Higgs to Invisible Searches with the CMS Experiment at the Large Hadron Collider

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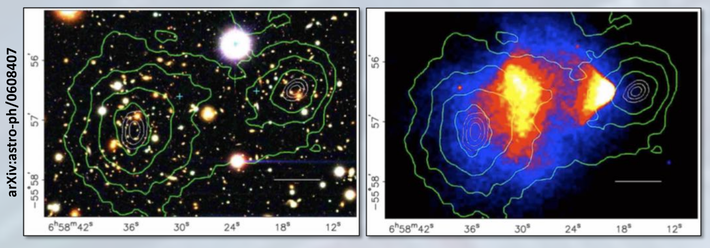
Theoretical Motivation

Decay of the Higgs boson to invisible final states is predicted by many theories that aim to describe phenomena beyond the standard model.
Some of these theories allow final states to be dark matter particles.

H → DARK MATTER



On the right, contours of the Bullet Cluster mass distribution from gravitational lensing (optical images from the Magellan telescope). On the left, data from Chandra x-ray, that traces hot plasma in a galaxy, plotted over the same contours.

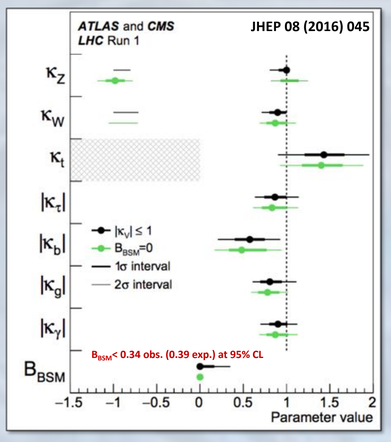
The results highlight that most of the matter resides in a different location to the plasma (which experienced friction during the merger and slowed down).

Experimental Motivation

The visible decays of the Higgs boson are used to constrain the invisible branching fraction (**indirect searches**) since beyond the standard model Higgs decays affect the total width of the Higgs boson.

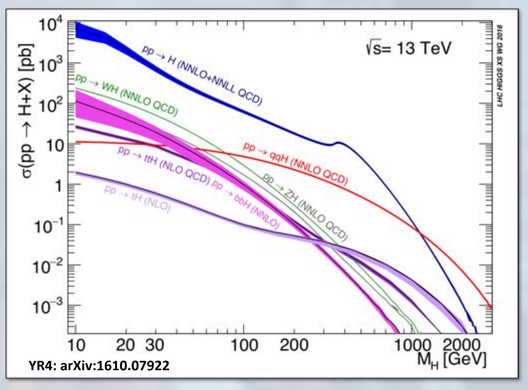
However, large uncertainties might accommodate beyond the standard model properties.

The standard model branching ratio H(inv.) is ≈0.12% for H(ZZ(4ν)).

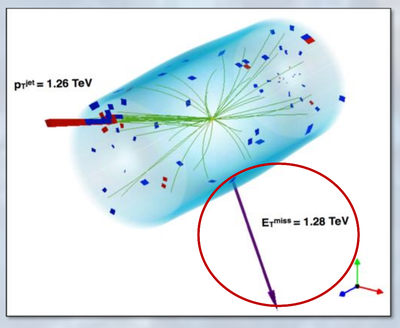


Direct Searches

Considering Higgs boson production mechanisms, **direct searches** can be performed.



The requirement is that the Higgs boson recoils against a visible system + MET (missing transverse energy) in the final states.

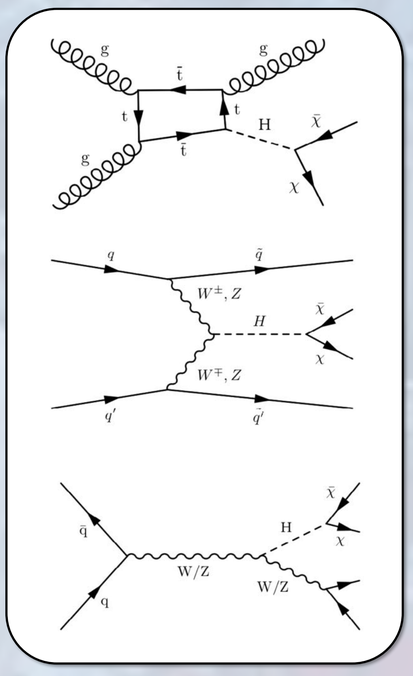


The **gluon-gluon fusion** (ggH) channel has the highest production cross-section.
However, it is possible not to have visible products in the final states.

The **vector boson fusion** (VBF) channel is the most sensitive even though it has a large background and it is hard to trigger on. The jets have a large pseudo-rapidity gap and there is no colour connection between them.

The **vector boson associated production** (VH) channel has a low rate and its final states contain leptons that could be missed. However, VH with V → *leptons* gives well isolated leptons to trigger on.

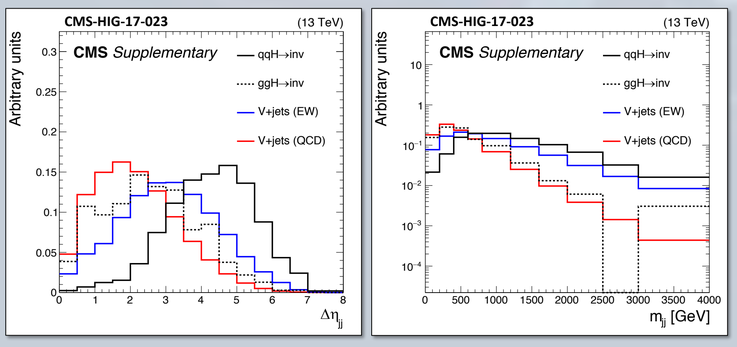
higher production cross-section



VBF Higgs to Invisible Searches

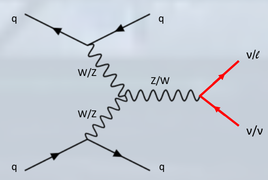
Signal topology:

- two jets with large pseudo-rapidity separation ($\Delta\eta_{jj}$);
- large dijet invariant mass (m_{jj});
- MET well separated from any jet.



Expected backgrounds:

- $Z \to \nu\nu$ + jets;
- $W \to \ell\nu$ + jets;



- Top quark, diboson, and QCD multi-jet.

Two different approaches used:

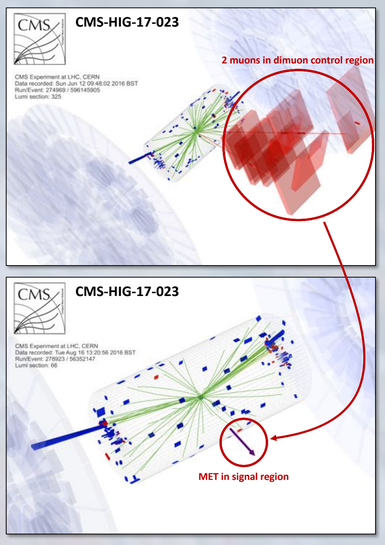
- *cut-and-count*, results directly translated into a limit on the visible cross-section in a model independent way;
- *shape*, improves the sensitivity for a SM-like H(inv.).

Control Regions

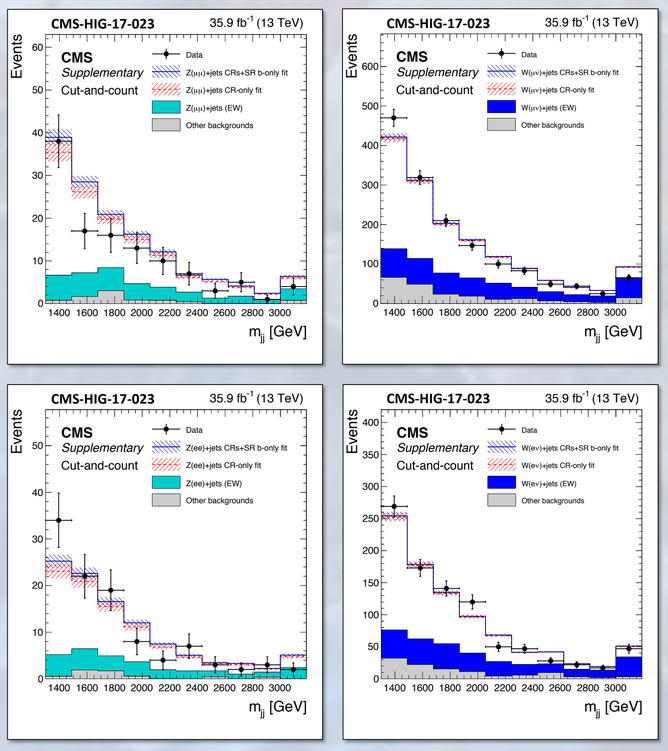
Most backgrounds come from misreconstructed jets and/or missed leptons. These backgrounds are estimated using control regions where leptons are identified.

To estimate the background in the signal region:

$$N^{SR}_{background} = \frac{N^{SR}_{MC}}{N^{CR}_{MC}} \cdot \left(N^{CR}_{data} - N^{CR}_{other\ backgrounds}\right)$$

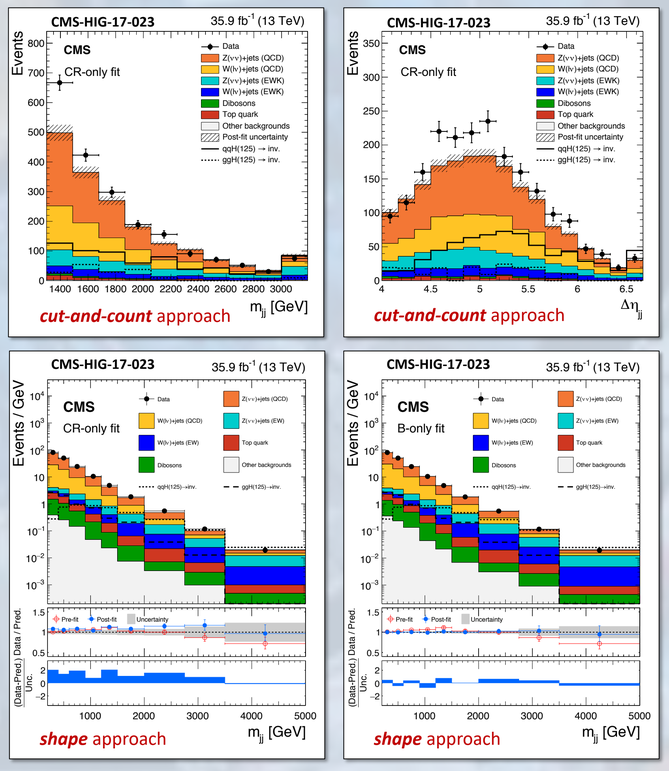


The V+jets represent the largest backgrounds in this search (≈95%), and are determined through a simultaneous maximum-likelihood fit across four control regions and the signal region.

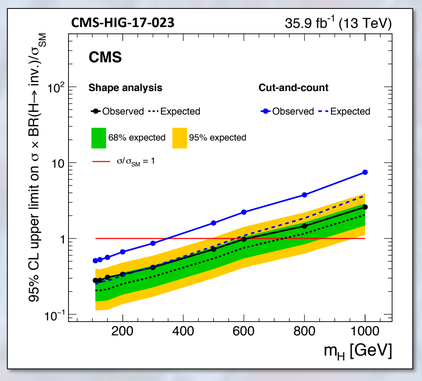


- p_T^{miss} is calculated excluding the p_T of the identified leptons (proxy for signal region).
- The signal region selection is used with specific lepton selections to construct the control regions.
- Hadronic-τ, γ, and additional muons or electrons are rejected.

Signal Region

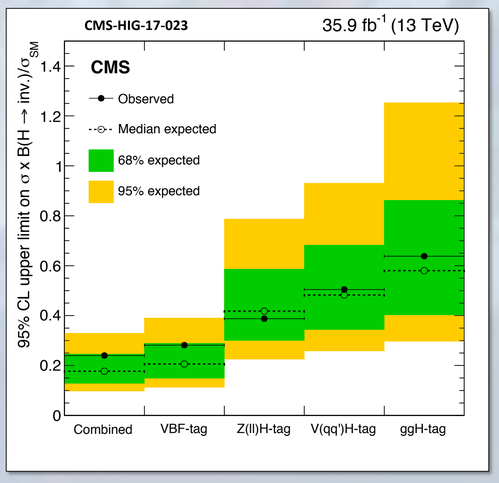


Assuming the standard model production cross-section, an observed (expected) upper limit on the invisible branching fraction of the 125 GeV Higgs boson is found to be 0.53 (0.27) for the cut-and-count and 0.28 (0.21) for the shape analyses at 95% confidence level, using the 2016 13 TeV dataset of 35.9 fb^{-1}.



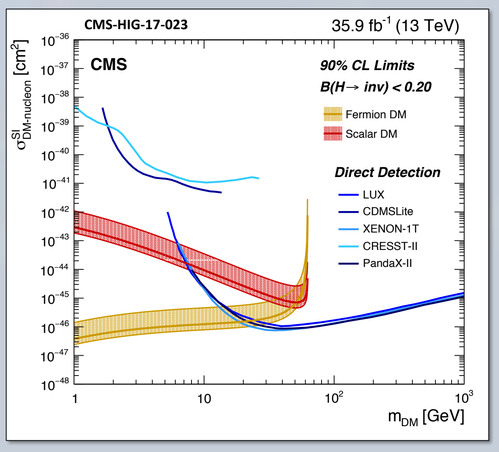
Combination and Dark Matter Interpretation

The combination of searches for Higgs decays to invisible final states can be used to probe the compatibility of the Higgs boson found at CMS with the standard model prediction. The searches target the ggH, VBF, and VH production modes, using 2016 13 TeV datasets.
The results indicate that the relative contributions between the different production mechanisms are consistent with their standard model predictions within the uncertainties. The combination yields an observed (expected) upper limit on the invisible branching fraction of the 125 GeV Higgs boson of **0.24** (**0.18**) at 95% confidence level assuming standard model production rates.



The $\mathcal{B}$(H(inv.)) can be translated into DM-nucleon spin-independent cross-section limits as a function of dark matter mass, using Higgs-Portal models and assuming **scalar**/**fermion** dark matter candidate.

The LHC limits are complementary to direct detection experiments.



LHCP2018: Sixth Annual Conference on Large Hadron Collider Physics, 4-9 June 2018, Bologna (Italy)