News from WHIZARD

PYTHIA8 Interface

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Outline

WHIZARD - General Purpose Event Generator

PYTHIA8 Interface

WHIZARD - General Purpose Event Generator

WHIZARD

- General purpose event generator for multi-particle states [W. Kilian 2001; Wolfgang Kilian, Ohl, and Reuter 2011]
    - Hadron and lepton collider → basis for many `CLIC` studies
- Under active development:
    - Current version: 2.6.4, `http://whizard.hepforge.org/`
    - Contact/help: whizard@desy.de
    - Team: Wolfgang Kilian, Thorsten Ohl, Jürgen Reuter
        - *SB*, Vincent Rothe, Christian Schwinn, Marco Sekulla, So Young Shim, Pascal Stienemeier, Zhijie Zhao + Master students
- Programming languages:
    - Fortran 2008 (gfortran ≥ `4.8.4`)
    - OCaml (≥ `3.12.0`)
- Standard installation:
    - `configure [FLAGS]`, `make`, `[make check]`, `make install`
- Large self test suite, unit tests [module tests], regression testing
    - Continous integration system (`gitlab CI` @Siegen)

WHIZARD technical overview

- Optimized tree matrix element generator `O'Mega` [Moretti, Ohl, and Reuter 2001]
    - NLO computations under construction
- Generator/simulation tool for *lepton collider* beam spectra `CIRCE1/2` [Ohl 1997]
- Interfaces to external packages for Feynman rules, hadronization, tau decays, event formats, analysis, jet clustering etc.:
    - `FastJet`, `GoSam`, `GuineaPig(++)`, `HepMC`, `HOPPET`, `LCIO`, `LHAPDF(5/6)`, `LoopTools`, `OpenLoops`, `PYTHIA6 [internal]`, `PYTHIA8 (upcoming)`, `Recola`, `StdHep [internal]`, `Tauola [internal]`
- Event formats: `LHE`, `StdHEP`, `HepMC`, `LCIO` + several `ASCII`
- Parallelization support with `OpenMP` and `MPI` for ME evaluation, integration and *event generation*

Steering WHIZARD

- Domain-specific scripting language: `SINDARIN`
- Process definition with different models SM, BSM, SUSY and different parametrizations
  - SM with anomalous top coupling
- Beam structure: polarization, asymmetric beams, crossing angle, structured beams
- Sophisticated expressions for cuts, sorting and selections
- Two-fold adaptive integration with `VAMP`, `VAMP2`
- Weighted or *unweighted* event simulation
- Event-by-event transformation:
  - ISR, EPA, Shower and Matching, *Hadronization*
- Insertion of (possible) resonance histories into an event
  - Allows for better resonance treatment in the parton shower, e.g. $\mathrm{e}^+\mathrm{e}^- \to jjjj$

Example: SINDARIN

```
! asymmetric beams
beams = e1, E1
beams_momentum = 100 GeV, 900 GeV

! beam polarization
! ...
beams_pol_density = @(-1), @(+1)
beams_pol_fraction = 80%, 30%

! CIRCE beam
beams = e1, E1 => circe1
$circe1_acc = “TESLA”
?circe1_generate = false
circe1_mapping_slope = 2

! beam chaining
beams = e1, E1 => circe2 => isr =>
 ↪  ewa
```

```
model = SM

$rng_method = "rng_stream"
$integration_method = "vamp2"
! Aliasing
alias q = u:d:s:c:b
alias qbar = U:D:S:C:B

process eeqq = e1, E1 => q, qbar
sqrts = 380 GeV
integrate(eeqq)

! Simulate events for the hard
 ↪  process
checkpoint = 1000
n_events = 10000
sample_format = lhef
$sample = "eeqq"
simulate(eeqq)
```

MPI-based Parallelization

- New integration method: `VAMP2`
  - adaptive multi-channel integrator (after `VAMP`)
  - fully MPI-parallelized version, using `RNGStream` [L'ecuyer et al. 2002] generator
- Distributes workers over multiple cores, grid adaption needs non-trivial communication
- `MPI` library: *OpenMPI* (≥ `2.0.0`), `MPICH` → ask your administrator

Configure

```
./configure FC=mpifort --enable-fc-mpi
```

Running WHIZARD with MPI

- Run management by **mpirun** → manpage
- Job control by **hostfile** or batch system, e.g. *SLURM*, **HTCondor**

```
mpirun --hostfile myhosts -np 20 --output-filename mpi.log \
       whizard process.sin
```

Sindarin

```
! Before integrate/simulate
$integration_method = "VAMP2"
$rng_method = "rng_stream"
```

Hostfile

```
cat myhosts
caesium slots=12 max_slots=8
xenon   slots=12 max_slots=4
neon    slots=5  max_slots=5
```

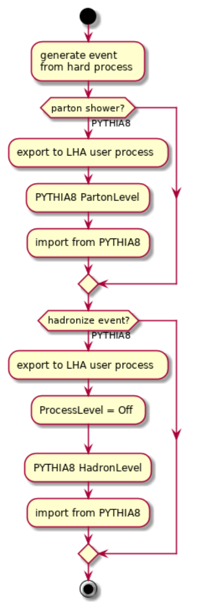
PYTHIA8 Interface

Partonic Events

- WHIZARD produces partonic events with *few* particles
- Hadronic events with *many* particles observed in the detector
  - Need for parton shower and hadronization
  - E.g.: PYTHIA6 in WHIZARD 1 (or HERWIG)
- → Implementation of a PYTHIA8 interface as *state-of-the-art*

Event transformation

- Retrieve event record
  - Generate weighted or unweighted event from hard process
  - Read from event file → HepMC, LHEF, LCIO, StdHEP,...
- Apply event transformation
  - ISR and EPA handler
  - Parton Shower → Matching (CKKW, MLM, POWHEG)
  - Hadronization
- Write event record to file



Parton shower and hadronization

- Parton shower and hadronization
  - Analytic shower [Wolfgang Kilian, Reuter, et al. 2012], PYTHIA6, PYTHIA8
- Matching and Merging (higher order QCD effects) with
  - MLM [Mangano, Moretti, Piccinini, et al. 2007; Mangano, Moretti, and Pittau 2002], CKKW (analytic shower *only*) and POWHEG (NLO)
- WHIZARD shipped with final PYTHIA6 release, version v6.427
  - Support due to backwards-compatibility to WHIZARD 1.97
  - Tightly integrated within WHIZARD
  - Export single event record to PYTHIA6 by HEP *common block*
  - Direct event handling → no event file detour
- PYTHIA8 [Torbjorn Sjöstrand, Mrenna, and Skands 2008; Torbjörn Sjöstrand et al. 2015] successor of PYTHIA6, complete rewrite in C++
  - Improved and expanded physic models
  - Own detailed τ-decay handling [Ilten 2014; Ilten 2013] → indepdendent of TAUOLA

PYTHIA8 Interface

- Event-by-event communication between `WHIZARD` and `PYTHIA8`
- Access matching and merging machinery of `PYTHIA8` → *under discussion*
- Separate parton shower and hadronization → access internal matching and merging machinery
    - Deactivate hadronization for parton shower `HadronLevel:all = off`
    - Deactivate hard process for hadronization
        - `ProcessLevel = off` skips also `PartonLevel` → no beam information available
- *complete* `PYTHIA8` configuration by
    - `$ps_PYTHIA8_config`, string separated by `;` or a newline
    - `$ps_PYTHIA8_config_file`
- `SINDARIN` switch only for ISR, FSR and hadronization
- `SINDARIN` flags > `$ps_PYTHIA8_config` > `$ps_PYTHIA8_config_file`

Example: PYTHIA8

```
$ps_PYTHIA_config = "
  option1; option2;
  option3; option4
"
$ps_PYTHIA8_config = "[option1];
↪  [option2]"
$ps_PYTHIA8_config_file =
↪  "p8-eeqq.cfg"
```

```
$shower_method = "PYTHIA8"
$hadronization_method = "PYTHIA8"
! Shower: HadronLevel:all = off
! PartonLevel:FSR = on
?ps_fsr_active = true
! PartonLevel:ISR = on
?ps_isr_active = true
! ProcessLevel:all = off
?hadronization_active = on
```

- Allowed to mix WHIZARD shower with PYTHIA6 *or* PYTHIA8 hadronization
- Disabled mixing of PYTHIA6 and PYTHIA8 shower/hadronization → issue a fatal error to the user

Implementation status

- PYTHIA8 supports external user processes by the Les Houches Accord [Boos et al. 2001]
    - Implement the base class LHAup for WHIZARD → C++ to Fortran binding ✓
- Export random number generator to PYTHIA8
    - Currently only settings seed of PYTHIA8's own RNG ✓
    - *Better*: Access WHIZARD's RNG
    - Implement the base class RndmEngine
    - Stochastic independence → parallelization runs with RNGstream
- Implementation of a Fortran interface to PYTHIA8 ✓
- Workflow → no need for *inbetween* event file
    - Export event to LHA user process
    - Shower/Hadronization in PYTHIA8 with $ps_PYTHIA8_config/_file
    - Import event back to WHIZARD
- Matching
    - MLM → *currently* under work
- Validation with several process:
    - $\mathrm{e}^+\mathrm{e}^- \to q\bar{q}$, $\mathrm{e}^+\mathrm{e}^- \to \mathrm{t}\bar{\mathrm{t}}$, Drell-Yan, ...

Validation (PRELIMINARY)

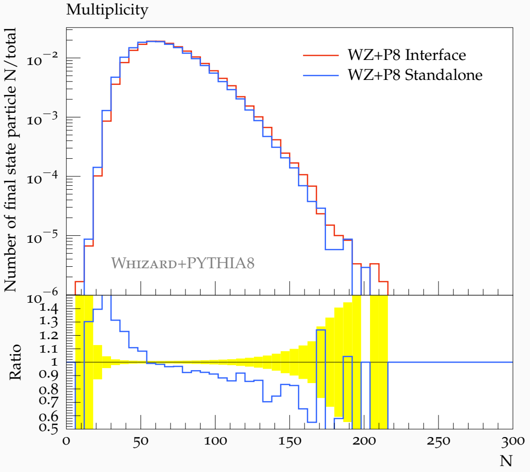


Figure 1: Multiplicity for showered and hadronized $e^+e^- \to q\bar{q}$.

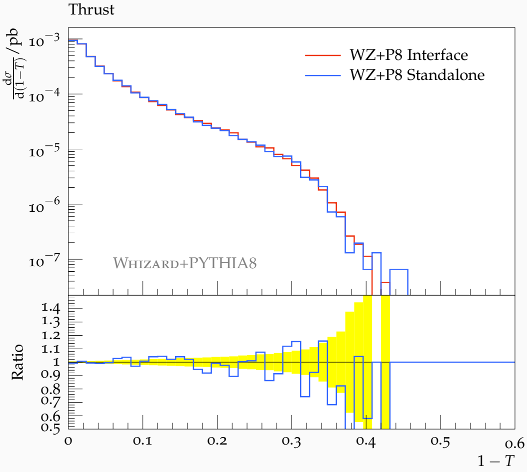


Figure 2: Thrust distribution for showered and hadronized $e^+e^- \to q\bar{q}$.

Deviation in multiplicity distribution → setup of `WZ+P8` Interface and Standalone

Conclusion

PYTHIA8

- Finalization of LHAup and PYTHIA8 interfaces
- Separated shower and hadronization → matching in WHIZARD
- Steerable by PYTHIA configuration variable or file
- PYTHIA8 implementation ready for lepton collider studies
    - Open for validation with experimental data

Parallelization suppport

- Parallel integration and event generation with VAMP2 and RNGStream
    - Calculation time goes down from weeks to hours!
    - Already used in [Ballestrero et al. 2018] and [Brass et al. 2018]
- VAMP2 and MPI are ready for producation runs!

Outlook

- *Complete* PYTHIA8+WHIZARD validation and first production runs.
    - We need input from experimental side!

The End

Thank you for your attention!

Implemented models

MODEL TYPE	with CKM matrix	trivial CKM
Yukawa test model	---	Test
QED with e, μ, τ, γ	---	QED
QCD with d, u, s, c, b, t, g	---	QCD
Standard Model	SM_CKM	SM
SM with anomalous gauge couplings	SM_ac_CKM	SM_ac
SM with Hgg, $H\gamma\gamma$, $H\mu\mu$, He^+e^-	SM_Higgs_CKM	SM_Higgs
SM with bosonic dim-6 operators	---	SM_dim6
SM with charge 4/3 top	---	SM_top
SM with anomalous top couplings	---	SM_top_anom
SM with anomalous Higgs couplings	---	SM_rx/NoH_rx/SM_ul
SM extensions for VV scattering	---	SSC/AltH/SSC_2/SSC_AltT
SM with Z'	---	Zprime
Two-Higgs Doublet Model	THDM_CKM	THDM
MSSM	MSSM_CKM	MSSM
MSSM with gravitinos	---	MSSM_Grav
NMSSM	NMSSM_CKM	NMSSM
extended SUSY models	---	PSSSM
Littlest Higgs	---	Littlest
Littlest Higgs with ungauged $U(1)$	---	Littlest_Eta
Littlest Higgs with T parity	---	Littlest_Tpar
Simplest Little Higgs (anomaly-free)	---	Simplest
Simplest Little Higgs (universal)	---	Simplest_univ
SM with graviton	---	Xdim
UED	---	UED
"SQED" with gravitino	---	GravTest
Augmentable SM template	---	Template

Table 1: List of models available in . There are pure test models or models implemented for theoretical investigations, a long list of SM variants as well as a large number of BSM models.

WHIZARD NLO automatation (ALPHA STATUS)

- NLO automatation with interfaces to *external* (virtual) ME provider:
  - RECOLA [Actis et al. 2013; Denner, Lang, and Uccirati 2018]
  - GOSAM [Soden-Fraunhofen 2015]
  - OpenLoops [Cascioli, Maierhofer, and Pozzorini 2012]
- FKS subtraction [Frixione, Kunszt, and Signer 1996]
  - Real and virtual subtraction terms internal
- Resonance-aware treatment [Ježo and Nason 2015]
  - enables consistent matching of fixed-order NLO with parton shower for processes with *intermediate* resonances (e.g. H)
- NLO decays available for the NLO processes
- Fixed order events for plotting (weighted)
- Automated POWHEG damping and matching
- Still under validation

Speedup of MPI

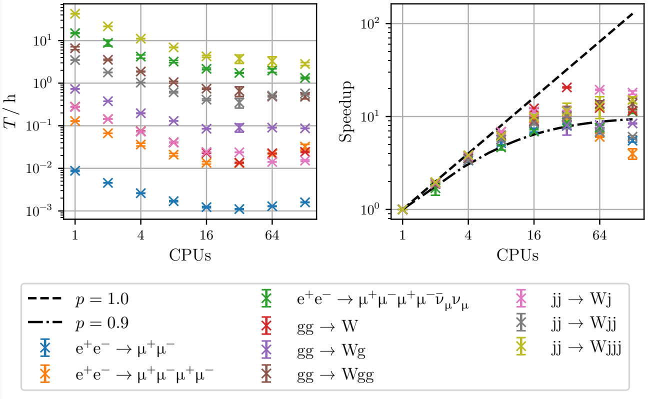


Figure 3: Benchmark for different complex processes. For reference Ahmdal's law is shown.

Discussion

- Speedup of $\mathcal{O}(10)$
  - not optimized for cluster topology
- Saturation after $N = 32$
- Parallel portion 90 %
- Ahmdal's law for N worker and parallel portion p

$$S(p; N) = \frac{T(p;N)}{T(0;1)} = \frac{1}{(1-p)+p/N}$$

Flavour Benchmark

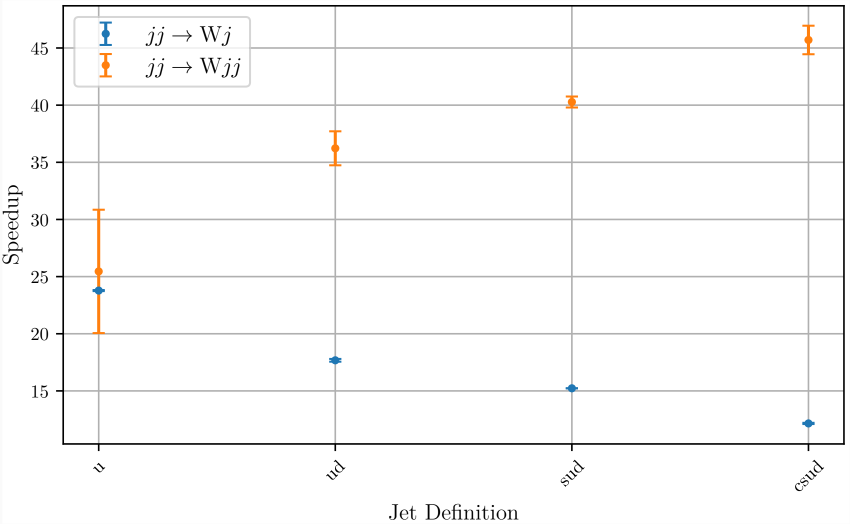


Figure 4: Benchmark for increasing jet flavours → increasing ME evaluation time. **Optimized** on cluster topology with 60 workers → $45\times$ **faster**.

List of Publications

General WHIZARD reference EPJ C71 (2011) 1742, arXiv:0708.4241

O'Mega (ME generator) LC-TOOL (2001) 040; arXiv:hep-ph/0102195

VAMP (MC integrator) CPC 120 (1999) 13; arXiv:hep-ph/9806432

CIRCE (beamstrahlung) CPC 101 (1997) 269; arXiv:hep-ph/9607454

Parton shower JHEP 1204 (2012) 013; arXiv:1112.1039

Color flow formalism JHEP 1210 (2012) 022; arXiv:1206.3700

NLO capabilities JHEP 1612 (2016) 075; arXiv: 1609.03390

Parallelization of MEs CPC 196 (2015) 58; arXiv:1411.3834

POWHEG matching EPS-HEP (2015) 317; arXiv: 1510.02739

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