traccc

on behalf of the traccc development team

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What is traccc

- Subproject of Acts focusing on using accelerators to run track reconstruction

Category	Algorithms	CPU	CUDA	SYCL	Futhark
Clusterization	CCL	✅	✅	✅	✅
	Measurement creation	✅	✅	✅	✅
	Spacepoint formation	✅	✅	✅	◯
Track finding	Spacepoint binning	✅	✅	✅	◯
	Seed finding	✅	✅	✅	◯
	Track param estimation	✅	✅	✅	◯
	Combinatorial KF	◯	◯	◯	◯
Track fitting	KF	🟡	🟡	◯	◯

✅: exists, 🟡: work started, ◯: work not started yet

Why is traccc

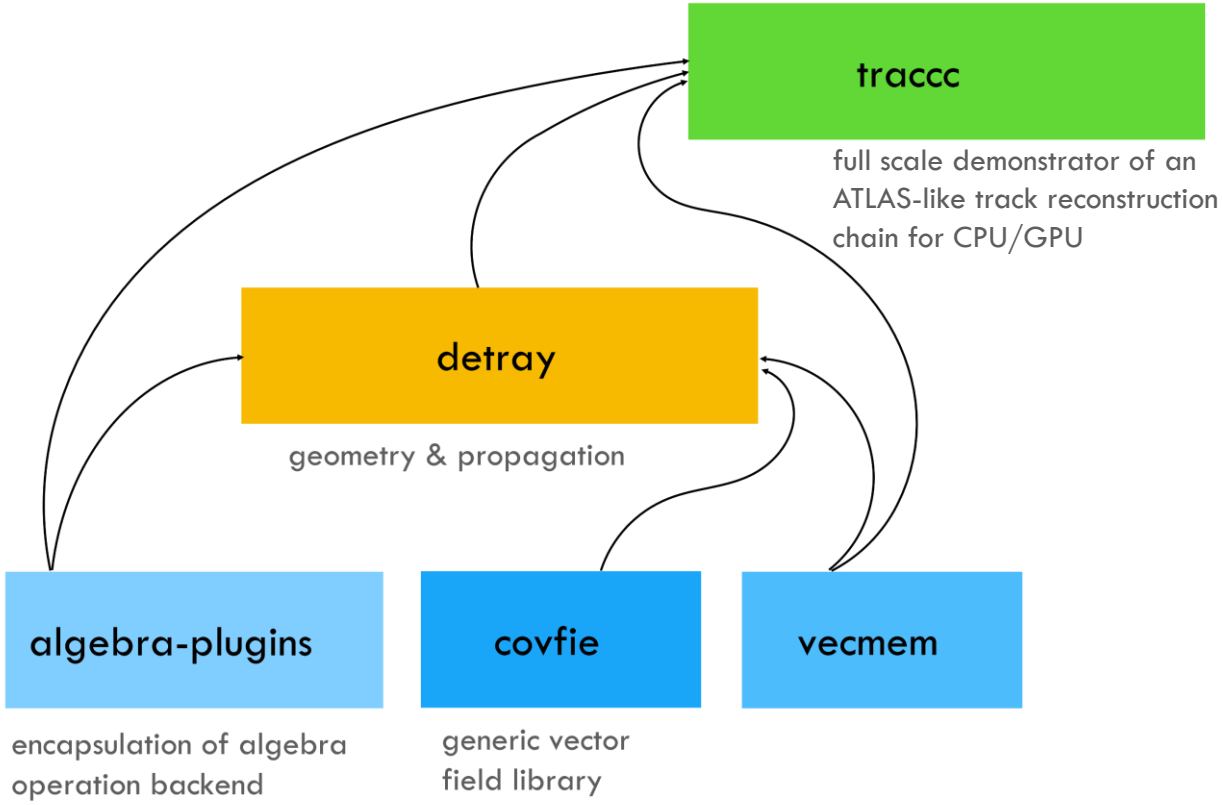
- Modern GPUs are capable of processing large amounts of data very efficiently through massively parallel execution of SIMD kernels
- HL-LHC upgrade demands faster execution times, to which GPUs could provide a solution

The big picture

- Acts – Main project

traccc's dependencies:

- vecmem – Memory classes based on standard C++ for heterogeneous computing
- detray – Geometry model of detector
- algebra plugins – Useful mathematical functions



source: Andreas Salzburger

Code organisation

acts-project / **traccc** Public

.githooks	Add some documentation about git hooks	15 months ago
.github	Switched the CI to the latest Acts Docker images.	8 days ago
cmake	Add support for the Futhark programming language	18 days ago
core	Made traccc::internal_spacepoint work with SYCL's NVIDIA backend.	3 days ago
data @ 92fde47	Make clusterization result correct	4 months ago
device	Add Futhark implementation of CCA	7 days ago
doc/images	Migrate README flowchart to Mermaid	6 months ago
examples	cuda seed_finding uses common triplet counting	last month
extern	Taught the project how to download/build Thrust as part of its build.	8 days ago
extras	Add a very short README to extras/	14 months ago
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Code organisation

CPU pipeline / Common code

acts-project / traccc Public

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Code organisation

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Device pipeline

Examples for testing

acts-project / traccc Public

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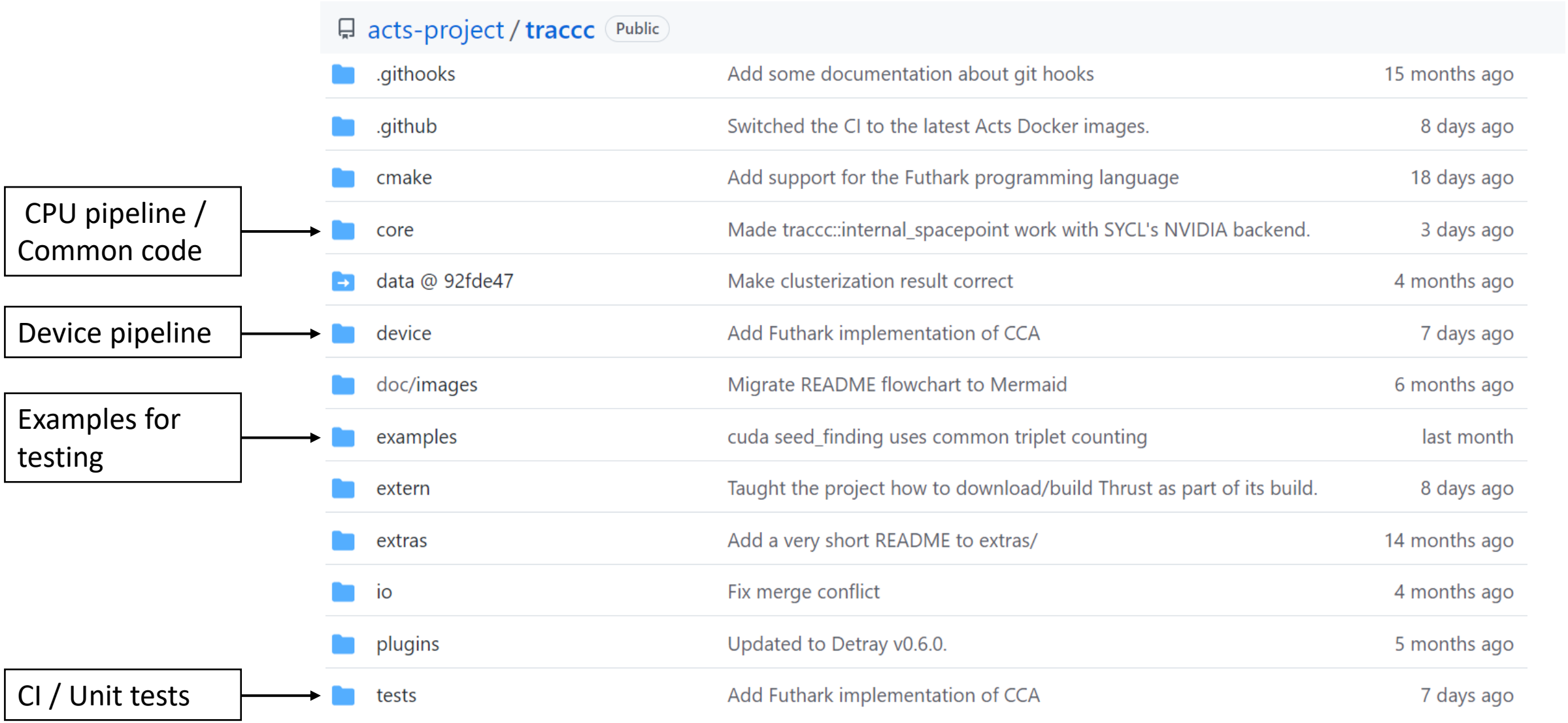
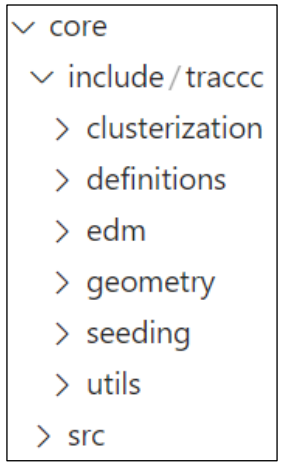
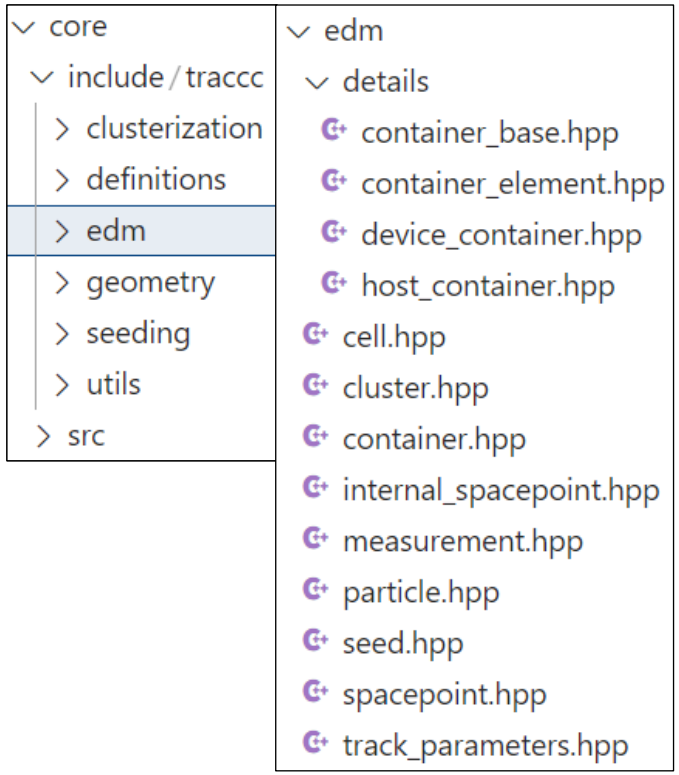


Code model


core
include / traccc
clusterization
definitions
edm
geometry
seeding
utils
src

Code model



device_container.hpp 4 × Settings

core > include > traccc > edm > details > device_container.hpp > ...

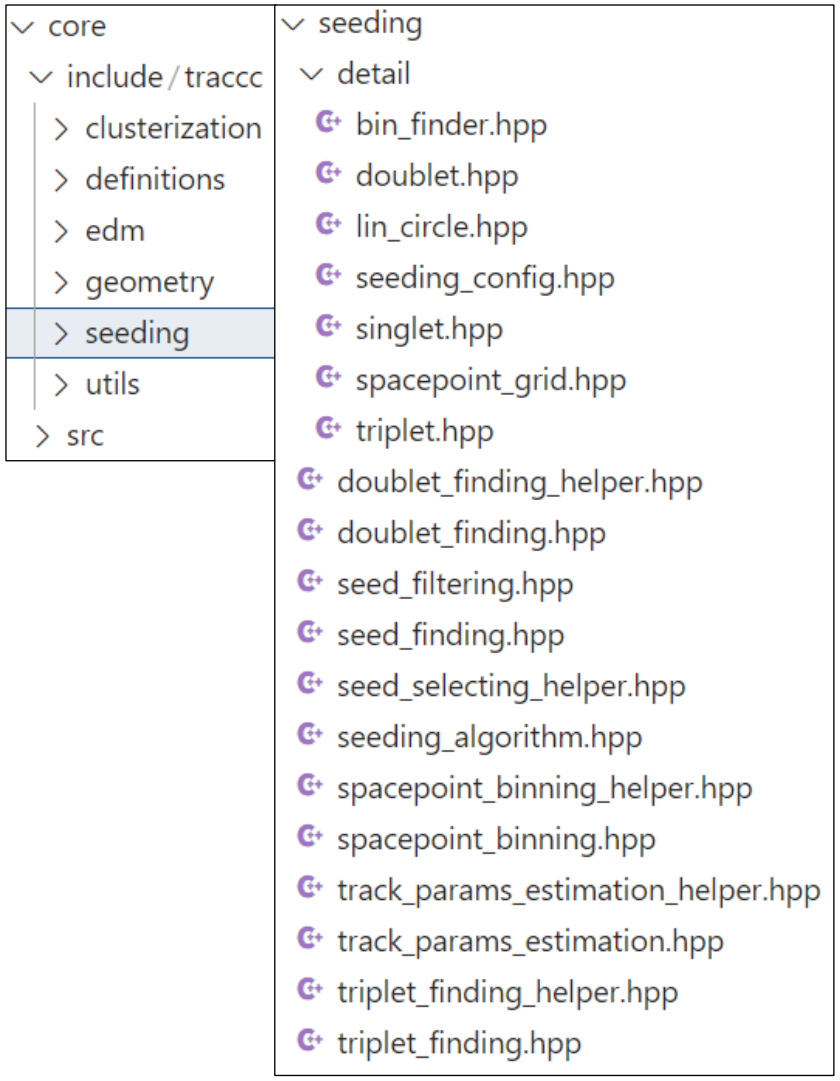
```
23  /// Host container describing objects in a given event
24  template <typename header_t, typename item_t>
25  class device_container
26      : public container_base<header_t, item_t, vecmem::device_vector,
27                              vecmem::jagged_device_vector> {
```

cell.hpp 1 × Settings

core > include > traccc > edm > cell.hpp > ...

```
22  /// Definition for one detector cell
23  ///
24  /// It comes with two integer channel identifiers, an "activation value"
25  /// and a time stamp.
26  ///
27  struct cell {
28      channel_id channel0 = 0;
29      channel_id channel1 = 0;
30      scalar activation = 0.;
31      scalar time = 0.;
32  };
```

Code model

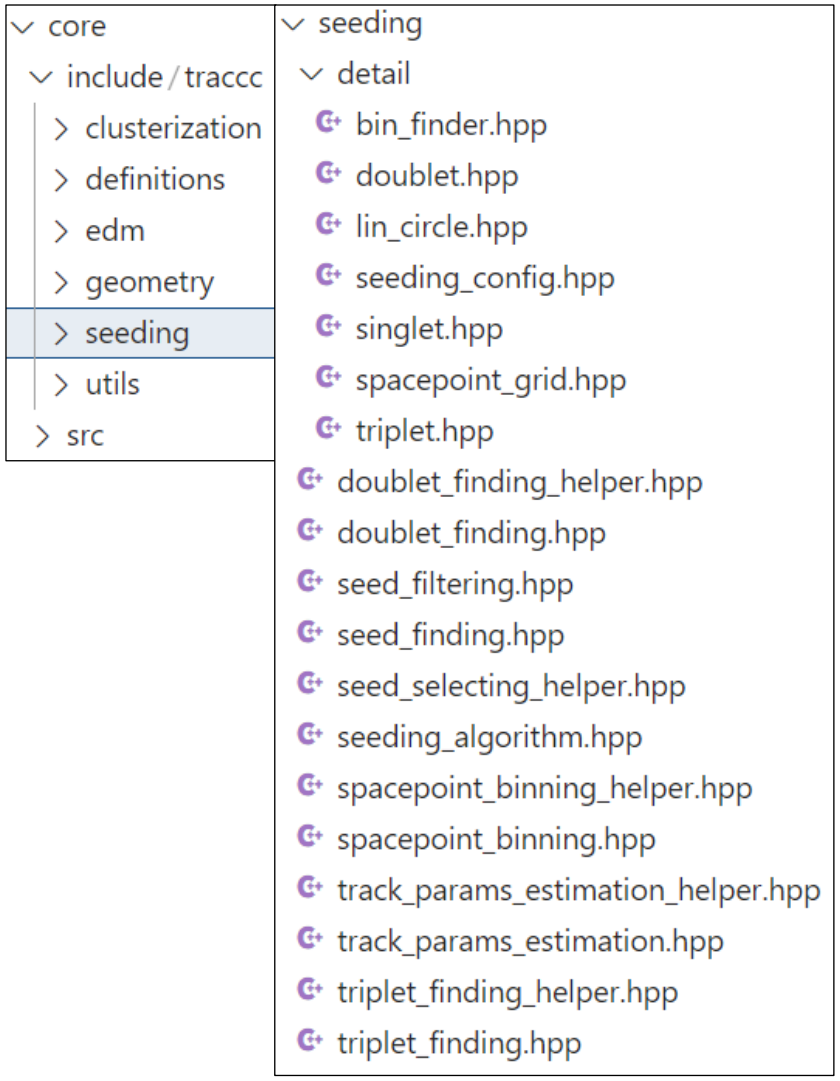


doublet.hpp 1 | Settings

core > include > traccc > seeding > detail > doublet.hpp > ...

```
15  struct doublet_per_bin {
16      unsigned int n_doublets = 0;
17  };
18
19  /// Item: doublet of middle-bottom or middle-top
20  struct doublet {
21      // midle spacepoint location in internal spacepoint container
22      sp_location sp1;
23      // bottom (or top) spacepoint location in internal spacepoint container
24      sp_location sp2;
25  };
```

Code model


core
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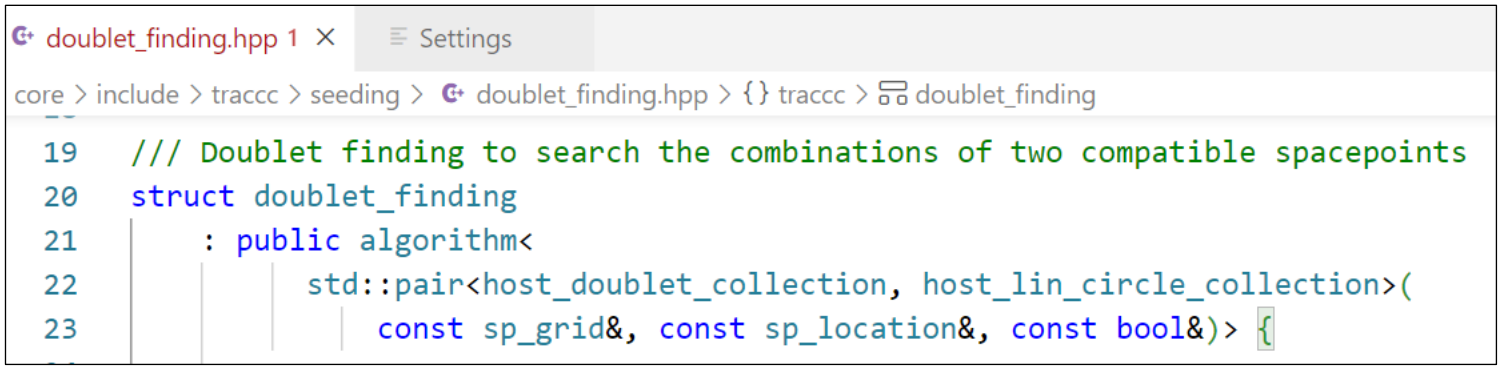
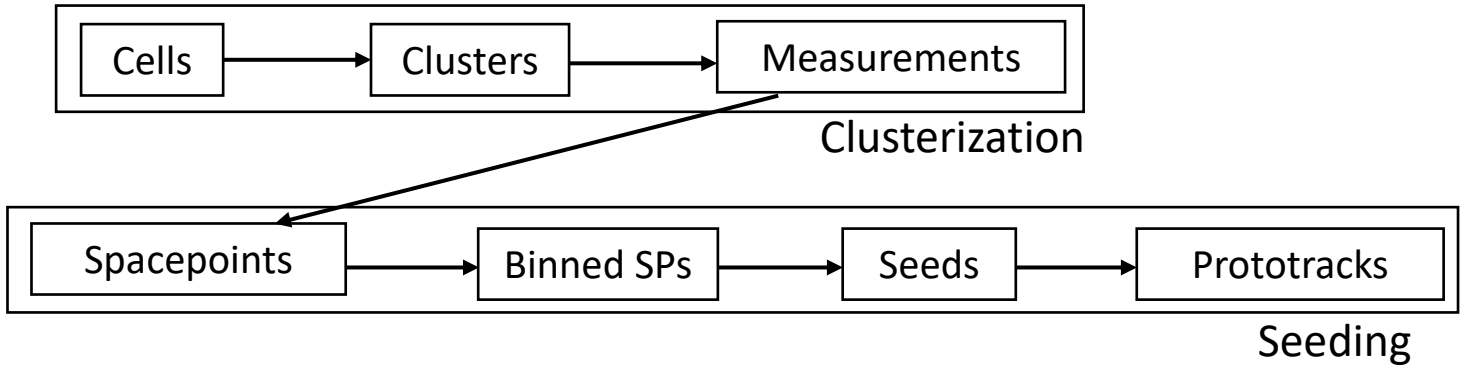
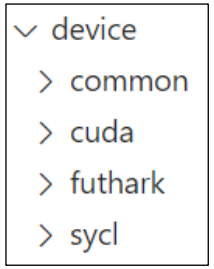
src
seeding
detail
bin_finder.hpp
doublet.hpp
lin_circle.hpp
seeding_config.hpp
singlet.hpp
spacepoint_grid.hpp
triplet.hpp
doublet_finding_helper.hpp
doublet_finding.hpp
seed_filtering.hpp
seed_finding.hpp
seed_selecting_helper.hpp
seeding_algorithm.hpp
spacepoint_binning_helper.hpp
spacepoint_binning.hpp
track_params_estimation_helper.hpp
track_params_estimation.hpp
triplet_finding_helper.hpp
triplet_finding.hpp

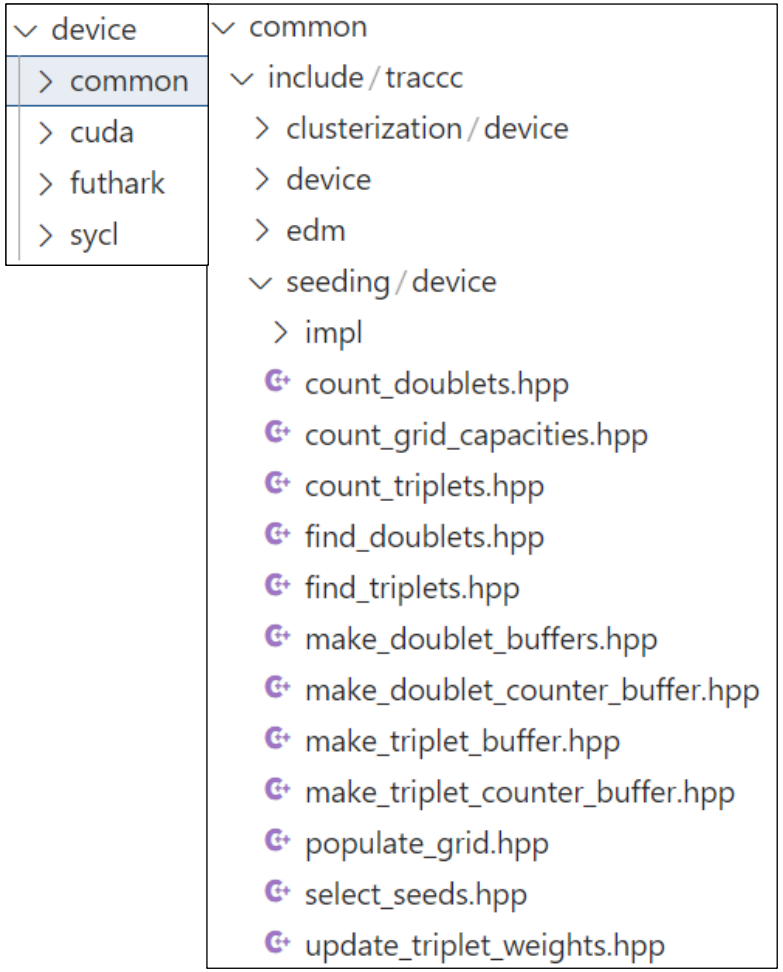

doublet_finding.hpp 1
Settings
core > include > traccc > seeding > doublet_finding.hpp > { } traccc > doublet_finding
19 /// Doublet finding to search the combinations of two compatible spacepoints
20 struct doublet_finding
21 : public algorithm<
22 std::pair<host_doublet_collection, host_lin_circle_collection>(
23 const sp_grid&, const sp_location&, const bool&)> {


Cells
Clusters
Measurements
Clusterization
Spacepoints
Binned SPs
Seeds
Prototracks
Seeding

Code model



Code model

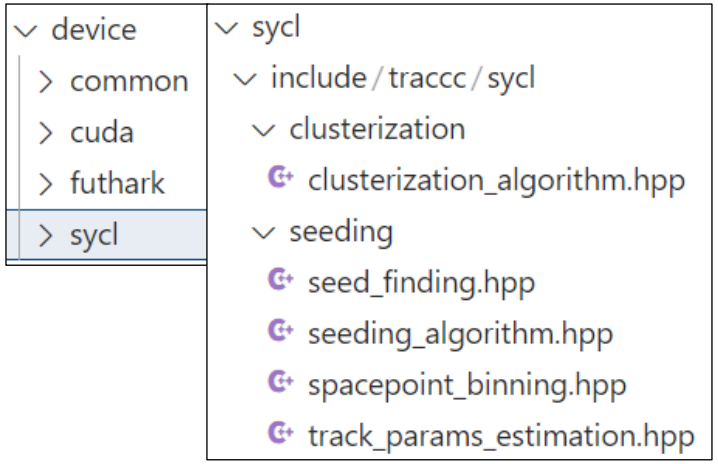


count_doublets.hpp 2, M Settings

device > common > include > traccc > seeding > device > count_doublets.hpp > ...

```
22  /// Function used for calculating the number of spacepoint doublets
23  ///
24  /// The count is necessary for allocating the appropriate amount of memory
25  /// for storing the information of the candidates in a next step.
26  TRACCC_HOST_DEVICE
27  void count_doublets(
28      std::size_t globalIndex, const seedfinder_config& config,
29      const sp_grid_const_view& sp_view,
30      const vecmem::data::vector_view<const prefix_sum_element_t>& sp_ps_view,
31      doublet_counter_container_types::view doublet_view);
```

Code model

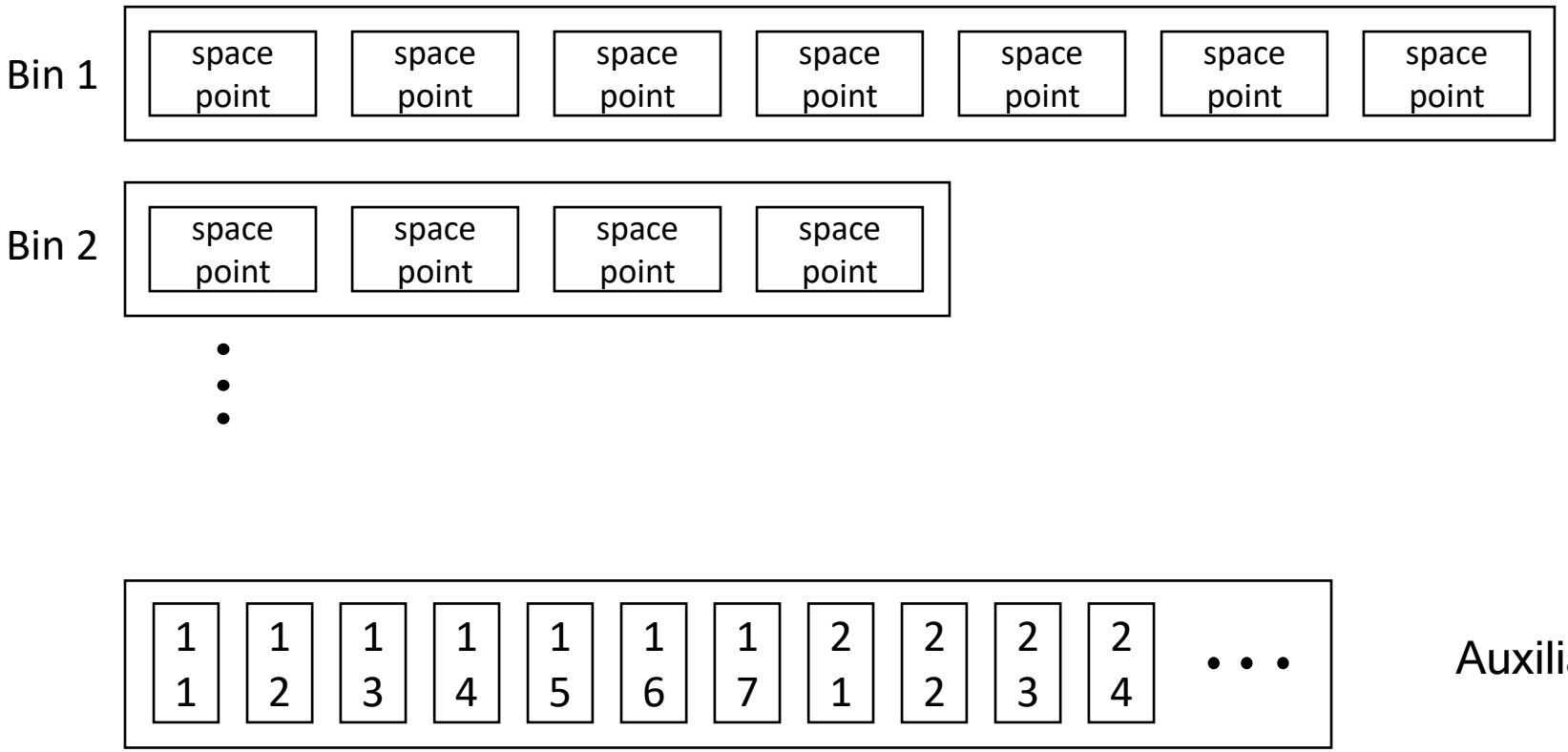


seeding_algorithm.hpp 4 Settings

device > sycl > include > traccc > sycl > seeding > seeding_algorithm.hpp > ...

```
28  /// Main algorithm for performing the track seeding using oneAPI/SYCL
29  class seeding_algorithm : public algorithm<vecmem::data::vector_buffer<seed>(
30                                const spacepoint_container_types::const_view&)>,
31                            public algorithm<vecmem::data::vector_buffer<seed>(
32                                const spacepoint_container_types::buffer&)> {
```

Algorithms in a CPU vs GPU



Input jagged vector

Auxiliary vector for memory access

Algorithms in a CPU vs GPU

Use Dynamic memory allocation.

- Take input jagged vector
- Do calculations
- Append members to result jagged vector

Dynamic memory allocation in device not possible.

- 1st kernel – Create auxiliary vector for input
- 2nd kernel – Count number of members needed for result jagged vector
- 3rd kernel – Create auxiliary vector for counts
- 4th kernel – Fill result jagged vector

Effectively need to run calculations twice (2nd & 4th kernels)

Algorithms in a CPU vs GPU

seed_finding.cu 9+ | Settings

device > cuda > src > seeding > seed_finding.cu > { } traccc > { } cuda

```
37
38  /// CUDA kernel for running @c traccc::device::fill_prefix_sum
39  __global__ void fill_prefix_sum(
40      vecmem::data::vector_view<const device::prefix_sum_size_t> sizes_view,
41  >   vecmem::data::vector_view<device::prefix_sum_element_t> ps_view) { ···
46
47  /// CUDA kernel for running @c traccc::device::count_doublets
48  __global__ void count_doublets(
49      seedfinder_config config, sp_grid_const_view sp_grid,
50      vecmem::data::vector_view<const device::prefix_sum_element_t> sp_prefix_sum,
51  >   device::doublet_counter_container_types::view doublet_counter) { ···
56
57  /// CUDA kernel for running @c traccc::device::find_doublets
58  __global__ void find_doublets(
59      seedfinder_config config, sp_grid_const_view sp_grid,
60      device::doublet_counter_container_types::const_view doublet_counter,
61      vecmem::data::vector_view<const device::prefix_sum_element_t>
62          doublet_prefix_sum,
63  >   doublet_container_view mb_doublets, doublet_container_view mt_doublets) { ···
```

Clusterization in a CPU vs GPU

For each cell:
- Find clusters

For each cluster:
- Create measurements

For each measurement:
- Form 3D spacepoints out of 2D measurements

Clusterization in a CPU vs GPU

For each cell:
- Find clusters

For each cluster:
- Create measurements

For each measurement:
- Form 3D spacepoints out of 2D measurements

CPU code easily portable to GPU!

Seed finding in a CPU vs GPU

For each spMiddle:
- Look for compat spTop
- Look for compat spBottom
- Make triplets
- Filter triplets sharing this spM
- Make seeds

For each spMiddle:
- Look for compat spTop
- Look for compat spBottom
- Make doublets

For each midBot doublet:
- Look for compat midTop doublet
- Make triplets

For each triplet:
- Filter triplets sharing same spM
- Make seeds

Testing traccc

seq_example_sycl.sycl 9+ | Settings

examples > run > sycl > seq_example_sycl.sycl > ...

```
158         /*-----------------------------------------------------
159             Clusterization & Spacepoint formation (SYCL)
160           -----------------------------------------------------*/
161
162         /*time*/ auto start_clusterization_sycl =
163             std::chrono::system_clock::now();
164
165         auto spacepoints_sycl_buffer = ca_sycl(cells_per_event_sycl);
166
167         /*time*/ auto end_clusterization_sycl =
168             std::chrono::system_clock::now();
169         /*time*/ std::chrono::duration<double> time_clusterization_sycl =
170             end_clusterization_sycl - start_clusterization_sycl;
171         /*time*/ clusterization_sycl += time_clusterization_sycl.count();
172
173         traccc::clusterization_algorithm::output_type measurements_per_event;
174         traccc::spacepoint_formation::output_type spacepoints_per_event;
175
176         if (run_cpu) {
177
178             /*----------------------------
179                 Clusterization (cpu)
180               ----------------------------*/
```

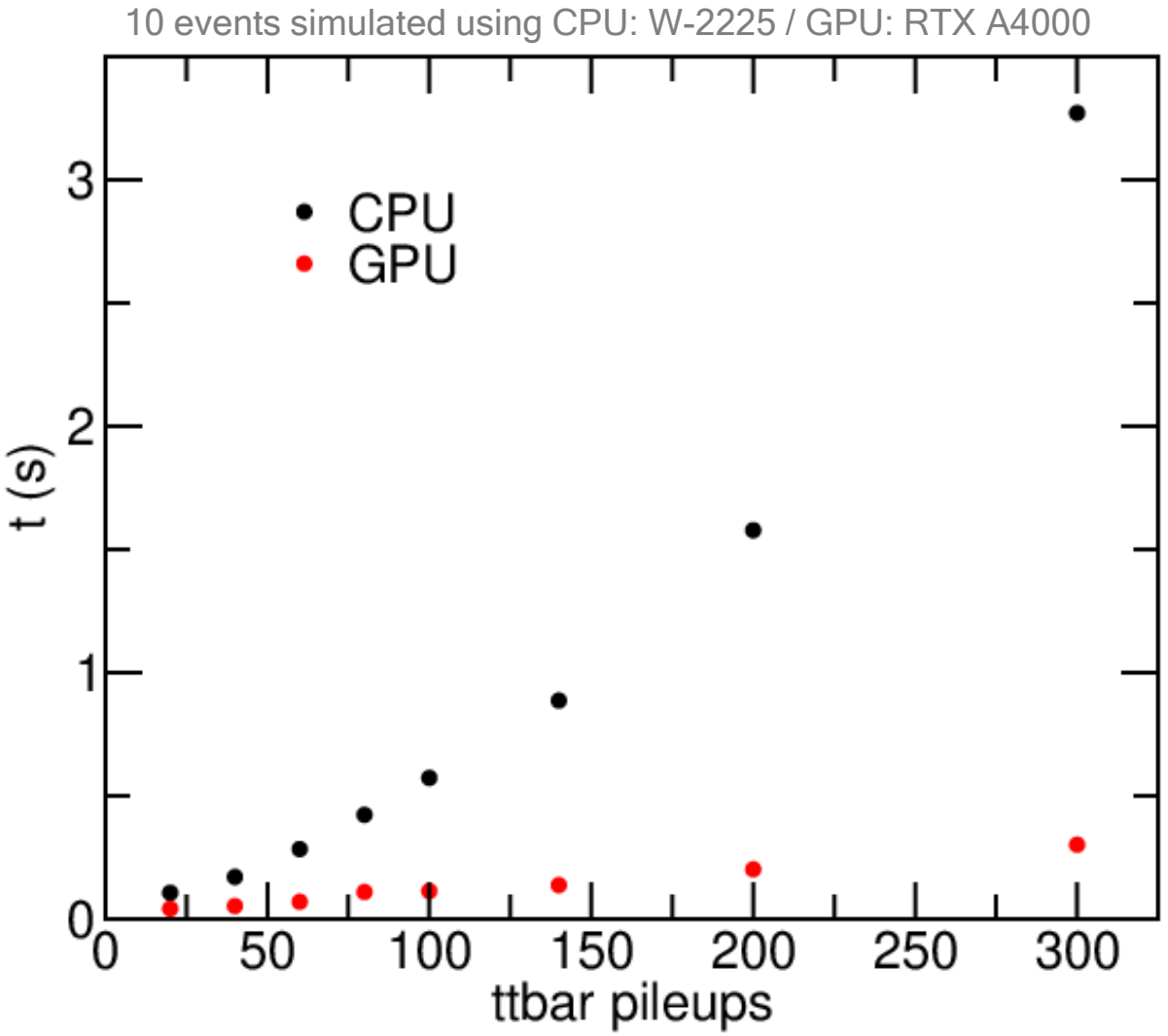
```
Running ./bin/traccc_seq_example_sycl tml_detect
or/trackml-detector.csv tml_full/ttbar_mu300/ 1
Running Seeding on device: NVIDIA RTX A4000
event 0
 number of seeds (cpu): 26743
 number of seeds (sycl): 26743
 measurements matching rate: 0.99957
 spacepoint matching rate: 0.96902
 seed matching rate: 0.955615
 track parameters matching rate: 0.999663
clusterization_time (cpu) 0.0294396
spacepoint_formation_time (cpu) 0.0031022
clusterization_time (sycl) 0.0139178
seeding_time (cpu)        0.298
seeding_time (sycl)       0.0141859
tr_par_esti_time (cpu)    0.00868278
tr_par_esti_time (sycl)   0.00358893
```

Testing traccc

Parallelizing introduces a lot of complexity to coding

Testing full tracking chain from reading input data from detector to seeds

- GPU can significantly boost performance as quantity of data increases



Future steps

- Working on re-synchronising traccc with main Acts
- Re-thinking in parallel
- Add additional functionality to traccc
- Performance optimizations