Status of the Event Generator WHIZARD

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with recent contributions from Felix Braam, Sebastian Schmitt

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The need for Multi-Particle Event Generators

New collider environments more complicated

Very complicated signal/background processes

New physics:

- DM: Conserved discrete parity: pair production, decay chains
- Complicated, quasi-degenerate spectrum at the Terascale
- High-multiplicity final states

ILC allows for precision measurements at least at per cent-level

Need for Multi-Particle Event Generators

JR, Snowmass 05; Hagiwara et al., 06; Hewett, 07; Kilian/JR

- BSM processes do not factorize into $2 \to 2$ production/decay
- Interferences of several (partially) resonant diagram groves
- Off-shell effects violate Breit-Wigner approximation

Berdine/Kauer/Rainwater 07;

The Multi-Particle Generator WHIZARD

Kilian/Ohl/JR, 07

Very high level of Complexity:

- $e^+e^- \to t\bar{t}H \to b\bar{b}b\bar{b}jj\ell\nu$ (110,000 diagrams)
- $e^+e^- \to ZHH \to ZWWWW \to bb + 8j$ (12,000,000 diagrams)
- $pp \to \ell\ell + nj, n = 0, 1, 2, 3, 4, \ldots$ (2,100,000 diagrams with 4 jets + flavors)
- $pp \to \tilde{\chi}_1^0\tilde{\chi}_1^0 bbbb$ (32,000 diagrams, 22 color flows, $\sim 10,000$ PS channels)
- $pp \to VVjj \to jj\ell\ell\nu\nu$ incl. anomalous TGC/QGC
- Test case $gg \to 9g$ (224,000,000 diagrams)

Current versions:

WHiZard 1.51 / O'Mega 000.011beta Ω $\to$ joint version:

WHIZARD 1.92 release date: 2008, April, 29th

one grand unified package (incl. VAMP, Circe, Circe 2, WHiZard, O'Mega)

New web address: `http://whizard.event-generator.org`

Standard Reference for 1.92 + new versions: Kilian/Ohl/JR, 0708.4233

- Major upgrade this summer (most code ready!!!): WHIZARD 2.0.0

Technical details about WHIZARD

Status of WHIZARD 1.92: Installation

- Download tar-ball from `http:whizard.event-generator.org`
- unpack, do `configure`, `make install` that's it!
- OK, granted: specify locations of external packages and O'Caml language (part of many Linux distributions, `http://caml.inria.fr`)

WHIZARD is written in Fortran 90/95. Compiler status?

- works w/ (almost) all commercial compilers: Intel, Lahey, NAG, Pathscale
- Portland has a severe compiler bug
- compiles with g95
- compiles with gfortran 4.3.0 (is part of new Linux SuSE 11.0, Debian lenny, ...)
- lots of Fortran2003 features (e.g. C bindings)
  (No need for reprogramming in C++)

Basic facts:

- Helicity amplitudes with complete avoidance of redundancies
- Iterative adaptive multi-channel phase space (viable for $2 \to 10$)
- **Unweighted events** (formats: binary, HEPEVT, ATHENA, LHA (old), LHE (new), STDHEP)
- Graphical analysis tool

Implemented Physics Content

Structured beams:

For Tevatron/LHC: PDFs from LHAPDF (or PDFLIB)
For ILC physics:

- ISR (implemented: Skrzypek/Jadach, Kuraev/Fadin)
- arbitrarily polarized beams
- beamstrahlung, photon collider spectra (CIRCE/CIRCE 2)

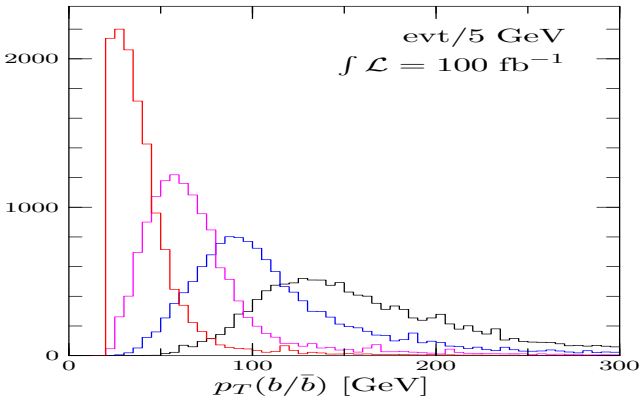
external (user-defined) beam spectra can be read in

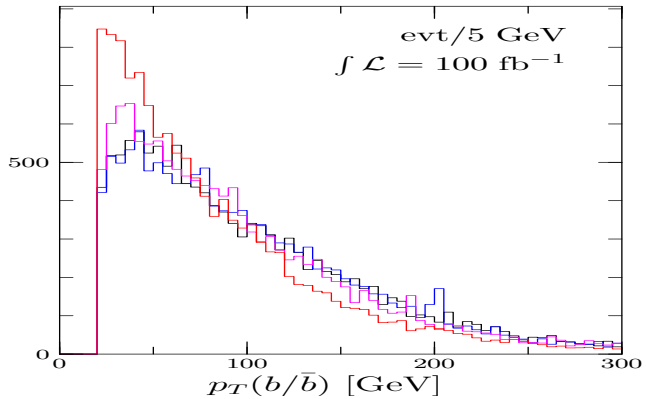
Supported Physics Models:

- Test models: QED, QCD
- SM
- Littlest/Simplest Little Higgs, Little Higgs Models with T parity
- Moose models: 3-site model
- MSSM, NMSSM, extended SUSY models, incl. gravitinos (SLHA/SLHA2)
- Graviton resonances, Universal extra dimensions, Randall-Sundrum
- Noncommutative Standard Model
- Higher-dimensional operators, SM effective field theory extensions
- Anomalous triple and quartic gauge couplings
- K-matrix/Padé unitarization, unitarized resonances Alboteanu/Kilian/JR, 0806.4145

WHIZARD LHC/Tevatron Application/Projects

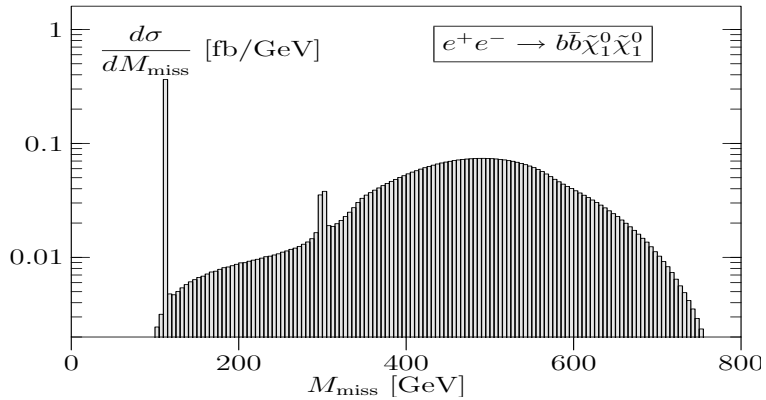
- SUSY Simulations and Studies — quasi World-Wide Study
- WW scattering + anomalous couplings — Bonn/Freiburg/Dresden/Siegen
- Determination of LHC signal significances — BNL/Edinburgh/Freiburg
- BSM mass spectrum determinations — CERN/Freiburg/UC Davis
- Lepton Flavor Violation — DESY/Manchester
- BSM CP properties — Bonn/Freiburg
- Little Higgs studies — Freiburg/Rochester/Siegen
- KK graviton studies — Freiburg/Moscow/Siegen
- general Z'/W' studies — Ottawa/Freiburg/Madison
- noncommutative SM extensions — Würzburg
- Interplay ATLFAST2–MC development — Freiburg
- BSM Multijet studies — DESY/Dresden/Edinburgh/KEK/Rochester





WHIZARD ILC Applications/Projects

- SUSY simulations and studies — quasi World-Wide study
- Detector optimization studies — DESY/Fermilab
- Electroweak precision studies — DESY/Fermilab/Freiburg/SLAC
- WW scattering/Triple boson production — DESY/Rostock
- Photon collider studies — DESY/Würzburg
- Top and Higgs studies — DESY/Freiburg/London/RAL
- Little Higgs Studies — Ottawa/Freiburg/Rochester/Siegen
- Dark matter studies — Bonn/DESY/Freiburg/SLAC
- Benchmarking/Standard Event Samples — DESY/SLAC
- ISR/beamstrahlung studies:



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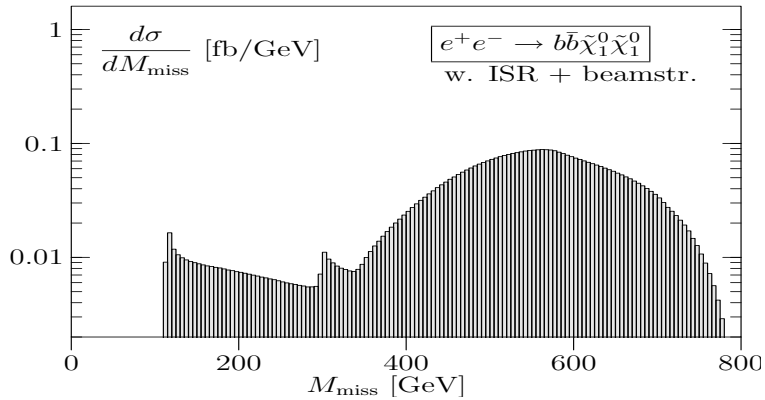
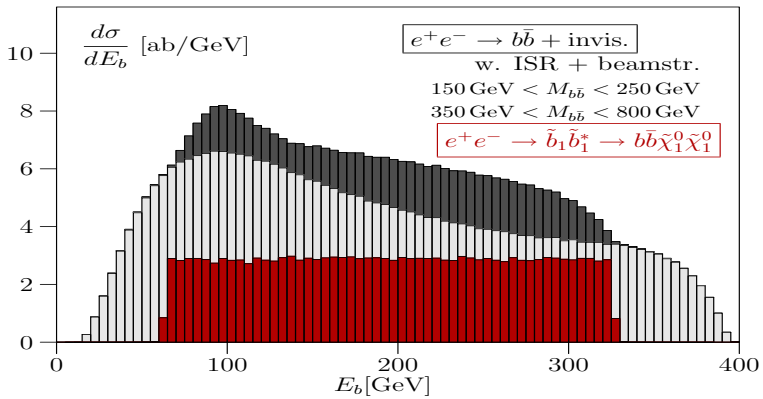




WHIZARD installation

- Direct `svn` checkout possible
- Create directory `[whizard_dir]` and unpack WHIZARD tarball
- Edit the file `config.site` and insert the locations of

  `CERNLIB_DIR=[cernlib_dir]` (optional)
  `STDHEP_DIR=[stdhep_dir]` (optional)
  `LHAPDF_DIR=[lhapdf_dir]` (optional)
- from the top directory do:

  `./configure` `FC=ifort` (optional: specify FORTRAN compiler)
  `make man`: creates the manual `manual.pdf/ps` in `doc/`
  `make doc`: creates docu. source code `whizard.pdf/ps` (if `noweave` present)
- Now, you can already specify a process in file `conf/whizard.prc`
- from the top directory do:

  `make install`

configure status

```
.................
config.status: creating Makefile
config.status: creating bin/whizard.ld
config.status: executing default-1 commands
config.status: executing default-2 commands
config.status: executing default-3 commands

--- Configure summary: ---
--- Enabled features: ---
O'Mega     (Matrix elements)
CIRCE      (Beamstrahlung)          circe-src/
CIRCE2     (Beamstrahlung)          circe2-src/
LHAPDF     (Structure functions) /usr/local/lib/libLHAPDF.a
LaTeX/Metapost   (Histograms)     /usr/bin/mpost
Autoconf   (Restricted bundle)    autoconf

--- Disabled or absent features: ---
PYTHIA     (Fragmentation)
STDHEP     (Binary event files)

--- Configuration complete. ---
```

Models currently supported by WHIZARD

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 couplings	SM_ac_CKM	SM_ac
MSSM	MSSM_CKM	MSSM
NMSSM	NMSSM_CKM	NMSSM
Littlest Higgs	—	Littlest
LH with ungauged $U(1)$	—	Littlest_Eta
LH w/ T parity	—	Littlest_Tpar
Simplest Little Higgs (anomaly-free)	—	Simplest
Simplest Little Higgs (universal)	—	Simplest_univ
SM with spin-2 graviton	—	Xdim
SM with gravitino and photino	—	GravTest
Augmentable SM template	—	Template

2.0.0: LH with T parity, SUSY exotics like ESSM/PSSSM, NCSM, UED

Process file: `conf/whizard.prc`

Model selection: we already had that

Particles names: look in `conf/whizard.prc.XXX` or `conf/models/Model.mdl`

`test`: Constant matrix elements for testing, e.g. structure function

```
# WHIZARD configuration file

# The selected model
model   SM

alias q u:d:s:c
alias Q U:D:S:C

# Processes
#  Methods: ....., omega=O'Mega, test=trivial)
#  Options: r      restricted intermediate state (O'Mega)
#           c      apply exact color algebra (O'Mega)
#           w:XXX  width scheme (O'Mega)
#           u      unit matrix element (test)
#
# Tag           In      Out             Method  Option
#=================================================
em              e1,E1   e2,E2           omega
em_test         e1,E1   e2,E2           test
em_test         e1,E1   e2,E2           test    u
eeqq            e1,E1   u:d:s,U:D:S     omega
uudd_nc         u,U     d,D             omega
uudd            u,U     d,D             omega   c
qqwz            q,Q     W,Z             omega
ee_z_only       e1,E1   e1,E1           omega   r:3+4~Z
```

Options available:

- `u (test)`: unit matrix element
- `c (omega)`: exact color amplitudes and full color flow information
  will be leading N_C in 2.0.0
- `r: (omega)`: restricted diagrams (cascading)
- `w: (omega)`: different width schemes (fudge, fixed, ...

After changes in `whizard.prc` do `make install`

Input file: `results/whizard.in` (NAMELIST fmt)

Let's just do a simple example (better than audience buffer overflow): $e^+e^- \to \mu^-\bar{\nu}_\mu u\bar{d}$

- `conf/whizard.prc`:

```
# The selected model
model   SM
# Tag   In      Out           Method  Option
#=======================================
cc10    e1,E1   e2,N2,u,D     omega
```

- `make install`
- edit `results/whizard.in`

```
&process_input
process_id = "cc10"
sqrts = 500
/
&integration_input
/
&simulation_input
/
&diagnostics_input
/
&parameter_input
Mmu = 0
/
&beam_input
/
&beam_input
/
```

- `whizard` executable in `results` is MC generator for process cc10, to run do
  a) Execute `./whizard` in `results` with command line options (cf. `./whizard --help`)
  b) `make run`, either in `results` or the top directory

```
! WHIZARD 1.92 (Mar 12 2008)
! Reading process data from file whizard.in
! Wrote whizard.out
!
! Process cc10:
!    e a-e ->  mu a-nu_mu   u a-d
!   32  16 ->   1       2   4   8
! Process energy set to     209.00     GeV
! Reading vertices from file whizard.mdl ...
! Model file:       54 trilinear vertices found.
! Model file:       54 vertices usable for phase space setup.
! Generating phase space channels for process cc10...
! Warning: Intermediate decay of zero-width particle mu may be possi
! Phase space:       8 phase space channels generated.
! Scanning phase space channels for equivalences ...
! Phase space:       8 equivalence relations found.
! Note: This cross section may be infinite without cuts.
! Wrote default cut configuration file whizard.cc10.cut0
! Wrote phase space configurations to file whizard.phx
!
! Created grids:      8 channels,  8 dimensions with 20 bins
```

```
! WHIZARD run for process cc10:
!=============================================================================
! It      Calls  Integral[fb]  Error[fb]   Err[%]    Acc  Eff[%]   Chi2 N[It]
!-----------------------------------------------------------------------------
! Reading cut configuration data from file whizard.cut1
! No cut data found for process cc10
! Using default cuts.
cut M of   12      within  1.00000E+01  1.00000E+99
! Preparing (fixed weights):   1 sample of      20000 calls ...
   1      20000  2.6806323E+02  1.01E+01    3.76    5.31*  1.66    0.00   1
!-----------------------------------------------------------------------------
! Adapting (variable wgts.):  10 samples of      20000 calls ...
   2      20000  2.7592027E+02  1.05E+01    3.81    5.38   1.50
   3      20000  2.7127725E+02  1.96E+00    0.72    1.02* 10.69
   4      20000  2.7123539E+02  1.51E+00    0.56    0.79* 11.73
   5      20000  2.7016999E+02  1.36E+00    0.50    0.71* 15.36
   6      20000  2.7204042E+02  1.32E+00    0.49    0.69* 16.44
   7      20000  2.7265921E+02  1.30E+00    0.47    0.67* 16.40
   8      20000  2.7105262E+02  1.28E+00    0.47    0.67* 13.70
   9      20000  2.7154268E+02  1.27E+00    0.47    0.66* 15.15
  10      20000  2.7265788E+02  1.33E+00    0.49    0.69  11.91
  11      20000  2.7105441E+02  1.32E+00    0.49    0.69  12.45
!-----------------------------------------------------------------------------
! Integrating (fixed wgts.):   3 samples of      20000 calls ...
  12      60000  2.7196199E+02  7.48E-01    0.27    0.67  10.72    1.39   3
!-----------------------------------------------------------------------------
!
! Time estimate for generating 10000 unweighted events:    0h 00m 03s
!=============================================================================
! Summary (all processes):
!-----------------------------------------------------------------------------
! Process ID     Integral[fb]  Error[fb]   Err[%]        Frac[%]
!-----------------------------------------------------------------------------
  cc10           2.7196199E+02  7.48E-01    0.27         100.00
!-----------------------------------------------------------------------------
  sum            2.7196199E+02  7.48E-01    0.27         100.00
!=============================================================================
! Wrote whizard.out
! Integration complete.
! No event generation requested
! WHIZARD run finished.
```

Further steps: Event Generation

`whizard.in`:

```
&process_input
process_id = "cc10"
sqrts = 500
luminosity = 10
/
&integration_input
read_grids = T
/
&simulation_input /
&diagnostics_input /
&parameter_input
Mmu = 0
/
&beam_input /
&beam_input /
```

`Screen output:`

```
! Using grids and results from file:
! Reading analysis configuration data from file whizard.cut5
! No analysis data found for process cc10
! Event sample corresponds to luminosity [fb-1] =    9.999
! Event sample corresponds to       22665  weighted events
! Generating       2717 unweighted events ...
!===============================================================================
! Analysis results for process cc10:
! It      Events Integral[fb]  Error[fb]   Err[%]    Acc  Eff[%]   Chi2 N[It]
!-------------------------------------------------------------------------------
  13       2717  2.7173259E+02  5.21E+00    1.92    1.00 100.00
!-------------------------------------------------------------------------------
! Warning: Excess events:    1.2       (    0.04% )  | Maximal weight:  1.04
! There were no errors and  2 warning(s).
! WHIZARD run finished.
```

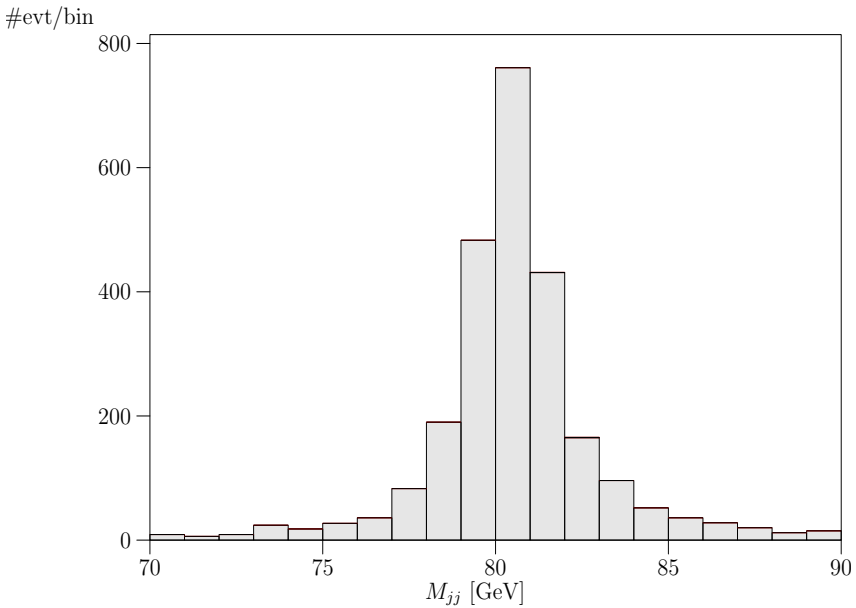
Further steps: Event Generation

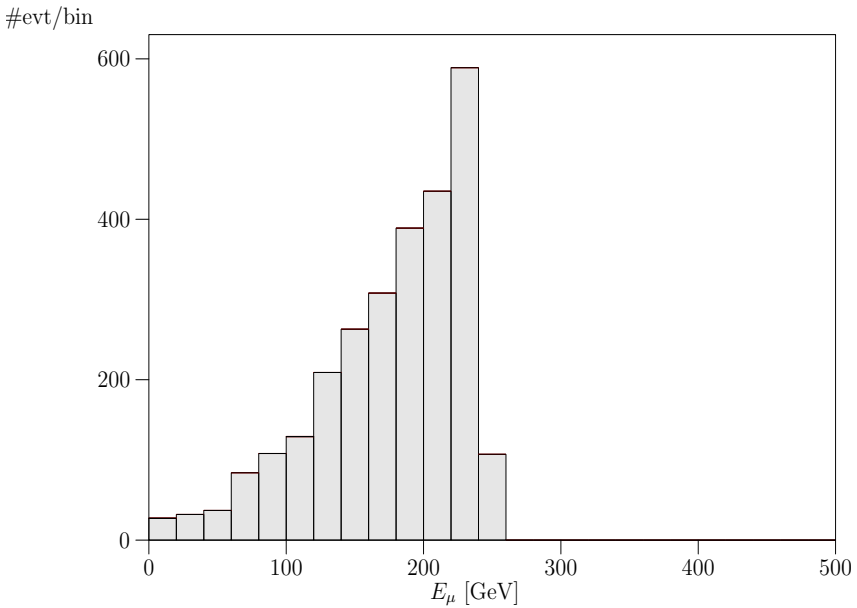
`whizard.in`:

```
&process_input
process_id = "cc10"
sqrts = 500
luminosity = 10
/
&integration_input
read_grids = T
/
&simulation_input /
&diagnostics_input /
&parameter_input
Mmu = 0
/
&beam_input /
&beam_input /
```

Screen output:

```
! Using grids and results from file:
! Reading analysis configuration data from file whizard.cut5
! No analysis data found for process cc10
! Event sample corresponds to luminosity [fb-1] =    9.999
! Event sample corresponds to       22665  weighted events
! Generating       2717 unweighted events ...
!=============================================================================
! Analysis results for process cc10:
! It      Events Integral[fb]  Error[fb]   Err[%]    Acc  Eff[%]   Chi2 N[It]
!-----------------------------------------------------------------------------
  13       2717  2.7173259E+02  5.21E+00    1.92    1.00 100.00
!-----------------------------------------------------------------------------
! Warning: Excess events:    1.2       (    0.04% )   | Maximal weight:  1.04
! There were no errors and  2 warning(s).
! WHIZARD run finished.
```





Useful: `results/make channels`

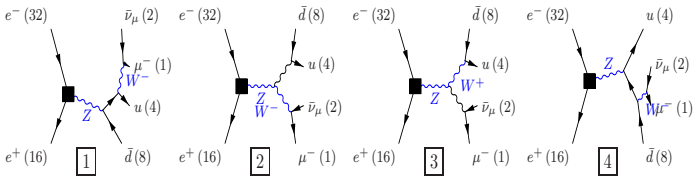
make channels in `results/` produces (graphical representation of) most important phase space channels:

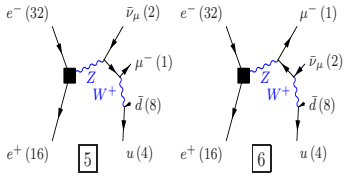
WHIZARD phase space channels March 15, 2007

Process: `cc10` ($e^-e^+ \to \mu^-\bar{\nu}_\mu u\bar{d}$)
Color code: resonance, t-channel, radiation, infrared, collinear, external/off-shell

Grove 1

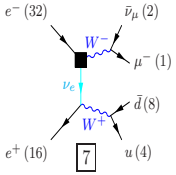
Multiplicity: 1
Resonances: 2
Log-enhanced: 0
t-channel: 0





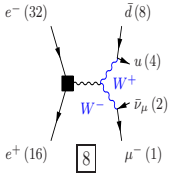
Grove 2

Multiplicity: 2
Resonances: 2
Log-enhanced: 1
t-channel: 1



Grove 3

Multiplicity: 2
Resonances: 2
Log-enhanced: 0
t-channel: 0

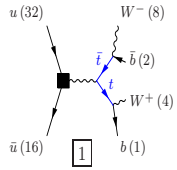


WHIZARD phase space channels March 16, 2007

Process: `qqttdec` ($u\bar{u} \to b\bar{b}W^+W^-$)
Color code: resonance, t-channel, radiation, infrared, collinear, external/off-shell

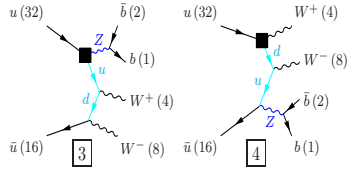
Grove 1

Multiplicity: 2
Resonances: 2
Log-enhanced: 0
t-channel: 0



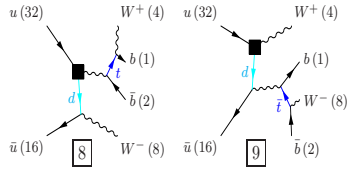
Grove 3

Multiplicity: 3
Resonances: 1
Log-enhanced: 2
t-channel: 2



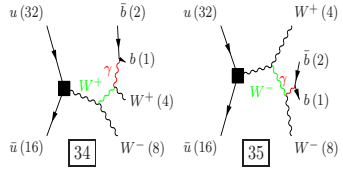
Grove 6

Multiplicity: 3
Resonances: 1
Log-enhanced: 1
t-channel: 1



Grove 19

Multiplicity: 4
Resonances: 0
Log-enhanced: 2
t-channel: 0



Input blocks in `results/whizard.in`

&process_input

```
process_id = ""          ! Process Name

sqrts = 0                ! CM energy
luminosity = 0           ! [fb^-1]

structured_beams = F     ! structur f.



input_file = ""          ! appends .in
input_slha_format = F    ! SLHA(2) format
```

&integration_input

```
calls = 1 10000 3 10000 ! process dep.



read_grids = F           ! avoids adap.
```

&simulation input

```
n_events = 0             ! N_unweighted
n_calls = 0              ! ME calls (weighted)

unweighted = T           ! unweighted samples


write_events = F         ! whizard.evt (ext. use)
write_events_format = 1  ! Event format
several_file_opt. = ""   ! user-def. files
write_events_raw = T     ! whizard.evx
```

&diagnostics_input

&parameters_input

depends on used model, e.g. `gg = 1.218 ! g_s`

&beam_input

```
polarization = 0 0 0     ! fraction of pols.
```

Input blocks in `results/whizard.in`

&process_input

```
process_id = ""           ! Process Name
cm_frame = T              ! CM frame
sqrts = 0                 ! CM energy
luminosity = 0            ! [fb^-1]
polarized_beams = F       ! Polarization
structured_beams = F      ! structur f.
beam_recoil = F           ! Beam recoil
recoil_cons._mom. = F     ! p, not E cons.
filename = ""             ! instead of W
directory = ""            ! dir. for I/O
input_file = ""           ! appends .in
input_slha_format = F     ! SLHA format
```

&integration_input

```
calls = 1 10000 3 10000 ! process dep.
seed = undef.           ! random seed
reset_seed_each_process = F
accuracy_goal = 0       ! stops grid adap.
efficiency_goal = 100   ! stops grid adap.
time_limit_adaption = 0 ! time limit
stratified = T          ! srat. vs. import.
use_efficiency = F      ! eff. vs. acc.
weights_power = 0.25    ! Channel adap.
min_bins = 3            ! bins per dim.
max_bins = 20           ! bins per dim.
min_calls_per_bin = 10  ! calls per bin
min_calls_per_channel = 0
write_grids = T         ! Grid output
write_grids_raw = F     ! grid raw fmt
write_all_grids = F     ! all grid adap.
read_grids = F          ! avoids adap.
read_grids_raw = F      !
read_grids_force = F    ! forces reading
generate_phase_space = T ! whizard.phx
read_phase_space = T    ! read whizard.phs
several_file_opt. = ""  ! user-def. files
phase_space_only = F    ! stop after PS gen.
use_equivalences = T    ! use permut. symm.
azimuthal_dependece = F ! no azimuth info.
phase_space_setup_opt.  ! detailed PS setup
```

&simulation input

```
n_events = 0              ! N_unweighted
n_calls = 0               ! ME calls (weighted)
N_events_warmup = 0       ! xtra warmup events
unweighted = T            ! unweighted samples
normalize_weight = T      ! norm. to 1 vs. sigma
write_weights = F         ! write weights
write_events = F          ! whizard.evt (ext. use)
write_events_format = 1   ! Event format
several_file_opt. = ""    ! user-def. files
write_events_raw = T      ! whizard.evx
read_events[_force] = F   ! read whizard.evx
keep_xxx = F              ! record remnants/beam
guess_color_flow = F      ! for non-ex. flow info
recalculate = F           ! reeval. ME
fragment = F              ! fragmentation on/off
fragmentation_method = 0  ! PYTHIA/Jetset
user_fragmentation_method = 0
pythia_parameters = ""    ! PYTHIA frag. params.
```

&diagnostics_input

```
chattiness = 4            ! Message level
catch_signals = T         ! catch ext. sign.
time_limit = F            ! see manual
warn_empty_channel = F    !    dto.
screen_xxx = F            ! show on screen
show_pythia_xxx = T       ! Pythia output
write_logfile = T         ! whizard.xxx.out
show_input = T            ! see manual
show_results = T          ! integr. results
show_phase_space = F      ! PS config.
show_cuts = T             ! cuts in log file
show_histories = F        ! detailed VAMP history
show_history = T          ! VAMP summary
```

&parameters_input

```
 depends on used model,      e.g. gg = 1.218 ! g_s
```

&beam_input

```
energy = 0                ! E of beam
angle = 0                 ! angle of beams
direction = 0 0 0         ! beam direction in LAB
vector_polarization = F   ! long./transv. vs. hel.
polarization = 0 0 0      ! fraction of pols.
```

Output files, Cuts and Histograms

When you run a process, then the following files are written in `results/`:

- `whizard.out`: generic output summary
- `whizard.XXX.out`: process specific output
- `whizard.XXX.grc`, `whizard.XXX.grb[grc]`: best [current] grid for process XXX
- `whizard.phx`: phase space for current process

```
!    u a-u ->   u a-u   g
!   16   8 ->   1   2   4
process uuuug
  cut Q of 10 within -99999 -1
  cut Q of 17 within -99999 -1
  cut M of  3 within 10 99999
  cut E of  4 within  5 99999
  cut PT of 4 within 19 99999
  cut THETA(DEG) of  4 1 within 5 180
  cut THETA(DEG) of  4 2 within 5 180
```

Cuts and Histograms:

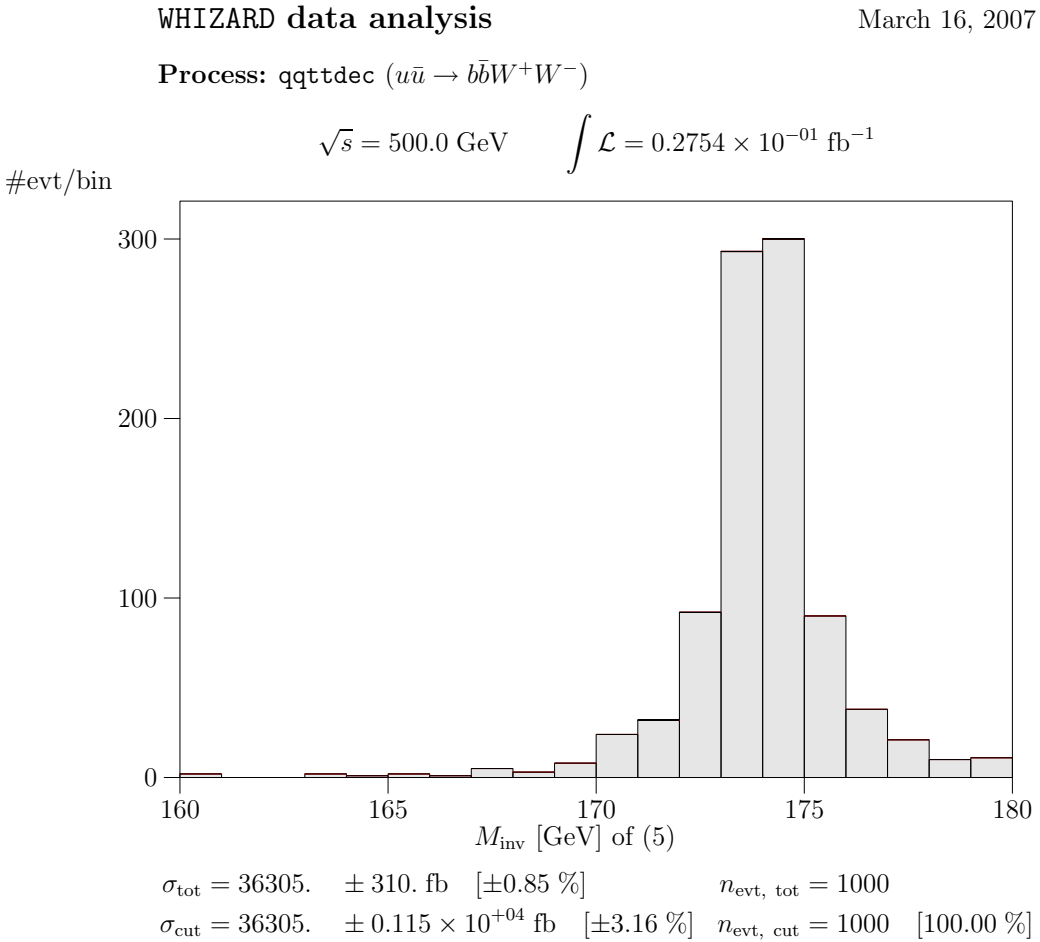
- File `results/whizard.cut1` Real kinematic cuts, taken into account for phase space int.
- File `results/whizard.cut5` Cuts for histogramming, declaration of desired histograms
- **Events needed for plots!**
- `make plots` produces `whizard-plots.ps`

```
!    u a-u ->   u a-u   g
!   16   8 ->   1   2   4
process uuuug
  cut M of 3 within  80 100
and
  cut M  of 3 within 180 200
  cut PT of 4 within 100 99999
and
  cut E of 4 within 0 100
  histogram PT of 1 within 0 500
histogram PT of 1 within 0 500
histogram PT of 1 within 0 500
```

Overview over allowed cuts and Histogram syntax

Code	Alternative code(s)	# Args	Description
-		$0-2$	No cut
M	Q	1	(Signed) invariant mass $M = \mathrm{sgn}(p^2)\sqrt{\lvert p^2\rvert}$
LM	LQ	1	$\log_{10} \lvert M\rvert$
MSQ	QSQ S T U	1	Squared invariant mass $M^2 = p^2$
E		1	Energy in the lab frame
LE		1	$\log_{10} E$
PT		1	Transverse momentum $p_\perp$
LPT		1	$\log_{10} p_\perp$
PL		1	Longitudinal momentum p_L
P		1	Absolute value of momentum $\lvert\vec{p}\rvert$
Y	RAP RAPIDITY	1	Rapidity y
ETA		1	Pseudorapidity η
DETA	DELTA-ETA	2	Pseudorapidity distance $\Delta\eta$
PH	PHI	1	Azimuthal angle ϕ (lab frame) in radians
PHD	PHID PHI(DEG)	1	Azimuthal angle ϕ (lab frame) in degrees
DPH	DPHI DELTA-PHI	2	Azimuthal distance $\Delta\phi$ (lab frame) in radians
DPHD	DPHID DELTA-PHI(DEG)	2	Azimuthal distance $\Delta\phi$ (lab frame) in degrees
AA	ANGLE-ABS TH-ABS THETA-ABS	1	Absolute polar angle θ_{abs} (lab frame) in radians. Reference axis is the z-axis.
AAD	ANGLE(DEG)		
	TH-ABS(DEG) THETA-ABS(DEG)	1	Absolute polar angle θ_{abs} (lab frame) in degrees
CTA	COS(TH-ABS) COS(THETA-ABS)	1	$\cos\theta_{\mathrm{abs}}$
A	ANGLE TH THETA	2	Relative polar angle θ (lab frame) in radians
AD	ANGLE(DEG)		
	TH(DEG) THETA(DEG)	2	Relative polar angle θ (lab frame) in degrees
CT	COS(TH) COS(THETA)	2	$\cos\theta$
A*	ANGLE* TH* THETA*	2	Relative polar angle θ^* (rest frame of part.#2) in radians
AD*	ANGLE*(DEG)		
	TH*(DEG) THETA*(DEG)	2	Relative polar angle θ^* (rest frame of part.#2) in degrees
CT*	COS(TH*) COS(THETA*)	2	$\cos\theta^*$
DR	DELTA-R CONE	2	Distance in η-ϕ space, i.e. $\sqrt{\Delta\eta^2+\Delta\phi^2}$
LDR	LOG-DELTA-R LOG-CONE	2	$\log_{10}\sqrt{\Delta\eta^2+\Delta\phi^2}$

WHIZARD histograms



New completely general cut syntax in WHIZARD 2.0.0 (`analysis.dat`)

```
process default
cut all E of visible (any) > 10
cut all M of visible (any), visible (any) > 10
cut all Q of incoming particle (any), visible (any) < -10
histogram max_val(PT of jet) within 50 400 nbin 35
```

Examples for structured beams

```
&beam_input
 particle_name = "p"
 LHAPDF_on = T
 LHAPDF_file = "cteq6l.LHpdf"
 LHAPDF_set = 0
 PDF_scale = 1000
! PDF_running_scale = T
 /

 &beam_input
 particle_name = "p"
 LHAPDF_on = T
 LHAPDF_file = "cteq6l.LHpdf"
 LHAPDF_set = 0
 PDF_scale = 1000
! PDF_running_scale = T
```

```
 &beam_input
 particle_name = "A"
 CIRCE2_on = T
 CIRCE2_file = "teslagg_500_rr.circe"
 CIRCE2_polarized = T
 /

 &beam_input
 particle_name = "A"
 CIRCE2_on = T
 CIRCE2_file = "teslagg_500_rr.circe"
 CIRCE2_polarized = T
/
```

```
 &beam_input
 USER_strfun_on = T /
 &beam_input
 USER_strfun_on = T /
```

```
&beam_input
 particle_name = "e-"
 polarization = 0.80 0
 CIRCE_on = T
 CIRCE_acc = 2
 ISR_on = T
 ISR_alpha = 0.0072993
 ISR_m_in = 0.000511
 /

 &beam_input
 particle_name = "e+"
 polarization = 0 0.40
 CIRCE_on = T
 CIRCE_acc = 2
 ISR_on = T
 ISR_alpha = 0.0072993
 ISR_m_in = 0.000511
```

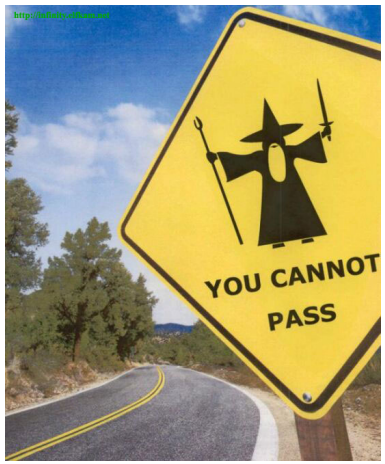
```
! WHIZARD 1.92 (Mar 12 2008)
! Reading process data from file whizard.in
! Wrote whizard.out
!
! Process uugg:
!    u a-u ->   g   g
!    8   4 ->   1   2
! Process energy set to     500.00     GeV
! Active structure functions for beam 1:
!   LHAPDF:         p -> u
************************************
*       LHAPDF Version 5.4.0       *
************************************

>>>>>> PDF description: <<<<<<
CTEQ6L - LO with NLO alpha_s
Reference:
J. Pumplin, D.R. Stump, J. Huston, H.L. Lai,
P. Nadolsky, W.K. Tung
>>>>>>                    <<<<<<

Parametrization: CTEQ6

! Active structure functions for beam 2:
!   LHAPDF:         p -> a-u
! Reading vertices from file whizard.mdl ...
! Model file:       54 trilinear vertices found.
! Model file:       54 vertices usable for phase space setup.
! Generating phase space channels for process uugg...
! Phase space:       3 phase space channels generated.
! Scanning phase space channels for equivalences ...
! Phase space:       6 equivalence relations found.
! Note: This cross section may be infinite without cuts.
! Wrote default cut configuration file whizard.uugg.cut0
! Wrote phase space configurations to file whizard.phx
```

The Phantom Menace – Checking new models

- E.g. MSSM
- 5318 couplings (with Goldstone/4-point)
- negative neutralino matrices: explicit factor of i
- Fully implemented, fully tested and fully functional
- Model `MSSM`
- Recommended usage: SUSY Les Houches Accord (SLHA)

```
&process_input
 process_id ``your_susy_proc''
 ......................
 input_file = "sps1a"
 input_slha_format = T
```

What about tests?
Have we checked?



- Unitarity Checks $2 \to 2, 2 \to 3$
- Ward-/Slavnov-Taylor identities for gauge symmetries and SUSY

Comparison of Automated Tools for Perturbative Interactions in SuperSymmetry

cf. http://whizard.event-generator.org/susy_comparison.html

$\tau^+\tau^- \to X$							
Process	status	Madgraph/Helas		Whizard/O'Mega		Sherpa/A'Megic	
		0.5 TeV	2 TeV	0.5 TeV	2 TeV	0.5 TeV	2 TeV
$\tilde{\tau}_1\tilde{\tau}_1^*$	●	257.57(7)	79.63(4)	257.32(1)	79.636(4)	257.30(1)	79.638(4)
$\tilde{\tau}_2\tilde{\tau}_2^*$	●	46.55(1)	66.86(2)	46.368(2)	66.862(3)	46.372(2)	66.862(3)
$\tilde{\tau}_1\tilde{\tau}_2^*$	●	95.50(3)	19.00(1)	94.637(3)	19.0015(8)	94.645(5)	19.000(1)
$\tilde{\nu}_\tau\tilde{\nu}_\tau^*$	●	502.26(7)	272.01(8)	502.27(2)	272.01(1)	502.30(3)	272.01(1)
$\tilde{\chi}_1^0\tilde{\chi}_1^0$	●	249.94(2)	26.431(1)	249.954(9)	26.431(1)	249.96(1)	26.431(1)
$\tilde{\chi}_1^0\tilde{\chi}_2^0$	●	69.967(3)	9.8940(3)	69.969(2)	9.8940(4)	69.968(3)	9.8937(5)
$\tilde{\chi}_1^0\tilde{\chi}_3^0$	●	17.0387(3)	0.7913(1)	17.0394(1)	0.79136(2)	17.040(1)	0.79137(5)
$\tilde{\chi}_1^0\tilde{\chi}_4^0$	●	7.01378(4)	1.50743(3)	7.01414(6)	1.5075(5)	7.0141(4)	1.50740(8)
$\tilde{\chi}_2^0\tilde{\chi}_2^0$	●	82.351(7)	18.887(1)	82.353(3)	18.8879(9)	82.357(4)	18.8896(1)
$\tilde{\chi}_2^0\tilde{\chi}_3^0$	●	—	1.7588(1)	—	1.75884(5)	—	1.7588(1)
$\tilde{\chi}_2^0\tilde{\chi}_4^0$	●	—	2.96384(7)	—	2.9640(1)	—	2.9639(1)
$\tilde{\chi}_3^0\tilde{\chi}_3^0$	●	—	0.046995(4)	—	0.0469966(9)	—	0.046999(2)
$\tilde{\chi}_3^0\tilde{\chi}_4^0$	●	—	8.5852(4)	—	8.55857(3)	—	8.5856(4)
$\tilde{\chi}_4^0\tilde{\chi}_4^0$	●	—	0.26438(2)	—	0.264389(5)	—	0.26437(1)
$\tilde{\chi}_1^+\tilde{\chi}_1^-$	●	185.09(3)	45.15(1)	185.093(6)	45.147(2)	185.10(1)	45.151(2)
$\tilde{\chi}_2^+\tilde{\chi}_2^-$	●	—	26.515(1)	—	26.5162(6)	—	26.515(1)
$\tilde{\chi}_1^+\tilde{\chi}_2^-$	●	—	4.2127(4)	—	4.21267(9)	—	4.2125(2)
h^0h^0	●	0.3533827(3)	0.0001242(2)	0.35339(2)	0.00012422(3)	0.35340(2)	0.000124218(6)
h^0H^0	●	—	0.005167(4)	—	0.0051669(3)	—	0.0051671(3)
H^0H^0	●	—	0.07931(3)	—	0.079301(6)	—	0.079311(4)
A^0A^0	●	—	0.07975(3)	—	0.079758(6)	—	0.079744(4)
Zh^0	●	59.591(3)	3.1803(8)	59.589(3)	3.1802(1)	59.602(3)	3.1829(2)
ZH^0	●	2.8316(3)	4.671(5)	2.83169(9)	4.6706(3)	2.8318(1)	4.6706(2)
ZA^0	●	2.9915(4)	4.682(5)	2.99162(9)	4.6821(3)	2.9917(2)	4.6817(2)
A^0h^0	●	—	0.005143(4)	—	0.0051434(3)	—	0.0051440(3)
A^0H^0	●	—	1.4880(2)	—	1.48793(9)	—	1.48802(8)
H^+H^-	●	—	5.2344(6)	—	5.2344(2)	—	5.2345(3)

Upcoming Features: WHIZARD 2.0.0

WHIZARD version 2.0.0 coming out soon this summer

- (More) Automatized (and even more USER-FRIENDLY) installation
- New syntax for defining cuts, scales and analyses: allows for arbitrary functions of kinematical variables
- fancier (and faster) color structures from O'Mega
- WHIZARD uses O'Mega info for better/faster phase space generation
- Cascade decays (apply with great care!!!)
  Recursive WHIZARD, breaks double decay chains down into subprocesses
- QCD parton shower for initial state and matching
- New manual
- Support for `ROOT` data format
- Interfaces: HERWIG++, TAUOLA, FeynRules

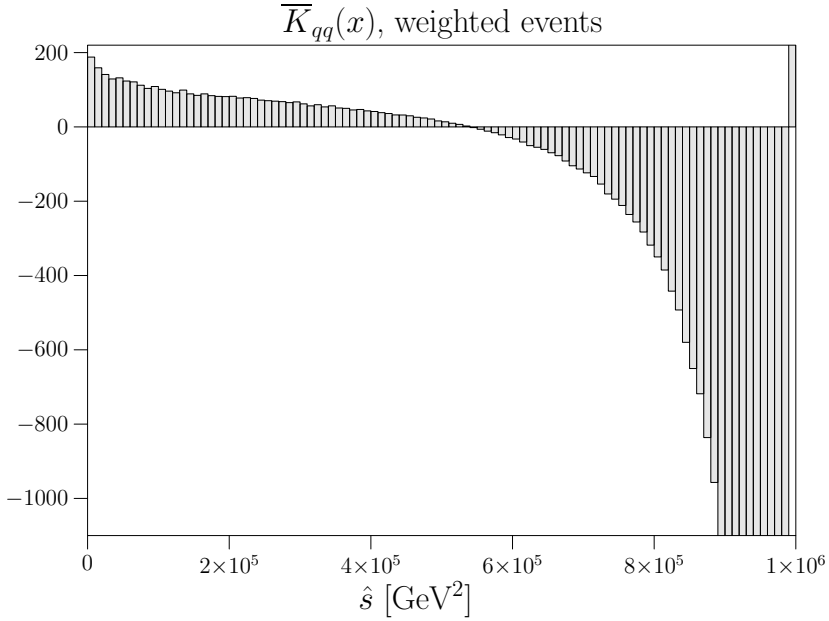
Most points close to finalization;
Major restructuring of the code

NLO QCD Applications / Future Features

Applications: $pp \to bbbb$ @ 1-loop

- Numerical QCD 1-loop matrix elements: GOLEM Binoth/Guillet/Heinrich/Reiter
- Interface WHIZARD – GOLEM virtual corrections incl., dipoles and integrated implemented

  Binoth/Guffanti/JR/Reiter
- Debugging phase



Upcoming future features, 2008/09ish

- Graphical User Interface (partially already there)
- Numerical loop integrations
- Interface to FeynArts/FormCalc/LoopTools
- Full-fledged parallelization (partially under way)
- Underlying event and hadronization routines

BSM,e.g. Resonances in VV scattering

Alboteanu/Kilian/JR, 0806.4145

Model-independent description for LHC, respect weak isospin ($\rho \approx 0$):

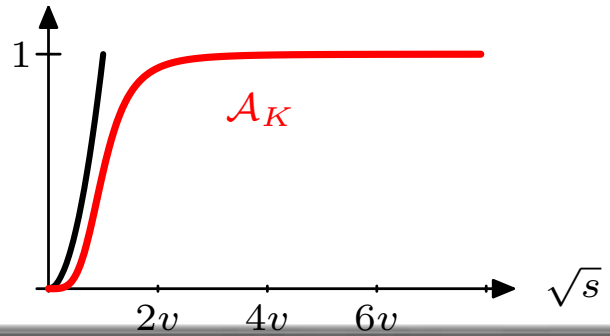
	$J=0$	$J=1$	$J=2$
$I=0$	σ^0 (Higgs ?)	ω^0 (γ'/Z' ?)	a^0 (Graviton ?)
$I=1$	$\pi^\pm, \pi^0$ (2HDM ?)	$\rho^\pm, \rho^0$ (W'/Z' ?)	$t^\pm, t^0$
$I=2$	$\phi^{\pm\pm}, \phi^\pm, \phi^0$ (Higgs triplet ?)	—	$f^{\pm\pm}, f^\pm, f^0$

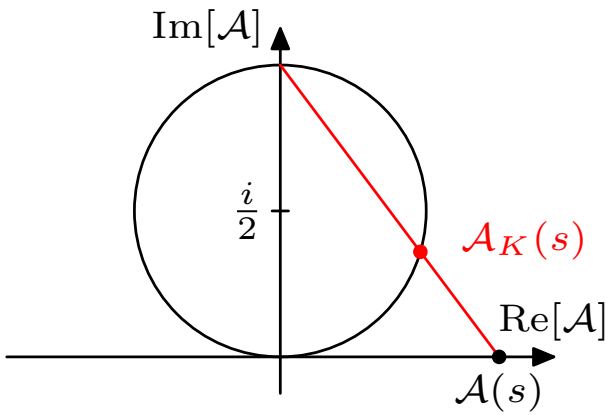
LHC access limited: 1. resonance correct, guarantee unitarity

K-Matrix unitarization

$$\mathcal{A}_K(s) = \mathcal{A}(s)/(1 - i\mathcal{A}(s))$$

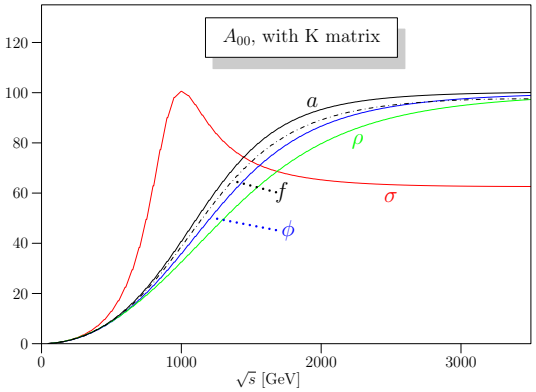
- Low-energy theorem (LET): $\frac{s}{v^2}$
- K-matrix ampl.: $|\mathcal{A}(s)|^2 \overset{s\to\infty}{\to} 1$
- Poles $\pm iv$: M_0, Γ large

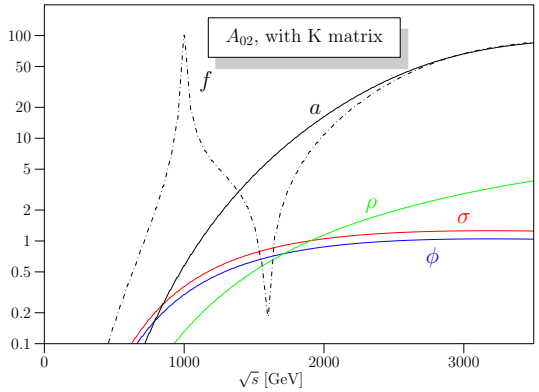


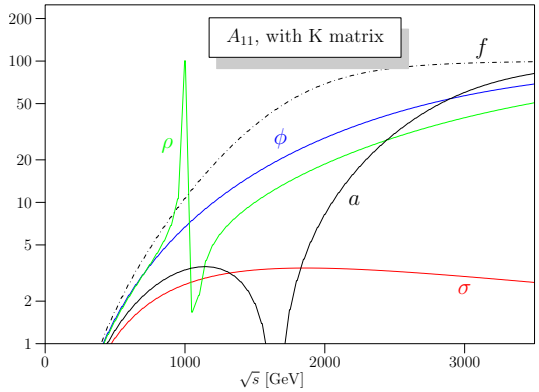


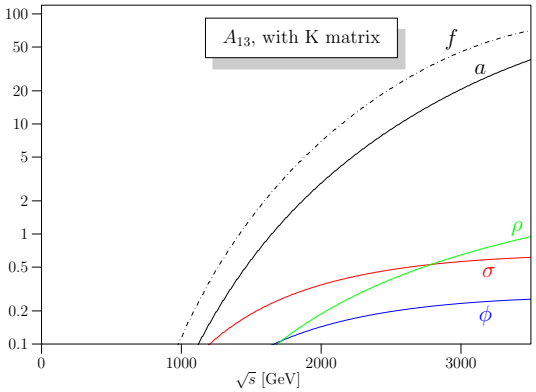
- Unitarization in each spin-isospin eigen-channel
- breaks crossing invariance
- Explicit “time arrow” in WHIZARD

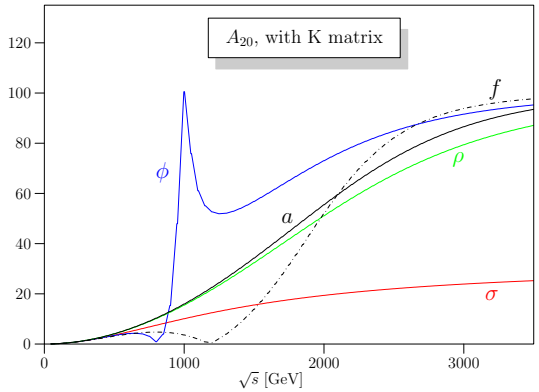
Implementation and Results

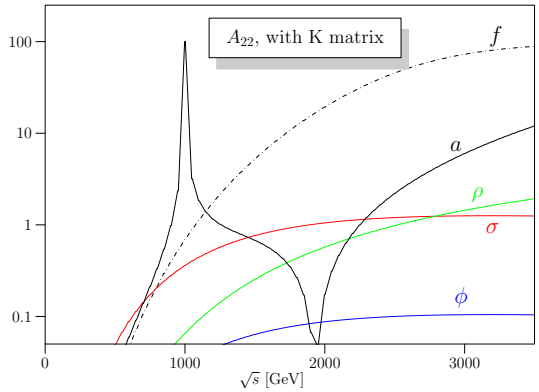


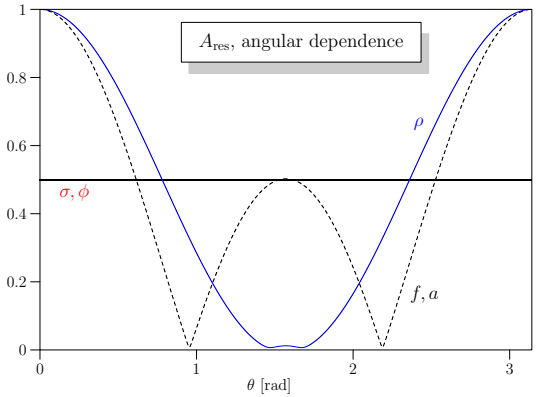


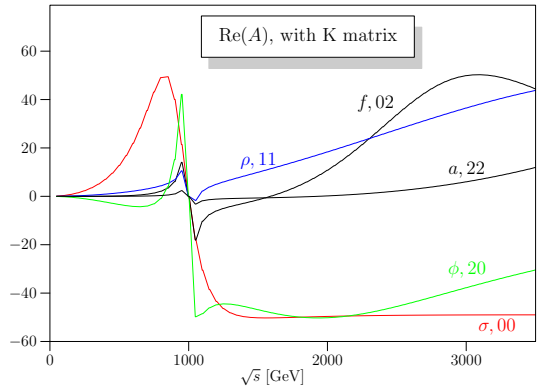


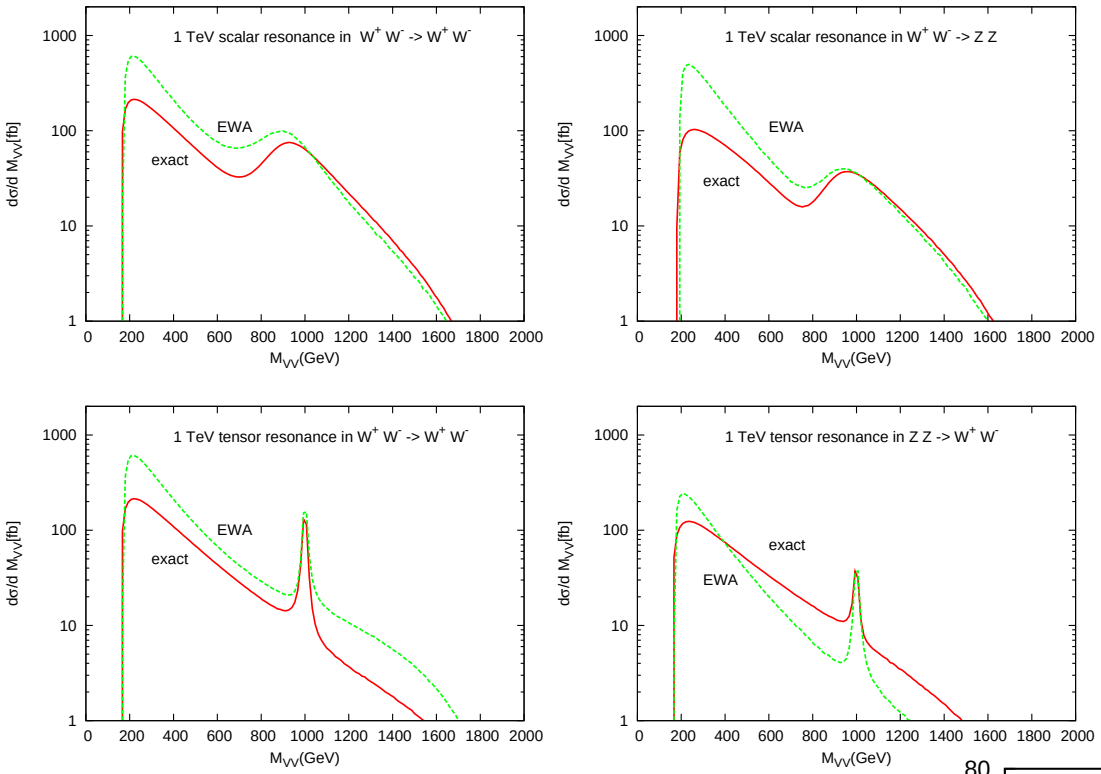






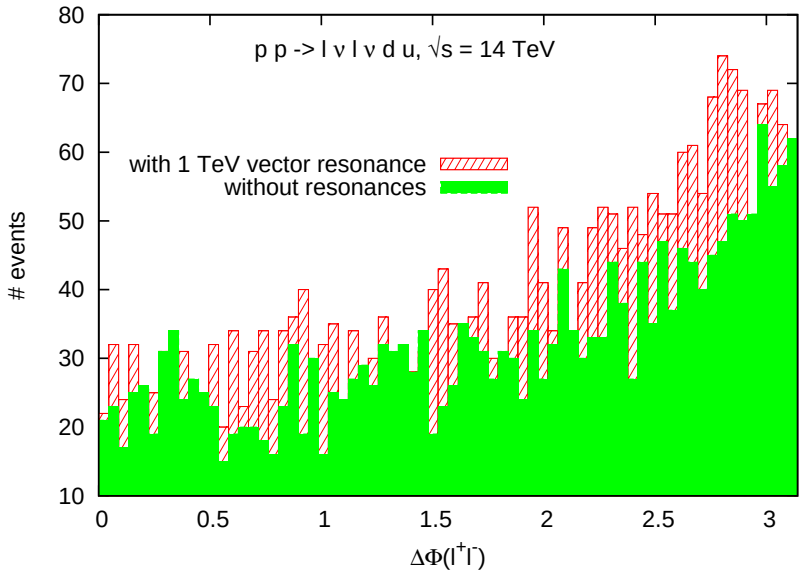






- Effective W approx. vs. WHIZARD full matrix elements
- Shapes/normalization of distributions heavily affected
- EWA: Sideband subtraction completely screwed up!

- Example: 850 GeV vector resonance
- coupling $g_\rho = 1$
- Discriminator: angular correlations
- Ongoing ATLAS study



Final Remarks and Outlook

Left out:

- Phase space generation/integration details — We don't use black boxes, we write them!
- No Advanced WHIZARD spells: grid adaptation, dirty tricks, ...

New version WHIZARD 1.92 → 2.0.0

http://whizard.event-generator.org

Updated reference: arXiv:0708.4233

Functional cut/analysis syntax, more models, recursive cascades, improved phase space, IS shower, ...

WHIZARD focused on BSM physics ⟶ complete event generator

- Initial state shower, underlying event, hadronization

Extended WHIZARD:

- SUSY NLO event generation cf. Tania Robens
- QCD NLO event generation: WHIZARD meets GOLEM

as usual: **we're open to users wish list!**

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Thanks to all contributors (list is not exhaustive!)

T. Barklow, P. Bechtle, M. Berggren, M. Beyer, F. Braam, R. Chierici, K. Desch, T. Kleinschmidt, M. Mertens, N. Meyer, K. Mönig, M. Moretti, H. Reuter, T. Robens, K. Rolbiecki, S. Rosati, A. Rosca, S. Schmitt, J. Schumacher, M. Schumacher, C. Schwinn

Upgrade ’08

Upgrade ’08