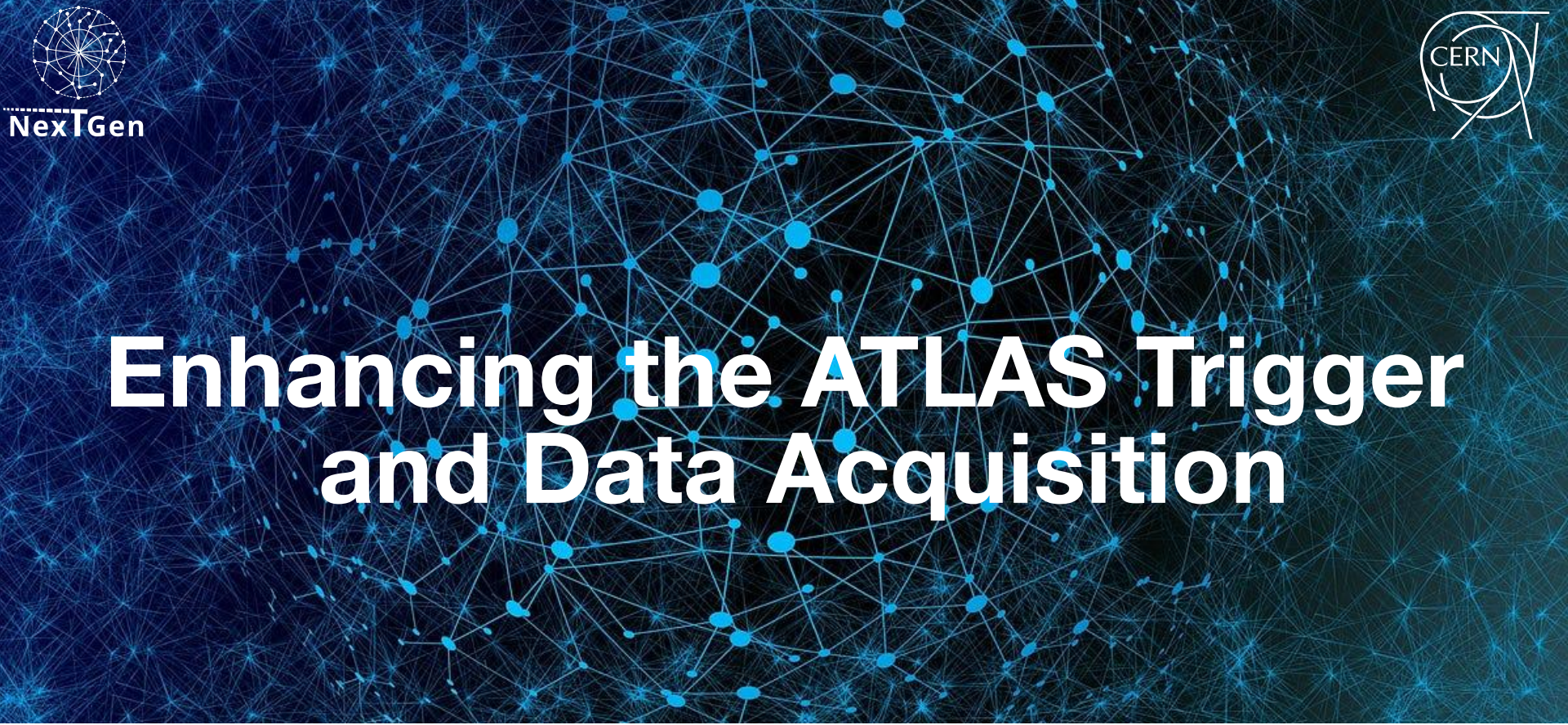


Enhancing the ATLAS Trigger and Data Acquisition

ATLAS Work Package 2 Report

Stefano Veneziano, Markus Elsing

24 September 2024,
NGT Workshop

NexTGen
Next Generation Triggers

ATLAS WP2 in the Context of NGT

Overall project structured in four work packages (WPs)

WP1 Common infrastructure

- Provision of hybrid structure to be deployed by CERN IT
- Framework developments
- **Hardware Aware Neural Architecture Optimisation**
- **HLS4ML developments**
- Quantum Tensor Networks for simulation of quantum many body
- Generator and HO calculations, new physics scenarios
- **Framework integration of accelerators**.

subject of this talk

WP2 ATLAS

1.- ML based algorithms at L0Global level.

2.- Enhancing L0Muon trigger with MDT use beyond current scope

3.- Optimisation of high throughput data collection.

4.- Enhancing EF tracking (classical/GNN) on optimal architecture.

5.- EF Muons track reconstruction migration to ACTS with novel alg.

6.- Development and optimisation of common ACTS infrastructure.

7.- EF reconstruction to enhance physics capability.

WP3 CMS

1.- Real time reconstruction and development of optimised data structure for extreme throughput

2.- Replace the trigger filtering task with an event processing similar to what happens with offline events stored on disk.

3.- Scouting at L1 and Practical AI algorithms for L1.

4.- Reduction (compression) of data size for HLT and L1 scouting data.

5.- Optimised calibration for HLT and real time analysis.

WP4 Education and outreach

- Promote exchanges across computer scientists and physics researchers, academia and industry.
- Training program in data science and AI for next generation of high energy physicists, including an AI and data science school
- Leverage the rich ecosystem of education programmes across HEP and computer sciences communities to provide targeted specialisation paths for new researchers

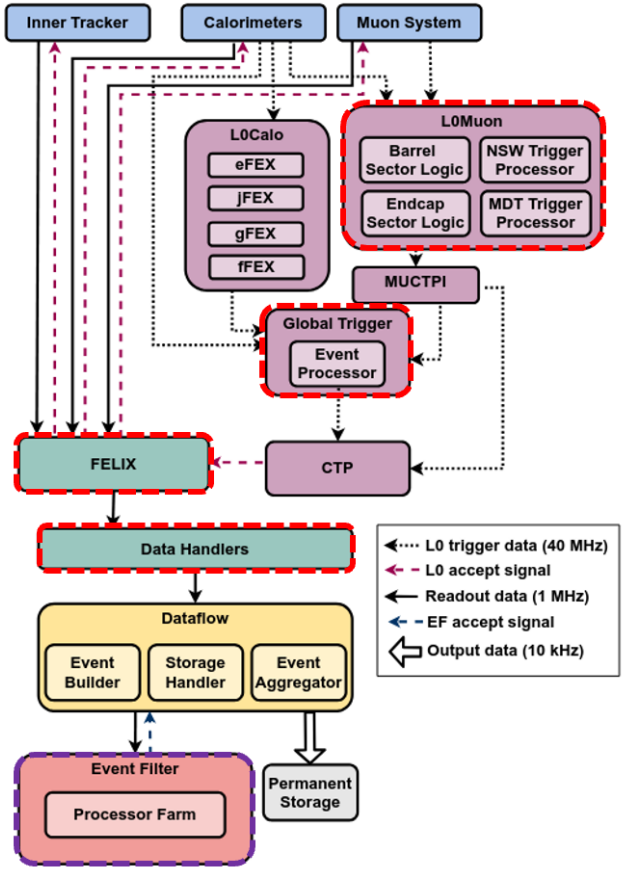
WP2 Tasks in the Context of ATLAS Phase-II T-DAQ

Diagram shows the overall T-DAQ architecture for Phase-II

- ATLAS WP2 focusses on **R&D,** novel **(AI) approaches** and **innovation** for several sub-systems (dotted boxes)

ATLAS NGT work package tasks cover:

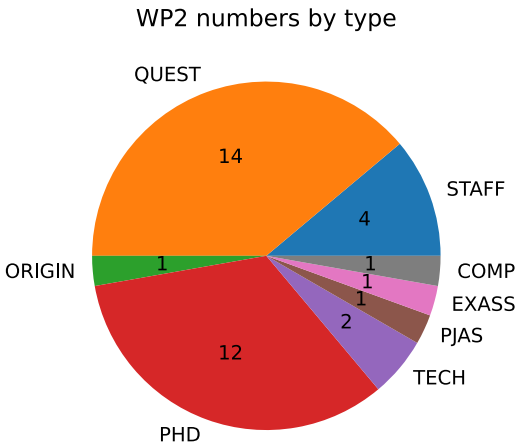
- **Level-0** hardware trigger: **L0Muon (WP2.2)** and **Global Trigger (WP2.1)**
- **FELIX** readout and **Data Handlers (WP2.3)**
- **Event Filter** event processing: **Track reconstruction** in the **ITk (WP2.4)** and **Muons (WP2.5),** plus **ACTS** tracking infrastructure **(WP2.6)**
- Novel trigger **signatures** and **physics optimisation (WP2.7)**

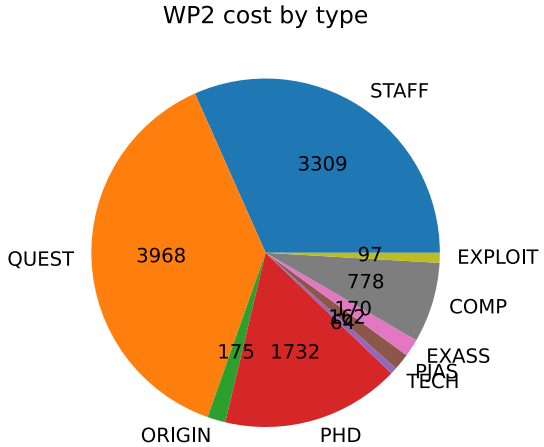


WP2 Hiring Status and Plans

WP2 hiring plan was adjusted for real funding and costs

- CHF/USD rate, real costs and overheads...





Total of 33 positions, hiring just completed for 2024

- 4 LDs, 8 QUESTs, 1 Origin, 3 PhDs and 2 TECHs
- Most of them started on June and July!

Highlights of WP2 Work ongoing / starting

Work on WP2 is just ramping up

- Activities are embedded in ATLAS T-DAQ groups and naturally benefit from previous and ongoing work

In the following I will go over a number of early highlights

- To structure it a bit, I will try to roughly **categorise** it into 3 types of activities:

Investigating new innovative R&D lines for algorithms and technologies

Providing support for and enabling of novel approaches and technologies

Collaborating on and adding to existing ATLAS R&D activities

- Work is carried out having the **WP2 milestones in 2024** in mind, but not focus on this talk today

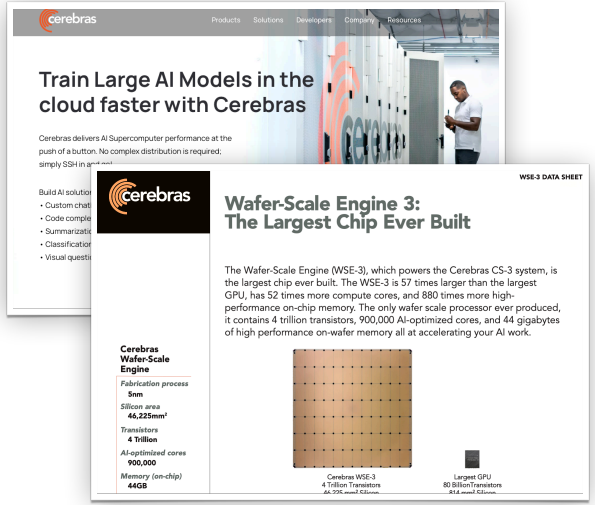
Computing and Collaboration with WP1 and WP4

We actively collaborate with WP1 and WP4

- Strong interest in results of **WP1.7** for the support of heterogeneous architectures
- Collaborating with **WP1.2** and **WP1.3** on HLS4ML and on the hardware aware ML architectures
- **WP1.1** is already providing us with HW resources, see below
- Intending to collaborate with **WP1.6** on New Physics and other trigger scenarios, as said before
- We are already benefitting from the training opportunities provided by **WP4** to our people

WP2 work benefit directly from computing resources made available to us

- Starting to actively use **IT resources** made available to us, for ML training and GNN deployment studies, first results are available based on it
- NGT people benefit as well from ATLAS and CERN **T-DAQ resources and test-beds** at CERN
- Collaborating with **Openlab** to get access to further HW architectures, e.g. Cerebras AI

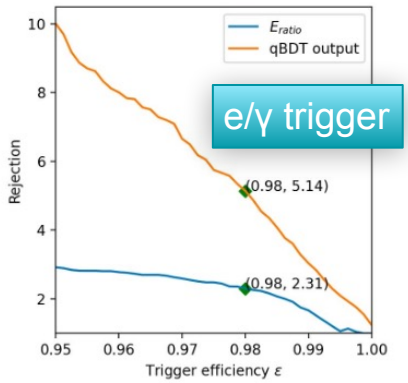


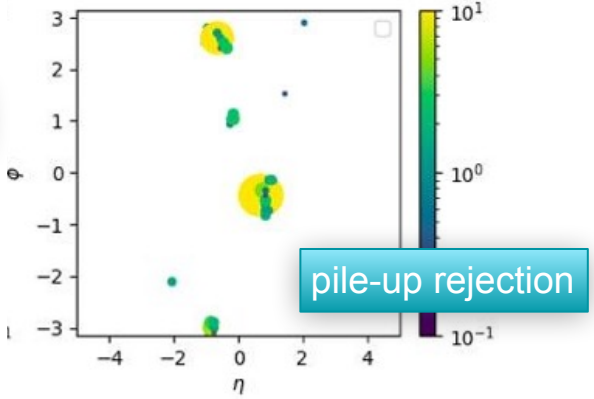
WP2.1: (L0) Global Trigger (I)

Task Leaders: D. Miller (Chicago), N. Konstantinidis (UCL) **Team:** I. Xiotidis (CERN)

Examples for ongoing ATLAS R&D on ML based L0 global trigger selections:

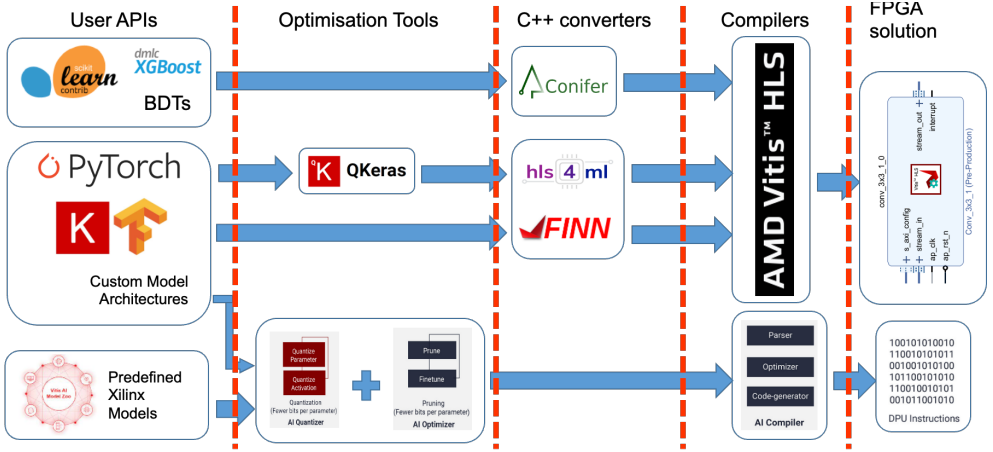
- BDT for L0 e/γ trigger selection
- CNN based pile-up rejection
- CNN based large-R jet tagging





ATLAS is investigating different pipelines to bring the ML approaches onto FPGAs

- WP2.1 explores **automating those pipelines** and potentially unifying then under a common framework



WP2.1: (L0) Global Trigger (II)

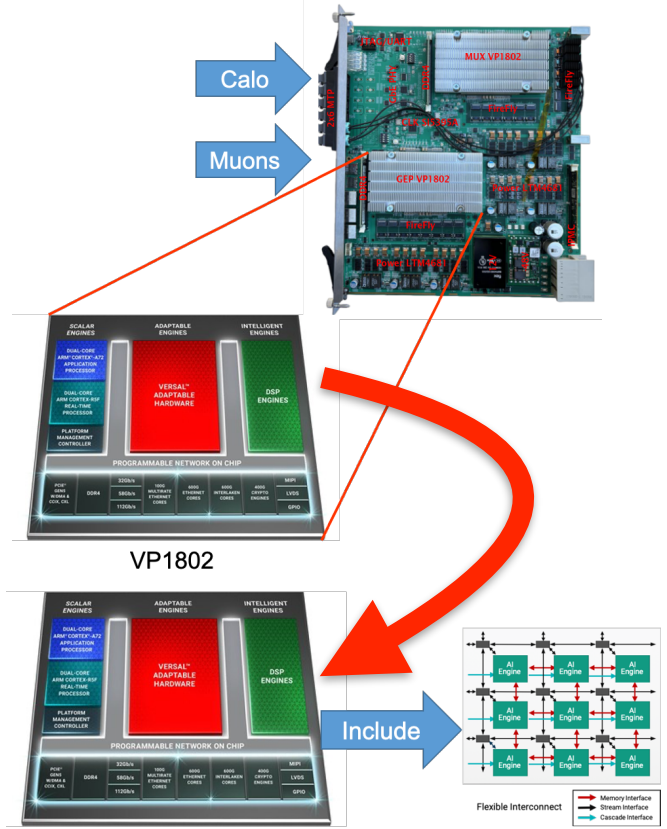
Task Leaders: D. Miller (Chicago), N. Konstantinidis (UCL) **Team:** I. Xiotidis (CERN)

Investigating new technologies:

- Global Common Module (**GCM**) hosts a Versal Premium device (**VP1802**) due to the big amount of input/output
- FPGA provides limited resources of ML algorithms
- AMD released a pin compatible package (**VP2802**) which includes dedicated AI engines

Planning to procure a prototype GCM with AI engines

- Will be installed in **L0Global test-bed** for detailed studies of ML based trigger strategies



WP2.2: L0 Muon Trigger

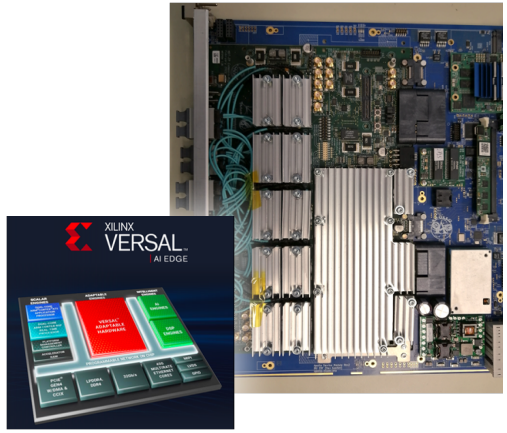
Task Leaders: O. Kortner (MPP) , V. M. Outschoorn (UMass) **Team:** M. Carnisale (CERN), R. R. Caballero (CERN)

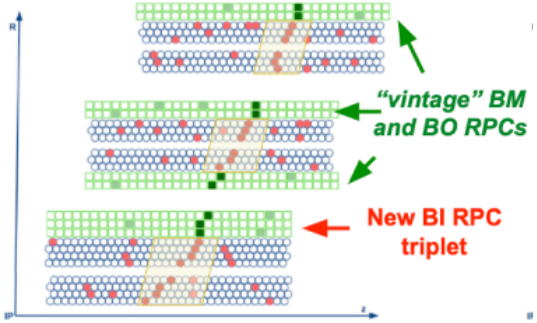
Improve robustness of L0 muon trigger against RPC aging, and improve overall acceptance

- Extend baseline algorithms and R&D on **ML** approaches
- Non-pointing (**exotic**) signatures, close-by muons, ...
- Benefit from **new RPCs** and **full MDT** information
- Target the Phase-II L0Muon standard FPGA package (**VU13P**) making use of **HLS4ML**, investigate alternatives if needed

Current activities

- MDT L0 trigger and exotic signature studies started with **sample production**
- **Initial studies** of ML approaches and signal characteristics





Pattern recognition algorithms to identify the regions of interest with only MDT hits

WP2.3: High Throughput Data-Collection

Task Leaders: T. Wengler (CERN), W. Vandelli (CERN) **Team:** C. Gottardo (CERN), M. Shehu (CERN)

Focus on improving the readout capabilities of ATLAS

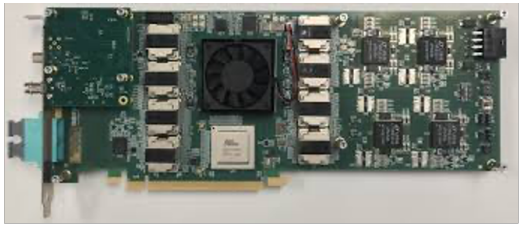
- Optimise the readout **firmware** for performance and address **bottlenecks** in the system
- Optimise current **ATLAS baseline** and study/evaluate **new architectures**

Exploring market solutions in SW and non-standard HW

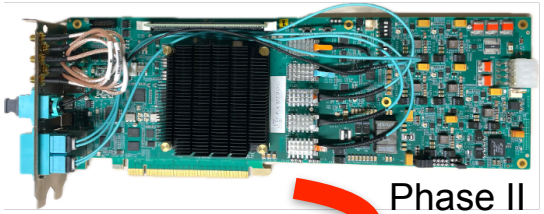
- Identifying required **lab setups** and defining baseline for comparisons

Ongoing work

- Optimisation of **network buffer format**
- Added **support** for ITk Pixel configuration
- Tested monitoring and integration with **external hardware**
- Tested of 46 **prototype cards** produced for detector integration
- To procure a prototype **host server**



Phase I



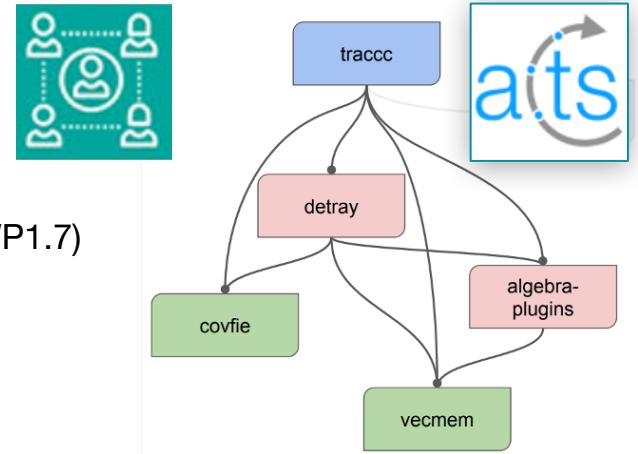
Phase II

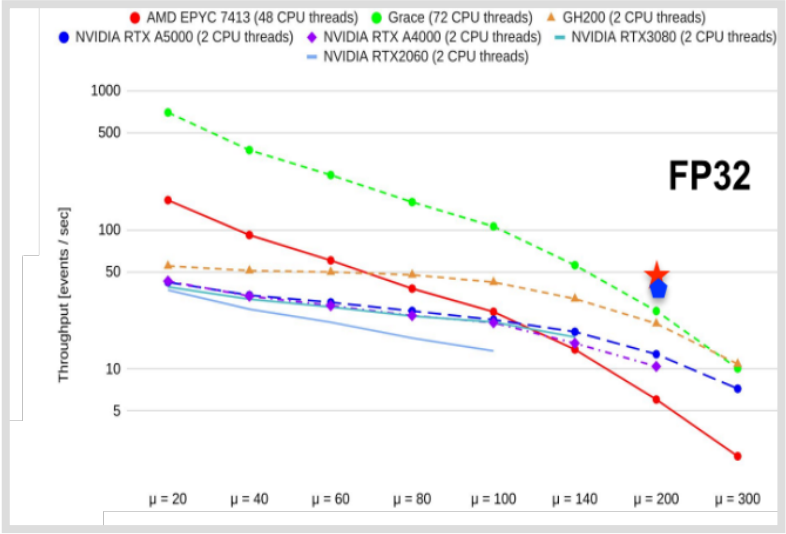
WP2.6: ACTS Event Filter Tracking Infrastructure

Task leaders: A. Salzburger (CERN), A. Krasznahorkay (CERN) **Team:** P. Gessinger (CERN) S. Swatman (CERN) F. Barba (exCERN)

Goal is to provide ACTS based EF tracking infrastructure to enable WP2.4 and WP 2.5 developments

- Strongly benefits from work within the **ACTS** open source project
- Support for integration of **accelerators** for the track reconstruction (see WP1.7)
- Participate in R&D like **TRACCC** GPU tracking and **GNN4ITk** (see WP2.4)





Obtained first performance results on full TRACCC chain

- Single **source code** for CPU and GPU deployment
- First TRACCC **throughput studies** on different GPUs and CPUs
- Currently still on the Open Data Detector (**ODD**) enabling R&D
- Early results, compare to **ACTS CPU** tracking chain throughput for ODD (★) and full ITk (●) on EPYC server

WP2.6: TRACCC with alternative Kalman Filter

Task leaders: A. Salzburger (CERN), A. Krasznahorkay (CERN) **Team:** P. Gessinger (CERN) S. Swatman (CERN) F. Barba (exCERN), M.E. (CERN)

TRACCC project strives to port ACTS tracking strategy onto GPU

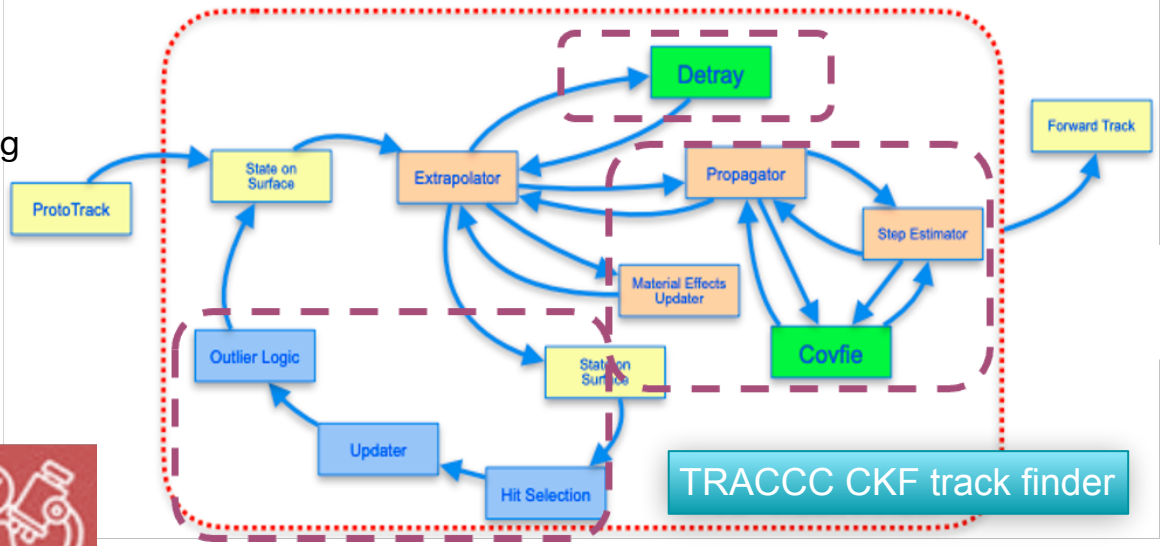
- Track finder using complex Combinatorial Kalman Filter (**CKF**) track finder
- Led to developments like:

  DETRAY - GPU track extrapolation, geometry and material modelling

  Covfie - B-field vector GPU library

New proposal to disentangle track propagation from Kalman filtering

- Based on **alternative** mathematical **formalism** for Kalman Filter



WP2.4: Event Filter ITk Reconstruction

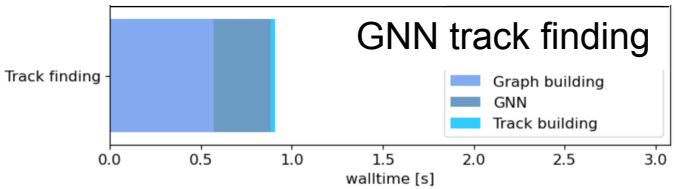
Task leaders: N.Calace (CERN), S. Majewski (Oregon) **Team:** P. Butti (CERN), B. Huth (CERN), J. Wollrath (CERN)

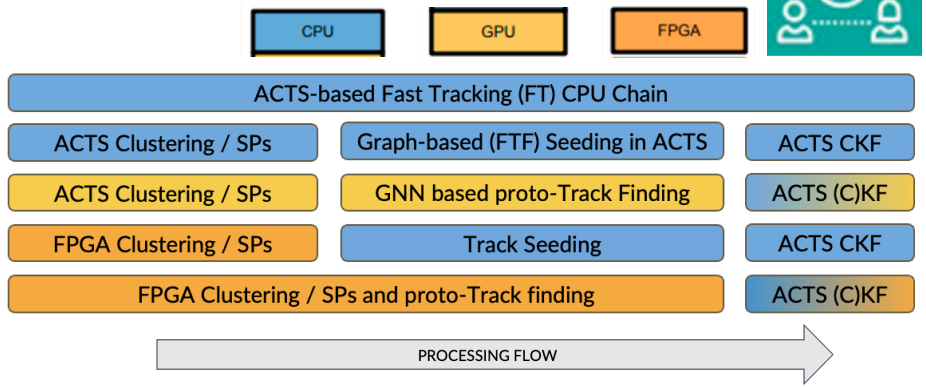
ATLAS to decide Event Filter technology in 2025

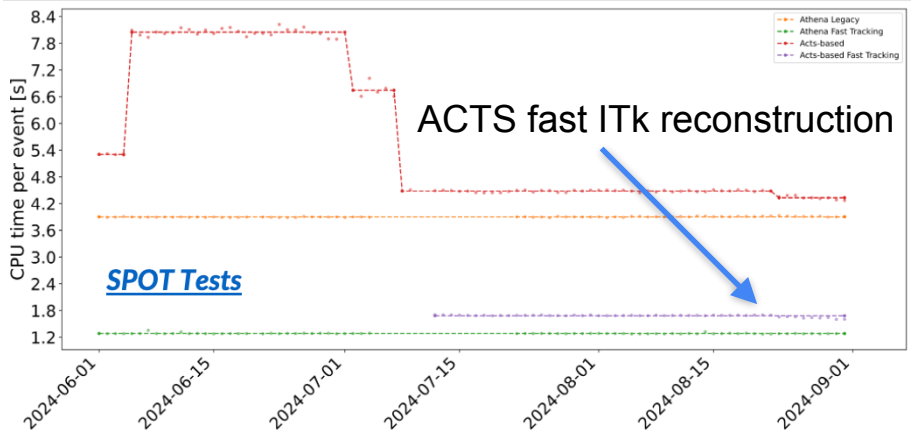
- WP2.4 currently contributing to R&D for number of chains
- Bringing **ACTS fast tracking** to production level
- Investigate use of **GPU** and **FPGA** processors and studying **GNNs** as an alternative track finding approach

Enabling integration and R&D work

- Development **support** for CPU aspects of FPGA chains
- ACTS fast ITk reconstruction no integrated in automated ATLAS **SPOT CPU monitoring**
- First results of **GNN track finding on A100**







WP2.5: Event Filter Muon Reconstruction

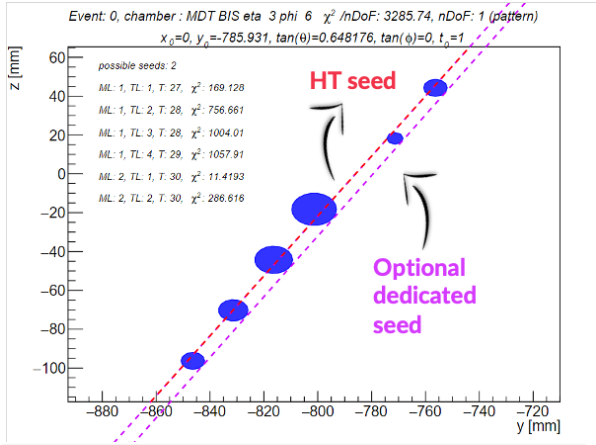
Task leaders: M. Owen (Glasgow) E. Moyse (UMass) **Team:** J. Junggeburth (CERN), D. Di Croce (CERN)

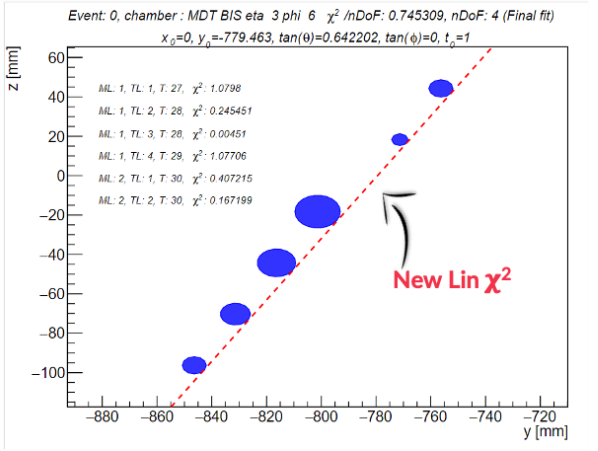
Goals for the EF Muon Reconstruction

- Develop an **ACTS based** Phase-II muon tracking for the EF
- Investigate novel (**ML**) algorithmic approaches for finding standard and **exotic muon signatures**

Current activities

- **Integrate** current ACTS based software into ATHENA muon chain and study its performance
- Develop a **novel segment finder** based on a **Hough Transform** (HT) and a novel linearised χ2 muon **segment fit**





WP2.7: Enhanced Event Filter Trigger Selection

Task leaders: M. E. Goblirsch-Kolb (CERN) A. Sfyrla (Geneva) **Team:** G. R. Boero (CERN), C. Sauer (CERN), T. Critchley (CERN), E. Staff (NTNU)

Scope is

- Develop novel **trigger signatures**, taking benefit of the work of **L0** (WP2.1, WP2.2) and **Event Filter** (WP2.4, WP 2.5)
- Collaborate with **W1.6** on **New Physics scenarios** and **Standard Model** trigger benchmarks
- Advanced **ML** approaches to boost trigger performance

Current activities

- Investigate **BSM scenarios** and **HH** with coupling modifiers
- Work starting on new trigger selections at L0 and EF using ML for e.g. **anomaly detection**
- Developing an **trigger analysis kit** to studying Phase-II signals acceptances, rates and efficiencies

We have started a survey (in cooperation with PPES) to collect feedback from analysis groups concerning trigger limitations and novel concepts

WP2.4/7: Exploring Level-1 Trackless b-Tagging

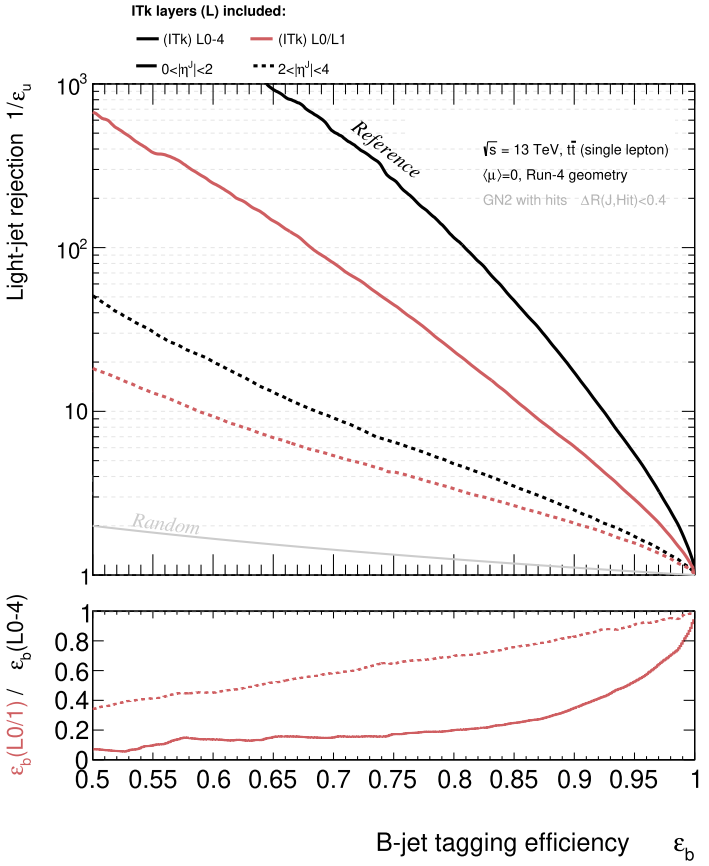
Team: P. Butti (CERN), C. Sauer (CERN), M.E. (CERN)

ATLAS foresees to replace 2 inner pixel layers half way through Phase-II

- May possibly use novel technologies
- Interesting R&D on monolithic **4D sensors**

Question: trigger prospects for trackless b-tagging with 4D inner pixel layers and a faster readout ?

- **Not an ATLAS official project**, would require a **L0-L1 scheme**
- Study leverages initial hit based b-tagging studies using offline ATLAS **GN2 transformer** approach
- Initially study of **trackless b-tagging** using zero pile-up to see if there is potential (work in progress)



NexTGen

Questions?

WP2 Milestones 2024

Financial Milestones in **RED**

- **WP 2.1: Develop framework/toolkit for optimizing ML algorithms in terms of physics performance vs. FPGA resource vs. latency.**
  - Deliverable: Groundwork for the development and optimization work.
- **WP 2.2: Conceptual study of different extensions of the L0 MDT trigger: RPC seed, addition of Tile seed, exotic signatures. Develop initial algorithms and estimate performance.**
  - Deliverable: Understand the challenges and potential solutions for each of the scenarios.
- **WP 2.3: Perform the team hiring and set the basis for the project. In particular perform a market survey of the existing technologies and understand the requirements in terms of hardware infrastructure.**
  - Deliverable: Team hiring. Downselection of promising technologies. Definition of the required lab setups.
- **WP 2.4: Review of existing Event Filter Tracking approaches, with particular emphasis on advanced Machine Learning methods. Implementation of suitable Machine Learning based models and contribute to the AI/ML optimisations for Event Filter Tracking.**
  - Deliverable: Identify areas of potential improvements among existing approaches and possible complementary methods.
- **WP 2.5: Measure the performance of the existing Muon Event Filter.**
  - Deliverable: Understanding of the current algorithm bottlenecks and hotspots.
- **WP 2.6: Review status of the ACTS CPU baseline and outcome of the ACTS R&D line on parallelization, identify and define showcase examples for data transfer pattern and algorithm execution and optimize them. Execute first test examples with different host/device workloads.**
  - Deliverable: Arrive at an understanding of work areas that have no, partial or full solution coverage. Definition of candidate algorithmic pipelines and necessary support software.
- **WP 2.7: Identify promising use-cases to benefit from enhanced EF reconstruction, by evaluating existing physics studies and performing new evaluations of interesting scenarios.**
  - Deliverable: Identify where enhanced EF reconstruction can yield largest benefits to physics sensitivity.

ATLAS WP2 Task Descriptions in a Nutshell (I)

as a reminder

Task 2.1 - Optimal Real-Time Event Selection in the (L0) Global Trigger system

- Global Trigger aims at **offline-like reconstruction** in hardware on **full-granularity** calorimeter data in real-time at 40 MHz
- **Novel ML-based** calorimeter reconstruction to be developed and implemented in **firmware**

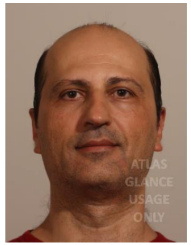
Task 2.2 - Enhancing the Level-0 Muon Trigger

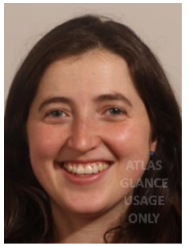
- **Robustness** of L0 muon trigger against **aging RPC detectors** and increase acceptance coverage
- Hence, seed trigger on **smaller number of RPC chambers** and rely on full **MDT information** to resolve candidates
- Additional trigger strategies for **non-pointing signatures** from decay of long-lived exotic particles
- Implement novel trigger strategies in **firmware**

Task 2.3 - High Throughput Data-Collection

- Optimise the readout **firmware** for performance and address bottlenecks in the system, to fully exploit the physics potential of the **novel L0 trigger** approaches developed in WP2


David Miller


Nikolaos Konstantinidis


Verena Ingrid


Oliver Kortner


Wainer Vandelli


Thorsten Wengler

ATLAS WP2 Task Descriptions in a Nutshell (II)

as a reminder

Task 2.4 - Event Filter Tracking

- **Classical** numerical and **ML techniques** for Event Filter tracking, deploy it on the best fitting hardware architecture (CPU/GPU/FPGA), base reconstruction on **ACTS infrastructure (**Task 2.6)
- Classical **CKF** based tracking, **TRACCC** on GPUs, **GNN** based tracking GPUs (and FPGAs), purely **FPGA-based** approaches

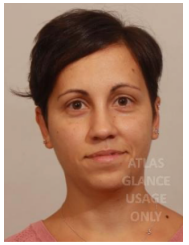
Task 2.5 - Optimised Event Filter Muon Trigger Selection

- Exploit the novel **L0 muon trigger** (Task 2.2) and the **ACTS infrastructure** (WP2.6) improve the physics performance of the **Event Filter muon** track reconstruction
- **Novel ML based reconstruction** techniques to improve over classical algorithmic chain

Task 2.6 - Common Event Filter infrastructure

- **ACTS based infrastructure** for Event Filter tracking, open-source SW shared across experiments
- Enable transparent algorithm **offloading** onto **hardware accelerators** (builds on **WP1.7**)


Stephanie Majewski


Noemi Calace


Edward Moyse


Mark Andrew Owen


Attila Krasznahorkay

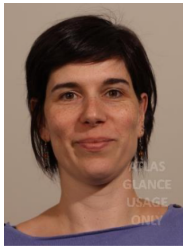

Andreas Salzburger

ATLAS WP2 Task Descriptions in a Nutshell (III)

as a reminder

Task 2.7 - Enhanced Reconstruction for Higher Level Event Filtering

- Novel algorithmic approaches to trigger on **exotic particle signatures**
- **Exploit** physics potential of the **L0** (WP2.1, WP2.2) and **Event Filter** (WP2.4 and 2.5)
- **Collaborate with WP1.6** on New Physics scenarios and Standard Model trigger benchmarks



Anna Sfyrla

Maximilian Emanuel Goblirsch-Kolb

ATLAS WP2 task leadership is shared between CERN team members and (external) ATLAS T-DAQ experts

- Also facilitates close **integration** of NGT R&D program within the overall ATLAS Phase-II upgrade activities !