# Study of the Exotic Higgs Decay $H \to Za$

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Theoretical Framework

- Many physics phenomena are **not** described by the Standard Model, which requires extensions.

- One such extension is the **Two-Higgs-Doublet Model** (2HDM), which makes use of two Higgs doublets.

- The model predicts the existence of **additional** scalar particles, such as a **CP-odd lightweight scalar particle** a.

- This analysis focuses on the Beyond-Standard-Model (BSM) decay process $H \to Za$, with m_a in a range of $0.5 - 3.0$ GeV and decaying hadronically.
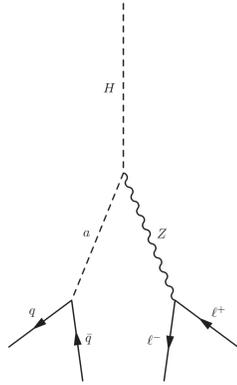
State of Art

- This work builds upon previous works in [1] and [2], using data from pp collisions of **LHC Run2** collected by the ATLAS experiment, with center-of-mass energy of 13 TeV.

- The search focuses on **decay** of the **Higgs boson** into a **light resonance**, identified with a BSM light elementary CP-odd scalar a.

- **Process kinematics**:
  1. Higgs boson decays into Z and a.
  2. Z **decays into** $\ell^+\ell^-$, and a decays into a **highly boosted jet** generated from two prongs.
  3. The main background is $Z+$ jets.

- **Event selection**:
  1. Jet with $p_T > 20$ GeV, lepton pair with $p_T > 18$ GeV, such that 81 GeV $< m_{\ell\ell} < 101$ GeV.
  2. Higgs candidate is reconstructed from the pair of Z leptons, plus a jet coming from the a. The invariant mass $m_{\ell\ell j}$ of the dilepton + jet signature peaks near the Higgs mass.
  3. Observed data compatible with SM predictions within uncertainties.
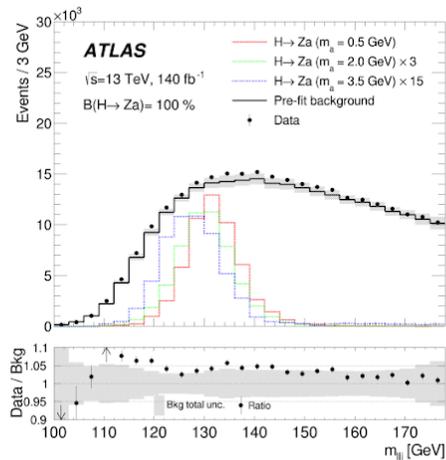
The previous analysis highlights a few **challenges**:
  1. The small mass of a leads to **very collimated hadronic** decay products, making the 2-prong jet hard to separate from QCD background.
  2. **Systematic uncertainties** limit the effectiveness of the analysis.

Goals & Outlook

- The goal of the work here presented is to **enhance the analysis sensitivity** for future searches by both improving the theoretical systematics in the $H \to Za$ model simulations as well as improving jet classification algorithms.

- Simulated data are generated through **Monte Carlo methods**, using POWHEG+PYTHIA/HERWIG for generation and DELPHES for reconstruction, and key kinematic observables are tested.

- Upcoming task is the development and training of an **improved neural network** to better discriminate signal from the dominant $Z+$jets background for different a-mass hypotheses.

Results

- **Sample consistency and validation**, comparison between ATLAS and our DELPHES detector response simulations:

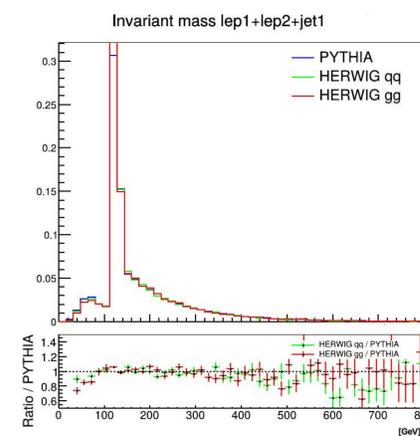p_T of electrons. p_T of muons. p_T of jets.
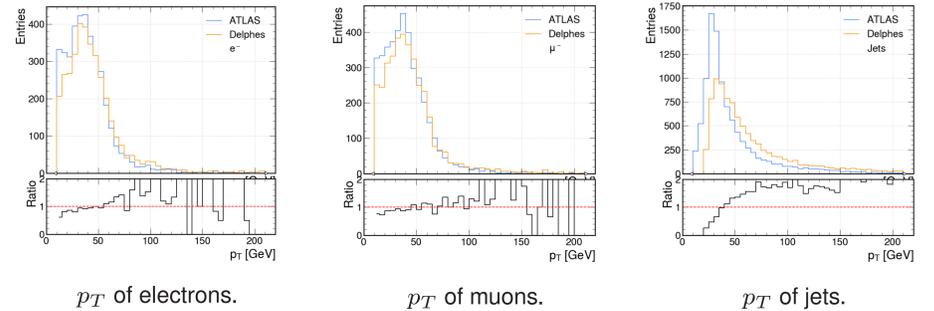
- **Study of kinematical variables**, using samples generated with PYTHIA and HERWIG:
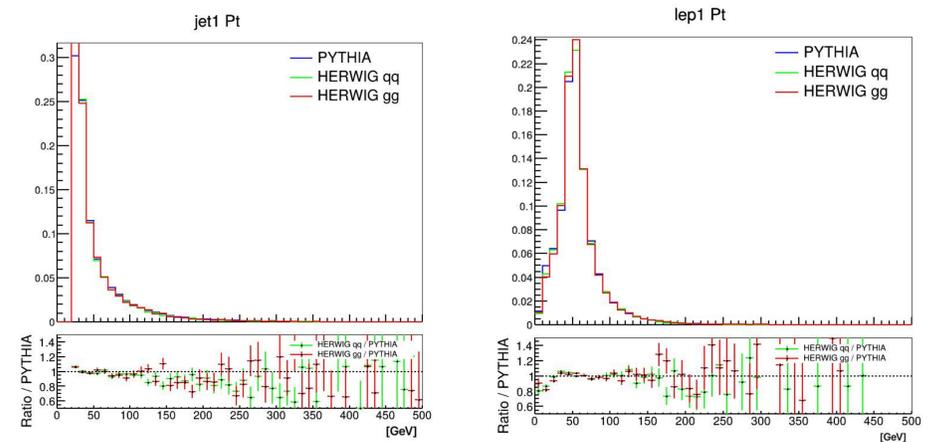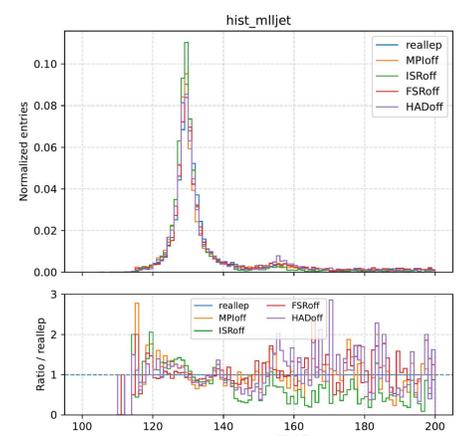

p_T of the leading jet, comparison between samples.

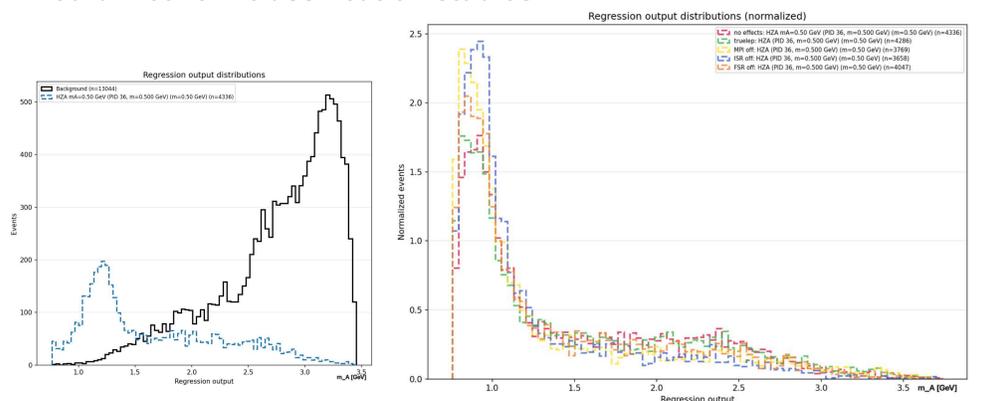p_T of leading lepton, comparison between samples.

$m_{\ell\ell j}$ comparison between standard shower and hadronization algorithms.

$m_{\ell\ell j}$ for different shower and hadronization physical processes.

- **Neural network classification studies:**

NN classification plot for $m_a = 0.5$ GeV.

Classification NN results for signals with different shower and hadronization physical processes from PYTHIA samples ($m_a = 0.5$ GeV).

KEY REFERENCES

[1] Chisholm, A. et al., *"Measuring rare and exclusive Higgs boson decays into light resonances"*, In: The European Physical Journal C 76.9 (Sept. 2016).

[2] The ATLAS Collaboration, *"Search for Higgs boson decays into a Z boson and a light hadronically decaying resonance in pp collisions at 140 fb^{-1} of 13 TeV with the ATLAS detector"*. In: Physics Letters B 868 (Sept. 2025), p. 139671.