19 Jan., 2016

Static Properties of SU(3) baryons in a Chiral Soliton Model

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Outline

- Motivation
- Chiral Soliton Model

  [Mass splittings for SU(3) baryons]

  [Axial-Vector Transitions]

  - HSD and Yukawa coupling constants of $m_8 B_8 B_{10}$
  - Decay Widths and Branching Ratios of $B_{10} \rightarrow B_8 m_8$
- Summary

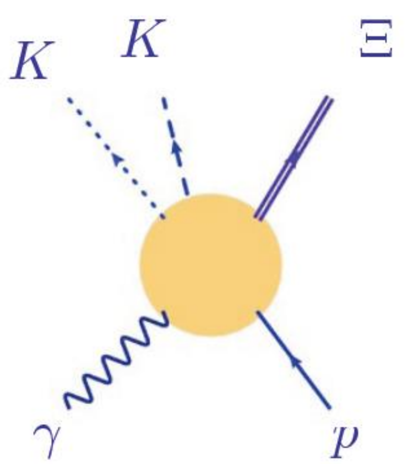
Motivation I

"**Yukawa coupling constants** for the vertices
of baryon decuplet-octet and pesudoscalar mesons" can be obtained
from **semileptonic decay constants** via (Generalized) Goldberger-Treiman
relation $n^0 \rightarrow p^+ + e^- + \bar{\nu}_e$ $g_{\pi NN} f_\pi = g_A M_N$

→ Decay widths and Branching Ratios

- Structure of SU(3) baryons and their production mechanism
(meson-baryon scattering, baryon-baryon scattering,
photoproductions and electroproductions of hadrons, nuclear physics)

- Productions of strangeness particles in experiments



Oh et al., Phys.Rev. C83 (2011) 055201

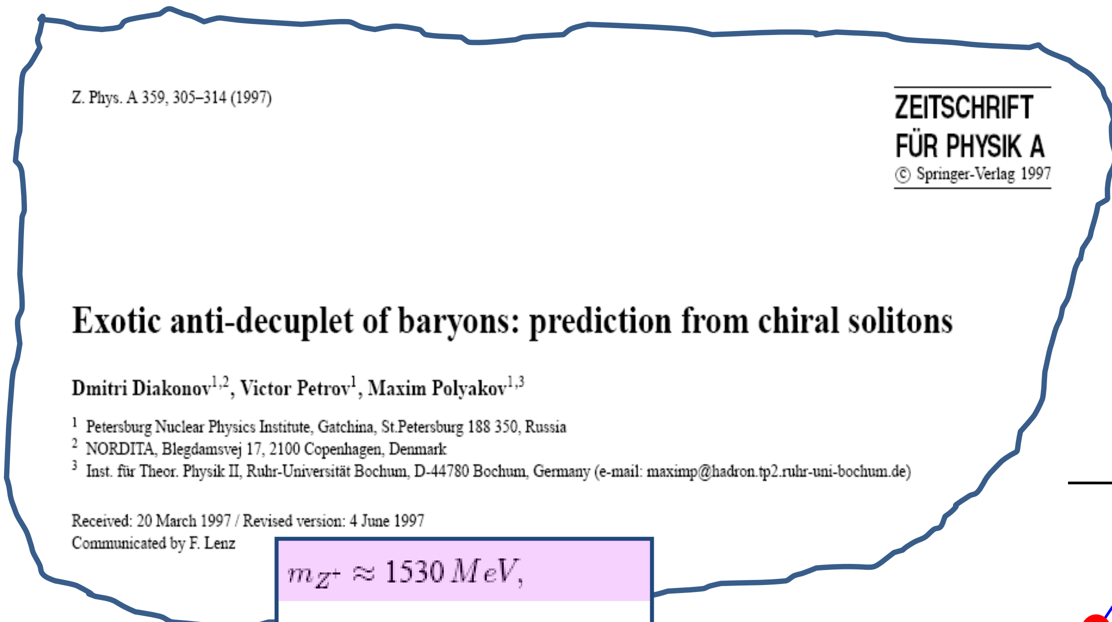
SU(3) symmetry + Quark model

$$g_{\Xi\Lambda K} = 3.27$$
$$g_{\Xi\Sigma K} = -13.26$$
$$g_{\Xi^*\Sigma K} = 3.22$$
$$f_{\Xi^*\Sigma K} = -2.83$$

$$g_{\Omega\Xi K} = ???$$
$$g_{\Omega\Xi^* K} = ???$$

Motivation II

1997, **Diakonov**, **Petrov**, and **Polyakov** : **Narrow 5-quark resonance** ($q^4\bar{q}$: Θ^+)
(**M = 1530**, **Γ~ 15** MeV from **Chiral Soliton Model**)



Z. Phys. A 359, 305–314 (1997)

ZEITSCHRIFT FÜR PHYSIK A
© Springer-Verlag 1997

Exotic anti-decuplet of baryons: prediction from chiral solitons

Dmitri Diakonov[1,2], Victor Petrov[1], Maxim Polyakov[1,3]

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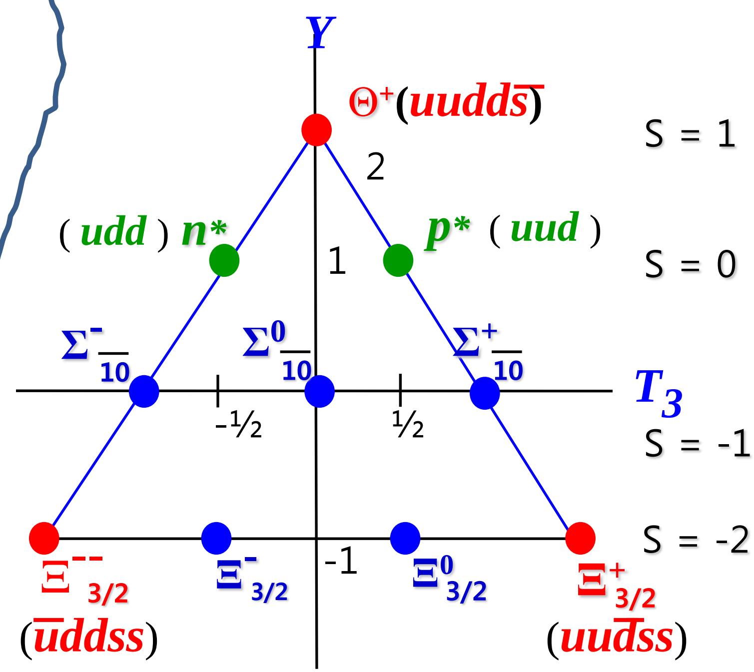
Communicated by F. Lenz

$$m_{Z^+} \approx 1530\,MeV,$$

$$m_{N_{\overline{10}}} \approx 1710\,MeV\,\text{(input)},$$

$$m_{\Sigma_{\overline{10}}} \approx 1890\,MeV,$$

$$m_{\Xi_{3/2}} \approx 2070\,MeV.$$



Anti-decuplet ($\overline{10}$)

Experimental Status

New positive experiments (2005 - 2010)

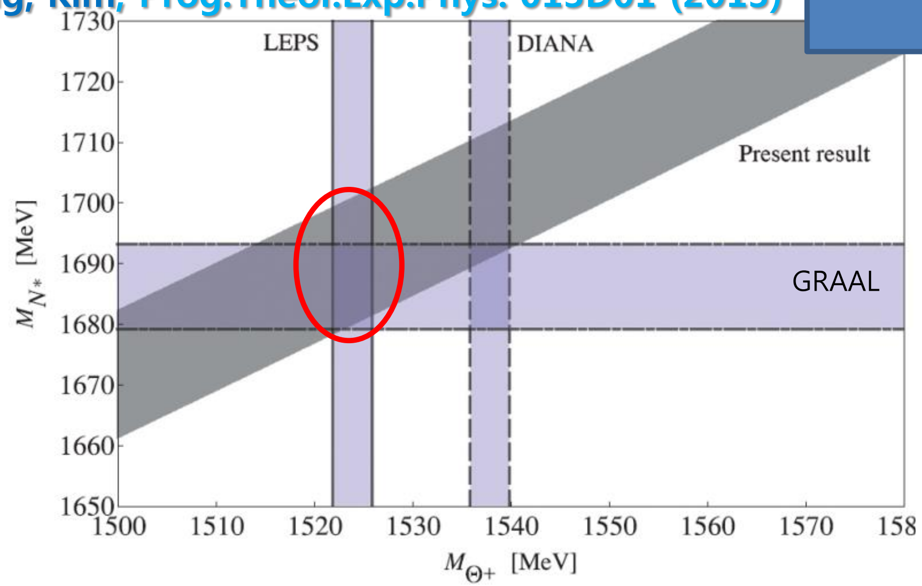
- *DIANA* 2010 (Θ^+) : M = 1538±2, Γ= 0.39±0.10 MeV
  ($K^+n \rightarrow K^0p$, higher statistical significance : 6σ - 8σ)
  [Signals are confirmed by *LEPS, SVD, KEK, …*]

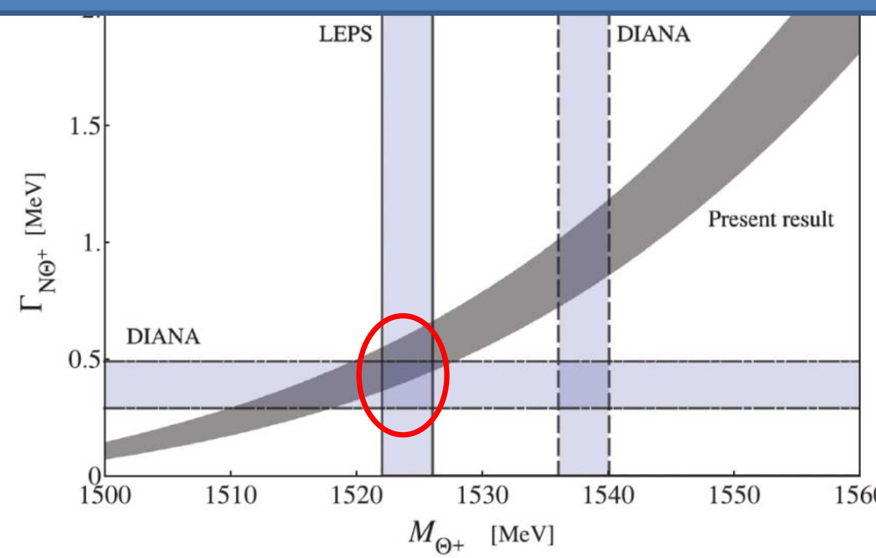
- *GRAAL* (*N**) : M = 1685±0.012
  (*CBELSA/TAPS…*)

Various experimental data for Θ^+ and *N**

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

Yang, Kim, Goeke, Phys.Rev.D 75,094004(2007)
Yang, Kim, Prog.Theor.Exp.Phys. 013D01 (2013)





Our study prefers to the result from LEPS for Θ^+ mass and that from DIANA for *N mass**

Different values in the previous solitonic approaches

		D.P.P	E.K.P	χQSM
Considered Effects		SU(3) *H.*	SU(3) *H.*	**SU(3)** *H.*
Input	**Masses [MeV]**	N^{*}(1710)	Θ^{+}(1539±2) Ξ^{--}(1862±2)	
	$\Sigma_{\pi N}$ [MeV]	**45**	**73**	**Predicted → 41**
Results $\mathcal{O}(m_s)$	I_2 [*fm*]	**0.4**	**0.49**	**0.48**
	$m_s\alpha$ [MeV] $m_s\beta$ [MeV] $m_s\gamma$ [MeV]	**-218** **-156** **-107**	**-605** **-23** **152**	**-197** **-94** **-53**
	$c_{\overline{10}}(I_2, \alpha, \gamma)$	**0.084**	**0.088**	**0.037**
	Γ_{Θ^+} [MeV]	**15 for sym**	**11.1 for sym**	**0.71 for sym**

D.P.P : *Diakonov, Petrov, Polyakov,* Z. Physics. A. 359, 305-314 (1997)
E.K.P : *Ellis, Karliner, Praszalowicz,* JHEP. 0405, 002 (2004)
χQSM : *Tim Ledwig, H.-Ch. Kim, K. Goeke*, Phys. Rev. D. 78, 054005 & Nucl. Phys. A 811 353 2008

Mass splittings of baryons : crucial !

→ model parameters : **vector** and **axial-vector** properties
in particular, the effect of SU(3) symmetry breaking

The full expression of the transition coupling constants for $B_{10} \rightarrow B_8$:

$$g_{BB'} = g_{BB'}^{(0)} + \underbrace{g_{BB'}^{(op)} + g_{BB'}^{(wf)}}_{\mathcal{O}(m_s)}$$

α, β, γ by mass splittings (octet)

Yang, Kim, Polyakov: Phys.Lett.B 695, 214 (2011)
Yang, Kim: Prog. Theor. Phys. 128, 397 (2012)
Yang, Kim: JKPS 61, 1956 (2012)

↓

$SU(3)_f$ symmetry breaking effect for wave functions

$\mathcal{O}(m_s)$

↓

Axial-vector coupling constants by HSDs (octet) with $SU(3)_f$ br effect

Yang, Kim, Goeke, Phys.Rev.D 75,094004(2007)
Yang, Kim, Phys.Rev.C.92.035206 (2015)

↓

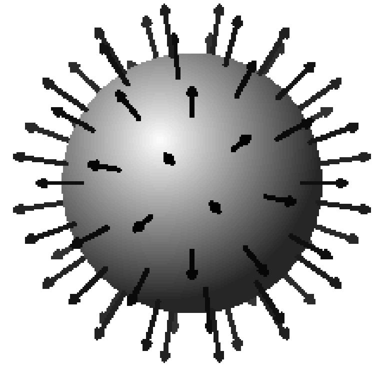
Yukawa coupling constants by G-T relation and Decay Widths with $SU(3)_f$ br effect

Chiral Soliton Model

Chiral Soliton Model

: Effective and relativistic low energy theory

: Large N_c limit : meson field
→ soliton



: Quantizing SU(3) rotated-meson fields
→ Collective Hamiltonian, model baryon states

Hedgehog Ansatz: $U_{\mathrm{SU(2)}} = \exp\left[i\gamma_5 \mathbf{n}\cdot\boldsymbol{\tau} P(r)\right]$

Collective quantization

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

SU(2) E. Witten's imbedding into **SU(3)**: SU(2) X U(1)

Talk given by **H.-Ch. Kim** on **Monday**

Chiral Soliton Model

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

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

$$|B, S\rangle = |R, B, S\rangle - \sum_{R' \neq R} |R', B, S\rangle \frac{\langle R', B, S|\, H'\, |R, B, S\rangle}{M^{(0)}(R') - M^{(0)}(R)}.$$

$$8 \otimes 8 = 1 \oplus 8 \oplus 8 \oplus 10 \oplus \overline{10} \oplus 27$$

Chiral Soliton Model

Mixing coefficients

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

$$d^B_8 = d_8 \begin{bmatrix} 0 \\ \sqrt{5} \\ \sqrt{5} \\ 0 \end{bmatrix}, \quad d^B_{27} = d_{27} \begin{bmatrix} 0 \\ \sqrt{3/10} \\ 2/\sqrt{5} \\ \sqrt{3/2} \end{bmatrix}, \quad d^B_{\overline{35}} = d_{\overline{35}} \begin{bmatrix} 1/\sqrt{7} \\ 3/(2\sqrt{14}) \\ 1/\sqrt{7} \\ \sqrt{5/56} \end{bmatrix}$$

respectively in the basis $[N, \Lambda, \Sigma, \Xi]$, $[\Delta, \Sigma^*, \Xi^*, \Omega]$, $[\Theta^+, N_{\overline{10}}, \Sigma_{\overline{10}}, \Xi_{\overline{10}}]$

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

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

$$d_8 = \frac{I_2}{15}(m_s - \hat{m})\left(\alpha + \frac{1}{2}\gamma\right), \qquad d_{27} = -\frac{I_2}{8}(m_s - \hat{m})\left(\alpha - \frac{7}{6}\gamma\right),$$

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

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

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

Chiral Soliton Model

Collective Hamiltonian for flavor symmetry breakings

$$H_{\text{Hadronic}} = H_{\text{cl}} + H_{\text{rot}} + H_{\text{sb}}$$

$$H_{\rm rot} = \frac{1}{2I_1}\sum_{i=1}^{3}\hat{J}_i^2 + \frac{1}{2I_2}\sum_{p=4}^{7}\hat{J}_p^2, \quad \Rightarrow \quad \overline{M}_{\mathbf{10}} - \overline{M}_{\mathbf{8}} = \frac{3}{2\,I_1}$$

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

$$\alpha = -\left(\frac{2}{3}\frac{\Sigma_{\pi N}}{m_{\rm u}+m_{\rm d}} - \frac{K_2}{I_2}\right), \quad \beta = -\frac{K_2}{I_2}, \quad \gamma = 2\left(\frac{K_1}{I_1} - \frac{K_2}{I_2}\right)$$

$$\sigma = -(\alpha+\beta) = \frac{2}{3}\frac{\Sigma_{\pi N}}{m_{\rm u}+m_{\rm d}}$$

Collective Hamiltonian for SU(3)$_f$ sym. br.

$$H_{\text{Hadronic}} = H_{\text{cl}} + H_{\text{rot}} + H_{\text{sb}}$$

$$\begin{aligned} H_{\rm sb} \;=\; & (m_{\rm s} - \hat{m}) \left(\alpha D^{(8)}_{88}(\mathcal{R}) + \beta \hat{Y} + \frac{1}{\sqrt{3}} \gamma \sum_{i=1}^{3} D^{(8)}_{8i}(\mathcal{R}) \hat{J}_i \right) \\ & + (m_{\rm d} - m_{\rm u}) \left(\frac{\sqrt{3}}{2} \alpha D^{(8)}_{38}(\mathcal{R}) + \beta \hat{T}_3 + \frac{1}{2} \gamma \sum_{i=1}^{3} D^{(8)}_{3i}(\mathcal{R}) \hat{J}_i \right) \end{aligned}$$

SU(3) flavor symmetry breaking + Isospin symmetry breaking

Chiral Soliton Model (mass)

★ In order to take fully into account the masses of the baryon octet as input, it is inevitable to consider the breakdown of isospin symmetry.

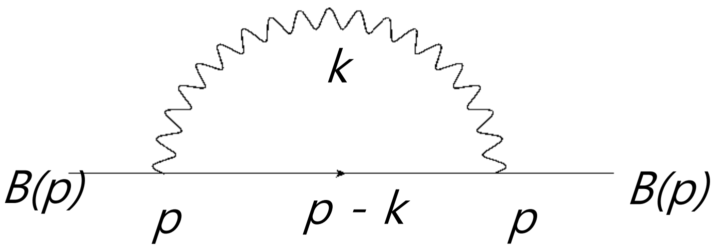
★Two sources for the isospin symmetry breaking

1. mass differences of up and down quarks (hadronic part)
2.Electromagnetic interactions (EM part)

$$\Delta M_B = M_{B_1} - M_{B_2} = (\Delta M_B)_{\mathrm{H}} + (\Delta M_B)_{\mathrm{EM}}$$

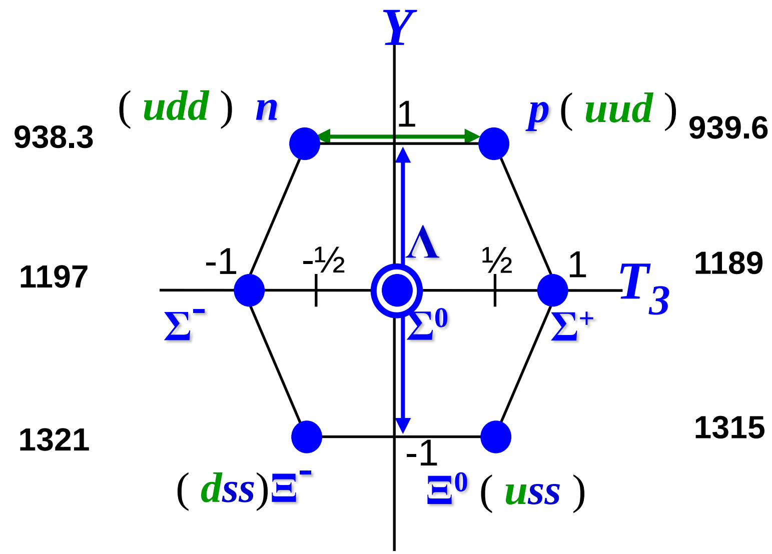
Chiral Soliton Model (mass)

- **EM mass corrections**



Electromagnetic (*EM*) self-energy

EM [MeV]	Exp.
$(p-n)_{EM}$	**0.76**±0.30
$(\Sigma^+ - \Sigma^-)_{EM}$	-0.17±0.30
$(\Xi^0 - \Xi^-)_{EM}$	-0.86±0.30



Gasser, Leutwyler, **Phys.Rep 87, 77** *"Quark Masses"*

$$\boxed{\Delta M_B = M_{B_1} - M_{B_2} = (\Delta M_B)_H + (\Delta M_B)_{EM}}$$

$(p-n)_{\mathrm{exp}} \sim$ **– 1.293** MeV

$(p-n)_{EM} \sim$ **0.76** MeV

Chiral Soliton Model (mass)

In the ChSM, $(\Delta M_B)_{\rm EM} = \langle B|J_\mu(x)J^\mu(0)|B\rangle = \langle B|\mathcal{O}_{\rm EM}|B\rangle$

$$\begin{aligned}\mathcal{O}_{\rm EM} &= -\frac{e^2}{2}\int d^3x\, d^3y D_\gamma(\boldsymbol{x},\boldsymbol{y})\int\frac{d\omega}{2\pi}{\rm tr}\left\langle \boldsymbol{x}\left|\frac{1}{\omega+iH}\gamma_\mu\lambda^a\right|\boldsymbol{y}\right\rangle\left\langle \boldsymbol{y}\left|\frac{1}{\omega+iH}\gamma_\mu\lambda^b\right|\boldsymbol{x}\right\rangle D^{(8)}_{Qa}D^{(8)}_{Qb}\\ &= \alpha_1\sum_{i=1}^{3}D^{(8)}_{Qi}D^{(8)}_{Qi}+\alpha_2\sum_{p=4}^{7}D^{(8)}_{Qp}D^{(8)}_{Qp}+\alpha_3 D^{(8)}_{Q8}D^{(8)}_{Q8}\end{aligned}$$

It can be further reduced to

$$\begin{aligned}\mathcal{O}^{\rm EM} &= c^{(27)}\left(\sqrt{5}D^{(27)}_{\Sigma_2^0\Lambda_{27}}+\sqrt{3}D^{(27)}_{\Sigma_1^0\Lambda_{27}}+D^{(27)}_{\Lambda_{27}\Lambda_{27}}\right)\\ &+ c^{(8)}\left(\sqrt{3}D^{(8)}_{\Sigma^0\Lambda}+D^{(8)}_{\Lambda\Lambda}\right)+c^{(1)}D^{(1)}_{\Lambda\Lambda}\end{aligned}$$

$$\begin{aligned}c^{(27)} &= \frac{1}{40}(\alpha_1-4\alpha_2+3\alpha_3)\,,\\ c^{(8)} &= \frac{1}{10}\left(\alpha_1-\frac{2}{3}\alpha_2-\frac{1}{3}\alpha_3\right),\\ c^{(1)} &= \frac{1}{8}(\alpha_1+\frac{4}{3}\alpha_2+\frac{1}{3}\alpha_3)\end{aligned}$$

$$\mathbf{8}\otimes\mathbf{8}=\mathbf{1}\oplus\mathbf{8}_s\oplus\cancel{\mathbf{8}_a}\oplus\cancel{\mathbf{10}}\oplus\cancel{\overline{\mathbf{10}}}\oplus\mathbf{27}$$

Because of Bose symmetry

Yang, Kim, Polyakov: Phys.Lett.B 695, 214 (2011)

Chiral Soliton Model (mass)

- **Physical mass differences of baryon decuplet**

$(\Delta M_{B_{10}})$	This work	Experimental data	
$(M_{\Delta^{++}} - M_{\Delta^{+}})$	-0.59 ± 0.47		
$(M_{\Delta^{+}} - M_{\Delta^{0}})$	-1.95 ± 0.13		
$(M_{\Delta^{0}} - M_{\Delta^{-}})$	-3.32 ± 0.32		
$(M_{\Sigma^{*+}} - M_{\Sigma^{*0}})$	-1.95 ± 0.13		
$(M_{\Sigma^{*0}} - M_{\Sigma^{*-}})$	-3.32 ± 0.32	-3.1 ± 0.6	[D.W.Thomas *et al.*]
$(M_{\Xi^{*0}} - M_{\Xi^{*-}})$	-3.32 ± 0.32	-2.9 ± 0.9	[PDG, 2010]
$(M_{\Delta^{++}} - M_{\Delta^{0}})$	-2.54 ± 0.57	-2.86 ± 0.30	[GW, 2006]
$(M_{\Delta^{+}} - M_{\Delta^{-}})$	-5.28 ± 0.30		
$(M_{\Delta^{++}} - M_{\Delta^{-}})$	-5.86 ± 0.38	-5.9 ± 3.1	[Gatchina, 1981]
$(M_{\Sigma^{*+}} - M_{\Sigma^{*-}})$	-5.28 ± 0.30		

$$\boxed{(M_{\Sigma^{*0}} - M_{\Sigma^{*-}}) = (M_{\Xi^{*0}} - M_{\Xi^{*-}})}$$

G. S. Yang, H.-Ch. Kim and M. V. Polyakov, Phys. Lett. B 695, 214 (2011)

Chiral Soliton Model (mass)

Mass splittings within a Chiral Soliton Model

Formulae for Baryon Octet Masses

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

$(\Delta M)_{EM}$

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

$(\Delta M)_H$

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

$$M_\Sigma = \overline{M}_{\mathbf{8}} + c^{(1)} + \frac{1}{2}c^{(8)}\,T_3 + \frac{2}{9}c^{(27)}\,T_3^2 - \frac{1}{10}\left(c^{(8)} + \frac{14}{9}c^{(27)}\right) - (m_d - m_u)\left(\delta_1 + \frac{1}{2}\delta_2\right)T_3 + (m_s - \hat{m})\,\delta_2,$$

$$M_\Xi = \overline{M}_{\mathbf{8}} + c^{(1)} + \frac{4}{5}\left(c^{(8)} - \frac{1}{9}c^{(27)}\right)T_3 - \frac{2}{5}\left(c^{(8)} - \frac{1}{9}c^{(27)}\right)\left(T_3^2 + \frac{1}{4}\right) - (m_d - m_u)(\delta_1 + 2\delta_2)T_3 + (m_s - \hat{m})\,\delta_1,$$

hadronic mass part in terms of δ_1 and δ_2

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

Chiral Soliton Model (mass)

Formulae for Baryon Decuplet Masses

$$M_{\Delta} = \overline{M}_{\mathbf{10}} + c^{(1)} + \frac{1}{4}\left(c^{(8)} + \frac{8}{63}c^{(27)}\right)T_3 + \frac{5}{63}c^{(27)}\,T_3^2 + \frac{1}{8}\left(c^{(8)} - \frac{2}{3}c^{(27)}\right)$$
$$- \left(\delta_1 - \frac{3}{4}\delta_2\right)(m_d - m_u)\,T_3 - \left(\delta_1 - \frac{3}{4}\delta_2\right)(m_s - \hat{m})\,,$$
$$M_{\Sigma^*} = \overline{M}_{\mathbf{10}} + c^{(1)} + \frac{1}{4}\left(c^{(8)} - \frac{4}{21}c^{(27)}\right)T_3 + \frac{5}{63}c^{(27)}\;(T_3^2 - 1)$$
$$- \left(\delta_1 - \frac{3}{4}\delta_2\right)(m_d - m_u)\,T_3,$$
$$M_{\Xi^*} = \overline{M}_{\mathbf{10}} + c^{(1)} + \frac{1}{4}\left(c^{(8)} - \frac{32}{63}c^{(27)}\right)T_3 - \frac{1}{4}\left(c^{(8)} + \frac{8}{63}c^{(27)}\right)\left(T_3^2 + \frac{1}{4}\right)$$
$$- \left(\delta_1 - \frac{3}{4}\delta_2\right)(m_d - m_u)\,T_3 + \left(\delta_1 - \frac{3}{4}\delta_2\right)(m_s - \hat{m})\,,$$
$$M_{\Omega^-} = \overline{M}_{\mathbf{10}} + c^{(1)} - \frac{1}{4}\left(c^{(8)} - \frac{4}{21}c^{(27)}\right) + 2\left(\delta_1 - \frac{3}{4}\delta_2\right)(m_s - \hat{m})\,.$$

hadronic mass part in terms of δ_1 and δ_2

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

Chiral Soliton Model (mass)

Present analysis reproduces all kind of well-known mass relations

- ***Coleman-Glashow*** relation is still satisfied

$$M_p - M_n = (M_{\Sigma^+} - M_{\Sigma^-}) - (M_{\Xi^0} - M_{\Xi^-})$$

- ***Generalized Gell-Mann-Okubo*** relation

$$2\,(M_p + M_{\Xi^0}) = 3M_\Lambda + \overline{M}_\Sigma + (M_{\Sigma^+} - M_{\Sigma^-}) + \frac{2}{3}\Delta M_\Sigma,$$

$$2\,(M_n + M_{\Xi^-}) = 3M_\Lambda + \overline{M}_\Sigma - (M_{\Sigma^+} - M_{\Sigma^-}) + \frac{2}{3}\Delta M_\Sigma,$$

$$\text{where } \Delta M_\Sigma = M_{\Sigma^+} + M_{\Sigma^-} - 2M_{\Sigma^0}.$$

When the effect of the ***isospin sym. br*** is turned off,

$$2\left(\overline{M}_N + \overline{M}_\Xi\right) = 3M_\Lambda + \overline{M}_\Sigma$$

★ **Generalized *Guadagnini* formulae**

$$8\left(\overline{M}_N + \overline{M}_{\Xi^*}\right) + 3\,\overline{M}_\Sigma = 11\,\overline{M}_\Lambda + 8\,\overline{M}_{\Sigma^*}$$

Chiral Soliton Model (mass)

Mass [MeV]		T_3	Y	Exp. [Inputs]	Numerical results
M_N	p	$1/2$	1	938.27203 ± 0.00008	938.76 ± 3.65
	n	$-1/2$		939.56536 ± 0.00008	940.27 ± 3.64
M_Λ	Λ	0	0	1115.683 ± 0.006	1109.61 ± 0.70
M_Σ	Σ^+	1		1189.37 ± 0.07	1188.75 ± 0.70
	Σ^0	0	0	1192.642 ± 0.024	1190.20 ± 0.77
	Σ^-	-1		1197.449 ± 0.030	1195.48 ± 0.71
M_Ξ	Ξ^0	$1/2$	-1	1314.83 ± 0.20	1319.30 ± 3.43
	Ξ^-	$-1/2$		1321.31 ± 0.13	1324.52 ± 3.44

$$\begin{aligned} R &= \frac{m_s - \hat{m}}{m_d - m_u} \\ &= \frac{M_p - M_{\Sigma^+} + M_{\Sigma^0} - M_{\Xi^-}}{2\,(M_{\Sigma^+} - M_{\Sigma^0})}, \end{aligned}$$

$$R = 58.1 \pm 1.3.$$

$$\boxed{\begin{aligned} (m_d - m_u)\,\alpha &= -4.390 \pm 0.004, & (m_s - \hat{m})\,\alpha &= -255.029 \pm 5.821, \\ (m_d - m_u)\,\beta &= -2.411 \pm 0.001, & (m_s - \hat{m})\,\beta &= -140.040 \pm 3.195, \\ (m_d - m_u)\,\gamma &= -1.740 \pm 0.006, & (m_s - \hat{m})\,\gamma &= -101.081 \pm 2.332, \end{aligned}}$$

Chiral Soliton Model (mass)

Numerical results of Decuplet mass

Mass [MeV]		T_3	Y	Experiment[41)]	Predictions
M_Δ	Δ^{++}	$3/2$	1	$1231 - 1233$	1248.54 ± 3.39
	Δ^{+}	$1/2$			1249.36 ± 3.37
	Δ^{0}	$-1/2$			1251.53 ± 3.38
	Δ^{-}	$-3/2$			1255.08 ± 3.37
M_{Σ^*}	Σ^{*+}	1	0	1382.8 ± 0.4	1388.48 ± 0.34
	Σ^{*0}	0		1383.7 ± 1.0	1390.66 ± 0.37
	Σ^{*-}	-1		1387.2 ± 0.5	1394.20 ± 0.34
$M_{\Xi^{*0}}$	Ξ^{*0}	$1/2$	-1	1531.80 ± 0.32	1529.78 ± 3.38
	Ξ^{*-}	$-1/2$		1535.0 ± 0.6	1533.33 ± 3.37
$M^\star_{\Omega^-}$	Ω^-	0	-2	1672.45 ± 0.29	Input

G. S. Yang, H.-Ch. Kim   Prog. Theor. Phys. (PTP) vol.128 p397 (2012)

The full expression of the transition coupling constants for $B_{10} \rightarrow B_8$:

$$g_{BB'} = g_{BB'}^{(0)} + g_{BB'}^{(op)} + g_{BB'}^{(wf)}$$

α, β, γ by mass splittings (octet)

Yang, Kim, Polyakov: Phys.Lett.B 695, 214 (2011)
Yang, Kim: Prog. Theor. Phys. 128, 397 (2012)
Yang, Kim: JKPS 61, 1956 (2012)

⇓

$SU(3)_f$ symmetry breaking effect for wave functions

⇓

Axial-vector coupling constants by HSDs (octet) with $SU(3)_f$ br effect

Yang, Kim, Phys.Rev.C.92.035206 (2015)

⇓

Yukawa coupling constants by G-T relation and Decay Widths with $SU(3)_f$ br effect

Chiral Soliton Model (Axial-Vector)

Axial-vector transitions

$$\langle B_2 | A_\mu^X | B_1 \rangle = \bar{u}_{B_2}(p_2, s_2) \left[g_1(q^2)\gamma_\mu - \frac{i g_2(q^2)}{M_1}\sigma_{\mu\nu} q^\nu + \frac{g_3(q^2)}{M_1} q_\mu \right] \gamma_5 u_{B_1}(p_1, s_1)$$

with $$A_\mu^X = \bar{\psi}(x)\gamma_\mu\gamma_5 \frac{1}{2}\lambda_X \psi(x)$$

The full expression for the axial-vector transitions

$g_{1BB'} = g_{1BB'}^{(0)} + g_{1BB'}^{(op)} + g_{1BB'}^{(wf)}$

$$\hat{g}_1^{(0)} = a_1 D_{X3}^{(8)} + a_2 d_{pq3} D_{Xp}^{(8)} \hat{J}_q + \frac{a_3}{\sqrt{3}} D_{X8}^{(8)} \hat{J}_3,$$

$$\hat{g}_1^{(1)} = \frac{a_4}{\sqrt{3}} d_{pq3} D_{Xp}^{(8)} D_{8q}^{(8)} + a_5 \left(D_{X3}^{(8)} D_{88}^{(8)} + D_{X8}^{(8)} D_{83}^{(8)} \right) + a_6 \left(D_{X3}^{(8)} D_{88}^{(8)} - D_{X8}^{(8)} D_{83}^{(8)} \right),$$

$\mathbf{a_i}$ will be adjusted by experimental data of hyperon semileptonic decays

Decay modes	$(g_1/f_1)^{\rm sym}$	$(g_1/f_1)^{\rm br}$	Exp. (Input)	Refs.
$n \to p$	1.230 ± 0.004	1.269 ± 0.006	1.2701 ± 0.0025	[11]
$\Sigma^- \to \Lambda$	0.769 ± 0.003	0.794 ± 0.004		
$\Sigma^- \to \Sigma^0$	0.461 ± 0.002	0.439 ± 0.003		
$\Xi^- \to \Xi^0$	-0.308 ± 0.002	-0.245 ± 0.004		
$\Lambda \to p$	0.717 ± 0.003	0.718 ± 0.003	0.718 ± 0.015	[11]
$\Sigma^- \to n$	-0.308 ± 0.002	-0.340 ± 0.003	-0.340 ± 0.017	[11]
$\Xi^0 \to \Sigma^+$	1.230 ± 0.004	1.210 ± 0.005	1.21 ± 0.05	[11]
$\Xi^- \to \Lambda$	0.204 ± 0.002	0.250 ± 0.002	0.25 ± 0.05	[11]
$\Xi^- \to \Sigma^0$	1.230 ± 0.004	1.210 ± 0.005		
$g_A^{(0)}$	0.604 ± 0.030	0.361 ± 0.031	0.36 ± 0.03	[43]
$g_A^{(8)}$	0.354 ± 0.003	0.325 ± 0.004		

$$g_A^{(8)} = 0.338 \pm 0.015$$

a_1	a_2	a_3	a_4	a_5	a_6
-3.51 ± 0.01	3.44 ± 0.03	0.60 ± 0.03	-1.21 ± 0.07	0.48 ± 0.02	-0.74 ± 0.04

Numerical results of vector HSD constants f_2/f_1

Numerical results for the ratios of the vector HSD constants f_2/f_1 of the baryon octet : SU(3) symmetry breaking effect is complicated

Decay mode	$(f_2/f_1)^{\mathrm{sym}}$	$(f_2/f_1)^{\mathrm{br}}$	Experimental data [PDG 2014]
$n \to p$	1.389 ± 0.042	1.883 ± 0.055	
$\Sigma^- \to \Lambda$	1.062 ± 0.037	1.268 ± 0.031	
$\Sigma^- \to \Sigma^0$	0.328 ± 0.037	0.448 ± 0.027	
$\Xi^- \to \Xi^0$	-0.734 ± 0.060	-0.786 ± 0.042	
$\Lambda \to p$	0.681 ± 0.035	0.637 ± 0.041	
$\Sigma^- \to n$	-0.734 ± 0.060	-0.709 ± 0.036	-0.97 ± 0.14
$\Xi^0 \to \Sigma^+$	1.389 ± 0.042	1.143 ± 0.061	2.0 ± 0.9
$\Xi^- \to \Lambda$	-0.026 ± 0.042	-0.069 ± 0.027	
$\Xi^- \to \Sigma^0$	1.389 ± 0.042	1.143 ± 0.061	

Yang, Kim, Phys.Rev.C 92, 035206 (2015)

Numerical results of axial-vector constants for 10 → 8

$B_{10} \overset{\chi=1+i2}{\longrightarrow} B_8$	$C_5^{A\,(\mathrm{sym})}$	$C_5^{A\,(\mathrm{br})}$
$\Delta^0 \to p$	-0.954 ± 0.003	-1.040 ± 0.005
$\Delta^- \to n$	-1.653 ± 0.006	-1.801 ± 0.008
$\Sigma^{*0} \to \Sigma^+$	0.675 ± 0.002	0.614 ± 0.004
$\Sigma^{*-} \to \Sigma^0$	0.675 ± 0.002	0.614 ± 0.004
$\Sigma^{*-} \to \Lambda$	-1.169 ± 0.004	-1.231 ± 0.005
$\Xi^{*-} \to \Xi^0$	0.954 ± 0.003	0.903 ± 0.006

$B_{10} \overset{\chi=1-i2}{\longrightarrow} B_8$	$C_5^{A\,(\mathrm{sym})}$	$C_5^{A\,(\mathrm{br})}$
$\Delta^{++} \to p$	1.653 ± 0.006	1.801 ± 0.008
$\Delta^+ \to n$	0.954 ± 0.003	1.040 ± 0.005
$\Sigma^{*+} \to \Sigma^0$	0.675 ± 0.002	0.614 ± 0.004
$\Sigma^{*+} \to \Lambda$	1.169 ± 0.004	1.231 ± 0.005
$\Sigma^{*0} \to \Sigma^-$	0.675 ± 0.002	0.614 ± 0.004
$\Xi^{*0} \to \Xi^-$	0.954 ± 0.003	0.903 ± 0.006

$B_{10} \overset{\chi=4+i5}{\longrightarrow} B_8$	$C_5^{A\,(\mathrm{sym})}$	$C_5^{A\,(\mathrm{br})}$
$\Sigma^{*0} \to p$	-0.675 ± 0.002	-0.755 ± 0.004
$\Sigma^{*-} \to n$	-0.954 ± 0.003	-1.067 ± 0.005
$\Xi^{*0} \to \Sigma^+$	0.954 ± 0.003	0.896 ± 0.004
$\Xi^{*-} \to \Sigma^0$	0.675 ± 0.002	0.633 ± 0.003
$\Xi^{*-} \to \Lambda$	-1.169 ± 0.004	-1.266 ± 0.005
$\Omega^- \to \Xi^0$	1.653 ± 0.006	1.612 ± 0.007

$B_{10} \overset{\chi=4-i5}{\longrightarrow} B_8$	$C_5^{A\,(\mathrm{sym})}$	$C_5^{A\,(\mathrm{br})}$
$\Delta^{++} \to \Sigma^+$	-1.653 ± 0.006	-1.547 ± 0.007
$\Delta^+ \to \Sigma^0$	-1.350 ± 0.005	-1.263 ± 0.005
$\Delta^+ \to \Lambda$	0	0
$\Delta^0 \to \Sigma^-$	-0.954 ± 0.003	-0.893 ± 0.004
$\Sigma^{*+} \to \Xi^0$	-0.954 ± 0.003	-0.928 ± 0.004
$\Sigma^{*0} \to \Xi^-$	-0.675 ± 0.002	-0.656 ± 0.003

Yang, Kim, Phys.Rev.C 92, 035206 (2015)

Numerical results of meson-baryon coupling constants for 10 → 8

$f[\pi^0 B_8 B_{10}]$	$\mathrm{sym}[\mathcal{O}(m_s^0)]$	$\mathrm{op}[\mathcal{O}(m_s^1)]$	$\mathrm{wf}[\mathcal{O}(m_s^1)]$	total
$\pi^0 N\Delta$	-1.385 ± 0.005	-0.058 ± 0.005	-0.065 ± 0.001	-1.509 ± 0.007
$\pi^0 \Lambda\Sigma^*$	-1.200 ± 0.004	-0.025 ± 0.004	-0.039 ± 0.001	-1.264 ± 0.006
$\pi^0 \Sigma\Sigma^*$	$T_3\,(0.693 \pm 0.002)$	$T_3\,(-0.054 \pm 0.003)$	$T_3\,(-0.009 \pm 0.001)$	$T_3\,(0.630 \pm 0.004)$
$\pi^0 \Xi\Xi^*$	$T_3\,(1.385 \pm 0.005)$	$T_3\,(-0.068 \pm 0.007)$	$T_3\,(-0.007 \pm 0.001)$	$T_3\,(1.310 \pm 0.008)$

Table X: Yukawa coupling constants of the $\pi^0 B_8 B_{10}$.

Numerical results of Decay width of Δ baryon

The partial decay width of $\Delta^+ \to p\pi^0$ is

$$\Gamma\left[\Delta^+ \to p\pi^0\right] = (61.7 \pm 0.7)\ \mathrm{MeV}.$$

The decay width of $\Delta \to N\pi$ can be written by

$$\Gamma\left[\Delta \to N\pi\right] = \frac{3}{2}\Gamma\left[\Delta^+ \to p\pi^0\right] = (92.7 \pm 0.9)\ \mathrm{MeV},$$

while its experimental value from PDG 2014 is shown as 116 – 120 MeV.

Numerical results of Decay widths of hyperons (10 → 8)

Decay modes	$\Gamma_i^{(\mathrm{sym})}$	$\Gamma_i^{(\mathrm{total})}$	$\sum_i \Gamma_i^{(\mathrm{sym})}$	$\sum_i \Gamma_i^{(\mathrm{total})}$	Γ [PDG 2014]
$\Sigma^{*+} \to \Sigma^0 \pi^-$	2.07 ± 0.01	1.71 ± 0.02	34.1 ± 0.2	36.5 ± 0.3	36.0 ± 0.7
$\Sigma^{*+} \to \Sigma^+ \pi^0$	2.57 ± 0.02	2.12 ± 0.03			
$\Sigma^{*+} \to \Lambda \pi^+$	29.45 ± 0.20	32.69 ± 0.29			
$\Sigma^{*0} \to \Sigma^0 \pi^0$	0	0	35.2 ± 0.2	37.9 ± 0.3	36 ± 5
$\Sigma^{*0} \to \Sigma^+ \pi^-$	2.36 ± 0.02	1.95 ± 0.03			
$\Sigma^{*0} \to \Sigma^- \pi^+$	1.81 ± 0.01	1.50 ± 0.02			
$\Sigma^{*0} \to \Lambda \pi^0$	31.03 ± 0.21	34.43 ± 0.31			
$\Sigma^{*-} \to \Sigma^- \pi^0$	2.31 ± 0.02	1.91 ± 0.03	36.0 ± 0.2	38.6 ± 0.4	39.4 ± 2.1
$\Sigma^{*-} \to \Sigma^0 \pi^-$	2.38 ± 0.02	1.97 ± 0.03			
$\Sigma^{*-} \to \Lambda \pi^-$	31.28 ± 0.21	34.72 ± 0.31			
$\Xi^{*0} \to \Xi^0 \pi^0$	4.71 ± 0.03	4.21 ± 0.05	12.2 ± 0.1	10.9 ± 0.1	9.1 ± 0.5
$\Xi^{*0} \to \Xi^- \pi^0$	7.48 ± 0.05	6.69 ± 0.09			
$\Xi^{*-} \to \Xi^- \pi^0$	4.36 ± 0.03	3.90 ± 0.05	13.8 ± 0.1	12.3 ± 0.2	$9.9^{+1.7}_{-1.9}$
$\Xi^{*-} \to \Xi^0 \pi^-$	9.39 ± 0.06	8.39 ± 0.11			

PDG 2014

$\Xi(1530)^-$ WIDTH

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
$9.9^{+1.7}_{-1.9}$ OUR AVERAGE				
9.6 ± 2.8	DEBELLEFON	75B	HBC	$K^- p \to \Xi^- \overline{K} \pi$
8.3 ± 3.6	ROSS	73B	HBC	$K^- p \to \Xi \overline{K} \pi (\pi)$
$7.8^{+3.5}_{-7.8}$	BALTAY	72	HBC	$K^- p$ 1.75 GeV/c
16.2 ± 4.6	KIRSCH	72	HBC	$\Xi^- \pi^0$, $\Xi^0 \pi^-$

Numerical results of Branching Ratios of hyperons

Decay modes	Branching Ratios	$\Gamma[\Sigma\pi]/\Gamma[\Lambda\pi]$
$\Sigma^{*+} \to \Sigma\pi$	$(10.5 \pm 0.1)\ \%$	0.117 ± 0.001
$\Sigma^{*+} \to \Lambda\pi$	$(89.5 \pm 0.1)\ \%$	
$\Sigma^{*0} \to \Sigma\pi$	$(9.1 \pm 0.1)\ \%$	0.100 ± 0.001
$\Sigma^{*0} \to \Lambda\pi$	$(90.9 \pm 0.1)\ \%$	
$\Sigma^{*-} \to \Sigma\pi$	$(10.0 \pm 0.1)\ \%$	0.112 ± 0.001
$\Sigma^{*-} \to \Lambda\pi$	$(90.0 \pm 0.1)\ \%$	
$\mathrm{Ave}[\Sigma^{*} \to \Sigma\pi]$	$(9.9 \pm 0.1)\ \%$ [PDG: $(11.7 \pm 1.5)\ \%$]	0.110 ± 0.001 [PDG: 0.135 ± 0.011]
$\mathrm{Ave}[\Sigma^{*} \to \Lambda\pi]$	$(90.1 \pm 0.1)\ \%$ [PDG: $(87.0 \pm 1$	

Table 2: Branching fractions and r

In preparation for publication

Σ(1385) BRANCHING RATIOS

$\Gamma(\Sigma\pi)/\Gamma(\Lambda\pi)$ Γ_2/Γ_1

VALUE	DOCUMENT ID		TECN	CHG	COMMENT
0.135±0.011 OUR AVERAGE					
0.20 ±0.06	DIONISI	78B	HBC	±	$K^- p \to Y^* K \overline{K}$
0.16 ±0.03	BERTHON	74	HBC	+	$K^- p$ 1.26–1.84 GeV/c
0.11 ±0.02	BERTHON	74	HBC	−	$K^- p$ 1.26–1.84 GeV/c
0.21 ±0.05	BORENSTEIN	74	HBC	+	$K^- p \to \Lambda\pi^+\pi^-$, $\Sigma^0\pi^+\pi^-$
0.18 ±0.04	MAST	73	MPWA	±	$K^- p \to \Lambda\pi^+\pi^-$, $\Sigma^0\pi^+\pi^-$
0.10 ±0.05	THOMAS	73	HBC	−	$\pi^- p \to \Lambda K\pi$, $\Sigma K\pi$
0.16 ±0.07	AGUILAR-...	72B	HBC	+	$K^- p$ 3.9, 4.6 GeV/c
0.13 ±0.04	COLLEY	71B	DBC	−0	$K^- N$ 1.5 GeV/c
0.13 ±0.04	PAN	69	HBC	+	$\pi^+ p \to \Lambda K\pi$, $\Sigma K\pi$
0.08 ±0.06	LONDON	66	HBC	+	$K^- p$ 2.24 GeV/c
0.163±0.041	ARMENTEROS	65B	HBC	±	$K^- p$ 0.95–1.20 GeV/c
0.09 ±0.04	HUWE	64	HBC	±	$K^- p$ 1.2–1.7 GeV

Summary

- Investigating the **mass splittings** and the **hyperon semileptonic decay** constants of the baryon octet and decuplet within the framework of a chiral soliton model.
- We found that the effects of flavor SU(3) symmetry breaking contributed to the f_2/f_1 appeared complicated.
- The present results for the axial-vector transition constants can be used to determine the meson-baryon Yukawa coupling constants by the Goldberger-Treiman relations.
- The results of **Decay widths** and **Branching ratios** with **SU(3) sym. br. effects** are in a very good agreement with experimental data.
  $\Rightarrow$ **SU(3) sym. br. effects** is **very important** on the baryon transitions
- SU(3) flavor structure might be applied to the **mass splittings** and **transitions** of Heavy baryons (Charmed, Bottom and Heavy Pentaquarks)

ありがとうございます

Thank you

Danke schön

감사합니다

Fundamental Particles ?

multiplets (proton, neutron) : isospin [SU(2)] → higher symmetry (Σ, K,⋯) : SU(3)

Naïve Quark Model (*up, down, strange* light quarks):

SU(3) scheme to classify particles with the same spin and parity

Hadron [baryon (qqq), meson ($q\bar{q}$)] : SU(3) color singlet

PHYSICAL REVIEW VOLUME 125, NUMBER 3 FEBRUARY 1, 1962

Symmetries of Baryons and Mesons*

Murray Gell-Mann
California Institute of Technology, Pasadena, California
(Received March 27, 1961; revised manuscript received September 20, 1961)

If the meson spectrum is consistent with broken unitary symmetry, we should examine the baryons, and see whether the various baryon states fit into the representations **3**, **6**, and **15** (or the representations **1**, **8**, **10**, **10***, and **27** that arise in the alternative form of unitary symmetry).

Why not 4, 5, 6, … quark states ? Nothing prevents such states to exist

representation **10*** ($\overline{\mathbf{10}}$)

Y. s. Oh and H. c. Kim, Phys. Rev. D 70, 094022 (2004)

VOLUME 91, NUMBER 1 PHYSICAL REVIEW LETTERS week ending 4 JULY 2003

Evidence for a Narrow $S = +1$ Baryon Resonance in Photoproduction from the Neutron

T. Nakano,[1] D. S. Ahn,[2] J. K. Ahn,[2] H. Akimune,[3] Y. Asano,[4,5] W. C. Chang,[6] S. Daté,[7] H. Ejiri,[7,1] H. Fujimura,[8] M. Fujiwara,[1,5] K. Hicks,[9] T. Hotta,[1] K. Imai,[10] T. Ishikawa,[11] T. Iwata,[12] H. Kawai,[13] Z. Y. Kim,[8] K. Kino,[1] H. Kohri,[1] N. Kumagai,[7] S. Makino,[14] T. Matsumura,[1,5] N. Matsuoka,[1] T. Mibe,[1,5] K. Miwa,[10] M. Miyabe,[10] Y. Miyachi,[15,*] M. Morita,[1] N. Muramatsu,[5] M. Niiyama,[10] M. Nomachi,[16] Y. Ohashi,[7] T. Ooba,[13] H. Ohkuma,[7] D. S. Oshuev,[6] C. Rangacharyulu,[17] A. Sakaguchi,[16] T. Sasaki,[10] P. M. Shagin,[1,†] Y. Shiino,[13] H. Shimizu,[11] Y. Sugaya,[16] M. Sumihama,[16,5] H. Toyokawa,[7] A. Wakai,[18,‡] C. W. Wang,[6] S. C. Wang,[6,§] K. Yonehara,[3,‖] T. Yorita,[7] M. Yoshimura,[19] M. Yosoi,[10] and R. G. T. Zegers[1]

Successful searches for Θ^+ (2003~2005) : 2007 PDG

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
1533.6± 2.4 OUR AVERAGE		Error includes scale factor of 2.1. See the ideogram below.		
1526 ± 3 ±3		[1] ALEEV 05	SVD2	p nucleus $\to$ $pK^0_S X$
1530 ± 5		[2] ABDEL-BARY 04	COSY	$pp \to \Sigma^+ K^0 p$
1528.0± 2.6±2.1	59	[3] AIRAPETIAN 04	HERM	$\gamma^* d \to pK^0_S X$
1533 ± 5	27	[4] ASRATYAN 04	BC	ν, $\overline{\nu}$ in p,d,Ne, BEBC, 15-ft
1521.5± $1.5^{+2.8}_{-1.7}$	221	[5] CHEKANOV 04A	ZEUS	$\gamma^* p \to p/\overline{p} K^0_S X$
1555 ±10	41	[6] KUBAROVSKY 04	CLAS	$\gamma p \to \pi^+ K^- K^+ n$
1539 ± 2	29	[7] BARMIN 03	XEBC	$K^+\mathrm{Xe} \to K^0 p\, \mathrm{Xe}'$
1540 ± 4 ±2	63	[8] BARTH 03	SPHR	$\gamma p \to nK^+ K^0_S$
1540 ±10	19	[9] NAKANO 03	LEPS	$\gamma\, ^{12}\mathrm{C} \to K^+ K^- n\, X$
1542 ± 5	43	[10] STEPANYAN 03	CLAS	$\gamma d \to K^+ K^- pn$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1559 ± 3		[11] GIBBS 04		$K^+ d$ total cross section

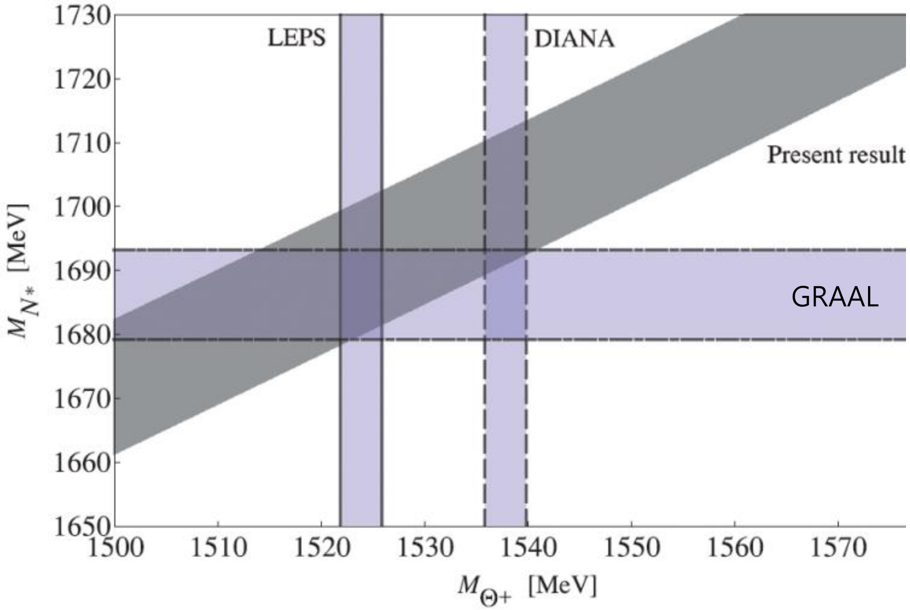
VALUE (MeV)	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
0.9 ±0.3 OUR ESTIMATE					
0.9 ±0.3			[12] CAHN 04		$K^+ n \to K^0 p$ in xenon
0.9 ±0.3			GIBBS 04	PWA	K^+d total cross section
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 0.64	90		[13] MIZUK 06	BELL	$K^+ n \to K^0_S p$
<24			ALEEV 05	SVD2	p nucleus $\to$ $pK^0_S X$
17 ±9 ±3			AIRAPETIAN 04	HERM	$\gamma^* d \to pK^0_S X$
<20			ASRATYAN 04	BC	ν, $\overline{\nu}$ in p,d,Ne, BEBC and 15-ft
8 ±4		221	CHEKANOV 04A	ZEUS	$\gamma^* p \to p/\overline{p} K^0_S X$
<26			KUBAROVSKY 04	CLAS	$\gamma p \to \pi^+ K^- K^+ n$
< 1			[14] SIBIRTSEV 04		$K^+ d \to K^0 pp$ reanalysis
$\lesssim 1$			[15] ARNDT 03	DPWA	$K^+ N$ partial-wave reanalysis
< 9	90		BARMIN 03	XEBC	$K^+\mathrm{Xe} \to K^0 p\, \mathrm{Xe}'$
<25	90		BARTH 03	SPHR	$\gamma p \to nK^+ K^0_S$
<25	90		NAKANO 03	LEPS	$\gamma\, ^{12}\mathrm{C} \to K^+ K^- n\, X$
<21			STEPANYAN 03	CLAS	$\gamma d \to K^+ K^- pn$

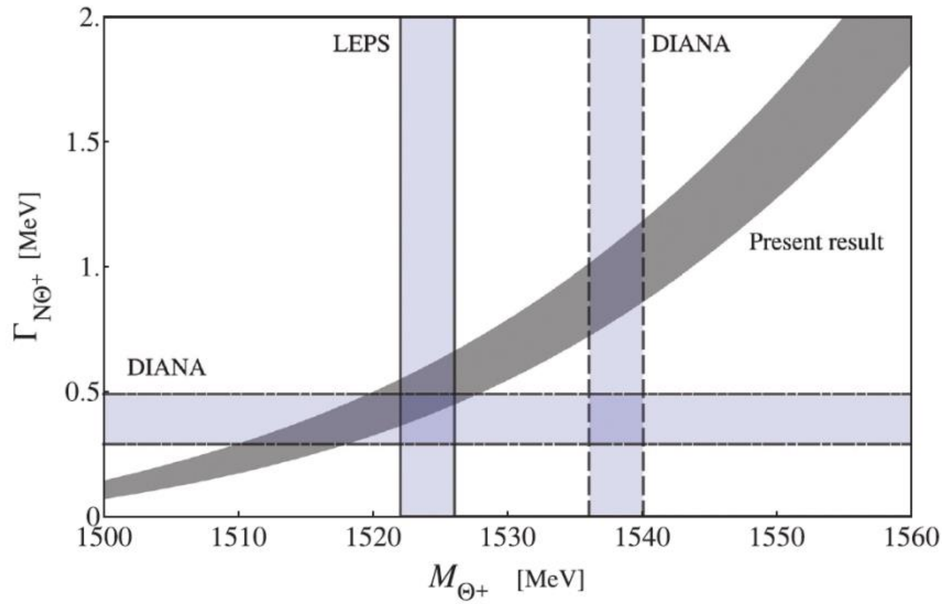
Unsuccessful searches for Θ^+ (2006~2008) : 2010 PDG

Experiment	Reaction	Energy, etc.	Limits, etc.
Searches for the $\Theta(1540)^+$			
BABAR [2]	$B^0 \to (pK^0_S)\bar{p}$	$\sqrt{s}$ 10.58 GeV	$< 2 \times 10^{-7}$ per B^0
CLAS [3]	$\gamma p \to (nK^+/pK^0_S)K^0$	E_γ 1.6–3.8 GeV	$\sigma < 0.7$ nb, 100k $\Lambda(1520)$
CLAS [4]	$\gamma d \to (nK^+)pK^-$	E_γ 0.8–3.6 GeV	$\sigma < 0.3$ nb
CLAS [5]	$\gamma d \to (nK^+)\Lambda$	E_γ 0.8–3.6 GeV	$\sigma <$ 5–25 nb
COSY-ANKE [6]	$pp \to (pK^0_S)\Lambda\pi^+$	p_p 3.65 GeV/c	$\sigma < 58$ nb
COSY-TOF [7]	$pp \to (pK^0_S)\Sigma^+$	p_p 3.059 GeV/c	$\sigma < 150$ nb
DELPHI [8]	$Z \to (pK^0_S)X$	$\sqrt{s}$ 91.2 GeV	$< 5.1 \times 10^{-4}$ per Z
FOCUS [9]	$\gamma A \to (pK^0_S)X$	$\bar{E}_\gamma$ 180 GeV	400k $\Sigma(1385)^+$
HERA-H1 [10]	$ep \to (p/\bar{p}K^0_S)eX$	$5 < Q^2 < 100$ GeV^2	$\sigma <$ 30–90 pb
KEK-E522 [11]	$\pi^- p \to K^-(X)$	p_π 1.9 GeV/c	$\sigma < 3.9$ nb
L3 [12]	$\gamma^*\gamma^* \to (p/\bar{p}K^0_S)X$	$E_{\gamma\gamma} > 5$ GeV	$\sigma < 1.8$ nb
NOMAD [13]	$\nu_\mu N \to (pK^0_S)X$		< 2.13x10^{-3} per evt

~~$\Theta(1540)$, $\Phi(1860)$, and $\Theta_c(3100)$~~ ???

	Diakonov et al.[2)]	Ellis et al.[43)]	χQSM[59)]	This work
Input masses	$N^*(1710\text{ MeV})$	$\Theta^+(1539 \pm 2\text{ MeV})$ $\Xi^{--}_{3/2}(1862 \pm 2\text{ MeV})$	$\cdots$ $\cdots$	$\Theta^+(1524 \pm 5\text{ MeV})$
$\Sigma_{\pi N}$	45 MeV*	73 MeV	41 MeV	36.4 ± 3.9 MeV
I_1	1.29 fm	1.27 fm	1.06 fm	1.230 ± 0.002 fm
I_2	0.4 fm	0.49 fm	0.48 fm	0.420 ± 0.006 fm
$m_s\alpha$	-218 MeV	-605 MeV	-197 MeV	-262.9 ± 5.9 MeV
$m_s\beta$	-156 MeV	-23 MeV	-94 MeV	-144.3 ± 3.2 MeV
$m_s\gamma$	-107 MeV	152 MeV	-53 MeV	-104.2 ± 2.4 MeV
$c_{\overline{10}}$	0.084	0.088	0.037	0.0434 ± 0.0006





Yang, Kim, Prog. Theor. Phys. 128, 397 (2012)

Chiral Soliton Model (mass)

$$
\begin{aligned}
M_N^{\mathrm{EM}} &= \frac{1}{5}\left(c^{(8)}+\frac{4}{9}c^{(27)}\right)T_3+\frac{3}{5}\left(c^{(8)}+\frac{2}{27}c^{(27)}\right)\left(T_3^2+\frac{1}{4}\right)+c^{(1)},\\
M_\Lambda^{\mathrm{EM}} &= \frac{1}{10}\left(c^{(8)}-\frac{2}{3}c^{(27)}\right)+c^{(1)},\\
M_\Sigma^{\mathrm{EM}} &= \frac{1}{2}c^{(27)}\,T_3+\frac{2}{9}c^{(27)}\,T_3^2-\frac{1}{10}\left(c^{(8)}+\frac{14}{9}c^{(27)}\right)+c^{(1)},\\
M_\Xi^{\mathrm{EM}} &= \frac{4}{5}\left(c^{(8)}-\frac{1}{9}c^{(27)}\right)T_3-\frac{2}{5}\left(c^{(8)}-\frac{1}{9}c^{(27)}\right)\left(T_3^2+\frac{1}{4}\right)+c^{(1)},
\end{aligned}
$$

$$
\begin{aligned}
M_\Delta^{\mathrm{EM}} &= \frac{1}{4}\left(c^{(8)}+\frac{8}{63}c^{(27)}\right)T_3+\frac{5}{63}c^{(27)}\,T_3^2+\frac{1}{8}\left(c^{(8)}-\frac{2}{3}c^{(27)}\right)+c^{(1)},\\
M_{\Sigma^*}^{\mathrm{EM}} &= \frac{1}{4}\left(c^{(8)}-\frac{4}{21}c^{(27)}\right)T_3+\frac{5}{63}c^{(27)}\,\left(T_3^2-1\right)+c^{(1)},\\
M_{\Xi^*}^{\mathrm{EM}} &= \frac{1}{4}\left(c^{(8)}-\frac{32}{63}c^{(27)}\right)T_3-\frac{1}{4}\left(c^{(8)}+\frac{8}{63}c^{(27)}\right)\left(T_3^2+\frac{1}{4}\right)+c^{(1)},\\
M_{\Omega^-}^{\mathrm{EM}} &= -\frac{1}{4}\left(c^{(8)}-\frac{4}{21}c^{(27)}\right)+c^{(1)},
\end{aligned}
$$

Weinberg-Treiman formula

$M^{\mathrm{EM}}(T_3) = \alpha T_3^2 + \beta T_3 + \gamma$

~~**Dashen ansatz**~~

$\cancel{\Delta M^{\mathrm{EM}} \sim \kappa T_3^2 \sim \kappa' Q^2}$

Chiral Soliton Model (mass)

$$(M_p - M_n)_{\rm EM} = \frac{1}{5}\left(c^{(8)} + \frac{4}{9}c^{(27)}\right)$$
$$(M_{\Sigma^+} - M_{\Sigma^-})_{\rm EM} = c^{(8)}$$
$$(M_{\Xi^0} - M_{\Xi^-})_{\rm EM} = \frac{4}{5}\left(c^{(8)} - \frac{1}{9}c^{(27)}\right)$$

Coleman-Glashow relation

$$(M_p - M_n)_{\rm EM} = (M_{\Sigma^+} - M_{\Sigma^-})_{\rm EM} - (M_{\Xi^0} - M_{\Xi^-})_{\rm EM}$$

EM [MeV]	**Exp.** [input]
$(M_p - M_n)_{EM}$	**0.76±0.30**
$(M_{\Sigma^+} - M_{\Sigma^-})_{EM}$	**-0.17±0.30**
$(M_{\Xi^0} - M_{\Xi^-})_{EM}$	**-0.86±0.30**

$$c^{(8)} = -0.15 \pm 0.23, \quad c^{(27)} = 8.62 \pm 2.39$$

Chiral Soliton Model (mass)

χ^2 fit

$$(M_p - M_n)_{\rm EM} = \frac{1}{5}\left(c^{(8)} + \frac{4}{9}c^{(27)}\right)$$
$$(M_{\Sigma^+} - M_{\Sigma^-})_{\rm EM} = c^{(8)}$$
$$(M_{\Xi^0} - M_{\Xi^-})_{\rm EM} = \frac{4}{5}\left(c^{(8)} - \frac{1}{9}c^{(27)}\right)$$

Coleman-Glashow relation

$$(M_p - M_n)_{\rm EM} = (M_{\Sigma^+} - M_{\Sigma^-})_{\rm EM} - (M_{\Xi^0} - M_{\Xi^-})_{\rm EM}$$

EM [MeV]	**Exp.** [input]	**reproduced**
$(M_p - M_n)_{EM}$	**0.76±0.30**	**0.74±0.22**
$(M_{\Sigma+} - M_{\Sigma-})_{EM}$	**-0.17±0.30**	**-0.15±0.23**
$(M_{\Xi 0} - M_{\Xi-})_{EM}$	**-0.86±0.30**	**-0.88±0.28**

$$c^{(8)} = -0.15 \pm 0.23, \quad c^{(27)} = 8.62 \pm 2.39$$

Chiral Soliton Model (mass)

$(\Delta M_{B_{10}})_{\rm EM}$	Numerical results	$(\Delta M_{B_{10}})_{\rm EM}$	Numerical results
$(M_{\Delta^{++}} - M_{\Delta^{+}})_{\rm EM}$	1.60 ± 0.46	$(M_{\Delta^{++}} - M_{\Delta^{0}})_{\rm EM}$	1.84 ± 0.54
$(M_{\Delta^{+}} - M_{\Delta^{0}})_{\rm EM}$	0.24 ± 0.10	$(M_{\Delta^{+}} - M_{\Delta^{-}})_{\rm EM}$	-0.89 ± 0.26
$(M_{\Delta^{0}} - M_{\Delta^{-}})_{\rm EM}$	-1.13 ± 0.30	$(M_{\Delta^{++}} - M_{\Delta^{-}})_{\rm EM}$	0.71 ± 0.29
$(M_{\Sigma^{*+}} - M_{\Sigma^{*0}})_{\rm EM}$	0.24 ± 0.10	$(M_{\Sigma^{*+}} - M_{\Sigma^{*-}})_{\rm EM}$	-0.89 ± 0.26
$(M_{\Sigma^{*0}} - M_{\Sigma^{*-}})_{\rm EM}$	-1.13 ± 0.30		
$(M_{\Xi^{*0}} - M_{\Xi^{*-}})_{\rm EM}$	-1.13 ± 0.30		

$(\Delta M_{B_{10}})_{\rm EM}$	This work	$(\Delta M_{B_{10}})_{\rm EM}$	This work
$(M_{p^*} - M_{n^*})_{\rm EM}$	-1.31 ± 0.31	$\left(M_{\Sigma^{+}_{\overline{10}}} - M_{\Sigma^{-}_{\overline{10}}}\right)_{\rm EM}$	-0.89 ± 0.26
$\left(M_{\Sigma^{+}_{\overline{10}}} - M_{\Sigma^{0}_{\overline{10}}}\right)_{\rm EM}$	-1.31 ± 0.31	$\left(M_{\Xi^{+}_{3/2}} - M_{\Xi^{-}_{3/2}}\right)_{\rm EM}$	-0.89 ± 0.26
$\left(M_{\Sigma^{0}_{\overline{10}}} - M_{\Sigma^{-}_{\overline{10}}}\right)_{\rm EM}$	0.24 ± 0.10	$\left(M_{\Xi^{0}_{3/2}} - M_{\Xi^{--}_{3/2}}\right)_{\rm EM}$	-1.84 ± 0.54
$\left(M_{\Xi^{+}_{3/2}} - M_{\Xi^{0}_{3/2}}\right)_{\rm EM}$	-1.31 ± 0.31	$\left(M_{\Xi^{+}_{3/2}} - M_{\Xi^{--}_{3/2}}\right)_{\rm EM}$	0.71 ± 0.29
$\left(M_{\Xi^{0}_{3/2}} - M_{\Xi^{-}_{3/2}}\right)_{\rm EM}$	0.24 ± 0.10		
$\left(M_{\Xi^{-}_{3/2}} - M_{\Xi^{--}_{3/2}}\right)_{\rm EM}$	1.60 ± 0.46		

Chiral Soliton Model (mass)

Formulae for Baryon Anti-Decuplet Masses

$$
\begin{aligned}
M_{\Theta^+} &= \overline{M}_{\overline{\mathbf{10}}} + c^{(1)} + \frac{1}{4}\left(c^{(8)} - \frac{4}{21}c^{(27)}\right) - 2\left(m_s - \hat{m}\right)\delta_3, \\
M_{N^*} &= \overline{M}_{\overline{\mathbf{10}}} + c^{(1)} + \frac{1}{4}\left(c^{(8)} - \frac{32}{63}c^{(27)}\right)T_3 + \frac{1}{4}\left(c^{(8)} + \frac{8}{63}c^{(27)}\right)\left(T_3^2 + \frac{1}{4}\right) \\
&\quad - \left(m_d - m_u\right)\delta_3 T_3 - \left(m_s - \hat{m}\right)\delta_3, \\
M_{\Sigma_{\overline{10}}} &= \overline{M}_{\overline{\mathbf{10}}} + c^{(1)} + \frac{1}{4}\left(c^{(8)} - \frac{4}{21}c^{(27)}\right)T_3 - \frac{5}{63}c^{(27)}\left(T_3^2 - 1\right) - \left(m_d - m_u\right)\delta_3 T_3, \\
M_{\Xi^+_{3/2}} &= \overline{M}_{\overline{\mathbf{10}}} + c^{(1)} + \frac{1}{4}\left(c^{(8)} + \frac{8}{63}c^{(27)}\right)T_3 - \frac{5}{63}c^{(27)}T_3^2 - \frac{1}{8}\left(c^{(8)} - \frac{2}{3}c^{(27)}\right) \\
&\quad - \left(m_d - m_u\right)\delta_3 T_3 + \left(m_s - \hat{m}\right)\delta_3,
\end{aligned}
$$

hadronic mass part in terms of δ_3

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

Results from Chiral Quark-Soliton Model in a self-consistent way (T. Ledwig, H.-Ch. Kim)

B	p	n	Λ	Σ^+	Σ^0	Σ^-	Ξ^0	Ξ^-
μ_{B_8}/n.m.	1.81	-1.20	-0.60	1.81	0.60	-0.61	-1.20	-0.61
exp.	2.793	-1.91	-0.613	2.458		-1.160	-1.250	-0.651

	Octet	Decuplet	Anti-decuplet
Θ	–	–	1532 (1540)
N/Δ	996 (939)	1313 (1232)	1654 (1675)
Σ	$(\Sigma+\Lambda)/2 = \text{input} = 1151.5$	1430 (1385)	1769 (–)
Ξ	1279 (1315)	1544 (1530)	1877 (1862)
Ω	–	1654 (1672)	–