Hunting the Higgs with an Adversary

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Outline

- Standard model, LHC and ATLAS
- Higgs discovery and production
- Event classification with neural networks
- The study:
    - A problem with Higgs classification
    - ATLAS solution and my solution
    - Comparing the two results
- Summary

The Standard Model of particle physics

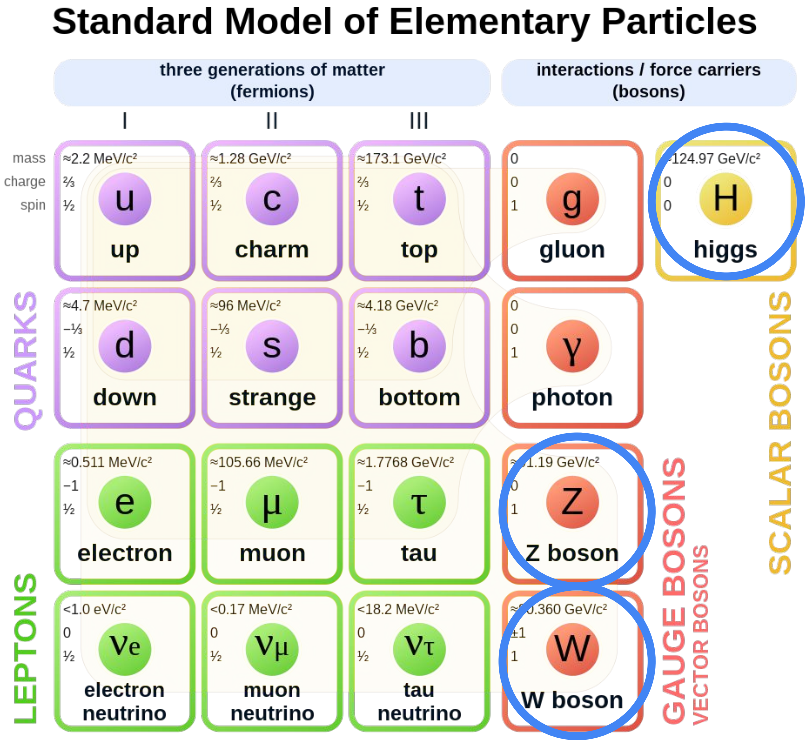
The standard model (SM) is the **most complete theory** we have of the universe

Describes the **electromagnetic**, **strong** and **weak** forces

Classifies all known **elementary particles**

Higgs boson was the last SM particle discovered

Will consider **Higgs boson** interaction with the **weak force** mediating **W and Z bosons**



https://en.wikipedia.org/wiki/Standard_Model

The LHC and ATLAS

LHC is a 27 km ring accelerating protons to high energies

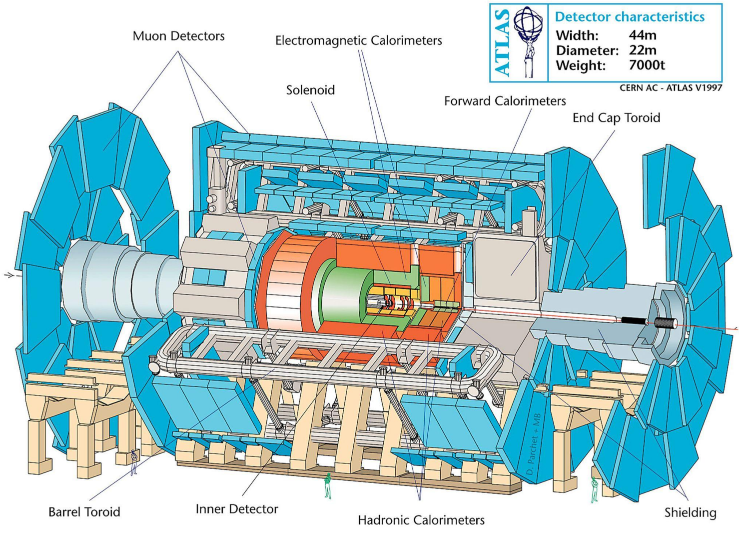
Collisions in middle of ATLAS detector

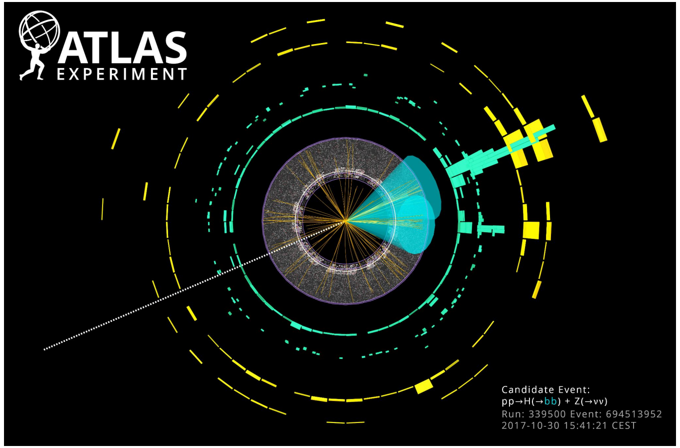
Energy can be converted to mass ($E=mc^2$)

Spray new particles in all directions

Background = boring

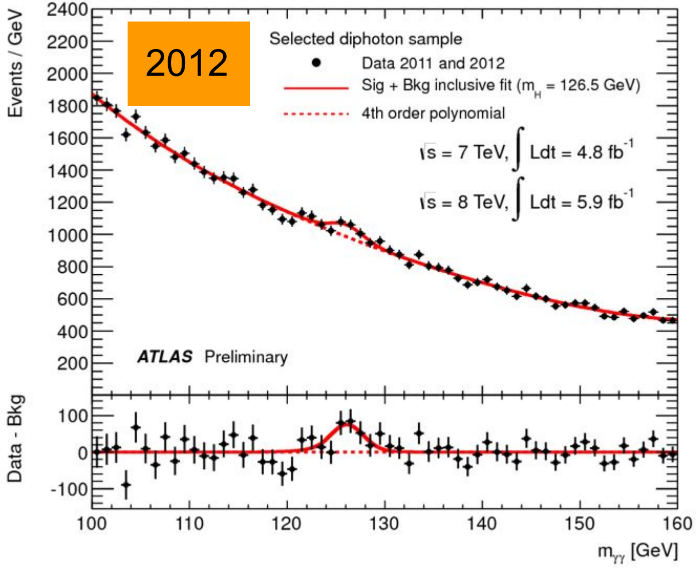
Signal = interesting

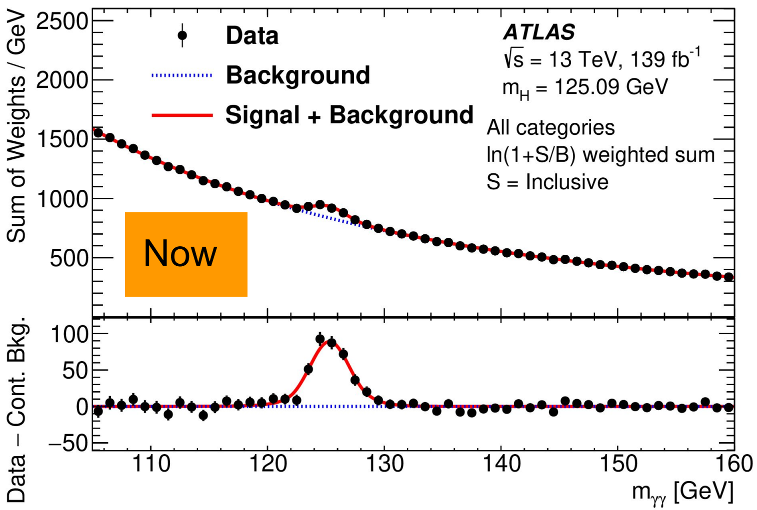




https://cds.cern.ch/record/39038 https://cds.cern.ch/record/2636049

Higgs discovery: diphoton decay channel





First signs of Higgs in diphoton channel

Two **well reconstructed** photons, **accurately measured** kinematics

Effective background rejection

More data has greatly **reduced statistical uncertainty**

Significant contribution to current Higgs measurements

https://cds.cern.ch/record/2627611 http://cds.cern.ch/record/2814946

Vector-boson fusion Higgs motivation

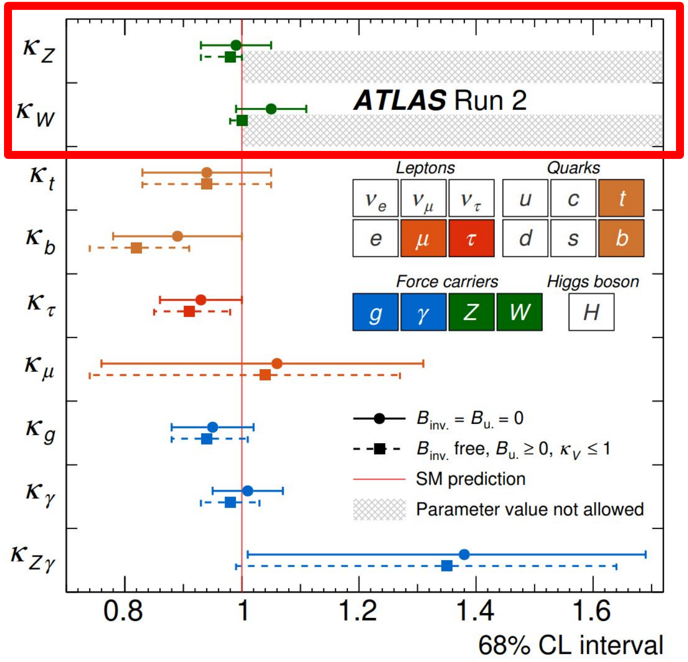
Higgs boson introduced in SM to give W and Z boson (**vector-bosons**) their **masses**

SM predicts **strict constraints** on Higgs to W and Z coupling strengths

Measuring these coupling strengths is a **powerful test for the SM**

Problem: A large uncertainty in Higgs to W and Z boson couplings

Solution: Improve classification of vector-boson fusion (VBF) Higgs events



http://cds.cern.ch/record/2814946

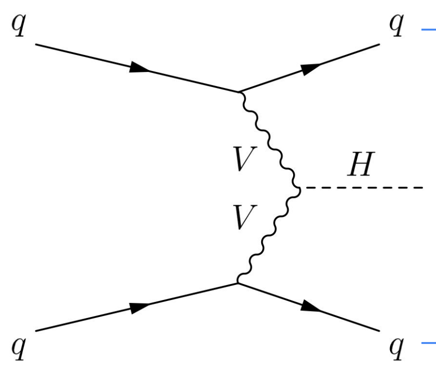
VBF Higgs production and background sources

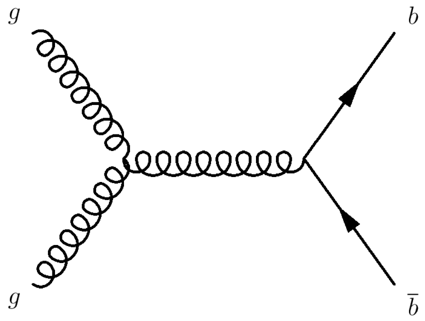
Higgs produced via VBF 7% of the time

Clear detector signature

VBF forms two energetic jets

Background has many sources, can radiate VBF-like jets





https://atlas.cern/glossary/vector-boson-fusion

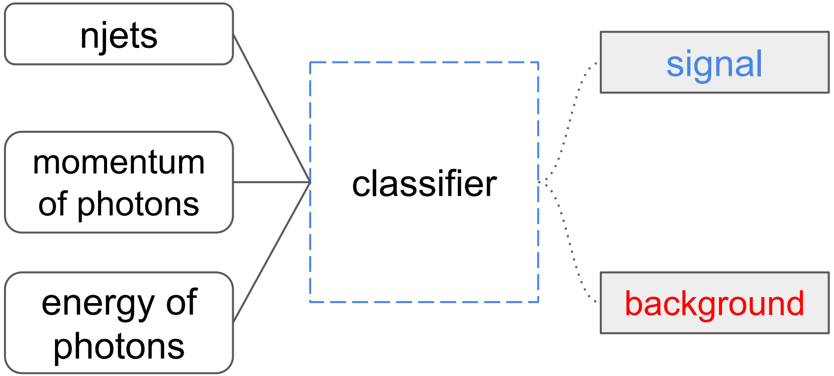
Classification using Neural Networks

Significantly improves classification over manual approach

Trains on simulated signal and background event features

Learn patterns in input features by minimising a loss function

Can then predict if new events are signal

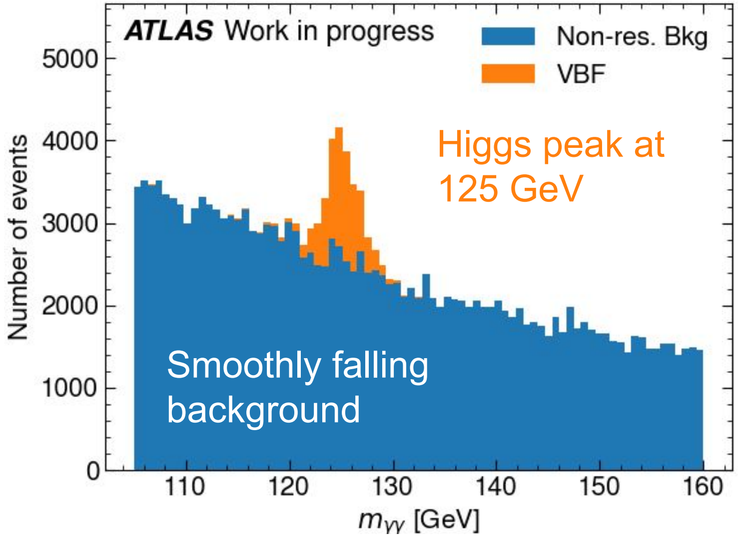


Study: A problem in classification between VBF Higgs and non-resonant background events

Problem: biased background acceptance

Signal and background obtained through simulated LHC collisions and ATLAS detector response

Original simulated distribution



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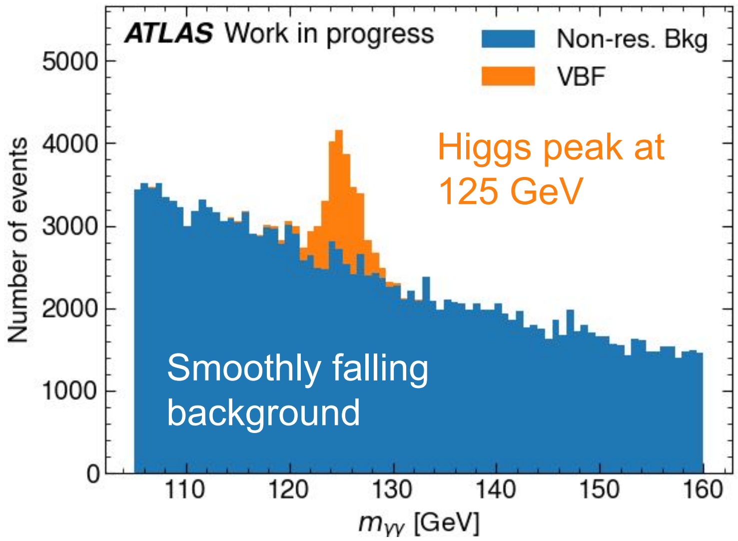
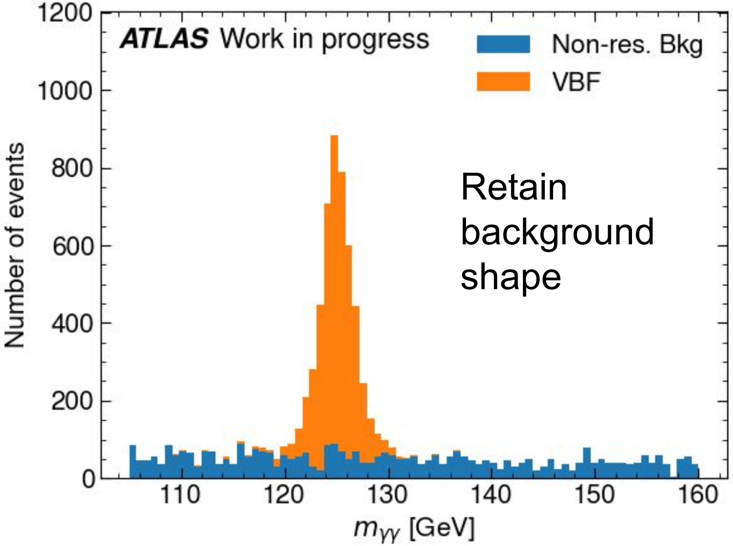


Ideal classification



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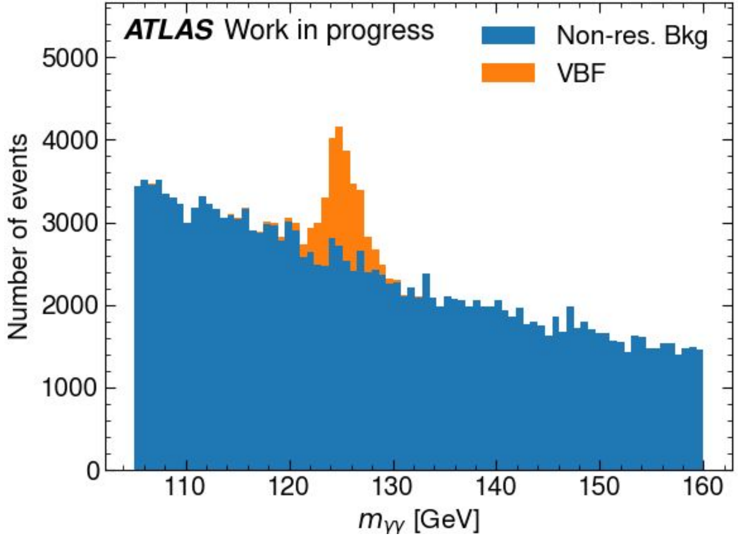

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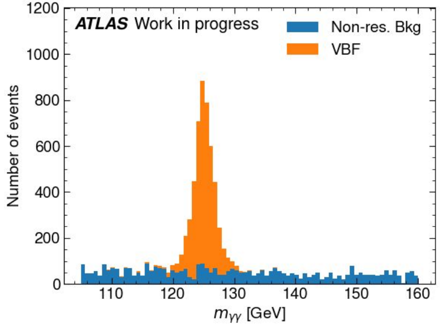
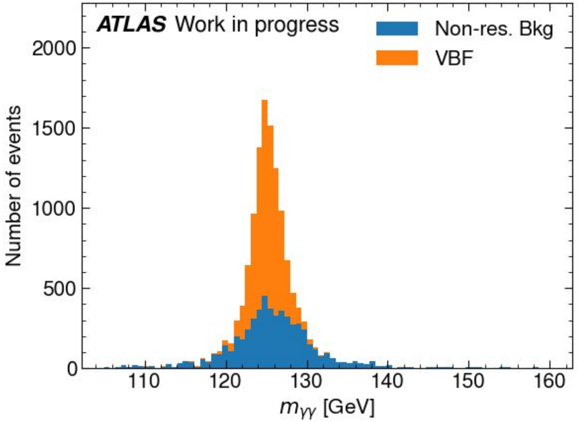


Biased acceptance



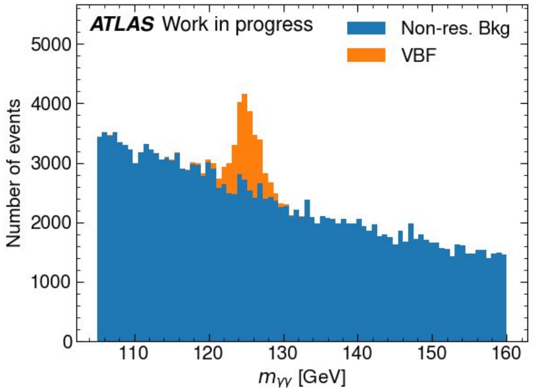
Problem: biased background acceptance

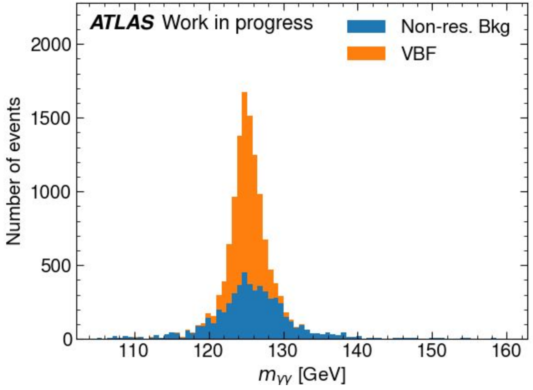
Problems:

Shape of accepted background distribution significantly distorted (**background sculpting**)

Introduces uncertainties in modelling of the background using non-signal regions

Leads to **uncertainty in number of VBF events** selected



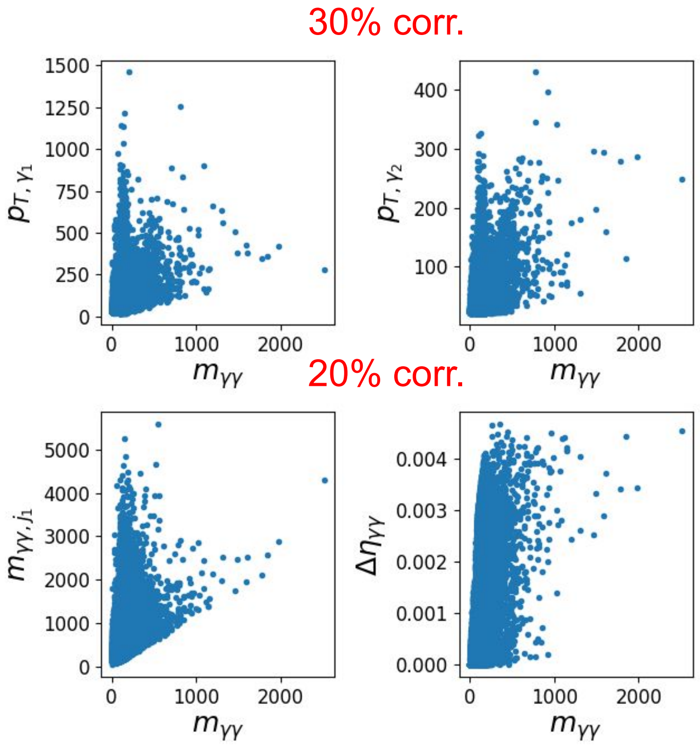


Why does background sculpting happen?

Reason: Many background features are **highly correlated** with the mass

Take the network's perspective:

- **m$\gamma\gamma$** signal **peak**, background **flat** ⇒ very good classification variable
- Network indirectly **learns mass of background**
- Can then **learn mass of signal**
- Good performance = reject everything outside Higgs region, accept rest



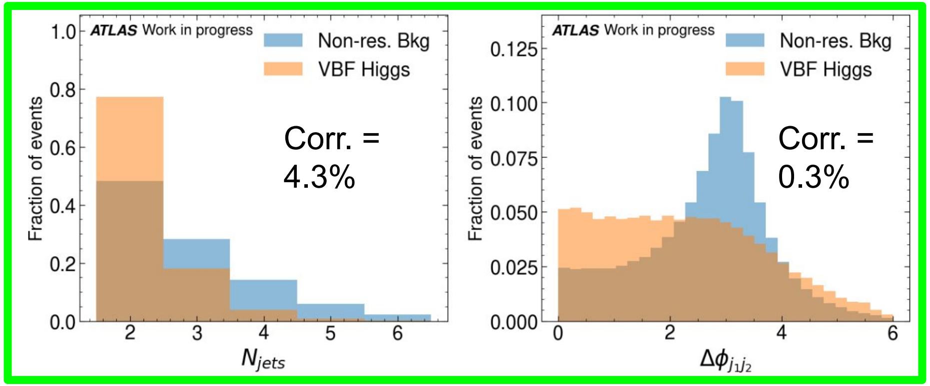
Performing mass de-correlation (ATLAS)

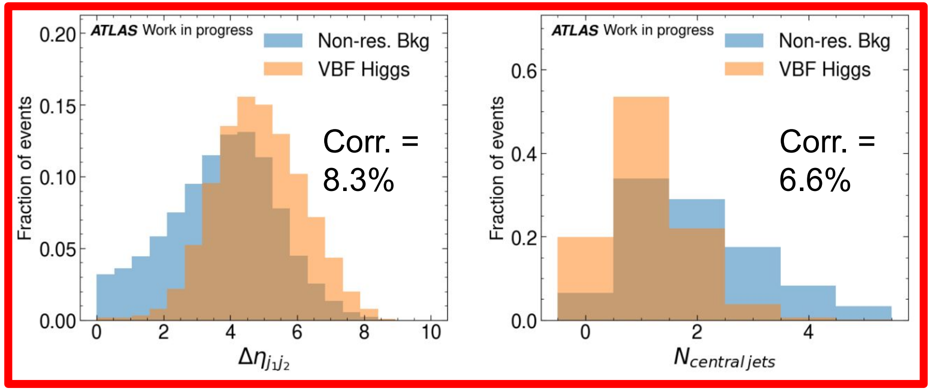
Current solution: **Removing variables** with mass correlation > 5%

No information left for classifier to learn mass

Problem: Only ⅓ of features left to train classifier

Limits classifier from learning differences between signal and background





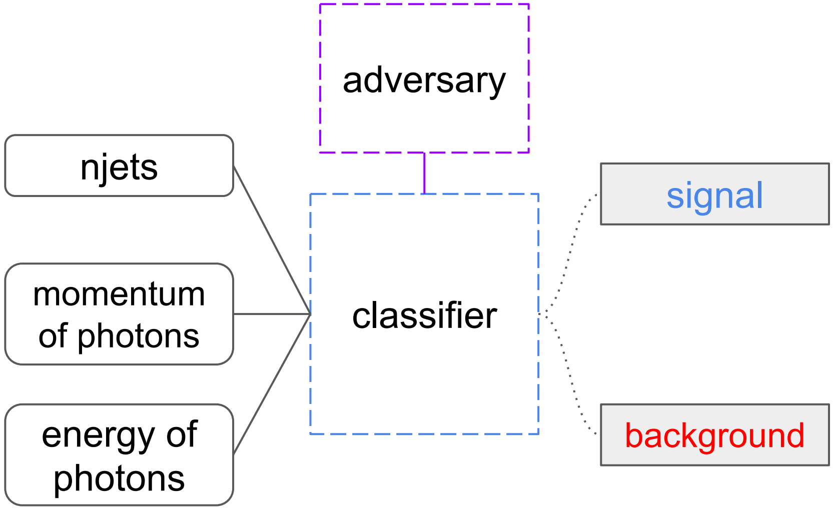
Performing mass de-correlation (This study)

Improved solution: Training the classifier by **controlling training** objectives

Include an **adversarial neural network** (ANN) to train with classifier

Monitor sculpting and regularise training by **modifying loss function**

Penalise the classifier if it learns the mass by increasing its loss function



Performance metrics

Discriminating power:

- Background efficiency at 80% signal efficiency

Level of background sculpting:

- Measure entropy between original and accepted background distributions
- Jensen-Shannon divergence metric will be used
- Report entropy for **inclusive region (105 GeV to 160 GeV)** and **Higgs region (121 GeV to 129 GeV)**

Results with the ATLAS approach

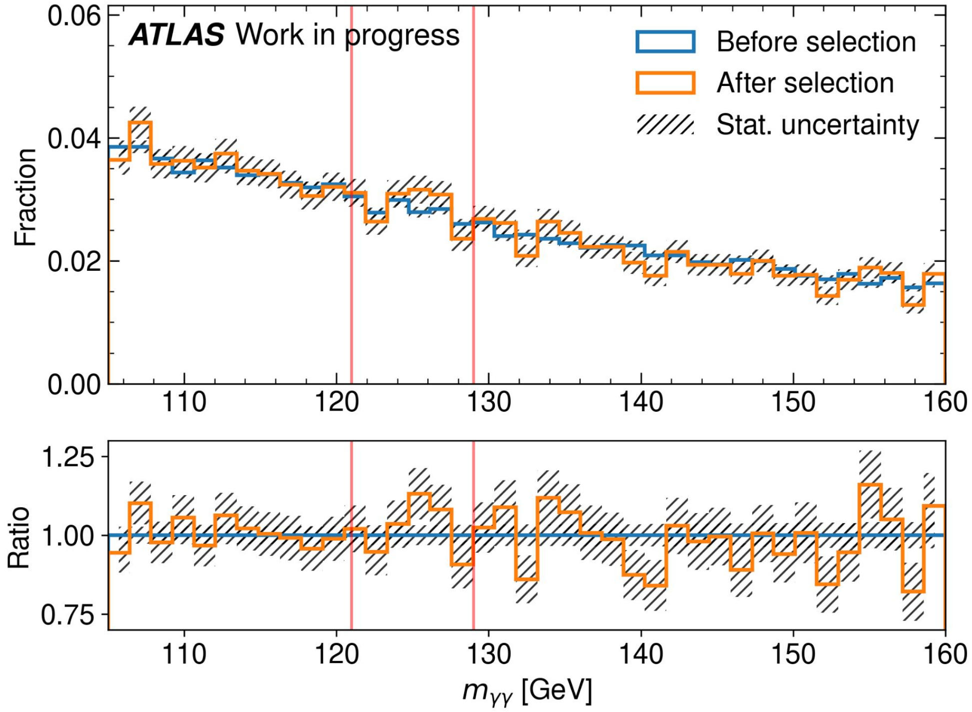
JSD inclusive = **7±4 × 10^{-4}**

JSD Higgs = **3±3 × 10^{-4}**

No visible background sculpting

Background efficiency = **0.165 ±0.002**

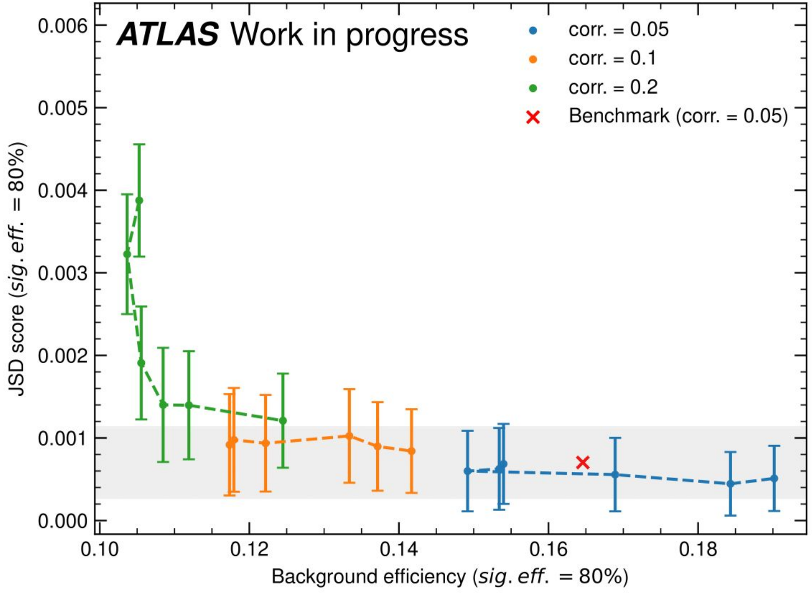
Will be used as a benchmark



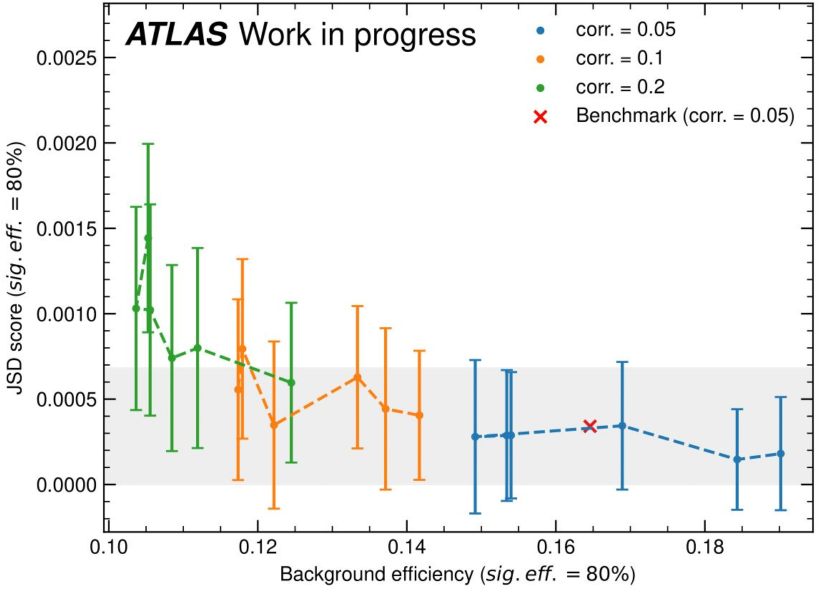
Optimising the ANN

Parameter	Value	Selected value
Training set correlation	[0.05, 0.1, 0.2]	0.1
Regularisation strength	[0.1875, 0.375, 0.75, 1.5, 3, 6]	0.1875

Inclusive region



Higgs region



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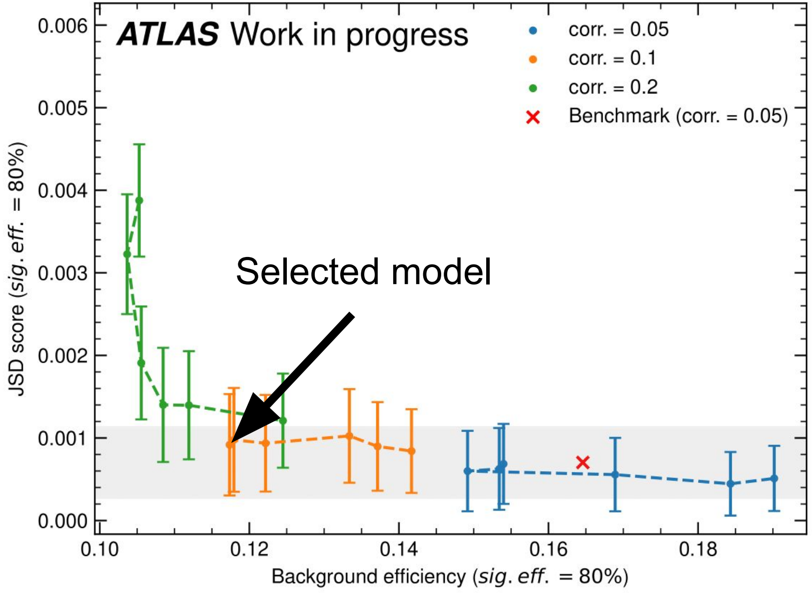
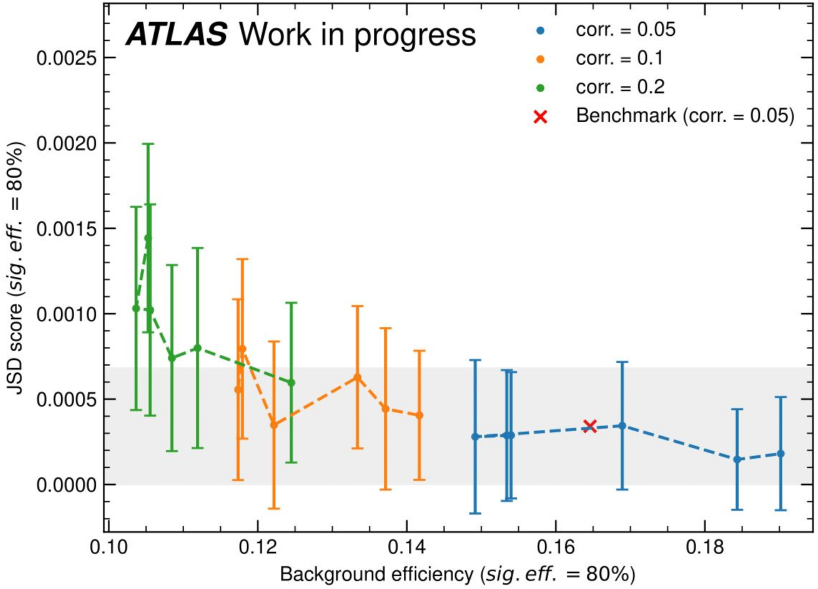
Inclusive region

Selected model

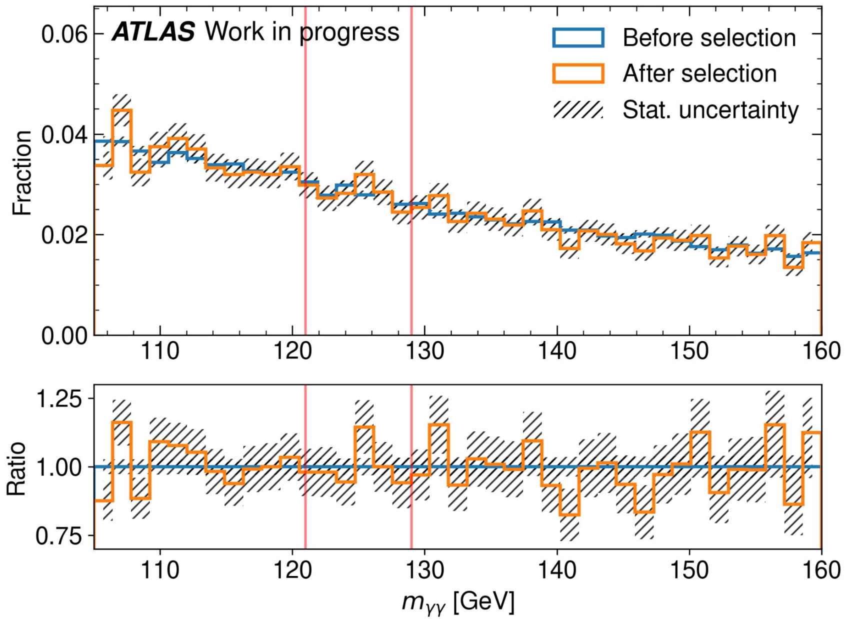


Higgs region



Comparing ANN with ATLAS solution

ANN solution

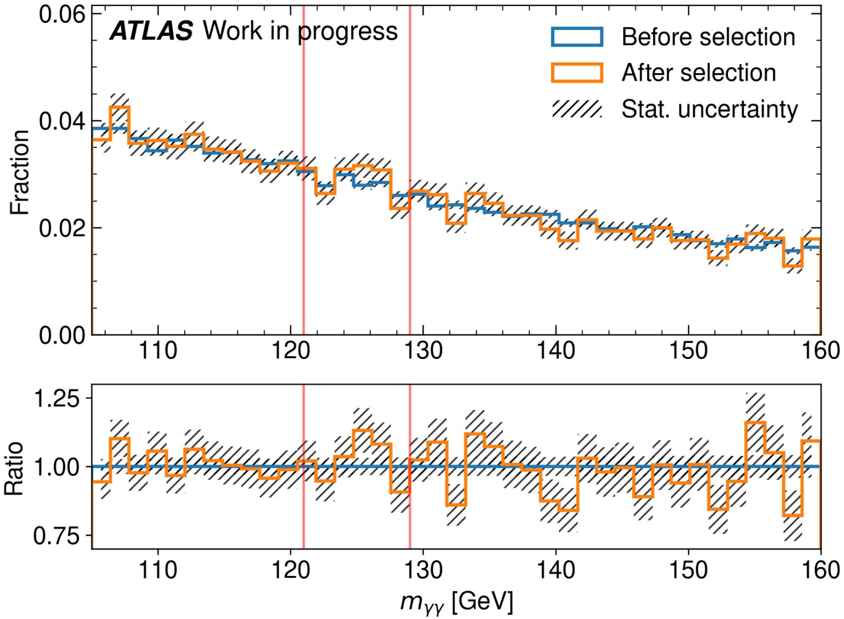


JSD inclusive = **9±6 × 10^{-4}**

JSD Higgs = **6±5 × 10^{-4}**

Background efficiency = **0.1174**

ATLAS solution



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JSD Higgs = **3±3 × 10^{-4}**

Background efficiency = **0.165±0.002**

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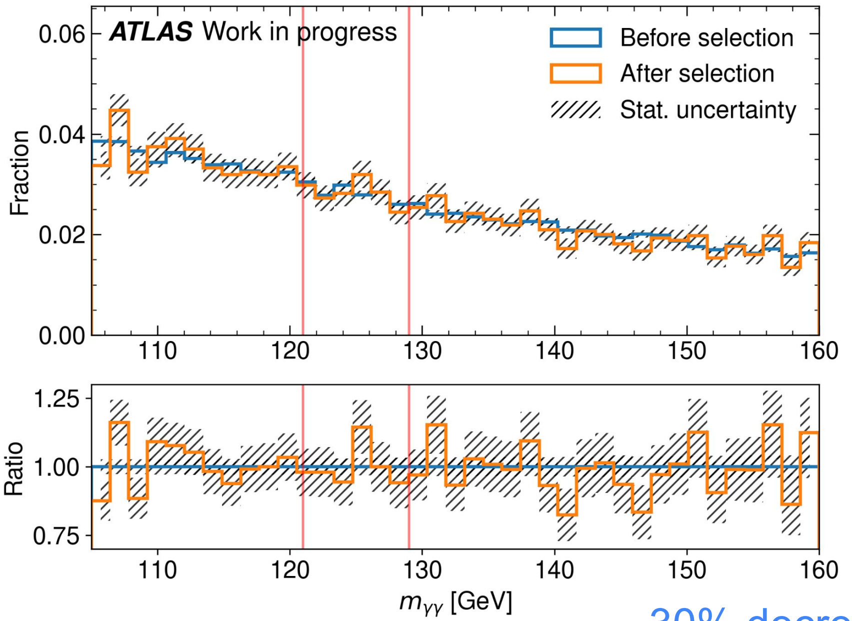


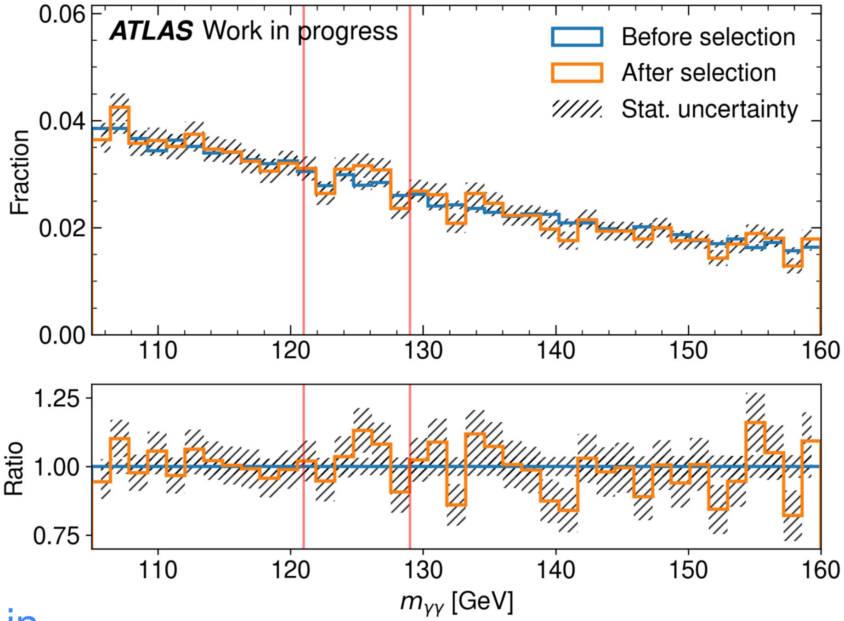
JSD inclusive = **9±6 × 10^{-4}**

JSD Higgs = **6±5 × 10^{-4}**

Background efficiency = **0.1174**

30% decrease in background efficiency, same level of sculpting

ATLAS solution



JSD inclusive = **7±4 × 10^{-4}**

JSD Higgs = **3±3 × 10^{-4}**

Background efficiency = **0.165±0.002**

Summary

Diphoton channel currently makes a significant contribution to **Higgs measurements**

VBF Higgs measurements in the **diphoton channel** create a **powerful test for the SM**

Large VBF Higgs **measurement uncertainties** can arise in the diphoton channel from **background sculpting** due to **mass correlation**

Classifier **training was modified** by an **adversarial network** to penalise background sculpting

The ANN solution achieves 30% lower background efficiency over ATLAS solution at same level of sculpting

Back up