HL-LHC ATLAS 4D tracking
Project schedule and GNN reconstruction

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Participation on 2024 ACTS Developers Workshop

- Presented our work to a great reception :)
  - [Impact of sensor degradation on the time reconstruction of CKF tracking](#)

- Nice integration with all the tracking collaborations
- Got tons of feedback and next steps suggestions
- Meet the important people responsible for ACTS (and ATLAS upgrade tracking)
- Got up to speed with the development of ACTS

CKF still important as ever

2025 Main Objectives

- Continue (and improve) the reconstruction with CKF
- Investigate two (or three) novel reconstruction methods
- Be prepared to present at a conference
- Finish ATLAS Qualification project
- Apply for CERN's doctoral program (to start 2026 onwards)

Continue (and improve) the reconstruction with CKF

- Have ACTS working on SAMPA with HTCondor (done)
- Use Geant4 for particle propagation
  - Need to wait for the ACTS to have the geometry working with Geant4
  - Simulate with Athena and analyse with ACTS
- Use traccc for GPU based ACTS algorithms
  - Lxplus setup
  - Run it on the institute cluster
- Improve primary vertex time reconstruction (t0)
  - Adapt particle gun so we can shoot a portion of the particles on the central region and others on the endcaps
  - Adapt vertex seed to use time information (Gaussian Track Density Seeder)
- Investigate the tails of residual distribution
  - Maybe caused by the approximation of the speed of low pT particles to c
  - Get PFG particle IDs on the track-states root file (to reconstruct pT)
  - Investigate CMS code for annealing vertex fitting, using different particle hypothesis

Investigate novel reconstruction methods

- What would be the best setup for development
- Method to test:
  - Transformers
  - Cellular Automata
  - CKF?

Conferences

Engineering Conferences:

- ICASSP (06-15 April)
  - Paper deadline submission - Sept. 2024
- IEEE SSP Workshop (June)
  - Paper deadline submission: February
- Eusipco (Aug/Sept)
  - Paper deadline submission - March
- Asilomar (was Oct.2024)
  - No info yet

Physics events:

- CERN Latin-American School of High-Energy Physics (30 April - 13 May)
  - No paper submission, but registration deadline - Jan 10

Finish ATLAS Qualification Project

- Need to end before August 2025

- HGTD TDC simulation on Athena
  - Integrate the TDC on the digitization chain (done)
  - Adapt the RDO struct to incorporate the ToA and ToT as output by the electronics

- Improve track to HGTD hit association
  - Setup with Geant4 simulation
  - Test CKF performance
  - Test other association methods (Gaussian Hit Density ?)

Revisiting the schedule

Atividade	S.1	S.2	S.3	S.4	S.5	S.6	S.7	S.8	S.9	S.10
Disciplinas do Programa da Pós-Graduação	■	■	■							
Revisão da Literatura	■	■	■	■	■	■	■	■	■	■
Familiarização com os frameworks de reconstrução e análise			■	■						
Implementação dos modelos GNN em reconstrução 3D				■	■					
Preparação para o exame de qualificação					■	■				
Implementação e dos modelos GNN em reconstrução 4D					■	■	■	■		
Introdução da informação de ToT e degradação do sinal dos sensores no modelo								■		
Implementação dos métodos em arquiteturas heterogêneas CPU+GPU								■	■	
Estudo do desempenho da reconstrução (incerteza sistemática, eficiência, desempenho computacional)					■			■	■	
Estágio no CERN (atividades no HGTD e estudos de reconstrução e validação)				■			■			
Preparação da Defesa									■	■

- We're ≈ 9 months ahead 😊
- There are still plenty of ACTS to uncover, but we need to start shifting gears
- Need to start discussing the implementation of new reconstruction methods

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Research on new methods

- The most prolific collaboration searching for new methods inside ATLAS is the GNN4ITk
  - Don't know of any other
- GNN4ITk acts as an extension of the Exa.trk collaboration ([web page](#)) to apply their solution for ITk
- Would recommend the following readings:

reports, publications & presentations

Publications
- Performance of a Geometric Deep Learning Pipeline for HL-LHC Particle Tracking (Associated Code) Eur. Phys. J. C **81**, 876 (2021) ⟵ **most known paper of GNN for tracking**

Conference Contributions
- Hierarchical Graph Neural Networks for Particle Track Reconstruction Presented at ACAT 2022 (Associated Code).
- ATLAS ITk Track Reconstruction with a GNN-based pipeline Presented at Connecting the Dots 2022 (Associated Code). ⟵ **PUB note of GNN4ITk**
- Accelerating the Inference Time of Machine Learning-based Track Finding Pipeline Presented at ACAT 2021 (Associated Code).
- Graph Neural Network for Large Radius Tracking Presented at ACAT 2021
- Graph Neural Network for Object Reconstruction in Liquid Argon Time Projection Chambers Presented at CHEP 2021
- Distributed Training of GNNs on HPCs Presented at the 4th Inter-experiment Machine Learning Workshop (Associated Code).
- "Track Seeding and Labelling with Embedded-space Graph Neural Networks". Presented at Connecting the Dots 2020 - (Associated Code).
- "Graph Neural Networks for Particle Reconstruction in High Energy Physics Detectors". Presented at NeurIPS 2019 Workshop "Machine Learning and the Physical Sciences" - (NeurIPS Poster) (Associated Code).

Presentations
- Full-length tutorial on Tracking with Graph Neural Networks (Sep 2023, Heidelberg) Part 1 - Part 2 ⟵ **most comprehensive summary**
- Graph Neural Networks for High Luminosity Track Reconstruction (CERN EP-IT Data science seminar).
- Graph Neural Networks for Reconstruction in DUNE (presented at the Dec 4th CLARIPHY topical meeting).
- Tracking with GNNs (in-depth code walk-through at the 4th Inter-experiment Machine Learning Workshop) (colab notebook) (Associated Code).
- Graph Neural Networks for Particle Tracking (A non-specialist introduction to Exa.TrkX tracking models).

Exa.Trk plugin on ACTS

- ACTS has a plugin to use Exa.Trk GNN reconstruction.
  - Almost sure not adapted to 4D reconstruction as we want
  -

TO DOs

- To make the plugin work, I'll have to install CUDA
  - If there's no nvidia card, will have to search for another machine to run with (lxplus?)
- Study the implementation
- Compare the performance with CKF
- How to include time information?

```python
from acts.examples.reconstruction import addExaTrkX,
ExaTrkXBackend

if backend == ExaTrkXBackend.Torch:
    modelDir = Path.cwd() / "torchscript_models"
    assert (modelDir / "embed.pt").exists()
    assert (modelDir / "filter.pt").exists()
    assert (modelDir / "gnn.pt").exists()
else:
    modelDir = Path.cwd() / "onnx_models"
    assert (modelDir / "embedding.onnx").exists()
    assert (modelDir / "filtering.onnx").exists()
    assert (modelDir / "gnn.onnx").exists()

s = runDigitization(
    trackingGeometry,
    field,
    outputDir,
    digiConfigFile=digiConfigFile,
    particlesInput=inputParticlePath,
    outputRoot=True,
    outputCsv=True,
    s=s,
)

addExaTrkX(
    s,
    trackingGeometry,
    geometrySelection,
    modelDir,
    outputDir,
    backend=backend,
)
s.run()
```

Backup