$\bar{K}$ induced formation of the $f_0(980)$ and $a_0(980)$ resonances on proton targets.

Ju Jun Xie, Wei Hong Liang and Eulogio Oset

Chiral dynamics and the $f_0(980)$, $a_0(980)$ resonances

B^0, B^0s decays into J/psi and $f_0(500)$, $f_0(980)$

D^0 decay into K^0 and $f_0(500)$, $f_0(980)$, $a_0(980)$

K^- and K^0bar induced production of $f_0(980)$ and $a_0(980)$

K induced production of $f'_2(1525)$, $f_0(1700)$, $f_1(1285)$,
a1, …………….new states which have strangeness

Meson interaction

Pseudoscalar-pseudoscalar interaction: channels

1) $\pi^+ \pi^-$
2) $\pi^0 \pi^0$
3) $K^+ K^-$
4) K^0 Kbar^0
5) $\eta\eta$

We use the chiral unitary approach: Bethe Salpeter equations in coupled channels

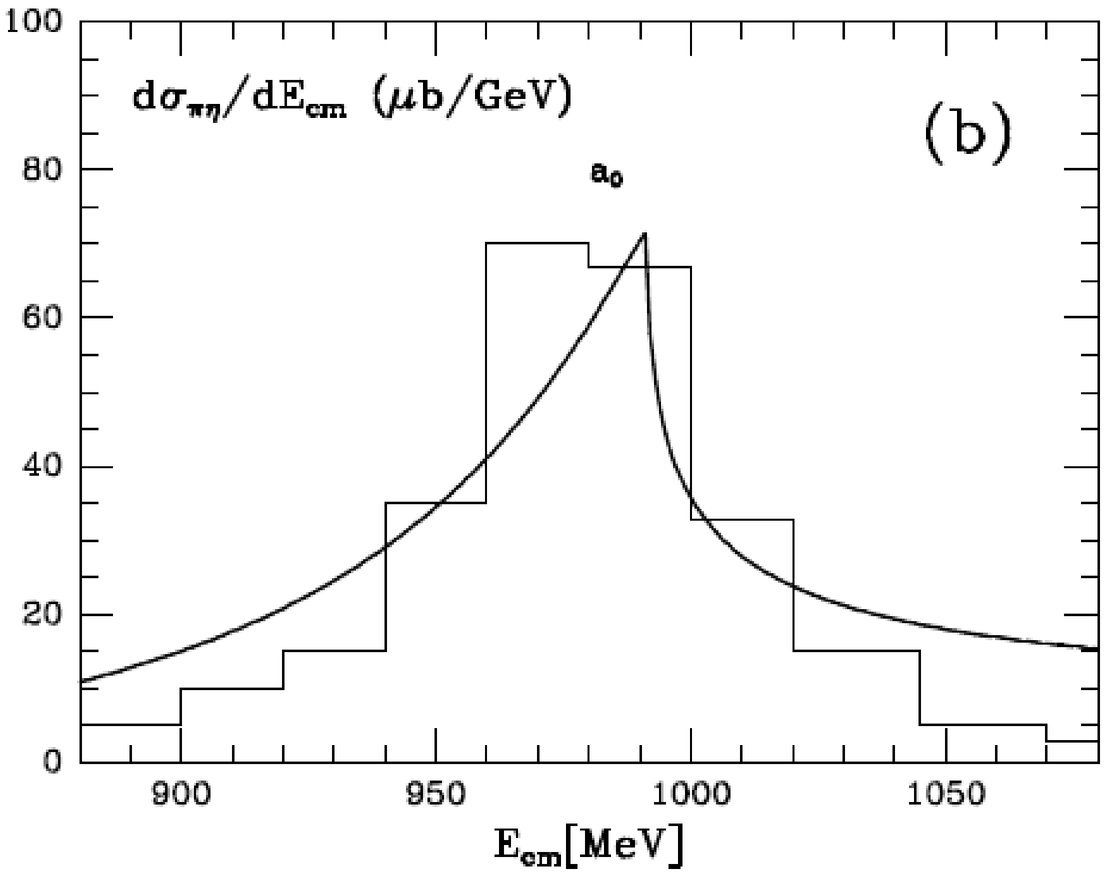
$$T=(1-VG)^{-1}\,V$$

With V obtained from the chiral Lagrangians and G the loop function of two meson propagators .

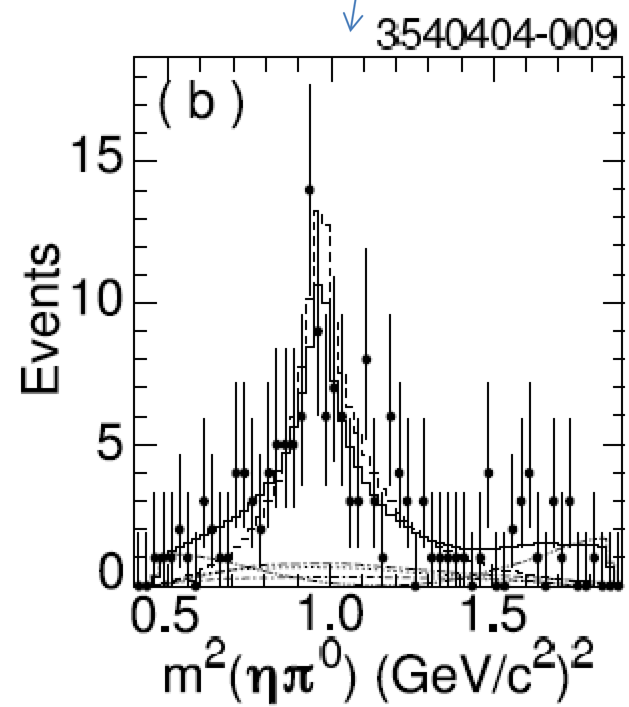
$$G_{jj}(s) = \int_0^{q_{max}} \frac{q^2 dq}{(2\pi)^2} \frac{\omega_1+\omega_2}{\omega_1\omega_2[P^{02}-(\omega_1+\omega_2)^2+i\epsilon]}$$

$$\begin{aligned}
&V_{11} = -\frac{1}{2f^2}s, && V_{12} = -\frac{1}{\sqrt{2}f^2}(s-m_\pi^2), && V_{13} = -\frac{1}{4f^2}s,\\
&V_{14} = -\frac{1}{4f^2}s, && V_{15} = -\frac{1}{3\sqrt{2}f^2}m_\pi^2, && V_{22} = -\frac{1}{2f^2}m_\pi^2,\\
&V_{23} = -\frac{1}{4\sqrt{2}f^2}s, && V_{24} = -\frac{1}{4\sqrt{2}f^2}s, && V_{25} = -\frac{1}{6f^2}m_\pi^2,\\
&V_{33} = -\frac{1}{2f^2}s, && V_{34} = -\frac{1}{4f^2}s, && V_{35} = -\frac{1}{12\sqrt{2}f^2}(9s-6m_\eta^2-2m_\pi^2),\\
&V_{44} = -\frac{1}{2f^2}s, && V_{45} = -\frac{1}{12\sqrt{2}f^2}(9s-6m_\eta^2-2m_\pi^2), && V_{55} = -\frac{1}{18f^2}(16m_K^2-7m_\pi^2),
\end{aligned} \tag{8}$$

For I=1 we add the πη channel and obtain the $a_0(980)$



$D^0 \rightarrow K^0_S \eta \pi^0$ **Decay**

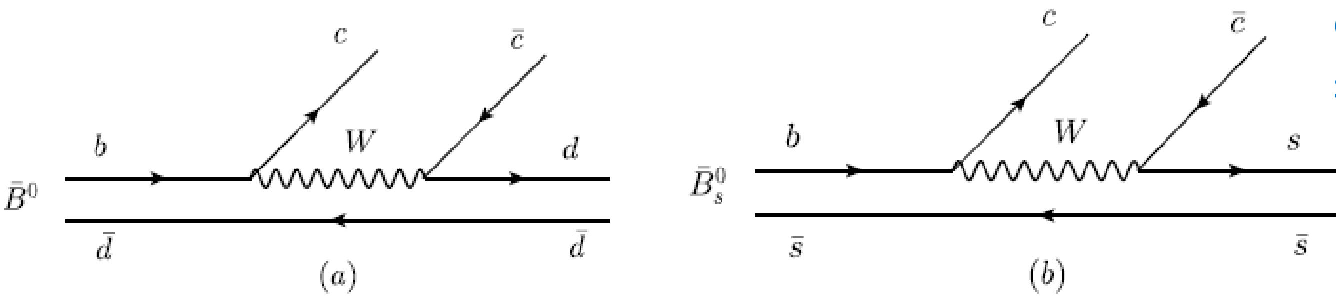


J.~R.~Pelaez, %``From controversy to precision on the sigma meson: a review on the status of the non-ordinary \$f_0(500)\$ resonance,''
arXiv:1510.00653 [hep-ph].

B^0 and B_s^0 decays into $J/\psi\ f_0(980)$ and $J/\psi\ f_0(500)$ and the nature of the scalar resonances

W.H. Liang, EO

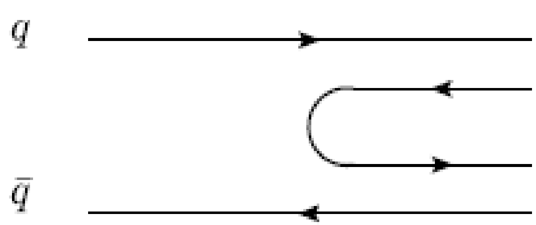
PLB 2014



Cabibbo suppressed

u	c	t
d	s	b

Cabibbo allowed



$q\bar{q}(u\bar{u} + d\bar{d} + s\bar{s})$

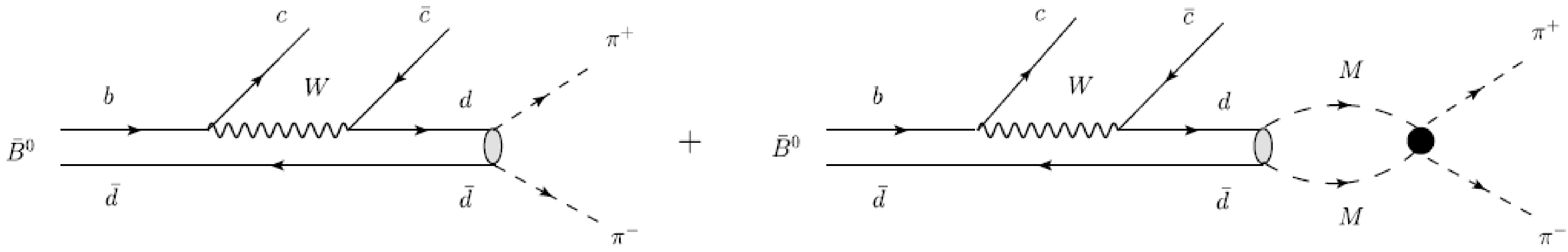
$$M = \begin{pmatrix} u\bar{u} & u\bar{d} & u\bar{s} \\ d\bar{u} & d\bar{d} & d\bar{s} \\ s\bar{u} & s\bar{d} & s\bar{s} \end{pmatrix}$$

$$M \cdot M = M \times (u\bar{u} + d\bar{d} + s\bar{s})$$

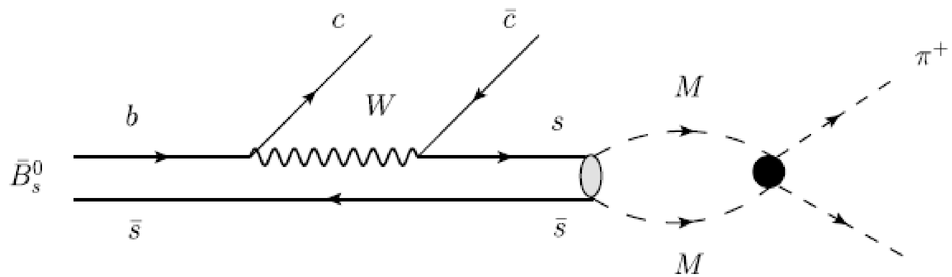
$$\phi = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix}$$

$$d\bar{d}(u\bar{u} + d\bar{d} + s\bar{s}) \equiv (\phi \cdot \phi)_{22}$$
$$= \pi^-\pi^+ + \frac{1}{2}\pi^0\pi^0 - \frac{1}{\sqrt{3}}\pi^0\eta + K^0\bar{K}^0 + \frac{1}{6}\eta\eta,$$

$$s\bar{s}(u\bar{u} + d\bar{d} + s\bar{s}) \equiv (\phi \cdot \phi)_{33} = K^-K^+ + K^0\bar{K}^0 + \frac{4}{6}\eta\eta. \qquad (4)$$



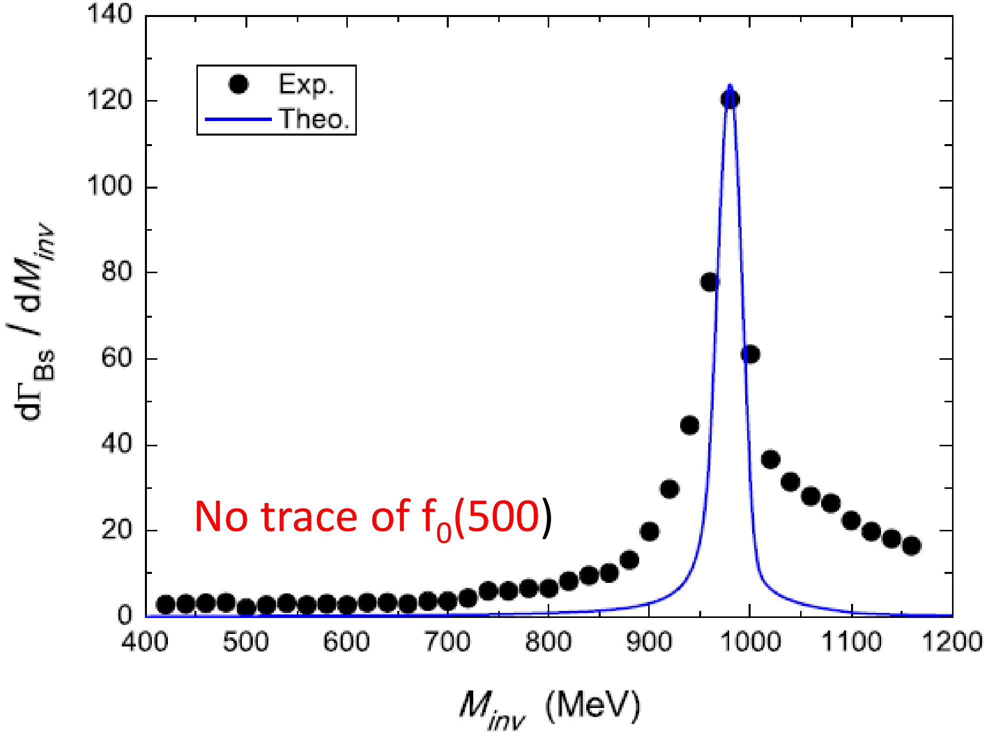
(a)



(b)

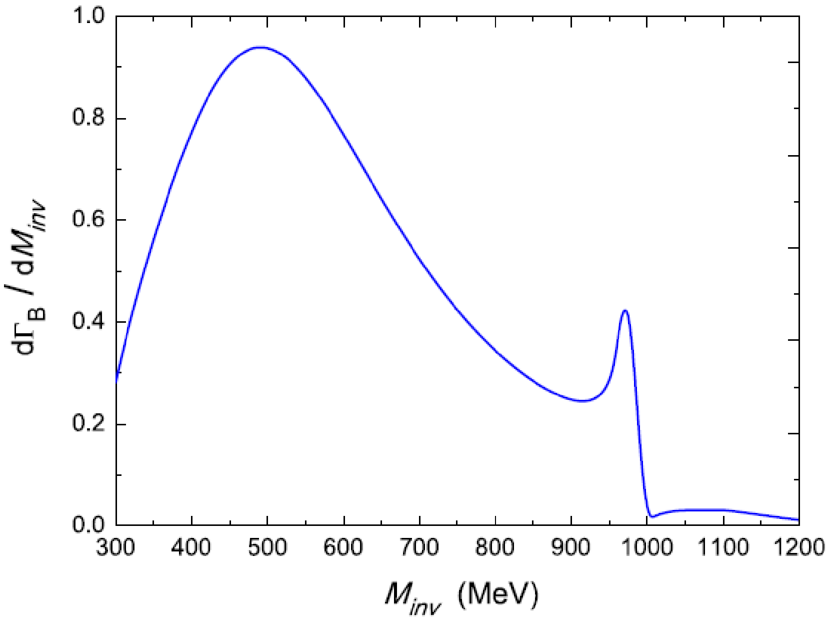
$$t(\bar{B}^0 \to J/\psi\pi^+\pi^-)$$
$$= V_P V_{cd}\left(1 + G_{\pi^+\pi^-}t_{\pi^+\pi^-\to\pi^+\pi^-} + \frac{1}{2}\frac{1}{2}G_{\pi^0\pi^0}t_{\pi^0\pi^0\to\pi^+\pi^-}\right.$$
$$\left.+ G_{K^0\bar{K}^0}t_{K^0\bar{K}^0\to\pi^+\pi^-} + \frac{1}{6}\frac{1}{2}G_{\eta\eta}t_{\eta\eta\to\pi^+\pi^-}\right),$$
$$t(\bar{B}_s^0 \to J/\psi\pi^+\pi^-)$$
$$= V_P V_{cs}\left(G_{K^+K^-}t_{K^+K^-\to\pi^+\pi^-}\right.$$
$$\left.+ G_{K^0\bar{K}^0}t_{K^0\bar{K}^0\to\pi^+\pi^-} + \frac{4}{6}\frac{1}{2}G_{\eta\eta}t_{\eta\eta\to\pi^+\pi^-}\right), \quad (5)$$

$$V_{cd} = -\sin\theta_c = -0.22534$$
$$V_{cs} = \cos\theta_c = 0.97427.$$



$\bar{B}_s^0 \to J/\psi \pi^+ \pi^-$ decay

One normalization is arbitrary but the two decays share the same normalization



$\bar{B}^0 \to J/\psi \pi^+ \pi^-$ decay

$$\frac{\mathcal{B}[\bar{B}^0 \to J/\psi f_0(980),\ f_0(980) \to \pi^+\pi^-]}{\mathcal{B}[\bar{B}^0 \to J/\psi f_0(500),\ f_0(500) \to \pi^+\pi^-]} = 0.033 \pm 0.007$$

Our result

Exp: $(0.6^{+0.7+3.3}_{-0.4-2.6}) \times 10^{-2}$ 0–0.046

$$\frac{\Gamma(B^0 \to J/\psi f_0(500))}{\Gamma(B_s^0 \to J/\psi f_0(980))} \simeq (4.5 \pm 1.0) \times 10^{-2}$$

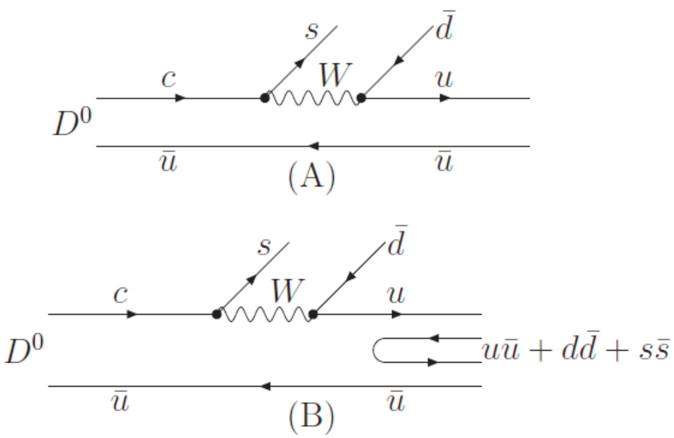
Our result

Exp: $(2.08\text{–}4.13) \times 10^{-2}$

Note: all the ratios and the mass distributions are obtained with no free parameters, the only one has been fitted to scattering data.

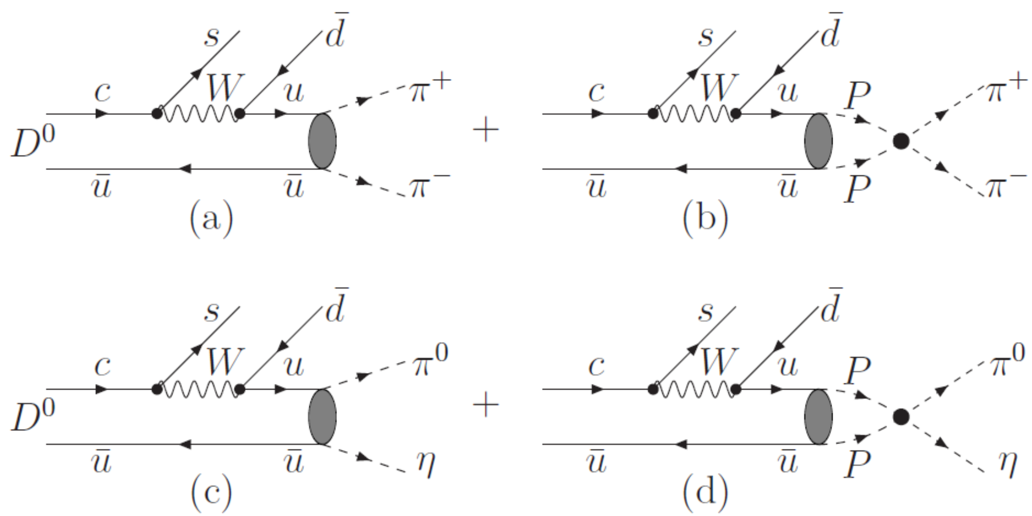
The low lying scalar resonances in the D^0 decays into K^0_s and $f_0(500)$, $f_0(980)$, $a_0(980)$

L. R. Dai, J. Jun Xie and E.O., PLB 2015



$$u\bar{u}(\bar{u}u + \bar{d}d + \bar{s}s) \equiv (\phi \cdot \phi)_{11} = \frac{1}{2}\pi^0\pi^0$$

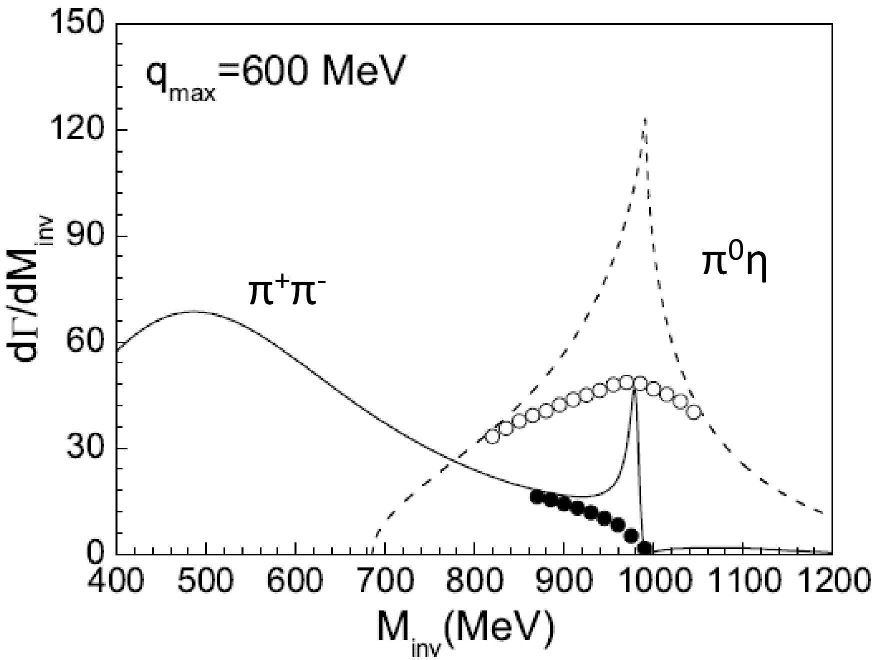
$$+\frac{1}{3}\eta\eta + \frac{2}{\sqrt{6}}\pi^0\eta + \pi^+\pi^- + K^+K^-,$$



$$t(D^0 \to \bar{K}^0\pi^+\pi^-) = V_P(1 + G_{\pi^+\pi^-}t_{\pi^+\pi^-\to\pi^+\pi^-}$$
$$+\frac{1}{2}\frac{1}{2}G_{\pi^0\pi^0}t_{\pi^0\pi^0\to\pi^+\pi^-} + \frac{1}{3}\frac{1}{2}G_{\eta\eta}t_{\eta\eta\to\pi^+\pi^-}$$
$$+G_{K^+K^-}t_{K^+K^-\to\pi^+\pi^-}),$$

$$t(D^0 \to \bar{K}^0\pi^0\eta) = V_P(\sqrt{\frac{2}{3}} +$$

(6) $$\sqrt{\frac{2}{3}}G_{\pi^0\eta}t_{\pi^0\eta\to\pi^0\eta} + G_{K^+K^-}t_{K^+K^-\to\pi^0\eta})$$



$$R = \frac{\Gamma(D^0 \to \bar{K}^0 a_0(980), a_0(980) \to \pi^0\eta)}{\Gamma(D^0 \to \bar{K}^0 f_0(980), f_0(980) \to \pi^+\pi^-)} = 6.7 \pm 1.3$$

Exp. $R = 5.33^{+2.4}_{-1.9}$ Muramatsu (CLEO) 2002, Rubin (CLEO) 2004

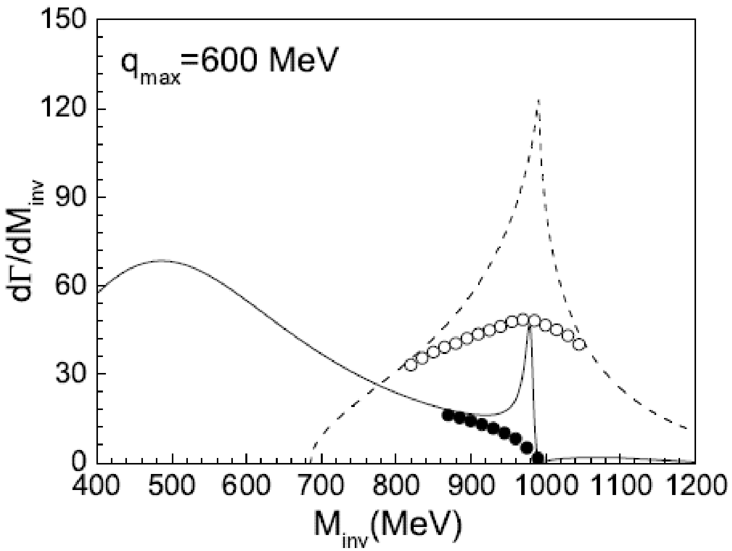
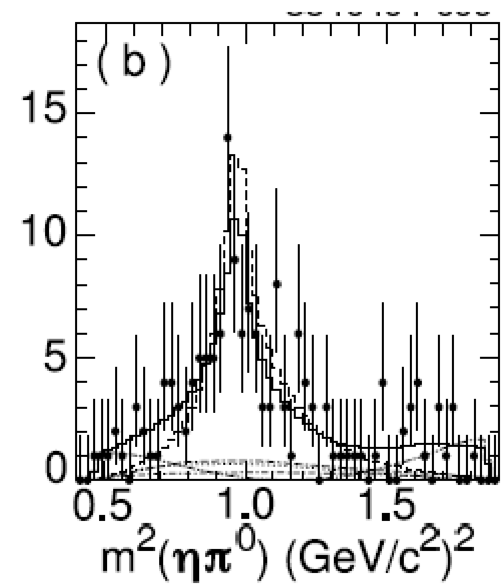


FIG. 3: The $\pi^+\pi^-$ (solid line) and $\pi^0\eta$ (dashed line) invariant mass distributions for the $D^0 \to \bar{K}^0\pi^+\pi^-$ decay and $D^0 \to \bar{K}^0\pi^0\eta$ decay, respectively. A smooth background is plotted below the $a_0(980)$ and $f_0(980)$ peaks.

Xie, Dai, E. O. PLB 742, 2015



P. Rubin *et al.* [CLEO Collaboration] Phys. Rev. Lett. **93**, 111801 (2004).

The coupling of the $f_0(980)$ to K Kbar should be obvious from the former discussion.

Yet, one can still read papers as

Meson resonances, large N_c and chiral symmetry

V. Cirigliano, G. Ecker, H. Neufeld, A. Pich, JHEP 0306 (2003) 012

“”Turning to the isoscalar sector, both scenarios A and B correctly predict that f0(980)couples predominantly to the ππ state.””

“”Altogether, our analysis favours a lightest “pre-existing” scalar nonet consisting of the states f0(980), K∗0(1430), a0(1450), f0(1500)””

Although support for the dynamically generated nature of the $f_0(980)$ has kept growing, opinions like this tell us that any extra information from new reactions should be most welcome.

Kaon induced ππ and πη production

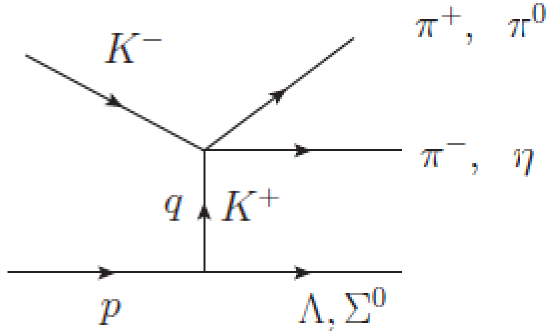


FIG. 1: Feynman diagram for the $K^-p \to \Lambda(\Sigma^0)\pi^+\pi^-(\pi^0\eta)$ reaction.

Ju-Jun Xie, We-Hong Liang, Eulogio Oset

arXiv:1512.01888

$$V_{K^+K^-\to\pi^+\pi^-}(pK^-, q) = V^{\text{on}}_{K^+K^-\to\pi^+\pi^-}(M_{\text{inv}}) + \beta(q^2 - m_K^2)$$

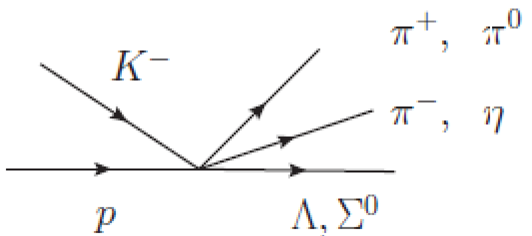


FIG. 2: Cotact term steming from the Feynman diagram of Fig.1 from the off shell part of the $K^+K^- \to \pi^+\pi^-(\pi^0\eta)$ transition potential.

The chiral Lagrangians of Ecker, Gasser, Leutwyler, Meissner…with mesons and Nucleons, contain terms with three mesons and one baryon which cancel exactly this off shell term → only on shell Kkbar -> π π must be used and not consider the contact term. MOST WELCOME. OBSERVABLES CANNOT DEPEND ON OFF SHELL TERMS

The Yukawa PBB vertex

$$\mathcal{L} = \frac{1}{2}D\langle \bar{B}\gamma^\mu\gamma_5\{u_\mu, B\}\rangle + F\langle \bar{B}\gamma^\mu\gamma_5[u_\mu, B]\rangle$$
$$= \frac{1}{2}(D+F)\langle \bar{B}\gamma^\mu\gamma_5 u_\mu B\rangle + \frac{1}{2}(D-F)\langle \bar{B}\gamma^\mu\gamma_5 B u_\mu\rangle$$

$$u_\mu \simeq -\sqrt{2}\frac{\partial_\mu\Phi}{f}$$

$$F = 0.795, \;\; D = 0465$$

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

$$\mathcal{L} = i\left(\alpha\frac{D+F}{2f} + \beta\frac{D-F}{2f}\right)\bar{u}\gamma^\mu\gamma_5 u q^\mu,$$

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

	$K^-p \to \Lambda$	$K^-p \to \Sigma^0$	$K^-n \to \Sigma^-$
α	$-\frac{2}{\sqrt{3}}$	0	0
β	$\frac{1}{\sqrt{3}}$	1	$\sqrt{2}$

	$\bar{K}^0 n \to \Lambda$	$\bar{K}^0 n \to \Sigma^0$	$\bar{K}^0 p \to \Sigma^+$
α	$-\frac{2}{\sqrt{3}}$	0	0
β	$\frac{1}{\sqrt{3}}$	-1	$\sqrt{2}$

$$T = -it_{K\bar{K}\to MM}\frac{1}{q^2 - m_K^2}\left(\alpha\frac{D+F}{2f} + \beta\frac{D-F}{2f}\right)$$
$$\times\, \bar{u}(p', s'_{\Lambda/\Sigma})\not{q}\gamma_5 u(p, s_p) F(q^2),$$

$$F(q) = \frac{\Lambda^2}{\Lambda^2 - q^2}$$

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}M_{\mathrm{inv}}\,\mathrm{d}\cos\theta} = \frac{M_p M'}{32\pi^3}\frac{|\vec{p'}|}{|\vec{p}|}\frac{|\vec{\tilde{p}}|}{s}\overline{\sum_{s_p}}\sum_{s'_{\Lambda/\Sigma}}|T|^2$$

Λ= 1 GeV

$$\overline{\sum}\sum|T_i|^2 = \left|t^{(i)}_{K\bar{K}\to MM}\right|^2\left(\frac{1}{q^2 - m_K^2}\right)^2$$
$$\times\frac{(M+M')^2}{4MM'}\left[(M-M')^2 - q^2\right]$$
$$\times\left(\alpha\frac{D+F}{2f} + \beta\frac{D-F}{2f}\right)^2 F(q)^2.$$

$$q^2 = M^2 + M'^2 - 2EE' + 2pp'\cos\theta.$$

We study 9 reactions

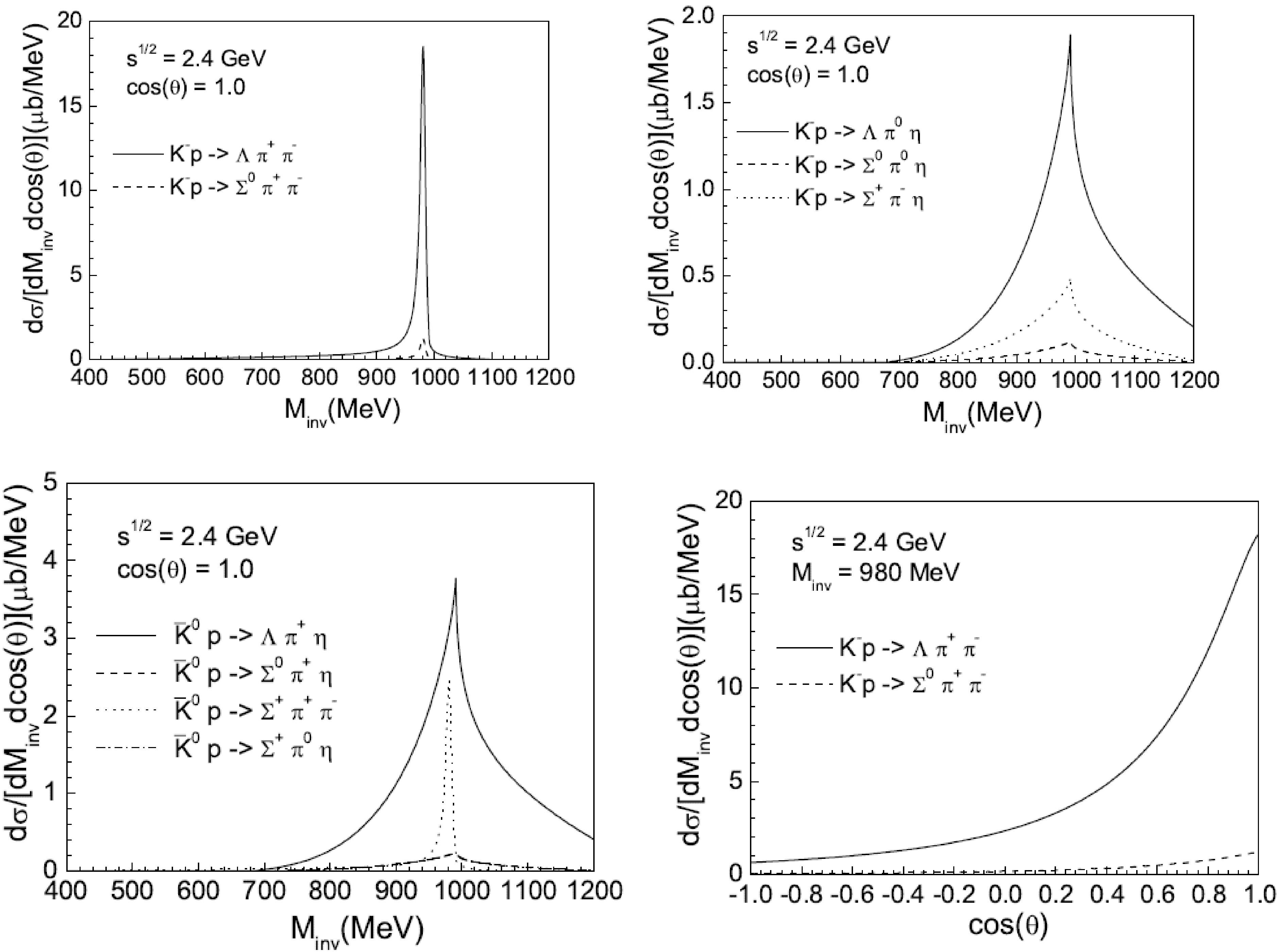
$$K^-p\to\Lambda\pi^+\pi^-,\quad K^-p\to\Sigma^0\pi^+\pi^-,\quad K^-p\to\Lambda\pi^0\eta$$
$$K^-p\to\Sigma^0\pi^0\eta,\quad K^-p\to\Sigma^+\pi^-\eta,\quad \bar{K}^0p\to\Lambda\pi^+\eta,$$
$$\bar{K}^0p\to\Sigma^0\pi^+\eta,\quad \bar{K}^0p\to\Sigma^+\pi^+\pi^-,\quad \bar{K}^0p\to\Sigma^+\pi^0\eta.$$

$$-|K^- >= |1/2, -1/2 > \qquad |\pi^+ >= -|1, 1 >$$

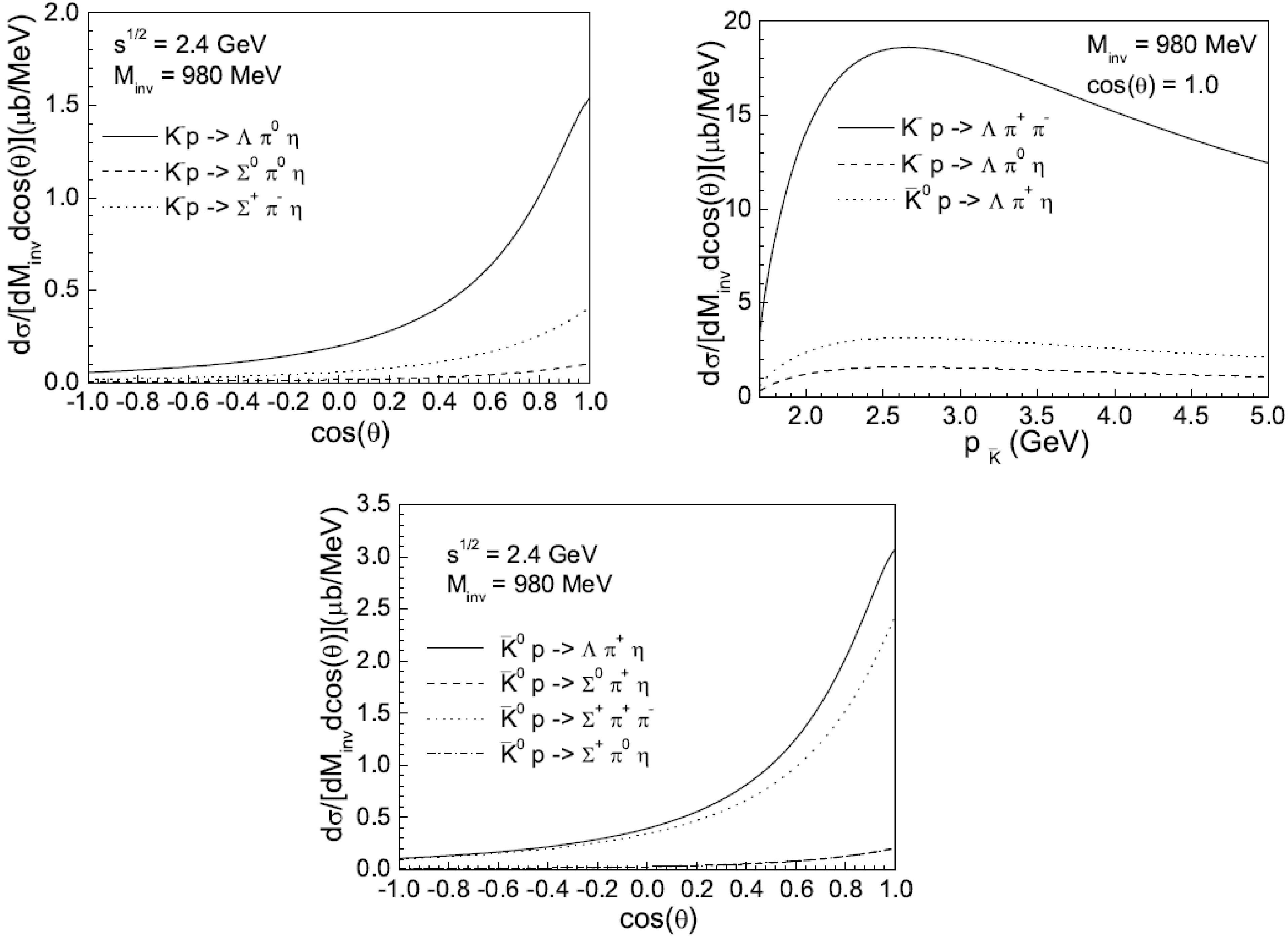
$$|K^+K^-\rangle = -\frac{1}{\sqrt{2}}|10\rangle - \frac{1}{\sqrt{2}}|10\rangle, \quad |K^0K^-\rangle = -|1,-1\rangle$$
$$|K^+\bar{K}^0\rangle = |1,-1\rangle, \quad |\pi^+\eta\rangle = -|11\rangle, \quad |\pi^-\eta\rangle = |11\rangle,$$
$$t_{K^+K^-\to\pi^0\eta} = -\frac{1}{\sqrt{2}}\ t^{I=1}_{K\bar{K}\to\pi\eta},$$
$$t_{K^0K^-\to\pi^-\eta} = \sqrt{2}\ t_{K^+K^-\to\pi^0\eta}$$
$$t_{K^+\bar{K}^0\to\pi^+\eta} = \sqrt{2}\ t_{K^+K^-\to\pi^0\eta}$$

TABLE III: Matrices $t_{K\bar{K}\to MM}$, α, β used in each reaction and resonance obtained.

Reaction	$t_{K\bar{K}\to MM}$	α	β	Resonance
$K^-p\to\Lambda\pi^+\pi^-$	$t_{K^+K^-\to\pi^+\pi^-}$	$-\frac{2}{\sqrt{3}}$	$\frac{1}{\sqrt{3}}$	$f_0(980)$
$K^-p\to\Sigma^0\pi^+\pi^-$	$t_{K^+K^-\to\pi^+\pi^-}$	0	1	$f_0(980)$
$K^-p\to\Lambda\pi^0\eta$	$t_{K^+K^-\to\pi^0\eta}$	$-\frac{2}{\sqrt{3}}$	$\frac{1}{\sqrt{3}}$	$a_0(980)$
$K^-p\to\Sigma^0\pi^0\eta$	$t_{K^+K^-\to\pi^0\eta}$	0	1	$a_0(980)$
$K^-p\to\Sigma^+\pi^-\eta$	$\sqrt{2}\ t_{K^+K^-\to\pi^0\eta}$	0	$\sqrt{2}$	$a_0(980)$
$\bar{K}^0p\to\Lambda\pi^+\eta$	$\sqrt{2}\ t_{K^+K^-\to\pi^0\eta}$	$-\frac{2}{\sqrt{3}}$	$\frac{1}{\sqrt{3}}$	$a_0(980)$
$\bar{K}^0p\to\Sigma^0\pi^+\eta$	$\sqrt{2}\ t_{K^+K^-\to\pi^0\eta}$	0	1	$a_0(980)$
$\bar{K}^0p\to\Sigma^+\pi^+\pi^-$	$t_{K^0\bar{K}^0\to\pi^+\pi^-}$	0	$\sqrt{2}$	$f_0(980)$
$\bar{K}^0p\to\Sigma^+\pi^0\eta$	$t_{K^0\bar{K}^0\to\pi^0\eta}$	0	$\sqrt{2}$	$a_0(980)$



s^1/2 = 2.4 GeV
cos(θ) = 1.0
K⁻p -> Λ π⁺ π⁻
K⁻p -> Σ⁰ π⁺ π⁻
dσ/[dM_inv dcos(θ)](μb/MeV)
M_inv(MeV)
s^1/2 = 2.4 GeV
cos(θ) = 1.0
K⁻p -> Λ π⁰ η
K⁻p -> Σ⁰ π⁰ η
K⁻p -> Σ⁺ π⁻ η
dσ/[dM_inv dcos(θ)](μb/MeV)
M_inv(MeV)
s^1/2 = 2.4 GeV
cos(θ) = 1.0
K̄⁰ p -> Λ π⁺ η
K̄⁰ p -> Σ⁰ π⁺ η
K̄⁰ p -> Σ⁺ π⁺ π⁻
K̄⁰ p -> Σ⁺ π⁰ η
dσ/[dM_inv dcos(θ)](μb/MeV)
M_inv(MeV)
s^1/2 = 2.4 GeV
M_inv = 980 MeV
K⁻p -> Λ π⁺ π⁻
K⁻p -> Σ⁰ π⁺ π⁻
dσ/[dM_inv dcos(θ)](μb/MeV)
cos(θ)



s^1/2 = 2.4 GeV
M_inv = 980 MeV
K⁻p -> Λ π⁰ η
K⁻p -> Σ⁰ π⁰ η
K⁻p -> Σ⁺ π⁻ η
dσ/[dM_inv dcos(θ)](μb/MeV)
cos(θ)
M_inv = 980 MeV
cos(θ) = 1.0
K⁻ p -> Λ π⁺ π⁻
K⁻ p -> Λ π⁰ η
K̄⁰ p -> Λ π⁺ η
dσ/[dM_inv dcos(θ)](μb/MeV)
p_K̄ (GeV)
s^1/2 = 2.4 GeV
M_inv = 980 MeV
K̄⁰ p -> Λ π⁺ η
K̄⁰ p -> Σ⁰ π⁺ η
K̄⁰ p -> Σ⁺ π⁺ π⁻
K̄⁰ p -> Σ⁺ π⁰ η
dσ/[dM_inv dcos(θ)](μb/MeV)
cos(θ)

New resonances that SHOULD be seen

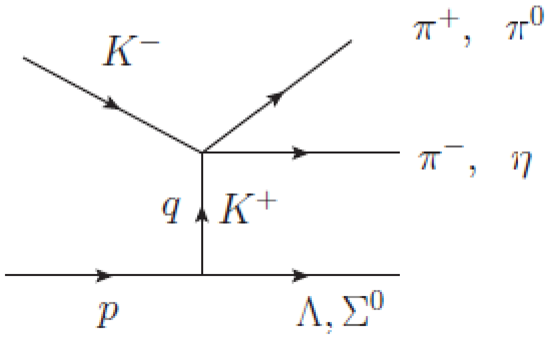


FIG. 1: Feynman diagram for the $K^- p \to \Lambda(\Sigma^0)\pi^+\pi^-(\pi^0\eta)$ reaction.

$f'_2(1525)$ mostly made from K* K*bar (L. S. Geng) but K* K*bar -> K Kbar

$f_0(1700)$ mostly made from K* K*bar (L. S. Geng) but K* K*bar -> K Kbar

$f_1(1285)$ mostly made from K K*bar (M. Lutz, L. Roca) exchange K* instead of K^+

The rates of production will tell us about the coupling of these components helping us undertand better their nature.

New resonances with strange quark content should be observable too

Conclusions

Kaon beams will be complementary to photon beams to produce mesonic resonances

The added value is that one learns about the coupling of such states to kaonic components, gaining further understanding on the nature of the resonances

Many mesonic resonances should be observable with these reactions, particularly those with strong couplings to kaonic components, while photons are less discriminating → strangeness filter -> extra information.

In the present reaction we have studied the $f_0(980)$ and $a_0(980)$ and made predictions of cross sections: This should help experimentalists to see the real chances of success in these reactions.