CENTRAL PRODUCTION OF MESONS USING THE CERN OMEGA SPECTROMETER AND THE GAMS 4000 ELECTROMAGNETIC CALORIMETER

WA91/WA102 Proposal 291

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Introduction

Experiments WA91/WA102 search for non-$q\overline{q}$ mesons produced in the central region in the reaction $pp \rightarrow p_f(X^0)p_s$ at 450 GeV/c using the CERN Omega Spectrometer and GAMS-4000. These experiments are a continuation of the WA76 and NA12/2 experiments which performed a dedicated search for non-$q\overline{q}$ mesons in centrally produced exclusive events.

One of the fundamental predictions of QCD is the existence of glueballs. Current theoretical predictions based on lattice gauge calculations indicate that the lowest lying scalar glueball should be in the mass range 1500-1700 MeV [1]. There is considerable interest in trying to isolate the lightest glueball. Several experiments have been performed using glue-rich production mechanisms. One such mechanism is Double Pomeron Exchange (DPE) where the Pomeron is thought to be a multi-gluonic object. Consequently it has been anticipated that production of glueballs may be especially favoured in this process [2].

The Omega central production experiments (WA76, WA91 and WA102) are designed to study exclusive final states formed in the reaction

$$pp \longrightarrow p_f X^0 p_s, \tag{1}$$

where the subscripts f and s refer to the fastest and slowest particles in the laboratory frame respectively and X^0 represents the central system. Such reactions are expected to be mediated by double exchange processes where both Pomeron and Reggeon exchange can occur.

The trigger was designed to enhance double exchange processes with respect to single exchange and elastic processes. Details of the trigger conditions, the data processing and event selection have been given in previous publications [3].

The search for glueballs

Originally glueball decays were predicted to be flavour blind, that is their decay branching ratios would be independent of the quark composition of the final state mesons after taking into account phase space effects. However, following the work of Amsler and Close [4], it would seem that if the mass of the glueball is such that it lies in the middle of a $q\overline{q}$ nonet with the same J^{PC} there may be substantial mixing between the glueball and the $q\overline{q}$ states which would destroy the flavour blind decay pattern. The $f_0(1500)$ and the $f_J(1710)$ display clear glueball characteristics in that they are both produced in glue-rich production mechanisms and are either not seen, or are heavily suppressed in normal hadronic interactions. In addition, the $f_J(1710)$ is observed to decay dominantly to $K\overline{K}$ and yet it is not produced in K^-p interactions [5]. However, the spin of the $f_J(1710)$ is still uncertain with J = 0 or 2 being possible.

It is essential to know the spin of the $f_J(1710)$ because measurements of its production rate in J/ψ decays indicates that if it has spin two then it would be consistent with being a normal $q\overline{q}$ meson whereas if it has spin zero it would be consistent with having a significant glueball component [6].

A partial wave analysis of the K^+K^- system

The WA102 experiment has published [7] the results from a a study of the K^+K^- and $K^0_SK^0_S$ final states formed in the reaction

$$pp \rightarrow p_f(K\overline{K})p_s \tag{2}$$

at 450 GeV/c. A Partial Wave Analysis (PWA) of the centrally produced K^+K^- system has been performed, using the reflectivity basis [8], in 40 MeV intervals of the K^+K^- mass spectrum using an event-by-event maximum likelihood method [7]. The S_0^- and D_0^--Waves from the physical solution are shown in fig. 1.

The S_0^--wave shows a threshold enhancement; the peaks at 1.5 GeV and 1.7 GeV are interpreted as being due to the $f_0(1500)$ and $f_J(1710)$ with J = 0. A fit has been performed to the S_0^- wave using three interfering Breit-Wigners to describe the $f_0(980)$, $f_0(1500)$ and $f_J(1710)$ and a background of the form $a(m-m_{th})^b exp(-cm-dm^2)$, where m is the K^+K^- mass, m_{th} is the K^+K^- threshold mass and a, b, c, d are fit parameters. The resulting fit is shown in fig. 1 and gives for the $f_0(980)$ M = 985 $\pm$ 10 MeV, Γ = 65 $\pm$ 20 MeV, for the $f_0(1500)$ M = 1497 $\pm$ 10 MeV, Γ = 104 $\pm$ 25 MeV and for the $f_0(1710)$ M = 1730 $\pm$ 15 MeV, Γ = 100 $\pm$ 25 MeV parameters which are consistent with the PDG [9] values for these resonances.

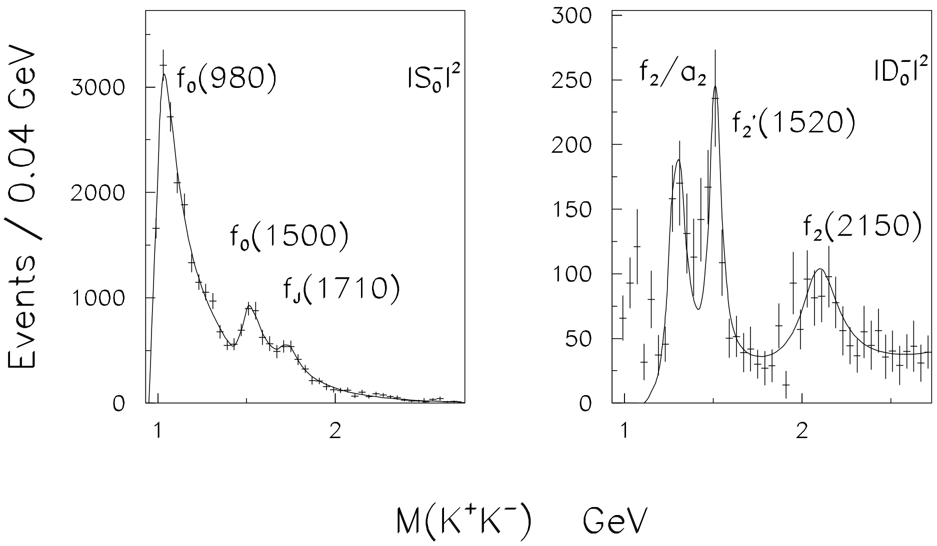

Figure 1: The S_0^- and D_0^--Waves resulting from a partial wave analysis of the K^+K^- system.

The D_0^--wave shows peaks in the 1.3 and 1.5 GeV regions, presumably due to the $f_2(1270)/a_2(1320)$ and $f_2'(1525)$ and a wide structure above 2 GeV. There is no evidence for any significant structure in the D-wave in the region of the $f_J(1710)$. In addition, there are no statistically significant structures in any of the other waves. A fit has been performed to the D_0^- wave above 1.2 GeV using three incoherent relativistic spin 2 Breit-Wigners to describe the $f_2(1270)/a_2(1320)$, $f_2'(1525)$ and the peak at 2.2 GeV and a background of the form described above. The resulting fit is shown in fig. 1 and gives for the $f_2(1270)/a_2(1320)$ M = 1305 $\pm$ 20 MeV, Γ = 132 $\pm$ 25 MeV, for the $f_2'(1525)$ M = 1515 $\pm$ 15 MeV, Γ = 70 $\pm$ 25 MeV and for the $f_2(2150)$ M = 2130 $\pm$ 35 MeV, Γ = 270 $\pm$ 50 MeV.

A partial wave analysis of the $\pi\pi$ system

The isolation of the reaction

$$pp \to p_f(\pi^+\pi^-)p_s \tag{3}$$

has been described in detail in a previous publication [10]. The resulting centrally produced $\pi^+\pi^-$ system consists of 2.87 million events. A PWA of the centrally produced $\pi^+\pi^-$ system has been performed, using the reflectivity basis [8], in 20 MeV intervals of the $\pi^+\pi^-$ mass spectrum using an event-by-event maximum likelihood method [10]. The S_0^--wave from the physical solution is shown in fig. 2. and shows a clear threshold enhancement followed by a sharp drop at 1 GeV.

In order to obtain a satisfactory fit to the S_0^- wave from threshold to 2 GeV it has been found to be necessary to use three interfering Breit-Wigners to de-

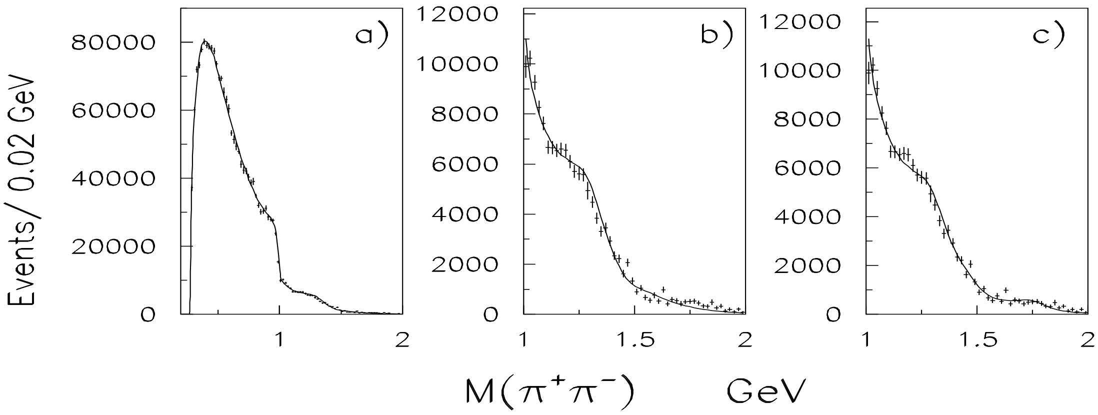

Figure 2: a), b), c) The S_0^- wave resulting from a partial wave analysis of the $\pi^+\pi^-$ system.

scribe the $f_0(980)$, $f_0(1300)$ and $f_0(1500)$ and a background of the form $a(m - m_{th})^b exp(-cm - dm^2)$, where m is the $\pi^+\pi^-$ mass, m_{th} is the $\pi^+\pi^-$ threshold mass and a, b, c, d are fit parameters. The fit is shown in fig. 2a) for the entire mass range and in fig. 2b) for masses above 1 GeV. The resulting parameters are for the $f_0(980)$ M = 982 ± 3 MeV, Γ = 80 ± 10 MeV, for the $f_0(1300)$ M = 1308 ± 10 MeV, Γ = 222 ± 20 MeV and for the $f_0(1500)$ M = 1502 ± 10 MeV, Γ = 131 ± 15 MeV which are consistent with the PDG [9] values for these resonances. As can be seen, the fit describes the data well for masses below 1 GeV. It was not possible to describe the data above 1 GeV without the addition of both the $f_0(1300)$ and $f_0(1500)$ resonances. However, even with this fit using three Breit-Wigners it can be seen that the fit does not describe well the 1.7 GeV region. This could be due to a $\pi^+\pi^-$ decay mode of the $f_J(1710)$ with J = 0. Including a fourth Breit-Wigner in this mass region decreases the χ^2 from 256 to 203 and yields for the $f_J(1710)$ M = 1750 ± 20 MeV and Γ = 160 ± 30 MeV parameters which are consistent with the PDG [9] values for the $f_J(1710)$. The fit is shown in fig. 2c) for masses above 1 GeV.

A coupled channel analysis of the $K\overline{K}$ and $\pi\pi$ systems

In order to determine the relative glue content in the $f_0(1500)$ and $f_J(1710)$ a measurement of their decay branching ratios is required. A coupled channel fit has been performed to the K^+K^- and $\pi^+\pi^-$ S-wave distributions. The branching ratios for the $f_0(1370)$, $f_0(1500)$ and $f_J(1710)$ have been calculated to be:

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

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

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

these values are to be compared with the PDG [9] values of 1.35 $\pm$ 0.68 for the $f_0(1370)$, 0.19 $\pm$ 0.07 for the $f_0(1500)$, which comes from the Crystal Barrel experiment [11], and 2.56 $\pm$ 0.9 for the $f_J(1710)$ which comes from the WA76 experiment [12].

A Glueball-$q\overline{q}$ filter in central production ?

The WA102 experiment studies mesons produced in double exchange processes. However, even in the case of pure DPE the exchanged particles still have to couple to a final state meson. The coupling of the two exchanged particles can either be by gluon exchange or quark exchange. Assuming the Pomeron is a colour singlet gluonic system if a gluon is exchanged then a gluonic state is produced, whereas if a quark is exchanged then a $q\overline{q}$ state is produced [13]. In order to describe the data in terms of a physical model, Close and Kirk [13], have proposed that the data be analysed in terms of the difference in transverse momentum (dP_T) between the particles exchanged from the fast and slow vertices. The idea being that for small differences in transverse momentum between the two exchanged particles an enhancement in the production of glueballs relative to $q\overline{q}$ states may occur.

The ratio of the number of events for $dP_T < 0.2$ GeV to the number of events for $dP_T > 0.5$ GeV for each resonance considered has been calculated [14]. It has been observed that all the undisputed $q\overline{q}$ states which can be produced in DPE, namely those with positive G parity and $I = 0$, have a very small value for this ratio (≤ 0.1). Some of the states with $I = 1$ or G parity negative, which can not be produced by DPE, have a slightly higher value (≈ 0.25). However, all of these states are suppressed relative to the the glueball candidates the $f_0(1500)$, $f_J(1710)$, and $f_2(1930)$, together with the enigmatic $f_0(980)$, which have a large value for this ratio [14].

The azimuthal angle between the outgoing protons

The azimuthal angle ϕ is defined as the angle between the p_T vectors of the two protons. Naively it may be expected that this angle would be flat irrespective of the resonances produced. Fig. 3 shows the ϕ dependence for two resonances with $J^{PC} = 0^{-+}$ (the η and η'), two with $J^{PC} = 1^{++}$ (the $f_1(1285)$ and $f_1(1420)$), two with $J^{PC} = 2^{++}$ (the $f_2(1270)$ and $f_2'(1525)$) and two with $J^{PC} = 0^{++}$ (the $f_0(1500)$ and $f_J(1710)$). The ϕ dependence is clearly not flat and considerable variation is observed between resonances with different J^{PC}s.

Several theoretical papers have been published on these effects [15, 16]. All agree that the exchanged particle (Pomeron) must have J $>$ 0 and that J $=$ 1 is the

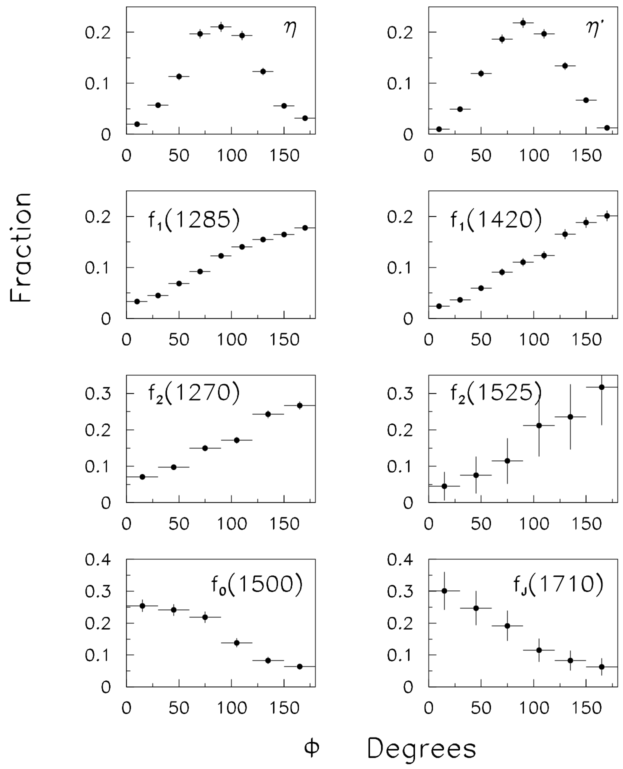

Figure 3: The azimuthal angle between the fast and slow protons ϕ for various resonances.

simplest explanation. Using $\gamma^*\gamma^*$ collisions as an analogy Close and Schuler[16] have calculated the ϕ dependencies for the production of resonances with different J^{PC}s. They have found that for a $J^{PC} = 0^{-+}$ state

$$\frac{d^3\sigma}{d\phi dt_1 dt_2} \propto t_1 t_2 sin^2\phi \tag{4}$$

as can be seen from fig. 3 the ϕ distributions are proportional to $sin^2\phi$ and it has been found experimentally that $d\sigma/dt$ is proportional to t [17]. For the $J^{PC} = 1^{++}$ states this model predicts that $J_Z = \pm 1$ should dominate, which has been found to be correct [18], and

$$\frac{d^3\sigma}{d\phi dt_1 dt_2} \propto (\sqrt{t_2} - \sqrt{t_1})^2 + \sqrt{t_1 t_2} sin^2\phi/2 \tag{5}$$

As can be seen from fig. 3 the ϕ distributions are proportional to $\alpha + \beta sin^2\phi/2$. In addition equation(5) would predict that when $|t_2 - t_1|$ is small $d\sigma/d\phi$ should be proportional to $sin^2\phi/2$ while when $|t_2 - t_1|$ is large $d\sigma/d\phi$ should be constant. As shown in fig. 4 this trend is observed in the data. The aim now is to study the ϕ dependences of other known $q\overline{q}$ states in order to understand more about the nature of the Pomeron and then to use this information as a probe for non-$q\overline{q}$ states.

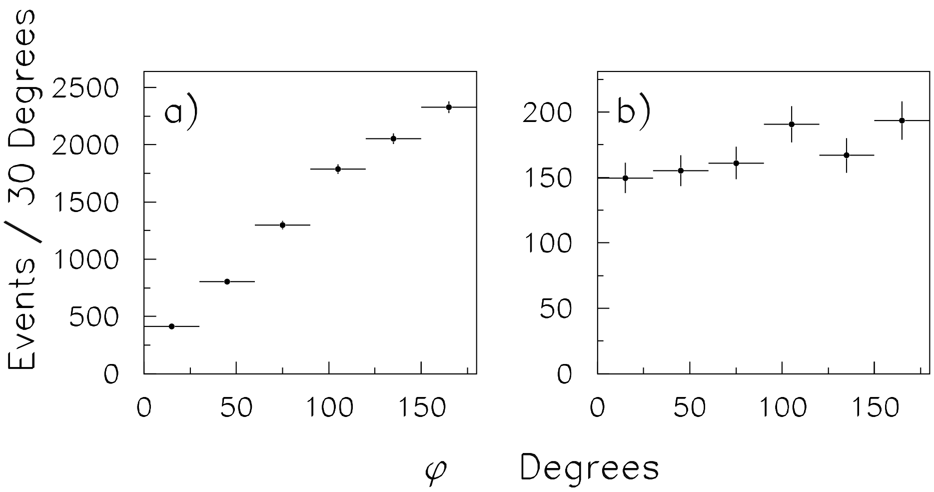

Figure 4: The azimuthal angle between the fast and slow protons ϕ for the $f_1(1285)$ for a) $|t_1 - t_2| \leq 0.2$ and b) $|t_1 - t_2| \geq 0.4$

Future analysis plans

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 finalised and these will be completed by the end of 2000. The request is for one more years travel money at the same level as last year.

Summary

In conclusion, a partial wave analysis of the centrally produced K^+K^- and $\pi^+\pi^-$ systems has been performed. The striking feature is the observation of the $f_J(1710)$ with J = 0 in the S_0^--wave.

A study of centrally produced pp interactions show that there is the possibility of a glueball-$q\overline{q}$ filter mechanism (dP_T). All the undisputed $q\overline{q}$ states are observed to be suppressed at small dP_T, but the glueball candidates $f_0(1500)$, $f_J(1710)$, and $f_2(1930)$, together with the enigmatic $f_0(980)$, survive. In addition, the production cross section for different resonances depends strongly on the azimuthal angle between the two outgoing protons which may give information on the nature of the Pomeron.

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Publications since January 1998

The Birmingham Group has had a major involvement in all these publications

1. 'A study of the centrally produced $\pi^+\pi^-\pi^0$ channel in pp interactions at 450 GeV/c'
   D. Barberis *et al.,* (61 authors)
   Phys. Lett. **B422** (1998) 399-404.

2. 'A study of pseudoscalar states produced centrally in pp interactions at 450 GeV/c'
   D. Barberis *et al.,* (60 authors)
   Phys. Lett. **B427** (1998) 398-402.

3. 'A study of the centrally produced $\phi\phi$ system in pp interactions at 450 GeV/c'
   D. Barberis *et al.,* (61 authors)
   Phys. Lett. **B432** (1998) 436-442.

4. 'A study of the centrally produced $K^*(892)\overline{K}^*(892)$ and $\phi\omega$ systems in pp interactions at 450 GeV/c'
   D. Barberis *et al.,* (58 authors)
   Phys. Lett. **B436** (1998) 204-210.

5. 'A measurement of the branching fractions of the $f_1(1285)$ and $f_1(1420)$ produced in central pp interactions at 450 GeV/c'
   D. Barberis *et al.,* (58 authors)
   Phys. Lett. **B440** (1998) 225-232.

6. 'A study of the centrally produced baryon-antibaryon systems in pp interactions at 450 GeV/c'
   D. Barberis *et al.,* (58 authors)
   Phys. Lett. **B446** (1999) 342-348.

7. 'A partial wave analysis of the centrally produced K^+K^- and $K^0_SK^0_S$ systems in pp interactions at 450 GeV/c and new information on the spin of the $f_J(1710)$'
   D. Barberis *et al.,* (58 authors)
   Phys. Lett. **B453** (1999) 305-315.

8. 'A partial wave analysis of the centrally produced $\pi^+\pi^-$ system in pp interactions at 450 GeV/c'
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10. ‘A search for non-$q\overline{q}$ mesons at the CERN Omega Spectrometer’
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11. ‘A partial wave analysis of the centrally produced K^+K^- system in pp interactions at 300 GeV/c’
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12. ‘A coupled channel analysis of the centrally produced K^+K^- and $\pi^+\pi^-$ final states in pp interactions at 450 GeV/c’
    D. Barberis *et al.,* (34 authors)
    Phys. Lett. **B462** (1999) 462-470.

13. ‘Experimental evidence for a vector like behaviour of Pomeron exchange’
    D. Barberis *et al.,* (34 authors)
    Phys. Lett. **B467** (1999) 165-170.

14. ‘A study of the $\eta\pi^+\pi^-$ channel produced in central pp interactions at 450 GeV/c’
    D. Barberis *et al.,* (34 authors)
    To be published in Phys. Lett.
    hep-ex/9911038.

15. ‘A study of the $\eta\eta'$ and $\eta'\eta'$ channels produced in central pp interactions at 450 GeV/c’
    D. Barberis *et al.,* (34 authors)
    To be published in Phys. Lett.
    hep-ex/9911041.

16. ‘A spin analysis of the 4π channels produced in central pp interactions at 450 GeV/c’
    D. Barberis *et al.,* (34 authors)
    To be published in Phys. Lett.
    hep-ex/9912005.

Conference presentations by Birmingham Physicists since January 1998

A. Kirk	Stickiness and the search for glueballs IOP annual conference, Manchester, UK, April 1998.
B. Earl	Evidence for a Glueball-$q\overline{q}$ filter Meson 98, Crakow, Poland, May 1998.
A. Kirk	New effects observed in central production by the WA102 experiment at the CERN Omega Spectrometer Multiparticle Dynamics, Delphi, Greece, September 1998.
A. Kirk	A partial wave analysis of the centrally produced $K\overline{K}$ and $\pi\pi$ systems Workshop on Hadron Spectroscopy, Frascati, Italy, 1999.
A. Kirk	The spin of the $f_J(1710)$ and new effects observed in the WA102 experiment the XXXIVth Rencontres de Moriond, Les Arcs, France, 1999
A. Kirk	New effects observed in central production by experiment WA102 at the CERN Omega Spectrometer PANIC 99, Uppsala, Sweden, 1999.
A. Kirk	A Glueball -$q\overline{q}$ filter in central production EPS-HEP 99, Tampere, Finland 1999.

Theses since January 1998

1. 'A study of the centrally produced K^+K^- system at the CERN Omega Spectrometer'
   B.C. Earl, University of Birmingham, March 1999.