IV Anomaly Detection

IV.1. Basics

Supervised „New Physics vs. background" classification

↑ „bread & butter", conventional LHC search (90%)
model specific

→ very few model-independent searches!

↳ opportunity for ML!!

↳ huge interest in Experiment now!

Two types of AD:

- outlier detection $p_{bg}(x) = 0$ ≃ in practice $p_{bg}(x) \ll 1$
  - not coordinate invariant!
  - [2209.06225] BN+DS+GK
- overdensities.

$$R = \frac{p_{data}(x)}{p_{bg}(x)}$$ ← Neyman-Pearson → optimal for data vs bg hypothesis test

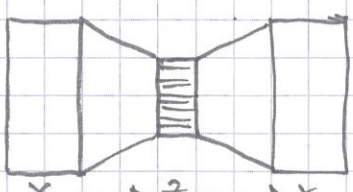
↑ „idealized anomaly detector"

↳ best you can do if you know p_{data} (?) and p_{bg} (?)

↳ $R > R_c > 1$

p_{data} (?), p_{bg} (?) → ML!

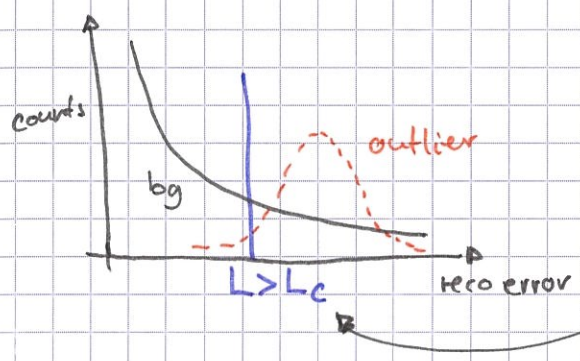
4.2. Autoencoder for outlier detection



- try to learn $X \to Z \to X$
- because $Z < X$ → no identity map
- Loss ~ MSE(X, AE(X)) ← „reconstruction error"

→ „non-linear PCA"

for AD: imagine AE trained on bg:



L is anomaly score
↳ L > Lc
use to cut interesting events!

↳ Heimel et al. [1808.08979] „QCD or what?"
DS, Farina, Nakai [1808.08992]

↳ detected top jets vs QCD jets (Pythia + Delphes)
gluino jets

Carefull: mention problem with Rüssel!

↳ ADC ← fast trigger AD

pros: works fully unsupervised
cons: generally not very sensitive, uncontrolled
↓
complexity bias ← ↳ Normalized AE
Dillon et al.
[2206.14225]

4.3 Overdensities

learn $R = \frac{p_{data}(x)}{p_{bg}(x)}$ from MC simulations

data vs. MC event → classifier
↳ R → R > Rc → # of events

↳ if MC not accurate
↓ all defects of MC
↳ use to improve MC

ELSA: [2305.07696]
Plehn et al.: [2305.16774]

from data?

↳ control region CR $p^{CR}_{data} \simeq p_{bg}(x) \equiv f_1 p_S + (1-f_1)\cdot p_B$

SR $p^{SR}_{data} \simeq (1-\varepsilon) p_{bg} + \varepsilon p_{sig} \ldots = f_2 p_S + (1-f_2) p_B$

Then classify CR ↔ SR to learn R:

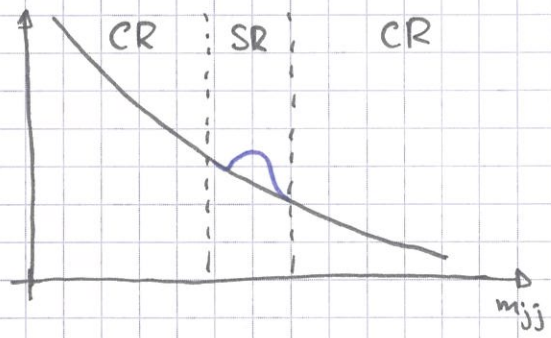
Mixed sample!

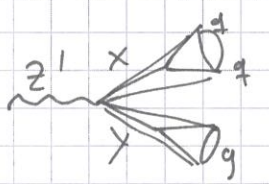
⇒ Classification without labels (CWoLa) → optimal for $\frac{p_S}{p_B}$

1. Idea: BN, Thaler, Metodiev [1708.02949]
2. AD: Collins, Howe, BN [1805.02664]

⇒ „CWoLa" hunting → „weak supervision" ↳ need to find SR and CR

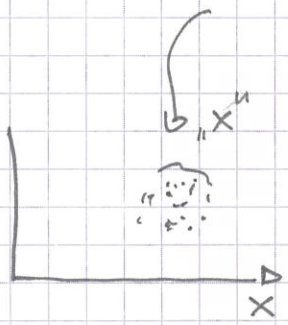
4.4. CWoLa hunting





$m_{Z'} > m_X, m_Y$

$(m_X, m_Y, \tilde{\tau}_{21}^{(1)}, \tilde{\tau}_{21}^{(2)})$



↳ with carefully chose X → independent of m_{jj} in bg → SR ↔ CR

Single dim (m_{jj} only) ~ 1σ

more X ~ 5σ

CWoLa

$R = \frac{p^{SR}_{data}(x)}{p^{CR}_{data}(x)} \simeq \frac{\varepsilon p_S + (1-\varepsilon) p_B}{1}$

$p^{CR}_{data} \simeq p_{bg}$

$p^{SR}_{data} = (1-\varepsilon) p_{bg} + \varepsilon \cdot p_{sig}$

4.5 Anomaly Detection through Density Est (ANODE)

BN, DS [2001.04990]

train DEs (NF) → $p_{data}(x|m_{jj})$ in SR
train DEs (NF) → $p_{data}(x|m_{jj})$ in CR → interpolates automatically into SR

R = ratio of DEs

⊕ robust against correlations in x & m_{jj}
⊖ less powerfull than classification
↳ classification is easier!

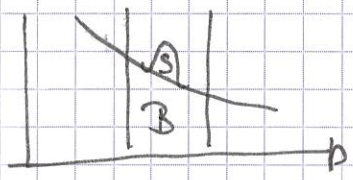
4.6. CATHODE

"... outer density estimation" : BN, DS, GK [2109.00546]

- combine CWoLa with ANODE
- train DE in CR → interpolate → generate samples in SR
- CWoLa (classifier) between data & bg!

↳ best of both worlds! ~~for sbeam~~

Metric for AD? → significance improvement



$$\frac{S}{\sqrt{B}} \xrightarrow{AD} \frac{S\cdot\varepsilon_S}{\sqrt{B\cdot\varepsilon_B}} = \frac{S}{\sqrt{B}}\left(\frac{\varepsilon_S}{\sqrt{\varepsilon_B}}\right)$$

factor by which significance improves!

→ show plots from 2109.00546

4.7. Future?

- LaCATHODE [2210.14924] → avoids scalping by doing the cut $R > R_c$ on the latent space!
- CURTAINS [2203.09470] → similar to CATHODE but not sampling it maps CR to SR!
- FETA [2212.11285] → simulation assisted

→ HEP-ML LIVING REVIEW