DETECTOR SIMULATIONS WITH DD4hep

WP14 Face to Face Meeting

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On behalf of the DD4hep developers

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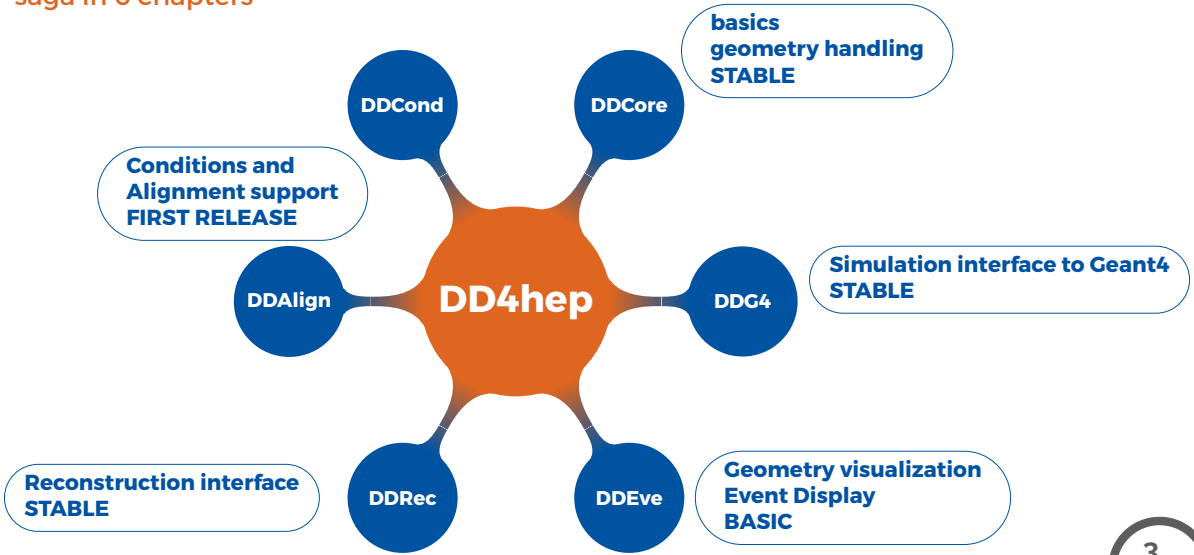
AIDA 2020

Overview

- Complete Detector Description
  - Providing geometry, materials, visualization, readout, alignment, calibration…
- Supports full experiment life cycle
  - Detector concept development, detector optimization, construction, operation
  - Facile transition from one stage to the next
- Single source of information → consistent description
  - Use in simulation, reconstruction, analysis, etc.
- Ease of Use
- Few places for entering information
- Minimal dependencies
- AIDA-2020 and HSF member project

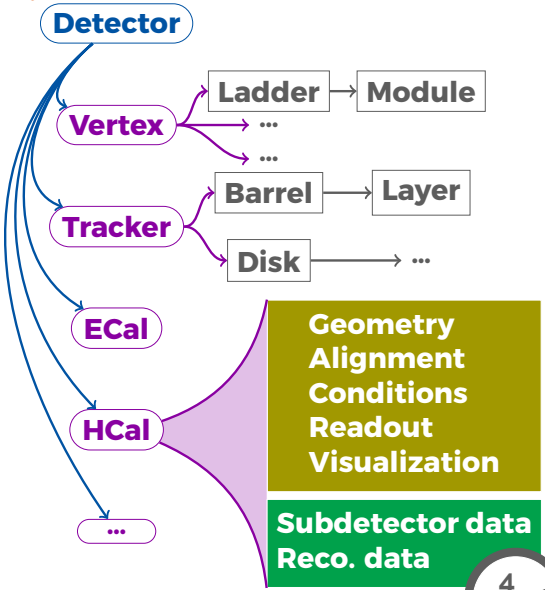
Structure and packages

saga in 6 chapters

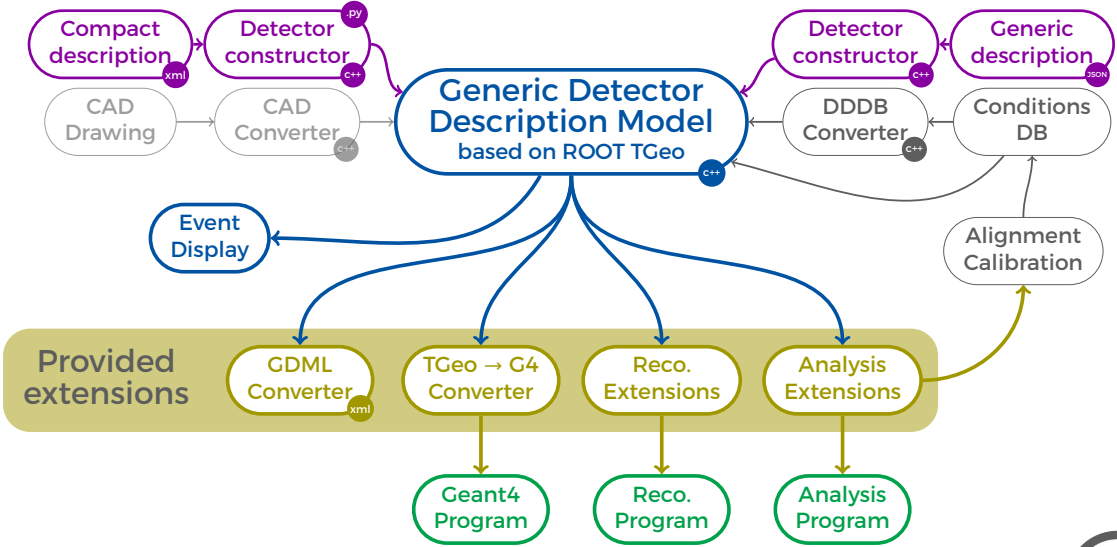


What is Detector description?

- Description of a tree-like hierarchy of 'detector elements'
  - Sub-detectors 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...



The Big Picture



The Generic Detector Palette

- Generic driver available → scalable and flexible
- Parameters are provided in compact XML files, e.g.

```
<detector id="15" name="HCal" type="GenericCalBarrel_o1_v01" readout="HCalCollection">
  <envelope vis="HCALVis">
    <shape type="PolyhedraRegular" numsides="HCal_sym" rmin="HCal_rmin" rmax="HCal_rmax" dz="HCal_dz" material="Air"/>
    <rotation x="0*deg" y="0*deg" z="90*deg-180*deg/HCal_symmetry"/>
  </envelope>
  <dimensions numsides="HCal_sym" rmin="HCal_rmin" z="HCal_dz*2"/>
  <layer repeat="(int) HCal_layers" vis="HCalLayerVis">
    <slice material="Steel235"    thickness="0.5*mm" vis="HCalAbsorberVis" radiator="yes"/>
    <slice material="Steel235"    thickness="19*mm"  vis="HCalAbsorberVis" radiator="yes"/>
    <slice material="Polystyrene" thickness="3*mm"   sensitive="yes"  limits="cal_limits"/>
    <slice material="Copper"      thickness="0.1*mm" vis="HCalCopperVis"/>
    <slice material="PCB"         thickness="0.7*mm" vis="HCalPCBVis"/>
    <slice material="Steel235"    thickness="0.5*mm" vis="HCalAbsorberVis" radiator="yes"/>
    <slice material="Air"         thickness="2.7*mm" vis="InvisibleNoDaughters"/>
  </layer>
</detector>
```

- You can scale, change layers, radii and compositions…
- Propagate visualization attributes to Display

Your Detector Palette

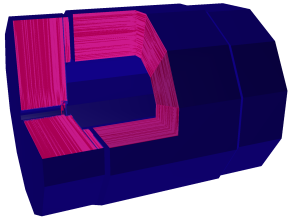
```
static Ref_t create_detector(LCDD& lcdd,
       xml_h e, SensitiveDetector sens) {

  xml_det_t x_det = e;
  Layering layering(x_det);
  xml_comp_t staves = x_det.staves();
  xml_dim_t dim = x_det.dimensions();
  DetElement sdet(det_name, x_det.id());
  Volume motherVol = lcdd.pickMotherVolume(sdet);

  PolyhedraRegular polyhedra(numSides, rmin, rmax, detZ);
  Volume envelopeVol(det_name, polyhedra, air);

  for (xml_coll_t c(x_det, _U(layer)); c; ++c) {
    xml_comp_t x_layer = c;
    int n_repeat = x_layer.repeat();
    const Layer* lay = layering.layer(layer_num - 1);
    for (int j = 0; j < n_repeat; j++) {
      string layer_name = _toString(layer_num, "layer%d");
      double layer_thickness = lay->thickness();
      DetElement layer(stave, layer_name, layer_num);
```

- Users can easily write their own detector drivers, if needed
- Detector geometry extendable with additional info.
- C++ model of separation of ‘data’ and ‘behavior’
  - Classes consist of a single ‘reference’ to the data object



DDG4 – Gateway to Geant4

- In-memory translation of geometry from TGeo to Geant4
  - Materials, Solids, Limit sets, Regions
  - Logical volumes, placed volumes and physical volumes
- External configuration:
  - Plugin mechanism
  - Property mechanism to configure plugin instances
  - Supports configuration via XML, Python or ROOT-AClick
- Use plugin mechanism to configure: Generation, Event Action, Tracking Action, Stepping Action, SensitiveDetector, PhysicsList…
- Provides out of the box MC truth handling **with** record reduction

DDG4 – Configuration example

- DDG4 is highly modular
- Very easily configurable through python

```
#...
gen = DDG4.GeneratorAction( kernel , "LCIOInputAction/LCIO1" )
gen.Input = "LCIOFileReader|" + inputFile
#...
```

- Or 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
#...
```

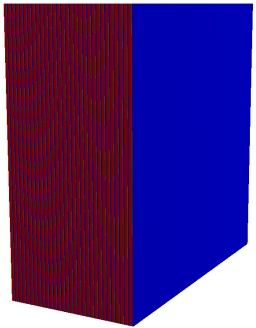
Plugin Palettes 1/2

- Providing input handlers, sensitive detectors for most cases...
- Hard to provide Geant4 Sensitive Detectors for all cases
  - Couples detector 'construction' to reconstruction, MC truth and Hit production
  - Too dependent on technology and user needs
  - Providing palette of most 'common' sensitive components
    1. trackers: `TrackerCombineAction` with several options
    2. calorimeters: `OpticalCalorimeterAction` and `ScintillatorCalorimeterAction` with Birks' law
    + Distinguish between different particles e.g. optical photon vs Cherenkov
    + No issue about where to place the hit: At the centre of the cell provided by the segmentation
    + Detailed shower mode: Store all contributions (hit time) to the energy in a cell
    + Store truth information about contribution of different hits

Plugin Palettes 2/2

- Physics lists, Physics/particle constructors etc.
  - Wrapped factory plugins directly taken from Geant4
  - Users extend physics list (e.g. QGSP)
- Several IO handlers (LCIO, ROOT, StdHep, HepEvt, HepMC)

```
<detector name="HBUTestBeam" type="CaloPrototype_v01"
          vis="HBUVis" id="3" readout="HBUCollection"
          insideTrackingVolume="false" >
  <layer repeat="30" vis="HBUVis">
    <slice material = "TungstenDens24" thickness = "10.0*mm"/>
    <slice material = "Air"            thickness = "1.0*mm" />
    <slice material = "Cu"             thickness = "0.1*mm" />
    <slice material = "PCB"            thickness = "0.7*mm" />
    <slice material = "G4_POLYSTYRENE" thickness = "3.0*mm"
           vis="SciVis" sensitive = "yes" />
    <slice material = "Air"            thickness = "1.0*mm" />
  </layer>
</detector>
```



DDSim

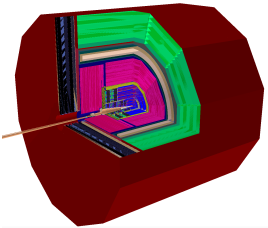
- `ddsim` python executable is part of the DD4hep release
- Get steering file `ddsim --dumpSteeringFile > mySteer.py`
  - Steering file includes documentation for parameters and examples
  - The python file contains a `DD4hepSimulation` object at global scope
  - Configure simulation directly from commandline

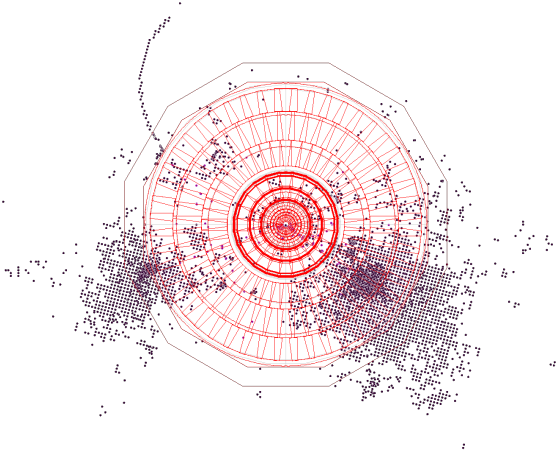
```
from DDSim.DD4hepSimulation import DD4hepSimulation
from SystemOfUnits import mm, GeV, MeV, keV
SIM = DD4hepSimulation()
SIM.compactFile = "CLIC_o3_v06.xml"
SIM.runType = "batch"
SIM.numberOfEvents = 2
SIM.inputFile = "electrons.HEPEvt"
SIM.part.minimalKineticEnergy = 1*MeV
SIM.filter.filters ['edep3kev'] =
dict (name="EnergyDepositMinimumCut/3keV" ,
      parameter={"Cut" : 3.0*keV} )
SIM.action.tracker = "Geant4TrackerWeightedAction"
SIM.action.calo = "Geant4ScintillatorCalorimeterAction"
```

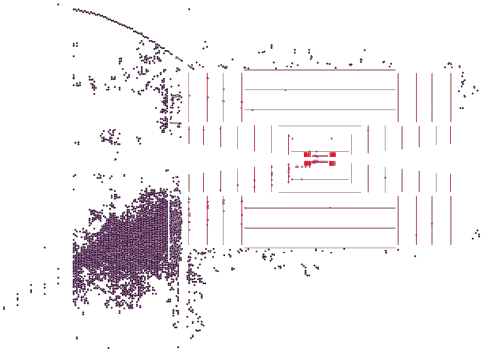
```
$ ddsim
--action.calo
--action.mapActions
--action.tracker
--compactFile
--crossingAngleBoost
--dump
--dumpParameter
--dumpSteeringFile
--enableDetailedShowerMode
--enableGun
--field.delta_chord
--field.delta_intersection
--field.delta_one_step
--field.eps_max
--field.eps_min
--field.equation
--field.largest_step
--field.min_chord_step
--field.stepper
--filter.calo
--filter.filters
--filter.mapDetFilter
--filter.tracker
-G
--gun.direction
--gun.energy
--gun.isotrop
--gun.multiplicity
--gun.particle
--gun.position
-h
--help
-I
--inputFiles
-M
--macroFile
-N
--numberOfEvents
-O
--outputFile
--output.inputStage
--output.kernel
--output.part
--output.random
--part.keepAllParticles
--part.minimalKineticEnergy
--part.printEndTracking
--part.printStartTracking
--part.saveProcesses
--physics.decays
--physics.list
--physicsList
--physics.rangecut
--printLevel
--random.file
--random.luxury
--random.replace_gRandom
--random.seed
--random.type
--runType
-S
--skipNEvents
--steeringFile
-v
--vertexOffset
--vertexSigma
```

CLIC Example

- The CLIC Detector Model
- $e^+e^- \rightarrow H(\rightarrow b\bar{b})\nu\nu$







Summary and Conclusion

- DD4hep provides a consistent single source of detector geometry for simulation, reconstruction, analysis
- Enables full simulation w/ Geant4 of particle collisions in detectors with minimal effort: simple, easy, flexible
- The DD4hep toolkit is getting accepted by wider HEP community
  - Used by CLIC, ILC, FCC, LHCb, CMS, SCT detector communities
- DD4hep can host user plugins: extensible
- Continued plugin suite development to cover all simulation needs (I/O, MC truth, etc)
- Find us at http://dd4hep.cern.ch