Photon pair production in BabaYaga@NLO with per mille accuracy

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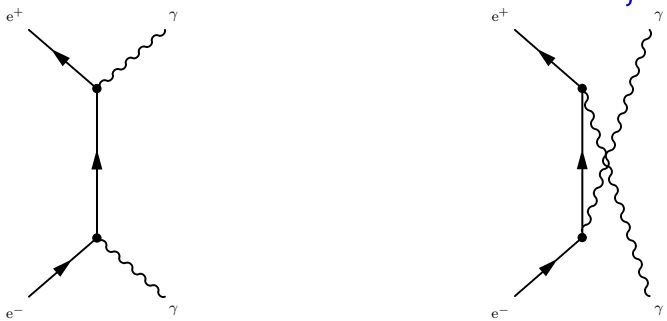
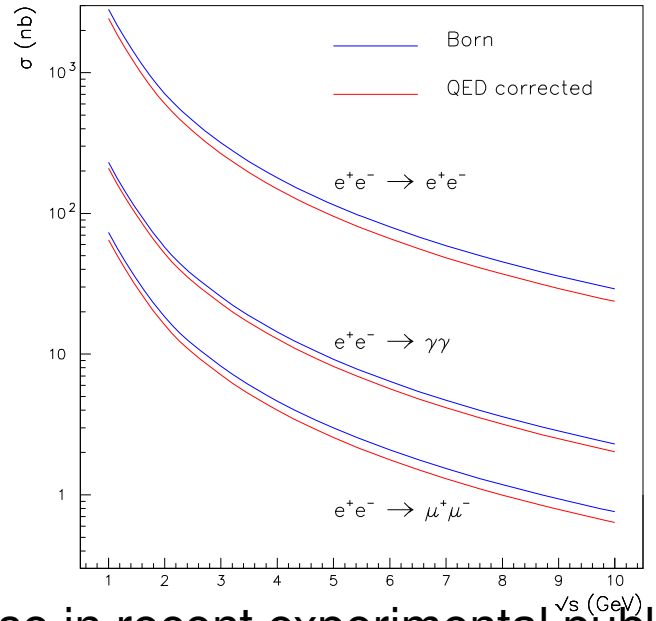


with G. Balossini, C. Bignamini, C.M. Carloni Calame, O. Nicrosini, F. Piccinini
Phys. Lett. **B663** (2008) 209 [arXiv:0801.3360]

$e^+e^- \to \gamma\gamma(n\gamma)$: motivations and related work

- Photon pair production is an important process to monitor luminosity. Used at BABAR, BES III an CLEO–c together with Bhabha and $\mu^+\mu^-$, and as a cross–check of Bhabha at KLOE (with $\sim 0.3\%$ agreement)

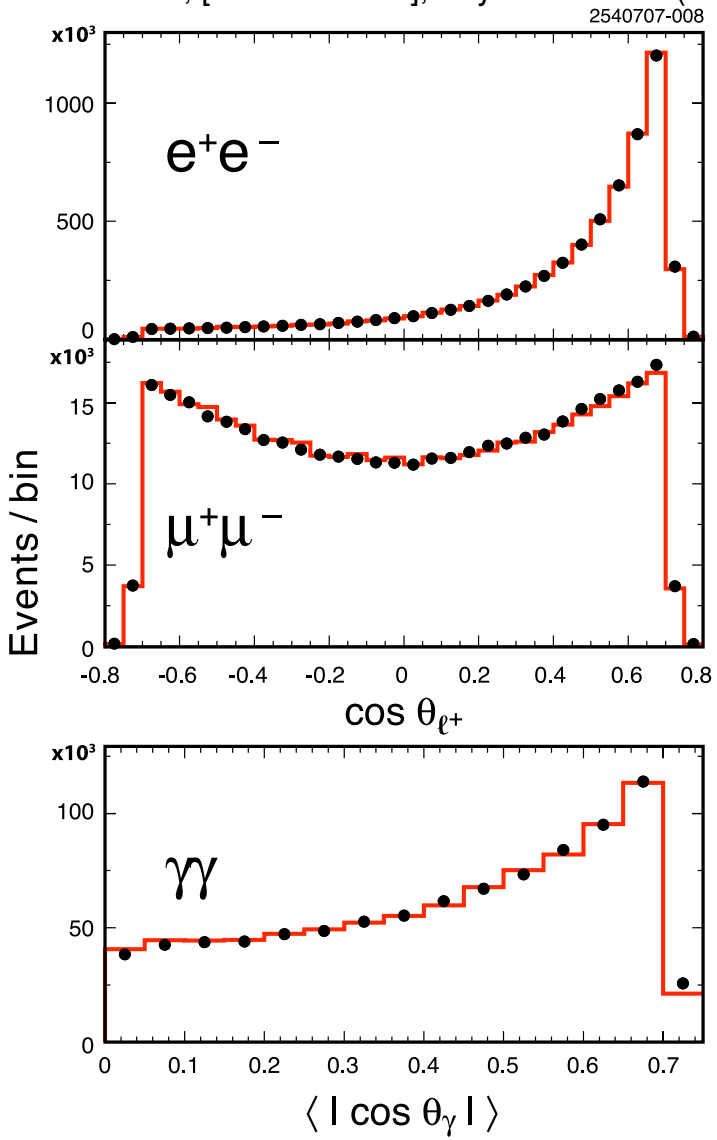


- Generators used also in recent experimental publications (BKQED, BabaYaga v3.5...) miss relevant theoretical pieces and have an accuracy of $\sim 1\% \Longrightarrow$ more precise tools necessary!
- Before our calculation, only Dubna–Novosibirsk Monte Carlo MCGPJ could claim an accuracy at the per mille level $\Longrightarrow$ independent calculations useful!

MCGPJ: A.B. Arbuzov *et al.*, Eur. Phys. J. **C46** (2006) 689
based on theory by A.B. Arbuzov *et al.*, JHEP **9710** (1997) 001

CLEO–c luminosity data vs BabaYaga v3.5

S. Dobbs *et al.*, [CLEO–c Coll.], Phys. Rev. **D76** (2007) 112001, `arXiv:0709.3783`



$$\frac{\delta\mathcal{L}^{\gamma\gamma}}{\mathcal{L}^{\gamma\gamma}} = \frac{\delta\mathcal{L}^{\gamma\gamma}_{\rm exp}}{\mathcal{L}^{\gamma\gamma}_{\rm exp}} \oplus \frac{\delta\sigma^{\gamma\gamma}_{\rm th}}{\sigma^{\gamma\gamma}_{\rm th}} = 1\%\,({\rm exp}) \oplus 1\%\,({\rm th}) = 1.4\%$$

Two photon production in BabaYaga@NLO

G. Balossini *et al.*, Phys. Lett. **B663** (2008) 209
th. ingredients as for Bhabha in BabaYaga@NLO, Nucl. Phys. **B758** (2006) 227

Exact $\mathcal{O}(\alpha)$ soft+virtual (SV) corrections and hard bremsstrahlung (H) matrix elements are combined with a QED multiple photon Parton Shower (PS) through a matching procedure

- $d\sigma^{\infty}_{LL} = \Pi(Q^2,\varepsilon)\ \sum_{n=0}^{\infty} \frac{1}{n!}\ |\mathcal{M}_{n,LL}|^2\ d\Phi_n$ [pure PS of BabaYaga v3.5]
- $d\sigma^{\alpha}_{LL} = [1 + C_{\alpha,LL}]\,|\mathcal{M}_0|^2 d\Phi_0 + |\mathcal{M}_{1,LL}|^2 d\Phi_1 \equiv d\sigma^{SV}_{LL}(\varepsilon) + d\sigma^{H}_{LL}(\varepsilon)$
- $d\sigma^{\alpha}_{\rm exact} = [1 + C_{\alpha}]\,|\mathcal{M}_0|^2 d\Phi_0 + |\mathcal{M}_1|^2 d\Phi_1 \equiv d\sigma^{SV}_{\rm exact}(\varepsilon) + d\sigma^{H}_{\rm exact}(\varepsilon)$
- $F_{SV} = 1 + (C_{\alpha} - C_{\alpha,LL})$ $\qquad F_H = 1 + \frac{|\mathcal{M}_1|^2 - |\mathcal{M}_{1,LL}|^2}{|\mathcal{M}_{1,LL}|^2}$

$$d\sigma^{\infty}_{\rm matched} = F_{SV}\ \Pi(Q^2,\varepsilon)\ \sum_{n=0}^{\infty} \frac{1}{n!}\ \left(\prod_{i=0}^{n} F_{H,i}\right)\ |\mathcal{M}_{n,LL}|^2\ d\Phi_n$$

in such a way that

- ⋆ $[\sigma^{\infty}_{\rm matched}]_{\mathcal{O}(\alpha)} = \sigma^{\alpha}_{\rm exact}$, avoiding double counting and preserving resummation of $\alpha^n L^n$, $L \equiv \log \frac{Q^2}{m^2}$ leading logs
- ⋆ momenta of all the final–state particles are exclusively generated

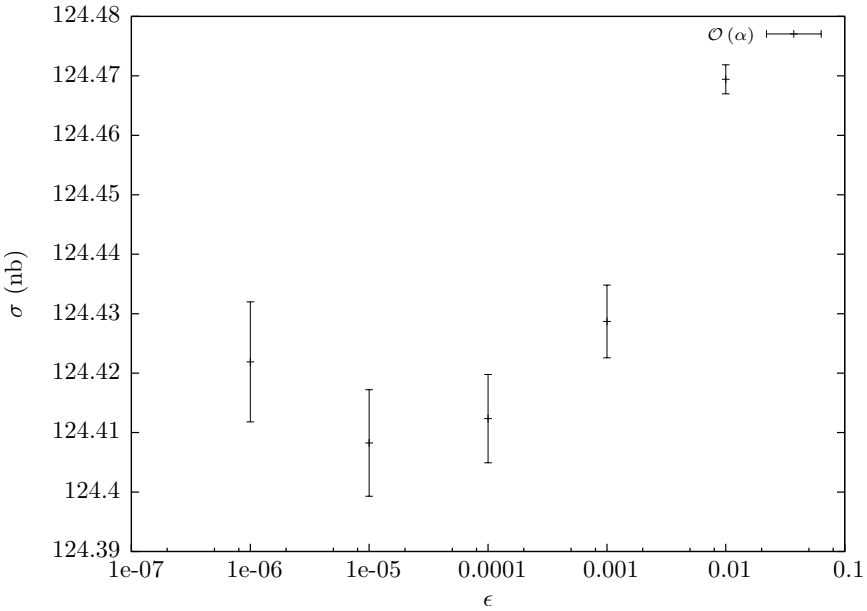
$e^+e^- \to \gamma\gamma(n\gamma)$ in BabaYaga@NLO: technical tests

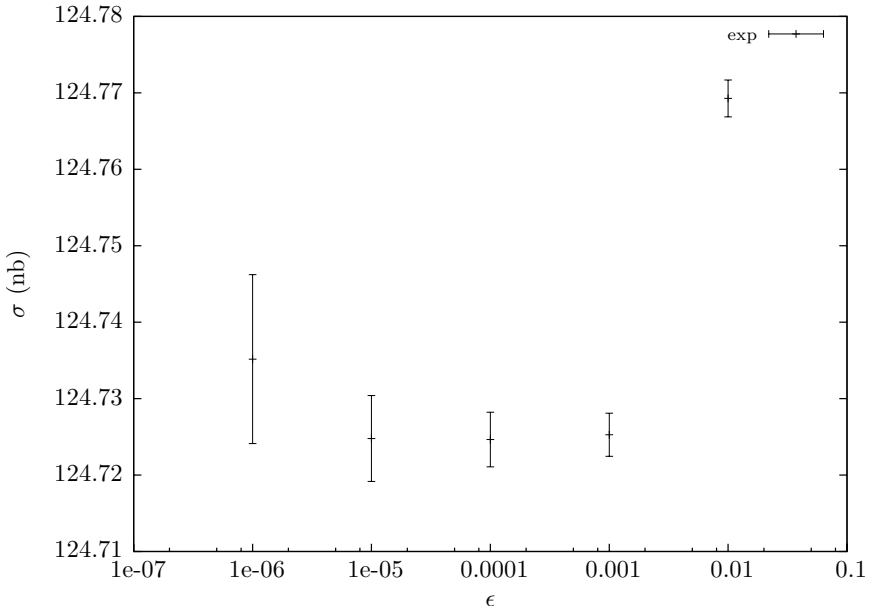
- Perfect agreement with BKQED for the $\mathcal{O}(\alpha)$ NLO corrections to the inclusive $e^+e^- \to \gamma\gamma(\gamma)$ cross section

F.A. Berends and R. Kleiss, Nucl. Phys. **B186** (1981) 22

$\sqrt{s}(\mathrm{GeV})$	6	10	20
$\delta_{\mathrm{T}}^{\mathrm{BKQED}}(\%)$	13.8	15.3	17.4
$\delta_{\mathrm{T}}^{\mathrm{BabaYaga@NLO}}(\%)$	13.81(1)	15.30(1)	17.51(10)

- Successful independence from the soft–hard photon separator ϵ, in the numerical limit $\epsilon \to 0$





$e^+e^- \to \gamma\gamma(n\gamma)$: size of radiative corrections

Selection criteria – ϕ, $\tau-$charm and B factories

a $\sqrt{s} = 1, 3, 10\,\mathrm{GeV}$, $E_{\mathrm{min}} = 0.3\sqrt{s}$, $\vartheta_\gamma^{\mathrm{min,max}} = 45^\circ \div 135^\circ$, $\xi_{\mathrm{max}} = 10^\circ$

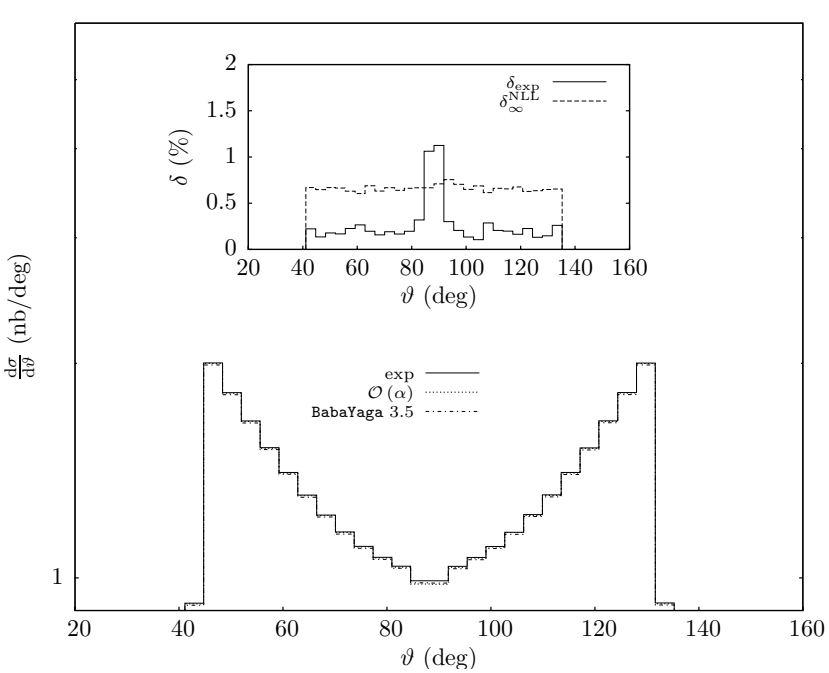
Cross sections (nb) & relative corrections (%)

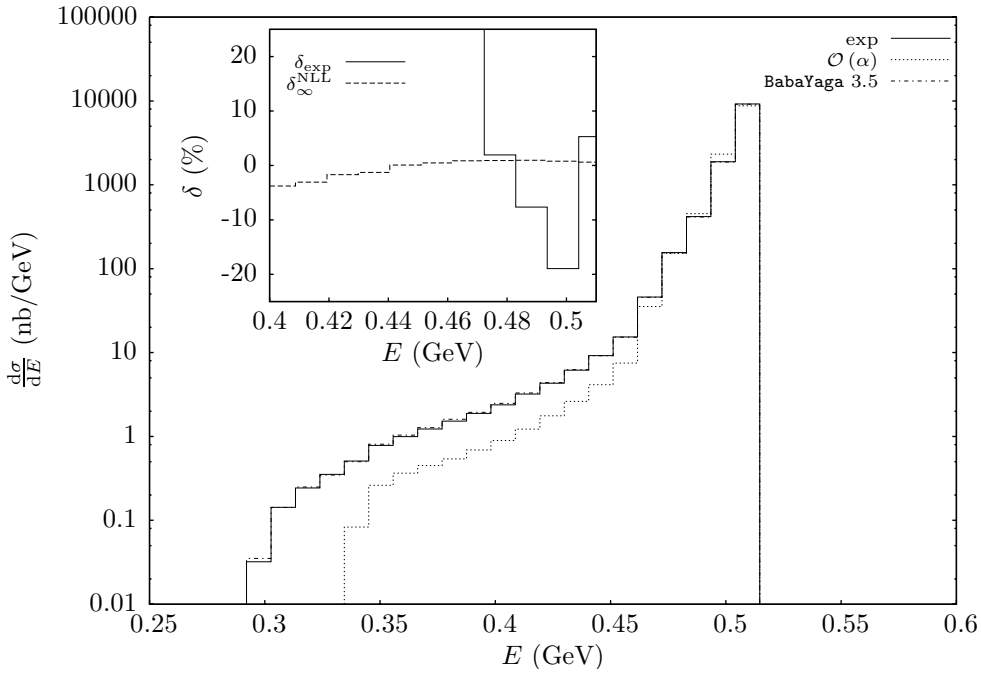
$\sqrt{s}$ (GeV)	1	3	10
σ	137.53	15.281	1.3753
$\sigma_\alpha^{\mathrm{PS}}$	128.55	14.111	1.2529
$\sigma_\alpha^{\mathrm{NLO}}$	129.45	14.211	1.2620
$\sigma_{\mathrm{exp}}^{\mathrm{PS}}$	128.92	14.169	1.2597
σ_{exp}	129.77	14.263	1.2685
δ_α	-5.87	-7.00	-8.24
δ_∞	-5.65	-6.66	-7.77
δ_{exp}	0.24	0.37	0.51
$\delta_\alpha^{\mathrm{NLL}}$	0.70	0.71	0.73
$\delta_\infty^{\mathrm{NLL}}$	0.66	0.66	0.69

- ★ Like for Bhabha, both exact $\mathcal{O}(\alpha)$ and higher–order corrections necessary for 0.1% theoretical precision ★
- No correction (and related $\Delta\alpha_{\mathrm{had}}^{(5)}$ uncertainty!) due to vacuum polarization

$e^+e^- \to \gamma\gamma(n\gamma)$: distributions [for $\Phi-$factories]

Angular and energy distribution of the most energetic photon





- Interplay of NLO and multiple photon corrections also necessary for precise simulations of differential cross sections

Conclusions

- The event generator BabaYaga has been significantly improved to provide predictions for
  - $e^+e^- \to \gamma\gamma(n\gamma)$ with per mille accuracy
  - $e^+e^- \to \gamma\gamma\gamma(n\gamma)$... with per cent (or better) accuracy

  You can download BabaYaga@NLO from

  http://www.pv.infn.it/~hepcomplex/babayaga.html

★ This improved description of the $\gamma\gamma$ channel can contribute to reduce the error in the luminosity measurement at flavour factories

- Like for Bhabha, both exact $\mathcal{O}(\alpha)$ and multiple photon corrections are necessary for 0.1% theoretical description of integrated cross sections and distributions
- The amount of the corrections to $\gamma\gamma$ is about one half of that to Bhabha scattering, when considering comparable experimental set–up
- It would be useful to compare BabaYaga@NLO with MCGPJ for this final state, to better asses the precision of the two generators. Maybe some experimentalists have already results at hand?