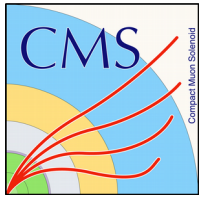


Searches for rare and BSM decays at ATLAS and CMS

Pedro Sales de Bruin - Uppsala University

on behalf of the ATLAS and CMS Collaborations

Outline

Introduction

Rare and BSM decays at ATLAS

- $h \to \mu\mu$
- $h \to$ invisible $(+ Z \to ll)$
- $h \to Z\gamma$
- $h \to \phi\gamma, \rho\gamma$
- $t\bar{t} \to Wb + q(H \to \gamma\gamma)$
- $h \to ZZ_d, Z_dZ_d, aa \to 4l$

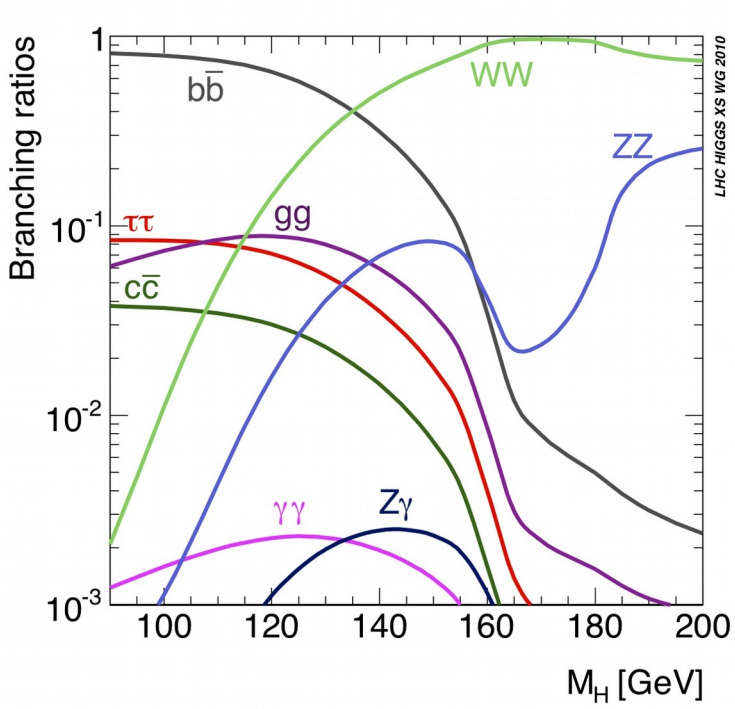
Rare and BSM decays at CMS

- $h \to$ invisible (VBF)
- $h \to$ invisible $(+ Z \to ll)$
- $h \to$ invisible (+ V(jj), monojet)
- LFV Higgs decays
- $h \to aa \to 4\tau, 2\mu2\tau, 2\mu2b$

Summary

Introduction

- BSM decays of SM particles an integral part of the search for new phenomena at the LHC
- Deviations from SM prediction in rare decays would be a very strong indication for underlying non-SM physics
- Many different models predict rare/BSM decays of SM particles, such as Higgs portal to DM, 2HDM(+S), extra dimensions, composite Higgs
- Large number of searches, I will focus on the results from ~ the past year from each experiment



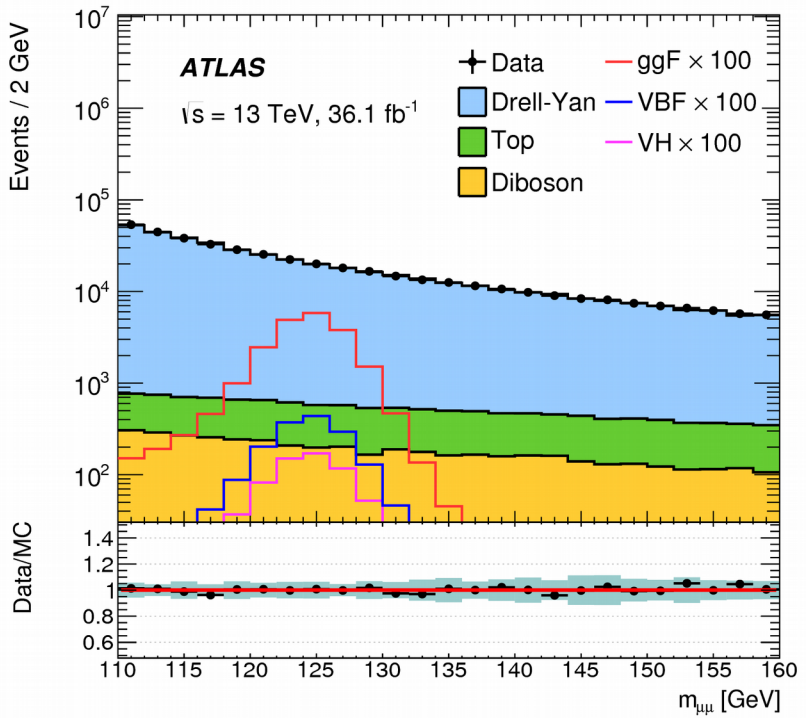
$h \to \mu\mu$ (1/2)

Phys. Rev. Lett. 119 (2017) 051802

Selection overview

- Single muon triggers (26 GeV isolated or 50 GeV muon)
- Two OS muons, $E_T^{miss} < 80$ GeV, $110 < m_{\mu\mu} < 160$ GeV, no b-tagged jets
- Events with $N_{jet} \geq 2$ are passed through a multivariate discriminant. Two VBF categories (0.7 < BDTscore < 0.9 and BDTscore > 0.9) are defined.
- Events with fewer jets or lower score are sorted into 6 ggF categories:

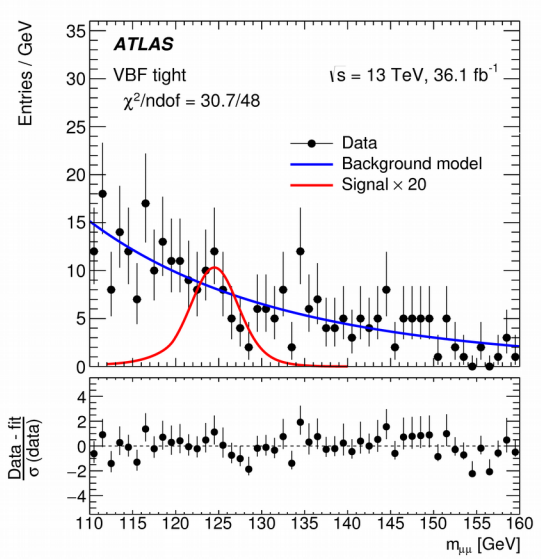
  3 $p_T^{\mu\mu}$ ranges × 2 pseudo-rapidity regions (central and forward)

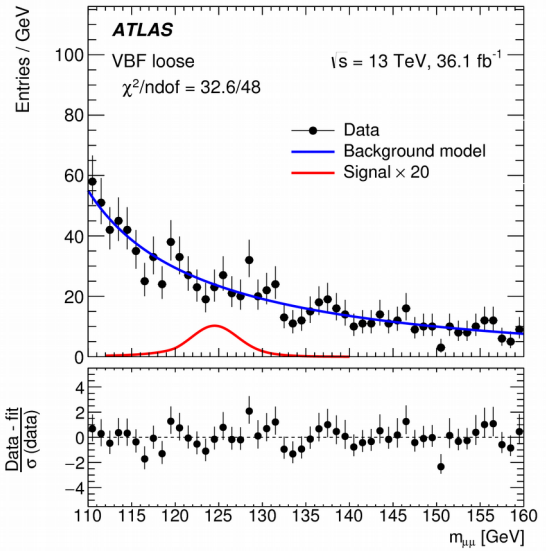


$\mathcal{L} = 36.1\ \text{fb}^{-1}$

$h \to \mu\mu$ (2/2)

- Observed (expected) 95% CL upper limit on signal strength set at 3.0 (3.1) times SM
- Limit driven by statistical uncertainty (systematic uncertainty has ~2.2% impact on limit)
- Result combined with Run-1 ATLAS data, signal strength upper limit set at 2.8 (2.9) times SM
- Improves on earlier CMS Run-1 result that set limit at 7.4 times SM
- CMS and ATLAS performed a combination in this channel, giving a best-fit value of the signal strength of 0.1 times SM





$h \to Z(\to ll)\gamma$ (1/2)

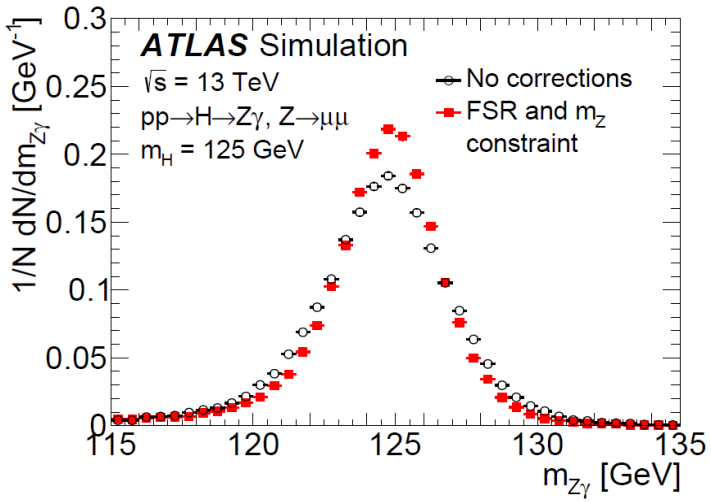
arXiv:1708.00212

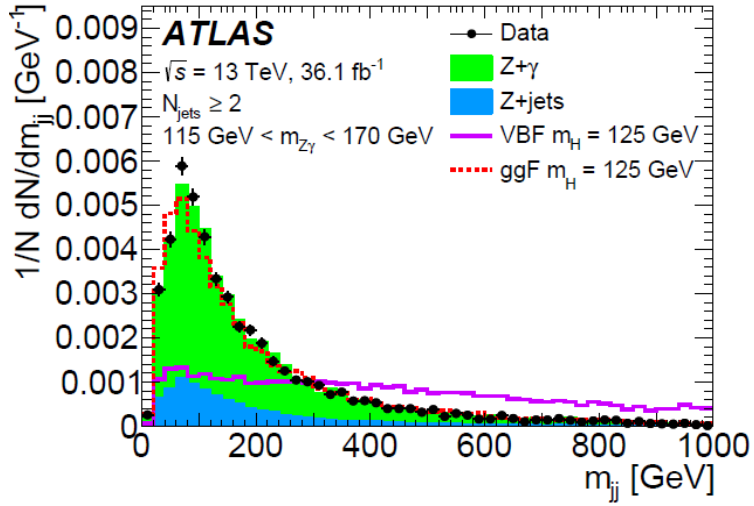
Selection overview

$\mathcal{L} = 36.1\ \text{fb}^{-1}$

- Single lepton and dilepton triggers. Require 2 same-flavor OS isolated leptons (e or μ) and at least one photon
- A constrained kinematic fit is applied to re-compute the momenta of the lepton pairs using the expected Z boson lineshape. An FSR correction also applied to lower m_Z $\mu\mu$ events
- Search is split into a low mass category for Higgs decays ($115 < m_{Z\gamma} < 170$ GeV) and a high-mass resonance search ($200 < m_{Z\gamma} < 2500$ GeV)
- The $h \to Z\gamma$ search is sub-divided into 6 categories:
  1. VBF-enriched: events with at least 2 jets that score highly with a dedicated VBF BDT
  2. High relative p_T: events with a high pT photon $\left(\frac{p_T^\gamma}{m_{Z\gamma}} > 0.4\right)$.
  3. High ee p_{Tt}: $p_{Tt} > 40$ GeV
  4. Low ee p_{Tt}: $p_{Tt} < 40$ GeV
  5. High $\mu\mu$ p_{Tt}: $p_{Tt} > 40$ GeV
  6. Low $\mu\mu$ p_{Tt}: $p_{Tt} < 40$ GeV

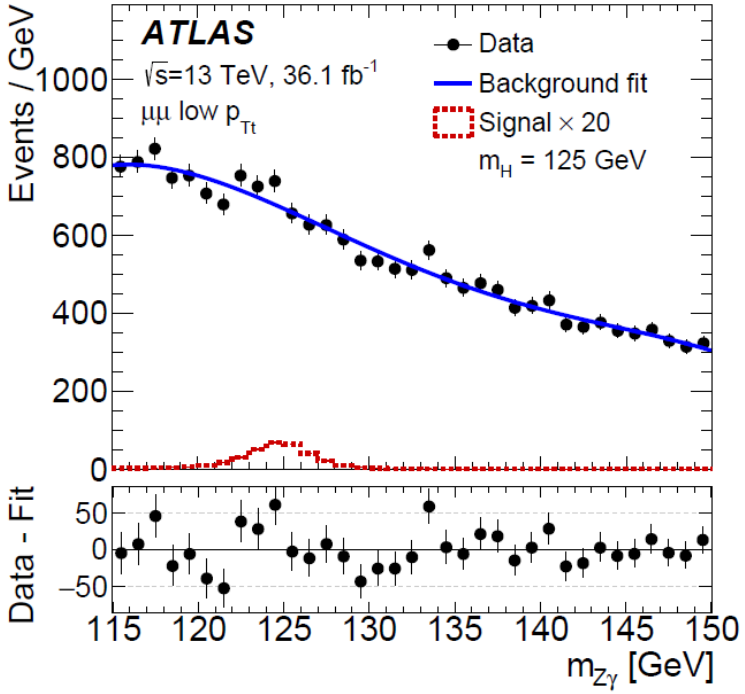
  , where p_{Tt} is the component of $p_T^{Z\gamma}$ perpendicular to $\vec{p}_Z - \vec{p}_\gamma$ and highly correlated to $p_T^{Z\gamma}$ but with better experimental resolution
- The high-mass search divided into ee and $\mu\mu$ categories

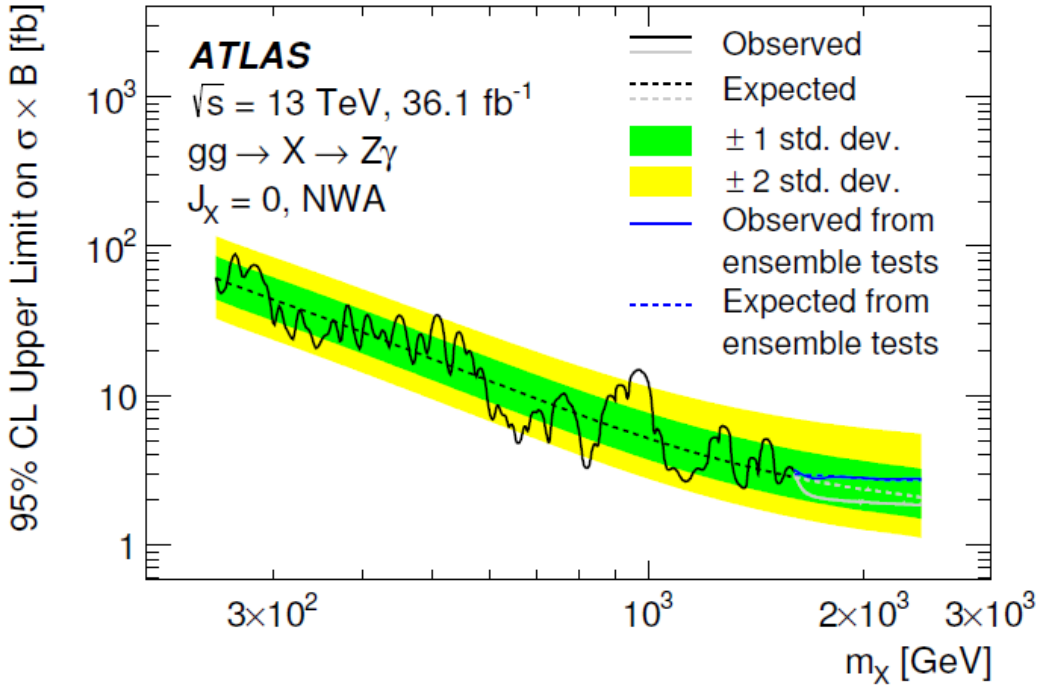


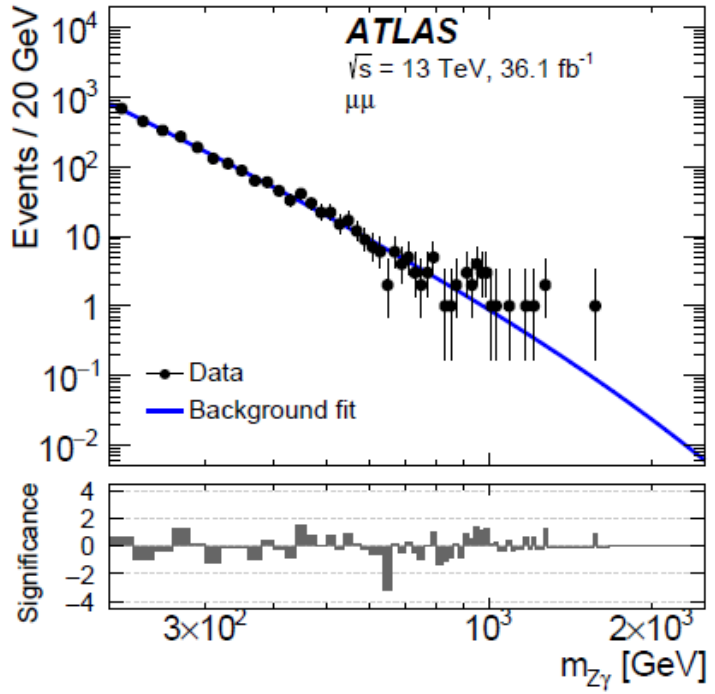


$h \to Z(\to ll)\gamma$ (2/2)

- Low pT $\mu\mu$ category gives strongest contribution to Higgs search
- No evidence for $h/X \to Z\gamma$ decays is observed, and 95% CL upper limits on $\sigma(pp \to h) \cdot B(h \to Z\gamma)$ is set at 6.6 times the SM prediction for $m_h = 125$ GeV and as a function of m_X
- Improves upon earlier CMS Run-1 result with observed limit of 9.5 times SM prediction





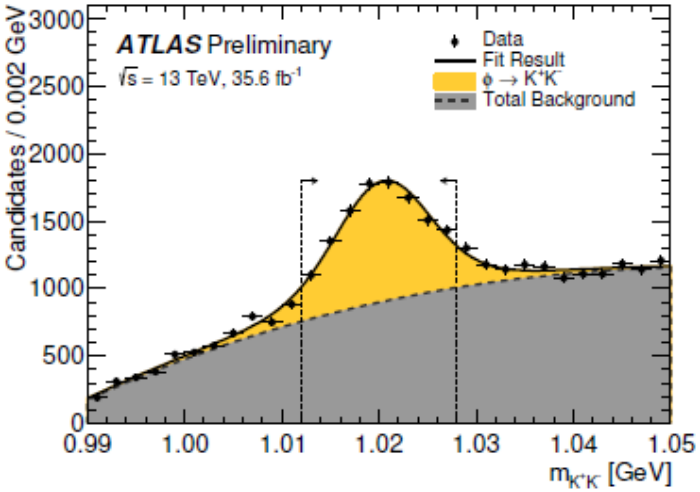


$h, Z \to \phi\gamma, \rho\gamma$ (1/2)

ATLAS-CONF-2017-057

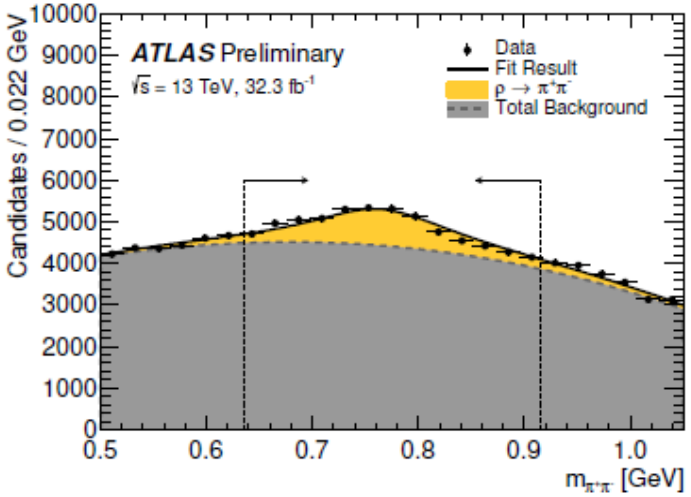
$\mathcal{L} = 35.6\ \text{fb}^{-1}$

- Probes Higgs coupling to light quarks
- The $\rho \to \pi^+\pi^-$ ($\phi \to K^+K^-$) decay is used to reconstruct the ρ (ϕ)



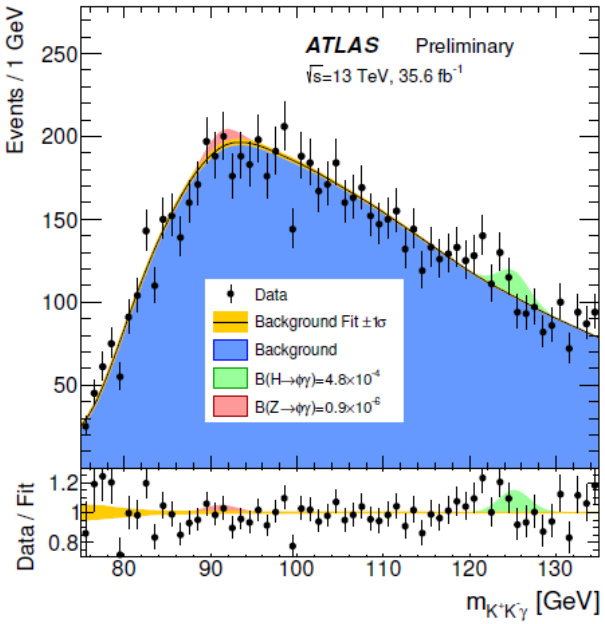
Selection overview

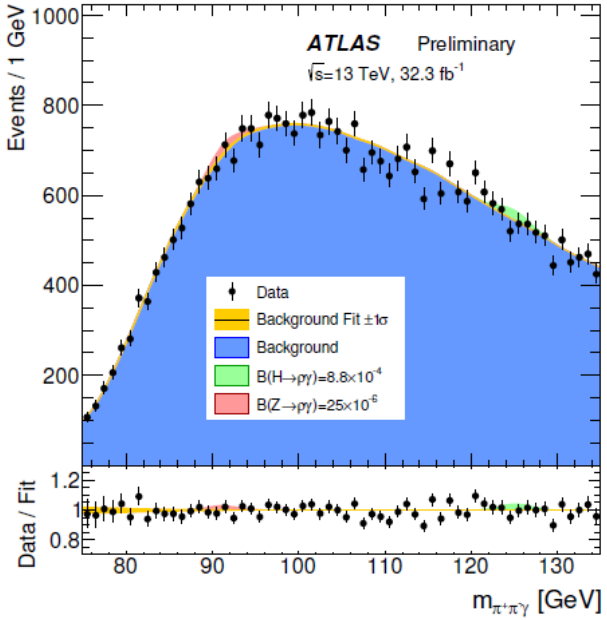
- Dedicated triggers that require a photon with $p_T > 35$ GeV and a pair of isolated ID tracks with $p_T > 15$ GeV and invariant mass consistent with the ρ or ϕ hypotheses
- Mass windows of $635 < m_{\pi^+\pi^-} < 915$ MeV and $1012 < m_{K^+K^-} < 1028$ MeV
- Meson (M) $\mathrm{p_T} > 40 - 47$ GeV, highest p_T photon used, $\Delta\phi(M, \gamma) > \frac{\pi}{2}$.
- Background dominated by multijet and photon + jet
- Background templates extracted from CR with looser isolation, lower p_T cuts
- Background normalized in $m_{K^-K^+}$, $m_{\pi^-\pi^+}$ sidebands



$h \to \phi\gamma, \rho\gamma$ (2/2)

- Observed yields consistent with SM prediction
- 95% CL upper limits on the $B(h \to \phi\gamma)$ and $B(Z \to \phi\gamma)$ are 208 and 87 times SM, respectively
- 95% CL upper limits on $B(h \to \rho\gamma)$ and $B(Z \to \rho\gamma)$ are 52 and 597 times SM, respectively



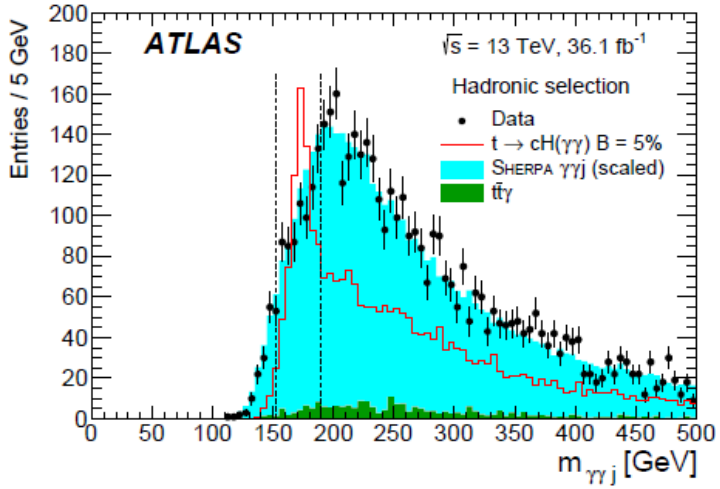


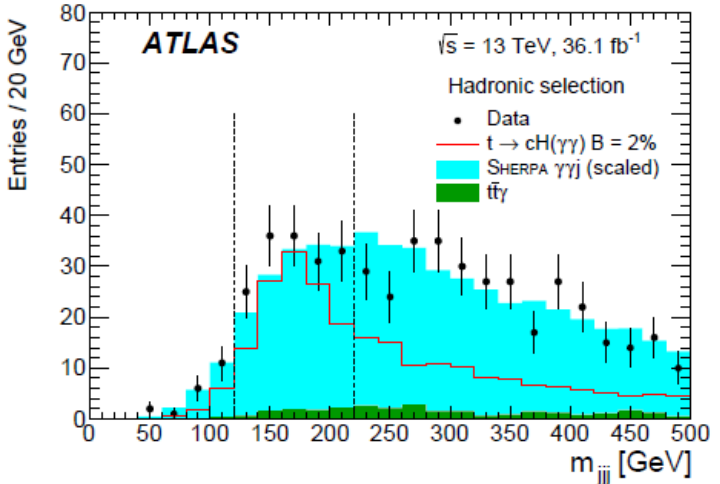
$t\bar{t} \rightarrow Wb + q(H \rightarrow \gamma\gamma)$

arXiv:1707.01404

- The decay of $t \rightarrow qH$ where $q = c, u$ proceeds via a FCNC and is negligible in the SM
- BSM models such as 2HDM, RPV SUSY and composite Higgs allow for BRs orders of magnitude beyond the SM BR
- The search is done in the clean $H \rightarrow \gamma\gamma$ decay mode, using 36.1 fb^{-1} Run-2 data and a diphoton trigger
- Both hadronic and leptonic *W* decays are considered
- Simulated $\gamma\gamma j$ normalised to data in $m_{\gamma\gamma}$ sideband

$\mathcal{L} = 36.1$ fb^{-1}





Hadronic selection

- At least 4 jets, one must be *b*-tagged
- Two 3-body objects with masses (M_1, M_2) compatible with top masses
- $M_1 \in [152,190]$ GeV, $M_2 \in [120,220]$ GeV.
- Events that fail M_2 mass window still used in final analysis ("category 2")
- $m_{\gamma\gamma} \in [122,129]$ GeV

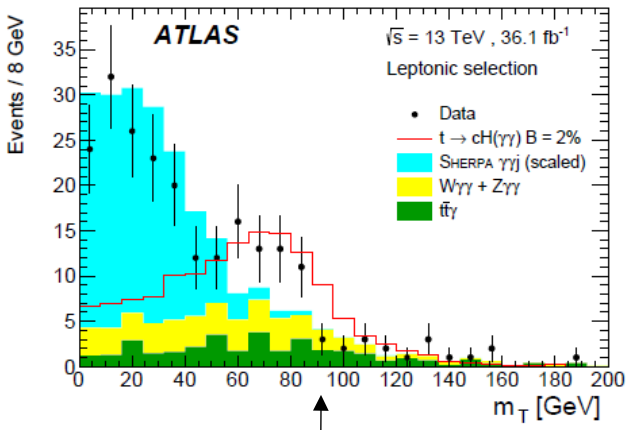
*briefly mentioned in H. Yang's gammagamma talk

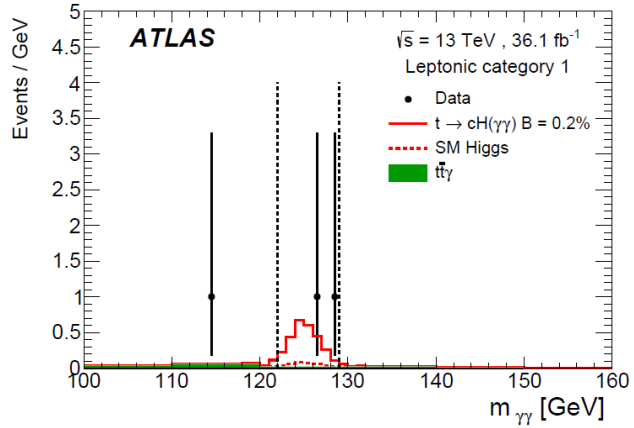
$t\bar{t} \rightarrow Wb + q(H \rightarrow \gamma\gamma)$

- Main background is $\gamma\gamma j$, $V\gamma\gamma$ and $t\bar{t}\gamma$
- After selection, categories 1 and 2 have only 3 events each
- Simulated $\gamma\gamma j$ normalised to data in $m_{\gamma\gamma}$ sideband

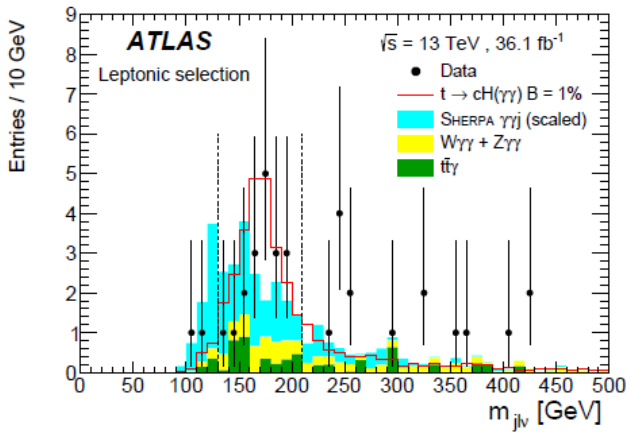
Leptonic selection

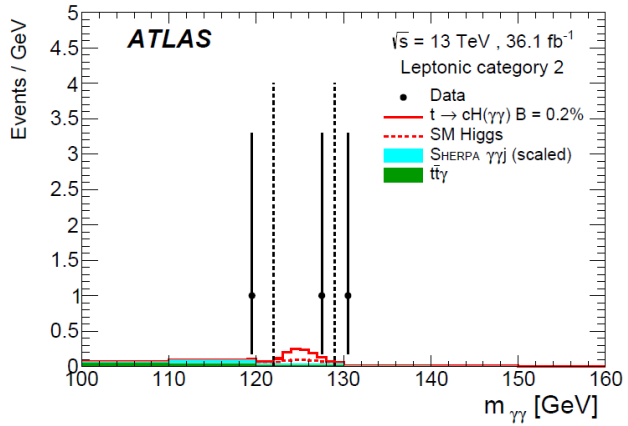
- 2 photons, at least 2 jets and one e or μ. One of the jets must be b-tagged
- $m_T\left(l, \vec{p}_T^{miss}\right) > 30$ GeV
- Two 3-body objects compatible with $t\bar{t}$ masses
- $M_{\gamma\gamma j} \in [152,190]$ GeV, $M_{jl\nu} \in [130,210]$ GeV.
- Events failing the $M_{jl\nu}$ window cut fall in category 2





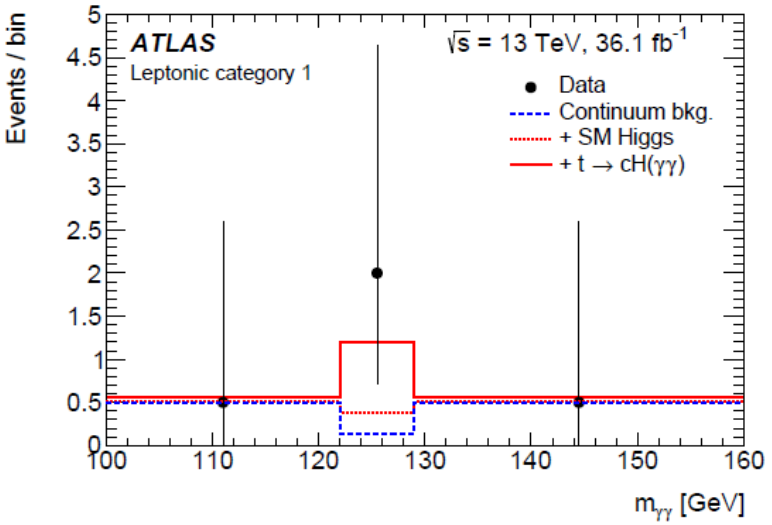
before b-tagging, m_T, $M_{jl\nu}$ cuts

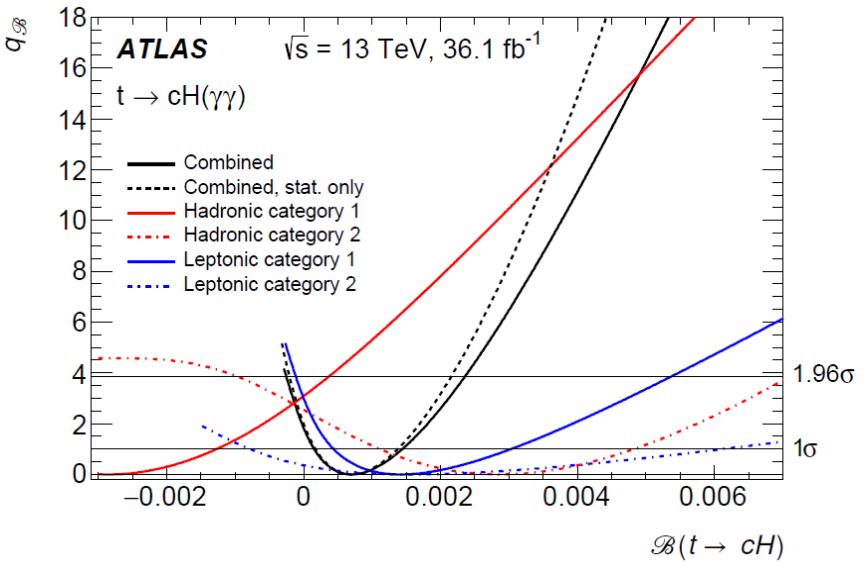


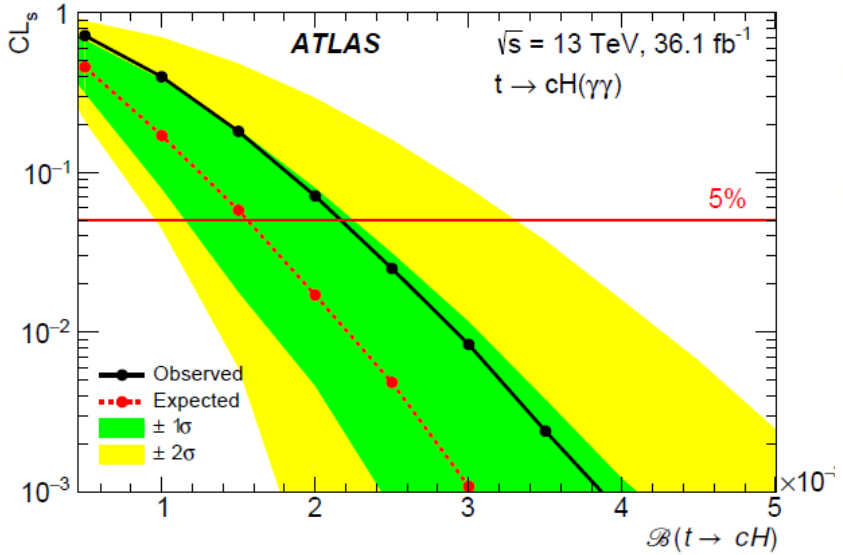


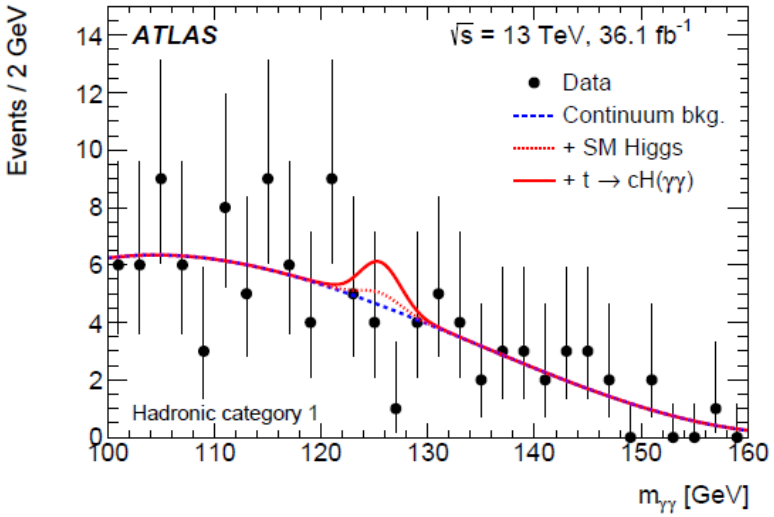
$t\bar{t} \rightarrow Wb + q(H \rightarrow \gamma\gamma)$

- The observed (expected) 95% CL upper limit on $B(t \rightarrow cH)$ is 2.2×10^{-3} (1.6×10^{-3})
- Analysis is almost equally sensitive to $t \rightarrow uH$, with observed (expected) upper limits of 2.4×10^{-3} (1.7×10^{-3})
- Branching ratio limits translated to limits on off-diagonal Yukawa couplings: $\lambda_{tcH} < 0.090$ (0.077) and $\lambda_{tcH} < 0.094$ (0.079)
- Improves upon Run-1 CMS result



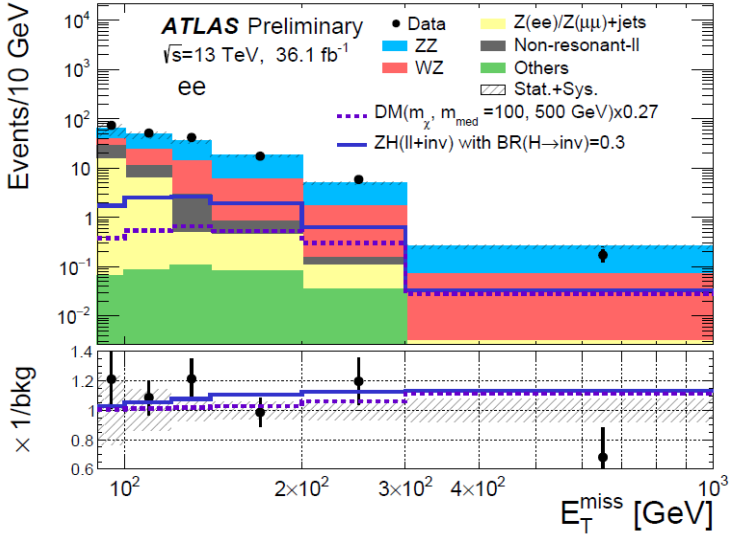






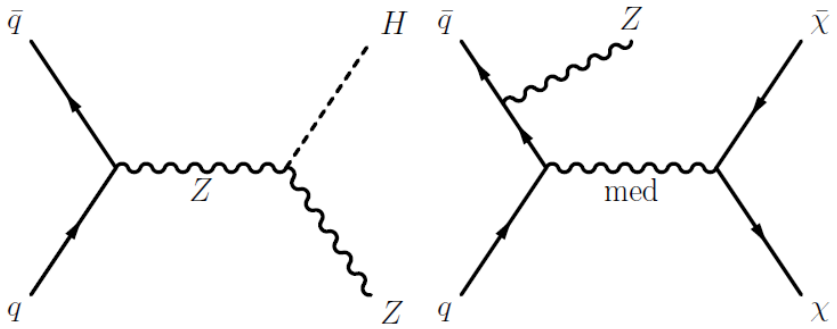
$Z(\rightarrow ll) + h \rightarrow \text{inv}$ (1/2)

- Search for invisibly decaying Higgs or BSM-mediated WIMP pair production, produced alongside $Z \rightarrow ll$ using 36.1 fb^{-1} 13 TeV data
- Main backgrounds are ZZ and WZ
- ZZ is taken from simulation, WZ as well but scaled with data-driven scale factor obtained in a high m_T^W, $N_l > 2$ CR
- Z+jets is ~8% of total background, estimated with a data-driven ABCD method



Selection overview

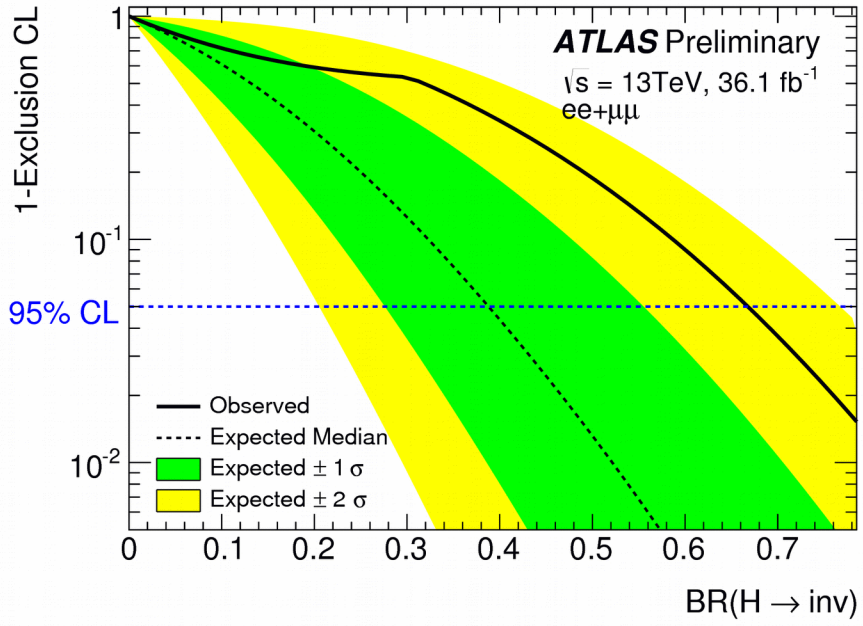
- Single lepton triggers
- Require a boosted Z recoiling off $\vec{p}_T^{miss}$. Veto events with b-jets and $N_l > 2$
- $E_T^{miss} > 90$ GeV, $E_T^{miss}/H_T > 0.6$
- $\Delta\phi(\vec{p}_T^{ll}, \vec{p}_T^{miss}) > 2.7$, $\Delta R_{ll} < 1.8$
- $\left|p_T^{ll} - p_T^{miss}\right| / p_T^{ll} < 0.2$

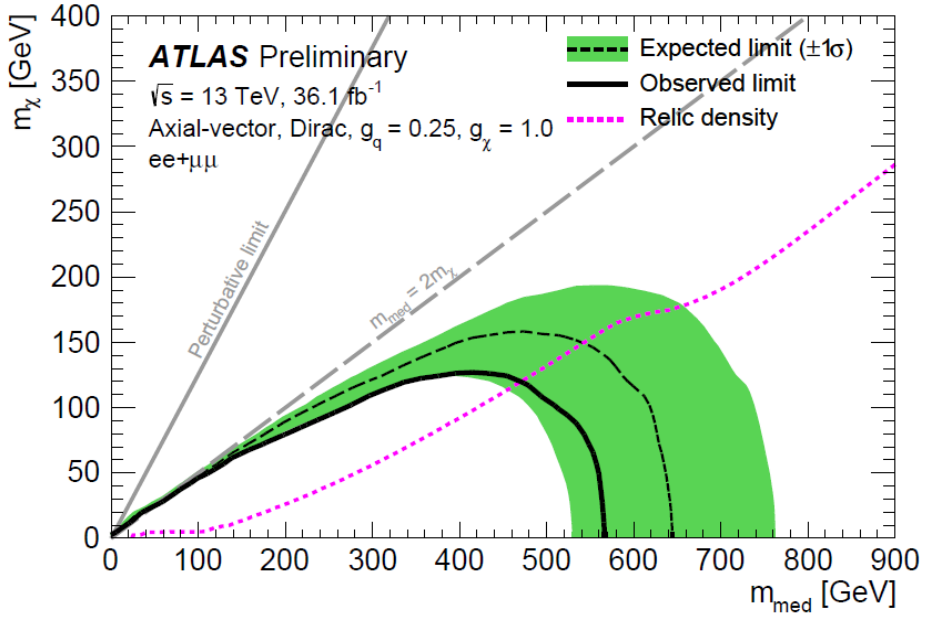


$\mathcal{L} = 36.1$ fb^{-1}

$Z(\rightarrow ll) + h \rightarrow \text{inv}$ (2/2)

- The E_T^{miss} distribution is used as a discriminant
- No significant excess over SM background expectation is observed
- The observed (expected) 95% CL upper limit on $B(h \rightarrow \text{inv})$ for the combined $ee + \mu\mu$ search is 67% (39%)
- Observed limit is worse due to a 2.2σ data excess in the $\mu\mu$ channel
- Limits are also placed on the m_χ, m_{med} masses, excluding m_χ up to 130 GeV for $m_{\text{med}} = 400$ GeV, and m_{med} up to 560 GeV for light m_χ

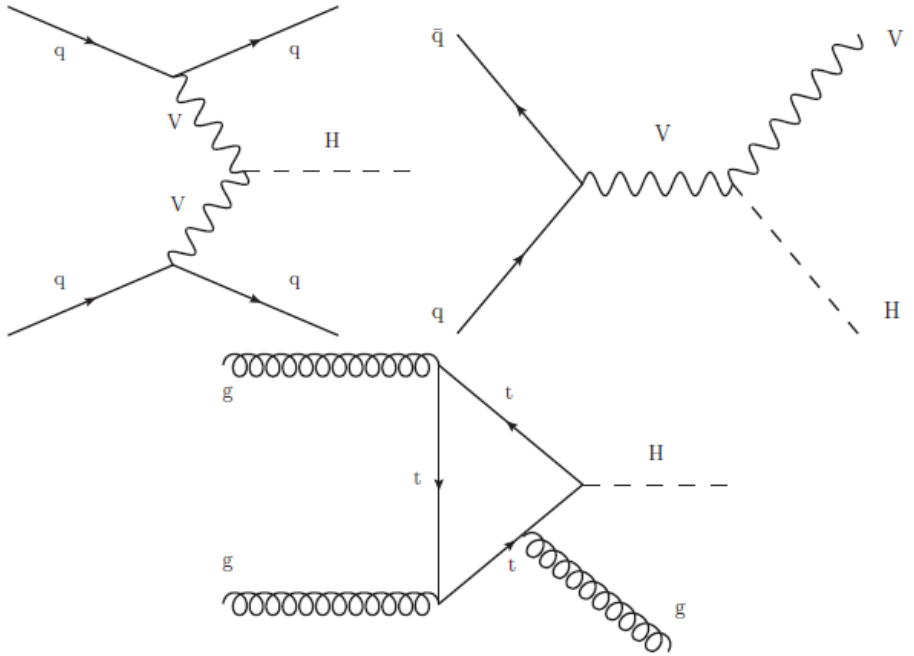




$h \rightarrow$ invisible

- **CMS-HIG-16-016**
- CMS has done a combination of several searches for invisible decays targeting qqH, VH and gluon+H production using both Run-1 and Run-2 data

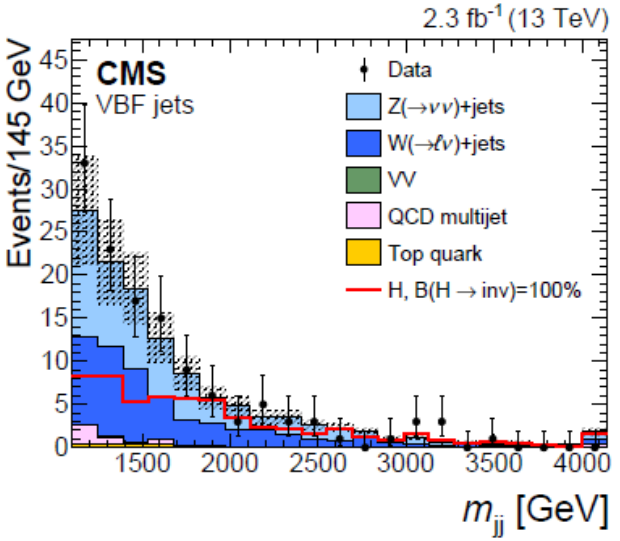
Production	Final state	Run-1 (fb^{-1})	Run-2 (fb^{-1})
qqH	VBF jets	19.2	2.3
VH	$Z \rightarrow ll$	24.6	2.3
	$Z \rightarrow b\bar{b}$	18.9	-
	$V \rightarrow jj$	19.7	2.3
ggH	monojet	19.7	2.3

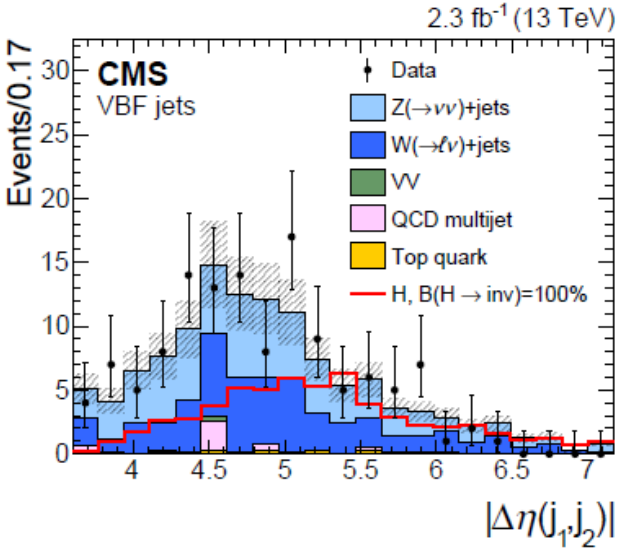


$h \rightarrow$ invisible (VBF)

Selection overview

- Uses dedicated VBF trigger, requires presence of a forward-backward jet pair with $p_T^{j_1} > 50\ (80)$, $p_T^{j_2} > 45\ (70)$GeV, $|\eta^j| < 4.7$ and $|\Delta\eta^{jj}| > 3.6$
- Also requires $m_{jj} \gtrsim 1200\ (1100)$ GeV and $E_T^{miss} > 90\ (200)$ GeV at 8 (13) TeV. A $S(E_T^{miss}) \equiv \sqrt{E_T^{miss}} > 4\sqrt{\text{GeV}}$ is applied to 8 TeV data
- Can reduce QCD background by requiring $\min\Delta\phi(\vec{p}_T^{miss}, j) > 2.3$
- Veto events with an e or μ





- Main backgrounds are $Z(\rightarrow \nu\nu) +$ jets and $W(\rightarrow l\nu) +$ jets, with a common scale factor obtained in a simultaneous fit in dimuon and single lepton CRs
- Multijet is extrapolated from CRs defined by inverting or loosening $\Delta\phi(E_T^{miss}, j)$ and $S(E_T^{miss})$ cuts. All CRs are simultaneously fit with a floating multijet SF

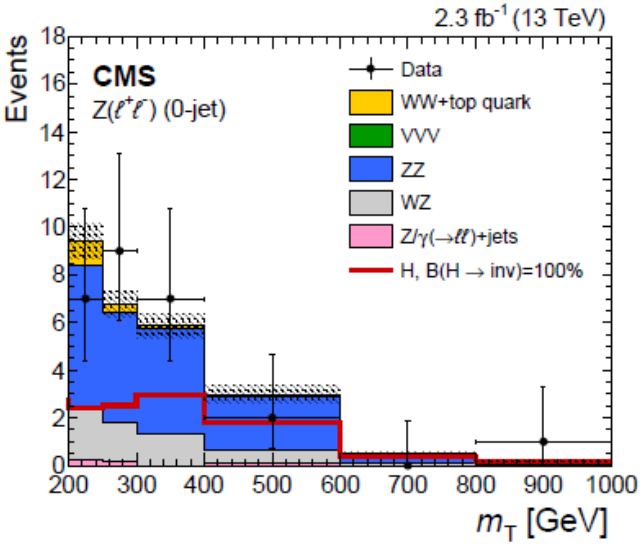
$h \rightarrow$ invisible ($Z \rightarrow ll$)

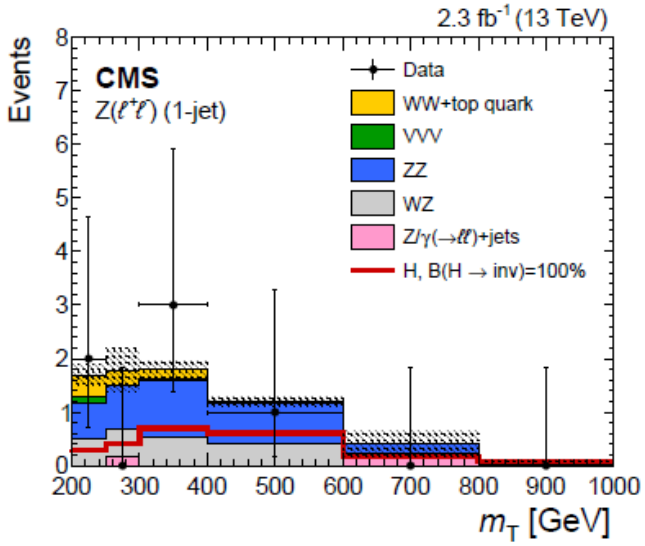
- Lower cross-section than qqH but cleaner final state
- Background dominated by diboson events, estimated via simulation
- Events with $N_l > 2$, $N_{jet} > 1$ or $\mu + b$-jet are vetoed to suppress diboson and $t\bar{t}$

Selection overview

Double (and single) lepton triggers

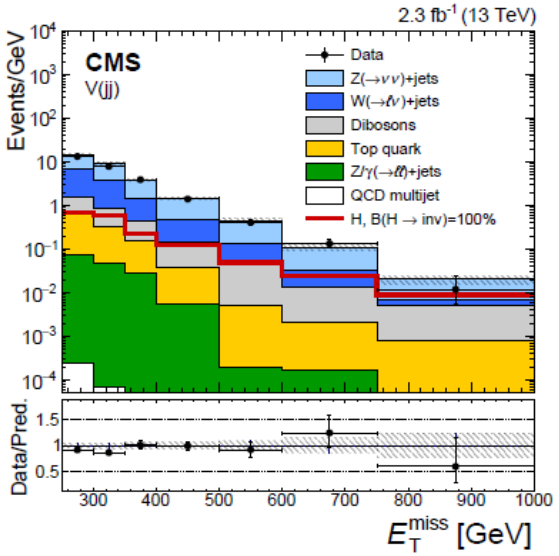
	7 and 8 TeV	13 TeV
$p_T^{e,\mu}$	> 20 GeV	
m_{ll}	$76 - 106$ GeV	
$\Delta\phi(l,l)$	-	$< \pi/2$
E_T^{miss}	> 120 GeV	> 100 GeV
$\Delta\phi(ll, \vec{p}_T^{miss})$	> 2.7	> 2.8
$\Delta\phi(j, \vec{p}_T^{miss})$	-	> 0.5
$\lvert E_T^{miss} - p_T^{ll}\rvert / p_T^{ll}$	< 0.25	< 0.4
m_T	> 200 GeV	





$h \rightarrow$ invisible ($V \rightarrow jj$, monojet)

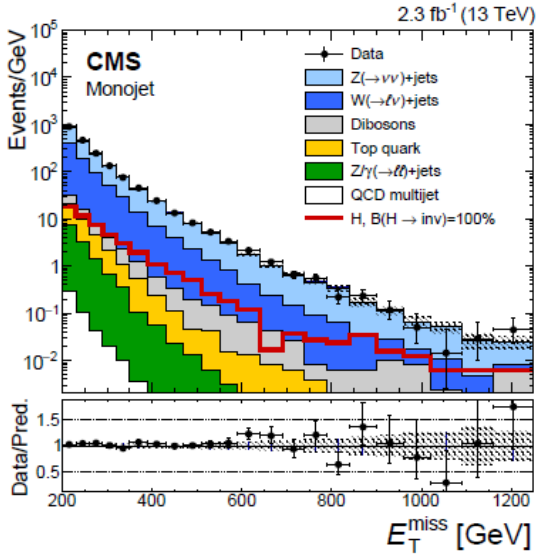
- Main backgrounds are $Z(\rightarrow \nu\nu)$ + jets and $W(\rightarrow l\nu)$ + jets. Multijet background is reduced by requiring the jets to be recoiling from $\vec{p}_T^{miss}$
- V(jj) events are identified by requiring a large R=0.8 jet, and exploiting 2 sub-jet topology variables such as the "subjettiness" τ_2/τ_1, pruned jet mass m_{prune}
- Events that fail the V(jj) and with a R=0.4 jet are considered in the monojet search
- The E_T^{miss} distribution is fitted in the SR and single or dilepton CRs. γ + jets events are used to reduce stat uncertainties. Leptons and photons are removed from the E_T^{miss} computation in the CRs



Selection overview

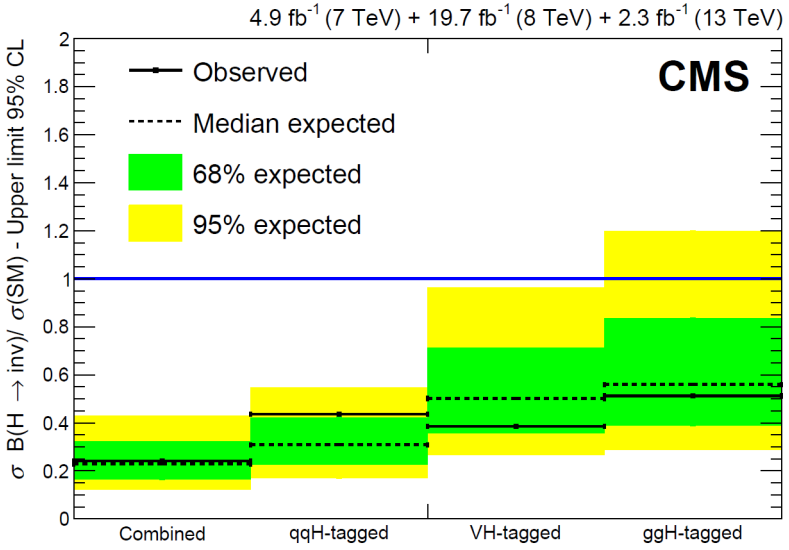
Triggers on events with high E_T^{miss} and p_T^j or $H_T^j \equiv \Sigma p_T^j$
Veto events with leptons or b-jets

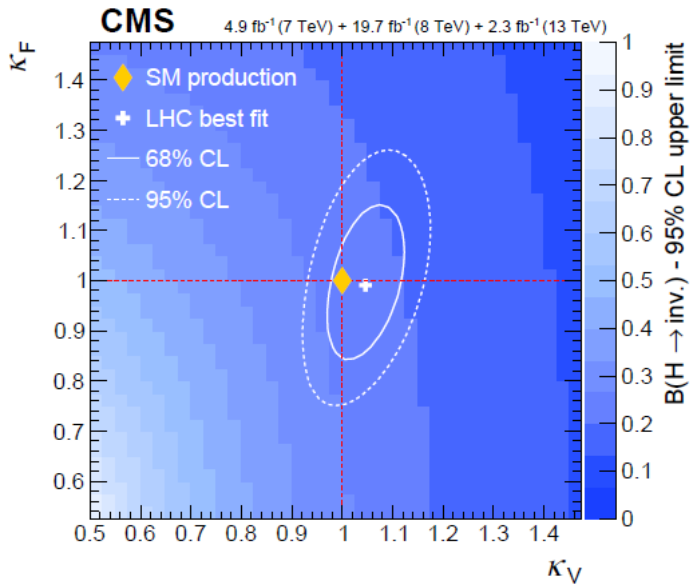
	8 TeV		13 TeV	
	V(jj)	Monojet	V(jj)	Monojet
p_T^j	> 200 GeV	> 150 GeV	> 250 GeV	> 100 GeV
$\lvert\eta^j\rvert$	< 2		< 2.4	< 2.5
E_T^{miss}	> 250 GeV	> 200 GeV	> 250 GeV	> 200 GeV
τ_2/τ_1	< 0.5	-	< 0.6	-
m_{prune}	60 – 110 GeV	-	65 – 105 GeV	-
$\min\Delta\phi(j, \vec{p}_T^{miss})$	> 2		> 0.5	
N_j	= 1 (or 2 if $\Delta\phi_{jj} < 0.2$)		-	

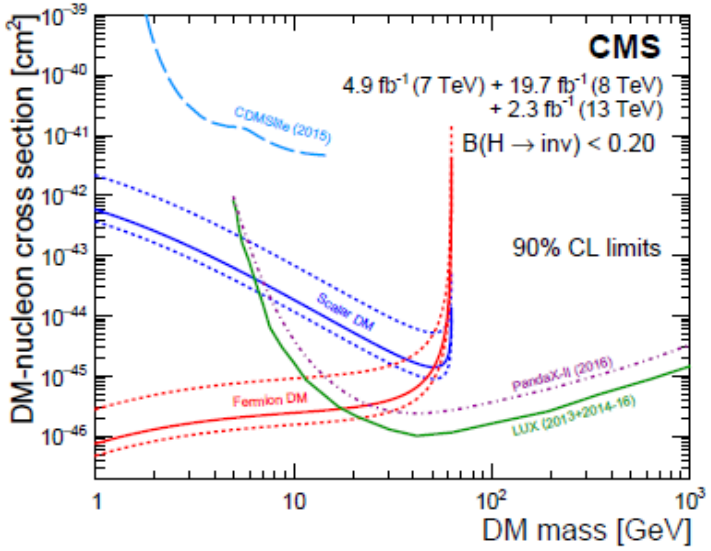


$h \rightarrow$ invisible – results

- No significant deviations from SM are observed
- Assuming SM production of ggH, qqH and VH, a 95% CL upper limit of $B(H \rightarrow \text{inv}) < 0.24$ is set
- Upper limits as a function of the fermion and vector boson couplings, κ_f and κ_V shown
- Results are interpreted in the context of Higgs-portal DM interactions
- Results improve upon LUX for DM mass below 20 (5) GeV assuming a fermion (scalar) DM particle







LFV Higgs decays (1/2)

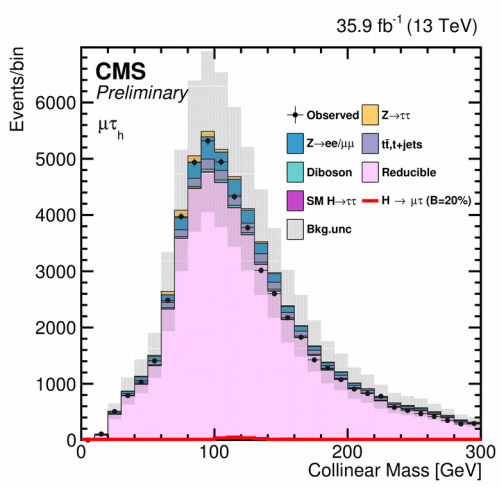
CMS-PAS-HIG-17-001

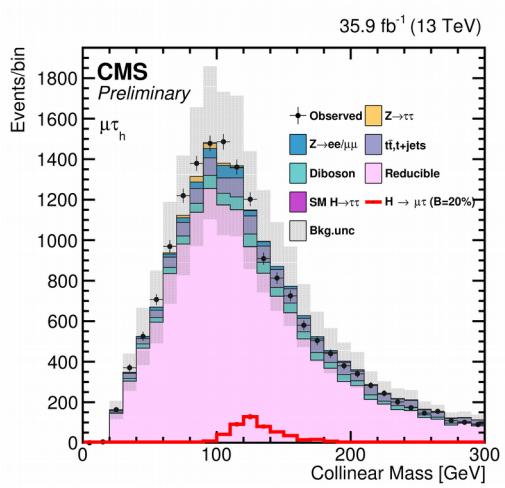
- LFV Higgs couplings allow $\tau \to \mu$, $\tau \to e$, $\mu \to e$ via a virtual H. Relevant for SUSY, R-S, composite Higgs and others
- Strong constraints from $\mu \to e\gamma$ give $B(H \to e\mu) < \mathcal{O}(10^{-8})$. Less stringent constraint for $B(H \to e\tau)$, $B(H \to \mu\tau)$
- 4 decay channels considered: $H \to e\tau_\mu, e\tau_h, \mu\tau_e$ and $\mu\tau_h$. Similar signature to SM but light leptons contain higher momentum fraction since prompt decay (instead of τ_l). Backgrounds are Z + jets, W + jets and multijet
- Multijet background estimated using SS prediction. Multijet CR from looser lepton isolation used to extract SFs
- Fully data-driven prediction using p_T-dependent misidentification rates for $j \to e$, $j \to \mu$ and $j \to \tau_h$ events
- Mis-ID rates obtained in control regions defined by inverting separately or simultaneously the relative lepton sign and isolation

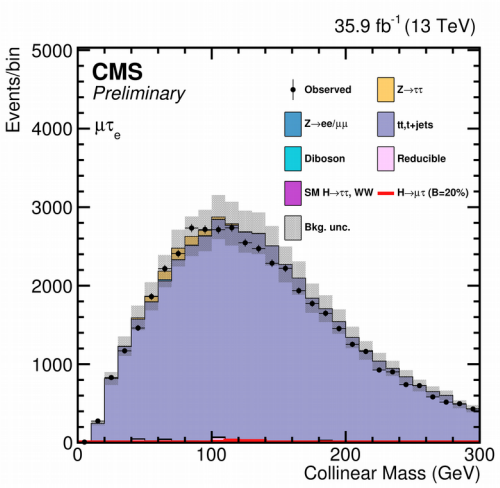
Selection overview

- Single lepton triggers
- Opposite sign, different flavor isolated leptons or lepton + τ_h
- Four additional sub-categories according to production mode: VBF, 0-jet, 1-jet and 2-jet

$$\mathcal{L} = 35.9\ \text{fb}^{-1}$$

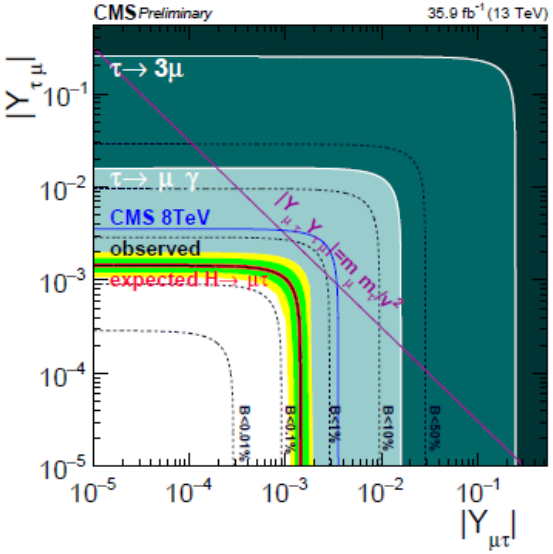


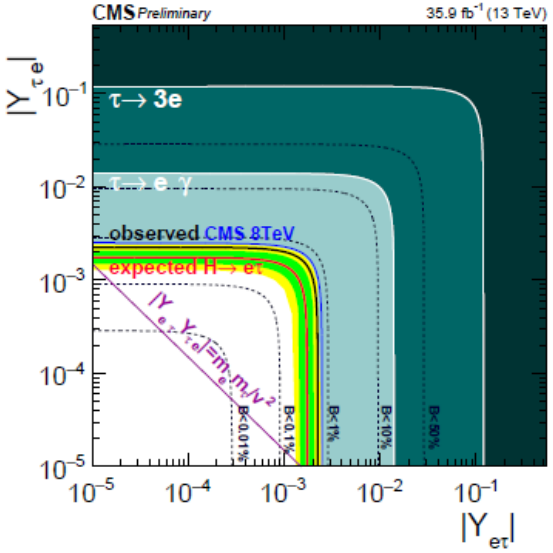


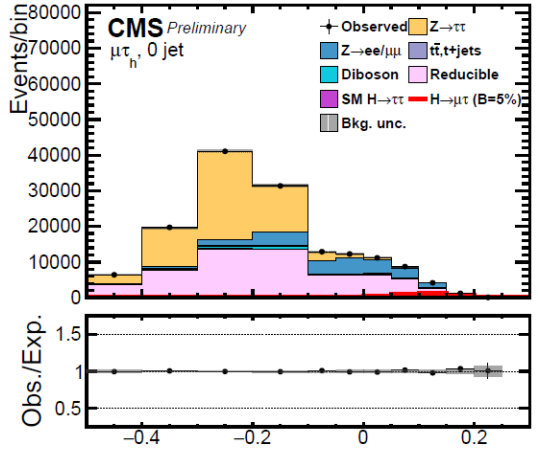


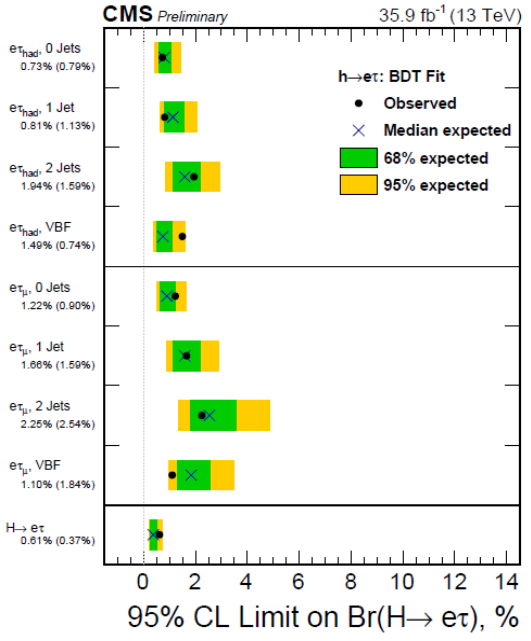
LFV Higgs decays (2/2)

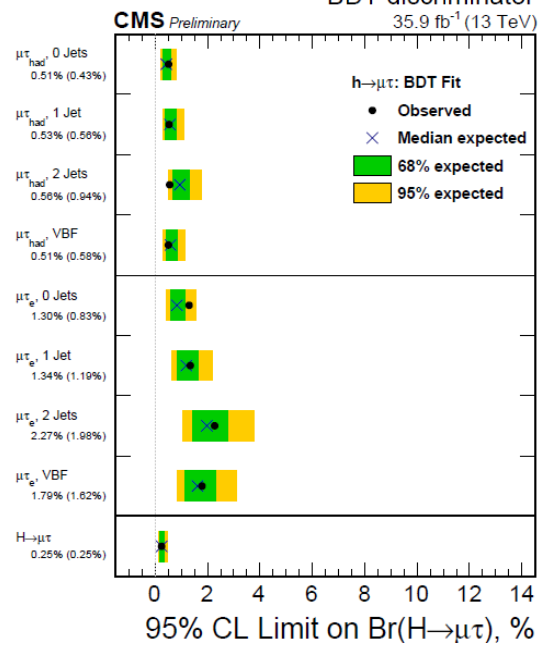
- Loose selection and a BDT discriminant used, but cross-checked with result from tighter selection and M_{col} fit. BDT-fit analysis has limits ~2 stronger
- BDT input variables vary for each channel, but typically include $p_T^{l,\tau}$, E_T^{miss}, M_{col}, $M_T^{l,\tau}$ and angular variables between l, τ_h and $\vec{p}_T^{miss}$
- Results are compatible with background expectation. 95% CL upper limit on $B(H \to e\tau)$ and $B(H \to \mu\tau)$ set at 0.25% and 0.61%, respectively
- Limits on off-diagonal $e\tau$, $\mu\tau$ Yukawa couplings set
- Improves on Run-1 ATLAS and CMS results







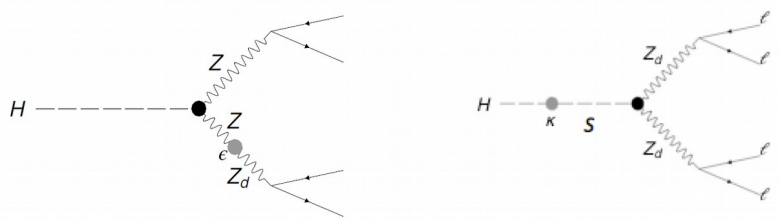




$H \to ZZ_d, XX \to 4l$

ATLAS-CONF-2017-042

- Search for ZZ_d, Z_dZ_d or aa in 4-lepton final states. Relevant for $U(1)_d$ or 2HDM+S extensions of the SM
- Dominant backgrounds are SM $H \to ZZ^* \to 4l$, followed by non-resonant $ZZ^* \to 4l$



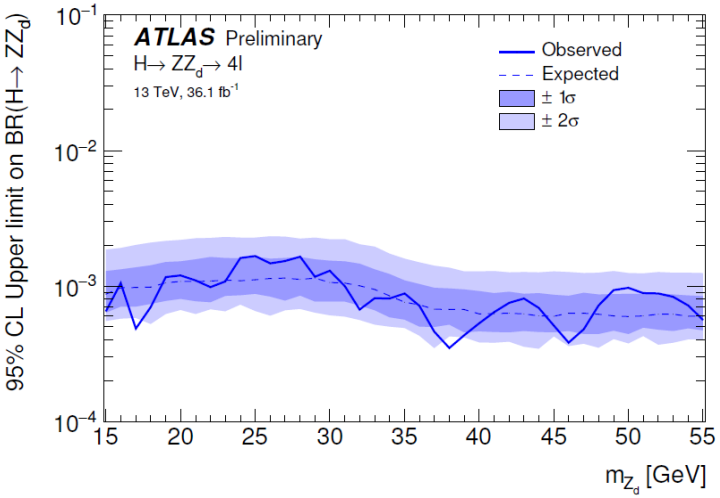
- Selection summarized in table, mostly angular separation between leptons and mass window cuts around m_h, m_Z and allowed range for m_{Z_d} and m_a.
- Low mass selection only considers 4μ final state
- J/ψ and Υ backgrounds removed via dedicated mass window cuts

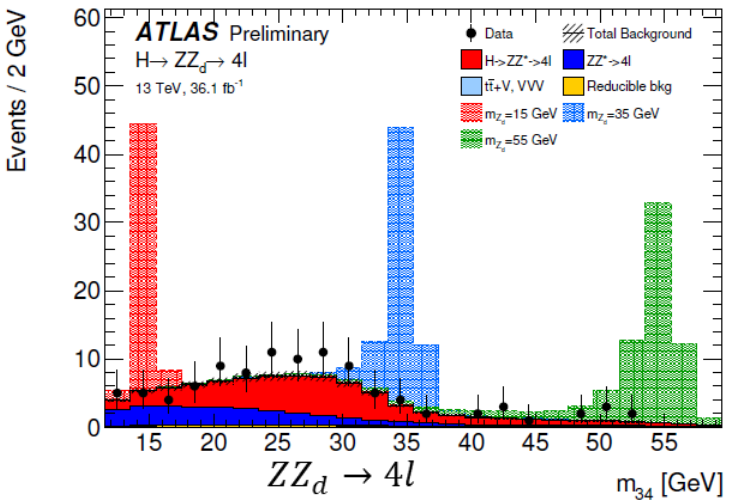
$\mathcal{L} = 36.1\ \text{fb}^{-1}$

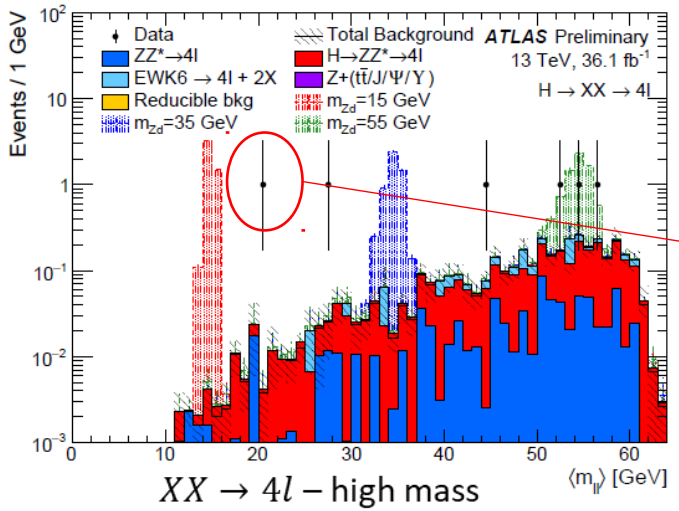
Object	$H \to ZZ_d \to 4\ell$	$H \to XX \to 4\ell$	
		High Mass selection	Low Mass selection
Quadruplet selection	- Require at least one quadruplet of leptons consisting of two pairs of same-flavour opposite-charge leptons - Three leading-p_T leptons satisfy $p_T > 20$ GeV, 15 GeV, 10 GeV. - At least three muons are required to be reconstructed by combining ID and MS tracks in the 4μ channel.		
	- Select best quadruplet (per channel) to be the one with the (sub)leading dilepton mass (second) closest the Z mass	- Leptons in the quadruplet responsible for firing at least one trigger	
	- Leading di-lepton mass requirement: 50 GeV $< m_{12} <$ 106 GeV - Sub-leading di-lepton mass requirement: 12 GeV $< m_{34} <$ 115 GeV - $\Delta R(\ell, \ell') > 0.10$ (0.20) for all same (different) flavour leptons in the quadruplet - Remove quadruplet if alternative same-flavour opposite-charge di-lepton gives $m_{\ell\ell} <$ 5 GeV	- $\Delta R(\ell, \ell') > 0.10$ (0.20) for all same (different) flavour leptons in the quadruplet	
Quadruplet ranking	- Select quadruplet with the highest expected signal rate, in the order: 4μ, $2e2\mu$, $2\mu2e$, $4e$	- Select quadruplet with smallest $\Delta m_{\ell\ell} = \lvert m_{12} - m_{34} \rvert$	
Event selection	- 115 GeV $< m_{4\ell} <$ 130 GeV	- Reject event if: $(m_{J/\Psi} - 0.25\ \text{GeV}) < m_{12,34,14,23} < (m_{\Psi(2S)} + 0.30\ \text{GeV})$ $(m_{\Upsilon(1S)} - 0.70\ \text{GeV}) < m_{12,34,14,23} < (m_{\Upsilon(3S)} + 0.75\ \text{GeV})$ - $m_{34}/m_{12} > 0.85$	
		- 115 GeV $< m_{4\ell} <$ 130 GeV - 10 GeV $< m_{12,34} <$ 64 GeV - 5 GeV $< m_{14,32} <$ 75 GeV for $4e$ and 4μ channels	- 120 GeV $< m_{4\ell} <$ 130 GeV - 0.88 GeV $< m_{12,34} <$ 15 GeV - No restriction on alternative pairing

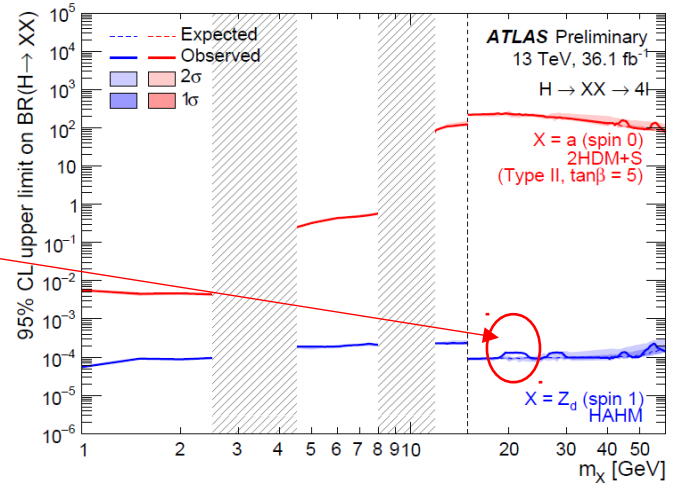
$H \to ZZ_d, XX \to 4l$

- ZZ_d search observes 102 events to 87 ± 7 predicted
- Low mass XX search observes no events to a predicted 0.4 ± 0.1
- High mass XX search observes 6 events, to a predicted 3.9 ± 0.3. There's a 3.8σ local significance excess at 20 GeV, but due to only one event
- 95% CL upper limits on the Higgs branching ratio to ZZ_d, Z_dZ_d and aa are set as a function of the BSM boson mass
- Limits on model-independent fiducial cross-sections are also derived









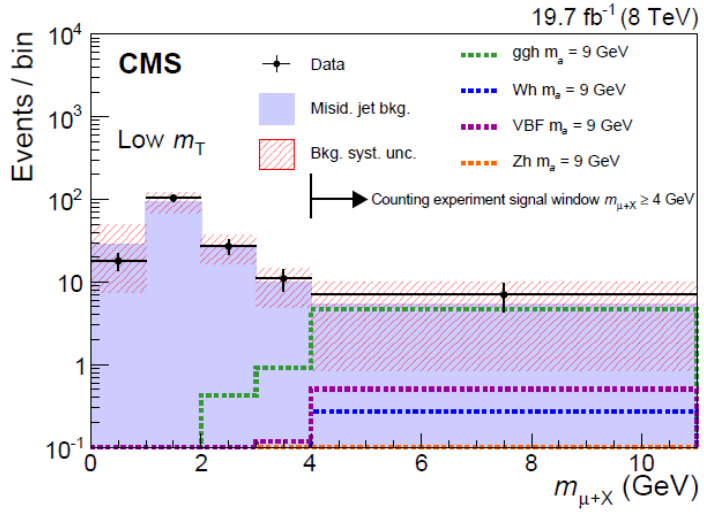
$h \to aa$

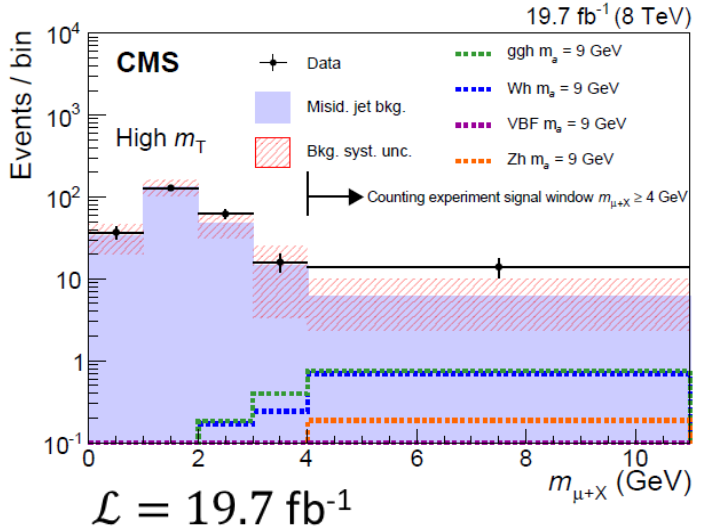
CMS-HIG-16-015

- Searches for $h \to aa$ decay in the 4τ, $2\mu 2\tau$, $2\mu 2b$ using Run-1 data
- Relevant for 2HDM+S models such as NMSSM. Considers final states from *gg*F, VBF and VH production

Overview of $h \to aa \to 4\tau$

- Single isolated muon trigger
- Only jets with a muon considered for tau pair reconstruction. First identify τ_μ then reconstruct other tau (τ_X) from jet while subtracting muon contribution. Doesn't consider bottom quark seeded jets
- Main backgrounds are $Z/\gamma^* \to \mu\mu$ + jets, $W \to \mu\nu$ + jets, $t\bar{t}$ and multijet
- At least one OS $\tau_\mu \tau_X$ pair in event
- Reduce Drell-Yan by having trigger muon be SS as τ_X. $m_{\mu+X} \geq 4$ GeV gives 95% background rejection
- Analysis split into $m_T\left(\mu^{\text{trig}}, \vec{p}_T^{\,miss}\right)$ above or below 50 GeV
- Mis-ID background estimated as mean of independent predictions from 3 background-rich regions where the τ_X is not isolated, each normalized to data in $m_{\mu+X} < 2$ GeV region

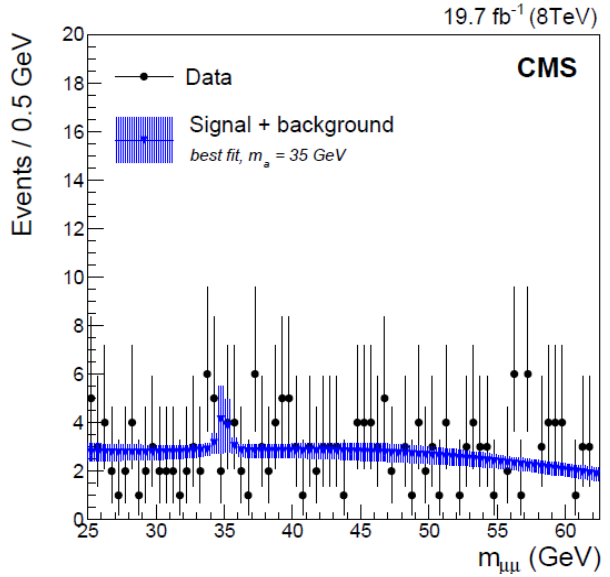




$h \to aa$

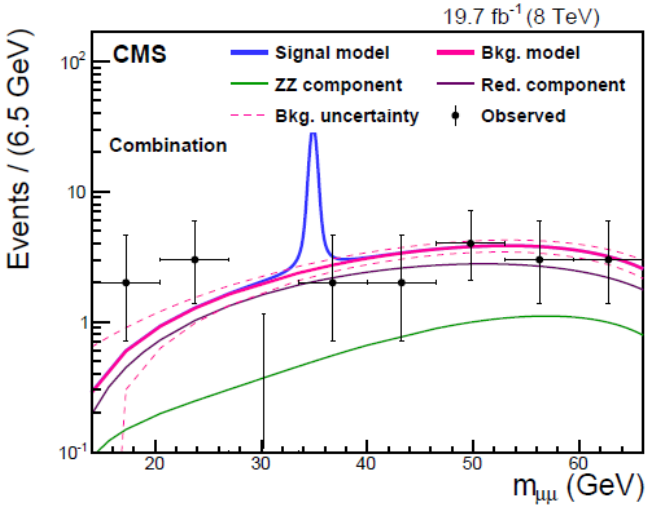
Overview of $h \to aa \to 2\mu 2b$

- Dimuon triggers
- $|m_{\mu\mu bb} - 125| < 25$ GeV,
- Main backgrounds from $Z/\gamma^* \to ll$ and fully leptonic $t\bar{t}$ decays
- Analytical functions are used for background and signal modelling and fit to $m_{\mu\mu} \in [25, 62.5]$ GeV in data



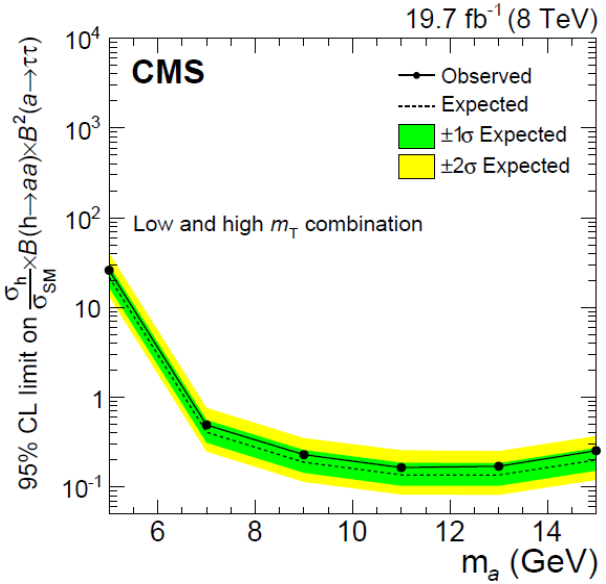
Overview of $h \to aa \to 2\mu 2\tau$

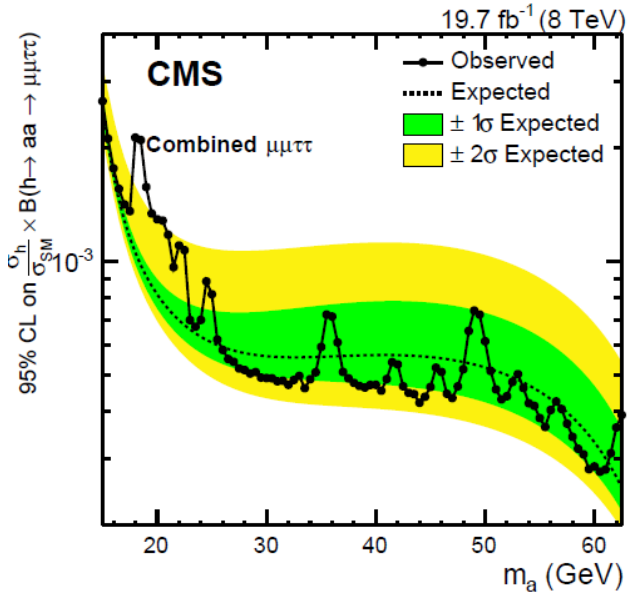
- 5 final states: $\mu^+\mu^-\tau_e^+\tau_e^-$, $\mu^+\mu^-\tau_e^\pm\tau_\mu^\mp$, $\mu^+\mu^-\tau_e^\pm\tau_h^\mp$, $\mu^+\mu^-\tau_\mu^\pm\tau_h^\mp$ and $\mu^+\mu^-\tau_h^+\tau_h^-$
- Dimuon trigger. Pairs highest p_T OS muons and taus, veto events with b-jets
- $|m_{\mu\mu\tau\tau}^{vis} - 125| > 30$ GeV, $|m_{\mu\mu\tau\tau} - 125| < 25$ GeV, $|m_{\mu\mu} - m_{\tau\tau}| \,/\, m_{\mu\mu} < 0.8$
- Irreducible ZZ background taken from simulation. Reducible Z + jets and W + jets events estimated using p_T-dependent jet $\to e, \mu$ or τ mis-ID rates computed in looser isolation and SS control regions
- Analytical functions for signal and background are fitted to $m_{\mu\mu} \in [15, 62.5]$ GeV in data

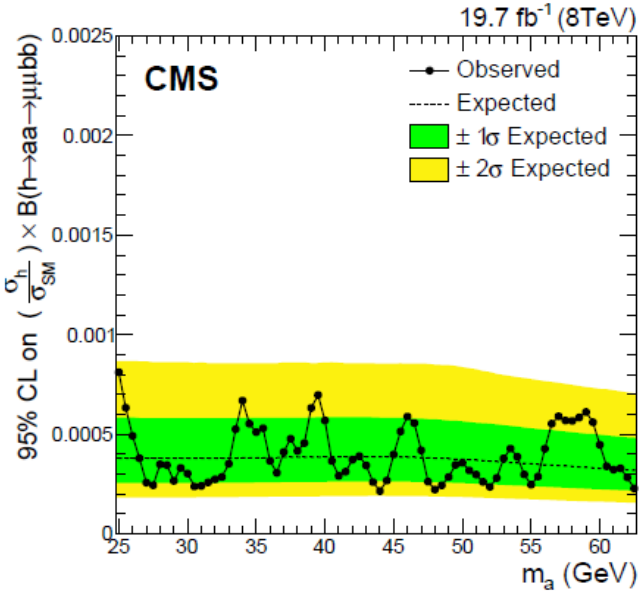


$h \rightarrow aa$ – limits

- 95% CL upper limits on production times BR of each $h \rightarrow aa$ decay mode are set as a function of the pseudoscalar mass
- 2 events in $\mu^+\mu^-\tau_e^+\tau_e^-$ with $m_{\mu\mu}$ equal to 18.4 and 20.7 GeV lead to a 3.5σ deviation. Expected background yield agrees with observed yield over full mass range

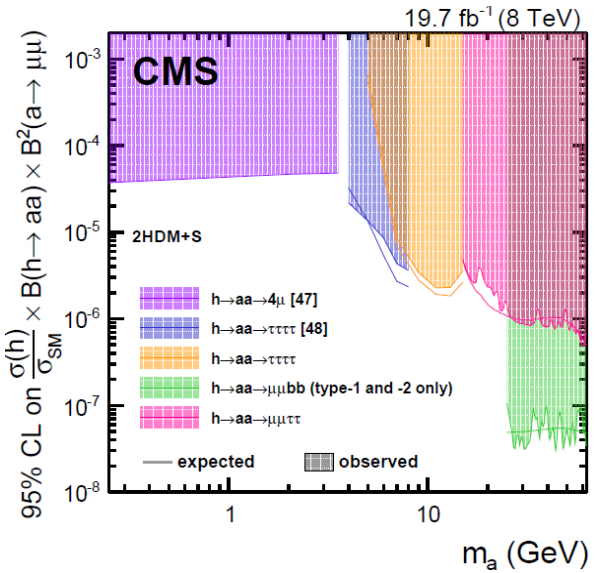


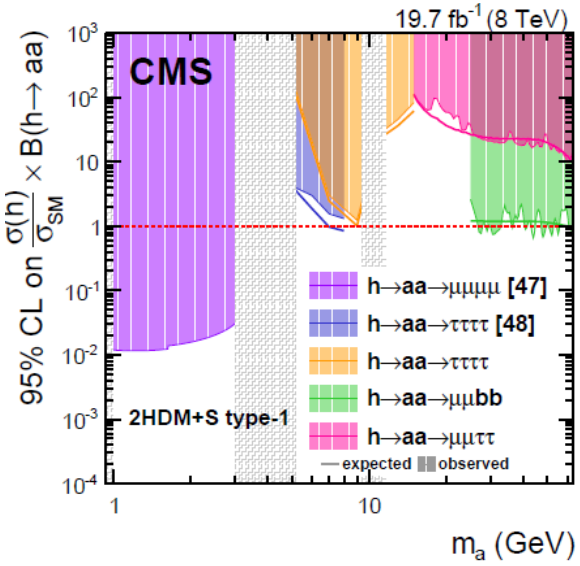


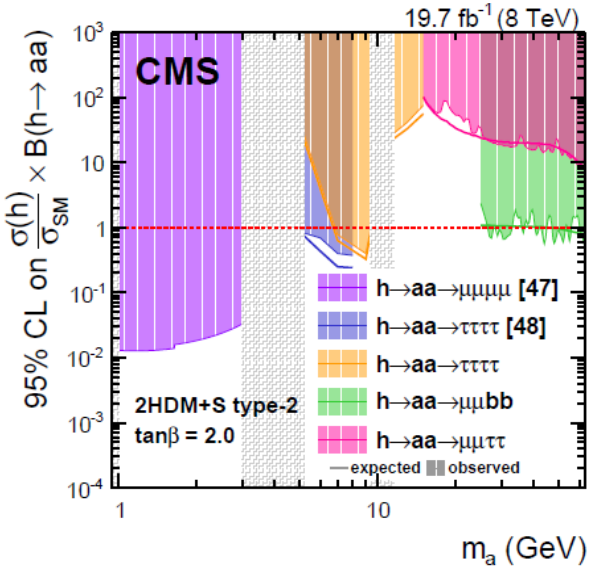


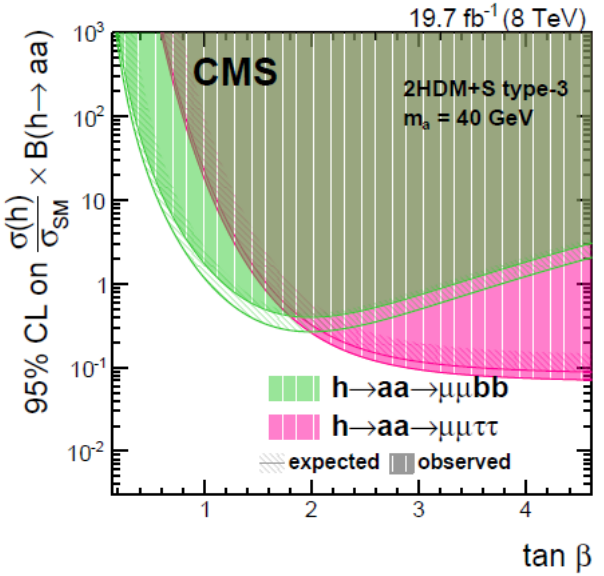
$h \to aa$ – interpretation

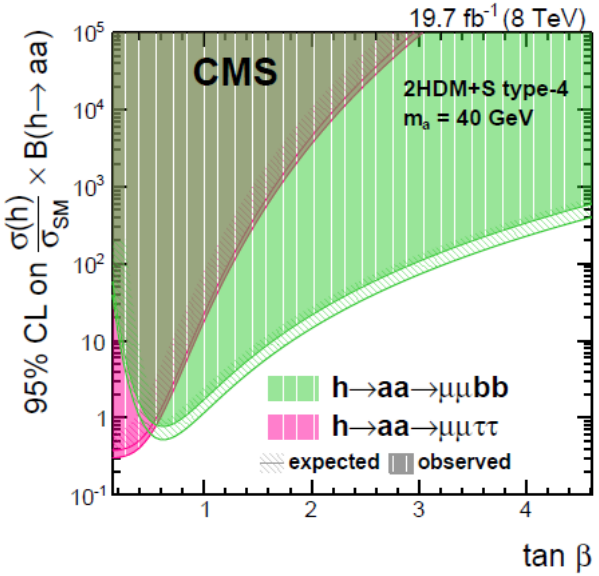
- Above results combined with earlier aa to 4μ and 4τ searches
- No significant excess observed for any of the five analyses
- Upper limits of 17%, 16% and 4% on $\frac{\sigma}{\sigma_{SM}} \times B(h \to aa)$ set from $4\tau, 2\mu 2b$ and $2\mu 2\tau$ analyses, respectively
- 95% CL upper limit also set separately for 2HDM+S of types 1, 2, 3 and 4





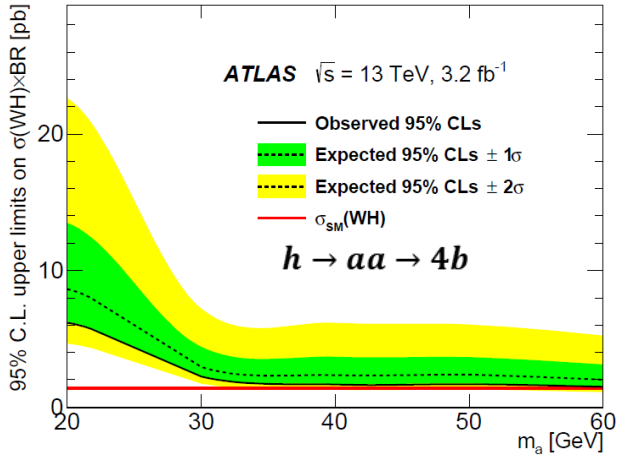


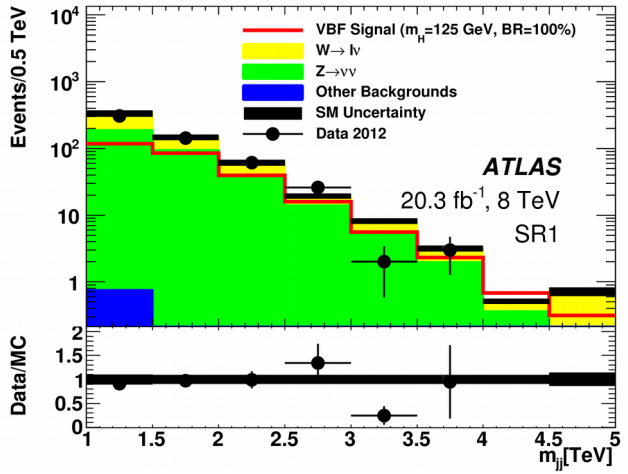




Previous results – ATLAS

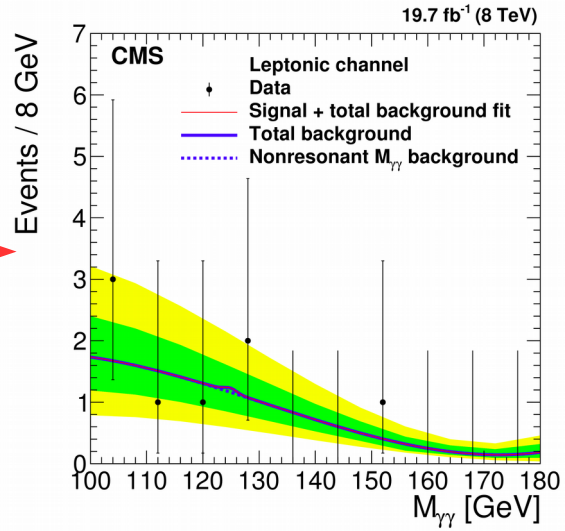
Search $\sqrt{s}$	7 TeV (fb^{-1})	8 TeV (fb^{-1})	13 TeV (fb^{-1})	reference
$W+(h\to aa\to 4b)$	-	-	3.2	Eur. Phys. J. C 76 (2016) 605
$t\bar{t}\to Wb+qH$	-	20.3	-	arXiv:1509.06047
VBF h to invisble	-	20.3	-	arXiv:1508.07869
$h\to Z_{(d)}Z_d, aa\to 4l$	-	20	-	arXiv:1505.07645
$h\to aa\to \mu\mu\tau\tau$	-	20.3	-	arXiv:1505.01609
$V(\to qq)h(\to invisible)$	-	20.3	-	arXiv:1504.04324
$h,Z\to J/psi\,\gamma, \Upsilon\,\gamma$	-	20.3	-	arXiv:1501.03276
$h\to\mu\mu$	4.5	20.3	-	arXiv:1406.7663
$h\to aa\to 4\gamma$	4.9	-	-	ATLAS-CONF-2012-079

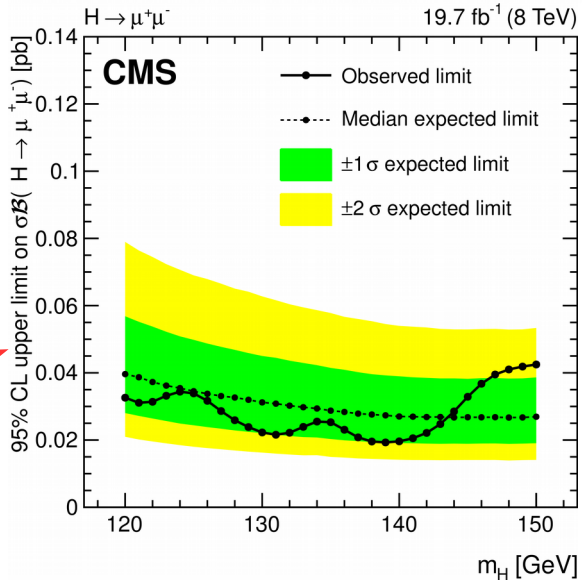




Previous results – CMS

Search $\sqrt{s}$	7 TeV (fb^{-1})	8 TeV (fb^{-1})	13 TeV (fb^{-1})	reference
$FCNC \quad ttZ, tgq+Z, tzq$	-	19.7	-	CMS-TOP-12-039
$t\bar{t} \rightarrow Wb+qH$	-	19.7	-	CMS-TOP-13-017
$FCNC \quad tgq$	5.0	19.7	-	CMS-TOP-14-007
$LFV\ h \rightarrow e\tau, e\mu$	-	19.7	-	CMS-HIG-14-040
ATLAS+CMS Higgs decays	~5	~20	-	J. High Energy Phys. 08 (2016) 045
$h \rightarrow aa \rightarrow 4\tau$	-	19.7	-	CMS-HIG-14-019
$h \rightarrow \gamma + inv$	-	19.4	-	CMS-HIG-14-025
$h \rightarrow \mu\mu, ee$	5.0	19.7	-	CMS-HIG-13-007
VBF + Zh, h to inv	4.9	19.7	-	CMS-HIG-13-030





Summary

- Showed recent results of rare and BSM decay modes of SM particles investigated by ATLAS and CMS
- No significant deviations from the SM observed
- Improved constraints on BSM branching ratios and parameter space exclusion in a wide range of models
- Several searches statistically limited and will benefit from more data so stay tuned!

Thank you!

BACKUP

$h(\rightarrow invisible)+Z(\rightarrow b\bar{b})$

- 4 MET triggers used
- 3 MET categories defined: 100 – 130 (“low”), 130 – 170 (“intermediate”), >170 GeV (“high”)
- BDT score used as discriminant
- 95% CL upper limit on σ B(h to inv) / σ_{SM} set at 1.82 (1.99)

Variable	Selection		
	Low E_T^{miss}	Intermediate E_T^{miss}	High E_T^{miss}
E_T^{miss}	100–130 GeV	130–170 GeV	>170 GeV
p_T^{j1}	>60 GeV	>60 GeV	>60 GeV
p_T^{j2}	>30 GeV	>30 GeV	>30 GeV
p_T^{jj}	>100 GeV	>130 GeV	>130 GeV
M_{jj}	<250 GeV	<250 GeV	<250 GeV
CSV_{max}	>0.679	>0.679	>0.679
CSV_{min}	>0.244	>0.244	>0.244
N additional jets	<2	—	—
N leptons	=0	=0	=0
$\Delta\phi(Z, H)$	>2.0 radians	>2.0 radians	>2.0 radians
$\Delta\phi(E_T^{miss}, j)$	>0.7 radians	>0.7 radians	>0.5 radians
$\Delta\phi(E_T^{miss}, E_T^{miss}{}_{trk})$	<0.5 radians	<0.5 radians	<0.5 radians
E_T^{miss} significance	>3	not used	not used

*CSV is the btagging algorithm