New results on the spin of the $f_J(1710)$ from the WA102 experiment

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An introduction to glueballs

Quantum ChromoDynamics, the field theory describing strong interactions, not only describes how quarks and antiquarks interact by the exchange of gluons to form mesons

- it also predicts a rich spectrum of non-$q\overline{q}$ states

Glueballs gg, ggg

Hybrids $q\overline{q}g$

Mass estimates

Lattice Gauge calculations predict that the mass of the lightest glueball has $J^{PC} = 0^{++}$ and

$$M(0^{++}) = 1500 \text{ - } 1700 \text{ MeV}$$

Where to look for glueballs

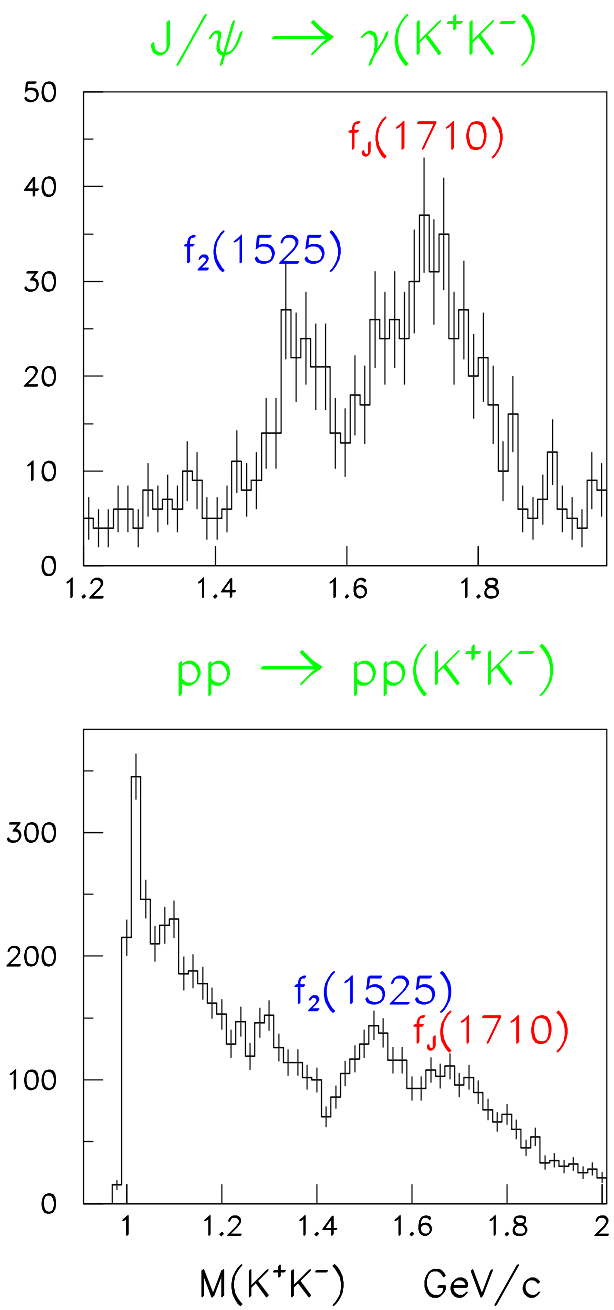
Glueballs should be preferentially produced in gluon rich interactions:

Radiative J/ψ decays, central pp interactions, $p\overline{p}$ annihilations

but should be suppressed in

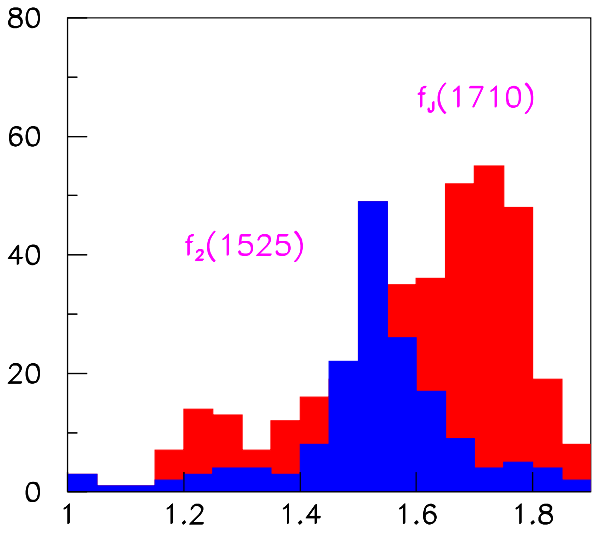
Normal hadronic interactions and $\gamma\gamma$ collisions.

The $f_J(1710)$



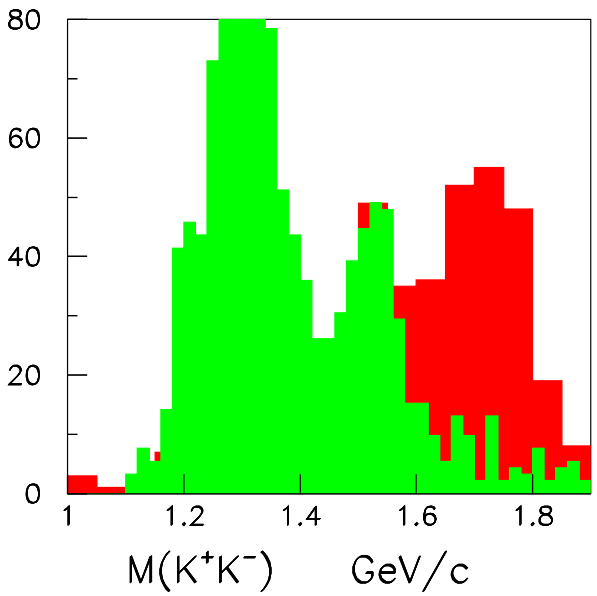
Clearly observed in glue rich interactions

The $f_J(1710)$



J/ψ

K^-p



J/ψ

$\gamma\gamma$

Not observed in K^-p or $\gamma\gamma$ collisions

Summary of $f_J(1710)$

The $f_J(1710)$ definitely has many of the properties expected for a glueball but for many years its spin has been uncertain: J = 0 or 2

1987 MARK III published a spin analysis of $J/\psi \to \gamma f_J(1710)$. Assumed pure spin zero or two. J = 2 preferred.

1989 WA76 published results on $pp \to pp(f_J(1710))$. The angular distributions in the 1.5 and 1.7 GeV mass regions were similar. 1.5 GeV signal assumed to be $f_2'(1525)$ - therefore $f_J(1710)$ had J = 2.

1990-97 Several single author analyses of the Mark III data including both spin 0 and 2 and interference gave J = 0.

1997 A partial wave analysis of $pp \to pp(f_j(1710))$. by the Fermilab E690 experiment showed that the peak at 1.5 GeV was the $f_0(1500)$ not $f_2'(1525)$. No information on spin of $f_J(1710)$.

It is essential to know the spin of the $f_J(1710)$ because from rate in J/ψ decays if

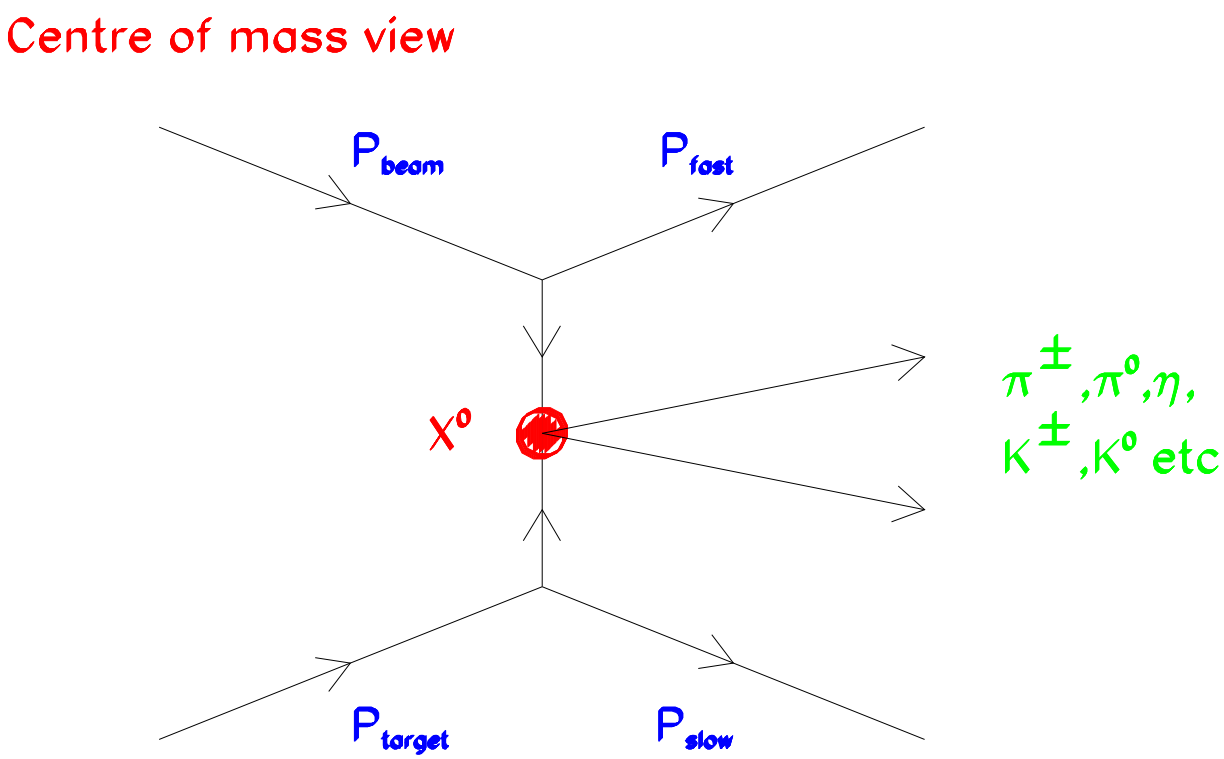
J = 2 consistent with being a normal $q\bar{q}$ meson

J = 0 consistent with having a significant glueball component.

Experiment WA102 has studied exclusive final states in the reaction

$$pp \to p_f p_s (X^0) \qquad (1)$$

at 450 GeV/c

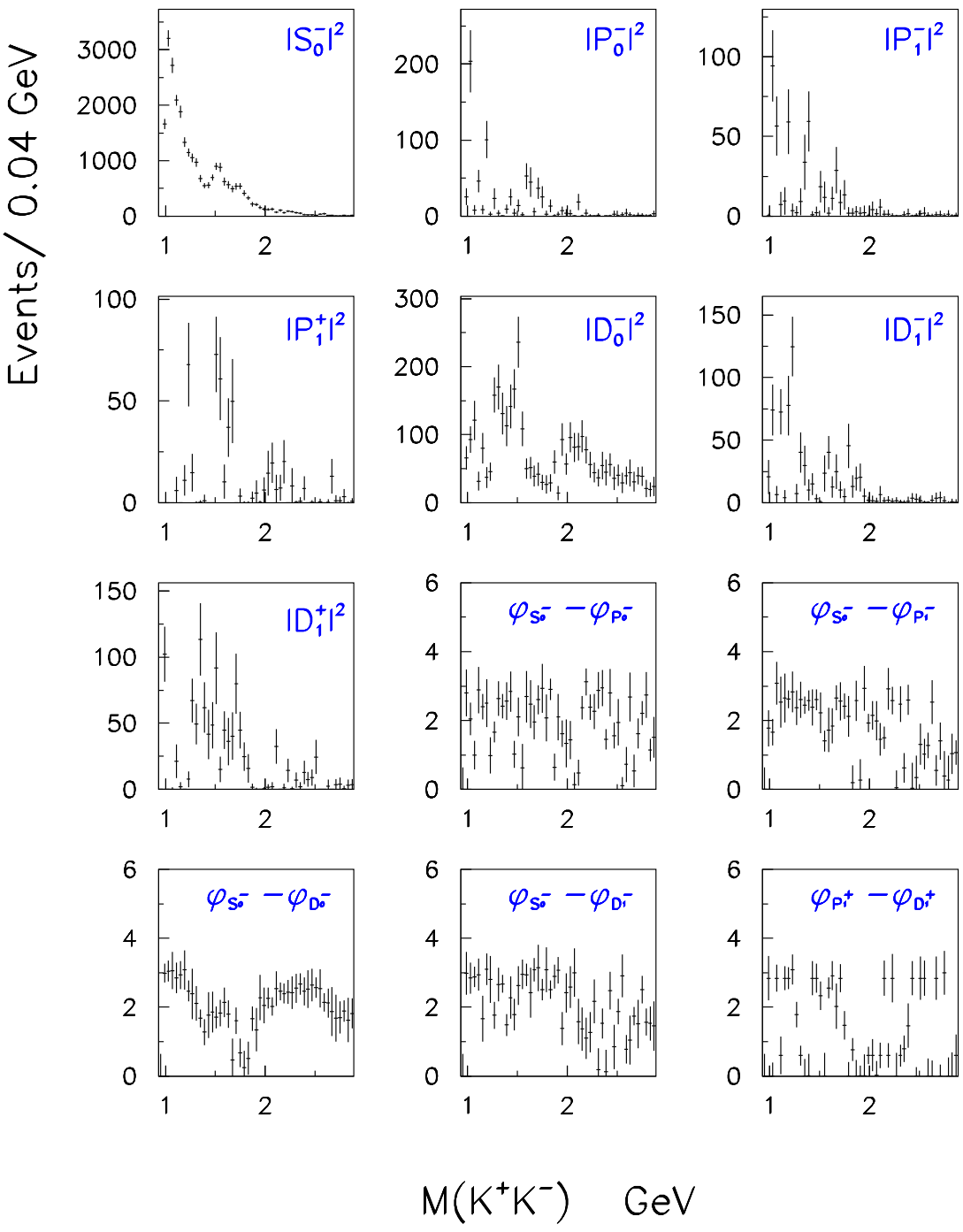


which is predicted to be a source of gluonic final states via double Pomeron exchange.

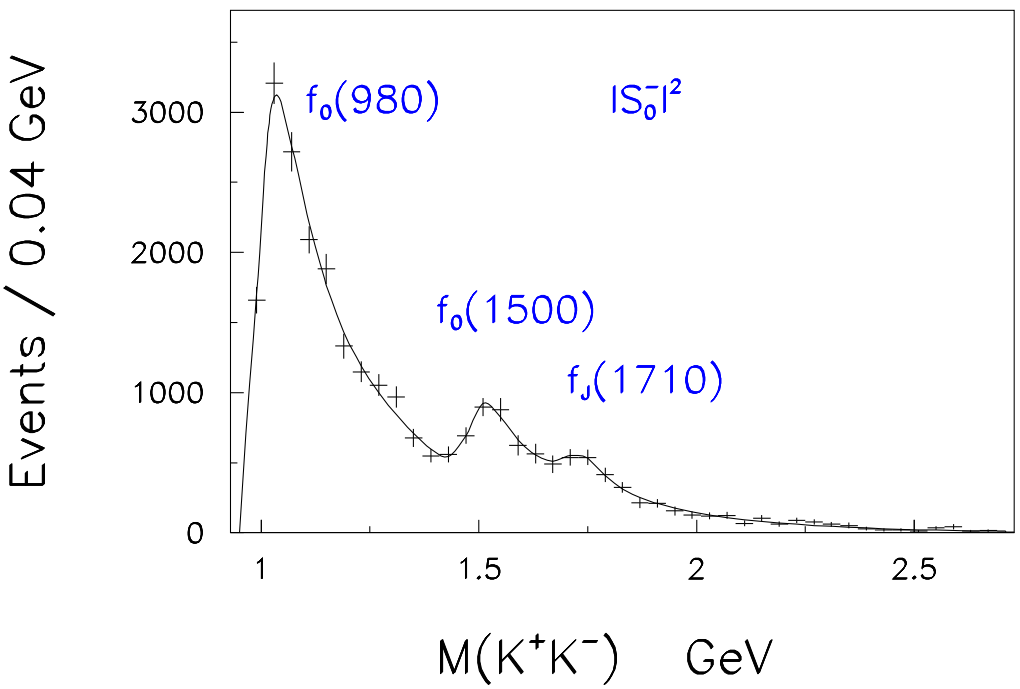
Results of the PWA

The PWA analysis has been performed in 40 MeV mass bins using an event-by-event maximum likelihood method.

The physical solution



The S-wave



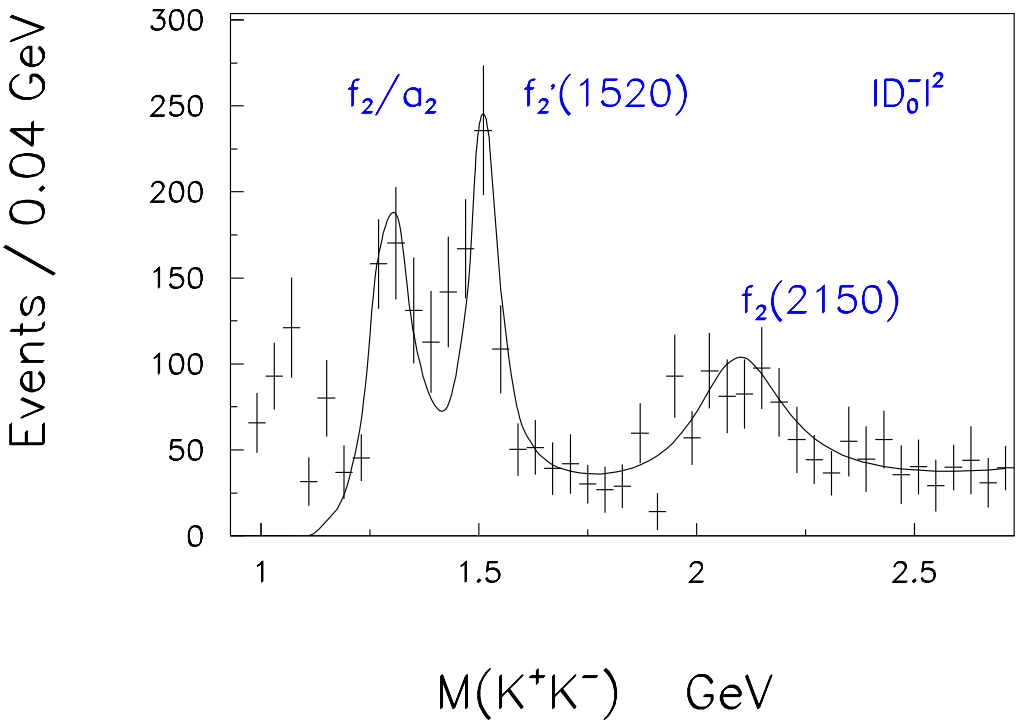
A fit using three interfering Breit-Wigners to describe the $f_0(980)$, $f_0(1500)$ and $f_J(1710)$ and a background gives

$f_0(980)$ M $=$ 985 $\pm$ 10 MeV, $\Gamma =$ 65 $\pm$ 20 MeV

$f_0(1500)$ M $=$ 1497 $\pm$ 10 MeV, $\Gamma =$ 104 $\pm$ 25 MeV

$f_0(1710)$ M $=$ 1730 $\pm$ 15 MeV, $\Gamma =$ 100 $\pm$ 25 MeV

The D-wave



A fit using three relativistic Breit-Wigners to describe the $f_2(1270)/a_2(1320)$, $f_2'(1525)$ and the peak at 2.2 GeV and a background gives

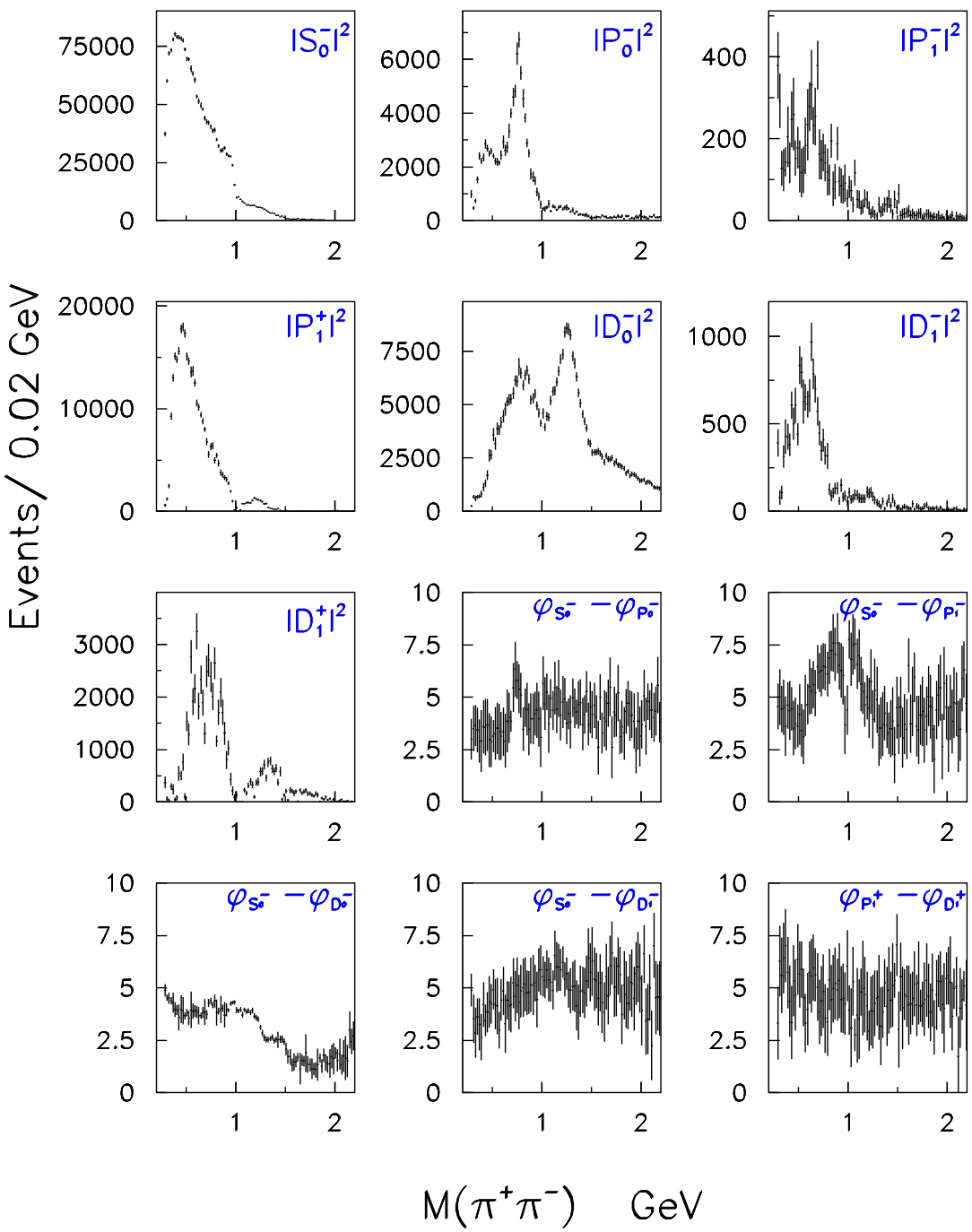
f_2/a_2 M $=$ 1305 $\pm$ 20 MeV, $\Gamma =$ 132 $\pm$ 25 MeV

$f_2'(1525)$ M $=$ 1515 $\pm$ 15 MeV, $\Gamma =$ 70 $\pm$ 25 MeV

$f_2(2150)$ M $=$ 2130 $\pm$ 35 MeV, $\Gamma =$ 270 $\pm$ 50 MeV.

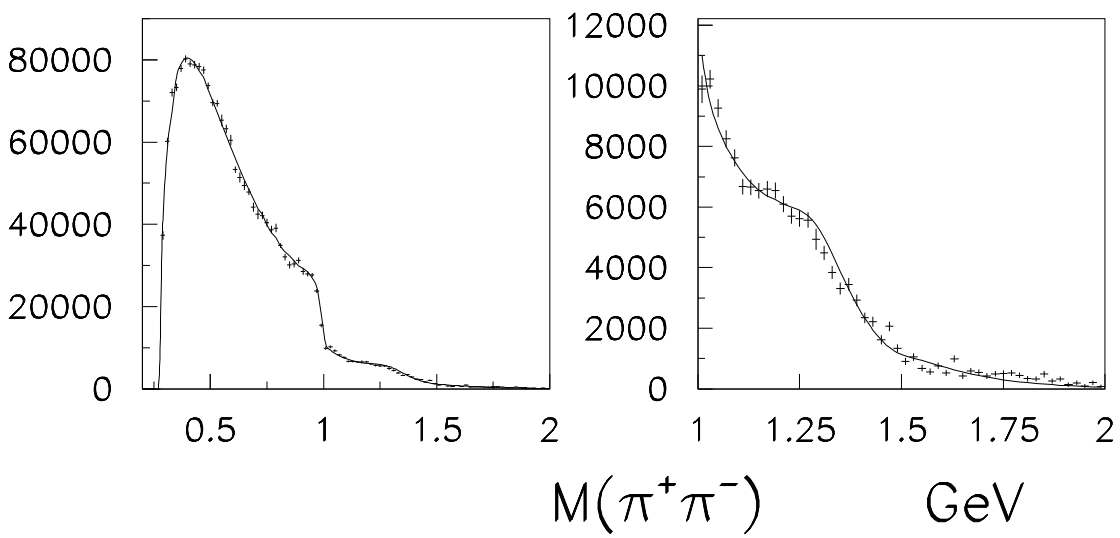
PWA of $pp \to p_f p_s(\pi^+\pi^-)$

The physical solution

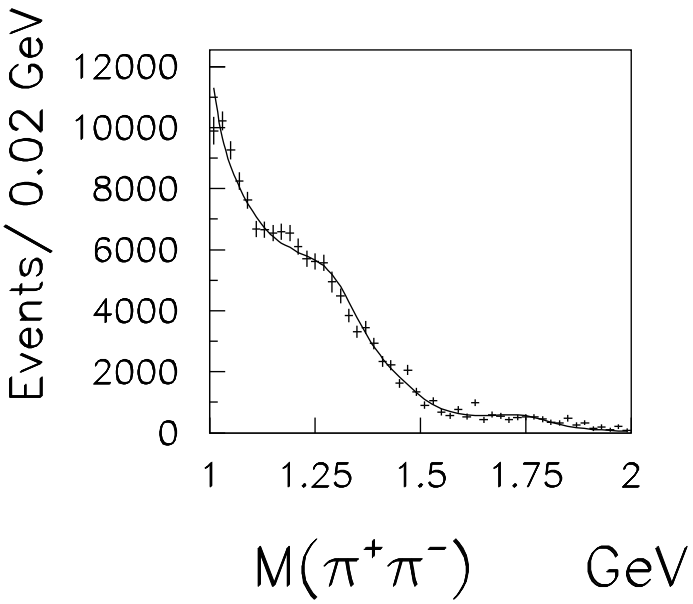


The S-wave

A fit using three interfering Breit-Wigners to describe the $f_0(980)$, $f_0(1300)$ and $f_0(1500)$



adding a Breit-Wigner to describe the $f_J(1710)$



Parameters from the fit to the S-wave

A fit using four interfering Breit-Wigners to describe the $f_0(980)$, $f_0(1300)$, $f_0(1500)$ and $f_J(1710)$ and a background gives

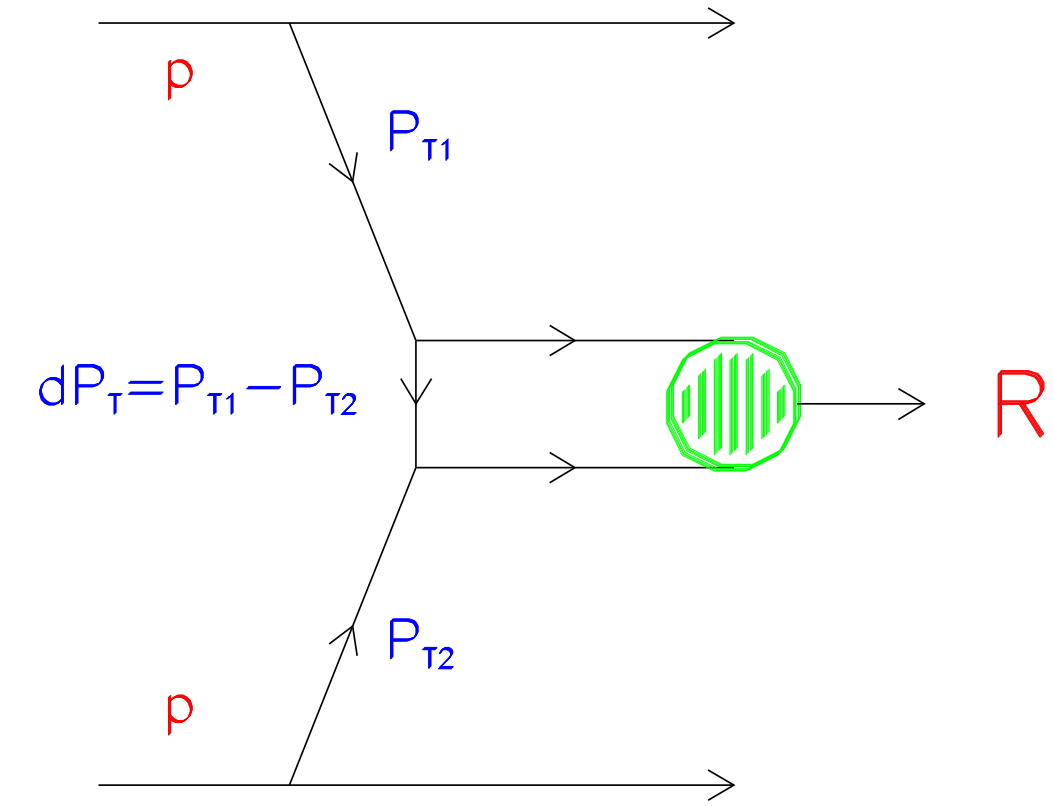
$f_0(980)$ M $= 982 \pm 3$ MeV, $\Gamma = 80 \pm 10$ MeV

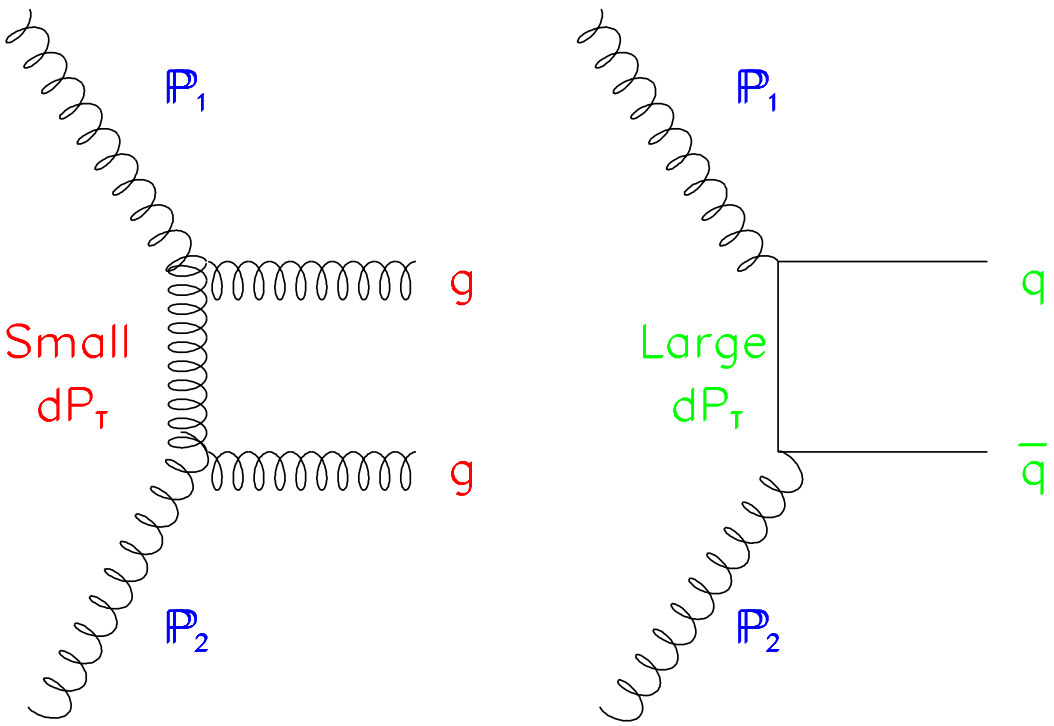
$f_0(1300)$ M $= 1308 \pm 10$ MeV, $\Gamma = 222 \pm 20$ MeV

$f_0(1500)$ M $= 1502 \pm 10$ MeV, $\Gamma = 131 \pm 15$ MeV

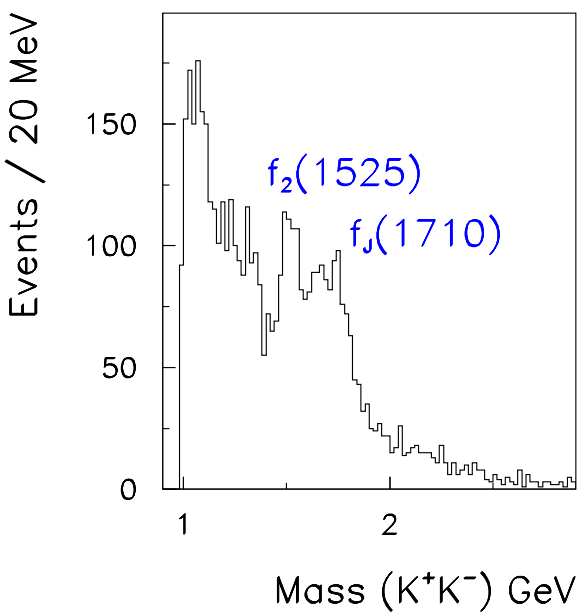
$f_0(1710)$ M $= 1750 \pm 20$ MeV, $\Gamma = 160 \pm 30$ MeV

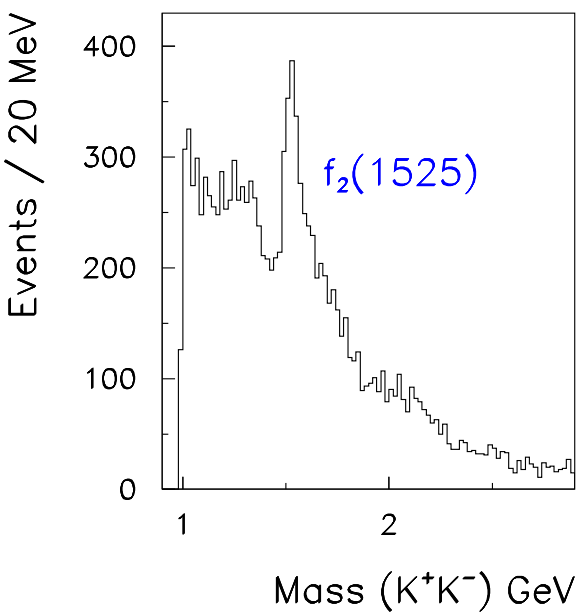
An update on the glueball-$q\bar{q}$ filter





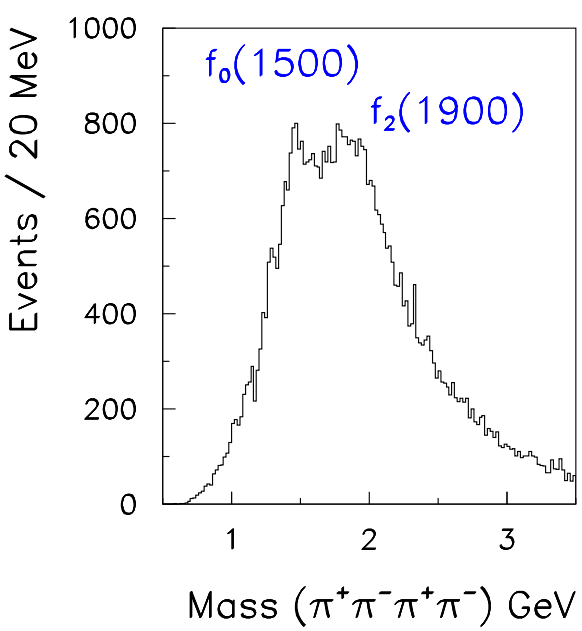
Examples of the glueball-$q\bar{q}$ filter

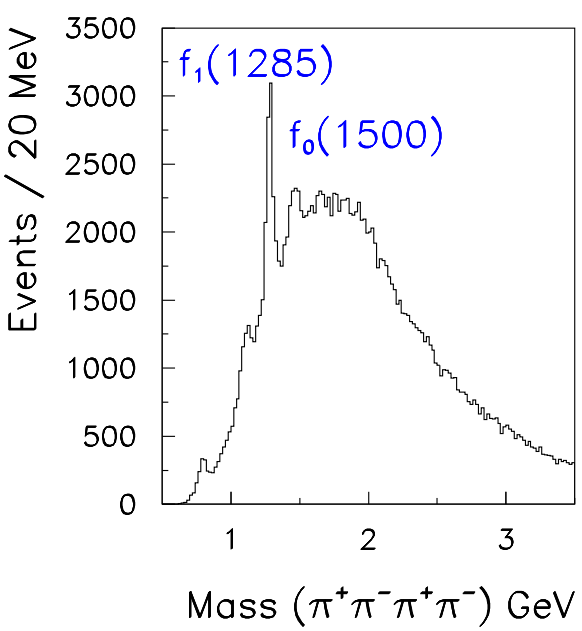




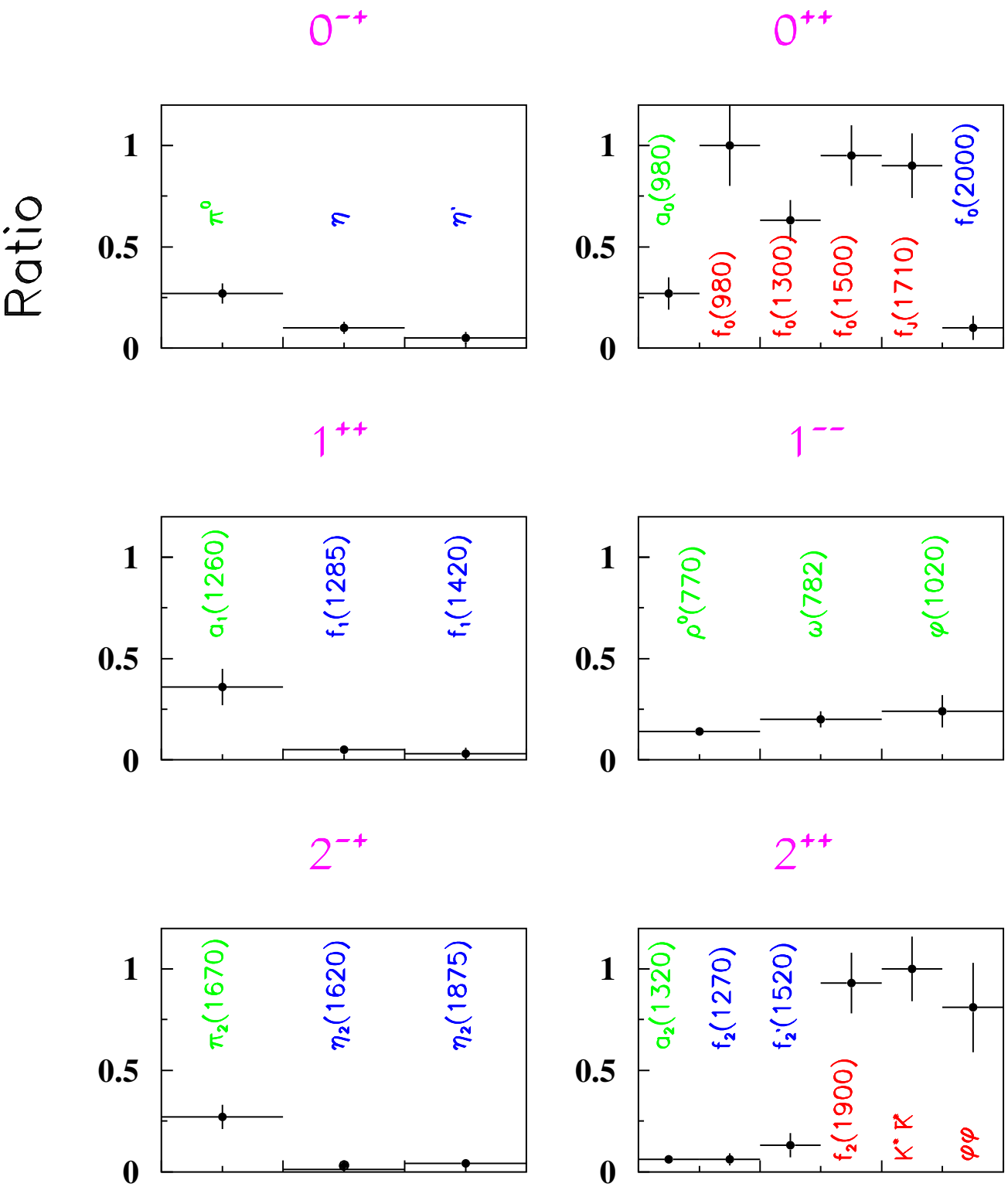
Small dP_T

Large dP_T

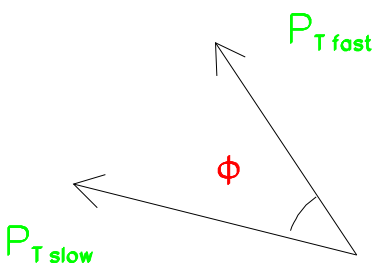




Ratio of number of events at small dP_T to large dP_T



The azimuthal angle ϕ between the outgoing protons



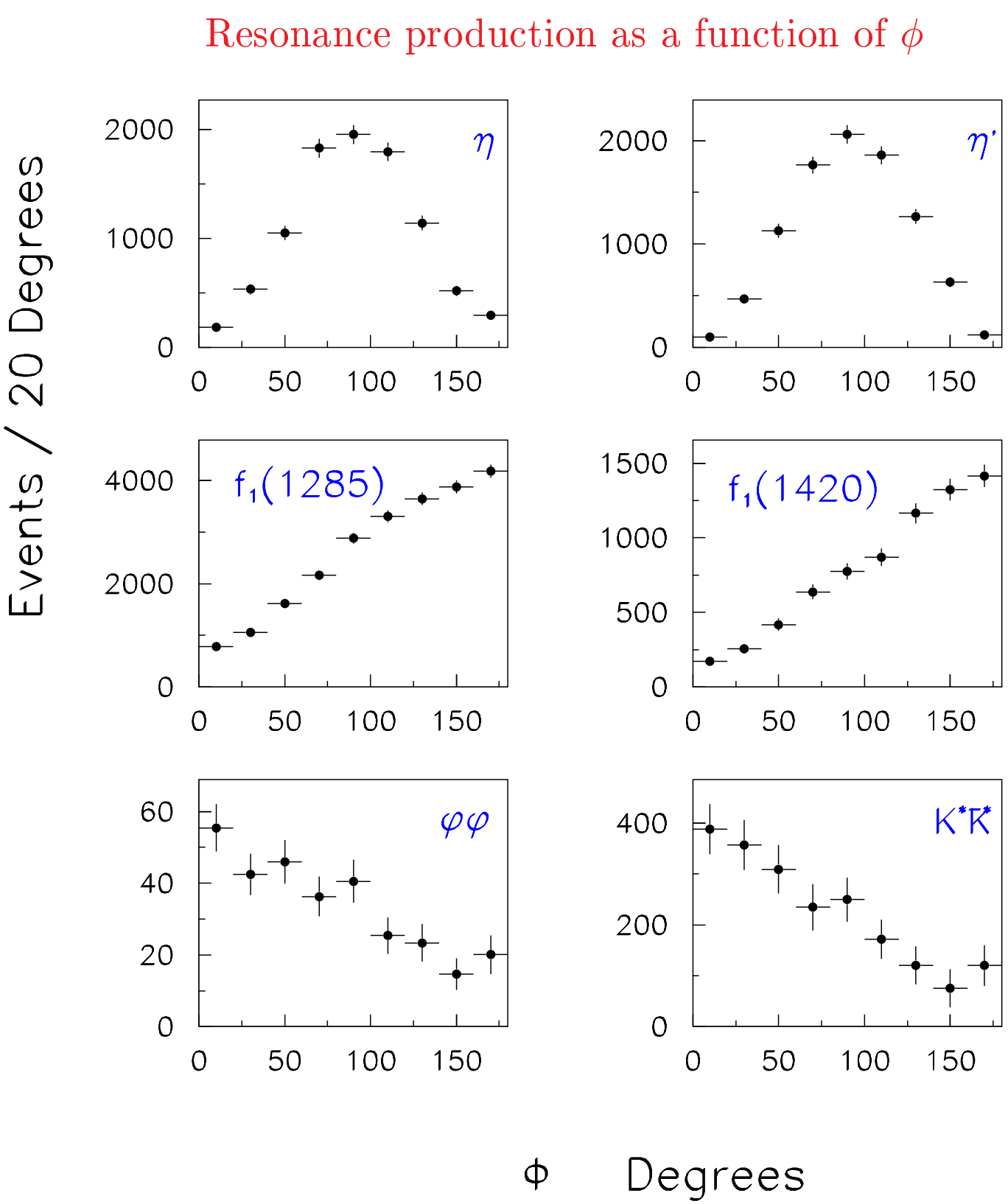
Naively expect a flat ϕ distribution.

There is a correlation between ϕ and dP_T

$$cos(\phi) = \frac{dP_T^2 - P_T^2}{4t_s t_f} \tag{2}$$

therefore may expect some ϕ dependence.

The observed ϕ distributions are more complex than this and are resonance dependent.


Resonance production as a function of ϕ
Events / 20 Degrees
η
η'
$f_1(1285)$
$f_1(1420)$
$\varphi\varphi$
$K^*\bar{K}^*$
2000
1000
0
4000
1500
500
60
40
20
400
200
0
50
100
150
Φ Degrees

Summary

A partial wave analysis of the centrally produced K^+K^- and $\pi^+\pi^-$ systems has been performed.

In the $K\overline{K}$ systems evidence is found for the $f_0(980)$, $f_0(1500)$ and $f_J(1710)$ with J = 0 in the the S-wave.

In the $\pi\pi$ systems evidence is found for the $f_0(980)$, $f_0(1300)$, $f_0(1500)$ and $f_J(1710)$ with J = 0 in the the S-wave.

There is evidence for a kinematical filter (dP_T) which selects out glueball candidates from known $q\overline{q}$ states.

There is also a interesting effect in the azimuthal angle of the two scattered protons which may give information on the nature of the Pomeron.