LC Physics Simulations With WHIZARD

Wolfgang Kilian (DESY)

LCWS Paris
April 2004

- 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:**

\[
\text{beams} \rightarrow e^+e^- \rightarrow \text{partons (+leptons, photons)} \rightarrow \text{hadrons} \rightarrow \text{tracks} \rightarrow \ldots
\]

- **Theory (integration/simulation)**
- **Parton-level simulation**
- **Physics simulation**

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

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

W. Kilian, LCWS Paris 2004
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

⇒ Complete helicity amplitudes computed numerically and recursively
⇒ All redundancies eliminated by organizing the calculation (DAG = Directed Acyclical Graph)
⇒ Computation cost $\propto n^k$ instead of $n!!$
⇒ Models: SM + extensions and MSSM

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

⇒ Coming soon: Cascades (narrow-width approximation)
⇒ QCD: under construction
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
What does this mean in practice?

- **WHIZARD has to find the important channels:** The Feynman diagram which have the strongest peaks $\Rightarrow$ 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)

$\Rightarrow 10^3 – 10^6$ 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
  ⇒ 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 $2 \rightarrow 4$, $2 \rightarrow 6$ [ok],
  $2 \rightarrow 8$ [few cases tested so far]
- **Parton shower** & fragmentation: **PYTHIA** interface (Les Houches Accord)
- ASCII or **STDHEP** event files (LCIO?)

W. Kilian, LCWS Paris 2004
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

Parameters:
- $p_s = 500$ 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

W. Kilian, LCWS Paris 2004
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 $\sqrt{s} = 800$ GeV:

  \[ e^+e^- \rightarrow b\bar{b}be^+\bar{\nu}_e\nu_e e^+ \quad 7.367(67) \text{ ab} \quad 3\text{M (adapt)} + 1\text{M (integ)} \]

  \[ e^+e^- \rightarrow b\bar{b}be^-\bar{\nu}_e\nu_e\mu^+ \quad 7.224(18) \text{ ab} \quad 1\text{M (adapt)} + 1\text{M (integ)} \]

  \[ e^+e^- \rightarrow b\bar{b}\bar{b}\mu^-\bar{\mu}_e\nu_e\mu^+ \quad 7.183(18) \text{ ab} \quad 1\text{M (adapt)} + 1\text{M (integ)} \]

  CPU time: 1-2 days per process

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

  SUSY spectrum and parameters: **SPS1a (SPHENO)**

  \[ e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 u\bar{d}e^-\bar{\nu}_e \quad 0.8114(7) \text{ fb} \quad 1\text{M (adapt)} + 1\text{M (integ)} \]

  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 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