Low Mass Meson Spectroscopy and Its Problems

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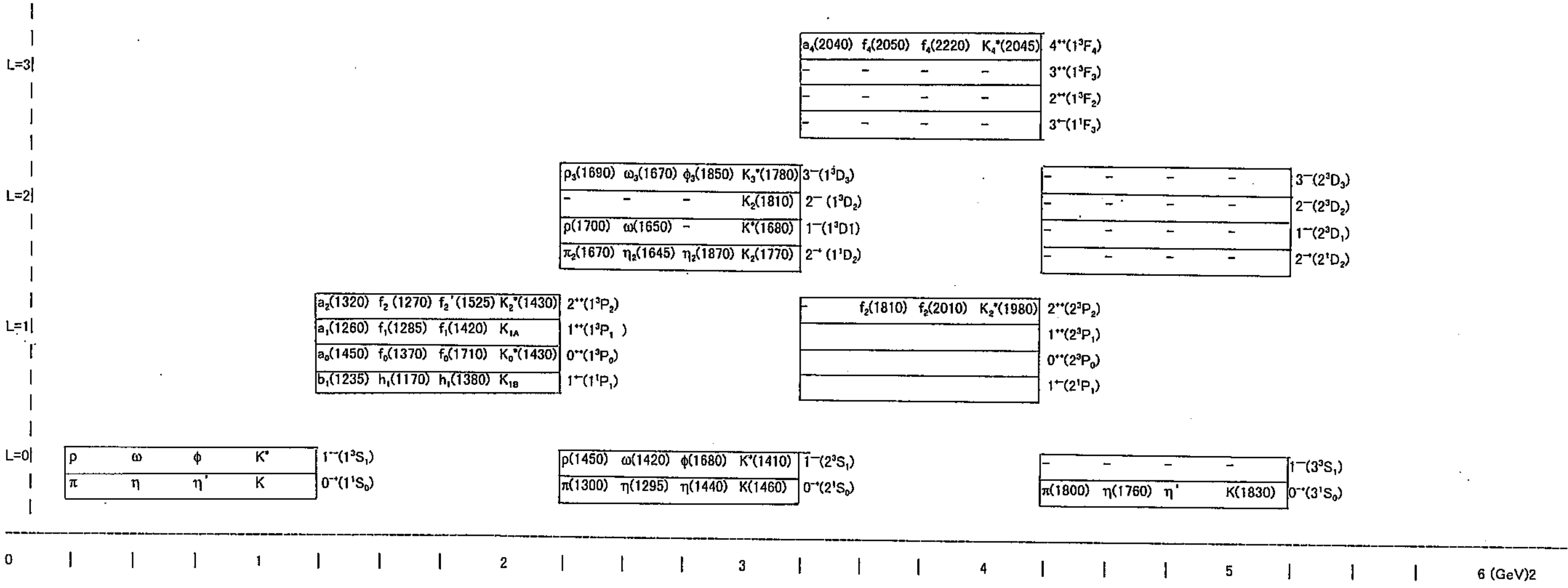
Contents.

図6-7-2　Rosner Box Score



1. Introduction

SU(3) qqbar meson states, Non-Relativistic Description

LS coupling scheme, Quantum numbers: J^{PC}

$S = S_1 + S_2$, $J = S + L$,

$P = (-1)^{L+1}$, $C = (-1)^{L+S}$

I = 0 and 1,.No I = 2

L=0	$^1S_0$	0^{-+}	π	2^1S_0 $\pi(1300)$
	$^3S_1$	1^{--}	ρ	2^3S_1 $\rho(1450)$
L=1	$^1P_1$	1^{+-}	$b_1(1235)$	
	$^1P_0$	0^{++}	$a_0(1450)$	
	$^3P_1$	1^{++}	$a_1(1260)$	
	$^3P_2$	2^{++}	$a_2(1320)$	
L=2	$^1D_2$	2^{-+}	π (1670)	
	$^3D_1$	1^{--}	ρ (1700)	
	$^3D_2$	2^{--}		
	$^3D_3$	3^{--}	ρ (1690)	

Rosner: Box Score, L vs M^2

Godfrey and Isgur: SU(3) qqbar meson spectra from π to $\Upsilon(6S)$ (1985)

Four relativised onstituent quark masses, QCD potential

SU(3) qqbar so called exotic states, 0^{+-}, 0^{--}, 1^{-+}, ···

gluonic degrees of freedom glueballs, gg, ggg: 0^{++}, 0^{-+}, 2^{++}, ···

hybrids, qqbarg: 1^{-+}, ···

multiquark states possible I=2, 1^{-+}, ···

chiral symmetry partners of π, ρ, ···, $\bar{q}q$: 0^{++}, 1^{++}, ···

Spontaneously breaking of chiral symmetry

Ground and first radial and orbital excited states:

below 1.7 GeV of mass and 0.1–0.3GeV of width.

$^1S_0$,	well established	2^1S_0,	E/ι (in 80's)	
$^3S_1$	well established	2^3S_1	ρ(1250)	A. Donnachie
$^3P_0$	controversial,			
$^3P_1$	$a_1(1260)$ mass and width			
$^3P_2$	well established,			

2. SU(3) qqbar nonets

2.1 Radially excited pseudoscalar nonet

<u>π(1300)</u>, <u>η(1295)</u>, <u>η(1410)</u>, <u>K(1460)</u>, and η (1470)
decay modes: $a_0(980)\pi$ η(1410) (ηππ/KKπ)
$K^*(892)K$ η (1470) (KKπ)

E/ι controversy and extra η on data with a desire for glueball
E(1420) $\bar{p}p$ ->KKπππ, KKπ, 0^{++}, 81cmHBC at CERN(1967)
π^-p -> KsKπn, K*K, 1^{++}, E(1420), 2mHBC at CERN(1980)
pp collision: KKπ 1^{++}, E(1420), Omega(1989)

<u>η(1420)</u> π^-p -> KKπn(1985), ηππn(1986), 0^{++}

Discovery of J/Ψ, hope for glueball search in radiative. decays. γ
Radiative decays: gluon rich c
J/Ψ hadrons
Flavor tagging $\bar{c}$
J/Ψ -> γKKπ , γηππ : ι, <u>η(1410)</u> and <u>η(1470)</u>
Mark II, a broad peak around 1440MeV $0^{-+}/1^{++}$
Mark III, resolving into two peaks; 1420MeV and 1490MeV
DM2, also 4πγ,
BES,
$\bar{p}p$ XB, OELIX
πp CEX: ηππ/KKπ: <u>η(1295)</u>, <u>η(1410)</u>,
$K^*(892)K$ <u>η(1410)</u>, <u>η(1470)</u>

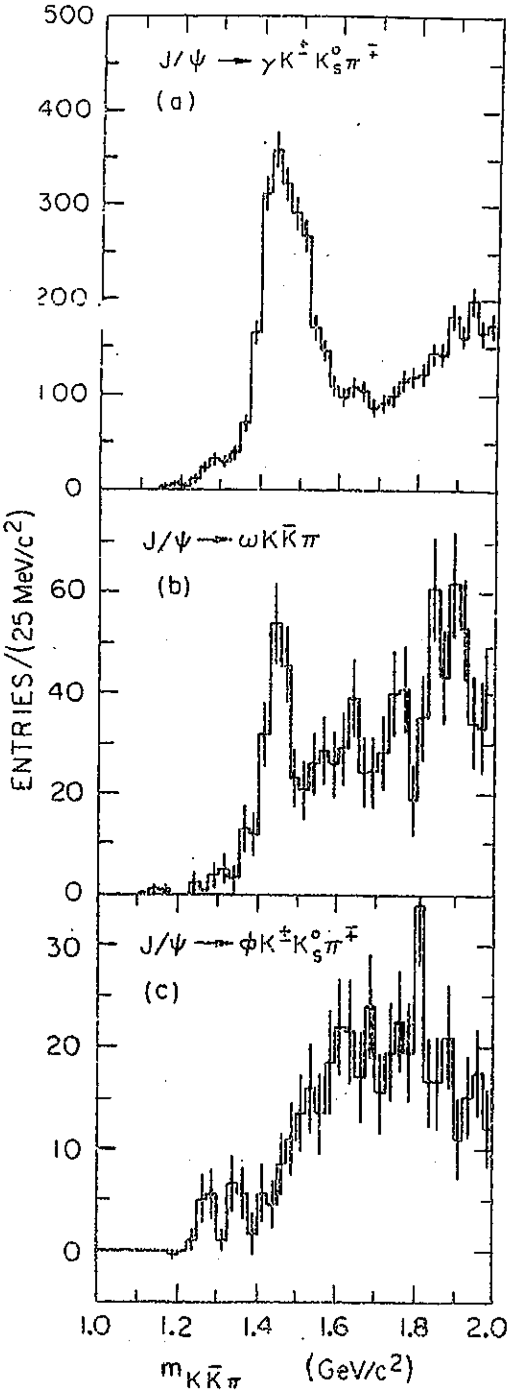
Lattice calculation, scalar, pseudoscalar glueballs

PS glueball: around 2.3GeV, Scalar glueball: around 1.6GeV

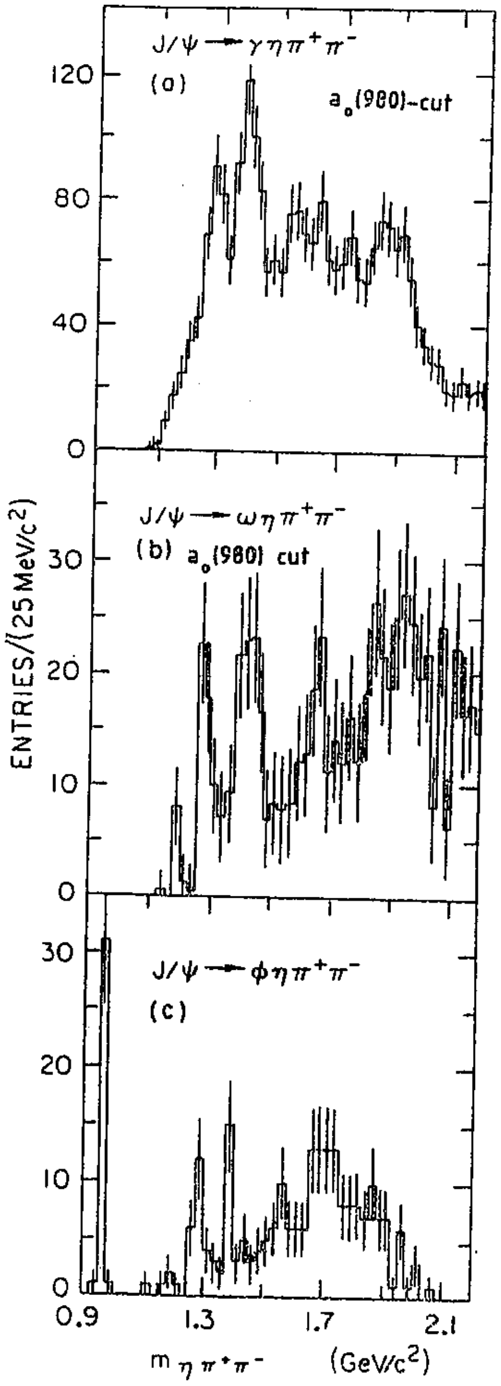
Extra states, chiral symmetry, S. Ishida and M. Ishida, PTP
Expect for extra η
$U^{\sim}(12)$ classification scheme for light quark mesons

J/Ψ -> γKKπ and γηππ, Mark III (1987)

KKπ



ηππ



J/Ψ -> $\gamma KK\pi$ and $\gamma\eta\pi\pi$, Mark III (1987)

$KK\pi$

- dominant 'iota' structure

- $f_1(1420)$ signal
- too narrow for 'iota'

- no 'iota' signal
- no $f_1(1420)$
- events in $f_1(1285)$ region

$\eta\pi\pi$

- signals in $f_1(1285)$, $f_1(1420)$ region
- no 'iota' signal
- further structures between 1.5 and 2.0 GeV

- possible $f_1(1285)$ and $f_1(1420)$ signals
- no 'iota' signal

- $f_1(1285)$ signal
- no 'iota' signal

2.2 Radially and orbitally excited vectors

ρ(1450), ρ(1700), and ρ(1250)

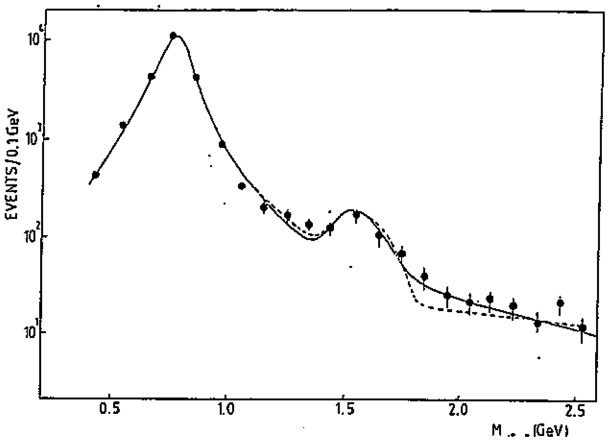
ρ(1450) and ρ(1700): ρ (1600) so far.

Comparison of ππ data between photoproduction, γp -> ππ,
and e^+e^- annihilation, e^+e^- -> ππ (1985,1989), -> ωπ (1986) Donnachie(1987)
πp -> ηππ, e^+e^- -> ηππ (KEK,DM2 1988)
e^+e^- -> ωπ, 4π (1991, 1981)
τ -> 3πν (1997, 1998)
$\bar{p}p$, $\bar{p}n$ -> 4π in 5π, ωπ and $a_1\pi p$, XB(2001), ππ OBELIX (1997)
Clegg and Donnachie (1990), Achasov(1997)
$\pi^- p$ -> $\phi\pi^0$, ρ(1480)(1987)

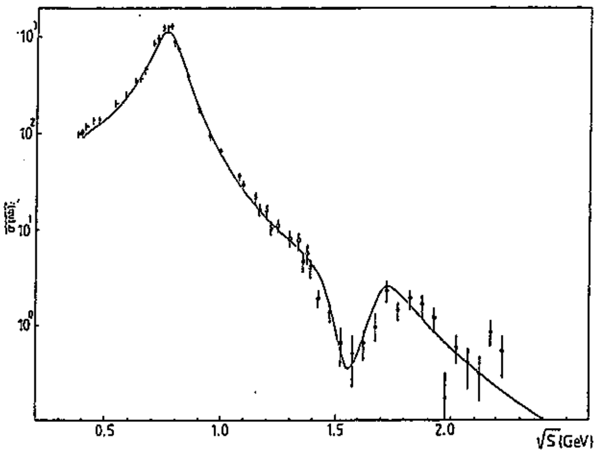
ρ (1250):
$\bar{p}p$ -> ωππ, ρ' -> ωπ 1250MeV (1972)
Photoproduction γp -> $\omega\pi^0 p$, ρ'(1974); b_1(1235) (84, 88)
$K^- p$ -> ππΛ, SLAC(1991), ρ' at 1300MeV
e^+e^- -> ππ (1983) ρ'
e^+e^- -> 4π, ρ' -> ρπ SND$_{(2001)}$ 1250MeV
$\bar{p}d$ -> ωππ, ρ' -> ωπ at 1180MeV XB$_{(2001)}$

((four quark states?: ρ (1200), ω (1200), K*(1410), C(1480)))

$\gamma p \rightarrow \pi\pi$



$e^+e^- \rightarrow \pi\pi$



$e^+e^- \rightarrow \pi\pi$, $|F_\pi^2|$, OLYA at VEPP2, 1985

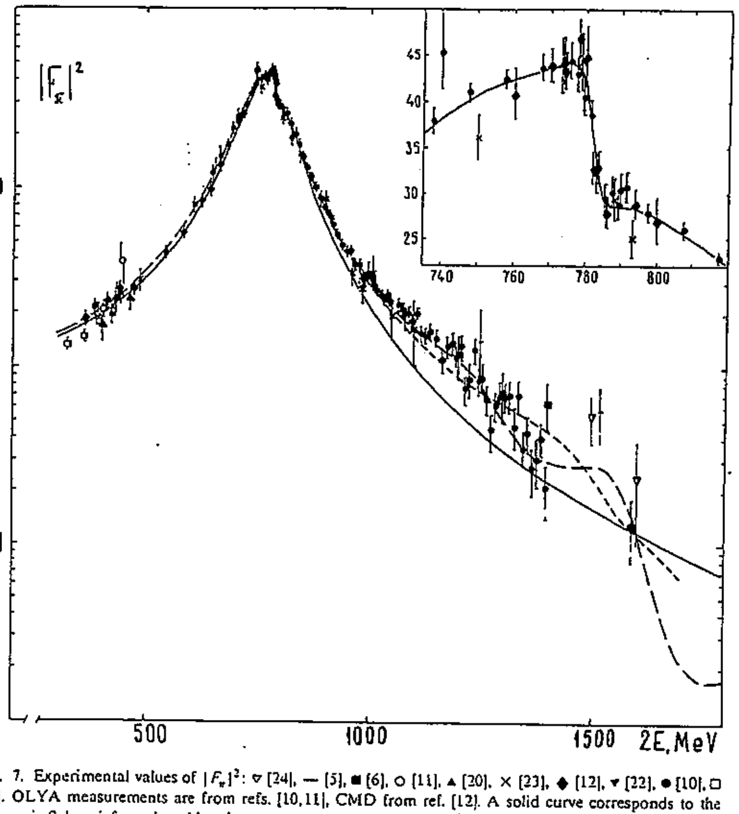


Fig. 7. Experimental values of $|F_\pi|^2$: ▽ [24], — [5], ■ [6], ○ [11], ▲ [20], × [23], ◆ [12], ▼ [22], ● [10], □ [27]. OLYA measurements are from refs. [10,11], CMD from ref. [12]. A solid curve corresponds to the Gounaris-Sakurai formula taking into account $\rho-\omega$ interference, dotted line – parametrization with $\omega, \rho, \rho'(1250), \rho''(1600)$ mesons.

m_ρ = 1290 MeV, Γ_ρ = 200MeV

3. $^3P_1$ Axialvector $a_1(1260)$

Mass and width parameters of $a_1(1260)$ in the PDG tables.

Wide spread for mass values in both hadronic production processes and τ decays. Extraordinarily wide width, Γ ~600MeV in τ decays.

Hadronic productions.

πp diffractive process,

m = 1240MeV, Γ = 380MeV. ACCMOR (1980). Corrected for Deck effects.

Charge exchange processes,

m = 1240MeV, Γ = 380MeV. ANL (1981). Corrected for Deck effects.

m = 1121MeV, Γ = 239 MeV. KEK (1992).

m = 1145 MeV, Γ = 272MeV. Corrected for Deck effects.

Kp backward scattering,

m = 1041MeV, Γ = 230MeV. CERN (1977)

pp centrall. Collision

m = 1240 MeV, Γ = 400MeV. CERN (1998).

τ decays, τ –> 3πν.

DELCO(1986), MARKII(1986), ARGUS(1986), MAC(1987), ARGUS(1993), OPAL(1997), DELPHI(1998), CLEO(2000).

experimental data: peak value =1000–1200MeV, Γ=400–500MeV

mass dependent decay amplitude, running mass shift in analyses;

—> 1260MeV, Γ >~ 600MeV.

N. Bowler (1986,88), N. Isgur, C.Morningstar and C.Reader(1989), J.M. Kuhn and A. Santamaria (1990) , N. Tornqvist (1995).

CLEO(2002), m =1330MeV, Γ =814MeV with a_1'(1700)

two resonant states: m(a_1)=1.11GeV, Γ=0.38GeV and m(a_1')=1.5GeV. J.Iizuka (1989).

qqbarqbar: m = 1100MeV. D. Peaslee (1987)

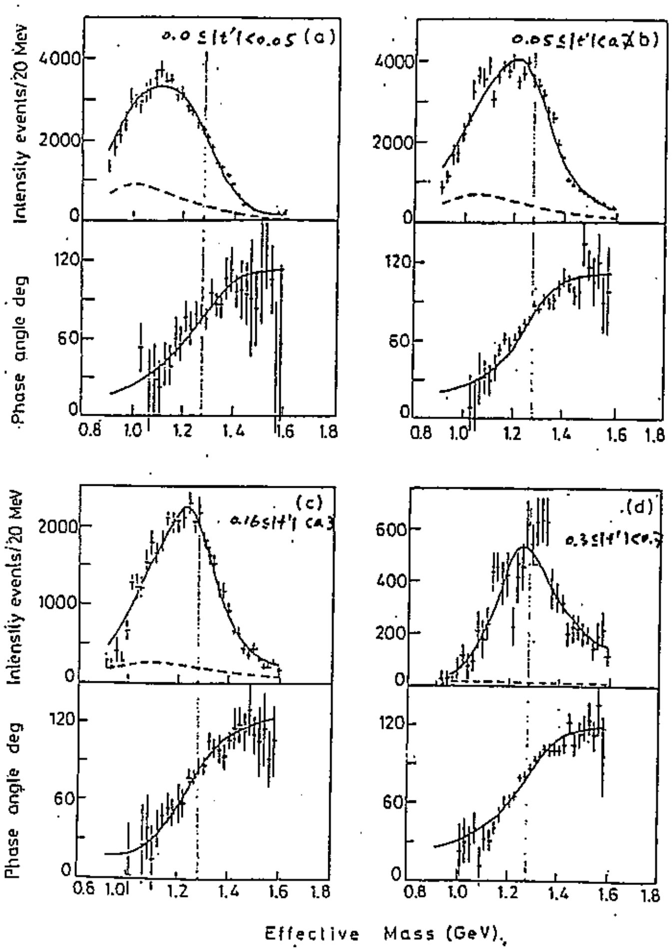
QCD sum rule: m = 1.15GeV. L.J.Reinders, S.Yazaki, H.R.Rubinstein (1982)

Lattice QCD: m = 1250MeV, $f_{a1} = 0.3(\mathrm{GeV})^2$ M.Wingate et al. (1995)

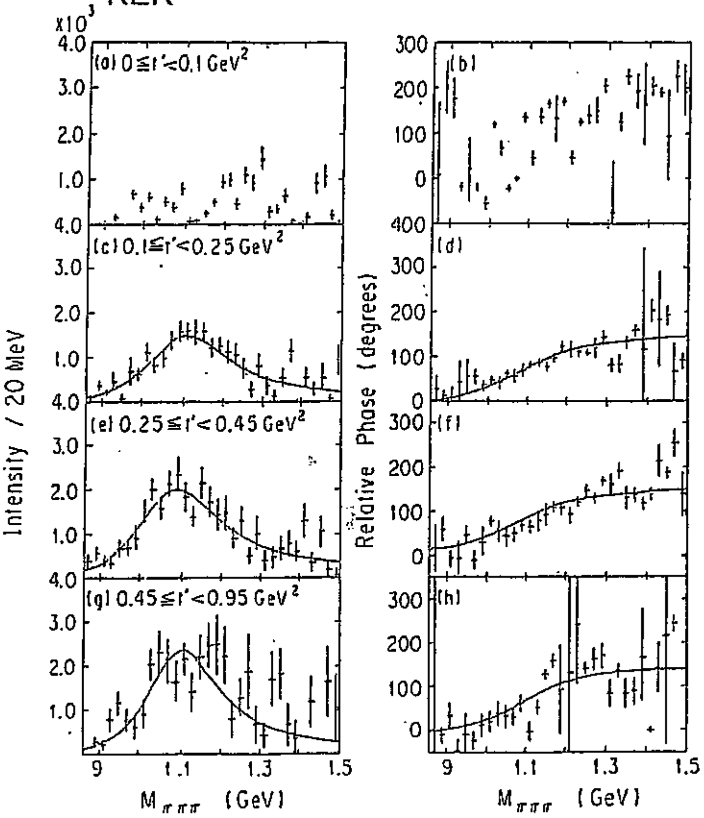
Resonance parameters of $a_1(1260)$ are, still, uncertain.

a_1^x: chiral partner of ρ meson: mass around1000MeV

ACCMOR



KEK



a$_1$(1260) (MeV)

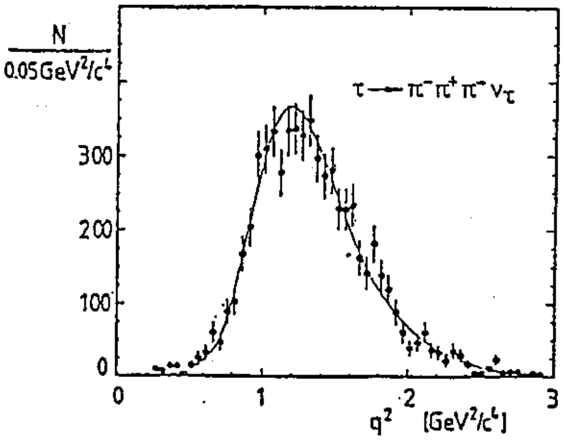
t' (GeV/c)^2		0.10 -0.25	0.25 -0.45	0.45 -0.95	Average
Breit-Wigner	M	1128±29	1112±54	1119±73	1122±48
	Γ	250±76	290±150	227±179	254±110
Bowler Model 1	M	1156±94	1145±42	1114±101	1143±62
	Γ	230±135	281±54	248±163	272±83
Bowler Model 2	M	1156±70	1148±46	1115±135	1147±64
	Γ	230±81	290±49	249±167	272±70

M: mass, Γ: width

Table 2 Parameters of Breit-Wigner fitting to intensity distributions of 11+ρS1+ wave.

τ decays, $\tau \to 3\pi\nu$

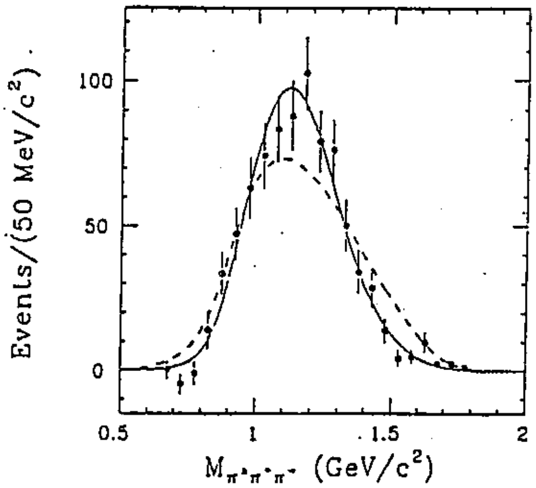
ARGAS(1986)



m=1046+−11MeV,

Γ=521+−27MeV.

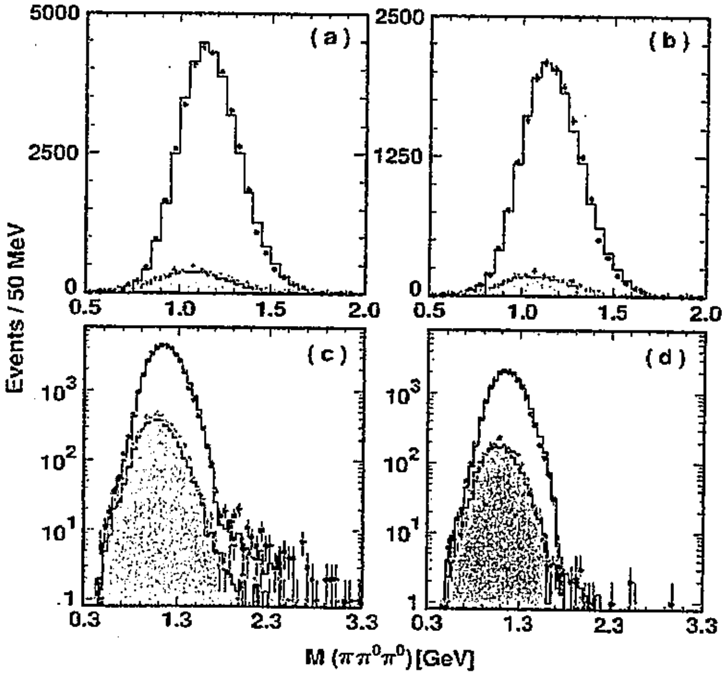
MARK II(1986)



m=1194+−14+−10MeV,

Γ=462+−56+−30MeV.

CLEOII(2002)



Running mass, m=1331+−10+−3MeV, Γ=814+−36+−13MeV.

$$m^2_{a1}(s) = m^2_{0a1}+\delta^2(s),\ \delta^2(s) = (1/\pi)\int_{s_{min}}^{\infty}(m_{0a1}\Gamma^{a1}_{tot}(s')/(s-s')ds'.$$

Possible a_1' contribution, m=1330+−11MeV, Γ=814+−38MeV.

Axialvector meson, a_1^χ, a chiral partner of ρ meson.

S. Weinberg:	$m(a_1^\chi) = 2\ m(\rho) \sim 1.1$GeV, $\Gamma(a_1^\chi) \sim 50$MeV ($a_1^\chi \to \sigma\pi$) Current algebra (1990).
S. Ishida:	$m(a_1^\chi) \sim 1$GeV, COQM (2000).
M.D. Scadron:	LσM and $a_1^\chi \to \sigma\pi$. (1991).

Hint for a_1^χ

$3\pi^0$ in the π^-p charge exchange process. GAMS, CERN (1984)

$\pi^-p \to \pi^0\pi^0\pi^0 n$ at 100GeV/c

$\pi^0\pi^0\pi^0$ scatter plot on the $2\pi^0$ vs $3\pi^0$ invariant mass plane.

$2\pi^0$ and $3\pi^0$ invariant mass spectra.

Rejection of K*(892): K^0_s cut in $m_{2\pi}$

Resonances taken into the analysis.

η, η'(958), a_1^χ, $a_1(1260)$ and $\pi_2(1670)$

$a_1^\chi \to \sigma\pi^0$; $\sigma \to 2\pi^0$,

$a_1(1260) \to \sigma\pi^0$ and $f_0(980)\pi^0$; σ and $f_0(980) \to 2\pi^0$,

$\pi_2(1670) \to \sigma\pi^0$, $f_0(980)\pi^0$ and $f_2(1270)\pi^0$; σ, f_0 and $f_2 \to 2\pi^0$,

$\eta'(1300) \to \sigma\ \pi^0$ and $f_0(1370)\pi^0$.

Fitting with the interfering BW amplitude method, the Variant Mass and Width (VMW) method.

$$M(s) = \Sigma_j r_j exp(i\theta j)\Delta_j$$

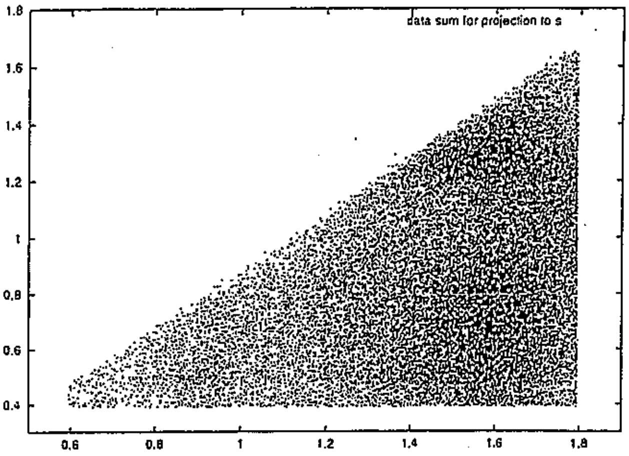
with

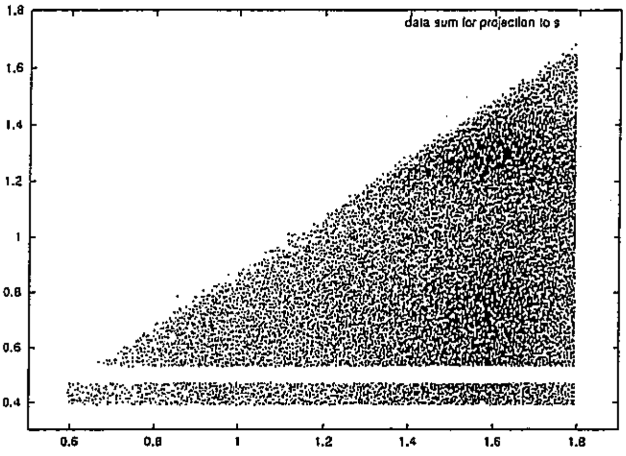
$$\Delta_j = \sqrt{s}\Gamma(s)_j / (s - m_j^2 + i\sqrt{s}\Gamma(s)_j),$$

where r_j : production amplitude of the jth resonance, and θ_j : production phase of the jth resonance.

$\pi^0\pi^0\pi^0$ scatter plot on the $2\pi^0$ vs $3\pi^0$ invariant mass plane.

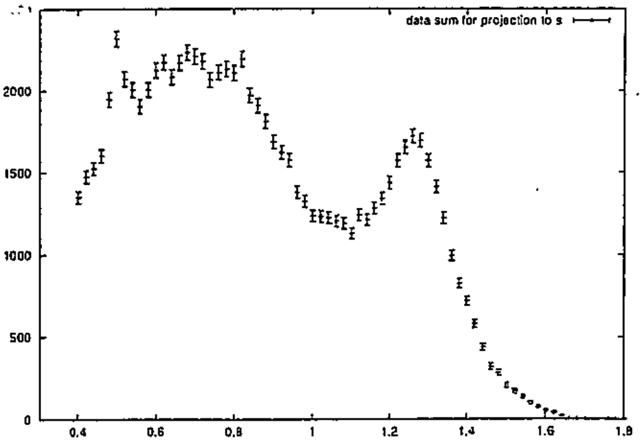
Rejection of K*(892): K^0_s cut in $m_{2\pi}$

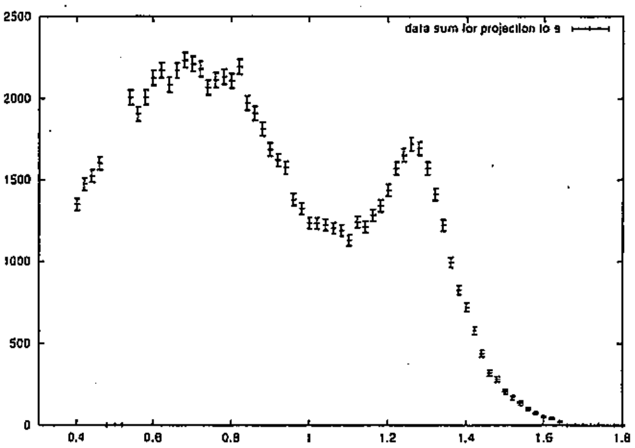




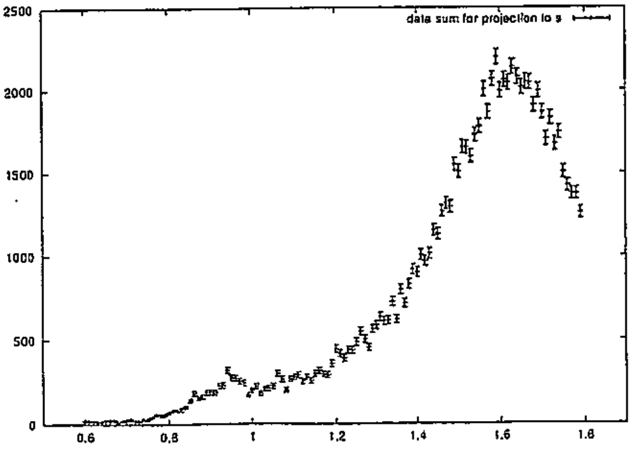
$2\pi^0$ and $3\pi^0$ invariant mass spectra.

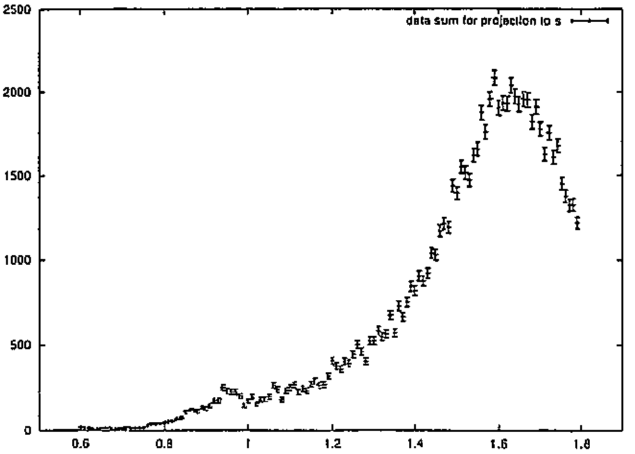
$2\pi^0$



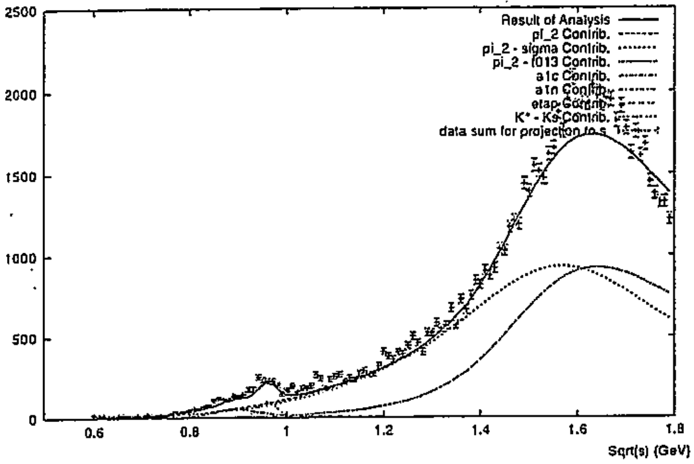


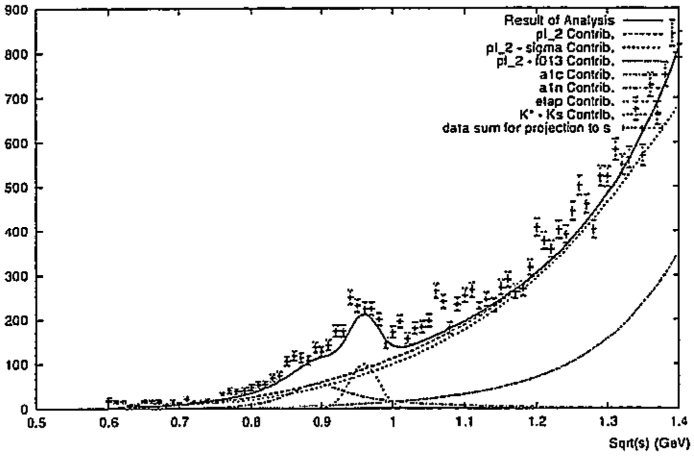
$3\pi^0$





Fitting results with a_1^{χ}.





Parameters obtained:

$m(a_1^{\chi})=884$MeV, $\Gamma(a_1^{\chi})=107$MeV, $r(a_1^{\chi})=49$
$m(\pi_2)=1521$MeV, $\Gamma(\pi_2)=615$MeV, $r(\pi_2)=85$
$m(\sigma)=667$MeV, $\Gamma(\sigma)=600$MeV, $r(\pi_2\text{->}\sigma)=0.59$
$m(f_2)=1290$MeV, $\Gamma(f_2)=200$MeV, $r(\pi_2\text{->}f_2)=1.0$, $\theta(\pi_2\text{->}f_2)=-24$
$m(\eta')=957$MeV, $\Gamma(\eta')=20$MeV. $r(\eta')=85$

4. Scalars,

I=0 $f_0(600)$ or σ, f_0 (980), $\underline{f_0(1370)}$, $f_0(1500)$, $\underline{f_0(1710)}$, $f_0(2020)$
I=1 $a_0(980)$, $\underline{a_0(1450)}$,

- Scalar glueball: around 1.6GeV by the QCD lattice calculations:

1.55(UKQCD), 1.63GeV(Morningstar), 1.74GeV(IBM), ***GeV(A. Nakamura)

- G(1590) (GAMS)/$f_0(1500)$ (XB)/$f_{0,2}(1710)$ (J/Ψ radiative decays) have been controversial.

- $\sigma(555)$: produced in pp central collision process, WA102, Hadron'95
Unitarity and universality arguments, Hadron'95, M. Pennington

$SS = 1$, and $F_{\pi\pi} = \alpha(s)T_{\pi\pi}$
$\alpha(s)$:slowly varying real function of s.
$F_{\pi\pi}$ and $T_{\pi\pi}$ have the same phases and the same structures.
No threshold suppression (Adler 0) exists in production processes, experimentally.

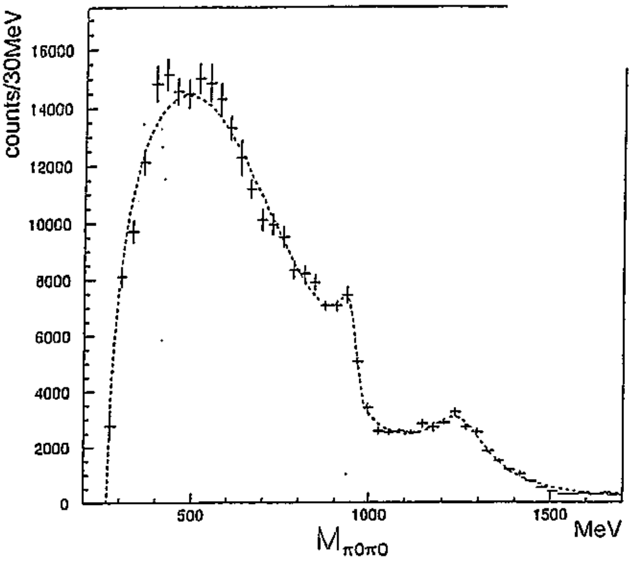
- Relation between scattering and production amplitudes, Hadron'97, S. Ishida and M. Ishida
- Final state interaction in production processes. Various final state interactions including resonance particles should be taken into account.
- The production process is to be studied independent of the scattering process. The importance and necessity of studies on resonant states in various production processes.

1976-1994: no σ in PDG tables, no low mass scalar below 1 GeV in the analysis of the scattering phase shifts data.
1996-2000: $f_0(400-1200)$ or σ , re-analyses of the scattering phase shifts data.
2002: $f_0(600)$ or σ, evidence for σ in various production processes: pp central collision, $p\bar{p}$ annihilation, J/Ψ decays, Υ decays, D decays in 1995-2003.

$\pi^0\pi^0$ states produced in the pp central collision process.

pp -> $p_f X^0 p_s$, X^0 -> $\pi^0\pi^0$ at 450GeV/c, GAMS4000, CERN,

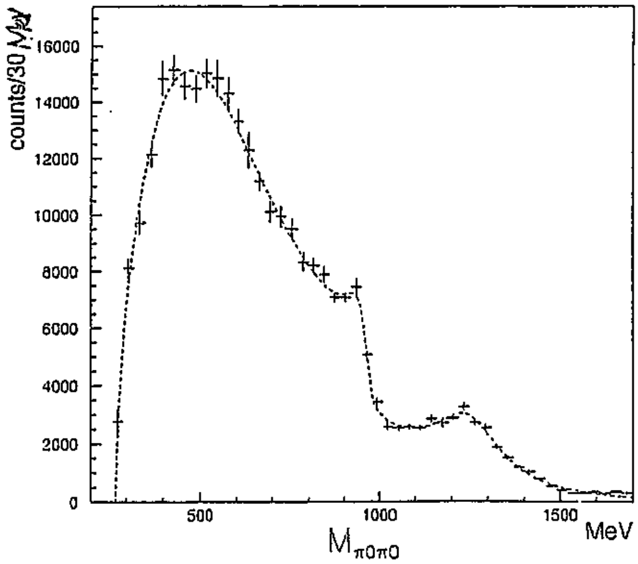
D. Alde et al., Phys. Lett. B397 (1997) 350



M_σ = 590+- 10MeV
Γ_σ = 710+- 30MeV

$$\begin{aligned}\mathcal{M} &= \mathcal{M}_0 + \mathcal{M}_c \\ &= \frac{\xi_{f_0}}{(s-m_{f_0}^2)+im_{f_0}\Gamma_{f_0}^{tot}(s)} + \frac{\xi_c e^{i\theta}}{(s-m_c^2)+im_c\Gamma_c^{tot}(s)}\end{aligned}$$

Analyzed with an conventional background (exponential type).



$$\begin{aligned}\mathcal{M} &= \mathcal{M}_0 + \mathcal{M}_{exp} \\ &= \frac{\xi_{f_0}}{(s-m_{f_0}^2)+im_{f_0}\Gamma_{f_0}^{tot}(s)} + a\cdot e^{i\theta}(\sqrt{s}/m_\pi - b)^c \cdot exp(-d\sqrt{s}/m_\pi).\end{aligned}$$

5. Chiral particles

σ(600): a chiral partner of π meson as a Nambu-Goldstone boson.

Low energy effective theory of QCD.

LσM of the Nambu-Jona-Lasinio Type.

M.D.Scadron(1984, 1985),
T.Hatsuda-T.Kunihiro(1985,1988),
S.Ishida-M.Ishida(1996,1997,2000)

σ in re-analyses of ππ scattering phase shifts.

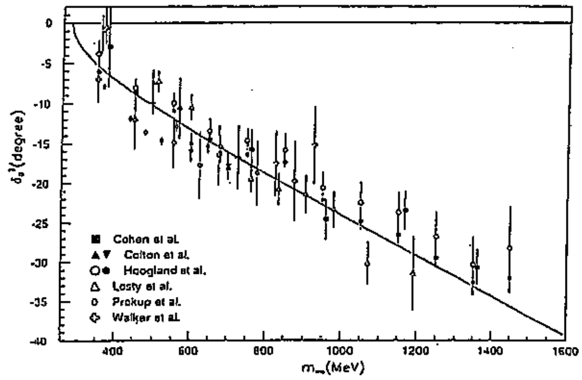
N.N.Achasov and G.N.Shestakov(1994), B.S.Zou and D.V.Bugg(1994), R.Kaminski et al.(1994,99), N.A.Tornqvist and M.Roos((1996), M.Harada et al.(1996), S.Ishida et al.(1996,97), V.V.Anisovich et al.(1997), J.A.Oller and E.Oset(1997), M.P.Locher et al.(1998), K.Igi and K.Hikasa(1999).

Negative phase shifts,

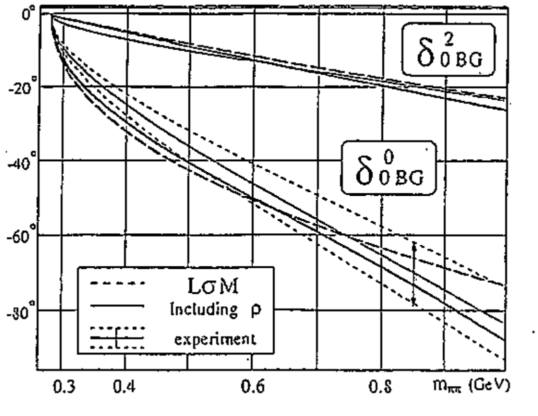
I=2, S wave ππ phase shifts, δ_0^2

Compensating $\lambda\phi^4$ contact interaction in LσM

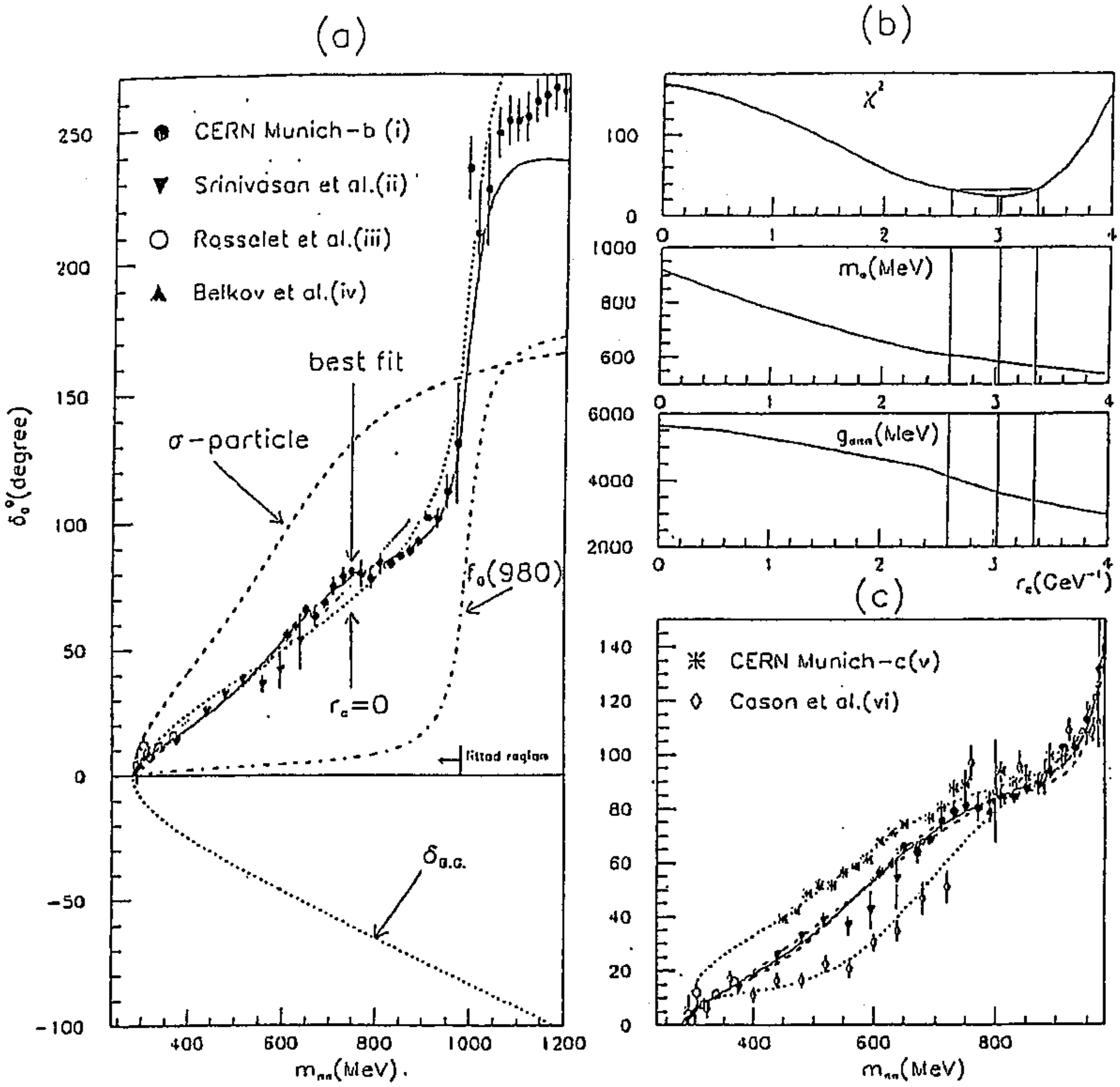
I=2 S wave ππ phaseshifts.



Repulsive core corresponds ompensating $\lambda\phi^4$ contact interaction.



Analysis on I=0, S wave $\pi\pi$ phase shifts Interfering amplitude method.



M_σ = 585 +- 20MeV, Γ_σ = 340 +- 45MeV, r_c =3.03GeV^{-1}

σ in prouction processes

Studies in production processes

No cancellation mechanism works, necessarily.

Analysis: VMW

pp central coll.; J /Ψ -> ωππ (DM2 data); ppbar -> $3\pi^0$(XB); Υ(2S), Υ(2S) decays.

mass and width in our observation and analysis.

ππ scattering($\pi^+\pi^-$):	m_σ = 585 +- 20MeV,	Γ_σ = 385 +- 70MeV
ππ scattering($\pi^0\pi^0$):	m_σ = 588 +- 12MeV,	Γ_σ = 281 +- 725MeV
pp central coll.:	m_σ = 590 +- 10MeV,	Γ_σ = 710 +- 30MeV
J /Ψ -> ωππ(DM2):	m_σ = 480 +- 5MeV,	Γ_σ = 325 +- 10MeV
$\bar{p}p$ -> $3\pi^0$:	m_σ = 540 +36-29MeV,	Γ_σ = 385+64-80MeV
Υ dcays:	m_σ = 526+48-37MeV,	Γ_σ = 301+145-100MeV
τ decay (CLEO)	m_σ = 555MeV,	Γ_σ = 540MeV
J /Ψ -> ωππ(BESI)	m_σ = 390+60-36MeV,	Γ_σ = 282+77-50MeV
J /Ψ -> ωππ(BESII)	(m_σ ,	Γ_σ) Next talk by Wu Ning
D -> 3π decays (E791)	m_σ = 483+25-26MeV,	Γ_σ=338+45-42MeV

σ(600): mass in a range 500-600MeV, width in 300-400MeV.

Υ decays, Υ(nS) -> Υ(mS)ππ.

T. Komada et al., P.L. B 508 (2001) 31; M.Ishida et al., P.L. B 518 (2001) 47.

Chiral symmetric effective amplitude in linear σ model.

- Non derivative coupling.

$$F_{\sigma+2\pi} = F_\sigma + F_{2\pi} \cong \text{(polarization vectors)(coupling)}(m_\pi^2 - s)/(m_\sigma^2 - s).$$

Adler 0 occurs at $s = -(p_1^{\,2} + p_2^{\,2}) = m\pi^2$, leading to the threshold suppression.

- Derivative coupling,

$$F^G{}_{2\pi} \cong \text{(polarization vectors)(coupling)} m_{Y'} m_Y p_{10} p_{20}.$$
$$\cong \text{(polarization vectors)(coupling)} m_{Y'} m_Y [(m_{Y'} + m_Y)/2]^2 = \text{constant}.$$

p_{10} and p_{20} are energy of pions. Not small near the threshold.

$F_{\sigma+2\pi}$ and $F^G{}_{2\pi}$

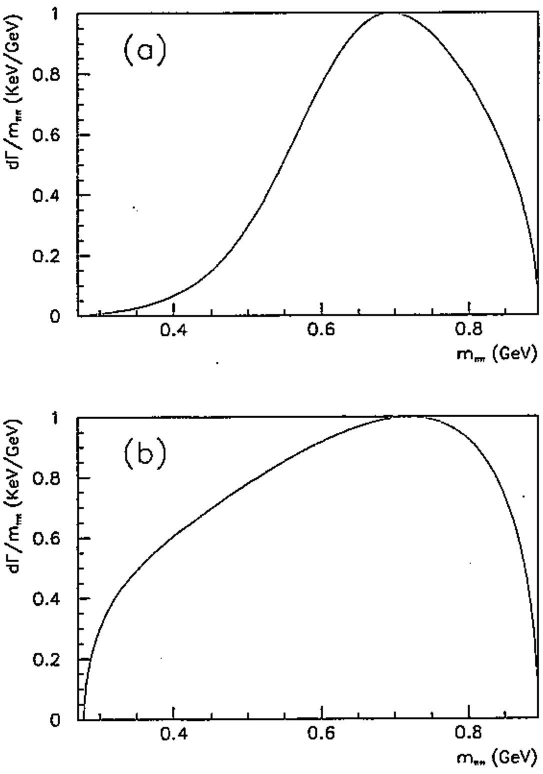


Fig. 1. The $\pi\pi$ mass spectrum obtained (a) from $\mathcal{F}^{\rm phen}_{\sigma+2\pi}$ in Eq. (3.1) and (b) from $\mathcal{F}^G_{2\pi}$ in Eq. (2.11) in case of $\Upsilon(3S) \to \Upsilon(1S)\pi\pi$ decay. The peaks are normalized to unity. Both amplitudes satisfy the derivative coupling property of π, and in (a) the spectrum is suppressed in the $\pi\pi$ threshold region, while (b) shows a steep increase from the threshold.

Fitting results

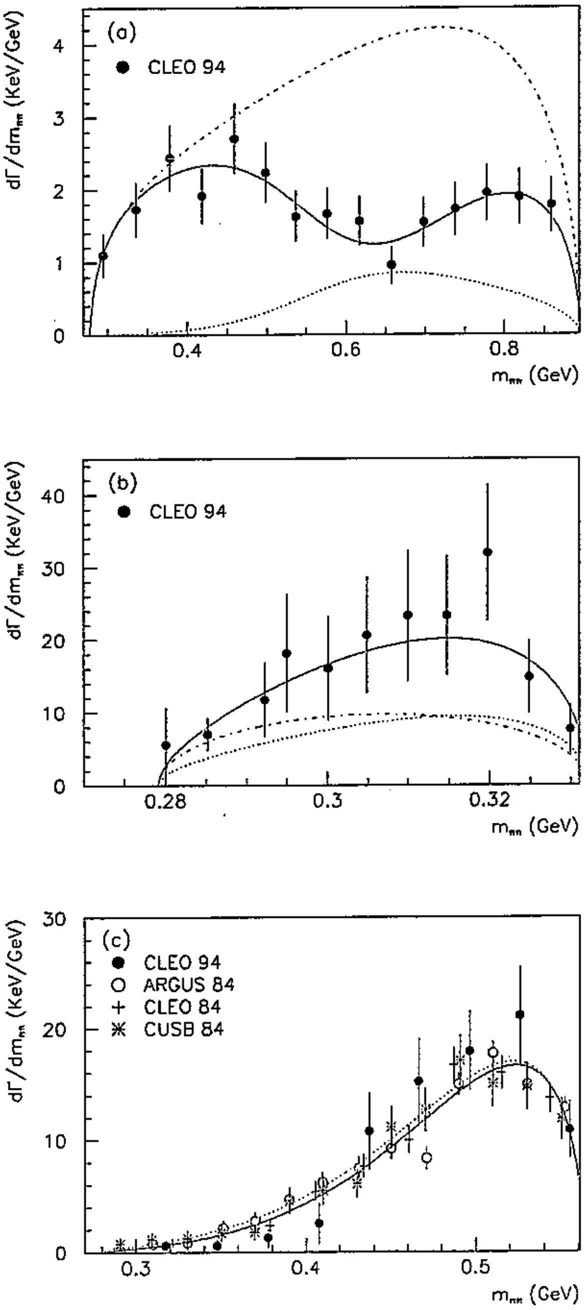


Fig. 2. Fit to the $\pi\pi$ invariant mass spectrum by the amplitude Eq. (3.1) explicitly consistent with chiral constraint: (a) $\Upsilon(3S) \to \Upsilon(1S)\pi\pi$, (b) $\Upsilon(3S) \to \Upsilon(2S)\pi\pi$ and (c) $\Upsilon(2S) \to \Upsilon(1S)\pi\pi$. The respective contributions from $\mathcal{F}^{\rm phen}_{\sigma+2\pi}$ and from $\mathcal{F}^G_{2\pi}$ are shown by dotted and dot-dashed lines. The $\mathcal{F}^G_{2\pi}$ contribution becomes dominant in the case (a) $\Upsilon(3S) \to \Upsilon(1S)$ transition in comparison with the case (c) $\Upsilon(2S) \to \Upsilon(1S)$ transition.

Existence of κ(900) in the analysis of Kπ scattering phase shifts.

m_κ = 905+63−30MeV, Γ_κ = 545+235−110MeV.
S. Ishida et al, Prog. Theor. Phys. 98(1997)621
m_κ = 897MeV, Γ_κ = 322MeV. D.Black et al. (1998).
m_κ = 727MeV, Γ_κ = 526MeV. E.VanBeveren et al. (1996)
m_κ = 900MeV; J.A.Ollerand E.Oset (1999)

in production processes

D decays, D-> Kππ(E791 FNAL) C. Goebel
D-> Kπμν(FOCUS FNAL) interfarence with S-wave res.
J /Ψ -> K*K π (BES) Wu Ning, and T. Komada

κ(900): mass in a range 800−900MeV, width in 300−600MeV.

New scalar nonet: σ(600), κ(900), a_0(980), f_0(980).

a chiral partner of the ground state pseudoscalar nonet..

S. Ishida and M.Ishida(1997), M.D.Scadron(1982)

Mass and width by SU(3) LσM (undelined values: inputs)

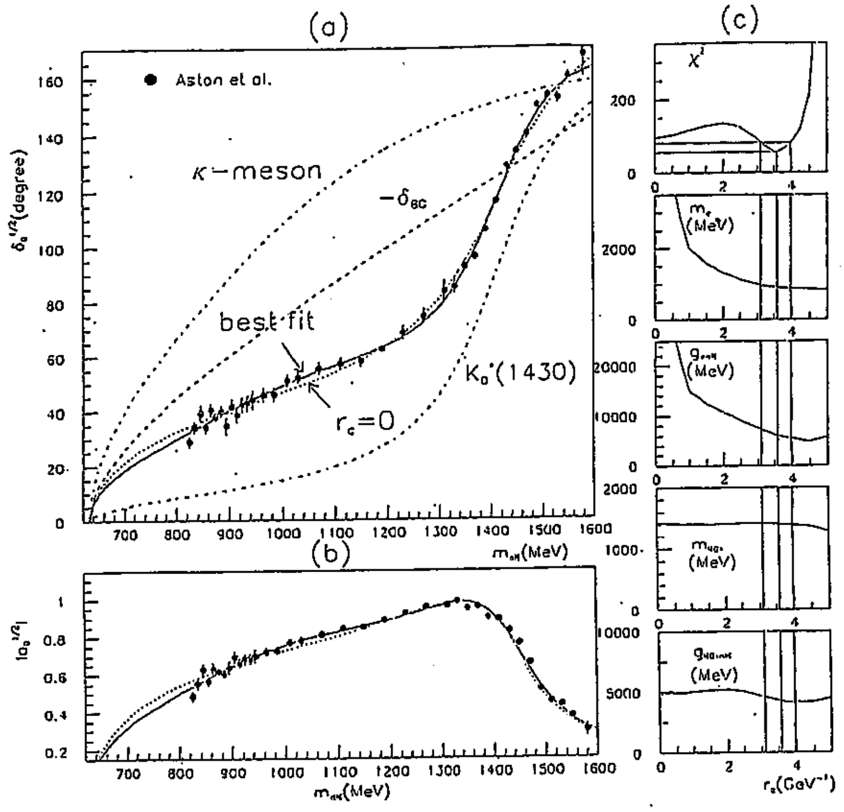
	M (MeV)	m(exp)(MeV)	Γ (MeV)	Γ (exp)(MeV)
σ	535−650	535−650	400−800	385+−70
κ	905+65−30	905+65−30	300−600	545+235−110
δ = a_0(980)	900−930	982.7+−2.0	110−170	95+−14
σ' = f_0(980)	1030−1200	993.2+−9.5	0−300	67.9+−9.4

M. Ishida, Sigma WS, Kyoto(2000).

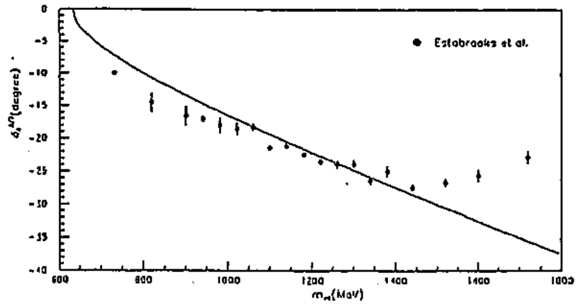
Analysis of K π scattering phase shift data

Data from LASS at SLAC, Kp -> $K^-\pi^+n$ at 11GeV/c, D. Aston et al.(1988)

I=1/2 K π scatt. S wave phase shifts and analysis



I=3/2 K π scattering phase shifts, P. Esterbrook et al. (1978)



New axial-vector nonet, a chiral partner of the ground state vector nonet.

S Ishida et al., Prog. Theor. Phys. 95 (1996) 745.
S. Ishida and M.Ishida, Hadron '97.

a_1^χ, K_1^χ, f_1^χ, $f_1^{\chi\prime}$.

Search for chiral particles

Possible channels for σ, κ and a_1^χ studies in J/Ψ and Ψ' decays.

σ in various J/Ψ and χ_{CJ} (Ψ' -> $\gamma\chi_{CJ}$) decays.

κ in χ_{CJ} decays. χ_{CJ} -> $\pi^+\pi^-K^+K^-$ ($K\pi\kappa$).

a_1^χ in J/Ψ -> ρa_1^χ, J/Ψ -> $\gamma\pi a_1^\chi$, and χ_{C0} -> πa_1^χ.

Possible channels for σ, κ and a_1^χ studies in J/Ψ and Ψ' decays

For κ: Ψ' -> $\gamma\chi_{CJ}$, χ_{CJ} -> $\pi^+\pi^-K^+K^-$.	$K\pi\kappa$
For a_1^χ: J/Ψ -> X, X -> VA^+, A^+A^-,	ρa_1^χ,
J/Ψ -> γX, X -> PA^+, A^+A^+,	πa_1^χ,
Ψ' -> $\gamma\chi_{CJ}$, χ_{C0} -> PA^+, TA^+, A^+A^+,	πa_1^χ,
χ_{C1} -> PA^+, SA^+, TA^+, A^+A^+,	πa_1^χ,
χ_{C2} -> PA^+, TA^+, A^+A^+.	πa_1^χ.

S: scalar, P: pseudoscalar, V: vector, T: tensor, A+: axialvector with positive C parity and A−: axialvector with negative C parity.

U˜(12), classification of mesons

	Non relativistic view		relativistic view			
model	non relativistic model		NLJ model			
	NRQM		COQM+chiral symmetry			
symmetry	LS symmetry		chiral symmetry			
evidence	LS coupling		π-nonet: NG-boson			
ground states	0^{-+}	π-nonet	0^{-+}	0^{++}	0^{-+}	0^{+-}
	1^{--}	ρ-nonet	1^{--}	1^{++}	1^{--}	1^{+-}

		I=1	I=0		I=1/2
ground states	0^{-+}	π	η	η'	K
	1^{--}	ρ	ω	φ	K*
1st exc. states	1^{+-}	$b_1(1235)$	$h_1(1170)$	$h_1(1380)$	$K_1(1270)$
	0^{++}	$a_0(1450)$	$f_0(1370)$	$f_0(1710)$	$K_0^*(1430)$
	1^{++}	$a_1(1230)$	$f_1(1285)$	$f_1(1420)$	$K_1(1400)$
	2^{++}	$a_2(1320)$	$f_2(1275)$	$f_2(1525)$	$K_2^*(1430)$

Exotic quantum numbers; 0^{+-}? 1^{-+}? 0^{--}? Naturally accommodated in U˜(12)

Where do we find them?

J/Ψ decays

$1^{--} \to 1^{--} + 0^{++}$	S wave decay
$1^{--} \to 1^{-+} + 0^{+-}$	S wave decay

$\chi_{C1}(1++)$, $\chi_{C0}(0^{++})$ decays

$1^{++} \to 1^{+-} + 0^{+-}$	S wave decay
$1^{++} \to 1^{--} + 0^{+-}$	P wave decay
$0^{++} \to 0^{++} + 0^{++}, 0^{+-} + 0^{+-}$	S wave decay