DD4hep

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Outline

- Motivation
- Design and Implementation (DDCore)
- DDG4
- DDRec
- DDAlign
- DDCond
- Requirements for EIC community

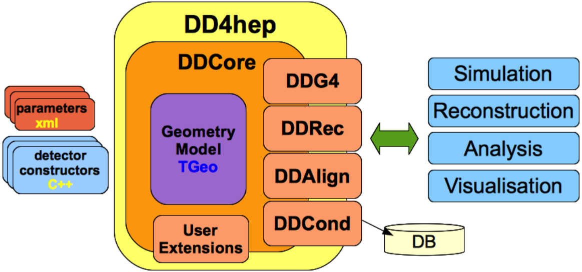
- lots of material in this talk taken from the main developer M.Frank (CERN)

Motivation

- 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), ...
- developed in AIDA and AIDA2020

- DD4hep follows a **modular, component based design**
  - **DDG4**: full simulation with Geant4
  - **DDRec**: *high level* interface for reconstruction
  - **DDAlign**: interface for (mis-)alignment of detector components
  - **DDCond**: interface to conditions data base

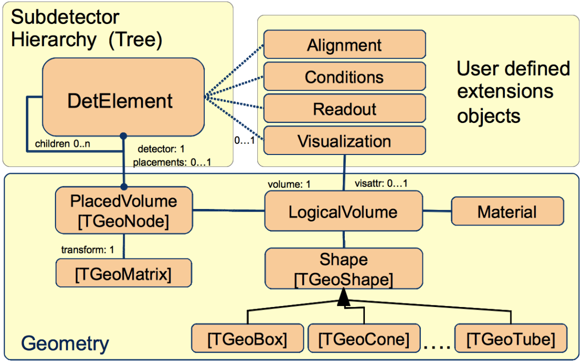
only use what you need ...



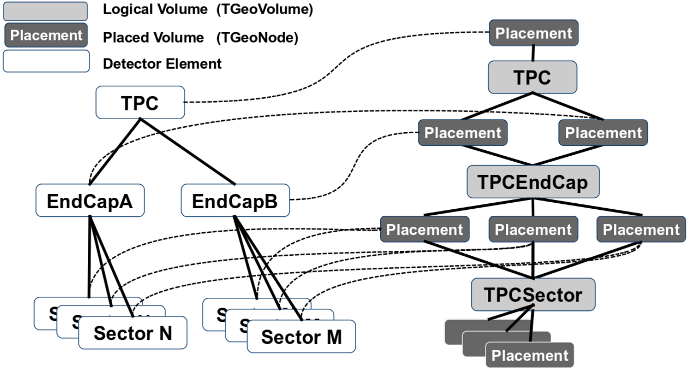
DDCore - core implementation of DD4hep

Implementation

- DD4hep uses **Root TGeo** for the underlying geometry description
  - access to ROOT Open GL viewer for geometry
  - debugging (overlap checking) of geometry
  - ROOT persistency for geometry
- additional hierarchy of *DetElements* provides access to
  - Alignment, Conditions, Readout (sensitive detectors), Visualization
  - arbitrary *user defined objects*



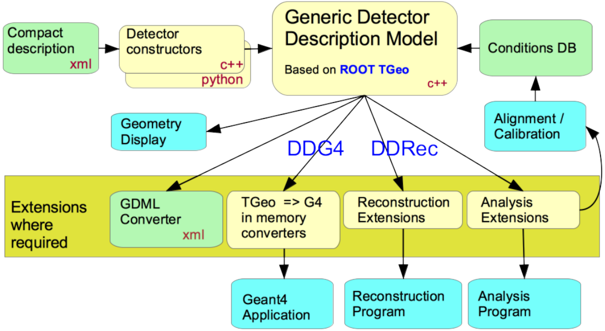
DetElements and Geometry Trees



- define *DetElements* for every *touchable object* that needs additional data

Implementation: geometry conversions

- default geometry description in DD4hep:
  - compact *xml-files* and *C++ drivers*
  - inspired by *org.lcsim/SLIC* geometry description
  - other input sources possible
- output formats/interfaces
  - GDML
  - Geant4 geometry
  - *easily extendible*



Compact Description - XML

- geometry defined in xml files
  - human readable
  - extendible
- interpreter supports units and formulas
- requires interpreting code to create detector geometry in memory: *C++ drivers*
- large palette of simple *'standard HEP detectors'* provided in **DDDetectors**

```xml
<detector id="9" name="Coil"
          type="Tesla_coil00"
          vis="CoilVis">
  <coil
    inner_r="Hcal_R_max+
             Hcal_Coil_additional_gap"
    outer_r="Hcal_R_max+
             Hcal_Coil_additional_gap+
             Coil_thickness"
    zhalf="TPC_Ecal_Hcal_barrel_halfZ+
           Coil_extra_size"
    material="Aluminum">
  </coil>
</detector>
```

C++ driver code

```
static Ref_t create_element(LCDD& lcdd, const xml_h& e, SensitiveDetector& sens)  {
 xml_det_t   x_det  = e;
 string      name   = x_det.nameStr();
 DetElement  sdet(name,x_det.id());
 Assembly    assembly(name);
 xml_comp_t  x_coil = x_det.child(Unicode("coil"));

 Tube   coilTub(x_coil.inner_r(),x_coil.outer_r(),x_coil.zhalf());
 Volume coilVol("coil",coilTub,lcdd.material(x_coil.materialStr()));
 coilVol.setVisAttributes(lcdd.visAttributes(x_det.visStr()));
 assembly.placeVolume(coilVol);

 PlacedVolume pv=lcdd.pickMotherVolume(sdet).placeVolume(assembly);
 sdet.setPlacement(pv);
 return sdet;
}

DECLARE_DETELEMENT(Tesla_coil00,create_element);
```

1) Create Detector Element

2) Create envelope

3) Create volume: *Shape of given Material*

4) Place volume in envelope

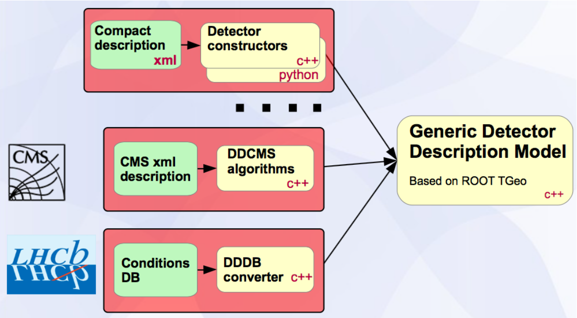
5) Place envelope

6) Publish constructor

- very simple example: more complex detectors have *tree-structure*

Other input sources for DD4hep

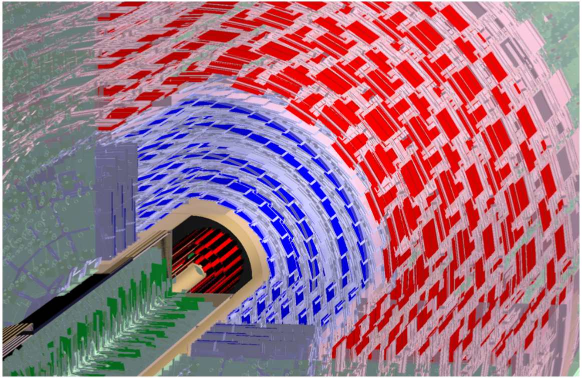
- the detector geometry in DD4hep can be read from any other format
- requires translation/conversion code
- we have for example code that reads the *original* geometry description from CMS (XML) and LHCb (database)
  - requested by these experiments for evaluation of DD4hep



other formats can be added

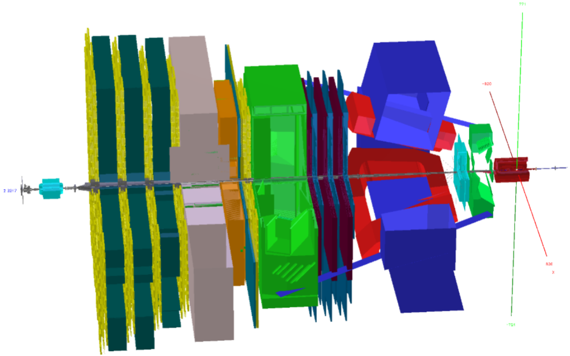
- if really needed
- original compact format is quite powerful

Example: CMS Tracker in DD4hep



- converted from *original* CMS XML-format

Example: LHCb detector in DD4hep



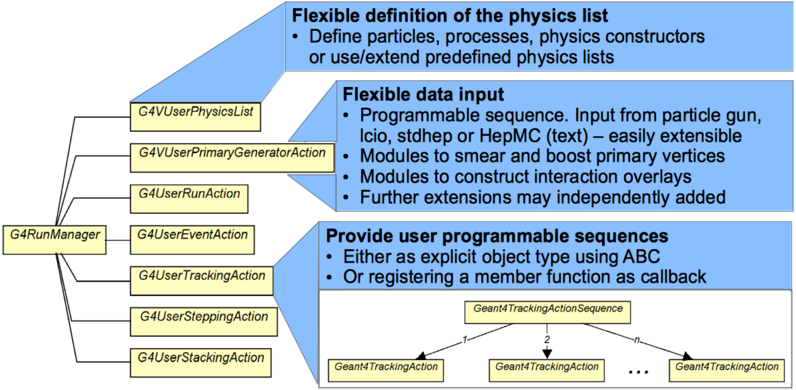
- converted from *original* LHCb database

DDG4 - Gateway to full simulations with Geant4

DDG4 Basic Concept

- walk through the geometry tree and convert *on the fly* from TGeo to Geant4
- hook into the user entry points provided by Geant4:
- instantiate detector response from (pre-defined) plugins (sensitive detectors)
- instantiate physics list from (pre-defined) plugins (particles, processes)
- start the simulation

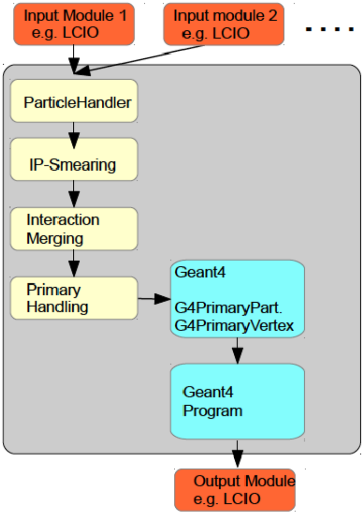
DDG4 Geant4 entry points - Sequences



- combine modules into sequences that are called by Geant4

DDG4 Geant4 Sequence Example

- combine simple and re-usable modules to configure the Geant4 simulation, e.g.
  - mix several input streams (signal and background)
  - smear the vertex position
  - combine various input and output formats
- can start sequences (Geant4 application) from:
  - Python program (ddsim from lcgeo)
  - C++ application configured with XML
  - ROOT C++ macros (!)



DDG4 features

- DDG4 provides all modules needed to run full simulations with Geant4 on any detector that is described in DD4hep
- pre-defined pallete of standard sensitive detectors (trackers, calorimeters)
  - extendible for special user needs
- pre-defined, extendible pallete of I/O handlers
  - Input: **stdhep, LCIO, HepEvt(ASCII), HepMC(ASCII)**
  - Output: **ROOT, LCIO**
- MC-Truth handling w/ and w/o record reduction
- physics lists: wrapped factory from Geant4
  - user defined physics lists

DDRec - Interface to the geometry for reconstruction (and analysis)

DDRec - Data classes

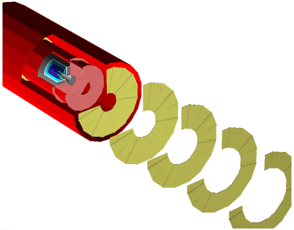
- `DetectorData` classes
  - describe high level view of generic detectors (motivated by ILC/CLIC detectors)
  - extends, #layers, thicknesses,...

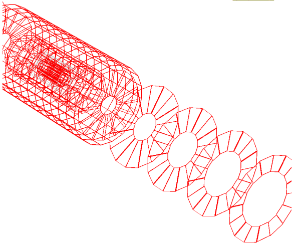
Data Structure	Detector Type
ConicalSupportData	Cones and Tubes
FixedPadSizeTPCData	Cylindrical TPC
LayeredCalorimeterData	Sandwich Calorimeters
ZPlanarData	Planar Silicon Trackers
ZDiskPetalsData	Forward Silicon Trackers

- `CellIDPositionConverter`
  - convert cellID to position and vice versa
- `MaterialManager`
  - access material properties at any point or along any straight line

DDRec tracking geometry: surfaces

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





surfaces:

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

DDRec surfaces and materials

- material properties are **automatically averaged**
  - from detailed model
  - along normal of the surface along given thicknesses

averaging materials

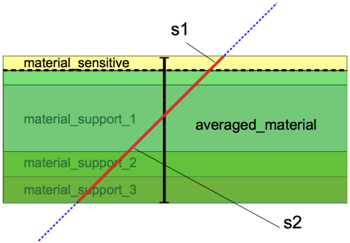
$$< A >= \left(\sum_i^N \rho_i t_i\right) / \left(\sum_i^N \rho_i \frac{t_i}{A_i}\right) \qquad t_i \textit{ thickness}$$

$$< Z >= \left(\sum_i^N \rho_i \frac{t_i Z_i}{A_i}\right) / \left(\sum_i^N \rho_i \frac{t_i}{A_i}\right) \qquad \rho_i \textit{ density}$$

$$< \rho >= \left(\sum_i^N \rho_i t_i\right) / \left(\sum_i^N t_i\right)$$

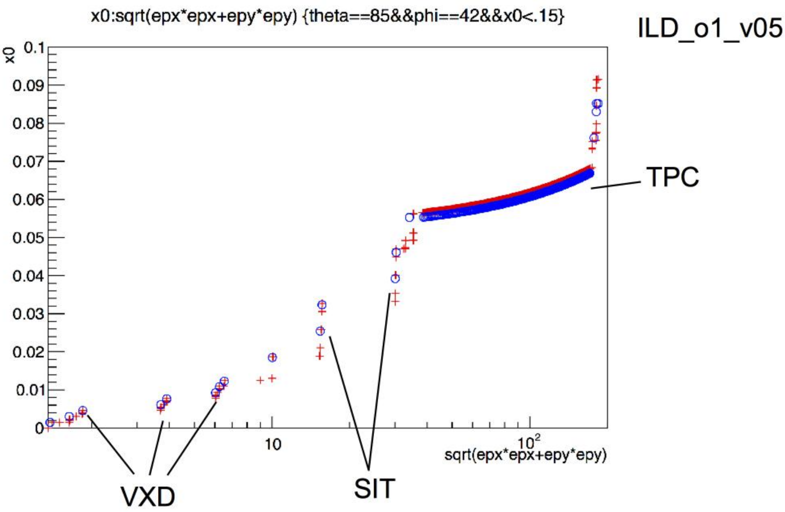
$$< X_0 >= \left(\sum_i^N t_i\right) / \left(\sum_i^N \frac{t_i}{X_{0i}}\right)$$

$$< \lambda >= \left(\sum_i^N t_i\right) / \left(\sum_i^N \frac{t_i}{\lambda}\right)$$



roughly equivalent for Bethe-Bloch - identical for multiple scattering

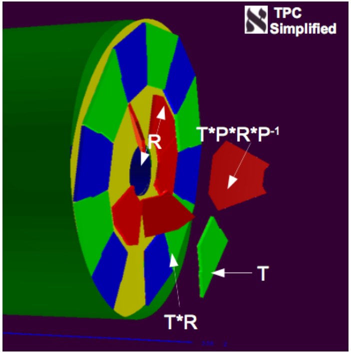
example: comparison of surfaces vs. detailed model for ILD



DDAlign - Describe misaligned detector geometries

DDAlign Overview

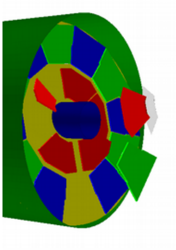
- real detectors have non-ideal placement of sub-detector elements
- DDAlign component allows to describe such *mis-aligned* geometries
- **NB:** DDAlign does not provide the algorithms to find the mis-alignment but only the tools to correctly simulate and reconstruct *mis-aligned* geometries

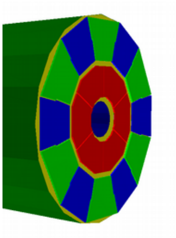


example: misaligned Aleph TPC

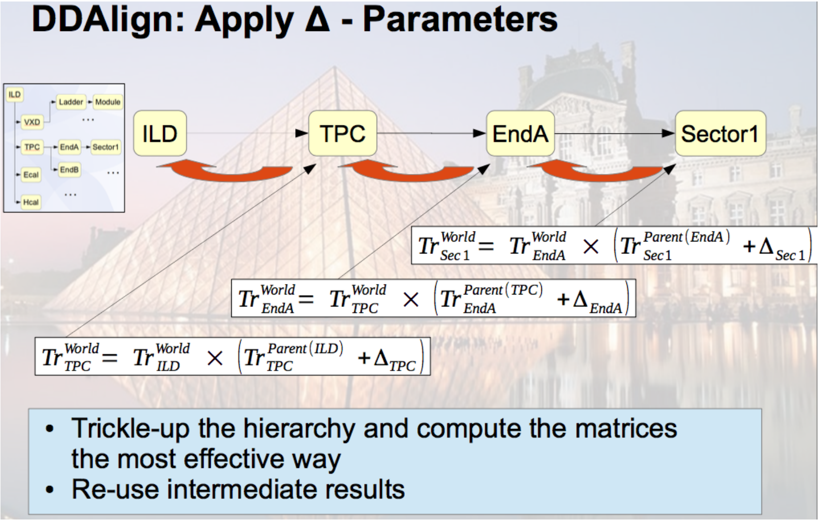
DDAlign Global and Local Alignment

- global alignment corrections
  - physically modify geometry in memory
  - supported 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
- both approaches are supported



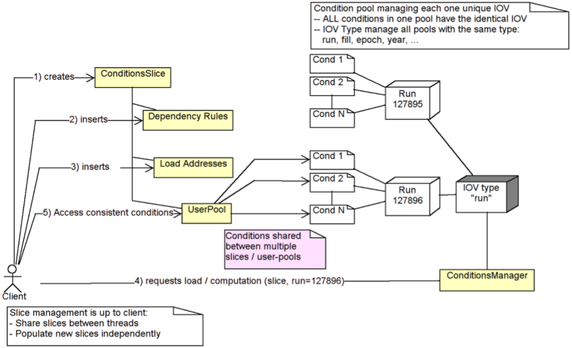


DDAlign Δ-alignment



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



for more details see:

https://indico.cern.ch/event/590645/contributions/2527144/attachments/1440284/2217047/2017-04-06-DD4hep-AIDA-Annual-Meeting.pdf

DD4hep users

- ILD and SiD (ILC)
- CLICdp
- Calice
- FCC-ee, FCC-hh, FCC-eh
- Interest from LHCb, CMS and CEPC

- DD4hep is an *HSF project*

Documentation and Websites

- Main Web page
  - `http://aidasoft.web.cern.ch/DD4hep`
- Github code repository:
  - `https://github.com/AidaSoft/DD4hep`
- Manuals
  - available from Github (`./doc`)
  - or main Web page
- Doxygen documentation
  - `http://test-dd4hep.web.cern.ch/test-dd4hep/doxygen/html/index.html`
  - or build from source

DD4hep Status

- DDCore, DDG4 and DDRec are mature and have reached **production quality**
  - large scale Monte Carlo productions for ILD and CLICdp to start soon
  - DDCore and DDG4 (partly) used by FCC
  - well documented
- DDAlign and DDCond:
  - more recent developments
  - plan to integrate into iLCsoft soon
  - more detailed documentation pending
- rather stable code basis
  - PRs only merged after successful CI-builds on several platforms
  - running $\sim$150 tests in CI

Requirements for EIC community

Requirements 1.

The geometry information should be the same in both simulation and reconstruction.

fulfilled

- this was one of the main motivations to develop DD4hep

Requirements 2.

Fast simulation systems should, as much as possible, be able to use the common exchange format.

mostly fulfilled

- if using parameterized fast simulation in Geant4 one can use existing conversion
- converters to any other geometry format can be (easily) added
- FCC uses Geant4 regions for Delphes

Requirements 3.

The geometry system should allow to include misalignment and more general condition data.

fulfilled

- see DDAlign and DDCond

Requirements 4.

Geometry description format should be independent of a specific software technology.

mostly fulfilled

- can read/write various input/output formats for simulation
- existing conversion of geometry to Geant4, TGeo, GDML
- existing import for CMS and LHCb
    - others could be added

Requirements 5.

Geometry description should be modular. It should be possible to specify different geometry components in isolation with ideally zero dependency between different modules (detectors).

fulfilled

- done in FCC implementation where any given set of XML files is read at program start
- partly done in LC implementations where include mechanism is used to read subdetector specific XML files that instantiate in mandatory envelope volumes

Requirements 6.

Geometry description should allow to specify logical information (sensitivity, B-Fields) in addition the solids, material and placements. In particular sensitivity is recognized as a critical issue.

fulfilled

- this is part of the design through existing or additional user extensions added to the 'DetElement'

Requirements 7.

It should be possible to make the geometry description persistent. Different equivalent output format should be supported (e.g. ROOT files, GDML files) and it should always be possible to translate one format into another in a simple manner.

fulfilled

- can write to and read from ROOT w/o data loss
  - GDML is incomplete
- in general conversions can only convert existing features in a given format

Requirements 8.

Hits output files produced in a simulation job should be as much as possible self-describing, in particular it should be possible to locate hits in space without the need to run the simulation job. A self-describing format for the hits would be ideal, but in case this is not possible , the additional libraries to manipulate hits should not depend on the simulation stack used to produce the hits.

fulfilled

- existing ROOT and LCIO output formats store the hit positions
  - together with cellIDs, if assigned
  - if positions are dropped from output, one can use the `CellIDPositionConverter` without having to instantiate the Geant4 geometry

Requirements 9.

It should be possible to change sensitivity attributes without changing other static aspects of the geometry.

fulfilled

- can add any (compatible) segmentation/readout to an existing sub-detector
  - e.g. change the granularity of a calorimeter layer

Requirements 10.

Geometry exchange format should allow clients to use a subset of the features clearly stating which are the optional ones. We should support existing interested frameworks (e.g.EicRoot, GEMC, Fun4ALL, SLIC,...), without discouraging other R&D activities (e.g. DD4hep). Since it is difficult to support all use-cases, the minimal set of mandatory elements to support should be clearly specified and what to do with non-supported one should be stated (e.g. ignore visualization attributes if not needed).

mostly fulfilled (?)

- see comments on exporting to other formats above
  - new formats could be added
- personal comment: I think it would be good to settle on one source for the geometry early on in the design phase of the experiment

Requirements 11.

Some support for import from CAD should be foreseen.

not yet fulfilled

- again this could be added if needed
  - with the usual caveats on missing information

Requirements 12.

Geometry information should have support for versioning.

(mostly) fulfilled

- versioning of the geometry is a client task
- for example the LC community has a dedicated package with C++ drivers and compact XML files
  - versioning done with software releases (code)
  - additionally naming convention for XML files (ILD_l5_v02.xml)
  - see: `https://github.com/iLCSoft/lcgeo`