ACTS status and plans

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What is ACTS?

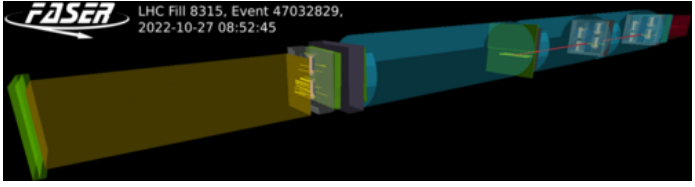
- A Common Tracking Software
- Experiment-independent toolkit for charged particle trajectory reconstruction
- Project goals:
  1. Provide production-ready implementations of state-of-the-art tracking methods
  2. Serve as algorithmic testbed, including ML methods and accelerated hardware
  3. Enable rapid development of new tracking detectors
- Design principles:
  1. Provide experiment-independent algorithms & allow efficient experiment-specific usage
  2. Thread-safe code across the board
  3. Focus on maintainability
- ACTS Website,
- Code on Github

Current Status & Accomplishements

- Project status:
  - Transitioning from R&D phase to mature production-ready framework (driven by HL-LHC timeline)
  - Supporting innovation (test-bed paradigm, fast prototyping) is still a key goal
- Recent Journal publications:
  - Non-linear Kalman Filter Nucl. Instrum. Meth. A 1049 (2023)
  - Track ML Challenge, Throughput Phase Comput. Softw. Big Sci. 7 (2023)
  - ACTS summary paper Comput. Softw. Big Sci. 6, 8 (2022)
  - GPU-based Kalman Filter Comput. Softw. Big Sci. 5 (2021)
- See also list of presentations by IRIS-HEP members

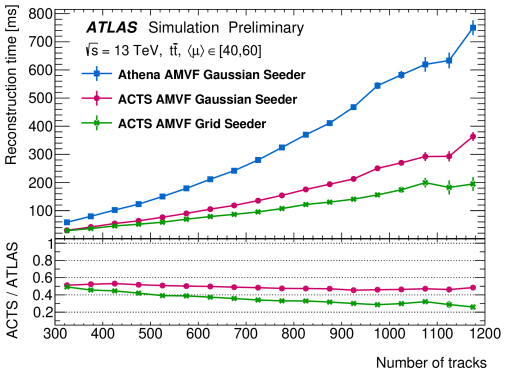
- Wide range of experiments now using ACTS
  - ALICE
  - ATLAS*
  - BELLE-2
  - BESIII
  - CEPC
  - EIC
  - FASER*
  - LDMX
  - PANDA
  - sPHENIX
  - STFC
  - ...

- FASER ν event, reconstructed with ACTS!



ACTS in the wild

- ATLAS Vertex Finding



- FASER Neutrino paper [2303.14185]

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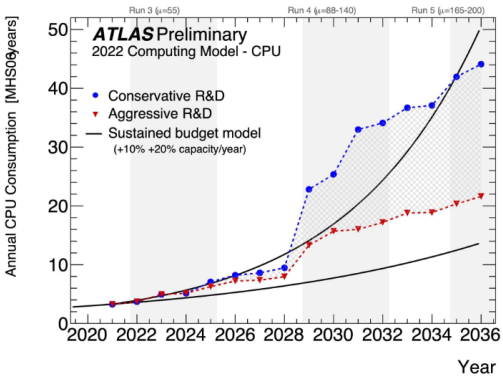
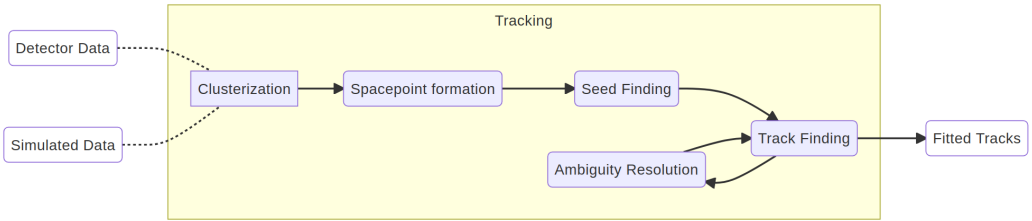
ACTS for ATLAS Run 4



source: ATLAS Software and Computing HL-LHC Roadmap

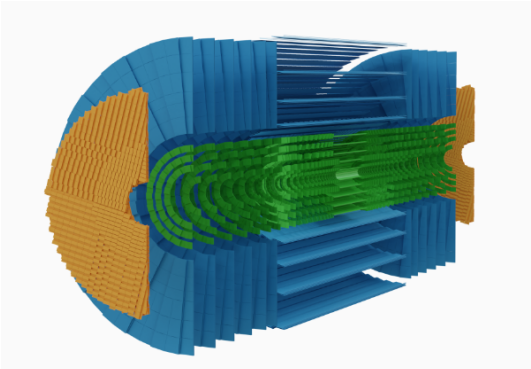
- High pileup at HL-LHC necessitate changes to tracking software to fit computational budget
- Current ATLAS tracking is unsustainable
  - "Organic" development → ad-hoc design
  - Parallelism is necessary speed, hard to retrofit
  - Lack of good documentation
  - Many of the key developers have left the field
- $\Longrightarrow$ ATLAS Tracking currently being re-implemented with ACTS

ATLAS/ACTS Tracking for Run 4



- Clusterization: Grouping discrete sensor readouts into clusters
- Spacepoint formation: Computing 3-D coordinates from clusters
- Seed Finding: Make initial set of tracks out of spacepoint triplets
- Track Finding: Find as many tracks as possible with Combinatorial Kalman Filter
  - "KF-only" paradigm: no standalone fitting stage needed
- Ambiguity resolution: Keep fake rate as low as possible

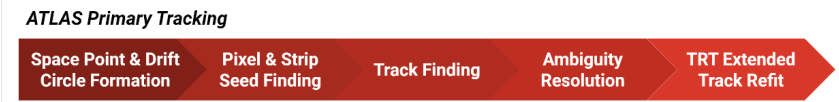
ACTS for ATLAS Run 4: Status and plans



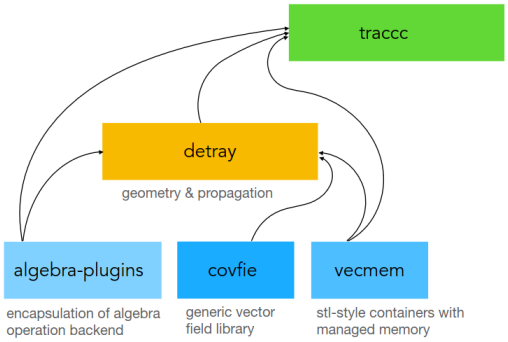
- ATLAS Tracking EDM being adapted for ACTS: $\approx$ 1 year
- Full chain ITk demonstrator in Athena currently being optimized: $\approx$ 1 year
- NN clustering being ported from Athena to ACTS Core: $\approx$ 1 year
- Missing piece: Ambiguity Resolution (see next slide)
- EF Tracking project: Opportunity to contribute to trigger-level tracking
  - Development process involving demonstrators and technology choice in Q4 2025
  - ACTS integration an explicit goal
- Strong involvement from US ATLAS and IRIS-HEP (C. Varni, T. Yamazaki, L-G Gagnon)

Core Library: Ambiguity Resolution

- Some tracking chains (e.g. ATLAS) need an Ambiguity Resolution stage
- Allows minimizing fake track creation rate for high tracking efficiency algorithms
- Allows algorithms to achieve high efficiency while minimizing fakes
- ACTS currently has:
  - An overly simplistic "greedy" implementation
  - A proof-of-concept ML-based implementation (Irina Ene, IRIS-HEP fellow)
- ACTS-ITk chain currently uses simplistic ACTS ambiguity resolution: not viable long term
- Work needed to implement a production ready algorithm
- *some* IRIS-HEP involvement (L-G Gagnon)
- Timescale: 1–3 years



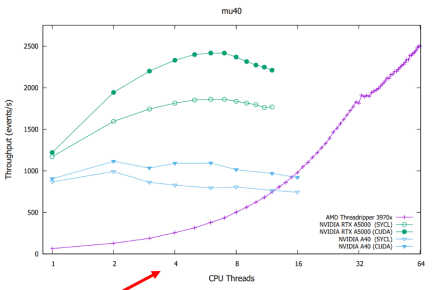
ACTS on accelerated hardware: traccc

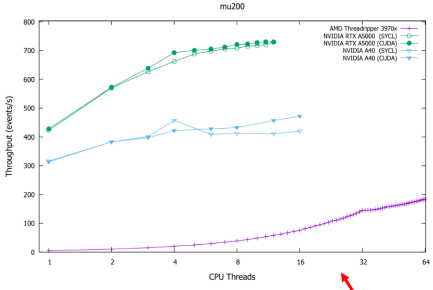


- traccc: Kalman Filter-based tracking for GPU
  - FPGA support in future
- KF is largely based on matrix algebra: good fit for such architectures
- Opportunity for large gains in throughput beyond CPU-based parallelism
  - Particularly relevant for EF tracking
- Multi-backend approach to allow technology comparison
  - CPU (reference)
  - CUDA (nvidia GPU)
  - SYCL (GPU, FPGA)
- Timeline
  - Full-chain demonstrator: $\approx$ 1 year
  - Full-chain with ITk geometry: $\approx$ 2 years
  - Full-chain optimized for ITk: $\approx$ 3 years
- Strong IRIS-HEP involvement (B. Yeo)

traccc - Performance on GPU/SYCL

clustering - space point formation - seeding - parameter estimation





- SYCL competitive with native CUDA implementation
- SYCL slower at low pile-up - kernel launching / scheduling. WIP

credit: A. Salzburger

- Left: pileup = 40, right: pileup = 200
- Large throughput gain esp. at high mu
  - Purple is CPU, Blue/Green is NVIDIA A40/A5000

Machine Learning Algorithms

- ACTS primarily already supports ML models through `ONNX` and `Torch` plugins
  - Irina Ene contributed to ONNX support as IRIS-HEP fellow
- A lot of R&D in recent past but work needed to integrate into production framework
- Many promising projects on a 1–3 years timescale:
  - GNN-based track finding (e.g. Exa.TrkX, Acc. GNN Tracking IA project – see talk by Kilian Lieret)
  - NN-based Ambiguity Solving (see earlier slide)
  - CNN-based primary vertex finding (PV finder – see talk by Mike Sokoloff)
  - Auto-tuning of tracking algorithms using derivative free (optuna) or derivative based (Surrogate methods) approaches. (R. Garg, E. Hofgard)
- IRIS-HEP involvement in all of the above
- Also supporting "Greenfield" R&D on hybrid ML/KF track finding
  - Max Zhao, IRIS-HEP undergraduate fellow
  - Presentation at IRIS-HEP topical meeting

Other goals

- Leverage 4D tracking (i.e. tracking with time)
  - Already supported out-of-the-box in Core library
  - Clear implications for pileup mitigation, vertexing, jet tagging
  - Long term goal; most relevant for next/next-to-next generation of detectors
- `key4hep support`
  - `key4hep support` is a "turn-key" HEP software stack developed for FCC-style experiments
  - ACTS integration is underway, timescale of 2–3 years
  - No IRIS-HEP involvement so far but nascent efforts in the US for FCC-ee
    $\rightarrow$ opportunity to make headway in FCC software
- Alignment support in Core library
  - Alignment == computing the real position of tracking sensors from data
  - Kalman Filter-based proof-of-concept in ACTS
    contributed by Xiaocong Ai (former IRIS-HEP postdoc, now faculty at Zhengzhou University)
  - Work ongoing to implement full fledged version for ATLAS ITk
  - More efficient algorithm $\rightarrow$ more fine-grained alignment than currently feasible with global χ^2 method
  - Other experiments are interested: Faser, LDMX, ...

Conclusion

- ACTS currently transitioning from R&D-first to production library
- Still a lot of work to do!
- IRIS-HEP involved in many areas:
  - Full ACTS-based tracking chain for ATLAS Run 4
  - Realistic ambiguity resolution
  - GPU/FPGA-based algorithms (detray, traccc)
  - ML-based algorithms
- Other opportunities
  - 4D tracking
  - Alignment
  - key4hep support

Thank you!