FCC software: Status and Plans

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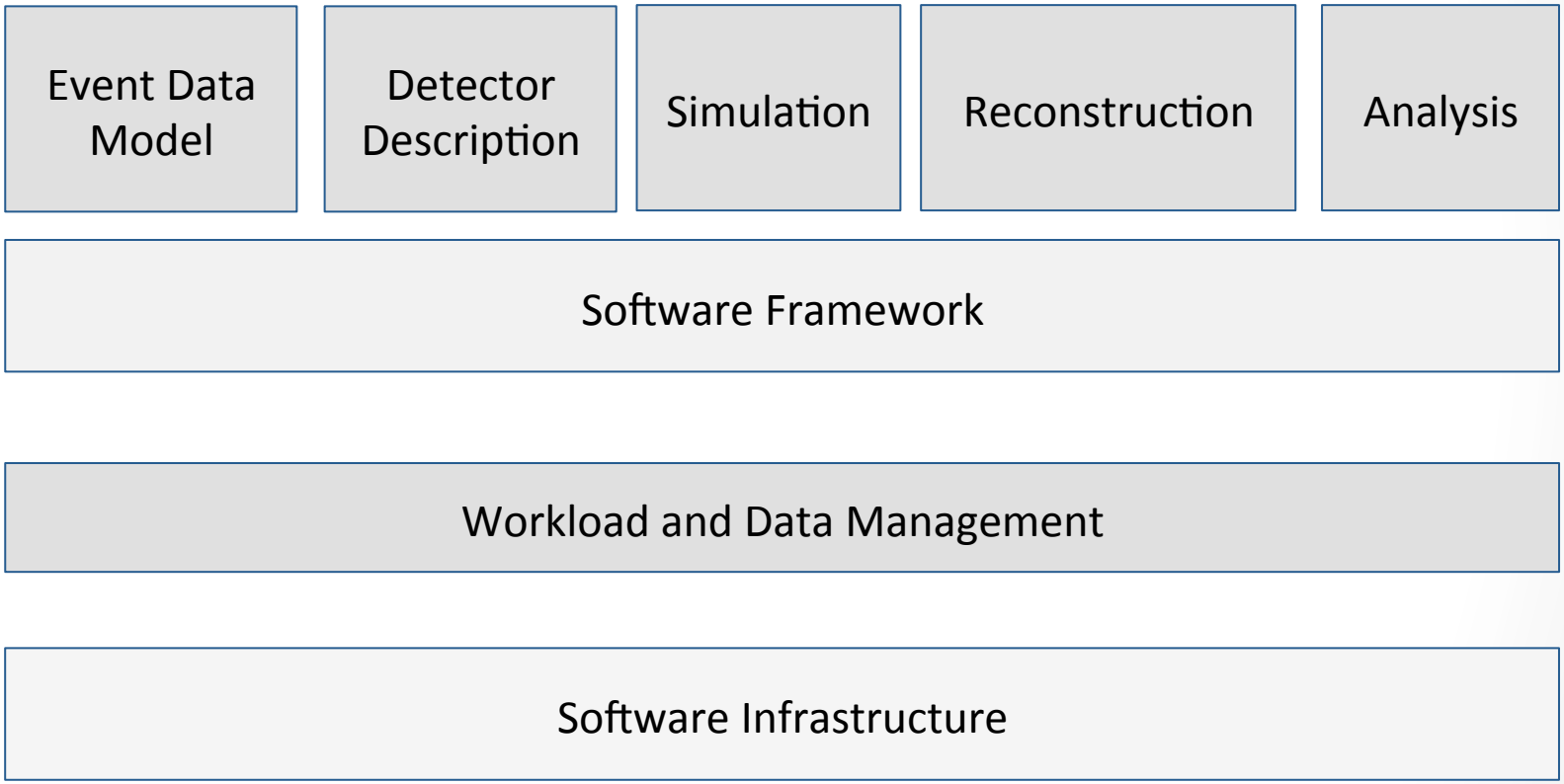
Basic Software Requirements

- Conceptual detector design studies
  - Flexibility
  - Ideal detector descriptions
  - Open to evolution
- Broad range of event complexity
  - e^+e^- *vs* pp *vs* e^-p
- Need to support physics and detector studies
  - Parameterised, fast and full simulation
- Aim to de-duplicate efforts
  - One software stack to support all the cases, all detector concepts and future (proto-)collaborations

Basic Software Requirements

We have achieved most of this with the publication of the FCC CDRs

Ingredients



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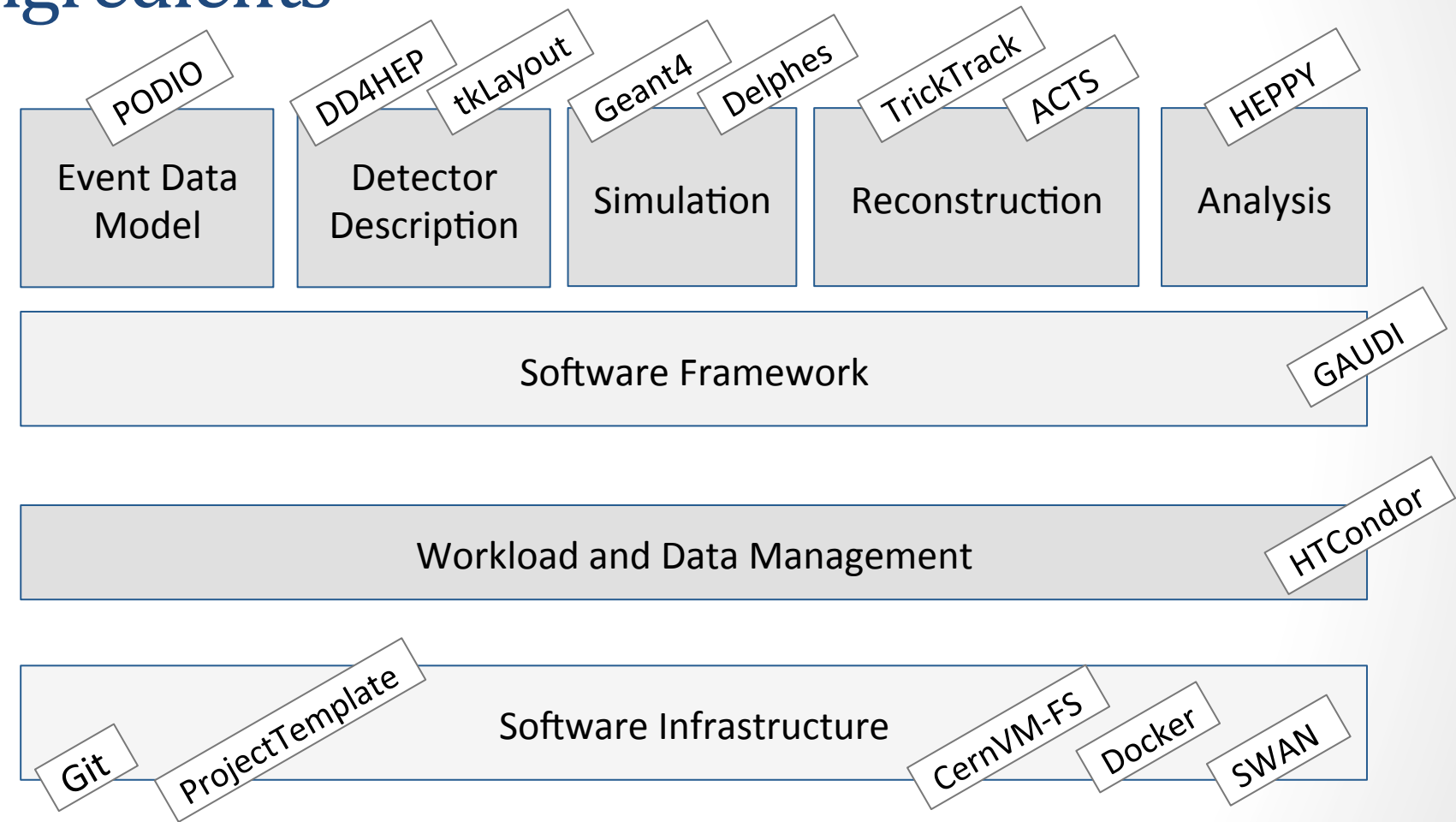


Outline

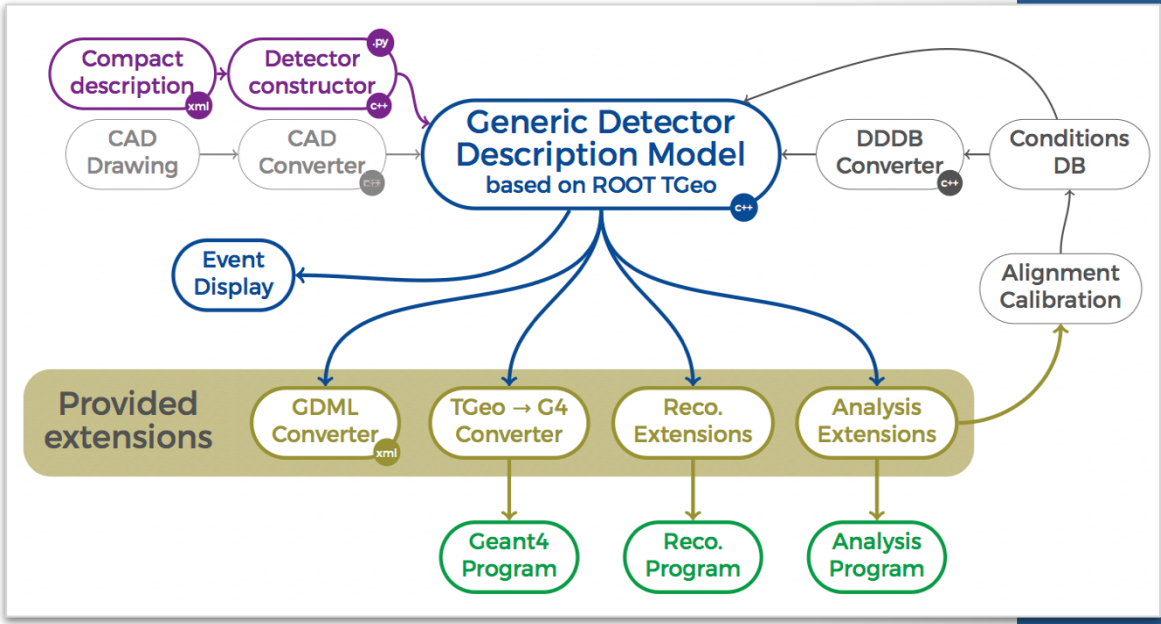
- Status
- Plans

Event Data Model

- Solutions adopted by LHC experiments and for LC studies proved to work but partly suffered from:
  - Overly complex data models with deep object-hierarchies
  - Unfavorable I/O performance
- PODIO: EDM toolkit
  - As much as possible based on Plain Old Data
    - Keeps memory model simple
    - Enables fast I/O operations and efficient vectorization
  - Automatic code generation
    - Consistent and homogeneous implementation, minimizes mistakes
  - Support different backend
  - Developed in the context of AIDA2020 EU programme

Detector description

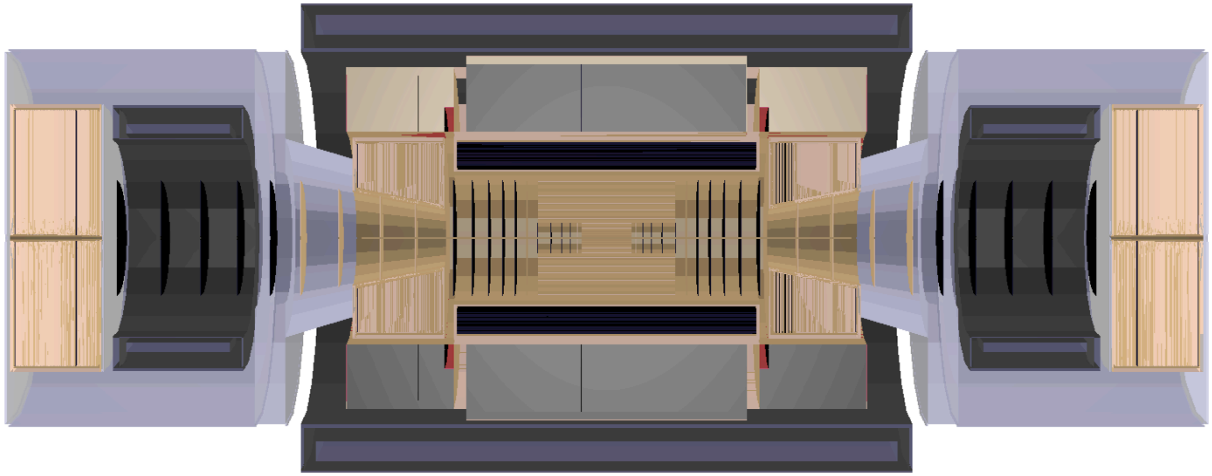
- DD4Hep generic detector description:
  - Support: Simulation, Reconstruction, Analysis
- Design goals:
  - Complete detector description
  - Supports all stages of the experiment
  - Single source of information
  - Easy to use



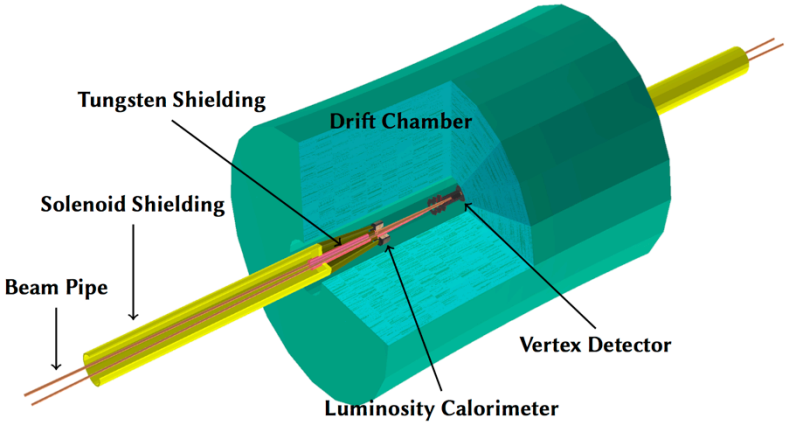
- Part of AIDA2020 EU programme
- Used by CLIC, CMS, FCC, ILC, LHCb

DD4Hep @ FCC

- FCC-hh
  - complete



- FCC-ee
  - IDEA concept
    - Beam pipe, instrumentation
    - Vertex detector, drift chamber
    - DREAM calorimeter (under dev)
  - LAr+Tile calo. concept (under dev)



Software Framework

- Provides:
  - Vocabulary: Algorithm, Tool, Service, etc…
  - Well defined, stable interfaces
  - Plug-in based, evolving implementations
  - Homogeneous configuration, logging, error reporting

- GAUDI: data processing framework
  - Designed to manage generic experiment workflows
  - Main concepts:
    - Separate data and algorithm; well defined interfaces
    - User code encapsulated in “Algorithms” and “Tools”
    - Different persistent and transient views of data
  - Originating from LHCb; also used by ATLAS, Daya Bay, LZ
    - Support for concurrent event processing, reduce memory footprint

GAUDI @ FCCSW

- Currently integrates:
  - Generation
  - Fast/Full Simulation
  - Parameterized simulation with Delphes and PAPAS
  - Track seeding
  - Calorimeter reconstruction

Identical outputs, makes it easy to compare

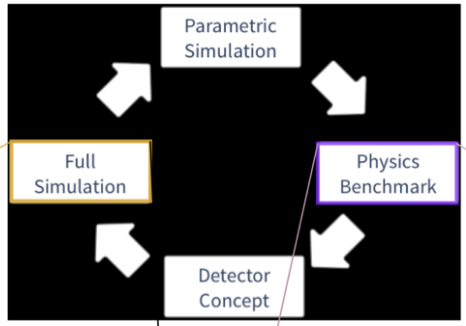
- Generation:
  - Pileup overlay
  - HepMC, HepEVT readers
  - Pythia8 as main generator, or for hadronisation of LHE/HepMC
    - All generators available in LCG_releases can in principle be used

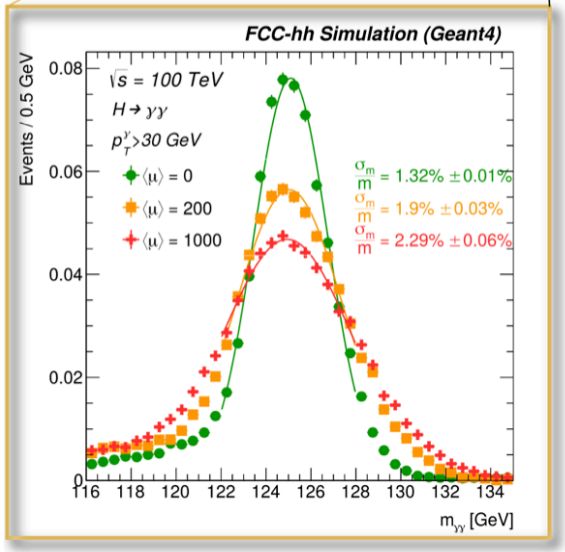
Fast/Full simulation interplay

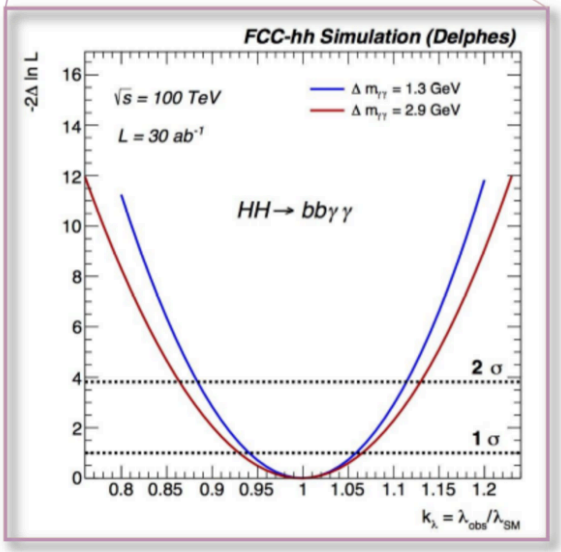
Example:

Higgs self-coupling

@ FCC-hh







Reconstruction

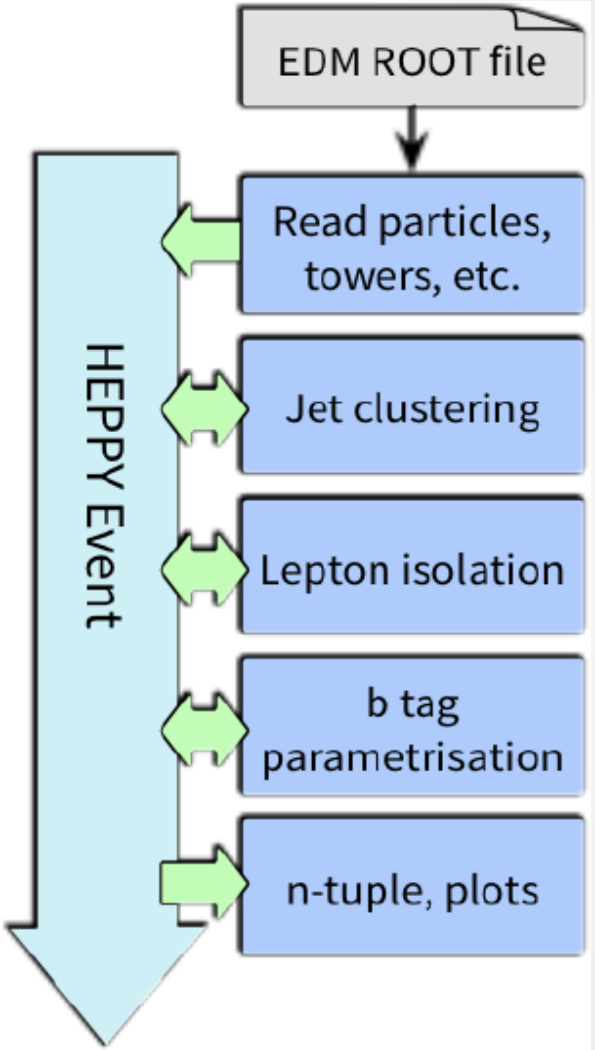
- Challenges
  - Reconstruction Algorithm as much as possible independent of the detector concept: full flexibility and avoid duplication

- Tracking
  - Track seeding (TrickTrack)
  - Hough transform for drift chambers
  - Conformal tracking (being implemented)
  - ACTS integrated in FCCS

- Calorimeters
  - Sliding window (rectangle/ellipse), also versus depth
  - 3D Topo-clustering

Analysis

- Order of 20-30 analyses carried out for the CDRs within the same analysis code in python
- Based on 100TB of Delphes events produced with an home made production system (used to produce and validate several billions of events)
- Heppy used to process the FCC EDM events and produce flat and light ROOT ntuples
- Other python codes to run on the flat ntuples
- Flexible but relatively slow
  - New analyses are being developed in DataFrames (orders of magnitude faster)



Software infrastructure

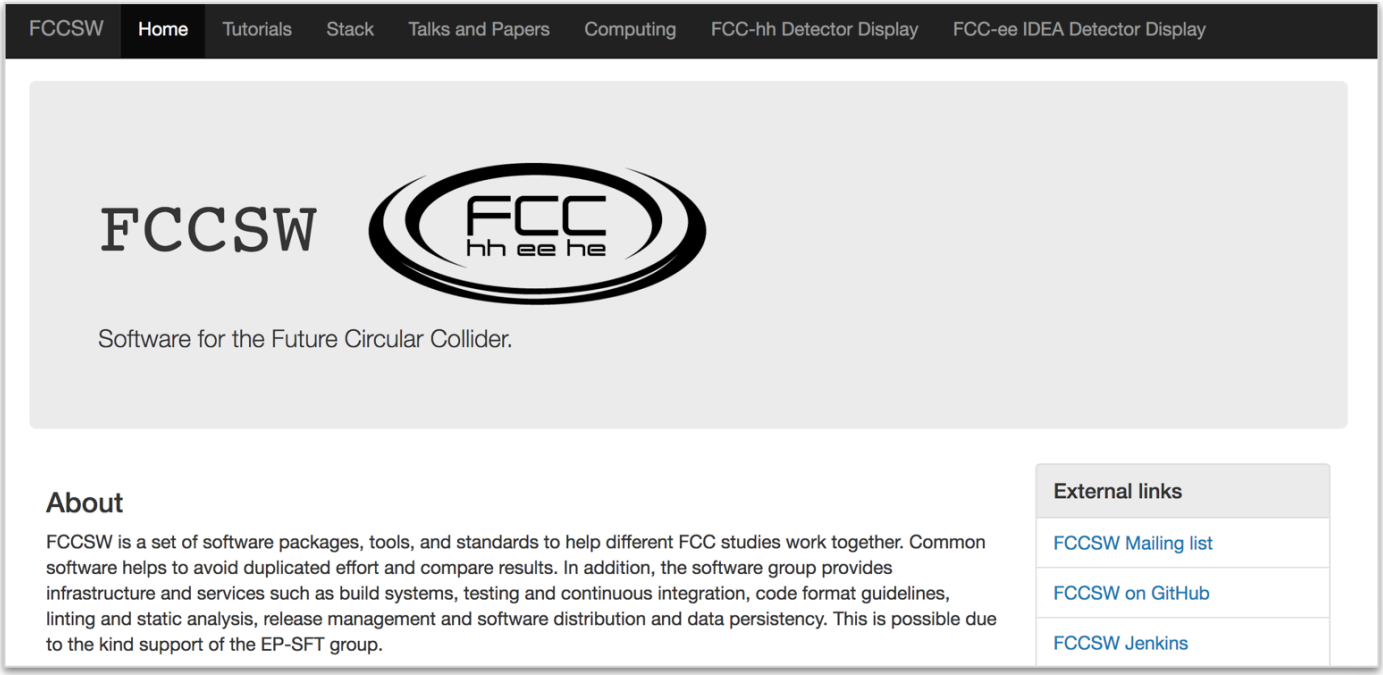
- Code repository
  - On GitHub: https://github.com/HEP-FCC
  - Development workflow: PR reviews, nightlies, Continous Integration
  - Coding guidelines, Automatic code formatting, static code analysis

- Deliverables
  - FCCSW: FCC sofware framework
  - Externals: FCCSW dependencies
  - Based onLCG releases

- Builds managed by Spack (HSF)
  - Configuration, build and installation
  - Actually run on LCG SFT resources
- Deployment: dedicated CVMFS repository
  - source /cvmfs/fcc.cern.ch/sw/views/releases/externals/94.2.0/x86_64-centos7-gcc62-opt/setup.sh

Documentation

- http://hep-fcc.github.io/FCCSW/



- Users Forum: https://fccsw-forum.web.cern.ch/

Outline

- Status
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Mandate for the after CDR FCCSW (in view of ESPP 2026)

- Support more detailed studies, in particular for FCC-ee, focusing on:
  - Completeness
    - State-of-the-art generators, beam/detector simulation, reconstruction/analysis algorithms,…
  - Flexible detector description
    - Easy switch/replace sub-detectors, change dimensions/layout
  - Low usability thresholds and fast/easy learning curve
  - Adequate computing support and CPU/storage resources
  - Extensive documentation and regular training

- Ensure that SW is a part-and-parcels of the Turnkey Software Stack Key4HEP

- Foster development and use in physics studies, detector optimization, machine-detector interface

- Support substantial participation from FCC institutes worldwide

Future plans

- Address missing/lacking/weak parts
  - Reconstruction tools
  - FCC-ee detector description, fast/full simulation
  - Simulation of beam related effects (ongoing with GUINEAPIG)
  - Workload & Data management
  - Analysis
  - …

- Foster the Turnkey Software Stack (Key4HEP)
  - Contribute with feedback and proposals to the development of already used components
  - Increase/usage integration of common components
    - DIRAC, RUCIO
    - ROOT new solutions
    - …

Future plans

- Follow/participate AIDA++ software projects
  - After meeting last week, few proposals have been agreed upon
- Follow relevant HSF working group activities
  - Simulation, Reconstruction, Analysis
- Main items for next year
  - Consolidate physics generators interface
  - Allow for an easy introduction of new detector concepts described in DD4HEP
  - Interface-to / Synergies-with Key4HEP
  - Develop analysis workflow based on RDataFrame
  - Define a well established platform for detector performance comparison
  - Enable DIRAC / Rucio …
- FCC-ee Software Tutorial hands on session during next FCC-ee WS Sep 9-12th

Preliminary agenda of the WS

- Half a day of parallel session
  - Intro and Status of Things
  - Key4HEP
  - Status/Plans of IDEA detector implementation
  - Status/Plans of Physics generators and their availability in FCCSW
  - Status/plans of MDI simulation and their availability in FCCSW
  - Status and plans of physics analyses framework

- Half day hands-on tutorial session
  - IDEA detector concept in Delphes
  - Full simulation (at least) of the vertex
  - Example analysis in HEPPY and RDataFrame

Outlook

- The FCCSW stack has been assembled using as much as possible existing components
- Served well the purposes of the CDRs
- Next phase
  - Further developments to support more detailed studies, in particular for FCC-ee
  - Follow closely, participate and collaborate
    - Turnkey (Key4Hep) software Stack R&D
    - HSF activities
    - Other new common activities