BSM Higgs decays at ATLAS and CMS

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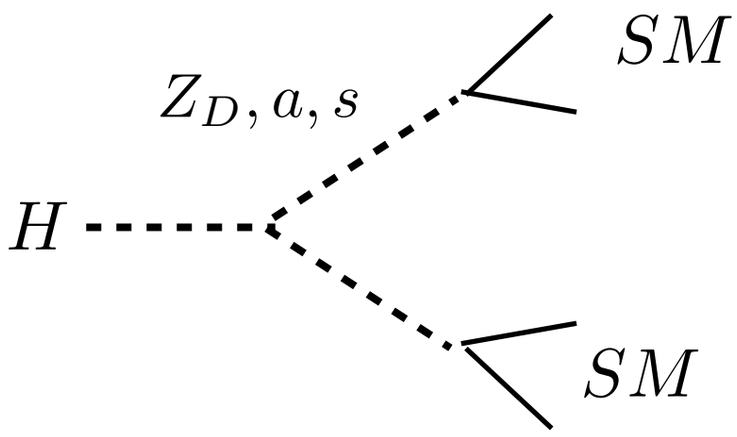
Javier Montejo Berlingen (CERN)
on behalf of the ATLAS and CMS collaborations

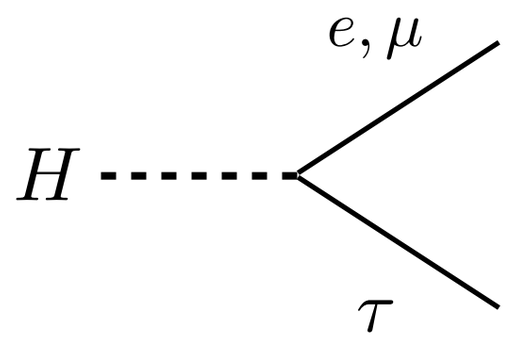
Higgs as a portal to BSM physics

- Strong motivation for new physics, but so far no evidence for direct production of BSM particles
- New physics could couple to the SM only through the Higgs boson, or have too small couplings to be directly produced
  - Higgs width is extremely small, additional widths can lead to substantial BR
- **Exotic Higgs decays as a signature for BSM**
- Current constraint from fits to SM Higgs couplings:
  BR(H→undetected) < 19% ATLAS-CONF-2020-027
  BR(H→ invisible) < 9%

Higgs decays to BSM



LFV Higgs decays



- Not covering decays to long-lived particles, invisible, and rare SM decays

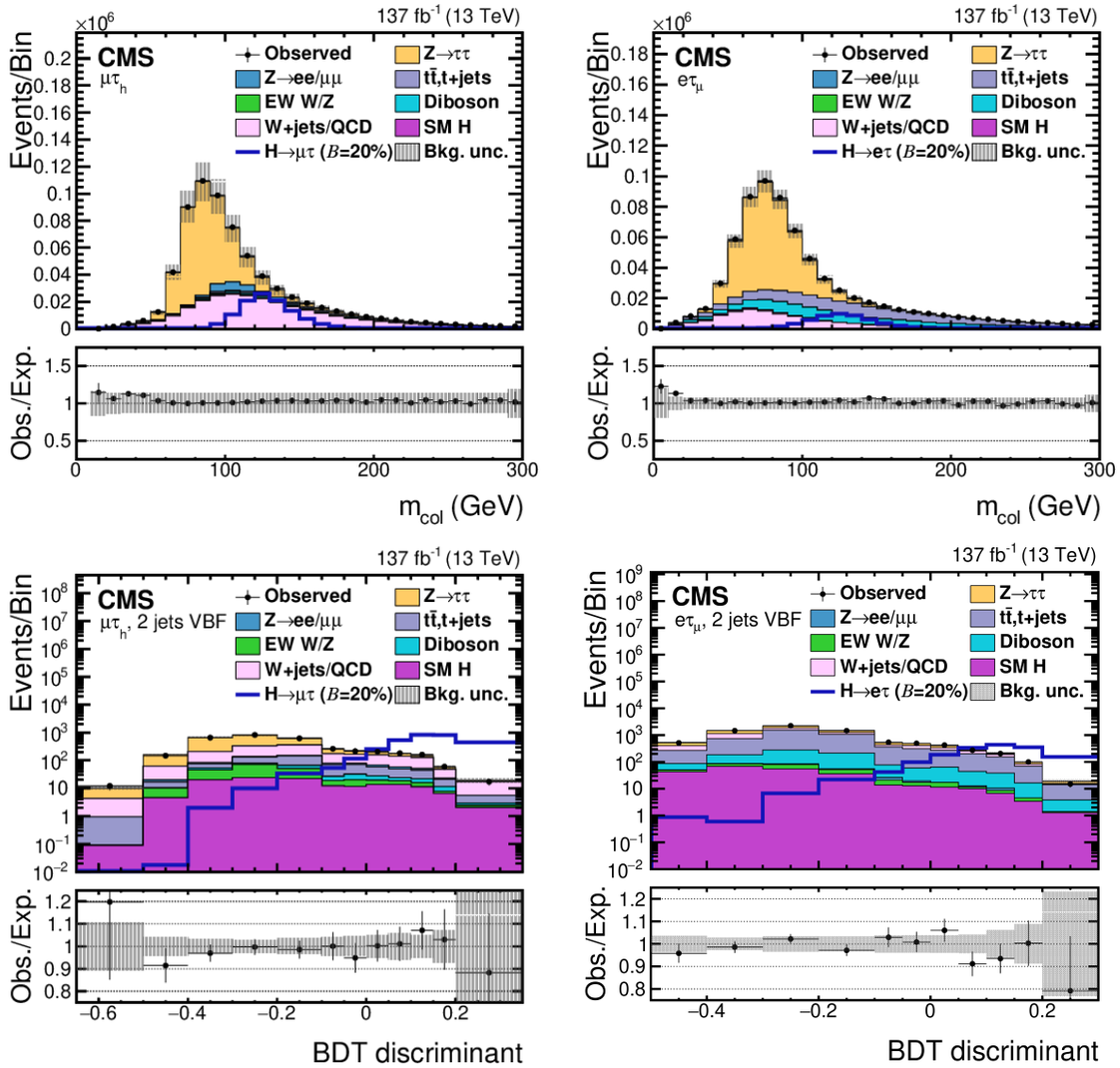
LFV H → eτ/μτ

- Focus on recent CMS result with full Run 2, similar result from ATLAS with 36 fb^{-1}
- Search performed in $\ell\tau_{had}$ and $\ell\tau_{lep}$ final state with different-flavour leptons
- Events are split into 16 categories:
  - [$e\tau_{had}$, $e\tau_{\mu}$, $\mu\tau_{had}$, $\mu\tau_{e}$] x [0, 1, 2 low-m_{jj}, 2 high-m_{jj}] jets

- A BDT is trained in each region to separate signal and backgrounds

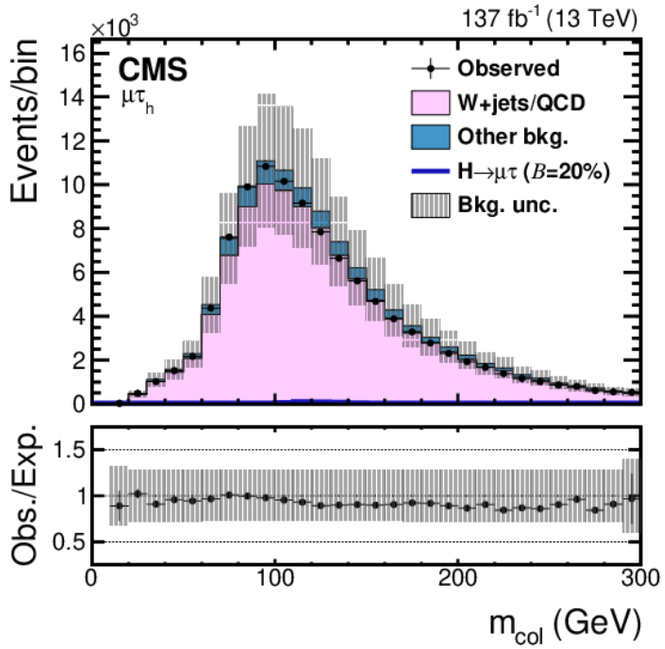
- Main backgrounds are Z→ττ, and misidentified leptons (and ttbar in $\ell\tau_{lep}$ regions)

- Data-driven Z→ττ estimation using the **embedding** technique from Z→μμ



LFV H → eτ/μτ

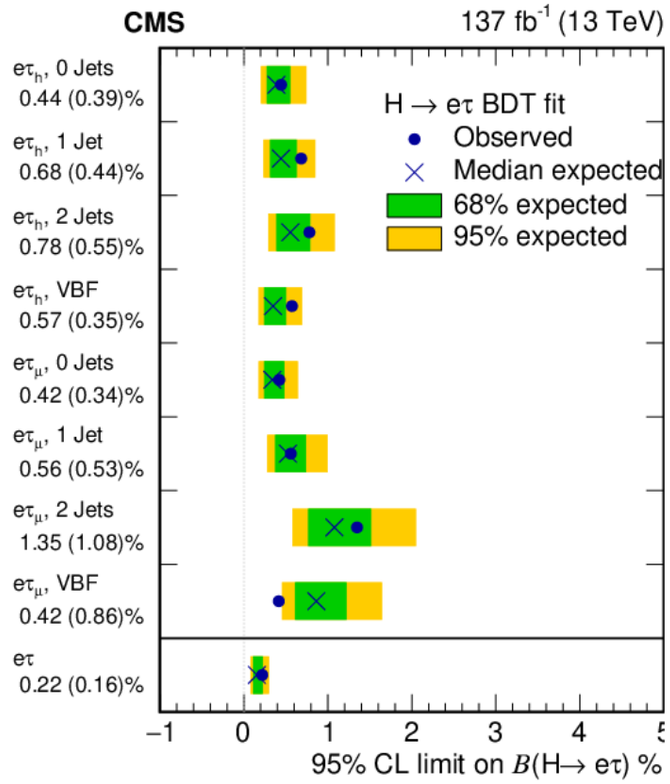
- Misidentified leptons are estimated as:
  - $\ell\tau_{had}$: using anti-isolated leptons, and measuring the misidentification rates
  - $\ell\tau_{lep}$: using same-sign leptons, with extrapolation factors parametrized vs jet multiplicity and ΔR(e,μ)
- Leading uncertainties in the analysis stem from misidentified leptons

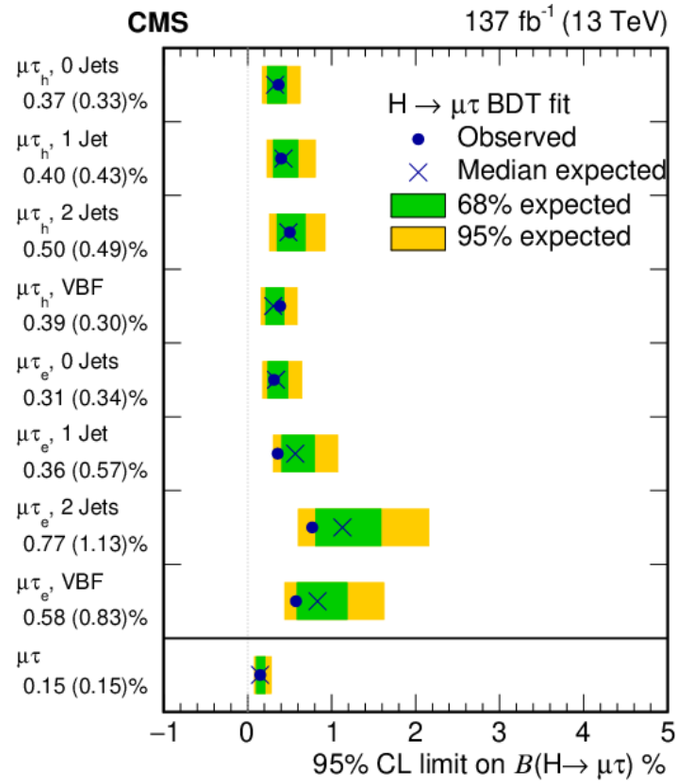


- No significant excess observed
- Limits at 95% CL are set on LFV Higgs decays

	Observed (expected) upper limits (%)
$H \to \mu\tau$	<0.15 (0.15)
$H \to e\tau$	<0.22 (0.16)

- Also limits from ATLAS on:
  $H \to e\mu$ < 0.0061 (0.0058) %

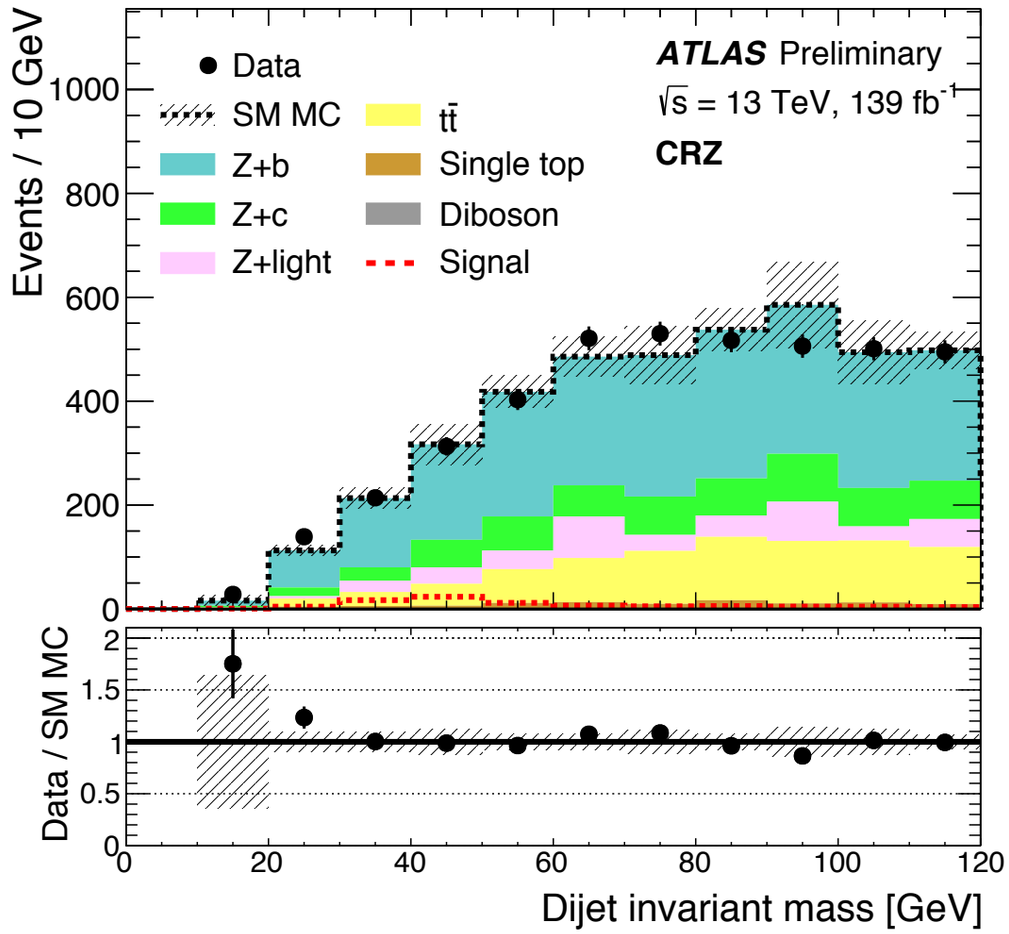


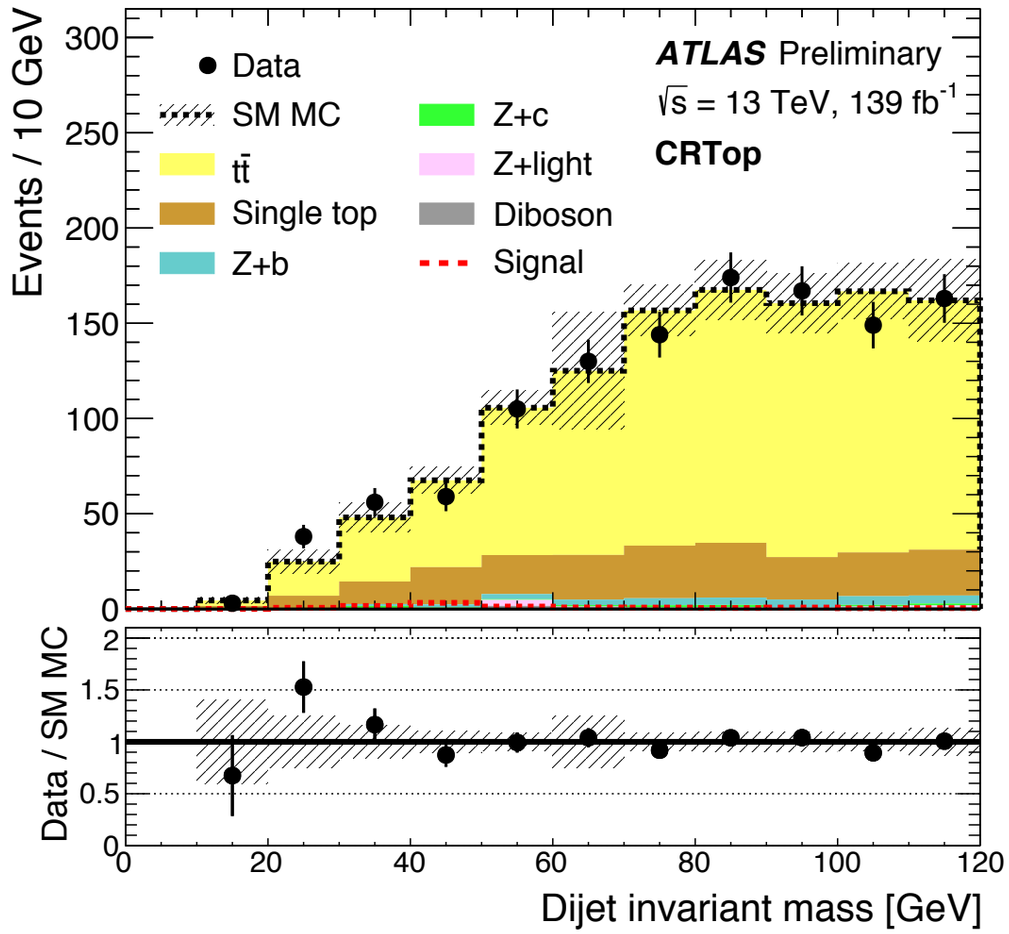


NEW

H → bb+MET

- Analysis targets ZH production with the decay $H \to \tilde{\chi}_2^0 \tilde{\chi}_1^0 \to a\tilde{\chi}_1^0 \tilde{\chi}_1^0$
- Final state is Z(ll)+bb+MET, with resonant m_{bb} as the main analysis variable
- Dijet mass templates for main backgrounds (Z+HF and ttbar) taken from CRs
- MC correction for the extrapolation of the shape (Z+HF only) and normalization to the SR

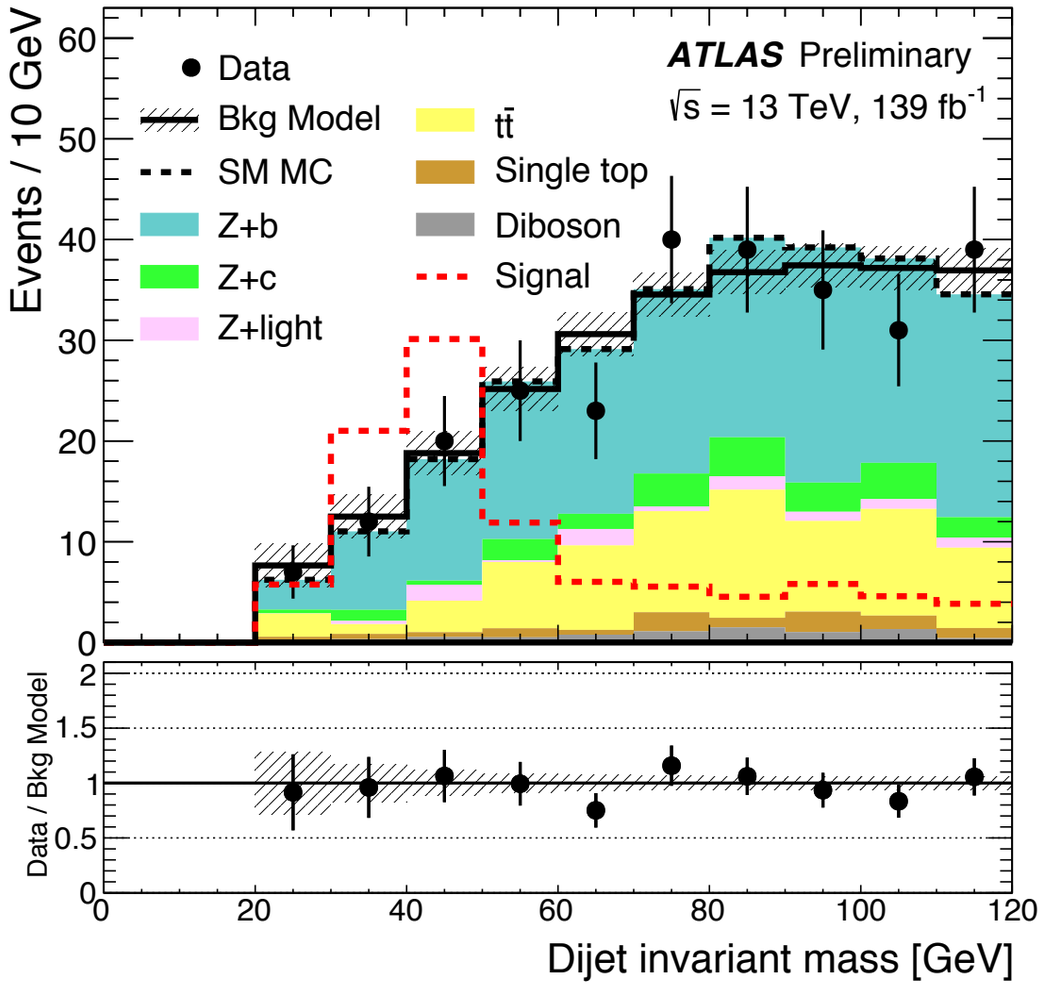


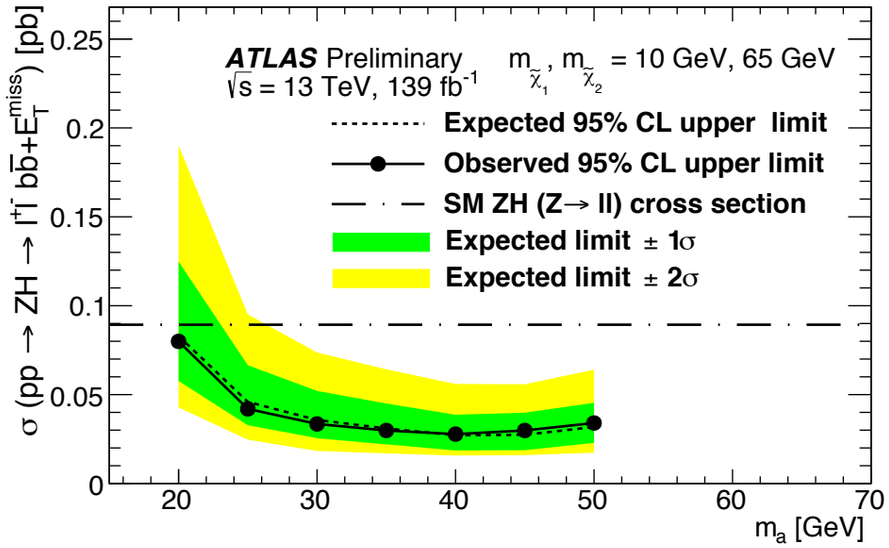


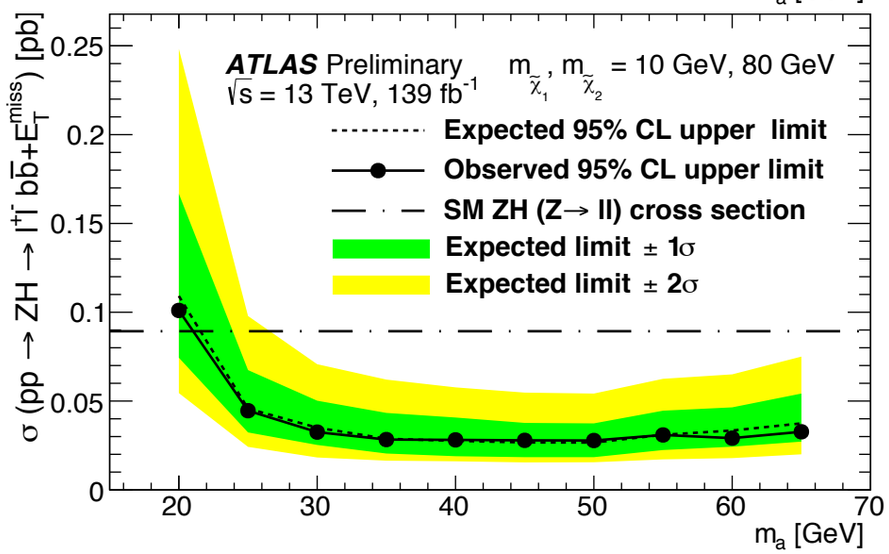
NEW

H → bb+MET

- Reduced sensitivity to systematics as MC is mainly used to predict ratios between CRs and SR
- Total background uncertainty < 10% over most of the dijet mass range
- No excess, set limits as a function of m_a for different choices of $m_{\chi 1}$, $m_{\chi 2}$



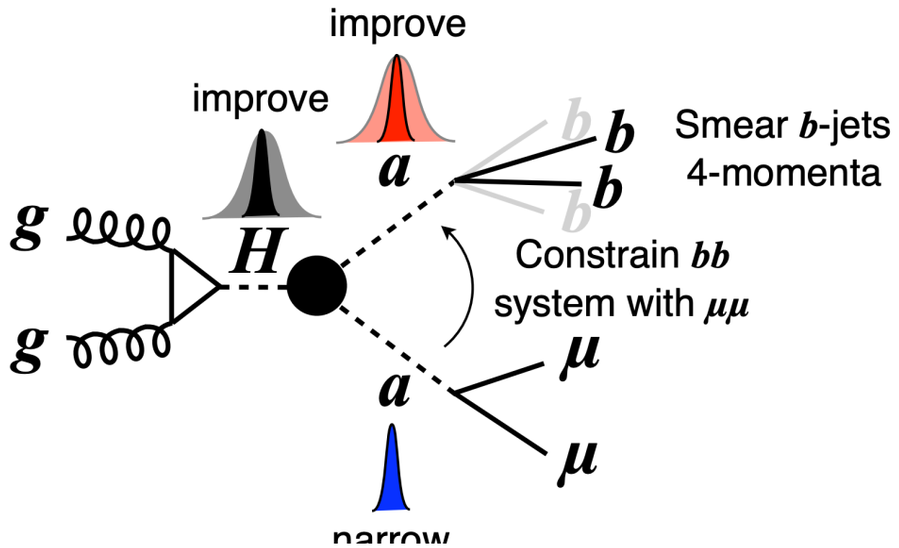




H→aa→2μ2b

- Search with full Run 2 dataset in a final state with two b-jets and two leptons
- Good balance between large BR(a→bb) and clean signature from a→μμ

- Exploit the great resolution of $m_{\mu\mu}$ to improve m_{bb} via a kinematic likelihood fit
  - Shift the b-jet energies within the resolution to maximize the likelihood
  - Cut on the kinematic likelihood fit score (L^{max}) to select $m_{\mu\mu} \sim m_{bb}$ events

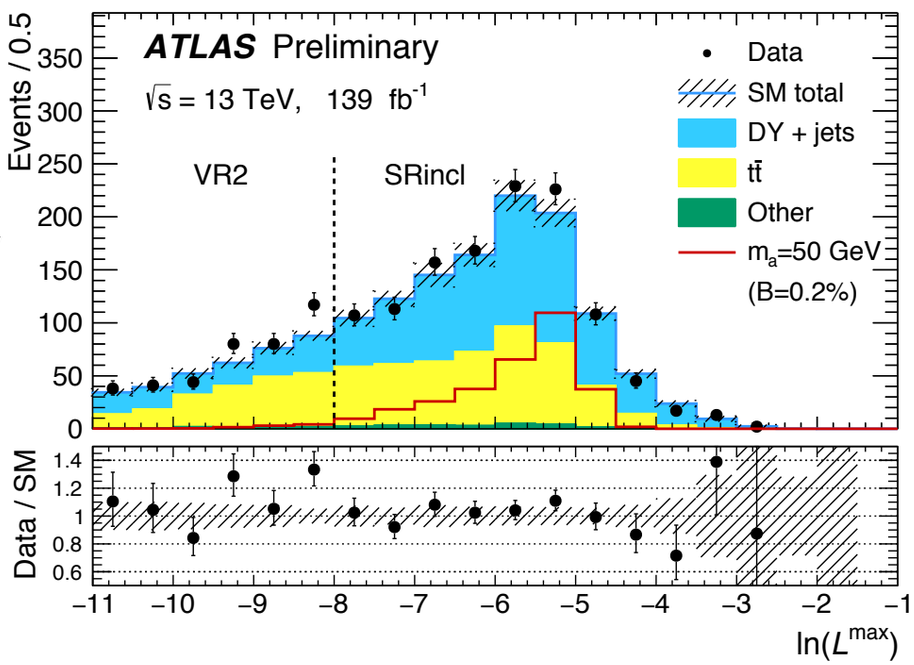


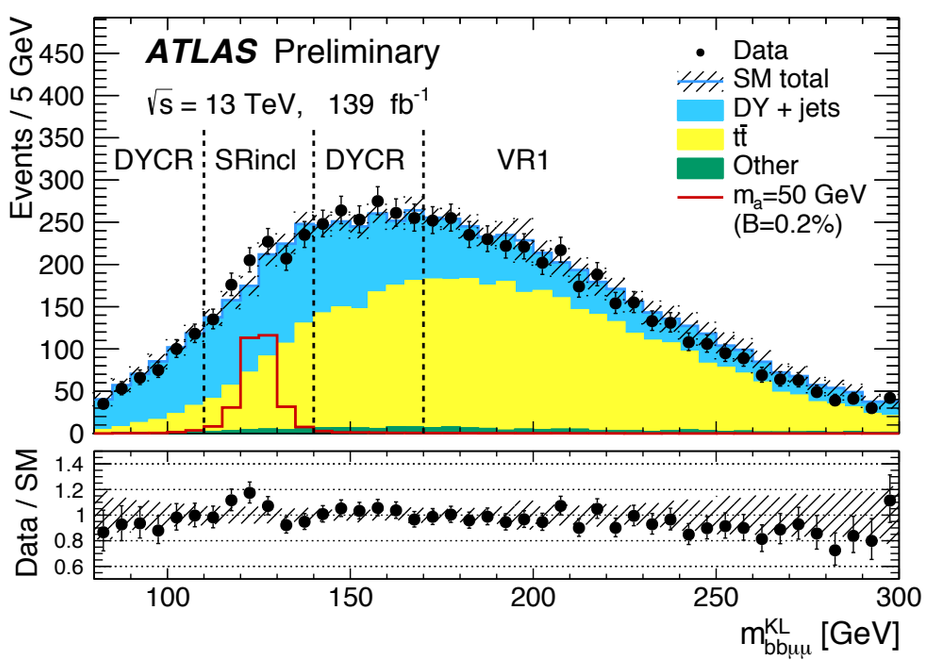
Selection:

$\ln(L^{max}) > -8$

$110 < m_{\mu\mu bb} < 140$ GeV

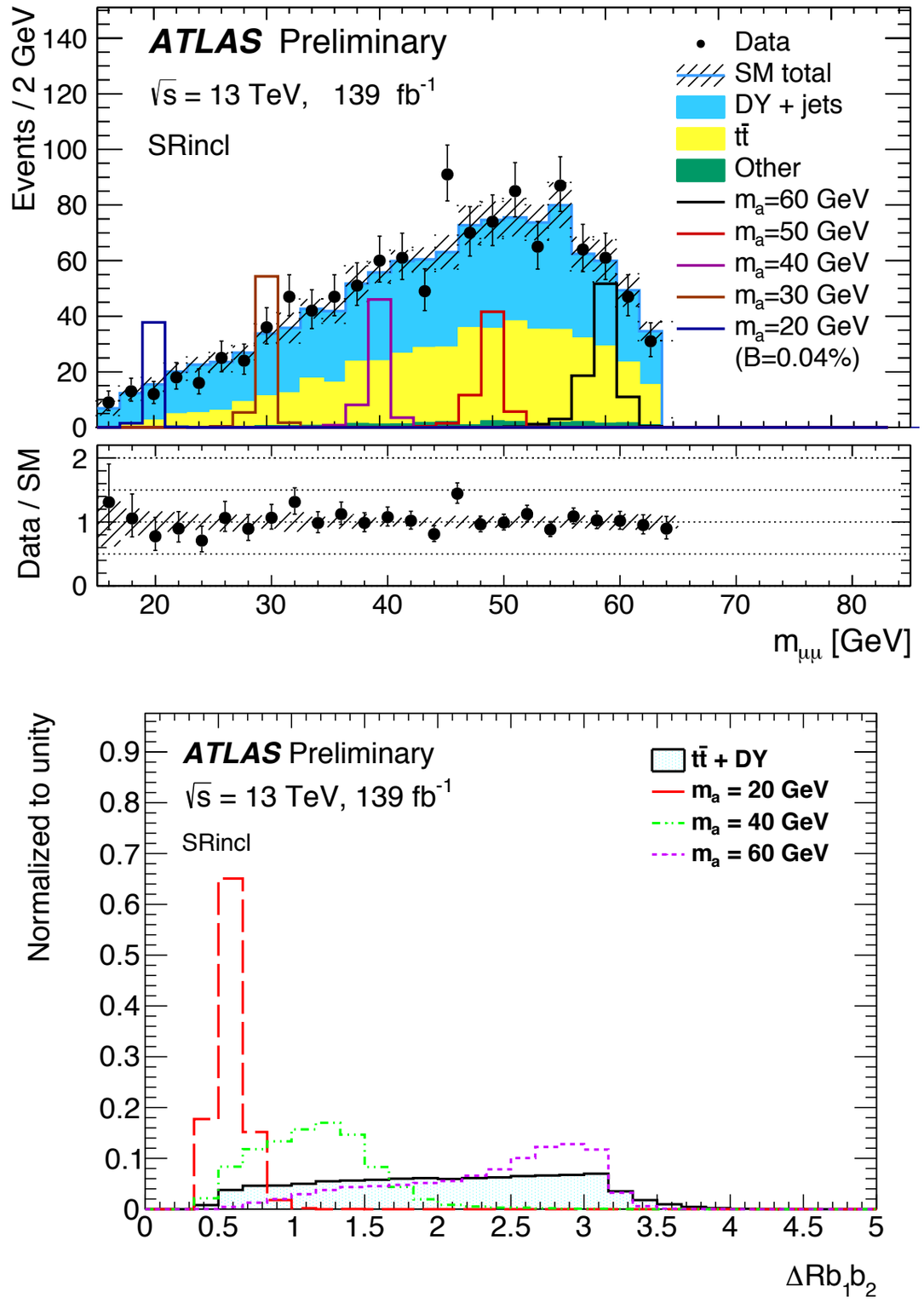
$E_T^{miss} < 60$ GeV





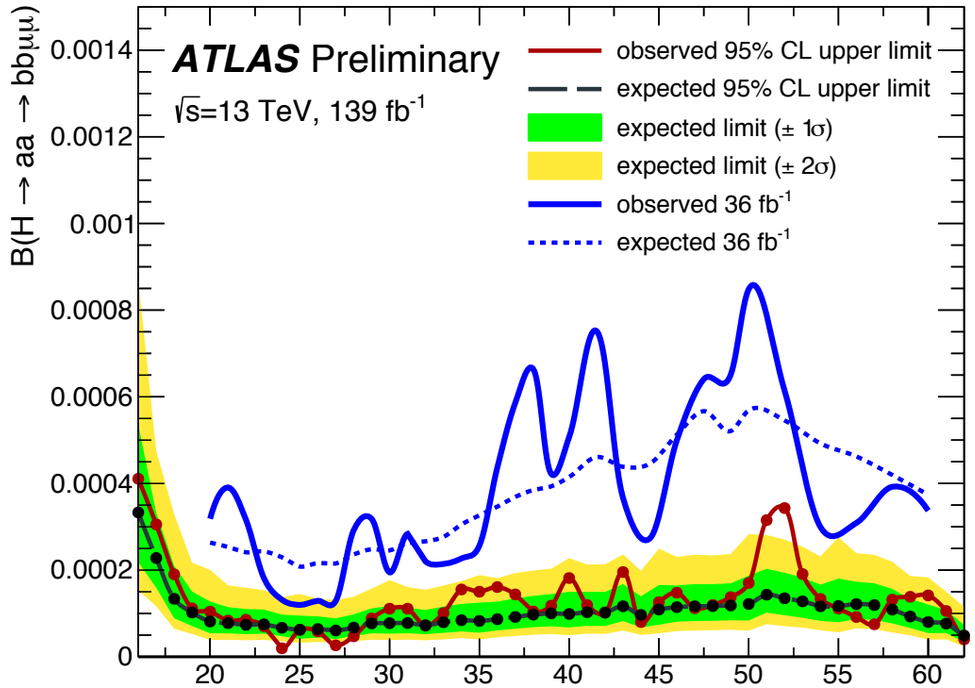
H→aa→2μ2b

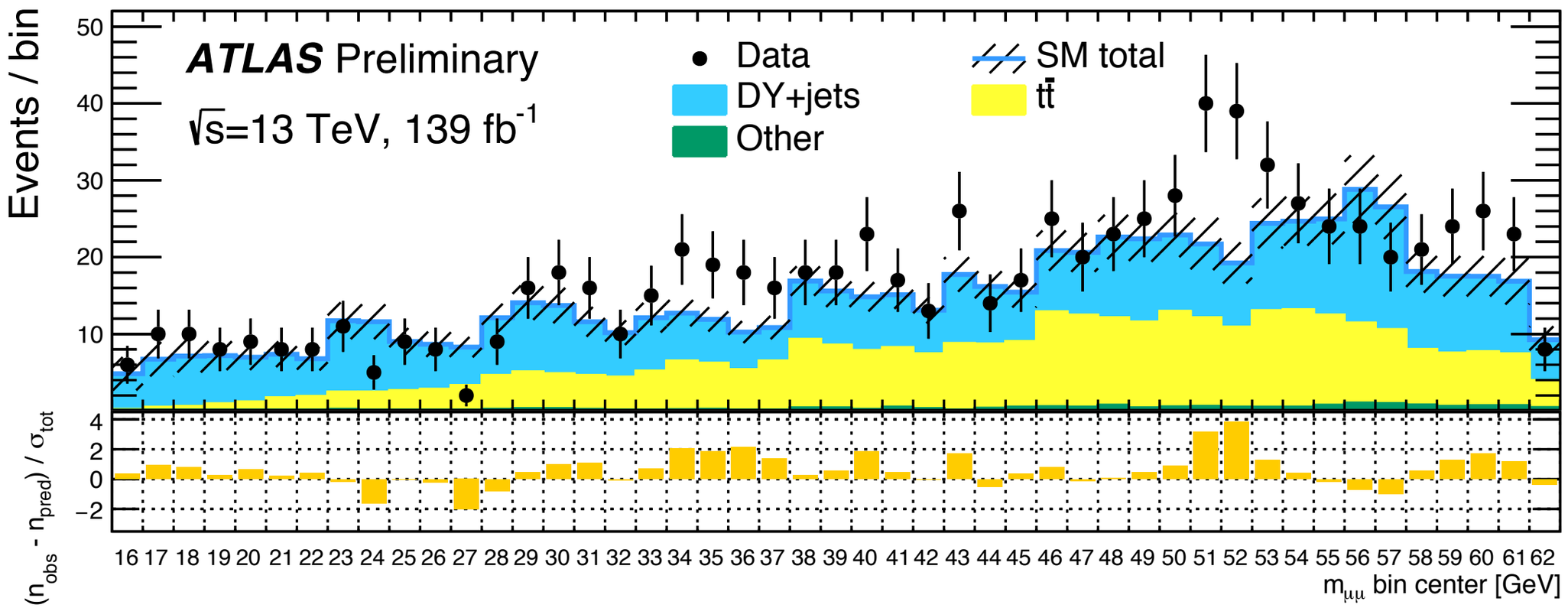
- Narrow resonance searched for in the $m_{\mu\mu}$ spectrum in bins defined as (m_a ± X) GeV:
  - X=1 GeV for $m_a \leq 45$ GeV
  - X=1.5 GeV for $m_a > 45$ GeV
- Train BDTs to separate the signal from the DY and ttbar backgrounds
- 12 BDTs trained in 8 GeV wide $m_{\mu\mu}$ windows, to exploit m_a kinematic dependence



H→aa→2μ2b

- Excess of 3.3σ (1.7σ) local (global) observed at m_a=52 GeV
- Large improvement in sensitivity wrt previous publication, due to increased luminosity and introduction of BDTs

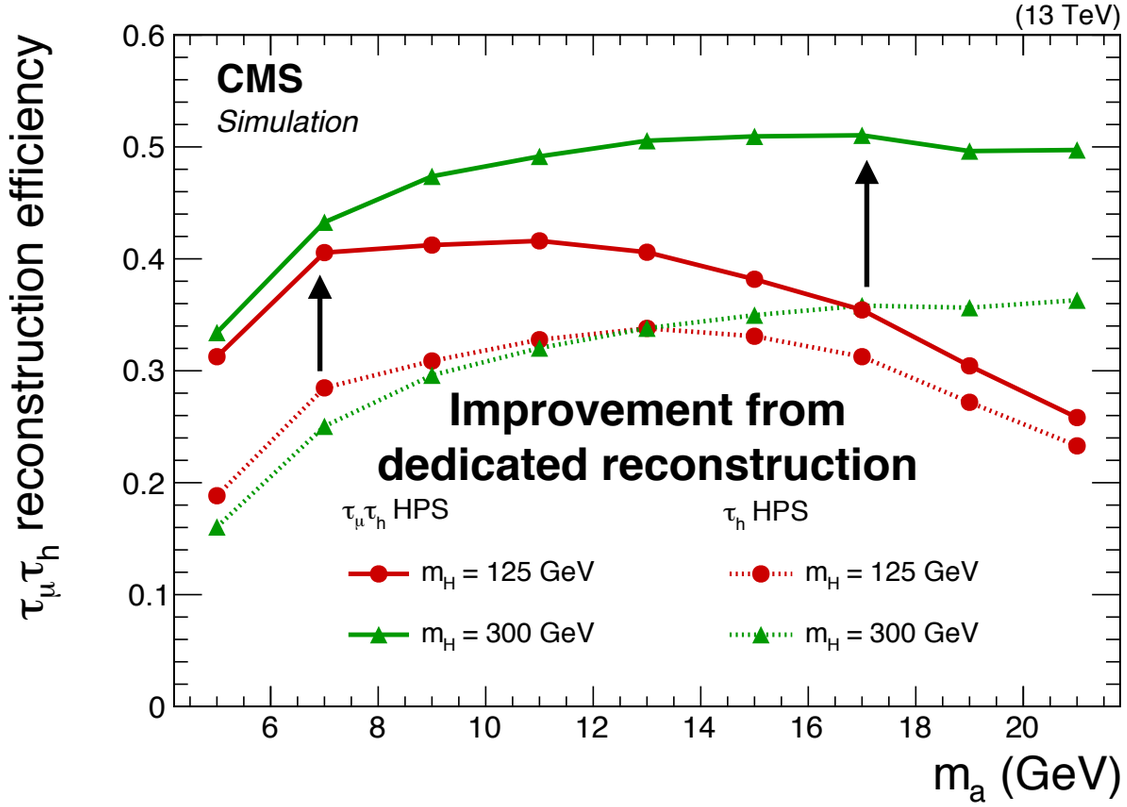




H→aa→2μ2τ boosted

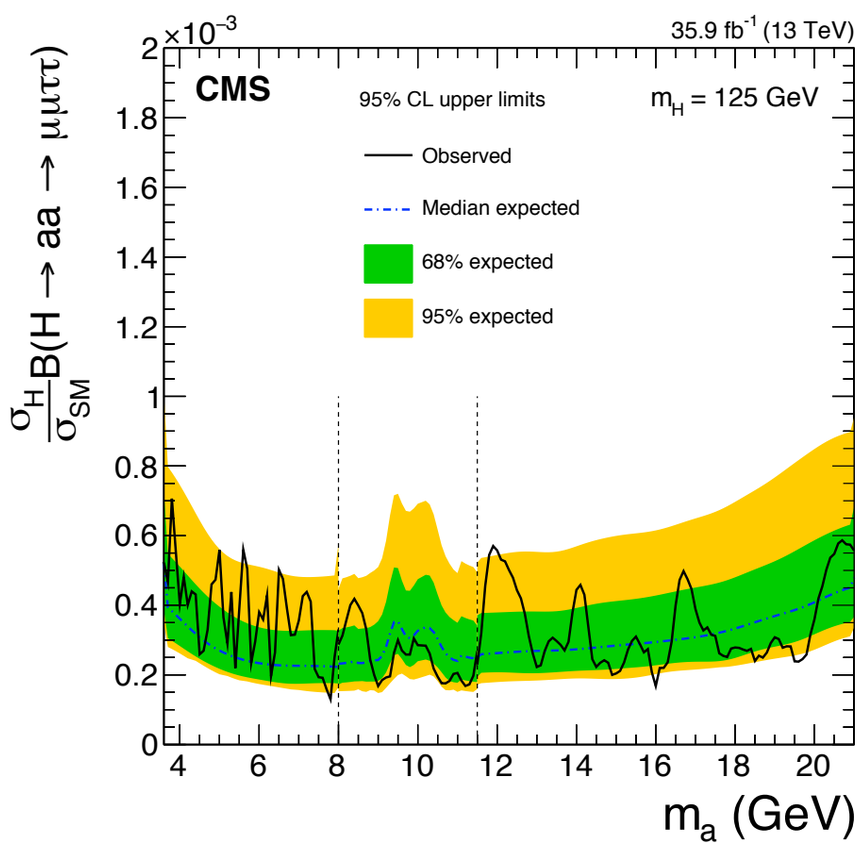
- Analysis focused on low-mass regime, boosted decay products are close-by
- Using $\tau_{had}\tau_{\mu}$ final state due to the high reconstruction efficiency and low misidentification
- Dedicated tau reconstruction algorithm, significant gain for the target topology:
  - muon removed from jet constituents used to seed the tau reconstruction
  - muon removed from tau isolation cone

- Background estimated from tight-to-loose method, measuring the rate of pass/fail isolation on the $\tau_{had}\tau_{\mu}$
- Measured in Zμμ+jets, applied on sideband region failing isolation
- Background constrained in a 2D unbinned fit to $m_{\mu\mu}$ vs $m_{\mu\mu\tau h\tau\mu}$ in 3 $m_{\mu\mu}$ fit ranges

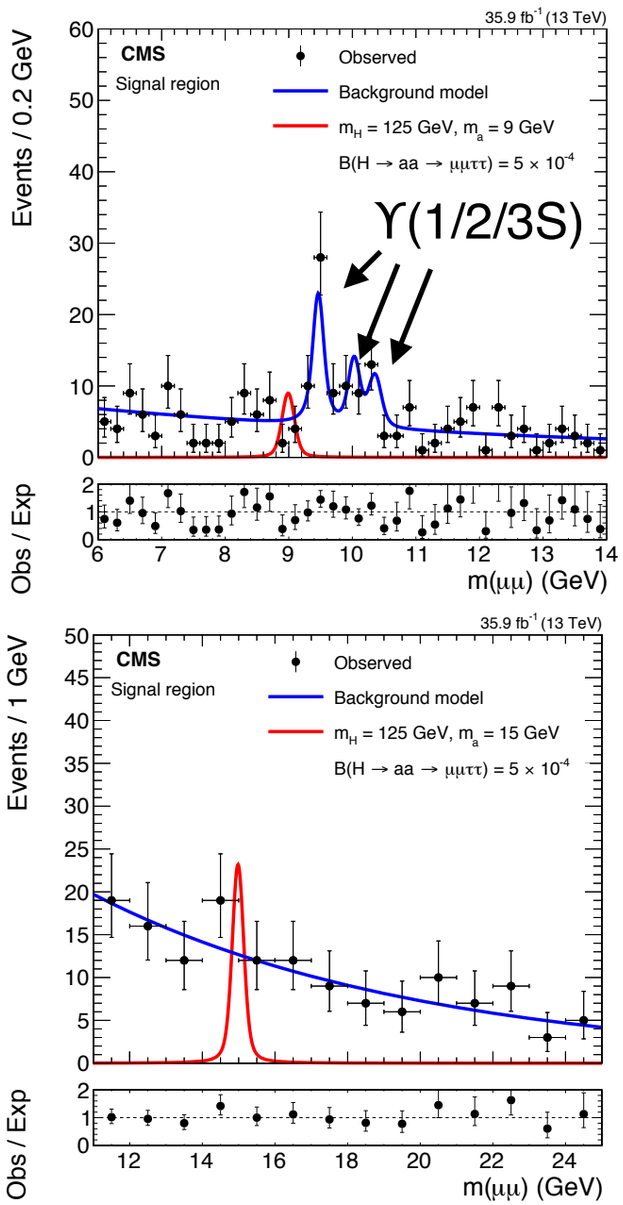


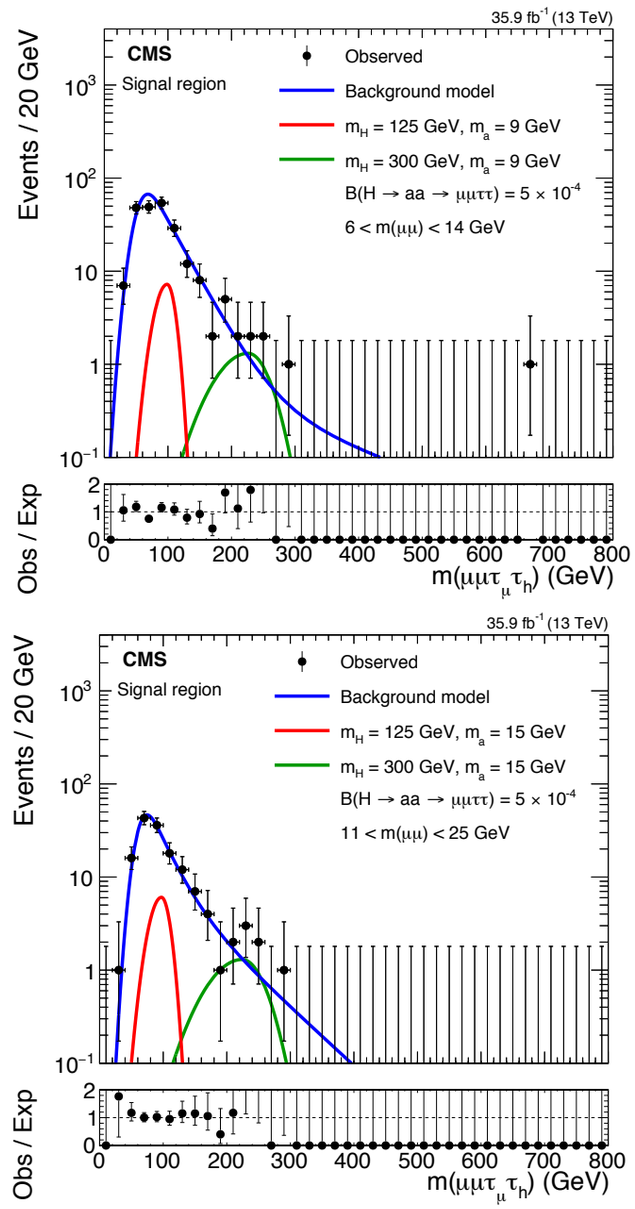
H→aa→2μ2τ boosted

- Leading uncertainty from the application of the tight-to-loose method in VR with anti-isolated muon
- No significant excess observed
- Similar sensitivity to <u>resolved analysis</u> in the overlapping mass range, but extends well below 15 GeV



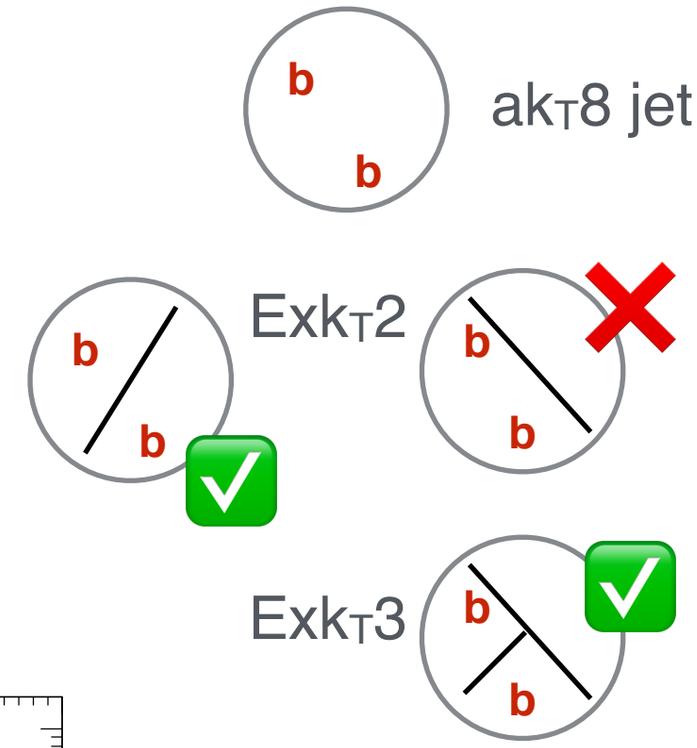
Projections of the 2D distribution in $m_{\mu\mu}$ and $m_{\mu\mu\tau\tau}$



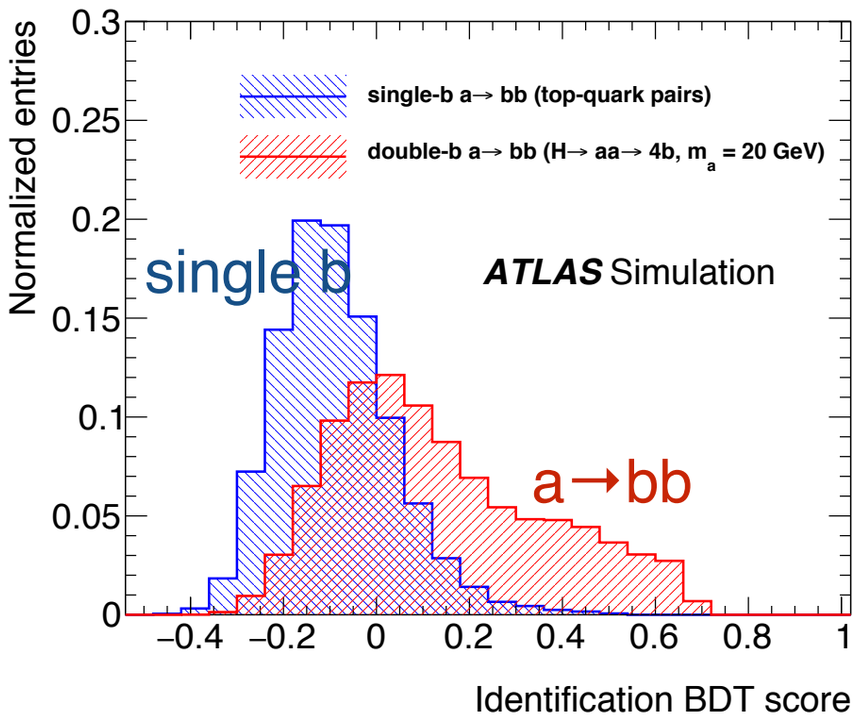


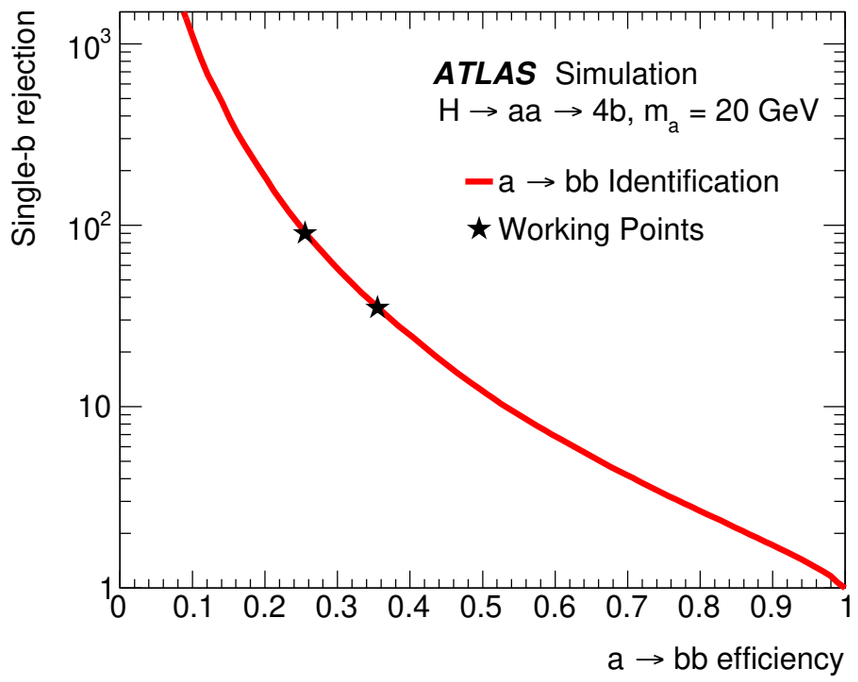
H→aa→4b low mass

- Analysis focused on low-mass regime, boosted decay products are close-by
- Dedicated identification algorithm for boosted a→bb decays:
  - Collection of ak$_T$4 jets are reclustered into ak$_T$8
  - The ghost-matched tracks to the ak$_T$8 jets are clustered using exclusive-k$_T$ into 2 or 3 jets
  - b-tagging algorithm is run on the exclusive-k$_T$ track jets
- b-tagging score and track-jet kinematics is fed to a BDT to distinguish a→bb decays from single-b jets



recovers wrong ExkT2 assignments



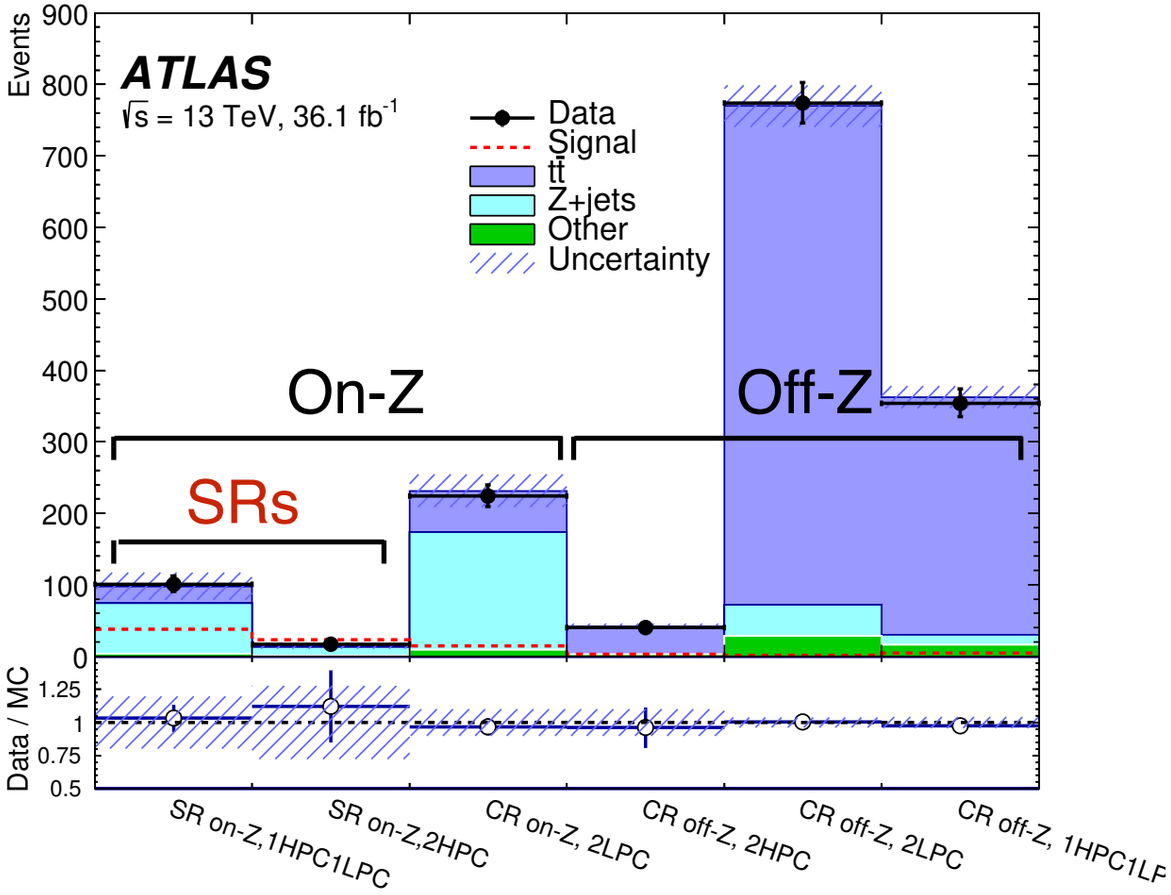


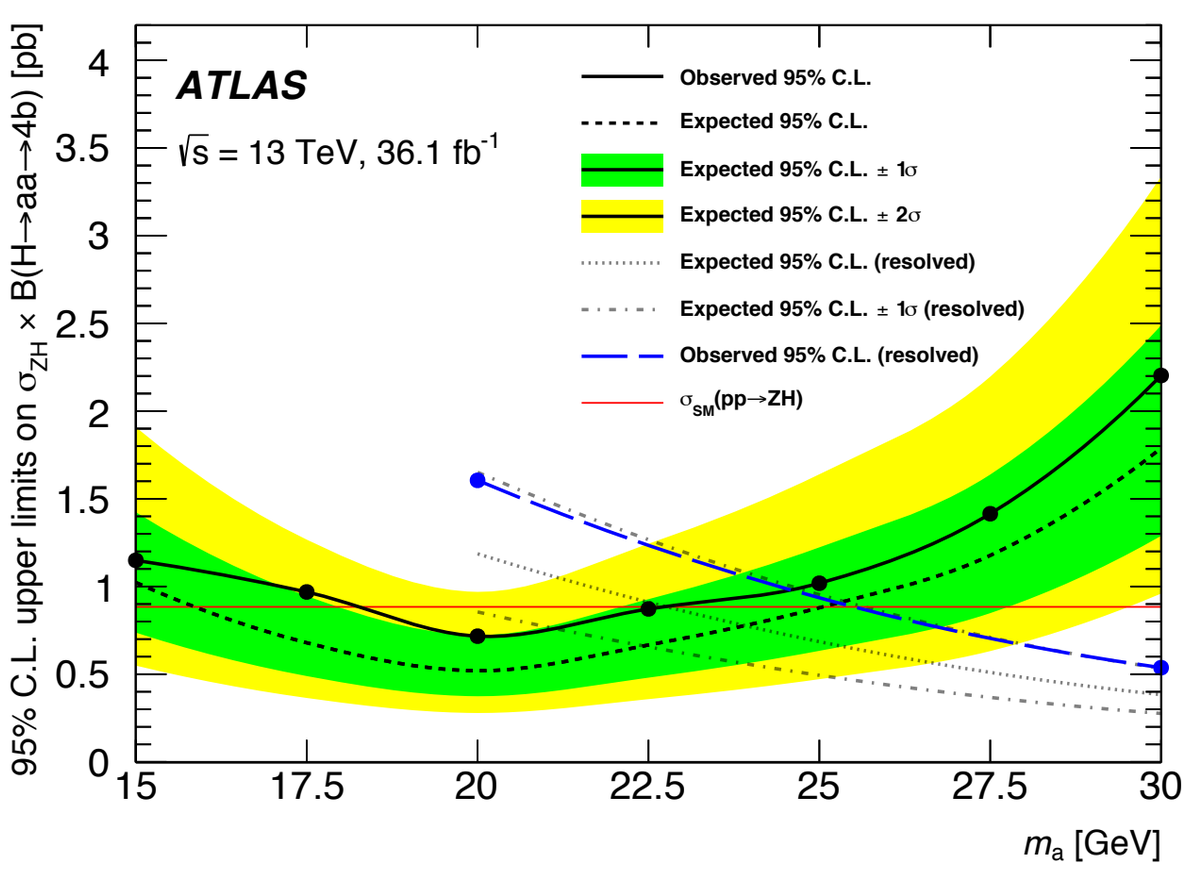
2 working points calibrated in data using g→bb events

H→aa→4b low mass

- Selection placed to ensure compatibility with H→aa→4b decay:
  - $-25\ \mathrm{GeV} < \Delta m^{a\to b\bar{b}} < 25\ \mathrm{GeV}$
  - $-40\ \mathrm{GeV} < m_{\mathrm{red}} < 20\ \mathrm{GeV}$

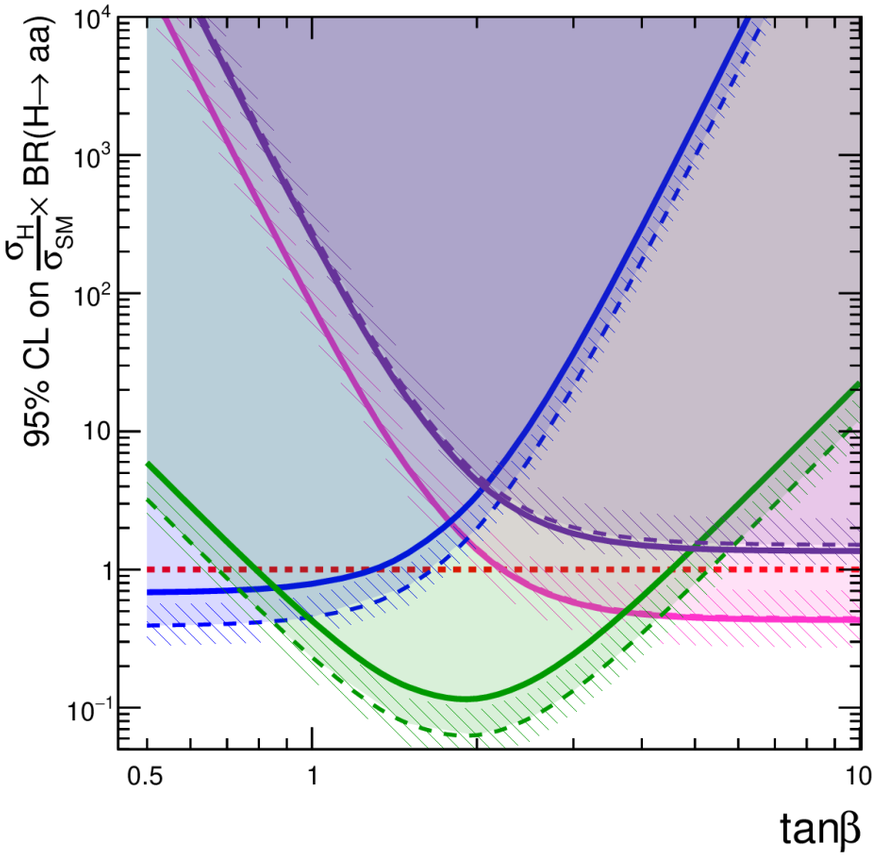
  (see backup for variable definition)
- Regions defined according to the number of loose and tight bb candidates, and the dilepton mass being inside/outside the Z mass window
- Complementary sensitivity at low mass wrt the resolved analysis

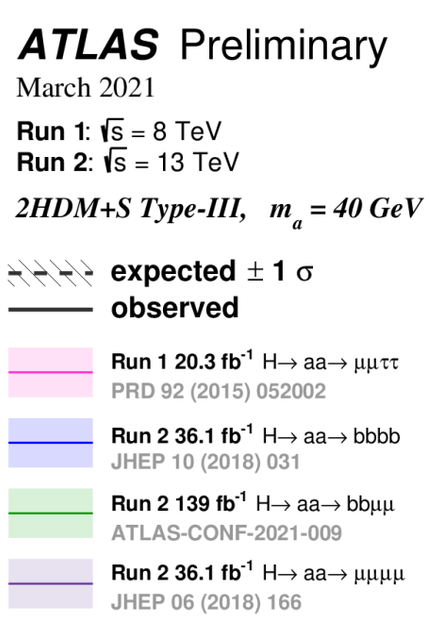


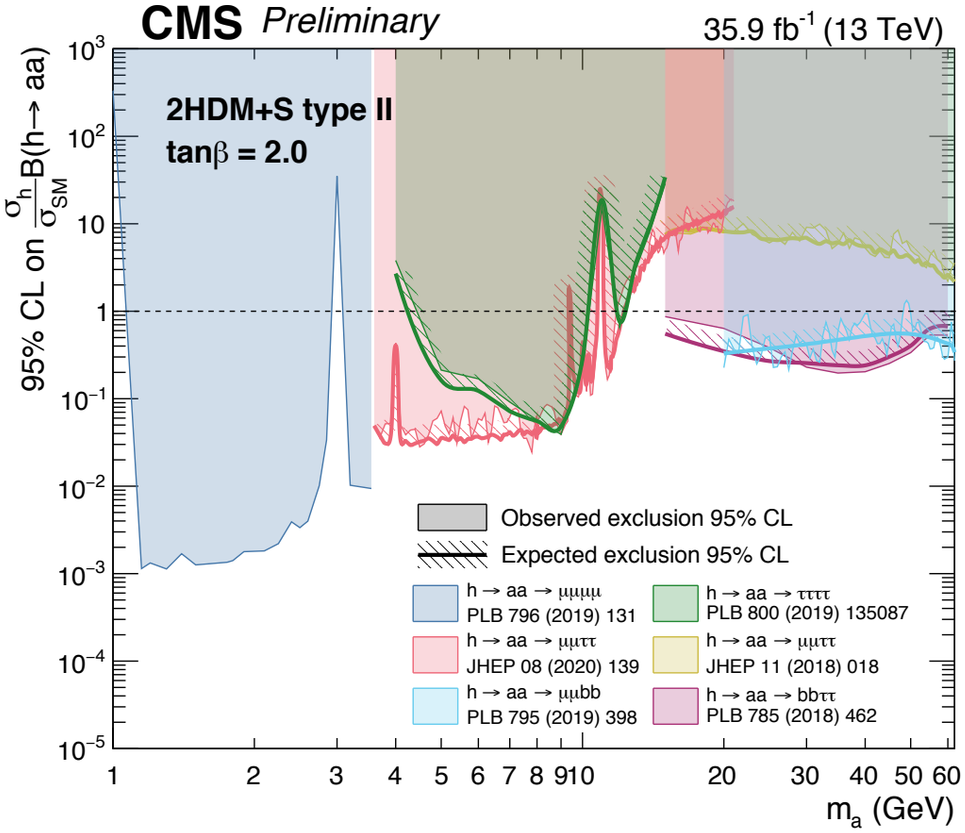


Conclusions

- Extensive program in both ATLAS and CMS searching for BSM Higgs decays
- Only covered some representative examples, please see backup for a more exhaustive list
- Available summary plots from ATLAS and CMS, showing the complementarity of analyses across the mass range, and also as a function of tan β







Backup

Exotic Higgs results

- In bold, covered in these slides

	ATLAS	CMS
H→ 2μ2τ boosted		**36 fb-1**
H→ 2μ2τ		36 fb-1
H→ 2μ2track		36 fb-1
H→ 2μ2b	**139 fb-1**	36 fb-1
H→ 2b2τ		36 fb-1
H → 4l resonances	36 fb-1	36 fb-1
VBF H→ $\gamma\gamma_D$		36 fb-1
H → 4b	36 fb-1	
H → 4b low mass	**36 fb-1**	
H → bb+MET	**139 fb-1**	
H → Za→llj	139 fb-1	
H → γγ jj	139 fb-1	
H→ eτ/μτ	36 fb-1	**137 fb-1**
H → eμ	139 fb-1	

H→aa→4b low mass

- Selection placed to ensure compatibility with H→aa→4b decay:

$$\Delta m^{a\to b\bar{b}} = m^{a_1} - m^{a_2}, \qquad -25\text{GeV} < \Delta m^{a\to b\bar{b}} < 25\text{GeV}$$

$$m_{\text{red}} = (m^{a_1,a_2} - m_H) - (m^{a_1} + m^{a_2} - 2m_a), \quad -40\text{GeV} < m_{\text{red}} < 20\text{GeV}$$