LC Physics Simulations With WHIZARD

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- The WHIZARD approach to multi-particle simulations
- How to use the program
- Features, recent add-ons and improvements
- Results and comparisons

http://www-ttp.physik.uni-karlsruhe.de/whizard/

Multi-Particle Simulations

Physics processes:

$$\underbrace{\underbrace{\text{beams} \quad \rightarrow \quad \underbrace{e^+e^- \quad \rightarrow \quad \text{partons (+leptons,photons)}}_{\text{Theory (integration/simulation)}}}_{\text{Parton-level simulation}} \quad \rightarrow \quad \text{hadrons}}_{\text{Physics simulation}} \quad \rightarrow \quad \text{tracks} \quad \rightarrow \ldots$$

LC: Need high precision – all those tiny (%) background and interference effects on resonance shapes, thresholds, edges . . .

$\Rightarrow$ Full matrix-element partonic simulations (not just integrations), properly interfaced to beams and hadronization, are necessary to meet requirements.

WHIZARD/O'Mega

Since 2000, WHIZARD (and several other programs) attack this problem:

- Fully automatic matrix element generators are available

These take a process definition and a set of Feynman rules to produce a (Fortran/C) function:

- The (squared) amplitude as a function of given momenta and helicities.

Preferred choice: call O'Mega T. Ohl

$\Rightarrow$ Complete helicity amplitudes computed numerically and recursively

$\Rightarrow$ All redundancies eliminated by organizing the calculation (DAG = Directed Acyclical Graph)

$\Rightarrow$ Computation cost $\propto n^k$ instead of n!!

$\Rightarrow$ Models: SM + extensions and MSSM J. Reuter

QCD amplitudes (gluons and interfering colors): alternatively, call Madgraph and/or CompHEP to generate the amplitudes

$\Rightarrow$ Coming soon: Cascades (narrow-width approximation)

$\Rightarrow$ QCD: under construction

WHIZARD

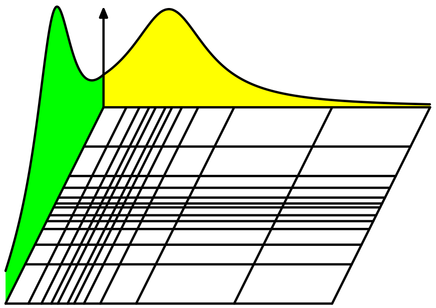
Matrix elements are complicated and vary over orders of magnitude

⇒ Uniform phase space sampling yields no result

⇒ No single parameterization allows for mapping the function into a constant

Solution: Multi-channel parameterization with mappings and parameterizations adapted to Feynman diagram structure

∗ WHIZARD: Improve by VEGAS adaptation within each channel



WHIZARD

What does this mean in practice?

- WHIZARD has to find the *important* channels: The Feynman diagram which have the strongest peaks ⇒ correspond to good parameterizations
- WHIZARD has many degrees of freedom to adapt:
  - The optimal binning of each integration dimension (10 – 50)
  - This is needed for each integration dimension (10 – 20)
  - The optimal relative weight of each channel (10 – 1000)

  ⇒ 10^3 – 10^6 degrees of freedom have to self-optimize

Apparently, this works – and at least as good as other methods

User interface

Configure the system: `./configure`

- Script searches for Fortran compiler, CERNLIB software, enabled modules, etc.

Make up a process list: Configuration file

- Model (SM, MSSM, ...) and arbitrary list of initial and final states

Compile and install in subdir: `make install`

- Script(s) call matrix element generators, collect results, compile matrix element code, make process library, compile main program and link with auxiliaries

Set up the parameters: Input file(s)

- Run control, physics parameters, beam properties, cuts, ...

Run program: `cd results; ./whizard`

- Adapt grids, integrate cross section(s), generate event sample(s)

Online analysis: `make plots`

- Fill histograms and process them into graphics

Features: LC Summary

- Beamstrahlung (CIRCE: analytic oder [new] beam-event generator)
- [new] Read beam events (GuineaPig) directly from file
  $\Rightarrow$ account for beamstrahlung, beam-energy spread, etc.
- ISR: Collinear initial photons
- Longitudinal or transverse (in fact: arbitrary) beam polarization
- Polarization carried through
- Fermion masses
- Physics models (depends on ME generator): QED, SM with variants,
  [new] MSSM (with Les Houches Accord parameter interface)
- Matrix element calculation and event generation works, e.g., for $2 \to 4$, $2 \to 6$ [ok],
  $2 \to 8$ [few cases tested so far]
- Parton shower & fragmentation: PYTHIA interface (Les Houches Accord)
- ASCII or STDHEP event files (LCIO?)

Results and comparisons

2002: Extensive comparison of WHIZARD and LUSIFER cross sections S. Dittmaier, M. Roth

6-fermion processes:

- LUSIFER: Analytically derived matrix elements for fixed class of processes, adaptive multi-channel integration with fixed channel mappings
- WHIZARD/O'Mega: Numerical matrix elements for arbitrary processes, adaptive multi-channel integration with adaptive channel mappings, interfaced to beams and events

Old result:

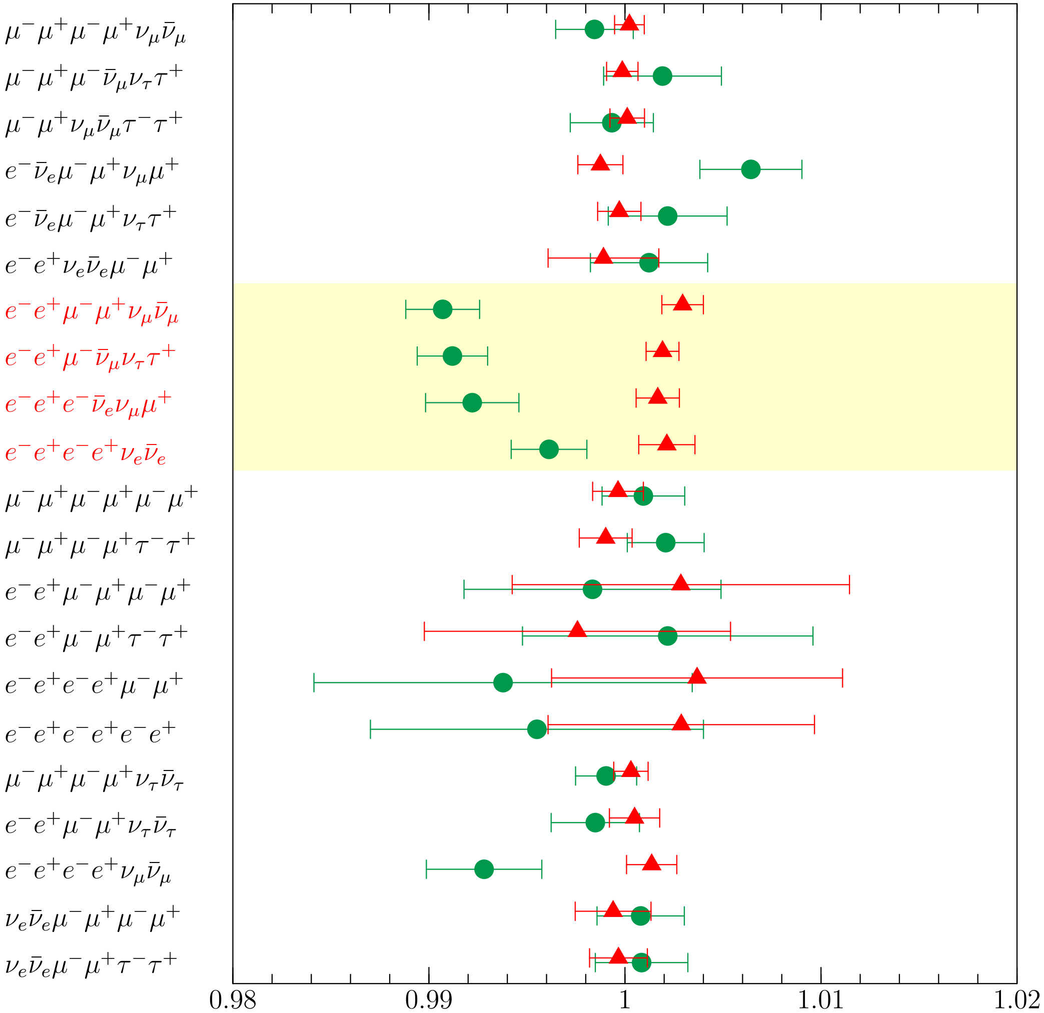
⇒ Agreement where applicable, for some processes no stable WHIZARD result

2004: New result (WHIZARD 1.30):

⇒ All processes yield stable result, complete agreement

Results and comparisons

Results LUSIFER/WHIZARD



Parameters:

- $\sqrt{s} = 500$ GeV, ISR
- Cuts: $\theta > 5^\circ$, $E > 10$ GeV

  LUSIFER: 10M points sampled

  WHIZARD: 5M adapt, 5M integration

White background:

⇒ Agreement within 1-3σ

⇒ WHIZARD error up to factor 2 smaller

Yellow band:

⇒ Gauge invariance violation

LUSIFER: Fixed width, Feynman gauge

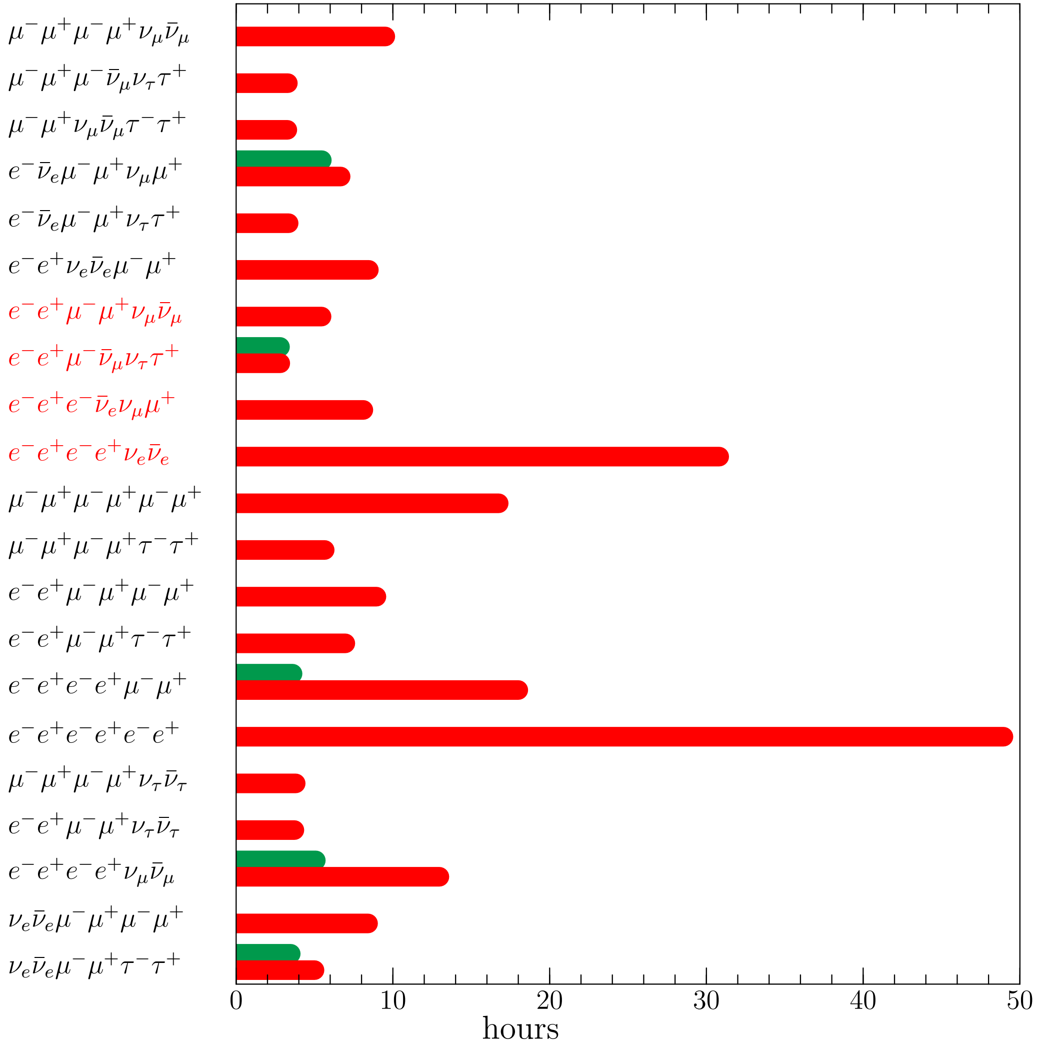
O'Mega: Step width, unitary gauge

Results and comparisons

How much does it cost to have a multi-purpose package?

CPU time:

- 10M points (as before)
- Intel Fortran 95 compiler for both WHIZARD/O'Mega and LUSIFER (40% faster than g77)
- 3 GHz Pentium



Result:

- Generic program more efficient for typical processes (same CPU time / smaller error)
- Taylored program more efficient in cases with many identical particles

Results and comparisons

New results:

- 8 fermions, e.g. background to ttH production at $\sqrt{s} = 800\ \mathrm{GeV}$:

$e^+e^- \to b\bar{b}b\bar{b}e^-\bar{\nu}_e\nu_e e^+$	$7.367(67)\ \mathrm{ab}$	3M (adapt) + 1M (integ)
$e^+e^- \to b\bar{b}b\bar{b}e^-\bar{\nu}_e\nu_\mu\mu^+$	$7.224(18)\ \mathrm{ab}$	1M (adapt) + 1M (integ)
$e^+e^- \to b\bar{b}b\bar{b}\mu^-\bar{\mu}_e\nu_\mu\mu^+$	$7.183(18)\ \mathrm{ab}$	1M (adapt) + 1M (integ)

CPU time: 1-2 days per process

- MSSM, e.g. $\tilde{\chi}^+\tilde{\chi}^-$ production and decay including background at $\sqrt{s} = 500\ \mathrm{GeV}$:

SUSY spectrum and parameters: SPS1a (SPHENO)

$e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 u\bar{d}e^-\bar{\nu}_e$	$0.8114(7)\ \mathrm{fb}$	1M (adapt) + 1M (integ)

CPU time: 3h (massless fermions)

Summary

- WHIZARD/O'Mega yields accurate and useful results
  for the simulation of multi-particle processes relevant at the LC
- SM e^+e^- event sample equivalent to $2\,\mathrm{ab}^{-1}$ available at SLAC

- WHIZARD/O'Mega support SM, MSSM and extensions
- ...and is integrated in the LC physics environment

- Efficiency problems have been resolved,
  and results are in complete agreement with semianalytic program LUSIFER
- Gauge invariant treatment of unstable particles is important for (some) 6f-processes