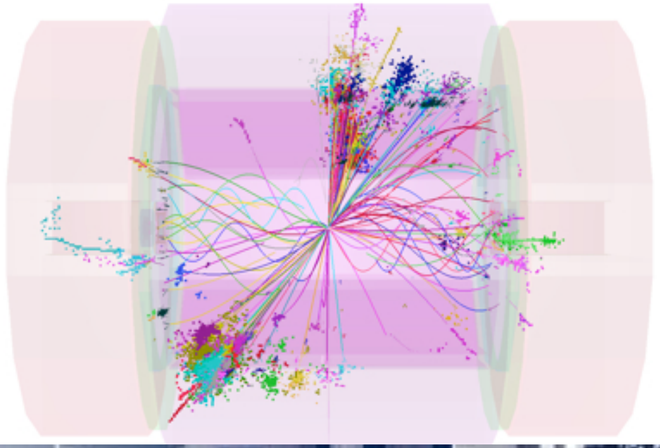
# ECFA Higgs Factory 1st Topical Workshop on Generators / Simulation




Jürgen Reuter

DESY.
HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG
CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

# On a personal note

- Great to have a workshop (again) in person
- Very appropriate for COVID-19 times, discussions were in the ***Filtration Plant***
- For justification of in-person meetings, one has to learn from the best:

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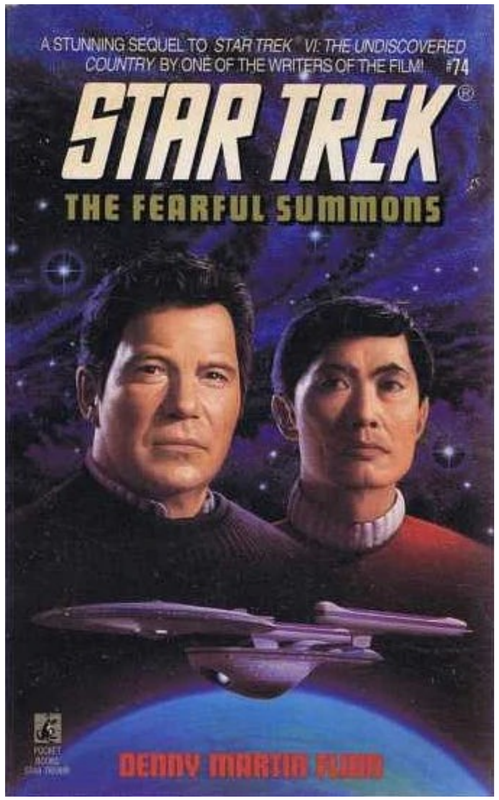


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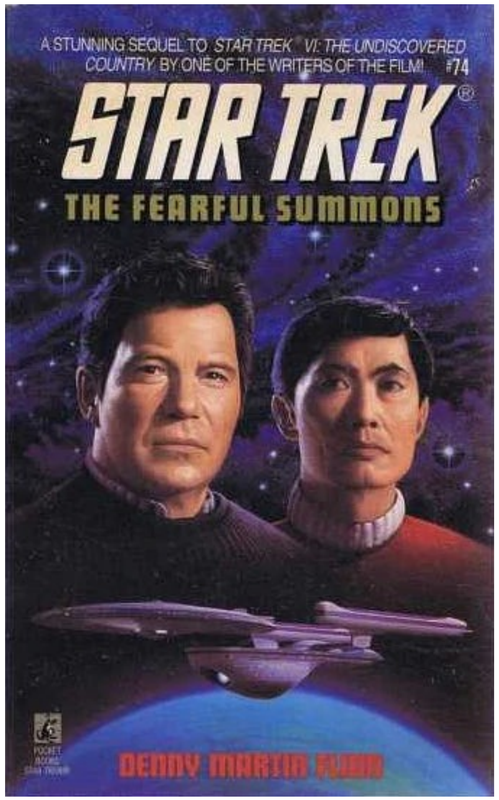


Denny Martin Flinn (1947-2007): *"The fearful summons"*

It was rumored that the Fleet's Department of Humanoid Resources began some years ago to encourage face-to-face meetings where possible. The department apparently now felt that the failure of electronic dialogue to carry useful nuances and improvised content was a factor in inhibiting the quality of collaborative decision making.

# ECFA H/EW/Top Factory 1st Topical Simulation WS

- Recommendation from the European Strategy Update 2020 (ESU2020) ⟹ ↪ ESU2020 document
- ECFA mandate to study the physics case for future Higgs/EW/Top factory ↪ Karl Jakobs, 18.6.21
- Short reminder on the Study Group Structure:


**WG 1: Physics Potential**

**WG 2: Physics Analysis Methods**
- Monte Carlo generators for $e^+e^-$ precision EW/top Higgs factory
- Software framework
- Fast simulation (and its limitations)
- Particle flow
- Luminosity measurement ...
- …

**WG 3: Detector R&D**

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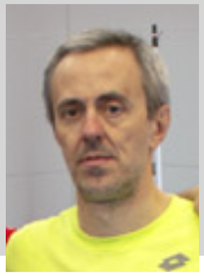
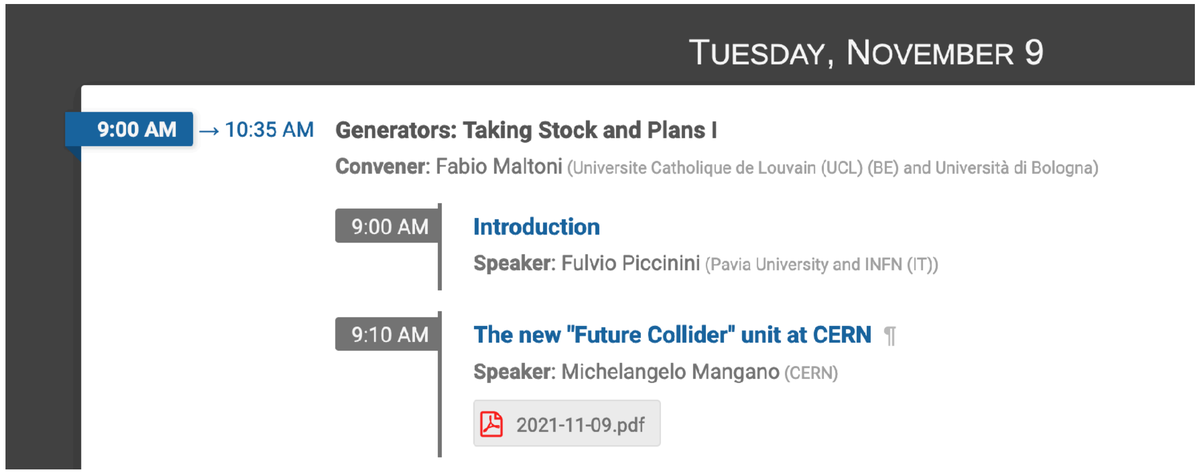
**WG 3: Detector R&D**

- 1st WG2 Topical WS on Generators / Simulation, @CERN: Nov. 9-10, 2021 https://indico.cern.ch/event/1078675/
- Very efficient and effective organization ⟹ Conveners: Patrizia Azzi Fulvio Piccinini Dirk Zerwas


- ≳ 100 participants, roughly 30 at CERN
- Quite intense discussions: true "work"shop

# Connection to Future Collider Unit at CERN




Michelangelo Mangano

**A “Future Colliders” Unit at CERN**

1. As of 1st of October, the unit exists as RCS/PRJ/FC, under the Directorate of Research and Computing [Joachim Mnich]
2. Users’ registration:
   - the unit allows those not affiliated with a CERN expt, or TH, to register as CERN user
3. Resources:
   - 24 months of scientific associates (SASS) per year, during the 2022-2024 period
   - budget to support short visits (per diem), organize activities (workshops), …
   - fellows, project associates or further SASS , as made available by the individual projects under their MTP allocations (FCC, CLIC, mucoll).

Suggestions / Proposals of Usage:

- Connect to the ECFA WGs
- organize workshops / tutorials
- help with tool validation / development
- storage of software projects / data

# Focus 1st WS: Generators, Beams & Software Frameworks

### PYTHIA
**Speaker**: Ilkka Helenius (University of Jyväskylä)

### Herwig
**Speaker**: Simon Platzer (University of Graz (AT))

### Madgraph5_aMC@NLO
**Speaker**: Stefano Frixione (INFN)

### Whizard
**Speaker**: Jürgen Reuter

### SHERPA
**Speaker**: Steffen Schumann (Georg-August-Universitaet Goettingen)

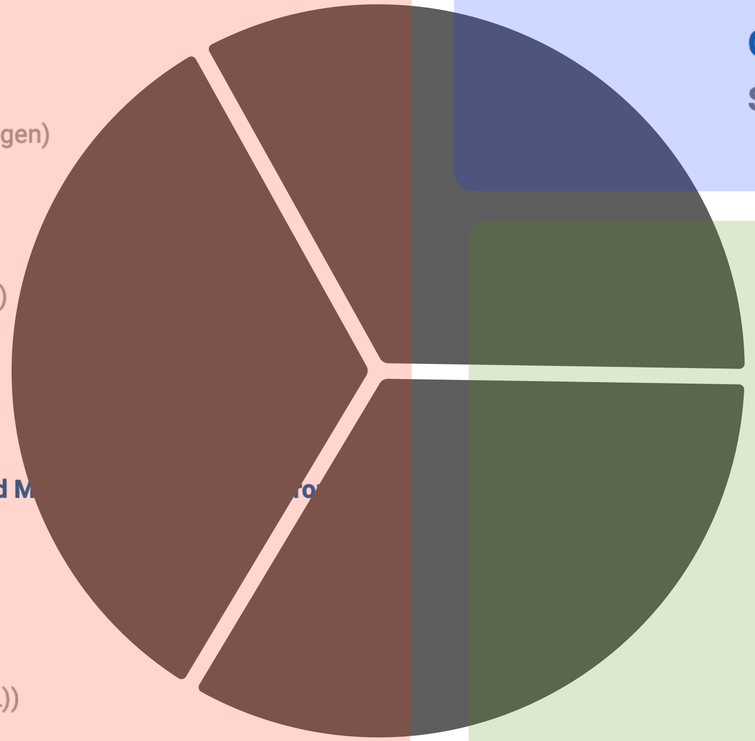
### Powheg
**Speaker**: Emanuele Re (Universita & INFN, Milano-Bicocca (IT))

### Geneva
**Speaker**: Simone Alioli (Universita & INFN, Milano-Bicocca (IT))

**Genuine weak corrections and tau lepton decays for phenomenology and M … to LHC, Belle2 and to FCC, ILC, CLIC**
**Speaker**: Zbigniew Andrzej Was (Polish Academy of Sciences (PL))

### KKMC
**Speaker**: Staszek Jadach (Polish Academy of Sciences (PL))

### BabaYaga
**Speakers**: Carlo Michel Carloni Calame (INFN - National Institute …



### Guinea Pig
**Speaker**: Daniel Schulte (CERN)

### Discussion on Benchmarks
1. Beamstrahlung
2. Processes for Performance
3. Processes for Physics Studies

### CIRCE
**Speaker**: Thorsten Ohl (Würzburg University)

### Production Experience LHC
**Speaker**: Andy Buckley (University of Glasgow (GB))

### Production Experience LC
**Speaker**: Mikael Berggren (Deutsches Elektronen-Synchrotron (DE))

### Production Experience FCC
**Speaker**: Clement Helsens (CERN)

### The Software Ecosystem
**Speaker**: Gerardo Ganis (CERN)

**Madgraph5_aMC@NLO on GPUs and Vectorized C++ and HEP Software Foundation Generator Group Activities**
**Speaker**: Andrea Valassi (CERN)

# Organizers' Task for the Speakers

- ☑ Beamstrahlung for FCC, CLIC, ILC: internal or external or ... ?
- ☑ Beamspot / crossing angle internal / external
- ☑ Beam Polarization: available, foreseen, not foreseen / full matrix

**Beam Setup**

- ☑ Interface to KEY4HEP: available, not doable, foreseen, need
- ☑ modifications in KEY4HEP, library or file interface
- ☑ Code management / availability or source code (website or Gitlab/Hepforge...) / feedback loop?

**Software maintenance**

- ☑ Output format: which type?
- ☑ LHE: don't care, need it, need an extension

**Event formats**

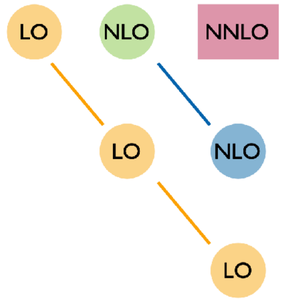
- ☑ NLO corrections : EW / QCD / none / planned
- ☑ Which hadronization model?
- ☑ External decays/FSR? Tauola / Photos / EvtGen

**Physics**

- ☑ CPU performance, support for multithreading, vectorization and GPUs
- ☑ Testing: interest in comparisons with other generators

**Performance, validation**

# Lessons from the Generators I

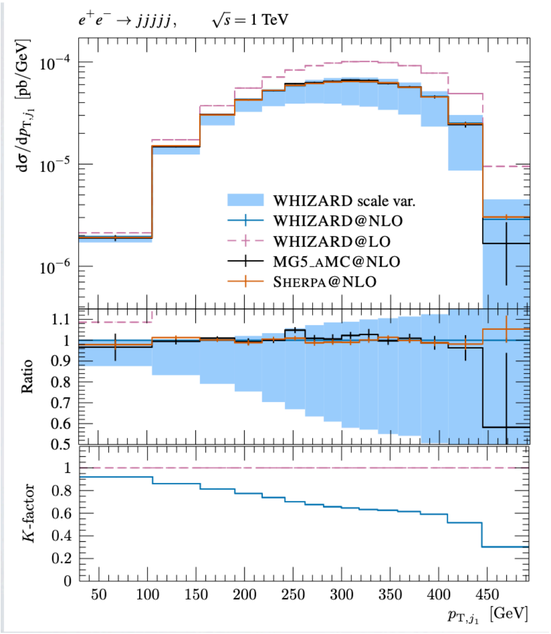


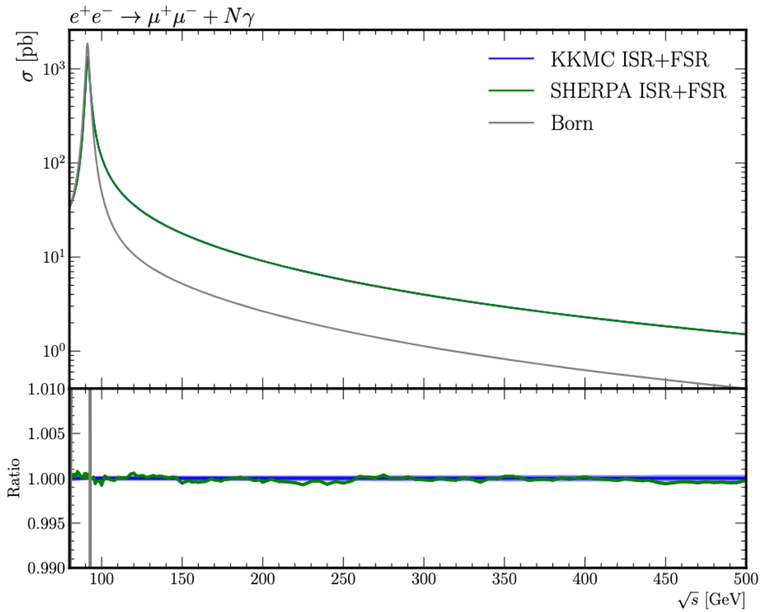

NLO QCD state-of-the-art
NLO EW for $e^+e^-$ to come
some NNLO (QED) started

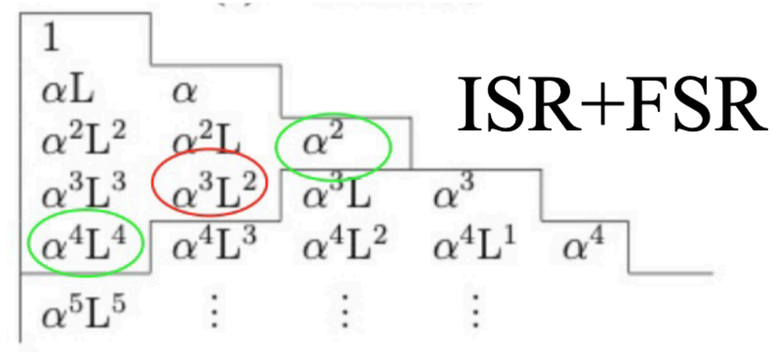
| Process | $\sigma_{\text{LO}}$ [fb] | $\sigma_{\text{NLO}}$ [fb] |
|---|---|---|
| $e^+e^- \to jj$ | 622.737(8) | 639.39(5) |
| $e^+e^- \to jjj$ | 340.6(5) | 317.8(5) |
| $e^+e^- \to jjjj$ | 105.0(3) | 104.2(4) |
| $e^+e^- \to jjjjj$ | 22.33(5) | 24.57(7) |
| $e^+e^- \to jjjjjj$ | 3.583(17) | 4.46(4) |

| | | | |
|---|---|---|---|
| $e^+e^- \to t\bar{t}$ | 166.37(12) | 174.55(20) | 1.05 |
| $e^+e^- \to t\bar{t}j$ | 48.12(5) | 53.41(7) | 1.11 |
| $e^+e^- \to t\bar{t}jj$ | 8.592(19) | 10.526(21) | 1.23 |
| $e^+e^- \to t\bar{t}jjj$ | 1.035(4) | 1.405(5) | 1.36 |
| $e^+e^- \to t\bar{t}t\bar{t}$ | $0.6388(8) \cdot 10^{-3}$ | $1.1922(11) \cdot 10^{-3}$ | 1.87 |
| $e^+e^- \to t\bar{t}t\bar{t}j$ | $2.673(7) \cdot 10^{-5}$ | $5.251(11) \cdot 10^{-5}$ | 1.96 |
| $e^+e^- \to t\bar{t}H$ | 2.020(3) | 1.912(3) | 0.95 |
| $e^+e^- \to t\bar{t}Hj$ | $2.536(4) \cdot 10^{-1}$ | $2.657(4) \cdot 10^{-1}$ | 1.05 |
| $e^+e^- \to t\bar{t}Hjj$ | $2.646(8) \cdot 10^{-2}$ | $3.123(9) \cdot 10^{-2}$ | 1.18 |
| $e^+e^- \to t\bar{t}Z$ | 4.638(3) | 4.937(3) | 1.06 |
| $e^+e^- \to t\bar{t}Zj$ | $6.027(9) \cdot 10^{-1}$ | $6.921(11) \cdot 10^{-1}$ | 1.15 |
| $e^+e^- \to t\bar{t}Zjj$ | $6.436(21) \cdot 10^{-2}$ | $8.241(29) \cdot 10^{-2}$ | 1.28 |
| $e^+e^- \to t\bar{t}W^{\pm}jj$ | $2.387(8) \cdot 10^{-4}$ | $3.716(10) \cdot 10^{-4}$ | 1.56 |
| $e^+e^- \to t\bar{t}HZ$ | $3.623(19) \cdot 10^{-2}$ | $3.584(19) \cdot 10^{-2}$ | 0.99 |
| $e^+e^- \to t\bar{t}ZZ$ | $3.788(6) \cdot 10^{-2}$ | $4.032(7) \cdot 10^{-2}$ | 1.06 |
| $e^+e^- \to t\bar{t}HH$ | $1.3650(15) \cdot 10^{-2}$ | $1.2168(16) \cdot 10^{-2}$ | 0.89 |
| $e^+e^- \to t\bar{t}W^+W^-$ | $1.3672(21) \cdot 10^{-1}$ | $1.5385(22) \cdot 10^{-1}$ | 1.13 |

$$d\sigma_{kl}(p_k, p_l) = \sum_{ij=e^+,e^-,\gamma} \int dz_+ dz_- \, \Gamma_{i/k}(z_+, \mu^2, m^2)\, \Gamma_{j/l}(z_-, \mu^2, m^2) \times d\hat{\sigma}_{ij}(z_+ p_k, z_- p_l, \mu^2) + \mathcal{O}\left(\left(\frac{m^2}{s}\right)^p\right)$$



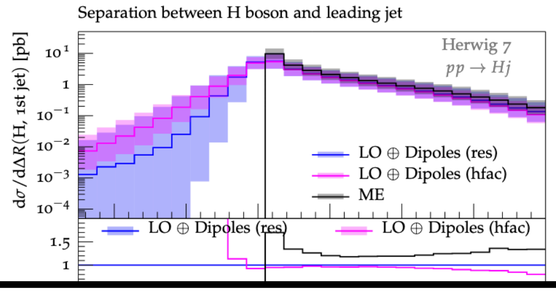




ISR+FSR

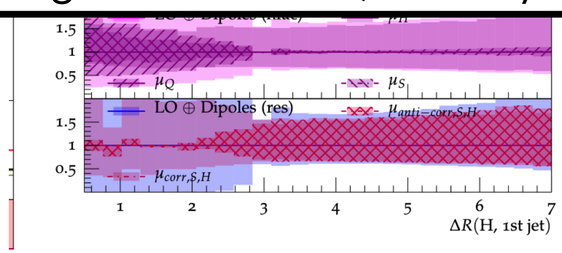
- Inclusive part: electron PDFs (polarized?)
- LL vs. NLL PDFs, PDFs from LHAPDF?
- Exclusive part: Matrix elements vs. YFS, fixed order vs. resummation

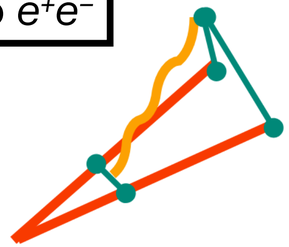
# Lessons from the Generators II



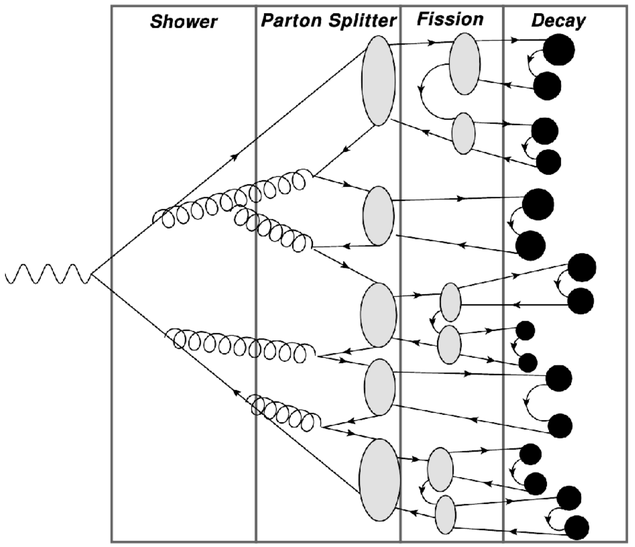

Parton branchings order in angle.

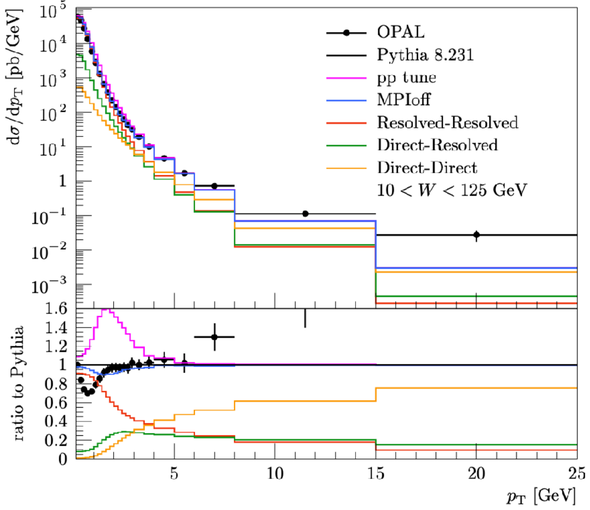
Amazing QCD shower & jet physics progress from LHC, to carry over to $e^+e^-$



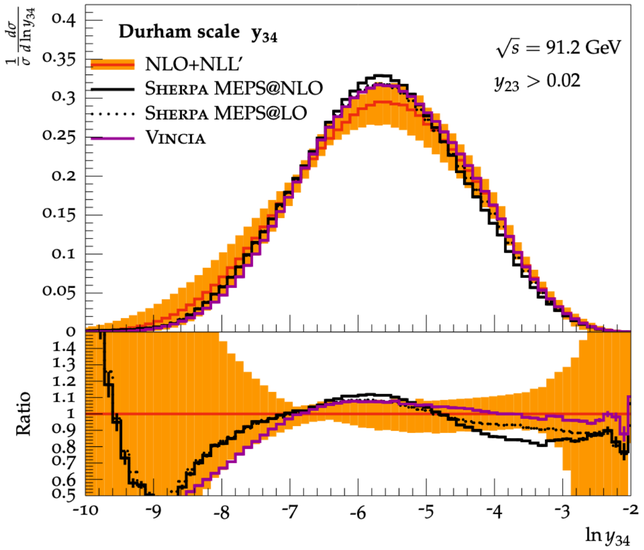



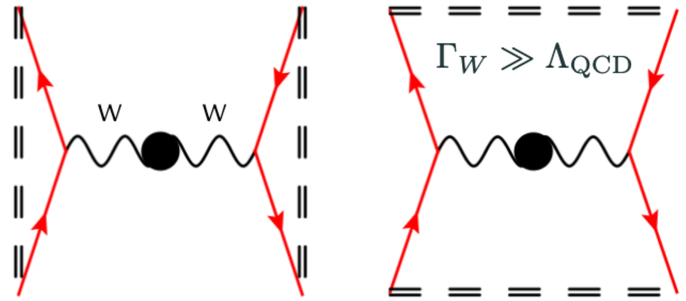
Dipole branchings order in transverse momentum.




[OPAL: Phys. Lett. B651 (2007) 92-101]



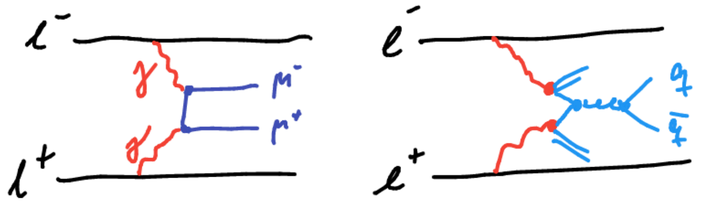

Modern hadronization tools tuned to LEP/OPAL data in all detail?

- High statistics for ee → *WW*

⇒ Clean environment to study CR effects, no-CR scenario excluded at 99.5% in LEP II

# Lessons from the Generators III

Several MCs have Weizsäcker-Williams / EPA
... many precision/validity studies needed



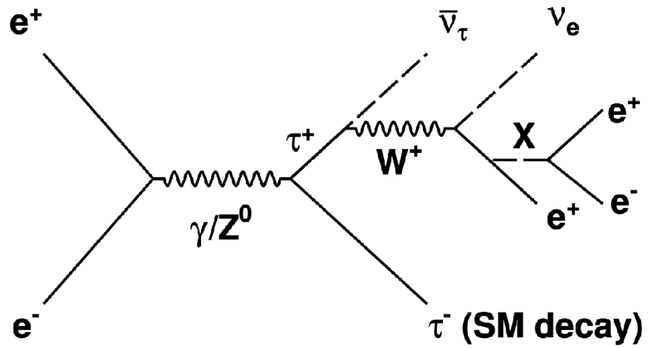

BSM: several tools with versatile support
via UFO and Lagrangian level tools

Complete support for SMEFTsim 3.0
Spin 0, 1/2, 1, 3/2, 2 supported
Arbitrary Lorentz structures supported
Support for customized propagators
5-, 6-, 7-, 8-point vertices
Majorana and Dirac statistics

`basf2` software of Belle II, new $\tau$ decay channels prepared for `tauola`:

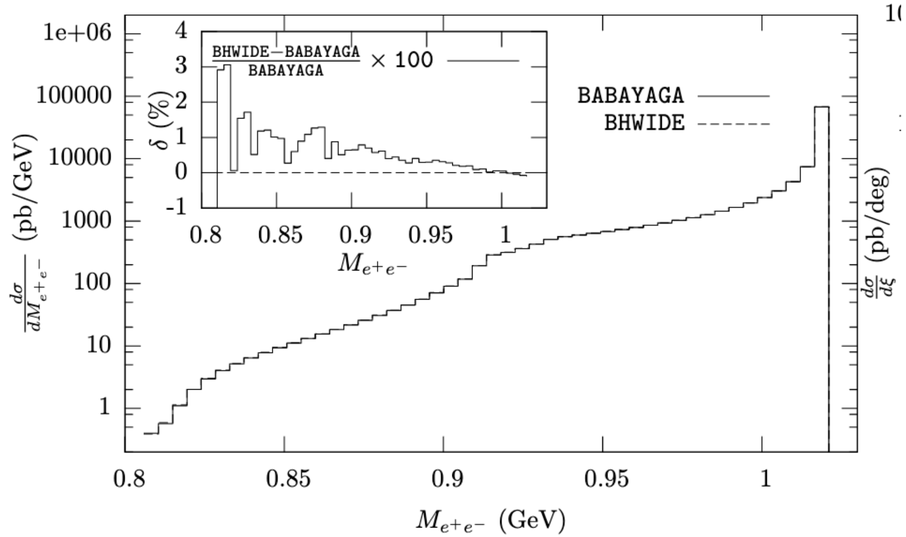
1. Total number of decay channels: 278
2. 2 body neutrinoless non SM decays: 58
3. 3 body neutrinoless non SM decays: 46

**... in tauola:**




Need for dedicated MCs:

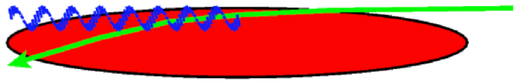
E.g. comparison `BabaYaga@NLO` vs. `BHWIDE` (Jadach, Płaczek, Ward) at KLOE




Polarization not available for some generators

**Event formats:**
LHE (v1-3), HepMC2/3 standard
LCIO not widely available,
confusion on scope of LCIO

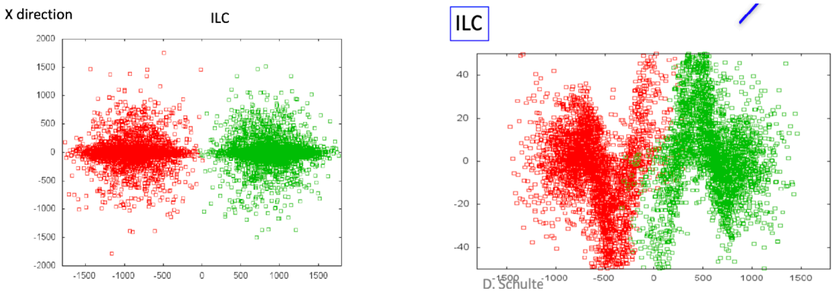
# Simulation of beam dynamics

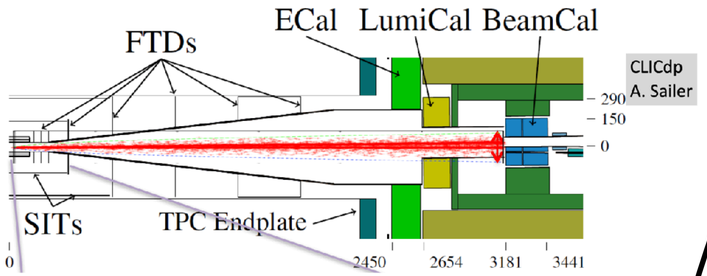


$$\Upsilon = \frac{2}{3}\frac{\hbar\omega_c}{E_0}$$

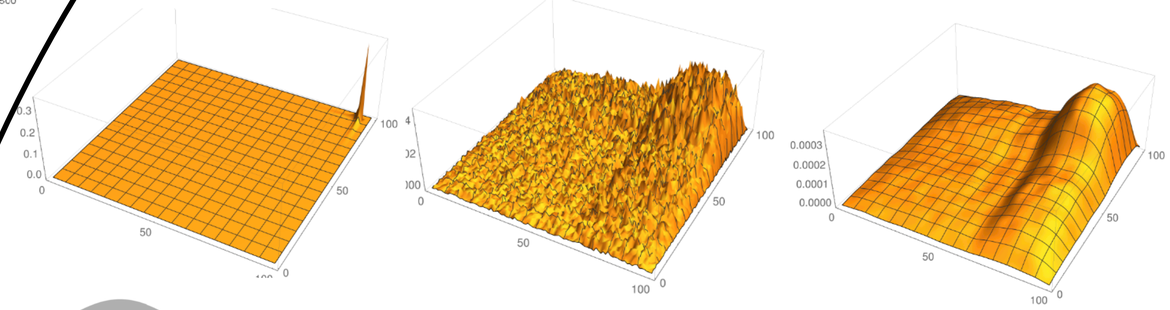
**Classical regime** $\Upsilon \ll 1$
ILC (0.06), CLIC at 380GeV (0.17)

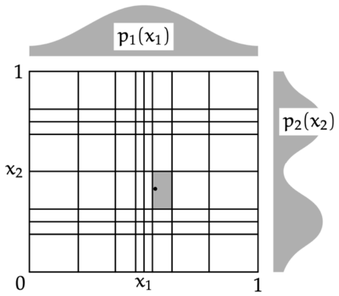
**Quantum regime** $\Upsilon \gg 1$
CLIC at 3TeV Y=5



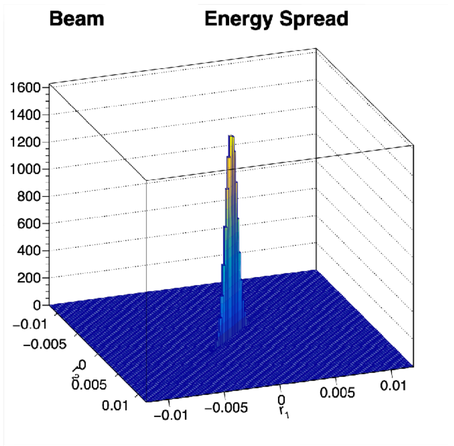

$$\begin{aligned}\mathcal{B}_{e^+e^-}(y_+,y_-) &= \hat{f}_{11}\,\delta(1-y_+)\,\delta(1-y_-)\\ &+ (1-y_+)^{\kappa_+} f_{01}(y_+)\,\delta(1-y_-)\\ &+ \delta(1-y_-)\,(1-y_-)^{\kappa_-} f_{10}(y_-)\\ &+ (1-y_+)^{\kappa_+} f_{00+}(y_+)\,(1-y_-)^{\kappa_-} f_{00-}(y_-)\end{aligned}$$






- GuineaPig standard beam simulation tool
- [in principle, there is also CAIN]
- Simulation of circular machines is tedious and tricky
- 6-7 parameter fits with delta peaks and tails insufficient
- CIRCE2 can simulate correlated statistics-improved Guinea Pig fits
- “Have your machine-physicist consultant” [Daniel Schulte]
- CIRCE3 will simulate *z*-dependence, supported in Whizard [Thorsten Ohl]
- Strong wish in MC community to define/standardize beam simulation

Note: Several codes support simple Gaussian beam spread

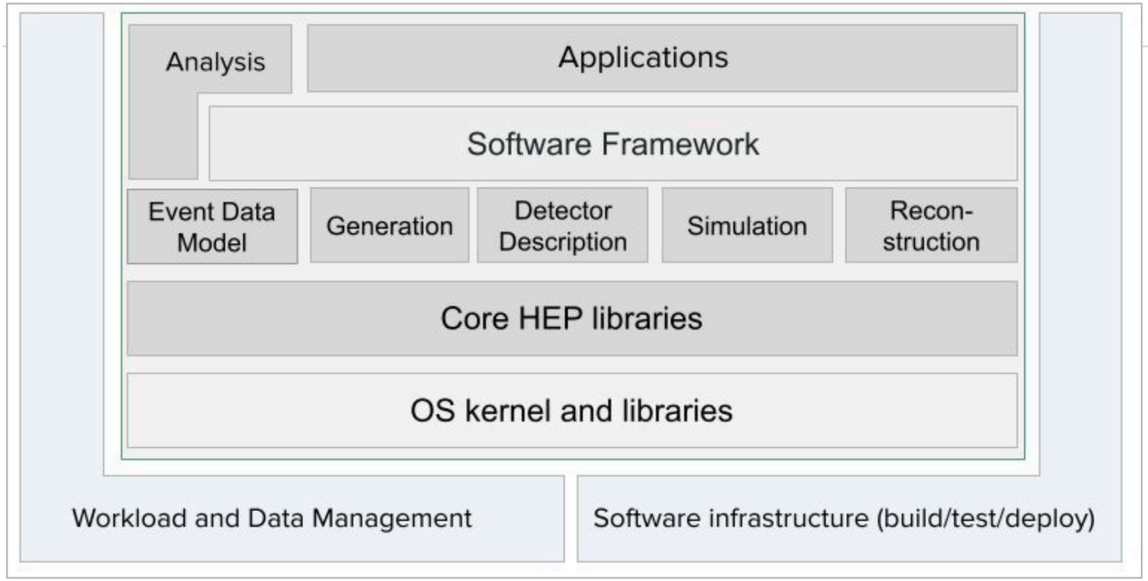


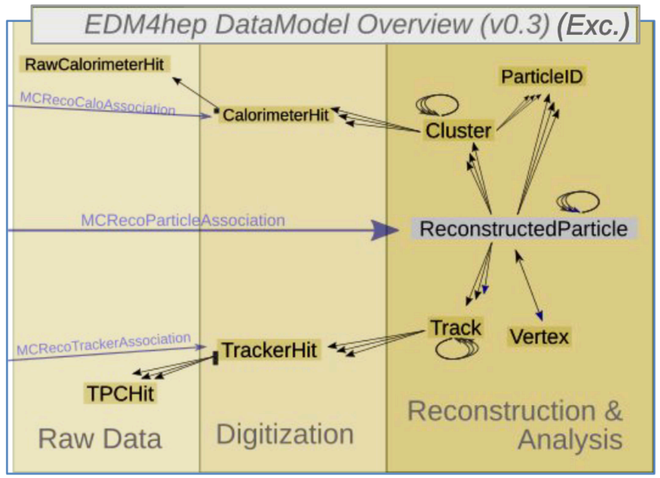
[Gerard Ganis]

# Software Ecosystems

## Complete set of tools for

- Generation, simulation, reconstruction, analysis
- Build, package, test, deploy, run



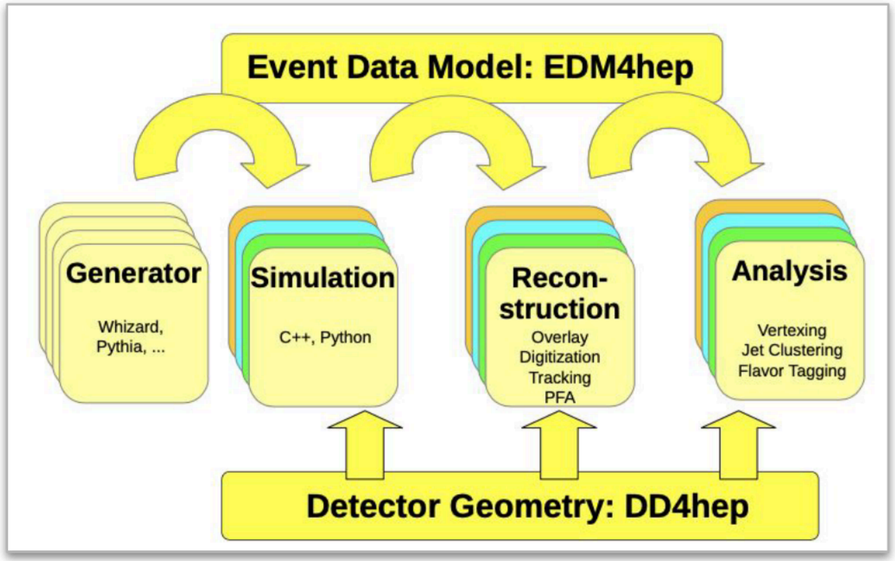




## Core Ingredients of current key4hep

- PoDIO for EDM4hep, based on LCIO and FCC-edm
- Gaudi framework, devel/used for (HL-)LHC
- DD4hep for geometry, adopted at LHC
- Spack package manager, lot of interest from LHC

Regular (weekly) meetings

O(10) people attending, mostly from CERN, DESY, CEPC




From key4hep-spack

guinea-pig 1.2.2rc
whizard 3.0.1
KKMCee 4.32.01
BHLUMI 4.04-linuxLHE
Babayaga fcc-1.0.0

Many discussions: how to inject tools? LCIO-based event format vs. HepMC
Generators as programs or libraries? Chains of generators supported?

# Lessons from MC mass productions

- **Report from LHC software frameworks:** [Andi Buckley]

  **Bulk of CPU comes from multileg NLO *V*+jets, *tt***

  40% of Sherpa CPU in PDFs!  ≈ 100,000 different Python options: jet slices, flavour filtering, BSM grid scans etc.

- **Report on ILC (CLIC) mass production:** [Mikael Berggren]

  ILC 250 GeV production: Generation status

  As of today, 104 channels are done, producing 2.7 billion events in 15788 LCIO files details, occupying 5.4 TB. This used 7233 CPU hours, obtained in ∼ 10 days.

  Medium-term wishes
  - $\gamma$ ISR/FSR matching
  - Work out priority processes for EW-NLO.

- **Report on FCC MC production:** [Clement Helsens]

  "Spring2021" production, EDM4hep
  - Delphes events IDEA with *Track Covariance full matrix lower triangle*
  - Total: ~$10^{10}$ events, ~53 TB, mostly at Z peak

- Review on HEP Software Foundation (HSF) [Andrea Valassi]

  All times are MC generator times only!

- Completely different simulation philosophies LHC vs. Higgs factories

  "stacked signal processes" vs. complete inclusive "multiplicity samples"

- Computing demands for ILC still slim — will change partially for N(N)LO productions

- Discussion on parallelization strategies: GPU vs. CPU, SIMD vs. SIMP, benchmarking

**Communication with authors essential**

- Physics content is very complex, many hidden wrinkles
- Design interfaces to enable communication with authors.
- Incentivise rapid responses, provide dev person-power to help

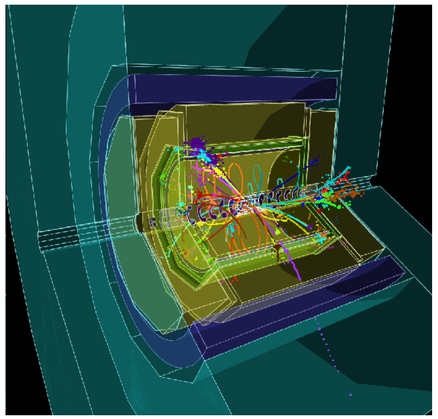
*"MC authors not strongly incentivised to solve expt. problems!"* [Andi Buckley]

*"Also 2nd ('validation') implementations have to get credit!"* [Thorsten Ohl]

# Summary & Conclusions

- Transferral of SLC/LEP legacy & LHC frameworks, reports on existing ILC / CLIC simulations
- Quite special rôle of CEPC (simulation framework): not excluded, but not officially invited (yet?)
- Lots of discussions: both *strategic* & *many technical*
- *Need for Les Houches/Aspen*-style workshops: CERN/ECFA as hub/platform for organization
- Three main parts: generators, beam simulation, software frameworks
- Discussion on specialized tools like higher-order calculators: *not highlighted at 1st workshop*
- Some concerns of duplication of efforts and person-power issues: ECFA vs. Snowmass vs. IDT vs. ....
- Great start and concrete plans to go ahead: **Meeting on beam spectra, 12.01.22**: https://indico.cern.ch/event/1100734/

  **Simulation/Reco-focused WS, 1.-2.2.22**: https://indico.cern.ch/event/1097819/ **MC Generator (esp. $\gamma\gamma$), 06/22** W. Kilian



ILD Event Display