Search for invisible Higgs bosons produced via vector boson and Higgs portal Vector-Dark-Matter Revisit

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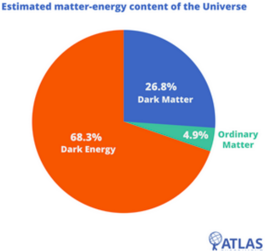
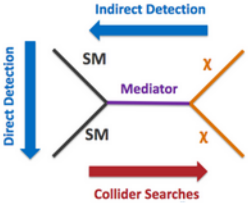
ATLAS EXPERIMENT

Motivation

- Strong evidence that dark matter (DM) exists.
- LHC searches complement evidence from direct and indirect detection.
  - Can actually produce DM mediators.
- Invisible decays of the Higgs boson, are good way of searching for new physics.
- Higgs boson could be a mediator between SM particles and ones that belong to the DM sector.

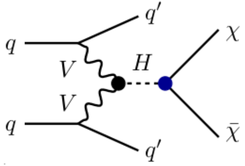




data sample: L=139 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV

Invisible decays of the Higgs boson:

$B^{SM}_{H\to inv}$: 0.1% vs. $B^{BSM}_{H\to inv}$: 10%



(e.i: H $\to$ WIMPs)

- powerful topology: VBF + MET
- signal: VBF, ggF
- main background: V+j, QCD

The experimental signature:

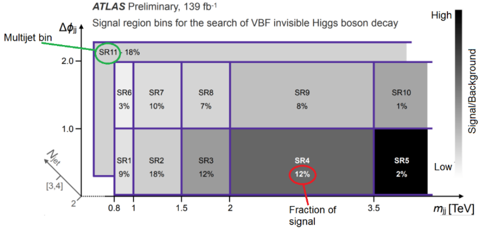
- pair of energetic jets
- wide gap in η_{jj}
- large invariant massess m_{jj}

Previous analysis result: (link)

- Limit on $B_{H\to inv}$: 0.37 at 95% CL.

Changes and improvements:

- Relaxed selection criteria on m_{jj}, $\Delta\eta_{jj} > 3.8$ and $\Delta\Phi_{jj}$
- $E_T^{miss} > 200$ GeV slightly increased



Improvements efficiency:
Better S/B ratio for selections with larger m_{jj} and smaller $\Delta\Phi_{jj}$

SR definitions:

Lepton/photon vet

$p_T(j_1) > 80$ GeV

$p_T(j_2) > 50$ GeV

$\eta_{j_1} * \eta_{j_2} < 0$

$E_T^{miss} > 200$ GeV

$H_T^{miss} > 180$ GeV

$E_{T,soft}^{miss} < 20$ GeV

$2 <= Njet <= 4$

$\Delta\Phi_{jj} < 2.0$

$\Delta\eta_{jj} > 3.8$

$mjj > 0.8$ TeV

$Nbjet < 2$

$p_T(j_{3,4}) > 20$ GeV

JVT or fJVT($j_{3,4}$)

$C_{j3,4} < 0.6$

$m_{j3,4}^{rel} < 0.05$

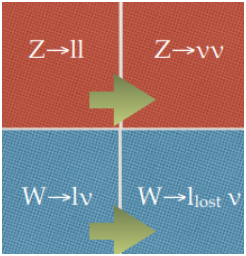
CR definitions:
to estimate V+jets background

$Z \to ll$

- $N_{lep} = 2$
- $p_T(l1) > 30$ GeV
- $|mll - mZ| < 25$ GeV
- $E_T^{miss} < 70$ GeV

$W \to l\nu$

- $N_{lep} = 1$
- $p_T(l1) > 30$ GeV
- MET sign. (e)$> 4\sqrt{GeV}$

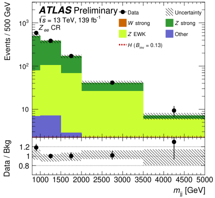


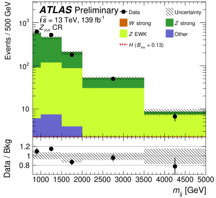
Background estimation

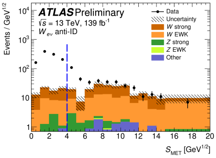
V+jets: about 95%

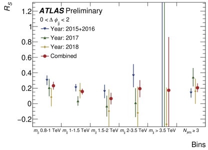
data driven technique uses CRs to constrain this Background.
CRs binned similarly to SR.

observed yield Vs expectation from simulation





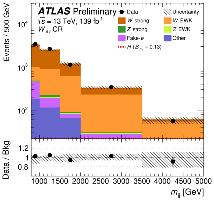


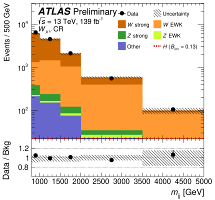


W CR can have small contribution from events with fake e^- originating from multijet jet.

estimated with W_e^{low} **CR:**

- enriched by fake electrons.
- loose identification requirement (e-).
- $R_s = \frac{S_{MET}^{high}}{S_{MET}^{low}}$ used to scale the fake electron contribution, to obtain the contribution in $W_{e\nu}^{high}$.





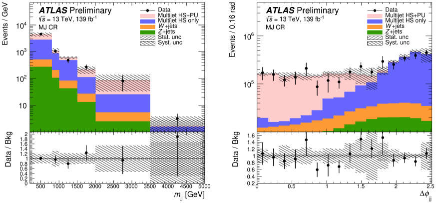
Background estimation

Other Background: Multijet, diboson, ttbar.

ttbar, diboson: predicted directly from simulation.

Multijet:

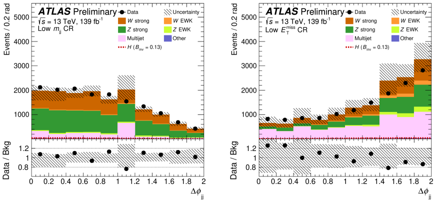
- large $\Delta\Phi_{jj}$ and little E_T^{miss}
- estimated from data using Rebalance and Smear technique.



- (HS, blue) and (HS+PU, red) templates are normalised to fit the $\Delta\Phi_{jj}$ distribution.

- Add correction to account for the ineficiency of the E_T^{miss} triggers.

agreement of predictions and data



- 2 CRs for validation: MJ prediction normalised by a factor to get agreement.

Systematic uncertainties

Theoretical uncertainties

V+jets:

high-order matrix element effects and parton shower matching unc: ren, fac, qsf, ckkw. Sherpa MC samples

- ren and fact:
  strong V+jets downward: 18 to 26%
  strong V+jets upward: 27% to 43%
  EWK V+jets downward 9% to 20%
  EWK V+jets upward: 11% to 29%.
- qsf: 4% to 8%
- ckkw: 4% to 6%
- PDF: 1% to 2%

Signal uncertainties:

- VBF:
  - p_T dependent NLO corr: 2%.
  - ren, fac: 1-3%.
  - parton shower: 2% to 4%.
  - PDF from NNPDF : 1-2%.
- ggF:

  ren and fac: 45% unc in the 2-jet bin and a 41% in the 3- and 4-jet bin

Experimental uncertainties

Luminosity: 1.7%

- Impacts only the signal yield.
- effect cancel on the backgrounds.

Triggers efficiency: 2%

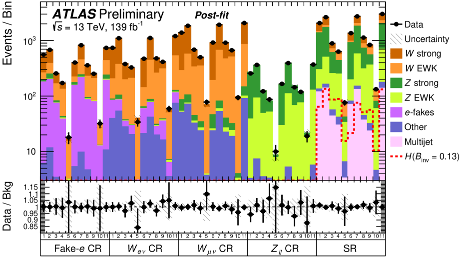
- To account for possible trigger efficiency differences between data and simulation.

physics objects:

- propagated to the calculation of E_T^{miss}

Results:

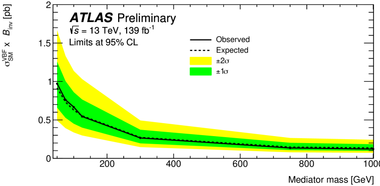
Postfit results of all SR and CR bins.



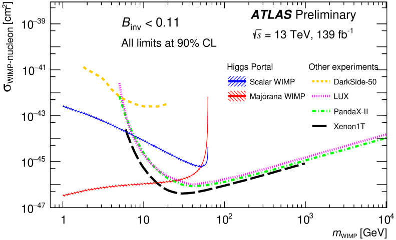
- good agreement of expected background yields and observed data
- set an upper limit on the $B_{H \rightarrow inv}$ of 13%.

Interpretation:

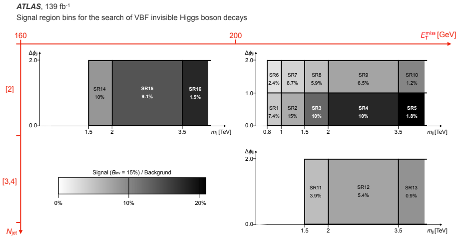
invisible decays of heavy scalar particles (med of DM)

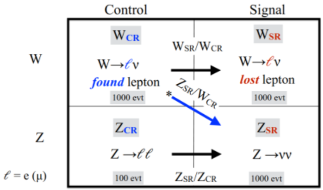


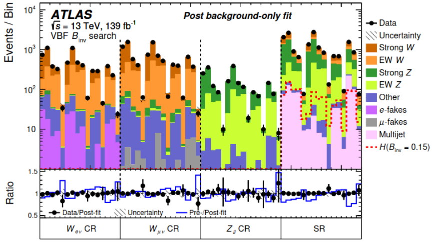
Upper limits on the SI $\sigma_{WIMP-nucleon}$ using Higgs portal interpretations



Changes:







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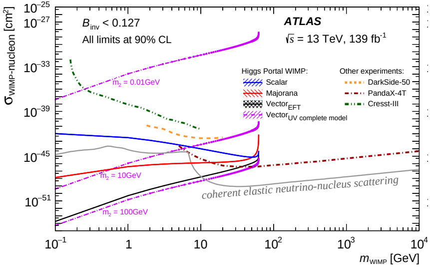
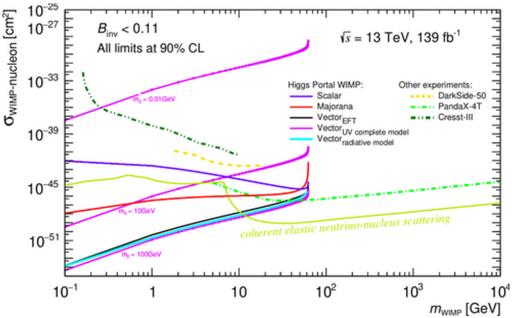


Vector DM: [arxiv.2107.01252]

Backup

- 3 different models are presented:
  - Calculated XS at UV seems to use approximation in 1st and 2nd models
  - Complicated XS calculation in 3rd UV model
- EFT is viable even though being opposed for diverse limits at UV
- Proposals for the vector DM interpretation in the DM overlay plot:
  - Re-introduce the EFT with the the new form factor uncertainty, since EFT is supported by 2nd UV model and is the same in all the models, and same calculation as in Run1.
  - Include the UV lines/bands (best and worst limits) for the 1st model, and also for 3rd models.
  - Add the sub-GeV domain.



"We submitted this work (link) as a white paper in the Energy Frontier of Snowmass"