ATLAS Higgs to Invisible

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Higgs to Invisible

Dark matter remains one of the major open questions in particle physics.

As the Higgs mechanism gives mass to visible matter, it may also couple to Dark matter in BSM scenarios known as Higgs Portal models.

This would allow the Higgs to decay invisibly into Dark matter.

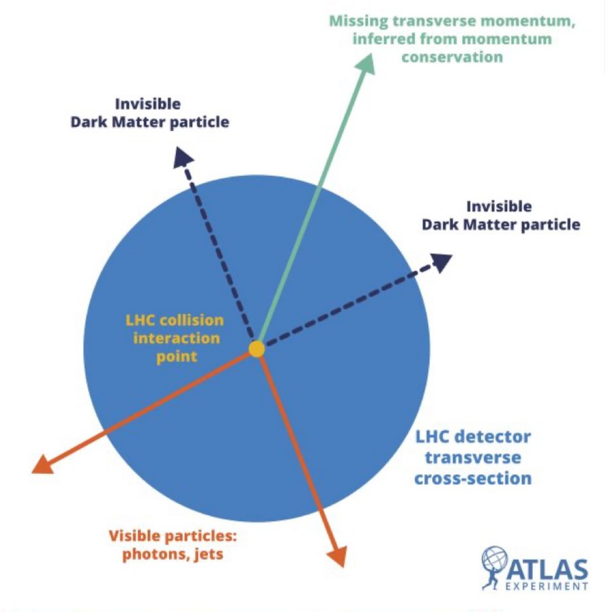
The Standard Model predicts a small Branching Ratio for Higgs decaying into invisible particles, 0.1%.

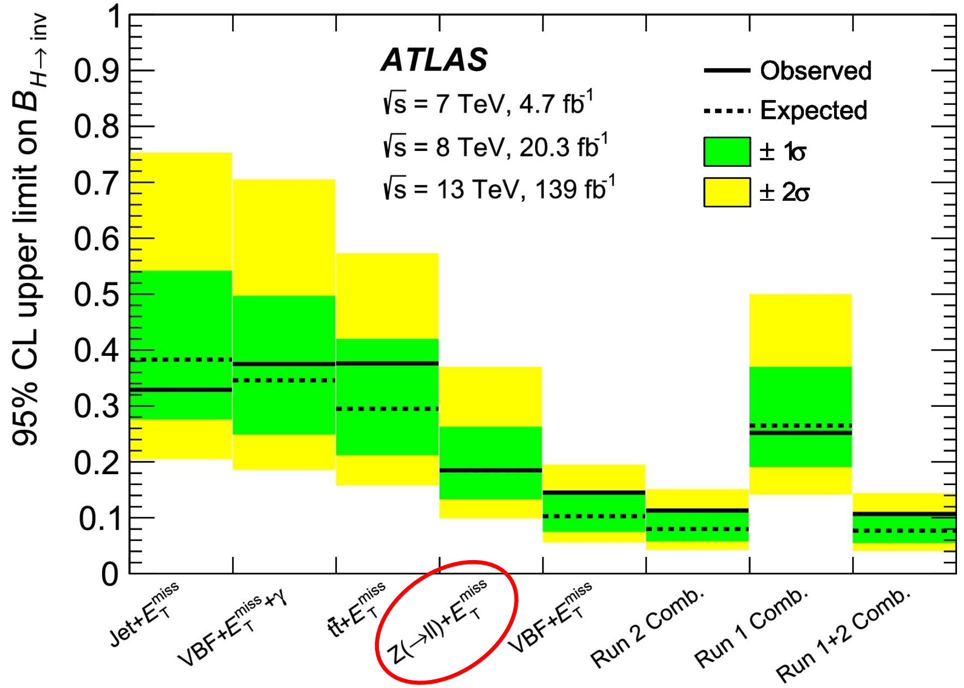
ATLAS Run2 limit on the decay is at 11%, leaving significant room for possible Dark matter contributions.

I work on the Run3 $Z(\rightarrow ll) + E_T^{miss}$ channel, the second most sensitive channel.

The previous Run2 analysis set a limit of 19%.

Sensitivity is heavily dependent on the ability to constrain the irreducible $ZZ \rightarrow llvv$ background.





Improving from Run2

Run2 used a BDT to separate the signal from background in the $2l + E_T^{miss}$ Signal Region.

This did well at separating the more reducible background (Non-res and Z+jets) but struggled with the more irreducible background (ZZ and WZ).

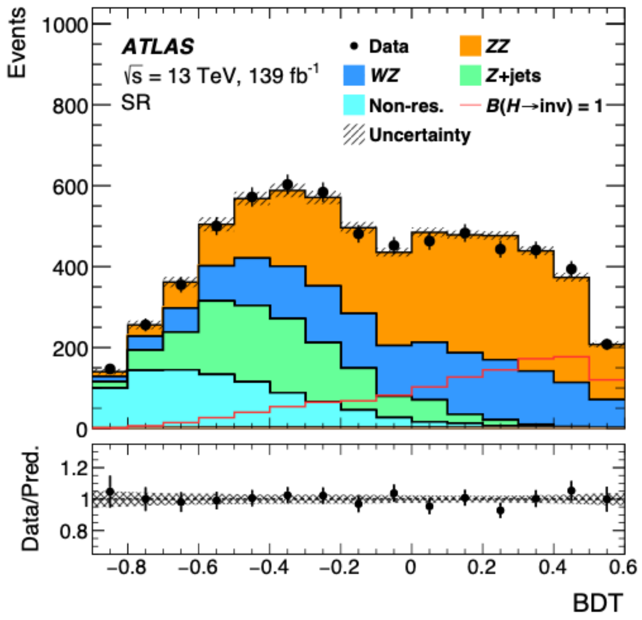
A simultaneous fit of the SR and dedicated CRs was used to constrain the dominate background's normalisation and modelling uncertainties directly from data.

The analysis also suffered from large systematic uncertainties mainly coming from:

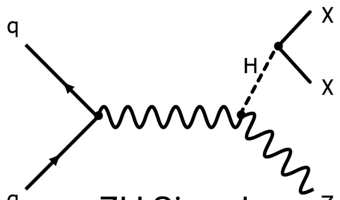
- ZZ modelling
- Jets and E_T^{miss} modelling

As the analysis is a Partial Run3 (165 fb^{-1}) the statistics will be very similar to Run2 (139 fb^{-1})

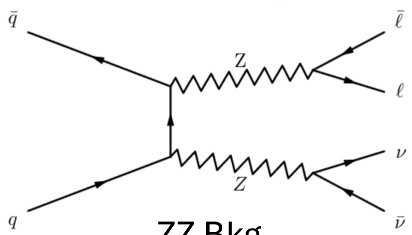
Therefore, to improve on the previous Run2 results a more advance neural-network based classifier (Graph NN and Dense NN) and better techniques to minimise the systematics.



Uncertainty source	$\Delta\mathcal{B}$ [%]
Statistical uncertainty	5.1
Systematic uncertainties	7.4
Theory uncertainties	4.9
Signal modelling	0.4
ZZ modelling	4.4
Non-ZZ background modelling	2.1
Experimental uncertainties (excl. MC stat.)	4.6
Luminosity, pile-up	1.5
Jets, E_T^{miss}	4.0
Flavour tagging	0.4
Electrons, muons	1.2
MC statistical uncertainty	1.6
Total uncertainty	9.0



ZH Signal

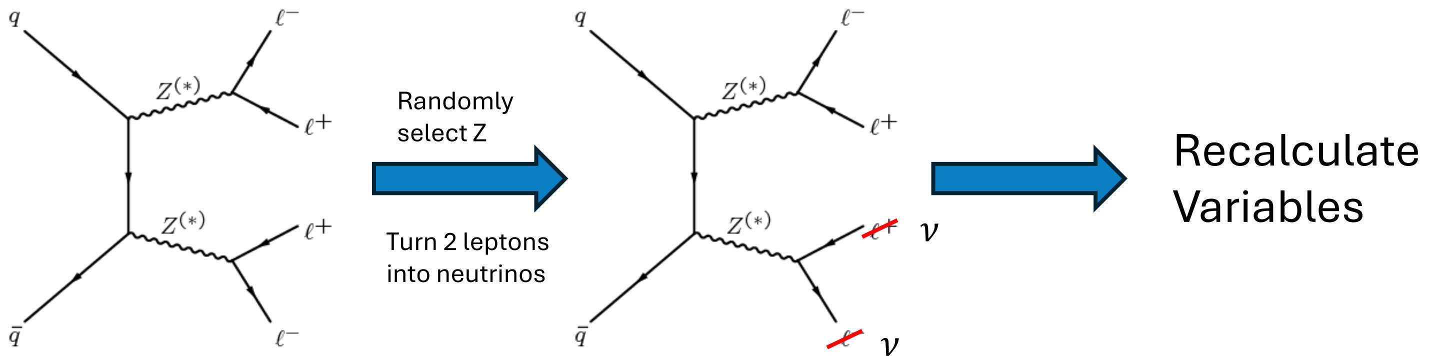


ZZ Bkg

Improving ZZ modelling

To better constrain the ZZ modelling systematics a pure $ZZ \rightarrow 4l$ CR is used.

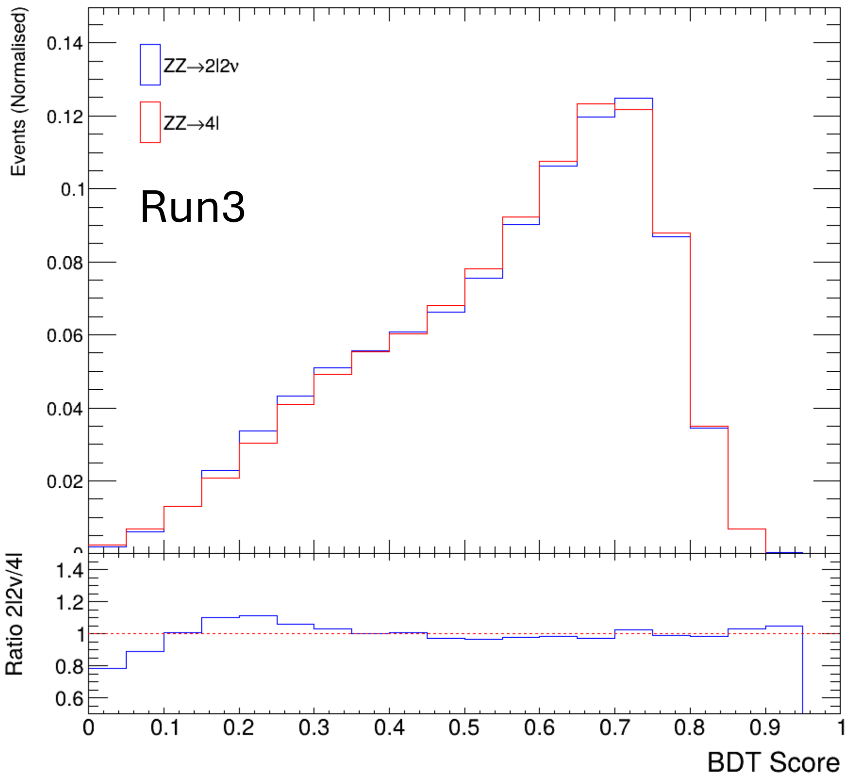
To accurately model the $2l + E_T^{miss}$ SR the 4l ZZ events are transformed into a $2l + E_T^{miss}$ by randomly selecting one Z-boson lepton pair and treating them as invisible.



After recalculating all the variables, the event is required to pass the same selections as the $2l + E_T^{miss}$ SR.

This procedure produces a ZZ shape in the CR that closely matches the SR, allowing shape systematics to be better constrained.

The BDT agreement for Run3 is very good, which was not achieved in Run2



Improving Signal Classification

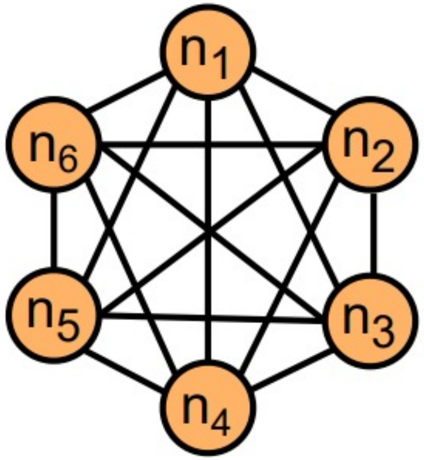
To better classify Signal a GNN is being investigated.

This GNN has been taken from ATLAS SUSY advanced studies and FCC-hh diHiggs analysis and modified for the $2l + E_T^{miss}$ Signal.

The Graphs are created from individual events. With each node representing particles or E_T^{miss} in the event.

The features of the nodes include basic variables such as pT, eta, phi and also more complex correlated variables such as ΔPhi(E_T^{miss}, Z) and ΔR(ll).

The network is limited by information in the event being only $2l + E_T^{miss}$ with jet information seeming to have little contribution to the results.



Features

Nodes	pT (GeV)	η	ϕ(rads)
Lepton 1	p_T l1	η l1	ϕ l1
Lepton 2	p_T l2	η l2	ϕ l2
MET	p_T MET	nan	ϕ MET
Z	p_T (ll)	η (ll)	ϕ (ll)

+ more complex features

Preliminary Results

Performing a simultaneous fit using the GNN output score as the SR and 4 different Control Regions: 4lCR (ZZ), 3lCR (WZ), $e\mu$CR (top/WW) and ZjetsCR.

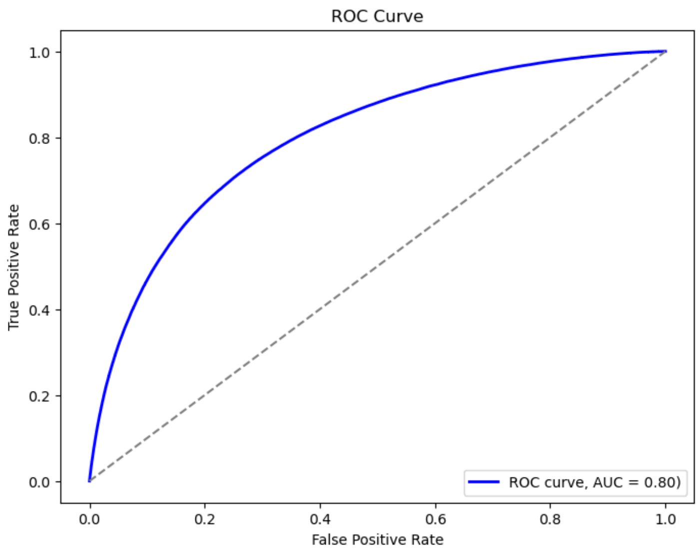
Resulted in a stat-only limit on the Branching Fraction of 10%.

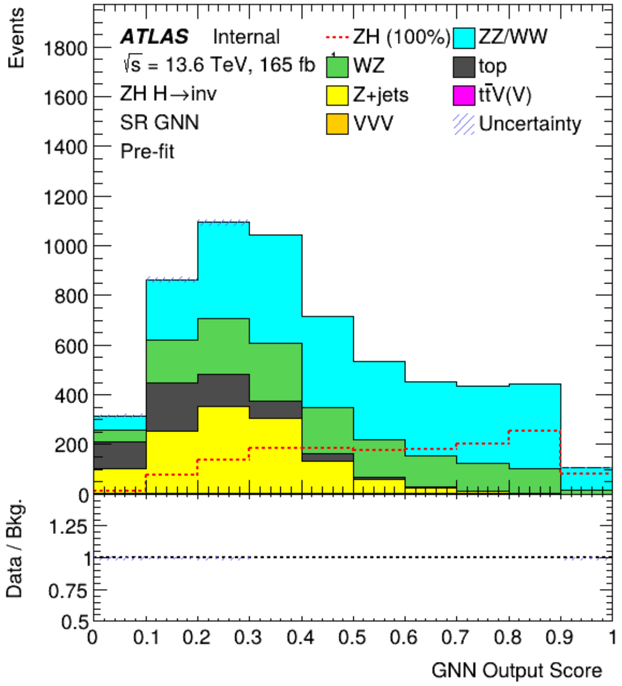
The group has also been working on a DNN and a BDT, similar to the one used in Run2.

Comparison between them have shown the GNN and DNN perform very similarly to each other with the BDT about 2% worse in the limit.

Attempts to create more advanced networks have shown little improvement.

Focus for the analysis now is to add in systematics and make the networks more robust to the systematic uncertainties.



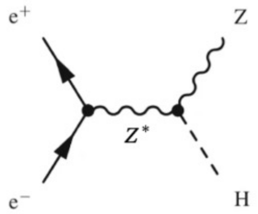


FCC-ee Higgs to Invisible

Changing from colliding protons to electrons makes a large difference when searching for invisible particles.

The exact energy of the collision is known allowing for the invariant mass everything missing to be easily calculated.

$$m_{miss} = \sqrt{(\sqrt{s} - E_Z)^2 - \overrightarrow{p_Z^2}}$$



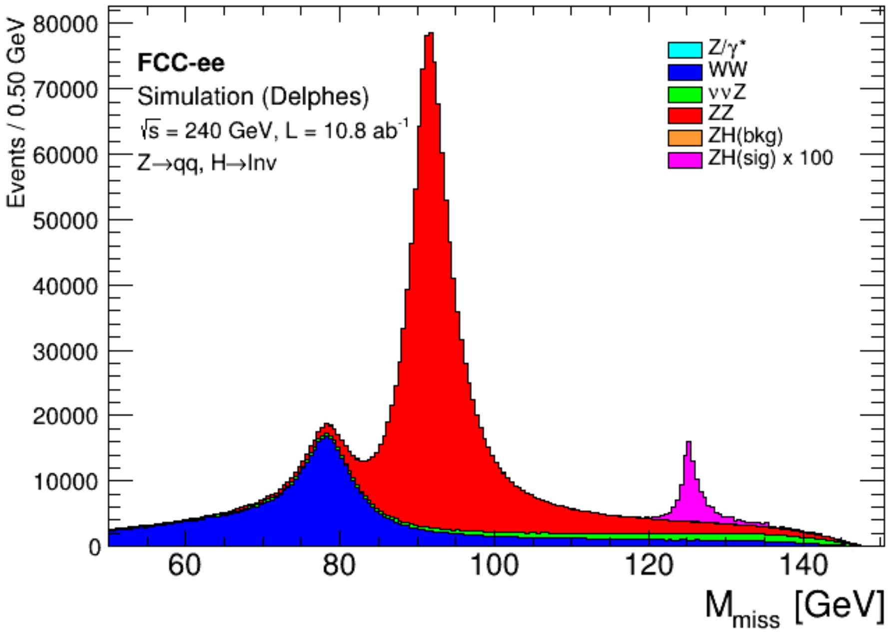
This extra variable allows for much better separation from the dominate ZZ background.

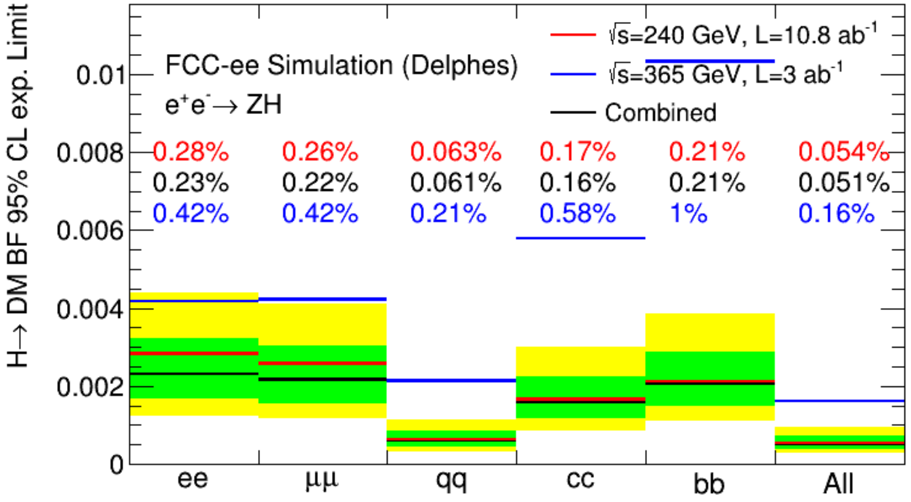
The less jet activity of the lepton collisions allow for the use of the quark decay modes of the Z boson. Which have much larger branching fractions.

Overall resulting in much better limits on the Branching Fraction, 0.05%.

With the sensitivity reaching the SM prediction for Higgs to Invisible, a 4σ measurement on the SM is possible.

Only have to wait 30 years.





Other Work

Completed ATLAS Qualification Task on ITk

- Developed environmental sensor setup to measure thermal cycles down to -55 °C for the ITk Upgrade.

ITk Slice Setup

- Currently on LTA at CERN working at the ATLAS SR1 cleanroom.
- Developing an interactive panel to display environmental sensor information.

Partial Run3 Heavy Higgs boson decaying to ZZ search.

- Searches a wide mass range of 200 GeV to 3 TeV.
- Analysis has preliminary results with systematics.
- Aiming for publication by the end of this year.