Charmonium in Fermilab Fixed Target Experiments

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Abstract

The current(1996–1997) and previous(1990–1991) Fermilab fixed target programs have included experiments that have studied charmonium. Charmonium was produced by 800 GeV/c proton beams interacting with solid targets (E771 and E789) and at charmonium threshold using a recirculating antiproton beam intersected by a hydrogen cluster jet target (E760 and E835). The most recent published results of the 1990–1991 experiments (E771, E789 and E760) are presented. Preliminary results from the current data taking of E835 are shown.

The most recent charmonium results of the 1990–1991 and current 1996–1997 Fermilab fixed target experiments are discussed. The discussion is split into three parts. In section 1 are the most recent charmonium results of E771 and E789 where 800 GeV/c proton beams interacted with solid targets during the 1990–1991 run. The precise charmonium measurements of E760 resulting from an antiproton beam intersecting a hydrogen gas target in the Fermilab Antiproton Accumulator during the 1990–1991 run are discussed in section 2. The 1996–1997 version of the E760 experiment, E835, is discussed in section 3.

1 800 GeV/c Proton–Target 1990–1991

During the 1990–1991 Fermilab fixed target run, E771 and E789 ran with 800 GeV/c proton beams interacting with different targets. The data discussed here are from the silicon target of E771 and gold target of E789. Reconstructed $\mu^+\mu^-$ pairs were identified by the magnetic spectrometers. The di-muon mass spectrum (for example see figure 1 of reference 1 and figure 3 of reference 2) from each experiment show clear J/ψ and ψ' signals. The spectra are fit for the two resonances and a background to determine the number of charmonium produced.

The differential distributions have been extracted by fitting the mass spectra in bins of x_F and p_T bins. Monte Carlo studies have been done to determine the acceptance and efficiency for each bin. The differential cross sections have been computed by assuming an atomic weight dependence A^α. Published data for silicon was used by E771: $\alpha = 0.920 \pm 0.008$. E789 determined the exponent from running with beryllium, carbon and tungsten targets [3]: $\alpha = 0.90 \pm 0.02$.

The differential cross sections per nucleon for $d\sigma/dx_F$ and $d\sigma/dp_T^2$ for both experiments can be seen in figures 6 and 7 of reference 4. The shapes of the $d\sigma/dp_T^2$ distributions agree well while the $d\sigma/dx_F$ show some discrepancy which is believed to be attributed to nuclear affects and the large difference of atomic weights of the targets: silicon ($A = 28$) and gold ($A = 197$).

Theoretical predictions using perturbative QCD based upon the Color Singlet Model (Color Octet Mechanism is not yet applicable at low p_T) have been scaled by the factor K and compared to the experimental data in the above referenced figures. The K factors needed to scale $d\sigma/dx_F$ are $K \approx 4$ for J/ψ and $K \approx 16$ for ψ'; it is noted that the theoretical shape disagrees with the J/ψ data sets and at low x_F for ψ'. The predicted shape agrees for $d\sigma/dp_T^2$ when $K \approx 9$ for J/ψ and $K \approx 14$ for ψ'.

The ratio of $BR(\psi' \to \mu^+\mu^-) \times \sigma(\psi')$ to $BR(J/\psi \to \mu^+\mu^-) \times \sigma(J/\psi)$ has been plotted by both experiments against x_F and p_T: see figure 5 of reference 4 and figure 8 of reference 2. E771 shows a constant ratio in all bins. T he ratio slightly increases as x_F and p_T increases for E789; the reason for the increase is not understood.

2 Antiproton–Proton 1990–1991

Another experiment of the 1990–1991 Fermilab fixed target run was E760 which used a stochastically cooled antiproton beam intersecting a hydrogen gas jet target located in Fermilab's Antiproton Accumulator. The antiproton beam energy was set to produce a charmonium state through the complete annihilation of an antiproton and proton; η_c, J/ψ, χ_1, ${}^1P_1$, χ_2, and ψ' were all studied. The method and description of the non-magnetic detector can be found in reference 5. E760 detected charmonium events through direct decays to

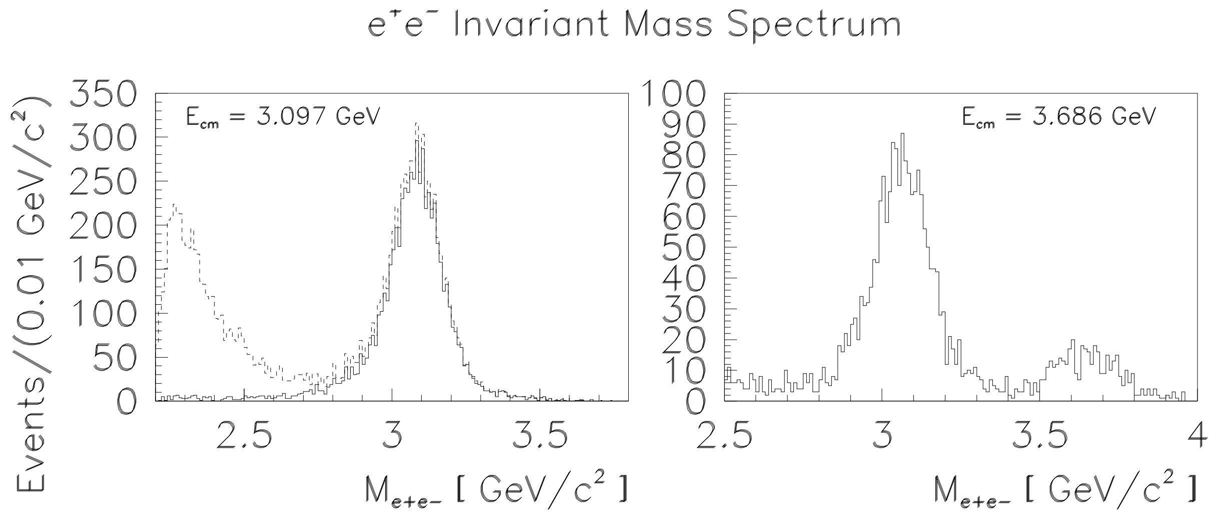

Figure 1: The invariant mass spectra for data collected at the J/ψ (dashed is all charged tracks and solid is from simple cuts to identify e^+e^- tracks) and ψ' (e^+e^- candidate tracks).

electro-magnetic final states, e^+e^- and $\gamma\gamma$, or via radiative/hadronic transitions to J/ψ and the subsequent decay to e^+e^-.

E760 measured the mass and/or width of the above listed charmonium states, which included the first observation [6] of the $^1\mathrm{P}_1$ (h_c), and searched for the η_c'. Only the two most recent charmonium publications of E760 are discussed below: the resonance parameter determination [7] for the η_c, search [7] for the η_c' and measurement of branching ratios [8] of ψ'.

Figure 6 of reference 7 shows the data taken in the η_c region. Background to the $\gamma\gamma$ decay of the η_c comes from $\bar{p}p \to \pi^\circ\pi^\circ$ and $\pi^\circ\gamma$ where only one photon of each π° decay is observed due to threshold or acceptance. Monte Carlo simulation has shown that this feed-down explains the background. A fit to the resonance and background provides a measurement of the η_c resonance parameters: mass of $2988.3^{+3.3}_{-3.1}$ MeV/c^2; width (Γ) of $23.9^{+12.6}_{-7.1}$ MeV; and $\Gamma_{\gamma\gamma}$ of $6.7^{+2.4}_{-1.7} \pm 2.3$ keV, where the last error is due to the uncertainty in the $BR(\eta_c \to \bar{p}p)$. The $\Gamma_{\gamma\gamma}$ measurement is close to the estimate presented by D. Klabucar at this conference.

Figure 7 of reference 7 shows the search for the η_c'; a signal [9] for $\bar{p}p \to \chi_2 \to \gamma\gamma$ can clearly be seen. No evidence was seen for a resonance corresponding to η_c'. The 90% CL upper limits for $\sigma(\bar{p}p \to \eta_c' \to \gamma\gamma)$ are shown in figure 15 of reference 7. The upper limits assuming widths of 5 and 10 MeV are shown along with the expected resonance based upon the following assumptions: $\Gamma_{\gamma\gamma}/\Gamma$ is the same for η_c and η_c'; and $\Gamma_{\bar{p}p}/\Gamma_{gluons}$ scales the same from η_c to η_c' as from J/ψ to ψ'. An upper limit for $BR(\eta_c' \to \bar{p}p) \times (\eta_c' \to \gamma\gamma)$ is easily set at 15×10^{-8} for $3584 < \sqrt{s} < 3624$ MeV.

The ψ' branching fractions for e^+e^-, $J/\psi\eta$, $J/\psi\pi^\circ\pi^\circ$, and $J/\psi\pi^+\pi^-$ were determined by measuring the ratio of collected events to the inclusive $J/\psi X$ events [8]. Corrections due to acceptance, trigger and analysis differences were taken into account. The systematic errors (the second error noted below) come from the uncertainties of $BR(\psi' \to J/\psi X)$ and $BR(J/\psi \to e^+e^-)$. The measurement of $BR(\psi' \to e^+e^-) = (8.3 \pm 0.5 \pm 0.7) \times 10^{-3}$ has errors smaller than the world average. Comparable to the world average are the E760 measurements of $BR(\psi' \to J/\psi\pi^+\pi^-) = 0.283 \pm 0.021 \pm 0.020$ and $BR(\psi' \to J/\psi\pi^\circ\pi^\circ) = 0.184 \pm 0.010 \pm 0.013$. The statistical error dominates the measurement of $BR(\psi' \to J/\psi\eta) = 0.032 \pm 0.010 \pm 0.002$.

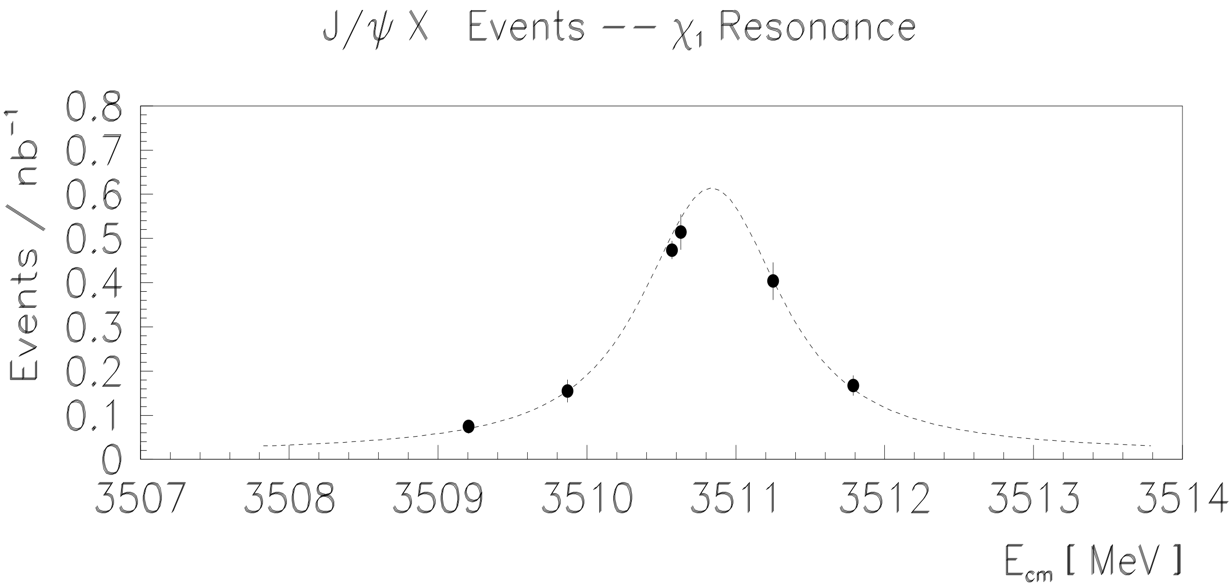

Figure 2: The χ_1 resonance mapped out by taking data at several beam energies.

3 Antiproton–Proton 1996–1997

E835 uses the same technique as E760 where the detector and data acquisition system have been upgraded [10]. With improvements to the the gas jet target and Fermilab Antiproton Accumulator, E835 is able to take data at a continuous rate of 1–3 $\times 10^{31}$ cm^{-2} s^{-1} which is on the average 4–5 times greater than E760. The greater rate has prompted a new inner tracking system that is comprised of straw tube chambers and scintillating fibers. The other major upgrade to the detector is new electronics for the calorimeters.

The detector is easily able to identify high invariant mass e^+e^- tracks. In figure 1a is the e^+e^- invariant mass spectrum of all events with charged tracks (dashed line) and for the charged tracks that are consistent with an electron/positron tracks; the ≈ 0.5 pb^{-1} of data collected at $\sqrt{s} = 3096$ MeV clearly shows the J/ψ. With the same track identification, the inclusive J/ψ and exclusive e^+e^- candidates can be easily be seen in figure 1b from ≈ 1.2 pb^{-1} of data collected at ψ'.

By taking data at several different beam energies, the resonance can be mapped out as shown for χ_1 in figure 2: the number of $J/\psi X$ events detected divided by the integrated luminosity is plotted against $\sqrt{s}$. The data shown were taken over several weeks but only is equivalent to several days of running. The resulting *resonance* is a convolution of a Breit–Wigner with the beam energy distribution, $\Gamma_{beam} \approx 500$ keV in the center of mass system [5]. The fit shown is this *resonance* and a small background; background points were taken far away from the resonance and are not within the energy of the plot.

Early running priority for E835 has been the search for the $\bar{p}p \to \eta_c' \to \gamma\gamma$ channel. Nearly 30 pb^{-1} of data has been taken: 1–1.5 pb^{-1} of data taken in 5 MeV steps between 3575 and 3660 MeV. The preliminary analysis shows no evidence for a resonance. From the E760 assumptions stated in the previous section, E835 expected to have seen the η_c' resonance. Possible/preliminary conclusions can be any combination of the following: the mass of the η_c' is not between 3575 and 3660 MeV; the η_c' is much narrower than 5 MeV; and/or the branching fraction assumptions are too large. Most likely it is the latter. The $\bar{p}p$ coupling to singlet states are not understood and the scaling could lead to an over estimate the the rate of η_c' formation.

During the remainder of the current Fermilab fixed target run, E835 plans to make precise measurements of the η_c, χ_0 and ${}^1\mathrm{P}_1$ resonance parameters, continue the search for the η_c' and if time permits search for the D states.

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5 References

References

[1] T. Alexopoulos et al., "Production of J/ψ, ψ' and Υ in 800 GeV/c Proton-Silicon Interactions" Phys. Lett. **B374**, 271 (1996).

[2] M. H. Schub et al., "Measurement of J/ψ and ψ' Production in 800 GeV/c Proton-Gold Collisions" Phys. Rev. **D52**, 1307 (1995).

[3] M. J. Leitch et al., "Nuclear Dependence of J/ψ Production by 800 GeV/c Protons near $x_F = 0$" Phys. Rev. **D52**, 4251 (1995).

[4] T. Alexopoulos et al., "Differential Cross Sections of J/ψ and ψ' in 800 GeV/c p-Si Interactions" to be submitted Phys. Rev. D.

[5] T. A. Armstrong et al., "Measurement of the J/ψ and ψ' Resonance Parameters in $\bar{p}p$ Annihilation" Phys. Rev. **D47**, 772 (1993).

[6] T. A. Armstrong et al., "Observation of the ${}^1\mathrm{P}_1$ State of Charmonium" Phys. Rev. Lett. **69**, 2337 (1992).

[7] T. A. Armstrong et al., "Study of the $\eta_c(1\ {}^1S_0)$ State of Charmonium Formed in $\bar{p}p$ Annihilations and a Search for the $\eta_c'(2\ {}^1S_0)$" Phys. Rev. **D52**, 4839 (1995).

[8] T. A. Armstrong et al., "Measurement of the Branching Ratios $\psi' \to e^+e^-$, $\psi' \to J/\psi\pi\pi$, and $\psi' \to J/\psi\eta$" Phys. Rev. **D55**, 1153 (1997).

[9] T. A. Armstrong et al., "Measurement of the $\gamma\gamma$ Partial Width of the χ_2 Charmonium Resonance" Phys. Rev. Lett. **70**, 2988 (1993).

[10] T. A. Armstrong et al., FERMILAB-PROPOSAL-P-835-REV (1992).