Flexible and minimal-overhead Event Data Model for track reconstruction in ACTS

Paul Gessinger

CERN

2023-05-09 - CHEP 2023

Introduction

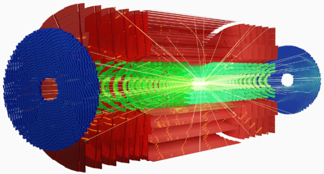
What is ACTS?

- Experiment-independent toolkit for track reconstruction applications
- Modern architecture and code, unit tested, continuous integration
- Minimal external dependencies
- Ready for multi-threading by design

Goals

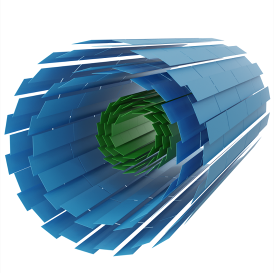
- Provide established algorithms in a modern package
- Community platform for R&D across various experiment
- Provide testbed for R&D activities including new algorithms, machine learning, heterogeneous computing

Evaluation and/or deployment by multiple experiments

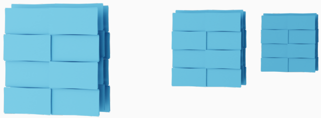


ATLAS EXPERIMENT

Inner Tracker



sPHENIX



FASER & FASER-2

ALICE

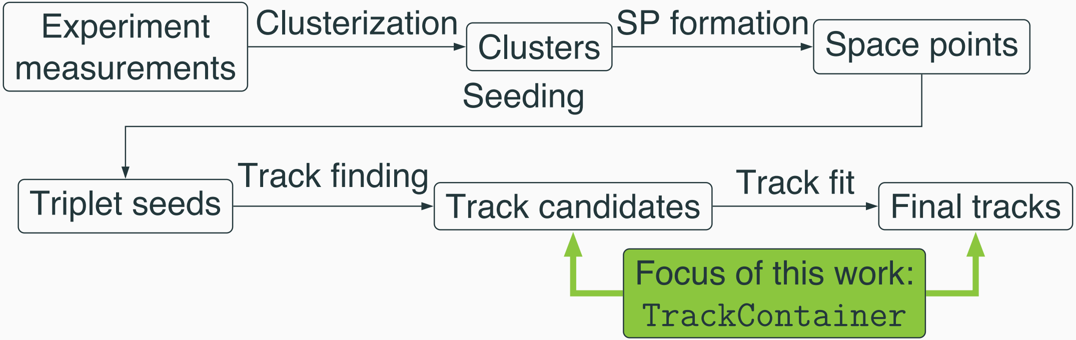
LDMX

ePIC (EIC)
(presentation
+ keynote yesterday)

STCF
(presentation just now)

Event Data Model

Event Data Model objects



ACTS Event Data Model

- Event Data Model (EDM) is critical piece of reconstruction software

Internal EDM

- Data objects to pass around between different parts of the library
- Library specific, tightly coupled to the algorithm

Public EDM

- Data objects clients directly interact with
- Should be experiment agnostic
- Extensible by experiment, easy integration

ACTS Event Data Model

- Event Data Model (EDM) is critical piece of reconstruction software

Internal EDM

- Data objects to pass around between different parts of the library
- Library specific, tightly coupled to the algorithm

Focus so far!

ACTS Event Data Model

- Event Data Model (EDM) is critical piece of reconstruction software

Focus now!

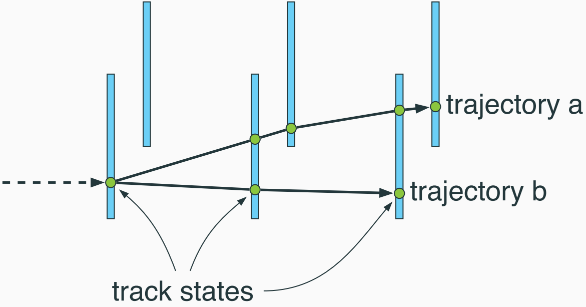
Public EDM

- Data objects clients directly interact with
- Should be experiment agnostic
- Extensible by experiment, easy integration

Acts::TrackContainer

- **Client-focused** primary output of tracking, used by track finding and fitting
- Track-level quantities + sequence of **track states** with intermediate information

- **Tracks**:
  - Defining parameters at perigee
  - Global track quantities (χ^2, num. hits, holes, outliers, etc)
- **Track states**:
  - Local parameters + cov. at geometric object (e.g. sensor)
  - Calibrated measurement, dimension, covariance
  - Auxiliary information like jacobian, type flags, etc

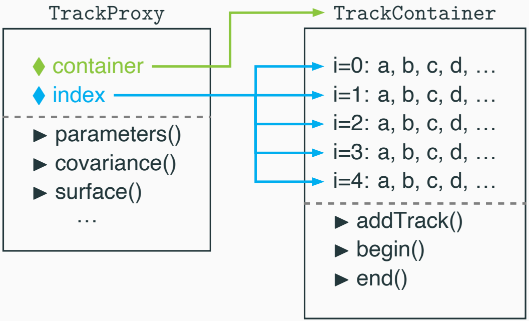


Architecture

Architecture

- **Container** is the **primary data object**
- Elements in containers are thin views (proxies) into them
- Container and proxy provide user-facing API
- **Want this to be fully integratable into experiment IO infrastructure!**

```
for (auto track : tracks) {
  track.parameters() = Acts::BoundVector::Zeros();
  track.nMeasurements() = 42;
  for (auto trackState: track.trackStates()) {
    trackState.referenceSurface();
  }
}
```



TrackProxy

♦ container

♦ index

▶ parameters()

▶ covariance()

▶ surface()

…

TrackContainer

i=0: a, b, c, d, …

i=1: a, b, c, d, …

i=2: a, b, c, d, …

i=3: a, b, c, d, …

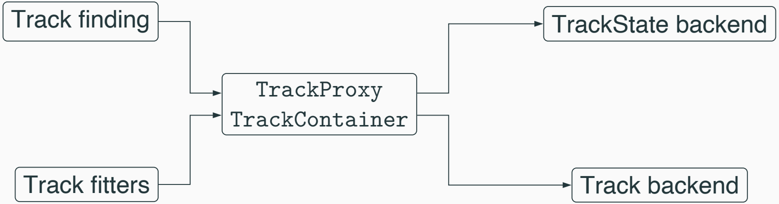
i=4: a, b, c, d, …

▶ addTrack()

▶ begin()

▶ end()

Architecture



Track finding

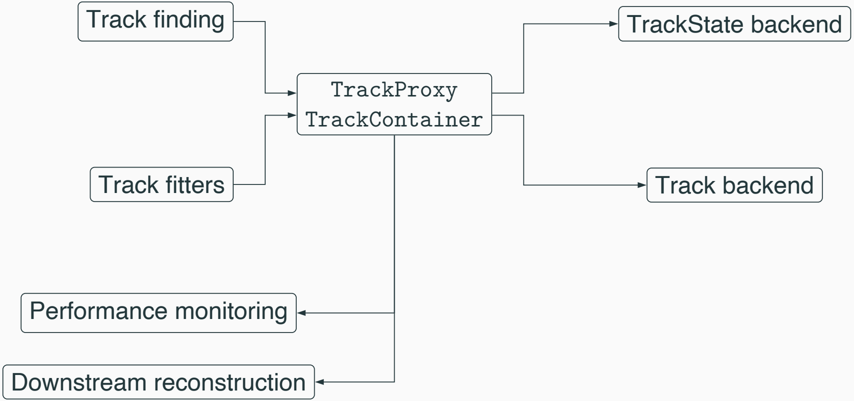
Track fitters

`TrackProxy`
`TrackContainer`

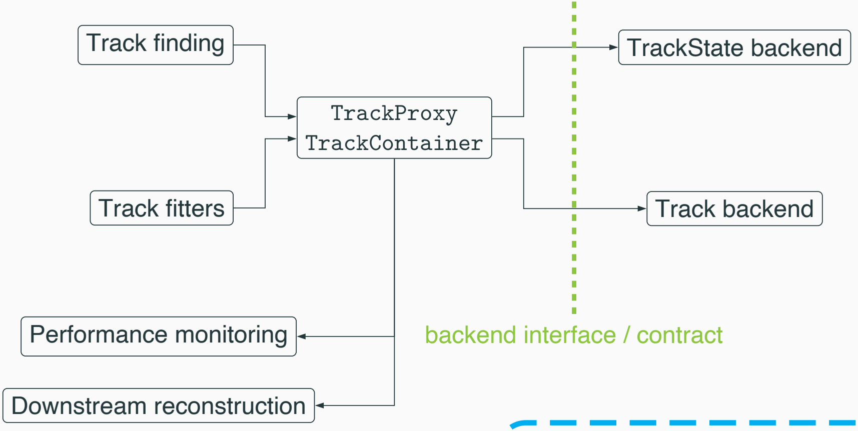
TrackState backend

Track backend

Architecture

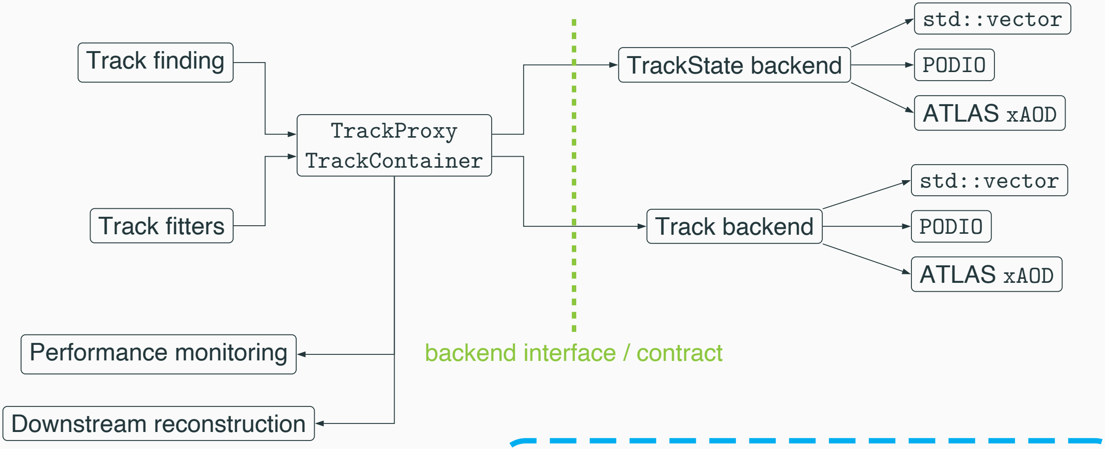


Architecture



Experiment agnostic: decouple interface from storage implementation

Architecture

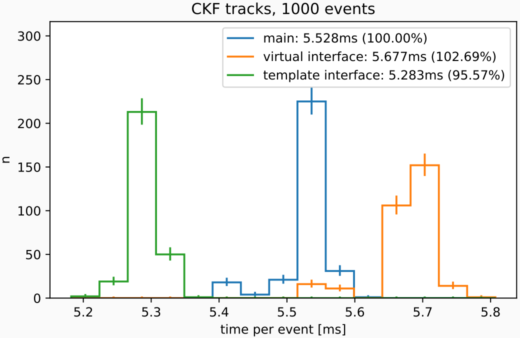


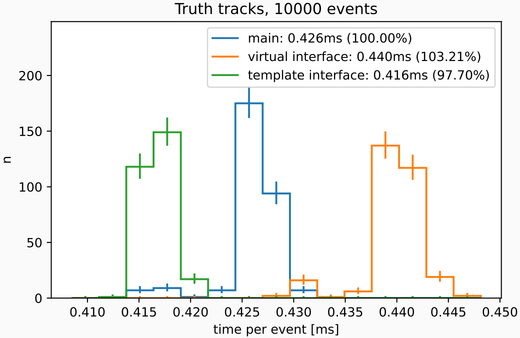
Experiment agnostic: decouple interface from storage implementation

Implementation

Acts::TrackContainer

- **Fully decoupled interface** seen by ACTS and client consumers from the backend implementation: **Backend can be fully experiment-specific**
  - **First attempt**: inheritance and virtual function calls: resulted in **undesirable overhead**
  - **Second attempt**: template based extension, **negative overhead** (likely due to better optimization)
- Supports dynamically added columns (if the backend supports it)





Backend interface / contract

- Interface-layer **expects backend** to implement set of methods
- Component access largely via **single function** and **compile-time hashes** of component names
- Dedicated methods where backends needs flexibility for implementation
- Design goal: **allow ACTS components to directly manipulate** the backend storage

```
track.parameters() = Acts::BoundVector::Zeros();
```

Core requirements

- Backend can return (non-dangling) references to memory representation
- Tracks and track states can be fully identified by an index
- Track states parameters, covariances + jacobians are in an indexed container somewhere

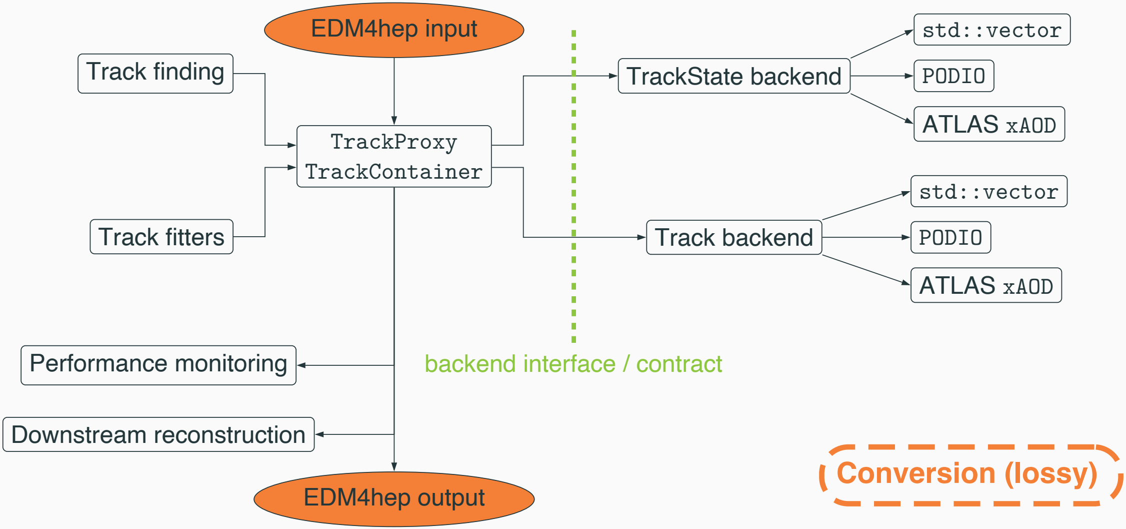
`EDM4hep` conversion

- Common EDM package for the key4hep software stack
- Built using `PODIO` framework: common definition of various data types, relationships
- Contain `edm4hep::Track` & `edm4hep::TrackState`
  - Uses the LCIO parametrization $d_0, z_0, \phi, \tan\lambda, \Omega$ (ACTS uses $l_0, l_1, \phi, \theta, q/p, t$)
  - Track states are described using perigee parameters only (ACTS uses varying local parametrization + link to geometry object)

Direct & transparent backend in EDM4hep not feasible

- **Required contract cannot be fulfilled**:
  - No stable references to native parametrization
  - Loss of on-surface hit position
- Instead: **Full (lossy) conversion** to and from EDM4hep tracks implemented (and in turn is backend agnostic)

Architecture



EDM4hep input

Track finding

Track fitters

TrackProxy
TrackContainer

TrackState backend

`std::vector`

`PODIO`

ATLAS `xAOD`

Track backend

`std::vector`

`PODIO`

ATLAS `xAOD`

backend interface / contract

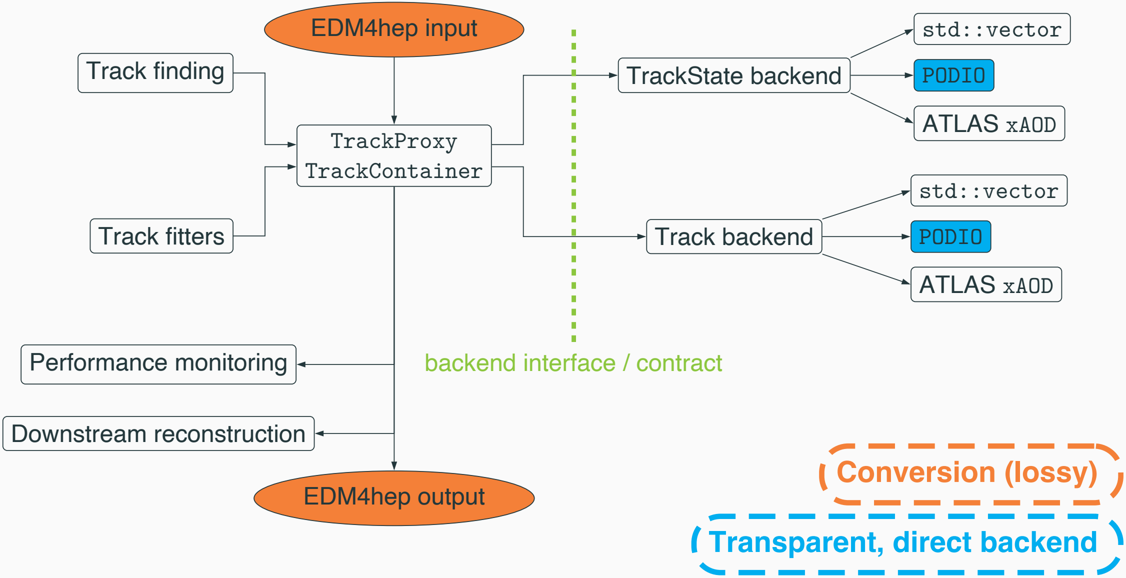
Performance monitoring

Downstream reconstruction

EDM4hep output

Conversion (lossy)

Architecture



EDM4hep input

Track finding

Track fitters

`TrackProxy`
`TrackContainer`

TrackState backend

`std::vector`

`PODIO`

ATLAS `xAOD`

Track backend

`std::vector`

`PODIO`

ATLAS `xAOD`

backend interface / contract

Performance monitoring

Downstream reconstruction

EDM4hep output

Conversion (lossy)

Transparent, direct backend

`PODIO` backend: `ActsPodioEdm`

Goal

- Demonstrate **ability to integrate** with an external IO solution like `PODIO`
- This is not an alternative to `EDM4hep`, but help us understand requirements

- Specify ACTS EDM in `PODIO`-yaml [1] in *plugin*
- Implemented `ActsPodioEdm::Track` + `ActsPodioEdm::TrackStates`
  - Use *components* to produce stable references to fulfill backend contract
  - Auxiliary data types for dense columns overallocated storage for measurements
  - Experiment-aware translation helper for surfaces and uncalibrated measurements
- **Full IO roundtrip implemented and tested, Kalman Filter can run on this without modifications**

[1] see also talk on `PODIO` on Thursday

Summary & conclusion

- **ACTS has gained client-facing *high-level* Track Event Data model!**
- Track finding + fitting already produce this data type (generic refitting pending)
- Interface layer is **fully separated** from backend implementation
- Backend allows **direct integration with experiment** IO framework
- Support conversion to and from `EDM4hep` for Tracks
- Implemented custom `PODIO`-based EDM demonstrator
  - Transparent backend with `PODIO` feasible

Further work

- Migrate all downstream tools to work on Track EDM
- Characterize `PODIO` backend performance

Backup

Experiment interface

- `PODIO` backend still supposed to be experiment agnostic
- Experiment-knowledge needed to persist otherwise transient information

Surfaces

- Two types: part of detector geometry, *ad-hoc* surfaces
- Encode known surfaces as identifiers, serialize ad-hoc surfaces
- Make no assumptions on identification model

Measurements

- ACTS uses strong type-erasure for experiment-specific input measurements
- Cannot serialize type-erased measurements automatically

- Factorized to experiment-specific helper class to implement these conversions