The Key4hep turnkey software stack for future colliders

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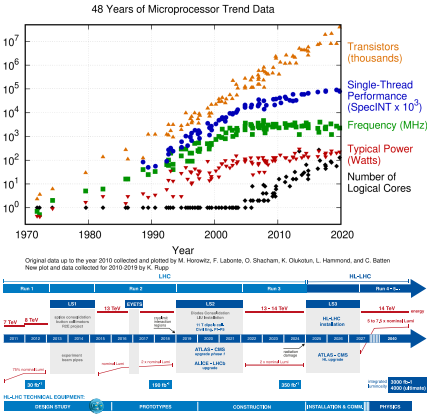
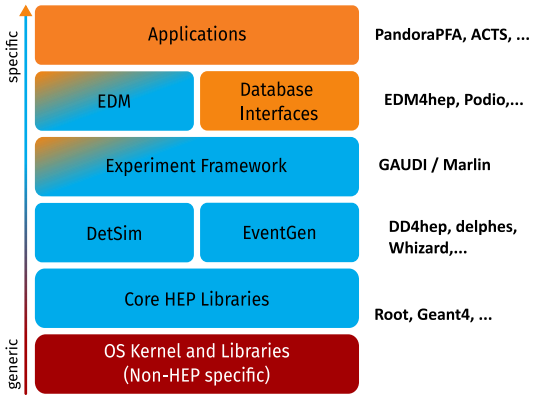
Software challenges on HEP

- Future detector studies rely on well maintained software: proper studies of detector concepts, their physics reach and limitations
- Long Lifetimes – Shift of priorities throughout the evolution of an experiment
  - Conceptual and design work: quick iterations relying on simulation
  - Production quality: requires stability & continual updates
  - Data preservation
  - Avoid amassing "technical debt"
  - Computing performance and efficiency
  - New technological developments and paradigms



HEP Software stack

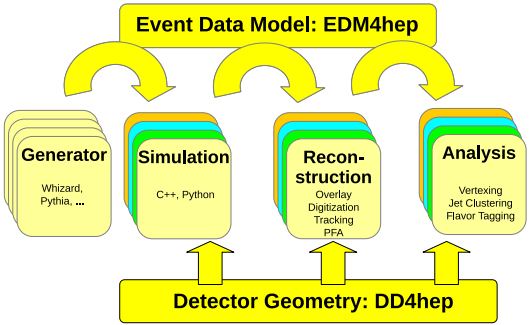
- Pieces of software are not living in isolation: interaction between components
- Compatibility between different elements doesn't come for free
  - Common standards can help a lot
- Building a consistent stack of software for an experiment is highly non-trivial
  - Benefits can be gained from using common approaches



Key4hep Goals

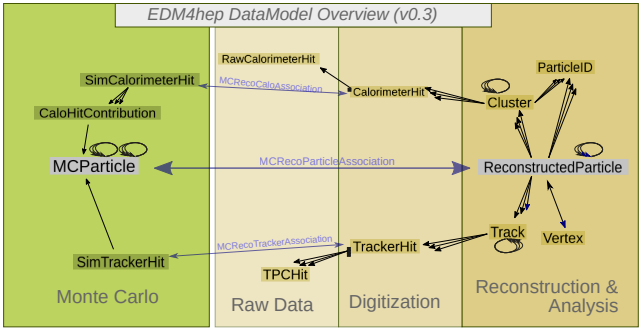
Software stack that connects and extends packages to provide a complete data processing framework, comprising fast and full simulation, reconstruction and analysis.

- Contributions from FCC, CLIC, ILC, CEPC
  - Re-use existing tools where possible
- EDM4hep: based on LCIO and FCC-edm
- Gaudi: framework
- DD4hep: geometry information
- Spack: package manager
- Ease of use for librarians, developers and users
- Provide examples, documentation, templates and common practices



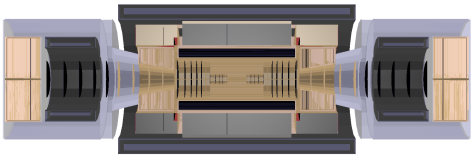
- To facilitate interoperability, different components should talk the same language
- In HEP this is the Event Data Model: describes structure of HEP data

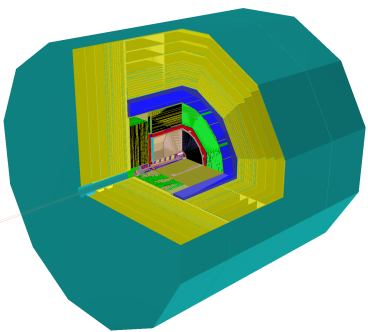
- Based on LCIO and FCC-edm
- Focus on: fast, efficient, multithreaded and transparent I/O system
- Implemented with PODIO - *vCHEP 2021: EDM4hep and podio*



DD4hep - Detector Description Toolkit for HEP

- Originally developed for ILC and CLIC but with all of HEP in mind
- Provides a complete detector description
  - Geometry, materials, visualization, readout, alignment, calibration, ...
- From a single source of information
  - Used in simulation, reconstruction, analysis
- Comes with a powerful plug-in mechanism that allows customization
- More or less “industry standard” by now
  - ILC, CLIC, FCC, CEPC, EIC, ...
  - LHCb and CMS to use DD4hep for Run3
- `ddsim` already directly outputs EDM4hep
  - when writing ...`edm4hep.root` files





Software Framework for HEP: Gaudi

- Traditionally HEP has not done too well with sharing efforts towards a common experiment framework. Notable exceptions are:
  - *Marlin* developed and used by ILC and CLIC
  - *Gaudi*[1], originally developed by LHCb, now also by ATLAS
    - Also used by FCCSW and other experiments (HARP, BESIII, Minerva, Daya Bay, ...)
- Key4hep has decided to adapt `Gaudi` as its base framework
  - Several Key4hep components are developed on top of it
  - Contribute to its development where necessary
- Integration and migration of iLCSoft algorithms into Key4hep with the help of a `Marlin`→`Gaudi` wrapper
  - Allows to use `Marlin` processors within the `Gaudi` framework

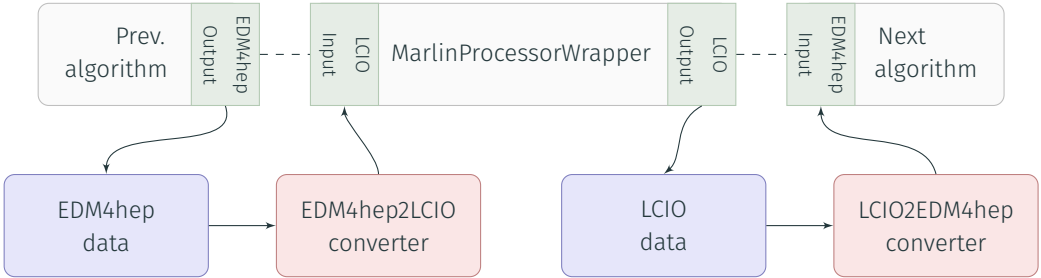
[1] https://cern.ch/gaudi

k4MarlinWrapper

- Run *Marlin* Processors through *Gaudi* Algorithms, without changes to *Marlin*
- Enhanced *Marlin* XML to *Gaudi* Python steering files converter
  - Optional execution markers
  - *Constants* parsing: propagated through the steering file
- Input and output support for LCIO and EDM4hep
  - Read events with *LcioEvent* or *PodioInput* using *k4DataSvc*
  - Write events with wrapped *LCIOOutputProcessor* or *PodioOutput*
- Uses cases with *k4MarlinWrapper*:
  - CLIC reconstruction: full CLIC processors sequence
  - LCFI+ algorithm: vertex and jet finding, and flavour tagging
    - Different EDMs mixed to run the sequence: EDM converters
  - SCT integration: use k4MarlinWrapper in Aurora framework

k4MarlinWrapper: EDM converters

- In-memory on-the-fly conversion for LCIO ↔ EDM4hep
- Implemented as Gaudi Tools, can be attached to any *MarlinProcessorWrapper*
- LCIO → EDM4hep conversion achieved through k4LCIOReader
- Metadata conversion is being implemented
- Time measurements for the converters



k4SimDelphes - First steps towards physics

- k4SimDelphes uses delphes to do the simulation and reconstruction, and creates output files in EDM4hep format
- Quick way to get your hands dirty and do some physics with EDM4hep
- Currently available as standalone executables
  - E.g. `DelphesPythia8_EDM4HEP`, `DelphesSTDHEP_EDM4HEP`, ...
- Part of a coherent approach to generation / simulation in Key4hep
  - Ideally no difference between the different approaches of simulating a detector response
  - Work on full integration is ongoing with a prototype

Key4hep Framework

- k4FWCore
  - Core Key4hep framework providing core functionality, e.g.
    - Data Service for PODIO collections
    - Overlay for backgrounds
  - Recently switched to Gaudi v35
- k4-project-template
  - template repository showing how to build new components on top of the core Key4hep framework
- Ongoing work to collaborate more with Gaudi ecosystem (Gaussino)
- Ongoing work to integrate more components (ACTS, ...)

Software Infrastructure

- Documentation
  - key4hep.github.io/key4hep-doc (main documentation)
  - cern.ch/edm4hep (doxygen code reference)
- Spack package manager to build whole stack from source
  - Emphasis on dealing with multiple configurations of same package
  - Several versions, compilers, external library version, ...
- Automated builds and continuous integration (CI) where possible
  - Regular nightly builds of the complete stack
- Distribution via CVMFS
  - Latest release can be found at `/cvmfs/sw.hsf.org/key4hep`
- Release early and release often
  - Make fixes available early
  - Discover problems and collect feedback as early as possible

Key4hep adaptations

- CEPC
  - Started with iLCSoft; adopted Gaudi, EDM4hep, DD4hep
  - Developed Geant4 based sim. Implemented k4LCIOReader
- FCCSW
  - Gaudi and DD4hep based; Adaptation to EDM4hep
  - FCCSW re-arranged into Key4hep components: k4FWCore, k4SimDelphes, k4RecCalorimeter, fccDetectors, and others
- iLCSoft
  - ILC and CLIC: keep existing software chains, enabled by k4MarlinWrapper
  - Port algorithms to Gaudi in the future
- SCT
  - Adaptation to EDM4hep in progress
  - Integration with k4MarlinWrapper to enable Marlin algorithms

Summary and outlook

- Core components of Key4hep already -or close to- a first production quality release
  - Provides framework, simulation and reconstruction
- Opportunity for HEP community to develop a common software ecosystem, for the first time.
  - Leverage synergies between communities and existing experiments to develop and maintain common core tools
- Projects have started migrating their software to Key4hep: FCCSW, ILC, CLIC & CEPC

Backup

Key4hep common tooling

- Not only common software HEP tools, but also general software tools and practices.
- Templates provided for new packages to follow common structure with folders.
- Common use of build systems: CMake, gcc, clang.
- Encourage use of common software analysis tools: sanitizers.
- Encourage uniform consistent code style and practices: clang format, clang tidy.
- Common testing tools: Catch2, Pytest.
- Unified building and deployment with Spack and CVMFS.
- Moving towards common interfaces, frameworks, packages, versions, etc.
- Modern tooling: compilers, language standards,

Spack for Key4hep

- Spack is a package manager
  - Does not replace CMake, Autotools, ...
  - Comparable to apt, yum, homebrew, ...
  - Independent of operating system
  - Builds all packages from source
- Originaly developed by the HPC community
  - Emphasis on dealing with multiple configurations of the same package
    - Different versions, compilers, external library versions, ...
  - Several versions of the same package can coexist on the same system
- The whole Key4hep software stack can be built from scratch using spack
- Spack allows different workflows for setting up consistent software stacks
  - Currently testing which one fits our purposes the best