NGT: WP 2.5 Status

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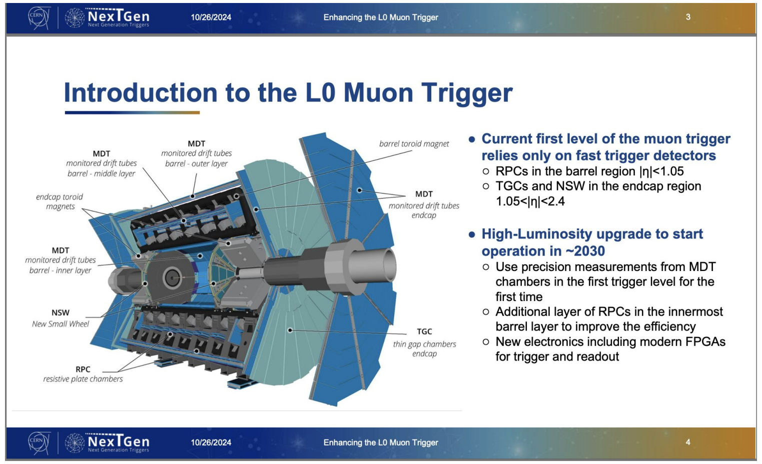
Overview



[Task 2.2: Enhancing the Level-0 Muon Trigger]

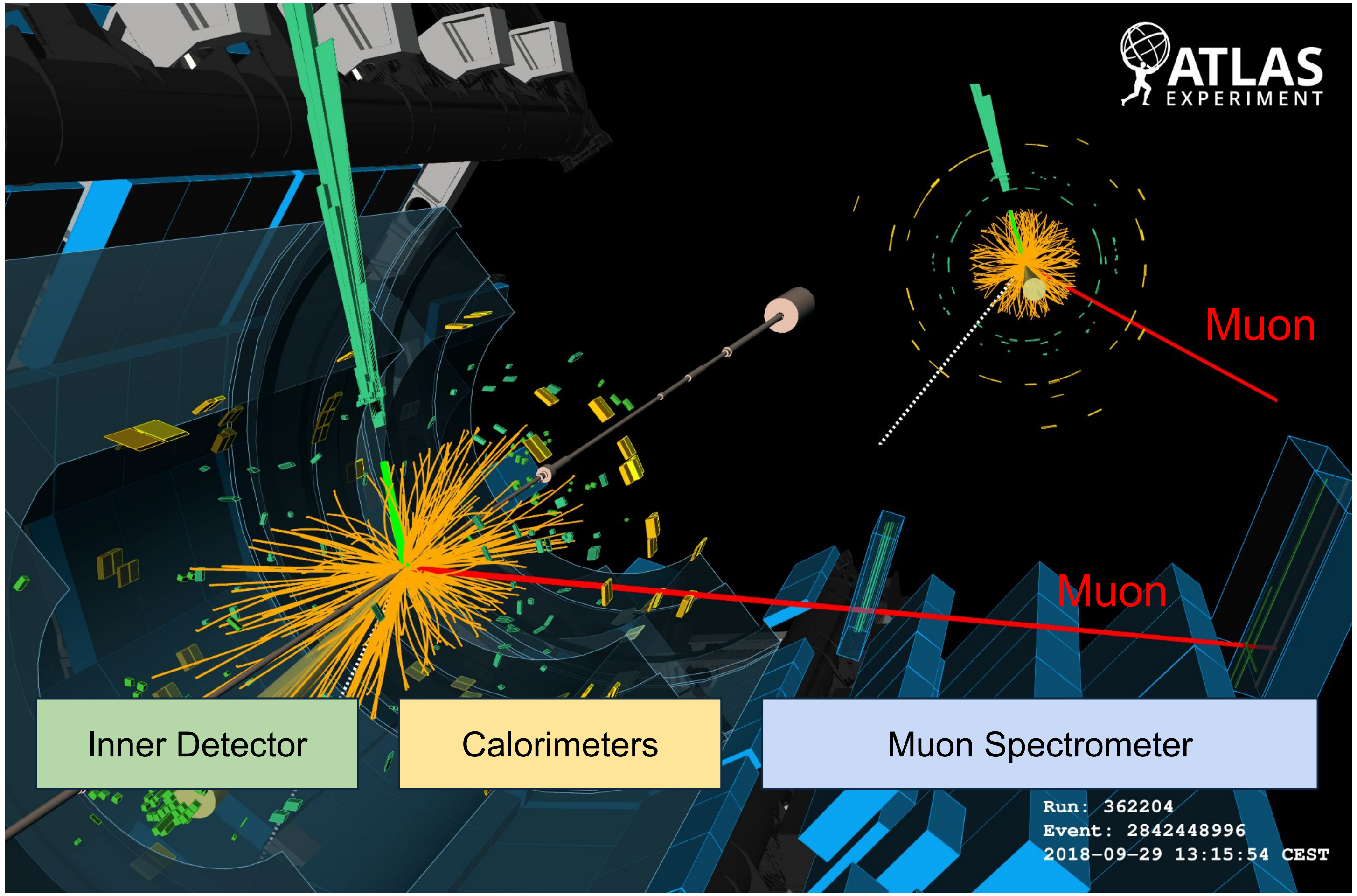
- **Goals**
  - WP 2.5 aims to fully exploit the extended coverage of the L0 muon trigger (Task 2.2) and the novel tracking infrastructure (ACTS) developed in Task 2.6 to improve the physics performance of the Event Filter muon track reconstruction
  - Develop novel ML based reconstruction techniques to improve on existing classical algorithm chain

2.5 Milestones

- **Main focus for this year is research**
  - Measure performance of existing reconstruction chain, look for bottlenecks and hotspots
  - Use this to focus effort in the right places

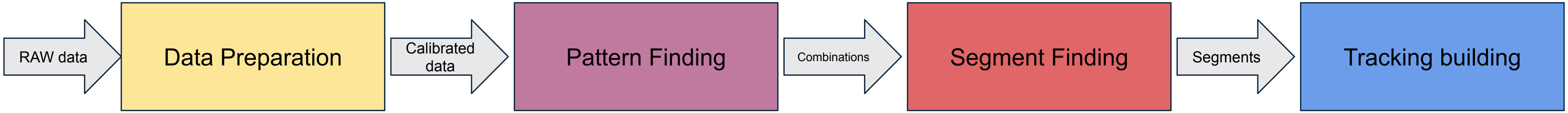
Time	Description	Objectives
12 m	Measure the performance of the existing Muon Event Filter.	Understanding of the current algorithm bottlenecks and hotspots.
24 m	Migrate current MS EF to use ACTS (via wrapping or complete rewrite within ACTS). This will involve working on components shared with the offline (non-trigger) reconstruction. Together with Task 2.6, evaluate potential novel AI reconstruction techniques.	First prototype of ACTS/AI Muon Event Filter running on simulated datasets.
36 m	Performance evaluation of prototype new reconstruction algorithms. The algorithms will be compared to the existing algorithms in terms of efficiency, misidentification rates and throughput.	Compare performance of prototype new reconstruction algorithms. Identify which algorithms should be further developed. Input to ATLAS decision on final hardware design.
48 m	R&D on selected algorithms to improve performance (efficiency, misidentification rates and throughput). Development of selected AI algorithms (together with Task 2.6) on selected hardware platforms. Integration into ATLAS HLT infrastructure.	Updated AI reconstruction running in ATLAS trigger. Algorithm robustness & documentation.

Overview of the problem



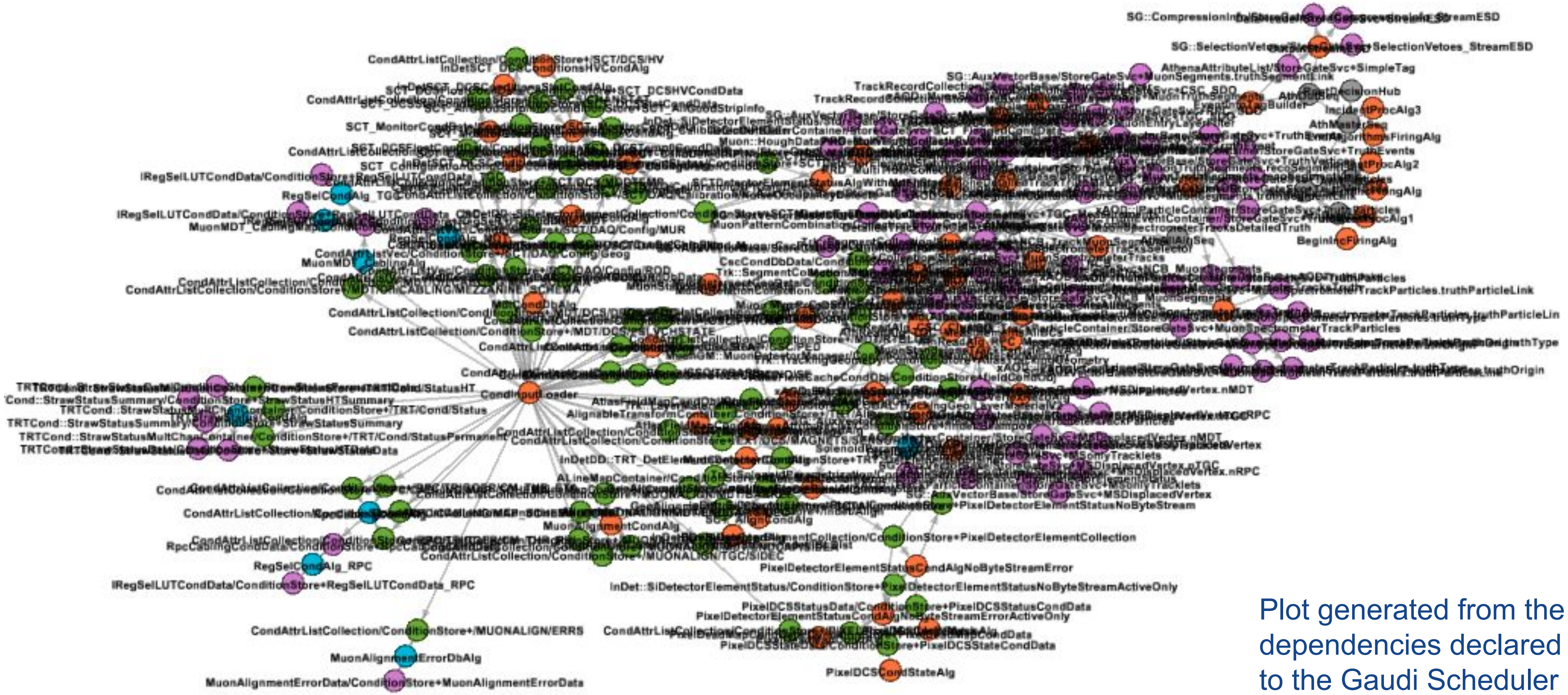
- **Event display shows a reconstructed muon, passing through the entire detector**
  - For the final physics analyses we combine information from all sub-detectors
    - Inner Detector/ITK
    - Calorimeters
    - Muon system
  - It is the *Muon standalone reconstruction* which is the focus of this talk
    - Here we look for **patterns** of measurements/hits in the spectrometer
    - Per-chamber **segments**
    - Whole spectrometer **tracks**

Muon Spectrometer track reconstruction



- **Existing chain**
  - Broadly dataflow is as follows (though it is actually a ***lot*** more complicated, with e.g. measurements (“calibrated data”) entering at every stage)
    - (This also only shows the event data - all stages also access “conditions data” e.g. geometry, detector parameters etc)
    - This is just from the Muon Spectrometer - eventually the muon tracks are combined with those from the Inner Detector / ITK. Currently calorimeter information is not used in the HLT.
  - Software chain is shared between offline and online, but configured differently in online (where processing time is much more limited)
    - Reconstruct only in “Regions of Interest”, versus whole detector
    - Prioritise speed over precision (and in particular, low p_T muons are not as important online)

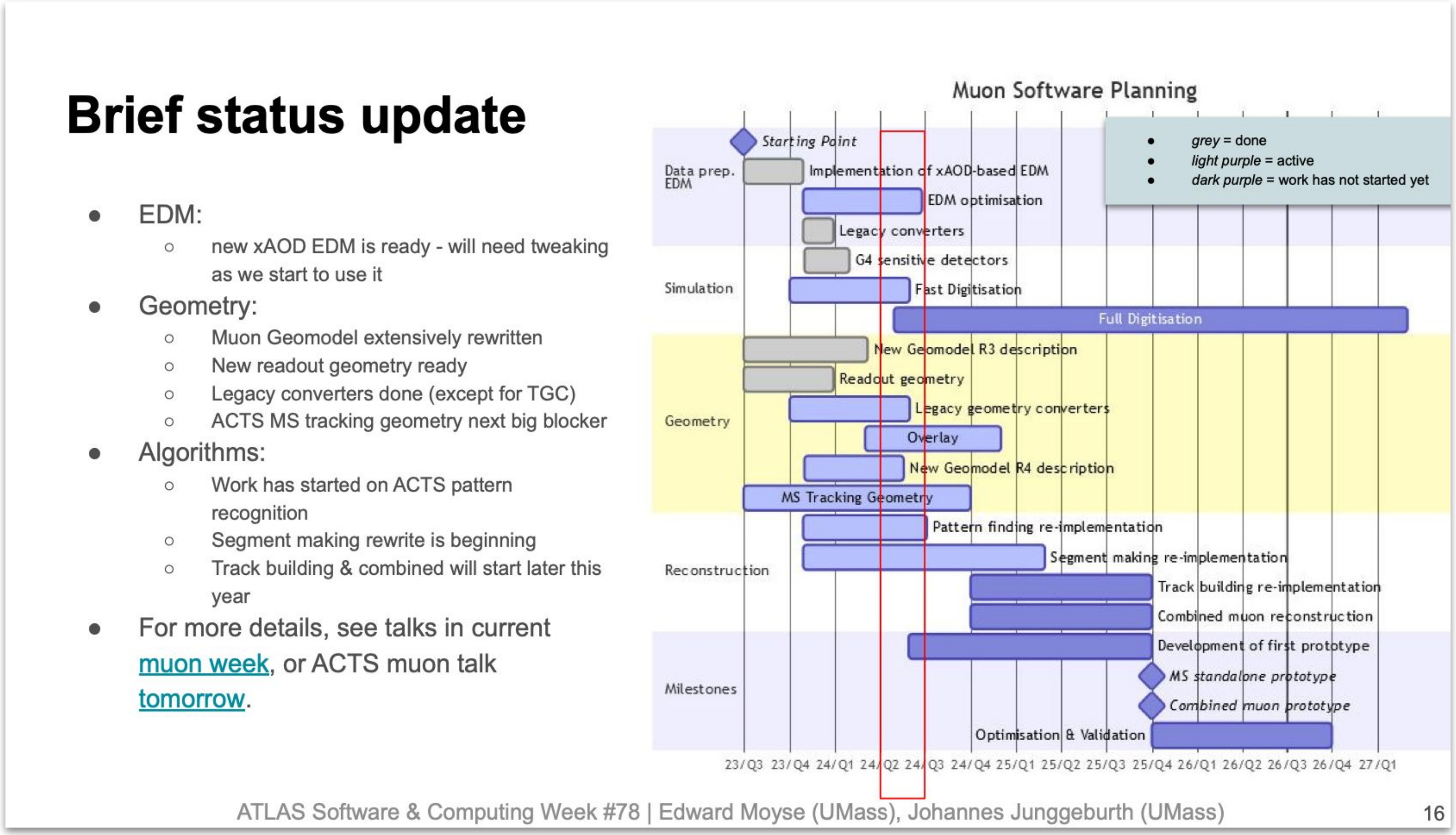
Actual data dependencies are (much) worse…



Plot generated from the actual data dependencies declared by the algorithms to the Gaudi Scheduler

General Muon HL-LHC plans

- **Together with offline, ongoing campaign to rewrite the entire Muon SW stack**
  - Migrating to ACTS
    - New event data model
    - New tracking geometry and navigation
    - Close cooperation with WP 2.6 (see next presentation for more)
  - New muon detector description representation (GeoModelXML)
  - Rationalise data-flow (c.f. earlier slide)
- **Work is closely integrated with this NGT work package**
  - When migrating to ACTS, can use **performance monitoring** to decide where best to concentrate optimisation efforts



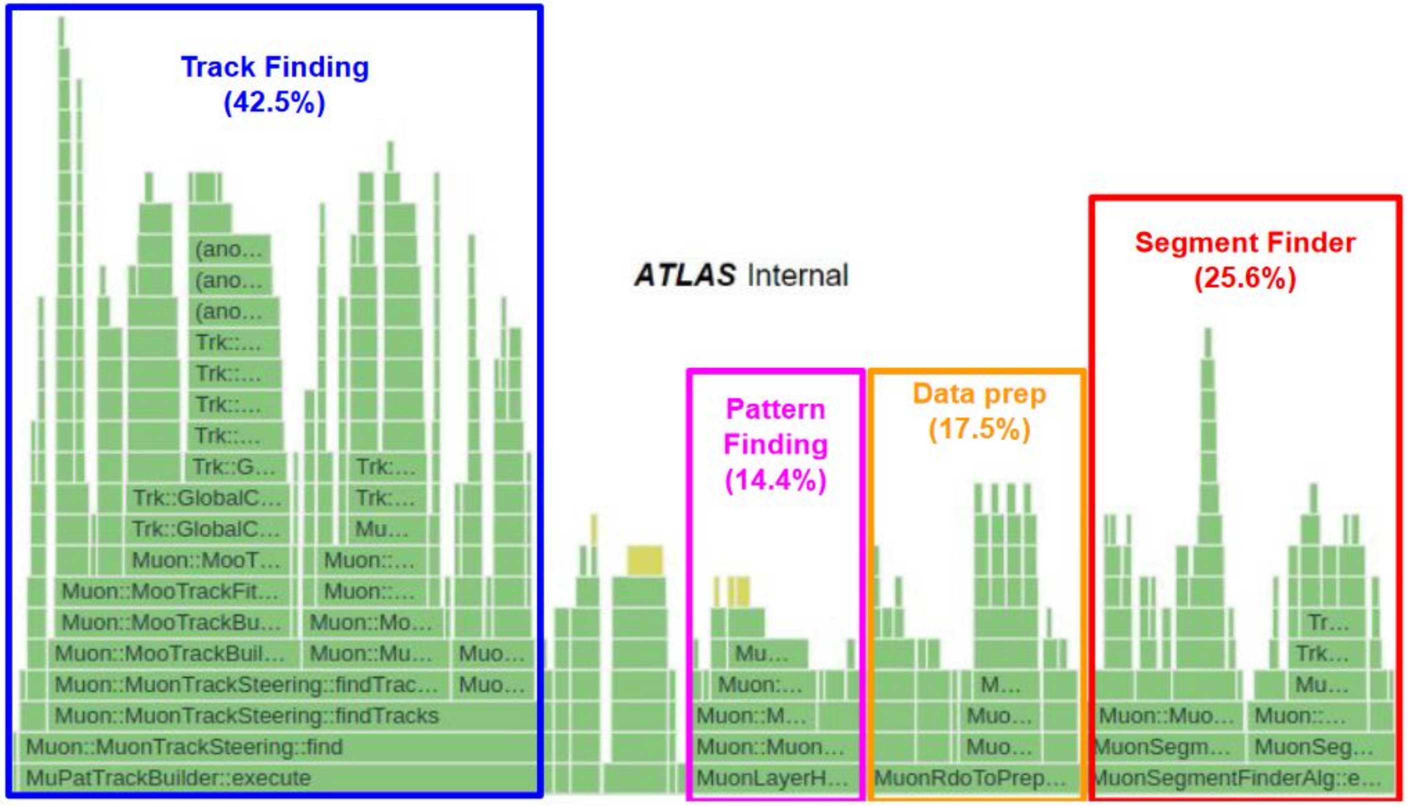
ATLAS Muon SW planning, as presented earlier this year

Time	Description	Objectives
12 m	Measure the performance of the existing Muon Event Filter.	Understanding of the current algorithm bottlenecks and hotspots.

WP 2.5, first milestone

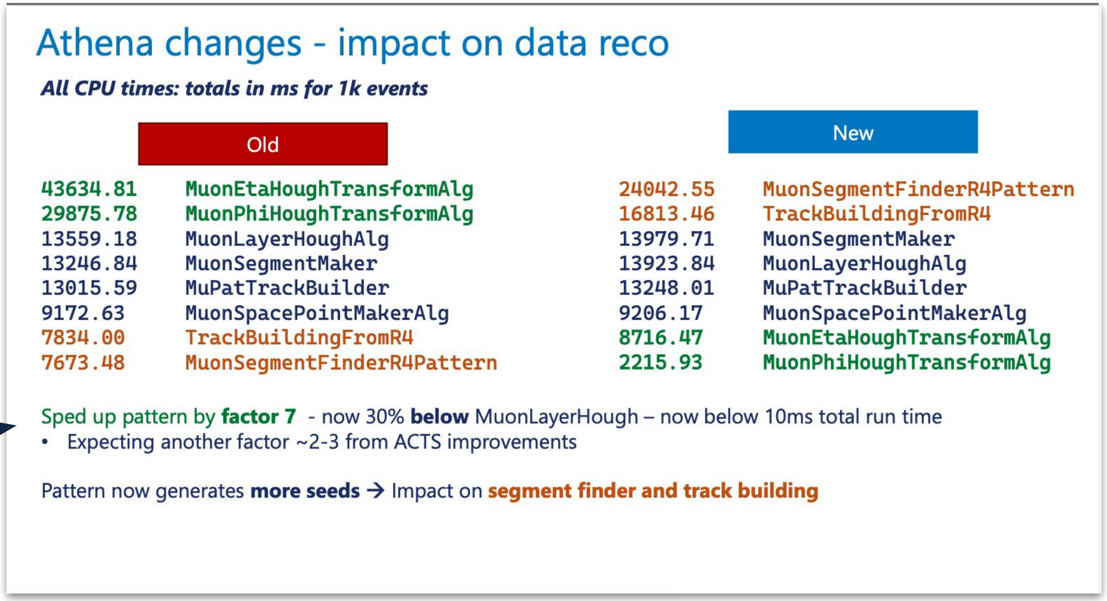
Performance

- **To investigate the performance of the existing chain, we monitored the reconstruction of a typical real data event (with pileup $\langle\mu\rangle \approx 45$) and generated this flamegraph**
  - The x-axis shows the proportion of time spent in different parts of the reconstruction code (function names truncated for visualization),
  - The y-axis indicates the call depth (the higher the function, the deeper the call in the code).
  - The coloured boxes represent the high level reconstruction step, and its percentage indicates the fraction of total time that is spent in each stage.
- **Track finding dominates the reconstruction time, though all stages are significant**



New Algorithmic approaches

- **Using understanding of bottlenecks, implement reconstruction improvements**
  - Interfaced muon tracking to ACTS library
  - New ACTS algorithm has significant muon reconstruction chain speed-up
    - Pattern recognition step **~7 times faster**
- **Deployment of new algorithms for segment finding**
  - New segment finding based on Hough Transform (HT)
    - + new linearized $\chi 2$ fitter closely tailored to the new HT
  - Algorithm extensively tested (see next slide)
  - Tuning chosen to maximize the pattern collection efficiency at a decent resolution of the estimated parameters
  - Currently just in Athena, but will be ported to ACTS



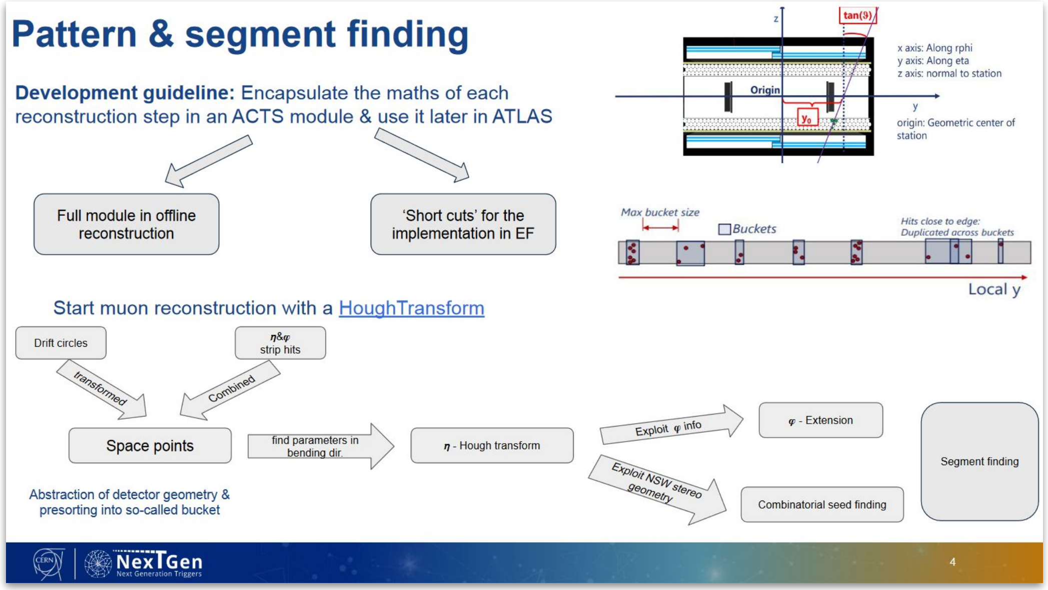
Athena changes - impact on data reco

All CPU times: totals in ms for 1k events

Old		New	
43634.81	MuonEtaHoughTransformAlg	24042.55	MuonSegmentFinderR4Pattern
29875.78	MuonPhiHoughTransformAlg	16813.46	TrackBuildingFromR4
13559.18	MuonLayerHoughAlg	13979.71	MuonSegmentMaker
13246.84	MuonSegmentMaker	13923.84	MuonLayerHoughAlg
13015.59	MuPatTrackBuilder	13248.01	MuPatTrackBuilder
9172.63	MuonSpacePointMakerAlg	9206.17	MuonSpacePointMakerAlg
7834.00	TrackBuildingFromR4	8716.47	MuonEtaHoughTransformAlg
7673.48	MuonSegmentFinderR4Pattern	2215.93	MuonPhiHoughTransformAlg

Sped up pattern by **factor 7** - now 30% **below** MuonLayerHough – now below 10ms total run time
- Expecting another factor ~2-3 from ACTS improvements

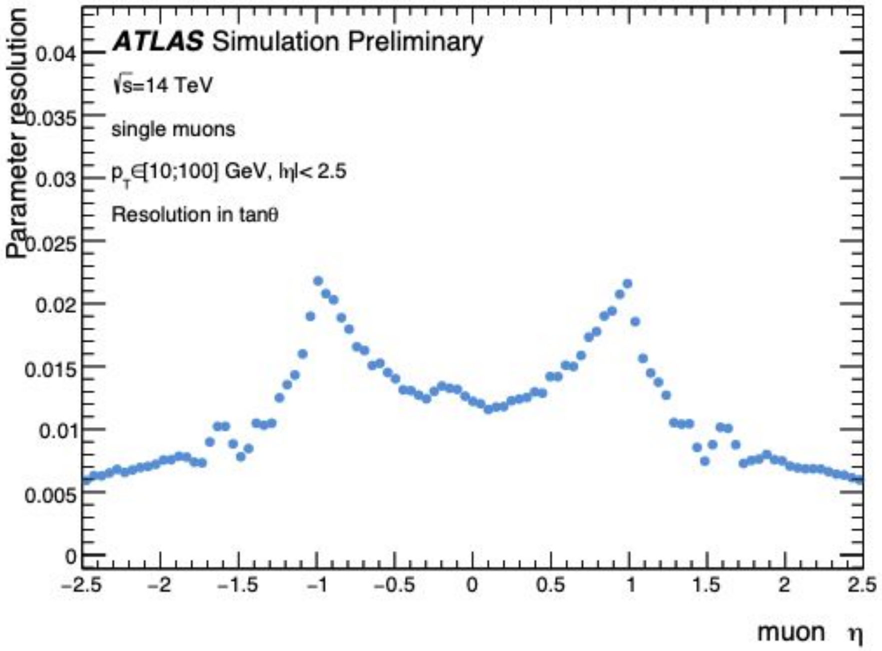
Pattern now generates **more seeds** → Impact on **segment finder and track building**

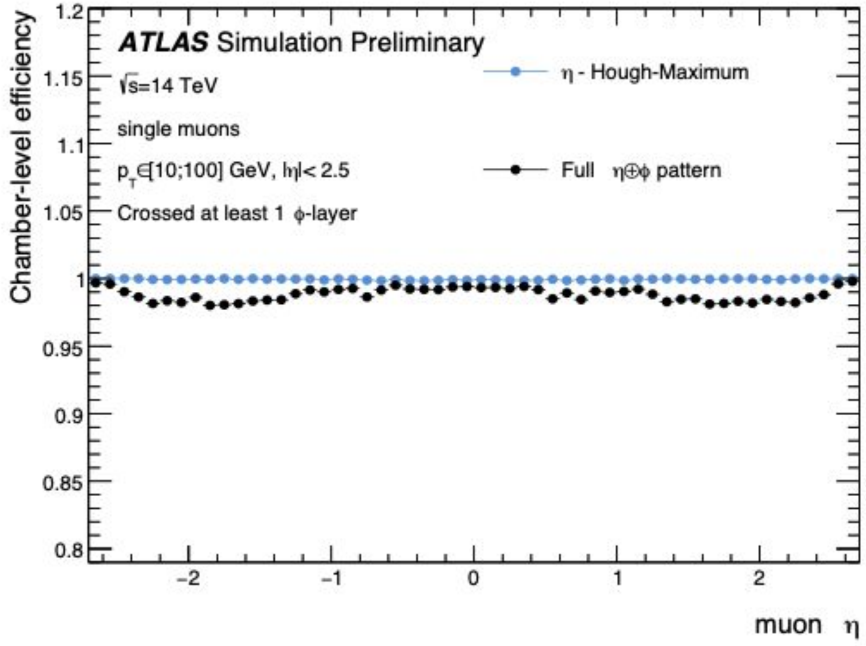


From J. Junggeburth's slides in a recent workshop

New segment finding - first results

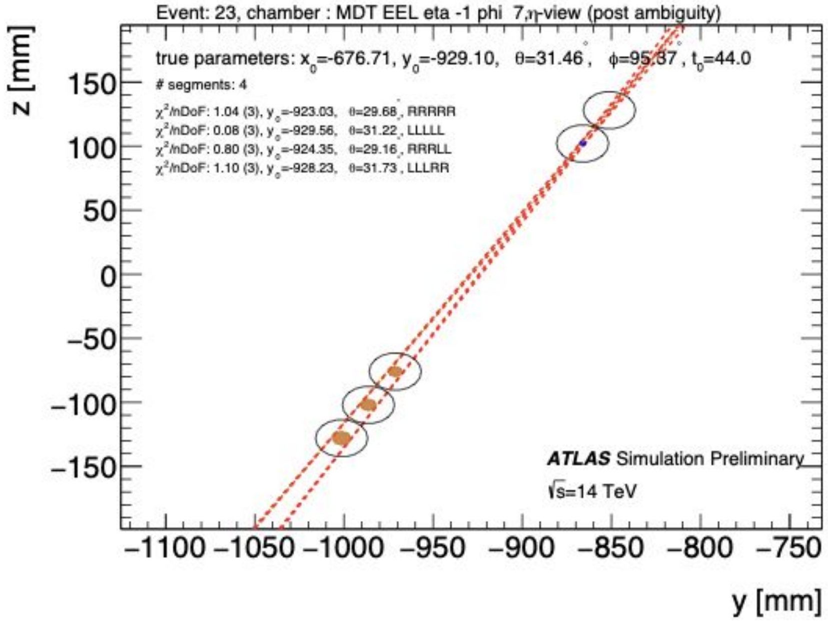
- **Single muon particle gun events used measure the performance of the new algorithm**
  - Top plot shows the **angular resolution** of the first stage of muon segment reconstruction as a function of the pseudo rapidity of the traversing module
  - Bottom shows **Efficiency** to combine the chamber hits from a traversing muon to a Hough maximum in the precision plane (blue) and to additionally construct a Hough estimate in the orthogonal plane as a function of the muon pseudo-rapidity in single muon simulated events
- ***Very* early in development, but performance already looks good**
  - This local approach should be easier to parallelise than the old global approach

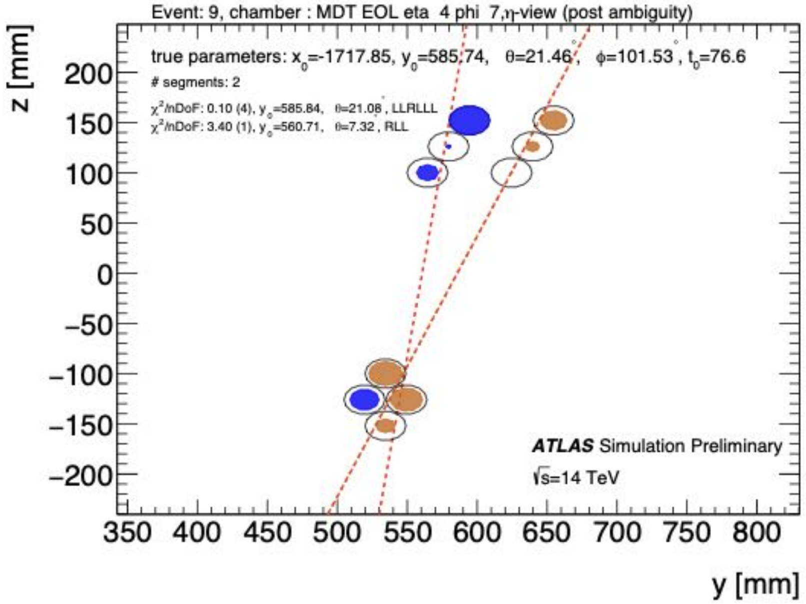




Limits of the classic approach

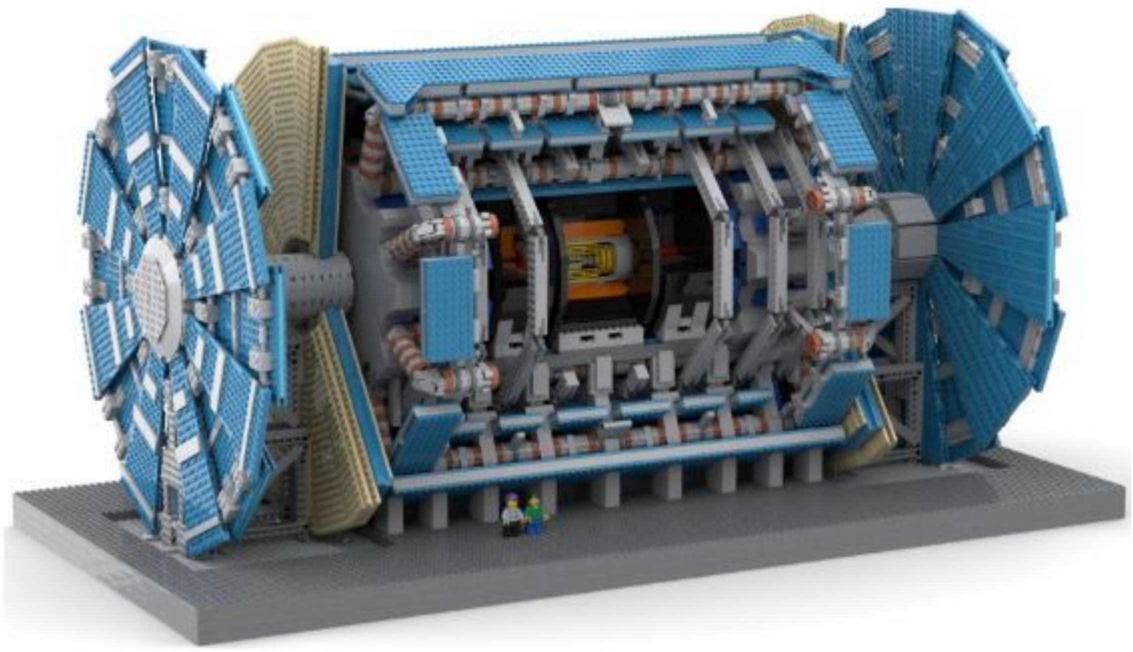
- **Plots to the right is a schematic of a side-on view of a muon chamber**
  - Circles represent the simulated “drift radius”, as simulated
  - We do not know the true tangent!
    - Multiple possible analytic solutions,
    - **… but only one segment is correct**
  - Also, there is significant background
    - Orange circles are from the muon, blue are from δ-electrons
    - **How do we find the correct segment?**





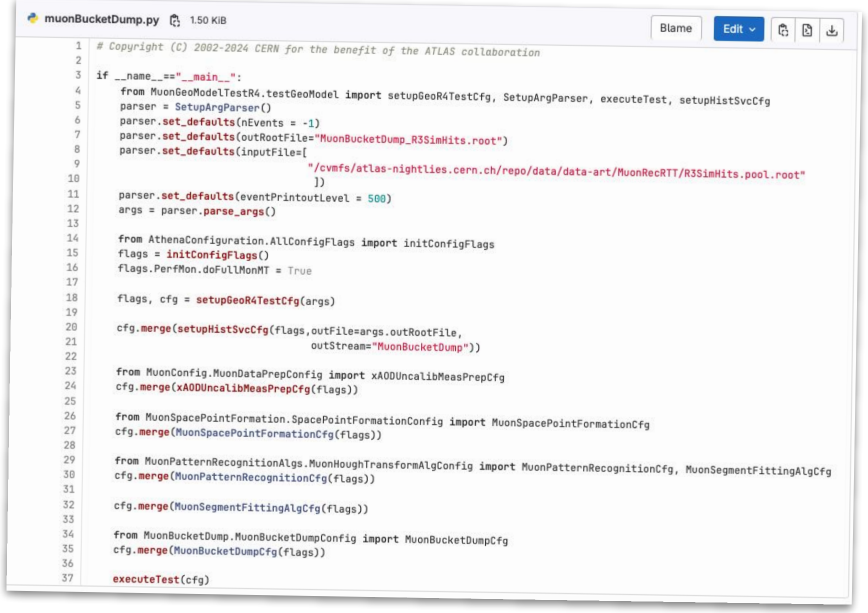
Why Machine Learning?

- **ML can potentially solve the issues:**
  - Reducing the likelihood of losing valid tracking seeds;
  - Improving overall tracking efficiency
- **High level summary of tasks:**
  - Classify which hits are making it onto the segment
  - Predict the segment parameters from the good ones
- **Aim to leverage GNNs**
  - Best suited for sparse data
  - … but also exploring transformers to further improve performance
- **Will need WP1 compute resources to train GNN**



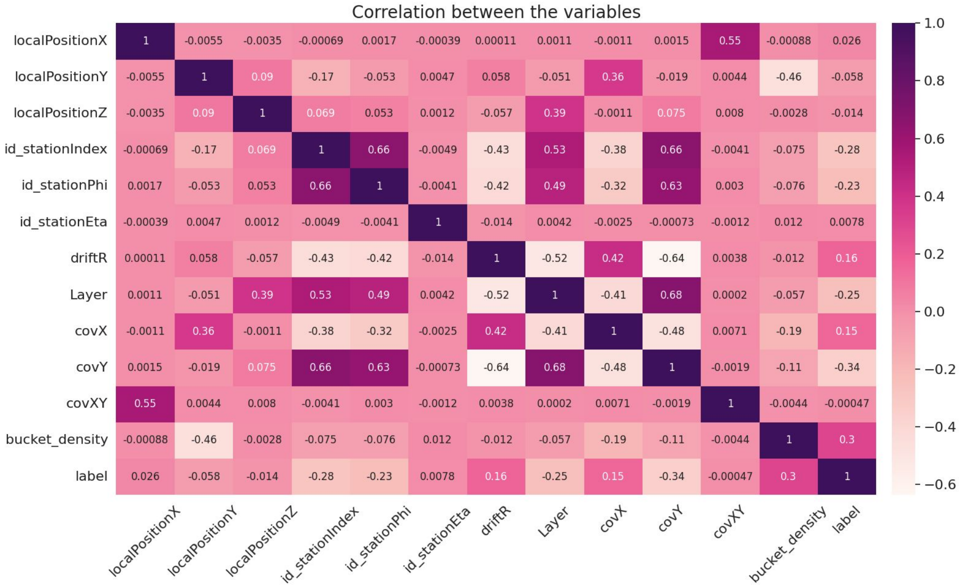
Data set preparation for ML

- **Athena module to extract relevant muon hits and segment data**
- **Graph builder: converts ROOT inputs into graph dataframes**
  - Able to save in multiple formats:
    - HDF5, TFRecord and Torch.
  - C++ version to be implemented, facilitating the ML model's inference within the Athena framework.
- **Comprehensive Dataset:**
  - **Recorded data**:
    - realistic background noise (e.g., electronic noise) essential for understanding non-muon hits
  - **Simulated data**:
    - Necessary for upgrades (i.e. hardware we do not have)
    - Complements recorded data by filling in gaps, potentially helping recover lost efficiencies in legacy reconstruction;
    - …however, it lacks the exact response of real detectors.



muonBucketDump.py 1.50 KiB

```python
# Copyright (C) 2002-2024 CERN for the benefit of the ATLAS collaboration

if __name__=="__main__":
    from MuonGeoModelTestR4.testGeoModel import setupGeoR4TestCfg, SetupArgParser, executeTest, setupHistSvcCfg
    parser = SetupArgParser()
    parser.set_defaults(nEvents = -1)
    parser.set_defaults(outRootFile="MuonBucketDump_R3SimHits.root")
    parser.set_defaults(inputFile=[
                                    "/cvmfs/atlas-nightlies.cern.ch/repo/data/data-art/MuonRecRTT/R3SimHits.pool.root"
                                    ])
    parser.set_defaults(eventPrintoutLevel = 500)
    args = parser.parse_args()

    from AthenaConfiguration.AllConfigFlags import initConfigFlags
    flags = initConfigFlags()
    flags.PerfMon.doFullMonMT = True

    flags, cfg = setupGeoR4TestCfg(args)

    cfg.merge(setupHistSvcCfg(flags,outFile=args.outRootFile,
                                    outStream="MuonBucketDump"))

    from MuonConfig.MuonDataPrepConfig import xAODUncalibMeasPrepCfg
    cfg.merge(xAODUncalibMeasPrepCfg(flags))

    from MuonSpacePointFormation.SpacePointFormationConfig import MuonSpacePointFormationCfg
    cfg.merge(MuonSpacePointFormationCfg(flags))

    from MuonPatternRecognitionAlgs.MuonHoughTransformAlgConfig import MuonPatternRecognitionCfg, MuonSegmentFittingAlgCfg
    cfg.merge(MuonPatternRecognitionCfg(flags))

    cfg.merge(MuonSegmentFittingAlgCfg(flags))

    from MuonBucketDump.MuonBucketDumpConfig import MuonBucketDumpCfg
    cfg.merge(MuonBucketDumpCfg(flags))

    executeTest(cfg)
```



Summary

- **First milestone is ~complete**
  - Have a good idea where to concentrate effort on traditional approach
- **In parallel, working on**
  - Migrating existing software to ACTS
  - New geometry representations
  - Code optimisation
  - … and novel (ML) reco techniques + associated tools
- **After the initial organisation/hiring phase, it is exciting to see the real work starting!**

The 2.5 Team…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Backup

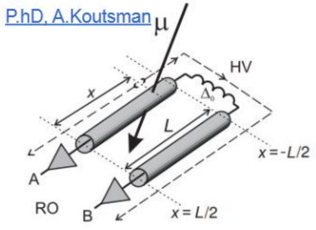
Other notable work

- **In parallel we have worked on**
  - Major updates to Muon tracking geometry
  - Investigating “twin-tubes” concept
    - Increases robustness against RPC loses
- **Next steps:**
  - Continue current developments
    - ACTS-based conventional tracking remains baseline
  - **But…**
    - **Investigate ML approaches**

Study the twin-tube concept

- φ-coordinate of the muon may only be provided by the attached trigger chambers
- Operation of RPCs have been a challenge in the recent past due to increasing gas leak rate → Can we mitigate the loss by modifying the ATLAS MS?

P.hD. A.Koutsman



Short-circuiting the MDTs at HV proposed at the early days of Run 1

BOL4A13M1 & BOL4C13M1 have that already

✓ Comparable resolution on the φ angle as using the RPCs

❓ Impact on the efficiency due to the increased electronics occupancy

❓ Practically feasible, as all the HV boards need to be exchanged in addition to the already tight LS3 schedule

CERN | NexTGen Next Generation Triggers

From J. Junggeburth’s slides in a recent workshop