CHIPP 2024 Annual meeting

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Uni Mail - University of Geneva

Book of Abstracts

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Machine learning Workshop report

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Machine Learning in b -> s ll

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Short-distance (SD) effects in $b \to sl^+l^-$ transitions can give large corrections to the Standard Model prediction. They can however not be computed from first principles. In my talk I will present a neural network, that takes such SD effects into account, when inferring the Wilson coefficients C_9 and C_{10} from $b \to sl^+l^-$ angular observables. The model is based on likelihood-free inference and allows to put stronger bounds on new phyiscs scenarios than conventional global fits.

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Towards an AI-based trigger system for the next-generation of imaging atmospheric Cherenkov telescope cameras

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Imaging atmospheric Cherenkov telescopes (IACTs) observe extended air showers (EASs) initiated by the interaction of very-high-energy gamma rays and cosmic rays with the atmosphere. Cherenkov photons induced by a given shower are focused onto the camera plane of the telescopes resulting into a spatial and temporal charge development in the camera pixels. Besides the Cherenkov light emitted by the EAS arriving within a few nanoseconds (depending on their primary energy, zenith angle, and distance from the telescope), the IACT cameras continuously record light from the night sky background (NSB), which is mainly composed of atmospheric star, moonlight scattering, galactic diffuse emission and other manmade sources of light. To ensure optimal data-taking under diverse observational conditions (zenith angle, moon phase, quality of the atmosphere,…), the trigger and data acquisition system of IACT cameras is designed to reduce the noise induced by the fluctuations of the NSB as well as the electronic noise of the photodetectors from the short Cherenkov light flashes as much as possible by carrying out an on-the-fly event selection process. In this contribution, we present some prospective studies for an application of an Artificial Intelligence (AI)-based trigger system for the next-generation of IACT cameras using the software package CTLearn. As a high-level step of the novel trigger system, we show that gamma/hadron separation could be performed at trigger-level to distinguish gamma-like events from hadronic showers initiated by cosmic rays, which is the dominant background for IACTs.

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Masked particle modelling

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The Bert pretraining paradigm has proven to be highly effective in many domains including natural language processing, image processing and biology. To apply the Bert paradigm the data needs to be described as a set of tokens, and each token needs to be labelled. To date the Bert paradigm has not been explored in the context of HEP. The samples that form the data used in HEP can be described as a set of particles (tokens) where each particle is represented as a continuous vector. We explore different approaches for discretising/labelling particles such that the Bert pretraining can be performed and demonstrate the utility of the resulting pretrained models on common downstream HEP tasks.

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Model agnostic searches in High Energy and Astrophysics with CURTAINs

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We present CURTAINs, a fully data driven paradigm that improves on the weakly supervised searches. CURTAINs is designed to be sensitive to small density perturbations in n-dimensional feature space caused by the presence of signals. CURTAINs can be shown to be very robust in the absence of any signals, and yet be highly sensitive to signals even at very low signal to background ratios.

Originally designed for new physics searches in High Energy Physics, we also show applications in astrophysics, where certain searches can be cast as overdensity estimation. Particularly, searches for stellar streams in the Milky Way can be improved significantly with data driven and model agnostic searches such as CURTAINs.

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Machine Learning Techniques to Probe HNLs at the FCC-ee

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In place of traditional cut and count methods, machine learning techniques offer powerful ways to optimise our searches for new physics. At the FCC-ee, we will probe the highest intensities and energies ever seen at a lepton collider, opening the possibly for discovery of massive right-handed neutrino states. In this work, existing searches for HNLs at the FCC-ee are optimised using a BDT and a DNN. We report an increase in the sensitivity of the considered parameter space by as much as two orders of magnitude in the couplings.

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Deep Learning-Based Data Processing in Large-Sized Telescopes of the Cherenkov Telescope Array: FPGA Implementation

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The Large-Sized Telescope (LST) is one of three telescope types being built as part of the Cherenkov Telescope Array Observatory (CTAO) to cover the lower energy range between 20 GeV and 200 GeV. The Large-Sized Telescope prototype (LST-1), installed at the La Palma Observatory Roque de Los Muchachos, is currently being commissioned and has successfully taken data since November 2019. The construction of three more LSTs at La Palma is underway. A next generation camera that can be used in future LSTs is being designed. One of the main challenges for the advanced camera is the 1GHz sampling rate baseline that produces 72 Tbps of data. After filtering events resulting from random coincidences of background light sources (night sky background, star light, sensor noise), the data rate must be brought down to 24 Gbps, corresponding to an event rate of about 30 kHz. At this stage, a software stereo trigger featuring deep learning inference running on a high-speed FPGA will lower the final event rate to < 10 kHz.

To achieve such a large reduction, several trigger levels are being designed and will be implemented in FPGA. The final trigger stage is a real-time deep learning algorithm currently under development. In this talk, we will focus on porting this algorithm to FPGAs using two different approaches: the Intel AI Suite and the hls4ml packages.

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Active deep learning for single-particle beam dynamics studies

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The dynamic aperture is defined as the region of phase space where the particle motion in circular particle accelerators remains bounded over a fixed and large number of turns. Understanding the key features of this concept offers insight into non-linear beam dynamics and factors affecting beam lifetime in accelerators, which are pivotal for the operation of machines like the CERN Large Hadron Collider (LHC) and the design of future ones, such as the Future Circular Collider (FCC). However, dynamic aperture calculation conventionally involves computationally intensive numerical simulations that track large sets of initial conditions distributed in phase space over multiple turns around the accelerator circumference. This study aims to identify an optimal accelerator parameter set that includes, e.g. betatron tunes, chromaticities, and Landau octupole strengths, which improves the dynamic aperture. This goal is achieved by using a deep neural network model that predicts the dynamic aperture limits using LHC data from numerical simulations. To enhance its performance, we have integrated this model into an innovative Active Learning framework. This framework not only facilitates the retraining and updating of the model but also enables efficient data generation through intelligent sampling.
The framework includes error estimation for predictions and interfaces with traditional simulation tools to correct high errors, improving the model by retraining with the new data.
The results obtained so far demonstrate that the Active Learning framework enables rapid scanning of LHC ring configuration parameters while maintaining the accuracy of dynamic aperture calculations, thereby improving the global efficiency of the non-linear beam dynamics simulations for circular particle accelerators.

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Machine Learning Methods to search for a scalar partner of the top quark in all-hadronic tt-MET final states with the ATLAS detector

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The ongoing Run-3 at the LHC is providing proton-proton collision data at the record energy of 13.6 TeV and, as of May 2024, a total integrated luminosity of almost 90 fb^-1 has been recorded by the ATLAS detector. This contribution presents preliminary results on the search for the pair production of stop squarks, the scalar supersymmetric partner of the top quark, based on the Run-2 and Run-3 data collected by the ATLAS detector, specifically focusing on the machine learning (ML) techniques that are being employed to boost the discovery potential. The main challenge that ML helps to tackle is the matching of the top decay products to the correct parent particle. A preliminary comparison between a basic feed-forward classifier for top reconstruction and a SPANet/Topograph-like architecture will be presented and finally the idea of an end-to-end classifier to discriminate between signal and background will be outlined.

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PIPPIN: Generating variable length full events from partons

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We present a novel approach for directly generating full events at detector-level from parton-level information, leveraging cutting-edge machine learning techniques. To address the challenge of multiplicity variations between parton and reconstructed object spaces, we employ transformers, score-based models and normalizing flows. Our method tackles the inherent complexities of the stochastic transition between these two spaces and achieves remarkably accurate results. This research contributes to the ongoing efforts in high-energy physics and generative modelling, providing a promising avenue for enhanced precision in fast detector simulation. The combination of innovative techniques and the achieved accuracy highlights the potential of our approach in advancing the field and opens avenues for further exploration.

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Unsupervised tagging of semivisible jets with normalized autoencoders in CMS

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A particularly interesting application of autoencoders (AE) for High Energy Physics is their use as anomaly detection (AD) algorithms to perform a signal-agnostic search for new physics. This is achieved by training AEs on standard model physics and tagging potential new physics events as anomalies. The use of an AE as an AD algorithm relies on the assumption that the network better reconstructs examples it was trained on than ones drawn from a different probability distribution, i.e. anomalies. Using the search for non resonant production of semivisible jets as a benchmark, we demonstrate the tendency of AEs to generalize beyond the dataset they are trained on, hindering their performance. We show how normalized AEs, specifically designed to suppress this effect, give a sizable boost in performance. We further propose a different loss function and using the Wasserstein distance as a metric to reach the optimal performance in a fully signal-agnostic way. Extension of this method to graph representation of the jets in the Lund jet plane are discussed.

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Fast b-tagging at the ATLAS Trigger

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Jets containing b-hadrons (b-jets) are a key signature to trigger events at collider experiments, as they're associated to many interesting physics processes, such as Higgs decays. Charged particle tracks reconstruction, the main input for b-tagging algorithms, makes the b-jet trigger selections some of the most CPU intensive ones at the ATLAS High-Level-Trigger (HLT). To cope with the real-time constraints and enhance the physics reach of the collected data, new trigger strategies were developed for the start of the LHC Run 3, involving Machine Learning (ML) techniques. The success of these strategies in the first years of LHC Run 3 data-taking encouraged the development of new algorithms to achieve better performances in HLT b-tagging for 2024 data-taking. The Run-3

b-jet trigger developments will be presented, as well their first performance assessment in LHC data and some possible future upgrades.

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Anomaly detection at the trigger level for LLPs

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Long lived particles (LLP) are ubiquitous in many Standard Model extensions, and could provide solutions to long-standing problems in modern physics. LLPs would present unique signatures, such as decays in flight far from the interaction point. New trigger and reconstruction techniques are required to search for such events. We propose using the LHCb muon detector as a sampling calorimeter.

In this work, machine learning based techniques are developed and compared, in order to detect the decays of such particles in the muon detector. The models are designed to be implemented in the software triggers, making use of the GPU accelerated hardware used in LHCb. In order to englobe a wide range of models, the techniques are chosen for their generality. Anomaly detection approaches, such as various types of autoencoders and Siamese neural networks, are benchmarked. Such models necessitate only (or mostly) background data to efficiently select signal events, leading to much improved model independence. Ultimately, such techniques can lead fewer trigger lines to develop, train and maintain, while improving the physics performances. The performances of the models are very promising, yielding similar or better signal efficiencies than BDTs and neural network classifiers.

Finally, a clustering method is designed to extract the signal shower from the background hits. Using properties of the cluster, kinematic information are retrieved using neural networks.

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Measurement of event shapes in minimum bias events from pp collisions at 13 TeV

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The event-wise multi-dimensional unfolding is performed with the machine-learning-based OMNIFOLD algorithm to measure the event shape observables of the minimum bias data of low pile-up proton-proton collisions at a centre-of-mass energy of 13 TeV collected by the CMS detector. A machine-learning-based uncertainty estimation method is used to estimate the unbinned uncertainty and the uncertainty covariances among different variables. The optimisation of the training and the validation of the unfolding algorithm will be presented. Simulations from several Monte Carlo event generators were investigated, including EPOS-LHC, Herwig, and Pythia with multiple options of underlying-event tunes. None of the models are able to satisfactorily describe the data, and there are significant trends in this misdescription which is common amongst all generator setups studied, particularly showing data being more isotropic than any of the simulations.

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Cluster Scanning

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We propose a new model-independent method for new physics searches called Cluster Scanning. It uses the k-means algorithm to perform clustering in the space of low-level event or jet observables, and separates potentially anomalous clusters to construct a signal-enriched region. The spectra of a selected observable (e.g. invariant mass) in these two regions are then used to determine whether a resonant signal is present. A pseudo-analysis on the LHC Olympics dataset with a Z′ resonance shows that Cluster Scanning outperforms the widely used 4-parameter functional background fitting procedures, reducing the number of signal events needed to reach a 3σ significant access by a factor of 0.61. Emphasis is placed on the speed of the method, which allows the test statistic to be calibrated on synthetic data.

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Machine-Learning Enhanced Optimal Detector Design

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In this talk, we address the challenge of optimizing detector design for advanced tasks in high energy particle physics. Our goal is to develop differentiable pipelines for the optimization of typical metrics sought out in particle physics applications. The approach is tailored with a focus on several critical design aspects, including optimizing detector performance, enhancing sensitivity to discoveries, and adhering to cost constraints. We explore innovative machine learning-based methods leveraging mutual information and generative AI. We present initial promising results from studies utilizing both methodologies and discuss potential directions for further development.

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Surrogate model for optimization of PSI muEDM experimental design

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A dedicated experimental search for a muon electric dipole moment (EDM) is being set up at Paul Scherrer Institute. This experiment will search for a muon EDM signal with a final precision of \SI{6e-23}{e \cdot cm} using the frozen-spin technique, improving the current experimental limit by 3 orders of magnitude. To achieve the precision objective, it is important to optimize the setup to ensure maximum efficiency for recording an experimental signal. However, the optimization procedure is computationally expensive owing to complex dynamics of charged particles in electromagnetic fields, conflicting objectives and a multi-dimensional input space. Thus, we employ a genetic algorithm based on surrogate models to gain orders of magnitude in computational speed. In this talk, we present an overview of this optimization study based on simulations and discuss various ways of constructing surrogate models aided by machine learning techniques.

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Vitis accelerator backend development for HLS4ML

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Leveraging the current industry shift towards heterogeneous computing and the widespread adoption of FPGAs as accelerators to deploy machine learning algorithms, this project introduces the Vitis accelerator backend, a novel backend for HLS4ML. HLS4ML is a python package tailored for machine learning inference on FGPAs that translates traditional open-source machine learning package models into High-Level Synthesis (HLS) language.
Vitis accelerator backend streamlines the creation of firmware implementations of machine learning algorithms using HLS and Vitis kernel acceleration flow, with a focus on automating project generation specifically for PCIe FPGA accelerators.

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GNN event interpretations at LHCb and SHIP

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Graph neural networks (GNNs) have recently emerged as state-of-the-art tools across various scientific disciplines due to their capability to represent complex relationships in datasets that lack simple spatial or sequential structures. This talk will explore the application of GNNs in two contrasting experimental environments. The first of which is the deep full event interpretation (dFEI) at the hadron collider experiment LHCb, which utilizes a novel GNN-based hierarchical reconstruction of b-hadron decays relying on an edge classification of lowest common ancestors. The structure and performance of this algorithm, as described in the publication [García Pardiñas, J., et al. Comput.Softw.Big Sci. 7 (2023) 1, 12], will be presented. Meanwhile, the second application is a GNN-based veto of neutrino and muon backgrounds at the recently approved fixed target experiment SHIP, which will search for hidden sector long lived particles.

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The DL Advocate: playing the devil's advocate with hidden systematic uncertainties

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This talk will summarize a method based on machine learning to play the devil's advocate and investigate the impact of unknown systematic effects in a quantitative way. This method proceeds by reversing the measurement process and using the physics results to interpret systematic effects under the Standard Model hypothesis. We explore this idea in arXiv:2303.15956 by considering the hypothetical possibility that the efficiency to reconstruct a signal is mismodelled in the simulation. We further discuss the extension to this method on which we are currently working on. We explore a combination of reinforcement learning and generative models to automatically find background decay modes which are potentially problematic for an analysis. We believe that this method has the potential to significantly streamline the analysis procedure in a complex experiment.

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Simulating Calorimeter Detector Signatures with the Lorenzetti Showers Framework for Electron Trigger Studies using Machine Learning

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The general-purpose Geant4 based calorimeter framework Lorenzetti Showers is being presented. It provides an ideal tool for simulating various configurations of calorimeter systems or testing their responses in complex scenarios. Its limits are being investigated by simulating a system very close to the ATLAS calorimeters and comparing their signatures under challenging conditions. Such a study is presented where forward calorimeter signatures are used for triggering on electrons with machine learning techniques where no tracking information is available. Those scenarios become even more challenging in extreme pile-up situations which are aimed to be recreated with Lorenzetti Showers to extend the studies.

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Human-in-the-loop Reinforcement Learning for Data Quality Monitoring in Particle Physics Experiments

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Data Quality Monitoring (DQM) is a crucial task in large particle physics experiments, since detector malfunctioning can compromise the data. DQM is currently performed by human shifters, which is costly and results in limited accuracy. In this work, we provide a proof-of-concept for applying human-in-the-loop Reinforcement Learning (RL) to automate the DQM process while adapting to operating conditions that change over time. We implement a prototype based on the Proximal Policy Optimization (PPO) algorithm and validate it on a simplified synthetic dataset. We demonstrate how a multi-agent system can be trained for continuous automated monitoring during data collection, with human intervention actively requested only when relevant. We show that random, unbiased noise in human classification can be reduced, leading to an improved accuracy over the baseline. Additionally, we propose data augmentation techniques to deal with scarce data and to accelerate the learning process. Finally, our studies can be found in arXiv by the following link: https://arxiv.org/abs/2405.15508.

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ML in CMS: new developments and challenges

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Machine learning has become an indispensable tool in the field of high-energy physics, particularly in the CMS experiment at CERN.

In this talk, we will discuss some of the new developments in ML techniques implemented in the CMS experiment. These advancements have improved tasks like event reconstruction, jet flavour tagging, data quality monitoring, anomaly detection in the triggers, and fast Monte Carlo generation.

All these ML applications have the potential to speed up the time-to-insight in HEP and improve CMS physics results. However, along with these advancements come technical challenges that must be addressed. These challenges include issues related to training data quality, reproducibility, model interpretability, and computational resources. We will explore these challenges and discuss potential solutions and future directions for ML in the CMS experiment.

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Identification of Jets and Regions of Interest in the ATLAS Calorimeter with Deep Convolutional Neural Networks in Real Time

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In the ATLAS trigger and data acquisition system we can use machine learning to approximate existing online algorithms and accelerate trigger decisions in real time. This will be particularly important for the ATLAS Phase II upgrade in the high-luminosity LHC which will enforce strict latency requirements in the trigger. This work introduces a novel application of a Convolutional Neural Network (CNN) to the task of identifying regions of interest and jets in the ATLAS calorimeter. We anticipate such an object detection model could be used as a preselection in the trigger to quickly produce jets directly from calorimeter cells, before proceeding with the slower iterative algorithms currently in use.

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Neutrino Reconstruction with Graph Neural Network on SND@LHC

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The SND@LHC experiment aims to observe and measure neutrinos produced at the LHC. The goal of the detector reconstruction is therefore to identify events as coming from neutrinos against the typical large background from neutral hadrons and muons, and to identify the type of neutrino interaction. Current reconstruction methods are based on reconstructing muon tracks and rectangular cuts, and only consider events that are fully in the detector acceptance. In this study, we applied a new machine learning model based on graph neural networks to achieve whole detector event reconstruction. Each individual detector hit is considered as a point (or node), and the graph neural network makes use of learned connections. We evaluated our method using simulated events, the current result shows our approach has the potential to significantly increase the precision of all measurements with neutrinos, and potentially to increase the reach of searches for feebly interacting particles.

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PLENARY DISCUSSION

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Welcome & Introduction

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Welcome from the Early Career Researcher (ECR) board

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Memoires of an SNSF Ambizione Grant Winner

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The way to becoming an assistant professor at EPFL

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Is the CERN fellowship the rockstar of postdocs?

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Climbing the ladder through ERC funded projects

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A good opportunity to ask the speakers all the things you were always afraid to ask.

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Edge ML school

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