Introduction: First ILC Software Tutorial

Snowmass Energy Frontier

Frank Gaede, Jenny List, **Chris Potter**, Jan Strube

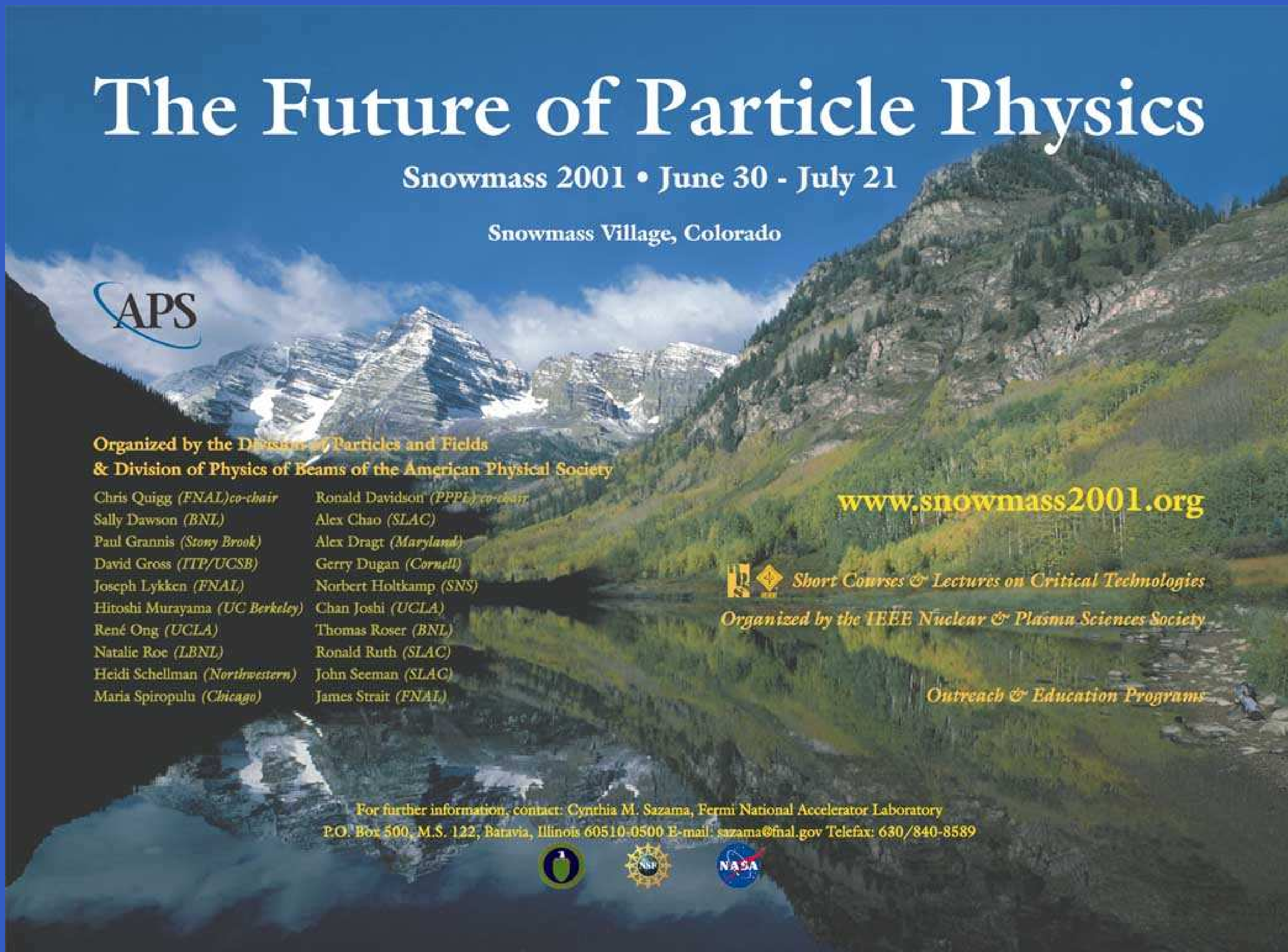
Linear Collider Collaboration

International Linear Collider

International Large Detector

Silicon Detector

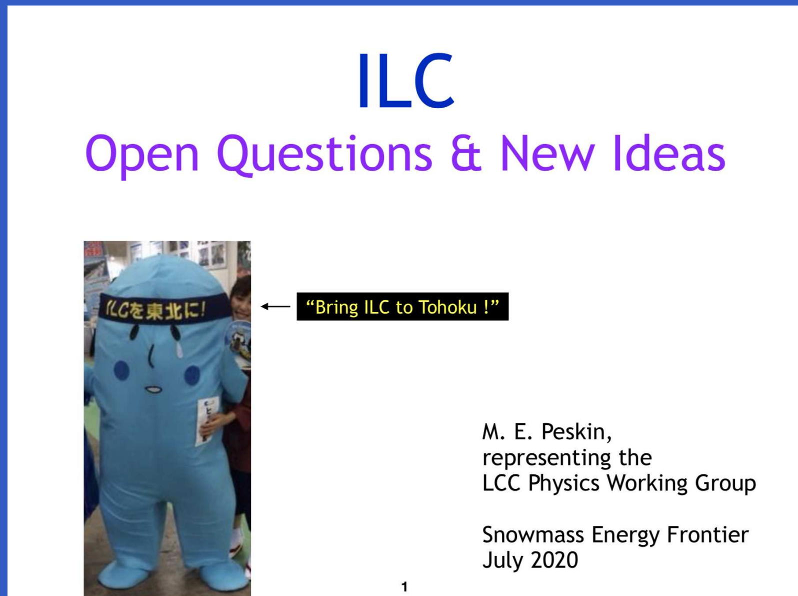
The Actual Snowmass, Colorado (2001)

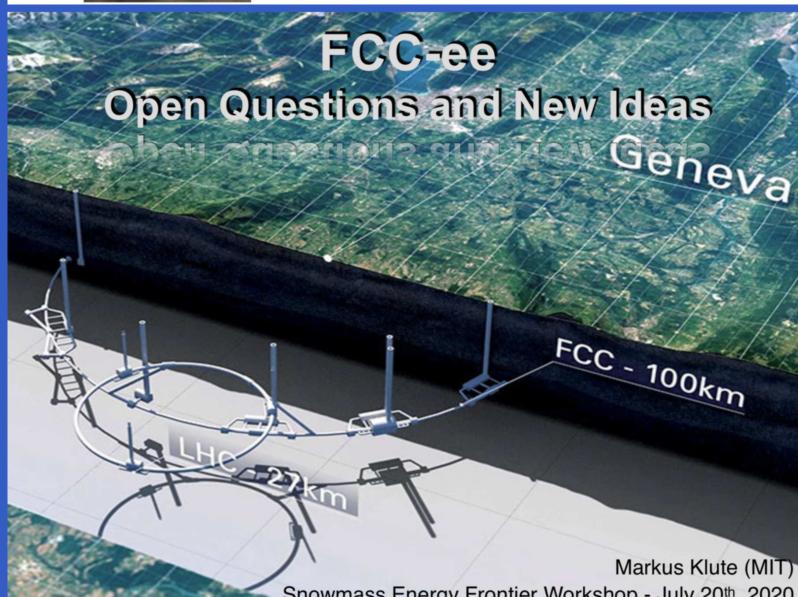


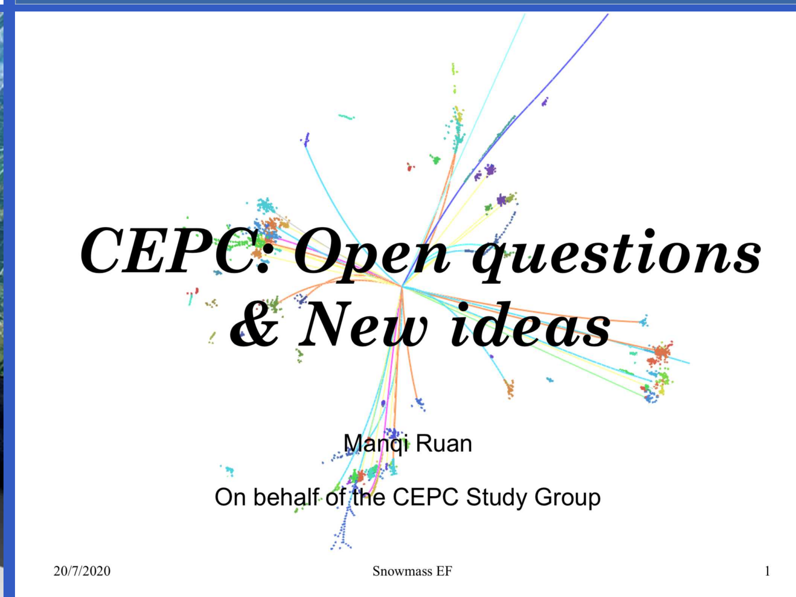
Personal Note: The Spirit of Snowmass

- I was lucky to be at Snowmass 2001, when it still took place in Snowmass, Colorado. The point then, as now, was to find commonality, build consensus, and not to deepen divisions.
- At the Snowmass Energy Frontier Plenary on 20 July, four options for the next e^+e^- collider were described in four talks:
  - International Linear Collider (ILC): Michael Peskin
  - Future Circular Collider, e^+e^- (FCCee): Markus Klute
  - Circular Electron Positron Collider (CEPC): Manqi Ruan
  - Compact Linear Collider (CLIC): Aidan Robson
- On one level, we are competitors betting on different horses and aggressively pushing different agendas.
- On a higher level, we are all colleagues who work together and want to see a new high energy e^+e^- collider built somewhere, anywhere, in the world.
- With that, we'll briefly consider the documentation, detectors and simulation frameworks discussed by each machine before focusing on the ILC.
- The physics, at least at common energies, is not so very different between the machines.

Snowmass Energy Frontier Plenary, 20 July 2020







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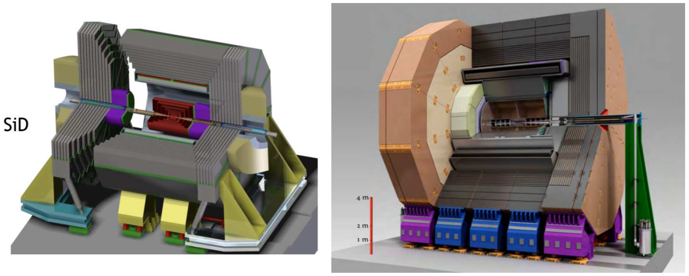
Documentation TLAs: TDRs and CDRs and EPJs

Published ILC physics analyses are generally done with full simulation of the SiD and ILD detectors,

SiD



ILD

Full description: ILC TDR vol. 4, arXiv:2003.01116

Simulation, reconstruction, and analysis tools in iLCSoft, data stored in LCIO format.

These tools and data format are also used by CLIC and CEPC.

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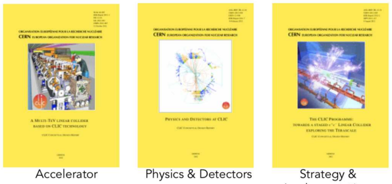
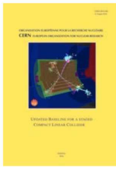
CLIC History

- 3-volume CDR 2012



Accelerator | Physics & Detectors | Strategy & Implementation

Updated Staging Baseline 2016



- 4 Yellow Reports 2018

Summary Report | Physics Potential | Project Implementation | Detector Technologies

- CLIC is now a mature project
  - technical timeline gives readiness for construction starting ~2026, with first collisions ~2035

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FCC documentation

Outcome of design studies recommended by the 2013 European Strategy

4 CDR volumes published in EPJ

FCC Physics Opportunities | **FCC-ee: The Lepton Collider**

FCC-hh: The Hadron Collider | **HE-LHC: The High Energy Large Hadron Collider**

Recent FCC publications

1) Future Circular Collider - European Strategy Update Documents

(FCC-ee), (FCC-hh), (FCC-int)

2) FCC-ee: Your Questions Answered - arXiv:1906.02693

3) Circular and Linear e+e- Colliders: Another Story of Complementarity

arXiv:1912.11871

4) Theory Requirements and Possibilities for the FCC-ee and other Future High Energy and Precision Frontier Lepton Colliders arXiv:1901.02648

5) Polarization and Centre-of-mass Energy Calibration at FCC-ee, arXiv:1909.12245

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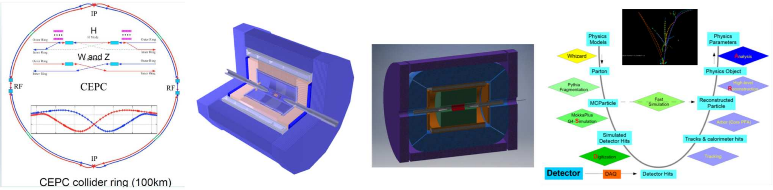
CDR @ 2018

- Baseline Accelerator, Detector, operation scenario
  - 1 Million Higgs boson in 7 years
  - 6E11 Z boson in 2 years
  - WW threshold scan: 1 year (1E7 W bosons)
- Baseline simulation tool:
  - Quantify the physics potential & comparative advantages
  - Guide the design/optimization of the facility & the detector



CEPC collider ring (100km)

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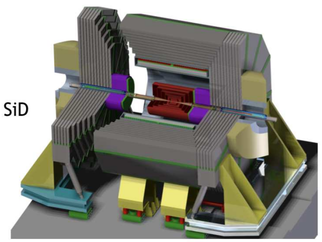
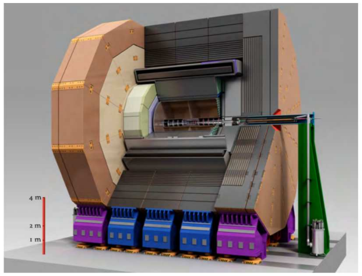
Detectors: ILD, SID, CLICdp, IDEA

Published ILC physics analyses are generally done with full simulation of the SiD and ILD detectors,





Full description: ILC TDR vol. 4, arXiv:2003.01116

Simulation, reconstruction, and analysis tools in iLCSoft, data stored in LCIO format.

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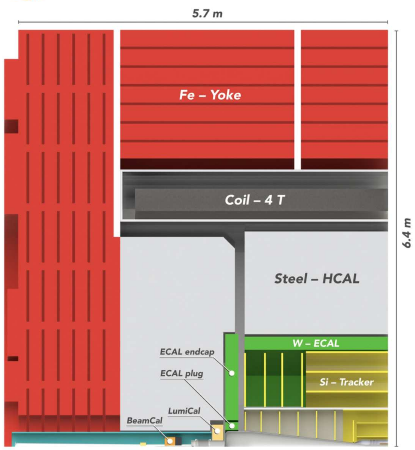
CLIC Detector Concept



Essential characteristics:
- B-field: 4T
- Vertex detector with 3 double layers
- Silicon tracking system: 1.5m radius
- ECAL with 40 layers (22 X_0)
- HCAL with 60 layers (7.5 λ)

Precise timing for background suppression (bunch crossings 0.5ns apart)
- ~10ns hit time-stamping in tracking
- 1ns accuracy for calorimeter hits

CLICdp-Note-2017-001
arXiv:1812.07337

+ Dedicated detector R&D programme, particularly on Vertex & Tracking

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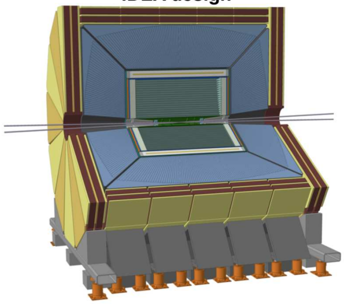
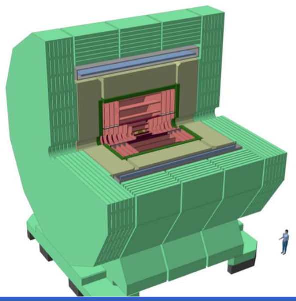
FCC-ee Detectors

Two detector concepts used for integration, basic performance and cost estimates:
- Linear Collider Detector group at CERN has undertaken the adaption of a detector for FCC-ee
- IDEA, detector specifically designed for FCC-ee (and CEPC)

IDEA design



CERN adapted design



Next step is to design detectors for physics

Opportunity to design multiple collider detector

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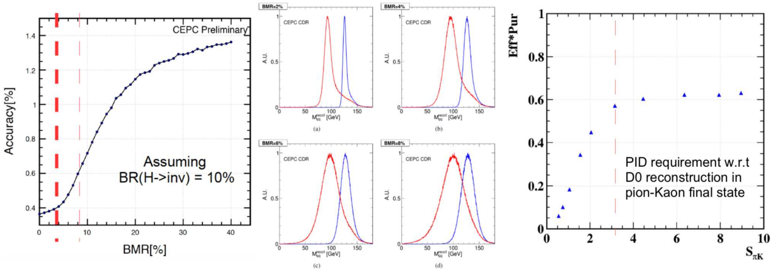
Performance study: bridging the physics & detector

- To bridging the physics reach & detector requirements – design/optimization...
- Contacts: M.Ruan, G.Li(IHEP)



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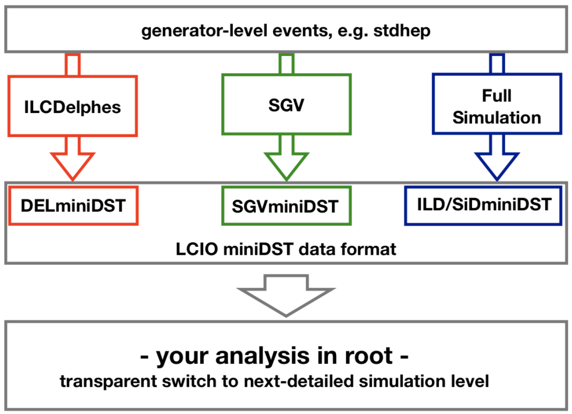
Simulation Frameworks: Delphes Fast, ILCSoft Full



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Tools for CLIC sensitivity studies

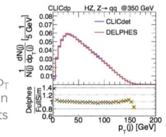
- A Delphes card for the CLICdet detector model is well-documented and has already been extensively used:

  Whizard settings for CLIC:
  https://gitlab.cern.ch/CLICdp/DetectorSoftware/clic-whizard2-settings

  CLICdet Delphes card description and validation:
  https://arxiv.org/abs/1909.12728

  Further information on the use of the CLICdet Delphes card can be found here:
  https://twiki.cern.ch/twiki/bin/view/CLIC/CLICdetDelphesInstructions

  - b-tagging working points
  - jet reconstruction choices
  - etc.



Delphes jet p_T validation in HZ events

- If you are interested in using the full simulation or have questions on Whizard and Delphes for CLICdet, you are very welcome to contact us: clicdp-snowmass-samples-contacts@cern.ch

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MC Task

- The CEPC MC Studies is supported by the Computing Center of IHEP
- The access of sample & software support is not ideal
  - Most works are operated with IHEP Cluster
  - Software releases at: http://cepcsoft.ihep.ac.cn/
- The Communication between the analyzer + pheno/theory, the MC Force, the CEPC sim team is essential:
  - What scientific problem the analyzer focus, what synergies can be made with existing/on going studies, what support she/he actually needs
- Depends on the actual demands/needs, the CEPC simulation group are happy to collaborate, to overcome the technical difficulties
  - Accessibility of Samples
  - Production of New Samples
  - Allocation on computing resource
- EF Conveners will play an important role...

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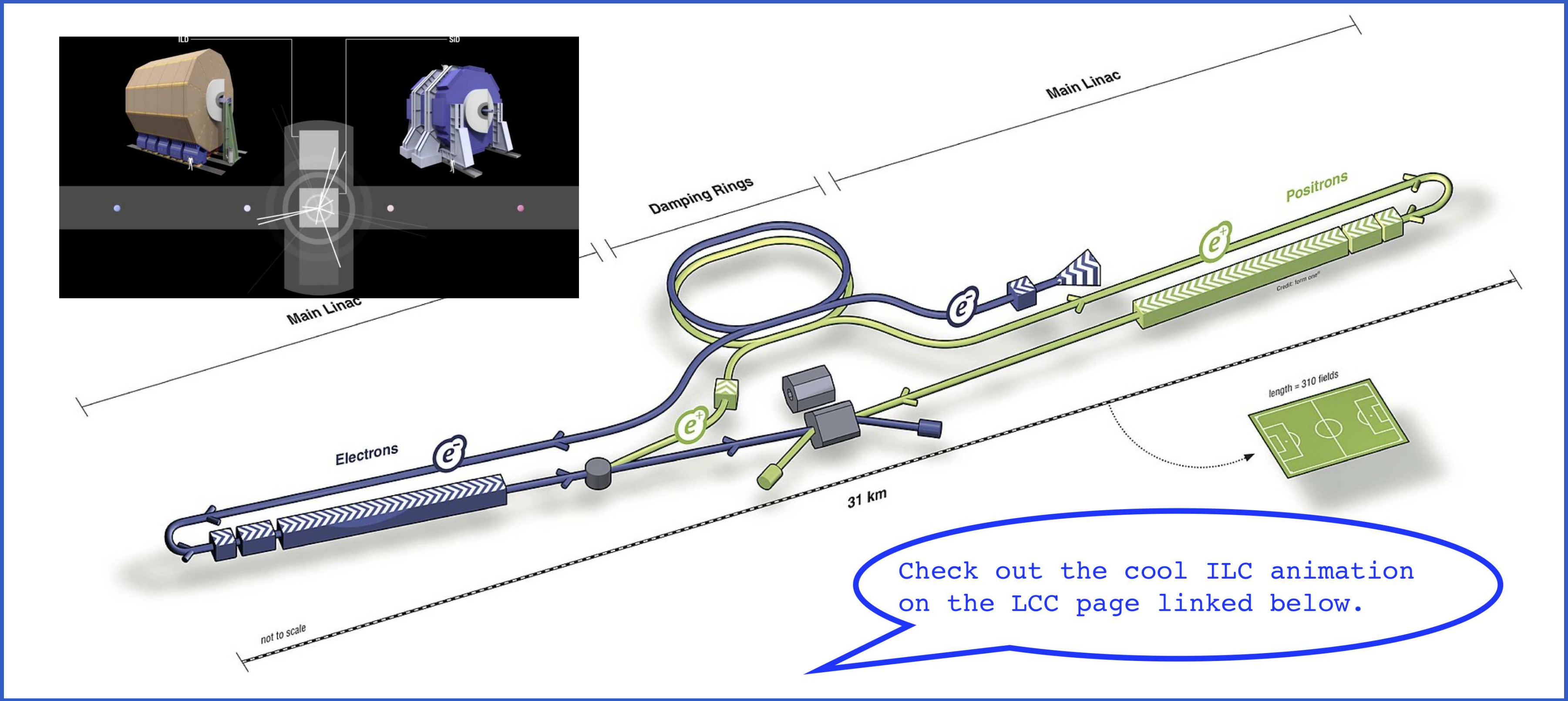
Introduction: ILC Status



- The ILC has been extensively documented in four volumes: Executive Summary, Accelerator, Physics and Detector. Link to the 2013 ILC Technical Design Report, Volumes 1-4.
- The Linear Collider Collaboration (LCC), operating under a mandate from the International Consortium for Future Accelerators (ICFA), is now passing the baton to an International Development Team in preparation for an ILC PreLab in Japan.
- DOE is moving forward with the 2014 P5 recommendation for ILC collaboration with Japan.

ILC Snowmass Resources

ILC Simulation Resources for Snowmass 2021

This page gives links to the various resources that the LCC Physics Working Group is making available for projects on e+e- collider physics for the US community study Snowmass 2021. At the moment, this page is a work in progress. As the resources become available, the links on this page will become active.

We are still working on the documentation of these tools, files, and other resources. For the moment, if you have a question about how to use these, send email to: ilcsnowmass@slac.stanford.edu .

- **"ILC Study Questions for Snowmass 2021"**, arXiv:2007.03650 [hep-ph]
  questions for possible Snowmass projects, description of our software framework, contact information

Tools:

Whizard: polarization-aware event generator

Whizard is the most complete generator for ILC conditions, as it takes both beam polarisation and beam-spectrum in account, and can handle up to 2->8 processes. It is not restricted to electrons as initial particles, so also photon-induced processes are generated.

We will provide substantial samples of all standard model processes with up to 6 fermions in the final state, generated with Whizard.

If you need to generate BSM samples, we highly recommend to use Whizard for that, as well. It can be done in a very general way using Whizard's UFO interface.

- Whizard home page on hepforge

ILCDelphes: Delphes model describing a parametrised generic ILC detector

- ILCDelphes model files on model distribution on github
- documentation of ILCDelphes
- your first higgs recoil mass plot from ILCDelphes via delphes2lcio & miniDST

SGV: an ILC fast detector simulation tool

- SGV documentation and download instructions
- SGV useful talk

miniDST data format

- your first higgs recoil mass plot from full simulation (or SGV) via miniDST

Monte Carlo event samples:

MC event samples at the various ILC energy stages

http://ilcsnowmass.org

ILC Physics and Simulation for Snowmass 2021

ILC Study Questions for Snowmass 2021

LCC Physics Working Group

Keisuke Fujii[1], Christophe Grojean[2,3], Michael E. Peskin[4] (Conveners); Tim Barklow[4], Yuanning Gao[5], Shinya Kanemura[6], Jenny List[2], Mihoko Nojiri[1,7], Maxim Perelstein[8], Roman Pöschl[9], Jürgen Reuter[2], Frank Simon[10], Tomohiko Tanabe[1], James D. Wells[11] (Physics WG); Mikael Berggren[2], Esteban Fullana[12], Juan Fuster[12], Frank Gaede[2], Daniel Jeans[1], Adrián Irles[9], Sunghoon Jung[13], Shin-Ichi Kawada[2], Shigeki Matsumoto[7], Chris Potter[14], Jan Strube[14,15], Taikan Suehara[16], Junping Tian[17], Marcel Vos[13], Graham Wilson[18], Hitoshi Yamamoto[19], Ryo Yonamine[19], Aleksander Filip Żarnecki[20] (Contributors); James Brau[15], Hitoshi Murayama[7,21,22] (ex officio)

ABSTRACT

To aid contributions to the Snowmass 2021 US Community Study on physics at the International Linear Collider and other proposed e^+e^- colliders, we present a list of study questions that could be the basis of useful Snowmass projects. We accompany this with links to references and resources on e^+e^- physics, and a description of a new software framework that we are preparing for e^+e^- studies at Snowmass.

https://arxiv.org/abs/2007.03650

Background Reading

2 General references on ILC physics

There are many references to get started with Linear Collider physics. Here we highlight a few that we think are particularly useful:

- "Primer on ILC Physics and SiD Software Tools," by Chris Potter [2]
- lectures from the Linear Collider Schools (https://lcschool.desy.de/), in particular, the lectures at the most recent schools in 2014 [3], 2016 [4], and 2018 [5].

A comprehensive overview of the ILC physics issues and the design of the proposed detectors is given in the ILC Technical Design report, in particular, in the executive summary [6] and the volumes devoted to Physics [7] and Detectors [8].

The most up-to-date detailed references on ILC physics are the papers prepared for the European Strategy for Particle Physics study [9, 10]. Note that the projections from the TDR are updated, in some cases substantially, in these documents. The ILD detector concept group has also produced an updated Interim Design Report [11].

https://arxiv.org/abs/1306.6329

Data Samples

3.1 Overview on data samples and tools to be provided

We are making available data samples of Standard Model events and additional signal processes, corresponding to a significant fraction of the expected ILC integrated luminosity. The data will be provided in the following formats:

1. at generator-level, in stdhep format. These samples can be used for generator level studies, as input to `Delphes` using the card describing a "generic ILC detector", or as input to **the ILD** fast-simulation tool `SGV` [23]. The `Delphes` and `SGV` tools are both described below.
2. as `Delphes` output. These files are the result of processing the stdhep files through the ILC `Delphes` implementation.
3. in miniDST format. This format, described below, contains a condensate of the high-level reconstruction output, readable in Root. We will provide at least two flavors of minDST: SGV-miniDST, produced with `SGV`, and ILD-miniDST, produced with the ILD full simulation and reconstruction chain.

http://ilcsnowmass.org

Beam Polarization, ISR and Beamstrahlung at e^+e^-

4 Notable features of e^+e^- collisions

We should note two important aspects of e^+e^- physics that might be unfamiliar to people who have worked only at hadron colliders. The first is that linear e^+e^- colliders will provide longitudinally polarized electron and positron beams. Control of the beam polarization can then be used as a powerful tool for e^+e^- physics. Beam polarization has an order-1 effect on ILC cross sections, since the e^-_L and e^-_R have different $SU(2) \times U(1)$ quantum numbers. The ILC expects to provide 80% polarization

in the electron beam and 30% polarization in the positron beam, with the possibility in both cases of rapidly switching the polarization orientation. This effectively

The second is that the nominal center of mass energy of e^+e^- collisions is affected both by initial-state radiation and by radiation from the beam-beam interaction ("beamstrahlung"). Beamstrahlung and ISR have three important effects. First, they broaden the e^+e^- center of mass energy distribution. This broadening is a few percent at energies up to 500 GeV. This effect is included in all of the samples that we provide; see Sec. 3.2. More importantly, ISR and beamstrahlung produce photons that induce hard $\gamma\gamma$ and $e\gamma$ reactions. Those processes are often the major source of background events, in particular for many types of searches. They are

Whizard: Polarized Beams, ISR and Beamstrahlung

- **WHIZARD**
- **HOME**
  - Main Page
- **MANUAL, WIKI, NEWS**
  - Manual
  - Wiki Page
  - CLIC page on WHIZARD
  - News
  - Tutorials
  - Delphes Fast Simulation
  - WHIZARD talks
  - ChangeLog
- **REPOSITORY, LAUNCHPAD, BUG TRACKER**
  - Launchpad Support Page
  - Subversion Repository
  - Public Git Repository
  - Support Questions
  - Bug Tracker

The WHIZARD Event Generator

The Generator of Monte Carlo Event Generators for Tevatron, LHC, ILC, CLIC, CEPC, FCC-ee, FCC-hh, SppC and other High Energy Physics Experiments

What is WHIZARD?

WHIZARD is a program system designed for the efficient calculation of multi-particle scattering cross sections and simulated event samples.

Tree-level matrix elements are generated automatically for arbitrary partonic processes by using the Optimized Matrix Element Generator O'Mega. Matrix elements obtained by alternative methods (e.g., including loop corrections) may be interfaced as well. The program is able to calculate numerically stable signal and background cross sections and generate unweighted event samples with reasonable efficiency for processes with up to eight final-state particles; more particles are possible. For more particles, there is the option to generate processes as decay cascades including complete spin correlations. Different options for QCD parton showers are available.

Polarization is treated exactly for both the initial and final states. Final-state quark or lepton flavors can be summed over automatically where needed. For hadron collider physics, an interface to the standard LHAPDF is provided. For Linear Collider physics, beamstrahlung (CIRCE) and ISR spectra are included for electrons and photons. The events can be written to file in standard formats, including ASCII, StdHEP, the Les Houches event format (LHEF), HepMC, or LCIO. These event files can then be hadronized.

WHIZARD supports the Standard Model and a huge number of BSM models. Model extensions or completely different models can be added. There are also interfaces to FeynRules and SARAH.

CURRENT RELEASE

- **The official versions are 2.8.4 (released: July 8th, 2020) and 3.0.0α (released March 3rd, 2020).**

  The distribution tarballs of the sources can be found here (2.8.4, link) and (3.0.0α, link).
- Nightly build tarballs can be downloaded: (link).

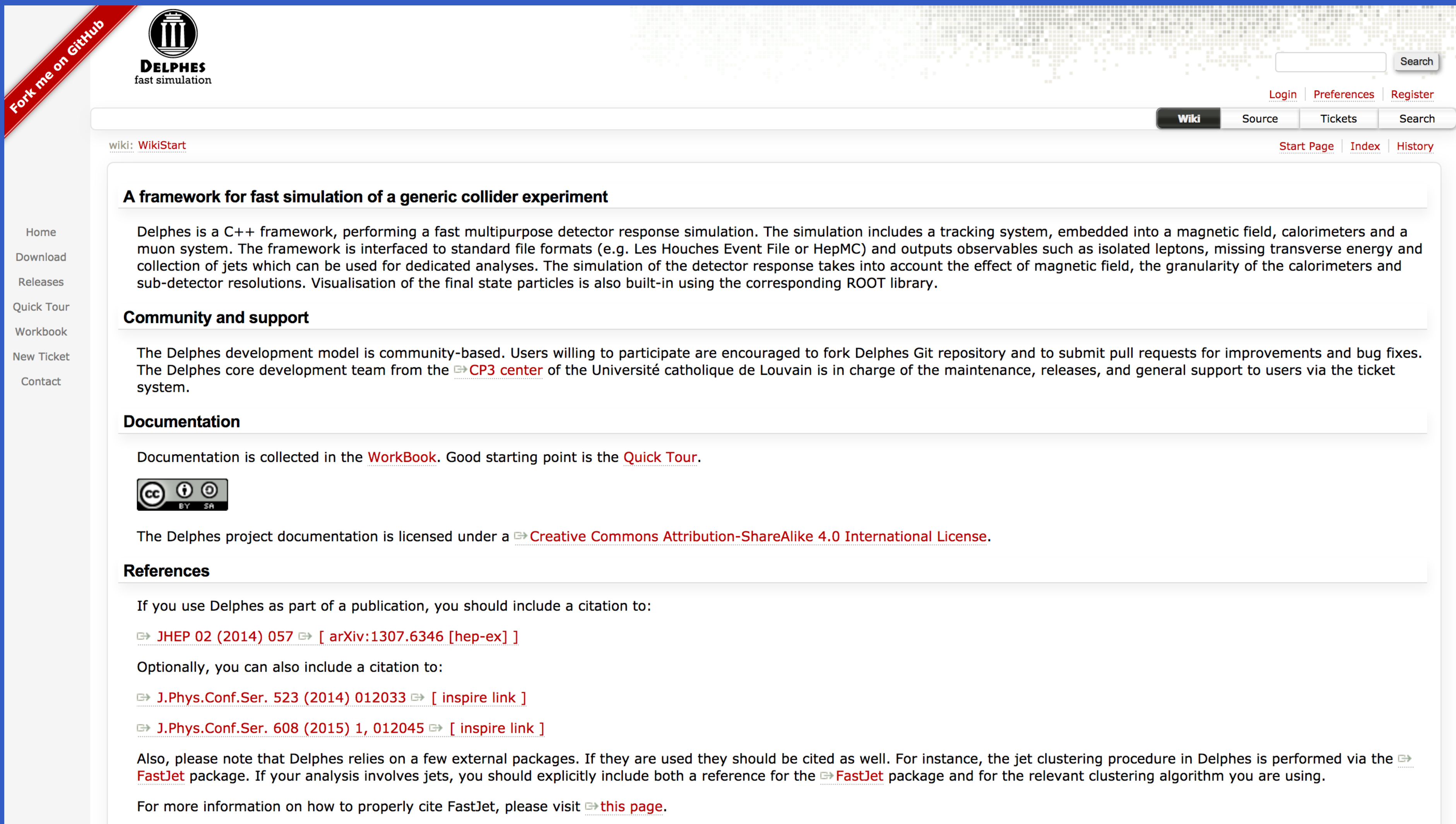
https://whizard.hepforge.org/

Example Whizard2 (Sindarin) Script

```
model=SM_CKM
mH=125.0 GeV
wH=0.004 GeV

process ilc250_eLpR_2f1h="e-", "e+" => "Z", "H"
compile

sqrts=250 GeV
beams= "e-", "e+"  => isr, isr
beams_pol_density=@(-1), @(+1)
beams_pol_fraction=80%, 30%
integrate(ilc250_eLpR_2f1h)

$shower_method="PYTHIA6"
?hadronization_active=true
$hadronization_method="PYTHIA6"
$ps_PYTHIA_PYGIVE="PMAS(25,1)=125.0; PMAS(25,2)=0.004"

n_events=10000
sample_format=stdhep
simulate(ilc250_eLpR_2f1h)
```

- Model and Model Parameters
- Higgstrahlung!!
- Center of mass energy, beam polarization and ISR. No beamstrahlung here...
- Use Pythia6 to decay Z and H, and to do parton shower and hadronization
- Several formats available, use stdhep here

Delphes: Fast Simulation of a Generic Collider Experiment



Fork me on GitHub

DELPHES
fast simulation

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wiki: WikiStart

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- Download
- Releases
- Quick Tour
- Workbook
- New Ticket
- Contact

A framework for fast simulation of a generic collider experiment

Delphes is a C++ framework, performing a fast multipurpose detector response simulation. The simulation includes a tracking system, embedded into a magnetic field, calorimeters and a muon system. The framework is interfaced to standard file formats (e.g. Les Houches Event File or HepMC) and outputs observables such as isolated leptons, missing transverse energy and collection of jets which can be used for dedicated analyses. The simulation of the detector response takes into account the effect of magnetic field, the granularity of the calorimeters and sub-detector resolutions. Visualisation of the final state particles is also built-in using the corresponding ROOT library.

Community and support

The Delphes development model is community-based. Users willing to participate are encouraged to fork Delphes Git repository and to submit pull requests for improvements and bug fixes. The Delphes core development team from the CP3 center of the Université catholique de Louvain is in charge of the maintenance, releases, and general support to users via the ticket system.

Documentation

Documentation is collected in the WorkBook. Good starting point is the Quick Tour.

References

If you use Delphes as part of a publication, you should include a citation to:

JHEP 02 (2014) 057 [arXiv:1307.6346 [hep-ex]]

Optionally, you can also include a citation to:

J.Phys.Conf.Ser. 523 (2014) 012033 [inspire link]

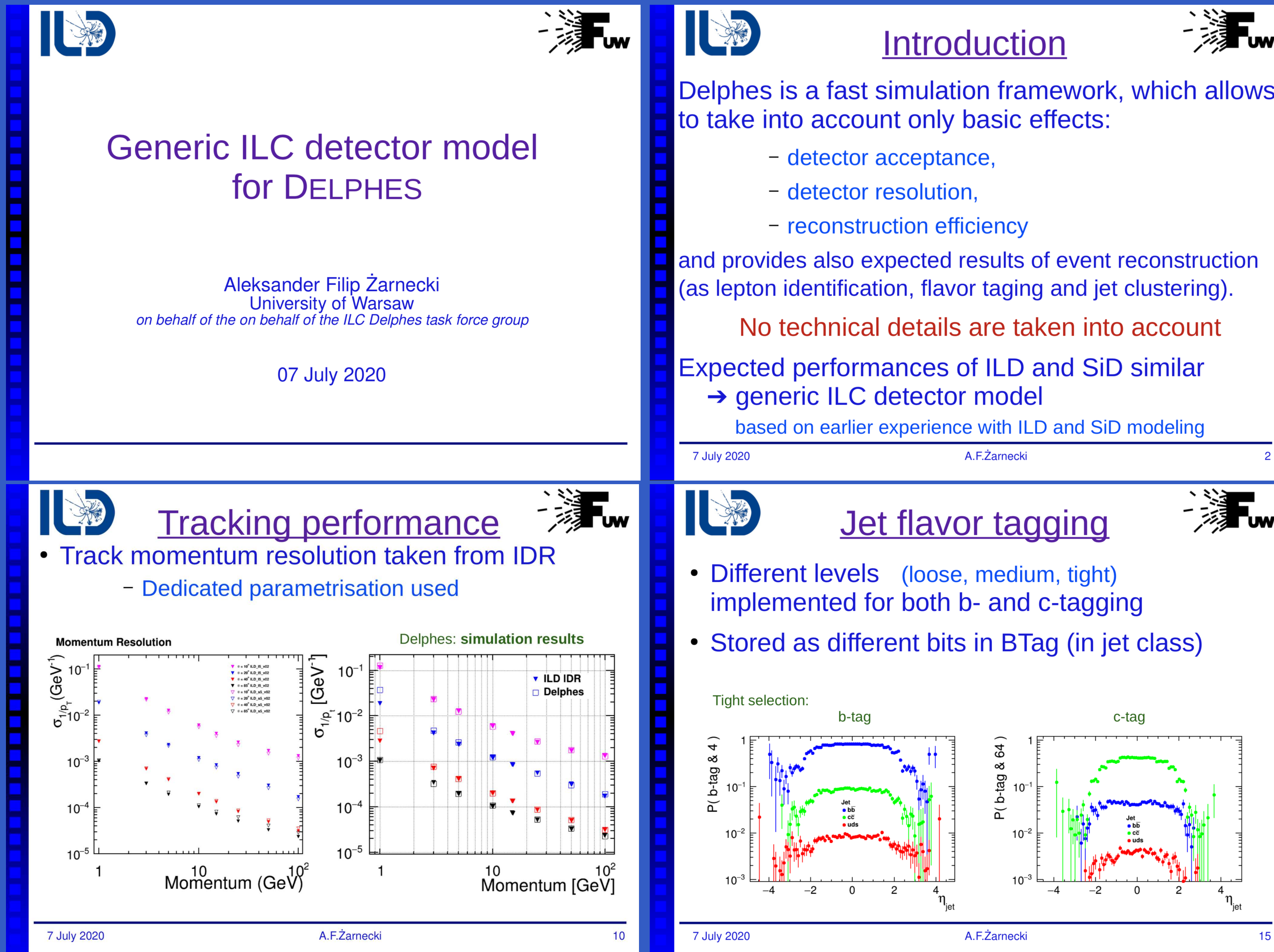
J.Phys.Conf.Ser. 608 (2015) 1, 012045 [inspire link]

Also, please note that Delphes relies on a few external packages. If they are used they should be cited as well. For instance, the jet clustering procedure in Delphes is performed via the FastJet package. If your analysis involves jets, you should explicitly include both a reference for the FastJet package and for the relevant clustering algorithm you are using.

For more information on how to properly cite FastJet, please visit this page.

https://cp3.irmp.ucl.ac.be/projects/delphes

ILCDelphes Detector Card for Delphes



https://github.com/iLCSoft/ILCDelphes

Options with Delphes

```
potter@lxplus7119 > mkdir ilc_tutorial
potter@lxplus7119 > cd ilc_tutorial

potter@lxplus7119 > wget http://cp3.irmp.ucl.ac.be/downloads/Delphes-3.4.2.tar.gz
potter@lxplus7119 > tar -xvzf Delphes-3.4.2.tar.gz
potter@lxplus7119 > cd Delphes-3.4.2
potter@lxplus7119 > source /cvmfs/sft.cern.ch/lcg/views/LCG_97a/x86_64-centos7-gcc8-opt/setup.sh
potter@lxplus7119 > make -j 4

potter@lxplus7119 > ./DelphesSTDHEP
 Usage: DelphesSTDHEP config_file output_file [input_file(s)]
 config_file - configuration file in Tcl format,
 output_file - output file in ROOT format,
 input_file(s) - input file(s) in STDHEP format,
 with no input_file, or when input_file is -, read standard input.

potter@lxplus7119 > ls cards/delphes_card_[CI][ELD]*
cards/delphes_card_CEPC.tcl             cards/delphes_card_CLICdet_Stage3.tcl
cards/delphes_card_CLICdet_Stage1.tcl  cards/delphes_card_IDEA.tcl
cards/delphes_card_CLICdet_Stage2.tcl  cards/delphes_card_ILD.tcl

potter@lxplus7119 > git clone https://github.com/iLCSoft/ILCDelphes
potter@lxplus71191 >ls ILCDelphes/cards/delphes_card_ILCgen.tcl
ILCDelphes/cards/delphes_card_ILCgen.tcl
```

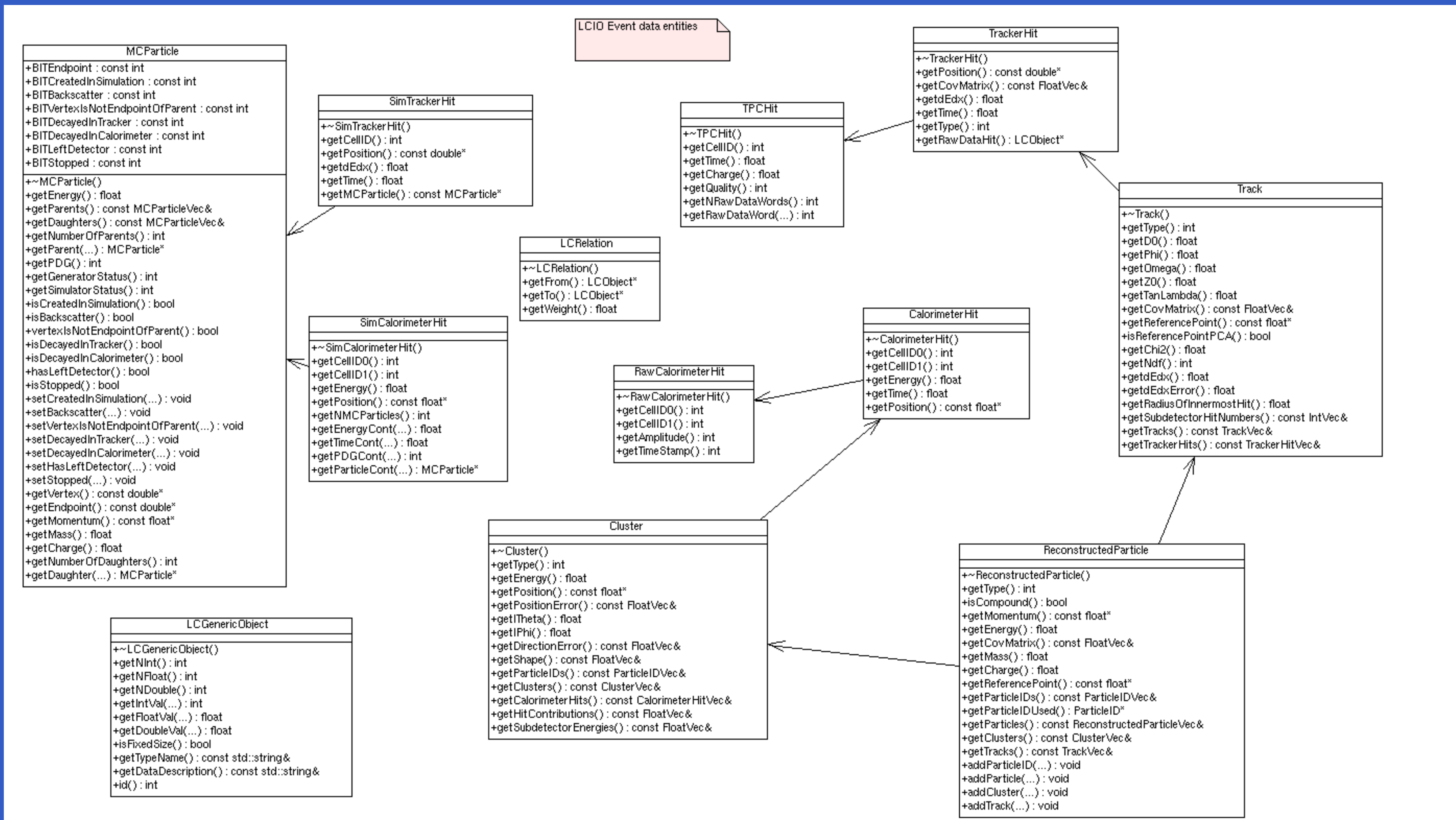
Install and build…

Syntax for the stdhep executable. Default output is Root format.

Detector configuration files for CEPC, CLIC, FCCee, ILC ship with Delphes

Our generic ILC detector configuration file

LCIO Format for Fast/Full Simulation



http://lcio.desy.de/v02-09/doc/manual_html/manual.html

Root Analysis of LCIO with Fast/Full Simulation

Easy e^+e^- event analysis with LCIO & mini-DST

Jenny List (DESY), Frank Gaede (DESY),
Mikael Berggren (DESY), Shin-ichi Kawada (DESY)
2020/July/7 - 8
Preparatory Joint Sessions on
"Open Questions and New Ideas"

1

Usage of mini-DST

- We are also developing a simple macro to create histograms using mini-DST file.
  - Require ROOT environment, and LCIO (Linear Collider I/O) library which will also be provided
  - You don't need to install entire iLCSoft to read mini-DST and create your histogram!

```
/*
put this into your .rootlogon.C file

{
 gInterpreter->AddIncludePath("$LCIO");
 gSystem->Load("${LCIO}/lib/liblcio.so");
 gSystem->Load("${LCIO}/lib/liblcioDict.so");
}

for the LCIO API documentation see:
http://lcio.desy.de/v02-09/doc/doxygen_api/html/index.html
*/
```

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Simple Macro

- The plots in previous pages were made by the same macro.
  - Just require ROOT, LCIO library, and mini-DST file
  - Usage of mini-DST format enables a seamless transition among Delphes, SGV, and full simulation

```
//----------  the actual event processing

LCIterator<ReconstructedParticle> jets( evt, "Jets" ) ;
LCIterator<ReconstructedParticle> muons( evt, "Muons" ) ;

if( jets.size() != 2)
  continue;

if( muons.size() != 2)
  continue;

auto mu1 = muons.next();
auto mu2 = muons.next();
hmuonmass->Fill( inv_mass( mu1, mu2) ) ;

auto j1 = jets.next();
auto j2 = jets.next();
hjetmass->Fill( inv_mass( j1, j2) ) ;


// the recoil mass
const auto& vm1 = v4(mu1) ;
const auto& vm2 = v4(mu2) ;
TLorentzVector ecms(0.,0.,0.,250.) ;
TLorentzVector recoil = ecms - ( vm1 + vm2 ) ;
hrecoilm->Fill( recoil.M() ) ;
```

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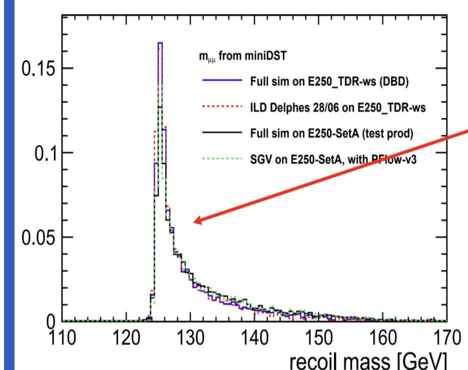
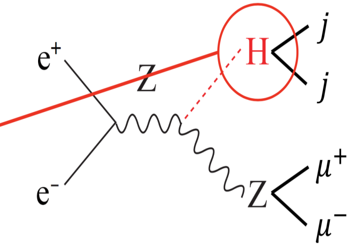
Example Study: Recoil mass at ILC250

$$e^+e^- \rightarrow ZH \rightarrow (\mu^+\mu^-)(jj)$$





plots with various types of mini-DST
ILD-mini-DST (old)
ILD-mini-DST (new)
SGV-mini-DST
Delphes-mini-DST

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https://github.com/ILDAnaSoft/miniDST

Last Remarks Before We Start!

- We will cover a lot of ground, but there is still a lot more to cover. Possible future topics:
  - How to generate and simulate your favorite signal process.
  - Install, build and run Whizard2. Investigate different processes.
  - What can Madgraph2_aMC@NLO do for e^+e^-?
  - An end-to-end analysis with fast simulation. Limitations of fast simulation.
  - Full simulation studies with ILCSoft.
  - Reconstruction algorithms: tracking, particle flow, ...
  - Running scenarios, recoil technique, beam energy spectrum, radiation environment, ...
  - Whatever you propose...within reason!
- We don't expect this process to end with these tutorials. Contact information:
  - Frank Gaede: frank.gaede@desy.de
  - Jenny List: jenny.list@desy.de
  - Chris Potter: ctp@uoregon.edu
  - Jan Strube: jan.strube@pnnl.gov
- Both detector collaborations, SiD and ILD, welcome participation from all Snowmass colleagues. We are trying to build a community of e^+e^- enthusiasts here in the US and abroad. Contact details follow on the next slide.

SiD and ILD Contacts

To join the SiD group, please contact

- Spokespersons: Andrew White (awhite@uta.edu), Marcel Stanitzki (marcel.stanitzki@desy.de)
- Physics Coodinator: Tim Barklow (timb@slac.stanford.edu)

To join the ILD group, please contact

- Spokesperson: Ties Behnke (ties.behnke@desy.de)
- Physics Coodinators: Keisuke Fujii (keisuke.fujii@kek.jp), Jenny List (jenny.list@desy.de)
- Executive Team member from the US: Graham Wilson (gwwilson@ku.edu)

https://www.ilcild.org/

https://pages.uoregon.edu/silicondetector/