

Key4hep: Progress Report on Integrations

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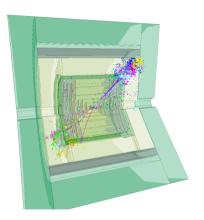
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Introduction Ongoing Integrations

Simulation Integrations Reconstruction Packages RDataFrame Analysis Visualisation with Phoenix Testing

Summary & Outlook

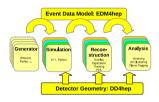


Key4hep: Turnkey Software Stack



Structured software stack integrating individual packages towards a complete data processing framework for HEP experiments

- Reduce overhead for adopting projects by sharing common components
- Easy to use for librarians, developers, users
- Functionality-complete: plenty of examples for simulation and reconstruction of detectors
- Preserve and adapt existing functionality into the stack, e.g., from iLCSoft. FCCSW. CEPCSW



Main ingredients

Event Data Model (podio/EDM4hep) (see **talk by T. Madlener**), Geometry Information (DD4hep), Processing Framework (Gaudi), Package manager (Spack)

International Community



- Contributors/Interest from China, Germany, Italy, Americas, CERN: CEPC, CLIC, EIC, FCC, ILC, MuonCol
 - Significant overlap with EIC software (DD4hep, podio/EDM4hep, ACTS, spack) (cf. EIC software talk)
- ► Funded by CERN EP R&D (WP7), AIDAInnova (WP12)
 - Supported by ECFA (connections w/ WG2, WG3)
- New communities are always welcome to
 - join our Meetings:
 - Tuesday, 9:00 AM CET, weekly alternating EDM4hep/Key4hep https://indico.cern.ch/category/11461/ (once per month: 3 PM CET for collaborators in Americas (EIC))
 - have a look at the documentation with some working examples: http://cern.ch/key4hep
 - browse the code: http://github.com/key4hep



Selected sample of recent Presentations (since vCHEP)

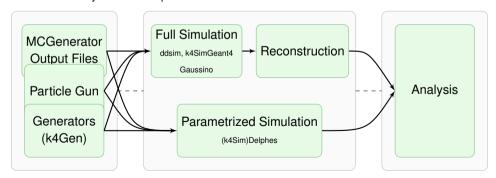


- ► Key4hep: Status and Plans (A. Sailer, vCHEP 2021, 18 May 2021)
- ► The Key4hep turnkey software stack for future colliders (P. Fernandez Declara, EPS-HEP Conference 2021, 29 July 2021)
- ► Common software for future colliders: The Key4hep turnkey ... (P. Fernandez Declara, ILCX2021, 28 October 2021)
- Key4hep software Stack for Detector Studies (P. Fernandez Declara, ACAT, 1 December 2021)
- ► Key4HEP: Common Software for Future Experiments (B. Hegner, IAS Program on HEP, 12 January 2022)
- ▶ A common software for future colliders: The Key4hep turnkey software stack (V. Volkl, Lepton-Photon 2021, 12 Jan 2022)
- ► Key4hep Project Status Update (V. Volkl et al., ICHEP, 9 July 2022)
- ► The Software Eco-System (T. Madlener, ECFA Workshop on e+e- Higgs/EW/Top Factories, 6 October 2022)
- ► Simulation: Going Fast, Full and Fully Fast (A. Sailer, ECFA Workshop on e+e- Higgs/EW/Top Factories, 6 October 2022)
- ▶ The Key4hep Turnkey Software Stack: Beyond Future Higgs Factories (V. Volkl et al., ACAT, 23 October 2022)
- ► Future Collider Framework (A. Sailer, Muon Collider Annual Meeting, 12 October 2022)
- ► Key4hep and FCC software (G. Ganis, FCC Physics Workshop, 24 January 2023)

Simulation Integrations



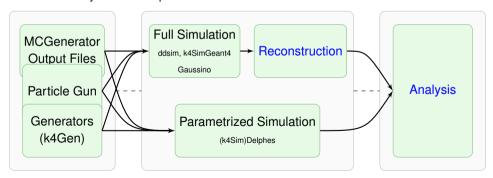
- Key4hep allows to run fast parameterized simulation via Delphes, or Geant4 Simulation via DD4hep::ddsim (standalone) and k4SimGeant4 (Gaudi interface)
 - ▶ All solutions output data in EDM4hep format to be used in digitisation / reconstruction
- ▶ k4SimGeant4 essentially has the same goal as Gaussino
 - Adoption of Gaussino planned as a replacement for k4SimGeant4, aligning-with/adopting functionality from DD4hep::DDG4



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Track Reconstruction

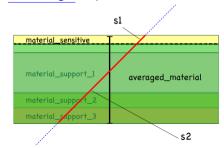


▶ iLCSoft tracking algorithms available through the *k4MarlinWrapper* approach



- Integration of the ACTS tracking toolkit as thin Gaudi Algorithm ongoing:
 - Converting from EDM4hep to ACTS formats (see P. Gessinger talk)

- Inject/add into ACTS surface information provided by dd4hep::rec::Surface
 - After the geometry instantiation, via DD4hep's plugin mechanism

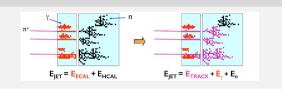


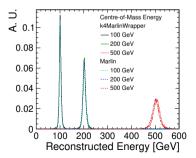
PandoraPFA: Particle Flow Clustering



PandoraPFA

Particle Flow clustering **toolkit** for high-granularity calorimeters. Currently available through the *k4MarlinWrapper* approach, validation wrt *Marlin* required.



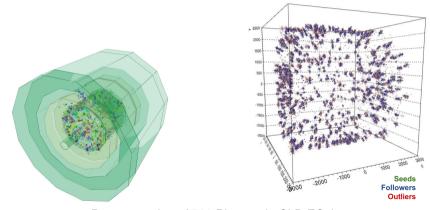


- Fairly consistent results for reconstruction comparing k4MarlinWrapper wrt Marlin including PandoraPFA
- Adaptation to new detector concepts, e.g. LAr-based, through DD4hep geometry drivers / plugins

Plan to develop Gaudi based interface to PandoraPFA

Clustering with Clue

- Clue (Clustering Energy) is a GPU friendly clustering algorithm developed for CMS HGCal
- ▶ **<u>k4CLUE</u>** integration of Clue for the Key4hep stack able to reconstruct clusters in different detectors, more flexible approach digesting DD4hep information to come



Reconstruction of 500 Photons in CLD ECal

Analysis with RDataFrame



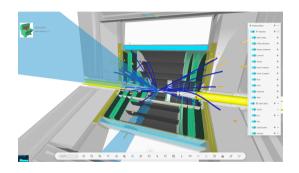
- EDM4hep data stored in ROOT Tree / RNTuple lends ideal candidate for analysis with RDataFrame
- ► Collection of tools in FCCAnalyses
- Example parts of the Higgs-Factory "Standard Candle" Higgs-Recoil analysis

```
theDataFrame
# define an alias for electron index collection
.Alias("Electron0", "Electron#0.index")
# define the electron collection
.Define("electrons", "ReconstructedParticle::get(Electron0, ReconstructedParticles)")
#select electrons on pT
.Define("selected electrons", "ReconstructedParticle::sel_pt(10.)(electrons)")
# . . .
.Define("zed_leptonic_recoil_m", "ReconstructedParticle::get_mass(zed_leptonic_recoil)")
# create branch with leptonic charge
.Define("zed_leptonic_charge", "ReconstructedParticle::get_charge(zed_leptonic)")
# Filter at least one candidate
.Filter("zed_leptonic_recoil_m.size()>0")
```

Visualisation with Phoenix



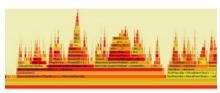
- Phoenix an experiment independent web-based event display for HEP, used by ATLAS, LHCb. . . .
- Adapted for use in Key4hep
 - Detector DD4hep-based geometries converted with <u>JSROOT</u>
 - Some pruning and configuration still needed to make detectors look nice
 - Event Data exported as JSON
- Example: https://fccsw.web.cern.ch/fccsw/phoenix/



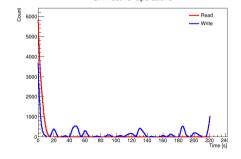
Testing



- The rate of changes and updates in the functionality requires monitoring and validation of performance
- Setting up continuous validation system able to monitor key performance indicators for any community (Detector Model) in Key4hep
- Valprod: toolkit to support building comprehensive validation jobs
 - Support CPU flame graph, I/O profiling
 - ► Integration with HSF::prmon



SimTest IO Operations



Summary & Outlook



- Key4hep project is providing a common framework for future Higgs factories
 - Fully adopted by FCC, increasing adoption by CLIC, ILC, CEPC
 - Interest grown beyond the initial electron–positron collider communities (EIC)
 - New collaborators are always welcome
- Consolidation and expansion of the software stack to match the needs of the community is ongoing
 - By integrating new state-of-the art tools: PandoraPFA, ACTS, CLUE, Phoenix
 - Continuous Validation System to ensure everything keeps working together with high performance

Acknowledgements



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Thank you for your attention!