Monte Carlo generation for Linear e^+e^- Colliders

Ulrike Schnoor
ulrike.schnoor@cern.ch
Linear Collider Generator Working Group

CERN

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Introduction

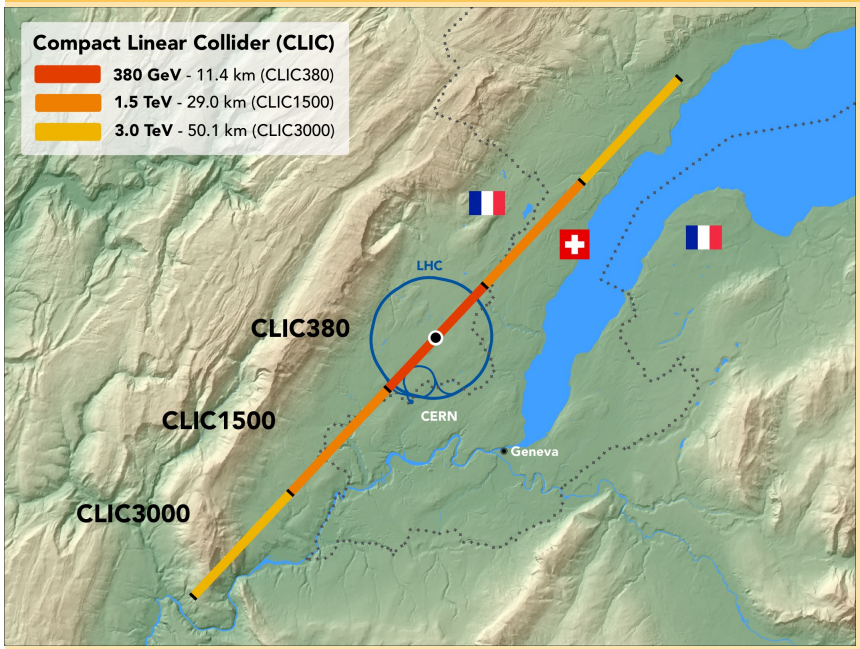
1. Linear colliders physics overview
2. Monte Carlo Generation for Linear Colliders
3. Generators Ingredients

Future linear colliders

International Linear Collider ILC

- Mature study of linear electron-positron collider up to 500 GeV; first stage at 250 GeV is proposed
- Extensive studies of physics potential, cf. [1506.05992], [1710.07621: 250 GeV]

Compact Linear Collider CLIC



- CDR published in 2012
- First beams in 2035
- Staged operation:

350 GeV	top threshold scan
380 GeV	Higgs physics
1.5 TeV	focus on BSM physics
3 TeV	focus on BSM physics

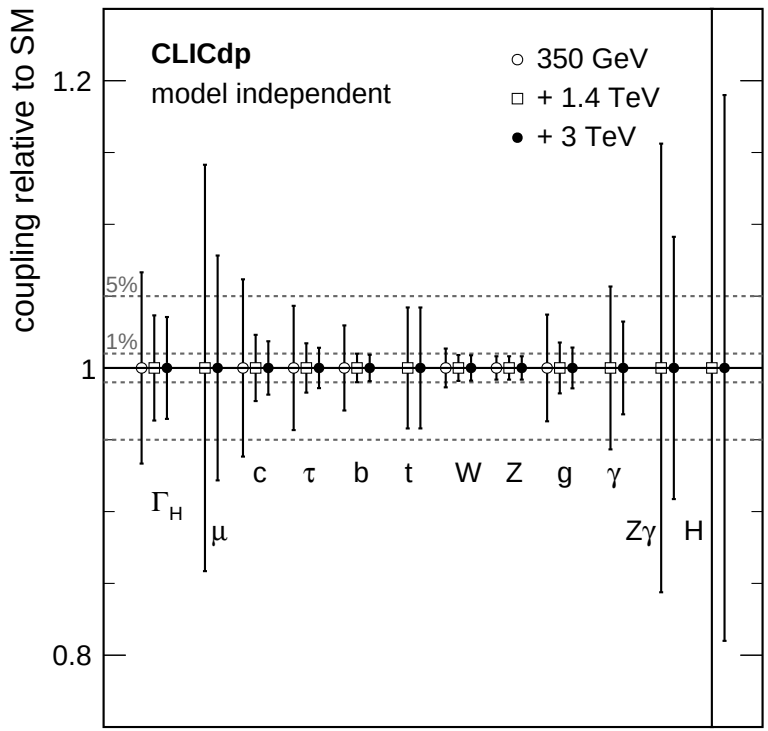
Recent overview talk on CLIC physics (Ph. Roloff): *https://indico.cern.ch/event/668147/*

Physics at CLIC: Higgs

- Measurements at all three energy stages explored in [1608.07538]
- Recoil mass in inclusive HZ production $\Rightarrow$ model-independent g_{HZZ} measurement
- Model-independent measurement of invisible Higgs decays
- Higgs self-coupling $\Delta\lambda/\lambda \approx 10\,\%$ using sensitive differential distributions in double Higgs production

Global fit

to extract Higgs properties from cross-section measurements:

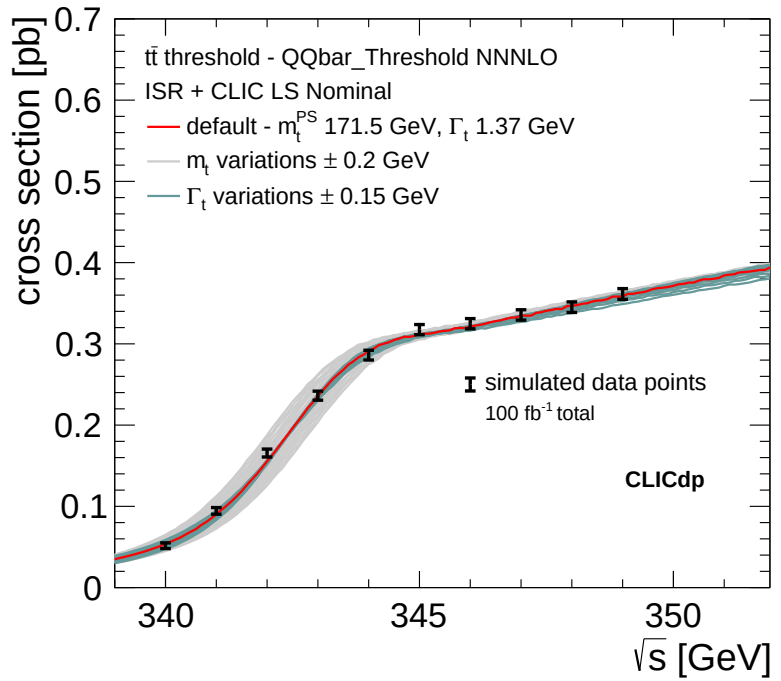


Physics at CLIC: Top

- Top physics report in publication
- Threshold scan to extract mass
- Measurement of top mass with ≈50 MeV precision (currently dominated by NNNLO scale uncertainty) in a theoretically well-defined manner
- Top Electroweak couplings, FCNC top decays, forward-background asymmetry, top Yukawa couplings, ...

Threshold scan

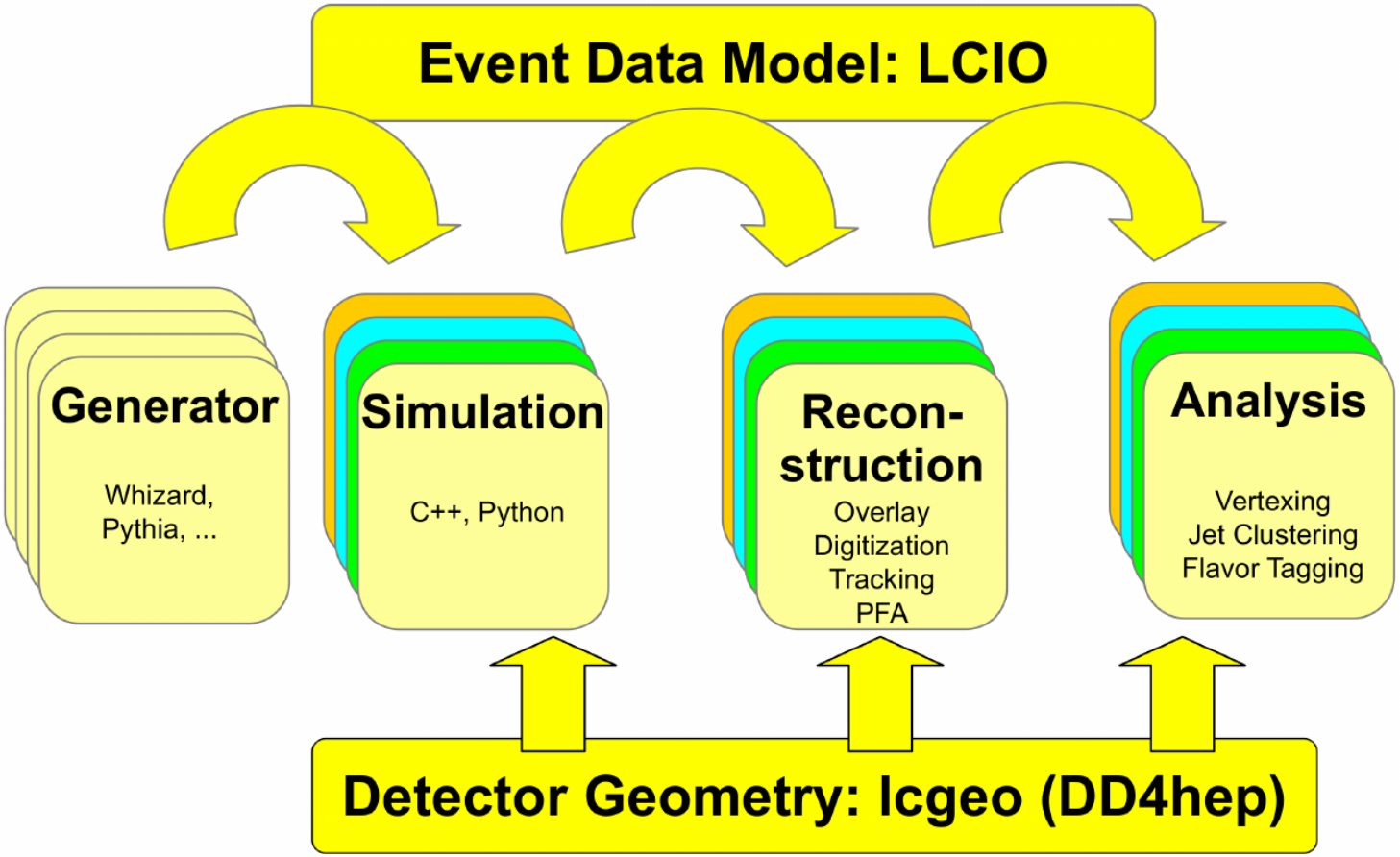
scan around 350 GeV



BSM physics: Yellow report in preparation

Software and simulation chain

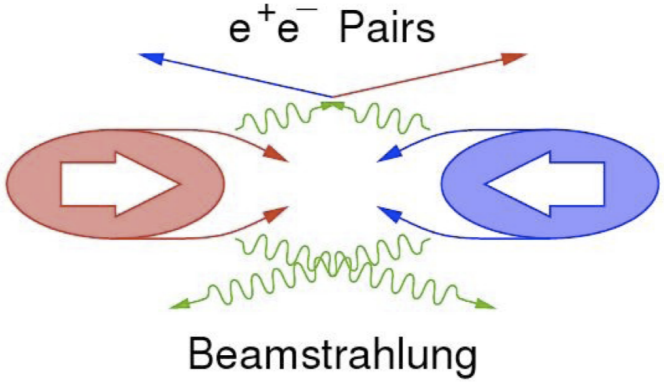
- Shared infrastructure by ILC and CLIC
- DD4hep shared also with other projects (e.g. FCC)

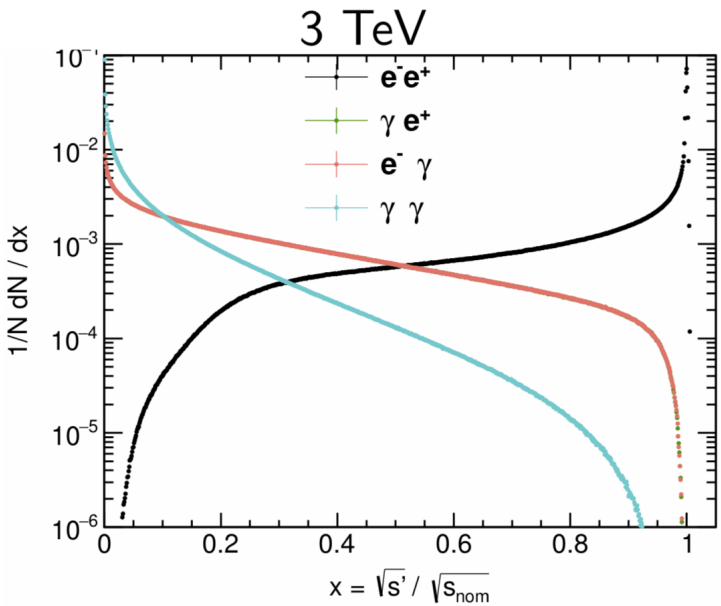


+ **DELPHES** card for fast simulation

Beamstrahlung and luminosity spectrum

- Very small beams to achieve high luminosity $\Rightarrow$ electromagnetic interaction of e^+ and e^- beams leads to synchrotron radiation: *beamstrahlung*
- Collective (beam) effect; real photons



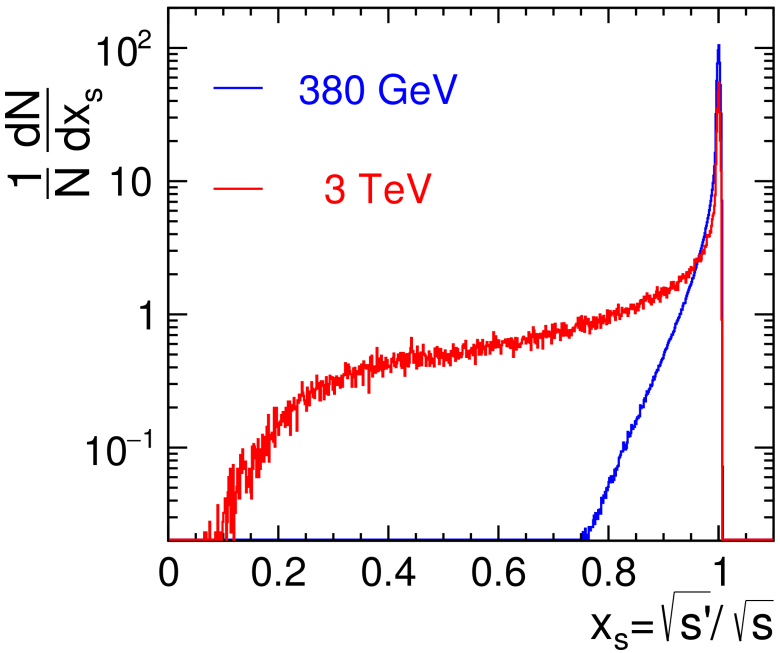


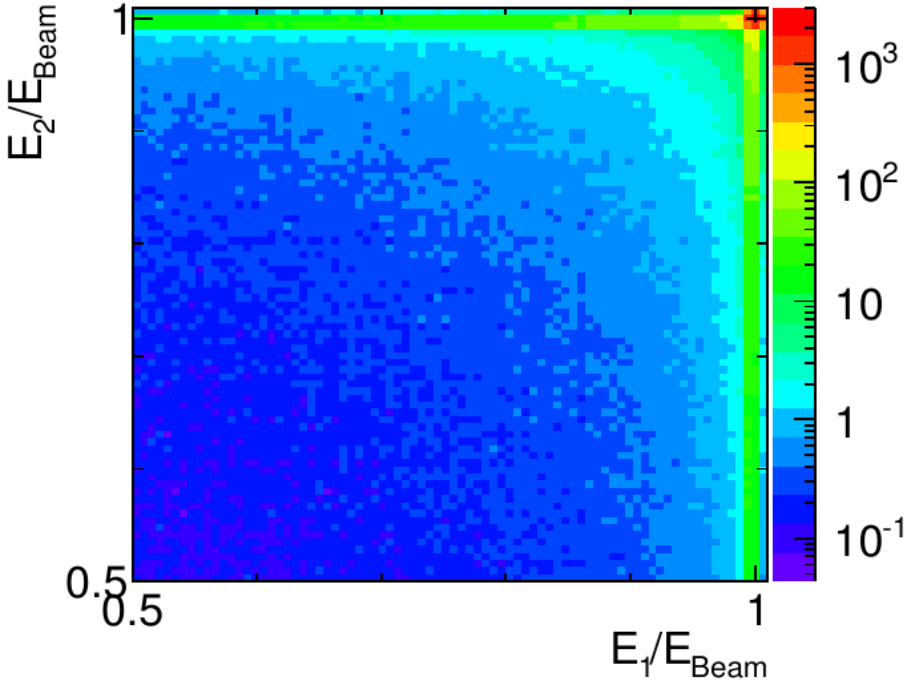
Beamstrahlung:

- modifies energy spectrum of the colliding e^+e^- pairs
- **produces $e^{\pm}\gamma$ and $\gamma\gamma$ collisions**

...need to be simulated in the event generation

Beam-beam interactions





- Correlations between beams are important [1309.0372]
- Impact on cross section measurements and lab-frame observables
- Simulation with beam-beam interactions tool GuineaPig [D. Schulte]
- Measured with Bhabha events
- Implementation in MC generator
  - Read (large!) beam-beam event files (e.g. from GuineaPig) **or**
  - Sample from a parametrization (e.g. CIRCE2 [T. Ohl]) ⇒ faster
- Important for both CLIC and ILC (depends on energy, beam size, bunch charge)

Event generation for Linear Colliders: Whizard

- ILC TDR, CLIC CDR studies based on WHIZARD1 [0708.4233, hep-ph/0102195]
- Moving to WHIZARD2, validated in collaboration with the authors
  - Top threshold simulation in WHIZARD2 to match the high experimental precision: Resum logarithms of the the top velocity $\sim \alpha_s \ln v$ and gluon Coulomb potential terms $\sim \alpha_s/v$ in non-relativistic approach; then match this to relativistic matrix elements in the continuum [1712.02220]

Simulation of beam effects

Effect	photons	interacting	how modeled
Energy spread	–	$e^{\pm}$	GuineaPig or CIRCE2
Beamstrahlung	real	γ	GuineaPig or CIRCE2
ISR	real	$e^{\pm}$	energy decrease of electron, resummed QED bremsstrahlung
Equivalent Photon Approximation EPA	virtual	γ	small virtuality photon: Improved Weizsaecker-Williams

Arbitrary beam polarisation

Other generators for linear colliders

PhysSim

used for $2 \to 8$ processes (e.g. ttH, ttZ, ttbb) [https://github.com/iLCSoft/Physsim]

MadGraph5_aMC@NLO: Madee Plugin

- Beam polarisation via helicity amptlitudes
- Photon initial states within Improved Weizsaecker-Williams formula
- Beamstrahlung using unweighted beam profile as input
- ISR via dedicated plugin [1804.00125]; work in progress for internal treatment

Pythia

- Used for parton shower, hadronization

Other generators

always welcome!

Ingredients for Linear Collider event simulation

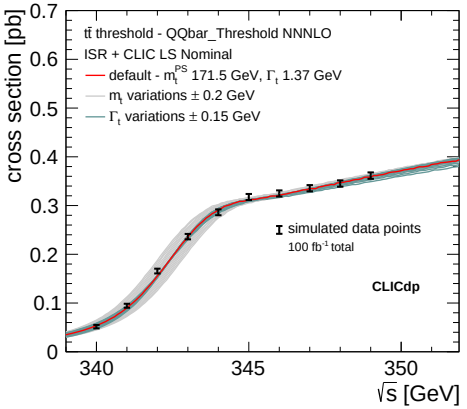
Ingredients:

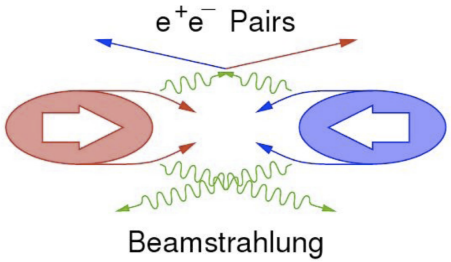
- Beam polarization
- Hard processes for e^+e^-, $e^\pm\gamma$, $\gamma\gamma$
- Simulation of ISR
- Capabilities to include beamstrahlung from parametrization (e.g. CIRCE2) or beam-beam event files
- Interface to hadronisation
- NLO QCD and EW including matching: nice to have
- Output ideally LCIO, currently also possible HepMC, StdHEP, HepEvt ($\longrightarrow$ can be extended!)

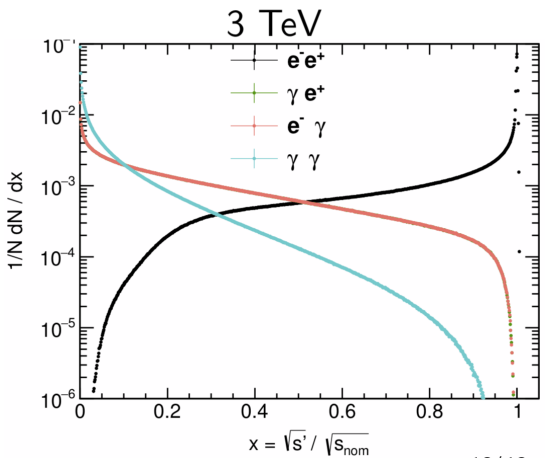
We would be happy to give advice and to test releases!

Summary

- Status of studies about potential of CLIC, ILC for Higgs physics, top physics and BSM physics
- Issues in MC generation for linear colliders:
  - Beam-Beam effects
  - Photon-induced processes
  - ISR
  - Beam parameters
- Ingredients for MC simulation for linear collider studies



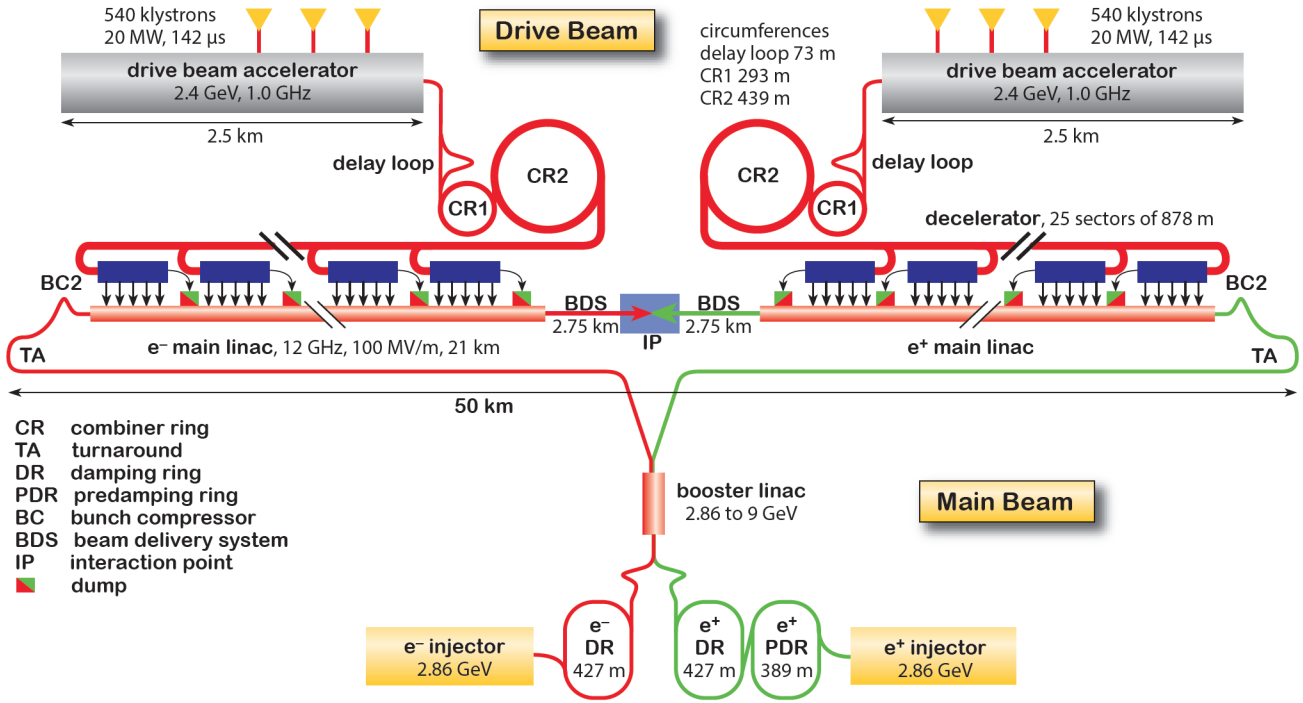




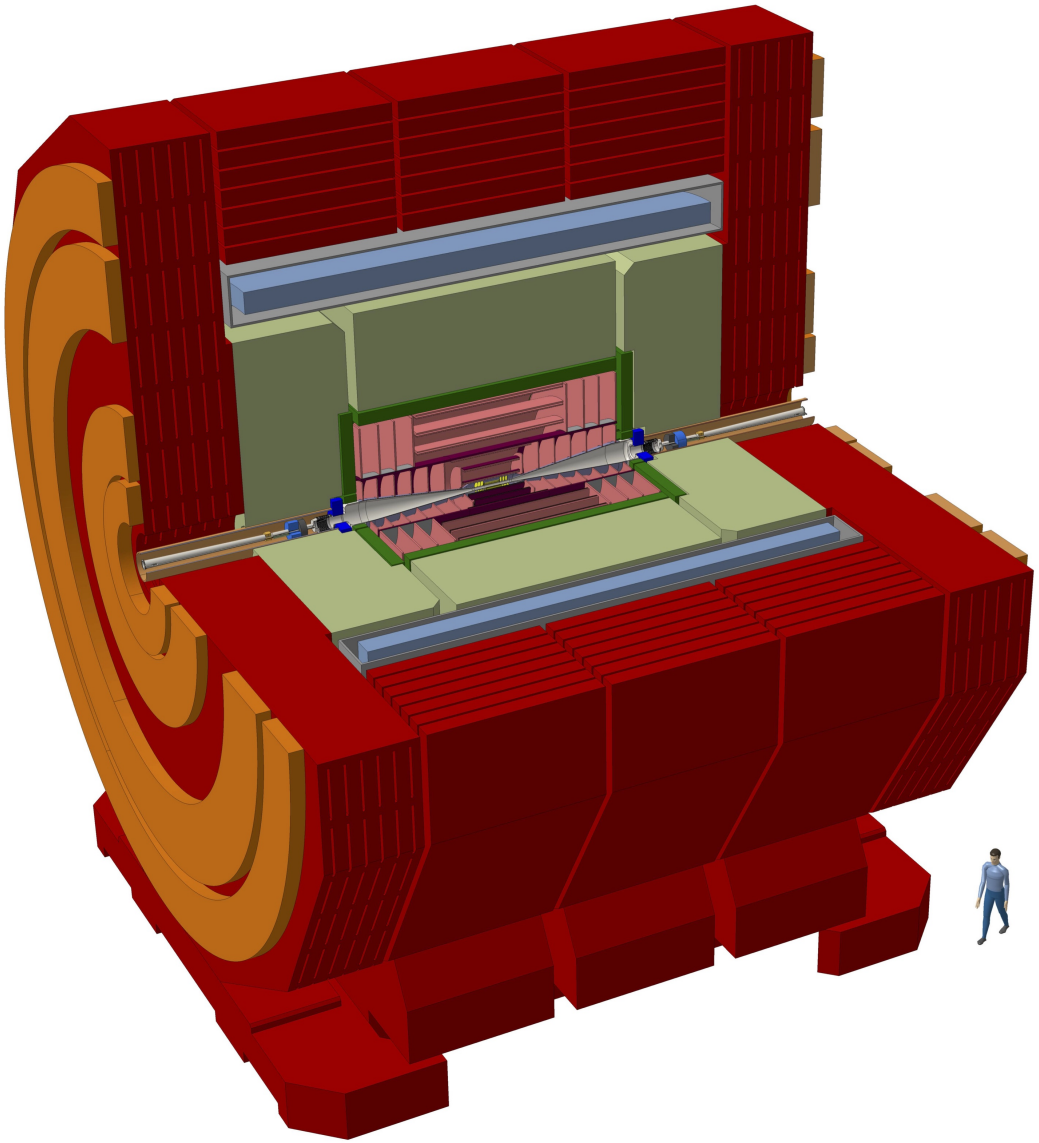
Additional material

The Compact Linear Collider CLIC

- Future e^+e^- collider at the TeV scale
- Novel accelerator technique based on radio-frequency devices and a two-beam acceleration scheme



CLIC Detector: CLICdet



Designed for Particle Flow Analysis and optimized for CLIC environment

- 4 T B-field
- Vertex detector (3 double layers)
- Large Silicon tracker R=1.5m
- Highly granular calorimeters:
  - Si-W-ECAL 40 layers (22 X_0)
  - Scint-Fe-HCAL 60 layers (7.5 λ_I)

Precise timing for background suppression

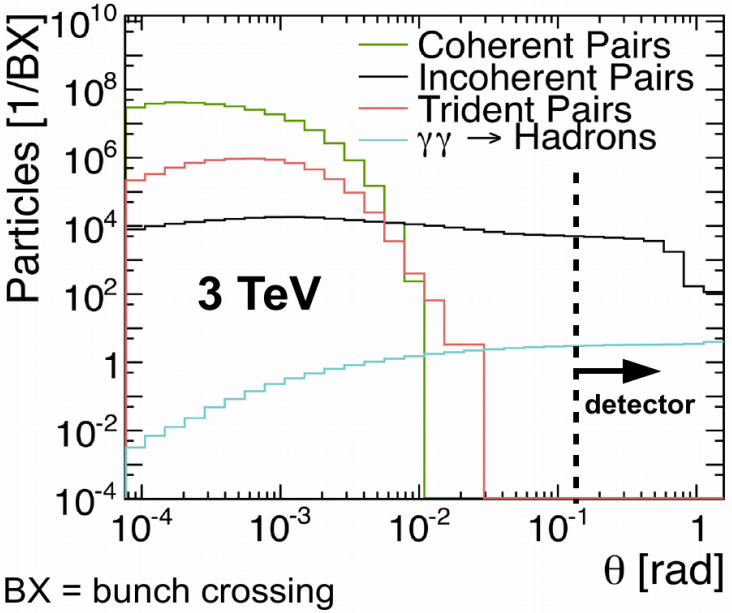
Simulation of beam-induced backgrounds

Coherent and incoherent e^+e^- pairs

simulated in the GuineaPig beam simulation [D. Schulte]

$\gamma\gamma \rightarrow$ hadrons

- Overlayed on hit level to the hard processes for full simulation and reconstruction according to average interactions per bunch crossing



- Bunch trains with 312 bunches every 0.5 ns
- $\gamma\gamma \rightarrow$ hadrons suppressed with timing cuts

Whizard for linear colliders

Universal Monte Carlo for elementary processes at (future lepton) colliders

- WHIZARD2 incorporated in ILC/CLIC simulation chain
- CIRCE2 for beamstrahlung spectra (validated for CLIC)
- Written in modern `Fortran`, matrix elements with `OCaml` in subpackage O'MEGA
- Parallelisation on HPCs
- Makes use of standard externals, e.g. LHAPDF, HEPMC etc
- NLO-QCD via one-loop providers:
  - GOSAM [G. Cullen et.al.]
  - OPENLOOPS [F. Cascioli et.al.]
  - RECOLA [A. Denner et.al.]
- Interfaces to FEYNRULES, SARAH for models