ATLAS RARE AND BSM DECAYS

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ATLAS

Motivation for rare and BSM decays of 125 GeV Higgs boson

- Higgs couplings to 1st and 2nd generation need to be measured to confirm the Standard Model (SM).
  - Only observations so far are with 3rd generation.
- Rare and invisible decay SM BR are tiny.

→ any significant deviation from SM could indicate new physics.

- Decay to two pseudoscalar bosons (a) is the simplest BSM decay mode.
- Decay to two vector bosons (Z/Z_d) is also a possibility.
  - Z_d = dark sector vector boson

→ More details in Zhen Liu's talk.

Rare decays

- μμ (BR = 0.022 %) [→ Jana Faltova's talk]

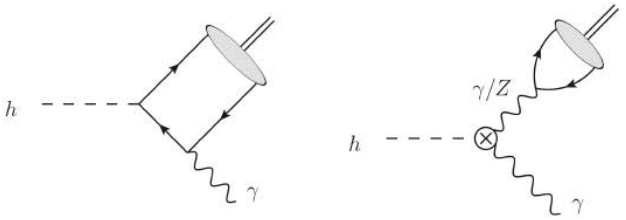
Mode	CM energy	Luminosity	$\sigma*BR/\sigma_{SM}$	Reference
μμ	13 TeV	79.8 fb^{-1}	< 2.1	ATLAS-CONF-2018-026

- Zγ, Qγ

Mode	CM energy	Luminosity	$\sigma*BR/\sigma_{SM}$	Reference
Z γ	13 TeV	36.1 fb^{-1}	< 6.6	JHEP 10 (2017) 112
ρ γ	13 TeV	35.6 fb^{-1}	< 52	arXiv:1712.02758
φ γ	13 TeV	35.6 fb^{-1}	< 209	arXiV:1712.02758
J/ψ γ	13 TeV	36.1 fb^{-1}	< 117	arXiv:1807.00802 *
Υ γ	13 TeV	36.1 fb^{-1}	< 10^5	arXiv:1807.00802 *

New

Search for enhanced Higgs couplings to 1st and 2nd generation quarks



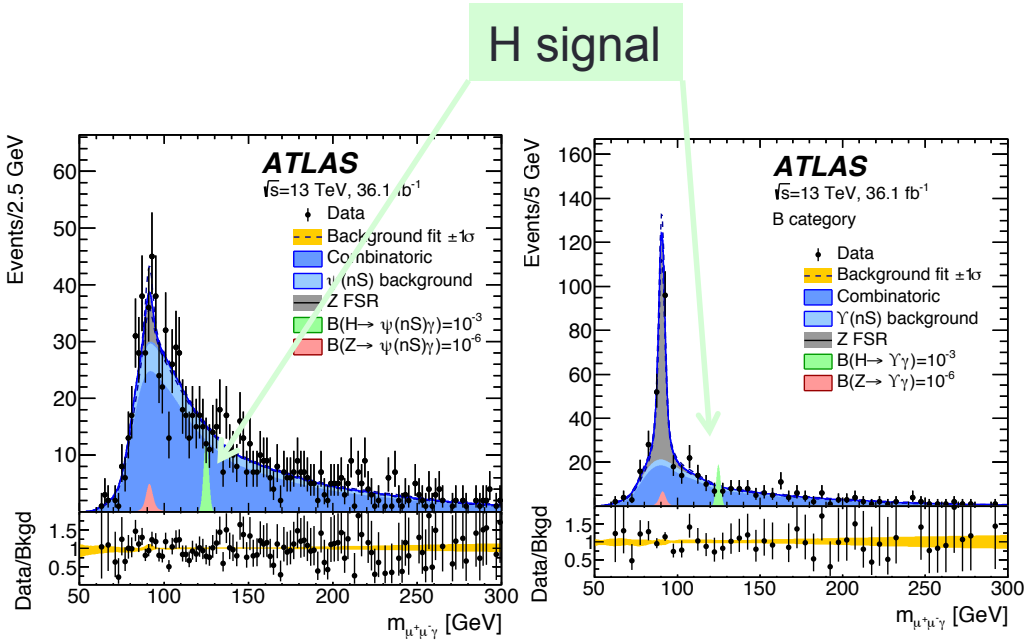
Direct Indirect

* Details in following slides

arXiv:1807.00802

H → J/ψγ, ψ(2S)γ, Υ(nS)γ

- ψ,Υ → $\mu^+\mu^-$;
- photon+muon trigger.
- Selection:
  - Good quality muons.
  - Mass window cut on m(μμ).
  - Good quality photon.
- Backgrounds:
  - Non resonant: data-driven.
  - Zγ: MC shape, fit to data.
- Statistically limited.
- SM BR
  - J/ψγ: 3.0e-6
  - Υ(1S)γ: 5.2e-9



Branching fraction limit (95% CL)	Expected	Observed
$\mathcal{B}(H \to J/\psi\,\gamma)$ [10^{-4}]	$3.0^{+1.4}_{-0.8}$	3.5
$\mathcal{B}(H \to \psi(2S)\,\gamma)$ [10^{-4}]	$15.6^{+7.7}_{-4.4}$	19.8
$\mathcal{B}(Z \to J/\psi\,\gamma)$ [10^{-6}]	$1.1^{+0.5}_{-0.3}$	2.3
$\mathcal{B}(Z \to \psi(2S)\,\gamma)$ [10^{-6}]	$6.0^{+2.7}_{-1.7}$	4.5
$\mathcal{B}(H \to \Upsilon(1S)\,\gamma)$ [10^{-4}]	$5.0^{+2.4}_{-1.4}$	4.9
$\mathcal{B}(H \to \Upsilon(2S)\,\gamma)$ [10^{-4}]	$6.2^{+3.0}_{-1.7}$	5.9
$\mathcal{B}(H \to \Upsilon(3S)\,\gamma)$ [10^{-4}]	$5.0^{+2.5}_{-1.4}$	5.7

BSM decays: H → aa/VV

- aa

Mode	CM energy	Luminosity	σ^*BR/σ_{SM}	Reference
2μ2τ	8 TeV	20.3 fb^{-1}	< 10^{-1} - 1	PRD92 (2015) 052002
4b	13 TeV	36.1 fb^{-1}	< 1 - 3	arXiv:1806.07355* New
4γ	8 TeV	20.3 fb^{-1}	< 10^{-3}	EPJC 76(4),1-26(2016)
2γ2j	13 TeV	36.7 fb^{-1}	< 0.03 – 0.16	PLB 782 (2018) 750
2b2μ	13 TeV	36.1 fb^{-1}	< $2*10^{-3}$ - 10^{-4}	arXiv:1807.00539* New
4μ	13 TeV	36.1 fb^{-1}	< $2*10^{-4}$ - 1	arXiv:1802.03388*

- ZZ_d/Z_dZ_d

Mode	CM energy	Luminosity	σ^*BR/σ_{SM}	Reference
4e, 4μ, 2e2μ	13 TeV	36.1 fb^{-1}	< 10^{-4} – 10^{-3}	arXiv:1802.03388*

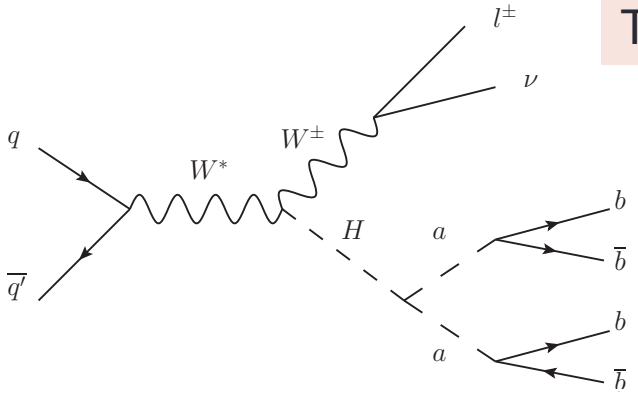
* Details in following slides

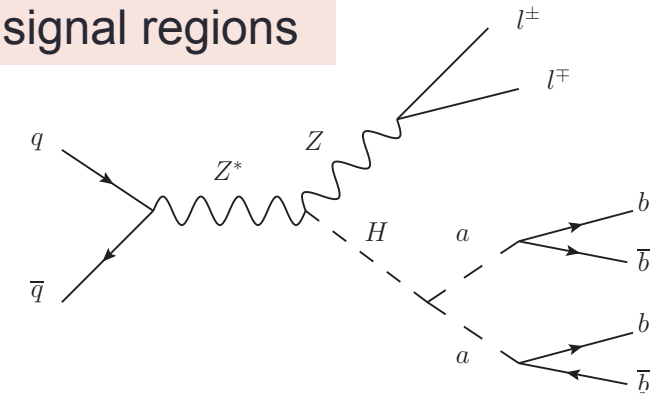
arXiv:1806.07355

H → aa → 4b analysis

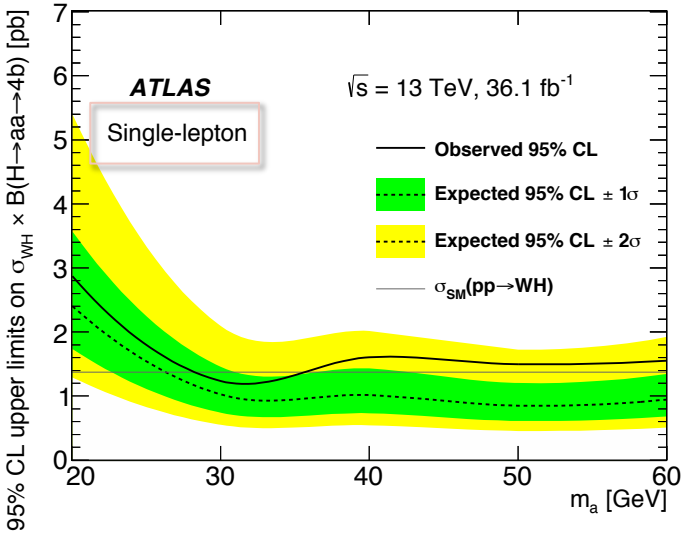
- WH/ZH production → lepton trigger

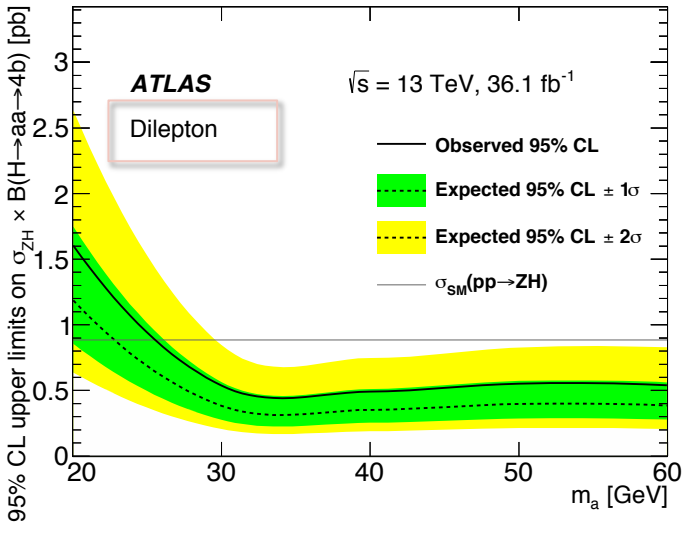
Two signal regions



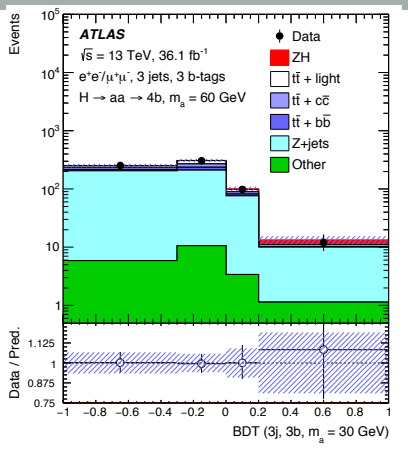


Selection:
nJets >= 3
nBJets >= 2
m_T cut or
Z mass cut

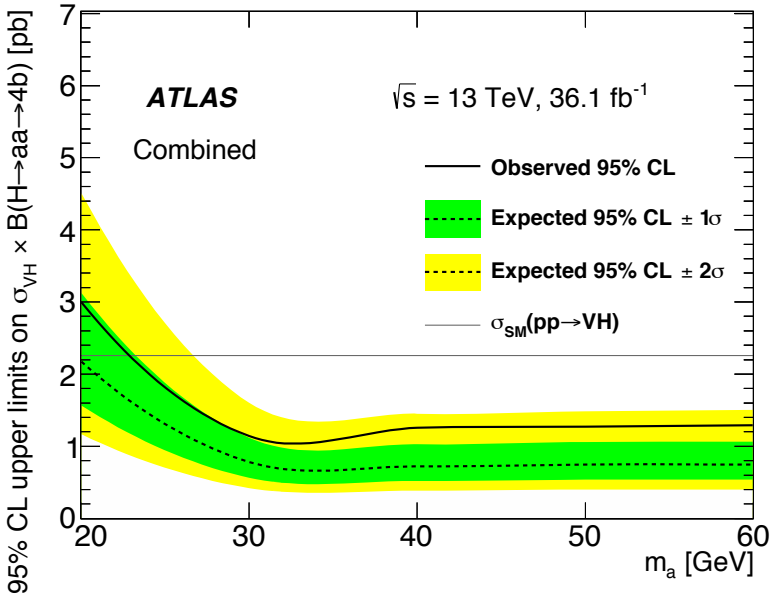


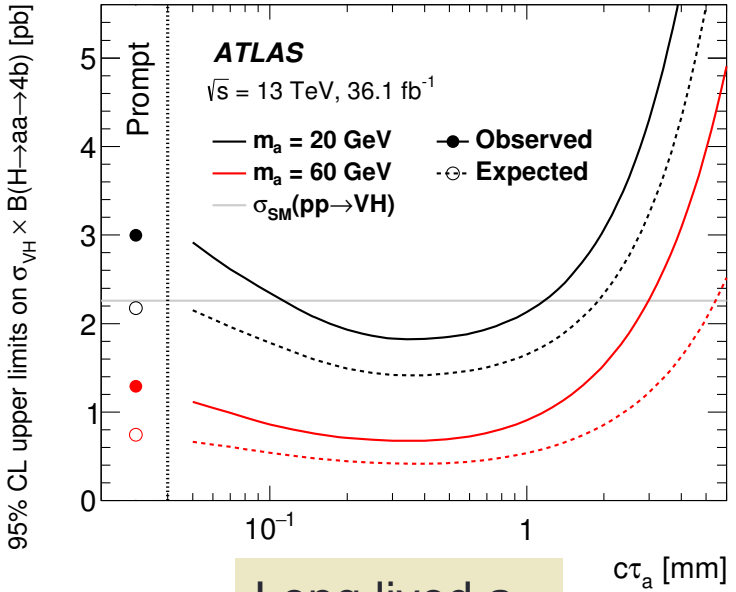


H → aa → 4b analysis



- Backgrounds: ttbar and Z+jets.
  - Use Boosted Decision Tree to categorize
    6 signal regions and 7 control regions, and determine backgrounds.
- Systematic errors:
  - B-tagging (10-20%), Jet energy (3-7%), ttbar modeling (10-40%)



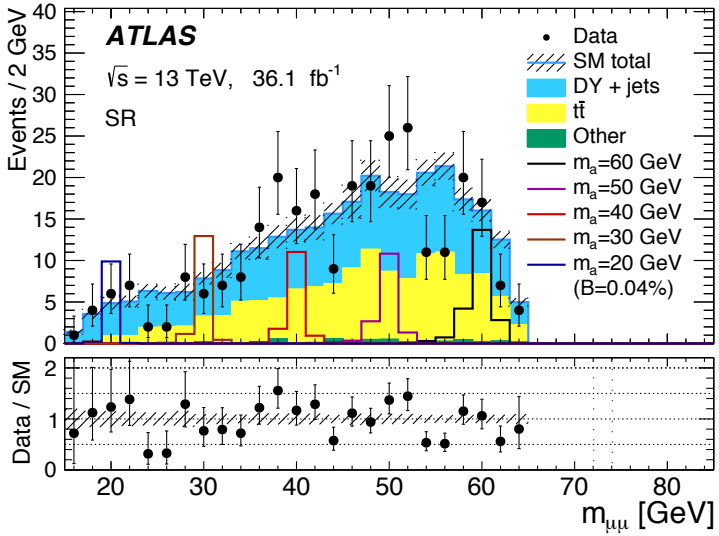


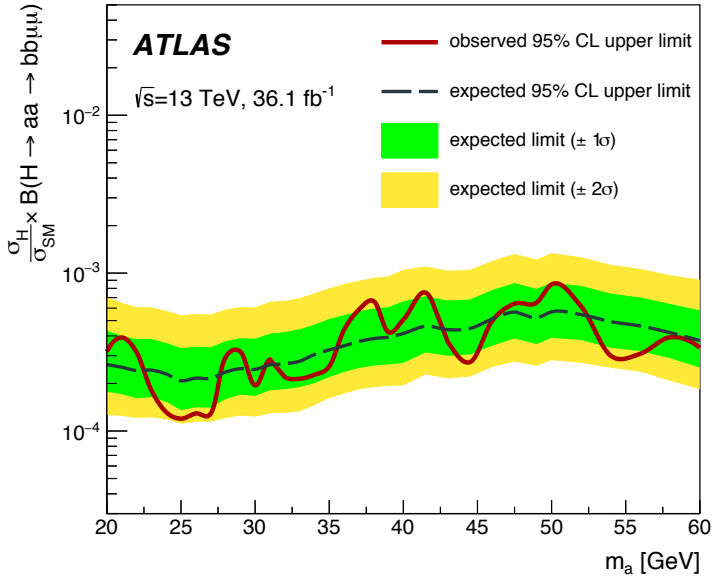
Long lived a

arXiv:1807.00539

H → aa → 2b2μ analysis

- Single muon triggers.
- Selection:
  - Exactly 2 b-jets.
  - Exactly 2 muons.
  - Higgs mass window cut.
  - Missing Et < 60 GeV to suppress ttbar events.
- Background:
  - Drell-Yan dimuon events.
    → data template method.
  - ttbar → simulation.
  - Normalized in control regions.
- Statistically limited.

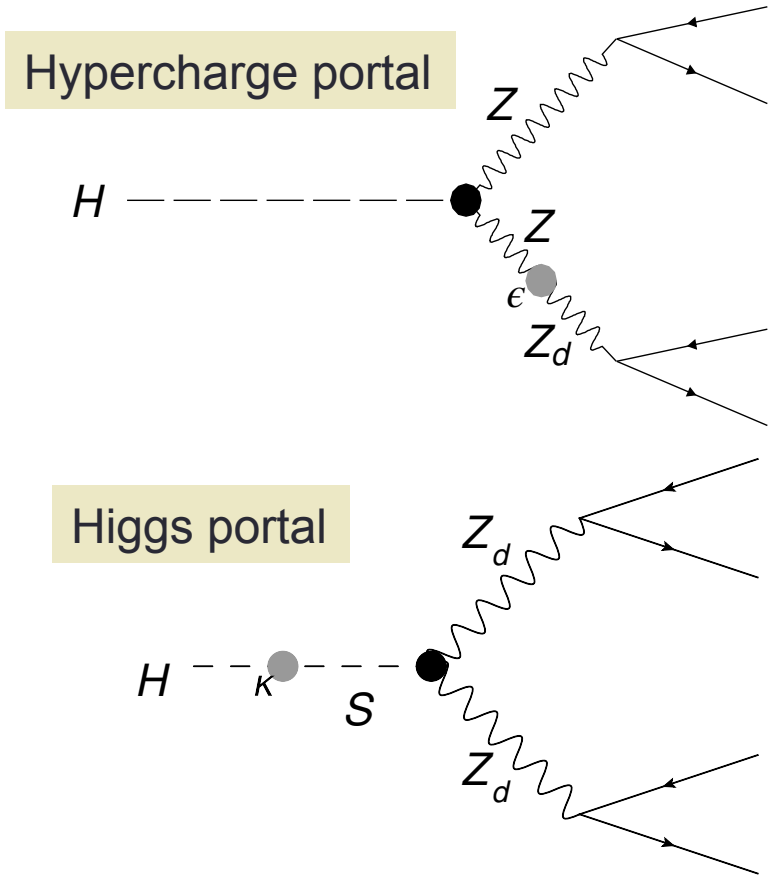




arXiv:1802.03388

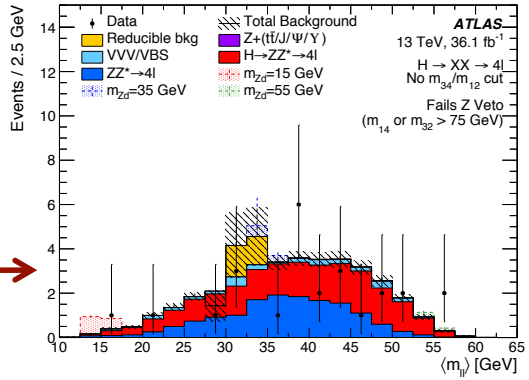
H → aa/ZZ$_d$/Z$_d$Z$_d$ → 4l analysis

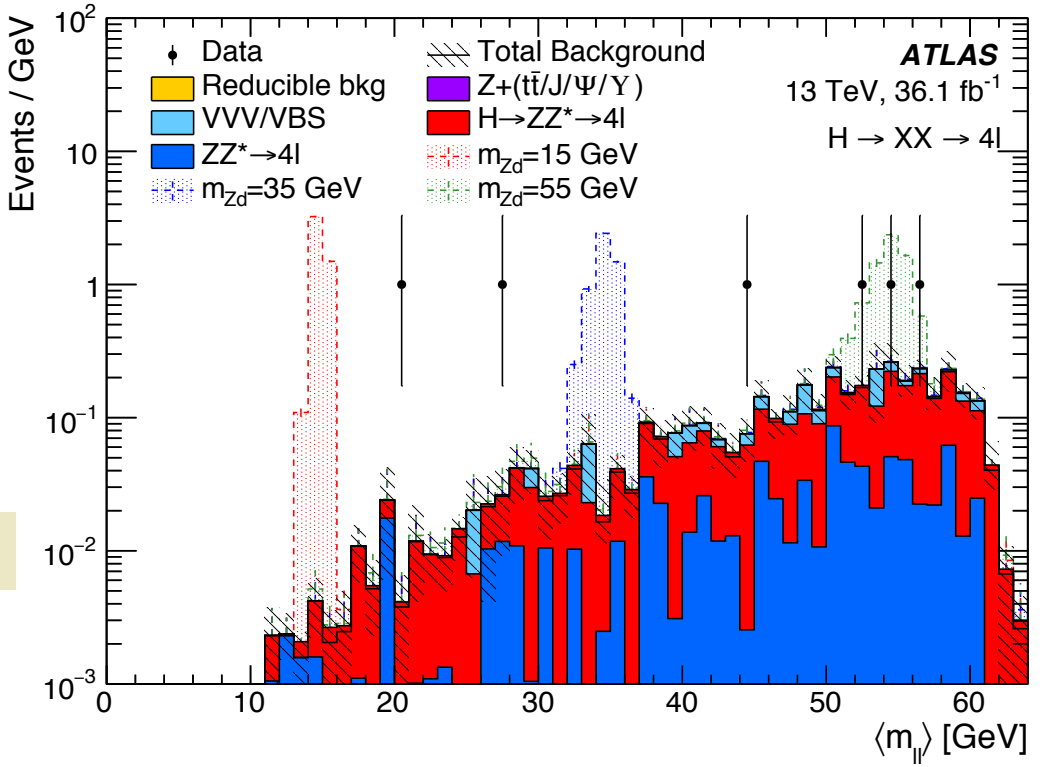
- Vector boson model:
  - Z_d = vector boson of dark sector $U(1)_d$
- Pseudo-scalar model:
  - 2HDM + pseudo-scalar (a)
  - H → aa is allowed.
- Combinations of lepton triggers.
- Selection:
  - Two pairs of same-flavor opposite-sign leptons.
  - Higgs mass window cut.



$H \rightarrow aa/ZZ_d/Z_dZ_d \rightarrow 4l$ analysis

- Background: $H \rightarrow ZZ^* \rightarrow 4l$ and $ZZ^* \rightarrow 4l$
  - Simulations were used.
  - Validated in background enriched regions.
- Statistically limited.
- Systematic errors:
  - Lepton related: 10 %
  - MC modeling: 3 – 9 %



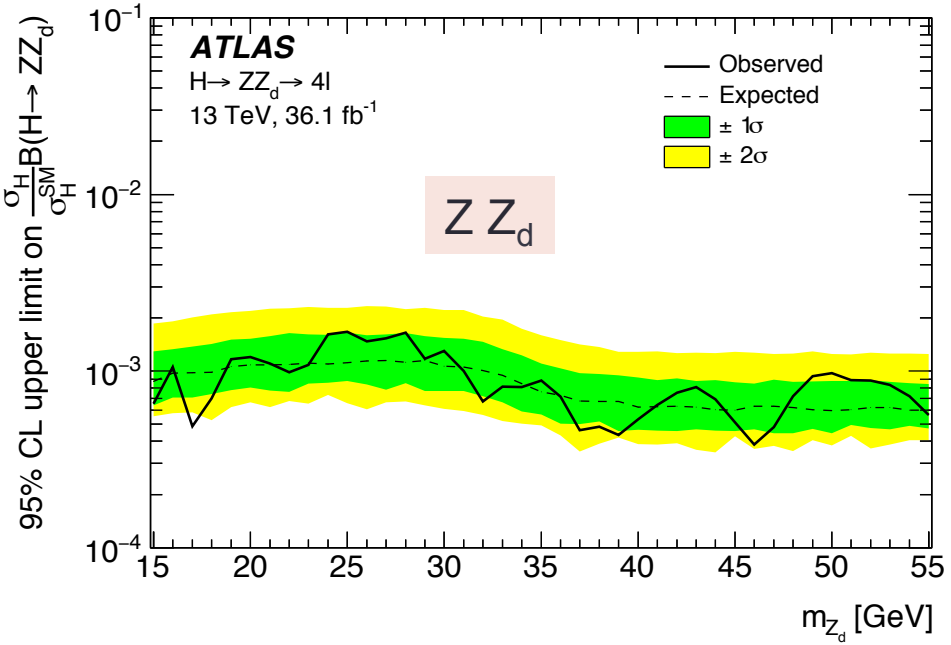


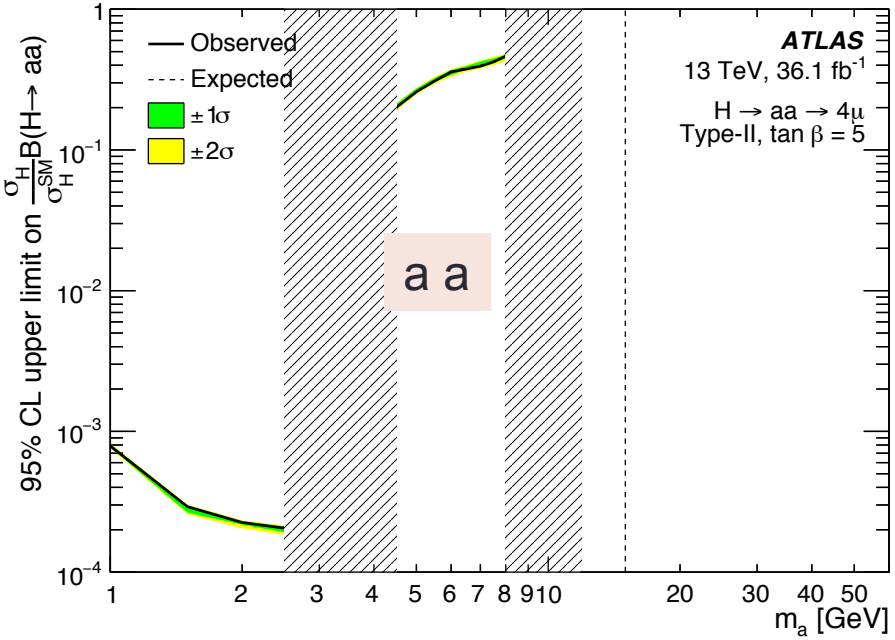
Average mass of 2 pairs.

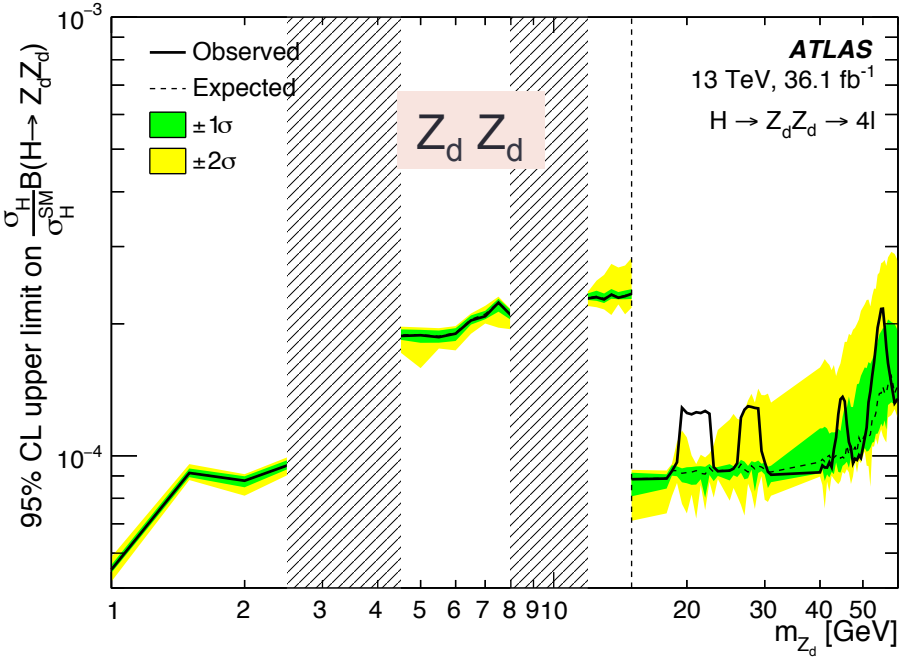
H → XX → 4l

- Results

Mode	BR limit
H → aa → 4μ	< 1 %
H → Z Z_d → 4l	< 0.1 %
H → $Z_d Z_d$ → 4l	< 0.01 %







BSM decays: H → invisible/LFV

- Invisible (SM BR(ZZ → 4ν) = 0.1 %)

Mode	CM energy	Luminosity	BR (expected)	Reference
VBFHinv	8 TeV	20.3 fb^{-1}	< 28 (31) %	JHEP 01 (2016) 172
Z(ll)Hinv	13 TeV	36.1 fb^{-1}	< 67 (39) %	PLB 776(2017)318
V(had)Hinv	13 TeV	36.1 fb^{-1}	< 83 (58) %	ATLAS-CONF-2018-005*
Combined	7TeV + 8TeV	4.7+20.3 fb^{-1}	< 25 %	JHEP11(2015)206

- Lepton flavor violation (→ Jana Faltova's talk)

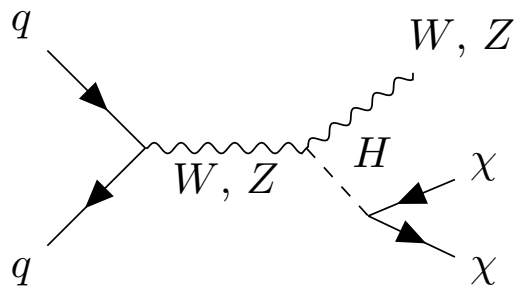
Mode	CM energy	Luminosity	BR	Reference
τμ	8 TeV	20.3 fb^{-1}	< 1.43 %	EPJC 77 (2017) 70
τe	8 TeV	20.3 fb^{-1}	< 1.04 %	EPJC 77 (2017) 70

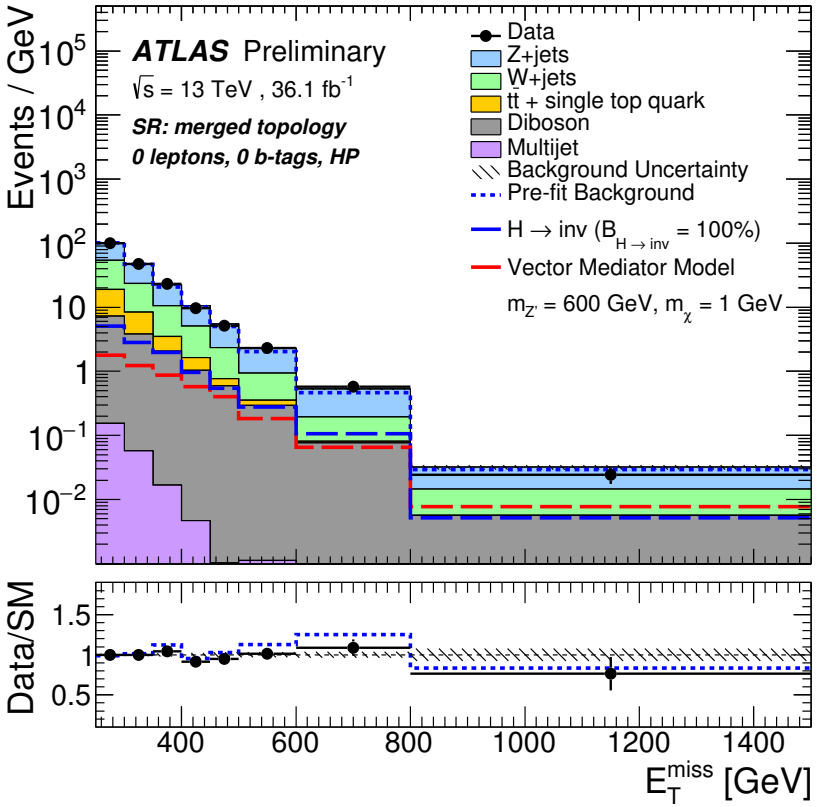
* Details in following slides

ATLAS-CONF-2018-005

VH -> jet(s) + invisible analysis

- Selection:
  - 2 jets or 1 large-R jet + mass cut for W or Z candidate.
  - Large missing E_T = invisible.
  - 0 lepton.
- Backgrounds:
  - V + jets and ttbar:
    - 1 and 2 lepton control region.
  - Multijet: enriched control region.
- Systematic errors:
  - Signal modeling 5-10%
  - Mulitijet 100%
  - Experimental 10%.





➔ Artem Basalaev's talk for Z(ll)Hinv.

Conclusion

- Rare Higgs boson decays to 1st and/or 2nd generation of quarks and leptons are searched.
  - Still statistically limited → limits were set.
- BSM Higgs decays were searched in 4 modes:
    - 2 new pseudo scalar bosons.
    - 2 new vector bosons.
    - Invisible particles (possibly dark matter particles).
    - Lepton flavor violating decays.
  - No observation beyond SM background.
  - Limits were set.
- Overall no evidence of BSM physics (yet).

Back up

Journal	arXiv	Part of the title
ATLAS-CONF-2018-026	n/a	Higgs boson to dimuons
JHEP 10 (2017) 112	1708.00212	$Z\gamma$ decay mode of the Higgs
Accepted by JHEP	1712.02758	Higgs decays to $\phi\gamma$ and $\rho\gamma$
Submitted to PLB	1807.00802	$J/\psi\gamma$, $\psi(2S)\gamma$ and $\Upsilon(nS)\gamma$
Eur. Phys. J. C 77 (2017) 70	1604.07730	lepton-flavour-violating decays
PRD92 (2015) 052002	1505.01609	*aa* in the $\mu\mu\tau\tau$ final state
Submitted to JHEP	1806.07355	$H \rightarrow aa \rightarrow 4b$ channel
Eur.Phys.J.C76(4),1-26(2016)	1509.05051	events with at least three photons
PLB 782 (2018) 750	1803.11145	the $\gamma\gamma jj$ final state
Submitted to PLB	1807.00539	the $bb\mu\mu$ final state
Accepted by JHEP	1802.03388	light bosons in four-lepton events
JHEP 01 (2016) 172	1508.07869	invisible … vector-boson fusion
PLB 776 (2017) 318	1708.09624	invisibly decaying Higgs … with a Z
ATLAS-CONF-2018-005	n/a	hadronically decaying vector boson
JHEP11(2015)206	1509.00672	invisible decays
PRD 90, 075004 (2014); arXiv:1312.4992[hep-ph]; Exotic Decays of the 125 GeV Higgs Boson		

Rare decays

- Main decay modes

Channel	BR [%]
bb	58
WW	21
gg	8.2
ττ	6.3
cc	2.9
ZZ	2.6
γγ	0.23
Sum	99.23

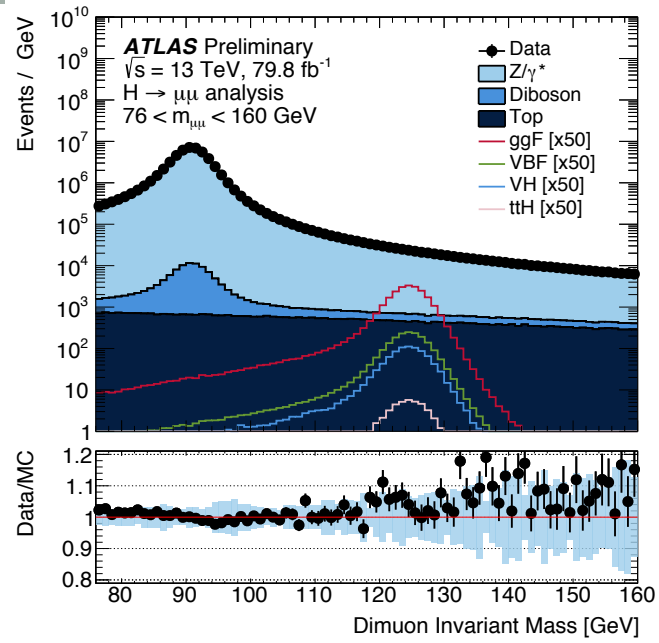
Rare decays

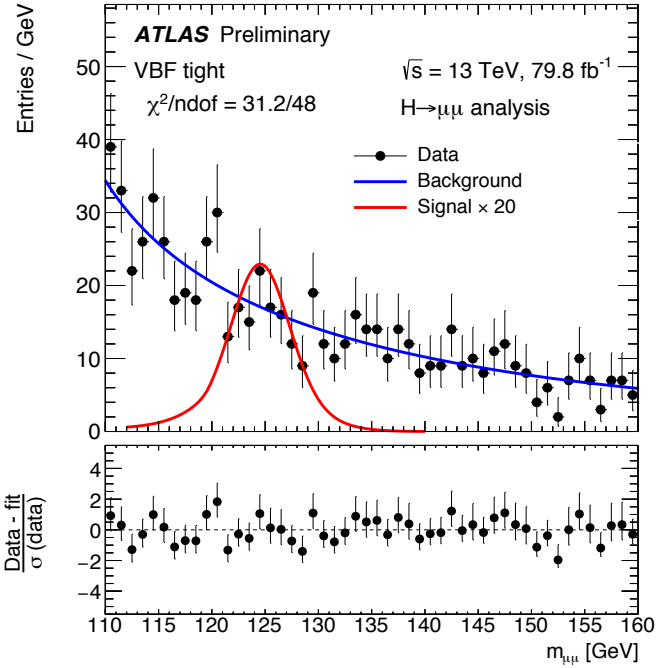
Channel	BR [%]
μμ	0.022
Z(ll)γ	0.15*0.067
ZZ(4v)	0.1

ATLAS-CONF-2018-026

H → μμ

- Single muon trigger.
- Selection:
  - Two opposite-charge muons.
  - Higgs mass window cut. Small missing E_T.
  - VBF category: two forward jets.
  - ggF category: fail VBF selection.
- Background: Drell-Yan Z/γ* → μμ
  - Constrained by Higgs mass window side bands.
- Statistically limited.
- Results: signal strength = 0.1 +1.0/-1.1.

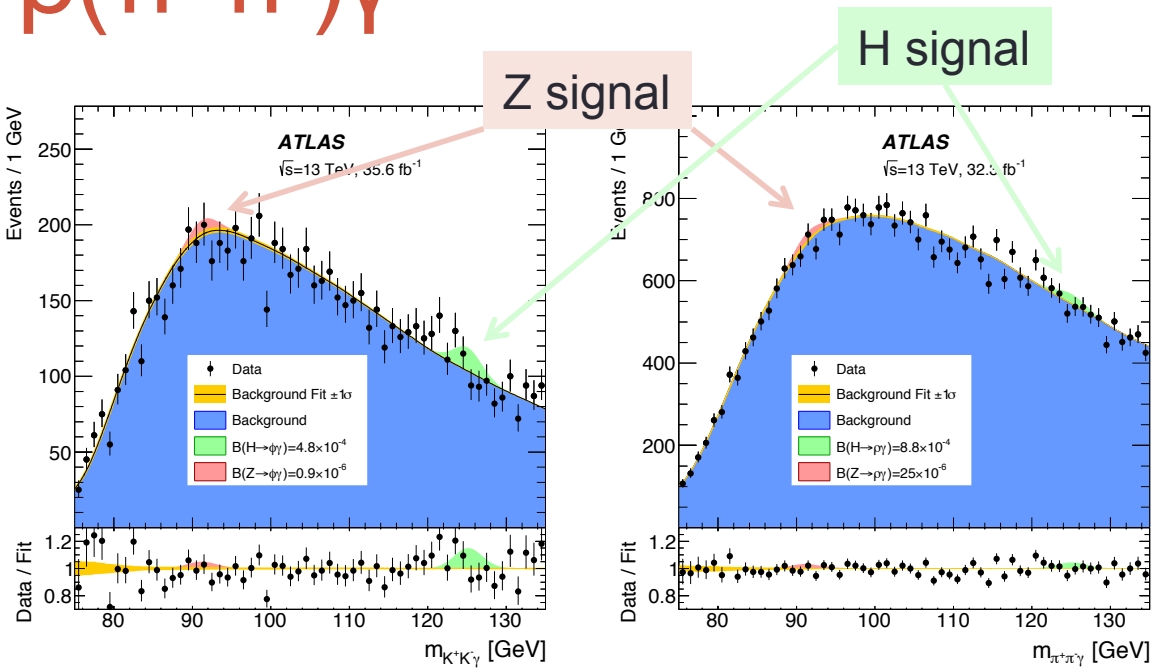




arXiv:1712.02758

H → φ(K^+K^-)γ, ρ($\pi^+\pi^-$)γ

- Special trigger:
  - 2 “track + jet” + photon
- Backgrounds:
  - Photon+jet and Multijet
  - Data driven method using templates.
- Statistically limited.
- Expected SM BR
  - φγ: 2.3e-6
  - ργ: 1.7e-5



Branching Fraction Limit (95% CL)	Expected	Observed
$\mathcal{B}(H \to \phi\gamma)\,[\,10^{-4}\,]$	$4.2^{+1.8}_{-1.2}$	4.8
$\mathcal{B}(Z \to \phi\gamma)\,[\,10^{-6}\,]$	$1.3^{+0.6}_{-0.4}$	0.9
$\mathcal{B}(H \to \rho\gamma)\,[\,10^{-4}\,]$	$8.4^{+4.1}_{-2.4}$	8.8
$\mathcal{B}(Z \to \rho\gamma)\,[\,10^{-6}\,]$	33^{+13}_{-9}	25

PLB 782 (2018) 750

H → aa → jjγγ analysis

- Diphoton triggers.
- Selections:
  - 2 photons + 2 jets
  - Higgs mass window cut.
  - VBF mode: H(jjγγ) + 2 jets
- Background: γγ+mulitijets
  - Estimated from looser photon ID and |m(γγ) − m(jj)| control regions.
- Statistically limited.