χ_{c_1} and χ_{c_2} production at e^+e^- colliders

Szymon Tracz
in collaboration with
H. Czyż, J.H. Kuhn

Institute of Physics, University of Silesia
Katowice

October 25, 2016

Outline

Production of charmonium resonances with J^{++}

$$\chi_{c_{0,1,2}} = |c\bar{c}> \to J^{PC} = 0^{++}, 1^{++}, 2^{++}$$

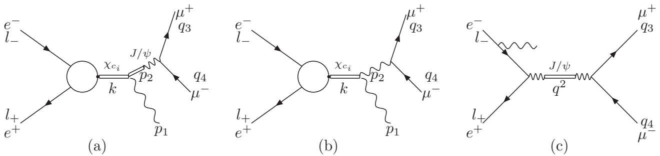
- Electromagnetic production only through higher order electromagnetic process.
- Strongly suppressed by ordinary annihilation through one photon to the J^{--} states.
- High luminosity colliders (eg. BESIII) are needed.
- Signal can be observed in the reactions:

$$e^+e^- \to \chi_{c_i} \to hadrons$$

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

- $Br(\chi_{c_1} \to J/\psi\gamma) = (33.9 \pm 1.2)\%$
- $Br(\chi_{c_2} \to J/\psi\gamma) = (19.2 \pm 0.7)\%$

Cross section for the process $e^+e^- \to \chi_{c_i} \to \gamma J/\psi(\to \mu^+\mu^-)$



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

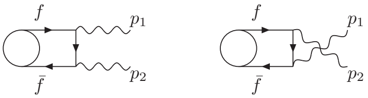
- Background (Fig.(c)) has to be taken into account
- possible contribution from a diagram from Fig.(b) is negligible for our event selections:

$$9.58916 < Q^2 < 9.59262$$

Q^2 - invariant mass of the muons system

- $\sqrt{s} = M_{\chi_{c_i}}$
- E_γ has to be chosen in the proper kinematic region

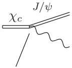
Quarkonium model



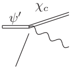
$$
\begin{aligned}
c &\equiv c((p_1+p_2)^2, p_1^2, p_2^2, m) \\
&= \frac{16\pi\alpha a}{\sqrt{m}} \frac{1}{((p_1-p_2)^2/4 - m^2 + i\epsilon)^2}
\end{aligned}
$$

J. H. Kuhn, J. Kaplan and E. G. O. Safiani, Nucl. Phys. B **157** (1979) 125.

$\chi_{c_i} - \gamma J/\psi$ and $\chi_{c_i} - \gamma\psi'$ FFs



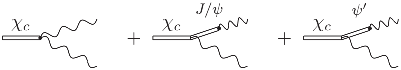
$$c_{J/\psi} = \frac{4ea_J}{\sqrt{m}} \frac{1}{(M_\chi^2/2+b^2/4+bM_\chi/2-M_{J/\psi}^2/2)^2}$$



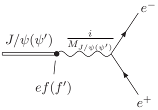
$$c_{\psi'} = \frac{4ea_{\psi'}}{\sqrt{m}} \frac{1}{(M_\chi^2/4+m^2-M_{\psi'}^2/2)^2}$$

- $b_i = 2m - M_{\chi_{c_i}}$
- $a = \sqrt{\frac{1}{4\pi} 3Q^2 \phi'(0)}$
- $f = \sqrt{\frac{3\Gamma_{J/\psi\to e^+e^-} M_{J/\psi}^3}{4\pi\alpha^2}}$
- $a_J,\ a_{\psi'}$ - free parameters

$\chi_{c_i} - \gamma\gamma$ FF



$$c_\gamma = \frac{4e^2}{\sqrt{m}}\left(a + \frac{f a_J}{M_{J/\psi}^2} + \frac{f' a_{\psi'}}{M_{\psi'}^2}\right)\frac{1}{(M_\chi^2/2+b^2/4+bM_\chi/2)^2}$$



H. Czyż, J. H. Kühn and S. Tracz, Phys. Rev. D **94** (2016) no.3, 034033

Determination of the model parameters

a[GeV$^{5/2}$]	$\|\phi^{'}(0)\|^2$ [GeV^5]	m [GeV]	a_J	$a_{\psi'}$
0.0786	0.04	1.69	0.15	-0.07

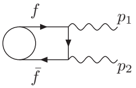
widths [MeV]	χ_{c1}	χ_{c2}
$\Gamma(\chi \to \gamma\gamma)_{th}$	-	$5.28820 \cdot 10^{-4}$
$\Gamma(\chi \to J/\psi\gamma)_{th}$	$2.8034 \cdot 10^{-1}$	$3.77784 \cdot 10^{-1}$
$\Gamma(\psi' \to \chi\gamma)_{th}$	$2.8557 \cdot 10^{-2}$	$2.7049 \cdot 10^{-2}$
$\Gamma(\chi \to \gamma\gamma)_{exp}$	-	$5.3(3) \cdot 10^{-4}$
$\Gamma(\chi \to J/\psi\gamma)_{exp}$	$2.8(2) \cdot 10^{-1}$	$3.7(3) \cdot 10^{-1}$
$\Gamma(\psi' \to \chi\gamma)_{exp}$	$2.8(1) \cdot 10^{-2}$	$2.7(1) \cdot 10^{-2}$

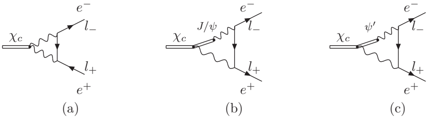
$\chi_{c_1} \not\to \gamma\gamma$ due to Yang theorem.

H. Czyż, J. H. Kühn and S. Tracz, Phys. Rev. D **94** (2016) no.3, 034033

E. Eichten, K. Gottfried, T. Kinoshita, Phys. Rev. D **17** (1978) 3090

Production of the χ_{c_i} in e^+e^- annihilation is an example of the process, which goes only through the radiative corrections.





- **Extended Quarkonium model.**
- $A(\chi_{c_i} \to \gamma\gamma) \propto \phi'(0)$

$$A(e^+e^- \to {}^3P_J) = ie^2 \int \frac{dp_1}{(2\pi)^4} \bar{v}(l_+)\gamma_\nu \not{h} \gamma_\mu u(l_-) \frac{1}{h^2}\frac{1}{p_1^2}\frac{1}{p_2^2} A_J^{\mu\nu}(p_1, p_2, \epsilon)$$

$$\Gamma_{1ee} = \frac{1}{3}\frac{|g_1|^2}{4\pi} M_{\chi_{c_1}}$$

$$\Gamma_{2ee} = \frac{1}{5}\frac{|g_2|^2}{8\pi} M_{\chi_{c_2}}$$

$$g_i = g_{i_{\gamma\gamma}} + g_{i_{J/\psi\gamma}} + g_{i_{\psi'\gamma}}$$

Electronic widths

$$\Gamma(\chi_{c_1} \to e^+e^-) = \frac{M_{\chi_{c_1}}}{3\pi}\left[\frac{|g_1|^2}{4} + \frac{aG_F}{\sqrt{2}mQ^2} Re(g1) + \frac{a^2 G_F^2}{mQ^4}\left(1 - 4\sin^2\theta_W + 8\sin^4\theta_W\right)\right],$$

	$\gamma\gamma + J/\psi\gamma + \psi'$	$\gamma\gamma$	$J/\psi\gamma$	ψ'	QED+Z^0
$\Gamma_{(\chi_{c_1}\to e^+e^-)}$ [eV]	0.43	0.10	0.008	0.094	0.41
$\Gamma_{(\chi_{c_2}\to e^+e^-)}$ [eV]	4.25	0.042	1.41	0.45	-

H. Czyż, J. H. Kühn and S. Tracz, Phys. Rev. D **94** (2016) no.3, 034033

Comparison of electronic widths calculated within different models

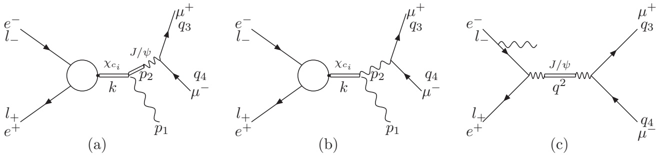
	1)	2)	3)	4)
$\Gamma_{(\chi_{c_1}\to e^+e^-)}$ [eV]	0.43	0.046	0.367	0.1
$\Gamma_{(\chi_{c_2}\to e^+e^-)}$ [eV]	4.25	0.037	0.137	-

1) H. Czyż, J. H. Kühn and S. Tracz, Phys. Rev. D **94** (2016) no.3, 034033

2) N. Kivel and M. Vanderhaeghen, JHEP **1602** (2016) 032
3) D. Yang and S. Zhao,Eur. Phys. J. C **72** (2012) 1996
4) A. Denig, F. K. Guo, C. Hanhart and A. V. Nefediev, Phys. Lett. B **736** (2014) 221

Implementation of the amplitudes for χ_{c_i} production

PHOKHARA 9.2 MC Generator http://ific.uv.es/ rodrigo/phokhara/



TESTS OF THE CODE

Helicity amplitude method vs Trace method

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

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

$$\sigma^1_{res} = \frac{12\pi}{s} Br(\chi_{c_1} \to e^+e^-) Br(J/\psi \to \mu^+\mu^-) Br(\chi_{c_1} \to J/\psi\gamma),$$

$$\sigma^2_{res} = \frac{20\pi}{s} Br(\chi_{c_2} \to e^+e^-) Br(J/\psi \to \mu^+\mu^-) Br(\chi_{c_2} \to J/\psi\gamma),$$

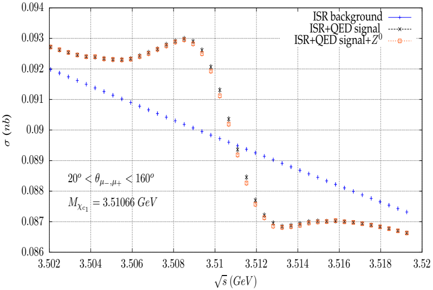
$(M_{J/\psi} - 30\Gamma_{J/\psi})^2 < Q^2 < (M^2_{J/\psi} + 30\Gamma_{J/\psi})^2$

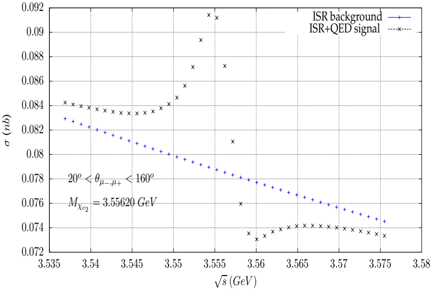
Relative differences: 3.4% for χ_{c_1} and 1.3% for χ_{c_2}

$e^+e^- \to \mu^+\mu^-\gamma$

$\Gamma_{1ee} = 0.41$ eV

$\Gamma_{2ee} = 4.25$ eV



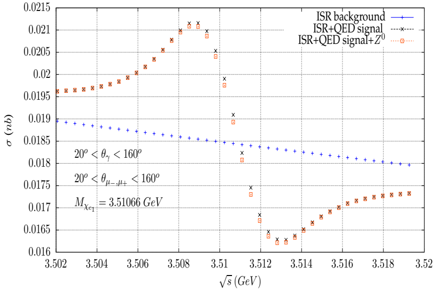


$\Delta E = 1$ MeV beam resolution per beam was assumed.

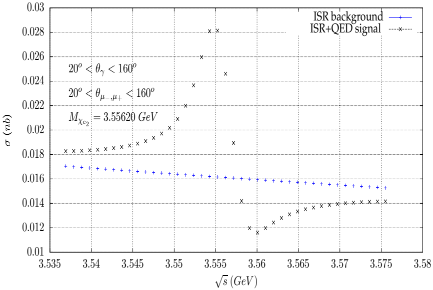
H. Czyż, J. H. Kühn and S. Tracz, Phys. Rev. D **94** (2016) no.3, 034033

$e^+e^- \to \mu^+\mu^-\gamma$

$\Gamma_{1ee} = 0.41$ eV



$\Gamma_{2ee} = 4.25$ eV



$\Delta E = 1$ MeV beam resolution per beam was assumed.

H. Czyż, J. H. Kühn and S. Tracz, Phys. Rev. D **94** (2016) no.3, 034033

Final remarks

- Direct resonant production of $\chi_{c_{1,2}}$ lead to measurable resonant enhancement in the cross section.
- The prediction exhibits a sizeable model dependence.
- Production of $\chi_{c_{1,2}}$ can be mainly observed as an interference between ISR and the signal.
- Resonant signal in the $\gamma\mu^+\mu-$ channel can be seen at the BESIII.