Two-meson cloud contribution to the baryon antidecuplet binding


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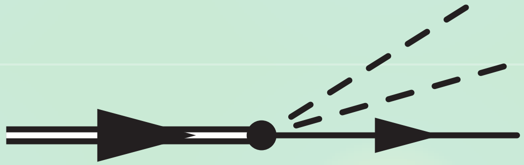
Contents

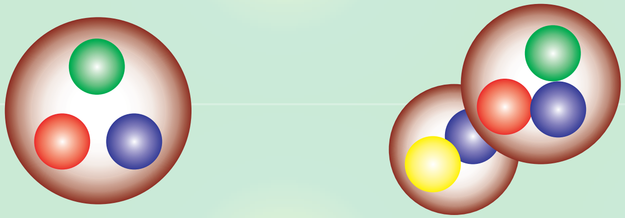
- Introduction
- Effective Lagrangians



- Self-energy of antidecuplet
- Other possible Lagrangians
  - Two-meson 27 combination
  - Chiral symmetric term
  - SU(3) breaking (mass) term
- Summary

Baryons in Fock space

$$|\, B \,\rangle = |\, qqq \,\rangle + |\, qqq(q\bar{q}) \,\rangle + \cdots$$



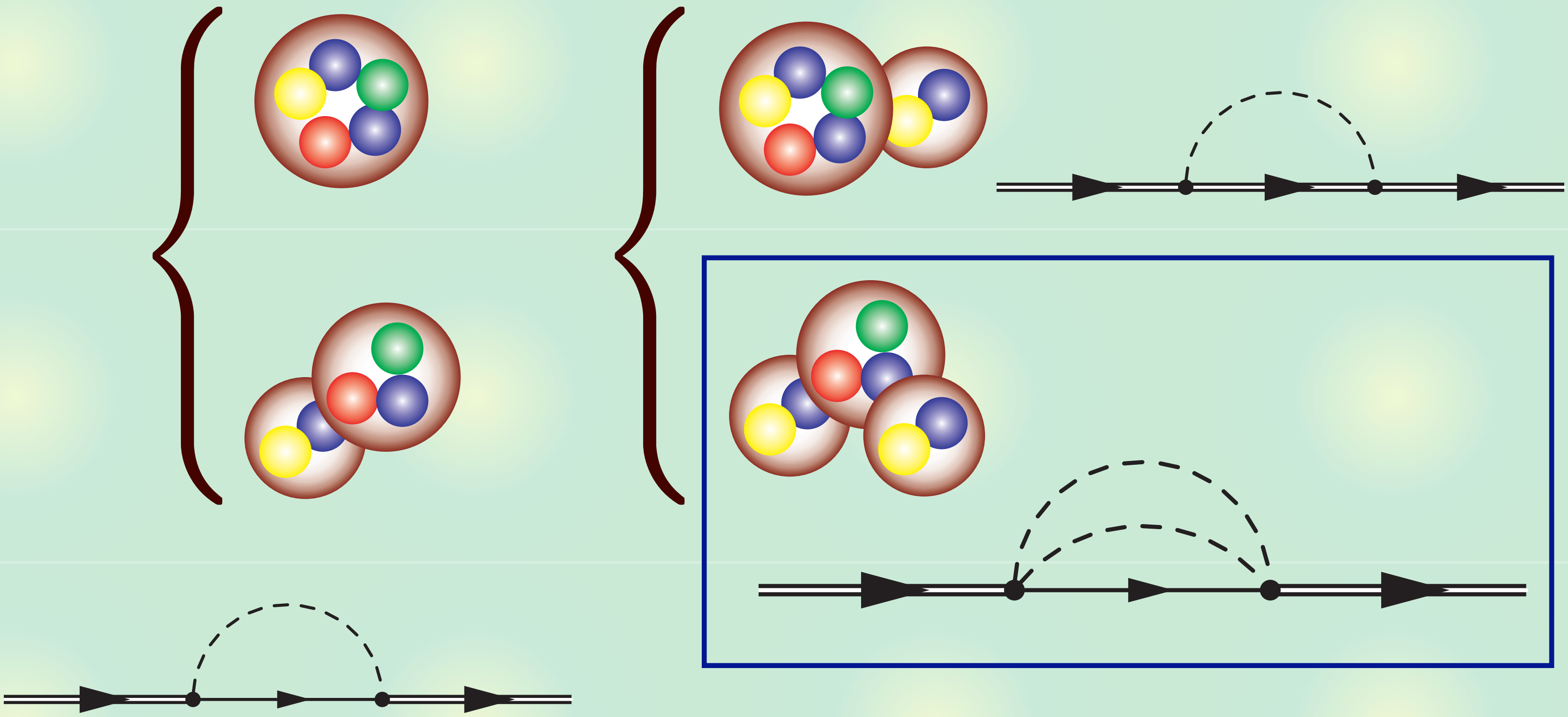
pion cloud

meson-baryon bound state

...

Pentaquarks in Fock space

$$|\,P\,\rangle = |\,qqqq\bar{q}\,\rangle + |\,qqqq\bar{q}(q\bar{q})\,\rangle + \cdots$$



V. Mohta, Phys. Rev. D70, 114022 (2004)

Motivations

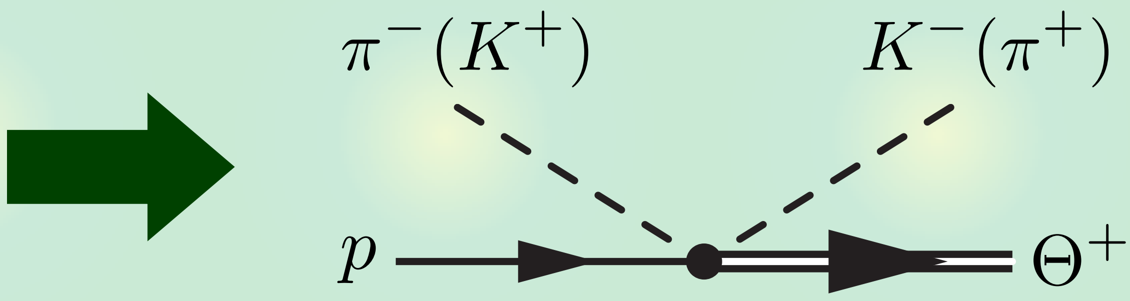
Possibility of Θ^+~KπN bound state

P. Bicudo, *et al*., Phys. Rev. C69, 011503 (2004)
T. Kishimoto, *et al*., hep-ex/0312003
F. J. Llanes-Estrada, *et al*., Phys. Rev. C69, 055203 (2004)

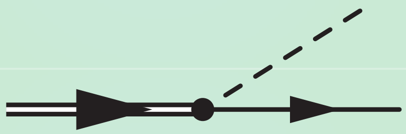
Anomalies in production experiments

$\pi^- p \to K^- \Theta^+$ at KEK

$\gamma d \to \Lambda^* \Theta^+$ at SPring-8

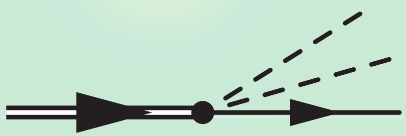


Two-meson coupling



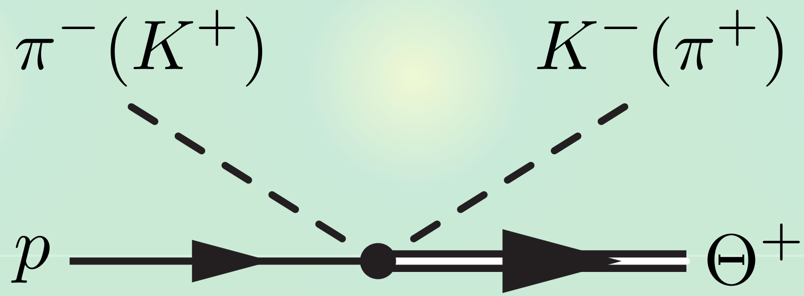
$\Theta^+ \to KN$ — **Very narrow**

$N(1710) \to \pi N$ — **10–20 %**



$\Theta^+ \to K\pi N$ — **Forbidden**

$N(1710) \to \pi\pi N$ — **40–90 %**



Large??

Effective interactions which account for the $N(1710) \to \pi\pi N$ decay

Criteria to construct the Lagrangian

Interaction is flavor SU(3) symmetric

Chiral symmetric? -> later

Small number of derivatives

low energy : OK

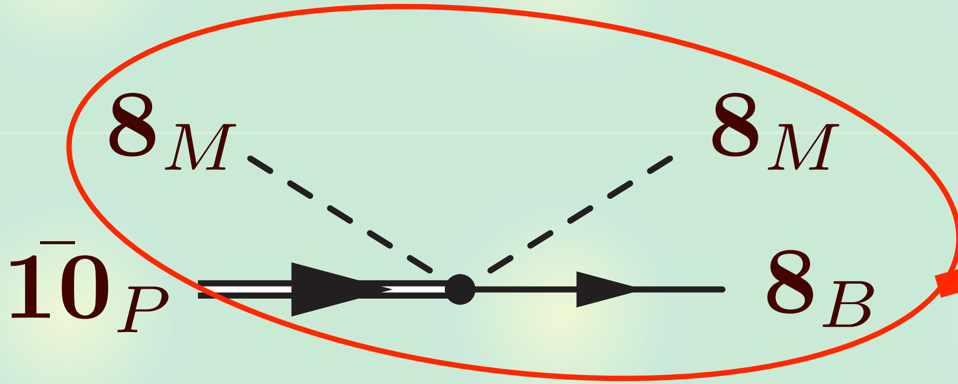
Assumptions for Θ^+

N(1710) is the S=0 partner of antidecuplet
-> $J^P = 1/2^+$

No mixing with 8, 27,... <- decay width

T.D. Cohen, Phys. Rev. D70, 074023 (2004)
S. Pakvasa and M. Suzuki, Phys. Rev. D70, 036002 (2004)
T. H. and A. Hosaka, Phys. Rev. D71, 054017 (2005)

SU(3) structure of effective Lagrangian



$$\mathbf{1} \in \overline{\mathbf{10}} \otimes \mathbf{10}$$

$$
\begin{aligned}
\mathbf{8}_M \otimes \mathbf{8}_M \otimes \mathbf{8}_B =& (\mathbf{1} \oplus \mathbf{8}^s \oplus \mathbf{8}^a \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{27})_{MM} \otimes \mathbf{8}_B \\
=& \mathbf{8} \quad \leftarrow \text{from } \mathbf{1}_{MM} \otimes \mathbf{8}_B \\
& \oplus (\mathbf{1} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{27}) \quad \leftarrow \text{from } \mathbf{8}^s_{MM} \otimes \mathbf{8}_B \\
& \oplus (\mathbf{1} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{27}) \quad \leftarrow \text{from } \mathbf{8}^a_{MM} \otimes \mathbf{8}_B \\
& \oplus (\mathbf{8} \oplus \mathbf{10} \oplus \mathbf{27} \oplus \mathbf{35}) \quad \leftarrow \text{from } \mathbf{10}_{MM} \otimes \mathbf{8}_B \\
& \oplus (\mathbf{8} \oplus \overline{\mathbf{10}} \oplus \mathbf{27} \oplus \mathbf{35}') \quad \leftarrow \text{from } \overline{\mathbf{10}}_{MM} \otimes \mathbf{8}_B \\
& \oplus (\mathbf{8} \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{27} \oplus \mathbf{27} \oplus \mathbf{35} \oplus \mathbf{35}'' \oplus \mathbf{64}) \quad \leftarrow \text{from } \mathbf{27}_{MM} \otimes \mathbf{8}_B
\end{aligned}
$$

Interaction Lagrangians 1

Antidecuplet field

$$P^{333} = \sqrt{6}\Theta^{+}_{\overline{10}}$$

$$P^{133} = \sqrt{2}\, N^{0}_{\overline{10}} \qquad P^{233} = -\sqrt{2}\, N^{+}_{\overline{10}}$$

$$P^{113} = \sqrt{2}\, \Sigma^{-}_{\overline{10}} \qquad P^{123} = -\Sigma^{0}_{\overline{10}} \qquad P^{223} = -\sqrt{2}\, \Sigma^{+}_{\overline{10}}$$

$$P^{111} = \sqrt{6}\Xi^{--}_{\overline{10}} \qquad P^{112} = -\sqrt{2}\, \Xi^{-}_{\overline{10}} \qquad P^{122} = \sqrt{2}\, \Xi^{0}_{\overline{10}} \qquad P^{222} = -\sqrt{6}\Xi^{+}_{\overline{10}}$$

Meson and baryon fields

$$\Phi = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix}$$

$$B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}$$

Interaction Lagrangians 3

Terms without derivative

$$\mathcal{L}^{8s} = \frac{g^{8s}}{2f}\bar{P}_{ijk}\epsilon^{lmk}\phi_l{}^a\phi_a{}^i B_m{}^j + h.c.$$

8s

$$\mathcal{L}^{8a} = 0$$

$$\mathcal{L}^{10} = 0$$

<- symmetry under exchange of mesons

$$\mathcal{L}^{27} = \frac{g^{27}}{2f}\left[4\bar{P}_{ijk}\epsilon^{lbk}\phi_l{}^i\phi_a{}^j B_b{}^a - \frac{4}{5}\bar{P}_{ijk}\epsilon^{lbk}\phi_l{}^a\phi_a{}^j B_b{}^i\right] + h.c.$$

Experimental information

$$N(1710) \to \pi\pi(s\text{-wave},\ I=0)N$$

$$N(1710) \to \pi\pi(p\text{-wave},\ I=1)N$$

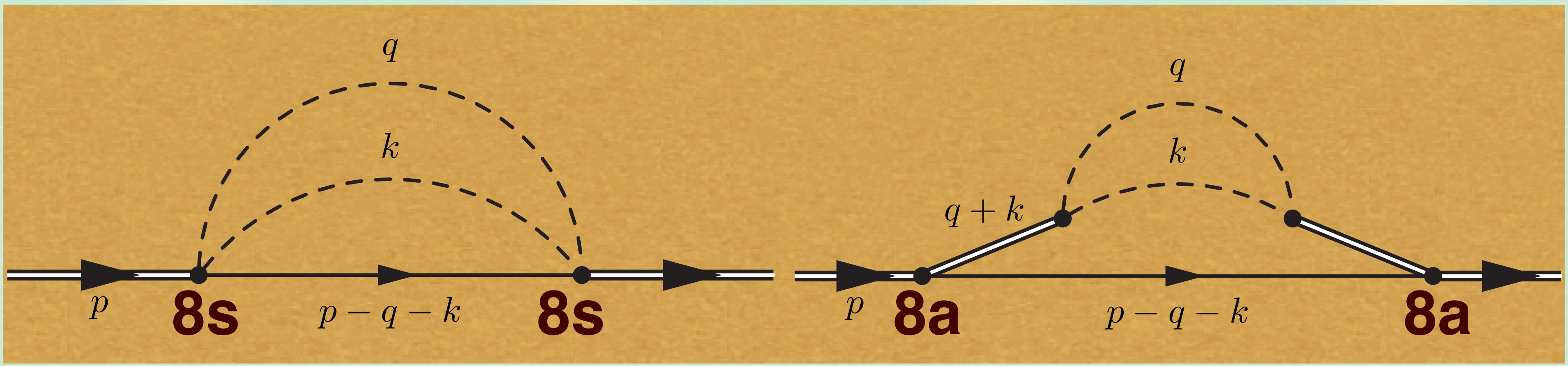
With one derivative

8a

$$\mathcal{L}^{8a} = i\frac{g^{8a}}{4f^2}\bar{P}_{ijk}\epsilon^{lmk}\gamma^\mu(\partial_\mu\phi_l{}^a\phi_a{}^i - \phi_l{}^a\partial_\mu\phi_a{}^i)B_m{}^j + h.c.$$

Diagrams for self-energy

Real part : mass shift
Imaginary part : decay width
SU(3) breaking : masses of particles

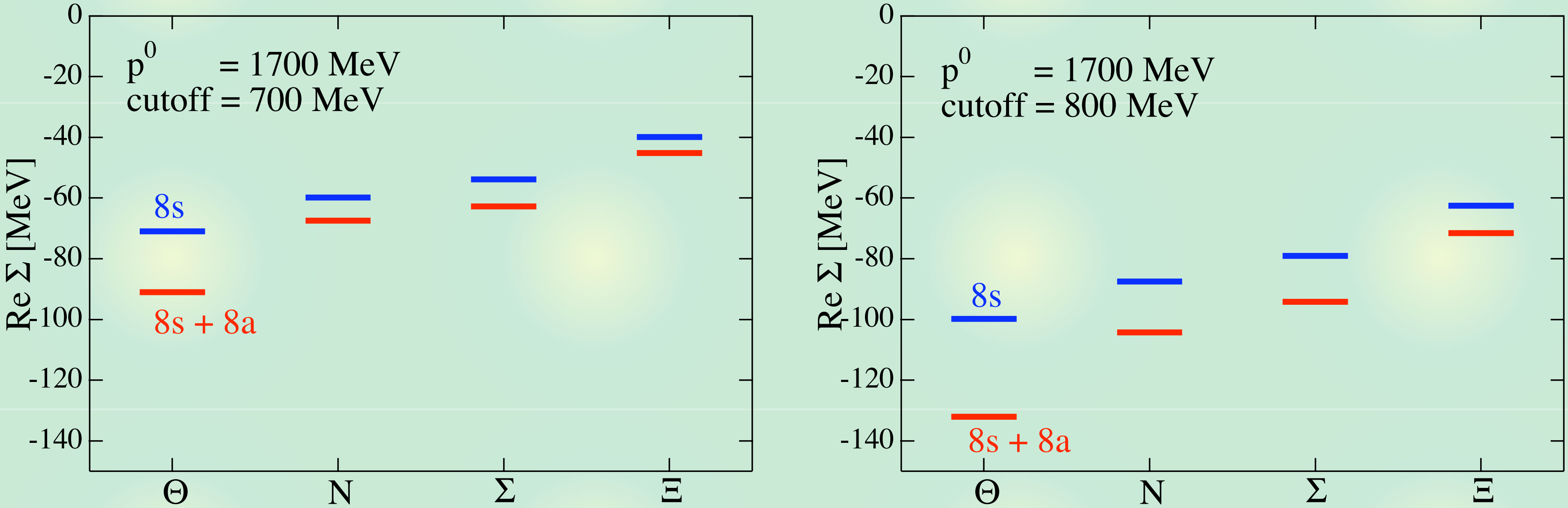


$$N(1710) \to \pi\pi(s\text{-wave},\ I=0)N$$ **25 MeV**

$$N(1710) \to \pi\pi(p\text{-wave},\ I=1)N$$ **15 MeV**

$$\Rightarrow \quad g^{8s} = 1.88\ , \qquad g^{8a} = 0.315$$

Results of self-energy : Real part (mass shift)



All mass shifts are attractive.

More bound for larger strangeness.

Mass difference between Ξ and Θ
-> 60 MeV : ~20 % of 320 = 1860–1540

Results of self-energy : Imaginary part (decay width)

Decay [MeV]	$\Gamma^{(8s)}$	$\Gamma^{(8a)}$	$\Gamma^{(tot)}_{BMM}$
$N(1710) \to N\pi\pi$ (inputs)	25	15	40
$N(1710) \to N\eta\pi$	0.58	-	
$\Sigma(1770) \to N\bar{K}\pi$	4.7	6.0	24
$\Sigma(1770) \to \Sigma\pi\pi$	10	0.62	
$\Sigma(1770) \to \Lambda\pi\pi$	-	2.9	
$\Xi(1860) \to \Sigma\bar{K}\pi$	0.57	0.46	2.1
$\Xi(1860) \to \Xi\pi\pi$	-	1.1	

Other possible Lagrangians : detail

$$\mathcal{L}^{8s} = \frac{g^{8s}}{2f} \bar{P}_{ijk} \epsilon^{lmk} \phi_l{}^a \phi_a{}^i B_m{}^j + h.c.$$

Two-meson 27 interaction

$$\mathcal{L}^{27} = \frac{g^{27}}{2f} \left[4\bar{P}_{ijk} \epsilon^{lbk} \phi_l{}^i \phi_a{}^j B_b{}^a - \frac{4}{5} \bar{P}_{ijk} \epsilon^{lbk} \phi_l{}^a \phi_a{}^j B_b{}^i \right] + h.c.$$

Chiral symmetric interaction

$$\mathcal{L}^{\chi} = \frac{g^{\chi}}{2f} \bar{P}_{ijk} \epsilon^{lmk} (A_\mu)_l{}^a (A^\mu)_a{}^i B_m{}^j + h.c.$$

$$A_\mu = \frac{i}{2} \left(\xi^\dagger \partial_\mu \xi - \xi \partial_\mu \xi^\dagger \right) = -\frac{\partial_\mu \phi}{\sqrt{2} f} + \mathcal{O}(p^3) \qquad \xi = e^{i\phi/\sqrt{2}f}$$

$$(A_\mu)_l{}^a (A^\mu)_a{}^i \to \frac{1}{2f^2} \partial_\mu \phi_l{}^a \partial^\mu \phi_a{}^i$$

SU(3) breaking interaction $M = \mathrm{diag}(\hat{m}, \hat{m}, m_s)$

$$\mathcal{L}^{M} = \frac{g^{M}}{2f} \bar{P}_{ijk} \epsilon^{lmk} S_l{}^i B_m{}^j$$

$$S = \xi M \xi + \xi^\dagger M \xi^\dagger = \mathcal{O}(\phi^0) - \frac{1}{2f^2} (2\phi M \phi + \phi\phi M + M\phi\phi) + \mathcal{O}(\phi^4)$$

Chiral symmetric Lagrangian

$$\mathcal{L}^{8s} = \frac{g^{8s}}{2f} \bar{P}_{ijk} \epsilon^{lmk} \phi_l{}^a \phi_a{}^i B_m{}^j + h.c.$$

$$\mathcal{L}^{\chi(2)} = \frac{g^{\chi}}{2f} \bar{P}_{ijk} \epsilon^{lmk} \frac{1}{2f^2} \partial_\mu \phi_l{}^a \partial^\mu \phi_a{}^i B_m{}^j + h.c.$$

SU(3) structure : Identical !

Only loop integral is changed
<- adjusting the cutoff, we would have the same results

N(1710) decay -> $g^{\chi} = 0.218$

Results of chiral Lagrangian

[MeV]

Re{Σ}	8s	χ(2)
Θ	-100	-99
N	-87	-83
Σ	-79	-70
Ξ	-63	-57
cutoff	800	525

Decay	8s	χ(2)
$N(1710) \to N\pi\pi$	25	25
$N(1710) \to N\eta\pi$	0.58	0.32
$\Sigma(1770) \to N\bar{K}\pi$	4.7	4.5
$\Sigma(1770) \to \Sigma\pi\pi$	10	3.6
$\Xi(1860) \to \Sigma\bar{K}\pi$	0.57	0.40

Almost the same results

Difference comes from the SU(3) breaking of momenta at the vertex

27 and mass Lagrangians

$$\mathcal{L}^{27} = \frac{g^{27}}{2f}\left[4\bar{P}_{ijk}\epsilon^{lbk}\phi_l{}^i\phi_a{}^j B_b{}^a - \frac{4}{5}\bar{P}_{ijk}\epsilon^{lbk}\phi_l{}^a\phi_a{}^j B_b{}^i\right] + h.c.$$

$$\mathcal{L}^{M} = \frac{g^{M}}{2f}\bar{P}_{ijk}\epsilon^{lmk}(-\frac{1}{2f^2})(2\phi M\phi + \phi\phi M + M\phi\phi)_l{}^i B_m{}^j + h.c.$$

Fitting couplings to the N(1710) decay
-> large binding energy of 1 GeV : unrealistic

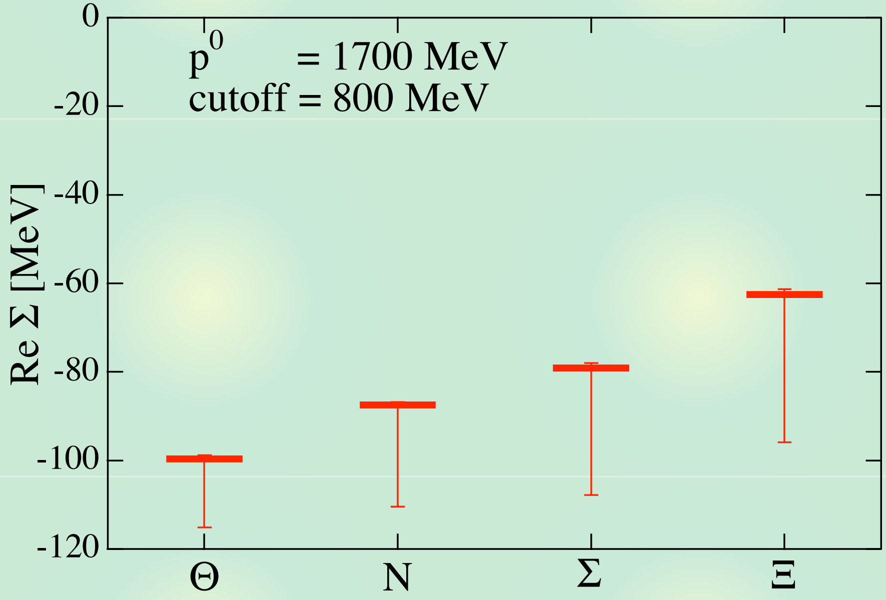
Treat them as a small perturbation to the 8s.

$$g^{27} = g^{M} = g^{8s} = 1.88\ , \quad b_{27} = -\frac{5}{4}(1-a)\ , \quad b_M = \frac{f^2}{m_\pi^2}(1-a)$$

$$\mathcal{L}^{int} = a\mathcal{L}^{8s} + b_{27,M}\mathcal{L}^{27,M}$$

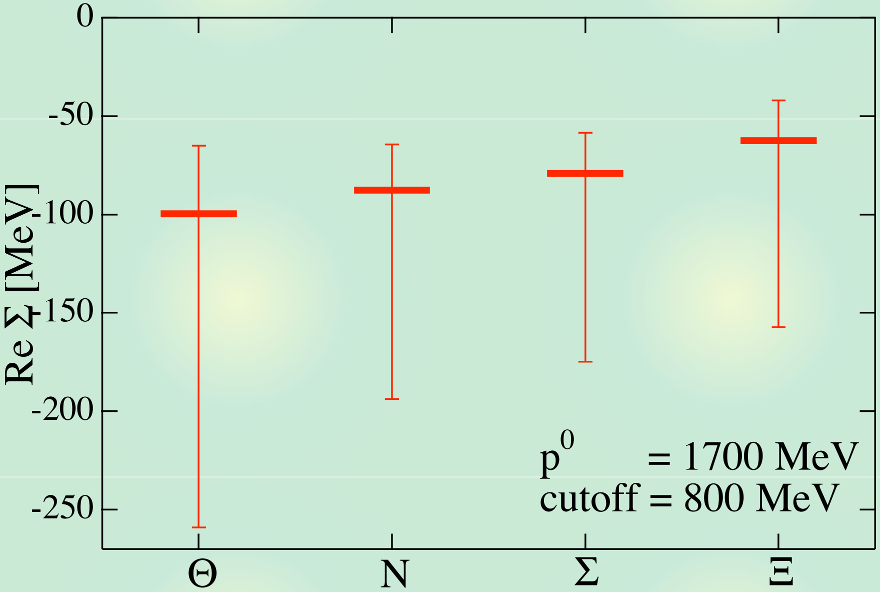
Deviation from a = 1 : weight of new terms

Results of 27 and mass Lagrangians



27

0.90 < a < 1.06



M

0.76 < a < 1.06

Contributions of these terms are considered as a theoretical uncertainty in the analysis.

Conclusion 1 : self-energy

We study the two-meson virtual cloud effect to the self-energy of baryon antidecuplet.

- **Two types of Lagrangians (8s, 8a) are important among several possible interaction Lagrangians.**

$$\mathcal{L}^{8s} = \frac{g^{8s}}{2f} \bar{P}_{ijk} \epsilon^{lmk} \phi_l{}^a \phi_a{}^i B_m{}^j + h.c.$$

$$\mathcal{L}^{8a} = i \frac{g^{8a}}{4f^2} \bar{P}_{ijk} \epsilon^{lmk} \gamma^\mu (\partial_\mu \phi_l{}^a \phi_a{}^i - \phi_l{}^a \partial_\mu \phi_a{}^i) B_m{}^j + h.c.$$

Conclusion 1 : self-energy

- **Two-meson cloud effects are always attractive, and contribute to the antidecuplet mass splitting, of the order of 20%.**
- **Antidecuplet members have relatively small decay widths to MMB channel.**

A. Hosaka, T. H., F. J. Llanes-Estrada, E. Oset, J. R. Pelaez, M. J. Vicente Vacas, hep-ph/0411311, Phys. Rev. C, in press.

Future works

- **Other spin parity assignments**
- **Possible mixing with the other multiplets (8,27, ...).**

T. H. and A. Hosaka, Phys. Rev. D71, 054017 (2005)