New generator for Bhabha scattering

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Physics studies (NN..LO)

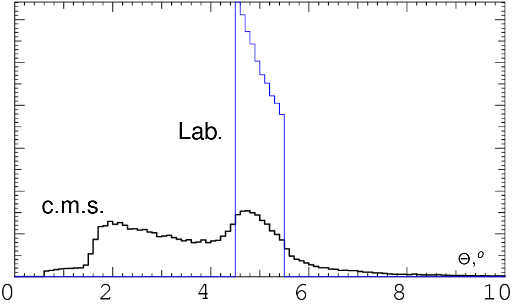
- **LABS**: A.B. Arbuzov, V.V. Bytev, E.A. Kuraev, E. Tomasi-Gustafsson, Yu.M. Bystritskiy
  *Phys.Part.Nucl. 41 (***2010***) 636-689*
- A. Arbuzov, E. Kuraev, B. Shaikhatdenov
  Published in Phys.Part.Nucl. 33 (2002) 1-36
  + a series of papers
- **SABS**: A.B. Arbuzov , V.S. Fadin, E.A. Kuraev, L.N. Lipatov et al.
  Published in Nucl.Phys.Proc.Suppl. 51C (1996) 154-163
- S. Jadach, M. Melles, W. Placzek, Z.Was et al.
  ICHEP 96:1072-1076
  + a series of papers
- Own calculations for one loop RC (NLO).

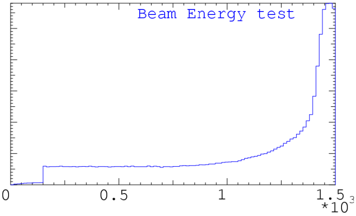
Basic codes

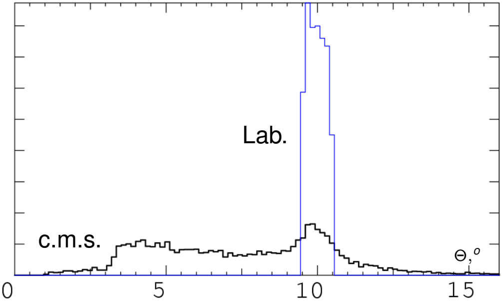
- BHWIDE for wide angle scattering
  S. Jadach, W. Placzek, Z. Was et al., *Comp.Phys.Comm. 102 (1997) 229-251*
  Precision: 0.1 – 0.5% (depending on c.m.s. energy);
- BHLUMI for forward region ($\sim 20 mrad$)
  S. Jadach, W. Placzek et al., *Phys.Lett. B390 (1997) 298-308*
  Precision: up to 0.06% (at LEP1 energy).

Lab. vs. c.m.s.

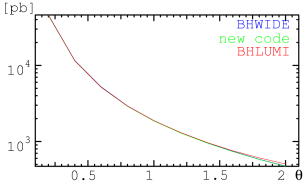
- Generator must cover both large and small angles

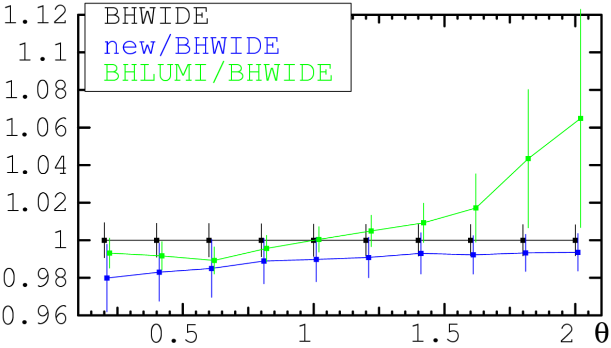






Low angle scattering: total cross sections vs. angular cut value





Lab. vs. c.m.s.

- Error in c.m.s.: up to 1-2%.
- Error in Lab. system: up to 1% for 1^o.

Cross section table (nb)

- Total cross section vs. angular cut on final lepton θ_{cut}

$\theta_{cut}, ^o$	BHWIDE	BHLUMI	new code
0.2	46.0 ± 0.4	45.71 ± 0.36	45.1 ± 0.8
0.4	11.6 ± 0.1	11.52 ± 0.08	11.4 ± 0.2
0.6	5.23 ± 0.05	5.169 ± 0.037	5.15 ± 0.08
0.8	2.93 ± 0.03	2.921 ± 0.020	2.90 ± 0.04
1.0	1.88 ± 0.02	1.880 ± 0.013	1.86 ± 0.02
1.2	1.31 ± 0.01	1.319 ± 0.011	1.30 ± 0.01
1.4	0.966 ± 0.008	0.975 ± 0.010	0.96 ± 0.01
1.6	0.741 ± 0.006	0.754 ± 0.014	0.736 ± 0.008
1.8	0.583 ± 0.005	0.609 ± 0.022	0.580 ± 0.006
2.0	0.474 ± 0.004	0.506 ± 0.029	0.472 ± 0.005

- Sample sizes for BHWIDE & BHLUMI : 10k events

Advantages

- polarized particles;
- allows to change initial momenta for every event;

  Error imposed by scaling of BHWIDE events is upto 1% (see appendix);

  Parametric Monte-Carlo method is used
- brick-based architecture allows to add other processes;

  (see appendix for details)
- allows to automatically recalculate most of NLO cross section code;
- 'Smooth cuts' algorithm for integration stability.

Implemented processes

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

Conclusions #1

- The generator 'as is' will be available at
  `http://cern.ch/~makarenko/bhabha/`
  in a couple of weeks.
  - NLO Bhabha scattering,
  - single hard photon bremsstrahlung,
  - basic background processes (LO),
  - internal histogram classes, eps-plots and LHE-output.
- The precision is about 1%;
- The precision of background processes is about 1–3% (but the cross section is much smaller).

On the other hand:

- The NLO generator allows to achieve only about 1% precision.
  - The error imposed by using of BHWIDE is of the same size.
- The generator is much slower than BHWIDE due to usage of Parametric-MC algorithm.
- The work on implementation of higher order radiative corrections is still ongoing.
  - The code for YFS exponentiation method is still not reliable.
- The correct error handling in generator depends strictly on the latter work.

Error handling in BHWIDE and BHLUMI

- The physical uncertainties were estimated by comparison to results of independent calculations:
    - YFS exponentiation with precise phase space integration of hard photons emission;
    - precise NLO calculation;
    - semi-analytical precise N.NLO calculations (with no MC), ...
- The semi-realistic acceptance fits were used if MC is available.

- **The independent calculation is required to estimate errors properly**

Conclusions #2

- The generator version to be released contains:
  - one-loop radiative correction to Bhabha scattering and background processes $e^+e^- \to e^+e^-e^+e^-$ and $e^+e^- \to e^+e^-\mu^+\mu^-$
- It contains the set of original algorithms (smooth cuts, parametric MC).
- It can be used e.g. to discuss further interfaces.
- For simulation purposes the BHWIDE code looks more suitable
  - until the better precision will be achieved in new generator.

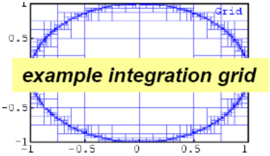
- I appreciate any help with multiloop radiative corrections calculation methods.

Back-up slides
and technical notes

Events with beam energy spectrum

Fixed energy generator

1. Integrate cross section and arrange a phase space grid. Each cell contains proper partial cross section.



2. Generate unweighted event:
   - select cell (according to its weight)
   - generate event in cell.
     - *using the approximate maximum function f_{max} value in the cell.*

Performance of generator appears equal to performance of the WORST cell!

Spread energy generator

1. Integrate cross section • ΔE for every energy step (in c.m.s.)

$[E_i–E_{i+1}]$.

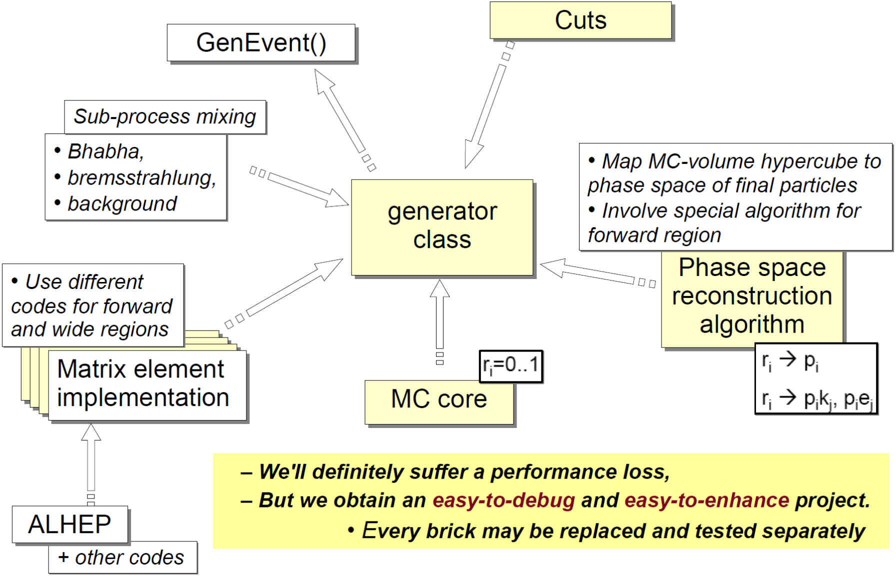
Arrange a separate phase space grid for every energy region.

2. Generate event for a certain energy:
   - select cell (according to its ***incorrect*** weight),
   - try to generate event **once** *using the* ***average function*** *f_{ave} in the cell, multiplied by safety factor k_{Safe}*
   - if failed – repeat cell selection.

Requirements:

1. $k_{Safe} \bullet f_{ave} > f_{max}$,
2. k_{Safe} **– *fixed in whole region*** $[E_i–E_{i+1}]$.

Brick-based architecture



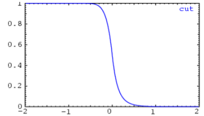
- ***We'll definitely suffer a performance loss,***
- ***But we obtain an easy-to-debug and easy-to-enhance project.***
  - ***Every brick may be replaced and tested separately***

Cross-checks available

compare to BHLUMI / BHWIDE (unpolarized case)

Cuts

use 'smooth' cuts at pre-integration step



'smooth' cut

tune forward-wide regions separator

generator class

try different variables selection for faster integration convergence

Phase space reconstruction algorithm

try different algorithms

try different forms of matrix elements

Matrix element implementation

keep automatically-built version of ME

MC core

try different MC algorithms

- *Own algorithm*
- *FOAM*
- *VEGAS**

Energy spread simulation

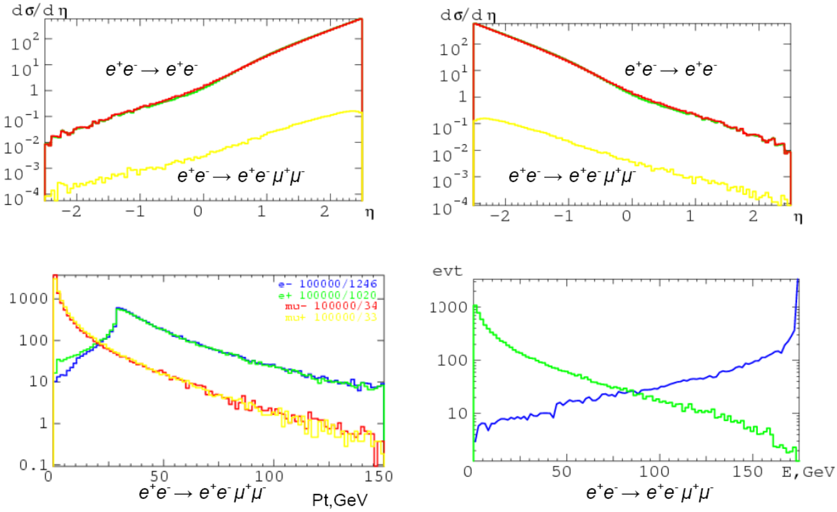
Fixed energy mode (simplistic):

```
evt->momentum[0].Set(E_0, Px_0, Py_0, Pz_0);
evt->momentum[1].Set(E_1, Px_1, Py_1, Pz_1);
gen->Initialize(E_cms);
...
for(;;){ gen->GenEvent(evt); }
```

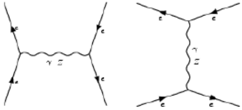
Variable energy mode (simplistic):

```
gen->Initialize(E_cms_Min, E_cms_Max);
...
for(;;) {
        evt->momentum[0].Set(E_0, Px_0, Py_0, Pz_0);
        evt->momentum[1].Set(E_1, Px_1, Py_1, Pz_1);
        gen->GenEvent(evt);
}
```

Some plots

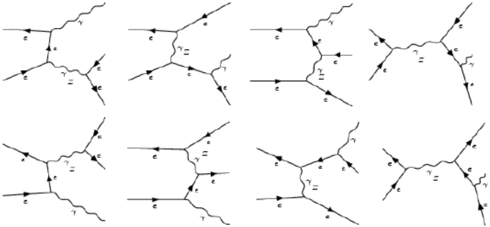

dσ/dη
10^2
10^1
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
−2
−1
0
1
2
η
$e^+e^- \to e^+e^-$
$e^+e^- \to e^+e^-\mu^+\mu^-$
e- 100000/1246
e+ 100000/1020
mu- 100000/34
mu+ 100000/33
1000
100
10
1
0.1
50
150
Pt,GeV
evt
E,GeV

Bhabha scattering (NLO)



LO

loops (total 298 diagrams)



single bremssthahlung

Background process

$$e^+e^- \to e^+e^- + e^+e^-$$

(total 88 diagrams)