Θ^+ production and two-meson coupling of antidecuplet

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2004, Nov. 18th

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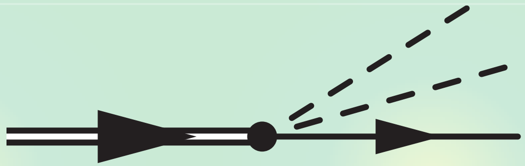
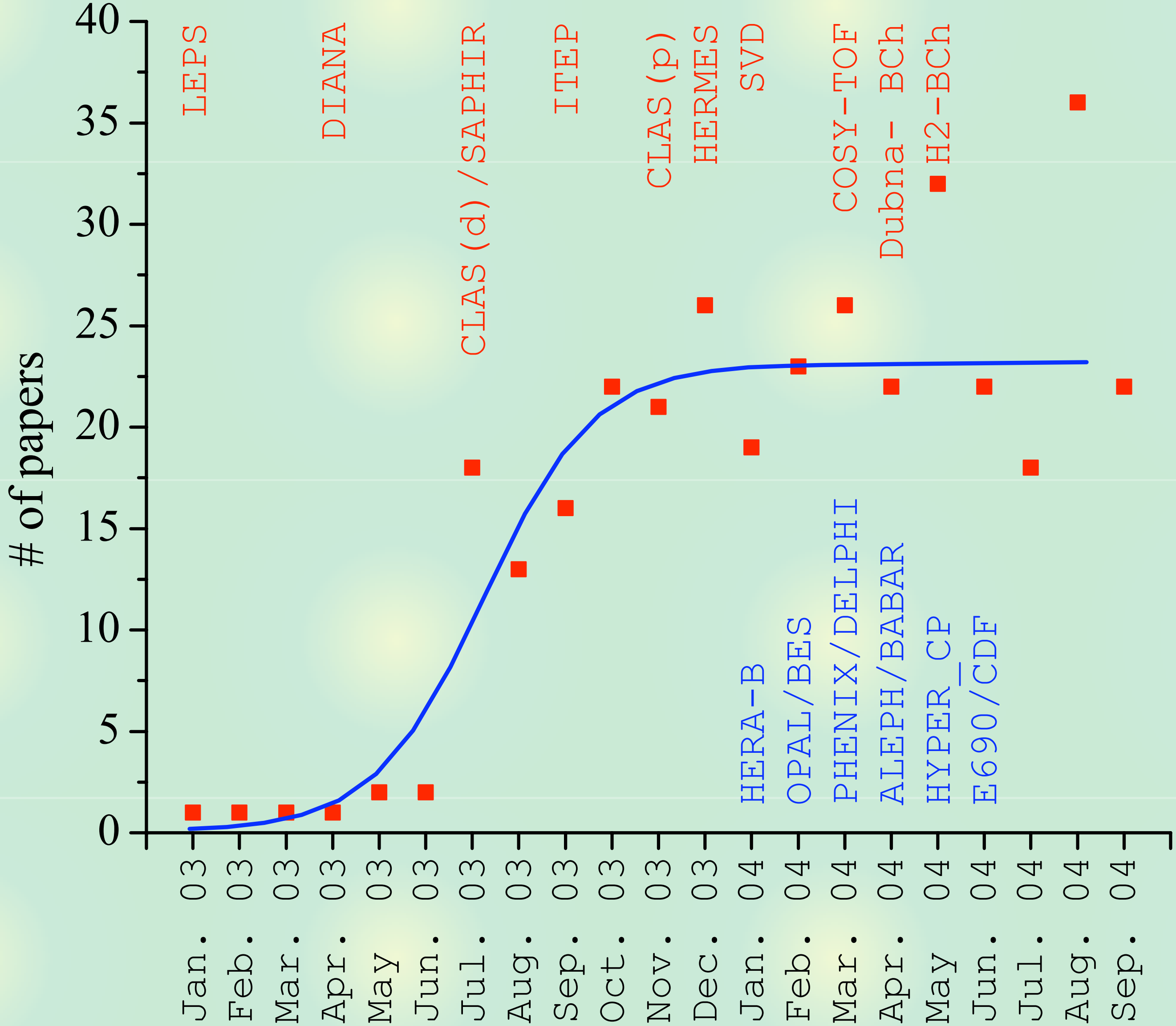


Introduction : Exotic activities



taken from K. Goeke, *et al.*, hep-ph/0411195

Introduction : Flavor SU(3) symmetry

Flavor SU(3) symmetry and its breaking by the strange quark mass

-> Phenomenologically well realized

Gell-Man—Okubo mass formulae ~ 3%

N(938), Λ(1116), Σ(1192), Ξ(1320),
Δ(1232), Σ(1385), Ξ(1530), Ω(1670)

Coleman-Glashow relation ~ 20%

Magnetic moments of baryon octet

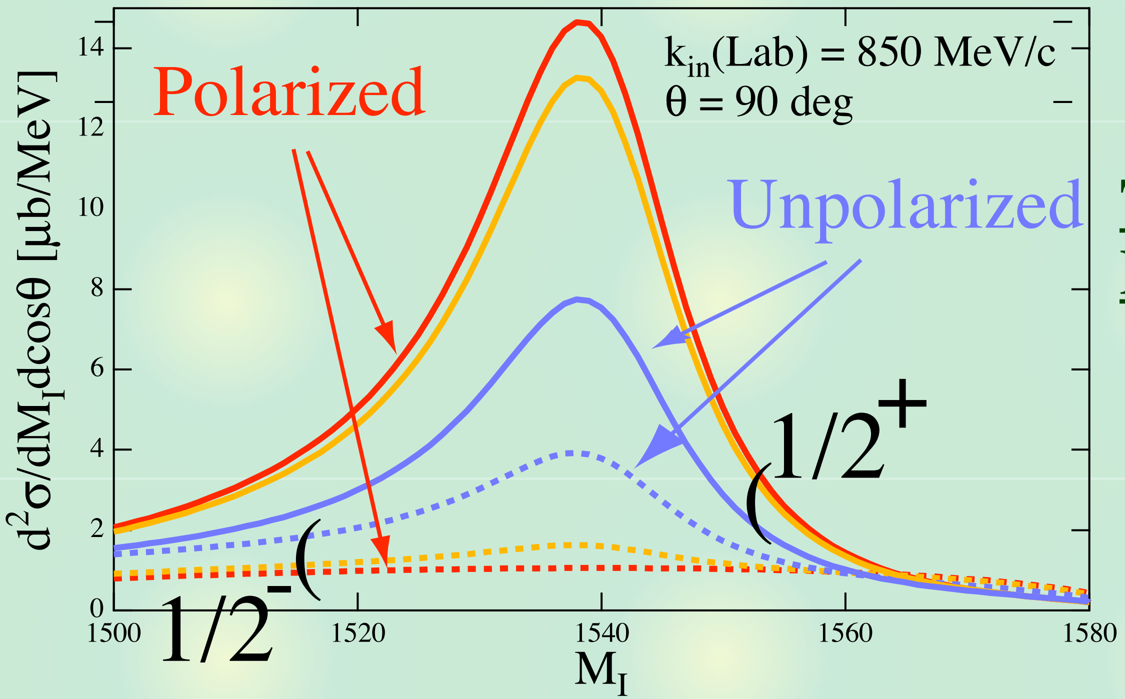
Existence of Θ^+ + Flavor SU(3) symmetry

➡ Existence of flavor partners of Θ^+

Introduction : determining the quantum numbers

We have proposed $K^+ p \to \pi^+ \Theta^+ \to \pi^+ K^+ n (K^0 p)$

Polarization observable can be used to determine the quantum numbers



T. H., A. Hosaka, E. Oset, Phys. Lett. B579, 290 (2004)

➡ **Understanding of reaction mechanism**

Motivations

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

Total cross section ~ 2 μb

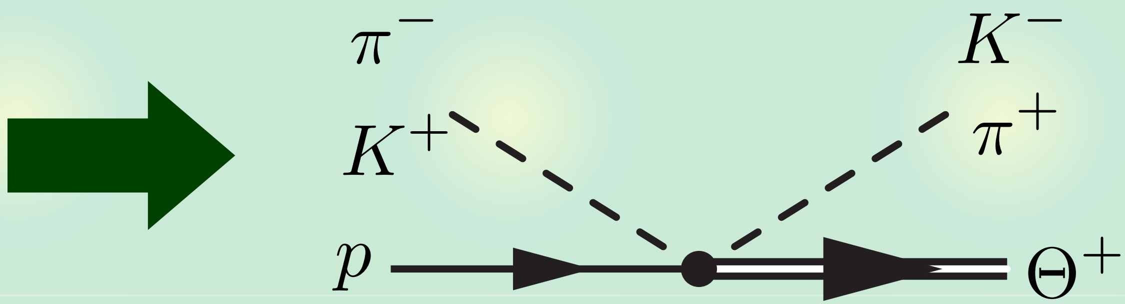
K. Miwa, talk given at PENTAQUARK04

Why so small? What about $K^+ p \to \pi^+ \Theta^+$?

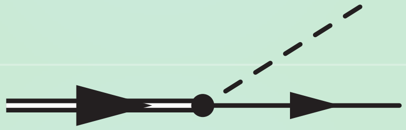
Two-meson coupling effects for Θ^+

Possibility of 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)

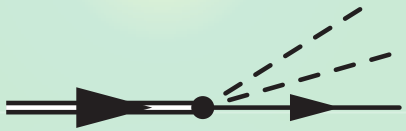


Two-meson coupling



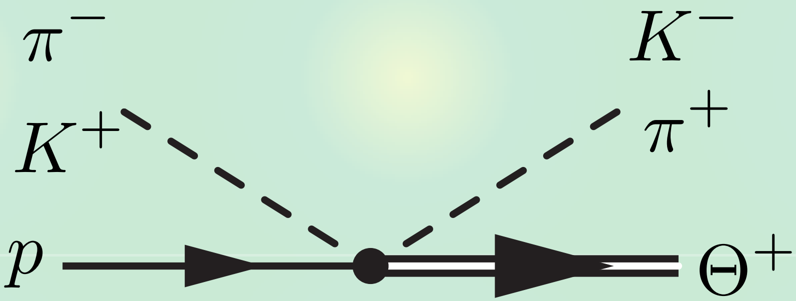
$$\Theta^+ \to KN$$ **Very narrow**

$$N(1710) \to \pi N$$ **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 SU(3) symmetric

Chiral symmetric? -> later

Small number of derivatives

low energy : OK

Assumptions for Θ^+

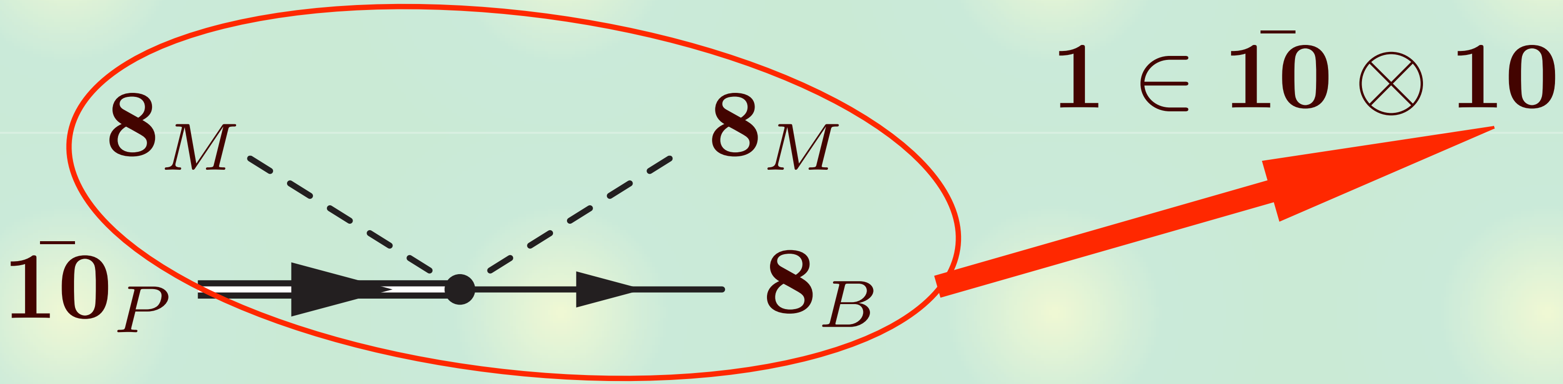
N(1710) is the S=0 partner of antidecuplet

-> $J^P = 1/2^+$

No mixing with 8, 27,...

T.D. Cohen, Phys. Rev. D70, 074023 (2004)
S. Pakvasa and M. Suzuki, Phys. Rev. D70, 036002 (2004)
S. Ceci, *et al.*, nucl-th/0406055

SU(3) structure of effective Lagrangian



$$\mathbf{8}_M \otimes \mathbf{8}_M \otimes \mathbf{8}_B = (\mathbf{1} \oplus \mathbf{8}^s \oplus \mathbf{8}^a \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{27})_{MM} \otimes \mathbf{8}_B$$

$$= \mathbf{8} \quad \leftarrow \text{from } \mathbf{1}_{MM} \otimes \mathbf{8}_B$$

$$\oplus (\mathbf{1} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{27}) \quad \leftarrow \text{from } \underline{\mathbf{8}^s_{MM}} \otimes \mathbf{8}_B$$

$$\oplus (\mathbf{1} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{27}) \quad \leftarrow \text{from } \underline{\mathbf{8}^a_{MM}} \otimes \mathbf{8}_B$$

$$\oplus (\mathbf{8} \oplus \mathbf{10} \oplus \mathbf{27} \oplus \mathbf{35}) \quad \leftarrow \text{from } \underline{\mathbf{10}_{MM}} \otimes \mathbf{8}_B$$

$$\oplus (\mathbf{8} \oplus \overline{\mathbf{10}} \oplus \mathbf{27} \oplus \mathbf{35}') \quad \leftarrow \text{from } \overline{\mathbf{10}}_{MM} \otimes \mathbf{8}_B$$

$$\oplus (\mathbf{8} \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{27} \oplus \mathbf{27} \oplus \mathbf{35} \oplus \mathbf{35}'' \oplus \mathbf{64}) \quad \leftarrow \text{from } \underline{\mathbf{27}_{MM}} \otimes \mathbf{8}_B$$

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

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

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

Construction of 8s Lagrangian

$$D_i{}^j[\mathbf{8}^s_{MM}] = \phi_i{}^a\phi_a{}^j + \phi_i{}^a\phi_a{}^j - \frac{2}{3}\delta_i{}^j\phi_a{}^b\phi_b{}^a$$
$$= 2\phi_i{}^a\phi_a{}^j - \frac{2}{3}\delta_i{}^j\phi_a{}^b\phi_b{}^a$$

$$T^{ijk}[\bar{\mathbf{10}}_{BMM(8s)}] = 2\phi_l{}^a\phi_a{}^i B_m{}^j\epsilon^{lmk} + (i,j,k \text{ symmetrized})$$

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

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

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

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

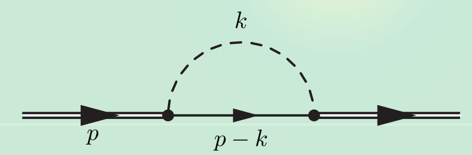
8a

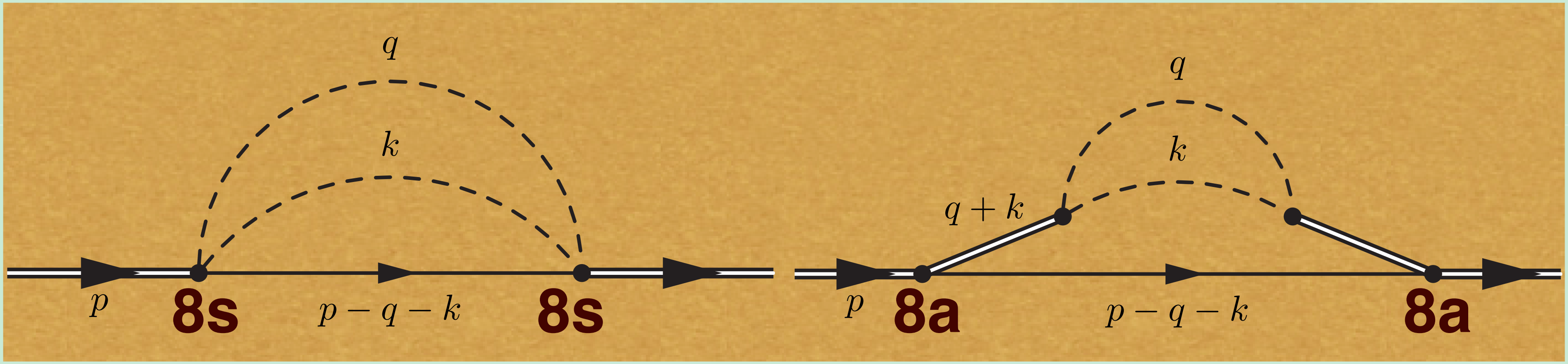
With one derivative

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

Diagrams for self-energy

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



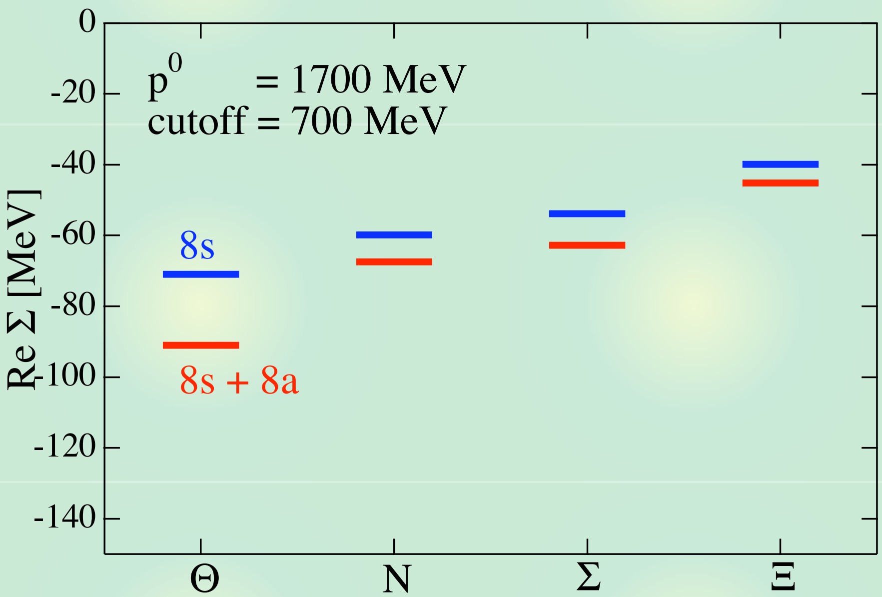


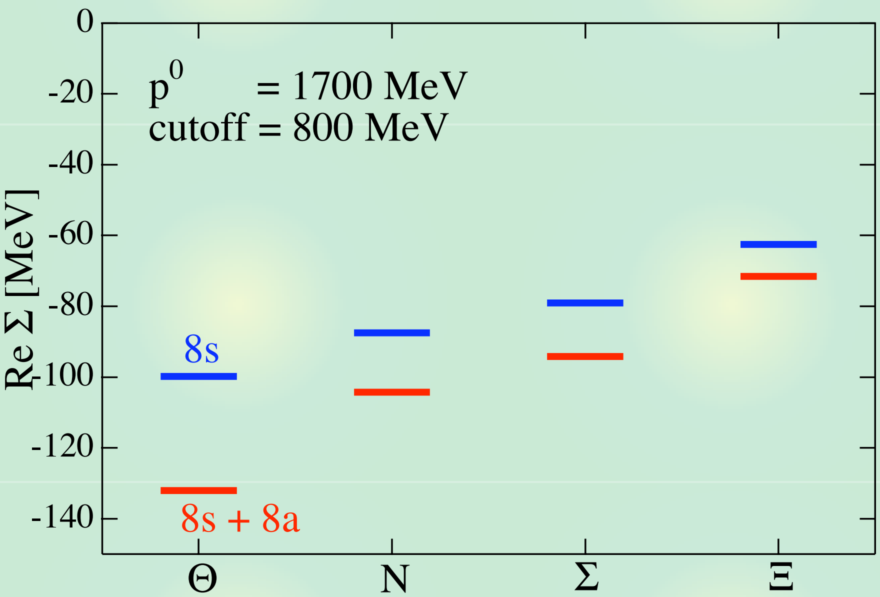
$N(1710) \to \pi\pi(s\text{-wave}, \ I = 0)N$ **25 MeV**

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

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

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





All mass shifts are attractive.

More bound for larger strangeness.

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

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

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

Other possible Lagrangians

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

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

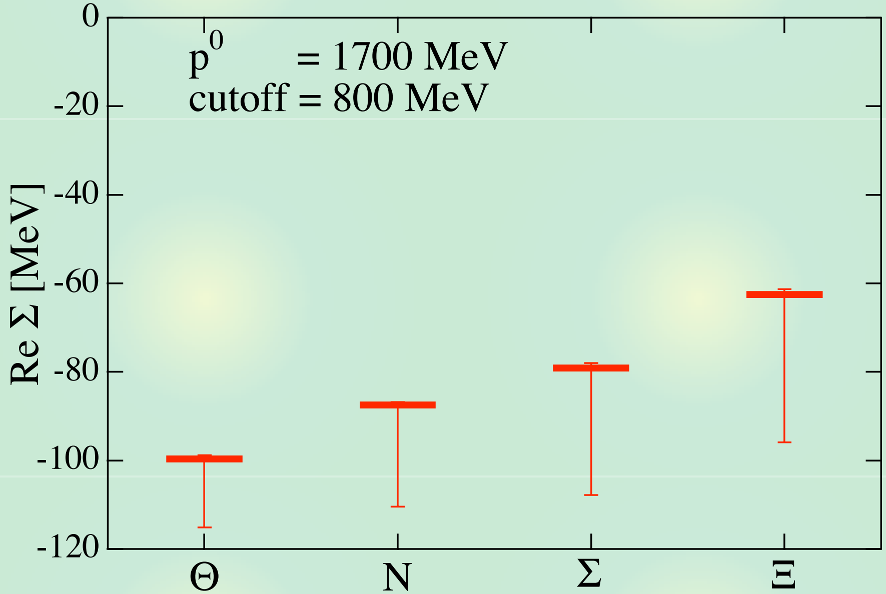
Treat them as a small perturbation to the 8s.

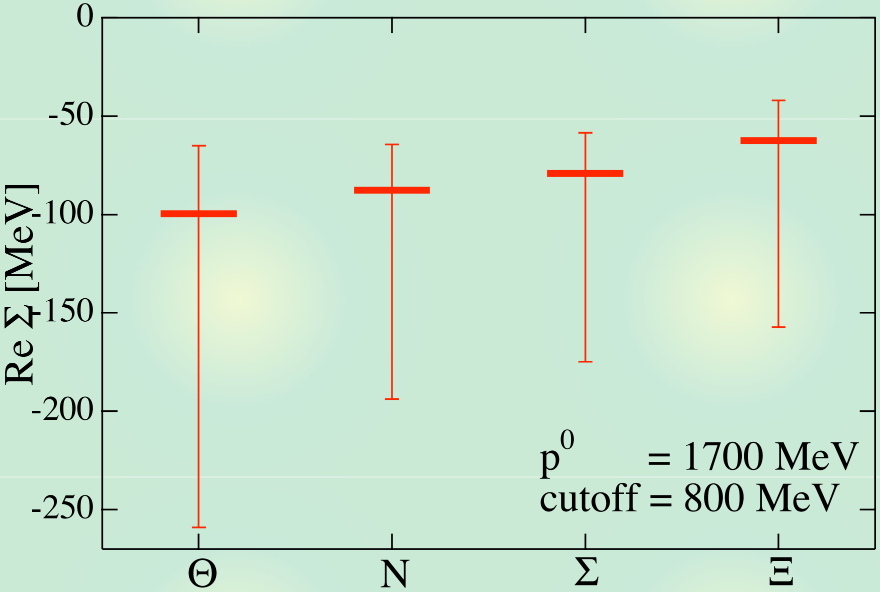
$$g^{27} = g^{M} = g^{8s} = 1.88\ , \quad b_{27} = -\frac{5}{4}(1-a)\ , \quad b_M = \frac{f^2}{m_\pi^2}(1-a)$$

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

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.**

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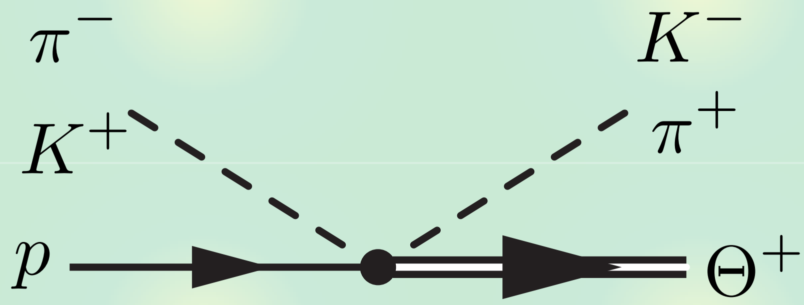
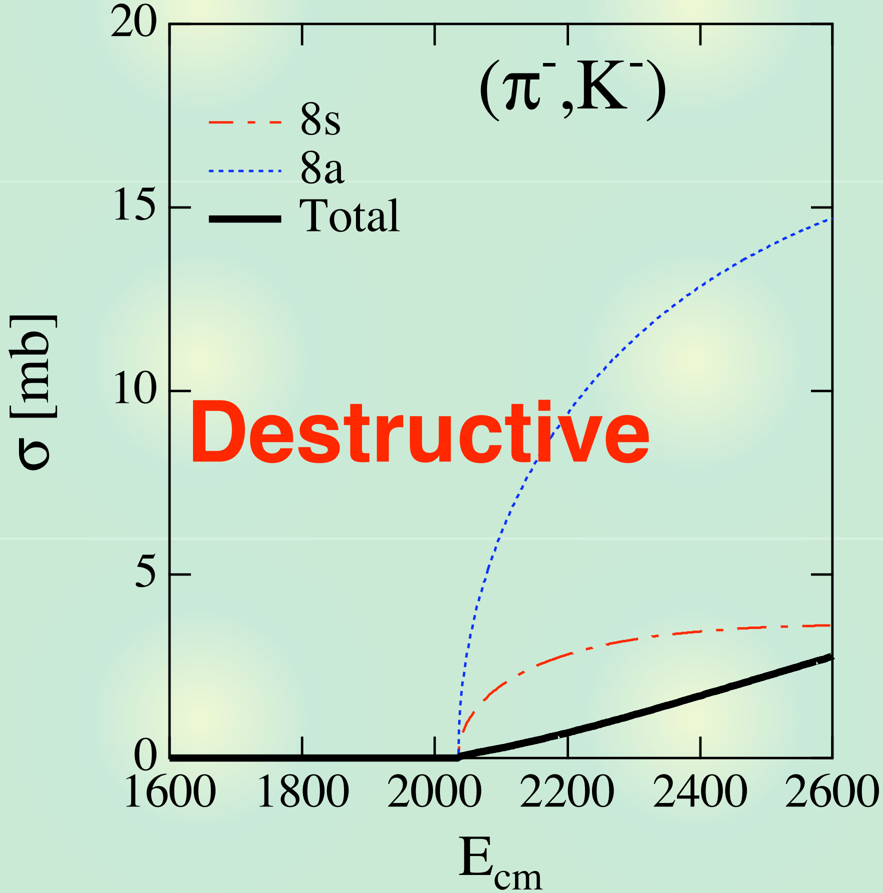
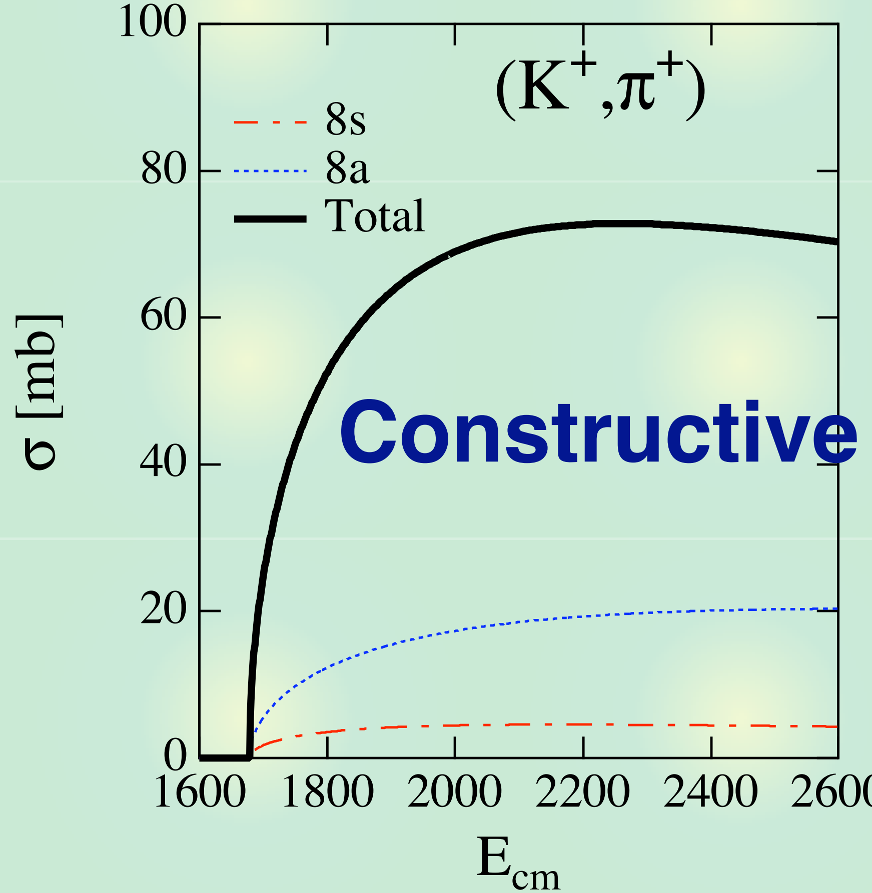
Results of reaction : cross sections

Total cross section of







Conclusion 2 : reactions

We investigate the Θ production in (π^-, K^-) and (K^+, π^+) reactions, with the vertices obtained from the self-energy study.

- The small cross section of the order of a few micro barn in (π^-, K^-) reaction may require some special mechanisms, such as **interference of two amplitudes**.

T. H., A. Hosaka, E. Oset, M. J. Vicente Vacas, *in preparation*

Future works

Self-energy

Chiral symmetric Lagrangian,
Possible mixing with the other flavor multiplets (8, 27, ...),

Reaction

Quantitative analysis (Form factor),
background cross section