$|S\rangle$ = unstable state

$$a(t) = \langle S | e^{-iHt} | S \rangle$$

$$p(t) = |a(t)|^2$$

$$p(t) \simeq 1 - \frac{t^2}{\tau_Z^2} + \dots$$ always non-exp for short times!!!

. two-level case

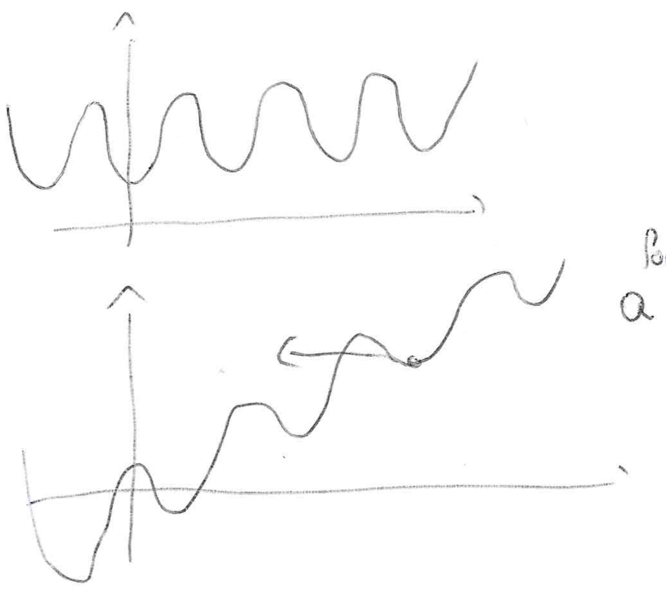
. n-level case and $n \to \infty$ (when $|S\rangle$ is genuinely non unstable state)

. "real" Rabi was in an ex.

Itano et al (Wineland)

$p(t) = \cos^2($

Raizen et al (



for a large enough!!!

· Lee Hamiltonian

$$H = M_0 |S\rangle\langle S| + \sum_k \omega_k |k\rangle\langle k| + \sum_k g \frac{f(k)}{\sqrt{L}} \left(|S\rangle\langle k| + |k\rangle\langle S| \right)$$

$$\begin{cases} \sum_k \mapsto L \int_{-\infty}^{\infty} \frac{dk}{2\pi} \\ |k\rangle \mapsto \frac{1}{\sqrt{L}} |k\rangle \end{cases}$$

· Ersak argument

· NR-BW limit

Non-relativistic propagator

spectral function

Model of Thomas

other interesting experiment:

· Keltale et al

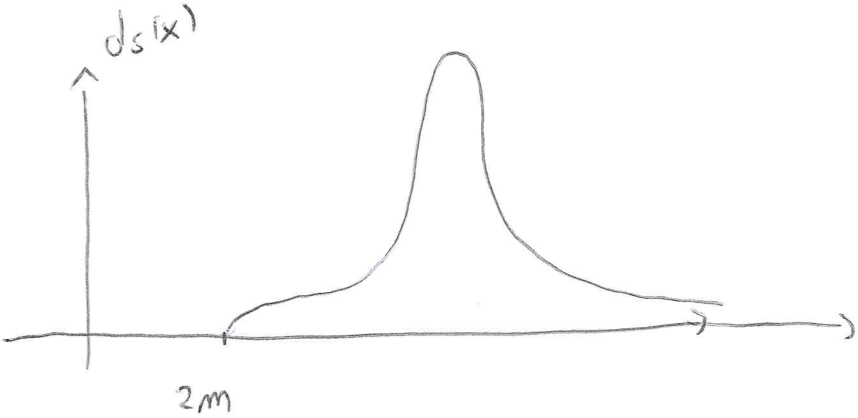
· Horde et al

We then turned to QFT

$$\mathcal{L}_{int} = g S \varphi^2$$

$$\Gamma_{S \to \varphi\varphi} = \frac{|\vec{k}|}{8\pi M_S^2}$$

$d_S(x)$



$$\int_0^\infty d_S(x)\,dx = 1$$

$$a(t) = \int_0^\infty e^{-ixt} d_S(x)\,dx$$

$$P(t) = |a(t)|^2 = 1 - t^2/\tau_Z^2 + \dots$$ also in QFT

Not only scalar fields...

$\mathcal{L} = g H \bar{\Psi} \Psi$

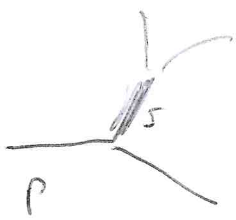
$\mathcal{L} = \rho_\mu \partial^\mu \varphi \varphi$ ρ meson

Not only two-body decay

$P \mapsto \varphi_1 \varphi_2 \varphi_3$

"directly" or with an

<u>Dalitz plot</u>



(non-fund, but effective, see in decay)

Last thing: $\sigma, \pi \to$ chiral symmetry, its spont. and expl. breaking and the decay $\sigma \mapsto \pi\pi$ in a simplified model!)

$f_0(500)$

Determination of its properties.

Coupling to pions

$\pi\pi \mapsto f_0(500) \mapsto \pi\pi$

Achtung: resonances are not always "bumps" in the cross section.

$f_0(980)$, for instance, appears as a "dip".

Reason:

$$\sigma \propto \left| A = \frac{g^2_{f_0(980)\mapsto\pi\pi}}{s - M^2_{f_0(980)} + i\Gamma_{f_0(980)} M_{f_0}} - \frac{g^2_{\sigma\mapsto\pi\pi}}{s - M_\sigma^2 + i\Gamma_\sigma M_\sigma} \right|^2$$

KLOE2 decays

$\eta \mapsto \pi\pi\pi$

$(m_d - m_u)$

$\eta \mapsto \pi^+\pi^-\pi^0$

$\eta \mapsto \pi^0\pi^0\pi^0$

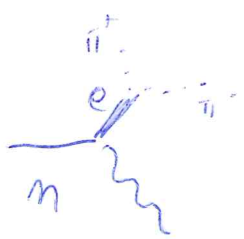
low-energy decays. Important for precision tests of ChPT.

(Still, there are some problems here).

Determination of m_u and m_d.

$\eta \mapsto \pi^+\pi^-\gamma$

(New result... lower than previous event.



other channels:

$\phi \mapsto \eta e^+e^-$; $\eta \mapsto \gamma\gamma$, $\pi^0 \mapsto \gamma\gamma$, $\eta' \mapsto \gamma\gamma$

exercise :

Which is the coupling of η and π^0 to $\gamma\gamma$?

How can we write it? Which is the ratio?

$$\pi^0 = \sqrt{\tfrac{1}{2}}\,(\bar{u}u - \bar{d}d)$$

$$\eta_N \equiv \sqrt{\tfrac{1}{2}}\,(\bar{u}u + \bar{d}d)$$

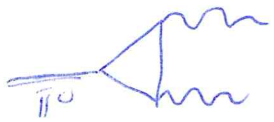
$$\eta_s = \bar{s}s$$

$$\mathcal{L} = \alpha_{\pi^0}\,\pi^0 F_{\mu\nu}\tilde{F}^{\mu\nu} + \alpha_{\eta_N}\,\eta_N F_{\mu\nu}\tilde{F}^{\mu\nu} + \alpha_{\eta_s}\,\eta_s F_{\mu\nu}\tilde{F}^{\mu\nu}$$

$$\Gamma_{\pi^0\mapsto\gamma\gamma} = \frac{\alpha_{\pi^0}^2}{4\pi} M_{\pi^0}^2$$

Can we evaluate the ratio $\alpha_{\pi^0}/\alpha_{\eta_N}$?

Actually Yes!!! For that we need to look at the microscopic treatment.



$$\alpha_{\pi} \propto \sqrt{\tfrac{1}{2}}\left(\frac{4}{9} - \frac{1}{9}\right)$$

$$\alpha_{\eta_N} \propto \sqrt{\tfrac{1}{2}}\left(\frac{4}{9} + \frac{1}{9}\right)$$

$$\alpha_{\eta_s} \propto \frac{1}{9}$$

$$\frac{\Gamma_{\eta_N\mapsto\gamma\gamma}}{\Gamma_{\pi^0\mapsto\gamma\gamma}} = \frac{M_{\eta_N}^3}{M_{\pi^0}^3}\cdot\frac{\left[\sqrt{\tfrac{1}{2}}\cdot\tfrac{5}{9}\right]^2}{\left[\sqrt{\tfrac{1}{2}}\cdot\tfrac{3}{9}\right]^2}$$

$$= \frac{M_{\eta_N}^2}{M_{\pi^0}^2}\cdot\frac{9}{25}$$

But indeed there is also mixing!

$$\begin{pmatrix} \eta \\ \eta' \end{pmatrix} = \begin{pmatrix} \cos\vartheta_P & +\sin\vartheta_P \\ -\sin\vartheta_P & \cos\vartheta_P \end{pmatrix} \begin{pmatrix} \eta_N \\ \eta_S \end{pmatrix}$$

$$\begin{pmatrix} \eta_N \\ \eta_S \end{pmatrix} = \begin{pmatrix} \cos\vartheta_P & -\sin\vartheta \\ \sin\vartheta_P & \cos\vartheta_P \end{pmatrix} \begin{pmatrix} \eta \\ \eta' \end{pmatrix}$$

Ergo:

$$\mathcal{L} = \alpha_{\pi^0} \pi^0 F\tilde{F} + \alpha_{\eta_N} (c\,\eta - s\cdot\eta') F\tilde{F} + \alpha_{\eta_S} (s\cdot\eta + c\cdot\eta')$$

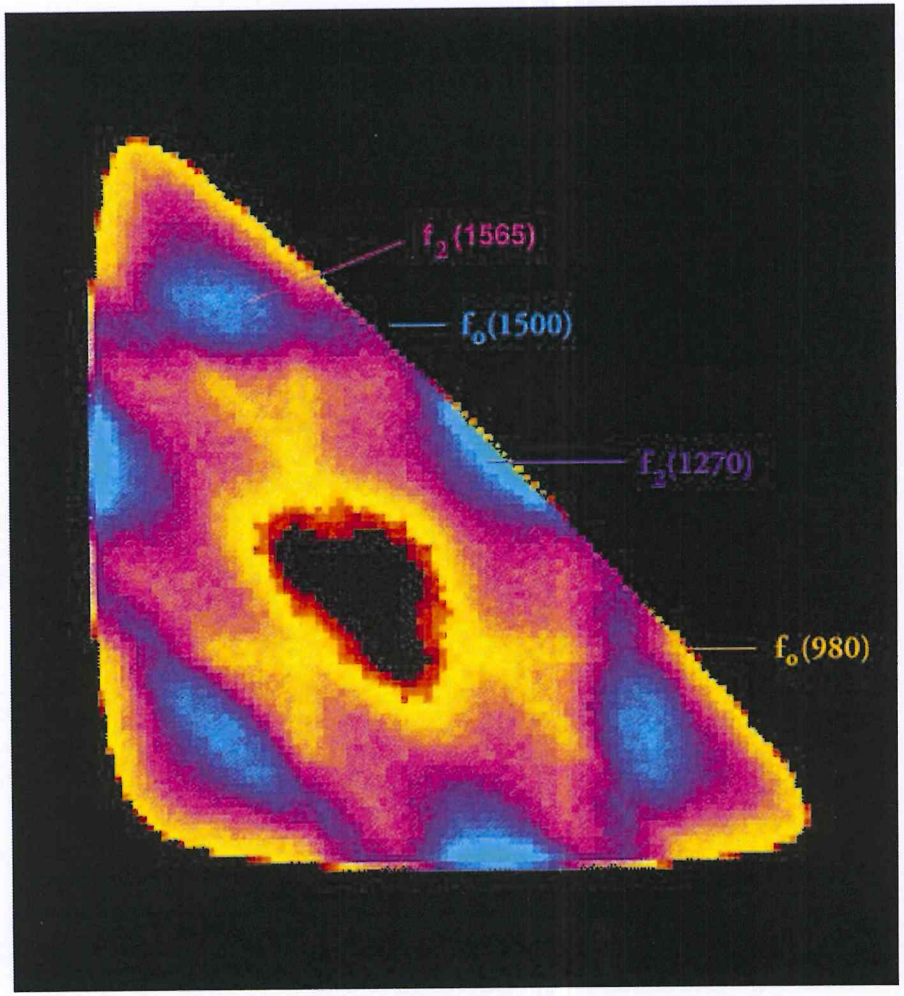
$$= \alpha_{\pi^0} \pi^0 F\tilde{F} + (\alpha_{\eta_N} c + \alpha_{\eta_S} s)\, \eta F\tilde{F}$$

$$+ (-\alpha_{\eta_N} s + \alpha_{\eta_S} c)\, \eta' F\tilde{F}$$

$$\frac{\Gamma_{\eta \to \gamma\gamma}}{\Gamma_{\pi^0 \to \gamma\gamma}} = \frac{M_\eta^3}{M_{\pi^0}^3} \cdot \frac{(\alpha_{\eta_N} c + \alpha_{\eta_S} s)^2}{\alpha_{\pi^0}^2} = \frac{M_\eta^2}{M_{\pi^0}^2} \cdot \frac{\left(\sqrt{\frac{1}{2}} \cdot \frac{5}{9} \cdot c + \frac{1}{9} s\right)^2}{\left(\sqrt{\frac{1}{2}} \cdot \frac{3}{9}\right)^2}$$

$$\vartheta_P \simeq -36^\circ$$

$\bar{p}p \rightarrow \pi^0\pi^0\pi^0$ Dalitz plot



700000 events = 6×700000 entries

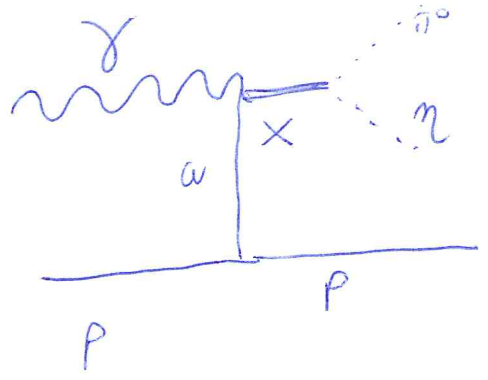
N.B.: the physics of η, η' mesons studied at WASA@COSY!

(Jülich).

J lab

(Gluex, Clas) $\gamma + p \to$ example!

γp



one can "factorize" this process in

$$\sigma_{tot} = \text{"production"} \cdot \text{"decay"}$$

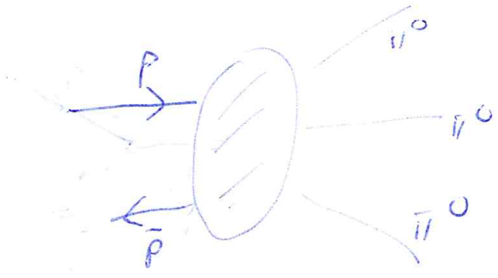
$$\downarrow$$

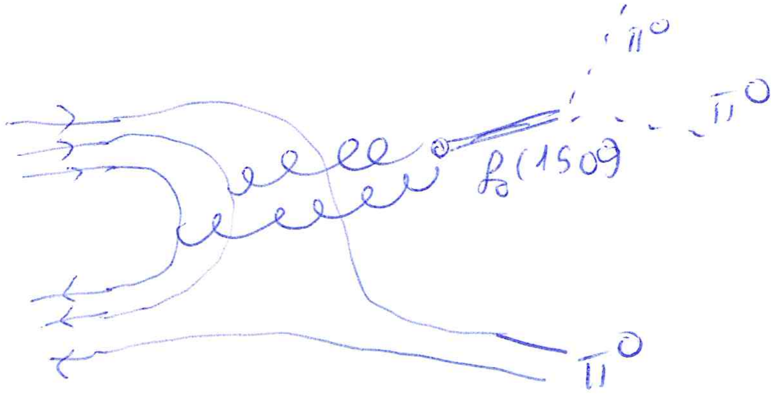
$$\Gamma_{X \mapsto \pi^0 \eta}$$

Glueballs and hybrids

$\bar{p}p \to \pi^0\pi^0\pi^0$

Dalitz plot always a crucial tool (3 body in the final state.





Microscopic scheme for the "glueball production"
in a gluon rich environment.

Future panda Physics!!!

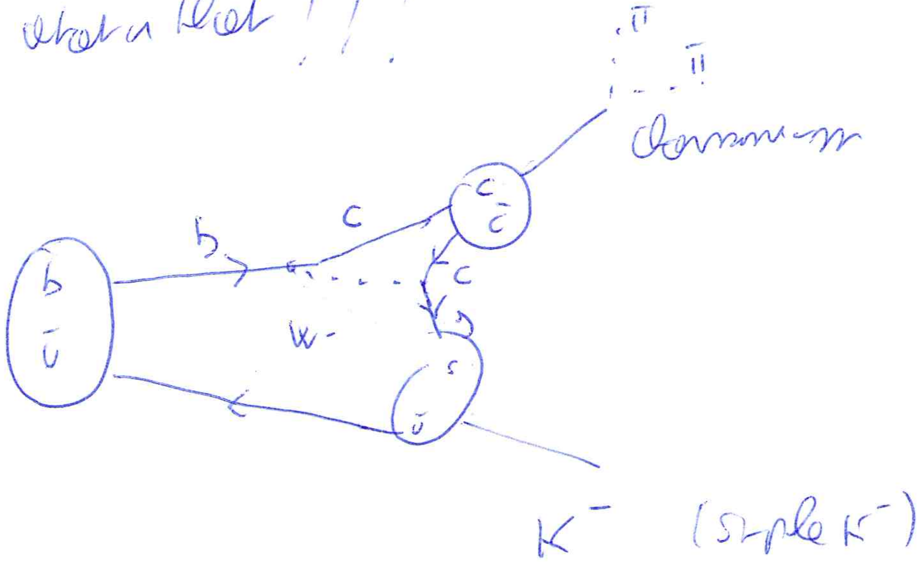
Exotic and charmonium states, decays.

Babar

$B \longmapsto K \pi\pi$

X (3872) has been seen...

what is that???



W^- is flavour changing

LHCb and the B_{s0} decays

[The last two DPG-Journals ....]

- $\Xi(38)$ state