ACTS Seeding Updates

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01 EDMs

Space point

Within ACTS core, template on experimental (external) space points

Information needed for seeding extracted

Stored in a space point container: ACTS Space Point EDM (Carlo Varni)

- `Acts::SpacePointContainer`- interface with experiment
- Owns `Acts::SpacePointData` object- stores variables for seeding
- Owns vector `Acts::SpacePointProxy`- simple object used for seeding, contains indices for navigating SpacePointData
- Navigate by index : nth space point in the container → nth value in the vectors

Internal navigation takes time- believed to cause CPU time increase

Idea to skip space point formation, seeding on clusters

xAOD Space point

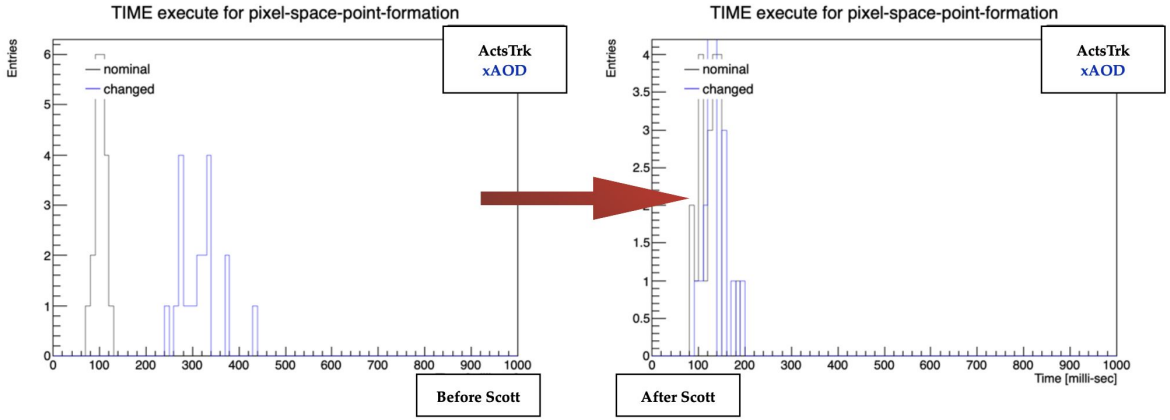
Space point type for Athena ACTS workflow

Originally a vector per spacepoint with all information

Switched to SOA (struct of arrays)

- xAOD format in Athena
- Better for gpu implementation and memory management
- Unexpected timing increase - now solved

Full details- ACTS ITk Jan 2023 (Carlo Varni)
Update- ACTS ITk Mar 2023(Carlo Varni)



Seed

ACTS current Seed EDM:

- Seed object in ACTS core, templated on space point type:
- `Acts::Seed<external_spacepoint_t, 3>`
- Contain pointers to space points

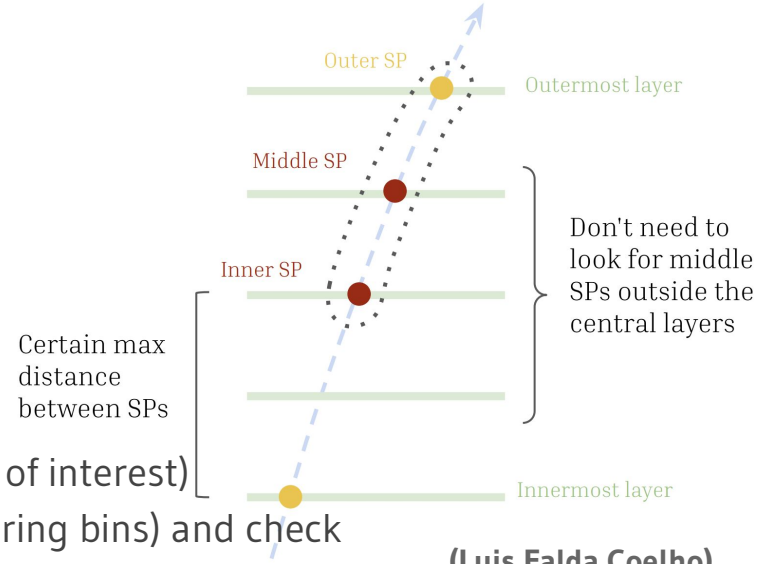
Can now have > 3 spacepoints (tracklets) `Acts::Seed<external_spacepoint_t, N>`

Ongoing discussion to switch to ACTS specific EDM, allowing for further optimisation- ACTS-ITk 8.11.24 (Andreas Stefl)

02 Seeding Algorithms

Midpoint

Algorithm Details



(Luis Falda Coelho)

Seed building:

- Space points in 3D grid of (ϕ, z, r) bins
- Based on helical path from centre of detector
- Select middle SP- check if in ROI (level 0 trigger region of interest)
- Make duplets with inner and outer SPs (from neighbouring bins) and check compatibility based on delta r and z
- Make triplet from inner and outer SPs sharing same middle SP

Seed filtering:

- Compare seeds with similar curvature
- Rank seeds using weight
- Reject lower quality seeds to improve tracks

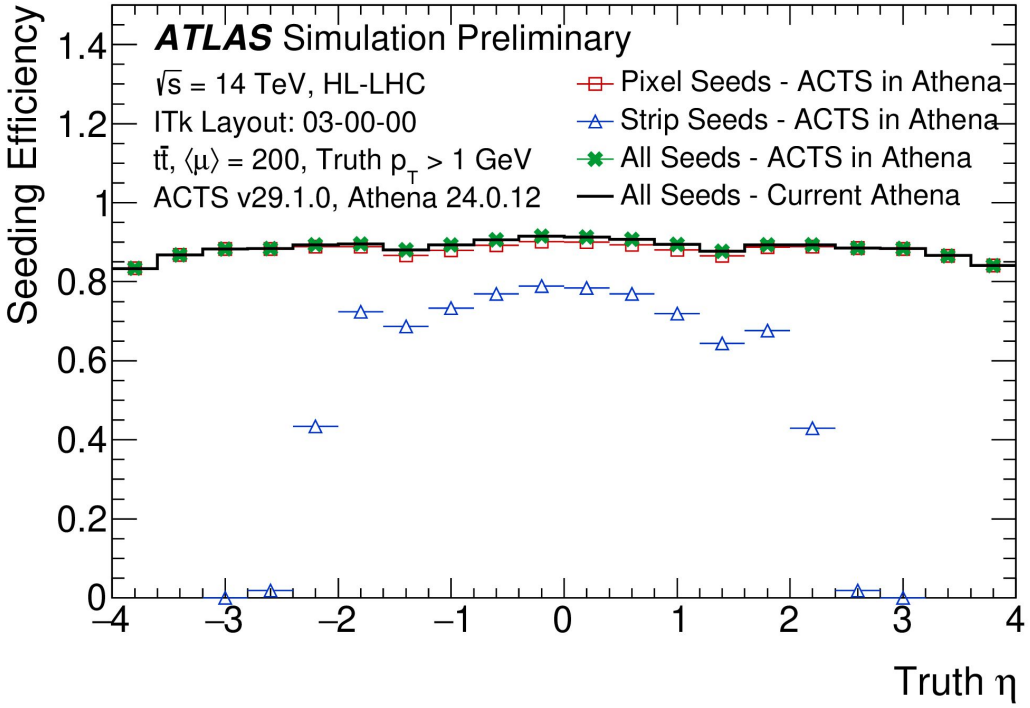
Full details- ACTS Workshop Nov 2023 (Luis Falda Coelho)

ITk Performance

1:1 identical seeds efficiency

15% slower than athena

Ongoing optimization



IDTR-2023-05

Fast Tracking

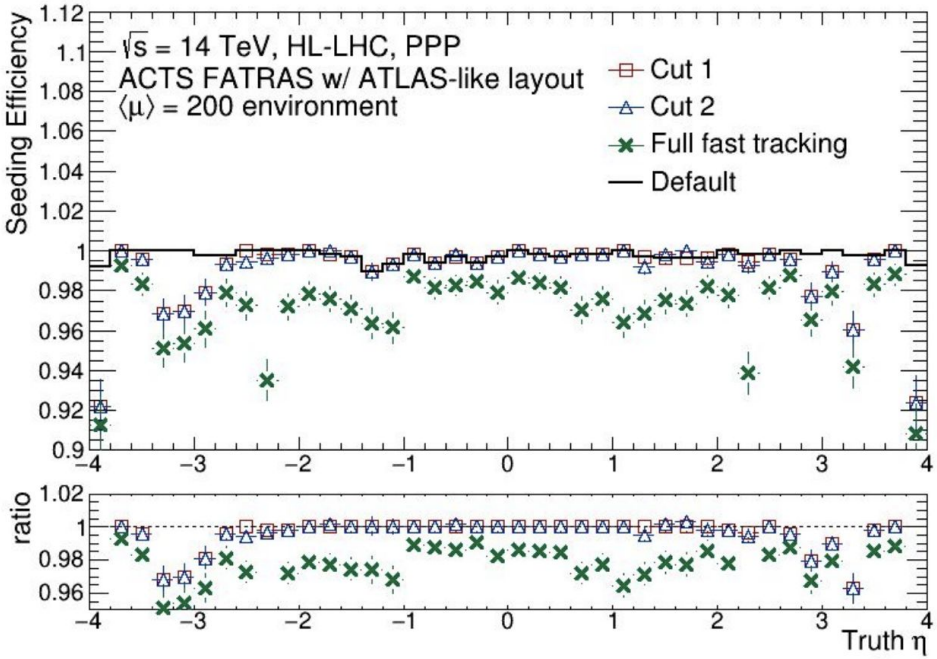
Fast tracking mode pixel space points only

In ACTS standalone and Athena workflow

ACTS-ATLAS Mini Hackathon 2023 (Luis Falda Coelho)

Updates:

- Ongoing study of parameter tuning
- Cuts updated to match new ITk layout
- Tuning of radius cut and Z binning to improve efficiency



Luis Falda Coelho

Developments

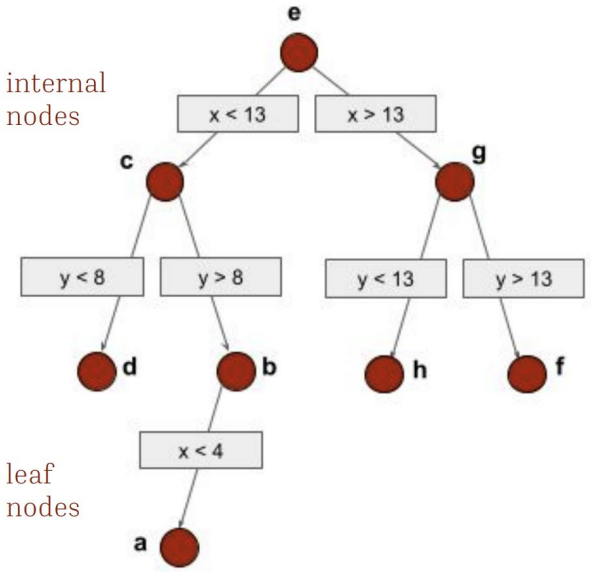
Update at ACTS ITk September 2024 (Carlo Varni)

Prototype seeding directly from clusters- pixel only

Idea to use cluster width information- filter doublets

Orthogonal

Algorithm Details



Search z-r-φ volumes using KD tree instead of 3D grid of (ϕ, z, r) bins

Splitting along one dimension, based on median:

- Exact median for small data sets
- Approximate median (mid point) for larger data sets as expensive

Creates 2 child nodes, recursively split each child node, alternating dimension

- Node= a subspace of the data

Full details- ACTS Workshop Nov 2023 (Luis Falda Coelho)

Finding middle space point: Range search tree using cuts orthogonal to tree dimensions

Space point combinations: Traverse tree comparing middle sp to each split-to find node in ROI

- If internal node stop search
- If get to leaf and not true then take only SP contained in region

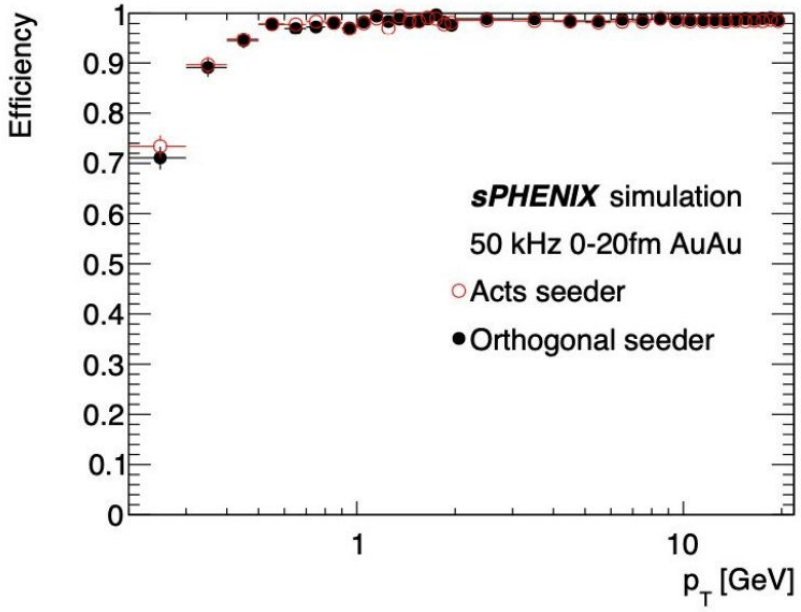
Features

Good for GPUs

Can be extended to 4D for future timing detectors

Performance dependant on detector geometry

Must find highly restricted search spaces in order to outperform the default seeding



(Luis Falda Coelho)

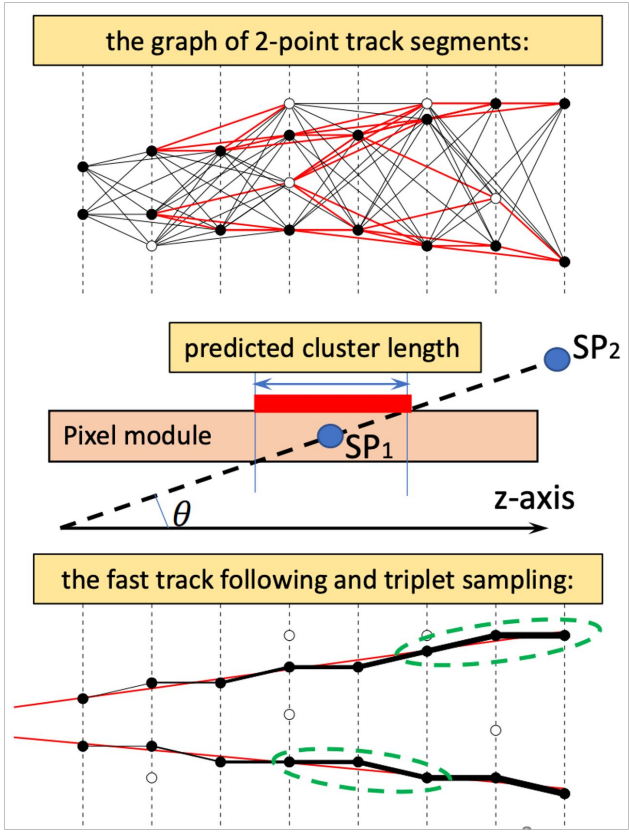
GBTS

Algorithm Details

FastTrackFinder (Dmitry Emeliyanov): HLT algorithm that produces tracks for the trigger

Just looking at seeding algorithm - **G**raph **B**ased **T**rack **S**eeding

- Takes input of relevant detector geometry information
- Graph building: A graph of two pixel space point track segments, known as edges, is created, based on a layer linking scheme (backup slides)
- The number of edges reduced using a machine learning classifier. It uses the cluster length to predict a range of probable angles of inclination
- Triplet making: Fast track candidate discovery is done using track following
- Triplets of space points are sampled from these to generate 3-spacepoint track seeds- long term want to pass on tracklets



Elliot's Upgrade Tracking talk

ACTS Standalone

Currently in ACTS Standalone - examples implementation on ITk geometry
Full results of Performance Study December 2023

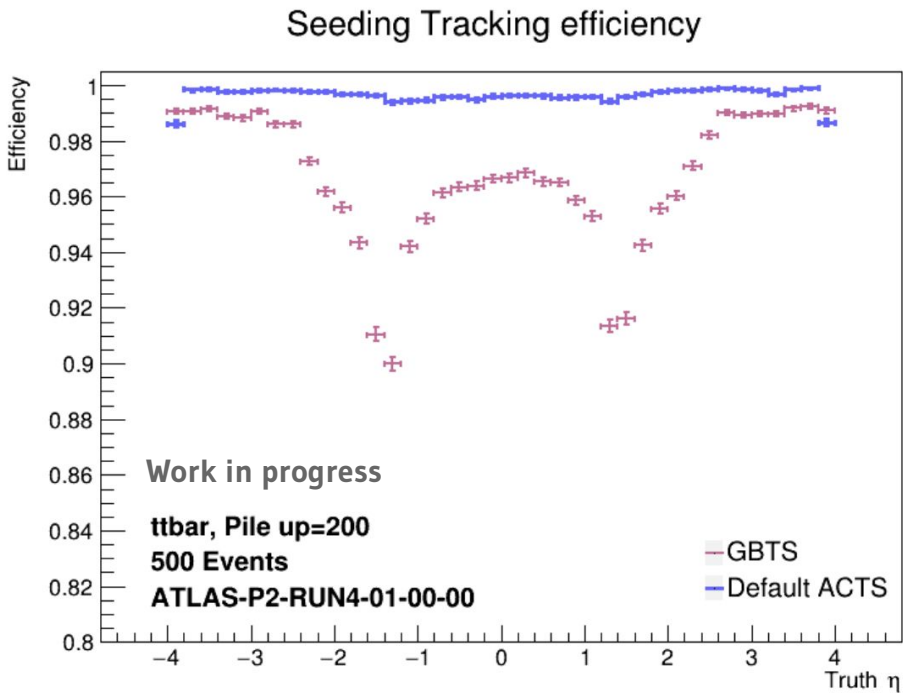
Comparing **ACTS default** seeding and **GBTS** seeding:

- Running in ACTS standalone Single threaded
- Seeding Tracking efficiency = nMatchedParticles / nAllParticles

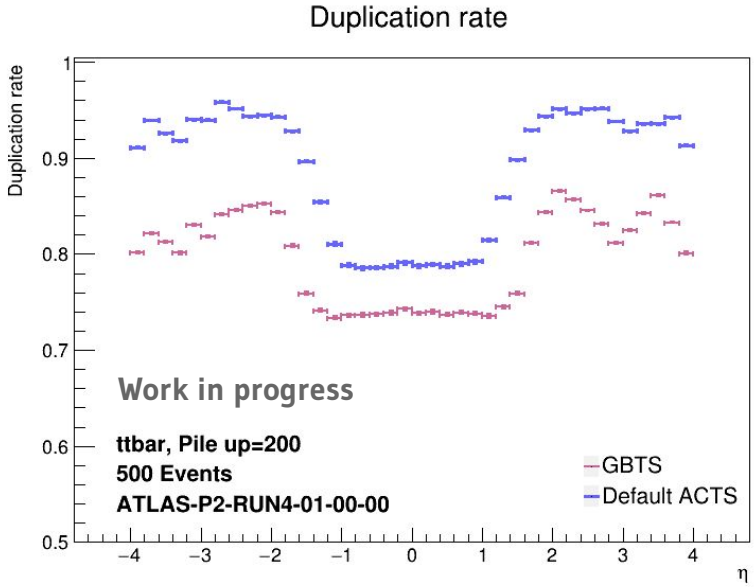
Ongoing work:

- Efficiency and timing optimisation
- Use of cluster width: not yet available in ACTS stand-alone for ITk as only have smeared digitization

ACTS Standalone Performance



	Ratio (GBTS/Default)
Total Seeds/event:	0.94
Total Time/event:	1.02
Seeding Algorithm:	2.86
Track Finding Algorithm:	0.97



Athena Implementation

Implementation in Athena workflow will allow for direct comparison to FTF in Athena

First Implementation now in athena- first merge

- Current results show still lots of work to do
- Clear issue with efficiency
- CPU timing not competitive

Ongoing work:

- Implementing cluster width
- Investigating efficiency issue
- Improvements to ACTS core implementation

Developments

Many updates to FTF code in athena- GBTS v2.0

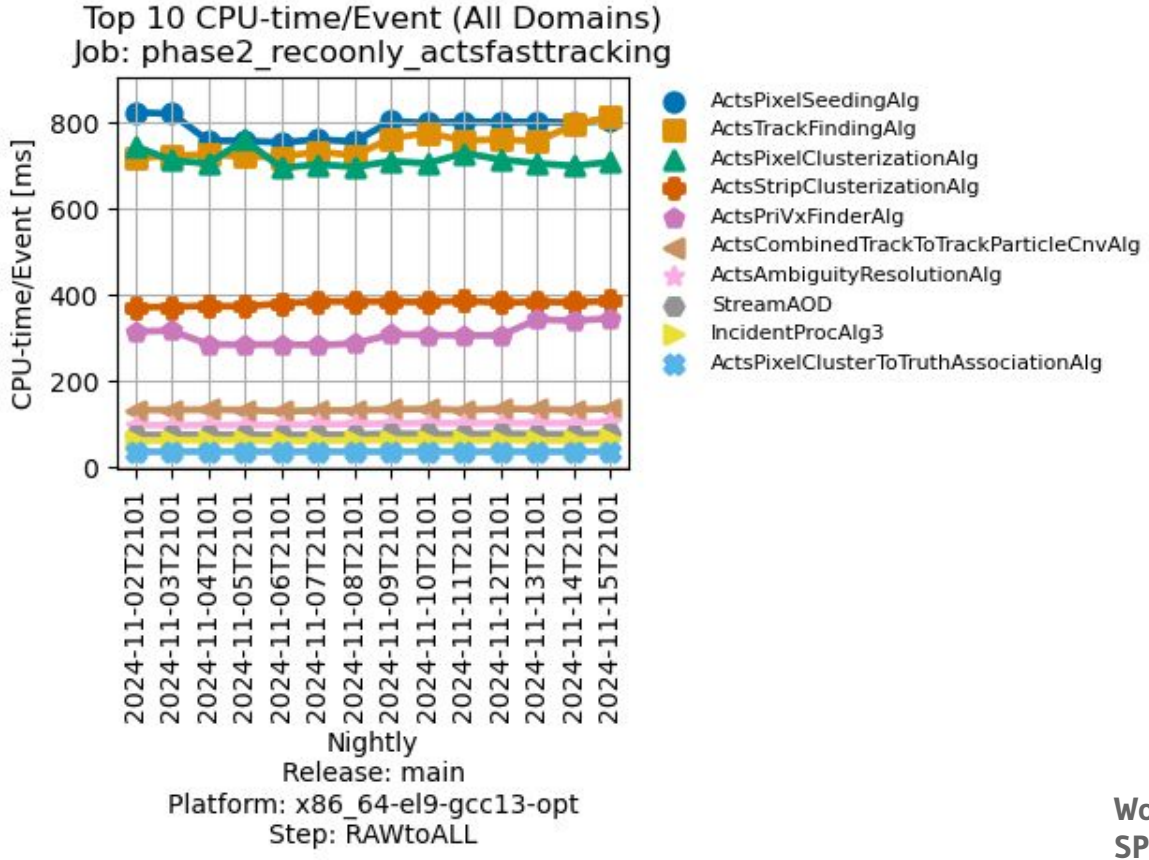
Dmitry has also developed a track finding code- Track Finding (Tim Adye)

ACTS preference to keep two tools separate

FTF in athena seeding tool in a wrapper for short term benchmark performance- Dmitry and Benjamin Kerridge ongoing work

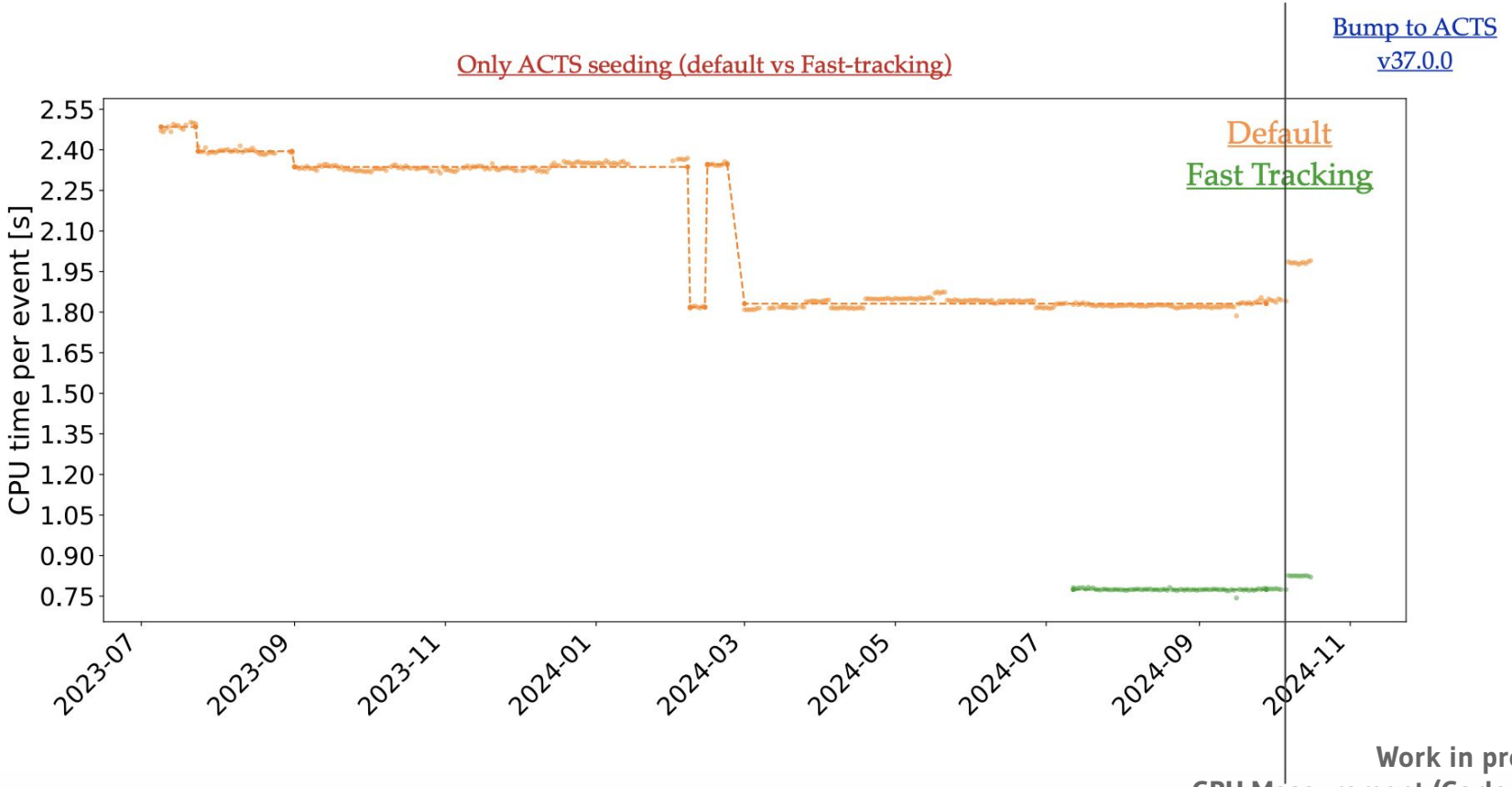
CPU

CPU Timing



Work in progress
SPOT tests

Timing Improvements



Work in progress
CPU Measurement (Carlo Varni)

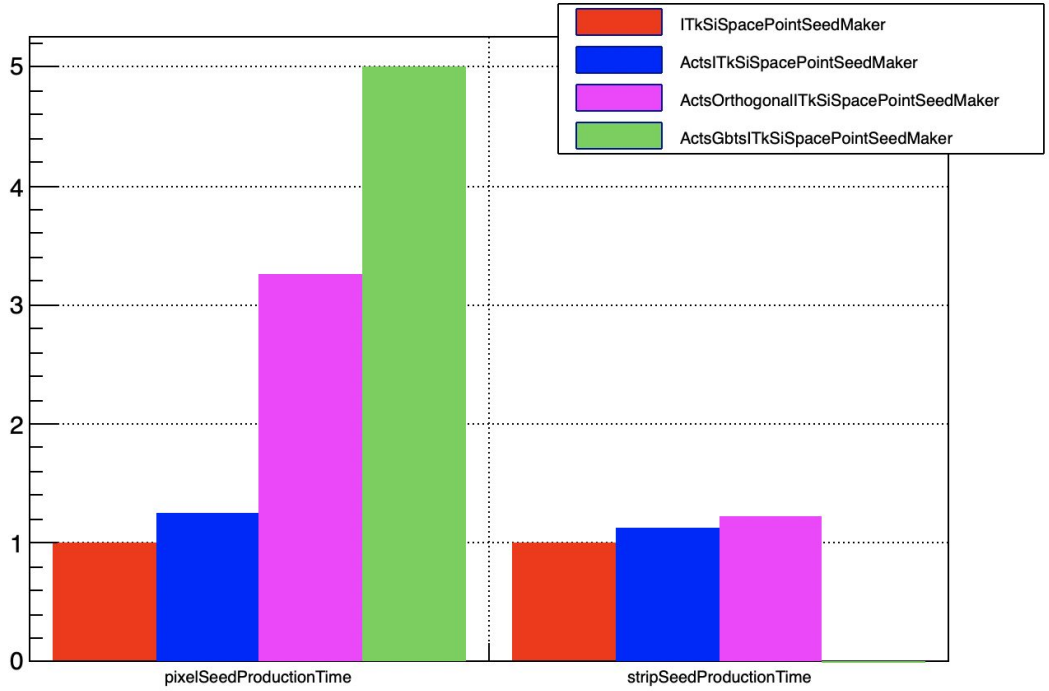
All vs Legacy Athena

ACTS in Athena workflow

Midpoint/Default:

- Pixel ~25% slower
- Strip ~10% slower

Orthogonal and Gbts need optimization



Work in progress
CPU Measurement (Carlo Varni)

03 Other Updates

Other Seeding Updates

GPU seeding

- traccc, implements middle point and orthogonal seeding algorithms for GPU devices
- Updates Wednesday

Hough Vertex

- Hough transform used to estimate the Z coordinate of the interaction vertex
- Idea to use before ACTS seeding to reduce complexity
- Paper: The application of Hough transform for fast interaction vertex position estimation in heavy-ion collisions
- Luthien's presentation

Summary

EDMs

- Idea to skip space point formation
- Switch to xAOD space points in Athena workflow
- New larger seeds
- Discussion of new defined ACTS seed EDM

Seeding algorithms

- Mid Point: identical efficiency, timing optimisations, seeding on clusters
- Orthogonal: GPU adaptability, timing optimisations
- GBTS: ACTS and Athena implementation, efficiency and timing optimisation, implementation of v2.0

Questions?

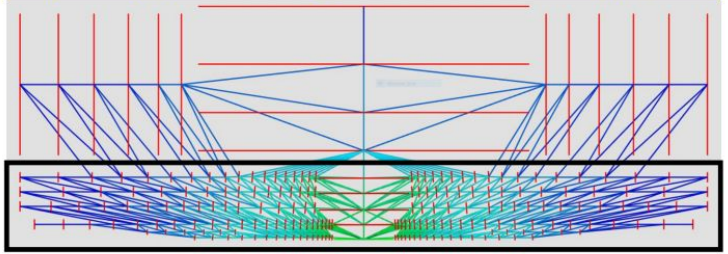
Backup

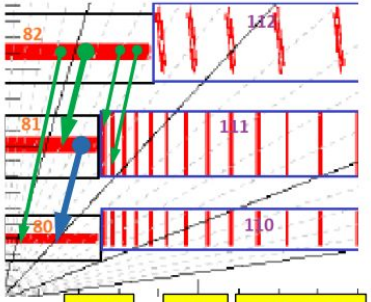
GBTS: Layer linking

Probabilistic layer linking

- Track movement from layer to layer is modelled as a Markov process and state transition probabilities are estimated using simulated reference tracks
- Layer linking graph is obtained after applying a cut of 10^{-5} on transition probabilities

Layer linking graph for Fastrack algorithm trained on $t\bar{t}$ MC data, $p_T \geq$1GeV



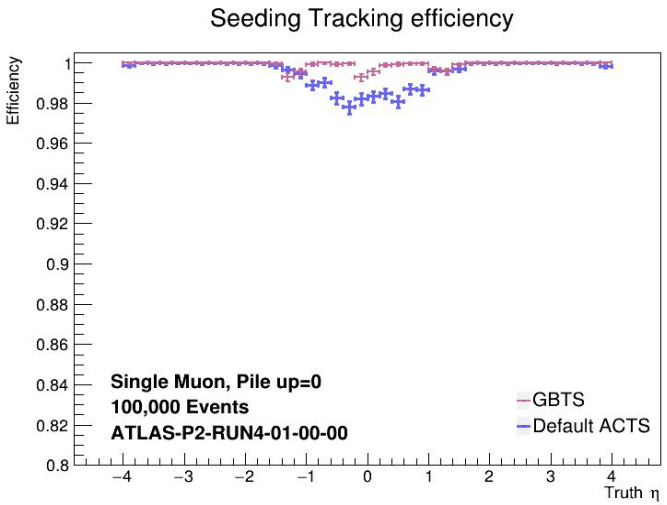


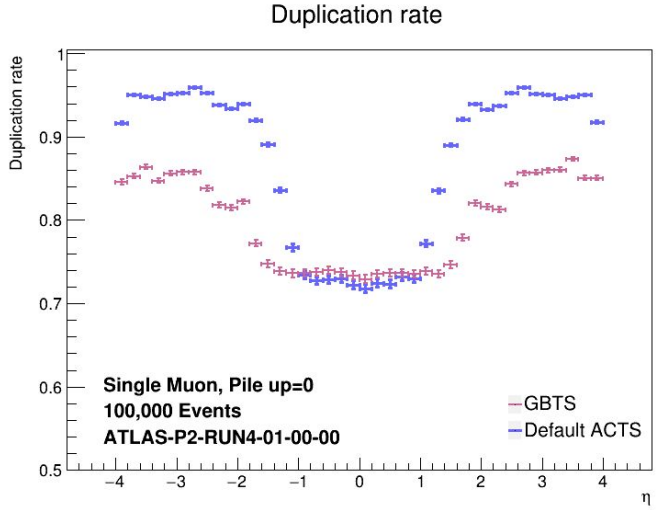
	from	to	probability
	A	B	C
25	81000	80000	1
26	82000	81000	0.941664
27	82000	80000	0.020266
28	82000	101000	0.01487
29	82000	111000	0.014688
30	82000	111001	0.004276
31	82000	101001	0.004237
32	83000	82000	0.977832
33	83000	81000	0.022168
34	84000	83000	0.976277
35	84000	82000	0.023723

Dmitry slides

GBTS ACTS Standalone

	Ratio (GBTS/Default)
Total Seeds/event:	0.41
Total Time/event:	0.77
Seeding Algorithm:	33
Track Finding Algorithm:	0.39





First results with ACTS standalone tracking chain, need to run in Athena for proper comparison
ttbar results in backup

GBTS Algorithm details

Geometry information:

- Input file of layer linking information to create a map of connections
- Function to loop over modules in ACTS and collects relevant information

Seeding:

- Graph building:
  - Node per space points
  - Graph edges made from two nodes, based on the layer they are in
- The number of track segments is reduced using a machine learning classifier. It uses the cluster length to predict a range of probable angles of inclination
- Triplet making:
  - Track following:
    - > Recursive branching and propagation
    - > Loops through edges, adding to vector
    - > Checks if accepted, based on triplet cuts and ROI information
    - > Only adds if better than previous edge
  - Sample triplets from produced tracklets (long term want to pass on tracklets)

More seeding details

Full details- ACTS Workshop Nov 2023 (Luis Falda Coelho)

Three specific parameters from orthogonal seeding:

max_exact_median - determines the maximum number of elements where we still calculate the exact median

LeafSize - The maximum number of elements stored in a leaf node

→ Not configurable and do not seem to affect much the performance for high pile-up

deltaPhiMax - Shrink the φ range of middle SP, analogous to φ bin size in grid from default seeding

→ Can significantly affect the performance and should be optimized

Default seeding weight:

$$w = (c_1 \cdot N_t - c_2 \cdot d_0 - c_3|z_0|) + \text{detector specific cuts}$$

- N_t: More measurements leads to higher quality
- d_0, z_0: Smaller IP → higher probability of track arriving from the interaction point