CERN

NexTGen

Next Generation Triggers

Enhancing the L0 Muon Trigger
ATLAS Work Package 2.2

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Verena Martinez Outschoorn (UMass Amherst), Rimsky Rojas Caballero (CERN)

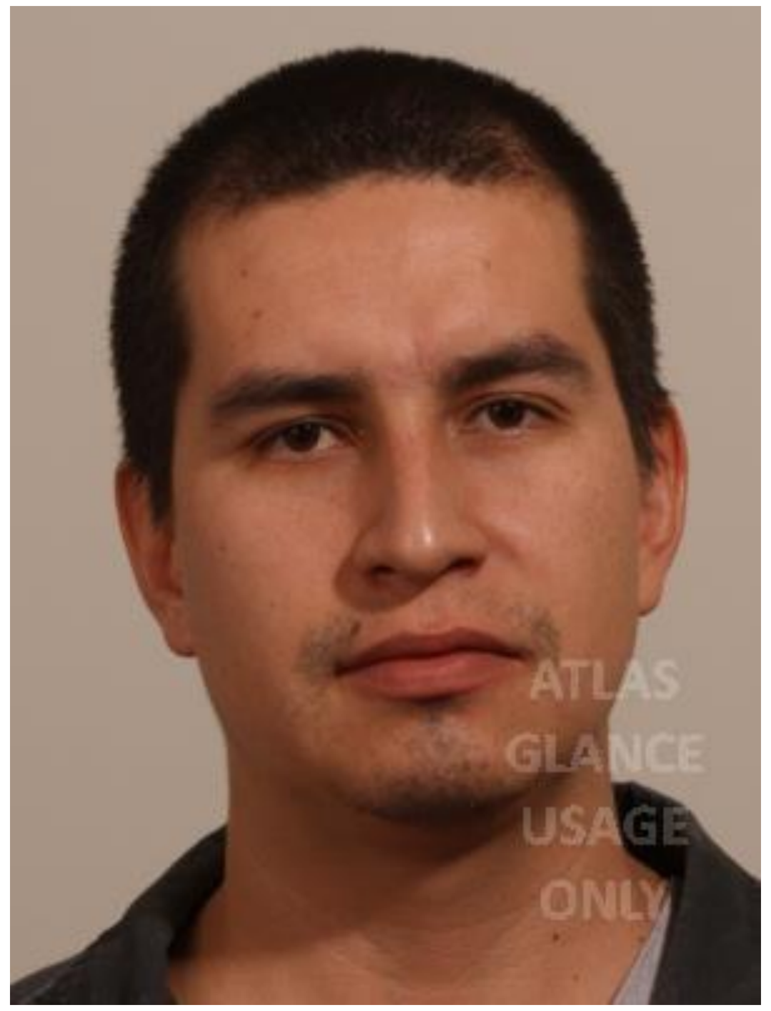
NextGen Trigger All Hands Meeting
November 26th, 2024

Introduction to the Team

Task leaders | Engineer | Postdoc | PhD Students

Oliver Kortner

Verena Martinez Outschoorn



Rimsky Rojas Caballero

Maria Carnesale

started summer 2024

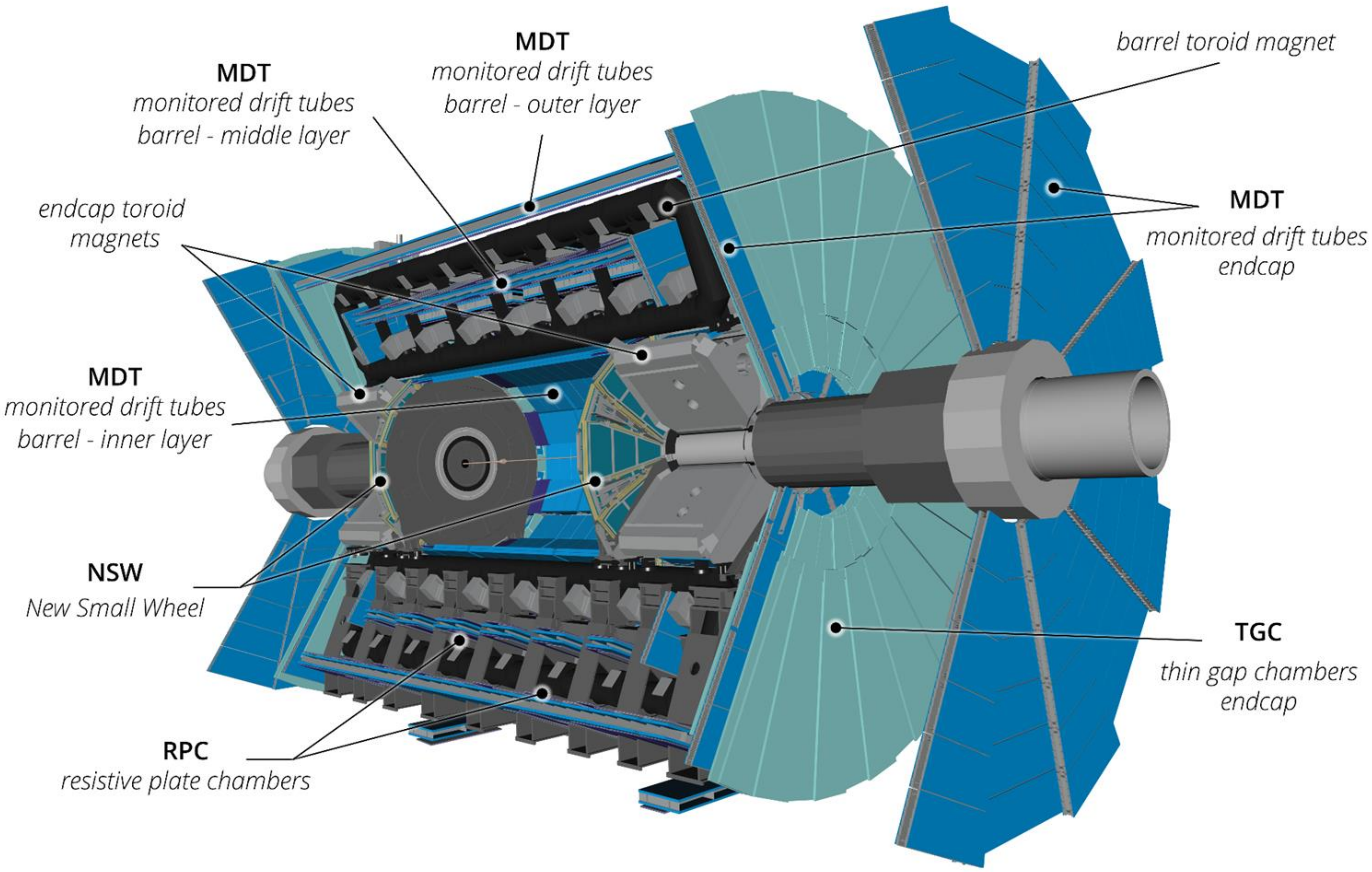
Nivedaa Dhandapani

Nadia Dobreva

starting spring 2025

- **Project start focused on recruitment, hiring and ramping up of personnel**
- **Additional effort recruited including groups not previously involved in L0 Muon**
    - New student research projects on NextGen Trigger include 2 doctoral, 3 masters and 2 bachelors students

Introduction to the L0 Muon Trigger



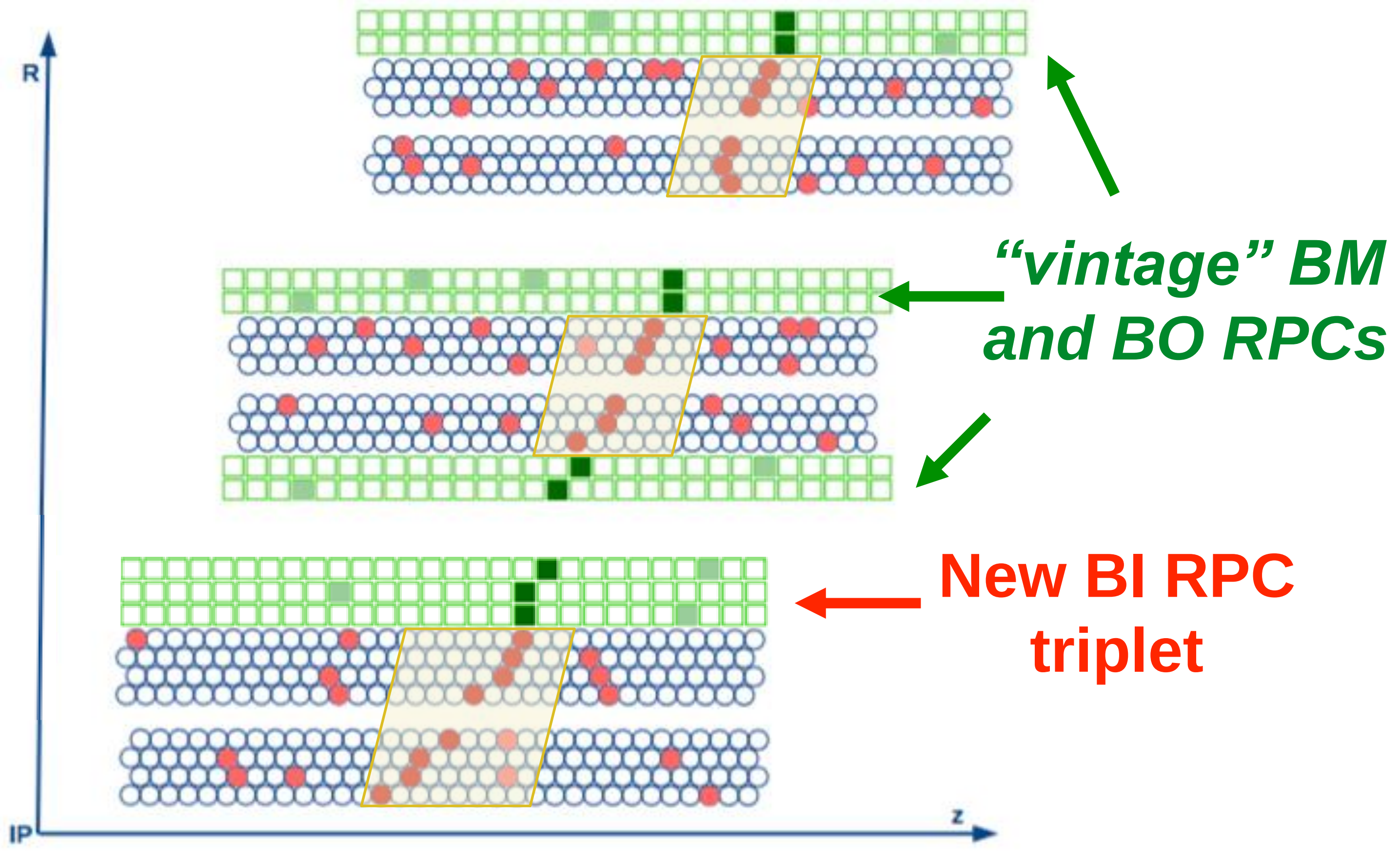
- **Current first level of the muon trigger relies only on fast trigger detectors**
  - RPCs in the barrel region $|\eta|<1.05$
  - TGCs and NSW in the endcap region $1.05<|\eta|<2.4$
- **High-Luminosity upgrade to start operation in ~2030**
  - Use precision measurements from MDT chambers in the first trigger level for the first time
  - Additional layer of RPCs in the innermost barrel layer to improve the efficiency
  - New electronics including modern FPGAs for trigger and readout

Goals: Improve Trigger Robustness

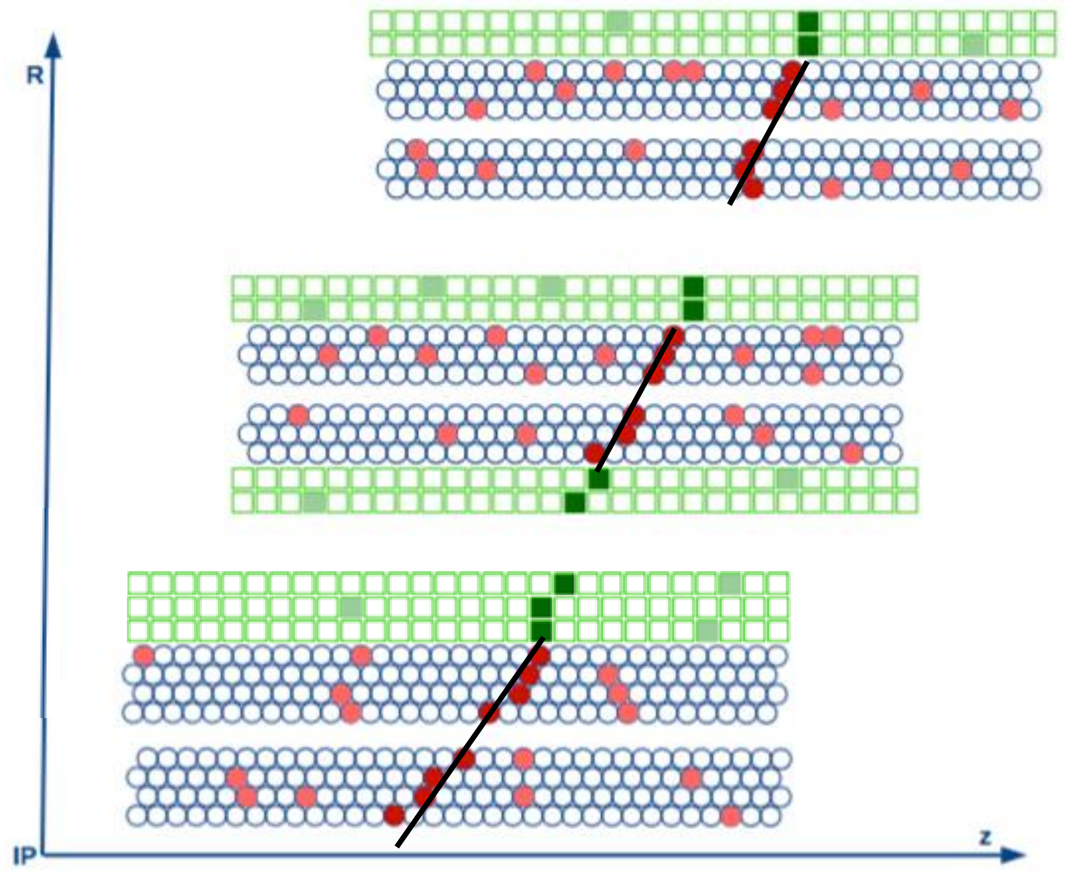
- **Baseline L0 Muon trigger in ATLAS barrel relies on RPCs for best selectivity & performance**
- Study different algorithms/approaches for L0 Muon triggers in case of reduced RPC performance or coverage for new RPC chambers

MDT trigger operating with poorer seeds from RPCs
seeded trigger

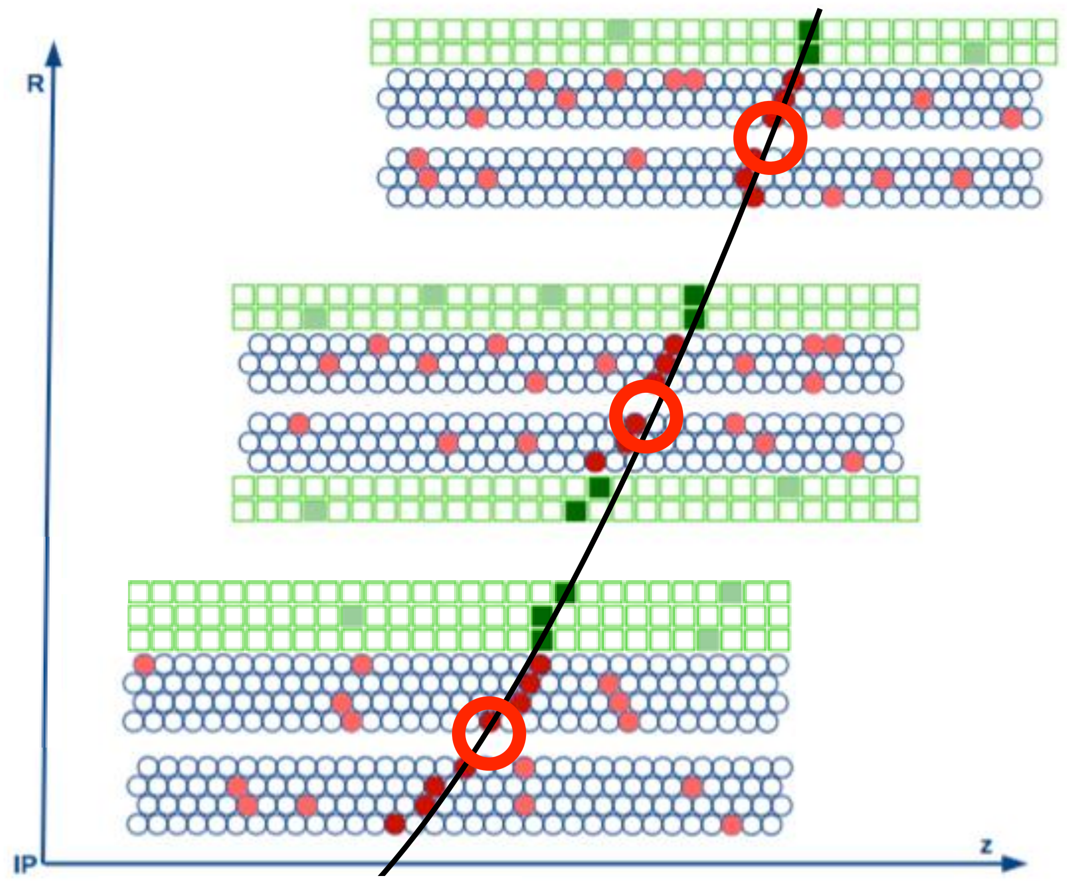
Hit Extraction
RPCs provide seeds to identify MDT hits from a muon & set up segment fitting



Segment Fitting
RPCs provide timing to calibrate hits and derive segments



Momentum Estimation
RPCs provide 2nd coordinate for the p_T estimate since B-field is non-uniform in phi



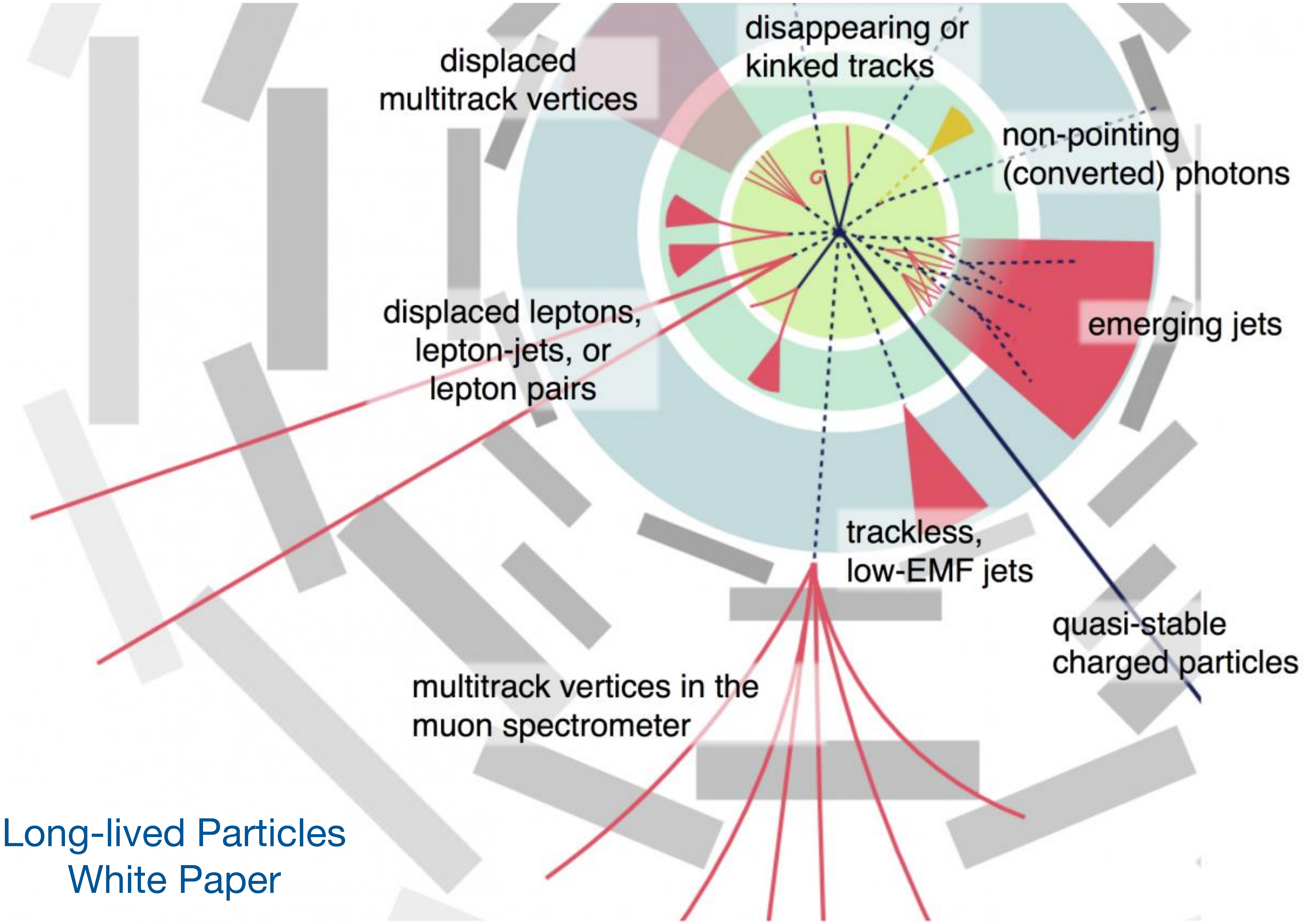
MDT trigger without RPCs
seedless trigger

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

Timing of the muons to determine bunch crossing with Tile or only MDTs

Momentum estimation without a 2nd coordinate phi from RPCs

Goals: Triggers for Exotic Signals



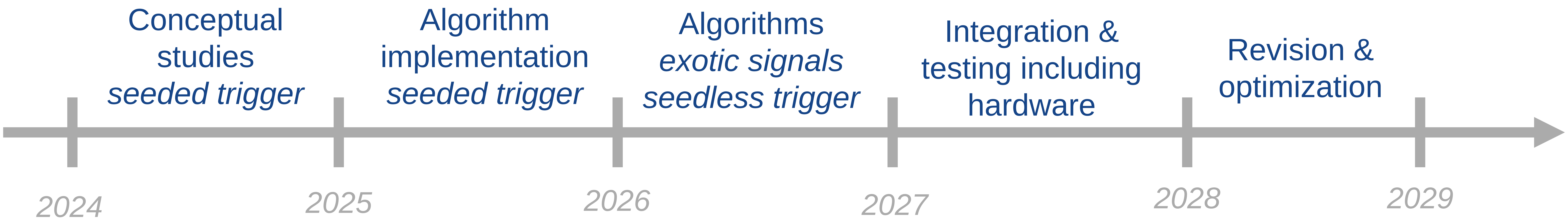
Long-lived Particles White Paper

- **Baseline L0 Muon trigger does not target exotic signatures from long-lived particles**
  - Dedicated muon triggers could enable new physics analyses or significantly enhance sensitivity

- **Developing new algorithms to target displaced muons**
  - From decays of long-lived particles - signature of non-pointing muons
  - Predicted by several models of new physics including dark photons, SUSY sleptons, RPV signals, Higgs portal models, hidden valley signals, etc

- **Many other ideas for signatures to explore in the future**
  - Slow moving or highly ionizing particles, high muon multiplicity, nearby muons, etc

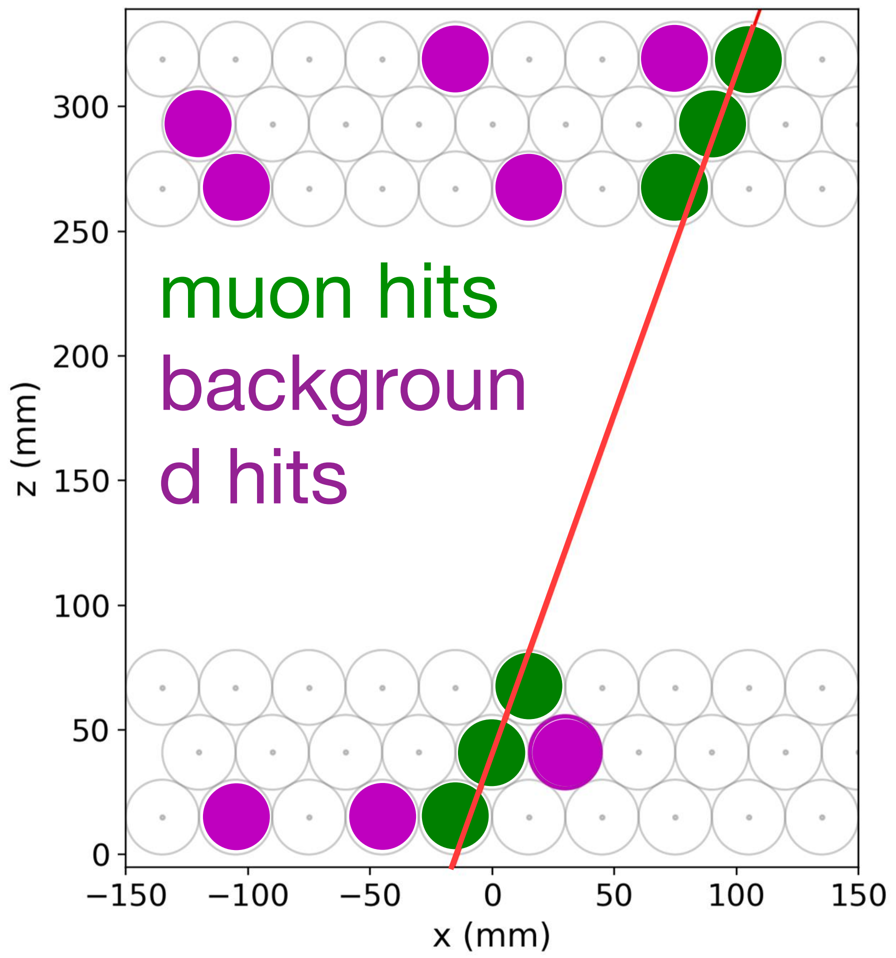
Project Timeline

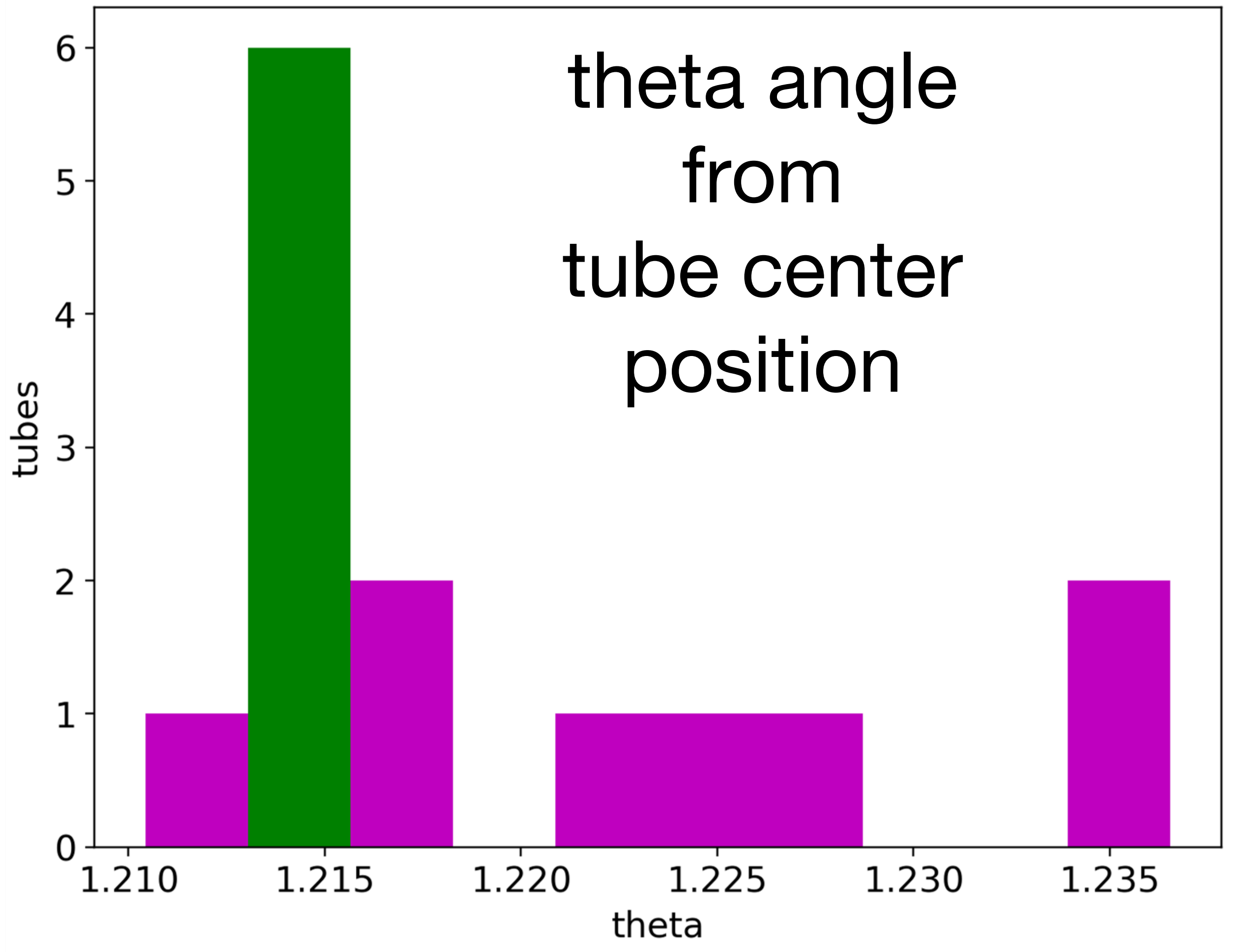


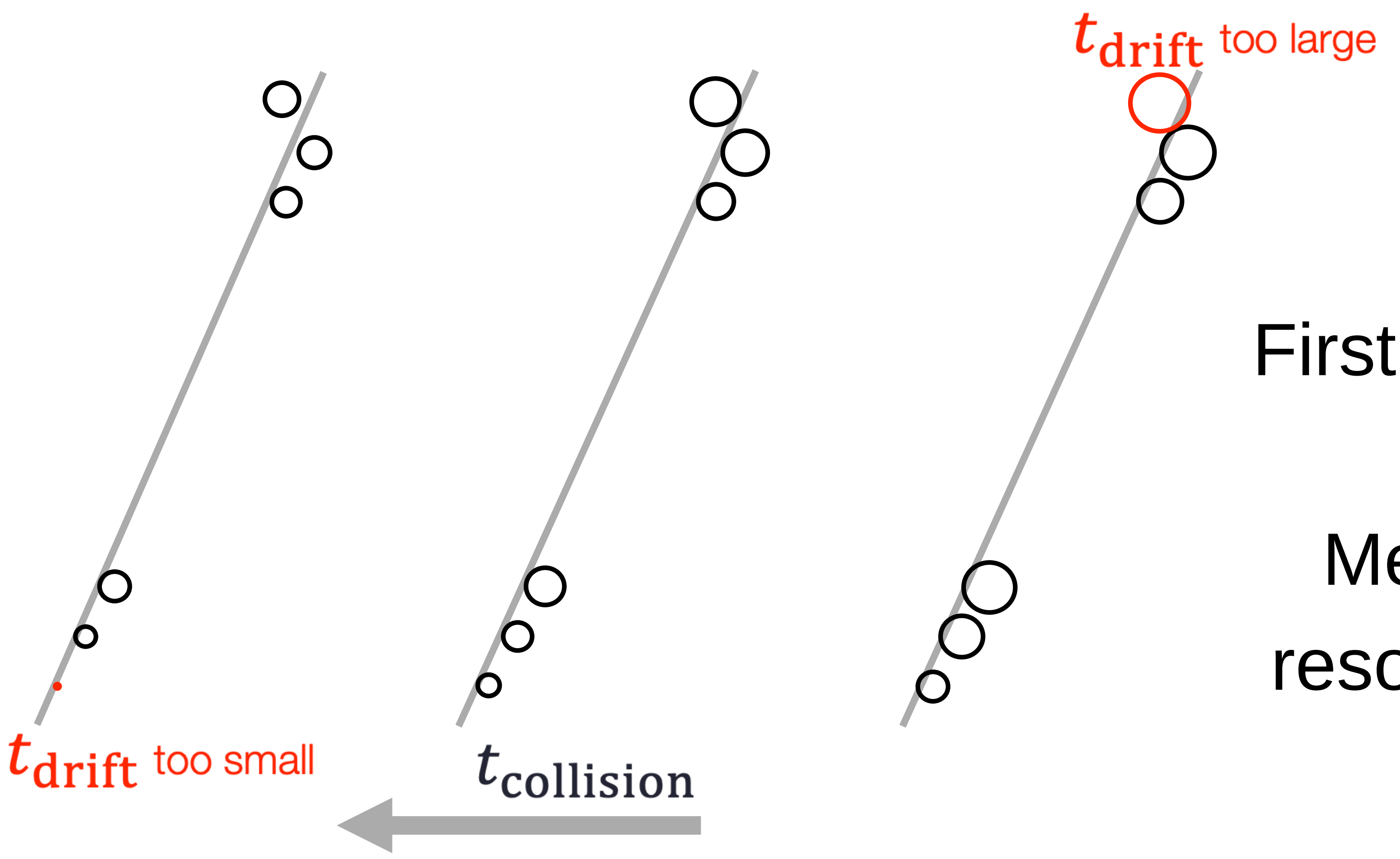
- **Activities include algorithm development, implementation and hardware**
  - Conceptual studies and algorithm development using simulation
    - Focus on both robustness (seeded & seedless) and exotic signals
  - Implementations of algorithms for FPGAs (RTL code)
  - Evaluation of hardware needs
    - Meet latency and resource constraints
  - Investigation of alternative possible hardware platforms
  - Revision of algorithm implementations, optimizations and refinements to meet performance goals

Evolution of Current Trigger Using Standard Techniques

- **MDT pattern recognition using coincidences in roads**
  - Match to input from RPC seeds when available & use to select good seeds
  - Recover missing RPC seeds using only MDT information and fit for collision time (BCID)

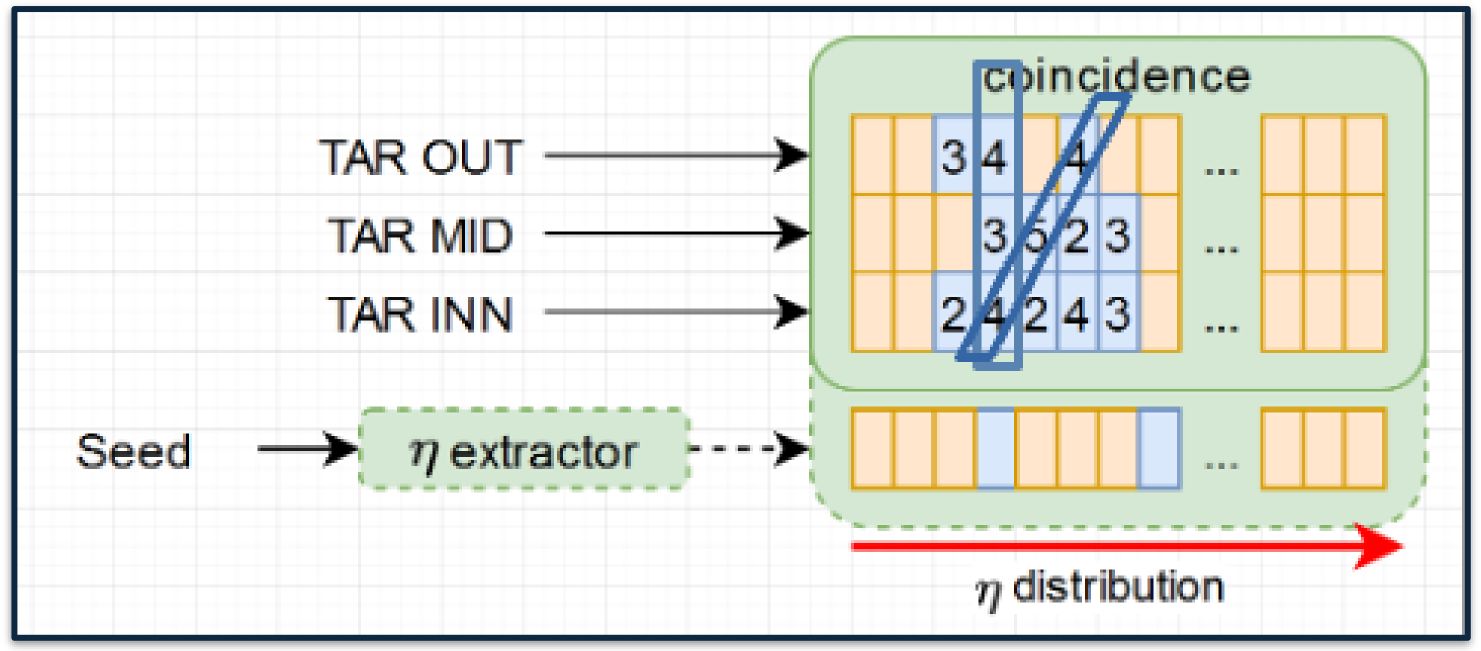






First implementations available

Meet latency and resource constraints



Firmware	LUTs	FFs	DSPs	BRAM	URAM
Baseline	21 %	13%	5%	8%	11%
Standalone	37%	14%	14%	20%	8%

Resource Usage

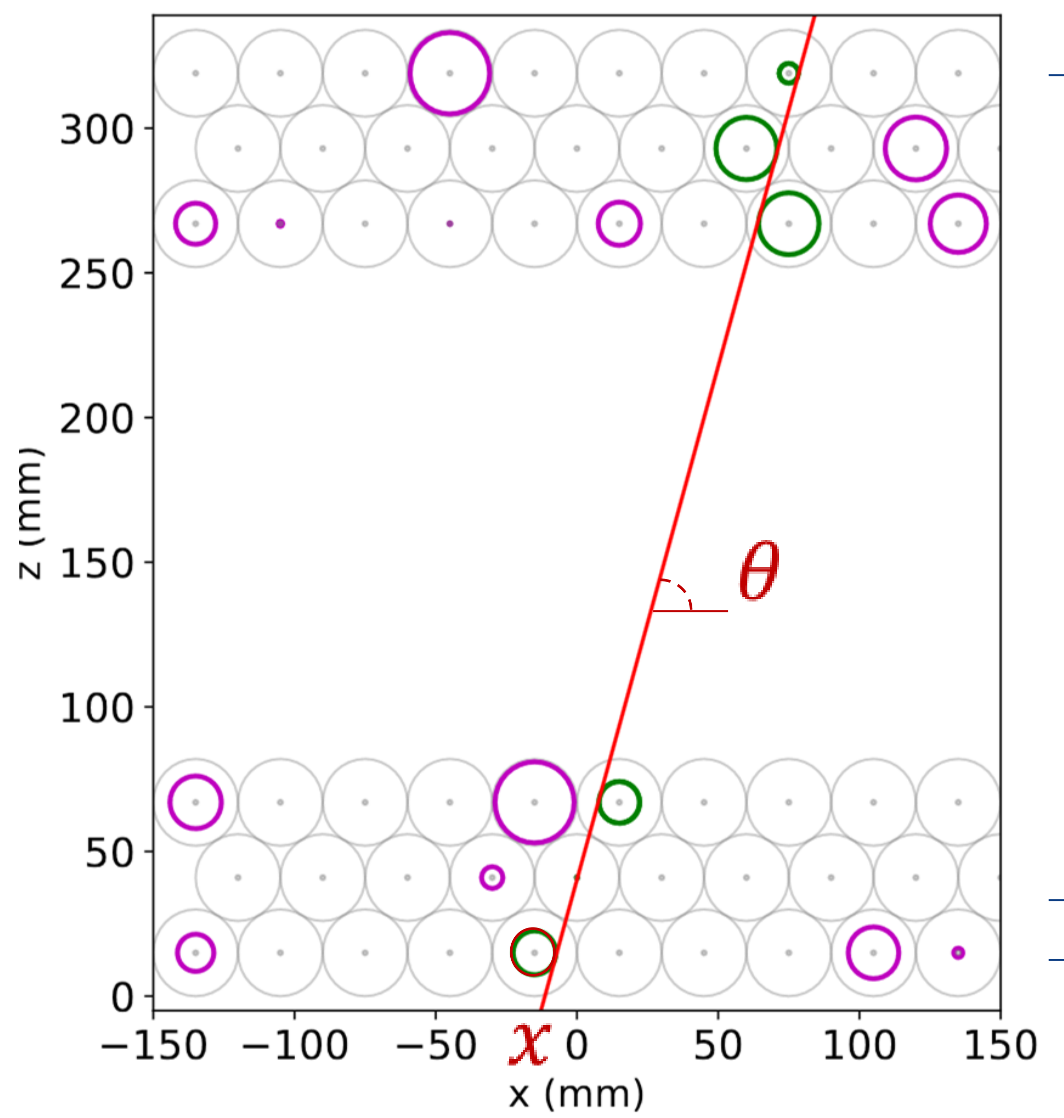
Firmware	Clocks @ 320 MHz	Latency (ns)
Baseline	526	1646
Standalone	324	1013

Latency

Preliminary studies from G. Loustau de Linares & D. Cieri

Exploring Approaches with Machine Learning

Simulation



Training

Sequence Processing → *Regression* → $\hat{x}$, $\hat{\theta}$

L1 hit data | L2 hit data | … | LN hit data

Post Training Conversion

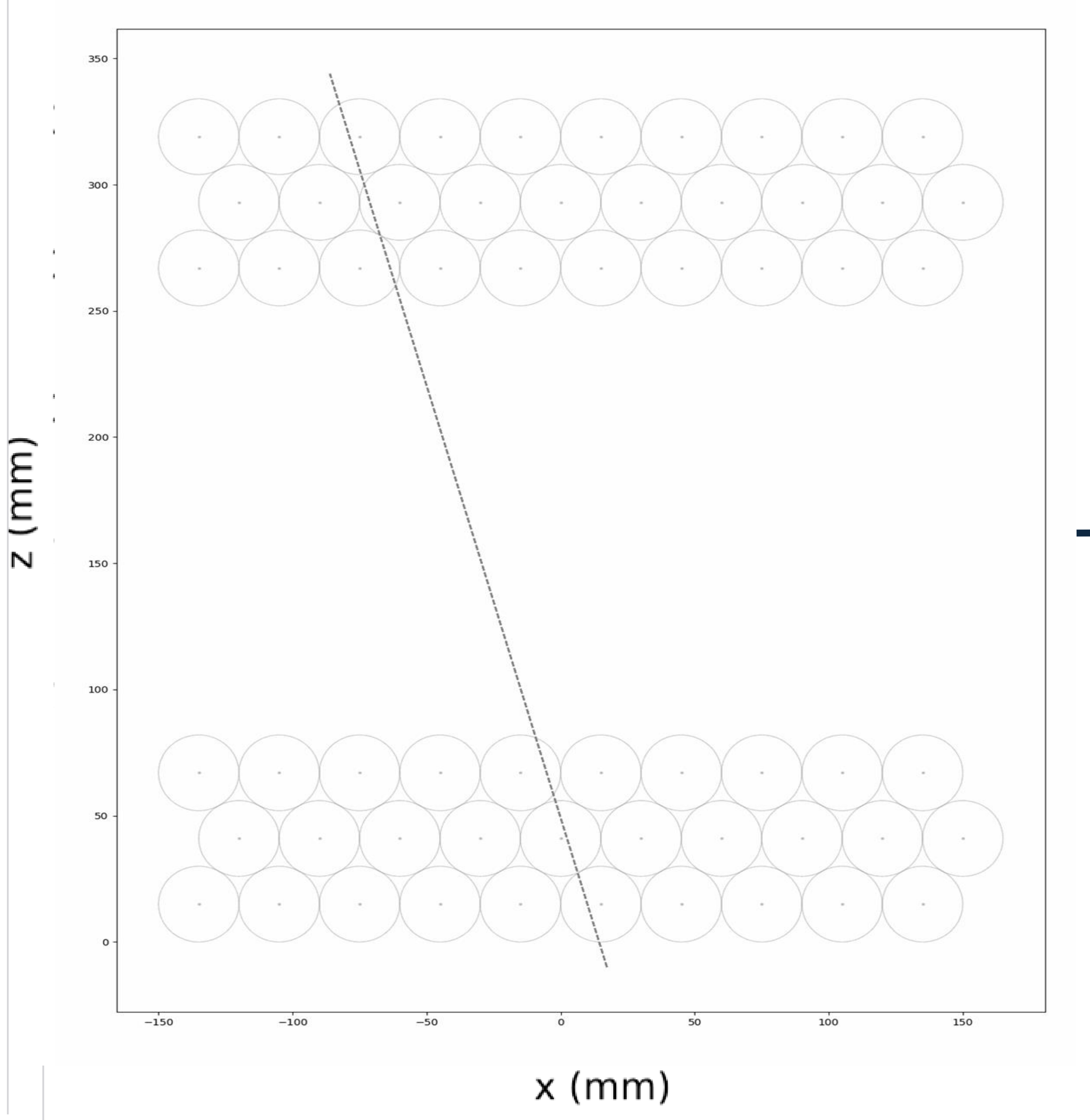
hls4ml
Quantization & HLS Model Creation → VIVADO Synthesis

HLS & RTL simulation

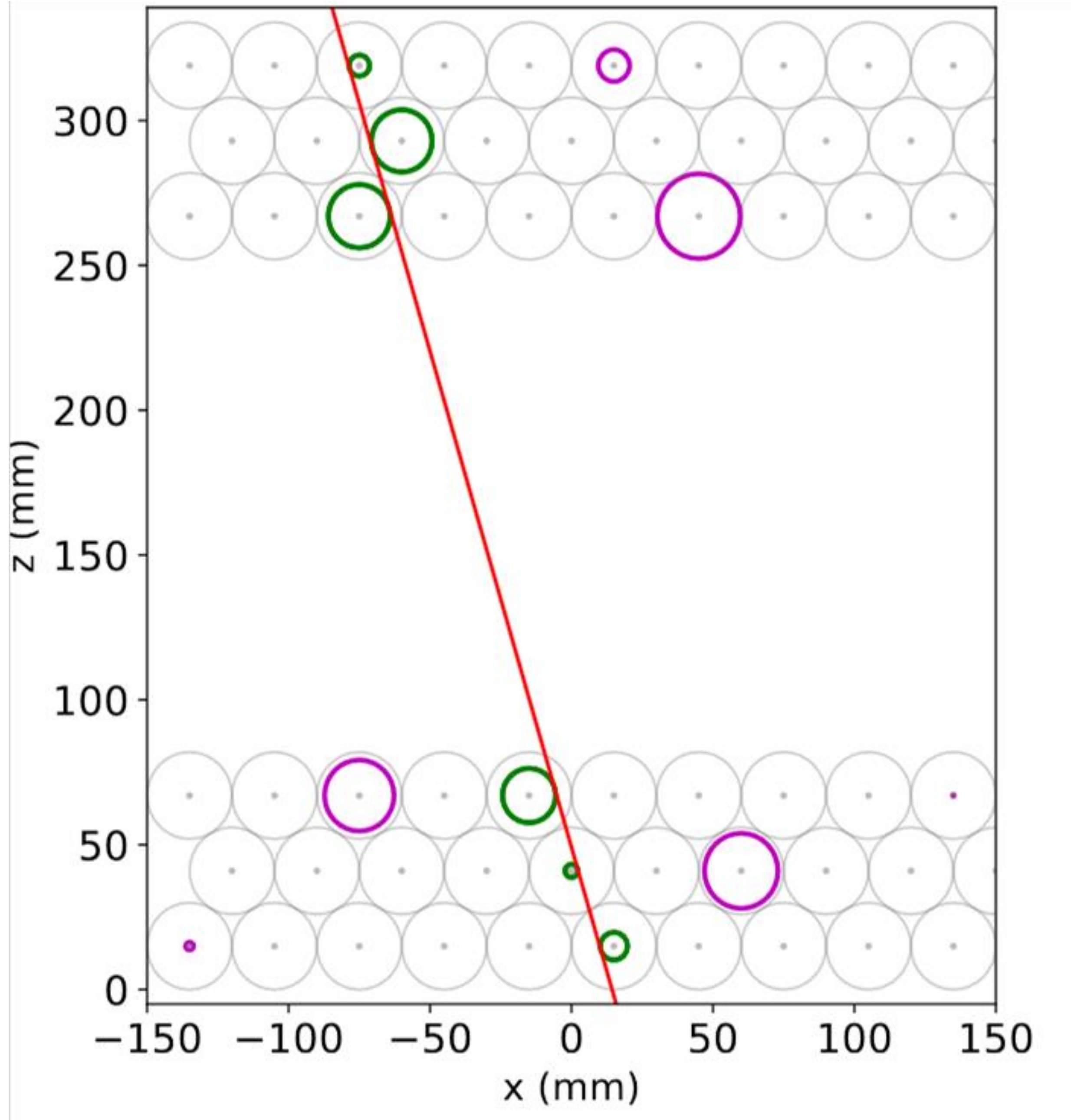
MDT Trigger Processor with XILINX VU13P FPGA

Development of Simulations

- **Toy simulations for rapid algorithm development and validation**
  - Short turn around and easy to produce large samples
- **Hit arrival time sequence as expected from the detector**



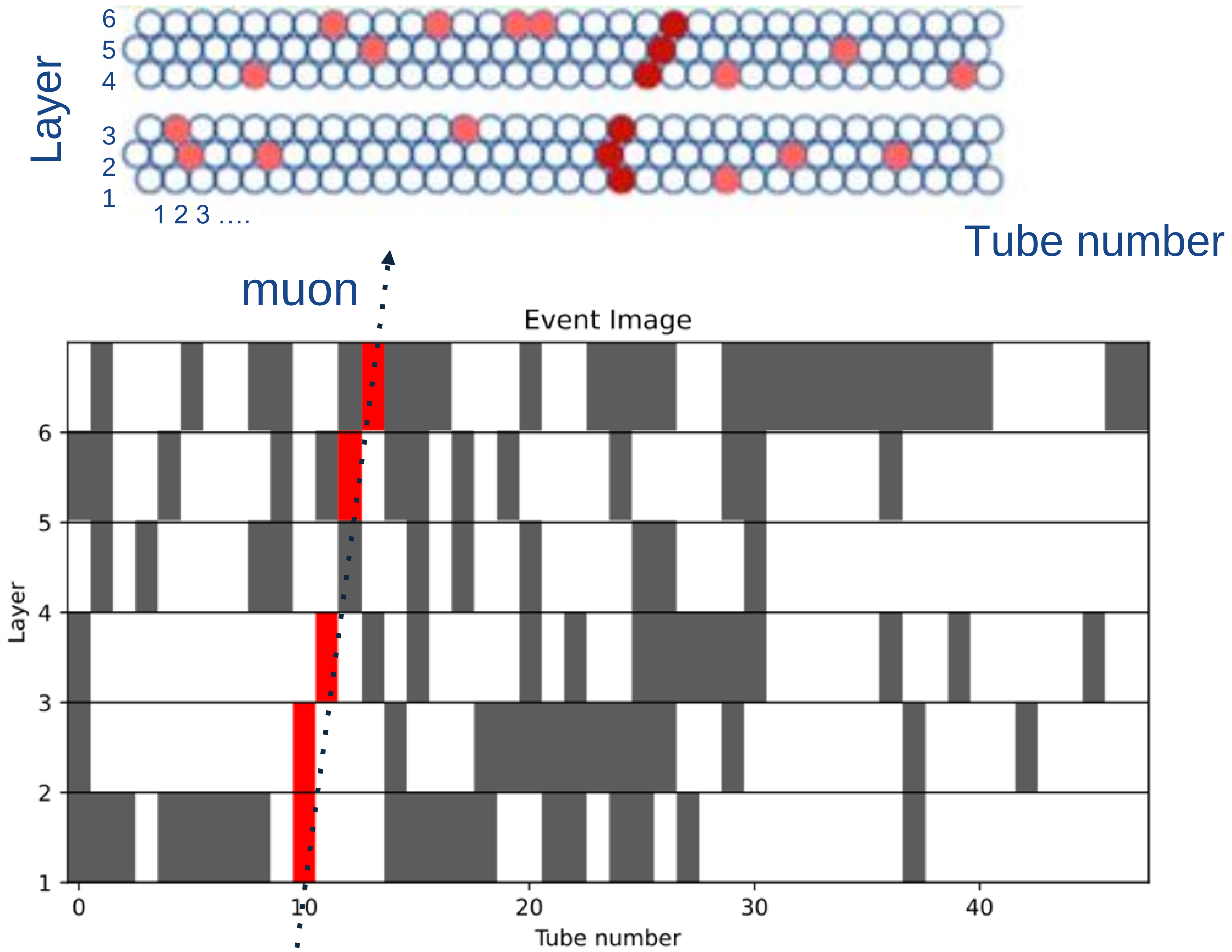
1us
Time
Integration



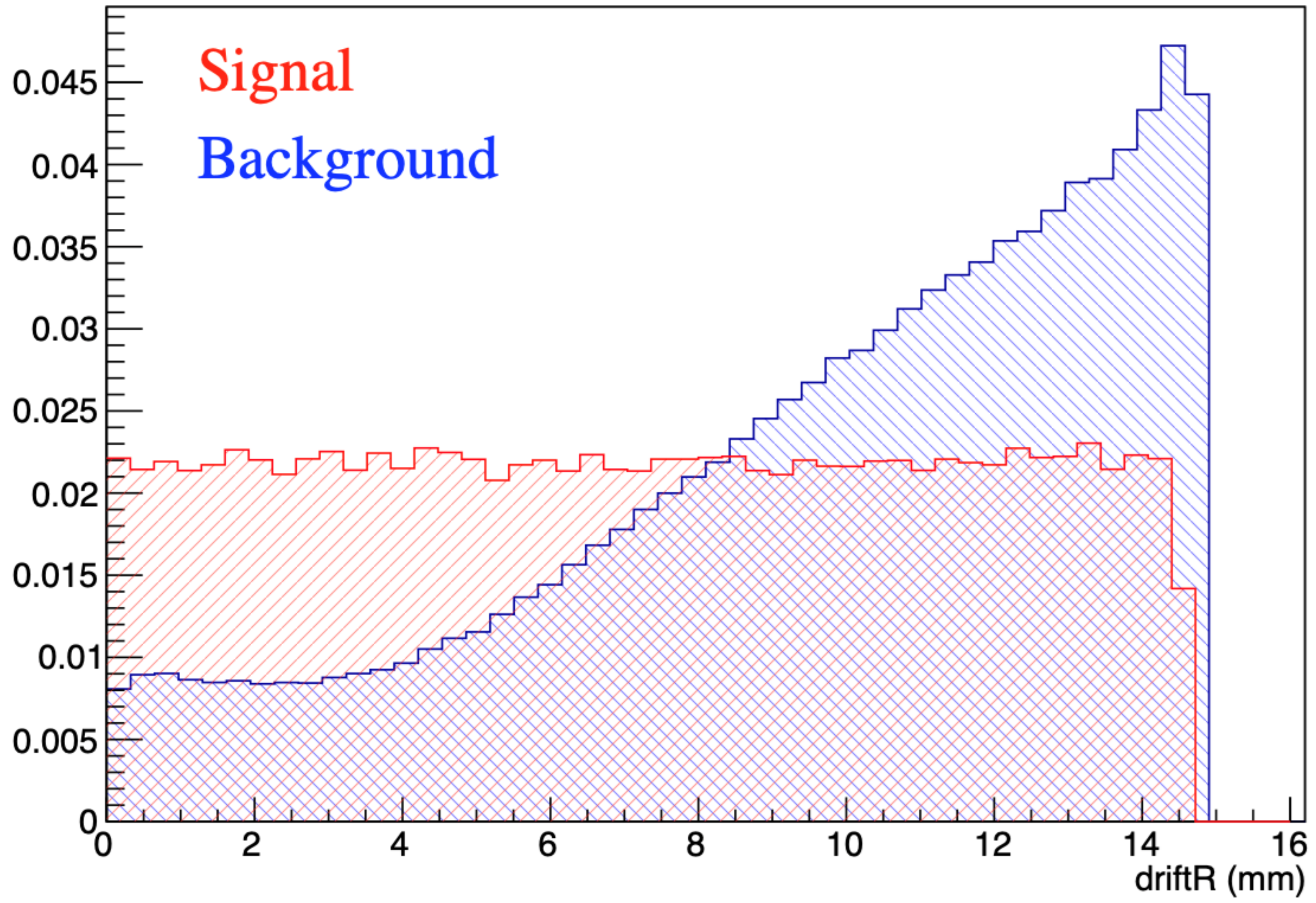
- **Also developing realistic simulations for expected signals and conditions**
  - Full geometry including new detectors
  - Backgrounds from data similar to HL-LHC conditions (detector regions and periods with high rates)

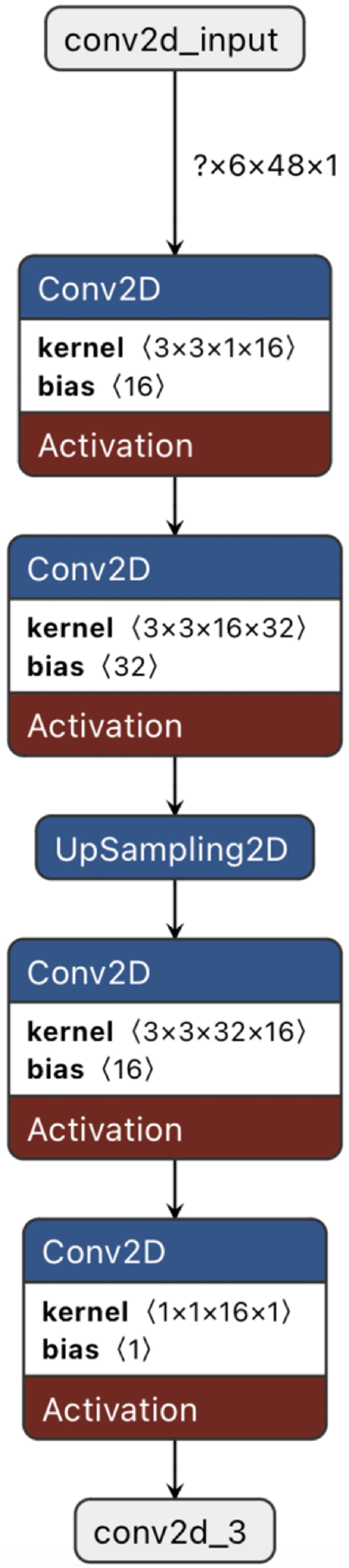
Algorithm Development R&D: Robustness

- **Investigating pattern recognition algorithms to identify the regions of interest using MDT hits**
  - Exploring the use of CNNs building images with the detector granularity



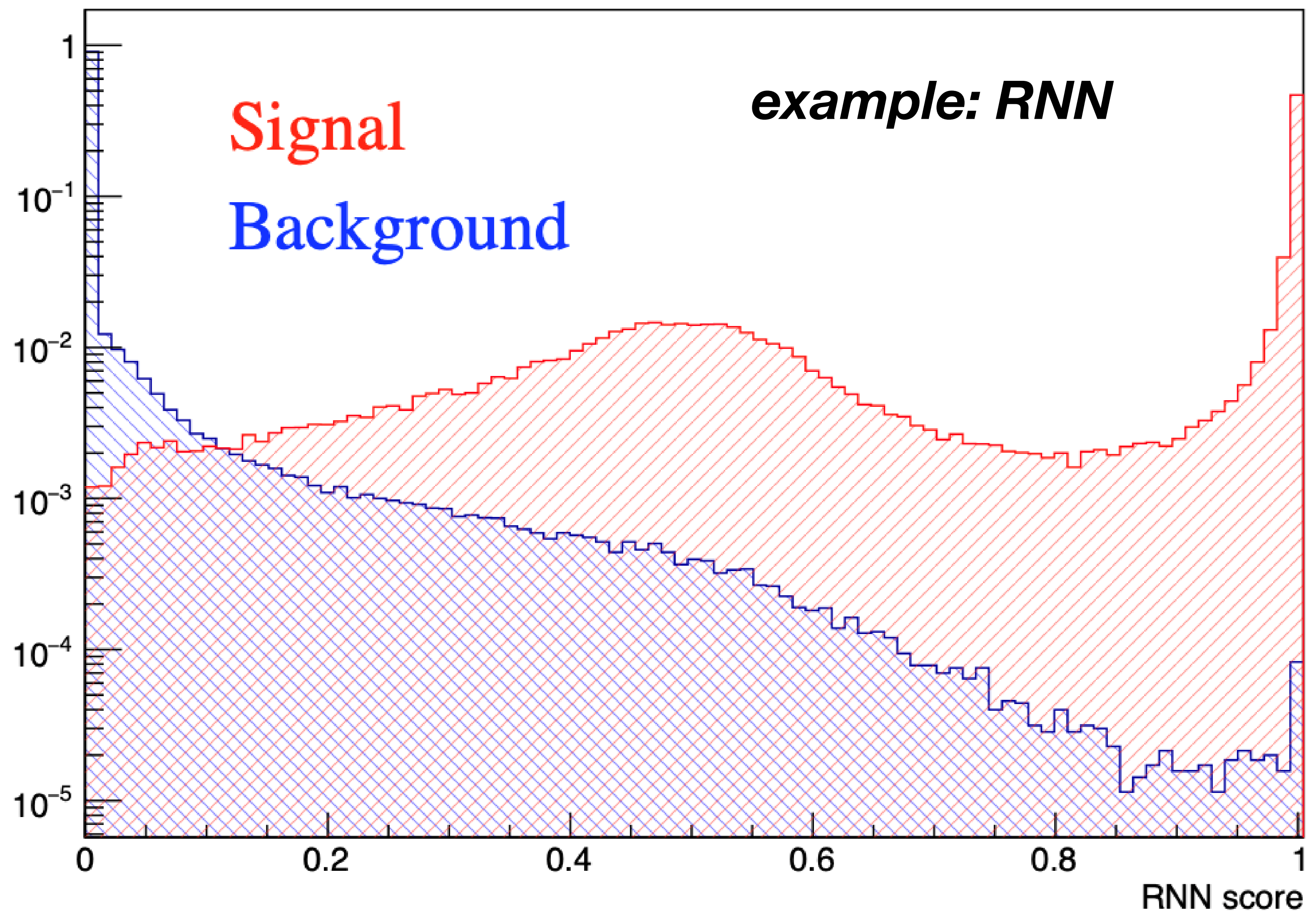
Distinguish muon hits from backgrounds

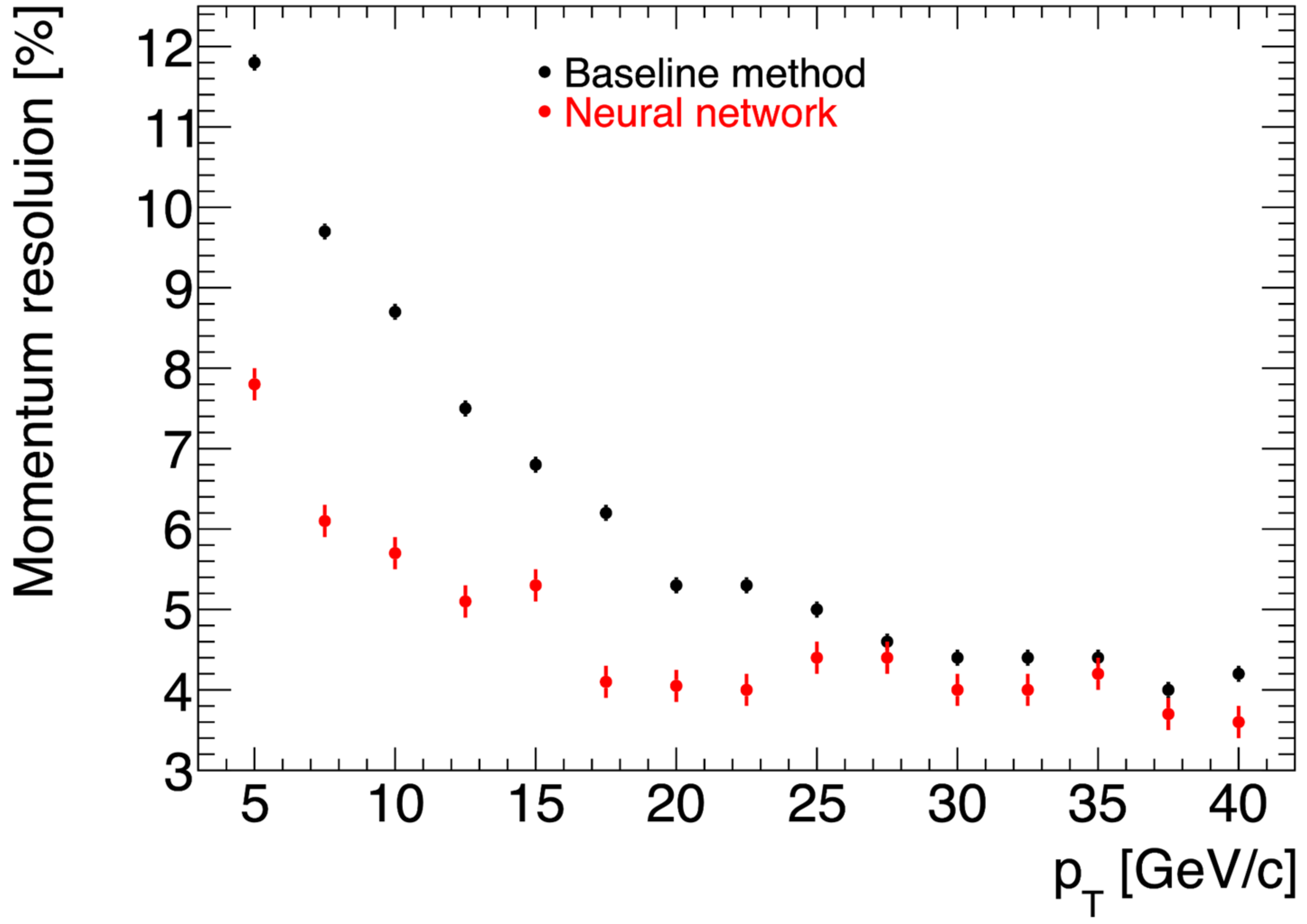


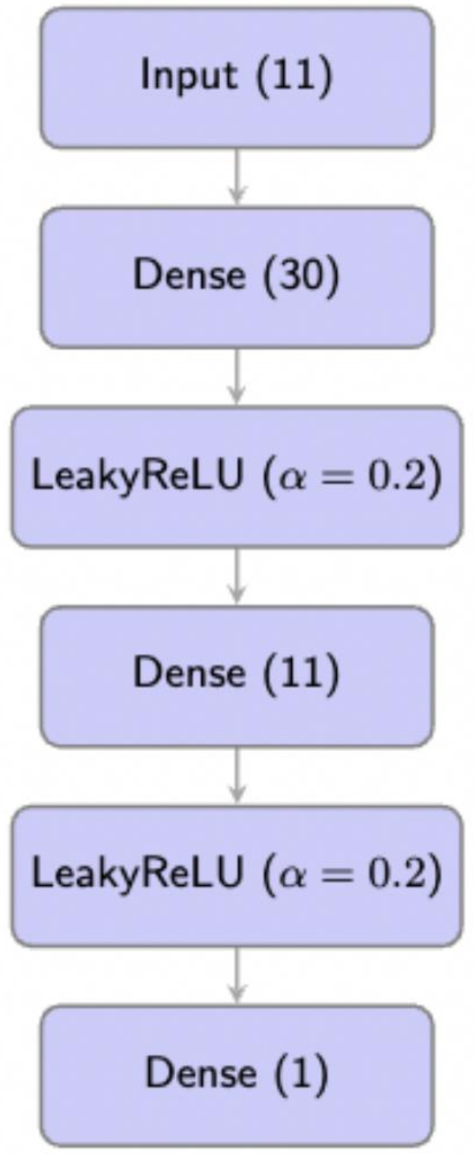


Algorithm Development R&D with ML

- **Exploring algorithms more suitable for sparse data such as RNNs and GNNs for pattern recognition**
- **Also using machine learning methods for momentum estimation**
  - Preliminary results show improvements in performance with Neural Networks with a few dense layers

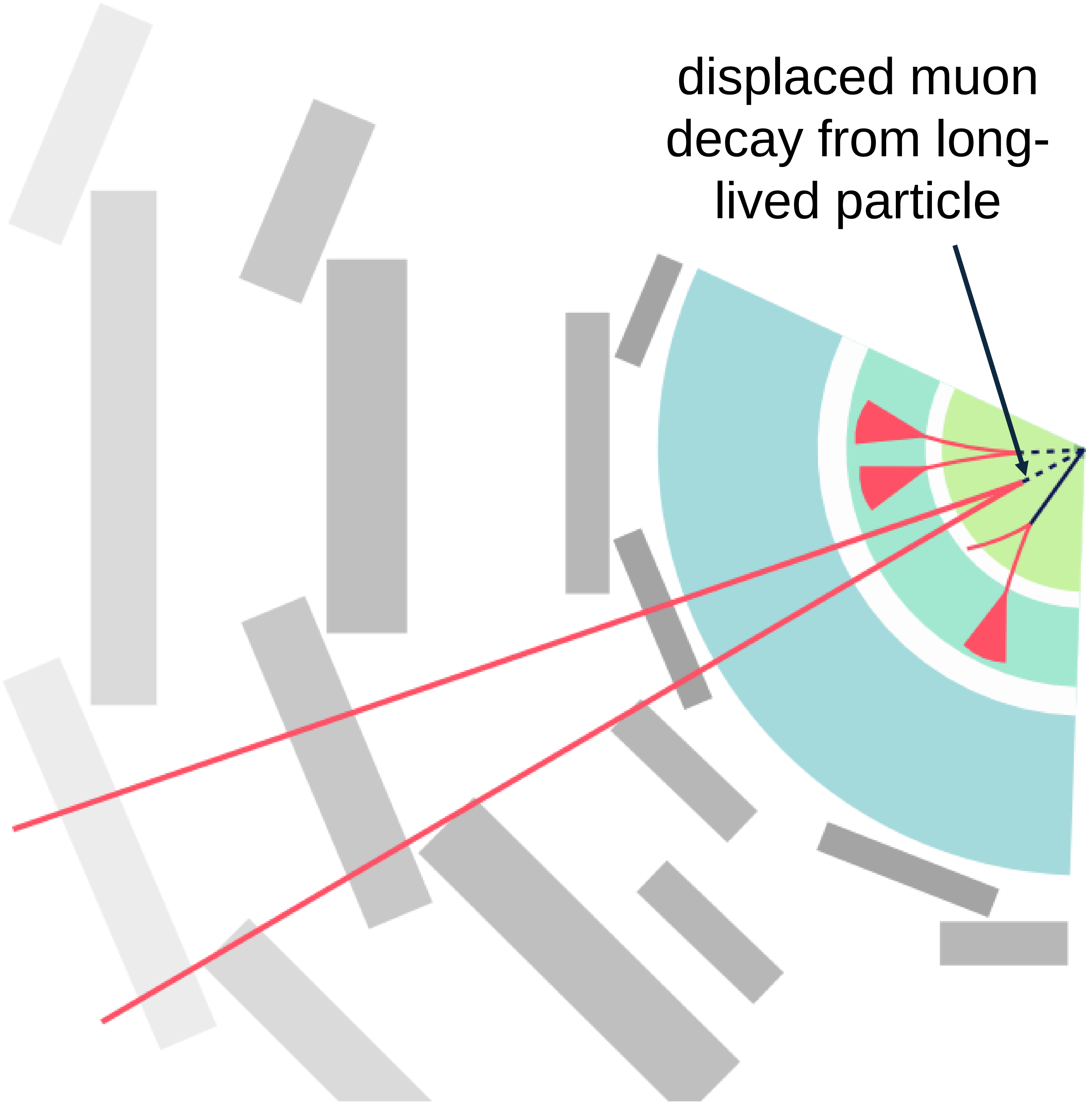


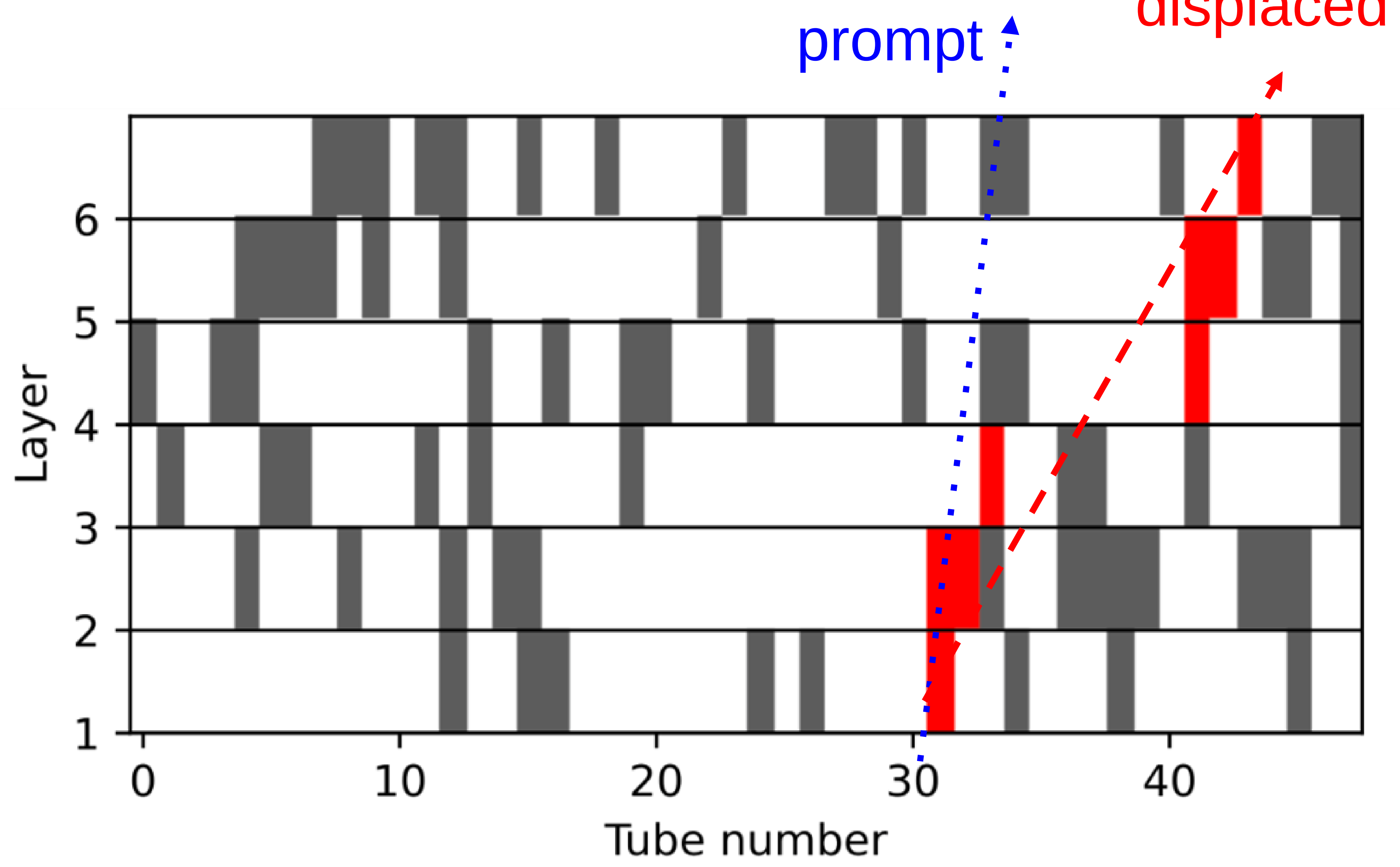




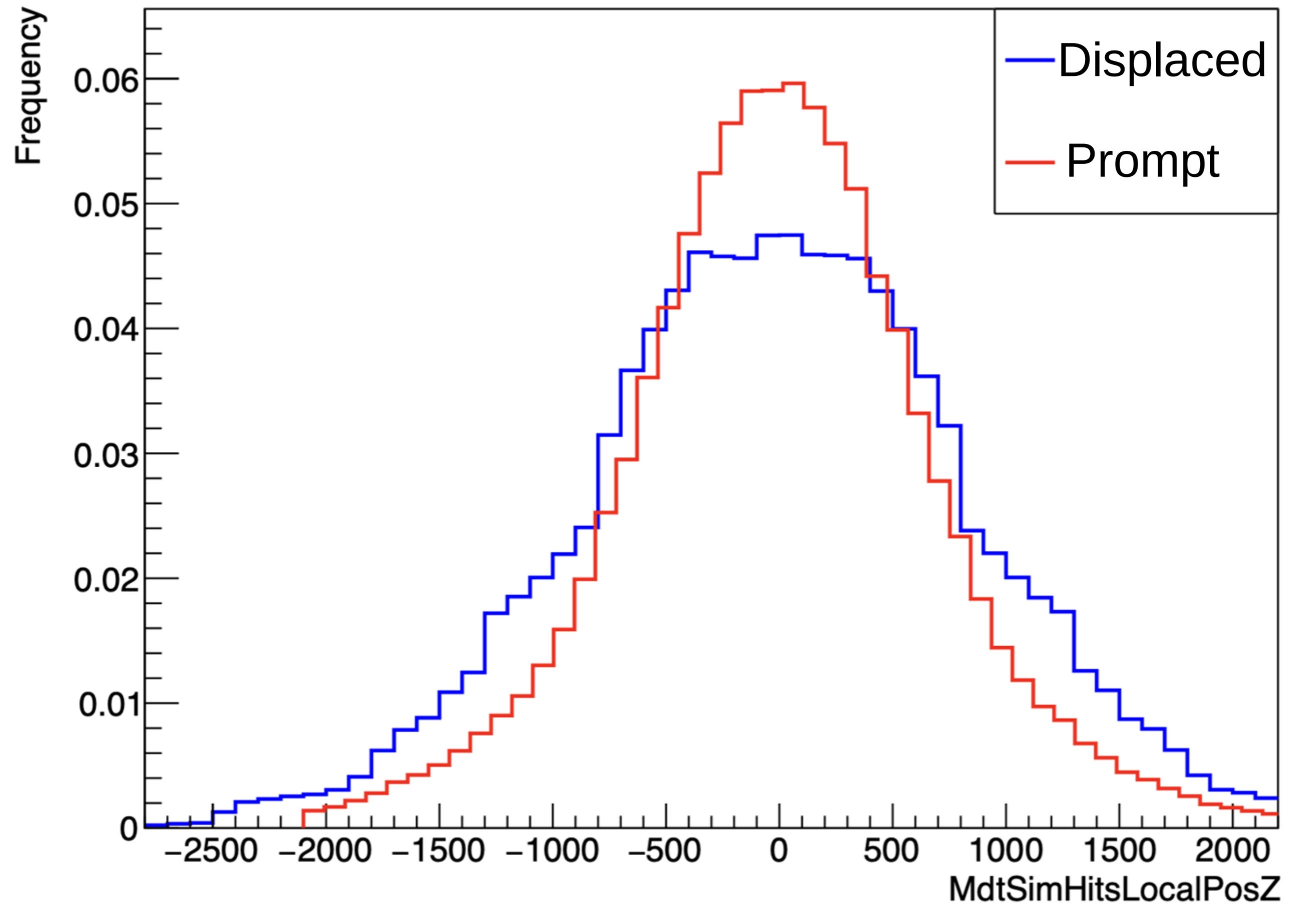
Preliminary studies from F. Resende (TUM, Bachelors student)

Algorithm Development R&D: Exotic Signatures





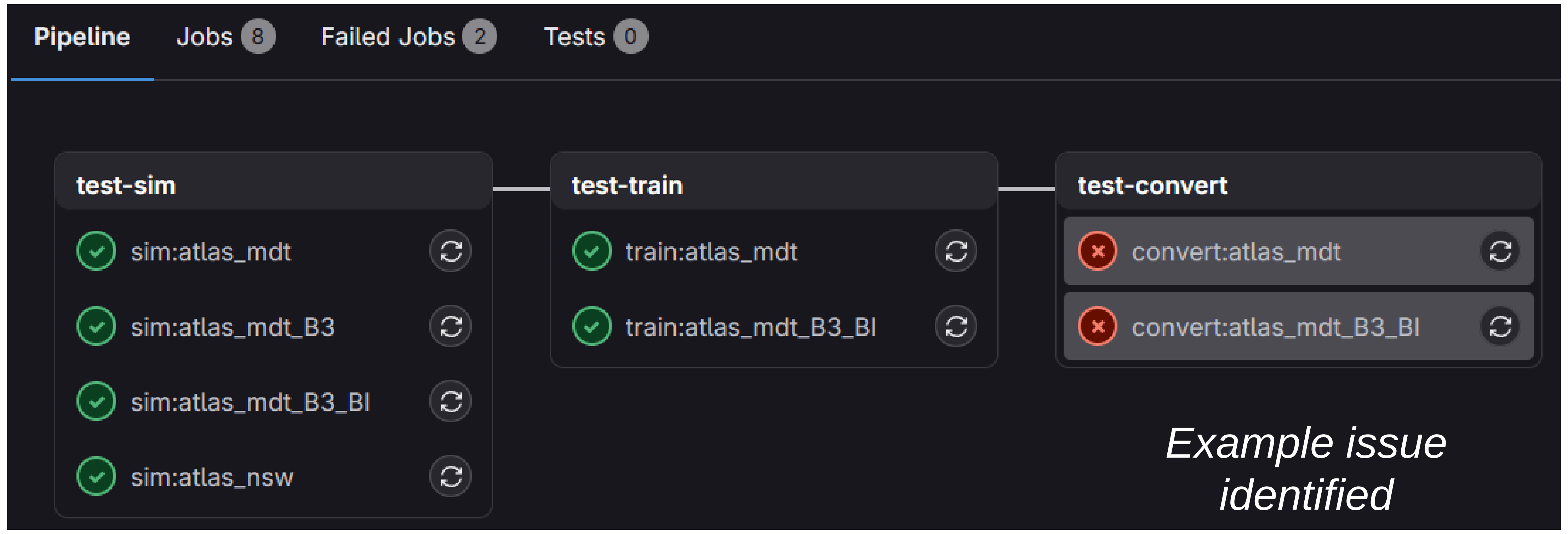
- **Studying displaced muon signatures**
  - Angles rejected by standard muon triggers - pointing requirement
  - Developing dedicated algorithms targetting signals



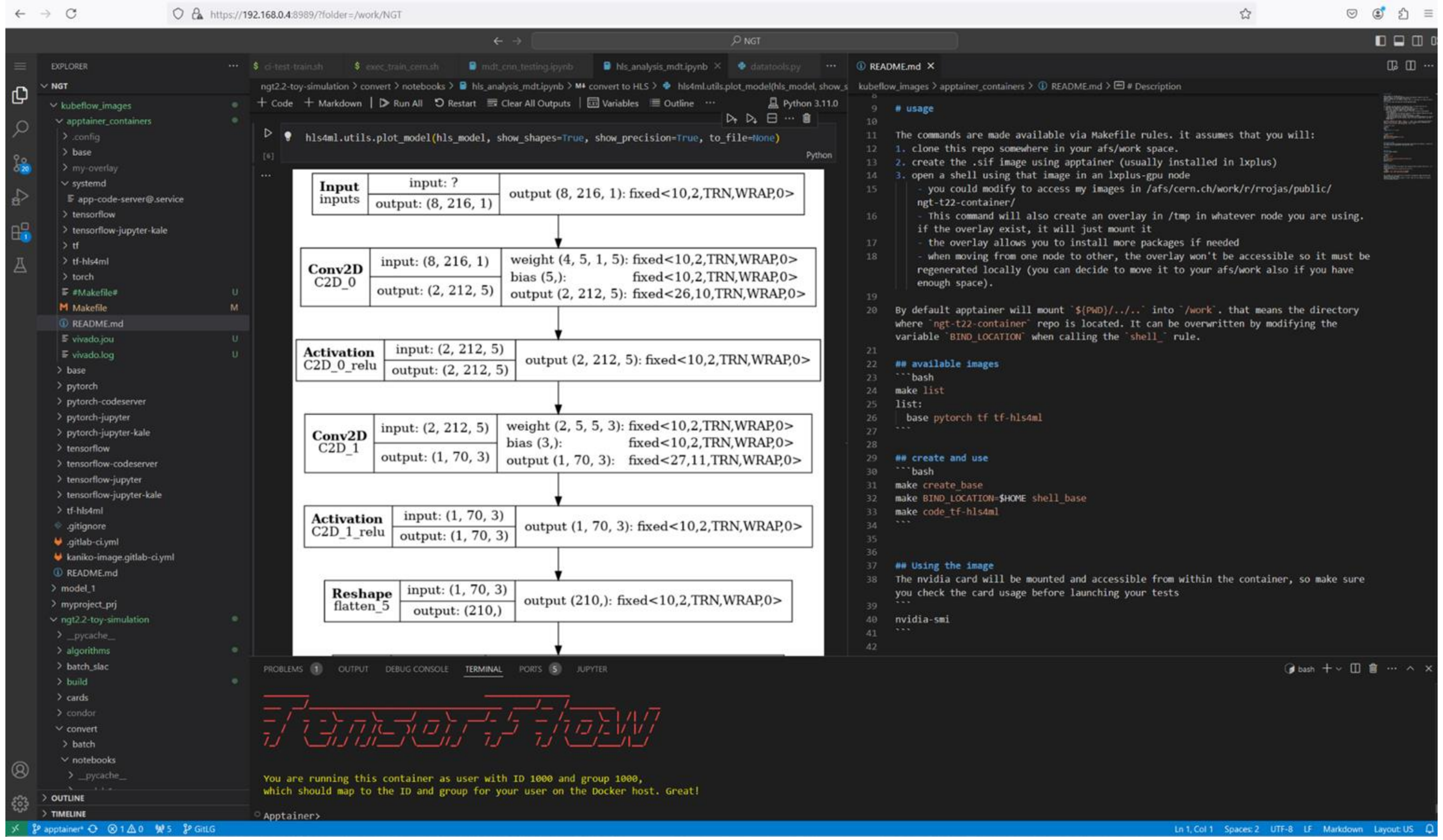
H. Russell

Algorithm Implementation

- **Progress on the implementation**
- **Automation of workflow including producing simulation, training algorithm, performing HLS conversion and RTL simulation**
  - Main goal is to ensure code runs as expected
- **All tools and code available in containers**
- **Synergy with WP1 to use the provided infrastructure and use the software tools**



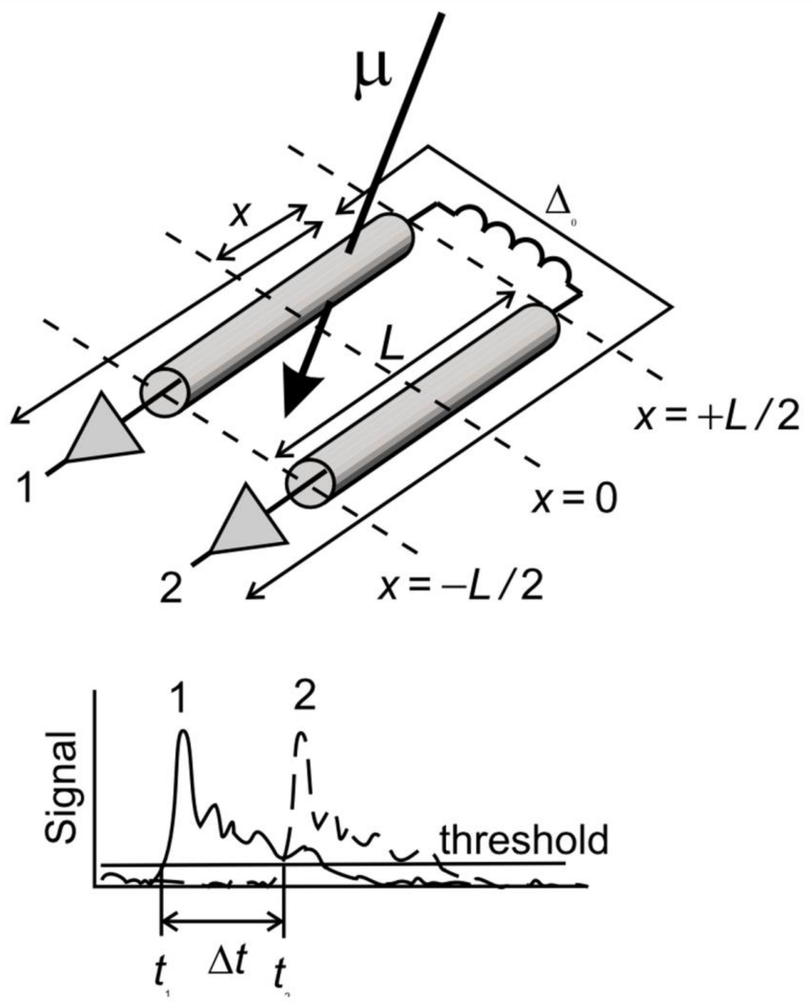
Example issue identified



Summary and Outlook

- **Main objective is to design and implement new algorithms to extend the L0 Muon trigger**
  - Focus on improving the robustness and extending to new signatures such as long-lived particle decays
- **Priorities of 2024**
  - Hiring of personnel including an engineer and postdoc and two PhD students
  - Ramping up simulation and algorithm design effort
  - Advancing on infrastructure for implementation as the resources become available from WP1
- **Investigating possible use of Machine Learning approaches**
  - Preliminary results are promising for pattern recognition and momentum estimation

- **Priorities for 2025**
  - Further development of algorithms
  - Focus shifting towards implementations for hardware
  - Eager to use computational resources that will become available from WP1
- **Investigating alternative ideas second coordinate along drift tube**
  - Using twin tubes or information from the outer layer of the Tile calorimeter



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