Search for Higgs beyond the Standard Model with the ATLAS Detector

Nikolina Ilic

Radboud University

May 9, 2018

Outline

- Introduction
- Beyond Standard Model Higgs theories
- Results for recently published channels
- Conclusion

Introduction

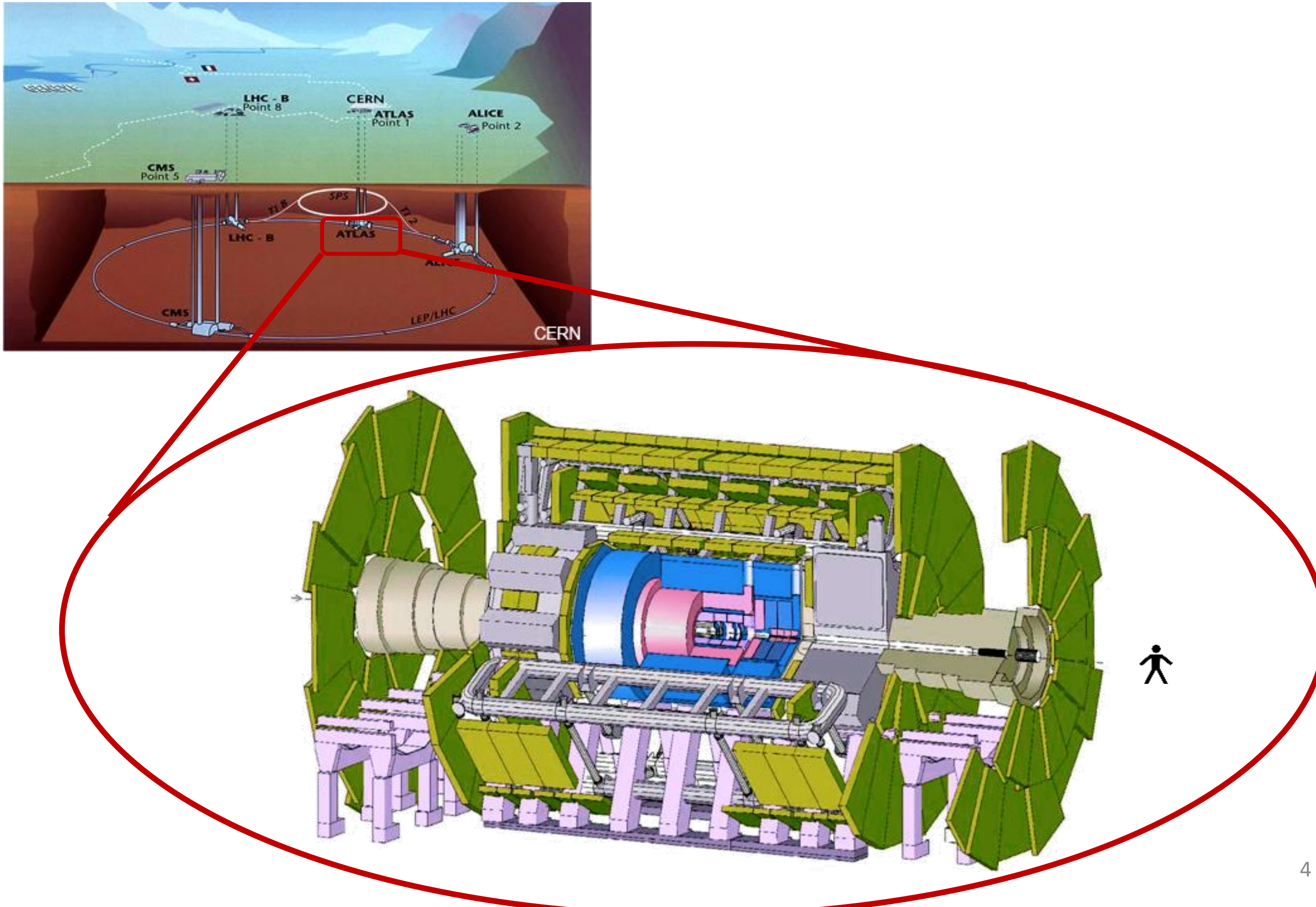
The Higgs boson was discovered in 2012

Need to extend SM to address issues like hierarchy problem, quantum gravity, baryon asymmetry, dark matter/energy, neutrino masses

Look for BSM physics by

- Looking for deviations from the SM in Higgs properties measurements
- Directly searching for beyond SM objects
  - Additional Higgs bosons decaying to SM particles
  - SM Higgs decays to BSM states (eg. invisible decays)

Introduction



Beyond Standard Model Higgs Theories

SM Higgs doublet + **Additional Field** = **Additional Higgs Bosons**

Neutral CP Even

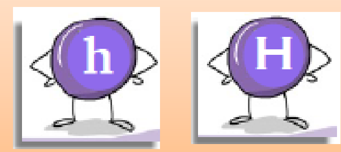
EWS: Additional EW Singlet Model =
SM + one scaler EW singlet

Beyond Standard Model Higgs Theories

SM Higgs doublet + **Additional Field** = **Additional Higgs Bosons**

EWS: Additional EW Singlet Model
SM + one scaler EW singlet =

Neutral CP Even

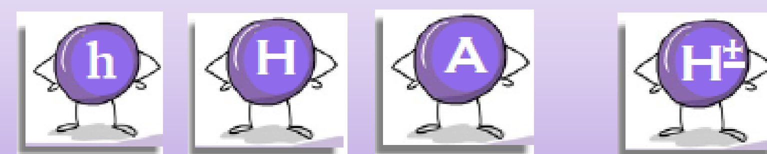


2HDM: Two Higgs Doublet Model
SM + another Higgs doublet =

Neutral

CP Even | CP Odd

Charged



Beyond Standard Model Higgs Theories

SM Higgs doublet ➕ **Additional Field** 〓 **Additional Higgs Bosons**

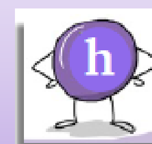
EWS: Additional EW Singlet Model
SM ➕ one scaler EW singlet 〓

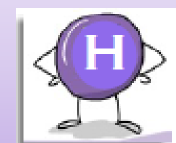
Neutral CP Even

2HDM: Two Higgs Doublet Model
SM ➕ another Higgs doublet 〓

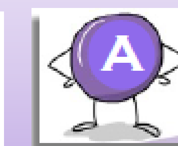
Neutral

CP Even





CP Odd



Charged

2HDM + Singlet (complex) Model
SM ➕ doublet & singlet 〓

Neutral

CP Even

CP Odd

+ 2HDM Higgses

Beyond Standard Model Higgs Theories

SM Higgs doublet + **Additional Field** = **Additional Higgs Bosons**

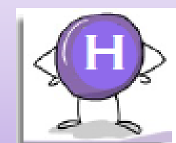
EWS: Additional EW Singlet Model
SM + one scaler EW singlet =

Neutral CP Even

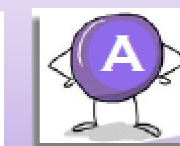
2HDM: Two Higgs Doublet Model
SM + another Higgs doublet =

Neutral

CP Even



CP Odd



Charged

2HDM + Singlet (complex) Model
SM + doublet & singlet =

Neutral

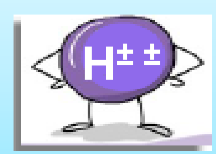
CP Even

CP Odd

+ 2HDM Higgses

Higgs Triplet Model
SM + triplet =

Double Charged



+ 2HDM Higgses

Beyond Standard Model Higgs Theories

EWS significantly constrained by Run 1 Higgs measurements

2HDM: two Higgs doublets Φ_1 and Φ_2

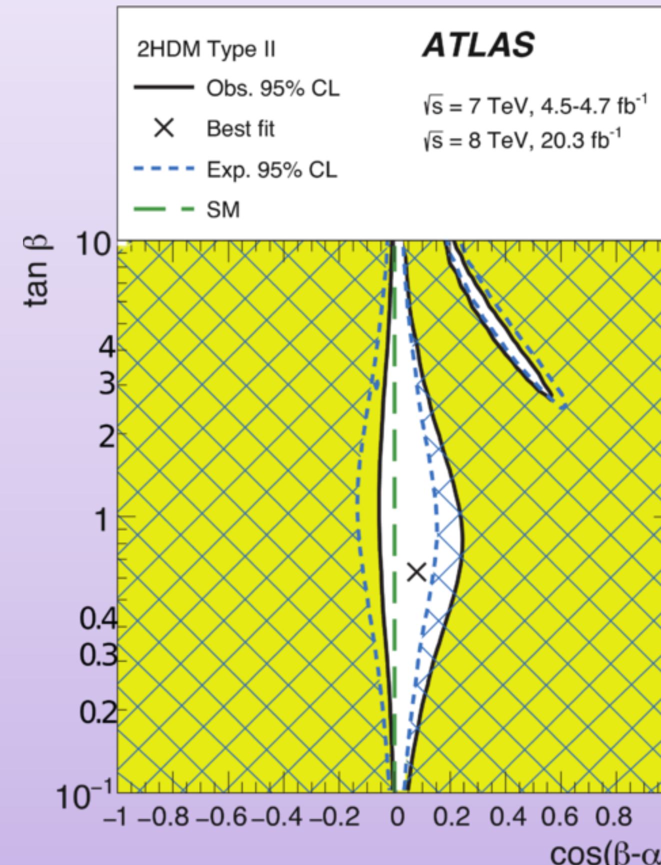
7 parameters:

$m_h,\ m_H,\ m_A,\ m_{H^\pm},\ m_{12},\ \tan\beta,\ \alpha$

Ratio of VEV of Φ_1 and Φ_2

h & H mixing angle

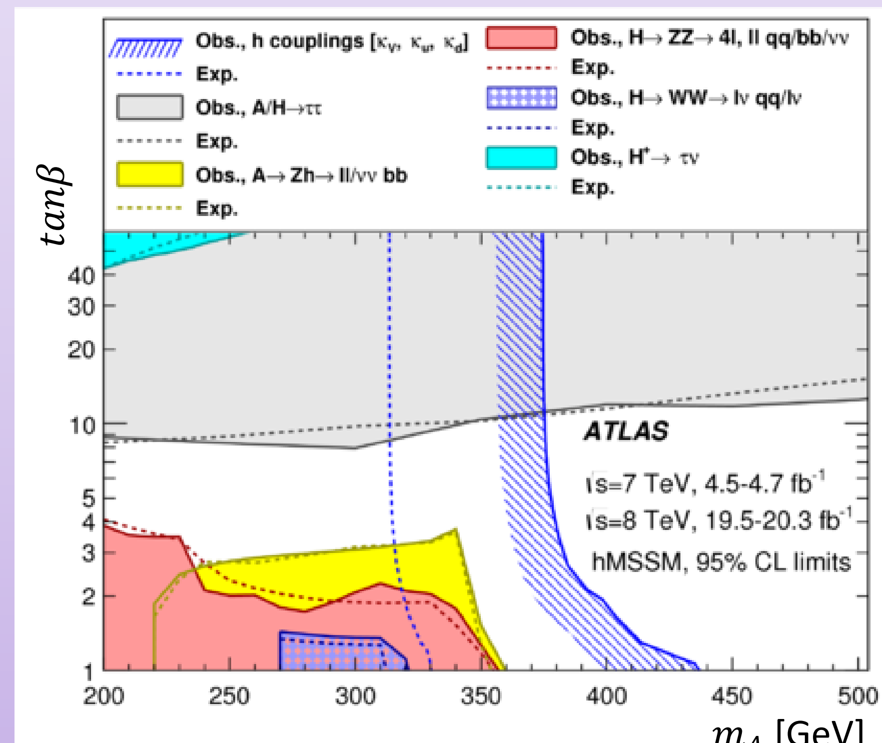
- Models motivated by bounds on FCNC
  - Type I : fermions couple to Φ_2
  - Type II : up type quarks couple to Φ_2, down-type quarks & charged leptons couple to Φ_1. Eg: MSSM
- Run 1 SM Higgs results give big constraints on 2HDM. Data prefers alignment limit: $\cos(\beta-\alpha) = 0$



Beyond Standard Model Higgs Theories

Minimal Supersymmetric SM (MSSM)

- Simplest extension of SM that includes SUSY
- Beyond tree level more than 2 parameters affect Higgs sector, benchmarks defined:
  - $m_{h,mod}^{\pm}: m_h$ is close to 125 GeV
  - hMSSM : measured value of m_h can be used to predict other masses
- In Run 1 excluded many regions of parameter space



Results for all published channels

Neutral Heavy Higgs to bosons	ZV → llqq /vvqq WV→ lvqq X->Zγ WW → lvlv ZZ → 4l VV→ 2j A→ Z/Wh (w h→bb)
	H→4γ H → WH
Neutral Higgs to fermions	A/H/h → ττ
	A/H/h → tt
Neutral Higgs to di-Higgs	hh → 4b hh → WWγγ
	hh → bbγγ
	hh → bbττ
Charged Higgs	$H^{\pm\pm} \to ll$
	$H^{\pm}$ → τν $H^{\pm}$ → tb
	Light $H^{\pm}$ → cs VBF $H^{\pm}$ → WZ
Higgs exotic with MET	H → γγ+MET H → bb+MET hZ → INV (lep)
	H → Z (ll)+MET
	VBF h → INV hV→ INV (had) H → γ+MET H→ INV (1 jet)
Rare decays/ LVF	h(125) → ϕ/ργ
	h(Z) → J/ψγ h → τμ / τe / eμ
Higgs to light res.	h (125)→ aa → 4ℓ h(125) → aa → 2j2γ
	h(125) → aa → 4b
	H/h → aa → μμττ

Legend

~36 fb^{-1} (up to 2017)
13.2-15.4 fb^{-1} (2015+2016)
3.2 fb^{-1} (2015)
5-20.3fb^{-1} (RUN 1)

Results for all published channels

Neutral Heavy Higgs to bosons
- ZV → llqq /vvqq
- WV→ lvqq
- X->Zγ
- WW → lvlv
- ZZ → 4l
- VV→ 2j
- A→ Z/Wh (w h→bb)
- H→4γ
- H → WH

Neutral Higgs to fermions
- A/H/h → ττ
- A/H/h → tt

Neutral Higgs to di-Higgs
- hh → 4b
- hh → WWγγ
- hh → bbγγ
- hh → bbττ

Charged Higgs
- $H^{\pm\pm} \to ll$
- $H^{\pm}$ → τν
- $H^{\pm}$ → tb
- Light $H^{\pm}$ → cs
- VBF $H^{\pm}$ → WZ

Higgs exotic with MET
- H → γγ+MET
- H → bb+MET
- hZ → INV (lep)
- H → Z (ll)+MET
- VBF h → INV
- hV→ INV (had)
- H → γ+MET
- H→ INV (1 jet)

Rare decays/ LVF
- h(125) → $\phi/\rho\gamma$
- h(Z) → J/ψγ
- h → τμ / τe / eμ

Higgs to light res.
- h (125)→ aa → 4ℓ
- h(125) → aa → 2j2γ
- h(125) → aa → 4b
- H/h → aa → μμττ

Legend
~36 fb^{-1} (up to 2017)
13.2-15.4 fb^{-1} (2015+2016)
3.2 fb^{-1} (2015)
5-20.3fb^{-1} (RUN 1)

Will focus on newer results

Updates on these + new channels coming soon

Results for all published channels

Neutral Heavy Higgs to bosons

- ZV → llqq /ννqq
- WV→ lνqq
- X->Zγ
- WW → lνlν
- ZZ → 4l
- VV→ 2j
- A→ Z/Wh (w h→bb)
- H→4γ
- H → WH

Neutral Higgs to fermions

- A/H/h → ττ
- A/H/h → tt

Neutral Higgs to di-Higgs

- hh → 4b
- hh → WWγγ
- hh → bbγγ
- hh → bbττ

Charged Higgs

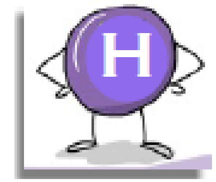
- $H^{\pm\pm} \to ll$
- $H^{\pm}$ → τν
- $H^{\pm}$ → tb
- Light $H^{\pm}$ → cs
- VBF $H^{\pm}$ → WZ

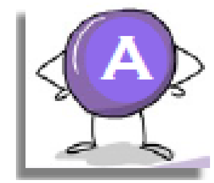
Higgs exotic with MET

- H → γγ+MET
- H → bb+MET
- hZ → INV (lep)
- H → Z (ll)+MET
- VBF h → INV
- hV→ INV (had)
- H → γ+MET
- H→ INV (1 jet)

Rare decays/ LVF

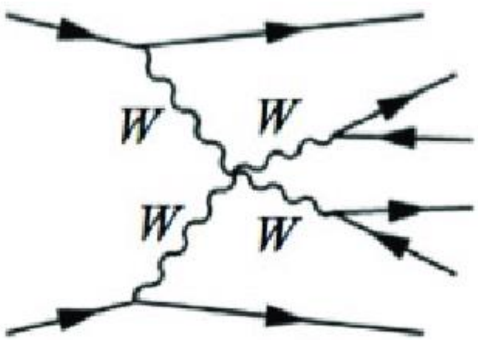
- h(125) → ϕγ
- h(Z) → J/ψγ
- h → τμ / τe / eμ

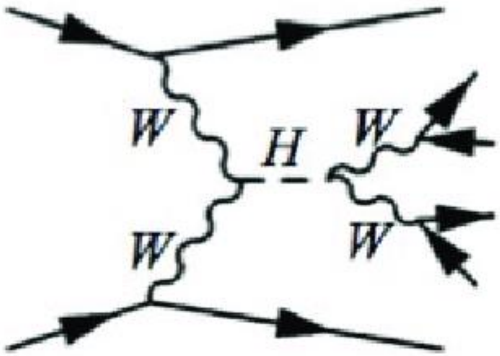




- Is unitarisation of WW scattering at high energy ensured ONLY by SM Higgs?
- Prominent decay is to W/Z in many BSM models

SM

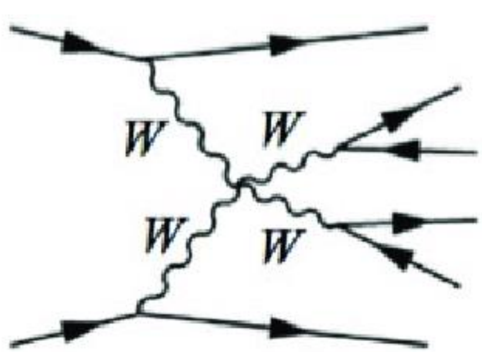


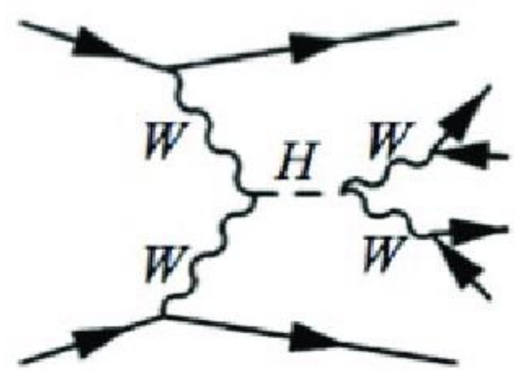


Why these channels?

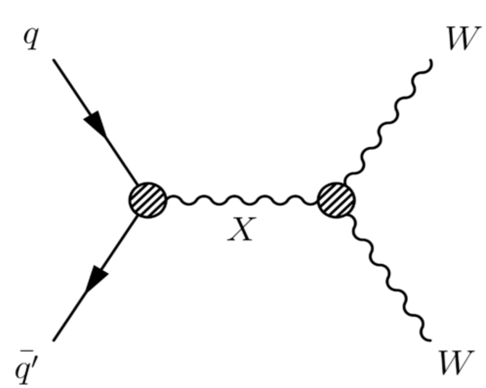
- Is unitarisation of WW scattering at high energy ensured ONLY by SM Higgs?
- Prominent decay is to W/Z in many BSM models

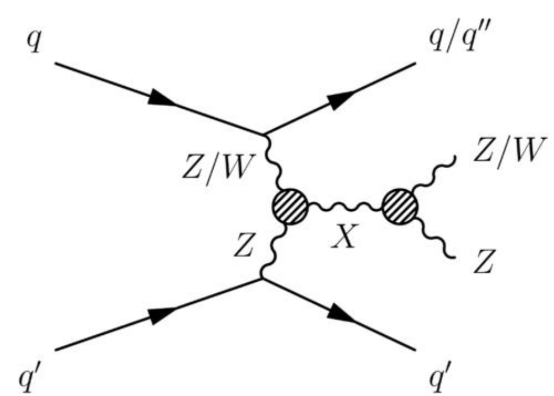
SM





BSM





ZV → llqq /vvqq
WV→ lvqq
X->Zγ

- Is unitarisation of WW scattering at high energy ensured ONLY by SM Higgs?
- Prominent decay is to W/Z in many BSM models

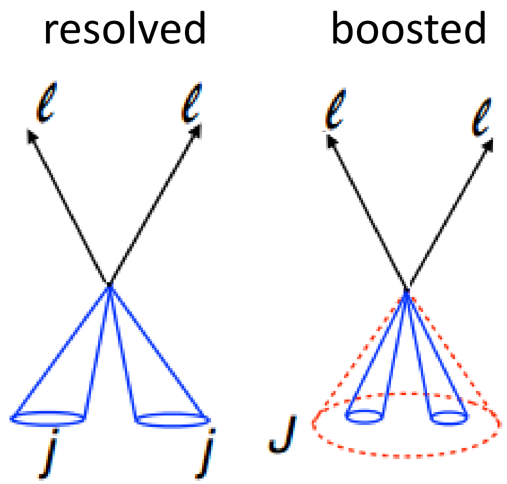
- **Heavy Higgs in Narrow Width Approximation (NWA): Higgs width smaller than experimental resolution (tests EWS, 2HDM, singlet+doublet)**

- Other BSM models tested: Spin 1 Z'/W', spin 2: Kaluza-Klein graviton (G_{kk^*})

- Resolved analysis at lower mass: 2 small radius jets (llqq)

- Boosted analysis: when resonance mass higher than W/Z mass 2 jets merge into 1 big radius jet (llqq, vvqq, lvqq)

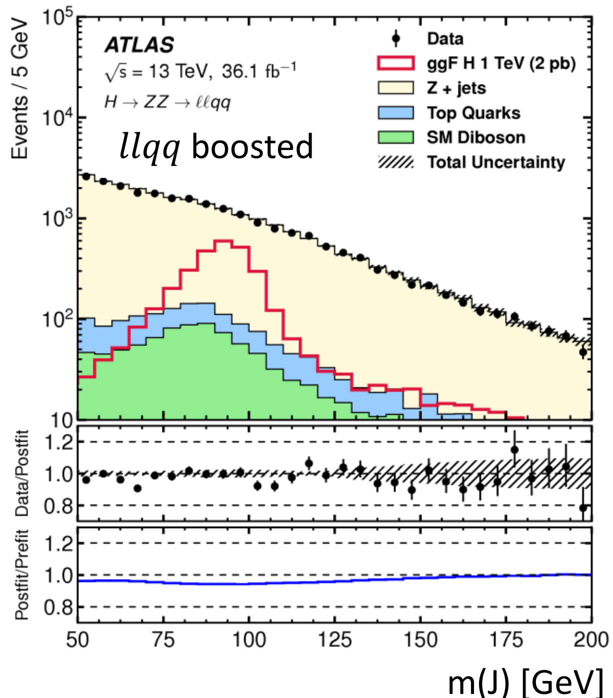
- Discriminating variable: invariant/transverse mass



Theories: heavy Higgs in NWA, Z', W', G_{kk^*}

ZZ $\longrightarrow$ $(ll/\nu\nu)(qq)$ where $l = e, \mu$

- ggF and VBF studied $llqq$ channel



Excluded

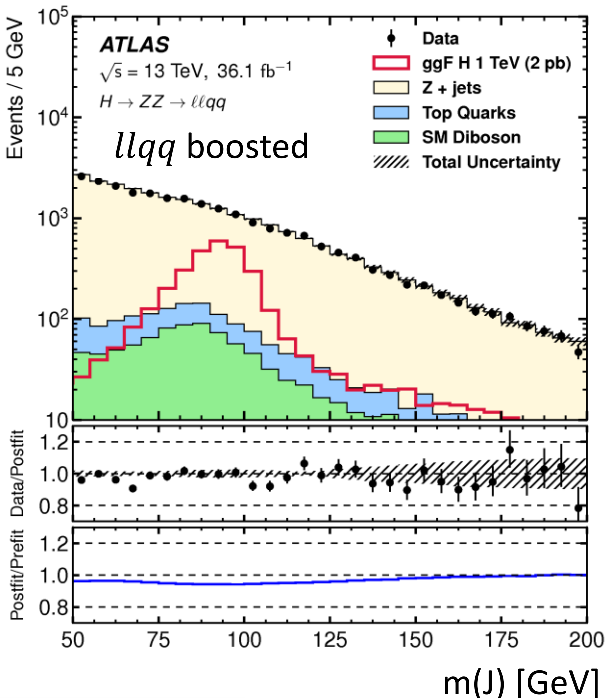
H_{ggf} $\sigma \times BR > 1.7$ pb – 1.4 fb

H_{VBF} $\sigma \times BR > 0.42$ pb – 1.1 fb

Theories: heavy Higgs in NWA, Z', W', G_{kk^*}

ZZ → $(ll/\nu\nu)(qq)$ where $l = e, \mu$

- ggF and VBF studied $llqq$ channel

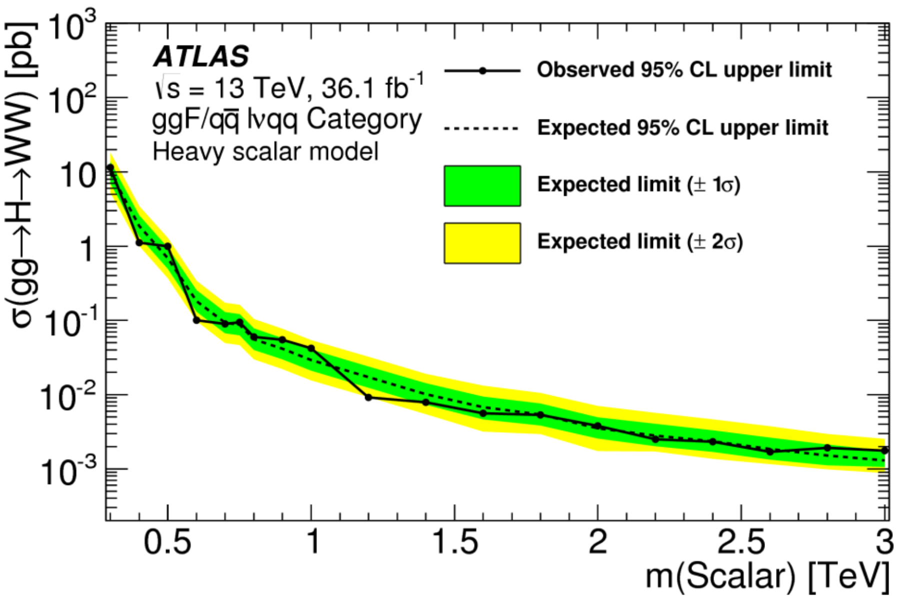


Excluded

H_{ggf} $\sigma \times BR > 1.7$ pb – 1.4 fb

H_{VBF} $\sigma \times BR > 0.42$ pb – 1.1 fb

WW → $(l\nu)(qq)$, where $l = e, \mu$



Excluded

H_{DY} $\sigma \times BR > 1.7$ pb – 1.3 fb

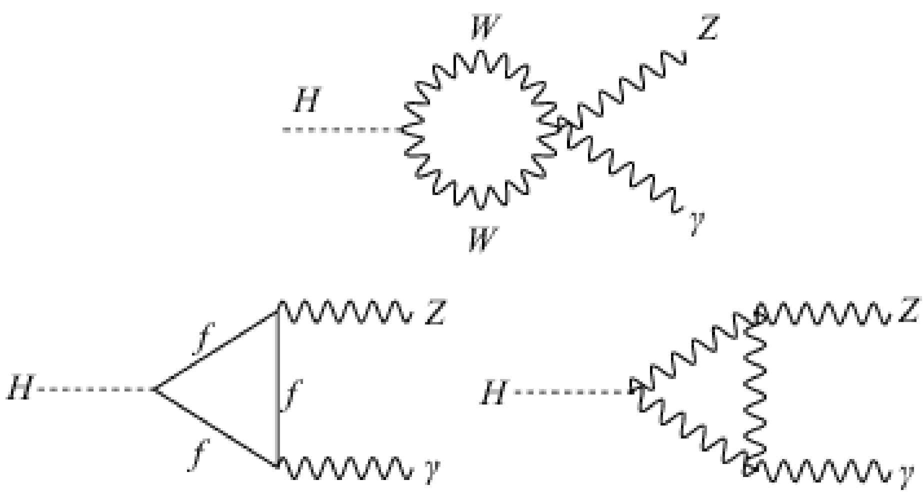
H_{VBF} $\sigma \times BR > 0.98$ pb – 2.8 fb

Neutral Heavy Higgs to bosons

ZV → llqq /ννqq
WV→ lνq
X->Zγ

Why this channels?

- Final state can be reconstructed with high efficiency and good invariant mass resolution,s, relatively small backgrounds
- Loop is sensitive to new physics, branching ratio is expected to be different from SM for many BSM theories (neutral/charged scaler Higgs, additional leptons coupling in loop)

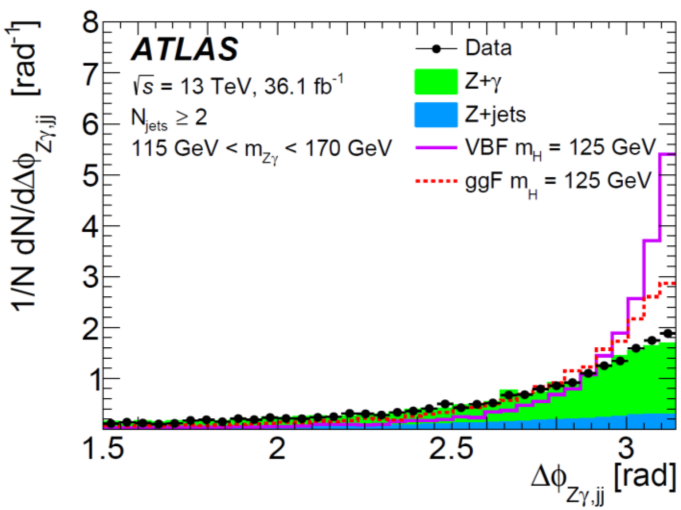


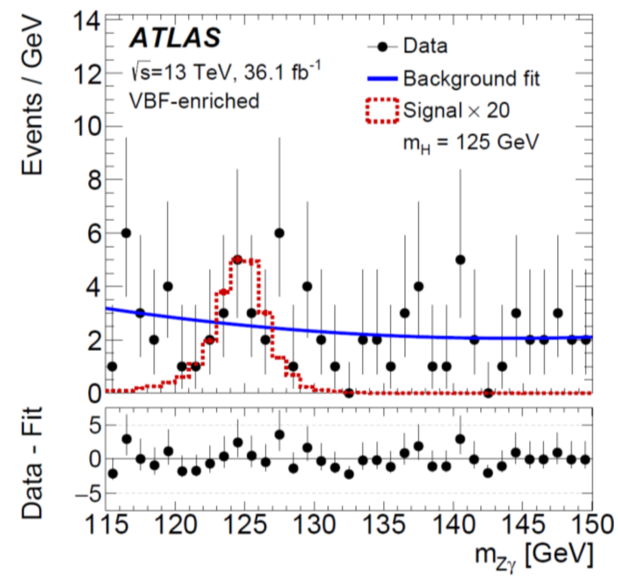
Neutral Heavy Higgs to bosons

ZV → llqq /ννqq
WV→ lνq
X->Zγ

Theories: heavy Higgs in NWA, spin 2 resonance

- ggF, VBF VH studied
- 6 categories defined based VBF production, high/low momenta leptons
- VBF is most sensitive category and uses Boosted Decision Tree





Excluded

$h\ \ \sigma \times BR > 6.6$ x SM prediction

$H\ \ \ \sigma \times BR > 88$ fb – 2.8 fb for $m_H = .25 - 2.4\ \ \text{TeV}$

Results for all published channels

Neutral Heavy Higgs to bosons
- ZV → llqq /ννqq
- WV→ lνqq
- X->Zγ
- WW → lνlν
- ZZ → 4l
- VV→ 2j
- A→ Z/Wh (w h→bb)
- H→4γ
- H → WH

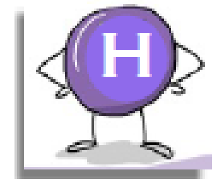
Neutral Higgs to fermions
- A/H/h → ττ
- A/H/h → tt

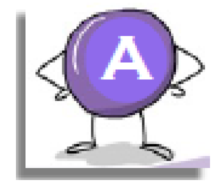
Neutral Higgs to di-Higgs
- hh → 4b
- hh → WWγγ
- hh → bbγγ
- hh → bbττ

Charged Higgs
- $H^{\pm\pm} \to ll$
- $H^{\pm}$ → τν
- $H^{\pm}$ → tb
- Light $H^{\pm}$ → cs
- VBF $H^{\pm}$ → WZ

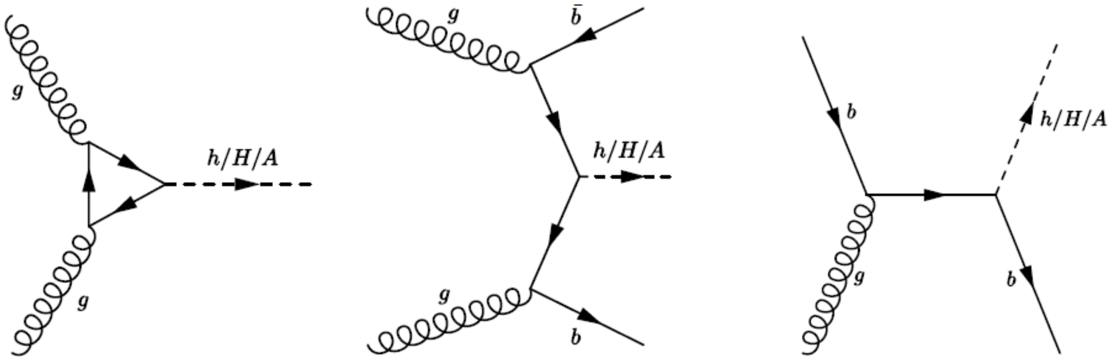
Higgs exotic with MET
- H → γγ+MET
- H → bb+MET
- hZ → INV (lep)
- H → Z (ll)+MET
- VBF h → INV
- hV→ INV (had)
- H → γ+MET
- H→ INV (1 jet)

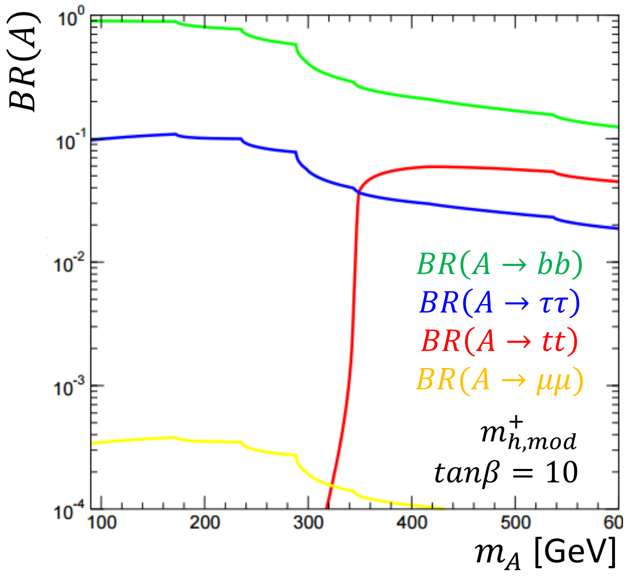
Rare decays/ LVF
- h(125) → ϕγ
- h(Z) → J/ψγ
- h → τμ / τe / eμ



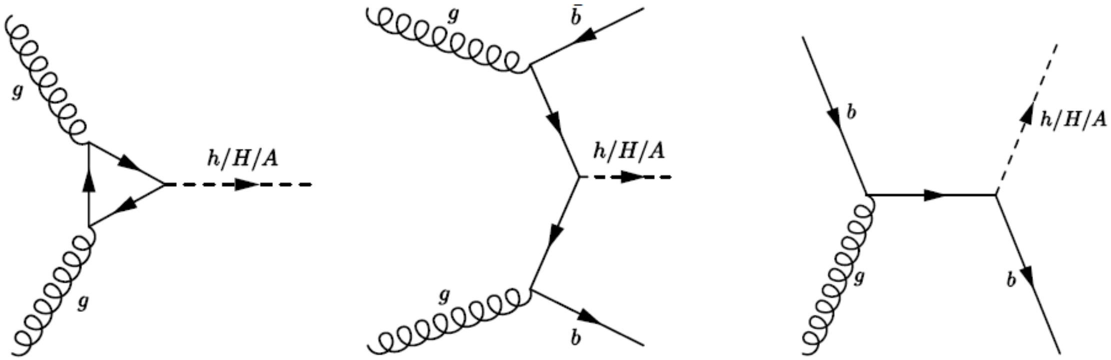


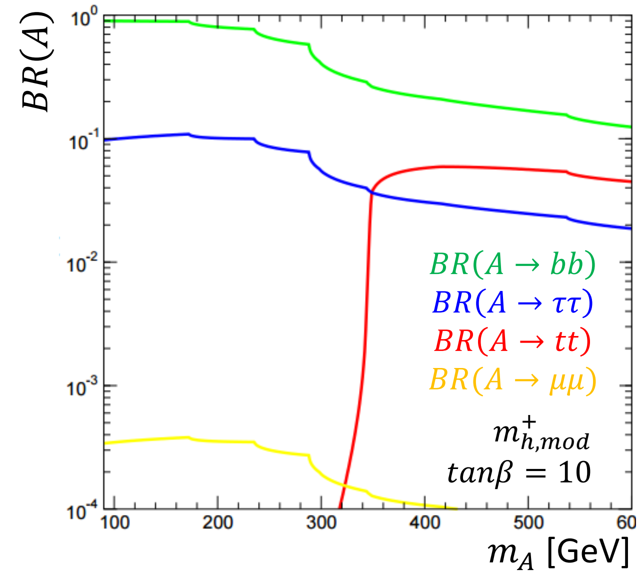
- In MSSM heavy Higgs boson coupling to down-type fermions (τ, b) strongly enhanced for high tan β





- In MSSM heavy Higgs boson coupling to down-type fermions (τ, b) strongly enhanced for high tan β



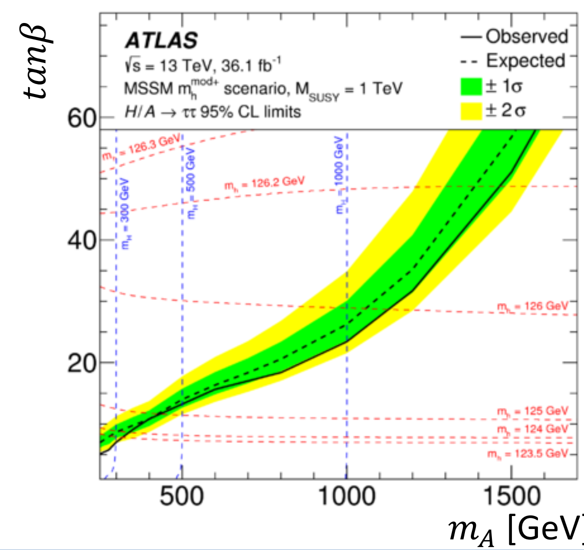


$\tau\tau \to$ (lep/had) (had)

- Theories: $m_{h,mod}^{\pm}$, hMMSM, Z'
- Discriminating variable is transverse mass

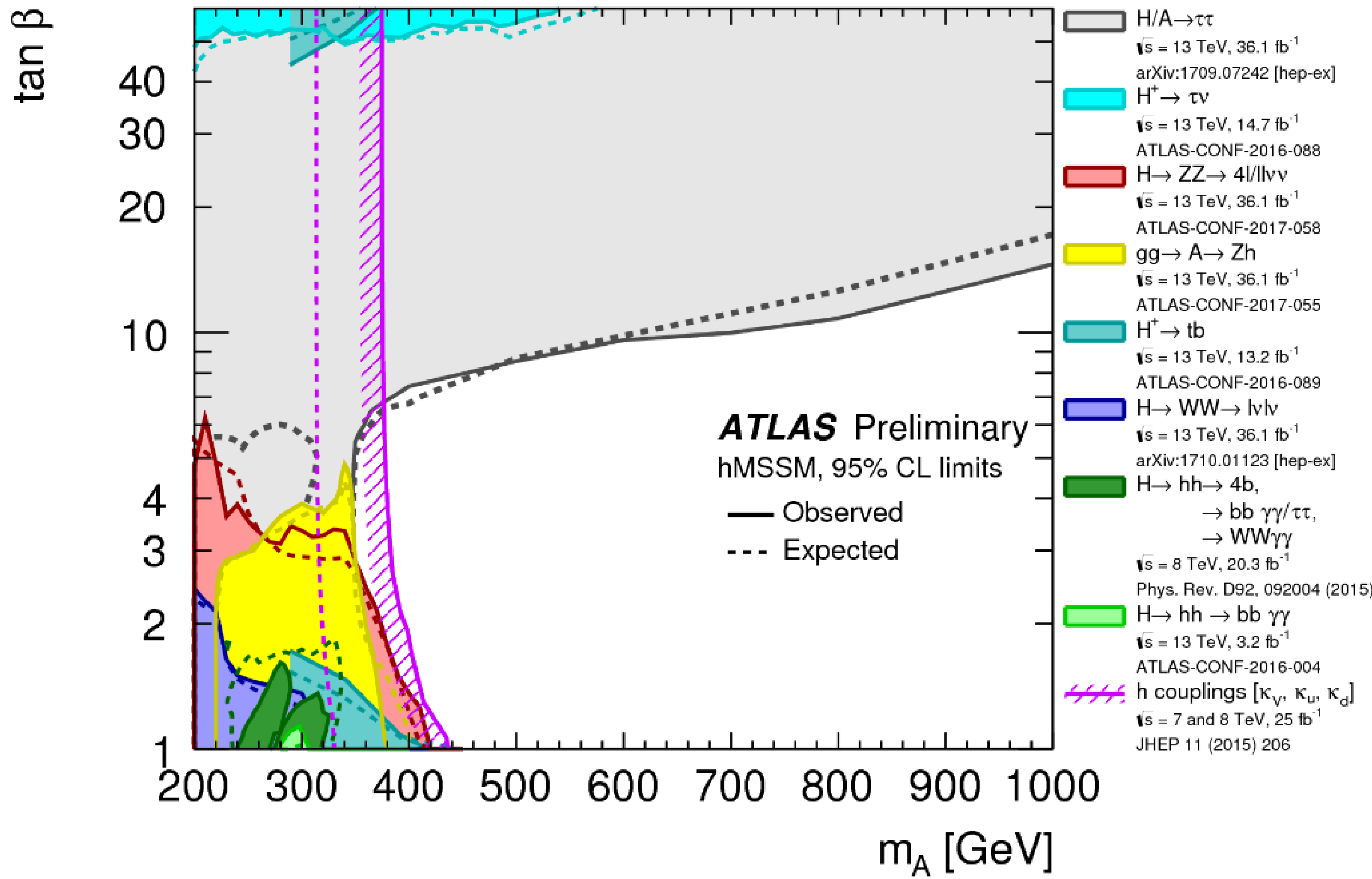
Excluded

- $\sigma \times BR$ < 0.78 (0.7) pb - 5.8 (3.7) fb for ggF (b-associated) for $m_{H/A}$ = 0.2-0.25 TeV
- $m_{h,mod}^{+}$: tanβ>1 (42) for $m_A = 0.25\ (1.5)$ TeV



Neutral Higgs to fermions

A/H/h → ττ



Results for all published channels

Neutral Heavy Higgs to bosons	
	ZV → llqq /vvqq WV→ lvqq X->Zγ WW → lvlv ZZ → 4l VV→ 2j A→ Z/Wh (w h→bb)
	H→4γ H → WH

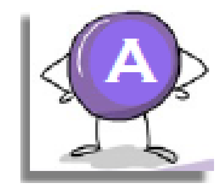
Neutral Higgs to fermions	
	A/H/h → ττ
	A/H/h → tt

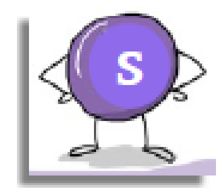
Neutral Higgs to di-Higgs	
	hh → 4b hh → WWγγ
	hh → bbγγ
	hh → bbττ

Charged Higgs	
	$H^{\pm\pm} \rightarrow ll$
	$H^{\pm}$ → τν $H^{\pm}$ → tb
	Light $H^{\pm}$ → cs VBF $H^{\pm}$ → WZ

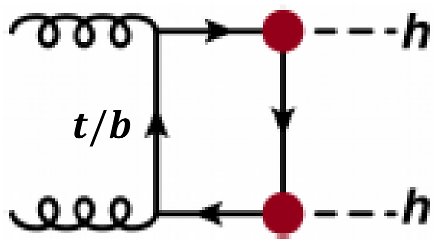
Higgs exotic with MET	
	H → γγ+MET H → bb+MET hZ → INV (lep)
	H → Z (ll)+MET
	VBF h → INV hV→ INV (had) H → γ+MET H→ INV (1 jet)

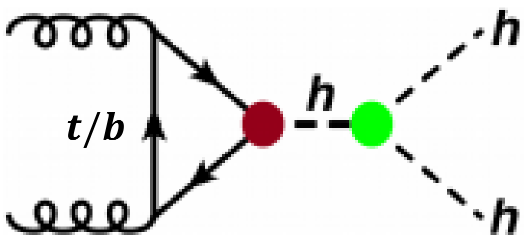
Rare decays/ LVF	
	h(125) → ϕγ
	h(Z) → J/ψγ h → τμ / τe / eμ



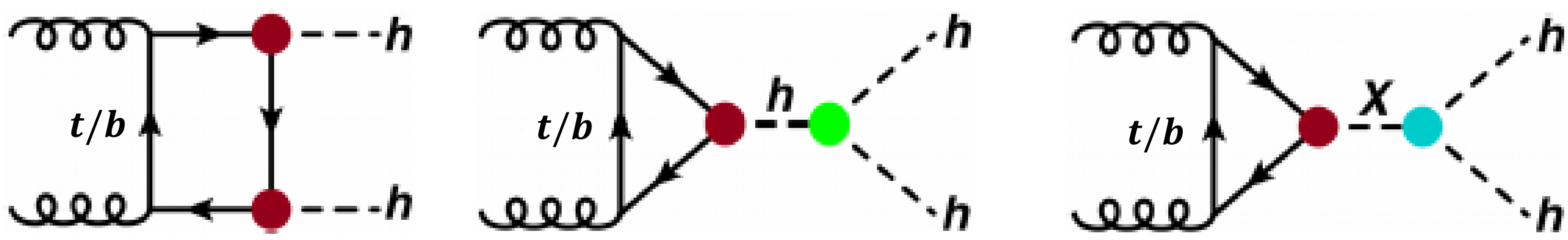


SM Di-Higgs production several orders of magnitude lower than single Higgs production AND destructive interference among diagrams makes it smaller





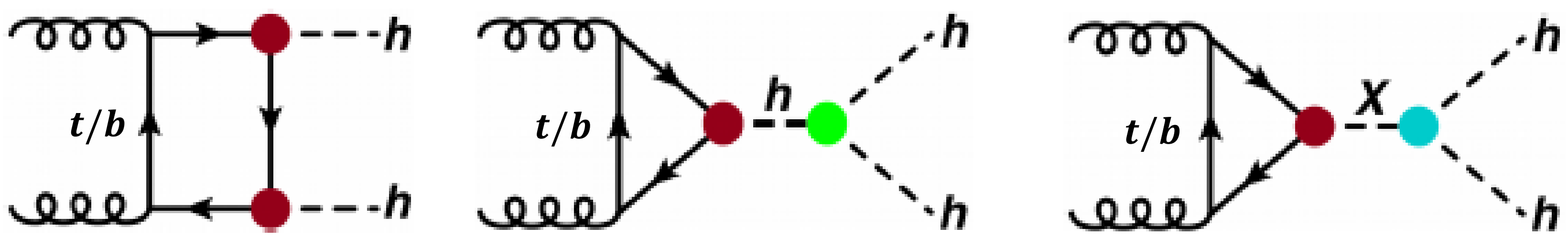
SM Di-Higgs production several orders of magnitude lower than single Higgs production AND destructive interference among diagrams makes it smaller



Di-Higgs production enhanced in many BSM models

- Non resonant production: Higgs coupling to t , b , h modified wrt SM values
- Resonant production: Replacing virtual Higgs boson with an intermediate heavy resonance (2HDM, G_{kk^*})

SM Di-Higgs production several orders of magnitude lower than single Higgs production AND destructive interference among diagrams makes it smaller



Di-Higgs production enhanced in many BSM models

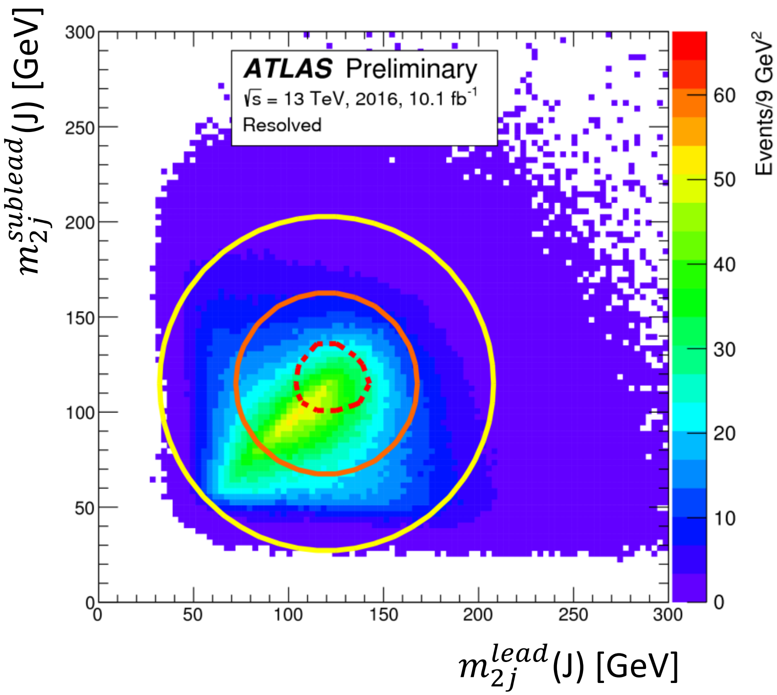
- Non resonant production: Higgs coupling to t , b , h modified wrt SM values
- Resonant production: Replacing virtual Higgs boson with an intermediate heavy resonance (2HDM, G_{kk^*})

- **hh → 4b:** highest branching ratio
- **hh → WWγγ:** clean signature and good di-photon invariant mass that gives good background rejection

BR	bb	WW
bb	**33%**	
WW	25%	4.6%
$\tau\tau$	7.4%	2.5%
ZZ	3.1%	1.2%
$\gamma\gamma$	0.26%	**0.10%**

hh → 4b

- Theories : ggF non-resonant, G_{kK^*}
- Signal selected in 2D plane of jet mass

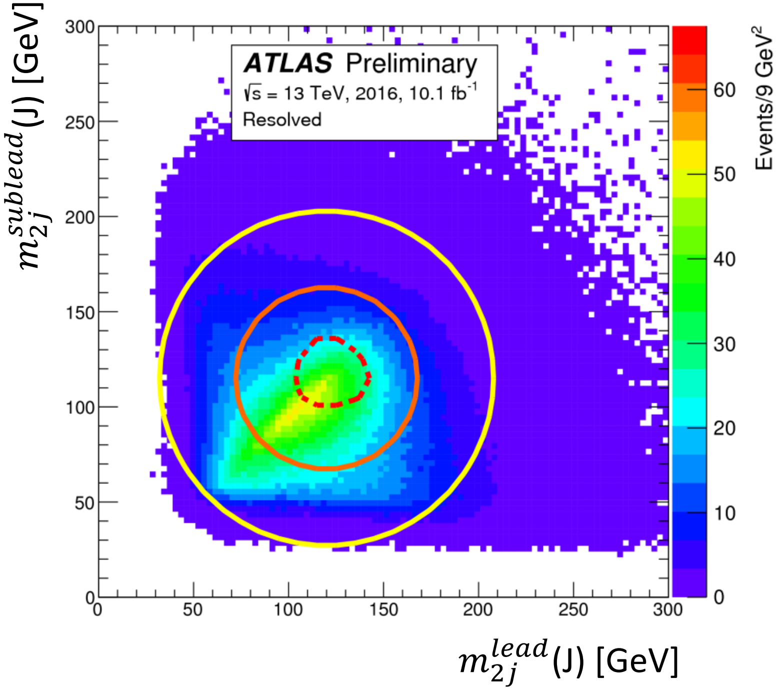


Excluded

Non-resonant: $\sigma \times BR$ < 300 fb
for 300-3000 GeV (SM : $11.3^{+0.9}_{-1.0}$)

hh → 4b

- Theories : ggF non-resonant, G_{kK^*}
- Signal selected in 2D plane of jet mass

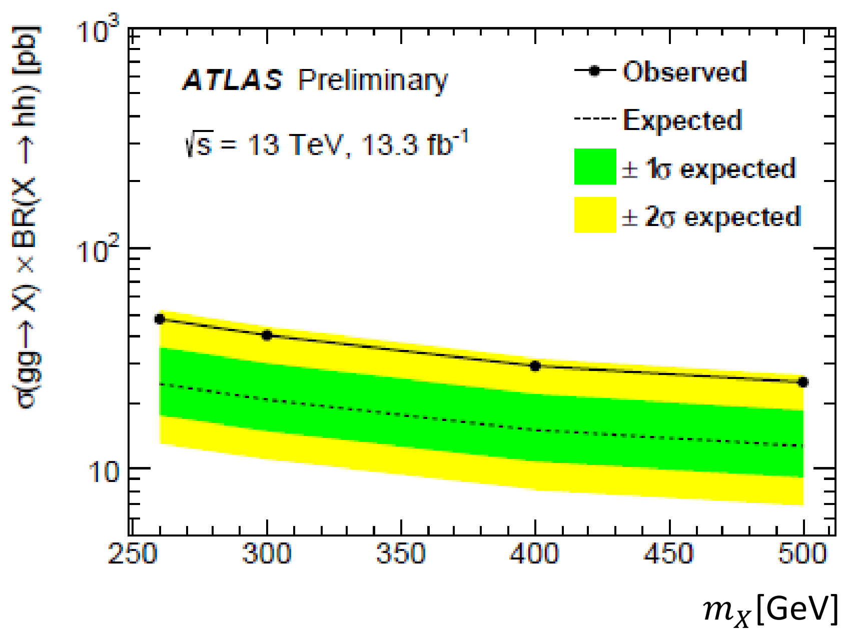


Excluded

Non-resonant: $\sigma \times BR$ < 300 fb
for 300-3000 GeV (SM : $11.3^{+0.9}_{-1.0}$)

γγWW(→ lν jj)

- Theories : Higgs in NWA, non-resonant
- Counting experiment in signal region



Excluded

Non- resonant: $\sigma \times BR$ < 25.0 pb
Resonant: $\sigma \times BR$ < 47.7pb -24.7 pb

Results for all published channels

Neutral Heavy Higgs to bosons
- ZV → llqq /vvqq
- WV→ lvqq
- X->Zγ
- WW → lvlv
- ZZ → 4l
- VV→ 2j
- A→ Z/Wh (w h→bb)
- H→4γ
- H → WH

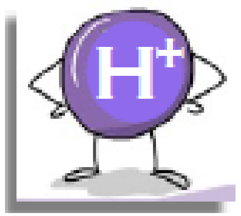
Neutral Higgs to fermions
- A/H/h → ττ
- A/H/h → tt

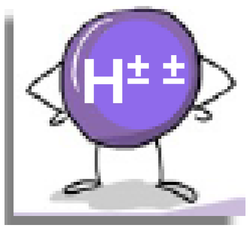
Neutral Higgs to di-Higgs
- hh → 4b
- hh → WWγγ
- hh → bbγγ
- hh → bbττ

Charged Higgs
- $H^{\pm\pm} \to ll$
- $H^{\pm}$ → τν
- $H^{\pm}$ → tb
- Light $H^{\pm}$ → cs
- VBF $H^{\pm}$ → WZ

Higgs exotic with MET
- H → γγ+MET
- H → bb+MET
- H→ $Z_{dark}Z_{dark}$
- hZ → INV (lep)
- H → Z (ll)+MET
- VBF h → INV
- hV→ INV (had)
- H → γ+MET
- H→ INV (1 jet)

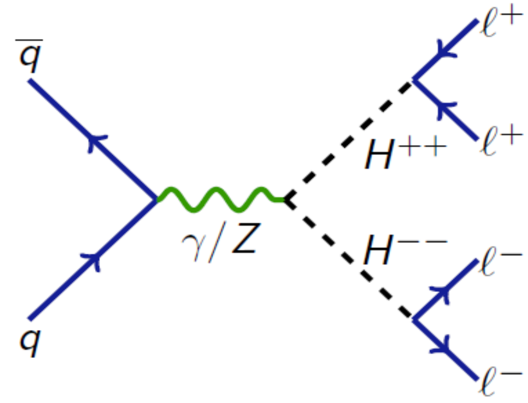
Rare decays/ LVF
- h(125) → ϕγ
- h(Z) → J/ψγ
- h → τμ / τe / eμ



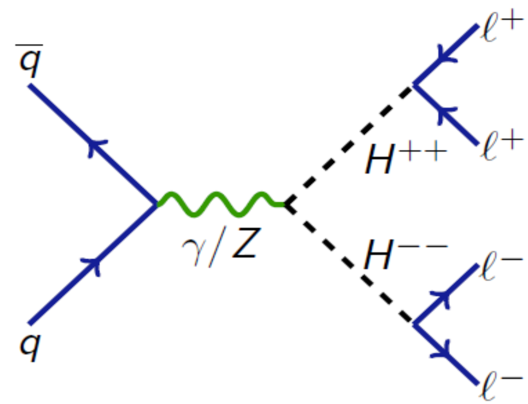


Why this channel?

- In SM events with 2 high momenta, same-charge electrons are rare
- $\mathrm{H}^{\pm\pm}$ is cleanest signature for triplet models
- $\mathrm{H}^{\pm\pm}$ produced via Drell-Yann process

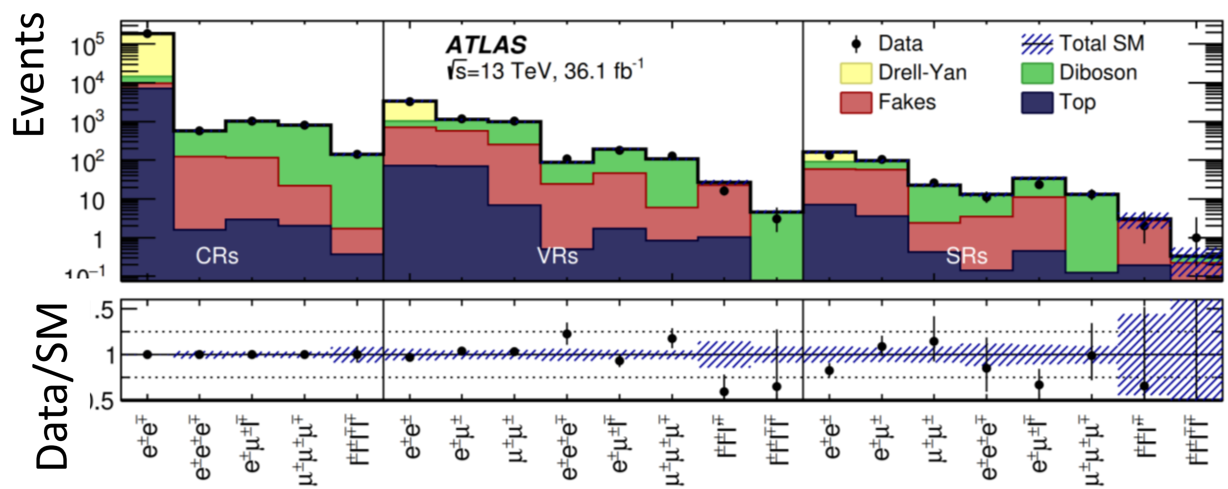


- In SM events with 2 high momenta, same-charge electrons are rare
- $\mathrm{H}^{\pm\pm}$ is cleanest signature for triplet models
- $\mathrm{H}^{\pm\pm}$ produced via Drell-Yann process



$\ell^{\pm}\ell^{\pm}$ (e and μ)

- Theory : left-right symmetric ($H_L^{\pm\pm}$, $H_R^{\pm\pm}$)
- Discriminating variable is di-lepton invariant mass

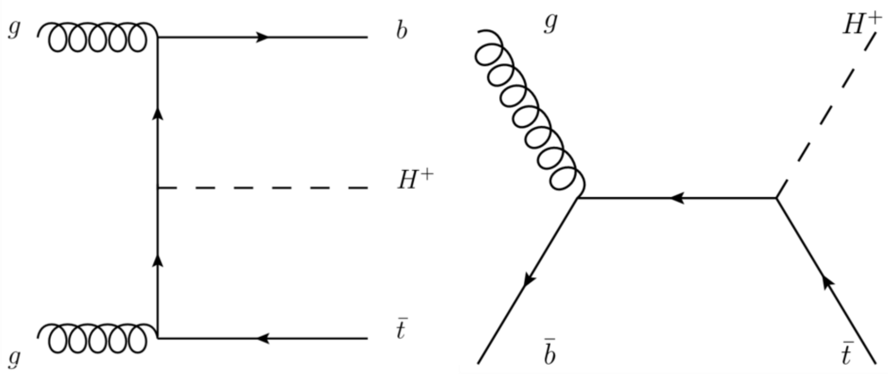


Excluded

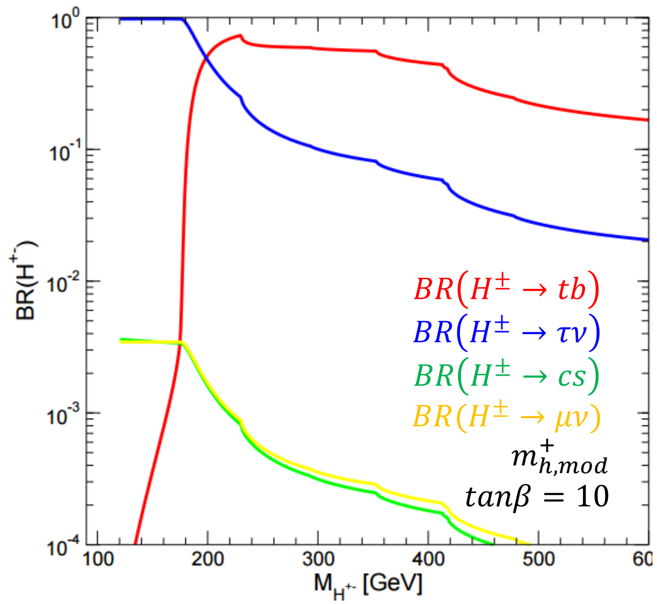
- m of $H_R^{\pm\pm}$ ($H_L^{\pm\pm}$), < 660-760 (770-870) GeV for BR = 100%

Why these channels?

- Charged Higgs bosons appears when doublet/triplet added
- For $m_{H^{\pm}} > (<)\ m_{top}$ the main production mode of charged Higgs is in association with t (b)
- Decay of $H^{\pm}$ to τν (tb) dominates below (above) top threshold
- Run 1: $H^{\pm} \rightarrow tb$ analysis excess of events above the background-only hypothesis observed (2.4 σ across wide mass range)

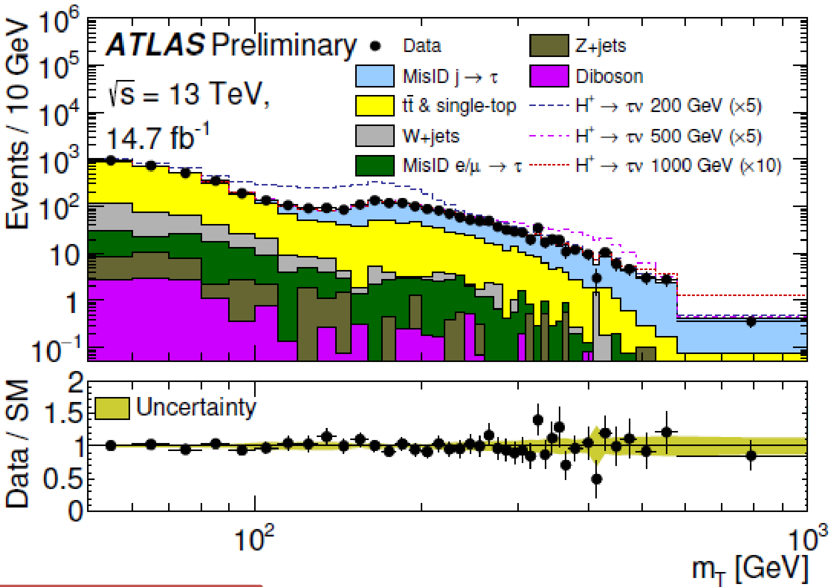


4-flavour scheme 5-flavour scheme



τν (hadronic)

- Theory: hMSSM
- Discriminating variable is transverse mass



Excluded

- $\sigma \times BR < 2.0 \; - 0.008 \, pb$

hMSSM

- 42 < tan $\beta < 60$ for $m_{H^{\pm}}$ = 200 GeV
- $m_{H^{\pm}}$ <540 GeV for tan $\beta = 60$

Heavy Charged Higgs

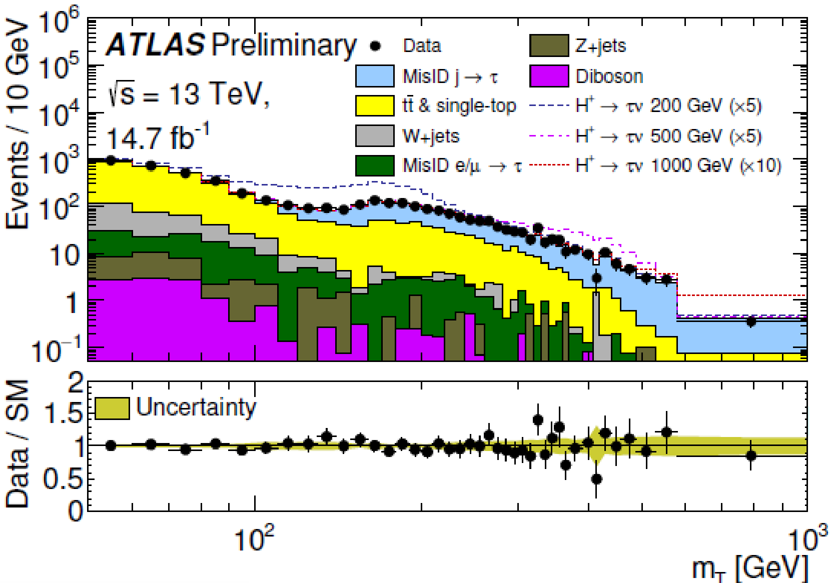
$H^{\pm\pm} \rightarrow ll$

$H^{\pm}$ → τν

$H^{\pm}$ → tb

τν (hadronic)

- Theory: hMSSM
- Discriminating variable is transverse mass



Excluded

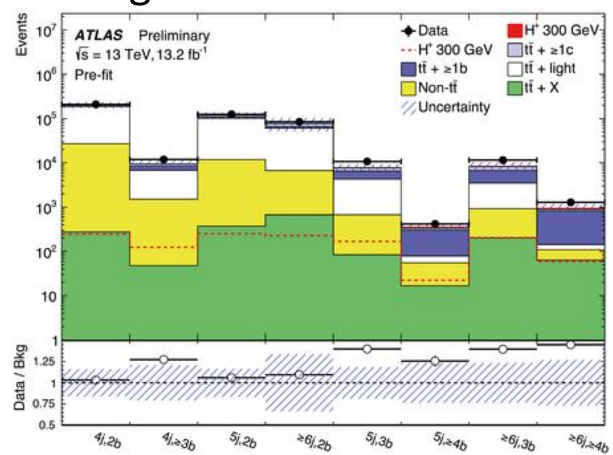
- $\sigma \times BR < 2.0\ - 0.008\, pb$

hMSSM

- 42 < tan β < 60 for $m_{H^{\pm}}$ = 200 GeV
- $m_{H^{\pm}}$ < 540 GeV for tan β = 60

tb (e/μ from t decay)

- Theory: $m_{h,mod}^{\pm}$
- Events are categorised according to the multiplicity of jets and b-tagged jets
- Multivariate techniques separate signal from background



Excluded No big excess above SM

- $\sigma \times BR$ <1.09 -0.18

$m_{h,mod}^{-}$

- 0.5 < tan β < 1.7 for $m_{H^{\pm}}$ = 300-855 GeV
- tan β > 44 (60) for $m_{H^{\pm}}$ = 300 (366) GeV

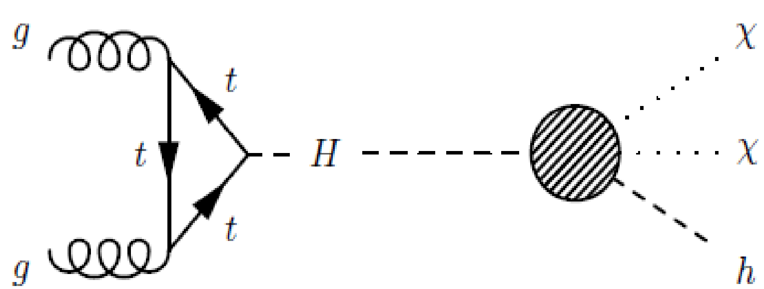
Results for all published channels

Neutral Heavy Higgs to bosons	ZV → llqq /ννqq WV→ lνqq X->Zγ WW → lνlν ZZ → 4l VV→ 2j A→ Z/Wh (w h→bb)
	H→4γ H → WH
Neutral Higgs to fermions	A/H/h → ττ
	A/H/h → tt
Neutral Higgs to di-Higgs	hh → 4b hh → WWγγ
	hh → bbγγ
	hh → bbττ

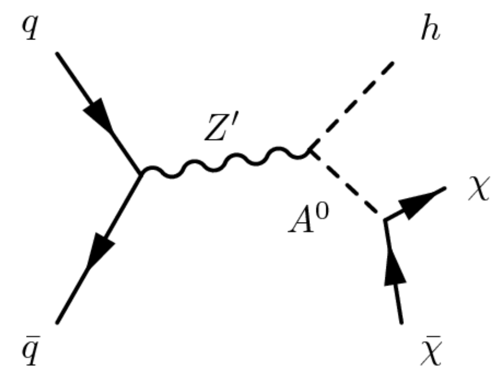
Charged Higgs	$H^{\pm\pm}$→ll
	$H^{\pm}$ → τν $H^{\pm}$ → tb
	Light $H^{\pm}$ → cs VBF $H^{\pm}$ → WZ
Higgs exotic with MET	$\boxed{\text{H → γγ+MET}\quad \text{H → bb+MET}}$
	hZ → INV (lep)
	H → Z (ll)+MET
	VBF h → INV hV→ INV (had) H → γ+MET H→ INV (1 jet)
Rare decays/ LVF	h(125) → ϕγ
	h(Z) → J/ψγ h → τμ / τe / eμ

- Models with Higgs and missing transverse energy (E_T^{miss}) are motivated by searches for Dark Matter (χ)
- γγ final states can be measured well with relatively low backgrounds
- bb final states have high SM higgs Branching ratios

Heavy Higgs scaler H $\rightarrow \chi\chi h, (h \rightarrow \gamma\gamma)$, parametrized by effective field theory

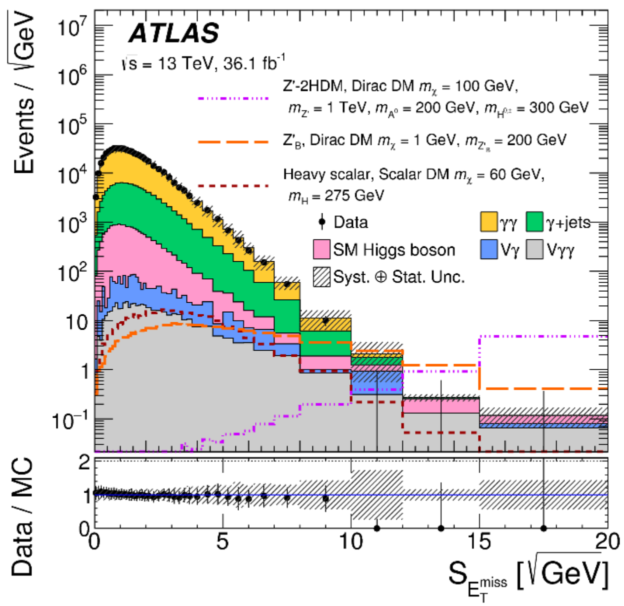


2HDM with U(1)$_A$ gives 5 Higgses, DM and Z':
$(h \rightarrow \gamma\gamma/bb)(A^0 \rightarrow \chi\chi)$



H → γγ+MET
H → bb+MET

- Signal selected in 5 categories defined by (E_T^{miss}) significance, $p_T^{\gamma\gamma}$, number of leptons.
- Significance of E_T^{miss} is less sensitive to pileup than E_T^{miss}



Excluded

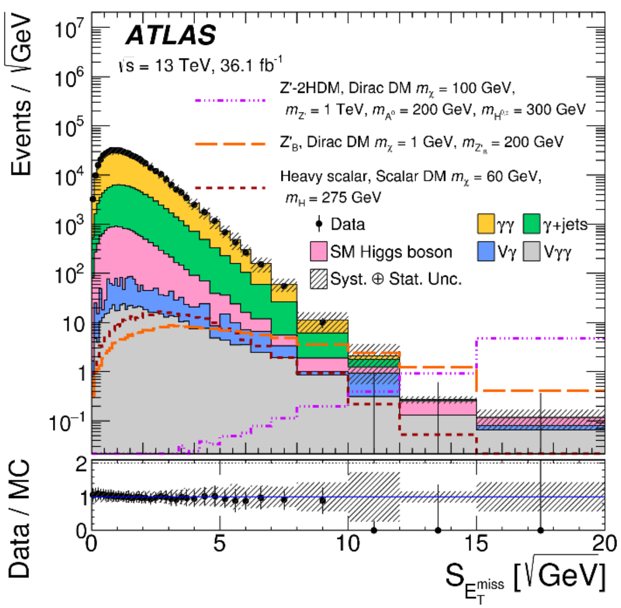
heavy Higgs: $\sigma \times BR > 15.4\ (4.3)$fb for

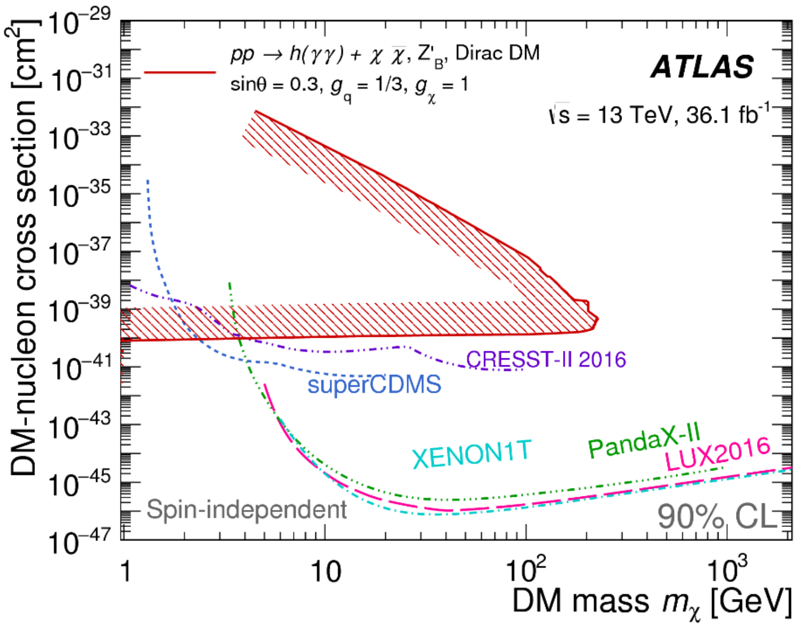
$m_H = 260\ (350)\ GeV$

Higgs exotic with MET

H → γγ+MET
H → bb+MET

- Signal selected in 5 categories defined by (E_T^{miss}) significance, $p_T^{\gamma\gamma}$, number of leptons.
- Significance of E_T^{miss} is less sensitive to pileup than E_T^{miss}



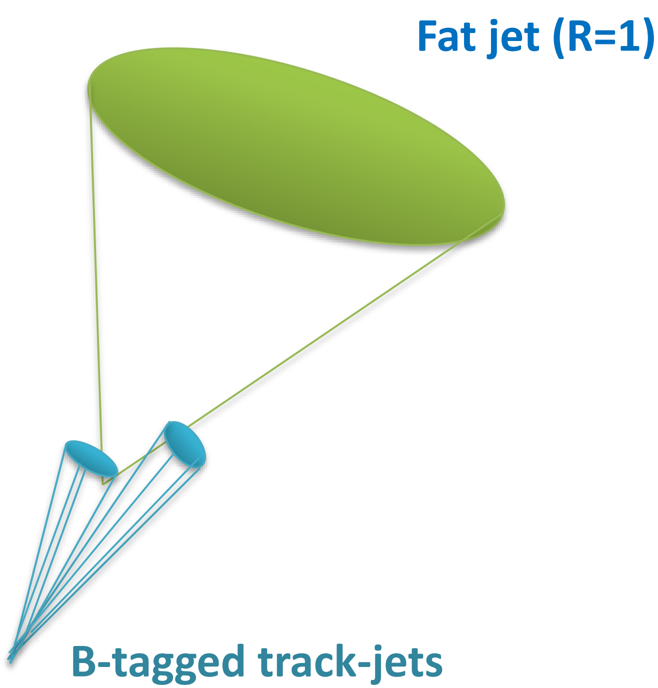


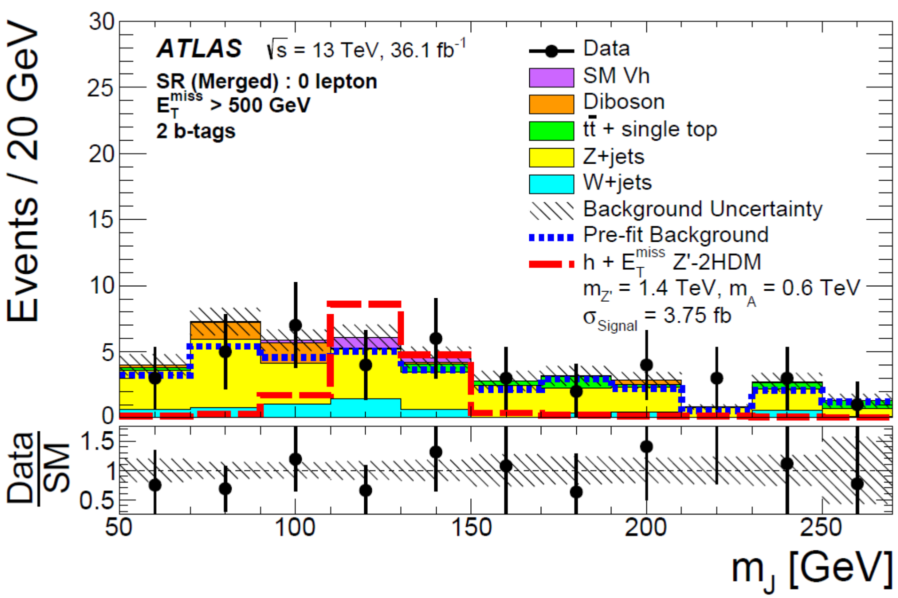
Excluded

heavy Higgs: $\sigma \times BR > 15.4\ (4.3)$fb for $m_H = 260\ (350)\ GeV$

For low DM mass limit better than in direct searches!

- Resolved and merged (with boosted b-tagging!)
- Separate 4 categories by E_T^{miss}





Excluded

$\sigma_{h+DM} x\ BR\ (H \to bb) > 1.7\ - 19.1$ fb (depending on E_T^{miss} range)

Results for all published channels

Neutral Heavy Higgs to bosons

- ZV → llqq /vvqq
- WV→ lvqq
- X->Zγ
- WW → lvlv
- ZZ → 4l
- VV→ 2j
- A→ Z/Wh (w h→bb)

- H→4γ
- H → WH

Neutral Higgs to fermions

- A/H/h → ττ

- A/H/h → tt

Neutral Higgs to di-Higgs

- hh → 4b
- hh → WWγγ

- hh → bbγγ

- hh → bbττ

Charged Higgs

- $H^{\pm\pm} \rightarrow ll$

- $H^{\pm}$ → τν
- $H^{\pm}$ → tb

- Light $H^{\pm}$ → cs
- VBF $H^{\pm}$ → WZ

Higgs exotic with MET

- H → γγ+MET
- H → bb+MET
- hZ → INV (lep)

- H → Z (ll)+MET

- VBF h → INV
- hV→ INV (had)
- H → γ+MET
- H→ INV (1 jet)

Rare decays/ LVF

- $\boxed{\text{h(125) → ϕγ}}$

- h(Z) → J/ψγ
- h → τμ / τe / eμ

Higgs to light res.

- H → aa → 4ℓ
- h(125) → aa → 2j2γ

- h(125) → aa → 4b

- H/h → aa → μμττ

$h(125) \rightarrow \phi/\rho\gamma$

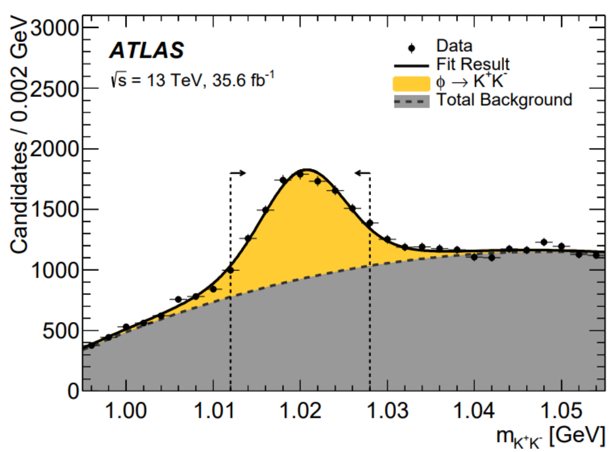
Why this channel?

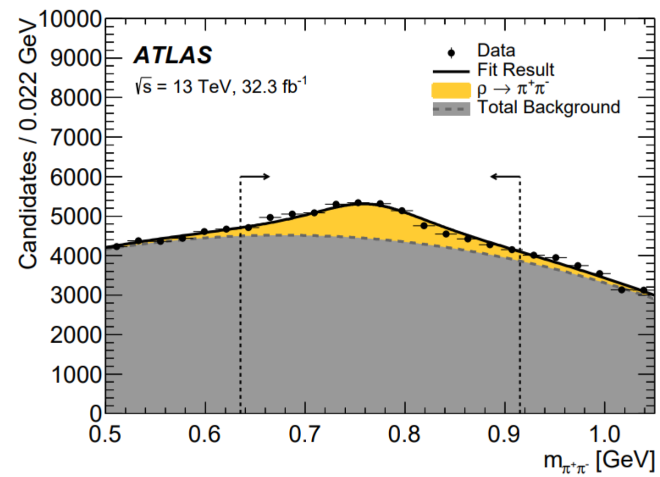
- Large multi-jet background makes it difficult to study $H \rightarrow qq$ decays: light quark couplings to Higgs are only loosely constrained by data
- Higgs decaying to ρ and ϕ can probe couplings of Higgs to light quarks!
- Many BSM theories predict deviations from SM couplings (Minimal Violation Framework, RS Gravitons model, composite Higgs model)

h(125) → ϕ/ργ

Why this channel?

- Large multi-jet background makes it difficult to study H → qq decays: light quark couplings to Higgs are only loosely constrained by data
- Higgs decaying to ρ and ϕ can probe couplings of Higgs to light quarks!
- Many BSM theories predict deviations from SM couplings (Minimal Violation Framework, RS Gravitons model, composite Higgs model)
- ϕ → K +K − is used to reconstruct the ϕ meson, and the decay ρ → π +π − is used to reconstruct the ρ meson





Excluded

$B(H \rightarrow \phi\gamma) > 4.2x10^{-4}$

$B(H \rightarrow \rho\gamma) > 8.8\, x10^{-4}$

Results for all published channels

Neutral Heavy Higgs to bosons	ZV → llqq /vvqq WV→ lvqq X->Zγ WW → lvlv ZZ → 4l VV→ 2j A→ Z/Wh (w h→bb)
	H→4γ H → WH

Neutral Higgs to fermions	A/H/h → ττ
	A/H/h → tt

Neutral Higgs to di-Higgs	hh → 4b hh → WWγγ
	hh → bbγγ
	hh → bbττ

Charged Higgs	$H^{\pm\pm} \to ll$
	$H^{\pm}$ → τν $H^{\pm}$ → tb
	Light $H^{\pm}$ → cs VBF $H^{\pm}$ → WZ

Higgs exotic with MET	H → γγ+MET H → bb+MET hZ → INV (lep)
	H → Z (ll)+MET
	VBF h → INV hV→ INV (had) H → γ+MET H→ INV (1 jet)

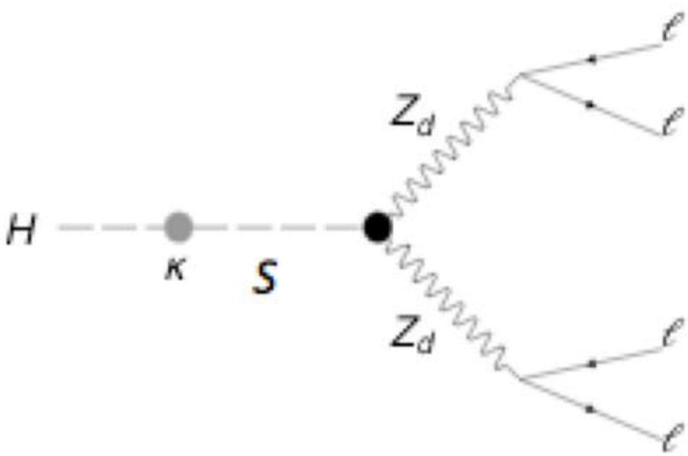
Rare decays/ LVF	h(125) → ϕγ
	h(Z) → J/ψγ h → τμ / τe / eμ

Higgs to light res.	$\boxed{\text{h (125)→ aa → }4\ell}$
	h(125) → aa → 2j2γ
	h(125) → aa → 4b
	H/h → aa → μμττ

h(125)→ aa/$Z_{dark}Z_{dark}$

Why this channel?

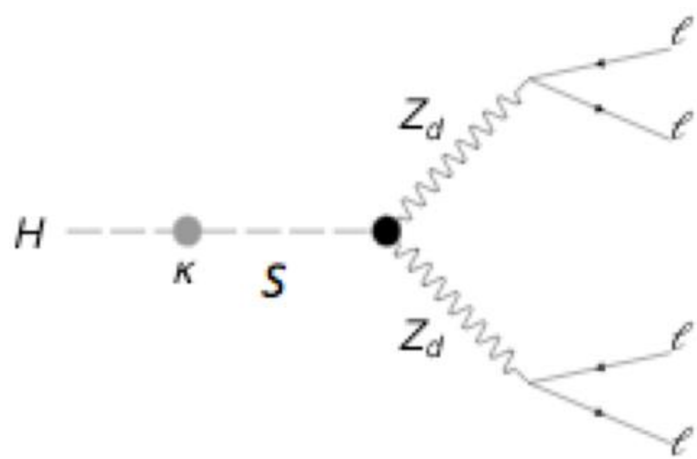
- Look for 2HDM H→ aa process
- Hidden or dark sector appears in many extensions to SM to provide DM candidate or explain astrophysical observation of positron excesses
- Dark sector can be induced by adding $U(1)_d$ gauge symmetry that predicts Z_d

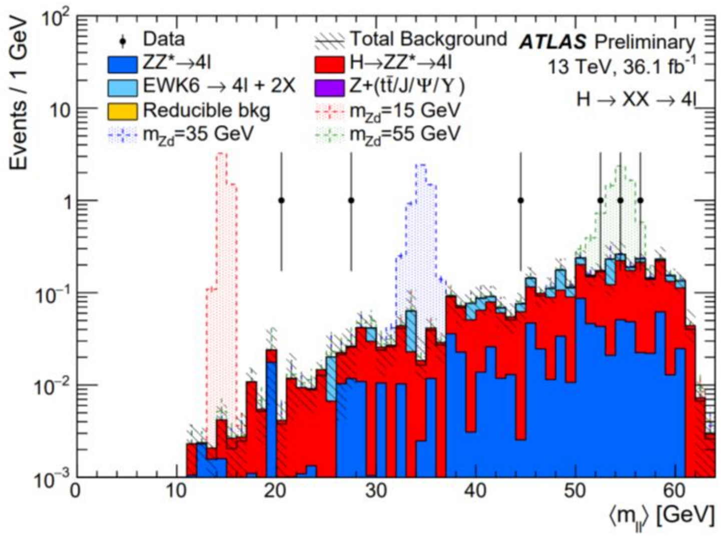


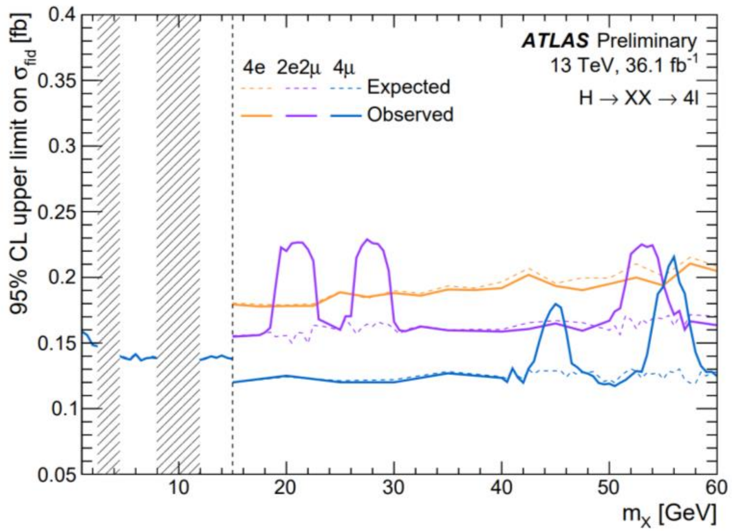
Higgs exotic with MET

h(125)→ $aa/Z_{dark}Z_{dark}$

- Look for 2HDM H→ aa process
- Hidden or dark sector appears in many extensions to SM to provide DM candidate or explain astrophysical observation of positron excesses
- Dark sector can be induced by adding $U(1)_d$ gauge symmetry that predicts Z_d
- Look in 4l final states that have low background. Optimize for different mass regions







Conclusions

- Many ATLAS searches for beyond Standard Model physics were explored
- No discoveries yet of BSM Higgs sector
- Significant excesses not found, but many stringent limits set in several models

References

- ATLAS Collaboration, Search for new phenomena in ttbar final states with additional heavy-flavour jets in 13.2/fb of pp collisions at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2016-104
- ATLAS Collaboration, Search for charged Higgs bosons in the H+ → tb decay channel in pp collisions at √s = 13 TeV using the ATLAS detector, ATLAS-CONF-2016-089
- ATLAS Collaboration, Search for charged Higgs bosons in the τ+jets final state with 14.7 fb-1 of pp collision data recorded at √s = 13 TeV with the ATLAS experiment, ATLAS-CONF-2016-088
- ATLAS Collaboration, A search for new phenomena in events with missing transverse momentum and a Higgs boson decaying to two photons in a 13.3 fb-1 pp collision dataset at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2016-087
- ATLAS Collaboration, Search for the Minimal Supersymmetric Standard Model Higgs bosons H/A in the ττ final state in up to 13.3 fb-1 of pp collision data at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2016-085
- ATLAS Collaboration, Searches for heavy ZZ and ZW resonances in the llqq and ννqq final states in pp collisions at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2016-082
- ATLAS Collaboration, Study of the Higgs boson properties and search for high-mass scalar resonances in the H → ZZ → 4l decay channel at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2016-079
- ATLAS Collaboration, Search for a high-mass Higgs boson decaying to a pair of W bosons in pp collisions at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2016-074
- ATLAS Collaboration, Search for Higgs boson pair production in the final state of γγWW*(→lνjj) using 13.3 fb-1 of pp collision data recorded at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2016-071
- ATLAS Collaboration, Search for diboson resonance production in the lνqq final state using pp collisions at √s = 13 TeV with the ATLAS detector at the LHC, ATLAS-CONF-2016-062
- ATLAS Collaboration, Search for scalar diphoton resonances with 15.4 fb-1 of data collected at √s = 13 TeV in 2015 and 2016 with the ATLAS detector, ATLAS-CONF-2016-059
- ATLAS Collaboration, Search for new phenomena in the Z(→ ll) + ETmiss final state at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2016-056
- ATLAS Collaboration, Search for doubly-charged Higgs bosons in same-charge electron pair final states using proton-proton collisions at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2016-051
- ATLAS Collaboration, Search for pair production of Higgs bosons in the bbbb final state using proton-proton collisions at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2016-049
- ATLAS Collaboration, Search for new resonances decaying to a Z boson and a photon in 13.3 fb-1 of pp collisions at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2016-044
- ATLAS Collaboration, Constraints on New Phenomena via Higgs Boson Couplings and Invisible Decays with the ATLAS Detector, arXiv:1307.1347

BACKUP

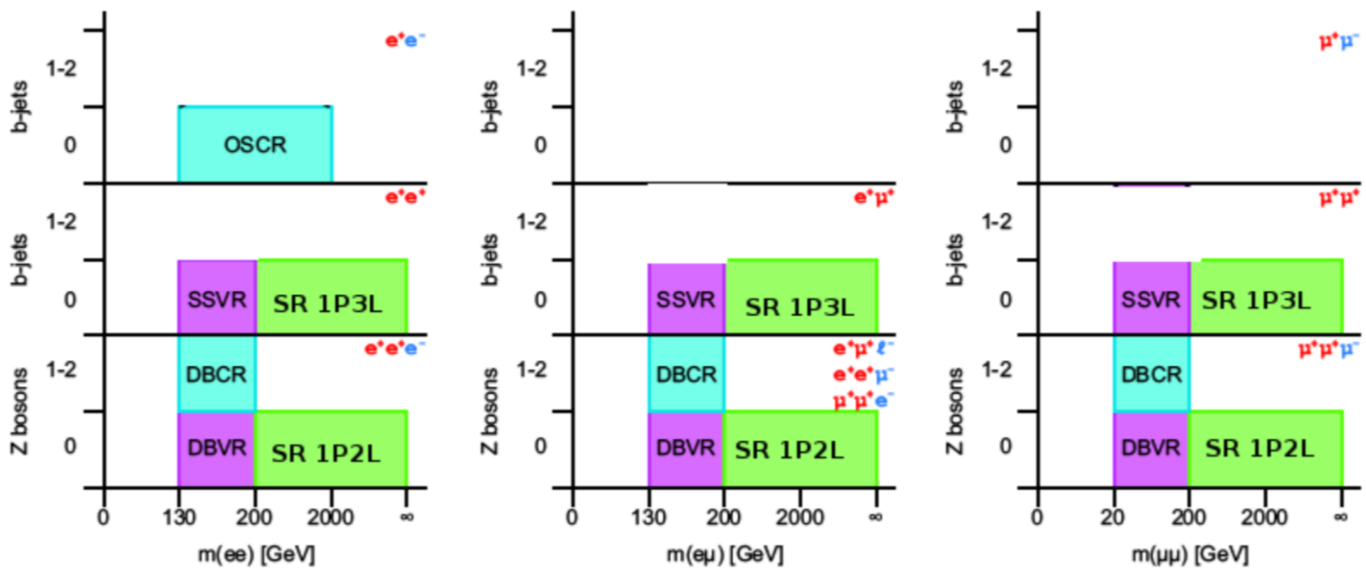


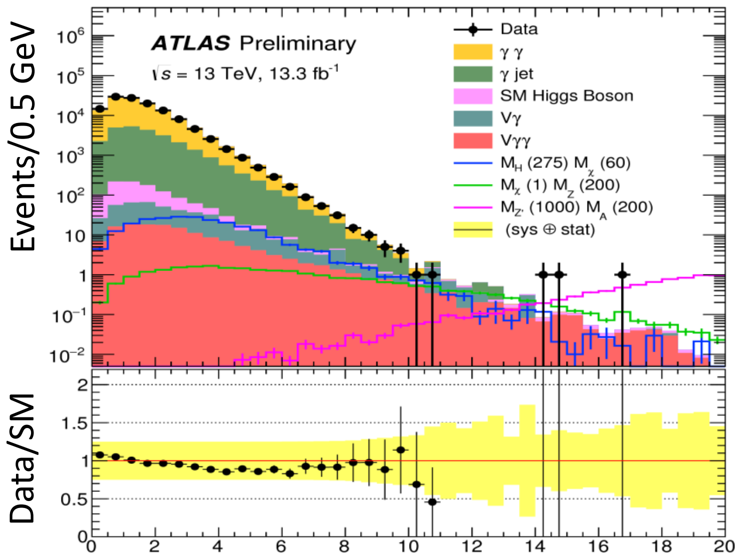
Figure 2: Cartoon of SR 1P2L and SR 1P3L and relative control and validation regions.

Higgs exotic with MET

H → γγ+MET
H→ Z (ll)+MET

γγ+MET

- Signal selected 2 or 4 categories defined by (E_T^{miss}) significance and $p_T^{\gamma\gamma}$
- Significance of E_T^{miss} significance is less sensitive to pileup than E_T^{miss}



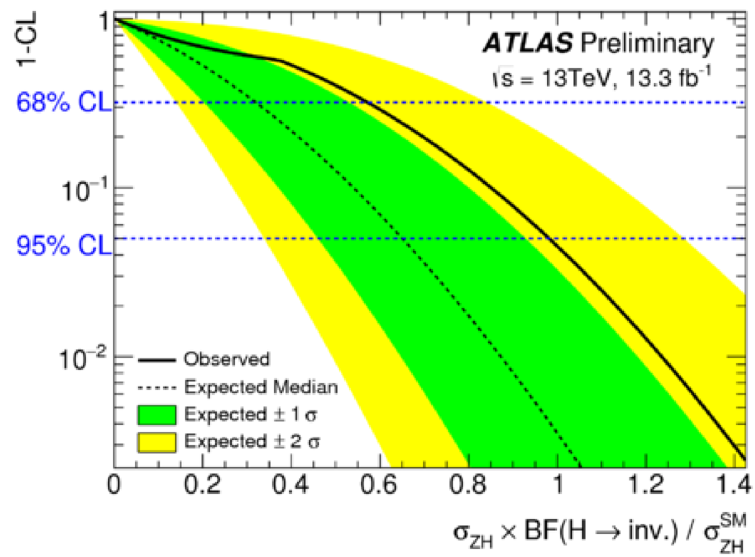
E_T^{miss} significance [GeV]

Excluded

heavy Higgs: $\sigma \times BR < 18.2\ (23.9)$ fb for $m_{DM} = 50\ (60)\ GeV$

Z (ll) + MET, where l= e, μ

- Theories: heavy Higgs in NWA, Z+ mediator (→ $\chi\chi$), ZH production with H→ $\chi\chi$, G_{kk^*}



Excluded

heavy Higgs: $\sigma \times BR <$ 67 (37) for m_H= 600 (1000) GeV 67 (37)