χ_{c_1} and χ_{c_2} production in e^+e^- annihilation

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Outline

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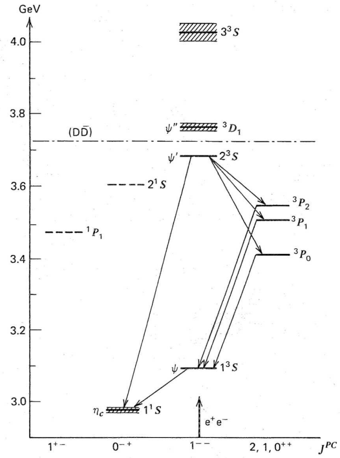
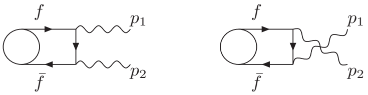


Charmonium spectrum ($\chi_{c_{0,1,2}} = |c\bar{c}>$) $\rightarrow J^{PC} = 0^{++}, 1^{++}, 2^{++}$

- Luminosity of electron positron colliders are sufficiently high to make possible direct resonant production of these states at low energies in e^+e^- colliders (BES - III).
- States $\chi_{c_{1,2}}$ with positive charge conjugation can be produced directly only through the neutral current or higher order electromagnetic process.
- We consider electromagnetic interaction of $|c\bar{c}>$ state.
- Measuring cross section for $e^+e^- \to \chi_{c_{1,2}} \to \gamma(J/\psi \to \mu^+\mu^-)$ allows for determiantion of $\Gamma(\chi_{c_{1,2}} \to e^+e^-)$.

QUARKONIUM MODEL



• fermion and antifermion are treated in the **non relativistic approximation**.

Form Factor $\chi_{c_i} - \gamma\gamma$:

$$\mathbf{c} \equiv c_i(M_{\chi_{c_i}}, p_1^2, p_2^2, m_i, a) = \frac{16\pi\alpha a}{\sqrt{m_i}} \frac{1}{((p_1^2 + p_2^2)/2 - M_{\chi_{c_i}} - b_i M_{\chi_{c_i}} - b_i^2/2)^2},$$

$$b_i = 2m_i - M_{\chi_{c_i}}, \; a = \sqrt{\frac{3}{4\pi} 3 Q_i^2 \phi'(0)} \text{ with } Q_i = 2/3$$

J. H. Kuhn, J. Kaplan and E. G. O. Safiani, Nucl. Phys. B **157**

$F_{\mu\nu} = \epsilon_\mu p_\nu - \epsilon_\nu p_\mu$

$\underline{J=0}$

$$A_0 = \frac{1}{6}\mathbf{c}\frac{1}{M_{\chi_{c_0}}}(I_1^0(M^2_{\chi_{c_0}} + p1\cdot p2) - 2I_2^0) \qquad (1)$$

where $I_1^0 = F^1_{\mu\nu}F^{2\mu\nu}$, $I_2^0 = p_1^\nu F^1_{\mu\nu}F^{2\mu\alpha}p_{2\alpha}$.

$\underline{J=1}$

$$A_1 = -i\frac{1}{2}\mathbf{c}(I_1^1 + I_2^1) \qquad (2)$$

where $I_1^1 = F^1_{\mu\nu}\epsilon^{\mu\nu\alpha\beta}F^{2\alpha\gamma}p^{2\gamma}\epsilon_\beta$.

$\underline{J=2}$

$$A_2 = -\mathbf{c}\sqrt{2}M_{\chi_{c_2}}I_2^2 \qquad (3)$$

where $I_2^2 = \epsilon^{\mu\nu}F^{1\beta}_{\mu}F^2_{\alpha\beta}$

Extraction of unknown parameters using the data for decay widths:

$$\Gamma(\chi_{c_i} \to \gamma\gamma) \qquad \Gamma(\chi_{c_i} \to \gamma J/\psi), \text{ for } i = 0, 1, 2$$

The same **Form factor** c used for $\underline{\chi_{c_i} - \gamma\gamma}$ and $\underline{\chi_{c_i} - J/\psi\gamma}$.

fit1 - χ_{c_0}, χ_{c_1}, χ_{c_2}

fit2 - χ_{c_1}, χ_{c_2}

$$b_i = 2m_i - M_{\chi_{c_i}}$$

	$a[GeV]^{5/2}$	$b_0[GeV]$	$b_1[GeV]$	$b_2[GeV]$	χ^2
fit1	0.065(2)	-0.338(7)	-0.577(6)	-0.652(8)	15.6
fit2	**0.062(2)**	-	**-0.584(6)**	**-0.661(6)**	-

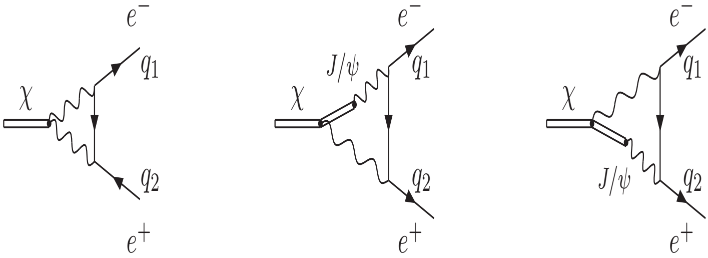
for fit1 $\chi^2 = 12.8$ for $\Gamma(\chi_{c_0} \to \gamma\gamma)$.

$$A(e^+e^- \to \chi_{c_0}) \propto m_e.$$

widths [MeV]	χ_{c_0}	χ_{c_1}	χ_{c_2}
$\Gamma(\chi \to \gamma\gamma)_{exp}$	$2.3(2) \cdot 10^{-3}$	-	$5.3(3) \cdot 10^{-4}$
$\Gamma(\chi \to \gamma\gamma)_{th}$	$1.66(1) \cdot 10^{-3}$	-	$5.3(3) \cdot 10^{-4}$
$\Gamma(\chi \to J/\psi\gamma)_{exp}$	$1.33(9) \cdot 10^{-1}$	$2.8(2) \cdot 10^{-1}$	$3.7(3) \cdot 10^{-1}$
$\Gamma(\chi \to J/\psi\gamma)_{th}$	$1.36(2) \cdot 10^{-1}$	$2.8(4) \cdot 10^{-1}$	$3.7(6) \cdot 10^{-1}$

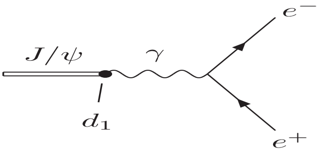
Table: Experimental (exp) and theoretical (th) values of $\Gamma(\chi_{c_{0,1,2}} \to \gamma\gamma, J/\psi\gamma)$.

$\chi_{c_1} \not\to \gamma\gamma$ according to Yang's Theorem.



$$\Gamma(\chi_{c_1} \to e^+e^-) = \frac{|g_1|^2}{12\pi} M_{\chi_{c_1}}$$
$$\Gamma(\chi_{c_2} \to e^+e^-) = \frac{|g_2|^2}{40\pi} M_{\chi_{c_2}}.$$

$$loop = g_i \equiv g_i(M_{\chi_{c_i}}, m_i, a, M_{J/\psi})$$
$$g_i = g_{i_{\gamma\gamma}} + e^{i\phi} g_{i_{\gamma J/\psi}}.$$

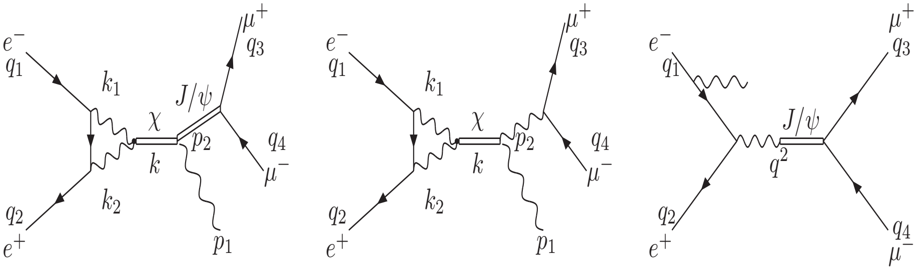


The coupling $J/\psi - \gamma$ d_1:

$$\Gamma(J/\psi \to \gamma \to e^+e^-) = \frac{\alpha d_1}{3M^3_{J/\psi}}.$$

Predictions of electronic widths

widths	fit1	fit2
$\Gamma(\chi_{c_1} \to e^+e^-)_{max}$	0.041 eV	0.037 eV
$\Gamma(\chi_{c_1} \to e^+e^-)$	0.040 eV	0.036 eV
$\Gamma(\chi_{c_1} \to e^+e^-)_{\gamma\gamma}$	0.040 eV	0.036 eV
$\Gamma(\chi_{c_2} \to e^+e^-)_{max}$	0.094 eV	0.087 eV
$\Gamma(\chi_{c_2} \to e^+e^-)$	0.093 eV	0.086 eV
$\Gamma(\chi_{c_2} \to e^+e^-)_{\gamma\gamma}$	0.022 eV	0.02 eV



+ Interferences (2 unknown phases).

$J/\psi - \mu^+\mu^-$ coupling: $\sqrt{\frac{3\Gamma_{J/\psi\to e^+e^-}}{\alpha\sqrt{p_2^2}}}$.

TESTS OF THE CODE

Helicity amplitude method vs Trace method

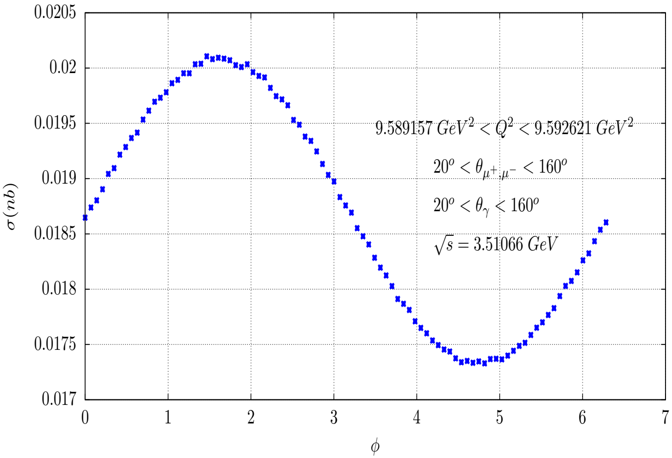
relative accuracy $\approx 10^{-15}$

Narrow width approximation ($\sqrt{s} = M_{\chi_{c_{1,2}}}$):

$$\sigma_{\chi_{c_1}} = \frac{12\pi}{s} Br(\chi_{c_1} \to e^+e^-) Br(J/\psi \to \mu^+\mu^-) Br(\chi_{c_1} \to J/\psi\gamma),$$

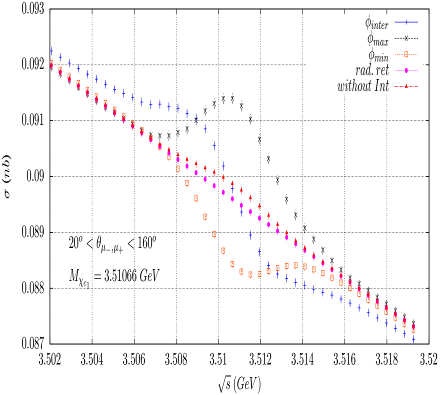
$$\sigma_{\chi_{c_2}} = \frac{20\pi}{s} Br(\chi_{c_2} \to e^+e^-) Br(J/\psi \to \mu^+\mu^-) Br(\chi_{c_2} \to J/\psi\gamma),$$

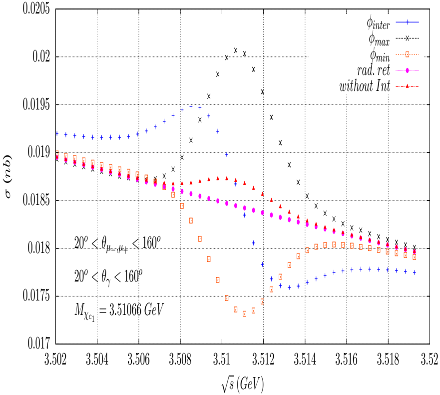
$(0.49 \pm 0.07)\%$ for χ_{c_1}
$(2.81 \pm 0.02)\%$ for χ_{c_2}



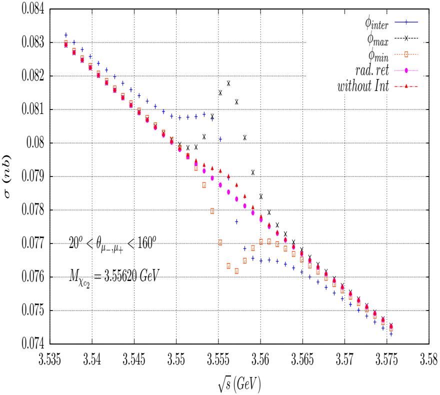
$\sigma \equiv \sigma(e^+e^- \to \chi_{c_1} \to \gamma(J/\psi \to \mu^+\mu^-))$

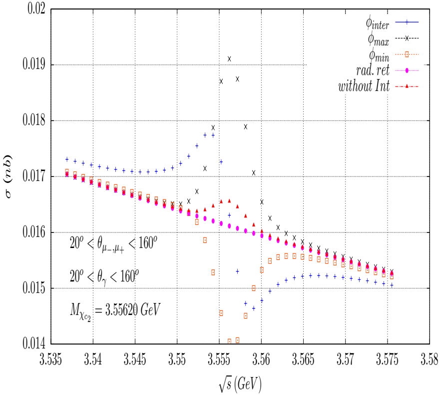
ϕ - relative phase signal-background, Q^2 - muons invariant mass.





Beam spread: $\Delta E = 1MeV$, $\Gamma_{ee} = 0.04eV$





Beam spread: $\Delta E = 1MeV$, $\Gamma_{ee} = 0.09eV$

Final remarks

• The production of $\chi_{c_{1,2}}$ have been implemented in PHOKHARA MC generator

• Results show that these processes can be measured in existing experiments (BES-III).

• Obtained results depend on relative phase of radiative return and $\chi_{c_{1,2}}$ production amplitudes.

Outlook

• Production of $\chi_{c_{0,1,2}}$ in two photon procesess can be also considered to check the corectness of charmonium states models.