NON-EXOTIC MESON-MESON SCATTERING DOMINATED BY S-CHANNEL $Q\bar{Q}$ CONFINEMENT STATES

and

CLASSIFICATION OF THE LIGHT SCALAR MESONS

prepared for

HADRON 2001

August 26 - September 2 (2001)

Protvino (Russia)

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coupled channel model
for
elastic and inelastic
PP, PV and VV scattering

P = pseudoscalar meson
V = vector meson

Example:

$K\pi$ S-wave scattering
involves 9 channels:

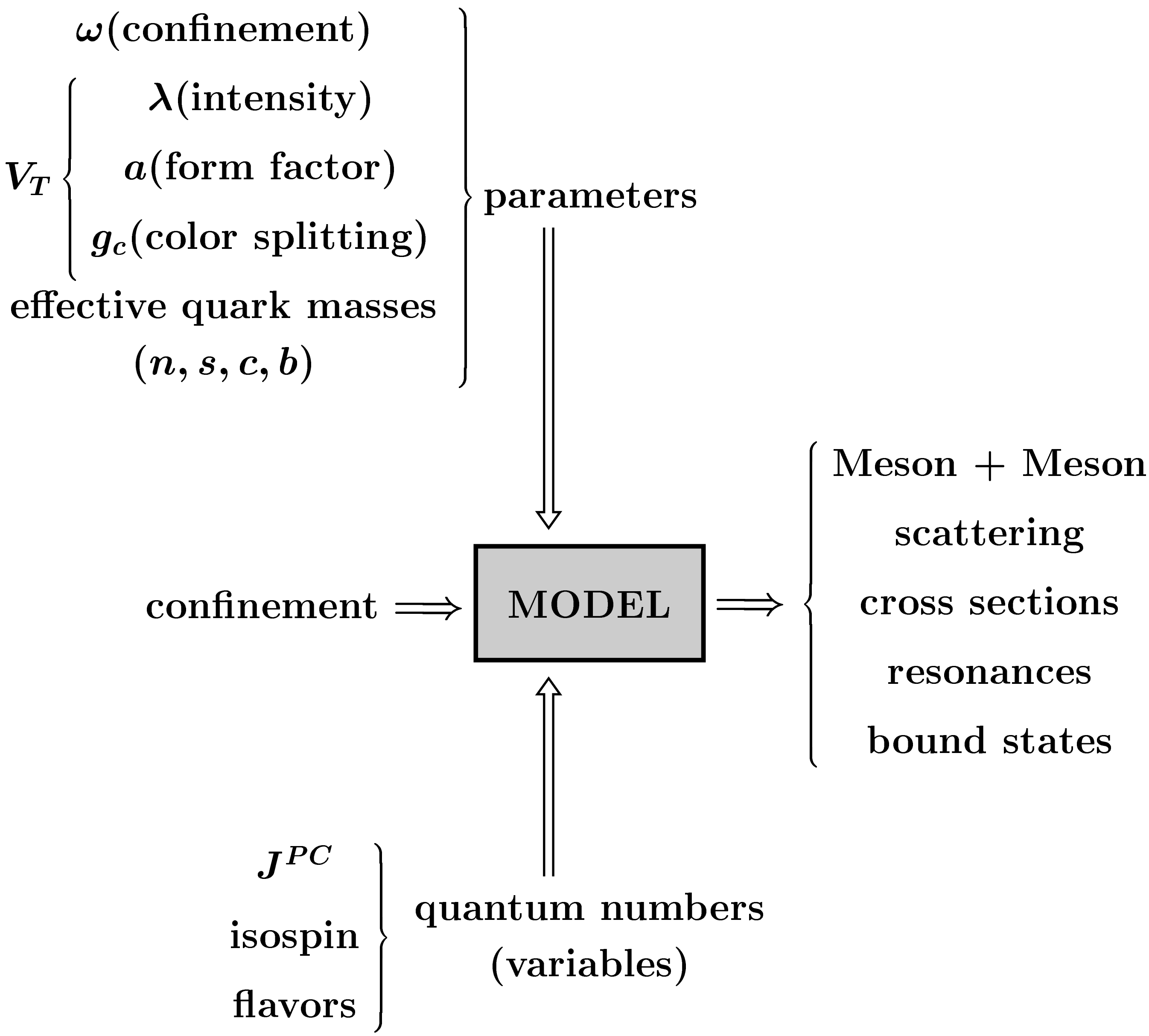
S-wave ($\ell = 0$ and $s = 0$) :
$K\pi$, $K\eta$, $K\eta'$, $K^*\rho$, $K^*\omega$ and $K^*\phi$,

D-wave ($\ell = 2$ and $s = 2$) :
$K^*\rho$, $K^*\omega$ and $K^*\phi$

all coupled through

nonstrange-strange

$q\bar{q}$ confinement states


ω(confinement)
V_T
λ(intensity)
a(form factor)
g_c(color splitting)
effective quark masses
(n, s, c, b)
parameters
confinement
MODEL
Meson + Meson
scattering
cross sections
resonances
bound states
J^{PC}
isospin
flavors
quantum numbers
(variables)

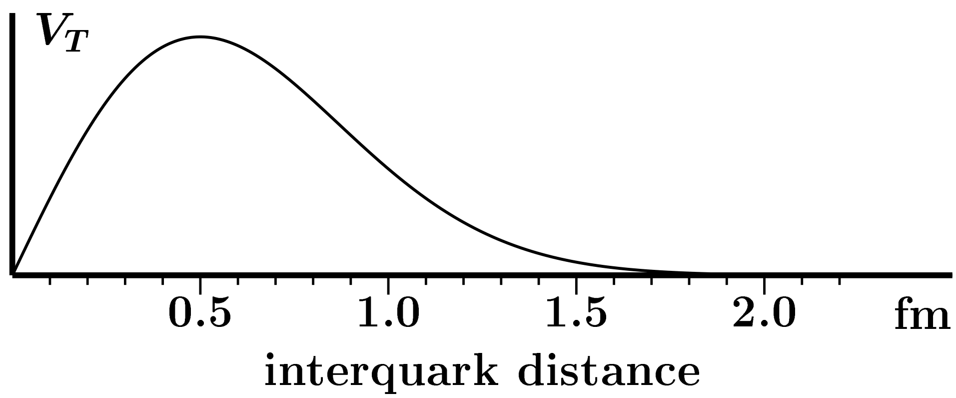
The relevant parameters of the model

$$\omega = 0.19 \text{ GeV}$$

masses:

m_n	m_s	m_c	m_b	
0.406	0.508	1.562	4.724	GeV

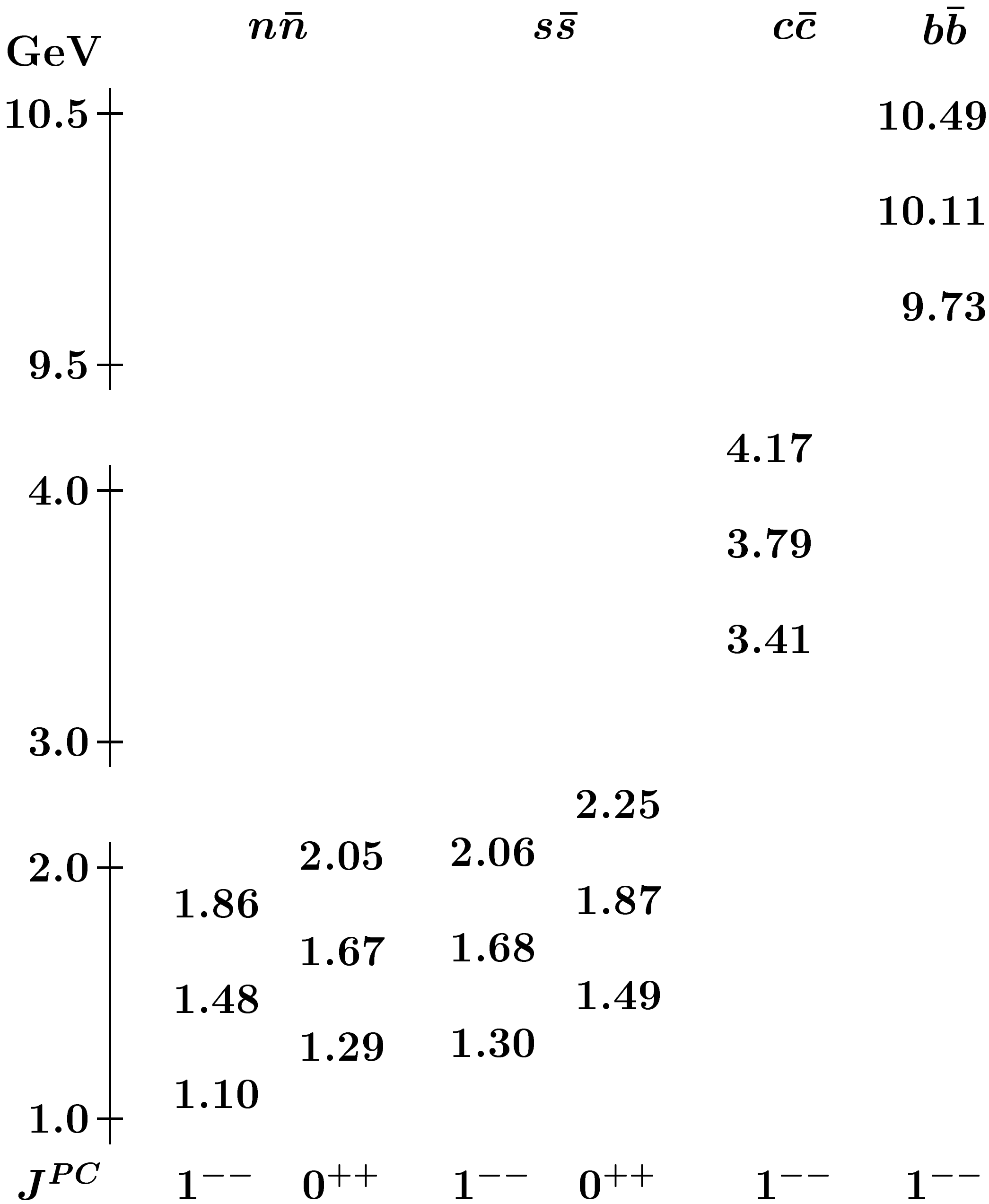
$^3P_0$ transition mechanism



functional dependence on J^{PC}, isospin and flavors

confinement spectrum
(the bare masses)

$$E_{HO} = \omega\left(2n + \ell_c + \frac{3}{2}\right) + m_q + m_{\bar{q}}$$



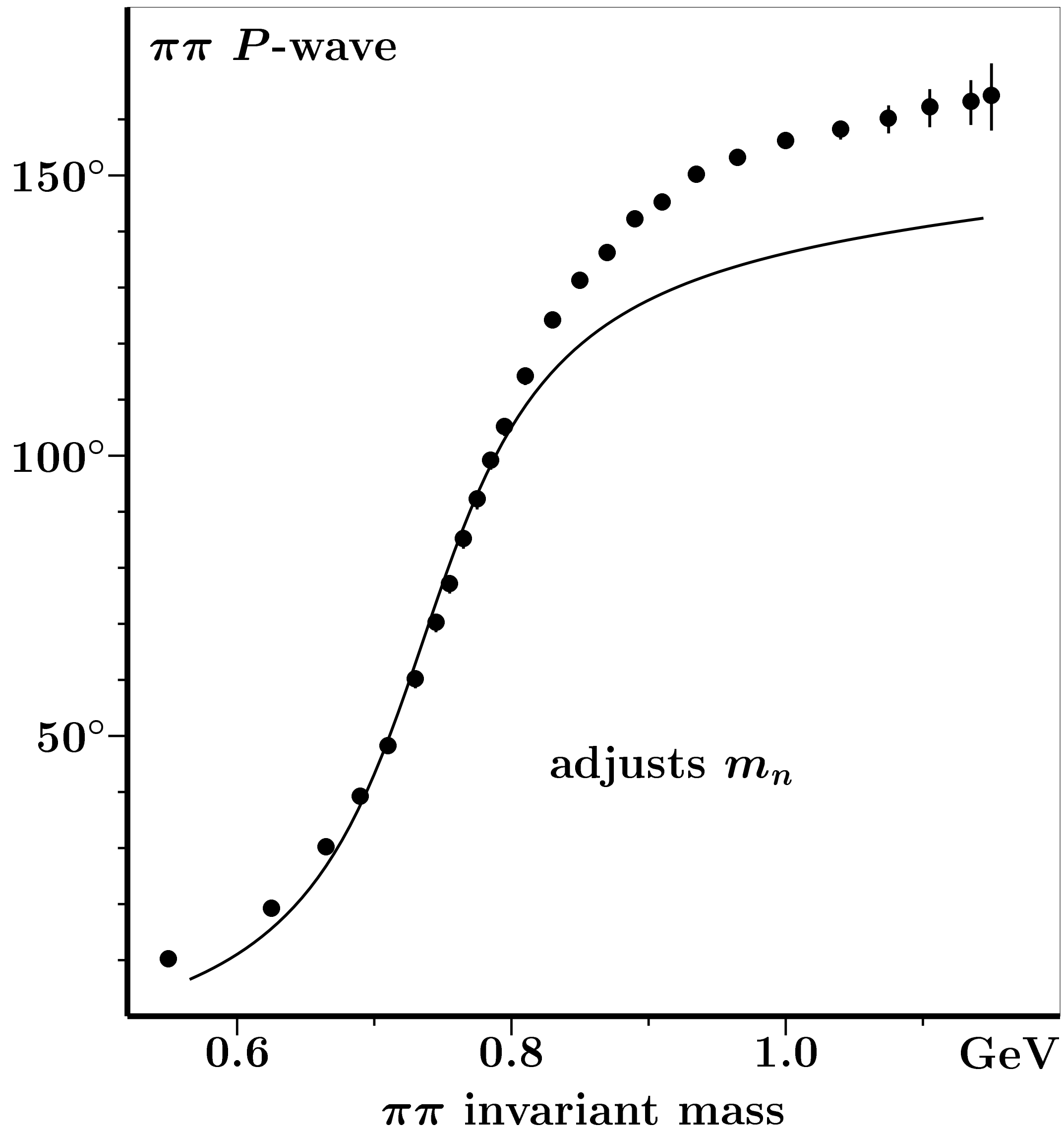
$J^{PC} = 1^{--}$ for $c\bar{c}$ and $b\bar{b}$

Mass	charmonium		beautonium	
GeV	theor	exp	theor	exp
1^3S_1	3.08	3.10	9.50	9.46
2^3S_1	3.66	3.69	10.00	10.02
1^3D_1	3.80	3.77	10.14	...
3^3S_1	4.04	4.04	10.39	10.36
2^3D_1	4.14	4.16	10.48	...
4^3S_1	4.42	4.42	10.77	10.58
3^3D_1	...	...	10.86	10.87
5^3S_1	...	...	11.15	11.02

comparison to experiment

Phys. Rev. D27,1527 (1983)

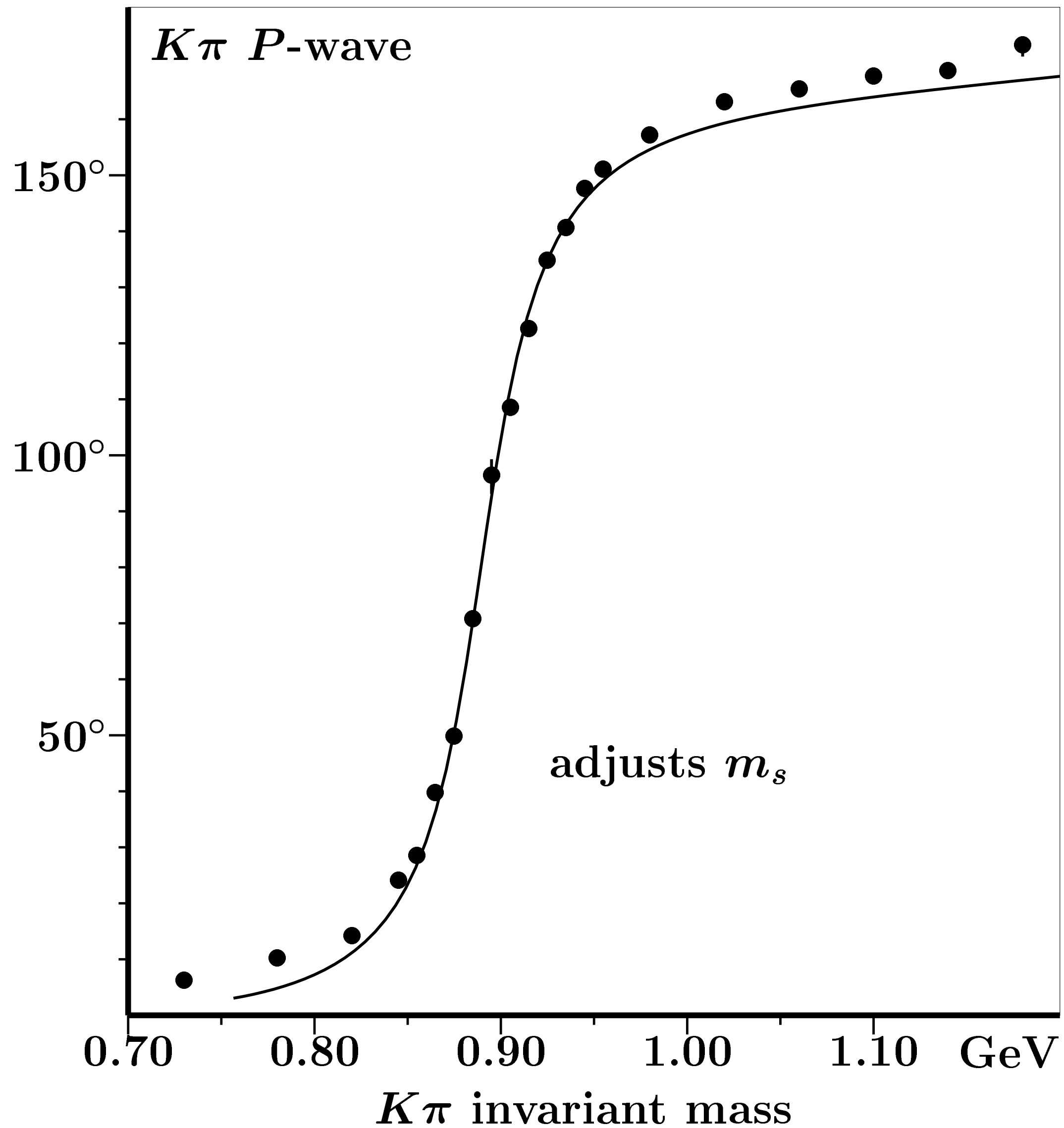
this adjusts:
transition potential(s)
ω (confinement)
m_c and m_b



$\pi\pi$ elastic P-wave phase shifts. The data (•) are taken from [?]. The model result is the solid line.

References

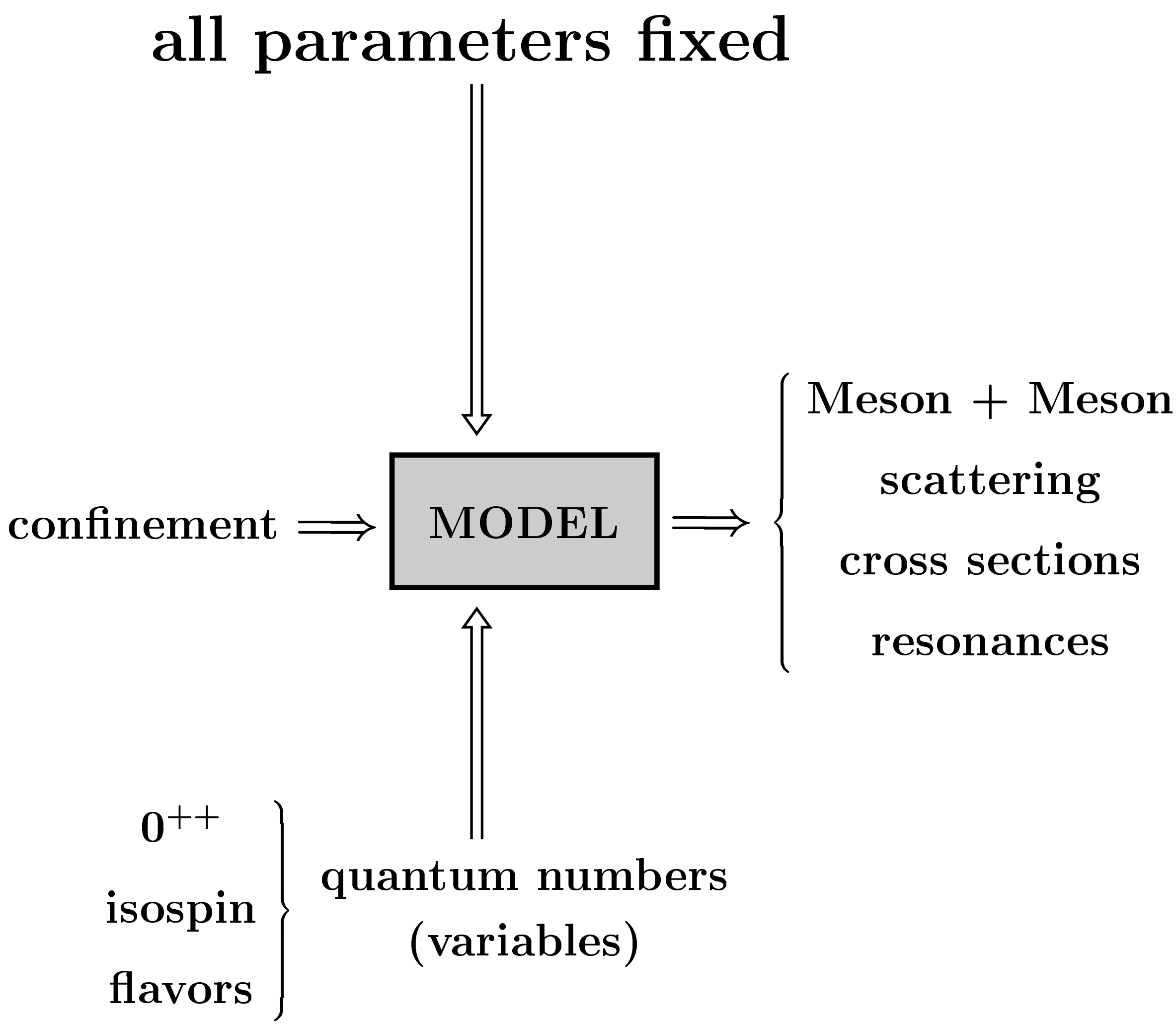
[1] S.D. Protopopescu et al. Phys. Rev. D7,1279 (1973).



Phase shifts for $K\pi$ elastic P-wave scattering. Data are taken from [?]. The model result is the solid line.

References

[1] P. Estabrooks et al. Nucl. Phys. B133,490 (1978).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MODEL
Meson + Meson
scattering
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0^{++}
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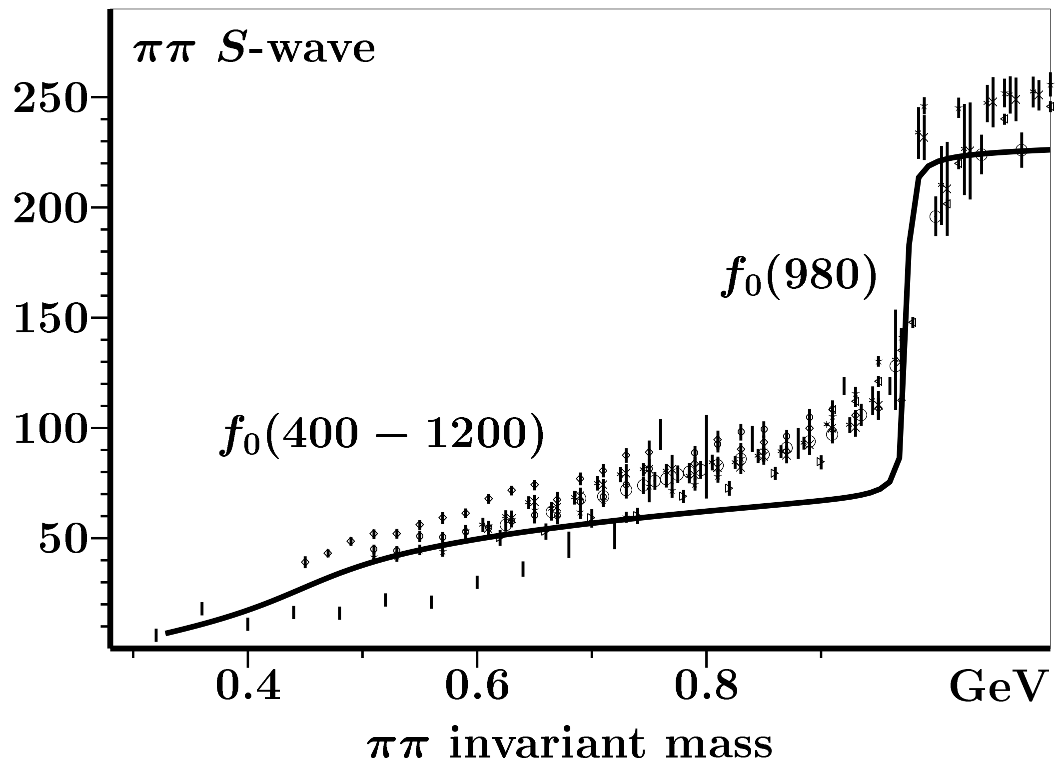


Remember:
0^{++} bare ground state
at 1.29 GeV

References

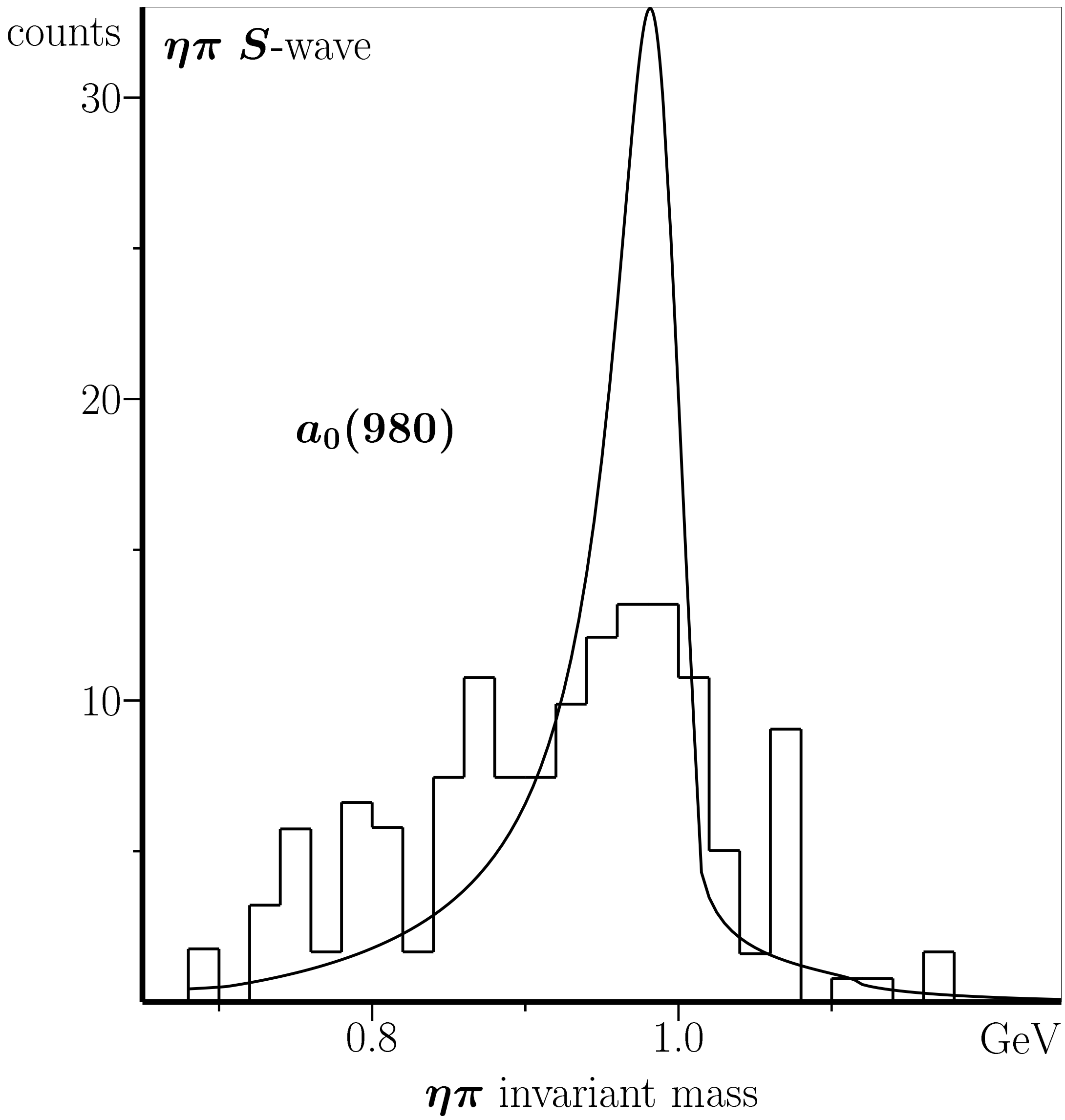
[1] S.D. Protopopescu et al. Phys. Rev. **D7**,1279 (1973).

[2] B. Hyams et al. Nucl. Phys. **B64**,134 (1973); Nucl. Phys. **B100**,205 (1975).

[3] G. Grayer et al. Nucl. Phys. **B75**,189 (1974).

[4] P. Estabrooks and A.D. Martin. Nucl. Phys. **B79**,301 (1974).

[5] N.N. Biswas et al. Phys. Rev. Lett. **47**,1378 (1981).



Remember:
0^{++} bare ground state at 1.29 GeV

References

[1] M.J. Corden et al. Nucl. Phys. **B144**,253 (1978).

Generalisation for arbitrary confinement spectrum (e.g. lattice spectrum)

in a simplified version of the coupled channel model limited to one channel

extension to many coupled channels and $^3P_0$ transitions is straightforward

$$\begin{cases} (E - H_c)\ \psi_c(\vec{r}\,) = V_t\, \psi_f(\vec{r}\,) \\ \left(E - H_f\right)\ \psi_f(\vec{r}\,) = [V_t]^T\ \psi_c(\vec{r}\,) \end{cases}$$

Elimination of confinement sector $\psi_c(\vec{r}\,)$:

$$\left(E - H_f\right)\ \psi_f(\vec{r}\,) =$$

$$= [V_t]^T\ (E - H_c)^{-1}\ V_t\, \psi_f(\vec{r}\,)$$

$$\Big\Downarrow\ J^{PC}$$

$$cotg\,(\delta_\ell(p)) = \frac{n_\ell(pa)}{j_\ell(pa)} +$$

$$- \left[2\lambda^2\ \mu\ pa\ j_\ell^2(pa) \sum_{n=0}^{\infty} \frac{\left|\mathcal{F}_{n\ell_c}(a)\right|^2}{E - E_{n\ell_c}} \right]^{-1}$$

$K\pi$ elastic scattering

$$H_f \;=\; -\tfrac{1}{2}\,\mu^{-1}\,\nabla_r^2 \;+\; M_K \;+\; M_\pi$$

$$V_t \;=\; \frac{\lambda}{a^{3/2}}\,\delta\,(r-a)$$

$$\lambda^2 \sum_{n=0}^{\infty} \frac{\left|\mathcal{F}_{n\ell_c}(a)\right|^2}{E - E_{n\ell_c}} \approx \lambda^2 \left(\sum_{n=0}^{N} \frac{B_{n\ell_c}}{E - E_{n\ell_c}} - 1 \right)$$

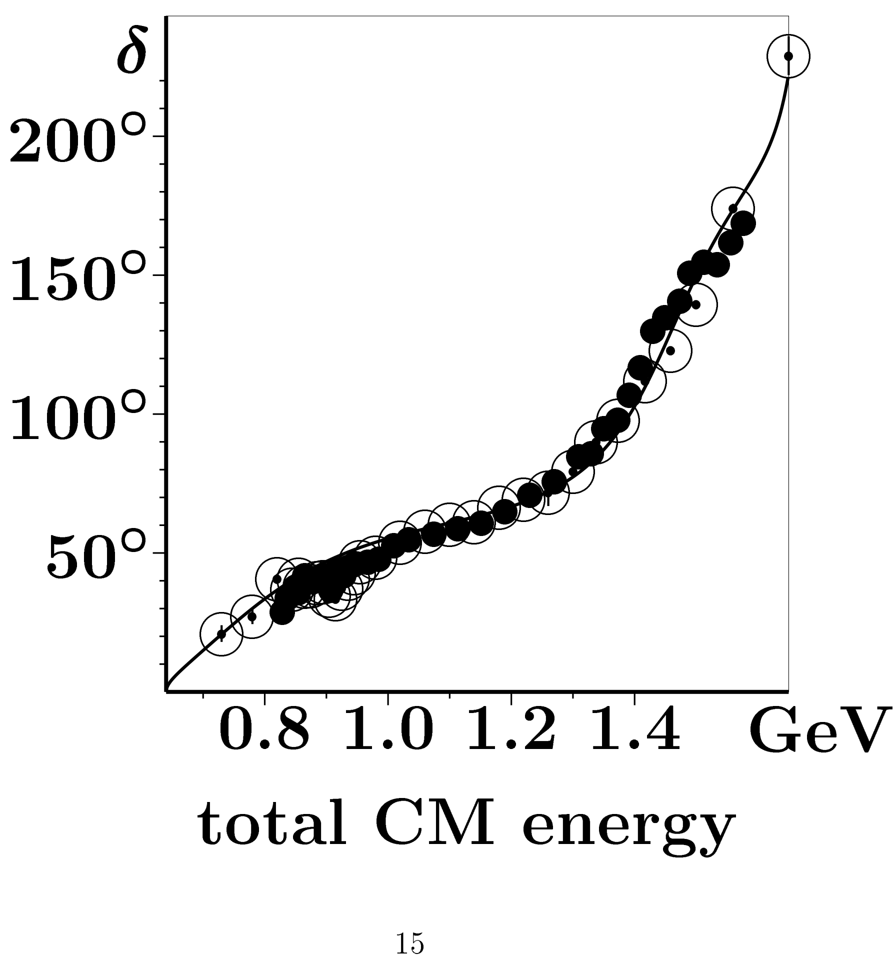
with a redefinition of λ

$K\pi$

Elastic $I = \frac{1}{2}$ P-wave scattering

$$\lambda = 0.75 \text{ GeV}^{-3/2} \text{ and } a = 5 \text{ GeV}^{-1}$$

$$\sum_{n=0}^{\infty} \frac{\left|\mathcal{F}_{n,0}(a)\right|^2}{E - E_{n,0}} \approx \left(\frac{0.5}{E - 0.945} - 1 \right) \text{GeV}^2$$



confinement sector

lowest $u\bar{s}$ $J^P = 1^-$ state at

$$E_{0,0} = 0.945 \text{ GeV}$$

scattering singularity can be searched for numerically from the analytic expression for the cotangent of the phase shift

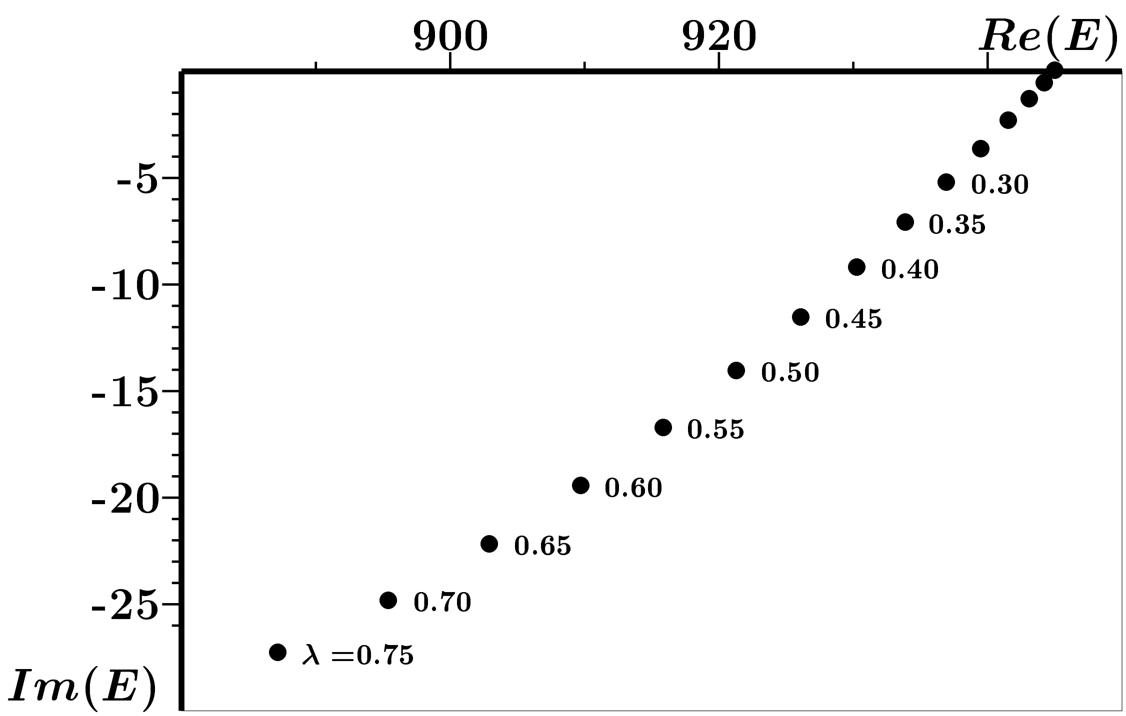
and is found at

$$0.887 - 0.027i \text{ GeV}$$

Complex-energy singularities of the S-matrix as function of λ

The point on the real axis corresponds to the bare state ($\lambda = 0$)

Units are in MeV



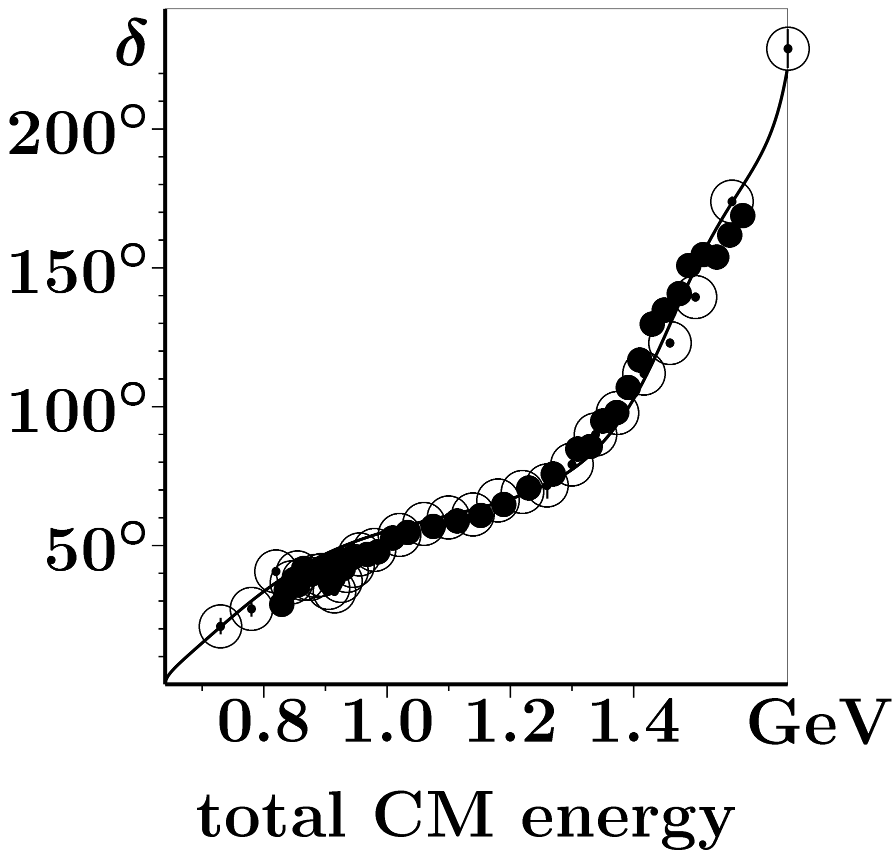
$K\pi$

Elastic $I = \frac{1}{2}$ S-wave scattering

$\lambda = 0.75$ GeV$^{-3/2}$ and $a = 3.2$ GeV^{-1}

$$\sum_{n=0}^{\infty} \frac{\left|\mathcal{F}_{n,1}(a)\right|^2}{E - E_{n,1}} \approx$$

$$\left(\frac{1.0}{E - 1.31} + \frac{0.2}{E - 1.65} - 1 \right) \text{GeV}^2$$



confinement sector

lowest bare $u\bar{s}$ $J^P = 0^+$ states at

$E_{0,1} = 1.31$ GeV, and $E_{1,1} = 1.65$ GeV

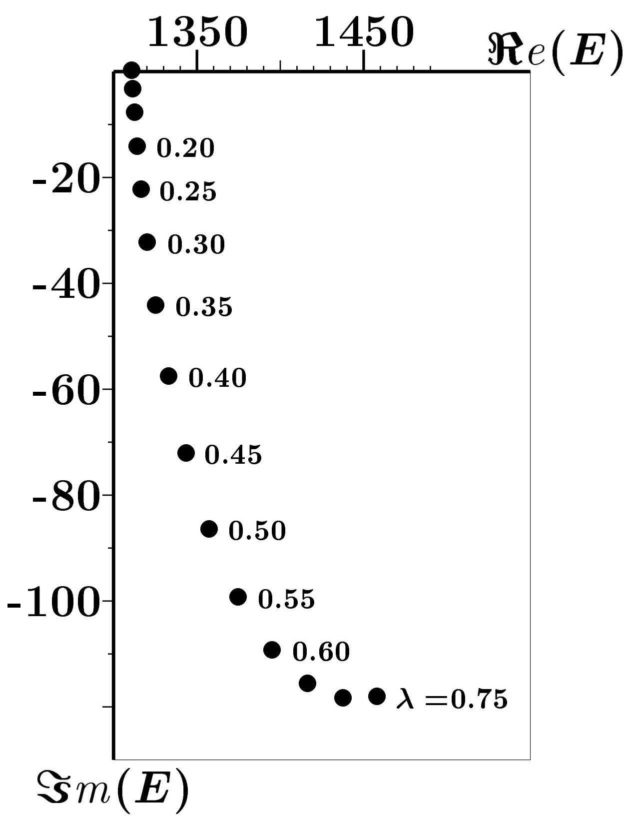
scattering singularities numerically are found at

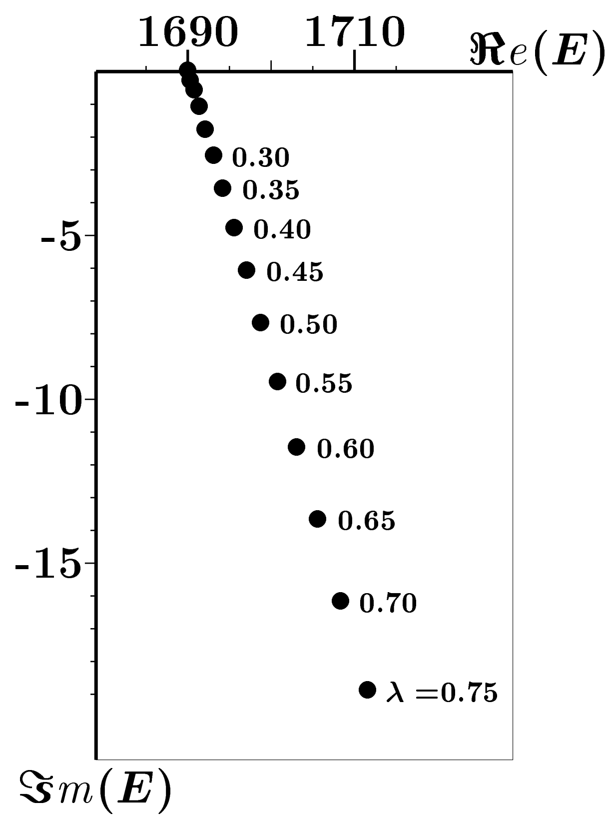
1460 - 114i MeV, 1673 - 24i MeV, and ...

Complex-energy singularities of the S-matrix as function of λ

The point on the real axis corresponds to the bare state ($\lambda = 0$)

Units are in MeV





Notice nonperturbative behaviour of lower singularity

and a singularity at

713 - 227i MeV

in

E. van Beveren, T. A. Rijken, K. Metzger, C. Dullemond, G. Rupp, and J. E. Ribeiro, Zeit. Phys. C30, 615 (1986)

found at

727 - 263i MeV

many more channels

full transition potential

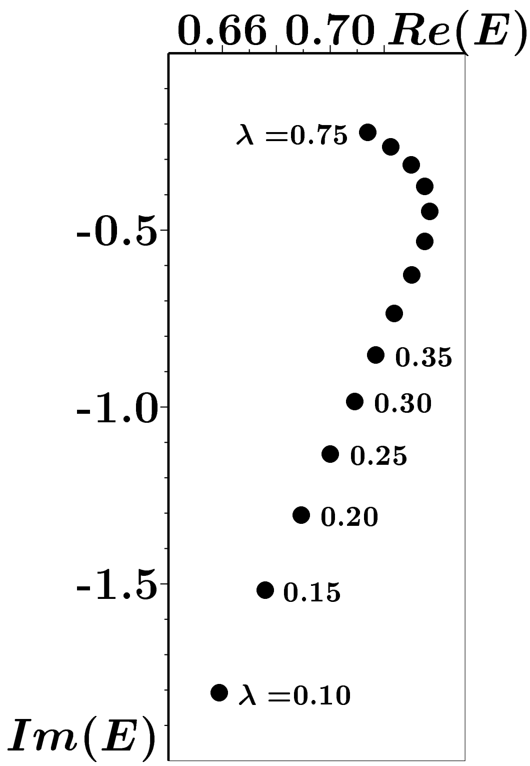
harmonic oscillator confinement

no free parameters

Complex-energy singularities of the S-matrix as function of λ

Singularity disappears in background for $\lambda = 0$

Units are in GeV

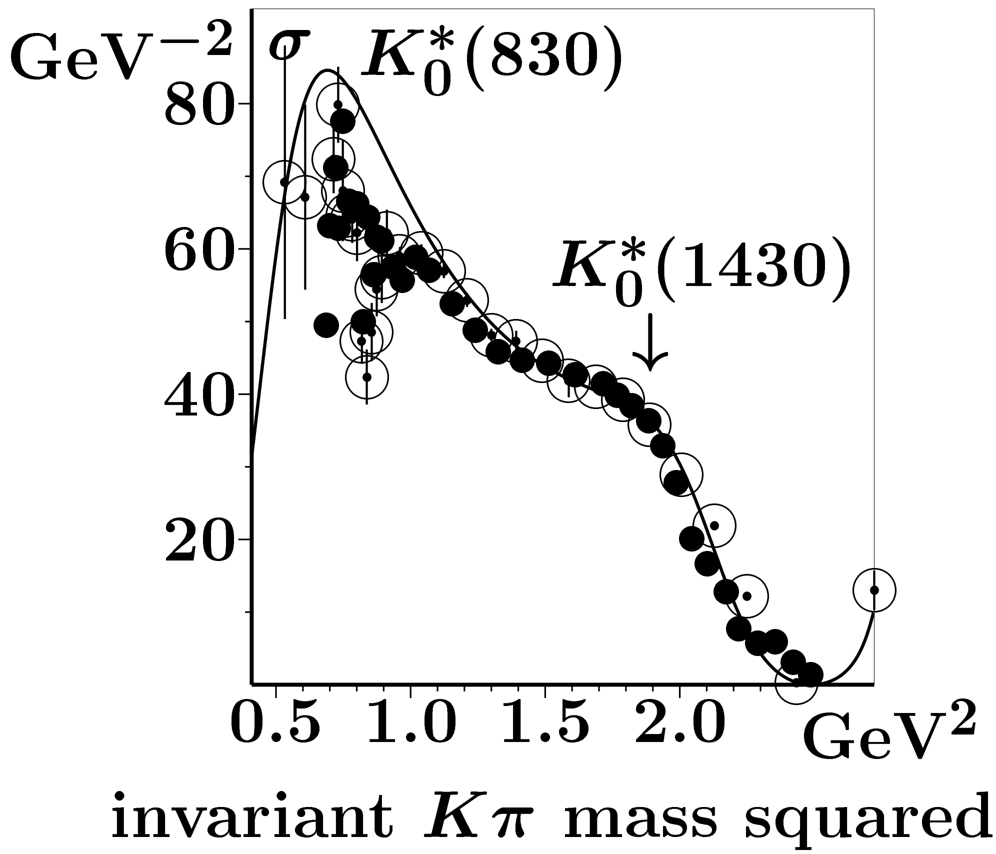


$K_0^*(727)$ completes nonet of light scalar mesons

Isospin	pole position (MeV)
$I = 1$	968-28i
$I = \frac{1}{2}$	727-263i
$I = 0$	470-208i and 994-17i

forms

THE nonet of
the lowest lying singularities
of the scattering matrix
for $J^{PC} = 0^{++}$ states



peak signal at 830 MeV

width of some 500 MeV

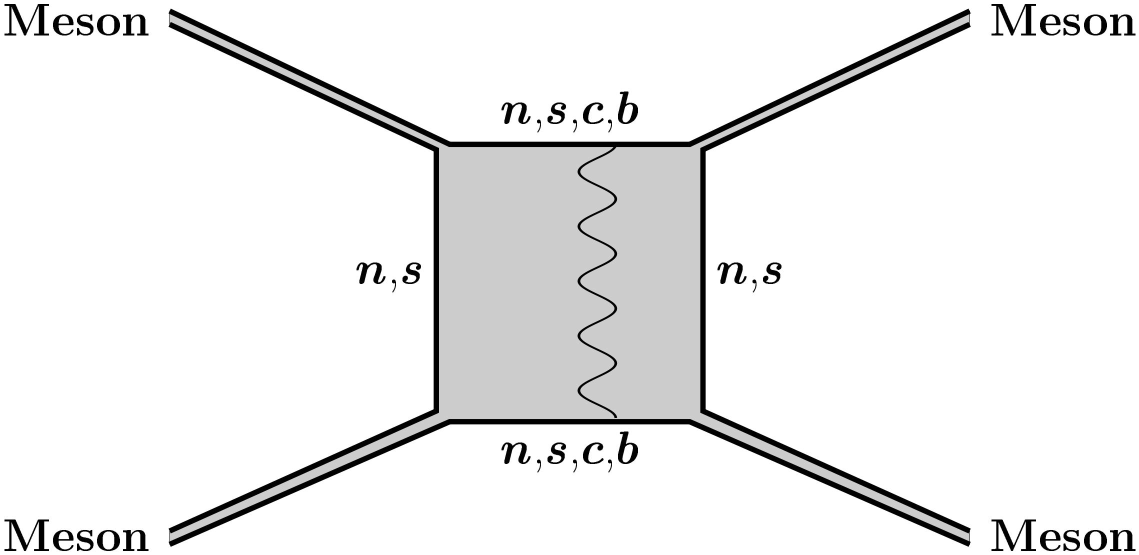
preliminary result E791 collaboration

Understanding the scalar meson nonet?

N.A. Törnqvist, Z.Phys. C68, 647 (1995)
N.A. Törnqvist and M. Roos, Phys.Rev.Lett. 76, 1575 (1996)

Comparison

	Törnqvist/and Roos	Beveren et al.
model details	unitarisation	unitarisation
	coupled channels	coupled channels
	ad hoc bare states	confinement
date	1995/1996	1986
nonet	$K_0^*(727)$ missing	full
heavy quarks	no relation	in the same model
decay products	pseudoscalars	pseudoscalars and vectors
flavour symmetry	broken	full
parameters	6	none, after fitting to $J^{PC} = 0^{-+}$ and 1^{--}
higher scalars	mixed up with light scalars	different nonet stemming from confinement
$f_0(1370)$	$s\bar{s}$	$n\bar{n}$
citations (Spires)	125/159	52



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[1] Eef van Beveren, and George Rupp, [hep-ex/0106077].

[2] Eef van Beveren, George Rupp, and Michael D. Scadron, Phys. Lett. **B495**, 300 (2000).

[3] E. van Beveren and G. Rupp, Eur. Phys. J. **C10**, 468 (1999).

[4] A.G.M. Verschuren, C. Dullemond and E. van Beveren, Phys. Rev. **D44**, 2803 (1991).

[5] E. van Beveren, Nucl. Phys. **B21**, 43 (1991).

[6] E. van Beveren, T. A. Rijken, K. Metzger, C. Dullemond, G. Rupp, and J. E. Ribeiro, Zeit. Phys. **C30**, 615 (1986).

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[8] E. van Beveren, G. Rupp, T.A. Rijken, and C. Dullemond. Phys. Rev. **D27**,1527 (1983).

[9] E. van Beveren, C. Dullemond, and G. Rupp. Phys. Rev. **D21**,772; (E) D22, 787 (1980).