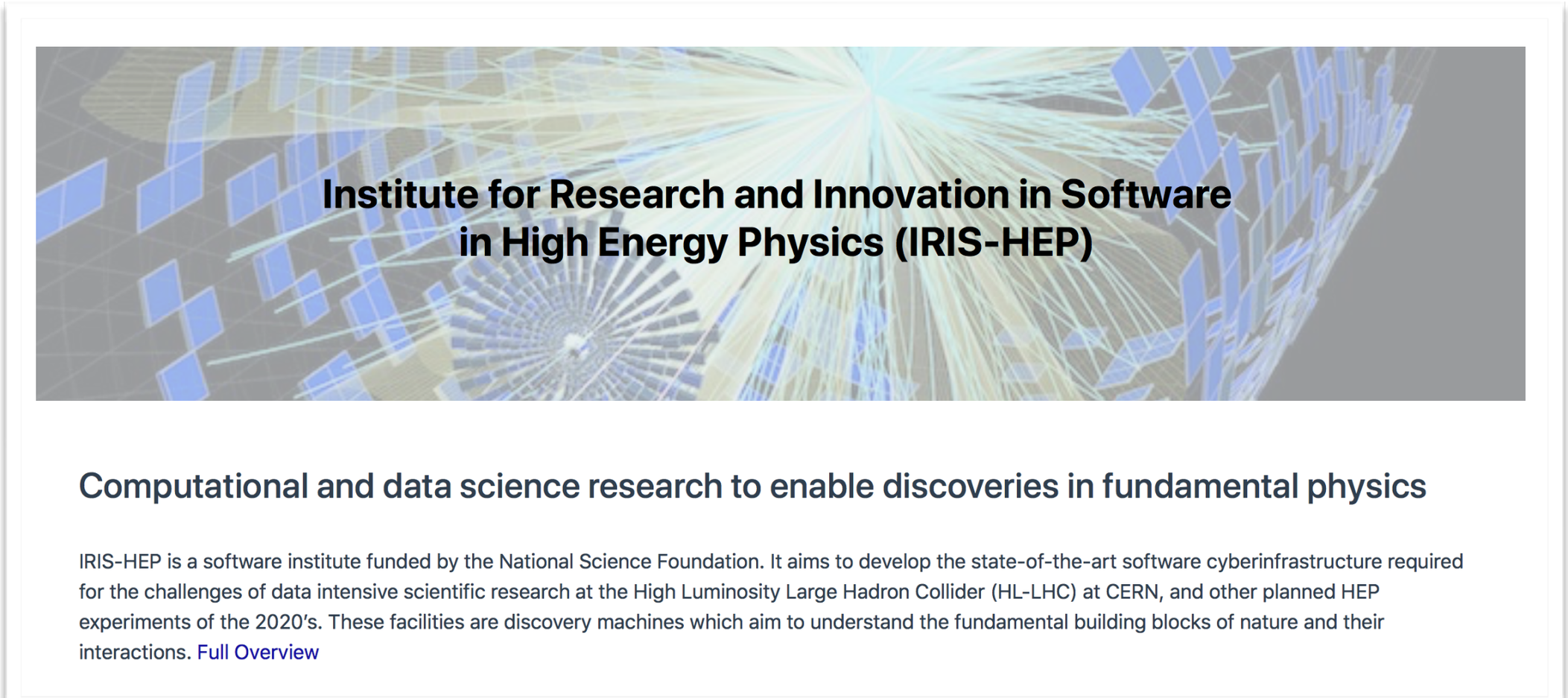
IRIS-HEP Report: Innovative Algorithms

Heather M. Gray

IRIS-HEP

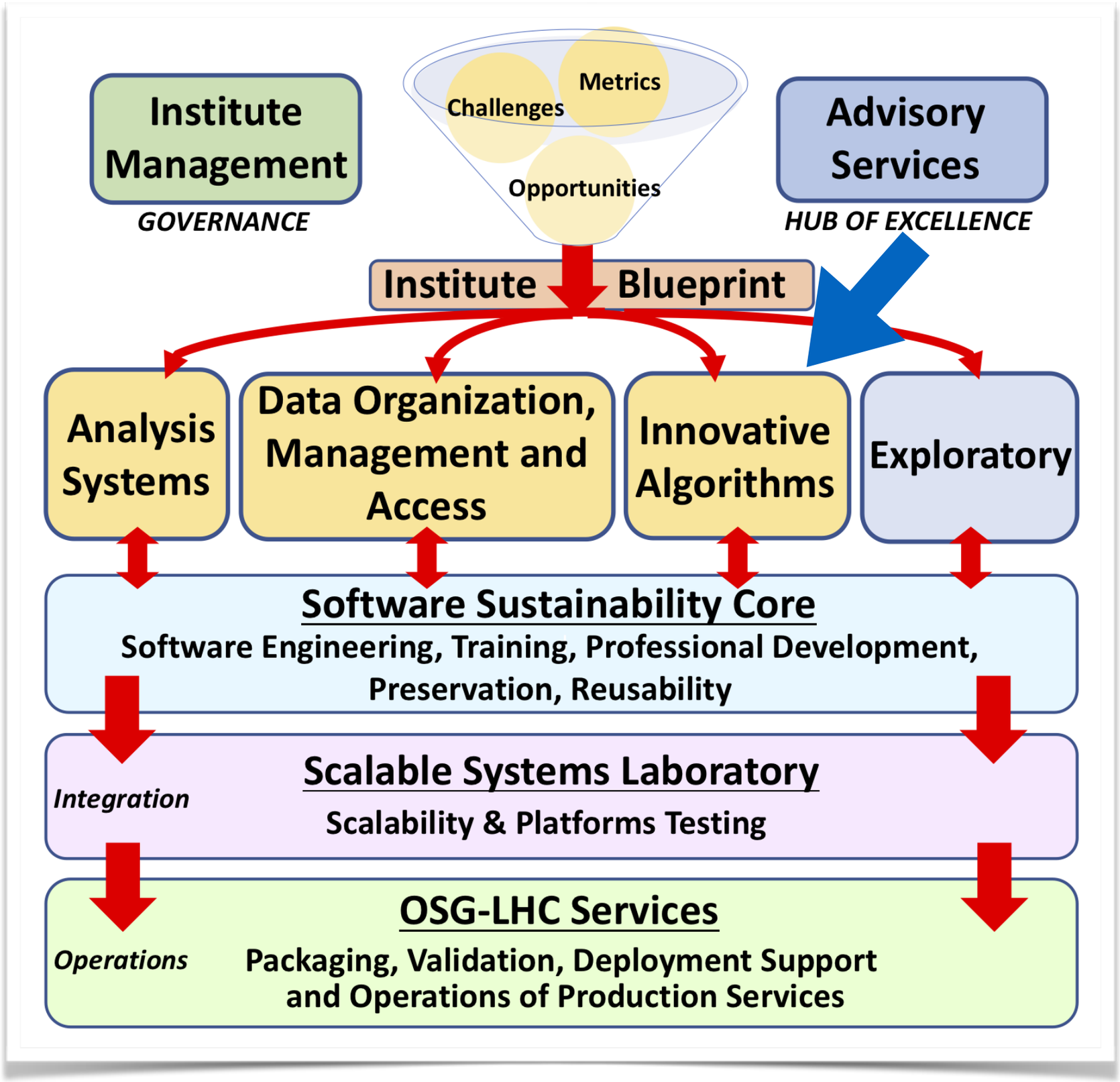


- NSF-funded software institute
  - Target for developments is HL-LHC
- University-based but inter-experiment:
  - includes ATLAS, CMS and LHCb

iris hep
Institute for Research & Innovation in Software for High Energy Physics

https://iris-hep.org/

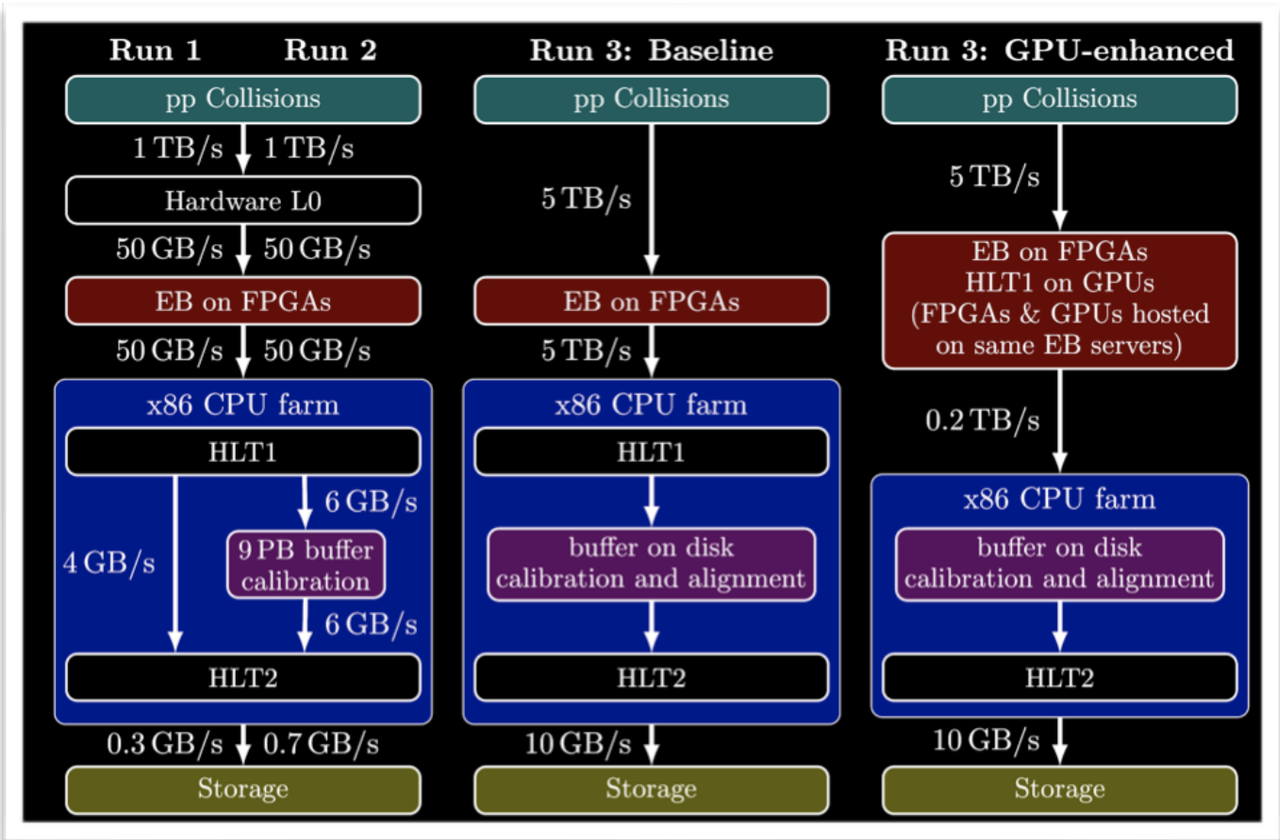
IRIS-HEP Overview



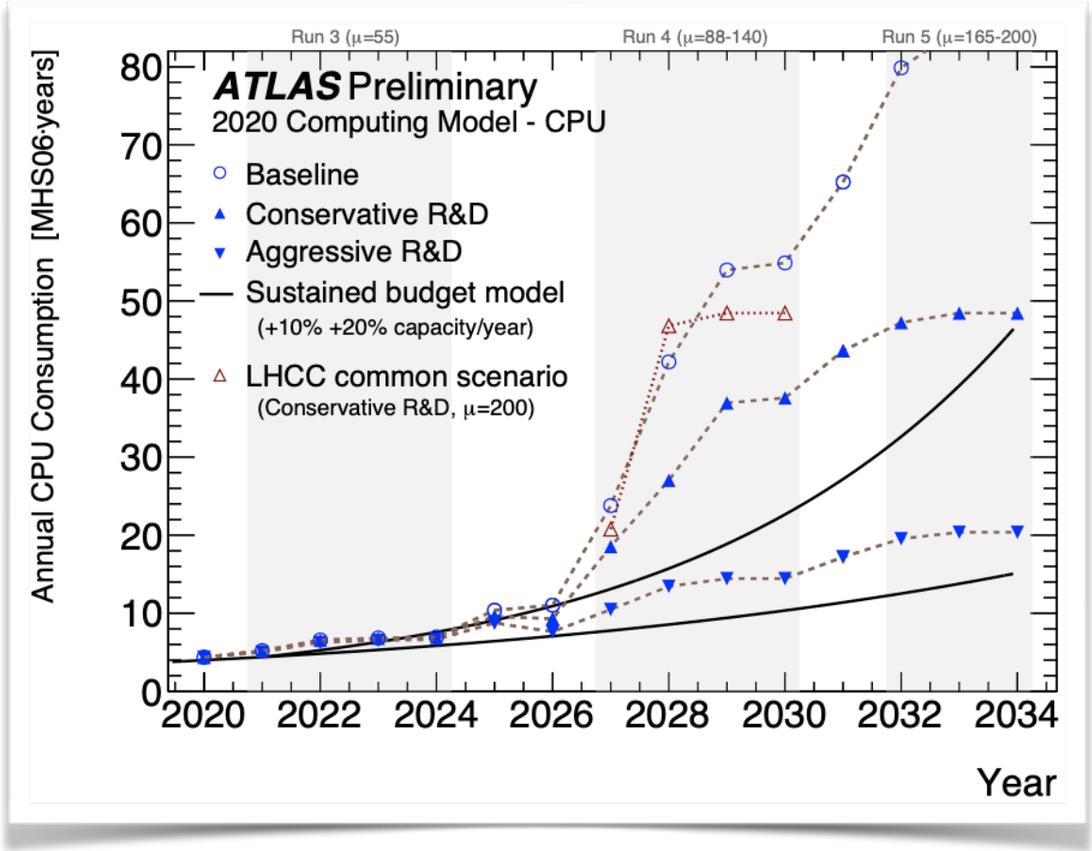
Co-leads
David Lange
Heather Gray

Computational challenges at the LHC

Evolution of LHCb HLT1 for Run 3



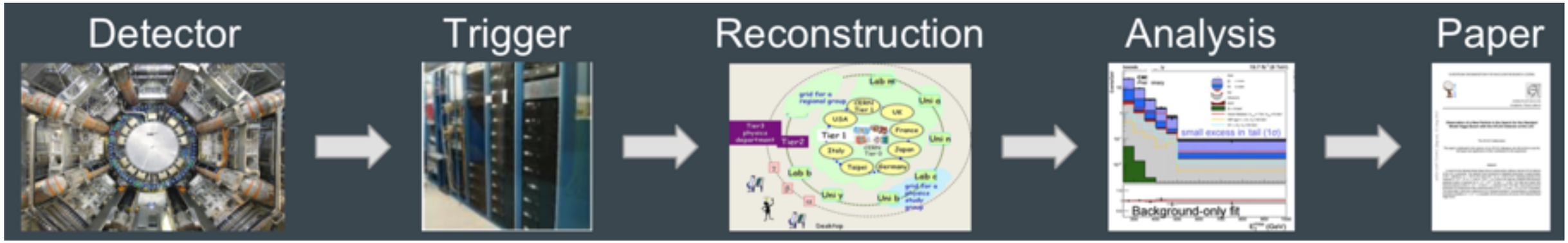
Reconstruction for ATLAS/ CMS at the HL-LHC



Focus Area: Innovative Algorithms

Developing and reengineering algorithms for critical HEP applications.

- **Software trigger**: Quasi-real-time processing of detector data to select most "interesting" events (reduce rate by 100x).
  - *Input rate is 1-30 MHz, required latencies are O(seconds).*
- **Offline reconstruction:** Processing raw data for analysts O(100) billion events per year processed by a globally distributed computing facility



The distinction between these areas is blurring given the evolution in software and hardware so we focus on both

Major Activities and Goals

Developing tracking algorithms for HL-LHC

Determining charged-particle trajectories ("tracking") requires most CPU in reconstruction

- Develop more efficient algorithms
- Develop more performant algorithms

Hardware accelerators are the way forward to speed up and reduce infrastructure cost

- Use of hardware accelerators for tracking
- ML on accelerators in realistic HEP apps

Re-engineering algorithms for hardware accelerators

Exploiting major advances in machine learning (ML)

Capitalize on industry and data science techniques and tools

- Investigate new HEP applications of ML
- Apply new ML techniques to HEP

IA projects in a slide..

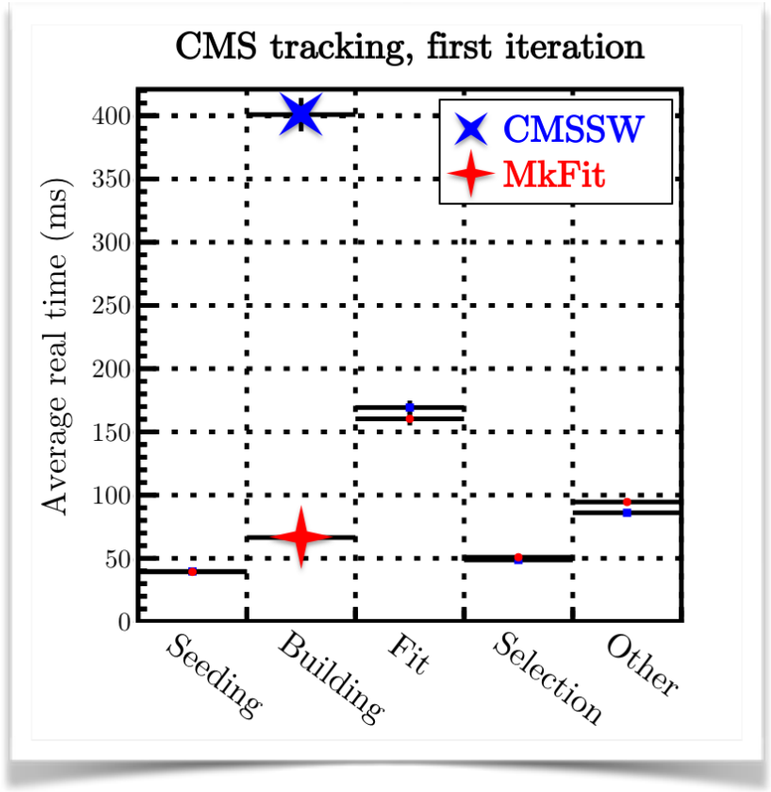
- **PVFinder**, ML approach to finding primary vertices (UC, MIT):
- **Allen framework**, Configuration and monitoring of GPU framework (MIT).
- **mkFit**, Efficient track finding on modern architectures (UCSD, Princeton, Cornell):
- **FPGAs and ML** for calorimetric reconstruction (MIT):
- **ACTS** tracking (UC-Berkeley, Stanford):
- **GNNs** for tracking (UIUC, Princeton):
- **ML for Jet** algorithms (NYU):

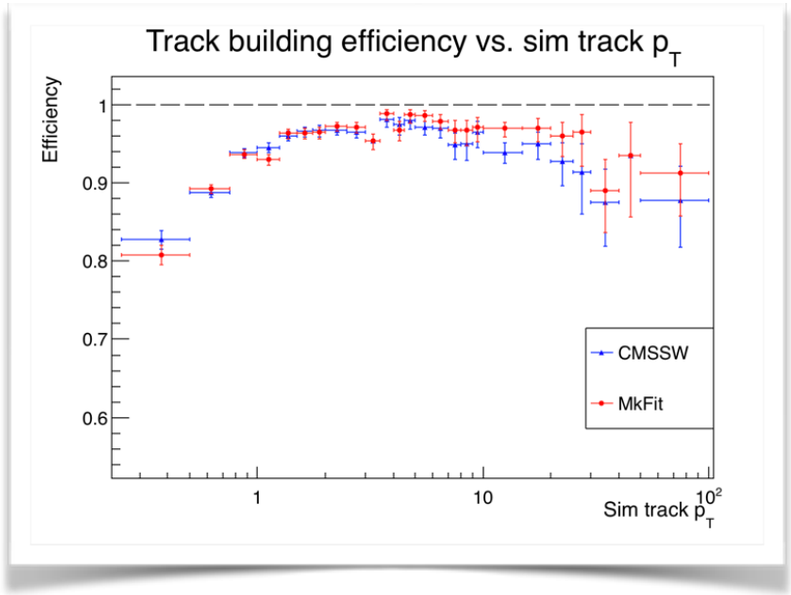
Many of these projects align well with the topics of this session

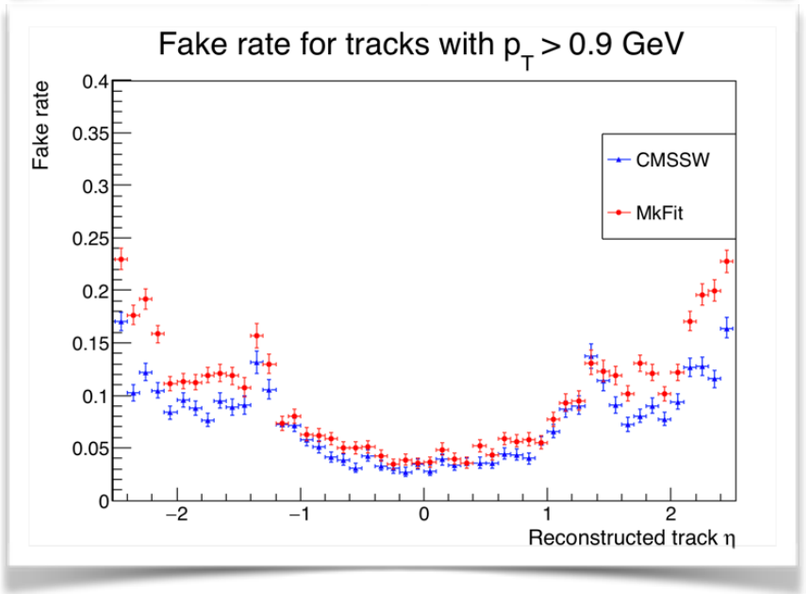
Most projects are collaborative and the IRIS-HEP effort is within the context of the larger project

MkFit

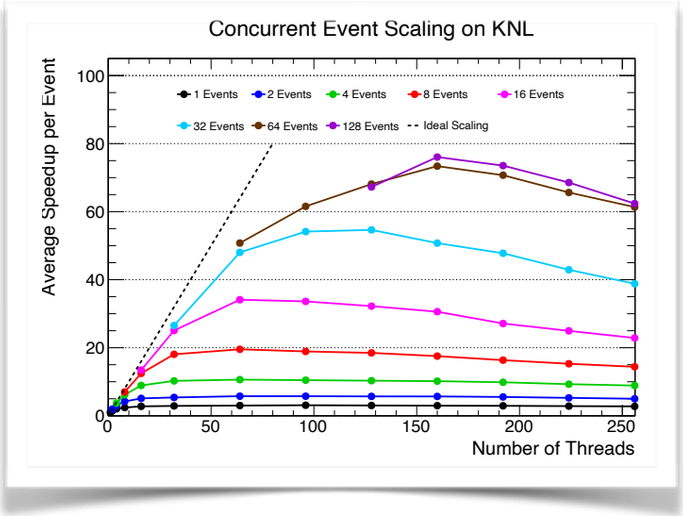
- Vectorized algorithms for track finding/ fitting implementations
  - 6x speed up vs single-threaded
- Ideas for GPU prototypes have been



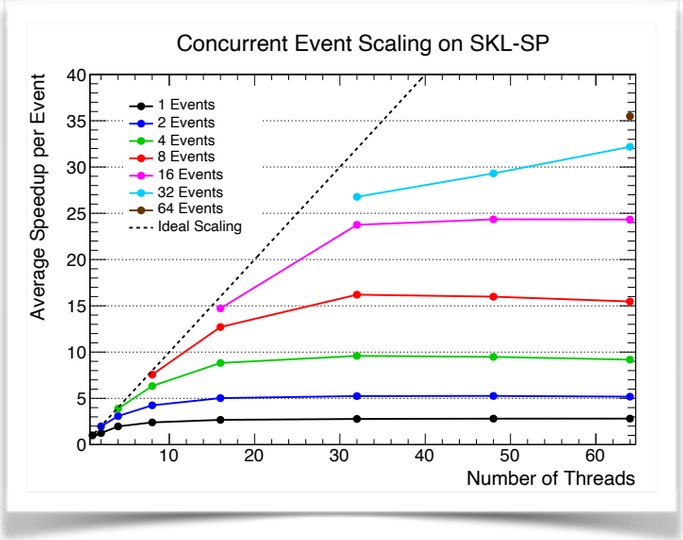




KNL = Knight's Landing



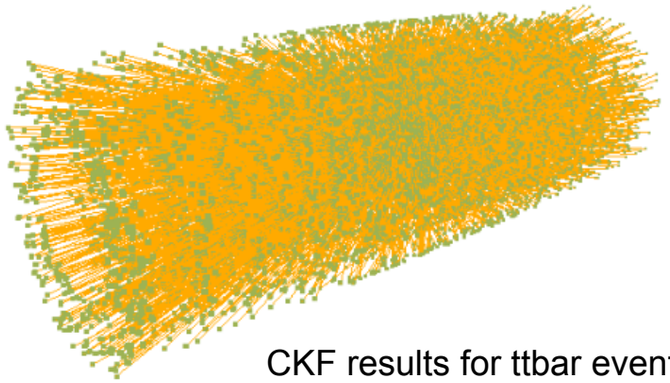
SKL-SP = Skylake Scalable Processor



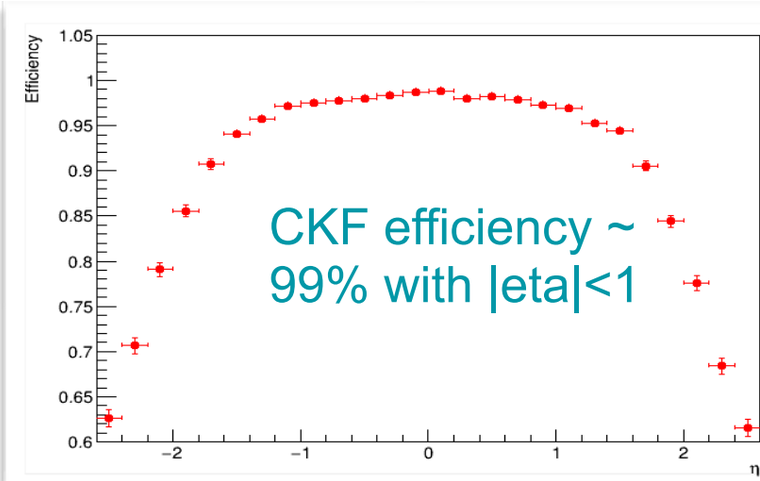
Lantz et al, arXiv: 2006.00071

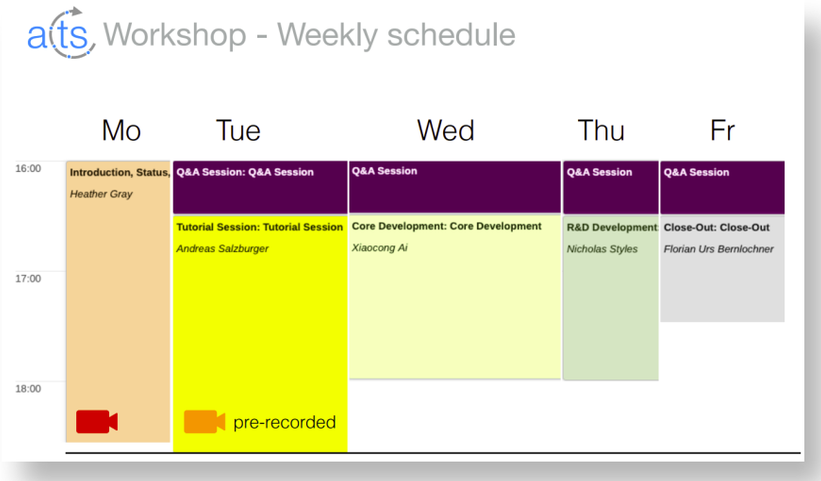
ACTS

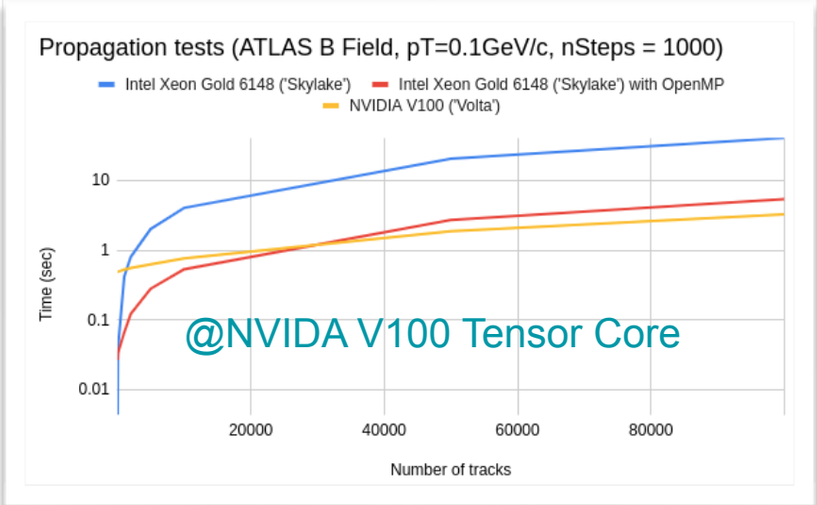
- ACTS is an open source project developing an experiment-independent set of track reconstruction tools.
- IRIS-HEP contributions include (Combinatorial) Kalman Filter implementation, alignment algorithms, tracking on GPUs (track seeding, Kalman Filter)
- More details in the ACTS Workshop "@" DESY
- Come to X. Ai's talk at the IRIS-HEP topical meeting next week to hear about ACTS tracking on GPUs

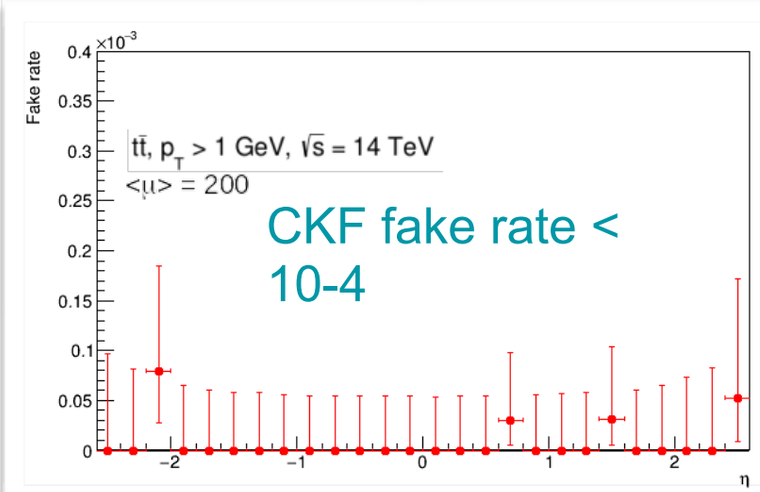


CKF results for ttbar events with mu = 200 (~7k particles, ~80k hits)







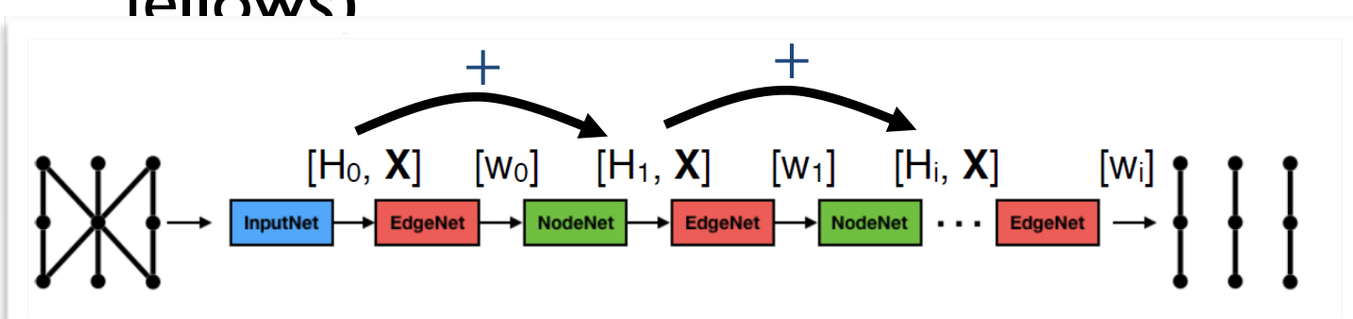


X. Ai, CTD 2020

P. Gessinger, CHEP 2019

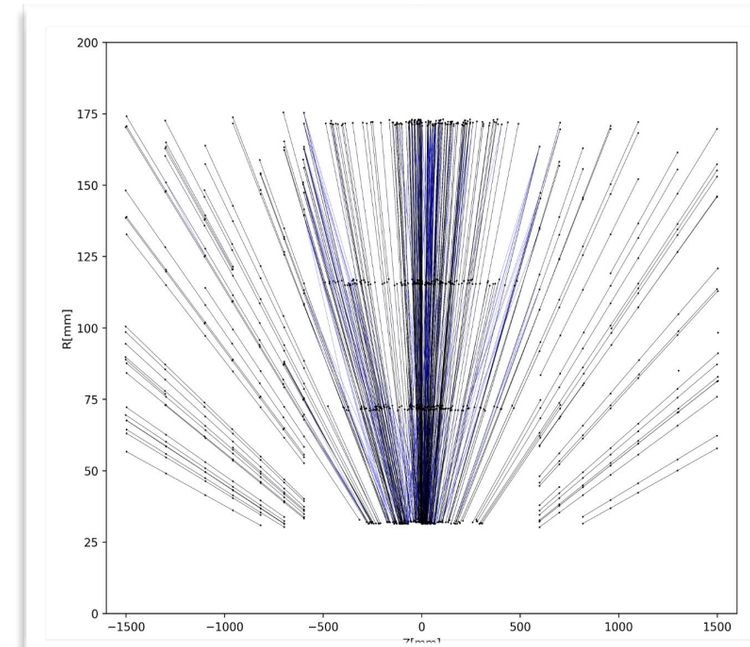
GNNs for Tracking

- Aims to improve HL-LHC tracking through the use of accelerators and ML algorithms (Graph Neural Networks)
  - Collaborators with the Exa.TrkX project
- Recent progress
  - Implementation of an interaction network GNN architecture
  - Inclusion of end-cap data in the graph construction and training
  - Optimizations for improved tracking performance
  - FPGA implementation of GNNs (IRIS-HEP fellows)

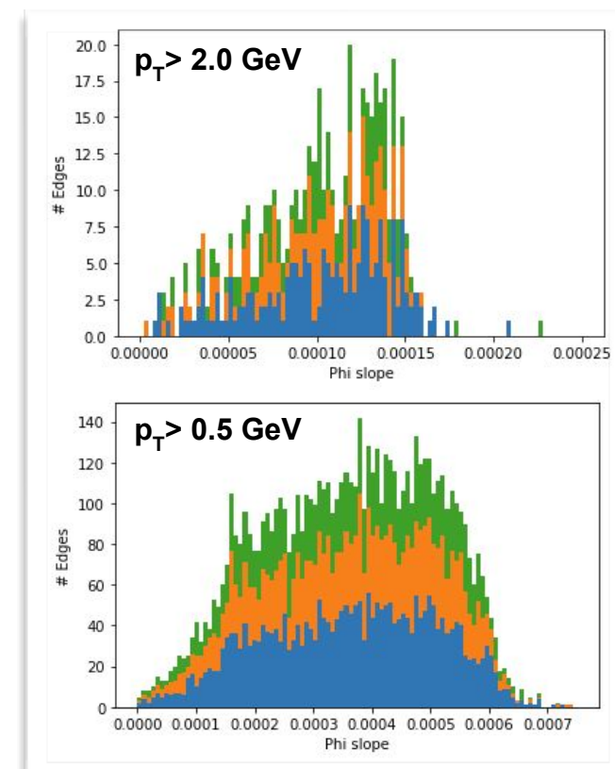


Exa.TrkX Workshop, April 2020

Visualization



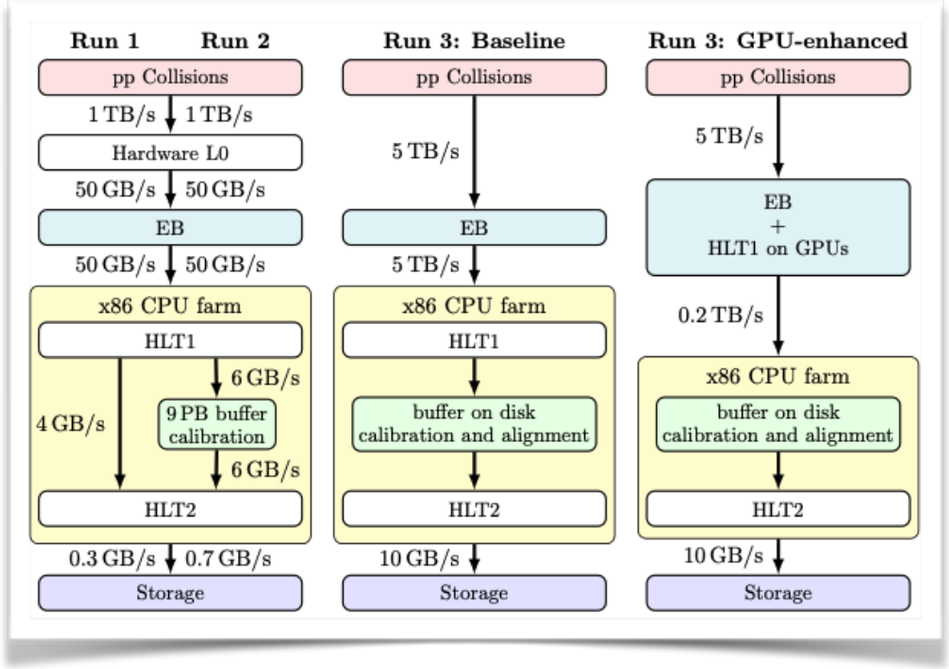
Parameter Optimization

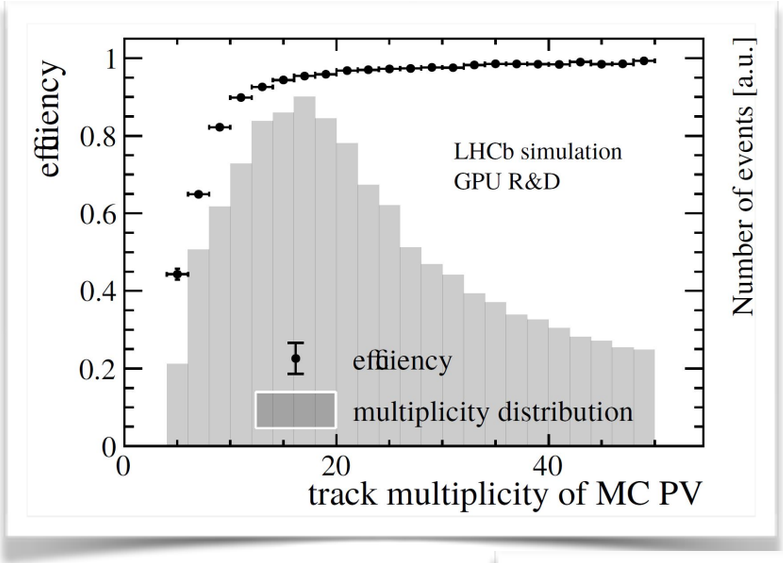


TrkX

Allen

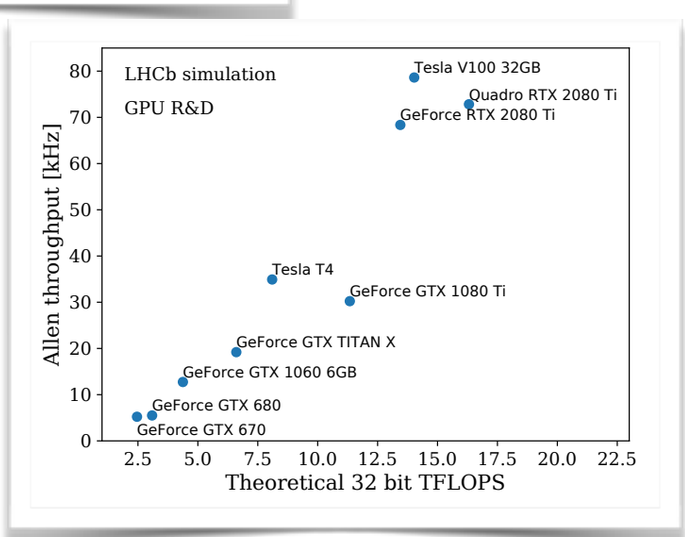
- Generic configurable framework for GPU-based execution of an algorithm sequence
  - Implement HLT1 on GPUs
- Stand-alone software package
- Dependencies: C++17 compiler, CUDA v10.2, boost, ZeroMQ
- Built-in validation and monitoring
- Process thousands of events in a sequence
- Opportunity for massive parallelisation
- Cross-platform compatibility with CPU architectures
- Named for Frances E. Allen





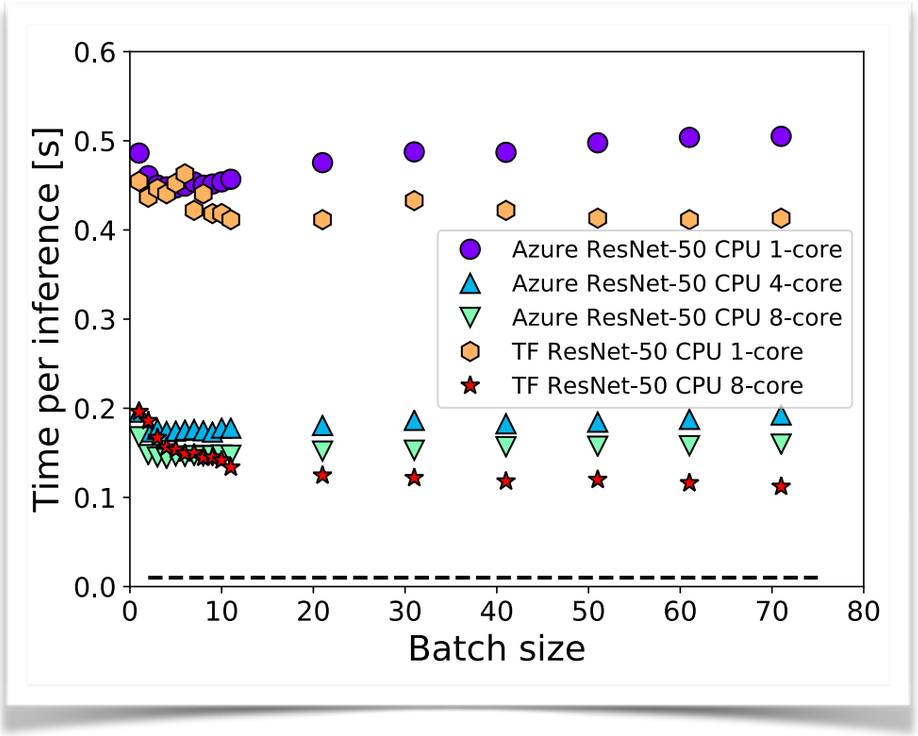
VELO vertexing

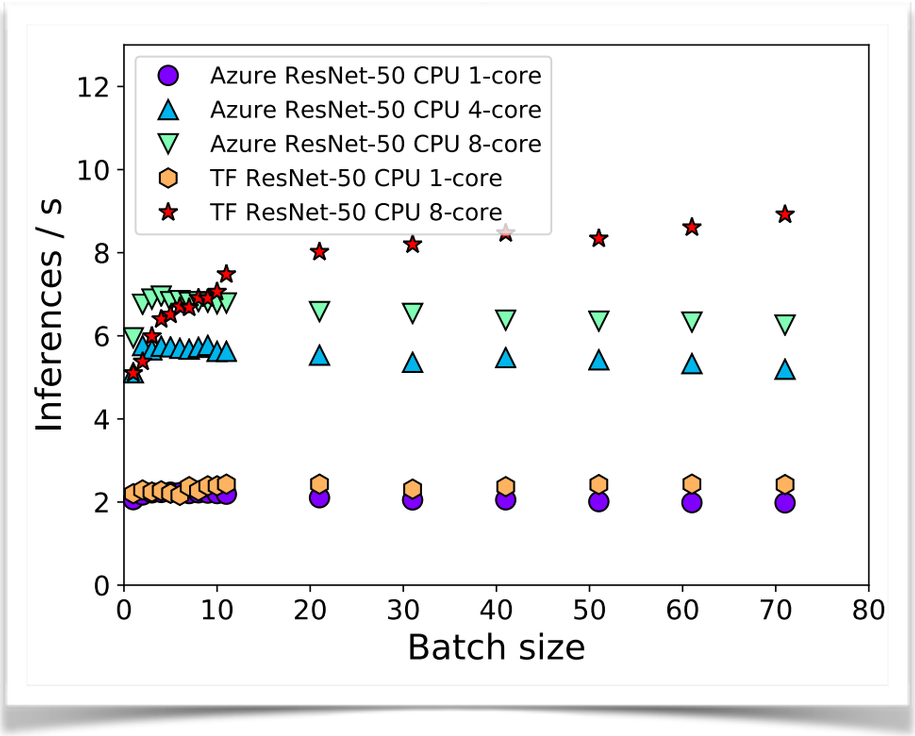
Throughput



T. Boettcher, CTD 2020 D. Craik, IRIS-HEP Topical Meeting Aaij, et al, arXiv:1912.09161

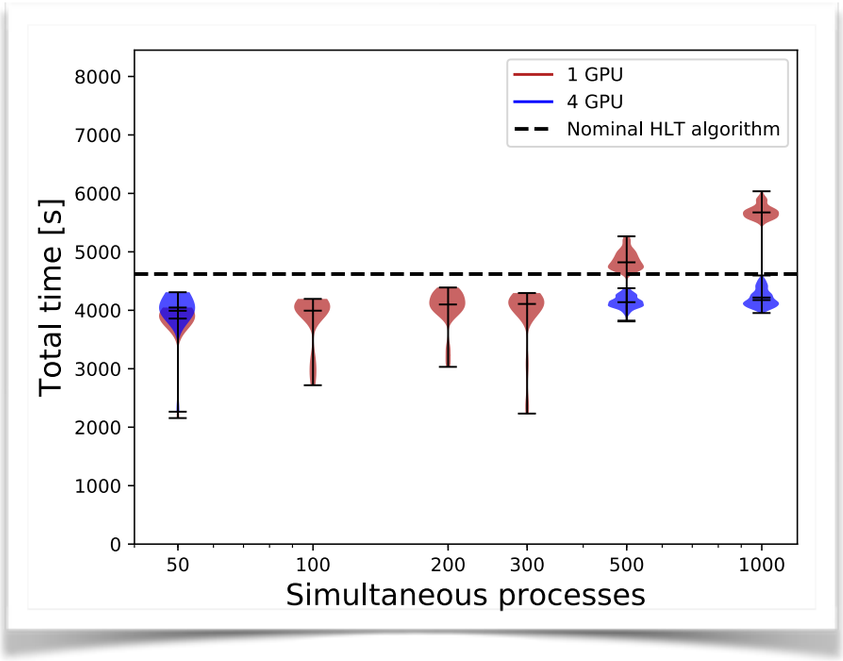
FPGAs/GPUs for Calo Reconstruction

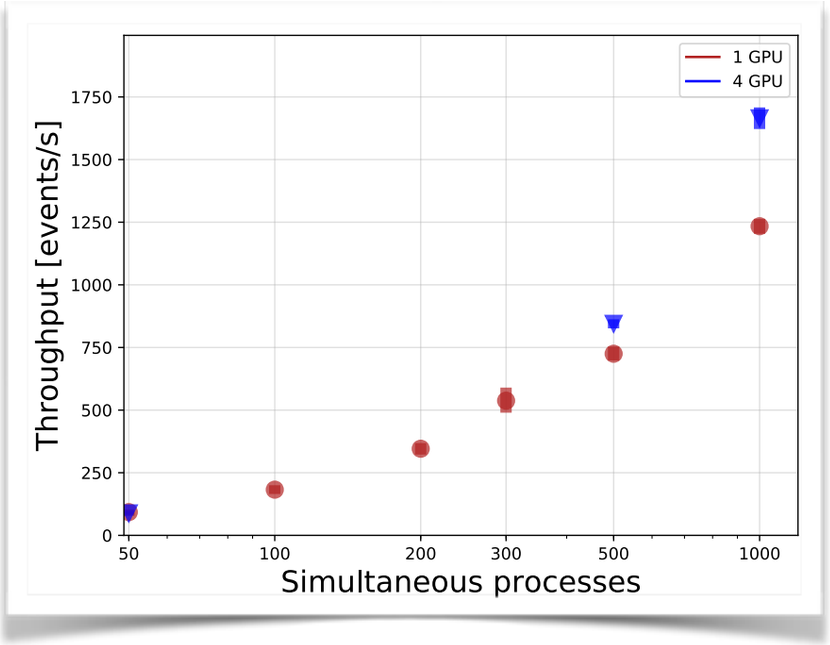




Duarte et al, arXiv:1904.08986

Krupa et al, arXiv:2007.10359





HCAL reconstruction using FACILE

IRIS-HEP Fellows

IRIS-HEP Fellows Program

Proposals for Summer 2020 are no longer being accepted. We are still accepting proposals for Fall 2020.

People are the key to successful software. IRIS-HEP aims to promote the development of advanced research software skills by providing opportunities for undergraduate and graduate students to connect with mentors within the larger HEP and Computational/Data Science community. At the same time, we aim to promote software as a collaborative activity and encourage collaborations which engage individuals in ways that maximize their potential and their potential impact on the community.

In order to accomplish these goals, IRIS-HEP has created a Fellow program. IRIS-HEP Fellows will spend 2-3 months working closely with a mentor on an R&D topic relevant to the Institute. Possible software R&D areas include:

https://iris-hep.org/fellows.html

Some of our summer 2020 fellows

IRIS-HEP Fellow: Sean Condon

Fellowship dates: June - August 2020
Home Institution: Massachusetts Institute of Technology

Developing selection algorithms to reduce output data rate from the Large Hadron Collider

The LHCb experiment at the Large Hadron Collider produces around 40 Tbits/s of data while running. The main goal of this project is to develop multivariate algorithms for run 3 of the LHCb experiment to select the interesting parts of this immense amount of data and discard the rest in real-time using only GPUs. To accomplish this, I will develop and evaluate many possible multivariate algorithms to find the best fitted for this task, and then deploy these into the baseline algorithm repository for LHCb run 3.

IRIS-HEP Fellow: Vesal Razavimaleki

Fellowship dates: July - September 2020
Home Institution: University of California, San Diego

Adapting GNN Tracking for FPGAs with hls4ml

Graph neural networks (GNNs) have demonstrated promise for pattern recognition problems like particle tracking. To meet the demands of the planned HL-LHC, there has been increased interest in accelerating large machine learning (ML) models with FPGA coprocessors for integration into the L1 trigger. Deployment of neural networks on FPGAs has been studied with the hls4ml compiler package which uses high-level synthesis to convert ML models to FPGA firmware. This project proposes to expand the hls4ml toolkit to support GNNs for particle tracking, allowing them to be implemented in FPGA coprocessor applications possibly including the L1 trigger.

IRIS-HEP Fellow: Aneesh Heintz

Fellowship dates: June - September 2020
Home Institution: Cornell University

Implementation of graph neural networks on CPU + FPGA co-processors for scalable track reconstruction tasks

Run 2 of the LHC on the CMS detector produced a data rate on the scale of hundreds of terabytes per second. Being able to reduce the data within a few milliseconds and sift through the data in a reasonable time frame to produce meaningful results is crucially important. Future increases in instantaneous luminosity, meaning more proton-proton collisions per bunch-crossing, will lead to data produced at increasingly larger rates, causing scalability issues in traditional particle track reconstruction algorithms. This project proposes to implement a graph network that can be evaluated on a CPU that has a FPGA co-processors. This will allow trained networks to be run online in a highly parallelized fashion, greatly accelerating data throughput.

Conclusion

- The Innovative Algorithms area in IRIS-HEP includes a wide range of projects aiming for the HL-LHC
- Our goals include
  - Developing tracking algorithms for the HL-LHC
  - Re-engineering algorithms for hardware accelerators
  - Exploiting major advances in machine learning
- We work within the larger software ecosystem with a wide range of collaborators on each of our projects

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