Linear Collider Software and Computing

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On behalf of the CLICdp and ILD collaborations

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

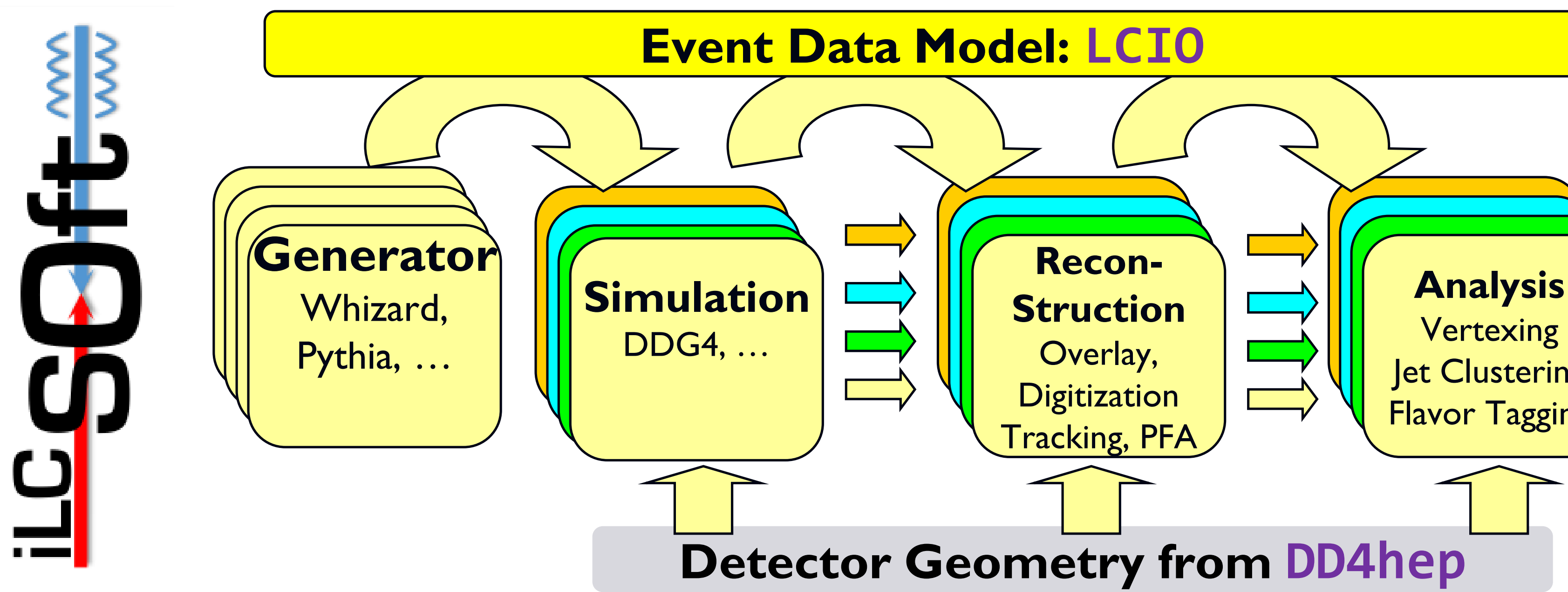
AIDA 2020

Introduction

- **The LC community has a tradition of common software development and tool sharing**
- Software is shared by the detector concepts of **both ILC** and **CLIC** and the **hardware R&D groups, and even projects like FCC, CEPC, …**
  - **Detector design and optimization**
  - **Technology studies**
  - **Physics performance studies**
- **The tools should be generic, flexible, and robust to be used with different detector concepts and their variations**
- **Collaborative SW development,** pooling of manpower and resources towards common goals

Linear Collider Software: iLCSOft

- Event Data Model **LCIO common** to all detector concepts
- Applications typically run via "***processors***" within a modular C++ application framework called **Marlin**
- New **common** Detector Geometry Description and Simulation Framework: **Detector Description 4 HEP (DD4hep)**

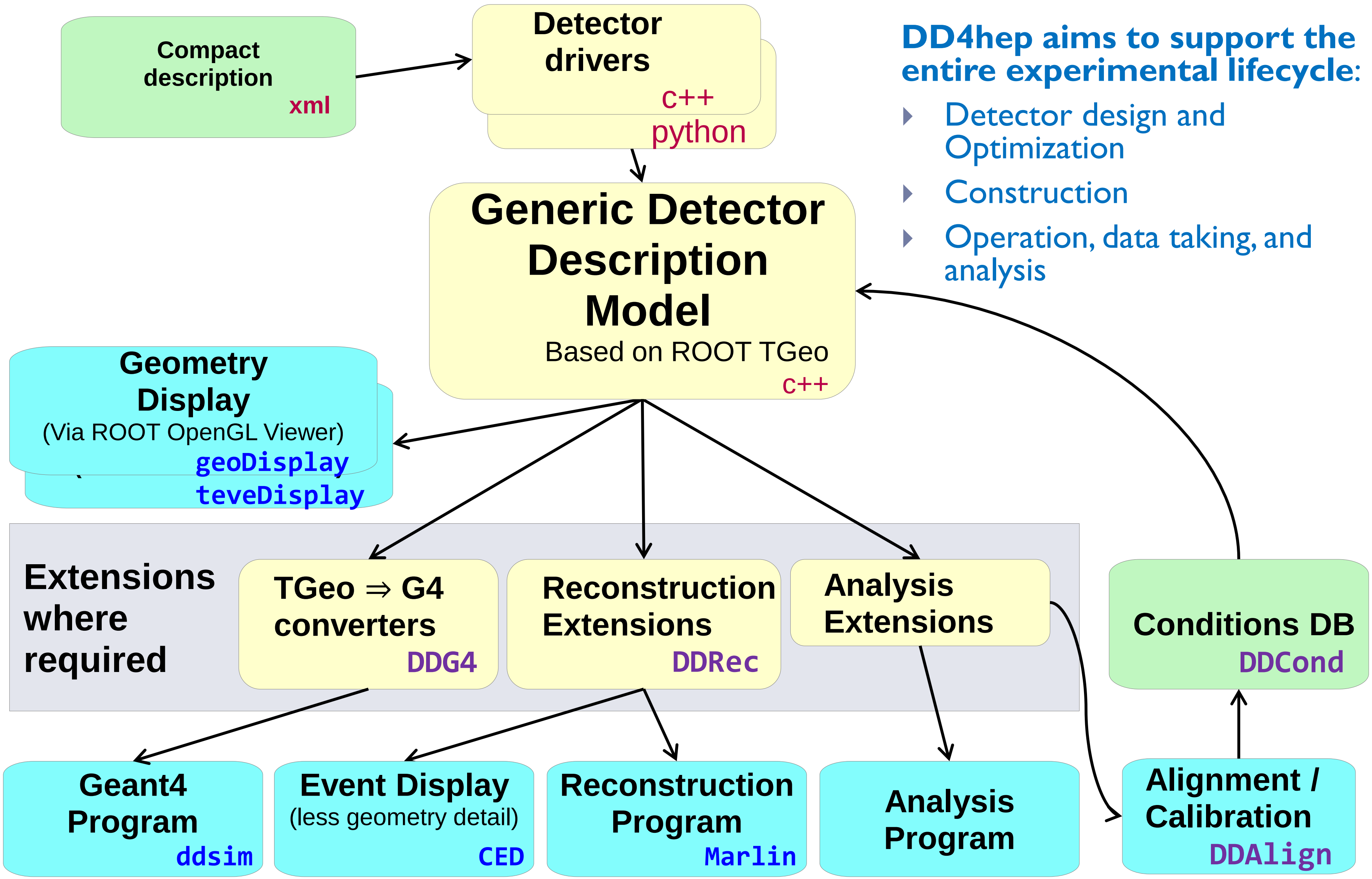


This talk: focus on new developments from ILD and CLICdp

DD4hep – A single source of information

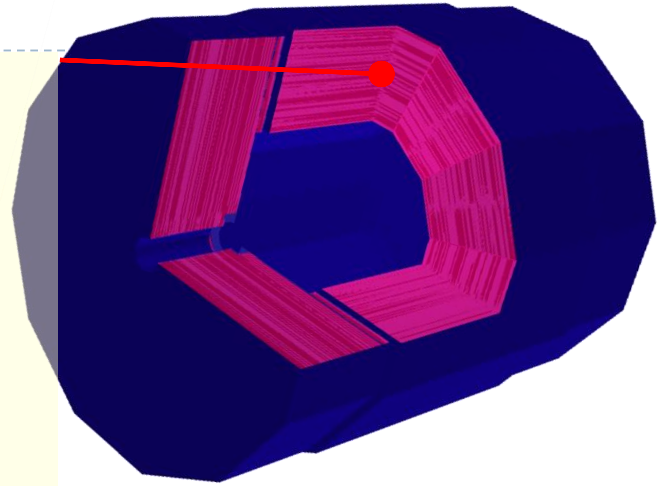
DD4hep aims to support the entire experimental lifecycle:

- Detector design and Optimization
- Construction
- Operation, data taking, and analysis



Detector drivers in DD4hep

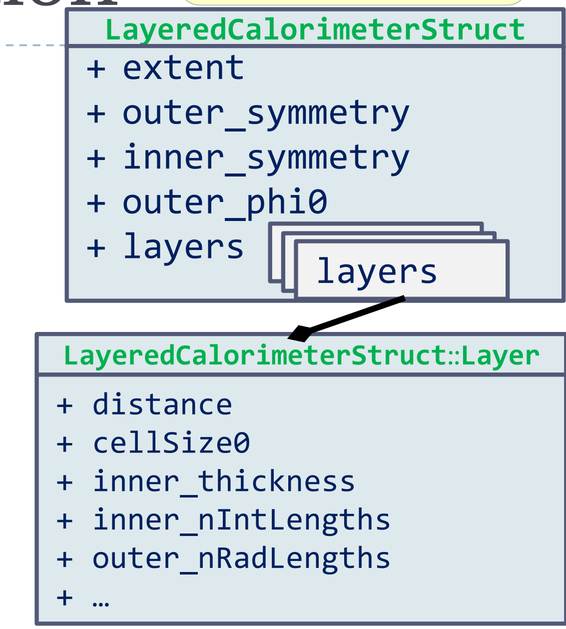
```xml
<detector id="DetID_HCAL_Barrel" name="HCalBarrel" type="HCalBarrel_o1_v01"
readout="HCalBarrelHits" vis="HCALVis" >
 <dimensions nsides="HCal_symm" rmin="HCal_Rin" z="HCal_Z" />
 <layer repeat="(int) HCal_layers" vis="HCalLayerVis" >
  <slice material="Steel235" thickness="0.5*mm" vis="AbsVis"/>
  <slice material="Steel235" thickness="19*mm" vis="AbsVis"/>
  <slice material="Polysterene" thickness="3*mm" sensitive="yes"/>
  <slice material="PCB" thickness="0.7*mm"/>
  <slice material="Steel235" thickness="0.5*mm" vis="AbsVis"/>
  <slice material="Air" thickness="2.7*mm"/>
  </layer>
</detector>
```



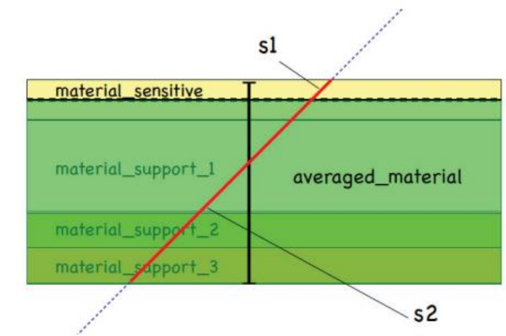
- Generic driver palette available: **Scalable and flexible detector drivers**
- You can adapt/write your own
  - User decides balance between detail and flexibility
- Visualization, Radii, Layer/module composition in compact xml
  - Example above
- Volume building in C++ driver
  - See backup
- **Once you have the detector geometry, you can *extend* it, i.e. add more information using the *Reconstruction Extensions*** (next slide)

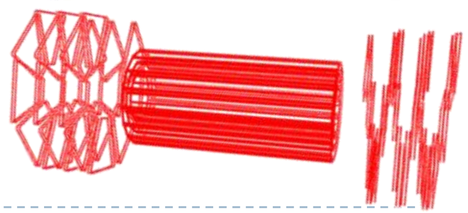
DDRec: Interface to Reconstruction

HCalBarrel



- The user can ***attach*** any object that could help during reconstruction to a **DetElement**
  - e.g. HCal barrel, ECal endcap, Vertex det., …
- The subpackage **DDRec** currently offers two main options:
  - **Simple data structures** that get filled by the detector constructor at creation time
    - Detector layout, symmetry, extent, ..
    - # layers, technology, material properties, …
  - **Surfaces:** special type of extension foreseen mainly for tracking
    - Measurement directions
    - Material effects automatically averaged from the detailed model





DDG4: Gateway to Geant4

- DD4hep performs **in-memory translation of geometry** from TGeo to Geant4
- Plugin Mechanism
  - Sensitive detectors, segmentations and configurable actions, …
- Configuration mechanism (via Python, XML, ROOT)
  - Physics lists, regions, limits, filters, fields, sensitive detectors, …
- MC Truth history and linking
- Support for different input/output file formats

- Users can write own simulation applications with DDG4

- **We already provide a fully working and flexible simulation program called** ddsim (next slide)

ddsim application

- Python executable with many configuration options
  - Configure most useful and common user options in the command line
    - Even supports tab-completion of arguments and their options!
  - Can also configure with a "steering file"

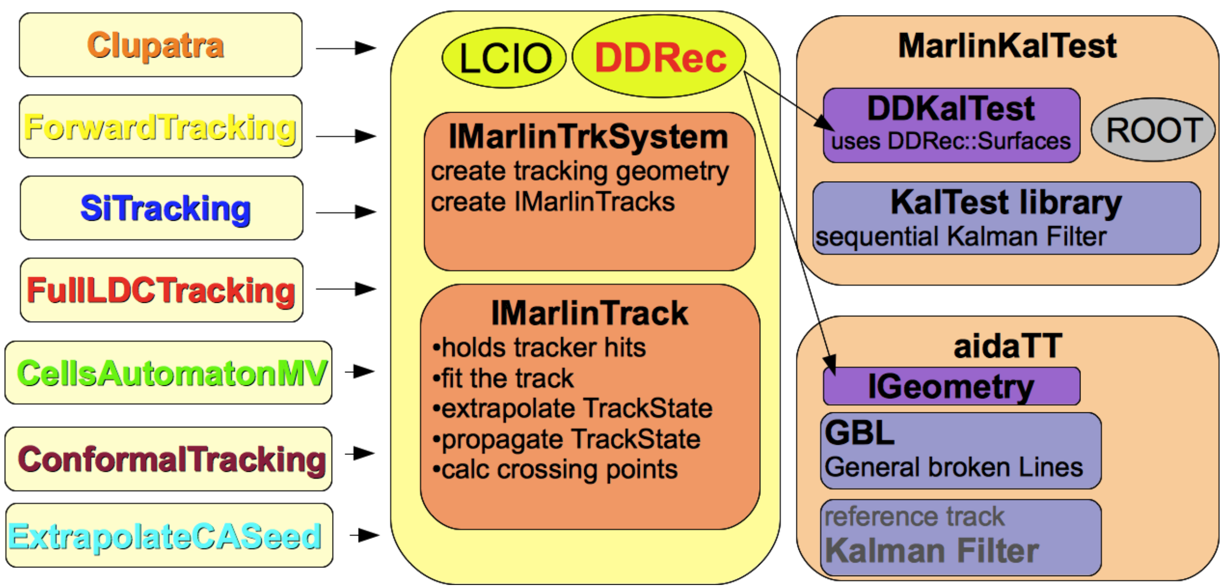
```
ddsim –h
usage: Running DD4hep Simulations: [-h] [--steeringFile STEERINGFILE]
[--compactFile COMPACTFILE] [--runType {batch,vis,run,shell}]
[--inputFiles INPUTFILES [INPUTFILES ...]] [--outputFile OUTPUTFILE] [-v PRINTLEVEL]
[--numberOfEvents NUMBEROFEVENTS] [--skipNEvents SKIPNEVENTS]
[--physicsList PHYSICSLIST] [--crossingAngleBoost CROSSINGANGLEBOOST]
[--vertexSigma VERTEXSIGMA VERTEXSIGMA VERTEXSIGMA VERTEXSIGMA]
[--vertexOffset VERTEXOFFSET VERTEXOFFSET VERTEXOFFSET VERTEXOFFSET]
[--macroFile MACROFILE] [--enableGun]
[--enableDetailedShowerMode] …
```

And much more… Continuously implementing more options!

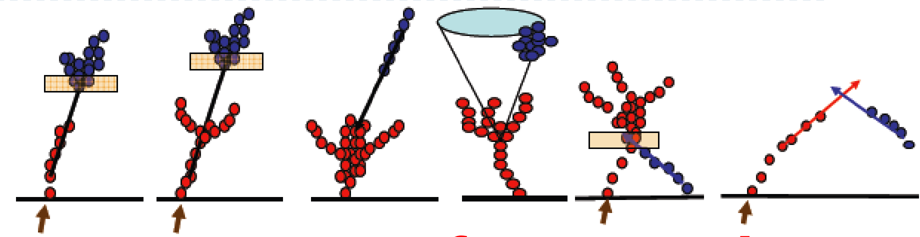
- **Mature**, validation in parallel to DDG4 in advanced stage
- To be used by ILD and CLICdp in the next large scale simulation productions

Tracking tools

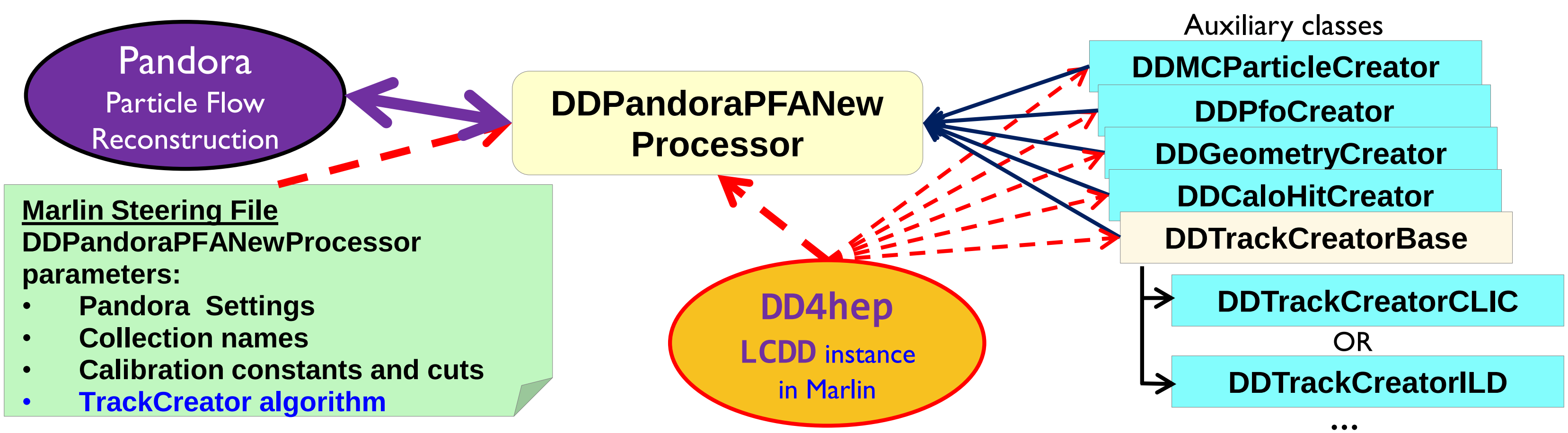
- A collection of pattern recognition tools and algorithms is available in iLCSoft, **shared by the various detector concepts**
  - Even with different technologies: Si+TPC (ILD) Vs Full-Si (CLICdp and SiD)
- `MarlinTrk` provides a common interface to pattern recognition
  - Interfaced with **DD4hep**
  - Could mix-and-match different pattern recognition algorithms with different track fitters
- **A generic Tracking Package is available to everybody out of the box**



Particle Flow Reconstruction

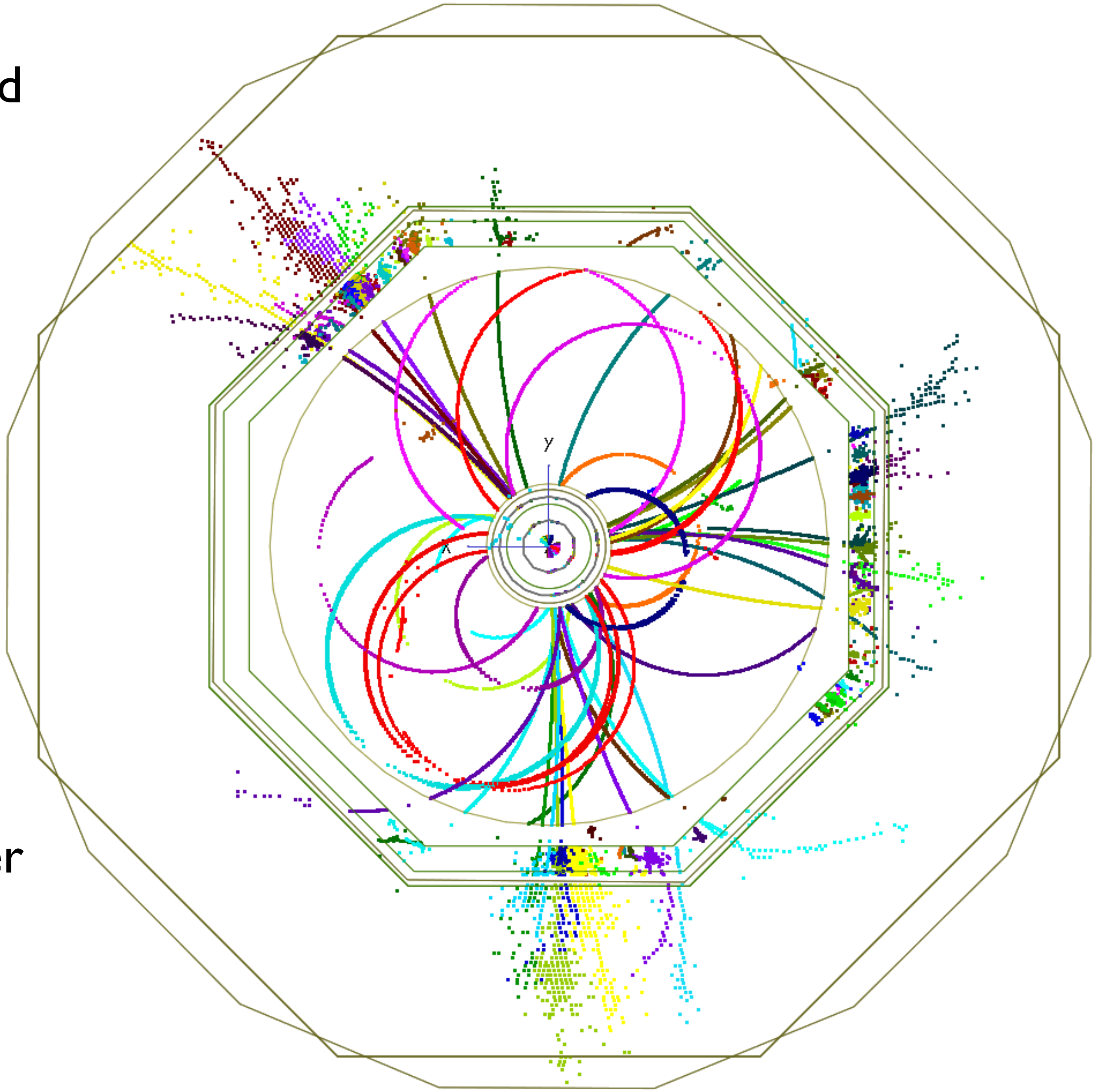


- Reconstruction of the individual visible final state particles
- **PandoraPFA**: Not tied to particular **geometry** or **framework**
  - Customers: CLICdp, ILD, SiD, Calice, LAr-TPC, …
- Run through **DDMarlinPandora** with **DD4hep** as single source of geometry information
  - No material or other geometry info in processor parameters
  - Preserve independence from particular detector geometry



Event simulated, reconstructed and visualized fully with DD4hep

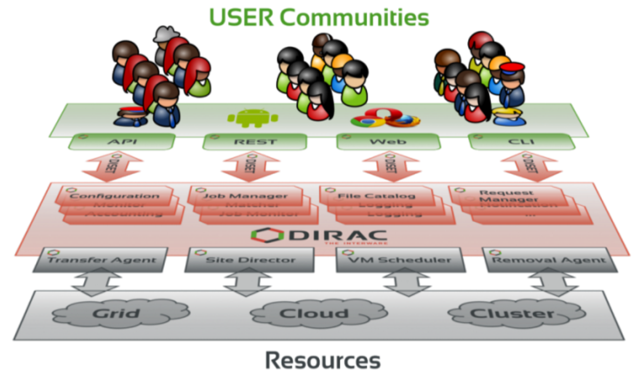
- **ILD_o1_v05** model implemented in **DD4hep**
- $Z' \to jj$ event at $\sqrt{s} = 500\ \mathrm{GeV}$ simulated in **DDSim**
- Tracks reconstructed using **DDSurfaces**
- PFOs from **DDMarlinPandora** using the **DDRec** data structures
- Event display from the **CED** viewer interfaced with **DD4hep**
  - Also uses **DDRec** and **DDSurfaces**



LC Computing with ILCDIRAC

iLCDirac is based on the **DIRAC** interware originally developed for LHCb

- **D**irac (**D**istributed **I**nfrastructure with **R**emote **A**gent **C**ontrol): High level interface between users and distributed resources
- **iLCDirac**: Additional functionality to provide simple interface for the users to the LC Software
- Central system for large scale productions

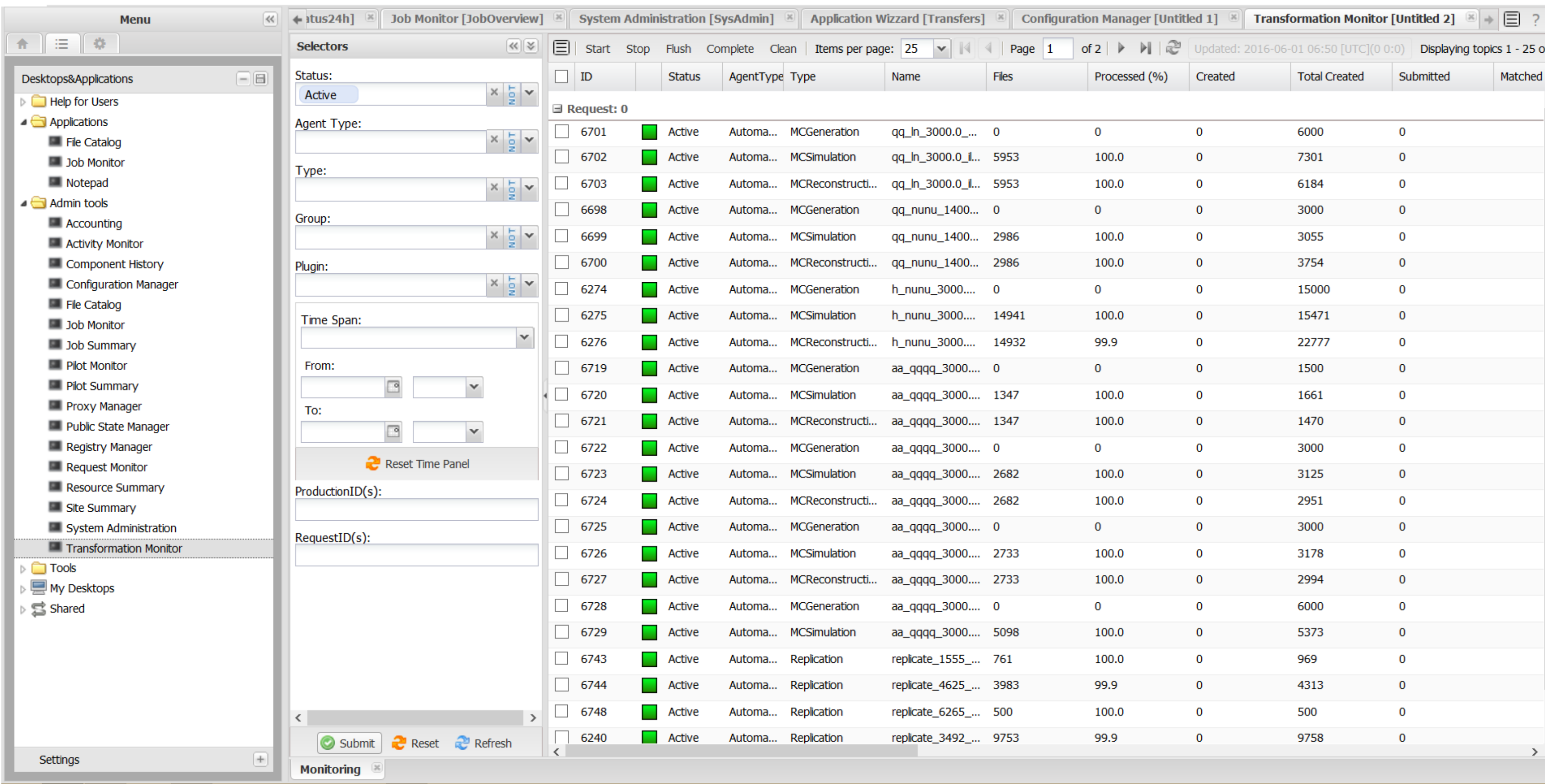



```
from ILCDIRAC ... Applications
import DDSim
dd = DDSim()
dd.setVersion("ILCSoft-01-18-00")
dd.setDetectorModel("CLIC_o2_v03")
dd.setInputFile("LFN:/ilc/prod/clic/500gev/Z_uds/gen/0/00.stdhep")
dd.setNumberOfEvents(30)
```

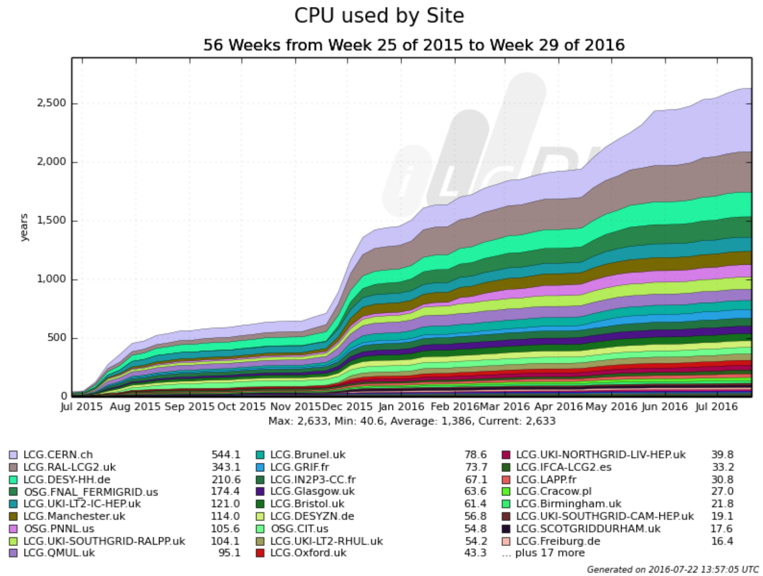
Full Generation, Simulation, Reconstruction and Analysis chain from iLCSoft available on iLCDirac

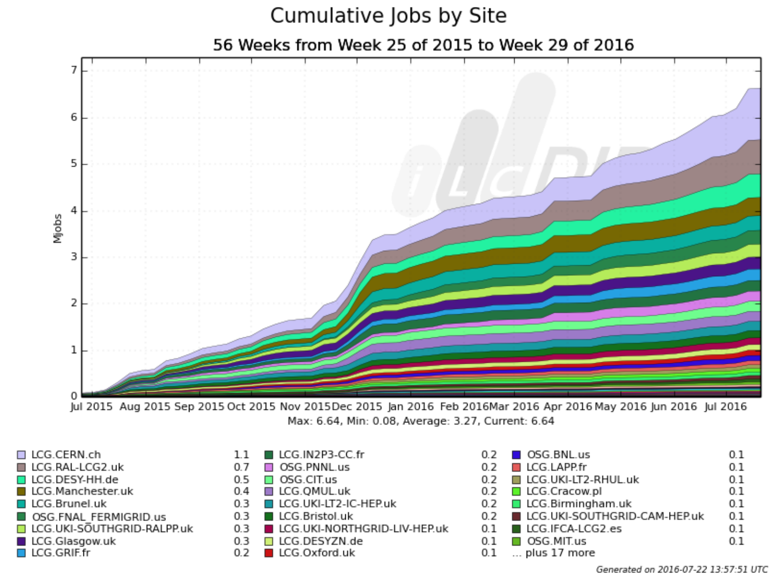
DIRAC Web interface

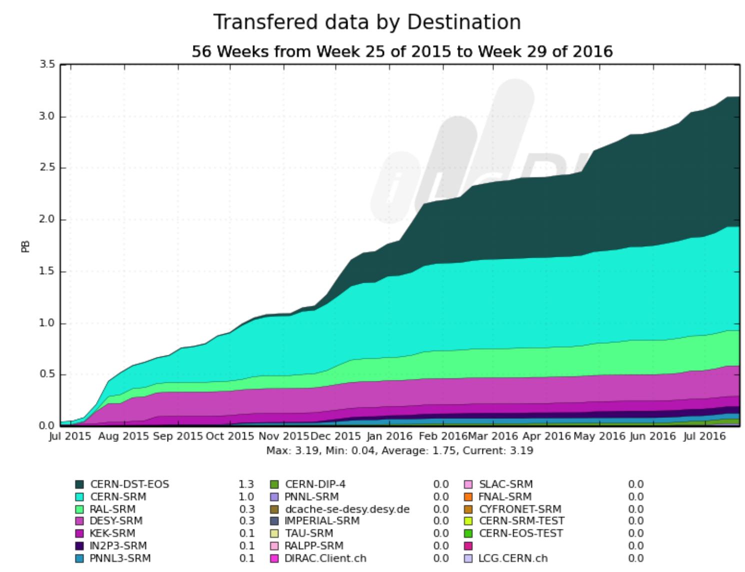
- Nice clean interface for configuration and management of both large scale production and user jobs



Utilization over the last year







- Using some dedicated and many opportunistic resources from LCG & OSG
- 4 Million jobs, 2500 CPU years
  - Peak of about 15 to 20 thousand jobs
- Created and transferred almost 2 PB
- Mainly simulation and reconstruction for detector optimization and physics benchmark studies

Summary

- Effort to have as much as possible common software in the Linear Collider community

- `iLCSoft` offers a collection of flexible tools for **not just the LC community**. It can be used out of the box to:
  - Develop and optimize detector designs and simulation models
  - Develop and test reconstruction algorithms and analysis tools
  - Run the full generation, simulation, and reconstruction chain

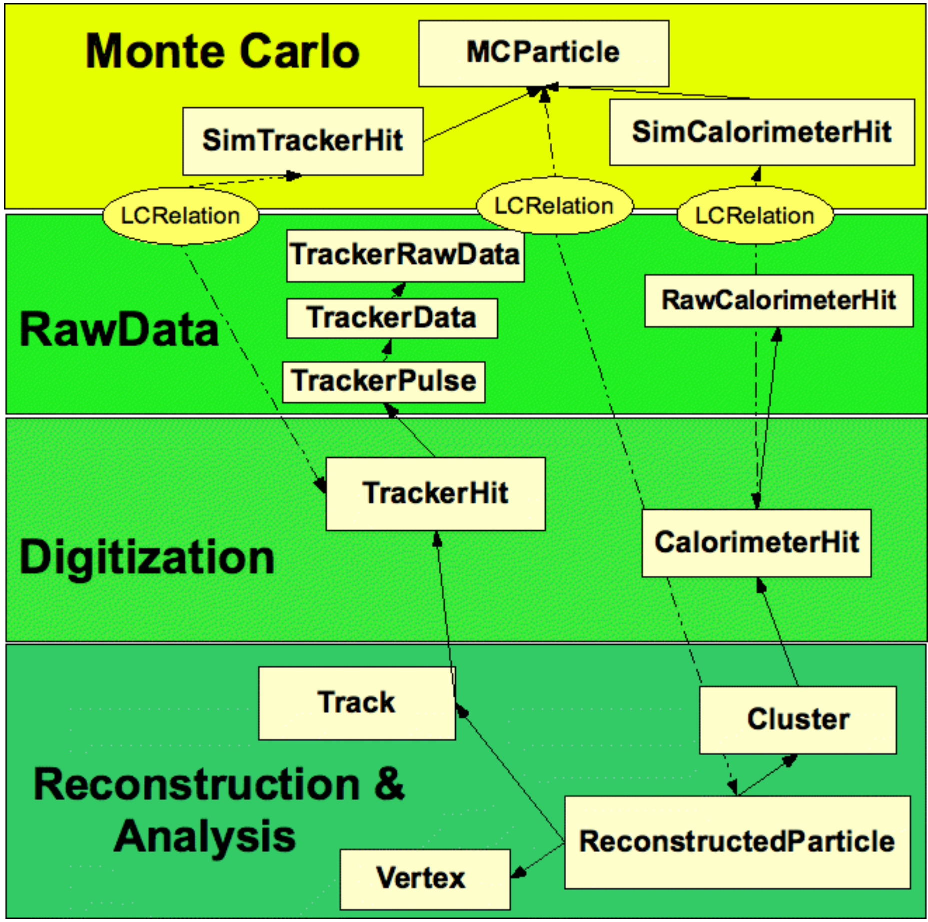
- Generic software tools made possible due to common EDM (`lcio`) and geometry support (`DD4hep/DDRec/DDG4`)

- `iLCDirac` provides a unified interface to the grid resources used by the LC community

BACKUP SLIDES

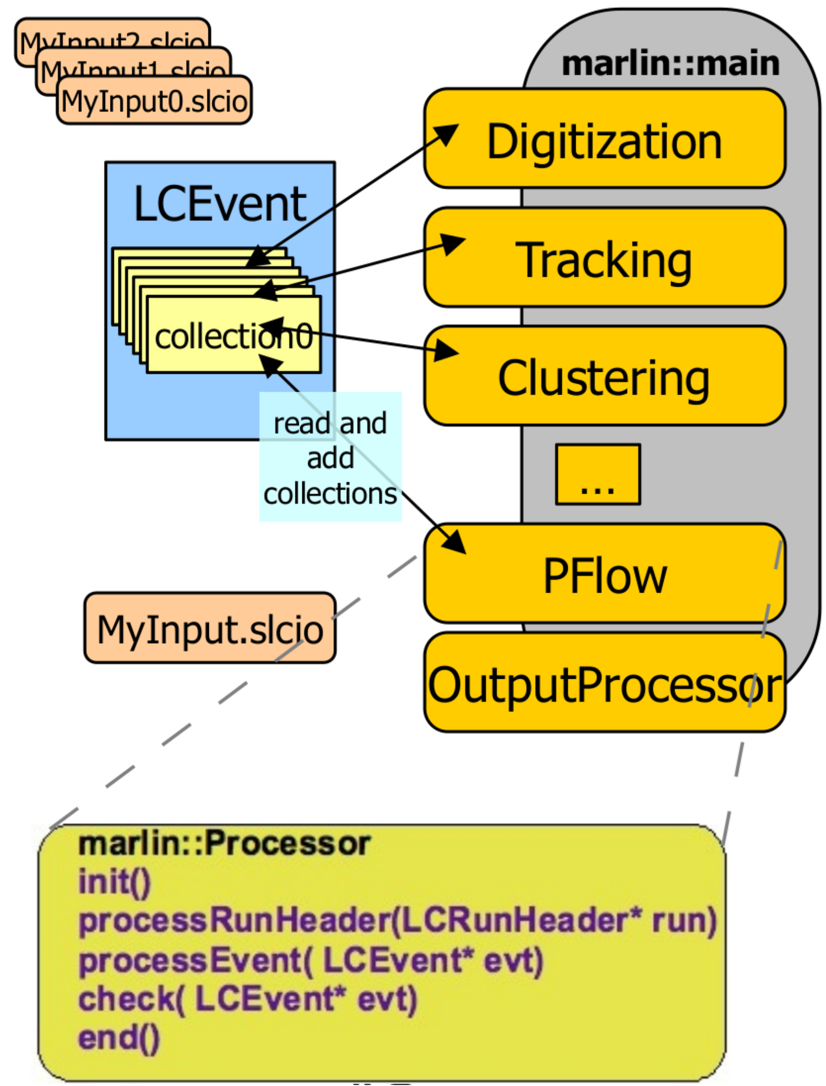
LCIO – Common Event Data Model

- Common event data model (EDM) and persistency for linear collider community
  - Joint DESY and SLAC (and LLR) project - first presented @ CHEP 2003
- **Used by ILD, SiD, CLICdp and test beams for more than 10 years**
- **Common EDM proven to be crucial for collaborative SW development across detector concepts**



Marlin

- **Modular Analysis & Reconstruction for the LINear collider**
- **modular C++ application framework** for the analysis and
- reconstruction of LC data
- `LCIO` as transient data model
  - event data bus/white board model
- `xml` steering files:
  - fully configure application
  - order of modules/processors
  - parameters global + processor
- self documenting
  - parameters registered in user code
- consistency check of input/output collection types
- **Plug & Play** of modules

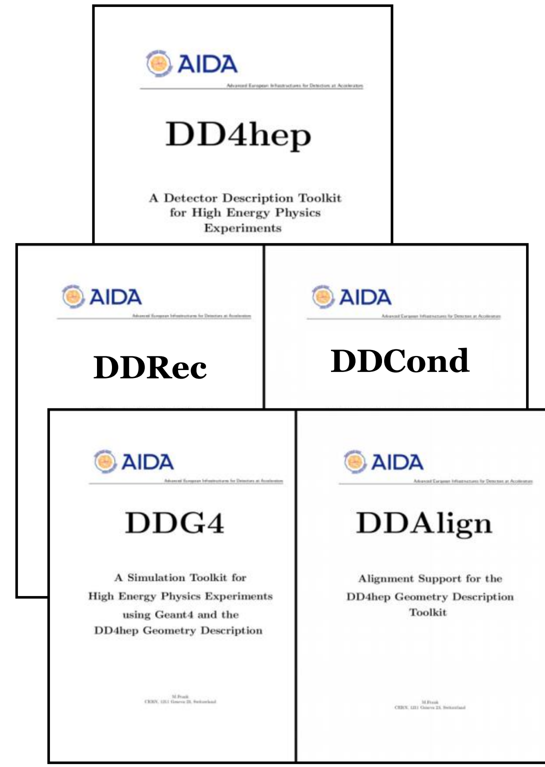


DD4hep motivation and goals

- Complete detector description
  - Includes geometry, materials, visualization, readout, alignment, calibration, etc.
- Support full experiment life cycle
  - Detector concept development, detector optimization, construction, operation
  - Easy transition from one phase to the next
- Consistent description, single source of information
  - Use in simulation, reconstruction, analysis, etc.
- Ease of use
- Few places to enter information
- Minimal dependencies

DD4hep components

- **DD4hep**: basics/core
  - Basically stable
- **DDG4**: Simulation using Geant4
  - Validation ongoing
- **DDRec**: Reconstruction support
  - **Driven by LC Community**
  - Covered in this talk
- **DDAlign, DDCond** : Alignment and Conditions support
  - Being developed



- **http://aidasoft.web.cern.ch/DD4hep**

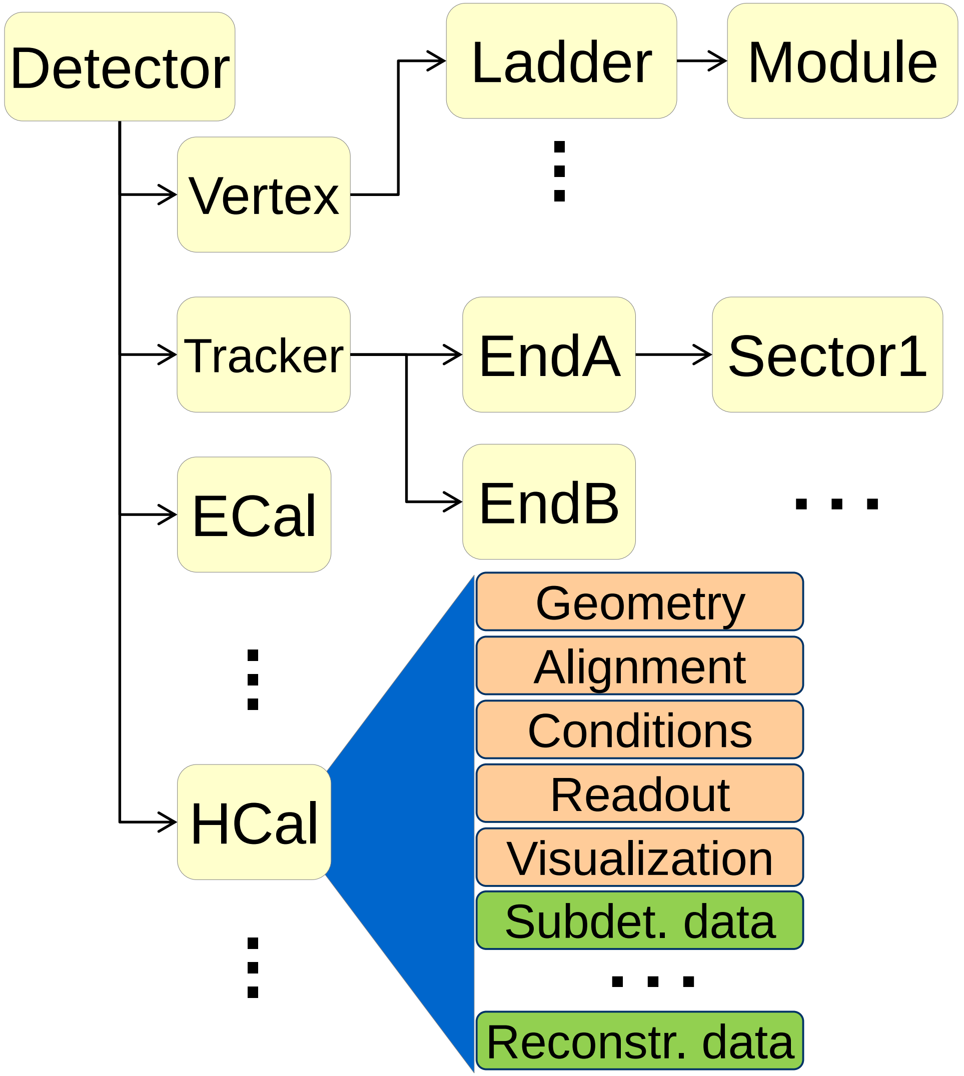
Current DD4hep Toolkit Users

		DD4hep	DDG4
ILD	F. Gaede et al., ported complete model ILD_o1_v05 from previous simulation framework (Mokka)	✓	✓
CLICdp	New detector model being implemented after CDR, geometry under optimization	✓	✓
SiD	Recently decided to move to DD4hep	✓	✓
CALICE	Started	✓	✓
FCC-eh	P. Kostka et al.	✓	✓
FCC-hh	A. Salzburger et al.	✓	
FCC-ee	Interest expressed, already used in studies	✓	
CEPC	Investigations ongoing	✓	
LHCb	Investigations started for LHCb upgrade	✓	

Feedback from users is invaluable and helps shaping DD4hep!

Describing a detector in DD4hep

- Description of a tree-like hierarchy of **“detector elements”**
  - Subdetectors or parts of subdetectors
- Detector Element describes
  - Geometry
  - Environmental conditions
  - Properties required to process event data
  - Extensions (optionally): experiment, sub-detector or activity specific data, measurement surfaces, …



M. Frank

Geometry Implementation

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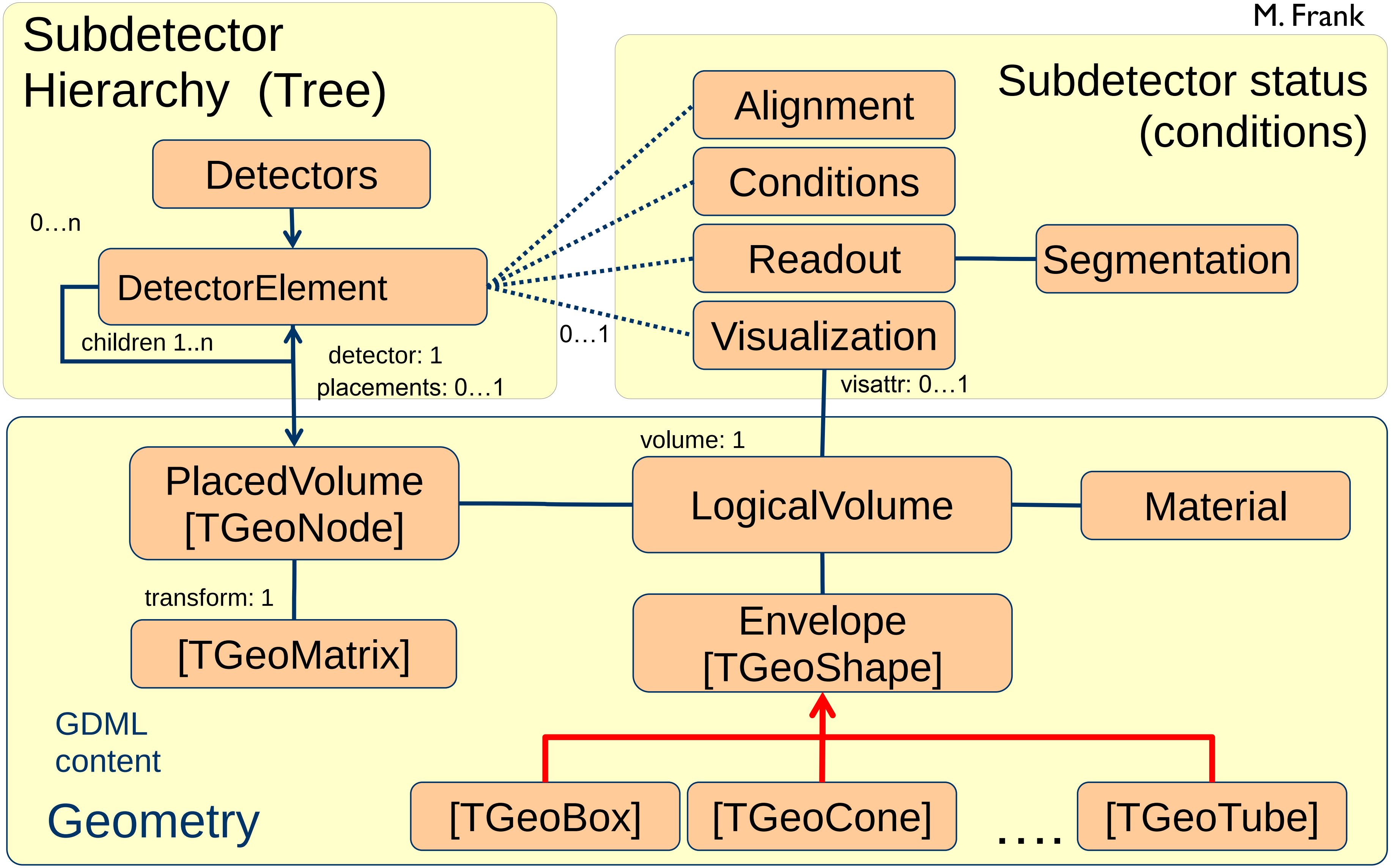
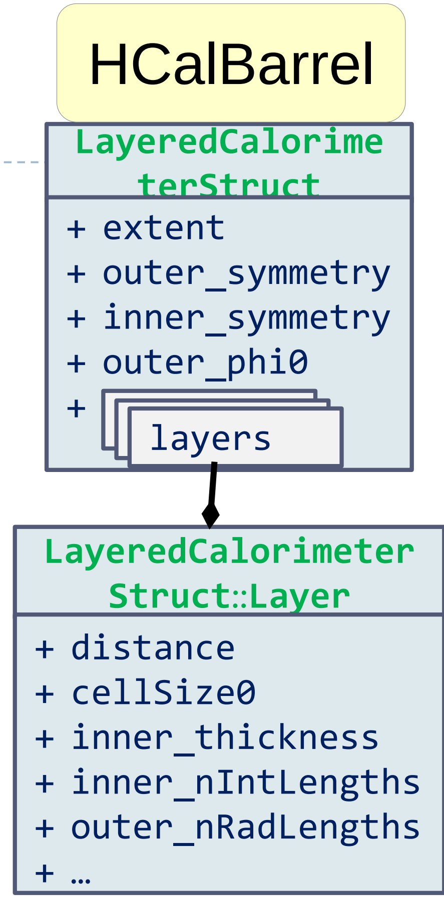


LayeredCalorimeterStruct



e.g: attach a `LayeredCalorimeterStruct` to the **DetElement** for HCalBarrel

- Developed with needs of **Pandora** in mind
- Fill all the dimension, symmetry and other info (almost definitely known to the driver)
- Fill a vector of substructures with info on the layers
  - Sum/average material properties from each slice:

```
nRadLengths += slice_thickness/(2*slice_material.radLength());
nIntLengths += slic_thickness/(2*slice_material.intLength());
thickness_sum += slice_thickness/2;
```

- After you are done, add the extension to the detector:

```
sdet.addExtension<DDRec::LayeredCalorimeterData>(caloData);
```

More DDRec Structures

- More *simple* data structures available in `DD4hep/DDRec/DetectorData.h`:
  - `FixedPadSizeTPCData`: Cylindrical TPC with fixed-size pads
  - `ZPlanarData`: Si tracker planes parallel to z
  - `ZDiskPetalsData`: Si tracker disks
  - `ConicalSupport`: e.g. beampipe

- Please consult documentation for conventions on the relevant quantities

Assuming the structures are filled according to the conventions, `DDMarlinPandora` will transparently (and correctly) convert the geometry and initialize `Pandora`

```
for (xml_coll_t c(x_det, _U(layer)); c; ++c) {
  xml_comp_t x_layer = c;
  int repeat = x_layer.repeat();            // Get number of times to repeat this layer.
  const Layer* lay = layering.layer(layer_num - 1); // Get the layer from the layering engine.
  // Loop over repeats for this layer.
  for (int j = 0; j < repeat; j++) {
    string layer_name = _toString(layer_num, "layer%d");
    double layer_thickness = lay->thickness();
    DetElement layer(stave, layer_name, layer_num);
    DDRec::LayeredCalorimeterData::Layer caloLayer ;
     // Layer position in Z within the stave.
    layer_pos_z += layer_thickness / 2;
    // Layer box & volume
    Volume layer_vol(layer_name, Box(layer_dim_x, detZ / 2, layer_thickness / 2), air);

    // Create the slices (sublayers) within the layer.
    double slice_pos_z = -(layer_thickness / 2);
    int slice_number = 1;
    double totalAbsorberThickness=0.;

    for (xml_coll_t k(x_layer, _U(slice)); k; ++k) {
      xml_comp_t x_slice = k;
      string slice_name = _toString(slice_number, "slice%d");
      double slice_thickness = x_slice.thickness();
      Material slice_material = lcdd.material(x_slice.materialStr());
      DetElement slice(layer, slice_name, slice_number);

      slice_pos_z += slice_thickness / 2;
      // Slice volume & box
      Volume slice_vol(slice_name, Box(layer_dim_x, detZ / 2, slice_thickness / 2), slice_material);
       if (x_slice.isSensitive()) {
        sens.setType("calorimeter");
        slice_vol.setSensitiveDetector(sens);
      }
      // Set region, limitset, and vis.
      slice_vol.setAttributes(lcdd, x_slice.regionStr(), x_slice.limitsStr(), x_slice.visStr());
      // slice PlacedVolume
      PlacedVolume slice_phv = layer_vol.placeVolume(slice_vol, Position(0, 0, slice_pos_z));

      slice.setPlacement(slice_phv);
      // Increment Z position for next slice.
      slice_pos_z += slice_thickness / 2;
      // Increment slice number.
      ++slice_number;
    }
```

Example HCal Barrel Driver

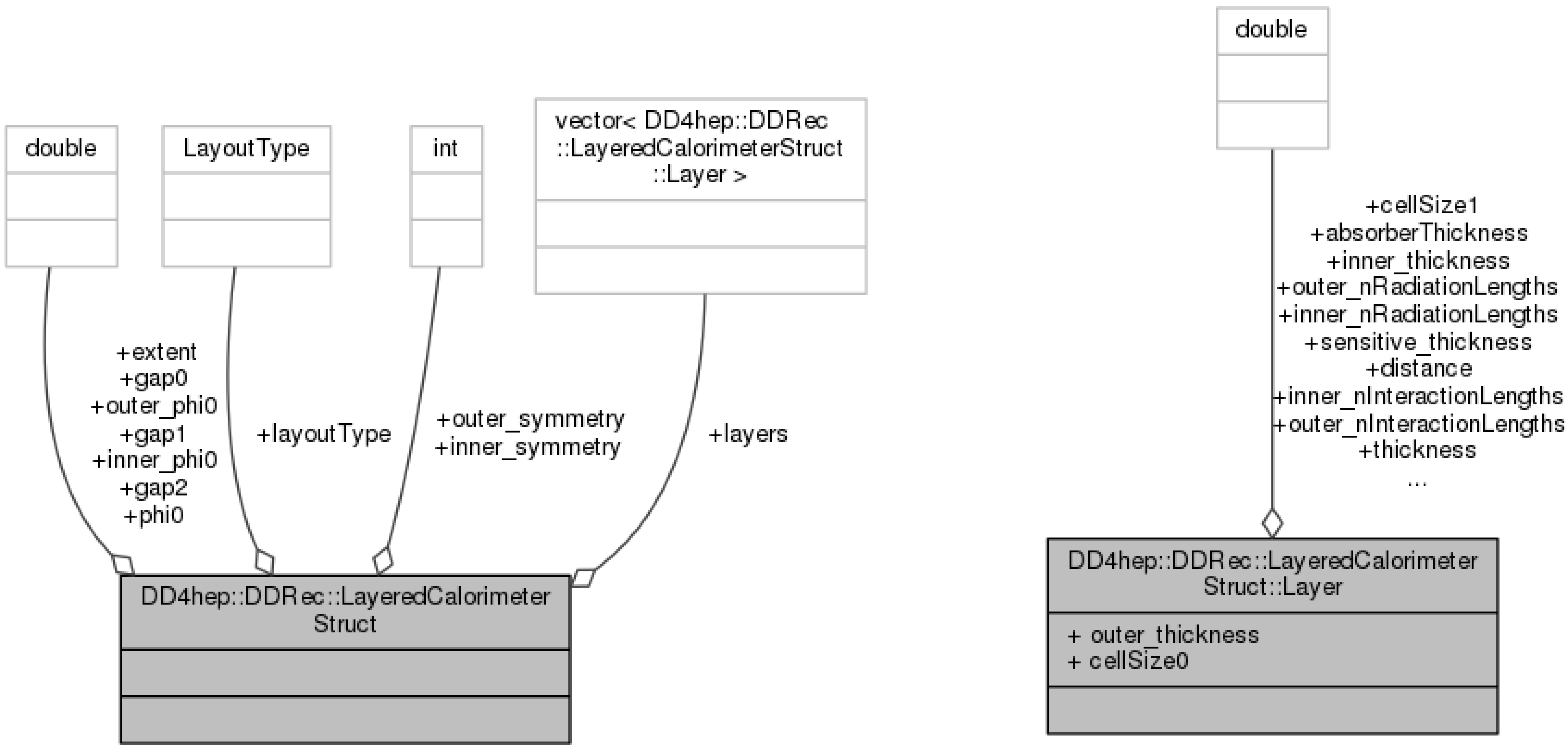
- Always within a function called

```
static Ref_t
create_detector(LCDD&
lcdd, xml_h e,
SensitiveDetector sens)
{

...

return sdet;

}
```

- Macro to declare detector constructor at the end:

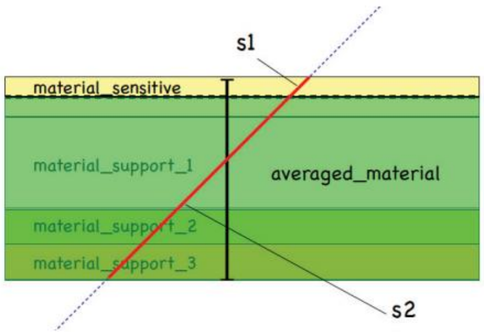
```
DECLARE_DETELEMENT(HCalBarrel_o1_v01,
create_detector)
```

LayeredCalorimeterStruct



Measurement surfaces

- Special type of extension, used primarily in **tracking**
- Attached to `DetElements` and `Volumes` (defining their boundaries)
  - Can be added to drivers via **plugins** without modifying detector constructor
- They hold **u**,**v**,**n**ormal and **o**rigin vectors and **inner/outer thicknesses**
- Material properties **averaged automatically**
- Could also be used for **fast simulation**



- Outlines of surfaces drawn in `teveDisplay` for CLICdp Vertex Barrel and Spiral Endcaps

DDG4: Gateway to Geant4

- DD4hep facilitates **in-memory translation of geometry** from TGeo to Geant4
- Plugin Mechanism:
  - Sensitive detectors, segmentations and configurable actions, …
- **All shared with Reconstruction!**
- Configuration mechanism (via python, XML, CINT)
  - Physics lists, regions, limits, fields, …
- For example, configure and launch the simulation using python (next slide)

DDG4 configuration

- DDG4 is highly modular
- Easy to configure, especially if one uses the python dictionaries
- Configure actions, filters, sequences, cuts, …

```
...
part = DDG4.GeneratorAction(kernel,
                            "Geant4ParticleHandler/ParticleHandler")
kernel.generatorAction().adopt(part)
part.SaveProcesses = ['Decay']
part.MinimalKineticEnergy = 1*MeV
part.KeepAllParticles = False
...
user = DDG4.GeneratorAction(kernel,
              "Geant4TCUserParticleHandler/UserParticleHandler")
user.TrackingVolume_Zmax = DDG4.tracker_region_zmax
user.TrackingVolume_Rmax = DDG4.tracker_region_rmax
...
```

Where can I find all this?

- **DD4hep** comes complete with example drivers and compact files in iLCSoft releases
  - Under `DD4hep/<version>/DDDetectors`
  - More examples and use cases under `DD4hepExamples`
- For the Linear Collider Community we have another package: **LCGeo**
  - We collect here the concrete implementations of Detector Models (currently for CLICdp and ILD)
    - All their versions, additional specialized subdetector drivers if needed
  - We also have use case examples, configuration files and tools **including `ddsim`, a tool to run DDG4 simulation**