PRELIMINARY RESULTS ON CHARMONIUM STATES FROM FNAL-E835

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Abstract

E835 is an high precision and high luminosity experiment for the study of charmonium states formed in $\bar{p}p$ annihilations.

Preliminary results on $\eta_c(1^1S_0)$ resonance parameters and $\chi_{c_2}(1^3P_2)$ $\gamma\gamma$ partial width are presented. First evidence for $\chi_{c_0}(1^3P_0)$ formation in $\bar{p}p$ is reported.

1 Introduction

In the charmonium spectrum, despite of the success of non relativistic potential models, both relativistic and higher order QCD corrections may have non negligible and possibly relevant effects on the energy splittings and the partial withds for those states.

Different methods have been used to predict discrepancies from the naive potential model, including some non perturbative ones such as QCD sum rules and non relativistic lattice QCD calculations. Precision measurements on the charmonium spectrum are a necessary test for any of these models.

E835 uses the same experimental technique pioneered by experiment R704[1] at CERN's ISR and succesfully adopted later by experiment E760[2] at Fermilab.

Charmonium states are studied in $\bar{p}p$ annihilations where all charmonium states can be formed. The signal is extracted from the huge non resonant hadronic background by selecting charmonium decay modes to electromagnetic final states. The required high luminosity is achieved by using a H_2 molecular cluster jet target[3] intersecting the coasting antiproton beam in the Fermilab Antiproton Accumulator. Resonance parameters are determined from the excitation curve with a precision depending only on the knowledge of the center of mass energy distribution.

2 Experiment E835 at FNAL

The E835 detector (Fig. 1) is an upgrade of the E760 detector[4]. It is a non-magnetic, large acceptance, cylindrical spectrometer, covering the complete azimuth (ϕ) and from $2°$ to $70°$ in polar angle (θ). It consists of a lead glass electromagnetic calorimeter divided into a barrel and a forward sections; the inner part of the barrel section is instrumented with a multicell threshold Čerenkov counter, triggering hodoscopes and a tracking system. The tracking system and the calorimeter read-out electronics had to be upgraded to withstand the $\approx \times 5$ increase in instantaneous luminosity.

The integrated luminosity for each energy setting was obtained by counting the number of recoil protons from $\bar{p}p$ elastic scattering in a silicon detector located at $\theta = 86.5°$ from the beam direction [5].

A typical stack of 5×10^{11} antiprotons was accumulated in 18 hours, the beam was decelerated from the accumulation energy (8.9 GeV) to the value appropriate of each resonance, then data were taken for approximately 48 h until the whole stack was used.

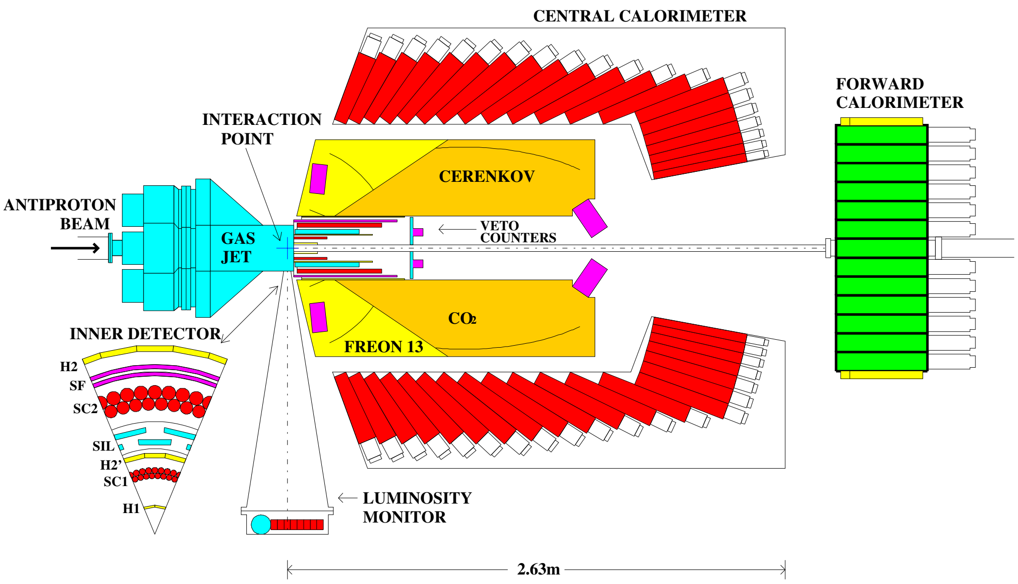

Figure 1: The E835 apparatus.

Resonance	η_c scan	J/Ψ	χ_0 scan	χ_1	χ_2	h_c search	η_c' search	Ψ'
$\int$ L dt (pb^{-1})	17.7	1.7	2.6	7.1	14.7	50	35	11.8

Table 1: Summary of data taken.

The density of the jet target was continuously adjusted (10^{13}–10^{14} atoms/cm^3) to compensate for the beam loss keeping the instantaneous luminosity constant at $\sim 2 \times 10^{31}$ cm^{-2}sec^{-1}. The stochastic cooling kept the beam momentum constant with a $(\Delta p/p)_{rms} \approx 2 \times 10^{-4}$, compensating for energy losses in the jet target.

3 Preliminary results

The experiment has taken data for about one year, collecting an integrated luminosity of ~ 150 pb^{-1} (a factor 5 larger than E760 and 200 than R704). The total number of triggers written to tape was of $\approx 5 \cdot 10^9$ events.

All charmonium states below open charm threshold were investigated (see Tab. 1);

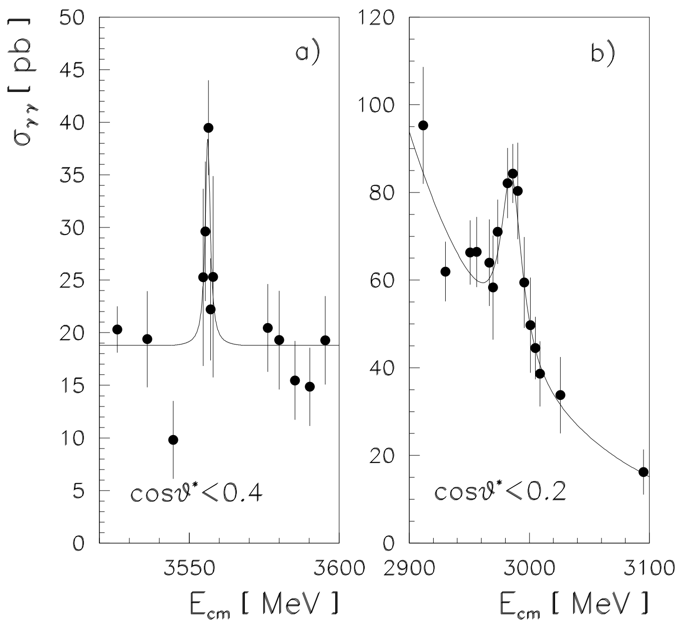

Figure 2: Measured cross section for $\bar{p}p \to \gamma\gamma$ vs center-of-mass energy at χ_2(a) and η_c(a)

the procedure is to scan across the resonance changing the value of the antiproton beam momentum detecting mainly $\gamma\gamma$ decay and inclusive decays to J/Ψ.

3.1 $\gamma\gamma$ final states

The $\gamma\gamma$ final states were selected by a topological trigger requiring two electromagnetic clusters on the CCAL with large invariant mass and no hits on the charged hodoscopes. The minimum energy of a cluster was 20 MeV. A kinematical fit was applied to events with exactly two clusters in-time with the interaction and those events with χ^2 probability $\geq$10% were selected as two photon candidates. As shown in E760 [7] the background is due to misidentified $\pi^0\pi^0$ and $\pi^0\gamma$ events.

The 1^1S_0 state (η_c) was observed in the reaction $\bar{p}p \to \eta_c \to \gamma\gamma$ (Fig. 2b) The events were selected for $|\cos\theta^*_\gamma| \leq 0.2$ and fitted with the maximum likelihood method to a Breit-Wigner shape plus a power law background of the form $\sigma_{back} = A \times (2988/E_{cm})^B$.

The preliminary values of the resonance parameters are $M_{\eta_c} = 2985.0^{+1.7}_{-1.8}$ MeV/c^2, total width $\Gamma = 17.8^{+7.2}_{-5.9}$ MeV and $BR(\eta_c \to \bar{p}p) \times BR(\eta_c \to \gamma\gamma) = 24.6^{+3.9}_{-3.8} \times 10^{-8}$. Using the Particle Data Group value [8] for $BR(\eta_c \to \bar{p}p)$ we obtain the partial width $\Gamma_{\gamma\gamma} = 3.7^{+1.5}_{-1.3} \pm 1.2$ keV. A comparison of these results with previous measurements and

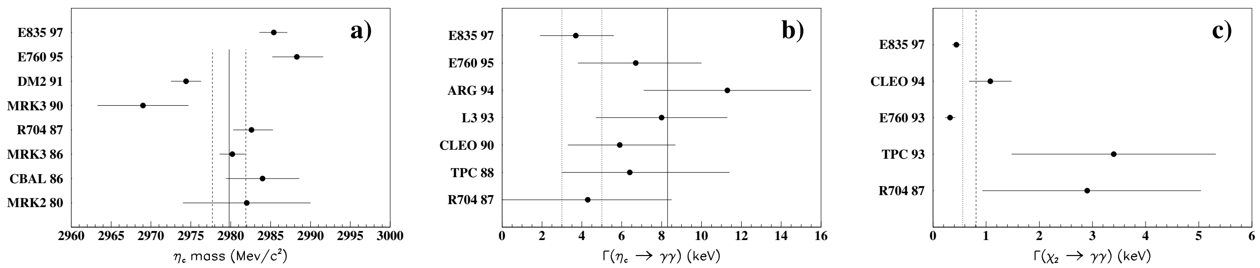

Figure 3: Comparison of E835 results with previous eperiments: a) η_c mass: solid and dotted lines denote the PDG average and error; b) $\Gamma(\eta_c \to \gamma\gamma$: shaded area show predictions of references [9] and [10]; c)$\Gamma(\chi_2 \to \gamma\gamma)$: dashed and dotted lines show predictions from references [9] and [11]

some theoretical predictions are shown in Fig. 3a-b.

The cross section for the process $\bar{p}p \to \gamma\gamma$ in the χ_2 energy region is shown in Figure 2a. The events were selected for $|\cos\theta^*_\gamma| \leq 0.4$ and were fitted to a Breit-Wigner with mass and width fixed to the PDG values.

The preliminary results are: $BR(\chi_2 \to \bar{p}p) \times BR(\chi_2 \to \gamma\gamma) = 2.19^{+0.34}_{-0.33} \times 10^{-8}$ and $\Gamma_{\gamma\gamma} = 0.44 \pm 0.08$ keV. A comparison with previous measurements and some theoretical predictions is shown in Fig. 3c.

A scan (5 MeV span) was performed in the mass interval $3575 \leq \mathrm{E}_{cm} \leq 3660$ MeV searching for the 2^1S_0 state (η_c') only seen so far by the Crystal Ball experiment[12] which measured a mass of 3594 ± 5 MeV/c^2.

No signal of the η_c' has been identified in the mass region $3575 \leq \mathrm{E}_{cm} \leq 3660$ MeV, either to $\gamma\gamma$ or $J/\Psi\gamma$ final states. Attempts to further reduce the $\gamma\gamma$ background are in progress.

3.2 e^+e^- and $\mathbf{J/\Psi} + X \to e^+e^-X$ final states

In our experiment, an e$^+$e$^-$ signal with a high invariant mass represents an almost background-free channel to study charmonium states: $\Psi', J/\Psi \to e^+e^-$, $\Psi' \to J/\Psi X$, $\chi_{0,1,2} \to J/\Psi\gamma$, $h_c \to J/\Psi X$, $\eta_c' \to J/\Psi\gamma$.

The events were selected by a topological trigger requiring two electromagnetic clusters

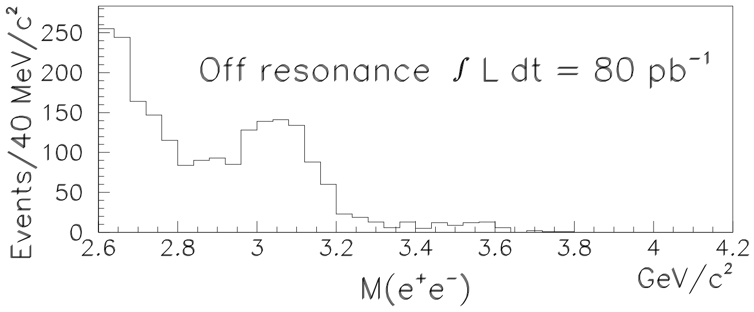

Figure 4: e^+e^- invariant mass for events with a pair of identified electrons. The peak at the J/Ψ mass is due to the J/$\Psi\pi^0 \to e^+e^-\gamma\gamma$ continuum cross section

on the CCAL with large invariant mass tagged by a signal in the threshold Čerenkov counter and trigger hodoscopes.

Electron identification is done with the likelihood-ratio method, based on Čerenkov analog signal, dE/dx in the hodoscopes and shower shape in the electromagnetic calorimeter. The background after electron identification is already at the few pb level (Fig. 4). Topological cuts and kinematic fits to the specific decay modes of each resonance can further reduce the non-physical background to an almost negligible level.

A clean $J/\Psi\gamma$ signal has been observed at the formation energy of the χ_0 (Fig. 5). The scan was performed across the unstable region of the transition energy of the Accumulator that is very close to the χ_0 formation energy.

The limited statistics and the small number of points in the energy scan do not allow to improve the precision of previous χ_0 mass and width determination, nevertheless it will provide the first measurement of $BR(\chi_0 \to p\bar{p})$

The study of narrow, low-cross section resonances depends crucially on the systematic error on the antiproton beam determination.

Nearly 50 pb^{-1} worth of data were taken the region of the χ center of gravity in the attempt to confirm the enhancement in the J/$\Psi\pi^0$ signal seen by E760 and attributed to formation of the $h_c(1^1P_1)$ state[6]. The analysis of these data is difficult: due to a malfunctioning of the Beam Position Monitor (BPM) system in the Accumulator, the antiproton energy measurement during the E835 run was affected by systematic errors much larger than expected. At the current status of the analysis the systematic error is too large to allow a reliable study of this resonance. The energy calibration problem also

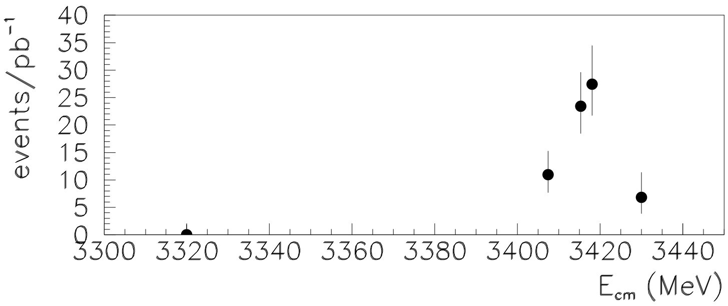

Figure 5: Number of events per pb^{-1} observed for $\bar{p}p \to J/\Psi\gamma \to e^+e^-\gamma$ vs center-of-mass energy at χ_0.

affects the precise measurements of χ_1 and χ_2 parameters, where 7.3 and 14.7 pb^{-1} were respectively collected.

The large number of events collected for the J/Ψ, Ψ', $\chi_{1,2}$ resonances will be used to determine their angular distribution and exclusive Ψ' Branching Ratios.

Selecting the $\bar{p}p \to e^+e^-$ events outside J/Ψ and Ψ' formation energies, the proton form factor in the time-like region can be measured in the energy region of 2920$\leq$ E$_{cm}$ $\leq$ 3687 MeV.

4 Conclusions

E835 is now analyzing the data it took during the 1996-97 Fixed Target run at Fermilab. The η_c resonance parameters and the partial width of $\chi_2 \to \gamma\gamma$ have been measured with preliminary errors significantly smaller than the errors reported by E760. So far the search for the η_c' has been unsuccessful, but more careful analysis of the data is in progress. The clean χ_0 signal allows the first determination of $\Gamma(\chi_0 \to p\bar{p})$. Substantial effort is being devoted to try to recover the information on the beam energy during the scan of h_c.

The physics program of E835 [13] was not completed during this run. The experiment plans to run again during 1999 with an increased intantaneous luminosity. The data taking will be mainly focused on confirming the h_c state and measuring, with larger statistics, the χ_0 resonance parameters, in particular its partial width to $\gamma\gamma$.

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