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REAL-TIME ANALYSIS FOR SCIENCE AND INDUSTRY

ESR12: Accelerated Anomaly Detection

Pratik Jawahar

Supervisors:
Caterina Doglioni, Jiri Masik, Alex Oh, Maurizio Pierini

Overview:

- Qualification Task - Heterogenous Tracking
- ML based Data Compression - Baler
- Misc. Activities

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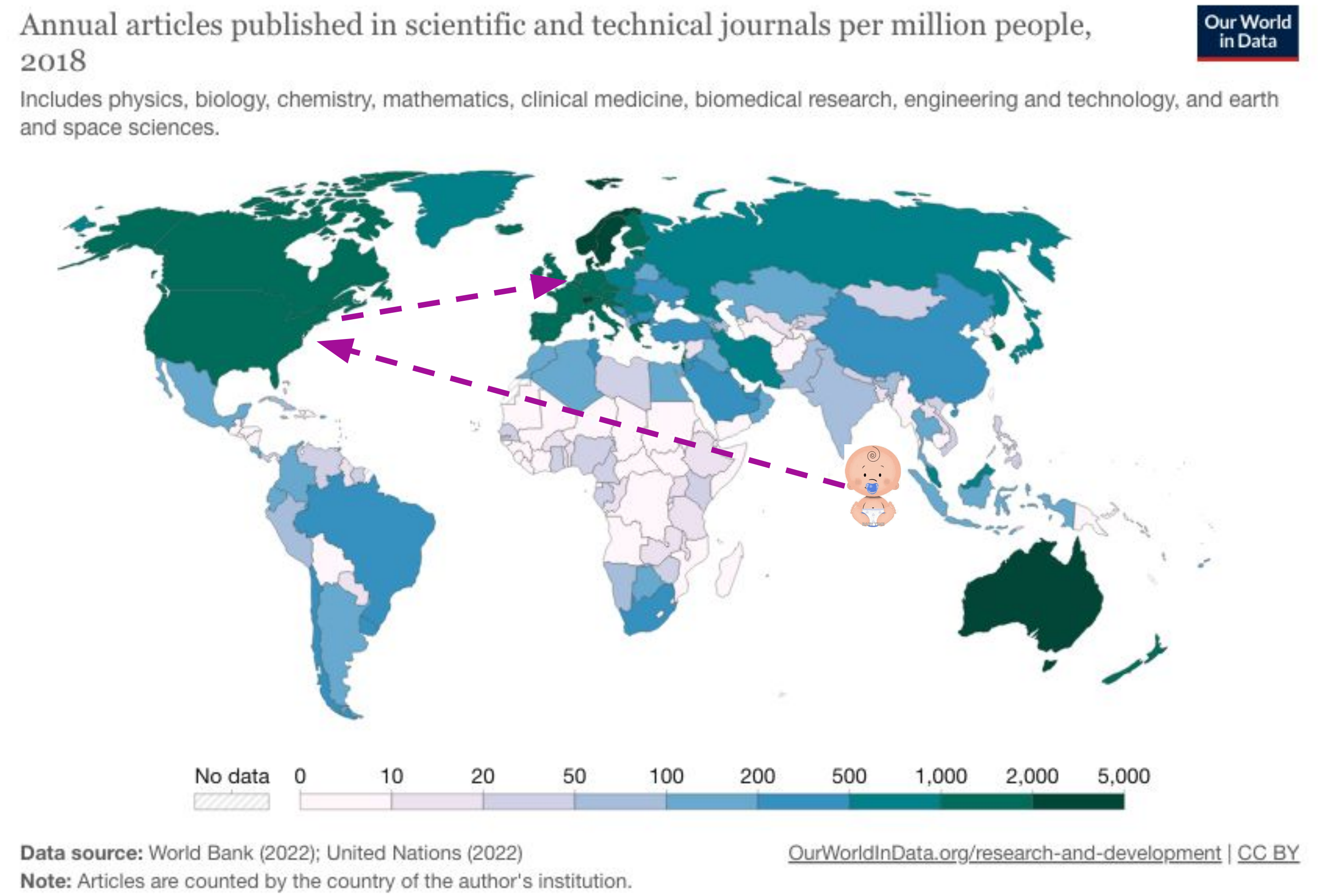
About me:

- BS: Mechanical Engineering (2019)
- MS: Robotics Engineering (2022)
- PhD: Robo.. *sike* Particle Physics
- Experience:
    - Summer student (CERN, 2018)
        - Control algorithms for GEM detectors (CMS)
    - Technical student (CERN, 2021), DIANA HEP Fellowship (2020)
        - ML based anomaly detection for new physics searches
- Website: https://www.pratikjawahar.com/



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Qualification Task: Heterogenous Track Reconstruction

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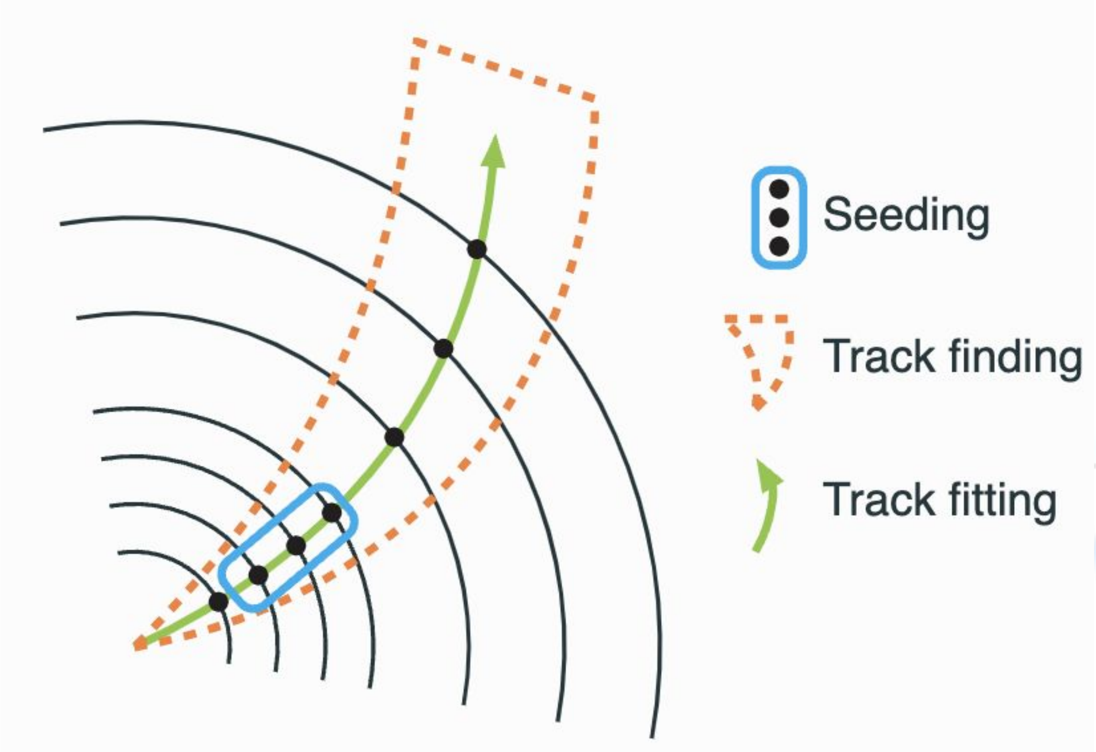
Track Reconstruction:

- Reconstruct trajectories of charged particles as they pass through different layers of the detector, subject to a magnetic field



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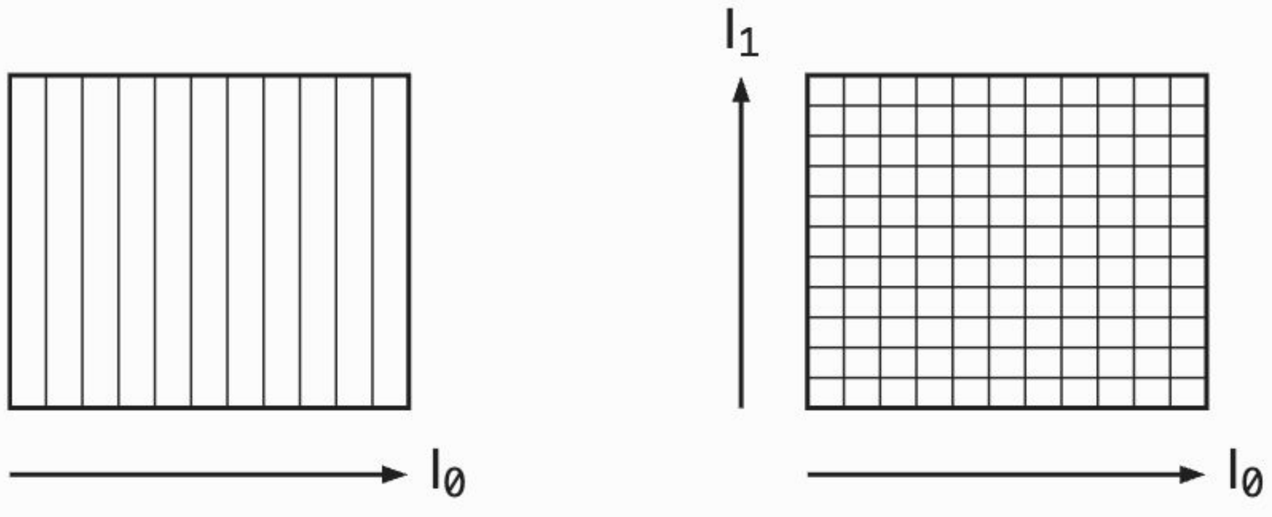
Track Reconstruction:

- Step 1: Detect a charged particle when it passes through a layer
  - Ionization in semiconductors



(a) strip (b) pixel

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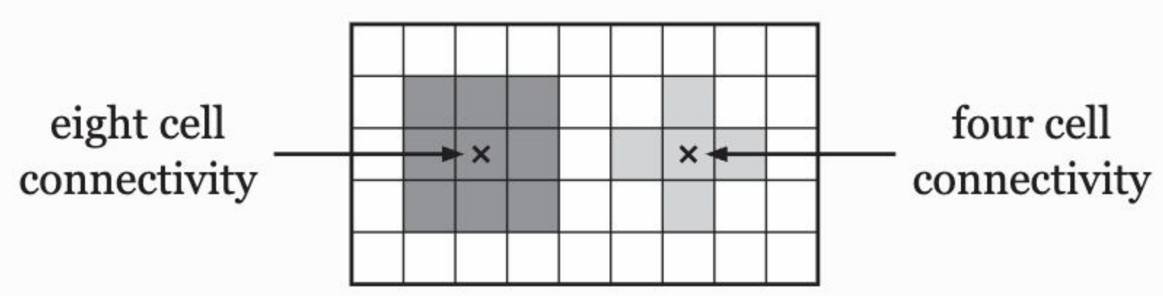
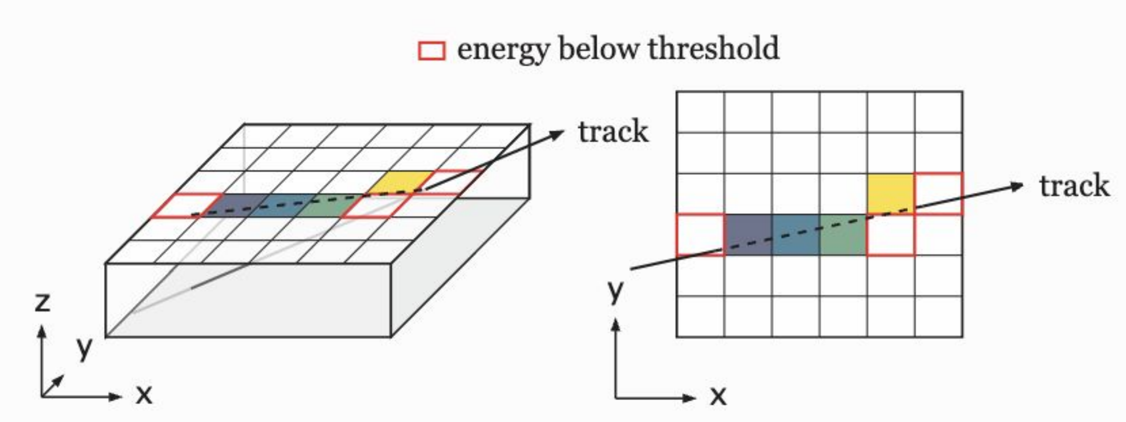
Track Reconstruction:

- Step 2: Clusterization
  - Depends on how you treat readout, detector design etc.
  - Connected Components Algo (CCA) iterated on edges





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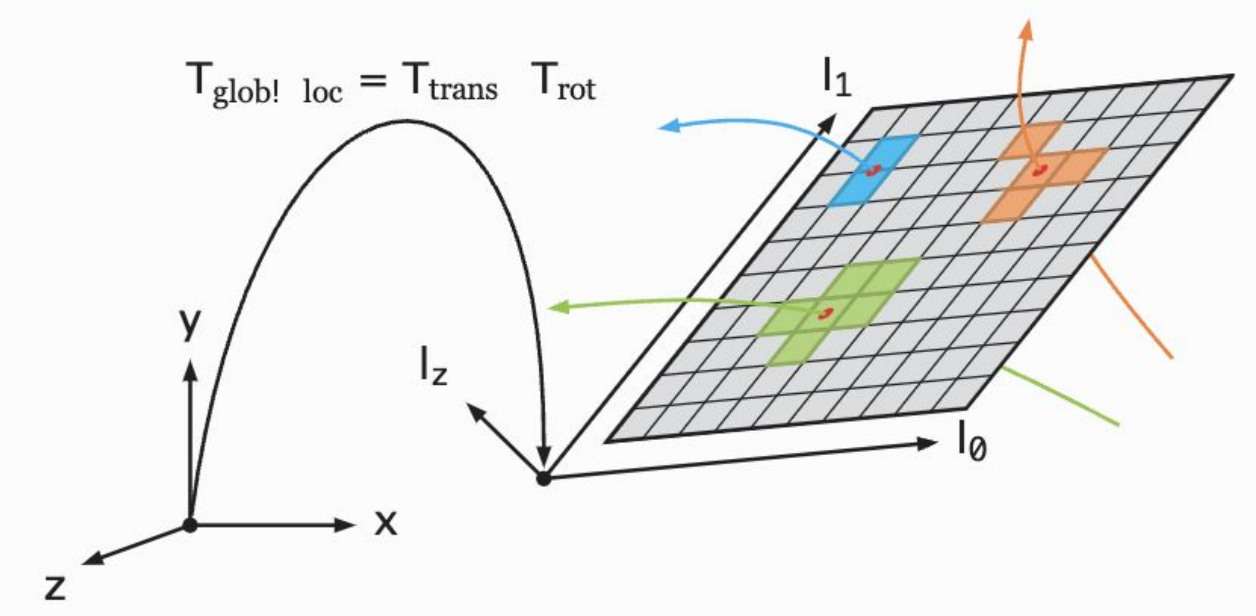
Track Reconstruction:

- Step 3: Spacepoint Formation
  - Move from local sub-detector frame to global detector frame



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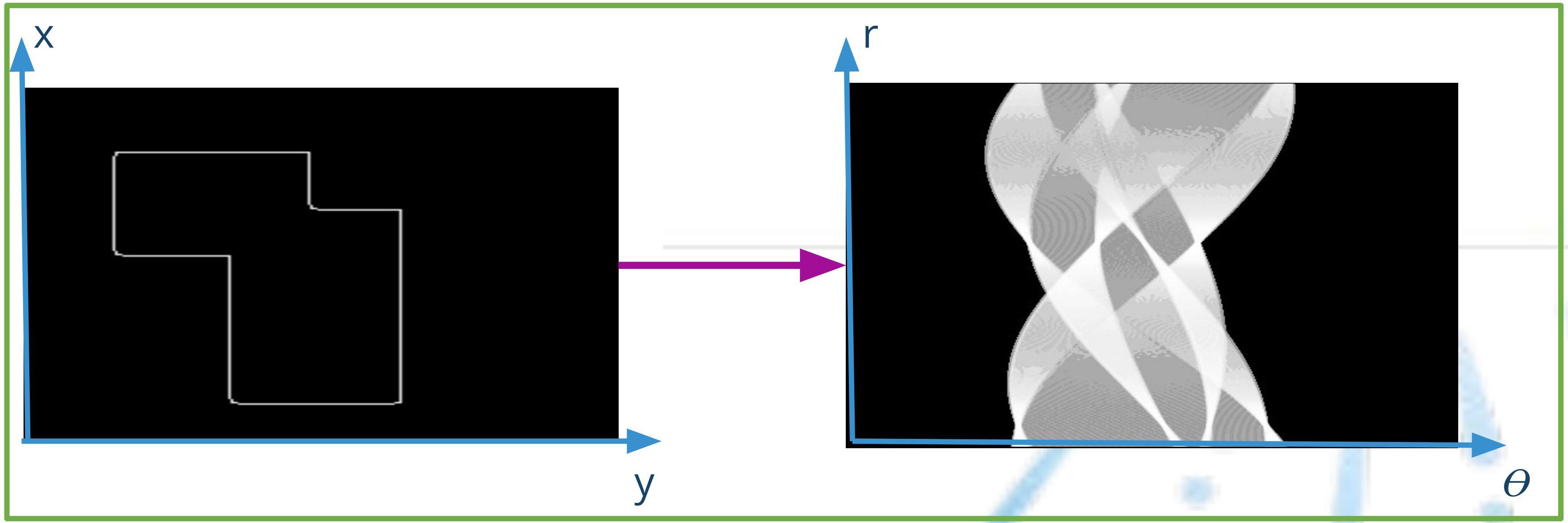
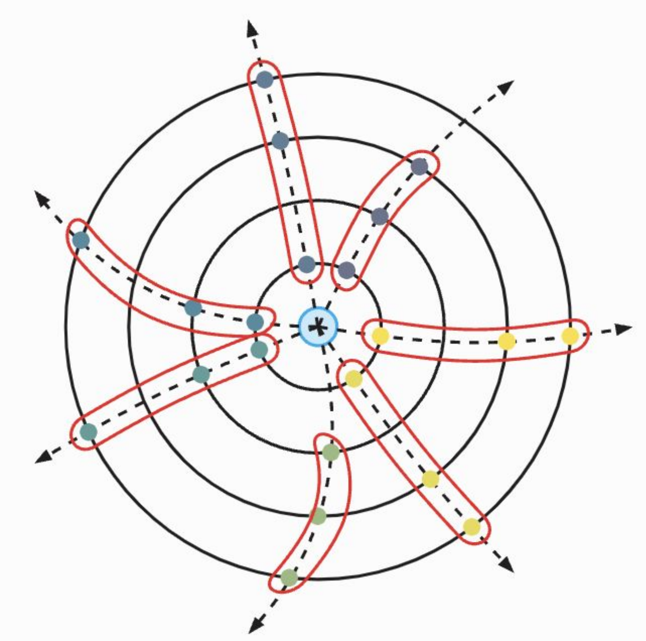
Track Reconstruction:

- Step 4: Seeding
  - Find triplets of spacepoints that could potentially belong to the same track
    - Conformal maps => Hough Transform





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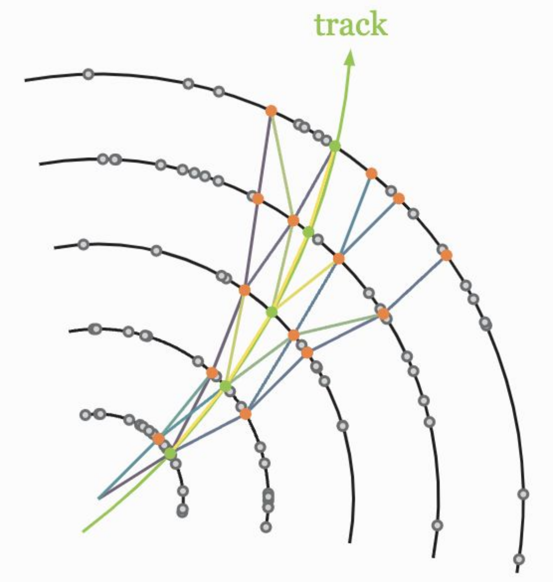
Track Reconstruction:

- Step 5: Track finding and fitting
  - Start from a seed
    - Kalman formalism (eg. Combinatorial KF) => Smoothing (eg. global χ^2 fit, or walk back with Kalman fit) => Ambiguity resolution



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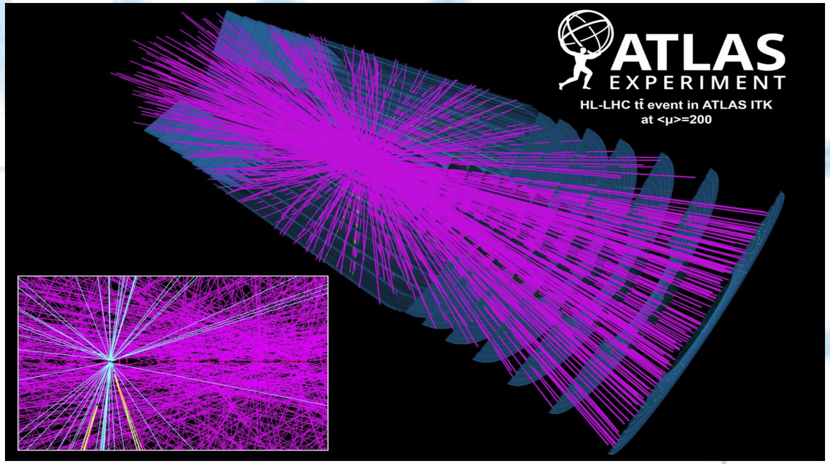
Problem(s)!



- No. of tracks per event for HL-LHC, expected to increase 2.5x
- Current R&D: Use GPUs for speedup via parallel computation
- However, sequential algorithms like CKF do much better on CPUs than GPUs!

acts → **traccc**

Demonstrator tracking chain for accelerators.

Computing term for specific purpose architectures (eg. GPU, TPU, IPU etc.)

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Track Reconstruction:

- Heterogeneous Track Reconstruction:
  - Step 1: Profiling CPU and GPU code to identify speed-up in inference time
    - Ideally without drop in tracking efficiency
  - Step 2: Identify bottlenecks
    - Points where one architecture outperforms the other
  - Step 3: Calculate data-transfer latencies at bottlenecks
    - Data transfer latencies between host (CPU) and device (GPU) eat up speed-up

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CUDA Profiling

Step 1: Ensure GPU computations do not decrease physics performance

D2H Calculations - CPU vs D2H CPU

```
Running seeding algo with CUDA spacepoints moved to host
Number of D2H seeds: 28346 (host), 28346 (device)
  Matching rate(s):
    - 88.6898% at 0.01% uncertainty
    - 98.9275% at 0.1% uncertainty
    - 99.2592% at 1% uncertainty
    - 99.2839% at 5% uncertainty
Running track param est with CUDA spacepoints and CUDA seeds moved to host
Number of D2H track parameters: 28346 (host), 28346 (device)
  Matching rate(s):
    - 99.2944% at 0.01% uncertainty
    - 99.7989% at 0.1% uncertainty
    - 99.8024% at 1% uncertainty
    - 99.8024% at 5% uncertainty
```

D2H Calculations - CPU vs CUDA

```
Number of seeds: 28346 (host), 28346 (device)
  Matching rate(s):
    - 87.6208% at 0.01% uncertainty
    - 98.797% at 0.1% uncertainty
    - 99.2345% at 1% uncertainty
    - 99.2733% at 5% uncertainty
Number of track parameters: 28346 (host), 28346 (device)
  Matching rate(s):
    - 98.7617% at 0.01% uncertainty
    - 99.7989% at 0.1% uncertainty
    - 99.8024% at 1% uncertainty
    - 99.8024% at 5% uncertainty
```

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CUDA Profiling - NSight Compute

Step 2: Profile code in as close-to-deployment conditions as possible

CUDA tools: NSight Compute, NSight Systems

ID	Issues Detected	Function Name	Demangled Name	Process	Device Narr	Grid Size	Block Size	Cycles [cycle]	Duration [msecond]	Compute Throughp	Memory Throughput [%]	# Registers [register/thread]
0	20	ccl_kernel	traccc::cuda::kernels::ccl_kernel(v...	[1138765] tracc...	Tesla T4	474, 1, 1	128, 1, 1	472435	0.81	43.75	43.72	49
1	14	form_spacepoints	traccc::cuda::kernels::form_space...	[1138765] tracc...	Tesla T4	137, 1, 1	1024, 1, 1	95281	0.16	5.95	36.43	36
2	11	count_grid_capacities	traccc::cuda::kernels::count_grid_...	[1138765] tracc...	Tesla T4	545, 1, 1	256, 1, 1	18692	0.04	22.31	50.49	20
3	14	populate_grid	traccc::cuda::kernels::populate_gri...	[1138765] tracc...	Tesla T4	545, 1, 1	256, 1, 1	35039	0.06	11.99	54.14	22
4	15	fill_prefix_sum	traccc::cuda::kernels::fill_prefix_su...	[1138765] tracc...	Tesla T4	18, 1, 1	32, 1, 1	23989	0.04	7.45	26.34	28
5	10	count_doublets	traccc::cuda::kernels::count_doubl...	[1138765] tracc...	Tesla T4	1131, 1, 1	64, 1, 1	848561	1.45	71.08	16.92	42
6	13	find_doublets	traccc::cuda::kernels::find_doublet...	[1138765] tracc...	Tesla T4	479, 1, 1	64, 1, 1	1211907	2.07	33.78	35.93	38
7	9	count_triplets	traccc::cuda::kernels::count_triplet...	[1138765] tracc...	Tesla T4	24496, 1, 1	64, 1, 1	1957486	3.33	68.04	23.78	45
8	15	reduce_triplet_counts	traccc::cuda::kernels::reduce_tripl...	[1138765] tracc...	Tesla T4	479, 1, 1	64, 1, 1	19298	0.03	2.52	11.65	16
9	15	find_triplets	traccc::cuda::kernels::find_triplets(...	[1138765] tracc...	Tesla T4	720, 1, 1	64, 1, 1	294522	0.51	29.96	27.57	45
10	18	update_triplet_weights	traccc::cuda::kernels::update_tripl...	[1138765] tracc...	Tesla T4	930, 1, 1	64, 1, 1	18140	0.04	13.81	48.89	23
11	19	select_seeds	traccc::cuda::kernels::select_seed...	[1138765] tracc...	Tesla T4	479, 1, 1	64, 1, 1	102384	0.18	26.16	26.16	39
12	14	estimate_track_params	traccc::cuda::kernels::estimate_tra...	[1138765] tracc...	Tesla T4	443, 1, 1	64, 1, 1	78502	0.14	5.62	44.97	52

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CUDA Profiling - NSight Compute

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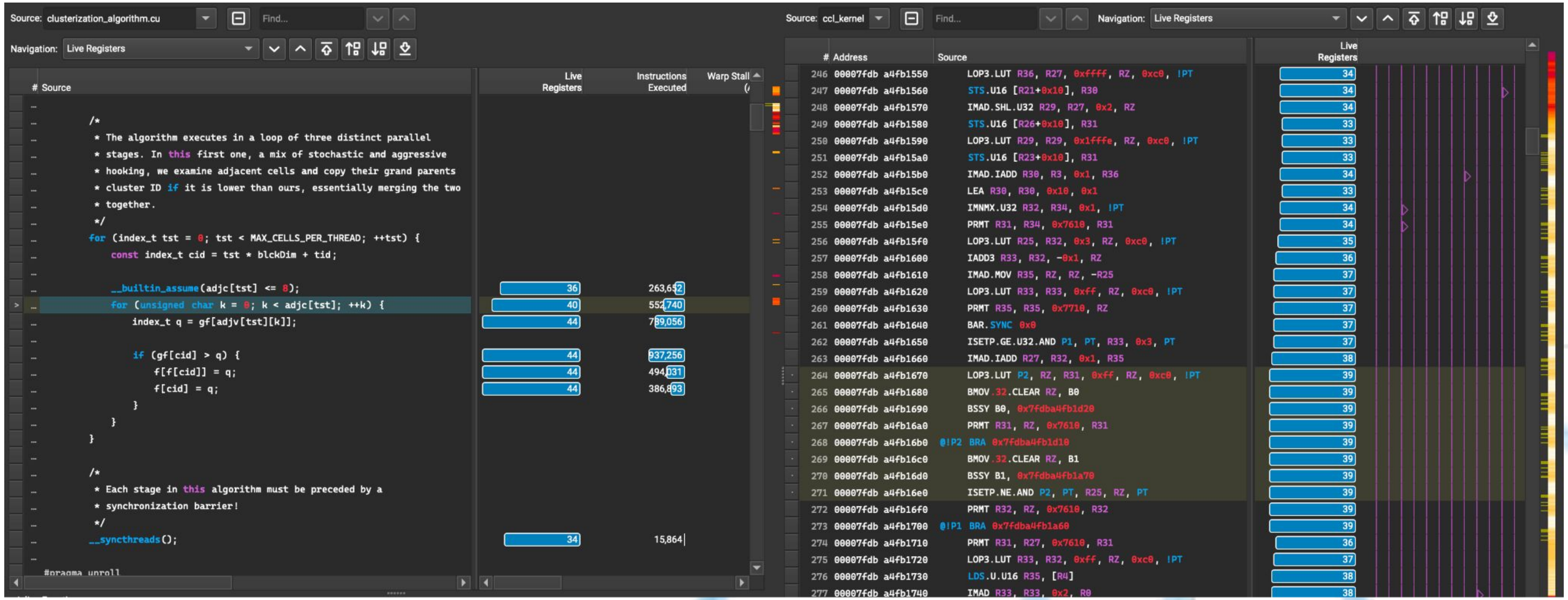

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CUDA Profiling

Data File	Detector Geometry	No. of Events
tml_full/ttbar_mu300	tml_detector/trackml-detector	1

Old Version

CPU				GPU		
	Parent process	**Duration [mu-sec]**			**Parent process**	**Duration [mu-sec]**
	Container Instantiation	**8**			Container Instantiation	**6**
	File reading	**1,720,207**			File reading	NA
	Clusterization	**40,197**			Clusterization	NA
	Spacepoint Formation	**6,078**			Spacepoint Formation	NA
	Clusterization + Spacepoints	**46,275**			Clusterization + Spacepoints	**40,197**
	Seeding	**1,075,583**			Seeding	**80,072**
	Track param est	**27,909**			Track param est	**2,651**

New Version - with FastSV

CPU				GPU		
	Parent process	**Duration [mu-sec]**			**Parent process**	**Duration [mu-sec]**
	Container Instantiation	**8**			Container Instantiation	**6**
	File reading	**1,288,893**			File reading	NA
	Clusterization	**36,070**			Clusterization	NA
	Spacepoint Formation	**3,131**			Spacepoint Formation	NA
	Clusterization + Spacepoints	**39,201**			Clusterization + Spacepoints	**2,433**
	Seeding	**792,729**			Seeding	**11,686**
	Track param est	**9,316**			Track param est	**411**

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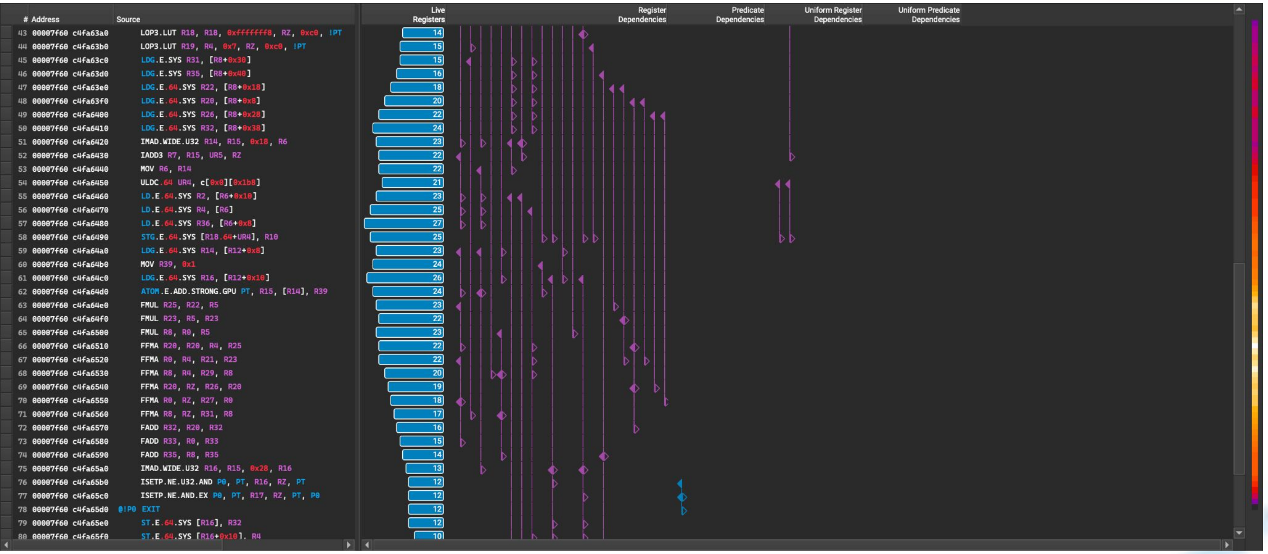
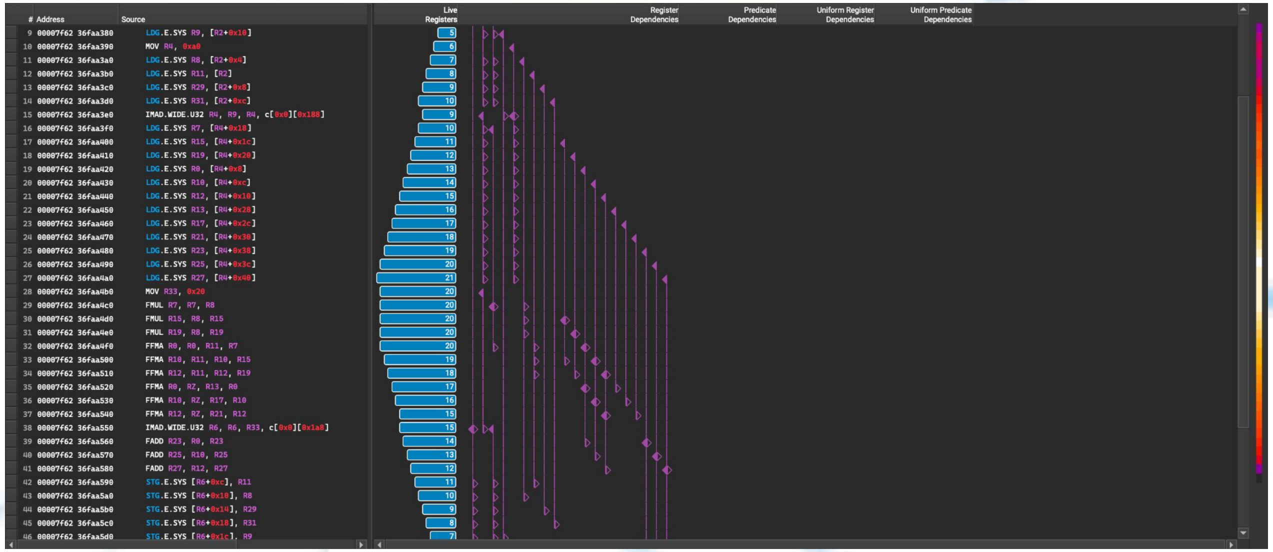
CUDA Profiling - NSight Compute

Data File	Detector Geometry	No. of Events
tml_full/ttbar_mu300	tml_detector/trackml-detector	1

Old Version



New Version - with FastSV



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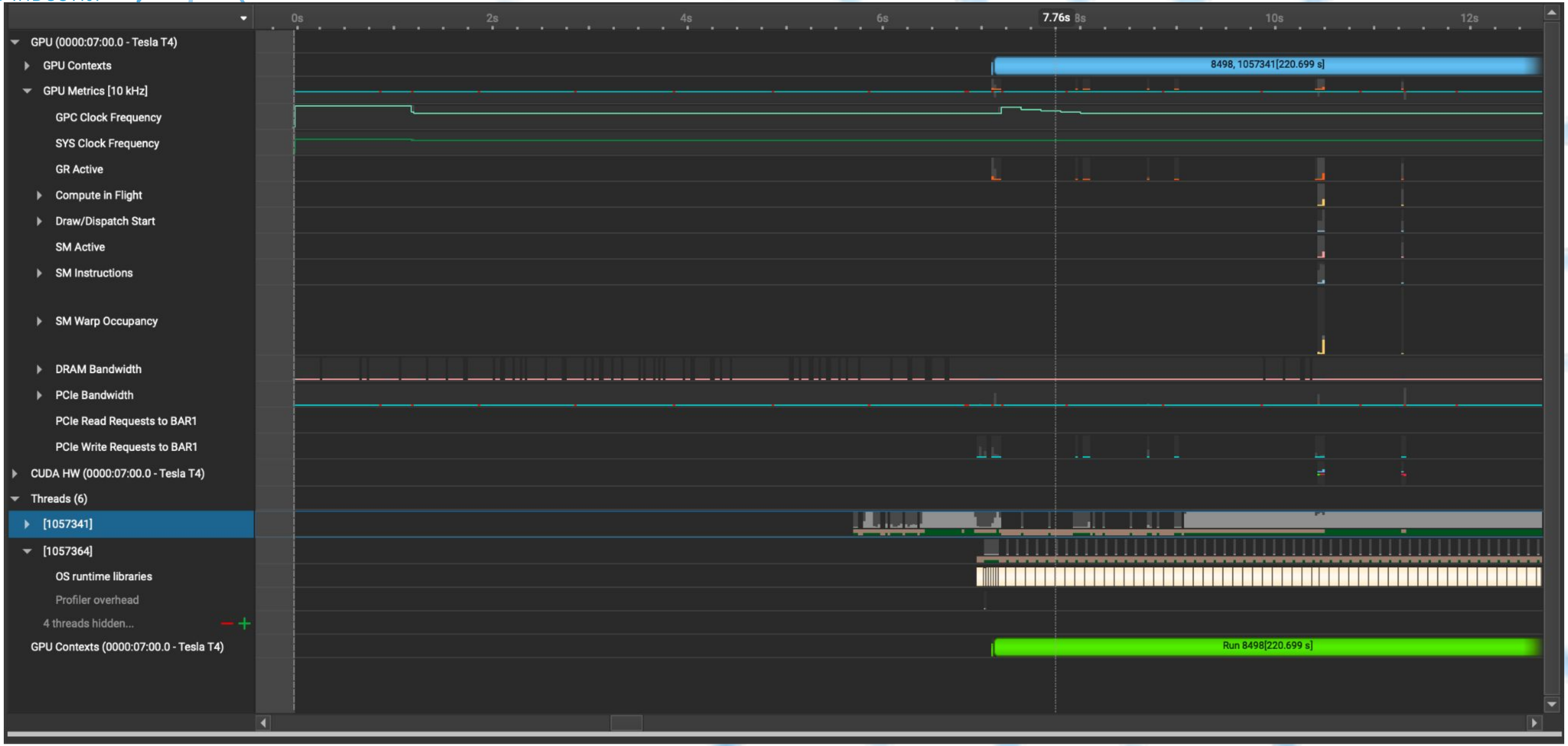
CUDA Profiling - NSight Systems



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CUDA Profiling

- POC feasibility example:
  - Clusterization, Spacepoint formation, Seeding are significantly faster on GPU
  - Considering Host-Device and Device-Host wall-time overheads,
    - there is still a speedup of ~O(800 msec)
- *Note* This is only an example for one event

Data File	Detector Geometry	No. of Events
tml_full/ttbar_mu300	tml_detector/trackml-detector	1

CPU				GPU		
	Parent process	Duration [mu-sec]			Parent process	Duration [mu-sec]
	Container Instantiation	15			Container Instantiation	5
	File reading	1,341,172			File reading	NA
	Clusterization	36,070			Clusterization	NA
	Spacepoint Formation	3,131			Spacepoint Formation	NA
	Clusterization + Spacepoints	39,201			Clusterization + Spacepoints	2,433
	Seeding	814,789			Seeding	11,686
	Track param est	9,316			Track param est	411

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CUDA Profiling

- POC feasibility example:
  - Clusterization, Spacepoint formation, Seeding are significantly faster on GPU
  - Considering Host-Device and Device-Host wall-time overheads,
    - there is still a speedup of ~O(800 msec)
- If CKF on GPU is considerably slower, it may still be feasible to run the first part of the chain on Device and move data to Host for CKF
  - Potential solution for net speedup in the tracking chain
- *Note* This is only an example for one event

Data File	Detector Geometry	No. of Events
tml_full/ttbar_mu300	tml_detector/trackml-detector	1

CPU			GPU		
Parent process	**Duration [mu-sec]**			**Parent process**	**Duration [mu-sec]**
Host to Device [Cells]	**3035**			Device to Host [Cells]	NA
Host to Device [Spacepoints]	**2,703**			Device to Host [Spacepoints]	**1087**
Host to Device [Seeds]	**781**			Device to Host [Seeds]	**349**
Host to Device [Track params]	**1,655**			Device to Host [Track params]	**1,161**

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Next Steps

- Extend studies to larger number of events with more realistic data (eg. mu=60, 140, 200 etc)
- Use seeds generated by traccc in ACTS CKF function to understand Device-Host costs
- Repeat overhead studies wrt other parameters such as Memory, GPU Occupancy etc.

Data File	Detector Geometry	No. of Events
tml_full/ttbar_mu300	tml_detector/trackml-detector	1

CPU			**GPU**		
Parent process	**Duration [mu-sec]**			**Parent process**	**Duration [mu-sec]**
Host to Device [Cells]	**3035**			Device to Host [Cells]	NA
Host to Device [Spacepoints]	**2,703**			Device to Host [Spacepoints]	**1087**
Host to Device [Seeds]	**781**			Device to Host [Seeds]	**349**
Host to Device [Track params]	**1,655**			Device to Host [Track params]	**1,161**

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Baler: ML based Data Compression

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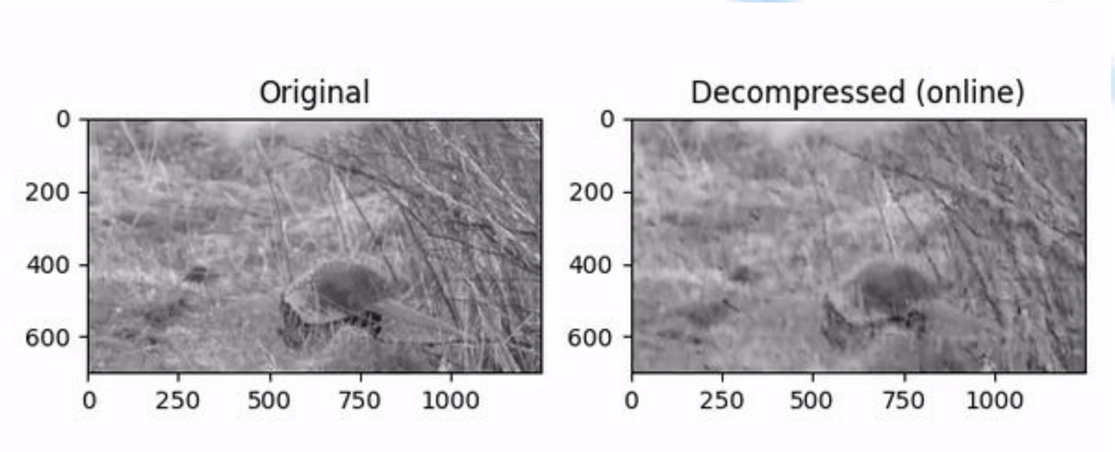
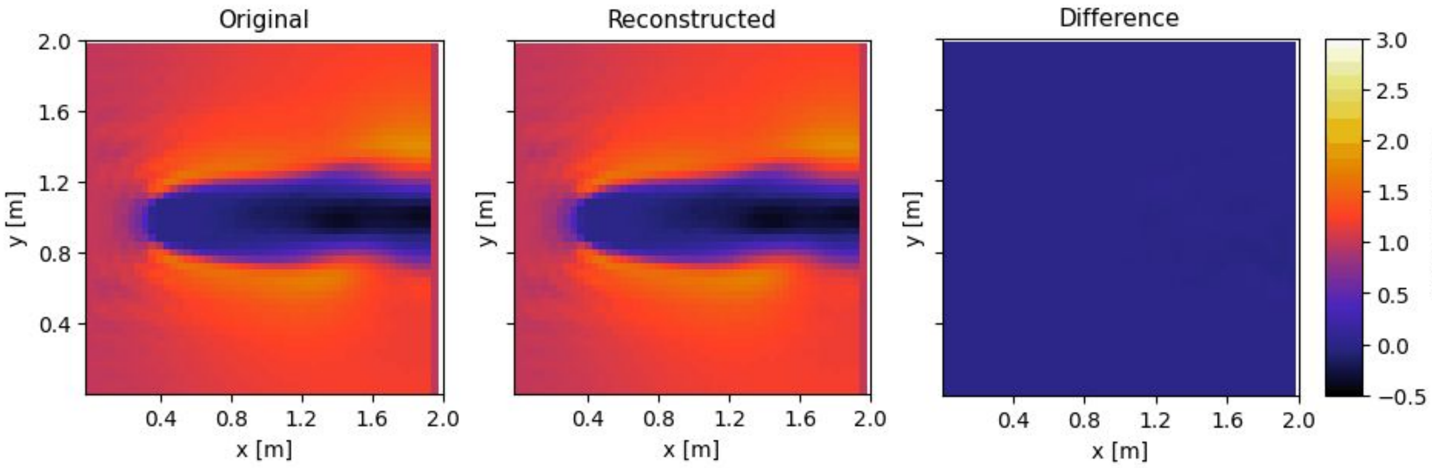
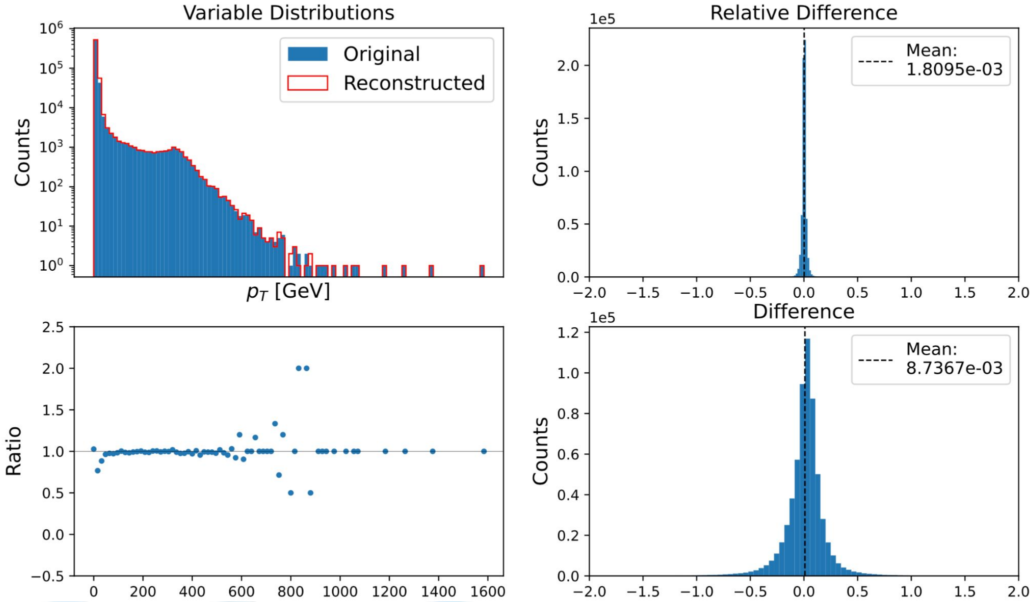
Baler: ML based Data Compression





Paper: https://arxiv.org/abs/2305.02283

Code: https://github.com/baler-collaboration/baler



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Misc Activities

Side Quests:

- Helped lift new wire bonder into the Lund Uni clean room
- Working on DDMTD corrections for mu-CTP trigger chip for temperature variance with Kalman Filters

Hackathons:

- DL in HEP - MIT
- Baler (Lund)

Workshops/Conferences:

- IOP APP&HEPP UK National - Talk
- FastML - Talk
- Hammers and Nails - Poster

Schools:

- tCSC Split
- HASCO particle physics
- STFC UK theory summer school

Teaching/Outreach:

- Jupyter Notebooks Intro - Lund
- Advanced C++ - Manchester

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Conclusions & Future Work

- Track reconstruction may not scale to HL-LHC
  - R&D required to speed up track reconstruction
    - without loss in tracking efficiency
    - GPUs could be a viable option
      - GPUs may not be able to speed up the full chain due to sequential algo (eg. CKF)
  - Heterogeneous computing solutions may be feasible
    - POC studies show:
      - First half of the chain on GPUs, followed by offloading to CPUs for CKF, could show order of 100msec speedup per event
- Work on novel anomaly detection solutions?
- Contribute to the HLS4ML project?
- Analysis: Semi-visible jet signatures for dark sector searches - ML based signal-background discrimination?
- TBD!

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Thank you!

Questions?

People are hungry, just putting it out there :)

Feel free to chat later as well! :)

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BACKUP

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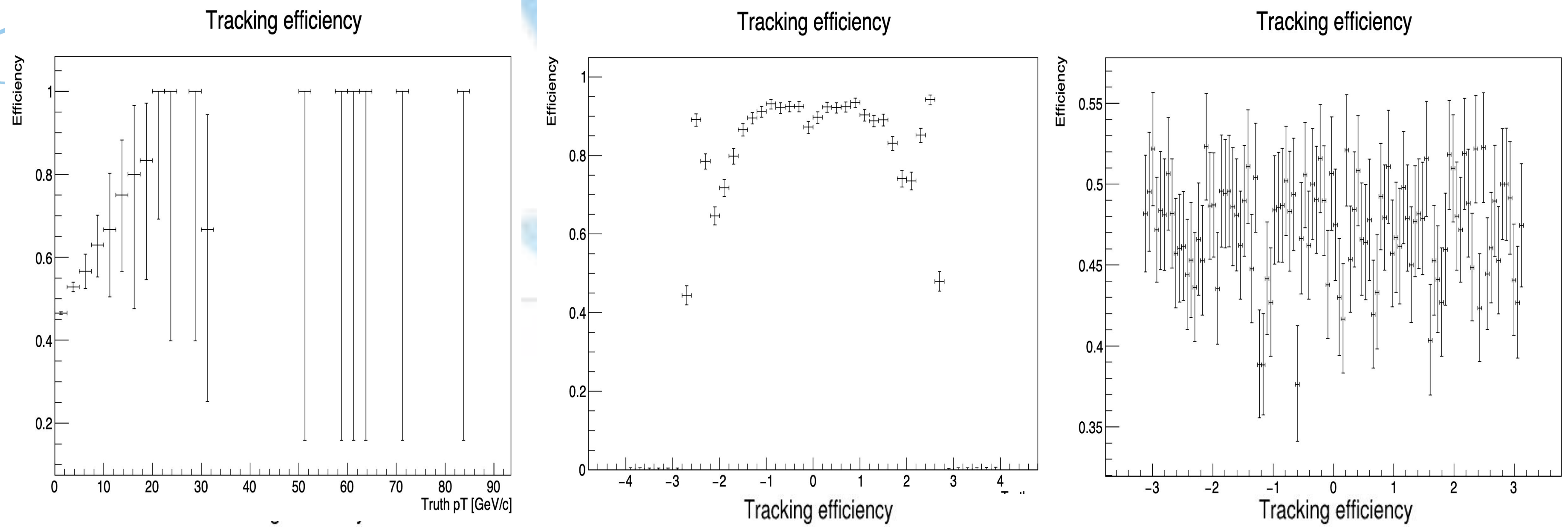
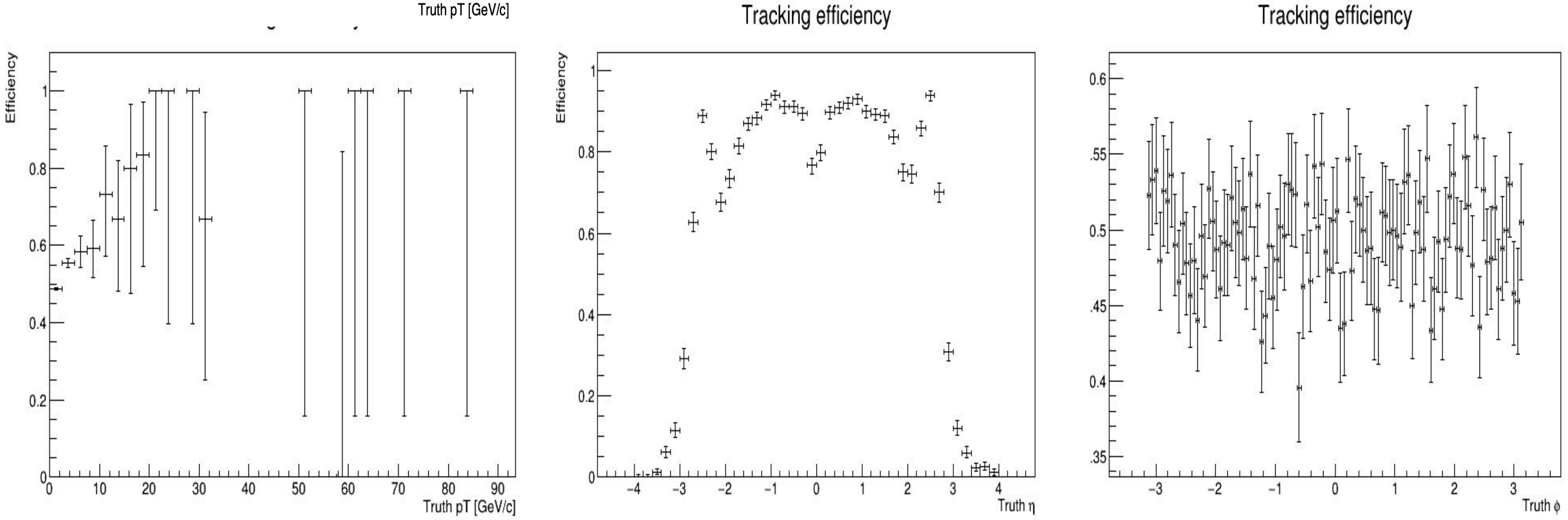
CPU



CUDA



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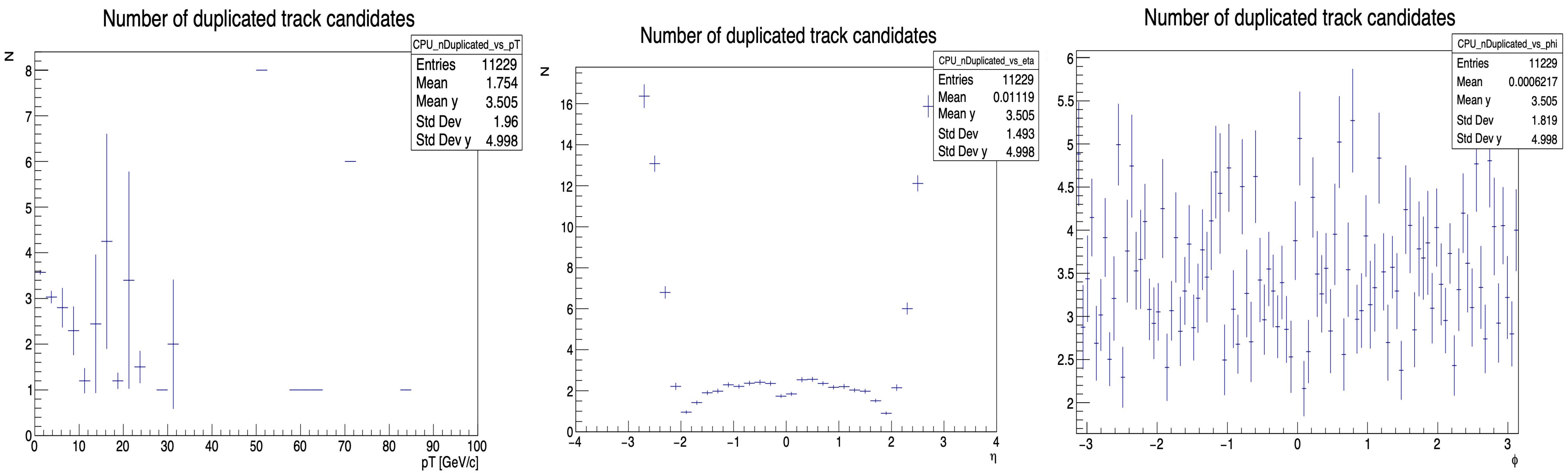
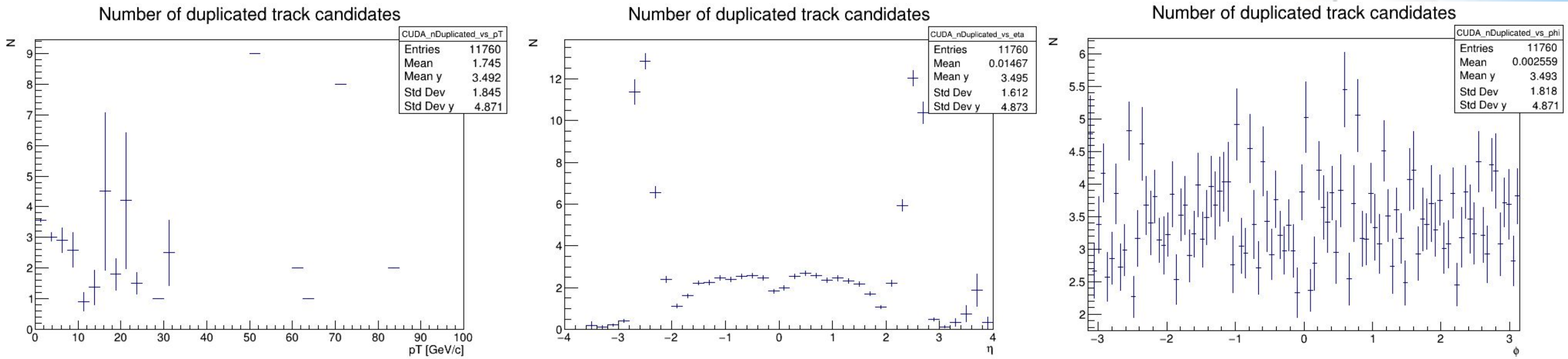
CPU



CUDA



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CUDA Profiling

Old Version

- Seeding - Synchronous kernel launches
  - fill_prefix_sum used for synchroniszation

ID	Issues Detected	Function Name	Demangled Name
0	2	find_clusters	traccc::cuda::kernels::find_...
1	2	fill_prefix_sum	traccc::cuda::kernels::fill_p...
2	2	count_cluster_c...	traccc::cuda::kernels::coun...
3	2	connect_compo...	traccc::cuda::kernels::conn...
4	3	create_measure...	traccc::cuda::kernels::creat...
5	2	fill_prefix_sum	traccc::cuda::kernels::fill_p...
6	2	form_spacepoints	traccc::cuda::kernels::form...
7	2	fill_prefix_sum	traccc::cuda::kernels::fill_p...
8	2	count_grid_capa...	traccc::cuda::kernels::coun...
9	2	populate_grid	traccc::cuda::kernels::popu...
10	3	fill_prefix_sum	traccc::cuda::kernels::fill_p...
11	2	count_doublets	traccc::cuda::kernels::coun...
12	3	fill_prefix_sum	traccc::cuda::kernels::fill_p...
13	2	find_doublets	traccc::cuda::kernels::find_...
14	3	fill_prefix_sum	traccc::cuda::kernels::fill_p...
15	2	count_triplets	traccc::cuda::kernels::coun...
16	3	fill_prefix_sum	traccc::cuda::kernels::fill_p...
17	3	find_triplets	traccc::cuda::kernels::find_...
18	3	fill_prefix_sum	traccc::cuda::kernels::fill_p...
19	3	update_triplet_w...	traccc::cuda::kernels::upda...
20	2	select_seeds	traccc::cuda::kernels::sele...
21	2	estimate_track_...	traccc::cuda::kernels::esti...

New Version - with FastSV

- Seeding - Asynchronous kernel launches
  - Increases paralellization

ID	Issues Detected	Function Name	Demangled Name
0	3	ccl_kernel	traccc::cuda::kernels::ccl_kernel(v...
1	3	form_spacepoints	traccc::cuda::kernels::form_space...
2	2	count_grid_capacities	traccc::cuda::kernels::count_grid_...
3	2	populate_grid	traccc::cuda::kernels::populate_gri...
4	3	fill_prefix_sum	traccc::cuda::kernels::fill_prefix_su...
5	2	count_doublets	traccc::cuda::kernels::count_doubl...
6	2	find_doublets	traccc::cuda::kernels::find_doublet...
7	2	count_triplets	traccc::cuda::kernels::count_triplet...
8	2	reduce_triplet_counts	traccc::cuda::kernels::reduce_tripl...
9	3	find_triplets	traccc::cuda::kernels::find_triplets(...
10	3	update_triplet_weights	traccc::cuda::kernels::update_tripl...
11	3	select_seeds	traccc::cuda::kernels::select_seed...
12	2	estimate_track_params	traccc::cuda::kernels::estimate_tra...

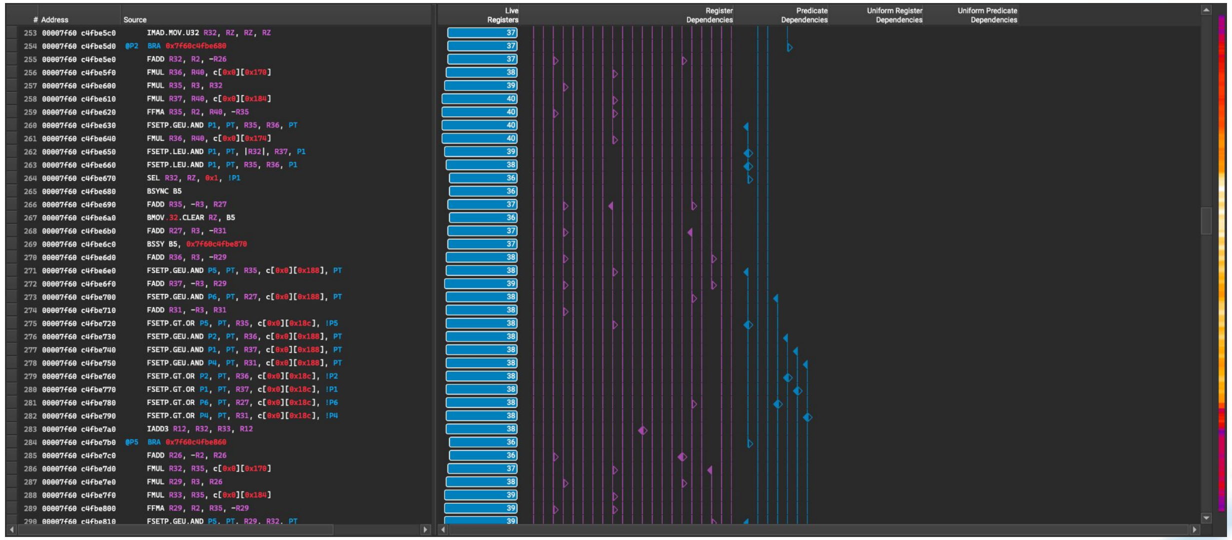
SMARTHEP is funded by the European Union's Horizon 2020 research and innovation programme, call H2020-MSCA-ITN-2020, under Grant Agreement n. 956086

MANCHESTER 1824
The University of Manchester

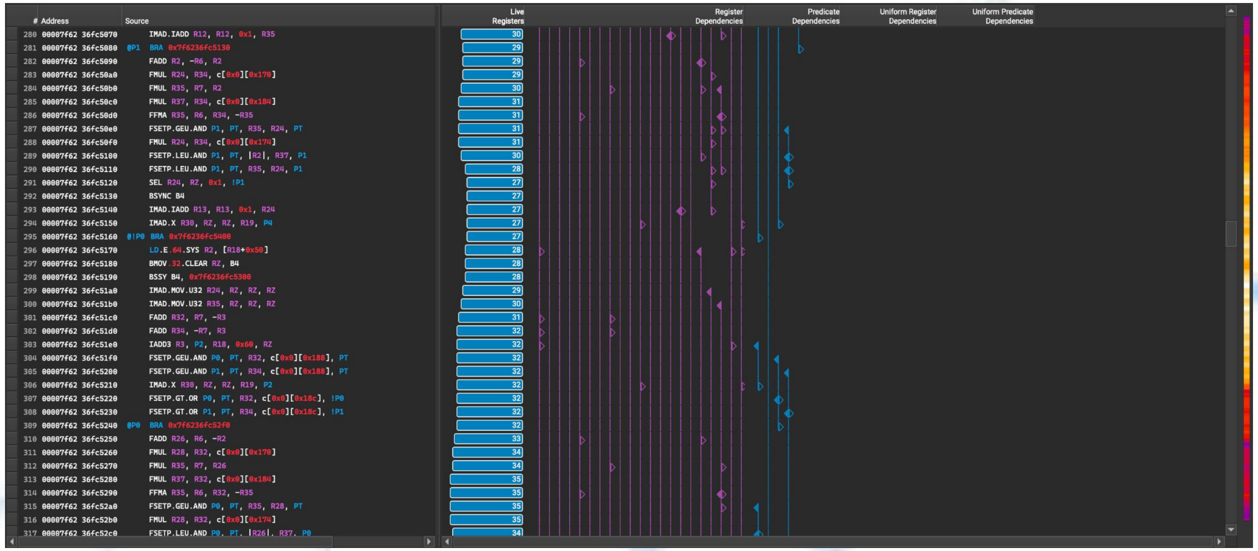
CUDA Profiling- NEW

Data File	Detector Geometry	No. of Events
tml_full/ttbar_mu300	tml_detector/trackml-detector	1

Old Version
count_doublets()



New Version - with FastSV
count_doublets()



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