PROPOSAL TO CONTINUE THE STUDY OF CHARMONIUM SPECTROSCOPY IN PROTON-ANTIPROTON ANNIHILATIONS.

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This is a proposal to continue the work of the "Charmonium" experiment in the study of charmonium spectroscopy in proton-antiproton annihilation. The goals of the "Charmonium" experiment are described in detail in the E835 proposal. This proposal should therefore be considered as an update of that document with a view to a run in the years 1999-2000 to complete the measurements outlined in that proposal. It takes into account what was achieved and what we learned in the E835 run. We note that data taking ended little more than a month before this writing and our understanding of the data is far from complete.

We recall that the measurements of highest priority for E835 were:

i. Determination of the line parameters of the η_c resonance detected through the $\gamma\gamma$ final state

ii. Confirmation of the $^1P_1$ and determination of its line parameters

iii. Search for the η_c'

iv. Study of the χ_0 resonance

Of these four items, only the first one, the study of the η_c resonance parameters has been concluded; it took an integrated luminosity of 18pb^{-1}. While the line parameters are reasonably measured and consistent with the E760 results, we note that the branching ratio is reduced from the E760 value.

$^1P_1$ Search

We took almost 50pb^{-1} of data in the region of the χ center of gravity to study the enhancement in the $\psi\pi^0$ signal seen by E760 and attributed to formation of the $^1P_1$ state. Unfortunately, the determination of the antiproton beam energy during the E835 run was affected by large systematic

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uncertainties due to problems with the Accumulator Beam Position Monitor (BPM) system which were only identified late in the data taking. These problems have prevented us from achieving a reliable study of this narrow, low cross-section resonance.

To estimate the luminosity required to complete the measurement in the next run, we assume that the measured background level of $\sim$ 2pb is due to the $p\bar{p} \to \psi + \pi^0$ continuum process and can therefore not be further reduced. Another goal of the experiment is to detect the $^1P_1$ state through the radiative decay to $\eta_c + \gamma \to 3\gamma$. This would provide strong support to the interpretation of the E760 findings. The feasibility of this depends on our ability to eliminate the background from feed down from the $2\pi^0$ and $3\pi^0$ channels, and the rate for the 3γ final state. As mentioned, our new measurement of the $B(\eta_c \to \gamma\gamma)$ gives a value lower than the E760 one. This, and the uncertainty on the background level that we will eventually achieve, make us increase the integrated luminosity estimate to a conservative figure of $\sim 200\text{pb}^{-1}$.

η_c' Search

We performed a systematic scan in E835 to search for the η_c' taking $\Delta E_{cm} = 5$ MeV steps and covering the region $3575 \leq E_{cm}(\text{MeV}) \leq 3660$ with a luminosity at each point of 1.5pb^{-1}. In all, we took 36pb^{-1} of data and their analysis is in progress. At this time there is no obvious signal and the product of branching ratios $B(\eta_c' \to p\bar{p}) \times B(\eta_c' \to \gamma\gamma)$ seems to be considerably lower than expected from simple calculations based on known charmonium formation and decay rates. As with the all-neutral final state in the $^1P_1$ study, feed-down from $\pi^0\pi^0$ and $\pi^0\gamma$ final states is the main source of background and we are working on the analysis to reduce this. It is however clear at this point that unless we find a signal in some other (and so far unstudied) decay channel ($3\eta, \eta\pi\pi$...), it will not be easy to find this state in the next run. (Guidance from theory that allows us to limit the range of our search would obviously be a help.) Our present request, therefore, is for 100 pb^{-1}, a factor $\times 3$ over what we collected in E835.

Study of the χ_0

The energy of formation of the χ_0 was close to the Accumulator transition energy where beam conditions were highly unstable. Toward the end of the run, however, we managed to collect 2.6 pb^{-1} around the χ_0 and performed a preliminary measurement of the resonance parameters in the $\psi\gamma$ decay channel. A measurement of the partial decay width to $\gamma\gamma$ is important and we expect a precise value with an integrated luminosity of 20pb^{-1}.

Requirements for the Proposed Run

A summary of the integrated luminosity required to complete the three measurements is given in Table 1. We would like of course, if possible, to perform the other measurements outlined in the E835 proposal.

The success of the experiment will depend crucially on the Accumulator performance and on the ability of the detector to acquire high quality data at the rate required. Of these, we believe the Accumulator presents the bigger challenge.

Beam Requirements:

For the Accumulator, we need to realize at least part of the increased stacking rate projected for the collider program with the Main Injector. We understand that, with the new Main Injector, the stacking rate should reach values close to 20 mA/hour. While we do not expect this to be the case during our data taking, we are assuming a significant improvement over the 2.5 to 3.5 mA/hour typical rates of the E835 run.

The planned Accumulator modifications will result in a shift of the transition c.m. energy from $\sim$ 3400 MeV (η = .023 at injection energy) to approximately 3650 MeV (η = .012 at injection energy). This implies that the formation energy for all states, with the exception of the ψ' and of the D-states, will be below transition. Efficiency and speed in the deceleration process are therefore essential. The η_c' may be very close to the transition energy and to achieve stable beam condition may require modifying the Accumulator lattice to shift the transition energy.

To study narrow states - notably the $^1P_1$ - we need the beam energy to be stable and to determine the c.m. energy to better than 50 keV. The experience of E835 teaches us that we need a fully functional and well monitored BPM system. The momentum spread of the beam of order 2×10^{-4} as achieved in E760 and E835 will be adequate.

Luminosity Improvements:

If we assume stable running for a period of six months, we would need to collect $\sim$ 12pb^{-1} per week to complete the program outlined in Table 1. During E835 we typically ran at an instantaneous luminosity of 2.5×10^{31}cm^{-2}sec^{-1}; the peak integrated luminosity in one week was 7.5pb^{-1} with routine running (above transition!) of $\sim$ 5pb^{-1} per week. In this regime the experiment deadtime was a few percent and all detectors could be operated comfortably. To assess the problems related to increasing the instantaneous luminosity, at the end of the data taking we had a test run at an instantaneous luminosity of $5.5 \times 10^{31}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ at the energy corresponding to the peak of the χ_2 resonance. With the exception of the wire chamber nearest to the beam-pipe, all detectors could still take the rates comfortably. In the data taking configuration at that time, the dead time increased to $\sim 10\%$ and we observed an inefficiency for neutral triggers caused by accidentals in the charged particle veto. We have studied these data and concluded that with some careful but minor modifications to the detector we could run at an instantaneous luminosity twice as high as in the E835 data taking. The beam consumption in this running was measured to be 2.5 mA/hr.

One of the major improvements of E835 over E760 was in the range of density and the control system of the Jet Target that allowed us to run at constant instantaneous luminosity as the antiproton current decreased. The maximum target density achieved in E835 was $3 \times 10^{14}\mathrm{atoms/cm}^3$ which implies beam currents greater than ~ 40 mA to produce instantaneous rates of $5 \times 10^{31}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$. With an initial stack of 80 mA and a beam consumption rate of 2.5 mA/hr we would collect, over 12 hours of data taking, an integrated luminosity of $\sim 2.2\mathrm{pb}^{-1}$. Assuming a stacking rate of 10 mA/hour, this mode of operation would result in a 24 hour cycle and hence to an integrated luminosity per week of $\sim 15\mathrm{pb}^{-1}$. Given our experience, however, we are not optimistic about the feasibility of taking a stack larger than 40 mA below transition and are studying modifications of the jet target to increase its maximum density.

Apparatus modifications:

We are studying what modifications need to be made to the apparatus to ensure quality data and high efficiency at the higher luminosity of the proposed run.

We are not considering any major changes to the Central Calorimeter, the Cerenkov counters, the outer hodoscopes or the Luminosity Monitor.

The trigger hodoscopes require some attention and we are looking at the possibility of increasing the granularity of the hodoscope closest to the beam-pipe from 8 to 16 counters. The scintillating fiber tracker proved reliable and capable of handling our rates. It enables us to trigger at specific θ (polar angle) ranges and we are looking at construction of an inner barrel which would significantly improve our θ resolution. We would do this within the constraints of the existing cryogenic infrastructure.

Most of the electronics in E835 performed very well and will be adequate for the proposed run. We plan to fix some operational issues with the Calorimeter signal shapers. We would require additional FERA ADC's for the extra fibers and we would like to replace the PCOS latches on the scintillating fibers with TDC's. The Dart based DAQ system would remain essentially as is. We would require the addition of 2 or 3 more readout controllers (DYC's) and request an upgrade of the computing power in the level 3 filter to handle the increased data rate.

Table 1: Luminosity and Beam Requirements

state	decay mode	Int.Lum.(pb^{-1})	Beam Requirements
χ_0	$\rightarrow \psi\gamma$ $\rightarrow \gamma\gamma$	20	
η_c'	$\rightarrow \gamma\gamma$	100	Shift of γ_T(?)
$^1P_1$	$\rightarrow \psi\pi^0$ $\rightarrow \eta_c\gamma$	200	$< 50keV$ on energy