WHIZARD:

Complete Simulations

for Electroweak Multi-Particle Processes

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- Overview and Status of WHIZARD
- First complete simulations for electroweak top-quark (8 fermion) processes

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

Exploring the mechanism of EWSB:

Scalars: Goldstone bosons = W_L, Z_L [+ Higgs bosons, Pseudo-Goldstone bosons]

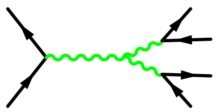
Fermions: Top quark, (bottom quark, τ lepton)

New heavy states?

LHC/LC: Precision measurements of

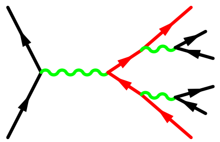
- Electroweak form factors of scalars: $W_L W_L$, $Z_L H$, $\ldots$

  $\Rightarrow$ 4–6 fermions



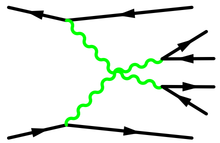
- Electroweak form factors of top quark: $t\bar{t}$

  $\Rightarrow$ 6 fermions



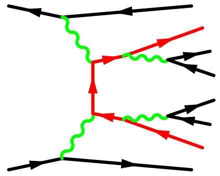
- Scattering amplitudes of scalars: $W_L W_L W_L W_L$, $Z_L Z_L H H$, $\ldots$

  $\Rightarrow$ 6–8 fermions



- Scattering amplitudes of top quarks: $W_L W_L t\bar{t}$, $t\bar{t}b\bar{b}$, $\ldots$

  $\Rightarrow$ 8–10 fermions



WHIZARD: *Modular structure*

- Matrix element generators (all tree-level)
  - O'Mega: Polarized matrix elements for arbitrary final states / all massive / no redundancies $\to$ optimal efficiency / Flavor summation
  - Alternatives: CompHEP and MadGraph (QCD color treatment)
  - PYTHIA: Fast generator for many simple processes
- Structure functions: ISR, EPA, beamstrahlung (CIRCE), PDF (from cernlib)
- Integration package: VAMP: Adaptive multi-channel Monte-Carlo integration
- Phase space: Selection and parameterization of integration channels done by WHIZARD / Arbitrary cuts and reweighting functions possible
- Unweighted event generation: Using adapted VAMP grids / Parton-level analysis tools included in WHIZARD
- Hadronization and Interface: PYTHIA / Event files in various formats / Java interface (JAS)

Phase space: WHIZARD

- WHIZARD generates Feynman diagrams and selects dominant topologies
- Phase space parameterizations written (readable, concise) to file, selection can be controlled by parameters and/or manipulated by hand (if desired)
- All phase space channels mapped onto s-channel topologies
- Analytic mappings for resonances and massless splitting or exchange topologies
- VAMP algorithm: iterative adaptation of channel weights and bins widths within channels

This works well for

- Processes with dominant signal
- $2 \to 2 \ldots 2 \to 8$
- Massless and massive, any cuts

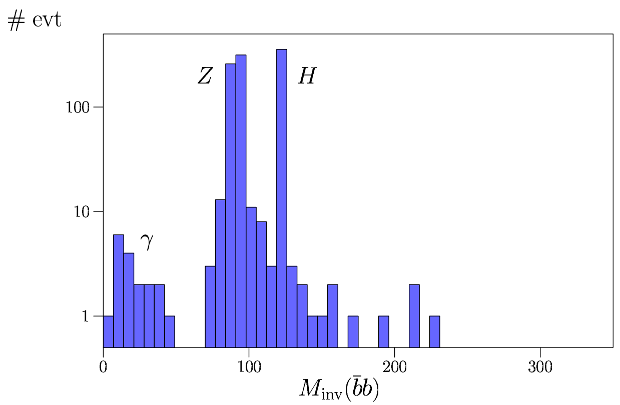
...not so well for

- Processes with many identical particles
- Many integration channels ($\gg$ 100)

$\Rightarrow$ Upcoming new version of WHIZARD: Make use of permutations, reduce number of d.o.f

Implementation and usage:

1. Generate executable: `./configure && make install`
   - Configuration of needed modules and process list in configuration file
   - Matrix element generation, compilation and linking steps controlled by standard UNIX Configure and Make tools
   - Involves shell, PERL scripts, C, Fortran and Objective CaML as programming languages
   - Everything ends up as Fortran 90 code, compiled as standalone executable or library
2. Run executable: `make run` / `make plots`
   - Set up process selection, collider parameters, physical constants, number of events, output formats etc. in input file
   - Set up cut configuration in separate file
   - Set up parton-level analysis and histograms
   - Grid adaptation and event generation
3. Use results: Run external simulation



Present Status:

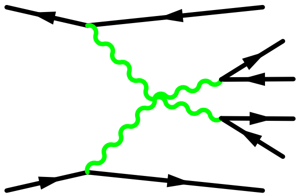
- Automatic process setup, integration and simulation work for SM processes
- Typical efficiency:
  - 4 fermions: $10 \times 20,000$ calls for adaptation: MC error $1/\sqrt{N}$, reweighting eff. 10%
  - 6 fermions: $15 \times 100,000$ calls for adaptation: MC error $2/\sqrt{N}$, reweighting eff. 3%
  - 8 fermions: $15 \times 200,000$ calls for adaptation: MC error $5/\sqrt{N}$, reweighting eff. 0.3%
- News: Improved ISR treatment, detailed cross-checks with LUSIFER, factor 2 speedup

Coming Soon:

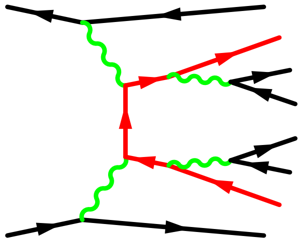
- Improvements in handling cases with large number of integration channels
  $\rightarrow$ better stability for difficult processes ($e^+e^- \rightarrow e^+e^-e^+e^-e^+e^-$)
- Updated matrix element generators: Full QCD with O'Mega, SM extensions
- CIRCE2 ($\gamma\gamma$ physics)
- Minor improvements, fixes of bugs and inconsistencies, . . .

Calculation

Matrix element complexity (O'Mega): 6-fermion vs. 8-fermion processes (no QCD)



$e^-e^+ \to$	$\nu_e\bar{\nu}_e u\bar{d}d\bar{u}$	$\nu_e\bar{\nu}_e b\bar{b}u\bar{d}d\bar{u}$	factor
# diagrams	618	$22,958$	37.1
# fusions	305	$1,371$	4.5
# helicities	32	128	4
total factor:			18



Increase in complexity requires increase in number of calls per iteration $\to$ another factor 2-5

$\Rightarrow$ need 2 orders of magnitude more CPU time!

Results

Top production in WW fusion ($\sqrt{s} = 1$ TeV, no ISR, no cuts): $e^-e^+ \to \nu\bar{\nu}b\bar{b}u\bar{d}d\bar{u}$

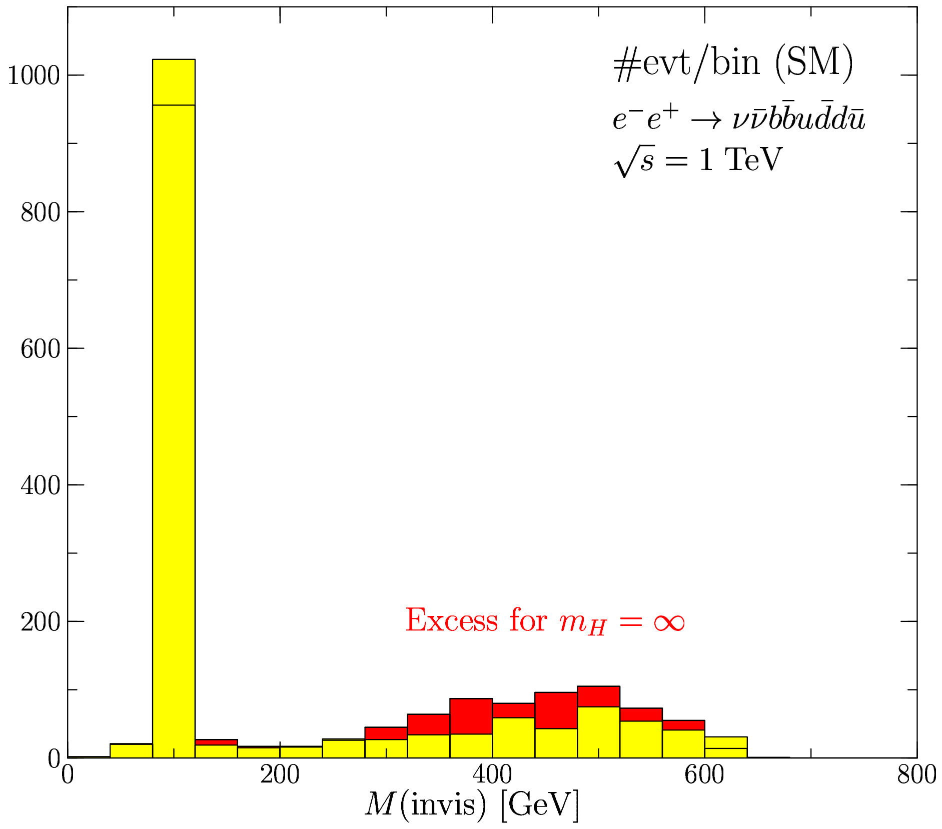
$$m_H = 115\ \text{GeV} \qquad \sigma_{\text{tot}} = 0.152(1)\ \text{fb}$$

$$m_H = \infty \qquad \sigma_{\text{tot}} = 0.169(1)\ \text{fb}$$

Signal and background

LC: Simulation of $10\ \mathrm{ab}^{-1}$ (unpolarized, final state $u\bar{d}d\bar{u}$ only)

$\approx 1\ \mathrm{ab}^{-1}$ (polarized, all final states)



Events with

$300\ \mathrm{GeV} < M(\mathrm{invis}) < 600\ \mathrm{GeV}$:

$$m_H = 115\ \mathrm{GeV} \qquad n_{\mathrm{evt}} = 353$$

$$m_H = \infty \qquad n_{\mathrm{evt}} = 585$$

- Complete tree-level calculations with final states of up to 6 fermions are under control
- 8 fermions are feasible (but CPU-consuming)
- Unweighted event samples can be generated for simulations
- This opens the road towards a detailed analysis of multi-particle electroweak processes at the LHC and a Linear Collider
- Complete tree-level calculations for multiparticle processes in the MSSM (and other extensions of the SM) will be available soon
- The next step: Automatic inclusion of radiative corrections . . .