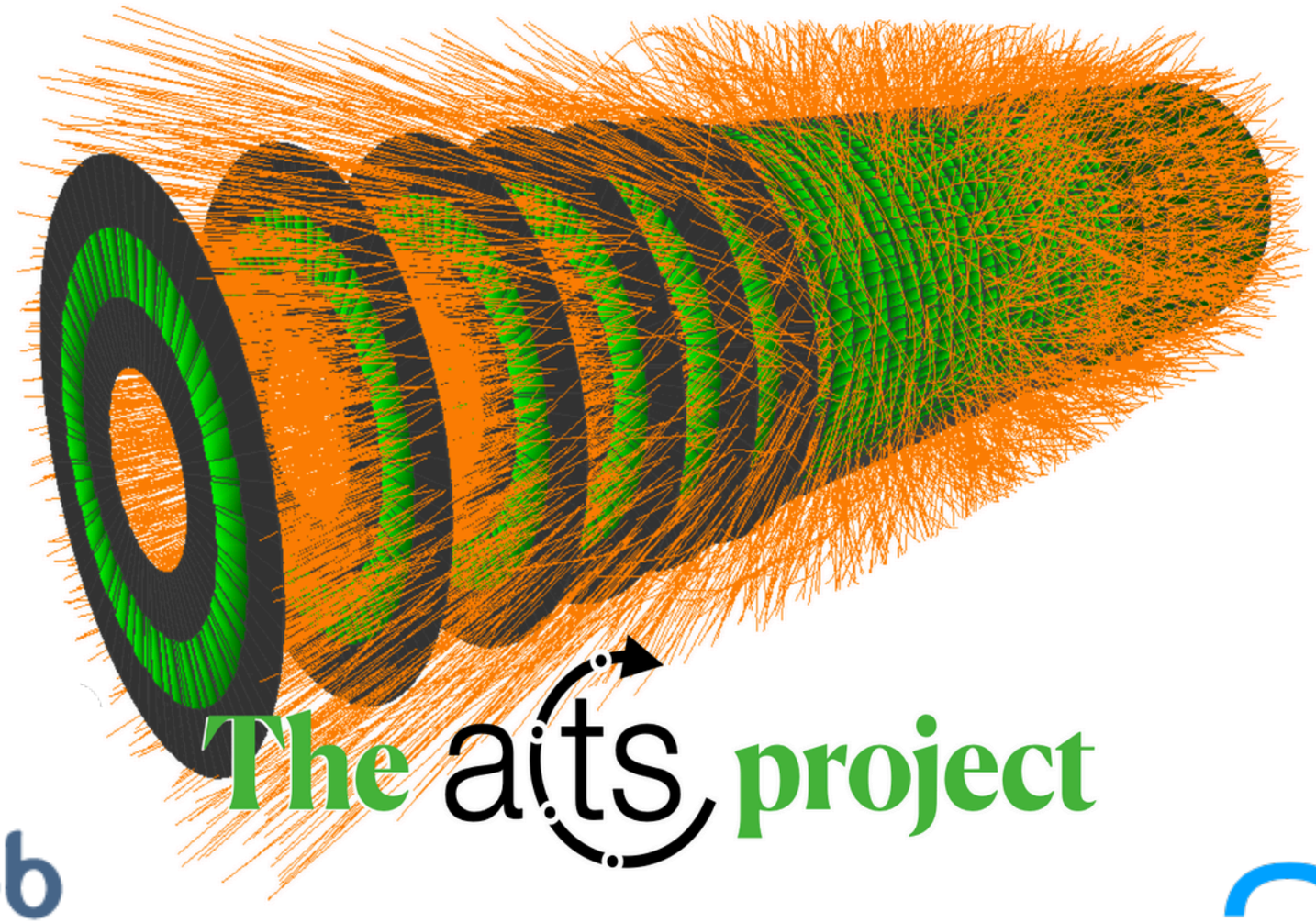
ACTS : A Common tracking software

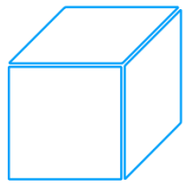


The acts project

Corentin Allaire

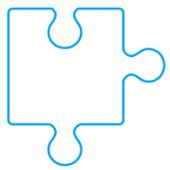
Acts: A Common Tracking Software

- Open source and **experiment-independent** toolkit for track reconstruction: https://github.com/acts-project/acts
- Developed with **modern C++**: unit testing, continuous integration…
- Minimal dependency for ease of building
- **Community** project: used by many **experiments** and **R&D** projects



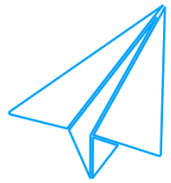
Geometry/Detector*
(Surface based geometry)

Plugins to DD4hep, TGeo, etc.

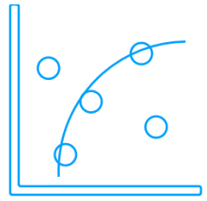


Event Data Model
target track reconstruction

backend separation
with different I/O models

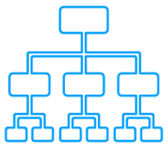


Propagation
parameter + covariance
transport through
magnetic field



Seeding
Seed finding with
Triplet seeder,
OrthogonalSeedFinder

Track Fitting
parameter estimation
with Kalman Filter,
GSF, GX2F**



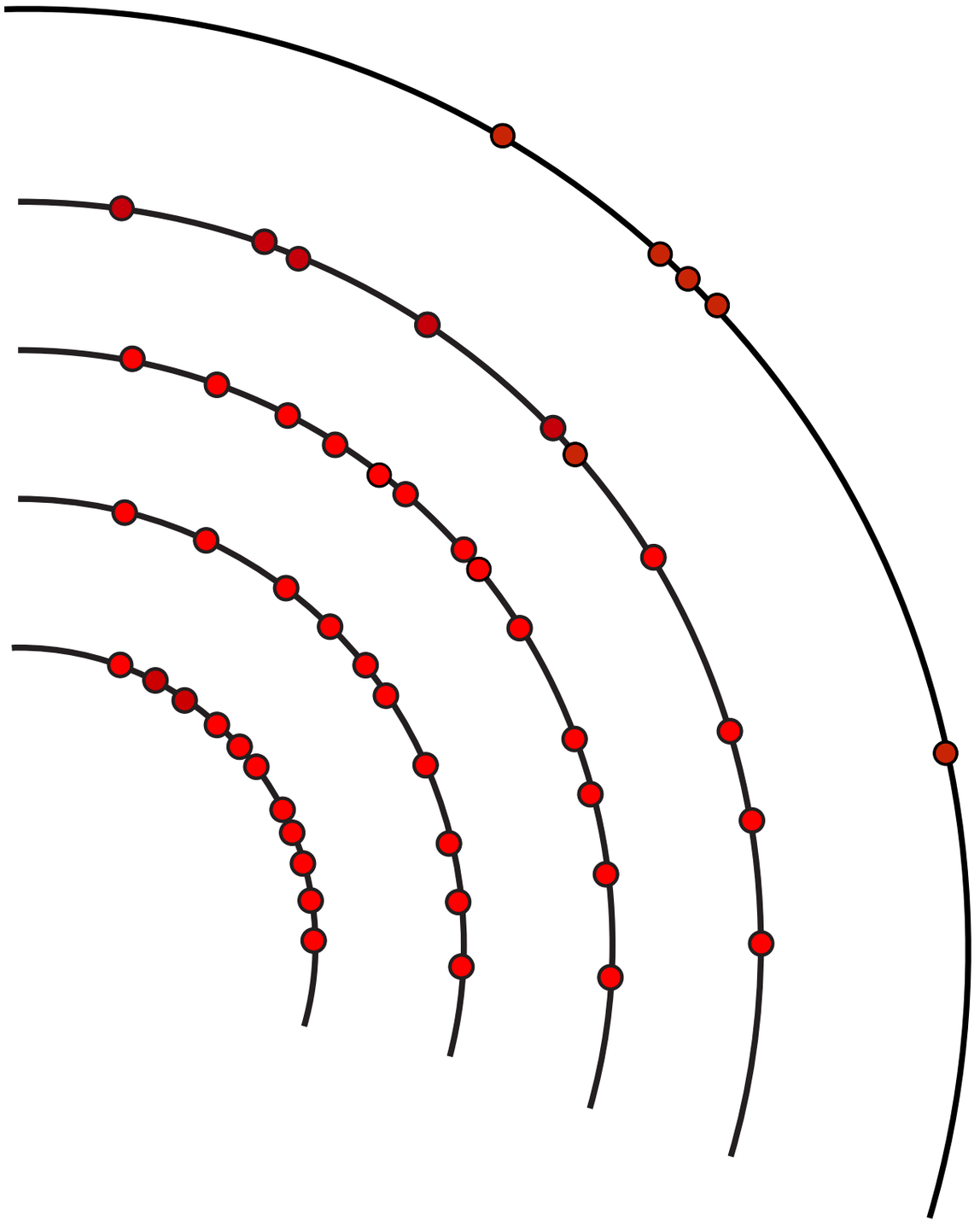
Combinatorial track finding
Combinatorial Kalman Filter
for track finding

Vertex finding + fitting
Iterative, multi variant
primary vertex finders
and fitters

Detector alignment
KF based alignment
functionality

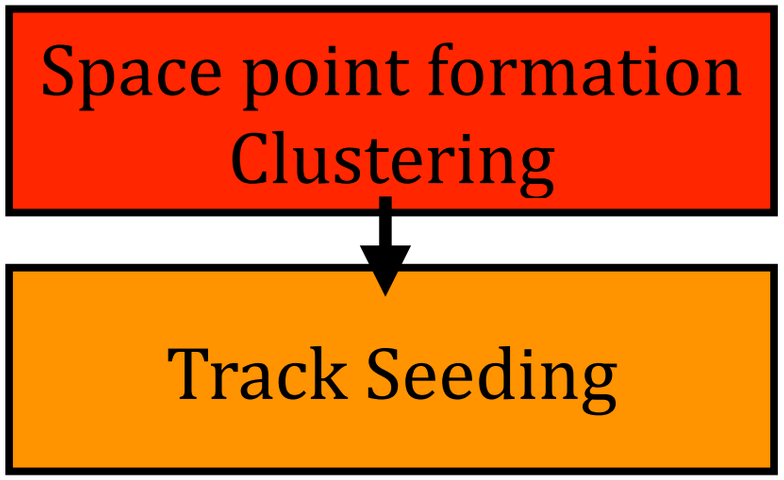
Track Reconstruction

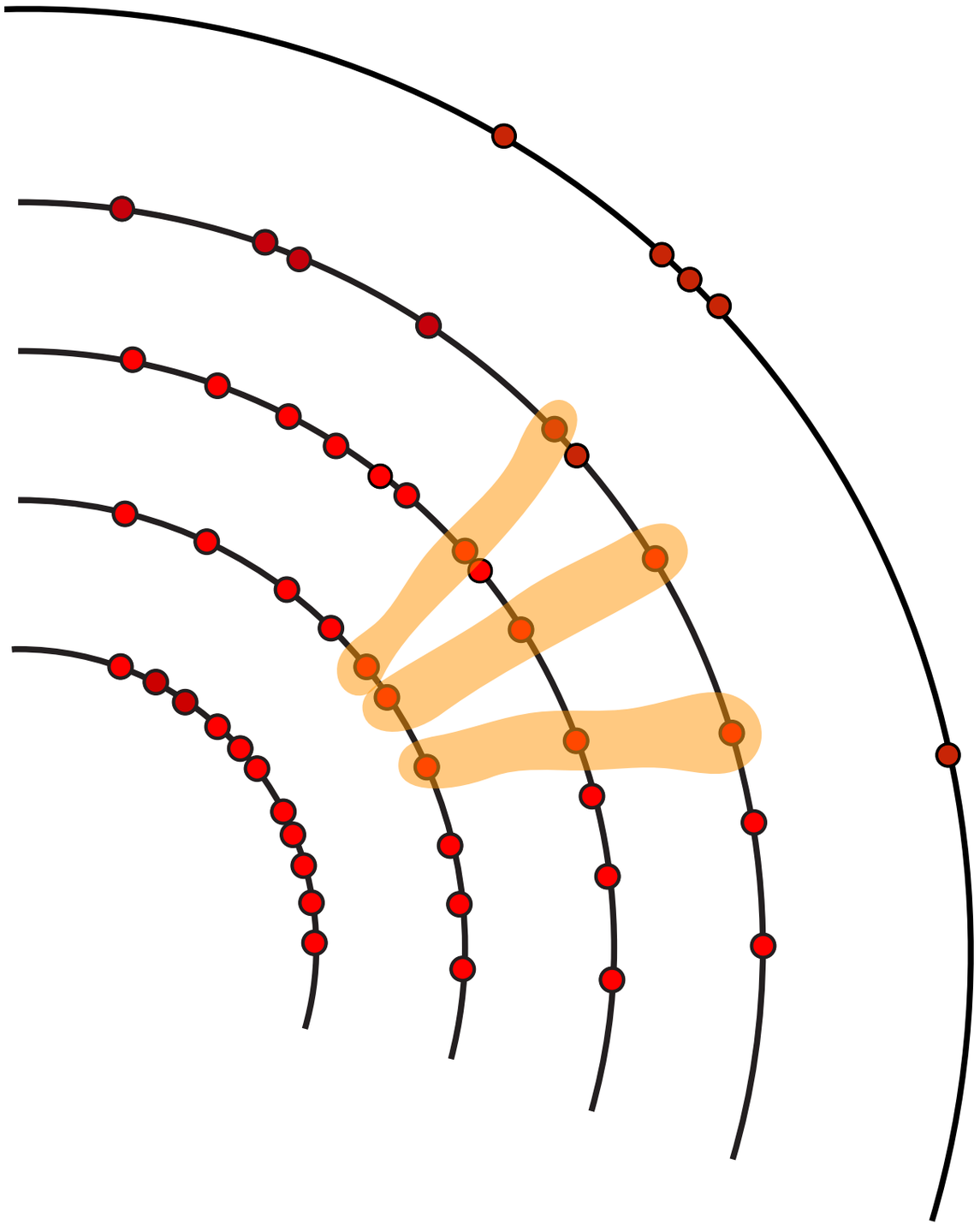
Space point formation
Clustering



- Hits in the detector are collected to create measurement points

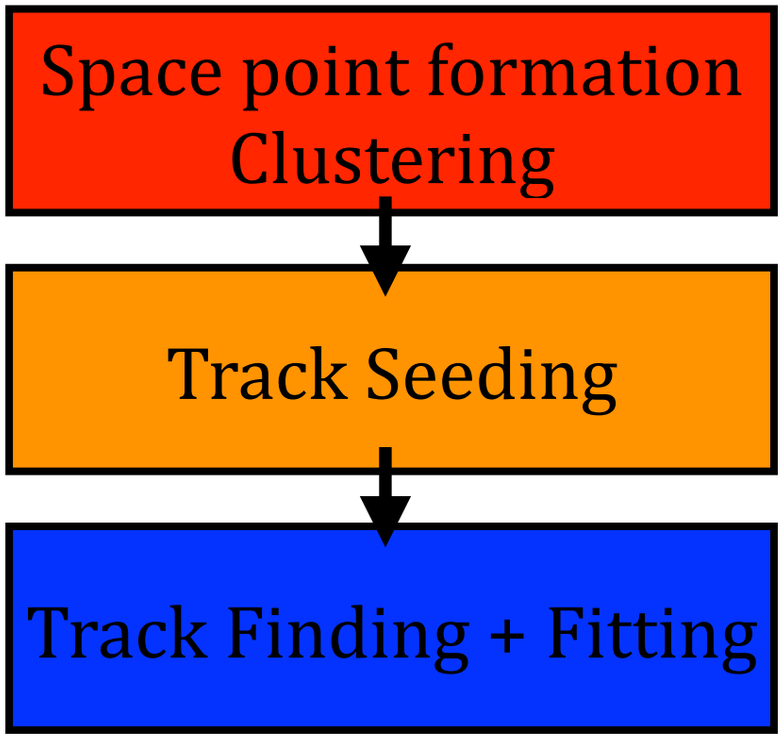
Track Reconstruction

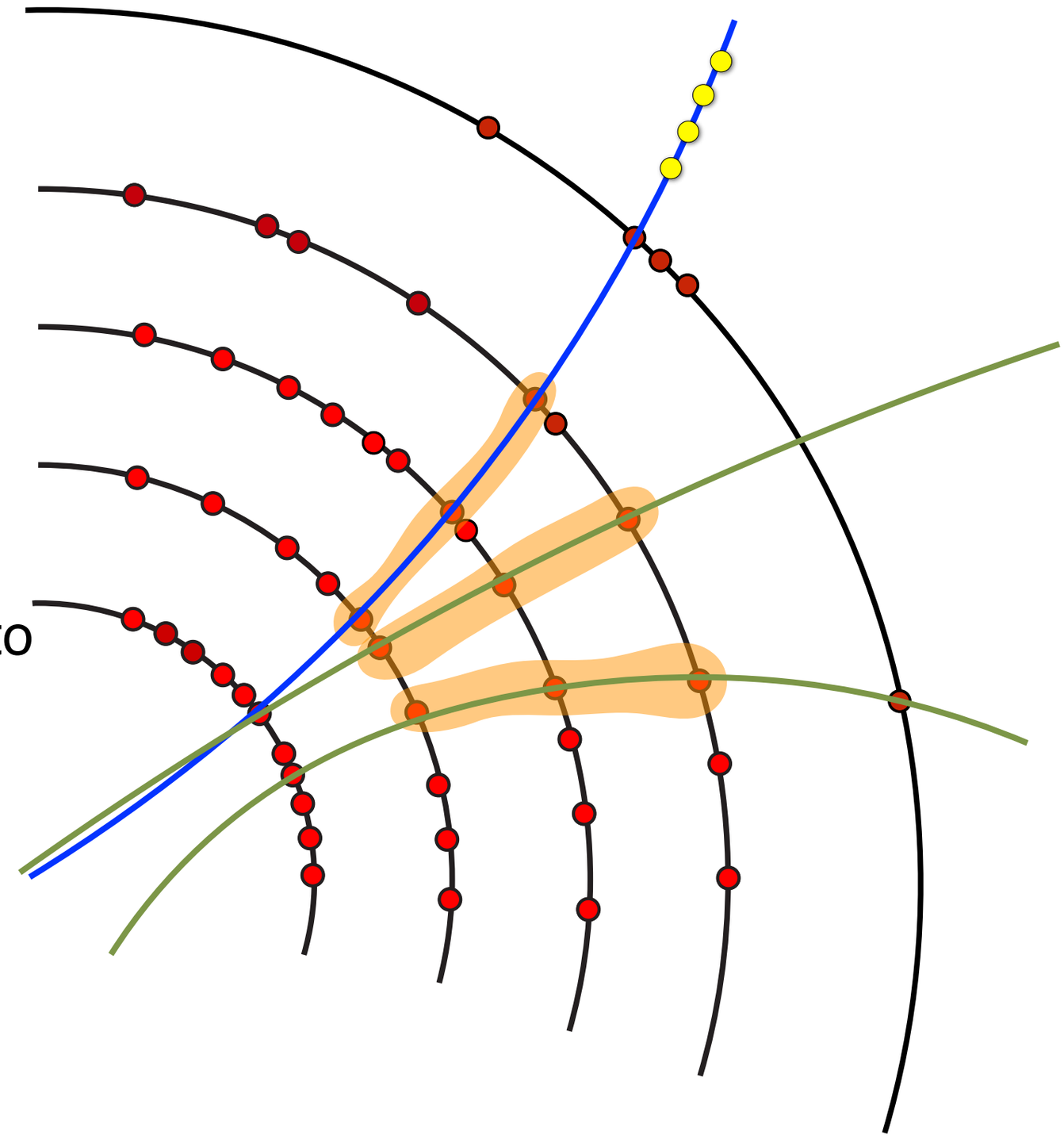




- **Seeds**: groups of **three measurements** compatible with track's hypothesis
- Extended to create the track candidates

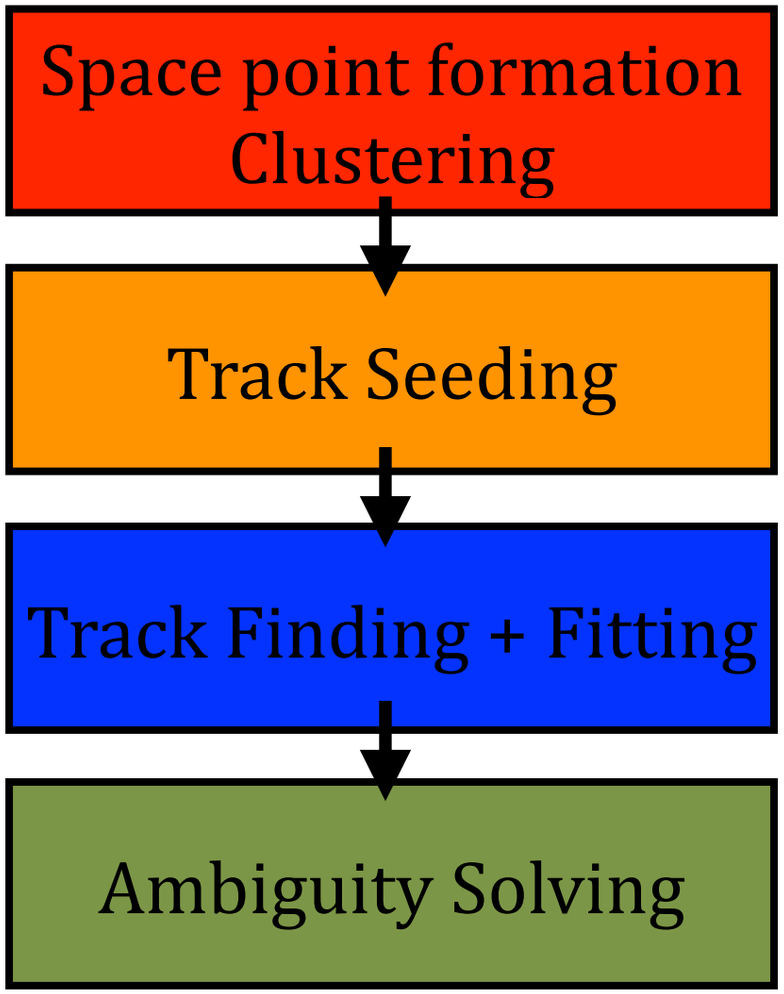
Track Reconstruction



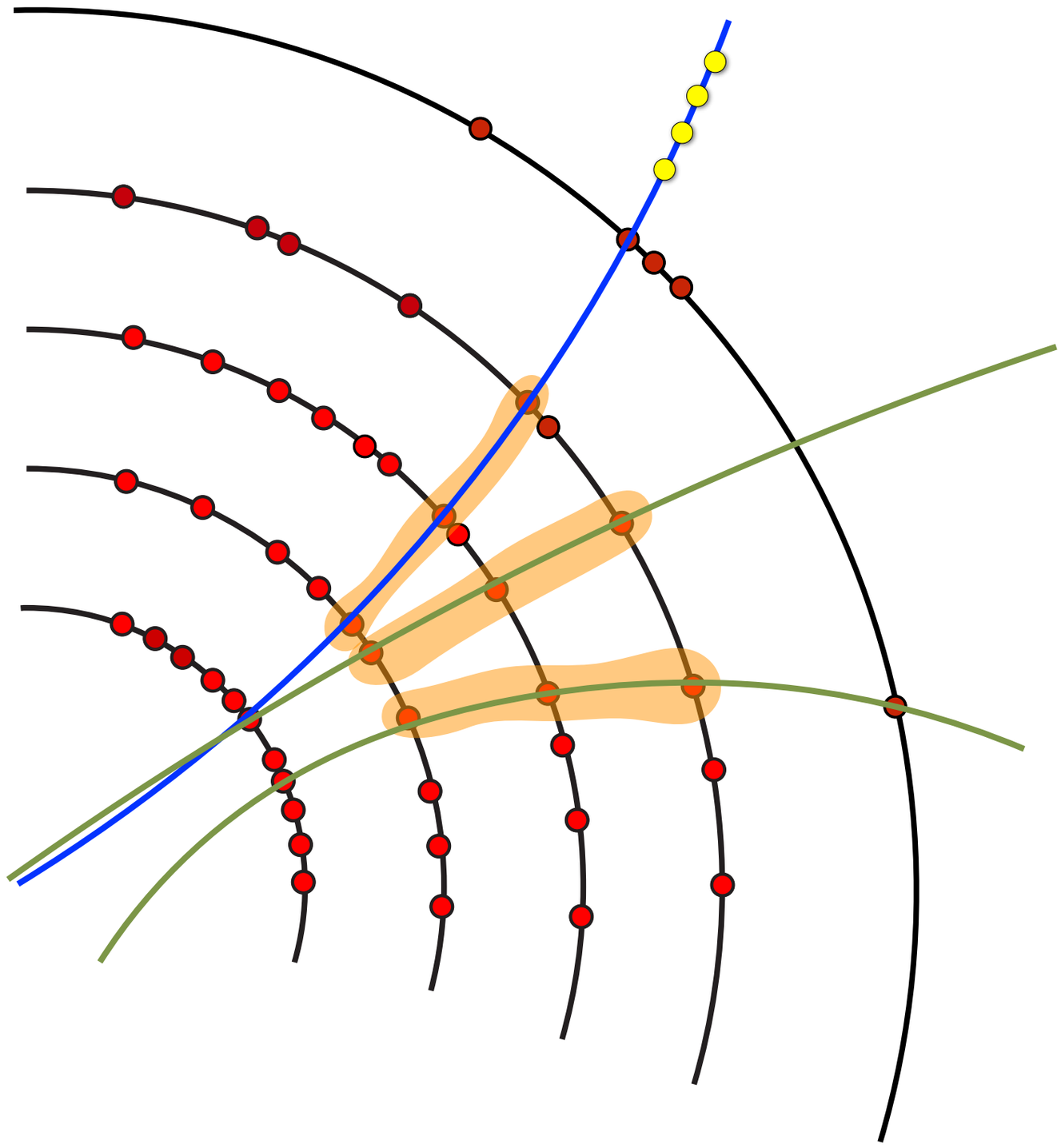


- Combinatorial Kalman filter used to build track candidates
- **Track Candidate** = Seed + compatible measurements
- More than one **track candidate** per seed if multiple paths are possible
- **Tracks** are fitted on the fly

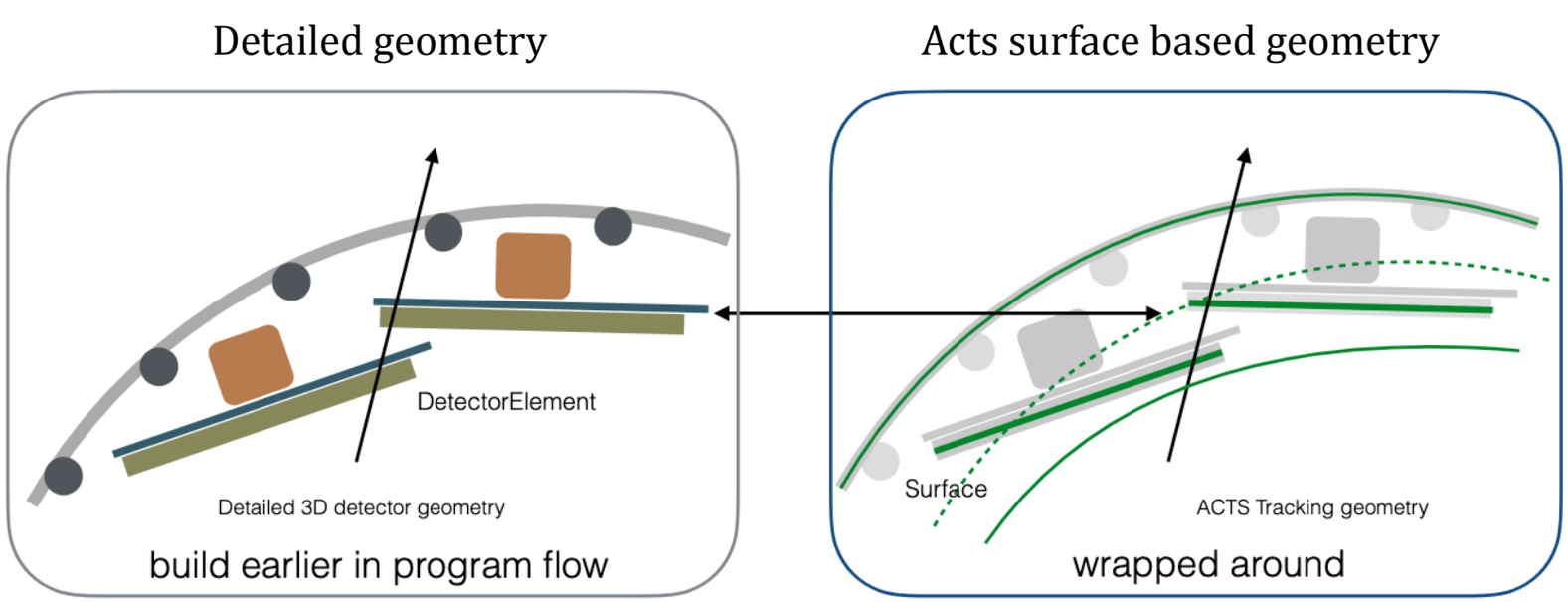
Track Reconstruction

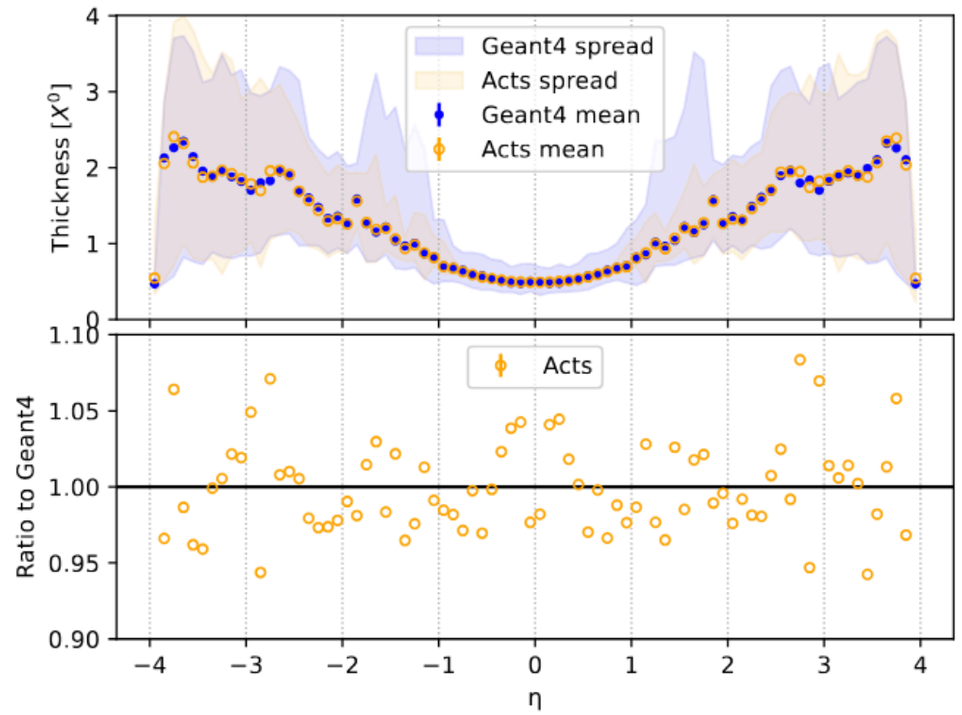


- Score associated with each track candidate
- **Resolve ambiguity**: reconstruct tracks in descending order of a track score



Geometry and detector

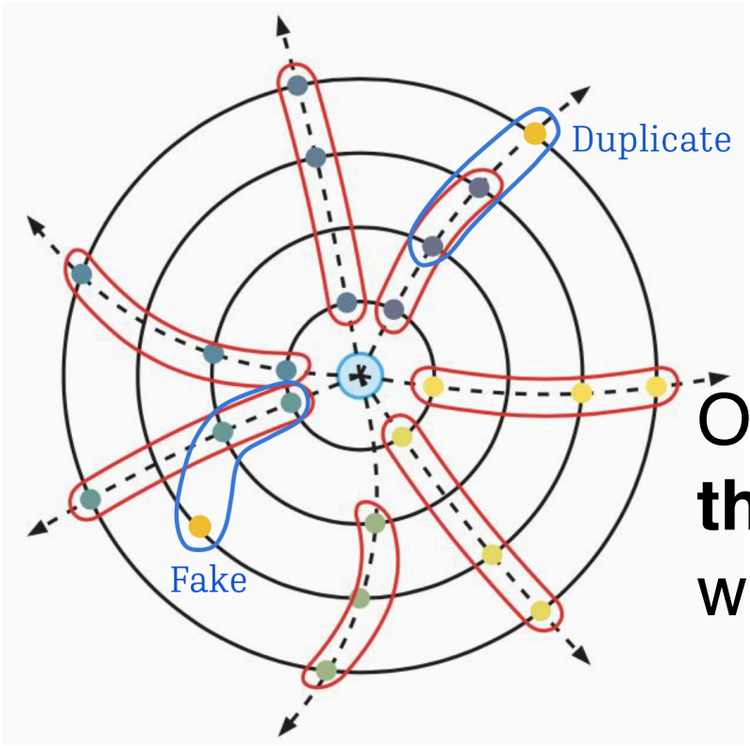




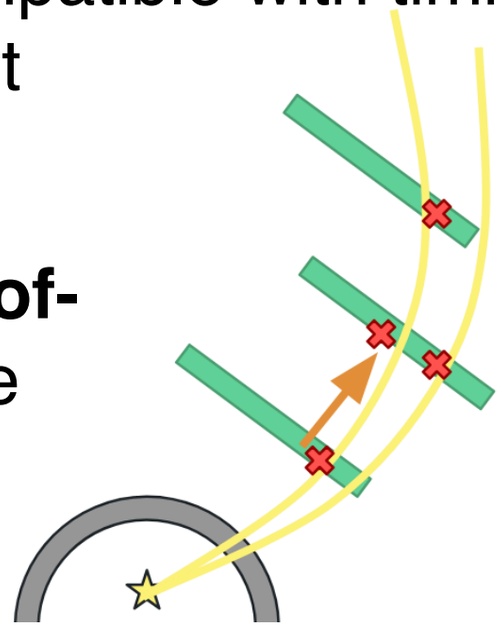
- Detector implementation done through **DD4Hep**, **TGeo** or **GeoModel**
- Automatic **translation algorithm:** go from those to a simplified « tracking optimised » geometry
- **Material interaction** module: account for particle/matter interaction during particle propagation
- **Material mapping** module: extract a simplified material representation from the full geometry

Trajectory reconstruction

- **Modular toolkit**: different implementations of the different tracking steps available
- Easy to develop and add new ones adapted for specific detector/physics case
- Two **seeding** algorithms:
  - ATLAS inspired one
  - Orthogonal seeding (KD-Tree based)
  - New experiment specific ones are being added
- Multiple **track fitting/finding** algorithm:
  - Combinatorial Kalman filter (fitting+filtering)
  - Chi2-based track finder
  - Gaussian Sum Fitter (fitting for electrons)
  - Graph Neural Network-based track finding
  - …
- Most are compatible with timing measurement

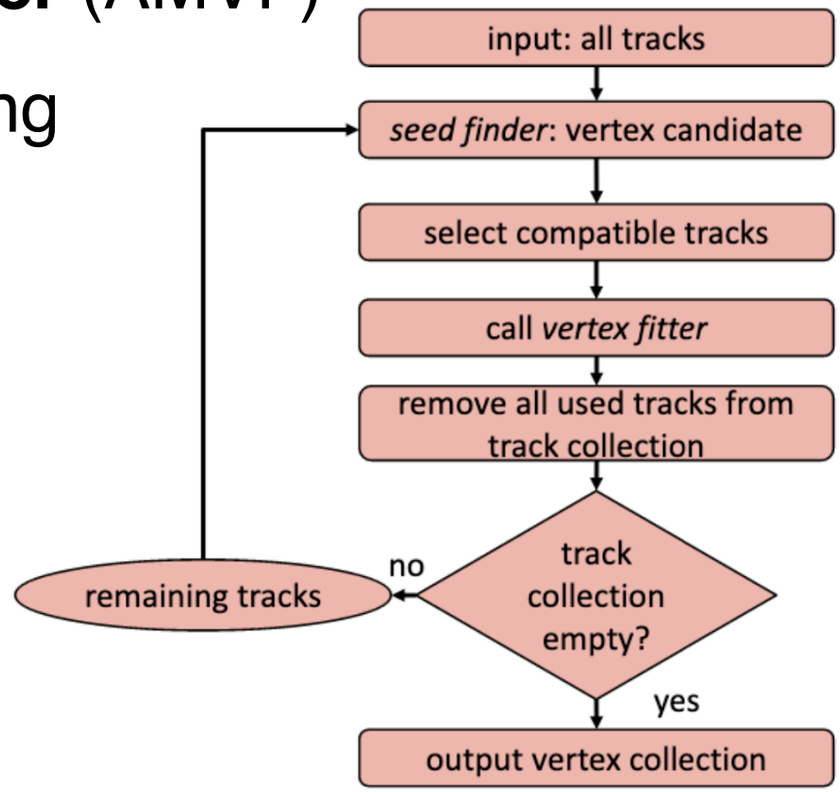


Opportunity to develop new **state-of-the-art** algorithms and easily share with the wider HEP community

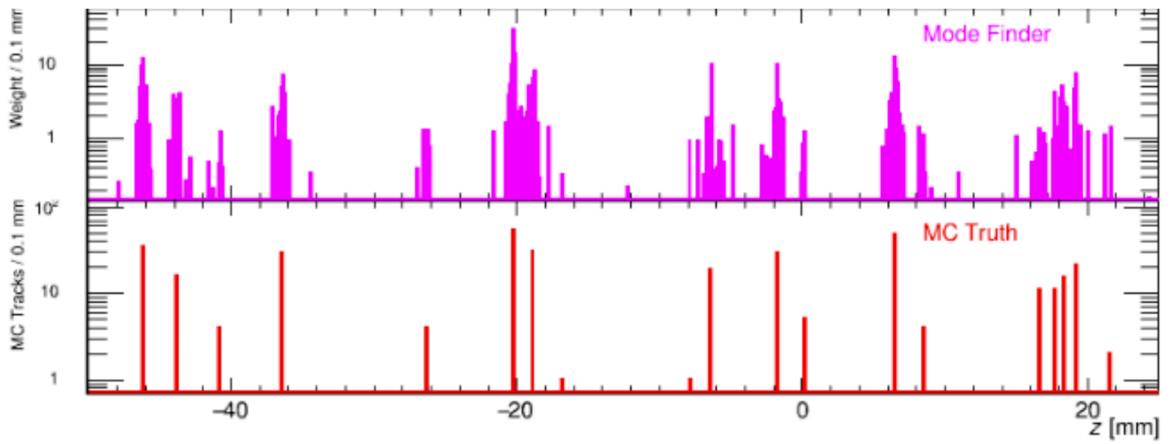


Vertexing

- Find back the interaction point from reconstructed tracks
- Two different implementations are currently available: **Iterative Vertex Finder** (IVF) and **Adaptive Multi Vertex Finder** (AMVF)
- It is being used right now in ATLAS for vertexing

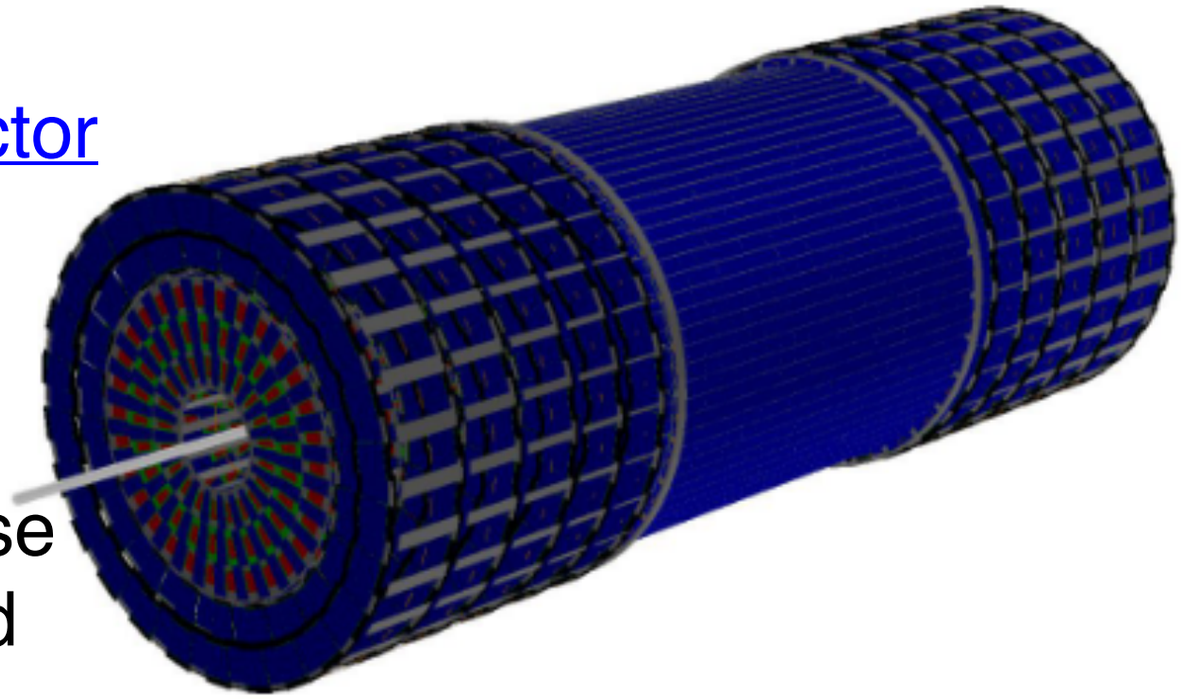


- **IVF** :
  - Reconstruct vertex seed based on an analysis of Z0 density
  - Vertex are fitted based on the nearby track (with outliers being progressively removed)
- **AMVF**:
  - At the start of the fit, tracks can belong to multiple vertex (but at the end, only 1 vertex per track)
  - More performant in high PU environments

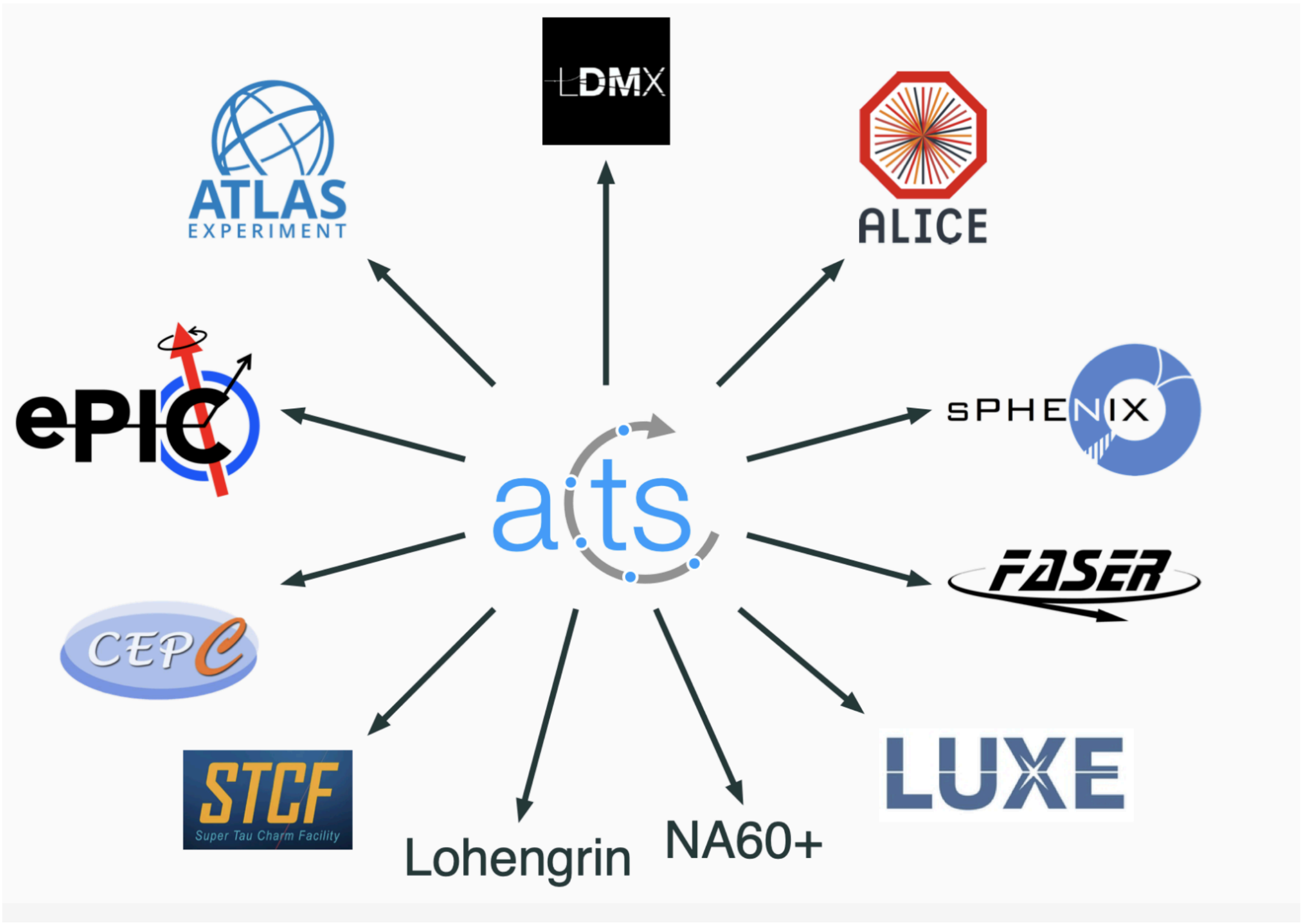


How to use ACTS ?

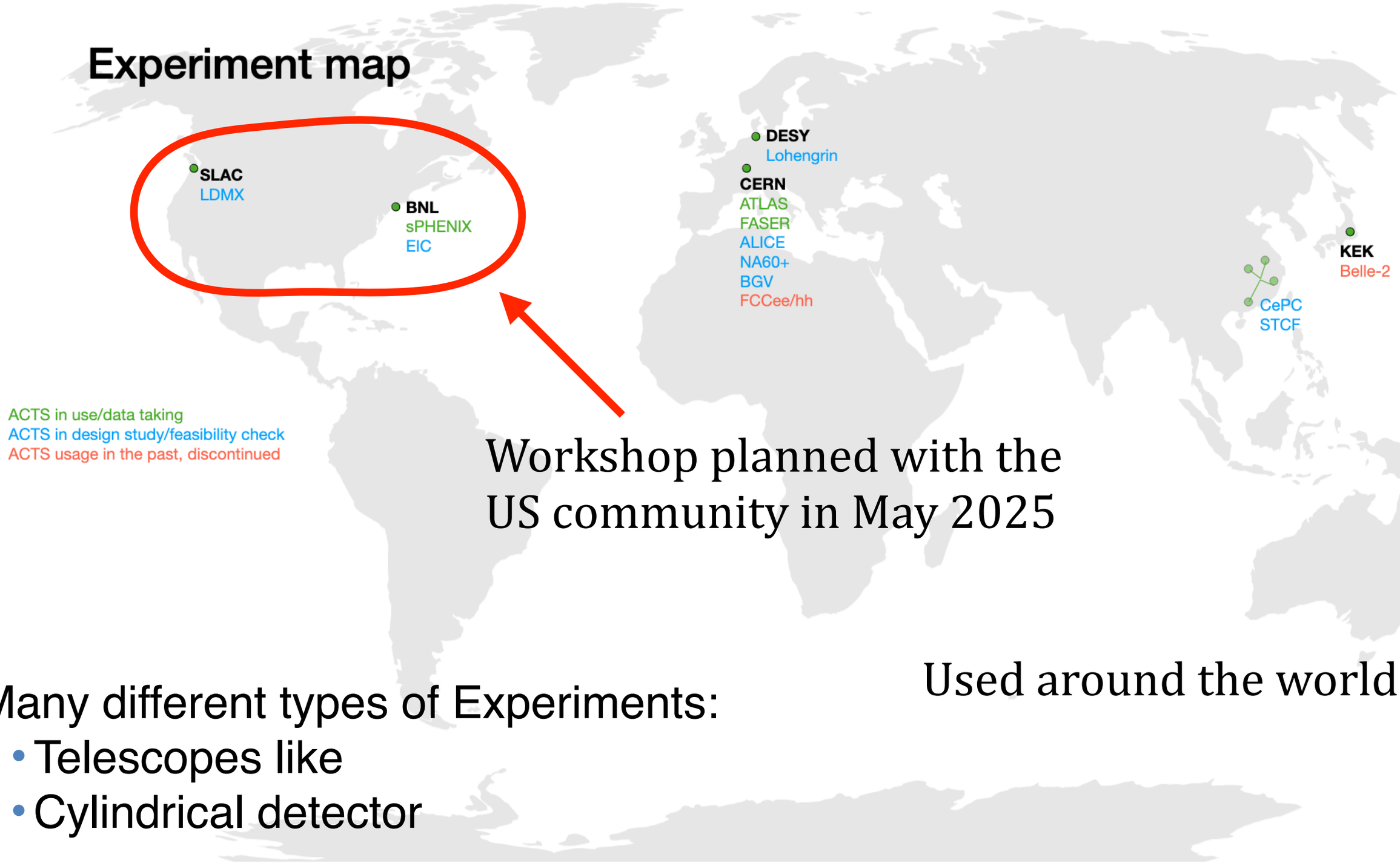
- ACTS: **not** a full event reconstruction software
- Provide a set of **building blocks** to be used to perform tracking tasks, needs to be integrated/interfaced with the experiment software suit (ie: Athena for ATLAS)
- Does provides a series of Examples for testing and performance evaluation. Can be used as a blueprint for integration
- Run by default on the OpenDataDetector (virtual detector, ITk adjacent)
- Also accept most **DD4Hep** detector
- For information on how to build and use ACTS, you can check the git page and the documentation



Many different users



Many different users



Workshop planned with the US community in May 2025

Used around the world !

Many different types of Experiments:

- Telescopes like
- Cylindrical detector

Development and R&D

Core

acts-developers@cern.ch

CPU multi-threaded library of
tracking reconstruction components

Large French involvement

R&D1

acts-parallelization@cern.ch

CPU/GPU “single source” demonstrator
re-implementing the main Core chain

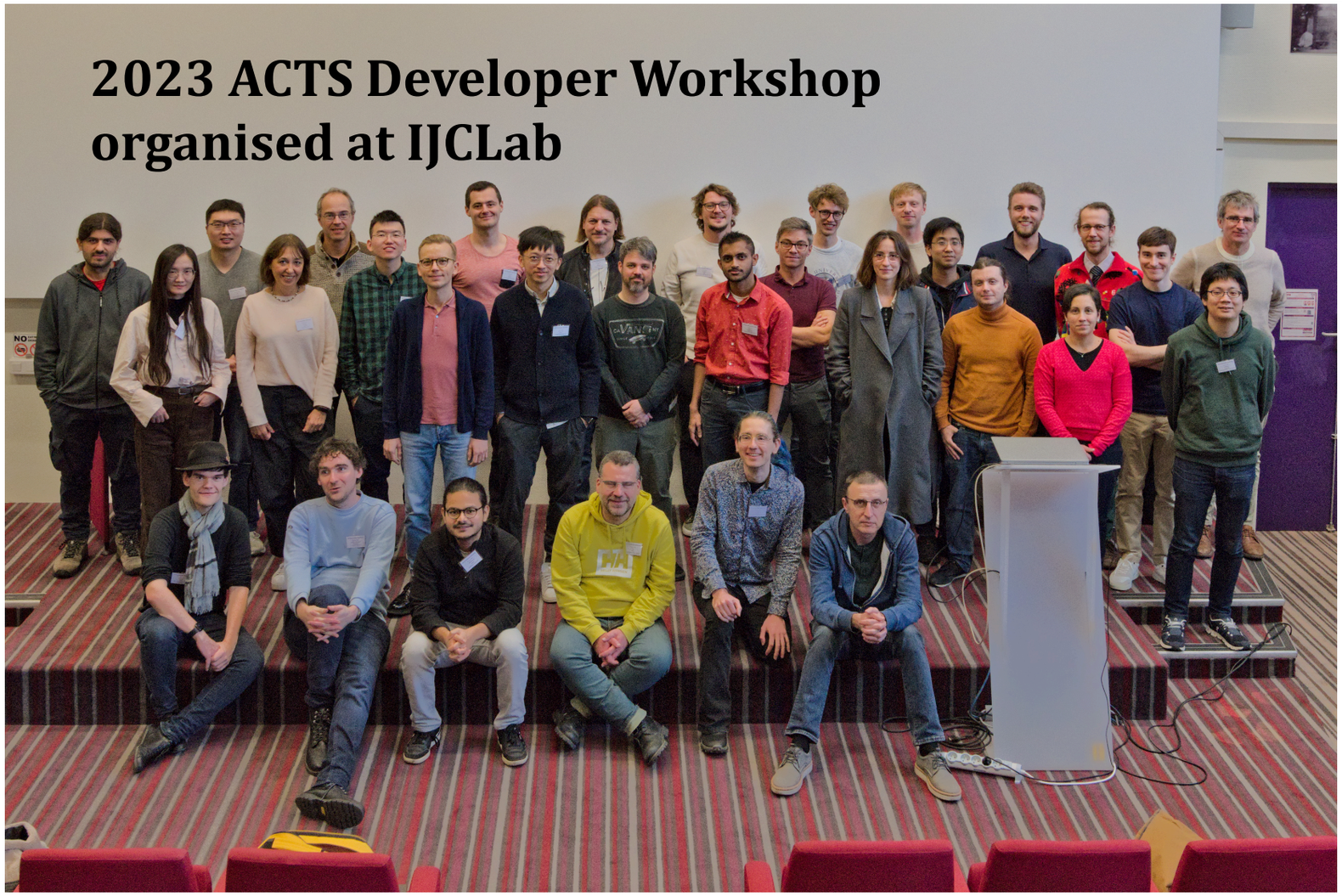
R&D2

acts-machinelearning@cern.ch

Machine learning and ML assisted
modules for track reconstruction

- Different R&D Branch are part of the project
- Development of a GPU-based tracking chain
- Test of Machine learning based tracking algorithm with easily available test bench

The ACTS Team

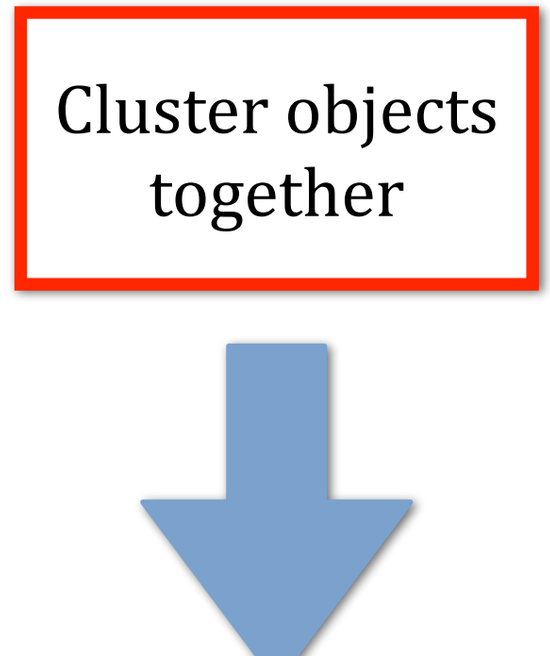


- The Core ACTS developer team are **CERN based, ATLAS tracking expert**
- Local development at IJCLab:
  - Material Interaction module
  - ML for tracking
  - Code optimisation
- Open Sourced project:
  - Contribution from the different ACTS users
  - Large involvement of **ATLAS**, **Faser** and **sPhenix**

Deep Learning for Tracking

Ranking based Deep Learning of object selection

- Idea presented in CHEP 2023 and 2024
- During the tracking chain, different **objects** are created (seed, tracks…)
- Use a Neural Network to determine which are **good** or **bad**
- Applied to Ambiguity resolution and Seed Selection



- Uses two steps:
  - **Clustering step**: cluster together objects coming from the **same particles**
  - **Scoring step**: compute a score per object; best object = highest score (in each cluster)

Ranking Neural Network

Goal: one score per seed, highest for the **good** one

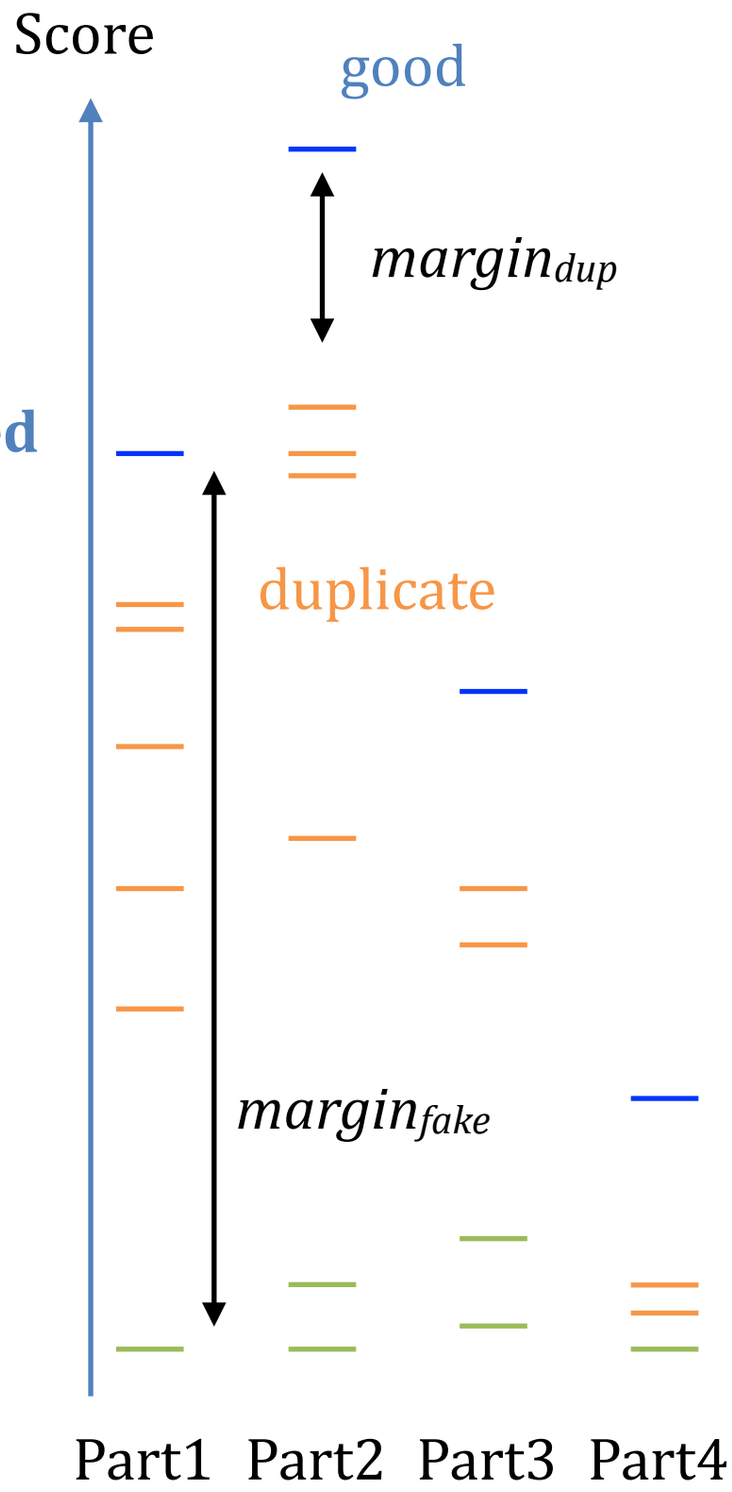
- Training without clustering ➔ use **truth** matching instead
- Compute one loss per **truth particle**
- Use a **Margin Ranking Loss :**

$$loss_{part} = \frac{1}{N_{tracks}} \sum^{tracks} max(0,\ x - y + margin)$$

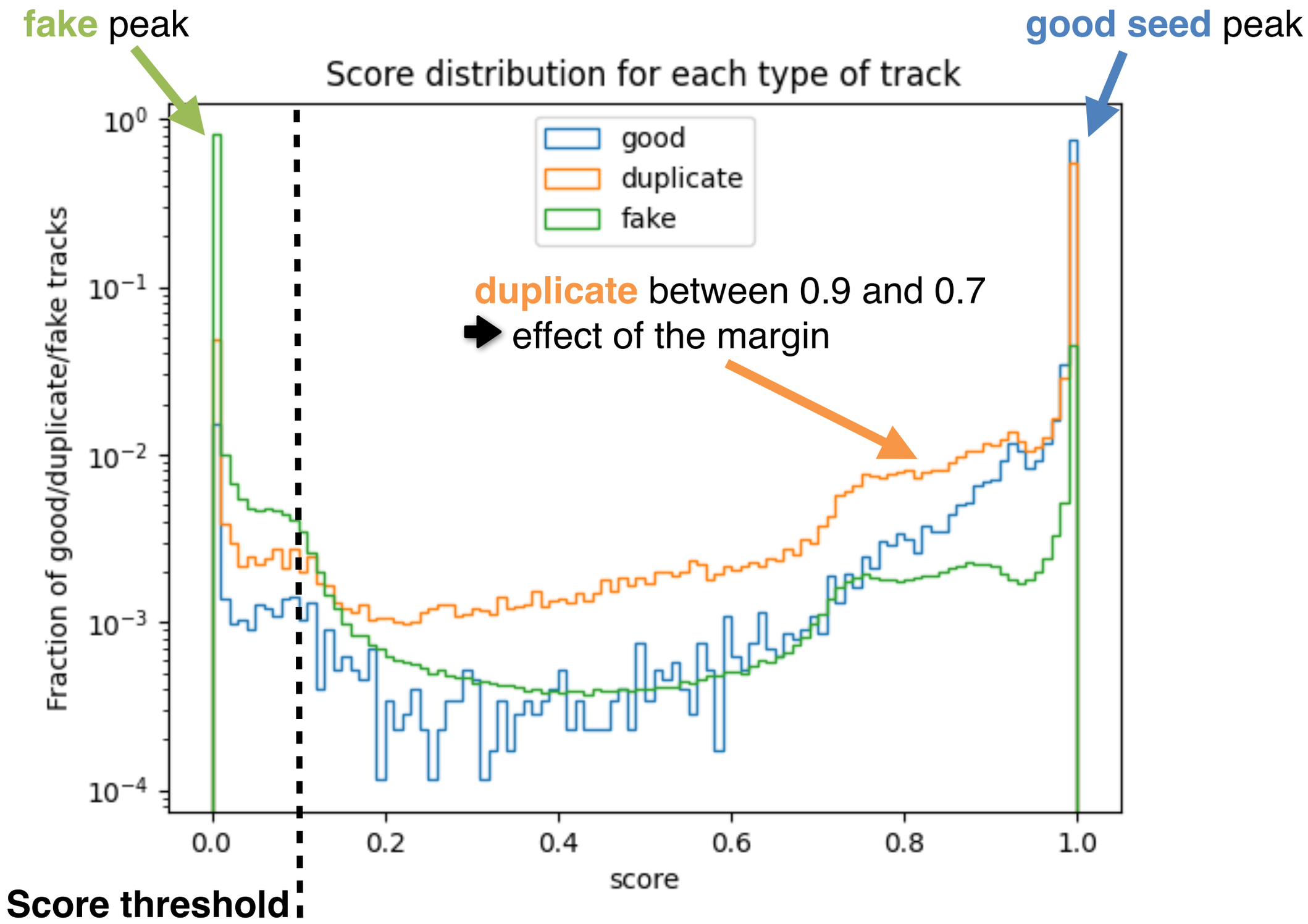
Good seed

duplicate/ fake

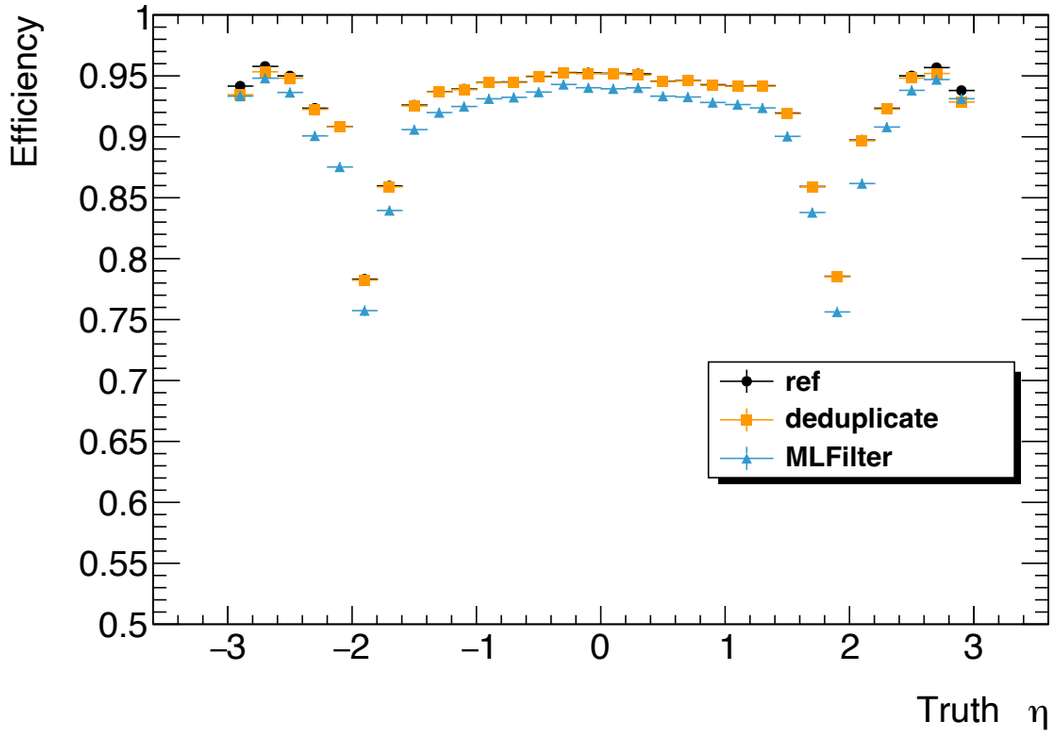
- x: seed score; y: **good** seed score;
- Uses 2 different margins :
  - $margin_{dup}$: between **good** and **duplicated** ~ 0.2
  - $margin_{fake}$: between **good** and **fake** = 0.9

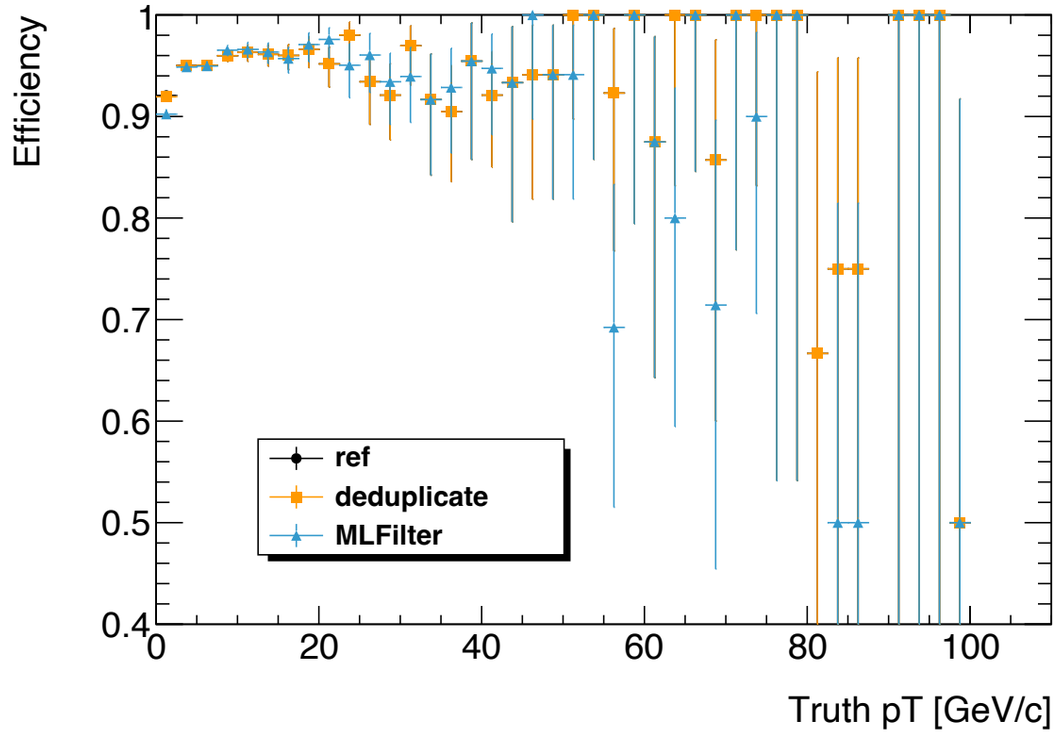


Score distribution (seed selection)



Efficiency (seed filter)



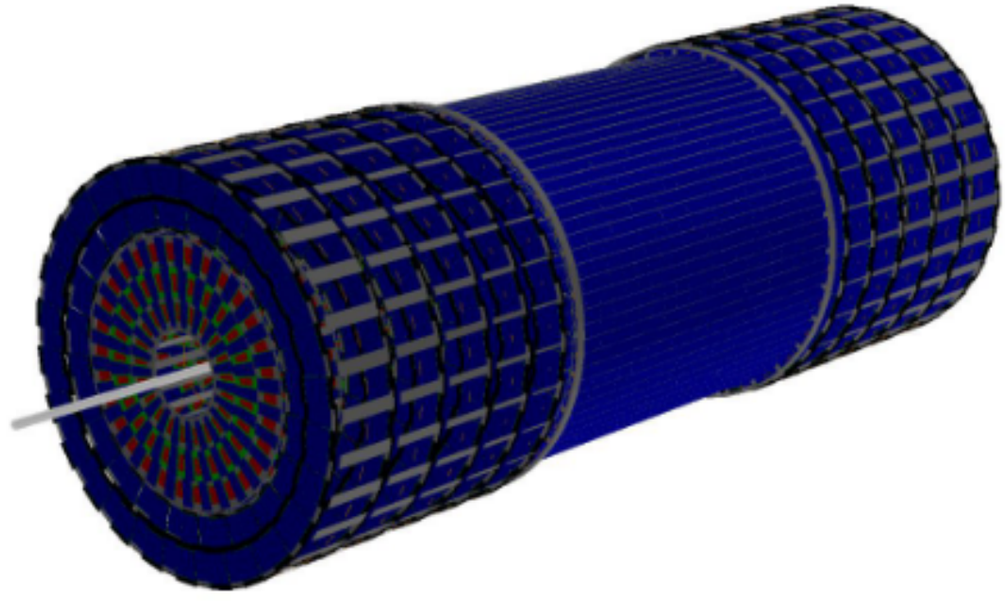


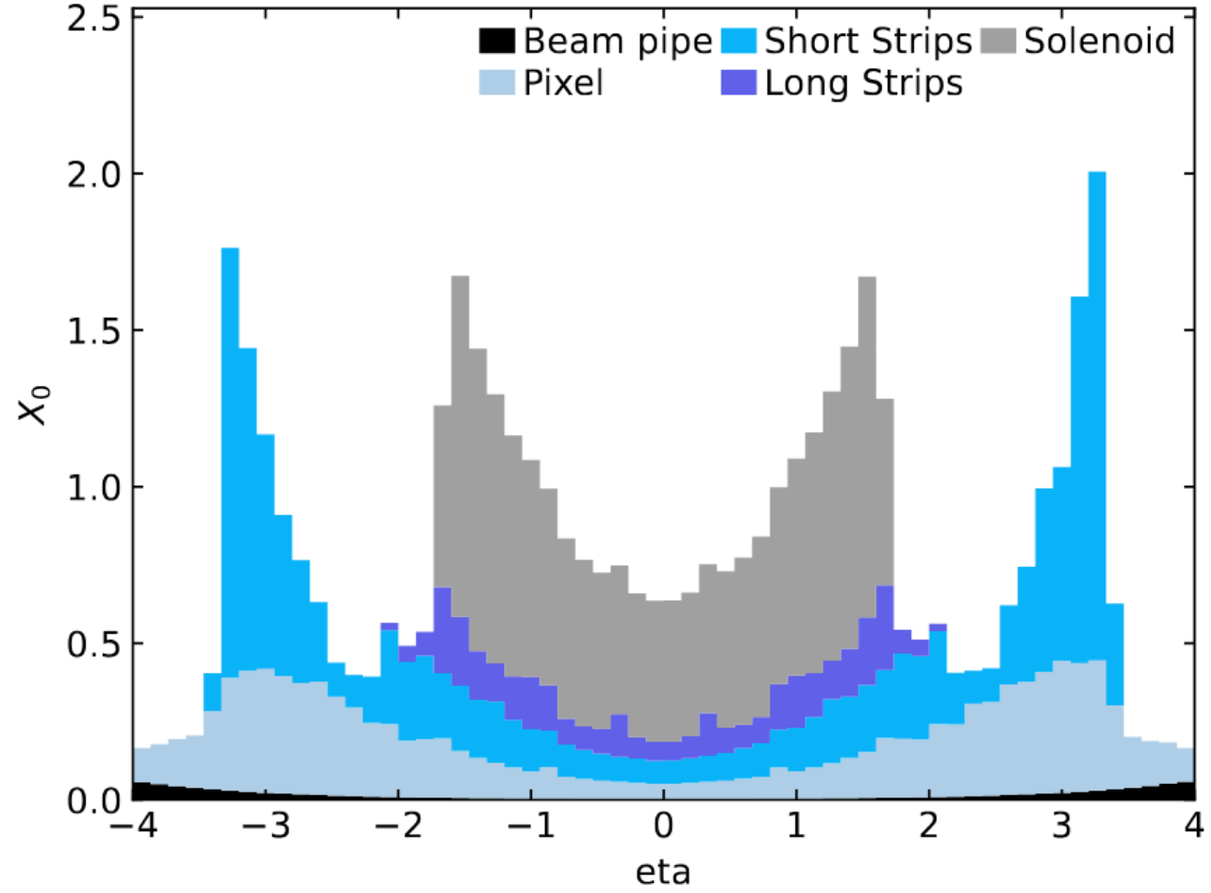
	Efficiency	Duplicate Rate	Fake Rate	Speed [s/event]
Default	92.6 %	2.5×10^{-3} %	0.22 %	7.2
Default + Seed deduplucation	92.5 %	1.5×10^{-3} %	0.22 %	3.4
Default + ML Seed Filter	91.0 %	2.1×10^{-3} %	0.17 %	1.1

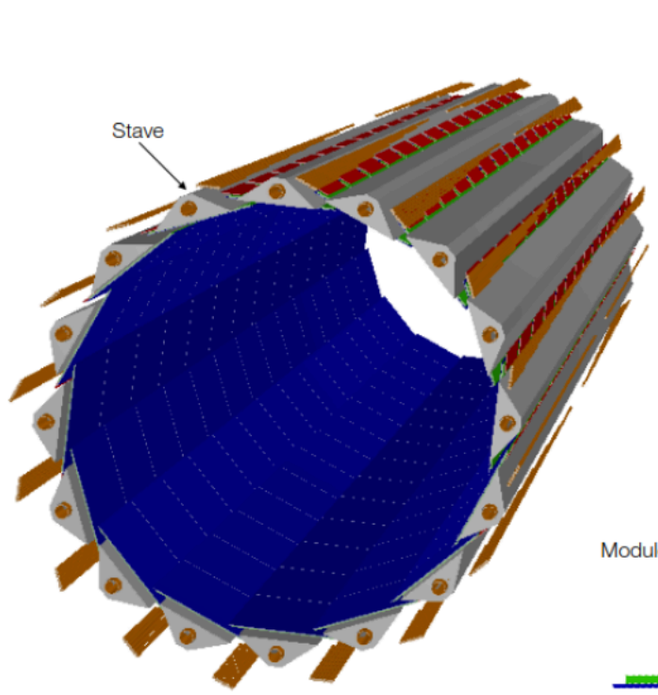
ODD Calorimeter extension

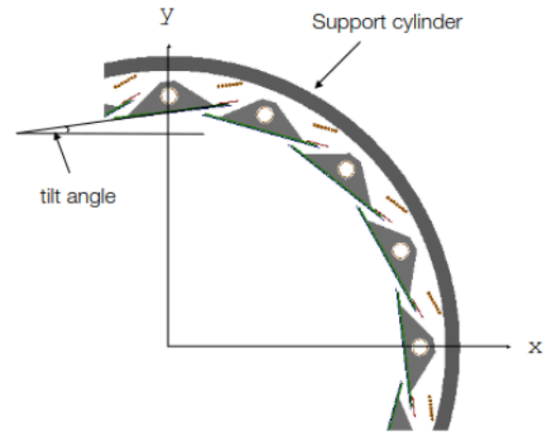
The Open Data Detector

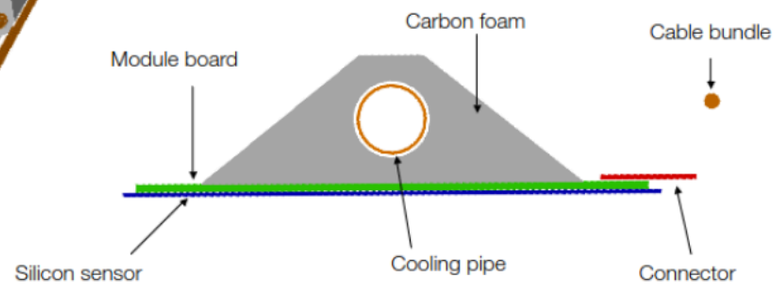
- Extension of the **TrackML** challenge detector
- **Silicon detector** with a similar design to the ATLAS ITk
- Increased complexity (material…)
- Usable with full G4 simulation





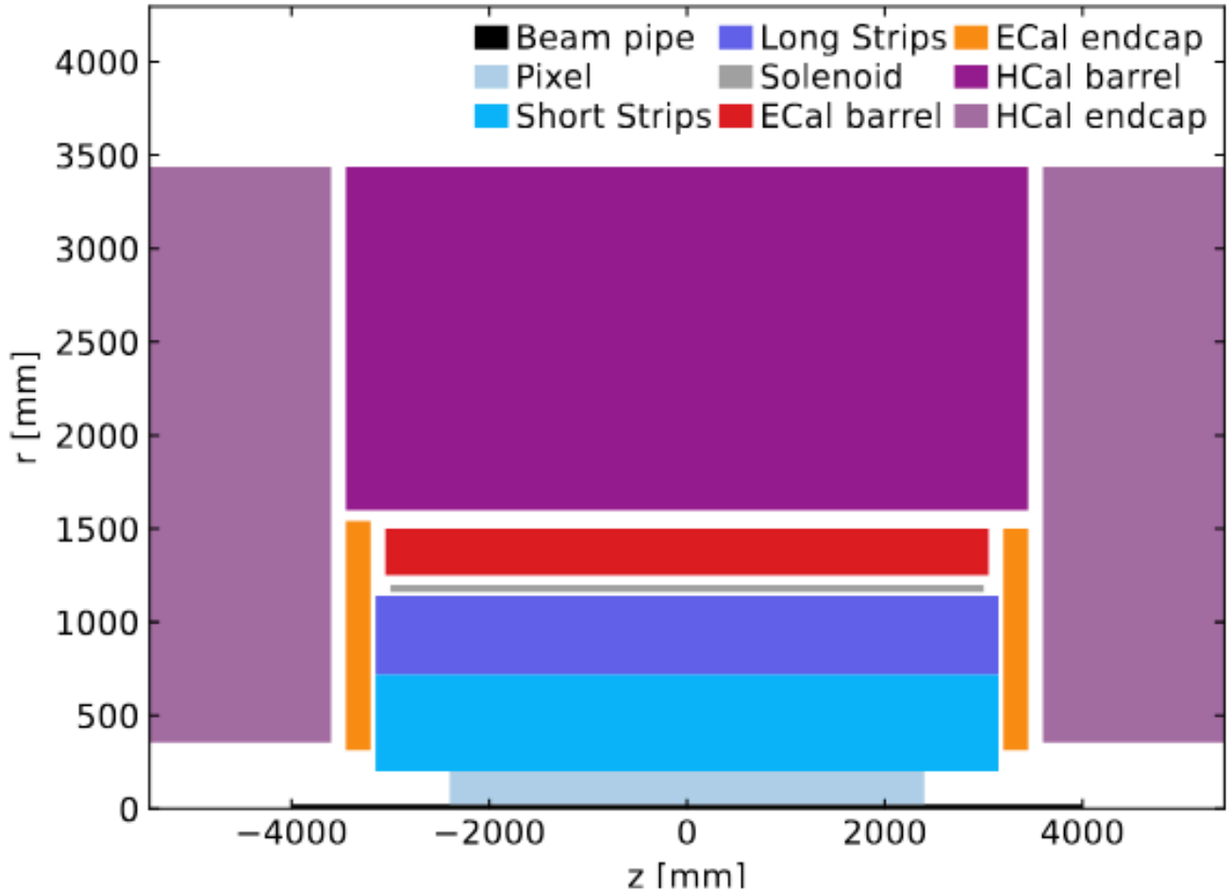


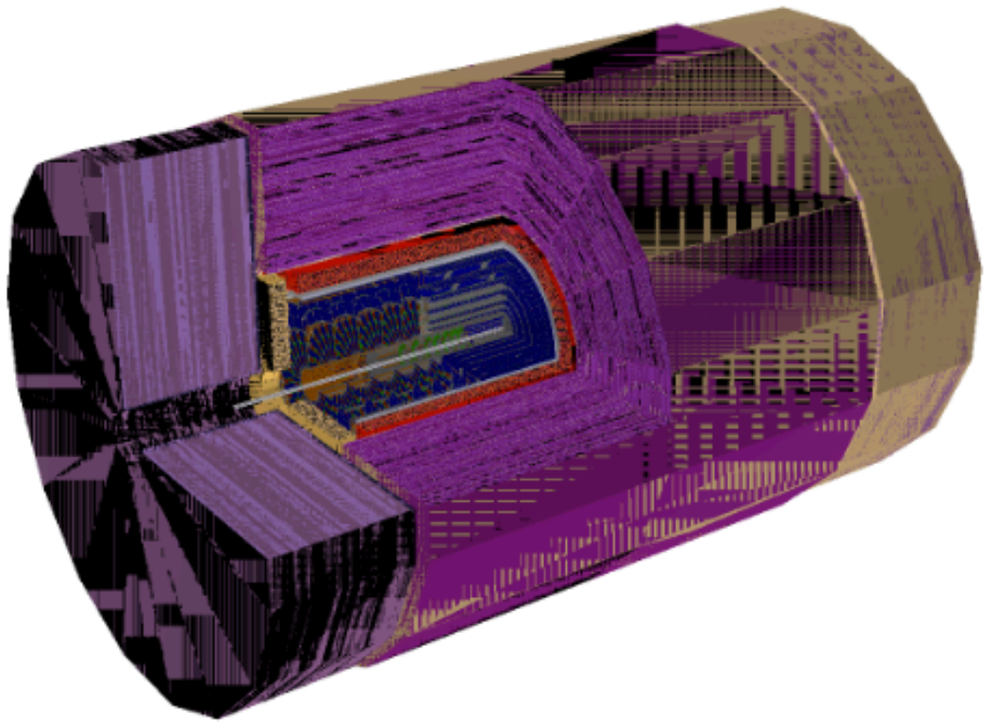




Extension toward a full detector

- **Goal**: Extend the ODD toward a full detector
  - Tracker (Silicon-based)
  - EM Calorimeter (Silicon-based: HGCal, CLD, SiD…)
  - Hadronic Calorimeter (Scintillator-based: HGCal, CLD, SiD…)
  - Muon Spectrometer (WIP)





Goals

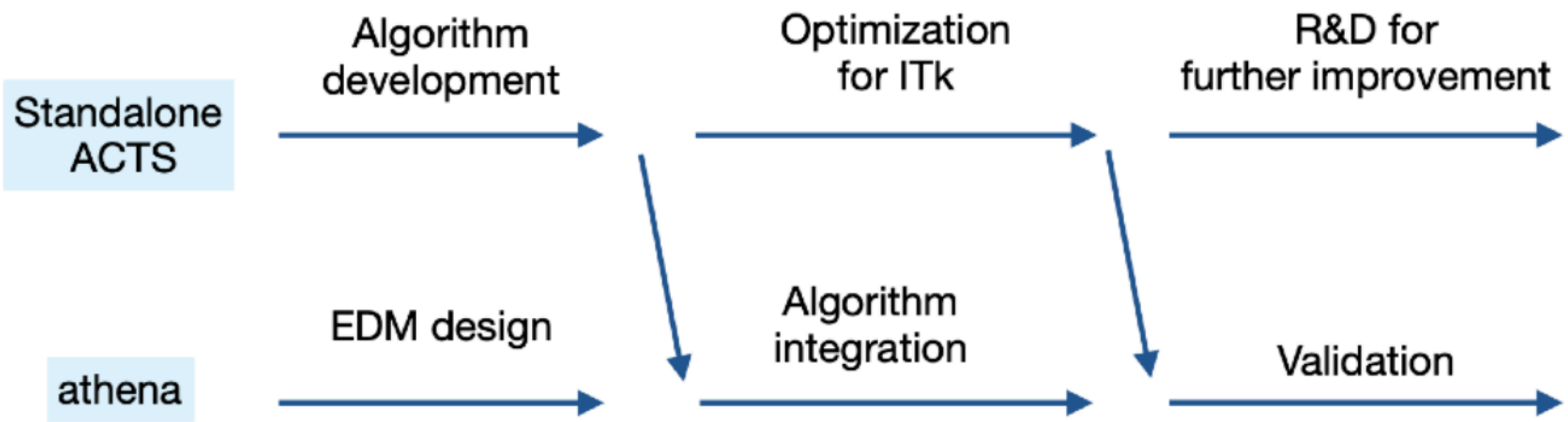
- New ODD available on GitLab
- Uses this new Detector to produce a reference **detector dataset**
- Useful for **new algorithm development** (Machine learning…)
- Study **cross-detector** reconstruction with ACTS

- Ongoing study at IJCLab: **Deep Learning-based calorimeter simulation** using the ODD dataset
  - 1 Post-doc as part of the **Intertwin** project
  - **Speed up** simulation using deep learning
  - Could be added to the ODD simulation chain aftesrward

Athena integration

Athena integration

- ACTS used a **sandbox** for R&D:
  - Used to test and develop new algorithms
  - Some Athena algorithms are also being reimplemented in ACTS
  - Periodically release to Athena
- A lot of work is necessary to connect the ACTS Event Data Model (EDM) to the ATLAS one (for downstream users)



Athena integration

- Conversion between the ACTS's EDM and ATHENA's EDM implemented
- Some Athena-specific concepts still missing, but work is ongoing

Internal ACTS EDM

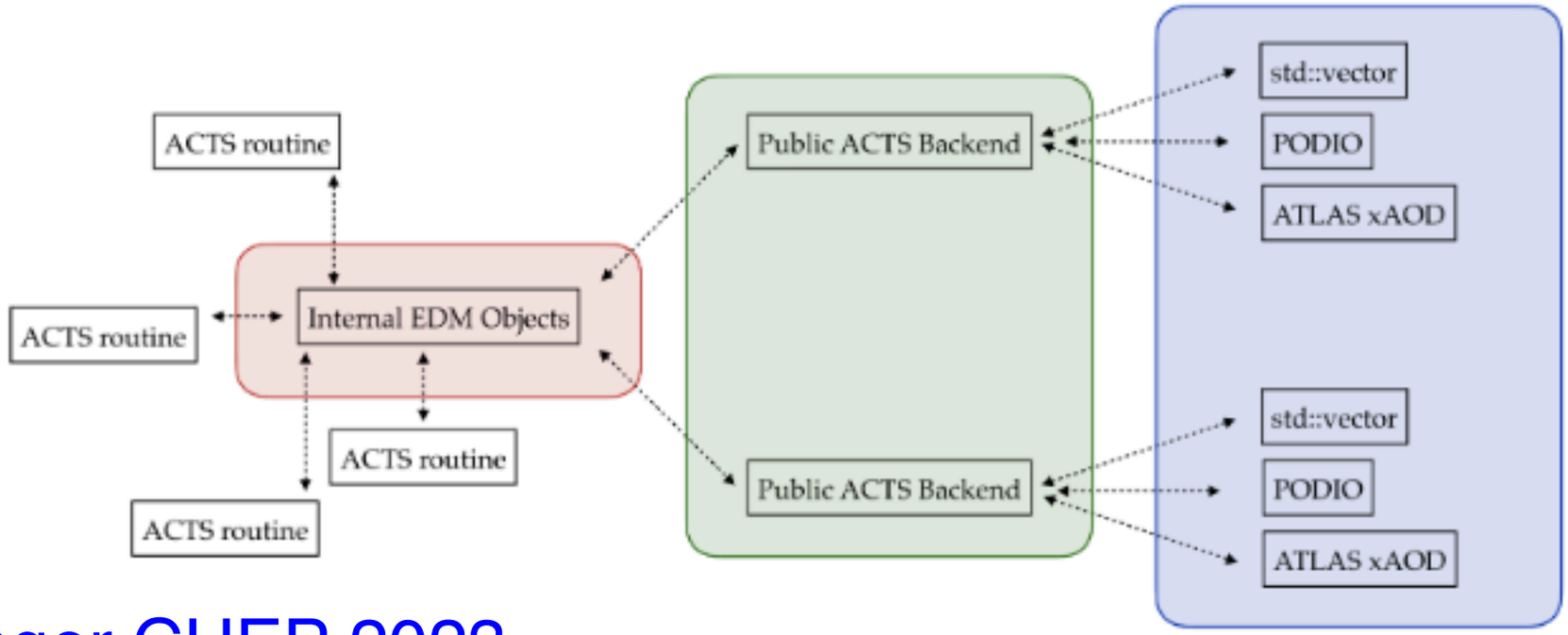
- Data objects to pass around between different parts of the ACTS library
- Library-specific, tightly coupled to the algorithm

Public ACTS EDM

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

Experiment ACTS EDM

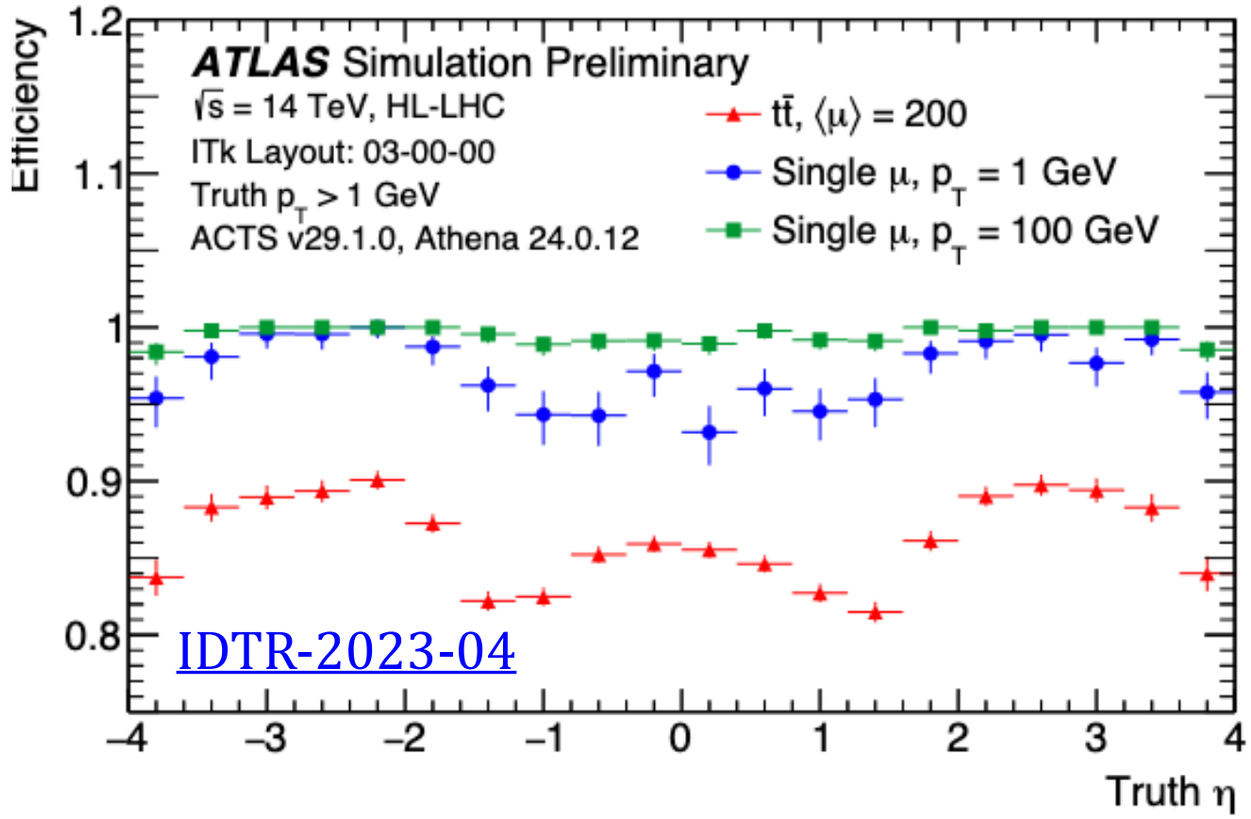
- Data objects experiments use, can save to file

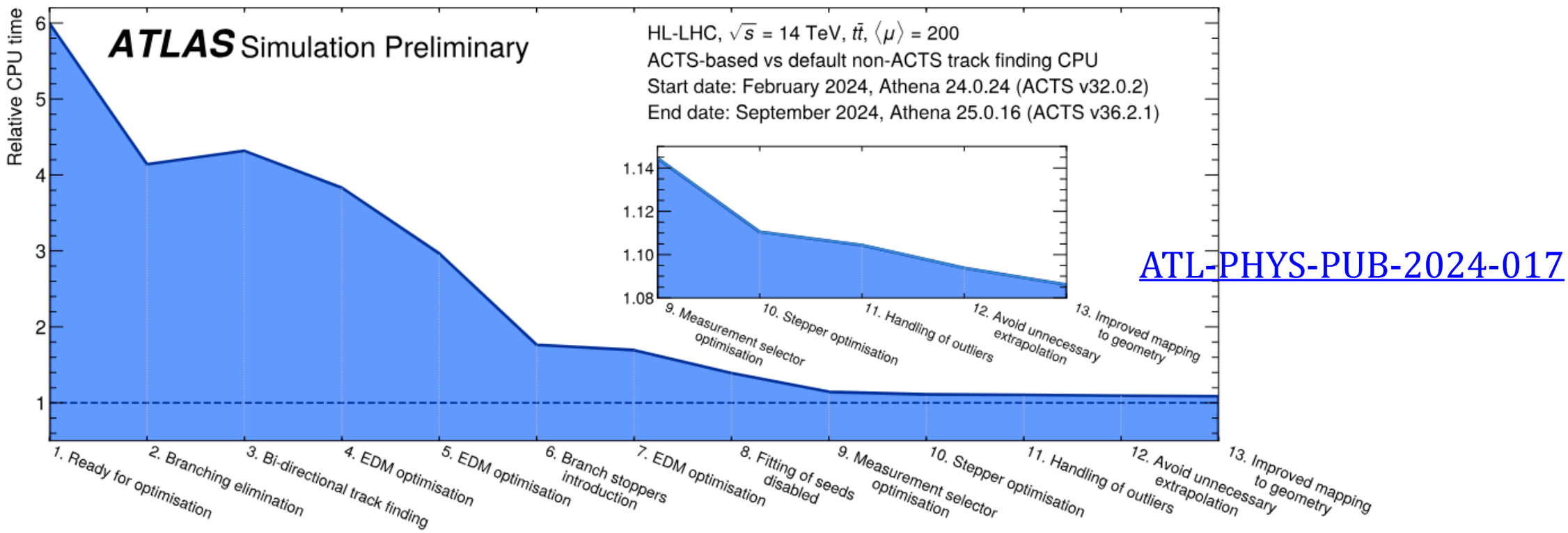


[Paul Gessinger CHEP 2023]

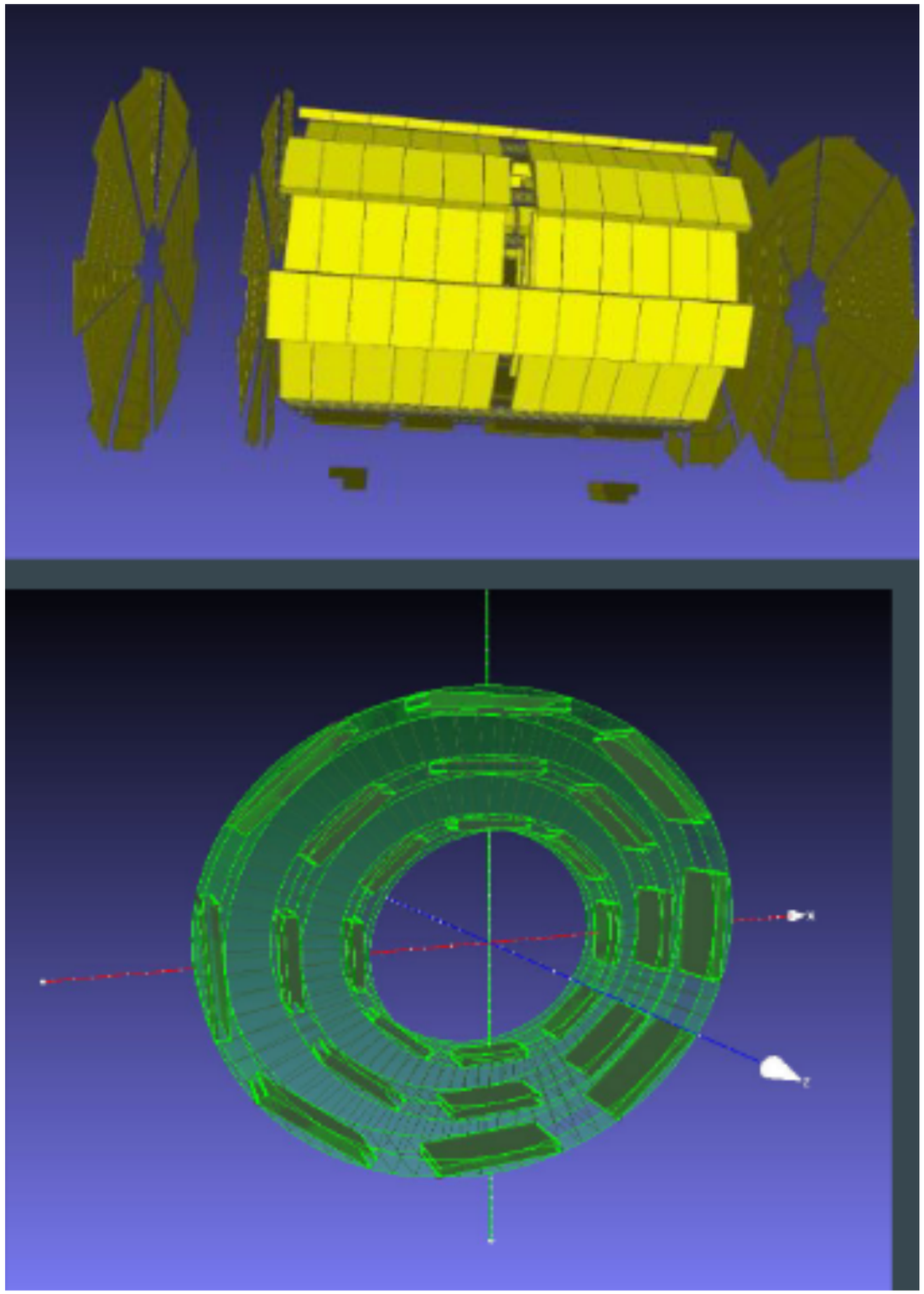
Athena integration

- The entire ACTS **tracking chain** is now available in Athena
- Performance compatible with the Athena one
- A lot of work has been performed to **match the speed** Athena speed (currently 8% slower)



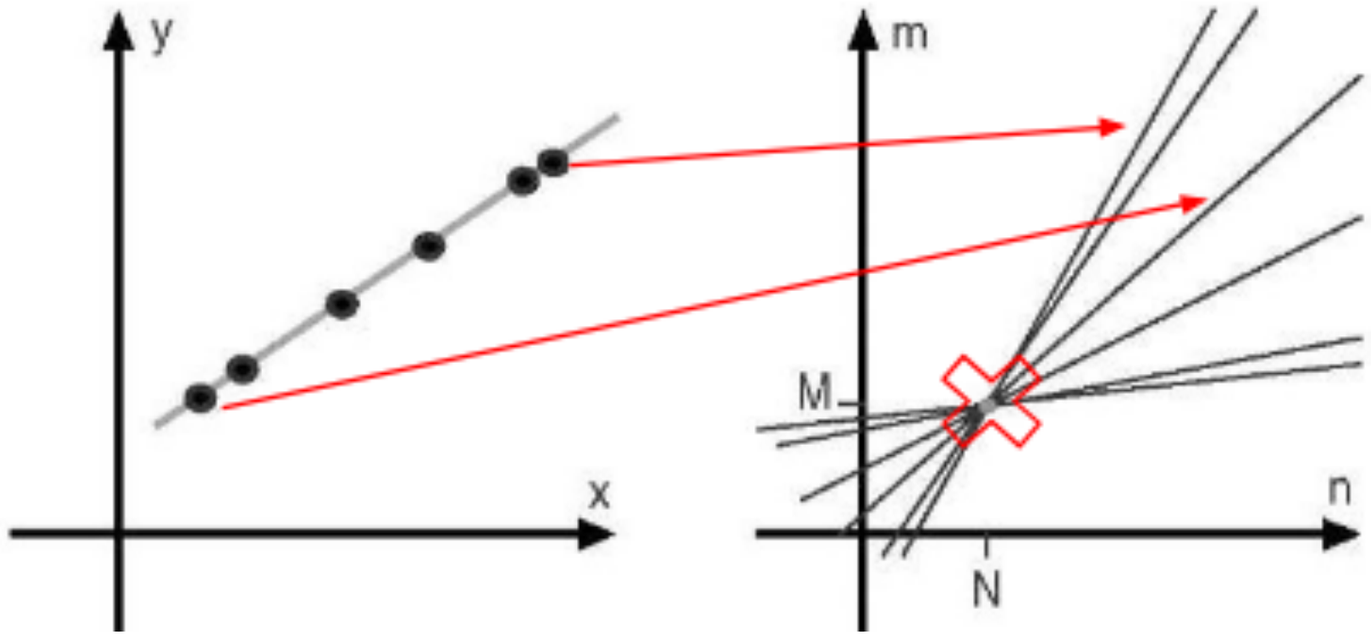


Athena integration



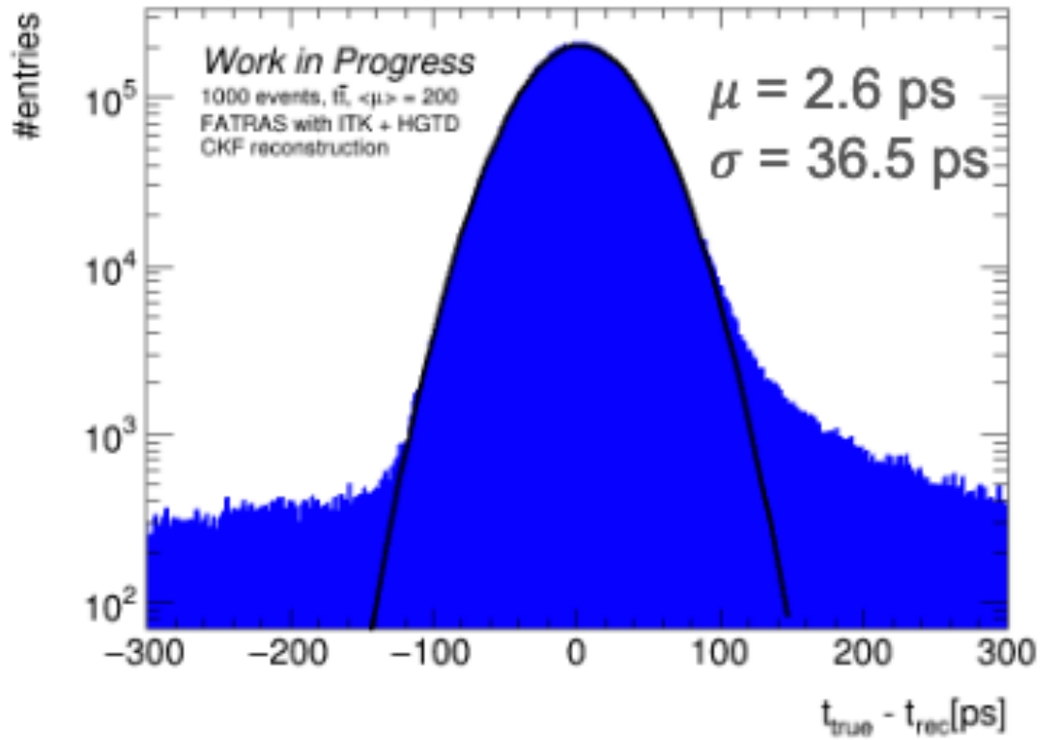
- Integration of the Muons system in ACTS
- Geometry available
- New seeding algorithm based on **Hough Transform** implemented
- Works ongoing and picking up speed

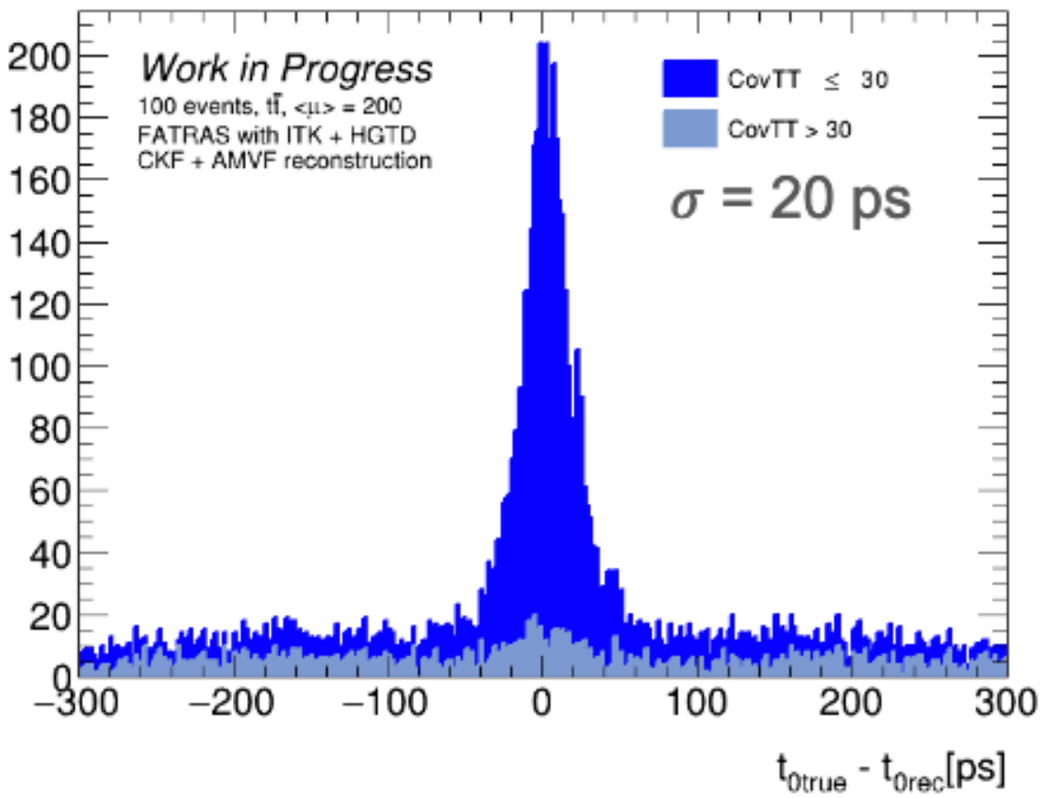
Dimitra Amperiadou



Athena integration

- **HGTD timing studies** are now being performed with ACTS
- Hits in the HGTD fitted with the CKF
- Can then be used in the **vertex fitting** procedure
- Study generalised to different levels of irradiation
- Using **fast simulation** due to limitations of their current setup need to move the G4





Rodrigo Estevam de Paula

Conclusion

- ACTS is a **major tracking library** implemented by many current and future experiments
- Offer an excellent **testing environment** for new tracking algorithms (ML)
- Comes with a virtual detector (**ODD**) for performance evaluation, now with an included calorimeter
- Integration in **Athena** is ongoing and progressing steadily

Backup