

Connecting The Dots 2018



Report of Contributions

Contribution ID: 2

Type: **Poster**

Using machine learning algorithms for Quality Assurance in ALICE experiment

Tuesday, March 20, 2018 4:00 PM (15 minutes)

Data Quality Assurance (QA) is an important aspect of every High-Energy Physics experiment, especially in the case of the ALICE experiment at the Large Hadron Collider (LHC) whose detectors are extremely sophisticated and complex devices. To avoid processing low quality or redundant data, and to classify it for analysis, human experts are currently involved in an offline assessment of the quality of the data itself and of the detectors' health during the collisions' recording. Since this assessment process is cumbersome and time-consuming, it typically takes experts days or months to assess the quality of the past data taking periods. Furthermore, since the ALICE Experiment is going to undergo a major upgrade in the coming years and it is planned to record much more data at higher frequency, manual data quality and detector health checks will simply not be feasible.

This is exactly the environment where machine learning can be utilized to its full extent. Based on the recent advancement in the field of machine learning and pattern recognition, we conducted several experiments that aim at automating QA for the ALICE experiment. More specifically, we collected a multi-dimensional dataset of attributes recorded during over 1'000 data taking periods by the Time Projection Chamber (TPC) and the corresponding quality labels. We normalized the data to disregard temporal dependencies as well as to minimize the noise. We cast our problem as a classification task whose goal is to assess the quality of the data collected by TPC detector. Since the space of assigned quality labels is very sparse, we simplified the multi-class problem to a binary classification task, by considering all bad and unlabeled data points as 'suspicious', while the remaining data portion was labeled as good. This normalization was recommended by detectors' experts, since the lack of labels is typically caused by unprecedented characteristics of the detector data.

The resulting binary classification task can be solved by several state-of-the-art machine learning algorithms. In our experiments, we have used both traditional shallow classification architectures, such as random trees and SVM classifiers, as well as modern neural network architectures. To ensure the generalization of our results and the robustness of the evaluated methods, we followed k-fold cross-validation procedure with k=10. The obtained results in terms of False Positive rate of less than 2% indicate that machine learning algorithms can be directly used to automatically detect the suspicious runs and hence reduce the human burden related to this task.

Our future research includes extending the analysis to other detectors' data, focusing first at those where the quality assessment procedure is more time-consuming. We then plan to investigate application of unsupervised machine learning methods to detect anomalies in detectors' data in real-time.

Primary author: Dr TRZCINSKI FOR THE ALICE COLLABORATION, Tomasz (Warsaw University of Technology)

Presenter: Dr TRZCINSKI FOR THE ALICE COLLABORATION, Tomasz (Warsaw University of Technology)

Session Classification: Poster

Track Classification: 4: Performance evaluation

Contribution ID: 3

Type: **Oral**

Fast track segment finding in the Monitored Drift Tubes (MDT) of the ATLAS Muon Spectrometer using a Legendre transform algorithm

Tuesday, March 20, 2018 3:00 PM (25 minutes)

Many of the physics goals of ATLAS in the High Luminosity LHC era, including precision studies of the Higgs boson, require an unprescaled single muon trigger with a 20 GeV threshold. The selectivity of the current ATLAS first-level muon trigger is limited by the moderate spatial resolution of the muon trigger chambers. By incorporating the precise tracking of the MDT, the muon transverse momentum can be measured with an accuracy close to that of the offline reconstruction at the trigger level, sharpening the trigger turn-on curves and reducing the single muon trigger rate. A novel algorithm is proposed which reconstructs segments from MDT hits in an FPGA and find tracks within the tight latency constraints of the ATLAS first-level muon trigger. The algorithm represents MDT drift circles as curves in the Legendre space and returns one or more segment lines tangent to the maximum possible number of drift circles. This algorithm is implemented without the need of resource and time consuming hit position calculation and track fitting procedures. A low-latency pure-FPGA implementation of a Legendre transform segment finder will be presented. This logic evaluates in parallel a total of 128 possible track segment angles for each MDT drift circle, calculating in a fast FPGA pipeline the offset of each segment candidate from an arbitrary origin for each angle and circle. The (angle, offset) pairs, corresponding to the MDT drift circles in one station, are used to fill a 2D histogram and the segment finder returns the position and angle of the maximum peak, corresponding to the most likely tangent line, this defines the reconstructed segment. Segments are then combined to calculate the muon's transverse momentum with a parametric approach which accounts for varying magnetic field strength throughout the muon spectrometer.

Primary author: NTEKAS, Kostas (University of California Irvine (US))

Co-author: KIRK, Julie Hart (STFC - Rutherford Appleton Lab. (GB))

Presenter: NTEKAS, Kostas (University of California Irvine (US))

Session Classification: Session2

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 4

Type: **Oral**

Improving jet substructure performance in ATLAS with unified tracking and calorimeter inputs

Wednesday, March 21, 2018 10:00 AM (25 minutes)

Jet substructure techniques play a critical role in ATLAS in searches for new physics, and are being utilized in the trigger. They become increasingly important in detailed studies of the Standard Model, among them the inclusive search for the Higgs boson produced with high transverse momentum decaying to a bottom-antibottom quark pair. To date, ATLAS has mostly focused on the use of calorimeter-based jet substructure, which works well for jets initiated by particles with low to moderate boost, but which lacks the angular resolution needed to resolve the desired substructure in the highly-boosted regime.

We will present a novel approach designed to mitigate the calorimeter angular resolution limitations, thus providing superior performance to prior methods. Similar to previous methods, the superior angular resolution of the tracker is combined with information from the calorimeters. However, the new method is fundamentally different, as it correlates low-level objects as tracks and individual energy deposits in the calorimeter, before running any jet finding algorithms. The resulting objects are used as inputs to jet reconstruction, and in turn result in improved resolution for both jet mass and substructure variables. It will be discussed how these jets could prove to be robust against pile-up due to the pile-up rejection capabilities of the tracker.

Primary author: JANSKY, Roland (Universite de Geneve (CH))

Co-authors: ATLAS; STYLES, Nicholas (Deutsches Elektronen-Synchrotron (DE)); DANNINGER, Matthias (University of British Columbia (CA)); CALACE, Noemi (Universite de Geneve (CH)); SCHRAMM, Steven (Universite de Geneve (CH))

Presenter: CALACE, Noemi (Universite de Geneve (CH))

Session Classification: Session3

Track Classification: 5: Advanced usage of tracks

Contribution ID: 5

Type: **Oral**

The Fast TracKer - A hardware track processor for the ATLAS trigger system

Tuesday, March 20, 2018 11:30 AM (25 minutes)

The Fast Tracker (FTK) is a hardware upgrade to the ATLAS trigger and data acquisition system providing global track reconstruction to the High-Level Trigger (HLT) with the goal to improve pile-up rejection. The FTK processes incoming data from the Pixel and SCT detectors (part of the Inner Detector, ID) at up to 100 kHz using custom electronic boards. ID hits are matched to pre-defined track patterns stored in associative memory (AM) on custom ASICs and data routing, reduction and parameter extraction is achieved with processing on FPGAs. With 8000 AM chips and 2000 FPGAs, the FTK provides enough resources to reconstruct tracks with transverse momentum greater than 1 GeV/c in the whole tracking volume with an average latency below 100 microseconds at collisions intensities expected in Runs II and III of the LHC. The tracks will be available at the beginning of the trigger selection process, which allows development of pile-up resilient triggering strategies to identify b-quarks and tau-leptons, as well as providing the potential to devise new selections to look for particular signatures (e.g. displaced vertices) in the search for New Physics phenomena.

This presentation describes the FTK system, with a particular emphasis on its massive parallelization capabilities, its installation and commissioning in 2016 and 2017, and the first data-taking experience including performance measurements.

Primary author: POTAMIANOS, Karolos (Deutsches Elektronen-Synchrotron (DE))

Co-author: KIRK, Julie Hart (STFC - Rutherford Appleton Lab. (GB))

Presenter: POTAMIANOS, Karolos (Deutsches Elektronen-Synchrotron (DE))

Session Classification: Session1

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 6

Type: **Oral**

Clustering with adaptive similarity measure for track reconstruction

Wednesday, March 21, 2018 4:10 PM (15 minutes)

The track reconstruction task of ATLAS and CMS will become computationally increasingly challenging with the LHC high luminosity upgrade. In the context of taking advantage of machine learning techniques, a clustering algorithm is proposed to group together hits that belong to the same particle. Clustering is referred to as unsupervised classification and is widely applied to big data. The unsupervised aspect in clustering allows it to generalize to any track size or properties as there are no defined classes.

The dataset considered is generated from ACTS fast simulation (A common tracking software) which provides simple and efficient event data modeling.

The algorithm uses the 3D spatial coordinates to group hits and uses the known detector geometry to exclude incompatible grouping. To efficiently cluster hits together which originate from a common particle, we define an adaptive distance which improves by adding more hits and quantifies how far a hit is from the particle's current reconstructed trajectory.

We show that the algorithm is able to adapt and generalize to kinematic range of interest for the tracks.

Primary author: AMROUCHE, Sabrina (RSA - Universite de Geneve (CH))

Co-authors: SALZBURGER, Andreas (CERN); GOLLING, Tobias (Universite de Geneve (CH))

Presenter: AMROUCHE, Sabrina (RSA - Universite de Geneve (CH))

Session Classification: Young Scientist Forum

Track Classification: 3: Machine learning approaches

Contribution ID: 7

Type: **Oral**

Quantum Pattern Recognition for High-Luminosity Era

Thursday, March 22, 2018 9:00 AM (25 minutes)

The data input rates foreseen in High-Luminosity LHC (circa 2026) and High-Energy LHC (2030s) High Energy Physics (HEP) experiments impose new challenging requirements on data processing. Polynomial algorithmic complexity and other limitations of classical approaches to many central HEP problems induce searches for alternative solutions featuring better scalability, higher performance and efficiency. For certain types of problems, the Quantum Computing paradigm can offer such asymmetrical-response solutions. We discuss the potential of quantum pattern recognition in the context of ATLAS data processing. In particular, we examine Quantum Associative Memory (QuAM) – a quantum variant of content-addressable memory based on quantum storage medium and two quantum algorithms for content handling. We examine the limits of storage capacity, as well as store and recall efficiencies, from the viewpoints of state-of-the-art quantum hardware and ATLAS real-time charged track pattern recognition requirements. We present QuAM simulations performed on LIQUi> - the Microsoft's Quantum Simulator toolsuite. We also review several difficulties integrating the end-to-end quantum pattern recognition into a real-time production workflow, and discuss possible mitigations.

Primary authors: SHAPOVAL, Illya (Lawrence Berkeley National Laboratory); CALAFIURA, Paolo (Lawrence Berkeley National Lab. (US))

Presenter: SHAPOVAL, Illya (Lawrence Berkeley National Laboratory)

Session Classification: Session5

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 8

Type: **Oral**

Neural Networks in FPGAs for Trigger and DAQ

Tuesday, March 20, 2018 12:00 PM (25 minutes)

Machine learning methods are becoming ubiquitous across the LHC and particle physics. However, the exploration of such techniques within the field in low latency, low power FPGA hardware has only just begun. There is great potential to improve trigger and data acquisition performance, more generally for pattern recognition problems, and potentially beyond. We present a case study for using neural networks in FPGAs. Our study takes jet substructure as an example since it is a field familiar with machine learning, but lessons are far-reaching. We map out resource usage and latency versus types of machine learning algorithms and their hyper-parameters to identify the problems in particle physics that would benefit. We develop a package based on High Level Synthesis (HLS) to build network architectures which is readily accessible to a broad user base.

Primary authors: TRAN, Nhan Viet (Fermi National Accelerator Lab. (US)); DUARTE, Javier Mauricio (Fermi National Accelerator Lab. (US)); KREIS, Ben (Fermi National Accelerator Lab. (US)); NGADIUBA, Jennifer (CERN); PIERINI, Maurizio (CERN); WU, Zhenbin (University of Illinois at Chicago (US)); KREINAR, Edward (Hawkeye 360); HAN, Song (Stanford University); HARRIS, Philip Coleman (Massachusetts Inst. of Technology (US))

Presenter: TRAN, Nhan Viet (Fermi National Accelerator Lab. (US))

Session Classification: Session1

Track Classification: 3: Machine learning approaches

Contribution ID: 9

Type: **Oral**

Track Reconstruction in the ALICE TPC using GPUs for LHC Run 3

Wednesday, March 21, 2018 2:30 PM (25 minutes)

In LHC Run 3, ALICE will increase the data taking rate significantly to 50 kHz continuous read out of minimum bias Pb-Pb collisions.

The reconstruction strategy of the online/offline computing upgrade foresees a first synchronous online reconstruction stage during data taking enabling detector calibration, and a posterior calibrated asynchronous reconstruction stage.

We present a tracking algorithm for the Time Projection Chamber (TPC), the main tracking detector of ALICE.

The reconstruction must yield results comparable to current offline reconstruction and meet time constraints like in the current High Level Trigger (HLT), processing 50 times as many collisions per second as today.

It is derived from the current online tracking in the HLT, which is based on a Cellular automaton and the Kalman filter, and we integrate missing features from offline tracking for improved resolution.

The continuous TPC read out and overlapping collisions pose new challenges: conversion to spatial coordinates and application of time- and location dependent calibration must happen in between of track seeding and track fit while TPC occupancy increases five-fold.

The huge data volume requires a data reduction factor of 20, which imposes additional requirements: the momentum range must be extended to identify low-Pt looping tracks and a special refit in uncalibrated coordinates improves the track model entropy encoding.

Our TPC track finding leverages the potential of hardware accelerators via the OpenCL and CUDA APIs in a shared source code for CPUs, GPUs, and both reconstruction stages.

Porting more reconstruction steps like the remainder of the TPC reconstruction and tracking for other detectors will shift the computing balance from traditional processors to GPUs.

We give an overview of the status of Run 3 tracking including track finding efficiency, resolution, treatment of continuous read out data, and performance on processors and GPUs.

Primary author: ROHR FOR THE ALICE COLLABORATION, David (CERN)

Presenter: ROHR FOR THE ALICE COLLABORATION, David (CERN)

Session Classification: Session4

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 10

Type: **Poster**

A novel deep neural network classifier for assessing track quality in the Iterative Track Reconstruction at CMS

Tuesday, March 20, 2018 4:15 PM (15 minutes)

In the track reconstruction in the CMS software, particle tracks are determined using a Combinatorial Track Finder algorithm. In order to optimize the speed and accuracy of the algorithm, the tracks are reconstructed using an iterative process: Easiest tracks are searched first, then hits, associated to good found tracks, are excluded from consideration in the following iterations (masking) before continuing with the next iteration. At the end of each iteration, a track selection is performed to classify different tracks depending on their quality. Currently we use classifiers (one for each iteration) based on a shallow Boosted-Decision-Tree whose inputs variables are track features, such as the goodness-of-fit and number of hits. To enhance the performance of this classification, we have developed a novel classifier based on a deep neural network trained using the TensorFlow framework. This new technique not only performs better, it also has the advantage to use a single classifier for all iterations: this simplifies the task of retraining the classifier and to maintain its high performance in the changing conditions of the detector. In this talk we will present the characteristic and performance of the new deep neural network classifier. We will also discuss the impact on both training and inference of changing some of the properties of the network such as topology, score function and input parameters.

Primary author: HAVUKAINEN, Joona Juhani (Helsinki Institute of Physics (FI))

Presenter: HAVUKAINEN, Joona Juhani (Helsinki Institute of Physics (FI))

Session Classification: Poster

Track Classification: 3: Machine learning approaches

Contribution ID: 11

Type: **Oral**

Track Reconstruction in the Pixel Detector for CMS High-Level Trigger using GPUs

The pixel detector in the CMS experiment has been upgraded with additional 4th barrel layer and 3rd forward disk while maintaining same pixel dimension (150 x 100 μm^2). Due to large volume of data from pixel detector, the processing power of the HLT CPUs is not sufficient to reconstruct tracks from all events. However, many trigger paths would benefit from pixel tracks to increase their efficiency and/or reduce their rate. In order to reconstruct tracks within the specified latency, it is imperative to process data using parallel computing techniques. We are developing algorithms to reconstruct tracks starting from raw pixel detector data for each event using GPUs. They provide large number of processing threads for performing similar tasks to be carried out for all the modules of the detector simultaneously. Initial assessment shows significant improvement in the timing performance of GPU when compared with the CPU. Results and future plans on these developments will be presented

Primary author: DUGAD, Shashi (Tata Inst. of Fundamental Research (IN))

Co-authors: PANTALEO, Felice (CERN); Mr DUBEY, Sushil (Junior Research Fellow)

Presenter: DUGAD, Shashi (Tata Inst. of Fundamental Research (IN))

Session Classification: Session4

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 12

Type: **Oral**

Implementation and Performance of FPGA based track fitting for the Atlas Fast Tracker

Wednesday, March 21, 2018 12:00 PM (15 minutes)

The Fast Tracker (FTK) within the ATLAS trigger system provides global track reconstruction for all events passing the ATLAS Level 1 trigger by dividing the detector into parallel processing pipelines that implement pattern matching in custom integrated circuits and data routing, reduction, and parameter extraction in FPGAs. In this presentation we will describe the implementation of a critical component of the system which does partial track fitting using a method based on a principal component analysis at a rate of greater than 1 fit per 10 ps, system-wide, to reduce the output of the pattern matching. Firmware design, timing performance and preliminary results will be discussed.

Primary author: ZOU, Rui (University of Chicago (US))

Co-author: KIRK, Julie Hart (STFC - Rutherford Appleton Lab. (GB))

Presenter: ZOU, Rui (University of Chicago (US))

Session Classification: Session3

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 13

Type: **Oral**

Implementation and performance of the ATLAS pixel clustering neural networks

Wednesday, March 21, 2018 4:30 PM (15 minutes)

The high particle densities produced by the Large Hadron Collider (LHC) mean that in the ATLAS pixel detector the clusters of deposited charge start to merge. A neural network-based approach is used to estimate the number of particles contributing to each cluster, and to accurately estimate the hit positions even in the presence of multiple particles. This talk or poster will thoroughly describe the algorithm and its implementation as well as present a set of benchmark performance measurements. The problem is most acute in the core of high-momentum jets where the average separation between particles becomes comparable to the detector granularity. This is further complicated by the high number of interactions per bunch crossing. Both these issues will become worse as the Run 3 and HL-LHC programme require analysis of higher and higher p_T jets, while the interaction multiplicity rises. Future prospects in the context of LHC Run 3 and the upcoming ATLAS inner detector upgrade will also be discussed.

Primary authors: ATLAS COLLABORATION; GAGNON, Louis-Guillaume (Universite de Montreal (CA)); STYLES, Nicholas (Deutsches Elektronen-Synchrotron (DE))

Presenter: GAGNON, Louis-Guillaume (Universite de Montreal (CA))

Session Classification: Young Scientist Forum

Track Classification: 5: Advanced usage of tracks

Contribution ID: 14

Type: **Oral**

Online Event Reconstruction in IceCube Using Deep Learning Techniques

Wednesday, March 21, 2018 9:30 AM (25 minutes)

The IceCube Neutrino Observatory is a Cherenkov detector deep in the Antarctic ice. Due to limited computational resources and the high data rate, only simplified reconstructions restricted to a small subset of data can be run on-site at the South Pole. However, in order to perform online analyses and to issue real-time alerts, fast and powerful reconstructions are desired.

Recent advances, especially in image recognition, have shown the capabilities of deep learning. Deep neural networks can be extremely powerful and their usage is computationally inexpensive once the networks are trained. These characteristics make a deep learning-based reconstruction an excellent candidate for the application on-site at the South Pole. In contrast to image recognition tasks, the reconstruction in IceCube poses additional challenges as the data is four-dimensional, highly variable in length, and distributed on an imperfect triangular grid.

A deep learning-based reconstruction method is presented which can significantly increase the reconstruction accuracy while reducing the runtime in comparison to standard reconstruction methods in IceCube.

Primary author: Mr HÜNNEFELD, Mirco (TU Dortmund, IceCube)

Presenter: Mr HÜNNEFELD, Mirco (TU Dortmund, IceCube)

Session Classification: Session3

Track Classification: 3: Machine learning approaches

Contribution ID: 15

Type: **Oral**

Expected performance of tracking and vertexing with the HL-LHC ATLAS detector

Wednesday, March 21, 2018 11:30 AM (25 minutes)

The High Luminosity LHC (HL-LHC) aims to increase the LHC data-set by an order of magnitude in order to increase its potential for discoveries. Starting from the middle of 2026, the HL-LHC is expected to reach the peak instantaneous luminosity of $7.5 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ which corresponds to about 200 inelastic proton-proton collisions per beam crossing. To cope with the large radiation doses and high pileup, the current ATLAS Inner Detector will be replaced with a new all-silicon Inner Tracker. In this talk the expected performance of tracking and vertexing with the HL-LHC tracker is presented. Comparison is made to the performance with the Run2 detector. Ongoing developments of the track reconstruction for the HL-LHC are also discussed.

Primary authors: STYLES, Nicholas (Deutsches Elektronen-Synchrotron (DE)); DANNINGER, Matthias (University of British Columbia (CA)); CALACE, Noemi (Universite de Geneve (CH))

Presenter: CALACE, Noemi (Universite de Geneve (CH))

Session Classification: Session3

Track Classification: 4: Performance evaluation

Contribution ID: 16

Type: **Poster**

The ATLAS Inner Detector track based alignment

Tuesday, March 20, 2018 4:45 PM (15 minutes)

The alignment of the ATLAS Inner Detector is performed with a track-based alignment algorithm. Its goal is to provide an accurate description of the detector geometry such that track parameters are accurately determined and free from biases. Its software implementation is modular and configurable, with a clear separation of the alignment algorithm from the detector system specifics and the database handling.

The alignment must cope with the rapid movements of the detector as well as with the slow drift of the different mechanical units. Prompt alignment constants are derived for every run at the calibration stage. These sets of constants are then dynamically split from the beginning of the run in many chunks, allowing to describe the tracker geometry as it evolves with time.

The alignment of the Inner Detector is validated and improved by studying resonance decays (Z and J/ψ to $\mu^+\mu^-$), as well as using information from the calorimeter system with the E/p method with electrons. A detailed study of these resonances (together with the properties of their decay products) allows correcting for alignment weak modes such as detector curls, twists or radial deformations that may bias the momentum and/or the impact parameters. On the other hand, the detailed scrutiny of the track-hit residuals serves to assess the shape of the Pixels and IBL modules.

Primary author: MARTI I GARCIA, Salvador (IFIC-Valencia (UV/EG-CSIC))

Co-authors: CAMARDA, Stefano (CERN); GOLLING, Tobias (Universite de Geneve (CH))

Presenter: MARTI I GARCIA, Salvador (IFIC-Valencia (UV/EG-CSIC))

Session Classification: Poster

Track Classification: 5: Advanced usage of tracks

Contribution ID: 17

Type: **Oral**

Tracking in Dense Environments for the HL-LHC ATLAS Detector

Wednesday, March 21, 2018 5:10 PM (15 minutes)

Tracking in dense environments, such as in the cores of high-energy jets, will be key for new physics searches as well as measurements of the Standard Model at the High Luminosity LHC (HL-LHC). The HL-LHC will operate in challenging conditions with large radiation doses and high pile-up (up to $\mu=200$). The current tracking detector will be replaced with a new all-silicon Inner Tracker for the Phase II upgrade of the ATLAS detector. In this talk, characterization of the HL-LHC tracker performance for collimated, high-density charged particles arising from high-momentum decays is presented. In such decays the charged-particle separations are of the order of the tracking detector granularity, leading to challenging reconstruction. The ability of the HL-LHC ATLAS tracker to reconstruct the tracks in such dense environments is discussed and compared to ATLAS Run-2 performance for a variety of relevant physics processes.

Primary author: CORMIER, Felix (University of British Columbia (CA))

Co-authors: DANNINGER, Matthias (University of British Columbia (CA)); STYLES, Nicholas (Deutsches Elektronen-Synchrotron (DE))

Presenter: CORMIER, Felix (University of British Columbia (CA))

Session Classification: Young Scientist Forum

Track Classification: 5: Advanced usage of tracks

Contribution ID: 18

Type: **Oral**

Conformal tracking for the CLIC detector

Thursday, March 22, 2018 10:00 AM (25 minutes)

Conformal tracking is the novel and comprehensive tracking strategy adopted by the CLICdp Collaboration. It merges the two concepts of conformal mapping and cellular automaton, providing an efficient pattern recognition for prompt and displaced tracks, even in busy environments with 3 TeV CLIC beam-induced backgrounds. In this talk, the effectiveness of the algorithm will be shown by presenting its performances for the CLIC detector, which features a low-mass silicon vertex and tracking system. Moreover, given its geometry-agnostic approach, the algorithm is easily adaptable to other detector designs and interaction regions, resulting in successful performances also for the CLIC detector modified for FCC-ee.

Primary authors: LEOGRANDE, Emilia (CERN); HYNDS, Daniel (University of Glasgow (GB))

Presenters: LEOGRANDE, Emilia (CERN); HYNDS, Daniel (University of Glasgow (GB))

Session Classification: Session5

Track Classification: 1: Algorithms and theoretical analysis

Contribution ID: 19

Type: **Oral**

Level-1 Track Finding with all-FPGA system at CMS for the HL-LHC

Tuesday, March 20, 2018 2:00 PM (25 minutes)

With the high luminosity upgrade of LHC, incorporating tracking information into the CMS Level-1 trigger becomes necessary in order to maintain a manageable trigger rate. The main challenges Level-1 track finding faces are the large data throughput from the detector at the collision rate of 40 MHz and 4 μ s time budget to reconstruct charged particle tracks with sufficiently low transverse momentum to be used in Level-1 trigger decision. Dedicated all-FPGA hardware systems with time-multiplexed architecture have been developed for track finding to deal with these challenges. The algorithm and performance of the pattern recognition and particle trajectory determination are discussed in this talk. The implementation on customized boards and commercially available FPGAs are presented as well.

Primary author: TAO, Zhengcheng (Cornell University (US))

Presenter: TAO, Zhengcheng (Cornell University (US))

Session Classification: Session2

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 20

Type: **Oral**

TrickTrack: An experiment-independent, cellular-automaton based track seeding library

Thursday, March 22, 2018 11:00 AM (25 minutes)

The design of next-generation particle accelerators evolves to higher and higher luminosities, as seen in the HL-LHC upgrade and the plans for the Future Circular Collider (FCC). Writing track reconstruction software that can cope in these high-pileup scenarios is a big challenge, due to the inherent complexity of current algorithmic approaches. In this contribution we present TrickTrack, a track reconstruction toolkit based on the hit-chain maker used for track seeding in the CMS experiment. It aims at solving pattern recognition problems efficiently in a concurrency-friendly implementation, while remaining general enough to be of use in most track detectors. The performance of TrickTrack in the FCC-hh design study is being presented as the first usecase beyond CMS, which features pileup rates of 1000 interactions per bunch crossing and a high-occupancy environment for tracking.

Primary authors: VOLKL, Valentin (University of Innsbruck (AT)); PANTALEO, Felice (CERN); HEGNER, Benedikt (CERN)

Presenters: VOLKL, Valentin (University of Innsbruck (AT)); PANTALEO, Felice (CERN)

Session Classification: Session5

Track Classification: 4: Performance evaluation

Contribution ID: 21

Type: **Poster**

Machine Learning When you Know (Basically) Nothing.

Tuesday, March 20, 2018 5:00 PM (15 minutes)

Machine learning in high energy physics relies heavily on simulation for fully supervised training. This often results in sub-optimal classification when ultimately applied to (unlabeled) data. At CTD2017, we showed how to avoid this problem by training directly on data using as input the fraction of signal and background in each training sample. We now have a new method that does not even require these fractions called Classification Without Labels (CWoLa). In addition to explaining this new method, we show for the first time how to apply these techniques to high-dimensional data, where significant architectural changes are required.

Primary authors: NACHMAN, Ben (Lawrence Berkeley National Lab. (US)); METHODIEV, Eric (Massachusetts Institute of Technology); KOMISKE, Patrick (Massachusetts Institute of Technology); RUBBO, Francesco (SLAC National Accelerator Laboratory (US)); SCHWARTZ, Matthew; THALER, Jesse; DERY, Lucio (Stanford University)

Presenter: NACHMAN, Ben (Lawrence Berkeley National Lab. (US))

Session Classification: Poster

Track Classification: 3: Machine learning approaches

Contribution ID: 22

Type: **Oral**

Splitting Strip Detector Clusters in Dense Environments

Wednesday, March 21, 2018 4:50 PM (15 minutes)

Tracking in high density environments, particularly in high energy jets, plays an important role in many physics analyses at the LHC. In such environments, there is significant degradation of track reconstruction performance. Between runs 1 and 2, ATLAS implemented an algorithm that splits pixel clusters originating from multiple charged particles, using charge information, resulting in the recovery of much of the lost efficiency. However, no attempt was made in prior work to split merged clusters in the Semi Conductor Tracker (SCT), which does not measure charge information. In spite of the lack of charge information in SCT, a cluster-splitting algorithm has been developed in this work. It is based primarily on the difference between the observed cluster width and the expected cluster width, which is derived from track incidence angle. The performance of this algorithm is found to be competitive with the existing pixel cluster splitting based on track information.

Primary authors: MCCORMACK, William (University of California Berkeley); GARCIA-SCIVERES, Maurice (Lawrence Berkeley National Lab. (US)); NACHMAN, Ben (Lawrence Berkeley National Lab. (US)); DANNINGER, Matthias; STYLES, Nick

Presenter: NACHMAN, Ben (Lawrence Berkeley National Lab. (US))

Session Classification: Young Scientist Forum

Track Classification: 5: Advanced usage of tracks

Contribution ID: 23

Type: **Oral**

Parallelized Kalman-Filter-Based Reconstruction of Particle Tracks with Accurate Detector Geometry

Wednesday, March 21, 2018 2:00 PM (25 minutes)

In the era of the High-Luminosity Large Hadron Collider (HL-LHC), one of the most computationally challenging problems is expected to be finding and fitting particle tracks during event reconstruction. The algorithms currently in use at the LHC are based on Kalman filter techniques, which are known to be robust and provide good physics performance. Given the need for improved computational performance, we explore Kalman-filter-based methods for track finding and fitting that are specially adapted for many-core SIMD and SIMT architectures, since processors of this type are becoming increasingly dominant in high-performance hardware.

For both track fitting and track building, our adapted Kalman filter software has obtained significant parallel speedups on Intel Xeon, Intel Xeon Phi, Intel Xeon, and (to a limited degree) NVIDIA GPUs. Results from our prior reports, however, were more focused on simulations of artificial events taking place inside an idealized barrel detector composed of concentric cylinders. In the current work, we shift focus to CMSSW-generated events taking place inside a geometrically accurate representation of the CMS-2017 tracker. To a large extent, the approaches that were previously developed for the idealized geometry have carried over to the more accurate case. For instance, groups of candidate tracks are still propagated to the average radius (or average axial distance) of the next detector layer; once the matching hits in that layer have been identified, candidate tracks are re-propagated to the exact hit locations and tested for viability. Special treatment is given to the overlap or transition region between barrel and endcaps, so that matching hits can be picked up from either area as required.

We summarize the key features of this software, including (1) the data structures and code constructs that facilitate vectorization and SIMT, and (2) the multiple levels of parallel loops that have been multithreaded using TBB. We demonstrate that, as compared to CMSSW, the present Kalman filter implementation is able to reconstruct events with comparable physics performance and generally better computational performance. The status of, and plans for, the software are discussed.

Primary authors: CERATI, Giuseppe (Fermi National Accelerator Lab. (US)); ELMER, Peter (Princeton University (US)); KRUTELYOV, Slava (Univ. of California San Diego (US)); LANTZ, Steven R (Cornell University (US)); LEFEBVRE, Matthieu (Princeton University (US)); MASCIOVECCHIO, Mario (Univ. of California San Diego (US)); MCDERMOTT, Kevin (Cornell University (US)); RILEY, Daniel Sherman (Cornell University (US)); TADEL, Matevz (Univ. of California San Diego (US)); WITTICH, Peter (Cornell University (US)); WUERHWEIN, Frank (Univ. of California San Diego (US)); YAGIL, Avi (Univ. of California San Diego (US))

Presenter: TADEL, Matevz (Univ. of California San Diego (US))

Session Classification: Session4

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 24

Type: **Poster**

A novel standalone track reconstruction algorithm for the LHCb upgrade

Tuesday, March 20, 2018 4:30 PM (15 minutes)

During the LHC Run III, starting in 2020, the instantaneous luminosity of LHCb will be increased up to $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$, five times larger than in Run II. The LHCb detector will then have to be upgraded in 2019. In fact, a full software event reconstruction will be performed at the full bunch crossing rate by the trigger, in order to profit of the higher instantaneous luminosity provided by the accelerator. In addition, all the tracking devices will be replaced and, in particular, a scintillating fiber tracker (SciFi) will be installed after the magnet, allowing to cope with the higher occupancy. The new running conditions, and the tighter timing constraints in the software trigger, represent a big challenge for the track reconstruction.

This talk presents the design and performance of a novel algorithm that has been developed to reconstruct track segments using solely hits from the SciFi. This algorithm is crucial for the reconstruction of tracks originating from long-lived particles such as K_S and Λ . The implementation strategy is based on a progressive cleaning of the tracking environment and on an active use of the information from the stereo hits in order to select tracks. It also profit from the definition of an improved track parameterization. When compared to its previous implementation, the new algorithm has significantly higher performances in terms of efficiency, number of fake tracks and timing, allowing to enhance the physics potential and capabilities of the LHCb upgrade.

Primary author: Mr QUAGLIANI, Renato (Centre National de la Recherche Scientifique (FR))

Co-author: DE CIAN, Michel (Ruprecht Karls Universitaet Heidelberg (DE))

Presenter: Mr QUAGLIANI, Renato (Centre National de la Recherche Scientifique (FR))

Session Classification: Poster

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 25

Type: **Poster**

Proton Track Reconstruction Inside a Digital Tracking Calorimeter for Proton CT

Tuesday, March 20, 2018 5:15 PM (15 minutes)

Background

Proton CT is a prototype imaging modality for the reconstruction of the Proton Stopping Power inside a patient for more accurate calculations of the dose distributions in proton therapy treatment dose planplanning systems. A prototype proton CT system, called the Digital Tracking Calorimeter (DTC) is currently under development where aluminum energy absorbers are sandwiched between ~40 MAPS-based pixel sensor layers.

The following measurements need to be performed in the DTC:

- The initial proton vector incident on the front face of the detector
- The stopping depth of each proton in the detector

These measurements necessarily require performing track identification and reconstruction inside the DTC. The track reconstruction will also allow disentangling a large number of protons thus contributing to increased rate capabilities of the DTC.

Methods

Methods

A DTC detector has been modeled using the GATE 7.2 Monte Carlo framework. A design having 3.5 mm aluminum absorbers has been suggested based on range accuracy requirements: The detector is modeled based on previous experience with track identification and reconstruction in similar prototypes, such as with the ALICE-FoCal experiment. A water phantom of variable thickness is used for degrading a 230 MeV proton beam to different energies.

Upon degradation by a water phantom, a proton beam of a up to a few thousands particles in a 100 cm^2 area and a mean energy of ~200 MeV is incident on the detector. In this regime, the proton tracks are heavily influenced by multiple Coulomb scattering. Each primary proton is tracked through the detector using a track-following approach, with a search cone depending on the expected scattering. A high quality tracking algorithm improves the detector characteristics in terms of contributing to increased rate capabilities, i.e. a higher incident beam intensity. The tracking quality is evaluated at various incident proton densities [$\text{protons} / \text{cm}^2$] by the fraction of tracks with correct endpoints. Quantitative evaluation is based on a comparison between the correctly identified and reconstructed proton tracks using the current algorithm and the true proton tracks from Monte Carlo simulations.

Results and conclusion

Preliminary results indicate that at $10 \text{ protons} / \text{cm}^2$ about 80% of the tracks are correctly identified and reconstructed, the remaining 20% are either “close misreconstructions” or protons that undergo large angle scatter and thus are are wrongly identified.

Primary authors: PETERSEN, Helge Egil Seime (University of Bergen (NO)); MERIC, Ilker (Western Norway University of Applied Sciences (NO)); Dr ODLAND, Odd Harald (Haukeland University Hospital); Mr SØLIE, Jarle Rambo (Western Norway University of Applied Sciences); ROHRICH, Dieter (Department of Physics & Technology-University of Bergen)

Presenter: PETTERSEN, Helge Egil Seime (University of Bergen (NO))

Session Classification: Poster

Track Classification: 4: Performance evaluation

Contribution ID: 26

Type: **Poster**

HL-LHC ATLAS Strip System Robustness

Tuesday, March 20, 2018 5:30 PM (15 minutes)

The High Luminosity LHC (HL-LHC) plans to increase the LHC dataset by an order of magnitude, increasing the potential for new physics discoveries. The HL-LHC upgrade, planned for 2025 will increase the peak luminosity to $7.5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$, corresponding to ~ 200 inelastic proton-proton collisions per beam crossing. To mitigate the increased radiation doses and pileup, the ATLAS Inner Detector will be replaced with an all-Silicon Inner Tracker made of Silicon Pixel and Strip systems. During the life-time of the HL-LHC, failures in the Strip system due to electronic and cooling failures and irradiation damage are expected. Estimating the effects of such failures is necessary to ensure the Strip system design is robust. In this poster the effects of the failures in the Strip system on the tracking performance are presented. With the planned ATLAS Strip system design the tracking efficiency, fake rates and resolutions are found to be robust to the anticipated failures.

Primary author: WOODS, Natasha Lee (University of California,Santa Cruz (US))

Presenters: WOODS, Natasha Lee (University of California,Santa Cruz (US)); Ms WOODS, Natasha (UCSC)

Session Classification: Poster

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 27

Type: **Poster**

Particle Flow and PUPPI in the Level-1 trigger at CMS for the HL-LHC

Tuesday, March 20, 2018 5:45 PM (15 minutes)

With the planned addition of the tracking information in the Level 1 trigger in CMS for the HL-LHC, the algorithms for Level 1 trigger can be completely reconceptualized. Following the example for offline reconstruction in CMS to use complementary subsystem information and mitigate pileup, we explore the feasibility of using Particle Flow-like and pileup per particle identification techniques at the hardware trigger level. This represents a new type of multi-subdetector pattern recognition challenge for the HL-LHC. We present proof-of-principle studies on both physics and resource usage performance of a prototype algorithm for use by CMS in the HL-LHC era.

Primary author: KREIS, Ben (Fermi National Accelerator Lab. (US))

Presenter: KREIS, Ben (Fermi National Accelerator Lab. (US))

Session Classification: Poster

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 28

Type: **Poster**

Uncertainty estimation of parameters with neural networks: Application to strong gravitational lensing

Recently we showed that deep learning can be used for model parameter estimation for strong gravitational lensing systems. Here we demonstrate a method for obtaining the uncertainties of these parameters. We use variational inference to obtain approximate posteriors of Bayesian neural networks and apply it to a network trained to estimate the parameters of the Singular Isothermal Ellipsoid plus external shear and total flux magnification. We show that the method can capture the uncertainties due to different levels of noise in the input data, as well as training and architecture-related errors made by the network. To evaluate the accuracy of the resulting uncertainties, we calculate the coverage probabilities of marginalized distributions for each lensing parameter. By tuning a single hyperparameter, the dropout rate, we obtain coverage probabilities approximately equal to the confidence levels for which they were calculated, resulting in accurate and precise uncertainty estimates. Our results suggest that neural networks can be a fast alternative to Monte Carlo Markov Chains for parameter uncertainty estimation in many practical applications, allowing more than seven orders of magnitude improvement in speed.

Primary author: Dr PERREAULT LEVASSEUR, Laurence (Stanford University)

Co-author: Dr HEZAVEH, Yashar (Stanford University)

Presenter: Dr PERREAULT LEVASSEUR, Laurence (Stanford University)

Session Classification: Poster

Track Classification: 6: Beyond the conventional tracking

Contribution ID: 29

Type: **Oral**

Machine Learning for transient noise event classification in LIGO and Virgo

Tuesday, March 20, 2018 10:00 AM (25 minutes)

Noise of non-astrophysical origin contaminates science data taken by the Advanced Laser Interferometer Gravitational-wave Observatory and Advanced Virgo gravitational-wave detectors. Characterization of instrumental and environmental noise transients has proven critical in identifying false positives in the first observing runs. Machine-Learning techniques have, in recent years, become more and more reliable and can be efficiently applied to our problems.

Different teams in LIGO/Virgo have applied machine-learning and deep-Learning methods to different aims, from control-lock acquisition, to GW-Signal detection, to noise-Event classification.

After a general introduction to the LIGO and Virgo detectors and the Data-Analysis framework, I will describe how machine learning methods are used in Transient-Signal classification. Following an introduction to the problem, I will go through the main algorithms and the technical solutions which we have efficiently used up to now and how we plan to develop the idea in the future.

Primary author: Dr CUOCO, Elena (EGO & INFN Pisa)

Presenters: CUOCO, Elena; CUOCO, Elena (INFN - National Institute for Nuclear Physics); Dr CUOCO, Elena (EGO & INFN Pisa)

Session Classification: Session1

Track Classification: 6: Beyond the conventional tracking

Contribution ID: 30

Type: **Oral**

First Steps Towards Four-Dimensional Tracking: Timing Layers at the HL-LHC

Tuesday, March 20, 2018 9:30 AM (25 minutes)

The projected proton beam intensity of the High Luminosity Large Hadron Collider (HL-LHC), slated to begin operation in 2026, will result in between 140 and 200 concurrent proton-proton interactions per 25 ns bunch crossing. The scientific program of the HL-LHC, which includes precision Higgs coupling measurements, measurements of vector boson scattering, and searches for new heavy or exotic particles, will benefit greatly from the enormous HL-LHC dataset. However, particle reconstruction and correct assignment to primary interaction vertices presents a formidable challenge to the LHC detectors that must be overcome in order to reap that benefit. Time tagging of minimum ionizing particles (MIPs) produced in LHC collisions with a resolution of 30 ps provides further discrimination of interaction vertices in the same 25 ns bunch crossing beyond spatial tracking algorithms. The Compact Muon Solenoid (CMS) and ATLAS Collaborations are pursuing in total two technologies to provide MIP time tagging for the HL-LHC detector upgrade: LYSO:Ce crystals read out by silicon photomultipliers (SiPMs) for low radiation areas (CMS only) and silicon low gain avalanche detectors (LGADs, CMS and ATLAS) for high radiation areas. This talk will motivate the need for a dedicated timing layer in the CMS and ATLAS upgrades, describe the two technologies and their performance, and present simulations showing the improvements in reconstructed observables afforded by four dimensional tracking.

Primary author: GRAY, Lindsey (Fermi National Accelerator Lab. (US))

Presenter: GRAY, Lindsey (Fermi National Accelerator Lab. (US))

Session Classification: Session1

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 31

Type: **Oral**

Developments in pileup suppression techniques at the LHC

Tuesday, March 20, 2018 9:00 AM (25 minutes)

The LHC accelerator is running at unprecedented high instantaneous luminosities, allowing the experiments to collect a vast amount of data. However this astonishing performance comes with a larger-than-designed number of interactions per crossing of proton bunches (pile-up). During 2017 values up to 60 interactions per bunch crossing were routinely achieved and capped by the ability of experiments to cope with such large occupancy. In the future an upgraded LHC accelerator (HL-LHC) is expected to routinely provide even larger instantaneous luminosities, with up to 200 interactions per bunch crossing. Disentangling the information from a single interesting proton-proton collision to the others happening in the same bunch crossing is of critical importance to retain high accuracy in physics measurements, and it is commonly referred to as pile-up suppression. In this talk I will review the main challenges and needs for pileup suppression at the LHC, mostly focusing on the ATLAS and CMS experiments; I will highlight the techniques used so far and what is planned in order to cope with the even larger pile-up expected at the HL-LHC.

Presenter: PAGAN GRISO, Simone (University of California Berkeley (US))

Session Classification: Session1

Contribution ID: 32

Type: **Oral**

Welcome

Tuesday, March 20, 2018 8:50 AM (10 minutes)

Presenter: HSU, Shih-Chieh (University of Washington Seattle (US))

Session Classification: Session1

Contribution ID: 33

Type: **Oral**

Fast Reconstruction and Data Scouting

Tuesday, March 20, 2018 11:00 AM (25 minutes)

Presenter: DUARTE, Javier Mauricio (Fermi National Accelerator Lab. (US))

Session Classification: Session1

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 34

Type: **Oral**

LHCB Trigger Upgrade

Tuesday, March 20, 2018 2:30 PM (25 minutes)

Presenter: QUAGLIANI, Renato (Centre National de la Recherche Scientifique (FR))

Session Classification: Session2

Track Classification: 2: Real-time pattern recognition and fast tracking

Contribution ID: 35

Type: **Oral**

Fast automated analysis of strong gravitational lenses with convolutional neural networks

Wednesday, March 21, 2018 9:00 AM (25 minutes)

Strong gravitational lensing is a phenomenon in which images of distant galaxies appear highly distorted due to the deflection of their light rays by the gravity of other intervening galaxies. We often see multiple distinct arc-shaped images of the background galaxy around the intervening (lens) galaxy, like images in a funhouse mirror. Strong lensing gives astrophysicist a unique opportunity to carry out different investigations, including mapping the detailed distribution of dark matter or measuring the expansion rate of the universe. All these studies, however, require a detailed knowledge of the distribution of matter in the lensing galaxies, measured from the distortions in the images. This has been traditionally performed with maximum-likelihood lens modeling, a procedure in which simulated observations are generated and compared to the data in a statistical way. The parameters controlling the simulations are then explored with samplers like MCMC. This is a time and resource consuming procedure, requiring hundreds of hours of computer and human time for a single system. In this talk, I will discuss our recent work in which we showed that deep convolutional neural networks can solve this problem more than 10 million times faster: about 0.01 seconds per system on a single GPU. I will also review our method for quantifying the uncertainties of the parameters obtained with these networks. With the advent of upcoming sky surveys such as the Large Synoptic Survey Telescope, we are anticipating the discovery of tens of thousands of new gravitational lenses. Neural networks can be an essential tool for the analysis of such high volumes of data.

Presenter: Dr HEZAVEH, Yashar (Stanford University)

Session Classification: Session3

Track Classification: 6: Beyond the conventional tracking

Contribution ID: 36

Type: **Oral**

Status and Challenges of Tracker Design for FCC-hh

Thursday, March 22, 2018 9:30 AM (25 minutes)

A 100 TeV proton collider represents a core aspect of the Future Circular Collider (FCC) study. An integral part of this project is the conceptual design of individual detector systems that can be operated under luminosities up to $3 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$. One of the key limitations in the design arises from an increased number of pile-up events $O(1000)$, making both particle tracking and identification of vertices extremely challenging. This talk reviews the general ideas that conceptually drive the current tracker/vertex detector design for the FCC-hh (proton-proton). These include material budget, detector granularity, pattern recognition, primary vertexing/pile-up mitigation and occupancy/data rates. Finally, the limits of current tracker technologies and requirements on their future progress, i.e. the dedicated R&D, will be briefly discussed.

Presenter: DRASAL, Zbynek (CERN)

Session Classification: Session5

Track Classification: 1: Algorithms and theoretical analysis

Contribution ID: 37

Type: **Oral**

ACTS Status

Thursday, March 22, 2018 11:30 AM (25 minutes)

Reconstructing charged particles trajectories is a central task in the reconstruction of most particle physics experiments. With increasing intensities and ever increasing track densities this combinatorial problem becomes increasingly challenging. Preserving physics performance in these difficult experimental conditions while at the same keeping the computational cost at a reasonable level, is a challenge for many experiments. A Common Tracking Software (ACTS) is an effort to bring a well-tested tracking software to modern compilers and computing architectures to allow easy computational optimization of existing algorithm as well as simple evaluation of new approaches. Based on the ATLAS tracking software, ACTS aims to provide a clean code base that is optimized for concurrent and vectorized execution. This talk will discuss the basic design decisions, its current status, and the future roadmap.

Presenter: KIEHN, Moritz (Universite de Geneve (CH))

Session Classification: Session5

Track Classification: 1: Algorithms and theoretical analysis

Contribution ID: 38

Type: **Oral**

HEP.TrkX: Novel deep learning methods for track reconstruction

Thursday, March 22, 2018 12:00 PM (25 minutes)

For the past year, the HEP.TrkX project has been investigating machine learning solutions to LHC particle track reconstruction problems. A variety of models were studied that drew inspiration from computer vision applications and operated on an image-like representation of tracking detector data. While these approaches have shown some promise, image-based methods face challenges in scaling up to realistic HL-LHC data due to high dimensionality and sparsity. In contrast, models that can operate on the spacepoint representation of track measurements (“hits”) can exploit the structure of the data to solve tasks efficiently.

In this presentation we will show two sets of new deep learning models for reconstructing tracks using spacepoint data arranged as sequences or connected graphs. In the first set of models, recurrent neural networks (RNNs) are used to extrapolate, build, and evaluate track candidates similar to Kalman Filter algorithms. Such models can express their own uncertainty when trained with an appropriate likelihood loss function. The second set of models use graph neural networks for the tasks of hit classification and segment classification. These models read a graph of connected hits and compute features on the nodes and edges. They adaptively learn which hit connections are important and which are spurious. The models are scaleable with simple architecture and relatively few parameters. Results for all models will be presented on ACTS generic detector simulated data.

Primary authors: CALAFIURA, Paolo (Lawrence Berkeley National Lab. (US)); Dr FARRELL, Steven Andrew (Lawrence Berkeley National Lab (US))

Presenter: Dr FARRELL, Steven Andrew (Lawrence Berkeley National Lab (US))

Session Classification: Session5

Track Classification: 3: Machine learning approaches

Contribution ID: 39

Type: **Oral**

Online Multi-target Tracking using Recurrent Neural Networks

Wednesday, March 21, 2018 11:00 AM (25 minutes)

We present a novel approach to online multi-target tracking based on recurrent neural networks (RNNs). Tracking multiple objects in real-world scenes involves many challenges, including a) an a-priori unknown and time-varying number of targets, b) a continuous state estimation of all present targets, and c) a discrete combinatorial problem of data association. Most previous methods involve complex models that require tedious tuning of parameters. Here, we propose for the first time, a full end-to-end learning approach for online multitarget tracking based on deep learning. Existing deep learning methods are not designed for the above challenges and cannot be trivially applied to the task. Our solution addresses all of the above points in a principled way. Experiments on both synthetic and real data show competitive results obtained at 300 Hz on a standard CPU, and pave the way towards future research in this direction.

Primary author: REZATOFIGHI, Hamid**Presenter:** REZATOFIGHI, Hamid**Session Classification:** Session3**Track Classification:** 2: Real-time pattern recognition and fast tracking

Contribution ID: 40

Type: **Oral**

Tracking Algorithms in the Belle II Drift Chamber with first pilot run results

Wednesday, March 21, 2018 3:00 PM (15 minutes)

Belle II - located at the e^+e^- collider SuperKEKB operating at the $\Upsilon(4S)$ energy - starts its first data taking run in February 2018.

Its ultimate goal is to measure with high precision multifaceted quantities in the flavor-sphere and explore the many opportunities beyond, e.g. exotic hadronic states, afforded by its record-breaking instantaneous luminosity of $8 \cdot 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$.

Belle II's tracking system consists of a DEPFET pixel device with very little material, a fast silicon strip detector, and a drift chamber of more than 2 meter diameter. Performing track finding in this heterogeneous environment at a high rate and with substantial beam background, demands specially designed and carefully implemented algorithms.

This talk will present the algorithms developed for the track finding in the central drift chamber of Belle II in detail. Additionally, first results of the performed pilot runs including tests with cosmic rays will be shown and the performance of the algorithms will be evaluated.

Presenters: BRAUN, Nils (KIT); BRAUN, Nils (KIT)

Session Classification: Session4

Track Classification: 1: Algorithms and theoretical analysis

Contribution ID: 41

Type: **Oral**

Belle II Tracking in Phase III with the Full Detector

Wednesday, March 21, 2018 3:20 PM (15 minutes)

Presenter: METZNER, Felix (Karlsruhe Institute of Technology)

Session Classification: Session4

Track Classification: 1: Algorithms and theoretical analysis

Contribution ID: 42

Type: **Poster**

COMET multi turn track fitting:

The reconstruction of multi-turn curling tracks on COMET Phase-I drift chamber is a challenge. A method of Deterministic Annealing Filter and implements a global competition between hits from different turn tracks is introduced. This method assigns the detector measurements to the track assumption based on the weighted mean of fitting quality on different turns. Studied have been done on the simulated tracks. We show that it can be a candidate to distinguish the hit turn.

Primary author: Ms ZHANG, Yao (Institute of High Energy Physics, CAS, China)

Co-author: Ms YUAN, Ye (Institute of High Energy Physics, CAS, China)

Presenter: Ms ZHANG, Yao (Institute of High Energy Physics, CAS, China)

Session Classification: Poster

Track Classification: 1: Algorithms and theoretical analysis

Contribution ID: 43

Type: **Poster**

BESIII low transverse momentum track finding based on Hough transform

In order to overcome the difficulty brought by the curling charged tracks in the BESIII drift chamber, we introduce the Hough transform based tracking method, which is used as a supplementary to find low transverse momentum tracks. This tracking algorithm is realized in the BESIII offline software system and its performance has been checked by both Monte Carlo and data. The results show that this tracking method could enhance the reconstruction efficiency at the low transverse momentum region.

Primary author: Prof. YUAN, Ye (Institute of High Energy Physics)

Presenter: Prof. YUAN, Ye (Institute of High Energy Physics)

Session Classification: Poster

Track Classification: 1: Algorithms and theoretical analysis

Contribution ID: 44

Type: **Poster**

Tracking Methods at CEPC Experiment

In the CDR study of the CEPC project, tracking algorithms and their performances are important task. For considering different design of tracker system, we are implementing corresponding tracking algorithms. Currently, we apply existing Clupatra as tracking for TPC, and also are exploiting ArborTracking at the same time. We attempt to use existing ConformalTracking as tracking for the design of full silicon-based tracker. The performances of these tracking algorithms for CEPC will be discussed.

Primary authors: FU, Chengdong (Institute of High Energy Physics, CAS); ZHAO, Mingrui (Tsinghua University); RUAN, Manqi (Institute of High Energy Physics, CAS); LI, Gang (Institute of High Energy Physics, CAS)

Presenter: FU, Chengdong (Institute of High Energy Physics, CAS)

Session Classification: Poster

Track Classification: 4: Performance evaluation

Contribution ID: 45

Type: **Oral**

Track Finding in the COMET Experiment using Boosted Decision Trees

Wednesday, March 21, 2018 5:30 PM (15 minutes)

The Coherent Muon to Electron Transition (COMET) experiment is designed to search for muon to electron conversion, a process which has very good sensitivity to Beyond the Standard Model physics. The first phase of the experiment is currently under construction at J-PARC. This phase is designed to probe muon to electron conversion 100 times better than the current limit. The experiment will achieve this sensitivity by directing a high intensity muon beam at a stopping target. The detectors probe the resulting events for the signal 105 MeV electron from muon to electron conversion.

A boosted decision tree (BDT) algorithm has been developed to find this signal track. This BDT is used to combine energy deposition and timing information with a reweighted inverse hough transform to filter out background hits. The resulting hits are fit using a RANdom SAMple Consensus (RANSAC) fit, which chooses the best fit parameters for an optimized selection of the filtered hits.

These hits are then passed to the track fitting algorithm. Results show that using a BDT significantly improves in background hit rejection when compared to traditional, cut-based hit rejection methods. At 99% signal hit retention, a cut on the energy deposition is able to remove 65% of background hits. By combining more multiple features, the BDT is able to remove 98% of background hits while still retaining 99% of signal hits.

Primary authors: GILLIES, Ewen (Imperial College London); ROGOZHNIKOV, Aleksei (Yandex School of Data Analysis (RU))

Presenter: GILLIES, Ewen (Imperial College London)

Session Classification: Young Scientist Forum

Track Classification: 3: Machine learning approaches

Contribution ID: 46

Type: **not specified**

Ultimate position resolution of pixel clusters with binary readout for particle tracking

Tuesday, March 20, 2018 6:00 PM (20 minutes)

Silicon tracking detectors can record the charge in each channel (analog or digitized) or have only binary readout (hit or no hit). While there is significant literature on the position resolution obtained from interpolation of charge measurements, a comprehensive study of the resolution obtainable with binary readout is lacking. It is commonly assumed that the binary resolution is $\text{pitch}/\sqrt{12}$, but this is generally a worst case upper limit. In this paper we study, using simulation, the best achievable resolution for minimum ionizing particles in binary readout pixels. A wide range of incident angles and pixel sizes are simulated with a standalone code, using the Bichsel model for charge deposition. The results show how the resolution depends on angles and sensor geometry. Until the pixel pitch becomes so small as to be comparable to the distance between energy deposits in silicon, the resolution is always better, and in some cases much better, than $\text{pitch}/\sqrt{12}$

Primary authors: NACHMAN, Ben (Lawrence Berkeley National Lab. (US)); WANG, Fuyue (Lawrence Berkeley National Lab. (US)); GARCIA-SCIVERES, Maurice (Lawrence Berkeley National Lab. (US))

Presenter: GARCIA-SCIVERES, Maurice (Lawrence Berkeley National Lab. (US))

Session Classification: Poster

Track Classification: 4: Performance evaluation

Contribution ID: 47

Type: **not specified**

Optimal use of Charge Information for the HL-LHC Pixel Detector Readout

Tuesday, March 20, 2018 6:20 PM (20 minutes)

The pixel detectors for the High Luminosity upgrades of the ATLAS and CMS detectors will preserve digitized charge information in spite of extremely high hit rates. Both circuit physical size and output bandwidth will limit the number of bits to which charge can be digitized and stored. We therefore study the effect of the number of bits used for digitization and storage on single and multi-particle cluster resolution, efficiency, classification, and particle identification. We show how performance degrades as fewer bits are used to digitize and to store charge. We find that with limited charge information (4 bits), one can achieve near optimal performance on a variety of tasks.

Primary authors: NACHMAN, Ben (Lawrence Berkeley National Lab. (US)); FRANGIPANE, Evan Dante (University of California Berkeley (US)); WANG, Fuyue (Lawrence Berkeley National Lab. (US)); JEANTY, Laura (University of California Berkeley (US)); GARCIA-SCIVERES, Maurice (Lawrence Berkeley National Lab. (US)); PAGAN GRISO, Simone (University of California Berkeley (US)); CHEN, Yitian

Presenter: GARCIA-SCIVERES, Maurice (Lawrence Berkeley National Lab. (US))

Session Classification: Poster

Track Classification: 4: Performance evaluation

Contribution ID: 48

Type: **Poster**

Splitting Strip Detector Clusters in Dense Environments

Tuesday, March 20, 2018 6:40 PM (20 minutes)

Tracking in high density environments, particularly in high energy jets, plays an important role in many physics analyses at the LHC. In such environments, there is significant degradation of track reconstruction performance. Between runs 1 and 2, ATLAS implemented an algorithm that splits pixel clusters originating from multiple charged particles, using charge information, resulting in the recovery of much of the lost efficiency. However, no attempt was made in prior work to split merged clusters in the Semi Conductor Tracker (SCT), which does not measure charge information. In spite of the lack of charge information in SCT, a cluster-splitting algorithm has been developed in this work. It is based primarily on the difference between the observed cluster width and the expected cluster width, which is derived from track incidence angle. The performance of this algorithm is found to be competitive with the existing pixel cluster splitting based on track information.

Presenter: MCCORMACK, William Patrick (University of California Berkeley (US))

Session Classification: Poster

Track Classification: 5: Advanced usage of tracks

Contribution ID: 49

Type: **not specified**

Final remark

Thursday, March 22, 2018 12:50 PM (10 minutes)

Presenter: HSU, Shih-Chieh (University of Washington Seattle (US))

Session Classification: Session5

Contribution ID: 50

Type: **not specified**

TrackML Hackathon results

Thursday, March 22, 2018 12:30 PM (20 minutes)

Presenter: ROUSSEAU, David (LAL-Orsay, FR)

Session Classification: Session5