

## **Anomaly Detection in Triggers**



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# **Anomaly Detection**

Are we looking in the **right places** for discovering New Physics?

What if we do not know how New Physics looks like?

**Unsupervised ML** - **Anomaly Detection**, **agnostic** to specific theoretical signal models.



A Kahn





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The Large Hadron Collider

Protons collide at an energy of 6.8 TeV at the 4 detector locations, every 25 ns ~ huge amount of data!

CMS

UISSE

FRANCE

Need a trigger to filter events

HCb

**CERN** Prévessin



SPS\_7 km

CERN-Mestin

CE

# AD Trigger



- Traditional triggers focus on "well-known" physics signatures, targeting high transverse momentum physics objects.
- AD trigger is not based on pre-defined signatures → Increase sensitivity to discover new physics at low energies.

# AD Trigger



### Level 1 AD Trigger

 Incorporate autoencoders in Field Programmable Gate Arrays (FPGAs).

### **High Level AD Trigger**

- Train on events passing L1 AD trigger
- Anomaly score = reconstruction loss

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#### Hunting for new physics

The Standard Model (SM) of particle physics is a remarkably successful model, passing stringent experimental tests.

Dark Energy



Are we looking for new physics in the right places? What if we do not know how new physics looks like!

But this is not the complete picture.

Matter, Matter-Antimatter asymmetry,

Several unsolved puzzles - Dark

#### Triggers



- Proton (or ion) collisions at 40MHz produces gigantic amount of data!
- Triggers are essential to filter events interesting for physics ~ 99% percent of the data is rejected.
- Two-level system with hardware- based Level 1 (L1) and software- based High Level Trigger (HLT).
- Triggers follow a specific "menu", accepting physics objects with certain kinematic variables, usually biased towards high transverse momentum objects.



#### Why go off the menu?

- Explore objects in the low energy regime, which may be missed by the current triggers.
- Unbiased selection of rare events, aiding in high sensitivity and model independent studies.



#### **Trigger-level implementation**

Focus on fast decisions and manageable trigger rates! Level 1

- Field-Programmable Gate Arrays (FPGAs) with encoded neural networks, using Qkeras, hIs4ml. Extremely low latency, inference time ~ ns.
- HLT
- Autoencoders trained on data received from L1, events passing a certain anomaly score threshold are stored for physics analyses.

#### Anomaly Detection

Anomaly detection (AD) is used to detect outlier events in data.

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#ADELAID

- Model-agnostic analyses benefit from deep neural network-based unsupervised AD.
- Common tools used to compute an anomaly score and apply a cut on that score, include autoencoders and variational autoencoders.



Autoencoders



- Define the autoencoder architecture with an encoder and decoder, neural networks are used.
- During the training, the network learns distinct data features and encodes it into a lower dimensional latent space.
- · Decompress the data to reproduce the input.
- Define and analyse the loss function the higher the reconstruction error, the more anomalous is the event.

#### **Preliminary studies**

- Design an autoencoder using LHC dataset collected at 40MHz<sup>1,2</sup>.
- Train a deep neural network- based autoencoder on a blackbox dataset-
- · SM W and Z boson, tt and multijet productions.
- BSM Charged higgs decaying to τ-lepton and a ν, scalar boson decaying into a pair of τ-leptons, scalar boson decaying into 4 leptons, leptoquark decaying to a b quark and a τ-lepton
- Define the reconstruction error (anomaly score)- mean squared error.
- · Evaluate model on background (SM) and signals.



 Analyze data collected by the AD trigger.
Explore data decorrelation techniques to build a robust model-agnostic background analysis<sup>3</sup>.

enal.com/, prgTree

# Visit the poster for a fun discussion!

Thank you!

Thanks to my collaborators at The University of Adelaide, UPenn, Stanford University.