



WHIZARD: BSM physics for the LHC



Jürgen Reuter

Albert-Ludwigs-Universität Freiburg $\Rightarrow$ School of Physics, University of Edinburgh



W. Kilian, T. Ohl, JRR

(arXiv:0708.4233)

MC4BSM, Copenhagen, 2010

The WHIZARD Event Generator – Release 2.0.0

- ▶ Acronym: **W**, **H**iggs, **Z**, **A**nd **R**espective **D**ecays (deprecated)
- ▶ Fast Multi-Channel Monte-Carlo integration
- ▶ Very efficient phase space and event generation
- ▶ Optimized matrix elements — Very high level of Complexity:
 - $e^+e^- \rightarrow t\bar{t}H \rightarrow b\bar{b}b\bar{b}jj\ell\nu$ (110,000 diagrams)
 - $e^+e^- \rightarrow ZHH \rightarrow ZWWWW \rightarrow bb + 8j$ (12,000,000 diagrams)
 - $pp \rightarrow \ell\ell + nj, n = 0, 1, 2, 3, 4, \dots$ (2,100,000 diagrams with 4 jets + flavors)
 - $pp \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 bbbb$ (32,000 diagrams, 22 color flows, $\sim 10,000$ PS channels)
 - $pp \rightarrow VVjj \rightarrow jj\ell\ell\nu\nu$ incl. anomalous TGC/QGC
 - Test case $gg \rightarrow 9g$ (224,000,000 diagrams)

WHIZARD 2.0.0 release: 2010, April, 12th



Old series: WHIZARD 1.95 (development stopped with 1.94)

The WHIZARD team: F. Bach, H.-W. Boschmann, [F. Braam], **W. Kilian**, **T. Ohl**, **JRR**, S. Schmidt, C. Speckner, [M. Trudewind], D. Wiesler, [T. Wirtz]

Web address: <http://projects.hepforge.org/whizard>
<http://whizard.event-generator.org>

Standard Reference for all versions: [Kilian/Ohl/JRR, 0708.4233](#)

O'Mega: Optimal matrix elements

Ohl/JRR, 2001



- [$\cdot$] Replace forest of tree diagrams by
Directed Acyclical Graph (DAG) of the algebraic expression.

$$ab(ab + c) =$$

$$=$$

O'Mega: Optimal matrix elements

Ohl/JRR, 2001

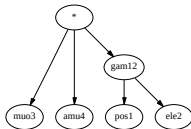


- $[\cdot]$ Replace forest of tree diagrams by
Directed Acyclical Graph (DAG) of the algebraic expression.

$$ab(ab + c) = \text{tree diagram 1} = \text{tree diagram 2}$$

The first tree diagram shows a root node with two children: a left child (node with children a and b) and a right child (node with children a and b). The second tree diagram shows a root node with two children: a left child (node with children a and b) and a right child (node with children a and b).

- simplest examples: $e^+e^- \rightarrow \mu^+\mu^-$, and



O'Mega: Optimal matrix elements

Ohl/JRR, 2001

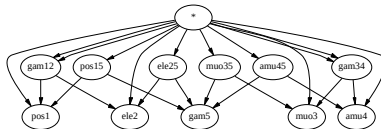
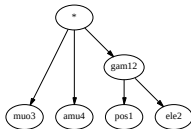


- $[\cdot]$ Replace forest of tree diagrams by
Directed Acyclical Graph (DAG) of the algebraic expression.

$$ab(ab + c) = \text{tree diagram} = \text{tree diagram}$$

The diagram shows the algebraic expression $ab(ab + c)$ being represented by two tree diagrams. The first tree diagram has a root node with two children: a left child (node with two children a and b) and a right child (node with two children a and b). The second tree diagram has a root node with two children: a left child (node with two children a and b) and a right child (node with two children a and b). The diagrams are connected by an equals sign, indicating they represent the same algebraic expression.

- simplest examples: $e^+e^- \rightarrow \mu^+\mu^-$, $e^+e^- \rightarrow \mu^+\mu^-\gamma$ and



O'Mega: Optimal matrix elements

Ohl/JRR, 2001

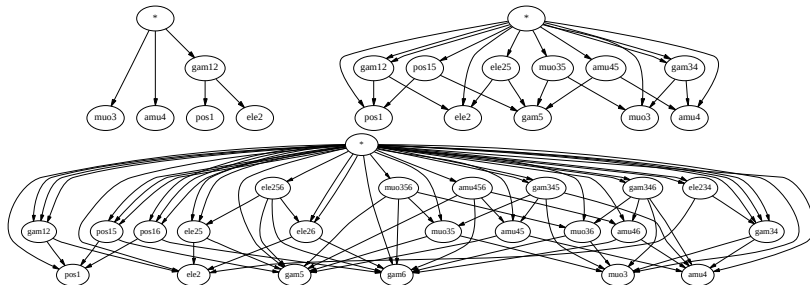


- $[\cdot]$ Replace forest of tree diagrams by

Directed Acyclical Graph (DAG) of the algebraic expression.

$$ab(ab + c) = \begin{array}{c} \times \\ \diagup \quad \diagdown \\ a \quad b \quad \times \quad \diagup \quad \diagdown \\ \quad \quad \quad a \quad b \quad c \end{array} = \begin{array}{c} \times \\ \diagup \quad \diagdown \\ \quad \quad \times \quad \diagup \quad \diagdown \\ a \quad b \quad c \end{array}$$

- simplest examples: $e^+e^- \rightarrow \mu^+\mu^-$, $e^+e^- \rightarrow \mu^+\mu^-\gamma$ and $e^+e^- \rightarrow \mu^+\mu^-\gamma\gamma$



O'Mega: Optimal matrix elements

Ohl/JRR, 2001

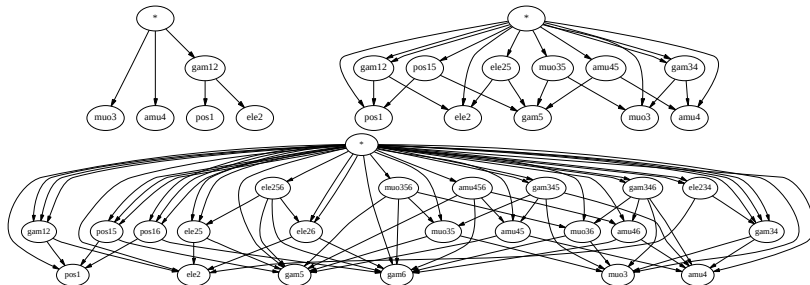


- $[\cdot]$ Replace forest of tree diagrams by

Directed Acyclical Graph (DAG) of the algebraic expression.

$$ab(ab + c) = \begin{array}{c} \times \\ \diagup \quad \diagdown \\ a \quad b \quad \times \quad + \\ \diagdown \quad \diagup \\ a \quad b \quad c \end{array} = \begin{array}{c} \times \\ \diagup \quad \diagdown \\ \times \quad + \\ \diagdown \quad \diagup \\ a \quad b \quad c \end{array}$$

- simplest examples: $e^+e^- \rightarrow \mu^+\mu^-$, $e^+e^- \rightarrow \mu^+\mu^-\gamma$ and $e^+e^- \rightarrow \mu^+\mu^-\gamma\gamma$



- **NEW: Colorized DAGs:** color flow decomposition inside DAG structure, much faster code generation (being prepared for flavor sums as well)

What's new? – Technical Features

- WHIZARD 2 basically rewritten: 60,000 lines of new code!!!
- Streamlining of code: only languages `O' Caml` for `O'Mega` and `Fortran 2003` (all system calls from Fortran)
- **Standardization** by usage of `autotools`: `automake/autoconf/libtool`
⇒ easier control of distributions, regressions etc.
- Version control (`svn`) at HepForge: use of ticket system and bug tracker
- Very clean modularization by using object-orientation
- WHIZARD as a shared library:
 - ▶ No core re-compilation when changing processes!!
 - ▶ Dynamical inclusion of new processes
 - ▶ Old static option still available
- Splitting amplitudes speeds up over-eager compilers
- WHIZARD works as a Shell – WHISH
- **Large test-suite for compatibility, sanity and regression checks**
- Cruise control system is being prepared
- **WHIZARD part of QA of gfortran, Intel, Portland, NAG compilers!!!**

WHIZARD 2 – Installation

- ▶ Download WHIZARD from <http://www.hepforge.org/downloads/whizard/whizard-2.0.0.tar.gz> and unpack it
- ▶ WHIZARD intended to be centrally installed on a system, e.g. in `/usr/local`
- ▶ Create build directory, configure

External programs (LHAPDF, StdHEP, HepMC) might need flags to be set
- ▶ `make, make install`
- ▶ Each user can work in his/her own home directory
- ▶ Extensive test-suite: `make check` (optional during installation) Numerics tests, vertex and wave function checks, Ward identities, compatibility of amplitudes, event generation, input scripts, PDFs, color correlation, cross sections etc. etc.

```
O'Mega self tests:
make check-TESTS
PASS: test_omega95
PASS: test_omega95_bispinors
PASS: test_qed_eemm
PASS: ectests
PASS: ward
PASS: compare_split_function
PASS: compare_split_module
=====
All 7 tests passed
=====
WHIZARD self tests:
make check-am
make check-TESTS
PASS: empty.run
PASS: vars.run
PASS: md5.run
XFAIL: errors.run
PASS: extpar.run
PASS: susyhit.run
PASS: libs.run
PASS: qedtest.run
PASS: helicity.run
PASS: smtest.run
PASS: defaultcuts.run
PASS: restrictions.run
PASS: decays.run
PASS: alphas.run
PASS: colors.run
PASS: cuts.run
PASS: lhapdf.run
PASS: ilc.run
PASS: mssmtest.run
PASS: models.run
PASS: stdhep.run
PASS: stdhep_up.run
=====
All 23 tests behaved as expected (1 e
```

What's new? – Physics/performance features

- **Phase space improvement**: performance gain through symmetrized PS forest construction
- New modular structure: event-dependent scales in PDFs and running α_s
- One single input file steers process generation, integration, event generation, analysis [inclusions possible]
- **SINDARIN** (**S**cripting **I**ntegration, **D**ata **A**nalysis, **R**esults display and **I**nterfaces) allows for arbitrary expressions for cuts and scales etc. (examples later)
- Process libraries: processes of different BSM models can be used in parallel
- **Decay cascades including full spin correlations** (cf. later)
- Inclusive decays
- Much improved flavor sums initial + final state (e.g. jet = quark:gluon)
- **FeynRules interface** (cf. Christian's talk)
- **MLM jet matching** (additional package linked to `PYTHIA`)
- Improved MD5 checksums allow reusing every single bit in a safe way
- Improved graphical analysis package

WHIZARD – Overview over BSM Models

MODEL TYPE	with CKM matrix	trivial CKM
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 anomalous top couplings	SMtop_CKM	SMtop
SM with K matrix	—	SM_KM
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
3-site model	—	Thresh1
UED	—	UED
SUSY Xdim. (inoff.)	—	SED
Noncommutative SM (inoff.)	—	NCSM
SM with Z'	—	Zprime
SM with gravitino and photino	—	GravTest
Augmentable SM template	—	Template

easy to implement new models (cf. Christian's talk)

Gravitinos in WHIZARD

JRR, PhD

```
*** Checking polarization vectorspinors: ***
p.ueps ( 2)= 0: passed at    86%
p.ueps ( 1)= 0: passed at    86%
.....
*** Checking the irreducibility condition: ***
g.ueps ( 2): passed at    95%
.....
g.ueps (-2): passed at    95%
g.veps ( 2): passed at    95%
.....
g.veps (-2): passed at    95%
*** Testing vectorspinor normalization ***
ueps( 2).ueps( 2)= -2m: passed at 100%
ueps( 1).ueps( 1)= -2m: passed at 100%
.....
*** Majorana properties of gravitino vertices: ***
f_sgr   + gr_sf   = 0: passed at   84%
slr_grf + slr_fgr = 0: passed at   88%
.....
v2lr_fgr + v2lr_grf = 0: passed at   77% [expected 0.000E+00, got 0.633E-12]
*** Testing the gravitino propagator: ***
Transversality:
p.pr.test: passed at   66% [expected 0.000E+00, got 0.437E-10]
p.pr.ueps ( 2): passed at   86%
.....
p.pr.ueps (-2): passed at   86%
p.pr.veps ( 2): passed at   79% [expected 0.000E+00, got 0.342E-12]
.....
p.pr.veps (-2): passed at   79% [expected 0.000E+00, got 0.342E-12]
Irreducibility:
g.pr.test: passed at   78% [expected 0.000E+00, got 0.471E-12]
g.pr.ueps ( 2): passed at   92%
.....
g.pr.ueps (-2): passed at   87%
```

Example: LHC SUSY cascade decays, Input File

```
model = MSSM

process dec_su_q = su1 => u, neu2
process dec_neu_sl2 = neu2 => SE12, e1

process susybg = u,U => SU1, su1
process full = u, U => SU1, u, e1, SE12

compile

?slha_read_decays = true
read_slha("spslap_decays.slha")

integrate (dec_su_q, dec_neu_sl2) { iterations = 1:1000 }

sqrts = 14000
beams = p, p => lhpdf

integrate (susybg) { iterations = 5:10000, 2:10000 }
integrate (full)

n_events = 10000

$title = "Full process"
$description =
  "$p + p \to u + \bar{u} \to \bar{\tilde{u}}_1 + u + \tilde{e}_{12}^+ + e^- $"
$xlabel = "$M_{\rm inv}(ue^-) $"
histogram inv_mass1_full (0,600,20)

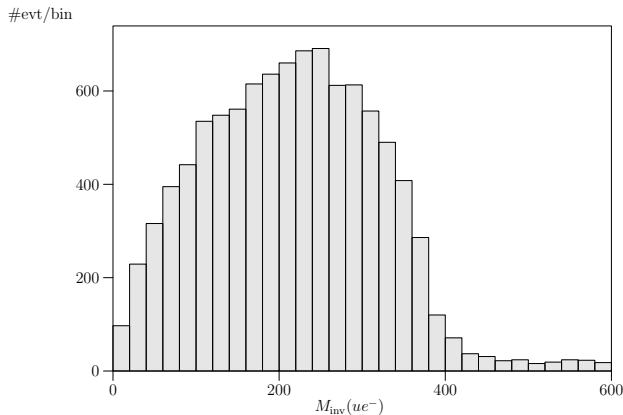
simulate (full) {
  $sample = "casc_dec_full"
  analysis =
    record inv_mass1_full (eval M / 1 GeV [combine[u,e1]])
}

write_analysis
$analysis_filename = "casc_dec"
write_analysis
```

Example: LHC SUSY cascade decays

$$p + p \rightarrow \tilde{u} + \tilde{u}^* \rightarrow \tilde{u}_1 + u + \tilde{e}_{12}^+ + e^-$$

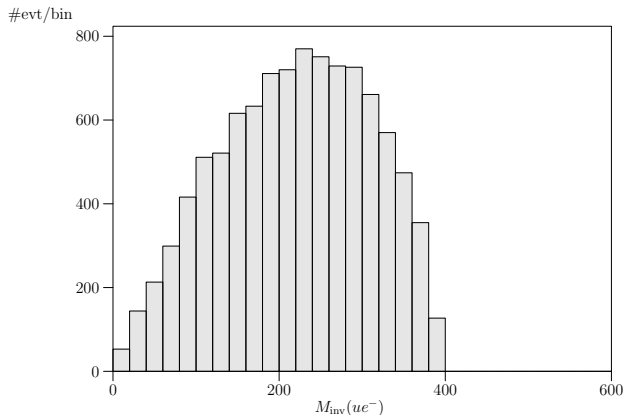
► Full process:



Example: LHC SUSY cascade decays

$$p + p \rightarrow \tilde{u} + \tilde{u}^* \rightarrow \tilde{u}_1 + u + \tilde{e}_{12}^+ + e^-$$

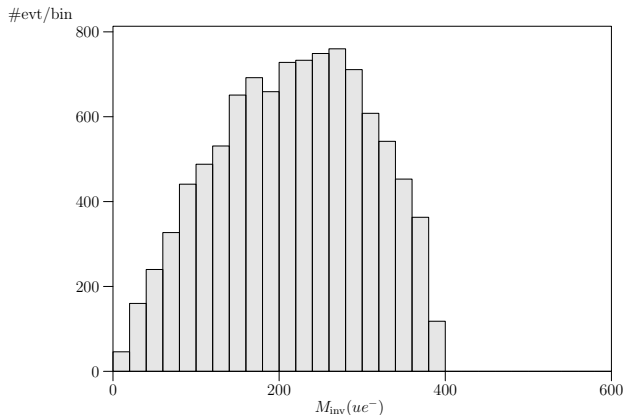
► **Factorized process w/ full spin correlations:**



Example: LHC SUSY cascade decays

$$p + p \rightarrow \tilde{u} + \tilde{u}^* \rightarrow \tilde{u}_1 + u + \tilde{e}_{12}^+ + e^-$$

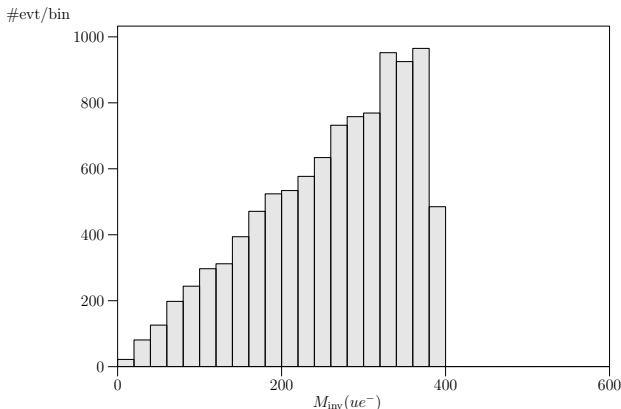
► Factorized process w/ classical spin correlations:



Example: LHC SUSY cascade decays

$$p + p \rightarrow \tilde{u} + \tilde{u}^* \rightarrow \tilde{u}_1 + u + \tilde{e}_{12}^+ + e^-$$

► **Factorized process w/ no spin correlations:**



Comparison for the NLO BSM

Braum, Fuks, JRR, 2010

Process	MG-FR	CH-FR	WO-ST	Comparison	Process	MG-FR	CH-FR	WO-ST	Comparison
CAU, CAU->CAU, RL	4.48997×10^{-3}	4.4892×10^{-3}	4.49008×10^{-3}	$\delta = 0.0330272$	W-, Z>b, t-	7.11557×10^{-1}	7.0989×10^{-1}	7.11436×10^{-1}	$\delta = 0.234537$
CAU, CAU->CAU, RL	7.2009×10^{-3}	7.2009×10^{-3}	7.2009×10^{-3}	$\delta = 0.0000000$	W-, Z>b, W-	3.01819×10^2	3.0264×10^2	3.0193×10^2	$\delta = 0.271739$
CAU, CAU->e, e-	4.49207×10^{-3}	4.4920×10^{-3}	4.49208×10^{-3}	$\delta = 0.0093631$	W-, Z>a, W-	7.4661×10^{-1}	7.4604×10^{-1}	7.43748×10^{-1}	$\delta = 0.384101$
CAU, CAU->e, e-	9.75351×10^{-3}	9.7635×10^{-3}	9.7635×10^{-3}	$\delta = 0.10288$	W-, Z>sl-, sv1-	2.36706×10^{-3}	2.369×10^{-3}	2.37235×10^{-3}	$\delta = 0.223033$
CAU, CAU->e, e-	9.75351×10^{-3}	9.7635×10^{-3}	9.7635×10^{-3}	$\delta = 0.10288$	W-, Z>sl-, sv2-	2.40865×10^{-3}	2.4109×10^{-3}	2.41163×10^{-3}	$\delta = 0.123994$
CAU, CAU->e, e-	3.35941×10^{-1}	3.3592×10^{-1}	3.3592×10^{-1}	$\delta = 0.167014$	W-, Z>sl1-, sv3-	1.16665×10^{-3}	1.1695×10^{-3}	1.17192×10^{-3}	$\delta = 0.45102$
CAU, CAU->e, e-	7.12912×10^{-3}	7.1259×10^{-3}	7.12673×10^{-3}	$\delta = 0.0451506$	W-, Z>sl6-, sv3-	1.2085×10^{-1}	1.2067×10^{-1}	1.20652×10^{-1}	$\delta = 0.164307$
CAU, CAU->e, e-	7.12592×10^{-3}	7.12592×10^{-3}	7.12592×10^{-3}	$\delta = 0.0000000$	W-, Z>sd4, su2-	3.51869×10^{-3}	3.5133×10^{-3}	3.51169×10^{-3}	$\delta = 0.199274$
CAU, CAU->e, e-	3.61339×10^{-3}	3.6131×10^{-3}	3.6177×10^{-3}	$\delta = 0.101598$	W-, Z>sd1, su1-	1.14587×10^{-2}	1.1447×10^{-2}	1.14423×10^{-2}	$\delta = 0.143534$
CAU, CAU->e, e-	3.61069×10^{-3}	3.6139×10^{-3}	3.6143×10^{-3}	$\delta = 0.0997308$	W-, Z>sd6, su6-	2.3412×10^{-2}	2.3479×10^{-2}	2.34716×10^{-2}	$\delta = 0.285674$
CAU, CAU->e, e-	1.00467×10^{-3}	1.0129×10^{-3}	1.0129×10^{-3}	$\delta = 0.077638$	W-, Z>sd6, su1-	1.27978×10^{-2}	1.2783×10^{-2}	1.27793×10^{-2}	$\delta = 0.144221$
CAU, CAU->e, e-	1.02967×10^{-3}	1.0315×10^{-3}	1.03164×10^{-3}	$\delta = 0.191255$	W-, Z>n1, xl-	5.58187×10^{-3}	5.5834×10^{-3}	5.5787×10^{-3}	$\delta = 0.0842243$
CAU, CAU->e, e-	4.2117×10^{-3}	4.2129×10^{-3}	4.21696×10^{-3}	$\delta = 0.124826$	W-, Z>n2, xl-	2.58653×10^{-2}	2.5885×10^{-2}	2.59104×10^{-2}	$\delta = 0.174$
CAU, CAU->e, e-	1.29047×10^{-3}	1.29047×10^{-3}	1.29047×10^{-3}	$\delta = 0.0000000$	W-, Z>n3, xl-	1.87516×10^{-1}	1.8743×10^{-1}	1.87014×10^{-1}	$\delta = 0.267929$
CAU, CAU->e, e-	1.17192×10^{-3}	1.172×10^{-3}	1.17143×10^{-3}	$\delta = 0.0487576$	W-, Z>n4, xl-	5.29225×10^{-2}	5.2915×10^{-2}	5.28743×10^{-2}	$\delta = 0.091285$
CAU, CAU->e, e-	1.17209×10^{-3}	1.1721×10^{-3}	1.17107×10^{-3}	$\delta = 0.0078297$	W-, Z>n5, xl-	8.68647×10^{-2}	8.6797×10^{-2}	8.68217×10^{-2}	$\delta = 0.0779207$
CAU, CAU->e, e-	1.05013×10^{-3}	1.05013×10^{-3}	1.05013×10^{-3}	$\delta = 0.0000000$	W-, Z>n1, x2-	4.25162×10^{-3}	4.2539×10^{-3}	4.25377×10^{-3}	$\delta = 0.0535405$
CAU, CAU->e, e-	1.41851×10^{-3}	1.4178×10^{-3}	1.41878×10^{-3}	$\delta = 0.0089563$	W-, Z>n2, x2-	1.86172×10^{-2}	1.8623×10^{-2}	1.86507×10^{-2}	$\delta = 0.179804$
CAU, CAU->e, e-	1.39313×10^{-3}	1.3925×10^{-3}	1.39156×10^{-3}	$\delta = 0.112937$	W-, Z>n3, x2-	5.08905×10^{-2}	5.0974×10^{-2}	5.10002×10^{-2}	$\delta = 0.215293$
CAU, CAU->e, e-	1.5723×10^{-3}	1.5715×10^{-3}	1.56948×10^{-3}	$\delta = 0.179775$	W-, Z>n4, x2-	3.87418×10^{-2}	3.8743×10^{-2}	3.87516×10^{-2}	$\delta = 0.0253781$
CAU, CAU->e, e-	1.46613×10^{-3}	1.46632×10^{-3}	1.46607×10^{-3}	$\delta = 0.0374058$	W-, Z>n5, x2-	2.30577×10^{-2}	2.3033×10^{-2}	2.3038×10^{-2}	$\delta = 0.107112$
CAU, CAU->e, e-	4.83808×10^{-4}	4.8377×10^{-4}	4.83538×10^{-4}	$\delta = 0.0557691$	W-, Z>h01, H-	3.06927×10^{-6}	3.069×10^{-6}	3.07074×10^{-6}	$\delta = 0.0566669$
CAU, CAU->e, e-	4.83818×10^{-4}	4.8377×10^{-4}	4.84209×10^{-4}	$\delta = 0.0506177$	W-, Z>h02, H-	2.10593×10^{-4}	2.1061×10^{-4}	2.10462×10^{-4}	$\delta = 0.124203$
CAU, CAU->e, e-	1.07924×10^{-3}	1.0791×10^{-3}	1.07878×10^{-3}	$\delta = 0.001321$	W-, Z>h03, H-	2.1414×10^{-3}	2.1392×10^{-3}	2.13929×10^{-3}	$\delta = 0.102916$
CAU, CAU->e, e-	1.69313×10^{-3}	1.6939×10^{-3}	1.69378×10^{-3}	$\delta = 0.115289$	W-, Z>A01, H-	2.71579×10^{-4}	2.7161×10^{-4}	2.71278×10^{-4}	$\delta = 0.122266$
CAU, CAU->e, e-	1.07887×10^{-3}	1.07891×10^{-3}	1.07862×10^{-3}	$\delta = 0.0041113$	W-, Z>A02, H-	1.28349×10^{-1}	1.2827×10^{-1}	1.28247×10^{-1}	$\delta = 0.0795463$
CAU, CAU->e, e-	1.33962×10^{-3}	1.3397×10^{-3}	1.34002×10^{-3}	$\delta = 0.0249072$	W-, Z>W-, h01	7.94029×10^1	7.9468×10^1	7.93492×10^1	$\delta = 0.149577$
CAU, CAU->e, e-	1.20597×10^{-3}	1.2063×10^{-3}	1.20707×10^{-3}	$\delta = 0.0912099$	W-, Z>W-, h02	1.70391	1.7037	1.7087	$\delta = 0.293178$
CAU, CAU->e, e-	9.46274×10^{-4}	9.4643×10^{-4}	9.46582×10^{-4}	$\delta = 0.0325597$	W-, Z>W-, h03	3.98499×10^{-5}	3.9924×10^{-5}	4.00474×10^{-5}	$\delta = 0.494346$
CAU, CAU->e, e-	2.8463×10^{-4}	2.8468×10^{-4}	2.78524×10^{-4}	$\delta = 0.141889$	W-, Z>W-, A01	6.99895×10^{-8}	6.985×10^{-8}	7.00424×10^{-8}	$\delta = 0.275123$
CAU, CAU->e, e-	1.1076×10^{-3}	1.1077×10^{-3}	1.10863×10^{-3}	$\delta = 0.0927793$	W-, Z>W-, A02	1.36107×10^{-5}	1.361×10^{-5}	1.36221×10^{-5}	$\delta = 0.0886822$
CAU, CAU->e, e-	1.10735×10^{-3}	1.1077×10^{-3}	1.1096×10^{-3}	$\delta = 0.144715$	W-, Z>Z, H-	1.40065×10^{-5}	1.4004×10^{-5}	1.39963×10^{-5}	$\delta = 0.0730172$
CAU, CAU->e, e-	4.50337×10^{-4}	4.5034×10^{-4}	4.49875×10^{-4}	$\delta = 0.103213$					
CAU, CAU->e, e-	2.69738×10^{-3}	2.697×10^{-3}	2.69575×10^{-3}	$\delta = 0.0603979$					
CAU, CAU->e, e-	3.73641×10^{-3}	3.7367×10^{-3}	3.74042×10^{-3}	$\delta = 0.107316$					
CAU, CAU->e, e-	2.76715×10^{-3}	2.76715×10^{-3}	2.76715×10^{-3}	$\delta = 0.0000000$					
CAU, CAU->e, e-	4.46003×10^{-3}	4.4579×10^{-3}	4.45993×10^{-3}	$\delta = 0.0478212$					
CAU, CAU->e, e-	2.76715×10^{-3}	2.76715×10^{-3}	2.76715×10^{-3}	$\delta = 0.0000000$					
CAU, CAU->e, e-	1.21883×10^{-3}	1.21883×10^{-3}	1.21746×10^{-3}	$\delta = 0.117815$					
CAU, CAU->e, e-	8.67964×10^{-4}	8.6792×10^{-4}	8.68336×10^{-4}	$\delta = 0.0939997$					
CAU, CAU->e, e-	3.89644×10^{-3}	3.89644×10^{-3}	3.89644×10^{-3}	$\delta = 0.0000000$					
CAU, CAU->e, e-	6.26043×10^{-3}	6.26043×10^{-3}	6.26043×10^{-3}	$\delta = 0.0000000$					
CAU, CAU->e, e-	9.2264×10^{-4}	9.2259×10^{-4}	9.21935×10^{-4}	$\delta = 0.076501$					
CAU, CAU->e, e-	6.51046×10^{-4}	6.4974×10^{-4}	6.49434×10^{-4}	$\delta = 0.247567$					
CAU, CAU->e, e-	3.1845×10^{-3}	3.1845×10^{-3}	3.1845×10^{-3}	$\delta = 0.0000000$					
CAU, CAU->e, e-	1.82736×10^{-3}	1.8266×10^{-3}	1.82605×10^{-3}	$\delta = 0.0721419$					
CAU, CAU->e, e-	6.13979×10^{-3}	6.13979×10^{-3}	6.13979×10^{-3}	$\delta = 0.0000000$					
CAU, CAU->e, e-	1.58933×10^{-3}	1.5892×10^{-3}	1.58917×10^{-3}	$\delta = 0.0712317$					
CAU, CAU->e, e-	1.76086×10^{-3}	1.7621×10^{-3}	1.76277×10^{-3}	$\delta = 0.108868$					
CAU, CAU->e, e-	3.30247×10^{-3}	3.30247×10^{-3}	3.30247×10^{-3}	$\delta = 0.0000000$					
CAU, CAU->e, e-	8.49209×10^{-3}	8.4901×10^{-3}	8.4722×10^{-3}	$\delta = 0.228377$					
CAU, CAU->e, e-	4.58133×10^{-3}	4.5956×10^{-3}	4.59502×10^{-3}	$\delta = 0.110892$					
CAU, CAU->e, e-	2.3941×10^{-3}	2.3941×10^{-3}	2.3941×10^{-3}	$\delta = 0.0000000$					
CAU, CAU->e, e-	4.92753×10^{-3}	4.9314×10^{-3}	4.9295×10^{-3}	$\delta = 0.0784249$					
CAU, CAU->e, e-	2.16262×10^{-3}	2.1626×10^{-3}	2.16185×10^{-3}	$\delta = 0.035671$					
CAU, CAU->e, e-	7.00572×10^{-4}	7.00572×10^{-4}	7.00463×10^{-4}	$\delta = 0.0099268$					
CAU, CAU->e, e-	5.11735×10^{-3}	5.1179×10^{-3}	5.12057×10^{-3}	$\delta = 0.0629171$					
CAU, CAU->e, e-	9.84532×10^{-3}	9.8445×10^{-3}	9.82302×10^{-3}	$\delta = 0.224698$					
CAU, CAU->e, e-	2.57031×10^{-3}	2.57031×10^{-3}	2.57031×10^{-3}	$\delta = 0.0000000$					
CAU, CAU->e, e-	2.36658×10^{-3}	2.36658×10^{-3}	2.36651×10^{-3}	$\delta = 0.076646$					
CAU, CAU->e, e-	1.07849×10^{-3}	1.07877×10^{-3}	1.07962×10^{-3}	$\delta = 0.105076$					
CAU, CAU->e, e-	1.48778×10^{-3}	1.48809×10^{-3}	1.48858×10^{-3}	$\delta = 0.003316$					
CAU, CAU->e, e-	4.85736×10^{-4}	4.8605×10^{-4}	4.89451×10^{-4}	$\delta = 0.762018$					
CAU, CAU->e, e-	1.04814×10^{-3}	1.0476×10^{-3}	1.04731×10^{-3}	$\delta = 0.0019548$					
CAU, CAU->e, e-	4.7139×10^{-3}	4.7139×10^{-3}	4.7139×10^{-3}	$\delta = 0.0000000$					
CAU, CAU->e, e-	9.0480×10^{-3}	9.0461×10^{-3}	9.03757×10^{-3}	$\delta = 0.12871$					
CAU, CAU->e, e-	3.33906×10^{-3}	3.36633×10^{-3}	3.66845×10^{-3}	$\delta = 0.08409$					
CAU, CAU->e, e-	4.79704×10^{-3}	4.7967×10^{-3}	4.79803×10^{-3}	$\delta = 0.0278007$					
CAU, CAU->e, e-	0.01345×10^{-3}	0.0134×10^{-3}	0.0137×10^{-3}	$\delta = 0.0099268$					
CAU, CAU->e, e-	2.81408×10^{-3}	2.8159×10^{-3}	2.82663×10^{-3}	$\delta = 0.416406$					
CAU, CAU->e, e-	1.08173×10^{-3}	1.0817×10^{-3}	1.08261×10^{-3}	$\delta = 0.0842393$					
CAU, CAU->e, e-	2.2849×10^{-3}	2.2849×10^{-3}	2.2849×10^{-3}	$\delta = 0.0000000$					
CAU, CAU->e, e-	2.93826×10^{-3}	2.9386×10^{-3}	2.93557×10^{-3}						

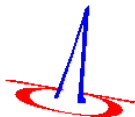
WHIZARD 2.1 – Outlook

- ▶ Lots of internal technical improvement and tuning
- ▶ Arbitrary Lorentz structures (beware of color!)
- ▶ Generalized color structures
- ▶ Automatic integration of decays
- ▶ $\Rightarrow$ Calculation of Dark Matter annihilation
- ▶ Much improved (analytical) helicity selection rules
- ▶ Parton shower (complete ISR/FSR; by S. Schmidt)
- ▶ $\Rightarrow$ MLM/CKKW(-L) mixing inside WHIZARD
- ▶ Underlying event (by H.-W. Boschmann)
- ▶ NLO interface (BLHA); automatic generation of dipole subtraction

Summary / Outlook

- ▶ **WHIZARD 2 released**

Ready for the LHC era



- ▶ Huge improve-/enhancement of versatile, successful tool
- ▶ **Focus on BSM physics**
- ▶ Steered via the HepFORGE page:
<http://projects.hepforge.org/whizard>
- ▶ After release: rapidly approaching design performance
- ▶ Waiting for LHC to reach design performance:

One Ring to Find Them ???

One Ring to Rule Them Out ???

