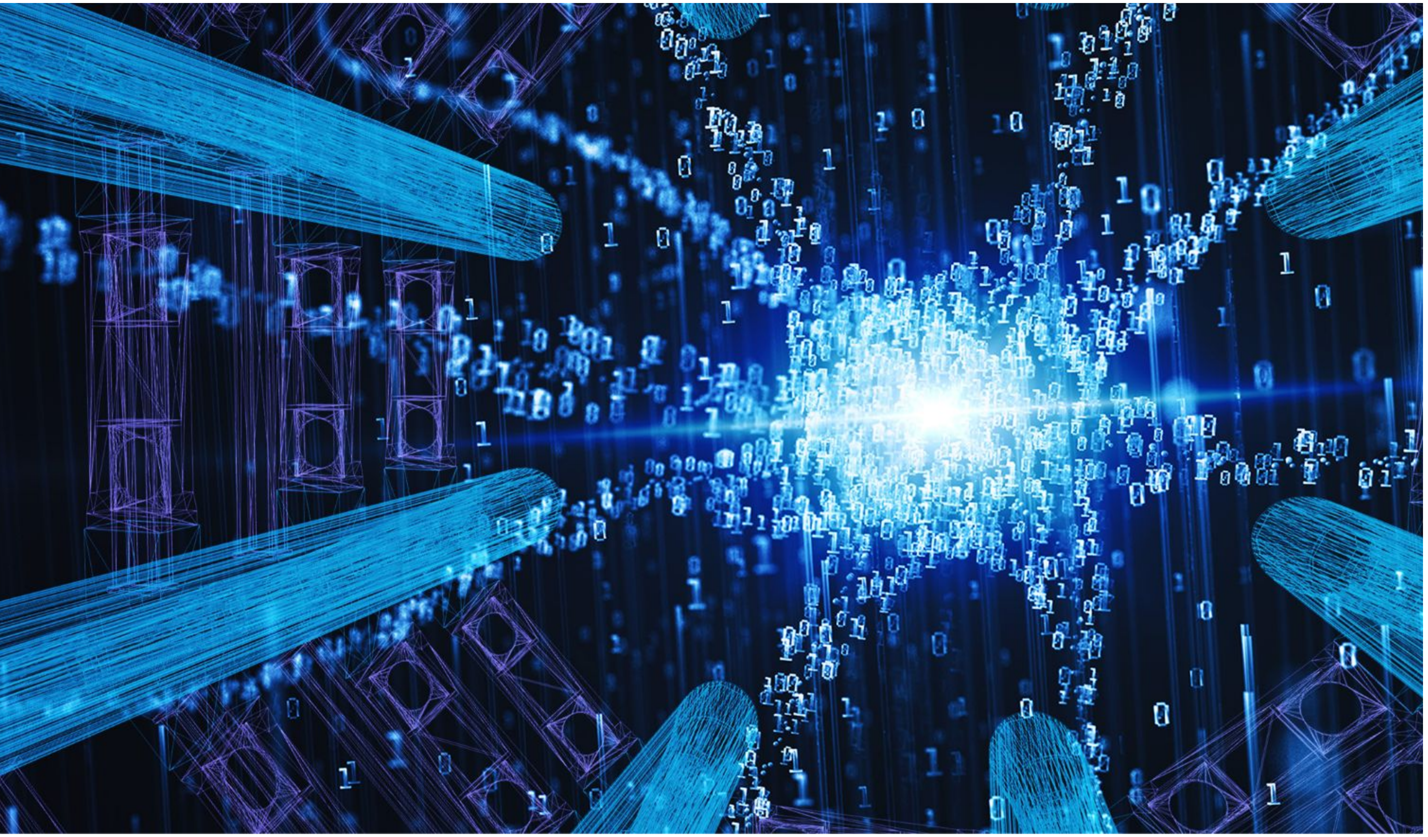
NGT & ATLAS

Noemi Calace
on behalf of the WP2 team

BSM benchmarks for Next Generation Triggers
4 July 2025

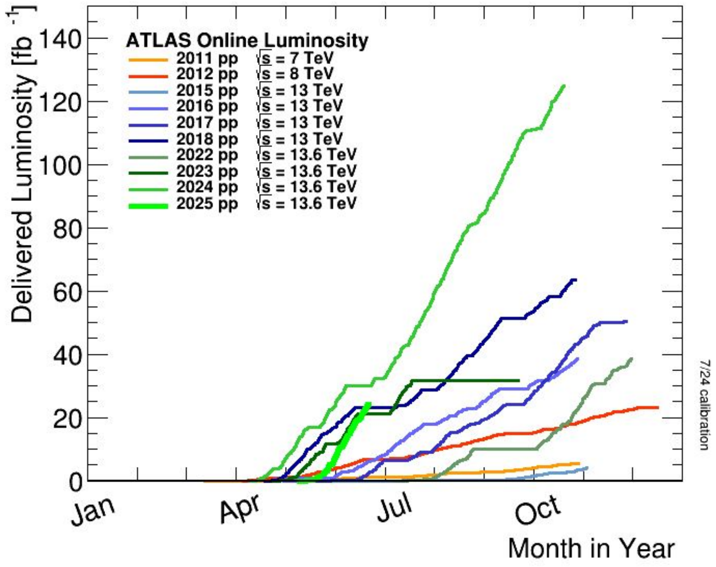
Outline of this talk

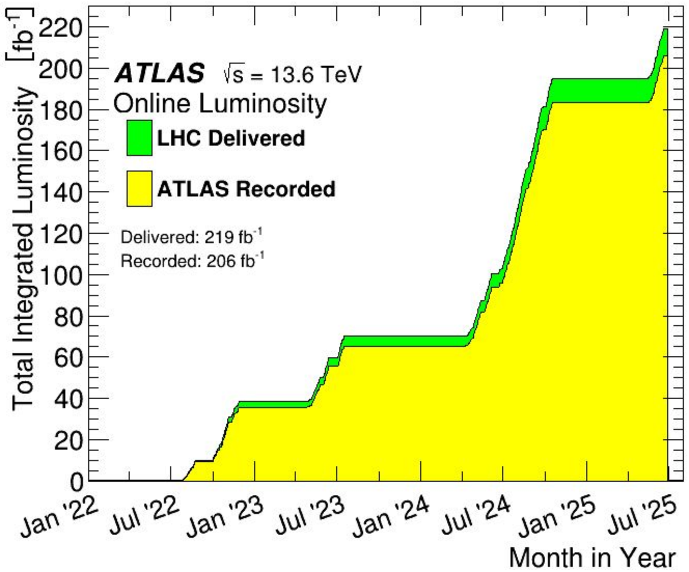


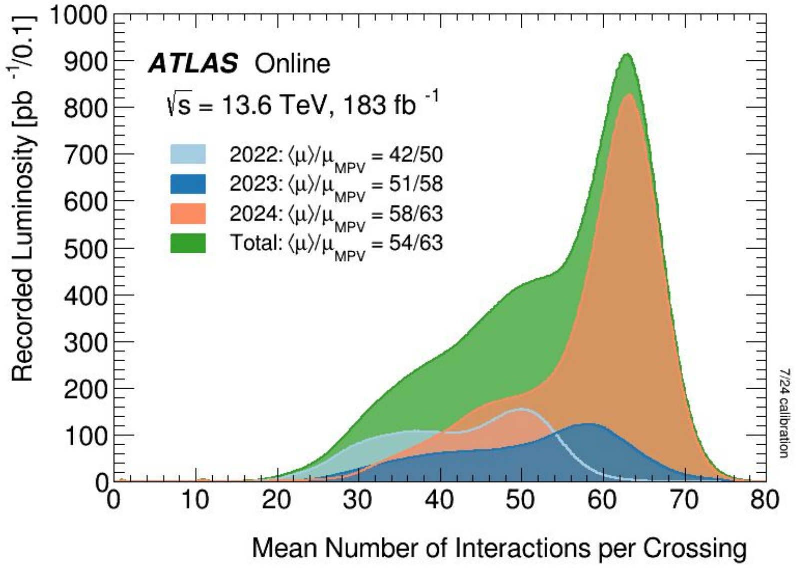
- **ATLAS Run 3 Trigger system**
- **ATLAS Phase-2 Upgraded Trigger system**
- **ATLAS NextGen Trigger program (WP2)**
    - WP 2.1 Optimal Real-Time Event Selection in the Global Trigger system
    - WP 2.2 Enhancing the Level-0 Muon Trigger
    - WP 2.3: High Throughput Data-Collection
    - WP 2.4: Event Filter Tracking
    - WP 2.5: Optimized Event Filter Muon Trigger Selection
    - WP 2.6: Common Tracking Event Filter infrastructure
    - WP 2.7: Enhanced Reconstruction for Higher Level Event Filtering

ATLAS operation status towards 2025 data taking

- **2024 was a very productive year for LHC/ATLAS, with a collected dataset of 118 fb^{-1}**
- **In total, collected over 203 fb^{-1} in Run 3, way more with respect to Run 2 (147 fb^{-1})**
- **Running at peak luminosity ~2.2 x 10^{34} $cm^{-2}s^{-1}$, with an average interaction per bunch crossing < μ > ~ 64**
- **Recording efficiency ~ 94%, increasing as data-taking continues:**
  - Careful follow-up of all issues causing dead-times
  - Continuously improving systems to be more robust against failures/mistakes

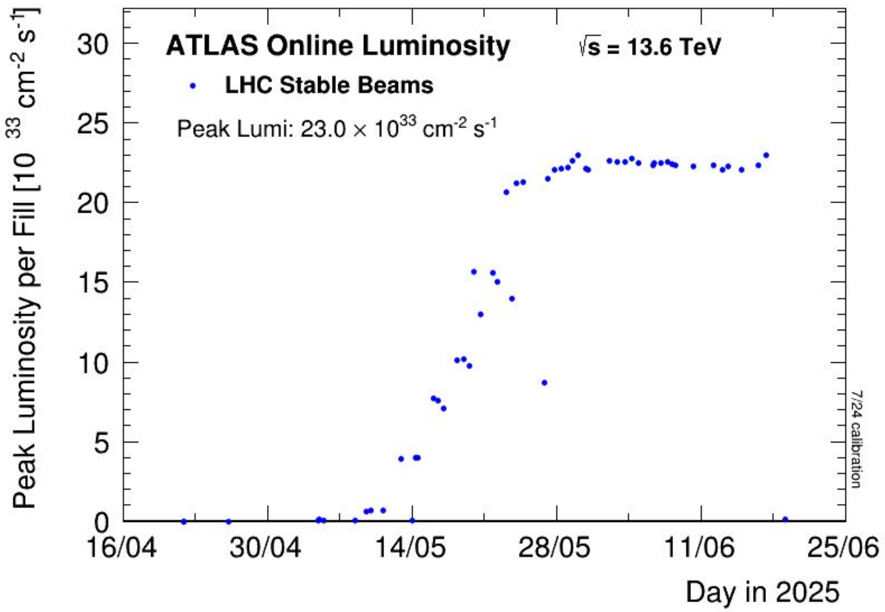


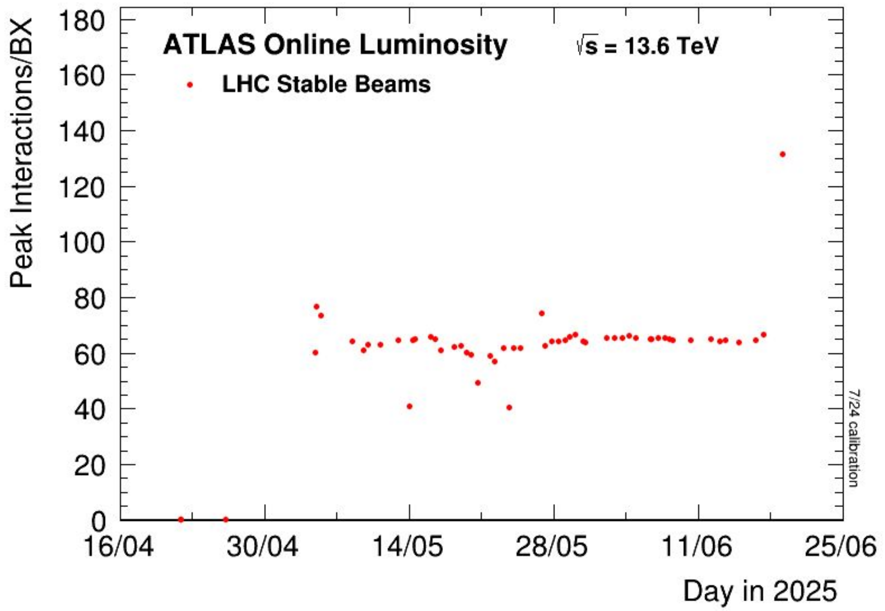


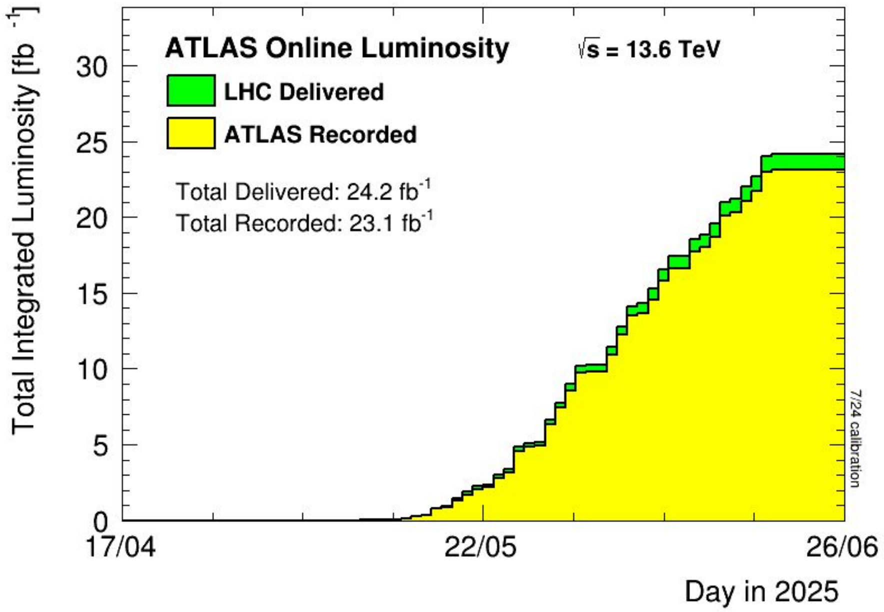


2025 data taking first results

- Already collected ~20 fb^{-1} running also at higher peak luminosity with respect to last year
- "Levelling" of the luminosity allow to keep a constant pileup over time

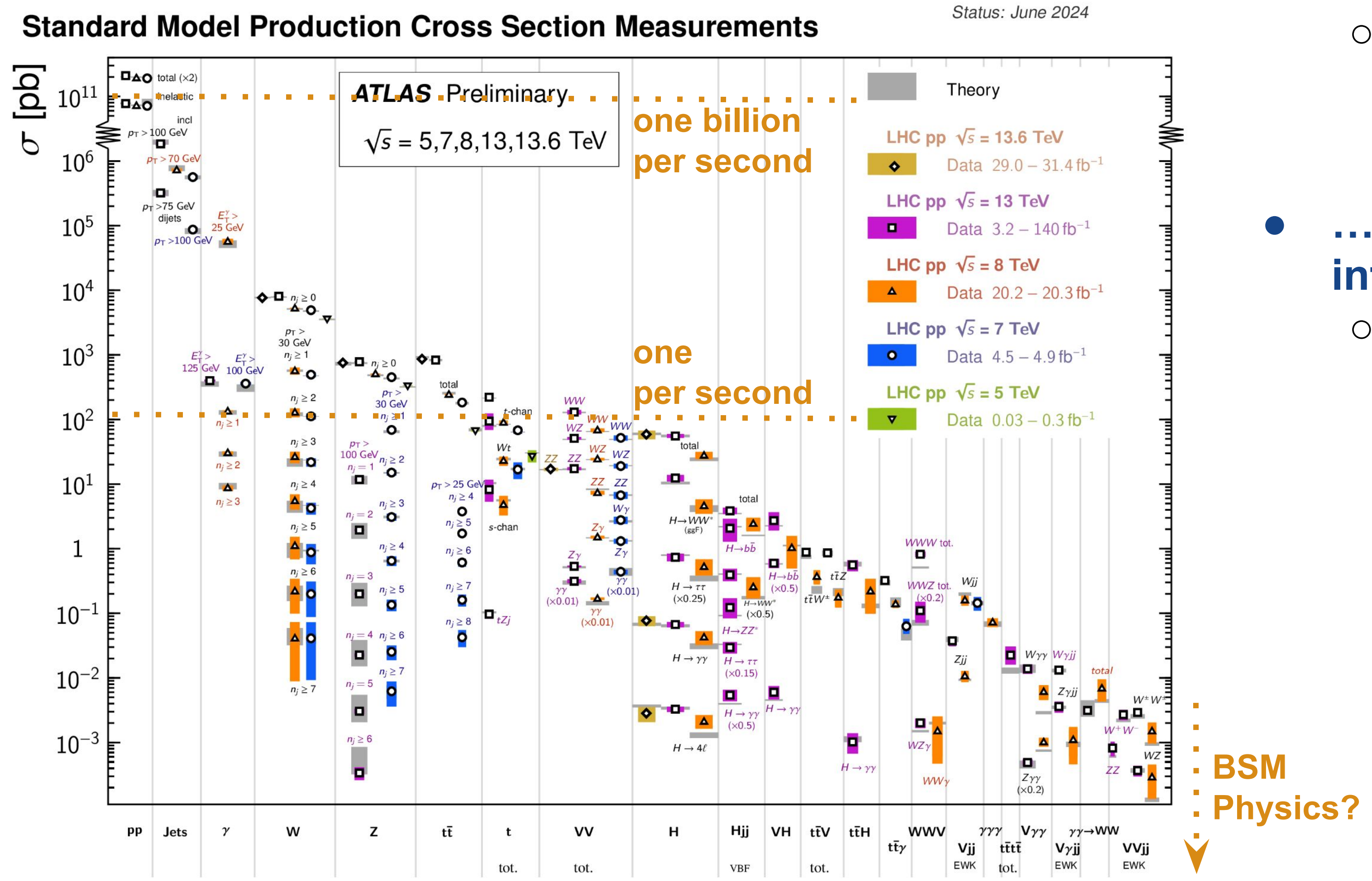






Main challenges

Standard Model Production Cross Section Measurements



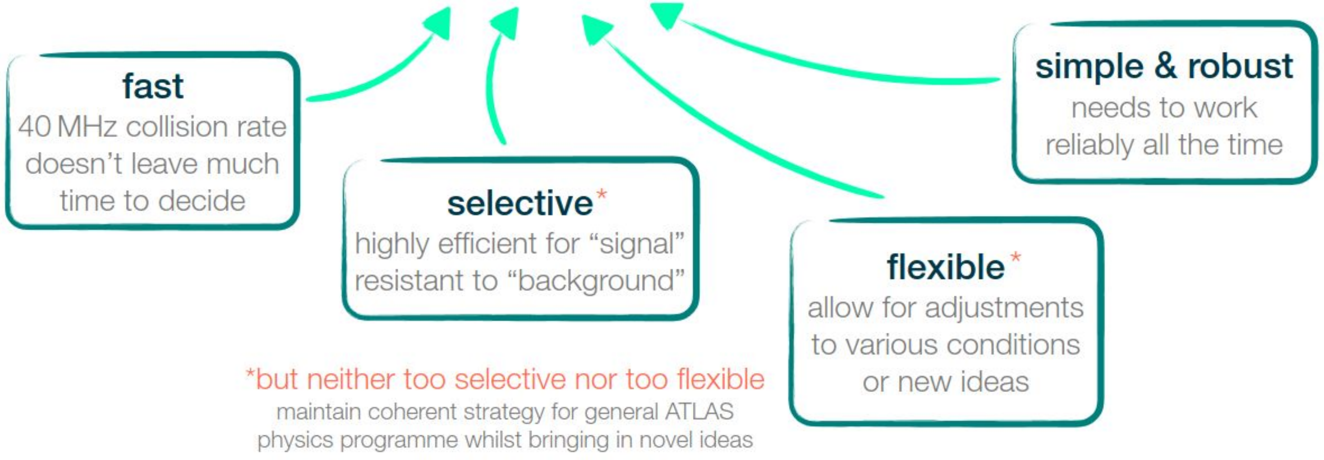
ATL-PHYS-PUB-2024-011

- **We can't deal with the full amount of data …**
  - too much for detector read-out and offline computing
    - event size ~ 2 MB -> ~80 TB/s… we can *only* afford 8 GB/s!
- **… but we want more of rare and interesting events!**
  - Literally like finding a needle in a haystack

Main challenges

Select only the most "interesting" events and reject "boring" ones

- **What is interesting and what is boring?**
  - Dependent on physics goals
    - Often something with a lot of energy, or more creative solutions exploiting event topologies.
- **How is the selection applied?**
  - Let's **TRIGGER**!



- Data processing (events) at a high rate (40 MHz)
- Each event is accepted or rejected: **What we don't record is lost forever!**
- Rate reduction to affordable level for the DAQ chain
  - Reduction over 4 orders of magnitude: 40 MHz to 3 kHz in Run 3
- Continuous tradeoff between reconstruction quality and time for taking decision
  - Separation power and resolution lowers rates for same efficiency and adds acceptance to signatures difficult to reconstruct
  - Stalled trigger system loses events forever…

Trigger Menu and signatures

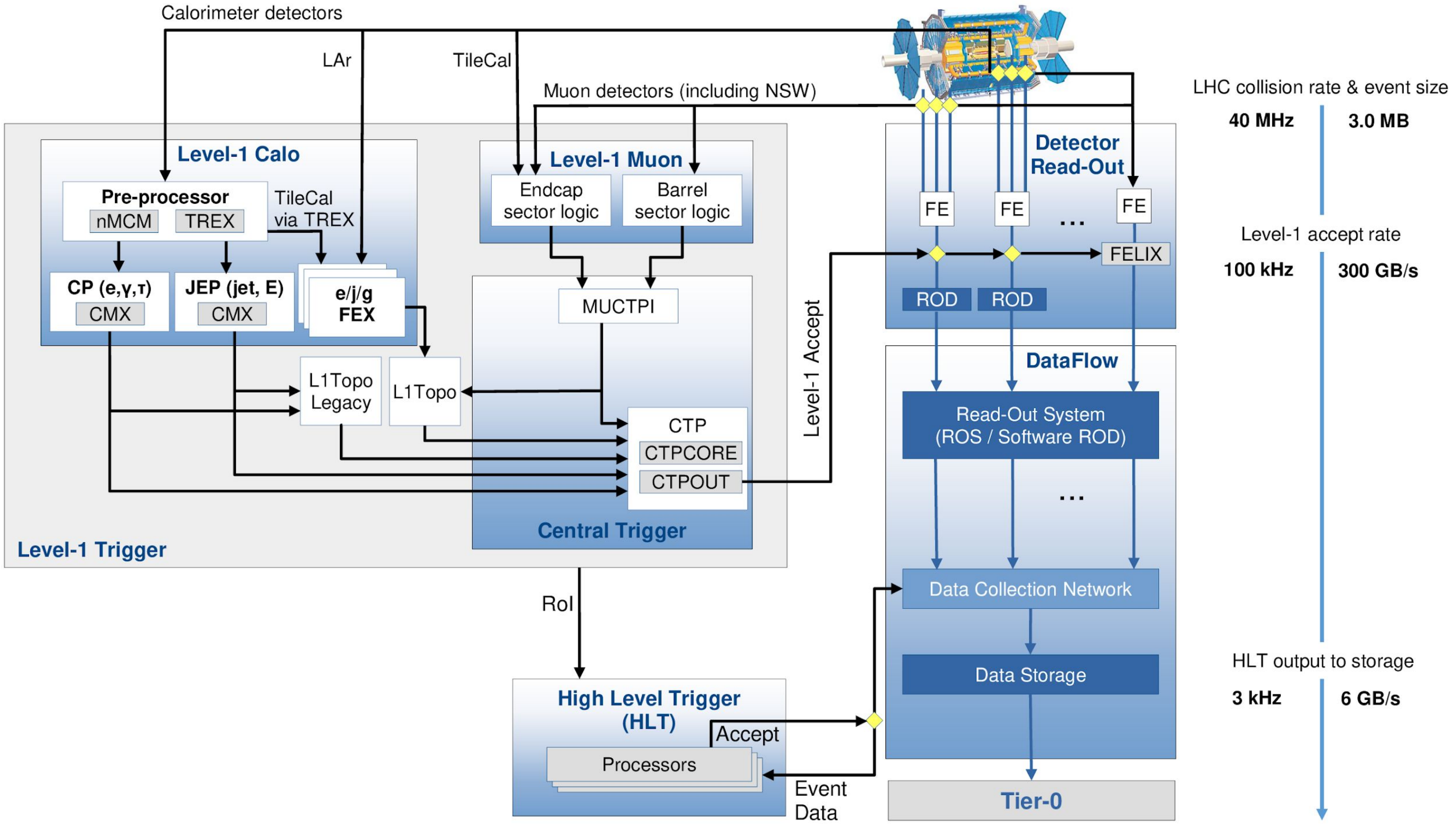
- **The menu is a collection of trigger chains and corresponding set of rules defining the rate each chain is allowed to write out**
  - **Defines the Physics program and reach of ATLAS**
- **Design is driven by**
  - Physics priorities aiming to record a balanced dataset for analyses
    - Representative of major processes; high efficiency for rare processes; supporting triggers for calibration, efficiency measurements, etc
  - Rate limitations at L1 and HLT
  - Online and offline resources
    - available CPU, bandwidth, and Tier-0 processing capacities
- **Varies with luminosity and time**
- **Different menus defined for specific purposes and conditions**

- **Trigger signatures correspond to groups of closely related chains motivated by physics signatures**
  - Inner detector tracking, calo clustering, e/gamma, tau, jet, b-jet, MET, muons, B-physics and light states, unconventional tracking, minimum bias.

ATL-DAQ-PUB-2019-001

Trigger	Typical offline selection	Trigger Selection		L1 Peak Rate [kHz]	HLT Peak Rate [Hz]
		L1 [GeV]	HLT [GeV]	$L=2.0\times10^{34}$ $cm^{-2}s^{-1}$	
Single leptons	Single isolated μ, $p_T > 27$ GeV	20	26 (i)	16	218
	Single isolated tight e, $p_T > 27$ GeV	22 (i)	26 (i)	31	195
	Single μ, $p_T > 52$ GeV	20	50	16	70
	Single e, $p_T > 61$ GeV	22 (i)	60	28	20
	Single τ, $p_T > 170$ GeV	100	160	1.4	42
Two leptons	Two μ, each $p_T > 15$ GeV	2×10	2×14	2.2	30
	Two μ, $p_T > 23, 9$ GeV	20	22, 8	16	47
	Two very loose e, each $p_T > 18$ GeV	2×15 (i)	2×17	2.0	13
	One e & one μ, $p_T > 8, 25$ GeV	20 (μ)	7, 24	16	6
	One loose e & one μ, $p_T > 18, 15$ GeV	15, 10	17, 14	2.6	5
	One e & one μ, $p_T > 27, 9$ GeV	22 (e, i)	26, 8	21	4
	Two τ, $p_T > 40, 30$ GeV	20 (i), 12 (i) (+jets, topo)	35, 25	5.7	93
	One τ & one isolated μ, $p_T > 30, 15$ GeV	12 (i), 10 (+jets)	25, 14 (i)	2.4	17
	One τ & one isolated e, $p_T > 30, 18$ GeV	12 (i), 15 (i) (+jets)	25, 17 (i)	4.6	19
Three leptons	Three very loose e, $p_T > 25, 13, 13$ GeV	$20, 2\times10$	$24, 2\times12$	1.6	0.1
	Three μ, each $p_T > 7$ GeV	3×6	3×6	0.2	7
	Three μ, $p_T > 21, 2\times5$ GeV	20	$20, 2\times4$	16	9
	Two μ & one loose e, $p_T > 2\times11, 13$ GeV	2×10 (μ)	$2\times10, 12$	2.2	0.5
	Two loose e & one μ, $p_T > 2\times13, 11$ GeV	$2\times8, 10$	$2\times12, 10$	2.3	0.1
Signle photon	One loose γ, $p_T > 145$ GeV	24 (i)	140	24	47
Two photons	Two loose γ, each $p_T > 55$ GeV	2×20	2×50	3.0	7
	Two γ, $p_T > 40, 30$ GeV	2×20	35, 25	3.0	21
	Two isolated tight γ, each $p_T > 25$ GeV	2×15 (i)	2×20 (i)	2.0	15
Single jet	Jet ($R = 0.4$), $p_T > 435$ GeV	100	420	3.7	35
	Jet ($R = 1.0$), $p_T > 480$ GeV	111 (topo: $R = 1.0$)	460	2.6	42
	Jet ($R = 1.0$), $p_T > 450$ GeV, $m_{jet} > 45$ GeV	111 (topo: $R = 1.0$)	420, $m_{jet} > 35$	2.6	36
b−jets	One b ($\epsilon = 60\%$), $p_T > 285$ GeV	100	275	3.6	15
	Two b ($\epsilon = 60\%$), $p_T > 185, 70$ GeV	100	175, 60	3.6	11
	One b ($\epsilon = 40\%$) & three jets, each $p_T > 85$ GeV	4×15	4×75	1.5	14
	Two b ($\epsilon = 70\%$) & one jet, $p_T > 65, 65, 160$ GeV	$2\times30, 85$	$2\times55, 150$	1.3	17
	Two b ($\epsilon = 60\%$) & two jets, each $p_T > 65$ GeV	4×15, $\lvert\eta\rvert < 2.5$	4×55	3.2	15
Multijets	Four jets, each $p_T > 125$ GeV	3×50	4×115	0.5	16
	Five jets, each $p_T > 95$ GeV	4×15	5×85	4.8	10
	Six jets, each $p_T > 80$ GeV	4×15	6×70	4.8	4
	Six jets, each $p_T > 60$ GeV, $\lvert\eta\rvert < 2.0$	4×15	6×55, $\lvert\eta\rvert < 2.4$	4.8	15
E_T^{miss}	$E_T^{miss} > 200$ GeV	50	110	5.1	94
B-physics	Two μ, $p_T > 11, 6$ GeV, $0.1 < m(\mu,\mu) < 14$ GeV	11, 6	11, 6 (di-μ)	2.9	55
	Two μ, $p_T > 6, 6$ GeV, $2.5 < m(\mu,\mu) < 4.0$ GeV	2×6 (J/ψ, topo)	2×6 (J/ψ)	1.4	55
	Two μ, $p_T > 6, 6$ GeV, $4.7 < m(\mu,\mu) < 5.9$ GeV	2×6 (B, topo)	2×6 (B)	1.4	6
	Two μ, $p_T > 6, 6$ GeV, $7 < m(\mu,\mu) < 12$ GeV	2×6 (Υ, topo)	2×6 (Υ)	1.2	12
Main Rate B-physics and Light States Rate				86	1750 200

Overview of the current ATLAS trigger system



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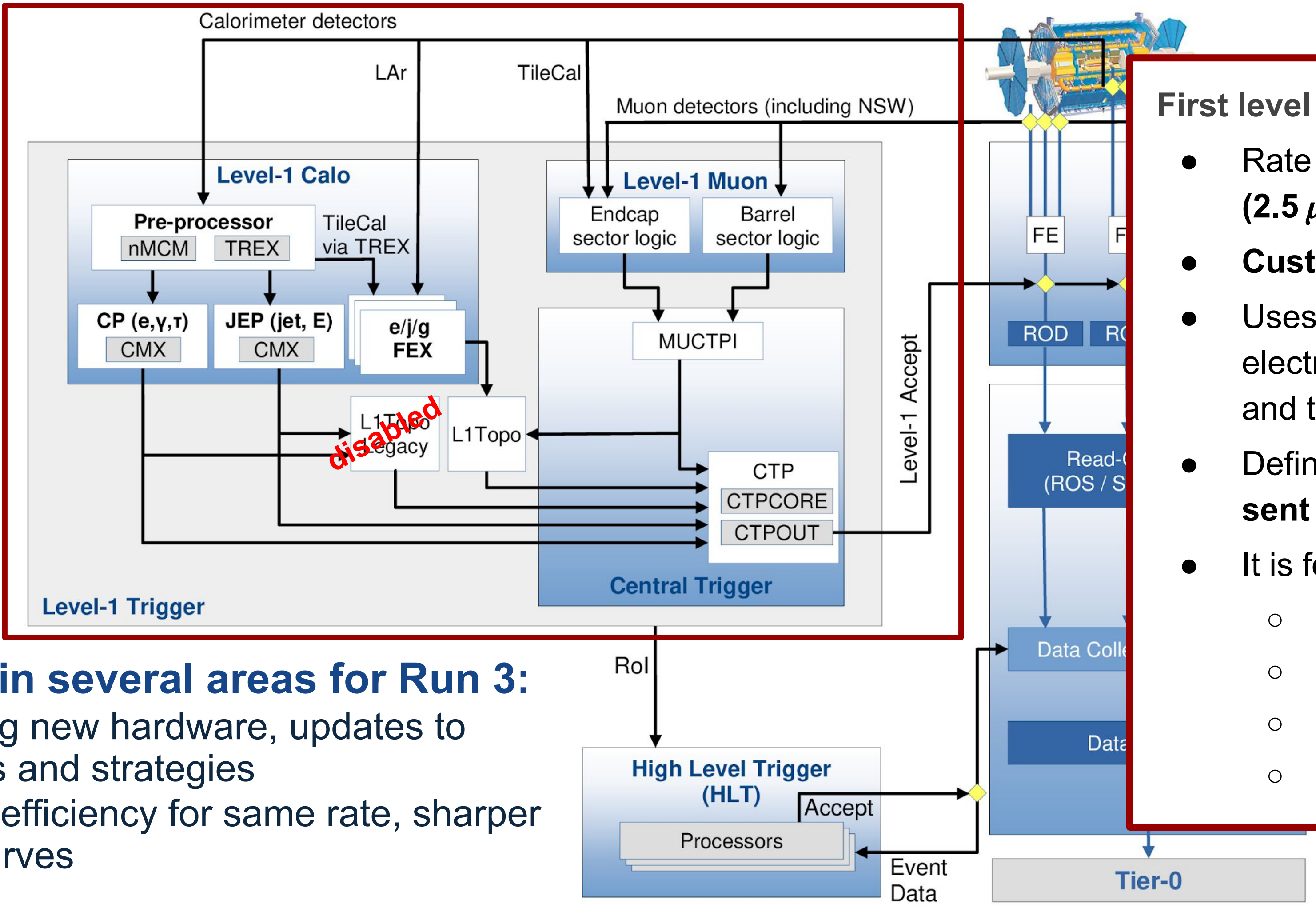

First level trigger (Level-1)

- Rate is reduced from **40 MHz to 100 kHz (2.5 μs)**
- **Custom electronics** (FPGAs)
- Uses reduced granularity of the electromagnetic and hadronic **calorimeters** and the **muon spectrometer**
- Defines Regions of Interest (**RoIs**) that are **sent to** the High Level Trigger (**HLT**)
- It is formed by:
  - Level-1 Calo (L1Calo)
  - Level-1 Muon (L1Muon)
  - Level-1 Topological Trigger (L1Topo)
  - Central Trigger (MUCTPI and CTP)

- **Upgrades in several areas for Run 3:**
  - Introducing new hardware, updates to algorithms and strategies
  - Improved efficiency for same rate, sharper turn-on curves

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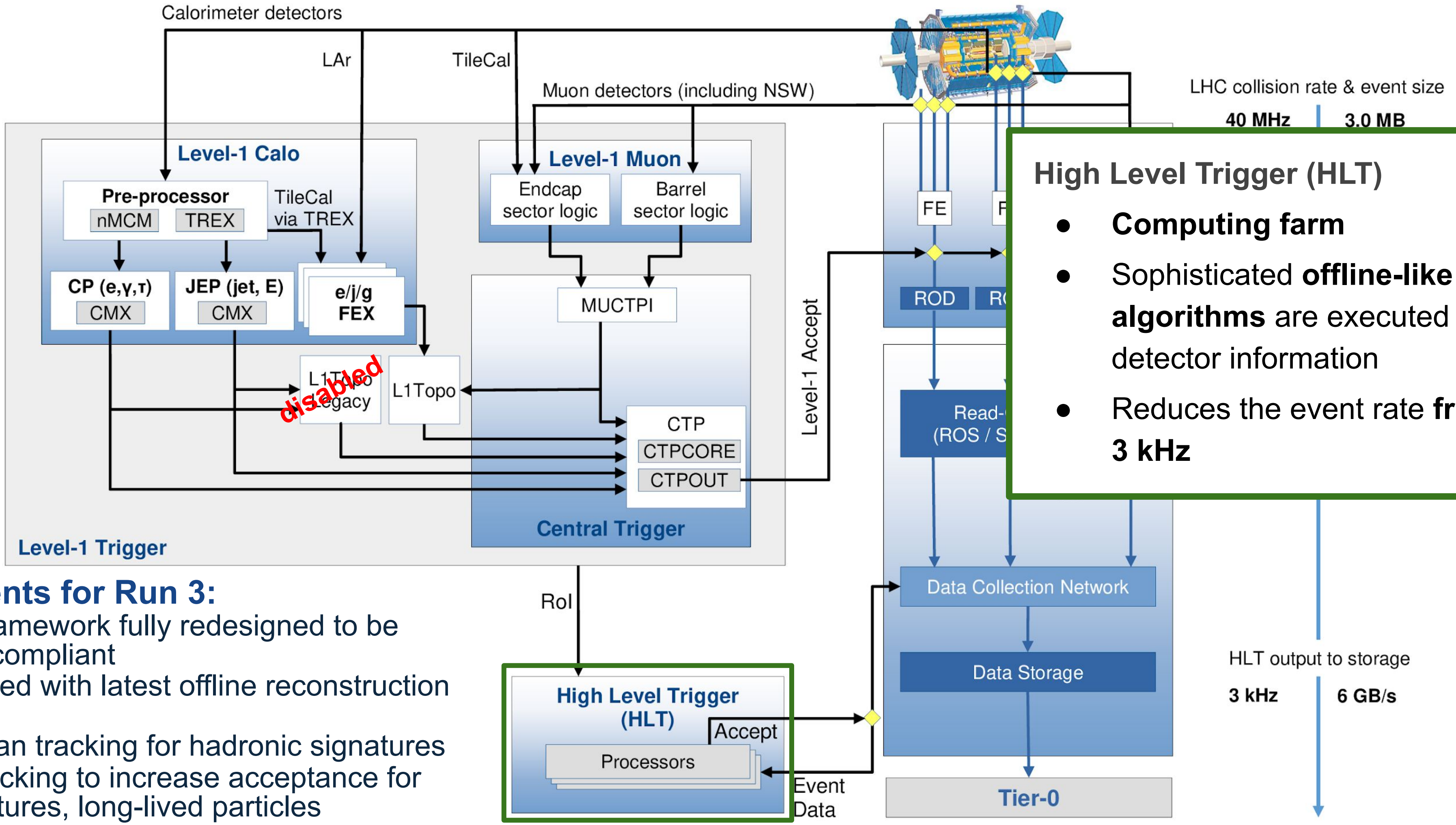


High Level Trigger (HLT)

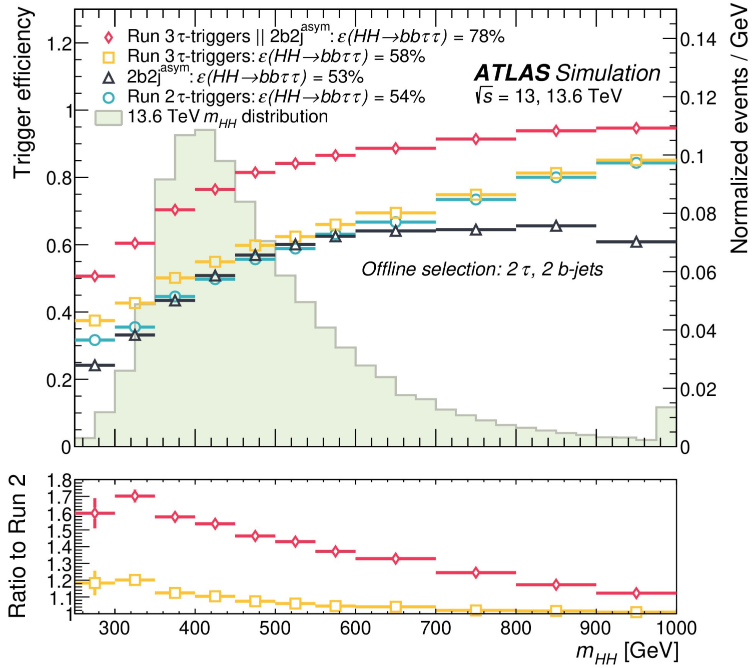
- **Computing farm**
- Sophisticated **offline-like selection algorithms** are executed using full detector information
- Reduces the event rate **from 100 kHz to 3 kHz**

- **HLT improvements for Run 3:**
  - HLT software framework fully redesigned to be multi-threaded compliant
  - Selections aligned with latest offline reconstruction techniques
  - Usage of full scan tracking for hadronic signatures
  - Large radius tracking to increase acceptance for displaced signatures, long-lived particles

Highlights on trigger developments

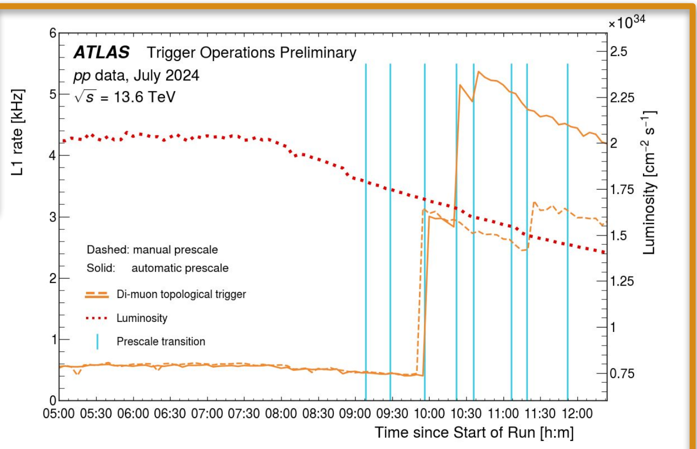
Fast b-tagging preselection, running on calorimeter-based jets, which is scheduled before the HLT precision-tracking-based b-tagging

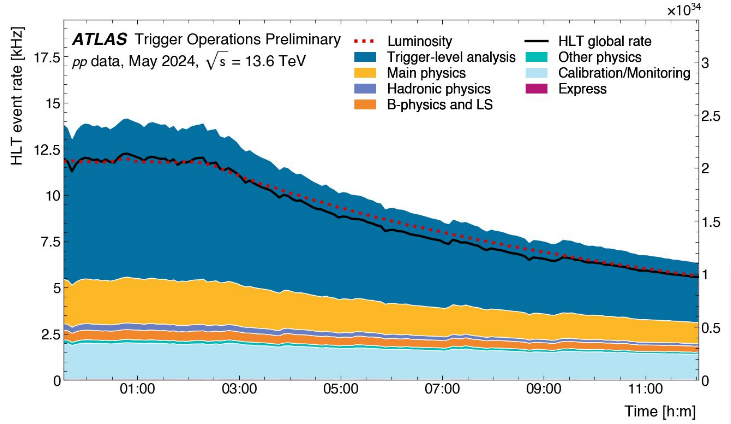
x5-10 event rejection for events entering the precision b-tagging algorithms



As a run progresses the delivered luminosity decreases and the rate of the various triggers drops creating "space" towards the end of run

Increase the rate of previously pre-scaled trigger chains based on physics-driven priority



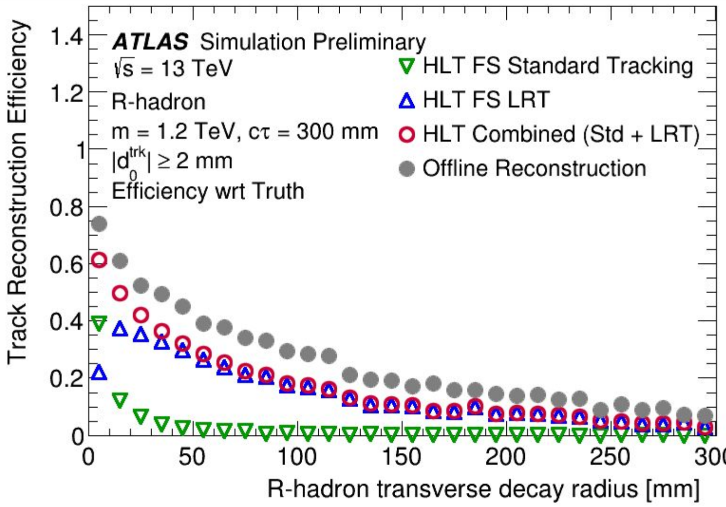


Trigger-Level Analysis (TLA): circumvent the bandwidth limitation using partial event building (0.3% of the size of a full event)

Used directly in the corresponding physics analysis, e.g. di-jet resonance searches

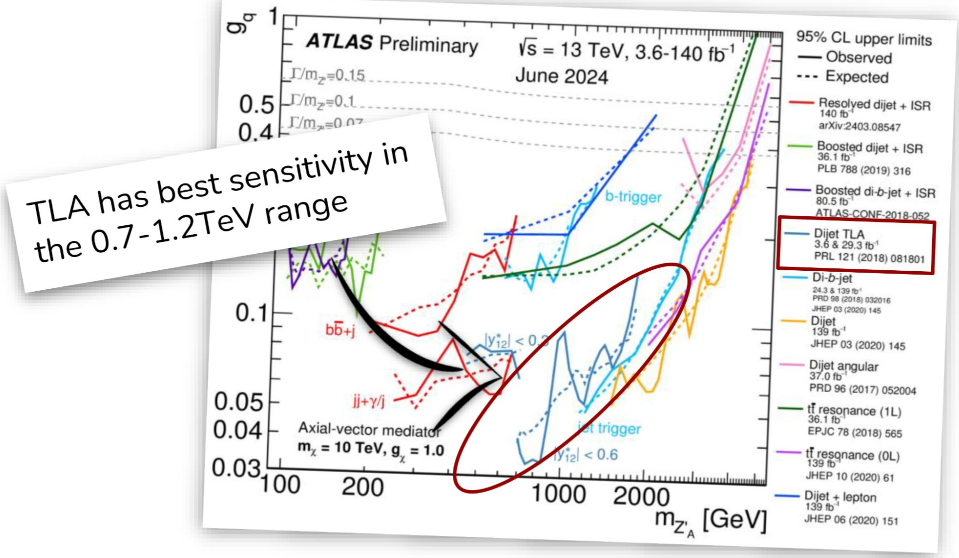
Large radius tracking to increase acceptance for displaced signatures

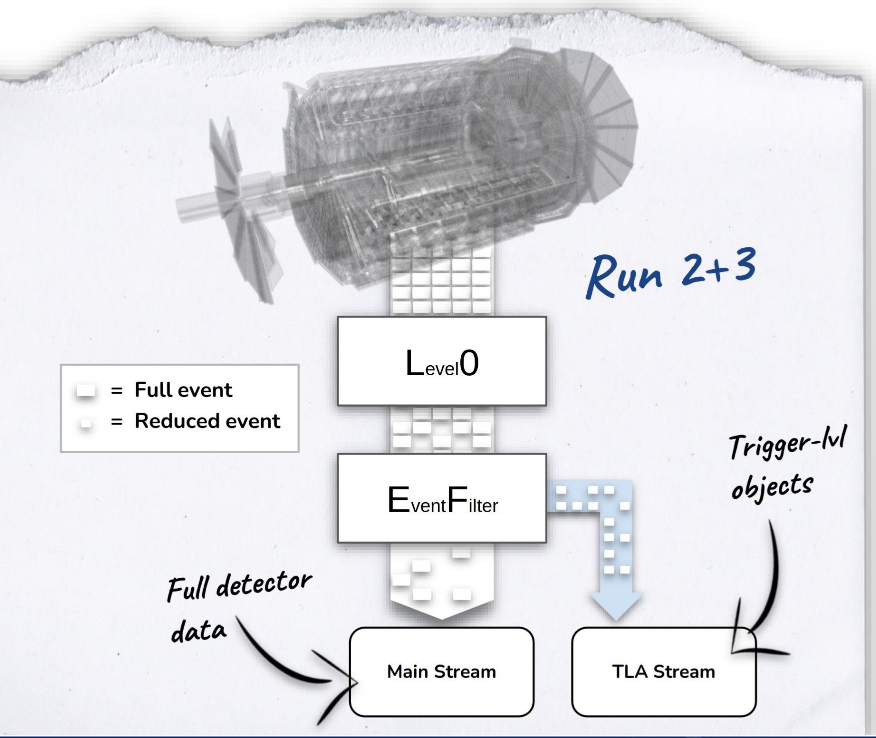
Targets charged particles with large displacements up to 300 mm improving acceptance for long-lived particles



What is Trigger Level Analysis (TLA)?

- **Why do TLA?**
  - Many BSM / exotics searches (e.g. dark matter mediators) **limited** by available **trigger bandwidth**
  - If we can not reduce trigger rate: **Reduce event size!**

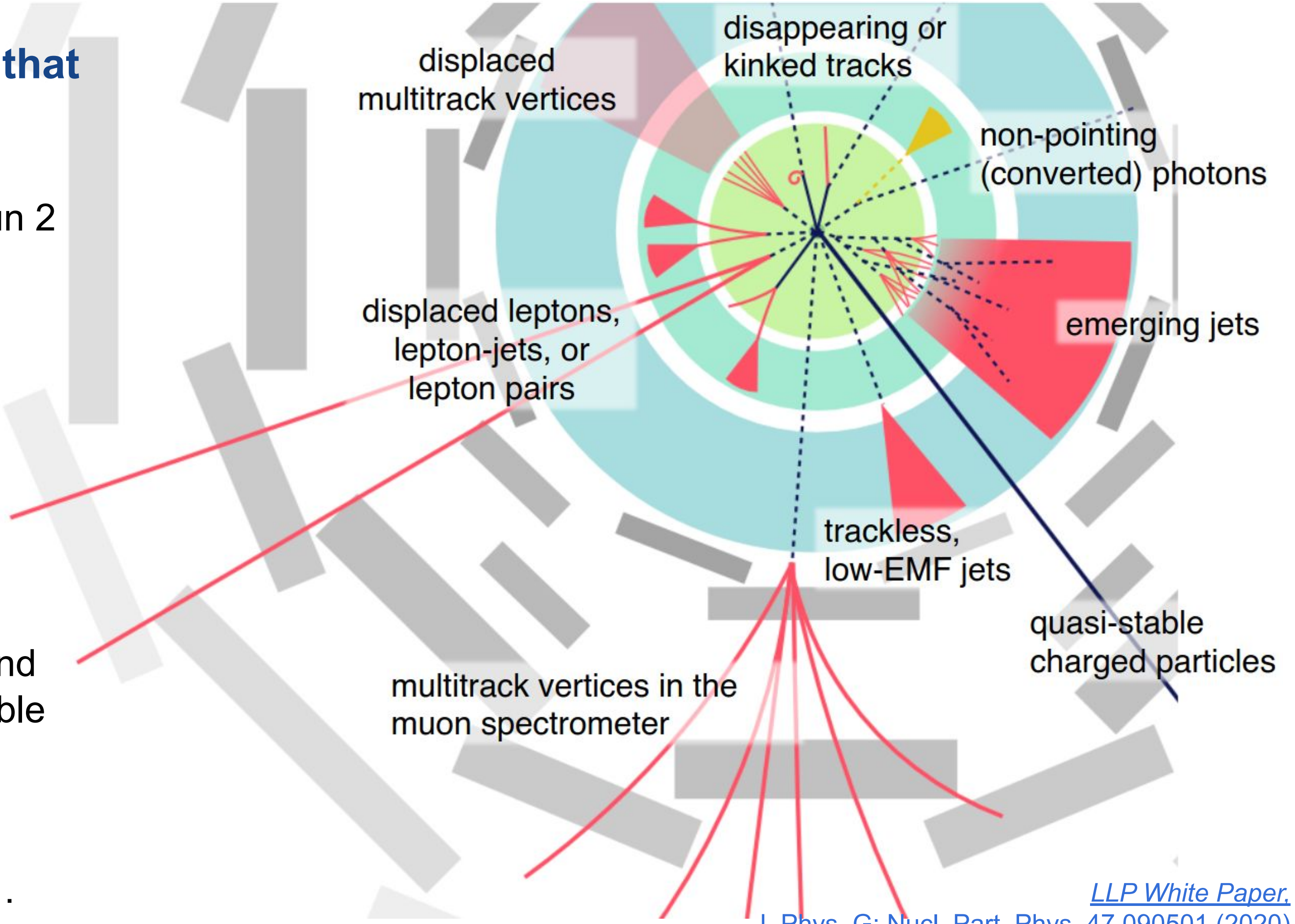




- **How to do TLA?**
  - Baseline TLA workflow only stores **lightweight high-level information** from **trigger reconstruction** (HLT-jets, -photons, -muons, etc.)
  - TLA Mechanism stores **robust information sufficient for analysis**, including information about shower profiles and isolation variables
  - … but **not** designed to allow full “offline” reconstruction from low-level information
  - TLA triggers operate in Run 3
    - Updated Trigger Menu to reflect physics priorities of ATLAS, hoping to further analyses probed by TLA in Run 2 (e.g. arXiv:1804.03496)

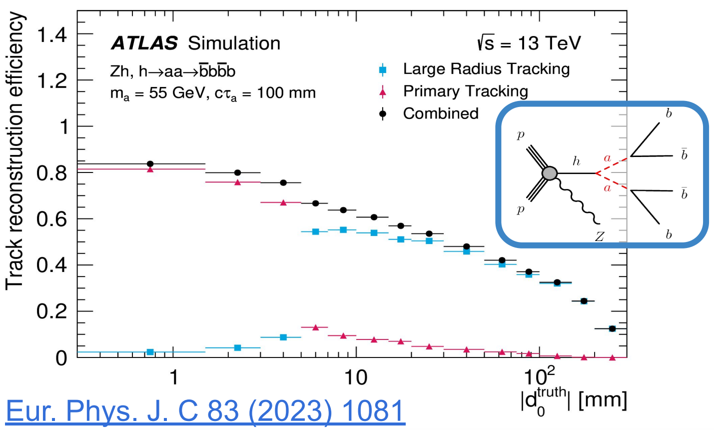
Unconventional Tracking for Long-Lived Particles

- **Many unique, non-standard signatures that rely on tracking information for identification**
  - Only standard tracking was used in the Run 2 trigger, with coverage out to $|d_0|$<5-10 mm
    - Not adequate for most LLPs
  - Extended to previously uncovered phase-space in Run 3 - next slide
- **Keeping rates under control!**
  - High thresholds in calo and muon triggers
  - Triggering on displaced objects
- **Several physics signatures:**
  - Massive charged LLP w/ (isolated track) and w/o (large energy deposit in silicon) ID stable lifetime, disappearing tracks, neutral LLP decaying into jet/displaced vertex in the ID volume, displaced vertices, emerging jets, displaced objects (objects with large d_0), …

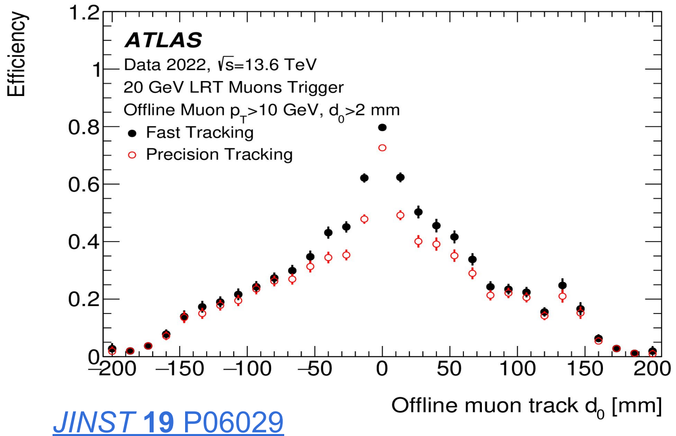


[LLP White Paper, J. Phys. G: Nucl. Part. Phys. 47 090501 (2020)]

Large Radius Tracking in trigger for Run 3



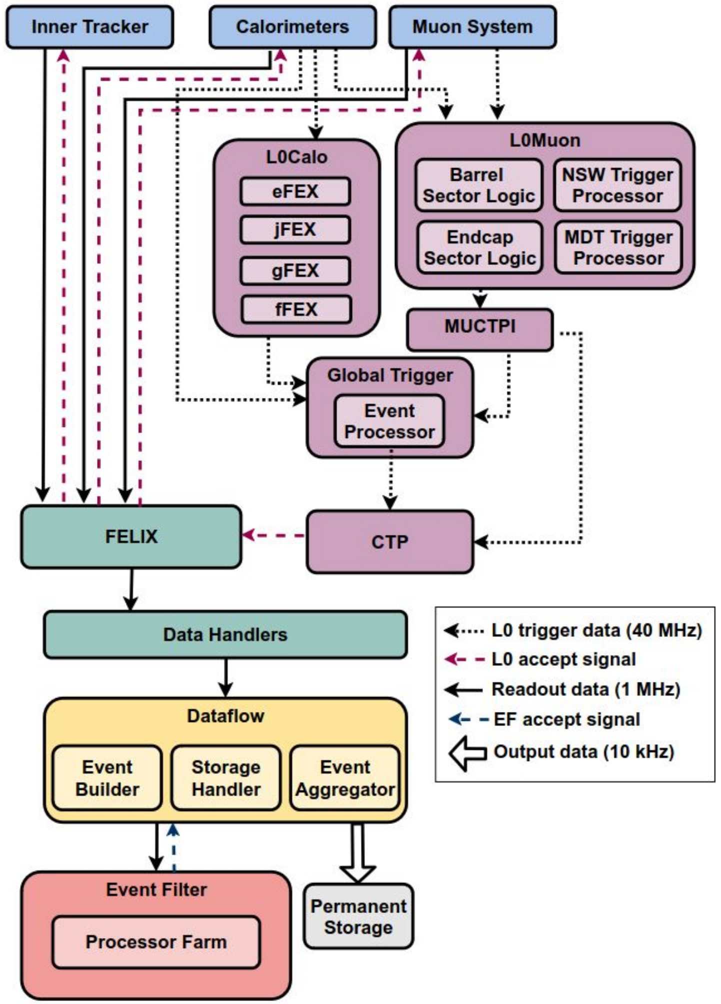
Eur. Phys. J. C 83 (2023) 1081



JINST **19** P06029

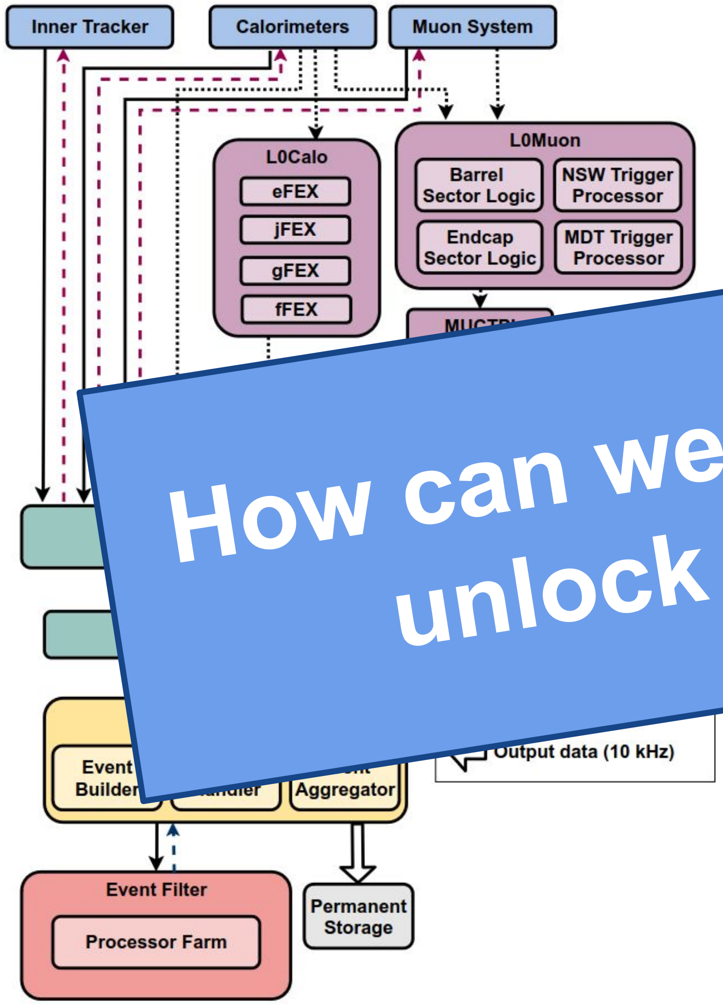
- **Plethora of long-lived particle triggers worked on and deployed for Run 3**
  - Charged LLP
    - Disappearing track triggers, large dE/dx, isolated high pT track
  - LLP decaying into jets
    - Hit-based displaced vertex, emerging jets, displaced jets
  - LLPs decaying into SM leptons
- **General approach:**
  - Apply requirements to reduce jet or MET thresholds
    - Single jet threshold: 420 GeV; ETmiss threshold: 90 GeV
  - Run Large Radius Tracking (LRT)
    - New feature introduced in the HLT for Run 3
    - Based on the offline LRT reconstruction: improved for Run 3 to reduce the number of fake tracks and processing time, while maintain high signal efficiency
    - Covers tracks with cover $|z_0|$ < 500 mm and $|d_0|$ < 300 mm, with tight quality requirements to reduce fake tracks

The ATLAS TDAQ Phase-II architecture



- **High-pileup conditions during the HL-LHC present a significant challenge to the ATLAS TDAQ system**
  - Extensive Phase-II upgrade program will encompass multiple systems, including tracking, triggering, and data acquisition
- **Hardware trigger at Level-0 (40 MHz ➞ 1 MHz @ 10 μs latency): process data from subdetectors, identifies physics objects, evaluate event-level physics quantities**
- **Accepted events are transmitted to the Event Filter (EF) that provides final accept/reject decision (1 MHz ➞ 10 kHz)**
  - EF farm will run tracking, calorimeter and muon algorithms

The ATLAS TDAQ Phase-II architecture



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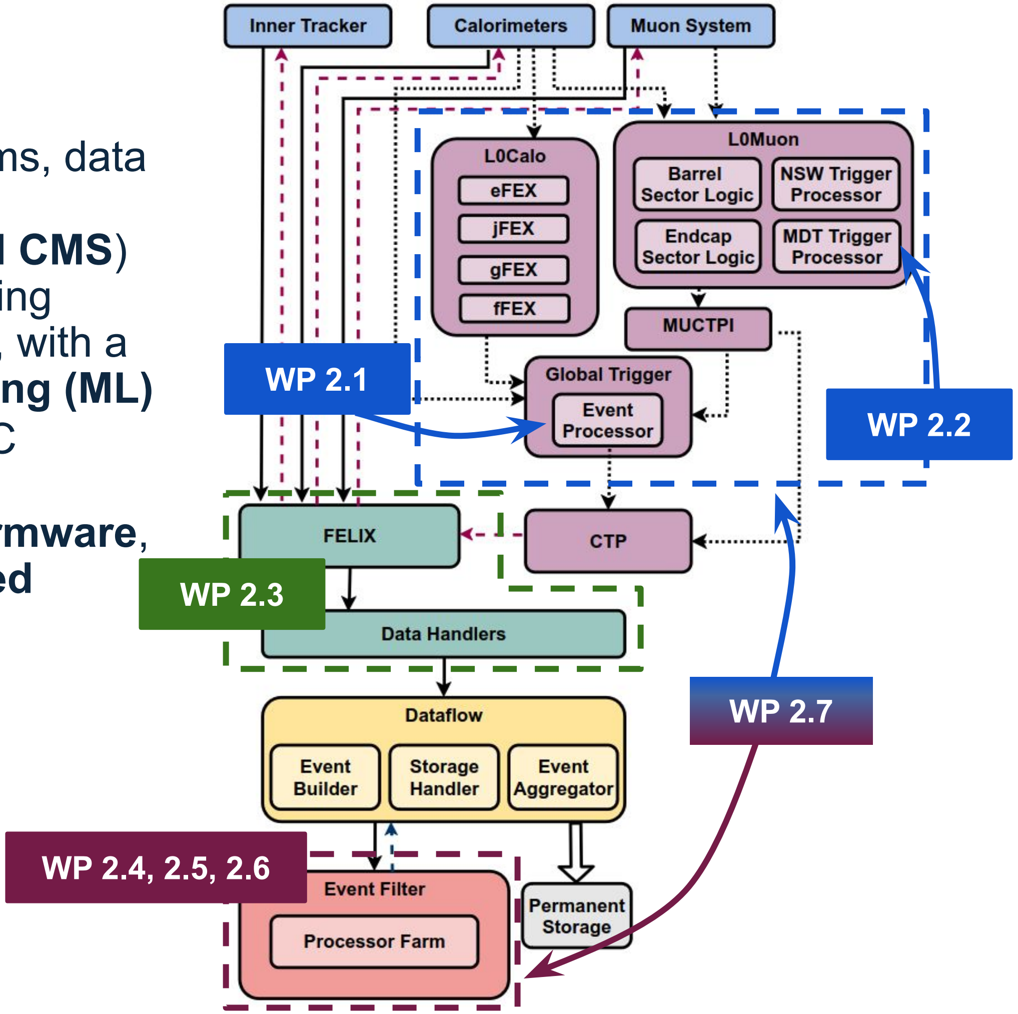
  - Extensive Phase-II upgrade program will … cluding tracking, triggering, and …
- … luate
- … Event Filter (EF) that … decision (1 MHz ➞ 10 kHz)
  - … will run tracking, calorimeter and muon algorithms

How can we build on the current program to unlock new physics opportunities?

The Next Generation Triggers Project & ATLAS: WP 2

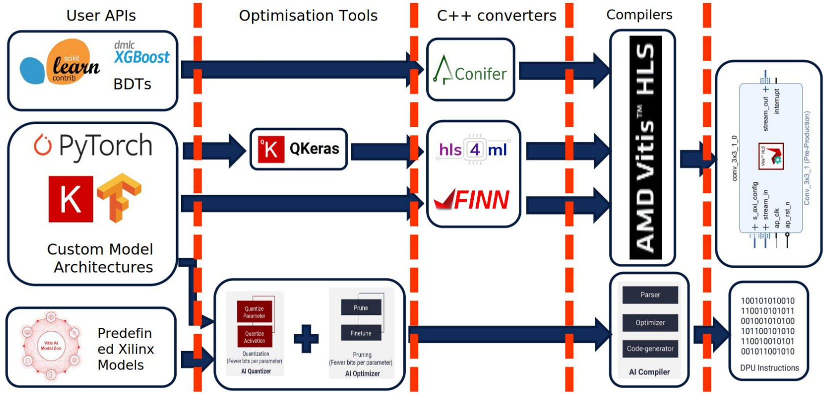
- **Main objectives:**
  - Enhance the trigger systems, data collection, and processing capabilities of **ATLAS** (and **CMS**) in the HL-LHC era, extending **beyond current baseline**, with a **focus on Machine Learning (ML)**
  - Drive innovation in HL-LHC triggers through **novel ML techniques**, **optimized firmware**, and **accelerator-supported software**

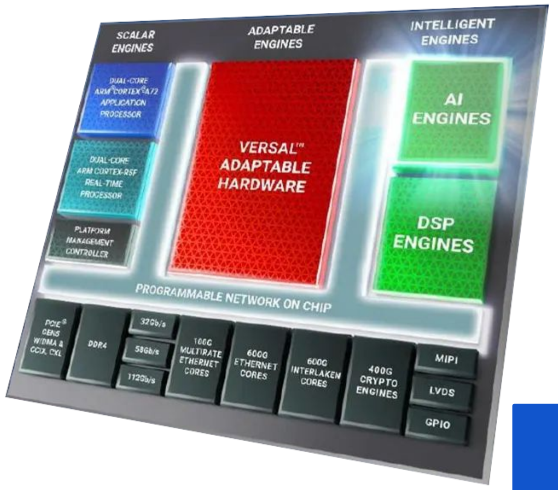


- **Project is developed within ATLAS TDAQ in collaboration with CERN Team:**
  - Tasks are **fully integrated** in ATLAS Phase-2 TDAQ Upgrade
  - Goal is to **extend** (**not replace!**) **the scope and functionality** of the **baseline trigger system**
  - **Focus** is **on innovation/R&D** (e.g., novel ML, optimized firmware, support for heterogeneous comp.)

Optimal Real Time Event Selection in the Global Trigger System

- **Focuses on extending the L0 Global Trigger using firmware-based offline-like algorithms for event selection**
  - Receives data at 50 Tbps, tight latency of 10 μs
  - System faces key constraints (which drive decisions on FPGA selection), e.g., number of links from pre-processors, complexity of algorithms
- **Main goal: Exploration of novel ML reconstruction within the ATLAS Global Trigger**
  - Explore novel ML algorithms for L0 Global
  - Develop a common framework for ML optimisation for FPGA development
    - FPGA model, performance metrics, resource constraints and latency budget
    - Easy to deploy now models on hardware (provides interface to firmware)
  - Evaluation of new industry technologies
    - New technology in AMD focuses on dedicated vector processors (AI-Engines) that are optimised for Digital Signal Processing and ML



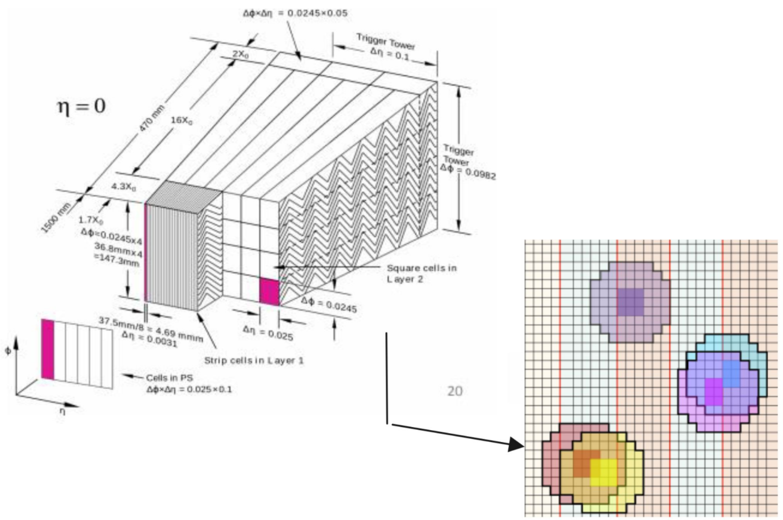


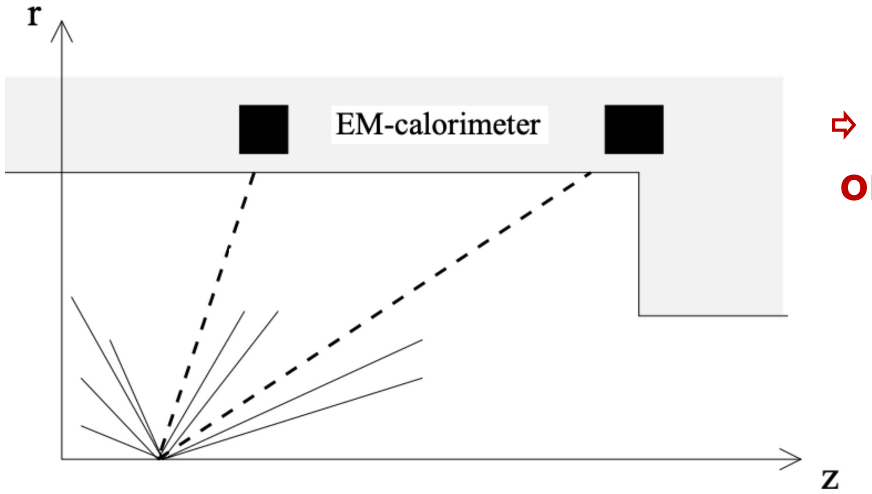
AMD VP2802

T. Du, N. Konstantinidis, D. Miller, P. Mucha, V. Petrovic, D. Reikher, I. Xiotidis

Work Package 2.1

Optimal Real Time Event Selection in the Global Trigger System





- **Ability to run more complex pattern recognition in the global (L0) trigger**
  - Using jet/global Feature EXtractors (j/gFEX) objects in L0 Global Trigger algorithms, benchmarking at high pileup
  - Enhanced pileup suppression using CNN (classify bkg, tau, electron, b-jet)
  - Vertex estimation using calorimeter shower shape information
  - Other ideas: jet reconstruction, fast jet calibration, boosted hadronic object identification, anomaly detection…
    - E.g. real-time jet finding directly from the cell information as preselection step to speed up trigger decisions for hadronic signals containing jets: ATL-DAQ-PUB-2024-003

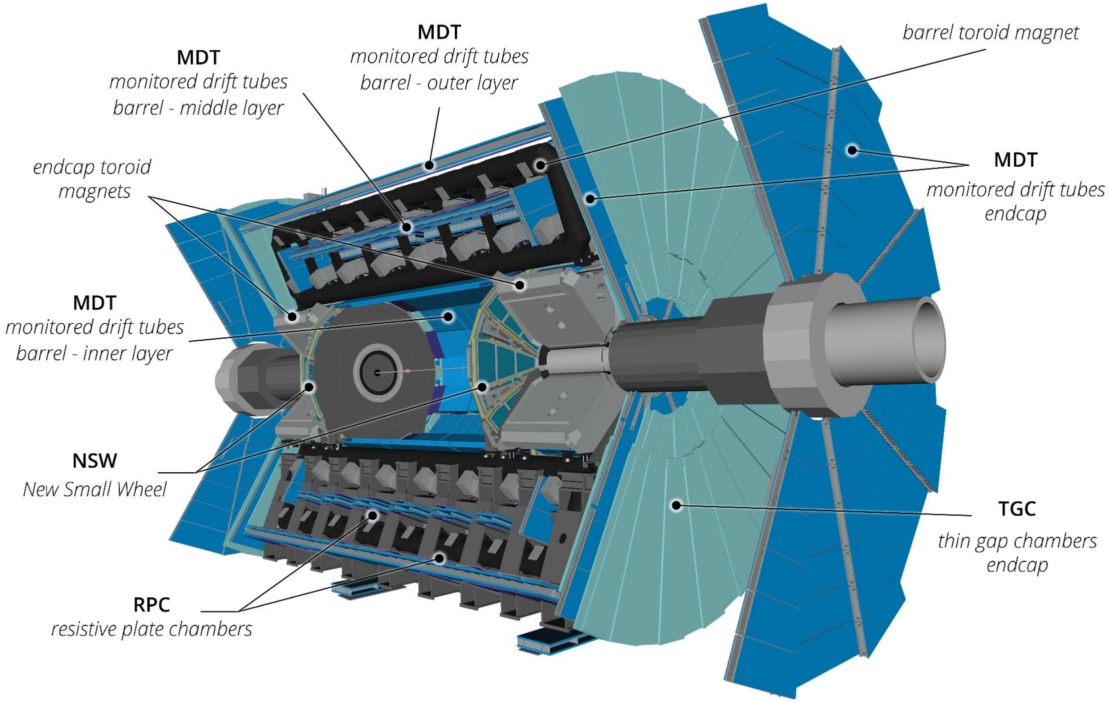
➪ **Most time-critical step, meaning that any improvement to resolution or ability to look for more complex topologies can give us a big gain!**

T. Du, N. Konstantinidis, D. Miller, P. Mucha, V. Petrovic, D. Reikher, I. Xiotidis

Work Package 2.2

Enhancing the Level-0 Muon Trigger

- **Muon trigger undergoes significant upgrade:**
  - measurements from MDT; additional layer of RPCs in the barrel; new electronics
- **Baseline L0 Muon trigger relies only on fast trigger detectors**
  - RPCs in the barrel, TGCs and NSW in the endcap
- **Main goals:**
  - **Alternative algorithms** (ML and non-ML) are being studied to adapt the L0 Muon triggers in **scenarios of reduced RPC performance** or coverage for new RPC chambers, **extending acceptance** using **MDTs**
  - Also study **exotic** (e.g., non-prompt) **muon signatures**



M. Carnesale, O. Kortner, V. M. Outschoorn, R. R. Caballero

Work Package 2.2

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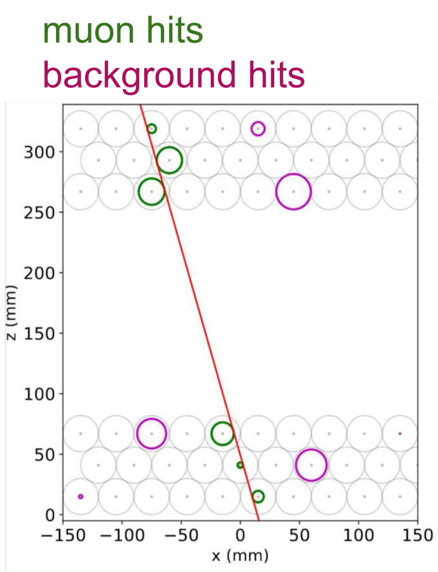
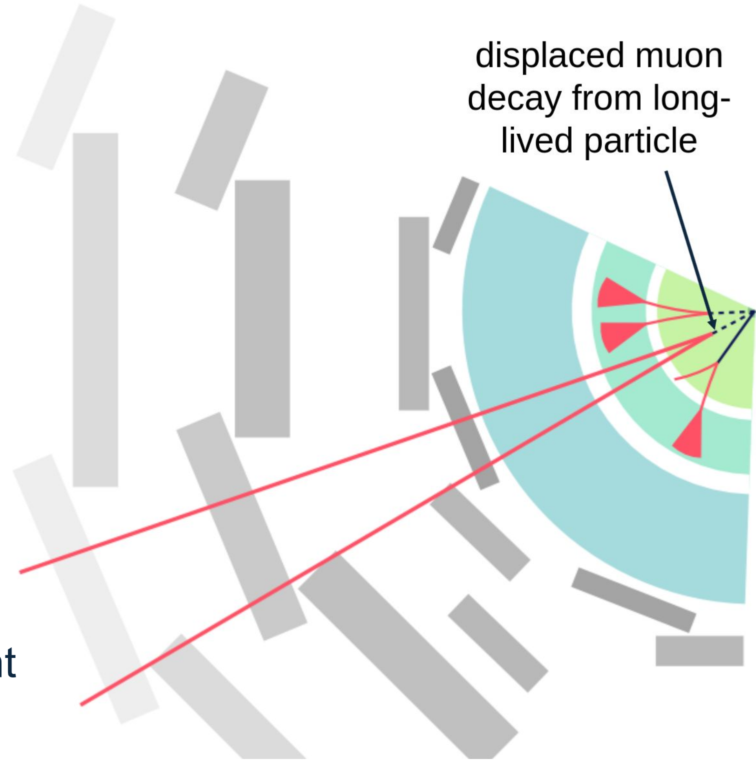
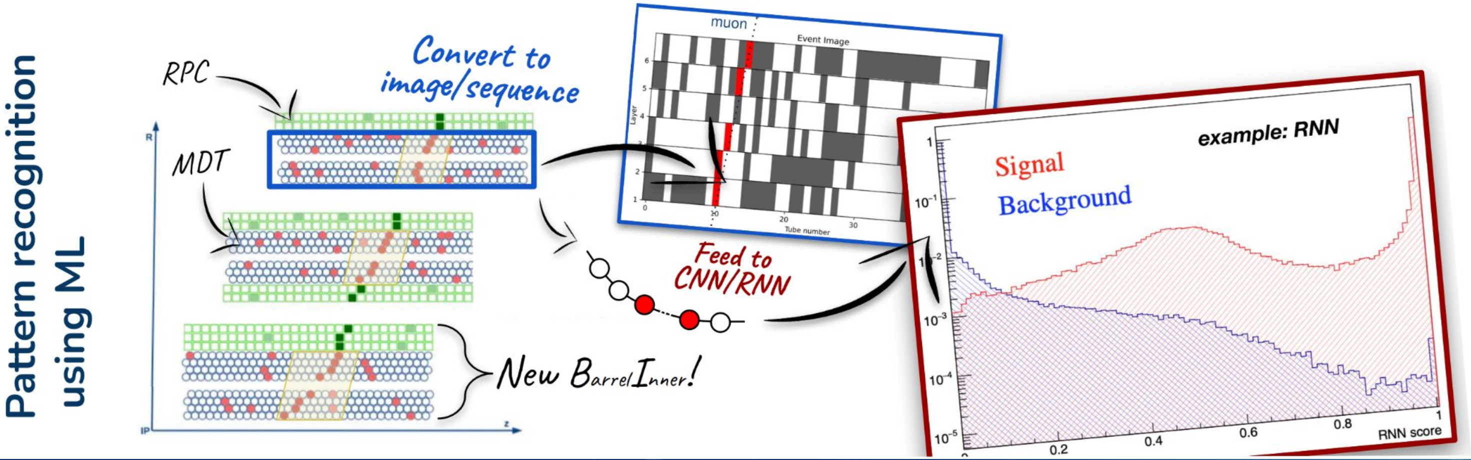


- **Supplement pattern recognition algorithms with MDT**
  - Used to **select** good RPC seeds or **recover** missing ones
  - **Exploring algorithms** more suitable for sparse data for pattern recognition as well as ML methods, e.g. for momentum estimation

- **Studying displaced muon signatures**
  - Angles rejected by standard muon triggers - pointing requirement
    - late decays in front of the MS: very non-pointing tracks
    - decays **within** the MS: diverging patterns of hits, rather than fully independent tracks
  - Developing dedicated algorithms targeting signals → **require novel trigger concepts**





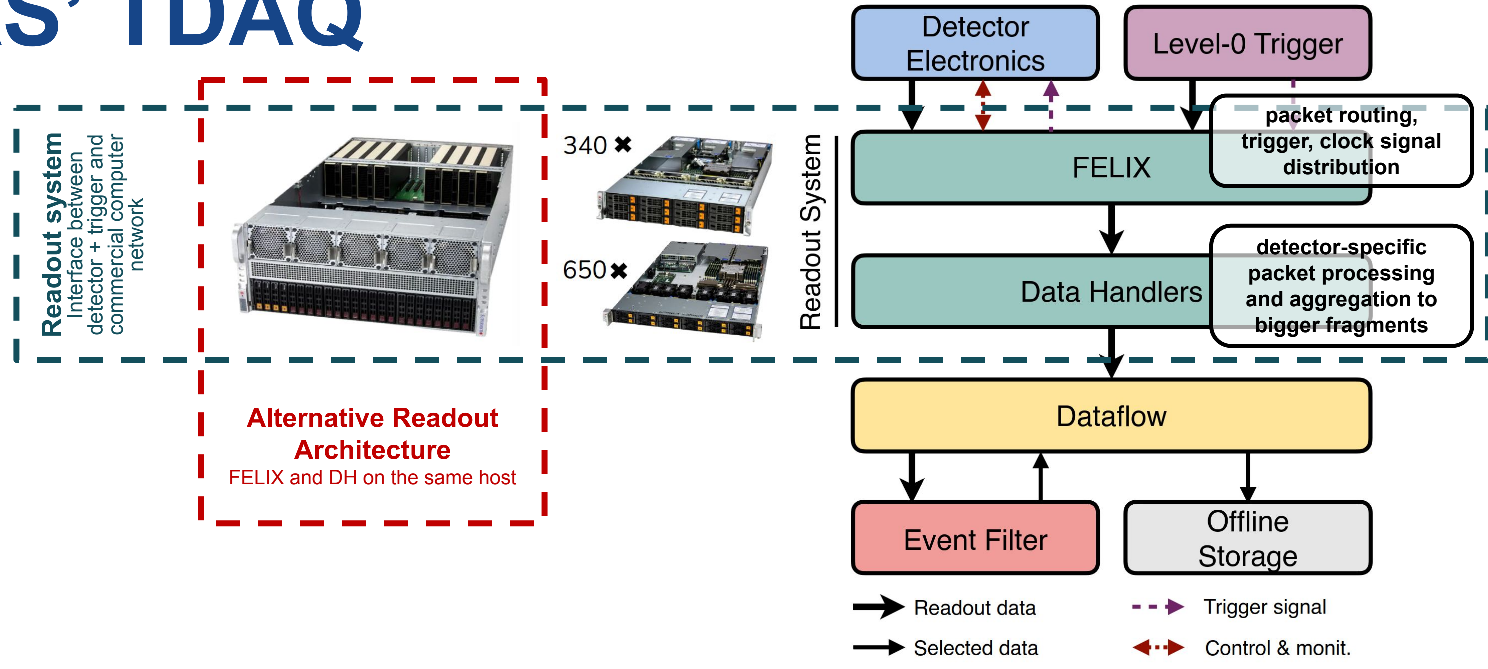
- **Overcoming current trigger limitations:**
  - **Collimated** muons **not resolved** as separate muons
  - **Mis-reconstructed p_T** for non-pointing muons failing the trigger coincidence window
  - **High p_T thresholds**, especially for single muon triggers

M. Carnesale, O. Kortner, V. M. Outschoorn, R. R. Caballero

Work Package 2.3

Enhancing the ATLAS' TDAQ

- **Main goal: Ensure the ATLAS data acquisition infrastructure delivers required event information reliably and with minimal latency to maximize the potential of WP2 trigger approaches**
  - The readout subsystem connects detector-specific optical links to a commercial network, posing **significant technical challenges**
  - **Optimize** readout performance and **eliminate** system **bottlenecks**
  - **Support application** such as TLA with sufficient sustainable bandwidth
- **Developments on alternative server architecture led to optimization in data-transmission to EF**
  - **Direct access** from DH to FELIX cards
  - Testing of end-to-end data transmission in progress
  - Downstream effects on detector interfaces being studied



Alternative readout systems to the baseline being **under investigation**

😃 **Cheaper**

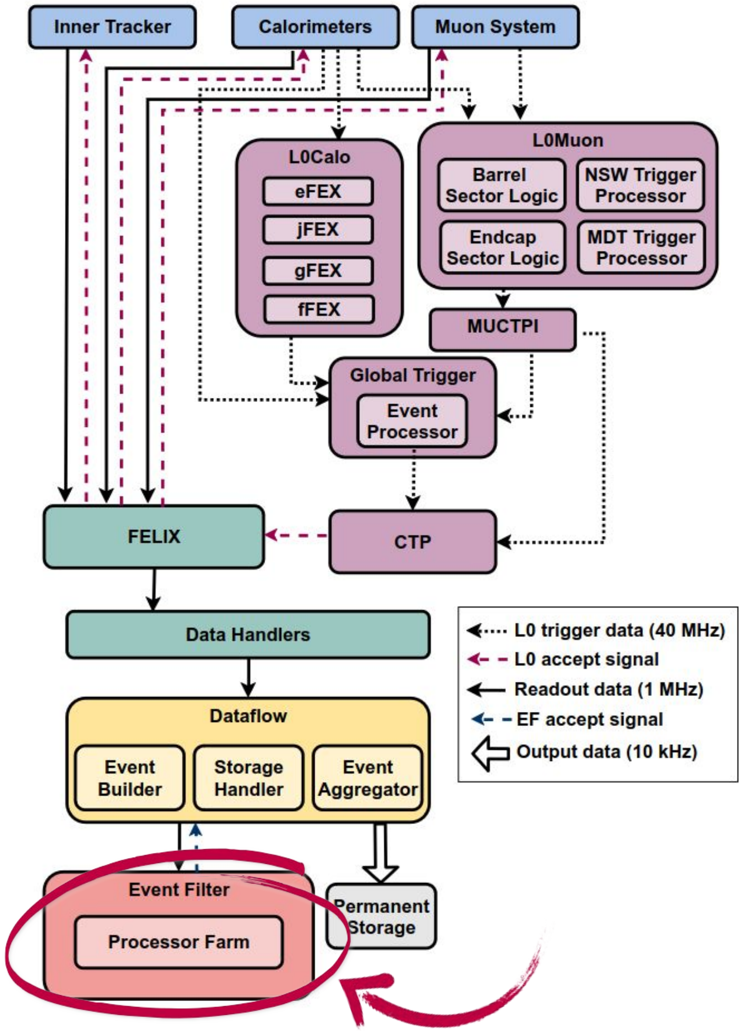
🙁 **No flexible data routing between FELIX and DH**

	Baseline	Alternative
CPU cores	42k	54k (+28%)
Number of Servers	990	280 (-70%)
Power (kW)	495	366 (-26%)
Racks	36	28 (-22%)
Relative Cost	100%	78%10

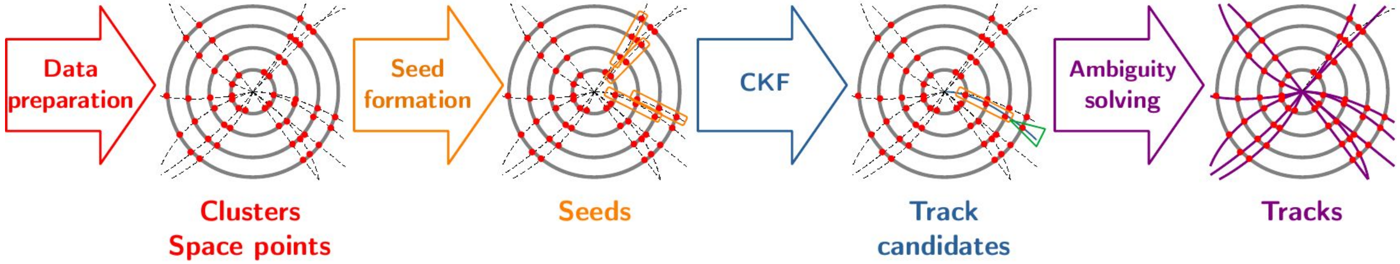
C. A. Gottardo, M. Shehu, W. Vandelli, T. Wengler

Work Package 2.4

Event Filter Tracking



- **EF farm will run tracking (WP 2.4), calorimeter and muon (WP 2.5) algorithms**
- **EF Tracking** refers to the **tracking algorithms running on flexible, heterogeneous commercial** system
  - TDR for Phase-II Upgrade of the ATLAS TDAQ System - Event Filter Tracking Amendment
  - Combines **regional tracking** on the majority of the events, with **full-scan tracking** at a reduced rate
  - Investigates **unconventional tracking** strategies for **new triggers**
- **Main goal: Development of an algorithmic solution for the ATLAS EF track reconstruction**
  - Exploring **optimal classical numerical** and **Machine Learning** (ML) **techniques**, e.g. Graph Neural Networks (GNN)
  - Deployment on the **most suitable hardware architecture**: FPGA, CPU, GPU



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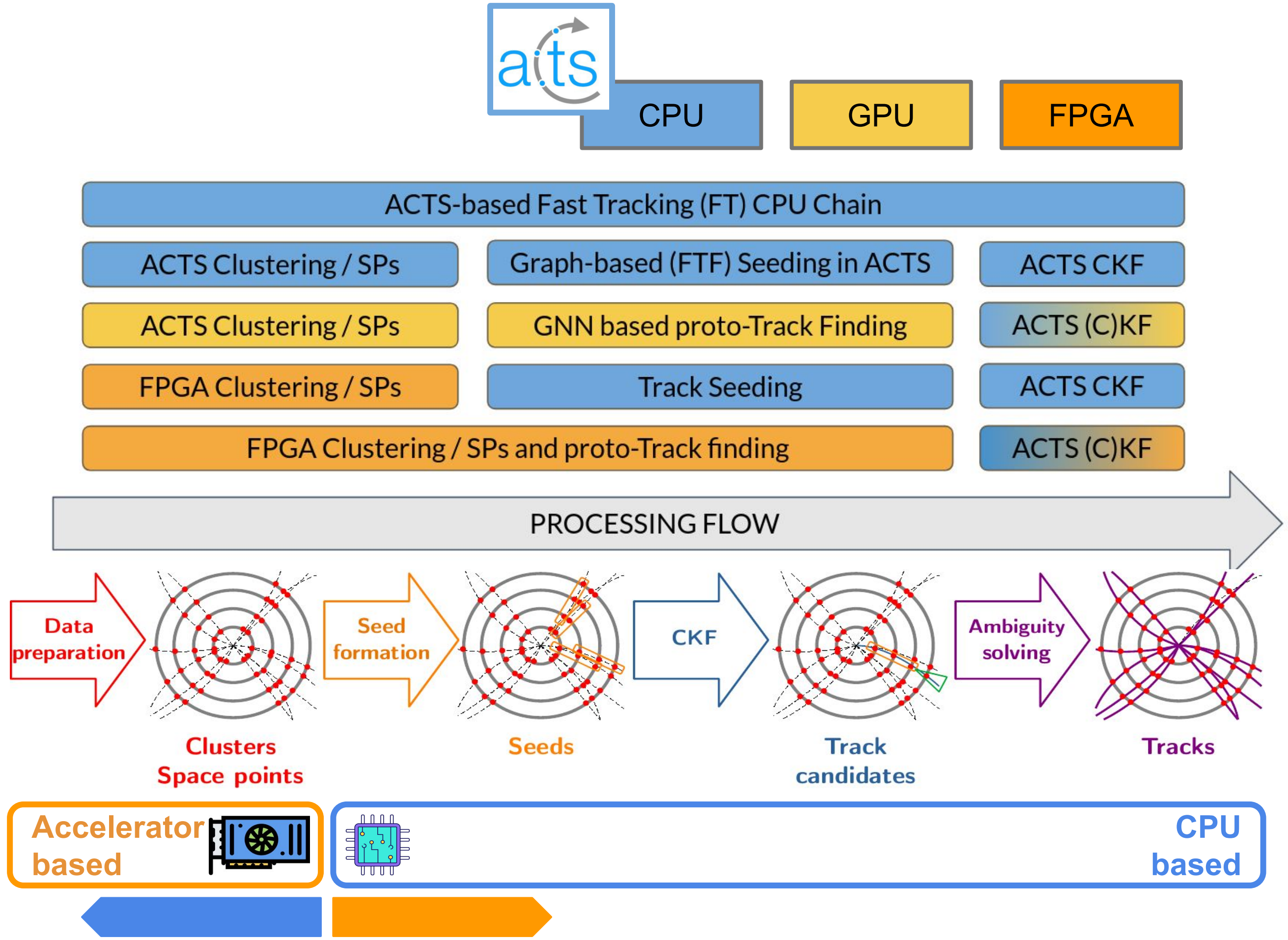
Work Package 2.4

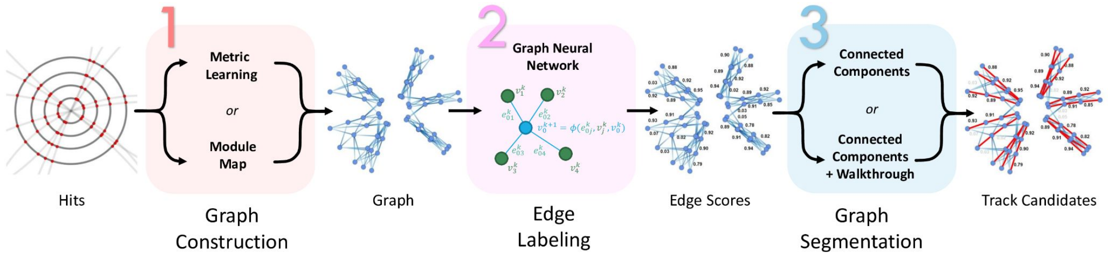
Event Filter Tracking

- **Development of an algorithmic solution for the ATLAS EF track reconstruction**
  - Exploring **optimal classical numerical** and **Machine Learning** (ML) **techniques**, e.g. Graph Neural Networks (GNN)
  - Deployment on the **most suitable hardware architecture**: FPGA, CPU (ACTS-based), GPU
- **Contributing to R&D lines** for algorithms and technologies to extend trigger event selection
- **Provide support and enable deployment** of the tracking chain at EF trigger
  - **Inputs for the 2025 technology choice report: hard deadline on August 1st!!**

➪ **Optimization of physics and processing performance of the track reconstruction at the EF**



Sliding window which can be optimized for FPGA solution



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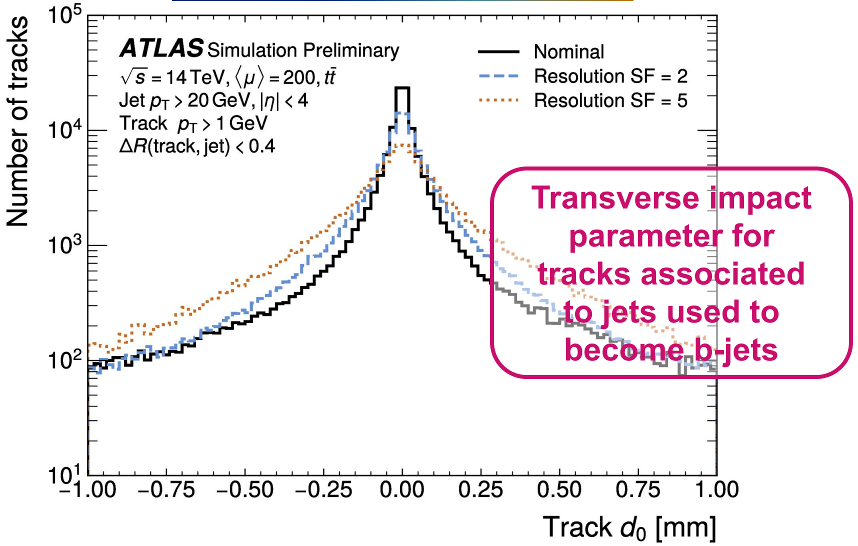
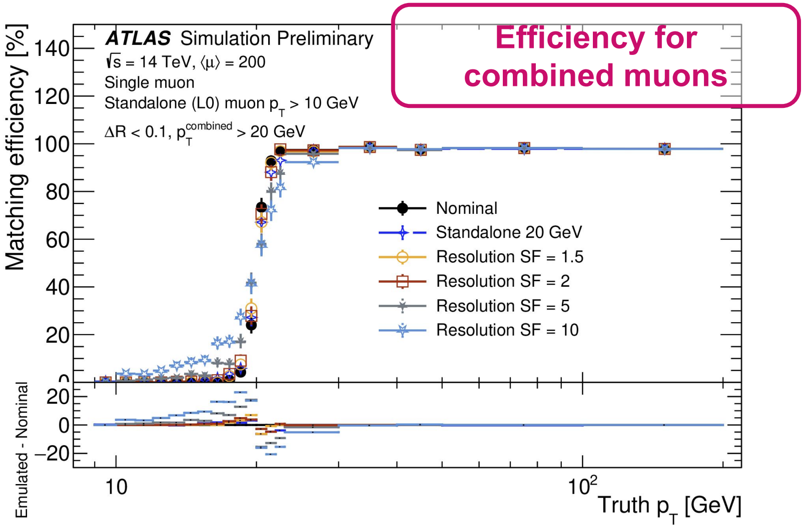
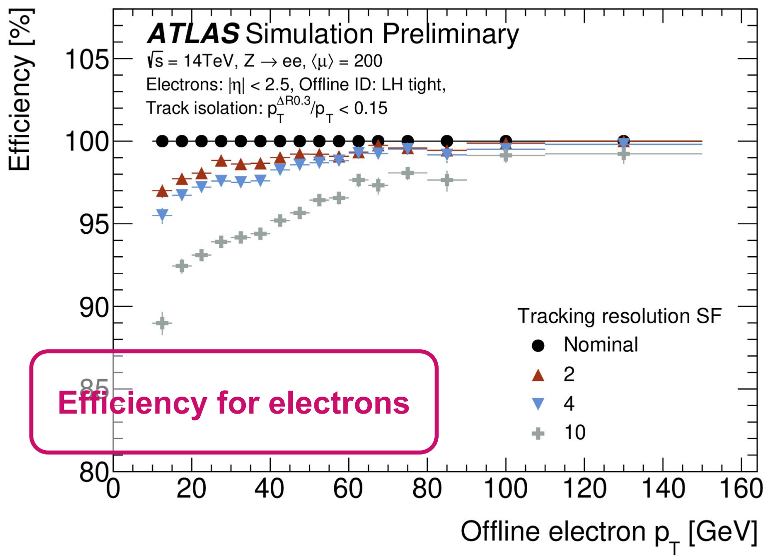
ATL-DAQ-PUB-2024-002

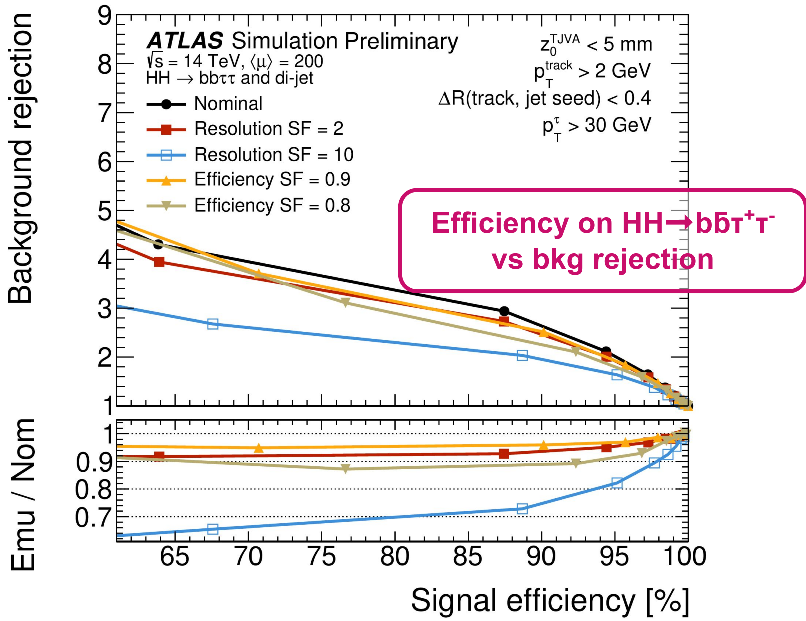
Work Package 2.4

Event Filter Tracking









- **Improving HLT Tracking provides:**
  - Offline-like performance: improved b-tagging, resonance reconstruction, vertexing, …
    - **loss of rejection (== rate increase for same efficiency) if degraded ID resolution**
  - Tighter turn ons: improved signal acceptance for same rate budget
  - Pileup suppression: helps keeping HLT rate under control
  - Support for TLA with offline-like tracking
  - Faster tracking add capacity to process more

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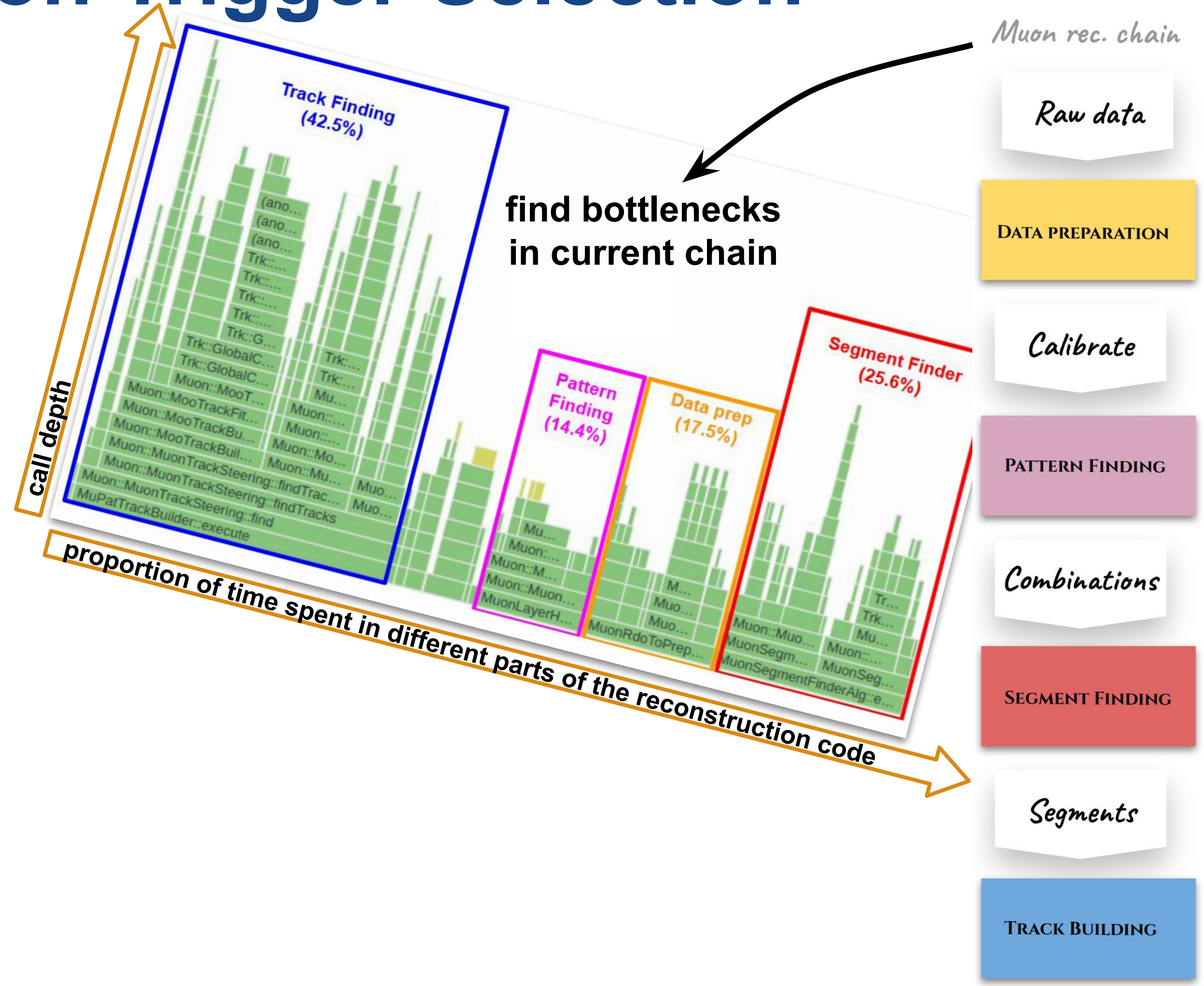
Work Package 2.5

Optimized Event Filter Muon Trigger Selection

- **<u>Main goal</u>: Providing advanced muon reconstruction with optimized precision and efficiency**
  - Leveraging muon track reconstruction by using **extended L0 muon trigger coverage** (WP 2.2) and the **ACTS tracking infrastructure**
  - Develop **novel ML-based reconstruction** techniques to surpass classical algorithms

- **Current focus: migrate / reimplement classical reconstruction based on ACTS**
  - Sharing as much code as possible with inner tracking (both online and offline)
  - Use understanding of bottlenecks, implement reconstruction improvements
  - New implementation has significant muon reconstruction chain speed-up (~2-3x) with no impact on physics performance

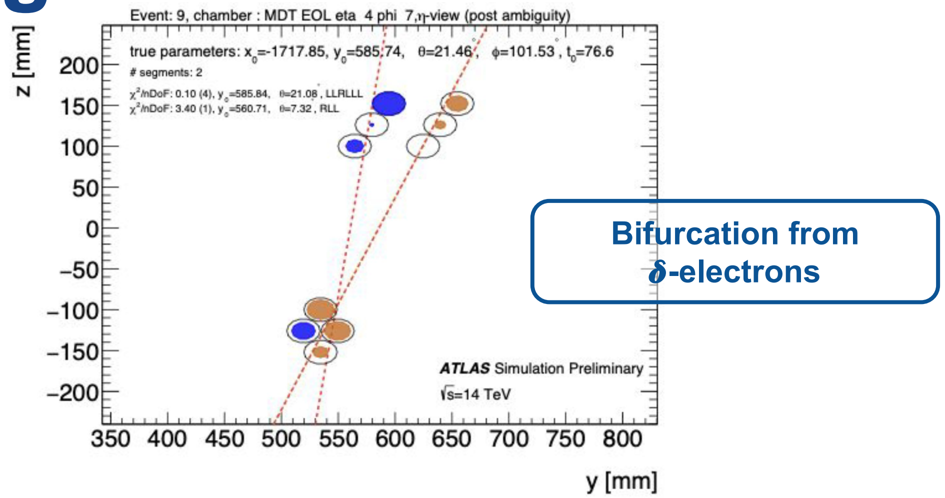


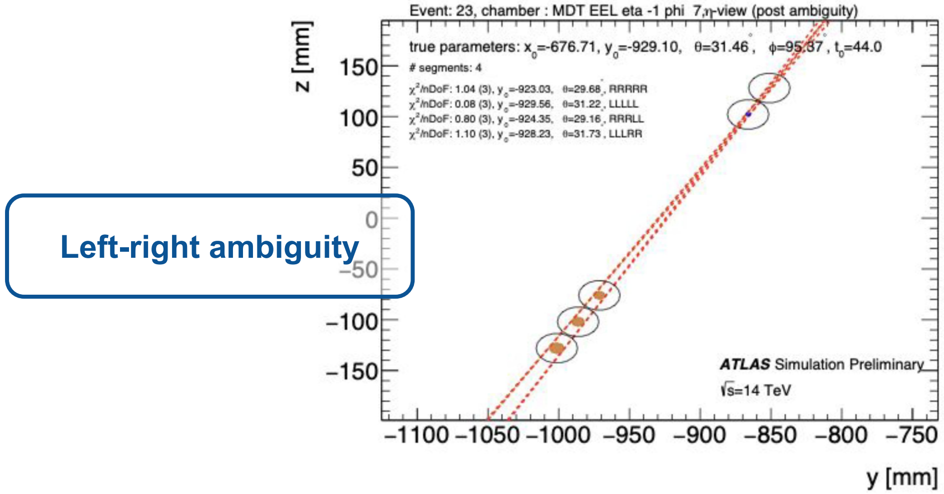
E. Moyse, M. Owen, J. Junggeburth, D. di Croce, L. Monaco, J. Renusch

Work Package 2.5

Optimized Event Filter Muon Trigger Selection

- **Solve limitations of classical approaches exploring strategies based on ML techniques**
  - Plots to the right is a schematic of a side-on view of a muon chamber. Circles represent the simulated “drift radius”, as simulated…
    - Left-right ambiguity of drift circles: the true tangent in **unknown**! Multiple analytical solutions, only one is correct.
    - Also with significant background from δ-electrons: Segment finding needs to suppress background drift circles
- **Use ML to solve ambiguity in segment finding and to deal with background**
  - Building GNN based segment finding:
    - Initial performance looks promising
  - Plan to add ML-based segment parameter regression
    - Might allow smaller search windows for segment attachment
- **Access to lower threshold and to more challenging signatures, combined with L0 muon efforts**





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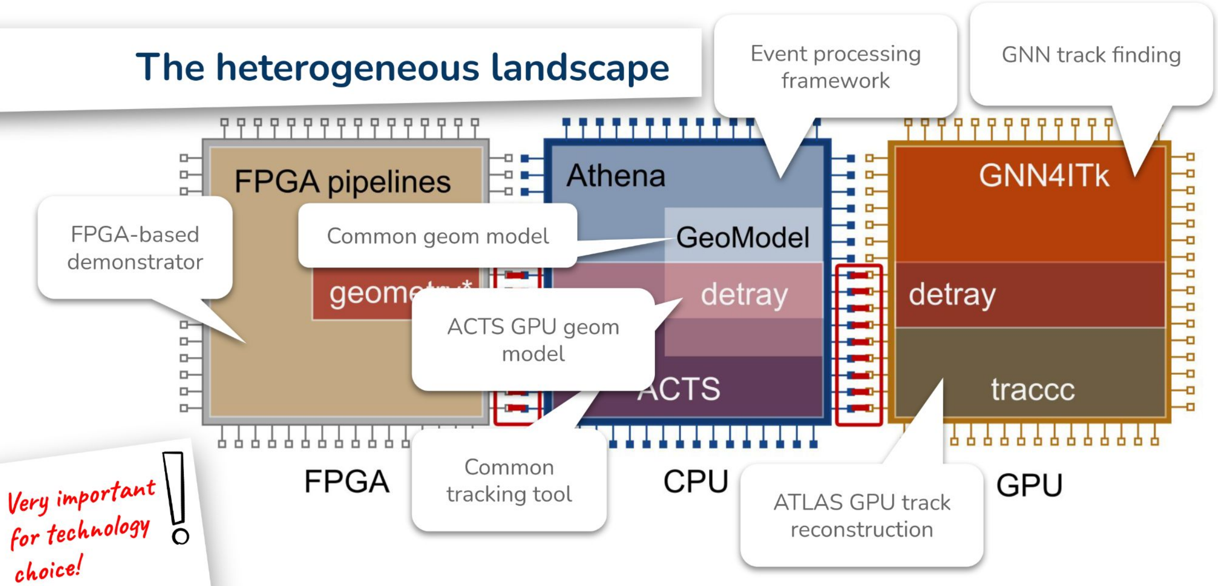
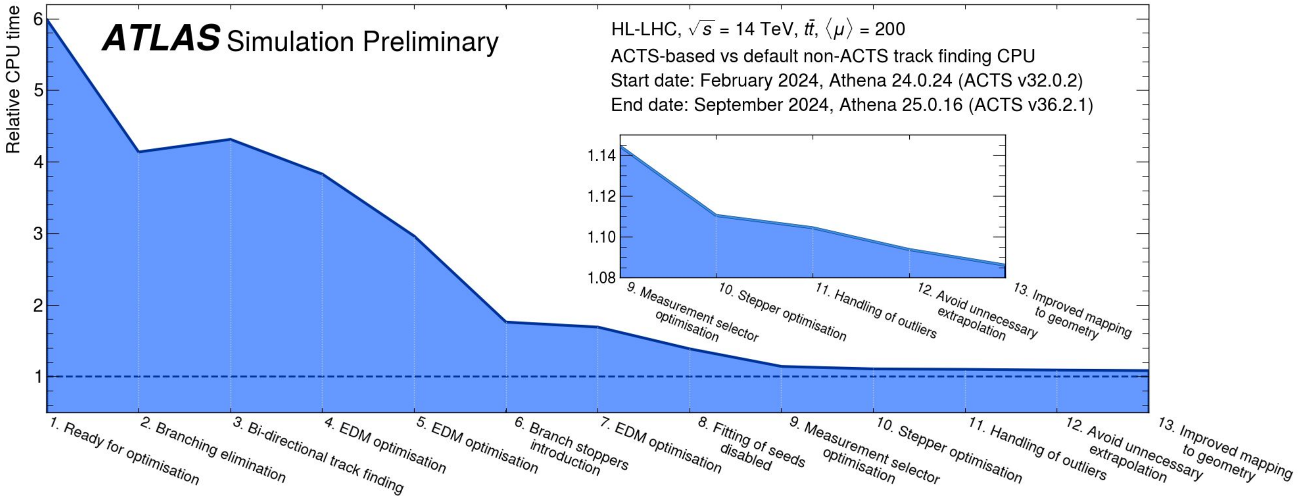
Work Package 2.6

Common Tracking EF infrastructure

- **Main goal: Development of core algorithm and infrastructure to support other WP on EF**
  - Support ATLAS EF prototypes within ACTS, including technical assistance and data modeling
  - Improve integration of GPU, CPU and FPGA based demonstrators
    - Common geometry model and tracking tools, enable ML pipeline interfacing ACTS, optimize data structures for diverse (heterogeneous) workflows
  - Major effort to improve ACTS track reconstruction chain
    - Benefit from ATLAS offline optimization effort (changes to ACTS + Athena code)
- **Increased commonality with offline implicitly makes TLA more feasible and understandable**



Very important for technology choice!



A. Krasznahorkay, P. Gessinger, S. Swatman, A. Salzburger (Not NGT: A. Stefl)

Work Package 2.7

Enhanced Reco for Higher Level Event Filtering

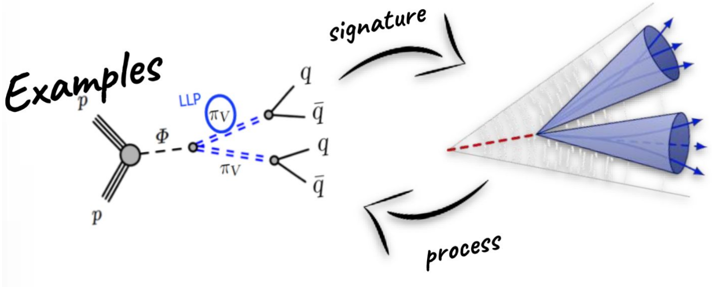
- **<u>Main goal</u>: Overall optimization of the Run-4 trigger menu with focus on physics application**
  - **Exploit capabilities** developed in other WPs, e.g. new reconstruction techniques for **enhanced particle identification**
    - Connect reconstruction and physics analysis
  - **Go beyond** conventional trigger strategies
    - Trigger concepts for exotic, non-standard signatures
    - Investigate TLA and other real-time analysis methods

➞ require close collaboration with other WP

- **Use results from WP 1.6 to define <u>new benchmarks for trigger algorithms</u>**

- **Conducted survey to assess trigger limitations in analysis**

- **Look in two directions: from physics to signatures as well as from signatures to physics applications**



T. Critchley, M. Goblirsch, A. Ruiz, C. Sauer, G. Rupnik Boero

Work Package 2.7

Trigger Emulation

Click to find out more!

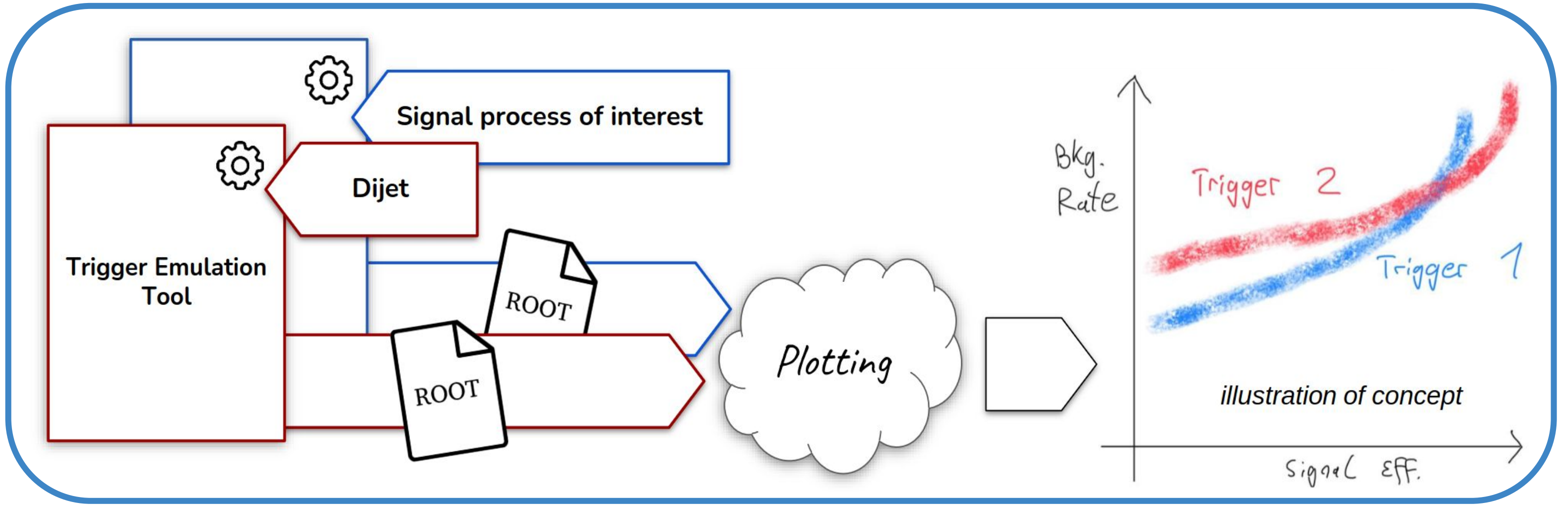
NGT WP 2.7 SQUEAK

- **Developing fast emulation tool to evaluate triggers without full menu simulation**
  - Use of modified **offline reconstruction as proxy for trigger reconstruction**
  - **Fast and flexible** definition of prototype triggers

→ **Simple QUick and Easy Analysis toolKit**

  - **Flexibility over precision**: not replacing baseline, just to scan different chains quickly for a **good working point**

- Simple to use
- Integration into Athena
- Allows for the implementation of new variables (also ML-based)
- Fast and reliable
- Mimics trigger conditions as close as possible



Interesting candidates investigated in full ATLAS trigger simulation

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Work Package 2.7

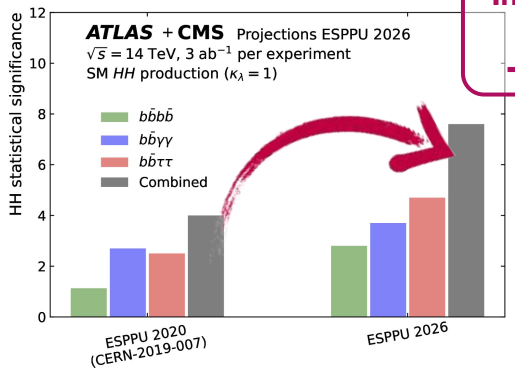
ATL-PHYS-PUB-2025-018

ATL-PHYS-PUB-2025-006

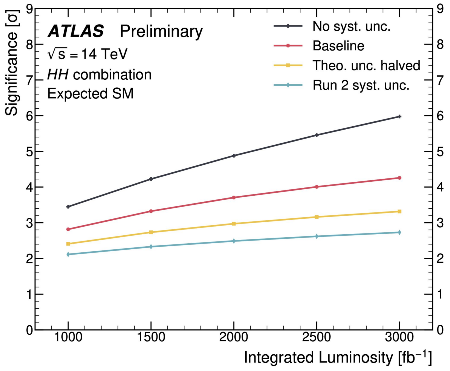
Identifying Interesting Physics Scenarios

$$V(H) = \frac{1}{2}M^2H^2 + \lambda v H^3 + \frac{1}{4}\lambda' H^4$$

- **Di-Higgs**
  - Rare process – essential to characterize self-coupling of the Higgs
    - Fundamental parameter of the Higgs potential
  - Recent advances: Potential for HH at HL-LHC **beyond original expectations ➞ Need triggers to make the most of it**



Improvements in analysis and reconstruction techniques ➞ much stronger projection

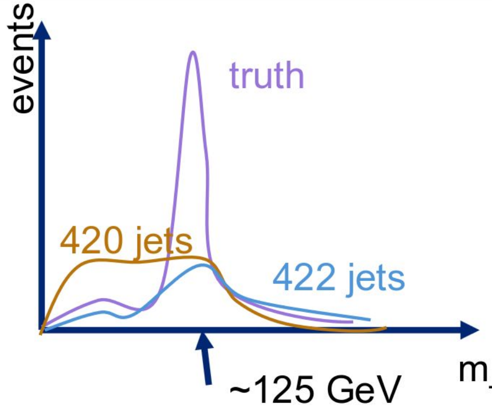


Physics projections for *European Strategy for Particle Physics*

Trigger Selection	Run 1 Offline p_T Threshold [GeV]	Run 2 (2017) Offline p_T Threshold [GeV]	Planned HL-LHC Offline p_T Threshold [GeV]	L0 Rate [kHz]	After regional tracking cuts [kHz]	Event Filter Rate [kHz]
isolated single e	25	27	22	200	40	1.5
isolated single μ	25	27	20	45	45	1.5
single γ	120	145	120	5	5	0.3
forward e			35	40	8	0.2
di-γ	25	25	25,25		20	0.2
di-e	15	18	10,10	60	10	0.2
di-μ	15	15	10,10	10	2	0.2
$e-\mu$	17,6	8,25 / 18,15	10,10	45	10	0.2
single τ	100	170	150	3	3	0.35
di-τ	40,30	40,30	40,30	200	40	0.5†††
single b-jet	200	235	180	25	25	0.35†††
single jet	370	460	400			0.25
large-R jet	470	500	300	40	40	0.5
four-jet (w/ b-tags)		45†(1-tag)	65(2-tags)	100	20	0.1
four-jet	85	125	100			0.2
H_T	700	700	375	50	10	0.2†††
E_T^{miss}	150	200	210	60	5	0.4
VBF inclusive			2x75 w/ ($\Delta\eta > 2.5$ & $\Delta\phi < 2.5$)	33	5	0.5†††
B-physics††				50	10	0.5
Supporting Trigs				100	40	2
Total				1066	338	10.4

Phase II TDR, trigger limitation ⟶ TLA prospect?

- **Using offline-like jets at L0**
  - Investigating HH➞bbbb at √s = 14 TeV with <μ> = 200
  - Jet building from topo clusters available at L0 (emulated for study "422")
  - LUT-based fast jet calibration
  - Usage in TLA being evaluated



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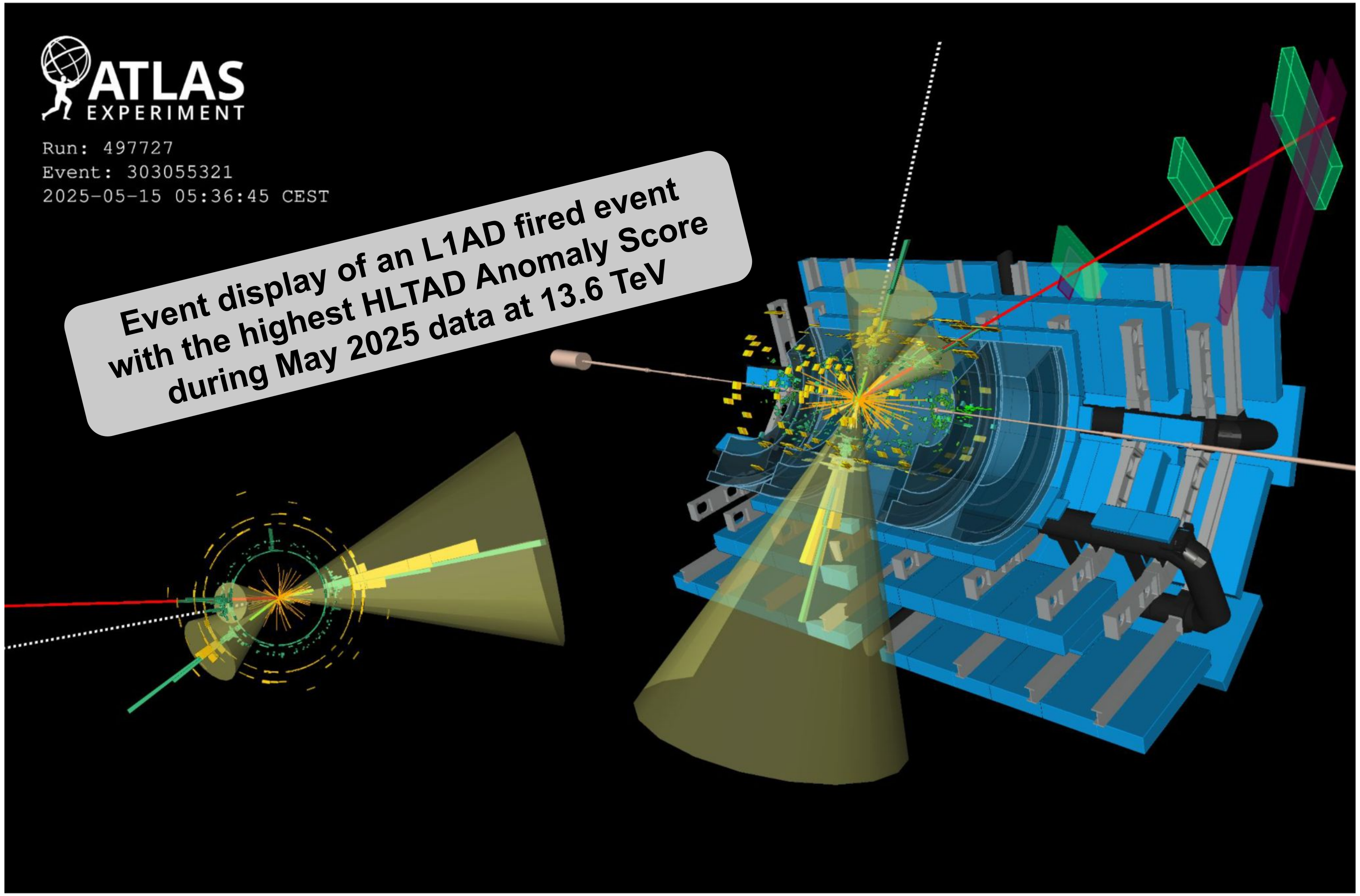
Work Package 2.7

Identifying Interesting Physics Scenarios

- **Exotic signatures**
  - Interested in **non-standard signatures** in the detector that require **novel trigger concepts,** e.g. investigating **TLA** scenarios **beyond baseline**
  - Particularly interested in **exotic** final states
  - Also exploring anomaly detection in the trigger
    - Enhance detection efficiency for unknown signatures while maintaining a model agnostic approach



In this event:

- **4 jets with p_T > 50 GeV** (p_T = 831 GeV, 304 GeV, 253 GeV, 56 GeV)
- **1 muon with pT > 30 GeV** (p_T= 113 GeV)
- **3 electrons with pT > 30 GeV** (p T = 209 GeV, 82 GeV, 60 GeV)
- **215 GeV of MET**

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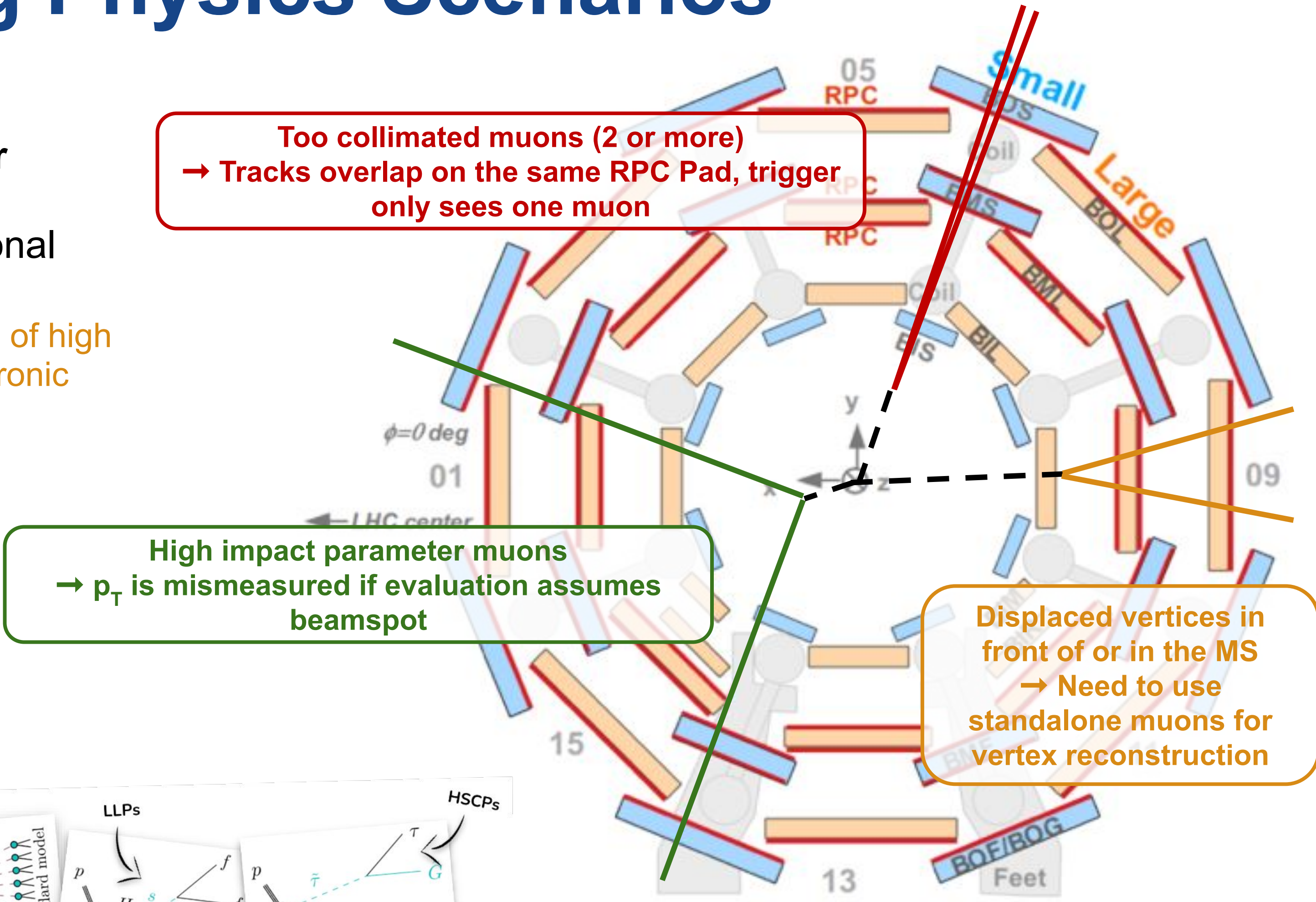
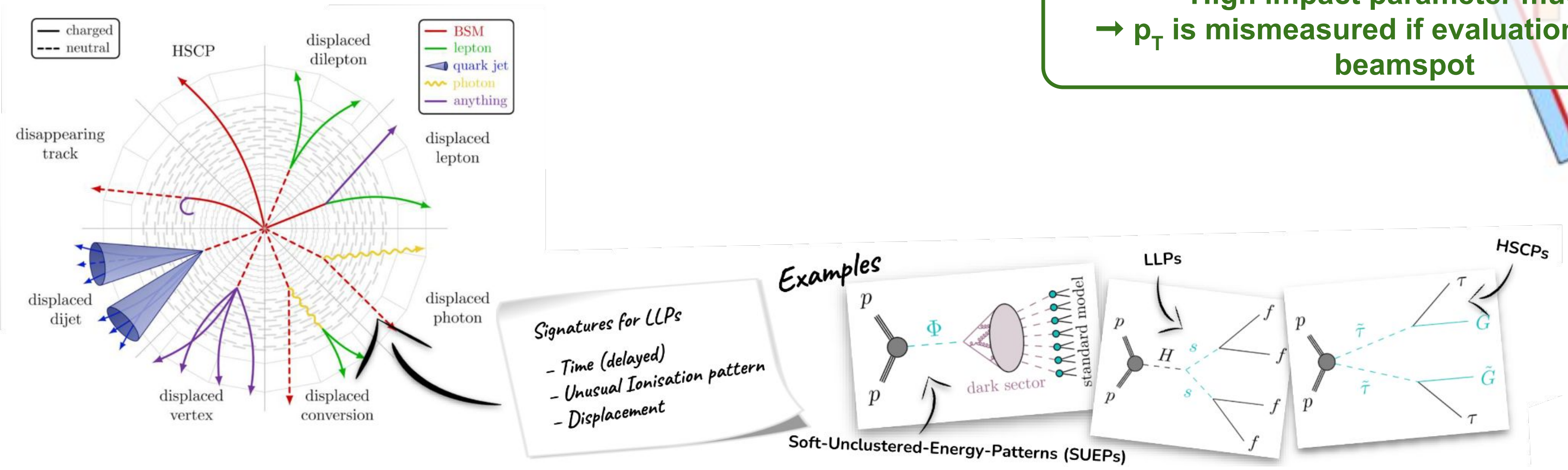
Work Package 2.7

Identifying Interesting Physics Scenarios

- **Exotic signatures with muons**
  - Provide **physics signature input to muon trigger developments**
  - Ongoing work **with 2.2 & 2.5** studying unconventional muon signatures (e.g. soft, displaced, collimated)
    - LLPs decaying to pairs of collimated muons, or to pairs of high impact parameter muons, highly ionizing particles, hadronic decays in the muons
  - Studies needed into the **feasibility** and **physics potential** of muons used in **Event Filter TLA**





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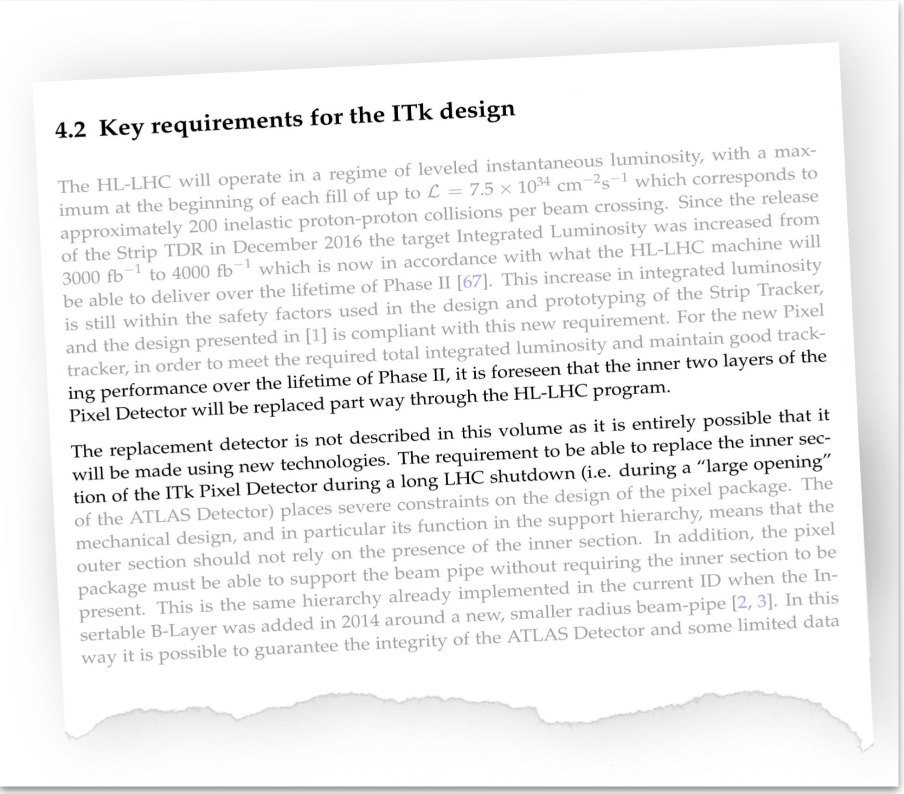
Work Package 2.7

Identifying Interesting Physics Scenarios

ATL-TDR-030, LHCC-2017-021

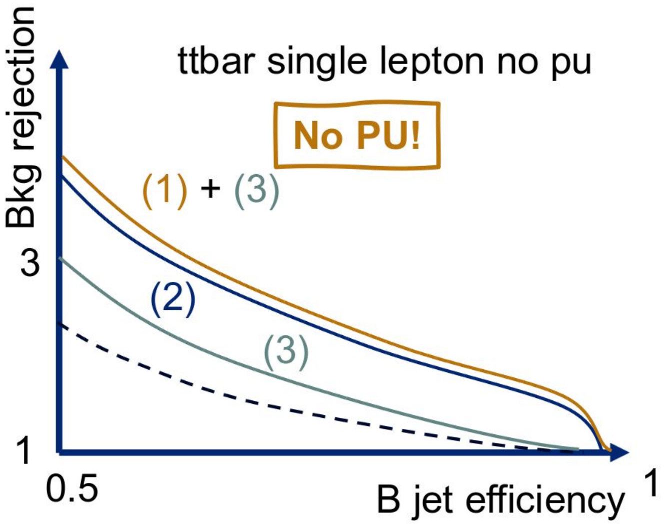


4.2 Key requirements for the ITk design

The HL-LHC will operate in a regime of leveled instantaneous luminosity, with a maximum at the beginning of each fill of up to $\mathcal{L} = 7.5 \times 10^{34}$ cm^{-2}s^{-1} which corresponds to approximately 200 inelastic proton-proton collisions per beam crossing. Since the release of the Strip TDR in December 2016 the target Integrated Luminosity was increased from 3000 fb^{-1} to 4000 fb^{-1} which is now in accordance with what the HL-LHC machine will be able to deliver over the lifetime of Phase II [67]. This increase in integrated luminosity is still within the safety factors used in the design and prototyping of the Strip Tracker, and the design presented in [1] is compliant with this new requirement. For the new Pixel tracker, in order to meet the required total integrated luminosity and maintain good tracking performance over the lifetime of Phase II, it is foreseen that the inner two layers of the Pixel Detector will be replaced part way through the HL-LHC program.

The replacement detector is not described in this volume as it is entirely possible that it will be made using new technologies. The requirement to be able to replace the inner section of the ITk Pixel Detector during a long LHC shutdown (i.e. during a "large opening" of the ATLAS Detector) places severe constraints on the design of the pixel package. The mechanical design, and in particular its function in the support hierarchy, means that the outer section should not rely on the presence of the inner section. In addition, the pixel package must be able to support the beam pipe without requiring the inner section to be present. This is the same hierarchy already implemented in the current ID when the Insertable B-Layer was added in 2014 around a new, smaller radius beam-pipe [2, 3]. In this way it is possible to guarantee the integrity of the ATLAS Detector and some limited data

- **Blue-sky R&D: Hit-based b-tagging (joint with WP 2.4)**
  - Assuming *new* ITk **pixel sensors** would provide **timing measurement** (starting ATL-PHYS-PUB-2023-023 where 4D tracking was studied) to help discriminate signal from pile-up hits,
  - Assuming a new **readout technology** that would allow to read the two Innermost Layers at a rate > 1MHz,
  - Would this allow **light-jet rejection** at trigger level **without tracks**?



- **GNN based algorithm based on raw hits under study**
  - Evaluating signal efficiency vs bkg rejection using different types of inputs:

    Calorimeter clusters (1)
    All ITk layers (2) [hypothetical]
    Two innermost ITk layers (3)

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Conclusions

- **Main objective of NGT project is to extend the Run-4 trigger to increase the physics reach of the HL-LHC**
  - **Develop, improve and deploy** reconstruction and trigger techniques
  - Investigate **new approaches**, including ML
  - NGT activities and personpower are integrated within the existing ATLAS structures especially extending R&D **beyond baseline approaches**!

- **Agenda plenty of interesting developments in front of us!**
  - NGT fuel is the **expertise of the entire community**: strongly benefits from collaboration within and across work packages!

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NexTGen
Next Generation Triggers