DD4hep

GENERIC DETECTOR DESCRIPTION IN PRACTICE

FCC Software Workshop

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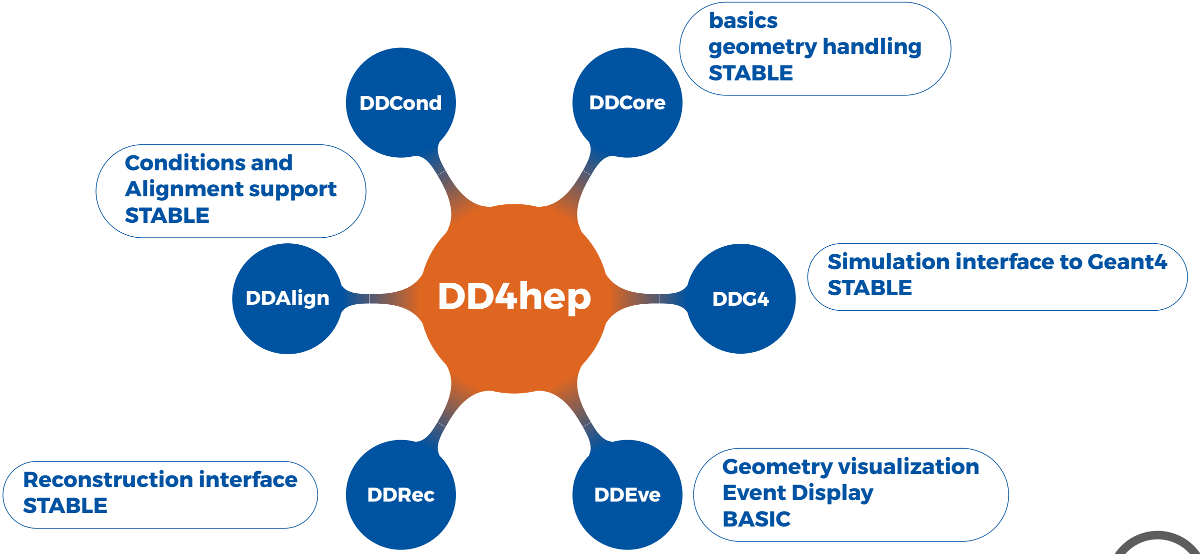
HEP Software Foundation

Overview

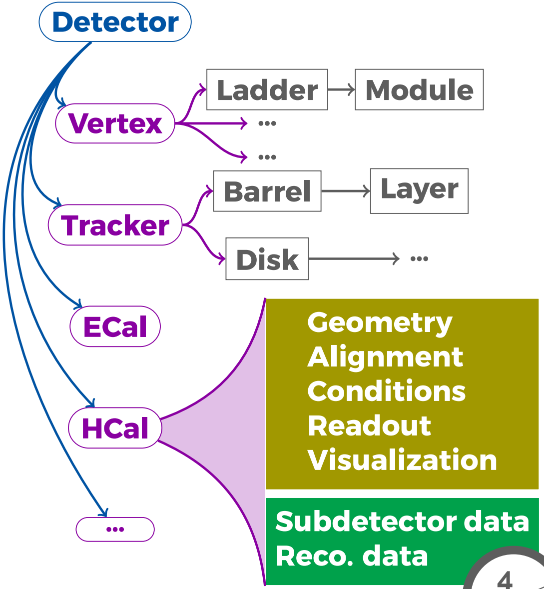
- Complete Detector Description
  - Providing geometry, materials, visualization, readout, alignment, calibration
- Supports full experiment life cycle
  - Detector concept development, detector optimization, construction, operation
  - Facile transition from one stage to the next
- Single source of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

Structure and packages



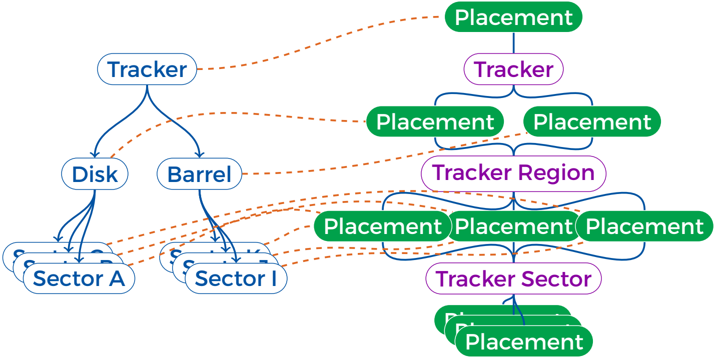
What is Detector description?

- Description of a tree-like hierarchy of ‘detector elements’
  - Sub-detectors or parts of subdetectors
- Detector Element describes:
  - Geometry
    - points to placed logical volumes
  - Environmental conditions
  - Properties required to process event data
  - Extenstions (optionally): experiment, sub-detector or activity specific data, measurement surfaces

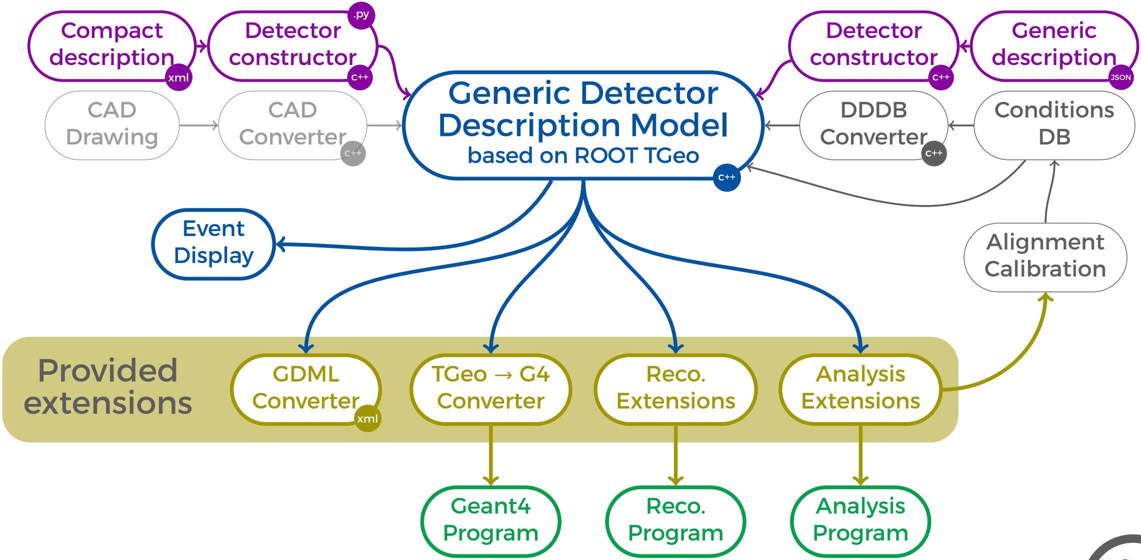


DetElement Tree vs. Geometry Hierarchy

- Logical Volumes used to build geometrical hierarchy
  - geometry part delegated to the ROOT classes
- Relationship between DetElement and placements through full path from top of geometry
- DetElement tree is fully expanded
  - DetElement is placed only once in the DetElement tree



The Big Picture



The Generic Detector Palette

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

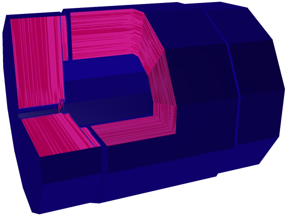
```
<detector id="15" name="HCal" type="GenericCalBarrel_o1_v01" readout="HCalCollection">
  <envelope vis="HCALVis">
    <shape type="PolyhedraRegular" numsides="HCal_sym" rmin="HCal_rmin" rmax="HCal_rmax" dz="HCal_dz" material="Air"/>
    <rotation x="0*deg" y="0*deg" z="90*deg-180*deg/HCal_symmetry"/>
  </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
- Inspect `${DD4hep_ROOT}/DDDetectors/src` or `compact`

Your Detector Palette

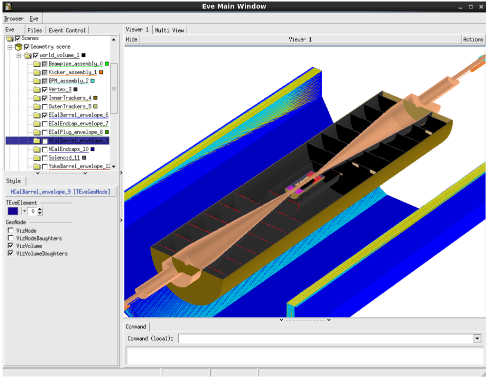
```
static Ref_t create_detector(Detector& theDetector,
                             xml_h e, SensitiveDetector sens) {

  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 = theDetector.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);
        ...}
  }
  DECLARE_DETELEMENT(GenericCalBarrel_o1_v01, create_detector)
```

- 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



Advice for detector builders

- Make you driver as generic as possible
- Nest your volumes as much as possible
- Don’t place all the volumes in the worldVolume
  - slow navigation in simulation
- Help yourself with `teveDisplay compact.xml`
- Check for overlaps:
  - `ddsim --runType=vis --compact=compact.xml`
  - Run overlap check from G4 shell
  - G4 overlap check better than ROOT in our experience



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
#...
```

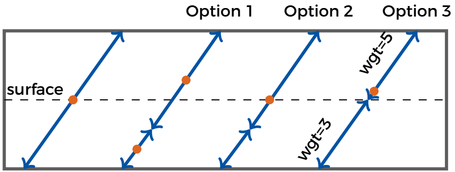
DDG4 – your friendly debugging tool

- No need to have the whole FCCSW on your computer/laptop
- DD4hep dependencies: ROOT, Geant4, Boost
- Easy access to G4 shell
- Interactive simulation control via `ddsim`
  - Is the conversion really working as planned
  - Do I see hits in the right detectors on the right spot
- Access to material scans
- Possibility to test a lot of machinery standalone before committing your code to FCCSW

Plugin Palettes

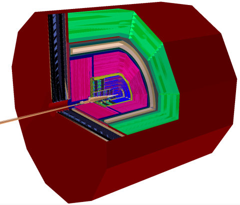
- Providing input handlers, sensitive detectors for most cases…
- Hard to provide Geant4 Sensitive Detectors for all cases
  - Couples detector 'construction' to reconstruction, MC truth and Hit production
  - Too dependent on technology and user needs

e.g. several possibilities for tracker

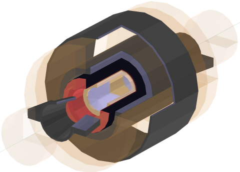


  - Providing palette of most 'common' sensitive components for trackers and calorimeters
- Physics lists, Physics/particle constructors etc.
  - Wrapped factory plugins directly taken from Geant4
  - Users extend physics list (e.g. QGSP)
- Several IO handlers (LCIO, ROOT, StdHep, HepEvt, HepMC)

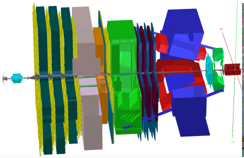
Users of DD4hep



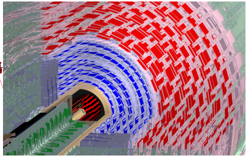
Production



Production

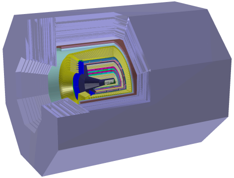


Production
Run 3



Under investigation
Run 3

Super Charm Tau Factories



Production

- The user base for DD4hep is growing

A bit more about `ddsim`

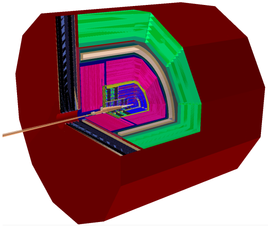
- Get steering file `ddsim --dumpSteeringFile > mySteer.py`
  - Steering file includes documentation for parameters and examples
  - The python file contains a `DD4hepSimulation` object at global scope
  - Configure simulation directly from commandline

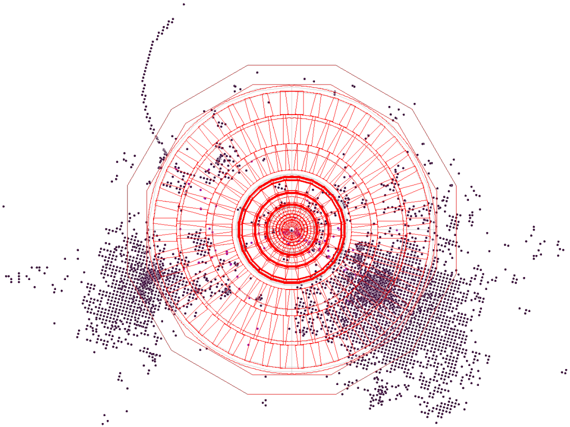
```python
from DDSim.DD4hepSimulation import DD4hepSimulation
from SystemOfUnits import mm, GeV, MeV, keV
SIM = DD4hepSimulation()
SIM.compactFile = "CLIC_o3_v06.xml"
SIM.runType = "batch"
SIM.numberOfEvents = 2
SIM.inputFile = "electrons.HEPEvt"
SIM.part.minimalKineticEnergy = 1*MeV
SIM.filter.filters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

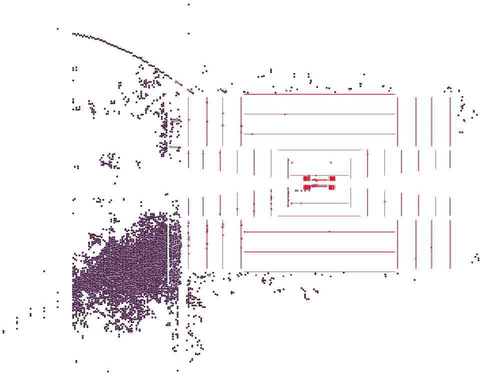
```
$ ddsim
--action.calo                    --filter.tracker        --part.keepAllParticles
--action.mapActions              -G                      --part.minimalKineticEnergy
--action.tracker                 --gun.direction         --part.printEndTracking
--compactFile                    --gun.energy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

Simulation Example

- The CLIC Detector Model
- Simulate and view =
  `ddsim` + `teveDisplay`





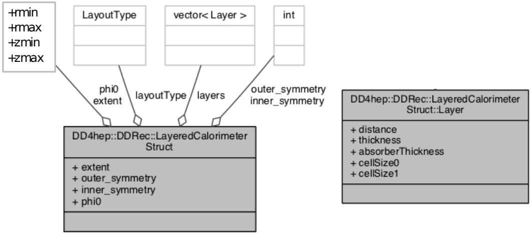


DDRec: High Level Information

High level view onto the detectors through DDRec `DataStructures` extensions for `DetElements`

- Constructors fill DDRec `DataStructures`
- `DataStructures` allow to decouple detector implementation from reconstruction algorithms

`DataStructures` contain sufficient information to provide geometry information to particle flow clustering via `PandoraPFA`



Data Structure	Detector Type
`ConicalSupportData`	Cones and Tubes
`FixedPadSizeTPCData`	Cylindrical TPC
`LayeredCalorimeterData`	Sandwich Calorimeters
`ZPlanarData`	Planar Silicon Trackers
`ZDiskPetalsData`	Forward Silicon Trackers

Geometry for Track Reconstruction

Information needed for track reco.

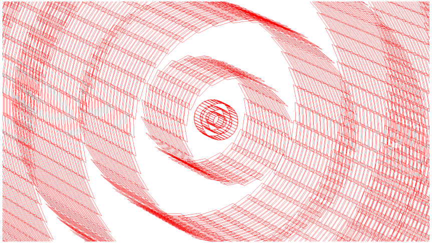
- measurement of directions of hits
- local-to-global transforms
- material properties

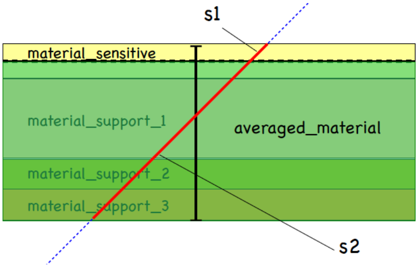
DD4hep surfaces provide this

- Surfaces can be auto. added

```
<plugin name="DD4hep_GenericSurfaceInstallerPlugin">
  <argument value="TrackDet"/>
  <argument value="dimension=2"/>
  <argument value="u_x=-1."/>
  <argument value="v_y=-1."/>
  <argument value="n_z=1."/>
</plugin>
```

  - Plugin loops over all `DetElements`
  - Configure surface type and direction in volume
  - Automatically average materials





ACTS Integration (1/2)

Provides DD4hepPlugin

- convertDD4hepDetector
  - Conversion from DD4hep geometry into ACTS geometry
  - Walks through detector geometry in order to access both geometrical and detector relevant information
- DD4hepLayerBuilder
  - Uses `DD4hep::DetElements` as input for sensitive surfaces

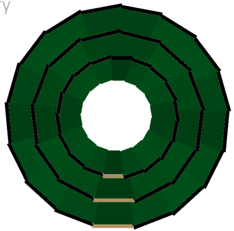
Usage:

- Declare layers of sensitive detector and sensitive detector modules as `DD4hep::DetElements` in the constructor
- Use the ActsExtensions

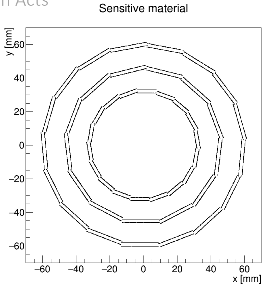
```
std::unique_ptr<Acts::TrackingGeometry>
convertDD4hepDetector(DD4hep::Geometry::DetElement worldDetElement,
                      Logging::Level  loggingLevel    = Logging::Level::INFO,
                      BinningType     bTypePhi        = equidistant,
                      BinningType     bTypeR          = equidistant,
                      BinningType     bTypeZ          = equidistant,
                      double          layerEnvelopeR = 0.,
                      double          layerEnvelopeZ = 0.);
```

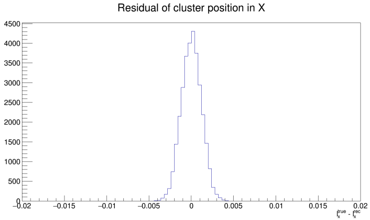
ACTS Integration (2/2)

DD4hep geometry



Hits in Acts





Very nice interplay

Sub-packages not in use by FCCSW

- DDCond:
  - Provide access to a consistent set of values according to a given time
  - Provide access to consistent set of accompanying data for processing event data
  - Supports multi-threading
  - Configurable and extensible
  - Defined mechanism to manage conditions
- DDAlign:
  - does not provide algorithms to determine alignment constants
  - supports hosting the results of such algorithms and applies the resulting imperfections
  - Implemented Global and Local (mis-)alignment
- Integrate solution that can handle running experiments and conceptual design phase projects

Implemented Features not released

- Several new features released since last v1.10
- Expected to be shipped sometime before CHEP
- CMake rewrite – you can comfortably build and develop against a LCG view
- Python 3 compatibility
- Ensure that dictionaries are relocatable
- Handling of optical properties (ROOT 6.20)
- Support for reflections (mirror right handed to left handed volumes)

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
- Generic reconstruction packages with *no* framework dependency: tracking, particle flow reconstruction
- If the detector is described via DD4hep, reconstruction comes almost for free
- The DD4hep toolkit is getting accepted by wider HEP community
  - Used by CLIC, LHCb, FCC, ILC, SCT detector communities
- Development continues in parallel with validation
- DD4hep can host user plugins: extensible
- Continued plugin suite development to cover all simulation req.
- Find us at http://dd4hep.cern.ch

Try on SLC6, CC7 or macOS

- git clone https://github.com/AIDASoft/DD4hep.git
- mkdir build
- cd build
- export LCG_RELEASE=”LCG_96b”
- source ../.dd4hep-ci.d/init_x86_64.sh
- cmake -DDD4HEP_USE_GEANT4=ON -DBoost_NO_BOOST_CMAKE=ON -DBUILD_TESTING=ON -DCMAKE_CXX_STANDARD=17 ..
- make; make install
- . ../bin/thisdd4hep.sh