GPUs in Triggers and Reconstruction

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on behalf of the ALICE, ATLAS, CMS, and LHCb Collaborations

LHCP
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Computing Challenges at the LHC

Run 3 (2022): “Triggerless” data collection at ALICE and LHCb
- LHCb: $pp$ at 40 MHz, 5 TB/s
- ALICE: PbPb at 50 kHz, 3.5 TB/s

Run 4 (2027): The HL-LHC
- ATLAS and CMS will collect $pp$ data at a pileup of 200
- Will increase hardware trigger rate from 100 kHz to 750 – 1000 kHz

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Why use GPUs

Affordable computing power in a compact package

![Graph showing theoretical peak GFLOPs/$ versus release date with data points for Nvidia consumer GPUs, AMD consumer GPUs, Nvidia scientific GPUs, AMD scientific GPUs, and Intel & AMD CPUs.


Also see talk by Ole Schmidt on June 8 for more on hardware acceleration in general.

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What is a GPU?

- Highly parallel processors with thousands of cores (threads)
- Many trigger and reconstruction tasks parallelize nicely (with some work)
ALICE Data Processing in Run 3

- Triggerless PbPb data taking at 50 kHz
- TPC must be reconstructed in real time for compression and calibration
- TPC reco on GPUs since Run 1
- Aim for full barrel track reco on GPUs

PoS (LHCP2020) 053
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GPU reco ready
GPU reco in development
Baseline: TPC reconstruction + whatever else is ready
Optimistic: Full barrel track reconstruction on GPUs

See David Rohr’s vCHEP talk
GPUs at ALICE vs. ATLAS and CMS

**ALICE**
- TPC reconstructions dominates
- Process 10 ms “timeframes”, $\mathcal{O}(10 \text{ GB})$
- $\sim 80 \times$ speedup on GPUs
- Clear use case for GPUs

**ATLAS and CMS**
- No single subdetector dominates
- Much higher rates of smaller events
- Advantages of GPUs compete with challenges: portability, overhead, etc.
ATTLAS: GPU R&D in ACTS

A Common Tracking Software (ACTS)

- Targeting end-to-end tracking on GPUs: traccc
- Includes R&D studies of data structures and memory management: VecMem

Track Seeding Algorithm

Kalman Filter


arXiv:2105.01796
CMS: Pixel Track and Calorimeter Reconstruction

CMS reconstruction on GPUs in Run 3

- Pixel track reconstruction: Front. Big Data 3 (2020) 601728
- Primary vertices from pixel tracks
- Calorimeter local reconstruction
- Out-of-time pileup subtraction
- Fully integrated into CMSSW. See arXiv:2004.04334

Other GPU R&D activities

- Particle Flow for Run 3
- HGCAL reco for Phase 2. See Front. in Big Data 3 (2020) 591315 and Bruno Alves’ vCHEP talk

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- CPU w/ GPU offload yields $\sim 25\%$ increase in HLT throughput
- Tesla T4 does about $70\%$ of the work of $2 \times$ AMD Rome CPUs
- Costs $< 25\%$ as much
- Uses $< 20\%$ as much power
GPUs at ATLAS and CMS: Performance Portability

Major obstacle of GPU computing in HEP

- Different languages for and algorithm design for GPUs and CPUs
- Different languages between GPU vendors (e.g. CUDA, HIP)
- New accelerators may appear

Want native performance on many architectures with one codebase → implement GPU algorithms with “performance portability” APIs

- Kokkos
- alpaka
- oneAPI/SYCL

NB: ALICE and LHCb use their own lightweight wrappers for performance portability
GPUs at ALICE, ATLAS, and CMS vs. LHCb

**ATLAS and CMS**
- GPUs as coprocessors in software triggers
- Perform reconstruction for a few individual detectors

**ALICE**
- No software trigger
- Use GPUs for reconstruction and data compression

**LHCb**
- Full first level software trigger (HLT1) on GPUs
- 30 MHz of small events → unique I/O challenge
Allen is LHCb’s GPU-based first level software trigger (HLT1)

- Decode data from the VELO, UT, SciFi, and Muon systems
- Cluster detector data into “hits”
- Build tracks (VELO, UT, and SciFi)
- Find primary vertices (PVs) (VELO)
- Match tracks to Muon hits

Works as a standalone application or as part of LHCb’s software stack

Can be compiled for CPU or GPU with CUDA or HIP
Can process the full LHC event rate at LHCb with $\sim 200$ RTX 2080 Tis
Achieves the baseline HLT1 physics goals for Run 3
Both CPU and GPU software triggers meet the basic requirements for HLT1.

CPU-GPU decision requires a detailed cost benefit analysis.

GPU solution leads to cost savings on processors and networking.

Enough throughput headroom for additional features.

The final verdict: A GPU-based software trigger will allow LHCb to expand its physics reach in Run 3 and beyond.
Conclusions

- All four LHC experiments are using or studying GPUs in triggers and reconstruction
- The experiments utilize GPUs in very different ways
- GPUs have the potential to expand the reach of the entire LHC physics program

Thank you!

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Backup
GPU studies for Run 3

- **ATL-DAQ-PROC-2012-006**
- **ATL-DAQ-PROC-2016-035**
- Not cost-effective for Run 3 trigger
- Re-evaluating for Run 4 and beyond

Heterogeneous Computing Forum

- Accelerator R&D for online and offline
- ML projects
- FastCaloSim: arXiv:2103.14737
- **A Common Tracking Software (ACTS):** See e.g. arXiv:1910.03128