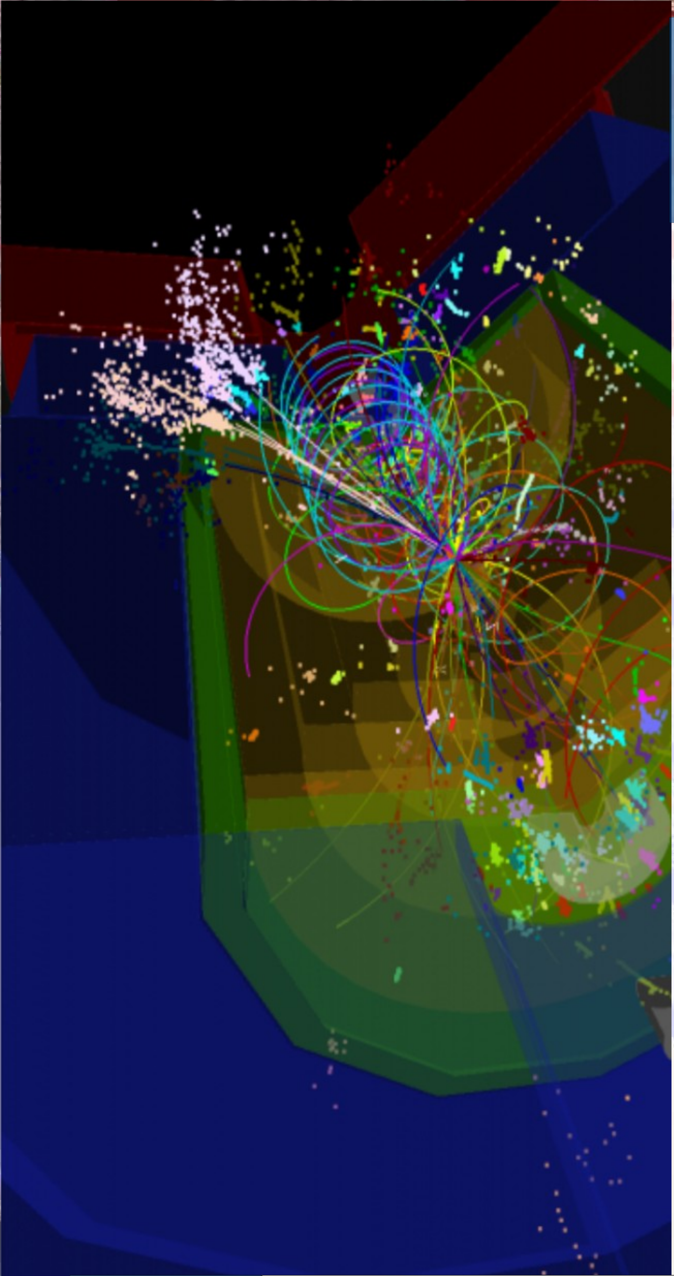


DD4hep

HEP detector description supporting the full experiment life cycle

- Basic overview and concepts
- Simulation topics
- Conclusions

M.Frank, F.Gaede, M.Petric, A.Sailer

CERN

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

AIDA 2020

ECFA Higgs Factories: 1st Topical Meeting on Simulation,
Markus Frank / CERN February 2nd, 2022

Motivation and Goal

DD4hep

- **Develop a detector description**
  - **For the full experiment life cycle**
    - **detector concept development, optimization**
    - **detector construction and operation**
    - **“Anticipate the unforeseen”**
  - **Consistent description, single source, supporting**
    - **simulation, reconstruction, analysis**
  - **Full description, including**
    - **Geometry, readout, alignment, calibration etc.**

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

Philosophy of DD4hep & Co

DD4hep

- **Effort of very few people with a simple, humble and comprehensive vision**

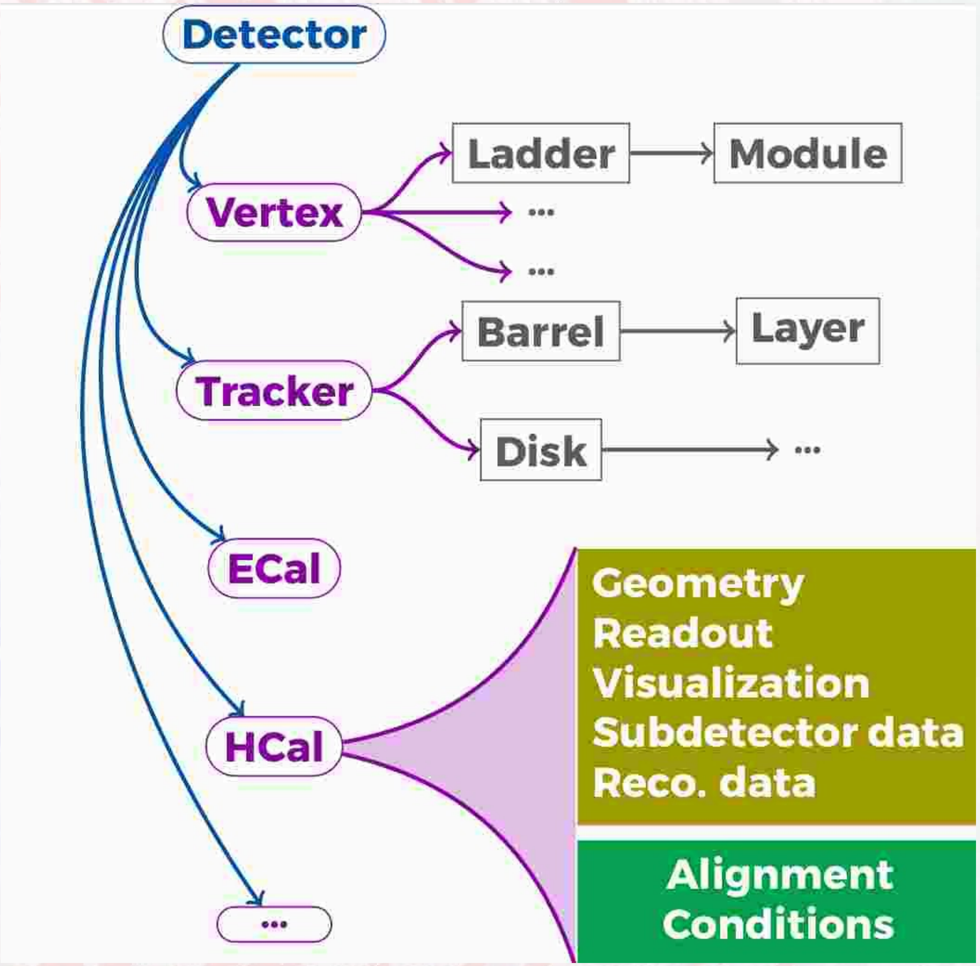
Detector description for the lazy
Minimal effort, pragmatic, no technical restrictions,
No religious wars

- **DD4hep is the "glue"**
  - **Bring together what belongs together:**
    Detector structure, geometry, simulation, conditions, etc
  - **Reuse existing modules: TGeo, Geant4, Assimp, etc**
- **'Responsible' users highly welcome**
- **Contributions even more !**

What is Detector Description ?

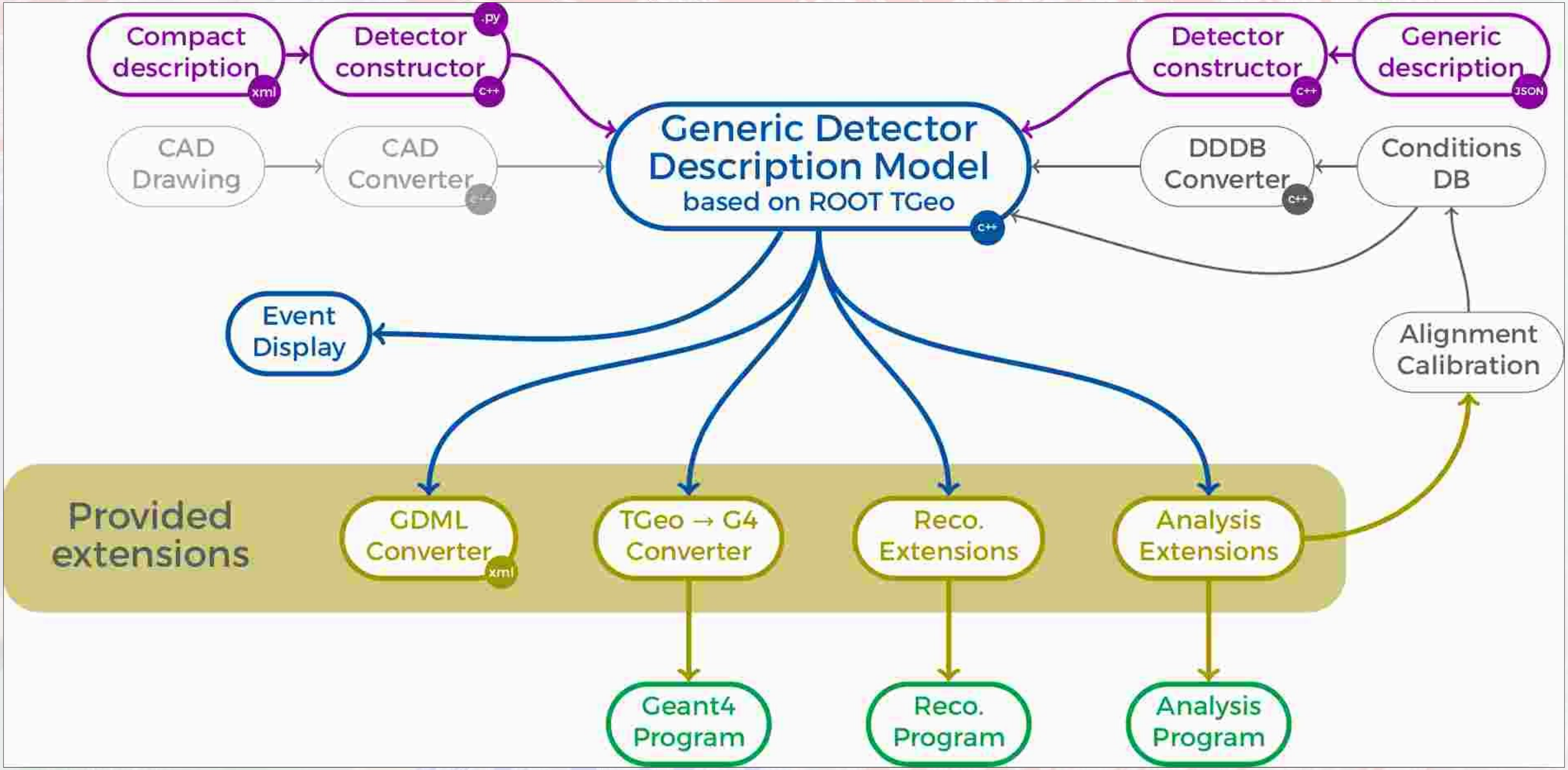
DD4hep

- Tree-like hierarchy of "detector elements"
  - Macroscopic (ie. not a strip)
  - Subdetectors or parts of subdetectors
- Detector Element
  - Geometry
  - Access to auxiliary data
    - Environmental data
    - Alignments
    - Derivatives of these
  - Optionally experiment, sub-detector or activity specific data

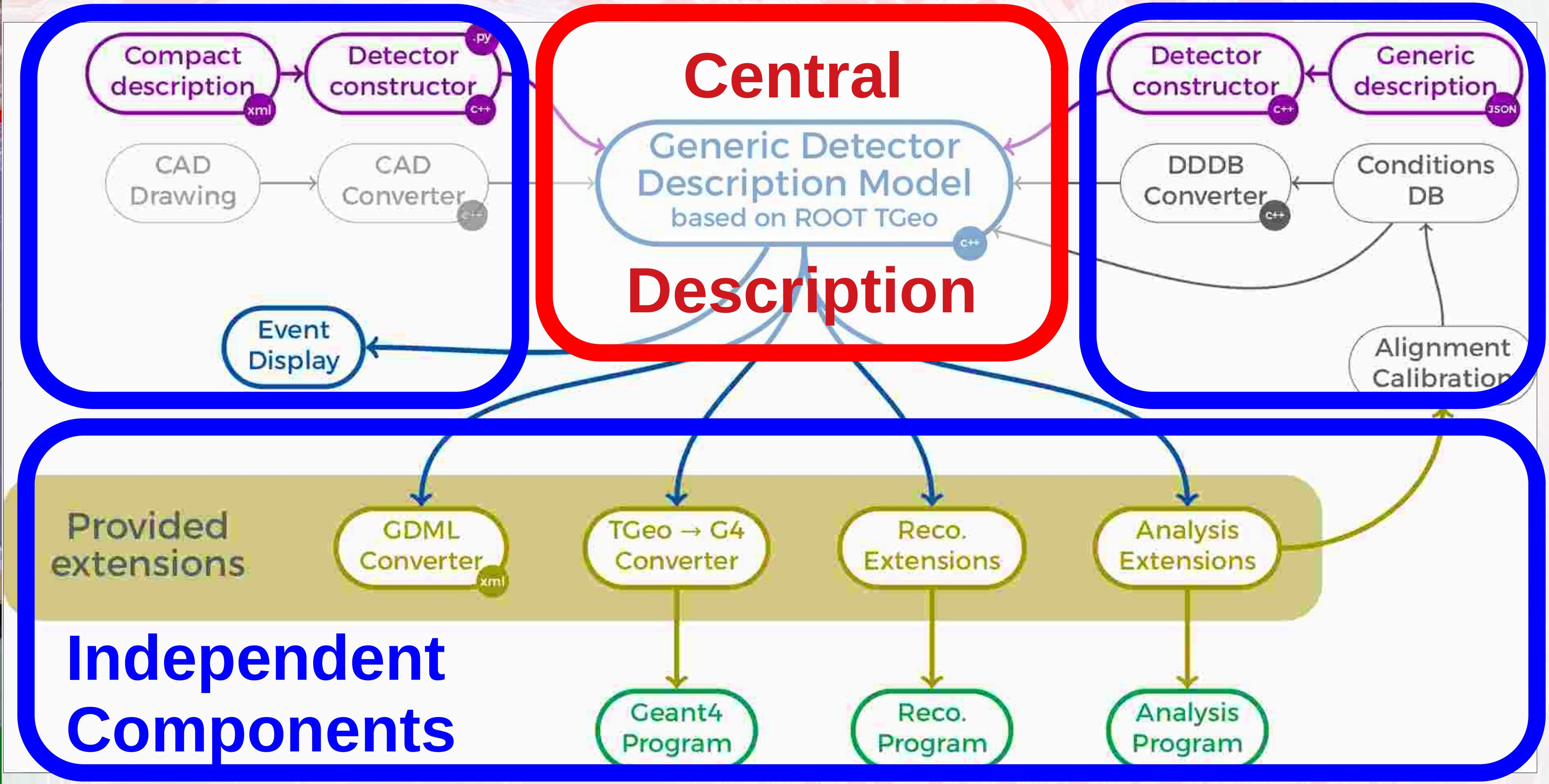


DD4Hep - The Big Picture

DD4hep



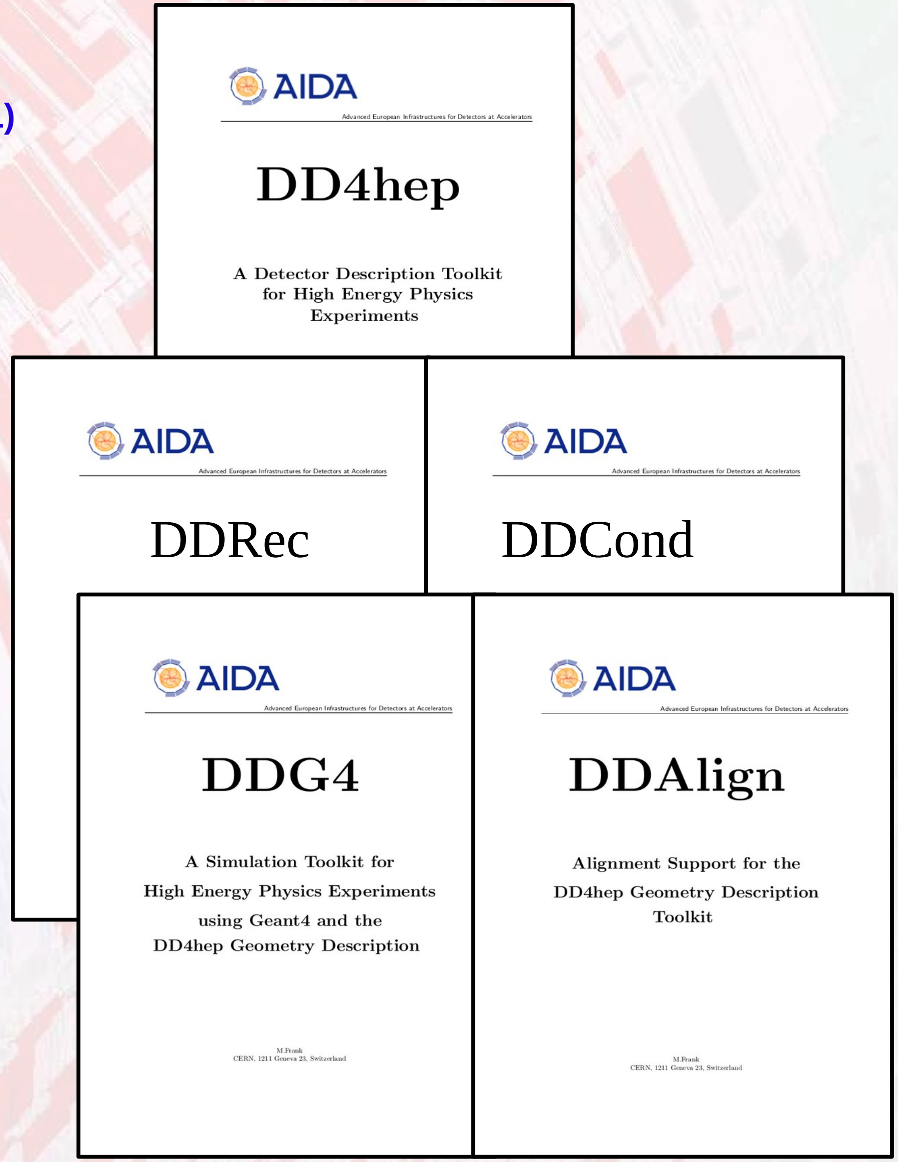
DD4Hep - The Big Picture



Saga in 6 Episodes

DD4hep

- **DD4hep – basics/core** (1)
- **DDG4 – Simulation using Geant4** (1)
  - **Fast simulation** (4)
- **DDRec – Reconstruction supp.** (2)
- **DDCond – Detector conditions** (3)
- **DDAlign – Alignment support** (3)
- **DDDigi – Generic Digitization** (4)


AIDA

Advanced European Infrastructures for Detectors at Accelerators

DD4hep

A Detector Description Toolkit for High Energy Physics Experiments

AIDA

DDRec

AIDA

DDCond

AIDA

DDG4

A Simulation Toolkit for High Energy Physics Experiments using Geant4 and the DD4hep Geometry Description

M.Frank

CERN, 1211 Geneva 23, Switzerland

AIDA

DDAlign

Alignment Support for the DD4hep Geometry Description Toolkit

M.Frank

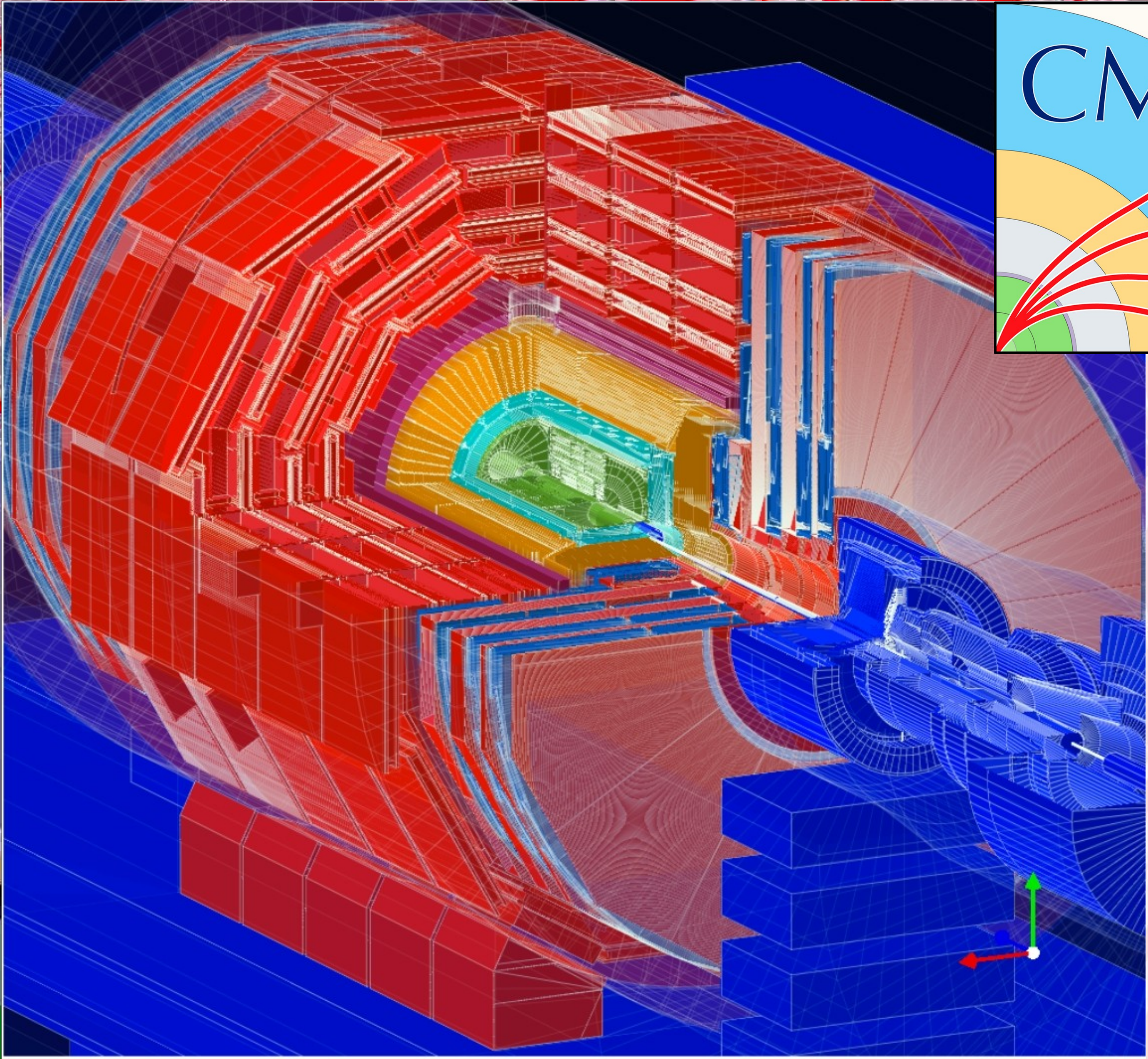
CERN, 1211 Geneva 23, Switzerland

(1) **Mature state: bug-fixes and maintenance**

(2) **F. Gaede (WP3, Task 3.6)**

(3) **Work since start of AIDA^{2020}**

(4) **Planned extensions**



CMS

DD4hep

CMS described with DD4hep

CHEP 2019, Adelaide, AU

(C.Vuosalo / CMS)

DD4hep Core

DD4hep

- Handles the detector element functionality
- Objects are fully reflective using Cling
  - C++ dictionary defined
  - Intrinsic support for cross-language development
  - Interactivity supported by ROOT (Cling, python-cppyy)

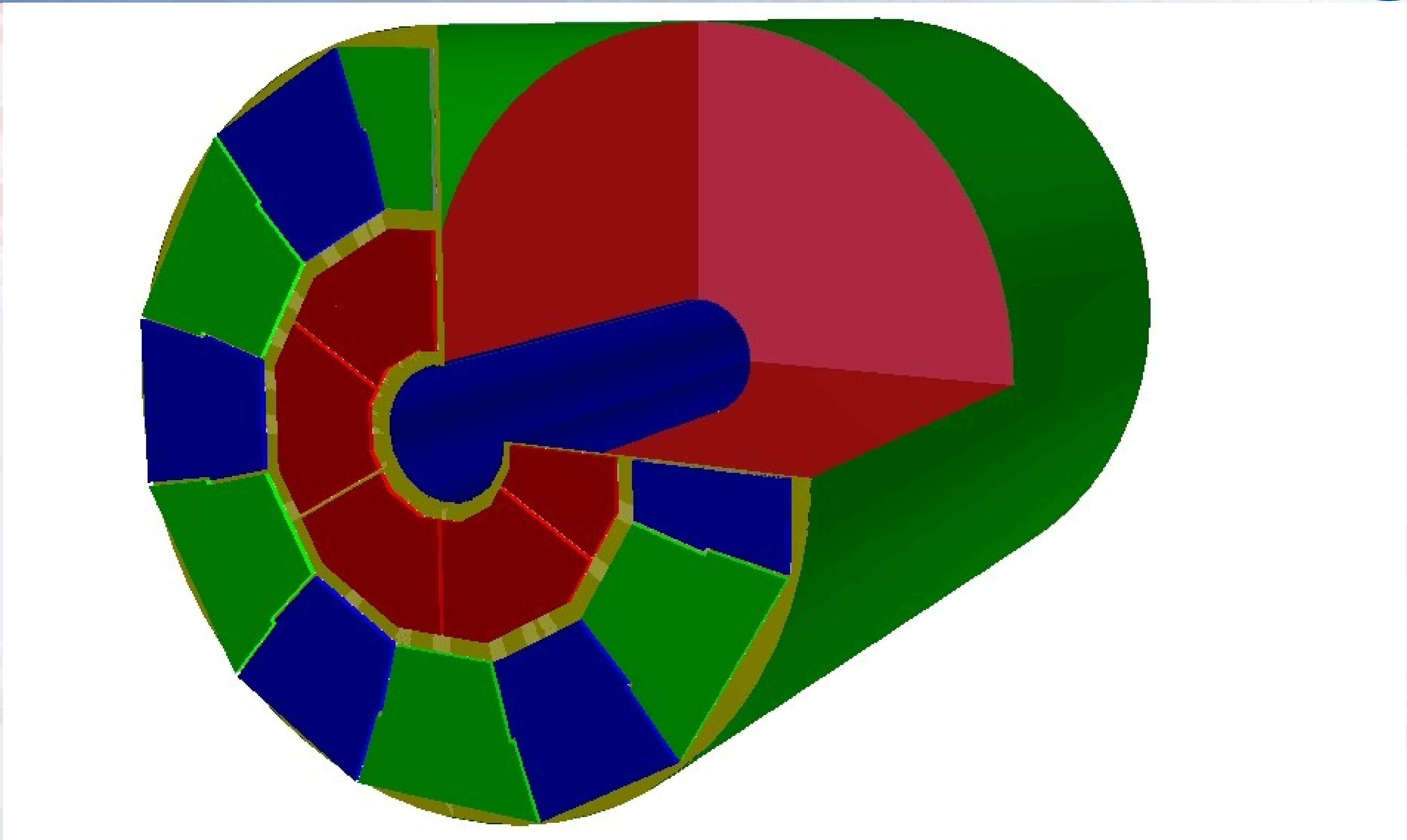
CHEP2013: DD4hep: A Detector Description Toolkit for High Energy Physics Experiments

Main Entities

DD4hep

- **Geometrical hierarchy**
  - **Volume:** — **Shape + Material**
  - **PlacedVolume** — **Volume + placement matrix → mother**
- **Structural hierarchy**
  - **Detector** — **Experiment**
  - **DetElement** — **Parts of the experiment**
- **The Structural hierarchy is what is normally in our imagination**
- **What is the difference between geometrical and structural hierarchy**
- **Remarks about the importance how to design such hierarchies**

Example: ALEPH TPC



$> geoDisplay -input examples/AlignDet/compact/AlephTPC.xml

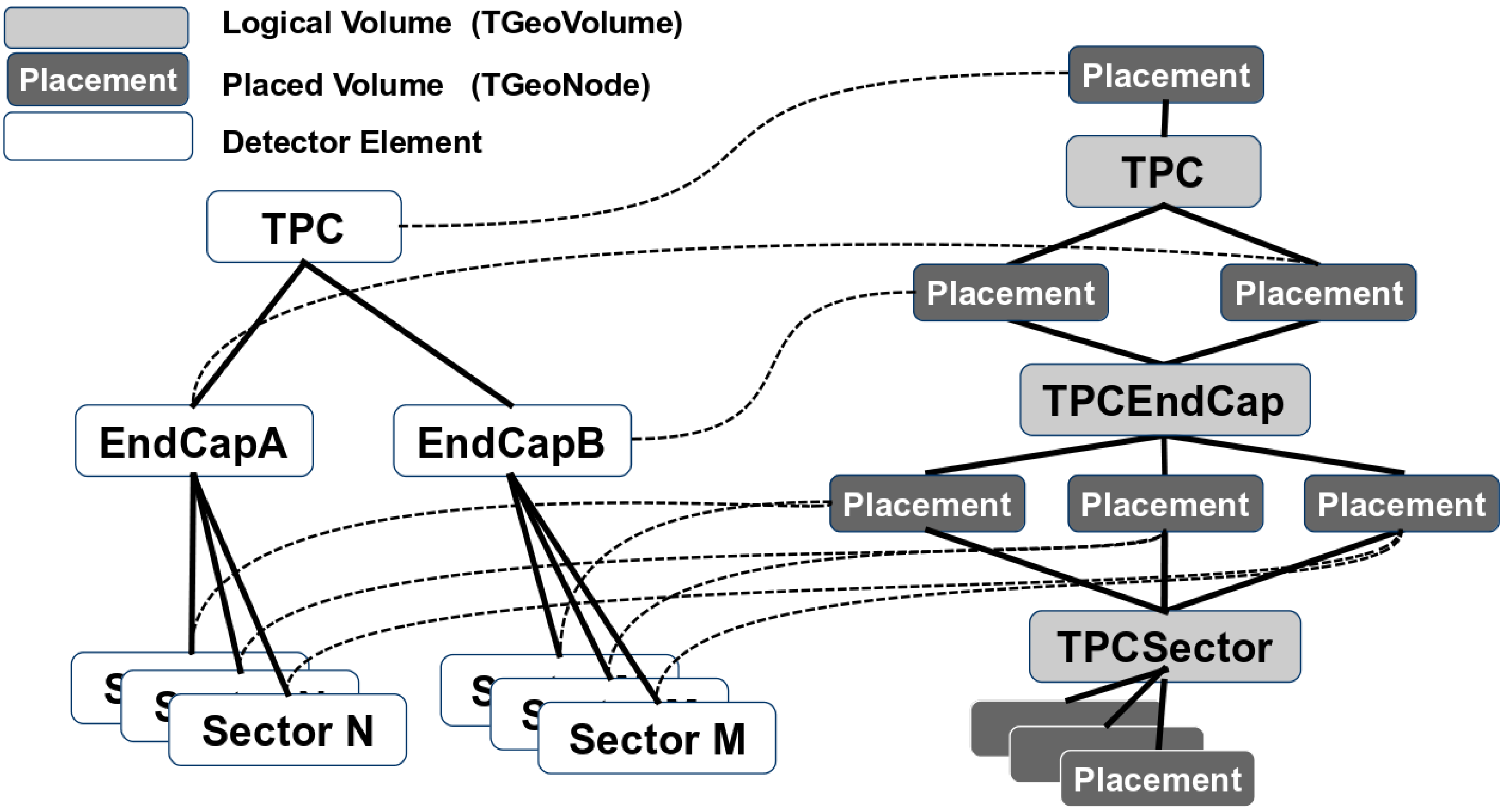
How to Define a Hierarchy

DD4hep

- We want reasonable hierarchies
  - Balanced trees: 5-20 children, NOT thousands
  - Important particularly for geometry:
    Geant4 will have the same layout and tracking with many daughters is expensive
- Structural hierarchy must fit the needs of reconstruction, calibration and analysis
- Hierarchy should be as simple as possible, but as complicated as necessary

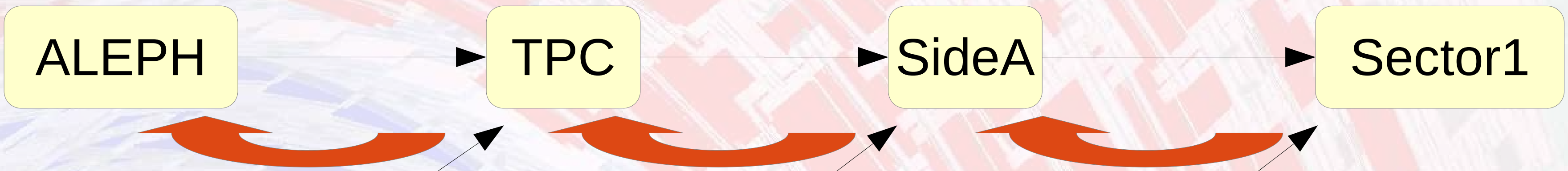
Structural and Geometrical Hierarchy

DD4hep



Why the Hierarchy Must be Effective: Alignment Overheads (Only one reason)

DD4hep



$$Tr^{World}_{Sec\,1} = Tr^{World}_{SideA} \times \left(Tr^{Parent(SideA)}_{Sec\,1} + \Delta_{Sec\,1}\right)$$

$$Tr^{World}_{SideA} = Tr^{World}_{Velo} \times \left(Tr^{Parent(Velo)}_{SideA} + \Delta_{SideA}\right)$$

$$Tr^{World}_{TPC} = 1 \times \left(Tr^{Parent(\aleph)}_{TPC} + \Delta_{TPC}\right)$$

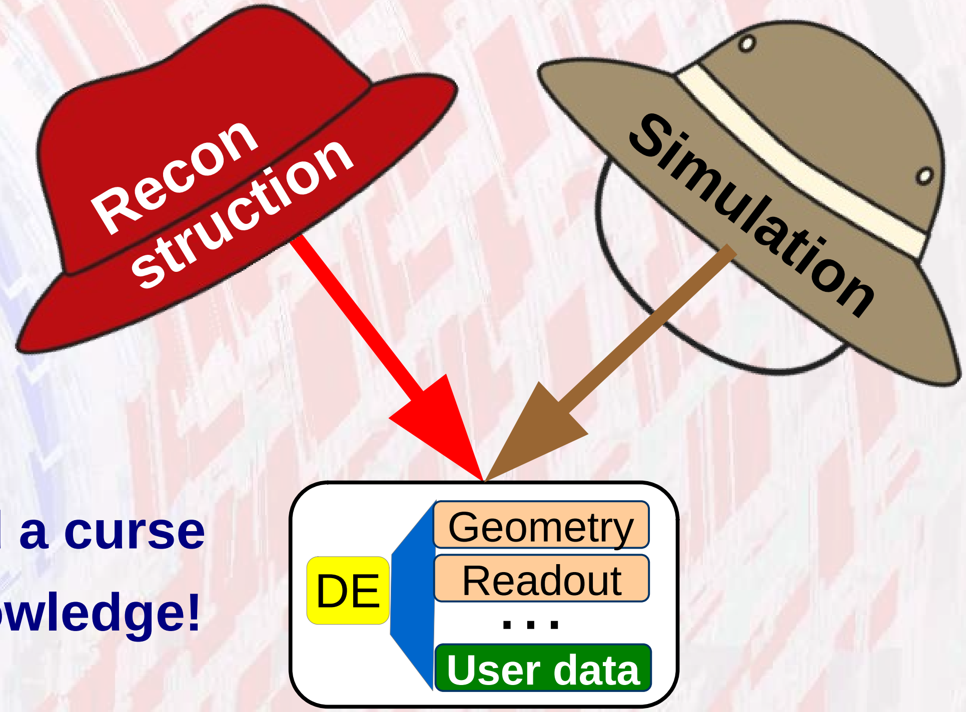
- Need to compute all matrices from the highest node shifted
- The deeper the hierarchy, the more matrices to be computed

Views & Extensions: Users Customize Functionality

DD4hep

DD4hep is based on handles (smart pointers)

- Rarely deal with data directly
- Possibility of many views based on the same DE data
  - Same ‘data’ associated to different ‘behaviors’
  - All views are consistent and creation is efficient: pointer-copy



- Possibility to extend data
  - Be prudent: a blessing and a curse
  - User data are common knowledge!

Simulation: DDG4

DD4hep

- **Simulation = Geometry +
  Detector response +
  Physics**
- **Mature status**
  - **Eventual bug fixes, smaller improvements**
  - **Phase of constant re-validation**
- **Automatic geometry conversion**
  - **Can be used also standalone in external frameworks (CMS, LHCb, FCC)**
- **Palette of standard sensitive detectors**
- **Support for MC truth handling**

CHEP 2015: DDG4 A Simulation Framework based on the DD4hep Detector Description Toolkit

Geant4 Provided Hooks

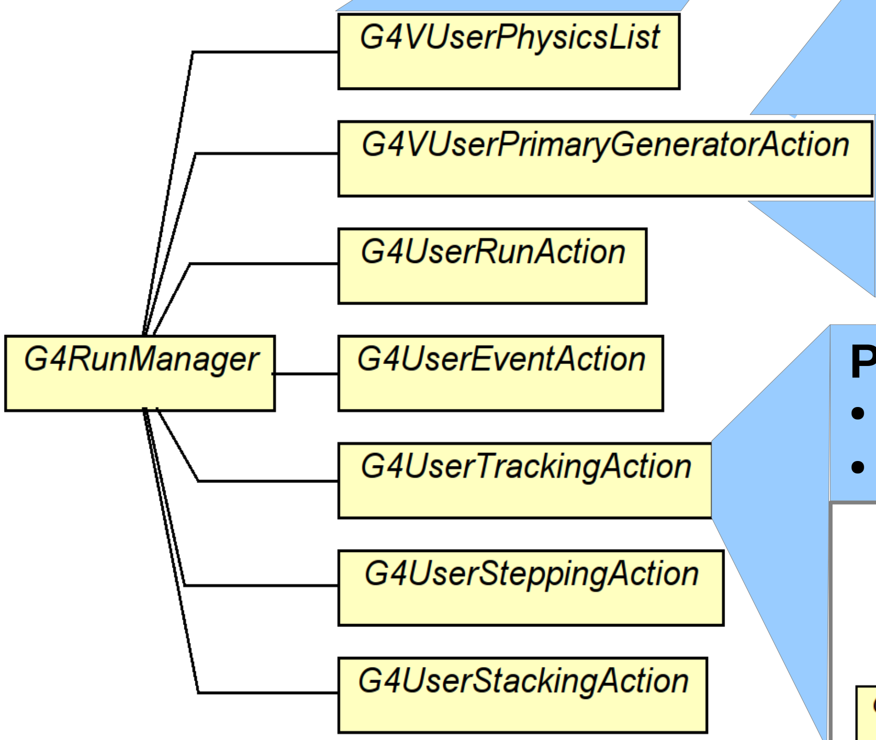
[and what we want to do inside]

DD4hep

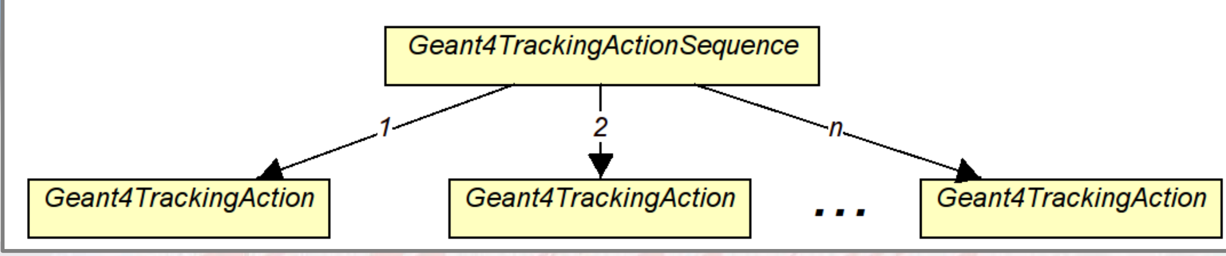
Main issue: flexible configuration

Flexible definition of the physics list
- Define particles, processes, physics constructors or use/extend predefined physics lists

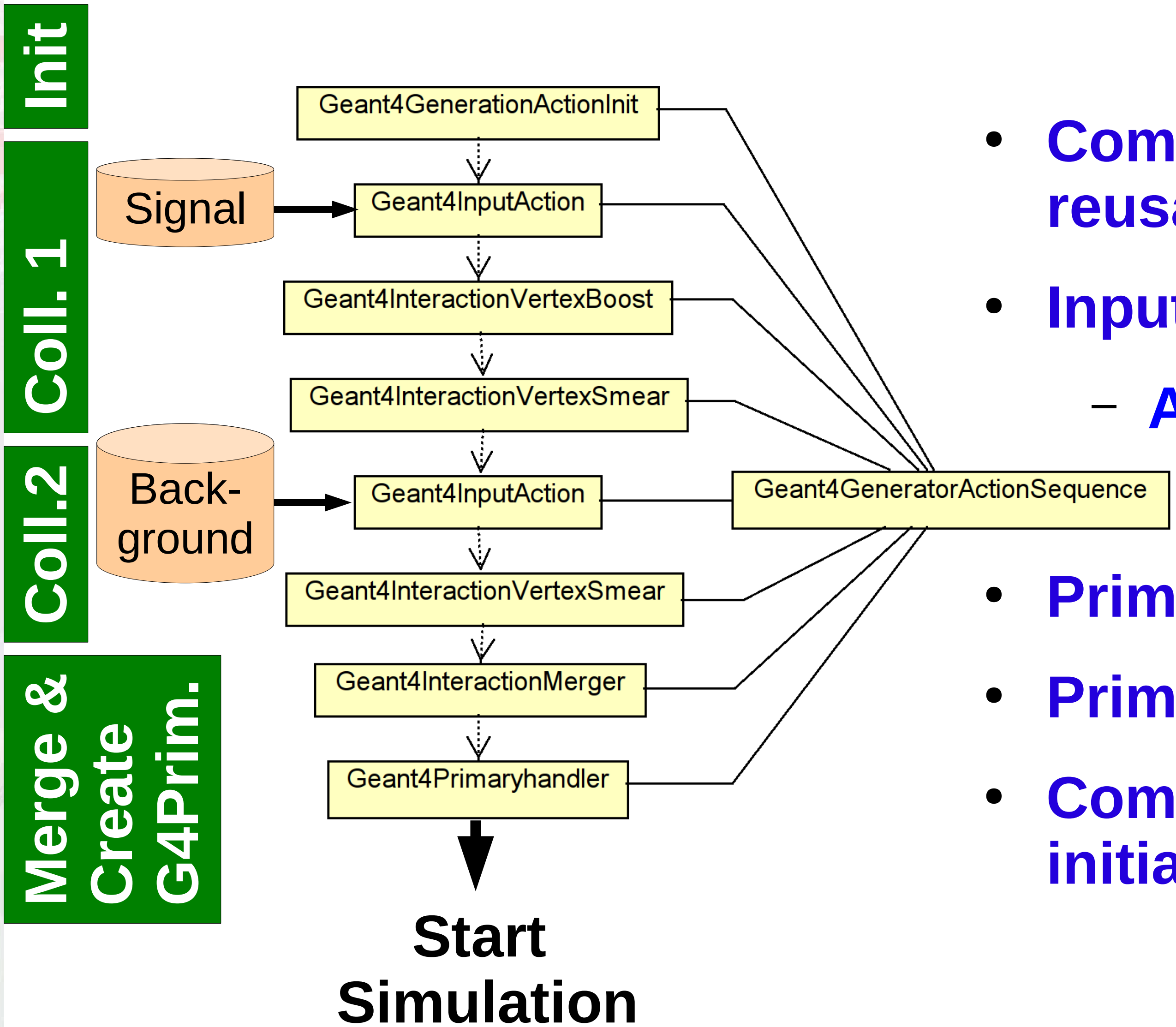
Flexible data input
- Programmable sequence. Input from particle gun, lcio, stdhep or HepMC (text) – easily extensible
- Modules to smear and boost primary vertices
- Modules to construct interaction overlays
- Further extensions may independently added



Provide user programmable sequences
- Either as explicit object type using ABC
- Or registering a member function as callback



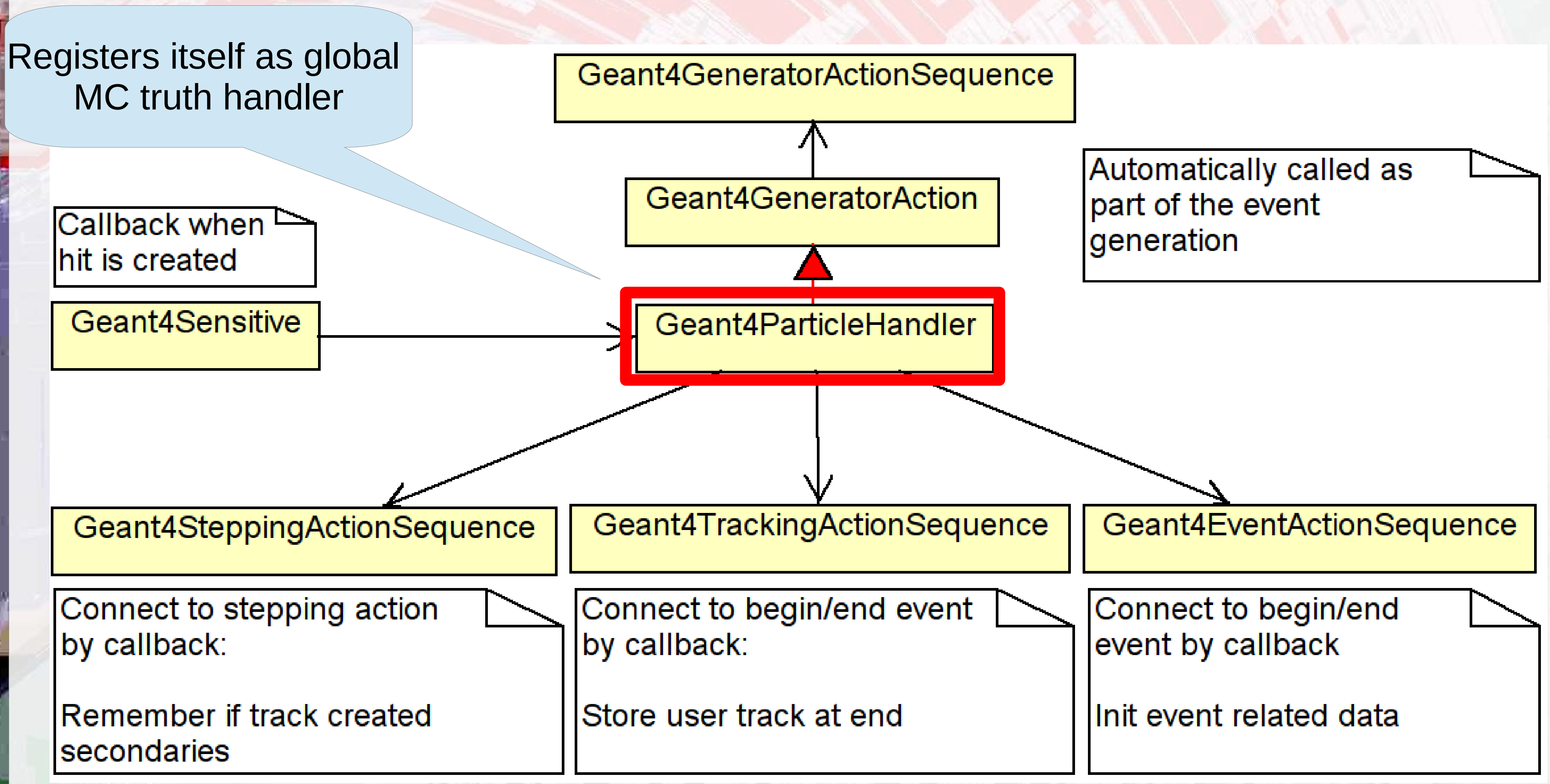
Example of an Action Sequence
Event Overlay with Features



- **Combine simple and reusable modules**
- **Input module**
  - **Any data format**
- **Primary vertex smearing**
- **Primary vertex boost**
- **Common: initialization, final merge**

Another Example:
MC Truth Handling (LC specific algorithm)

DD4hep



External Framework Support

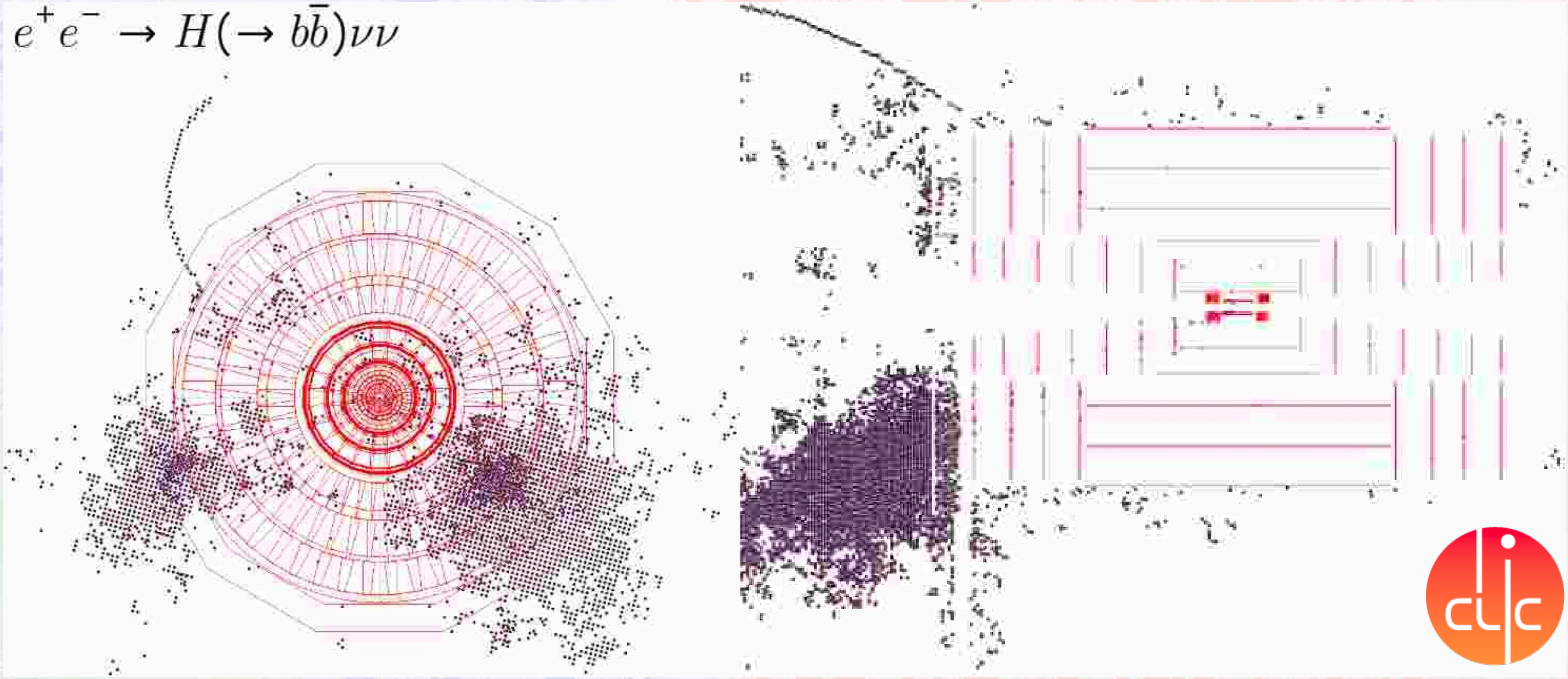
DD4hep

- 2 possibilities
  - DDG4 (Geant4) takes over event loop from framework
  - Framework steers event loop (overloading run manager)
- Everything is a plugin (or could be made one)
  - External frameworks can overload all central entities
  - G4RunManager
  - Geant4 action routines
  - Physics …
- External framework context
  - Typed pointer available to every user action
  - User defined structure allows to interact with any framework service: histograms, I/O, etc.

DDG4 in Production

DD4hep

- **Example from CLICdp**
  - **For multiple detector studies**
- **ILC started mass production**



Standard Detector Palette DDDetectors

DD4hep

- Used for design studies (LC, FCC-eh)
- Origin from the SiD detector model
  - Layer/disk based trackers
  - Layered tracker barrel & endcap
  - Several calorimeter constructs
- Partially with measurement surfaces (F. Gaede)
  - Uses plugin mechanism to enhance detector elements
    - Non intrusive mechanism to attach user defined optional data

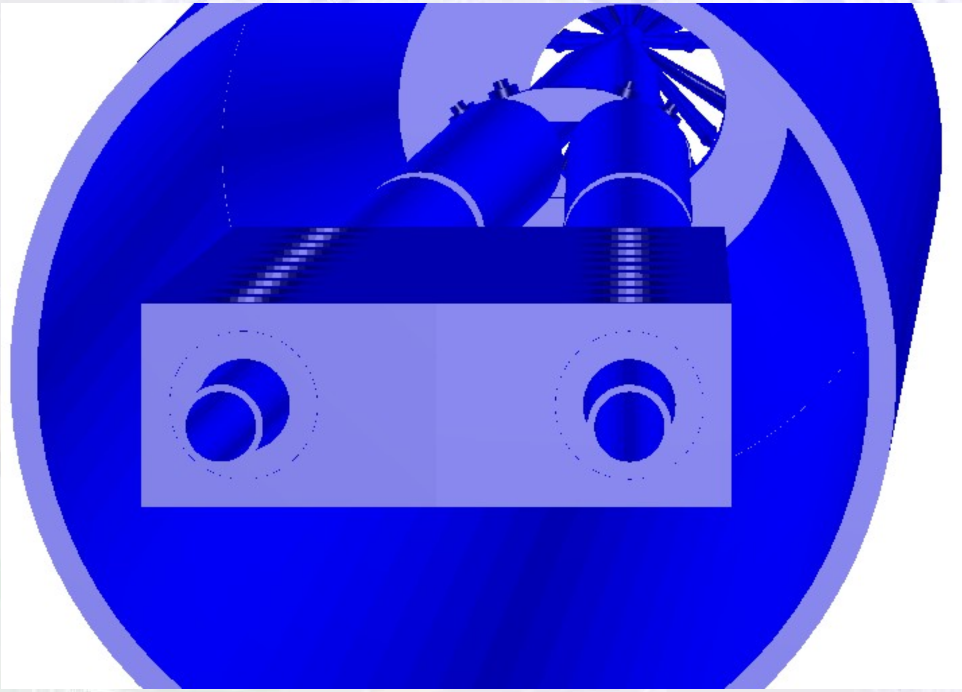
      => 'anticipate the unforeseen'
- Sensitive volumes identified by CellID: up to the pixel
  - Sensitive volume path reduced to 64 bit number (CellID)
  - CellID in simulated hit + detector description → placement

CAD Import, Export and Round-Trips

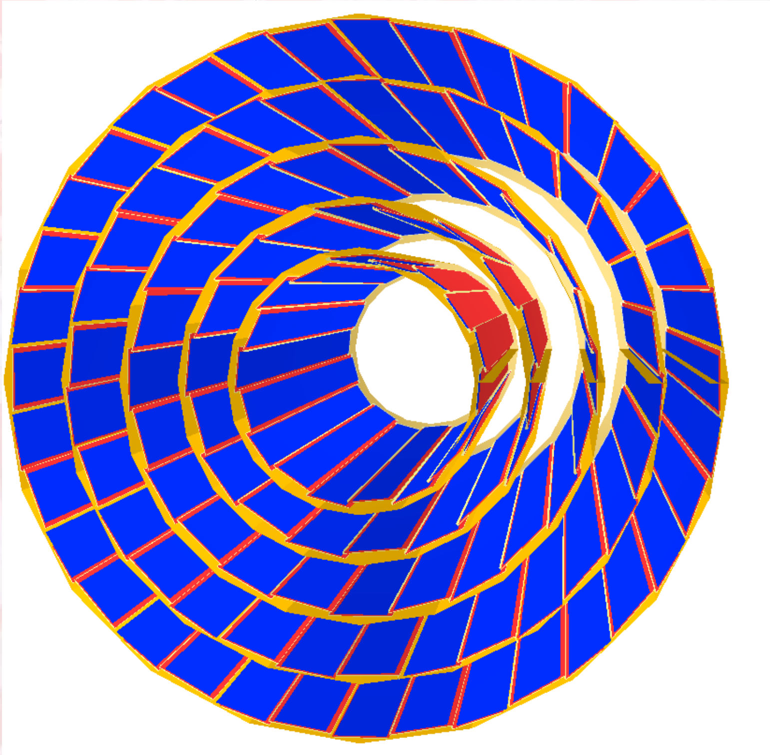
DD4hep

- **If supported by Assimp, DD4hep supports**
  - **Import of shapes/volumes defined in CAD files into DD4hep**
  - **Export of partial geometries to CAD format**

Import from CAD (STL)



Round-trip:
DD4hep / TGeo => CAD => TGeo



CAD: Limitations and Remarks

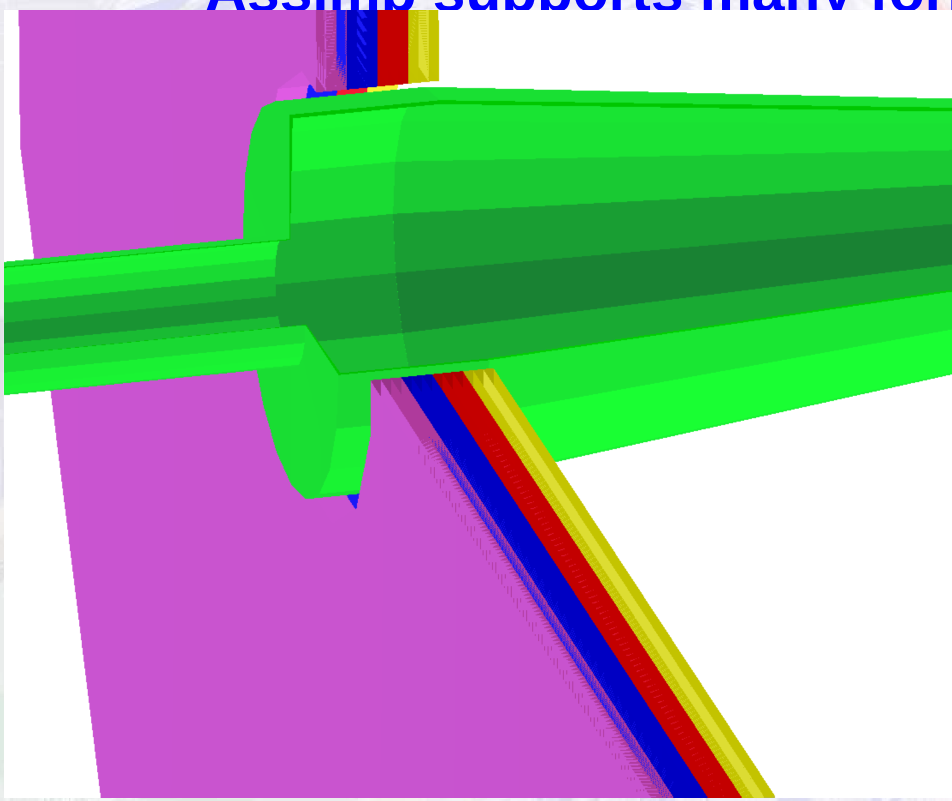
DD4hep

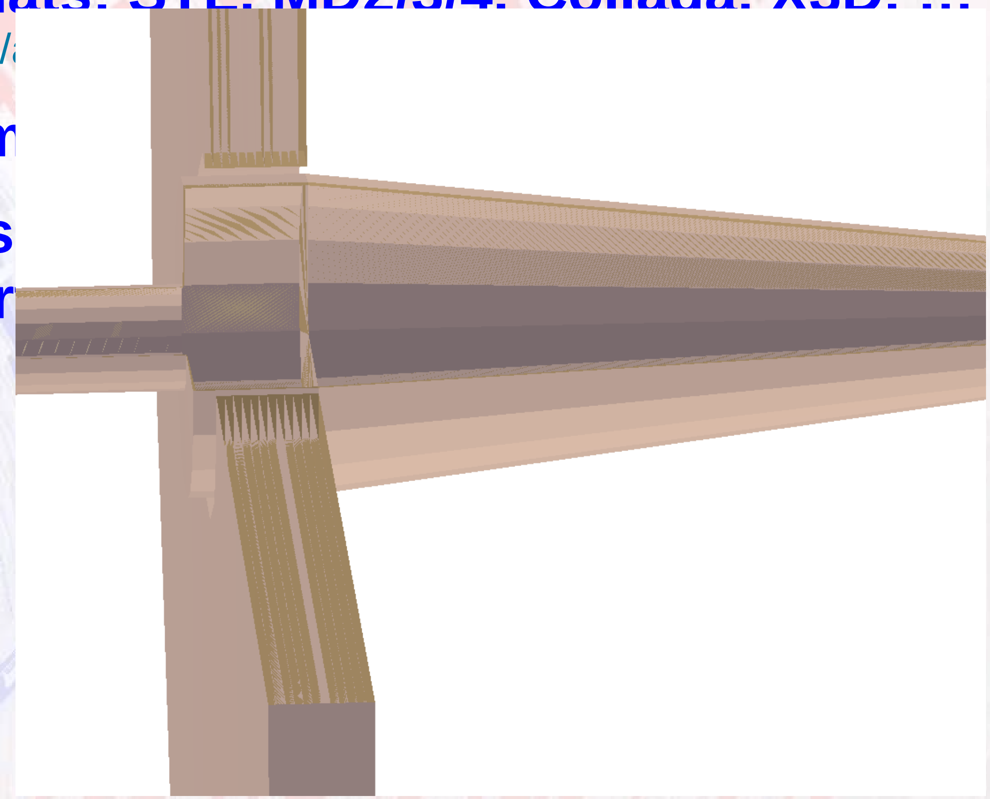
- **CAD Meshes are complex**
  - **Limitation of the total number of manageable vertices/facets**
- **CAD comes in many dialects**
  - **Assimp supports many formats: STL, MD2/3/4, Collada, X3D, …**
    For details see: https://github.com/assimp/assimp/tree/master/code/AssetLib
  - **Single mesh CAD, multiple mesh CAD**
  - **Not all support materials, visualization attributes etc.**
    Need to be injected by import mechanism

CAD: Limitations and Remarks

DD4hep

- **CAD Meshes are complex**
  - **Limitation of the total number of manageable vertices/facets**
- **CAD comes in many dialects**
  - **Assimp supports many formats: STL, MD2/3/4, Collada, X3D, …**





CAD: Limitations and Remarks

DD4hep

- CAD Meshes are complex
  - Limitation of the total number of manageable vertices/facets
- CAD comes in many dialects
  - Assimp supports many formats: STL, MD2/3/4, Collada, X3D, …
    For details see: https://github.com/assimp/assimp/tree/master/code/AssetLib
  - Single mesh CAD, multiple mesh CAD
  - Not all support materials, visualization attributes etc.
    Need to be injected by import mechanism
- Round-trips are not unambiguously reversible
  - Example: Tube => Tessellated cannot be converted back
- Include complicated passive shapes undergoing complicated machining

Toolkit Users

DD4hep

Increasing interest in the HEP community

- ILD F. Gaede et al.
- CLICdp A. Sailer et al.
- SiD D. Protopopescu et al.
- FCC-eh P. Kostka et al.
- FCC-hh A. Salzburger et al.
- FCC-ee O. Viazlo (CLD design), N. Alipour, G. Voutsinas
- SCTF Super-Charm-Tau Factory designs (Novosibirsk, Bejing)
- EIC/Athena W. Armstrong et al.
- CEPC Used for design studies (W. Li et al., IHEP)
- CALICE Calorimeter R&D, started

- LHCb LHCb Upgrade for Run III (B.Couturier et al.)
- CMS Usage for upgrade - CHEP2020 (C.Vuosalo et al.)

Rules Learned from Client Support

DD4hep

- **Linear Collider Community**
  - **Participation in development: By construction no conflicts**
- **CMS**
  - **Active participation in meetings etc: quite smooth transition**
  - **Required extensions: Reflections, LH coordinate systems, …**
- **LHCb**
  - **Attempts to tweak DD4hep and components**
- **FCC (and nearly all other)**
  - **Smooth, eventual participation in meeting for topical problems**
  - **Help to accommodate ACTS**

Basic lesson: If you need to extensively tweak a tool, think twice before you use it!

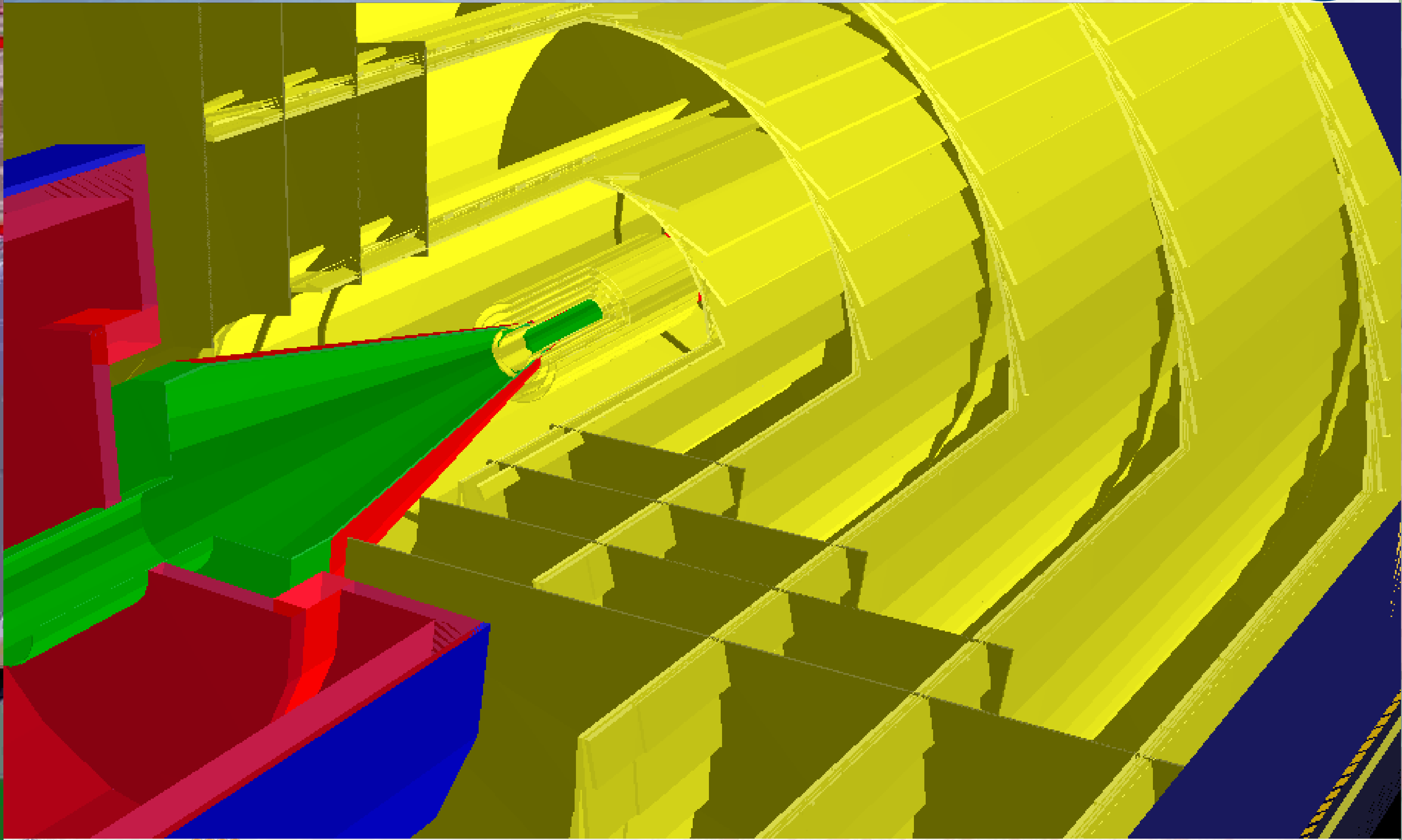
Summary

DD4hep

- I hope I could give you some short introduction how to use DD4hep to build a Detector
- Some insights on DD4hep's view to simulation
- Visit us on:
  - `http://dd4hep.cern.ch`
  - Up to date doxygen information
  - User Manuals: have improved but not perfect

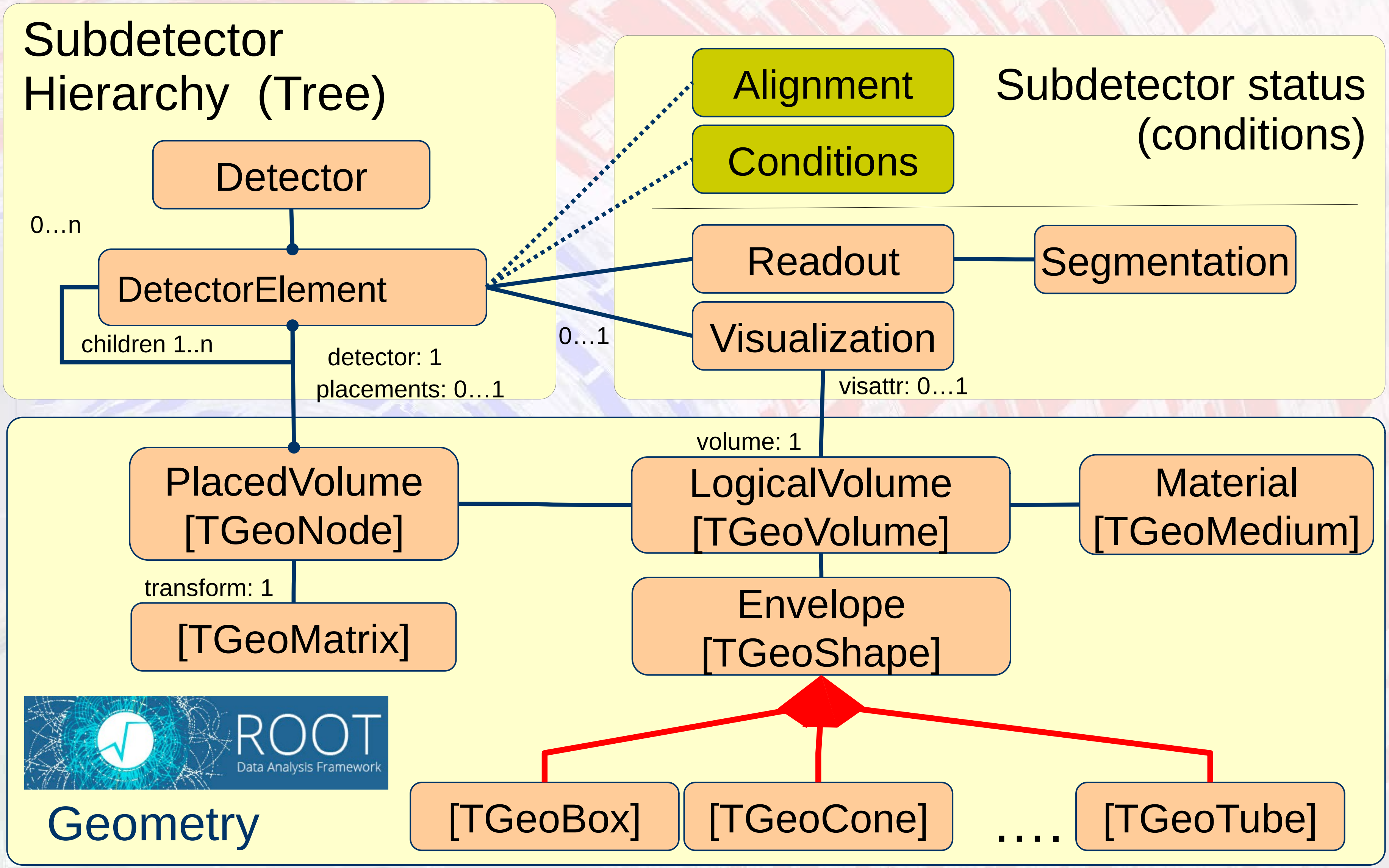
Questions and Answers

DD4hep

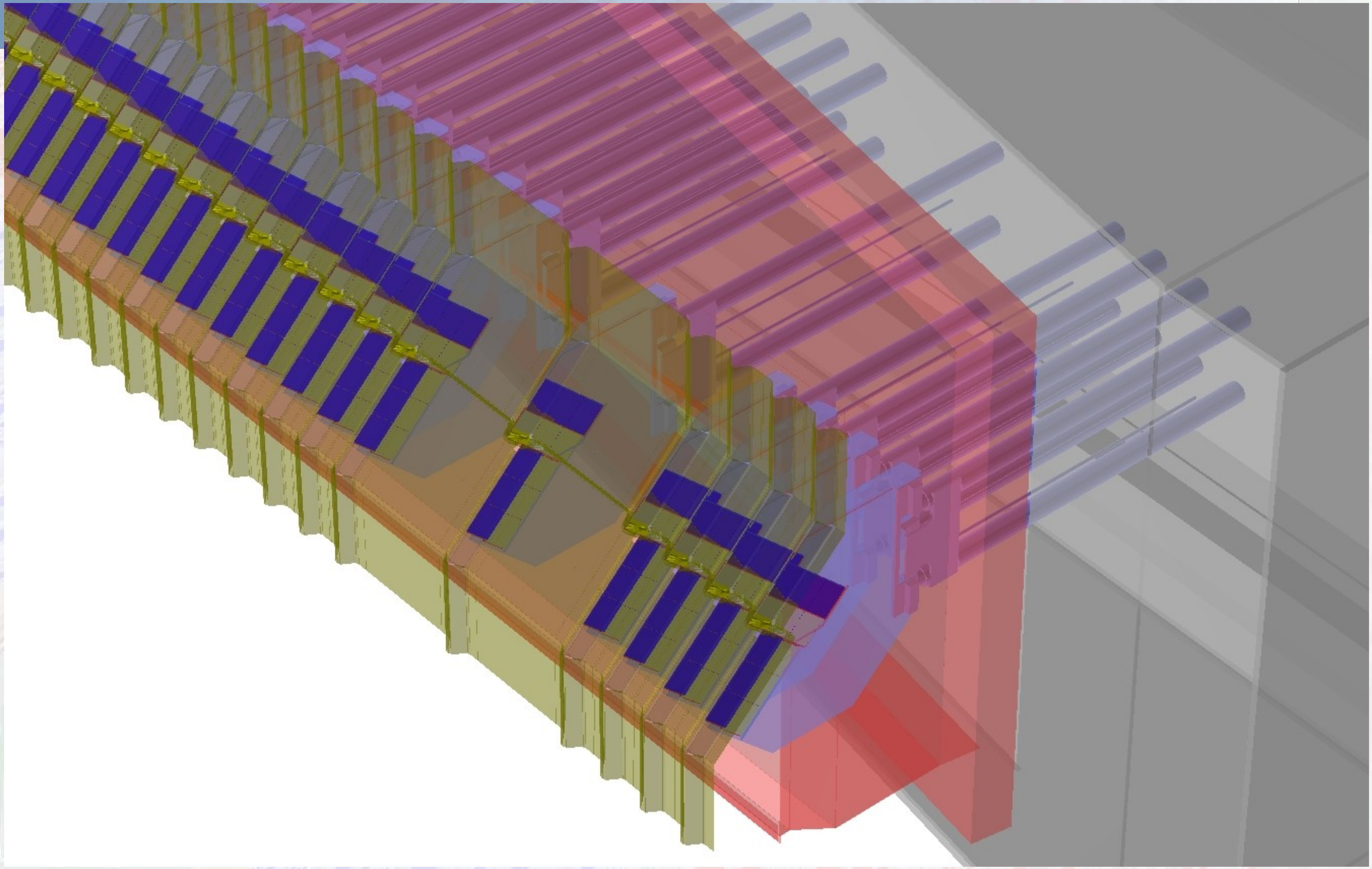


Class Diagram: Detector Element Sort of Standard...

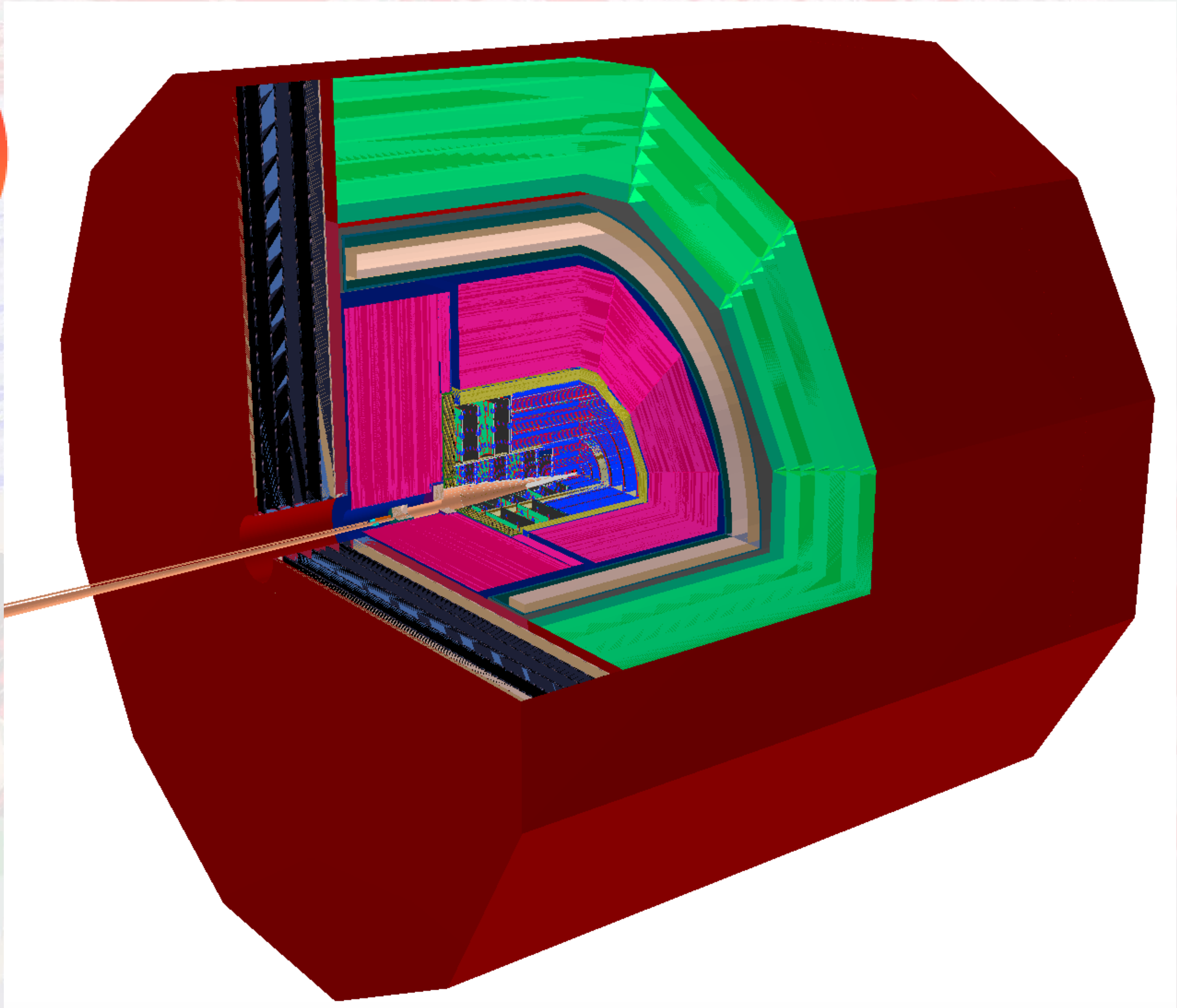
DD4hep



Velo Pixel: One Side

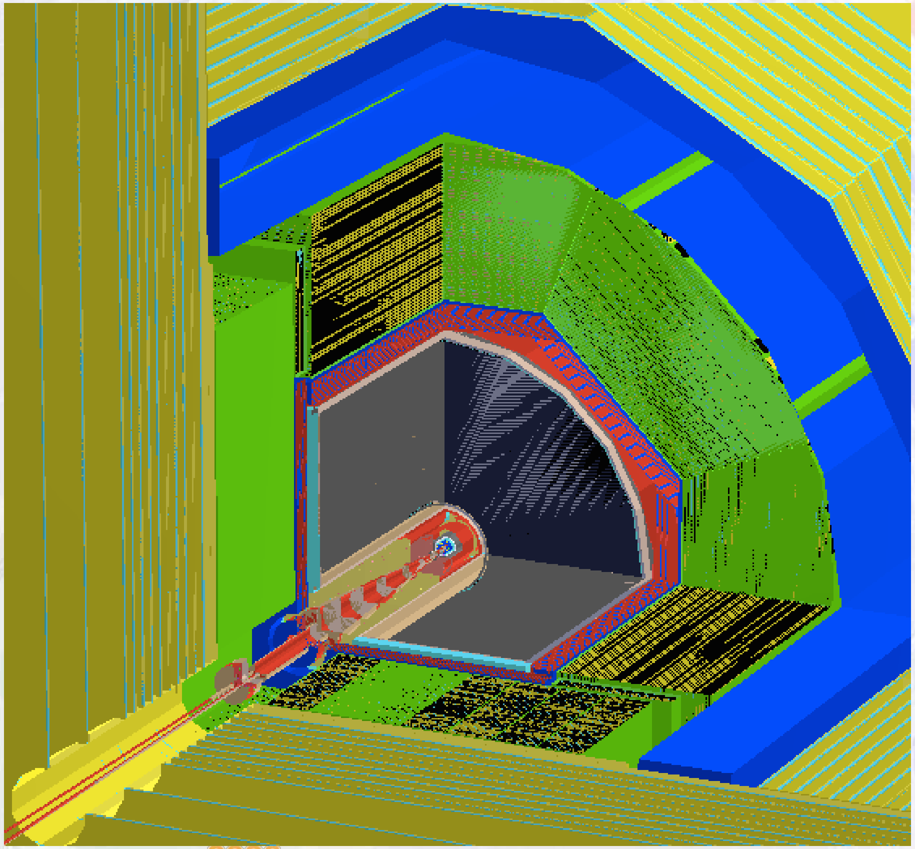


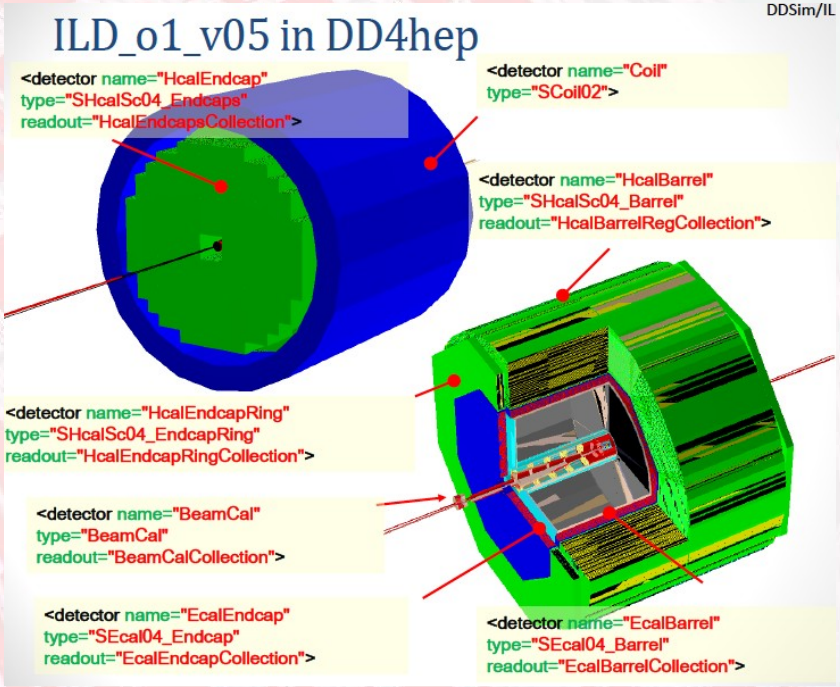
PR: CLICdp

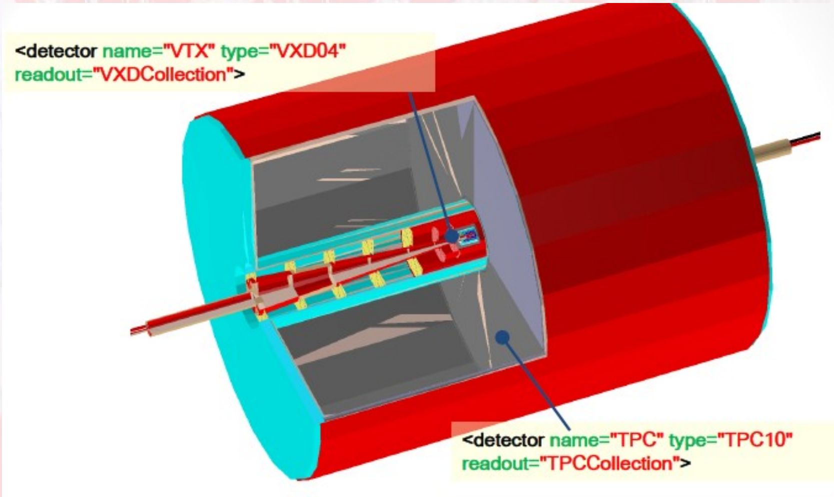


ILD Model ILD_o1_v05

(F.Gaede, L.Shaojun)







SCTF - Novosibirsk

L. Shekhtman, A. Sokolov, Vijayanand KV, T. Maltsev
Budker Institute of Nuclear Physics (BINP)

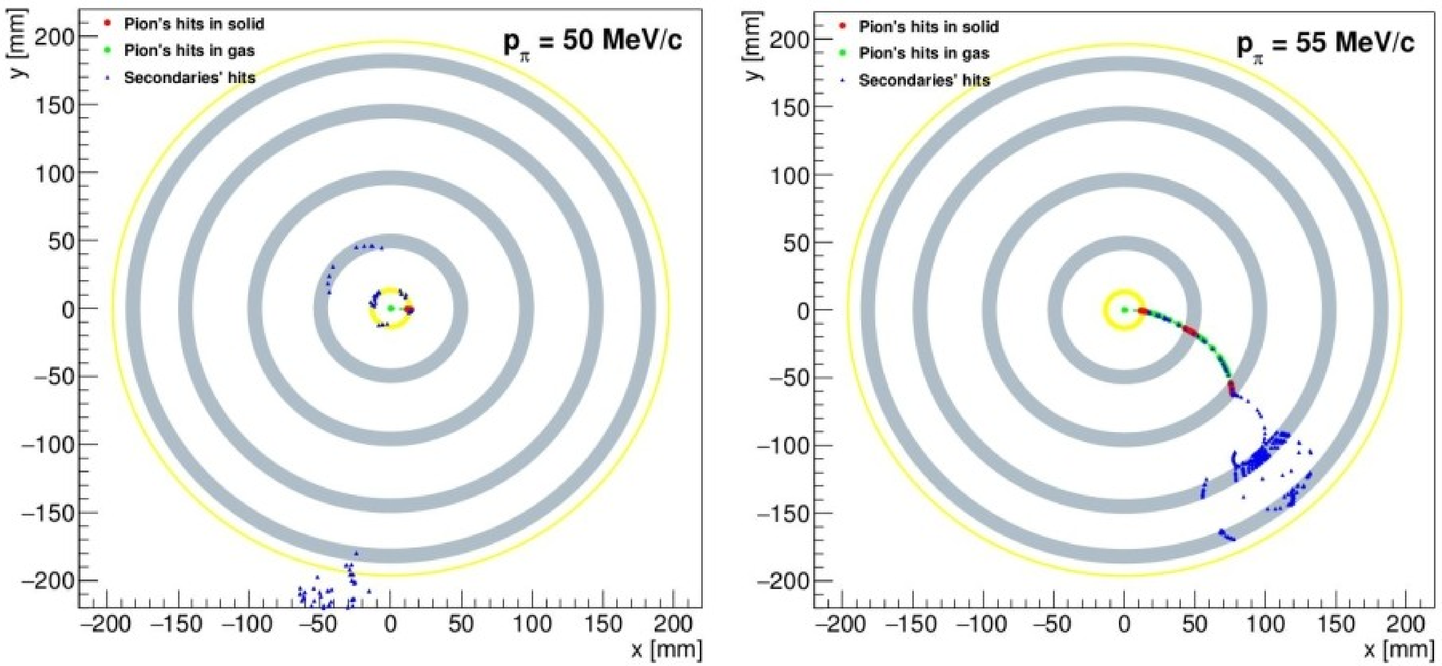
Joint Workshop on Future Tau-Charm Factory
2018.12.4-2018.12-7, Paris

DD4hep

Inner Tracker

DD4hep simulation

CGEM



- Pions with momenta less than 50 MeV/c do not pass through the beampipe
- Starting from p_π = 55 MeV/c two layers can be reached by pions

12

SCTF - Bejing

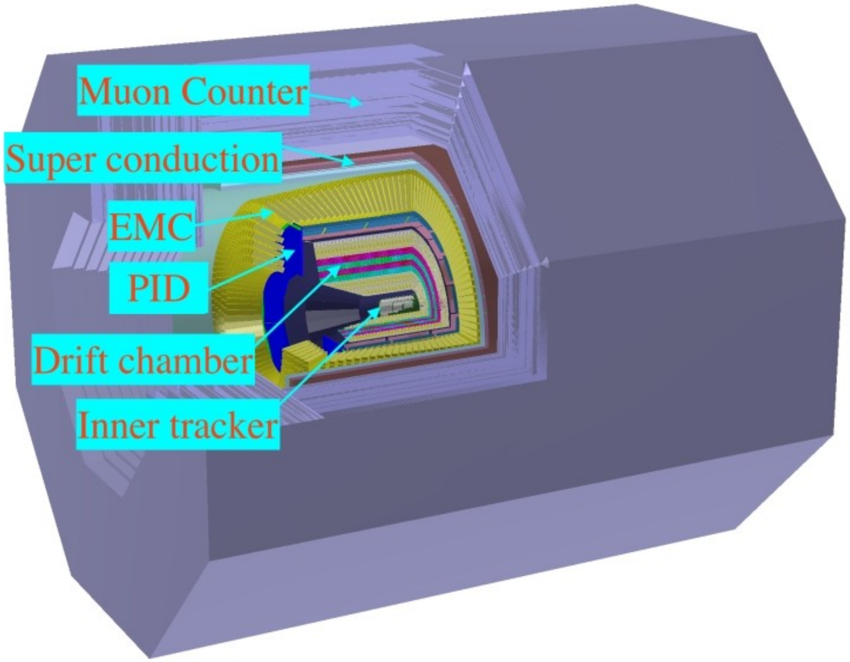
Xiaorong Zhou
State Key Laboratory of Particle Detection and Electronics
University of Science and Technology of China

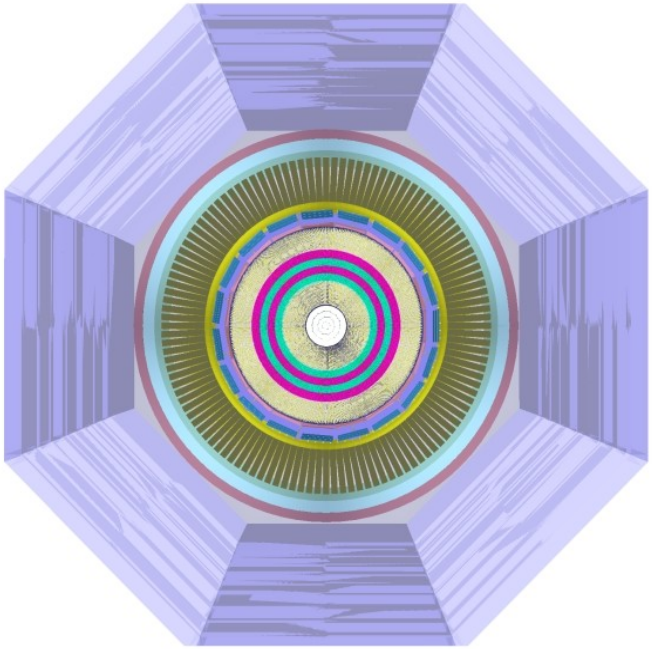
Joint Workshop on Future Tau-Charm Factory
2018.12.4-2018.12-7, Paris

DD4hep

Progress on detector simulation

- STCF software team has been formed.
- OSCAR: Offline Software of Super Tau-Charm Facility.
- Detector geometry with DD4hep.





18