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ABSTRACT

Several experiments at LEAR concern themselves with meson spectroscopy and searches for exotics in the annihilation of antiprotons with protons at rest. In JETSET we will exclusively study in-flight annihilations in a search for gluonic states and exotics in the mass region from 1.96 to 2.43 GeV. The experiment uses a molecular hydrogen gas jet target and an advanced general purpose detector, which surrounds the interaction point. One of the unique features of the detector is its excellent kaon identification at the trigger level. This will enable us to achieve our first physics goal of searching for resonances in the excitation function of the OZI-forbidden, "gluon rich" reaction $\bar{p}p \rightarrow \phi\phi$. The physics interest in the $\phi\phi$ channel and additional goals of the collaboration will be outlined.

INTRODUCTION

At this conference and in the last few years we have seen a wealth of new data pertaining to searches for possible gluonic resonances (gg and $g\bar{q}q$) and to "ordinary" quarkonium ($\bar{q}q$) states. Many of these data suggest interesting new physics at masses above 2 GeV. We have begun a dedicated experimental program at LEAR (PS202) measuring $\bar{p}p \rightarrow M_1 M_2$ and we will begin taking data in 1990. The initial (Phase I) focus of this program is a detailed study of the in-flight production of $K^+ K^- K^+ K^-$, including $\phi K^+ K^-$ and most importantly $\phi\phi$. In Phase II, the detector will include additional sophisticated components which will open up a wide variety of physics channels, some of which are discussed below.

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JETSET AT A GLANCE

The JETSET experiment at LEAR will be unique among the new generation post-ACOL efforts in that it will be built around one of the straight sections of the antiproton facility itself. A molecular hydrogen gas jet target will cross the ring, providing a "massless" pure proton target for in-flight interactions. With a gas jet density of 8×10^{13} atoms/cm², a LEAR $\bar{p}$ revolution frequency of 3.2×10^6 s⁻¹ and an assumed injection of 4×10^{10} $\bar{p}$ into the storage ring, a peak luminosity of 10^{31} cm⁻² s⁻¹ will be achieved. This luminosity exceeds the most optimistic external-beam experiments by about a factor of 20 or more and opens up the possibility of doing high statistics measurements in rare channels.

Due to continuous stochastic cooling, the momentum uncertainty of the LEAR beam is quite small, $\Delta p/p \approx 10^{-3}$. With this small momentum spread, even very narrow width states can be probed effectively by varying the beam momentum, the practical range is from 600 to 2000 MeV/c, while measuring the production cross section. The experimental mass resolution with this method is about 0.5 MeV. With high statistics and a full solid angle detector, a partial-wave analysis becomes possible, allowing a determination of the quantum numbers of any new state.

From an experimental point of view, the environment is particularly hostile. At LEAR energies, $\sigma_{total}(\bar{p}p)$ is approximately 100 mb, implying an interaction rate of about 10^6 Hz. In order to realize our first goal of collecting $\bar{p}p \rightarrow K^+ K^- K^+ K^-$ events ($\sigma \approx 4 \mu b$) and $\bar{p}p \rightarrow \phi\phi$ events (which have never been observed!), a very compact, fast, and modern detector has been designed. With such a device and an assumed cross section for $\bar{p}p \rightarrow \phi\phi$ of about $0.4 \mu b$, we would collect a few times 10^4 events per day, far exceeding the world total for any final-state " $\phi\phi$ " events.

The detector will surround the beam pipe and the gas jet, and will be divided into a "barrel" and a "forward" region of essentially identical components. The Phase I detector, which is shown in the bottom half of Figure 1, will be ready by early 1990. It will have no magnet and will include

- an innovative set of interwoven, multilayered plastic scintillation counters used as a high granularity charged multiplicity trigger. Unique (θ, ϕ) coordinates are determined in less than 100 ns and will be used with a fast kinematic filter in order to select only those events with a correct $4K^\pm$ topology.
- a fast, segmented threshold Čerenkov counter in the barrel region in order to reject the dominate charged pion background. Additionally, there will be a ring-imaging Čerenkov counter (RICH) in the forward region. The RICH will provide needed redundancy on the momentum assignment of measured tracks.
- a precision wire tracker made from self-supporting "straw tube" technology. There will be about 1600 such cylindrical drift tubes in the barrel region. They will be made from rolled aluminized mylar and are packed and glued tightly together around the beam pipe. The total structure will have excellent mechanical rigidity and will not require massive endplates characteristic of ordinary cylindrical wire chamber designs. Each straw tube will house a single resistive wire and will be equipped with appropriate electronics to determine the transverse coordinate $\sigma_t \leq 100 \mu m$ (by drift time) and the longitudinal coordinate $\sigma_l \leq 0.5$ cm (by charge division).

Figure 1: JETSET detector in Phase I (bottom) and Phase II (top).

- a fast γ veto detector with a low threshold surrounding the barrel in order to identify events with π^0 s. In the forward region, there will be a fast, dense electromagnetic calorimeter having excellent spatial resolution and good energy resolution ($\sigma_{xy} \approx 5\text{mm}$, $\sigma(E)/E \approx 9\%/\sqrt{E}$; E in GeV). This calorimeter will be based on the new technology of plastic scintillating fibers embedded within specially formed Pb foils in a close-packed geometry. The detectors will be oriented such that the fibers point toward the interaction region, allowing photomultiplier tube readout on the outside of the detector, while also eliminating dead spaces. The phase I detector will have a complete γ veto counter in the forward region, which will also aid in particle identification by a crude energy measurement for charged particles.
- a fast, modular data acquisition system based on multiple, VME-based, CERN Valet-Plus [1] systems interconnected with a transputer network. Event data will flow from the respective detector components to individual data acquisition systems and will be gathered by a final master Valet-Plus system where they will be logged to tape.

We are already developing several important components in order to enhance the

overall performance of the basic detector and to lead to a broader physics program. The complete general purpose device for Phase II is shown schematically in the top half of Figure 1 and includes additionally

- a warm, solenoidal magnet which will surround the entire detector. The LEAR team is modeling the effect of such an element on the circulating beam (which couples the horizontal and vertical oscillations). With the use of a pair of opposite-polarity compensating solenoids, Baird [2] has demonstrated that a magnet with an $\int B \cdot dl \leq 1.5 \text{ T}\cdot\text{m}$ appears to be acceptable.
- a high-precision Si μ strip tracker capable of a transverse resolution of better than $50\mu\text{m}$. This will be used in conjunction with the magnet and the straws in order to make an accurate measurement of $p_{\perp}$ for charged tracks.
- the electromagnetic calorimeter extended to the barrel region. This will allow a much wider physics program by including identifiable neutrals in the final state. With the resolution as projected, neutrals-only final states such as $\pi^0\pi^0$, $\pi^0\eta$, and $\eta\eta$ will become realistic objectives.

LIFE ABOVE $\sqrt{s} = 2m_p$

The $\bar{p}p \rightarrow M_1 M_2$ “in-flight” reaction at LEAR can explore the mass range from 1.96 to 2.43 GeV in direct formation experiments. While this range represents a rather narrow window of opportunity (for example, compared to the natural width of strongly decaying high-mass states), it is actually relatively unexplored and potentially rich in new physics. The reasons for the experimental neglect may be loosely tied to the fact that much of the older data coming from $\bar{p}p$ and the newer LEAR data are based on annihilations at rest. Spectroscopy coming from radiative J/Ψ decays, while capable of seeing structure all the way up to the η_c , tends to be rather low in statistics in the high-mass region. Also, many of the past experiments have lacked the ability to look into channels involving neutrals.

A few tantalizing and promising signs of life above $2m_p$ have recently appeared from both the experimental and theoretical side. A partial list of unexplained, observed resonances in this region at this writing includes

- three broad, $J^{PC} = 2^{++}$ states labeled $g_T(2011)$, $g_{T'}(2297)$, and $g_{T''}(2339)$ and seen as $\phi\phi$ resonances at Brookhaven [3] in the OZI-forbidden reaction $\pi^- p \rightarrow \phi\phi n$. These states were found through a sophisticated partial-wave analysis and are interpreted by the authors as potential glueball states due, in part, to their copious production compared to other OZI-allowed background reactions.
- structure in the $\phi\phi$ invariant mass spectrum from an inclusive experiment at the CERN Ω Spectrometer which studied the reaction $\pi^- Be \rightarrow \phi\phi X$ at 85 GeV (the WA67 [4] collaboration). The structure is compatible with the Brookhaven measurement at least for the higher-mass states.
- a single 0^- state at about 2.2 GeV which was seen by the MARK III collaboration [5] and (possibly?) the DM2 collaboration [6] in radiative J/Ψ decays to $\phi\phi$ final states. These data are interesting both for the structure which is seen and, moreover, for the non-observation of the prominent, “glueball candidate” g_T ’s.

Figure 2: Possible diagram for $\bar{p}p \rightarrow \phi\phi$.

- the narrow $\xi(2230)$ state first seen by MARK III [8] in $J/\Psi \rightarrow \gamma \bar{K} K$, including $K_s K_s$ and $K^+ K^-$, which remains a mystery [7]. However, there now appears to be at least some independent confirmation from the GAMS [9] collaboration in $\pi^- p \rightarrow \eta \eta' n$ and from the LASS [10] collaboration in the reaction $K^- p \rightarrow \bar{K} K \Lambda$. The $\eta \eta'$ invariant mass plot from GAMS shows a clear narrow peak, and in the partial-wave analysis of the LASS $K^+ K^-$ data, a narrow structure stands out with a J^{PC} of 4^{++} . Are these all the $\xi(2230)$? If these are, then the $^3F_4 s\bar{s}$ meson interpretation of the ξ by Godfrey and Isgur [11] is the likely explanation. We would expect approximately a 10% branching ratio to a $\phi\phi$ final state and a family ($^3F_2, ^3F_3$) nearby in mass which would also decay to $\phi\phi$.
- possible (??) peaks around 2.1-2.3 GeV in the MARK III data shown by Wisniewski [5] at this conference in the reactions $J/\Psi \rightarrow \gamma \eta \eta$ and $J/\Psi \rightarrow \gamma \bar{K}^* K^*$. These spectra were quite preliminary and the bumps in the data were not identified by the collaboration as an indication of new states.

In summary, this “unexplored” region between $2m_p$ and the η_c is already showing signs of lots of life. Certainly, more dedicated studies would be welcome.

WHY $\phi\phi$?

The reaction $\bar{p}p \rightarrow \phi\phi$ provides a very special filter to the world of hidden strangeness and gluonic intermediate states. The reaction can proceed through several competing processes. First, an $s\bar{s}$ pair can be scattered from the quark sea (the strange quark content of the proton). Second, an allowed reaction can proceed via the non-strange component of the ϕ ($\approx 1\%$) which then decays through the dominate $s\bar{s}$ component by $\omega - \phi$ mixing. Finally, as in Figure 2, coherent annihilation of the incoming non-strange quarks and antiquarks is followed by production of a $\phi\phi$ pair through a 2-gluon intermediate state. It is in this reaction that one hopes for production of glueballs. But as mentioned above, ordinary $s\bar{s}$ quarkonium states which decay to $\phi\phi$ are also expected in our mass region.

If one sees a resonance in a gluon-rich channel, is it a glueball? Not necessarily, but it immediately becomes a candidate on which a number of traditional tests can be made. These traditional tests include: flavor independent decays ($gg \rightarrow \phi\phi, \rho\rho, \omega\omega$ approximately equally), narrow widths ($\sqrt{OZI}$ rule implies $\Gamma \approx 10\text{-}30$ MeV), and predicted radiative decay ratios ($gg \rightarrow \gamma\rho : \gamma\omega : \gamma\phi = 9:1:2$), however the first two tests are now questioned and the last is nearly impossible experimentally! Following the suggestion of

Figure 3: Diagram for $\bar{p}p \rightarrow \phi\omega$.

Close [12], we can make tests which might exclude rather than confirm a glueball candidate. In the JETSET context, such anti-tests might include observation of the same resonance in both $K\bar{K}$ and in $K^*\bar{K}$, or into both $\phi\phi$ and $\phi\eta$, or $\phi\pi^0$ final states. We will be sensitive to $K_s K_s$ events from the beginning. Other tests have been suggested and can be found in excellent reviews on the subject [13]. The overall message is that it will take a multi-channelled, multi-experimental approach in order to confirm fully a state as a pure gluonic hadron, and that more experimental inputs are needed in this field.

WHAT ELSE CAN WE DO...BEYOND $\phi\phi$

There are several attractive approaches to finding exotics, which we are beginning to study within the capabilities of our complete general-purpose detector. The reaction $\bar{p}p \rightarrow \phi\omega$ is an OZI-forbidden decay from any ordinary $q\bar{q}$ state and therefore promises to be a hunting ground for interesting states of matter. Close [14] predicts that the natural “pecking order” for decays to $\phi\omega$ would be $qq\bar{q}\bar{q}, gq\bar{q}, gg$, then $q\bar{q}$. Chanowitz and Sharpe [15] have suggested that the $\xi(2230)$ might be a hybrid state which would have an appreciable branching fraction to $\phi\omega$. Under the assumption that the color-rescattering graph shown in Figure 3 has a non-negligible probability, then production of hybrid states as described in the bag model would be a possibility within the JETSET direct production approach.

The clearest signature for an exotic is one which has a J^{PC} combination forbidden to any $q\bar{q}$ state ($0^{+-}, 1^{-+}, 2^{+-}, \dots$). Indeed, at this conference the GAMS [16] collaboration showed (controversial!) data indicating a possible “CP-exotic” 1^{-+} state at 1405 MeV. For JETSET, no such state can be directly formed ($\bar{p}p$ is like $\bar{q}q$). However, with LEAR operating at 2 GeV/c, data taken in association with an outgoing π^0 such as $\bar{p}p \rightarrow (\phi\pi^0)\pi^0$, or $(\phi\eta)\pi^0$ or $(\bar{K}K^*(1420))\pi^0$ could lead to sensitive and interesting tests. Isgur *et al.* [17] predict that the latter reaction would lead to a hybrid meson with exotic quantum numbers at a mass of 2.1 GeV and a width of about 0.35 GeV.

SUMMARY

In summary, the JETSET collaboration is actively building a state-of-the-art detector capable of probing rare, exclusive reactions from $\bar{p}p$ annihilations in flight. We plan to exploit fully our unique experimental situation and to expand our Phase I detector capabilities in order to meet the challenge of this very promising, yet largely unexplored, physics arena.

We are particularly grateful for the stimulating dialog which has begun with F. Close and N. Isgur at our most recent JETSET collaboration meeting. One of us (DWH) wishes to acknowledge partial support for this project from the University of Illinois Research Board and from the United States National Science Foundation contract NSF PHY 86-10493.

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