New results in central production by experiment WA102 at the CERN Omega Spectrometer

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2. An analysis of the K^+K^- and $\pi^+\pi^-$ channels
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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

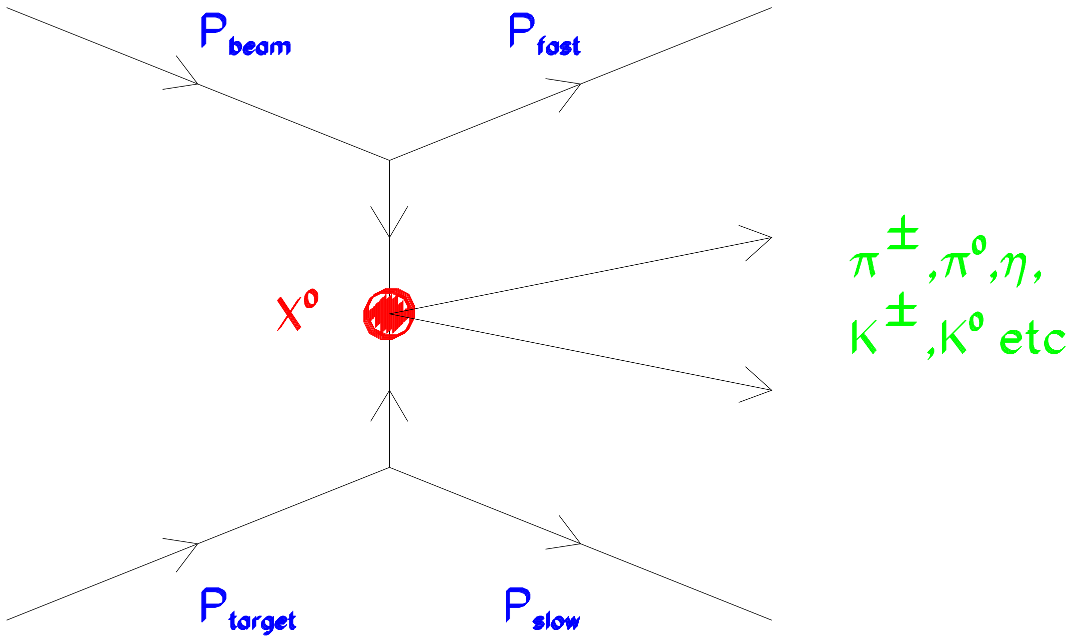
Normal hadronic interactions and $\gamma\gamma$ collisions.

Experiment WA102 has studied exclusive final states in the reaction

$$pp \rightarrow p_f p_s (X^0)$$

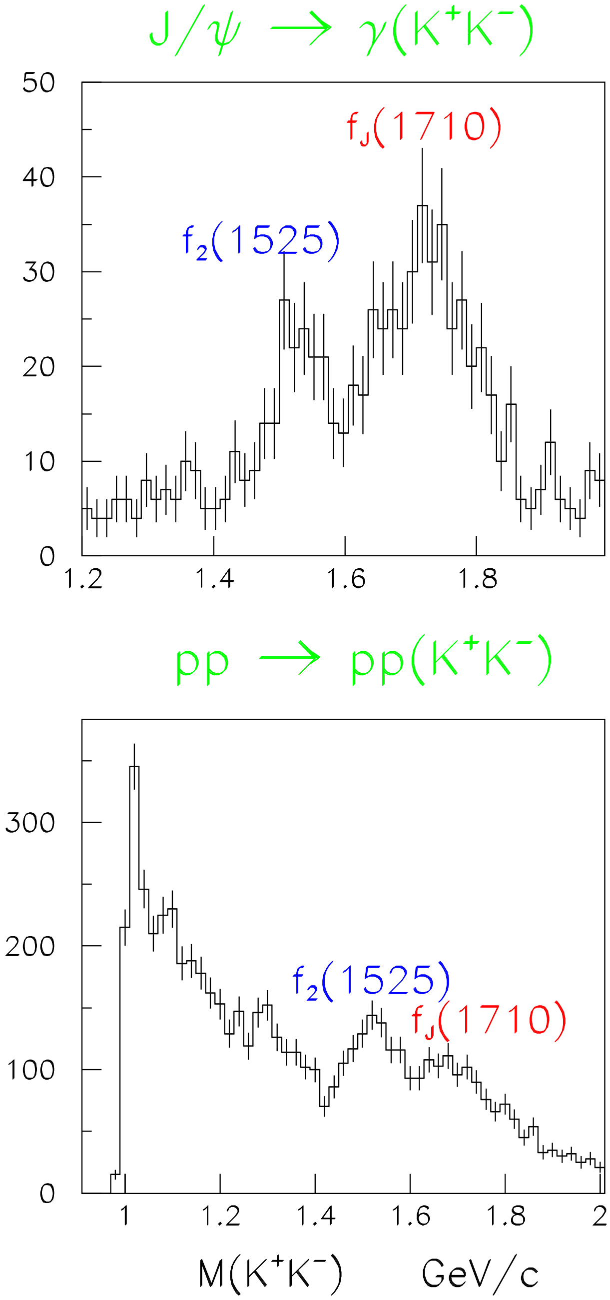
at 450 GeV/c

Centre of mass view



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

The $f_J(1710)$



Clearly observed in glue rich interactions

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 $f_J(1710)$.

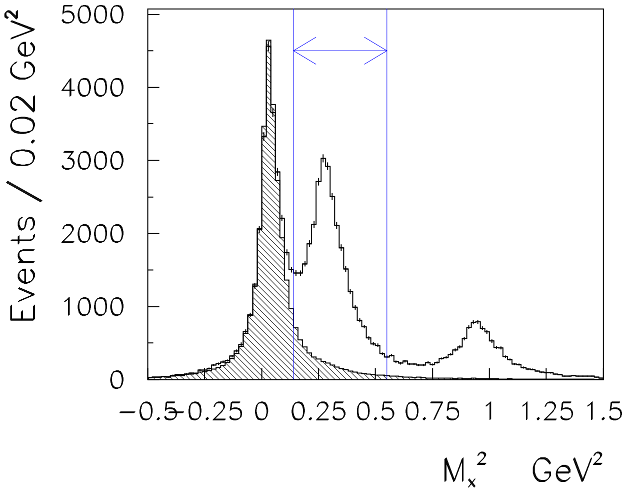
It is essential to know the spin of the $f_J(1710)$ because from rate in J/ψ decays if

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

J = 0 consistent with having a significant glueball component.

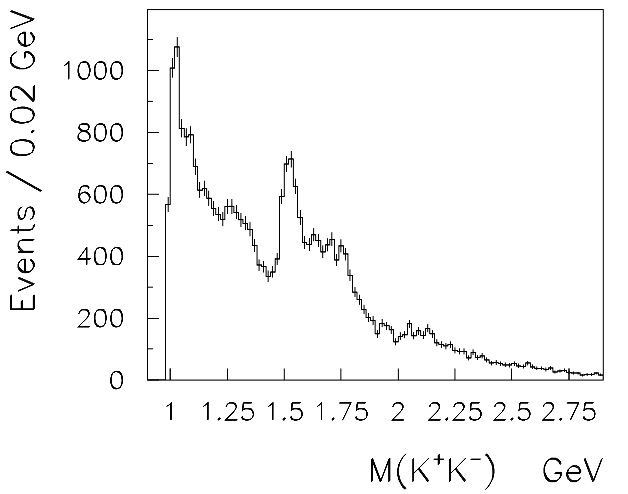
Selection of the reaction $pp \to p_f p_s (K^+K^-)$

The K^+K^- channel is selected using Cerenkov information and energy balance



The residual contamination from the $\pi^+\pi^-$ channel is small and does not effect the results.

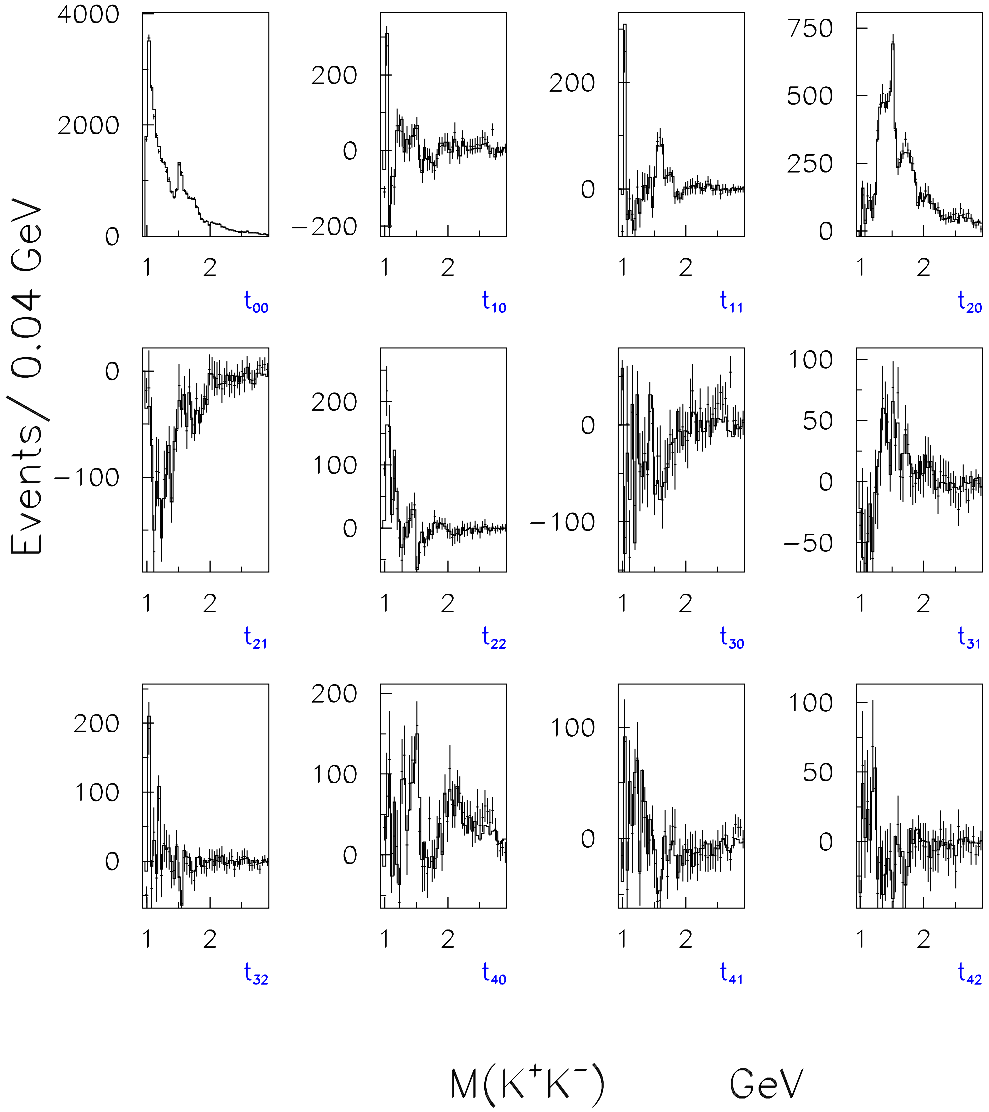
The K^+K^- mass spectrum



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

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

The moments calculated from the partial amplitudes are shown superimposed on the experimental moments.



The results of the PWA reproduce well the moments.

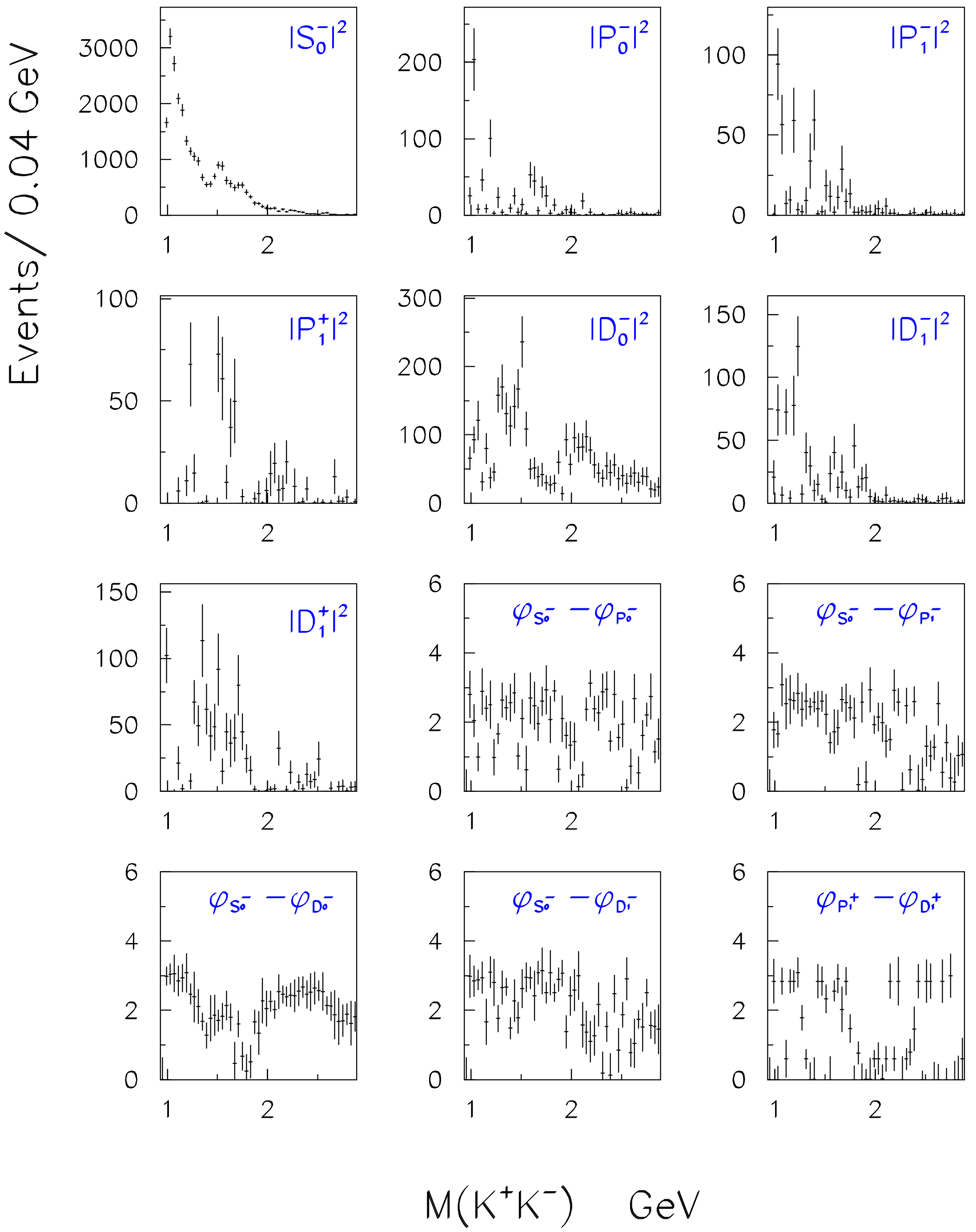
The Physical solution

For S, P and D waves there are eight solutions.

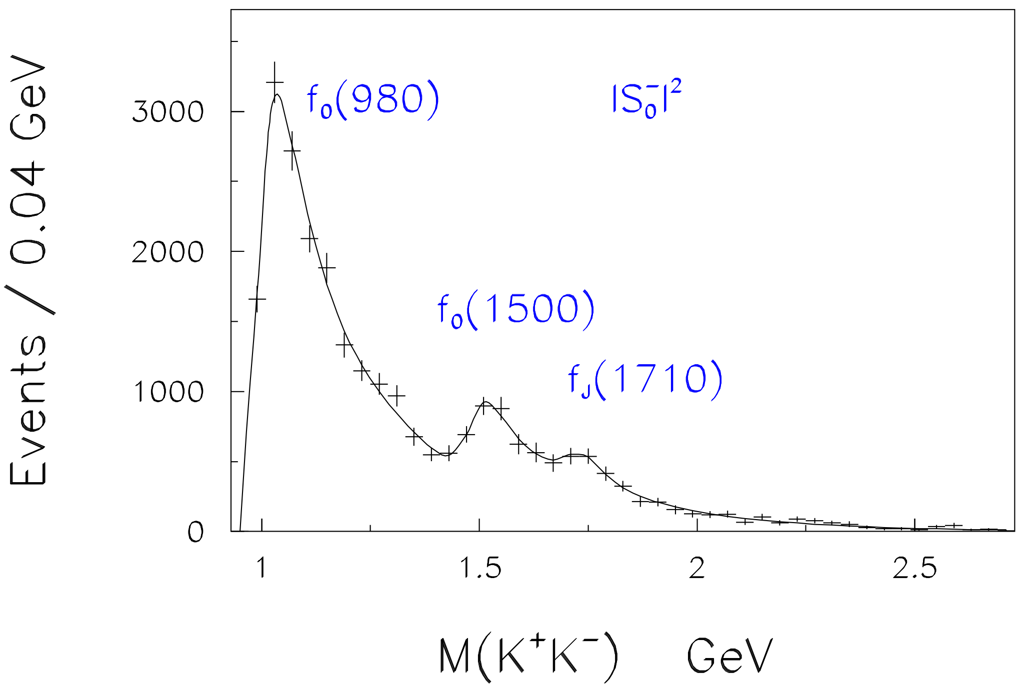
5 Solutions P-wave dominant at threshold

1 Solution D-wave dominant at threshold

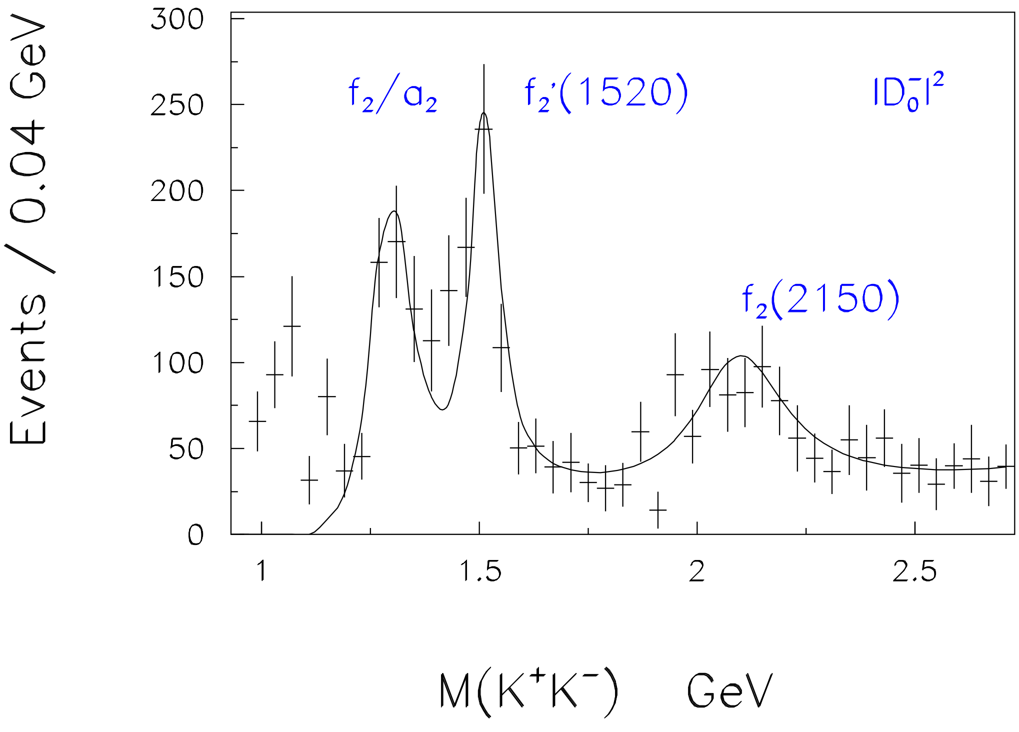
1 Solution equal S and P-wave at threshold



The S-wave



The D-wave



Summary of the K^+K^- analysis

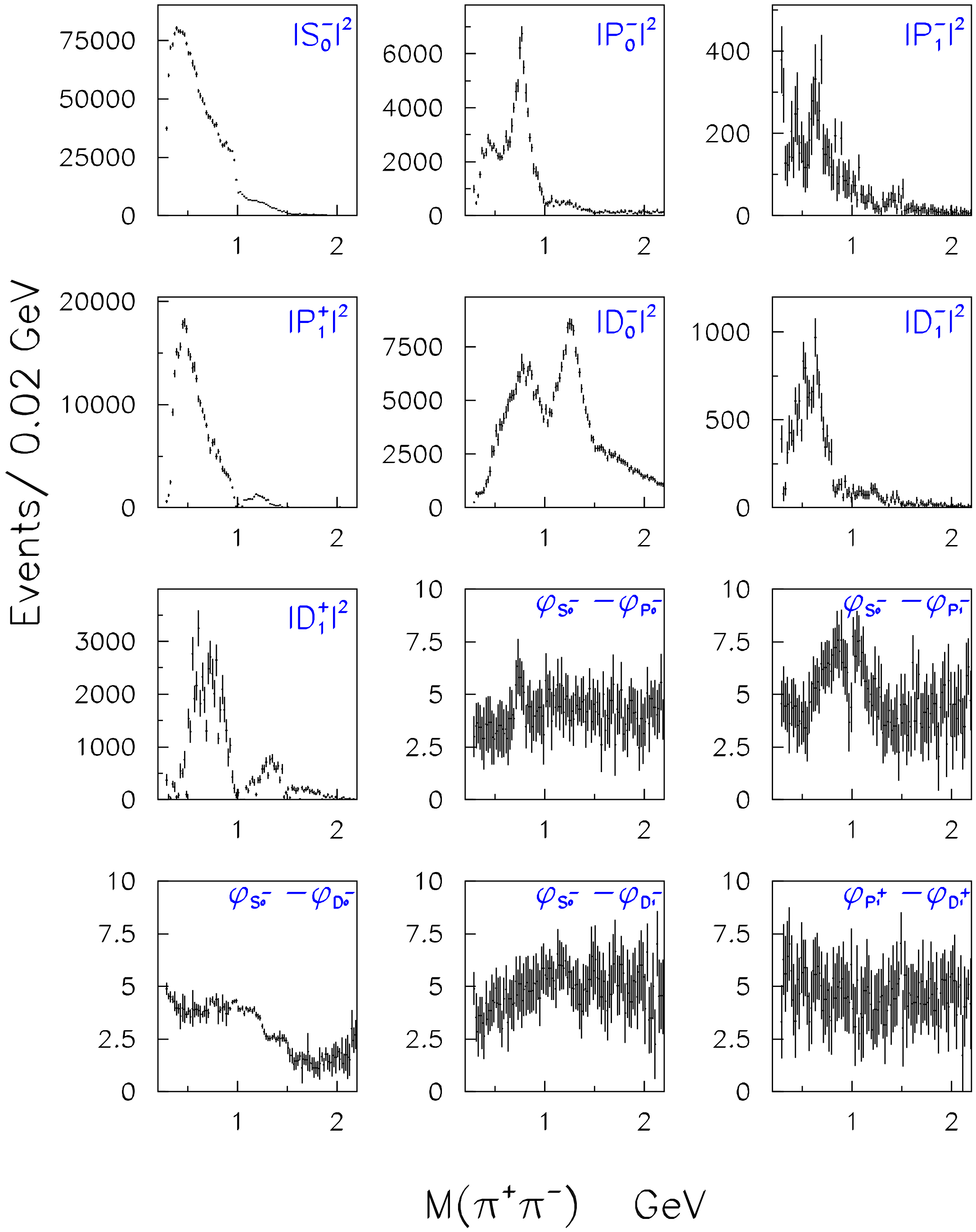
An unambiguous physical solution has been found from a partial wave analysis of the centrally produced K^+K^-system.

The striking feature is the observation of peaks in the S-wave corresponding to the $f_0(1500)$ and $f_J(1710)$ with $J = 0$.

The D-wave shows evidence for the $f_2(1270)/a_2(1320)$, the $f_2'(1525)$ and the $f_2(2150)$ but there is no evidence for a statistically significant contribution in the D-wave in the 1.7 GeV mass region.

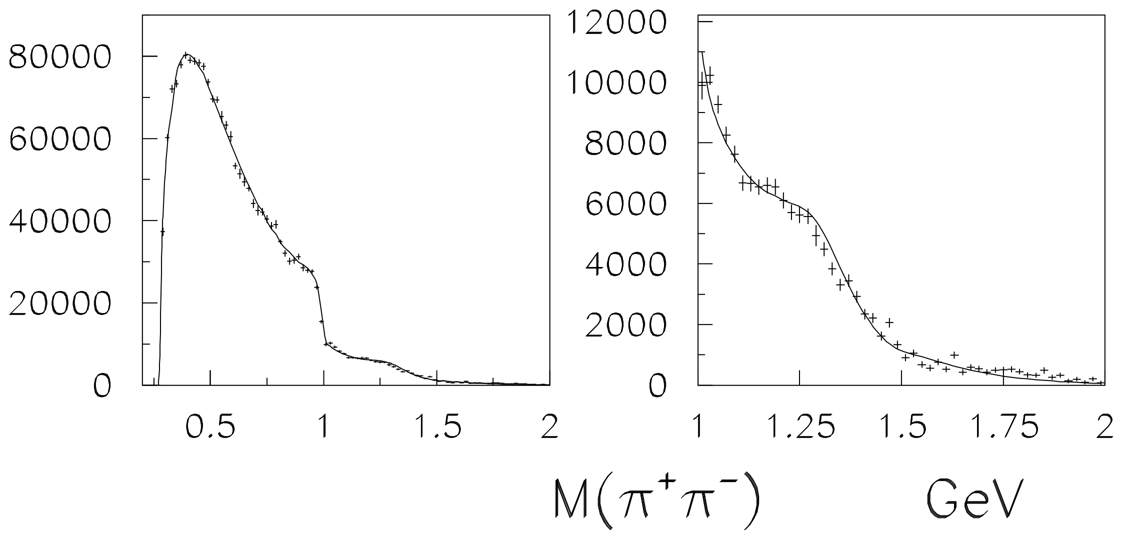
PWA of $pp \to p_f p_s(\pi^+\pi^-)$

The physical solution

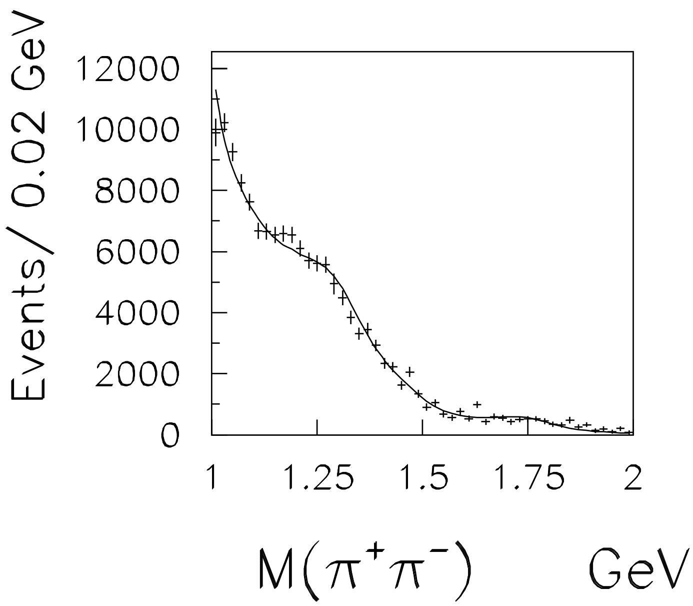


The S-wave

A fit using three interfering Breit-Wigners to describe the $f_0(980)$, $f_0(1370)$ and $f_0(1500)$



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



Summary of the $\pi^+\pi^-$analysis

An unambiguous physical solution has been found from a partial wave analysis of the centrally produced $\pi^+\pi^-$ system.

Evidence is found for the $f_0(980)$, $f_0(1370)$, $f_0(1500)$ and $f_J(1710)$ with J = 0 in the the S-wave.

The $\rho(770)$ is observed dominantly in the P_0^--wave.

The $f_2(1270)$ is observed dominantly in the D_0^--wave.

There is evidence for a broad enhancement in the D-wave below 1 GeV.

A coupled channel analysis of the K^+K^- and $\pi^+\pi^-$ channels

A coupled channel analysis has been performed in order to determine the pole positions and branching ratios of the resonances observed.

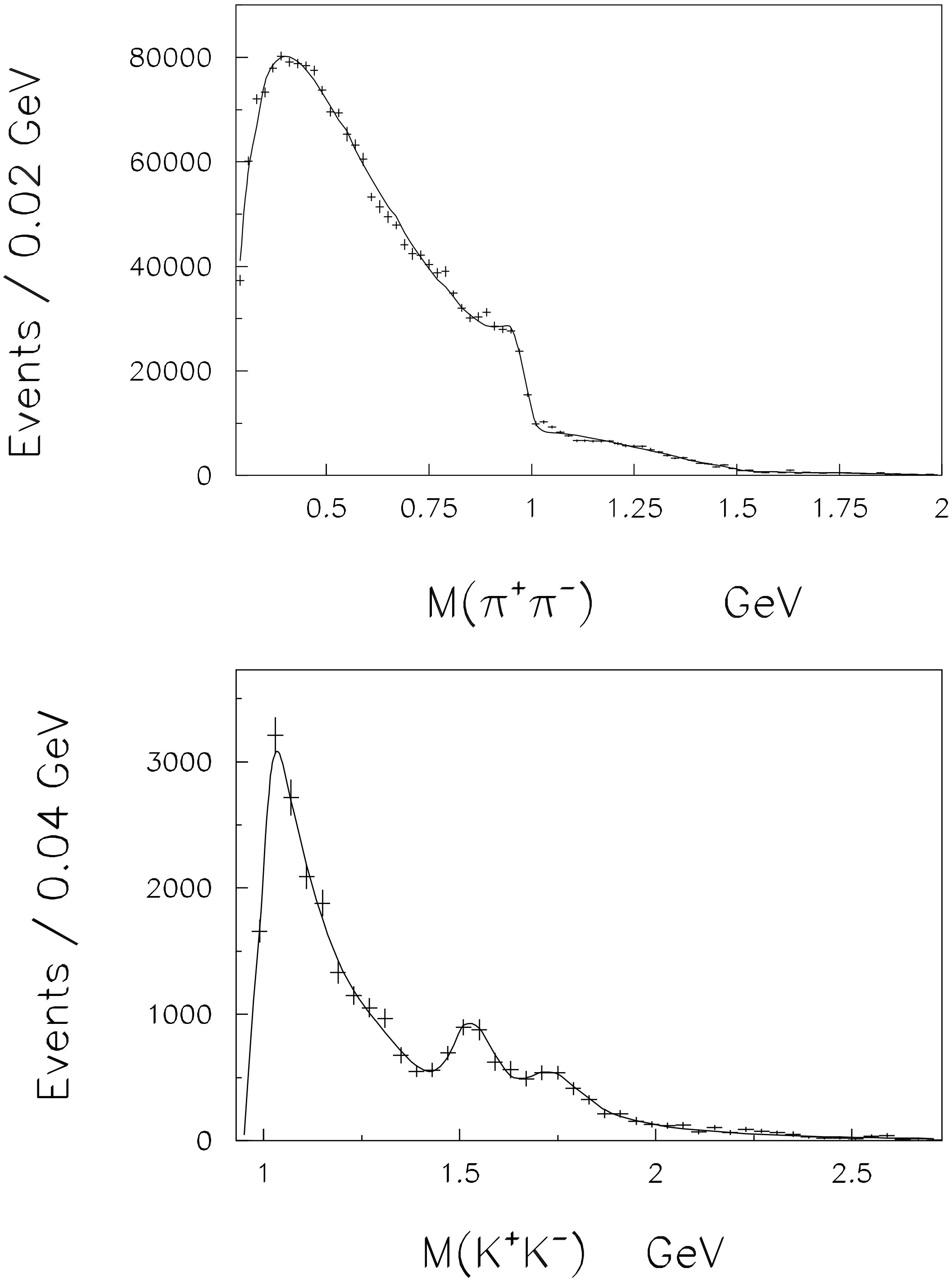
Three methods of fitting the data have been used

1. Interfering Breit-Wigners
2. T-Matrix analysis
3. K-Matrix analysis

The pole positions and branching fractions found from the three methods are found to be compatible.

A mean value of the three methods is quoted and the spread between the methods is used to calculate a systematic error.

Coupled channel fit



Pole positions

The pole positions are

$$
\begin{array}{llll}
f_0(980) & \mathrm{M} & = (\ \ 987 \pm \ \ 6 \pm \ \ 6) & -i\,(\ \ 48 \pm 12 \pm \ 8)\ \ \mathrm{MeV} \\
f_0(1370) & \mathrm{M} & = (1312 \pm 25 \pm 10) & -i\,(109 \pm 22 \pm 15)\ \ \mathrm{MeV} \\
f_0(1500) & \mathrm{M} & = (1502 \pm 12 \pm 10) & -i\,(\ \ 49 \pm \ \ 9 \pm \ 8)\ \ \mathrm{MeV} \\
f_0(1710) & \mathrm{M} & = (1727 \pm 12 \pm 11) & -i\,(\ \ 63 \pm \ \ 8 \pm \ 9)\ \ \mathrm{MeV}
\end{array}
$$

For the $f_0(980)$ the couplings were determined to be

$$
g_\pi \ = \ 0.19 \ \pm \ 0.03 \ \pm \ 0.04 \quad g_K \ = \ 0.40 \ \pm \ 0.04 \ \pm \ 0.04
$$

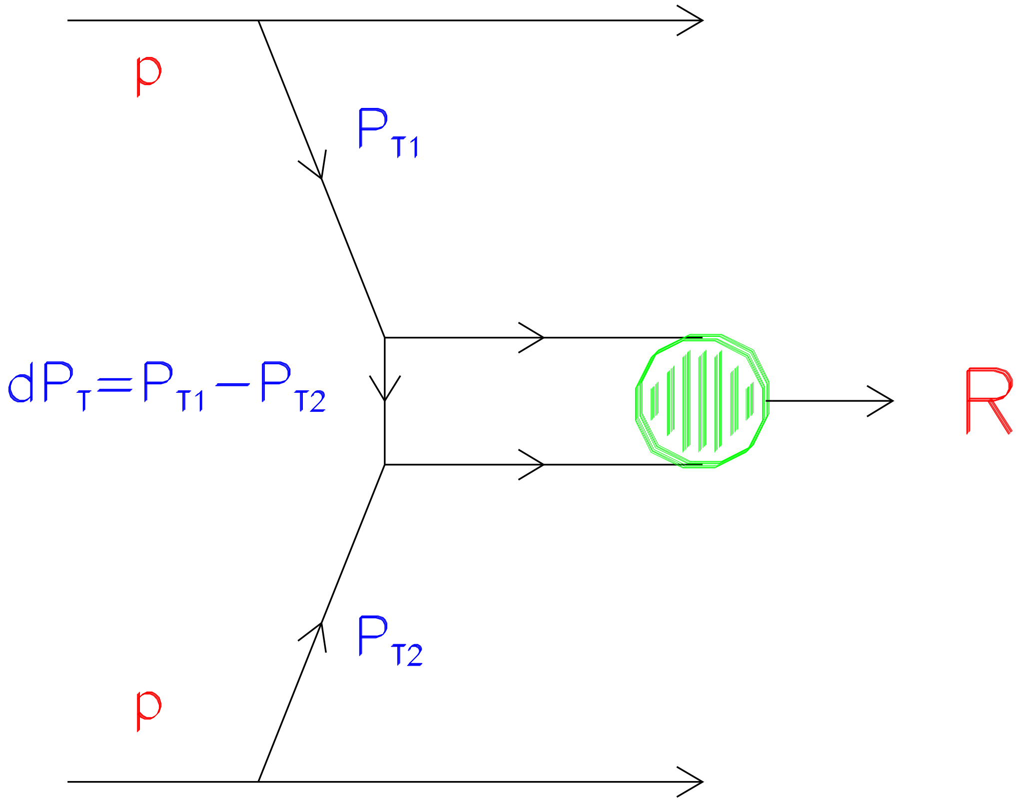
Branching ratios

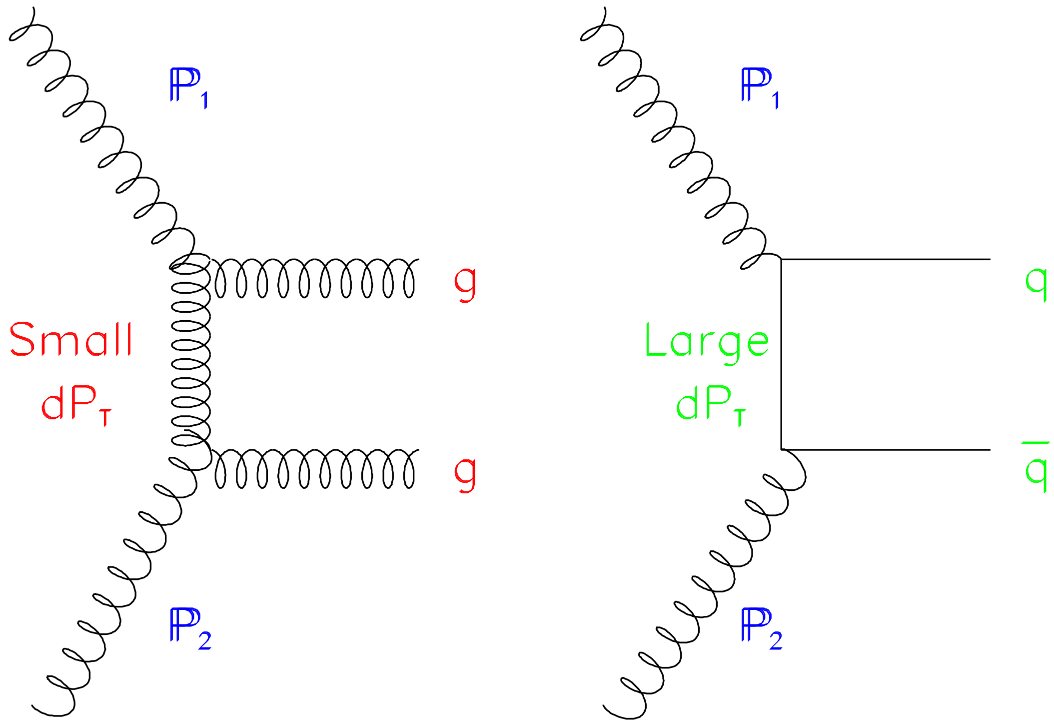
$$
\frac{f_0(1370) \to K\overline{K}}{f_0(1370) \to \pi\pi} = 0.46 \pm 0.15 \pm 0.11
$$

$$
\frac{f_0(1500) \to K\overline{K}}{f_0(1500) \to \pi\pi} = 0.33 \pm 0.03 \pm 0.07
$$

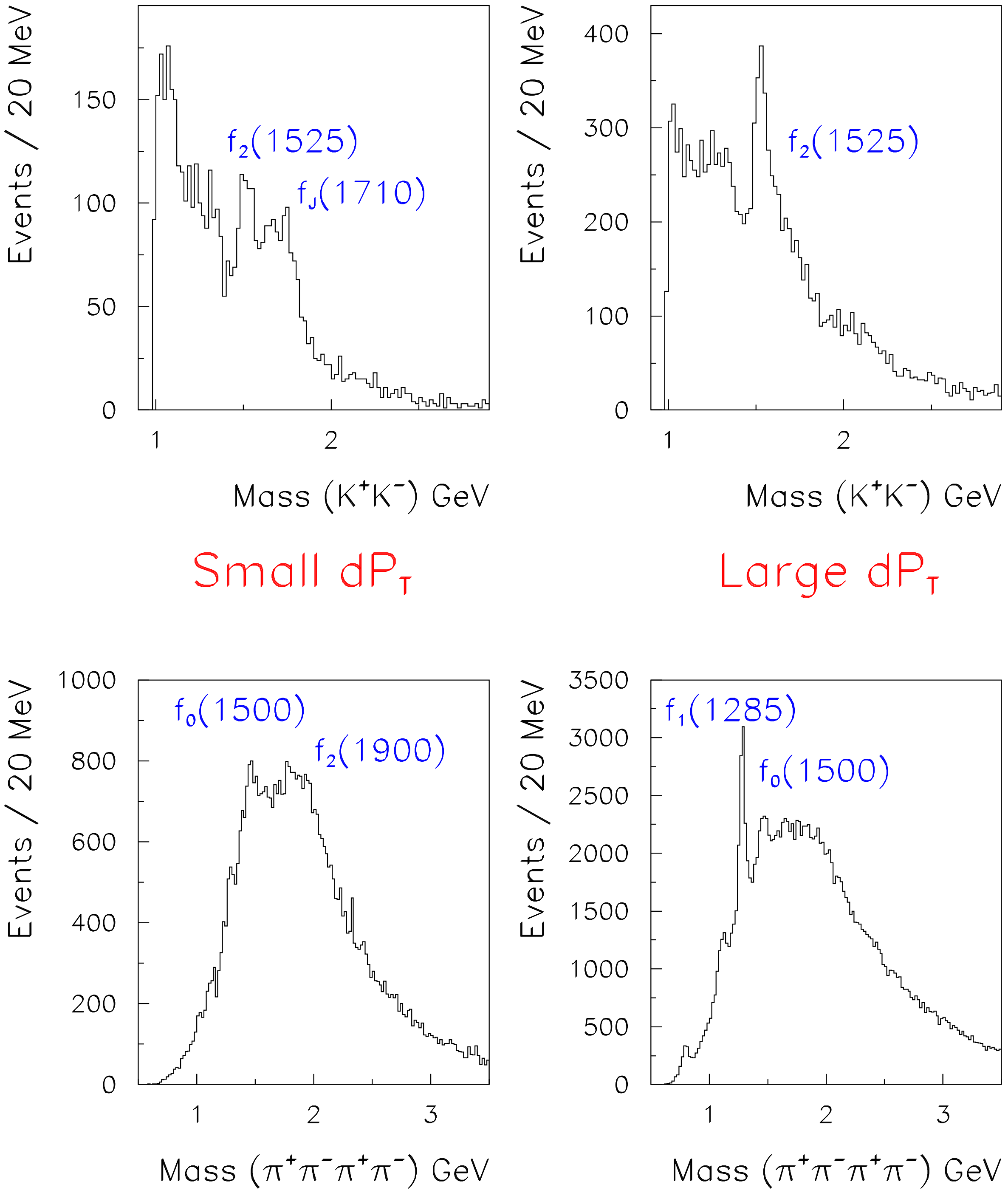
$$
\frac{f_0(1710) \to K\overline{K}}{f_J(1710) \to \pi\pi} = 5.0 \pm 0.6 \pm 0.9
$$

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

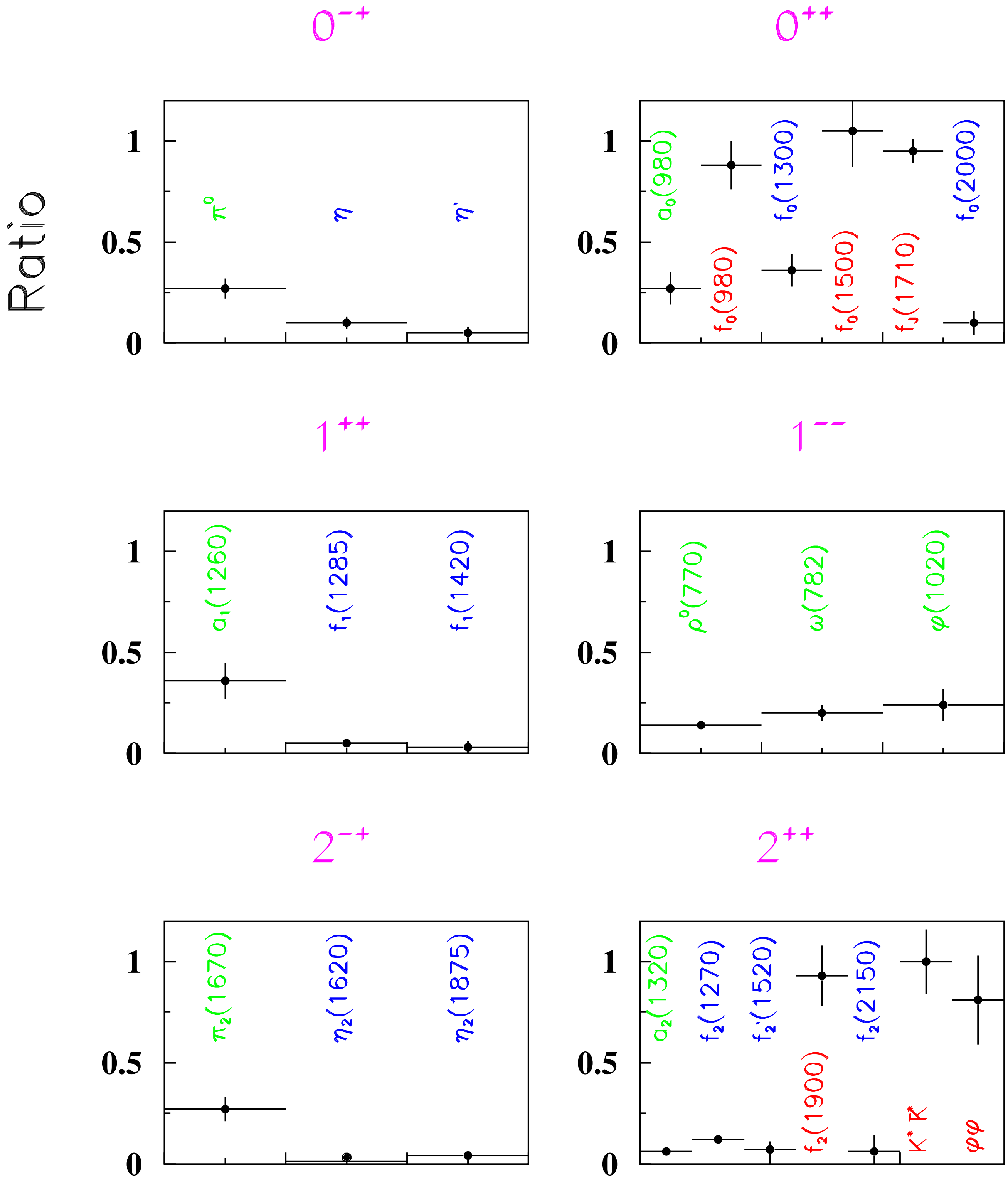




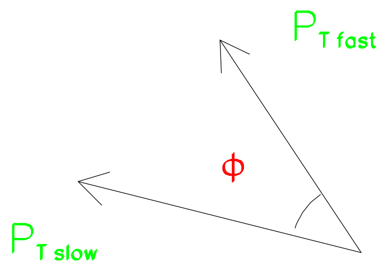
Examples of the glueball-$q\bar{q}$ filter



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.

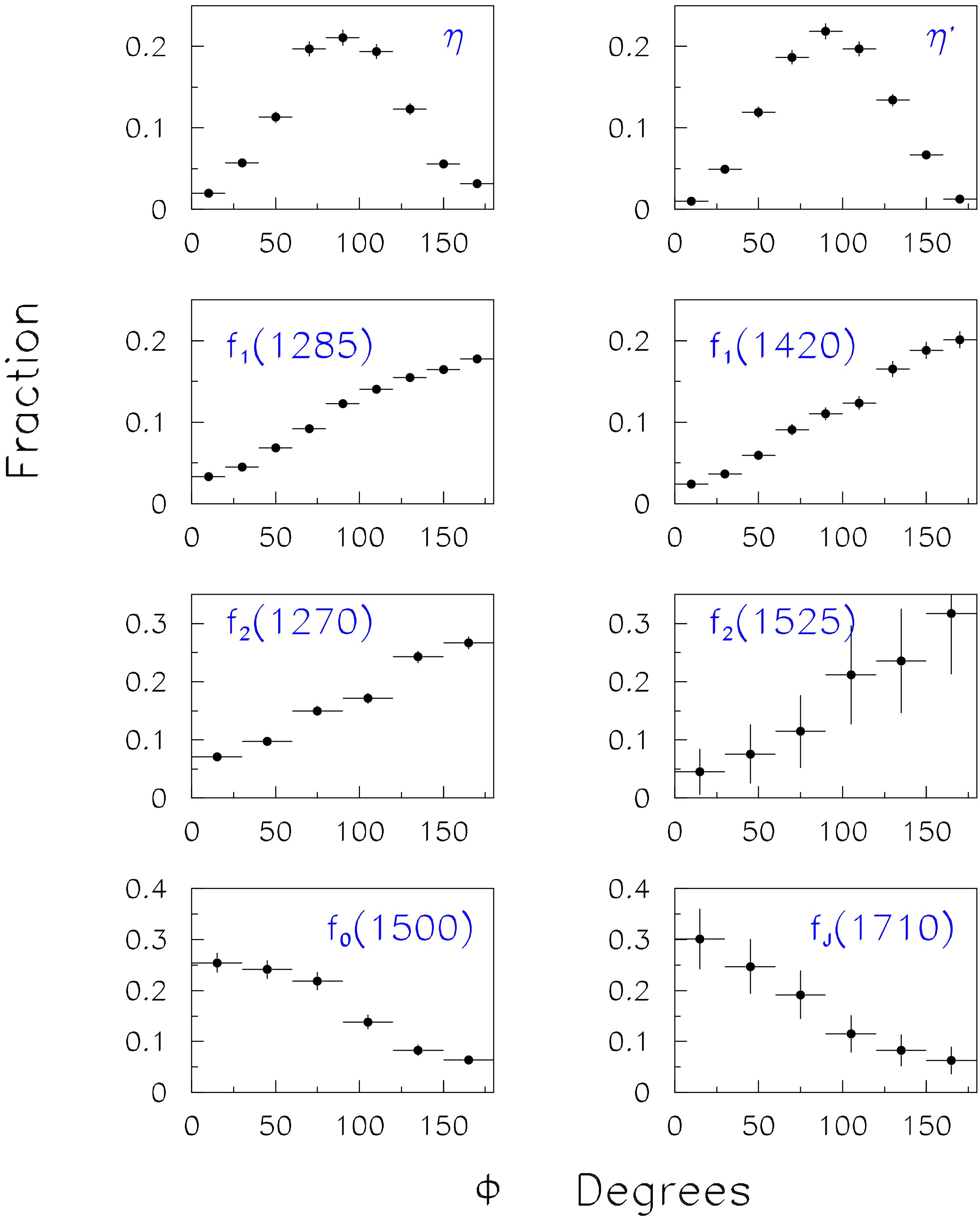
There is a correlation between ϕ and dP_T

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

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



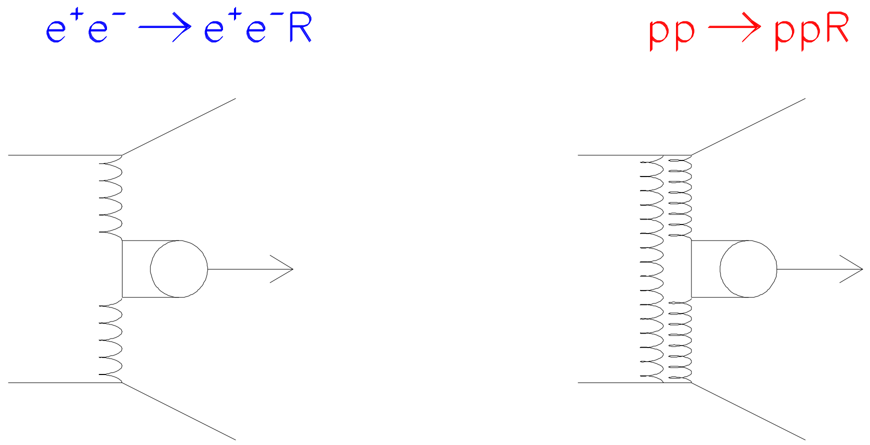
Progress on understanding these effects

Several theoretical papers have been published on these effects

- ‘A Glueball-$q\bar{q}$ filter in central hadron production’ F.E. Close and A. Kirk Phys. Lett. **B397** (1997) 333-338.
- ‘Filtering glueball from $q\bar{q}$ production in proton proton or double tagged $e^+e^- \to e^+e^- R$ and implications for the spin structure of the Pomeron’ F.E. Close Phys. Lett. **B419** (1998) 387.
- ‘Central pseudoscalar production in pp scattering and the gluon contribution to the proton spin’ P. Castoldi, R. Escribano and J.-M. Frere, Phys. Lett. **B425** (1998) 359.
- ‘The glueball filter in central production and broken scale invariance’ J. Ellis and D. Kharzeev hep-ph/9811222
- ‘Unusual properties of the central production of glueballs and instantons’ N. I. Kochelev hep-ph/9902203
- ‘Central production of mesons: Exotic states versus pomeron structure’ F.E. Close and G. Schuler hep-ph/9902243
- ‘Pomeron fusion and central η and η' meson production’ N. I. Kochelev, T. Morii and A.V. Vinnikov hep-ph/9903279
- ‘Evidence that the Pomeron transforms as a non-conserved vector current’ F.E. Close and G. Schuler hep-ph/9905305

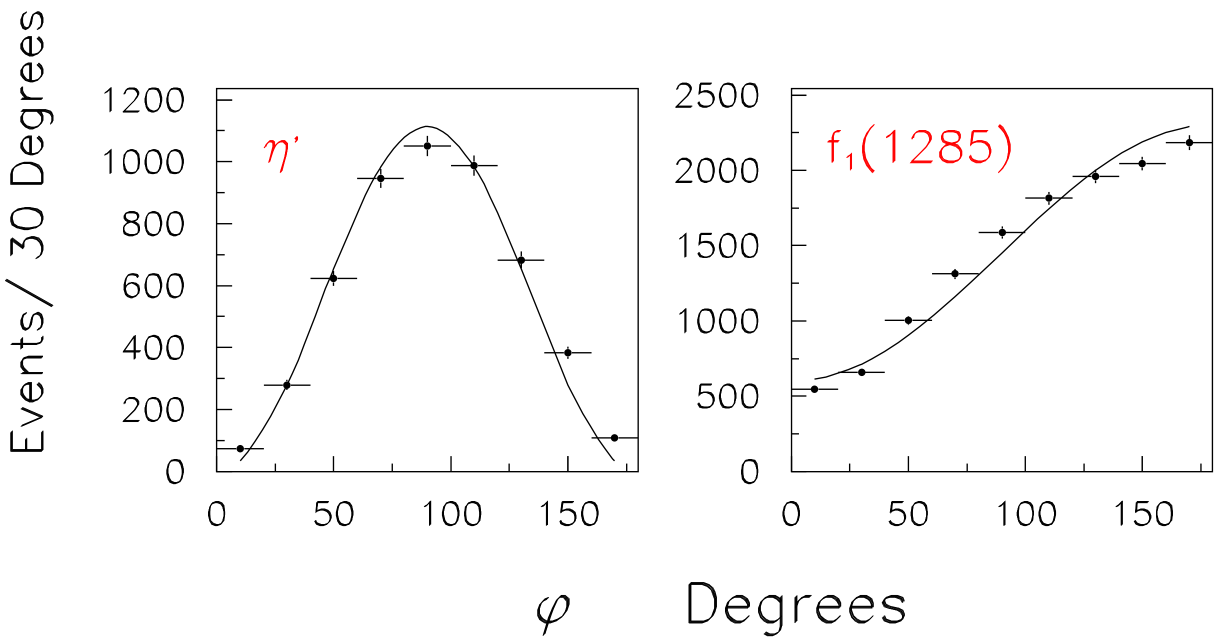
All agree that the exchanged particle (Pomeron) must have $J > 0$ and that $J = 1$ is the simplest explanation

Using $\gamma^*\gamma^*$ collisions as an analogy



Close and Schuler have calculated the ϕ dependencies for the production of resonances with different J^{PC}s.

Predict: 0^{-+} $sin^2(\phi)$ 1^{++} $\alpha + sin^2(\phi/2)$



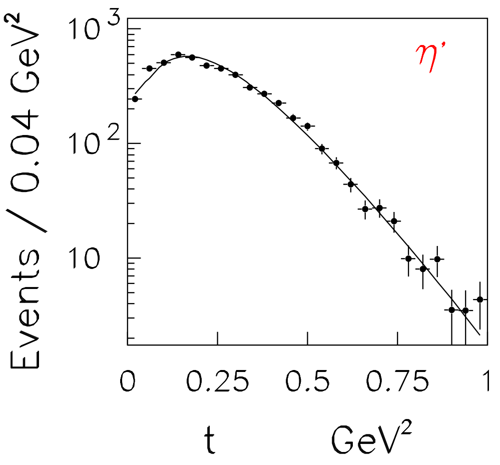
good agreement

Further predictions

Predict: 0^{-+}

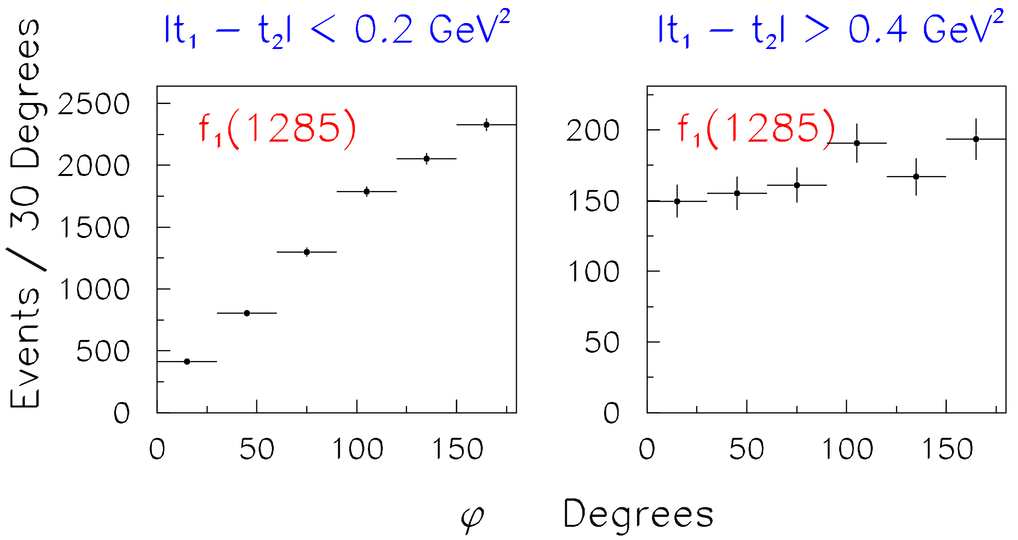
$d\sigma/dt_1t_2 \propto t_1t_2$

good agreement



Predict: 1^{++} $J_Z = 1$ Dominant Observed

$d\sigma/dt_1t_2 \propto \sqrt{t_1t_2}sin^2(\phi/2) + (\sqrt{t_2} - \sqrt{t_1})^2$



After understanding the Pomeron we then want to go on to understand how we can use this to extract the structure of the produced mesons

Summary

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

In the K^+K^- system 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 $\pi^+\pi^-$ system evidence is found for the $f_0(980)$, $f_0(1370)$, $f_0(1500)$ and $f_J(1710)$ with J = 0 in the the S-wave.

The branching ratios of the $f_0(980)$, $f_0(1370)$, $f_0(1500)$ and $f_J(1710)$ to $\pi^+\pi^-$ and K^+K^- have been determined.

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.

Possibilities for a future study

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

ALICE/98-45
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A study of Double Pomeron Exchange in ALICE

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Abstract

The non-Abelian nature of QCD suggests that particles that have a gluon constituent, such as glueballs or hybrids, should exist. Experiments WA76, WA91 and WA102 have performed a dedicated search for these states in central production using the CERN Omega Spectrometer. New results from central production show that there is a kinematical filter which can select out glueball candidates from known $q\overline{q}$ states. A further study of this at high energies is essential in order to get information on the $M(X^0) > 2$ GeV region. This paper describes how this could be done using the the ALICE detector at the LHC.

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