The ILD Software Tools and Detector Performance.

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DESY

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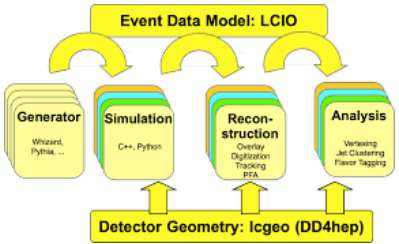
HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

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



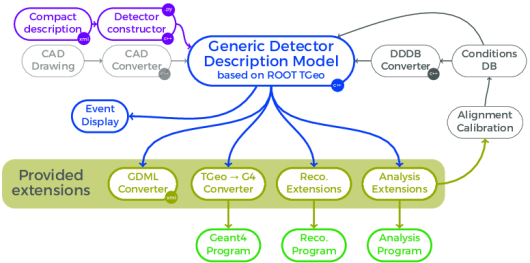
Main components

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

DD4hep: detector geometry package

https://github.com/AIDASoft/DD4hep

- Generic detector description for HEP
- Single complete description source for
  - Simulation
  - Reconstruction
  - Analysis
- **DDG4** for simulation
  - Gateway to Geant4
  - Fully customizable: input / output, Geant4 actions, physics list, etc...
- **DDRec** for reconstruction
  - High level view of detectors: # layers, thicknesses, dimensions, etc...
  - Tracking surfaces, material properties, cellID converter



Philosophy:
single source of geometry, **different interfaces**

The ILD detector description

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

ILD detector(s) described in detail:

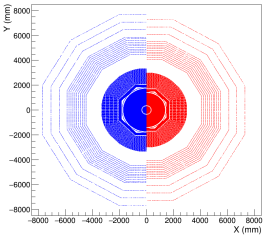
- Materials, extents, sensitive volumes, services, etc...
- ILD-S (small TPC radius) vs. ILD-L (large TPC radius)

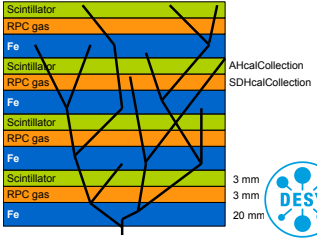
Hybrid simulation with 4 calorimeter options:

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

- 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`

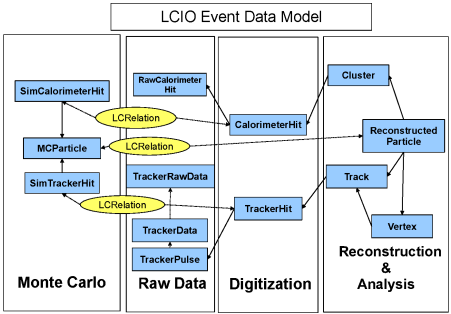




LCIO: the Linear Collider event data model

https://github.com/iLCSoft/LCIO

- Data handling for all steps in HEP workflow:
  - Generator, simulation, reconstruction, analysis
- Standalone IO library:
  - Binary data format (XDR), ZLIB compression
  - Schema evolution (block versioning)
  - Extensible and backward compatible format
  - Endianness agnostic (big / little endian)
  - Recently re-implemented for multi-threading usage
- Very robust: 20 years of usage...



The Marlin framework

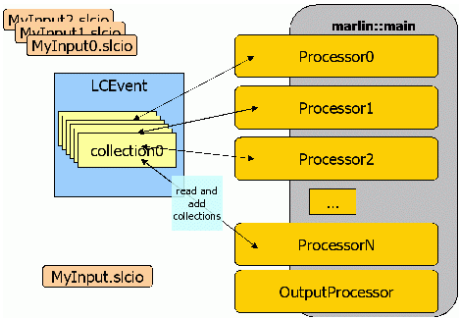
https://github.com/iLCSoft/Marlin

Standard HEP event processing framework

- Based on LCIO event data model
- Reconstruction and analysis
- Handles histogramming and conditions data

The Marlin framework

- Describes a task list (`Processor`) to execute
- Read events and process them through the chain
- Each `Processor` read and/or create new collections in the event
- Standard sequential event processing pipeline in HEP



The Monte Carlo mass production system

The production system

DIRAC 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

Main transformations:

1. GenSplit: split generator files
2. Simulation: runs `ddsim`
3. OverlayBKG: prepare reconstruction for bkg overlay
4. Reconstruction: runs `Marlin`
5. DSTMerge: merge DST files after reconstruction

The Monte Carlo mass production system

Recent data production: dataset and statistics

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

event class	description	events processed
2f	two fermion final states	60.0×10^6
4f	four fermion final states	22.6×10^6
5f	five fermion final states	4.01×10^6
6f	six fermion final states	13.8×10^6
aa_4f	two fermion by $\gamma\gamma$ interaction	1.63×10^6
higgs	higgs process	3.97×10^6
np	new physics process	3.25×10^6
aa_lowpt	$\gamma\gamma \rightarrow$ *hadrons* background	2.50×10^6
seeablepairs	e^+e^--pair background	1.00×10^5 BXs
calibration	single particle, $q\bar{q}$ events	27.71×10^6
6f(WW)	dedicated 6f sample at $E_{cms} = 1$ *TeV*	1.75×10^6

Table: Number of Monte Carlo events produced

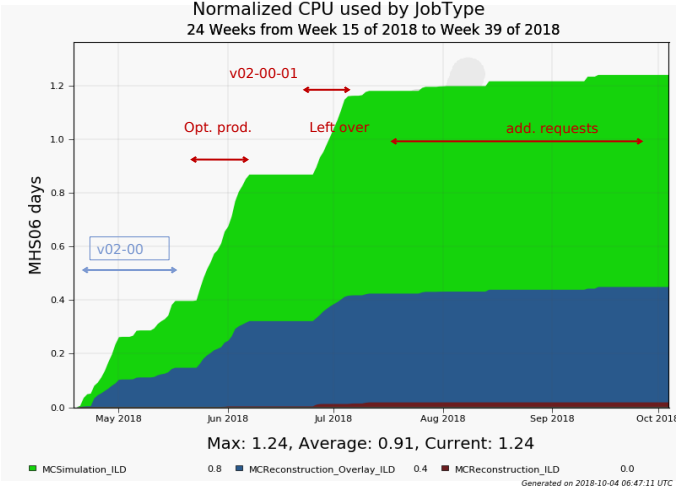
The Monte Carlo mass production system

Recent data production: cummulative CPU

Simulation

Reconstruction

Reconstruction (calib)



The ILD reconstruction chain

https://github.com/iLCSoft/ILDConfig

Background overlay

Digitization

Tracking

Particle Flow

High Level Reco

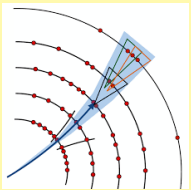
1 BX overlay

~ 1 BKG event / collision

Energy calibration

Inefficiency & noise randomization

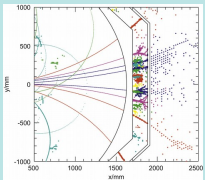
Time integration



TPC : Kalman filter

Vertex : Cellular automaton

Fwd detectors : Triplet seeds + extrapolation



PandoraPFA

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

- Goal for momentum resolution:

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

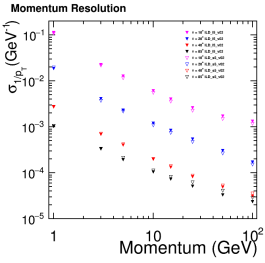
- Tracking efficiency close to 1!

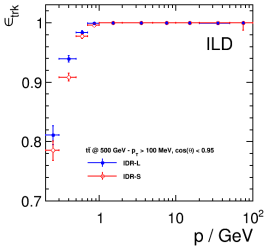
Jet energy resolution

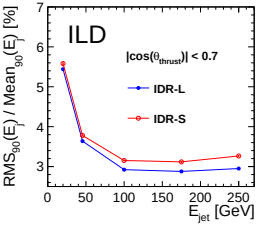
- Jet energy resolution (JER) defined as:

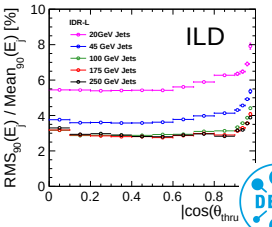
$$\frac{\sigma_{E_{jet}}}{E_{jet}} := \frac{\text{rms}_{90}(E_{jet})}{\text{mean}_{90}(E_{jet})}$$

- JER $\sim 3 - 4\%$
- Getting worse in the forward direction









The ILD detector performance

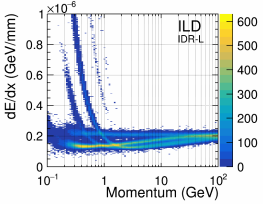
Particle ID and flavour tag

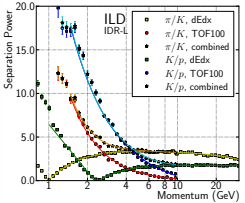
Particle ID

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

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

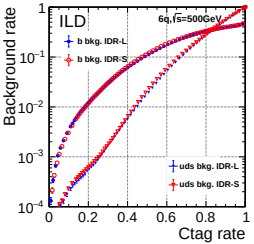
- Improvement at low P with TOF

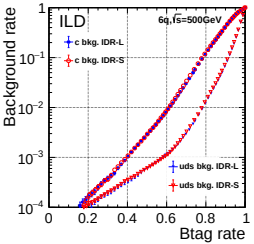




Flavour tag

- 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
  - Realistic full simulation and reconstruction
- iLCDirac: the ILC Monte-Carlo mass production software
- Recent MC production:
  - 500 GeV CMS, 1 PB produced
  - Learnt a lot about massive data production...
- Excellent ILD detector performance

Outlook

- Software tools evolving towards multi-threading
- Reconstruction performance: still place for improvement
  - Timing detectors?