Progress on PHOKHARA

Szymon Tracz

Institute of Physics, University of Silesia
Katowice

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Outline

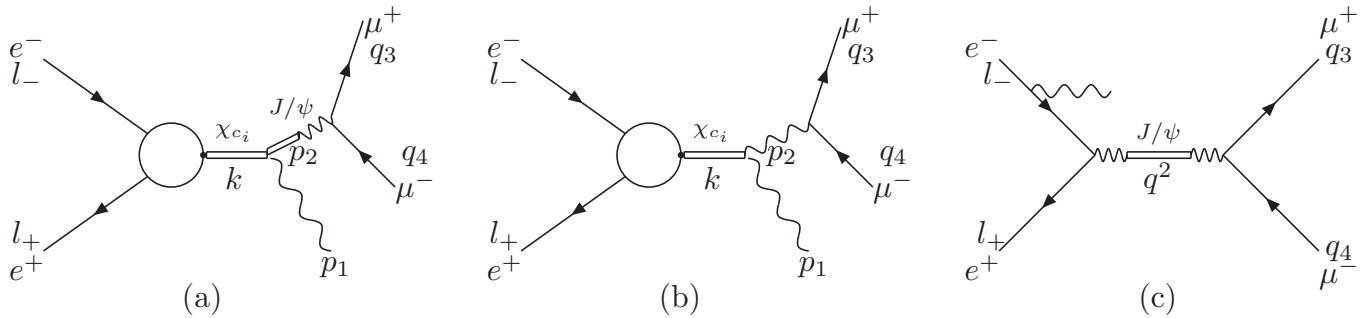
Production of charmonium resonances with J^{++}

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

$$e^+e^- \to \chi_c \to \textit{hadrons}$$

$$e^+e^- \to \chi_c \to \gamma J/\psi(\to \mu^+\mu^-)$$

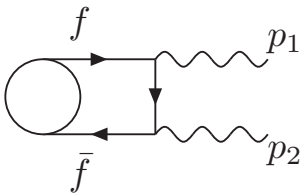
Cross section for the process $e^+e^- \to \chi_c \to \gamma J/\psi(\to \mu^+\mu^-)$

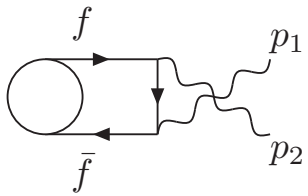


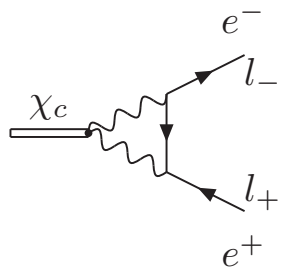
- Background (Fig.(c)) has to be taken into account
- $\sqrt{s} = M_{\chi_c}$
- ω_γ has to be chosen in the proper kinematic region
- possible contribution from a diagram from Fig.(b) is negligible for our event selections:

$$9.58916 < Q^2 < 9.59262$$

Short distance approximation







- $A(\chi_c \to \gamma\gamma) \propto \phi^{'}(0)$
- Terms $\propto b$ in the A($\chi_c \to \gamma\gamma$) break gauge invariance

$$c_\gamma = \frac{4e^2 a}{\sqrt{m}} \frac{1}{(M_\chi^2/2 + b^2/4 + bM_\chi/2)^2}$$

- $b = 2m - M_{\chi c}$
- $a = \sqrt{\frac{1}{4\pi}} 3Q^2 \phi^{'}(0)$

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

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

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

$$x = \frac{4m^2}{M^2_{\chi c_i}} \to 1$$

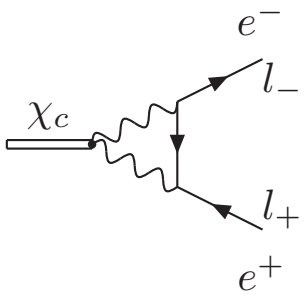
$$g_{1_{\gamma\gamma}} \to \frac{16\sqrt{2}\alpha^2 a}{M^{5/2}_{\chi c_1}} 2(\log(-2z_i) - i\pi)$$

$$g_{2_{\gamma\gamma}} \to \frac{64\alpha^2 a}{M^{5/2}_{\chi c_2}} [(\log(-2z_i) - i\pi) + \frac{1}{3}(i\pi + \log 2 - 1)]$$

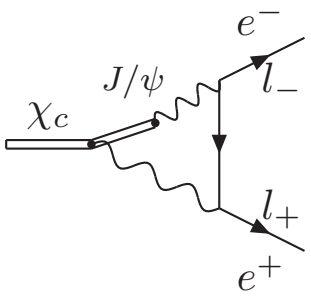
$z_i = \frac{b_i}{M_{\chi c_i}}$, $\quad |\phi'(0)|^2 = 0.1 GeV^5$

	Γ_{1ee}	Γ_{2ee}
	$b = 0.5\ GeV$	
Leading term	0.0226 eV	0.0243 eV
exact result	0.0317 eV	0.0159 eV
	$b = -0.5\ GeV$	
Leading term	0.164 eV	0.0512 eV
exact result	0.141 eV	0.0731 eV

Binding energy corrections



(a)



(b)

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

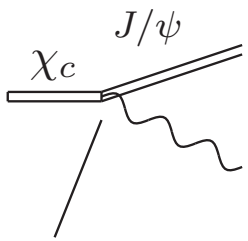
$$\Gamma_{2ee} = \frac{1}{5}\frac{|g_2|^2}{8\pi} M_{\chi_{c_2}}$$

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

$\chi_c - \gamma\gamma$ FF

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

$\chi_c - \gamma J/\psi$ FF



$$c_{J/\psi} = \frac{4e a_J}{\sqrt{m}}\frac{1}{(M^2_\chi/2+b^2/4+bM_\chi/2-M^2_{J/\psi}/2)^2}$$

- $b = 2m - M_{\chi_c}$
- $a = \sqrt{\frac{1}{4\pi}}3Q^2\phi'(0)$
- $f = \sqrt{\frac{3\Gamma_{J/\psi\to e^+e^-}M^3_{J/\psi}}{4\pi\alpha^2}}$
- a_J - free parameter

H. Czyż, J. H. Kühn and S. Tracz (in preparation)

a=0.073GeV $^{5/2}$
$|\phi^{'}(0)|^2 = 0.04$ GeV^5
$a_J = 0.11$

$m = 1.7$ GeV
$b_1 = -0.204$ GeV
$b_2 = -0.249$ GeV

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

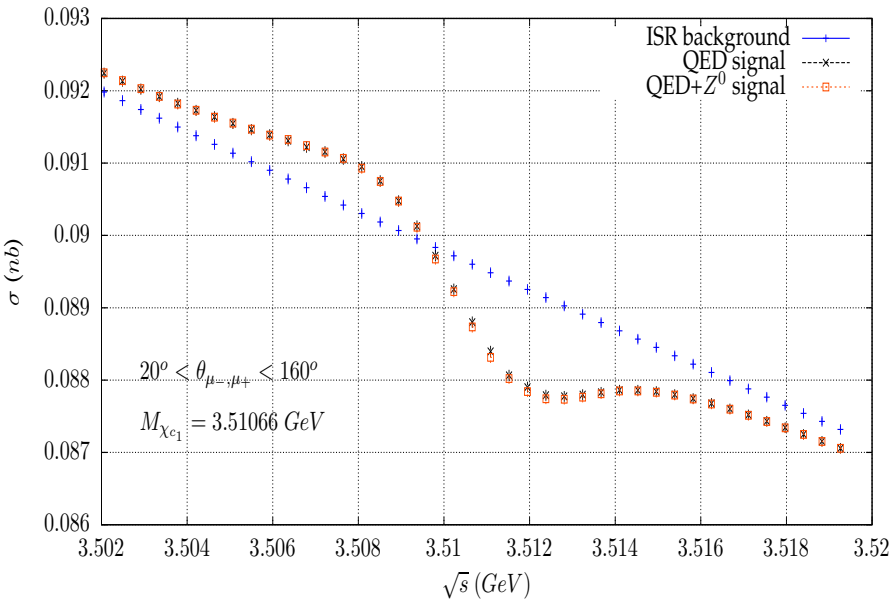
Electronic widths

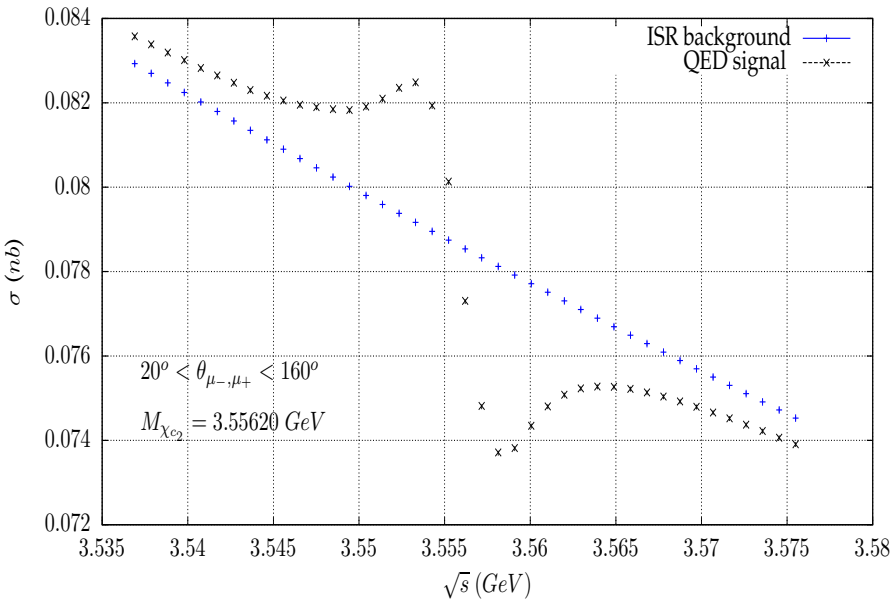
	$\gamma\gamma + J/\psi\gamma$	$\gamma\gamma$	$J/\psi\gamma$	QED+Z^0
Γ_{1ee} [eV]	0.078	0.073	0.003	0.071
Γ_{2ee} [eV]	1.35	0.032	0.975	-

$e^+e^- \to \chi_c \to \gamma J/\psi(\to \mu^+\mu^-)$

$\Gamma_{1ee} = 0.071$ eV

$\Gamma_{2ee} = 1.35$ eV





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

H. Czyż, J. H. Kühn and S. Tracz (in preparation)

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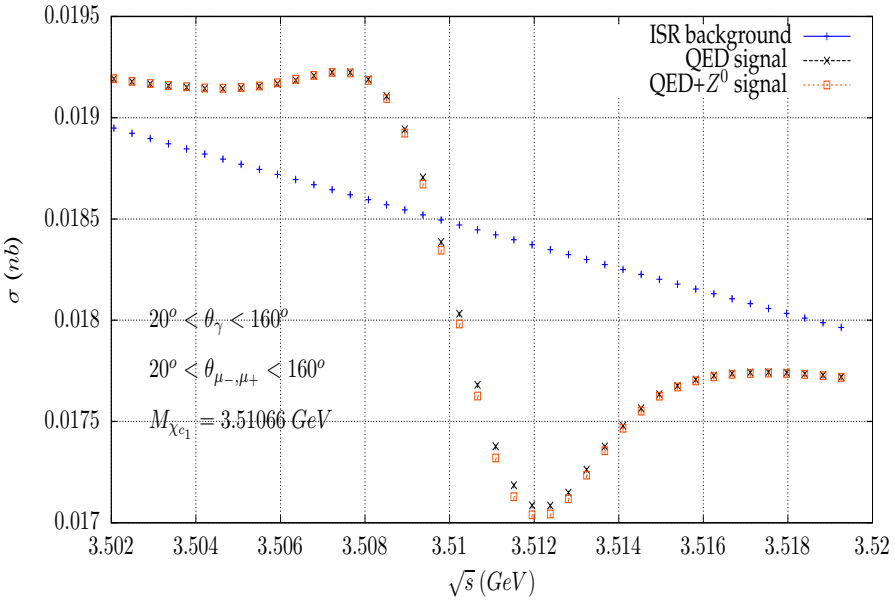

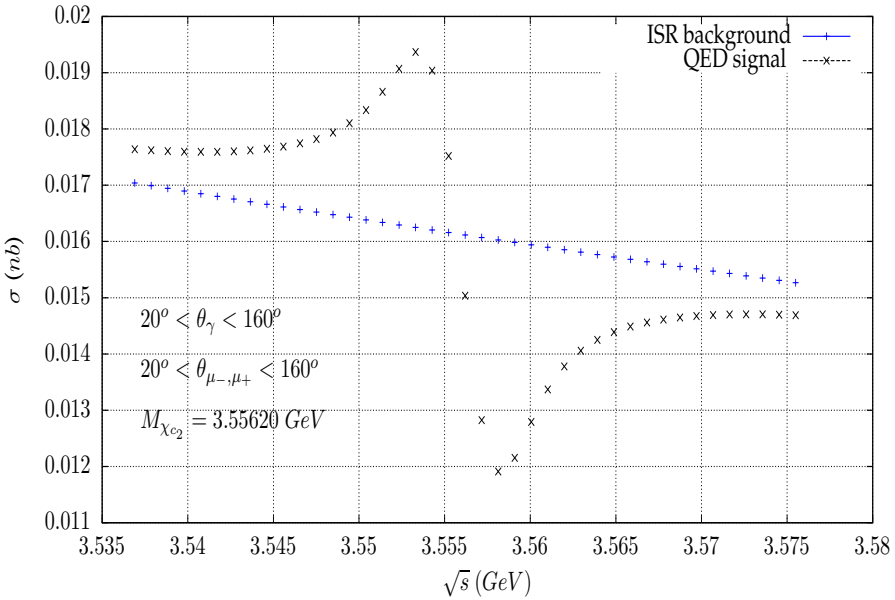

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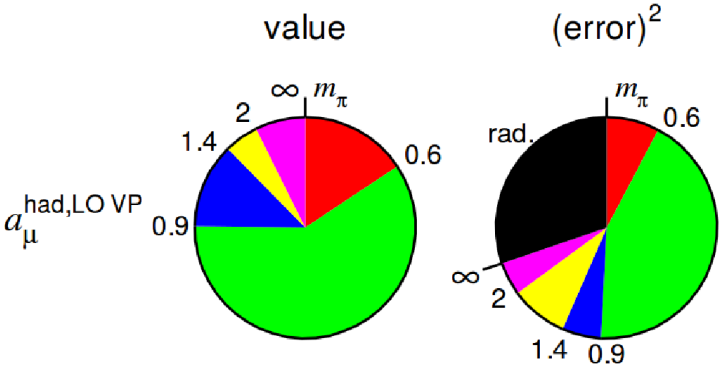
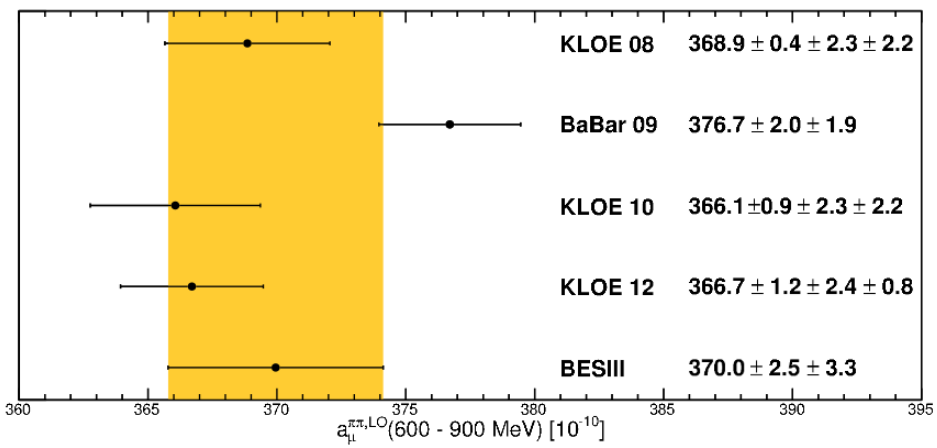
Corrections to the reaction $e^+e^- \to \pi^+\pi^-\gamma$

F. Campanario, H.Czyż, Sz. Tracz, D. Zhuridov, J. Gluza, T. Jeliński,T. Riemann





D. Nomura's talk

Matter to the Deepest, Ustroń

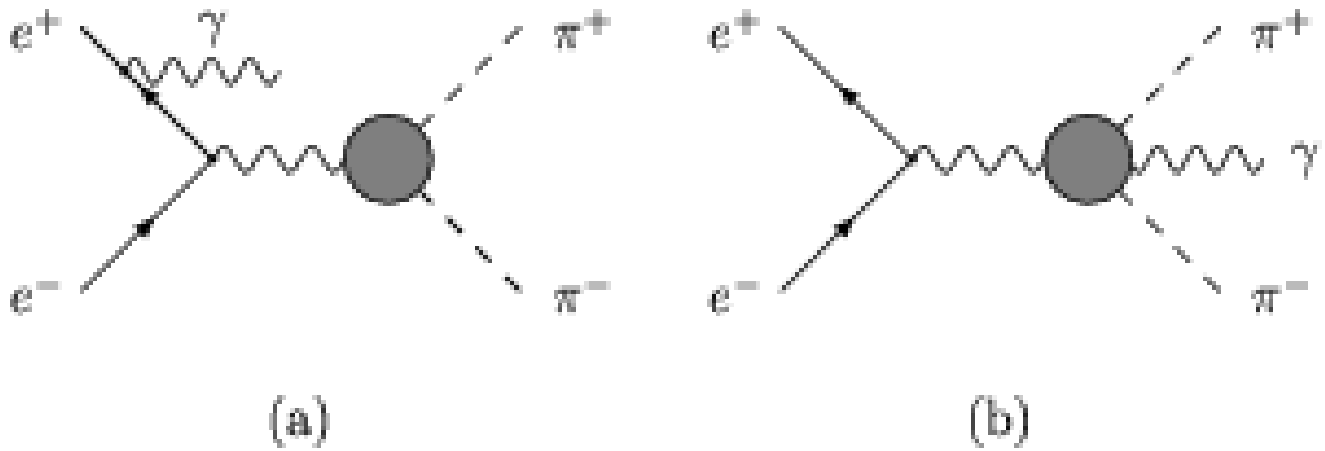
2015.

M. Ripka [BESIII Collaboration],

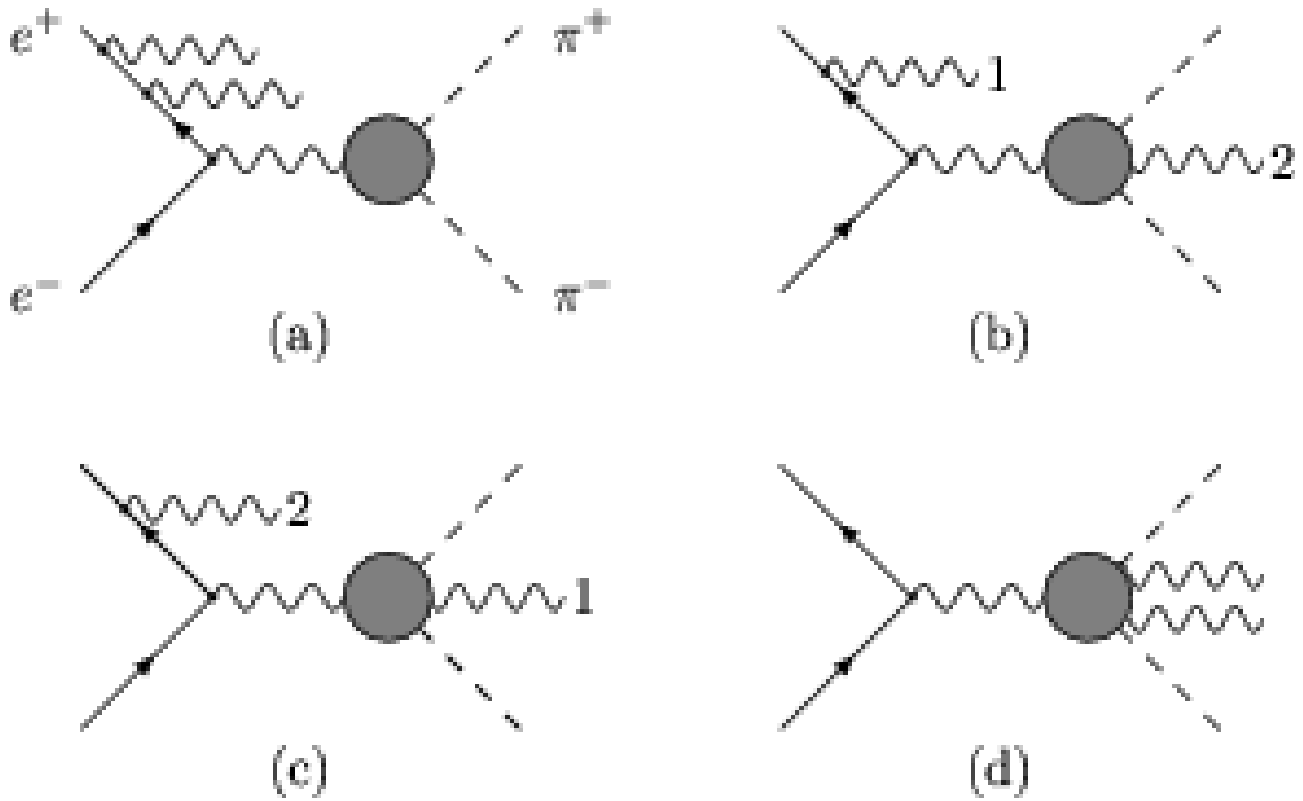
Acta Phys. Polon. B **46** (2015)

no.11, 2261.

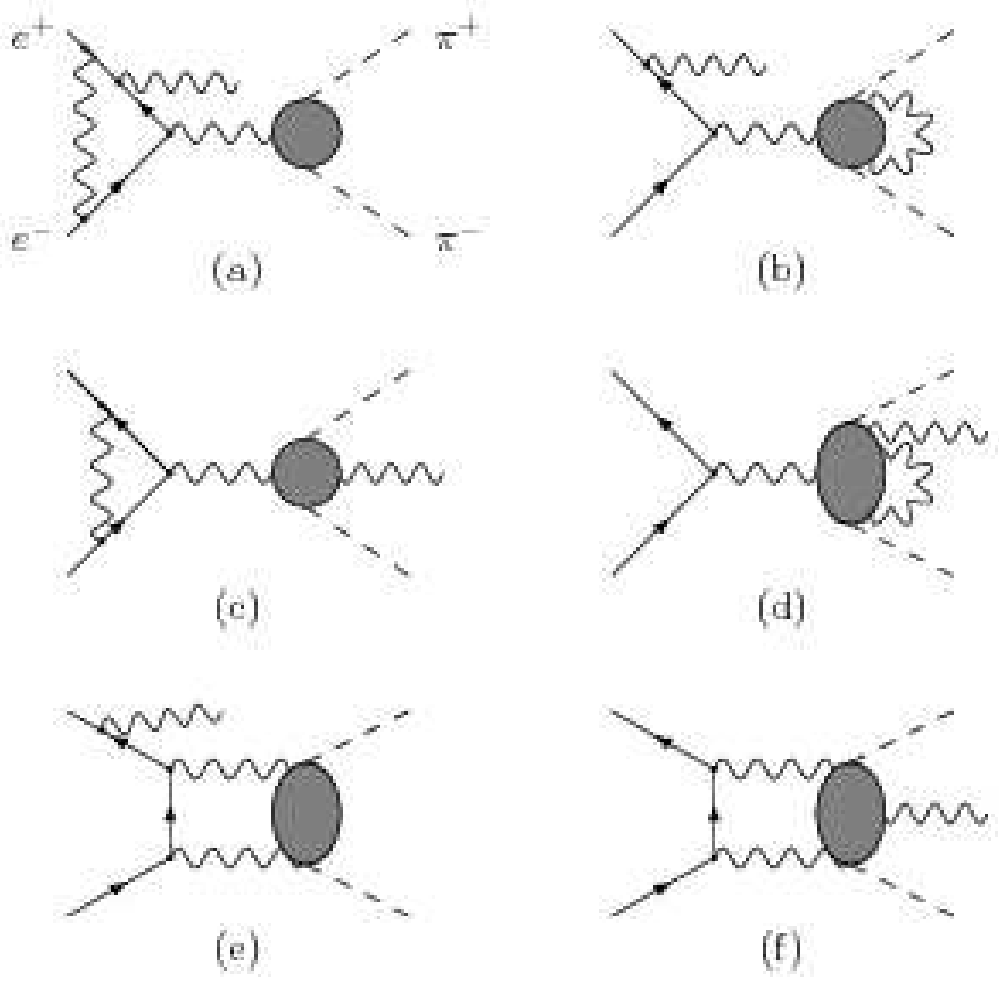
Born amplitudes



Two photons emission



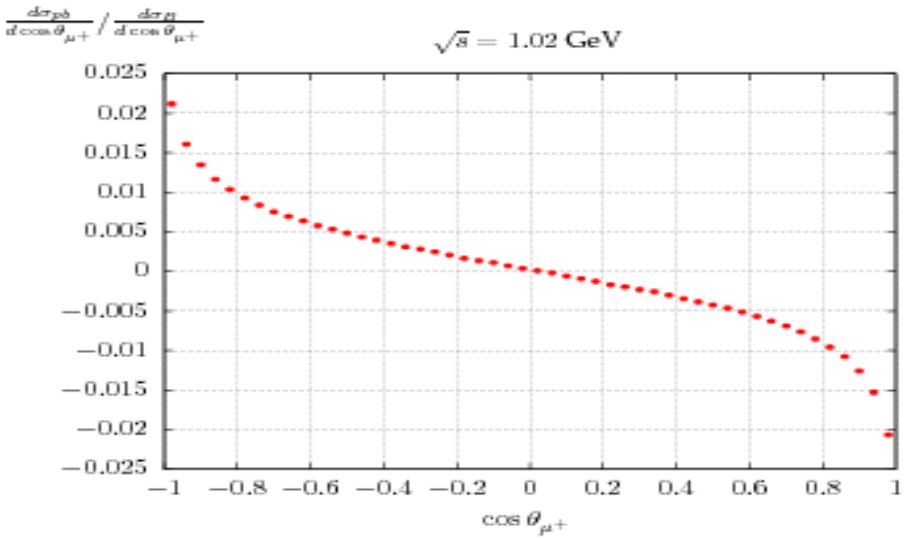
Virtual corrections

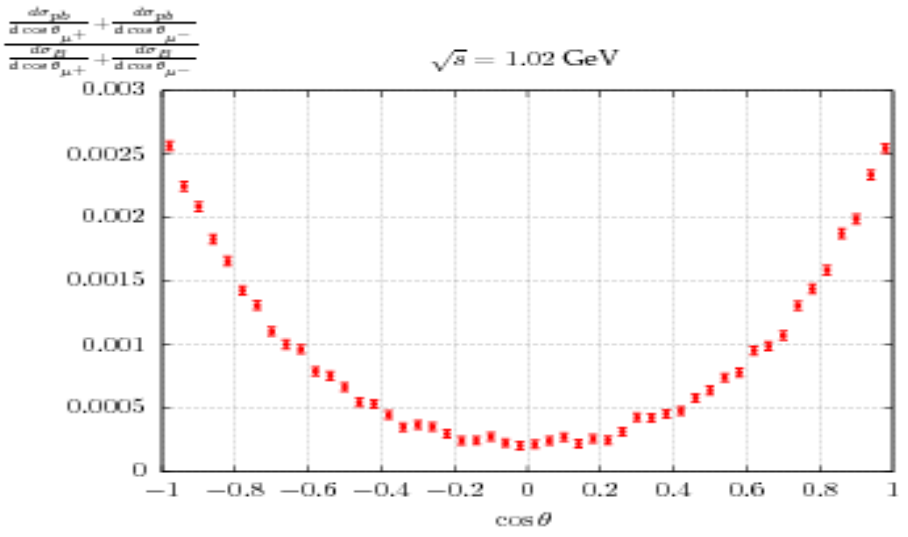


- Diagrams describing virtual corrections contribute through their interference with the Born amplitude.

- sQED
- including form Factor
- 2 independent codes

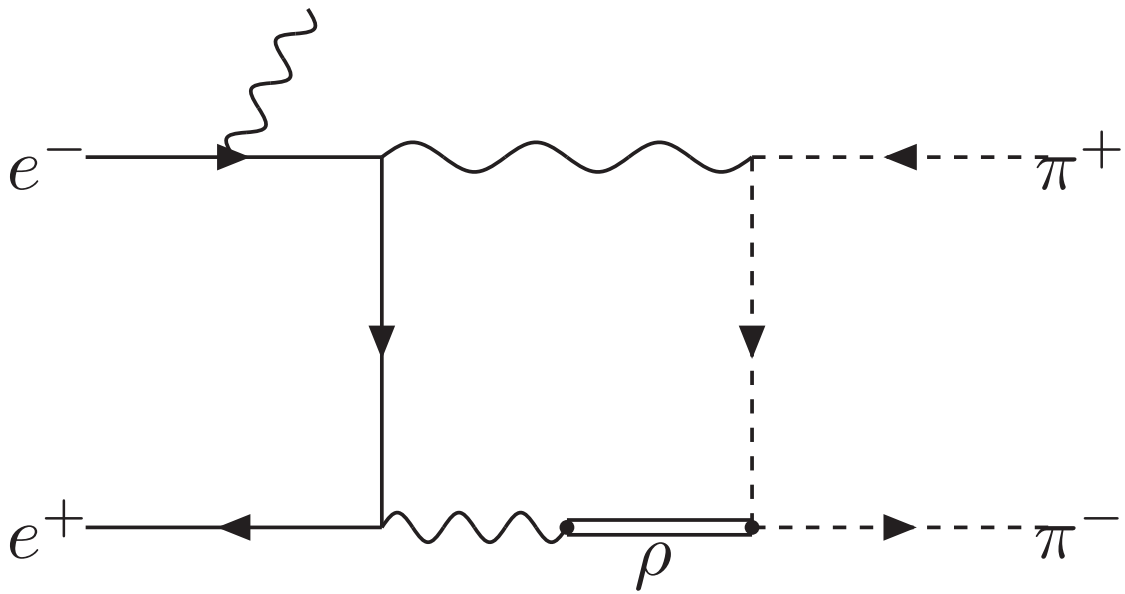
sQED - we do not expect large contributions





F. Campanario, H. Czyż, J. Gluza, M. Gunia, T. Riemann, G. Rodrigo and V. Yundin, JHEP **1402** (2014) 114,[arXiv:1312.3610 [hep-ph]].

FF -possible resonant enhancement for Q near to the mass of the ρ



Final remarks

- Direct resonant production of $\chi_{c_{1,2}}$ lead to measurable resonant enhancement in cross section.
- The prediction exhibits a sizeable model dependence.
- Resonant signal both in the hadronic cross section and in the $\gamma\mu^+\mu-$ channel could be seen at the BESIII
- We keep working on radiative corrections to pions pair production and expect the first results soon.