RECENT RESULTS FROM LEAR

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ABSTRACT

Experiments running at LEAR have strongly contributed to many different fields of high-energy physics. The most recent results coming from two experiments in the final year of LEAR running will be presented, and I will indicate where they have improved our understanding of CP violation and of QCD at low energies.

CP, T, and CPT symmetries in the neutral kaon system are studied by the CPLEAR experiment by measuring the decay rates of neutral kaons as a function of the proper time τ. Many of the parameters of these symmetries are measured at a level rivaling the world averages, and some are measured for the first time.

Tests of QCD in the nonperturbative regime via searches for bound states outside of the standard quark model have a long history, but in spite of many observed candidates, no compelling experimental evidence was available until recently. Now however, strong indications exist for non-$\bar{q}q$ states in the scalar sector, and forthcoming data should allow an unambiguous assignment.

1. CPLEAR

The aim of the CPLEAR experiment is to study CP, T, and CPT symmetries in the neutral-kaon system. The CPLEAR experiment measures the decay rates of initially tagged neutral kaons as a function of the proper time τ. Physics parameters are extracted from the decay-rate asymmetries

$$A_f(\tau) = \frac{R(\overline{\mathrm{K}}^0 \to \overline{f}) - R(\mathrm{K}^0 \to f)}{R(\overline{\mathrm{K}}^0 \to \overline{f}) + R(\mathrm{K}^0 \to f)} \,, \tag{1}$$

where f is one of the final states $\pi^+\pi^-, \pi^0\pi^0, \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$, and $\pi e \nu$. The asymmetry has the advantage to be only weakly dependent on detector efficiencies. The neutral kaons are produced in the reactions

$$\mathrm{p\overline{p}}\ (\text{at rest}) \quad \to \quad \begin{array}{l} \mathrm{K}^-\pi^+\mathrm{K}^0 \\ \mathrm{K}^+\pi^-\overline{\mathrm{K}}^0, \end{array}$$

with a branching ratio of $\approx 2 \times 10^{-3}$ each. The strangeness of the neutral kaon at its creation is defined by the reconstructed charged kaon.

A detailed description of the experiment can be found elsewhere.[1] Antiprotons of 200 MeV/c are stopped inside a high-pressure gaseous hydrogen target at a rate of about 10^6/s. The cylindrical detector is placed inside a solenoid of 1 m radius, 3.6 m length, which provides a magnetic field of 0.44 T. The tracking system consists of two proportional chambers, six drift chambers, and two layers of streamer tubes. Fast kaon identification is provided by a threshold Cherenkov counter sandwiched between two scintillators (also used for electron/pion separation). A lead/gas sampling calorimeter is used for photon detection. Fast and efficient online data selection is achieved with a multilevel trigger system based on custom-made hardwired processors. The cross section of the CPLEAR detector with a typical event ($\mathrm{K}^0 \to \pi^+\pi^-$ decay) is shown in Fig. 1. As an example, from which one can extract the CP-violation parameters η_{+-} and ϕ_{+-}, the rate asymmetry A_{+-} for the decay to $\pi^+\pi^-$ is shown in Fig. 2 (τ_S is the $\mathrm{K_S}$ mean life).

The current status of the CPLEAR measurements is shown in Table 1 (Ref.[2]). For the first time, a violation of T invariance has been directly determined. CPLEAR is able to disentangle CP- and CPT-violating quantities from each other. In many cases, the measurements of CPLEAR are comparable in precision to previous world averages.

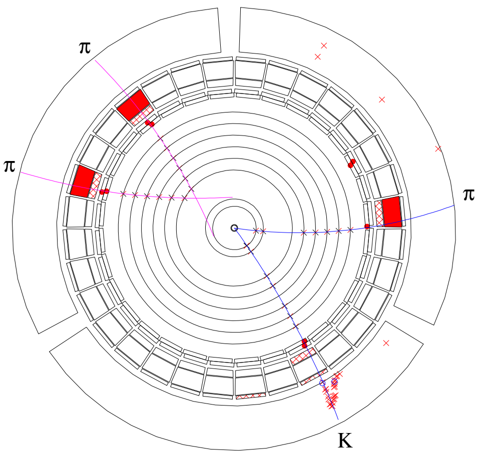


Fig. 1. *Typical CPLEAR event.*

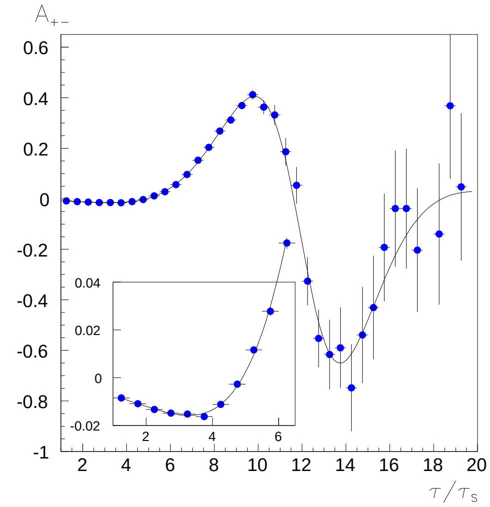


Fig. 2. *The asymmetry A_{+-}.*

2. Crystal Barrel

The strong interaction is successfully described by Quantum Chromodynamics, but its distinctive feature—the self-interactions of gluons—has been tested only indirectly and only at high energies through multijet cross sections and angular distributions. At low energies, however, the expected multigluon bound states have been searched for unsuccessfully. If such a state is composed entirely of valence gluons (gg or ggg), the resulting meson is called a glueball; if it is composed of a mixture of valence quarks, antiquarks, and gluons (i.e., $q\bar{q}g$), it is called a hybrid. In addition, $q\bar{q}q\bar{q}$ states are also predicted. An unambiguous confirmation of these states would be an important test of QCD and would give fundamental information on the behavior of this theory in the nonperturbative region.

In the absence of exact calculations, the spectroscopy of the $q\bar{q}$ meson system can best be accounted for by QCD-inspired models. The most complete of these, built by S. Godfrey and N. Isgur[3] in 1985, is able to describe with sufficient accuracy the $q\bar{q}$ spectrum from the pion to the Υ. This model is therefore often used in order to test whether a newly discovered resonance belongs or not to one of the $q\bar{q}$ multiplets.

Recent advances in lattice gauge theory calculations[4] are beginning to shed light on ordering of states, mass scale, and widths of the glueball spectrum. The most recent predictions[4] for the lowest lying 0^{++} and 2^{++} glueballs give masses in the range 1500–1800 MeV and 2200–2500 MeV respectively, and a total width of the 0^{++} of 108 ± 29 MeV. The mass of the 0^{-+} state is predicted to be similar to that of the 2^{++}. While the absolute mass scale is still uncertain at the 10% level, mainly because of uncertainties due to finite lattice spacing, use of the quenched approximation and uncertainties in mapping the string tension to the mass scale, the mass ratio prediction is in line with previous values from various other theoretical models (MIT bag model, potential models, QCD sum rules, flux-tube model).[5] The mass ordering of states is thus: $0^{++} < 2^{++} \sim 0^{-+}$.

The strategy developed over the last years for finding glueballs is based essentially on the comparison of meson spectroscopy from different production mechanisms, with the most recent experimental input concentrating on 0^{-+}, 2^{++}, and 0^{++} states. Given that glueballs may mix with nearby $q\bar{q}$ states with the same quantum numbers, it has also become clear that it will not be possible to identify a glueball in isolation, but that any candidate state has to be understood in the context of the $\bar{q}q$ multiplet with same the J^{PC}. Before proceeding with the identification of a glueball, however, the composition of the corresponding $\bar{q}q$ multiplet must, of course, be known, and much of the discussion is centered on determining this composition.

3. The 0^{++} Multiplet

At present, the most active area in terms of glueball searches is the scalar sector, since the lowest lying glueball is predicted to be a scalar state around 1.5 GeV. Until recently, the number of low-mass scalar states was consistent with the expectations of the quark model. Using the Godfrey-Isgur model as a guide, one can tentatively assign the low-mass scalar states listed in the following with those making up the 0^{++} multiplet. Although such an assignment is not necessarily unique, it has been shown by Törnqvist[6] that with very few parameters, one can fit the available data on the states in this assignment in the framework of a distorted 0^{++} $q\bar{q}$ nonet. The numbers in square brackets in the following table are the Godfrey-Isgur predictions for the masses (in MeV) for each state.

This assignment has several problems, and new data suggest a modified composition of the 0^{++} nonet. Much controversy surrounds the $f_0(975)$ and $a_0(980)$, mostly due to the proximity of the $K\bar{K}$ threshold, which suggests that $a_0(980)$ and the $f_0(975)$ might be weakly bound $K\bar{K}$ systems ("molecules") or of other non-$\bar{q}$q origin.[7] Also, the (mostly elastic) $f_0(1300)$ is seen strongly in further decay modes,[8] indicating at least one further isoscalar scalar state at this mass: in all observations, the dominant decay modes for this state are $\rho\rho$ and $\sigma\sigma$, with further decay modes amounting to less than 20% of all decay modes being $\pi^0\pi^0$ and $\eta\eta$ (Ref.[9]). Finally, the situation is confused by the large number of (often low statistics) observations of isoscalar scalar states below 2 GeV, unfortunately all called "f_0," but with various masses and widths. Recent advances on the experimental and theoretical side have considerably clarified the situation.

3.1 $\pi\pi$ S Wave

The inflation of isoscalar scalar states coupling to $\pi\pi$ final states has underlined the importance of understanding the $\pi\pi$ S wave, in order to identify clearly the observed resonances (and thus construct the 0^{++} multiplet), and to understand their widths and couplings. Anisovich *et al.*[10] have performed a coupled channel analysis of Crystal Barrel data[11] on $\bar{p}p \to \pi^0\pi^0\pi^0$, $\eta\eta\pi^0$, $\pi^0\pi^0\eta$ at rest, data on $\pi\pi$ scattering from GAMS[12] ($\pi p \to \pi^0\pi^0$n), CERN-Munich[13] ($\pi p \to \pi^+\pi^-$n), and BNL[14] ($\pi N \to K\bar{K}$n) as well as the inelastic cross section for the $\pi\pi$ interaction[15] to determine the $\pi\pi$ S-wave amplitudes.

In their best fit, four T-matrix poles are found below 1550 MeV, with masses of 1008, 1290, and 1497 MeV as relatively narrow states [identified with the observed scalar states $f_0(975)$, $f_0(1370)$ and $f_0(1500)$—see below], along with a very broad state with a mass between 1300 and 1600 MeV and a width of about 600 MeV [identified with the elastic $f_0(1300)$]. This broad state (referred to as "σ") is needed to account for interferences in most of the above data sets.

The lightest state has a large $\bar{s}s$ component; its partner in the 0^{++} nonet could be the $f_0(1370)$, leaving the very broad state as the first (nonstrange quark) radial excitation ($2\ {}^3P_0$), and the $f_0(1500)$ as the lightest glueball. This model predicts the existence of one further $\bar{s}s$-rich state in the region 1550–1850 MeV.

3.2 Experimental Situation: Isoscalar Scalars

Experimental information on the scalar sector comes mainly from new results from $\bar{p}p$ annihilation at rest and reanalysis of radiative J/ψ decays, with supporting information coming from $\gamma\gamma$ collisions and central and diffractive production.

The Crystal Barrel experiment has accumulated very large data samples in a large number of final states in the gluon-rich environment of $\bar{p}p$ annihilation.

Partial wave analyses of individual final states, or coupled channel analyses of several final states, have led to the observation of two scalar states, the $f_0(1370)$ and the $f_0(1500)$. The $f_0(1370)$ has been seen as a very broad $(4\pi)^0$ enhancement in nucleon-antinucleon annihilation into five pions by several experiments.[8] The mass and width of this state are compatible with the $f_0(1300)$, but its decay modes—which are compatible with those expected for a $(u\bar{u} + d\bar{d})$ state in the same nonet as $K_0^*(1430)$—are not. This state decays mostly to $\rho\rho$ and $\sigma\sigma$, and to a lesser degree to $\pi^0\pi^0$ and $\eta\eta$ (Ref.[9]).

In addition to this state, the Crystal Barrel group has observed a further new scalar state with a mass of 1500 MeV via its $\eta\eta$ and $\pi^0\pi^0$ decays. The band at 2.25 GeV^2 in the $3\pi^0$ Dalitz plot corresponds to the new state. The same scalar $f_0(1500)$ is seen in the $\pi\eta\eta$ Dalitz plot (Fig. 3) as the lower of the two diagonal bands (which correspond to states decaying into $\eta\eta$). In a coupled channel analysis, the following masses and widths for the two isoscalar scalar resonances are found:[16]

$$f_0(1370) \quad m = 1390 \pm 30 \text{ MeV} \quad \Gamma = 380 \pm 80 \text{ MeV}$$
$$f_0(1500) \quad m = 1500 \pm 10 \text{ MeV} \quad \Gamma = 154 \pm 30 \text{ MeV} .$$

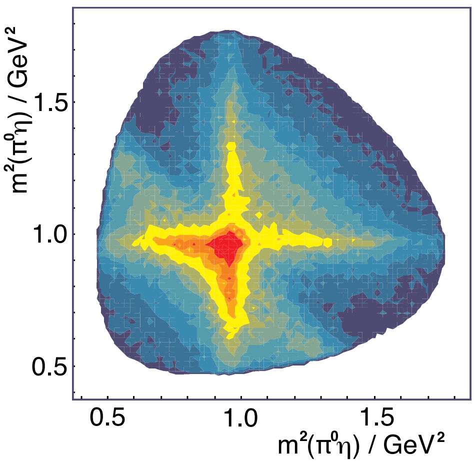
A state with values for mass and width consistent with those of the $f_0(1500)$ has also been observed in $\bar{p}p$ annihilation at 2.98 GeV (c.m. energy) by E-760 at Fermilab in the channels $\bar{p}p \to \pi^0\eta\eta$ and $\bar{p}p \to \pi^0\pi^0\pi^0$ (Ref.[17]); the resulting values are

$$\begin{aligned} M &= (1488 \pm 10 \text{ MeV, resp. } 1525 \pm 10 \text{ MeV }) \\ \Gamma &= (148 \pm 17 \text{ MeV, resp. } 111 \pm 10 \text{ MeV }), \end{aligned}$$

although until a partial wave analysis is performed, identification of either observation with the $f_0(1500)$ is based only on the similarity of the mass, width, and decay channels, and can thus only be tentative.

A third decay of the same state $f_0(1500)$ has been observed[18] in the channel $\bar{p}p \to \pi^0 f_0, f_0 \to \eta\eta'$ as a threshold enhancement. This enhancement is unlikely to be due to the decay $a_2 \to \eta'\pi^0$, since the corresponding decay $a_2 \to \eta\pi^0$ is not observed in $\pi^0\eta\eta$, and in fact, a spin-parity analysis of this $\eta\eta'$ resonance has confirmed the $f_0(1500)$ assignment.

More recently, the channel $\bar{p}p \to K_L K_L \pi^0$ has been observed [Fig. 5(b)] and a spin-parity analysis performed by the Crystal Barrel experiment.[19] Contrary



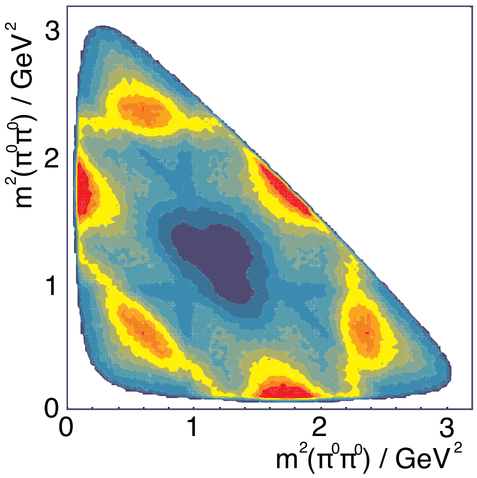


Fig. 3. *(a) Dalitz plot for $\pi^0\eta\eta$ events from the Crystal Barrel. Resonances in the $\eta\pi^0$ system are seen as horizontal and vertical bands, while resonances in the $\eta\eta$ system are seen as diagonal bands. The $f_0(1500)$ corresponds to the lower diagonal band; the $f_0(1370)$ to the upper diagonal band. (b) Dalitz plot for $3\pi^0$ events from the Crystal Barrel. The scalar amplitude $f_0(1500)$ corresponds to the narrow vertical band that crosses the Dalitz plot at $\sim$ 2.3 GeV^2 (and threefold symmetry).*

to previous bubble chamber experiments which only gave an upper limit[20] for the presence of a scalar state at 1500 MeV, this analysis with strongly increased statistics finds a nonzero signal for $f_0(1500) \to \bar{K}K$. At the same time, the $\bar{K}K$ coupling of the $f_0(1370)$ is measured; interestingly, neither state couples strongly to $\bar{K}K$, and neither is thus dominantly $\bar{s}s$.

Finally, the same state is also observed to decay into four pions via intermediate two-pion resonances[21] in the process $\bar{p}p \to 5\pi^0$. By comparing the production of $f_0(1500)$ in all observed decay channels, one finds that the coupling to four pions (i.e., $\rho\rho$ and $\sigma\sigma$) is dominant over all other couplings. Correcting for phase space, the following decay pattern, which is not the one expected for a standard $q\bar{q}$ state, is obtained:

$$\begin{aligned} f_0(1500) \to \quad & \pi\pi : \eta\eta : \eta\eta' : K\bar{K} : 4\pi = \\ & 3 : (0.72 \pm 0.37) : (1.05 \pm 0.44) : (0.72^{+0.49}_{-0.34}) : (10.2 \pm 2.4), \end{aligned}$$

although these values are somewhat analysis dependent.

Given its many decay channels, it would be surprising if this scalar state $f_0(1500)$ had not been observed before. Although initial analyses of radiative J/ψ decay and central production either ruled out a state at 1500 MeV, or gave different spin parity assignments, recent re-analyses[22] of the same data show clear evidence for a scalar state in the same mass region of ~ 1500 MeV in several decay modes in radiative J/ψ decay. Supporting evidence comes from central production,[23] where a compatible signal is observed.

In the original analysis of $J/\psi \to \gamma 4\pi$, only $\rho\rho$ decays of a scalar state were allowed, while the reanalysis greatly improves the fit by also allowing $\sigma\sigma$. The fit gives a width of the $f_0(1500)$ of $\Gamma \sim 120$ MeV, and a production branching ratio $\mathrm{BR}(J/\psi \to \gamma X \to \gamma 4\pi) \sim 10^{-3}$.

The $f_0(1500)$ also appears in other final states in radiative J/ψ decays, in particular in Mark III and DM2 data on $J/\psi \to \gamma\pi^0\pi^0$, but also in more recent data from BES. Their $\pi^0\pi^0$ spectrum [Fig. 4(b)] based on $7 \cdot 10^6$ J/ψ decays is fitted with five resonances at 1246 ± 31, 1477 ± 31, 1724 ± 36, 2042 ± 31, and 2230 ± 35 MeV (Ref.[24]). Assigning the 1477 MeV signal in Fig. 4 (b) to the $f_0(1500)$ and taking the known production branching ratio of $4 \pm 0.4 \cdot 10^{-4}$ for $J/\psi \to \gamma f_2(1270) \to \gamma\pi^0\pi^0$, one obtains a production branching ratio for $J/\psi \to \gamma f_0(1500) \to \gamma\pi^0\pi^0$ of $\sim 2 \cdot 10^{-4}$. Using the Crystal Barrel couplings of the $f_0(1500)$ to different final states, one then arrives at an independent and consistent estimate for the production branching ratio $\mathrm{BR}(J/\psi \to \gamma X \to \gamma 4\pi) \sim 1 \cdot 10^{-3}$. Adding all further decay modes observed by the Crystal Barrel would then bring the total branching ratio for $\mathrm{BR}(J/\psi \to \gamma f_0(1500))$ to $\sim 2 \cdot 10^{-3}$.

This (high) number allows one to draw conclusions on the nature of this state. Cakir and Farrar[25] have used semiperturbative QCD to derive a relationship between the branching fraction for a resonance in radiative quarkonium decay and its branching fraction into gluons. This analysis has been used in a recent paper by Close, Farrar, and Li[26] to analyze the $\bar{q}q$, resp. gluon content of several resonances produced in radiative J/ψ production. In particular, a 0^{++} state with width $\Gamma \sim 100$ MeV should have a branching ratio of $\sim 0.2 \cdot 10^{-3}$. Branching ratios $\sim 10^3$ require either a large width (~ 500 MeV) or a large gluonic content.

The fact that QCD sum rules predict a suppression by one order of magnitude for scalar glueballs relative to tensor glueballs in radiative J/ψ production,[27] coupled to the paucity of the available statistics, explain the initial non-observation of the $f_0(1500)$ in J/ψ radiative decays. In central production, on the other hand, a signal was observed,[28] but at a lower mass of 1450 MeV; this shift can be explained[23] by interference effects between the $f_0(1370)$ and the $f_0(1500)$. The upward shift in mass of the signal observed at 1590 MeV in $\pi^- p$ by GAMS[29] relative to the 1500 MeV of the $f_0(1500)$ is due to its observation in the final state

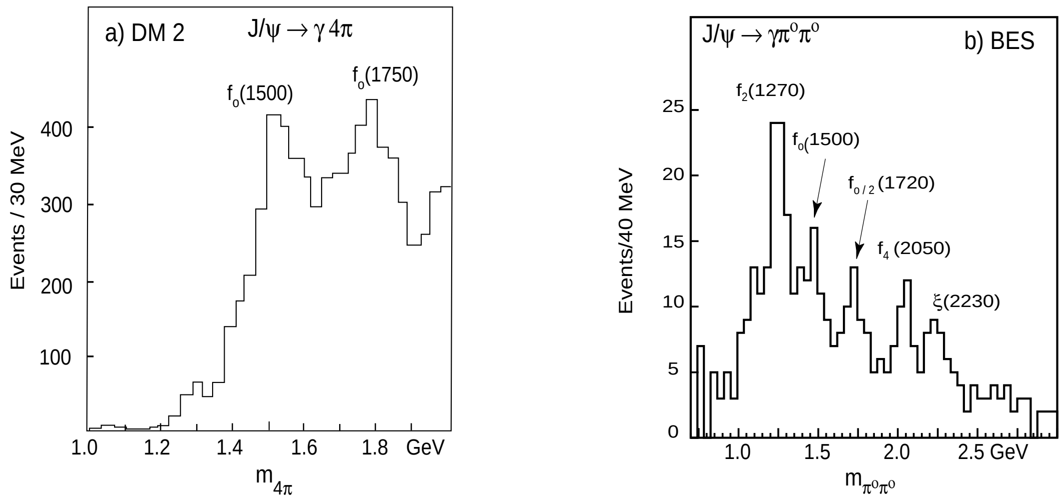


Fig. 4. *Radiative J/ψ decays: (a) Four-pion invariant mass spectrum from $J/\psi \to \gamma 4\pi$ from DM2. (b) Two π^0 invariant mass spectrum from $J/\psi \to \gamma 2\pi^0$ from BES. Both spectra indicate the presence of the $f_0(1500)$ in radiative J/ψ decays.*

$\eta\eta'$, where it appears just above the threshold for this channel. Its relative decays are mostly compatible with those of the $f_0(1500)$.

To summarize the scalar isoscalar situation, recent analyses have shown the presence of two new 0^{++} states, the $f_0(1370)$ and the $f_0(1500)$, neither of which is dominantly $\bar{s}s$, in addition to the already well-known $f_0(980)$ and $f_0(1300)$, while the quark model predicts only two states in the mass region below 1500 MeV.

3.3 Experimental Situation: Isovector Scalars

In addition to the above two new states, the Crystal Barrel group has presented evidence[30] for a new isoscalar scalar $\pi\eta$ resonance seen in a spin-parity analysis of a high-statistics Dalitz plot for the reaction $\bar{p}p \to \eta\pi^0\pi^0$. The pronounced interference pattern [Fig. 5(a)] is a reflection of the dominance of a single initial state, the $^1S_0$ state of the $\bar{p}p$ atom. The main structures of the Dalitz plot are a $\pi\pi$ S wave [$f_0(975)$ and $f_0(1370)$], an $\eta\pi$ D wave [$a_2(1320)$], and an $\eta\pi$ S wave. This $\eta\pi$ S wave consists of the $a_0(980)$, as well as of an $a_0(1450)$, although the later is not observed directly in the $\eta\pi$ spectrum but is a necessary ingredient in the fit. Although the $\bar{K}K$ decay of the $a_0(1450)$ has been searched for in the process $\bar{p}p \to \pi^0 K_L K_L$, the experimental data are not sensitive to this state. This state has however been seen[31] in three other decay channels, $\pi^0 K_L K_L$, $\bar{p}p \to K^0 K^\pm \pi^\mp$, and $\pi^0\pi^0\eta'$. Fits of Crystal Barrel data on $\bar{p}p \to \eta'\pi^0\pi^0$ accommodate $2.8^{+3.3}_{-0.7}$ % of

$a_0(1450) \rightarrow \eta'\pi^0$, corresponding to a ratio of branching ratios $a_0 \rightarrow \eta'\pi$ / $a_0 \rightarrow \eta\pi$ of $0.31^{+0.38}_{-0.14}$, whereas SU_3 would predict 0.38±0.06.

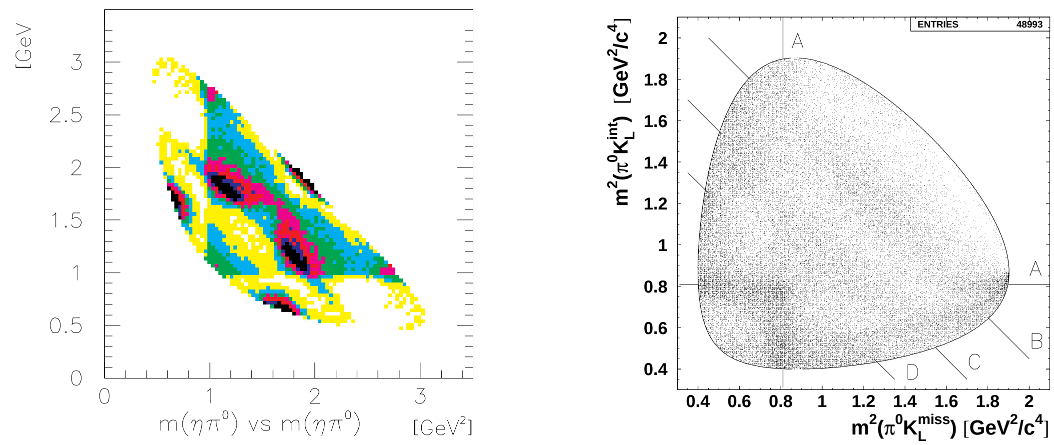


Fig. 5. *(a) Dalitz plot for* $\eta\pi^0\pi^0$ *events from the Crystal Barrel. (b) Dalitz plot for* $\pi^0 K_L K_L$ *events from the Crystal Barrel. The lines indicate the positions of the* $K\pi$ *resonance* K^**(892) (line A), and of the* $\bar{K}K$ *resonances* f_2*(1270)/*a_2*(1320),* f_0*(1370)/*a_0*(1450), and* f_0*(1500)/*f_2*(1525) (lines B, C and D).*

3.4 Interpretation of the Scalar States

With the observation of three new scalar states [$f_0(1370)$, $f_0(1500)$, and $a_0(1450)$] in very high statistics experiments, the number of low-mass states exceeds that expected for the scalar nonet. The branching fractions of the $f_0(1370)$ and $f_0(1500)$ into $\pi\pi$, $\eta\eta$, $\eta\eta'$, and $\bar{K}K$ are both inconsistent with being dominantly $\bar{s}s$, and are consistent with both being mostly $\bar{u}u+\bar{d}d$ (although clearly, both cannot belong to the same scalar nonet), while the $\bar{s}s$ is not yet identified. The $f_0(1500)$ is unusual in that it is not observed in $\gamma\gamma$ collisions[32] (although the current upper limits are not sufficient to exclude a $\bar{q}q$ assignment) and in that it is relatively narrow ($\Gamma \sim 120$ MeV). In particular, its $\pi\pi$ partial width is of the order of 20 MeV, while $\bar{q}q$ states—like the $K^*(1430)$ with its dominant decay mode of Kπ—have a width of 290 MeV. It is this later property, along with its various decay modes, that makes it very unlikely that it is the first radial excitation, i.e., the $2\ ^3P_0$ state. Drawing further conclusions requires comparing the properties of all scalar states with those expected for $q\bar{q}$ states individually and for the nonet as a whole, as well as for gg states.

Although several recent approaches, such as the unitarized quark model,[6] or the instanton model,[33] address this problem and are able to account for part of the experimental data, the resulting picture is incomplete since neither model accounts for all observed states, nor their properties. In the later, the $f_0(1500)$ is the $(u\bar{u}{+}d\bar{d})$ member of the scalar nonet (whose $\bar{K}K$ decay mode is suppressed), while the singlet (mostly $s\bar{s}$) state is the $f_0(980)$, leaving the $f_0(1370)$ unexplained. In the unitarized quark model, the roles of $f_0(1500)$ and $f_0(1370)$ are exchanged, leaving the $f_0(1500)$ isolated.

An alternative approach, developed by Amsler and Close,[34] makes testable predictions on couplings and masses of the scalar states. Assuming SU(3), the relative couplings of a $q\bar{q}$ state are calculated for different mixing nonet angles, and they find that seen in isolation, the couplings of the $f_0(1370)$ and of the $f_0(1500)$ are consistent with a dominantly $u\bar{u} + d\bar{d}$ composition. Assigning either state to the scalar nonet leaves the other state isolated and requires that the $\bar{s}s$ state, which has not yet been discovered, be heavier than the $f_0(1500)$. They show that the decay rates of the $f_0(1500)$ are compatible with those of a glueball state with mass intermediate between the $(\bar{u}u{+}\bar{d}d)$ and $\bar{s}s$ states of the multiplet, whose proximity in mass leads to mixing of the three scalar states. The state $f_0^{\bar{s}s}$ is predicted to lie in the mass range (1600–1800), and should couple mainly to $\bar{K}K$ and $\eta\eta'$. Due to mixing, the width of this state should be reduced relative to the widths of the $K^*(1430)$ or of the $a_0(1450)$. Similar conclusions are reached by V. Anisovitch *et al.*, who find that $f_0(975)$ and $f_0(1600--1800)$ could be the (dominantly) $\bar{s}s$ $1\ ^3P_0$ and $2\ ^3P_0$ members of the scalar $\bar{q}q$ nonets, while $f_0(1370)$, $f_0(1500)$, and $f_0(400--1400)$ could be a mix of (mostly non-$\bar{s}s$) $1\ ^3P_0$, $2\ ^3P_0$ and the lowest lying glueball. In their latest analysis,[35] they find that it is the broad resonance $f_0(400--1400)$ which contains the largest (40–50%) glueball component, with the remainder being shared among the narrower resonances $f_0(1370)$ and $f_0(1500)$, which are then mostly the $1\ ^3P_0$ and $2\ ^3P_0$ states.

4. Conclusions

CPLEAR has directly determined, for the first time, a violation of T invariance and is able to disentangle CP– and CPT–violating quantities from each other. This allows, in particular, the mass and width equality between the K^0 and $\overline{K}^0$ to be tested down to the level of 10^{-19} GeV. Moreover, the precision of the CPLEAR measurements allows us to probe for the first time physics on a scale approaching the Planck mass.

The recent observations of at least three scalar states [$f_0(1370)$, $f_0(1500)$ and $a_0(1450)$] in very high statistics and large acceptance experiments have contributed to a reappraisal of the scalar nonet. Given the masses, widths, and decay patterns of these scalars, it is possible to propose an assignment for the scalar nonet which consists of the mostly $u\bar{u} + d\bar{d}$ isoscalar $f_0(1370)$, and the isovector $a_0(1450)$, whose masses and widths are comparable to the strange member of the scalar nonet, the $K^*(1430)$. The $f_0(1500)$, on the other hand, has a very different and much smaller width than any of these states, but its decays are not those one would naively expect for a glueball. In the model of Amsler and Close, this state is a glueball, but is mixed with the $q\bar{q}$ states in the nonet, both the $f_0(1370)$ and a mostly $s\bar{s}$ isoscalar state, which remains to be discovered. The characteristics of this predicted state (mass, width, and decay pattern) are strongly constrained by this model.

Crucial tests of this assignment are the determination of the nature of the $f_0(975)$, for example, in radiative decays of the ϕ to $f_0(975)$ (Ref.[36]), confirmation of the $a_0(1450)$ seen by the Crystal Barrel, a reduction of the systematic errors for the $K\bar{K}$ coupling of the $f_0(1350)$ and $f_0(1500)$ seen by the Crystal Barrel and possibly by E-760, and finally, a detection and study of the predicted $f_0^{\bar{s}s}(1600$–$1800)$. Given this list of open questions, it is natural that kaonic final states dominate the agenda for the final year of spectroscopy at LEAR.

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Table 1. The current status of the CPLEAR measurements.

Δm	$(529.2 \pm 1.8_{stat} \pm 0.5_{syst})10^7 \hbar s^{-1}$	$K_L - K_S$ mass difference
$\|\eta_{+-}\|$	$(2.316 \pm 0.025_{stat} \pm 0.030_{syst})10^{-3}$	CP violation
ϕ_{+-}	$(43.5 \pm 0.5_{stat} \pm 0.5_{syst} \pm 0.4_{\Delta m})^o$	Test of CPT invariance
$\|\eta_{00}\|$	$(2.49 \pm 0.40_{stat} \pm 0.23_{syst})10^{-3}$	CP violation
ϕ_{00}	$(51.7 \pm 7.1_{stat} \pm 1.5_{syst} \pm 0.4_{\Delta m})^o$	Test of CPT invariance
$Re\eta_{+-0}$	$(-4 \pm 8_{stat} \pm 2_{syst})10^{-3}$	CP violation in K_S domain
$Im\eta_{+-0}$	$(-3 \pm 10_{stat} \pm 2_{syst})10^{-3}$	”
$Re\eta_{000}$	$0.15 \pm 0.30_{stat} \pm 0.04_{syst}$	CP violation in K_S domain
$Im\eta_{000}$	$0.29 \pm 0.40_{stat} \pm 0.03_{syst}$	”
A_T	$(6.3 \pm 2.1_{stat} \pm 1.8_{syst})10^{-3}$	Direct evidence for T violation
A_{CPT}	$(0.28 \pm 2.1_{stat} \pm 1.8_{syst})10^{-3}$	Direct meas.^{t} of CPT invariance
Rex	$(8.5 \pm 7.5_{stat} \pm 6.9_{syst})10^{-3}$	Test of $\Delta S = \Delta Q$ rule
$Im(x + \delta)$	$(0.5 \pm 2.4_{stat} \pm 0.6_{syst})10^{-3}$	”
α	$(-0.5 \pm 2.8)10^{-17}$ GeV	Test of Quantum Mechanics
β	$(2.5 \pm 2.3)10^{-19}$ GeV	”
γ	$(1.1 \pm 2.5)10^{-21}$ GeV	”

I=1	I=0	I=1/2
$a_0(980)$ [1090]	$f_0(975)$ [1090] $f_0(1300)$ [1360]	$K_0^*(1430)$ [1240]