The Monte Carlo Event Generator WHIZARD

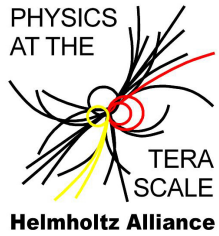
Jürgen R. Reuter

DESY Hamburg











LC Top Workshop, LPNHE Paris, Mar 6th, 2014

WHIZARD in a Nutshell

WHIZARD is a universal event generator for elementary processes at colliders:

- e^+e^-: LEP and TESLA/NLC $\Rightarrow$ ILC, CLIC, TLEP ...
- pp: Tevatron $\Rightarrow$ LHC, HL/E-LHC, VLHC, XXX ...

It contains

1. O'Mega: Automatic matrix elements for arbitrary elementary processes, supports SM and many BSM extensions
2. Phase-space parameterization module
3. VAMP: Generic adaptive integration and (unweighted) event generation
4. Intrinsic support or external interfaces for: Feynman rules, beam properties, cascade decays, shower, hadronization, analysis, event file formats, etc., etc.
5. Free-format steering language SINDARIN

Milestones

1.0 Project started around 1999: Studies for electroweak multi-particle processes at TESLA (W, Higgs, Z)

Event samples for LC studies at SLAC

1.9 Full SM w/ QCD, beam properties, SUSY/BSM, event formats

2.1 QCD shower+matching, FeynRules support, internal density-matrix formalism (cascade decays), language SINDARIN as user interface, OpenMP parallelization, ...
(production version)

2.2 Major refactoring of internals (same user interface), event sample reweighting, inclusive processes and selective decay chains
(public beta version/release candidate)

Plan Improve LC support; NLO + matching; improve user interface
$\Rightarrow$ adapt to specific needs of user groups

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(previous version)

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$\Rightarrow$ adapt to specific needs of user groups

The WHIZARD Event Generator – Release 2.1

- Multi-Channel Monte-Carlo integration
- Efficient phase space and event generation (weighted & unweighted)
- Optimized tree-level matrix elements (O'Mega)
  - $e^+e^- \to t\bar{t}H \to b\bar{b}b\bar{b}jj\ell\nu$ (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)



WHIZARD 2.1.1 release: Sep. 18, 2012

Old series: WHIZARD 1.97 (development stopped with 1.94)

The WHIZARD team: F. Bach, B. Chokoufé, W. Kilian, T. Ohl, JRR, M. Sekulla, F. Staub, C. Weiss,

Web address: `http://projects.hepforge.org/whizard`

Standard Reference: Kilian/Ohl/JRR, EPJC 71 (2011) 1742, arXive:0708.4233

The WHIZARD Event Generator – Release 2.2

- Multi-Channel Monte-Carlo integration
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WHIZARD 2.2.0_β release: Feb. 3, 2014 (CLIC)

Old series: WHIZARD 1.97 (development stopped with 1.94)

The WHIZARD team: F. Bach, B. Chokoufé, W. Kilian, T. Ohl, JRR, M. Sekulla, F. Staub, C. Weiss,

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WHIZARD 2.2.0 release: (Mar. 6 + ϵ), 2014

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The WHIZARD team: F. Bach, B. Chokoufé, W. Kilian, T. Ohl, JRR, M. Sekulla, F. Staub, C. Weiss, + 2 bachelors

Web address: `http://projects.hepforge.org/whizard`

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WHIZARD 2: Status 2010-14 – Technical Features

- WHIZARD 2: code basically rewritten, only `Fortran 2003` and `O'Caml`
- Clean modularization of code/(First) object-oriented implementation
- OpenMP parallelization
- Operation modes:
  - Dynamic linking (default mode) with on-the-fly generation of process code
  - Static linking (for batch clusters)
  - Library mode, callable from C/C++/Python/...
  - Interactive mode: WHIZARD works as a Shell – WHISH
- Standard conformance: uses `autotools`: `automake`/`autoconf`/`libtool`
- Large self test suite
- Version control (`svn`) at HepForge: use of ticket system and bug tracker
- Continuous integration system (`jenkins`) linked with svn repository

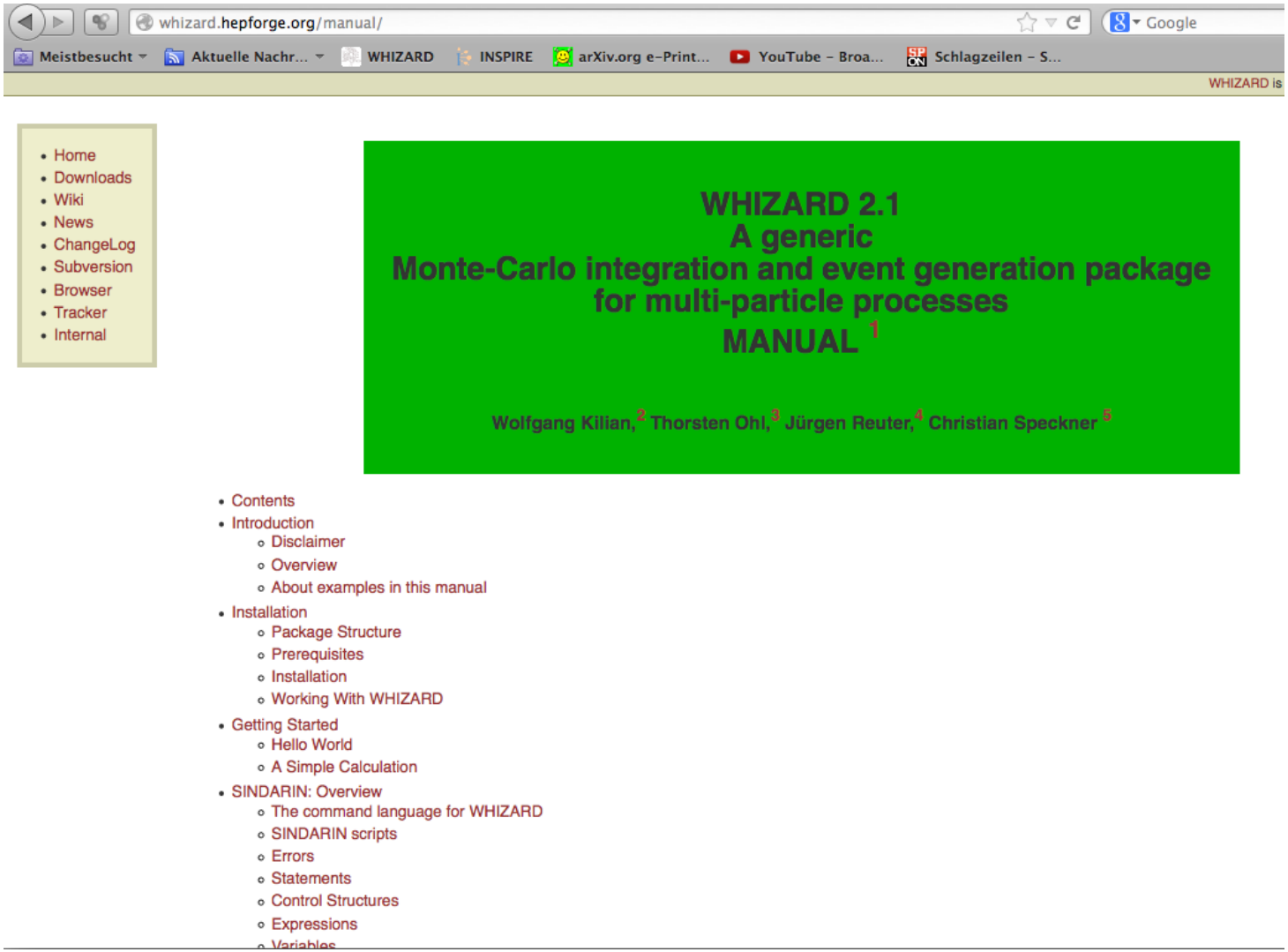
WHIZARD 2 – Installation and Run

- Download WHIZARD from `http://www.hepforge.org/archive/whizard/whizard-2.2.0_beta.tar.gz` and unpack it
- WHIZARD intended to be centrally installed on a system, e.g. in `/usr/local` (or locally on user account)
- Create build directory and `configure`
  External programs (LHAPDF, StdHEP, HepMC) might need flags
- `make`, `make install`
- Create SINDARIN steering file (in any working directory)
- Run `whizard` (in working directory)
- Supported event formats: HepMC, StdHEP, LHEF, LHA, div. ASCII formats

```
WHIZARD self tests:
make  check-am
make  check-TESTS
PASS: expressions.run
PASS: beams.run
PASS: cputime.run
PASS: state_matrices.run
PASS: interactions.run
PASS: beam_structures.run
PASS: models.run
[............]
PASS: phs_forests.run
PASS: rng_base.run
PASS: selectors.run
PASS: phs_wood.run
PASS: mci_vamp.run
PASS: particle_specifiers.run
PASS: prclib_stacks.run
PASS: slha_interface.run
PASS: subevt_expr.run
PASS: process_stacks.run
PASS: cascades.run
PASS: processes.run
PASS: decays.run
PASS: events.run
PASS: eio_base.run
PASS: rt_data.run
PASS: dispatch.run
PASS: process_configurations.run
PASS: event_weights_1.run
PASS: integrations.run
PASS: simulations.run
PASS: process_libraries.run
PASS: compilations.run
PASS: prclib_interfaces.run
PASS: commands.run
XFAIL: errors.run
PASS: helicity.run
PASS: prc_omega.run
PASS: qedtest_1.run
PASS: beam_setup_1.run
PASS: reweight_1.run
PASS: colors.run
PASS: lhef_1.run
PASS: alphas.run
PASS: smtest_1.run
PASS: hepmc.run
PASS: restrictions.run
PASS: pdf_builtin.run
PASS: stdhep_1.run
PASS: static_1.run
============================================
Testsuite summary for WHIZARD 2.2.0
============================================
# TOTAL: 181
# PASS:  180
# SKIP:  0
# XFAIL: 1
# FAIL:  0
# XPASS: 0
# ERROR: 0
============================================
```

WHIZARD Manual

Online only 2.1 Manual for now, 2.2 ships with distr.



whizard.hepforge.org/manual/

Meistbesucht | Aktuelle Nachr... | WHIZARD | INSPIRE | arXiv.org e-Print... | YouTube - Broa... | Schlagzeilen - S...

WHIZARD is

- Home
- Downloads
- Wiki
- News
- ChangeLog
- Subversion
- Browser
- Tracker
- Internal

WHIZARD 2.1
A generic
Monte-Carlo integration and event generation package
for multi-particle processes
MANUAL [1]

Wolfgang Kilian,[2] Thorsten Ohl,[3] Jürgen Reuter,[4] Christian Speckner [5]

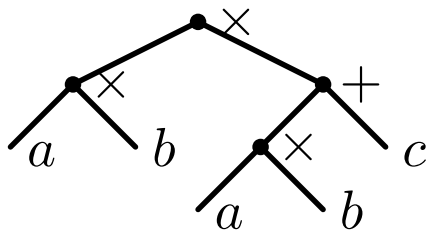
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  - Hello World
  - A Simple Calculation
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  - The command language for WHIZARD
  - SINDARIN scripts
  - Errors
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  - Control Structures
  - Expressions
  - Variables

O'Mega: Optimal matrix elements

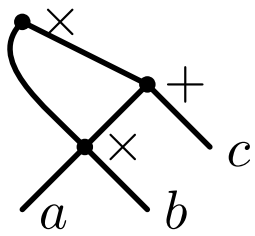
Ohl/JRR, 2001 Ω

- Replace forest of tree diagrams by
  Directed Acyclical Graph (DAG) of the algebraic expression (including color).

$$ab(ab+c) =$$



$=$

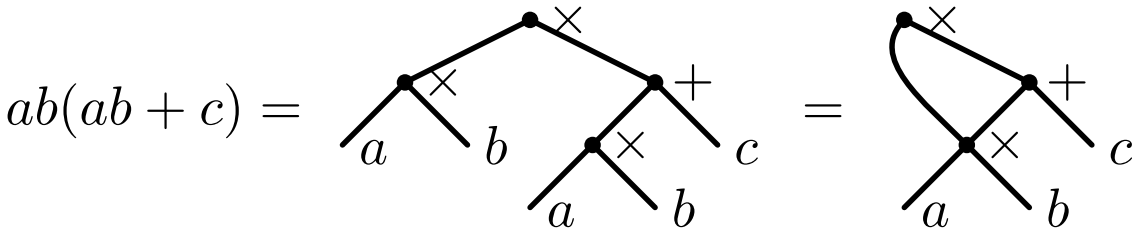


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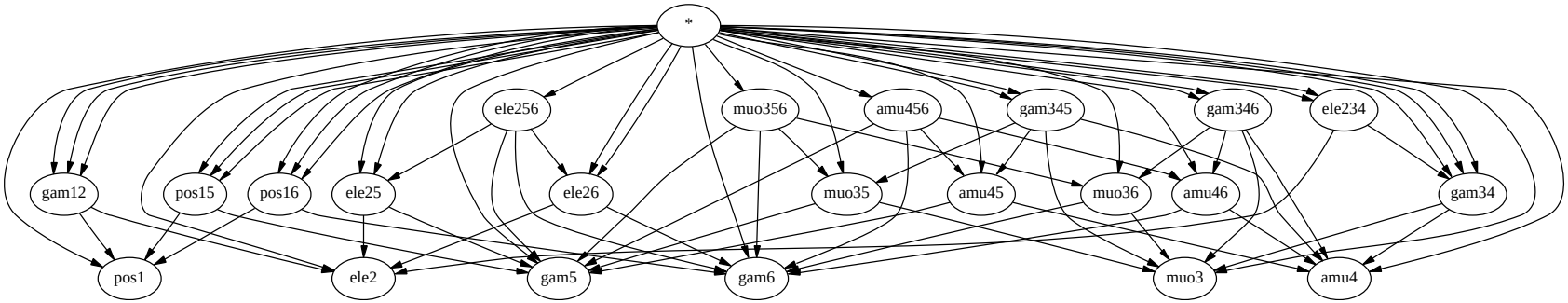
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- LC example: $e^+e^- \to \mu^+\mu^-\gamma\gamma$

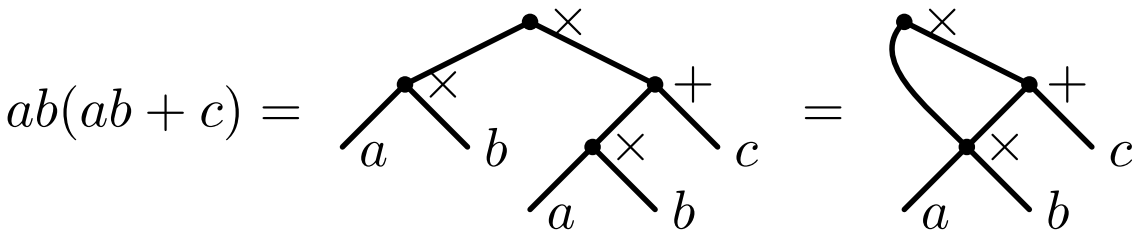


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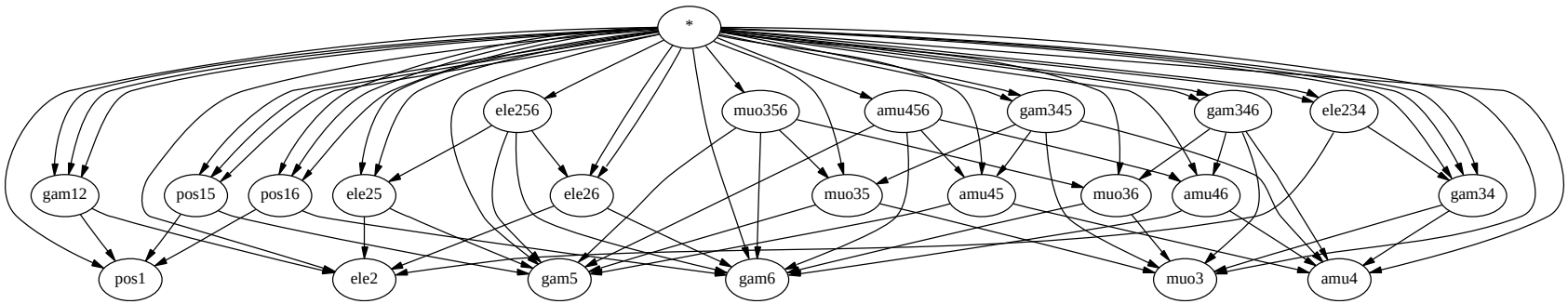
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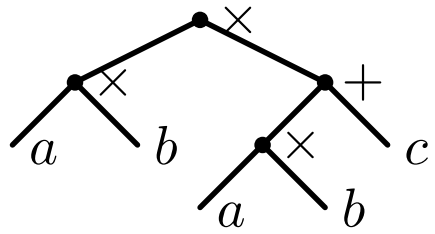
- Specification of order of strong or EW coupling (2.2.x)

O'Mega: Optimal matrix elements

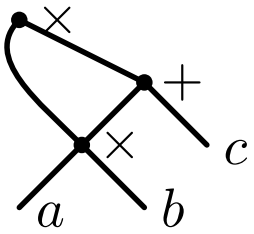
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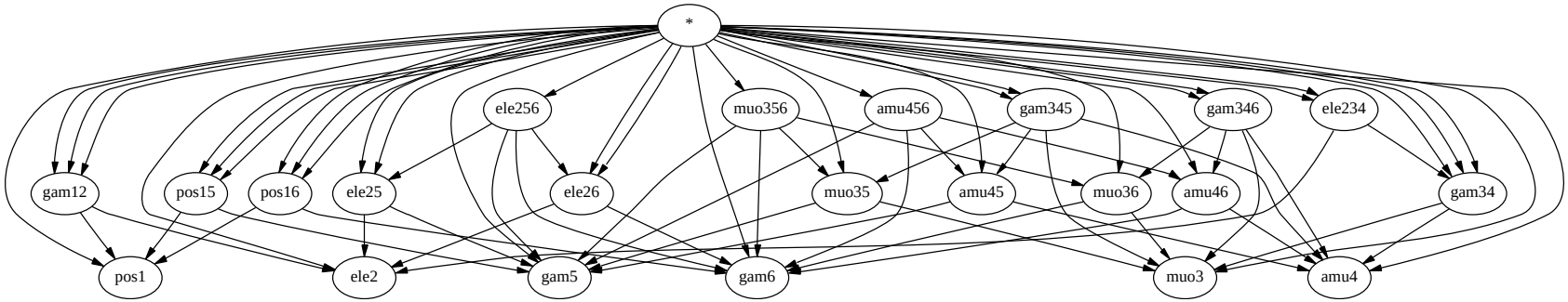
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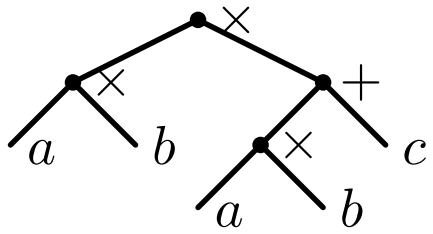
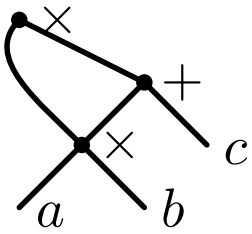


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- Unification of model setup: only one binary (2.3)

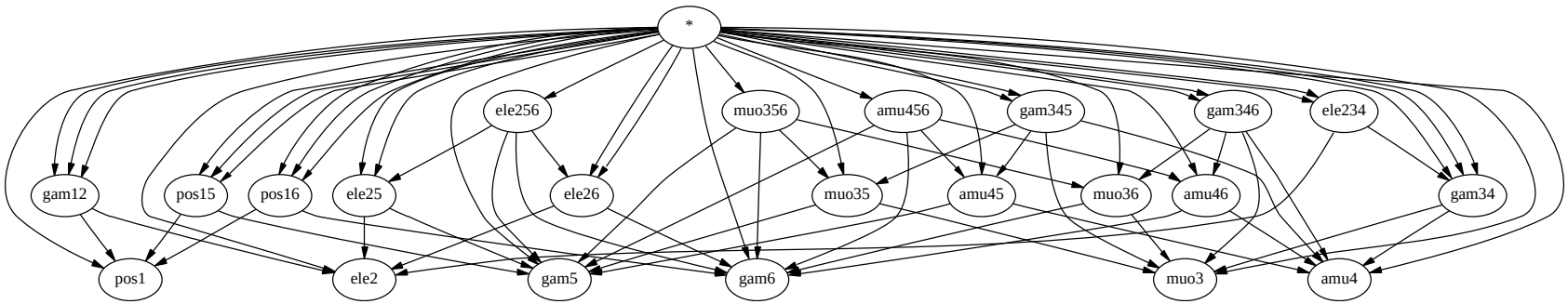
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- Specification of order of strong or EW coupling (2.2.x)
- Unification of model setup: only one binary (2.3)
- Teaser: new algorithm for generating loop diagrams (2.4 ?)

Beams and hard matrix elements

- **Hadron Colliders structured beams**
  - LHAPDF interface (5.x for now), most prominent PDFs directly included
  - QCD ISR and FSR (2 diff. own implementations, interface to PYTHIA)
  - Matching matrix elements/showers
  - Underlying event/multiple interactions (proof of principle)
- **Hadronic events/hadronic decays + hadronic (QED) FSR** (ext.)
- **Lepton Colliders structured beams**
  - QED ISR (Skrzypek/Jadach, Kuraev/Fadin , incl. p_T distributions)
  - arbitrarily polarized beams (density matrices)
  - Beamstrahlung (CIRCE module) **more later**
  - Photon collider spectra (CIRCE2 module)
  - external beam spectra can be read in (files/generating code)

Hard matrix elements:

- Particle spins: $0, \frac{1}{2}, 1, \frac{3}{2}, 2$
- Lorentz structures: hugh set of hard-coded structures
- Fully general Lorentz structures foreseen for 2.3.0
- Color structures: $\mathbf{3}, \overline{\mathbf{3}}, \mathbf{8}, [\mathbf{6}]$
- Color flow formalism Stelzer/Willenbrock, 2003; Kilian/Ohl/JRR/Speckner, 2011
- General color structures $\mathbf{6}, \mathbf{10}, \epsilon_{ijk}\phi^i\phi^j\phi^k$

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 coupl.	**`SM_ac_CKM`**	**`SM_ac`**
SM with anomalous top coupl.	**`SMtop_CKM`**	**`SMtop`**
SM with anom. Higgs coupl.	—	`SM_rx / NoH`
SM ext. for VV scattering	—	`SSC / AltH`
SM with Z'	—	`Zprime`
2HDM	`2HDM_CKM`	`2HDM`
MSSM	`MSSM_CKM`	`MSSM`
MSSM with gravitinos	—	`MSSM_Grav`
NMSSM	`NMSSM_CKM`	`NMSSM`
extended SUSY models	—	`PS/E/SSM`
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	—	`Threeshl`
UED	—	`UED`
SM with gravitino and photino	—	`GravTest`
Augmentable SM template	—	`Template`

new models easily: FeynRules interface Christensen/Duhr/Fuks/JRR/Speckner, 1010.3251

Interface to SARAH in the SUSY Toolbox Staub, 0909.2863; Ohl/Porod/Speckner/Staub, 1109.5147

Input files: Basic features

```
model = SM

process helloworld = E1, e1 => t, tbar, H

compile

sqrts = 500
beams = E1, e1 => circe1 => isr

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

n_events = 10000

simulate (helloworld)
```

Input files: Basic features

```
model = SM


process helloworld = E1, e1 => t, tbar, H


compile


sqrts = 500
beams = E1, e1 => circe1 => isr

cuts = any 5 degree < Theta < 175 degree
         [select if abs (Eta) < eta_cut [lepton]]
cuts = any E > 2 * mW [extract index 2
         [sort by Pt [lepton]]]

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

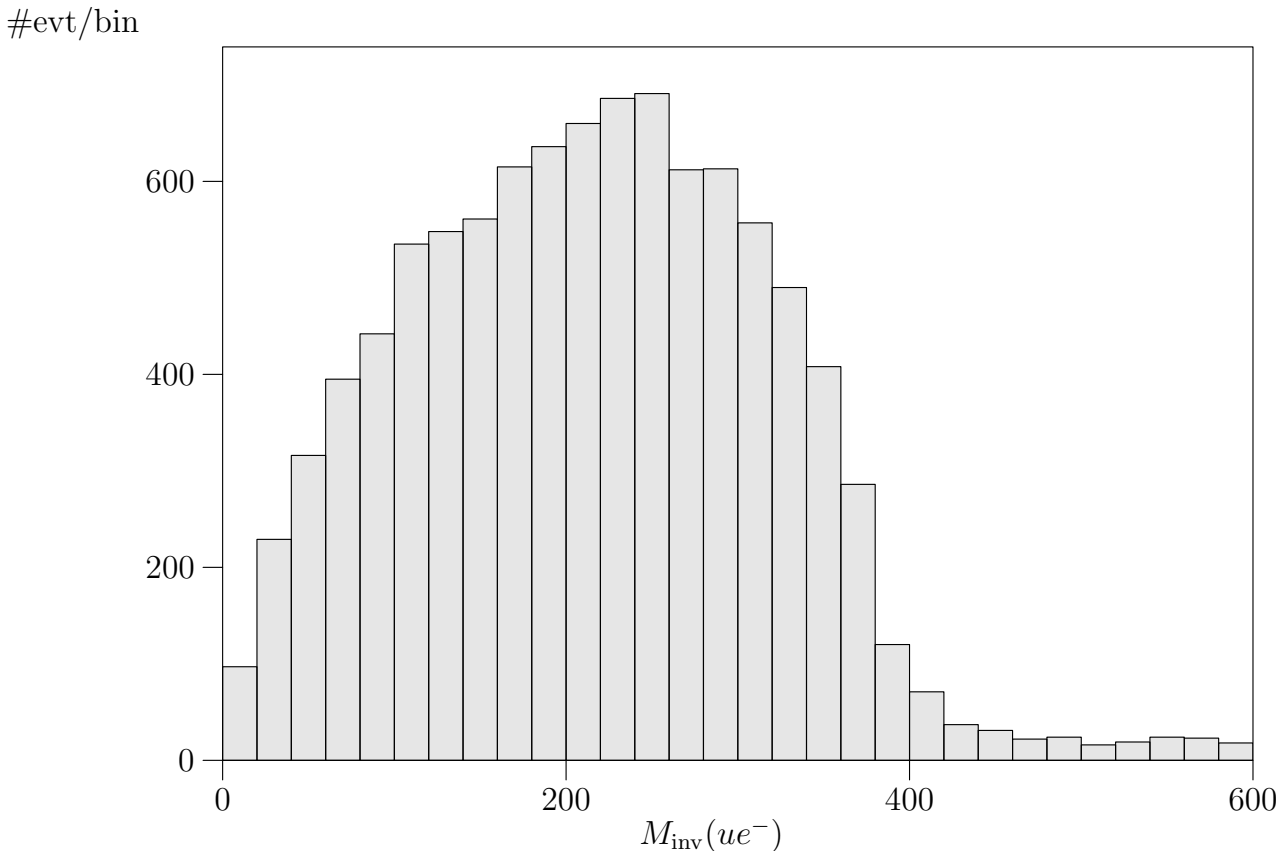

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```

Example: LHC SUSY cascade decays

$$p + p \to \tilde{u}^* + \tilde{u} \to \tilde{u}^* + u + \tilde{e}^+ + e^-$$

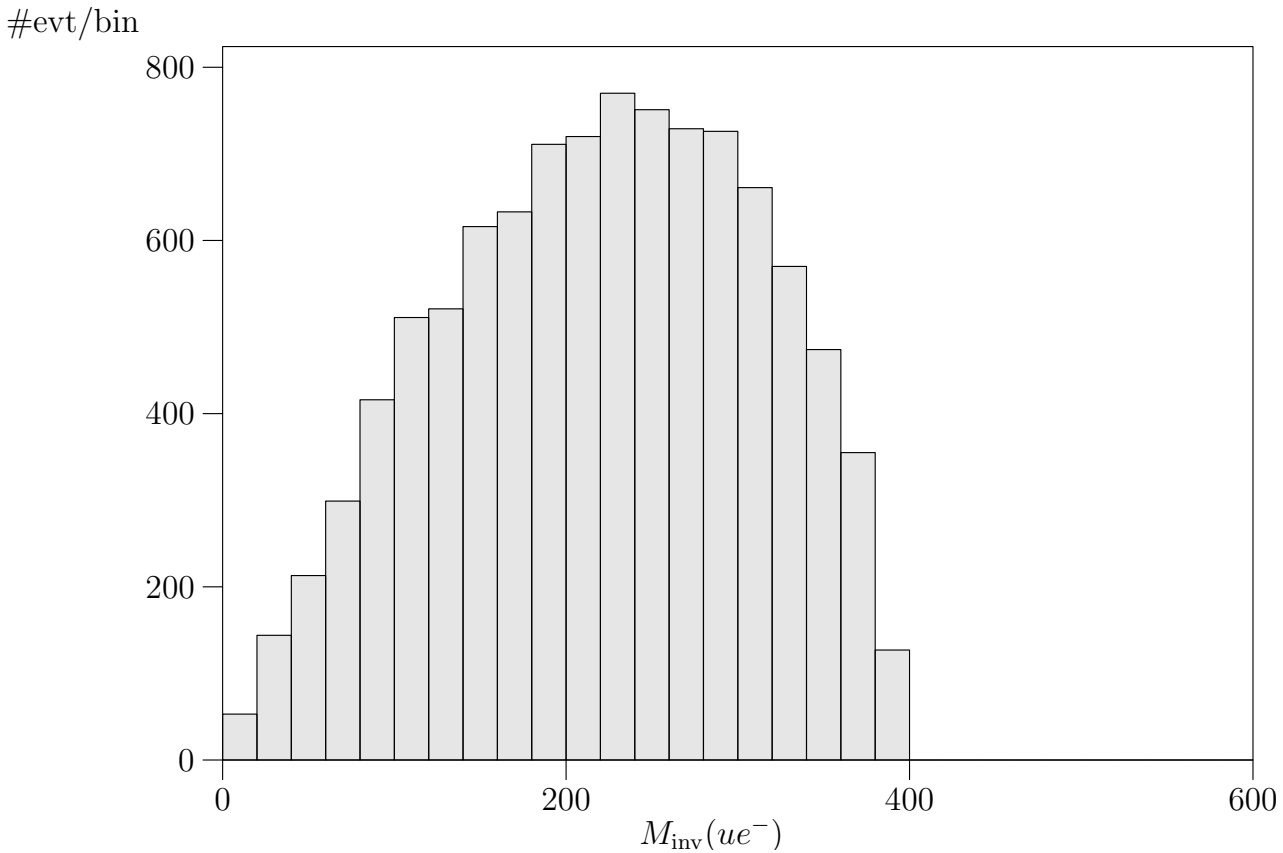
- **Full process:**



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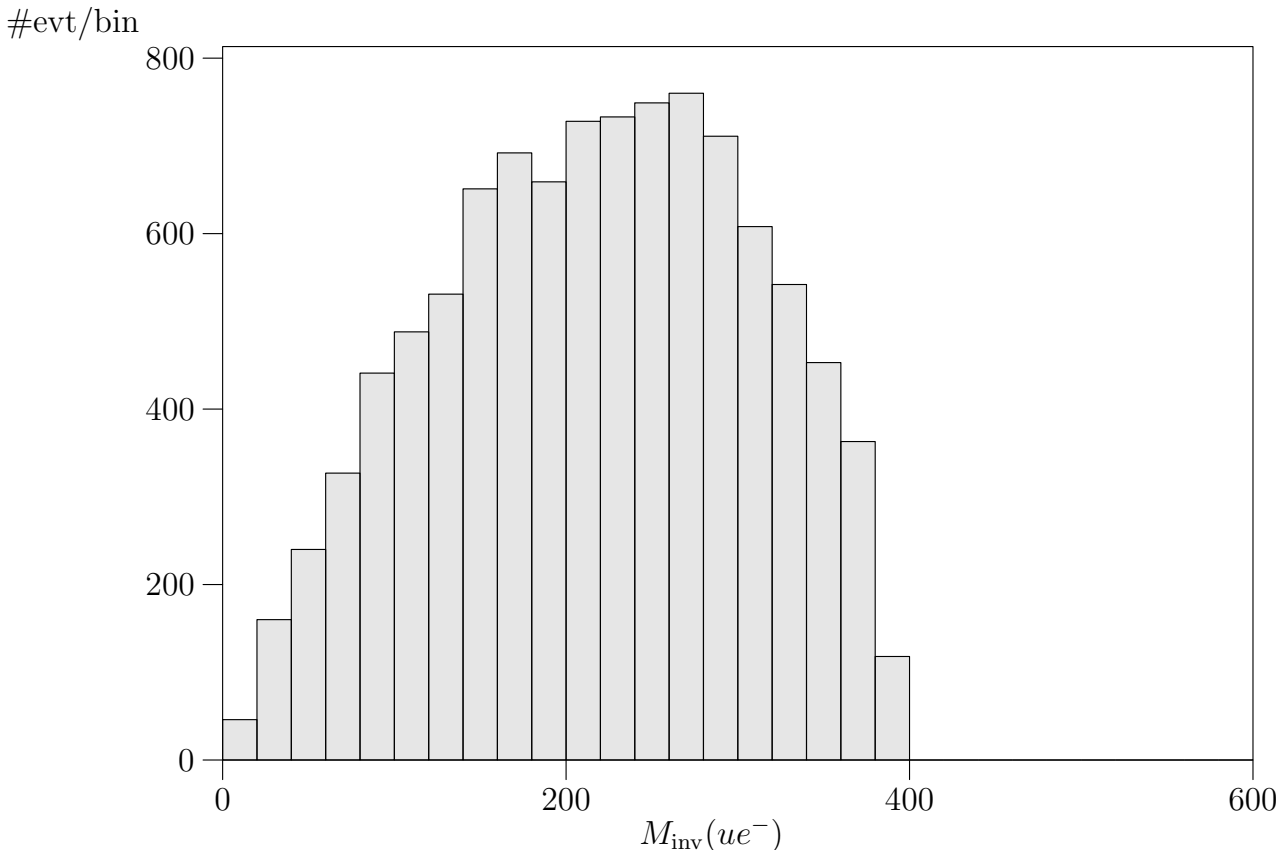
- **Factorized process w/ full spin correlations:**



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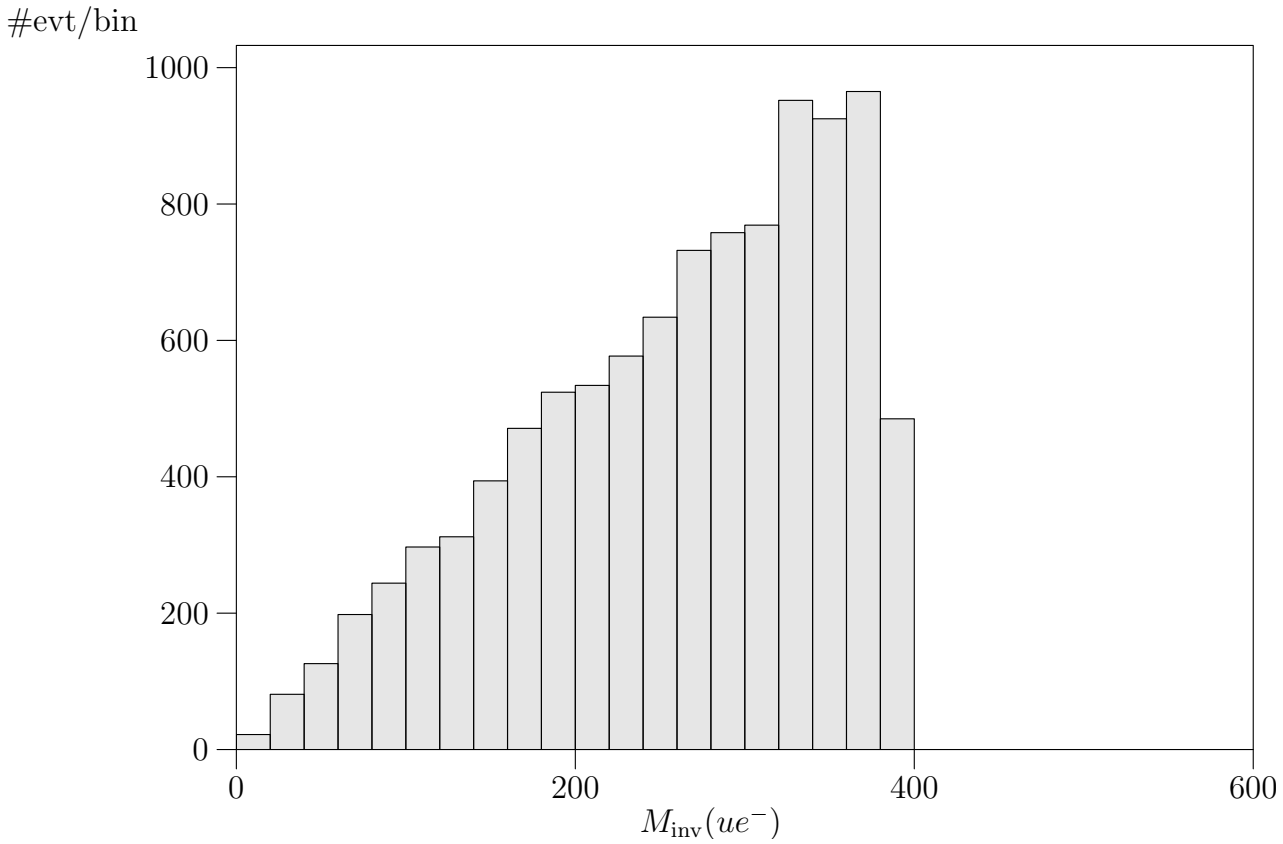
- **Factorized process w/ classical spin correlations:**



Example: LHC SUSY cascade decays

$$p + p \to \tilde{u}^* + \tilde{u} \to \tilde{u}^* + u + \tilde{e}^+ + e^-$$

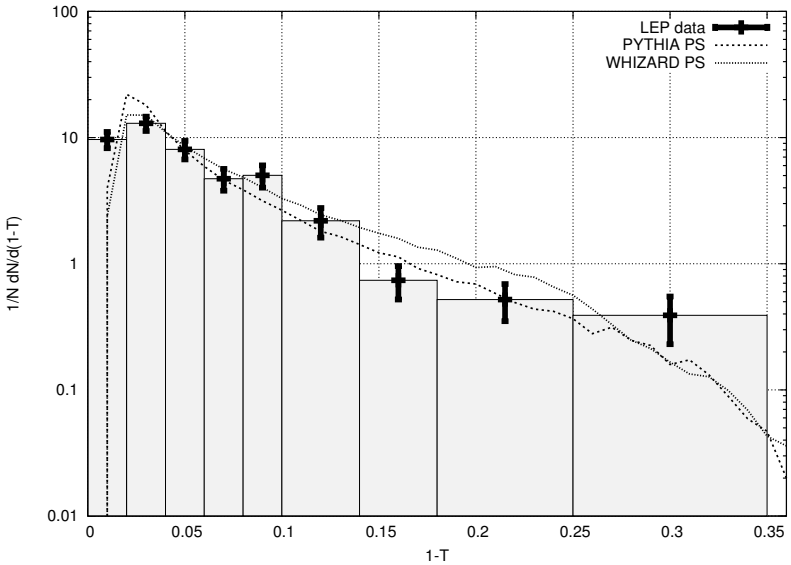
- **Factorized process w/ no spin correlations:**

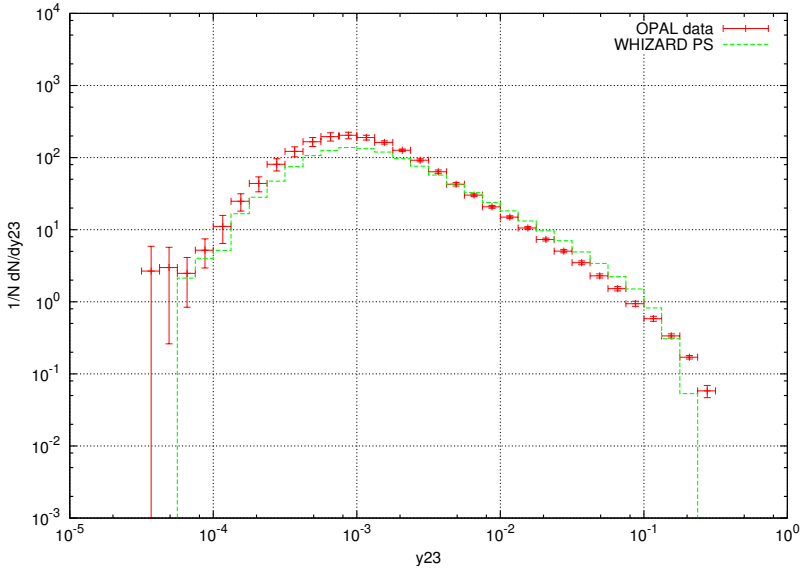


Analytic Parton Shower

Kilian/JRR/Schmidt/Wiesler, JHEP 2012

- Analytic Parton Shower:
  - no shower veto: shower history is exactly known
  - allows reweighting and maybe more reliable error estimate
- new algorithm for initial state QCD radiation



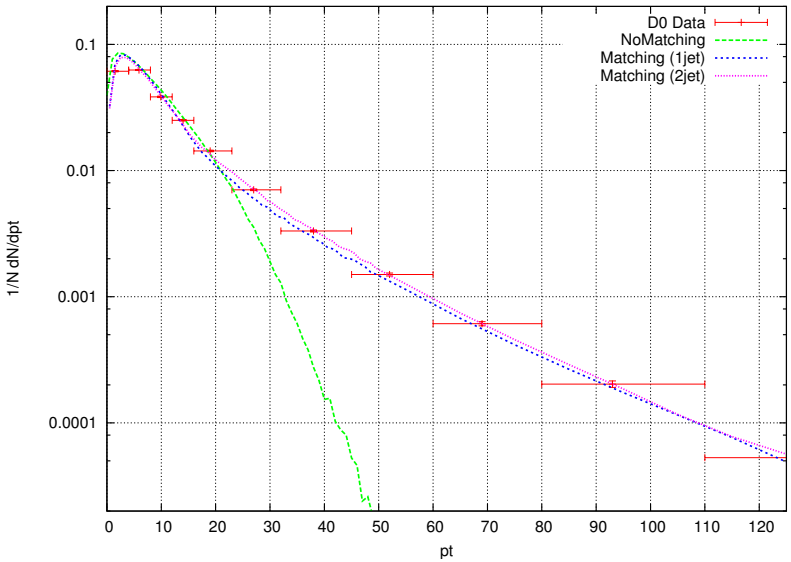


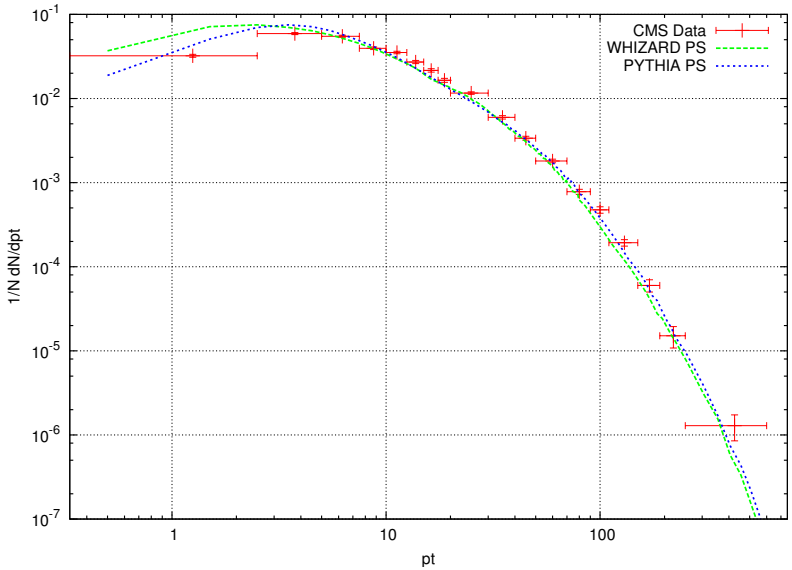
- matching with hard matrix elements, no ”power-shower”

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- matching with hard matrix elements, no ”power-shower”

Status of NLO development in WHIZARD

- BLHA interface: workflow Speckner, 2012
  1. Process definition in SINDARIN $\Rightarrow$ WHIZARD writes contract file
  2. NLO generator generates code, WHIZARD reads contract
  3. NLO matrix element loaded as shared library

- First implementation: interfacing `GoSAM` and `FeynArts/FormCalc`

- Automatic generation of subtraction terms Speckner, 2012; Kilian/JRR/Weiss, 2014
  - proof-of-concept code in WHIZARD 2.1
  - implementation in the context of the revised WHIZARD 2.2 core
  - both dipole and FKS subtraction will be available
  - Provide PowHeg box formalism for NLO processes
  - Special focus on LC physics: top, Higgs, EW processes, BSM

News 2013/early 2014: upcoming official release 2.2.x

- Lost of WHIZARD members 2012: some features delayed in 2013

  release candidate version 2.2.0_β/_rc available!

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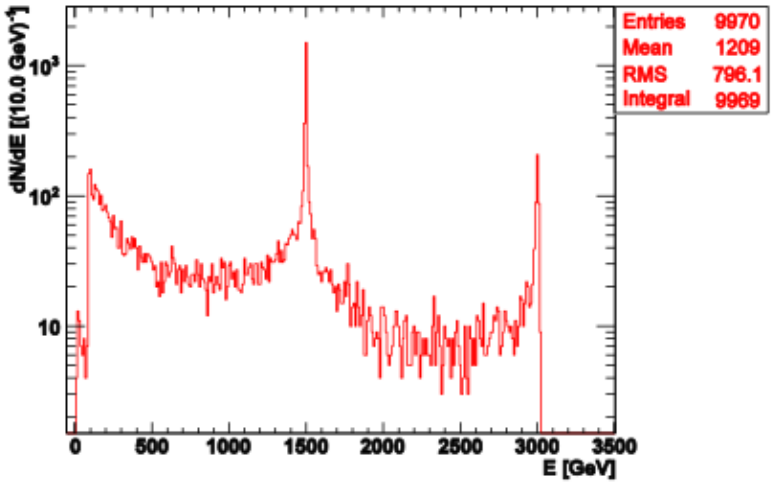
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- New syntax/features decays and chains:

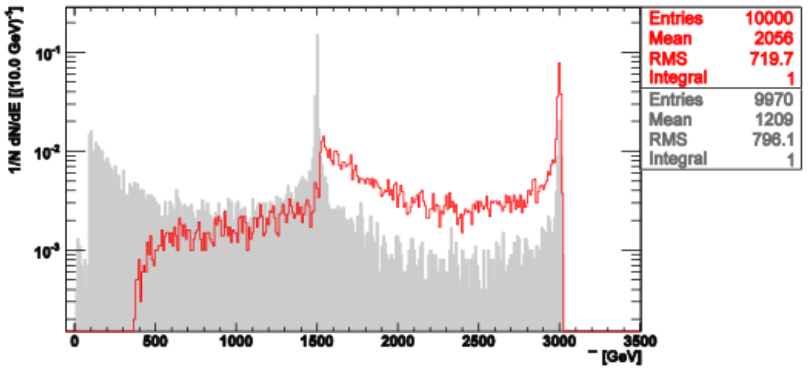
```
process higgsstr = e1, E1 => (Z => e2, E2), (H => b, bbar)

process inclusive = e1, E1 => (Z, h) + (Z, H) + (A, H)
```

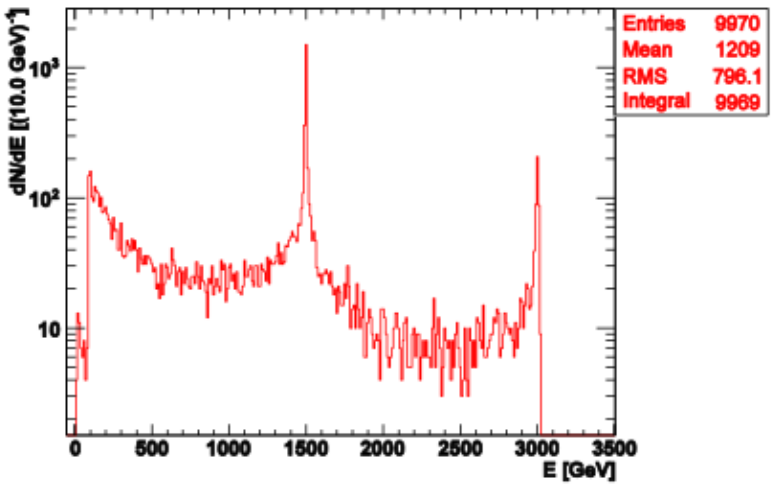
- Specification of QCD and electroweak order
- Improvements to the SINDARIN steering language

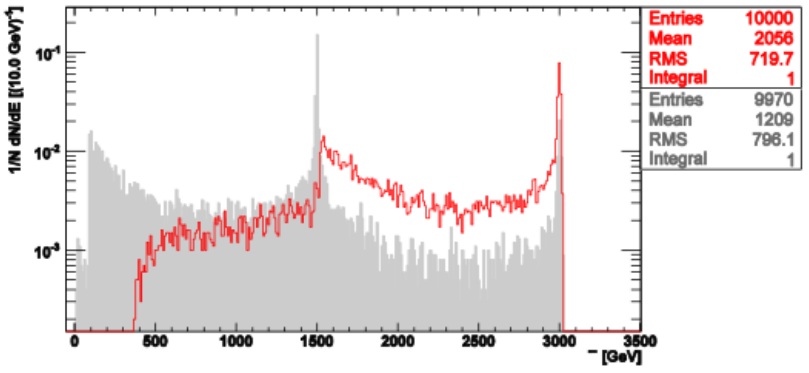
Difficulties of LC beam simulation





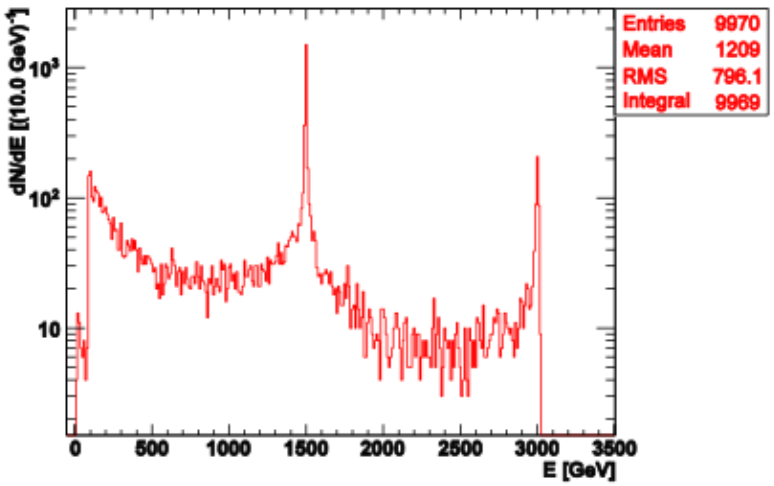
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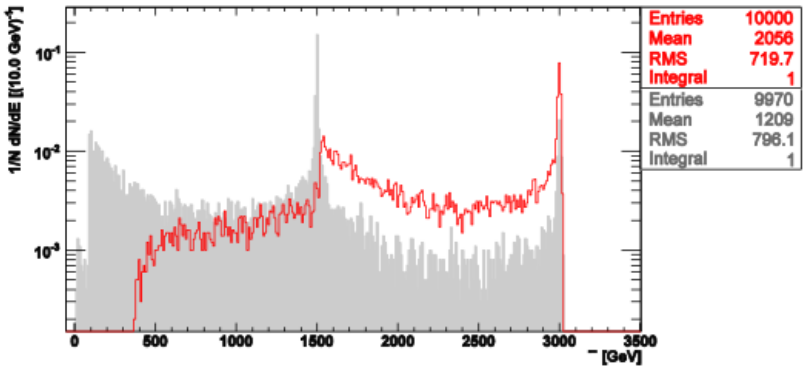




- $E = 3000$ GeV (luminosity spectrum peak)
- $E = 1500$ GeV (Z peak and lumi spectrum)
- $E = M_Z$ (Z resonance)
- $E \approx 30$ GeV (due to $e^+e^- \to \gamma^* \to b\bar{b}$)

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- Simulation with WHIZARD (2.1.1)
- Beam spectrum properly described in WHIZARD

New (LC-related) features / Plans

- LCIO support courtesy of F. Gaede
- ILC TDR beam spectra within `CIRCE1` courtesy of A. Hartin / J. List / G. Wilson
- also more than the official ILC TDR spectra (200 GeV and below)
- CLIC spectra: a lot more difficult: also available
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cf. Fabian's talk yesterday!

Questions to the User Community?

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- External code for structure functions, analysis, cuts? What form?
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WHIZARD workshop 16.-18.3.2015





Würzburg baroque castle: “fake” Versailles from “Les trois mousquetaires” (2011)

Summary and Outlook



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- Versatile, user-friendly tool for SM & BSM physics
- Highest-possible support for LC beam structures
- Covers the whole SM, and most possible paths beyond
- Shooting out after a long technical overhaul
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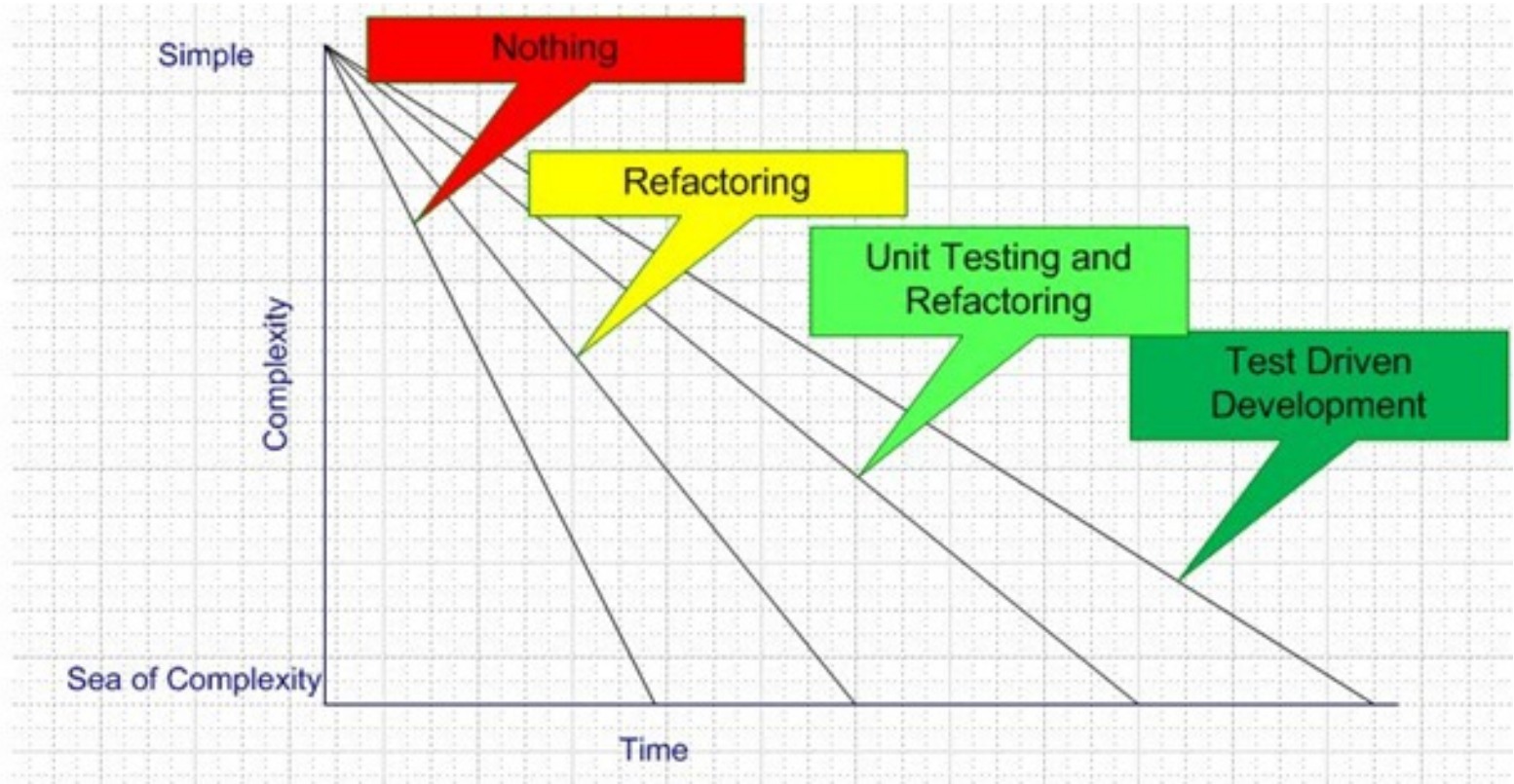


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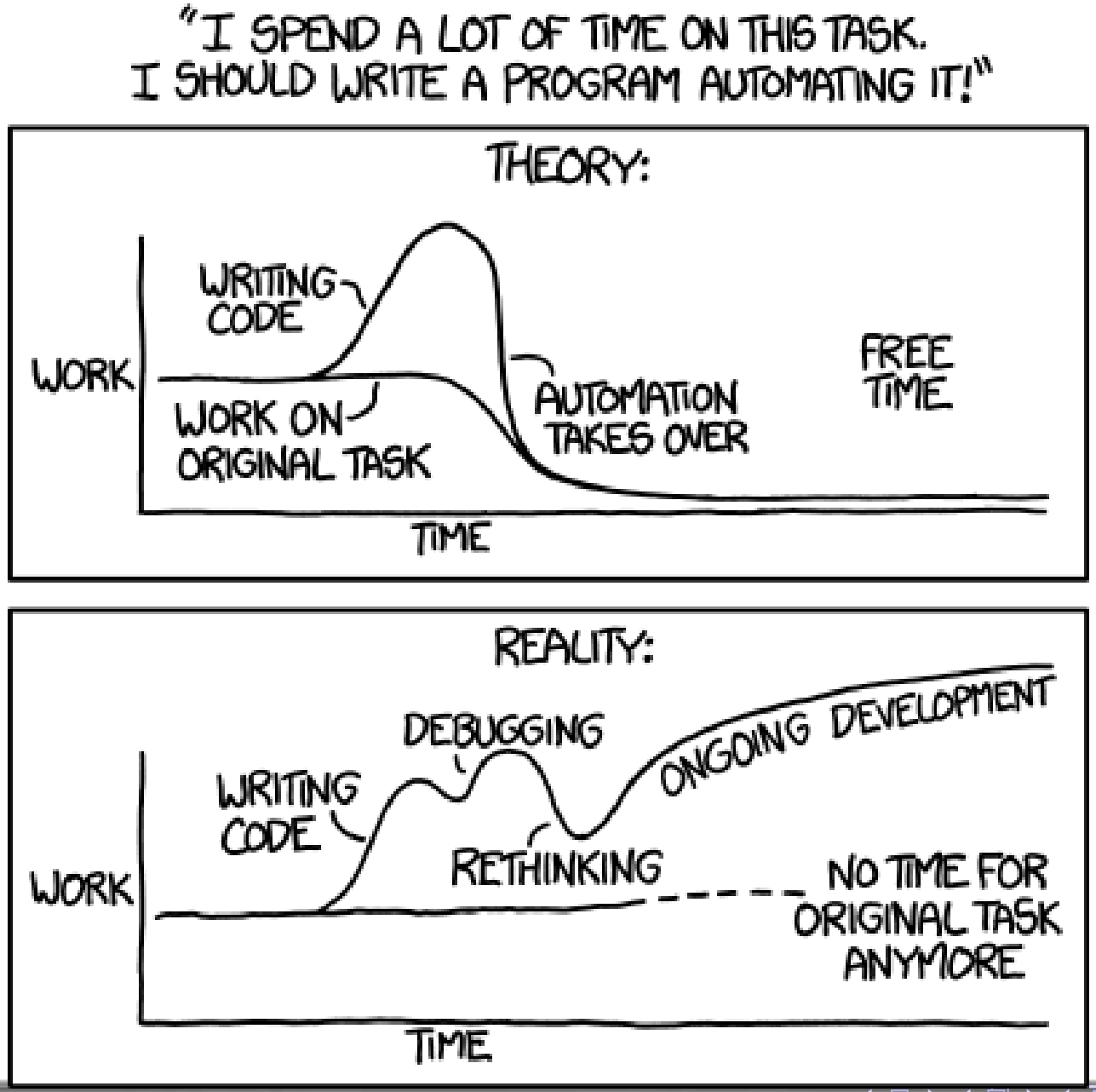
Let us know of your needs!

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Theory predictions

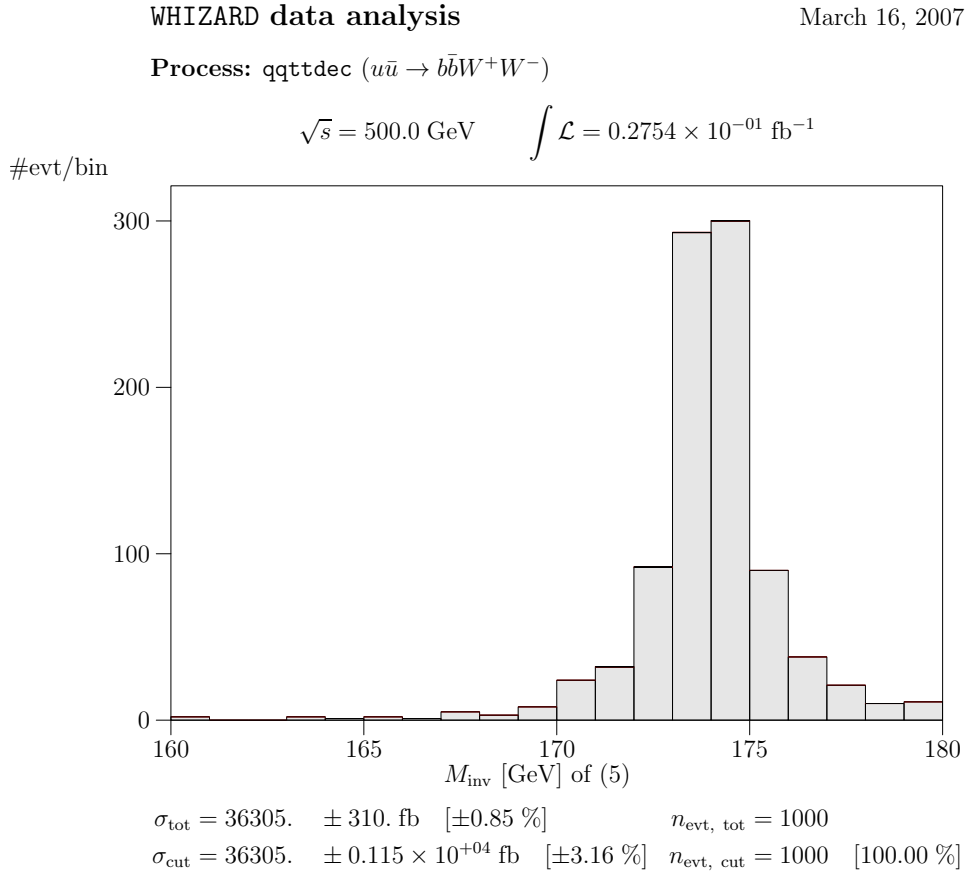


Reality ... (?) ...


"I SPEND A LOT OF TIME ON THIS TASK.
I SHOULD WRITE A PROGRAM AUTOMATING IT!"
THEORY:
WORK
WRITING CODE
WORK ON ORIGINAL TASK
AUTOMATION TAKES OVER
FREE TIME
TIME
REALITY:
WORK
WRITING CODE
DEBUGGING
RETHINKING
ONGOING DEVELOPMENT
NO TIME FOR ORIGINAL TASK ANYMORE
TIME

BACKUP SLIDES:

WHIZARD histograms



New completely general syntax in WHIZARD 2.x

```
$title = "Jet Energy in $pp\to \ell\bar\nu j$"
$x_label = "$E$/GeV"
histogram e_jet (0 GeV, 80 GeV, 2 GeV)
analysis = record pt_lepton (eval Pt [extract index 1 [sort by Pt [lepton]]]);
           record pt_jet (eval Pt [extract index 1 [sort by Pt [jet]]]);
           record e_lepton (eval E [extract index 1 [sort by Pt [lepton]]]);
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```