Radiative corrections to hadron production in e^+e^- annihilation

Szymon Tracz

Institute of Physics, University of Silesia
Katowice

May 15, 2016

Outline

$g-2$

$$a_\mu^{SM} = 11659180.2 \pm 4.2 \pm 2.6 \pm 0.2$$
$$a_\mu^{exp} = 11659208.9 \pm 5.4 \pm 3.3$$

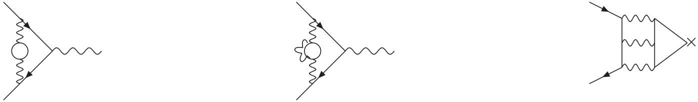
Fermilab E989 (2017) - will improve precision about 4 times

$$a_\mu^{exp} - a_\mu^{SM} = 28.7 \pm 8.0$$
$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{had}$$

$$a_\mu^{QED} = 11658471.809 \pm 0.015$$
$$a_\mu^{EW} = 15.4 \pm 0.1 \pm 0.2$$

M. Davier, A. Hoecker, B. Malaescu,Z. Zhang, Eur. Phys. J. **C71** (2011) 1515.

Muon g-2 Collaboration (G.W. Bennett et al.), Phys. ReV. D 73, 072003 (2006) [hep-ex/0602035].

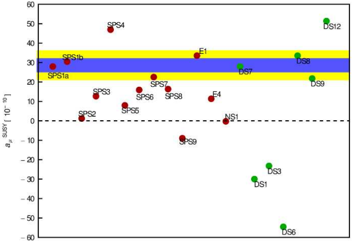


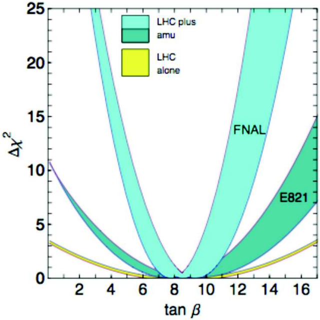
$$a_\mu^{had} = a_\mu^{had,LO} + a_\mu^{had,HO} + a_\mu^{had,LBL}$$

$$a_\mu^{had,HO} = -9.79 \pm 0.09$$
$$a_\mu^{had,LO} = 692.3 \pm 4.2$$
$$a_\mu^{had,LBL} = 10.5 \pm 2.6$$

$$a_\mu^{had,LO} = \frac{\alpha^2}{3\pi^2} \int_{m_\pi^2}^{\infty} \frac{ds}{s} K(s) R(s)$$

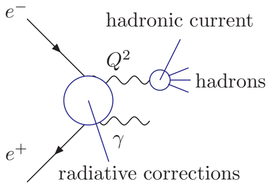
$$R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma_0}$$





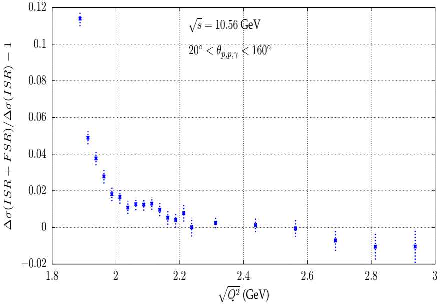
M. Bach, D. Stöckinger, H. Stöckinger-Kim and J. H. Park, Acta Phys. Polon. B **46** (2015) no.11, 2243, B. C. Allanach *et al.*, Eur. Phys. J. C **25** (2002) 113, [hep-ph/0202233], C. Adam, J. L. Kneur, R. Lafaye, T. Plehn, M. Rauch and D. Zerwas, Eur. Phys. J. C **71** (2011) 1520, [arXiv:1007.2190 [hep-ph]], J. P. Miller, E. d. Rafael, B. L. Roberts and D. Stöckinger, Ann. Rev. Nucl. Part. Sci. **62** (2012) 237.

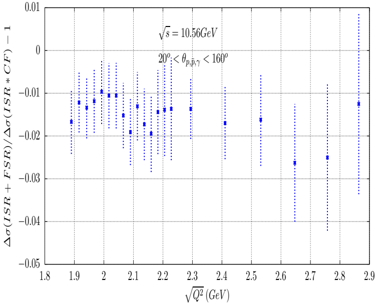
$$d\sigma(e^+e^- \to hadrons + \gamma_{isr}) = H(Q^2, \theta_\gamma) d\sigma(e^+e^- \to hadrons)(Q^2)$$



- measurement of $R(s)$ over the wide range of energies, from threshold up to $\sqrt{s}$
- large luminosity from factories compensate α/π from photon radiation
- precise measurement involves radiative corrections
- Monte Carlo generators needed (Phokhara)

- $e^+e^- \to p\bar{p}\gamma$, nucleon FFs, FSR with Columb factor
- FSR corrections are small except the Columb factor corrections

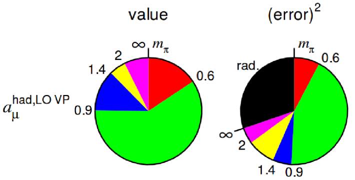


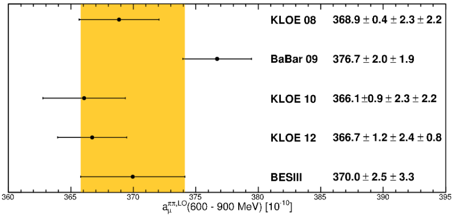


H. Czyż, J. H. Kühn and S. Tracz, Phys. Rev. D **90** (2014) no.11, 114021, [arXiv:1407.7995 [hep-ph]]

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

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

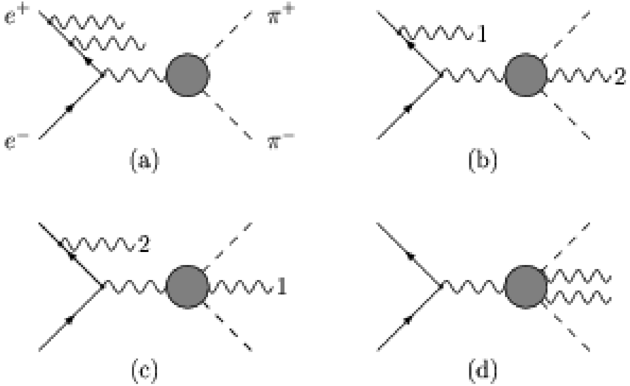




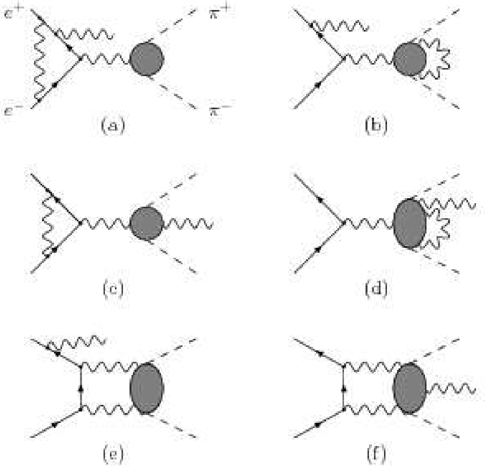
D. Nomura's talk Matter to the Deepest, Ustroń 2015.

M. Ripka [BESIII Collaboration], Acta Phys. Polon. B **46** (2015) no.11, 2261.

Two photons emission



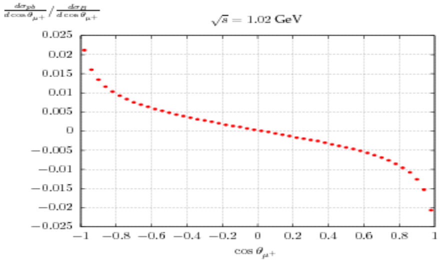
Virtual corrections

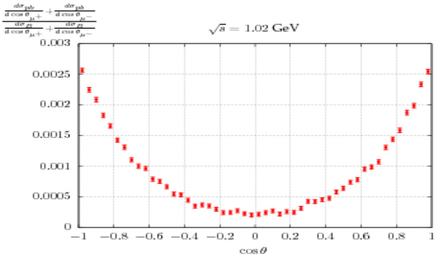


- Diagrams describing virtual corrections contribute through their interference with the Born amplitude.

- sQED
- including form Factor
- 2 independent codes

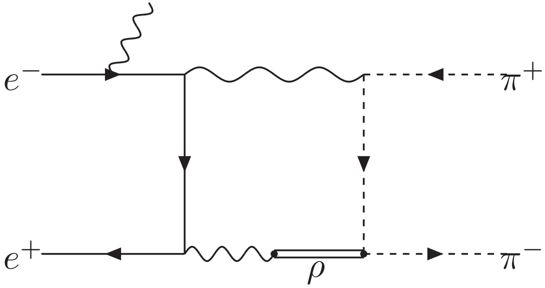
sQED - we do not expect large contributions





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



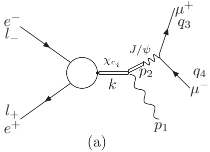
Production of charmonium resonances with J^{++}

- 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:

$$e^+e^- \to \chi_c \to hadrons$$

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

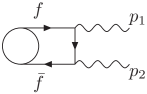
Cross section for the process $e^+e^- \to \chi_c \to \gamma J/\psi(\to \mu^+\mu^-)$

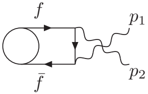


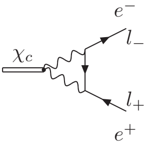
- Background (Fig.(c)) has to be taken into account
- $\sqrt{s} = M_{\chi_c}$
- ω_γ has to be chosen in the proper kinematic region
- possible contribution from a diagram from Fig.(b) is negligible for our event selections:

$$9.58916 < Q^2 < 9.59262$$

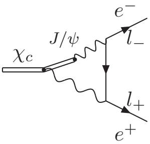
Production of the χ_c in e^+e^- annihilation is an example of the process, which goes only through the radiative corrections.







(a)



(b)

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

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

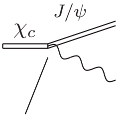
$$\Gamma_{2ee} = \frac{1}{5}\frac{|g_2|^2}{8\pi}M_{\chi_{c_2}}$$

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

$\chi_c - \gamma\gamma$ 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



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

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

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

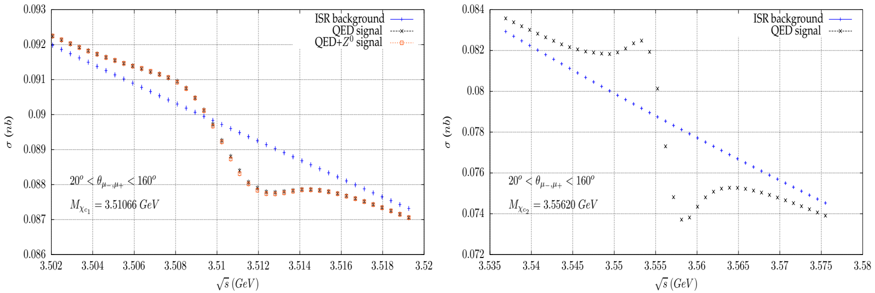
Electronic widths

	$\gamma\gamma + J/\psi\gamma$	$\gamma\gamma$	$J/\psi\gamma$	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



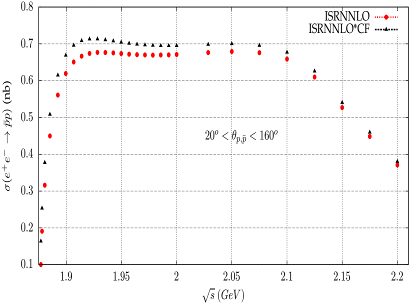
$\Delta E = 1$ MeV beam resolution per beam was assumed.

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

Final remarks

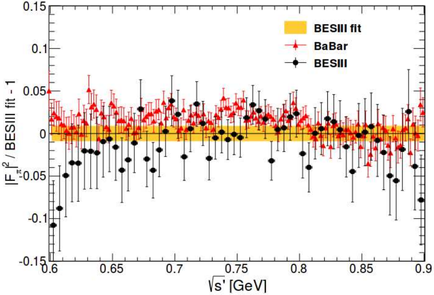
- Direct resonant production of $\chi_{c_{1,2}}$ lead to measurable resonant enhancement in cross section.
- The prediction exhibits a sizeable model dependence.
- Resonant signal both in the hadronic cross section and in the $\gamma\mu^+\mu-$ channel could be seen at the BESIII
- We keep working on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

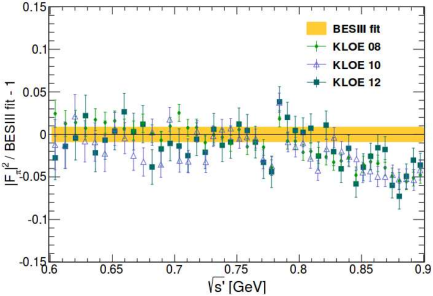
Backup slide



H. Czyż, J. H. Kühn and S. Tracz, Phys. Rev. D **90** (2014) no.11, 114021, [arXiv:1407.7995 [hep-ph]]

Backup slide





M. Ripka [BESIII Collaboration], Acta Phys. Polon. B **46** (2015) no.11, 2261.