US LUA annual meeting

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SLAC

Book of Abstracts

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Heavy-Flavour Jet Tagging Using Graph Neural Networks at LHCb

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Event reconstruction and particle analyses in high-energy physics (HEP) rely on effective jet-flavour tagging. This presentation introduces a novel b-jet classification method using Graph Neural Networks (GNNs), which are adept at capturing complex relationships in graph-structured data. This is the first application of a GNN b-jet tagger at LHCb, aimed to enhance jet flavour-tagging through deep learning. The GNN leverages the particle identification (PID) capabilities of the LHCb detector to improve performance of the classifier. Fully-connected graphs are constructed using daughter particle information as nodes, with jet kinematics at the global level. This GNN framework is intended for further expansion with different jet architectures, allowing for more diverse applications of jet flavour-tagging.

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Automating ATLAS control room anomaly detection with deep learning

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To ensure high-quality data acquisition at ATLAS, the detector status is monitored by a team of shifters in the control room where they watch plots of the incoming data and compare them with the expected standards. We propose the use of an online anomaly detection model to facilitate the detection of issues during data-taking and decrease the workload of the control room staff. Our model is a predictive long short-term memory autoencoder that takes in time-series data on a range of Level-1 rates and instantaneous luminosity and then, via unsupervised learning, learns to predict how those rates will change such that the level of error between the prediction and real data can be used to classify the data as clean or anomalous. We show that our model effectively detects anomalies in all features and that such an approach shows promise for online use in the control room. This model can easily be adapted to run in real-time, alerting shifters to potential anomalies as the data comes in.

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Anomaly Detection and Stability Measurements with the CMS Pixel Luminosity Telescope

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Data from the pixel luminosity telescope (PLT) for CMS needs to be cleaned thoroughly before being submitted for final integrated luminosity calculations for Run 3 data. Cleaning this data by hand is quite labor intensive, however very important to do so. In this talk I will discuss the anomaly detection algorithm I crafted to flag a variety of "anomalies" in the data - data points that need to be removed due to various errors in the detector. The algorithm is based on an unsupervised learning package but doesn't utilize machine learning; as such, it doesn't require training and can be implemented almost immediately on other luminosity based detectors (with additional tuning of the model). The talk will discuss future endeavors with utilizing the model and plans to implement it in real time.

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Transformer networks for constituent-based b-jet calibration with the ATLAS detector

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The precise measurement of kinematic features of jets is key to the physics program of the LHC. The determination of the energy and mass of jets containing bottom quarks (b-jets) is particularly difficult given their distinct radiation patterns and production of undetectable neutrinos via leptonic heavy flavor decays. This talk will describe a novel calibration technique for the b-jet kinematics using transformer-based neural networks trained on simulation samples. Separate simulation-based regression methods have been developed to estimate the transverse momentum of small-radius jets and the transverse momentum and mass of large-radius jets. These algorithms improve the mass resolution of heavy particle decays to b-jets by 30% (15%) in resolved (boosted) decays. The talk will finish with an outlook of the calibration strategy.

Lightning Round Talks / **26**

Harnessing Anomaly Detection Tools as Novel Analysis Resources for High Energy Physics

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In the realm of High-Energy Physics (HEP), the quest for new physics phenomena demands innovative approaches to data analysis. Anomaly detection (AD) tools, traditionally employed in fields such as cybersecurity and industrial quality control, are emerging as potent resources for uncovering rare and unexpected signals amidst vast datasets generated by particle colliders. By leveraging machine learning algorithms, statistical methods, and advanced data preprocessing techniques, anomaly detection tools offer a promising avenue for identifying elusive signals of new physics beyond the Standard Model. Notably, one distinct advantage of AD tools is their model independence, enabling the exploration of signals not constrained by any theoretical framework.
This study delves into the transformative potential of anomaly detection tools as innovative analytical resources within the domain of HEP. Through a detailed case study utilizing auto-encoders for

a Run-2 physics analysis conducted with ATLAS data, we aim to showcase the efficacy and versatility of AD tools in uncovering novel physics phenomena. Additionally, we examine the potential benefits and challenges associated with these approaches.

Lightning Round Talks / **27**

The BEST Searches for Vector Like Quarks at CMS

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The Boosted Event Shape Tagger is a multi-class jet tagger optimized for the diverse final states inherent to all-hadronic decays of Vector-Like Quarks. Its architecture is a simple DNN whose discriminating power benefits from physics-driven observables calculated in the lab frame, but also in a series of Lorentz-boosted frames aiming to provide the network with over/rest/under-boosted frame information. The tagger is applied to a search for pair-produced Vector-Like Quarks, each which decay to a third-generation quark and a massive boson, for T- and B-like interpretations in the all hadronic channel.

Lightning Round Talks / **28**

Using Unsupervised Machine Learning to Rediscover Standard Model Physics at CMS

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Despite extensive search efforts at the LHC, no clear evidence of physics beyond the Standard Model (BSM) has emerged. This raises the possibility that either new physics lies beyond the LHC's reach or we are not searching in the right places. The CMS Level-1 Trigger (L1T) serves as the first step in selecting events for further analysis. If L1T algorithms fail to select events containing new physics, that data will never be analyzed. The CMS experiment has recently implemented CICADA, a novel L1T algorithm that uses machine learning-based anomaly detection to identify and store atypical events based on calorimeter deposit patterns. Any physics process—Standard Model or BSM—with a detector signature that differs from the majority of LHC events can be flagged by CICADA. We present the first studies using CICADA to analyze CMS Run 3 data. As a case study, we focus on top-antitop quark pair production—a Standard Model process that is relatively rare at the LHC which can register as anomalous to the CICADA algorithm. We demonstrate how CICADA can be used to select for this process from QCD background. By showing how an unsupervised trigger can rediscover known phenomena, we highlight CICADA's potential to uncover unknown physics.

Lightning Round Talks / **29**

Integration Testing of the Global Common Modules for the ATLAS Global Trigger

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ATLAS is expected to receive 10 times the integrated luminosity from the High-Luminosity Large Hadron Collider (HL-LHC) than the previous three LHC runs combined, with approximately 200 interactions per bunch crossing, leading to significant pileup. The ATLAS Trigger and Data Acquisition system is undergoing significant upgrades to manage this pileup increase. As a part of these upgrades, the planned Global Trigger system will implement offline-inspired algorithms on full-granularity calorimeter information distributed by a series of time multiplexers (MUX) at 40 MHz.
GEP and MUX nodes are housed on Field Programmable Gate Arrays (FPGA). The Global Trigger design will be realized through a common hardware module, the Global Common Module (GCM). Each GCM will contain two FPGAs, one for a MUX and a GEP, with roughly 60 GCMs planned in total. Time multiplexing and inter-GCM communication are challenging to synchronize at this scale, and require a tiered approach to testing. Integration and production tests on GCMs are being conducted at Brookhaven National Lab, and testing will continue on a "slice"of 5 GCMs next year. This presentation will focus on the current software package for these tasks, the general status of the GCM testing, as well as progress on MUX firmware testing.

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Standalone Barrel Electron/Photon Reconstruction Performance in the CMS Level-1 Phase-2 Calorimeter Trigger

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To mitigate high pileup conditions in the High-Luminosity Large Hadron Collider (HL-LHC), the Phase-2 upgrade to the Compact Muon Solenoid (CMS) detector will make use of tracking and high-granularity calorimeter information for the first time at the Level-1 Trigger. We focus on the barrel region ($|\eta| < 1.5$) of the electromagnetic calorimeter (ECAL) where the granularity of the ECAL barrel trigger and electronics systems will increase by a factor of 25 compared to the Phase-1 calorimeter trigger. The upgraded calorimeter trigger object reconstruction algorithms for electrons (e) and photons (γ) are emulated using realistic firmware implementation on the VU9P Xilinx FPGA board. We present an overview of the performance of these reconstruction algorithms obtained from firmware emulation using simulated HL-LHC Monte Carlo samples. The Level-1 Trigger reconstruction efficiencies of e/γ objects as a function of generator-level transverse momentum reach 99% while maintaining expected rates in a scenario with 200 average pileup interactions.

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Glue, Cracking, and Interposers: The ATLAS Inner Tracker Upgrade

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The ATLAS Inner Tracker upgrade (ITk) is a silicon detector that will replace the existing Inner Detector in preparation for the HL-LHC. The subsystem of the ITk that I will be discussing is the ITk strips (more specifically ITk strips barrel) and the difficulties that have appeared in the past year

of attempted production, such as module cracking. The ITk strips barrel subsystem is comprised of a concentric multilayered barrel structure. This is then further comprised of 392 mounted staves (long carbon fiber mounting boards that supply power, readout, and cooling to each sensor). Each stave houses 28, 97x97mm, 75.5 um pitch strip silicon detectors, or modules, which are mounted via conductive adhesive, SE4445. Over the past year, module cracking had been noticed to appear in some modules, noted initially as High Voltage Breakdown, but later discovered to be a result of physical strain on the module during thermal cycling due to the differing Thermal Expansion Coefficients (CTE values) between the silicon and the power board/hybrid data readout chips. In this lightning talk, I will discuss the R&D that has gone into resolving module cracking and the interposer solution that provides a transition between the CTE mismatch of the sensor and mounted circuit boards.

Lightning Round Talks / 32

Real-time analysis in HLT1 at LHCb in Run 3

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The LHCb upgrade achieved for Run 3 includes a groundbreaking entirely software-based trigger. The removal of the hardware trigger is not only a significant technical advancement, but also enables substantial improvements in physics sensitivity. This presentation focuses on the performance of the first stage of the real-time analysis system (HLT1) running on GPUs. The flexibility provided by the software trigger has enabled the implementation of algorithms beyond the original Technical Design Report goals, opening possibilities for novel analyses previously unattainable at LHCb. Additionally, the talk will cover real-time alignment and calibration procedures, the monitoring implementation, and machine learning models in use within HLT1.

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eFPGA-based ML Implementation on Future Collider Detector Readout

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Next generation high energy physics experiments face challenges with high data rates and stringent hardware constraints, driving the need for resources-efficient on-detector readout processing solutions. This work explores the novel application of embedded field programmable gate arrays (eFPGA) technology in detector readout systems. Leveraging eFPGA's unique combination of FPGA's reconfigurability and ASIC's low power consumption, we successfully implemented a proof-of-concept boosted decision tree (BDT) classifier for pileup track rejection and validated designs on 28nm CMOS chip using the open-source FABulous framework. Our eFPGA implementation achieved perfect reproduction of the BDT algorithm, demonstrating its viability for HEP applications. In parallel, variational autoencoder models were developed for data compression and real-time sensor defect monitoring, showing promise for reducing off-detector data rates at ultra low latency. These efforts advance ML inference in detector subsystems, with our eFPGA implementation providing a promising pathway for integrating ML algorithms in future collider subsystems.

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Studies into di-Tau mass reconstruction for high mass resonances at the ATLAS experiment

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Waveform Sampling for Future Detector Timing Layers

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Detectors in HL-LHC and future colliders such as the FCC will be subjected to large amounts of pileup due to increases in luminosity over LHC run 2. Disentangling pileup is critical for proper event reconstruction, thus the need arises for detectors with fine spatial granularity and picosecond level timing information. Both in-time pileup (multiple MIPs hitting the same cell during the same bunch crossing) and out-of-time pileup (the signal of one MIP distorted from a different MIP in the previous bunch crossing) will occur in the LHCb PicoCal intended for Upgrade 2. Therefore, a proposed timing layer that would give the PicoCal 5-D tracking capabilities is actively being investigated. Waveform sampling architectures facilitate novel feature extraction techniques, including digital constant fraction discrimination, curve fitting, and machine learning algorithms. In addition, ps timing will permit effective use of time-of-flight techniques for low momentum hadron identification. This talk will focus on novel approaches to time-stamp determination with waveform sampling electronics, applicable for HL-LHC 4D trackers, 5D calorimeters or TOF measurements at future colliders.

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Studies into di-Tau mass reconstruction for high mass resonances at the ATLAS experiment

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The invariant mass of particle resonances is a key analysis variable for LHC physics. For analyses with di-tau final states, the direct calculation of the invariant mass is impossible because tau decays always include neutrinos, which escape detection in LHC detectors. The Missing Mass Calculator (MMC) is an algorithm used by the ATLAS Experiment to calculate the invariant mass of resonances decaying to two tau particles. The MMC solves the system of kinematic equations involving the tau visible decay products by minimizing a likelihood function, making use of the tau mass constraint

and probability distributions from Z → ττ decays. Because the algorithm uses Z decays it is most accurate in the Z mass range. This presentation will show that for high mass BSM resonances the MMC mass increasingly deviates from the true value, warranting further studies and the search for solutions to this discrepancy. We will show studies into machine learning solutions to di-tau mass reconstruction, aimed at providing improved accuracy for high-mass resonances. The specific use case is the search for X → SH → bbττ, sensitive to the Two-real-scalar-singlet extension to the Standard Model (TRSM), in which the Standard Model scalar sector is extended by two scalar singlets, labeled as X and S.

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Primary Vertex identification using deep learning in the ATLAS Experiment

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The reconstruction of primary vertices will become significantly more challenging with the High Luminosity Large Hadron Collider (HL-LHC) upgrade, as the number of simultaneous collisions, or pileup, is expected to reach up to $<\mu>= 200$. This high pileup places substantial computational demands on conventional combinatorics-based algorithms, resulting in significantly increased latency and reduced accuracy. Machine learning offers a scalable and efficient alternative to address these challenges. This talk presents PV-Finder, a deep learning-based algorithm that uses reconstructed track parameters to directly predict primary vertex locations. The algorithm transforms track data into dense one-dimensional probability distributions, also referred to as kernel density estimations (KDEs), using a deep neural network. These KDEs serve as inputs to a convolutional neural network (CNN) to predict vertex position. We evaluate the performance of PV-Finder under Run 3 conditions ($<\mu>= 60$) and benchmark it against other reconstruction algorithms, including the adaptive multi-vertex finder (AVMF) and earlier PV-Finder iterations. The results demonstrate its potential to improve vertex reconstruction efficiency and accuracy in high-pileup environments.

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Search for $t\bar{t}HH$ production at CMS Run 2 with each Higgs boson decaying to a b-quark pair

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Precision measurements of Higgs boson couplings to Standard Model (SM) particles remain a central focus at the LHC and the upcoming HL-LHC. In particular, the interaction between the Higgs boson and the top quark is particularly compelling due to the large $\sim O$(nb) $t\bar{t}$ cross section and $O(1)$ top-quark Yukawa coupling. The $t\bar{t}HH$ process offers a unique opportunity to probe the top-quark Yukawa coupling while enabling a direct measurement of the Higgs boson's trilinear self-coupling. This analysis searches for SM $t\bar{t}HH$ production with the CMS detector, focusing on single-lepton and di-lepton decays of the top-quark pair and Higgs decay to b-quarks using full Run 2 data. Advanced machine learning techniques are employed for event reconstruction and classification to enhance sensitivity.

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A journey through module quality control of the ATLAS Inner Tracker pixel upgrade

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In the high-luminosity era of the Large Hadron Collider (HL-LHC), the instantaneous luminosity will reach unprecedented levels, with up to 200 proton-proton interactions in a typical bunch crossing. To meet the challenges posed by the HL-LHC environment, the ATLAS Inner Detector will be replaced with an all-silicon system known as the Inner Tracker (ITk). The innermost part of the ITk will consist of a pixel detector, composed of approximately 10,000 pixel modules covering a combined active area of 13 m². Each of these pixel modules will undergo a rigorous electrical quality control (QC) testing procedure to ensure they meet the required electrical specifications for optimal performance in the final detector. Ensuring uniformity of electrical tests across 25 different testing sites and consistency across multiple testing stages is of utmost importance. This talk will present the specially designed tools developed to address these challenges, as well as the lessons learned so far during module preproduction.

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Search for millicharged particles with the MilliQan experiment using Run 3 data

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The milliQan experiment searches for milli-charged particles, with electric charge O(10^{-3})e or less, produced in pp collisions at the LHC. The milliQan bar detector has collected ~141 fb^{-1} of data during LHC Run 3 and this presentation will focus on the detector performance, study of beam muons to calibrate the detector and the search strategy. The talk will also focus on the newly constructed milliQan slab detector which provides complimentary phase space coverage to the bar detector, especially at high masses. The focus of the talk will be on the powerful impact of small scale AGILE experiments on the search for beyond standard model physics.

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Performance and production of the COLUTA ADC ASCI for the ATLAS HL-LHC Liquid Argon Calorimeter

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To handle the intense radiation at the High-Luminosity LHC, the ATLAS Liquid Argon Calorimeter readout electronics are being upgraded. The includes the production of custom ASICs, including the COLUTA chip—an 8-channel, 15-bit, 40 MSPS ADC.
The ADC meets and exceeds the specifications for the analog performance and the HL-LHC radiation tolerance. With 80,000 chips needed, robotic test stands are performing quality control, with performance metrics stored locally and in a centralized database. Updates on chip performance, radiation testing, robotic systems, and production yields will be presented.

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GPU-Accelerated Particle Tracking as-a-Service

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Particle tracking at Large Hadron Collider (LHC) experiments is a crucial component of particle reconstruction, yet it remains one of the most computationally challenging tasks in this process. As we approach the High-Luminosity LHC era, the complexity of tracking is expected to increase significantly. Leveraging coprocessors such as GPUs presents a promising solution to the rising computational demands. The traccc project is a tracking demonstrator under A Common Tracking Software (ACTS) designed to harness GPU resources for tracking. Despite promising initial results, the deployment of GPU algorithms such as traccc in production chains remains a significant challenge. In this talk, we present an as-a-service (aaS) approach to address these deployment challenges. A dedicated backend written to efficiently manage multiple concurrent requests from the server and load multiple model instances onto a dedicated GPU server is presented. Our results demonstrate increased resource utilization and a significant improvement in throughput compared to standalone traccc implementations with the open data detector.

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A foundational model for particle physics discovery

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Bumblebee is a foundation model for particle physics discovery, inspired by BERT. By removing positional encodings and embedding particle 4-vectors, Bumblebee captures both generator- and reconstruction-level information while ensuring sequence-order invariance. Pre-trained on a masked task, it improves dileptonic top quark reconstruction resolution by 10-20% and excels in downstream tasks, including toponium discrimination (AUROC 0.877) and initial state classification (AUROC 0.625). The flexibility of Bumblebee makes it suitable for a wide range of particle physics applications, especially the discovery of new particles.

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Updated measurement prospects for di-Higgs production in the $HH \rightarrow bb\gamma\gamma$ channel with the ATLAS experiment at the HL-LHC

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We present an updated prospect study on di-Higgs production in the $HH \rightarrow bb\gamma\gamma$ decay channel with the ATLAS experiment at the High Luminosity LHC (HL-LHC). The latest projections are based on extrapolating the recent legacy Run 2 ATLAS search and improve over the previous results shown at Snowmass 2022. We describe in detail the extrapolation process and assumptions, and multiple scenarios for the treatment of systematic uncertainties at the HL-LHC are considered.

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Diversity & Inclusion Initiatives by the LHC Experiments

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