Simulation of the electron-positron annihilation into hadrons with the event generator PHOKHARA

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Collaboration

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SWIDER

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Aim of the work

The aim of the work is to construct a new NNLO (for ISR) generator for the scanning mode, which is based on the already existing PHOKHARA, as far as radiative corrections from one and two photon emmission are concerned for processes: $e^+e^- \to hadrons$ and $e^+e^- \to \mu^+\mu^-$.

The missing ingredient, the two loop virtual corrections, are available in the literature: F. A. Berends, W. van Neerven and G. Burgers, Higher Order Radiative Corrections at LEP Energies,Nucl.Phys. B297 (1988) 429

This program will be complementary to the two main generators currently in use, KKMC [1] and MCGPJ [2],[3].

[1] S. Jadach, B. Ward and Z. Was, Comput.Phys.Commun. 130 (2000) 260325
[2]A. Arbuzov, V. Astakhov, A. Fedorov, G. Fedotovich, E. Kuraev et. al., JHEP 9710 (1997) 006

[3] A. Arbuzov, G. Fedotovich, E. Kuraev, N. Merenkov, V. Rushai et. al., JHEP 9710 (1997) 001 [hep-ph/9702262].

The NNLO corrections

The present version of the PHOKHARA program is limited to initial state emission and only the photon emission from electron and positron is taken into account.

$$
\begin{aligned}
d\sigma(e^+e^- \to \mathrm{hadrons} + \mathrm{photons}) &= d\sigma(e^+e^- \to \mathrm{hadrons}) \\
&+ d\sigma(e^+e^- \to \mathrm{hadrons} + \mathrm{one\ hard\ photon}) \\
&+ d\sigma(e^+e^- \to \mathrm{hadrons} + \mathrm{two\ hard\ photons})
\end{aligned}
$$

where available modes: $\mu^+\mu^-$, $\pi^+\pi^-$, $2\pi_0\pi^+\pi^-$, $2\pi^+2\pi^-$, $\bar{p}p$,$\bar{n}n$, K^+K^-, $\bar{K}^0K^0$, $\pi^+\pi^-\pi^0$,$\eta\pi^+\pi^-$

The NNLO corrections - zero photon emission in LO,NLO,NNLO

The new part, $d\sigma(e^+e^- \to \mathrm{hadrons})$, added to the code is written as:

$$d\sigma(e^+e^- \to \mathrm{hadrons}) = \frac{1}{2s} L^0_{\mu\nu} H^{\mu\nu} d\Phi_n(p_1 + p_2; q_1, \cdot, q_n)$$

The leptonic tensor contains the virtual and soft radiative corrections up to the second order:

$$L^0_{\mu\nu} = 4(p_{1\mu}p_{2\nu} - g_{\mu\nu}\frac{s}{2} + p_{1\mu}p_{2\nu})4\pi\alpha|\frac{1}{1-\Delta_{VP}(s)}|^2(1+\Delta)$$

$\Delta_{VP}(s)$ - vacuum polarisation correction.

$$\Delta = \Delta_{virt,1ph} + \Delta_{soft,1ph} + \Delta_{virt,2ph} + \Delta_{soft,2ph} + \Delta_{virt,soft,1ph}$$

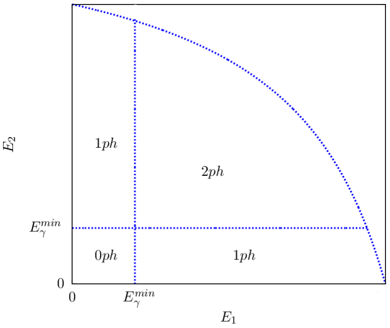
with $w = E_\gamma^{min}/\sqrt{s}$;

$$\Delta_{soft,1ph} = \frac{1}{2}\log^2(s/m_e^2) + 2\log(2w)(\log(s/m_e^2) - 1) - 2\zeta_2$$

$$\Delta_{soft,2ph} = \frac{\Delta^2_{soft,1ph}}{2} + \frac{\alpha^2}{\pi^2}[-2\zeta_2(\log(s/m_e^2) + 1)^2]$$

The red part of Berends formula isn't use in our program, beceause of different bit of phase space for photon energy.

Division of contributions from two photon phase space into three parts of the cross section



$0ph$-part is added into $d\sigma(e^+e^- \to \mathrm{hadrons})$;
$1ph$-part is added into $d\sigma(e^+e^- \to \mathrm{hadrons} + \text{one hard photon})$;
$2ph$-part is calculated in $d\sigma(e^+e^- \to \mathrm{hadrons} + \text{two hard photons})$.

Generation of the phase space

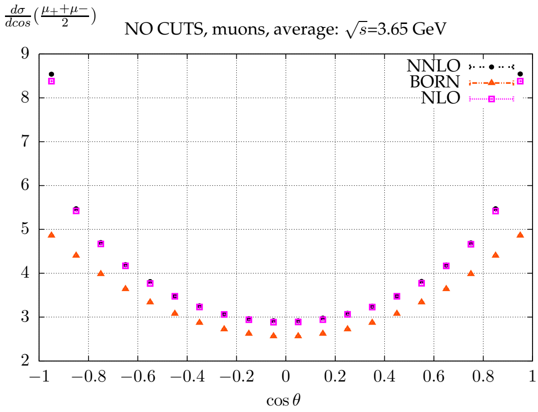
Generation of the phase space of the hadrons + two photons:

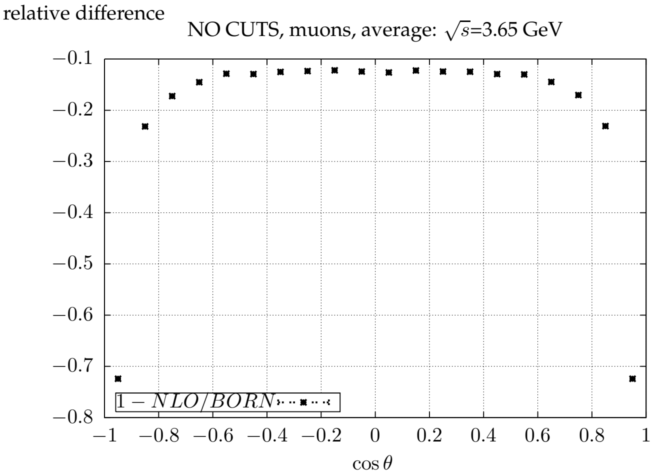
- the program generates first the invariant mass of the hadronic system q^2;
- the program generates the angles of the photons in the center-of-mass-frame of the initial fermions;
- the energy of one of the photons is generated in the center-of-mass-frame of the initial fermions ;
- the energy of the second of the photons is calculated from the relation:

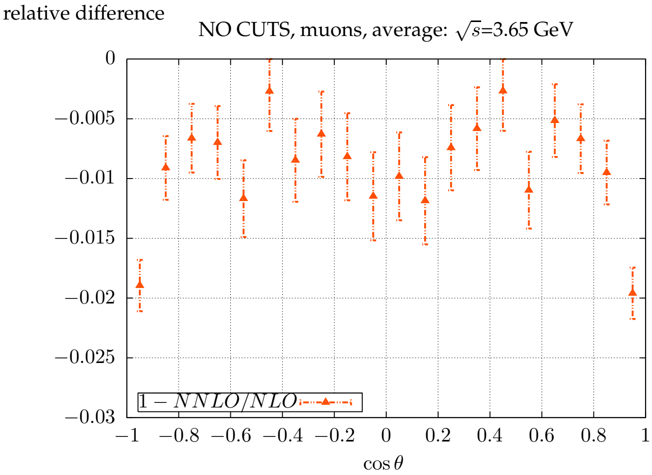
$$q^2 = s - 2(E_1 + E_2)\sqrt{s} + 2E_1E_2(1 - \cos\theta_{12})$$

where E_1, E_2 are the energies of the photons and θ_{12} is the angle between their momenta

The size of NLO and NNLO corrections to the muon polar angle distribution

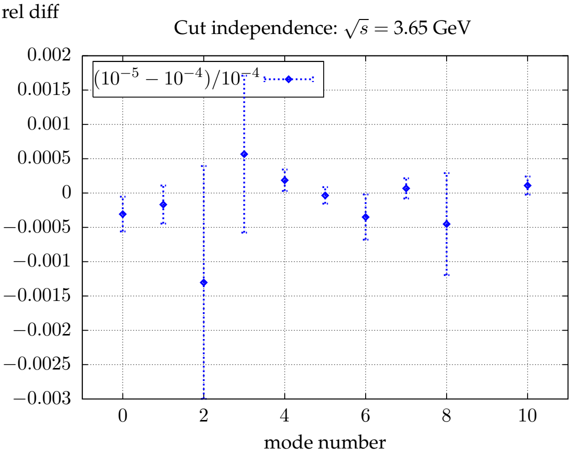



relative difference
NO CUTS, muons, average: $\sqrt{s}$=3.65 GeV
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1
$1 - NLO/BORN$
$\cos\theta$

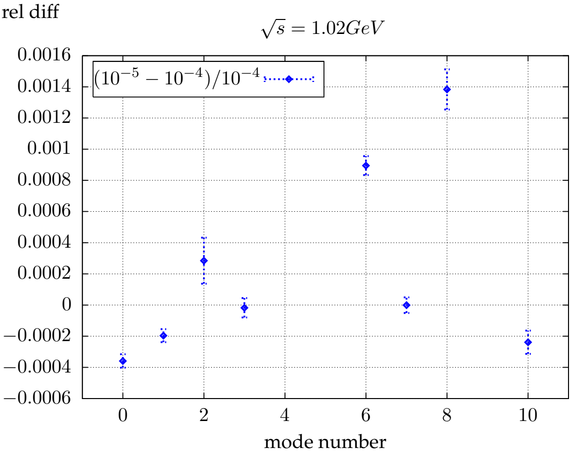

relative difference
NO CUTS, muons, average: $\sqrt{s}$=3.65 GeV
0
−0.005
−0.01
−0.015
−0.02
−0.025
−0.03
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1
$\cos\theta$
$1 - NNLO/NLO$

The tests presented here concentrate on the testing of the implementation of the new (zero-photon emission) part since the other parts were already well tested.

- for the sum of all contributions we have tested the independence of the integrated cross section from the separation parameter between soft and hard parts - the recommended cut to be used is $w = 10^{-4}$;
- comparision for the muon pair invariant mass distributions obtained with PHOKHARA and with KKMC ;
- comparision for the muon pair missing transverse momentum distributions obtained with PHOKHARA and with KKMC ;

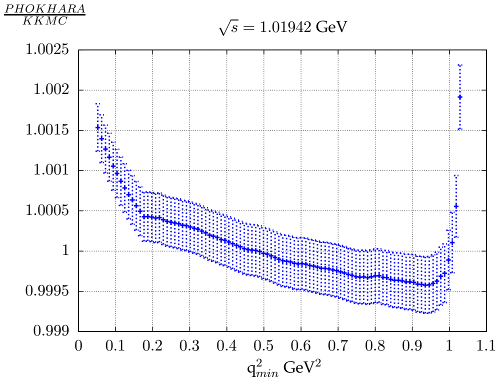


$\mu^+\mu^-(0)$, $\pi^+\pi^-(1)$, $2\pi_0\pi^+\pi^-(2)$, $2\pi^+2\pi^-(3)$, $\bar{p}p(4)$,$\bar{n}n(5)$, $K^+K^-(6)$, $\bar{K}^0K^0(7)$, $\pi^+\pi^-\pi^0(8)$,$\eta\pi^+\pi^-(10)$

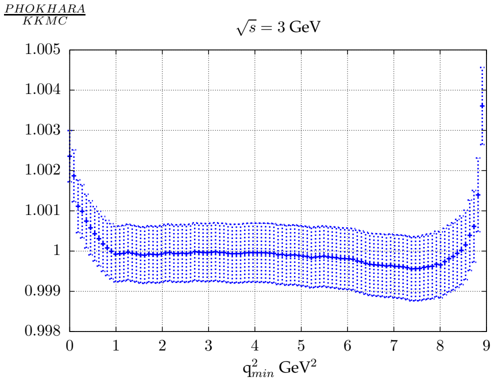


$\mu^+\mu^-$(0), $\pi^+\pi^-$(1), $2\pi_0\pi^+\pi^-$(2) , $2\pi^+2\pi^-$(3), $\bar{p}p$(4),$\bar{n}n$(5), K^+K^-(6),

$\bar{K}^0K^0$(7),$\pi^+\pi^-\pi^0$(8),$\eta\pi^+\pi^-$(10)

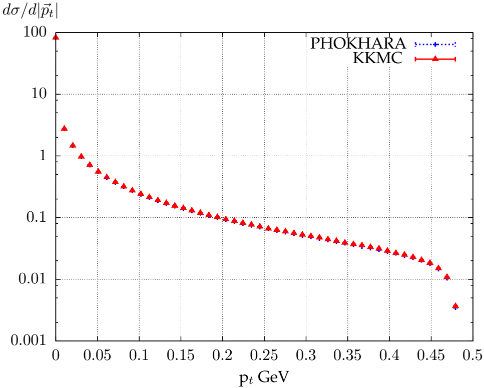


Ratio of the integrated cross section obtained by KKMC and PHOKHARA as a function of the lower limit of the muon pair invariant mass q^2_{min} ($\int_{q^2_{min}}^{s} \frac{d\sigma}{dq^2} dq^2$ as a function of q^2_{min}). S.Jadach,Acta. Phys. Polon. B(2005) 2387



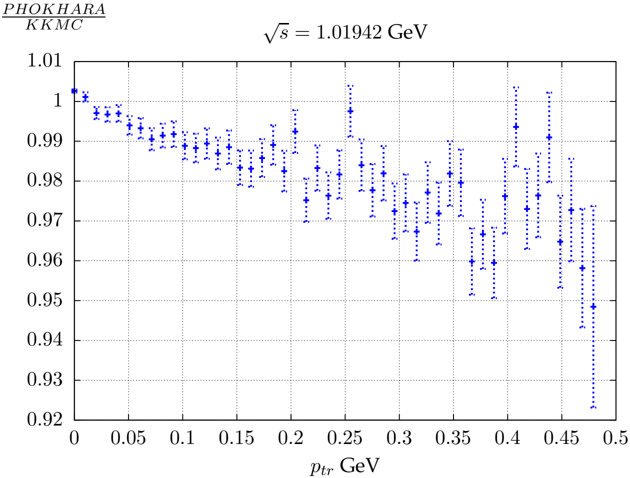
Ratio of the integrated cross section obtained by KKMC and PHOKHARA as a function of the lower limit of the muon pair invariant mass q^2_{min} ($\int_{q^2_{min}}^{s} \frac{d\sigma}{dq^2} dq^2$ as a function of q^2_{min}).

The missing transverse momentum distributions

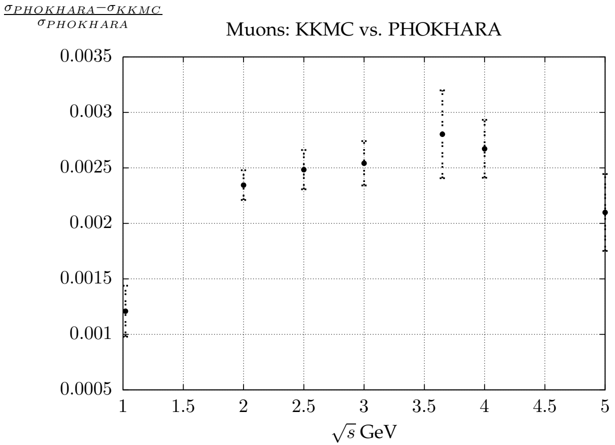


The small difference between these distributions can be attributed to the missing multi-photon corrections in PHOKHARA generator. $\sqrt{s} = 1.019$ GeV

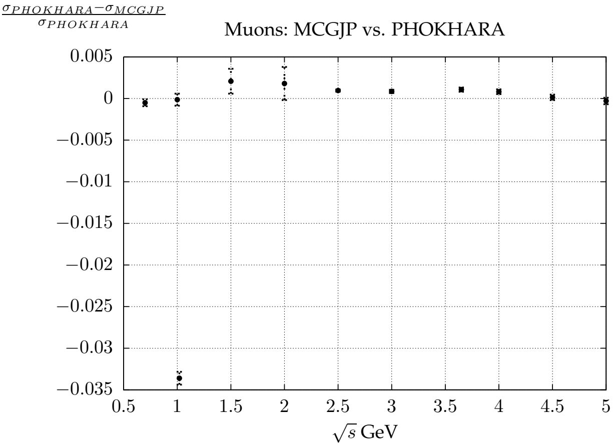
The missing transverse momentum distributions

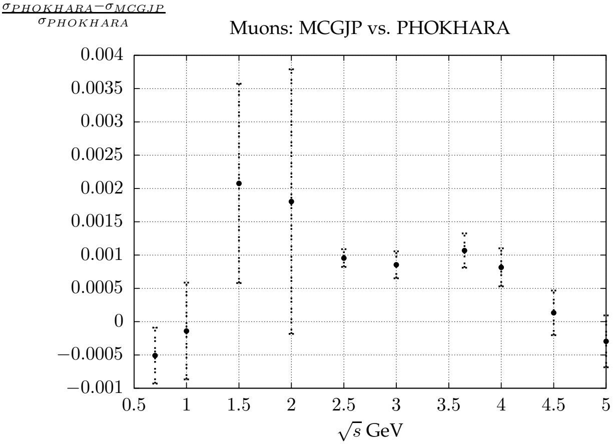


PHOKHARA vs.KKMC



PHOKHARA vs. MCGJP




$\frac{\sigma_{PHOKHARA}-\sigma_{MCGJP}}{\sigma_{PHOKHARA}}$
Muons: MCGJP vs. PHOKHARA
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
−0.0005
−0.001
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
$\sqrt{s}$ GeV

Conclusions

- New PHOKHARA MC generator is complementary to the two other MonteCarlo programms currently in use, KKMC and MCGPJ;
- PHOKHARA does not include multi-photon (beyond two) emission;
- it can be used to simulate a multitude of exclusive hadronic final states;
- some further tests with MCGPJ are in progress;