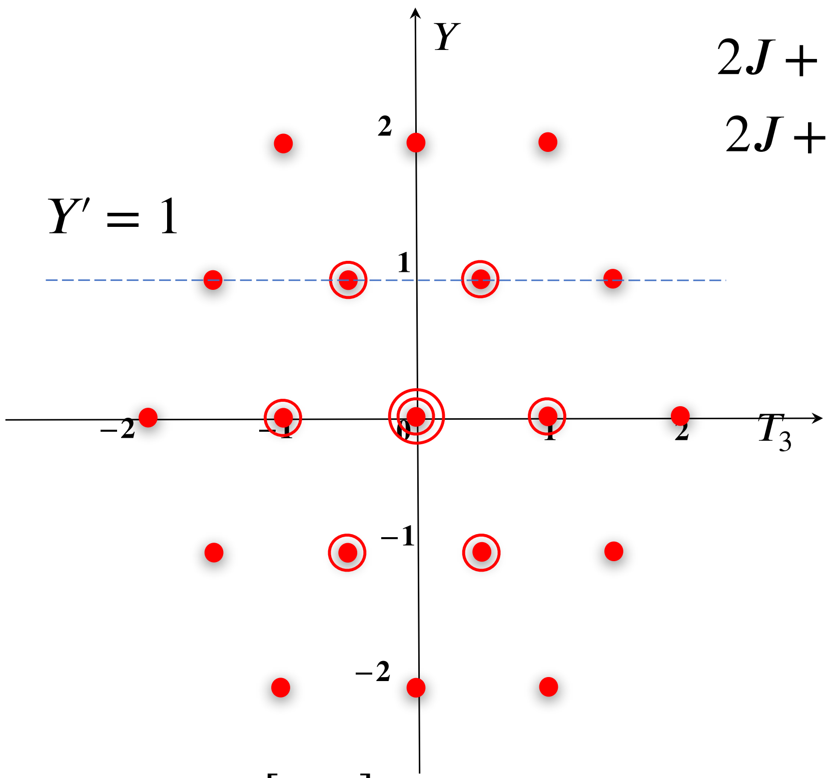
$[\,\overline{\mathbf{10}}\,] = D(0,3)$



$[\,\mathbf{10}\,] = D(3,0)$

Mass [MeV]		T_3	Y	Exp.	Predicted
M_Δ	Δ^{++}	$3/2$	1	$1231 - 1233$	1244.1 ± 0.6
	Δ^+	$1/2$			1243.8 ± 0.4
	Δ^0	$-1/2$			1244.9 ± 0.4
	Δ^-	$-3/2$			1247.3 ± 0.5
M_{Σ^*}	Σ^{*+}	1	0	$1382.8 \pm 0.4^*$	1383.3 ± 0.4
	Σ^{*0}	0		$1383.7 \pm 1.0^*$	1384.3 ± 0.4
	Σ^{*-}	-1		$1387.2 \pm 0.5^*$	1386.8 ± 0.4
$M_{\Xi^{*0}}$	Ξ^{*0}	$1/2$	-1	1531.80 ± 0.32	1523.8 ± 0.4
	Ξ^{*-}	$-1/2$		1535.0 ± 0.6	1526.2 ± 0.4
M_{Ω^-}	Ω^-	0	-2	1672.45 ± 0.29	Input

Masses of Nucleon-like states in eikosiheptaplet



$[\,27\,] = D(2,\ 2)$

$2J+1=2 \longrightarrow J=1/2$

$2J+1=4 \longrightarrow J=3/2$

$$\overline{M}^{1/2}_{\mathbf{27}} = \overline{M}_{\mathbf{8}} + \frac{5}{2I_2},$$

$$\overline{M}^{3/2}_{\mathbf{27}} = \overline{M}_{\mathbf{8}} + \frac{3}{2I_1} + \frac{1}{I_2},$$

Without any free parameters,

$\mathbf{27}_{1/2}$	$N_{\mathbf{27}}$	$p_{\mathbf{27}}$	$1/2$	2115.7 ± 17.0	2116.6 ± 17.0
		$n_{\mathbf{27}}$	$-1/2$	2117.4 ± 17.0	
$\mathbf{27}_{3/2}$	$N_{\mathbf{27}}$	$p_{\mathbf{27}}$	$1/2$	1718.6 ± 7.4	1719.6 ± 7.4
		$n_{\mathbf{27}}$	$-1/2$	1720.6 ± 7.4	

GS Yang, HCh Kim, arXiv:1809.07489

?

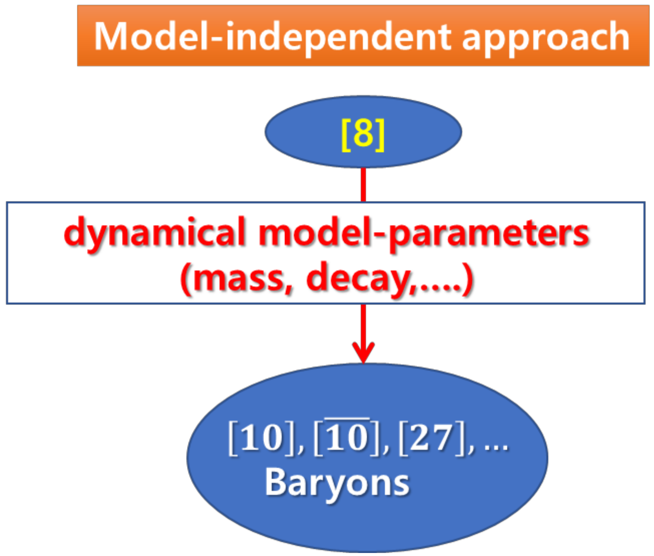
Mass of new narrow structure can be described by eikosiheptaplet nucleon

Model parameters of axial-vector and magnetic moments

In the very same way,
widths of strong and radiative decays can be estimated.

Collective operators of axial-vector
and magnetic moment in a chiral soliton model

$$\hat{g}_1 = \hat{g}_1^{(0)} + \hat{g}_1^{(1)},$$
$$\hat{\mu} = \hat{\mu}^{(0)} + \hat{\mu}^{(1)},$$



where

$$\hat{g}_1^{(0)} = a_1 D_{\varphi 3}^{(8)} + a_2 d_{3bc} D_{\varphi b}^{(8)} \hat{J}_c + \frac{a_3}{\sqrt{3}} D_{\varphi 8}^{(8)} \hat{J}_3,$$
$$\hat{g}_1^{(1)} = \frac{a_4}{\sqrt{3}} d_{pq3} D_{\varphi p}^{(8)} D_{8q}^{(8)} + a_5 \left(D_{\varphi 3}^{(8)} D_{88}^{(8)} + D_{\varphi 8}^{(8)} D_{83}^{(8)} \right) + a_6 \left(D_{\varphi 3}^{(8)} D_{88}^{(8)} - D_{\varphi 8}^{(8)} D_{83}^{(8)} \right),$$

$$\hat{\mu}^{(0)} = w_1 D_{Q3}^{(8)} + w_2 d_{3bc} D_{Qb}^{(8)} \hat{J}_c + \frac{w_3}{\sqrt{3}} D_{Q8}^{(8)} \hat{J}_3,$$
$$\hat{\mu}^{(1)} = \frac{w_4}{\sqrt{3}} d_{pq3} D_{Qp}^{(8)} D_{8q}^{(8)} + w_5 \left(D_{Q3}^{(8)} D_{88}^{(8)} + D_{Q8}^{(8)} D_{83}^{(8)} \right) + w_6 \left(D_{Q3}^{(8)} D_{88}^{(8)} - D_{Q8}^{(8)} D_{83}^{(8)} \right).$$

values from hyperon semi-leptonic decays of Octet baryons

values from magnetic moments of Octet baryons

Magnetic moments for baryon decuplet (in units of μ_N)

B_{10}	Exp.	$\mu^{(0)}_{B_{10}}\ (\mathcal{O}(m_s^0))$	$\mu^{(\mathrm{op})}_{B_{10}}\ (\mathcal{O}(m_s^1))$	$\mu^{(\mathrm{wf})}_{B_{10}}\ (\mathcal{O}(m_s^1))$	$\mu^{(\mathrm{total})}_{B_{10}}$
Δ^{++}	$3.7 - 7.5$	4.957 ± 0.053	0.414 ± 0.018	0.033 ± 0.002	5.405 ± 0.057
Δ^{+}	$2.7^{+1.0}_{-1.3} \pm 1.5 \pm 3$	2.479 ± 0.027	0.040 ± 0.003	0.061 ± 0.011	2.580 ± 0.036
Δ^{0}		0	-0.334 ± 0.019	0.090 ± 0.021	-0.244 ± 0.028
Δ^{-}		-2.479 ± 0.027	-0.708 ± 0.037	0.118 ± 0.031	-3.068 ± 0.042
Σ^{*+}		2.479 ± 0.027	0.253 ± 0.022	0.035 ± 0.003	2.767 ± 0.033
Σ^{*0}		0	-0.040 ± 0.003	0.062 ± 0.009	0.022 ± 0.010
Σ^{*-}		-2.479 ± 0.027	-0.334 ± 0.019	0.090 ± 0.021	-2.723 ± 0.025
Ξ^{*0}		0	0.253 ± 0.022	0.035 ± 0.003	0.288 ± 0.022
Ξ^{*-}		-2.479 ± 0.027	0.040 ± 0.003	0.061 ± 0.011	-2.377 ± 0.020
Ω^{-}	-2.02 ± 0.05	-2.479 ± 0.027	0.414 ± 0.018	0.033 ± 0.002	-2.031 ± 0.032

mass splitting analysis

GS Yang et al., Phys. Rev. D 70, 114002 (2004)

Transition magnetic moments (in units of μ_N)

	$\mu^{(0)}(\mathcal{O}(m_s^0))$	$\mu^{(\text{op})}(\mathcal{O}(m_s^1))$	$\mu^{(\text{wf})}(\mathcal{O}(m_s^1))$	$\mu^{(\text{total})}$	Exp. (PDG)
$\mu_{N\Delta}$	-2.332 ± 0.020	-0.494 ± 0.026	-0.252 ± 0.004	-3.079 ± 0.032	$\lvert\mu_{N\Delta}\rvert \sim 3.1$
$\mu_{\Lambda\Sigma^0}$	1.234 ± 0.012	0.308 ± 0.024	0.044 ± 0.002	1.586 ± 0.027	1.61 ± 0.08
$\mu_{\Sigma^+\Sigma^{*+}}$	2.332 ± 0.020	-0.036 ± 0.013	-0.098 ± 0.001	2.198 ± 0.024	
$\mu_{\Sigma^0\Sigma^{*0}}$	1.166 ± 0.010	-0.187 ± 0.012	-0.103 ± 0.002	0.876 ± 0.016	
$\mu_{\Sigma^-\Sigma^{*-}}$	0	-0.338 ± 0.026	-0.109 ± 0.002	-0.446 ± 0.026	<0.82
$\mu_{\Lambda\Sigma^{*0}}$	-2.020 ± 0.017	-0.324 ± 0.020	-0.179 ± 0.003	-2.522 ± 0.026	
$\mu_{\Xi^0\Xi^{*0}}$	2.332 ± 0.020	-0.120 ± 0.013	-0.048 ± 0.001	2.164 ± 0.024	
$\mu_{\Xi^-\Xi^{*-}}$	0	-0.338 ± 0.026	-0.105 ± 0.002	-0.442 ± 0.026	

Since the magnetic dipole transitions (M1) are experimentally dominant over the electric quadrupole transitions (E2) in hyperon radiative decays, one can neglect the E2 transitions.

$$\Gamma(B_{\overline{10}} \to B_8\gamma) = 4\alpha_{\text{EM}} \frac{E_\gamma^3}{(M_8 + M_{\overline{10}})^2} \left(\frac{\mu_{B_8 B_{\overline{10}}}}{\mu_N}\right)^2,$$

$$\Gamma(B_{10} \to B_8\gamma) = \frac{\alpha_{\text{EM}}}{2} \frac{E_\gamma^3}{M_8^2} \left(\frac{\mu_{B_8 B_{10}}}{\mu_N}\right)^2,$$

GS Yang et al., Phys. Rev. D 71, 094023 (2005)

Radiative Decay Widths

Radiative decay widths of states

$N_{\overline{\mathbf{10}}} \to \gamma + N$	$\mu^{(0)}_{N_{\overline{\mathbf{10}}}N}$	$\mu^{(\mathrm{tot})}_{N_{\overline{\mathbf{10}}}N}$	$\Gamma^{(\mathrm{tot})}_{N_{\overline{\mathbf{10}}}N\gamma}$ [keV]
$p_{\overline{\mathbf{10}}} \to \gamma + p$	0	0.15 ± 0.04	18.78 ± 0.52
$n_{\overline{\mathbf{10}}} \to \gamma + n$	-0.38 ± 0.08	-0.44 ± 0.09	161.83 ± 64.72
$N_{\mathbf{27}} \to \gamma + N$	$\mu^{(0)}_{\mathbf{27}}$	$\mu^{(\mathrm{tot})}_{\mathbf{27}}$	$\Gamma^{(\mathrm{tot})}_{\gamma N_{\mathbf{27}} N}$ [MeV]
$p_{\mathbf{27}} \to \gamma + p$	-0.93 ± 0.04	-0.75 ± 0.05	1.43 ± 0.19
$n_{\mathbf{27}} \to \gamma + n$	-0.46 ± 0.02	-0.38 ± 0.02	0.38 ± 0.04

$$\frac{\Gamma_\gamma\left[n_{\overline{\mathbf{10}}} \to n\right]}{\Gamma_\gamma\left[p_{\overline{\mathbf{10}}} \to p\right]} = 8.62 \pm 3.45.$$

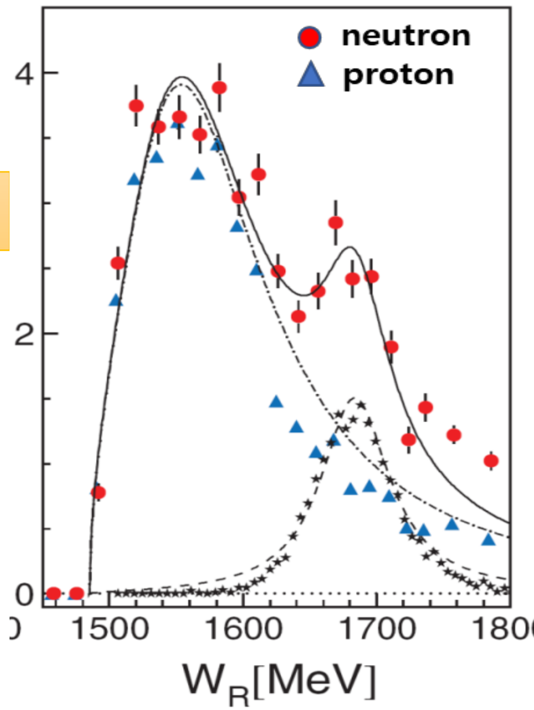
$$\frac{\Gamma_\gamma\left[p_{\mathbf{27}} \to p\right]}{\Gamma_\gamma\left[n_{\mathbf{27}} \to n\right]} = 3.76 \pm 0.64.$$

GS Yang, HCh Kim, arXiv:1809.07489

For , the neutron anomaly can be explained by this ratio.

On the contrary,

is more likely to be found
in photoproduction off the **proton target**



CBELSA/TAPS 2008

Strong decay widths

Strong decay widths of decuplet baryons

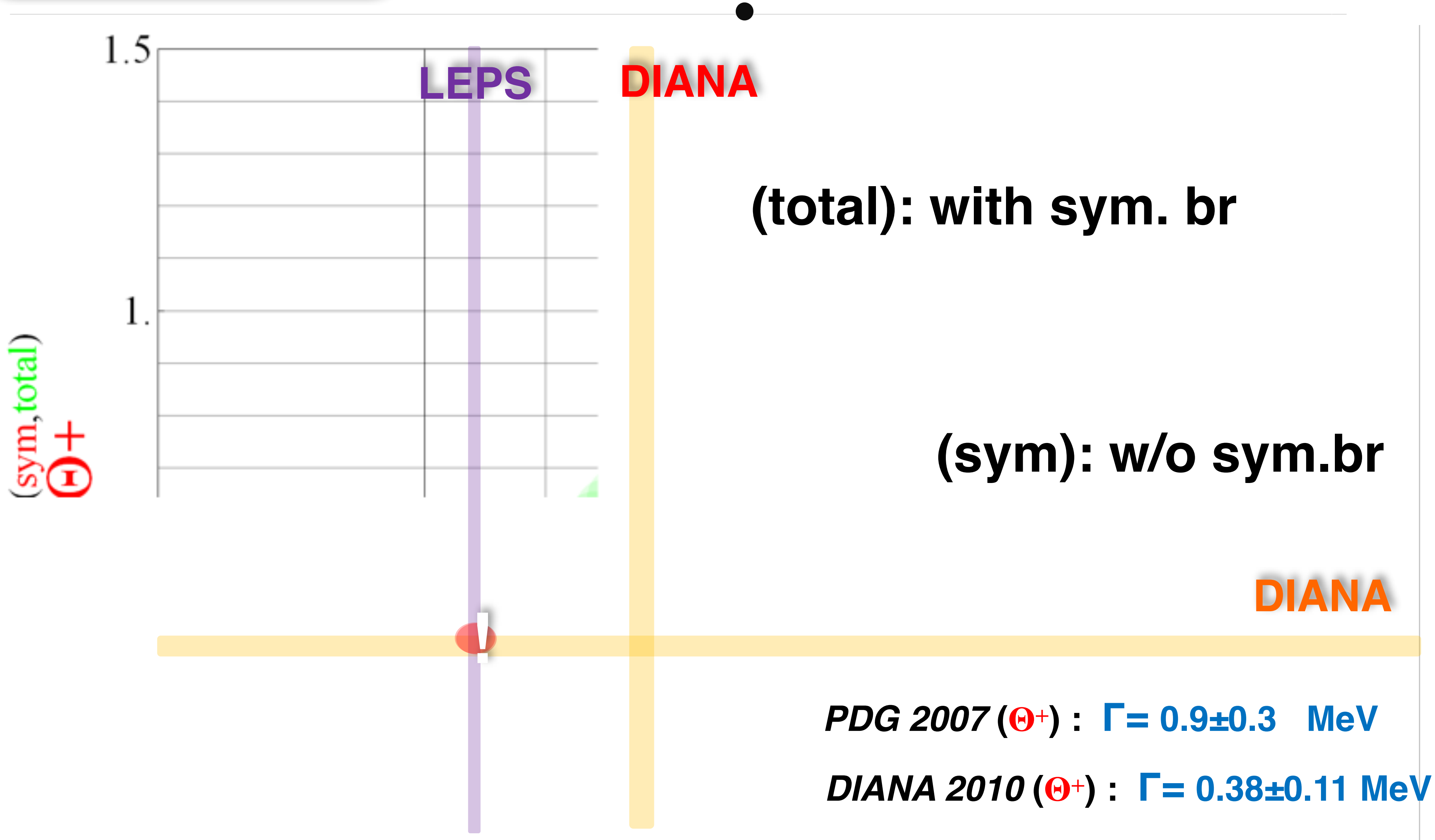
From hyperon semileptonic decays of octet baryons, values of are determined.
Employing the generalized Goldberger-Treiman relation, meson-baryon coupling constants are obtained.

Decay modes	$\Gamma_i^{(0)}$	$\Gamma_i^{(\text{total})}$	Γ	Γ(Exp.) [2]
$\Delta \to N\pi$	75.98 ± 1.01		88.58 ± 1.31	116–120
$\Sigma^{*+} \to \Sigma^0\pi^+$	2.59 ± 0.03	3.22 ± 0.06		
$\Sigma^{*+} \to \Sigma^+\pi^0$	3.17 ± 0.05	2.62 ± 0.05	36.25 ± 0.42	36.0 ± 0.7
$\Sigma^{*+} \to \Lambda\pi^+$	29.68 ± 0.26	30.41 ± 0.33		
$\Sigma^{*0} \to \Sigma^0\pi^0$	0	0		
$\Sigma^{*0} \to \Sigma^+\pi^-$	3.61 ± 0.11	2.98 ± 0.1	37.21 ± 0.69	36 ± 5
$\Sigma^{*0} \to \Sigma^-\pi^+$	2.78 ± 0.1	2.30 ± 0.09		
$\Sigma^{*0} \to \Lambda\pi^0$	31.15 ± 0.47	31.92 ± 0.52		
$\Sigma^{*-} \to \Sigma^-\pi^0$	3.50 ± 0.06	2.89 ± 0.06		
$\Sigma^{*-} \to \Sigma^0\pi^-$	3.64 ± 0.06	3.01 ± 0.06	38.18 ± 0.48	39.4 ± 2.1
$\Sigma^{*-} \to \Lambda\pi^-$	31.50 ± 0.30	32.28 ± 0.37		
$\Xi^{*0} \to \Xi^0\pi^0$	4.76 ± 0.05	4.33 ± 0.06	11.26 ± 0.17	9.1 ± 0.5
$\Xi^{*0} \to \Xi^-\pi^+$	7.61 ± 0.08	6.93 ± 0.10		
$\Xi^{*-} \to \Xi^-\pi^0$	4.76 ± 0.05	4.33 ± 0.06	13.01 ± 0.21	$9.9^{+1.7}_{-1.9}$
$\Xi^{*-} \to \Xi^0\pi^-$	8.20 ± 0.13	8.68 ± 0.16		

GS Yang, HCh Kim, Phys. Rev. C **92** 035206 (2015)
GS Yang, HCh Kim, Phys. Lett. B **785** 434 (2018)

Strong decay widths

Decay width of as a function of mass



Within the framework of SM,
mass from LEPS is consistent with decay width from DIANA .

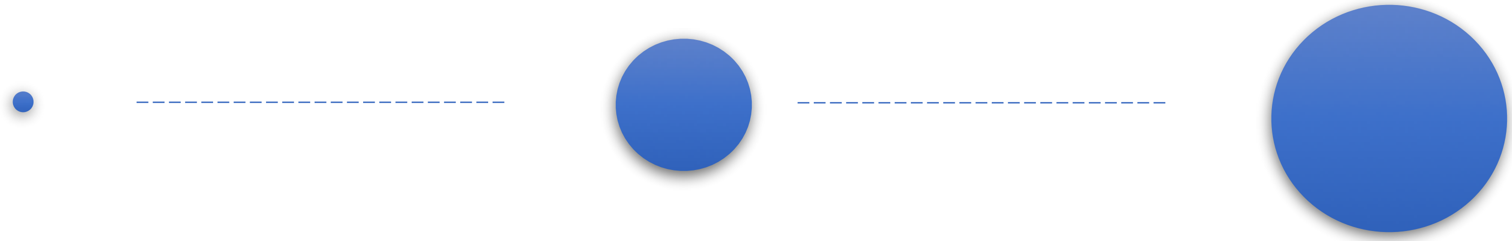
Strong decay widths

Why the decay **width** of is extremely **narrow ?**

χSM interpolates between the **naive non-relativistic quark model** and the **Skyrme model**.

M. Praszalowicz et al., Nucl.Phys A 647, 49 (1999)

naive non-relativistic quark model	χSM	**Skyrme model**



soliton size → :
valence level joins continuum,
sea contribution vanishes

soliton size → **large**:
valence level sinks into the sea,
valence contribution vanishes

The axial-vector operator for describing the strong decay widths of baryons

$$\hat{g}_1^{(0)} = a_1 D^{(8)}_{\varphi 3} + a_2 d_{3bc} D^{(8)}_{\varphi b} \hat{J}_c + \frac{a_3}{\sqrt{3}} D^{(8)}_{\varphi 8} \hat{J}_3,$$

In the limit of small soliton size (→),

GS Yang, HCh Kim, M Praszalowicz, M Polyakov., Phys. Rev. D **96** 094021 (2017)

Why the decay **width** of is extremely **narrow ?**

In the limit of small soliton size (→),

$$\Gamma_{10\to 8+\varphi} \sim \left(a_1 - \frac{1}{2}a_2\right)^2$$

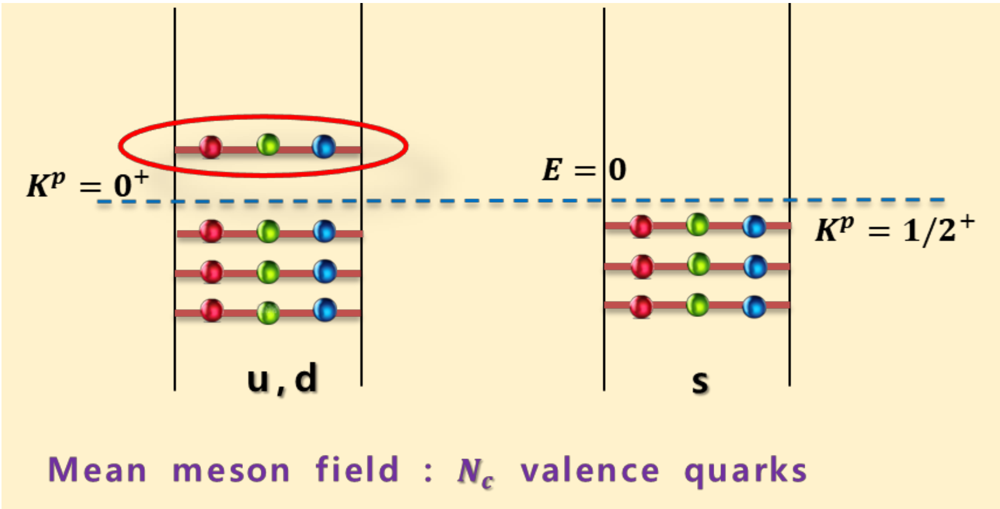
where

$$\Gamma_{\Theta NK} = \frac{\left|\vec{p}\right|^3}{2\,\pi\, f_K^2}\frac{M_N}{M_\Theta}\frac{1}{60}\left(a_1 + a_2 + \frac{1}{2}a_3\right)^2$$

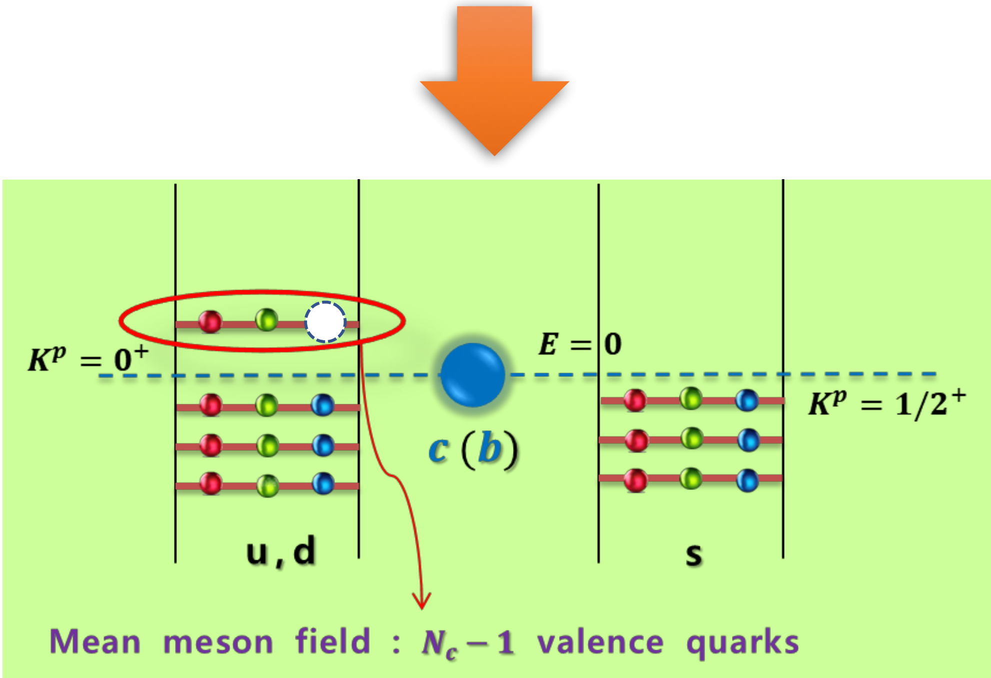
where !

Strong decay widths of antidecuplet baryons should be very small !

Taking into account **the large limit** and model structure in the **small soliton limit,** strong decay widths of **Heavy baryons** can be estimated !

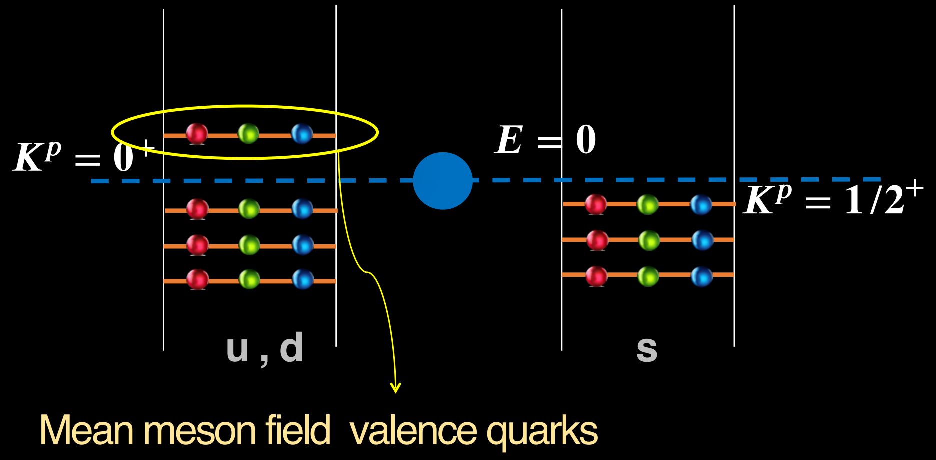


light baryons ()



Singly heavy baryons ()

Theoretical Framework Hamiltonian for Heavy baryons



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

where

Masses of Heavy baryons

$\mathcal{R}_J^Q$	B_c	Mass	Experiment [17]	Deviation ξ_c
$\bar{\mathbf{3}}_{1/2}^c$	Λ_c	2272.5 ± 2.3	2286.5 ± 0.1	-0.006
	Ξ_c	2476.3 ± 1.2	2469.4 ± 0.3	0.003
	Σ_c	2445.3 ± 2.5	2453.5 ± 0.1	-0.003
$\mathbf{6}_{1/2}^c$	Ξ_c'	2580.5 ± 1.6	2576.8 ± 2.1	0.001
	Ω_c	2715.7 ± 4.5	2695.2 ± 1.7	0.008
	Σ_c^*	2513.4 ± 2.3	2518.1 ± 0.8	-0.002
$\mathbf{6}_{3/2}^c$	Ξ_c^*	2648.6 ± 1.3	2645.9 ± 0.4	0.001
	Ω_c^*	2783.8 ± 4.5	2765.9 ± 2.0	0.006

$\mathcal{R}_J^Q$	B_b	Mass	Experiment [17]	Deviation ξ_b
$\bar{\mathbf{3}}_{1/2}^b$	Λ_b	5599.3 ± 2.4	5619.5 ± 0.2	-0.004
	Ξ_b	5803.1 ± 1.2	5793.1 ± 0.7	0.002
	Σ_b	5804.3 ± 2.4	5813.4 ± 1.3	-0.002
$\mathbf{6}_{1/2}^b$	Ξ_b'	5939.5 ± 1.5	5935.0 ± 0.05	0.001
	Ω_b	6074.7 ± 4.5	6048.0 ± 1.9	0.004
	Σ_b^*	5824.6 ± 2.3	5833.6 ± 1.3	-0.002
$\mathbf{6}_{3/2}^b$	Ξ_b^*	5959.8 ± 1.2	5955.3 ± 0.1	0.001
	Ω_b^*	6095.0 ± 4.4	–	–

Yang et al., Phys. Rev. D 94 (2016) 071502 (RAPID COMM.)

$$\hat{g}_1^{(0)} = a_1 D^{(8)}_{\varphi 3} + a_2 d_{3bc} D^{(8)}_{\varphi b} \hat{J}_c + \frac{a_3}{\sqrt{3}} D^{(8)}_{\varphi 8} \hat{J}_3,$$

$$= \left[M_3 - \frac{2iQ_{12}}{I_1} \right] D^{(8)}_{X3} + \left[-\frac{4M_{44}}{I_2} \right] d_{pq3} D^{(8)}_{Xp} \hat{J}_q + \left[-\frac{2M_{83}}{I_1} \right] \frac{1}{\sqrt{3}} D^{(8)}_{X8} \hat{J}_3 + \cdots$$

where

$$M_{3,\,\mathrm{val}} = N_c \langle v | \gamma_0 \gamma_3 \gamma_5 \lambda_3 | v \rangle ,$$

$$Q_{bc,\,\mathrm{val}} = \frac{N_c}{2} \sum_n \frac{\langle n | \sigma_3 \lambda_b | v \rangle \langle v | \lambda_c | n \rangle}{E_n - E_v} \mathrm{sign} E_n ,$$

$$M_{bc} = \frac{N_c}{4} \sum_{n,m} \langle n | \sigma_3 \lambda_b | m \rangle \langle m | \lambda_c | n \rangle \frac{1}{2} \frac{\mathrm{sign}(E_n - \mu) - \mathrm{sign}(E_m - \mu)}{E_n - E_m}$$

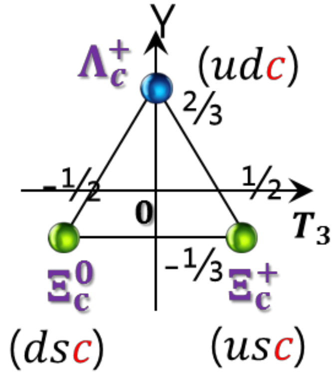
$N_c \rightarrow N_c - 1$

For heavy baryons

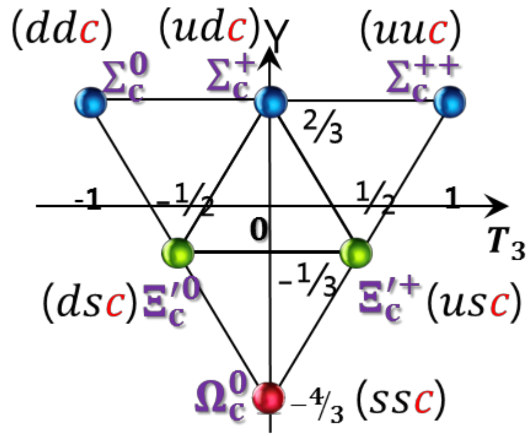
$$M_{3,\ \mathrm{val}} = \frac{N_c - 1}{N_c} N_c \langle v | \gamma_0 \gamma_3 \gamma_5 \lambda_3 | v \rangle$$

from octet baryons

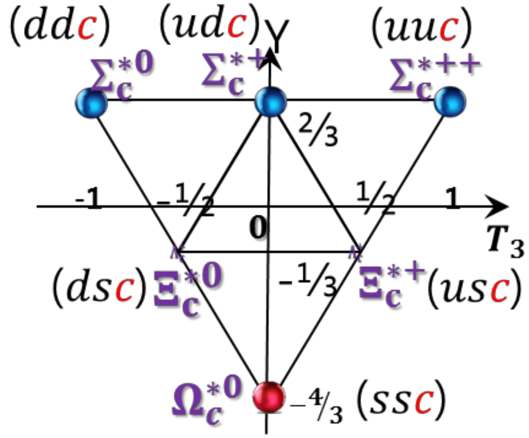
Strong decay widths



$[\bar{3}]=D(0,1)$,
$J = 1/2$

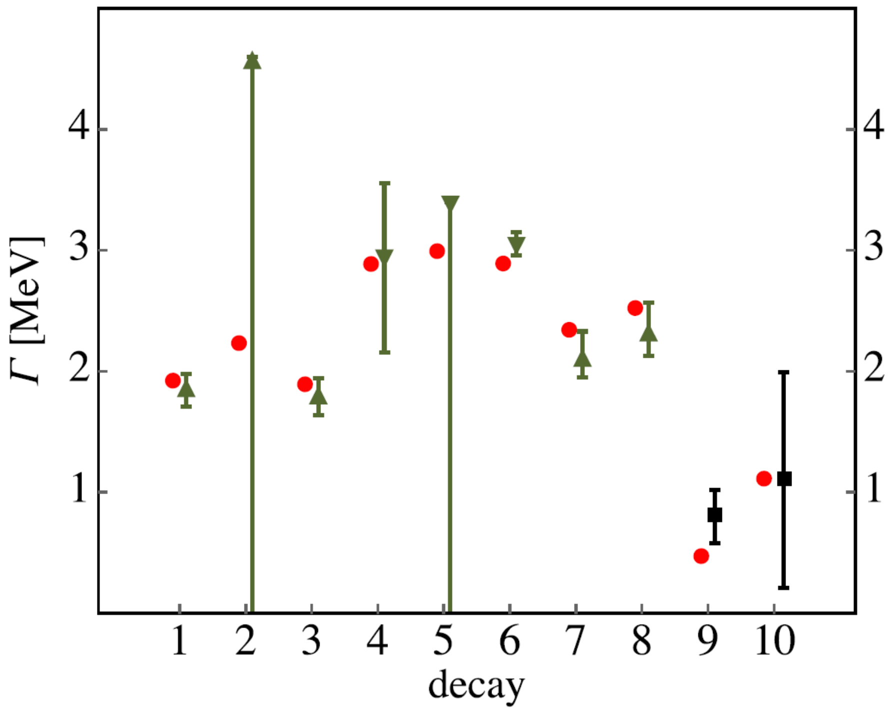


$[6]=D(2,0)$,
$J = 1/2$



$[6]=D(2,0)$,
$J = 3/2$

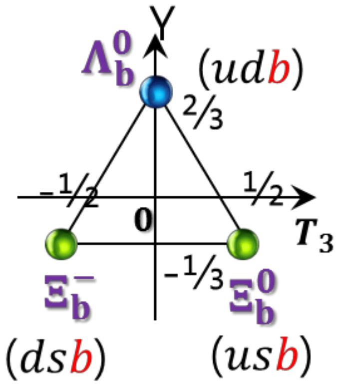
#	Decay	This work	Exp.
1	$\Sigma_c^{++}(\mathbf{6}_1, 1/2) \to \Lambda_c^+(\bar{\mathbf{3}}_0, 1/2) + \pi^+$	1.93	$1.89^{+0.09}_{-0.18}$
2	$\Sigma_c^{+}(\mathbf{6}_1, 1/2) \to \Lambda_c^+(\bar{\mathbf{3}}_0, 1/2) + \pi^0$	2.24	<4.6
3	$\Sigma_c^{0}(\mathbf{6}_1, 1/2) \to \Lambda_c^+(\bar{\mathbf{3}}_0, 1/2) + \pi^-$	1.90	$1.83^{+0.11}_{-0.19}$
4	$\Sigma_c^{++}(\mathbf{6}_1, 3/2) \to \Lambda_c^+(\bar{\mathbf{3}}_0, 1/2) + \pi^+$	14.47	$14.78^{+0.30}_{-0.19}$
5	$\Sigma_c^{+}(\mathbf{6}_1, 3/2) \to \Lambda_c^+(\bar{\mathbf{3}}_0, 1/2) + \pi^0$	15.02	<17
6	$\Sigma_c^{0}(\mathbf{6}_1, 3/2) \to \Lambda_c^+(\bar{\mathbf{3}}_0, 1/2) + \pi^-$	14.49	$15.3^{+0.4}_{-0.5}$
7	$\Xi_c^{+}(\mathbf{6}_1, 3/2) \to \Xi_c(\bar{\mathbf{3}}_0, 1/2) + \pi$	2.35	2.14 ± 0.19
8	$\Xi_c^{0}(\mathbf{6}_1, 3/2) \to \Xi_c(\bar{\mathbf{3}}_0, 1/2) + \pi$	2.53	2.35 ± 0.22



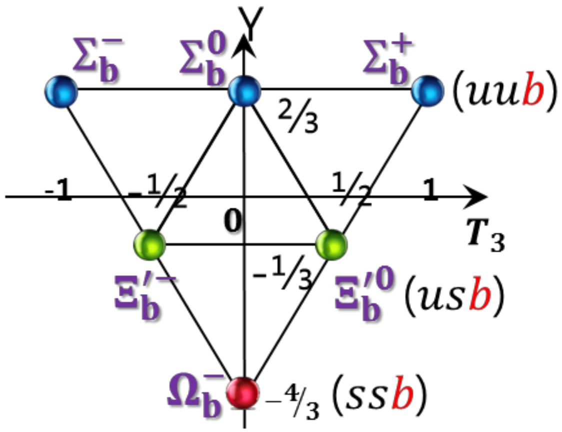
GS Yang, HCh Kim, M Praszalowicz, M Polyakov., Phys. Rev. D **96** 094021 (2017)

Strong decay widths

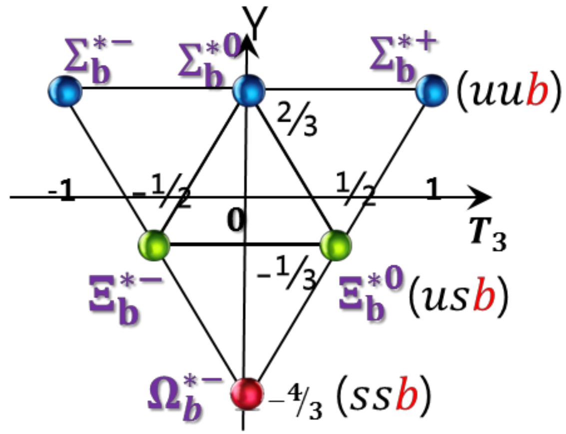
Decay widths of Bottom baryons



$[\bar{3}]=D(0,1)$,
$J = 1/2$

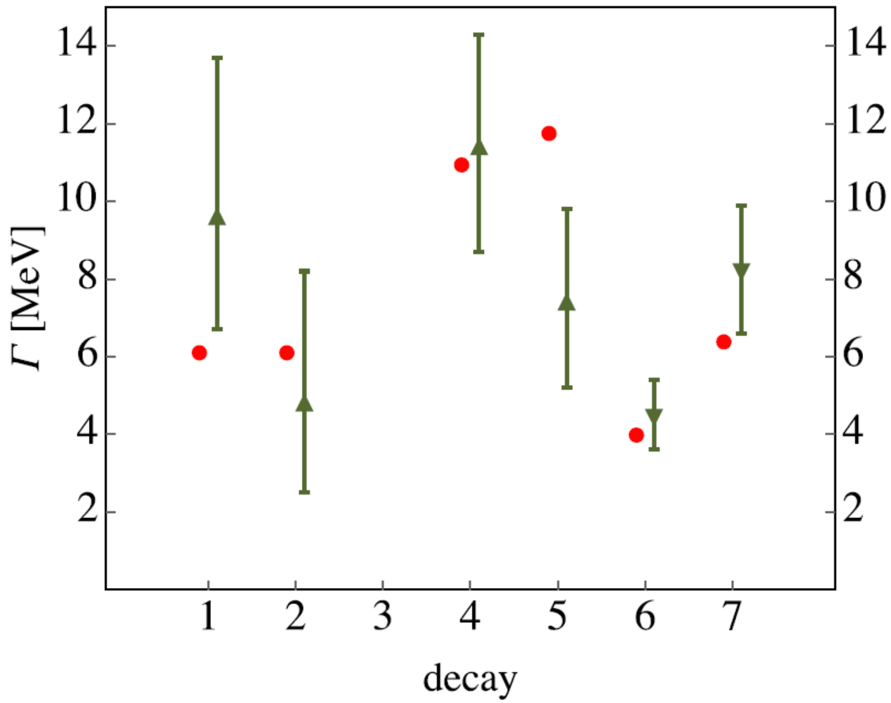


$[6]=D(2,0)$,
$J = 1/2$



$[6]=D(2,0)$,
$J = 3/2$

#	Decay	This work	Exp.
1	$\Sigma_b^+(\mathbf{6}_1, 1/2) \to \Lambda_b^0(\bar{\mathbf{3}}_0, 1/2) + \pi^+$	6.12	$9.7^{+4.0}_{-3.0}$
2	$\Sigma_b^-(\mathbf{6}_1, 1/2) \to \Lambda_b^0(\bar{\mathbf{3}}_0, 1/2) + \pi^-$	6.12	$4.9^{+3.3}_{-2.4}$
3	$\Xi_b'(\mathbf{6}_1, 1/2) \to \Xi_c(\bar{\mathbf{3}}_0, 1/2) + \pi$	0.07	<0.08
4	$\Sigma_b^+(\mathbf{6}_1, 3/2) \to \Lambda_b^0(\bar{\mathbf{3}}_0, 1/2) + \pi^+$	10.96	11.5 ± 2.8
5	$\Sigma_b^-(\mathbf{6}_1, 3/2) \to \Lambda_c^0(\bar{\mathbf{3}}_0, 1/2) + \pi^-$	11.77	7.5 ± 2.3
6	$\Xi_b^0(\mathbf{6}_1, 3/2) \to \Xi_b(\bar{\mathbf{3}}_0, 1/2) + \pi$	0.80	0.90 ± 0.18
7	$\Xi_b^-(\mathbf{6}_1, 3/2) \to \Xi_b(\bar{\mathbf{3}}_0, 1/2) + \pi$	1.28	1.65 ± 0.33



GS Yang, HCh Kim, M Praszalowicz, M Polyakov., Phys. Rev. D **96** 094021 (2017)

Decay widths of Heavy baryons

TABLE III. $\Omega_c(\overline{\mathbf{15}}_1, 1/2)$ partial and total decay widths in MeV. Experimental value is from the LHCb measurement [2].

# 3050 *MeV*	Decay	This work	Exp.
	$\Omega_c(\overline{\mathbf{15}}_1, 1/2) \to \Xi_c(\bar{\mathbf{3}}_0, 1/2) + K$	0.339	...
	$\Omega_c(\overline{\mathbf{15}}_1, 1/2) \to \Omega_c(\mathbf{6}_1, 1/2) + \pi$	0.097	...
	$\Omega_c(\overline{\mathbf{15}}_1, 1/2) \to \Omega_c(\mathbf{6}_1, 3/2) + \pi$	0.045	...
9	Total	0.48	$0.8 \pm 0.2 \pm 0.1$

TABLE IV. $\Omega_c(\overline{\mathbf{15}}_1, 3/2)$ partial and total decay widths in MeV. Experimental value is from the LHCb measurement [2].

# 3119 *MeV*	Decay	This work	Exp.
	$\Omega_c(\overline{\mathbf{15}}_1, 3/2) \to \Xi_c(\bar{\mathbf{3}}_0, 1/2) + K$	0.848	...
	$\Omega_c(\overline{\mathbf{15}}_1, 3/2) \to \Xi_c(\mathbf{6}_1, 1/2) + K$	0.009	...
	$\Omega_c(\overline{\mathbf{15}}_1, 3/2) \to \Omega_c(\mathbf{6}_1, 1/2) + \pi$	0.169	...
	$\Omega_c(\overline{\mathbf{15}}_1, 3/2) \to \Omega_c(\mathbf{6}_1, 3/2) + \pi$	0.096	...
10	Total	1.12	$1.1 \pm 0.8 \pm 0.4$

TABLE V. Predictions in MeV for the partial and total decay widths of explicitly exotic $\Xi_c^{3/2}(\overline{\mathbf{15}}_1, J)$.

Decay	$J = 1/2$	$J = 3/2$
$\Xi_c^{3/2}(\overline{\mathbf{15}}_1, J) \to \Xi_c(\bar{\mathbf{3}}_0, 1/2) + \pi$	1.67	2.49
$\Xi_c^{3/2}(\overline{\mathbf{15}}_1, J) \to \Xi_c(\mathbf{6}_1, 1/2) + \pi$	0.045	0.079
$\Xi_c^{3/2}(\overline{\mathbf{15}}_1, J) \to \Xi_c(\mathbf{6}_1, 3/2) + \pi$	0.022	0.046
$\Xi_c^{3/2}(\overline{\mathbf{15}}_1, J) \to \Sigma_c(\mathbf{6}_1, 1/2) + K$	...	0.019
Total	1.74	2.64
	2931 *MeV*	3000 *MeV*

GS Yang, HCh Kim, M Praszalowicz, M Polyakov., Phys. Rev. D **96** 094021 (2017)

SUMMARY

- Assuming that the valence quarks are bound by the pion mean fields, we can regard the nucleon as a chiral soliton.

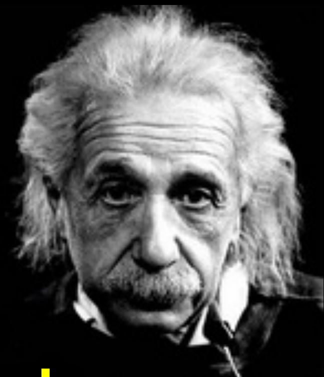
- The framework of this study are very successful for describing static properties of decuplet baryons, such as mass, magnetic moment, transition magnetic moments, widths of radiative and strong decays.

- Due to the SU(3) structure,
  we show that strong decay widths of antidecuplet baryons should be small.
  Nucleon-like states of antidecuplet and eikosiheptaplet can be strong candidates of new narrow nucleon states and , respectively.

- Dynamical parameters and flavor quantum numbers of the collective operators and wave functions are modified for **mean field**.

- We have obtained excellent description of physical observables of heavy baryons (Masses, Widths of strong and radiative decays)

- It is shown that **light quarks** govern their structure of singly heavy baryons.



"Why 100? If I were wrong, one would have been enough.

[In response to the book "*Hundred Authors Against Einstein*"]"

from Stephen Hawking, "A Brief History of Time"