

ALEPH: Status Report to the PPESP

Glasgow University
Imperial College
Lancaster University
RAL
Royal Holloway College
Sheffield University

1 Introduction

The past two years have been extremely successful for the Collaboration with new records being set for the performance of the detector and colliding beams from LEP at the highest energies.

In 1997, the integrated luminosity delivered above 181 GeV was 63.5pb^{-1} of which ALEPH recorded “on tape” 59.6pb^{-1} , an overall efficiency of 93.9%. This global efficiency was again an improvement on previous years reflecting the excellent low background conditions as well as the detector performance. The on-line run quality assessment of the data reported very few problems throughout the year. The year’s data also included 7.0pb^{-1} collected at 130/136 GeV repeating the experiment of three years ago when the 4-jet anomaly was observed. This anomaly did not reappear.

In 1998, the whole year was devoted to running at a CM energy of 189 GeV. A record integrated luminosity of 196.02pb^{-1} (including 3.3pb^{-1} at the Z for calibration) was delivered which ALEPH recorded with 92.0% efficiency. Although the most efficient of the 4 LEP experiments, this was slightly lower than the previous year due to increased dead time and detector problems arising in part from thunderstorms. Following a full quality assessment, 91% of these data at 189 GeV are already available for the extraction of the preliminary results presented to the winter conferences in 1999.

All the UK groups continue to participate heavily in the running of the experiment at Echenevex. We provided 4 run co-ordinators and 2 ‘Echenevex’ group members each year who assisted in shift training and general organisation as well as two ‘LEP contact’ persons to liaise with the LEP machine group, on a daily basis, throughout the whole LEP running periods. Also, the long standing commitments to the inner tracking chamber (ITC), the electromagnetic calorimeter endcaps (ECAL), the second level trigger, the Time Projection Chamber (TPC) laser system and the vertex detector (VDET2) electronics have been maintained each requiring co-ordination with the shift crew during running and preparation during the winter shutdown.

ALEPH has published 59 papers since March ’97; 22 of these with major UK involvement as detailed in the Appendix. Fifty-two contributed papers were sent to the Vancouver conference last year and 21 to Moriond ’99 with UK members making major contributions to 6 of them. Twenty presentations have been given at International Conferences by UK members. We have taken leading rôles in the physics analysis particularly in searches for the Higgs boson and R-parity violating SUSY particles, the study of QCD parameters and the measurement of the W mass. We have continued to co-ordinate and dominate the $\gamma\gamma$ physics.

In the UK, two analysis groups have met occasionally over the past two years. They are the W mass/ WW pair cross section group (Glasgow, IC and RAL) and the $\gamma\gamma$ group (Lancaster, RAL and Sheffield).

Peter Dornan was elected as ALEPH spokesman from July ’97 for 3 years.

2 Experimental Commitments

2.1 ITC (Imperial College)

The ITC has continued to provide data reliably and with very high operational efficiency over the past 2 years thanks, in part, to the normally very low background conditions which have been experienced in ALEPH. In general, the high voltage behaviour becomes stable during long periods of steady data-taking. The majority of the 1998 data were recorded with 21 out of the 960 wires inactive - only a slight increase on 1997. Mainly the failure of ageing power supplies caused the loss of 30nb^{-1} last year. At this level it is not felt useful to embark on preventative replacement. There have been continued improvements in our understanding of some of the basic parameters such as alignment stability and systematics. During the last year such studies have resulted in some fine-tuning of the reconstruction code and Monte Carlo parameters. In particular a new parameterisation of the drift-time relationship in terms of cubic splines has been implemented. This has improved the reconstruction performance at the very edges of each wire cell.

2.2 ECAL endcaps (Glasgow, Lancaster, RAL, Sheffield)

Over the past 2 years, the detector has performed with excellent reliability with only minor losses on-line due to HV trips. Only 14 out of 1080 high voltage wire planes are permanently disconnected after 10 years of operation which effectively has no impact on data quality. As in the past, interventions to replace front-end electronics have been rare and limited to a few channels.

2.3 New Vertex Detector (Glasgow, Imperial, RAL)

VDET2 consists of two concentric cylinders of double-sided Silicon wafers with radii 6.3 and 11.0 cm respectively, both 40 cm long. The RAL group is responsible for the front-end MX7RH multiplexers and Glasgow the on-board electronics. In '97, the detector performed superbly except for the temporary loss of one module (out of 48) near the end of the run due to a 'short' on a 5v line. During the '98 run, the detector also performed well except for the failure of the Z side readout on one module. The detector was again removed in the winter shutdown and the fault traced to bad cable connections. Six spare modules have been assembled at RAL with new MX7RH chips and tested at Glasgow. Together with existing spares, these should provide all the faces likely to be required to the end of running in 2000, given that so far only one face has been changed since installation in 1996.

2.4 TPC Laser System (Glasgow)

The TPC laser calibration system is used routinely to monitor the electron drift velocity in the TPC gas, and to determine the track distortions caused by inhomogeneities in the TPC electric field and the solenoid's magnetic field. The laser system has performed almost perfectly throughout the running periods. The laser is triggered during normal data taking. During 1997, the off-line reconstruction of the charged tracks revealed unexpected time-dependent fluctuations in the TPC alignment constants which were attributed to a large beam loss incident in August inside ALEPH. This has required delicate retuning of the alignment to recover the expected precision in momentum reconstruction for the full dataset.

2.5 Second Level Trigger (Royal Holloway)

The second level trigger, based on TPC track segment finding, has continued to perform with very high reliability. It is a vital component of the low transverse momentum track triggers used for detecting gamma-gamma interactions. In 1998, the track selection parameters in the trigger were adjusted to improve the rejection of multiple photon background events. A 10% reduction of trigger rate was achieved with no measurable loss of trigger efficiency.

2.6 New Small-Angle Luminosity Monitor (Lancaster, RAL)

Positioned ± 7.7 m from the interaction point at the centre of ALEPH, this upgraded detector (BCAL++) consists of tungsten/scintillator sampling modules with embedded silicon layers to determine the lateral position of electromagnetic showers. It also acts as a very low-angle tagger for $\gamma\gamma$ events triggered from a high energy electromagnetic deposit in a module and at least one track accompanied by associated energy in the main ALEPH detector. In '97, some damage occurred to part of the silicon detector electronics during LEP filling. However, an energy resolution per module of $22\%/\sqrt{E}(\text{GeV})$ was achieved using an APD readout chosen for its insensitivity to magnetic fields and a significant sample of single tag triggers were analysed off-line. In '98, the silicon detectors within the modules have performed reliably following the decision to switch off the HV bias during filling of LEP. Unfortunately, lack of manpower has prevented a detailed analysis of the tagged $\gamma\gamma$ data so far.

2.7 Run Selection (Imperial)

Run selection and data quality checks are carried out on all data taken on a daily basis during the running periods. Overseeing of these procedures and the maintenance of the run quality software was the responsibility of an Imperial physicist in '97.

2.8 Monte Carlo production (Glasgow)

As in past years, a large number of fully simulated events (~ 2 million/year) have been generated on the CSF farm at RAL mainly for W physics at 183 and 189 GeV. RAL is one of three centres (with Lyon and Copenhagen) outside CERN upon which the Collaboration now heavily depends for all main productions. The range of energies and variety of processes needed at LEP2 has meant that MC productions are just as complex and time consuming as at LEP1.

3 Physics Analyses

The analysis of LEP2 data has dominated our UK activity. Of the five ALEPH-wide groups at LEP2 covering: (a) Searches including the Higgs and SUSY, (b) WW production, (c) QCD, (d) $\gamma\gamma$ interactions and (e) standard electroweak 2-fermion processes, we are deeply involved in all but the last topic. In addition, we have retained a small but significant effort in LEP1 analyses of heavy flavour physics, QCD and electro-weak physics. A considerable effort has gone into re-processing all LEP1 data to benefit from the reconstruction code improvements and better understanding of the apparatus accumulated over the past few years. Some of this activity will continue.

The following subsections describe the main areas of analysis activity pursued by the UK groups in the past 2 years:

3.1 Searches at LEP1 and LEP2

3.1.1 Higgs boson

The Glasgow group continues to be a major contributor to the ongoing search for the Standard Model Higgs boson at LEP2. The group's efforts are concentrated on the hadronic channel, $HZ \rightarrow b\bar{b}q\bar{q} \rightarrow 4$ jets using a cut-based analysis. The results from this and other channels analysing the data taken at $\sqrt{s} = 183$ GeV have now been published. A principal co-editor was one of the Glasgow group members who is now one of two ALEPH members of the LEPC Higgs group.

The main backgrounds to this signature are $e^+e^- \rightarrow q\bar{q}gg, W^+W^-, ZZ$. For the most recent data, at $\sqrt{s} = 189$ GeV, ZZ background becomes dominant. For a signal with $m_H \simeq m_Z$, this background is largely irreducible, and can only be partly discriminated against by using observables that reflect the differences in the spin and $b\bar{b}$ decay branching ratio of the H and Z bosons. The group has pursued both aspects to improve the sensitivity to a possible signal. In the signal four jet final state, one does not know a priori which pair of jets originated from the H or Z decay. In previous years, the two jets with invariant mass closest to m_Z were assigned to the Z. We have demonstrated that using instead the distribution of the decay angle of the dijet systems, one can improve the rate of correct assignments of dijets to the H and Z bosons. Altogether, 48 events (one of them is shown in Fig. 1) were selected by the HZ searches with cut-based methods in agreement with 43.3 events expected from all background processes. Fig. 2 shows the reconstructed Higgs boson mass of the selected events by (a) the Neural Network-based and (b) the cut-based set of selections compared with SM predictions. The 95% C.L. lower SM Higgs mass limit is expected to be 95.7 GeV/ c^2 but the observed limit is 90.2 GeV/ c^2 . The probability that such or even a lower observed limit is obtained is about 1%. These results were presented to the '99 winter conferences.

The tagging of b-flavoured mesons is one of the most important tools for the identification of a possible Higgs signal. This relies to a large extent on the measurement of the impact parameters of tracks in the jets together with an estimate of the direction of flight of the b-hadron in the jet. The flight direction has been approximated by the jet axis direction. A Glasgow student has shown that the efficiency and purity of b-jet tagging can be significantly improved if the b-hadron flight vector is estimated instead from a subjet within the jet or from a well reconstructed secondary vertex in the jet. This has led to a systematic reduction of the background by at least 5% in the 4-jet channel and has been incorporated into the standard ALEPH b-tagging algorithm.

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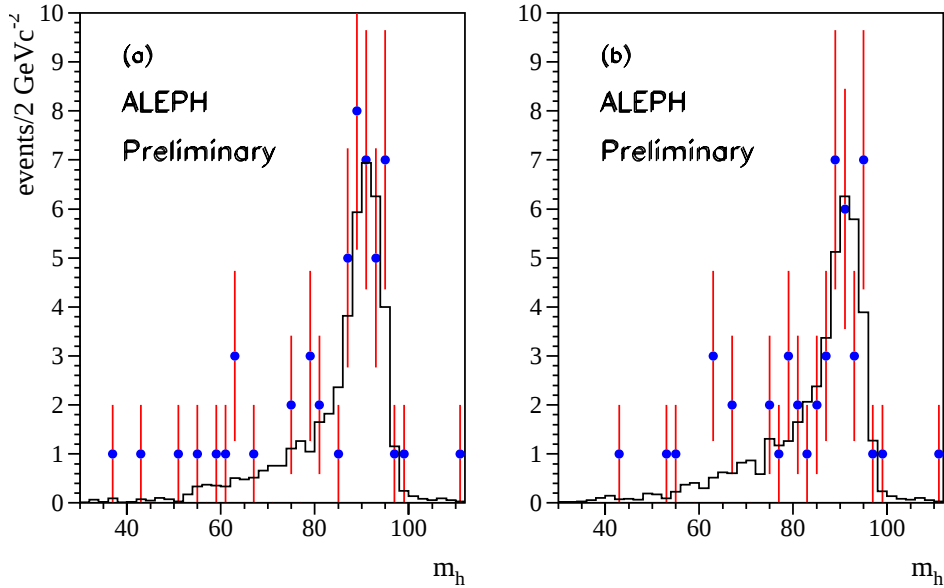


Figure 2: The reconstructed Higgs boson mass of the selected events in the hZ searches by (a) the NN-based and (b) the cut-based set of selections. The histograms show the SM expectations for known processes.

3.1.2 Search for invisible decays of the Higgs boson

Higgs boson decays into invisible final states are predicted by many extensions of the standard model. In these models, the reaction $e^+e^- \rightarrow hZ$ may lead to topologies involving either acoplanar lepton pairs, when the Z decays to e^+e^- or $\mu^+\mu^-$, or acoplanar pairs of jets when the Z decays to $q\bar{q}$. In particular, within the minimal supersymmetric extension of the standard model (MSSM), the lighter CP-even Higgs boson h can decay into a pair of lightest neutralinos $h \rightarrow \chi\chi$, when the neutralino χ is light enough. This decay leads to an invisible final state under the hypothesis of R-parity conservation.

In a data sample of 78.3 pb^{-1} collected in 1996 and 1997 by the ALEPH detector at centre-of-mass energies from 161 to 184 GeV, invisible decays of a Higgs boson have been searched for by an Imperial College physicist in the reaction $e^+e^- \rightarrow hZ$, where the Z can decay into e^+e^- , $\mu^+\mu^-$ or $q\bar{q}$. This work is now published. The much larger data sample at 189 GeV has now been analysed and preliminary results submitted to the '99 winter conferences. No evidence for a signal has been found and limits on the production cross section have been derived as a function of the Higgs boson mass. Combining all channels in the 189 GeV analysis, masses lower than $92.8 \text{ GeV}/c^2$ are excluded at the 95% C.L. for an expected limit of $94 \text{ GeV}/c^2$ (see Fig. 3).

3.1.3 Search for R-parity violating Supersymmetry at LEP2

If R-parity is violated then additional terms are allowed in the superpotential resulting in tri-linear couplings between lepton (L , $\bar{E}$) and quark (Q , $\bar{U}$, $\bar{D}$) superfields. These terms allow the lightest supersymmetric particle to decay resulting in a topology which depends on which of the three terms ($LL\bar{E}$, $LQ\bar{D}$, $\bar{U}\bar{D}\bar{D}$) is dominant. The many possibilities, depending not only on the coupling but also the generation of the fermions, give rise to a large number of signatures. The Imperial team has concentrated on the $LL\bar{E}$ and $LQ\bar{D}$ analyses with the former study now published and the latter accepted for publication using data from 130 to 172 GeV. In both cases it has been possible to set limits which are very similar to those of corresponding particles in R-parity conserving SUSY. These searches for the pair-production of sparticles were continued in the 183 GeV data addressing the decays allowed from all three terms considered in turn. A draft paper has been prepared with improved lower

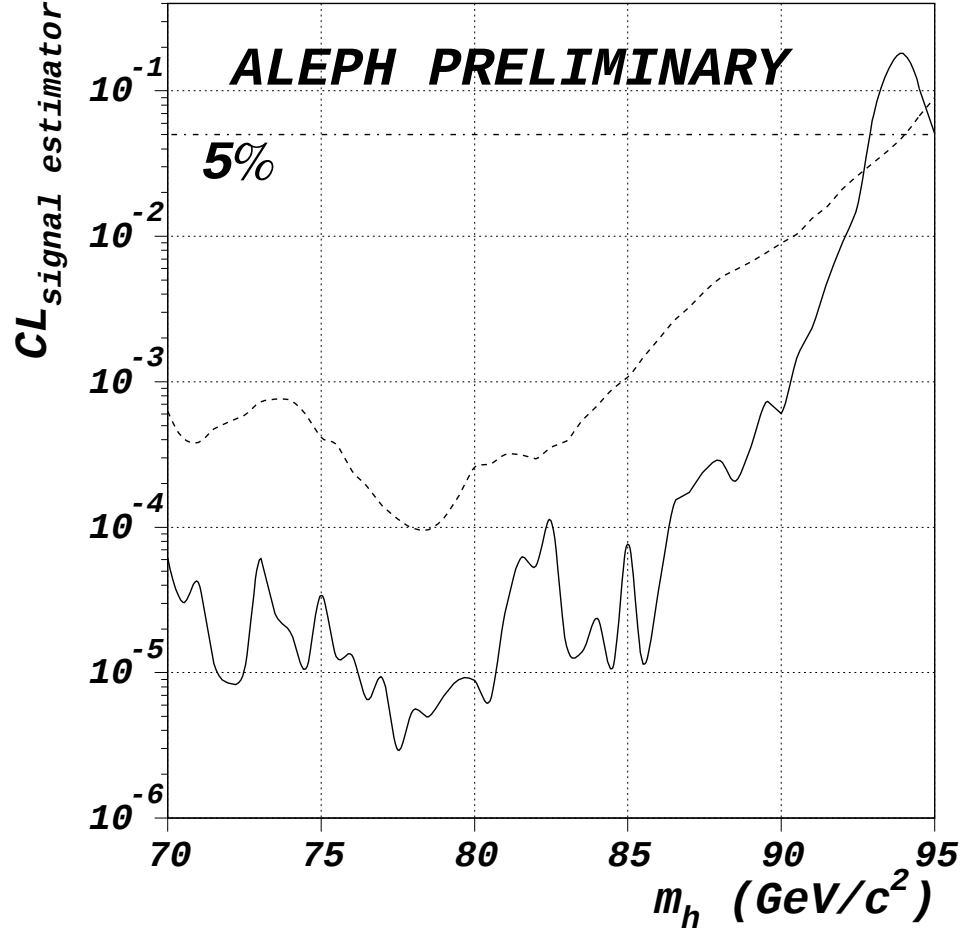


Figure 3: Observed (solid line) and expected (dashed) confidence levels for the combination of the leptonic and hadronic channels in the invisible Higgs search at 189 GeV

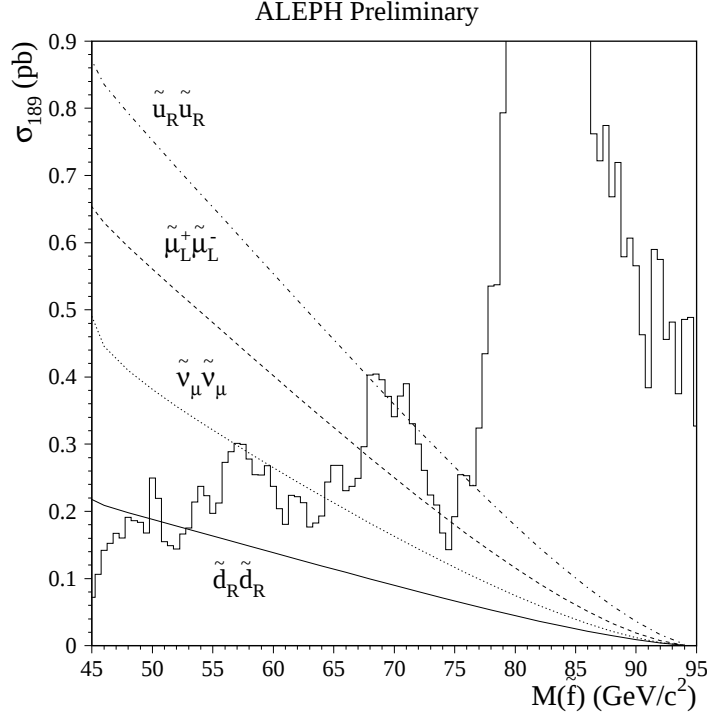


Figure 4: The 95% C.L. excluded cross-sections for sleptons (via $LQ\bar{D}$), sneutrinos (via $LQ\bar{D}$) and squarks (via $\bar{U}\bar{D}\bar{D}$) decaying *directly* to four jets at 189 GeV. The MSSM cross-sections for pair production of muon sneutrinos, left-handed smuons and right-handed squarks are superimposed.

limits on the particle masses.

The UK participation in this work has been taken over by a Royal Holloway physicist who initially studied the effects of cascade decays on the efficiencies for various chargino and neutralino channels, particularly the effect of the decay $\chi' \rightarrow \chi\gamma$ (the second lightest neutralino decaying to the lightest neutralino and a photon). Parts of this work were included in a paper on “Searches for charginos and neutralinos in e^+e^- collisions at $\sqrt{s} \approx 183$ GeV and the limit on the lightest neutralino” submitted to Vancouver. In the 189 GeV data, he has searched for $LL\bar{E}$ and $LQ\bar{D}$ pair-production as well as 4 jets from squarks decaying via $\bar{U}\bar{D}\bar{D}$. Sparticles may also be produced singly via a R-parity violating coupling. For indirect decays the single sneutrino will decay via the $LL\bar{E}$ coupling to two charged leptons and a neutrino. This search was carried out by a Royal Holloway student.

There is no excess of data events over expected standard model background in any of these searches, so limits were derived on the masses of charginos, sleptons, squarks and sneutrinos for the worst case RPV couplings. For example, the mass of the chargino is excluded essentially up to the kinematic limit, $M_\chi > 94$ GeV for $m_0 = 500$ GeV and $\tan\beta = 1.41$. Also, fig. 4 shows the exclusions for the direct decays of sleptons (via $LQ\bar{D}$), sneutrinos (via $LQ\bar{D}$) and squarks (via $\bar{U}\bar{D}\bar{D}$). Preliminary values of all the limits obtained were sent to the '99 winter conferences.

3.1.4 Search for Gauge Mediated Supersymmetry

Supersymmetry breaking is generally assumed to occur through gravitational strength interactions (supergravity). An alternative approach is to assume that the messenger sector for SUSY breaking is not gravity, but the normal gauge interactions of the Standard Model. This is Gauge Mediated Supersymmetry Breaking (GMSB). The model has attractive features: because gauge interactions do not distinguish between generations, universality of sleptons and squarks is automatic and the number of free parameters in the model is very much reduced, perhaps to only two (the soft SUSY breaking scale λ and $\tan\beta$). GMSB phenomenology is significantly different from supergravity. Most importantly, the LSP is always a light gravitino with a mass in the eV to keV range. The next-to-lightest superparticle

(NLSP) is often the neutralino, but this will be unstable with a lifetime dependent on the SUSY breaking scale. A Sheffield student has carried out a search for all three flavours of charged slepton ($\tilde{e}$, $\tilde{\mu}$, $\tilde{\tau}$) in the framework of a GMSB model where the NLSP is a short-lived neutralino. The decay chain is:

$$e^+e^- \rightarrow \tilde{\ell}^+\tilde{\ell}^- \rightarrow \ell^+\ell^-\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \ell^+\ell^-\gamma\gamma\tilde{G}\tilde{G},$$

where the gravitinos are unobserved. Data from the 1996 and 1997 run periods were analysed and mass limits of around 80–85 GeV were set for the selectron and the smuon (the limit for the stau is around 50 GeV). This work has formed part of a general publication on slepton searches.

In addition, an Imperial physicist and student are completing a search for very heavy sleptons which by their ionisation loss would saturate the TPC response.

3.1.5 Excited Fermions

The Royal Holloway group have continued their work on compositeness searching directly for excited quarks and leptons by their radiative decay modes. The comprehensive paper on compositeness searches at LEP 1 has now been published. The 183 GeV data in the radiative decay channels are fully analysed. No signal has been seen. The 'Hagiwara' model predicts that pair production of e^* 's is still radiatively dominated at these energies although the branching ratio to the radiative decay mode for single production ($e^+e^- \rightarrow e^+e^{*-} \rightarrow e^+e^-\gamma$) has dropped radically above 100 GeV centre-of-mass energy. Possible weak decay modes ($e^* \rightarrow \nu_e W$ and $e^* \rightarrow eZ$) are also being studied. The 189 GeV data analysis is almost completed and a paper will be submitted for publication. The group are also carrying out a search for axions in the detector searching for evidence of photon-like depositions in the ECAL.

3.2 W and other electro-weak physics

3.2.1 W mass and W^+W^- cross section

The groups at Glasgow, Imperial and RAL have continued to play a leading part in the determination of the W mass. The first papers on the measurement of the cross section at 161 GeV and 172 GeV were published in which the selection procedure developed by the UK groups for the $W^+W^- \rightarrow q\bar{q}q\bar{q}$ (4q) channel was included. The first measurement of the mass was derived from these cross sections.

The extraction of the mass from event reconstruction of W^+W^- pairs in both the 4q and $\ell\nu q\bar{q}$ channels well above threshold required the development of new software tools. In the 4q channel, the UK groups proposed the Monte Carlo reweighting technique to evaluate the mass at 172 GeV. An Imperial physicist provided the tool to identify the best jet pairings for mass reconstruction and a Glasgow student participated in the study of jet finding algorithms. ALEPH-wide, a RAL physicist co-ordinated these activities at this stage. As expected, the much larger samples of W^+W^- pairs recorded at 183 GeV in 1997 allowed more sophisticated methods to be developed in both channels with corresponding improvements in the understanding of systematics. A 2-dimensional reweighting procedure in the 4q channel, developed initially by a RAL physicist, produced a 10% improvement in the mass measurement. An Imperial student made a detailed study of the kinematic fitting procedures and provided the parametrisations of the jet errors which led to a better understanding of the final errors in the mass. In the $e(\mu)\nu q\bar{q}$ channels, a Glasgow student developed an improved event selection used initially at 172 GeV and then played a major rôle in the adoption of a new kinematic fitting package to sharpen the mass distribution from a 2-constraint fit. Her thesis work produced the results from these channels for the publication at 183 GeV. The final mass of 80.423 ± 0.124 GeV/ c^2 extracted from all data up to this CM energy has been submitted for publication.

These results are based on a Monte Carlo reweighting procedure which finds the best fit to the observed mass spectrum in each channel by adjusting the generated reference W mass. The matching Monte Carlo spectra are necessarily binned in this procedure. To avoid binning and so much reliance on Monte Carlo, an Imperial student has implemented an analysis in the 4q channel which employs a deconvolution method wherein the binned spectra are effectively replaced by a smooth function in 2-D which is derived from Breit-Wigners modified by phase space limits and the apparatus resolution. In addition, this analysis also uses the event-by-event mass error matrix derived from the kinematic

fit to each event. A comparable result is found for the 183 GeV data. A RAL physicist and Imperial student are continuing this work using the 189 GeV data and expect to improve on the precision already achieved by the reweighting method. An alternative approach to avoid any bias arising from binning has been pursued by a Glasgow student for the 189 GeV 4q data. It is based on the Kolmogorov-Smirnov statistical test extended to 2-D.

The large data sample collected at 189 GeV in '98 has imposed a new rigour on the data analysis since the systematics are now critical. Nevertheless, the understanding of the data and Monte Carlo was sufficiently advanced to send a paper with preliminary results to the winter conferences. Fig. 5 shows the 1-D mass distributions for the 4q and $e(\mu)\nu q\bar{q}$ channels at 189 GeV.

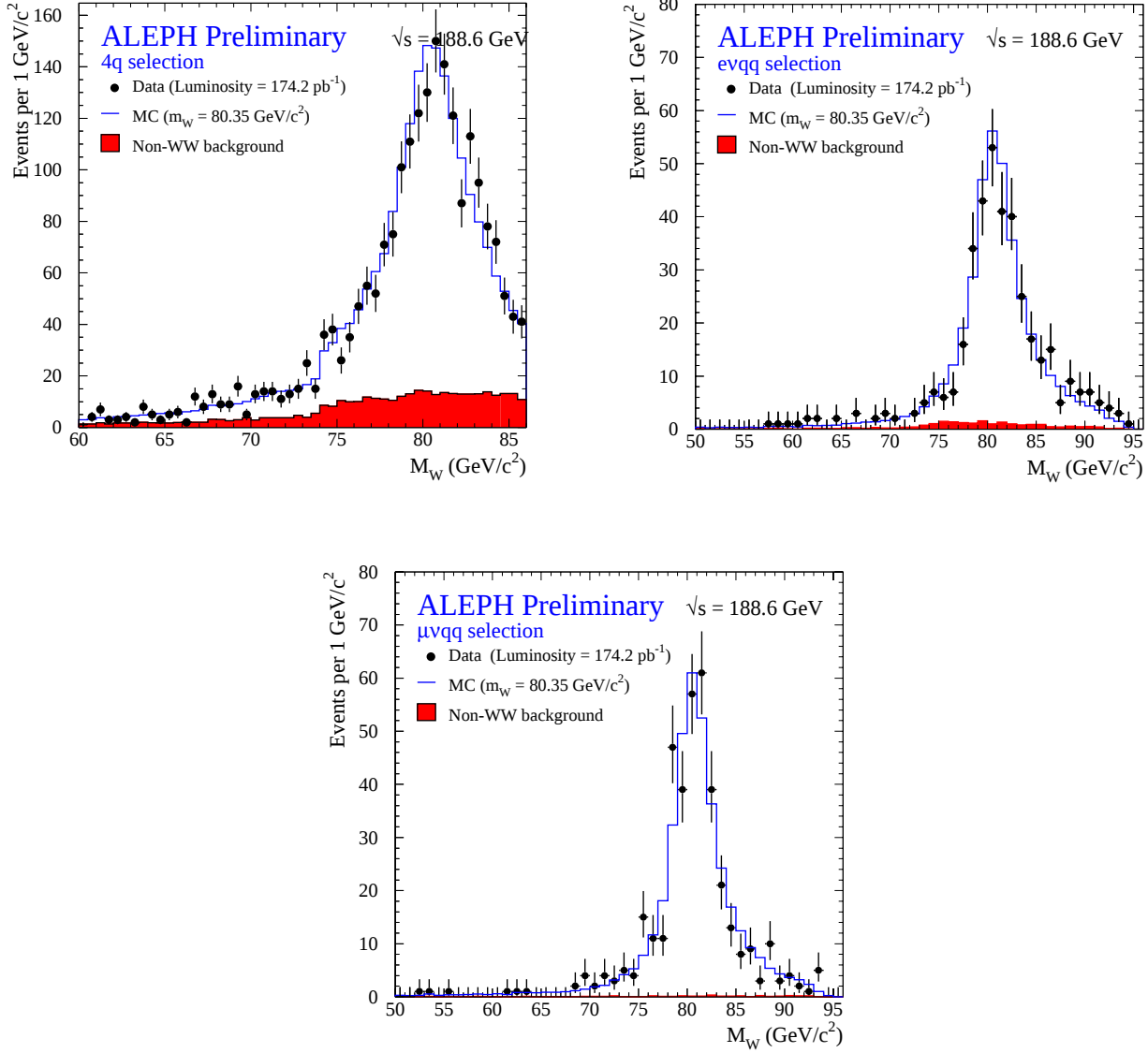


Figure 5: (a),(b) and (c) Mass distributions for the 4q, e and μ data (points with error bars) at 189 GeV, non W^+W^- background (shaded area) and signal+background Monte Carlo with m_W values set by the reference Monte Carlo at 80.35 GeV/c^2 (solid line histogram).

To date, the mass derived for all data from 161 to 189 GeV is $80.411 \pm 0.064(\text{stat}) \pm 0.046(\text{syst}) \text{ GeV}/c^2$. In addition, motivated by the possible influence of final state interactions between the W 's when both decay hadronically, the 'hadronic' and 'semileptonic' masses were compared. The difference is $0.219 \pm 0.132 \text{ GeV}/c^2$ providing the first hint that such interactions may be playing a rôle. In the 189 GeV analysis of the $e(\mu)\nu q\bar{q}$ channels, a new Glasgow student has implemented an improved selection to accomodate the changing kinematics as the CM energy increases and to improve the treatment of

leptons which pass through cracks between the calorimeter modules. All ALEPH semileptonic channel analyses over the past 18 months have been led by a RAL physicist.

The principle systematic uncertainty on the mass in the 4q channel is the effect of final state interactions. The size of this uncertainty currently exceeds the statistical error from all experiments combined. One aspect of this is colour reconnection which is being investigated by the Lancaster group who have compared multiplicity distributions from purely hadronic and semileptonic events. Some models have predicted measurable differences. This is the first stage of a more detailed analysis and is the thesis topic of a Lancaster student. The results using the data taken at 183 GeV were presented at the summer conferences, and preliminary measurements made at 189 GeV were sent to the '99 winter conferences. These show that the average charged di-jet multiplicities observed in both channels are consistent with each other and with models tuned at the Z without colour reconnection. However, JETSET models of colour reconnection which favour a small reduction in the 4q channel multiplicity cannot be excluded.

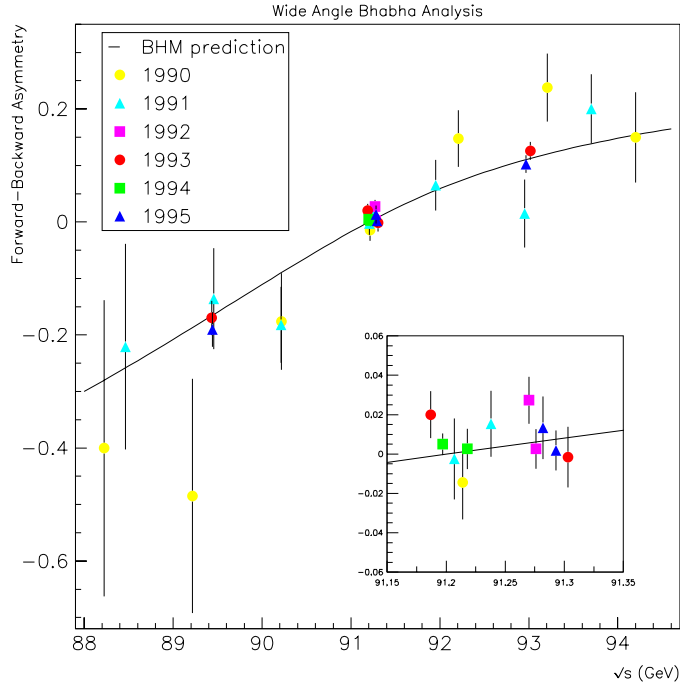


Figure 6: Final results on the forward-backward electron asymmetry at the Z compared with the Standard Model prediction obtained from fits to all electro-weak data

3.2.2 Bhabha Cross Section at LEP1

Analysis of wide-angle Bhabha production in LEP 1 data was completed this year in which a Sheffield group has a long standing commitment. This exercise formed part of a major effort by the Electroweak analysis group to analyse all the LEP 1 electroweak data in a coherent fashion in order to minimise systematic errors. A total of 4.5 million Z decays into fermions pairs were analysed corresponding to data taken from 1990 to 1995 inclusive. In the case of the Bhabha data, selected events were analysed to give the total s-channel cross-section. The total systematic error at the peak data points was typically 0.2% to 0.3%, this being dominated by the theoretical uncertainty in the t-channel subtraction cross-section. In order to correctly facilitate the full electroweak fits it was necessary to construct a 27×27 correlation matrix for the the measured cross-sections and to assess the nature of the correlations for each source of systematic error.

Similarly, the forward-backward asymmetries for all the data samples were evaluated by fitting the number of events as a function of $\cos \theta$ to the expected angular dependance. A log-likelihood fit was

performed to each dataset to extract the overall normalisation and the forward-backward asymmetry, A^{FB} . The total systematic error was once again dominated by the t-channel subtraction uncertainty and was of the order of 0.001 (absolute) for peak values of the cross-section. Fig. 6 illustrates the final results for the electron asymmetries along with the theoretical prediction. A final paper on Z resonance parameters will be submitted to the European Journal of Physics shortly.

3.3 QCD Topics

3.3.1 Hadronic events at LEP2

The Lancaster group has continued to analyse the event shapes and their moments in the $e^+e^- \rightarrow q\bar{q}$ annihilation events at high energy. Comparisons with QCD-motivated models have been made and the more common models, PYTHIA, HERWIG and ARIADNE, have all been found to give an adequate description of the data (see Fig. 7). Various event shape variables have been used to determine α_s (previously only the jet-rate variable, $\log y_3$, had been used), and with increasing statistics more significant tests of its running will be made. A new approach undertaken by the Lancaster group is the analysis of the first, second and third moments of the event shape distributions. While not providing as much statistical power as the full distributions, the higher powers have the advantage that hadronisation uncertainties decrease, and the running of α_s with energy can again be tested. Preliminary results from the 189 GeV data were sent to the '99 winter conferences. A Lancaster

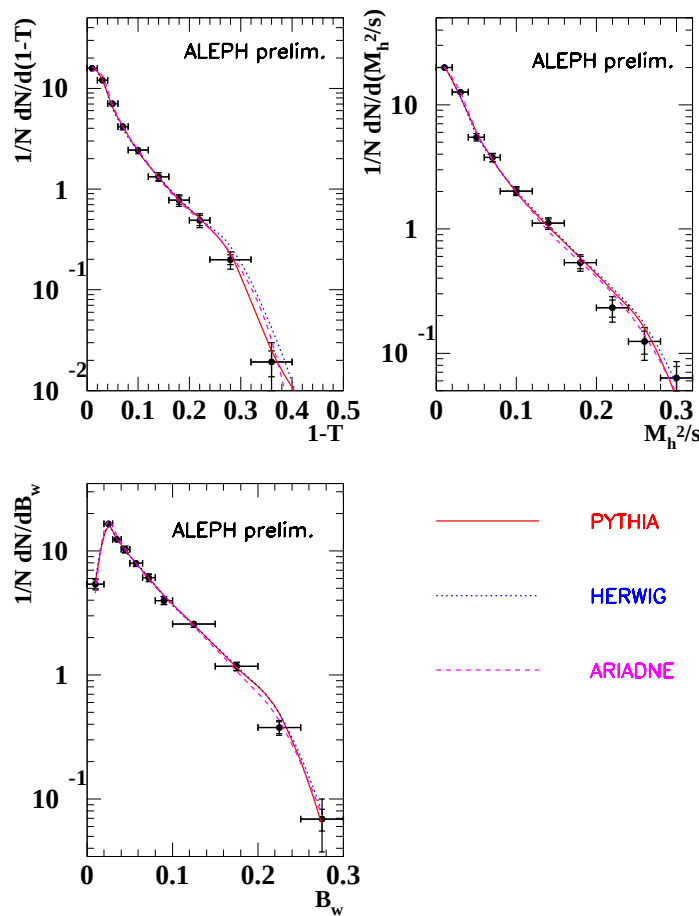


Figure 7: Distributions of the hadronic event shapes for (1-Thrust), Heavy Jet Mass (M_h^2), and Wide Jet Broadening (B_w) at 183 GeV compared with Monte Carlo models

physicist has continued to convene the LEPC QCD working group.

3.3.2 Hemisphere Correlations at the Z

Studies of correlations in hadronic events at the Z continue to be made by an Imperial physicist. In a recent paper, evidence was presented for a significant, positive correlation between the total transverse momenta of particles on opposite hemispheres of hadronic events. A new, model independent analysis of the data has been made. The behaviour of the correlation as the events are clustered (using the Durham cluster algorithm) enables two components, denoted by soft and hard, to be distinguished. Quantitative estimates of each are given. The results form a significant test of Monte Carlo models and some of the physics behind them, for example they show a clear tendency for JETSET to give too many strongly asymmetric events. They may also shed light on a possible perturbative explanation of the JADE string effect. A paper has just been accepted by Physics Letters B.

3.4 $\gamma\gamma$ Physics

ALEPH's $\gamma\gamma$ working group continued to be convened by two UK physicists from Lancaster and RAL. The following topics are being studied:

3.4.1 Photon structure function

The hadronic structure function of the photon, F_2^γ , has been measured in three bins of Q^2 centred at mean values of 9.9, 20.7 and 284 GeV² by members of the Lancaster group and submitted for publication. After unfolding in Bjorken x , $F_2^\gamma(x)$ is extracted from the differential cross sections in each bin taking into account the small contribution from the longitudinal component. Fig. 8 shows the values of $F_2^\gamma(x)$ obtained compared with three theoretical predictions, one of which (LAC1) contains a large gluon content resulting in a rapid rise at low x . Such parton density functions are strongly disfavoured by the data indicating that the photon does not emulate the proton in its gluon content.

3.4.2 Azimuthal asymmetries

Azimuthal asymmetries in $\gamma\gamma \rightarrow f\bar{f}$ provide a method of measuring structure functions other than F_2 . In particular, the structure function F_B can be measured: for fermionic final states this is numerically equal to F_L , which is sensitive to the gluon content of the photon. A Sheffield student carried out such an analysis for the leptonic process $\gamma\gamma \rightarrow \mu^+\mu^-$, where the structure functions can be predicted from QED. The results were presented at PHOTON '97. Unfortunately it appears that the accuracy with which parton directions can be reconstructed from jet analyses is presently insufficient to allow this technique to be extended to the more interesting hadronic case.

3.4.3 Jet production

Work is continuing on the analysis of the jet structure of two-photon events at Sheffield. Modifications to HERWIG suggested in the Oxford LEP2 workshop of April 1997 have greatly improved the agreement between tagged data and Monte Carlo, and a new program called JETViP is being used to calculate theoretical jet cross-sections in LO and NLO. It has been shown that the LO prediction of the jet p_T cross section is in reasonable agreement with HERWIG. A paper describing this study is in preparation.

For the untagged sample, the PHOJET Monte Carlo provides a good description of the data. A Sheffield student is presently conducting detailed studies of jet algorithms and systematics aimed at optimising the correlation between the found jets and the underlying partons in untagged $\gamma\gamma$ events, working closely with a Manchester theorist to ensure that the final prescription is optimised both for experimental reconstruction and for theoretical tractability. NLO theoretical calculations are also available for untagged jets.

3.4.4 Charm production

Charm production in untagged $\gamma\gamma$ interactions is being revisited by the Lancaster group with all LEP1 data and the large statistics accumulating at LEP2. As well as D^* 's, other charm-tagging methods

are being investigated and there are plans to extend to high Q^2 in which there is strong theoretical interest.

3.4.5 Exclusives

In $\gamma\gamma$ interactions, production of a pure glue state would be suppressed. Measuring the two-photon width, $\Gamma_{\gamma\gamma}$, of the $f_0(1500)$ and the $f_J(1710)$, or setting an upper limit on $\Gamma_{\gamma\gamma}$, would indicate whether either is likely to be a pure glueball or has quark content. In an analysis carried out by a RAL physicist, the processes $\gamma\gamma \rightarrow f_0(1500) \rightarrow \pi^+\pi^-$ and $\gamma\gamma \rightarrow f_J(1710) \rightarrow \pi^+\pi^-$ have been studied. Fig. 9 shows a fit to the $\pi^+\pi^-$ mass spectrum of a Breit-Wigner shape for the $f_2(1270)$ and polynomial for the background processes. There is no indication of either resonance or for the tensor glueball candidate $f_J(2220)$. A paper is being prepared for publication.

3.4.6 Tagging with BCAL++

The data obtained at 183 and 189 GeV from the very low angle BCAL++ tags in coincidence with the rest of the ALEPH detector have opened up an interesting region of study where the interacting photons have very low virtuality. As a first step, a RAL physicist has analysed the hadronic final state of single tag events from the 183 GeV run where the probing photon has a mean mass squared $\langle Q^2 \rangle = 0.4 \text{ GeV}^2$. Using only the BCAL modules on the inner side of the LEP ring to reduce random backgrounds from off-axis beam particles, it was possible to obtain an almost pure sample ($\sim 95\%$) of $\gamma\gamma$ events. From measurements of the charged track multiplicity, visible mass per event and energy flow as a function of pseudorapidity it was found that the PHOJET Monte Carlo gave a good description of the shape and normalisation of the data in contrast to comparisons made at higher values of Q^2 with HERWIG. These results were submitted to the DIS98 winter conference.

3.4.7 Monte Carlos and LEP-wide meetings

A Lancaster physicist has made a concerted effort in a LEP-wide group including OPAL and L3 to compare the measured hadronic final state in deep inelastic $e\gamma$ scattering with the HERWIG and PHOJET Monte Carlos. Each experiment has prepared corrected hadron distributions using commonly agreed procedures for the first time. The results are in broad agreement and appear to show that both models fail to give a satisfactory description of the data. A paper is in preparation.

3.5 Heavy Flavours at LEP1

3.5.1 Inclusive Search for $b \rightarrow s\gamma$

A major advance has been made by the Lancaster group in publishing the first measurement at LEP of the inclusive branching ratio for the electromagnetic decay $b \rightarrow s\gamma$. The decay is a flavour changing neutral current transition induced at leading order by so-called penguin diagrams which can be sensitive to physics beyond the Standard Model. Hence, the decay mode has attracted much theoretical interest. Within the Standard Model, the inclusive branching ratio is expected to be 3.76×10^{-4} on the Z resonance. Thus, this is a difficult process to separate from the many backgrounds and it was thought that it would be an impossible measurement at LEP. However, a signal was isolated from the backgrounds thanks mainly to the finely grained electromagnetic calorimeter, the ability to separate the b-jets and an innovative technique for reconstructing the strange quark jets which benefits from the precision vertex detector in ALEPH. The branching ratio has been measured to be $3.29 \pm 0.71 \pm 0.68 \times 10^{-4}$. Fig.10 shows comparisons of the data and Monte Carlo distributions. This result has a similar precision but quite different systematics from the only previous measurement by CLEO and made quite an impact at the Vancouver conference.

3.5.2 The width difference between B_s mass eigenstates

Mixing phenomena in neutral B meson systems provide an important test for standard model flavour dynamics. In the $B_s - \bar{B}_s$ system, the direct measurement of ΔM_{B_s} could yield precious information for our understanding of the CKM parameters. Complementary insights can be gained from the width

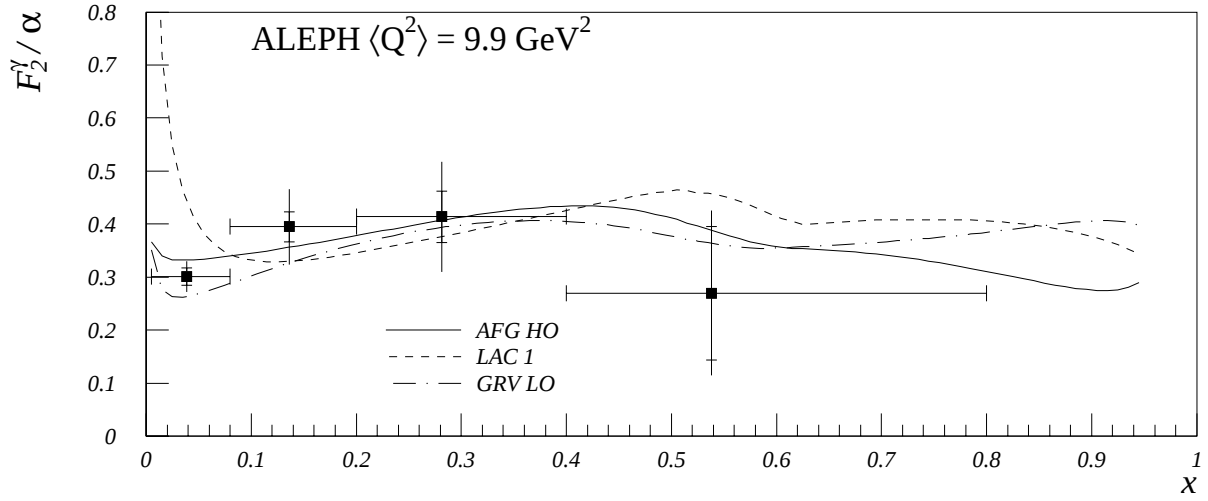


Figure 8: The hadronic photon structure function $F_2^\gamma(x)/\alpha$ at $\langle Q^2 \rangle = 9.9 \text{ GeV}^2$ compared with three theoretical parametrisations.

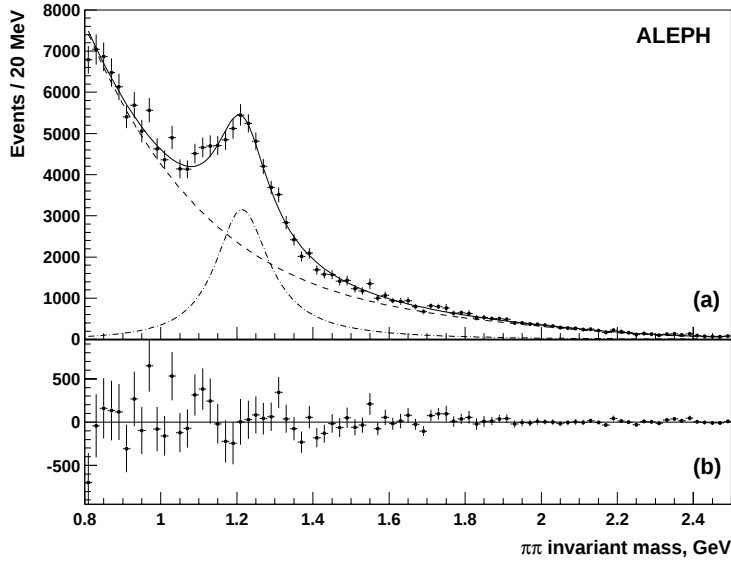


Figure 9: (a) The fit to data with a Breit-Wigner for the $f_2(1270)$ (dot-dash line), a polynomial for the background (dashed line) and the combination of these functions (solid line); and (b) the data after subtraction of the fitted curve. Error bars indicate statistical errors only.

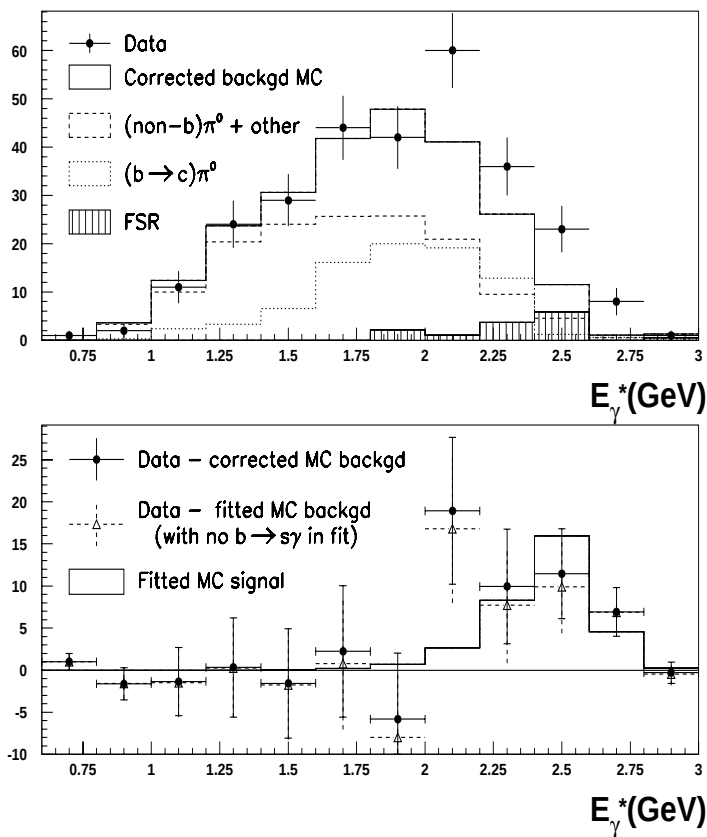


Figure 10: The energy of a photon in the rest frame of the reconstructed jet. The top figure shows the data and Monte Carlo background events in a selected sub-sample. The bottom figure shows the excess in data after subtraction of the Monte Carlo background and the signal distribution resulting from a multivariate fit. Also shown is the excess remaining in the data when the fit is performed without $b \rightarrow s\gamma$.

difference $\frac{\Delta\Gamma}{\Gamma}$ between the B_s mass eigenstates. This width difference is expected to be the largest among bottom hadrons and recent theoretical predictions find a sizeable value of $(\frac{\Delta\Gamma}{\Gamma})_{B_s} = 0.16^{+0.11}_{-0.09}$.

The simplest way to investigate $\frac{\Delta\Gamma}{\Gamma}$ is to measure directly one of the two components of the B_s lifetime. The decay $B_s \rightarrow D_s^{(*)+} D_s^{(*)-}(X)$, which is dominantly CP even, can be partially reconstructed in the $\phi\phi X$ final state. In the $B_s - \bar{B}_s$ system the CP even state decays more rapidly than the CP odd state. This follows from the fact that most of the decay products in the $b \rightarrow c\bar{c}s$ transition, which are common to B_s and $\bar{B}_s$, are CP even.

An Imperial physicist has studied the selection of the $B_s \rightarrow D_s^{(*)+} D_s^{(*)-}(X)$ decays in ALEPH, using the correlation between two ϕ 's in the same hemisphere. The two ϕ 's are selected to tag the double D_s decay, benefiting from the large inclusive branching ratio of $D_s \rightarrow \phi X$. The $\phi\phi$ vertex is used to reconstruct the B_s decay length and eventually the proper time. From the proper time distribution it is possible to extract the lifetime of the B_s candidates and to give an estimation of $\frac{\Delta\Gamma}{\Gamma}$ from a lifetime fit. The $\phi\phi$ correlation after the selection cuts in the data is plotted as a function of the mass of the two K^+K^- combinations. A clear excess is observed in the region where the $\phi\phi$ signal is expected. This excess of events is attributed to the B_s decay to the mostly CP even eigenstate $D_s^{(*)+} D_s^{(*)-}(X)$ that correspond to the short-lived mass state. A lifetime $\tau_s = 1.42 \pm 0.23 \pm 0.16$ ps for this eigenstate is extracted from a maximum likelihood fit to the proper times of the B_s candidates. Finally it is possible to extract $\frac{\Delta\Gamma}{\Gamma}$, (where $\Gamma = \frac{\Gamma_s + \Gamma_l}{2}$, $\Delta\Gamma = \Gamma_s - \Gamma_l$ and $\Gamma_{s,l} = 1/\tau_{s,l}$) under the hypothesis that the world average B_s lifetime, $\bar{\tau} = 1.61 \pm 0.10$ ps is equal to $\frac{\tau_s + \bar{\tau}}{2}$. Then $\frac{\Delta\Gamma}{\Gamma} = 2(1 - \frac{\tau_s}{\bar{\tau}})$, so that a lifetime $\tau_s = 1.41 \pm 0.20 \pm 0.16$ ps in the $B_s - \bar{B}_s$ system would correspond to $\frac{\Delta\Gamma}{\Gamma} = (24 \pm 35)\%$ where the statistical and systematic errors are combined. These preliminary results have been presented to the ICHEP98 conference in Vancouver.

3.5.3 Determination of A_{FB}^b using a measurement of the forward-backward hemisphere charge asymmetry

The measurement carried out by two physicists from Lancaster and one from Glasgow of the forward-backward asymmetry of b quarks in $Z \rightarrow b\bar{b}$ production has now been published. This provides the most accurate measurement of $\sin^2 \theta_W$ at LEP, improving on the previous published analysis by considering a wider range of b -purities, a bigger angular acceptance and different momentum weightings in the jet charge. Combining statistical and systematic errors, the asymmetry and effective mixing angle are given by:

$$A_{FB}^b(\sqrt{s} = M_Z) = 0.1056 \pm 0.0054,$$
$$\sin^2 \theta_W^{eff} = 0.23109 \pm 0.00096.$$

This result has been included in the LEP averages performed by the LEP Electroweak Working Group and used to constrain the mass of the SM neutral Higgs boson.

4 Future Plans

(a) We shall not be making any new request for upgrading the detector.

(b) Our commitment to Part A of the M+O is essentially fulfilled and only our share of the dismantling costs remain in the calendar years 2000/2001. However, we request that Part B of the M+O and the travel budgets are kept at a level sufficient to sustain our experimental commitments until the end of running and, most important also, allow us to participate fully in the LEP2 and remaining LEP1 analyses.

(c) Our physics goals are well established in the Searches, W^+W^- and $\gamma\gamma$ areas at LEP2. We foresee that the Searches will continue at least a year after the end of running. For the W mass and parts of QCD/ $\gamma\gamma$, final publications are likely to continue into 2002/3. In addition, we have a small but active programme in heavy flavour physics using the fully reprocessed data from LEP1 which we are anxious to complete.

5 ALEPH Publications since March '97

Major UK involvement noted by ** with the contributing Institutes given in brackets as follows: Glasgow = GL, Imperial = IC, Lancaster = LA, Royal Holl = RH, Rutherford = RAL and Sheffield = SH.

1. (**RH) Studies of QCD in $e^+e^- \rightarrow$ Hadrons at 130 and 136GeV
Z.Phys. C73 (1997) 409
2. (**IC) Transverse momentum correlations in hadronic Z decays
Z.Phys. C73 (1997) 421
3. Production of orbitally excited charm mesons in semileptonic B decays
Z.Phys. C73 (1997) 601
4. A study of τ decays involving η and ω mesons
Z.Phys. C74 (1997) 263
5. Measurement of the τ lifetime by a 3-D impact parameter method
Z.Phys. C74 (1997) 387
6. Inclusive production of π^0 s in hadronic Z decays
Z.Phys. C74 (1997) 451
7. Improved measurement of the $B^0 - \bar{B}^0$ oscillation frequency
Z.Phys. C75 (1997) 397

8. Measurement of $|V_{cb}|$, form factors and branching fractions in B^0 decays
Phys.Lett. B395 (1997) 373
9. Measurement of the QCD colour factors and a limit on the light gluino
Z.Phys. C76 (1997) 1
- 10.(**IC) The topology dependence of charged particle multiplicities in 3-jet events
Z.Phys. C76 (1997) 191
11. Measurement of the spectral functions of vector current hadronic τ decays
Z.Phys. C76 (1997) 15
- 12.(**SH) Study of μ pair production from $\sqrt{s}=20$ to 136GeV
Phys.Lett. B399 (1997) 329
- 13.(**IC) Measurement of R_b using a lifetime tag method
Phys.Lett. B401 (1997) 150
14. Measurement of R_b using mutually exclusive tags
Phys.Lett. B401 (1997) 163
- 15.(**GL/IC/RAL) Measurement of the W mass in e^+e^- collisions at threshold
Phys.Lett. B401 (1997) 347
16. Search for the B_c meson in hadronic Z decays
Phys.Lett. B402 (1997) 213
17. Measurement of transverse spin correlations in the decay $Z \rightarrow \tau\tau$
Phys.Lett. B405 (1997) 191
18. Measurement of the Branching Fraction for $D^0 \rightarrow K^-\pi^+$
Phys.Lett. B403 (1997) 367
19. Search for the pair-production of long-lived heavy charged particles
Phys.Lett. B405 (1997) 379
20. Search for sleptons at 161 and 172GeV
Phys.Lett. B407 (1997) 377
- 21.(**GL) Search for the SM Higgs at $\sqrt{s} = 161, 170$ and 172GeV
Phys.Lett. B412 (1997) 155
22. Search for the Neutral Higgs of the MSSM at $\sqrt{s} = 130$ to 172GeV
Phys.Lett. B412 (1997) 173
- 23.(**RH) Studies of Quantum Chromodynamics with the ALEPH Detector
Physics Reports 294 (1998) 1
24. Three-prong tau decays with charged kaons
Eur.Phys. J. C1 (1998) 65
25. Searches for Scalar Top and Scalar Bottom Quarks at LEP2
Phys.Lett. B413 (1997) 431
26. Updated measurement of the τ lepton lifetime
Phys.Lett. B414 (1997) 362
- 27.(**IC/RAL) Measurement of the W-pair cross section in e^+e^- collisions at 172 GeV
Phys.Lett. B415 (1997) 435
- 28.(**IC) Measurement of the b baryon lifetime and branching fractions in Z decays
Eur.Phys. J. C2 (1998) 197

29. Search for Supersymmetry in the photon(s) plus missing energy channel at $\sqrt{s} = 161$ GeV and 172 GeV
Phys.Lett. B420 (1998) 127
30. Searches for Charginos and Neutralinos in e^+e^- Collisions at $\sqrt{S} = 161$ and 172 GeV
Eur. Phys. J. C2 (1998) 417
31. Search for charged Higgs bosons in e^+e^- collisions at centre-of-mass energies from 130 to 172 GeV
Phys.Lett. B418 (1998) 419
32. (**RH) An upper-limit on the τ neutrino mass from three-and five-prong tau decays
Eur.Phys. J. C2 (1998) 395
33. (**IC) Search for Supersymmetry with a dominant R-Parity violating $LL\bar{E}$ Coupling in e^+e^- Collisions at centre-of-mass energies of 130GeV to 172GeV
Eur.Phys. J. C4 (1998) 433
34. A Measurement of the semileptonic branching ratio $\text{BR}(b\text{-baryon} \rightarrow p\bar{\nu}X)$ and a study of inclusive $\pi^\pm$, $K^\pm$, $(p, \bar{p})$ production in Z decays
Eur.Phys. Journal C5 (1998) 205
35. (**IC) A Combination of Preliminary Electroweak Measurements and Constraints on the Standard Model
The LEP Collaborations, the LEP Electroweak Working Group and the SLD Heavy Flavour Group
36. Four-jet final state production in e^+e^- collisions at centre-of-mass energies ranging from 130 to 134 GeV
Phys. Lett. B420 (1997) 196
37. Study of B_S^0 oscillations and lifetime using fully reconstructed D_S^- decays
Eur.Phys. J. C4 (1998) 367
38. (**GL/IC/RAL) Measurement of the W Mass by Direct Reconstruction in e^+e^- Collisions at 172 GeV
Phys.Lett. B422 (1998) 384
39. Measurement of Triple Gauge-Boson Couplings at 172GeV
Phys.Lett. B422 (1998) 369
40. K_S^0 production in τ decays
Eur.Phys. J. C4 (1998) 29
41. Measurement of the Spectral Functions of Axial-Vector Hadronic τ Decays and Determination of $\alpha_S(M_\tau^2)$
Eur.Phys. J. C4 (1998) 409
42. (**IC) Resonant structure and flavour tagging in the $B\pi^\pm$ system using fully reconstructed B decays
Phys.Lett. B425 (1998) 215
43. (**RH) Search for evidence of compositeness at LEP1
Eur.Phys. J. C4 (1998) 571
44. Measurement of the Fraction of Hadronic Z Decays into Charm Quark Pairs
Eur.Phys. J. C4 (1998) 557
45. Observation of doubly-charmed B decays at LEP
Eur.Phys. J. C4 (1998) 387

46. (**GL/LA) Determination of A_{FB}^b using Jet Charge Measurements in Z Decays
Phys.Lett. B426 (1998) 217
47. (**LA) A measurement of the inclusive $b \rightarrow s\gamma$ branching ratio
Phys.Lett. B429 (1998) 169
48. Lower bound for the Standard Model Higgs boson mass from combining the results of the four LEP experiments
Aleph, Delphi, L3 and Opal experiments
49. Single- and multi-photon production in e^+e^- collisions at a centre-of-mass energy of 183GeV
Phys.Lett. B429 (1998) 201
50. (**SH) Search for sleptons in e^+e^- collisions at centre-of-mass energies up to 184GeV
Phys.Lett. B433 (1998) 176
51. Scalar quark searches in e^+e^- collisions at $\sqrt{s} = 181\text{-}184\text{GeV}$
Phys.Lett. B434 (1998) 189
52. The forward-backward asymmetry for charm quarks at the Z
Phys.Lett. B434 (1998) 415
53. A measurement of the gluon splitting rate into $b\bar{b}$ pairs in hadronic Z decays
Phys.Lett. B434 (1998) 437
54. A study of $D^0\bar{D}^0$ mixing and D^0 doubly Cabbibo suppressed decays
Phys.Lett. B436 (1998) 211
55. (**GL) Search for the Standard Model Higgs Boson at the LEP2 Collider near $\sqrt{s} = 183\text{ GeV}$
Phys.Lett. B440 (1998) 403
56. Searches for the Neutral Higgs Boson of the MSSM in e^+e^- Collisions at Centre-of-mass Energies of 181-184 GeV
Phys.Lett. B440 (1998) 419
57. (**IC) Analysis of transverse momentum correlations in hadronic Z decays
Phys.Lett. B447 (1999) 183
58. (**IC) Search for invisible Higgs decays in e^+e^- collisions at centre-of-mass energies up to 184 GeV
Phys.Lett. B450 (1999) 301
59. Search for B_s^0 oscillations using inclusive lepton events
Eur.Phys. J. C7 (1999) 553

6 International Conference Presentations by UK Physicists since Apr '97

P Morawitz	R-parity violating SUSY	Apr 97	LEP2 Workshop, Oxford
JC Thompson	W Mass review	Apr 97	LEP2 Workshop, Oxford
P Colrain	R_b and R_c	Apr 97	San Miniato
C Brew	Muonic structure	May 97	Photon 97, Egmont
A Finch	Photon Structure	May 97	Photon 97, Egmont
L Moneta	Higgs from LEP1	May 97	SUSY 97, Philadelphia
M Girone	ν_τ mass limit	Aug 97	EPS Jerusalem
R Jones	QCD results LEP2	Aug 97	EPS Jerusalem
A Wright	Glueball Candidate	Aug 97	EPS Jerusalem
C Booth	LEP2 results	Sep 97	Samaria, Russia
M Williams	Sfermions and R_P	Sep 97	Workshop on the MSSM, Barcelona
P Teixeira-Dias	Higgs search at LEP	Jan 98	Aspen, Colorado
MI Williams	$b \rightarrow s + \gamma$	Mar 98	Moriond 2, Les Arcs
A Moutoussi	WW cross sections	Mar 98	Moriond 2, Les Arcs
P Spagnolo	Λ_b lifetime	Mar 98	La Thuile, Italy
MI Williams	$b \rightarrow s + \gamma$	Mar 98	PASCOS98, Boston
TR Edgecock	W mass	Apr 98	SILAF98, Puerto Rico
R Jones	Colour Reconnection	Jul 98	QCD98, Montpellier
A Halley	A_b^{fb} and A_c^{fb}	Jul 98	ICHEP98, Vancouver
JC Thompson	α_s from evt shapes	Jul 98	ICHEP98, Vancouver

7 PhDs awarded in the past 2 years:

Glasgow

Simon Dorris “Measurement of the Colour factors of QCD from 4-jet events at LEP”

Fiona Thomson “Measurements of $B_d^0 - \overline{B}_d^0$ Oscillations and the Inclusive b Lifetime at the Z ”

Stephen Thorn “Observation of semileptonic charmless bottom meson decays with the Aleph detector at LEP”

Lee Curtis “A topological study of multiplicity in the three jet $q\bar{q}g$ events at LEP”

Evelyn Thomson “Measurement of the W boson mass from $e^+e^- \rightarrow W^+W^- \rightarrow \ell\bar{\nu}q\bar{q}$ events with the ALEPH detector”

Imperial

Matthew Williams “Searches for Supersymmetry when R-Parity is violated at LEP2”

Lancaster

Mark Williams “Measurement of the inclusive branching ratio for $b \rightarrow s\gamma$ ”

Royal Holloway

Laurence Bryant “A Study of Isosinglet Neutral Heavy Leptons”

Jon Chambers “A precision measurement of the D^0 mass”

Sheffield

Robin Boswell “A Study of Wide-angle Bhabha Events at LEP1”

Warrick Newton “Measurement of the Inclusive 1-jet and 2-jet Cross Sections in $\gamma\gamma$ events at $\sqrt{s} = 91\text{GeV}$ ”

John Reeve “A Study of Hard Radiation in the Decay of $Z \rightarrow \mu^+\mu^-$ ”

Chris Brew “Measurement of the F_2 , F_A and F_B muonic structure functions of the photon”

Mandy Kelly “A search for gauge mediated supersymmetry breaking using the signal $e^+e^- \rightarrow \tilde{\ell}^+\tilde{\ell}^- \rightarrow \ell^+\ell^-\chi_1^0\chi_1^0 \rightarrow \ell^+\ell^-\tilde{G}\tilde{G}\gamma\gamma$ ”

8 List of UK people currently working on ALEPH

Key:

A = academics/advanced fellows

S = PPARC physics/programmers (who sign papers)

R = research associates/other fellows

T = technical hardware support staff

L = students

Glasgow

A — A Halley†, J Lynch, P Negus

S — AS Thompson

T — V O'Shea

R — P Teixeira-Dias, J Ward

L — M Chalmers, B Raeven, D Smith, J Kennedy

† CERN fellow until 30/6/00

Imperial College

A — D Binnie, I Butterworth, P Dornan, J Sedgbeer, JC Thompson (from 11/99)

S — W Cameron

T — G Barber, D Price, D Gentry

R — M Girone, A Sciaba, E Thomson

L — S Goodsir, J Nowell, R White

Lancaster

A — C Bowdery, F Foster, G Hughes, R Jones

S — A Finch

T — S Holt

R — M Smizanska (25%), AN Other

L — D Clark, G Ellis, N Robertson

Royal Holloway

A — G Blair, G Cowan, M Green, T Medcalf, J Strong

R — D Hutchcroft

T — B Green, G Boorman

L — J Coles, L Jones, J von Wimmersperg-Toeller

Sheffield

A — F Combley, C Booth, S Cartwright

S — L Thompson

R — M Lehto

L — P Hodgson

RAL

A — P Norton, JC Thompson (to 10/99)

S — RW Clift, TR Edgecock

T — J Bizzell

9 Staff Years/Category/Institute 1999-2003

Academic = HEFC Staff + PPARC Adv Fellows; Phys Prog = PPARC support physicist/programmers

RAs = PPARC RAs + other Fellows.

FTE units/year 99/00 00/01 01/02 02/03

Glasgow:

Academic	0.8	1.0	0.4	-
Phys Prog	0.2	0.2	0.1	-
Engineers/Tech	0.1	0.1	-	-
RA's	1.3	0.5	-	-
Students	3.5	2.0	0.5	-

ICSTM:

Academic	2.5	2.8	1.6	0.5
Phys Prog	0.6	0.4	-	-
Engineers/Tech	0.3	0.1	-	-
RA's	2.1	2.0	1.0	0.5
Students	3	2	1	-

Lancaster:

Academic	1.6	1.4	1.0	0.3
Phys Prog	1.0	1.0	0.5	0.2
Engineers/Tech	0.2	0.2	-	-
RA's	1.2	1.2	1.0	-
Students	3	3	2	1

RHC:

Academic	1.2	0.5	0.5	-
Engineers/Tech	0.1	0.1	-	-
RA's	1	1	0.5	-
Students	2	1	-	-

Sheffield:

Academic	1.0	0.5	0.3	-
Phys Prog	0.7	0.7	-	-
RA's	1	1	0.2	-
Students	1	1	-	-

RAL/PPD:

Faculty	0.6	0.1	0.1	-
Phys Prog	1.1	0.8	0.2	-
Engineers/Tech	0.1	0.3	-	-
RA's	-	-	-	-

TOTALs :

Academics	7.7	6.3	3.9	0.8
Phys Prog	3.6	3.1	0.8	0.2
Eng/Technicians	0.8	0.8	-	-
RA's	6.6	5.7	2.7	0.5
Students	12.5	9.0	3.5	1.0

RAL line 1999-2003

	99/00	00/01	01/02	02/03
(a) Funds:	(£k)			
o Maintenance/operations:				
Part A common (£1=2.2sf)	2	-	-	-
Part B	20	15	5	-
o Dismantling	-	51	-	-
o New Equipment	0			
o Travel	177	170	50	10
Totals	199	236	55	10
(b) Effort non-PPD:				
o Staff (FTE units)				
Indirect (Tech. Dept)	0.1	0.3	0.3	-