Generating the full SM at linear colliders

Mikael Berggren[1]

[1] DESY, Hamburg, On behalf of the generator group (LCGG) of the Linear Collider Collaboration (LCC)

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Outline

1. Linear colliders
2. Generating the full SM
   - Process classification
   - Physics generator
   - Generating beam properties
   - Setup, integration, event generation, documentation
3. Outlook
4. Conclusions

Outline

Disclaimer

This is not a talk about physics in event generators, nor about detector simulation.

Linear colliders

- polarised e^+e^- colliders with E_{CMS} = (90)-250 - 3000 GeV.
- e^+e^- means EW-production $\Rightarrow$ Low background.
  - Detectors w/ $\sim 4\pi$ coverage.
  - Rad. hardness not needed: only few % X_0 in front of calorimters.
  - No trigger
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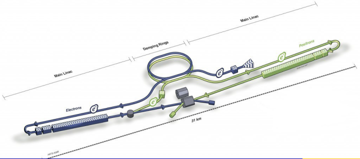
ILC:

- 20 year running $\rightarrow$ 4 ab^{-1} @ 500 GeV, 2 ab^{-1} @ 250 GeV.
- Construction under political consideration in Japan.



CLIC:

- 20 year running $\rightarrow$ 5 ab^{-1} @ 3 TeV, 2.5 ab^{-1} @ 1.5 TeV, 1 ab^{-1} @ 380 GeV.
- Possible future CERN project.

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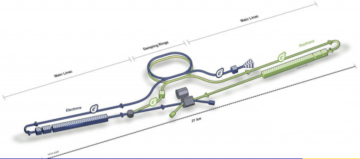

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MC requirements for linear colliders

- Future LCs aim for extremely high precision measurements.
  - $\Rightarrow$ Need excellent detector, well controlled machine conditions
  - But also the best possible estimate of backgrounds.
- MC statistics or lacking channels must not be a major source of systematic errors $\Rightarrow$
  - All SM channels yielding at least a few events under the full lifetime of the projects need to be generated, with statistics largely exceeding that of the real data.
  - Also machine conditions need to be accurately taken into account.
- In addition: at an LC ALL events are interesting, and often fully reconstructed. More like a B-factory than LHC!
- This endeavour has been organised as a common effort between ILD and SiD at ILC and CLICdp at CLIC. The work is done within the generator group, LCGG.

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Generating the full SM

Generate the full SM? What's the problem?

- Just select a generator, and press <RET>, right?
- Noooo..., not really. Lots of details:
  - What collides ($e^{+/-}$ or γ ?)
    - What energy do they have, and how are they polarised ?
  - Where do they collide ?
    - Beam-spot properties
  - What else happens?
    - Beam-strahlung gives pairs.
      Do they hit anything ? Maybe forward calorimetry, or the tracking system ?
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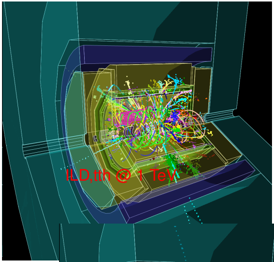
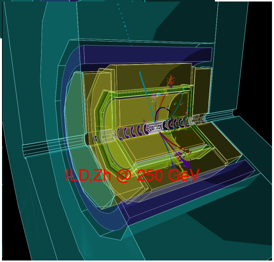
In addition, the physics channels themselves:

- At an LC, ALL events are interesting !
- Huge spread in cross-sections
- But for any given study, it might be a tiny cross-section one that dominates...
- ... or maybe a tiny fraction of a huge cross-section one.
- We want to make nice stacked histos of different backgrounds - different from analysis to analysis.
- ⇒ Good idea to separate channels in an intelligent and well documented way





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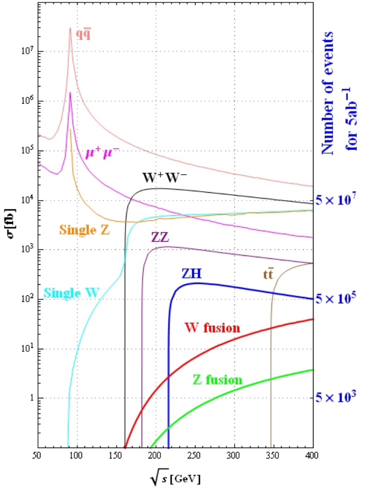

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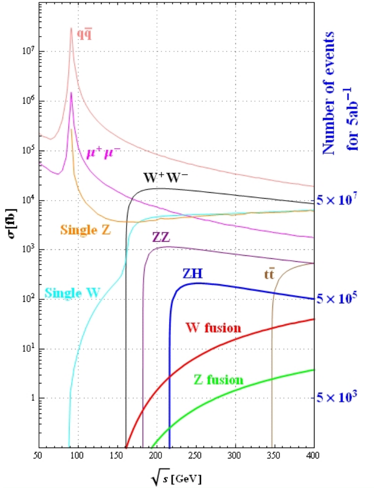

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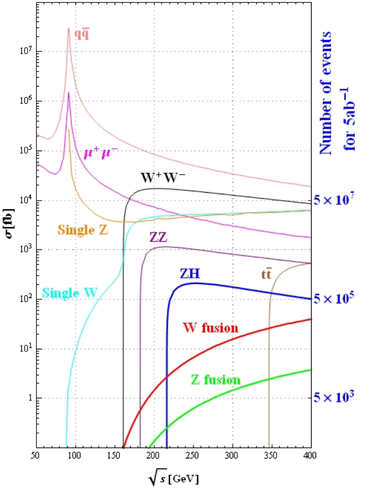

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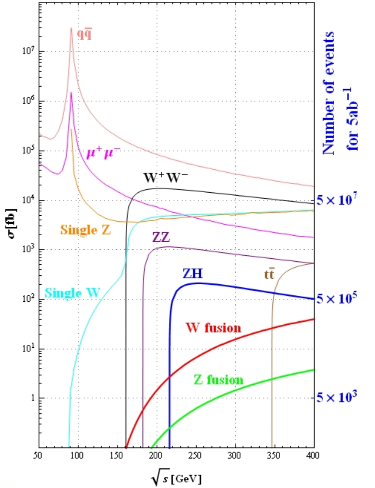

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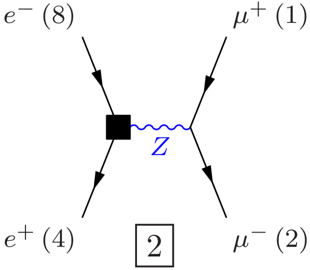
Process classification

- Initial state
  - ee, eγ or $\gamma\gamma$
  - e - polarisation and γ type (real or virtual)
- Final state
  - Number of fermions (1 to 8)
  - Flavour-grouping: W or Z, or ambiguous
  - leptonic, hadronic, semi-leptoni (+ neutrino only, for Z-leptonic)
- Special considerations
  - Eg. 4f with $|L_e|$=2 $\Rightarrow$ dominated by single W or single Z (t-channel !)
  - Avoid double-counting: Eg. $\gamma^*\gamma^* \rightarrow f\bar{f}$ vs. $e^+e^- \rightarrow e^+e^- f\bar{f}$.



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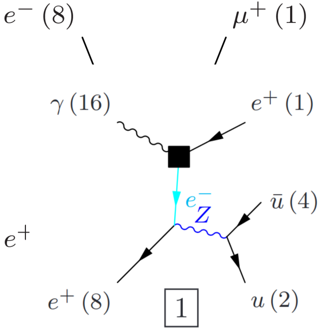

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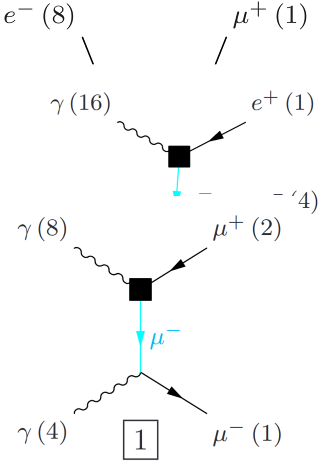

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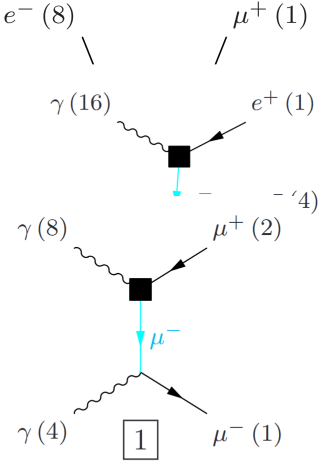

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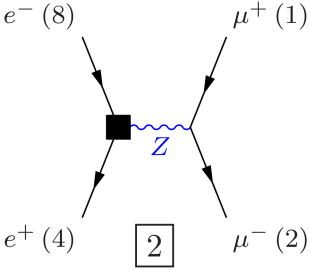

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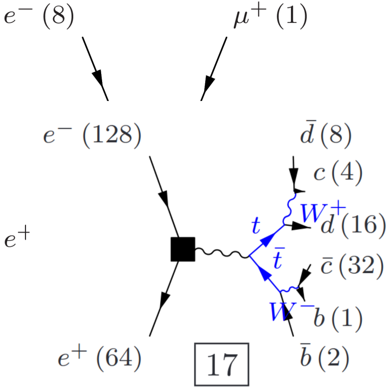

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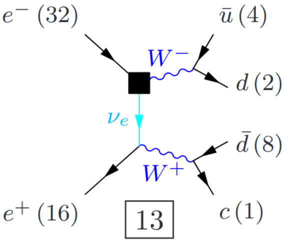

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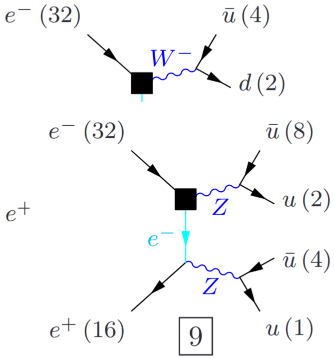

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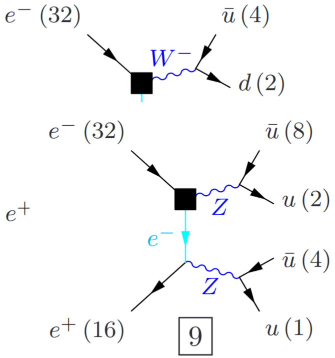

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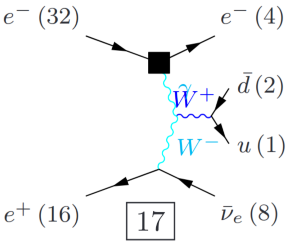

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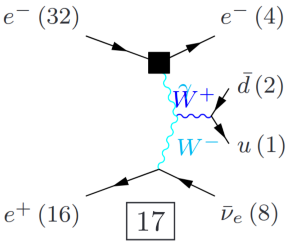
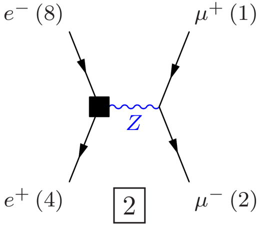


Main generator: Whizard

Whizard is the generator of choice for e^+e^-

- Full matrix-element evaluation.
  Only at tree-level but:
  - Polarised beams.
  - Full helicity treatment.
  - Full colour flow, passed from the hard interaction to the P.S. code.
  - Can handle beam-spectrum, using Circe2.
  - Can handle polarised τ-decays, using TAUOLA [Comp Phys Comm,64,p275].
  - And: Can do $2 \rightarrow 8$ processes.
- ... which is more important than NLO for e^+e^- ! That was just one 5f tree-level diagram of ~ 500...



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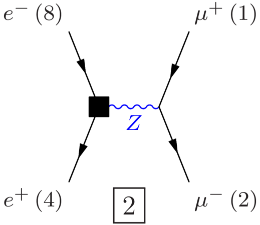

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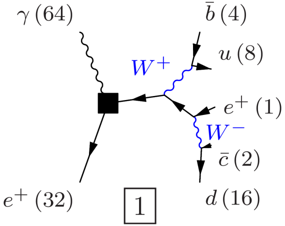

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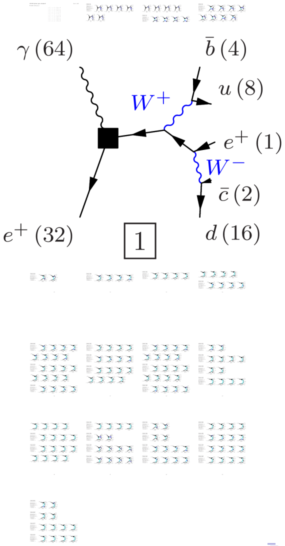

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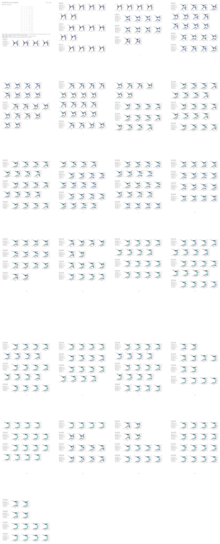

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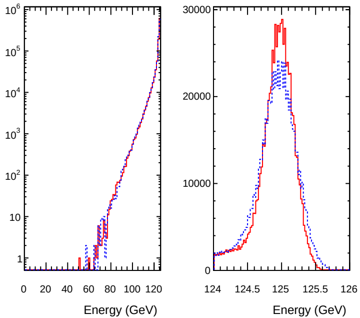
Main generator: Whizard

- The subsequent parton-shower and hadronisation is done by PYTHIA6.4.
  - LCGG has tuned hadronisation using input from OPAL at LEPII [Phys.Rept. 291 (1997) 107-217, D. Ward, private communication.].
- The process-definition given in the Whizard steering file (aka the *sindarin*) is also the driver for the scripts that organises the production: One ring to rule them all.
- Use powerful grouping and aliasing capabilities of sindarin to assure that no processes are over-looked.

Beam effects

- Beam-spectrum.
  1. Incoming beam-spread
  2. But also: very strongly focused beams ⇒ Beam-beam interactions



- Photons
  1. How many photons?
  2. Are they virtual or real?
- Need beam-beam interaction simulation input.
- Simulate interaction region: GuineaPig [CERN-PS-99-014-LP]. Gives:
  - Beam-spectrum for electrons and positrons independently
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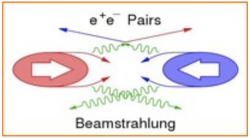

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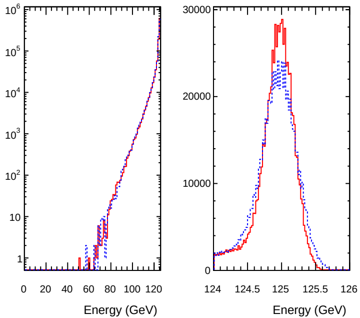

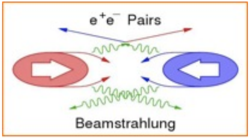

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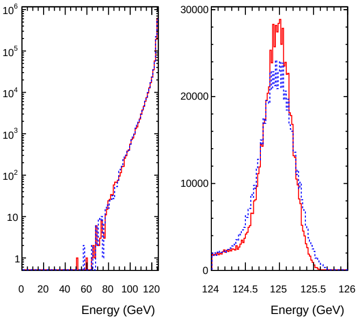

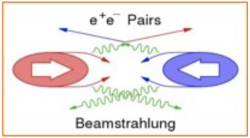

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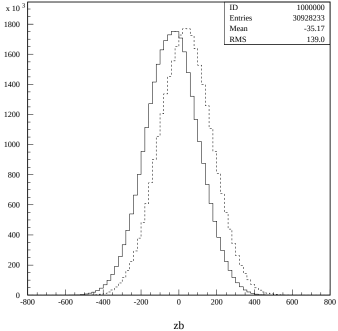
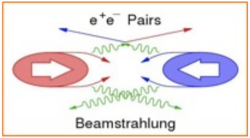
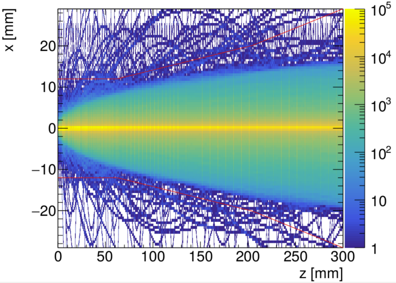




Spurious interactions ("pile-up")

Two types:

- Pair-background: Pair-creation of photons in the beam by the strong fields. GuineaPig can generate the full activity during a beam-crossing (a "BX").
- low-p$_\perp$ hadrons, ie. $\gamma^{(*)}\gamma^{(*)}$ interaction with small $M_{\gamma\gamma}$ and multiplicity. NB: only $\mathcal{O}(1)$/BX !
  - ME can't do this, and PYTHIA is good down to $M_{\gamma\gamma} \sim 2$ GeV.
  - Below: fit to data - Custom generator developed by LCGG.
- Both types: Pre-generate pool of events, pick at random and overlay on main event.



- For pairs: Do $\sim 10^5$ BXes, use fast detector simulation SGV to filter out track hitting tracking ($\sim$10/BX), rest used to build a map of background on BeamCal.

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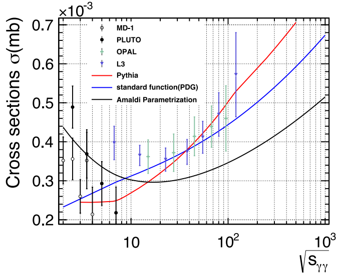

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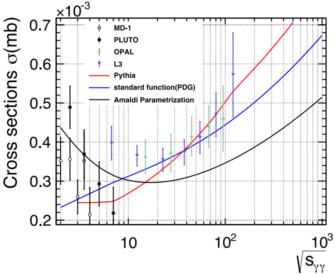

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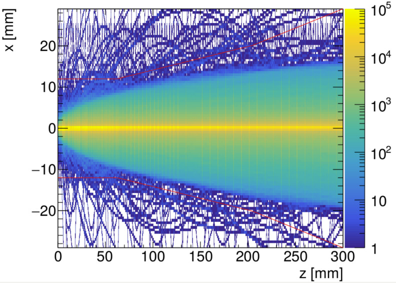

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Setup & integration

- Whizard process definition is parsed to build a directory-tree structure - one unique directory per process.
- Process-specific code is generated and compiled (interactive)
- The tree is traversed to do a "pre-integration" of all channels, to flag zero cross-section ones (interactive).
- Full integration of all channels, with error goal 0.1 % submitted (local batch-farm under Condor). Over-night for $\leq$ 5f.
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At this point, the system is ready to generate the full SM

Generation

- Done on a batch-farm.
- In most cases: one process per generation job.
- Some processes alone represent $\sim$ billion events. These must be split in several jobs.
- At the end of each job, the events (in LCIO format), metadata, and input+logfile tarballs are uploaded to the grid, where the simulation and reconstruction system under DIRAC kicks in - details in talk of R. Ete in this track on Friday.
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Future tasks

Soon: massive generation for ILC@250, with latest ILC parameters

- $\mathcal{O}(10)$ times more than the DBD, more than expected real data.
  - For $\leq$ 5f: CPU $\sim$20000 h - Disk $\sim$10 TB : Much, but not too much...
  - Using $\mathcal{O}(100)$ cores, this generation is done in 1 to 2 weeks.

Whizard developments

- gluon matching between ME and PS:
  - Now: no gluons included in ME (setting $\alpha_s = 0$) to avoid double-counting with (unmatched) parton shower in PYTHIA.
  - Whizard 2 does parton-shower with "MLM matching". Exploit this !
- Medium-term wishes for Whizard:
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  - Work out priority processes for EW-NLO (!)

In general it would be nice to also have other generators

- BHWide for better Bhabhas. BDK/BDKRC for $\gamma\gamma \to \ell\ell$
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Conclusions

- We have explained that the precision-goal of future e^+e^- colliders are such that it is not permissible that MC statistics or coverage could constitute an major systematic uncertainty.
- We showed how the generation of the full SM can be achieved.
  - It consists of bringing a large number of different codes together:
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