The ILD Software Tools and Detector Performance.

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Rémi Été, on behalf of the ILD concept group

DESY

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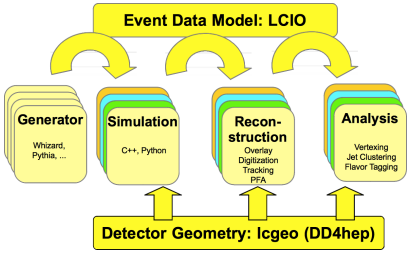
HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

The iLCSoft software stack

https://github.com/iLCSoft

- Software stack of the ILC experiment
- Nowadays used by many other experiments/collaborations
  → e.g: CLICdp, CEPC, CALICE, LCTPC, EU-Telescope
- Maintained by FLC @ DESY and CLICdp @ CERN



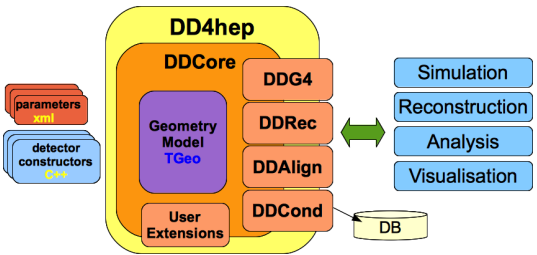
Core components

- **DD4hep**: Geometry description for simulation (Geant4) and reconstruction
- **LCIO**: Linear Collider IO and Event Data Model (EDM)
- **Marlin**: Reconstruction framework based on LCIO

DD4hep: detector geometry package

https://github.com/AIDASoft/DD4hep

- Generic detector description for HEP
  - Project started by the LC community
  - Developed in the context of AIDA2020
  - Nowadays used by other experiments
    → SiD, CLICdp, CEPC, CMS, LHCb, FCCee
  - A beautiful example of collaborative software
- Single complete description source for
  - Simulation, reconstruction, analysis, visualization
- **DDG4** for Geant 4 simulation
- **DDRec** for reconstruction
  → high level view: # layers, extents, etc...



Philosophy:
single source of geometry,
different interfaces

The ILD detector description

Optimizing ILD: ILD-L vs. ILD-S. arXiv:2003.01116

Very realistic ILD detector description:

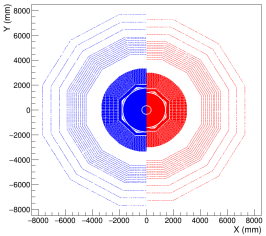
- Materials, extents, services, gaps, cooling pipes, etc...
- ILD-S (small TPC radius) vs. ILD-L (large TPC radius)

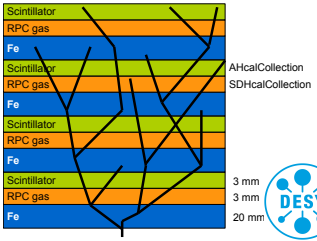
Hybrid simulation with 4 calorimeter options:

Detector	Si-ECal	Sc-Ecal	AHCal	SDHCal
ILD_l5_o1_v02	×		×	
ILD_l5_o2_v02	×			×
ILD_l5_o3_v02		×	×	
ILD_l5_o4_v02		×		×

- Simulate 4 options, reconstruct 1 option
  → Save CPU time and minimize storage

For the ILD concept and technologies:
→ ICHEP talk `the ILD detector by T. Tanabe`

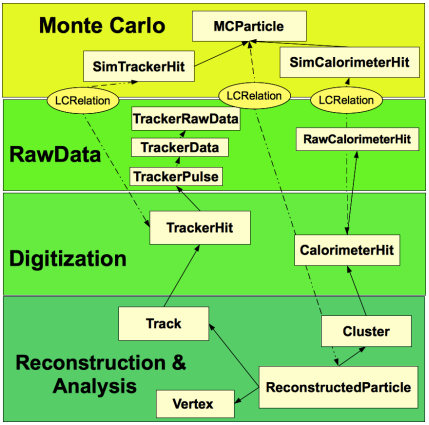




LCIO: the Linear Collider event data model

https://github.com/iLCSoft/LCIO

- Data handling for all steps in HEP workflow:
  - Generator, simulation, reconstruction, analysis
  - Very robust: almost 20 years of usage...
- Standalone IO library:
  - Binary data format (XDR), ZLIB compression
  - Block versioning
  - Recently made threade-safe
- LCRelation: weighted link between objects
  - Very convenient for MC $\leftrightarrow$ Reco navigation
- LCIO file content is user dependant
  - SIM, REC, DST
  - Working on a mini-DST format for US Snowmass



The Marlin framework

https://github.com/iLCSoft/Marlin

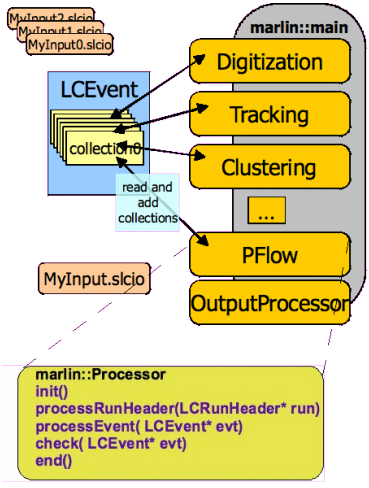
Standard HEP event processing framework

- Based on LCIO
- Focus on reconstruction and analysis

The Marlin framework

- Describes a task (`Processor`) list to execute
- Reads events and processes them through the chain
- Each `Processor` reads and/or creates new collections in the event

Framework being re-implemented for multi-threading (MarlinMT)



The Monte Carlo mass production system

DIRAC grid system

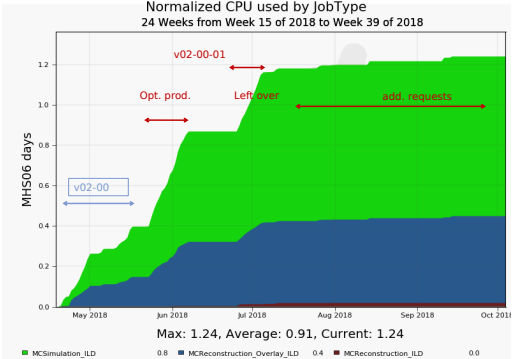
- Job management, file catalog, ...
- Transformation system for productions
- Written in Python

iLCDirac system

- DIRAC extension for ILC/CALICE VOs
- Specific to iLCSoft applications
- Developed and operated by CLIC @ CERN

Recent mass production (IDR)

- E_{cms} = 500 GeV, L$\sim$ 500 fb^{-1}
- Storage $\sim$ 1 PB



The ILD reconstruction chain

https://github.com/iLCSoft/ILDConfig

Background overlay

Digitization

Tracking

Particle Flow

High Level Reco

1 BX overlay

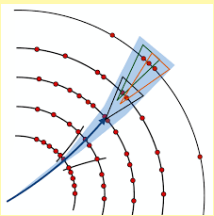
~ 1 BKG event / collision

Background sources:
- γγ to low pt hadrons
- e^+e^- pairs

Energy calibration

Time integration

Inefficiency & noise randomization



Vertex : Cellular automaton

TPC : Outer pads clustering + Kalman filter

Fwd detectors : Triplet seeds search + extrapolation

Combination + Kalman filter re-fit

Final tracks

The ILD reconstruction chain

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Background overlay

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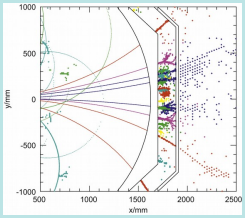
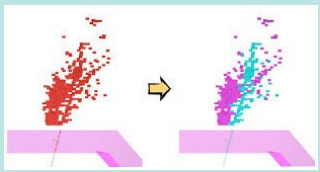




Reclustering

PandoraPFA reconstructs particles individually:

1) Calorimeter clustering algorithm
2) Pattern recognition association algorithms
3) Iterative re-clustering recovery
4) Particle identification
→ e^{+-}, γ, n^0, μ^{+-}, π^{+-}

Particle ID
(de/dX + shower + MVA)

γγ-Finders
(kinematic fit)

Primary vertex finder
(LCFIPlus)

Time Of Flight
(fast timing calorimeters)

The ILD detector performance

Tracking and jet energy resolution

Tracking

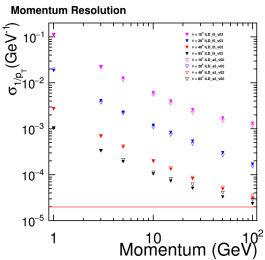
- Central tracks momentum resolution:

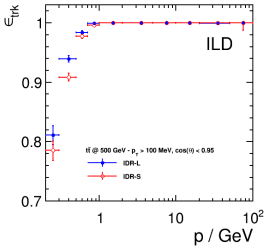
$$\sigma_{1/p_T} \approx 2 \times 10^{-5}\ \text{GeV}^{-1}$$

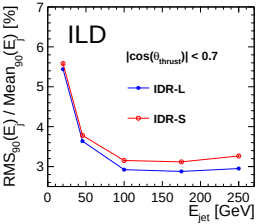
- Tracking efficiency close to 1!

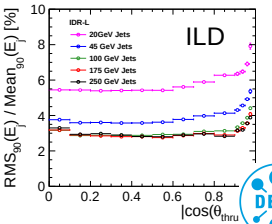
Jet energy resolution (JER)

- Using Z *"at rest"*: $Z \to qq$ (uds)
- Jet energy $E_{jet} = E_{tot}/2$
- Performance: JER $\sim 3 - 4\%$
- Getting worse in the forward direction









The ILD detector performance

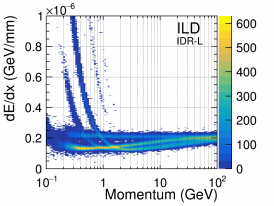
Particle ID and flavour tag

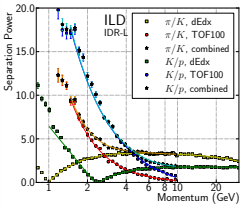
Particle ID

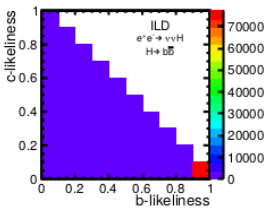
- TPC dE/dX with/without TOF
- Separation power:

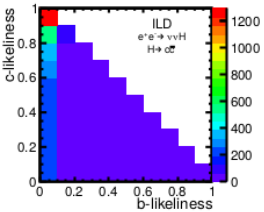
$$\eta_{A,B}(p) = \frac{|\mu_A(p) - \mu_B(p)|}{\sqrt{\frac{1}{2}(\sigma_A^2(p) + \sigma_B^2(p))}}$$

- Improvement at low P with TOF









Flavour tag

- c and b jet identification crucial for physics analysis ($H \to c\bar{c}$, $H \to b\bar{b}$)
- Identification using BDTs

Conclusion and outlook

Conclusion:

- iLCSoft: a software stack for future colliders studies
- iLCDirac: the ILC Monte-Carlo mass production software
  - Recent MC production: $\sqrt{s}$ =500 GeV, 1 PB produced
- Excellent ILD detector performance

Outlook

- Software tools evolving towards multi-threading
- Part of iLCSoft tools used as basis for Key4Hep (e.g LCIO)
  - Lots of software development shared
- Reconstruction performance: still place for improvement
  - Detector features not yet fully exploited in reconstruction
  - Fast timing detectors?