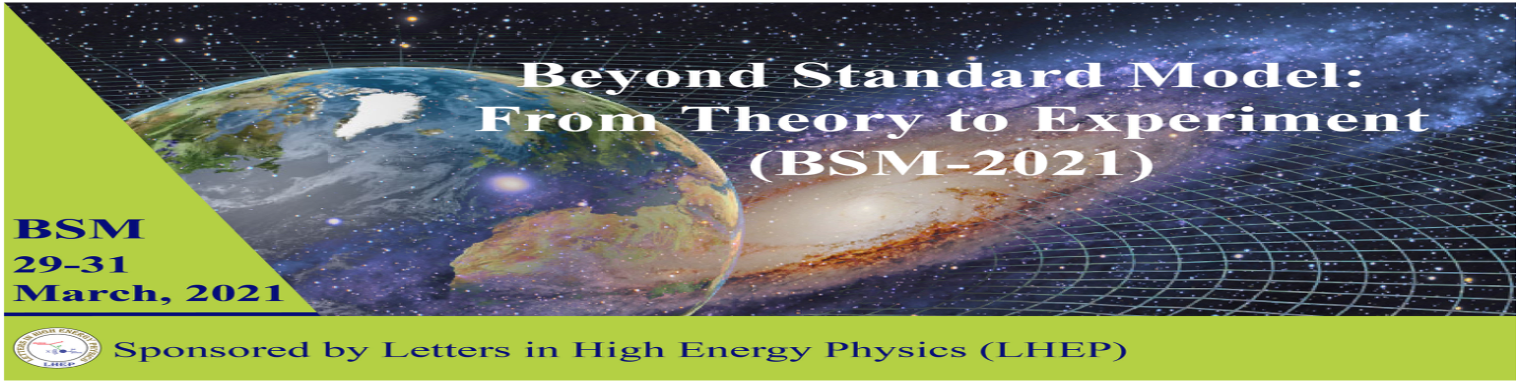

Search for Higgs boson decays to beyond-the-Standard-Model light bosons in four-lepton final states with the ATLAS detector at the LHC

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Christian Weber[3]

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Motivation-Theoritical context-

Two BSM benchmark models considered:

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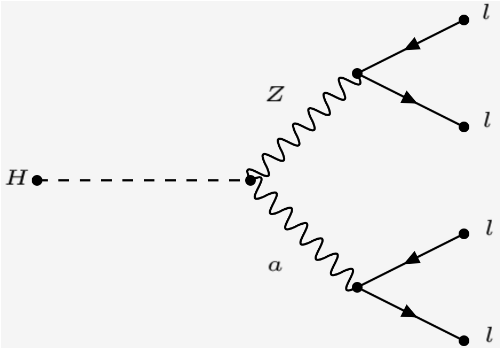

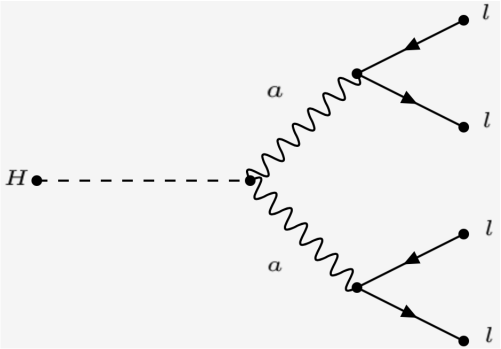

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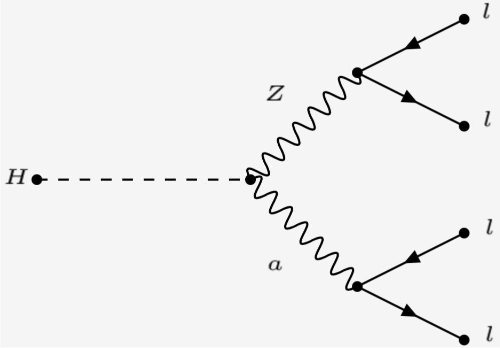

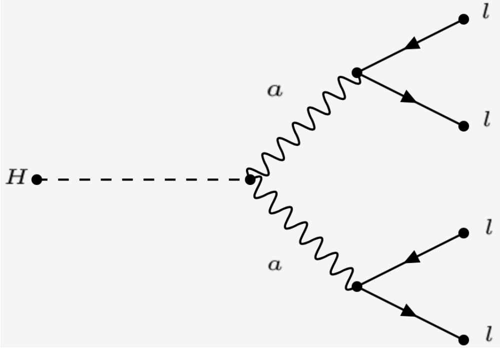

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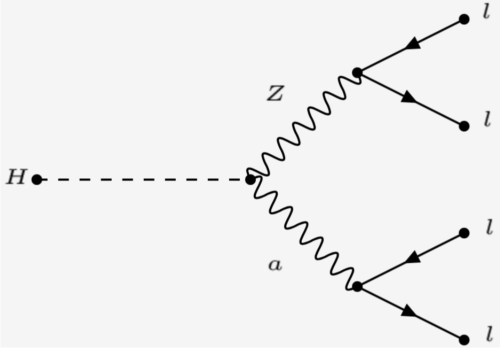

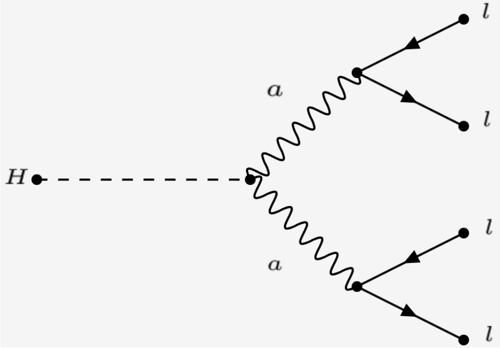

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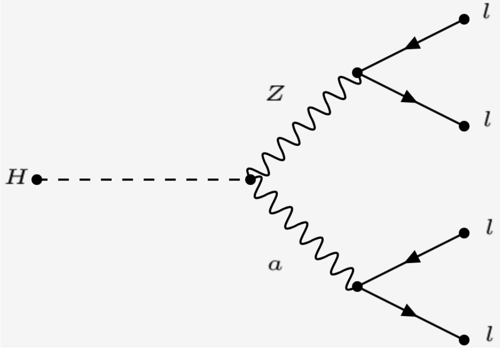

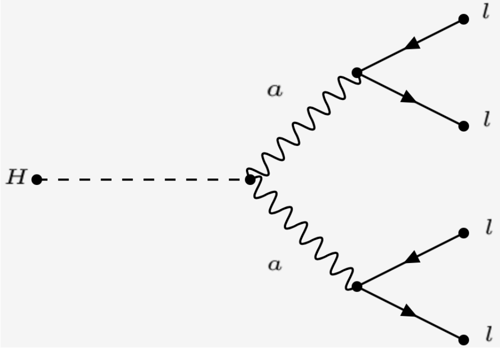

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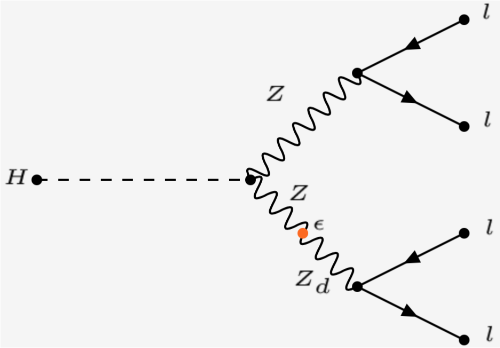

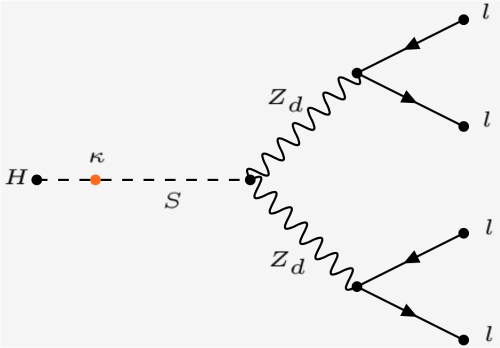

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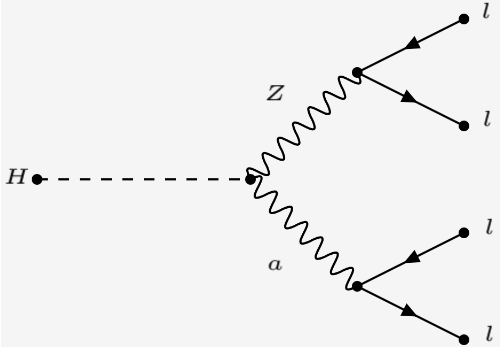

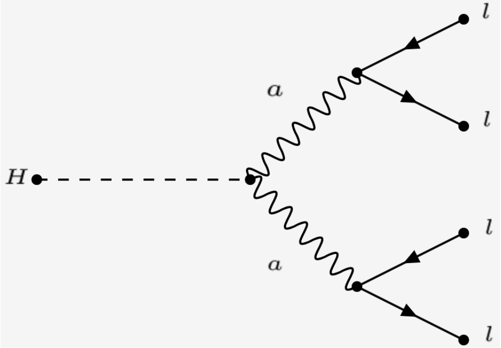

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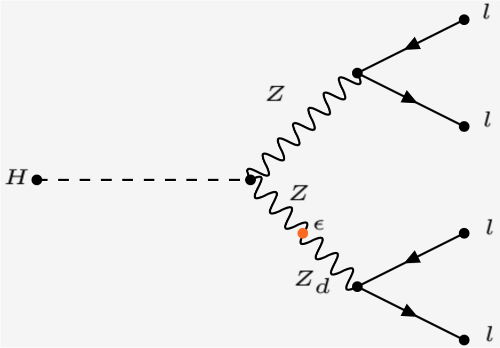

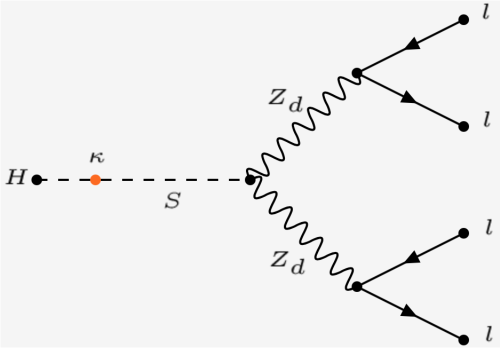

→ Introduce an additional $U(1)$ dark gauge symmetry mediated by a dark gauge boson Z_d.

→ The Z_d boson interacts with a SM gauge particle and the strenght of this coupling is defined by the Kinetic mixing parameter ϵ.

→ When the $U(1)_d$ is broken by a dark Higgs boson, the SM Higgs boson is then mixing with a dark Higgs boson and their coupling is controled by the strenght parameter κ.

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- The results using 2015-6 data ($36 fb^{-1}$) are published (using release 20) [arXiv:1802.03388]
- These results conver three channels with $4e$, $2e2\mu$ and 4μ in the final state:
  - **High-Mass (HM)**: $H \rightarrow Z_d Z_d(aa) \rightarrow 4l$, 15 GeV $< m_{Z_d}(m_a) <$ 60 GeV.
  - Low Mass(LM): $H \rightarrow Z_d Z_d(aa) \rightarrow 4\mu$, 1 GeV $< m_{Z_d}(m_a) <$ 15 GeV.
  - ZZ_d: $H \rightarrow ZZ_d \rightarrow 4l$, 15 GeV $< m_{Z_d} <$ 55 GeV.

Today, we are going to focus on the **HM** channel.

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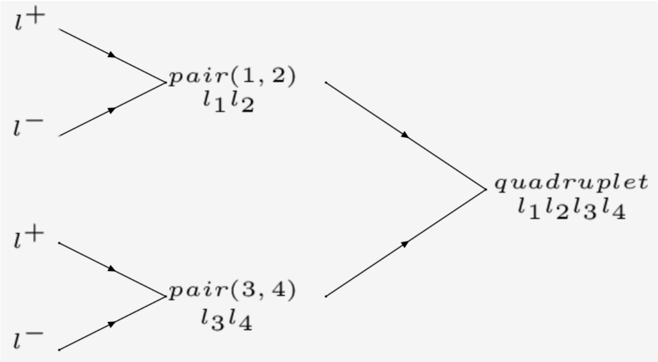
- Quadruplet formation and selection
  - in each event, a quadrulpet is formed from two lepton pairs each with same flavour opposite sign leptons: "1,2" and "3,4"
  - each lepton should fire at least 1 trigger.
  - Three leading-*pt* leptons must have: $pt > 20$, 15 and 10 GeV.
  - $\Delta R(l, l^{'}) > 0.10(0.20)$ for same-flavour (different-flavour) leptons in the quadruplet



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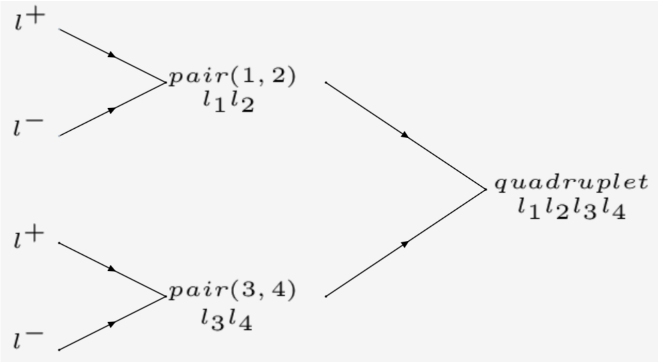

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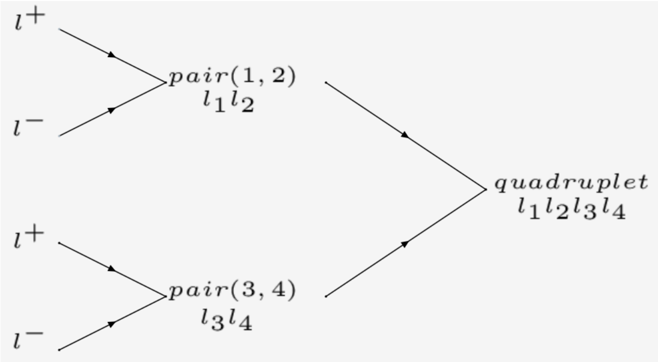

- Quadruplet ranking
  - The selected quadruplet should have the smallest difference in mass between lepton pairs:$\Delta m_{ll} = | m_{12} - m_{34} |$
- Event selection
  - Higgs boson mass window:115 GeV $< m_{4l} <$ 130 GeV
  - Z veto: 10 GeV $< m_{12,34} <$ 64 GeV and 5 GeV $< m_{14,32} <$ 75 GeV
  - Quarkonia veto: event is rejected if either (or both) condition are fulfilled

    $(m_{J/\Psi} - 0.25 \text{ GeV}) < m_{12,34,14,32} < (m_{\Psi(2S)} + 0.30 \text{ GeV})$ or $(m_{\Upsilon(1S)} - 0.70 \text{ GeV}) < m_{12,34,14,32} < (m_{\Upsilon(3S)} + 0.75 \text{ GeV})$
  - Medium Signal Region (SR): $m_{34}/m_{12} > 0.85$

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The background processes considered in this analysis are as followed:

Dominant backgrounds

- $H \rightarrow ZZ^* \rightarrow 4l$ represents 63% of the total
- non-resonant $ZZ^* \rightarrow 4l$ represents 19% of the total

Sub-Dominant backgrounds

- WZ, VVV/VBS processes
- $t\bar{t}$, $t\bar{t}Z$ and Z+Jet(reducible background)

- All backgrounds estimates for this search rely basically on using MC simulations.
- Dominant backgrounds are cross-checked using validation regions.
- The data-driven ABCD method is used to estimate the reducible backgrounds.

HM Signal region

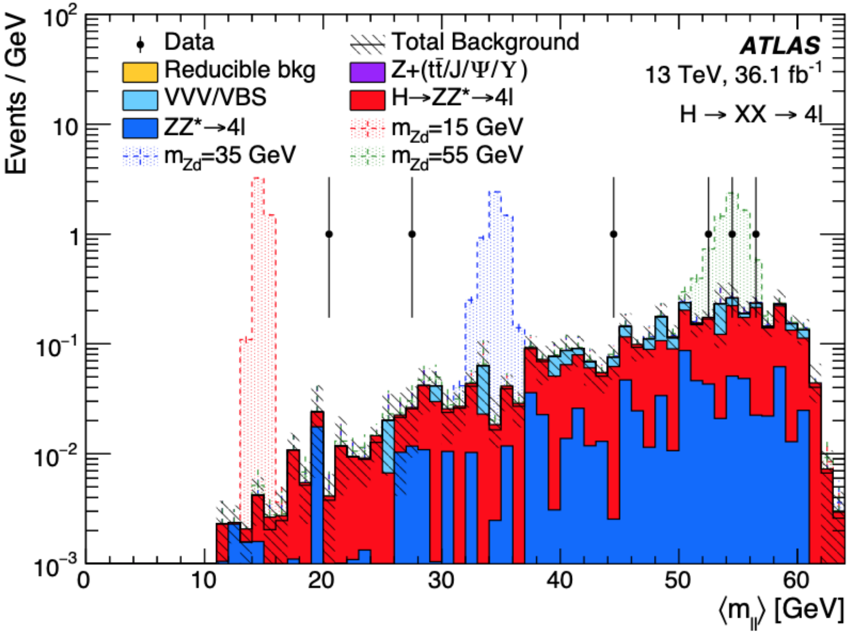


Figure: $\langle m_{ll} \rangle$ distribution in Signal region with all channels combined in 2015-6 data.

Process	Yield
$ZZ^* \to 4\ell$	0.8 ± 0.1
$H \to ZZ^* \to 4\ell$	2.6 ± 0.3
VVV/VBS	0.51 ± 0.18
$Z + (t\bar{t}/J/\Psi) \to 4\ell$	0.004 ± 0.004
Other Reducible Background	Negligible
Total	3.9 ± 0.3
Data	6

A total of 6 events are observed, with a total predicted background of 3.9 ± 0.3 events.

The signal distributions correspond to the expected yield normalized with:
$\sigma(pp \to H \to Z_d Z_d \to 4l) = \frac{1}{10}\sigma_{SM}(pp \to H \to ZZ^* \to 4l)$

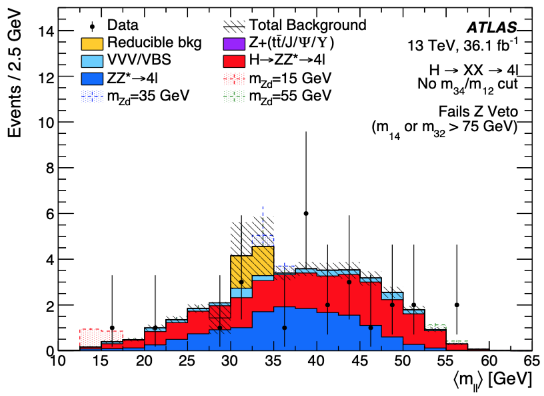


Figure: VR1

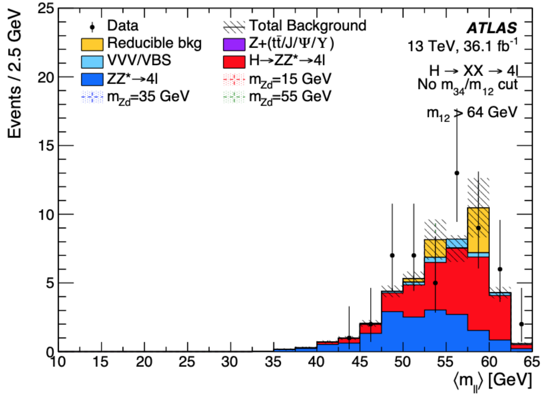


Figure: VR2

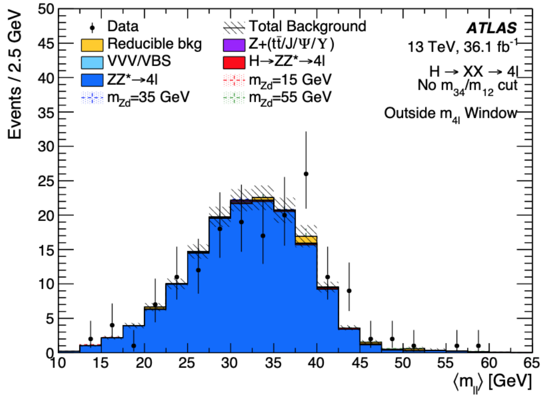
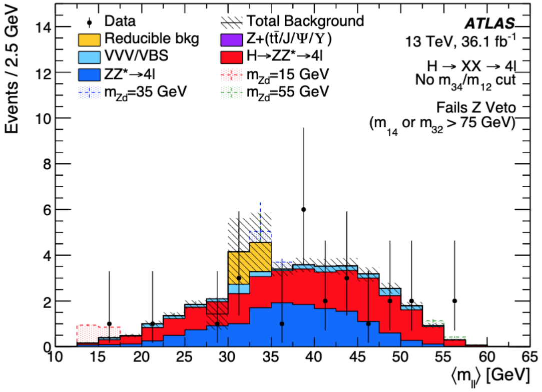


Figure: VR3

HM Validation Regions



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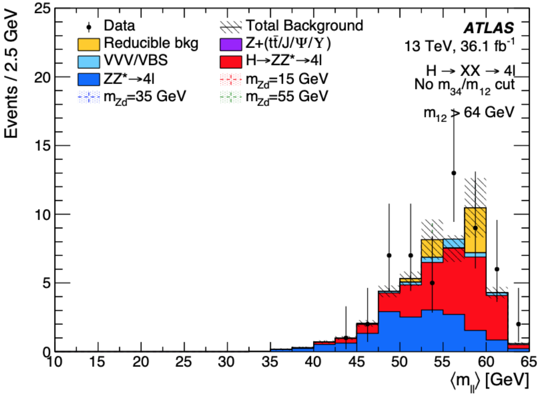


Figure: VR2

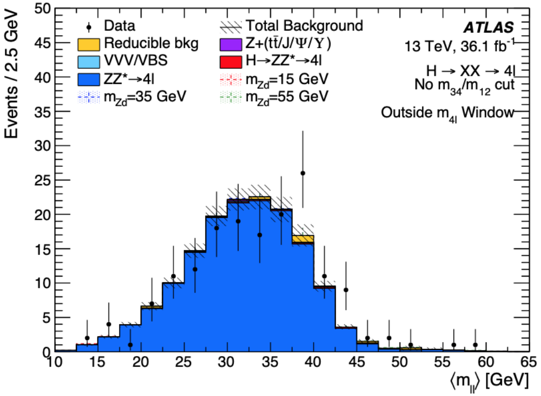
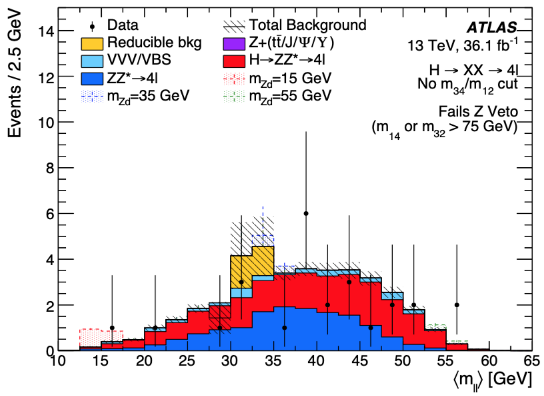


Figure: VR3

- VR1
  - SR cut: $m_{12,34} < 64$ GeV and $m_{14,32} < 75$ GeV.
  - VR1 cut: No m_{34}/m_{12} cut m_{14} or $m_{32} > 75$ GeV.



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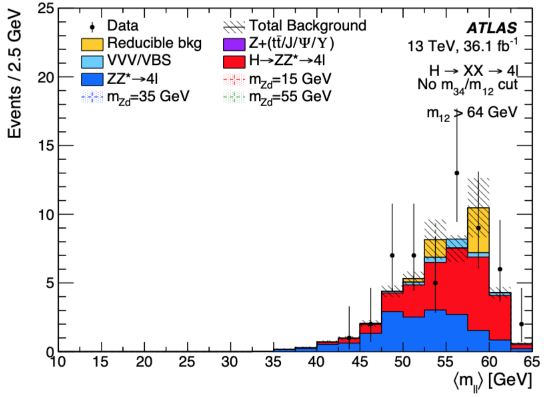
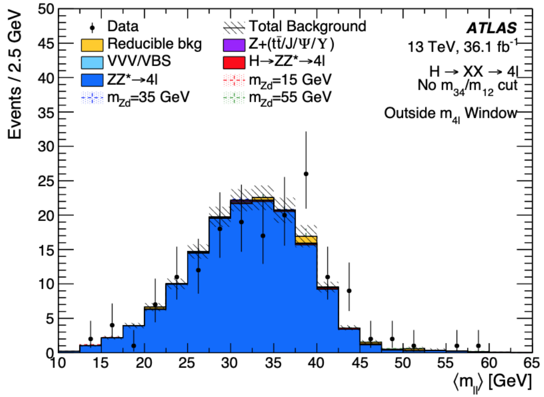


Figure: VR2



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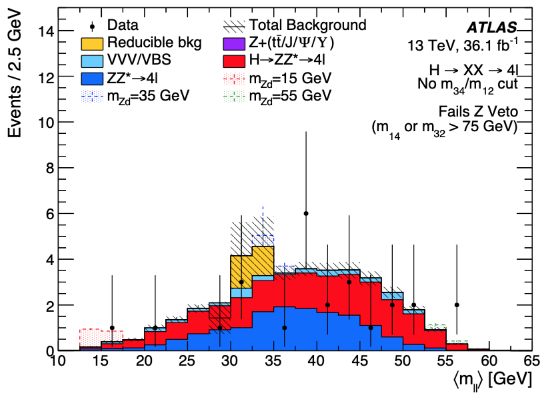
  - VR2 cut: No m_{34}/m_{12} cut $m_{12} > 64$ GeV.



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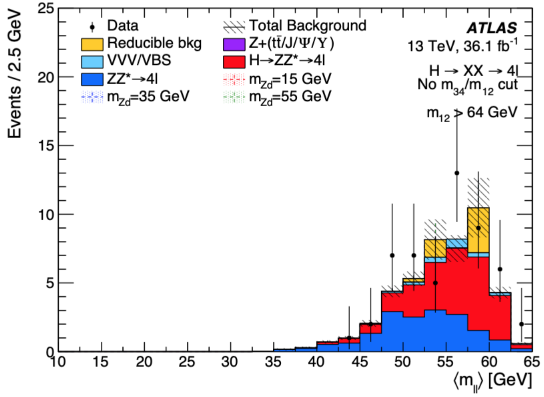
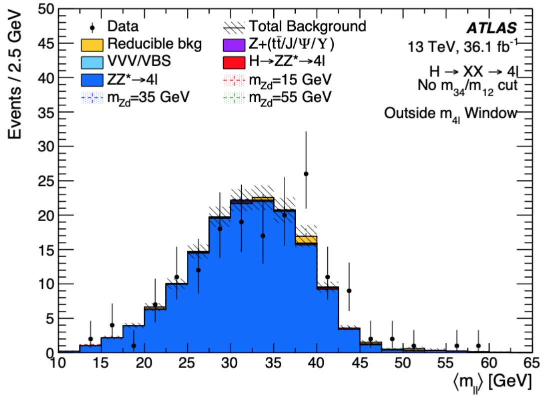


Figure: VR2



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  - VR2 cut: No m_{34}/m_{12} cut $m_{12} > 64$ GeV.
- VR3
  - SR cut:$m_{12,34} < 64$ GeV and $m_{14,32} < 75$ GeV.
  - VR3 cut: No m_{34}/m_{12} cut $m_{4l} > 130$ GeV or $m_{4l} < 115$ GeV.

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Results-Interpretaion and limit setting-

Different statistical analysis procedure are constructed to interpret the results according to our benchmark model:

Model-independent limits

Set limits on the cross section in a fiducial volume such that the limit is suitably model-independent.

- → The fiducial volume is defined in a way to mimic the selection aplied in this analysis and appropriate for a Higgs boson ($m_H = 125$ GeV) decaying to 2 intermidiate, on-shell, narrow X boson (Z_d, a).
- → Model-independent efficiency: $\epsilon_c = \frac{N^c_{reco}}{N^c_{fid}}$
- → Expectation: $N^c_{exp}(\langle m_{ll} \rangle) = N^c_{bkg} + \sigma^c_{fid}.\mathcal{L}umi.\epsilon_c.Gaus(\langle m_{ll} \rangle, \overline{\langle m_{ll} \rangle}, \sigma^c_{\langle m_{ll} \rangle})$

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Model-dependent limits

Set limits on total cross section for $Z_d Z_d$ model.

→ In that model, the total cross section for a specific model is in request: $\sigma_H \mathcal{BR}(H \rightarrow Z_d Z_d \rightarrow 4l)$

→ Model-dependent acceptance in "total phase space" of a given model: $\alpha_c = \frac{N^{Z_d c}_{fid}}{N^{Z_d c}_{tot}}$

→ Expectation: $N^c_{Z_d,exp}(\langle m_{ll}\rangle) = N^c_{Z_d,bkg}(\langle m_{ll}\rangle) + \sigma_H \mathcal{BR}(H \rightarrow Z_d Z_d \rightarrow 4l).\mathcal{L}umi.\frac{\Gamma^c_{Z_d}}{\Gamma^{4l}_{Z_d}}.\alpha^{Z_d}_c.\epsilon_c.Gaus(\langle m_{ll}\rangle, \overline{\langle m_{ll}\rangle}_c, \sigma^c_{\langle m_{ll}\rangle})$

Fiducial cross section and branching ratio limits

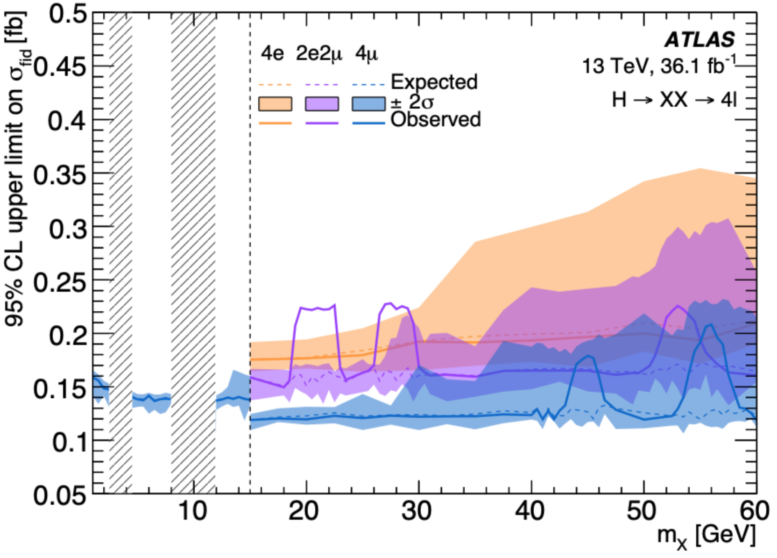

Figure: Upper limits at 95% CL on fiducial cross-sections for the $H \to XX \to 4l$ process

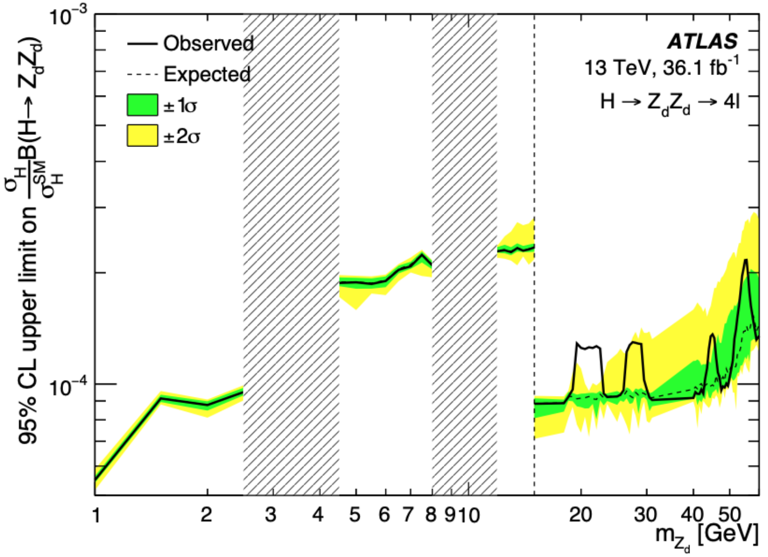

Figure: Branching ratio limit on $H \to Z_d Z_d$ for the high-mass channel using the 2015–6 36 fb^{-1} data set

- Model-independent fiducial cross-section limit (36 fb^{-1}) is calculated .
- The limit on $\mathcal{BR}(H \to Z_d Z_d)$ is model dependent because one needs the $\mathcal{BR}(Z_d \to ll)$ from a model.
- The upper limit on the $\mathcal{BR}(H \to Z_d Z_d)$ is approximately 0.01%

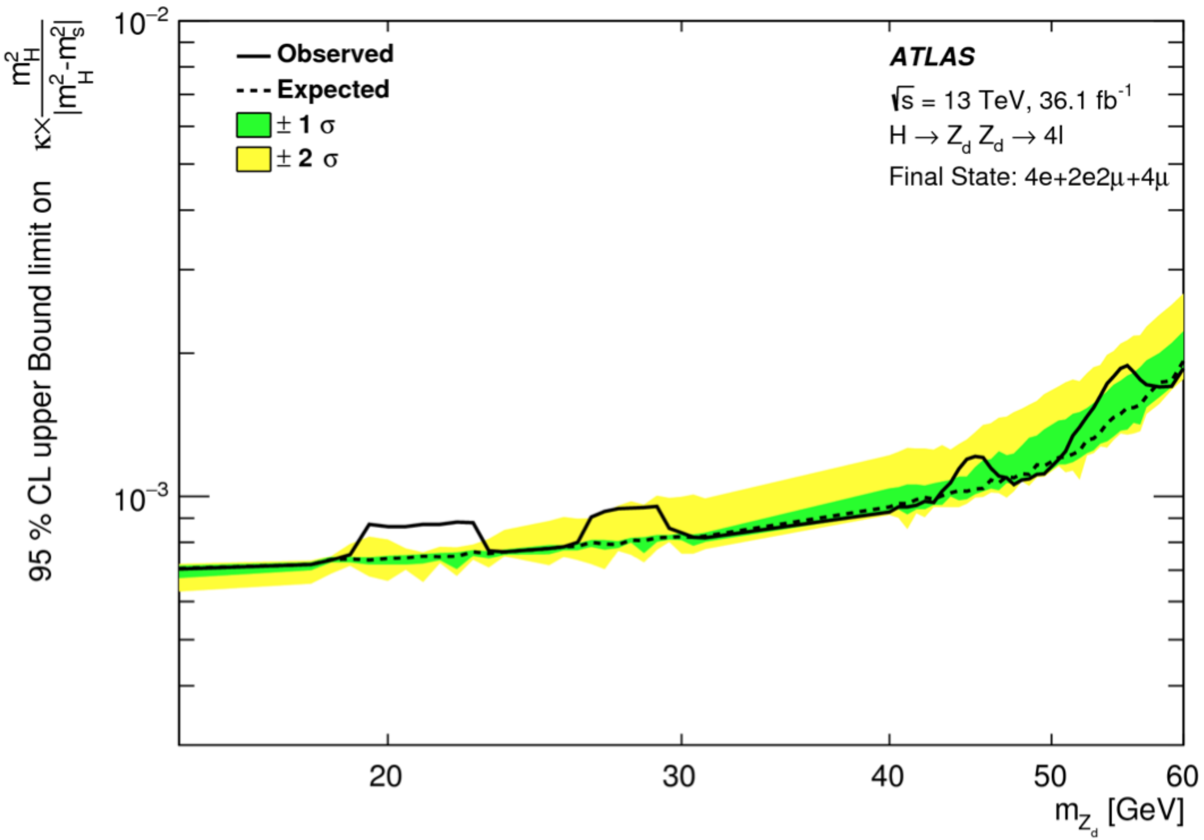

Figure: Upper limit on κ'

The upper limit on the the higgs mixing parameter κ is around 0.1%

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Conclusion

- Searches are performed for exotic decays of SM Higgs boson to two Z_d givin 4 leptons in the final state.
- The data are found to be globally consistent with the SM backgroud expectations.
- Limits on fiducial cross-sections are computed in order to be used for testing other benchmark models than treated in this analysis.
- Upper limits; with dependence on the itermediate exotic boson's mass (m_{Z_d}); are set on the branching ratio of Higgs boson to $Z_d Z_d$ and on κ.


Thank
You
Vinaka
köszönöm
Kiitos
Maake
Asante
Shukria
Dhanyavadagalu
감사합니다
Dankscheen
спасибо
Kam Sah Hammida
Manana
Dankon
Dank Je
Mauruuru
Biyan
Diolch i Chi
Terima Kasih
Matondo
Taiku
Tack
Blagodaram
Ngiyabonga
Dziekuje
Chokrane
Grazie
Juspaxar
Arigato
Mochchakkeram
Gracias
Khap
Tingki
நன்றி
Bedankt
Dakujem
धन्यवाद
cảm ơn bạn
Paldies
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Ua Tsaug Rau Koj
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Danke
Merci
Go Raibh Maith Agat
Tuke
Eskerrik Asko
Salamat
Najis

BackUp

Data-driven estimate for non-dominant processes with Fake leptons

Processes such as $t\bar{t}$ and WZ may contribute to our selected events if non-lepton objects such as jets are incorrectly reconstructed as leptons.

1. Events are selected in an inverted signal region (region **B**): a region defined by identical cuts to the normal signal region (region **A**) except with a few cuts inverted: the selected quadruplet in the event must contain one or two (but not more) leptons that are:
   - Electrons failing the `LooseLH` identification working point or failing the `FixedCutLoose` isolation working point, but not failing both of these requirements, or
   - Muons failing the `FixedCutLoose` isolation working point or d_0 significance requirement
     - $\Rightarrow$ Those are bad leptons
2. Events are selected in two regions that are rich in Z+jets events, where the event contains two leptons consistent with Z boson and exactly one other baseline reconstructed lepton. These third leptons, which are predominantly leptons faked by hadronic jets, either pass all requirements imposed in the standard analysis selection (the event then contributes to region **C**) or are leptons failing the cuts described above (the event contributes to region **D**).
3. *Fake Factors* are calculated as: $f = \frac{N_C}{N_D}$
4. Those factors are applied to the events in region **B**: events with exactly one bad lepton (**B1**) receive a weight given by the fake factor corresponding to the bad lepton, and events with exactly two bad leptons (**B2**) receive a weight given by the product of the fake factors of the two bad leptons and an additional factor of -1: $N_{B_1} f - N_{B_2} f_1 f_2$
5. The contribution to this estimate from processes producing four (or more) real leptons is estimated from the MC contribution to the inverted signal region ($N_{B_1}^{real}$ and $N_{B_2}^{real}$) with fake factors applied.

$$\boldsymbol{N_A^{fake} = (N_{B_1} f - N_{B_2} f_1 f_2) - (N_{B_1}^{real} f - N_{B_2}^{real} f_1 f_2)}$$

For more details, see 2226555

Local p-value