Status report on experiment WA102 in 2000

A search for centrally produced non-$q\overline{q}$ mesons

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Outline

1. An introduction to the WA102 experiment
2. Status of data analysis
3. Future plans
4. Summary

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

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

$$M(2^{++}) \approx 2200 \text{ MeV}$$

How to look for glueballs

Look for Oddballs - states with J^{PC} not allowed for $q\overline{q}$

Look for extra states - states with J^{PC} of an already completed nonet

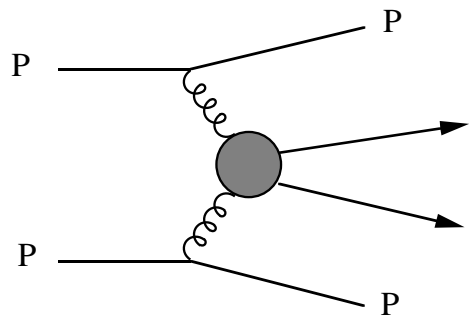
Look for states with unusual branching ratios

Look for states preferentially produced in gluon rich processes

Gluon rich processes

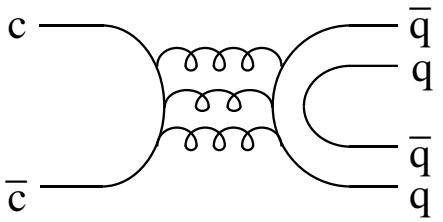
Double Pomeron Exchange

a)



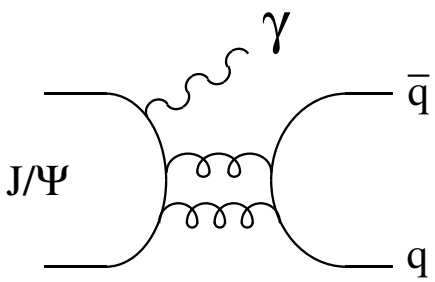
Hadronic J/ψ decay

b)



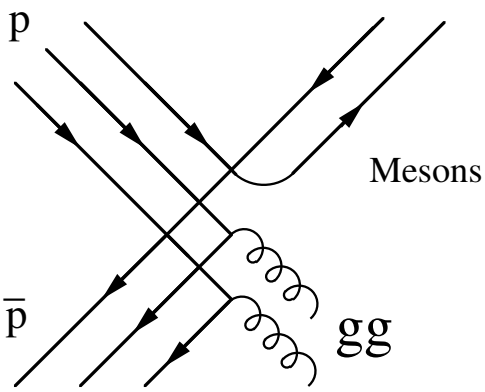
Radiative J/ψ decay

c)

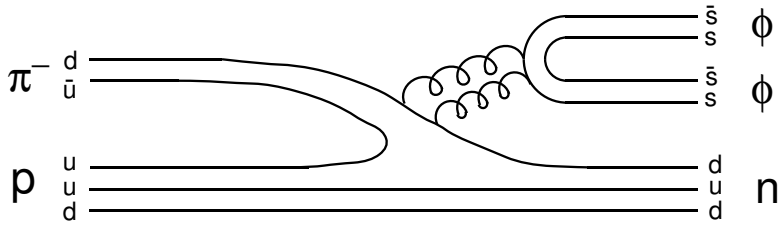


$p\bar{p}$

d)



e)



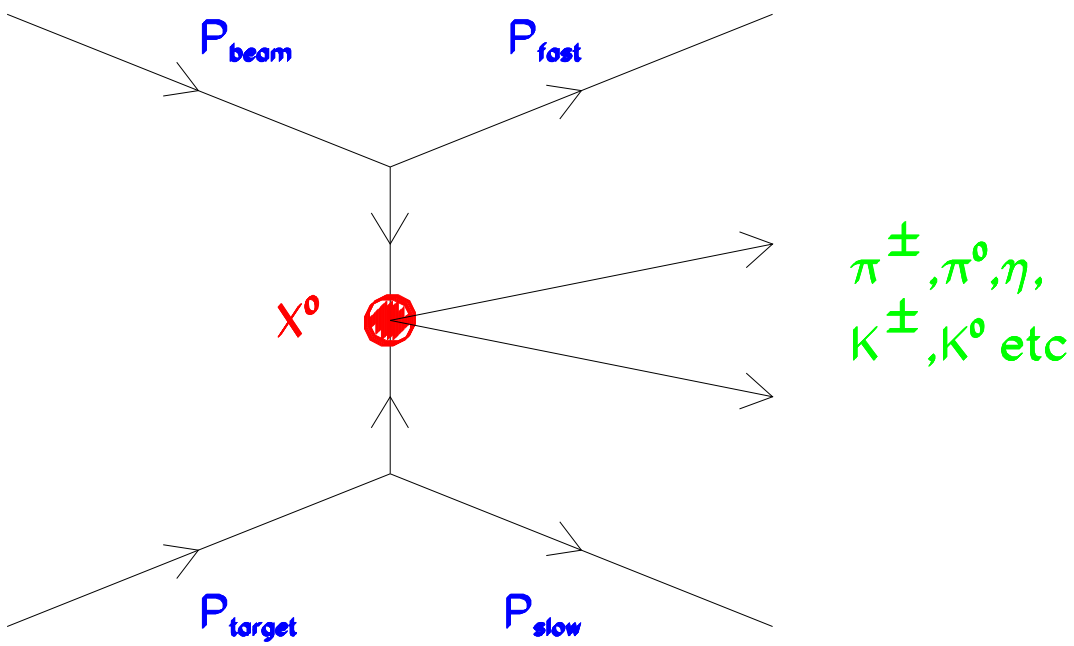
Reactions involving disconnected quark lines

Experiment WA102 has studied exclusive final states in the reaction

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

at 450 GeV/c

Centre of mass view



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

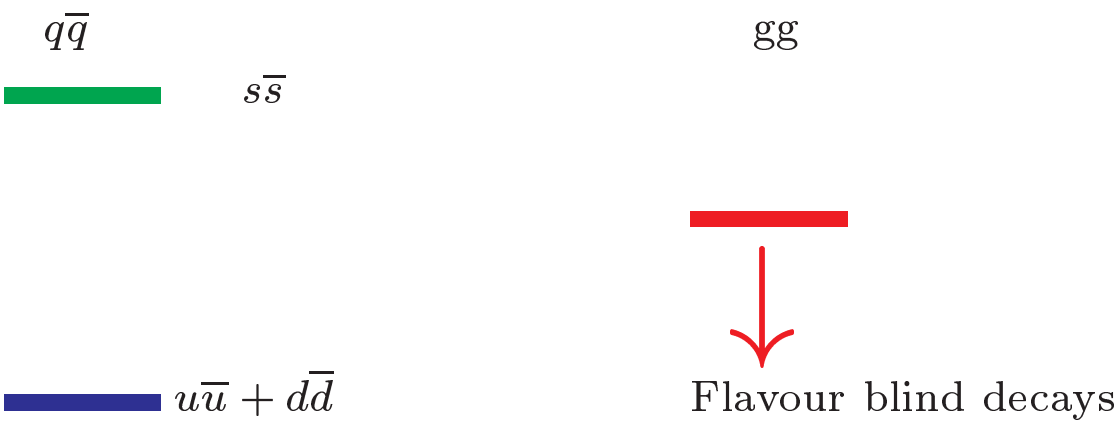
Data taking history

Year	Expt	Momentum GeV/c	$\sqrt{s}$ GeV	Particle I.D.	Triggers 10^6
1982	WA76	85	12.7	$\pi/K/p$	10
1986	WA76′	300	23.8	$\pi/K/p + \gamma$	12
1992	WA91	450	29	γ	40
1994	WA91	450	29	$\pi/K/p + \gamma$	40
1995	WA102	450	29	γ	200
1996	WA102	450	29	$\pi/K/p + \gamma$	300

Progress in the search for Glueballs and new results from WA102

Theoretical progress has been made on understanding how the bare $q\overline{q}$ states mix with glueballs to give the observed mesons

The original picture based on the underlying bare states



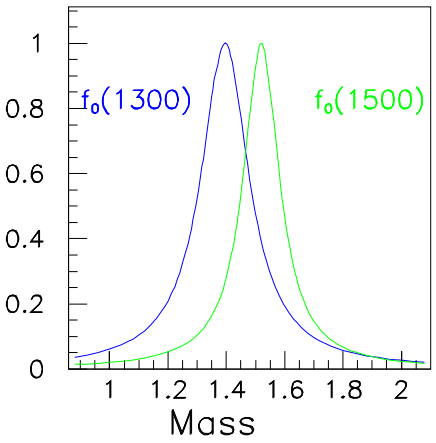
Glueballs with the same J^{PC} as nearby in mass $q\overline{q}$ states will mix

depending on the mass differences the observed states will be a mixture of $u\overline{u} + d\overline{d}$, $s\overline{s}$ and gg.

hence flavour blind decays are no longer expected BUT an excess of states is.

How many $J^{PC} = 0^{++}$ resonances are there ?

Interference between states of the same J^{PC}

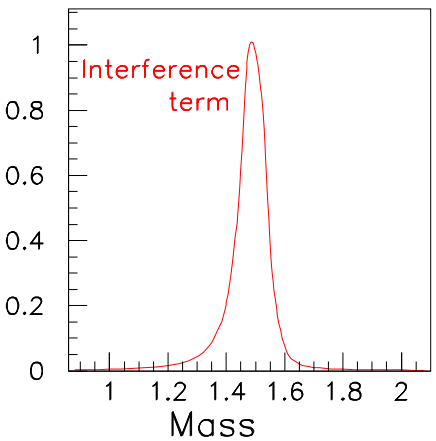


Same J^{PC} – therefore they can interfere

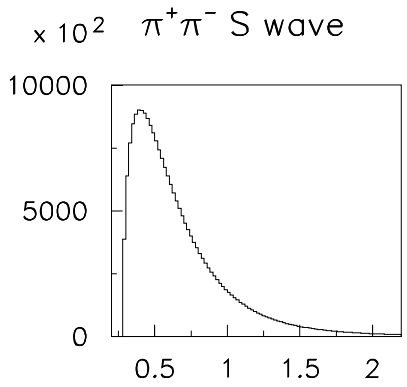
$$| f_0(1300) + A\, e^{i\varphi}\, f_0(1500)|^2$$

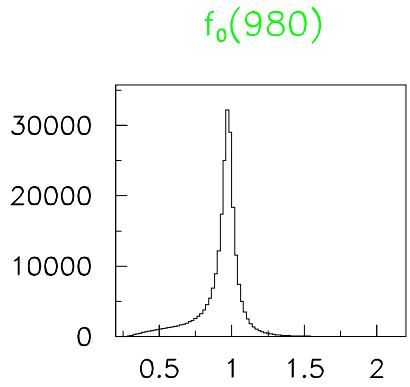
A and φ may depend on the production mechanims

For $A = 0.8$ and $\varphi = 180^0$

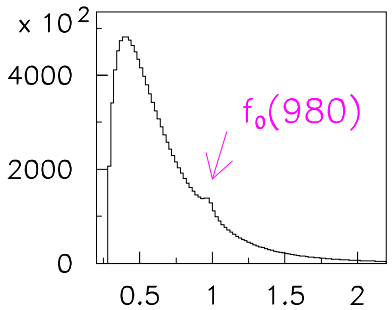


A known example of interference

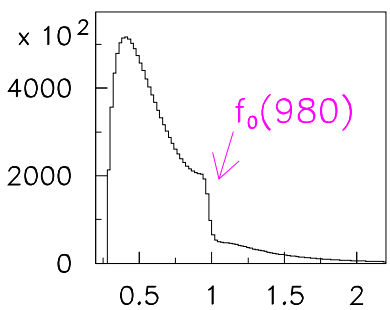




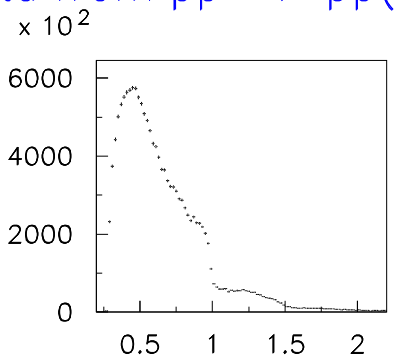
Incoherent sum



Coherent sum – 180° phase



Data from $pp \rightarrow pp(\pi^+\pi^-)$

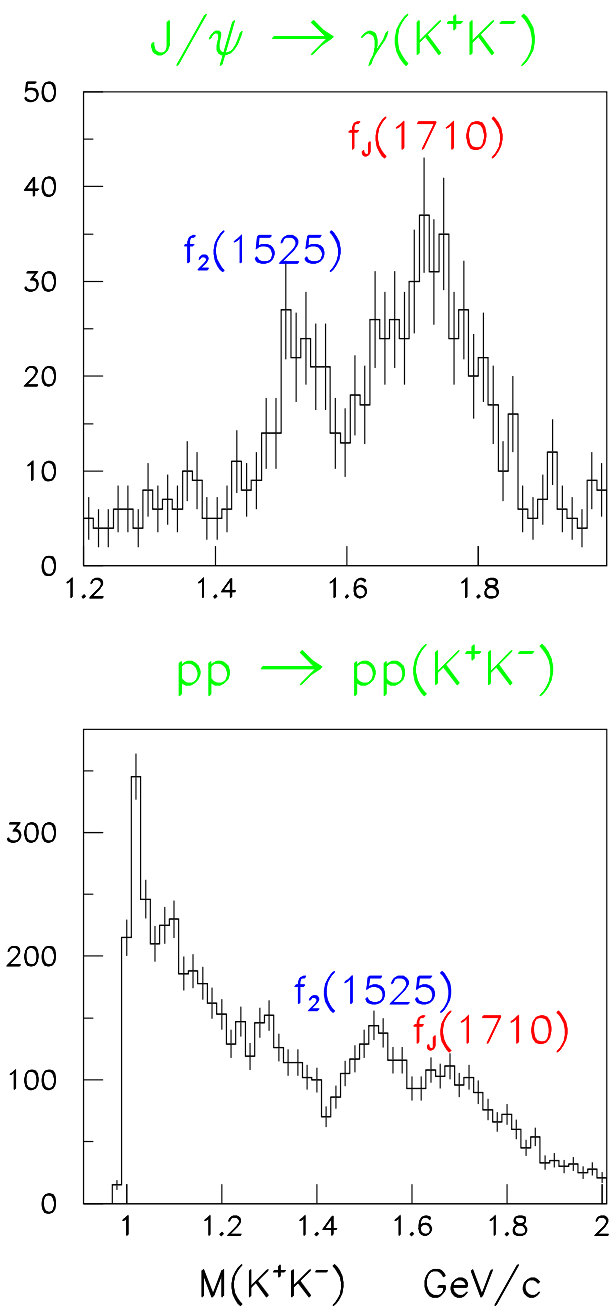


Mass $(\pi^+\pi^-)$ GeV

The resolved $J^{PC} = 0^{++}$ resonances

WA102 has played a crucial role in unravelling the
1.5 GeV region and has resolved the 1.7 GeV region

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 $pp \to pp(K\overline{K})$ 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 $f_J(1710)$.

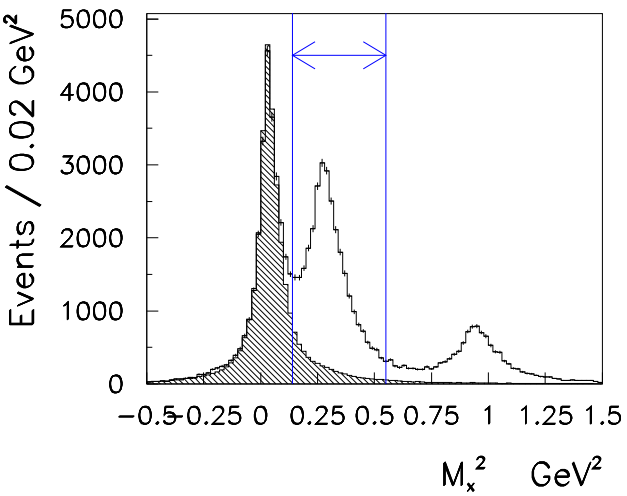
It is essential to know the spin of the $f_J(1710)$ because from rate in J/ψ decays if

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

J = 0 consistent with having a significant glueball component.

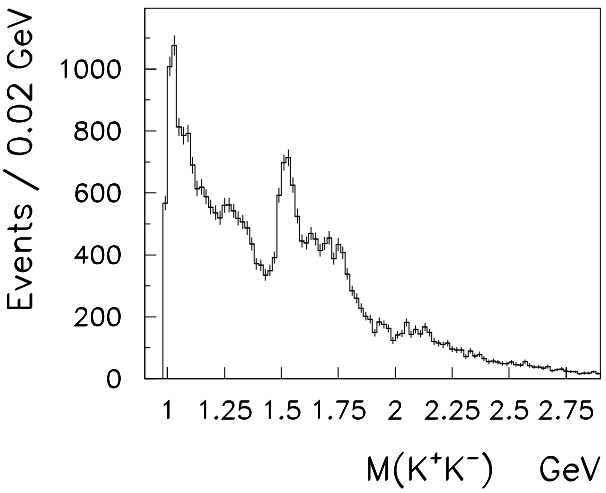
Selection of the reaction $pp \to p_f p_s(K^+K^-)$

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.

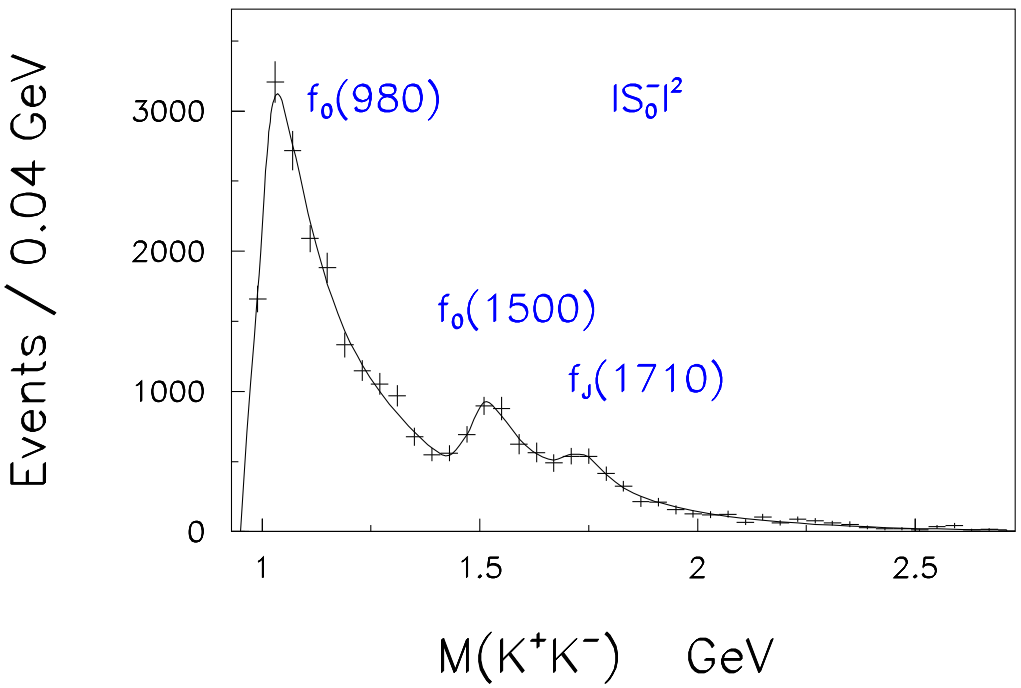
The K^+K^- mass spectrum



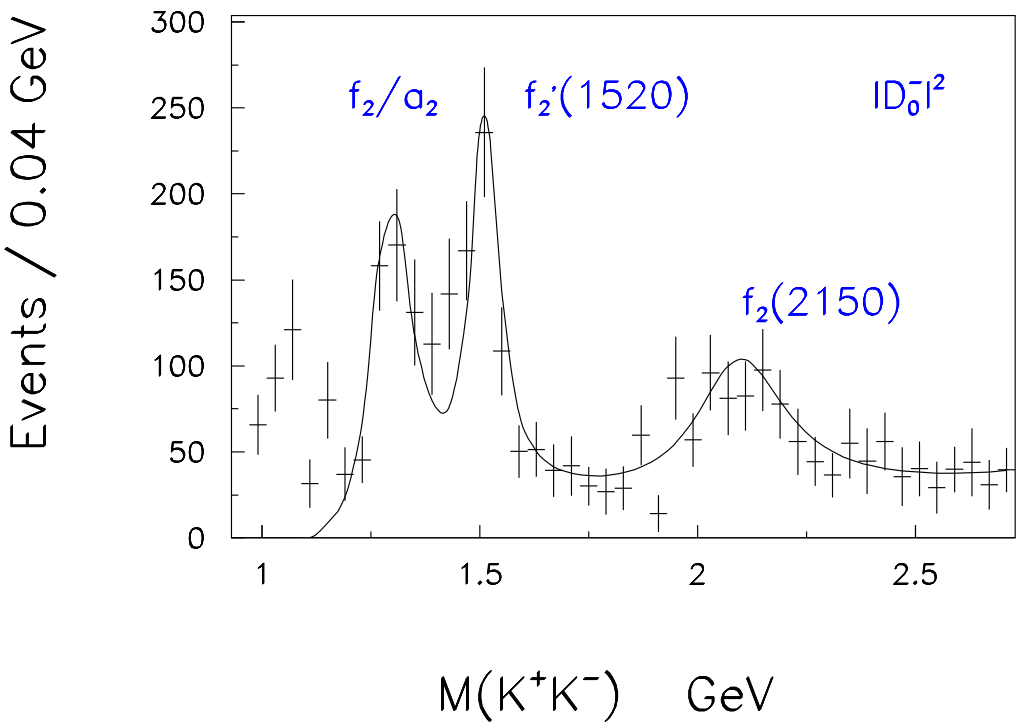
The spin of the $f_J(1710)$

D. Barberis et al.; Phys. Lett. B453 (1999) 305

The K^+K^- S-wave



The K^+K^- 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.

The established $J^{PC} = 0^{++}$ I = 0 states

$f_0(980)$ $f_0(1370)$ $f_0(1500)$ $f_0(1710)$

There are many scenarios of which state has the largest 'glue' content

The most important thing is that there is not a single scenario that can account for all these states without the existence of an underlying glueball state

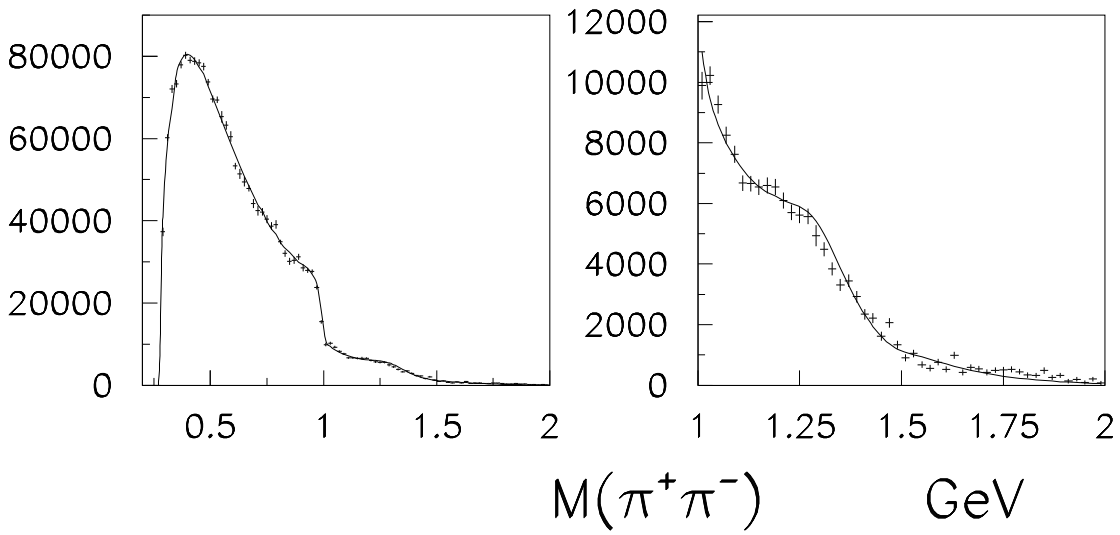
Therefore the scalar glueball has been found even if the bare states has not been observed

Its characteristics will be revealed when the decay branching ratios of the observed mesons have finally been determined

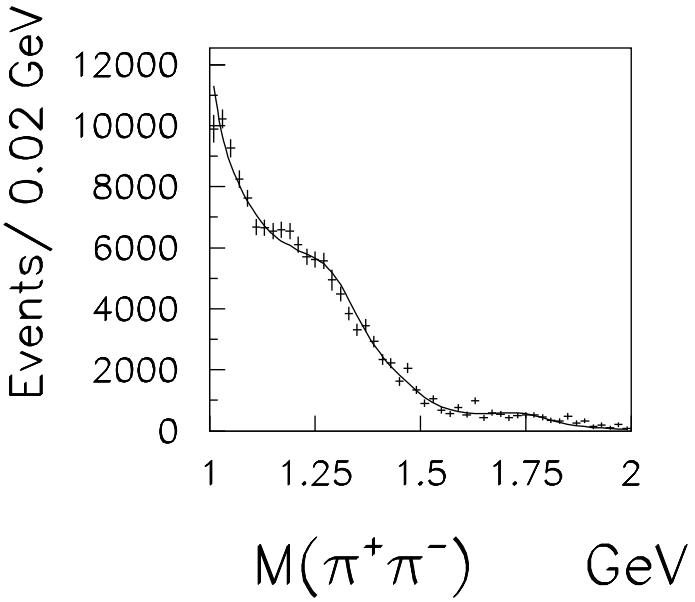
PWA of $pp \to p_f p_s(\pi^+\pi^-)$

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 $f_J(1710)$



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.

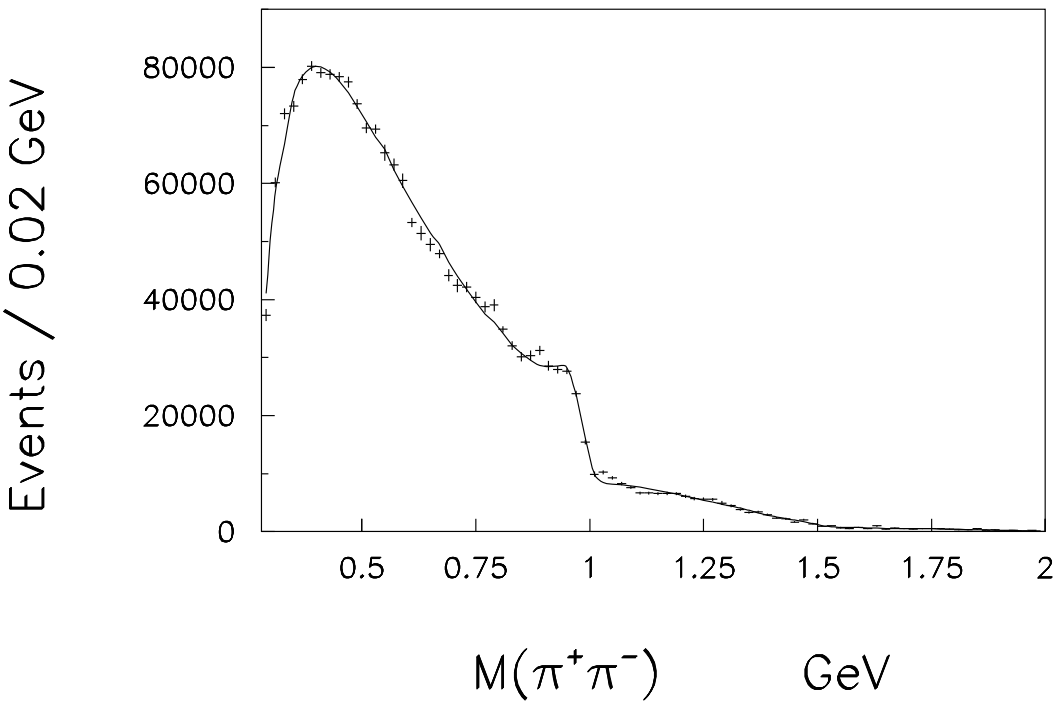
Three methods of fitting the data have been used

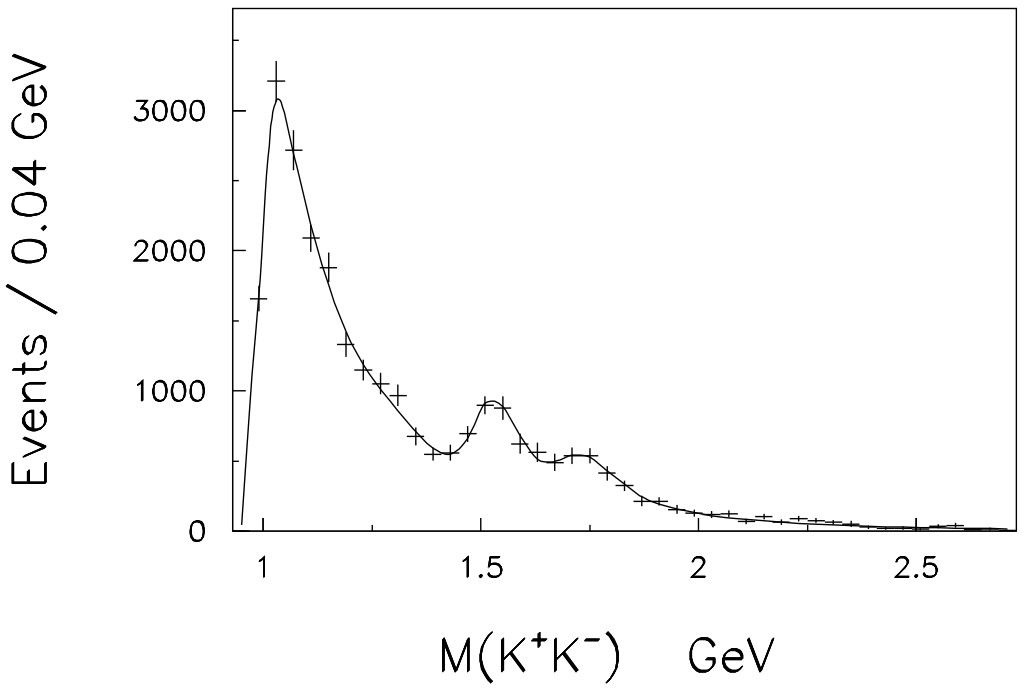
1. Interfering Breit-Wigners
2. T-Matrix analysis
3. K-Matrix analysis

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.

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





Pole positions

The pole positions are

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

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

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

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

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

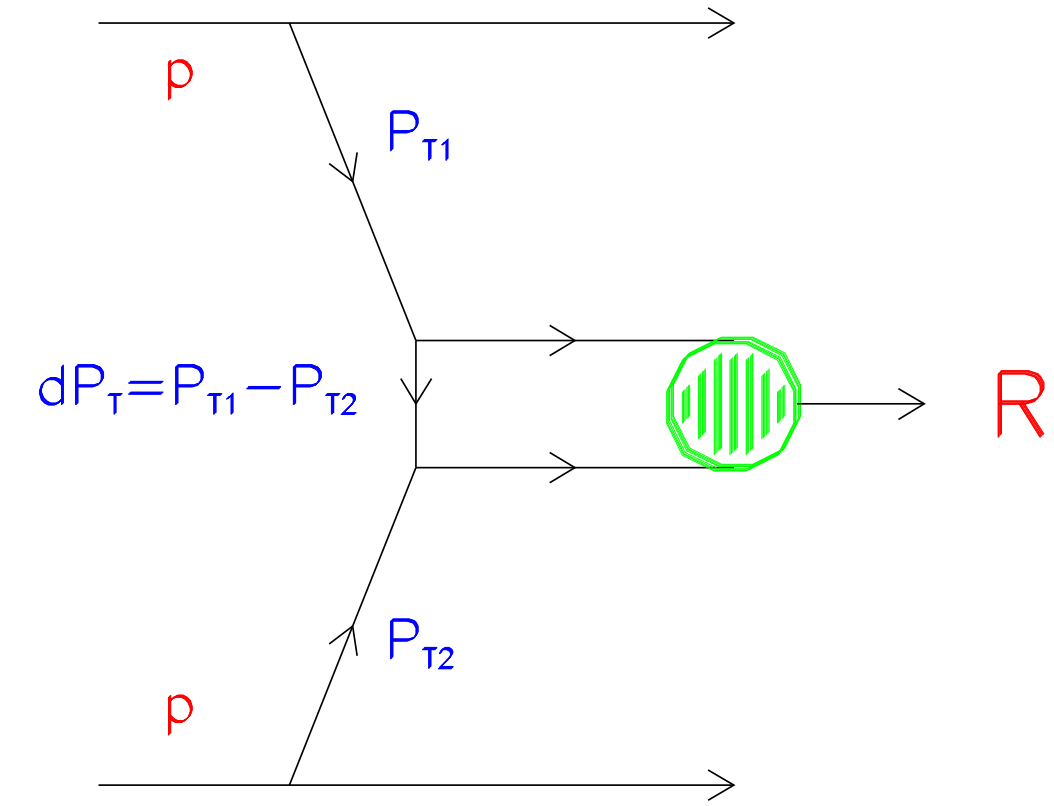
Work in progress to determine other branching ratios

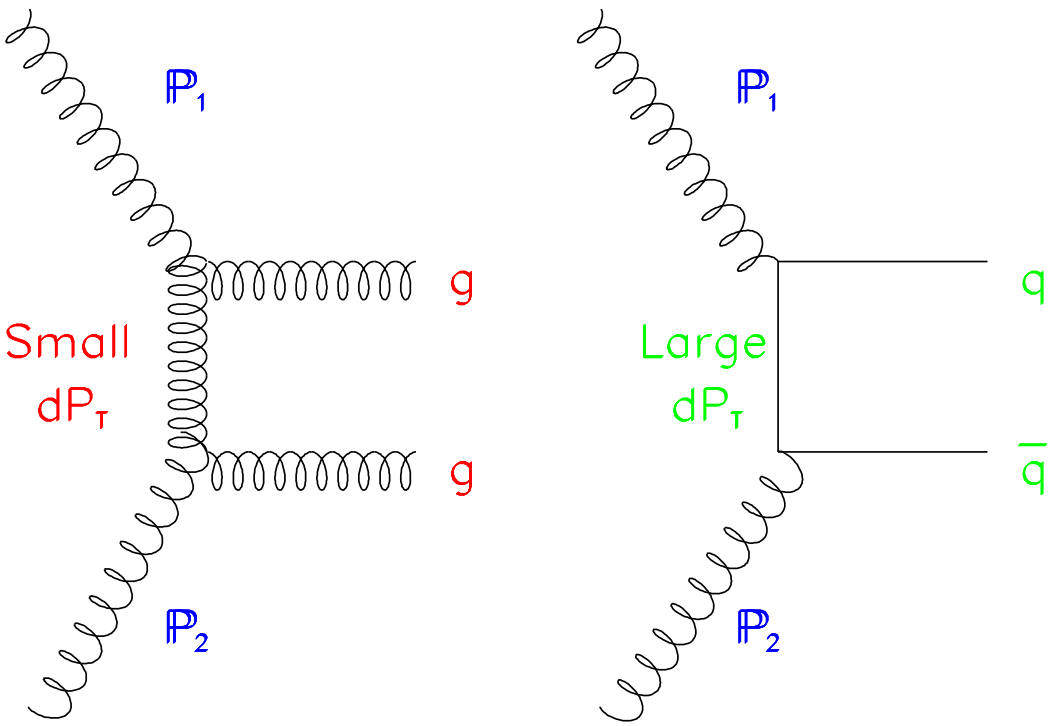
How many $J^{PC} = 2^{++}$ resonances are there ?

need to determine the number of unique states

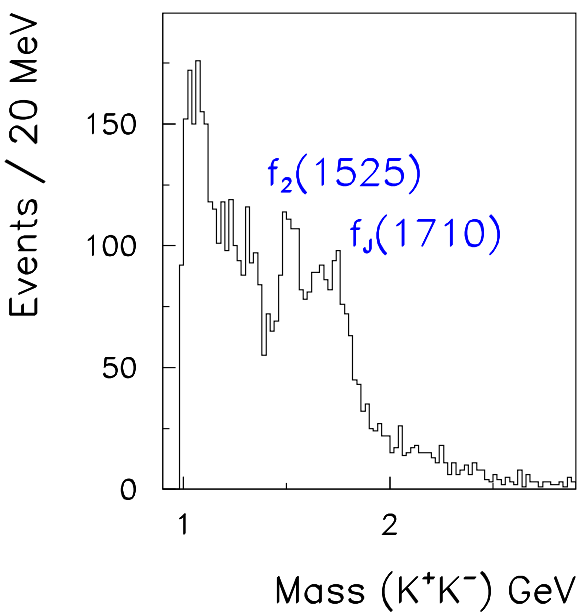
Work in progress

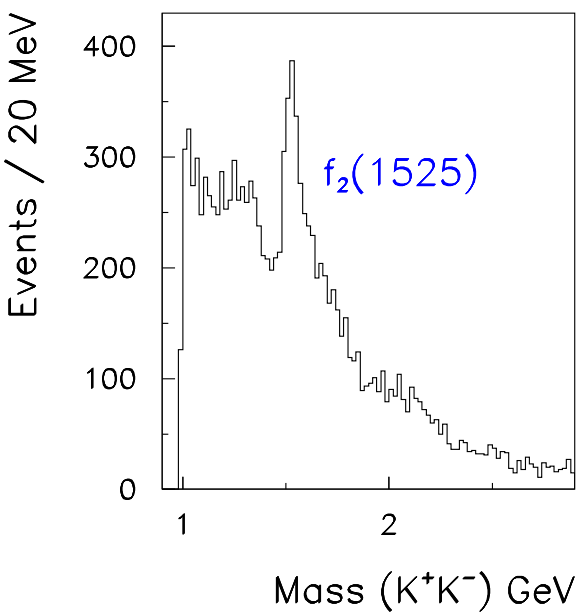
An update on the glueball-$q\bar{q}$ filter





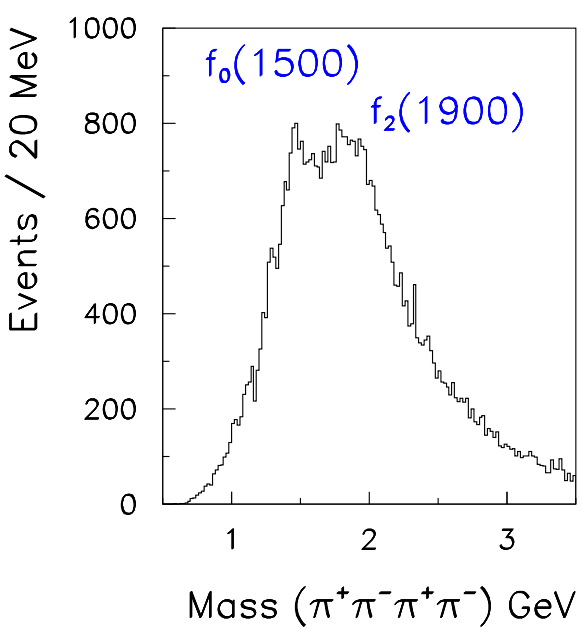
Examples of the glueball-$q\bar{q}$ filter

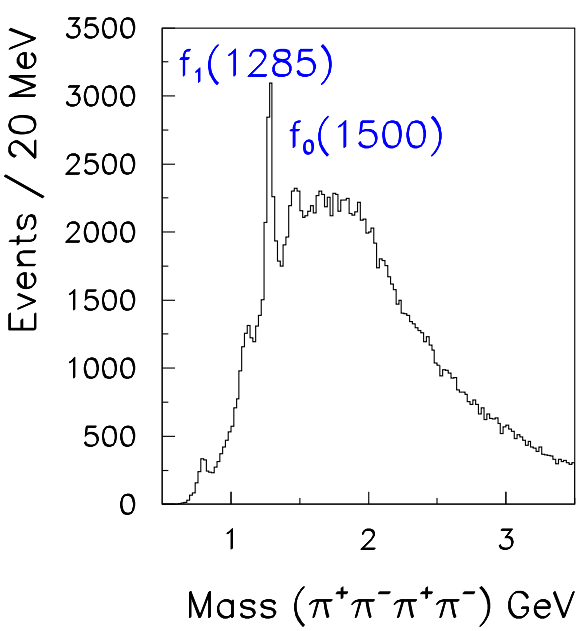




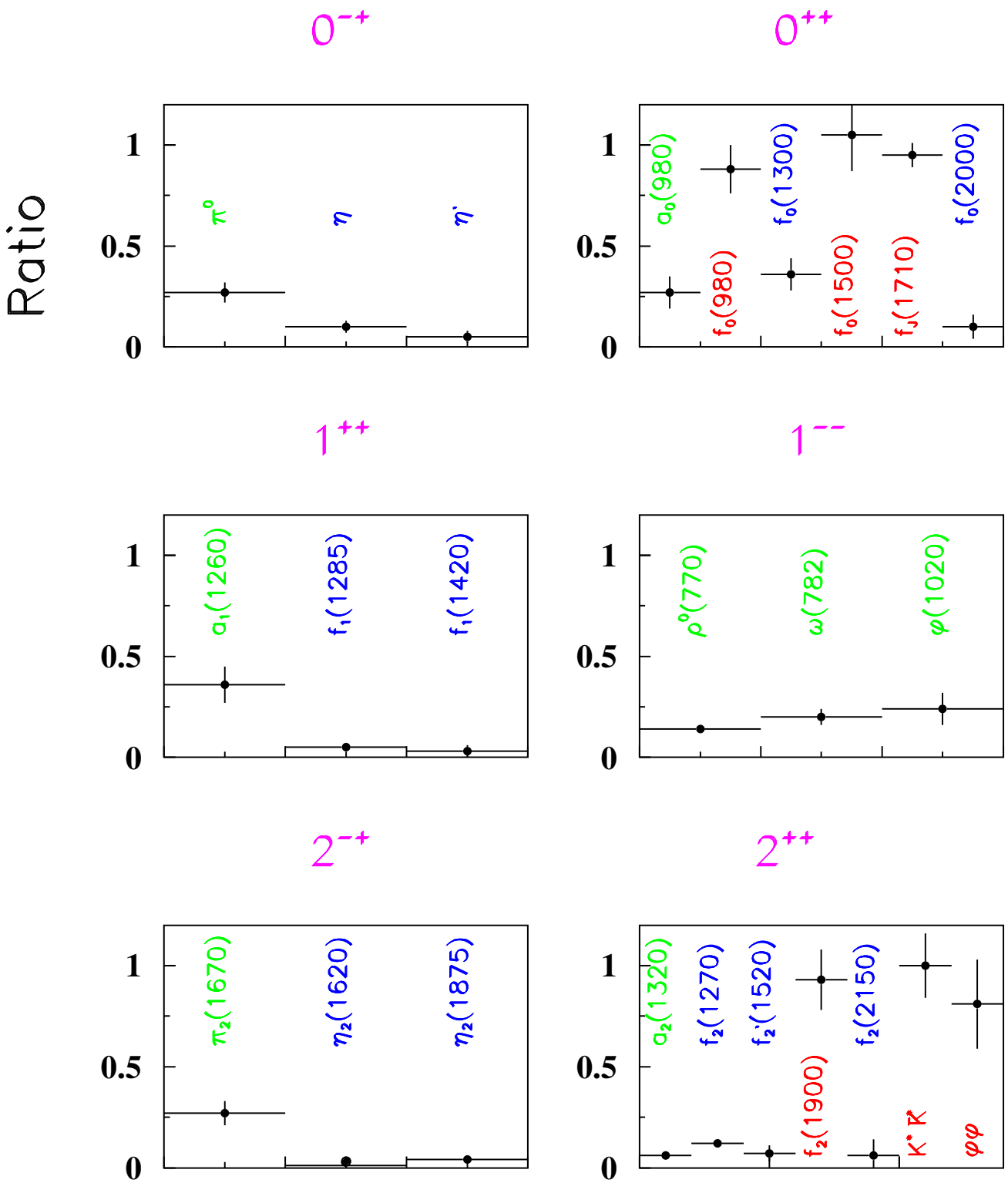
Small dP_T

Large dP_T

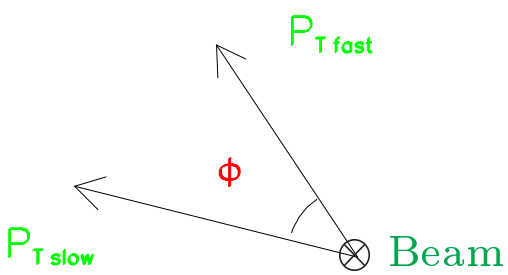




Ratio of number of events at small dP_T to large dP_T



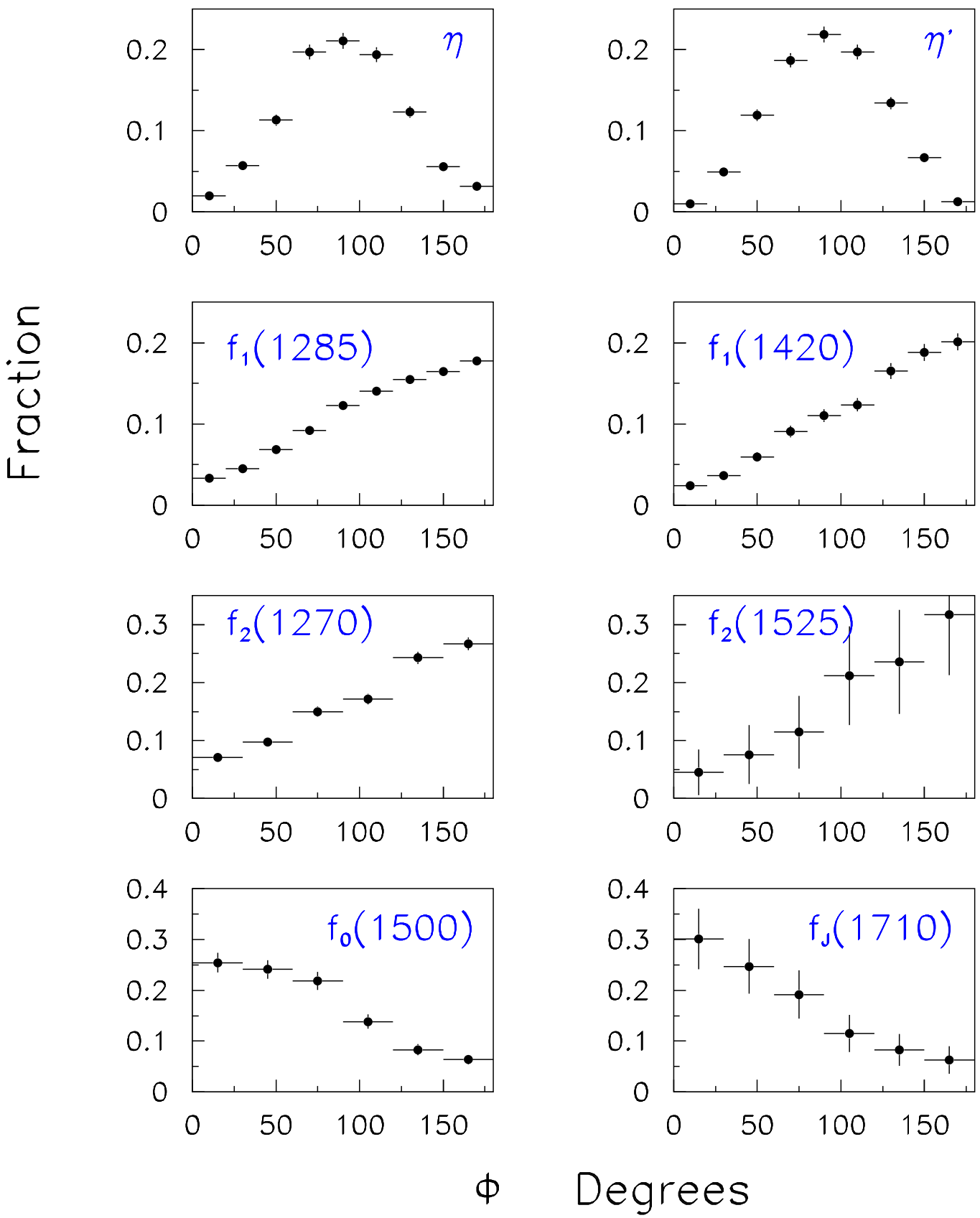
The azimuthal angle ϕ between the outgoing protons



If the Pomeron has spin zero would expect a flat ϕ distribution.

The observed ϕ distributions are NOT flat and are resonance dependent.

Resonance production as a function of ϕ



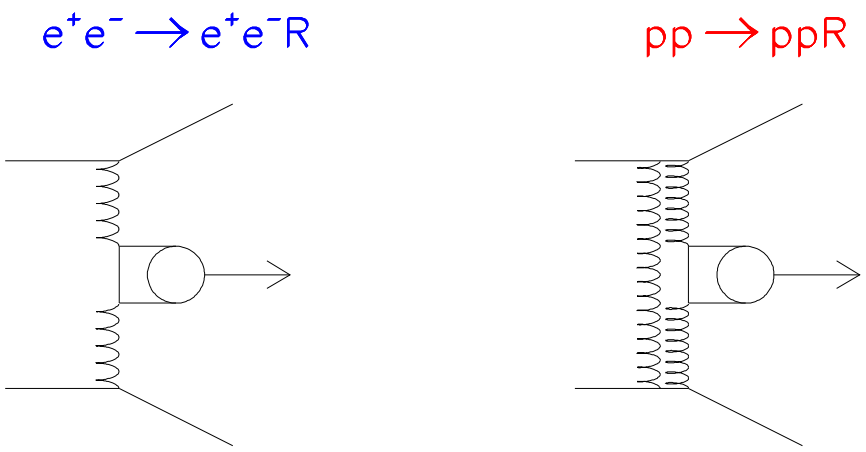
Progress on understanding these effects

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

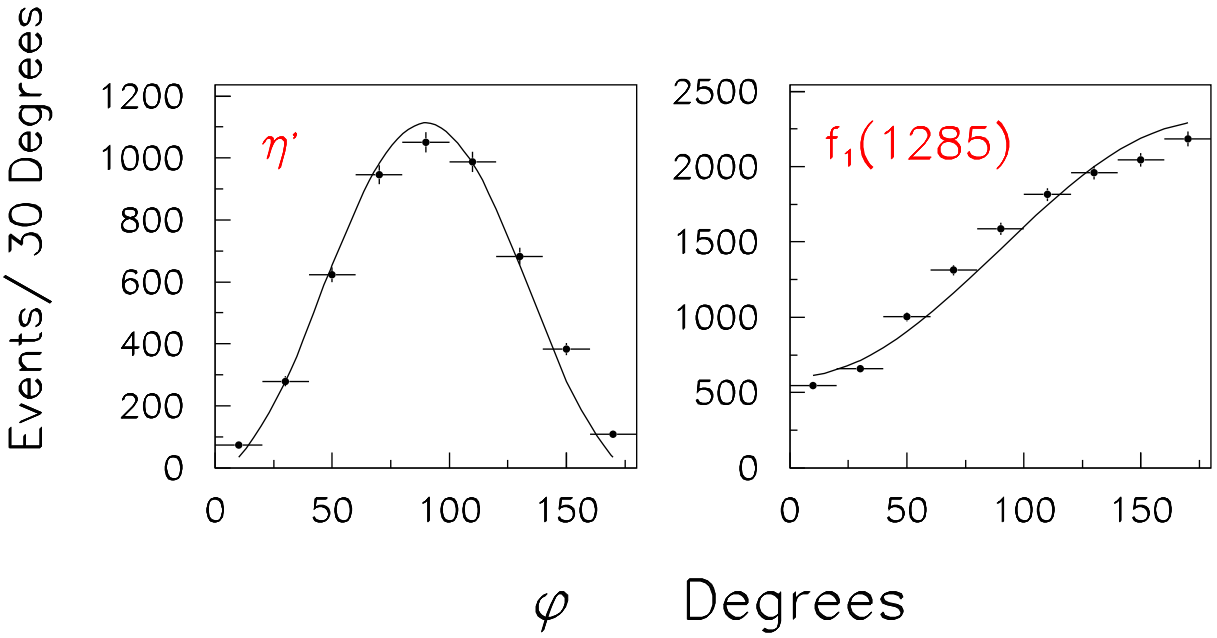
All agree that the exchanged particle (Pomeron) must have $J > 0$ and that $J = 1$ is the simplest explanation

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



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

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



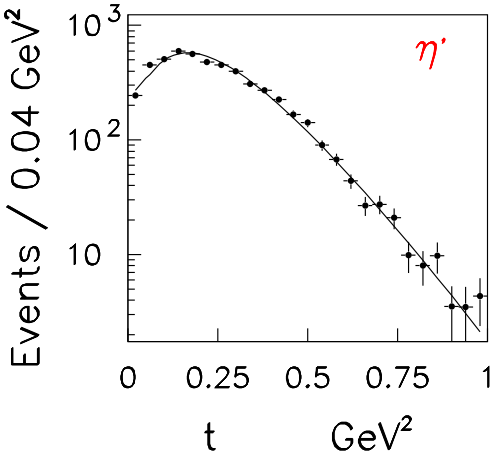
good agreement

Further predictions

Predict: 0^{-+}

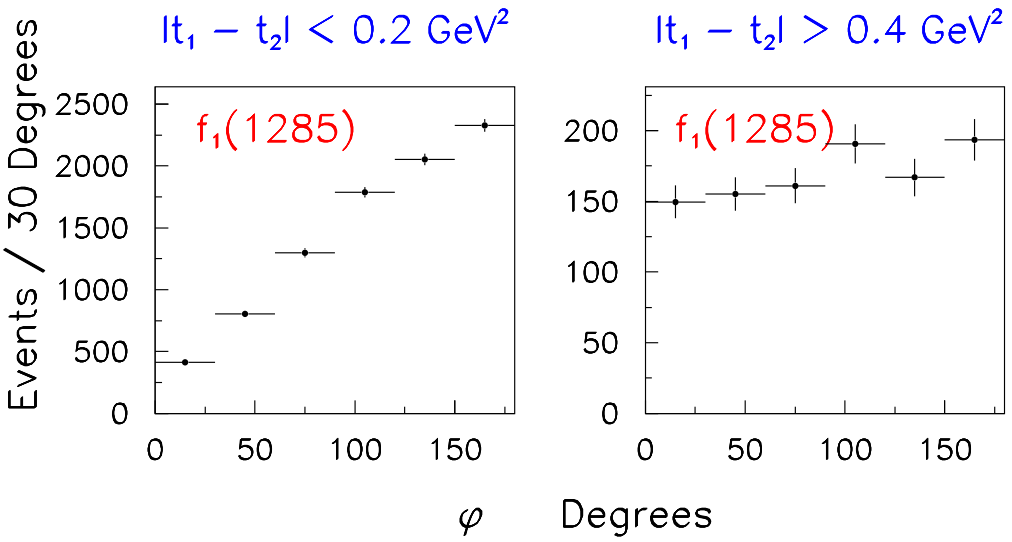
$d\sigma/dt_1 t_2 \propto t_1 t_2$

good agreement



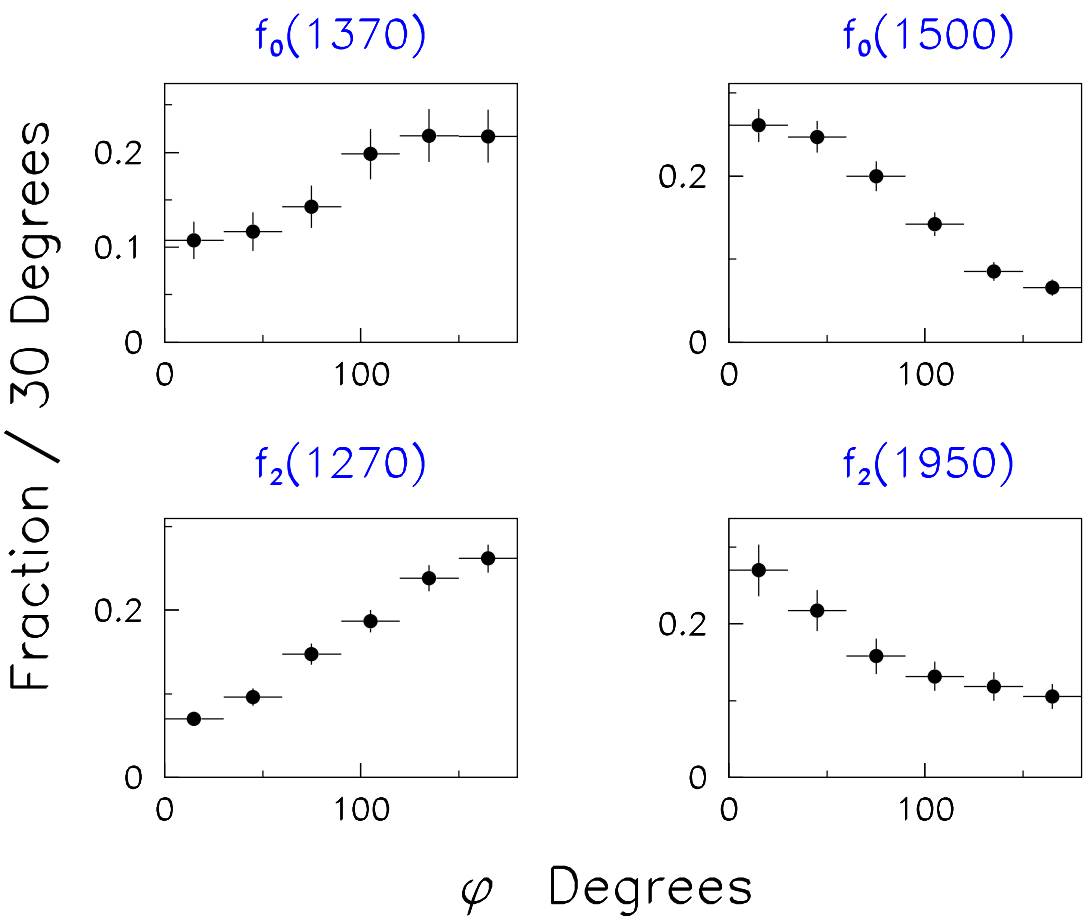
Predict: 1^{++} $J_Z = 1$ Dominant Observed

$d\sigma/dt_1 t_2 \propto \sqrt{t_1 t_2} sin^2(\phi/2) + (\sqrt{t_2} - \sqrt{t_1})^2$



All the effects are consistent with a vector like behaviour of Pomeron exchange

Not just a J dependent phenomenon



In addition to the properties of the Pomeron there may be some underlying effects due to the constituents of the mesons

Summary

The WA102 experiment has played a vital role in unravelling the properties of the scalar mesons

In particular the properties of the $f_0(1500)$ and $f_0(1710)$

We are now finalising the branching ratios of $f_0(980)$, $f_0(1370)$, $f_0(1500)$ and $f_J(1710)$ which should allow the glue content in each to be calculated

Work on the tensor sector is still continuing

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

There is also an interesting effect in the azimuthal angle of the two scattered protons which gives information on the nature of the Pomeron and which in turn may resolve the constituents of the produced mesons

Future plans and requests

The WA102 experiment has already published 20 Physics Letters. The Birmingham group has been responsible for the majority of these publications and for 12 talks at international conferences.

There are still several areas of analysis to be completed which will be completed by the end of 2000.

The request is for one more year's travel money at the same level as last year.