On the nature of $K_0^*(800)$

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Outline

1. Motivation
2. Characteristics of vector kaon $K^*(892)$
3. Characteristics of scalar kaons $K_0^*(800)$ and $K_0^*(1430)$
4. Conclusions

Motivation

- Understanding of hadronic resonances.
- Determination of the position of the poles.
- Role of quantum loops.
- Vector kaonic sector: nice example of a Breit-Wigner-type narrow resonance ($K^*(892)$).
- Investigation of the scalar kaonic sector, which is more difficult (Two resonances:$K_0^*(1430)$ is very broad but well established, $K_0^*(800)$ is not yet in the summary of PDG).

vector kaon $K^*(892)$
PDG

$\boxed{K^*(892)}$ $I(J^P) = \frac{1}{2}(1^-)$

$K^*(892)^\pm$ hadroproduced mass $m = 891.66 \pm 0.26$ MeV
$K^*(892)^\pm$ in τ decays mass $m = 895.5 \pm 0.8$ MeV
$K^*(892)^0$ mass $m = 895.81 \pm 0.19$ MeV $(S = 1.4)$
$K^*(892)^\pm$ hadroproduced full width $\Gamma = 50.8 \pm 0.9$ MeV
$K^*(892)^\pm$ in τ decays full width $\Gamma = 46.2 \pm 1.3$ MeV
$K^*(892)^0$ full width $\Gamma = 47.4 \pm 0.6$ MeV $(S = 2.2)$

$K^*(892)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K\pi$	~ 100 %		289
$K^0\gamma$	$(2.46 \pm 0.21) \times 10^{-3}$		307
$K^\pm\gamma$	$(9.9 \pm 0.9) \times 10^{-4}$		309
$K\pi\pi$	$< 7 \times 10^{-4}$	95%	223

Lagrangian:

$$\mathcal{L}_v = cK^*(892)^+_\mu \partial^\mu K^- \pi^0 + \ldots \tag{1}$$

decay width:

$$\Gamma_{K^*}(m) = 3\frac{\left|\vec{k}_1\right|}{8\pi m^2}\frac{c^2}{3}\left[-M_\pi^2 + \frac{(m^2 + M_\pi^2 - M_K^2)^2}{4m^2}\right] e^{-2\left|\vec{k}_1\right|^2/\Lambda^2} \tag{2}$$

where:

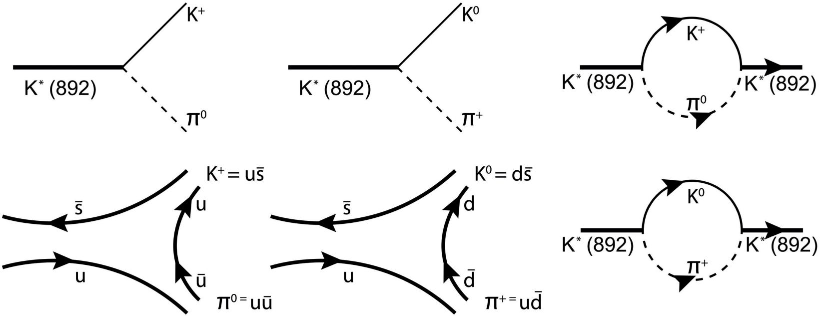
$$\left|\vec{k}_1\right| = \frac{\sqrt{m^4 + \left(M_K^2 - M_\pi^2\right)^2 - 2\left(M_K^2 + M_\pi^2\right)m^2}}{2m}\theta\left(m - M_K - M_\pi\right) \tag{3}$$

The scalar part of the propagator of $K^*(892)$:

$$\Delta_{K^*}(p^2 = m^2) = \frac{1}{m^2 - M_0^2 + \Pi(m^2) + i\varepsilon} \tag{4}$$

where M_0 is the bare mass of the vector kaon and $\Pi(m^2) = Re(m^2) + iIm(m^2)$ is the one-loop contribution.

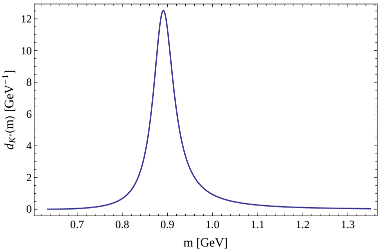
Feynman diagram



vector kaon $K^*(892)$
spectral function

Spectral function $d_{K^*}(m)dm$ determines the probability that $K^*(892)$ has a mass beetwen m and $m + dm$.

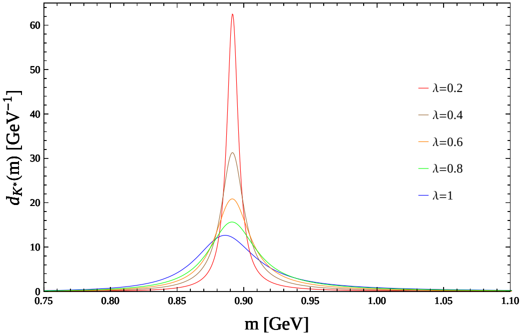
- Specral function:
  $d_{K^*}(m) = \frac{2m}{\pi} |\operatorname{Im} \Delta_{K^*}(p^2 = m^2)|$
- normalization condition:
  $\int_0^\infty d_{K^*}(m)\mathrm{dm} = 1$.



According to the optical theorem, $\operatorname{Im} \Pi(m) = m\Gamma_{K^*}(m)$.

vector kaon $K^*(892)$

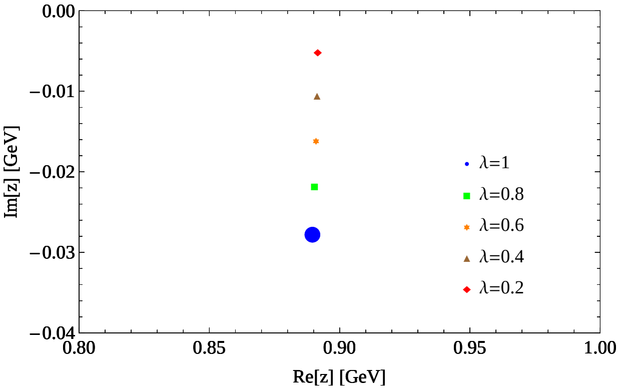
Large-N_c study of the resonance



$c \to \sqrt{\lambda}c, \quad \lambda \equiv \frac{3}{N_c}$ $\quad N_c$ is the number of colors

For large-N_c the spectral function tends to a Dirac$-\delta$, as expected.

vector kaon $K^*(892)$
pole



0.889543 – 0.0278042i

For large N_c the pole tends to the real axis.

- It behaves like a Breit-Wigner resonance.
- one peak – one single pole.
- Large$-N_c$ in agreement with $q\bar{q}$.

$\boxed{K_0^*(1430)}$ [nn] $I(J^P) = \frac{1}{2}(0^+)$

Mass $m = 1425 \pm 50$ MeV
Full width $\Gamma = 270 \pm 80$ MeV

$K_0^*(1430)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(93 ± 10) %	619
$K\eta$	$(8.6^{+2.7}_{-3.4})$ %	486

$K_0^*(800)$
or κ

$I(J^P) = \frac{1}{2}(0^+)$

OMITTED FROM SUMMARY TABLE

Needs confirmation. See the mini-review on scalar mesons under $f_0(500)$ (see the index for the page number).

$K_0^*(800)$ MASS

VALUE (MeV)			EVTS	DOCUMENT ID		TECN	COMMENT
682	**±29**	**OUR AVERAGE**		Error includes scale factor of 2.4. See the ideogram below.			
826	±49	$^{+49}_{-34}$	1338	[1] ABLIKIM	11B	BES2	$J/\psi \to K_S^0 K_S^0 \pi^+ \pi^-$
849	±77	$^{+18}_{-14}$	1421	[2,3] ABLIKIM	10E	BES2	$J/\psi \to K^\pm K_S^0 \pi^\mp \pi^0$
841	±30	$^{+81}_{-73}$	25k	[4,5] ABLIKIM	06C	BES2	$J/\psi \to \overline{K}^*(892)^0 K^+ \pi^-$
658	±13			[6] DESCOTES-G..	06	RVUE	$\pi K \to \pi K$
797	±19	±43	15k	[7,8] AITALA	02	E791	$D^+ \to K^- \pi^+ \pi^+$

Lagrangian:

$$\mathcal{L}_{int} = aK_0^{*+}K^-\pi^0 + bK_0^{*+}\partial_\mu K^-\partial^\mu\pi^0 + \ldots \tag{5}$$

decay width:

$$\Gamma_{K_0^*}(m) = 3\frac{\left|\vec{k}_1\right|}{8\pi m^2}\left[a - b\frac{m^2 - M_K^2 - M_\pi^2}{2}\right]^2 e^{-2\left|\vec{k}_1\right|^2/\Lambda^2} \tag{6}$$

where:

$$\left|\vec{k}_1\right| = \frac{\sqrt{m^4 + \left(M_K^2 - M_\pi^2\right)^2 - 2\left(M_K^2 + M_\pi^2\right)m^2}}{2m}\theta\left(m - M_K - M_\pi\right) \tag{7}$$

for $m = M_{K_0^*} \simeq 1.43$ GeV we have tree-level decay width $\Gamma_{K_0^*}^{tl} = \Gamma_{K_0^*}(M_{K_0^*})$.

propagator of the scalar kaonic field:

$$\Delta_{K_0^*}(p^2 = m^2) = \frac{1}{m^2 - M_0^2 + \Pi(m^2) + i\varepsilon} \tag{8}$$

where M_0 is the bare mass of the scalar kaon and $\Pi(m^2) = Re(m^2) + iIm(m^2)$ is the one-loop contribution.
Specral function:

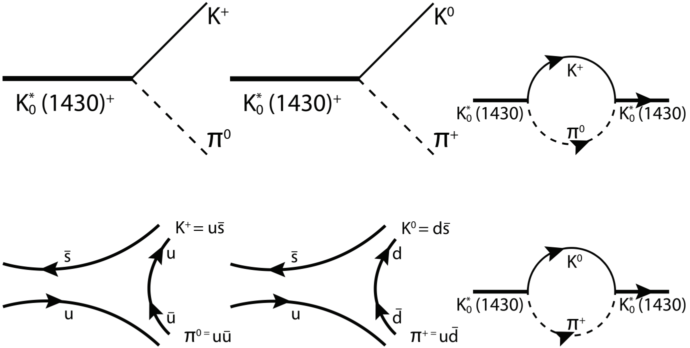
$$d_{K_0^*}(m) = \frac{2m}{\pi} |\operatorname{Im} \Delta_{K_0^*}(p^2 = m^2)| \tag{9}$$

normalization condition:

$$\int_0^\infty d_{K_0^*}(m)\mathrm{dm} = 1. \tag{10}$$

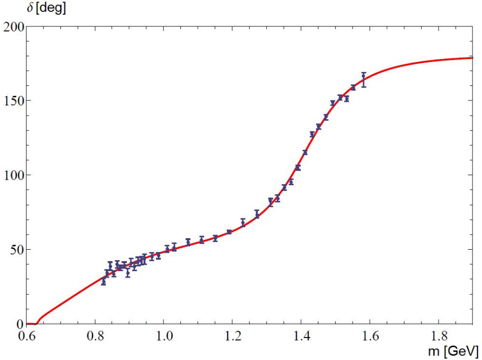
According to the optical theorem, $\operatorname{Im} \Pi(m) = m\Gamma_{K_0^*}(m)$.

Feynman diagram



scalar kaons
phase-shift

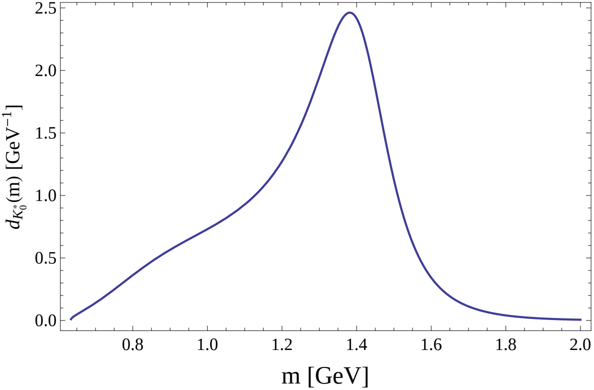
$$\delta(m) = \frac{1}{2}\arccos\left[1 - \pi\Gamma_{K_0^*}(m)d_{K_0^*}(m)\right] . \qquad (11)$$



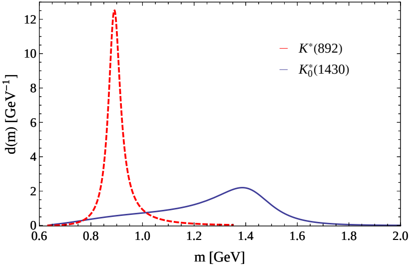
Fit

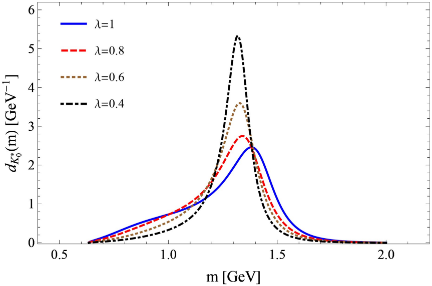
a	1.6007 *GeV*
b	-11.1599 GeV^{-1}
Λ	0.4958 *GeV*
M_0	1.2035 *GeV*

Is there a $K_0^*(800)$ or not?



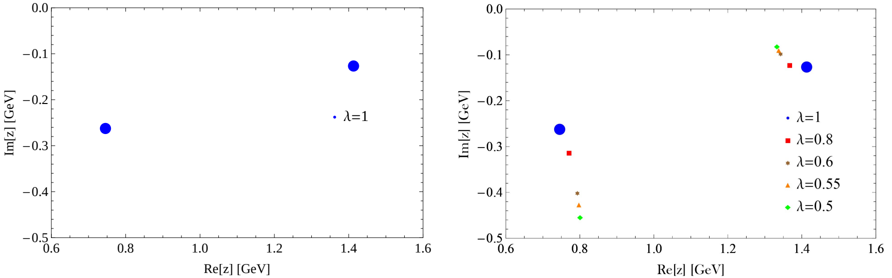
scalar kaons
spectral function





$a \to \sqrt{\lambda} a \qquad b \to \sqrt{\lambda} b$

scalar kaons
poles



$K_0^*(1430) : 1.412973 - 0.126548i$
$K_0^*(800) : 0.745554 - 0.262443i$

Summary

- Vector kaon behaves like a Breit-Wigner resonance, for one peak there is one pole.
- Scalar kaon: out of one ”seed” state $\rightarrow$ 2 poles appear
  - $K_0^*(1430)$ corresponds to a peak
  - $K_0^*(800)$ ”no peak” but there is a pole.
- We determined the position of the poles
  - for vector kaon (0.889543 – 0.0278042i)
  - for scalar kaons
    $K_0^*(1430)$: 1.412973 – 0.126548i
    $K_0^*(800)$: 0.745554 – 0.262443i
- $K^*(892)$ is a quark-antiquark state.
- $K_0^*(1430)$ is predominantly a quark-antiquark state.
- $K_0^*(800)$ is a molecular-like dynamically generated state.

Thank you for your attention