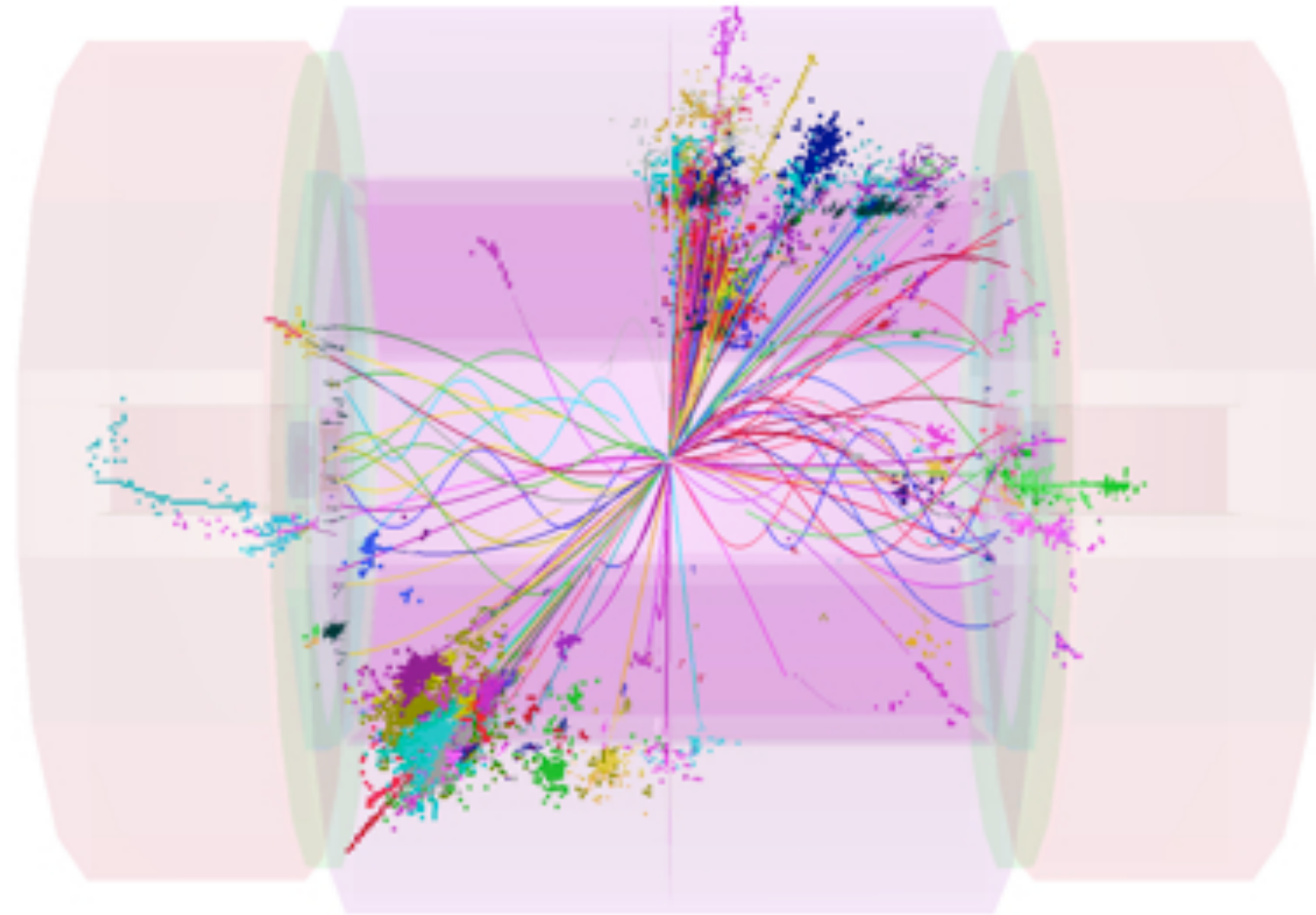# ECFA Higgs Factory 1st Topical Workshop on Generators / Simulation

ECFA
European Committee for Future Accelerators

Jürgen Reuter

DESY.

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

- Recommendation from the European Strategy Update 2020 (ESU2020) $\implies$ ↪ 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
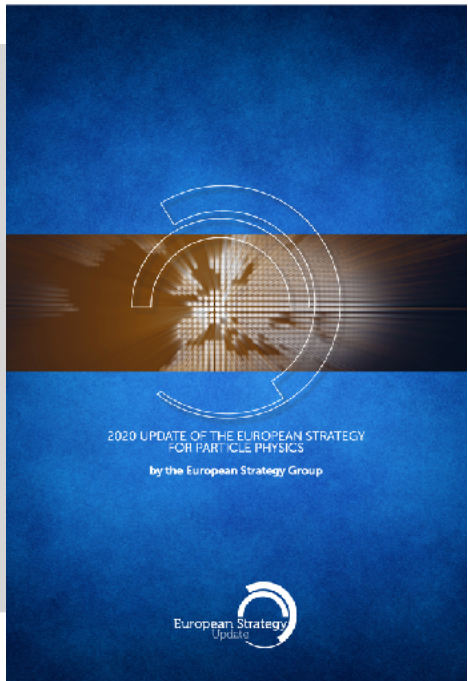- Luminosity measurement ...
- …

WG 3: Detector R&D

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

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- Fast simulation (and its limitations)
- Particle flow
- Luminosity measurement ...
- …

- 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
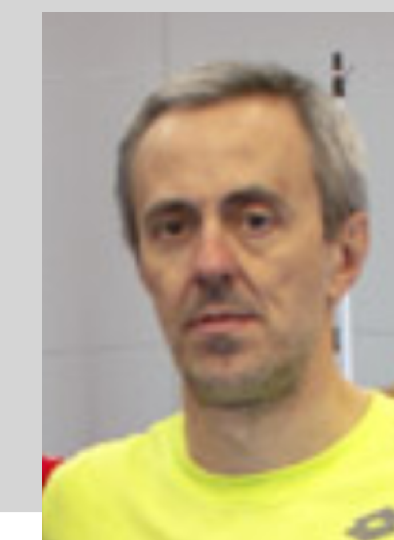
Connection to Future Collider Unit at CERN

TUESDAY, NOVEMBER 9

9:00 AM → 10:35 AM **Generators: Taking Stock and Plans I**
Convener: Fabio Maltoni (Universite Catholique de Louvain (UCL) (BE) and Università di Bologna)

9:00 AM **Introduction**
Speaker: Fulvio Piccinini (Pavia University and INFN (IT))

9:10 AM **The new "Future Collider" unit at CERN** ¶
Speaker: Michelangelo Mangano (CERN)
📄 2021-11-09.pdf

Michelangelo Mangano

A "Future Collider__s__" 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

Madgraph5_aMC@NLO

Speaker: Stefano Frixione (INFN)

PYTHIA

Speaker: Ilkka Helenius (University of Jyväskylä)

Herwig

Speaker: Simon Platzer (University of Graz (AT))

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... **ro**
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 1

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)

J. R. Reuter, DESY

Future Colliders at DESY, 18.11.2021

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
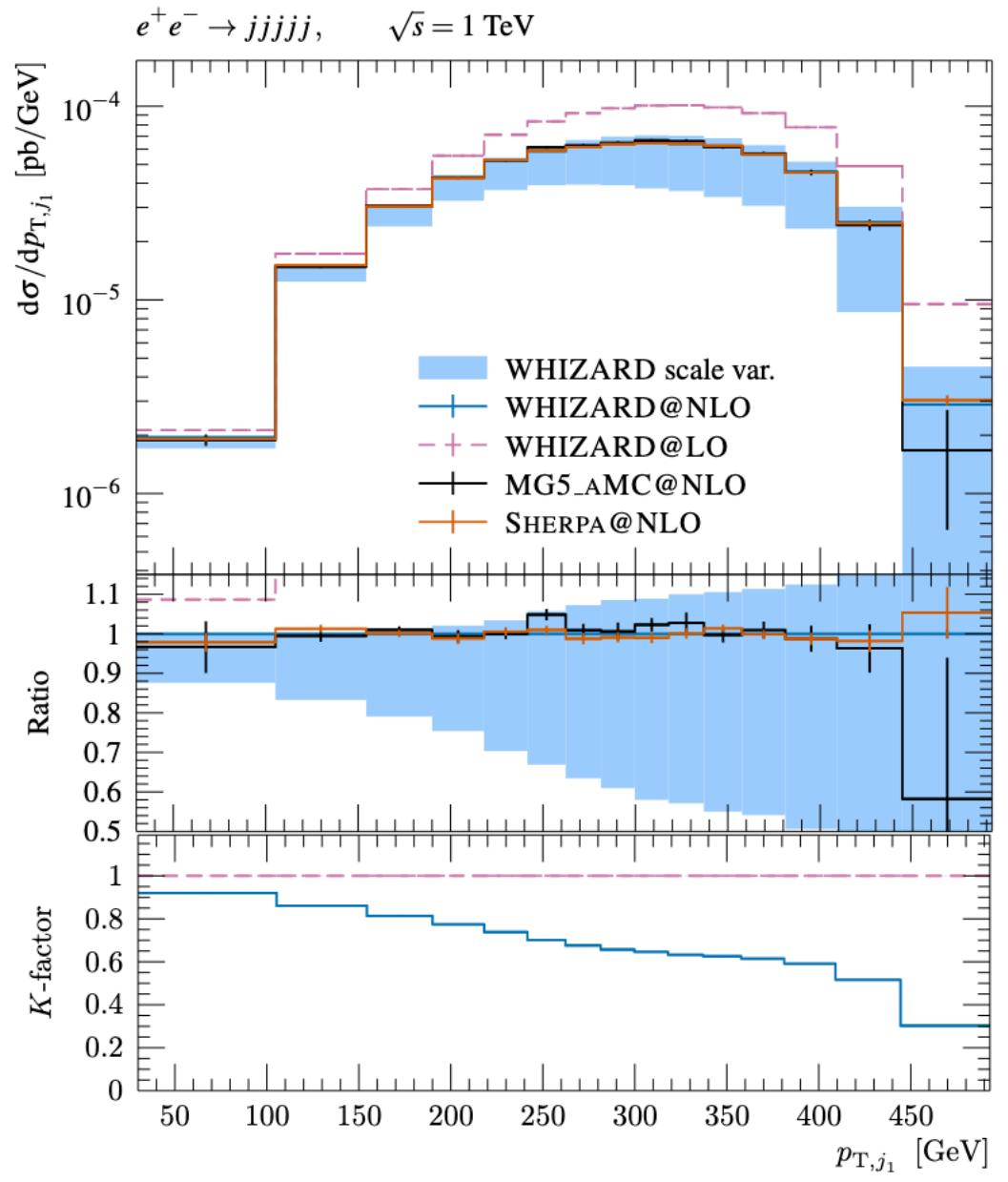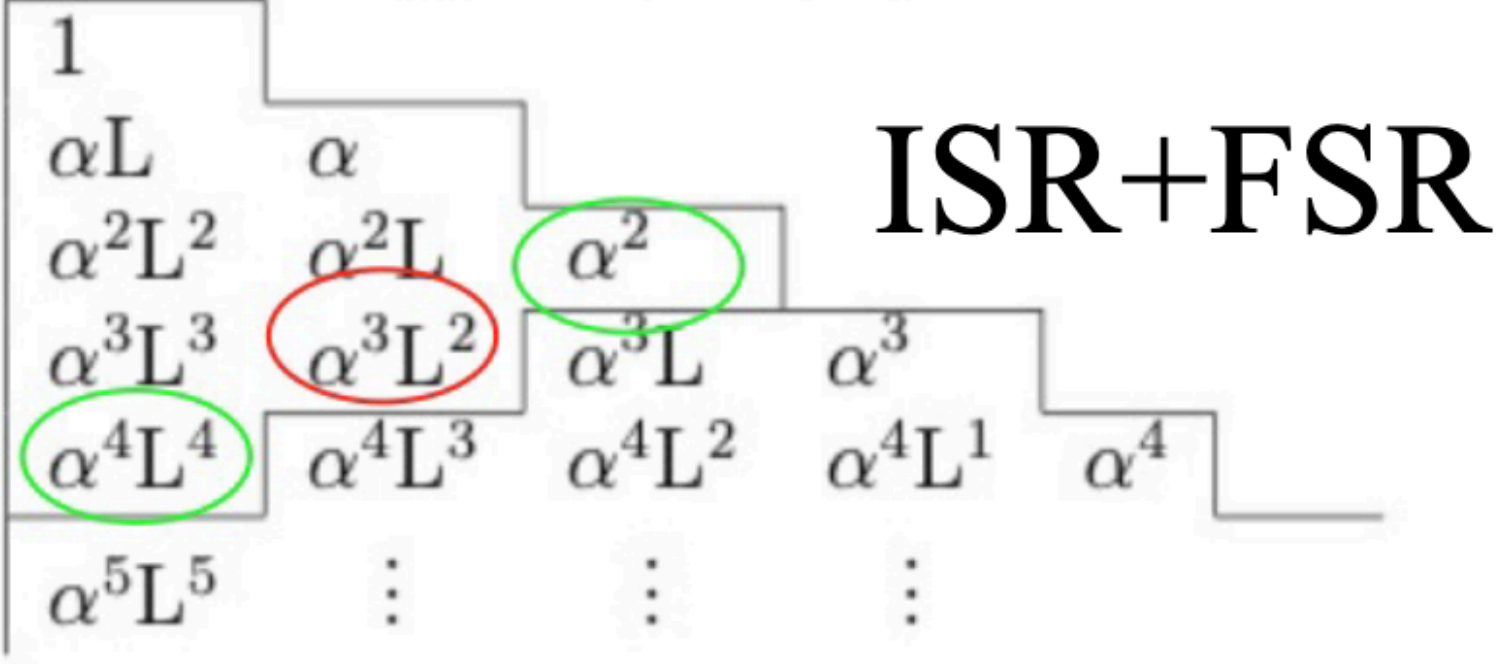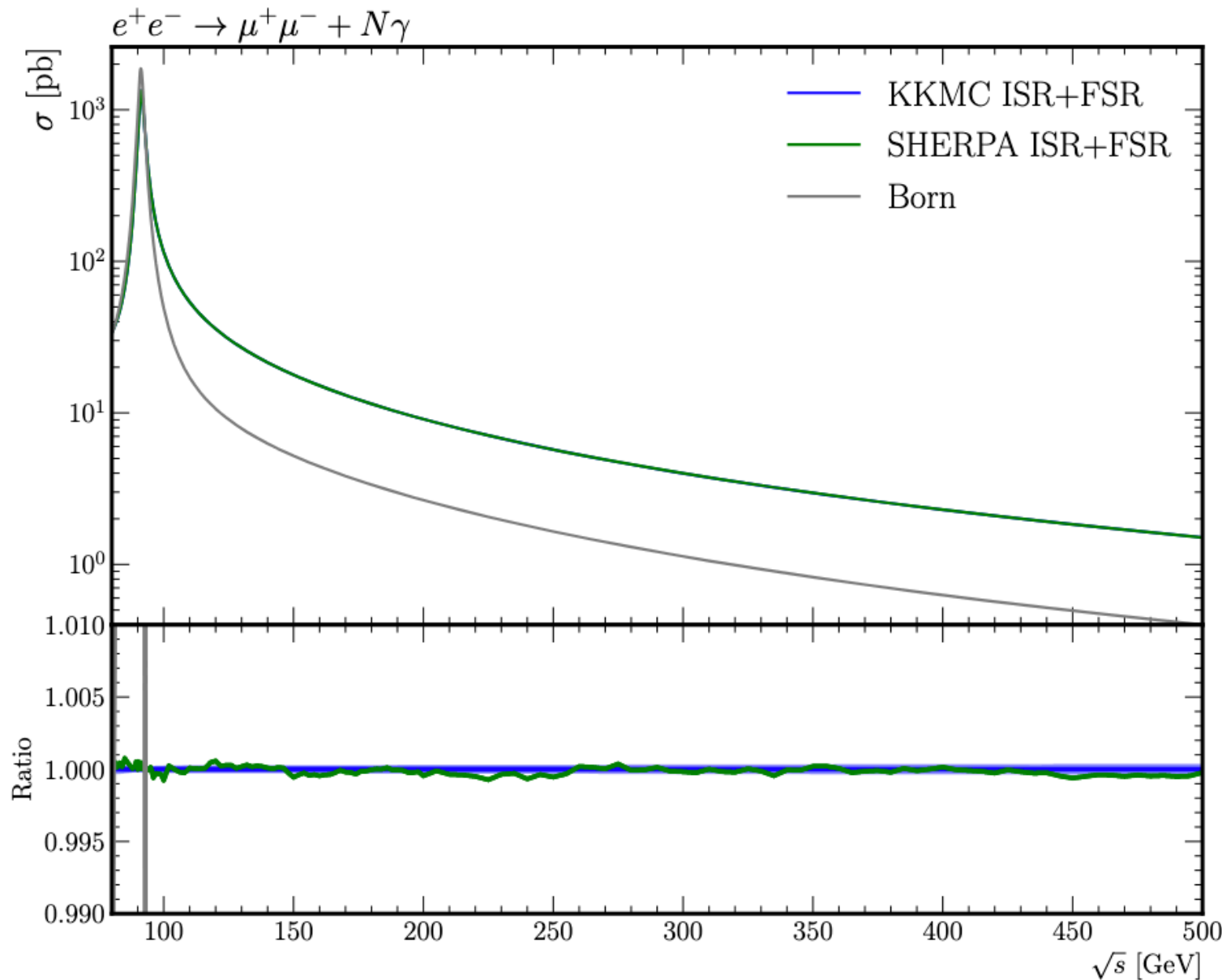
Performance, validation

LO NLO NNLO

LO NLO

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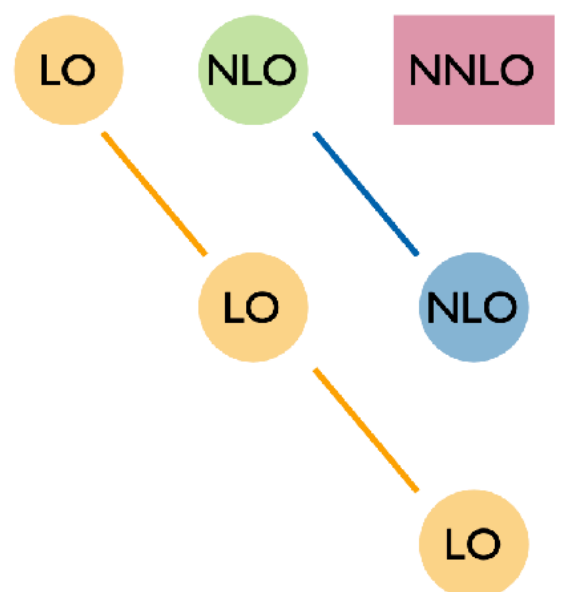
NLO QCD state-of-the-art
NLO EW for e^+e^- to come
some NNLO (QED) started

Process	σ_{LO} [fb]	σ_{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

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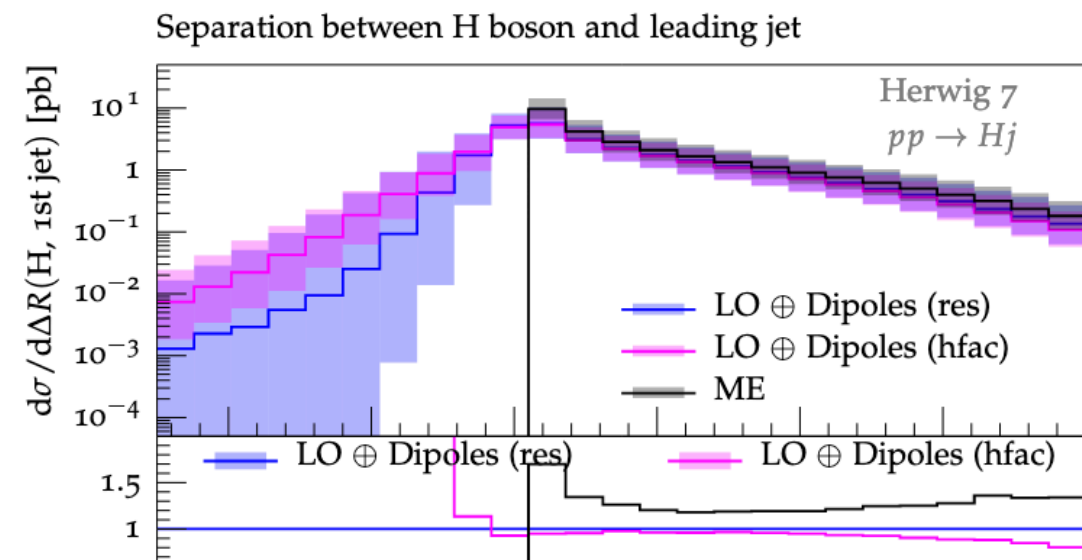$$\times \, d\hat{\sigma}_{ij}(z_+ p_k, z_- p_l, \mu^2) + \mathcal{O}\left(\left(\frac{m^2}{s}\right)^p\right)$$

$e^+e^- \to jjjj$, $\sqrt{s} = 1$ TeV

WHIZARD scale var.
WHIZARD@NLO
WHIZARD@LO
MG5_AMC@NLO
SHERPA@NLO

$e^+e^- \to \mu^+\mu^- + N\gamma$
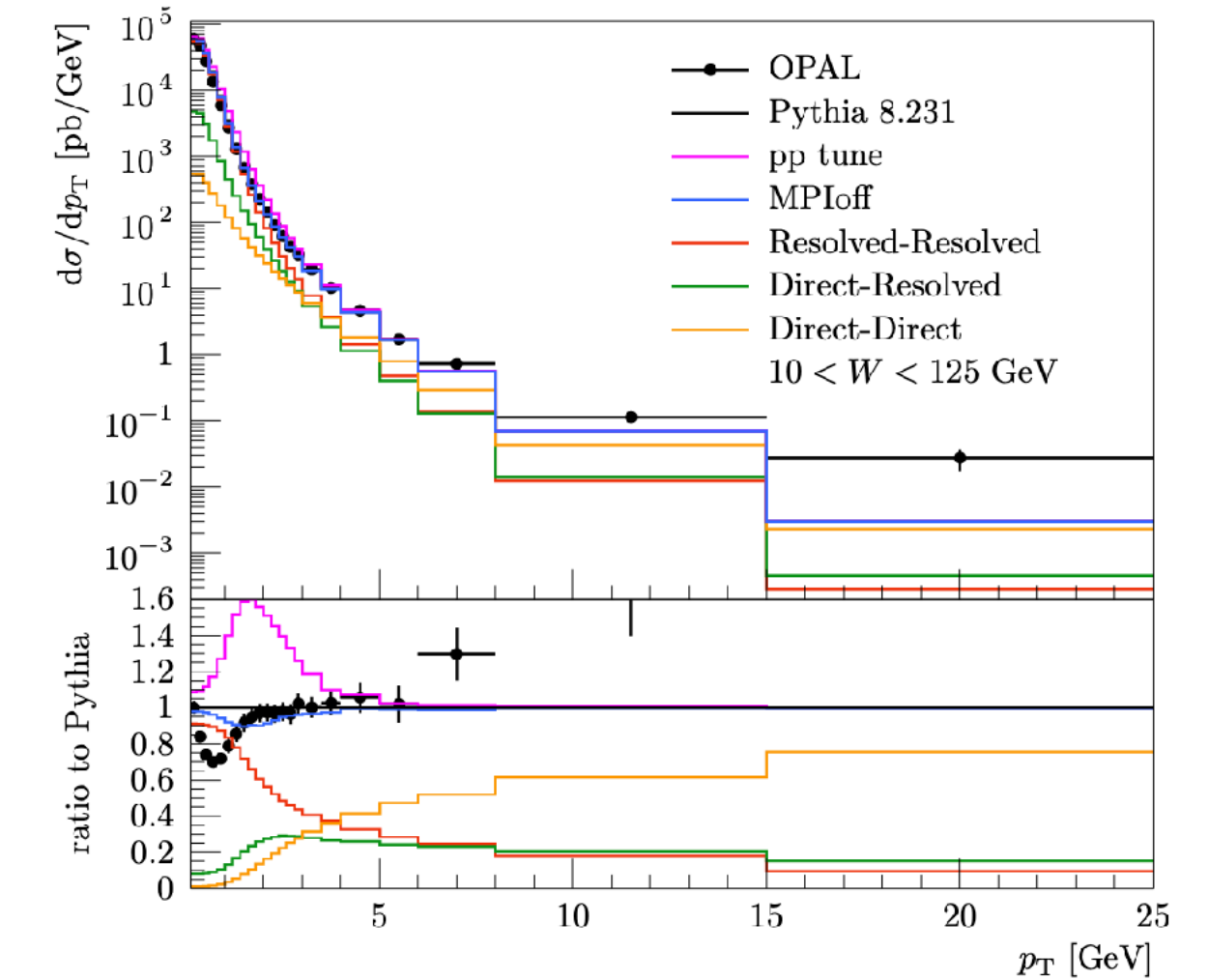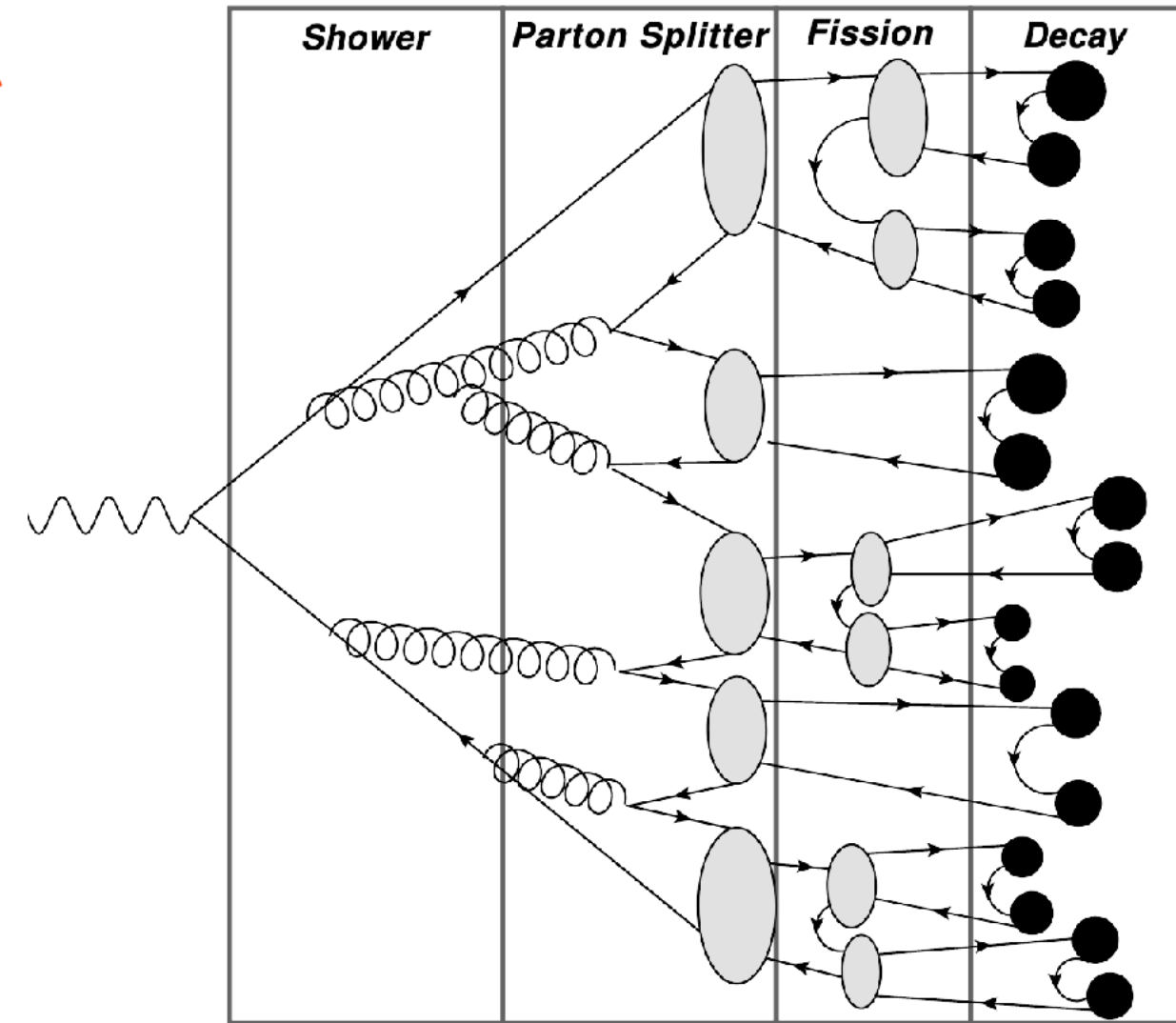
KKMC ISR+FSR
SHERPA ISR+FSR
Born

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

ISR+FSR

1				
αL	α			
$\alpha^2 L^2$	$\alpha^2 L$	α^2		
$\alpha^3 L^3$	$\alpha^3 L^2$	$\alpha^3 L$	α^3	
$\alpha^4 L^4$	$\alpha^4 L^3$	$\alpha^4 L^2$	$\alpha^4 L^1$	α^4
$\alpha^5 L^5$				

Separation between H boson and leading jet

Herwig 7
$pp \to Hj$

LO ⊕ Dipoles (res)
LO ⊕ Dipoles (hfac)
ME

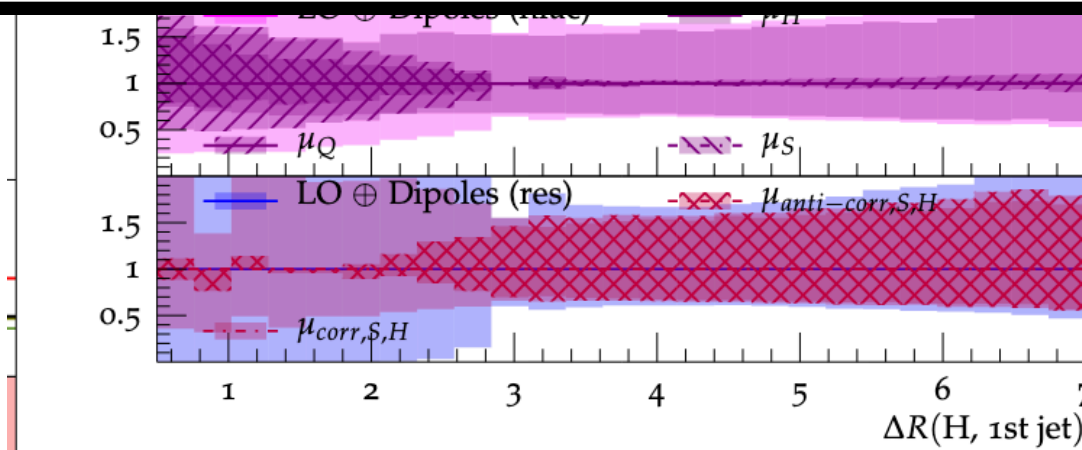$\Delta R(H, \text{1st jet})$

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

Parton branchings order in angle.

Dipole branchings order in transverse momentum.

Durham scale y_{34}

$\sqrt{s} = 91.2$ GeV
$y_{23} > 0.02$

NLO+NLL'
SHERPA MEPS@NLO
SHERPA MEPS@LO
VINCIA

Ratio

$\ln y_{34}$

Shower | Parton Splitter | Fission | Decay

OPAL
Pythia 8.231
pp tune
MPIoff
Resolved-Resolved
Direct-Resolved
Direct-Direct
$10 < W < 125$ GeV

ratio to Pythia

p_T [GeV]

[OPAL: Phys. Lett. B651 (2007) 92-101]
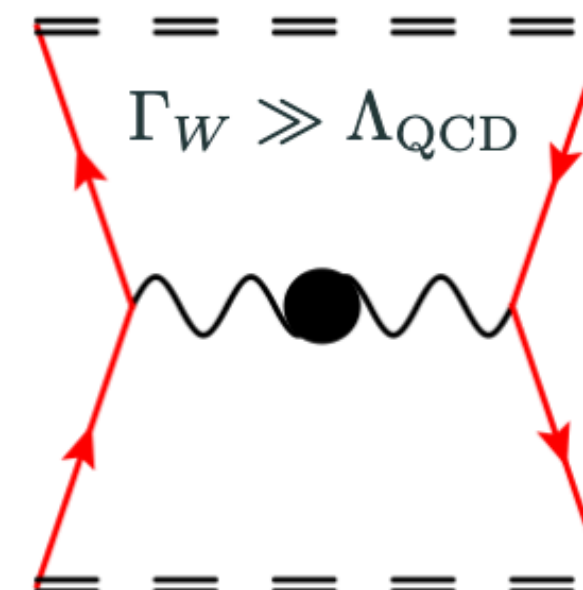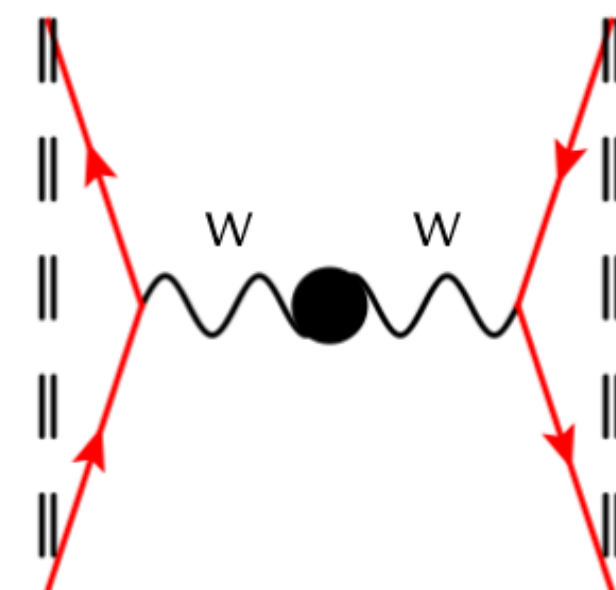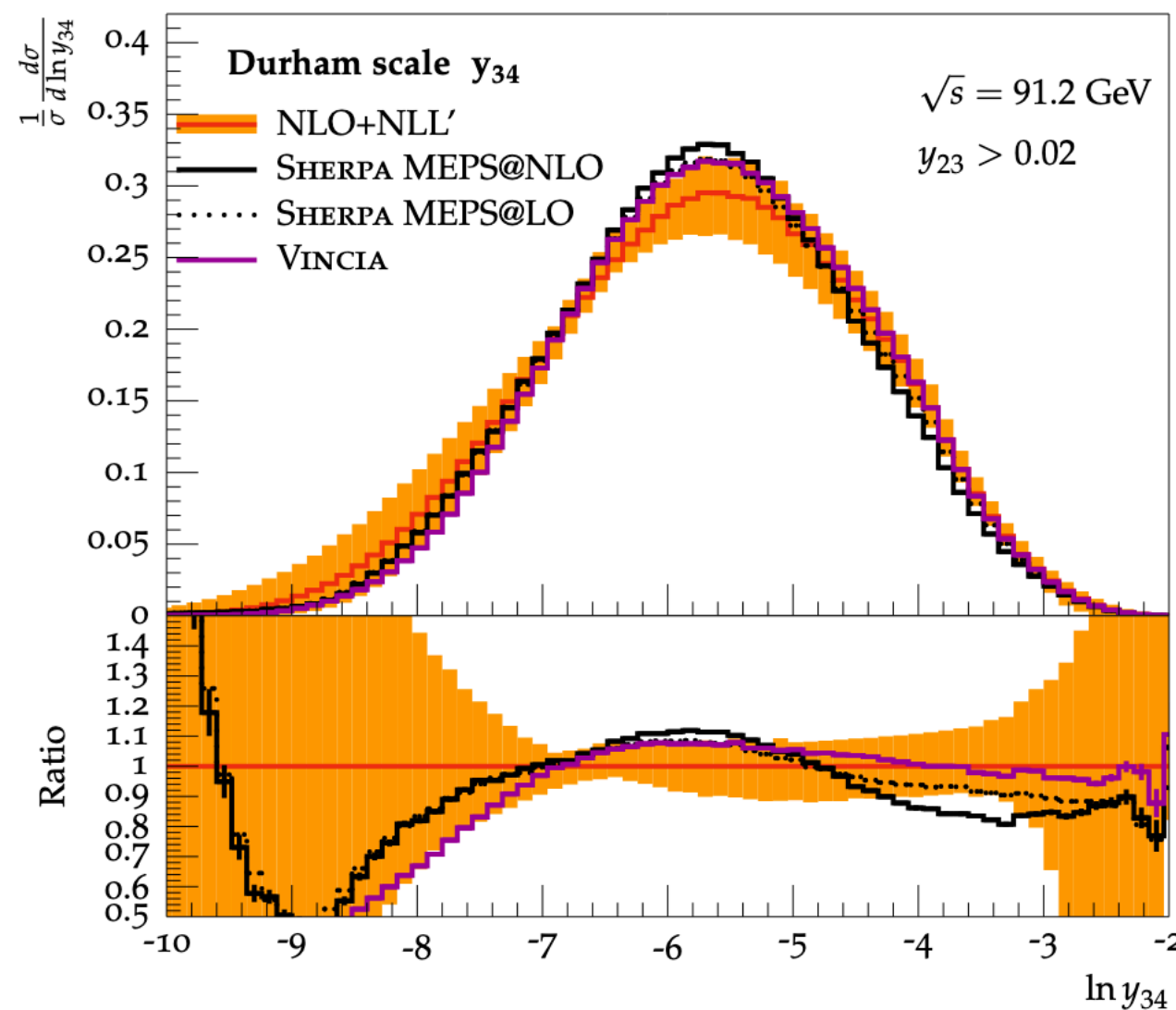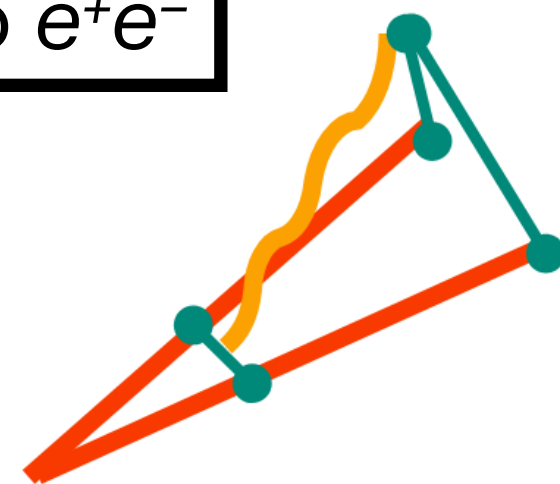
Modern hadronization tools tuned to LEP/OPAL data in all detail?

$\Gamma_W \gg \Lambda_{QCD}$

· High statistics for ee → WW

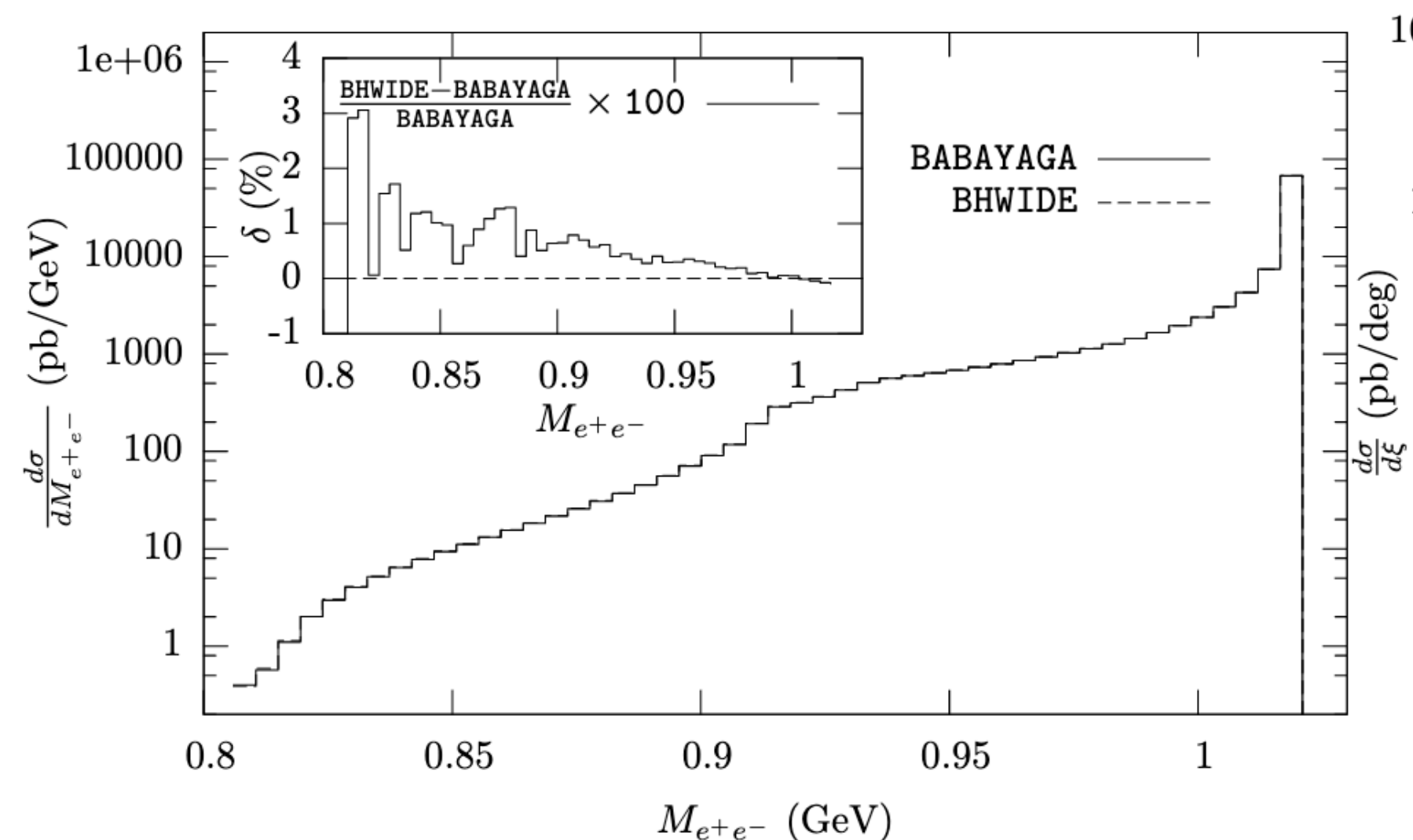⇒ Clean environment to study CR effects, no-CR scenario excluded at 99.5% in LEP II

J. R. Reuter, DESY

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

... in tauola:

`basf2` software of Belle II, new τ 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

Need for dedicated MCs:

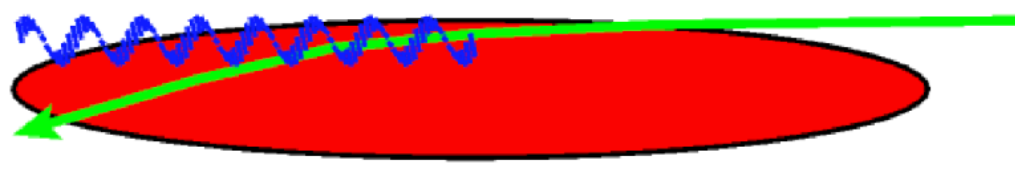E.g. comparison `BabaYaga@NLO` vs. `BHWIDE` (Jadach, Płaczek, Ward) at KLOE
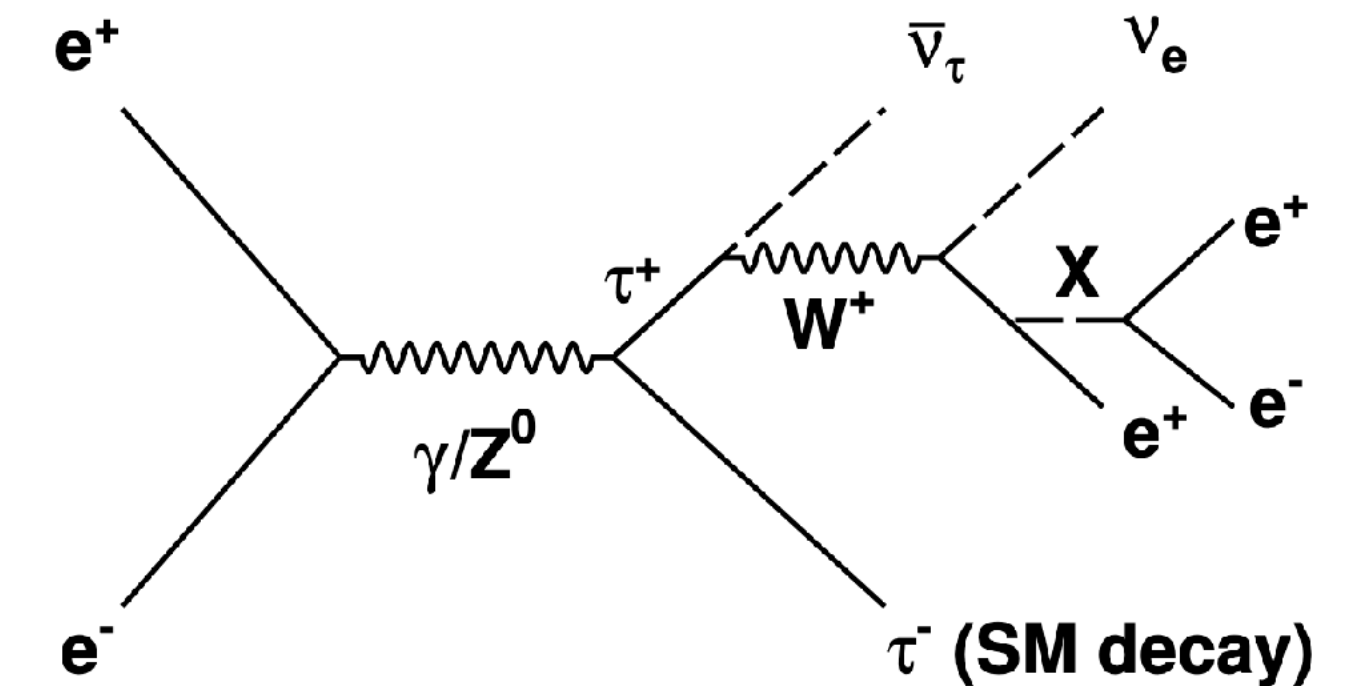
Polarization not available
for some generators

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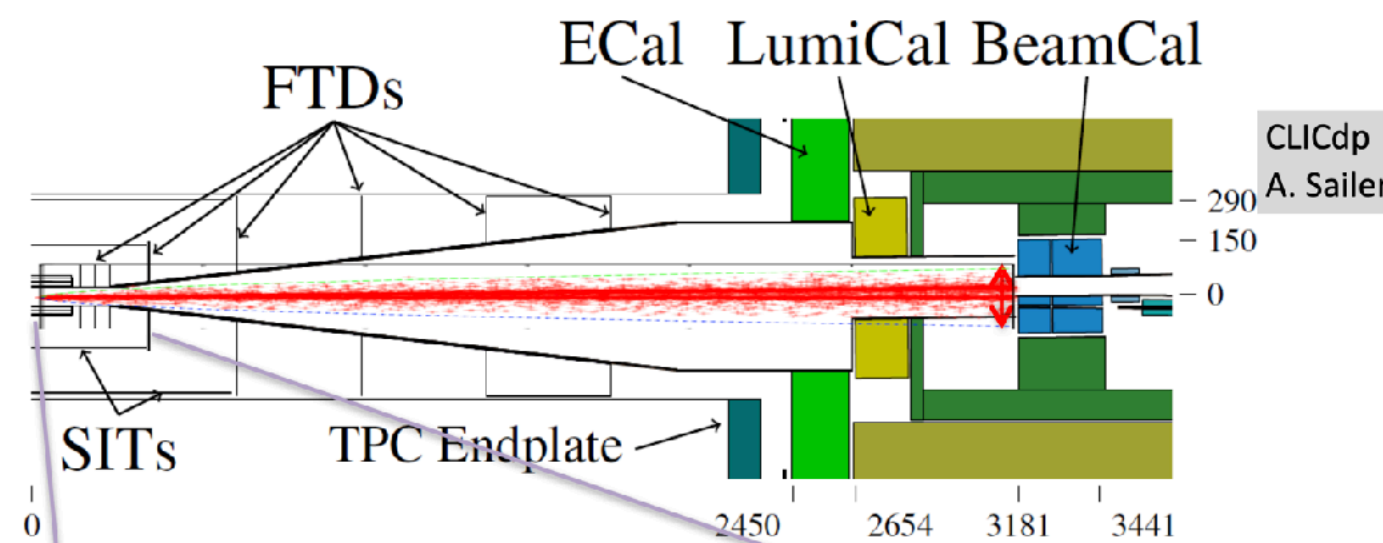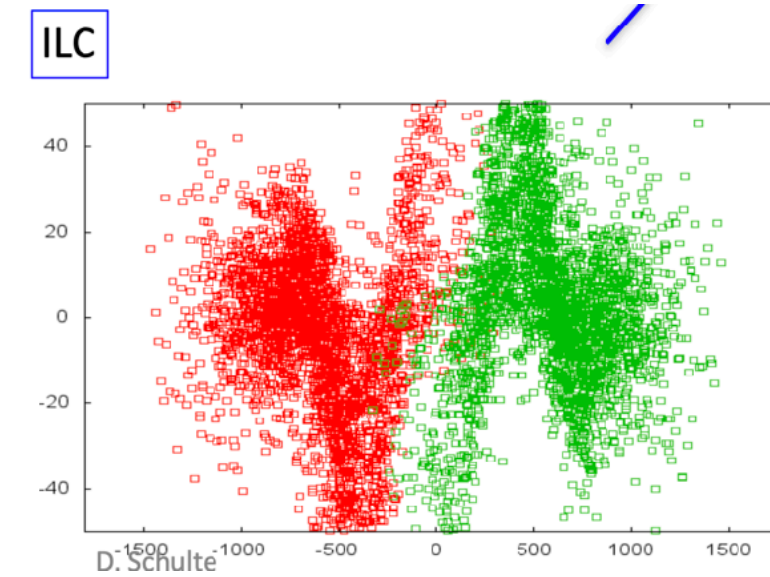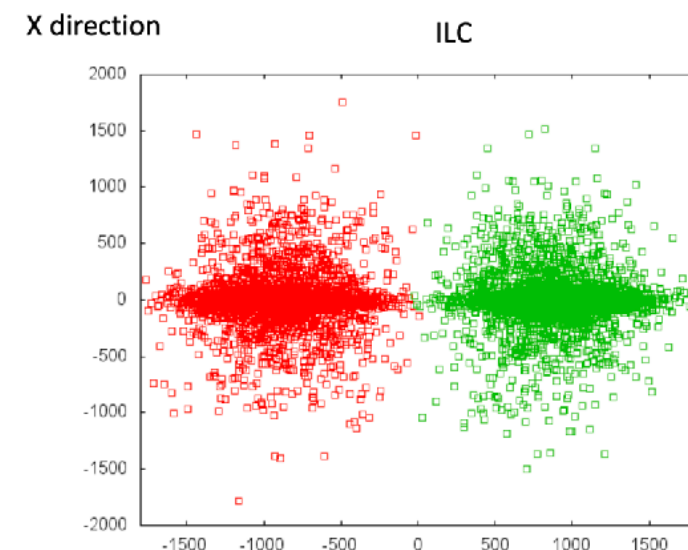LHE (v1-3), HepMC2/3 standard
LCIO not widely available,
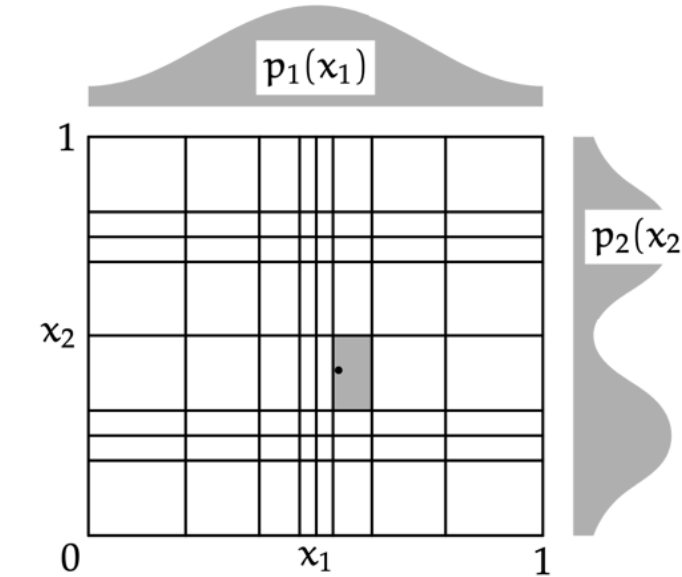confusion on scope of LCIO

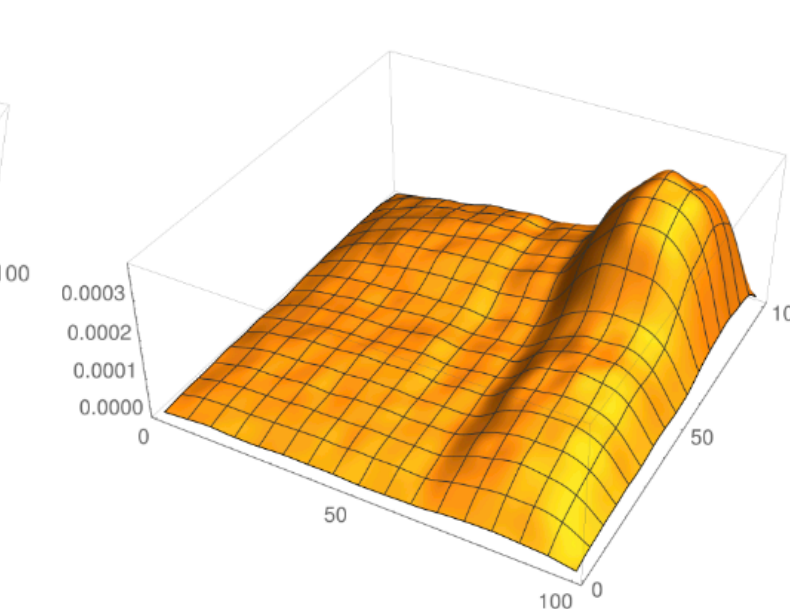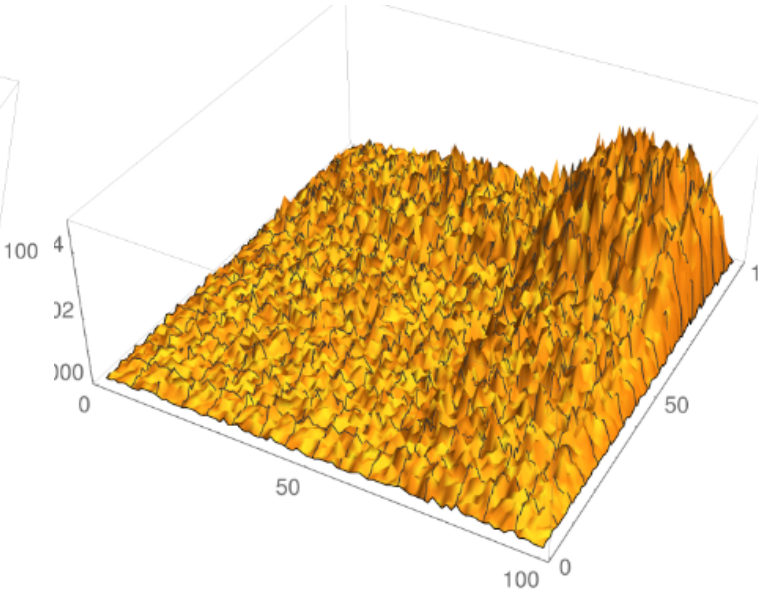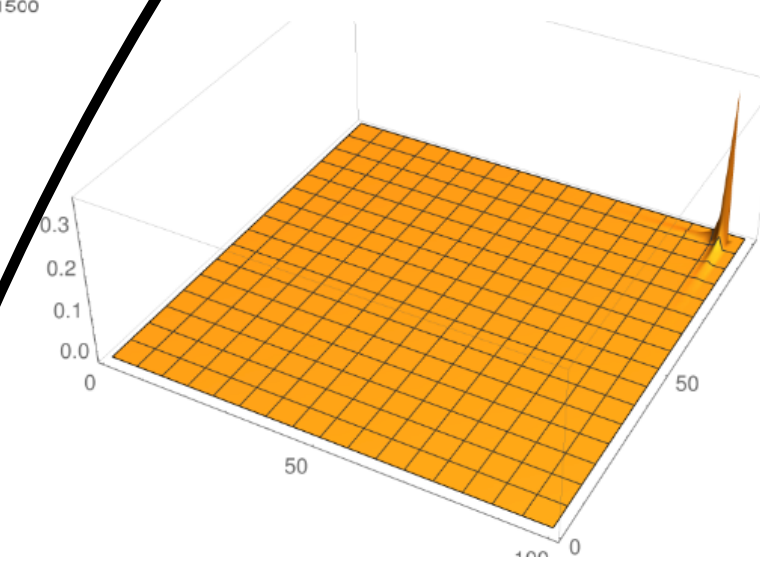# Simulation of beam dynamics

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

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

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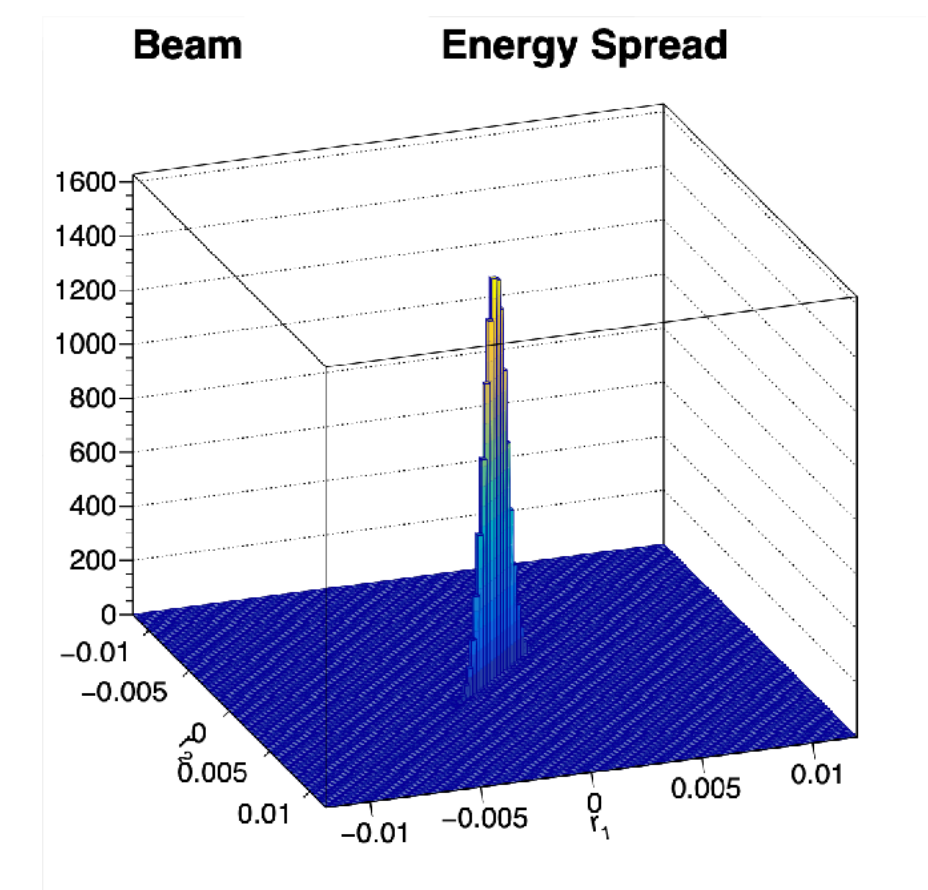CLIC at 3TeV Y=5

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

Note: Several codes support simple Gaussian beam spread

- 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

Software Ecosystems

Complete set of tools for

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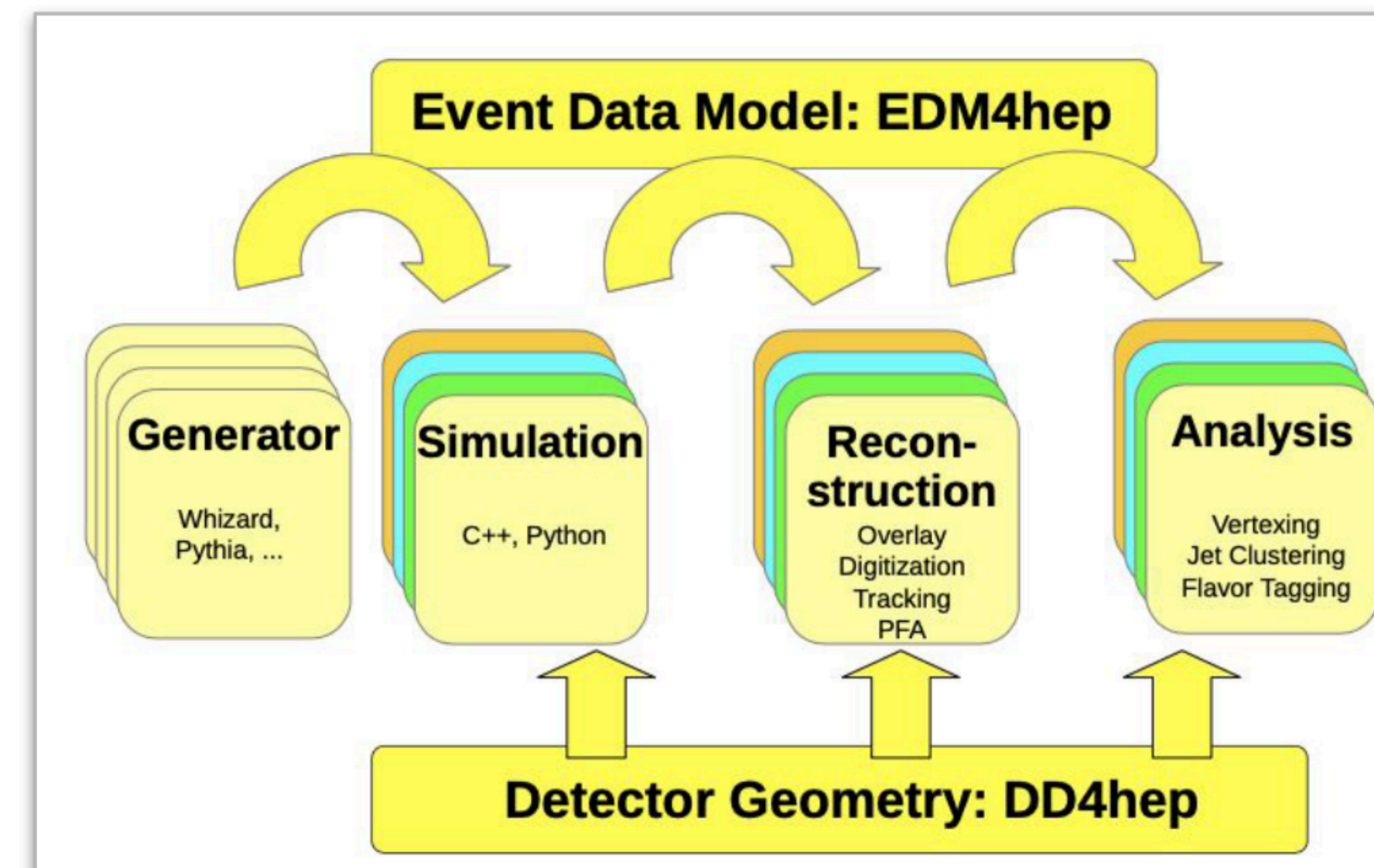- Build, package, test, deploy, run

EDM4hep DataModel Overview (v0.3) (Exc.)
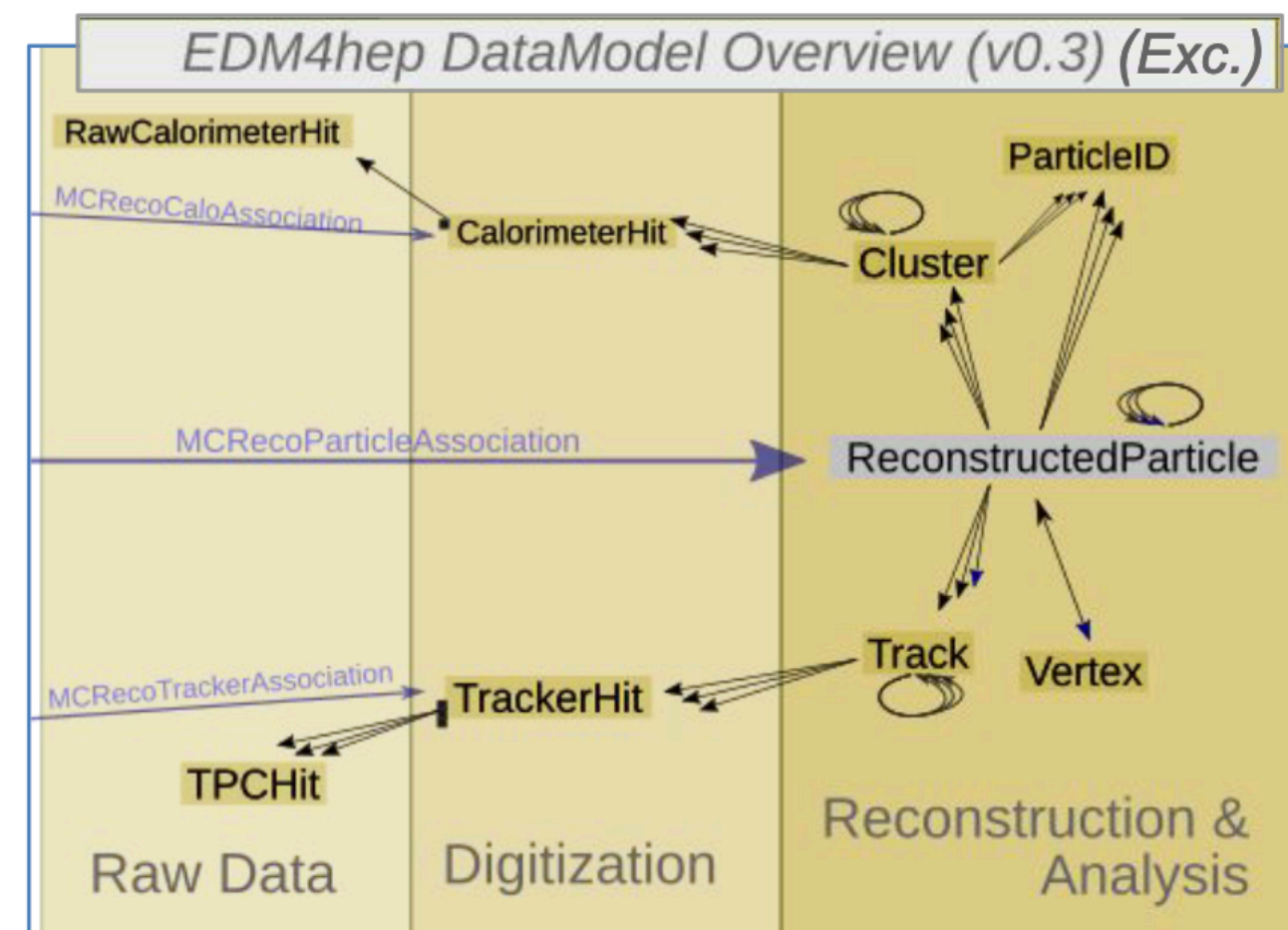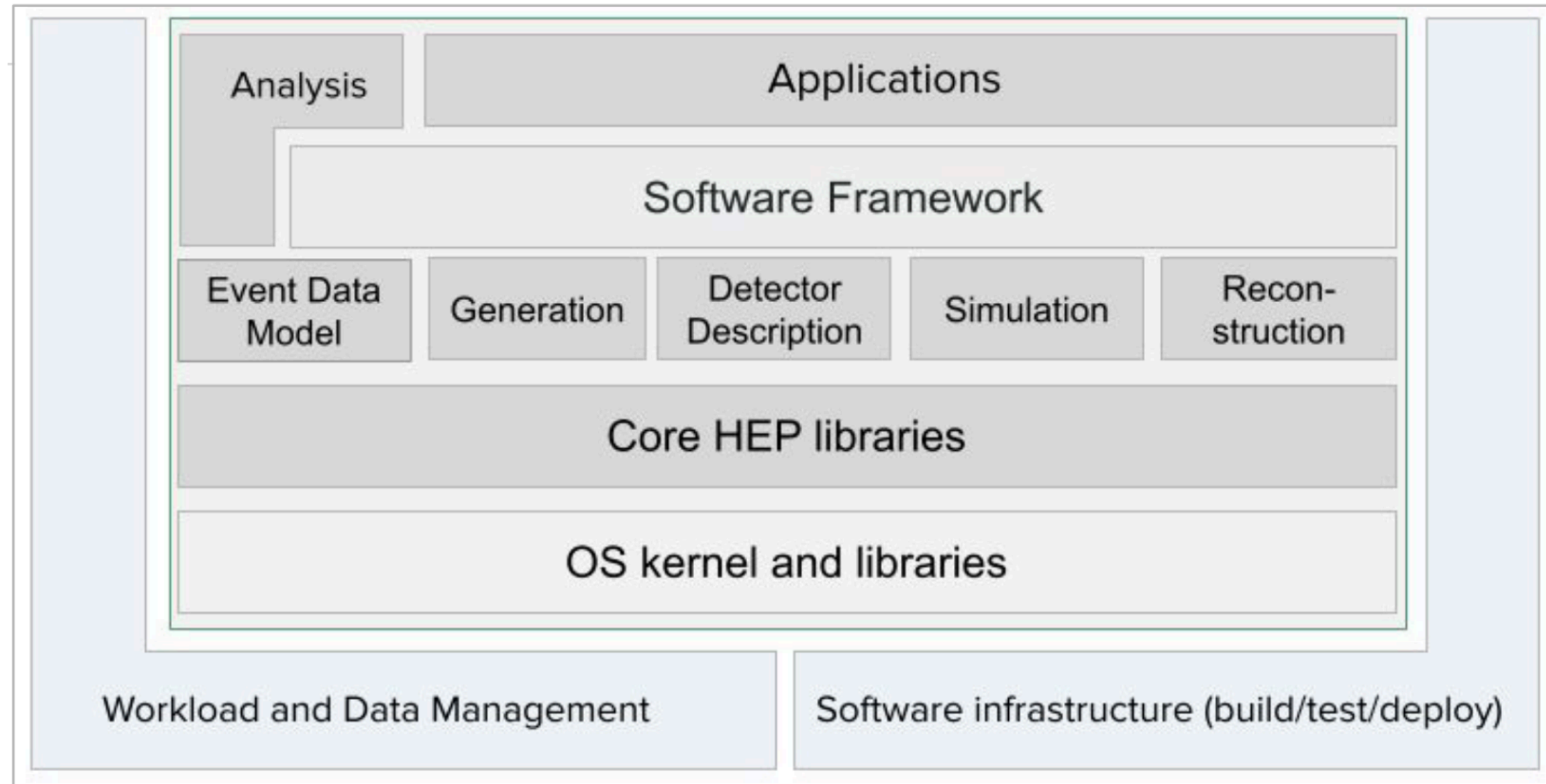
Core Ingredients of current key4hep

- 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]

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

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

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
- γ 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]

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]
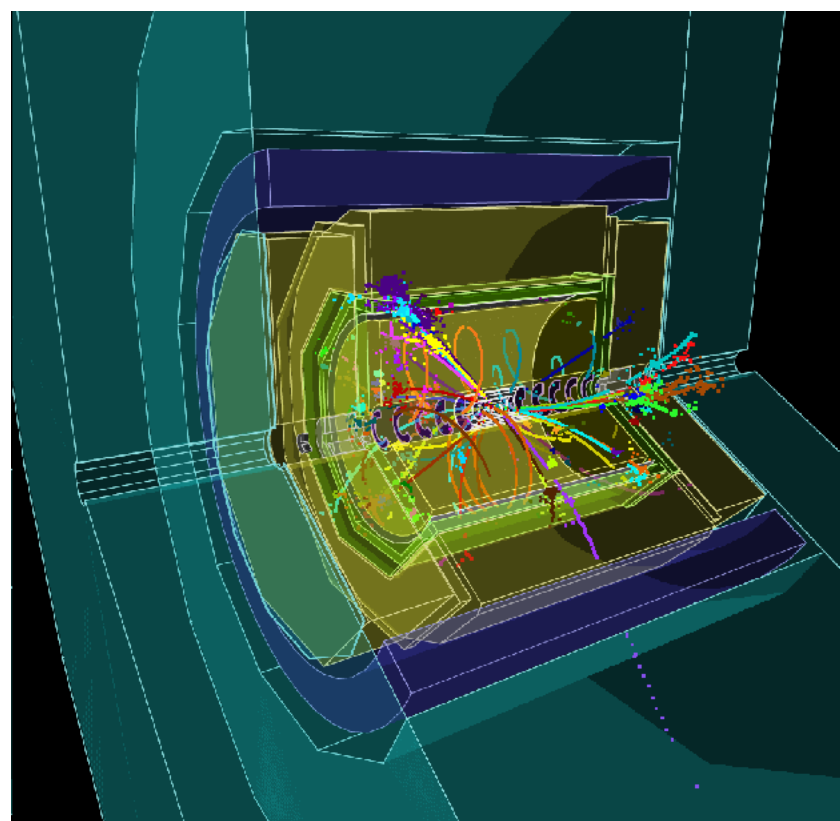
J. R. Reuter, DESY

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:

   Simulation/Reco-focused WS, 01/22: Patrizia Azzi   **MC Generator (esp. $\gamma\gamma$), 06/22**   Wolfgang Kilian

ILD Event
Display

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:
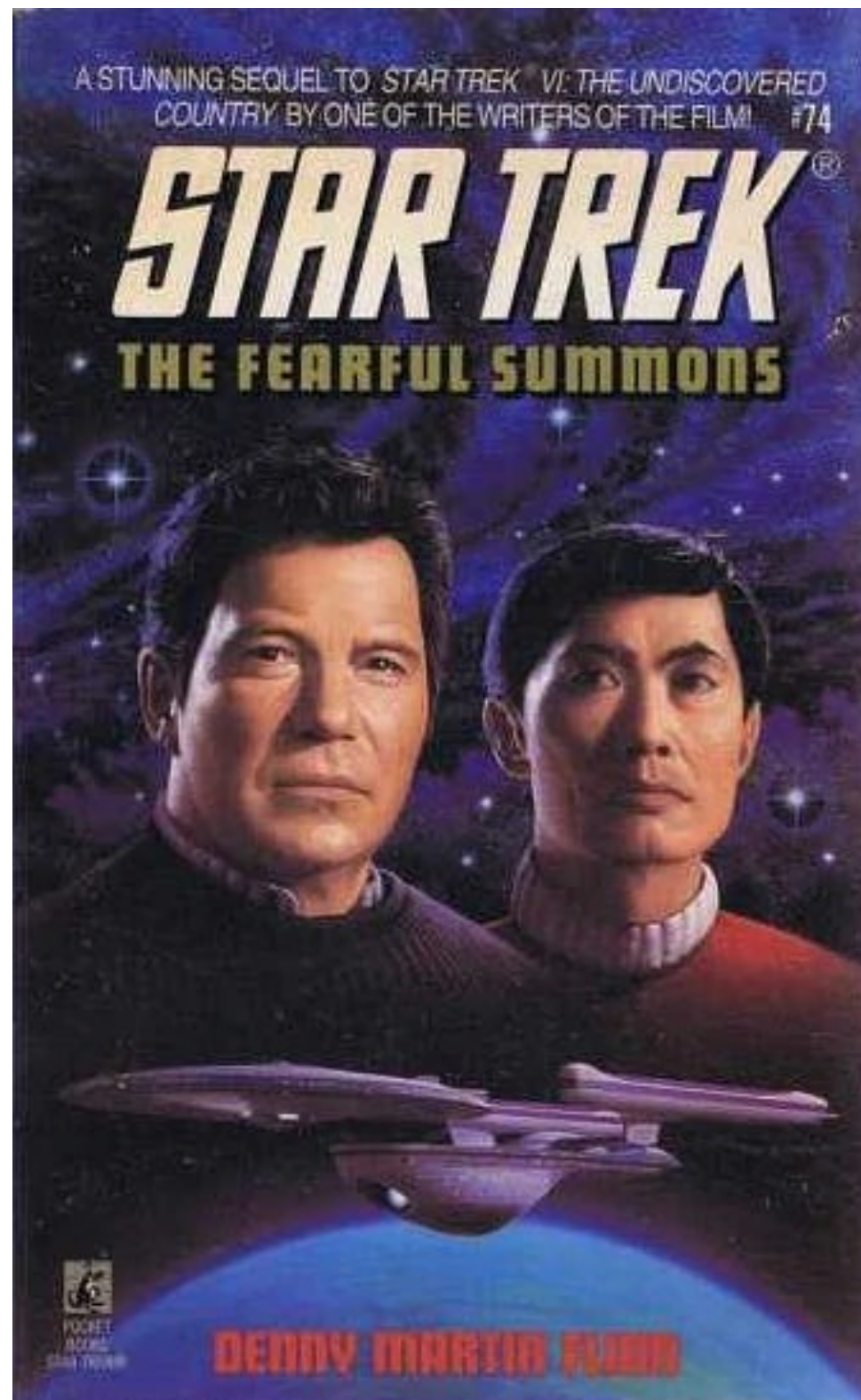
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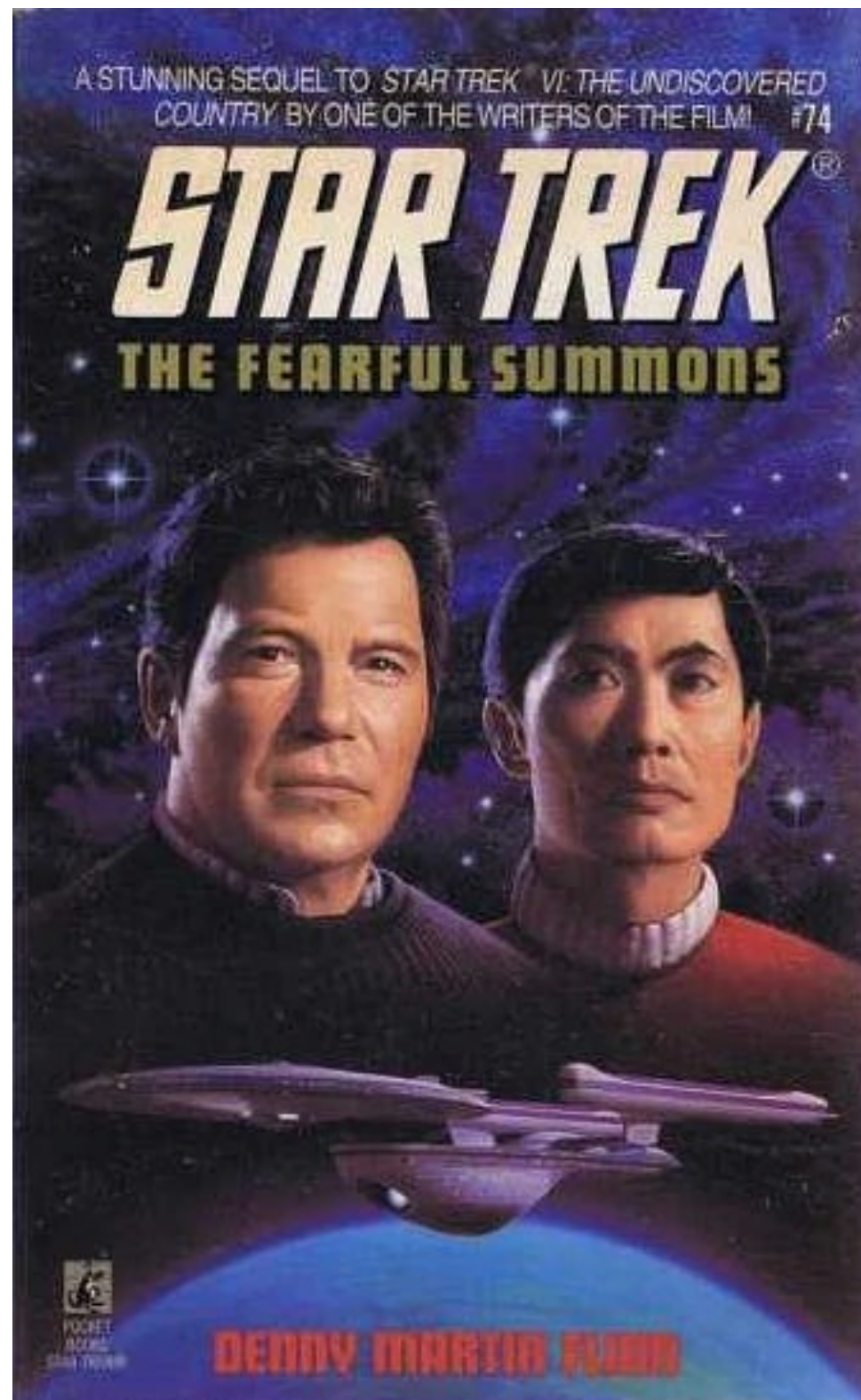- For justification of in-person meetings, one has to learn from the best:

On a personal note

- Great to have a workshop (again) in person

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- For justification of in-person meetings, one has to learn from the best:

Denny Martin Flinn: *"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.