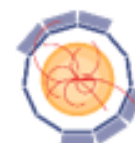


HEP detector description supporting the full experiment life cycle

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



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

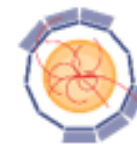


AIDA²⁰²⁰

- **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.



AIDA²⁰²⁰

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

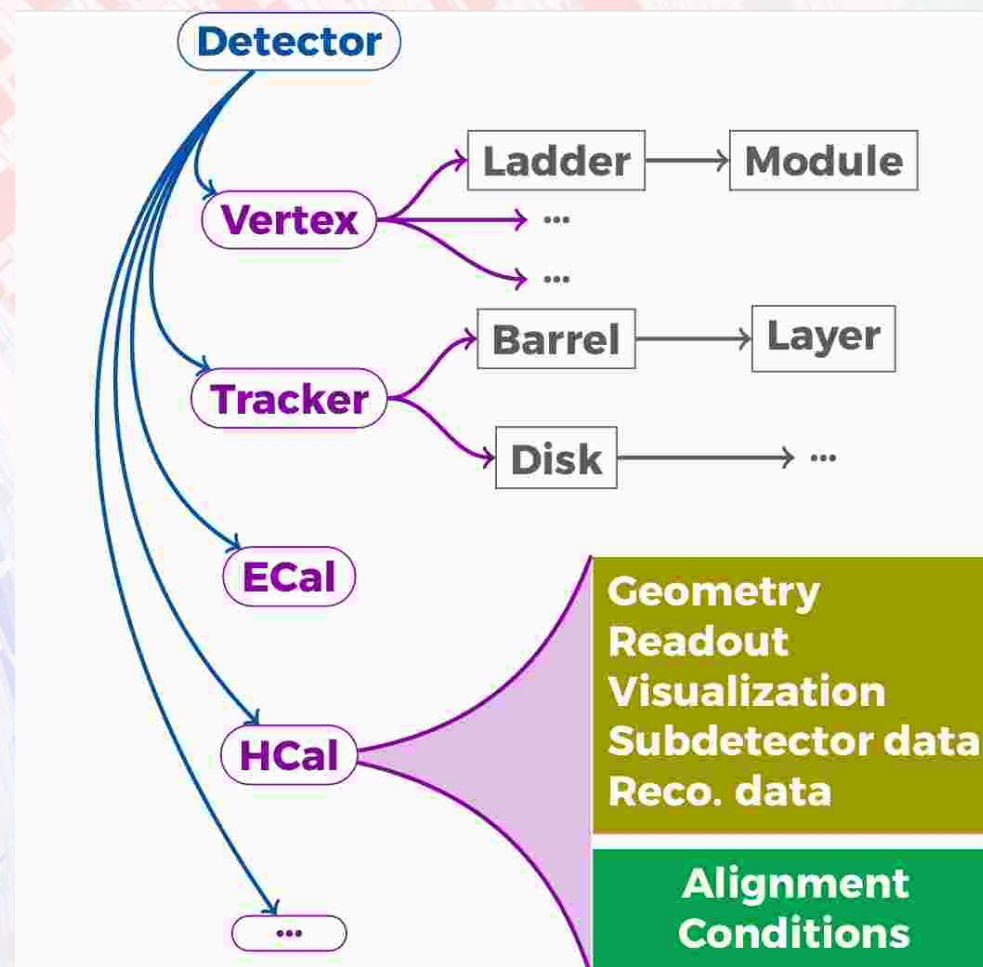
Detector description for the lazy

Minimal effort, pragmatic, no technical restrictions,
No obstacles induced by religious wars

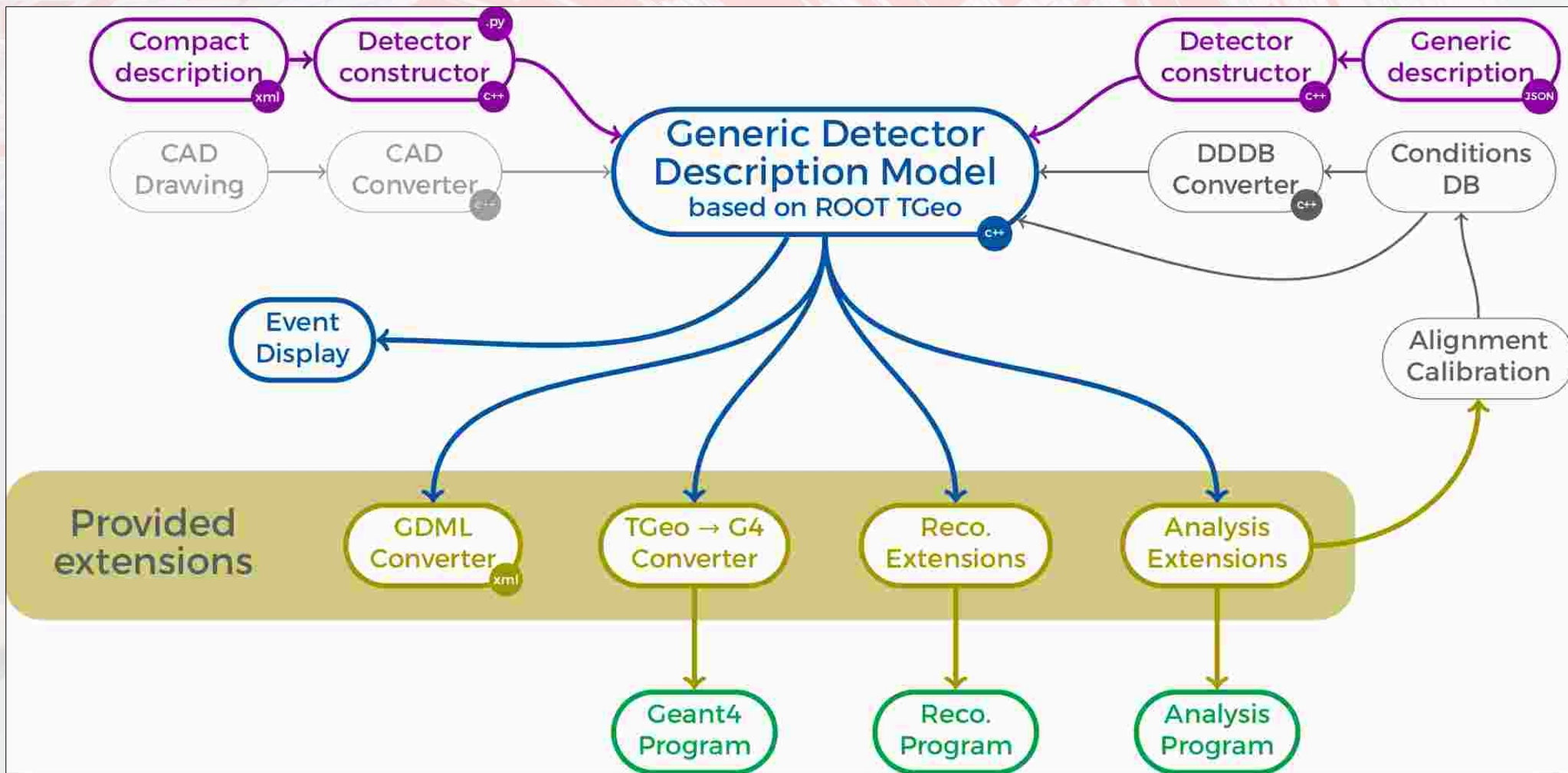
- **DD4hep is the “glue”**
 - **Bring together what belongs together:
Detector structure, geometry, simulation, conditions, etc**
 - **Reuse existing modules: TGeo, Geant4, GitCondDB, etc**
- **‘Responsible’ users highly welcome**
- **Contributions even more!**

What is Detector Description ?

- **Tree-like hierarchy of “detector elements”**
 - Macroscopic (ie. not a strip)
 - Subdetectors or parts of subdetectors
- **Detector Element**
 - Geometry
 - Properties to process events
 - Environmental data
 - Alignments
 - Derivatives of these
 - Optionally experiment, sub-detector or activity specific data



DD4Hep - The Big Picture



Saga in 5 Episodes

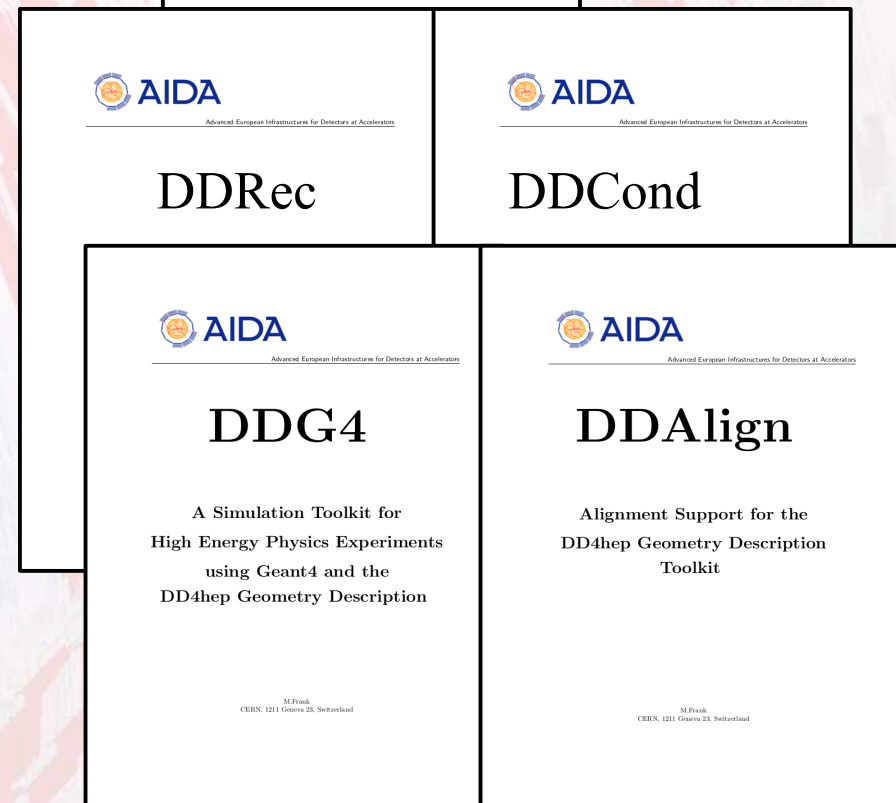
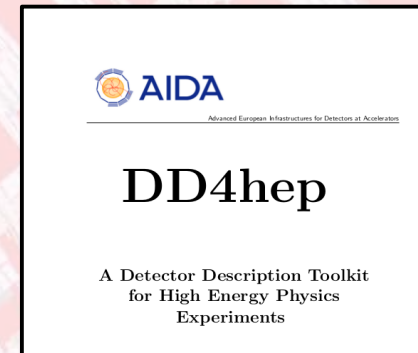
- **DD4hep – basics/core** ⁽¹⁾
- **DDG4 – Simulation using Geant4** ⁽¹⁾
 - **Fast simulation** ⁽⁴⁾
- **DDRec – Reconstruction supp.** ⁽²⁾
- **DDCond – Detector conditions** ⁽³⁾
- **DDAlign – Alignment support** ⁽³⁾
- **DDDigi – Generic Digitization** ⁽⁴⁾

⁽¹⁾ Mature state: bug-fixes and maintenance

⁽²⁾ F. Gaede (WP3, Task 3.6)

⁽³⁾ Work since start of AIDA²⁰²⁰

⁽⁴⁾ Planned extensions



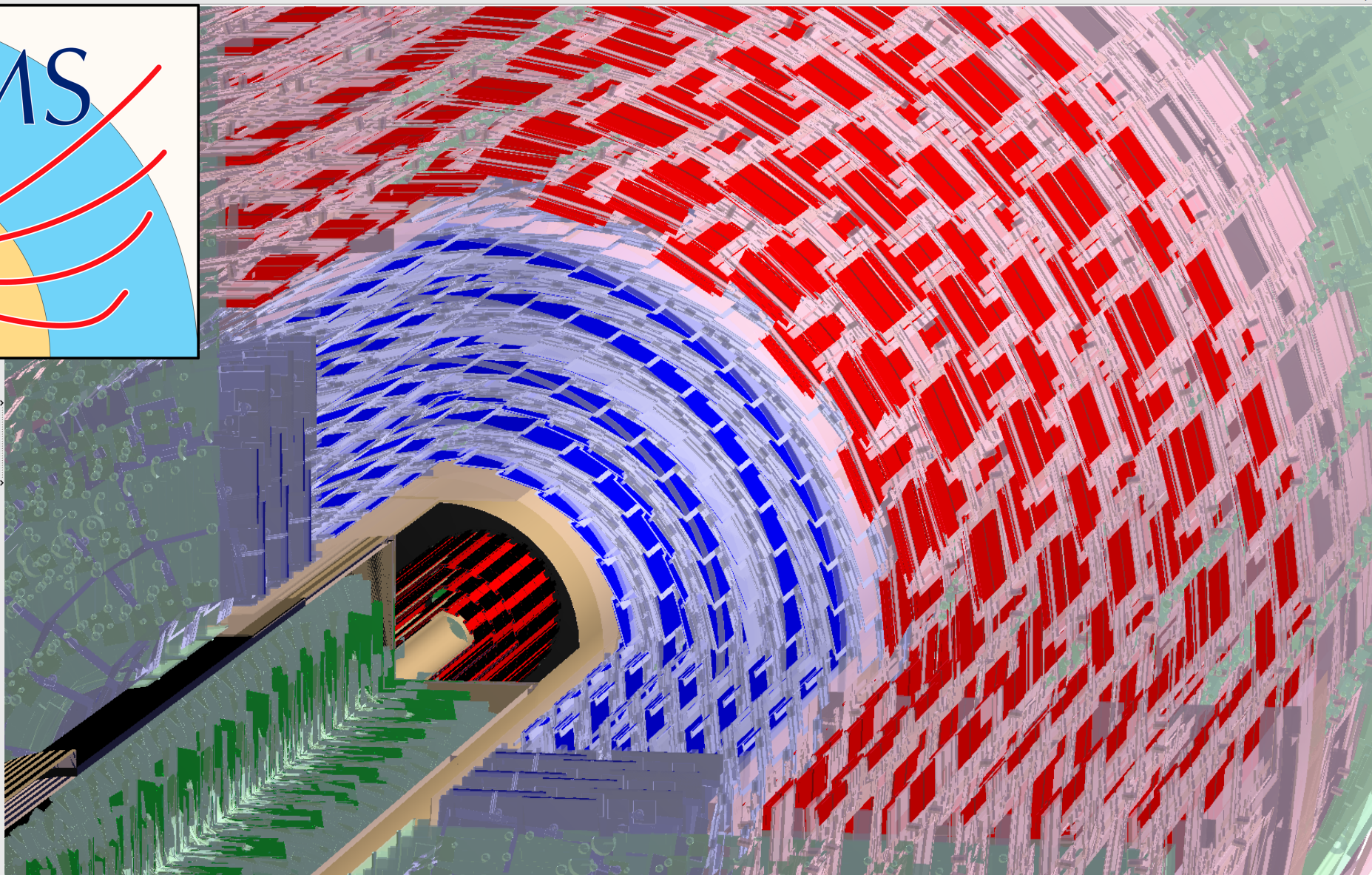
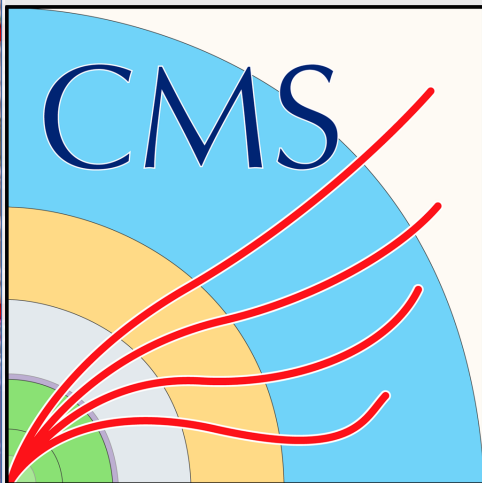
PR: CMS Trackers

DD4hep

ROOT's GL viewer

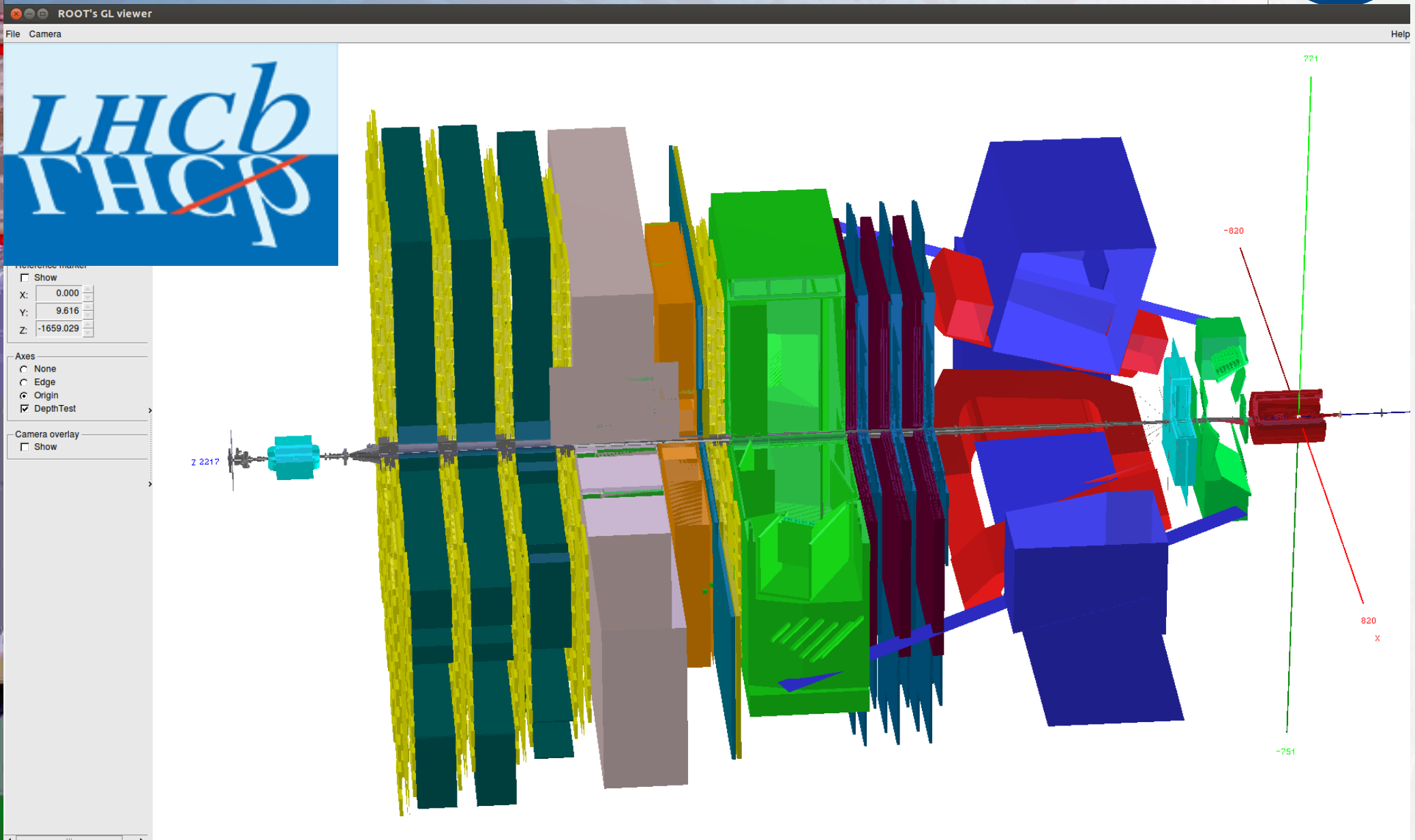
File Camera

Help



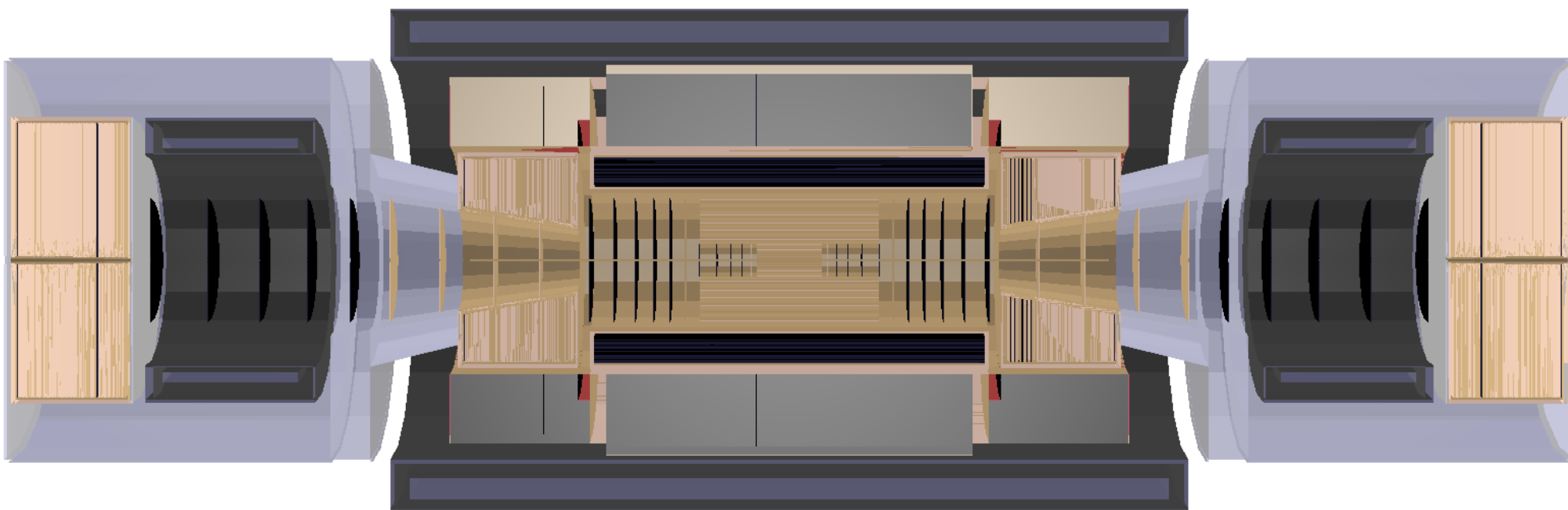
PR: LHCb Detector of Run I / II

DD4hep



PR: FCC Design Study

DD4hep



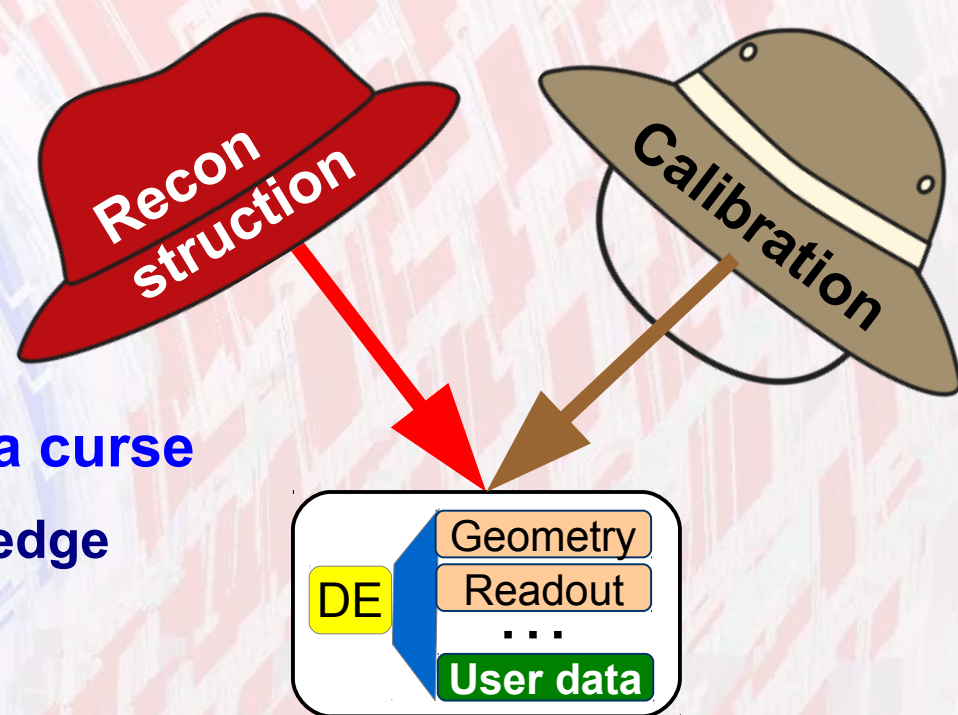
- **Handles the detector element functionality**
- **Basically stable**
 - Bug fixes, enhancements
- **Objects are fully reflective**
 - C++ dictionary defined
 - Intrinsic support for cross-language development
- **Reflection supports interactivity**
 - Cint (Cling) and python (cppyy)
- **CHEP 2013**

DD4hep: A Detector Description Toolkit for High Energy Physics Experiments

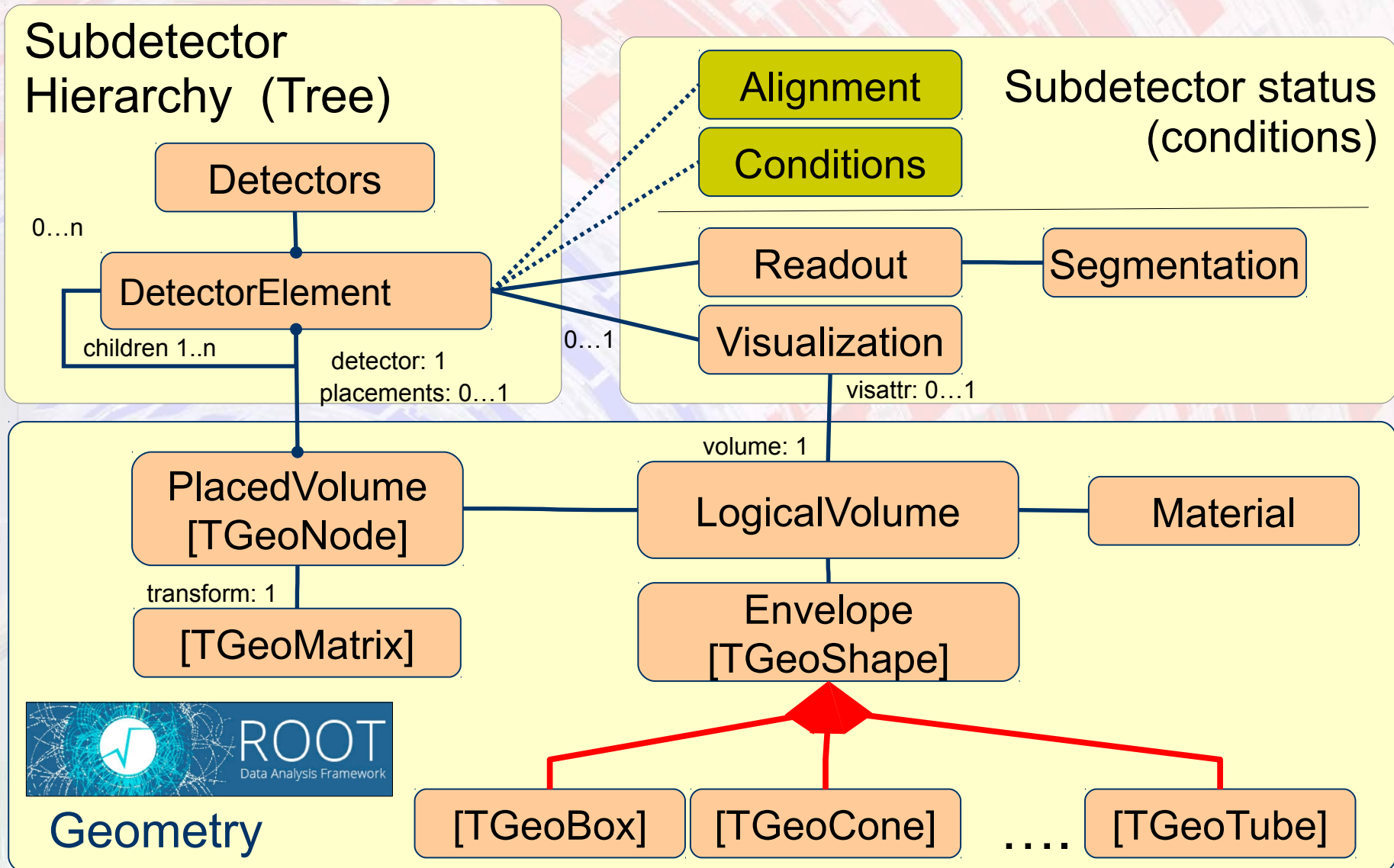
Views & Extensions: Users Customize Functionality

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
- Be prudent: a blessing and a curse
 - User data: common knowledge



Class Diagram: Detector Element Sort of Standard...

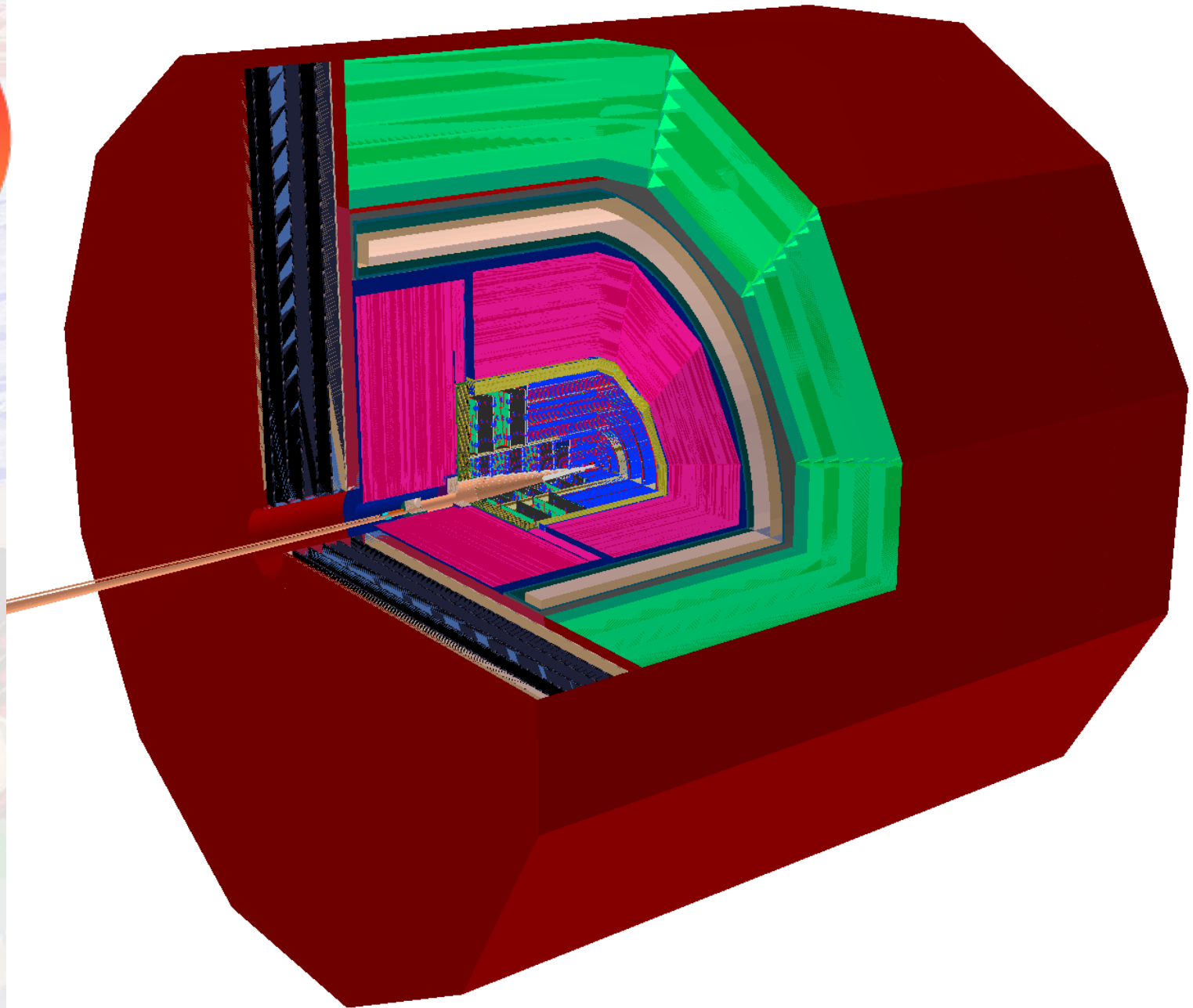


Geometry

Standard Detector Palette

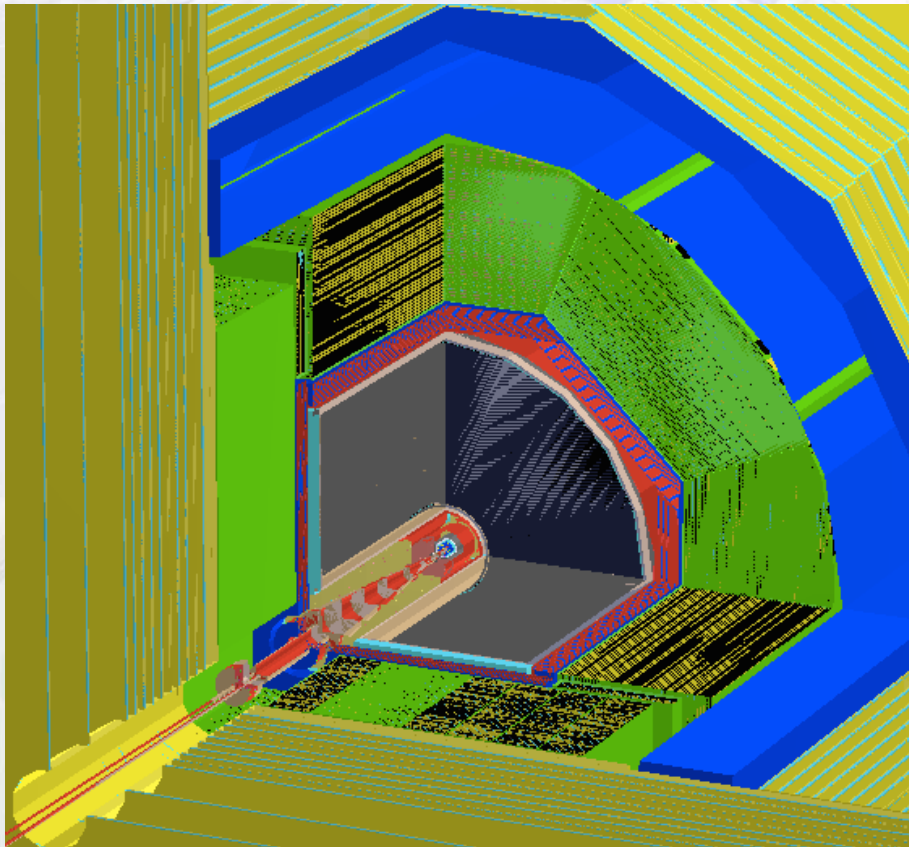
DDDetectors

- **Used for design studies (LC, FCC-eh)**
- **Origin from the SiD detector model**
 - **Layer based detectors**
 - **Tracker barrel & endcap**
 - **Several calorimeter constructs**
- **Partially with measurement surfaces (F. Gaede)**
 - **Uses plugin mechanism to enhance detector elements**
 - **Mechanism to attach user defined optional data**
=> Proof that 'anticipate the unforeseen' works
 - **NOT intrusive to detector constructors**



ILD Model ILD_o1_v05

(F.Gaede, L.Shaojun)



ILD_o1_v05 in DD4hep

DDSim/IL

`<detector name="HcalEndcap"
type="SHcalSc04_Endcaps"
readout="HcalEndcapsCollection">`

`<detector name="Coil"
type="SCoil02">`

`<detector name="HcalBarrel"
type="SHcalSc04_Barrel"
readout="HcalBarrelRegCollection">`

`<detector name="HcalEndcapRing"
type="SHcalSc04_EndcapRing"
readout="HcalEndcapRingCollection">`

`<detector name="BeamCal"
type="BeamCal"
readout="BeamCalCollection">`

`<detector name="EcalEndcap"
type="SEcal04_Endcap"
readout="EcalEndcapCollection">`

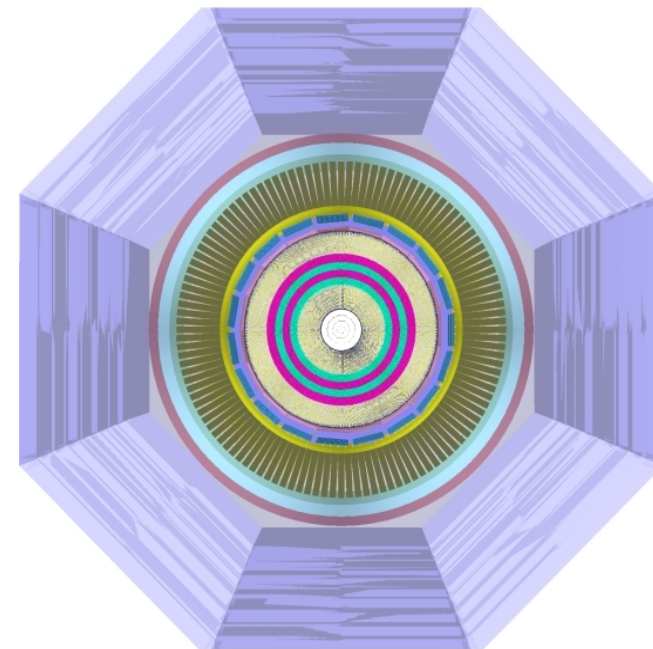
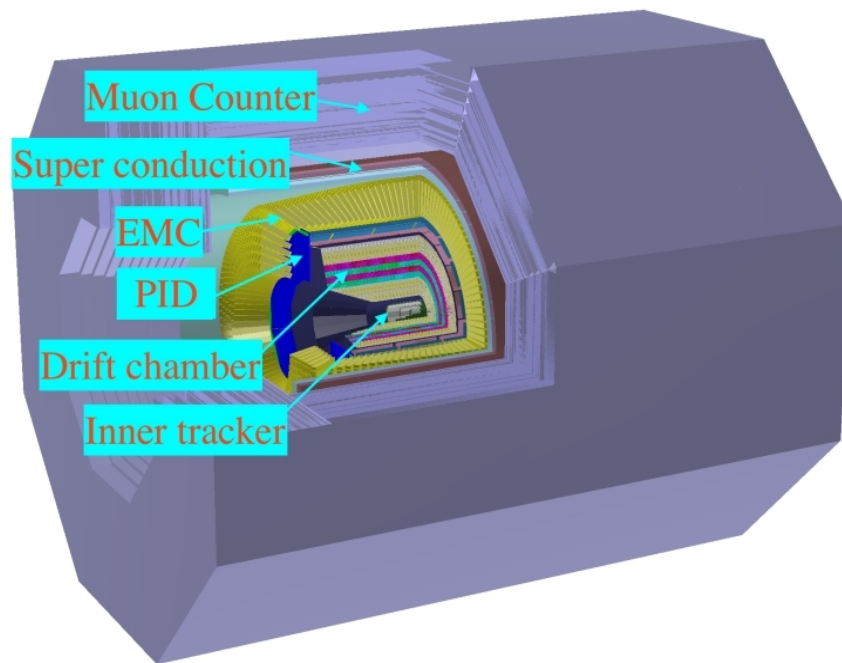
`<detector name="EcalBarrel"
type="SEcal04_Barrel"
readout="EcalBarrelCollection">`

`<detector name="VTX" type="VXD04"
readout="VXDCollection">`

`<detector name="TPC" type="TPC10"
readout="TPCCollection">`

Progress on detector simulation

- STCF software team has been formed.
- OSCAR: **O**ffline **S**oftware of Super Tau-**C**harm Facility.
- Detector geometry with DD4hep.



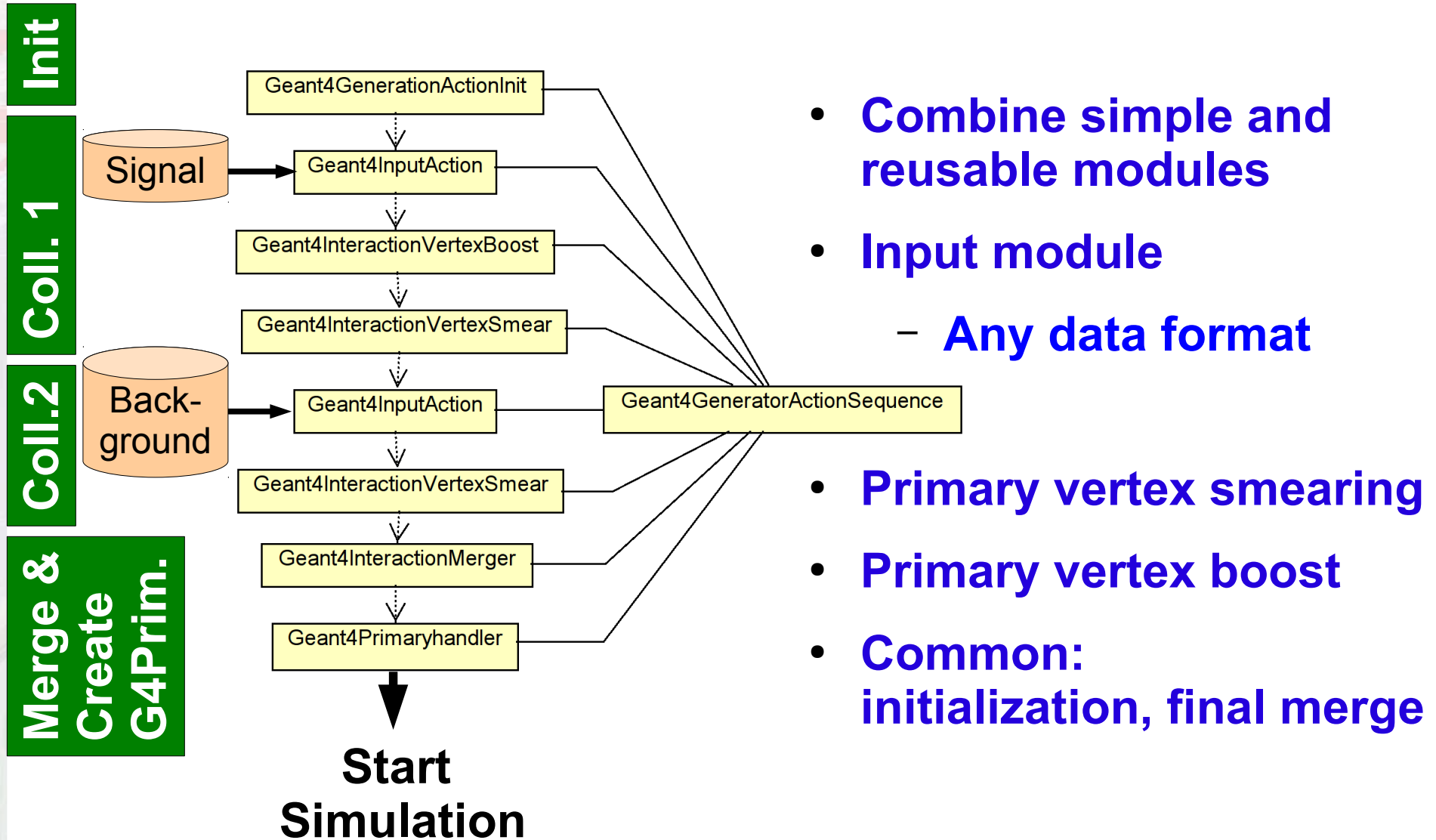
18

- **Simulation = Geometry + Detector response + Physics**
- **Mature status**
 - **Eventual bug fixes, smaller improvements**
 - **Phase of constant re-validation**
- **Automatic geometry conversion**
- **Palette of standard sensitive detectors**
- **Support for MC truth handling**
- **CHEP2015**

DDG4 A Simulation Framework based on the DD4hep Detector Description Toolkit

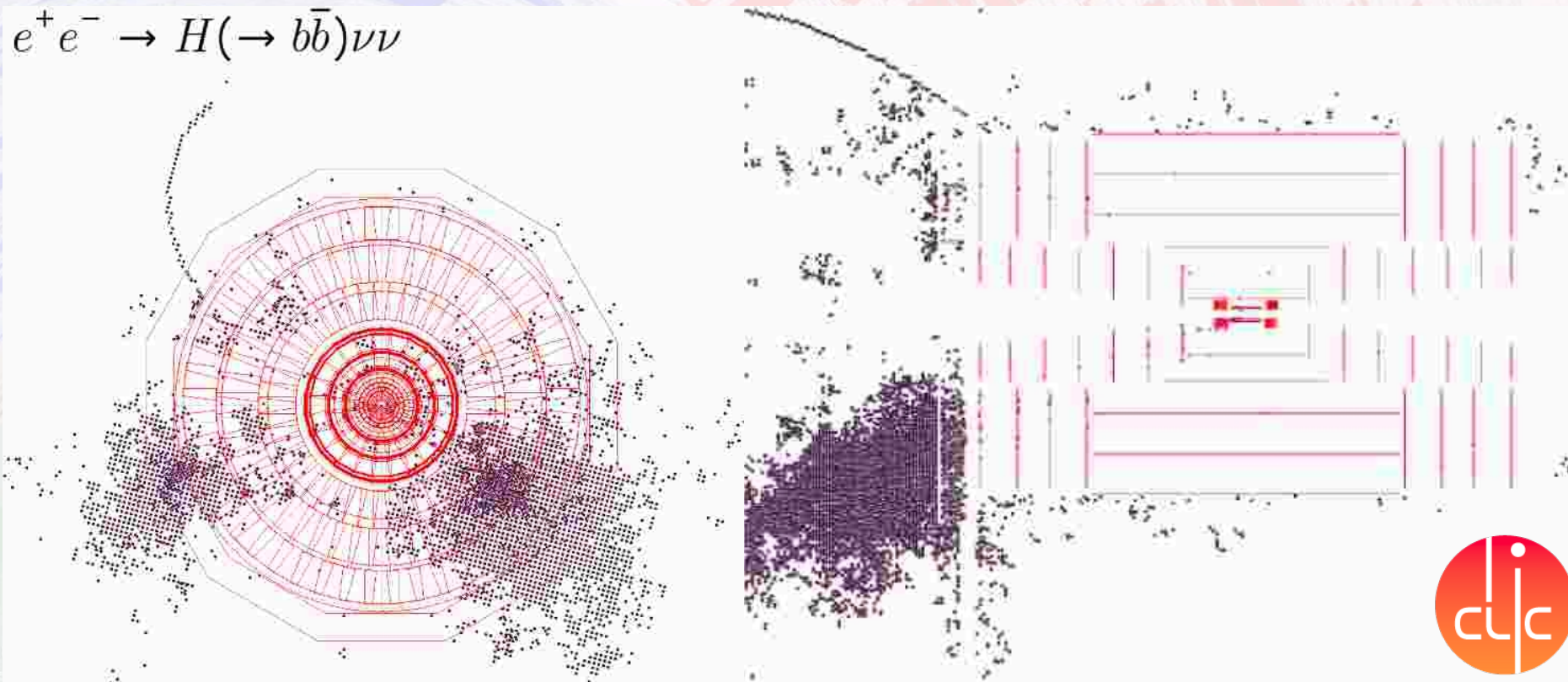
Example of an Action Sequence

Event Overlay with Features



- **Deployed for CLICdp in DIRAC**
 - **For every detector study (now ~14) central generation**
- **ILC started mass production**

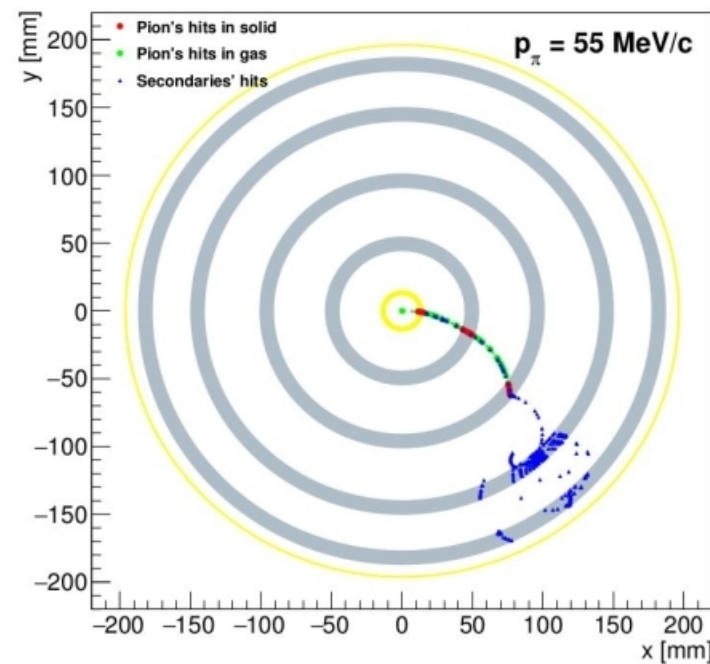
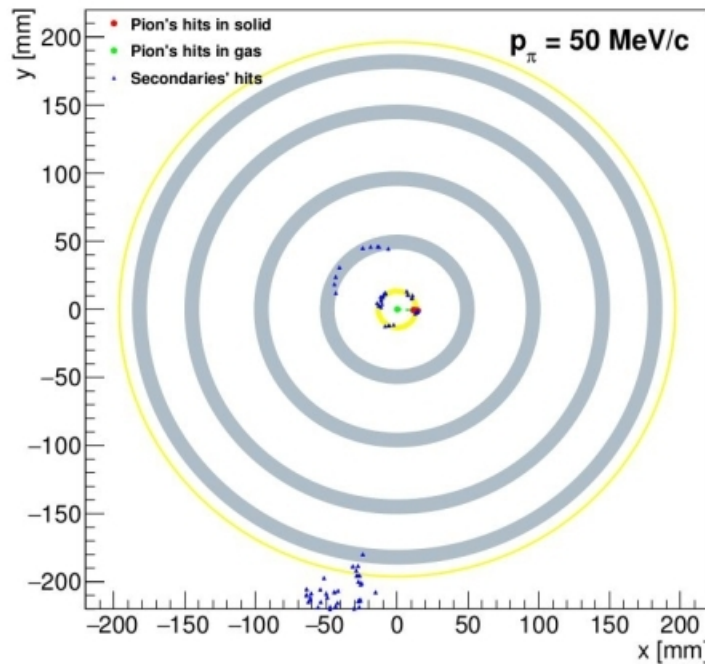
$$e^+e^- \rightarrow H(\rightarrow b\bar{b})\nu\nu$$



Inner Tracker

DD4hep simulation

CGEM



- Pions with momenta less than 50 MeV/c do not pass through the beampipe
- Starting from $p_\pi = 55 \text{ MeV}/c$ two layers can be reached by pions

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- **Time dependent data necessary to process the detector response [of particle collisions]**
 - slowly changing: every run $O(1h)$, lumi section $O(10min)$...
 - multiple conditions change in batches: require discipline
 - conditions may be the result of computation(s)
- **DDCond deals with the management of these data**
 - Efficient and fast, if used according to design ideas
 - Manages resources
 - Supports multi threading by design
Well defined locking points
 - Cache where necessary but no more

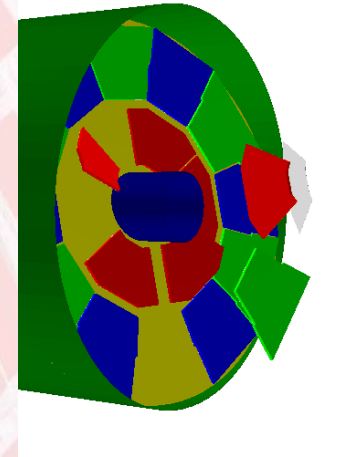
- **CHEP2018**

Conditions and Alignment extensions to the DD4hep Detector Description Toolkit

Global and Local Alignments

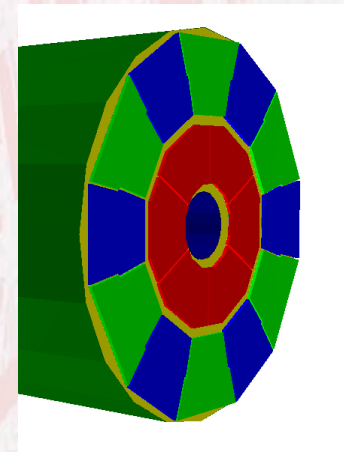
- **Global alignment corrections**

- Physically alters geometry
Intrinsically supported by ROOT
- By construction not multi-threaded
- Possibility to simulate misaligned geometries



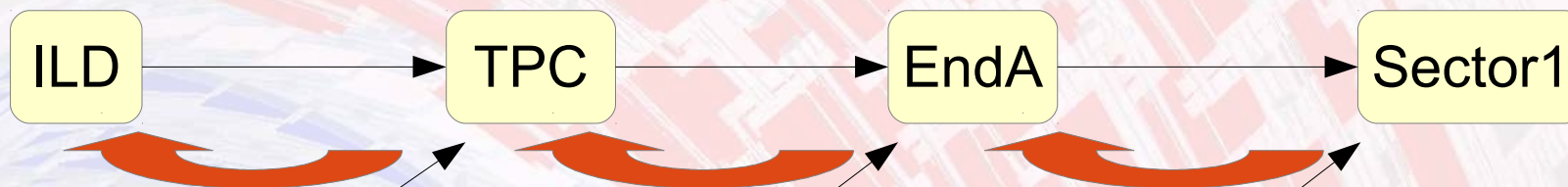
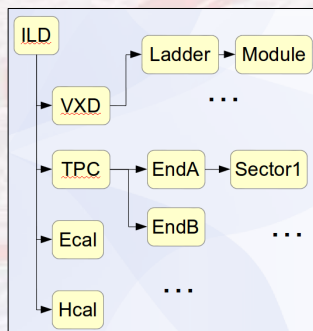
- **Local alignment corrections**

- Geometry stays intact (either ideal or globally aligned)
- Multi-threading supported, multiple versions
- Local alignment corrections are conditions
- Provide matrices from ideal geometry to world
e.g. to adjust hit positions



- **Both supported**

Local Alignment Δ - Parameters



$$Tr_{Sec1}^{World} = Tr_{EndA}^{World} \times \left(Tr_{Sec1}^{Parent(EndA)} + \Delta_{Sec1} \right)$$

$$Tr_{EndA}^{World} = Tr_{TPC}^{World} \times \left(Tr_{EndA}^{Parent(TPC)} + \Delta_{EndA} \right)$$

$$Tr_{TPC}^{World} = Tr_{ILD}^{World} \times \left(Tr_{TPC}^{Parent(ILD)} + \Delta_{TPC} \right)$$

- Trickle-up the hierarchy and compute the matrices the most effective way with re-use of intermediate results
- Math verified by AIDA²⁰²⁰ alignment task force (C.Burr)

Increasing interest in the HEP community

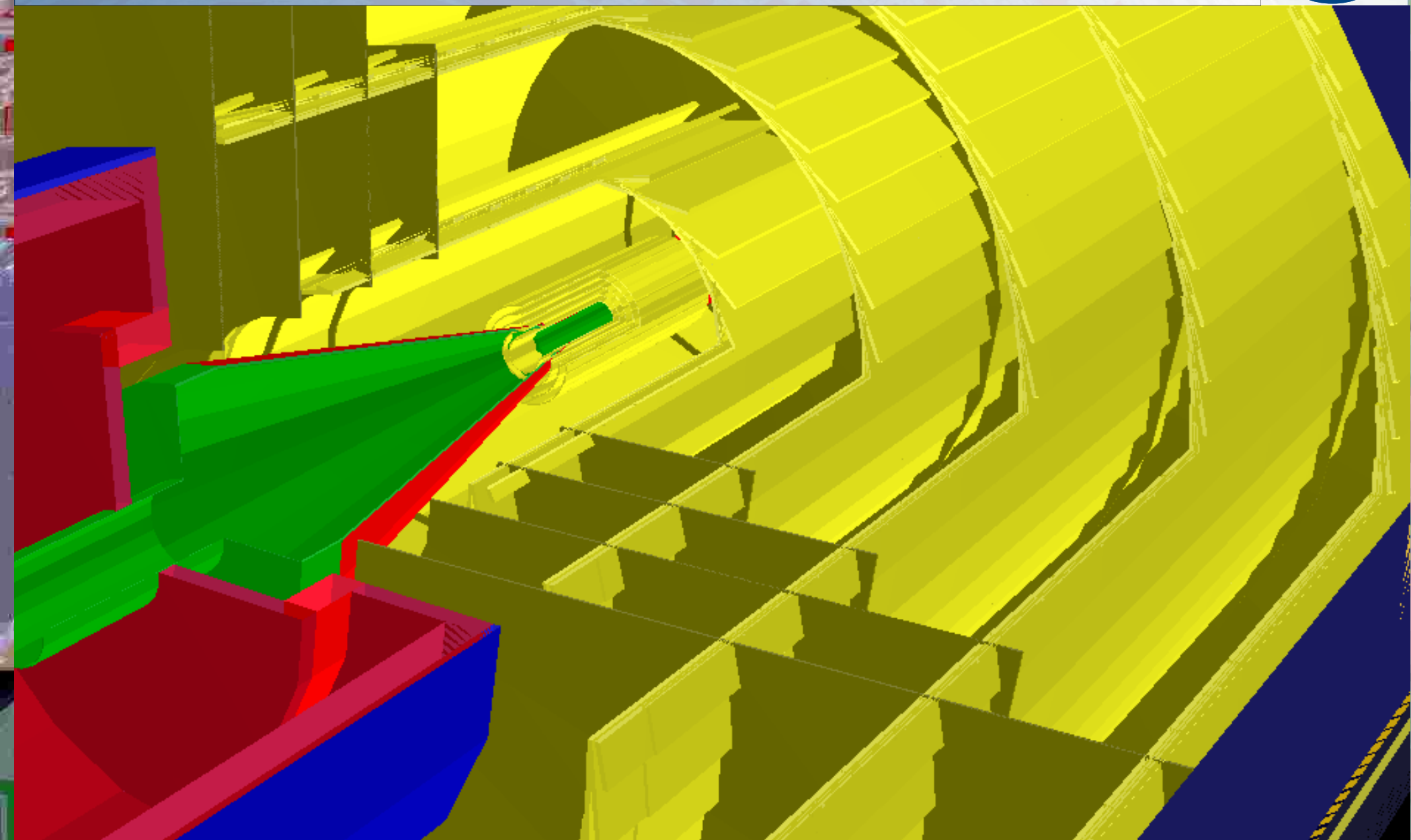
- **ILC** F. Gaede et al.
- **CLICdp** A. Sailer et al.
- **SiD** D. Protopopescu et al.
- **FCC-eh** P. Kostka et al.
- **FCC-hh** A. Salzburger et al.
- **FCC-ee** O. Viazlo (CLD design), N. Alipour, G. Voutsinas
- **SCTF** Super-Charm-Tau Factory designs (Novosibirsk, Beijing)
- **EIC** Evaluation considered/started (W. Armstrong et al.)

- **LHCb** LHCb Upgrade for Run III (B.Couturier et al.)
- **CMS** Evaluation for upgrade started (202x) (Y.Osborne et al.)
- **CALICE** Calorimeter R&D, started

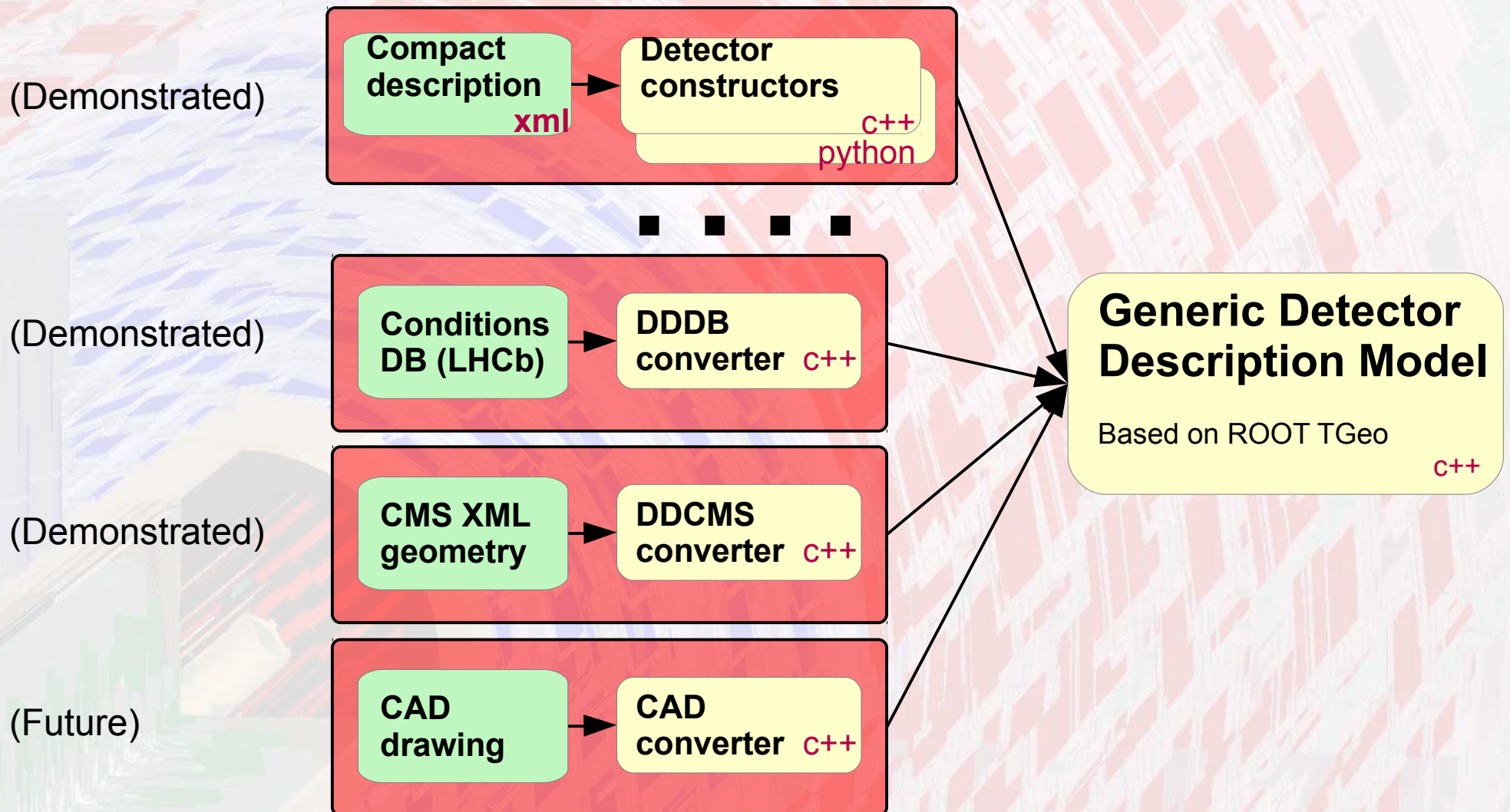
- **DD4hep is getting mature**
- **Starts being capable of handling all aspects of detector description for the lifetime of an experiment**
- **Increasing interest in the community and increasing number of users**
- **Visit us on:**
 - <http://dd4hep.cern.ch>
 - **Up to date doxygen information**
 - **User Manuals: have improved but not perfect**

Questions and Answers

DD4hep

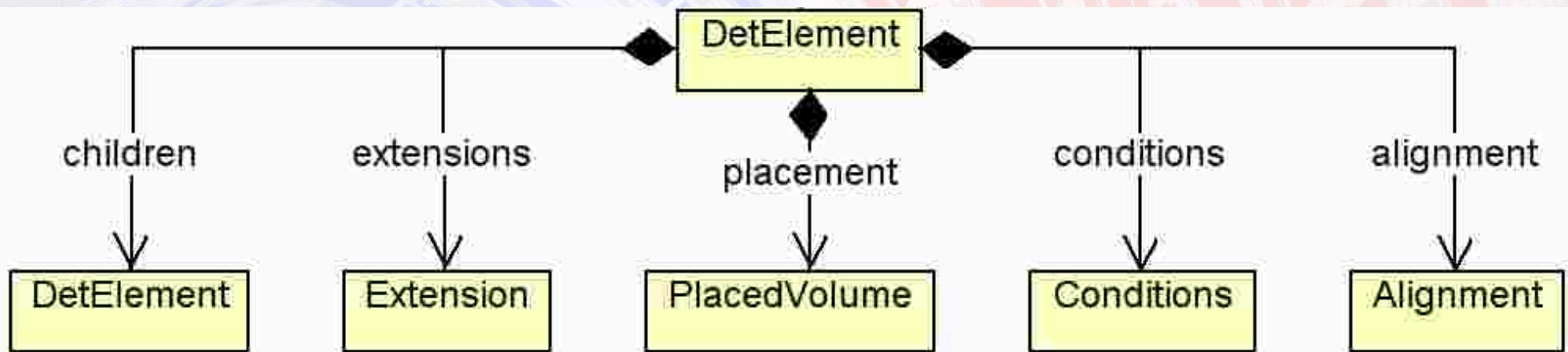


Multiple Input Sources



Get Fingers Dirty LHCb Velo Detector

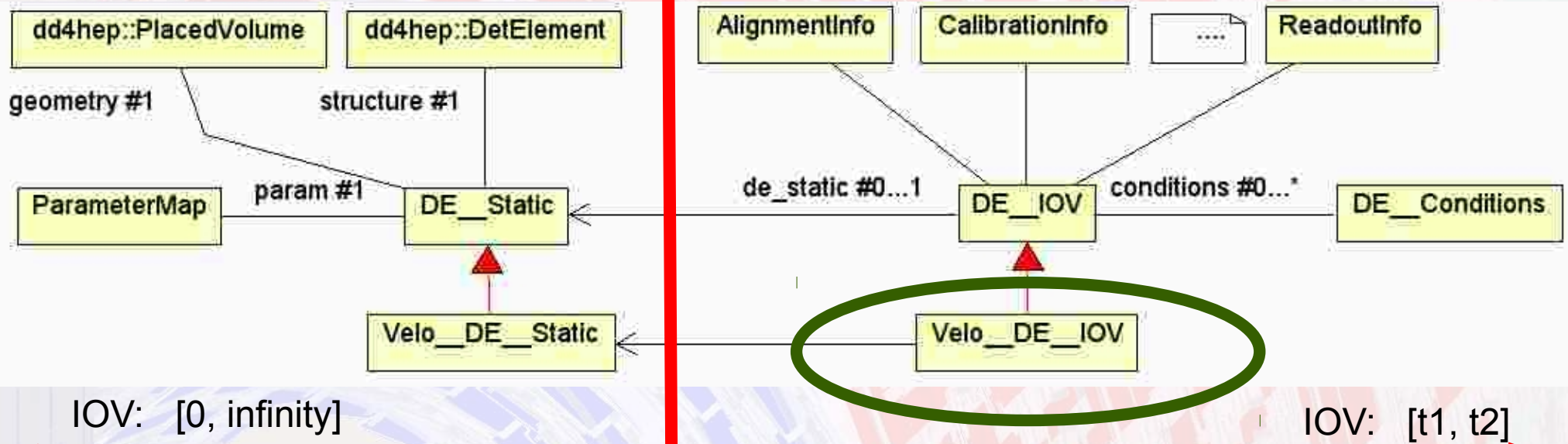
- **People want to see “Detector elements”**
 - **Fully functional description of parts of the detector**
 - Long term valid stuff (structure)
 - Short lived quantities (temperature, alignment, ...)
- **A “natural” aggregation would be similar to:**



- **Intuitive, but not good: violates multi-threading**

Real World Use Case LHCb Velo Detector

- Chosen solution:**



- Use IOV dependent projection for event processing**
 - This is our new “detector element”
 - Keeps reference to the not changing properties
- Dress with facade to provide required functionality(ies)**