Preliminary results of χ_{c1} and χ_{c2} production at e^+e^- colliders.

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- States with positive charge conjugation can be produced directly only through the neutral current or higher order electromagnetic processes.
- Luminosity of electron positron collider is sufficiently high to make possible production of these states.
- It allows to measure $\Gamma(\chi \to e^+e^-)$.

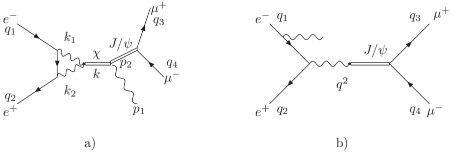
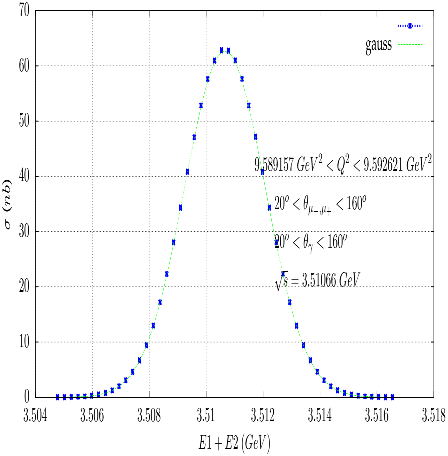


Figure: Diagrams for process $e^+e^- \to \mu^+\mu^-$ with χ production.

$$A(e^+e^- \to \chi_0) = 0$$
$$\Gamma(\chi_1 \to e^+e^-) = 0.4eV$$
$$\Gamma(\chi_2 \to e^+e^-) = 0.1eV$$
$$e^+e^- \to \chi(\to J/\psi(\to \mu^+\mu^-)\gamma)$$

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



$$\Delta E_{1,2} = 1MeV$$

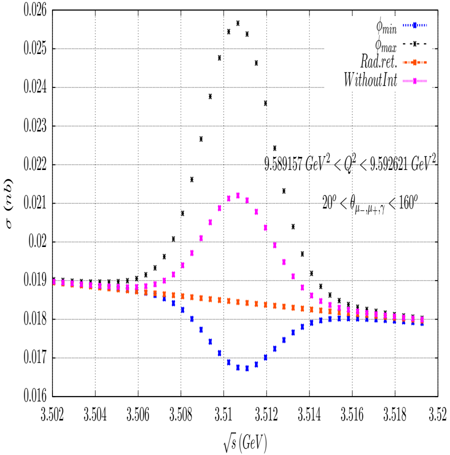


Figure: Cross section as a function of $\sqrt{s}$ for χ_{c1} production with $\Delta E_{1,2} = 1MeV$
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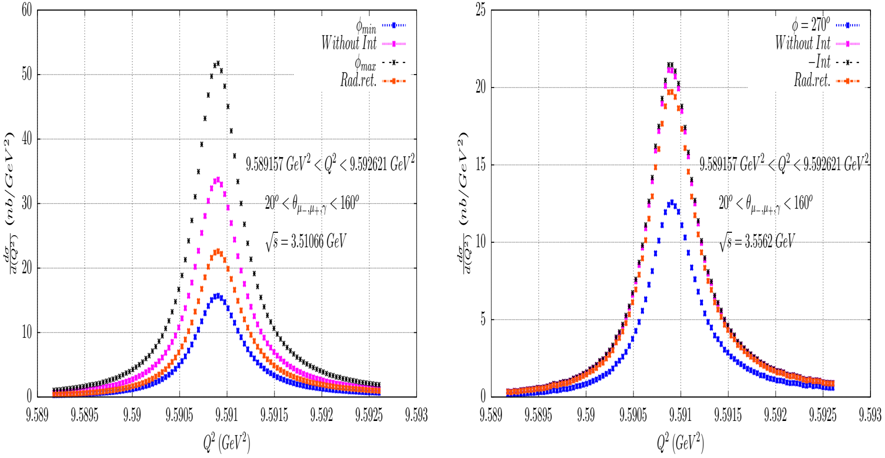

Figure: Q^2 distribution for χ_{c1} and χ_{c2}.

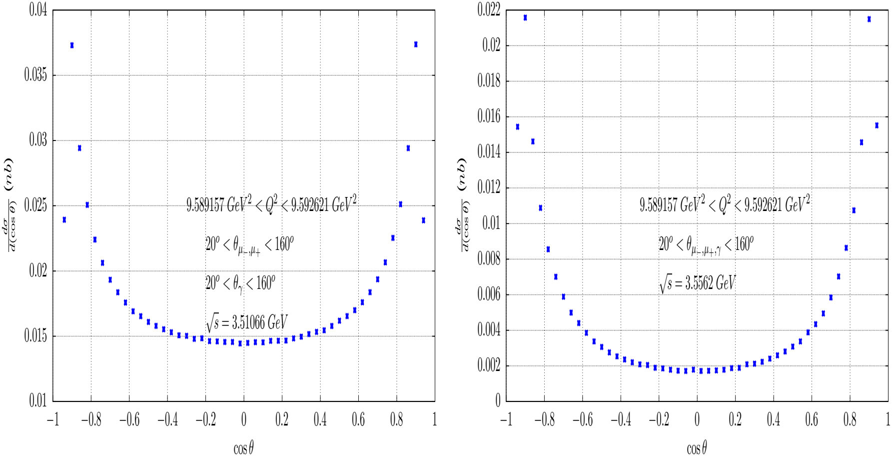

Figure: Angular distribution for χ_{c1} and χ_{c2}.

Type of cross section	cross section [nb]
minph	$(1.2864 \pm 0.0004) \cdot 10^{-2}$
maxph	$(4.219 \pm 0.001) \cdot 10^{-2}$
Rad. ret	$(1.8445 \pm 0.0005) \cdot 10^{-2}$
Without INT	$(2.7512 \pm 0.0007) \cdot 10^{-2}$

Table: Total cross section for different type of cross section χ_1.

Type of cross section	cross section [nb]
$\phi = 270^o$	$(1.027 \pm 0.001) \cdot 10^{-2}$
-INT	$(1.755 \pm 0.001) \cdot 10^{-2}$
Rad. ret	$(1.6131 \pm 0.0001) \cdot 10^{-2}$
Without INT	$(1.726 \pm 0.001) \cdot 10^{-2}$

Table: Total cross section for different type of cross section for χ_2.

In considered model coupling constant of amplitudes for production od χ_i, $i = 0, 1, 2$ is described in terms of two parameters a,b, where $b = 2m - M$ is the binding energy and $a = \sqrt{\frac{3}{4\pi}\phi^{'}(0)\sqrt{3}(\frac{2}{3})^2}$ is coupling constant.

$$c = 4e^2 a \frac{1}{\sqrt{m}}[-p1 \cdot p2 - \frac{1}{2}bM + i\epsilon]^{-2}. \quad (1)$$

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

$$F_{\mu\nu} = \epsilon_\mu p_\nu - \epsilon_\nu p_\mu \tag{2}$$

$J = 0$

$$A_0 = \frac{1}{6} c \frac{1}{M} (I_1^0 (M^2 + p1 \cdot p2) - 2 I_2^0) \tag{3}$$

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

$$A_1 = -i \frac{1}{2} c (I_1^1 + I_2^1) \tag{4}$$

where $I_1^1 = F^1_{\mu\nu} \epsilon^{\mu\nu\alpha\beta} F^{2\alpha\gamma} p^{2\gamma} \epsilon_\beta$, $I_2^1 = 0$, I_3^1.
$J = 2$

$$A_2 = -c\sqrt{s} M I_2^2 \tag{5}$$

where $I_2^2 = \epsilon^{\mu\nu} F_\mu^{1\beta} F^2_{\alpha\beta}$, I_1^2, I_3^2, I_4^2, I_5^2.

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Model with the assumption that c quarks effective masses are different for χ_0, χ_1, χ_2. We have fitted $\Gamma(\chi_{0,1,2} \to \gamma\gamma)$ and $\Gamma(\chi_{0,1,2} \to J/\psi\gamma)$. Determining m and a only from χ_0 and χ_2.

For χ_0:

$$\begin{aligned} a &= 7.950619254608049 \cdot 10^{-2} \\ m_0 &= 1.55505193299033. \end{aligned}$$

For χ_2:

$$\begin{aligned} a &= 6.196728634814685 \cdot 10^{-2} \\ m_2 &= 1.44751007368050. \end{aligned}$$

Fit only to the χ_1 and χ_2.

$$\begin{aligned} a &= 6.196730302582831 \cdot 10^{-2}. \\ m_1 &= 1.46316061479881 \\ m_2 &= 1.44751010082441 \end{aligned}$$

Fit only to the χ_0 and χ_1.

$$\begin{aligned} a &= 7.950613760834835 \cdot 10^{-2}. \\ m_0 &= 1.55505186315755 \\ m_1 &= 1.48186322342452 \end{aligned}$$

$$\chi^2 \sim 10^{-10}.$$

$$
\begin{aligned}
a &= 6.522777038283634 \cdot 10^{-2}, \\
m_0 &= 1.53834244071372 GeV, \\
m_1 &= 1.46684772162752 GeV, \\
m_2 &= 1.45219724899374 GeV, \\
\chi^2 &= 15.6200684380771.
\end{aligned}
$$

$$
\begin{aligned}
\Gamma(\chi_0 \to \gamma\gamma)_{exp} &= (2.34 \pm 0.19) \cdot 10^{-6} MeV, \\
\Gamma(\chi_0 \to \gamma\gamma)_{fit} &= 1.66 \cdot 10^{-6} MeV, \\
\chi^2 = 13.
\end{aligned}
$$

width	fit1	fit2	fit3
$\Gamma(\chi_0 \to e^+e^-)$	0	0	0
$\Gamma(\chi_1 \to e^+e^-)$	0.03 eV	0.06 eV	0.04 eV
$\Gamma(\chi_2 \to e^+e^-)$	0.05 eV	0.08 eV	0.06 eV

For χ_0:

$$\begin{aligned} E_{CMS} &= 4.24 GeV \\ \sigma &\simeq 0.004 fb \\ E_{CMS} &= 10.56 GeV \\ \sigma &\simeq 3 fb \end{aligned}$$

where $\sigma = \sigma(e^+e^- \to e^+e^-\chi_0(\to J/\psi(\to \mu^+\mu^-)\gamma))$.
BES-III:
$L_{INT} = 10fb^{-1}$ 0.04 events,
BaBar:
$L_{INT} = 530fb^{-1}$ 1600 events,
BELLE:
$L_{INT} = 1000fb^{-1}$ 3000 events,
BELLE-2:
$L_{INT} = 50ab^{-1}$ 150000 events.

For χ_1:

$$\begin{aligned} E_{CMS} &= 4.24 GeV \\ \sigma &\simeq 0.03 fb \\ E_{CMS} &= 10.56 GeV \\ \sigma &\simeq 27 fb \end{aligned}$$

where $\sigma = \sigma(e^+e^- \to e^+e^-\chi_1(\to J/\psi(\to \mu^+\mu^-)\gamma))$.
BES-III:
$L_{INT} = 10 fb^{-1}$ 0.3 events,
BaBar:
$L_{INT} = 530 fb^{-1}$ 14000 events,
BELLE:
$L_{INT} = 1000 fb^{-1}$ 28000 events,
BELLE-2:
$L_{INT} = 50 ab^{-1}$ 1.4 mln events.

Data with angular cuts $20^o < \theta_{e^+,e^-} < 160^o$.

Single tag

CMS - Energy [GeV]	χ_0 no. of events	χ_1 no. of events
4.23 BES -III	0.02	0.4
10.56 BELLE-2	1225	1.75 mln

Double Tag

CMS - Energy [GeV]	χ_0 no. of events	χ_1 no. of events
4.23 BES-III	0.002	0.1
10.56 BELLE-2	405	435000

χ_2 in progress...

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

• χ_0 and χ_1 production was added in EKHARA MC generator

• Preliminary results show that these processes can be measured in existing or near future experiments.

• One should take into account relative phase of radiative return and $\chi_{1,2}$ production amplitudes.