CMS Level-1 trigger Data Scouting for online trigger-less data processing

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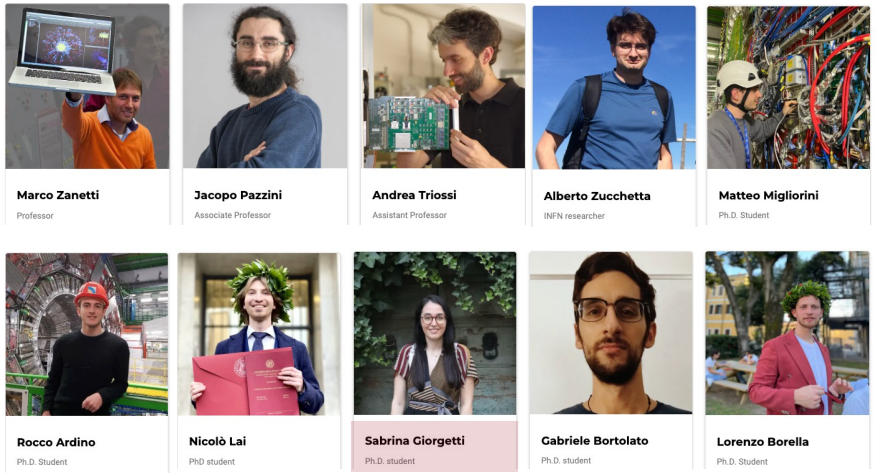
Introduction

Research group

- Our team is mainly active in the CMS experiment at the Physics and Astronomy Department of the University of Padova
- Closely collaboration with CMS DAQ and Level-1 trigger groups

BOOSTLab



Involvement in ICSC Spoke2

- Activities concerning FPGAs at various level within the **WP4**
- Training courses: Introductory course to HLS FPGA programming & Porting of GPUs of code an algorithms
- Flagship use case UC2.2.3: Ultra-fast algorithms running on FPGA (FAST_FPGA)
  - **Scouting and processing of Level-1 trigger data using FPGA to run on-the-fly momentum object calibration with ML-based algorithms**
  - Online reconstruction algorithms for data scouting
  - Development and testing of RDMA over converged ethernet (ROCE) on FPGA for data transfer from detectors' front-end to computing servers
  - Development of quantum-inspired Tree Tensor Networks for classification in Trigger on FPGA

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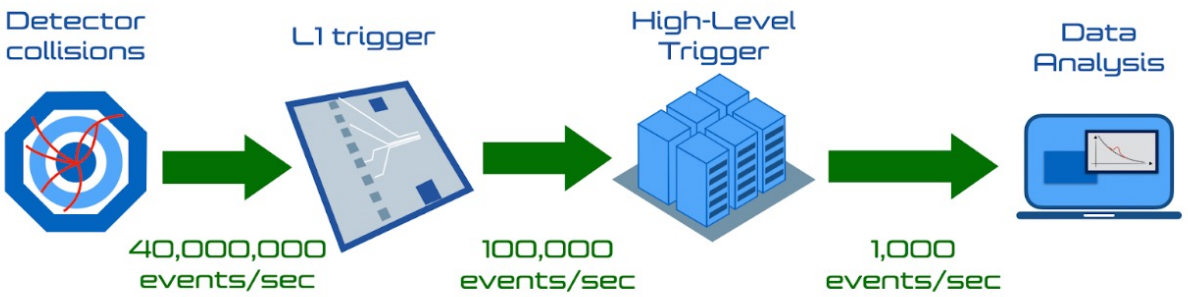
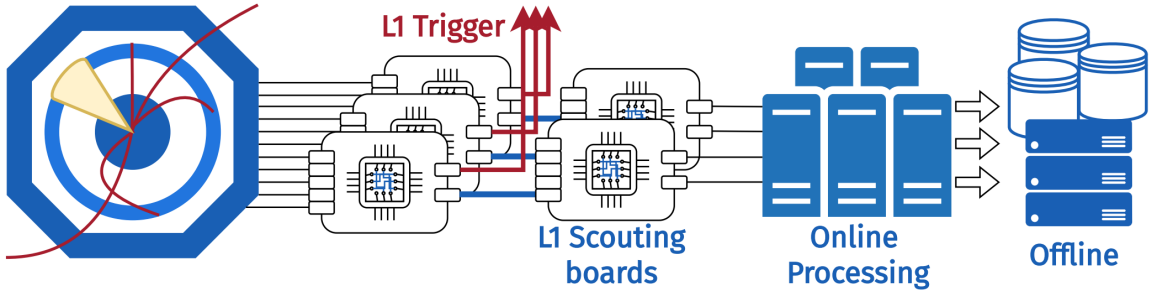
40MHz Scouting for online trigger-less data processing



CMS data flow



Level-1 Scouting data flow

The CMS data flow

- Massive data flow (TB/s) from pp collisions at the LHC
- CMS employs a two-level trigger system to select events of physics interest to store for analysis
- Events rejected at the trigger levels are lost: what if new physics was there?
  - ↠ Reduce the bias of new physics searches with a triggerless infrastructure

Phase-2 Level-1 Data Scouting (L1DS)

- Scouting: acquisition of reduced-event-content data at considerably higher rates than the standard accept rate
- The L1DS is a novel data acquisition system under development for CMS Phase-2 at the HL-LHC
- L1DS read out the L1 trigger objects at the full bunch crossing (BX) rate of 40MHz with the aim of performing online physics analysis
- Potential ranges from improving trigger diagnostic to enabling the study of otherwise inaccessible signatures

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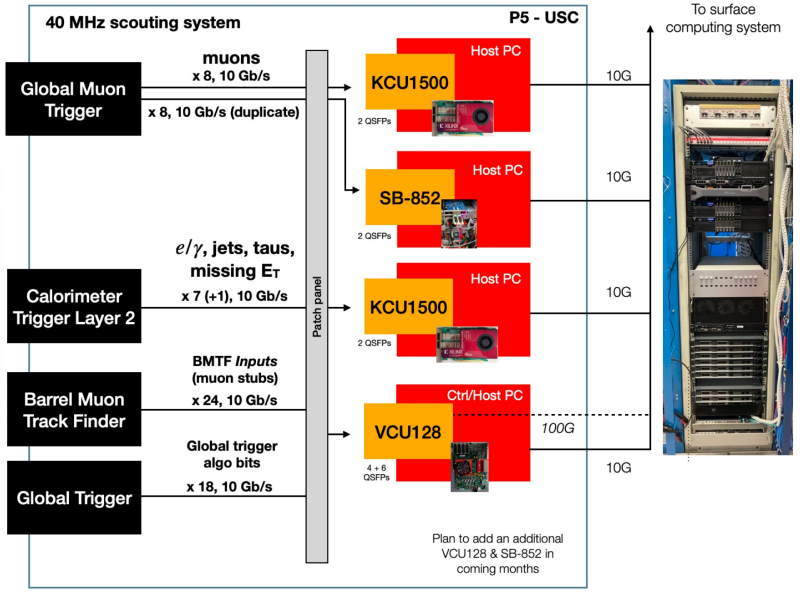


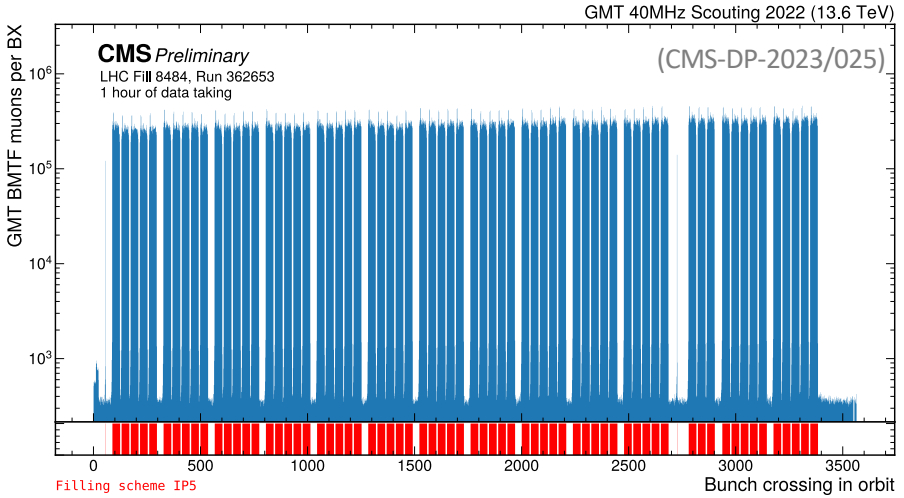
40MHz Scouting demonstrator for LHC Run-3 (2022-2025)

- Demonstrator tested as proof of concept with three types of FPGA-based receiving boards
- Acquisition of L1 trigger primitives at the full BX rate from multiple sources:
  - Global Muon Trigger (GMT): **up to 8 GMT muons**
  - Calo Layer 2 (DeMux): **Up to 12 e/γ, jets, τ and missing E_T**
  - Barrel Muon Track Finder (BMTF): **BMTF inputs**
  - Global trigger (GT): **GT algorithm bits**

Studies for the 40MHz Scouting demonstrator

- Characterization of data collected by the system
- Computing models for online/offline analysis
- Exploration of distributed frameworks for data analysis:

  1 min of L1DS ⟹ 2.5GB of unpacked GMT data (parquet)
  - CERN Spark cluster within the CERN SWAN platform
  - Distributed RDataFrame with Spark/Dask back-end



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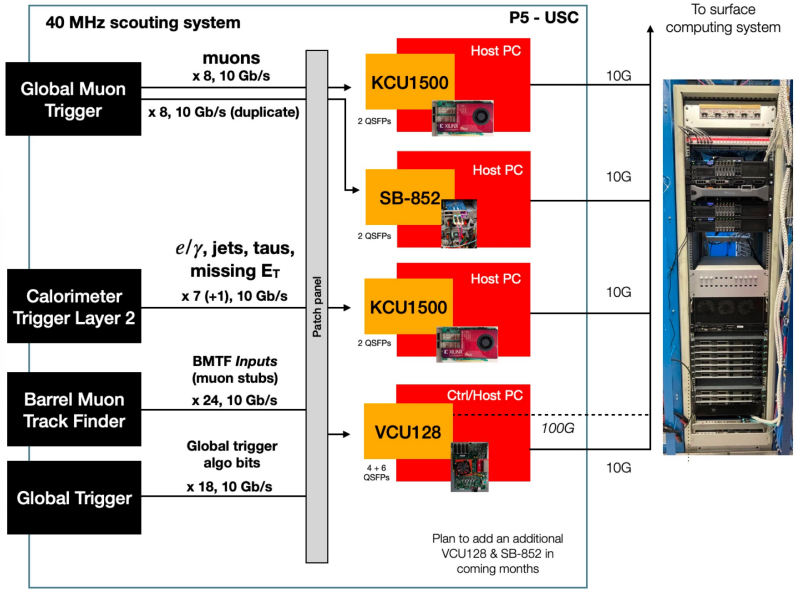

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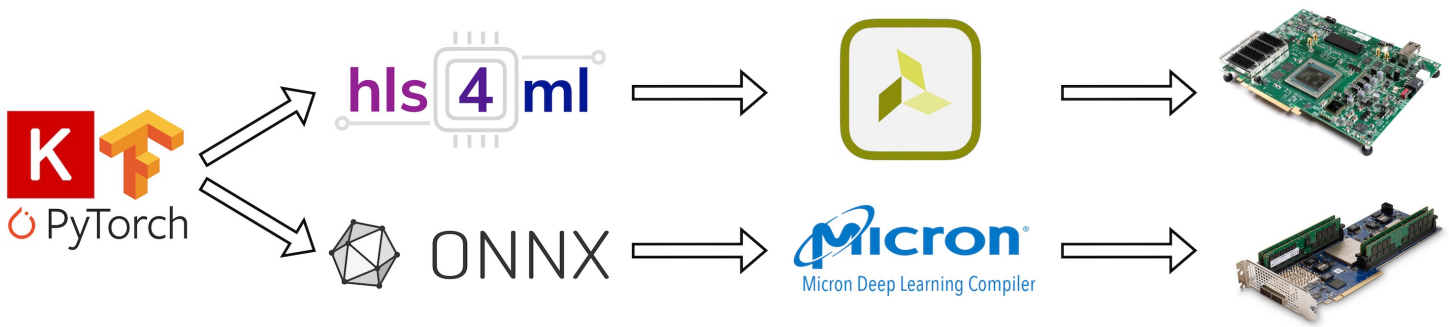
- For close-to-real-time analysis ML algorithms can be developed in hardware for the 40MHz Scouting pipeline



ML pipeline for the 40MHz Scouting system

- `hls4ml`: firmware implementations of machine learning algorithms using high level synthesis language (HLS)

- `Micron Deep Learning Accelerator` (MDLA): Micron proprietary inference engine to run ML models on FPGAs

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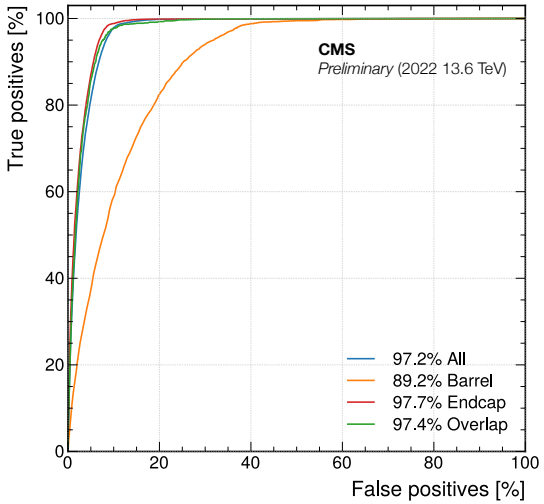
Deep learning on FPGAs for L1DS

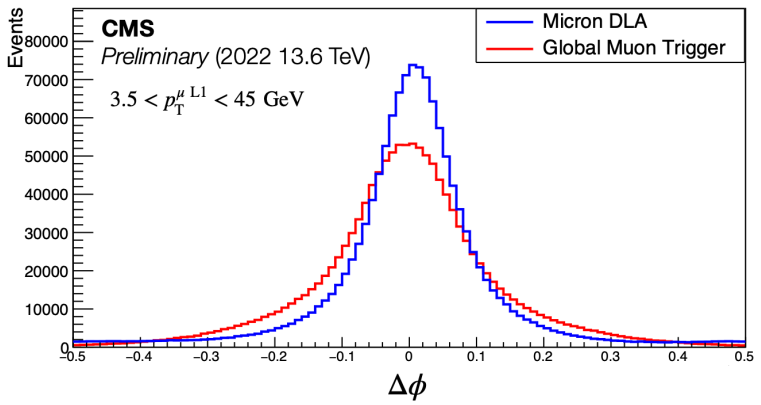
Recalibration of L1 muons

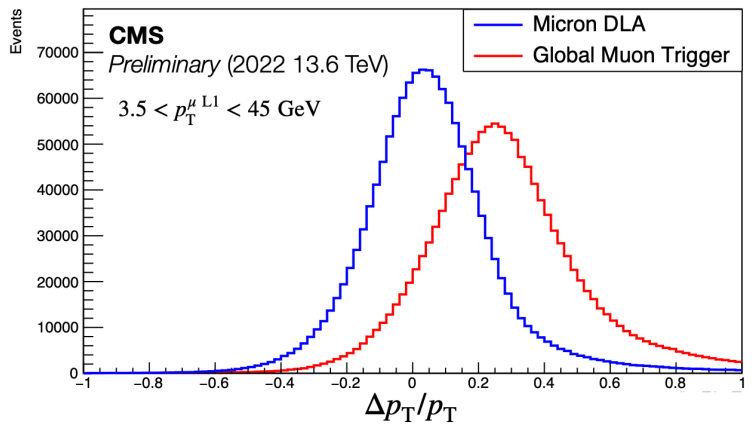
- Limited resolution of the trigger objects: no tracker information plus calibrated for a given efficiency at threshold
- Improve calibration for for a physics analysis
- Use the offline reconstructed (RECO) objects as the learning target of a neural network (NN)
- First implementation in a test setup with the MDLA hardware and collision data collected at the start of LHC Run-3

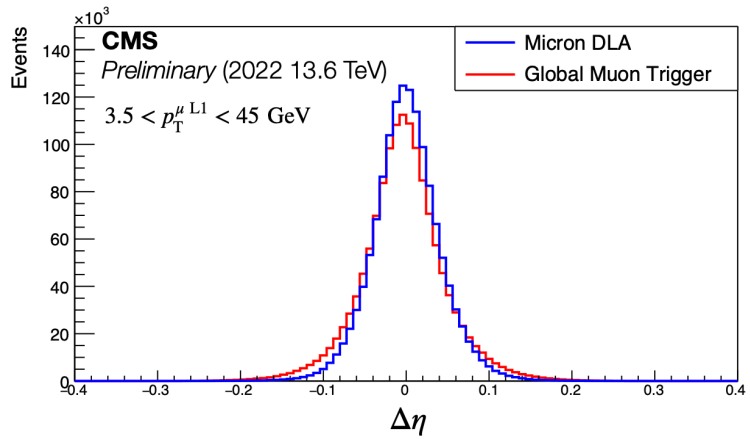
Muon pairs classifier

- Trained a NN for binary classification to distinguish real/fake L1 muon pairs
- Real (fake) → muon (not) matched to a RECO track
- Employ a classifier to select higher purity samples for study of di-muon events









The distribution of differences between the Micron Deep Learning Accelerator (MDLA) prediction (or GMT) values, and the offline reconstructed muon tracks.

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Conclusions and outlook

CMS Level-1 trigger Data Scouting for online trigger-less data processing

- Continuous efforts in advancing trigger-less data acquisition and processing techniques.
- Ongoing development addressing both firmware (receiving streams from L1 boards) and software aspects (online and offline computing models).
- First promising deployment of ML implementations on FPGA targeting L1 Muon objects:
  - NN models for calibration and fake detection
  - Exploring the potential to extend ML algorithms beyond L1 Muon objects
  - Current focus on transitioning to Xilinx VCU128 boards and `hls4ml`

More on the other activities of the group

Online reconstruction algorithms for data scouting

- Data scouting of new CMS Drift Tubes Front-End electronics with FPGA-based boards
- CHEP2023 – M.Migliorini et al *"Triggerless data acquisition pipeline for Machine Learning based statistical anomaly detection"*

Development and testing of RDMA over converged ethernet (RoCE) on FPGA for data transfer from detectors' front-end to computing servers (FERoCE)

- Dynamic simulation implemented and now working towards RoCEv2 with UDP/IP transport protocol targeting Xilinx VCU118
- TWEPP23 – G.Bortolato et al "Front-End RDMA Over Converged Ethernet, real-time firmware simulation"

Development of quantum-inspired Tree Tensor Networks for classification in Trigger on FPGA

- Project in its initial phase, synergy with colleagues from CN1 Spoke 10

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