Higgs Physics at ATLAS and FCC-ee
ATLAS ITk Pixel Thermal Study

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First Year Particle Physics Presentation

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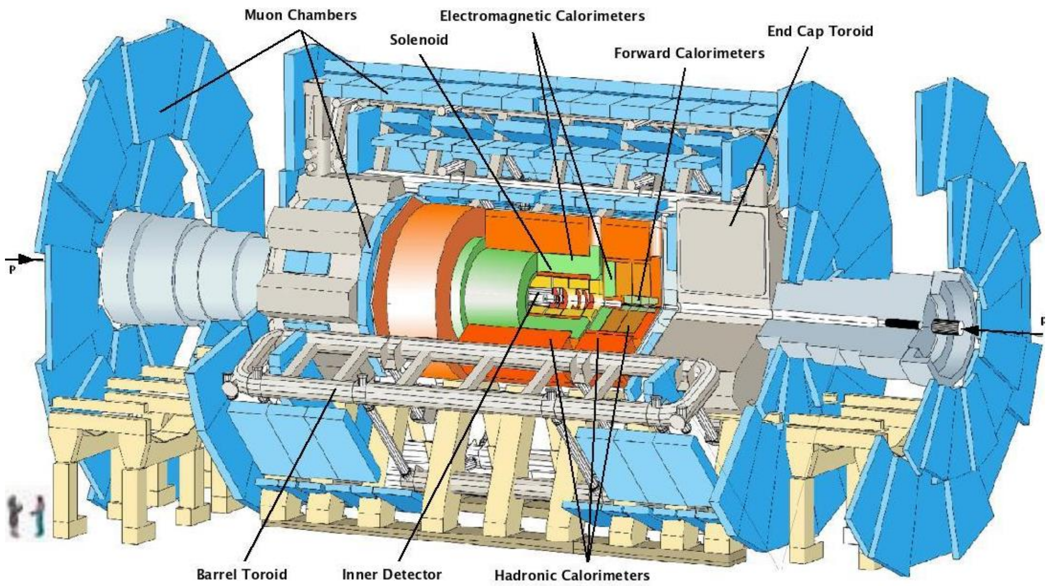
ATLAS Higgs Physics

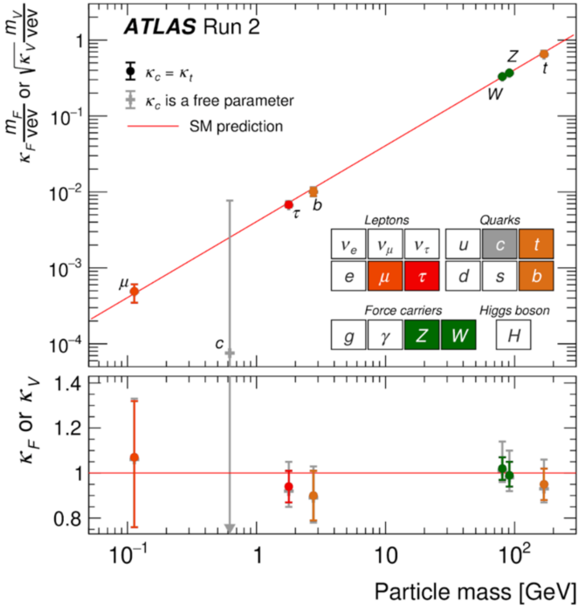
- The ATLAS detector is one of four main detectors on the LHC.
- Being a general purpose detector focusing on colliding protons at the highest energies.
- The aims of ATLAS is to search for new physics, test the Standard Model and to improve our understanding of the Higgs boson.



Since the discovery of the Higgs boson in 2012 understanding the Higgs mechanism has become a major focus as it could be a gateway to new physics.

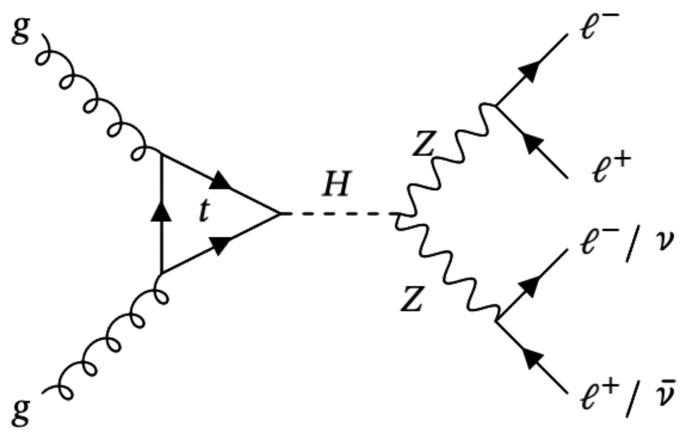
Some key areas of interest are:

- Precision measurements on the Higgs boson
- Searches for an Extended Higgs sectors (addition scalars)
- Probing the Higgs boson decay to invisible particles



Extended Higgs Sector

ATLAS Run2 + partial Run3
Heavy Resonance Search $S \rightarrow ZZ \rightarrow llll/ll\nu\nu$

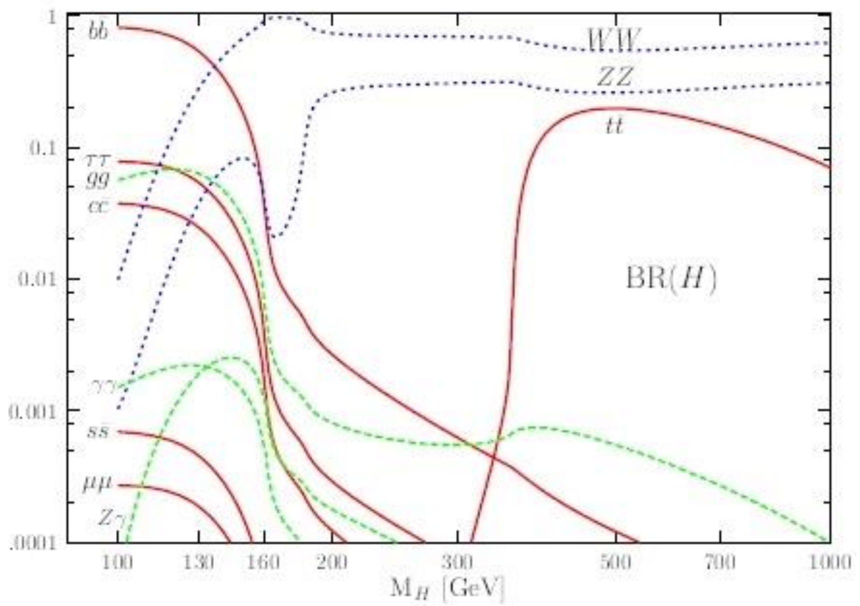


The Standard Model Higgs boson could be part of an extended Higgs sector such as in theories of two Higgs doublet model (2HDM) which predicts an extra complex scalar field resulting in 4 extra Higgs bosons.

One of these extra Higgs bosons will be a neutral CP-even scalar similar to the SM Higgs just with a larger mass.

At this larger mass the decay to ZZ will have a larger branching fraction making it ideal for the search. With the search looking at the 4 lepton or 2 lepton 2 neutrino final states.

However, we will also interpret the results for a spin-2 Kaluza-Klein excitations of Graviton and Radion which both decay to ZZ.



Background estimation for $llvv$

The dominate backgrounds for the analysis are ZZ, WZ, non-resonant leptons (WW and $t\bar{t}$) and $Z + jets$.

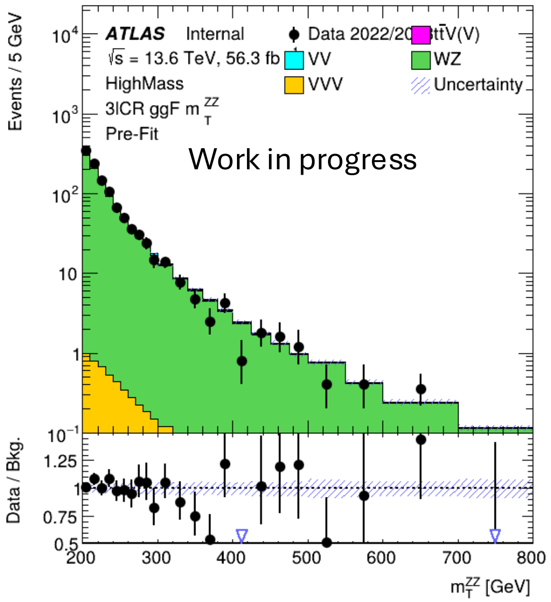
To better estimate the background processes Control Regions are used with high background purity.

For the WZ background a 3 lepton Control Region is used and for the non-resonant leptons a $e\mu$ Control Region.

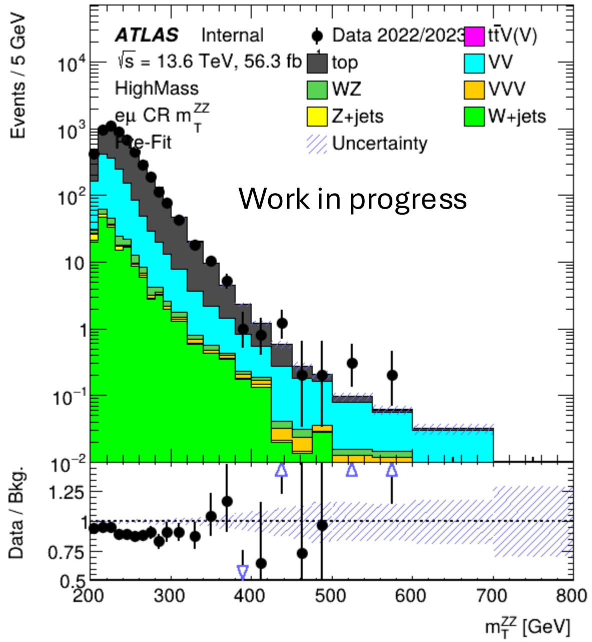
The CRs also provide a way of comparing the MC distribution to data for a range of kinematic variables and showed good distributional agreement.

These Control Regions are put into a fit and given a normalisation parameter for the variable.

3 lepton Control Region



$e\mu$ Control Region

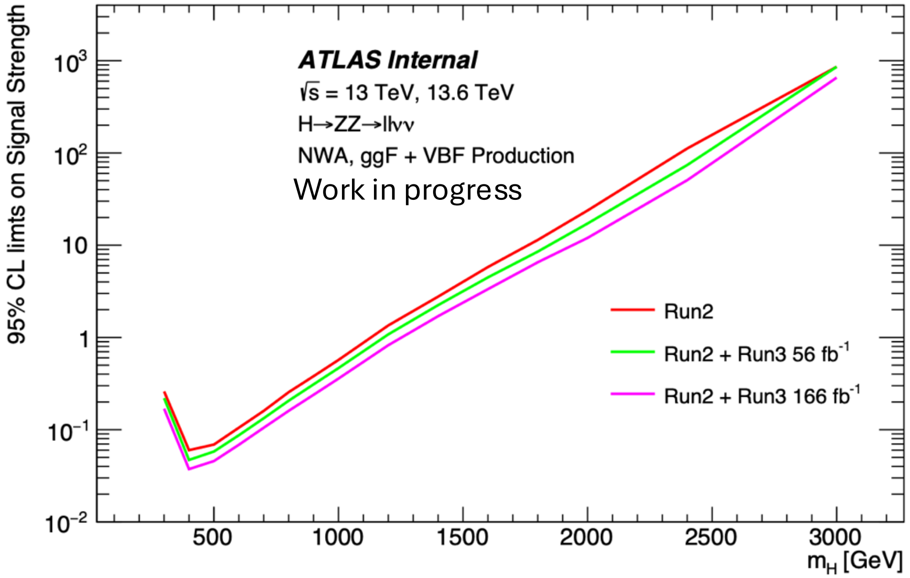


Fitting $llvv$ Channel

The signal region is divided into the lepton generation (ee or $\mu\mu$) and then into production methods with ggF- or VBF-enriched regions.

The current plans are to just include the Run 3 data from years 2022 and 2023 resulting in 56 fb^{-1} of data. However, an investigation into including the data from 2024, totalling 166 fb^{-1}.

The investigation found the 95% CL limits on the Signal Strength of the Heavy Higgs sample using an Asimov dataset for the mass range of 300 – 3000 GeV. The results showed including 2024 would improve upon the limits of Run 2 by around 40% whereas including only 2022 and 2023 will improve the limits by around 20%.



What's next

- The group is currently developing a pNN to improve the selections on the signal.

- The $Z + jets$ Control Region needs to be defined.

- Systematic uncertainties are being produced for all the samples and need to be evaluated.

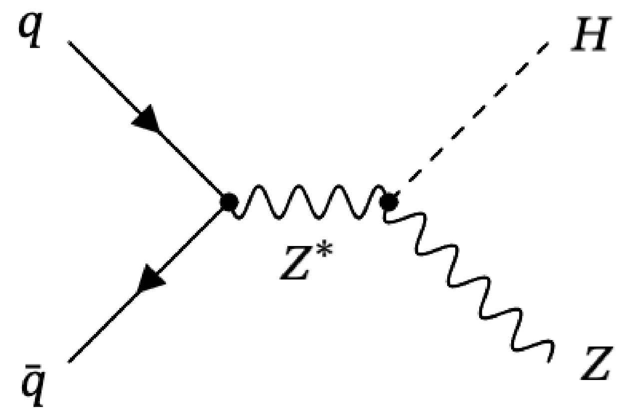
- The merging strategy to combine the $llll$ and the $ll\nu\nu$ channels.

- Potentially add data from 2024, so will have to produce new samples.

Higgs to invisible particles

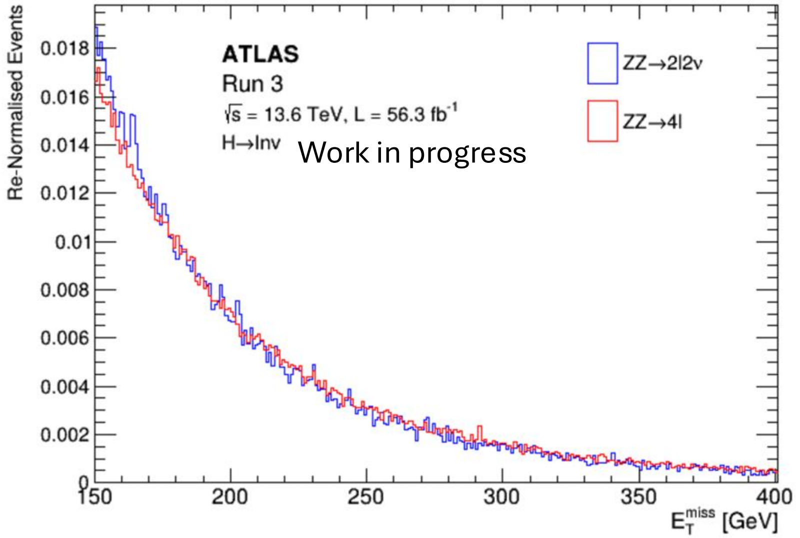
Higgs to invisible

In the Standard Model the Higgs boson decays to invisible particles through $H \rightarrow ZZ^* \rightarrow \nu\nu\nu\nu$ which has a small branching fraction of 0.106%.



In extensions to the SM such as the Higgs portal model it is possible the Higgs boson can decay to non-SM invisible particles potentially related to dark matter, increasing the branching fraction.

ATLAS and CMS currently have limits on the Higgs decaying to invisible particles of 11% and 15% respectively, using Run1 and Run2 data.



The main focus of my PhD is on ATLAS Run3 Higgs to invisible searches from ZH production which shares a lot of similarities to the $ll\nu\nu$ Heavy Resonance search due to the having the same background processes requiring the same Control Regions.

This analysis is just about to start with only the overlapping work completed and a preliminary study into the 4lCR to improve the ZZ modelling.

FCC-ee Precision Measurements

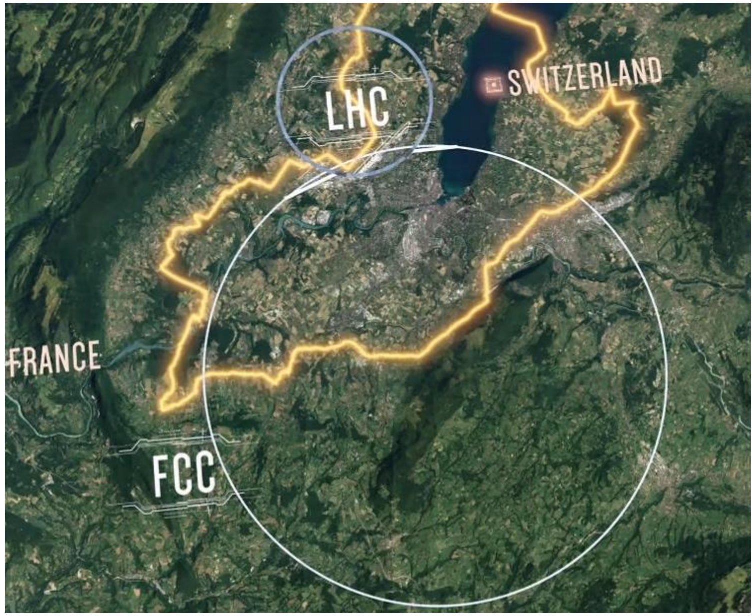
The Future Circular Collider is a proposed next generation particle collider which will be much bigger than the current LHC.

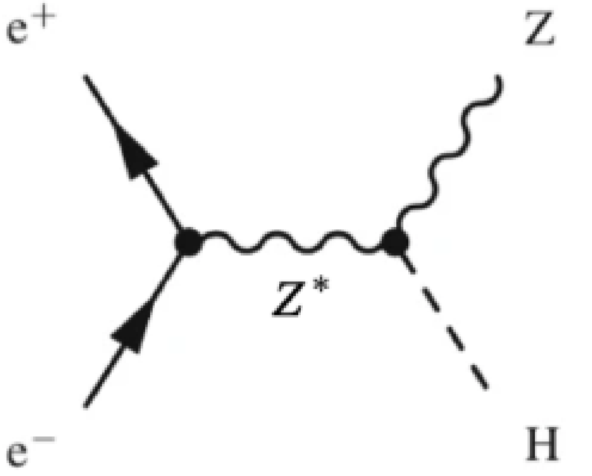
The first phase of the FCC will have electron and positrons collided which allows for much better precision measurements compared to hadron colliders. Due to electrons being fundamental particles.

Higgs physics at the FCC-ee will be mainly done at centre-of-mass energy of 240 GeV but also possible at 365 GeV. At these energy the dominate Higgs production with a Z boson (ZH).

In the case of the Higgs decaying to invisible particles, since the energy of the collision is known the missing mass can be calculated from the recoiling Z boson if the Z decays visibly:

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



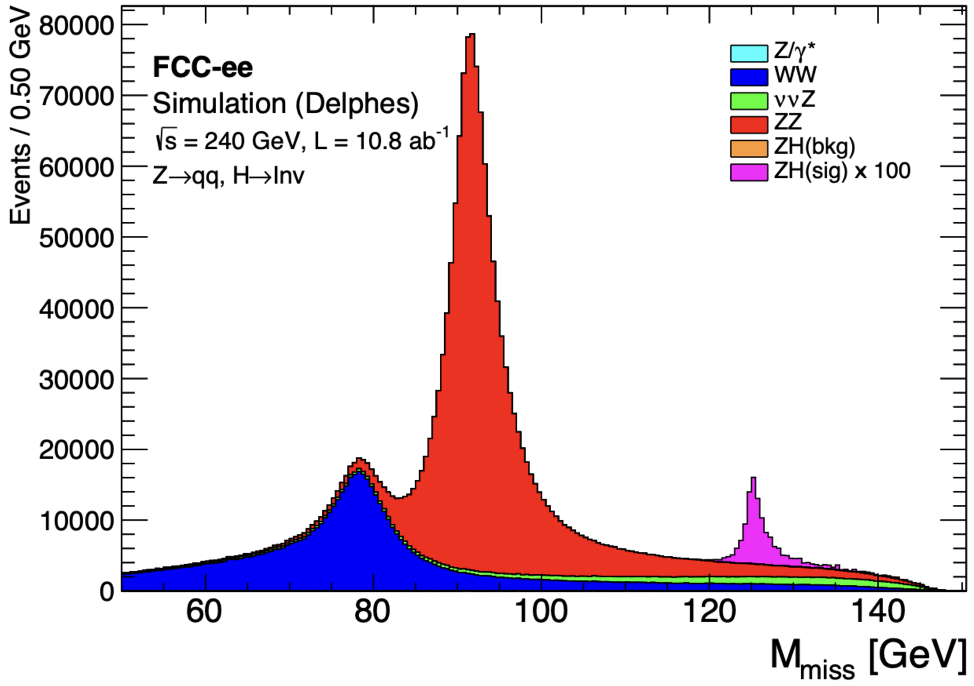


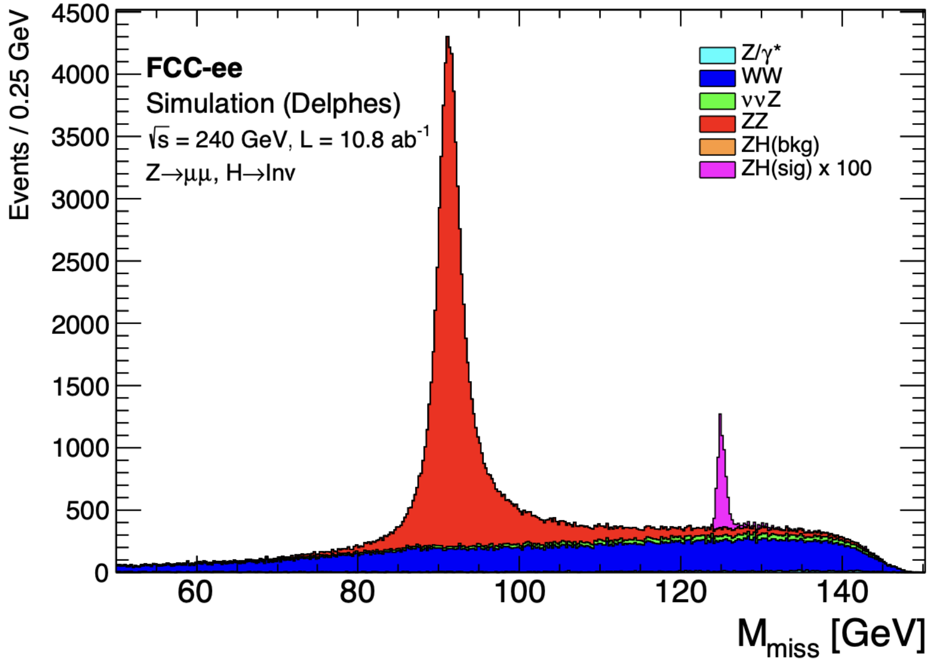
FCC-ee H → inv M_{miss} plots

When plotting this missing mass it results in a well defined peak at the Higgs boson mass.

The analysis was divided into the different Z boson decay channels of: $e^+e^-, \mu^+\mu^-, b\bar{b}, c\bar{c}$ and lighter quarks.

With the electrons and muons providing the best precision but suffer from the lower branching fraction of the Z boson.





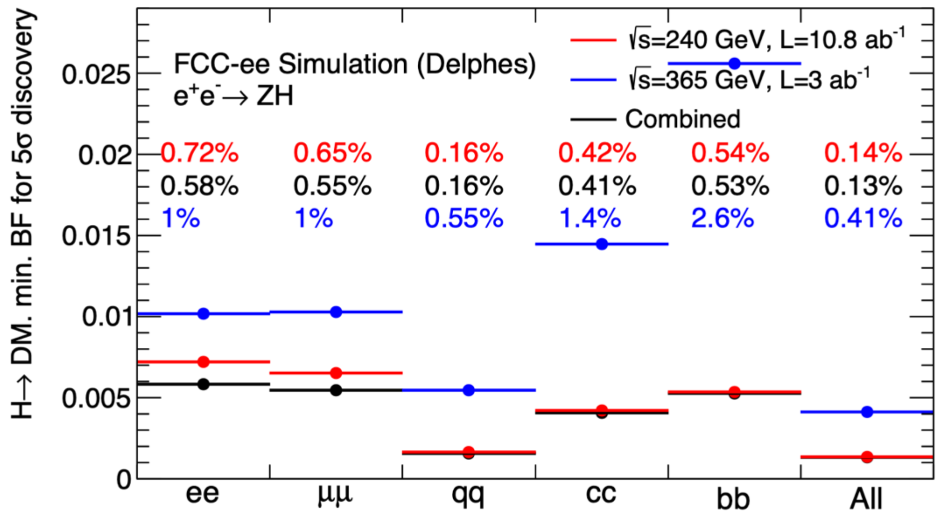
FCC-ee H → inv Results

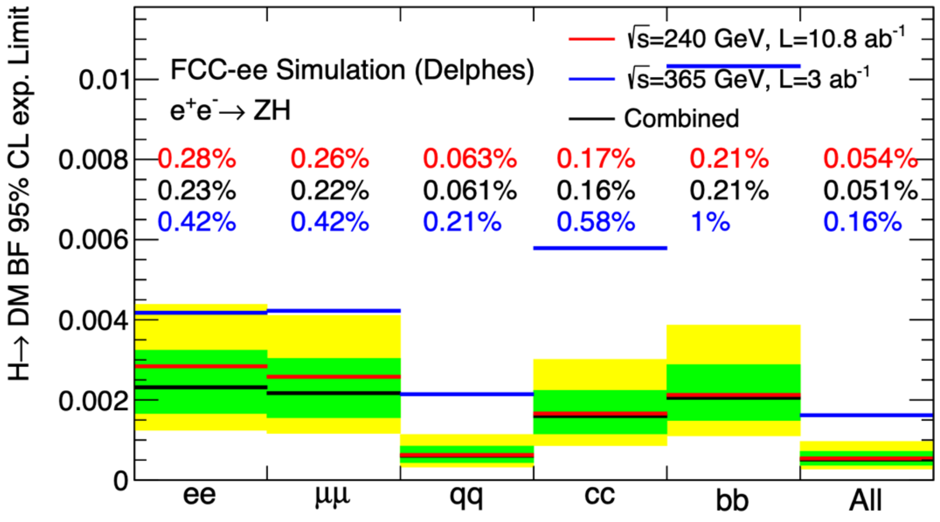
If the SM branching fraction is assumed, a 25% relative uncertainty measurement on the branching fraction is possible after the full proposed run time of the FCC-ee.

Assuming the scenario of the Higgs decaying to invisible non-SM particles, the SM Higgs is treated as a background and the new signal is floated.

If the branching fraction is larger than 0.13% a 5σ discovery is possible.

In the case of no discovery, the decay with a branching fraction larger than 0.051% can be ruled with a 95% confidence.





ATLAS Inner Tracker Upgrade

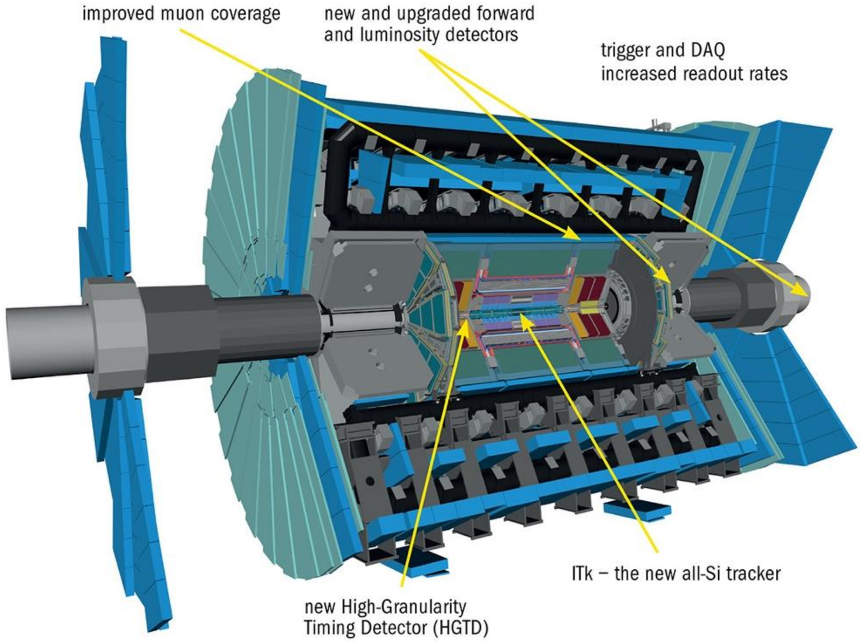
ATLAS ITk Upgrade

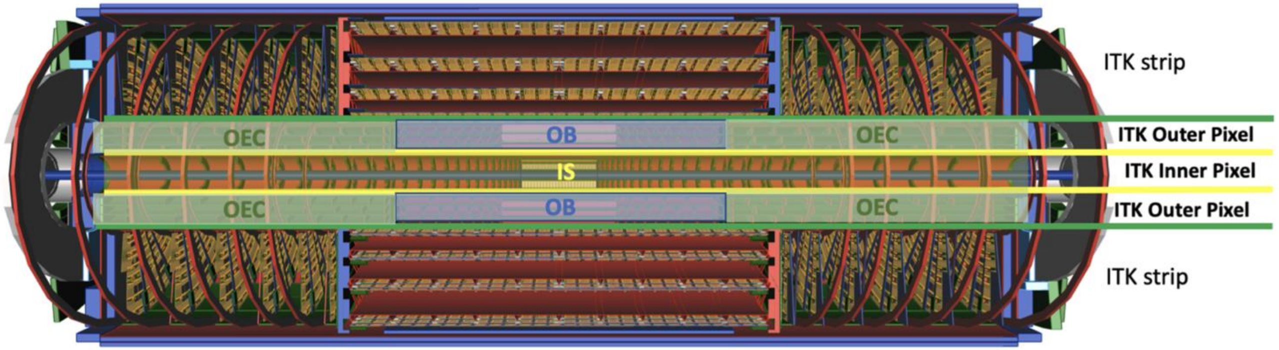
The ATLAS detector is about to undergo improvements in preparation for the High Luminosity Upgrade of the LHC (HL-LHC).

At the HL-LHC the ATLAS detector will see an increase of instantaneous luminosity by a factor of 5 to 7.5 times. Expected to record 3000 fb^{-1} over the 10 years of data taking.

This increased luminosity requires improvements in the current ATLAS detector to deal with the extra challenges of pile-up and radiation.

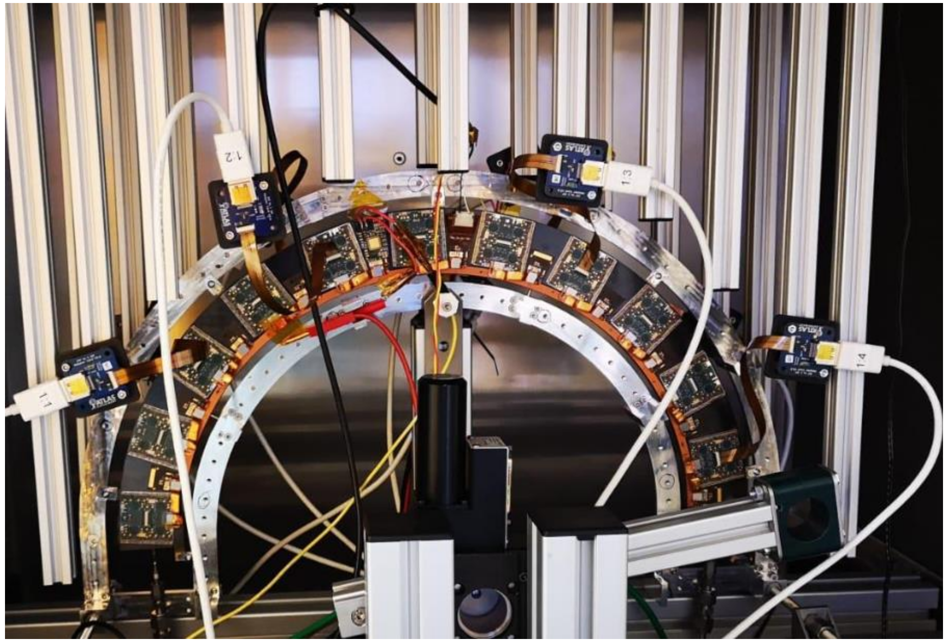
Therefore the inner detector is being replaced with an improved Inner Tracker made up of silicon pixel and silicon strip modules.





ITk Pixel Modules Thermal Testing

Liverpool has a prototype pixel detector half-ring (Ring 1) for the Outer-End Cap (OEC). Which features 22 RD53A pixel modules.

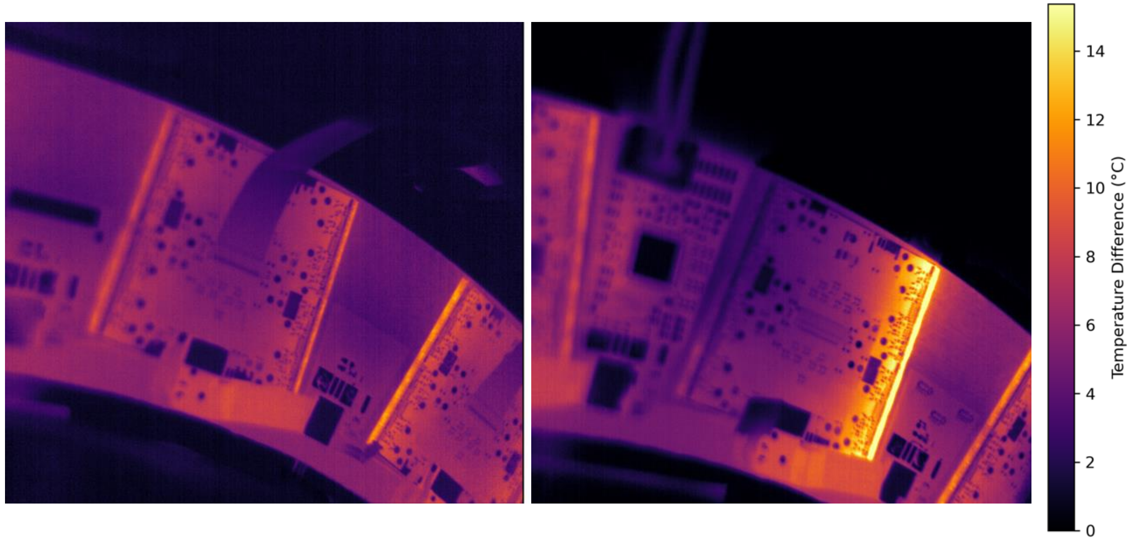


As part of my Qualification task, I investigated the temperature of the modules on Ring 1 to look for potential hot spots or faults.

The results showed:

- Most modules performed well and had a uniform temperature, apart from one damaged module.
- Overall the temperature variation was low enough to not cause large uncertainty in the Lorentz angle of the silicon, therefore not affecting the track reconstruction.

Working module Damaged module



Preparation to Thermal Cycle the Pixel Outer End Cap

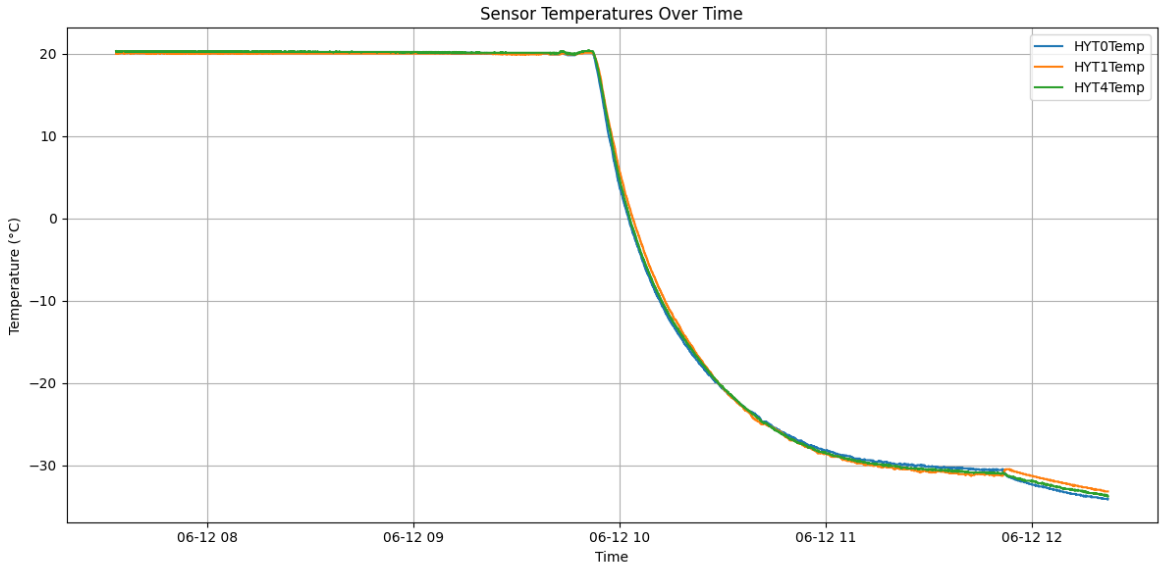
Once the ITk is installed it will have a operating temperature of -35℃ but will likely fluctuate between -45℃ and 40℃ over the life time of the detector.

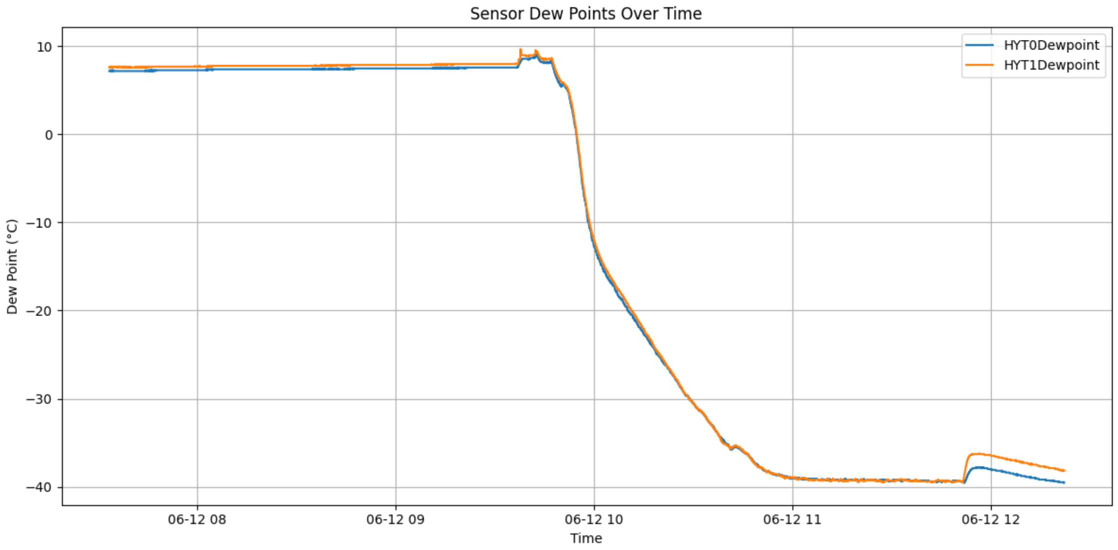
If there is a problem with the cooling some parts could reach -55℃.

To verify the ITk will survive these conditions it will be safely Thermal cycled to -55℃.

The second part of my Qualification task focuses on setting up temperature and humidity sensors to monitor the temperature of the Environmental Chamber in the clean room down to -20℃ and a test box placed inside which will go down to -55℃.

Currently the sensors are being calibrated and have only managed to do down to -35℃. So more work is needed.





Any Questions