An online GPU hit finder for the STS detector in CBM

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CBM

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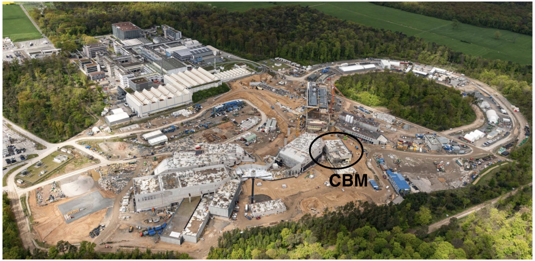
The Compressed Baryonic Matter (CBM) experiment at FAIR



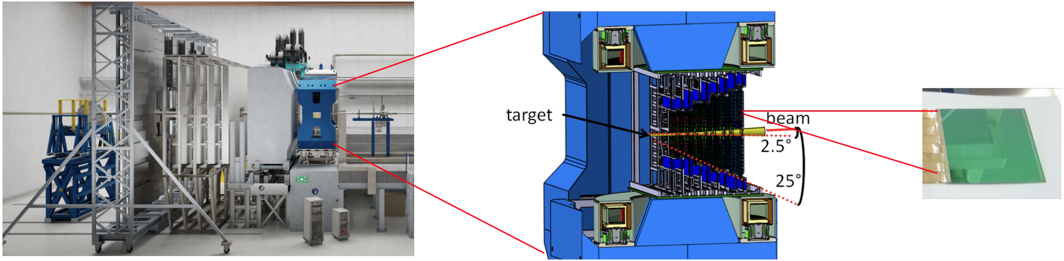
FAIR construction site, Apr. 2024

Render of CBM (© GSI/FAIR, Zeitrausch)

- Fixed target heavy ion experiment
- Under construction at the FAIR facility
- High reaction rates up to 10 MHz

- Exp. data rate: > 500 GB/s average
- Efficient online reconstruction + event selection required

The Silicon Tracking System (STS) detector

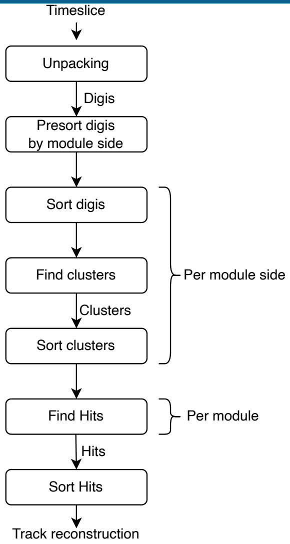


- Closest detector to the target
- High spatial (25 µm) and temporal (5 ns) resolution
- Key detector for track reconstruction
- 8 stations with ∼ 900 modules total

- Module: double sided sensor with 1024 channels on each side
- ∼ 1.8 million read-out channels
- Hit finder: match data from front and back side of same particle

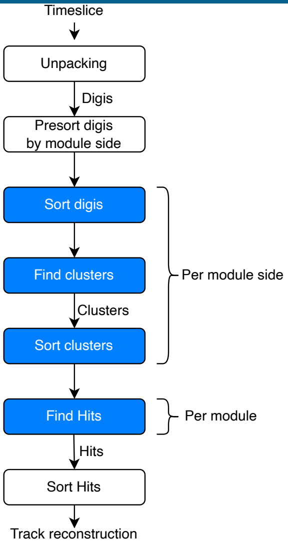
(online) STS reconstruction

- Raw detector data accumulated into timeslices
- Timeslices unpacked into digis
    - Digi: tuple of module, timestamp, channel and charge
- Combine neighboring digis into clusters
    - Cluster: 2D object with channel and time
- Combine clusters from front and back side into hits
    - Hit: 4D object with global coord and time
- Hits used for track reconstruction
- Hits divided into streams, streams sorted again by time before passed to tracking



(online) STS reconstruction

- Focus of this talk:
  - Digi / cluster sorting
  - Cluster finding
  - Hit finding
- Implementation part of CBMRoot online code
- Written in xpu[1]
  - Compiles GPU code to CUDA, HIP, SYCL or regular C++ with OpenMP



[1] https://github.com/fweig/xpu

Sorting on GPU

- Sort contents of module side (digis or clusters)
- Custom sorting algorithm:
  - One GPU block per module side
  - Parallel merge sort within block
  - Parallel merge step per GPU thread via Merge Path[1]
  - Preserves coalesced memory access within blocks

Further studies: compare with `cub::DeviceSegmentedSort`[2]

→ not available during first implementation

[1] O. Green et al., Merge Path - A Visually Intuitive Approach to Parallel Merging, 2014

[2] `https://nvidia.github.io/cccl/cub/api/structcub_1_1DeviceSegmentedSort.html`

Cluster finder (sequential)

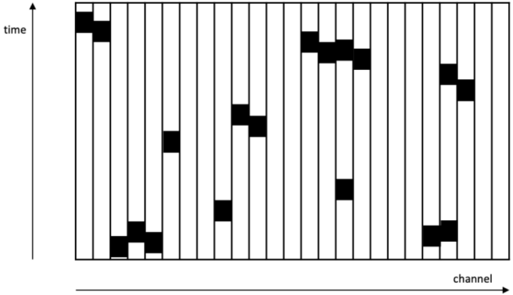
Sort digis by time

For all digis:

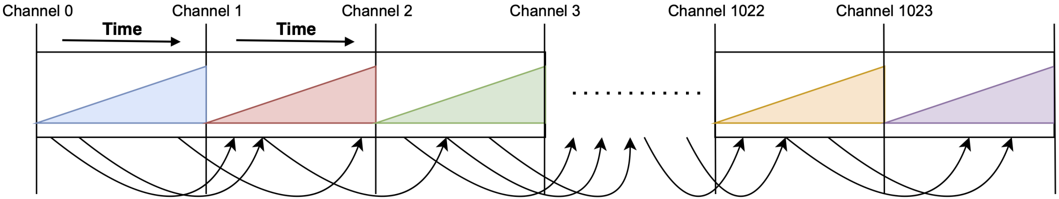
1. Try to mark channel of digi as active
2. If channel already active:
    - 2.1 Create cluster around digi (neighboring digis must fall within Δ time)
    - 2.2 Mark channels of cluster as inactive

Assumes sequential processing of digis, can't parallelize across digis

→ not suited for GPU

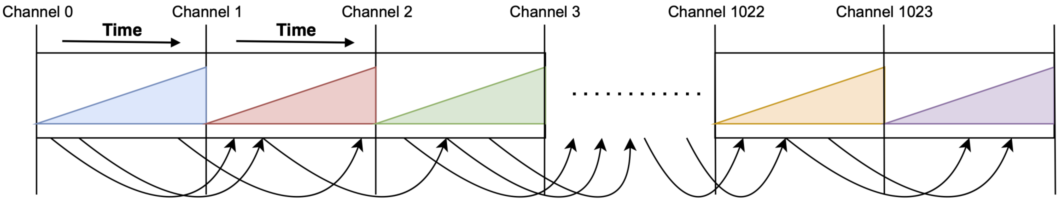


Parallel cluster finder



- Sort digis by channel and time instead
- Connect digis in same cluster via linked list
- → Store additional 32 bit connector object per digi

Parallel cluster finder



1. Find offset of each channel
2. Create connections:
   - Look for candidate *C* in next channel
   - If *C* found: Set index to *C* in connector, set prev bit for *C*
3. Create clusters:
   - Thread of first digi (prev bit not set) creates clusters
   - Iterate connectors to combine digis

Step 2 + 3: Parallel across all digis via atomic operations

Hit finding

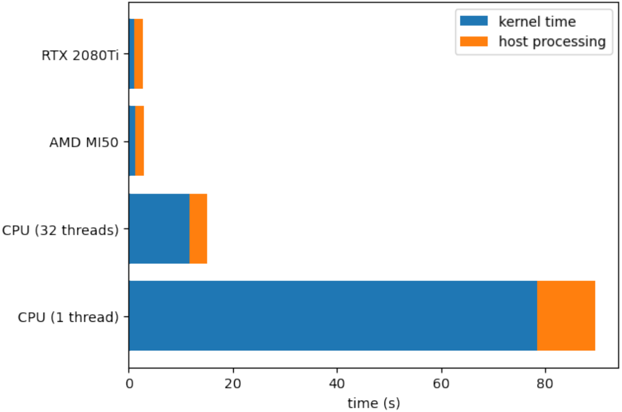
- Attempt to combine clusters from front and back side into hits if they overlap in time
- Time sorting required to reduce combinatorics
- Original algorithm[1] was straightforward to move to GPU
- Parallel across front side clusters

[1] H. Malygina, Hit reconstruction for the Silicon Tracking System of the CBM experiment, 2018

Performance

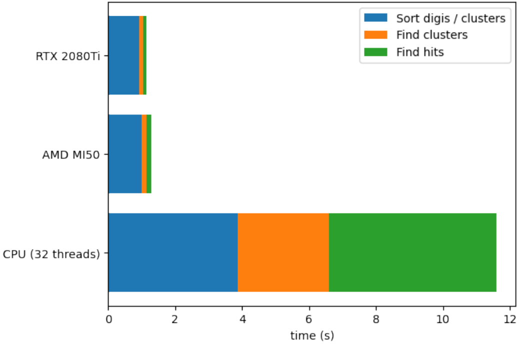
The mCBM setup

- Time accumulated over 20 timeslices (2.5 s of data)
- Real data from mCBM ($\sim 160 \cdot 10^6$ digis)
- CPU: Intel Xeon 6130 (16 cores, 32 threads)



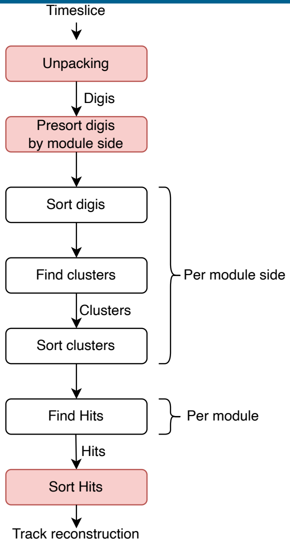
Kernel times

- Sorting predominant on GPU
  - only uses 22 blocks / compute units, occupies $\sim 1/3$ of device!
- Cluster and hit creation can exploit parallelism on GPU . . .
- . . . but the unmodified GPU code doesn't work that well here on CPU
- Hit creation on CPU: static thread distribution → few threads stuck on clusters with high combinatorics



Conclusion and next steps

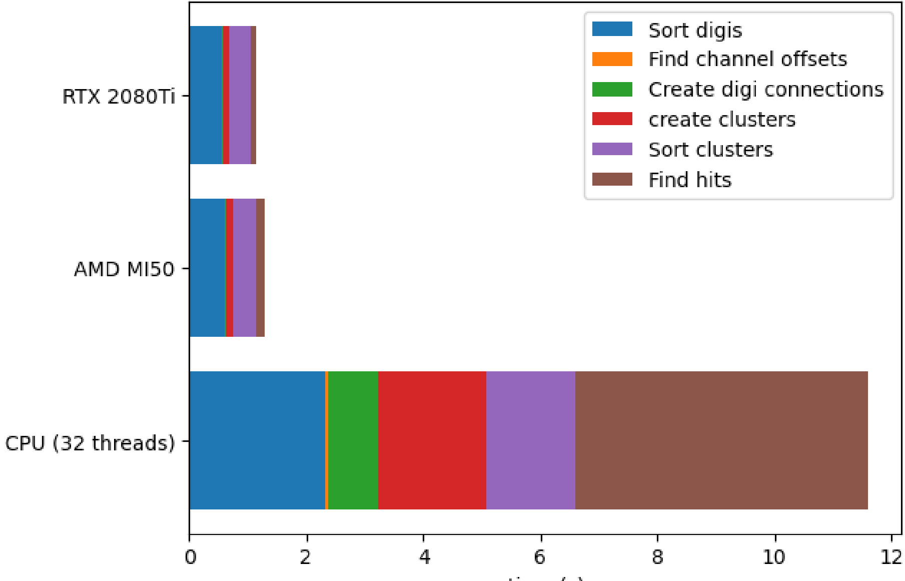
- Key steps of hit finder show promising performance on GPU
- 50 % runtime still spent on host
- Unpacking proof-of-concept on GPU
    - Shows great performance: 40 GB/s per timeslice
    - Currently being integrated into CBMRoot
- Remaining steps should be moved to GPU (digi presorting, hit sorting)



Thank you for your attention!

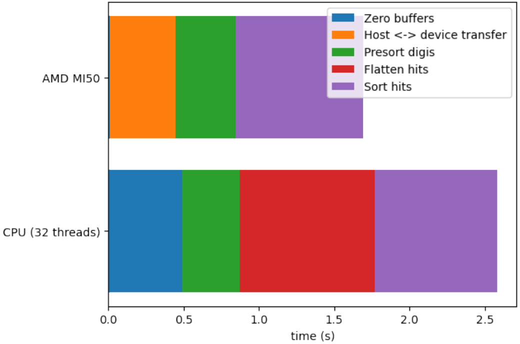
Backup Slides

Kernel times (detailed)



Processing on host

- Digi presorting and hit sorting: should be moved to GPU eventually
- Hits are stored into buckets, need separate step to flatten into single array
  - → Done on GPU during device to host copy.
- Zeroing buffers not yet parallel on host


Zero buffers
Host <-> device transfer
Presort digis
Flatten hits
Sort hits
AMD MI50
CPU (32 threads)
time (s)