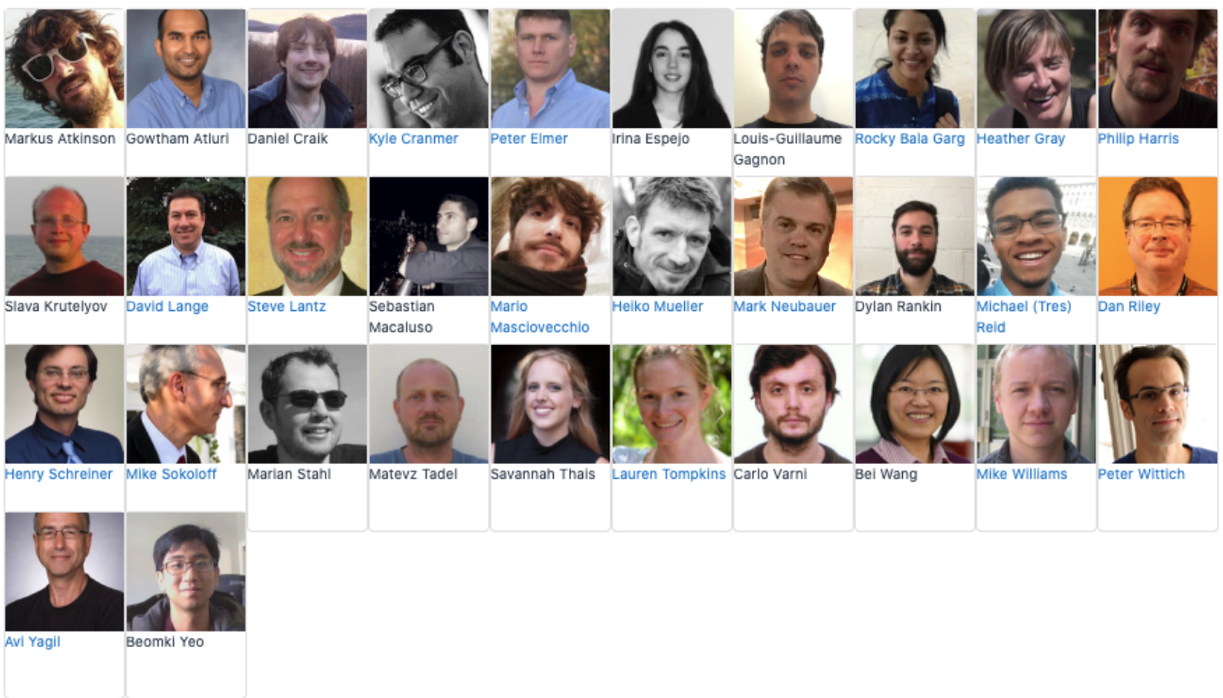
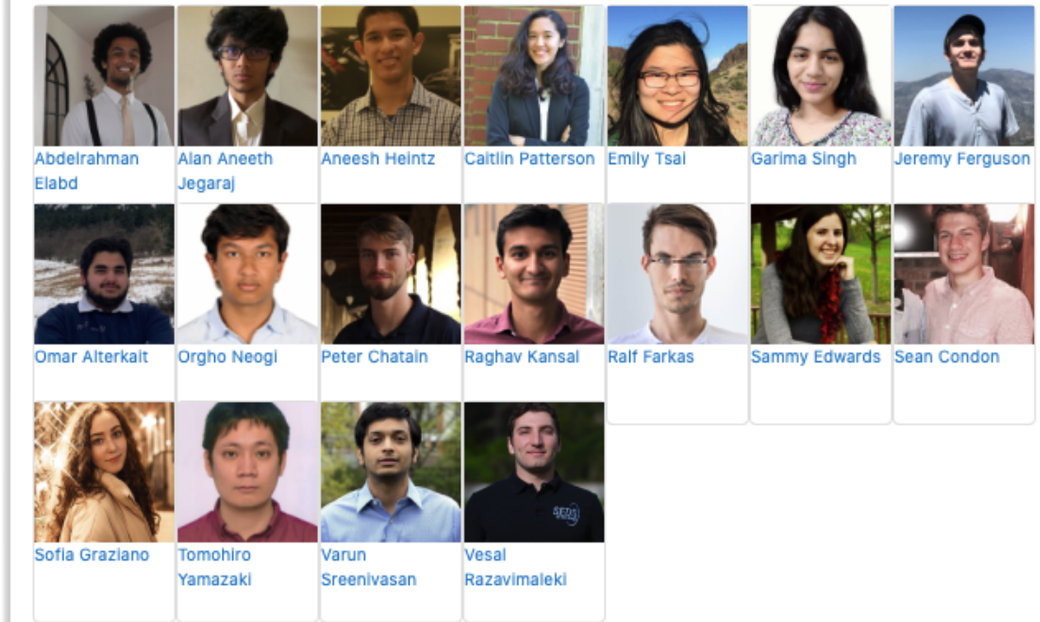
# Innovative Algorithms

## IA Team




## Current and Former Fellows

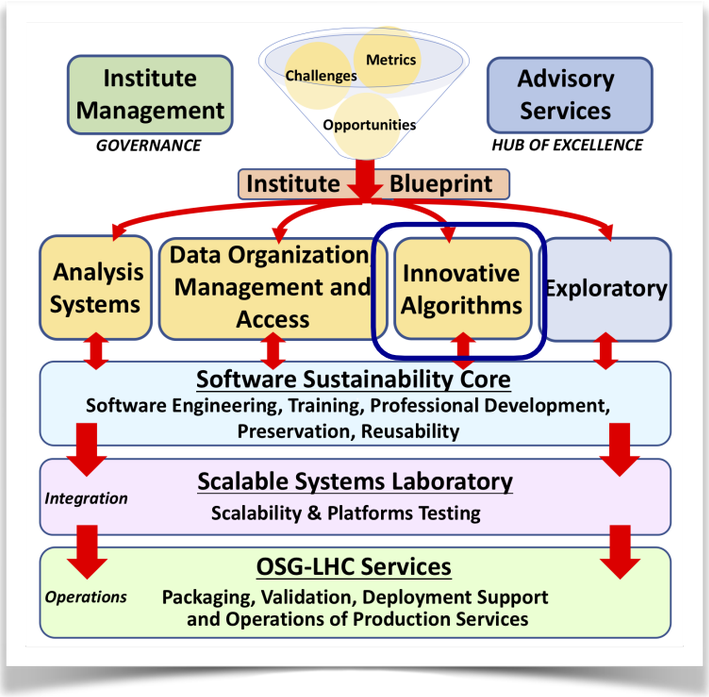



**David Lange,** Princeton
**Heather M. Gray,** UC Berkeley/LBNL

http://iris-hep.org

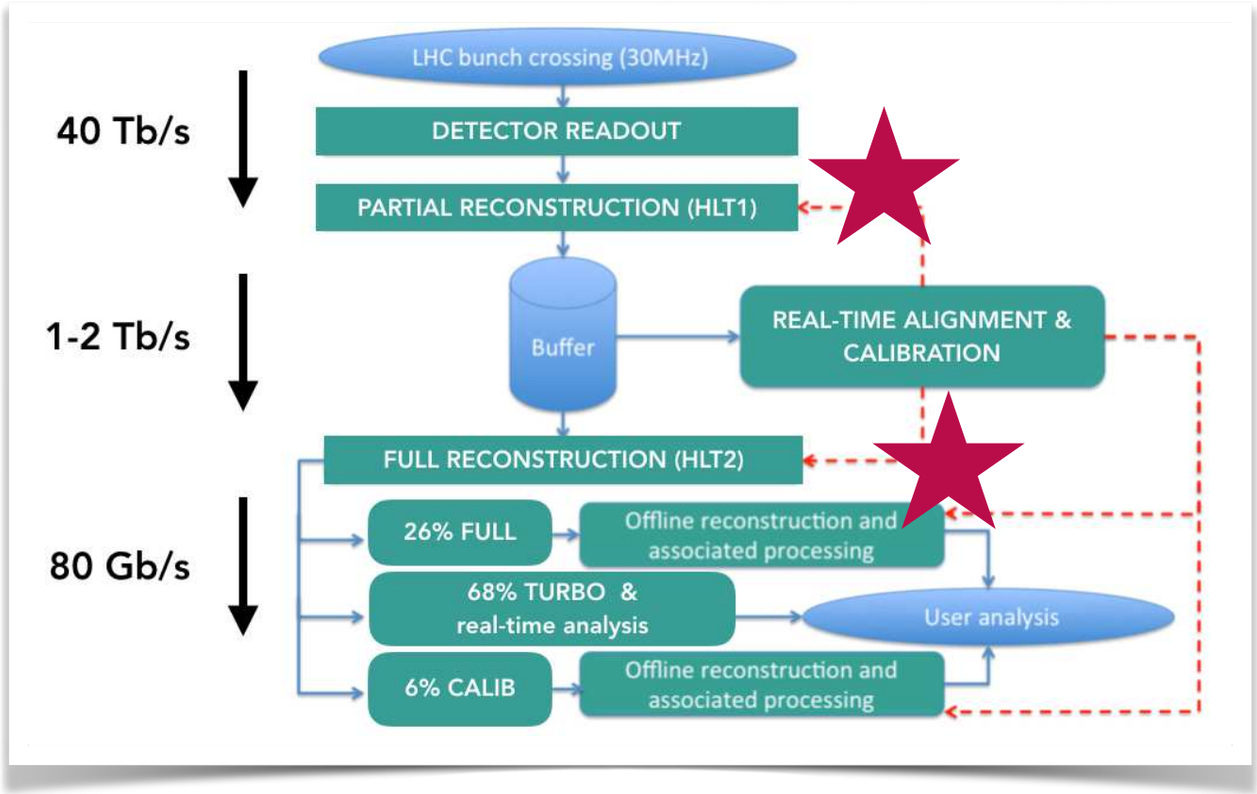
# Overview

- Innovative Algorithms is one of the three focus areas in IRIS-HEP
- We develop and re-engineer algorithms for some of the most compute-intensive high-energy physics applications




## Software Trigger

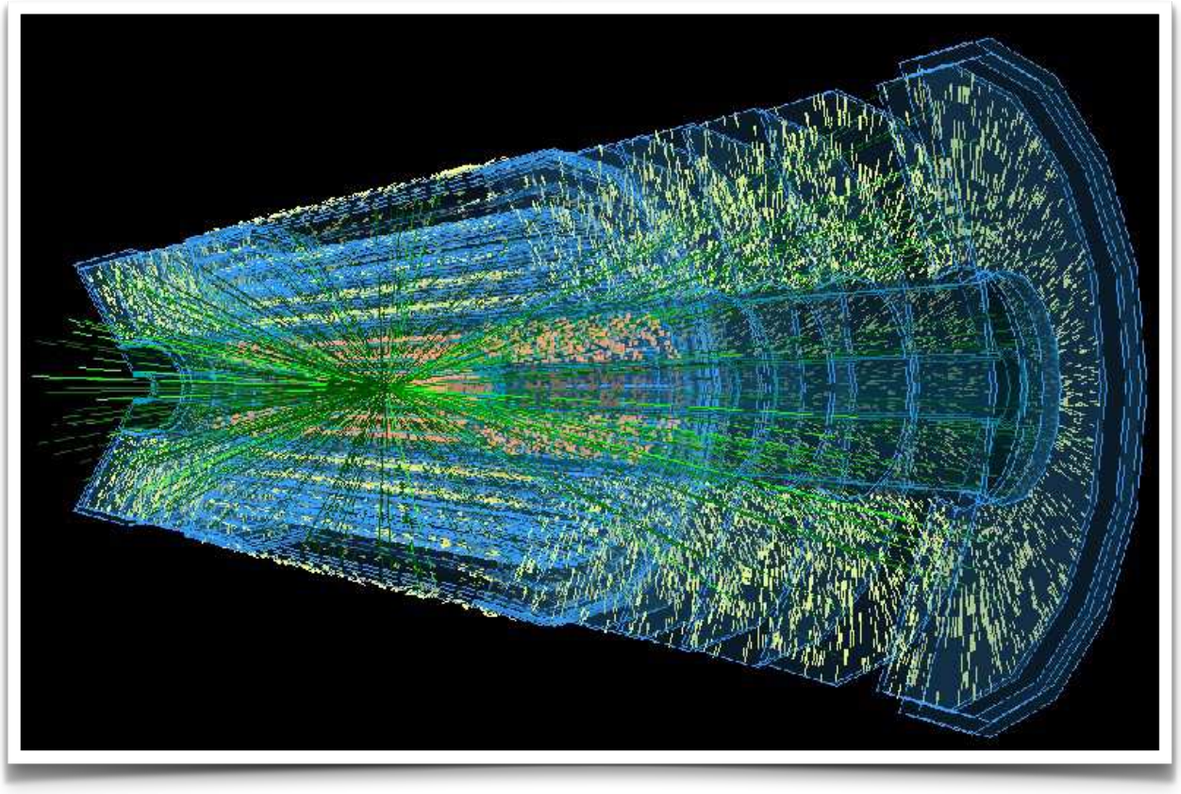
*Filter events to keep*




HLT = High Level Trigger

## Offline Reconstruction

*Detector output → analysis objects*

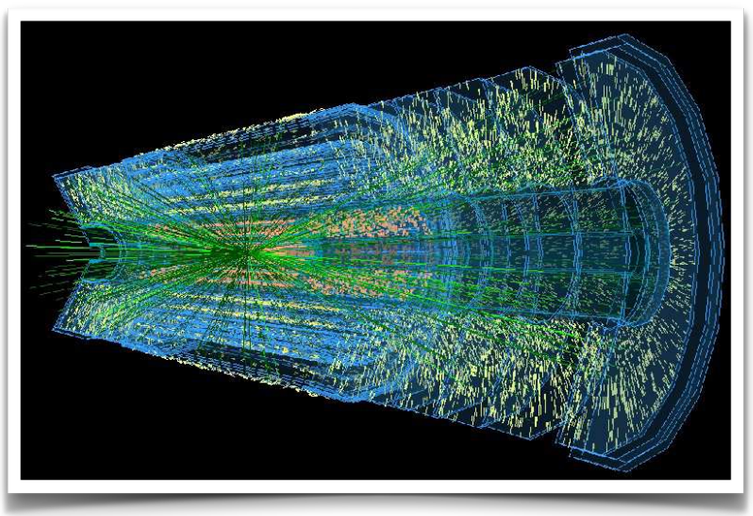


~100 billion events per year

# Three major themes

## Tracking

- Requires the largest fraction of CPU during reconstruction
- New algorithms with
  - Better efficiency
  - Reduced computational cost



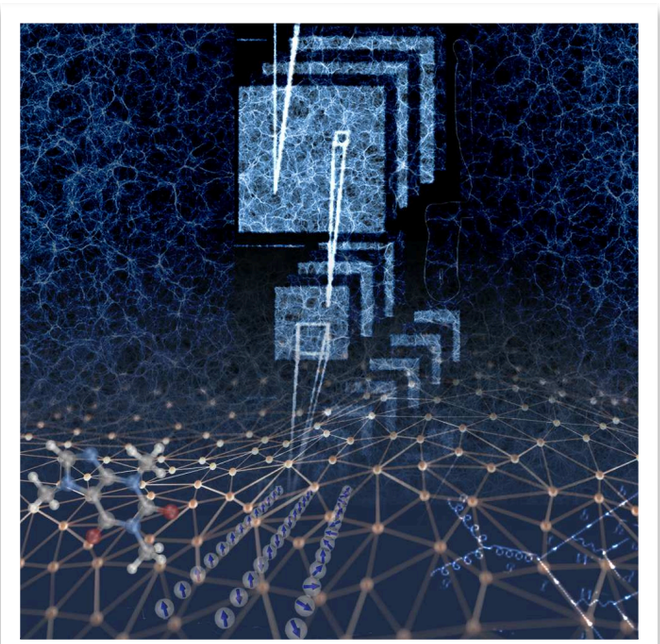
## Accelerators

- Rapid growth in terms of power and availability of hardware accelerators
  - Reco applications on accelerators
  - ML on accelerators

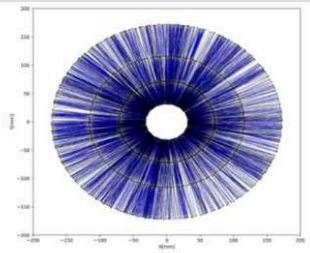


## Machine Learning (ML)

- Exploit major advances in ML
  - Apply new ML techniques to HEP
  - New applications of HEP in ML
  - ML on accelerators

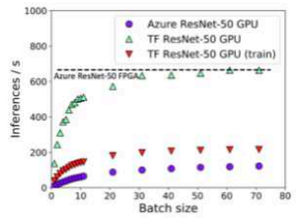


# Projects and Themes



**Accelerated GNN Tracking**

accel-gnn-tracking
More information




**Accelerators and ML for reconstruction**

Accelerated calorimeter reconstruction using Machine Learning as a Service
More information

**ACTS**

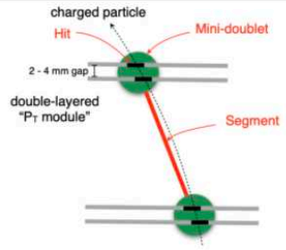
Development of experiment-independent, thread-safe track reconstruction.
More information

**exploratory-ml**

Analysis Reinterpretation
More information

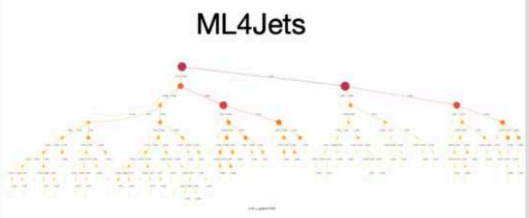
**GPU Trigger Project**

Allen: a GPU trigger for LHCb
More information



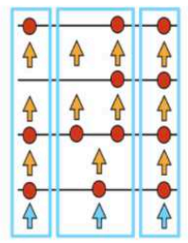

**Line-Segment tracking**

Segment linking tracking for CMS
More information



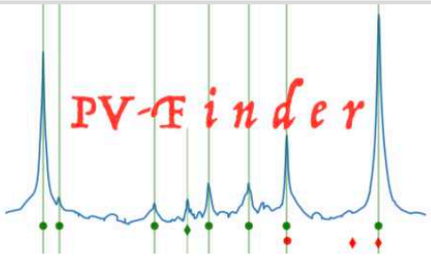

**Machine Learning for jets**

Machine learning for jets
More information



**mkFit**

Modernizing Kalman filter tracking for CMS
More information




**PV-Finder**

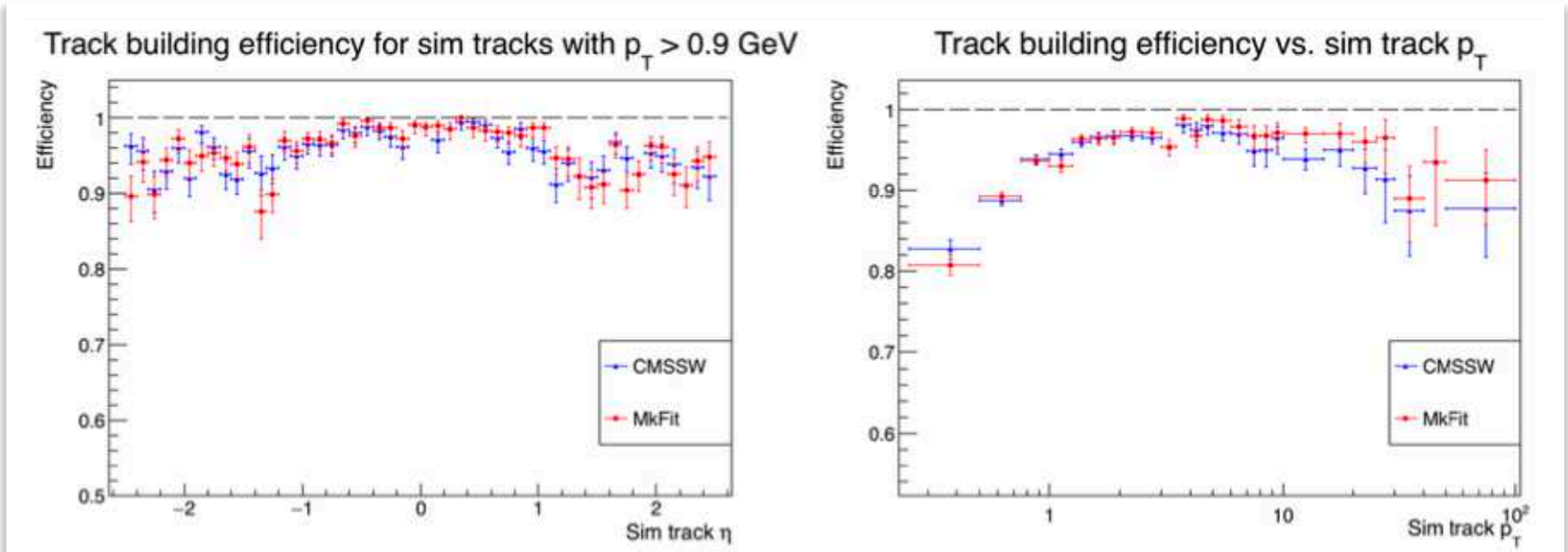
CNNs to find primary vertices
More information

Tracking Accelerators Machine Learning

# Tracking Highlights: Maturing Projects

## ***Parallelized*** *and* ***vectorized*** *Kalman Filter tracking*

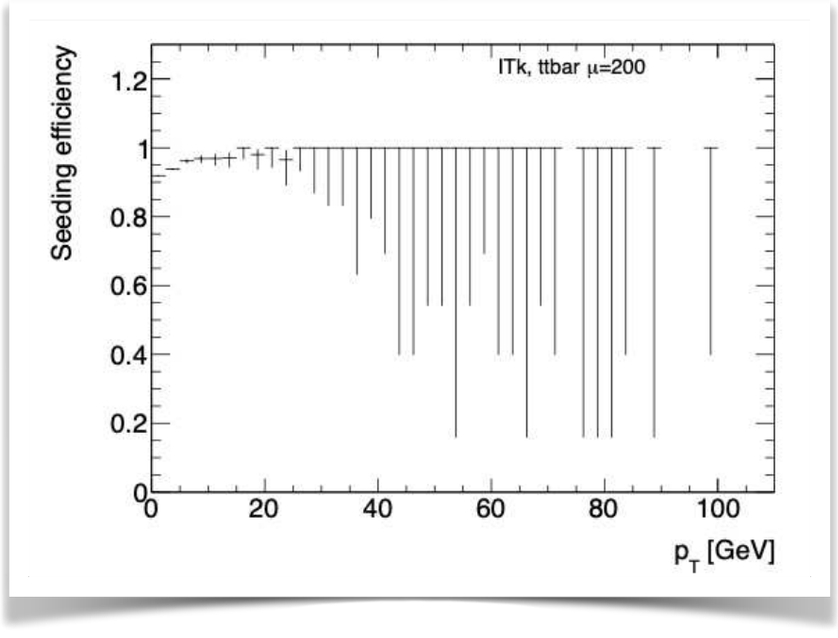
Performance on CMS Run-3 detector

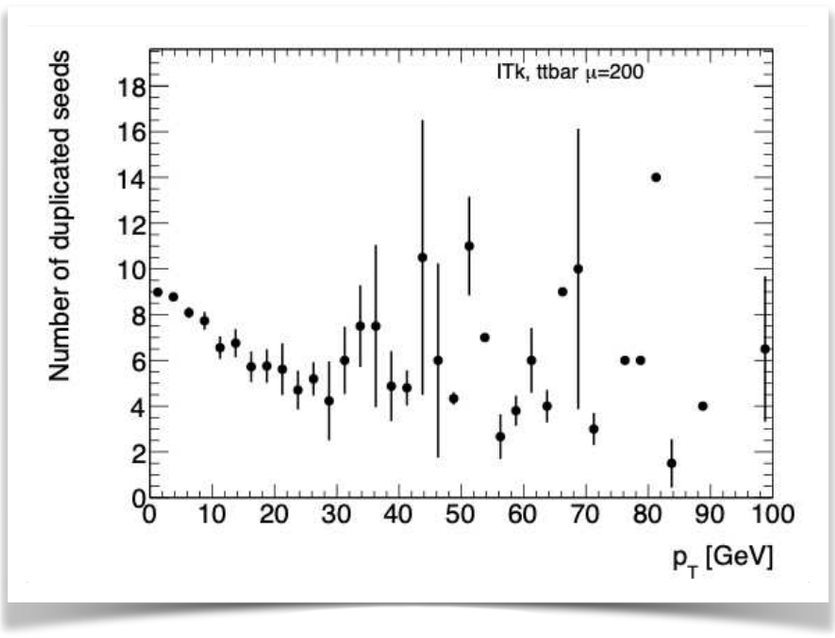



S. Lantz et al, JINST 15 P09030 (2020) (29 May 2020).

## ***Experiment-independent****, thread-safe track reconstruction algorithms*

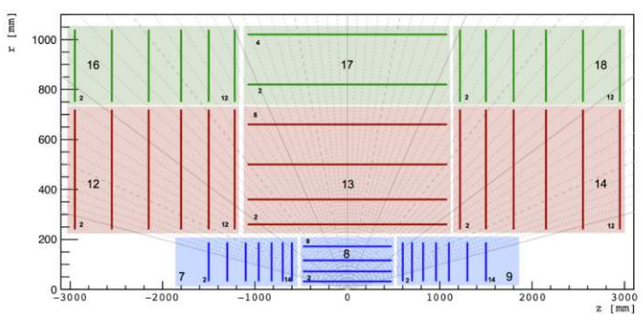
Seeding performance on ATLAS ITk detector



# Tracking Highlights: Newer projects

***ML evolutionary algorithms*** *to automatically tune algorithm parameters*



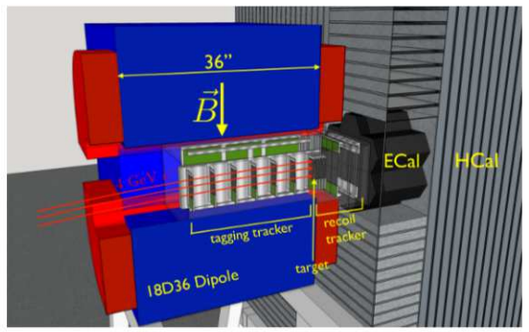
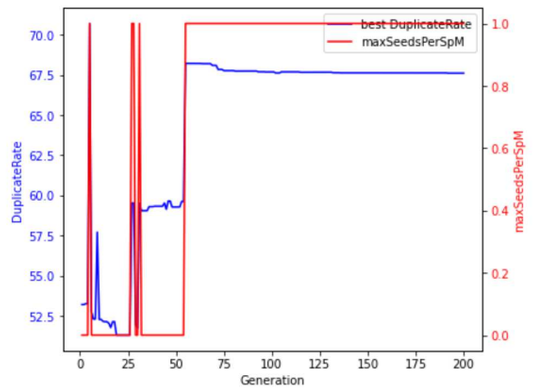
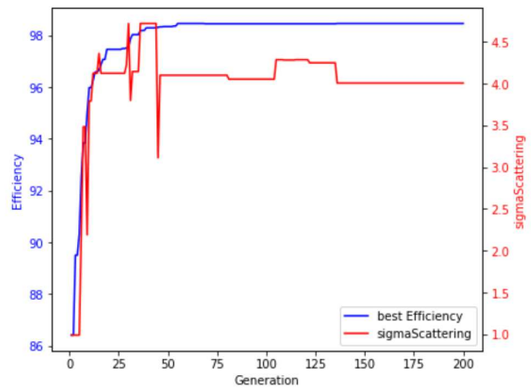
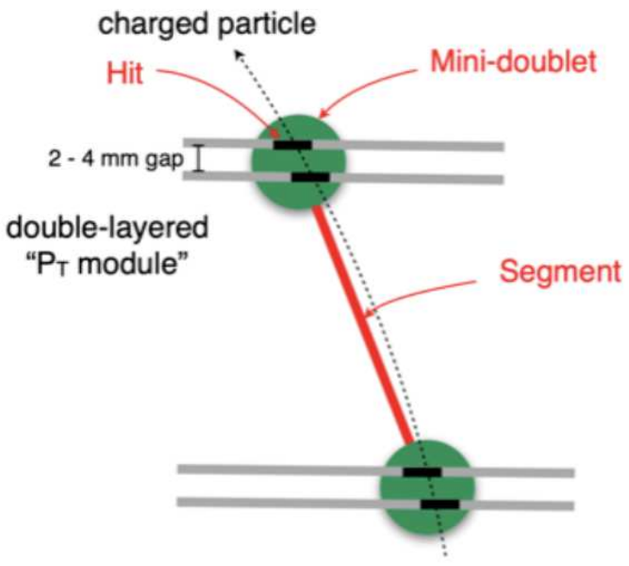



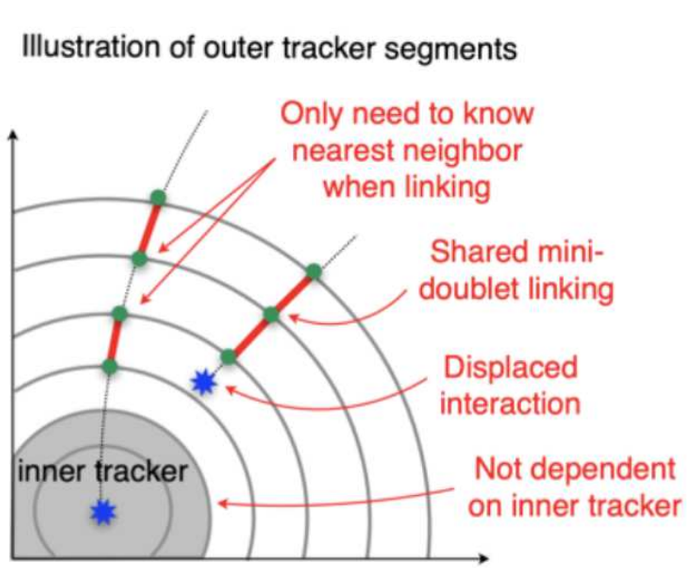

Figure 1. Generic Detector (left). LDMX Detector (right)

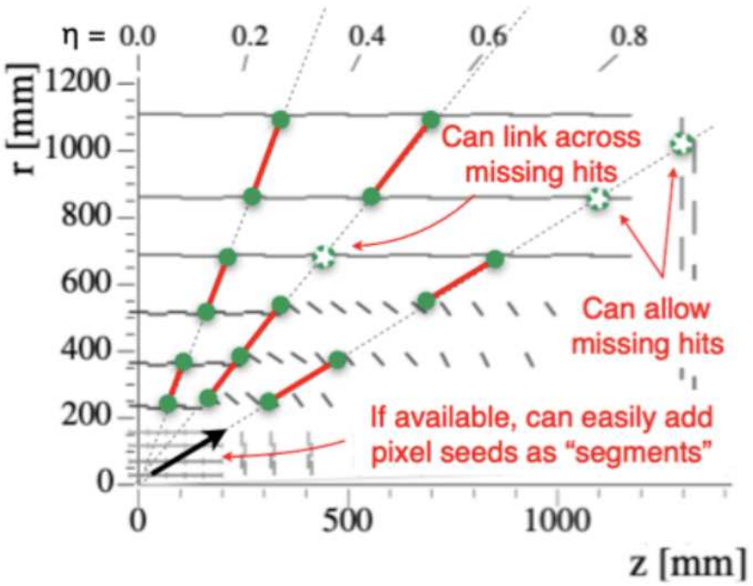



***Line-segment*** *tracking algorithms for parallelization and* ***accelerators***

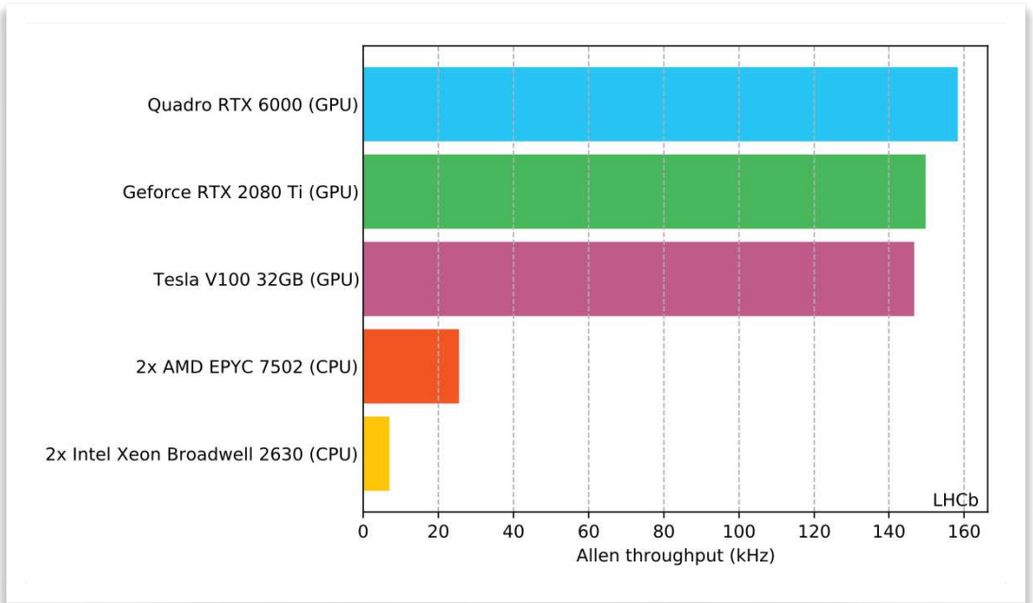


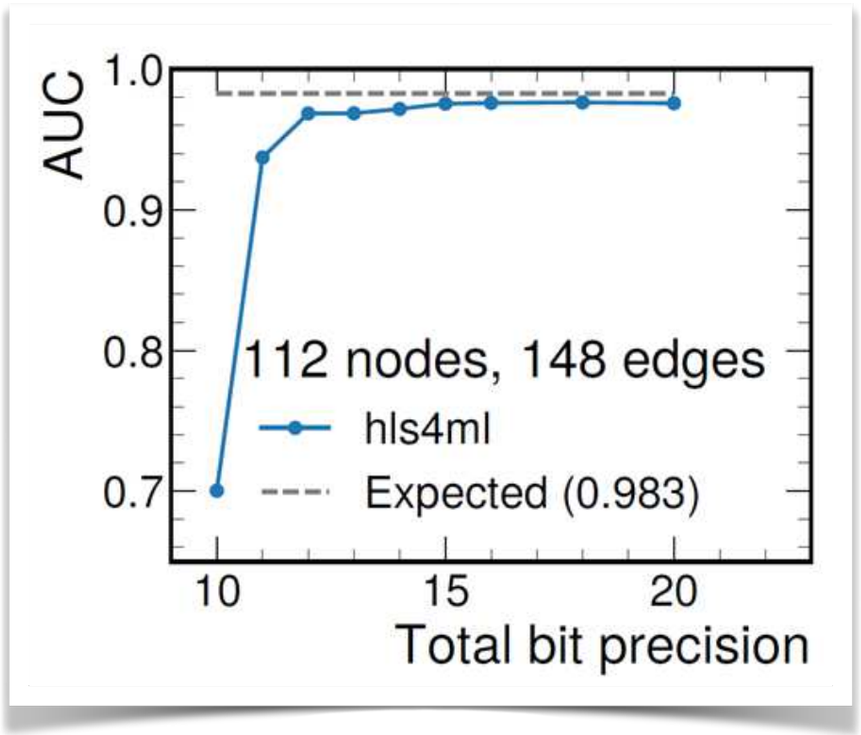
# Accelerators Highlights

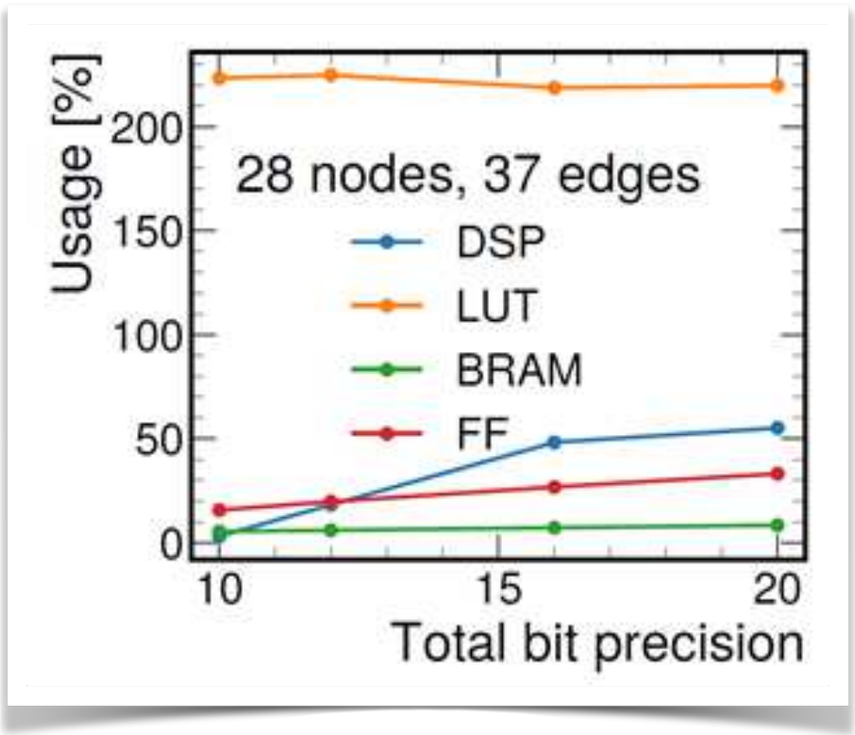
*Full HLT1 **trigger** reconstruction and selection on **GPUs** adopted by LHCb in Run-3*




Allen: A high level trigger on GPUs for LHCb, R. Aaij et. al., Comput.Softw.Big Sci. 4 7 (2020) (19 Dec 2019)

*Graph Neural Network (GNN) tracking algorithms on FPGAs*



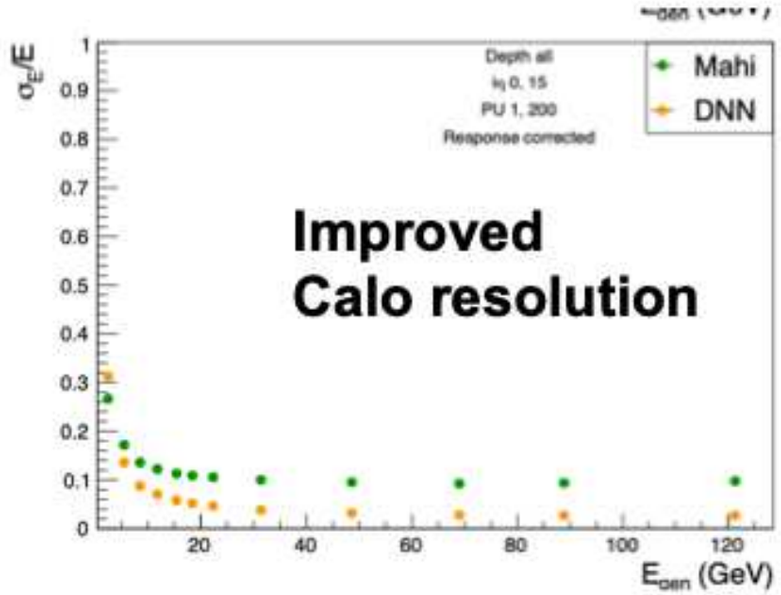



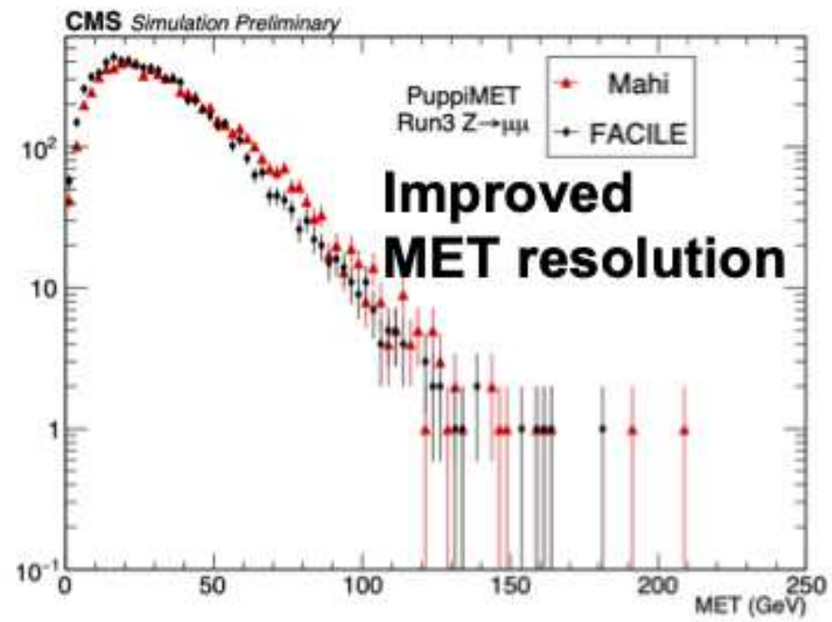

GPU=Graphical Processing Unit, FPGA = Field Programmable Gate Array

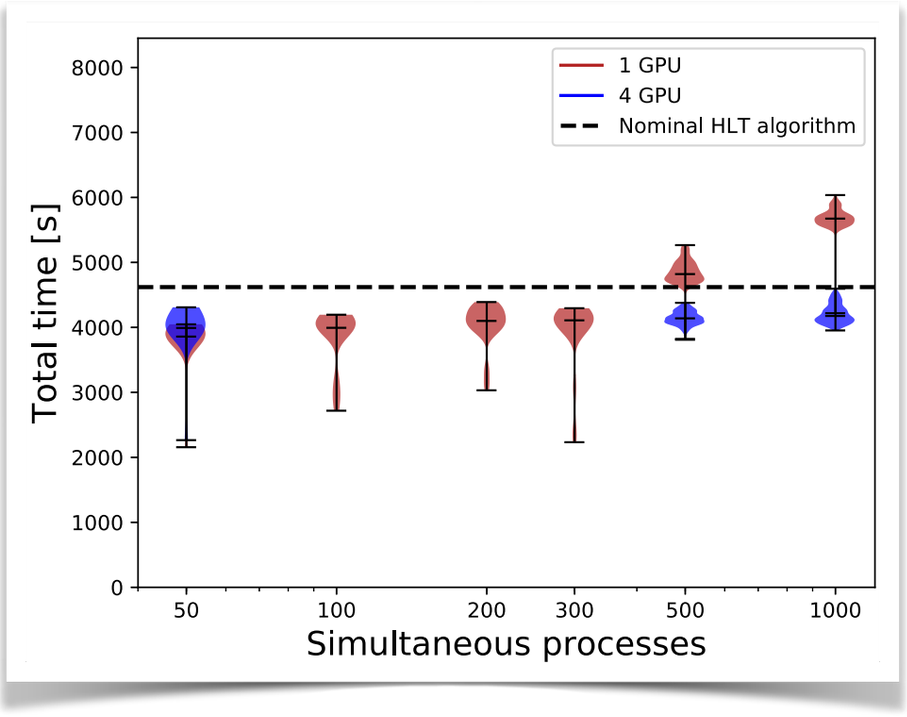
# Accelerators Highlights

*CMS hadronic calorimeter with GPU trigger*

| ALGO | Throughput |
|---|---|
| MAHI CPU | 60ms/evt |
| HCal (FACILE) GPU | 0.45 ms/evt |
| HCal(FACILE) FPGA | 0.10 ms/evt |



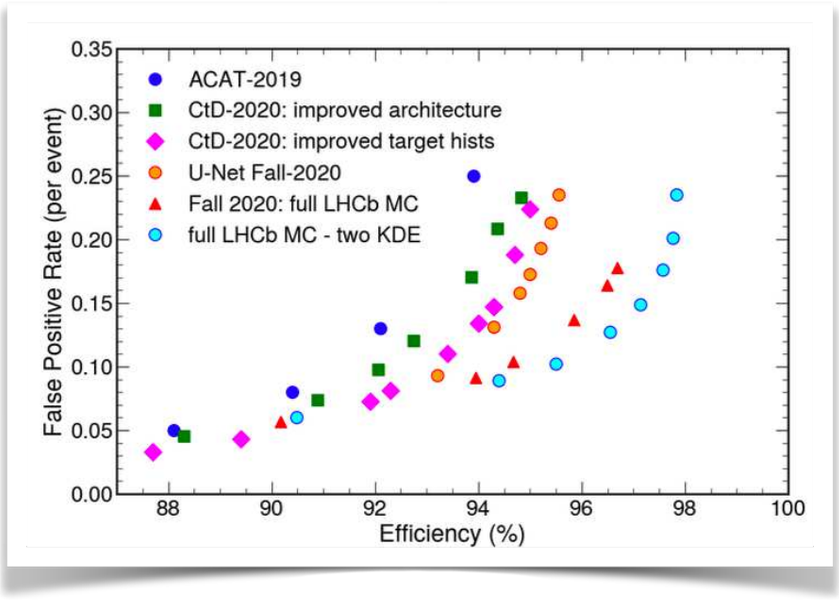



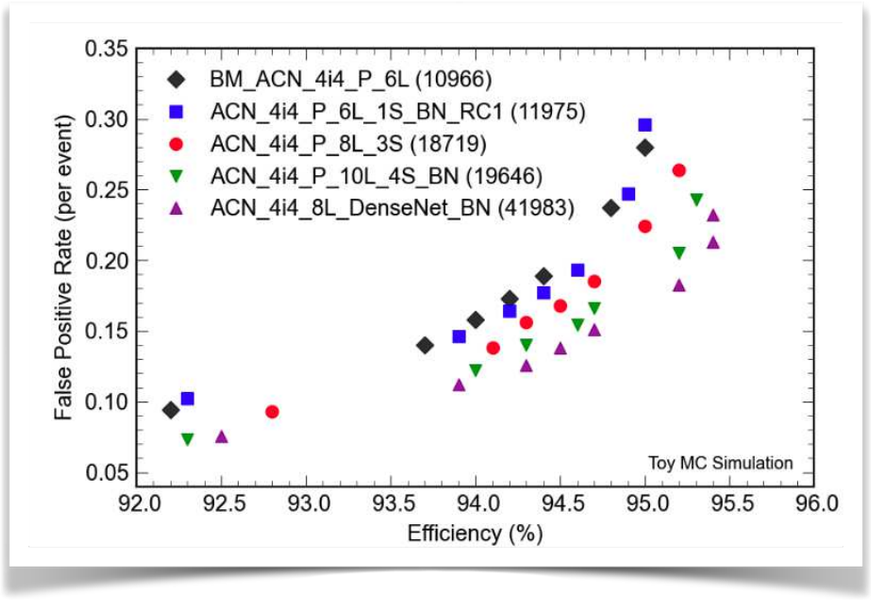

FPGA-accelerated machine learning inference as a service for particle physics computing, J. Duarte et. al., Comput.Softw.Big Sci. 3 13 (2019) (18 Apr 2019)

MET=missing energy, HCal = hadronic calorimeter

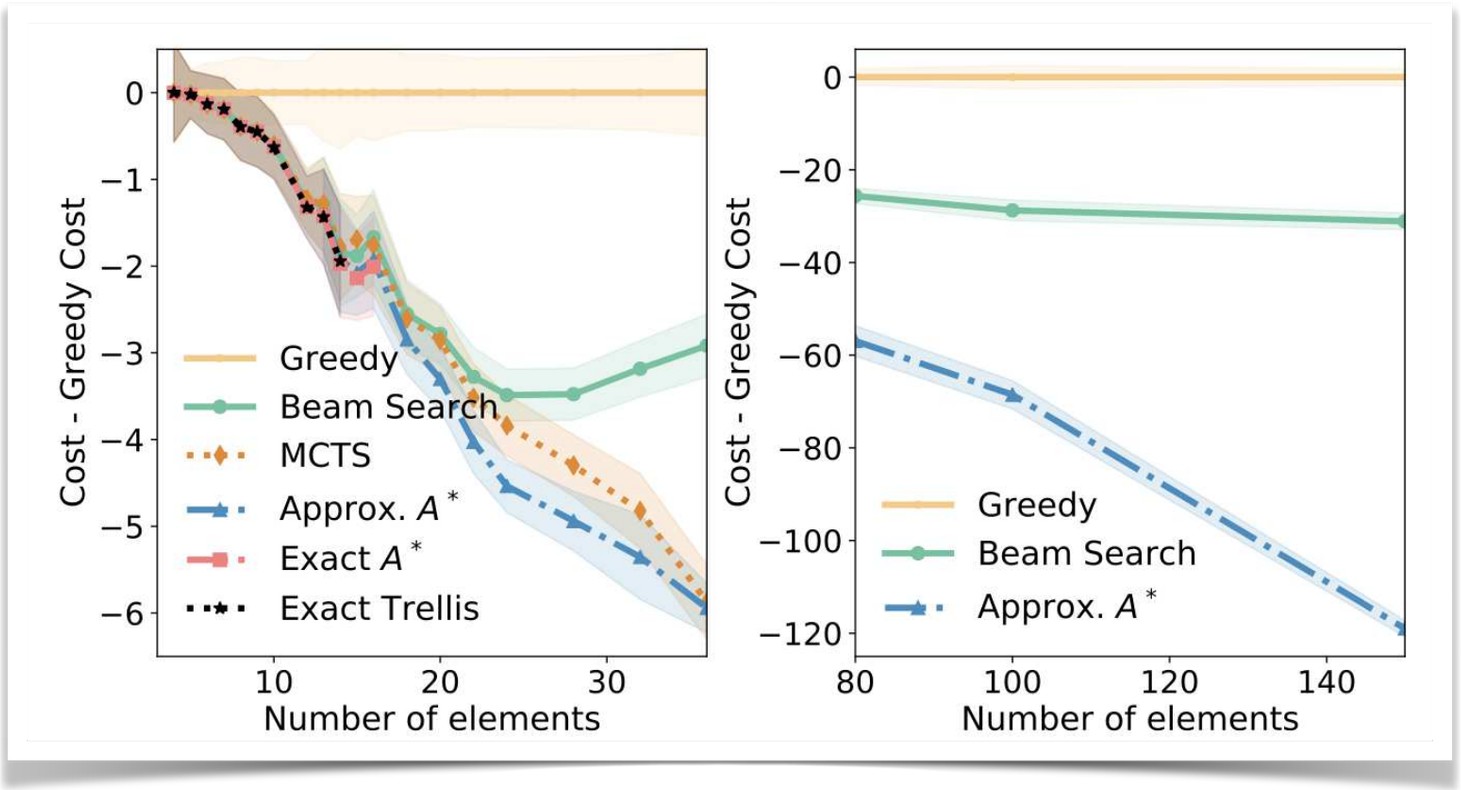
# Machine Learning Highlights

*KDEs and DNNs for **primary vertex** reconstruction for LHCb*




*Probabilistic treatment of **hierarchical clustering** for jet physics*




KDE=Kernel Density Estimator, DNN=Deep Neural Network

# We have lots of IA Fellow projects to follow

**Projects finishing up**

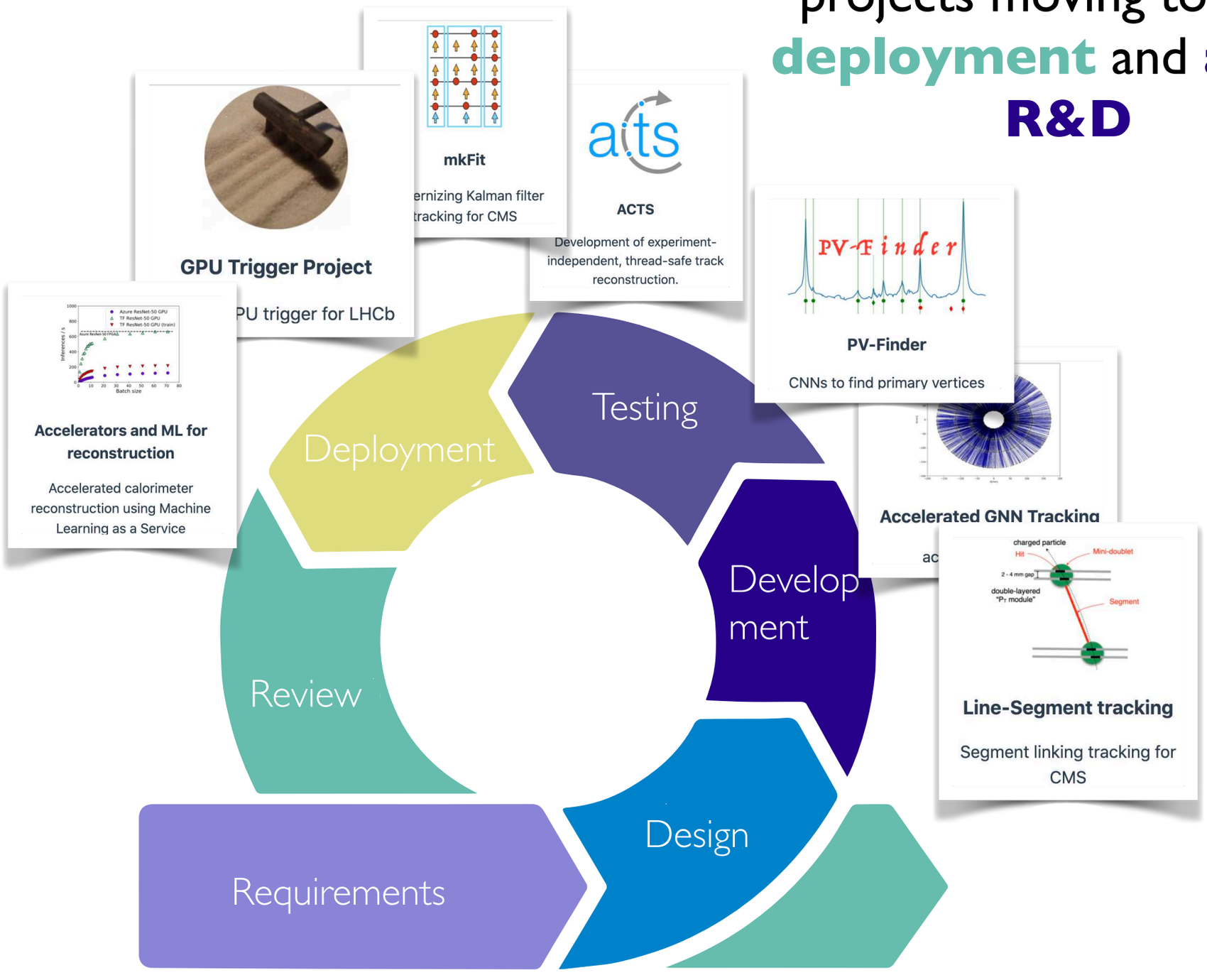
- Creating a Python Front-End for HLS Implementation of GNNs on FPGA (Presentation July 7th)
- Scaling up implementations of GNNs with FPGA co-processors for charged particle track reconstruction (Presentation July 7th)
- Floating Point Error Evaluation With Clad (Presentation June 21st)
- Graph Methods for Particle Tracking (Presentation June 28th)
- Offline Track Selection (Presentation July 7th)
- Machine Learning inference as a Service optimization in neutrino reconstruction
- OpenCL based implementation of graph neural networks on FPGA (Presentation June 28th)

**Projects starting up**

- Analyzing Neutrino Interactions
- Developing Symmetric Graph Neural Networks for Charged Particle Tracking
- Graph Methods for Particle Tracking

# IA Projects in the Software Lifecyle

Maintain a mixture of projects moving towards **deployment** and **active R&D**



# Conclusion

- Significant progress in **Innovative Algorithms** over the past year
- Many exciting **results**, many interesting **papers** and **talks**
- Active **fellows** program is enabling us to **broaden participation**
- A number of projects are **maturing** and moving towards **deployment**
  - e.g. Allen, MkFit, HLS4ML, ACTS
- Other **new opportunities** for R&D are just getting started
  - e.g. Line-Segment Tracking, ACTS on GPUs