Status of Key4hep and EDM4hep

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for the Key4hep developers

2023 International Workshop on Circular Electron Positron Collider

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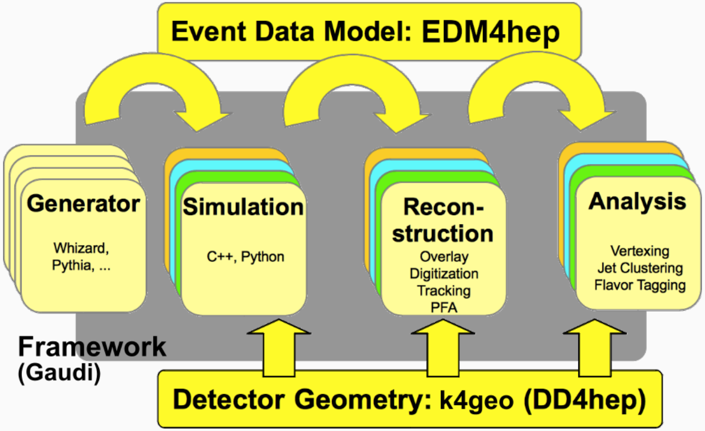
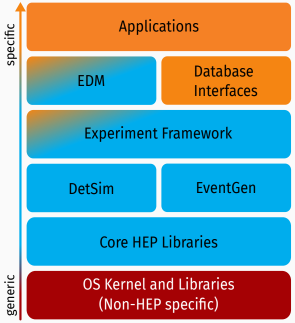
From generation to analysis - the general workflow



- Many steps involved from generating events to analyzing them
- Hundreds of SW packages
    - Building & deploying
    - Consistency
    - Reproducibility
- Try to give an overview of the **Key4hep** SW ecosystem

Key4hep - A (very) brief introduction

- Future detector studies rely on well maintained software for studying their potential
- Maintenance of a consistent HEP SW stack is non-trivial
    - Ecosystem of interacting components
- Sharing the burden allows everybody to reap the benefits
    - Make best use of scarce (human) resources
- **Regular contributions from ILC, CLIC, FCC, CEPC, EIC, (MuonCollider), ...**
- Support from major R&D initatives
    - CERN R&D for Future Experiments, AIDAinnova WP12, ECFA



Key4hep goals

- Provide and maintain a consistent SW stack that allows to do physics studies for **all projects**
- Ensure interoperability of the necessary building blocks
- Reuse existing solutions where possible
    - A lot of experience from LHC experiments and LC communities
- Focus new developments on EW/Higgs factory specifics
- Share knowledge, processes, workflows and resources
    - Best practices, tutorials, documentation, ...

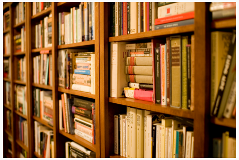
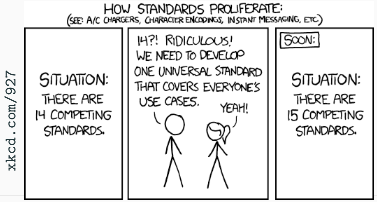


Photo by Stewart B. / CC-BY

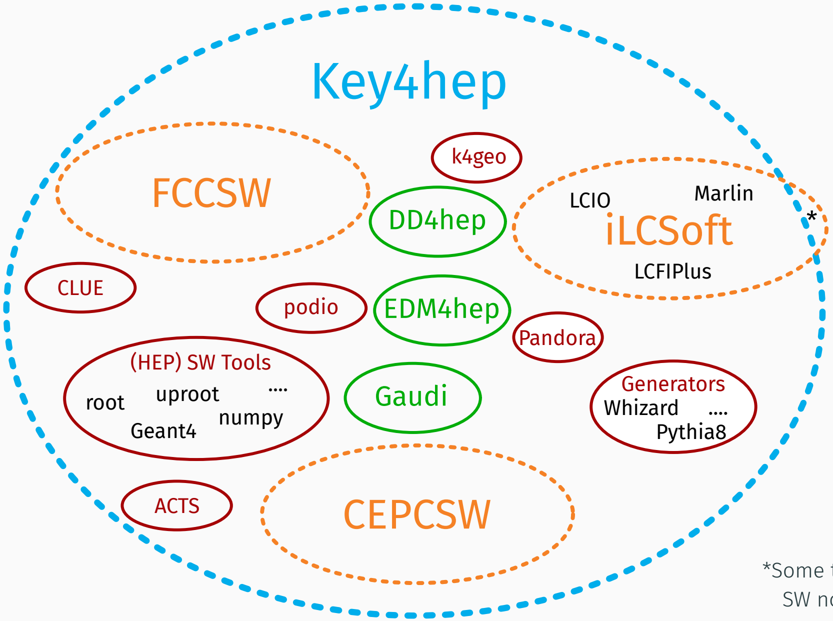
Non-goal

- Develop and maintain project specific software and workflows



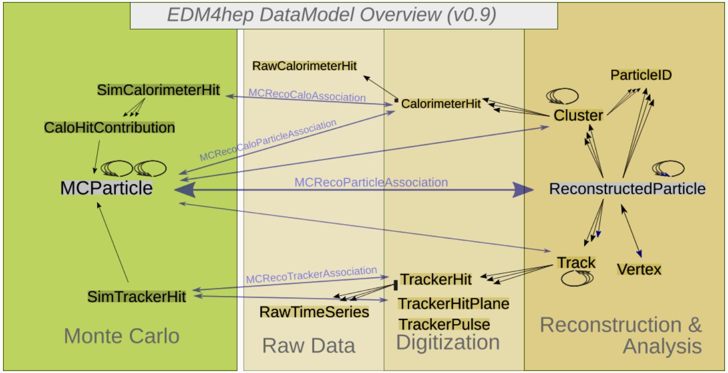
xkcd.com/927
HOW STANDARDS PROLIFERATE:
(SEE: A/C CHARGERS, CHARACTER ENCODINGS, INSTANT MESSAGING, ETC)
SITUATION: THERE ARE 14 COMPETING STANDARDS.
14?! RIDICULOUS! WE NEED TO DEVELOP ONE UNIVERSAL STANDARD THAT COVERS EVERYONE'S USE CASES.
YEAH!
SOON:
SITUATION: THERE ARE 15 COMPETING STANDARDS.

Key4hep (simplified) overview



*Some testbeam related SW not yet included

EDM4hep - The common EDM for Key4hep



key4hep/EDM4hep

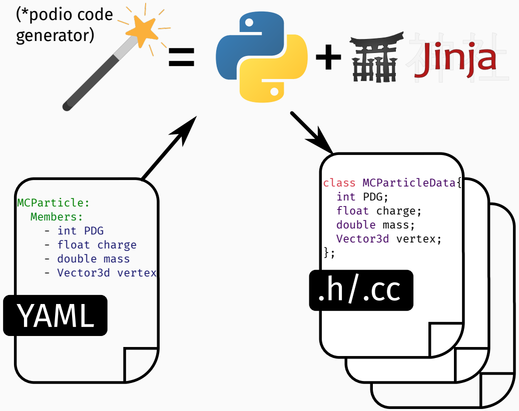
edm4hep.web.cern.ch

AIDASoft/podio

- Based on `LCIO` and `FCC-edm`
  - Focus on usability in analysis
- Quite stable over the last two years
- Addition of datatypes for **CEPC drift chamber study**
- Can easily be extended
  - Used by EDM4eic
  - Main purpose: prototyping
- Generated via `podio`

The podio EDM toolkit

- Implementing a performant event data model (EDM) is non-trivial
- Use `podio` to generate code starting from a high level description
- Provide an easy to use interface to the users
- Main customers
  - [key4hep/EDM4hep](#)
  - [eic/EDM4eic](#)
- **Finishing schema evolution for v1.0**



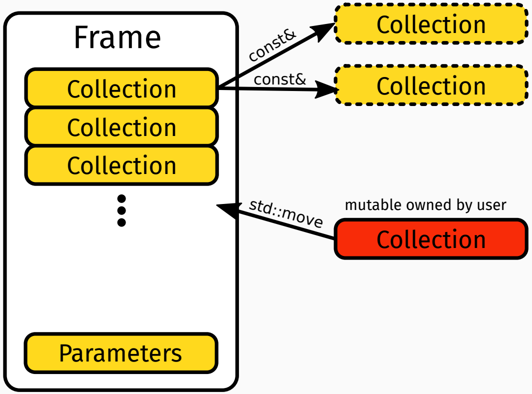
```
MCParticle:
  Members:
    - int PDG
    - float charge
    - double mass
    - Vector3d vertex
```

```
class MCParticleData{
  int PDG;
  float charge;
  double mass;
  Vector3d vertex;
};
```

[AIDASoft/podio](#)

The `Frame` - A generalized (event) data container

- Replaces deprecated `EventStore`
- *Type erased* container aggregating all relevant data
- Defines an *interval of validity* / category for contained data
  - Event, Run, readout frame, ...
- Easy to use and thread safe interface for data access
  - Immuatable read access only
  - Ownership model reflected in API
- Decouples I/O from operating on the data

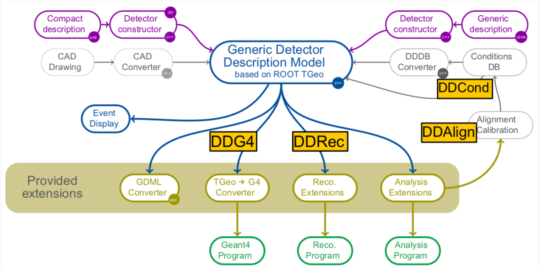


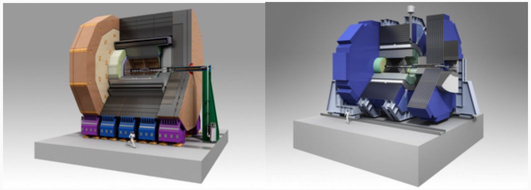
```cpp
template<typename CollT>
const CollT& get(const std::string& name) const;

template<typename CollT, /*enable_if*/>
const CollT& put(CollT&& collection,
                 const std::string& name);
```

DD4hep - Detector description

dd4hep.web.cern.ch

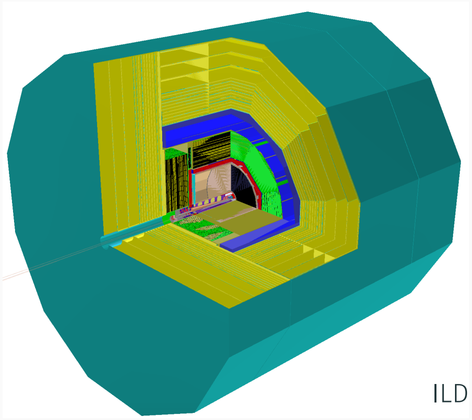
- Complete detector description
    - Geometry, materials, visualization, readout, alignment, calibration, ...
- From a **single source of information**
    - Simulation, reconstruction, analysis
- Comes with a powerful plug-in mechanism that allows customization
- More or less "industry standard" now
    - ILC, CLIC, FCC, CEPC, EIC, LHCb, CMS, ...
- `ddsim` - standalone simulation executable

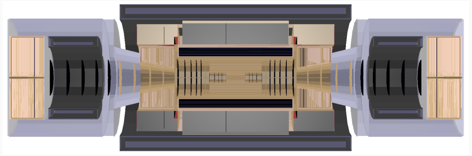




k4geo - The detector geometry repository

- `iLCSoft/lcgeo` $\rightarrow$ `key4hep/k4geo`
- Many existing detector models from LC studies
- Ongoing migration of detector concepts from HEP-FCC/FCCDetectors
  - Noble liquid ECAL
- New ARC detector concept in CLD
- IDEA detector (work in progress)
- Goal: central repository for detector descriptions


ILD


FCC-hh

Experiment Framework

- `Gaudi`, originally developed by LHCb, now also used by ATLAS, FCCSW and smaller experiments
  - Supports concurrency
  - “Battle-proven” from data taking during LHC operations
- Key4hep has decided to adapt `Gaudi` as its experiment framework
  - 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
  - key4hep/k4MarlinWrapper

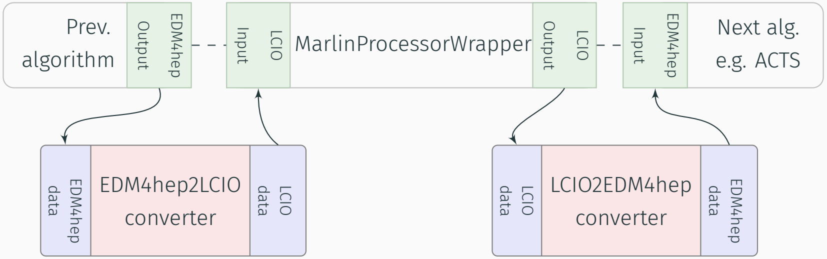
Frame based I/O in k4FWCore

- key4hep/k4FWCore offers core Key4hep services for Gaudi
  - **Data service for podio generated EDMs**
  - Historically grown separate implementation
- Replaced custom Reader / Writer with podio provided ones
  - (Almost) completely transparent
- `podio::Frame` not visible to user
- Some usability improvements in the works

```cpp
using namespace edm4hep;

// declare handle
DataHandle<MCParticleCollection> m_pHandle{
    "Particles",
    Gaudi::DataHandle::Reader,
    this};

// declare handle as property
declareProperty("ParticleColl",
                m_pHandle,
                "mc collection");

// use as
const auto particle = m_pHandle.get();
```

k4MarlinWrapper

- Wraps **Marlin processor** in a Gaudi algorithm and allows to **run them unchanged**
- Automatic, on-the-fly conversion between LCIO and EDM4hep
- **Allows to “mix and match” existing reconstruction algorithms with new developments**

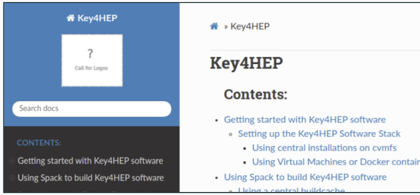


Key4hep resources

- (Rolling) latest release of the complete Key4hep software stack

```
source /cvmfs/sw-nightlies.hsf.org/key4hep/setup.sh
source /cvmfs/sw.hsf.org/key4hep/setup.sh
```

- **Release early and release often**
  - Solicit feedback as early as possible
- Documentation available at key4hep.web.cern.ch
- Active weekly meetings ($\sim 10 - 15$ attendees)
  - https://indico.cern.ch/category/11461/
- **Feedback and contributions are greatly appreciated**



Key4HEP
?
Call for Logos
Search docs
CONTENTS:
Getting started with Key4HEP software
Using Spack to build Key4HEP software
» Key4HEP

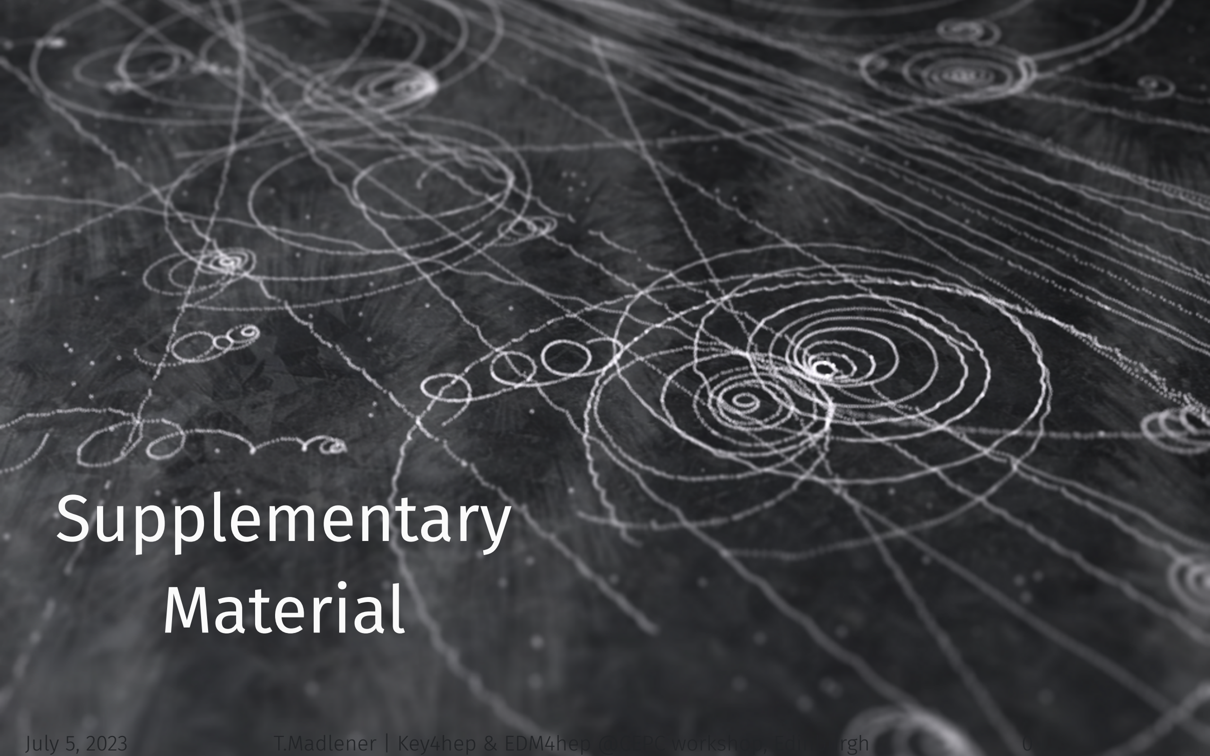
Key4HEP

Contents:

- Getting started with Key4HEP software
  - Setting up the Key4HEP Software Stack
    - Using central installations on cvmfs
    - Using Virtual Machines or Docker contair
- Using Spack to build Key4HEP software
  - Using a central buildcache

Summary

- Key4hep aims at providing a common software stack for **all future collider projects**
- Very successful in **bringing together communities** and **focusing on common approaches**
- Ongoing effort to stabilize core components
- **Key4hep can be used for future collider studies now**
    - CEPCSW is doing this already
- **Still a lot of work ahead**
    - Very happy to welcome new contributors



Supplementary Material

Pointers to software (re)sources

- Key4hep
  - key4hep.github.io/key4hep-doc
  - key4hep - github organisation
- EDM4hep
  - key4hep/EDM4hep
  - cern.ch/edm4hep
- DD4hep
  - AIDASoft/DD4hep
  - dd4hep.web.cern.ch
- iLCSoft
  - iLCSoft - github organisation
  - ilcsoft.desy.de

MAN, I SUCK AT THIS GAME. CAN YOU GIVE ME A FEW POINTERS?
0x3A28213A 0x6339392C, 0x7363682E.
I HATE YOU.

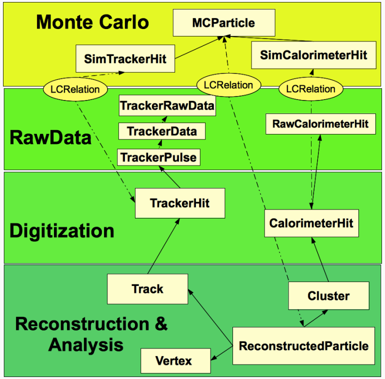
xkcd.com/138

Key4hep packages

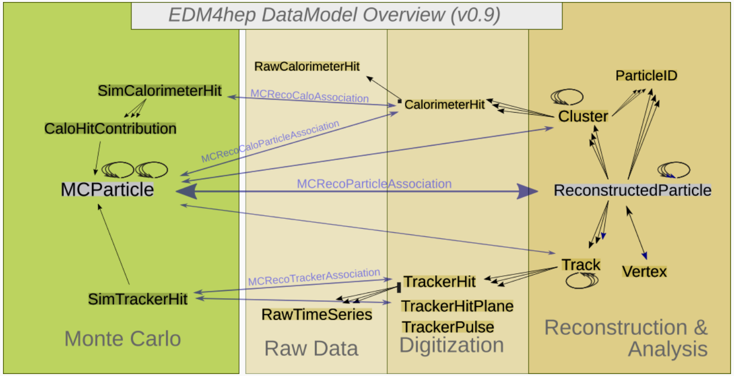
- `k4FWCore` key4hep/k4FWCore
  - Core Key4hep framework providing core functionality, e.g.
    - Data Service for EDM4hep inputs
    - Overlay for backgrounds
- `k4SimDelphes` for Delphes fast simulation key4hep/k4SimDelphes
- `k4MarlinWrapper` Marlin proc. wrapper key4hep/k4MarlinWrapper
- Many packages migrated from FCCSW to Key4hep
  - `k4SimGeant4` for Geant4 simulation integration HEP-FCC/k4SimGeant4
  - `k4Gen` for generic generator interface HEP-FCC/k4Gen
  - ...
- Ongoing work to integrate more components
  - ACTS tracking framework acts-project/acts | key4hep/k4ActsTracking
  - CLUE fast clustering algorithms .cern.ch/kalos/CLUE | key4hep/k4CLUE

LCIO → EDM4hep converter reloaded

LCIO



EDM4hep



- Large existing data sets in LCIO format
- Very similar high level structure but some differences in details

LCIO → EDM4hep converter reloaded

- Complete overhaul of pre-existing functionality
    - Shared library in key4hep/k4EDM4hep2LcioConv
    - Originally implemented in key4hep/k4LCIOReader
- Standalone executable (no Gaudi or Marlin!)

```
lcio2edm4hep input.slcio output.edm4hep.root
```

  - For all details see README
  - Available in recent nightly builds
- Using the `podio::Frame`
- Support all features that are necessary for ILD

Ongoing work (selection)

ACTS integration

- ACTS can now digest DD4hep detectors (with annotations)
- Minimal EDM4hep I/O support
  - More general solution under discussion
- Major effort with significant personpower requirements

Gaudi modernization

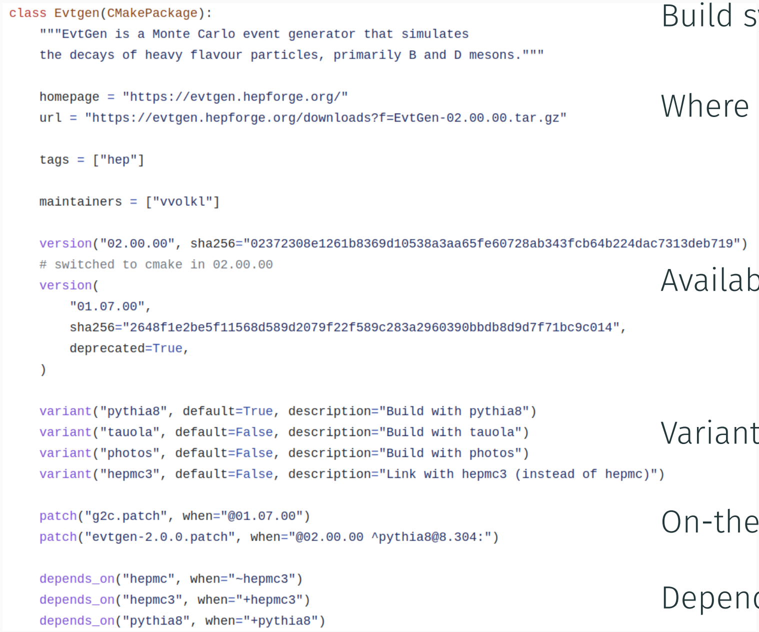
- Switch towards more modern Gaudi approach (*Gaudi Functional*)
  - “Thread safe by default”
- Missing documentation is a major hurdle

Spack for Key4hep

- Spack is a package manager
  - 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
- Basic building block is a formalized build procedure $\rightarrow$ **spack recipe**
  - Build instructions, dependencies, versions and location of source code
  - $\sim$ 6650 packages currently available from spack
  - Key4hep maintains repository with additional packages
- The whole Key4hep software stack can be built from scratch using spack

```
spack install key4hep-stack
```

Spack recipe



```
class Evtgen(CMakePackage):
    """EvtGen is a Monte Carlo event generator that simulates
    the decays of heavy flavour particles, primarily B and D mesons."""

    homepage = "https://evtgen.hepforge.org/"
    url = "https://evtgen.hepforge.org/downloads?f=EvtGen-02.00.00.tar.gz"

    tags = ["hep"]

    maintainers = ["vvolkl"]

    version("02.00.00", sha256="02372308e1261b8369d10538a3aa65fe60728ab343fcb64b224dac7313deb719")
    # switched to cmake in 02.00.00
    version(
        "01.07.00",
        sha256="2648f1e2be5f11568d589d2079f22f589c283a2960390bbdb8d9d7f71bc9c014",
        deprecated=True,
    )

    variant("pythia8", default=True, description="Build with pythia8")
    variant("tauola", default=False, description="Build with tauola")
    variant("photos", default=False, description="Build with photos")
    variant("hepmc3", default=False, description="Link with hepmc3 (instead of hepmc)")

    patch("g2c.patch", when="@01.07.00")
    patch("evtgen-2.0.0.patch", when="@02.00.00 ^pythia8@8.304:")

    depends_on("hepmc", when="~hepmc3")
    depends_on("hepmc3", when="+hepmc3")
    depends_on("pythia8", when="+pythia8")
```

Build system

Where to find source code

Available versions

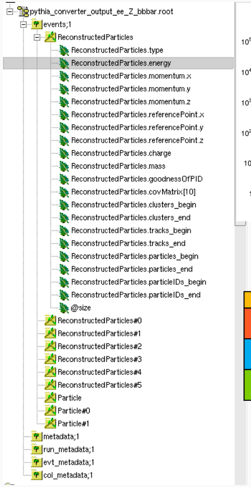
Variants / build options

On-the-fly patches

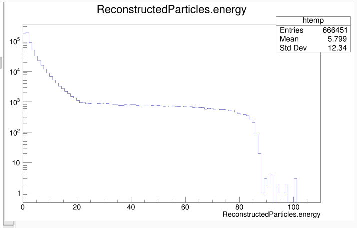
Dependencies

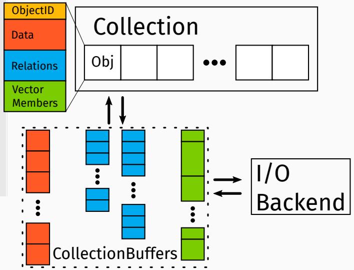
podio supports different I/O backends

- Default **ROOT** backend
  - POD buffers are stored as branches in a `TTree`
  - Files can be interpreted **without EDM library**(!)
  - Can be used in `RDataFrame` or with `uproot`
- Alternative **SIO** backend
  - Persistency library used in `LCIO`
  - Complete events are stored as binary records
- Adding more I/O backends is possible



```
pythia_converter_output_ee_Z_bbbar.root
  events;1
    ReconstructedParticles
      ReconstructedParticles.type
      ReconstructedParticles.energy
      ReconstructedParticles.momentum.x
      ReconstructedParticles.momentum.y
      ReconstructedParticles.momentum.z
      ReconstructedParticles.referencePoint.x
      ReconstructedParticles.referencePoint.y
      ReconstructedParticles.referencePoint.z
      ReconstructedParticles.charge
      ReconstructedParticles.mass
      ReconstructedParticles.goodnessOfPID
      ReconstructedParticles.covMatrix[10]
      ReconstructedParticles.clusters_begin
      ReconstructedParticles.clusters_end
      ReconstructedParticles.tracks_begin
      ReconstructedParticles.tracks_end
      ReconstructedParticles.particles_begin
      ReconstructedParticles.particles_end
      ReconstructedParticles.particleIDs_begin
      ReconstructedParticles.particleIDs_end
      @size
    ReconstructedParticles#0
    ReconstructedParticles#1
    ReconstructedParticles#2
    ReconstructedParticles#3
    ReconstructedParticles#4
    ReconstructedParticles#5
    Particle
    Particle#0
    Particle#1
  metadata;1
  run_metadata;1
  evt_metadata;1
  col_metadata;1
```


ReconstructedParticles.energy
htemp
Entries 666451
Mean 5.799
Std Dev 12.34
10^5
10^4
10^3
10^2
ReconstructedParticles.energy


ObjectID
Data
Relations
Vector Members
Collection
Obj
•••
CollectionBuffers
I/O Backend