The race to the pole
Heavy quarks and light resonances

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The question

What is a resonance ?

- a bump or a dip
- a would-be bound-state
- a Breit-Wigner
- a relativistic Breit-Wigner
- a pole

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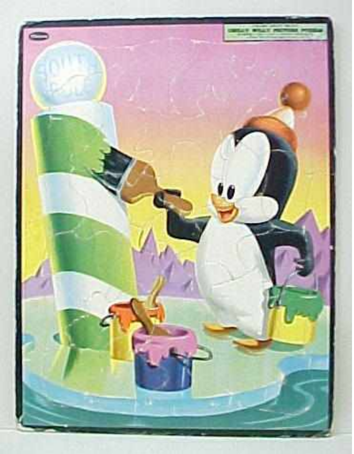
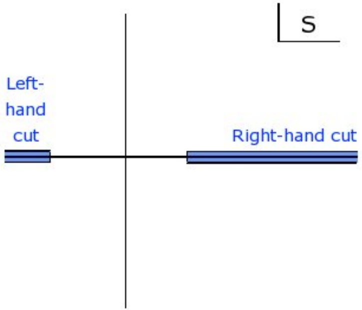
and where to find the lightest ones ?



Thanks to M. Pennington (IPPP-Durham) for advice and material

Analyticity

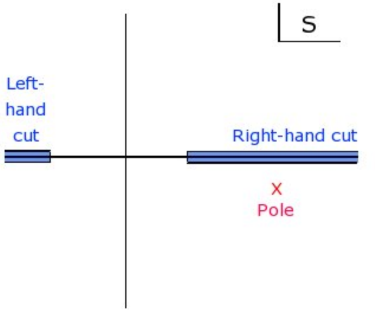


Amplitude A for $a + b \to c + d$ analytic almost everywhere in $s = (p_a + p_b)^2$-plane

Cuts and poles corresponding to physical information

- RHC : $a + b \to c + d$
- LHC : $a + \bar{c} \to d + \bar{b}$
- Real poles $\to$ bound states

Analyticity



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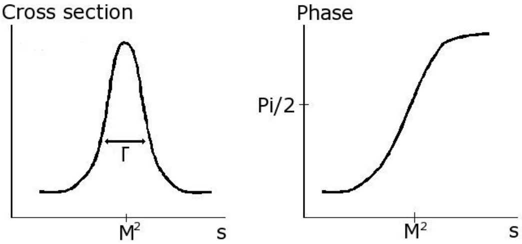
Analytic continuation under RHC rim

Poles in 2nd Riemann sheet $\to$ resonances !

Care with analytic continuation with more complicated processes

$\to$ already non-trivial if $m_a \neq m_b$

Experimentally



If pole not far from cut,

$$A(s \simeq M^2) \propto \frac{1}{M^2 - iM\Gamma - s}$$

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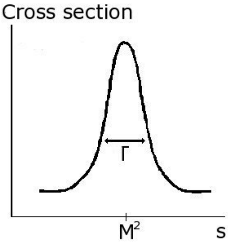

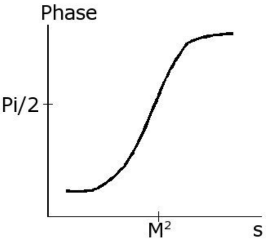

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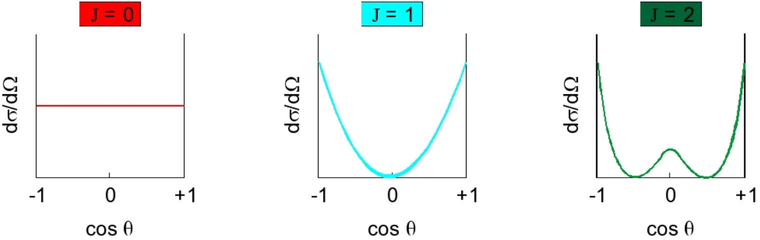
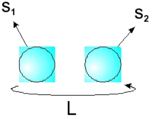
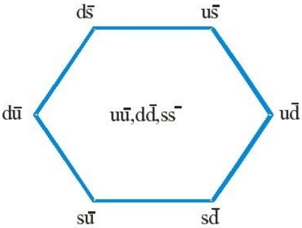
with spin related to zeroes in angular analysis



A canonical example : vectors

$$J^{PC} = 1^{--}$$
$$(S = 1, L = 0)$$





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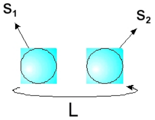

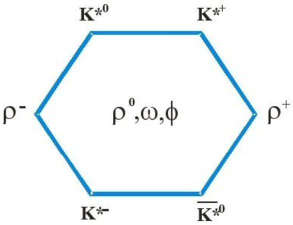

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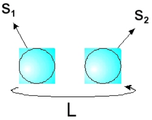

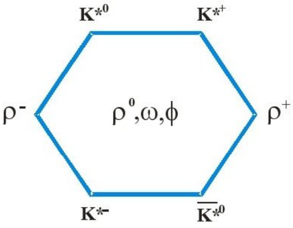

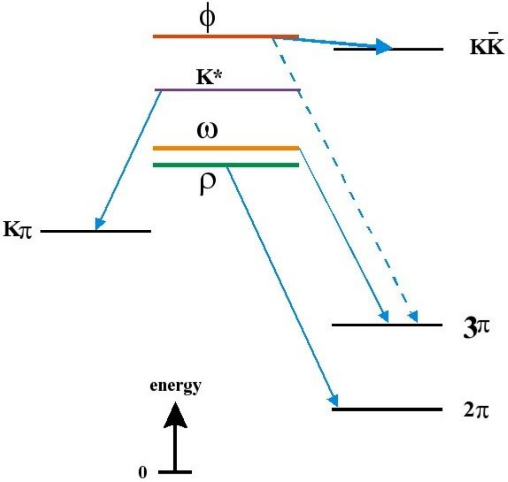

Ideal mixing $\begin{cases} \rho^0, \omega = (u\bar{u} \pm d\bar{d})/\sqrt{2} \\ \phi = s\bar{s} \end{cases}$ from $\begin{cases} \phi \to K\bar{K} \\ \Gamma(V \to e^+e^-) \end{cases}$

Another canonical example : tensors

$$J^{PC} = 2^{++}$$
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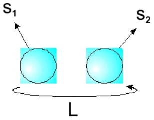

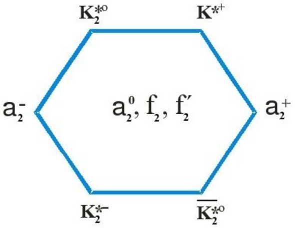

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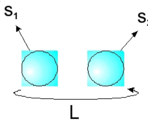
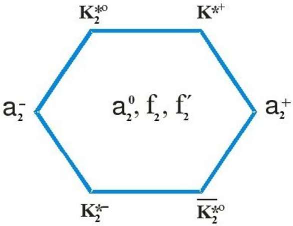
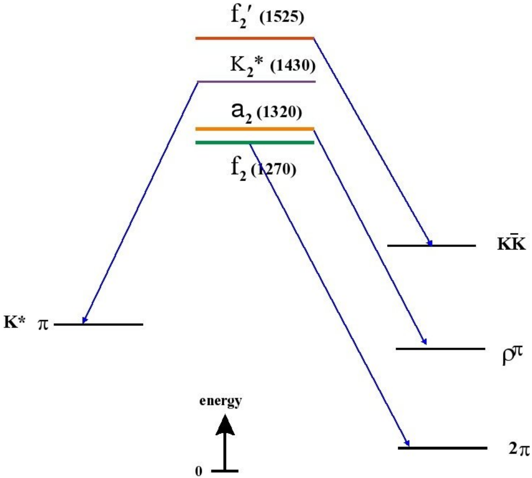
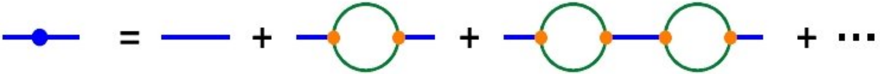






Ideal mix $\left\{ \begin{array}{c} f_2(1270), a_2(1320) = (u\bar{u} \pm d\bar{d})/\sqrt{2} \\ f_2'(1525) = s\bar{s} \end{array} \right.$ from $\left\{ \begin{array}{c} f_2' \to K\bar{K} \\ \Gamma(T \to \gamma\gamma) \end{array} \right.$

Easy and uneasy resonances



s-dependent shift $M_\rho^2 \to M_\rho^2 + \mathrm{Re}\ \Sigma_{\pi\pi}(s) - i\ \mathrm{Im}\ \Sigma_{\pi\pi}(s)$

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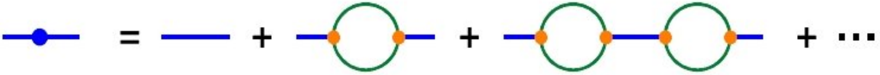

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- Threshold suppression (P-wave couplings)
- Poles do not move very far from the real axis
- Breit Wigner approximation not so bad

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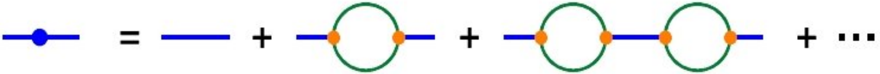

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For scalars, much harder to describe the shift

- No threshold suppresion
- Poles far away from real axis
- Poles not enough to describe amplitude (not Breit-Wigner !)

A non canonical example : I=0 scalars

Hard to see (and understand) the scalars

- Pole (if any) away from the real axis
- No angular dependence in cross section
- No direct scalar probe (light Higgs of 1 GeV !)
- Mixing with glueball (quantum numbers of vacuum)

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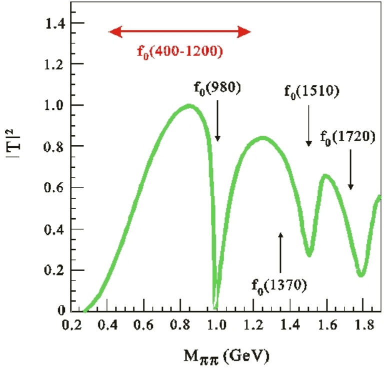

$I = 0, J = 0$

Information from $\pi\pi$-scattering
Dips rather than peaks

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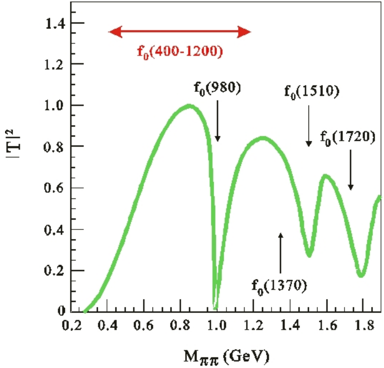

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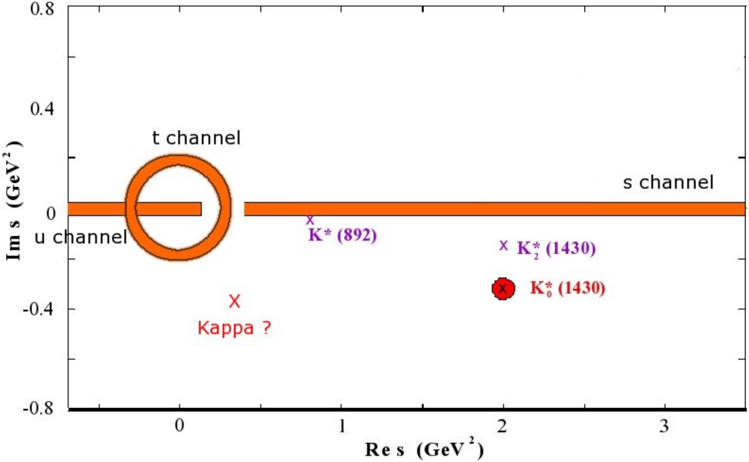
Information from $\pi\pi$-scattering
Dips rather than peaks

From dispersive methods
σ very far away from axis

$M_\sigma \simeq 441 \quad \Gamma_\sigma \simeq 544$ MeV
(Caprini et al. 2005)

A non canonical example : $I = 1/2$ scalars



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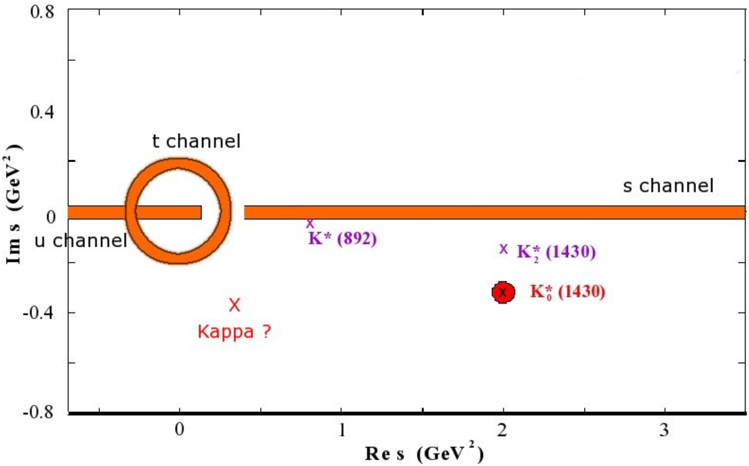

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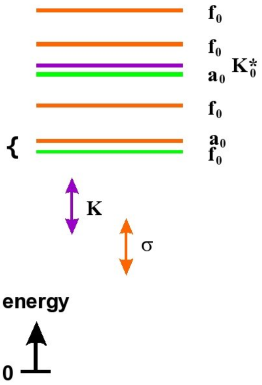
Information from πK scattering

From dispersive methods,
determination of existence and properties of κ under way

(SDG, Moussallam)

A non canonical example : the scalar nonet (?)



$K_0^*(1430)$
$a_0(980)$, $a_0(1430)$
$f_0(980)$, $f_0(1370)$
$f_0(1500)$, $f_0(1710)$
...
$\sigma ? \kappa ?$

Hard to classify, and not really helpful

$\rightarrow$ Poles not the essential element of the scalar amplitudes

For B-decays

Constraints on physically relevant models

- Cuts at the right place
- Position of the poles always the same (if close real axis, BW OK)
- Light-flavour symmetry in octet

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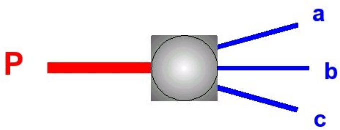

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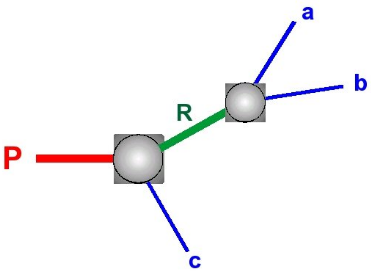

In isobar-like models,
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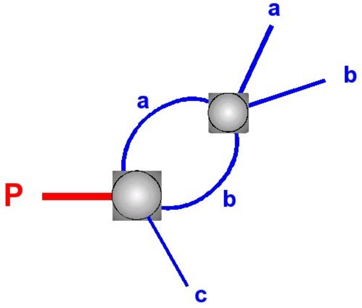

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unitarity relates phases (not moduli !)
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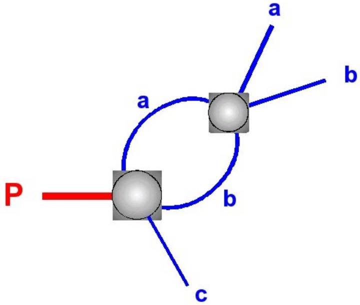

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Main problem : model interaction of resonances with another state
$\rightarrow$ $q\bar{q}$, meson molecule, di-quark states, large-N_c inspired models. . .