Key4hep: A Software Stack for Future-Collider Studies

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for the Key4hep Developers

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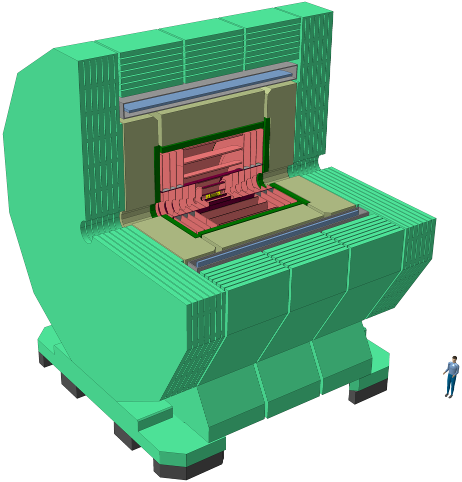
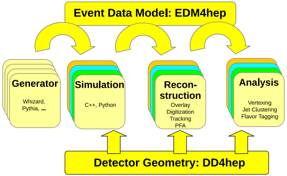


Key4hep Software Stack

Key4hep: Turnkey Software Stack

Create a software stack that connects and extends individual packages towards a complete data processing framework for detector studies with fast or full simulation, reconstruction, and for analysis

- Major ingredients: Event Data Model (EDM), Geometry Information, Processing Framework
- Sharing common components reduces overhead for all users
- Should be easy to use for librarians, developers, users
    - **easy to deploy, extend, set up**
- Full of functionality: plenty of examples for simulation and reconstruction of detectors
- Preserve and adapt existing functionality into the stack, e.g., from iLCSoft, FCCSW, CEPCSW



Event Data Model: EDM4hep

Generator
Whizard,
Pythia, ...

Simulation
C++, Python

Recon-struction
Overlay
Digitization
Tracking
PFA

Analysis
Vertexing
Jet Clustering
Flavor Tagging

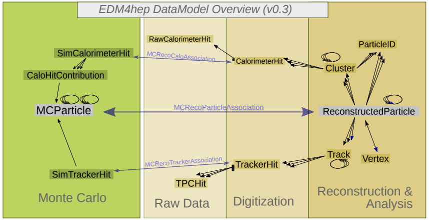
Detector Geometry: DD4hep

Ingredients

The Key4hep EDM: EDM4hep

For a high degree of interoperability, EDM4hep provides a common event data model

- Using podio to manage the EDM (described by `yaml`) and easily change the persistency layer (ROOT, SIO, . . .)
- EDM4hep data model based on LCIO and FCC-edm
- http://github.com/key4hep/edm4hep
- Recent developments for podio or EDM4hep
  - EDM4hep: additional types, associations
  - podio: event, run, collection metadata; UserDataCollection, Subset Collections, Frame
- A number of issues still need to be resolved
  - “Wrapper” for using different hit types transparently
  - multi-threading (the *frame* was recently added to simplify this)
  - schema evolution



Framework: Gaudi

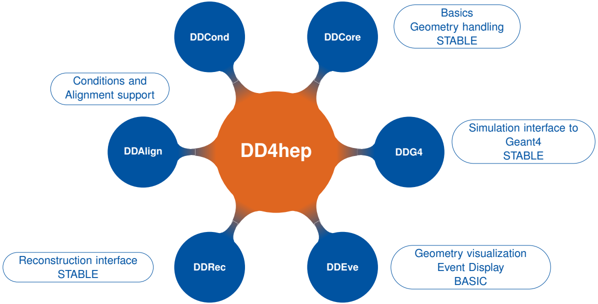
- Data processing frameworks are the skeleton on which HEP applications are built
- Gaudi was chosen as the framework, based on considerations for
  - portability to various computing resources, architectures and accelerators
  - support for task-oriented concurrency
  - adoption and developer community size; is used by LHCb, ATLAS
- Contribute developments were we see a need

k4FWCore

- Basic IO functionality: podio data service
- Reproducible random number seeding

Geometry Information: DD4hep

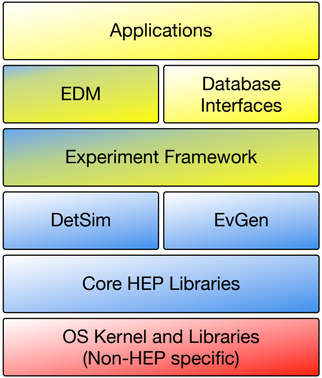
- Complete Detector Description
  - Providing geometry, materials, visualization, readout, alignment, calibration. . .
- Single source of information → consistent description
  - Use in simulation, reconstruction, analysis
- Supports full experiment life cycle
  - Detector concept development, detector optimization, construction, operation
  - Facile transition from one stage to the next



- DD4hep already in use by ILC, CLIC, FCC, and many more

Packaging: Spack

- Need to build a large number of packages to run our applications
- Adopted **spack** as the package manager
- Go beyond sharing of *build results* to sharing of *build recipes*
    - Many packages have build recipes provided by the spack community
    - Separate repository for Key4hep specific recipes
- Can build any and all pieces of the stack with minimum effort
    - `spack install key4hep-stack`
    - `spack dev-build conformaltracking@master`
- Used for nightly builds and releases of the stack
    - `source /cvmfs/sw-nightlies.hsf.org/key4hep/setup.sh`



Applications

EDM

Database Interfaces

Experiment Framework

DetSim

EvGen

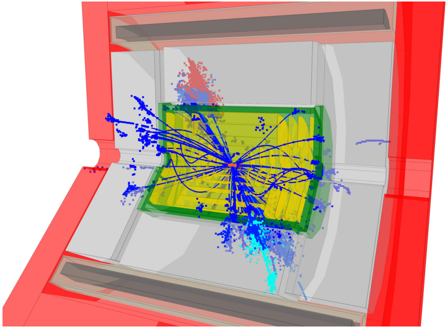
Core HEP Libraries

OS Kernel and Libraries (Non-HEP specific)

From Marlin to Gaudi

CLIC Reco Evolution: Adiabatic Changes

- Full CLIC reconstruction implemented in iLCSoft
- While transitioning to Key4hep, need to be able to keep running the CLIC reconstruction
- Switch components one by one, validate changes
  - Geometry provided by DD4hep, no changes needed
  - Move framework from Marlin to Gaudi: wrap existing processors
  - Move from `LCIO` to EDM4hep
  - Replace wrapped processors with native Gaudi algorithms, where necessary
- Incidentally will make iLCSoft functionality available to other users of the stack



Marlin & Gaudi

Apart from some naming conventions, very similar ideas in the two frameworks*

	Marlin	Gaudi
language	`c++`	`c++`
working unit	Processor	Algorithm
configuration language	XML	Python
set up function	`init`	`initialize`
working function	`processEvent`	`execute`
wrap up function	`end`	`finalize`
Transient data format	`LCIO`	anything
Executable	Marlin	k4run

- To start using Gaudi: use a generic wrapper around the processors.
- Implementation: **https://github.com/key4hep/k4MarlinWrapper**
- Read LCIO files and pass the `LCIO::Event` to our processors

---

*Of course subtle differences emerge

Wrapper Configuration

- Translate the `XML` to `python`, using a stand alone python script: `convertMarlinSteeringToGaudi.py`
- Pass arbitrary number, types, and names of parameters to the processor

Marlin/XML

```
<processor name="VXDBarrelDigitiser" type="DDPlanarDigiProcessor">
  <parameter name="SubDetectorName" type="string">Vertex </parameter>
  <parameter name="IsStrip" type="bool">false </parameter>
  <parameter name="ResolutionU" type="float"> 0.003 0.003 0.003 0.003 0.003 0.003 </parameter>
  <parameter name="ResolutionV" type="float"> 0.003 0.003 0.003 0.003 0.003 0.003  </parameter>
  <parameter name="SimTrackHitCollectionName" type="string" lcioInType="SimTrackerHit">
          VertexBarrelCollection </parameter>
  <parameter name="SimTrkHitRelCollection" type="string" lcioOutType="LCRelation">
          VXDTrackerHitRelations </parameter>
  <parameter name="TrackerHitCollectionName" type="string" lcioOutType="TrackerHitPlane">
          VXDTrackerHits </parameter>
  <parameter name="Verbosity" type="string">WARNING </parameter>
</processor>
```

Wrapper Configuration

- Translate the `XML` to `python`, using a stand alone python script: `convertMarlinSteeringToGaudi.py`
- Pass arbitrary number, types, and names of parameters to the processor

Gaudi/Python

```
VXDBarrelDigitiser = MarlinProcessorWrapper("VXDBarrelDigitiser")
VXDBarrelDigitiser.OutputLevel = WARNING
VXDBarrelDigitiser.ProcessorType = "DDPlanarDigiProcessor"
VXDBarrelDigitiser.Parameters = {
                                 "IsStrip": ["false"],
                                 "ResolutionU": ["0.003"] * 6,
                                 "ResolutionV": ["0.003"] * 6,
                                 "SimTrackHitCollectionName": ["VertexBarrelCollection"],
                                 "SimTrkHitRelCollection": ["VXDTrackerHitRelations"],
                                 "SubDetectorName": ["Vertex"],
                                 "TrackerHitCollectionName": ["VXDTrackerHits"],
                                 }
```

Configuration: Control flow

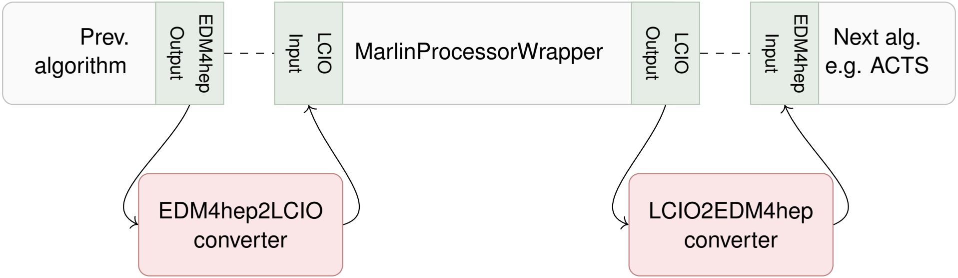
- XML `execute` section translated to a python list

```xml
<execute>
  <processor name="MyAIDAProcessor"/>
  <processor name="EventNumber" />
  <processor name="InitDD4hep"/>
  <processor name="Config" />
  <!-- ... -->
</execute>
```

```python
algList = []
algList.append(lcioReader)
algList.append(MyAIDAProcessor)
algList.append(EventNumber)
algList.append(InitDD4hep)
algList.append(OverlayFalse)
algList.append(VXDBarrelDigitiser)
#...
```

Event Data Model Conversion in Memory

- To use EDM4hep files as primary input, have to convert EDM4hep to LCIO and back at run time
- Integrate iLCSoft processors with Gaudi-based processors
- Configurable which collections to convert for which processor



Event Data Model Conversion in Memory

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- Integrate iLCSoft processors with Gaudi-based processors
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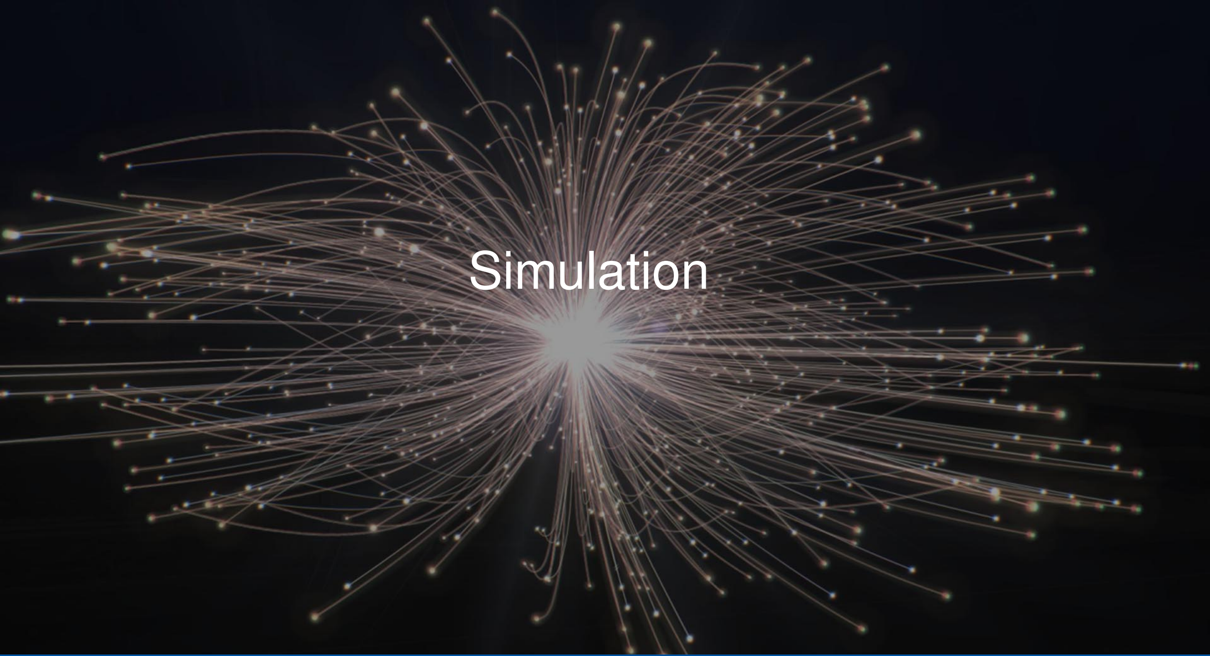
```
# EDM4hep to LCIO
edmConvTool = EDM4hep2LcioTool("VXDBarrelEDM4hep2lcio")
edmConvTool.Parameters = [
  "VertexBarrelCollection", "VertexBarrelCollection",
  ]
edmConvTool.OutputLevel = DEBUG
VXDBarrelDigitiser.EDM4hep2LcioTool = edmConvTool
```

```
# LCIO to EDM4hep
VXDBarrelDigitiserLCIOConv =
   Lcio2EDM4hepTool("VXDBarrelDigitiserLCIOConv")
VXDBarrelDigitiserLCIOConv.Parameters = [
  "VXDTrackerHits", "VXDTrackerHits",
  "VXDTrackerHitRelations", "VXDTrackerHitRelations"
  ]
VXDBarrelDigitiserLCIOConv.OutputLevel = DEBUG
VXDBarrelDigitiser.Lcio2EDM4hepTool =
    VXDBarrelDigitiserLCIOConv
```

Running with Gaudi

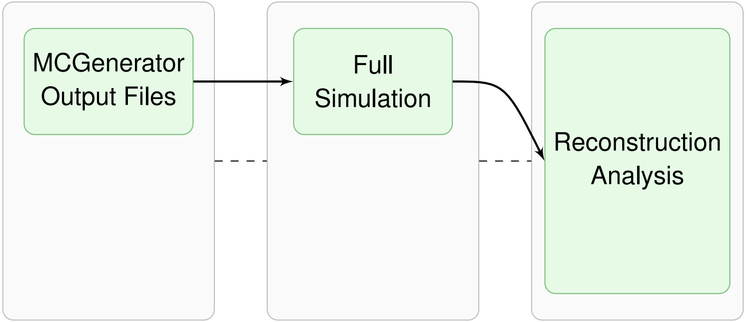
- After conversion of the Marlin steering file with `convertMarlinSteeringToGaudi.py`, and maybe some tweaks for the EDM4hep to LCIO conversions
- Run the workflow with: `k4run muonRec.py`



Simulation

Simulation Integration in the Software Stack

- The simulations can be run in a stand-alone mode using the output from a Generator as input
- Create its own input via “particle gun”, at least for full simulation
- Run as part of a chain inside a framework, where k4Gen calls a MC Generator, or reads an input file
- In all cases, the following step of (high level) reconstruction or analysis should be usable in the same way



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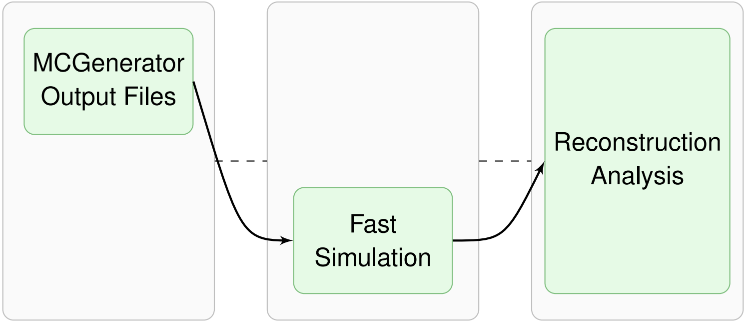

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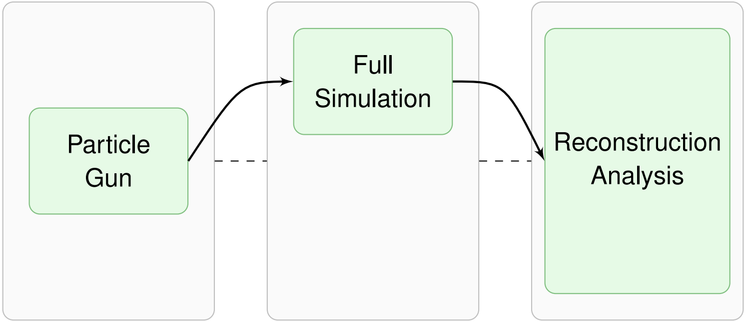

Particle Gun

Full Simulation

Reconstruction Analysis

Simulation Integration in the Software Stack

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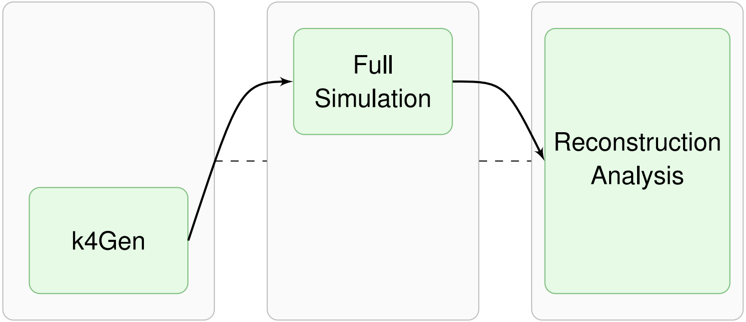

Simulation Integration in the Software Stack

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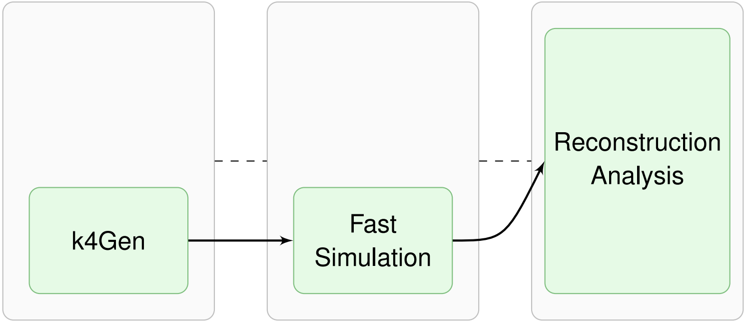


Geant4 Full Simulation Interfaces

- `ddsim` standalone program and `k4SimGeant4` framework integrated solution
  - Also looking at integrating with LHCb's `Gaussino` (Using DD4hep geometry, gaudi based processing)
- Both approaches have to provide the same functionality: sensitive detectors, MC History, particle guns, physics list construction and configuration,
  - Ideally by the same implementation, but we are not there yet

ddsim: Full Simulation Example

- Only change needed to go from **LCIO** to EDM4hep output is the output file name

https://key4hep.github.io/key4hep-doc/examples/clic.html

```
source /cvmfs/sw-nightlies.hsf.org/key4hep/setup.sh
git clone https://github.com/iLCSoft/CLICPerformance
ddsim --compactFile $LCGEO/CLIC/compact/CLIC_o3_v14/CLIC_o3_v14.xml \
      --outputFile ttbar.slcio \
      --steeringFile clic_steer.py \
      --inputFiles ../Tests/yyxyev_000.stdhep \
      --numberOfEvents 3
```

ddsim: Full Simulation Example

- Only change needed to go from LCIO to **EDM4hep** output is the output file name

https://key4hep.github.io/key4hep-doc/examples/clic.html

```
source /cvmfs/sw-nightlies.hsf.org/key4hep/setup.sh
git clone https://github.com/iLCSoft/CLICPerformance
ddsim --compactFile $LCGEO/CLIC/compact/CLIC_o3_v14/CLIC_o3_v14.xml \
      --outputFile ttbar_edm4hep.root \
      --steeringFile clic_steer.py \
      --inputFiles ../Tests/yyxyev_000.stdhep \
      --numberOfEvents 3
```

Configuring and Running k4SimGeant4

```
from Configurables import (SimG4Alg, SimG4SaveTrackerHits, SimG4UserLimitPhysicsList, GeoSvc, SimG4Svc,
                           SimG4FullSimActions)
# parse the given xml file
geoservice = GeoSvc("GeoSvc")
geoservice.detectors = [os.path.join(path_to_detectors, 'Detector/DetFCCeeIDEA/compact/FCCee_DectMaster.xml')]
# configure sensitive detector
savetrackertool_DCH = SimG4SaveTrackerHits("saveTrackerHits_DCH")
savetrackertool_DCH.readoutNames = ["DriftChamberCollection"]
savetrackertool_DCH.SimTrackHits.Path = "positionedHits_DCH"
SimG4Alg("SimG4Alg").outputs += [savetrackertool_DCH]
# Setup for physicslist
physicslisttool = SimG4UserLimitPhysicsList("Physics");     physicslisttool.fullphysics = "SimG4FtfpBert"
# enable MC history
actions = SimG4FullSimActions();      actions.enableHistory=True
# configure geant4
geantservice = SimG4Svc("SimG4Svc")
geantservice.detector = 'SimG4DD4hepDetector'
geantservice.physicslist = physicslisttool;      geantservice.actions = actions
geantservice.magneticField = field
geantservice.g4PostInitCommands +=["/process/eLoss/minKinEnergy 1 MeV", "/tracking/storeTrajectory 1"]
```

- Execute with `k4run simGeant4.py`
- Some steering files available for **FCC detectors**.

Delphes Fast Simulation

- “Delphes is a modular framework that simulates the response of a multipurpose detector in a parameterised fashion”
  - See **M. Selvaggi: Progress in DELPHES**
- Delphes integration to Key4hep framework: **key4hep/k4SimDelphes** and its **documentation**
- To integrate Delphes to Key4hep, we need to obtain EDM4hep output from it

Using Delphes Fast Simulation: Standalone

- Pick the Delphes card of your chosen detector
- Configuration for EDM4hep output: `edm4hep_output_config.tcl` which collections to store in the output file
- Pythia8 configuration: `p8_noBES_ee_ZH_ecm240.cmd`
- output file name: `delphes_events_edm4hep.root`

```
DelphesPythia8_EDM4HEP ${DELPHES_DIR}/cards/delphes_card_IDEA.tcl \
                       ${K4SIMDELPHES}/edm4hep_output_config.tcl \
                       p8_noBES_ee_ZH_ecm240.cmd \
                       delphes_events_edm4hep.root
```

There are other standalone programs in Key4hep to run for different input sources:

- `DelphesPythia8EvtGen_EDM4HEP`
- `DelphesROOT_EDM4HEP`
- `DelphesSTDHEP_EDM4HEP`

Using Delphes Fast Simulation: Framework Integrated

- Configure Delphes 'Algorithm' with similar arguments as standalone

```
#...
from Configurables import k4SimDelphesAlg
delphesalg = k4SimDelphesAlg()
delphesalg.DelphesCard = "delphes_card_IDEA.tcl"
delphesalg.DelphesOutputSettings = "edm4hep_output_config.tcl"
delphesalg.GenParticles.Path = "GenParticles"
#...
```

- Execute complete steering file: `k4run simDelphes.py`
  - Example **steering file**

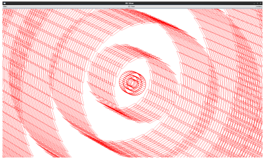
Developments

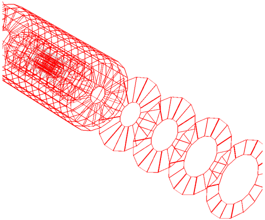
k4Clue

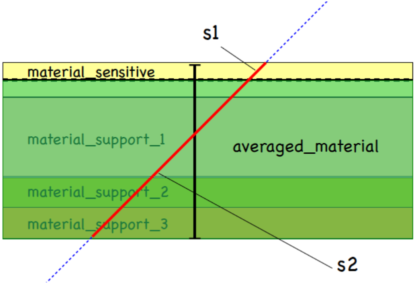
- Investigating use of the GPU friendly algorithm **CLUE** (CLUstering of Energy) as part of particle flow reconstruction
- CLUE Gaudi algorithm created: **k4Clue** and run as part of the CLIC reconstruction chain
- Validation and use of the clusters pending

k4ActsTracking

- Started work towards integration of the ACTS tracking toolkit with Key4hep:
  - Planning to create thin Gaudi Algorithm(s) converting necessary information for ACTS and tracks back to EDM4hep
- Try to use information provided by `dd4hep::rec::Surface` class to ACTS
  - Surfaces can be added after the fact to the geometry instantiation



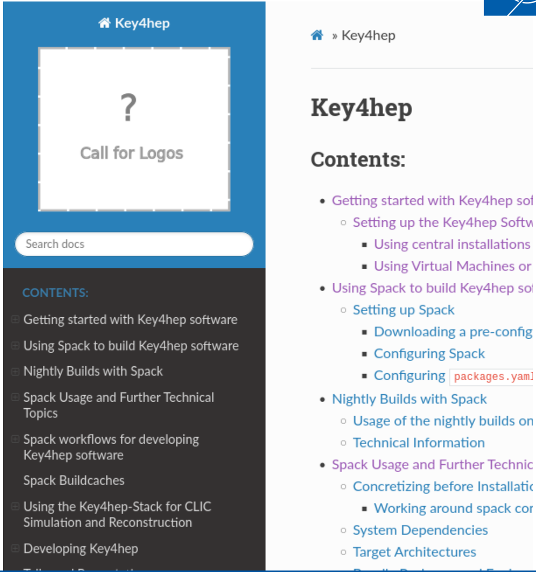




Documentation

Documentation

- Main documentation page key4hep.github.io based on GitHub pages https://github.com/key4hep/key4hep-doc
- Test the examples in the documentation via `notedown`
- Doxygen, e.g., EDM4hephttps://edm4hep.web.cern.ch/
- CLIC simulation and reconstruction example
  - Would be nice to add the CEPC workflows as well
- Restructuring of documentation in the works
  - Separate *User*, *Developer*, *Librarian* content



Key4hep

Call for Logos

Search docs

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» Key4hep

Key4hep

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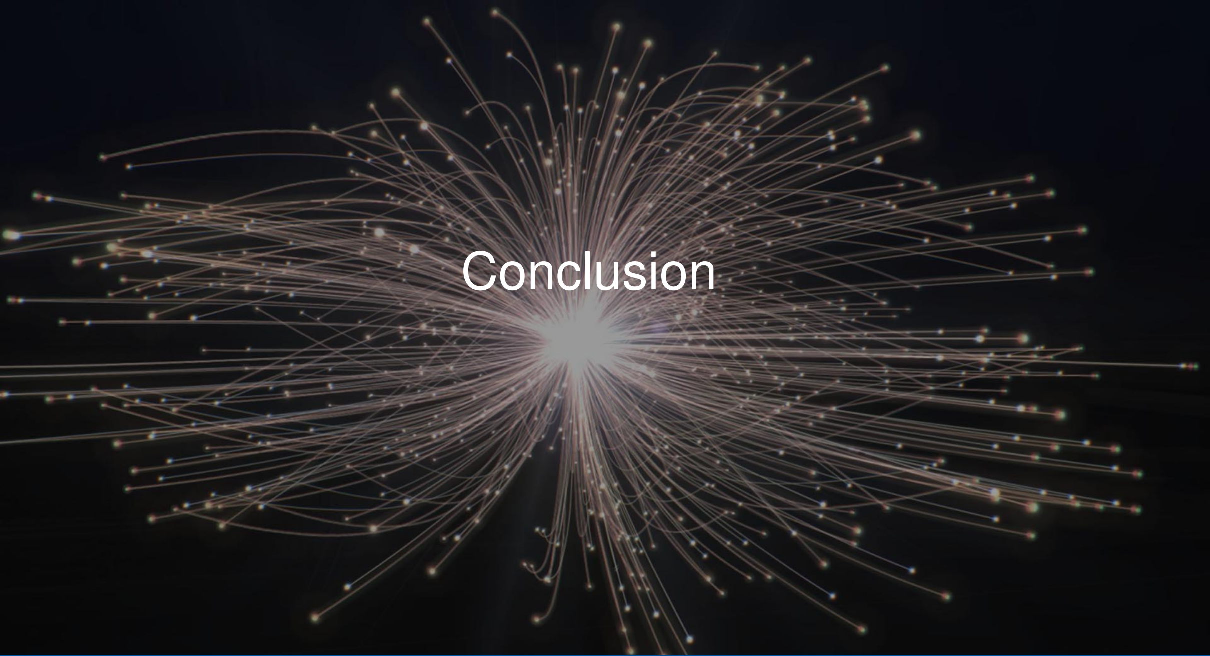
Conclusion



Conclusion

- Key4hep is the common framework of future Higgs factory studies: CEPC, CLIC, FCC, ILC
  - Parts of the stack also adopted by the EIC
  - New parties always welcome
- Essentially all functionality from iLCSoft preserved in the process
- On going developments to support multi-threading
- Integration of new common solutions: Gaussino, ACTS, CLUE

Thank you for your attention!

Acknowledgements

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