E835 results on χ_c states of charmonium

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The experiment E835 at FNAL has done an extensive set of studies on charmonium triplet P states. Precision measurements on mass and width of the χ_{c0} resonance, not studied by the predecessor experiment E760, are reported. Results on both partial widths and higher multipoles of the radiative transitions $\chi_c \to J/\psi\gamma$ are given, together with the $\gamma\gamma$ widths of χ_{c0} and χ_{c2}. The first clear evidence of charmonium from $p\bar{p}$ annihilations in hadronic decay modes is described, and preliminary results on $BR(\chi_{c0} \to \pi^o\pi^o, \eta\eta) * BR(\chi_{c0} \to p\bar{p})$ are given.

1. Introduction

The charmonium system has been a rich source of both experimental and theoretical information on the dynamics of $q\bar{q}$ bound states. The first precision measurements were done in e^+e^- annihilations experiments, where only vector states can be formed directly. In e^+e^- colliders, the production of states with positive C-parity is allowed only via radiative decays and/or via photon-photon fusion processes. In both cases the resolution of the detector is limiting the precision of mass and width measurements.

The $p\bar{p}$ annihilation allows the direct formation of all charmonium states via 2 or 3 perturbative gluons; the resonant signal is usually extracted from the huge hadronic background by selecting charmonium decay modes to EM final states. This limitation can be also overcome by studying scattering at large angles in the CM frame, as well as OZI violating processes (e.g. $\phi\phi$). Here we also report on the first evidence of charmonium detection in hadronic final states, namely $\pi^o\pi^o$ and $\eta\eta$.

In 1984, the experiment R704 at Cern ISR pioneered the study of charmonium states in $p\bar{p}$ annihilations [1], and the experiment E760 at the FNAL $\bar{p}$ accumulator has brought the technique to a mature stage. The scans done by E760 (1989-91) at the χ_{c1} and χ_{c2} resonances [2] gave the most accurate measurements available so far on the masses and widths of these two states.

2. The E835 Experiment

The experiment is located in the Fermilab Antiproton Accumulator, where a stochastically cooled ($\Delta p/p \sim 10^{-4}$) beam intersects a variable density internal jet target, in order to keep a constant instantaneous luminosity (L$\sim 2 * 10^{31}$) throughout each stack.The E835 detector, described in detail in [3], is a major upgrade of the E760 detector. It is a non-magnetic cylindrical spectrometer with full azimuthal coverage and polar angle acceptance from 2 to 70 degrees in the lab frame. It consists of a lead-glass EM calorimeter divided into a barrel and a forward section. The inner part of the barrel is instrumented with a multicell threshold Čerenkov counter, triggering hodoscopes and charged tracking chambers. In order to withstand the ~3 MHz interaction rate, all channels are instrumented with multihit TDCs. The experiment collected 143 pb^{-1} of data in Run I (Oct.1996-Sept.1997) and 113 pb^{-1} in Run II(Jan.-Nov.2000).

During Run I, E835 collected large samples of χ_{c1} and χ_{c2} events, mostly on the resonance peaks, to study the angular distribution of their radiative decay, as well as the $\chi_{c2} \to \gamma\gamma$ partial width. A failure in the beam orbit measurement system prevented to use the Run I data samples to improve our knowledge on masses and widths of these states.

For both E760 and E835-I, the transition en-

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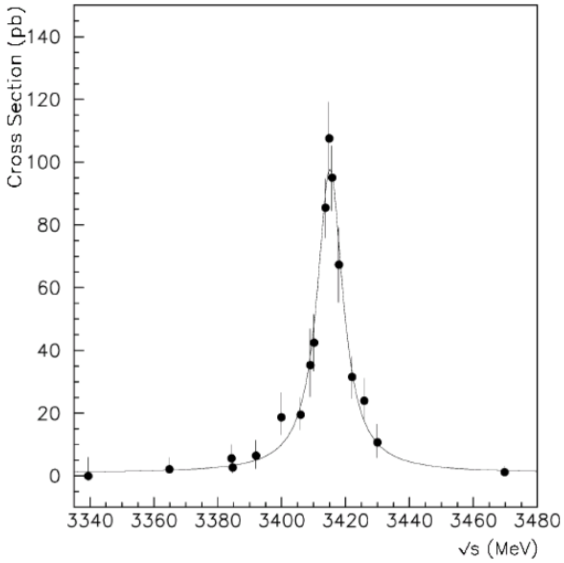

Figure 1. Cross section of $p\bar{p} \to J/\psi\gamma \to e^+e^-\gamma$

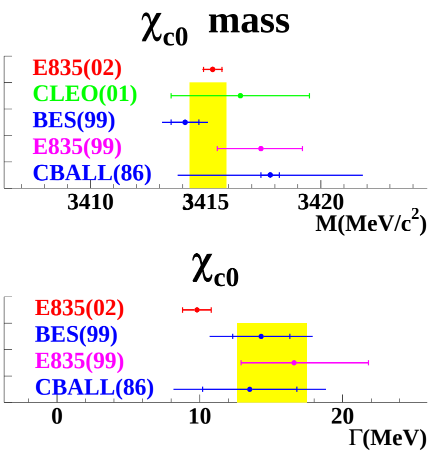

Figure 2. χ_{c0} mass and width results.

ergy of the accumulator was close enough to the χ_{c0} mass to prevent stable running with large stacks in this energy region. Nevertheless, a few stacks were decelerated to the χ_{c0} region at the end of Run I, yielding an unexpectedly high rate of $J/\psi\gamma$ events. The Accumulator underwent a major upgrade between 1997 and 2000, shifting the transition energy upwards and allowing a smooth running at the χ_{c0}.

3. Masses and total widths

The 32 pb^{-1} of data taken in scanning the χ_{c0} during Run II yield the most accurate measurement of the excitation parameters of this resonance. Figure 1 shows the experimental cross section of $J/\psi\gamma$ events for the entire scan, and Fig.2 compares the E835-II measurement [4] of mass and width with former experiments [5–8]: the bands show the PDG 2002 values[11].

Scans at the χ_{c1} and χ_{c2} were also made, to cross-check the energy calibration. The results are consistent with E760 [2], as shown in Table 1.

4. Radiative transitions $\chi_c \to J/\psi\gamma$

According to a non relativistic calculation, the radiative widths $\Gamma_{rad}(\chi_c)$ are supposed to scale with E_γ^3, and deviations from this simple scaling rule allow to study the relativistic corrections [9] to these predictions, as well as the O(α_s) corrections on the orbital wavefunctions. The determination of the radiative width cannot be extracted by a single measurement , as ψ' factories determine BR($\psi' \to \chi_c\gamma$)*BR($\chi_c \to J/\psi\gamma$) from the double radiative decay $\psi' \to J/\psi\gamma\gamma$, $\gamma\gamma$ analyses measure the product $\Gamma_{rad}(\chi_c)$*BR($\chi_c \to \gamma\gamma$) (only the χ_{c2} has been seen in this process), and $p\bar{p}$ experiments measure $\Gamma_{rad}(\chi_c) * BR(\chi_c \to p\bar{p})$. A set of cross-checks is mandatory, to reach < 10% accuracies on these widths. The global refitting [10,11] of all the $\psi' \to \gamma\chi_c$ and $\chi_c \to J/\psi\gamma$ branching fractions hints to larger systematic errors on the double cascades. The rightmost column in Table 1 shows the E760 and E835-II results on $\Gamma(\chi_c \to J/\psi\gamma) * BR(\chi_c \to p\bar{p})$.

The radiative transitions $\chi_{c1,2} \to J/\psi\gamma$ are dominated by the electric dipole term (E1). The higher multipoles, arising in the relativistic treatment of the transitions, can be studied by measuring the E1-M2 and E1-E3 interference terms in the angular distributions of the radiative decays. Previous measurements of the M2/E1 ratio were done by E760 [12] and Crystal Ball[13]. E835 results[14] are compared with them in Fig.3.

Table 1
Parameters of χ_c states from E760 and E835-II

R	Expt.	Mass(MeV/c^2)	Γ(MeV)	$\Gamma(J/\psi\gamma) * BR(p\bar{p})$(eV)
χ_{c0}				
	E835-II	3415.4±0.4±0.2	9.9±1.0±0.1	26.6±2.5±1.4
χ_{c1}				
	E760	3510.53±0.04±0.12	0.88±0.11±0.08	21.8±1.5±2.2
	E835-II	3510.62±0.02±0.17	0.88±0.06±0.09	19.0±0.7±0.9
χ_{c2}				
	E760	3556.15±0.07±0.12	1.98±0.17±0.07	28.2±1.5±2.0
	E835-II	3556.10±0.09±0.17	1.93±0.19±0.09	25.3±1.3±1.0

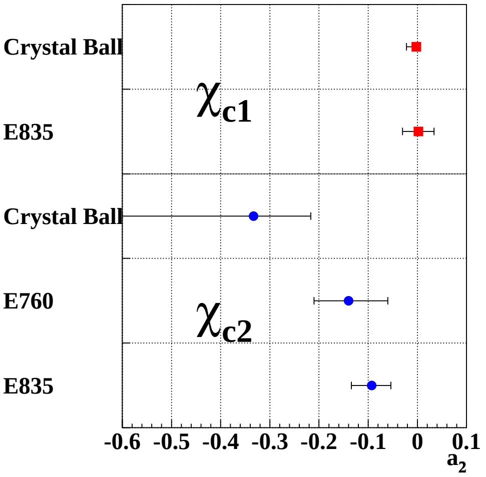

Figure 3. $a_2 = M2/E1$ results

5. Two photon widths

Using the data taken at χ_{c0} and χ_{c2} energies during Run I, the E835 collaboration has published[15] the value of the ratio $R_{\gamma\gamma}(\chi_{cJ}) = BR(\chi_{cJ} \to \gamma\gamma)/BR(\chi_{cJ} \to J/\psi\gamma)$:

$$R_{\gamma\gamma}(\chi_{cJ}) = \begin{cases} (1.45 \pm 0.74\%) * 10^{-2} & \text{for J=0} \\ (0.99 \pm 0.18\%) * 10^{-3} & \text{for J=2} \end{cases}$$

A substantial contribution to the background on this process comes from the feeddown of $\pi^0\gamma$ and $\pi^o\pi^o$ with one or two undetected photons: the cross section of both reactions is measured with our detector and a MonteCarlo simulation of the showers is used to calculate the feeddown. The $\gamma\gamma$ width is obtained from $\Gamma_{tot}(\chi_c) * R_{\gamma\gamma}(\chi_c) * BR(\chi_c \to J/\psi\gamma)$. Fig.4 shows all the latest measurements [16–20] of the partial width $\chi_{c2} \to \gamma\gamma$, corrected using the new PDG value [11] for $BR(\chi_{c2} \to J/\psi\gamma) = 18.7 \pm 2.0\%$.

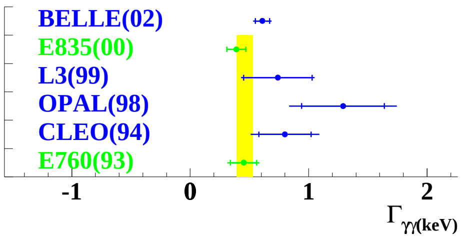

Figure 4. Results on $\Gamma(\chi_{c2} \to \gamma\gamma)$.

The discrepancy between published $p\bar{p}$ and e^+e^- results on this quantity was probably due to larger systematic errors on the measure of $BR(\chi_{c2} \to J/\psi\gamma)$. The analysis of the large sample of χ_{c0} events taken in Run II is under way. This will allow a 20% measurement of the ratio $R_{\gamma\gamma}(\chi_{c0})$. The large error on both $BR(\chi_{c0} \to p\bar{p})$ and $BR(\chi_{c0} \to J/\psi\gamma)$, limits the precision on the evaluation of $\Gamma(\chi_{c0} \to \gamma\gamma)$ from our result.

6. Recent evidence of $p\bar{p} \to \chi_{c0} \to \pi^o\pi^o, \eta\eta$

Other than in the radiative decay modes, the E835-II data taking has yielded the observation of a resonant χ_{c0} signal in two more decay channels, $\pi^o\pi^o$, $\eta\eta$. Despite the large continuum cross-section in the hadronic reactions , the observation of the charmonium signal is made possible by the interference between resonant and non-resonant amplitudes at $\theta_{CM} = 90^o$. The differential cross section of the $p\bar{p} \to \pi^o\pi^o$ reaction can be written as :

$$\frac{d\sigma}{dz} = |\frac{-A_R}{x+i} + A_I(x,z)e^{i\delta_I(z)}|^2 + |A_{NI}(x,z)|^2$$

where x=2($\sqrt{s}$-M)/Γ and z=cos(θ_{CM}). The helicity one amplitude A$_{NI}$ dominates the cross-section at large cosθ_{CM}, does not interfere with the resonant amplitude, and goes to zero at cosθ_{CM}=0. The interference effect magnifies by a factor 20 the resonant signal, and explains the skewness of the cross-section around the peak, as shown in Fig.6. The fit to the data allows to calculate the product of branching ratios:

$$BR(\chi_{c0} \to \pi^o\pi^o)*BR(\chi_{c0} \to p\bar{p}) = (5.1\pm0.8)*10^{-7}$$

An analogous interference signal was observed in the $\eta\eta$ channel and yields:

$$BR(\chi_{c0} \to \eta\eta)*BR(\chi_{c0} \to p\bar{p}) = (4.0\pm1.2)*10^{-7}$$

The results are preliminary and a study of statistical errors is under way.

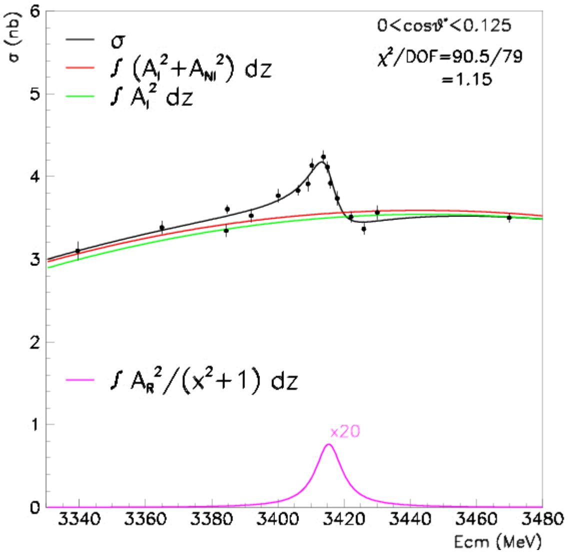

Figure 5. The cross section $\sigma(p\bar{p} \to \chi_{c0} \to \pi^o\pi^o)$ for $|cos(\theta_{CM})| < 0.125$.

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