HOLES NOT TO FALL INTO

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1) Pseudo-exotic states explained as cusps

2) Low mass non-q-qbar states and chiral symmetry breaking

3) Mistakes being made in fitting strong phases in CP violation by some authors

Enthusiasm for `exotic states' resembling the deuteron:

Examples: $f_0(980)$ and $a_0(980)$ at the KK threshold

$f_2(1565)$ at the $\omega\omega$ threshold, 2 x 782 MeV

X(3872) at the DD* threshold within 1 MeV

$Z^+(4430)$ at the $D_1(2420)D^*(2010)$ threshold,

see arXiv: 0802.0934

$Z^+_b(10608$ +- 2) and $Z^+_b(10653$ +-1.5) just above the

B B* (10605) and B*B*(10650) thresholds,

see 1105.5492

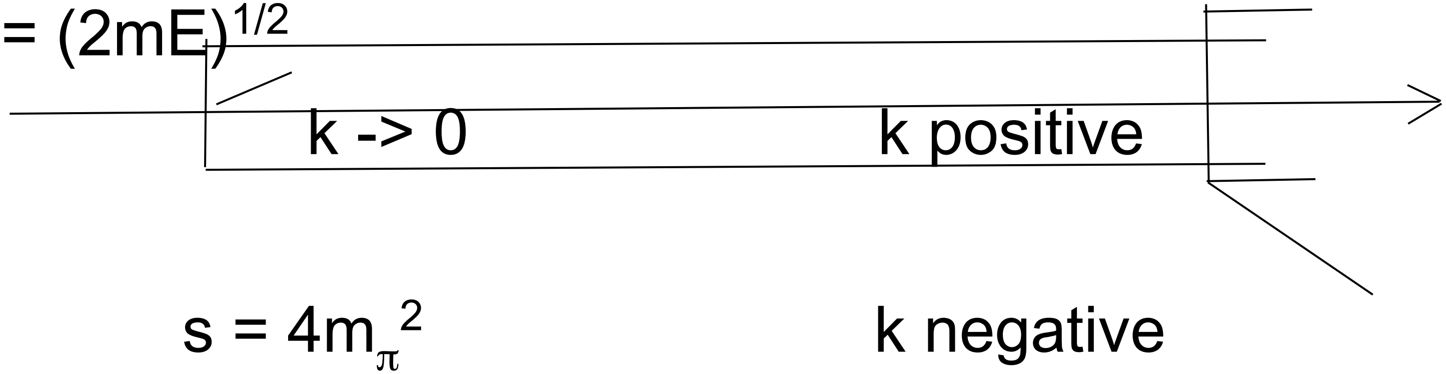
Λ_c (2940) close to the D*(2007)N threshold,

Cusps

Elementary Scattering Theory:

ψ = A(E) exp (-ikr) + B(E) exp(+ikr).

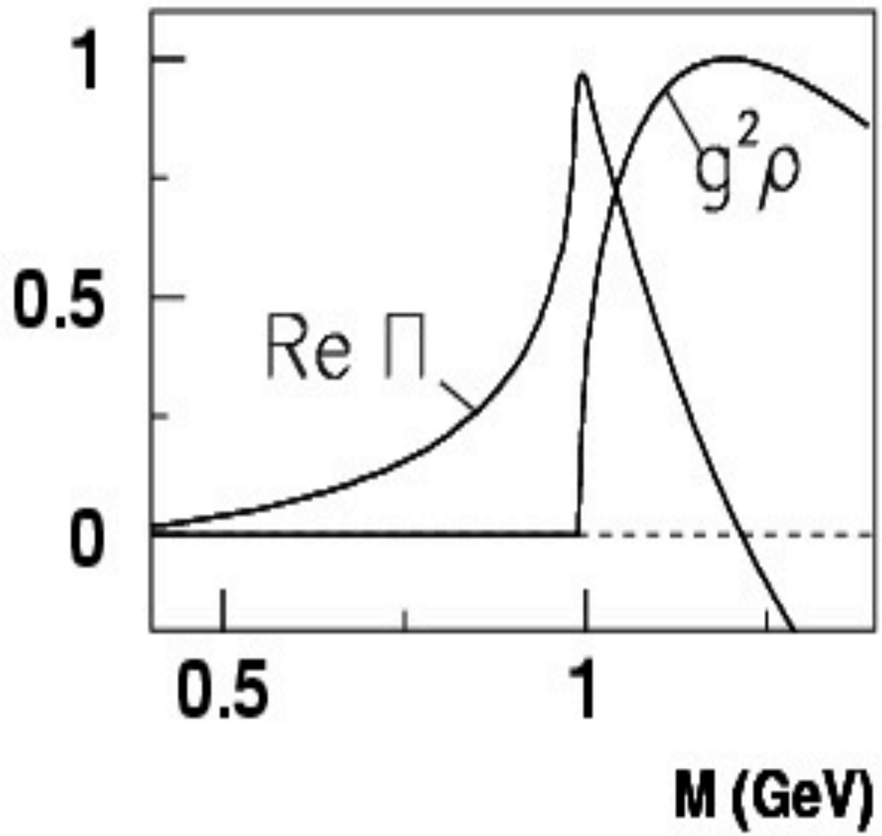
k = $(2mE)^{1/2}$



$$BW = \frac{M\Gamma_{\pi\pi}}{M^2 - s - iM\Gamma_{tot}} = \frac{g^2(s)\,\rho(s)}{M^2 - s - i\,\Sigma_i\,[g_i^2(s)\,\rho_i\,(s)]}$$

$s = 4m_K^2$

Remember that s is the pole of the Breit-Wigner for complex s, and the amplitude is a complex function of complex s (analyticity). This obeys a dispersion relation:



FF = exp(-3k^2);

R = 0.8 fm

Re Π = Re [g^2_{KK} FF(s) ρ_{KK}(s)] appears in the Breit-Wigner denominator and acts as an effective attraction pulling f_0(980) and and a_0(980) to the KK threshold.

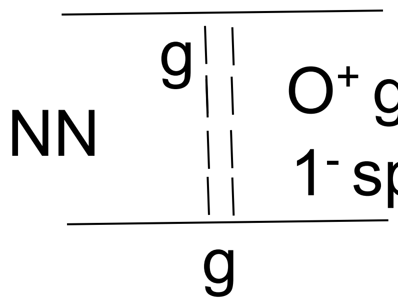
A sunami is an example: a travelling cusp.

For $f_0(980)$, $g^2_{KK}/g^2_{\pi\pi}$ = 4.21 +- 0.25 +- 0.21 from BES II data on $J/\psi \to \phi\pi^+\pi^-$ and ϕK^+K^- in a single set of data (Ablikim et al. Phys. Lett. B598 (2004) 149). [Almost all other results are obtained from decays to $\pi\pi$ but get wrong answers because they ignore the cusp effect]. If one plays games varying the mass M of the Breit-Wigner, one finds that the pole position is very stable even if one varies M over the mass range 500 to 1150 MeV, arXiv: 0802.0934.

A further warning is that the form factor FF(s) is needed also below the KK threshold as $\exp(-\alpha|k|^2)$, with perhaps larger α. Effects both above and below the sharp $\omega\omega$ threshold are very large for $f_2(1565)$ which lies far below its isospin partner

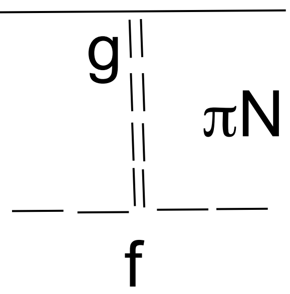
NON q-qbar STATES and CHIRAL SYMMETRY BREAKING

Sigma = $f_0(500)$, Kappa -> $K\pi$, $a_o(980)$ and $f_0(980)$ make a nonet of abnormal states driven by meson exchanges.



O^+ gives attraction

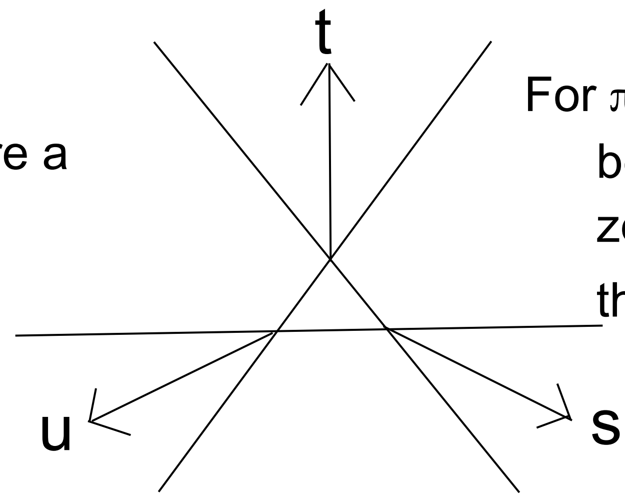
1^- spin-orbit



$f^2 = 0.075$(Said)

I get 0.0771+ 0.014

For πN, data require a zero at $t = m_\pi^2$



For $\pi\pi$, Adler (1965) used self-consistency between s,t and u channels to derive a zero at $s = m_\pi^2/2$, just below the $\pi\pi$ threshold.

Chiral symmetry breaking means that σ etc have charge 0, while q-qbar states include charged states.

In elastic scattering, the amplitude is $T = M\Gamma(s)/[M^2 - s - iM\Gamma(s)]$; but in a production reaction such as

$J/\psi \to \omega\pi^+\pi^-$, in BES 2 data it is

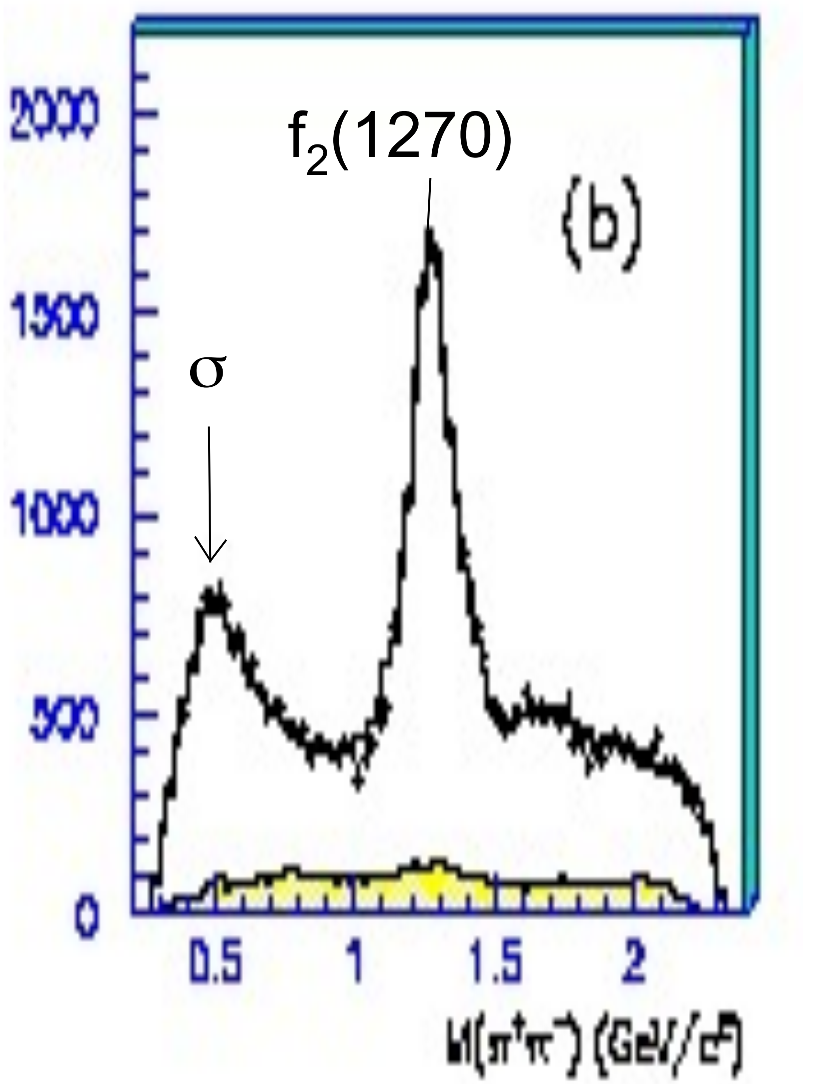
$T = g^2/[M^2 - s - iM\Gamma(s)]$. One then sees the f_0(500) directly.

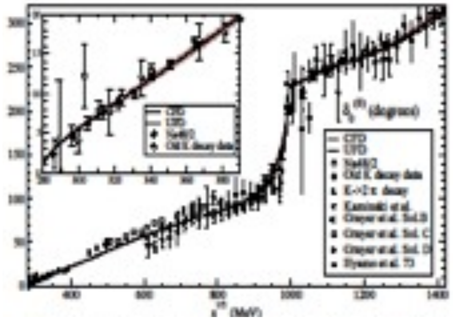
Phys. Lett. B 598 (2004) 149.

A key point is that in extrapolating to the pole, the amplitude obeys the Cauchy-Riemann relations:

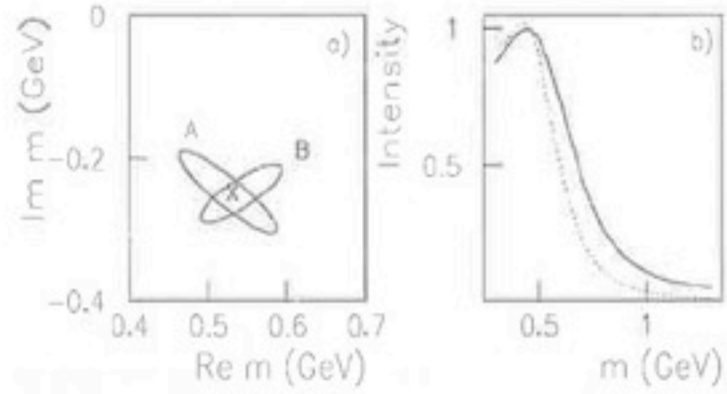
d(Re f)/d(Re s) = d(Im f)/d(Im s);

d(Im f)/d(Re s) = -d(Re f)/d(Im s).



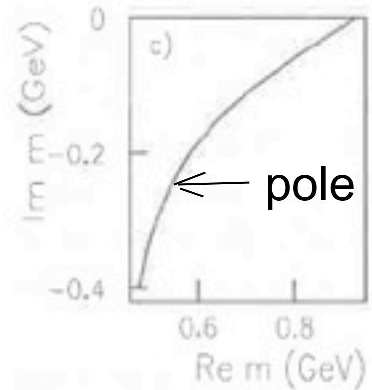


(d) ππ–>ππ phase shifts near threshold(inset) and up to 1400 MeV mass; the steep rise at 1000 MeV is due to interference with $f_0(980)$.



(a)shows the error ellipse Im M and Re M for elastic data; B the ellipse for J/ψ–>$\omega\pi^+\pi^-$ (complementary).

(b) full curve shows the correct line-shape, the dashed one a Breit Wigner of constant width (E791).



(c) shows the mass in the complex plane where the phase goes through 90^0, against Im M vertically and Re M horizontally; the arrow shows the pole position (at that time – now M ~ 470 – i 270 MeV)

The q-qbar 0^+ states are $f_o(1370)$ (mostly n-nbar), $f_0(1710)$ (mostly s-sbar), f_0(1790) (the radial excitation of 1370). There is an extra state $f_0(1500)$ and it is believed that there is mixing between all these states and the 0^+ glueball. The σ has a long tail above 1 GeV; I have fitted all the good data on σ decays to KK, $\eta\eta$ and 4π. The next slide gives a full set of formulae and three alternative prescriptions for it near the pole.

$$
\begin{aligned}
T_{11}(s) &= M\Gamma_1(s)/[M^2 - s - g_1^2 \frac{s - s_A}{M^2 - s_A} z(s) - iM\Gamma_{tot}(s)] && (3)\\
M\Gamma_1(s) &= g_1^2 \frac{s - s_A}{M^2 - s_A} \rho_1(s) && (4)\\
g_1^2(s) &= M(b_1 + b_2 s)\exp[-(s - M^2)/A] && (5)\\
j_1(s) &= \frac{1}{\pi}\left[2 + \rho_1 ln_e \left(\frac{1-\rho_1}{1+\rho_1}\right)\right] && (6)\\
z(s) &= j_1(s) - j_1(M^2) && (7)\\
M\Gamma_2(s) &= 0.6 g_1^2(s)(s/M^2)\exp(-\alpha|s - 4m_K^2|)\rho_2(s) && (8)\\
M\Gamma_3(s) &= 0.2 g_1^2(s)(s/M^2)\exp(-\alpha|s - 4m_\eta^2|)\rho_3(s) && (9)\\
M\Gamma_4(s) &= M g_4 \rho_{4\pi}(s)/\rho_{4\pi}(M^2) && (10)\\
\rho_{4\pi}(s) &= 1.0/[1 + \exp(7.082 - 2.845 s)]. && (11)
\end{aligned}
$$

see hep-ph/0608081, J. Phys. G 34 (2007) 151.

I have also fitted the $\kappa \rightarrow K\pi$, $K\eta$ (almost negligible), $K\eta'$ and interferences with K_0(1430), arXiv: 0906.3992, PRD 81 (2010) 014002 using data from the Focus expt, LASS, BES II and E791. The pole position is

M = 663 +- 8 +- 353 –i(329 +- 5 +- 22), rather close to the $K\pi$ threshold. There is a rather revealing point in the results. A point not generally realised is that the unitarity constraint only applies on the real s axis. As a result, the amplitude is not constrained to rise from 0 at the $K\pi$ threshold. In fact it moves steadily negative as the amplitude moves into the complex plane. That accounts for the low mass of the pole. The $K\pi$ phase shift reaches only 55^o at 1.5 GeV/c and may never reach 90^o.

There are extensive data on B -> 3π, $K\pi\pi$, $KK\pi$ and 3K but with complex interferences on the Dalitz plots. It is unfortunate that fits to these data and D decays to similar channels have used Breit-Wigners of constant width, which is wrong. As a result, they find discrepancies with data which they patch up with interference with a constant background all over the Dalitz plot. This hides the interferences which would reveal the

Extended Unitarity is wrong! In its simplest form, it states that the $\pi\pi$ pair in ALL production processes should have the same phase variation with s in all reactions. This was conjectured by Ian Aitchison in 1972. I checked it against four sets of data and it failed in all of them, in some cases clearly visible by eye in modern raw data, see arXiv: 0801,1908, Eur. Phys. J C 54 (2008) 73. It is obvious it is untenable: the $f_0(980)$ amplitude is quite large in $\pi\pi \to \pi\pi$. However, in production data it has quite different magnitudes. Suppose this magnitude went to 0. Extended Unitarity then predicts that its phase would be there, even if there is no magnitude to support it!

I mention this because Bediaga, Fredorico and Lourenco use it to predict strong phases in CP violation and tests of CPT invariance (arXiv: 1307.8164). The same idea was used some years ago by Loiseau, El-Bennich and others (arXiv:

Back to Chiral Symmetry Breaking: an Analogy with the covalent bond in chemistry: see arXiv:075002 for details.

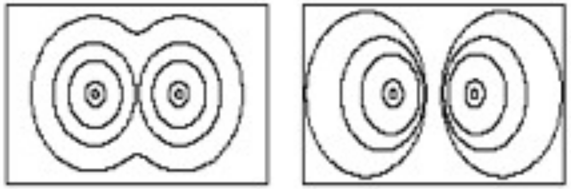
The Hamiltonian for a q-qbar state decay into meson-meson is

$$H \psi = \begin{bmatrix} H_{11} & V \\ V & H_{22} \end{bmatrix} \psi$$

H_{11} refers to q-qbar forces; H_{22} describes ingoing and outgoing states; V describes s-channel decays and t+u channel exchanges. The solution is the Breit-Rabi equation:

$$E = (E_1 + E_2)/2 +- [(E_1 + E_2)^2 + |V|^2]^{1/2}.$$

One linear combination of q-qbar and MM goes down and the other is pushed up. If E_1 is close to an S-wave threshold, there is large mixing.

(a)  (b)

In (a), there is attraction, in (b) repulsion. The stable state decreases slightly in radius.

σ = n-nbar, κ = n-sbar, $f_0(980)$ and $a_0(980)$ = s-sbar:

lightest, medium, heaviest

Bob Jaffe (MIT) predicted members of 27, 10 and $\overline{10}$ states in addition. But in these, meson exchanges are repulsive and unbound. He therefore withdrew his scheme. A detail is that the $a_0(980)$ might migrate to the $\eta\pi$ threshold. This does not happen because there is a nearby Adler zero at

$s = m^2_\eta - m_\pi{}^2/2$.

Food for thought for this meeting:

Why do q-qbar combinations come as pairs?

u-ubar and d-dbar; s-sbar and c-cbar; b-bbar and t-tbar.

Why do quarks have charges 1/3 and 2/3?

There are 3 colours, 3 pairs of quarks and 3 neutrinos up to the energy scale of W and Z, correlating with e,μ,τ.

Section 15 of the PDG comments on Grand Unified Theories, currently based on the Pati-Salam group SO(10) and broken symmetries. I am doubtful this is the right guess. The problem is that the energies are presently limited to those of the LHC and the right scale may be much higher.

There is an important new paper by Martin Faessler 1308.5900. He points out that Han and Nambu suggested a different scheme in 1965 with quarks having integer charges:

	red	blue	green
up quark	+1	+1	0
down	0	0	-1

As long as quarks are colour singlets, the average charge of up quarks is 2/3 and for down quarks is -1/3. Charges of Δ and Ω^- are unchanged (as for all s,c,b and t mesons). The Weinberg angle of the Z changes, and agrees much better with $\sin^2 \theta_W(M_Z)$. It also gives a better prediction for $\gamma\gamma$ physics at LEP. Neutrinos are not affected. What grand unified group can account for these different charges??