Study of $p\bar{p} \rightarrow \chi_{c1,2} \rightarrow J/\psi\gamma$

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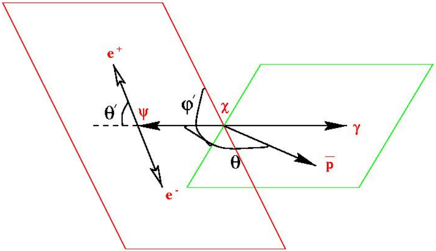
χ_{c1} and χ_{c2} angular distributions



- θ is the polar angle of the J/ψ with respect to the antiproton in the $\bar{p}p$ center of mass system
- θ' is the polar angle of the positron in the J/ψ rest frame with respect to the J/ψ direction in the χ rest of mass system
- ϕ' is the azimuthal angle between the J/ψ decay plane and the χ_c plane

$\bar{p}p \to \chi_1 \to J/\psi\gamma$

- Production amplitudes: $B_0 = 0$
- Decay Amplitudes: a_2
  $a_2 = 0.002 \pm 0.032 \pm 0.004$

$\bar{p}p \to \chi_2 \to J/\psi\gamma$

- Production amplitudes: B_0^2
  $B_0^2 = 0.16^{+0.09}_{-0.10} \pm 0.01$
- Decay Amplitudes: a_2, a_3
  $a_2 = -0.076^{+0.054}_{-0.050} \pm 0.009$
  $a_3 = 0.020^{+0.055}_{-0.044} \pm 0.009$

* E835 Collaboration, Nucl. Phys. B 717, 34 (2005)

$\bar{p}p \to \chi_{1,2} \to J/\psi\gamma \to \ell^+\ell^-\gamma$

Cross section

$\sigma(\chi_{c1} \to J/\psi\gamma) \sim 1.7$ nbarn

$\sigma(\chi_{c2} \to J/\psi\gamma) \sim 2$ nbarn

E835 Collaboration, Nucl. Phys. B 717, 34 (2005)

Background: $\bar{p}p \to \pi^+\pi^-\pi^0$: $\sigma(\chi_{c2})$=0.12 mb

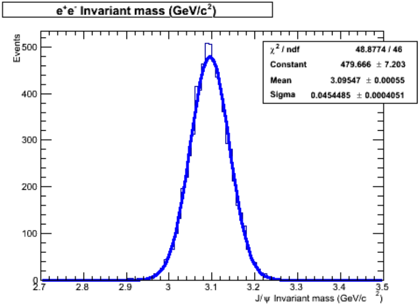
CERN-HERA 70-03 (1970)

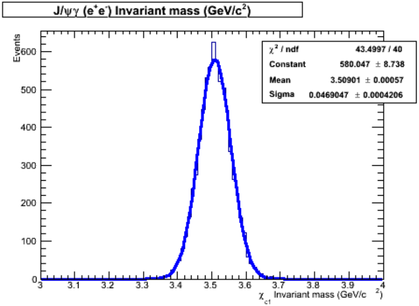
- Fast Simulation
- $J/\psi \to e^+e^-$; $J/\psi \to \mu^+\mu^-$
- PID for Electrons: ElectronLoose
- PID for Muons: MuonLoose
- PID for Photons: Neutral
- MC Truth Match
- 10.000 events generated
- Decay model: $\chi_{c1,2} \to J/\psi\gamma$: Chic1toJpsiGam
- Decay model: $J/\psi \to \ell^+\ell^-$: VLL

$\overline{p}p \to \chi_{c1} \to J/\psi\gamma \to \ell^+\ell^-\gamma$

$$\overline{p}p \to \chi_{c1} \to J/\psi\gamma \to \ell^+\ell^-\gamma$$

Invariant mass distributions for $J/\psi \to e^+e^-$





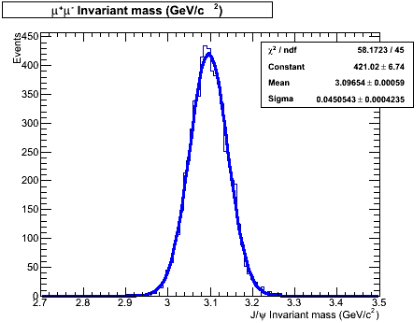
$J/\psi \to e^+e^-$

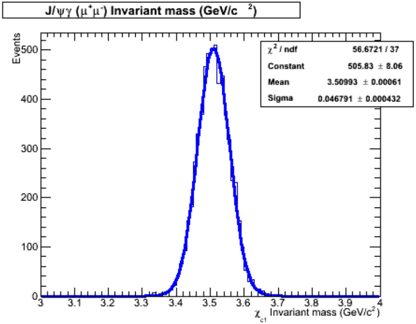
- Mean = 3.095 GeV
- Sigma = 45.4 MeV
- Eff = 68.8%

$\chi_{c1} \to J/\psi\gamma$

- Mean = 3.509 GeV
- Sigma = 46.9 MeV
- Eff = 68.6%

Invariant mass distributions for $J/\psi \to \mu^+\mu^-$





$J/\psi \to \mu^+\mu^-$

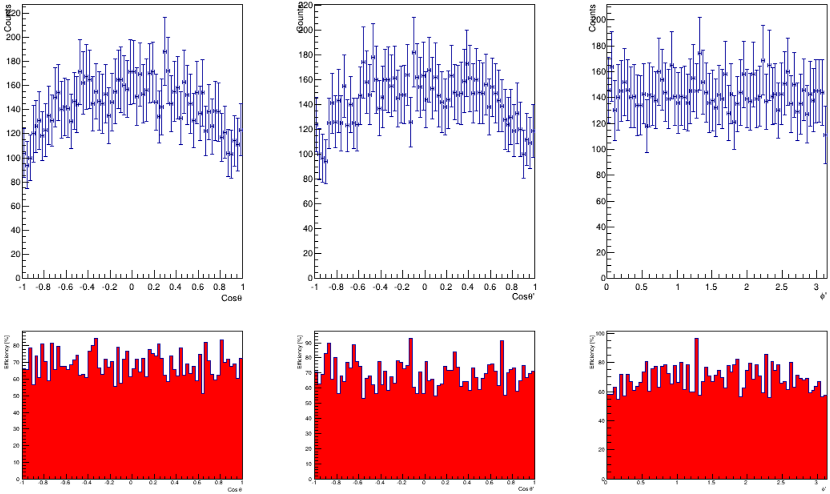
- Mean = 3.097 GeV
- Sigma = 45.1 MeV
- Eff = 60.0%

$\chi_{c1} \to J/\psi\gamma$

- Mean = 3.510 GeV
- Sigma = 46.8 MeV
- Eff = 59.9%

Angular distributions for $J/\psi \rightarrow e^+e^-$

The angles distributions corrected with the efficiency, which is presented in the lower part of the plot.



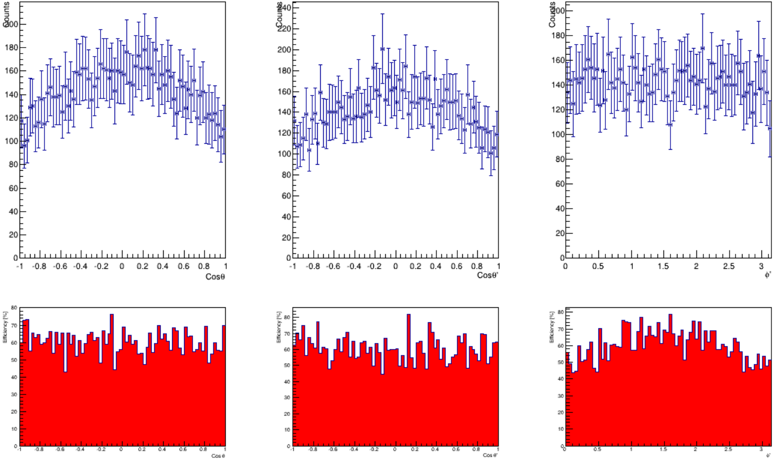
$W(cos\theta) = 1 - \frac{1}{3}cos^2\theta$

$W(cos\theta') = 1 - \frac{1}{3}cos^2\theta'$

$W(\phi) = \text{flat}$

Angular distributions for $J/\psi \to \mu^+\mu^-$

The angles distributions corrected with the efficiency, which is presented in the lower part of the plot.



$W(cos\theta) = 1 - \frac{1}{3}cos^2\theta$

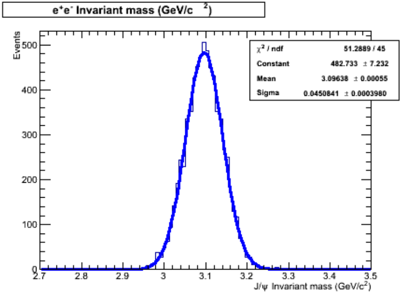
$W(cos\theta') = 1 - \frac{1}{3}cos^2\theta'$

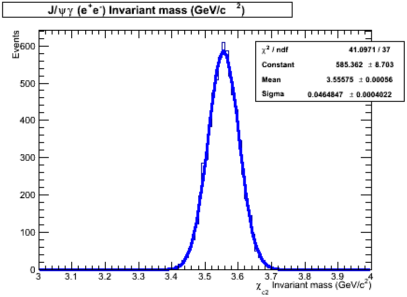
$W(\phi') = \text{flat}$

$\overline{p}p \to \chi_{c2} \to J/\psi\gamma \to \ell^+\ell^-\gamma$

$$\overline{p}p \to \chi_{c2} \to J/\psi\gamma \to \ell^+\ell^-\gamma$$

Invariant mass distributions for $J/\psi \to e^+e^-$





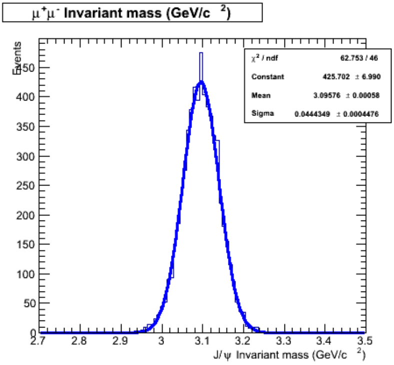
$J/\psi \to e^+e^-$

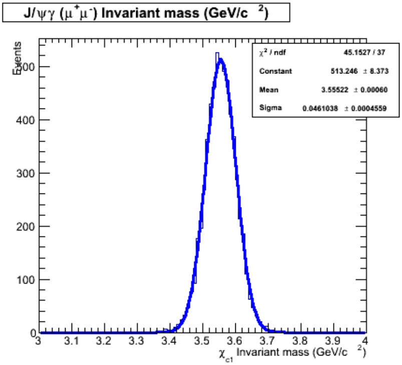
- Mean = 3.096 GeV
- Sigma = 45.1 MeV
- Eff = 68.2%

$\chi_{c2} \to J/\psi\gamma$

- Mean = 3.556 GeV
- Sigma = 46.5 MeV
- Eff = 68.1%

Invariant mass distributions for $J/\psi \to \mu^+\mu^-$





$J/\psi \to \mu^+\mu^-$

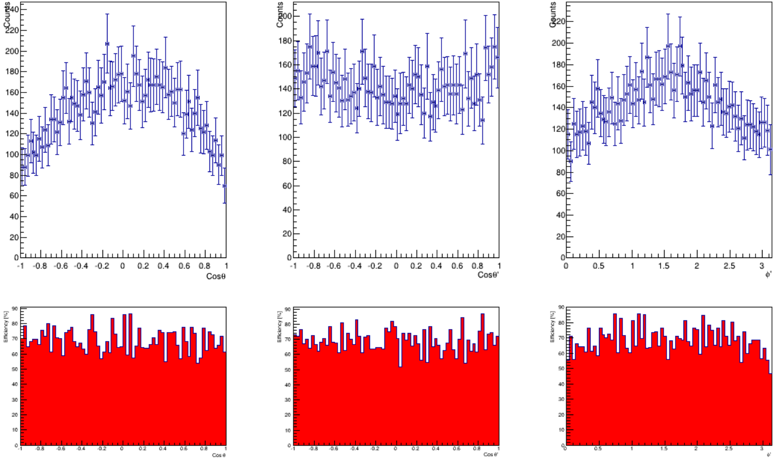
- Mean = 3.096 GeV
- Sigma = 44.43 MeV
- Eff = 59.9%

$\chi_{c2} \to J/\psi\gamma$

- Mean = 3.555 GeV
- Sigma = 46.10 MeV
- Eff = 59.8%

Angular distributions for $J/\psi \rightarrow e^+e^-$

The angles distributions corrected with the efficiency, which is presented in the lower part of the plot.



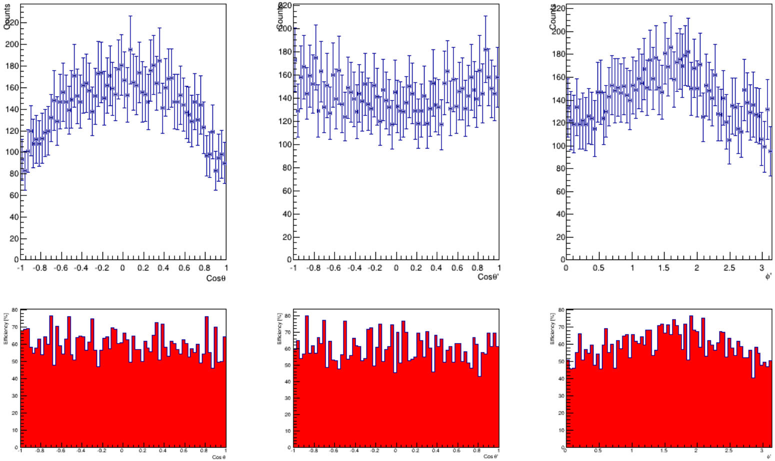
$W(cos\theta) = 1 - \frac{1}{3}cos^2\theta$

$W(cos\theta') = 1 + \frac{1}{13}cos^2\theta'$

$W(\phi') = 1 - \frac{8}{71}cos(2\phi')$

Angular distributions for $J/\psi \to \mu^+\mu^-$

The angles distributions corrected with the efficiency, which is presented in the lower part of the plot.



$W(cos\theta) = 1 - \frac{1}{3}cos^2\theta$

$W(cos\theta') = 1 + \frac{1}{13}cos^2\theta'$

$W(\phi') = 1 - \frac{8}{71}cos(2\phi')$

BACK-UP SLIDES

Radiative transitions of the χ_{cJ} charmonium states

The measurement of the angular distributions in the radiative decays of the χ_c states provides the multipole structure of the radiative decay and the properties of the $\overline{c}c$ bound state.

$$\overline{p}p \to \chi_c \to J/\psi\gamma \to e^+e^-\gamma$$

dominated by the dipole term E1.
M2 and E3 terms arise in the relativistic treatment of the interaction between the electromagnetic field and the quarkonium system. They contribute to the radiative width at the few percent level.
The angular distribution of the χ_1 and χ_2 are described by 4 indipendent parameters:

$$a_2(\chi_{c1}), a_2(\chi_{c2}), B_0^2(\chi_{c2}), a_3(\chi_{c2})$$

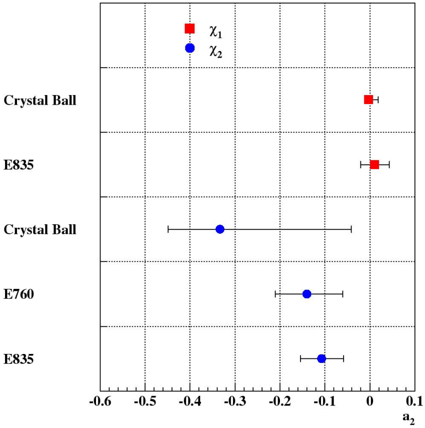
Angular distribution of the χ_{cJ} states

- The coupling between the set of χ states and $\bar{p}p$ is described by four indipendent helicity amplitudes:
  - χ_0 is formed only through the helicity 0 channel
  - χ_1 is formed only through the helicity 1 channel
  - χ_2 can couple to both
- The fractional electric octupole amplitude, $a_3 \approx E3/E1$, can contribute only to the χ_2 decays, and is predicted to vanish in the single quark radiation model if the J/ψ is pure S wave.
- For the fractional M2 amplitude a relativistic calculation yields:

$$a_2(\chi_{c1}) = -\frac{E_\gamma}{4m_c}(1+\kappa_c) = -0.065(1+\kappa_c)$$
$$a_2(\chi_{c2}) = -\frac{3}{\sqrt{5}}\frac{E_\gamma}{4m_c}(1+\kappa_c) = -0.096(1+\kappa_c)$$

where κ_c is the anomalous magnetic moment of the c-quark

χ_{c1} and χ_{c2} angular distributions



$$\left(\frac{a_2(\chi_1)}{a_2(\chi_2)}\right)_{Th} = \frac{\sqrt{5}}{3}\frac{E_\gamma(\chi_1 \to J/\psi\gamma)}{E_\gamma(\chi_2 \to J/\psi\gamma)} = 0.676$$

McClary and Byers (1983) predict that ratio is indipendent of c-quark mass and anomalouse magnetic moment

E835 have been measured for the first time this ratio:

$$\left(\frac{a_2(\chi_1)}{a_2(\chi_2)}\right)_{E835} = -0.02 \pm 0.34$$

Experimental result is $\sim 2\sigma$ away from prediction.

High statistics measurements of these angular distributions are needed to solve this question

E835 Reference "Ambrogiani et al. Physical Review D, Vol. 65, 05002"