Hints at the light scalar glueball

Wolfgang Ochs
MPI Munich

1. Expectations in QCD
2. Where to look for glueballs
3. Scalar meson spectrum
   - $q\bar{q}$ nonet
   - glueball
4. Arguments for glueball

work with Peter Minkowski

Bern, 5.5. 2006

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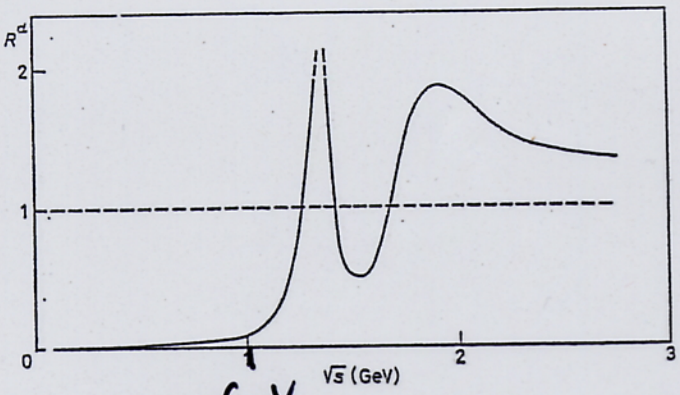
QCD predictions

H. Fritzsch & P. Minkowski 1975

Ψ-RESONANCES, GLUONS AND THE ZWEIG RULE

R^d

Case A
resonating gluons



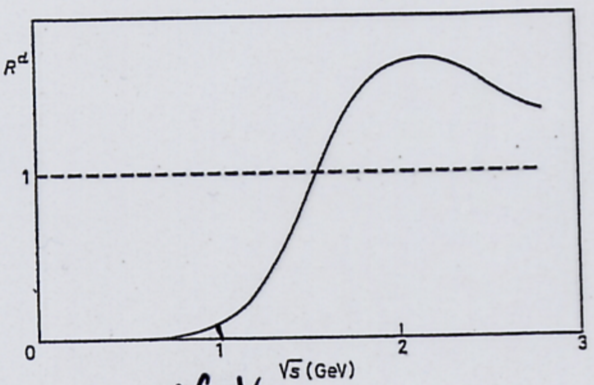
1 GeV

spectral fct.

$$R^d(s) = \frac{\rho^d(s)}{\rho^d_0(s)}$$

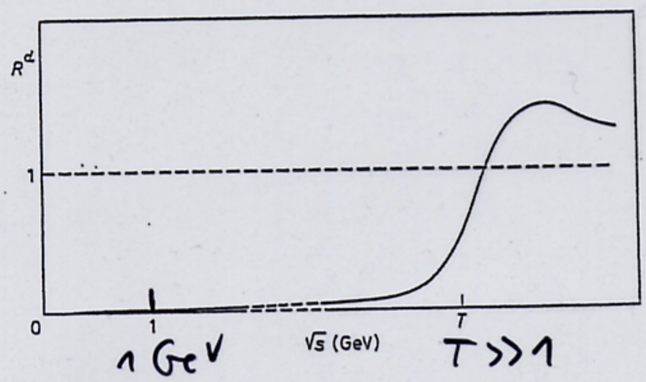
$\to 1$
$(s \to \infty)$

Case B
inconspicuous gluons



1 GeV

Case C
delayed saturation



1 GeV   T >> 1

$\to \sqrt{s}$

Today

lightest glueball $J^{PC} = 0^{++}$

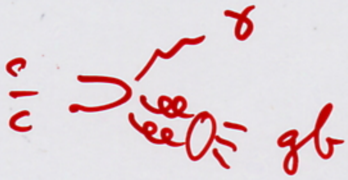
Lattice QCD (quenched approximation) $M \sim 1.4 - 1.8$ GeV
Bali 2003

QCD sum rules $M \sim 1$ GeV   Narison
$M \sim 1.2$ GeV   Forkel

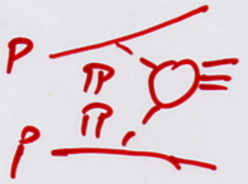
where to look for glueballs?

"classic" proposals

a) $J/\psi \to \gamma X$



b) $pp \to p X p$



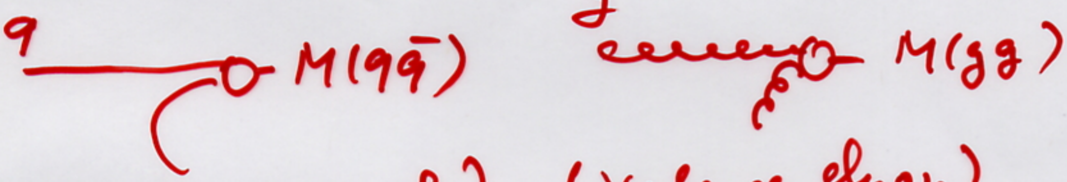
IP ~~~ gluonic object

c) $p\bar{p} \to M X$
annihilation

more recent proposals

Minkowski, W.O.

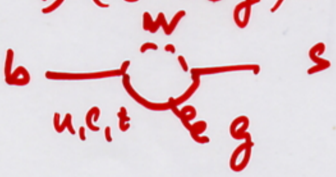
a) leading part in gluon jet (rapidity gap)



(valence quark) (valence gluon)

b) B-decay
$B \to K\, gb$

$B(b \to sg) = 5 \times 10^{-3}$ Greub & Liniger



"penguin"

problems 0^{++}

+ scalar meson spectrum difficult to disentangle
$q\bar{q}$, $qq-\bar{q}\bar{q}$, gb

but additional component in gluon jets besides standard q,g + hadronization physics

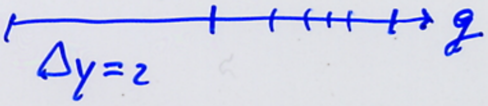
Delphi
OPAL
ALEPH

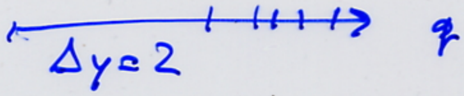
leading charge in

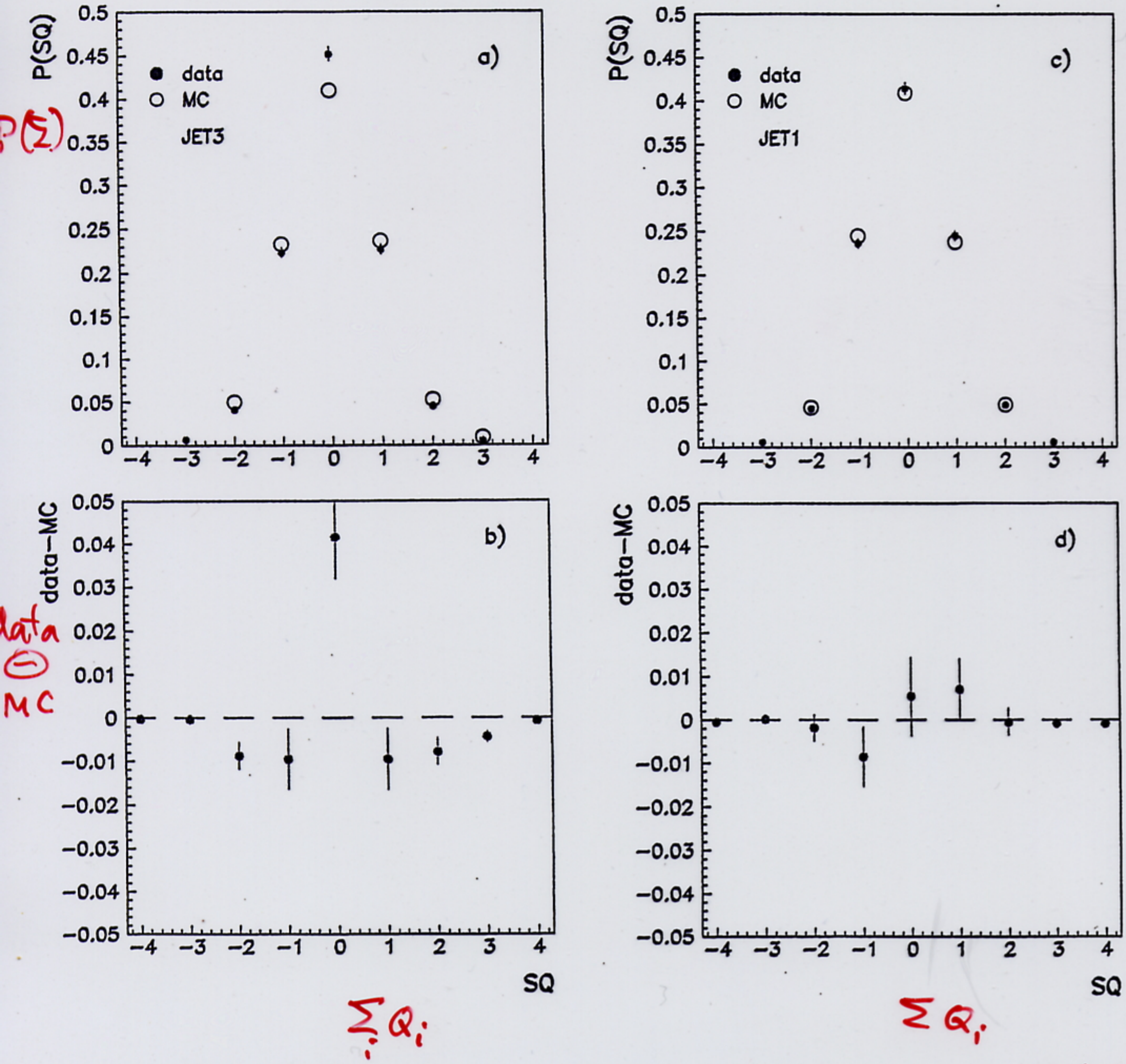
Delphi
hep-ph/0111408
(ISMD2001)

gluon jet

quark jet

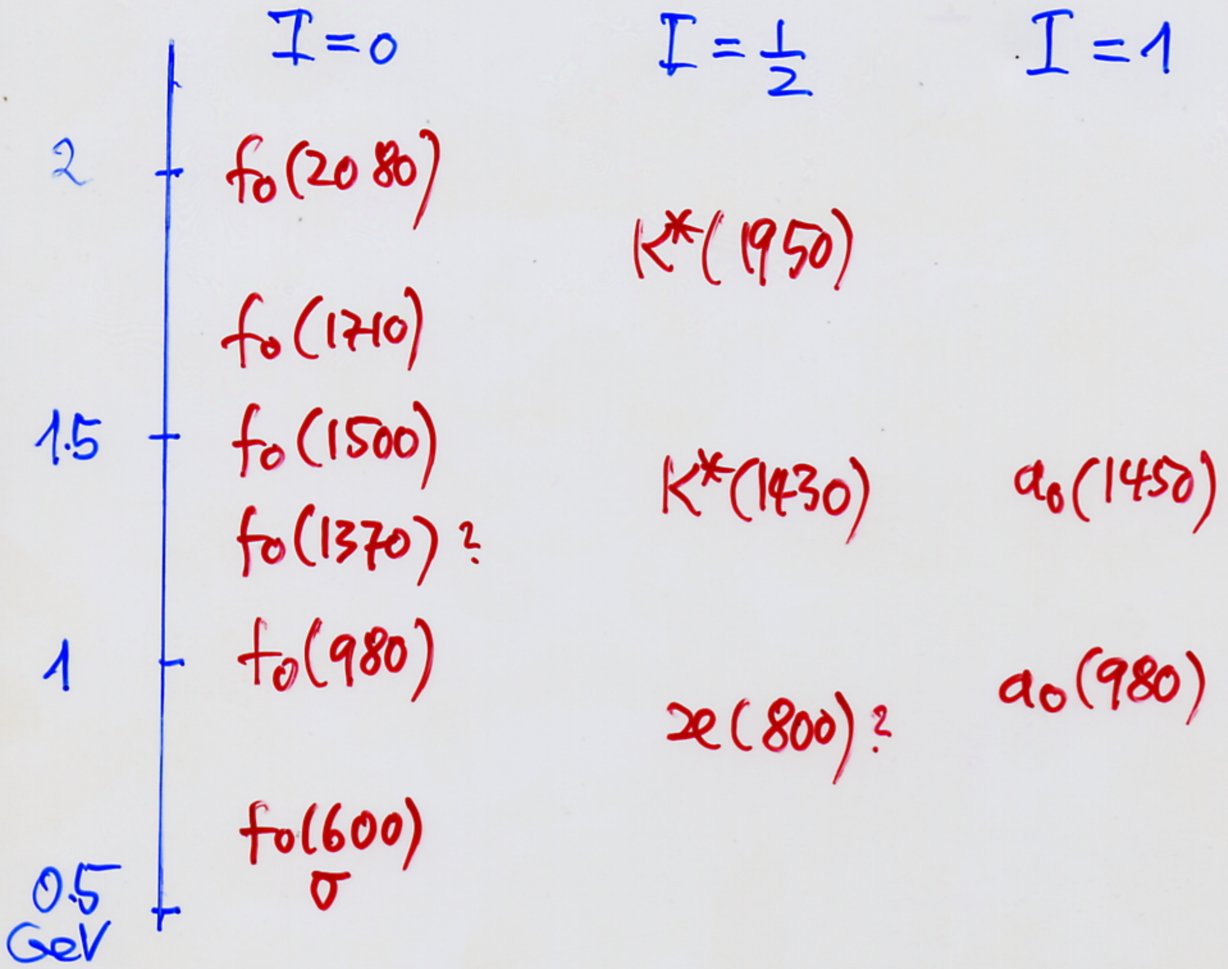




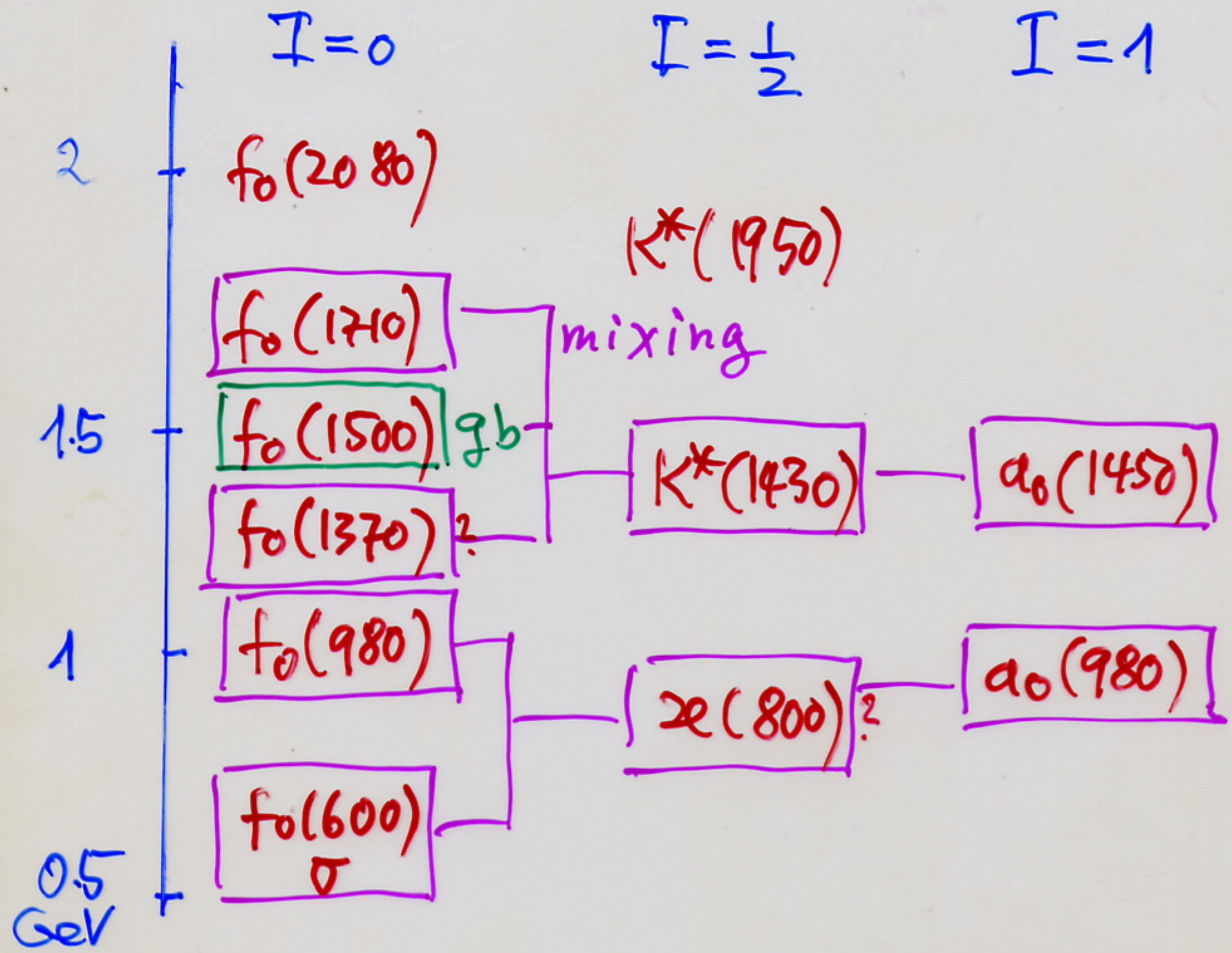


excess of charge Q = 0
in gluon jet
(with respect to Jetset string MC)

$J^{PC} = 0^{++}$ spectrum (PDG)



$J^{PC} = 0^{++}$ spectrum (PDG)



Two routes for classification

① 2 Multiplets below 1700 MeV

upper multiplet $L=1$ $q\bar{q}$ with $K^*(1430)$

0^{++} glueball expected around 1600 MeV in quenched Lattice calculations

two isoscalars mix with glueball — Amsler & Close et al.

⟺ $f_0(1710)$, $f_0(1500)$, $f_0(1370)$

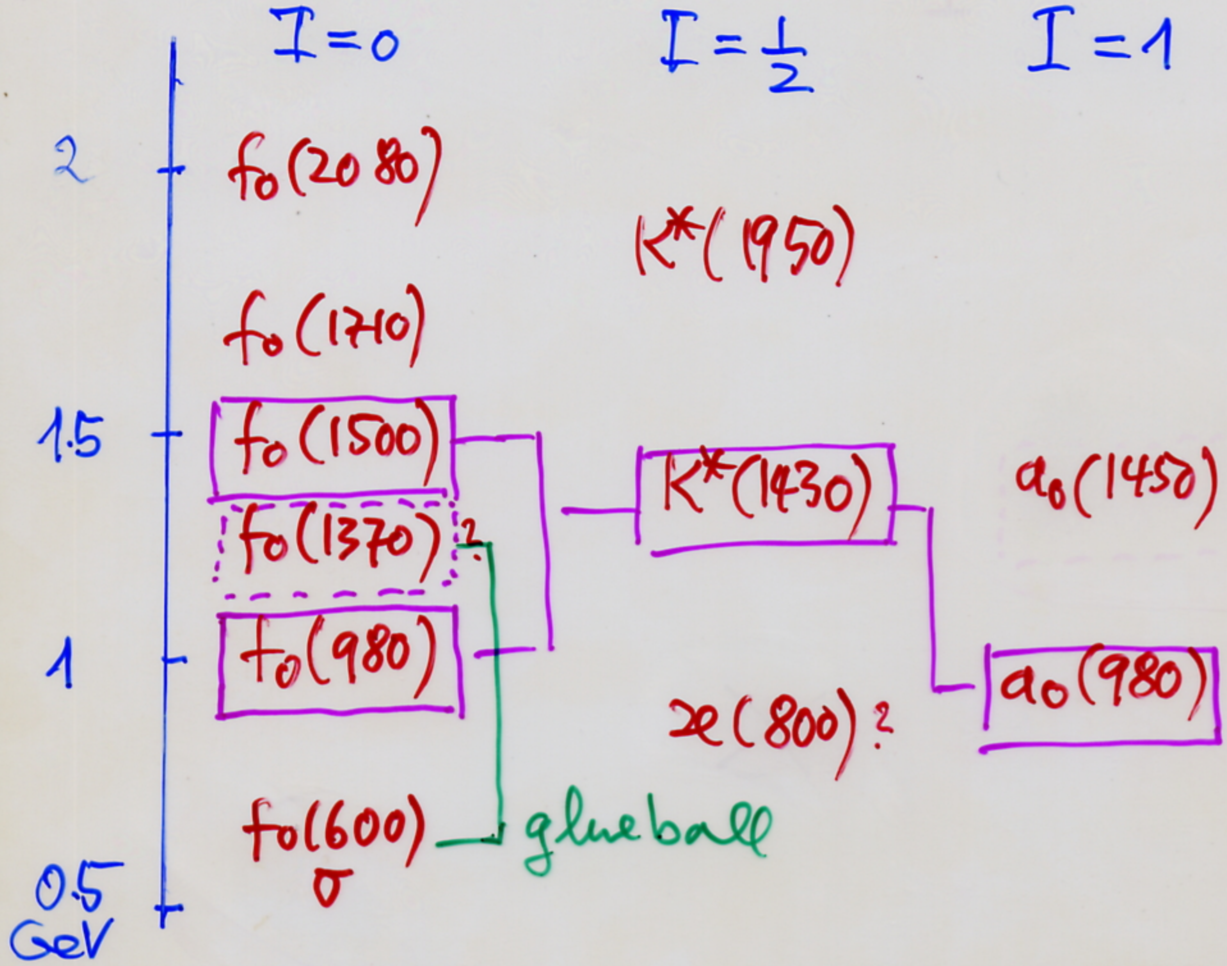
Lower multiplet

$q\bar{q}$, compact qq-$\bar{q}\bar{q}$, $K\bar{K}$ molecule — Jaffe, Achasov, Isgur Weinstein

low mass nonet $f_0(980)$, $a_0(980)$, σ, κ appears in theories of meson meson scattering realizing chiral symmetry

review: Spanier, Törnqvist

$J^{PC} = 0^{++}$ spectrum (PDG)



② 1 Multiplet below 1700 MeV

- $q\bar{q}$ nonet with $f_0(980)-f_0(1500)$ mixed like $\eta' - \eta$

  Klempt Metsch et al.
  Minkowski, W.O.
  Anisovich et al.
  Narison

- broad glueball around 1 GeV, $\Gamma \sim M$

  differences in details but

- σ, κ not members of nonet

- $f_0(980)$ is the lightest $q\bar{q}$ scalar.

$J^{PC} = 0^{++}$ nonet

$f_0(1500)$

$K^*(1430)$

$f_0(980)$

$a_0(980)$

flavour mixing

1. $J/\psi \to \phi/\omega + f_0(980)$
2. Gell-Mann Okubo
3. $f_0, a_0 \to \gamma\gamma$
4. $f_0(980) \to K\bar{K}, \pi\pi$
5. $f_0(1500) \to \pi\pi, K\bar{K}, \eta\eta, \eta\eta'$ (?)

phases of $s\bar{s}$ component

6. $D_s \to f_0(980) / f_0(1500) + \pi$
7. $D \to \rho, f_0(980) + \pi$
8. $D_s \to \phi, f_0(980) + \pi$
9. Sign $f_0(980) \to K\bar{K} / \pi\pi$

future

$B \to K +$ scalar, $K^* +$ scalar

penguin dominance → symmetry relations

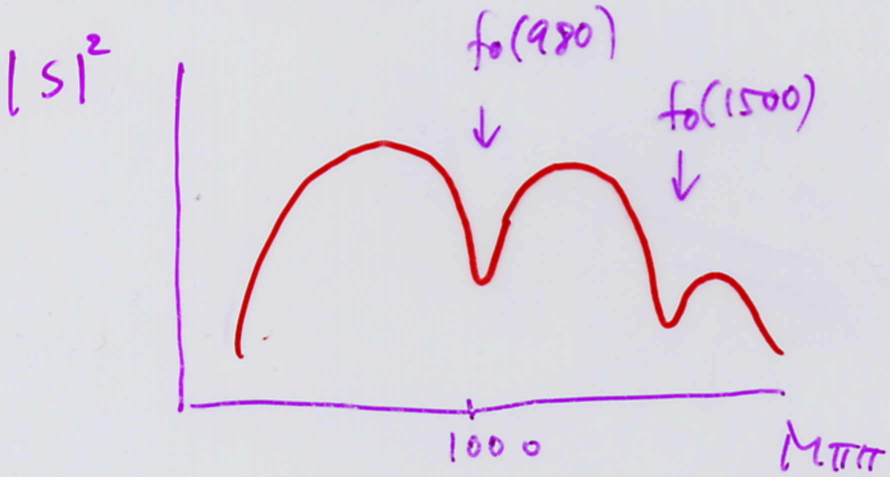
→ find $q\bar{q}$ nonet

The lightest 0^{++} glueball

left over!

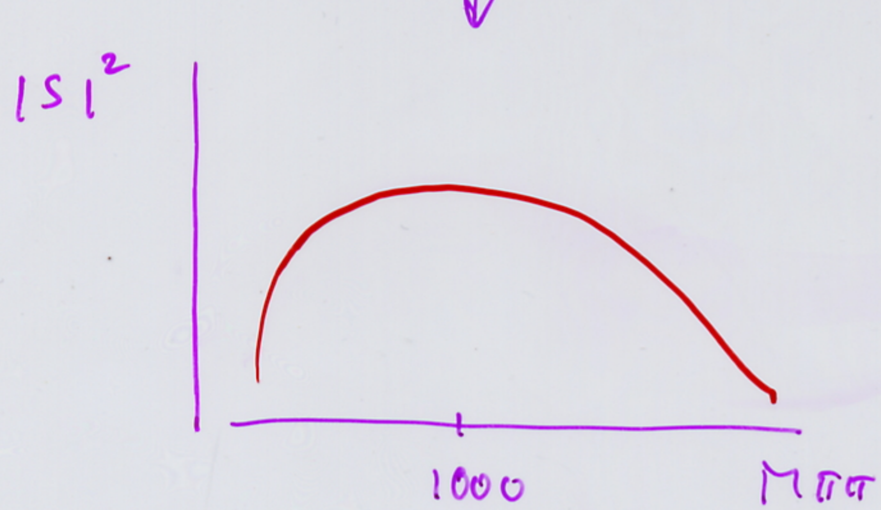
Minkowski a.o.

$f_0(1370)$
$f_0(600)$ [σ]
} gb(1000)



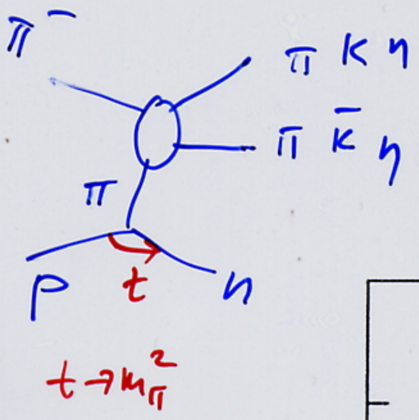
$\pi\pi \to \pi\pi$

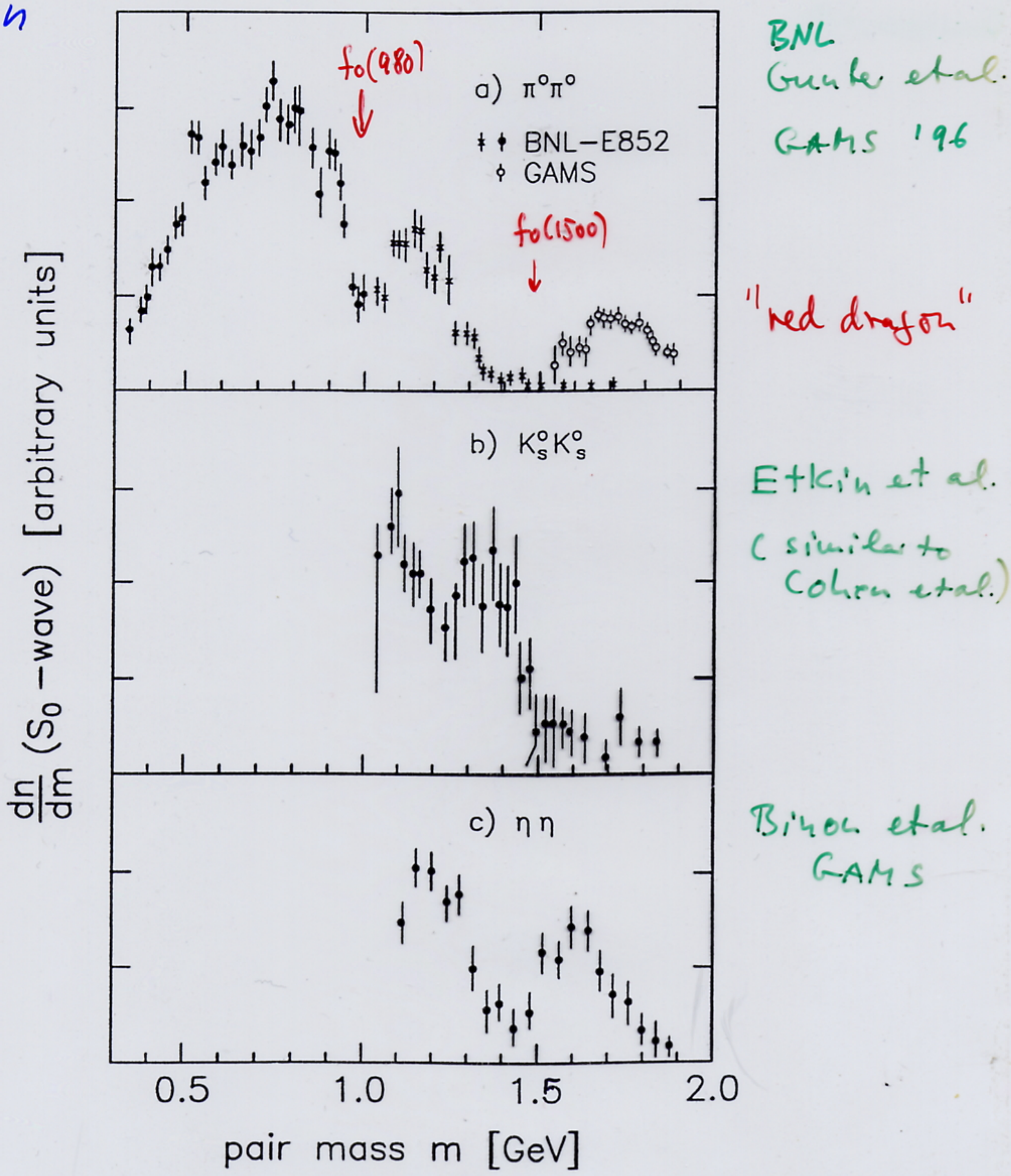
"red dragon"



global fits yield broad state

S-wave in elastic and inelastic ππ scattering





Interpretation of $\pi\pi$ S-wave

* ## low mass studies ($m_{\pi\pi} \lesssim 1.2$ GeV)

phase shifts rize slowly with mass
$\delta_0^0 = 90°$ at $m_{\pi\pi} \sim 900$ MeV

behaviour reproduced by σ - pole

* early history : Berkeley $\pi\pi$ (Protopopescu '73)
* recently : $D \to 3\pi$ (E791, FOCUS) $J/\psi \to \omega\pi\pi$ (BES)
* new "model independent" result Caprini, Colangelo, Leutwyler 2005

Based on Roy eqs.

$M_\sigma = 441 {}^{+16}_{-8}$ MeV $\Gamma_\sigma = 544 {}^{+23}_{-18}$ MeV

→ higher energies?

* ## high mass studies ($m_{\pi\pi} \lesssim 1800$ MeV)

all studies suggest broad state

* early history CERN-Munich (Hyams '75)
* coupled channel $\pi\pi, K\bar{K}$ (Estabrooks '79)
* more channels Morgan, Pennington, Anisovich, Sarantsev

mass 1-1.5 GeV $\Gamma \sim 0.5 - 1.0$ GeV

arguments for glueball assignment Anisovich, Sarantsev Minkowski W.O.

* Puzzle:

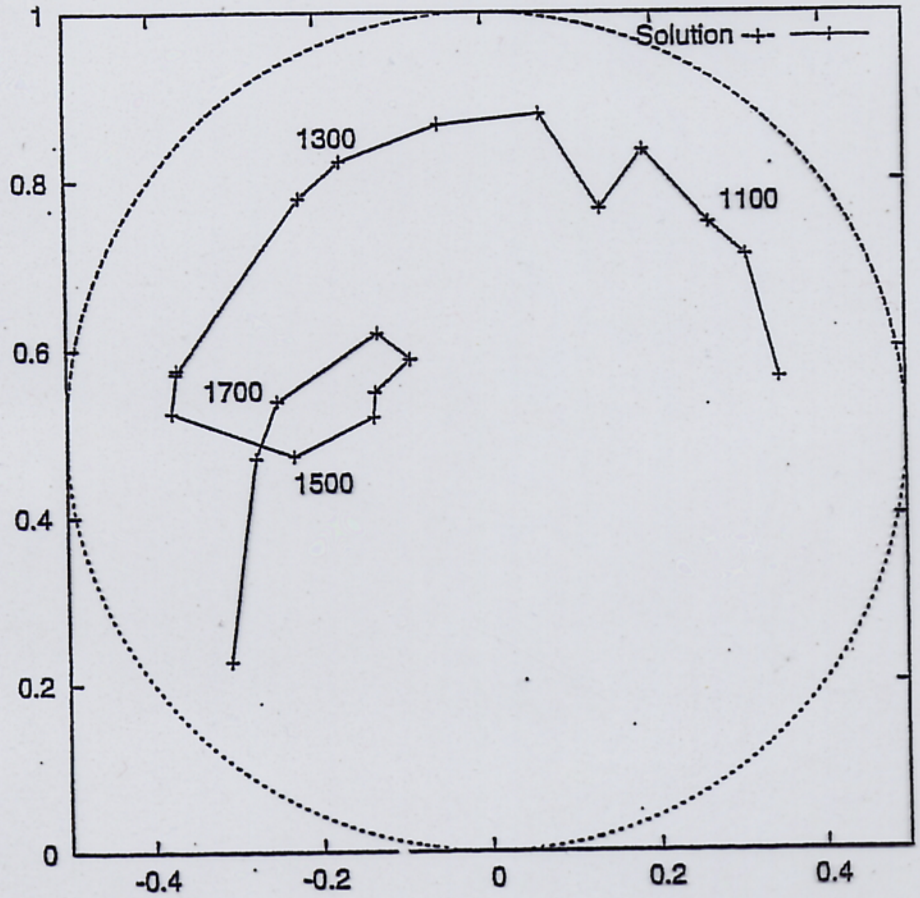
one amplitude circle - 2 poles?

CERN MUNICH II

T_0^0 I=0 S-wave sol. -+- preferred

Im T_0^0

pi pi S wave amplitude in Argand diagram



Re T_{00}

M > 1 GeV : 4 solutions
2 excluded

unique up to M ~ 1.4 GeV

Comparison of different analyses

CM 1 — Hyams '73

CM 2 [(− − −) = (− + −)] — Hyams '75

CKM polarized target — Kaminski

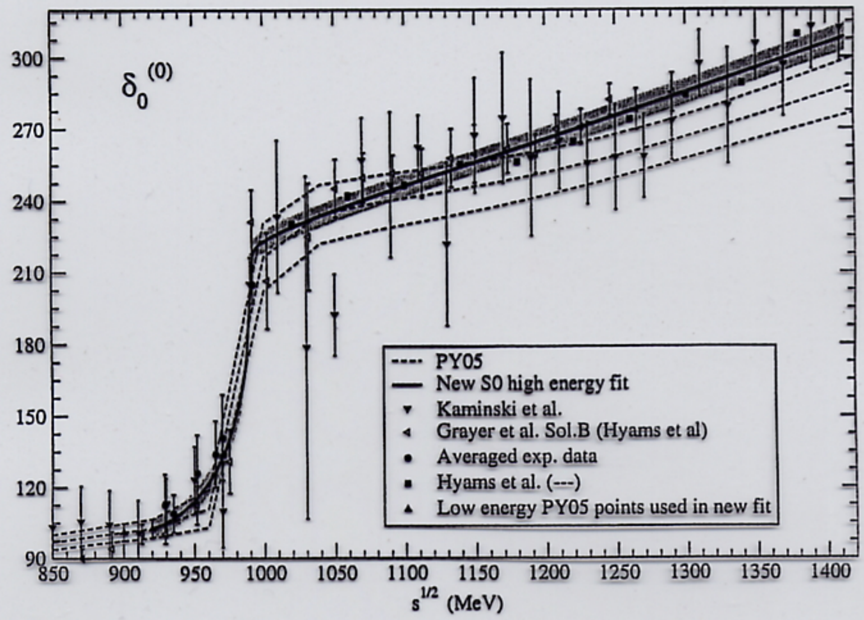
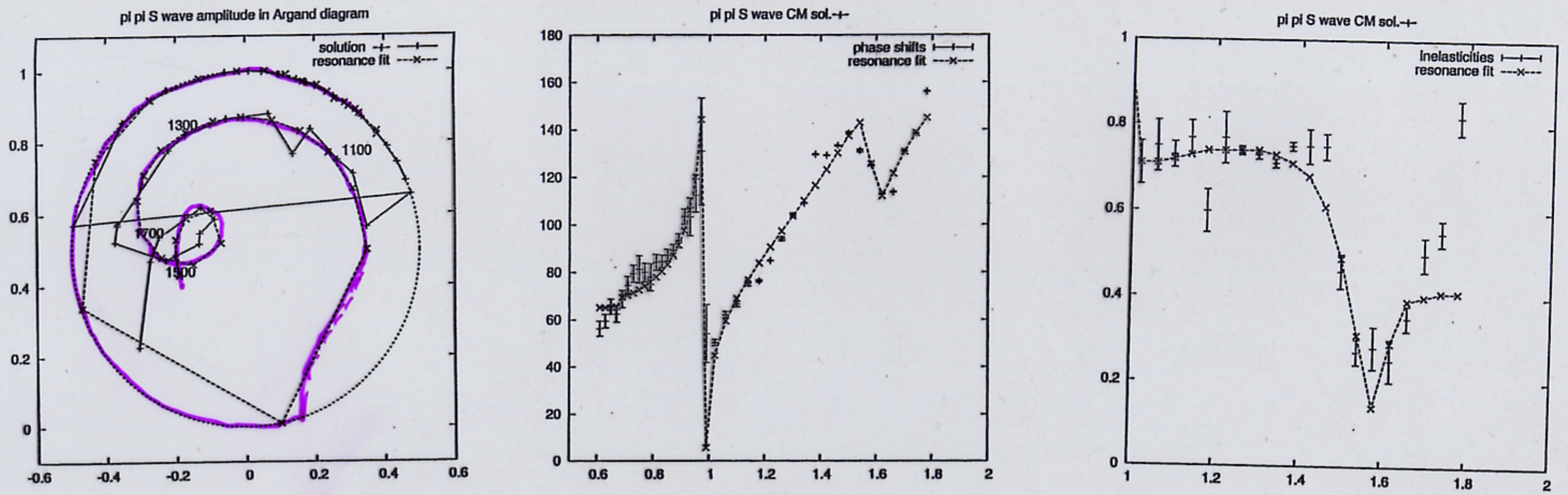


FIGURE 1. New fit to $\delta_0^{(0)}$ (solid line and dark area). The dashed lines stand for the phase shift from PY05 and its uncertainties. Note that the errors are now substantially smaller than in PY05, and that we now have a smooth matching with the PY05 low energy fit at 0.92 GeV.

sol. + − − , + + − excluded

⇒ all solutions agree below $M = 1.4$ GeV ππ S wave (preliminary) Sol. − + −

T_0^0 — δ_0^0 — η_0^0

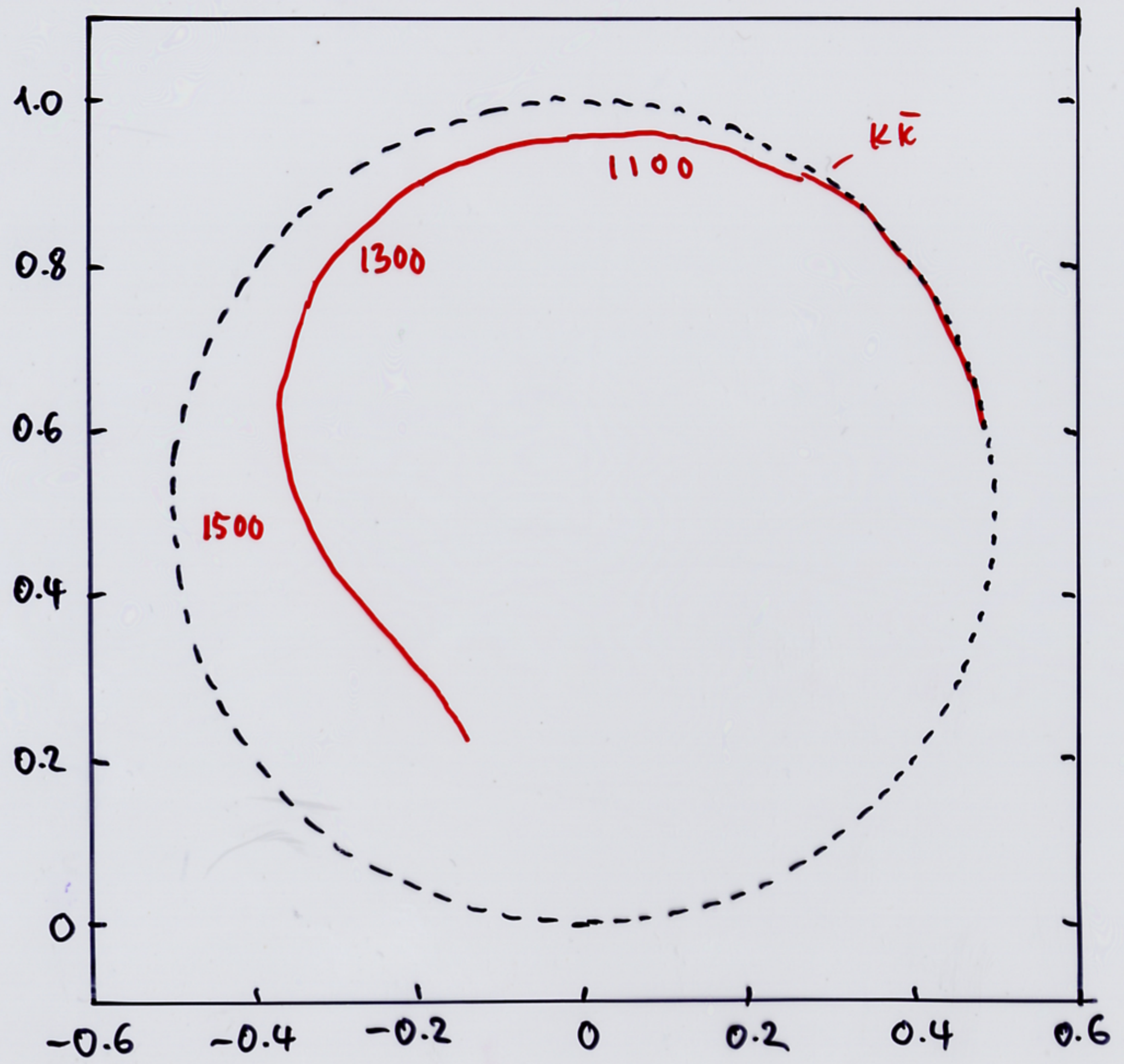


$M_{\pi\pi} \rightarrow$

$$T = f_0(1000) + f_0(980) \cdot e^{i\phi_1} + f_0(1500)\, e^{i\phi_2}$$

no $f_0(1370)$ included

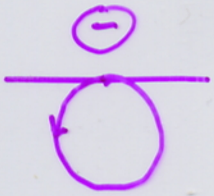
$\pi\pi$ S wave : "glueball" component

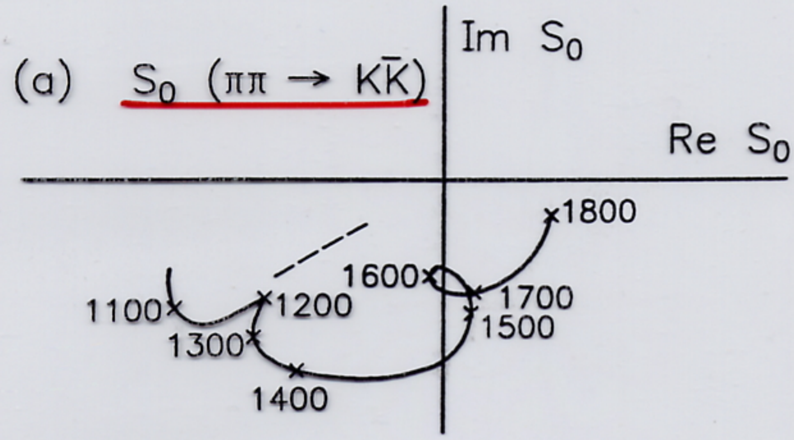


Relative signs of decay amplitudes

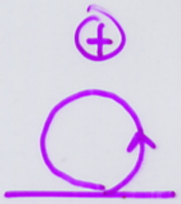
	$f_0(980)$	$f_0(1500)$	glueball
$K\bar{K}$	+	⊖	+
$\eta\eta$	+	⊕	+
$(u\bar{u}\ d\bar{d}\ s\bar{s})$	$(1\ 1\ 2)/\sqrt{6}$	$(1\ 1\ -1)/\sqrt{3}$	$(1\ 1\ 1)/\sqrt{3}$
$n\bar{n}$	+	⊕	+

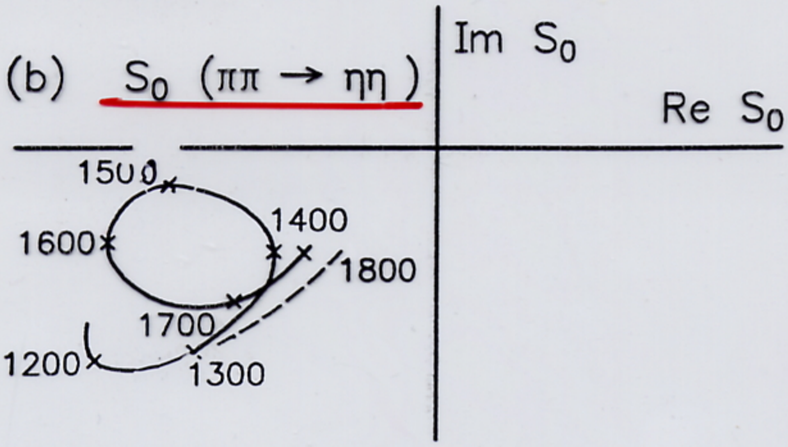
Minkowski w.-O. '99 $f_0(1500)$





⊖ $s\bar{s}$



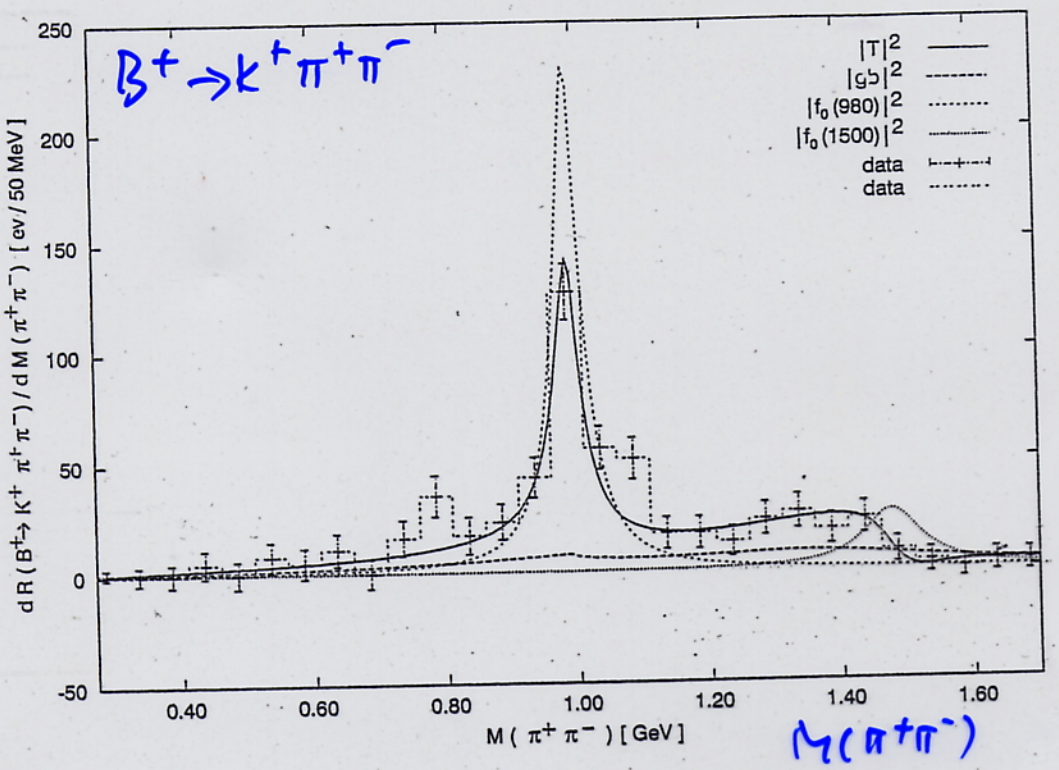


⊕ $n\bar{n}$

Amplitudes reconstructed from $|S|$, $|D|$, ϕ_{SD},
absolute phase: D wave Breit Wigner

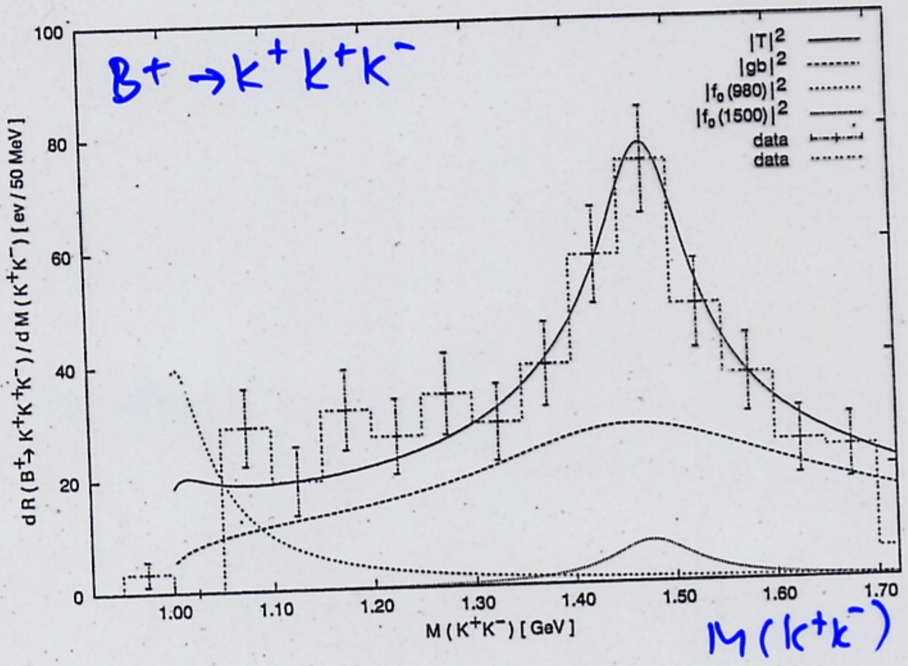
X(1500) (BaBar) & $f_x(1500)$ (Belle) as $f_0(1500)$

Belle data
fits
Minkowski
ZW-O-2004



bg − f_0

$$\frac{\Gamma(K\bar{K})}{\Gamma(\pi\pi)} = 0.24$$



bg + f_0

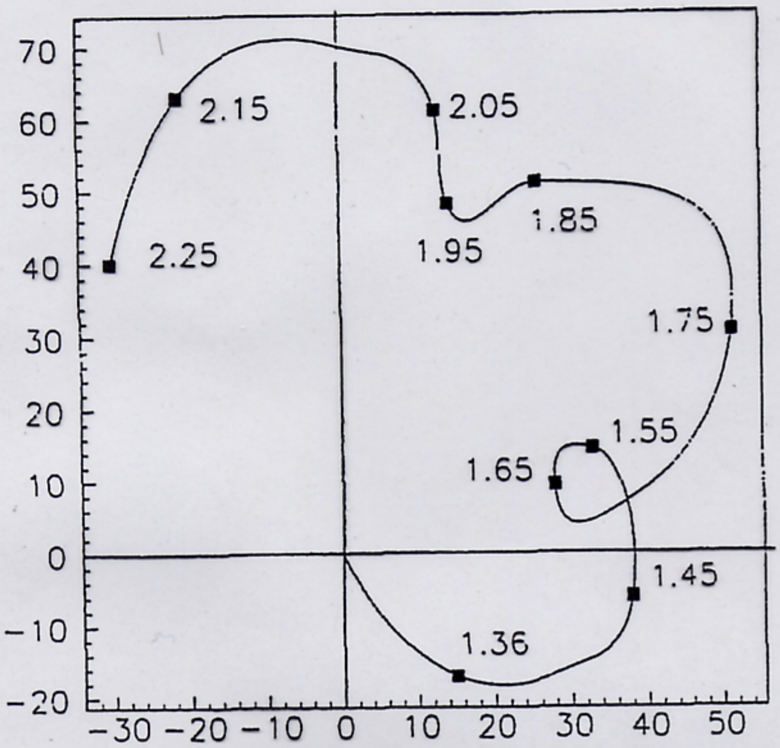
$$\frac{d\Gamma}{dm} = |c_1|^2\, qp\, |T_{gb} + c_2 T_{f_0} S_{gb} + c_3 T_{f_0'} S_{gb}|^2$$

$a: gb, f_0, f_0'$ $\quad T_a = m_a \Gamma_a / (m_a^2 - m^2 - i m_a \Gamma_a (1 + G_a(m)))$

$$S_{gb} = e^{2i\delta_{bg}} \; ; \; T_{gb} = |T_{gb}|\, e^{i\delta_{bg}}$$

Analysis $J/\psi \rightarrow \gamma(\pi^+\pi^-\pi^+\pi^-)$

MARK III



← $f_0(1500)$

sign as in $\bar{p}p \rightarrow \pi\pi$, $\rightarrow \eta\eta$

Fig. 3. The Argand diagram for the 0^+ scattering amplitude. $M(4\pi)$ is shown in GeV/c^2.

Table 3
Changes ΔS in log likelihood when various components of the fit are dropped and remaining contributions are re-optimised

Contribution	ΔS
$f_2(1270) \rightarrow \rho\rho$	41.0
$\iota(1440) \rightarrow \rho\rho$	813.2
→ $f_0(1505) \rightarrow \sigma\sigma$	38.0
$f_0(1505) \rightarrow \rho\rho$	0.41; omitted
$f_2(1640) \rightarrow \sigma\sigma$	0.02; omitted
$f_2(1640) \rightarrow \rho\rho$	41.1
$f_2(1750) \rightarrow \sigma\sigma$	72.7
$f_2(1750) \rightarrow \rho\rho$	14.4
$f_0(2104) \rightarrow \sigma\sigma$	72.6
$f_0(2104) \rightarrow \rho\rho$	0.56; omitted
Background term	172.4

no $f_0(1370)$

Glueball interpretation of "$f_0(1000)$"

- partial wave amplitude in $\pi\pi \to \pi\pi$ 0^{++} describes circle: "left over state"

  $m \sim 1000-1400$ MeV

  $\Gamma \sim 500-1000$ MeV

- interference $f_0(1500)$ - gb in

  $\pi\pi \to \pi\pi, \eta\eta, K\bar{K}$

  $B \to K(\pi\pi), K(K\bar{K})$

- production in

  $J/\psi \to \gamma\pi\pi$?, $\gamma K\bar{K}$ ✓, $\gamma 4\pi$ ✓

  $pp \to p(\pi\pi)p$ ✓ central

  $p\bar{p} \to 3\pi$ ✓

- suppression in $\gamma\gamma$ of $f_0(400-1200)$