APPENDIX I.

SUMMARY

A SUMMARY OF THE TOPICS DISCUSSED AT THE FIRST FERMILAB ANTIMATTER PHYSICS AT LOW ENERGY WORKSHOP

INTRODUCTION

A workshop was held at Fermilab during April 10-12, 1986 for the purpose of identifying the physics that could be done at Fermilab with cooled antiprotons below 10 GeV/c. A complete proceedings will be available soon; the purpose of this letter is to give a brief overview of the topics which were discussed at the workshop.

The present and future experimental programs at LEAR were detailed in talks by Kilian[1] and Landua.[2] An additional talk by Mohl[3] presented the machine development possibilities and then the harsh realities imposed by budget shortfalls and competition with LEP. During the three years that LEAR has operated, it has provided beam for experiments 30 days per year. Looking ahead to post-ACOL operation, Mohl estimated that in 1992, LEAR would still be expected to provide beam for experiments 30 days per year and even that would be with an average flux limited to 10^6/sec. A study was made to upgrade LEAR significantly in several parameters (SUPERLEAR); the Research Board regretfully rejected this on the basis of lack of resources.[4] Therefore, the likelihood that LEAR can achieve its promise of doing all the significant physics below 2 GeV/c is vanishingly small. There is an abundance of good physics to justify an additional facility at Fermilab that would cover the LEAR range as well as go beyond the 2 GeV/c upper limit at LEAR.

A simple example of the capabilities that would be available at Fermilab is provided by the $\Delta S=1$ CP violation experiment, $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$, discussed at the workshop.[5] In order to detect this effect at the predicted level of 10^{-4}, one must measure 10^8 $\Lambda\Lambda$ pairs. At post-ACOL LEAR one requires 100 days at 10^7 $\bar{p}$/sec (an unimaginable scenario). At its anticipated rate of 30 days/yr at 10^6 $\bar{p}$/sec, this experiment will require 30 years. At a Fermilab facility it would take a month.

It is important to realize that a low energy $\bar{p}$ program can be implemented at Fermilab without competing with the high energy program.[6] That this is not the case at CERN is the source of much of the difficulty.

PHYSICS OVERVIEW

In the opening talk at the workshop, Jaffe outlined his view of the significant physics that could be addressed with a $\bar{p}$ machine.[7] He began by reviewing two broad general areas of concern in particle physics today. These are the "Origins of the Standard Model", and "Dynamics of Confinement in QCD".

The Standard Model has of course met with considerable success. This very success has tended to obscure the point that there are many parameters and inputs which are arbitrary and unexplained. For example, we do not know the sources of weak symmetry breakdown, the origins of CP violations, the source of quark and lepton masses and angles, and even the fundamental gauge group. Low energy antiproton machines can contribute to our knowledge in these areas most directly through opportunities to investigate various invariance principles and their violations such as T, CP, and CPT.

QCD is another theory that has arrived with much fanfare, but even after more than a decade of work many fundamental questions still remain to be answered. In particular, how does confinement come about? The naive models at hadronic length scales are rich but surprisingly simple. How does one go beyond these naive models? Where are the gluonic and relativistic degrees of freedom? Low energy antiproton machines can go far in providing the data required to answer these hard questions. First, $\bar{p}p$ offers an excellent initial state to couple directly to the rich spectroscopy of heavy quark systems, in particular Charmonium physics. Bottomonium is likely to be out of the question because of its small couping to $\bar{p}p$. However, nucleon-antinucleon initial states also offer an excellent vehicle to study meson spectroscopy and the world of gluons, meiktons, and baryonia. Further, detailed studies of annihilation mechanisms offer the prospect of following individual quarks through various dynamical processes.

One can add to the above lists the prospects of having cold trapped antiprotons for use in gravity and condensed matter studies. One might even conjecture the possible transport of bottled antiprotons to other laboratories for use in other accelerators. There is also the continued study of antiproton-atomic physics, and antiproton-nuclear physics which includes possible quark-gluon plasma studies. One can also use the $\bar{p}p \rightarrow \bar{Y}Y$ reaction to produce beams of tagged hyperons. The potential for polarized antinucleons would imply a new powerful tool to investigate the spin dependence of most of the physics considered.

INVARIANCE PRINCIPLES

There are several interesting techniques to probe invariance principles that can be addressed uniquely at an antiproton facility. First, in the reactions:

$$\bar{p}p \rightarrow \begin{array}{l} K^-\pi^+K^0 \\ K^+\pi^-\bar{K}^0 \end{array} ,$$

the sign of the Kaon (and the initial pion) tags the K^0 or $\bar{K}^0$ uniquely. One can then use these initial states to explore CP violation. A first generation experiment to explore CP violation in this manner has been proposed and approved for running at LEAR.[8] That experiment hopes to achieve the following values:

Parameter	Proposed at LEAR	Present
$\lvert \varepsilon'/\varepsilon \rvert$	$\rightarrow 2 \cdot 10^{-3}$	$< 4.7 \cdot 10^{-3}$
η_{+-0}	$\rightarrow 6 \cdot 10^{-4}$	$< 1.2 \cdot 10^{-1}$
η_{000}	$\rightarrow 8 \cdot 10^{-4}$	$< 10^{-1}$
$\phi_{+-} - \phi_{00}$	$\rightarrow 2^{\circ}$	5°

Using the same production reaction, one can also compare rates K^+e^+/K^-e^- where the electrons come from K^o or $\overline{K}^o$ weak decay. If CPT holds, one expects the first direct observation of T violation at a level of 10^{-3} in this ratio. CPT itself can be directly tested by careful $K^o\overline{K}^o$ mass measurements and K^+K^- lifetime measurements. These experiments have been considered at LEAR but probably will not be done there.[9]

Finally, a recent suggestion of Donoghue is to look for $\Delta S=1$ CP violation in $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$.[10] This can be accomplished by measuring the asymmetry between the Λ and $\overline{\Lambda}$ decay product directions with respect to their production plane. The asymmetry is proportional to $\alpha + \overline{\alpha}$ where α is the Λ decay parameter. Constraints on ε' yield estimates of the asymmetry in the range of 10^{-4} which means that an experiment must examine 10^8 $\Lambda\overline{\Lambda}$ pairs. Note that $\varepsilon'=0$ still gives a possible asymmetry in $\Lambda\overline{\Lambda}$ decays. Such a flux is unreasonable for LEAR with the present constraints but would be quite feasible at a new Fermilab facility. There are further experiments on cascade and Σ decays that could add even more information on CP violations such as a measurement of β, the imaginary companion to α for the appropriate hyperon decay. Even the observation of CP violation in hyperons would have a profound implication. Its very existence would mean that CP violation is a "milliweak" and not a "superweak" phenomenon. Since the decays of $\Sigma^{\pm}$, Λ, and Ξ all provide different tests of the CP odd interaction, and since the weak interaction models each have a different SU(3) structure, it is likely that if these systems are well studied, the true nature of CP violations can be determined.

CHARMONIUM

The existence of E760 at Fermilab shows the present level of interest in this area of physics at Fermilab already. The use of the accumulator as an experimental facility with an internal target is cumbersome. It is clear that any improvement over the proposed E760 apparatus will be impractical due to space limitations or constraints on magnetic spectroscopy.

The first generation Fermilab Charmonium experiment will attempt to continue the R704 effort from the ISR with higher statistics and better resolution.[11] They hope to discover the $^1P_1(1^{+-})$, $^3D_2(2^{--})$, and $^1D_2(2^{-+})$ as well as confirm η_c'. They can measure masses and widths (the latter to ~ 70 KeV) for all the known or discovered states and may even acquire enough statistics to extract the multipole contributions in the χ_2 decay to $\psi\gamma$, for example. The potential for this realm of QCD exploration is great, and a timely commitment to a dedicated facility at Fermilab will allow a smooth follow on to exploit the successes of E760 with the promise of 10 KeV resolution, polarized beams and targets, and more sophisticated hardware. Further, it has been pointed out that at Fermilab in 10^7 sec (4 months) one could easily produce $5\cdot10^8$ J/ψ's, 250 times the total of all J/ψ's produced at e^+e^- machines to date.[12] The charm system is a potential proving ground for QCD theories. It lies at the confluence of perturbative and non-perturbative calculations as well as Monte Carlo Lattice Gauge techniques.[13] Precise measurements in this system of total widths and partial decay widths, as well as the angular correlations in radiative decay and helicity amplitudes, can provide detailed tests for the theories. Finally, the prospect that exclusive QCD calculations will be successfully accomplished implies a need for careful comparison with measurements of the formation process itself.

MESON SPECTROSCOPY
(VOODOO QCD)

In what may be termed conventional meson spectroscopy (1-2 GeV mass range) there are two general areas of interest. First there are existing states that are not understood.[14] Their identification and the detailed measurement of their quantum numbers should be done. Consider for example the $\iota(1460)$ or the $\theta(1720)$. Possible claims for identification of these and other states as glueballs requires clear careful determination of their J^{PC} quantum numbers (0^{++}, 2^{++}, 0^{-+}, 2^{-+}, etc. are possible glueball candidates) as well as studies of their exclusive final states, partial widths and branching ratios. Even more conventional high statistics $q\bar{q}$ meson spectroscopy may have to be done first to fill in the "normal" object tables to allow recognition of what is exotic.[15]

The second area of interest is the search for the so called exotic states.[16] Since $C = (-1)^{L+S}$ and $P = (-1)^{L+1}$, $J^{PC} = 0^{--}$, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}, etc. are forbidden in $q\bar{q}$. The discovery of such a state would herald a new degree of freedom and possibly signal the existence of the oft predicted mixed quark-gluon states (Meiktons).

The prediction of $qq\bar{q}\bar{q}$ states has lead to a sordid past of fading baryonium. The theoretical arguments remain compelling so one can conclude that the states must be broad and any further experimental attempts in this field must be in the form of detailed amplitude analyses rather than bump hunting.[17]

TRAPPED ANTIPROTONS

The prospects for decelerating antiprotons to low enough energies to allow their capture in a Penning Trap, has lead to a proposal which will attempt to measure the sign of the gravitational mass of the antiproton.[18] Such a measurement has enormous fundamental importance and will be attempted in a first generation experiment at LEAR.

The concept of having trapped cold antiprotons available has led to a number of suggestions for interesting physics experiments of the type not normally associated with accelerators.[19] These include experiments in atomic physics, chemical physics, solid-state physics, and condensed matter physics. As an example, it has been predicted that cold $\overline{p}$'s in superfluid helium would act as condensation centers forming charged "bubbles" and "snowballs". These ideas have been extended to include the possiblility of interstitial $\overline{p}$'s in crystal lattices, and possible stable interstitial orbits within the lattice. These prospects not only represent interesting physics by themselves, but have potential application for providing new probes in condensed matter physics, as well as possible applications. Although these ideas would not alone argue successfully for a $\overline{p}$ facility, they show the breadth of possible interest.

FURTHER INTERESTS

There is a large body of work begun at LEAR to study antinucleon-nucleon and antinucleon-nucleus interactions. These include such subjects as studies of annihilation,[20] elastic scattering, charge exchange and $\overline{p}$ atoms.[21] To these we add the possible studies of quark-gluon plasmas resulting from 6-8 GeV antiprotons annihilating in heavy nuclei,[22] the production of tagged hyperons,[23] and the study of charmed baryons.[24]

These last items of course are beyond the LEAR momentum range, but even looking at the potential LEAR program versus the probable running time, it is likely that if a facility were to become available at Fermilab within the next five years, that proposals would be forthcoming to continue or extend the LEAR program. Further, the prospect of having polarized antiprotons could give a Fermilab facility a major advantage in pursuing second generation LEAR type experiments.

Given the strong physics case for such a machine the question is how should this be pursued. To that end, a working group has been assembled (a list of the names is attached). We would like to continue our effort to obtain a dedicated antiproton facility at Fermilab by submitting a formal proposal to the Fermilab Advisory Committee. Some support from the laboratory during this proposal effort is required. In particular, in the area of machine design and detailed costing, the participation of Fermilab staff would be essential.

B. E. Bonner
Department of Physics
Rice University
Houston, Texas

L. S. Pinsky
Department of Physics
University of Houston
Houston, Texas

REFERENCES

(Unless otherwise indicated all references herein are to contributions to the First Fermilab Workshop on Antimatter Physics at Low Energy, the proceedings of which are in preparation and will be published as a Fermilab Report)

1. K. Kilian, "Results from LEAR"
2. R. Landua, "Future Physics at LEAR"
3. D. Mohl, "Future Machines Improvements at LEAR"
4. D. Mohl, "Future Machine Improvements at LEAR"
5. J. Donoghue, "CP Violation using Hyperons"
6. P. Rapidos, "Fermilab Antiproton Source" and
   J. Peoples, "Summary of the Exposed Machine Requirements"
7. R. Jaffe, "perspectives in Low Energy Antiproton Physics"
8. R. Landua, "Future Physics at LEAR"
9. CERN/PSCC/86-8 Minutes of the forty fifth meeting of the PSCC, 3-4 Feb.,1986
10. J. Donoghue, "CP Violation using Hyperons"
11. Fermilab E760 proposal, March, 1985, amended Nov. 1985
12. M. Chanowitz, "An Overview of the Potentially Accessible Physics"
13. M. Olsson, "Charmonium Spectroscopy and Heavy Quark Physics"
14. H. Lipkin, "Delta, Iota, and Other Meson Spectroscopies"
15. M. Chanowitz, "An Overview of the Potentially Accessible Physics" and
    N. Isgur, "Gluonic Excitations of Mesons: Why Are They Missing, and How to Find Them"
16. S. Sharpe, "Glueballs and Other Exotics in $\bar{p}p$ Annihilation"
17. B. Wicklund, "Baryonium and Amplitude Analyses"
18. M. Hynes, "Physics with Bottled $\bar{p}$'s"
19. M. Hynes, "Physics with Bottled $\bar{p}$'s"
20. F. Myhrer, "$\bar{p}$ Annihilation Channels and Quark Dynamic Selection Rules"
21. H. Poth, $\bar{p}$ Atoms, Anti Hydrogen, and Hyperonic Atoms"
22. W. Gibbs, "Quark-Gluon Plasma in $\bar{p}$-Nucleon Interactions"
23. H. Poth, "$\bar{p}$ Atoms, Anti Hydrogen, and Hyperonic Atoms"
24. M. Chanowitz, "An Overview of the Potentially Accessible Physics"
25. C. Dover, "Physics with Polarized $\bar{p}$'s",
    E. Steffens, "Prospects for Polarizing $\bar{p}$'s", and
    Y. Onel, k"The Spin Splitter, A Method of Polarized Antiprotons"