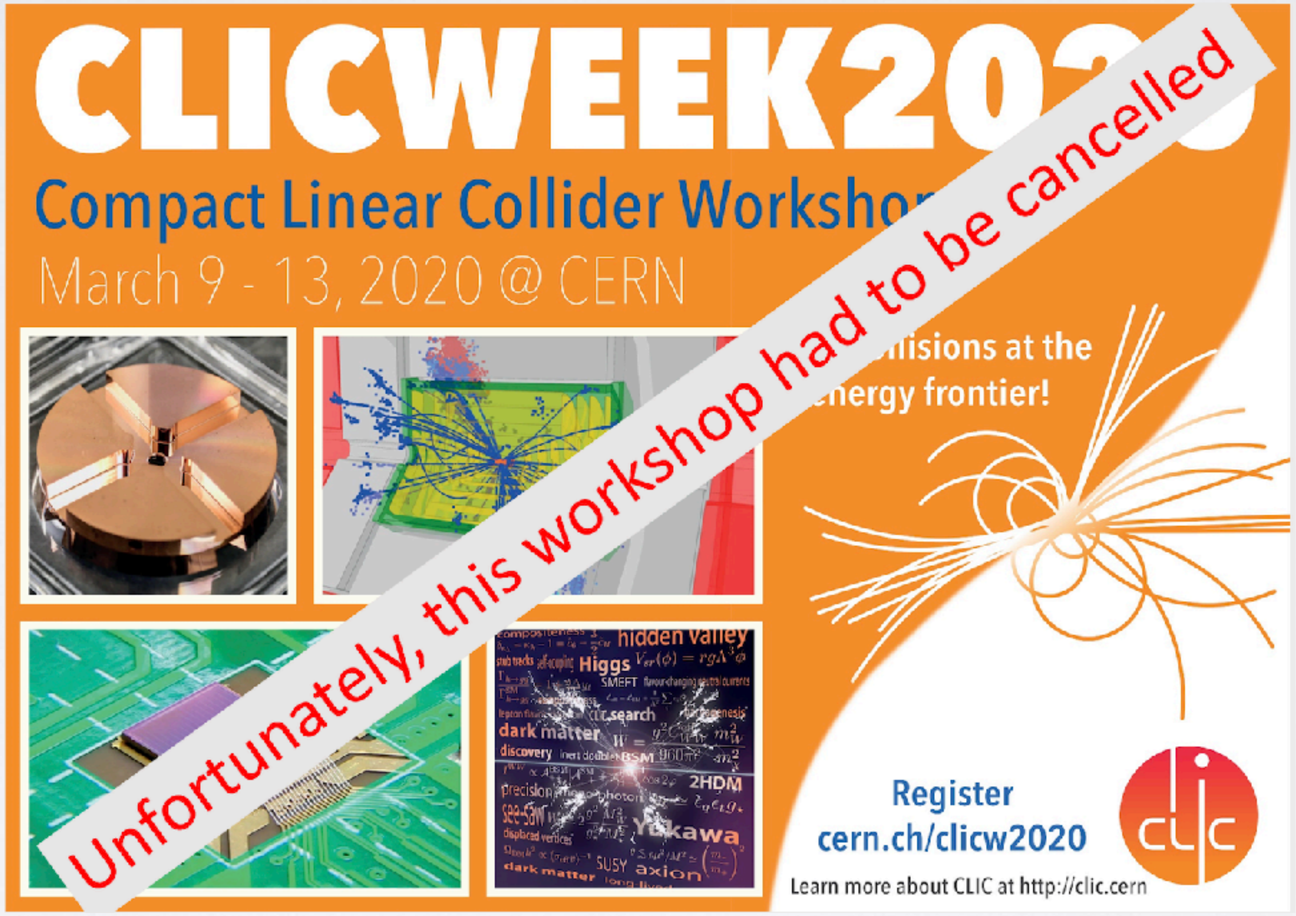
Status of WHIZARD 3.0.0α



Jürgen R. Reuter

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

CLUSTER OF EXCELLENCE
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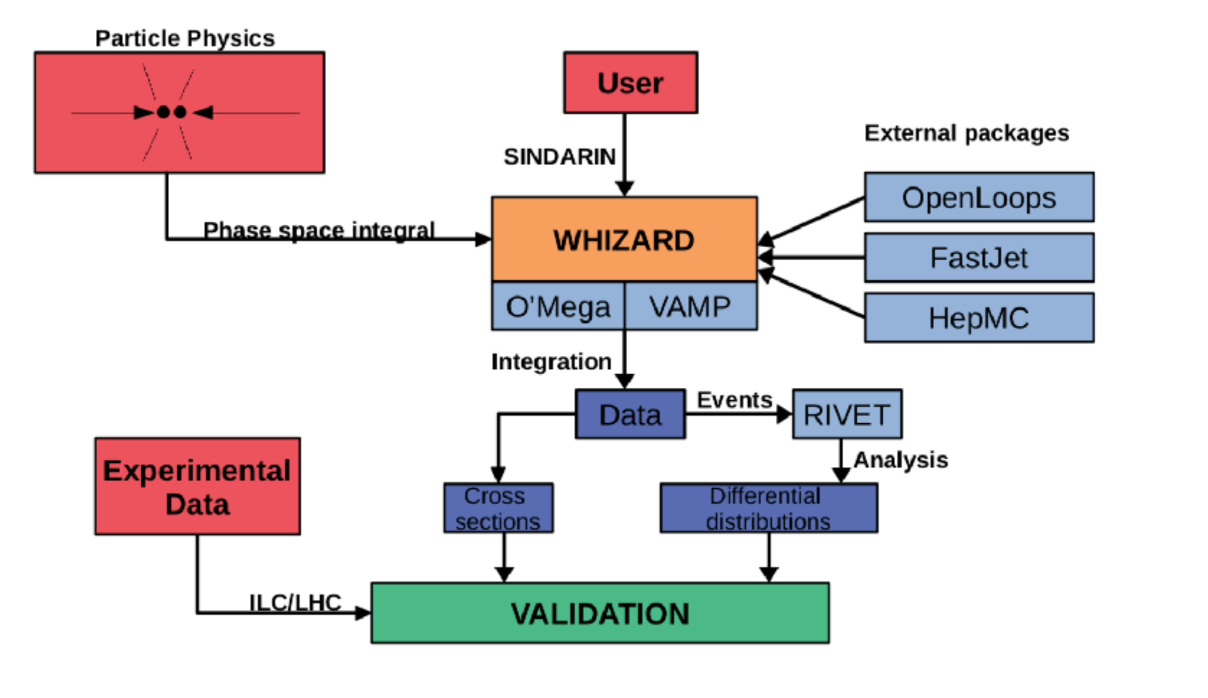
HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

DESY.

WHIZARD: Introduction / Technical Facts

WHIZARD v2.8.3 (xx.03.2020) http://whizard.hepforge.org <whizard@desy.de>

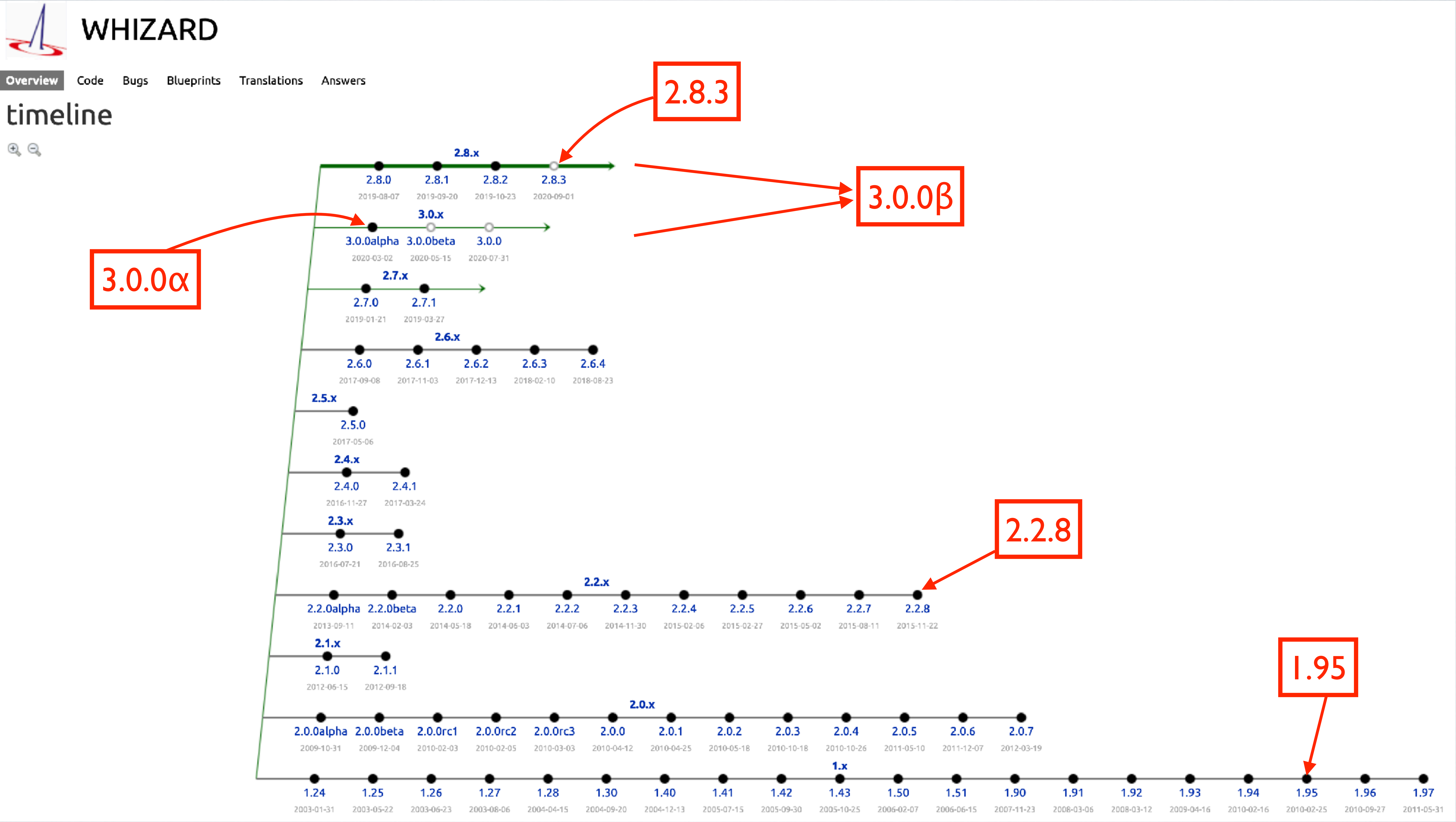
WHIZARD Team: *Wolfgang Kilian, Thorsten Ohl, JRR*
Simon Braß / Pia Bredt / Nils Kreher / Vincent Rothe / Pascal Stienemeier + *master students*



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

- Universal event generator for lepton and hadron colliders (SM and BSM physics)
- Tree ME generator O'Mega optimized ME generator Ω
- Generator/simulation tool for lepton collider beam spectra: CIRCE1/2
- Scattering processes ($2\rightarrow 10$ etc.) and [auto-] decays, factorized processes

WHIZARD: Timeline



WHIZARD: User support / bug tracker

WHIZARD v3.0.0α (03.03.2020) https://launchpad.net/whizard

☑ User questions & bug reports channeled through Launchpad site

Juergen Reuter (j.r.reuter) • Log Out

WHIZARD

Overview Code Bugs Blueprints Translations Answers

https://launchpad.net/whizard

Registered 2019-06-26 by Juergen Reuter

WHIZARD Event Generator

WHIZARD is a program system designed for the efficient calculation of multi-particle scattering cross sections and simulated event samples.

Tree-level matrix elements are generated automatically for arbitrary partonic processes by using the Optimized Matrix Element Generator O'Mega. Matrix elements obtained by alternative methods (e.g., including loop corrections) may be interfaced as well. The program is able to calculate numerically stable signal and background cross sections and generate unweighted event samples with reasonable efficiency for processes with up to eight final-state particles; more particles are possible. For more particles, there is the option to generate processes as decay cascades including complete spin correlations. Different options for QCD parton showers are available.

Polarization is treated exactly for both the initial and final states. Final-state quark or lepton flavors can be summed over automatically where needed. For hadron collider physics, an interface to the standard LHAPDF is provided. For Linear Collider physics, beamstrahlung (CIRCE) and ISR spectra are included for electrons and photons. The events can be written to file in standard formats, including ASCII, StdHEP, the Les Houches event format (LHEF), HepMC, or LCIO. These event files can then be hadronized.

WHIZARD supports the Standard Model and a huge number of BSM models. Model extensions or completely different models can be added. There are also interfaces to FeynRules and SARAH.

The code of released WHIZARD versions is hosted in a publically accessible GitLab:
https://gitlab.tp.nt.uni-siegen.de/whizard/public

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- Ask a question
- Register a blueprint
- Help translate

Configuration Progress

Configuration options
- Code ✗
- Bugs ✓
- Translations ✓
- Answers ✓

Downloads

Latest version is 2.8.2

whizard-2.8.2.tar.gz

released on 2019-10-24

All downloads

Project information

Maintainer: WHIZARDs

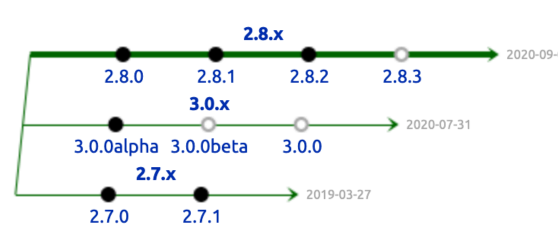
Driver: WHIZARDs

Licence: GNU GPL v3

RDF metadata

Series and milestones

View full history



Announcements

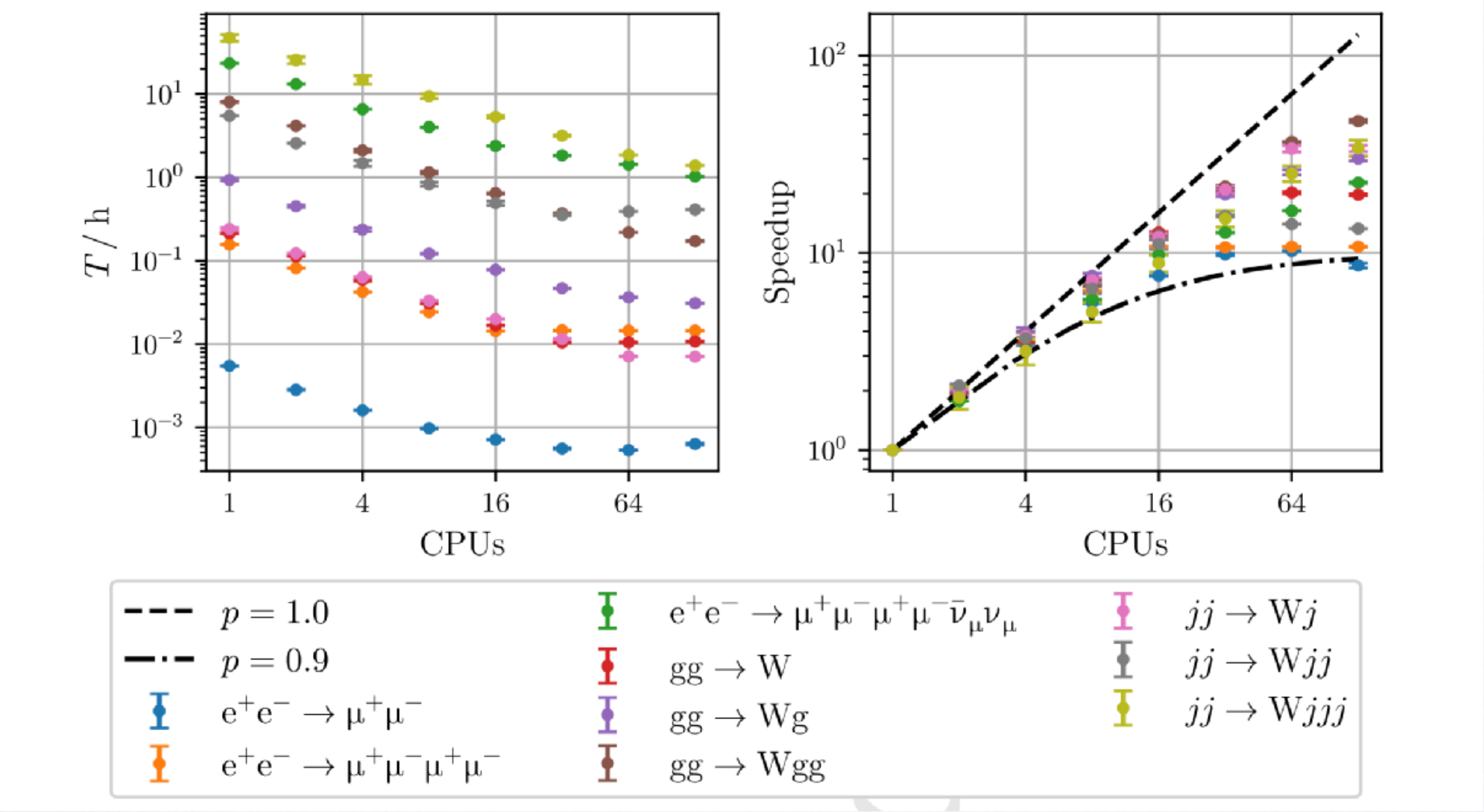
WHIZARD 3.0.0alpha 20 hours ago
First officially endorsed version that supports NLO QCD.

WHIZARD 2.8.2 on 2019-10-24

MPI-parallelization of phase space integration

Braß/Kilian/JRR, 1811.09711 [EPJC]

- Event generation trivially parallelizable
- Major bottleneck: adaptive phase space integration (generation of grids)
- Parallelization of integration: OMP multi-threading for different helicities since long
- NEW (after v2.5.0/2.6.4/2.7.1): MPI parallelization (using OpenMPI or MPICH)
- Distributes workers over multiple cores, grid adaption needs non-trivial communication
- Amdahl's law: $s = \frac{1}{1-p+\frac{p}{N}}$
- Speedups of 10 to 30, saturation at O(100) tasks
- Integration times go down from weeks to hours! [can do also parallel event generation]
- Load balancer is being implemented [expected for v2.8.3/v3.0.0β]



Event Formats

Event formats: conventions for outputting details of the events

```
sample_format = hepmc
sample_format = lhef  {$lhef_version = “3.0”}
sample_format = stdhep, stdhep_up, stdhep_ev4
sample_format = ascii,debug,mokka,lha
sample_format = lcio
simulate (<process>)
```

- External format, ASCII: HepMC [Dobbs/Hansen, 2001]
- External format, binary: LCIO [Gaede, 2003]
- Internal formats, binary: StdHEP [Lebrun, 1990]
- Internal formats, ASCII: LHA, LHEF [Alwall et al. , 2006]

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- Internal formats, binary: StdHEP [Lebrun, 1990]
- Internal formats, ASCII: LHA, LHEF [Alwall et al., 2006]

LCIO Format: (ASCII transcription from binary)

```
============================================================================
        Event  : 1 - run:  0 -  timestamp [...]
============================================================================
 date: [...]
 detector : unknown
 event parameters:
 parameter Event Number [int]: 1,
 parameter ProcessID [int]: 1,
 parameter Run ID [int]: 0,
 parameter beamPDG0 [int]: 11,
 parameter beamPDG1 [int]: -11,
 parameter Energy [float]: 500,
 parameter Pol0 [float]: 0,
 parameter Pol1 [float]: 0,
 parameter _weight [float]: 1,
 parameter alphaQCD [float]: 0.1178,
 parameter crossSection [float]: 338.482,
 parameter crossSectionError [float]: 7.2328,
 parameter scale [float]: 500,
 parameter BeamSpectrum [string]: ,
 parameter processName [string]: lcio_5_p,
 collection name : MCParticle
 parameters:
--------------- print out of MCParticle collection ---------------
  flag:  0x0
  simulator status bits: [sbvtcls]  s: created in simulation b: backscatter v: vertex is not endpoint of parent t: decayed in tracker c: decayed in
calorimeter l: has left detector s: stopped o: overlay
[   id   ]index| PDG |    px,     py,        pz    | energy  |gen|[simstat]| vertex x,y,z |    mass |  charge |      spin      | colorflow | [par] - [dau]
[00000004]    0|   11| 0.00e+00, 0.00e+00, 2.50e+02| 2.50e+02| 3 |[    0   ]| 0.0, 0.0, 0.0| 5.11e-04|-1.00e+00| 0.0, 0.0, 0.0|  (0, 0)   | [] - [2,3]
[00000005]    1|  -11| 0.00e+00, 0.00e+00,-2.50e+02| 2.50e+02| 3 |[    0   ]| 0.0, 0.0, 0.0| 5.11e-04| 1.00e+00| 0.0, 0.0, 0.0|  (0, 0)   | [] - [2,3]
[00000006]    2|   13| 1.42e+02, 1.99e+02,-5.22e+01| 2.50e+02| 1 |[    0   ]| 0.0, 0.0, 0.0| 1.06e-01|-1.00e+00| 0.0, 0.0, 1.0|  (0, 0)   | [0,1] - []
[00000007]    3|  -13|-1.42e+02,-1.99e+02, 5.22e+01| 2.50e+02| 1 |[    0   ]| 0.0, 0.0, 0.0| 1.06e-01| 1.00e+00| 0.0, 0.0,-1.0|  (0, 0)   | [0,1] - []
```

Event header information as agreed upon with LC Gen Group

Event Formats

Event formats: conventions for outputting details of the events

```
sample_format = hepmc
sample_format = lhef  {$lhef_version = "3.0"}
sample_format = stdhep, stdhep_up, stdhep_ev4
sample_format = ascii,debug,mokka,lha
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simulate (<process>)
```

- External format, ASCII: HepMC [Dobbs/Hansen, 2001]
- External format, binary: LCIO [Gaede, 2003]
- Internal formats, binary: StdHEP [Lebrun, 1990]
- Internal formats, ASCII: LHA, LHEF [Alwall et al. , 2006]

HepMC3 Format: modern implementation

```
HepMC::Version 3.01.01
HepMC::Asciiv3-START_EVENT_LISTING
E 1 3 8
U GEV MM
A 0 alphaQCD 0.116258482977402
A 0 alphaQED -1
A 0 event_scale 100
A 3 flow1 1
A 4 flow1 3
A 5 flow1 2
A 6 flow1 1
A 7 flow1 3
A 3 flow2 2
A 4 flow2 1
A 5 flow2 1
A 6 flow2 3
A 8 flow2 2
A 0 signal_process_id 1
P 1 0 2212 0.0000000000000000e+00 0.000000000
P 2 0 2212 0.0000000000000000e+00 0.000000000
P 3 1 21 0.0000000000000000e+00 0.00000000000
P 4 2 21 0.0000000000000000e+00 0.00000000000
P 5 1 93 0.0000000000000000e+00 0.00000000000
P 6 2 93 0.0000000000000000e+00 0.00000000000
V -3 0 [3,4]
P 7 -3 2 -5.0143659198302345e+01 -6.869560414
P 8 -3 -2 5.0143659198302345e+01 6.8695604145
HepMC::Asciiv3-END_EVENT_LISTING
```

```
HepMC::Version 2.06.09
HepMC::IO_GenEvent-START_EVENT_LISTING
E 1 -1 1.0000000000000000e+02 1.1625848297740160e-01 -1.0000000
U GEV MM
V -1 0 0 0 0 0 1 2 0
P 10001 2212 0 0 4.0000000000000000e+03 4.0000000000000000e+03
P 10003 21 0 0 1.1139107692024313e+01 1.1139107692024313e+01 0
P 10005 93 0 0 3.9888608923079760e+03 3.9888608923079760e+03 0
V -2 0 0 0 0 0 1 2 0
P 10002 2212 0 0 -4.0000000000000000e+03 4.0000000000000000e+03
P 10004 21 0 0 -3.2685024745934277e+02 3.2685024745934277e+02 0
P 10006 93 0 0 -3.6731497525406571e+03 3.6731497525406571e+03 0
V -3 0 0 0 0 0 0 2 0
P 10007 2 -5.0143659198302345e+01 -6.8695604145339697e+00 -2.49
P 10008 -2 5.0143659198302345e+01 6.8695604145339697e+00 -6.584
HepMC::IO_GenEvent-END_EVENT_LISTING
```

NEW in WHIZARD v2.8.1

Rescanning of Event Files

- Scanning parameter space of BSM models (or SM templates)
- Major bottleneck: MC samples have to be produced over and over again
- Feature: rescanning of event files with different setup
- Assumption: phase space is identical, sampling can be done in the same way
- works also w/ differently concatenated structure functions (e.g. ISR + beamstr.)
- Open issues: rescanning with resonance matching in showered events

```
process reweight_8_p1 = e1, E1 => e2, E2

sqrts = 1000
n_events = 10000

?unweighted = false
sample_format = weight_stream

simulate (reweight_8_p1) {
  $sample = "reweight_8a"
  iterations = 1:1000
}

?update_sqme = true
rescan "reweight_8a" (reweight_8_p1) {
  $sample = "reweight_8c"
  ee = 3 * ee     ! should update sqme
}
?update_weight = true
rescan "reweight_8a" (reweight_8_p1) {
  $sample = "reweight_8d"
  ee = 3 * ee     ! should update sqme and event
weight
```

WHIZARD v2.8.2

- Rescan now also works with LCIO
- Alternative weights/ cross sections can be written to LCIO

Rescanning of Event Files

```
---------------------------------------------------------------------------
       Event  : 1 - run:  0 - timestamp 1569613753000000000 - weight 1
===========================================================================
 date:      27.09.2019  19:49:13.000000000
 detector : unknown
 event parameters:
 parameter Event Number [int]: 1,
 parameter ProcessID [int]: 1,
 parameter Run ID [int]: 0,
 parameter beamPDG0 [int]: 2212,
 parameter beamPDG1 [int]: 2212,
 parameter Energy [float]: 8000,
 parameter Pol0 [float]: 0,
 parameter Pol1 [float]: 0,
 parameter _weight [float]: 1,
 parameter alphaQCD [float]: 0.1178,
 parameter alternateSqme1 [float]: 135.189,
 parameter alternateSqme10 [float]: 3.54389e+07,
 parameter alternateSqme2 [float]: 540.754,
 parameter alternateSqme3 [float]: 2163.02,
 parameter alternateSqme4 [float]: 8652.07,
 parameter alternateSqme5 [float]: 34608.3,
 parameter alternateSqme6 [float]: 138433,
 parameter alternateSqme7 [float]: 553732,
 parameter alternateSqme8 [float]: 2.21493e+06,
 parameter alternateSqme9 [float]: 8.85972e+06,
 parameter alternateWeight1 [float]: 1.12598,
 parameter alternateWeight10 [float]: 295168,
 parameter alternateWeight2 [float]: 4.50391,
 parameter alternateWeight3 [float]: 18.0156,
 parameter alternateWeight4 [float]: 72.0625,
 parameter alternateWeight5 [float]: 288.25,
 parameter alternateWeight6 [float]: 1153,
 parameter alternateWeight7 [float]: 4612,
 parameter alternateWeight8 [float]: 18448,
 parameter alternateWeight9 [float]: 73792,
 parameter crossSection [float]: 97927.9,
 parameter crossSectionError [float]: 20802.6,
 parameter scale [float]: 488.791,
 parameter BeamSpectrum [string]: ,
 parameter processName [string]: lcio_10_p,

 collection name : MCParticle
 parameters:

--------------- print out of MCParticle collection ---------------

  flag:  0x0
  simulator status bits: [sbvtcls]  s: created in simulation b: backscatter v: vertex is not endpoint of parent t: decayed in tracker c: decayed in calorimeter l: has left de


[   id   ]index|      PDG |    px,     py,        pz    | px_ep,   py_ep , pz_ep      | energy  |gen|[simstat ]| vertex x,     y   ,   z     | endpoint x,    y  ,   z    |

[00000004]    0|      2212| 0.00e+00, 0.00e+00, 4.00e+03| 0.00e+00, 0.00e+00, 0.00e+00| 4.00e+03| 4 |[    0    ]| 0.00e+00, 0.00e+00, 0.00e+00| 0.00e+00, 0.00e+00, 0.00e+00| 0
[00000005]    1|      2212| 0.00e+00, 0.00e+00,-4.00e+03| 0.00e+00, 0.00e+00, 0.00e+00| 4.00e+03| 4 |[    0    ]| 0.00e+00, 0.00e+00, 0.00e+00| 0.00e+00, 0.00e+00, 0.00e+00| 0
[00000006]    2|        21| 0.00e+00, 0.00e+00, 7.22e+01| 0.00e+00, 0.00e+00, 0.00e+00| 7.22e+01| 3 |[    0    ]| 0.00e+00, 0.00e+00, 0.00e+00| 0.00e+00, 0.00e+00, 0.00e+00| 0
[00000007]    3|        21| 0.00e+00, 0.00e+00,-8.27e+02| 0.00e+00, 0.00e+00, 0.00e+00| 8.27e+02| 3 |[    0    ]| 0.00e+00, 0.00e+00, 0.00e+00| 0.00e+00, 0.00e+00, 0.00e+00| 0
[00000008]    4|        93| 0.00e+00, 0.00e+00, 3.93e+03| 0.00e+00, 0.00e+00, 0.00e+00| 3.93e+03| 1 |[    0    ]| 0.00e+00, 0.00e+00, 0.00e+00| 0.00e+00, 0.00e+00, 0.00e+00| 0
[00000009]    5|        93| 0.00e+00, 0.00e+00,-3.17e+03| 0.00e+00, 0.00e+00, 0.00e+00| 3.17e+03| 1 |[    0    ]| 0.00e+00, 0.00e+00, 0.00e+00| 0.00e+00, 0.00e+00, 0.00e+00| 0
[00000010]    6|         6| 1.60e+02,-2.33e+01,-4.88e+02| 0.00e+00, 0.00e+00, 0.00e+00| 5.42e+02| 1 |[    0    ]| 0.00e+00, 0.00e+00, 0.00e+00| 0.00e+00, 0.00e+00, 0.00e+00| 1
[00000011]    7|        -6|-1.60e+02, 2.33e+01,-2.67e+02| 0.00e+00, 0.00e+00, 0.00e+00| 3.57e+02| 1 |[    0    ]| 0.00e+00, 0.00e+00, 0.00e+00| 0.00e+00, 0.00e+00, 0.00e+00| 1
```

Alternative weights / cross sections entries in the LCIO event header

BSM Models in WHIZARD

Hard-coded 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
Higgs Singlet Extension	---	HSExt
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

(external) UFO models:

- ☑ WHIZARD 2.8.3: Full UFO support
- ☑ New version demands OCaml ≥4.02.3
- ☑ LO externals UFO models
- ☑ Spin 0, 1/2, 1, 3/2, 2, 3, 4, 5 supported
- ☑ Arbitrary Lorentz structures supported
- ☑ 5-, 6-point vertices (and even higher)
- ☑ UFO customized propagators
- ☑ Majorana statistics, incl. 4-fermion (2.8.3)
- ☑ BSM SLHA input (2.8.2)
- ☑ Crazy color structures (as internal particles)

Old FeynRules / SARAH interface **is deprecated**

kept at the moment for user backwards compatibility

Models from UFO Files in WHIZARD


```
model = SM  (ufo)
```

UFO file is assumed to be in working directory OR

```
model = SM  (ufo ("<my UFO path>"))
```

UFO file is in user-specified directory

```
|                              WHIZARD 2.5.1
|=============================================================================|
| Reading model file '/Users/reuter/local/share/whizard/models/SM.mdl'
| Preloaded model: SM
| Process library 'default_lib': initialized
| Preloaded library: default_lib
| Reading model file '/Users/reuter/local/share/whizard/models/SM_hadrons.mdl'
| Reading commands from file 'ufo_2.sin'
| Model: Generating model 'SM' from UFO sources
| Model: Searching for UFO sources in working directory
| Model: Found UFO sources for model 'SM'
| Model: Model file 'SM.ufo.mdl' generated
| Reading model file 'SM.ufo.mdl'
```

```
| Switching to model 'SM' (generated from UFO source)
```

All the setup works the same as for intrinsic models

Models from UFO Files in WHIZARD


```
model = SM  (ufo)
```

UFO file is assumed to be in working directory OR

```
model = SM  (ufo ("<my UFO path>"))
```

UFO file is in user-specified directory

```
pure function VVVV4_p0123 (g, a2, k2, a3, k3, a4, k4) result (a1)
  type(vector) :: a1
  complex(kind=default), intent(in) :: g
  type(vector), intent(in) :: a2
  type(vector), intent(in) :: a3
  type(vector), intent(in) :: a4
  type(momentum), intent(in) :: k2, k3, k4
  ! ------------------------------------------------------------------
  ! 1 *  * Metric(2,4) * Metric(1,3) + -1 *  * Metric(3,4) * Metric(1,2)
  ! ------------------------------------------------------------------
  complex(kind=default), dimension(0:3) :: a1a
  complex(kind=default), dimension(0:3) :: a2a
  complex(kind=default), dimension(0:3) :: a3a
  complex(kind=default), dimension(0:3) :: a4a
  real(kind=default), dimension(0:3) :: p1, p2, p3, p4
  integer :: nu1
  integer :: nu2
  integer :: nu3
  integer :: nu4
  ! ------------------------------------------------------------------
  a2a(0) = a2%t
  a2a(1:3) = a2%x
  a3a(0) = a3%t
  a3a(1:3) = a3%x
  a4a(0) = a4%t
  a4a(1:3) = a4%x
  p2(0) = k2%t
  p2(1:3) = k2%x
  p3(0) = k3%t
  p3(1:3) = k3%x
  p4(0) = k4%t
  p4(1:3) = k4%x
  p1 = - p2 - p3 - p4
```

```
pure function FFS4_p012 (g, psibar2, k2, phi3, k3) result (psi1)
  type(conjspinor) :: psi1
  complex(kind=default), intent(in) :: g
  type(conjspinor), intent(in) :: psibar2
  complex(kind=default), intent(in) :: phi3
  type(momentum), intent(in) :: k2, k3
  ! ------------------------------------------------------------------
  ! 1 * <2|(1-g5)/2|1> *  + 1 * <2|(1+g5)/2|1> *
  ! ------------------------------------------------------------------
  real(kind=default), dimension(0:3) :: p1, p2, p3
  complex(kind=default), dimension(1:4) :: bra01
  complex(kind=default), dimension(1:4) :: bra02
  integer :: alpha
  ! ------------------------------------------------------------------
  p2(0) = k2%t
  p2(1:3) = k2%x
  p3(0) = k3%t
  p3(1:3) = k3%x
  p1 = - p2 - p3
  ! ------------------------------------------------------------------
  ! <2|(1-g5)/2|1>
  bra01(1) = 0 + psibar2%a(1)
  bra01(2) = 0 + psibar2%a(2)
  bra01(3) = 0
  bra01(4) = 0
  ! ------------------------------------------------------------------
  ! <2|(1+g5)/2|1>
  bra02(1) = 0
  bra02(2) = 0
  bra02(3) = 0 + psibar2%a(3)
  bra02(4) = 0 + psibar2%a(4)
  ! ------------------------------------------------------------------
```

Models from UFO Files in WHIZARD


```
model = SM  (ufo)
```

UFO file is assumed to be in working directory OR

```
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```

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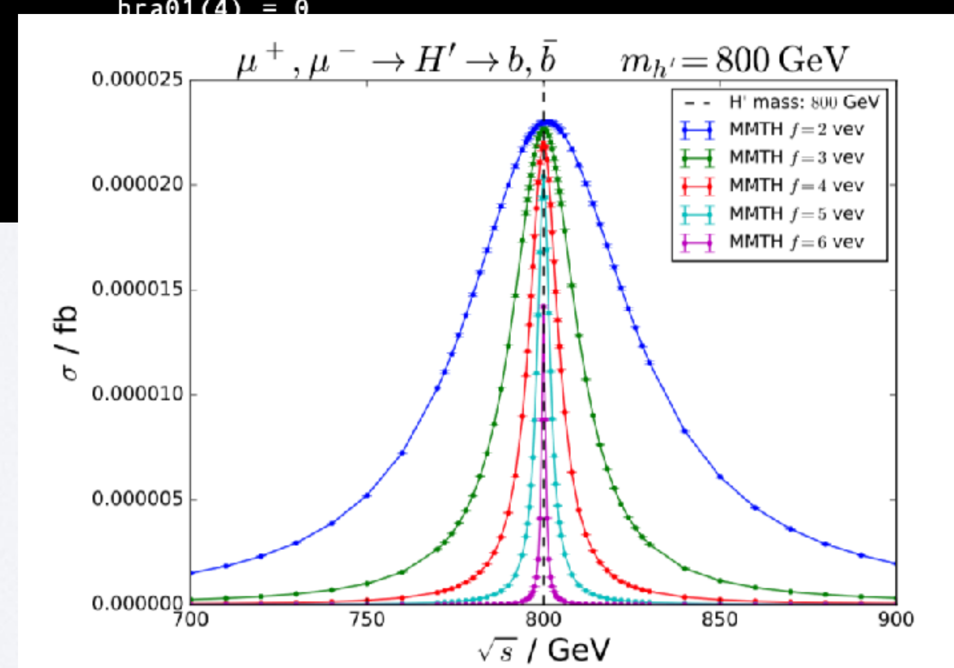
```
pure function VVVV4_p0123 (g, a2, k2, a3, k3, a4, k4) result (a1)
  type(vector) :: a1
  complex(kind=default), intent(in) :: g
  type(vector), intent(in) :: a2
  type(vector), intent(in) :: a3
  type(vector), intent(in) :: a4
  type(momentum), intent(in) :: k2, k3, k4
  ! ---------------------------------------------------------------
  ! 1 *  * Metric(2,4) * Metric(1,3) + -1 *  * Metric(3,4) * Metric(1,2)
  ! ---------------------------------------------------------------
  complex(kind=default), dimension(0:3) :: a1a
  complex(kind=default), dimension(0:3) :: a2a
  complex(kind=default), dimension(0:3) :: a3a
  complex(kind=default), dimension(0:3) :: a4a
  real(kind=default), dimension(0:3) :: p1, p2, p3, p4
  integer :: nu1
  integer :: nu2
  integer :: nu3
  integer :: nu4
  ! ---------------------------------------------------------------
  a2a(0) = a2%t
  a2a(1:3) = a2%x
  a3a(0) = a3%t
  a3a(1:3) = a3%x
  a4a(0) = a4%t
  a4a(1:3) = a4%x
  p2(0) = k2%t
  p2(1:3) = k2%x
  p3(0) = k3%t
  p3(1:3) = k3%x
  p4(0) = k4%t
  p4(1:3) = k4%x
  p1 = - p2 - p3 - p4
```

```
pure function FFS4_p012 (g, psibar2, k2, phi3, k3) result (psi1)
  type(conjspinor) :: psi1
  complex(kind=default), intent(in) :: g
  type(conjspinor), intent(in) :: psibar2
  complex(kind=default), intent(in) :: phi3
  type(momentum), intent(in) :: k2, k3
  ! ---------------------------------------------------------------
  ! 1 * <2|(1-g5)/2|1> *  + 1 * <2|(1+g5)/2|1> *
  ! ---------------------------------------------------------------
  real(kind=default), dimension(0:3) :: p1, p2, p3
  complex(kind=default), dimension(1:4) :: bra01
  complex(kind=default), dimension(1:4) :: bra02
  integer :: alpha
  ! ---------------------------------------------------------------
  p2(0) = k2%t
  p2(1:3) = k2%x
  p3(0) = k3%t
  p3(1:3) = k3%x
  p1 = - p2 - p3
  ! ---------------------------------------------------------------
  ! <2|(1-g5)/2|1>
  bra01(1) = 0 + psibar2%a(1)
  bra01(2) = 0 + psibar2%a(2)
  bra01(3) = 0
  bra01(4) = 0
```



Minimal Mirror Twin Higgs: Lipp / JRR , *in preparation*

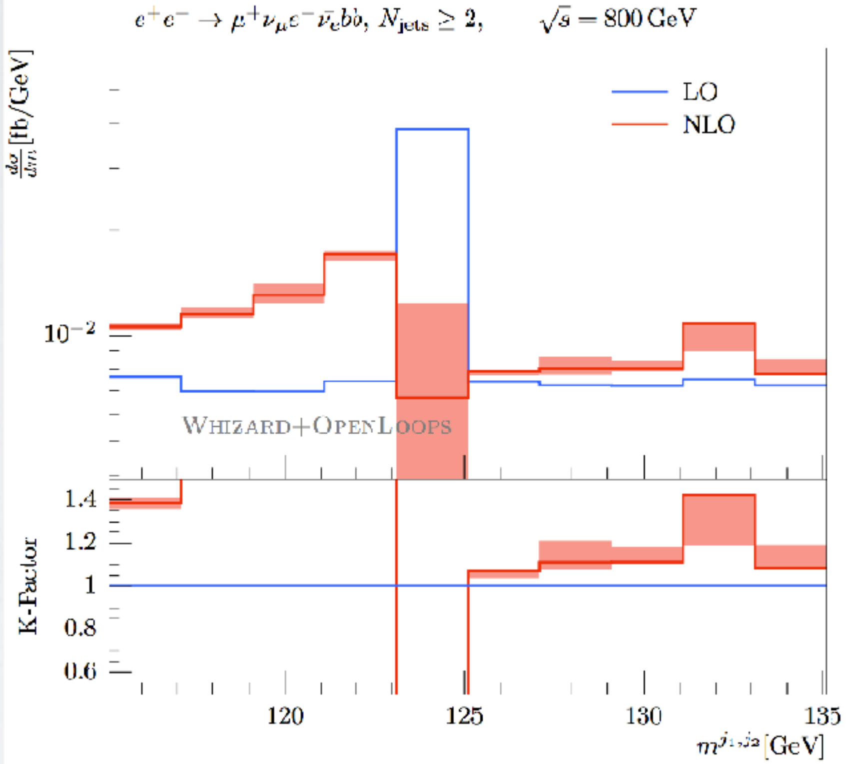
NLO Automation in WHIZARD

Working NLO interfaces to:

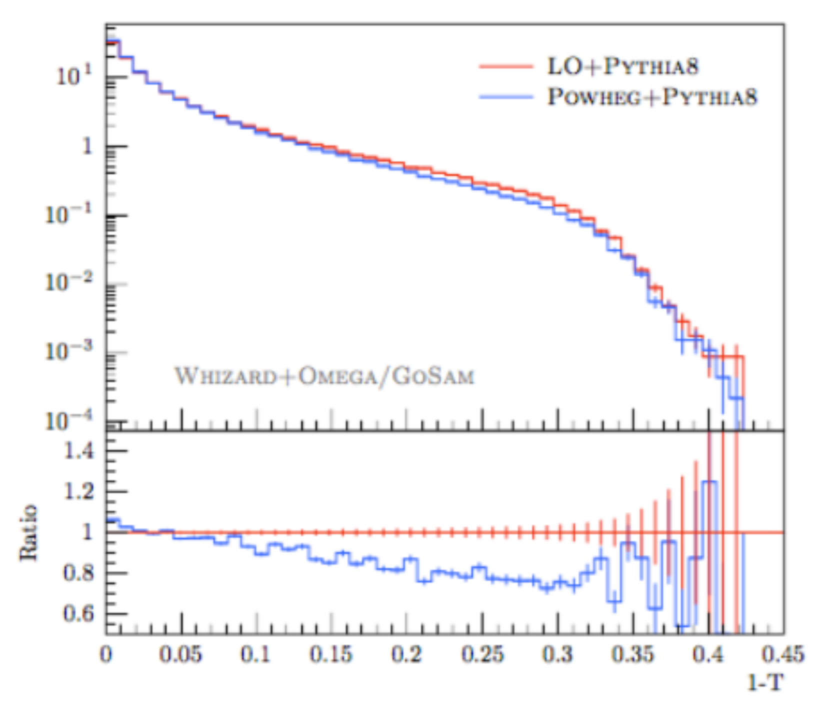
- ★ GoSam [N. Greiner, G. Heinrich, J. v. Soden-Fraunhofen et al.]
- ★ OpenLoops [F. Cascioli, J. Lindert, P. Maierhöfer, S. Pozzorini]
- ★ Recola [A. Denner, L. Hofer, J.-N. Lang, S. Uccirati]

NLO QCD (massless & massive) fully supported

```
alpha_power = 2
alphas_power = 1

process eejjj = e1,E1 => j, j, j { nlo_calculation = full }
```



- FKS subtraction [Frixione/Kunszt/Signer, hep-ph/9512328]
- Resonance-aware treatment [Ježo/Nason, 1509.09071]
- Virtual MEs external
- Real and virtual subtraction terms internal
- NLO decays available for the NLO processes
- Fixed order events for plotting (weighted)
- Automated POWHEG damping and matching
- NLO QCD: final clean-up NLO EW first results
- Release WHIZARD 3.0.0α (March 2020)



Validation of NLO QCD for e^+e^- Collisions

1 TeV

		MG5_aMC			WHIZARD	
Process	σ^{LO}[fb]	σ^{NLO}[fb]	K	σ^{LO}[fb]	σ^{NLO}[fb]	K
$e^+e^- \to jj$	622.3(5)	639.3(1)	1.02733	622.73(4)	639.41(9)	1.02678
$e^+e^- \to jjj$	340.1(2)	317.3(8)	0.93297	342.4(5)	318.6(7)	0.9305
$e^+e^- \to jjjj$	104.7(1)	103.7(3)	0.99045	105.1(4)	103.0(6)	0.98003
$e^+e^- \to jjjjj$	22.11(6)	24.65(4)	1.11488	22.80(2)	24.35(15)	1.06798
$e^+e^- \to jjjjjj$	N/A	N/A	N/A	3.62(2)	0.0(0)	0.0
$e^+e^- \to b\bar{b}$	92.37(6)	94.89(1)	1.02728	92.32(1)	94.78(7)	1.02664
$e^+e^- \to b\bar{b}b\bar{b}$	$1.644(3) \cdot 10^{-1}$	$3.60(1) \cdot 10^{-1}$	2.1897	$1.64(2) \cdot 10^{-1}$	$3.67(4) \cdot 10^{-1}$	2.2378
$e^+e^- \to t\bar{t}$	166.2(2)	174.5(3)	1.04994	166.4(1)	174.53(6)	1.04886
$e^+e^- \to t\bar{t}j$	48.13(5)	53.36(1)	1.10867	48.3(2)	53.25(6)	1.10248
$e^+e^- \to t\bar{t}jj$	8.614(9)	10.49(3)	1.21777	8.612(8)	10.46(6)	1.21458
$e^+e^- \to t\bar{t}jjj$	1.044(2)	1.420(4)	1.3601	1.040(1)	1.414(10)	1.3595
$e^+e^- \to t\bar{t}t\bar{t}$	$6.45(1) \cdot 10^{-4}$	$11.94(2) \cdot 10^{-4}$	1.85117	$6.463(2) \cdot 10^{-4}$	$11.91(2) \cdot 10^{-4}$	1.8428
$e^+e^- \to t\bar{t}t\bar{t}j$	$2.719(5) \cdot 10^{-5}$	$5.264(8) \cdot 10^{-5}$	1.93602	$2.722(1) \cdot 10^{-5}$	$5.250(14) \cdot 10^{-5}$	1.92873
$e^+e^- \to t\bar{t}b\bar{b}$	0.1819(3)	0.292(1)	1.60533	0.186(1)	0.293(2)	1.57527
$e^+e^- \to t\bar{t}H$	2.018(3)	1.909(3)	0.94601	2.022(3)	1.912(3)	0.9456
$e^+e^- \to t\bar{t}Hj$	$0.2533(3) \cdot 10^{-0}$	$0.2665(6) \cdot 10^{-0}$	1.05212	0.2540(9)	0.2664(5)	1.04889
$e^+e^- \to t\bar{t}Hjj$	$2.663(4) \cdot 10^{-2}$	$3.141(9) \cdot 10^{-2}$	1.1795	$2.666(4) \cdot 10^{-2}$	$3.144(9) \cdot 10^{-2}$	1.17928
$e^+e^- \to t\bar{t}\gamma$	12.7(2)	13.3(4)	1.04726	12.71(4)	13.78(4)	1.08418
$e^+e^- \to t\bar{t}Z$	4.642(6)	4.95(1)	1.06636	4.64(1)	4.94(1)	1.06467
$e^+e^- \to t\bar{t}Zj$	0.6059(6)	0.6917(24)	1.14168	0.610(4)	0.6927(14)	1.13565
$e^+e^- \to t\bar{t}Zjj$	$6.251(28) \cdot 10^{-2}$	$8.181(21) \cdot 10^{-2}$	1.30875	$6.233(8) \cdot 10^{-2}$	$8.201(14) \cdot 10^{-2}$	1.31573
$e^+e^- \to t\bar{t}W^{\pm}jj$	$2.400(4) \cdot 10^{-4}$	$3.714(8) \cdot 10^{-4}$	1.54747	$2.41(1) \cdot 10^{-4}$	$3.695(9) \cdot 10^{-4}$	1.5332
$e^+e^- \to t\bar{t}\gamma\gamma$	0.383(5)	0.416(2)	1.08618	0.382(3)	0.420(3)	1.09952
$e^+e^- \to t\bar{t}\gamma Z$	0.2212(3)	0.2364(6)	1.06873	0.220(1)	0.240(2)	1.09094
$e^+e^- \to t\bar{t}\gamma H$	$9.75(1) \cdot 10^{-2}$	$9.42(3) \cdot 10^{-2}$	0.96614	$9.748(6) \cdot 10^{-2}$	$9.58(7) \cdot 10^{-2}$	0.98277
$e^+e^- \to t\bar{t}ZZ$	$3.788(4) \cdot 10^{-2}$	$4.00(1) \cdot 10^{-2}$	1.05597	$3.756(4) \cdot 10^{-2}$	$4.005(2) \cdot 10^{-2}$	1.0663
$e^+e^- \to t\bar{t}W^+W^-$	0.1372(3)	0.1540(6)	1.1225	0.1370(4)	0.1538(4)	1.12257
$e^+e^- \to t\bar{t}HH$	$1.358(1) \cdot 10^{-2}$	$1.206(3) \cdot 10^{-2}$	0.888	$1.367(1) \cdot 10^{-2}$	$1.218(1) \cdot 10^{-2}$	0.8909
$e^+e^- \to t\bar{t}HZ$	$3.600(6) \cdot 10^{-2}$	$3.58(1) \cdot 10^{-2}$	0.99445	$3.596(1) \cdot 10^{-2}$	$3.581(2) \cdot 10^{-2}$	0.9958

Validation of NLO QCD for *pp* Collisions

13 TeV

Process	MG5_AMC σ^{LO}[pb]	MG5_AMC σ^{NLO}[pb]	MG5_AMC K	WHIZARD σ^{LO}[pb]	WHIZARD σ^{NLO}[pb]	WHIZARD K
$pp \to jj$	$1.162(1) \cdot 10^{-6}$	$1.580(7) \cdot 10^{-6}$	1.36	$1.157(2) \cdot 10^{-6}$	$1.604(7) \cdot 10^{-6}$	1.39
$pp \to jjj$	$8.940(21) \cdot 10^{-4}$	$7.791(37) \cdot 10^{-4}$	0.87	$8.921(47) \cdot 10^{-4}$	$22.73(1) \cdot 10^{-4}$	2.55
$pp \to Z$	$4.248(5) \cdot 10^{-4}$	$5.410(22) \cdot 10^{-4}$	1.27	$4.2536(3) \cdot 10^{-4}$	$5.4067(2) \cdot 10^{-4}$	1.27
$pp \to Zj$	$7.209(5) \cdot 10^{-3}$	$9.745(32) \cdot 10^{-3}$	1.35	$7.207(2) \cdot 10^{-3}$	$9.720(17) \cdot 10^{-3}$	1.35
$pp \to Zjj$	$2.348(6) \cdot 10^{-3}$	$2.684(5) \cdot 10^{-3}$	1.14	$2.352(8) \cdot 10^{-3}$	$2.735(9) \cdot 10^{-3}$	1.16
$pp \to W^{\pm}$	$1.375(2) \cdot 10^{-5}$	$1.773(7) \cdot 10^{-5}$	1.29	$1.3750(5) \cdot 10^{-5}$	$1.7696(9) \cdot 10^{-5}$	1.29
$pp \to W^{\pm}j$	$2.045(1) \cdot 10^{-4}$	$2.839(9) \cdot 10^{-4}$	1.39	$2.043(1) \cdot 10^{-4}$	$2.845(6) \cdot 10^{-4}$	1.39
$pp \to W^{\pm}jj$	$6.805(15) \cdot 10^{-3}$	$7.780(13) \cdot 10^{-3}$	1.14	$6.798(7) \cdot 10^{-3}$	$7.93(3) \cdot 10^{-3}$	1.17
$pp \to ZZ$	$1.097(3) \cdot 10^{-1}$	$1.4190(25) \cdot 10^{-1}$	1.29	$1.094(2) \cdot 10^{-1}$	$1.4192(32) \cdot 10^{-1}$	1.3
$pp \to ZZj$	$3.662(3) \cdot 10^{-0}$	$4.830(16) \cdot 10^{-0}$	1.32	$3.659(2) \cdot 10^{-0}$	$4.820(11) \cdot 10^{-0}$	1.32
$pp \to ZW^{\pm}$	$2.777(3) \cdot 10^{-1}$	$4.485(12) \cdot 10^{-1}$	1.62	$2.775(2) \cdot 10^{-1}$	$4.488(4) \cdot 10^{-1}$	1.62
$pp \to ZW^{\pm}j$	$1.605(5) \cdot 10^{-1}$	$2.100(5) \cdot 10^{-1}$	1.31	$1.604(6) \cdot 10^{-1}$	$2.103(4) \cdot 10^{-1}$	1.31
$pp \to W^+W^-(4f)$	$0.7355(5) \cdot 10^{-2}$	$1.028(3) \cdot 10^{-2}$	1.4	$0.7349(7) \cdot 10^{-2}$	$1.027(1) \cdot 10^{-2}$	1.4
$pp \to W^+W^-j\ (4f)$	$2.865(3) \cdot 10^{-1}$	$3.730(13) \cdot 10^{-1}$	1.3	$2.868(1) \cdot 10^{-1}$	$3.733(8) \cdot 10^{-1}$	1.3
$pp \to W^+W^+jj$	$1.484(3) \cdot 10^{--1}$	$2.251(11) \cdot 10^{--1}$	1.52	$1.483(4) \cdot 10^{--1}$	$2.238(6) \cdot 10^{--1}$	1.51
$pp \to W^-W^-jj$	$6.752(7) \cdot 10^{--2}$	$9.99(1) \cdot 10^{--2}$	1.48	$6.755(4) \cdot 10^{--1}$	$9.97(3) \cdot 10^{--1}$	1.48
$pp \to W^+W^-W^{\pm}(4f)$	$1.307(3) \cdot 10^{--1}$	$2.111(4) \cdot 10^{--1}$	1.62	$1.309(1) \cdot 10^{--1}$	$2.117(2) \cdot 10^{--1}$	1.62
$pp \to ZW^+W^-(4f)$	$0.966(7) \cdot 10^{--1}$	$1.679(5) \cdot 10^{--1}$	1.74	$0.966(2) \cdot 10^{--1}$	$1.682(2) \cdot 10^{--1}$	1.74
$pp \to W^+W^-W^{\pm}Z(4f)$	$0.639(8) \cdot 10^{--3}$	$1.230(3) \cdot 10^{--3}$	1.92	$0.642(2) \cdot 10^{--3}$	$1.240(2) \cdot 10^{--3}$	1.93
$pp \to W^{\pm}ZZZ$	$0.586(1) \cdot 10^{--5}$	$1.240(4) \cdot 10^{--5}$	2.12	$0.588(2) \cdot 10^{--5}$	$1.229(2) \cdot 10^{--5}$	2.09
$pp \to t\bar{t}$	$4.584(3) \cdot 10^{-2}$	$6.746(14) \cdot 10^{-2}$	1.47	$4.588(2) \cdot 10^{-2}$	$6.740(9) \cdot 10^{-2}$	1.47
$pp \to t\bar{t}j$	$3.135(2) \cdot 10^{-2}$	$4.095(8) \cdot 10^{-2}$	1.31	$3.131(3) \cdot 10^{-2}$	$4.194(9) \cdot 10^{-2}$	1.34
$pp \to t\bar{t}t\bar{t}$	$4.505(5) \cdot 10^{--3}$	$9.076(13) \cdot 10^{--3}$	2.01	$4.511(2) \cdot 10^{--3}$	$9.070(9) \cdot 10^{--3}$	2.01
$pp \to t\bar{t}Z$	$5.273(4) \cdot 10^{--1}$	$7.625(25) \cdot 10^{--1}$	1.45	$5.281(8) \cdot 10^{--1}$	$7.639(9) \cdot 10^{--1}$	1.45

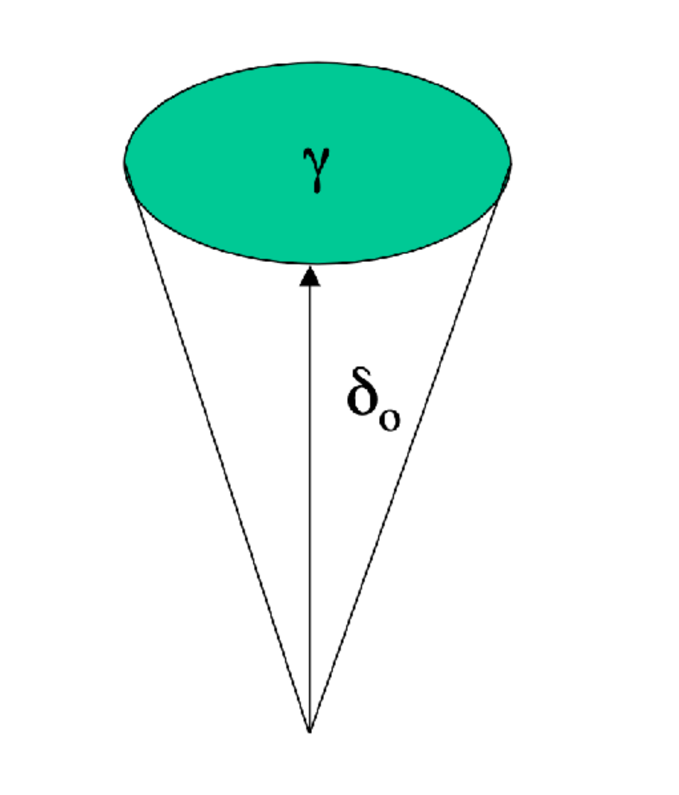
b-jet selection
c-jet selection

```
alias ljet = u:U:d:D:s:S:gl
alias jet = ljet:c:C

process charm_selec = e1, E1 => c, C, ljet, ljet, ljet, ljet

jet_algorithm = antikt_algorithm
jet_r = 0.5

cuts = let subevt @clustered = cluster [jet] in
       let subevt @cjets = select_c_jet if Pt > 30 GeV [@clustered] in
       count [@selected] >= 4 and count [@cjets] == 2
```

Photon isolation in WHIZARD

Frixione, hep-ph/9706545; hep-ph/9801442; hep-ph/9809397

- Isolate perturbative and fragmentation contributions to photons
- Partons must be allowed inside isolation cone (IR-safe observables!)
- Otherwise: soft-collinear IR cancellations would be spoiled
- Define isolation cone around each photon: Radius δ (η–Φ space)



R distance (photon-parton): $R_{i\gamma} = \sqrt{\Delta\eta_{i\gamma}^2 + \Delta\phi_{i\gamma}^2}$

Reject event if partons inside δ_0 -cone don't fulfill jet isolation criterion:

$$\sum_{i\in\text{partons}} E_i \theta(\delta - R_{i\gamma}) \leq \mathcal{X}(\delta) \quad \text{for all} \quad \delta \leq \delta_0$$

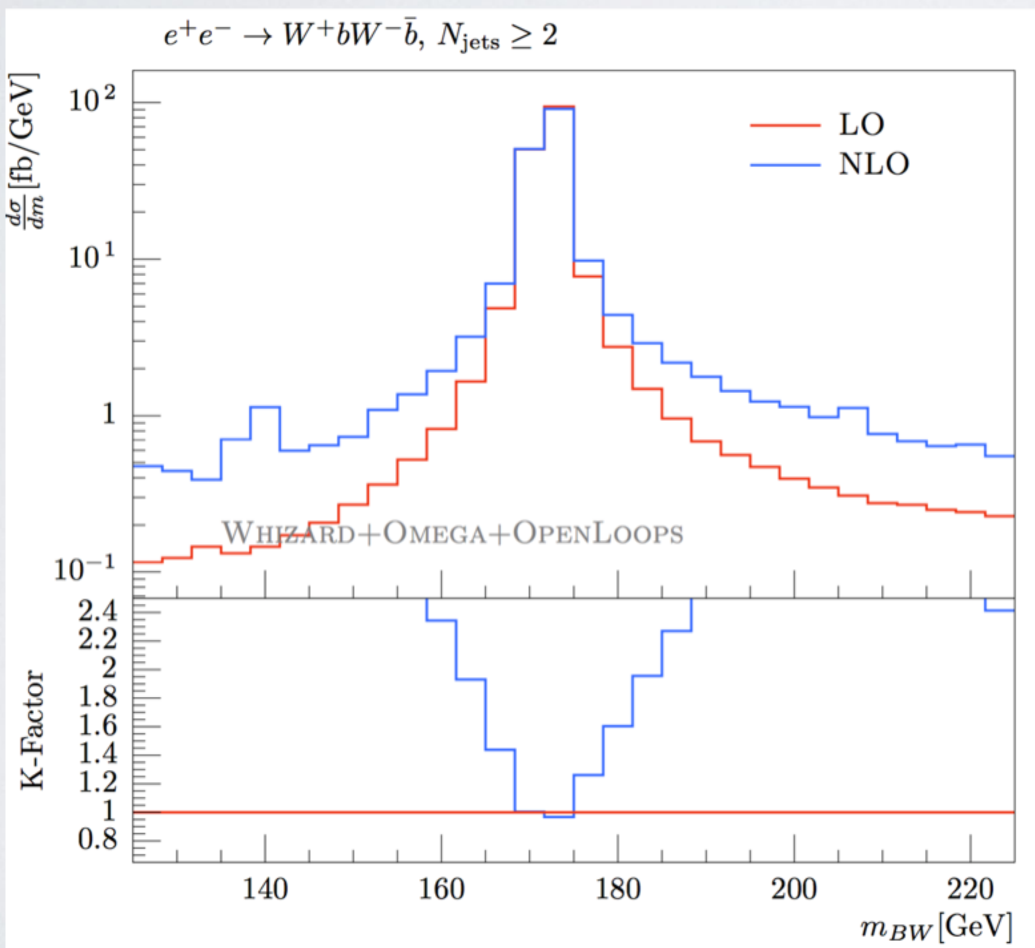
$$\mathcal{X}(\delta) = E_\gamma \epsilon_\gamma \left(\frac{1-\cos\delta}{1-\cos\delta_0}\right)^n \qquad \lim_{\delta\to\infty} \mathcal{X}(\delta) = 0$$

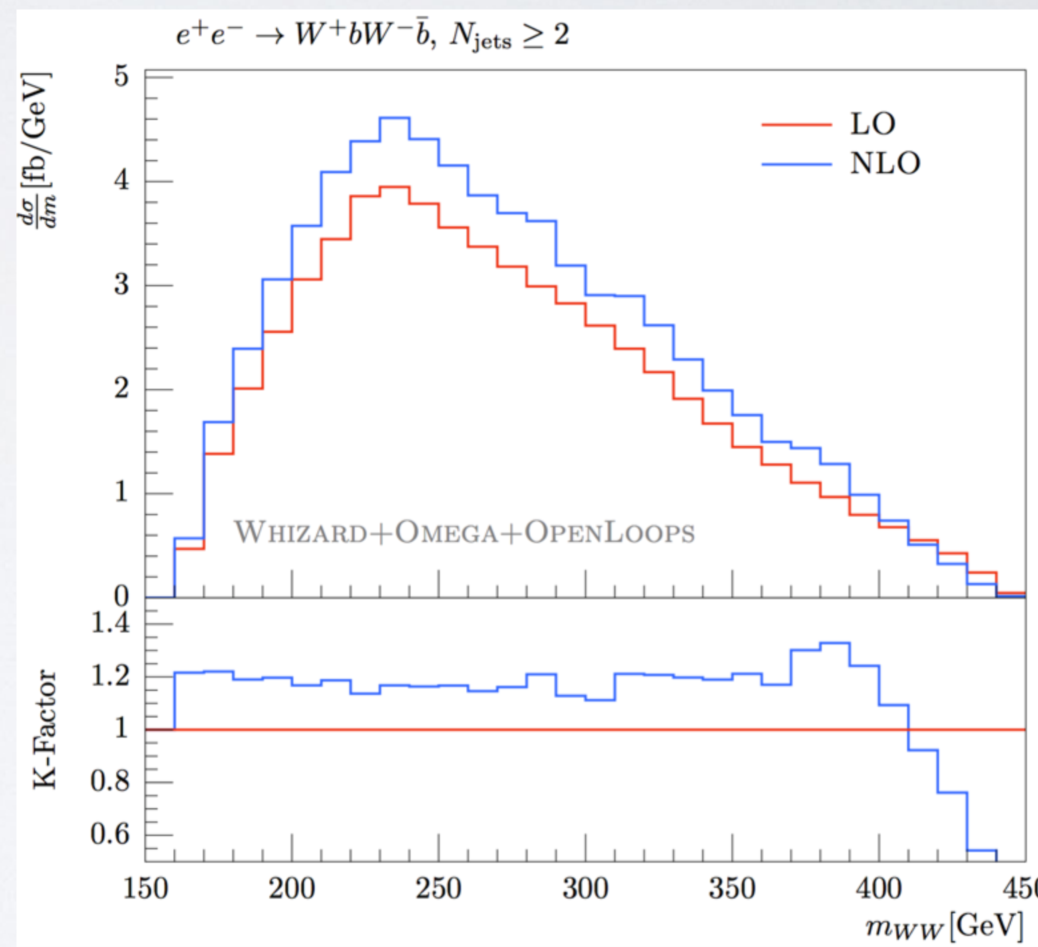
```
photon_iso_eps = 1.0
photon_iso_n = 1
photon_iso_r0 = 0.4
```

```
alias ljet = u:U:d:D:s:S:gl
jet_algorithm = antikt_algorithm
jet_r = 0.5

process ee_aajj = e1, E1 => A, A, ljet, ljet

cuts = let subevt @clustered = cluster [jet] in
       photon_isolation [A, @clustered]

process ee_mmaa = e1, E1 => e2, E2, A, A

cuts = photon_isolation if Pt > 5 GeV [A, e2:E2:A]
```

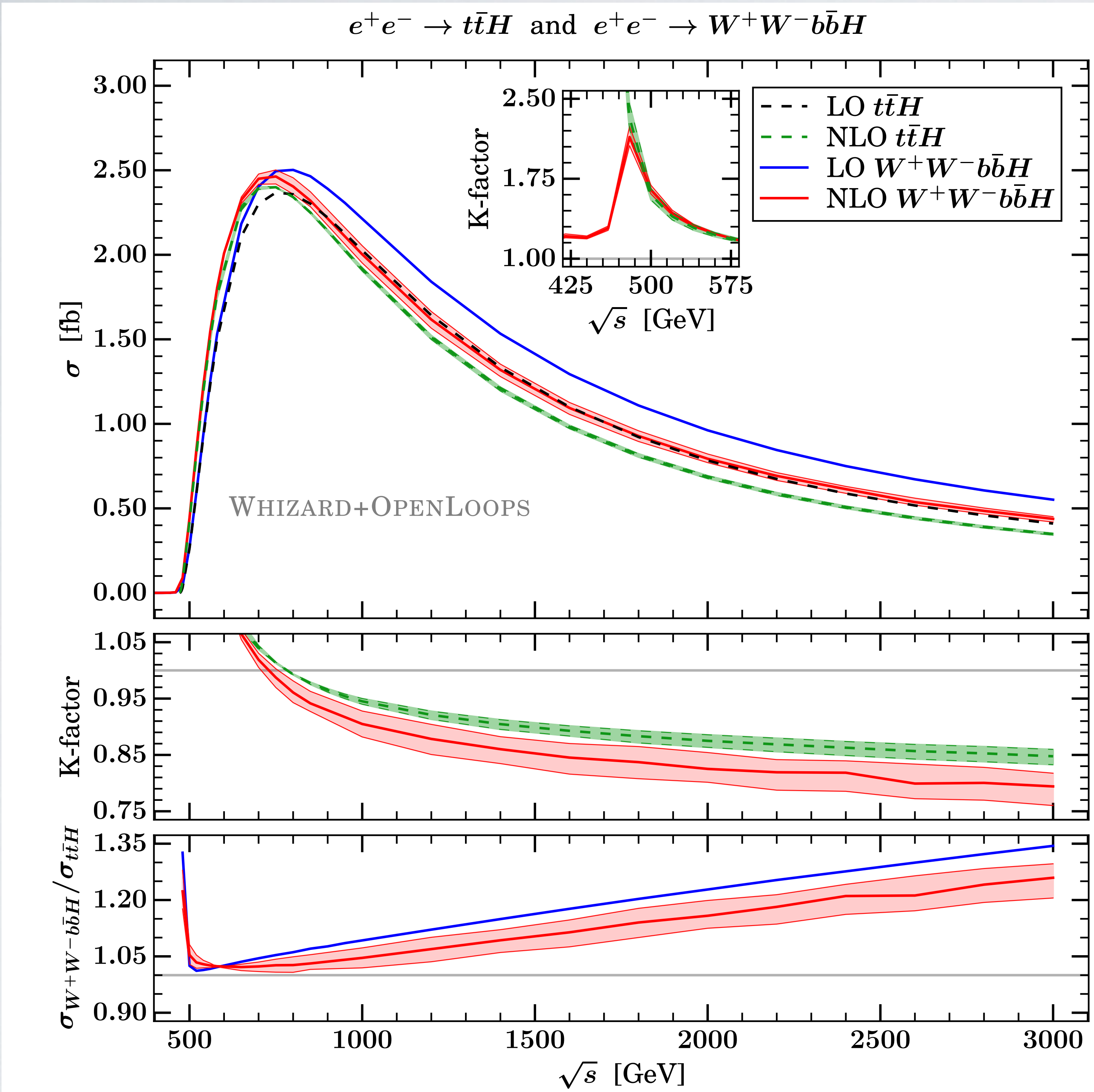
NLO Fixed-Order Events

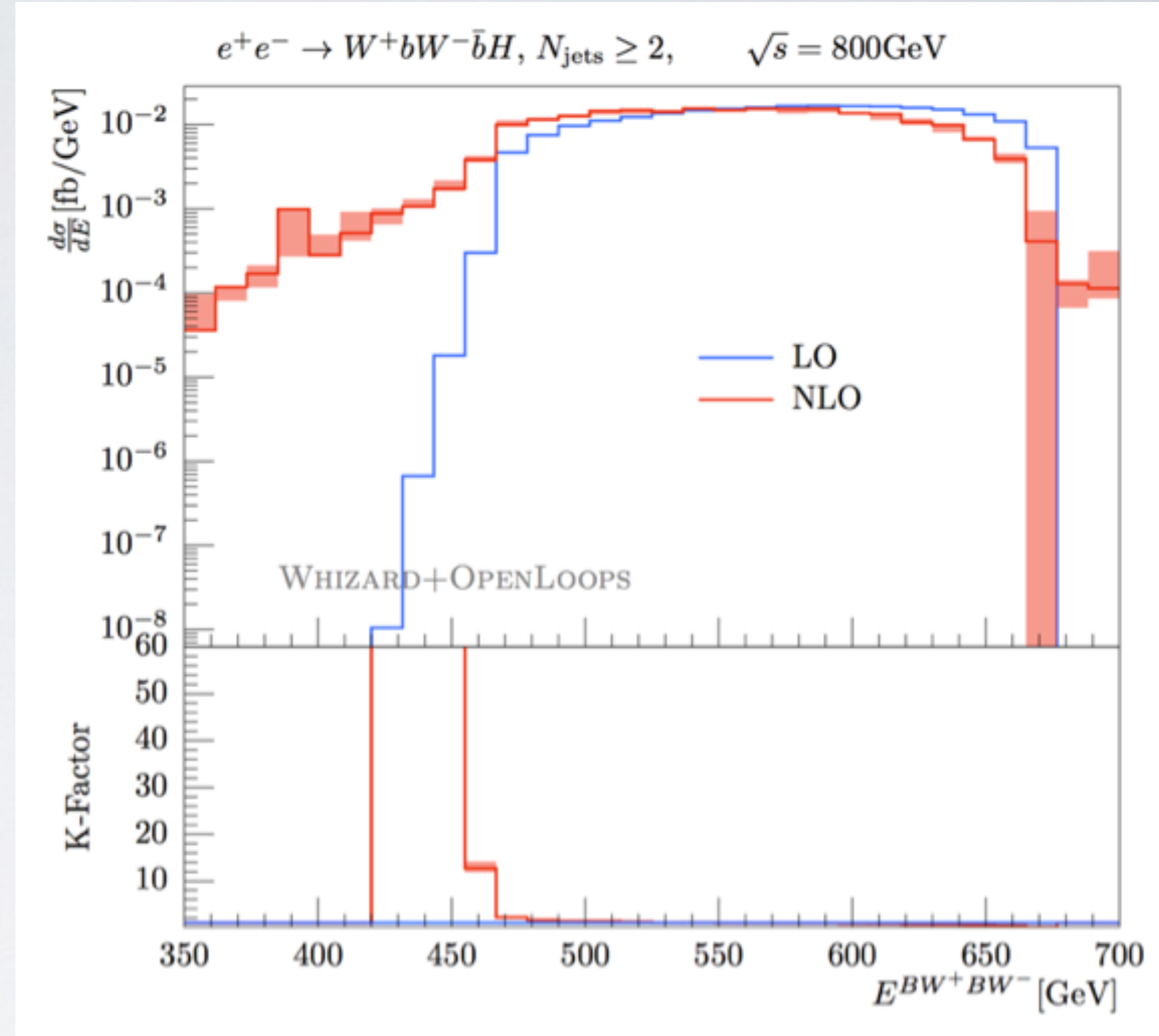
- Add weights of real emission events to weight of Born kinematics using the FKS mapping
- Output weighted events in `WHIZARD` (e.g. using `HepMC`), then analysis with `Rivet`
- `Rivet3:` interesting new features (e.g. bin smearing), but not yet completely bugfree
- Example process: $e^+e^- \to W^+W^-b\bar{b}$





NLO QCD Results for off-shell $e^+e^- \to ttH$

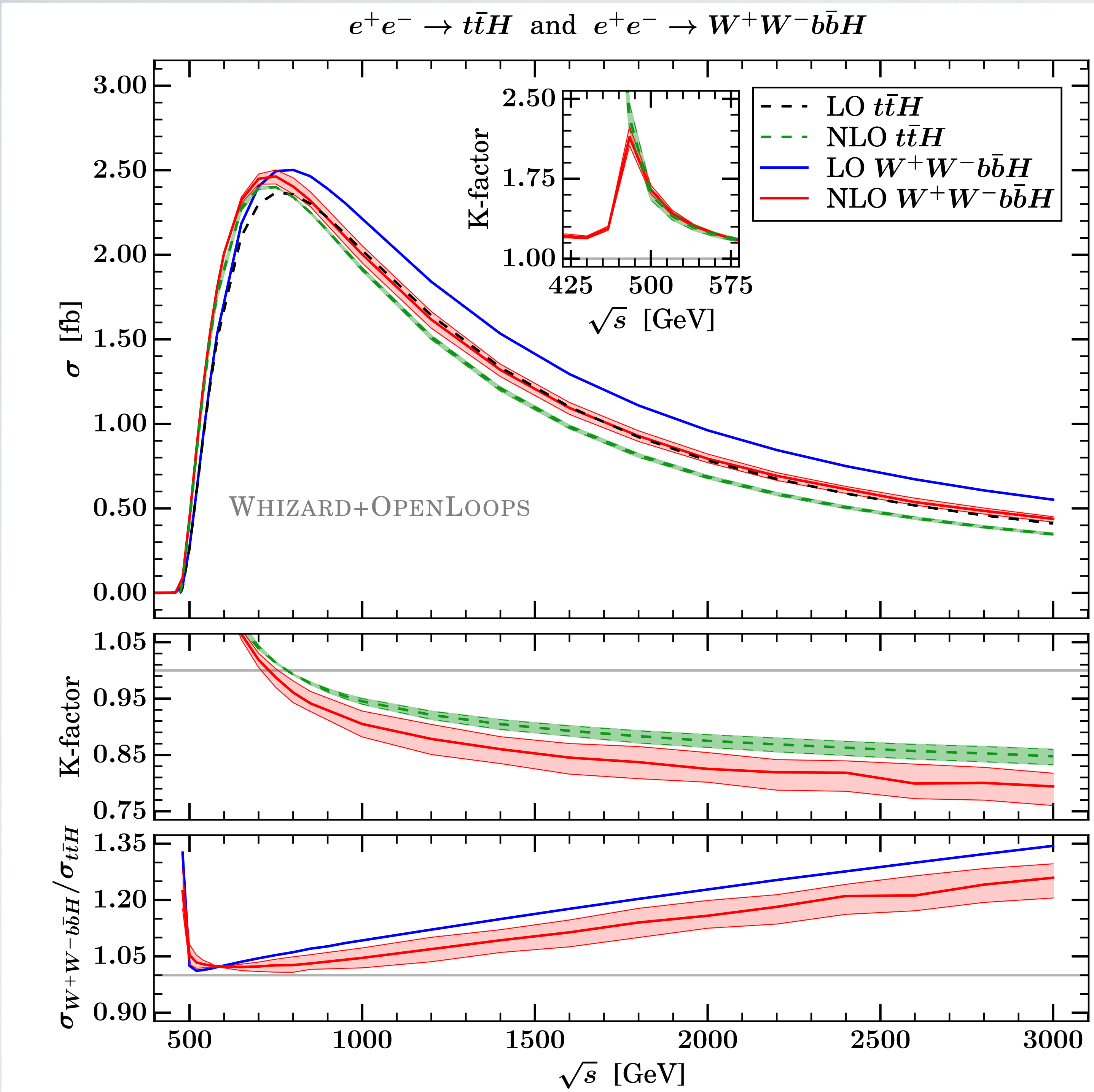


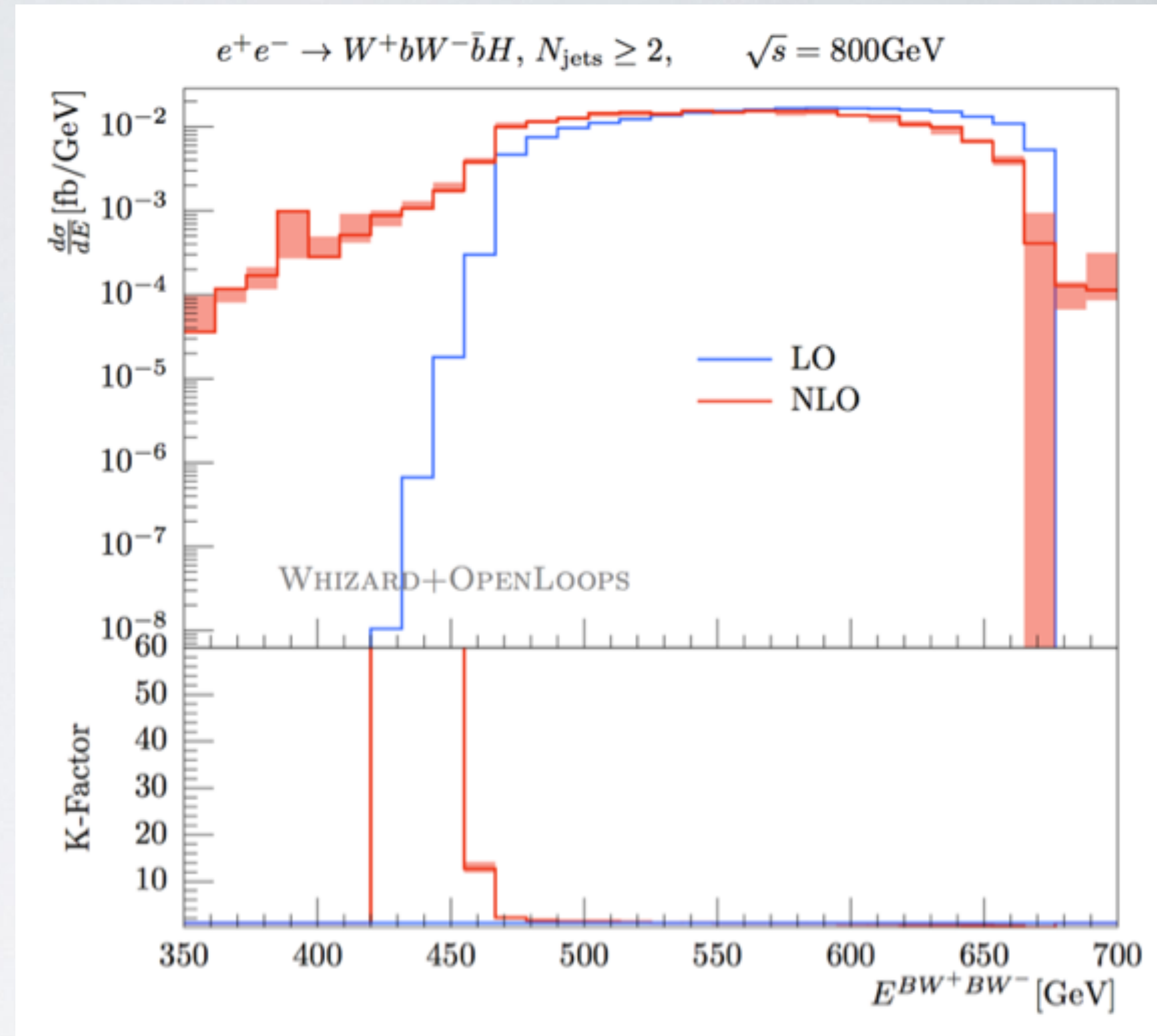


	$e^+e^- \to t\bar{t}H$			$e^+e^- \to W^+W^-b\bar{b}H$		
$\sqrt{s}$ [GeV]	σ^{LO}[fb]	σ^{NLO}[fb]	K-factor	σ^{LO}[fb]	σ^{NLO}[fb]	K-factor
500	0.26	$0.42^{+3.6\%}_{-3.1\%}$	1.60	0.27	$0.44^{+2.6\%}_{-2.4\%}$	1.63
800	2.36	$2.34^{+0.1\%}_{-0.1\%}$	0.99	2.50	$2.40^{+2.1\%}_{-1.9\%}$	0.96
1000	2.02	$1.91^{+0.5\%}_{-0.5\%}$	0.95	2.21	$2.00^{+2.5\%}_{-2.5\%}$	0.90
1400	1.33	$1.21^{+0.9\%}_{-1.0\%}$	0.90	1.53	$1.32^{+2.6\%}_{-3.0\%}$	0.86
3000	0.41	$0.35^{+1.4\%}_{-1.8\%}$	0.84	0.55	$0.44^{+2.9\%}_{-4.3\%}$	0.79

Chokoufé/Kilian/Lindert/Pozzorini/JRR/Weiss, 1609.03390

NLO QCD Results for off-shell $e^+e^- \to ttH$



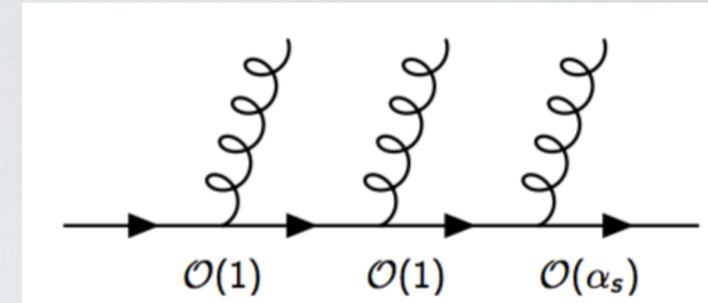


	$e^+e^- \to t\bar{t}H$			$e^+e^- \to W^+W^-b\bar{b}H$		
$\sqrt{s}$ [GeV]	σ^{LO}[fb]	σ^{NLO}[fb]	K-factor	σ^{LO}[fb]	σ^{NLO}[fb]	K-factor
500	0.26	$0.42^{+3.6\%}_{-3.1\%}$	1.60	0.27	$0.44^{+2.6\%}_{-2.4\%}$	1.63
800	2.36	$2.34^{+0.1\%}_{-0.1\%}$	0.99	2.50	$2.40^{+2.1\%}_{-1.9\%}$	0.96
1000	2.02	$1.91^{+0.5\%}_{-0.5\%}$	0.95	2.21	$2.00^{+2.5\%}_{-2.5\%}$	0.90
1400	1.33	$1.21^{+0.9\%}_{-1.0\%}$	0.90	1.53	$1.32^{+2.6\%}_{-3.0\%}$	0.86
3000	0.41	$0.35^{+1.4\%}_{-1.8\%}$	0.84	0.55	$0.44^{+2.9\%}_{-4.3\%}$	0.79

Chokoufé/Kilian/Lindert/Pozzorini/JRR/Weiss, 1609.03390

Automated POWHEG Matching in WHIZARD

- Soft gluon emissions before hard emission generate large logs
- Consistent matching of NLO matrix element with shower
- POWHEG method: hardest emission first [Nason et al.]



- Complete NLO events

$$\overline{B}(\Phi_n) = B(\Phi_n) + V(\Phi_n) + \int d\Phi_{\mathrm{rad}} R(\Phi_{n+1})$$

- POWHEG generate events according to the formula:

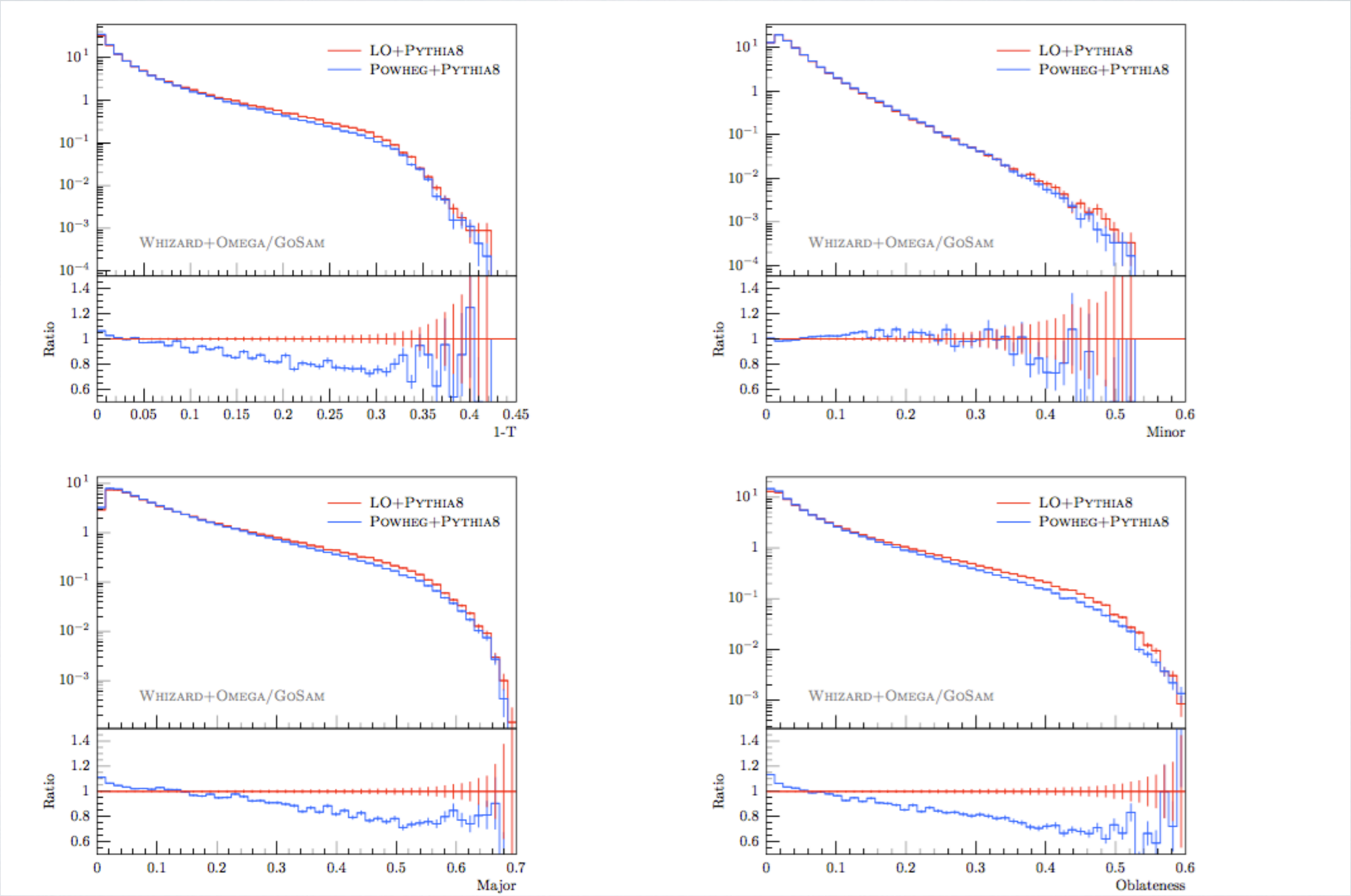
$$d\sigma = \overline{B}(\Phi_n)\left[\Delta_R^{\mathrm{NLO}}(k_T^{\mathrm{min}}) + \Delta_R^{\mathrm{NLO}}(k_T)\frac{R(\Phi_{n+1})}{B(\Phi_n)} d\Phi_{\mathrm{rad}}\right]$$

- Uses the modified Sudakov form factor

```
$loop_me_method = "openloops"
?alphas_is_fixed = false
?alphas_from_mz = true
?alphas_from_lambda_qcd = false

alpha_power = 2
alphas_power = 0

?combined_nlo_integration = true

?powheg_matching = true
powheg_grid_size_xi = 5
powheg_grid_size_y = 5
powheg_grid_sampling_points = 1000000
powheg_pt_min = 1
?powheg_use_singular_jacobian = false

scale = 2 * mtop

jet_algorithm = antikt_algorithm
jet_r = 1
```

```
process nlo_tt_powheg = E1, e1 => t, T { nlo_calculation = full }

sqrts = 500 GeV

integrate (nlo_tt_powheg)  {iterations = 5:50000:"gw", 5:50000:""}

y_min = 1
y_max = n_events
histogram Pt_j1 (0 GeV, 200 GeV, 10 GeV)
histogram E_g (0 GeV, 30 GeV, 1 GeV)

analysis = let subevt @clustered_jets = cluster [colored] in
           let subevt @Eselected_jets = select if (E > 1 GeV)
                   [@clustered_jets] in
           let subevt @jetsbypt = sort by -Pt [@Eselected_jets] in
           record Pt_j1 (eval Pt [extract index 1 [@jetsbypt]])
      and  record E_g (eval E [g])

$sample = "nlo_tt_powheg"

simulate (nlo_tt_powheg)   {  n_events = 20000 }
```

POWHEG Matching, example: e^+e^- to dijets



Minor things and bug fixes

Reporting the time since the last CLIC workshop talk 01 / 2019

- ☑ `WHIZARD 2.7.0` ⟶ `WHIZARD 2.8.2/3, 3.0.0α`
- ☑ Bug fix debug output moved (performance issue)
- ☑ Bug fix for most recent LHAPDF version
- ☑ Bug fix for a bad design choice in OCaml 4.06.x — 4.08.x
- ☑ Bug fix prevents re-generating MC integration in case of CIRCE1/2 beam spectra
- ☑ Bug fix several for rescanning / reweighting
- ☑ Bug fix for random number sequence and event generation in MPI VAMP2
- ☑ Bug fix for normalization of polarized cross sections with EPA and CIRCE/ISR
- ☑ Bug fix for EPA parameters: confusion between E_{max} and Q_{max}
- ☑ Bug fix / feature: CIRCE2 now allows for explicit beam particle masses
- ☑ Feature: MSSM radiative neutralino decays [CLICdp]
- ☑ Feature: binary MC adaption grid files for VAMP2, now default (performance)

Conclusions & Outlook

- WHIZARD 2.8 well-known event generator for CLIC physics
- (Hopefully) ready for ILC 250 GeV 2/ab full SM mass production
- ee physics: beamspectra, LCIO, LC top threshold
- Full UFO support → WHIZARD 2.8.3
- NLO QCD automation: → WHIZARD 3.0.0α released
- First NLO EW cross section numbers produced
- allows to produce NLO fixed-order histograms

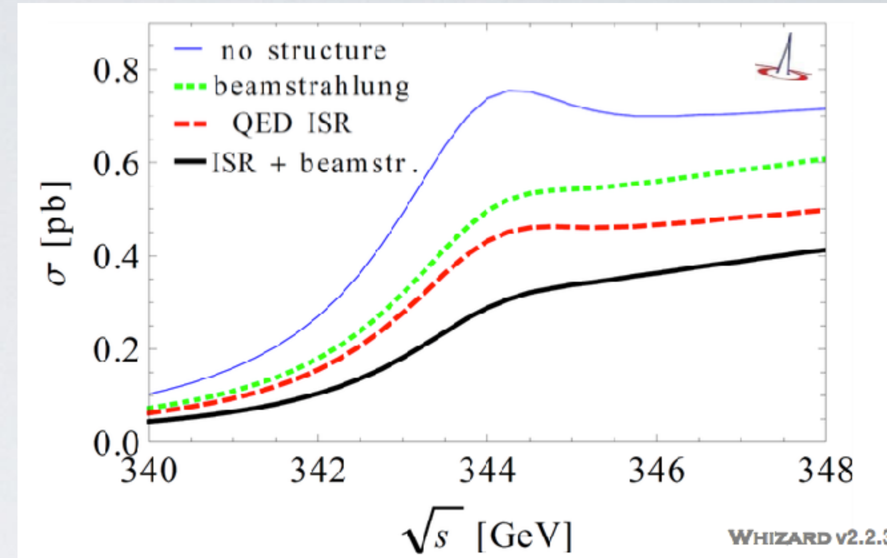
WHIZARD STRATEGY

WE'RE HAPPY TO ACCOMODATE WELL-POSED USER REQUESTS
PLEASE USE: *https://launchpad.net/whizard*

BACKUP

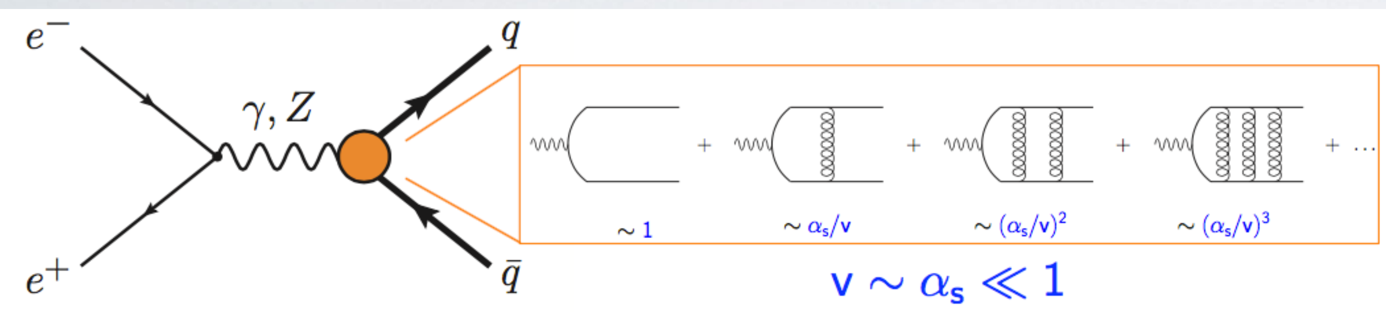
Top Threshold in WHIZARD

- Why include LL/NLL in a Monte Carlo event generator?
- Important effects: beamstrahlung; ISR; LO EW terms
- More exclusive observables accessible

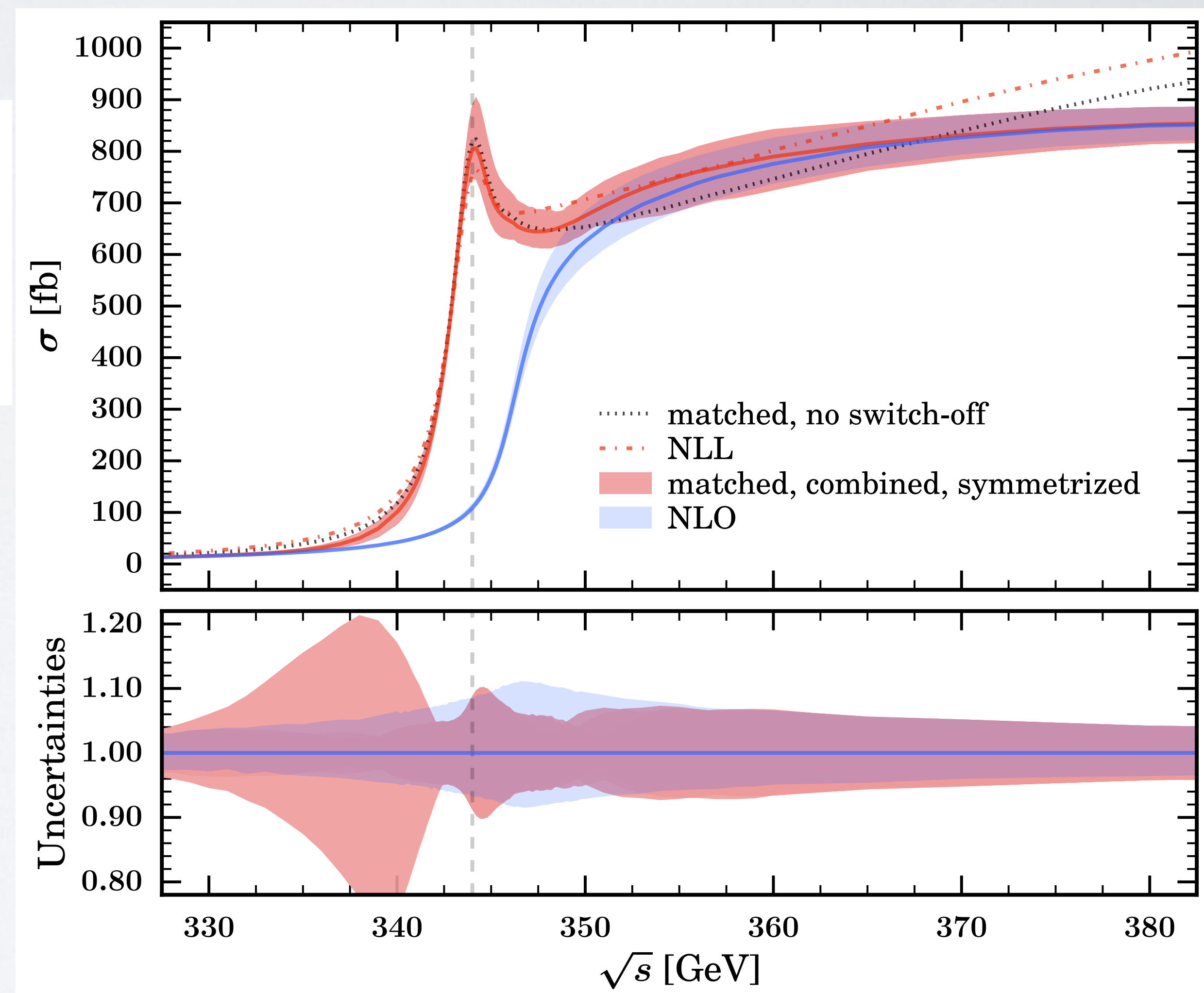


- Resummed threshold effects as vertex form factor
- TOPPIK code [Jezabek/Teubner], included in WHIZARD

Threshold region: top velocity $v \sim \alpha_s \ll 1$




```
model = SM_tt_threshold

nrqcd_order = 1
FF = 1   ! NLL resummed
mpole_fixed = 1
Vtb = 1
m1S = 172 GeV
scale = m1S

$method = "threshold"
process eett_threshold = E1, e1 => Wp, Wm, b, B {
  $restrictions = "3+5~t && 4+6~tbar" nlo_calculation = real }

sqrts = 350 GeV
integrate (eett_threshold)
```



Chokoufé/Hoang/Kilian/JRR/Stahlhofen/Teubner/Weiss, 1712.02220

Resonance mappings for NLO processes

- Amplitudes (except for pure QCD/QED) contain resonances (*Z*, *W*, *H*, *t*)
- In general: resonance masses *not* respected by modified kinematics of subtraction terms
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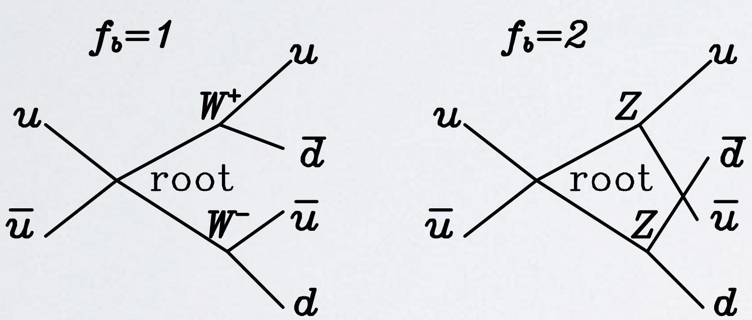

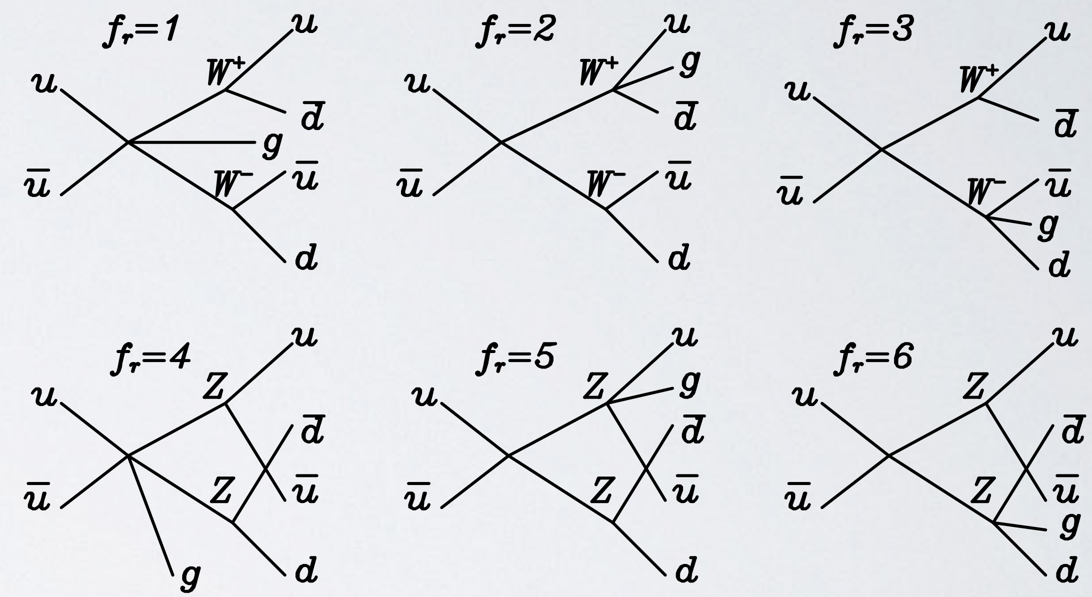

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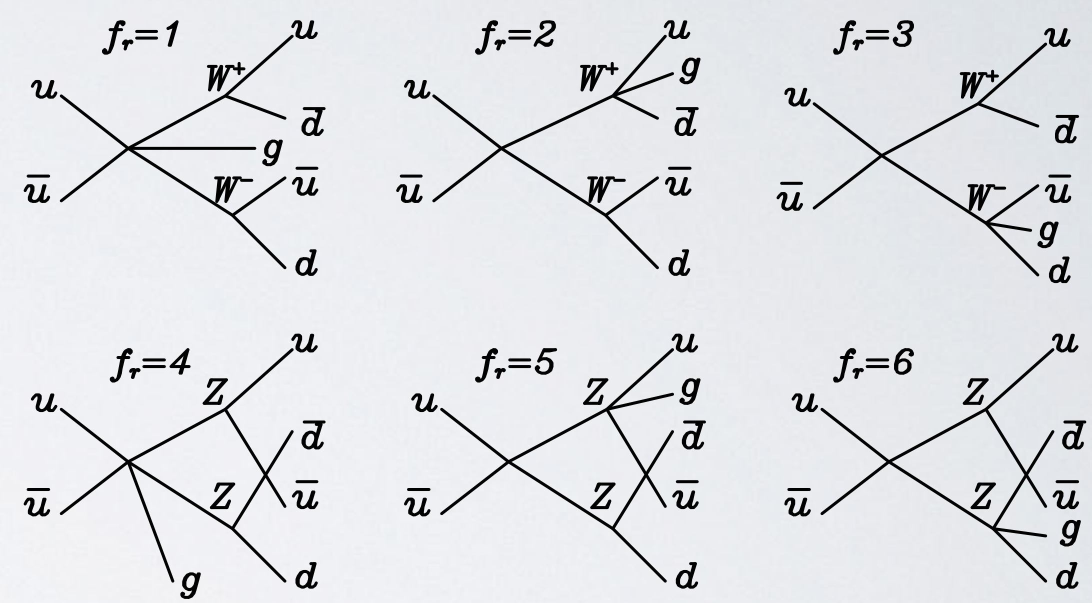

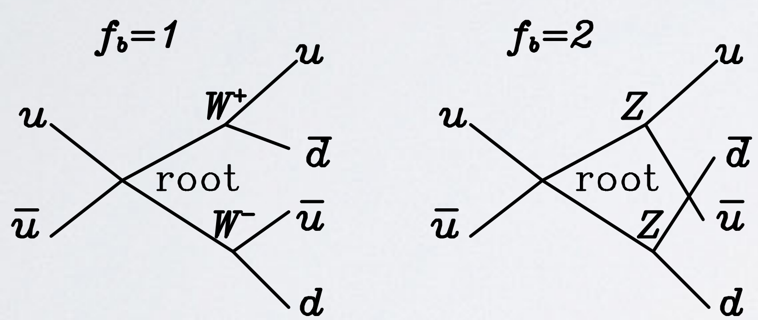

- WHIZARD complete automatic implementation: example $e^+ e^- \to \mu\mu bb$ (ZZ, ZH histories)

It	Calls	Integral[fb]	Error[fb]	Err[%]	Acc	Eff[%]	Chi2	N[It]
1	11988	9.6811847E+00	6.42E+00	66.30	72.60*	0.65		
2	11959	2.8539703E+00	2.35E-01	8.25	9.02*	0.69		
3	11936	2.4907574E+00	6.54E-01	26.25	28.68	0.35		
4	11908	2.7695559E+00	9.67E-01	34.91	38.09	0.30		
5	11874	2.4346151E+00	4.82E-01	19.80	21.57*	0.74		
5	59665	2.7539078E+00	1.97E-01	7.15	17.47	0.74	0.49	5

standard FKS

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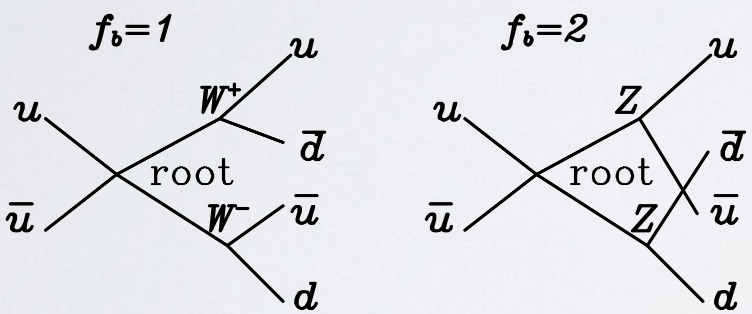

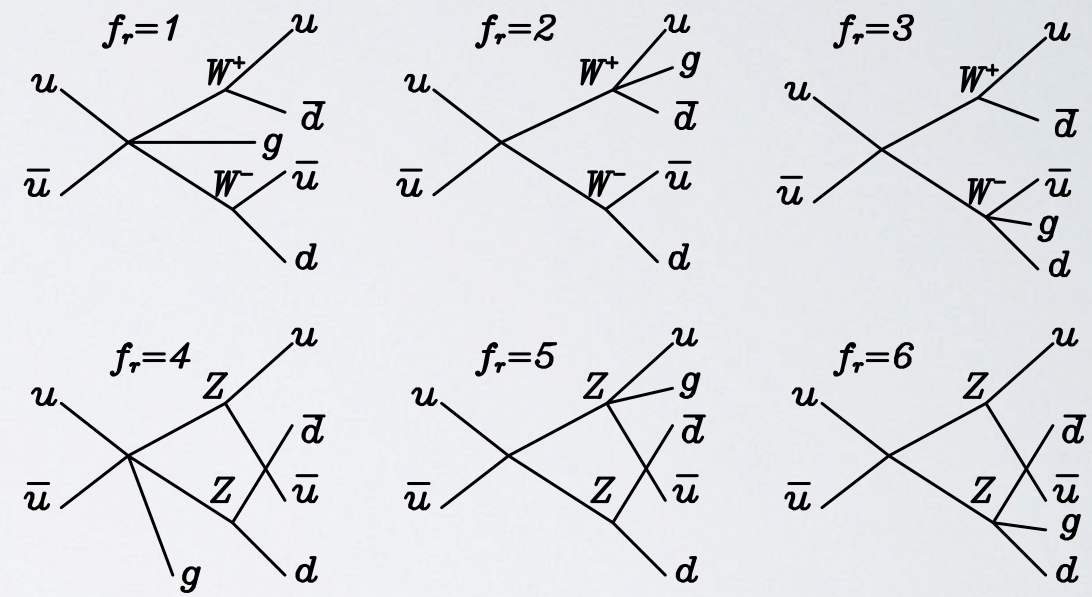

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standard FKS

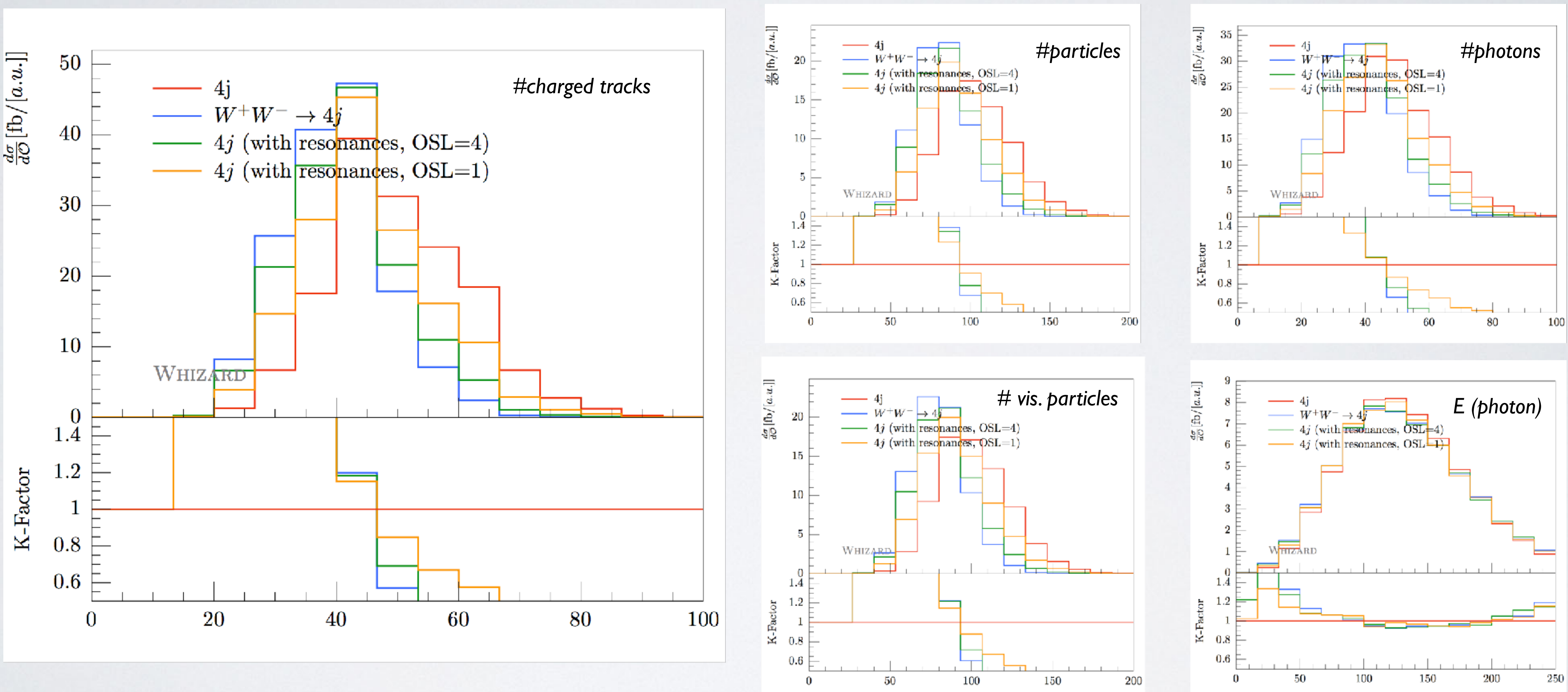
It	Calls	Integral[fb]	Error[fb]	Err[%]	Acc	Eff[%]	Chi2	N[It]
1	11988	2.9057032E+00	8.35E-02	2.87	3.15*	7.90		
2	11962	2.8591952E+00	5.20E-02	1.82	1.99*	10.91		
3	11936	2.9277880E+00	4.09E-02	1.40	1.52*	14.48		
4	11902	2.8512337E+00	3.98E-02	1.40	1.52*	13.70		
5	11874	2.8855399E+00	3.87E-02	1.34	1.46*	17.15		
5	59662	2.8842006E+00	2.04E-02	0.71	1.72	17.15	0.53	5

FKS with resonance mappings

Keep resonances in ME-PS merging

```
?resonance_history = true
resonance_on_shell_limit = 4
resonance_on_shell_turnoff = 1
resonance_background_factor = 1e-10
```

- **Problem:** $e^+e^- \to jjjj$ not dominated by highest α_s power, but by resonances $e^+e^- \to WW/ZZ \to (jj)(jj)$
- **Solution:** proper merging with resonant subprocesses by means of resonance histories
- `WHIZARD v2.6.0`: option to set resonance histories



- LC Generator Group first successful tests on $e^+e^- \to 6j$; includes tests w/ resonant $H \to bb$

Interface between WHIZARD – PYTHIA8

- Intention: directly communicate between event records of WHIZARD and PYTHIA8
- No intermediate files: direct communication between event records
- Allows for using all the machinery for matching and merging from PYTHIA8

```
| ===========================================================================
| Running self-test: whizard_lha
| ---------------------------------------------------------------------------
Running test: whizard_lha_1
 --------  LHA initialization information  ------------

  beam    kind      energy  pdfgrp  pdfset
     A    2212    6500.000      -1      -1
     B    2212    6500.000      -1      -1

  Event weighting strategy = -3

  Processes, with strategy-dependent cross section info
  number      xsec (pb)      xerr (pb)      xmax (pb)
       1     1.0000e+00     5.0000e-02     1.0000e+00
       2     1.2000e+00     6.0000e-02     1.0000e+00
       3     1.4000e+00     7.0000e-02     1.0000e+00
       4     1.6000e+00     8.0000e-02     1.0000e+00
       5     1.8000e+00     9.0000e-02     1.0000e+00

 --------  End LHA initialization information  --------
 ... success.
Running test: whizard_lha_2
 --------  LHA initialization information  ------------

  beam    kind      energy  pdfgrp  pdfset
     A    2212    6500.000      -1      -1
     B    2212    6500.000      -1      -1

  Event weighting strategy = -3

  Processes, with strategy-dependent cross section info
  number      xsec (pb)      xerr (pb)      xmax (pb)
       1     1.0000e+00     5.0000e-02     1.0000e+00

 --------  End LHA initialization information  --------

 --------  LHA event information and listing  -------------------------------------------------------------

    process =        1     weight =    1.0000e+00     scale =    1.0000e+03 (GeV)
                         alpha_em =    7.8740e-03    alpha_strong =    1.0000e-01

    Participating Particles
    no        id stat      mothers      colours        p_x         p_y         p_z          e          m       tau      spin
     1      2011   -9      0     0      0     0      0.000       0.000       0.000      1.000      1.000     0.000     0.000
     2      2012   -9      0     0      0     0      0.000       0.000       0.000      2.000      2.000     0.000     0.000
     3        11   -1      1     0      0     0      0.000       0.000       0.000      4.000      4.000     0.000     0.000
     4        12   -1      2     0      0     0      0.000       0.000       0.000      6.000      6.000     0.000     0.000
     5        91    3      1     0      0     0      0.000       0.000       0.000      3.000      3.000     0.000     0.000
     6        92    3      2     0      0     0      0.000       0.000       0.000      5.000      5.000     0.000     0.000
     7         3    1      3     4      0     0      0.000       0.000       0.000      7.000      7.000     0.000     0.000
     8         4    1      3     4      0     0      0.000       0.000       0.000      8.000      8.000     0.000     0.000
     9         5    1      3     4      0     0      0.000       0.000       0.000      9.000      9.000     0.000     0.000

 --------  End LHA event information and listing  -------------------------------------------------------------
```

```
$shower_method = "PYTHIA8"
$hadronization_method = "PYTHIA8"
```

Allows to use the PYTHIA8 toolbox for matching