

# PHOKHARA

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## Abstract

PHOKHARA is a Monte Carlo generator which simulates at the next-to-leading order in QED the cross-section for  $e^+e^-$  annihilation into a real tagged photon and a virtual photon converting into hadrons, where the tagged photon is radiated off the initial electron or positron. This includes virtual and soft photon corrections to the leading process  $e^+e^- \rightarrow \gamma + \gamma^*$  and the emission of two real hard photons:  $e^+e^- \rightarrow \gamma + \gamma + \gamma^*$ . The present version simulates the production of a pair of charged pions or muons in  $e^+e^-$  collisions at centre-of-mass energies between 1 and 10 GeV.

## 1 Introduction

PHOKHARA simulates the production of two charged pions or muons together with one or two hard photons in  $e^+e^-$  collisions; it includes virtual and soft photon corrections to the emission of one single real photon. It supersedes the previous versions of the EVA [4] Monte Carlo generator. The program exhibits a modular structure, which preserves the factorization of the initial state QED corrections. The simulation of other exclusive hadronic channels can therefore be easily included with the simple replacement of the current(s) of the existing modes, and the corresponding multiparticle hadronic phase space. The simulation of the four-pion channel [5] will be incorporated soon, as well as other multihadron final states.

The program provides predictions either at leading order (LO) or at next-to-leading order (NLO). In the former case only single photon events are generated. In the latter, both events with one or two photons are generated at random. For simplicity, final state radiation (FSR) is not considered in the new generator, which however can be estimated from EVA [4].

## 2 The program

PHOKHARA is written in FORTRAN 77. All the real variables and functions are defined `double precision`. The present distribution consists of the following files:

- **phokhara.f** : the main program.

- **phokhara.inc** : defines some variables and **COMMON** blocks which are used by most of the subroutines in the main program.
- **input.dat** : all the constants and specific parameters needed for the generation are given through this file. The values of these input parameters can be varied by the user.
- **seed.dat** : contains the seed used to initialize RM48, the double precision random number generator from the CERN Program library CERNLIB. After each generation run a new seed is stored in this file.

The program has to be linked with the CERNLIB library; e.g.

```
f77 phokhara.f 'cernlib mathlib'
```

Further information and updates of the program can be found in the following web address: <http://cern.ch/grodrigo/phokhara>

### 3 Input file

The interaction of the user with the program is made through the file **input.dat**. It defines some physical constants and the specific parameters needed for the generation. The values of these parameters can be changed by the user.

**nges** – number of events which shall be generated. The number of events accepted and returned in the output file depends on the kinematical constraints, the energy of the collision and the generated final state. Typically, the acceptance rate varies between 30% and a few per cent.

**nm** – number of events used to scan the integrand and find its maximum. A preliminary scan is made to find the maximum(s) of the integrand(s) before the true generation starts. The value of the maximum used in the generation phase is slightly greater than this approximated maximum.

**outfile** – name of the output file where the four-momenta of the particles of the accepted events are stored.

**nlo** – whether the program should provide predictions at LO (**nlo=0**) or NLO (**nlo=1**).

**vacua** – includes (**vacua=1**) or not (**vacua=0**) vacuum polarization corrections to the virtual photon line. Only the real part of the lowest order leptonic loops is considered.

$w$  – energy cutoff of soft photon emission, normalized to the centre-of-mass energy. The physical result is independent of its value. Recommended value  $w = 10^{-4}$ .

**pion** – which final state channel shall be simulated: two muons (**pion**=0) or two charged pions (**pion**=1).

The next set of parameters defines physical constants: coupling constants, masses, and decay widths. The following values are used:

$1/\alpha = 137.03599976$  – fine structure constant  
 $m_e = 0.51099906 \cdot 10^{-3}$  GeV – electron mass  
 $m_\mu = 0.1056583568$  GeV – muon mass  
 $m_\tau = 1.77703$  GeV – tau mass  
 $m_\pi = 0.13956995$  GeV – pion mass  
 $m_\rho = 0.7685$  GeV –  $\rho$ -meson mass  
 $\Gamma_{ee} = 0.677 \cdot 10^{-5}$  GeV – partial decay width for  $\rho \rightarrow e^+ e^-$   
 $\Gamma_\rho = 0.1507$  GeV – total decay width of the  $\rho$ -meson  
 $m_{\rho'} = 1.37$  GeV –  $\rho'$ -meson mass  
 $\Gamma_{\rho'} = 0.51$  GeV – total decay width of the  $\rho'$ -meson  
 $m_{\omega'} = 0.78194$  GeV –  $\omega$ -meson mass  
 $\Gamma_\omega = 0.00843$  GeV – total decay width of the  $\omega$ -meson

For the parametrization of the pion form factor [6], two more constants are needed:

$a = 0.00185$   
 $b = -0.145$

These two constants are given by the fits from reference [6]. Other parametrizations can be introduced in the program from subroutine **PionFormFactor2**.

The remaining set of parameters defines the specific experimental settings:

**E** – centre-of-mass energy (GeV).  
**q2min** – minimal squared invariant mass of the system formed by the hadrons and the tagged photon (GeV<sup>2</sup>).  
**gmin** – minimal energy of the tagged photon (GeV).

`phot1cut` – lower cut on the azimuthal angle of the tagged photon (degrees).

`phot2cut` – upper cut on the azimuthal angle of the tagged photon (degrees).

`pi1cut` – lower cut on the azimuthal angle of the muons or pions (degrees).

`pi2cut` – upper cut on the azimuthal angle of the muons or pions (degrees).

All the kinematical cuts are given in the centre-of-mass system of the initial particles. The azimuthal angles are defined with respect to the positron momentum.

The program offers the possibility of presenting various differential distributions as histograms. If this option is used, the name of the output file where the histograms are stored and the attributes of each histogram must be given.

`fname` – name of the output file where the histograms are stored.

`title(i)` – title of histogram `i`

`xlow(i)` – lower edge in `x` for histogram `i`

`xup(i)` – upper edge in `x` for histogram `i`

`bins(i)` – number of bins for histogram `i`

where  $i=1, \dots, 10$ .

## 4 Output

PHOKHARA presents the output information in several forms and saves it in different files.

The four-momenta of the particles of the accepted events are stored in the file given by `outfile`. The format of the output is determined by the subroutine `writteevent(pion)` and can be changed by the user. All the momenta are given in the centre-of-mass system of the colliding electron and positron.

The subroutine `inithisto` books the histograms being based on the information given by the input file. The subroutine `endhisto(fname)` fills the histograms at the end of the generation run and save the result in the output file given by `fname`. These two subroutines use `HBOOK` to create and manipulate the histograms. A later manipulation of the histograms is

possible with PAW. For accuracy reasons – HBOOK works only in single precision – the histogram information is stored in the intermediate steeps of the calculation in the matrix `histo(i, j)`, where `i` identifies the histogram number and `j` the bin. Only at the end of the generation run it is transferred to the histograms. The user can therefore use its favourite histogramming tool simply modifying the subroutines `inithisto` and `endhisto`.

By default only the  $Q^2$  distribution, where  $Q^2$  is the squared invariant mass of the hadronic (muonic) system, is calculated. The contribution from single photon events is stored in histogram 1. The contribution from two photon events is stored in histogram 2. The final  $Q^2$  distribution is given by the sum of both results. Other differential distributions can be defined though the subroutine `addiere(wgt, qq, i)`, where `wgt` is the weight of the event, `qq` is the value of  $Q^2$  and `i` is equal to 1 for single photon events and 2 for two photon events. The four-momenta of the events are given by the matrix `momenta(i, 0:3)`, where `i=1, ..., 7`, for the positron, the electron, the two real photons (for single photon events `momenta(4, 0:3)` is set to zero), the virtual photon converting into hadrons, the  $\pi^+(\mu^+)$  and  $\pi^-(\mu^-)$  respectively. It can be used by the user to define other differential distributions.

At the end of the run, PHOKHARA displays also the total number of accepted events, the value of the cross section, the value of the scanned maximum(s) and the biggest value of the integrand(s) found during the Monte Carlo generation. The last should be always smaller than the scanned maximum. If during the generation a value of the integrand is found to be bigger than the scanned maximum, a warning is given. Then, the number of events used for the initial scan should be increased.

## 5 Forthcoming features

- Inclusion of FSR.
- Simulation of other exclusive hadronic channels.

## References

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- [4] S. Binner, J. H. Kühn and K. Melnikov, Phys. Lett. **B459** (1999) 279 [hep-ph/9902399].
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