Phenomenological study for the Θ^+ and two-meson coupling

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Introduction : Flavor SU(3) symmetry

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

➡ Existence of flavor partners of Θ^+

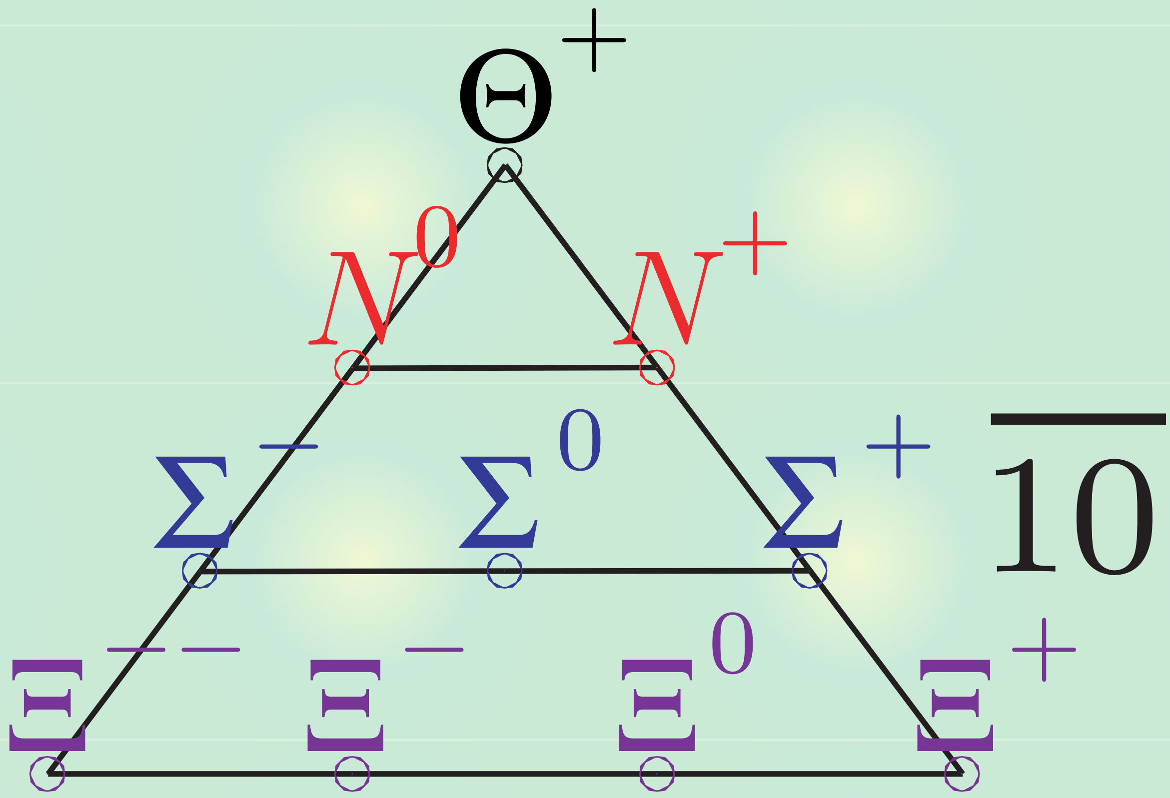
Assuming the flavor multiplet that Θ^+ belongs to, we examine its properties by symmetry relation, in connection with known baryon resonances.

➡ to determine the J^P of Θ^+

Phenomenological but model independent analysis up to $O(m_s)$

Pure antidecuplet case

Simplest assignment for Θ^+



Test the masses and widths of partners via flavor SU(3) symmetry relations

Pure antidecuplet case

Mass : Gell-Mann—Okubo formula

$$M(\overline{\mathbf{10}}; Y) = M_{\overline{\mathbf{10}}} - aY$$

Two parameters <— Mass of Θ and N*

Width : SU(3) symmetric coupling

$$g_{\Theta K N} = \sqrt{6} g_{N^* \pi N}$$

$$\Gamma_R = g_R^2 F_I \frac{p^{2l+1}}{M_R^{2l}}$$

One parameter <— Width of N*

Pure antidecuplet case

Mass and width [MeV]

$$M(\overline{\mathbf{10}};Y) = M_{\overline{\mathbf{10}}} - aY, \quad g_{\Theta KN} = \sqrt{6} g_{N^*\pi N}, \quad \Gamma_R = g_R^2 F_I \frac{p^{2l+1}}{M_R^{2l}}$$

J^P	M_Θ	M_N	M_Σ	M_Ξ	Γ_Θ
$1/2^-$	1540	1647	1753	1860	156.1
exp.	Θ(1540)	N(1650)	Σ(1750)	Ξ(1860)	
$1/2^+$					
exp.					
$3/2^+$					
exp.					
$3/2^-$					
exp.					

Pure antidecuplet case

Mass and width [MeV]

$$M(\overline{\mathbf{10}};Y) = M_{\overline{\mathbf{10}}} - aY, \quad g_{\Theta KN} = \sqrt{6} g_{N^*\pi N}, \quad \Gamma_R = g_R^2 F_I \frac{p^{2l+1}}{M_R^{2l}}$$

J^P	M_Θ	M_N	M_Σ	M_Ξ	Γ_Θ
$1/2^-$ exp.	1540 Θ(1540)	1647 N(1650)	1753 Σ(1750)	1860 Ξ(1860)	156.1
$1/2^+$ exp.	1540 Θ(1540)	1710 N(1710)	1880 Σ(1880)	2050 Ξ(2030)	7.2
$3/2^+$ exp.					
$3/2^-$ exp.					

Pure antidecuplet case

Mass and width [MeV]

$$M(\overline{\mathbf{10}};Y) = M_{\overline{\mathbf{10}}} - aY, \quad g_{\Theta KN} = \sqrt{6}g_{N^*\pi N}, \quad \Gamma_R = g_R^2 F_I \frac{p^{2l+1}}{M_R^{2l}}$$

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$3/2^+$ exp.	1540 Θ(1540)	1720 N(1720)	1900	2080	10.6
$3/2^-$ exp.					

Pure antidecuplet case

Mass and width [MeV]

$$M(\overline{\mathbf{10}};Y) = M_{\overline{\mathbf{10}}} - aY, \quad g_{\Theta KN} = \sqrt{6}g_{N^*\pi N}, \quad \Gamma_R = g_R^2 F_I \frac{p^{2l+1}}{M_R^{2l}}$$

J^P	M_Θ	M_N	M_Σ	M_Ξ	Γ_Θ
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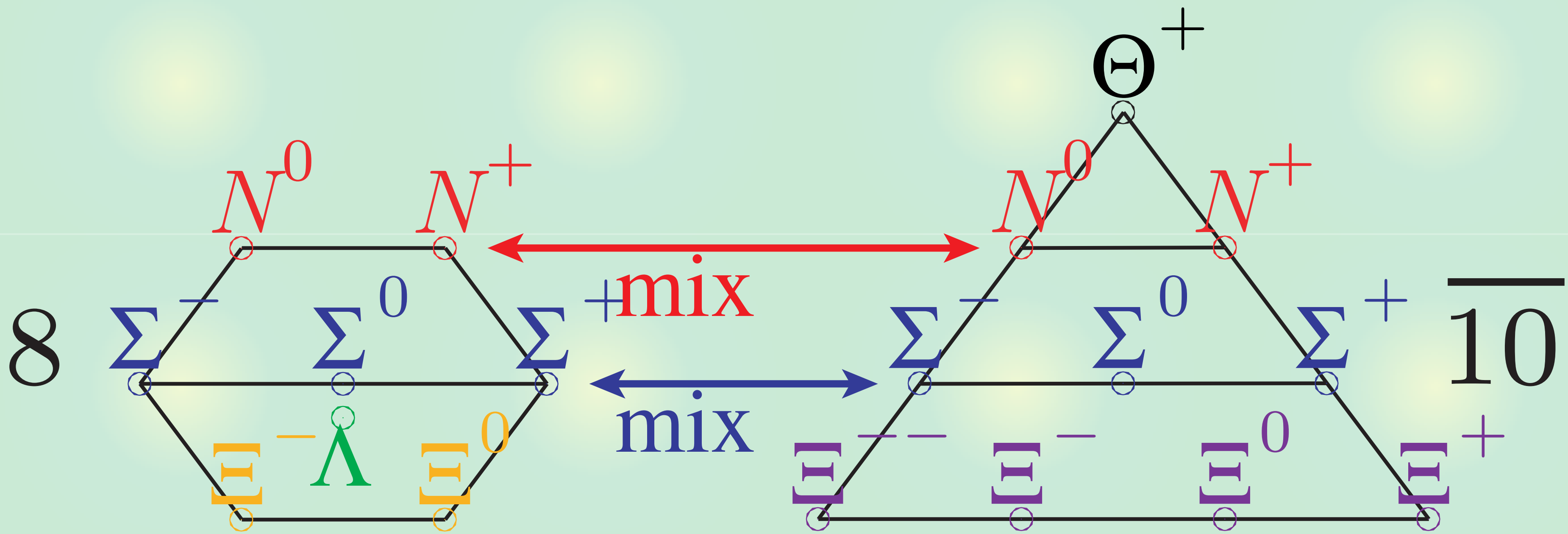
$3/2^+$ exp.	1540 Θ(1540)	1720 N(1720)	1900	2080	10.6
$3/2^-$ exp.	1540 Θ(1540)	1700 N(1700)	1860	2020 Ξ(2030)	1.3

are not reproduced simultaneously.

Octet-antidecuplet mixing

Second simplest assignment for Θ^+



Mixing is induced by the SU(3) breaking in mass term.

Octet-antidecuplet mixing

Mass formulae : GMO + mixing (N,Σ)

$$M_\Theta = M_{\overline{\mathbf{10}}} - 2a \qquad M_{\Xi_{\overline{10}}} = M_{\overline{\mathbf{10}}} + a$$

$$M_\Lambda = M_{\mathbf{8}} \qquad M_{\Xi_8} = M_{\mathbf{8}} + b + \frac{1}{2}c$$

$$M_{N_1} = \left(M_{\mathbf{8}} - b + \frac{1}{2}c\right)\cos^2\theta_N + (M_{\overline{\mathbf{10}}} - a)\sin^2\theta_N - \delta\sin 2\theta_N$$

$$M_{N_2} = \left(M_{\mathbf{8}} - b + \frac{1}{2}c\right)\sin^2\theta_N + (M_{\overline{\mathbf{10}}} - a)\cos^2\theta_N + \delta\sin 2\theta_N$$

$$M_{\Sigma_1} = (M_{\mathbf{8}} + 2c)\cos^2\theta_\Sigma + M_{\overline{\mathbf{10}}}\sin^2\theta_\Sigma - \delta\sin 2\theta_\Sigma$$

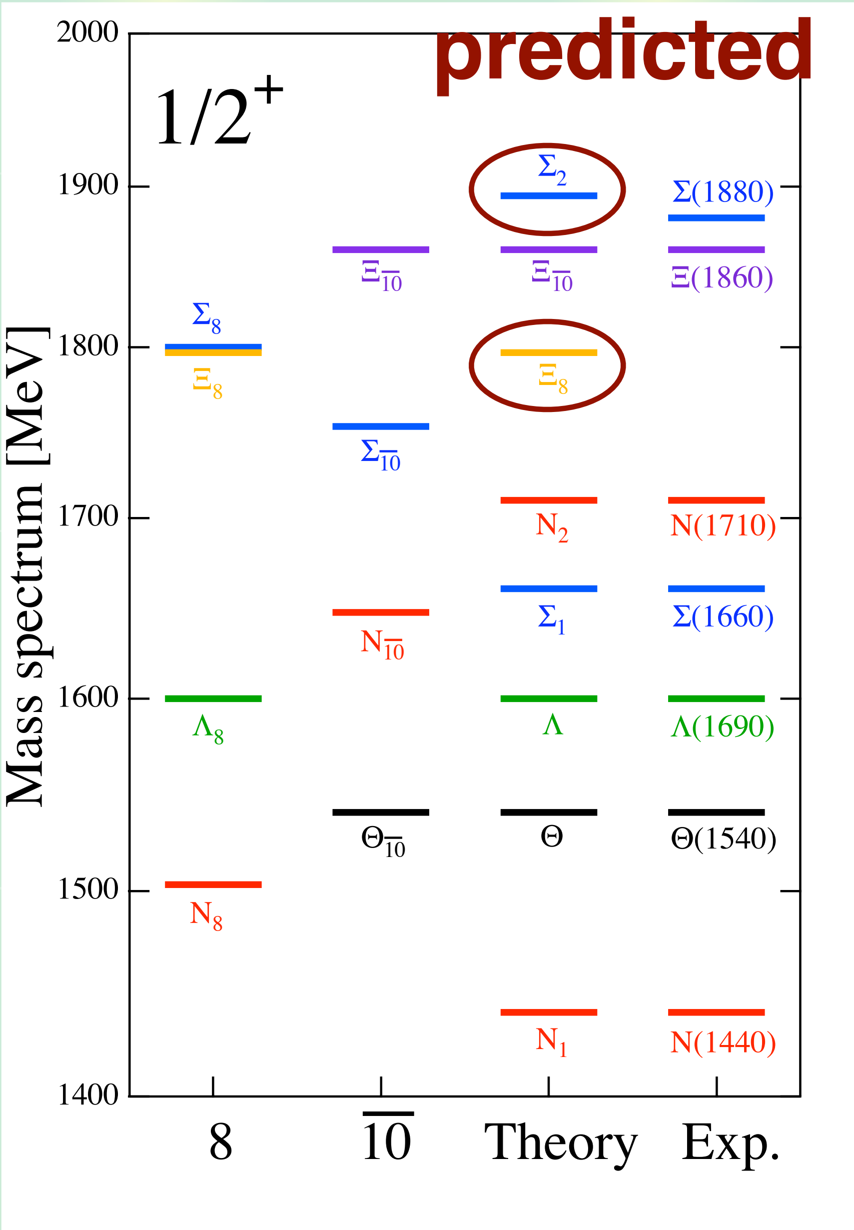
$$M_{\Sigma_2} = (M_{\mathbf{8}} + 2c)\sin^2\theta_\Sigma + M_{\overline{\mathbf{10}}}\cos^2\theta_\Sigma + \delta\sin 2\theta_\Sigma$$

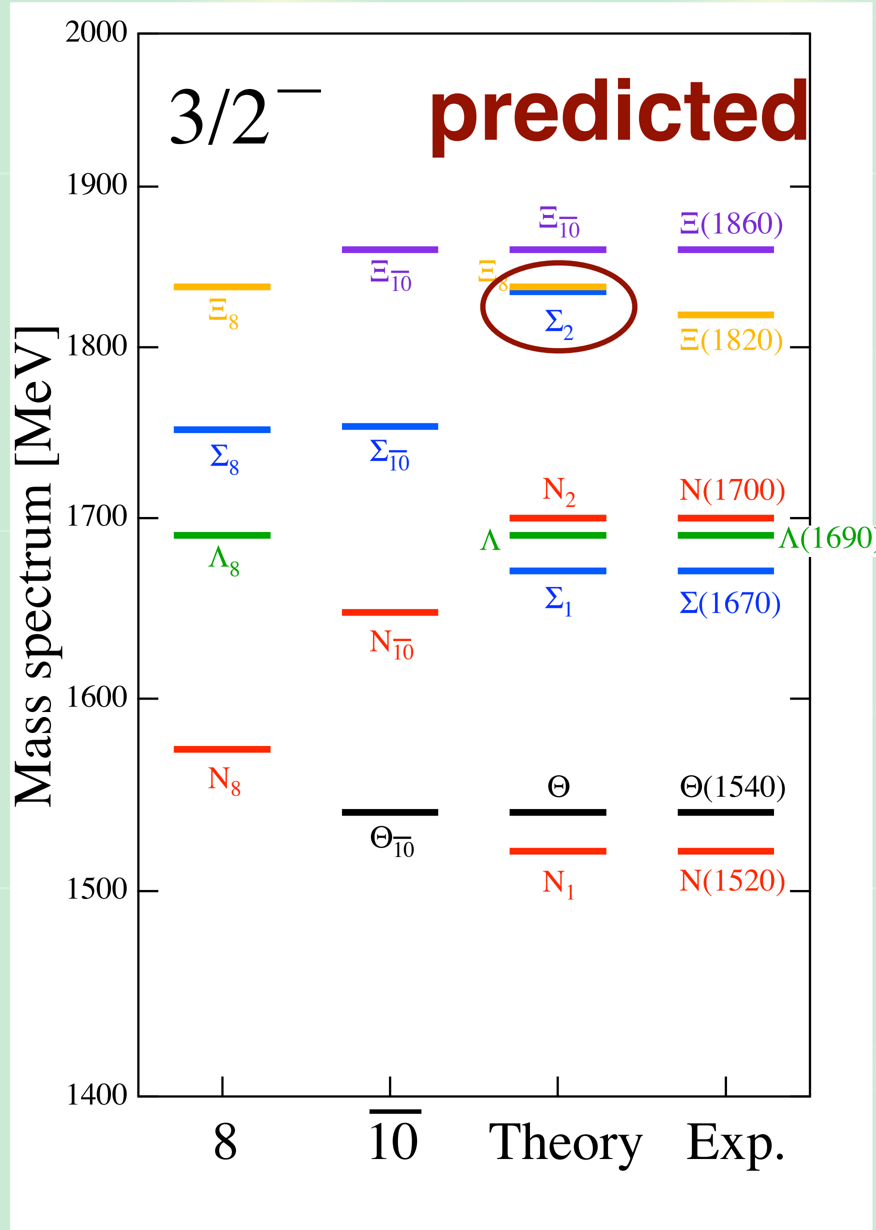
8 masses v.s. 6 parameters

$J^P = 1/2^-$: too wide width

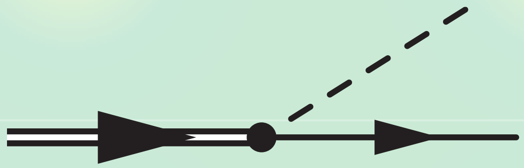
$J^P = 3/2^+$: states are not well established

Mass spectra





Decay width of Θ



N* decay

$$g_{\Theta} = \sqrt{6}(\underline{g_{N_2}}\, \underline{\cos\theta_N} - \underline{g_{N_1}}\, \underline{\sin\theta_N})$$

from masses

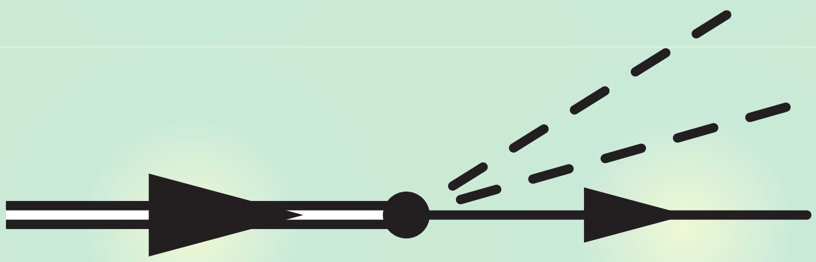
$$\Gamma_R = g_R^2 F_I \frac{p^{2l+1}}{M_R^{2l}}$$

J^P	θ_N [deg]	Γ_Θ [MeV]
$1/2^+$	29	29.1
$3/2^-$	33	3.1

Narrow width

Two-meson coupling

Then, what about two-meson coupling?

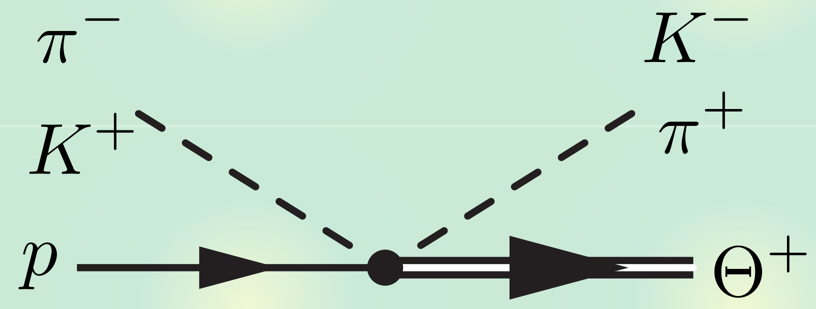


: large branching ratio of N* —> π π N

: π K N molecule picture for the Θ

SU(3) relation enable us to calculate

the cross section of



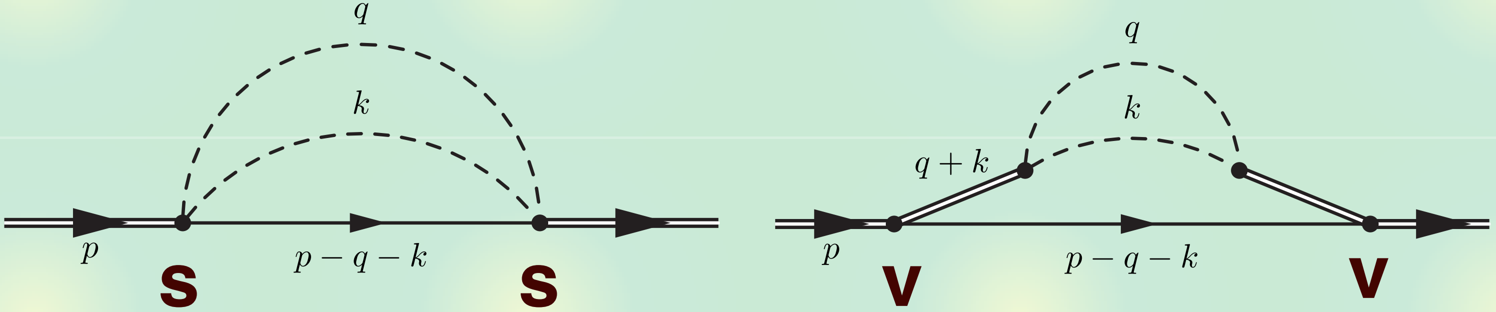
from the decay of N* —> π π N

Two-meson coupling

The structure of the two-meson coupling

Hosaka, Hyodo, Estrada, Oset, Peláez, Vacas, PRC71, 074021 (2005).

- The effect of the two-meson coupling was studied by evaluating the self-energy.
- We examined possible structures, and found that **two types** of the interaction Lagrangians were important.

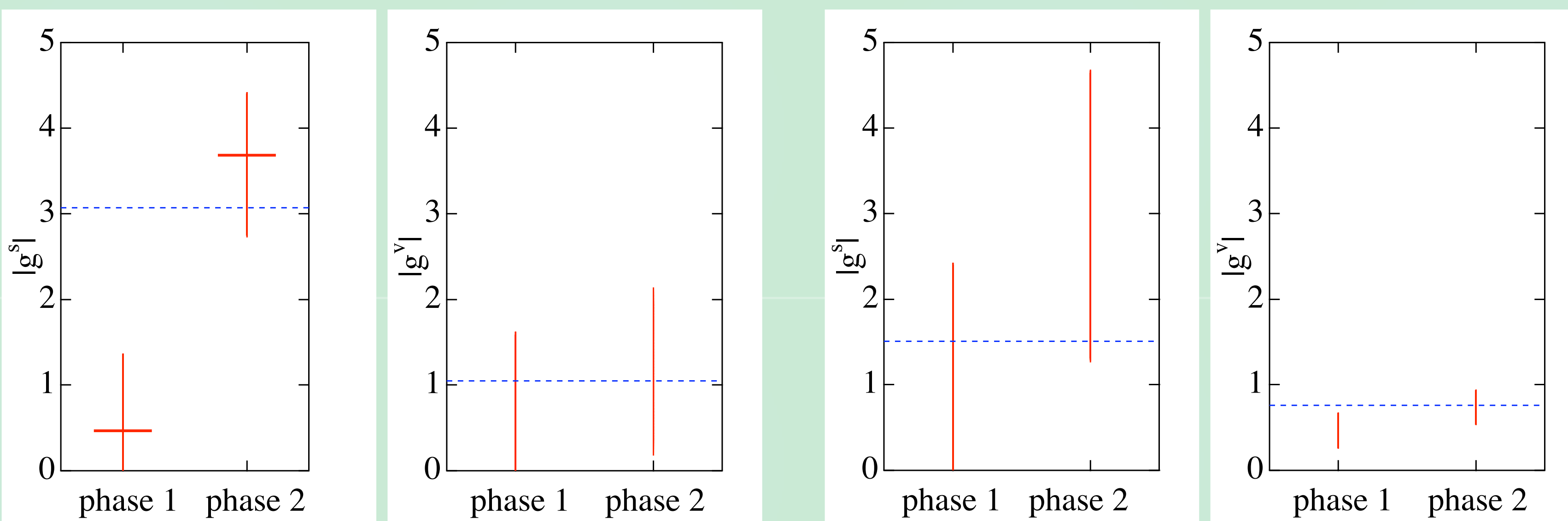


- These terms provided a sizable contribution.

Two-meson coupling

Branching fraction [%]

J^P	state	πN	$\pi\pi N(s)$	$\pi\pi N(v)$
$1/2^+$	N(1440)	65	7.5	<8
	N(1710)	15	25	15
$3/2^-$	N(1520)	55	25	20
	N(1700)	10	<85-95	<35

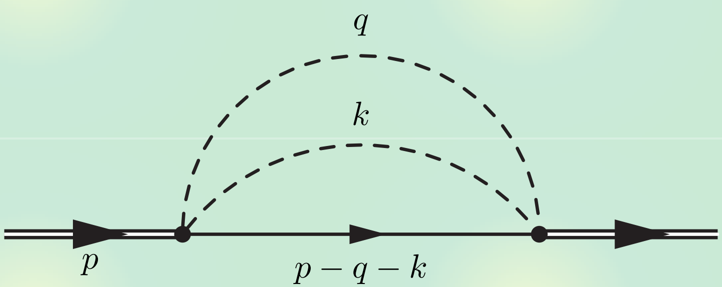


Still large uncertainty

Constraints on the coupling

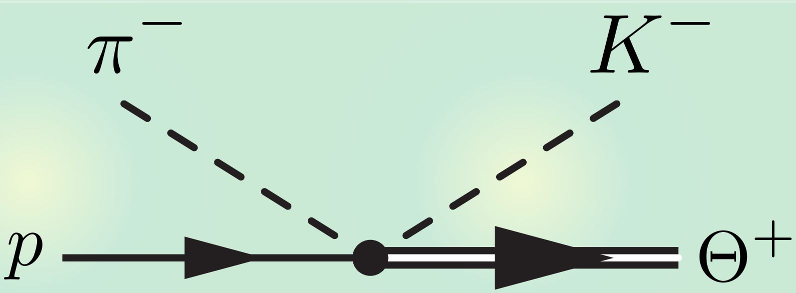
We impose phenomenological constraints.

Self-enefgy : not too large, but not too small



~ 100 MeV

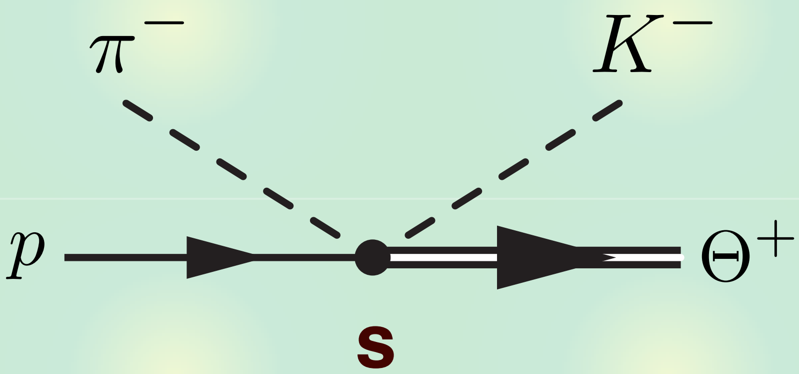
$\pi^- p \rightarrow K^- \Theta^+$ at KEK : upper limit is ~ 4.1 μb

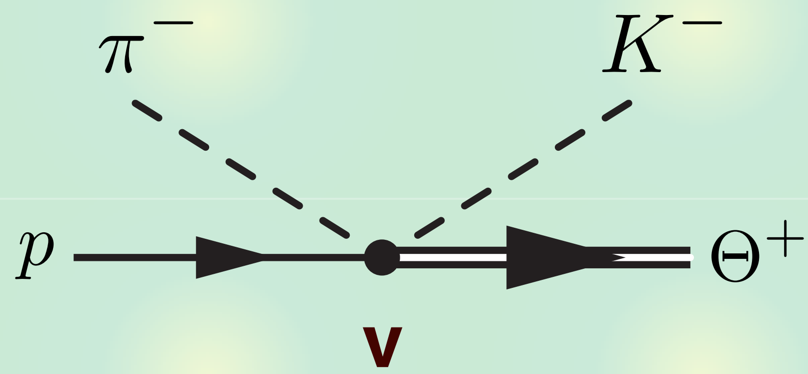


< 4.1 μb

Constraints on the coupling

Two structures should be added coherently.



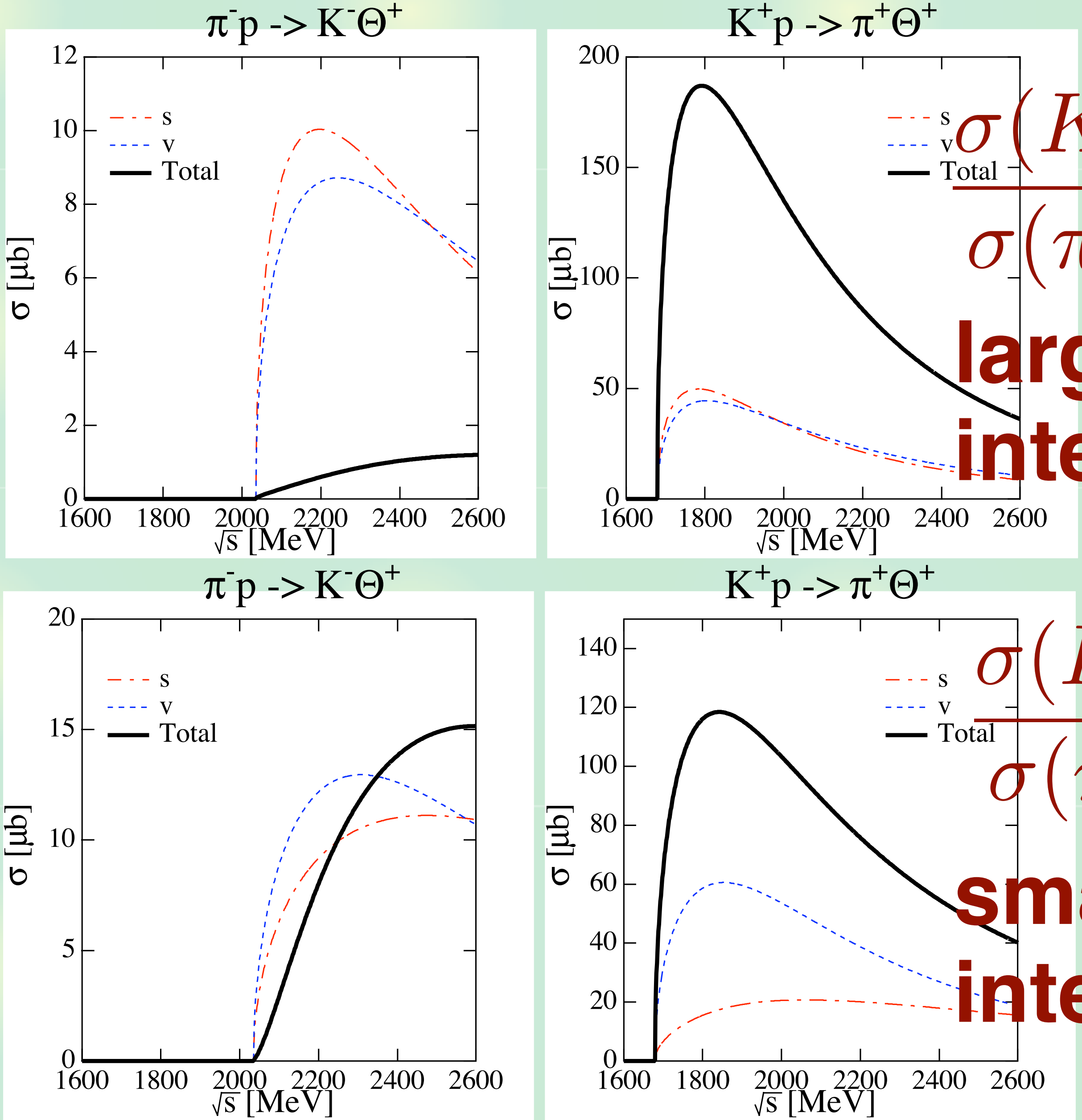


—> interference effect among s and v.

Θ production

$1/2^+$

$3/2^-$



$$\frac{\sigma(K^+)}{\sigma(\pi^-)} \sim 50$$

large interference

$$\frac{\sigma(K^+)}{\sigma(\pi^-)} \sim 3$$

small interference

Summary 1 : mixing scheme

We examine $8\text{–}\overline{10}$ mixing scheme for the exotic and non-exotic baryon resonances.

- Masses of Θ(1540) and Ξ(1860) are well fitted in the $8\text{–}\overline{10}$ mixing scheme with $J^P = 1/2^+$ or $3/2^-$ baryons.
- A very narrow width of Θ can be obtained for the $J^P = 3/2^-$ case.
- For both J^P, the mixing angle is close to the ideal angle.

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

Summary 2 : Two-meson coupling and Θ producion

Based on the mixing scheme, we evaluate the two-meson coupling of Θ, and calculate the reaction process for Θ production

- **There is an interference effect between two amplitudes, which is prominent for 1/2+ case and rather moderate for 3/2- case**

J^P	g^s	g^v	$\sigma_{K^+}/\sigma_{\pi^-}$	$\mathrm{Re}\Sigma_\Theta$
$1/2^+$	1.59	-0.27	50	-78 MeV
$3/2^-$	0.104	0.209	3	-23 MeV

T. Hyodo and A. Hosaka, Phys. Rev. C72, 055202 (2005)