Radiative return: progress and prospects

H. CZYŻ, IF, UŚ, Katowice, FlaviA net, **Kazimierz 2009**

The radiative return

10 years of intensive work

- experimental
- and theoretical

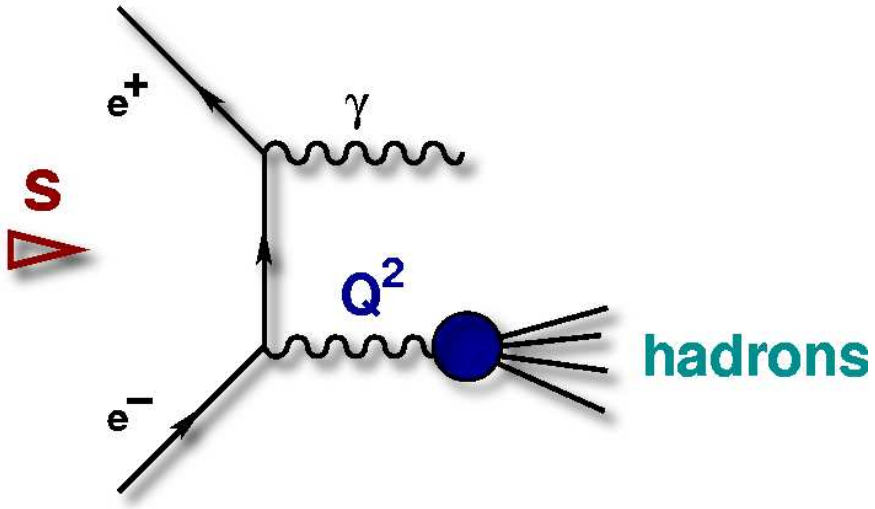
The current studies

Conclusions

THE RADIATIVE RETURN METHOD

$$d\sigma(e^+e^- \to \text{hadrons} + \gamma(ISR)) =$$

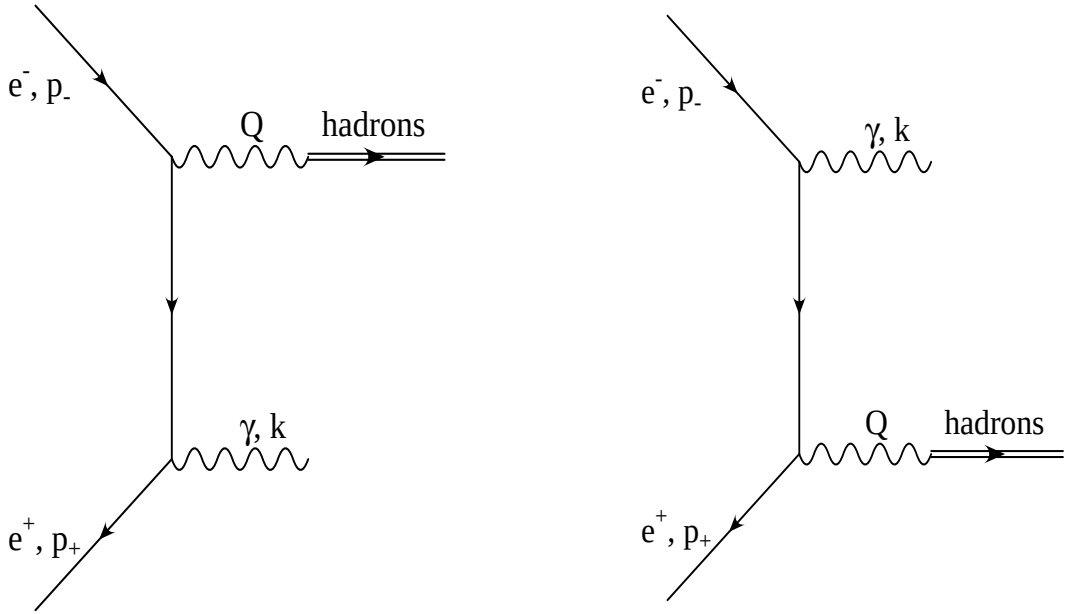
$$H(Q^2, \theta_\gamma)\; d\sigma(e^+e^- \to \text{hadrons})(s = Q^2)$$



- measurement of $R(s)$ over the full range of energies, from threshold up to $\sqrt{s}$
- large luminosities of factories compensate α/π from photon radiation
- radiative corrections essential (NLO,...)

High precision measurement of the hadronic cross-section at meson-factories

BASIC IDEA - more details



$$\mathcal{M} \sim \bar{v}\left(p_{+}\right)\left[\gamma^{\nu}\frac{1}{\not{p}_{-}-\not{k}-m}\not{\epsilon}^{*}(k)+\not{\epsilon}^{*}(k)\frac{1}{\not{k}-\not{p}_{+}-m}\gamma^{\nu}\right]u(p_{-})$$

$$\frac{1}{Q^{2}}\,J_{\nu}^{em}\,.$$

BASIC IDEA - more details

$$\mathcal{M} \sim \bar{v}\,(p_+)\left[\gamma^\nu \frac{1}{\not{p}_- - \not{k} - m}\not{\epsilon}^*(k) + \not{\epsilon}^*(k)\,\frac{1}{\not{k} - \not{p}_+ - m}\gamma^\nu\right] u(p_-)$$

$$\frac{1}{Q^2}\, J^{em}_\nu \ .$$

$$\int J^{em}_\mu (J^{em}_\nu)^* \quad d\bar{\Phi}_n(Q; q_1, \ldots, q_n) =$$

$$\frac{1}{6\pi}\left(Q_\mu Q_\nu - g_{\mu\nu} Q^2\right) R(Q^2)$$

$$d\sigma(e^+e^- \to \text{hadrons} + \gamma) =$$

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

MC generators needed

EVA: $e^+e^- \to \pi^+\pi^-\gamma$

- tagged photon ($\theta_\gamma > \theta_{cut}$)
- ISR at LO + Structure Function
- FSR: point-like pions

[Binner et al.]

$e^+e^- \to 4\pi + \gamma$

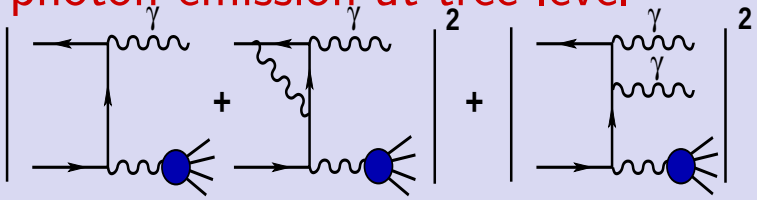
- ISR at LO + Structure Function

[Czyż, Kühn,2000]

H.C., A. Grzelińska,
J. H. Kühn, E. Nowak-Kubat,
G. Rodrigo, A. Wapienik

PHOKHARA 6.0: $\pi^+\pi^-$, $\mu^+\mu^-$, 4π, $\bar{N}N$, 3π, KK, $\Lambda(\to\cdots)\bar{\Lambda}(\to\cdots)$

- **ISR at NLO:** virtual corrections to one photon events and two photon emission at tree level



- FSR at NLO:$\pi^+\pi^-$, $\mu^+\mu^-$,K^+K^-
- tagged or untagged photons
- Modular structure

http://ific.uv.es/~rodrigo/phokhara/

MC generators for ISR

$e^+e^- \to 4\pi + \gamma$

- ISR at LO + Structure Function

[Czyż, Kühn]

→

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

- upgraded by BaBar - not public (?)
- PHOTOS [Barberio et al.] for FSR

EVA: $e^+e^- \to \pi^+\pi^-\gamma$

- tagged photon ($\theta_\gamma > \theta_{cut}$)
- ISR at LO + Structure Function
- FSR: point-like pions

[Binner et al.]

→

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

- FSR studies, FEVA

$e^+e^- \to \pi^0\pi^0 + \gamma$

- FASTERD

[Pancheri,Shekhovtsova,Venanzoni]

Experimental studies at meson factories

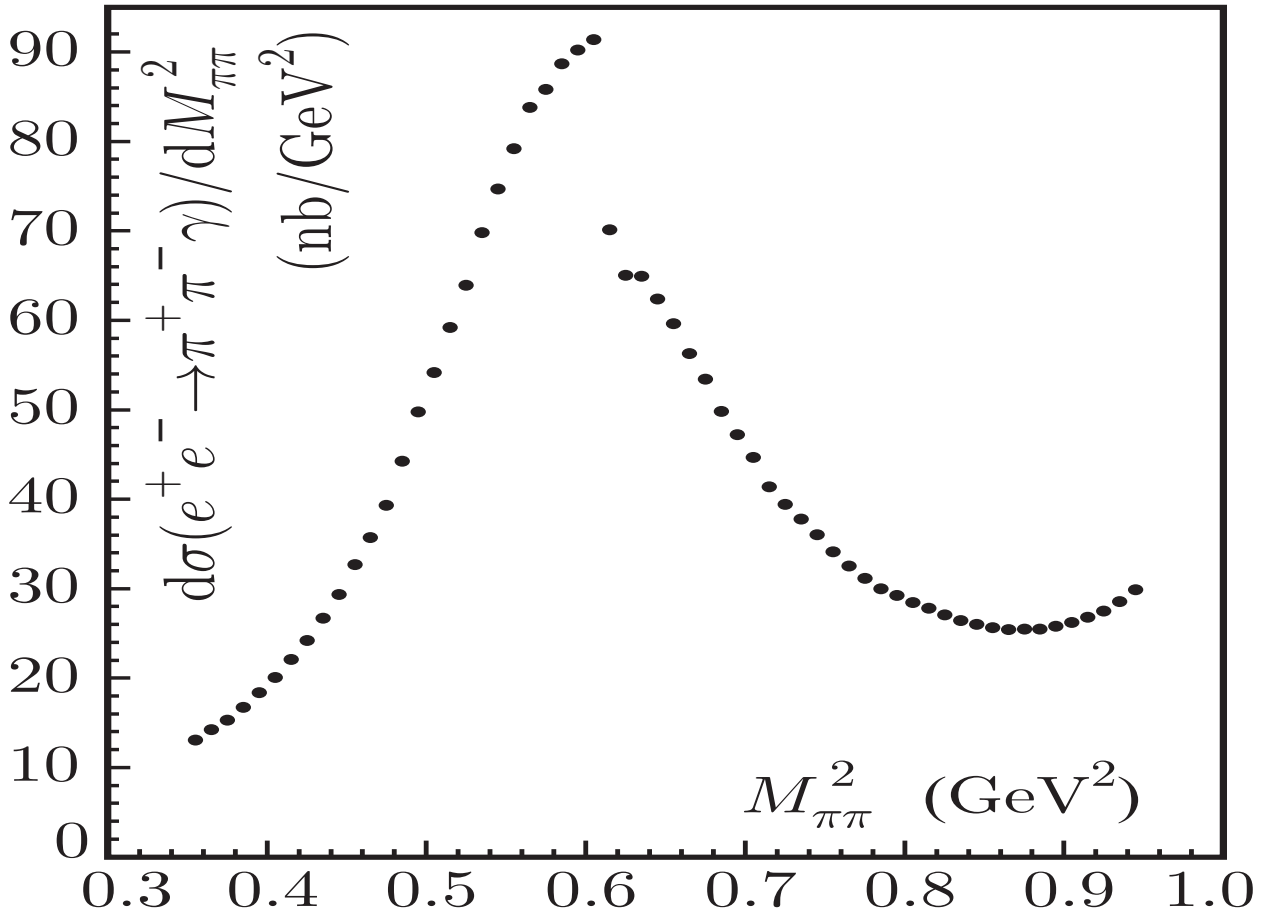
KLOE  **1999**

BABAR  **2001**

BELLE 

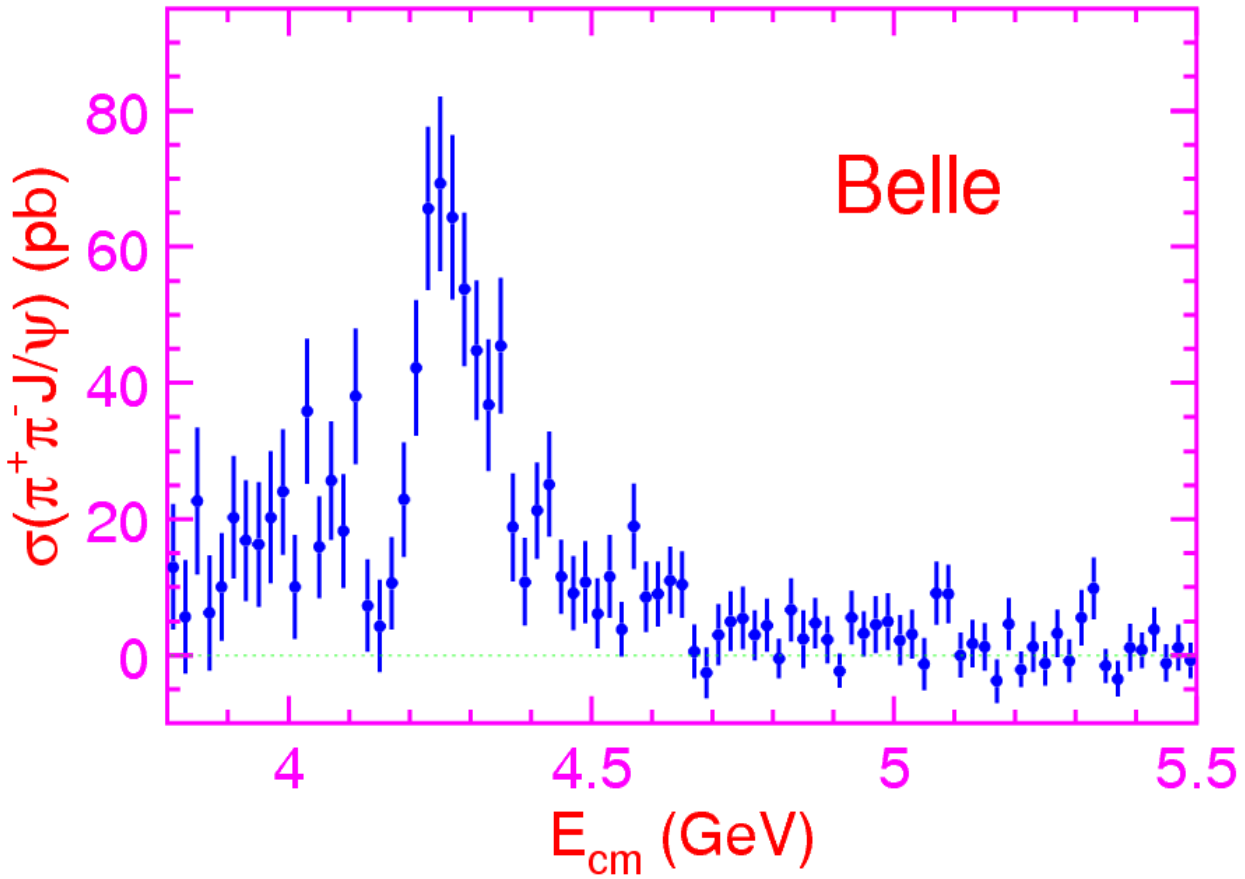
2006

KLOE



KLOE: Phys. Lett. B670(2009)285.

Y(4260) via radiative return

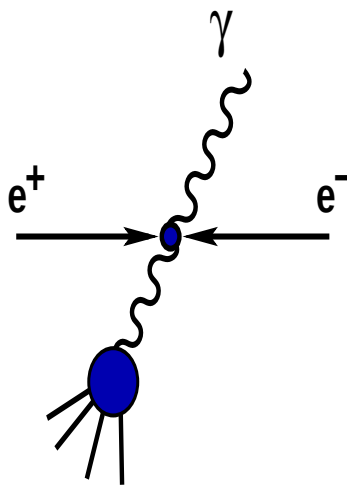


BELLE: Phys.Rev.Lett.99:182004,2007.

FSR - carefull studies needed

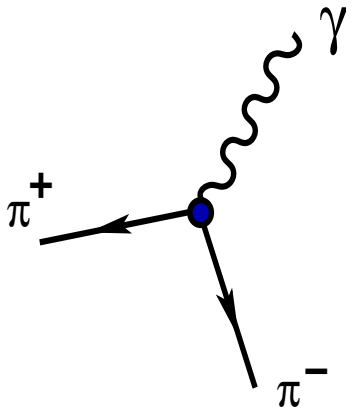
configurations in the cms - frame

10 GeV



very hard photon: clear kinematic separation between photon and hadrons

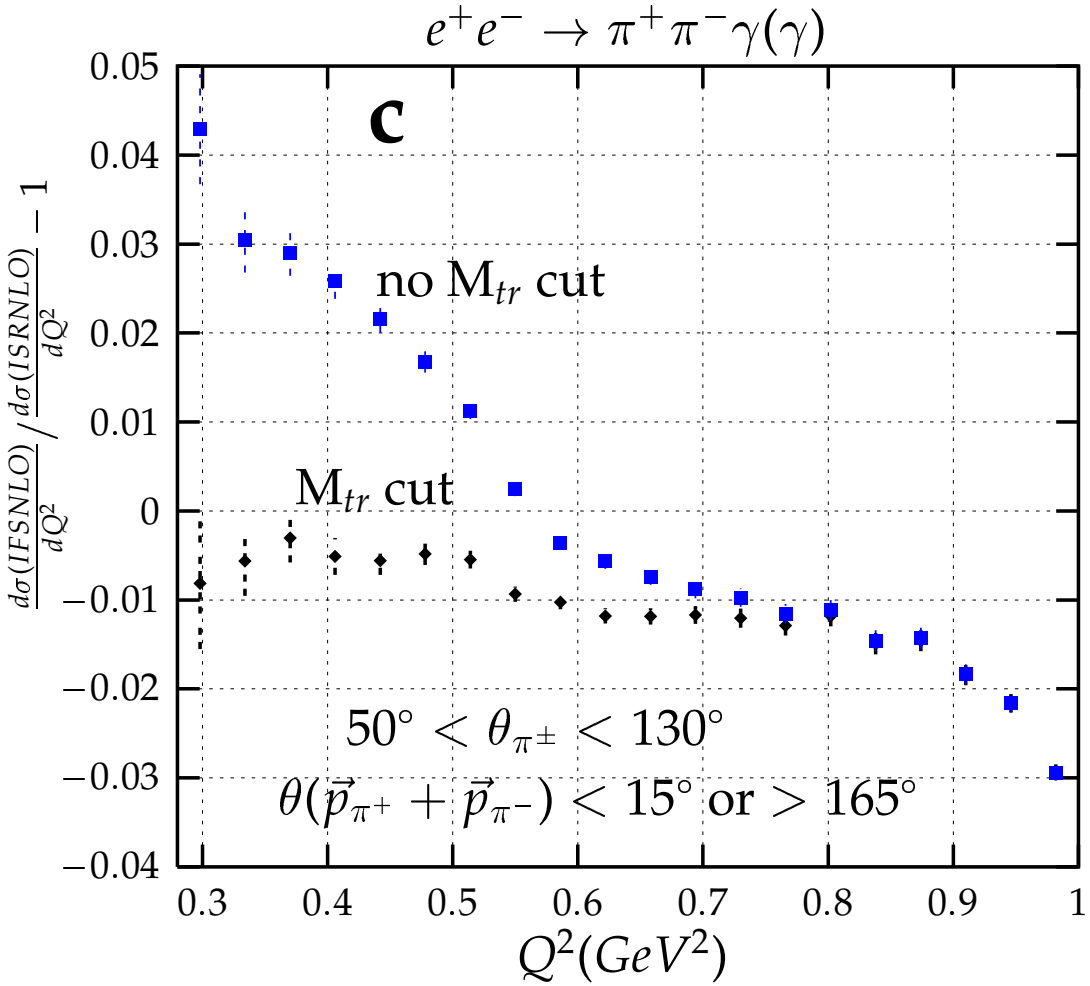
1 GeV



no natural kinematic separation

➪ cuts to control FSR versus ISR

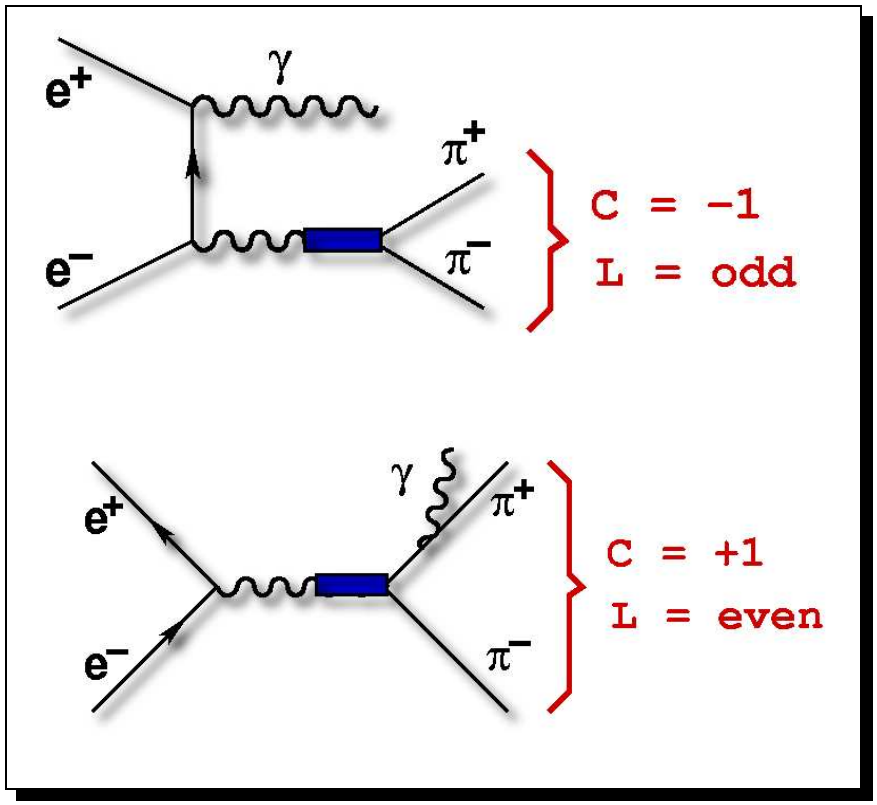
Solution I: kill FSR



KLOE: small angle analysis

Solution II: test of a FSR model

interference:

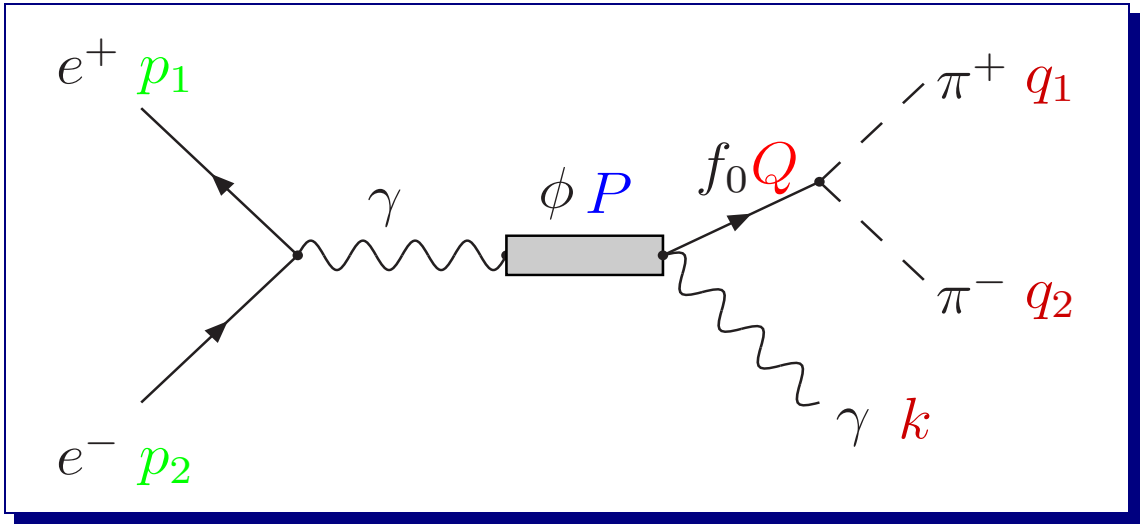


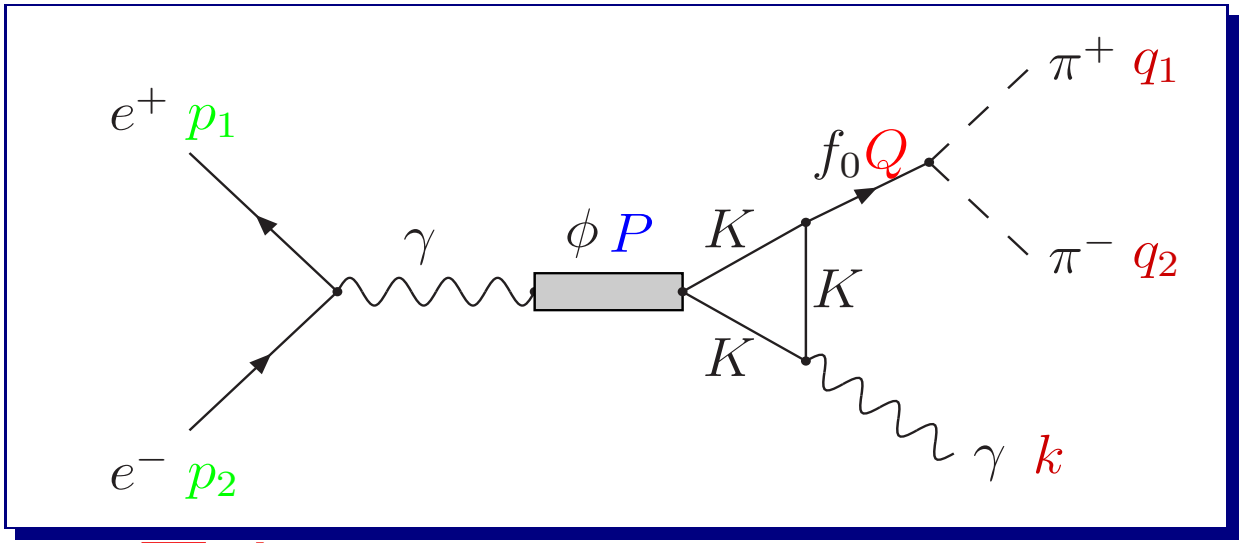
- interference odd under $\pi^+ \leftrightarrow \pi^-$
- asymmetric differential distribution: $\int$ interf. $= 0$

$$A(\theta) = \frac{N^{\pi^+}(\theta) - N^{\pi^-}(\theta)}{N^{\pi^+}(\theta) + N^{\pi^-}(\theta)}$$

FSR at KLOE, additional contributions:

$$e^+e^- \to \phi^* \to (f_0(980)_{f_0} + f_0(600)_{\sigma})\gamma \to \pi\pi\gamma$$





Progress and prospects

- **KLOE + Olga Shekhovtsova**

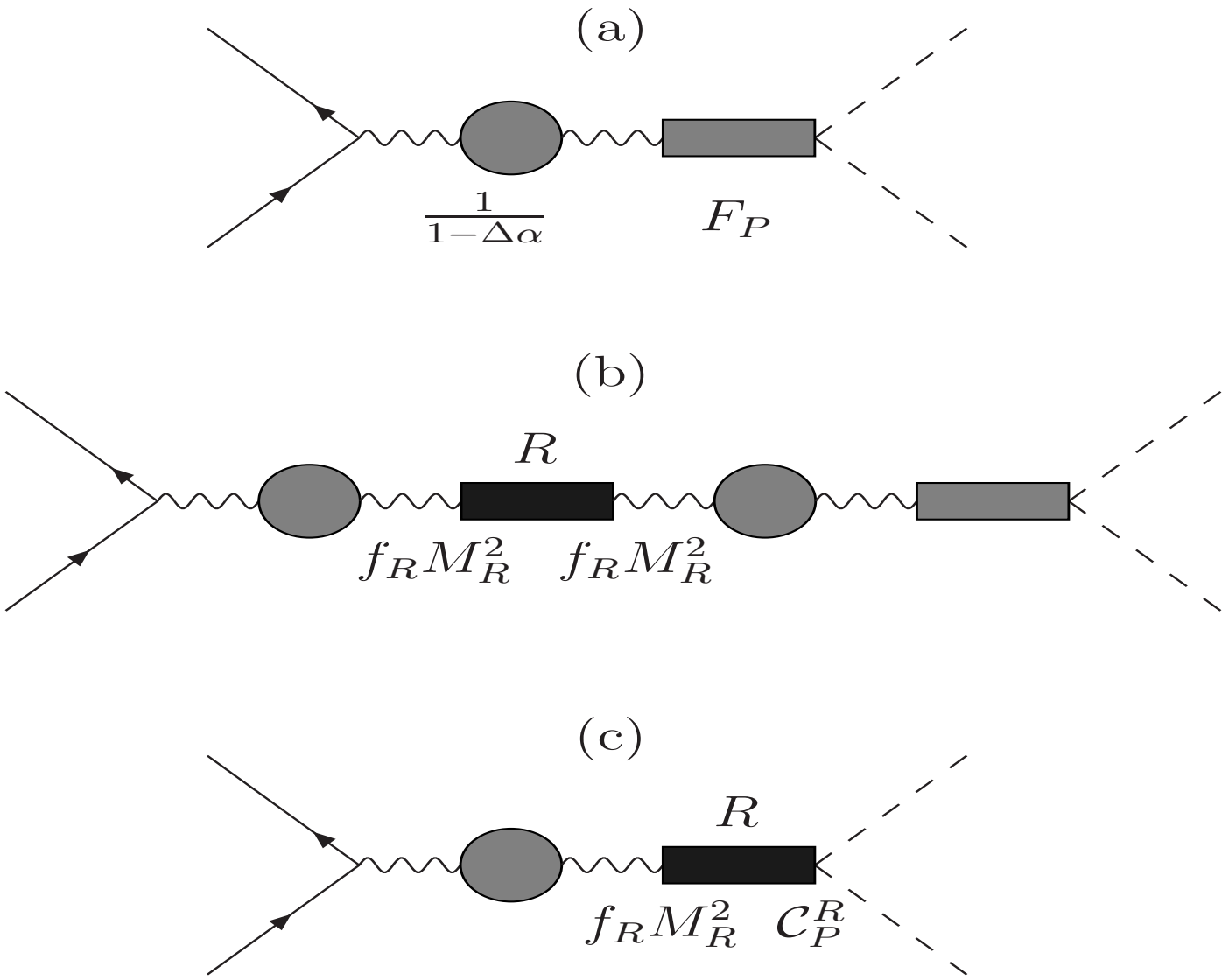
neutral mode KLOE data + isospin symmetry

PHOKHARA 6.1

- **confronting the outcome with KLOE off peak data + ...**

see talk by Sergiy Ivashyn

Contributions to $e^+e^- \to M\bar{M}$



Contributions to $e^+e^- \to P\bar{P}$

$$\sigma\left(e^+e^- \to P\bar{P}\right) = \frac{\pi\alpha^2}{3s}|F_P|^2\,\beta^3$$

$$\times\left|\frac{1}{1-\Delta\alpha} + \sum_R \frac{3\sqrt{s}}{\alpha}\frac{\Gamma_e^R(1+c_P^R)}{s-M_R^2+i\Gamma_R M_R}\right|^2$$

Contributions to $e^+e^- \to P\bar{P}$

$$\sigma\left(e^+e^- \to P\bar{P}\right) = \frac{\pi\alpha^2}{3s}|F_P|^2\,\beta^3$$

$$\times\left(\frac{1}{(1-\Delta\alpha)^2} + \sum_R\left\{\frac{9s}{\alpha^2}\frac{(\Gamma_e^R)^2}{(s-M_R^2)^2+\Gamma_R^2M_R^2}\right.\right.$$

$$\times\left[|1+c_P^R|^2 + \frac{2\alpha M_R}{3\sqrt{s}(1-\Delta\alpha)}\frac{\Gamma_R}{\Gamma_e^R}\mathrm{Im}(c_P^R)\right]$$

$$\left.\left.+\frac{6\sqrt{s}\Gamma_e^R}{\alpha(1-\Delta\alpha)}\frac{\left(1+\mathrm{Re}(c_P^R)\right)(s-M_R^2)}{(s-M_R^2)^2+\Gamma_R^2M_R^2}\right\}\right)$$

Decay width

One should not use

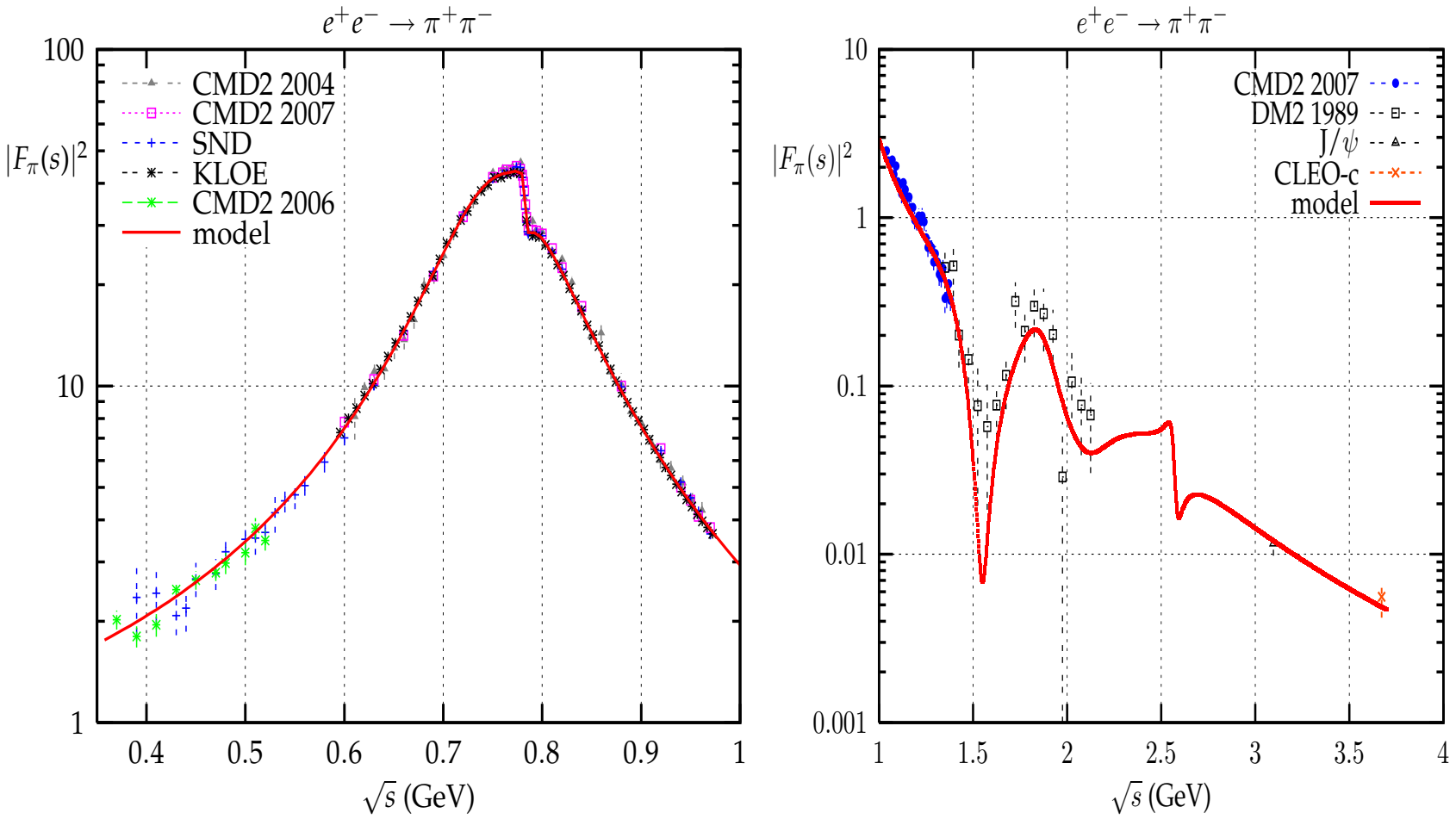
$$\Gamma(R \to P\bar{P}) = \Gamma^{QED} \times |1 + c_P^R|^2$$

but

$$\Gamma(R \to P\bar{P}) = \Gamma^{QED} \times \left[|1 + c_P^R|^2 + \frac{2\alpha M_R}{3\sqrt{s}(1-\Delta\alpha)} \frac{\Gamma_R}{\Gamma_e^R} \mathrm{Im}(c_P^R)\right]$$

HC, J. Kühn , arXiv:0904.0515

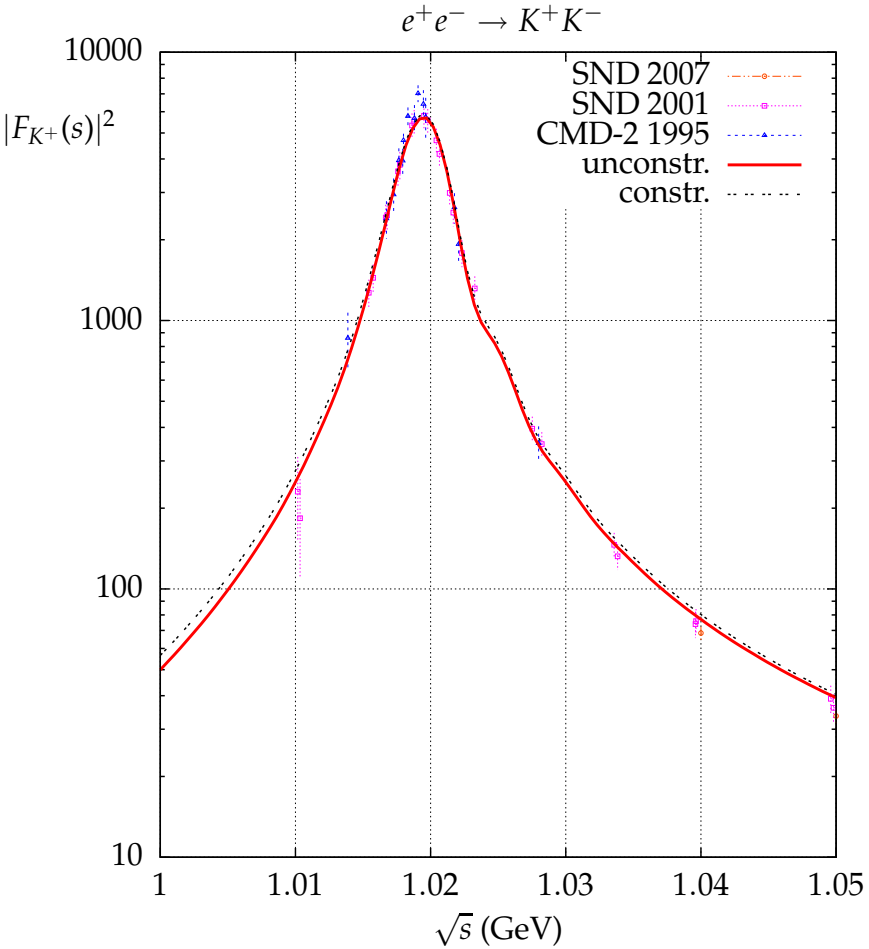
Pion form factor

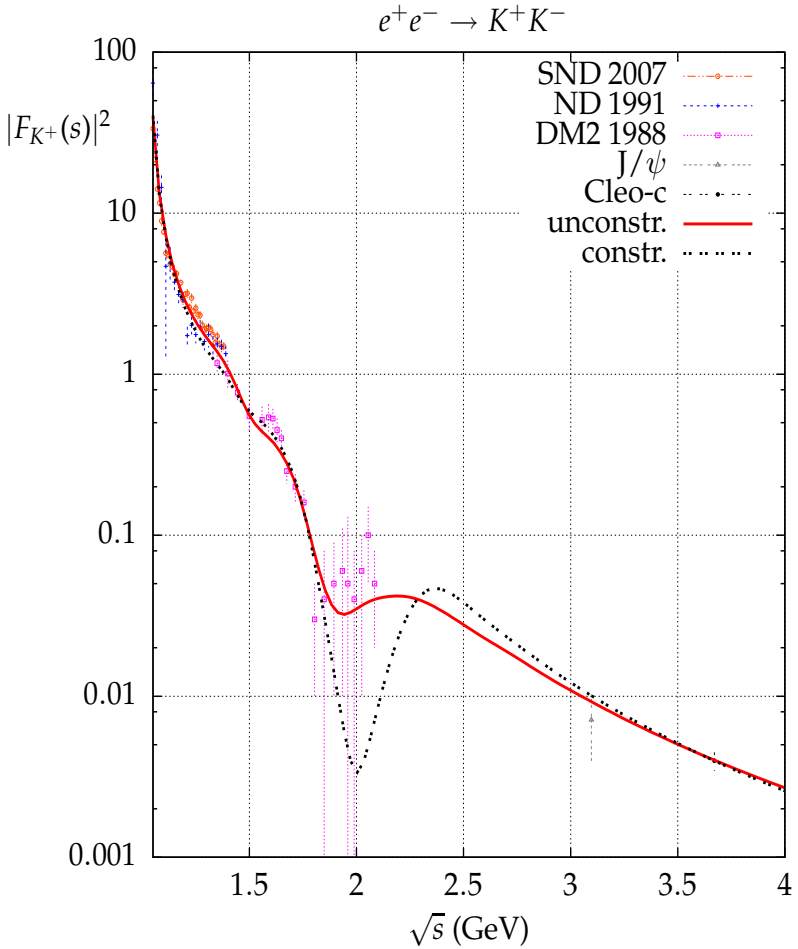


C. Bruch, A. Khodjamirian and J.H. Kühn, Eur. Phys. J. C39(2005)41

H. C., A. Grzelińska and J.H. Kühn, in preparation

Kaon form factor





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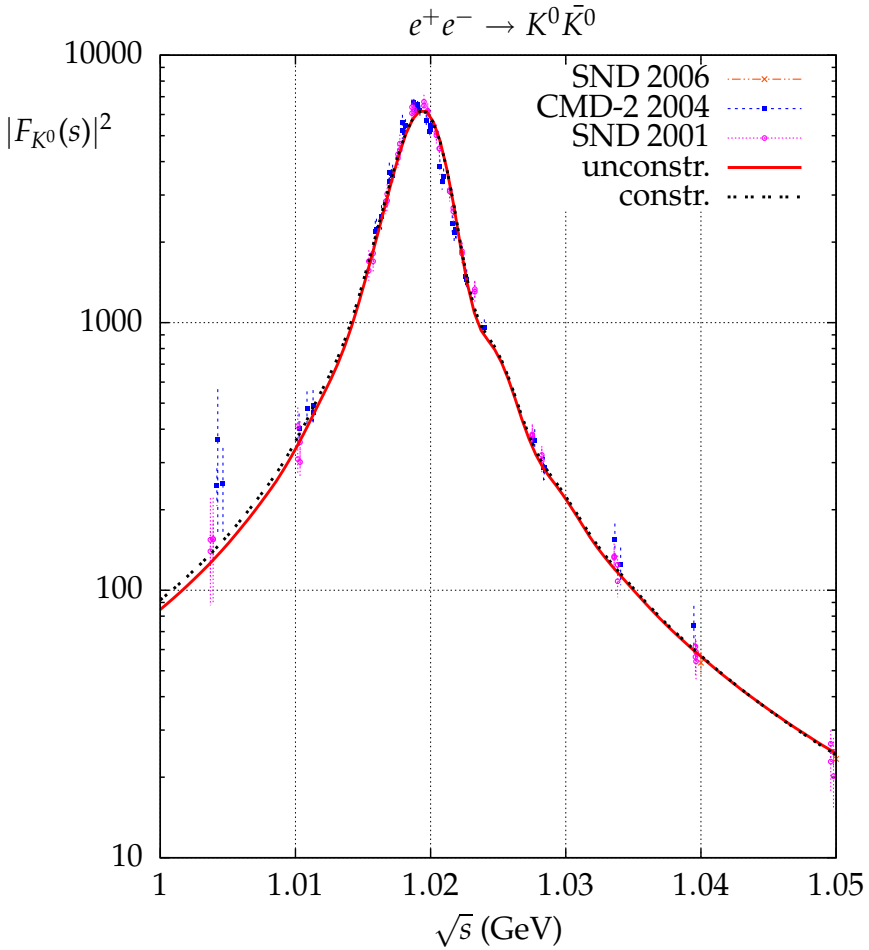

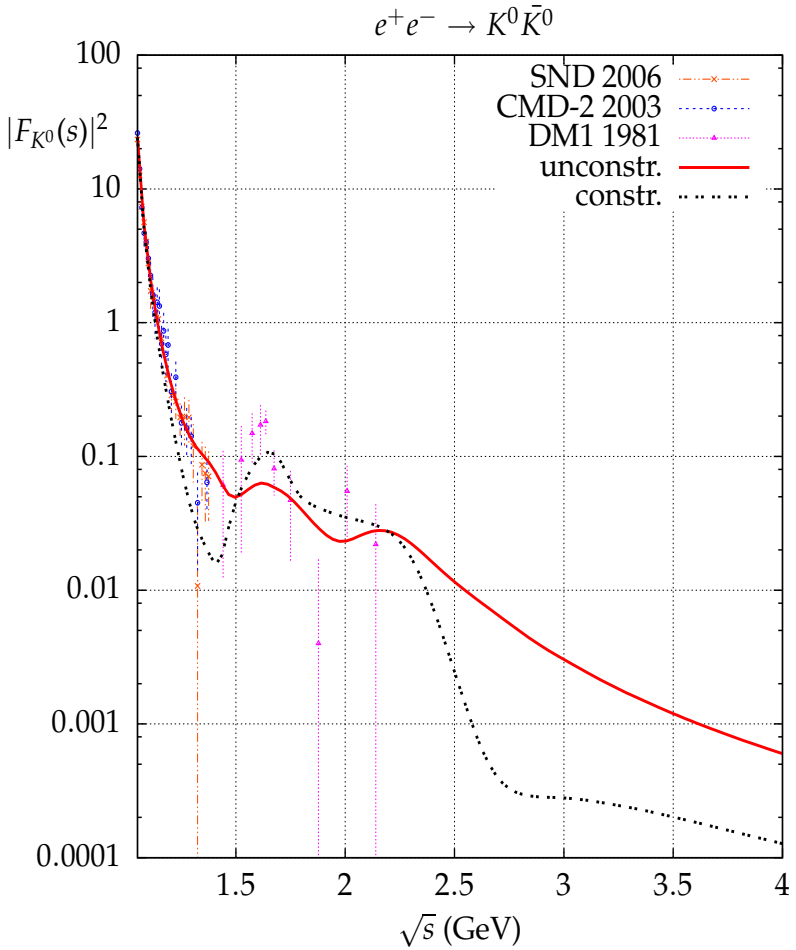

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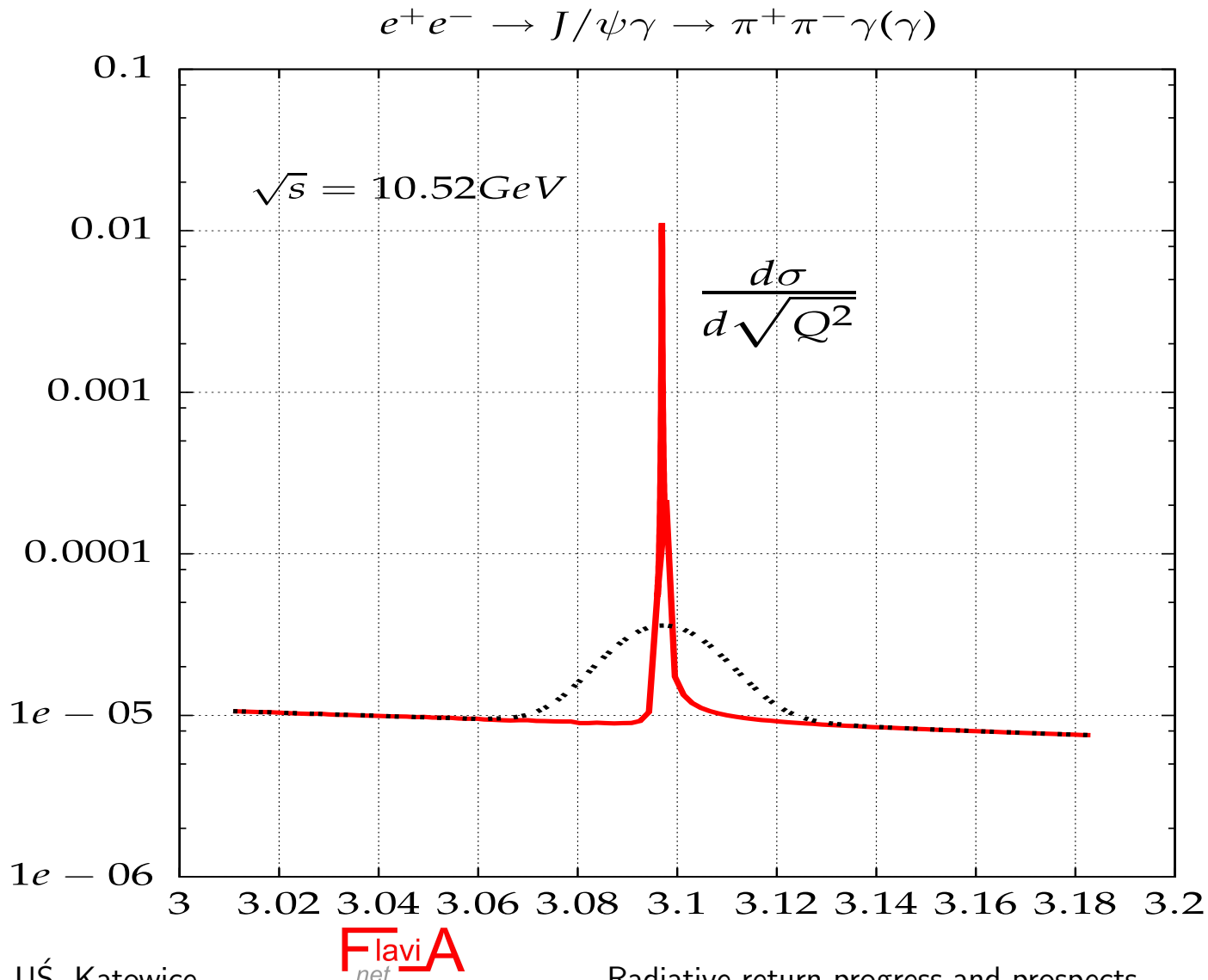
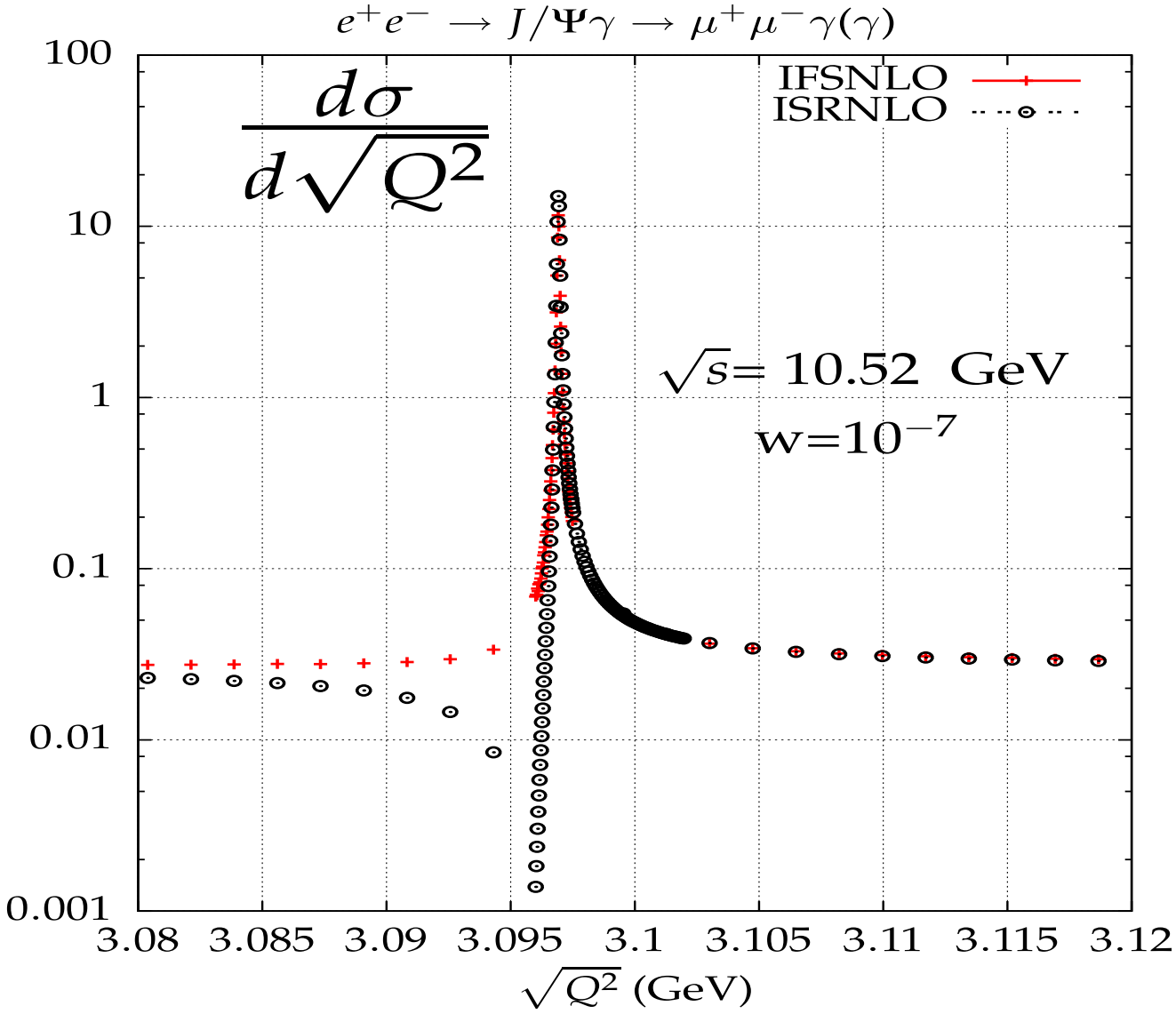
Energy resolution

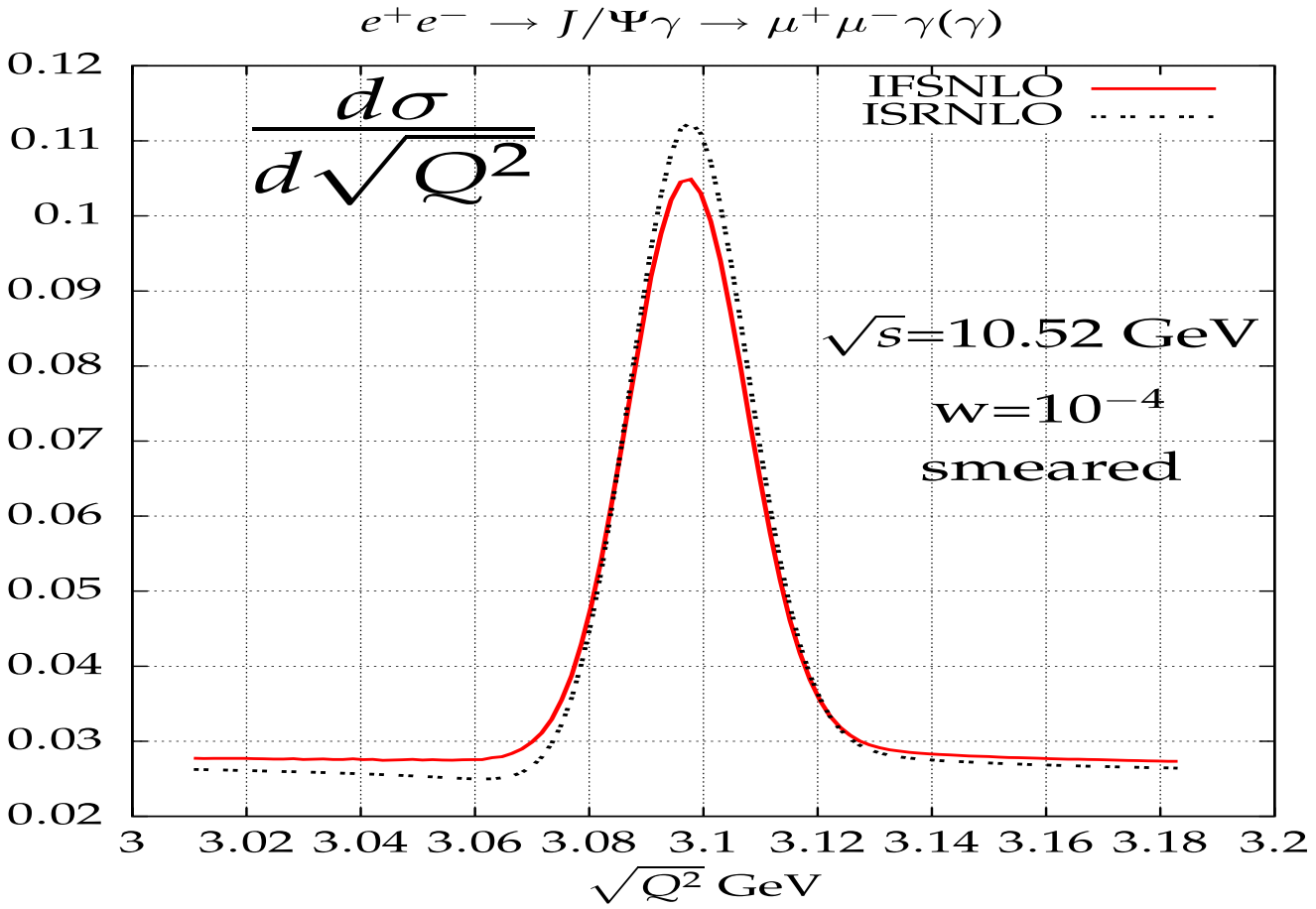
$\Delta q = 14.5$ MeV



FSR - muons


$e^+e^- \to J/\Psi\gamma \to \mu^+\mu^-\gamma(\gamma)$
$\frac{d\sigma}{d\sqrt{Q^2}}$
IFSNLO
ISRNLO
$\sqrt{s}$= 10.52 GeV
w=10^{-7}
100
10
1
0.1
0.01
0.001
3.08
3.085
3.09
3.095
3.1
3.105
3.11
3.115
3.12
$\sqrt{Q^2}$ (GeV)

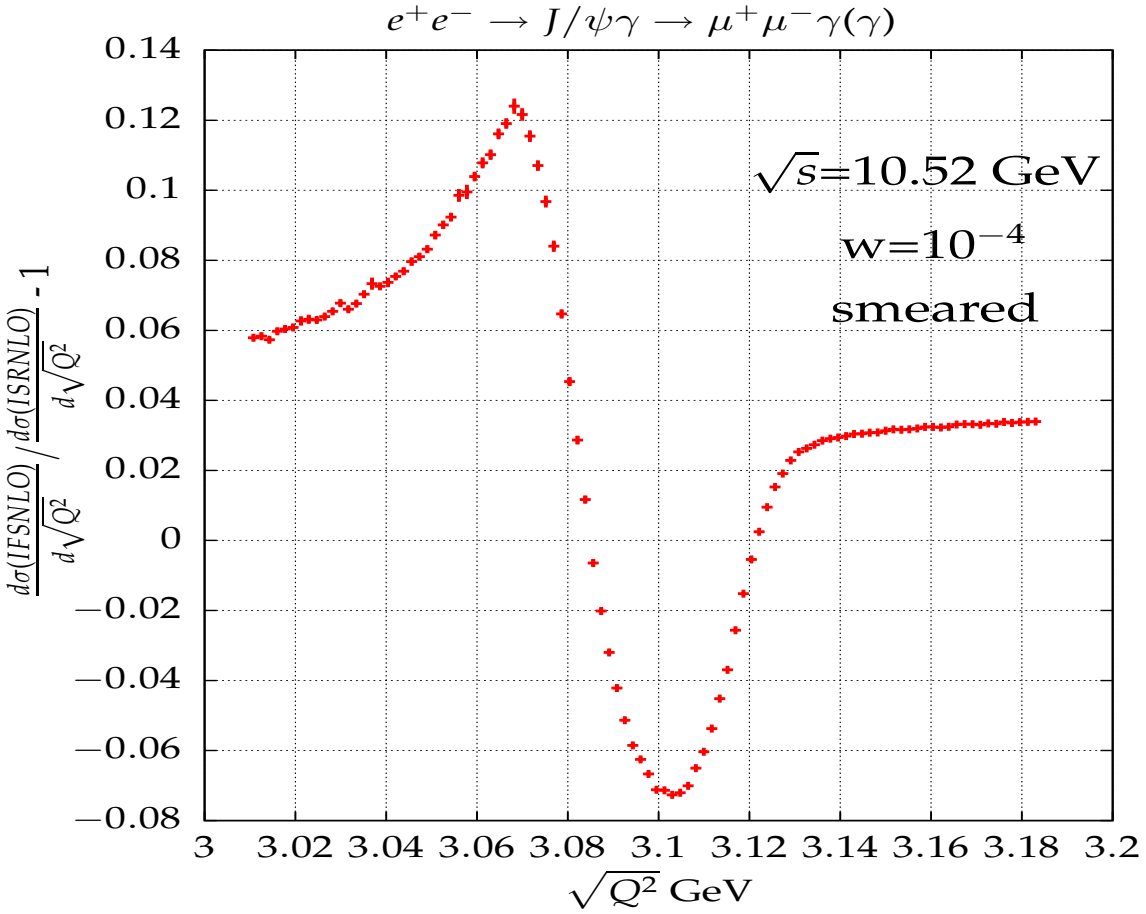
FSR - muons



$\sigma(IFSNLO) =$ (6.8527 $\pm$ 0.0006) pb

$\sigma(ISRNLO) =$ (6.79862 $\pm$ 0.00008) pb

FSR - muons



$\sigma(IFSNLO) = (\ 6.8527 \pm 0.0006\ )$ pb

$\sigma(ISRNLO) = (\ 6.79862 \pm 0.00008\ )$ pb

Left over 1-loop corrections to

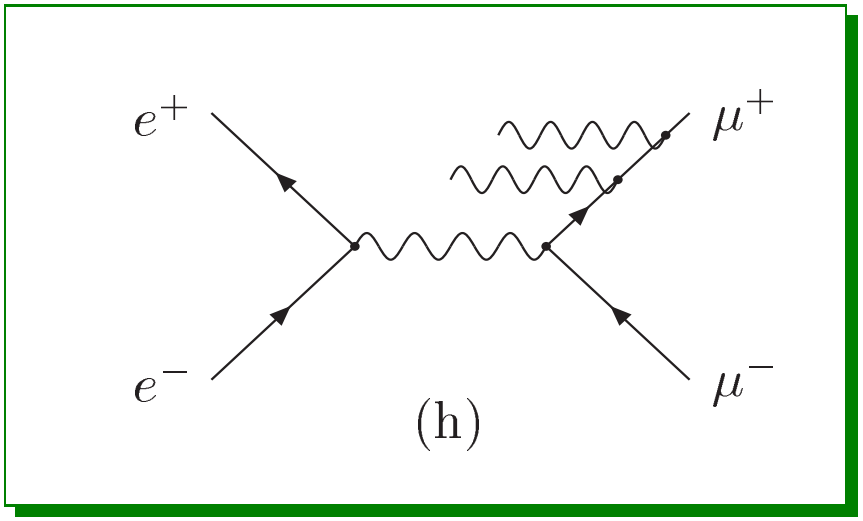
$$e^+e^- \to \mu^+\mu^-\gamma$$

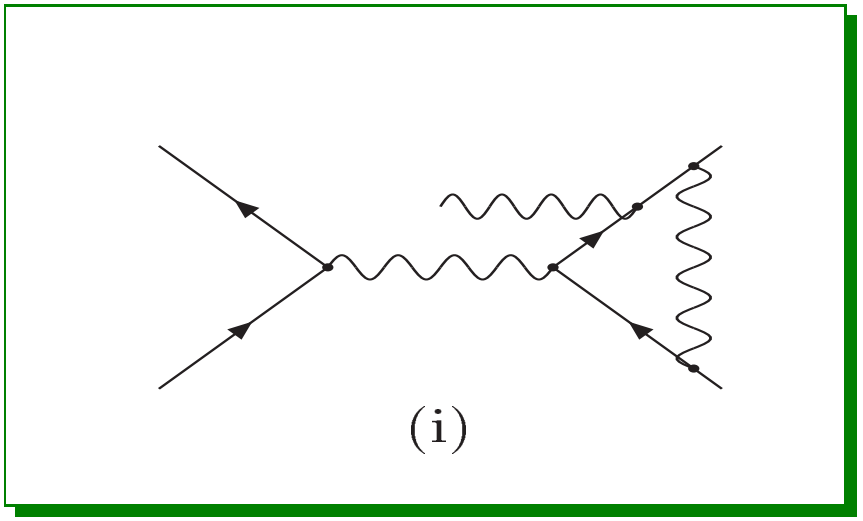
$$\mathcal{R}(s) = \frac{\sigma(e^+e^- \to hadrons + \gamma)}{\sigma(e^+e^- \to \mu^+\mu^- + \gamma)}$$

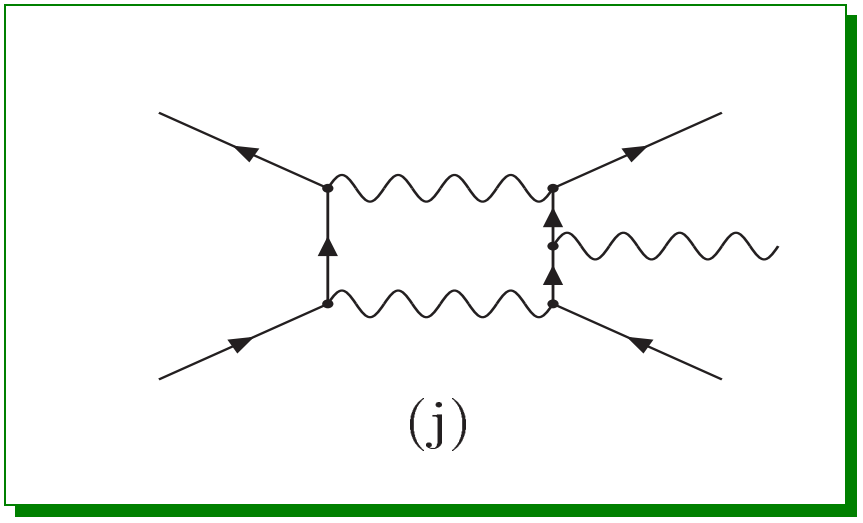
HC, J. Gluza, M. Gunia, K.Kajda

Progress and prospects

Left over 1-loop corrections to $e^+e^- \to \mu^+\mu^-\gamma$





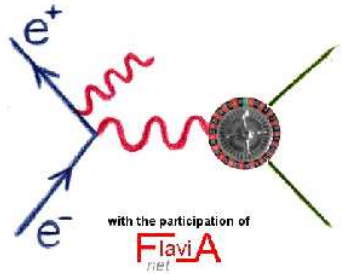


Conclusions

- slow but steady progress in understanding photon-hadron interactions

- close experiment-theory collaboration needed

Working Group on Rad. Corrections
and MC Generators for Low Energies



Group coordinators: H. Czyż, G. Venanzoni (Frascati,KLOE)