DD4hep

a community driven detector description tool for HEP

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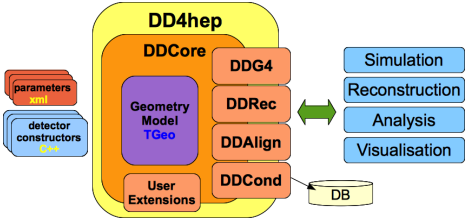
Outline

- Introduction
- DD4hep Features
- Recent Developments
- Future Plans
- Summary and Outlook

- see also related talks:
  - A.Sailer: Towards a Turnkey Software Stack for HEP Experiments
  - C.Vuasolo: CMS Experience with Adoption of the Community-supported DD4hep Toolkit
  - D.Muller: Gaussino - a Gaudi-based core simulation framework

Introduction - Overview

- **Goal:** develop a generic detector (geometry) description for HEP
- support the **full life cycle** of the experiment
  - detector concept development
  - detector optimization
  - construction and operation
  - extendible for future use cases
- consistent description with one single data source
  - for simulation, reconstruction, analysis
- complete description:
  - geometry readout, alignment, calibration (conditions), . . .

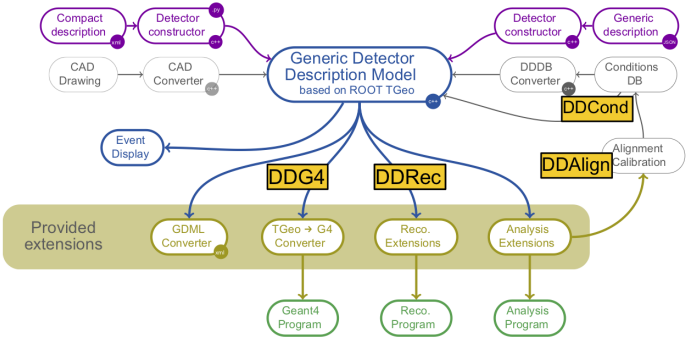


component based design

- developed in AIDA/AIDA2020
- HSF incubator project

DDCore - core implementation of DD4hep

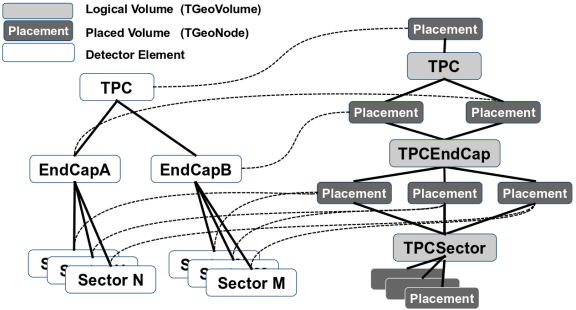
- DD4hep uses **Root TGeo** as geometry implementation
- geometry description in
  - compact *xml-files* and *C++ drivers*
  - other (generic) input sources
- output formats/interfaces
  - Geant4, GDML, *easily extendible*
- various interfaces (views) on geometry:
  - DDRec, DDEve, DDAlign, ...



DDCore - DetElements and Geometry Trees

- additional hierarchy of *DetElements* provides access to
  - Alignment, Conditions, Readout (sensitive detectors), Visualization
  - arbitrary *user defined objects*
- define for every *touchable* that needs extra data

- the tree of *DetElements* provides the *high level view* into the detector geometry with subdetectors, measurement layers, etc. . .



DDG4: gateway to full simulation with Geant4

- convert geometry *on the fly* from TGeo to Geant4
- hook into the user entry points provided by Geant4:
  - Stepping, Stacking, Tracking,...
- choose detector response and physics list from pre-defined plugins
- start the simulation

provided by DDG4 and DDDetectors

- pre-defined palette of standard **sensitive detectors** (trackers, calorimeters)
- large set of **standard HEP detectors** to get quickly started for conceptual studies

- DDG4 provides all modules needed to run full simulations with Geant4 on any detector that is described in DD4hep
  - either from *DDDetectors* or *user-defined*

- pre-defined, extendible palette of I/O handlers
  - Input: **stdhep, LCIO, HepEvt(ASCII), HepMC(ASCII)**
  - Output: **ROOT, LCIO**
  - easily extendible, e.g. with **EDM4hep**

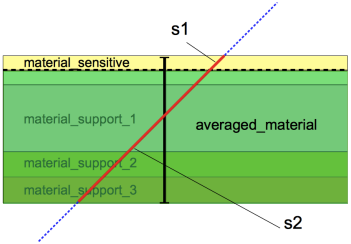
- detailed **MC-Truth** handling w/ and w/o record reduction

DDRec: *high level* interface for reconstruction

- `DetectorData` classes
  - describe high level view of generic detectors (motivated by ILC/CLIC detectors): *dimensions, #layers, thicknesses,...*
- `CellIDPositionConverter`
  - convert cellID to position and vice versa
- `MaterialManager`
  - access material properties at any point or along any straight line

- **tracking** needs special interface to geometry
- measurement and dead material *surfaces* (planar, cylindrical, conical)
- **surfaces** *attached to volumes* in detailed geometry model

- u,v, origin and normal
- inner and outer thicknesses and material properties
- local to global and global to local coordinate transformations:
  - $(x, y, z) \leftrightarrow (u, v)$



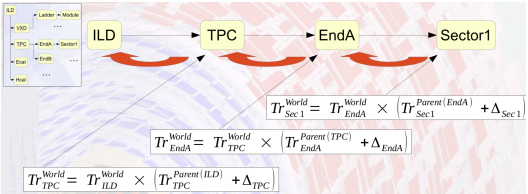
- materials are automatically averaged over surface thickness
  - roughly equivalent for E-loss (Bethe-Bloch)
  - identical for multiple scattering

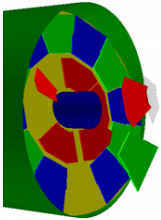
DDAlign: interface for alignment of detector components

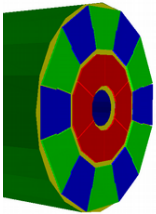
- global alignment corrections
  - physically modify geometry in memory (by TGeo)
  - **not thread safe**
  - possibility to simulate mis-aligned geometries

local alignment corrections

- geometry is static (ideal or mis-aligned)
- **thread-safe**
- local alignments are conditions
- provide *delta-transformations* for hit positions

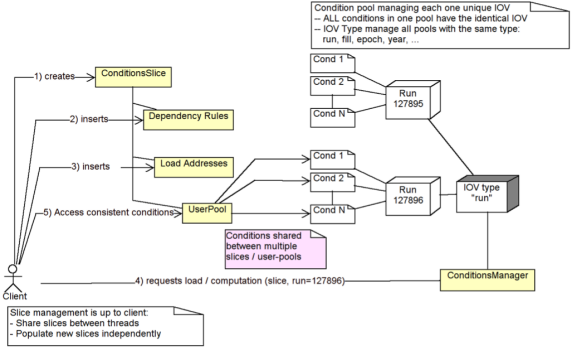






DDCond - Interface to conditions data

- DDCond provides an interface to access conditions data
  - *'slowly'* varying data
  - access through *DetElement* and *Key*
  - organized in IOVs (*Interval of Validity*)
- allow for *derived conditions data*
- **thread-safe** access
- use for example for (delta)-misalignments



- presented in detail at CHEP 2018: M.Frank: Conditions and Alignment extensions to the DD4hep Detector Description Toolkit

Recent developments - since last CHEP

- DD4hep is fully functional for many years and was heavily used in large scale Monte Carlo productions for the **ILD** and **CLICdp** detector concepts, as well as for many **FCC-ee** and **FCC-hh** studies
- interest from **LHCb** and **CMS** has triggered many developments and bug fixes
  - adaptation of geometry input to *legacy* format used by these experiments
  - implementation of more *exotic* shapes not used in the linear collider detectors: *TGeoCtub, TGeoScaledShape, TGeoArb8* and *G4GenericTrap*
  - **surfaces and optical photons**
  - **reflection implementation for left handed coordinates**
- continuous evolution of DD4hep
  - introduce **Python 3** compatibility
  - update cmake builds
  - make compatible with C++17
  - prepared switch to Geant4 system of units *(mm, nsec, MeV)*
  - improved the *plugin manager*

Surfaces and optical photons

- import of surface optical objects in compact input files
  - surface types and optical properties (*refraction, absorption, . . .*)
  - create TGeo surface objects and tabulated properties
- translation from TGeo to Geant4
- physics components in DDG4, handling:
  - scintillation, Cerenkov and transition radiation
  - reflection, refraction, absorption, wavelength shifting

```
<opticalsurface name="/world/BubbleDevice#WaterSurface" finish="ground" model="unified"
                type="dielectric_dielectric">
  <property name="RINDEX"                coldim="2" values="2.034*eV  1.35  4.136*eV  1.40"/>
  <property name="SPECULARLOBECONSTANT"  coldim="2" values="2.034*eV  0.3   4.136*eV  0.3 "/>
  <property name="SPECULARSPIKECONSTANT" coldim="2" values="2.034*eV  0.2   4.136*eV  0.2 "/>
  <property name="BACKSCATTERCONSTANT"   coldim="2" values="2.034*eV  0.2   4.136*eV  0.2 "/>
</opticalsurface>
```

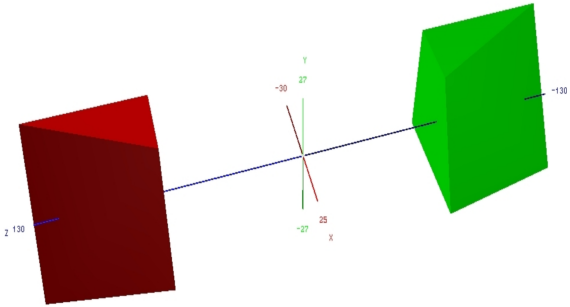
```
#if ROOT_VERSION_CODE >= ROOT_VERSION(6,17,0)
  // Now attach the surface
  OpticalSurfaceManager surfMgr = description.surfaceManager();
  OpticalSurface waterSurf  = surfMgr.opticalSurface("/world/"+det_name+"#WaterSurface");
  OpticalSurface airSurf    = surfMgr.opticalSurface("/world/"+det_name+"#AirSurface");
  BorderSurface  tankSurf   = BorderSurface(description, sdet, "HallTank",   waterSurf,
                                            tankPlace,   enclPlace);
  BorderSurface  bubbleSurf = BorderSurface(description, sdet, "TankBubble", airSurf,
                                            bubblePlace, tankPlace);
  bubbleSurf.isValid();
  tankSurf.isValid();
```

- implemented complete treatment of Optical Photons and surfaces as defined in Geant4

Reflection implementation for left handed coordinates

- reflection with left-handed coordinates in the reflected volumes
- used for *endcap-like* detectors in CMS

```
Rotation3D rot3D(RotationZYX(...));
Position pos3D(...);
if ( reflect )
 rot3D = Rotation3D(1., 0., 0.,
                    0., 1., 0.,
                    0., 0., -1.) * rot3D;
Transform3D tr(rot3D, pos3D);
pv = assembly.placeVolume(volume,tr);
```



Made DD4hep compatibility with Python 3

- make codebase **python 2 and 3 compatible** at the same time
  - don't maintain two codebases
- replace `print` statements with the python logging module
- used `caniusepython3.pylint_checker` module to identify critical code segment groups
  - address as many as possible of these groups with `python-modernize`
  - run test suite after application of every fix
  - use the `six` module for easier python 2 and 3 compatibility (shipped w/ DD4hep)
- at the end mostly two groups remain: division and unicode
  - use new style division and check all division cases by hand
  - use `unicode_literals` in all files and fix calls to externals API where string is required
  - special care needed to be taken when de-unicoding dicts

users decide whether to use python 2 or python 3 in their software ecosystem

Next evolution step: DDDigi

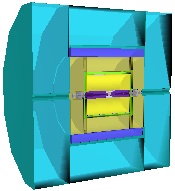
- digitization is the logical next step after simulating the detector response in **DDG4**
- keep separate from simulation step - if possible
  - important for overall CPU usage and re-use of simulated data
- study detector segmentation effects
- detector response to energy depositions
  - Hit/Cluster creation
  - charge sharing
- Incorporate electronics effects
  - noise, cross-talk, etc

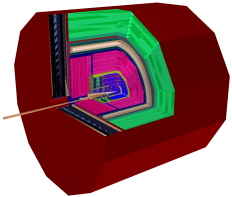
work plan

- develop a suitable data model,
  - consistent with experiments' models – needs to match input and output data
- investigate digitization types
  - detailed models for specialized studies
  - simplified model for bulk productions
- develop a palette of digitization plugins for typical subdetector types
  - parameterized and flexible
  - valid for *most readouts*

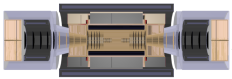
Examples of DD4hep users

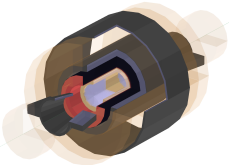
- ILC/CLICdp



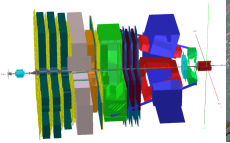


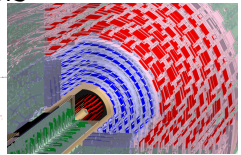
- FCC





- LHCb and CMS





- DD4hep user community is continuously growing:
  - Calice, Super-Charm-Tau factories in Novosibirsk and China,. . .
- we are happy to support more use cases
  - expected with *Turnkey Software Stack*

Documentation and Websites

- Main Web page
  - http://dd4hep.cern.ch
  - main entry point for DD4hep
- Github code repository:
  - https://github.com/AidaSoft/DD4hep
- Manuals
  - available from Github (`./doc`)
  - or main Web page
- Doxygen documentation
  - https://dd4hep.web.cern.ch/dd4hep/reference
    - or build from source

Summary and Outlook

- **DD4hep** is fully functional for many years
- **DDCore, DDG4 and DDRec** have long reached **production quality**
  - used for large scale Monte Carlo productions of ILD and CLICdp
  - DDCore and DDG4 (partly) used for FCC CDRs
- **DDAlign** and **DDCond** are more recent developments
  - full integration in iLCsoft still pending
- recent adoption of **DD4hep** by LHCb and CMS has triggered lots of activity
  - bug fixes, missing shapes, new features

Outlook

- will continue to improve and evolve DD4hep as a true community tool
- next step: implement **DDDigi** and integration in *Turnkey Software Stack*
- **new users are welcome**