# WHIZARD 2.0: A Universal Event Generator for LHC


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# Outline

# Universal Monte-Carlo Event Generators I

Pre-2000:

Hard processes ($2 \to n$) partons factorized into production and decay of $2 \to 2$ and $1 \to 2$ type, tree-level, hard-coded processes.

Focus on semi-hard and soft hadronic interactions

- Parton shower / radiation, beam properties, hadronization models, decays, multiple interactions, etc.

Well-known implementations: PYTHIA, HERWIG, ISAJET, ...

$\Rightarrow$ Multi-parton matrix elements: Madgraph, CompHEP, Grace, ...

# Universal Monte-Carlo Event Generators II

2000–2010

Hard processes ($2 \to n$) with complete tree-level matrix elements, beyond factorization in production and decay.

Focus on hard multi-parton interactions: ILC, LHC

- Automatic generation of matrix element code, SM and BSM models, interfacing to soft hadronic interactions

Programs: WHIZARD, MadEvent, Sherpa, HELAC/PHEGAS, AlpGen, . . .

$\Rightarrow$ NLO matrix elements: MC@NLO, Golem, BlackHat, . . .

# WHIZARD 1 (1999–)

Matrix element generator: CompHEP, Madgraph, O'Mega (complete tree-level matrix elements)

Phase-space parameterization: Constructed by determining dominant Feynman graphs

Phase-space integration: VAMP (multichannel, intrinsically adaptive)

Modelling beams: ILC: ISR, beamstrahlung, polarization L/T, energy spread. Tevatron/LHC: PDFlib

Unweighted event generation: Output in standard formats (e.g., LHA, StdHEP), to COMMON blocks or files

Automatic workflow: PERL and shell scripts, Makefiles

User interface: Input files for (1) process, parameters, beams, diagnostics, (2) user-defined cuts

Collaboration WK + Thorsten Ohl

# Algorithms

Important: different and independent implementations of matrix element (physics models) and phase-space integration and sampling.

O'Mega matrix element generator:
Symbolical generation of matrix elements free of common subexpressions
$\Rightarrow$ DAG algorithm.
Result: Fortran 95 code.

(numerical implementation: cf. Alpha / AlpGen)

WHIZARD/VAMP integration:
Channel selection, multi-channel intrinsically adaptive integration.

- Relative weights of phase-space parameterizations are automatically adapted to achieve minimum variance
- Each parameterization is binned in each integration dimension (VEGAS) and simultaneously adapted to minimum variance

# New in WHIZARD 2

Decays with exact color and spin correlations supplementing the complete matrix-element approach

LHC Physics: LHAPDF, inclusive parton summation, QCD scale

Simplified Workflow: Just run executable, no separate scripts/makefiles/compilation

Flexible User interface: Unified script language SINDARIN for input, control, cuts, analysis, . . . ; read/write HepMC, LHEF etc.

Rescan event files: apply decays, recalculate ME, reweight events

Maintenance and Extensibility: consistent Autotools installation, modular and object-oriented implementation in Fortran 2003, dynamic memory allocation, shared libraries

Collaboration WK (Siegen), Thorsten Ohl (Würzburg), Jürgen Reuter (Freiburg)

# A Simple Example

Input script file `ttbar_ee.sin`:

```
process ee_tt = e1, E1 => b, B, Wp, Wm
sqrts = 100 GeV
luminosity = 100 / 1 fbarn
sample_format = hepmc
simulate (ee_tt)
```

This will happen:

1. The complete tree-level matrix element for process `ee_tt` is generated by O'Mega, compiled, and linked into the running program.
2. The program generates a suitable phase-space setup
3. It performs adaptive integration, result: 562.6(9) fb
4. It generates 56267 events and writes them in LHEF format to file `ee_tt.lhef`. Time: 15 min, laptop.

# An LHC Example

Input script file `ttbar_lhc.sin`:

```
alias q = d:u:s:c
alias Q = D:U:S:C
parton = g:d:u:s:c:D:U:S:C

process ttbar = parton, parton => b, bbar, e1, N1, q, Q

ms = 0    mc = 0    me = 0
mtop = 175.3 GeV

beams = p, p => lhapdf { sqrts = 14 TeV }

include ("default_cuts.sin")
integrate (ttbar) { iterations = 10:20000, 3:100000 }

simulate (ttbar) { n_events = 1000
    $sample = "ttbar_events"    sample_format = lhef
}
```

# More Possibilities

- Cuts, analysis, QCD scale, user weight: expressions

```
all Pt > 10 [photon]
any mZ - 10 GeV < M < mZ + 10 GeV ["mu+", "mu-"]
eval cos (Theta) [extract index 2 [sort by -Pt [jet]]]
```

- Histograms, plots, observables

```
histogram pt_distribution (0, 100 GeV)
analysis = record pt_distribution (eval Pt [jet])
```

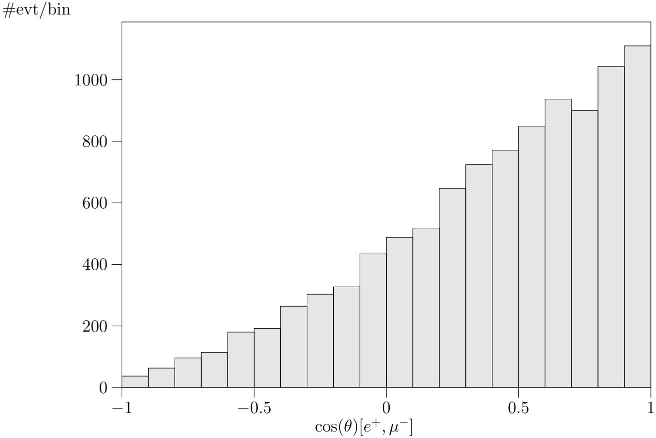
- Conditionals, loops, include files

```
if mH > 2 * mtop then ...endif
scan mH = (100 GeV, 200 GeV /+ 10 GeV) { integrate (foo) }
```

# Decays and Spin Correlations

Complete matrix elements have all quantum spin correlations built-in.
What about factorized matrix elements?

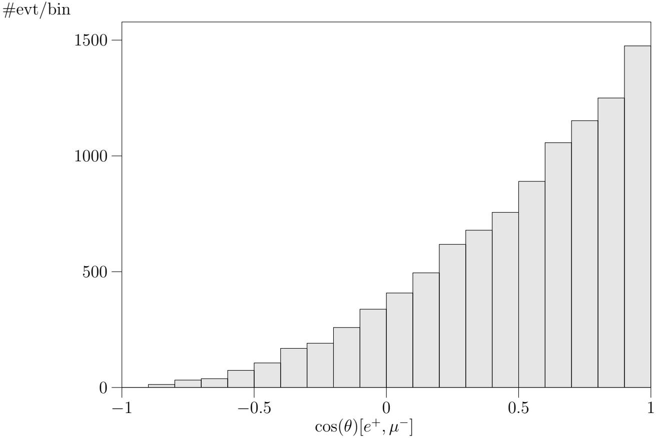
$H \to e^+\nu_e\mu^-\bar{\nu}_\mu$ near threshold: complete ME.



# Decays and Spin Correlations

Complete matrix elements have all quantum spin correlations built-in.
What about factorized matrix elements?

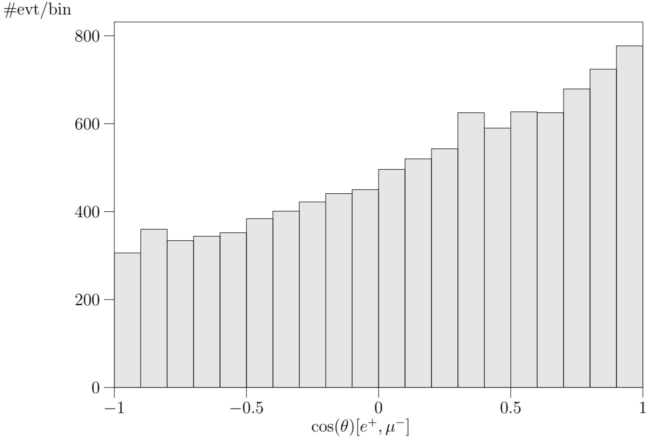
$H \to W^+W^- \to e^+\nu_e\mu^-\bar{\nu}_\mu$ near threshold: factorized.



# Decays and Spin Correlations

Complete matrix elements have all quantum spin correlations built-in.
What about factorized matrix elements?

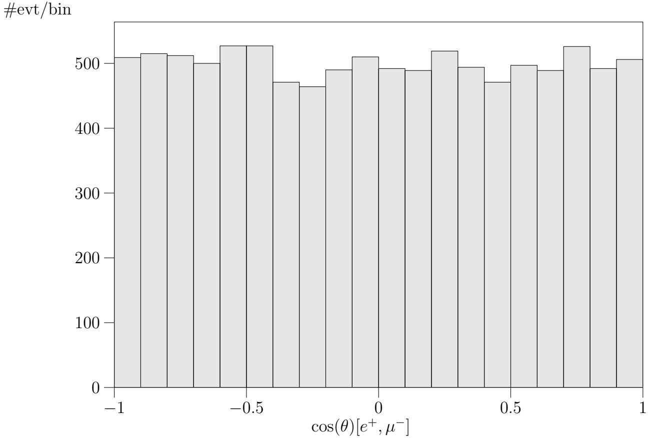
$H \to W^+W^- \to e^+\nu_e\mu^-\bar{\nu}_\mu$ near threshold: `?diagonal_decays = true`



# Decays and Spin Correlations

Complete matrix elements have all quantum spin correlations built-in.
What about factorized matrix elements?

$H \to W^+W^- \to e^+\nu_e\mu^-\bar{\nu}_\mu$ near threshold: `?isotropic_decays = true`



# Models in the WHIZARD distribution

- Standard Model, QCD and QED as subsets, SM with anomalous couplings and/or with CKM matrix
- SM without Higgs but strongly interacting $W$ bosons (anomalous couplings and resonances)
- SM with generic $Z'$ boson
- MSSM (complete, cross-checked with Madgraph and Sherpa)
- NMSSM and further extended SUSY models (PSSSM, ...)
- Various Little Higgs models
- Extra-dimension models (UED, large extra dimensions)
- Gravitinos

More models: FeynRules interface (C. Speckner)

# Plan: QCD

QCD shower in WHIZARD 2.0 is available via the external LHEF interface.

Under Construction (WHIZARD 2.1):

- Parton-shower matching. (Daniel Wiesler)
- Intrinsic module for (analytic) parton showers. (Sebastian Schmidt)
- Intrinsic module for multiple parton interactions, combined with parton shower. (Hans-Werner Boschmann)
- Automatic dipole subtraction $\Rightarrow$ interface for NLO amplitudes. (Jürgen Reuter, Sebastian Schmidt)

Furthermore

- ILC-specific features re-enabled: CIRCE, ISR, EPA etc.
- Generic Lorentz structures (Thorsten Ohl)

# Summary

Current version: WHIZARD 2.0.1

- Complete rewriting of WHIZARD, aimed at LHC physics
- Large range of SM and BSM physics
- Supports non-factorized (complete matrix elements) and factorized amplitudes and events
- Scripting/analysis language SINDARIN
- Extensible, intrinsic QCD (parton shower) coming soon
- Interfaced to the outside using standard formats

Reference: WK, T. Ohl, J. Reuter, arXiv:0708.4233 [to be updated for version 2.0]

http://whizard.event-generator.org

or via HEPFORGE: project WHIZARD.

# Appendix

# Reminder: Fortran

Fortran has evolved a lot recently, and learned from the gains and mistakes in other languages, especially C++.

Fortran 1 to 77: Numerical mathematics, structured programming

Fortran 90: Dynamical data allocation, pointers, efficient array handling, modules, derived types

Fortran 95: Minor improvements

TR 15581: Distinction between allocatables and pointers

Fortran 2003: C interoperability, allocatable scalars and strings, polymorphism, type inheritance ⇒ object orientation

Fortran 2008: OS interface, submodules, parallelization support (coarrays)

WHIZARD 2 adopts a subset of F2003 as supported by current compilers:

- gfortran 4.5, NAGFOR 5.2, Intel Fortran 11.1
- (in progress:) g95, Portland pgf95

# The Acronyms

(If you are curious:)

WHIZARD:

W, HIggs, Z, And Respective Decays

(summarizes the initial (1999) application of the program)

SINDARIN:

Scripting Integration, Data Analysis, Results display, and INterfaces

(the proper language for communicating with w(h)izards)