# Search for Dark Matter produced in association with a Standard Model Higgs boson decaying to *b*-quarks with 139 fb$^{-1}$ of pp collision data with the ATLAS detector

## Motivation

Various astrophysical observations indicate the existence of **Dark Matter (DM)** which interacts neither via the electromagnetic nor the strong force. Therefore **Imbalance in the transverse momentum (MET)** can be an indication for DM.

If the Higgs boson couples directly to DM then in **mono-Higgs** searches it would be predominantly produced in the final state. **This allows the mono-Higgs searches to directly probe the DM and SM interaction vertex.**

The **Higgs boson decay to *b*-quarks** is the most promising final state to probe DM + Higgs production due to this decay having the largest branching ratio (~58%).

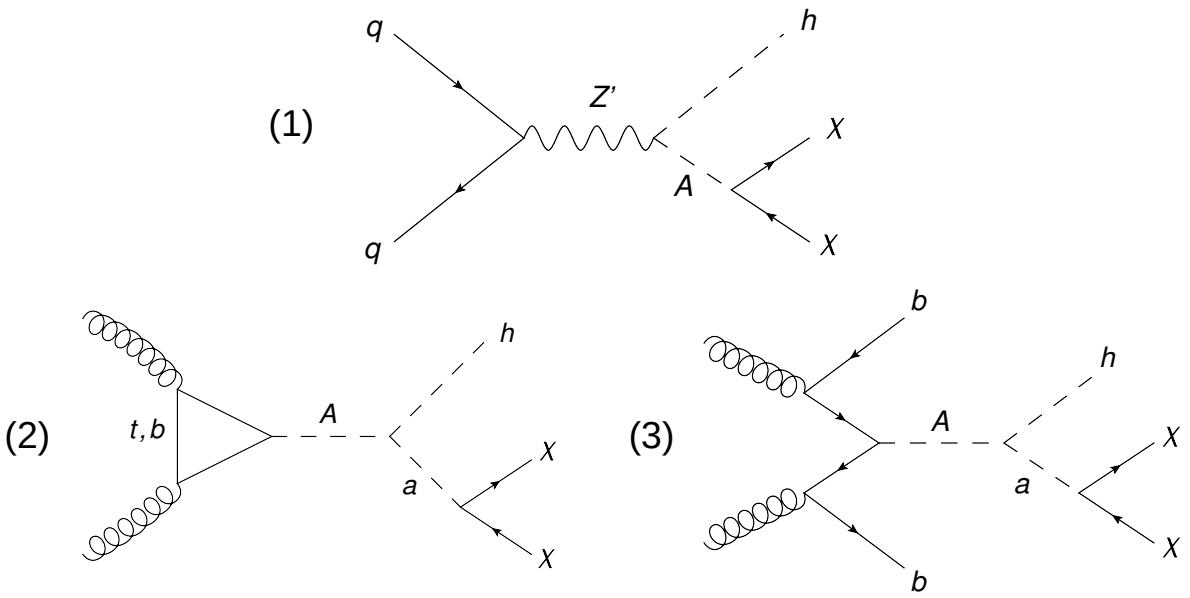


Fig.: Feynman diagrams for the dominating production modes for the Z'-2HDM (1) and the 2HDM+a (2, 3) models. Which production mode dominates for 2HDM+a depends on the tan(β) parameter of the model.

The **Two-Higgs-Doublet model (2HDM)** is a model which extends the SM with a second Higgs doublet. In this analysis two variations of the 2HDM are used for interpreting the results.

The **Z'-2HDM** model further extends the SM by with an additional heavy vector boson (Z'). This model is mainly used as a benchmark for high-mass resonances.

The second variation is the **2HDM+a** model which adds a new pseudoscalar singlet and has the following advantages:

- simplest renormalisable and gauge-invariant extension of a simplified pseudoscalar mediator model
- wide variety of experimental signatures which can provide complementary sensitivity

ATLAS EXPERIMENT

DESY.

PIER
Partnership of Universität Hamburg and DESY

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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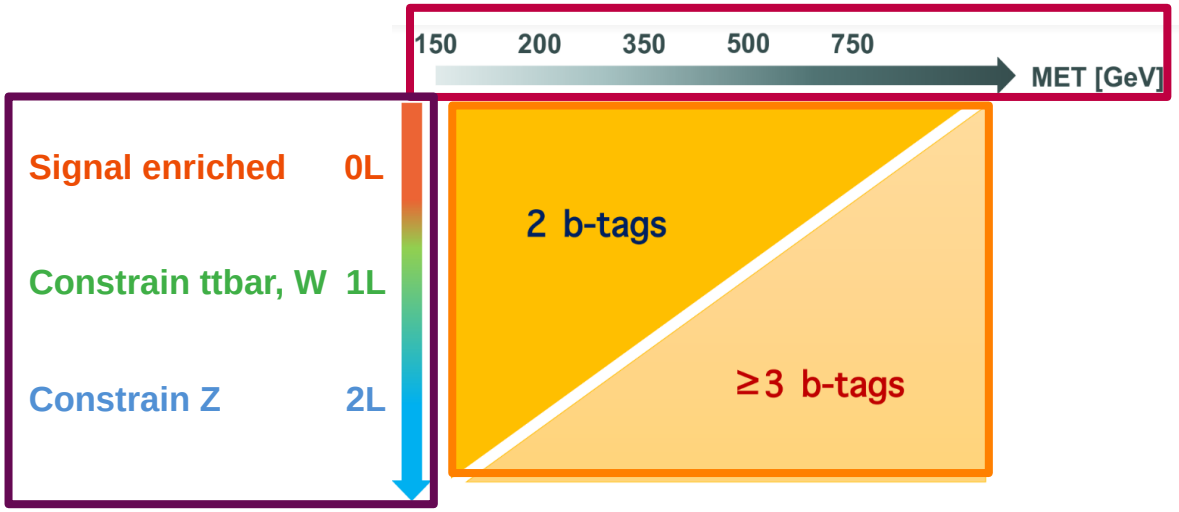
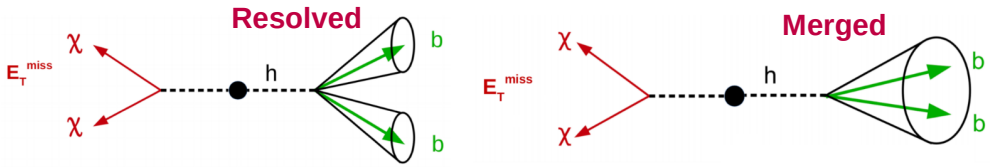
# Analysis Strategy



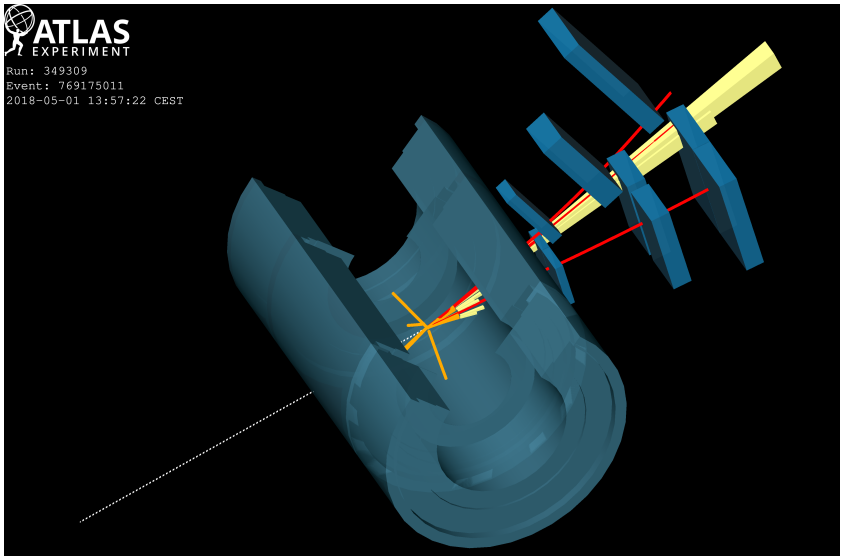




The Higgs is recoiling against the MET, hence the MET can serve as a proxy for the transverse momentum of the Higgs.

- **Resolved region** (150<MET<500 GeV): the Higgs boson decay can be reconstructed as two separate jets
- **Merged region** (MET>500 GeV): the two b-quarks are close together and are reconstructed as one large radius jet that has two b-tagged variable-radius track jets associated to it

**Signal events are expected to have no isolated leptons.**
Two control regions (CR) are used to constrain the normalization of the major backgrounds: a **one-muon CR** that is enriched in ttbar and W+jets and a **two-lepton CR** ($e^+e^-$, $\mu^+\mu^-$) for Z+jets.

Two sets of regions are required, one with **2 *b*-tags to capture the Higgs decay** and one with **>= 3 *b*-tags to enhance sensitivity to the *bb*A production** predicted by the 2HDM+a model.




**Event display for an event selected in the 2 *b*-tag merged signal region.** The event contains a large radius jet (with the yellow bar indicating the associated energy deposit in the hadronic calorimeter) with a reconstructed mass of 121 GeV and with a pT of 1.2 TeV. The direction of the missing transverse momentum is indicated by the dashed white line. Muons from decays in the b-tagged jets are indicated with red lines.

# Results

**Fit discriminant**
Selection of the post-fit signal regions are shown.
The final fit discriminant for each MET bin is the **invariant mass of the two leading *b*-jets** (resolved region) or the **mass of the large radius jet** (merged region).

In the one-muon CR the fit discriminant is the **muon-charge** which exploits the asymmetry of W+jets production at the LHC in this variable.

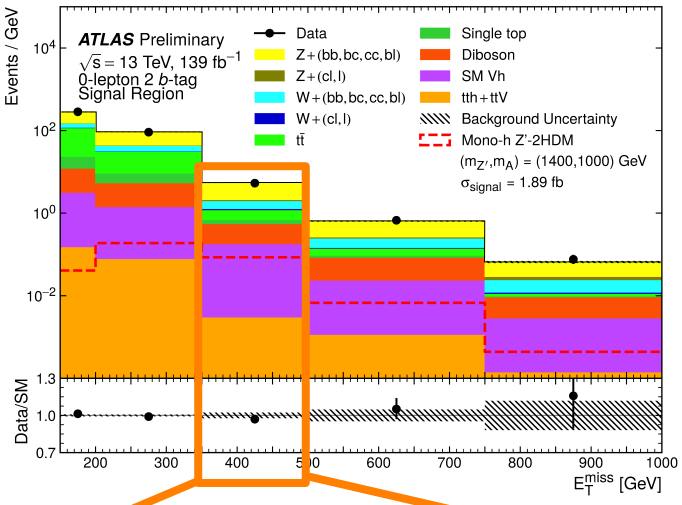
For the two-lepton CR only the **yield** is fitted.

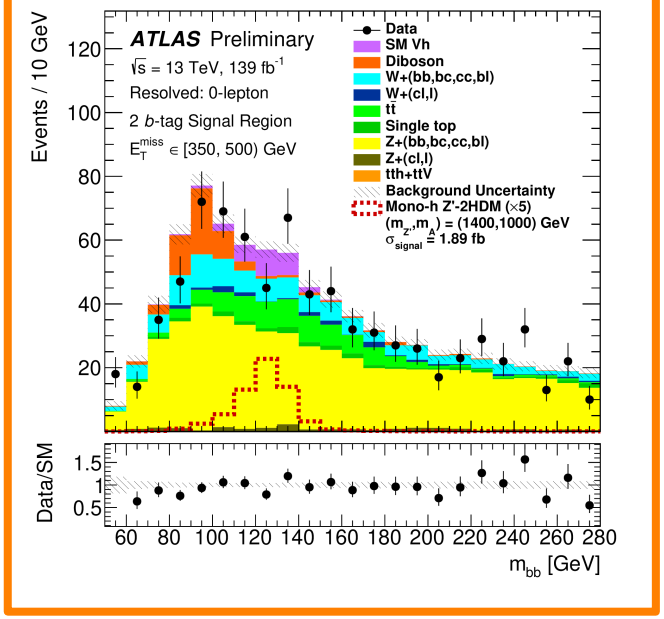
**Uncertainties**
- The **low MET** region is dominated by **systematic uncertainties** (jet uncertainties + modeling of top processes)
- In the **high MET** region, the **statistical uncertainty** from data dominates

**No significant deviation from the Standard Model is observed**

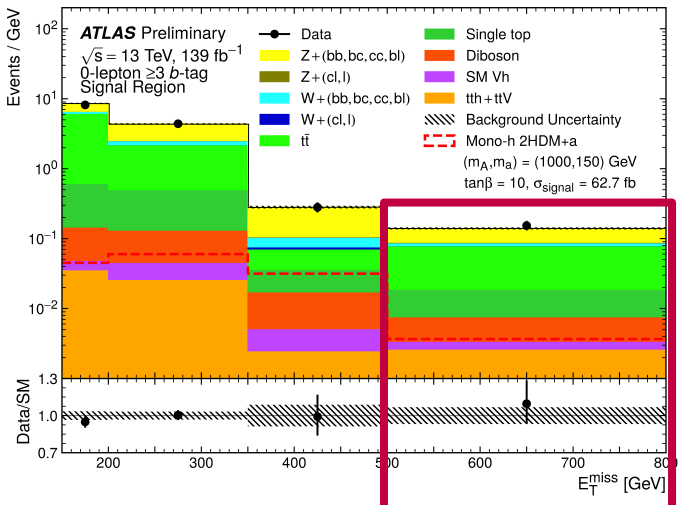
**=> Setting limits**

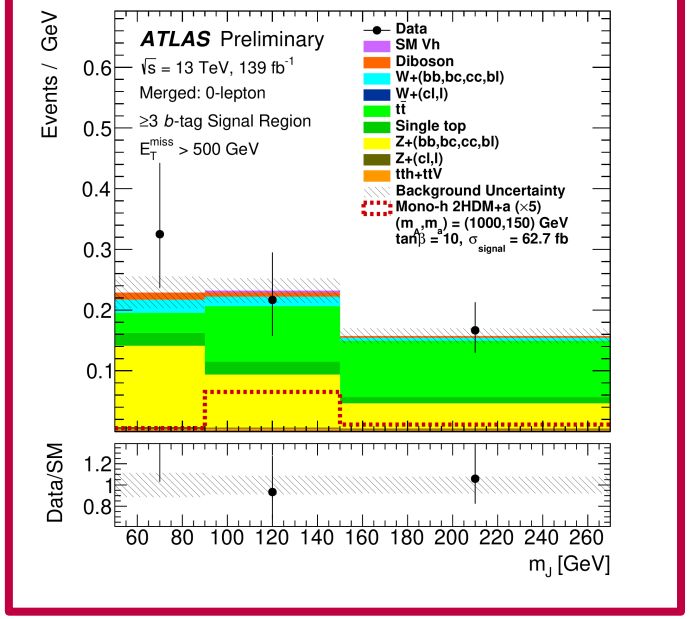
## 2 *b*-tag



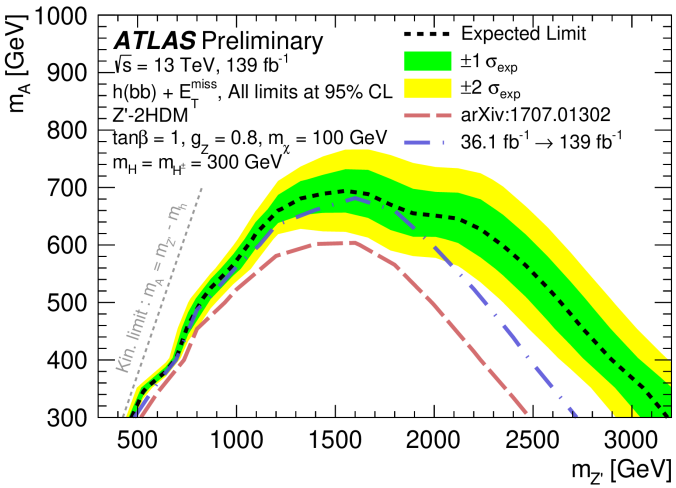




## ≥ 3 *b*-tag



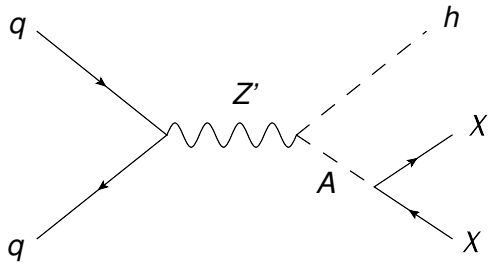



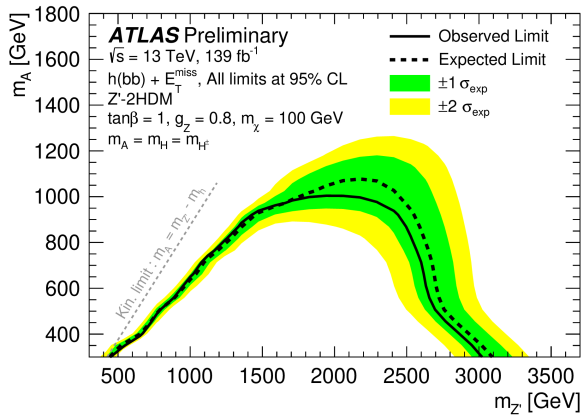
# Interpretation

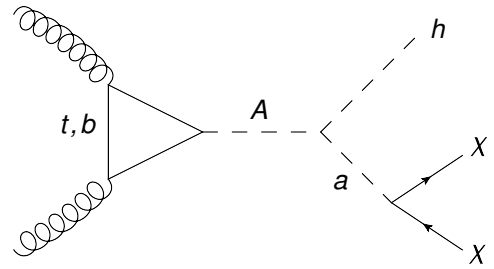


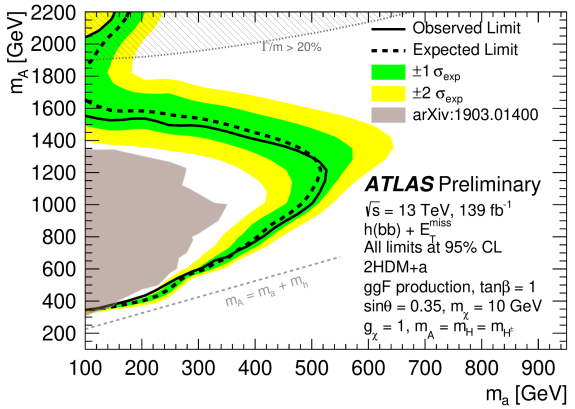

Compared to the previous ATLAS iteration of this analysis from 2017 the increased data statistics as well as many analysis optimizations have led to a stronger expected exclusion limit. Some of the **notable analysis optimizations** are:

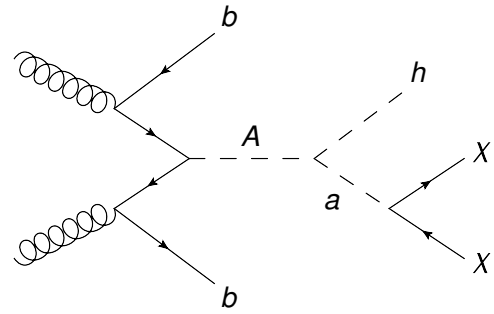
- Muon in jet correction: decays of b-quarks can produce muons inside the jet that previously were not taking into account for the jet reconstruction
- Finer MET binning: previously only one MET bin was used in the merged region
- Additional cut on total number of jets
- Improved *b*-tagging

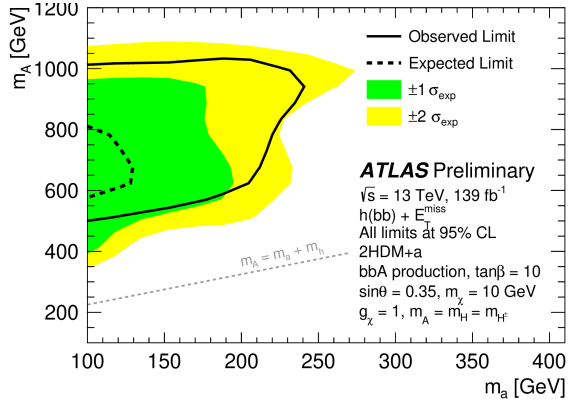



Exclusion contours for the Z'-2HDM and 2HDM+a models. This is the first time that a limit on the 2HDM+a (tan(β)=10) model is set in this final state.
Model-independent limits are also set but not shown here.