Topics in Spectroscopy

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1) Comments on X,Y,Z
2) Chiral Symmetry Breaking and how to parametrise Sigma, Kappa, and Dabba

There is a $^3P_2$ state Z(3930) in $\gamma\gamma$->DD .
In B->K(J/$\Psi\omega$) also X(3943+-11+-13),Γ=87+−22+−26 (Belle) and X(3915+-4+-2), Γ=34+−10+−5 (Babar).
It seems likely/possible all three are the same state.
0905.5506 of Li and Chao predicts only one c-cbar state in this mass range, [though a $^3P_1$ state distinct from X(3872) is also possible].

GENERAL remark; need to analyse both production and decay of these states. Usually only decays are analysed. But that discards valuable information. I believe many J^P could be established fitting BOTH.

Example: $^3P_1$ has matrix element K.e x W, where W describes the ω; W α n; e is the polarisation vector of J/ψ.

$^3P_2$ production is described by the tensor $\tau_{\alpha\beta} = K_\alpha K_\beta - (1/3)(K.K)$ and decay is described by $T_{\alpha\beta} = e_\alpha W_\beta + e_\alpha W_\beta - (2/3)(e.W)$. The complete matrix element is simply $\tau^{\alpha\beta} T\alpha\beta$, so again there are strong correlations between K, e and W.

[For details of how to handle e, see hep-ph/ 0410168].

For 0^+ the matrix element is simply e.W

Sigma, Kappa and Dabba

There are extensive data from Belle, Babar, Cleo C, E791 and Focus on D and B decays to these resonances. ALL these analyses have ignored the constraints of Chiral Symmetry Breaking. All but one has ignored the s-dependence of Widths. That is wrong: the widths are proportional to a coupling constant which increases linearly with s. The result is that phases have been fitted incorrectly and there <u>may</u> be significant corrections CP phases α and γ.

Chiral Symmetry Breaking - History

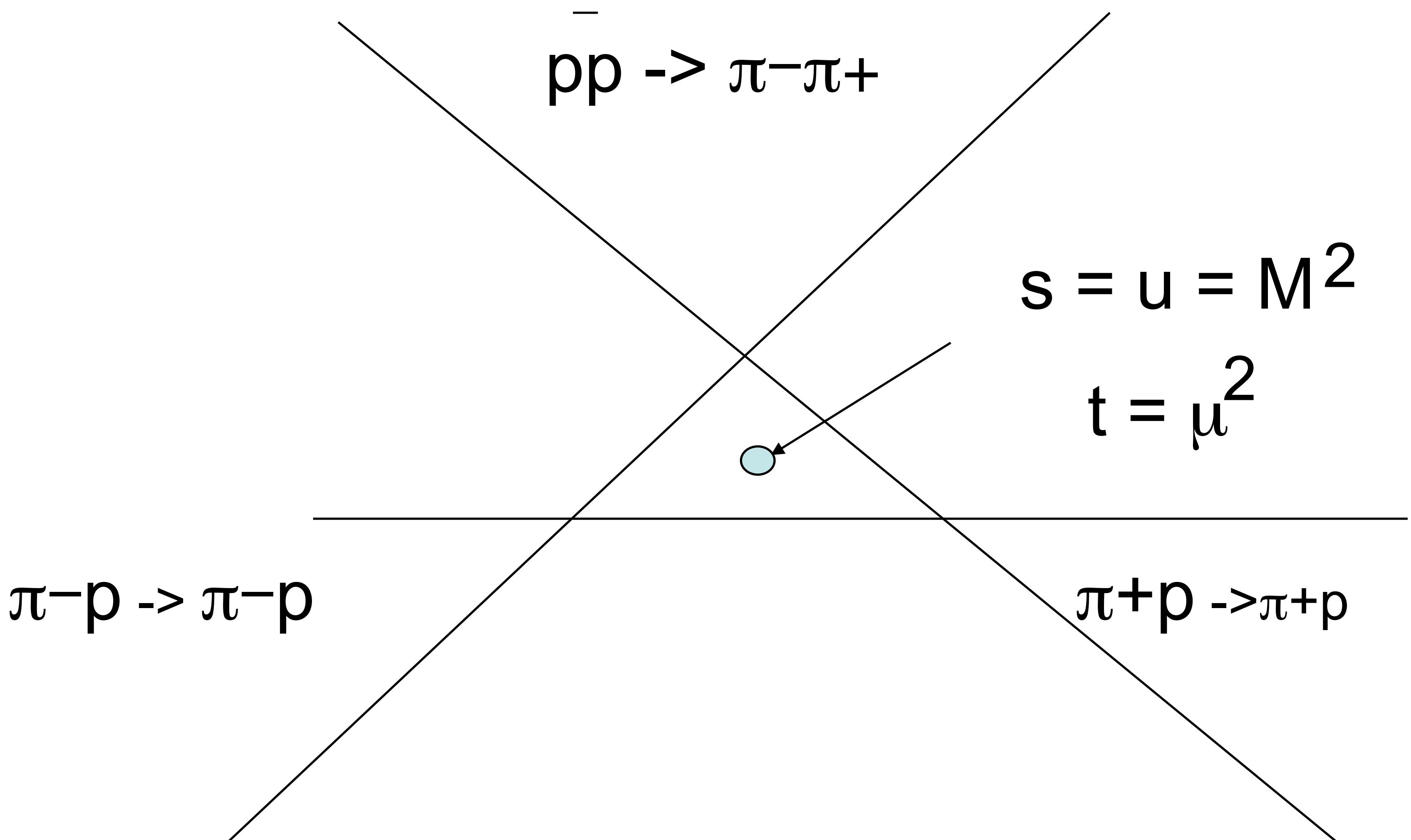
Early 1960s: Even-even Nuclei have $J^P = 0^+$ I=0, but the lightest MESON has $J^P=0^-$, I=1. WHY?

Now we know the answer: most mesons are $q\bar{q}$ and quarks have colour. In the 1960's, it was a puzzle how to understand $\pi\pi$ elastic scattering with I=0, which goes through the S-wave.

Nambu and Jona-Lasinio: `Dynamical Model of Elementary Particles Based on an Analogy with Superconductivity, PR 121 (1961) 122.

Gell-Mann and Levy: Nu. Cim 16 (1960) 1729 – the Linear Sigma Model.

Both embody Chiral Symmetry Breaking into Lagrangians



There is a zero at the centre of the Mandelstam triangle. When the S-wave is projected out of the T-matrix, there is a zero at $s = M^2 - 0.5\mu^2$ and a linear rise of T with s.

How to allow for this.

See Phys. Lett. B 572 (2003) 1; Erratum in one formula B595 (2004) 556.

$$f = \frac{N(s)}{D(s)} = \frac{g^2_{K\pi}\rho_{K\pi}(s)}{M^2 - s - \Sigma_i\, g^2_i \rho_i(s)}$$

$g^2_{K\pi} = B(s - s_A)\exp[-\alpha(s-s_A)]$; $s_A = m^2_K - 0.5m^2_\pi$

For D-pi, M is very large and it helps to divide N and D by M^2: see 0901.2217.

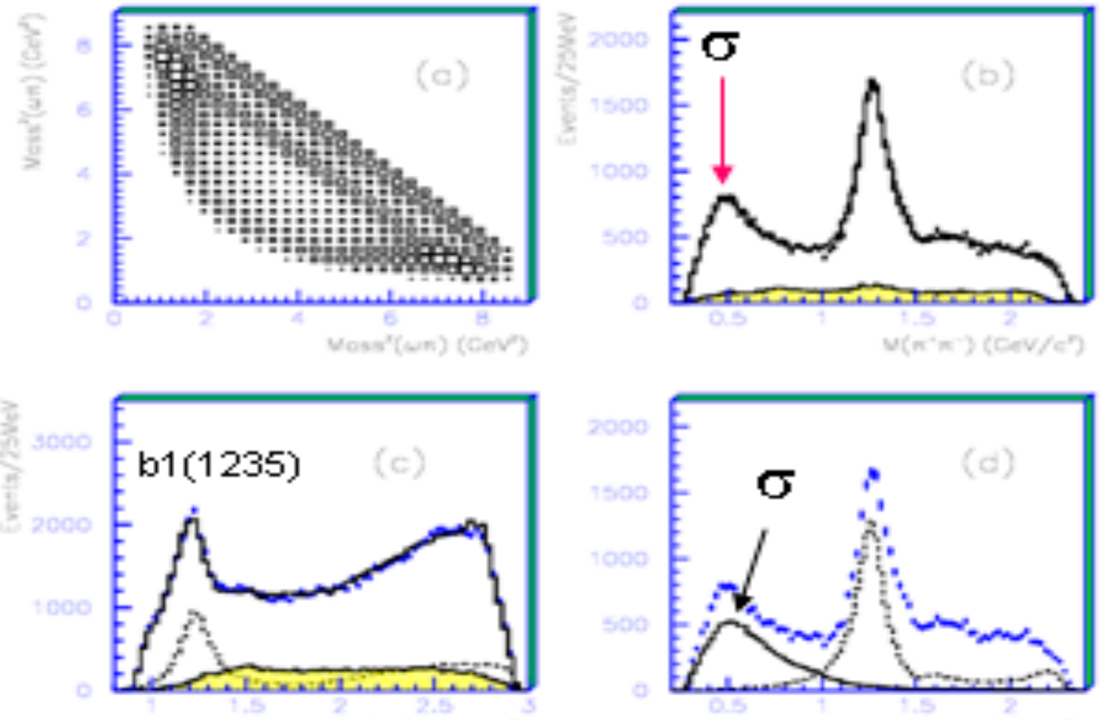
Weinberg (1966) predicted the scattering lengths
for scattering of π from ANY particle: N, π, K, D, B, etc.
Predictions are well verified for πN and $\pi\pi$.
It is then valuable to fix the scattering length for
$K\pi$ and $D\pi$.
A fit to LASS data for $K\pi$ elastic scattering plus the
scattering length gives a κ pole at
722 +- 60 – i(386 +- 50) MeV, close to threshold
even without considering production data.
Leutwyler et al find the σ pole at 441 - i272 MeV.

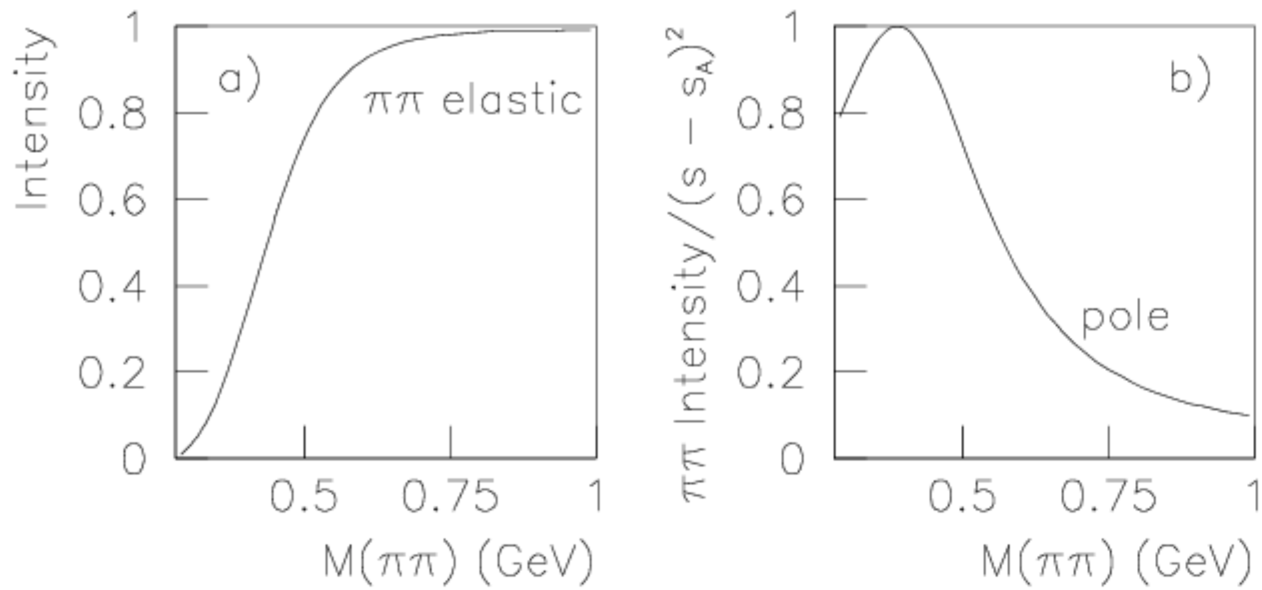
Aside: More history of Chiral Symmetry Breaking:
Goldstone, Salam and Weinberg: Broken Symmetries PR. 127 (1962) 965
Gasser and Leutwyler: 1984, Chiral Perturbation Theory.
The fundamental point is that u and d current quarks are almost massless and therefore highly relativistic. They interact with the confining potential via the Dirac equation and the pion becomes almost massless: see Bicudo and Ribiero, PR. D 42 (1990) 1611,
Bicudo et al, PR D 65 (2002) 076008.

At high masses, Chiral Symmetry is restored and parity doubling is observed (Crystal Barrel in flight).

BES data.

Phase in production consistent with elastic scattering_





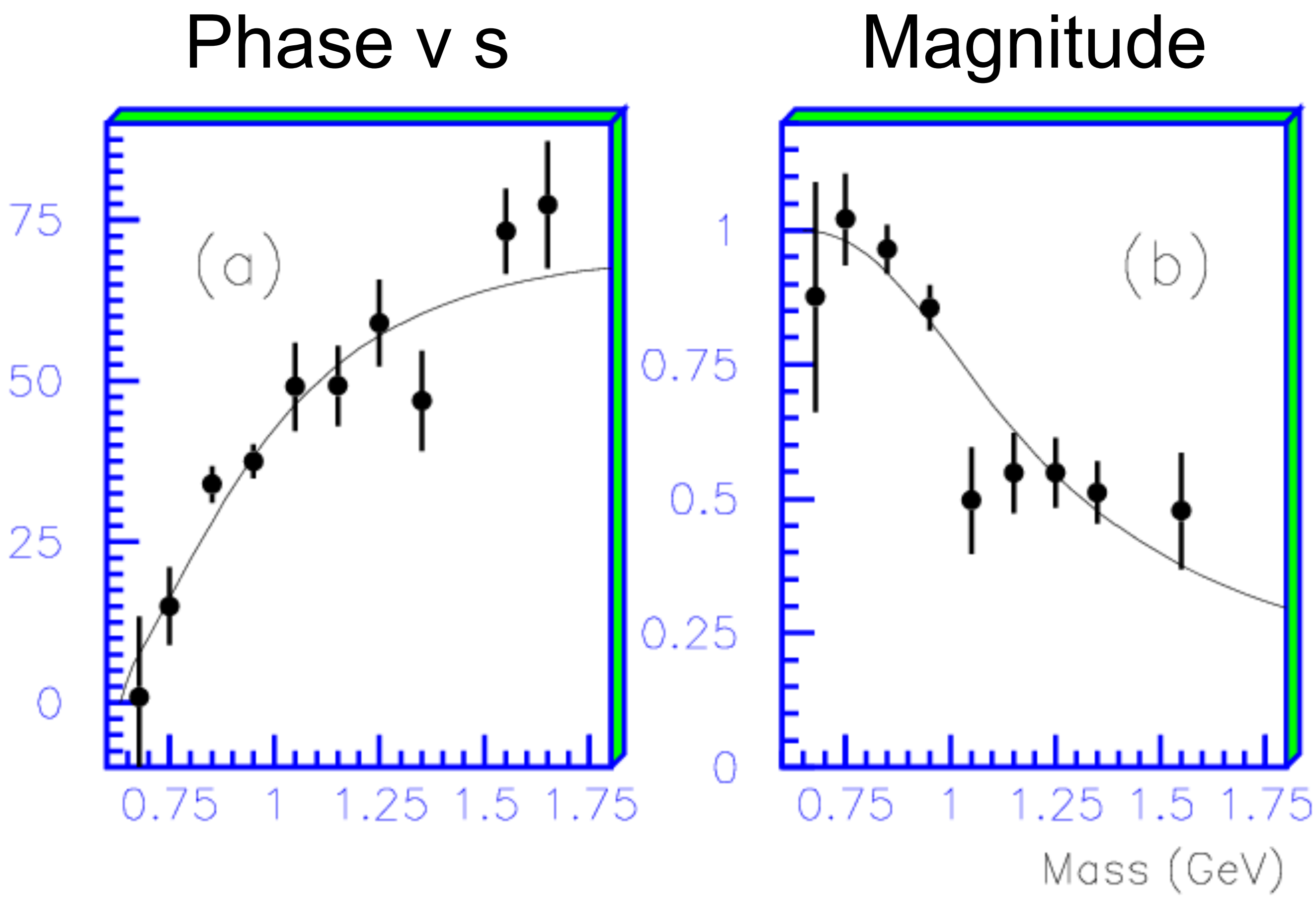
The data imply that N(s) for the production reaction is NOT the same as for elastic scattering, but is nearly constant.

Explanation: Elastic scattering is driven by ρ, σ and f_2 exchange but in D and J/Psi decays, t-channel processes are very distant -> N(s) nearly constant.

In general it could be A + Bs.

The denominator D(s) must however be identical in elastic scattering and production. This constraint on D(s) has NOT been obeyed by high energy groups except one publication. That causes trouble: they find they need `background' which further distorts the fits.

Kappa



Why does the phase not go through 90 deg?

Amplitudes are complex functions of complex s.

The Cauchy-Riemann relations are:

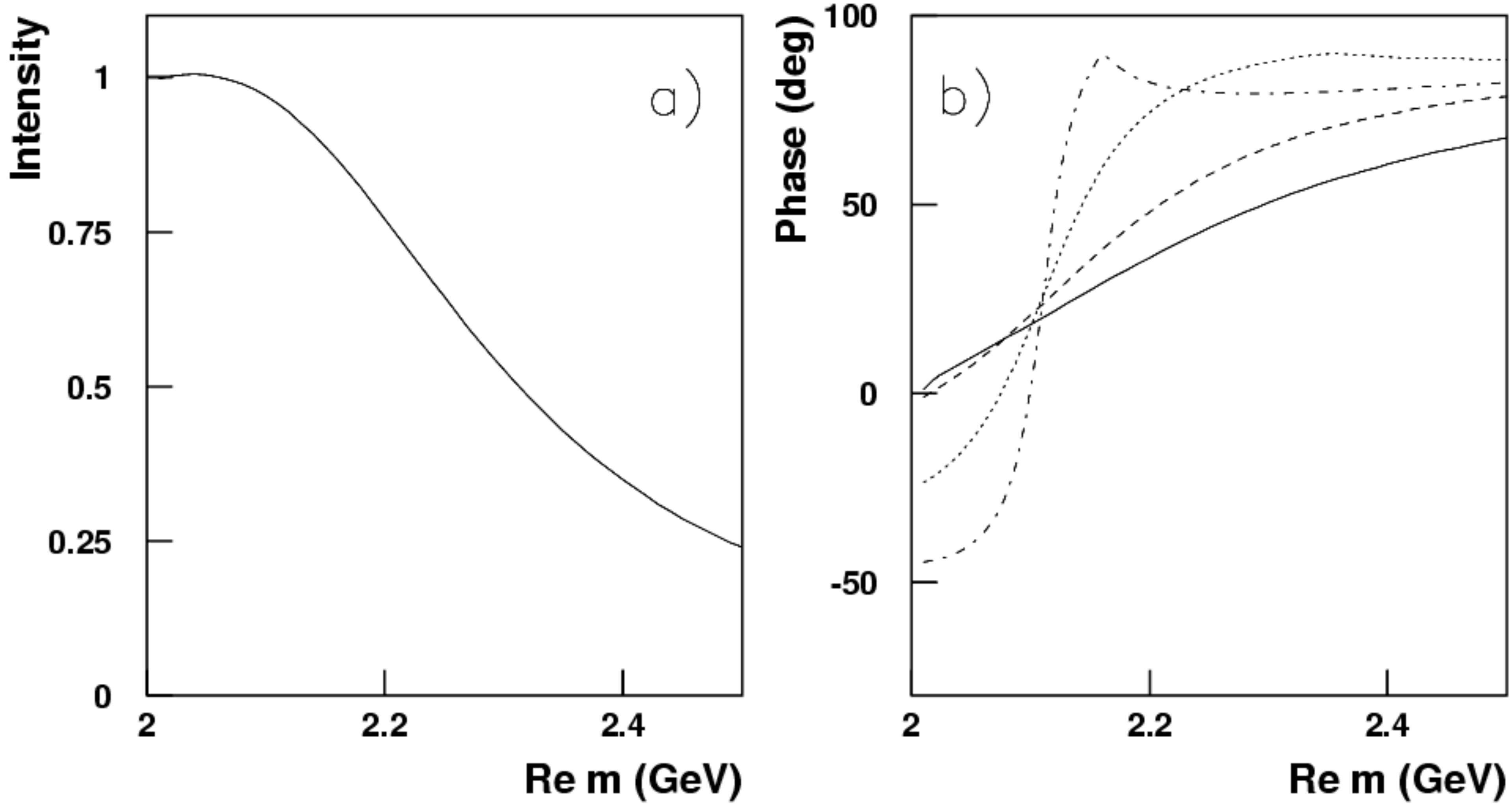
d(Re f)/d(Re s) = d(Im f)/d(Im s)

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

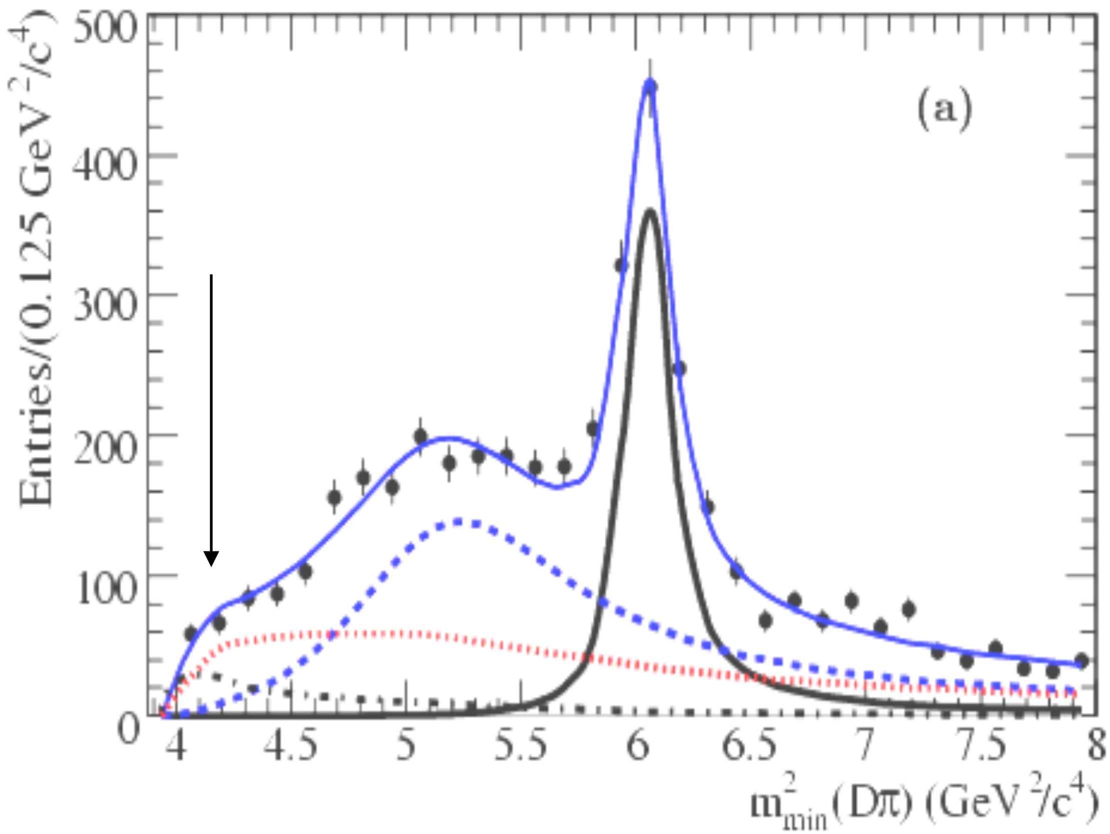
Im f varies nearly linearly along the real s axis.

This implies Re f has the reverse variation as one moves off the real s-axis to complex s.

On the real s-axis for ELASTIC scattering, unitarity requires zero phase at threshold. BUT this constraint disappears as one moves into the complex plane.



Intensity
1
0.75
0.5
0.25
0
2
2.2
2.4
Re m (GeV)
a)
Phase (deg)
100
50
0
-50
2
2.2
2.4
Re m (GeV)
b)



Belle: 0901.1291 B^- -> $D^+\pi^-\pi^-$

In a <u>production</u> process, the 2 -> 2 unitarity relation no longer applies. So you see the pole undistorted by the Adler zero near threshold.

<u>Conclusion</u>: in fitting production data, you MUST fit a phase which is consistent with elastic scattering, i.e. use the same D(s) as for elastic scattering. But take N(s) = constant or perhaps A + Bs.

I applied this to E791 data on $D^+ \to K^-\pi^+\pi^+$, and it fits data well, see hep-ex/05110019 and PLB 632 (2006) 471: κ at 750 +- 43 – i(342 +- 60) MeV

There are however, some further details.

1) The Adler zero is a feature of the FULL $\pi\pi$, $K\pi$ or $D\pi$ amplitude and must be included into $f_0(980)$, $K_0(1430)$ and $D_0(2350)$.

2) In elastic scattering, both σ and $f_0(980)$ amplitudes move round the Argand circle. They need to be combined by multiplying $S = \exp(2i\delta)$, i.e. adding their phases. But in production reactions the 2 ->2 constraint no longer applies and one should ADD amplitudes (multiplied by complex coupling constants) i.e. use the isobar model. [ISR data on central production rule out the prescription of EU, see 0808.2706 and Eur. Phys. J C54(2008) 73.]

3) There are problems with the K-matrix:
$T = K\rho/(1 - iK\rho)$. If two resonances overlap, phases need to be added for elastic scattering. Since $K = \tan\delta$, the prescription needed for 2 or more resonances is:

$$K_{total} = (K_A + K_B)/(1 - iK_A K_B \rho^2)$$

[but there is still uncertainty about what prescription to use above the inelastic theshold].

Because EU fails, the K-matrix is NOT convenient for producton processes: use the isobar model.

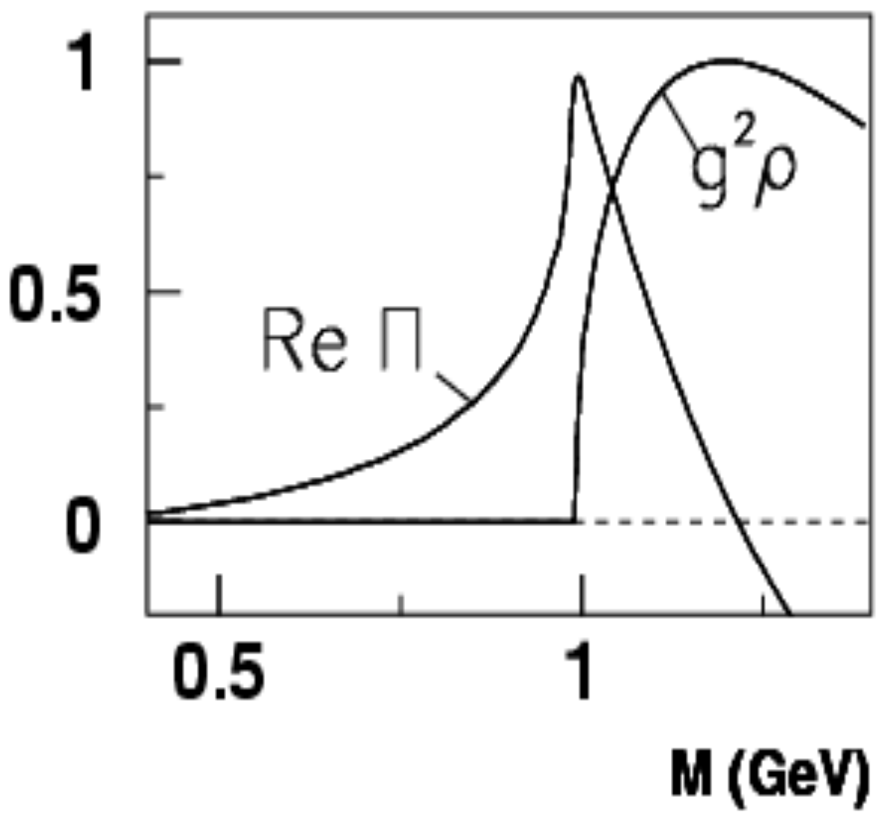
The future

It is possible that Chiral Symmetry Breaking and Confinement are one and the same phase transition. It is of GREAT interest to extend knowledge of the σ over the mass range of 0^+ q-qbar states and the probable glueball near 1600 MeV. At present, the problem is that σ -> KK, $\eta\eta$ and particularly 4π and $\omega\omega$ are not known well enough. New data on $\pi\pi \rightarrow 4\pi$, KK and $\eta\eta$ are badly needed (Compass?) Data on B -> K$\eta\eta$ and K$\omega\omega$ and would be valuable.

Threshold cusps

D(s) should be $M^2 - s - \Pi(s)$ where

$$\mathrm{Im}\,\Pi(s) = \Sigma_i\, g^2_i\, \rho_i(s);\ \mathrm{Re}\,\Pi(s) = \frac{P}{\pi}\int \frac{\mathrm{Im}\,\Pi(s')\,ds'}{(s' - s)}$$



for $f_0(980)$.

[Evaluating loop diagram gives an identical result].
The peak in Re f corresponds to attraction.
The cusp may therefore attract resonances to thresholds, e.g. f0(980), a0(980) at the KK threshold, K0(1430) near the Kη' threshold and f2(1565) at the ωω threshold.

Oset, Oller et al find they can generate many states from meson exchanges (and including Adler zeros). Hamilton and Donnachie found in 1965 that meson exchanges have the right signs to generate P33, D13, D15 and F15 baryons. Suppose contributions to the Hamiltionian are H_{11} from $q\bar{q}$ and H_{22} from meson exchanges; the eigenvalue equation is

$$\begin{pmatrix} H_{11} & V \\ V & H_{22} \end{pmatrix} \Psi = E\,\Psi$$

The Variational Principle ensures the lowest eigenstate minimises E. Most non $q\bar{q}$ states are pushed up and become too broad to observe. This is analogous to the <u>covalent bond</u> in chemistry.