



Exotic decays of the Higgs bosons

Cristiano Sebastiani



UNIVERSITY OF
LIVERPOOL

Intro

- Overview of recent searches by the ATLAS experiment for BSM decays of the Higgs bosons to:
 - lepton-flavor-violating decays
 - hidden-sector states that do not interact under Standard Model gauge transformations
 - rare decays
- Current constraints from global fits and searches to SM Higgs couplings leave room for New Physics
- LFV observed in neutrino oscillation but not in charged LFV yet... suppressed in SM may be enhanced in BSM Higgs decays
- Hidden sectors present a huge model-space: identification of general enough benchmarks allow for a systematic programme of searches (at colliders and elsewhere)

ATLAS has a great potential to discover dark sectors and unveil their structure with the finalisation of Run2 searches and the new Run3 programme!

Higgs to BSM

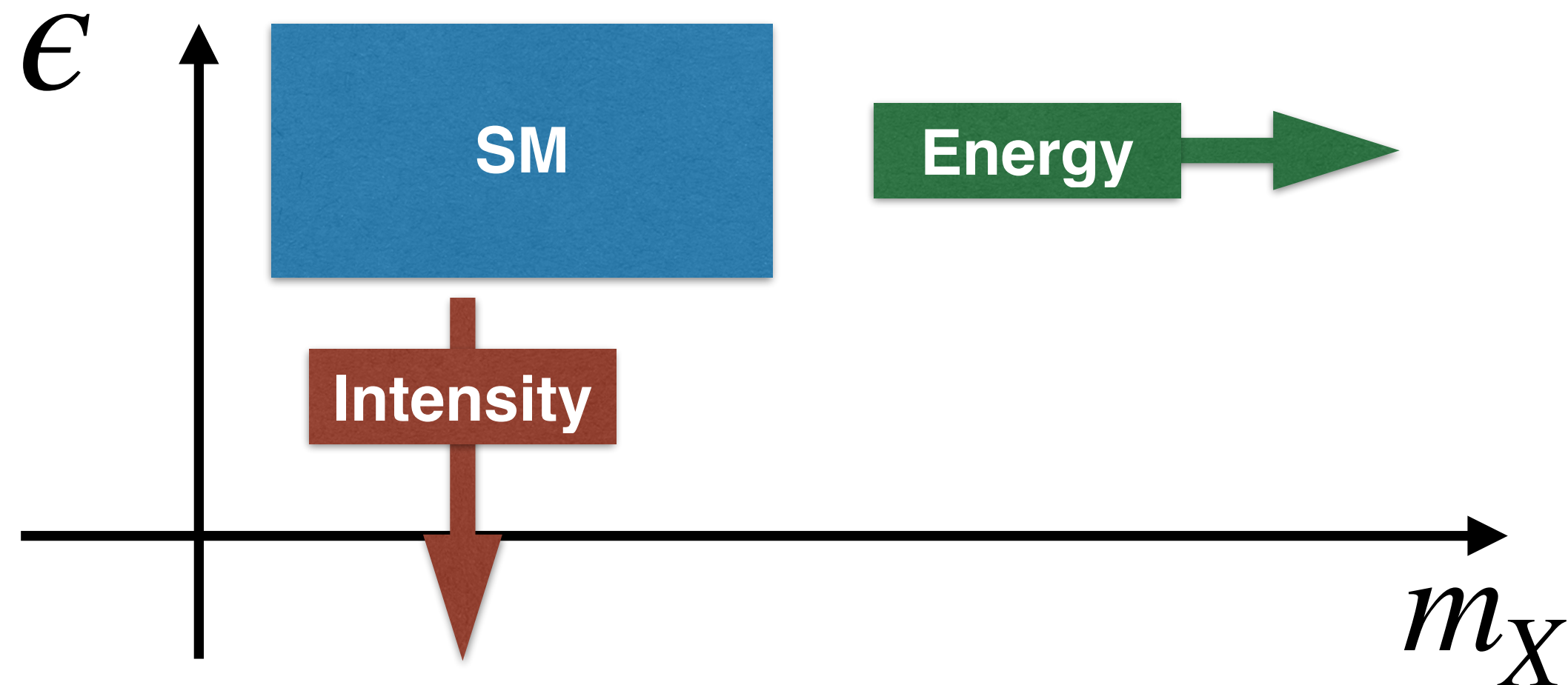
Access New Physics through the Higgs boson: LFV decays, new mediators (light bosons, HNL, ALPs)...

Pseudoscalar portal: $\delta_\mu \bar{\psi} \gamma^\mu \gamma^5 \psi$, $\frac{a}{f_a} F'_{\mu\nu} \tilde{F}^{\mu\nu}$ axions/ALPs

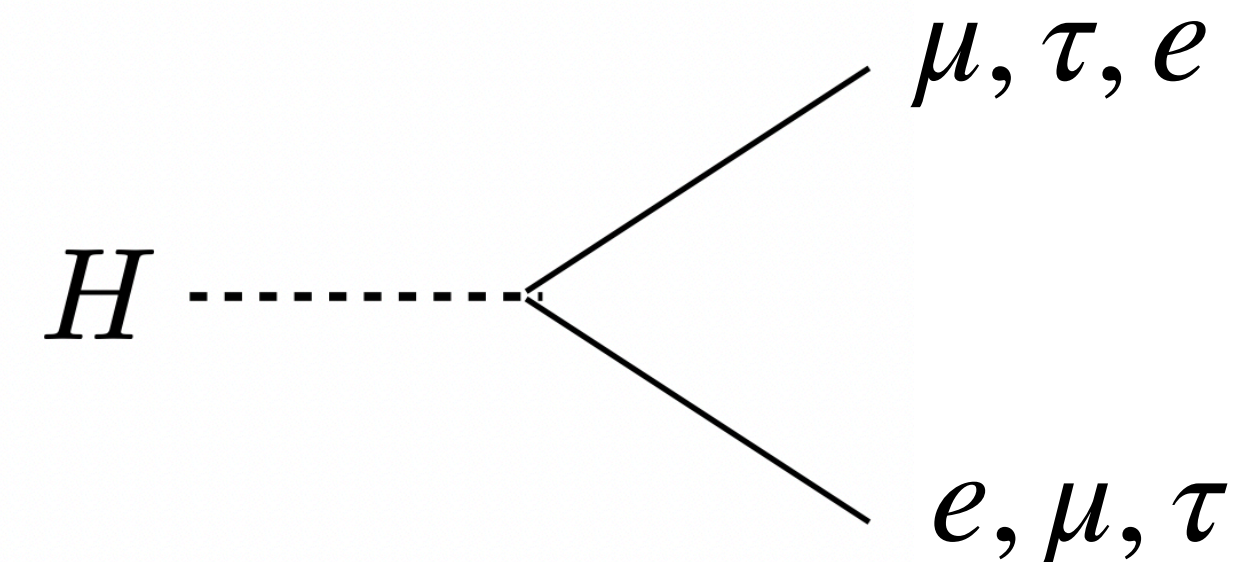
Vector portal: $\epsilon F^{\mu\nu} F'_{\mu\nu}$ 'dark' vector boson (A' , γ_d , Z_d) which mixes with SM photon

Higgs portal: $\kappa H^2 S^2 + \mu H^2 S$ 'dark' scalar boson (S)

Neutrino portal: $\kappa(HL)N$ no more sterile neutrino



Extensions with at least two sources of EWSB can lead to charged LFV, like MSSM with LFV soft terms and vector like fermions



List of analyses

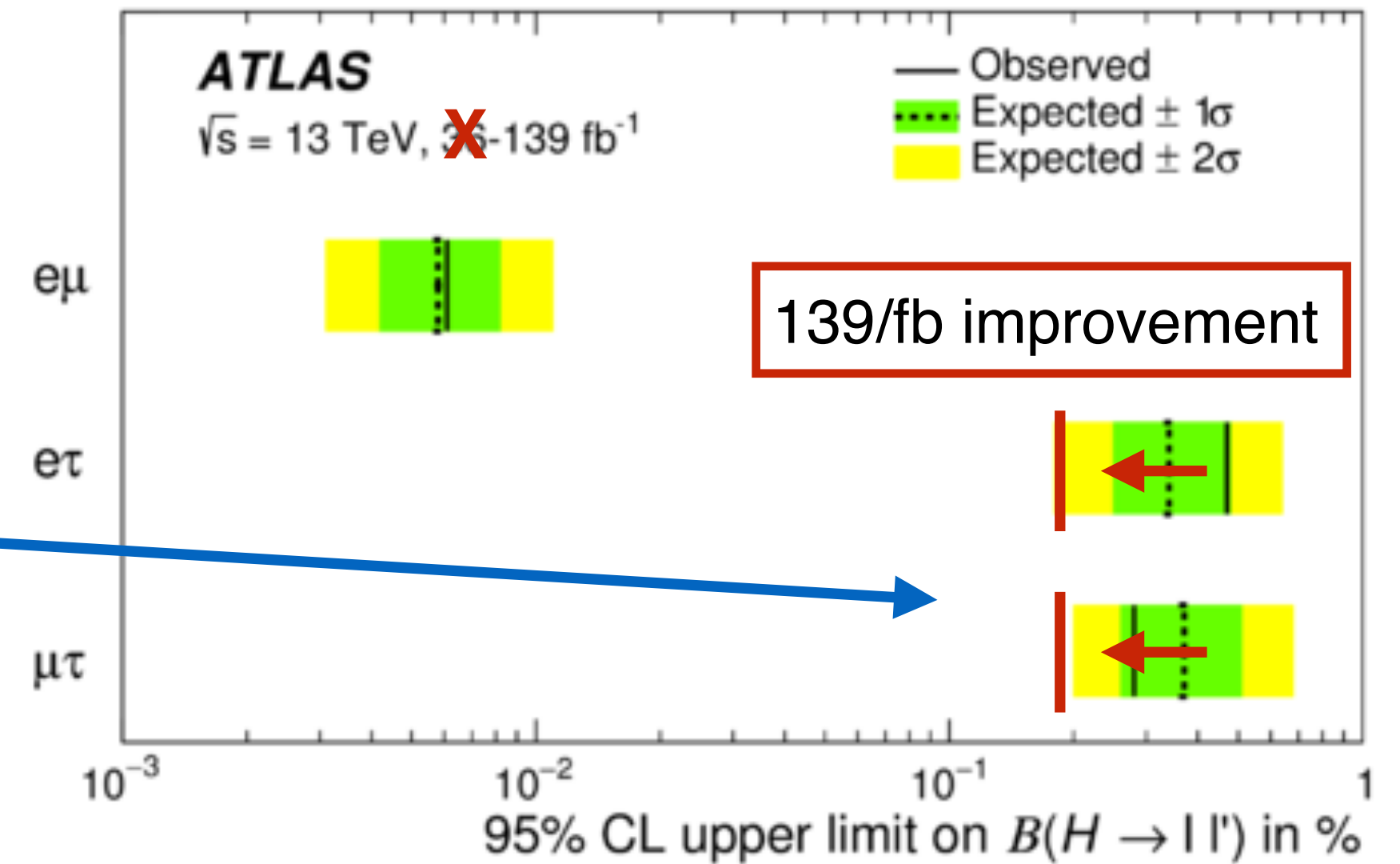
Today will cover the following prompt analyses

LFV decays

- $H \rightarrow e\tau/\mu\tau$ ([NEW!](#))
- $H \rightarrow e\mu$

BSM decays

- $ZH, H \rightarrow \gamma\gamma_d(\text{invisible})$ ([NEW!](#))
- $H \rightarrow bb + \text{MET}$
- $H \rightarrow 2b2\mu$
- $H \rightarrow XX/ZX \rightarrow 4l$



For massless γ_d

		Observed	Expected	
CMS	VBF	3.5%	2.8%	(arXiv)
CMS	ZH	4.6%	3.6%	(arXiv)
ATLAS	VBF	1.8%	1.7%	(arXiv)
ATLAS	ZH	2.3%	2.8%	

H \rightarrow e τ / $\mu\tau$

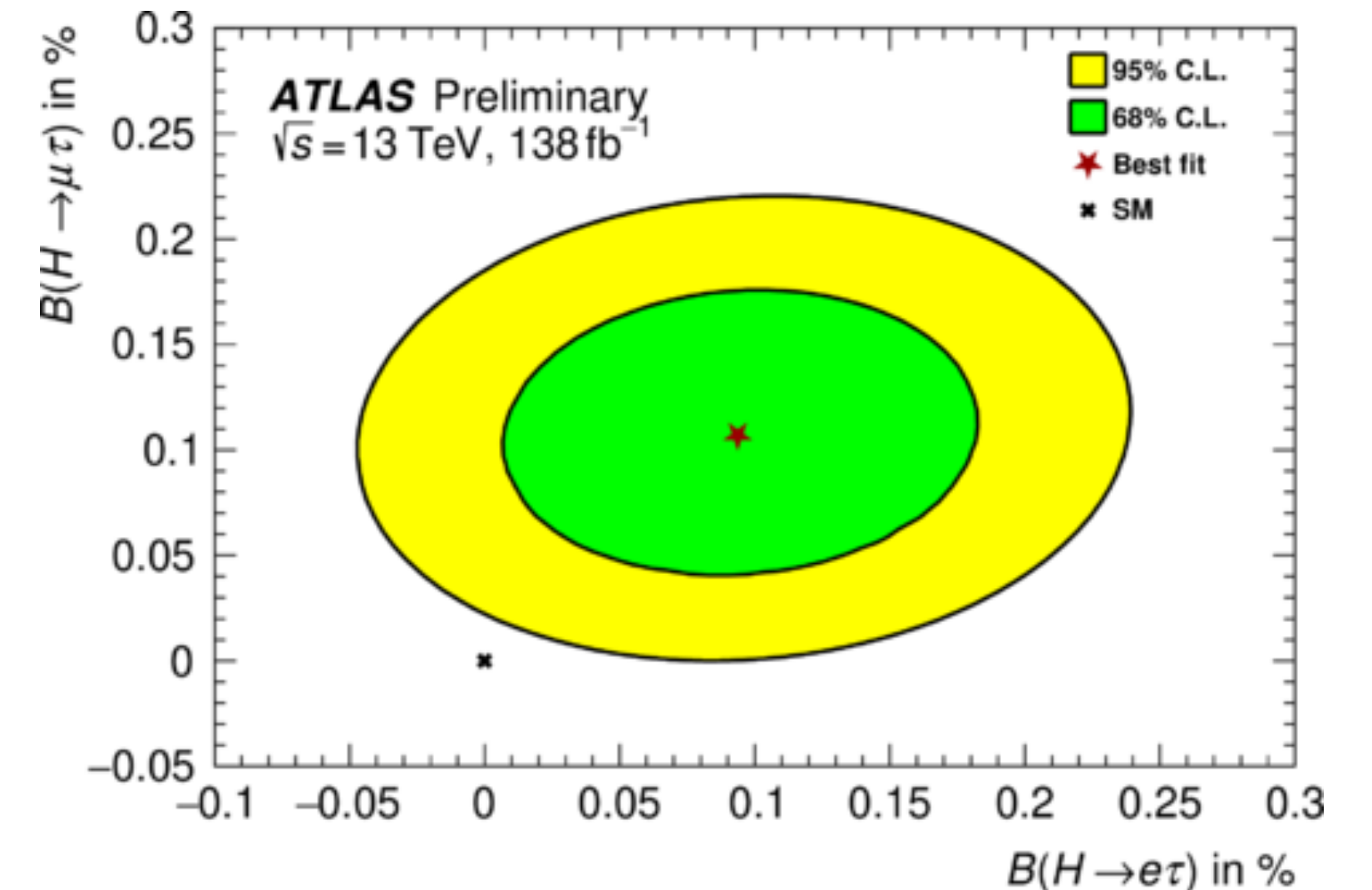
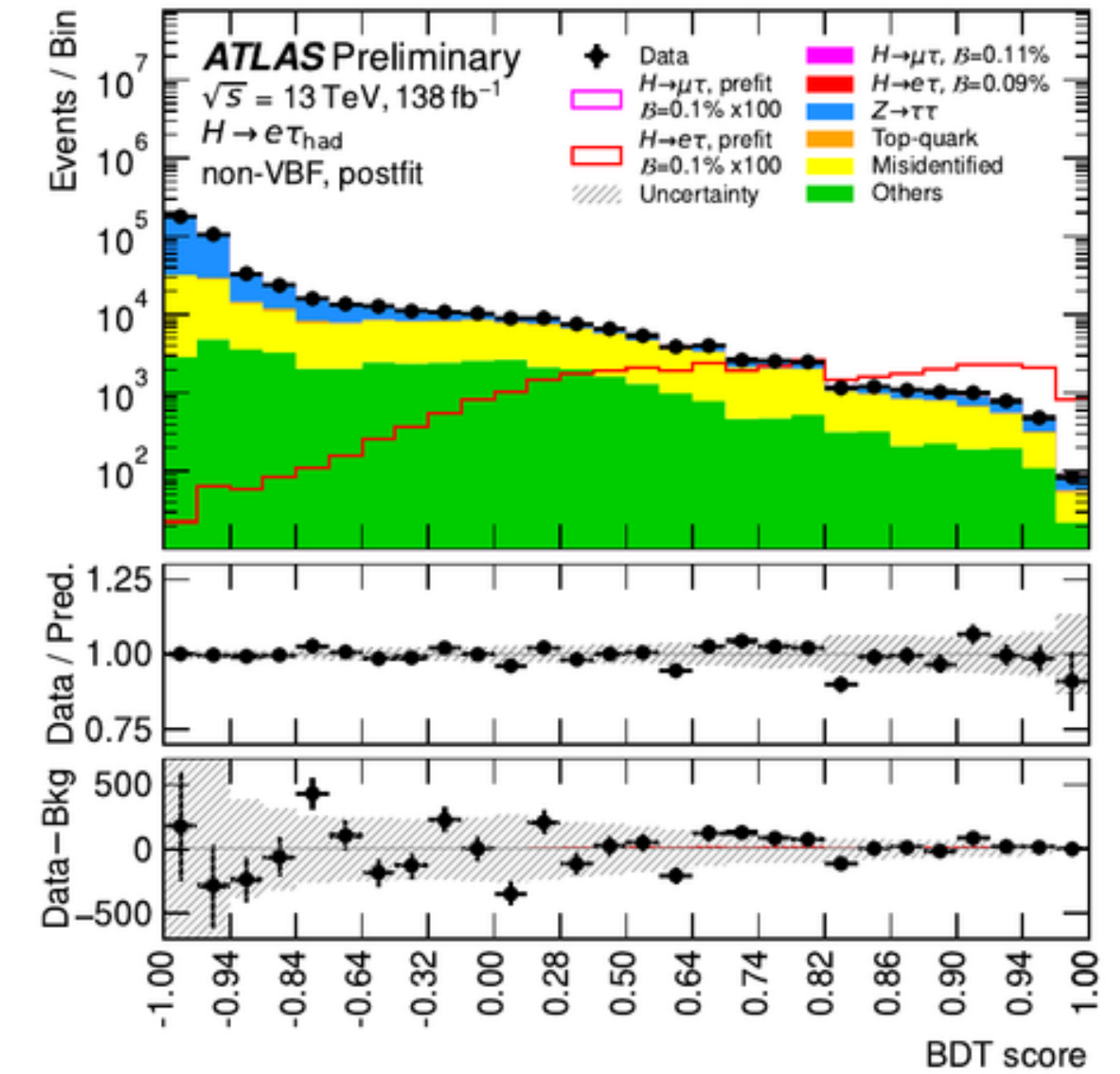
LFV searches for $H \rightarrow e\tau$ and $H \rightarrow \mu\tau$ signals using the complete Run2 dataset:

- Two channels, lep-lep and lep-had are used and they are further categorised into VBF and non-VBF regions, with different background estimations:
 - **MC-template method**
 - **Symmetry method** (main bkg in one channel estimated using the data yields in the other channel)
- MVA score as final discriminant

$$B(H \rightarrow e\tau) < 0.19\% \text{ (0.11\%)}$$

$$B(H \rightarrow \mu\tau) < 0.18\% \text{ (0.09\%)}$$

More details in Kieran Robert Amos [talk](#)

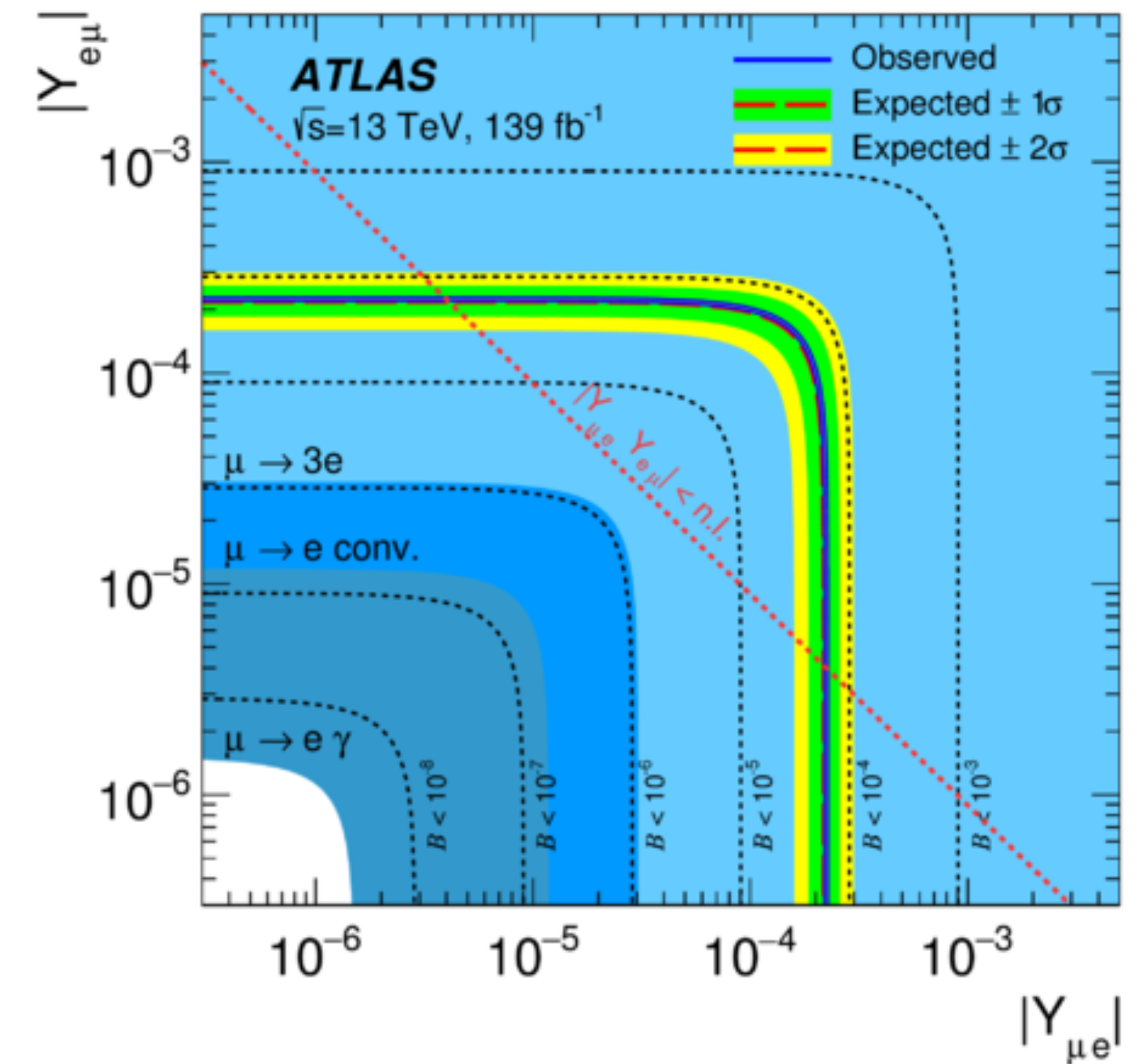
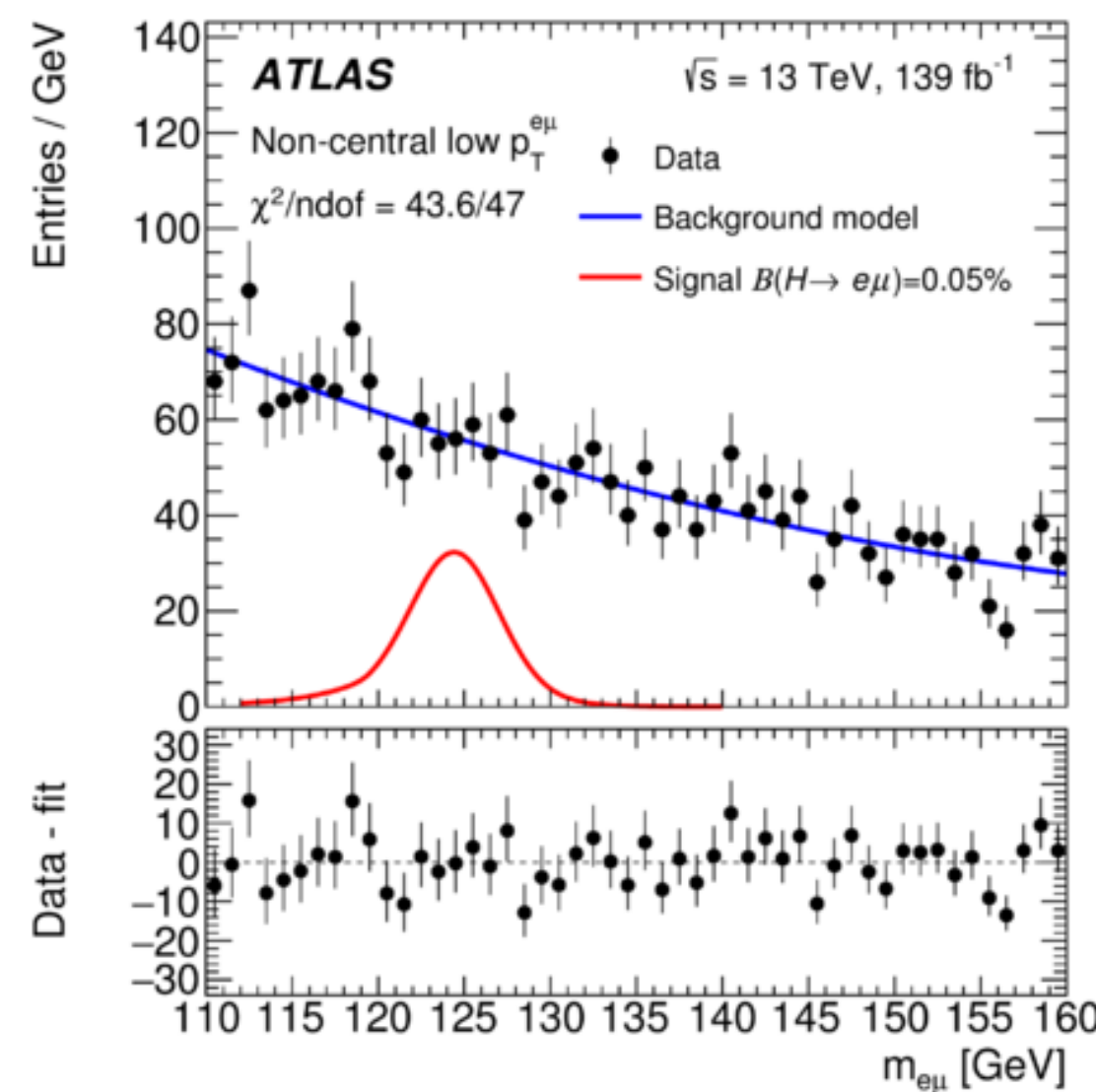
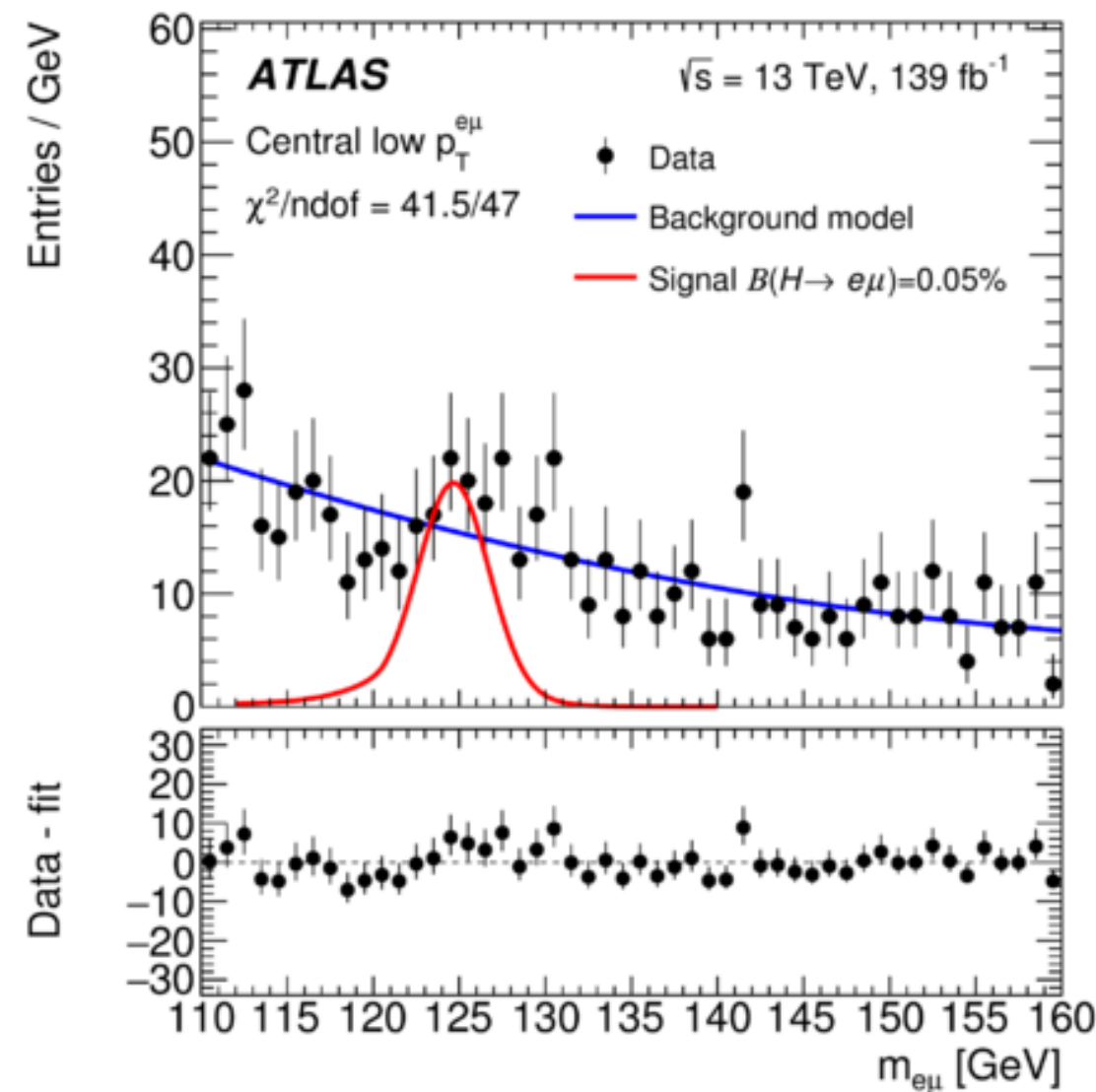


Compatibility with SM within 2.17sigma

H \rightarrow $e\mu$

First ATLAS result for LFV $H \rightarrow e\mu$ decay:

- Peak search in $H(e\mu)$ invariant mass distribution
 - Smooth falling background determined with analytic functions constrained in the sidebands
- Eight SR: VBF, low- p_T lepton, central/non-central x dilepton p_T (low, mid, high)
- Observed (exp) upper limit $BR(H \rightarrow e\mu) < 6.2 \times 10^{-5}$ (5.9×10^{-5})



Limits on the branching ratio interpreted in flavour violating Yukawa couplings $Y_{e\mu}$ and $Y_{\mu e}$

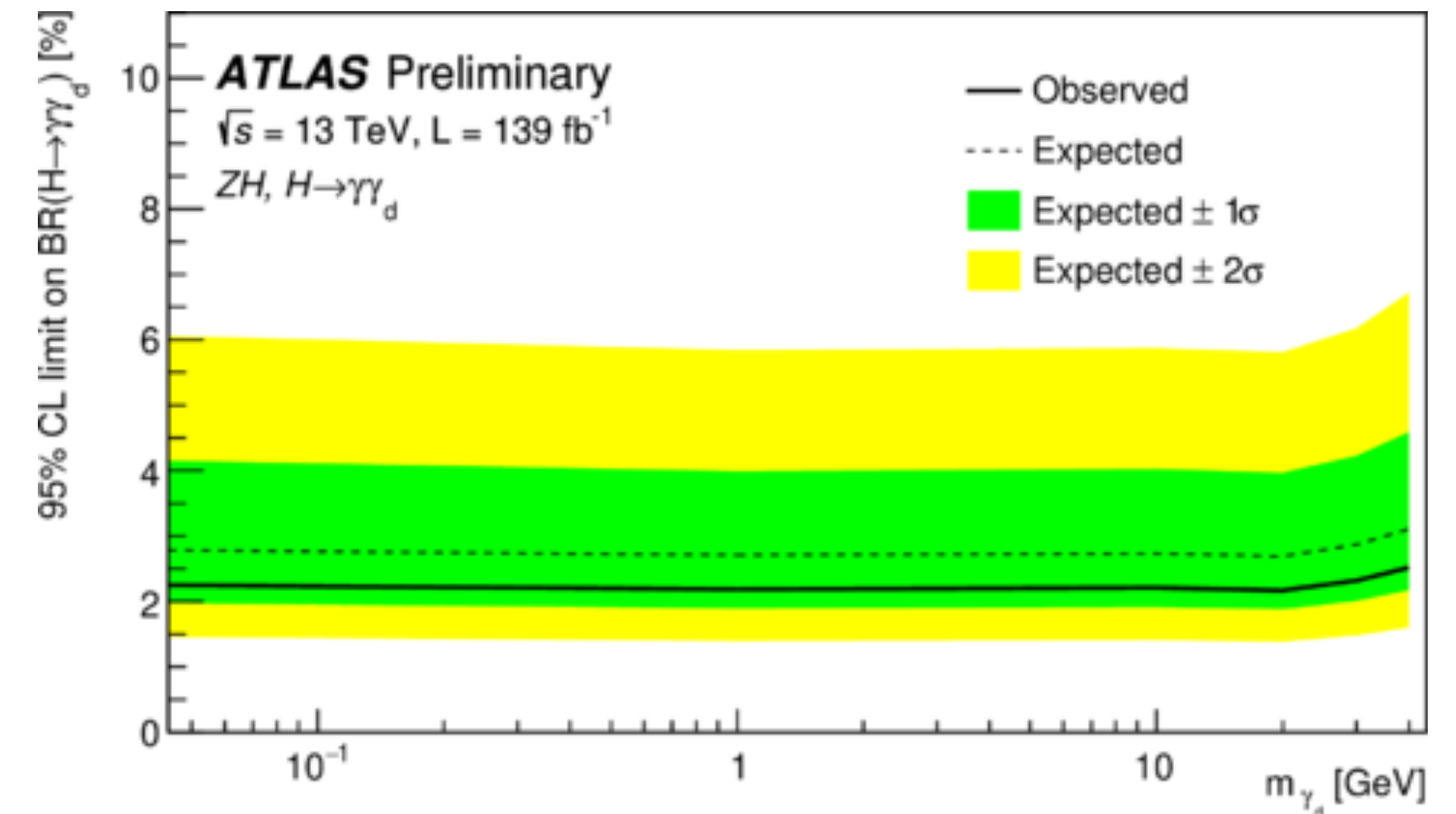
ZH, H → $\gamma\gamma_d$ (inv)

Dedicated search for BSM Higgs to invisible decay in ZH production, SM invisible decay is much smaller than our sensitivity (Br ~0.1%)

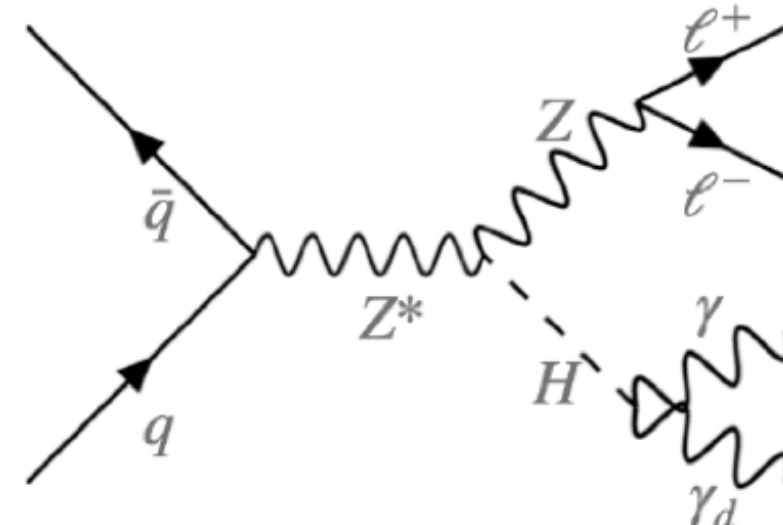
[ATLAS-CONF-2022-064](#)

Search for H → $\gamma\gamma_d$, γ_d → invisible

- Main backgrounds estimated through data-driven techniques and BDT as discriminant variable
- Exclusion limits are provided on Br(H → $\gamma\gamma_d$) assuming the SM Higgs boson gg/qq ZH production cross-section



Clean final state where one of the two photon mixes with a dark photon $\ell + \gamma + \text{MET}$



For massless γ_d

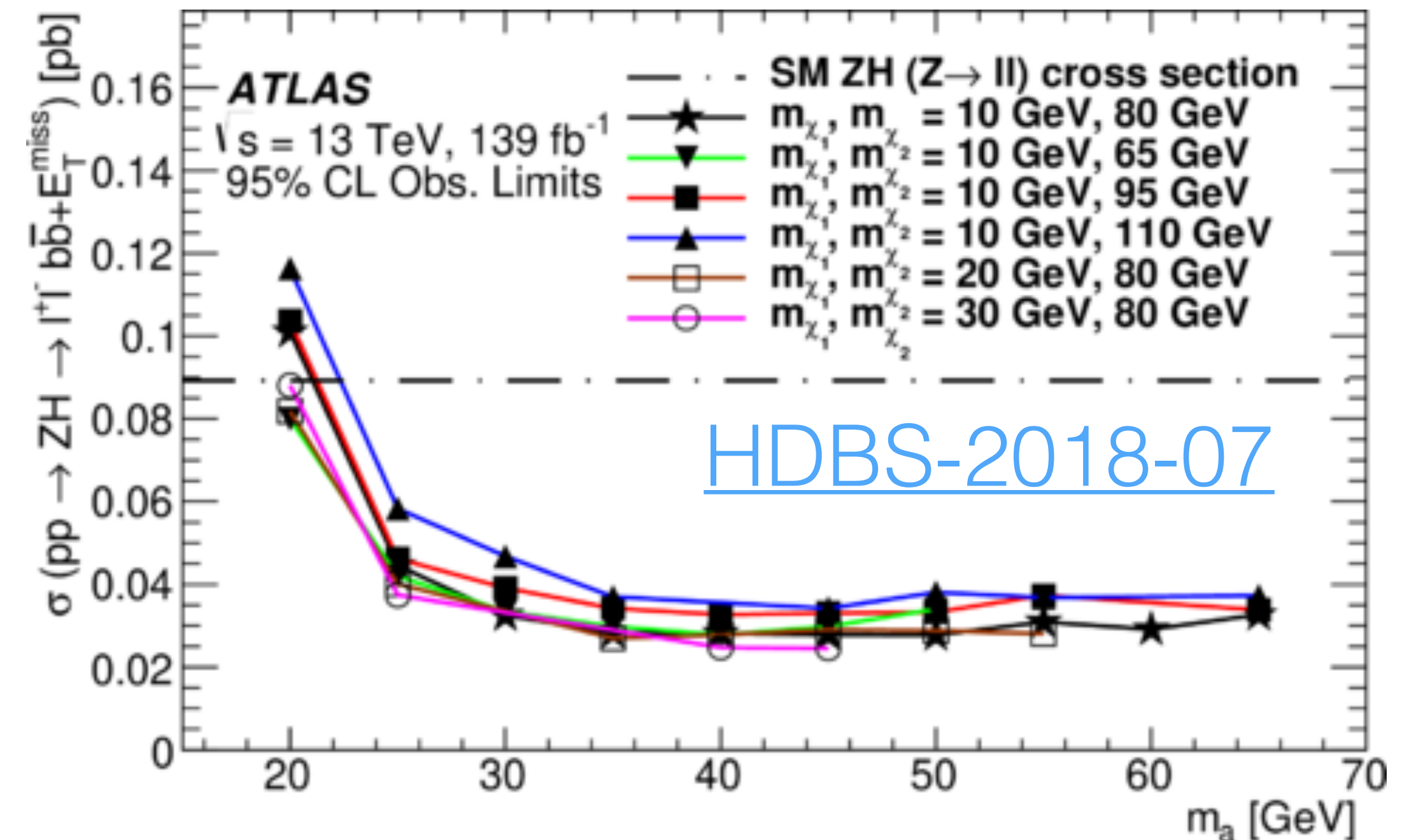
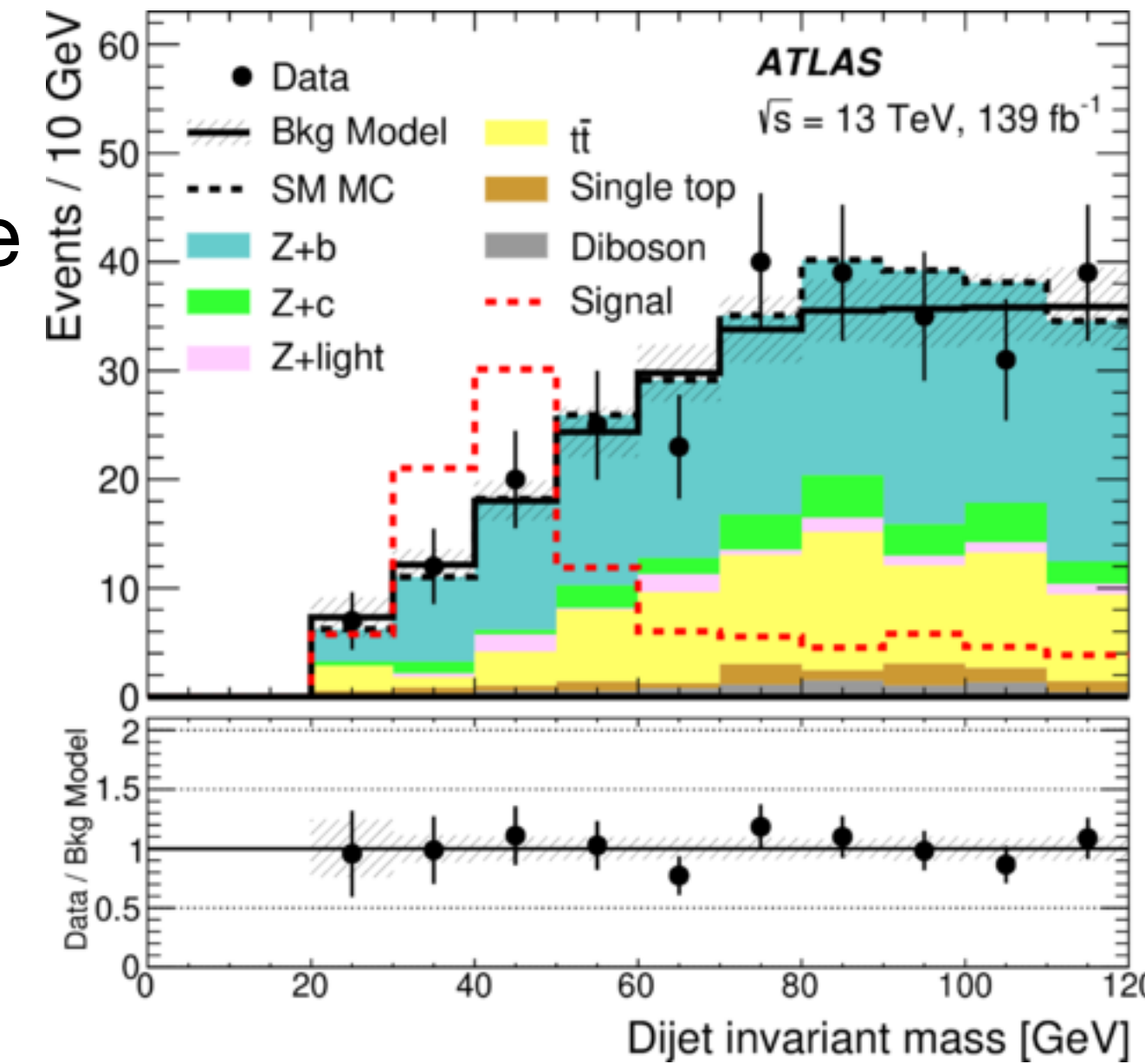
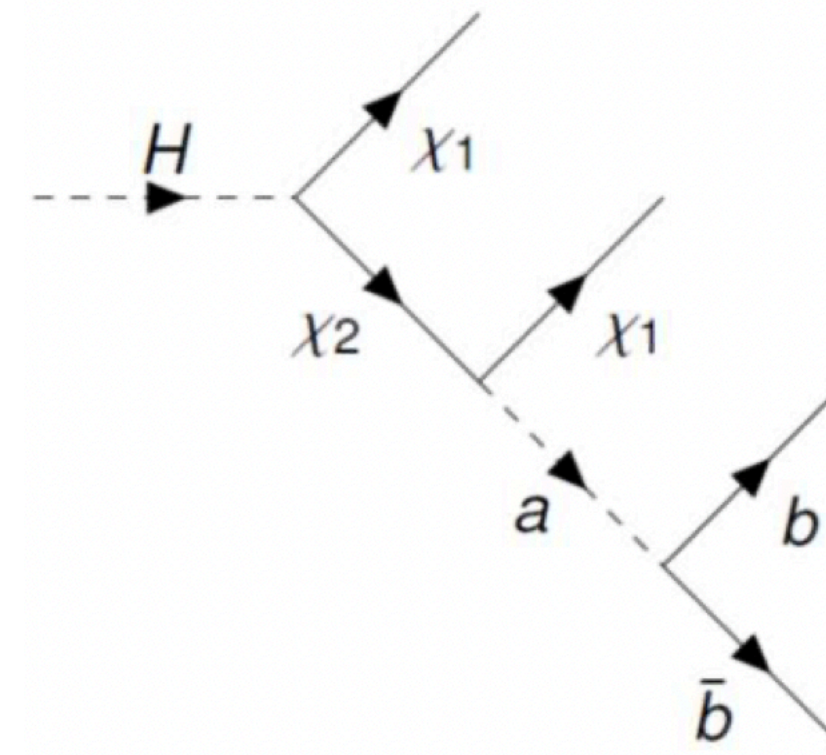
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H \rightarrow bb+MET

Searches for rare and exotic decays of the Higgs boson into bbar + MET final state

Exploit ZH production to trigger and target high MET region ($>100\text{GeV}$):

- NMSSM models and axions searches above b-pair mass threshold
- Scan dijet invariant mass, templates for main backgrounds (Z+HF and ttbar) taken from CRs
- First direct search for this process at the LHC: upper limit on BR ($H \rightarrow \chi_2\chi_1$) of 31% in the region of highest sensitivity

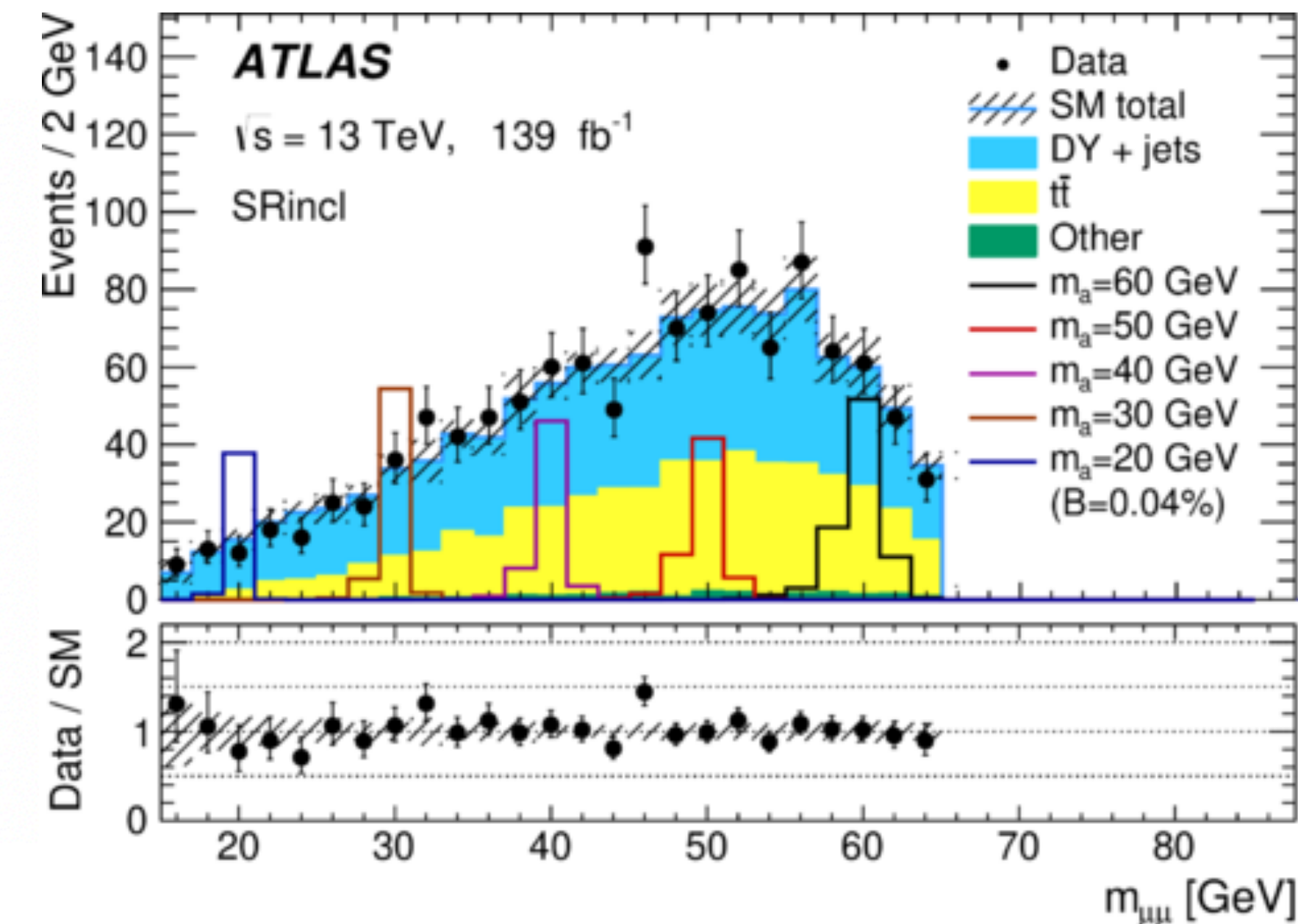
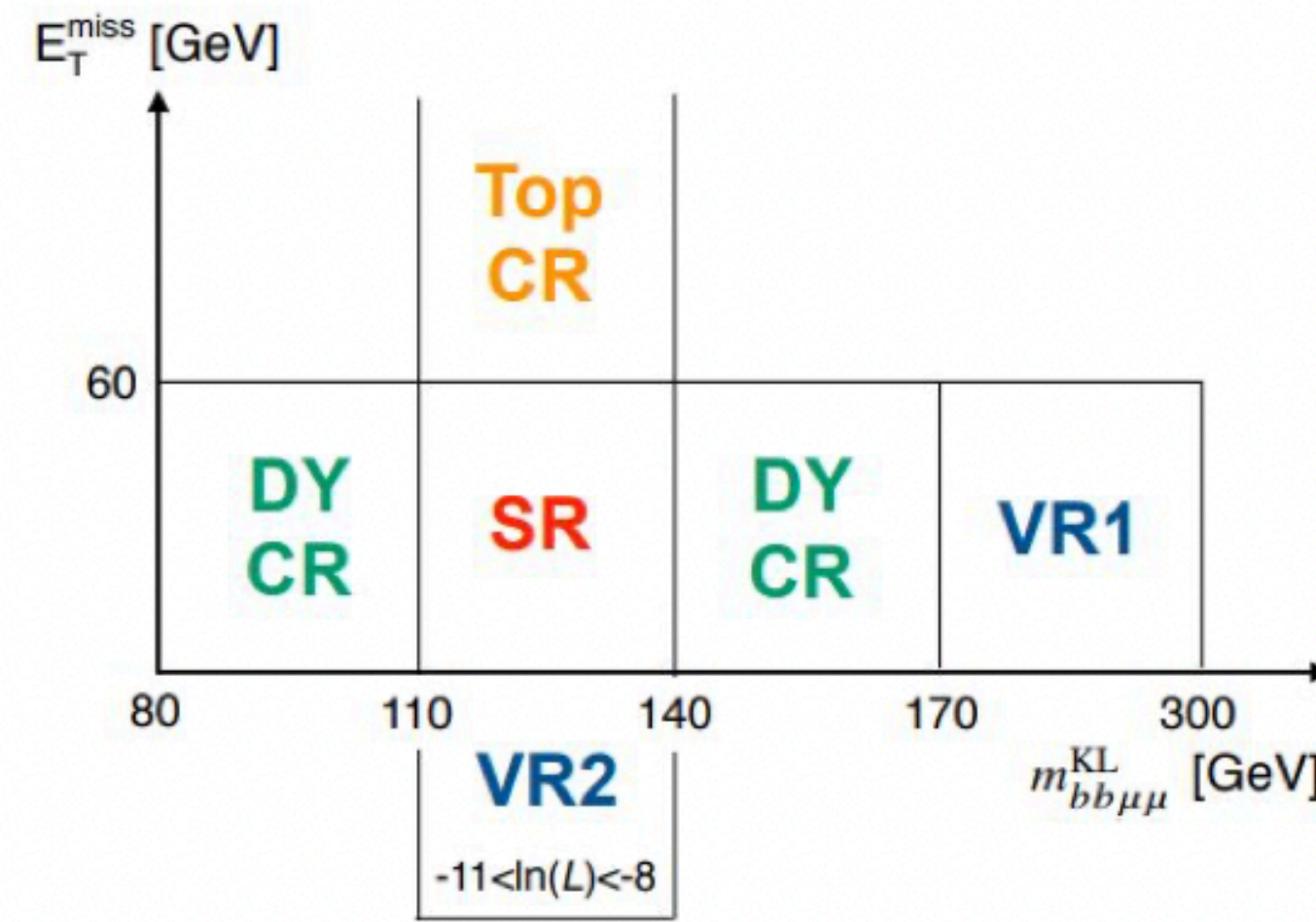
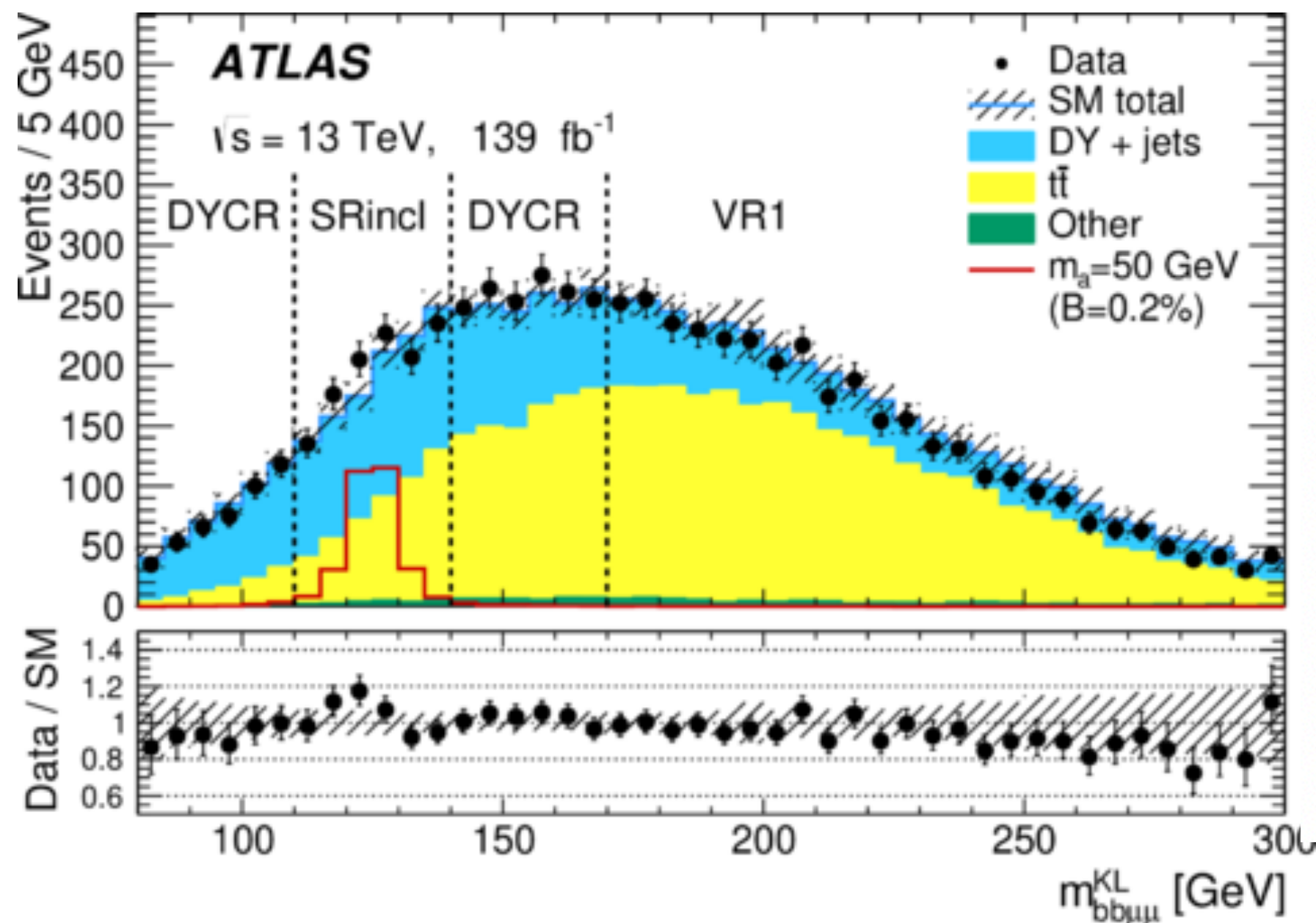
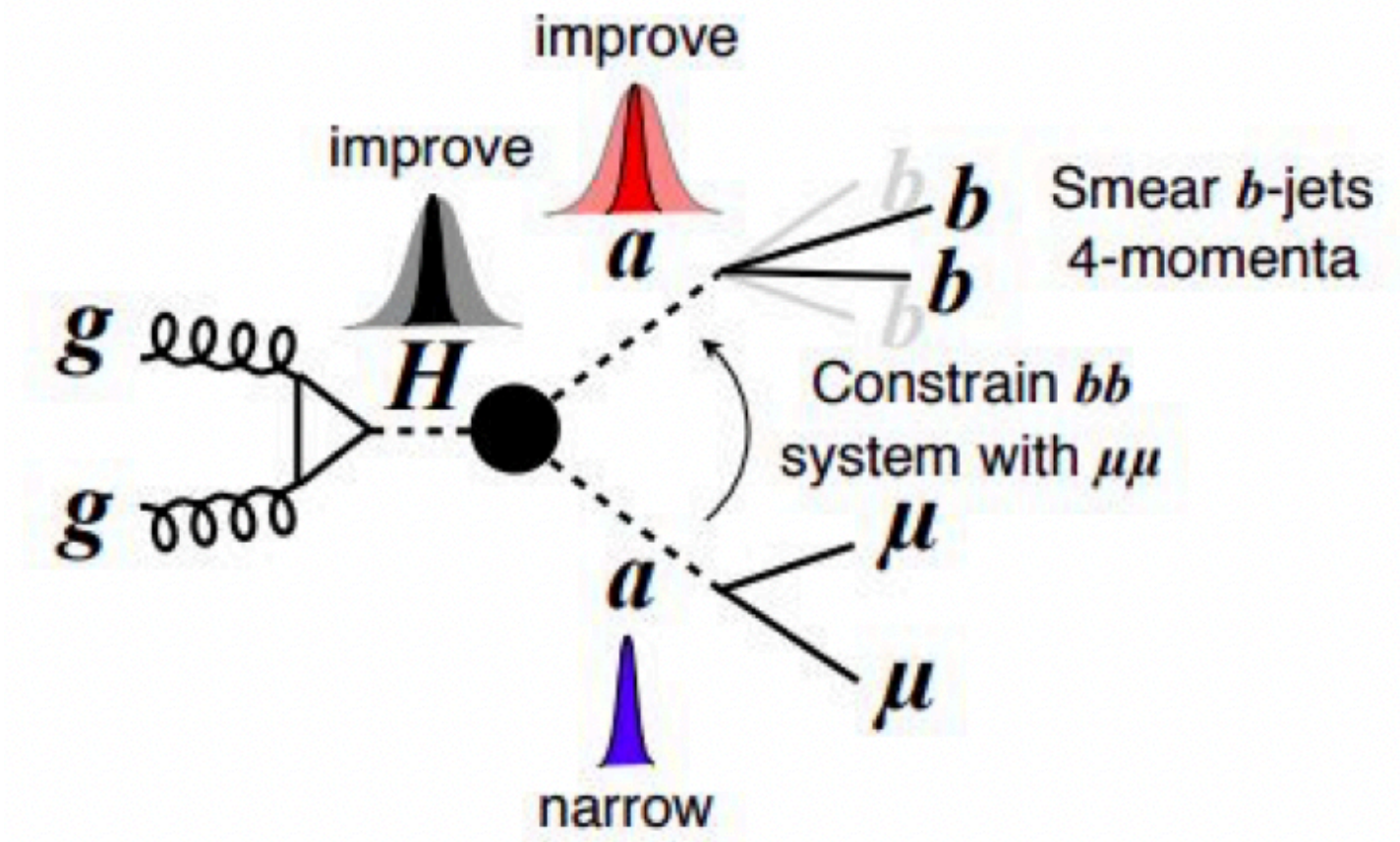


$H \rightarrow 2a \rightarrow 2b 2\mu$

HDBS-2021-03

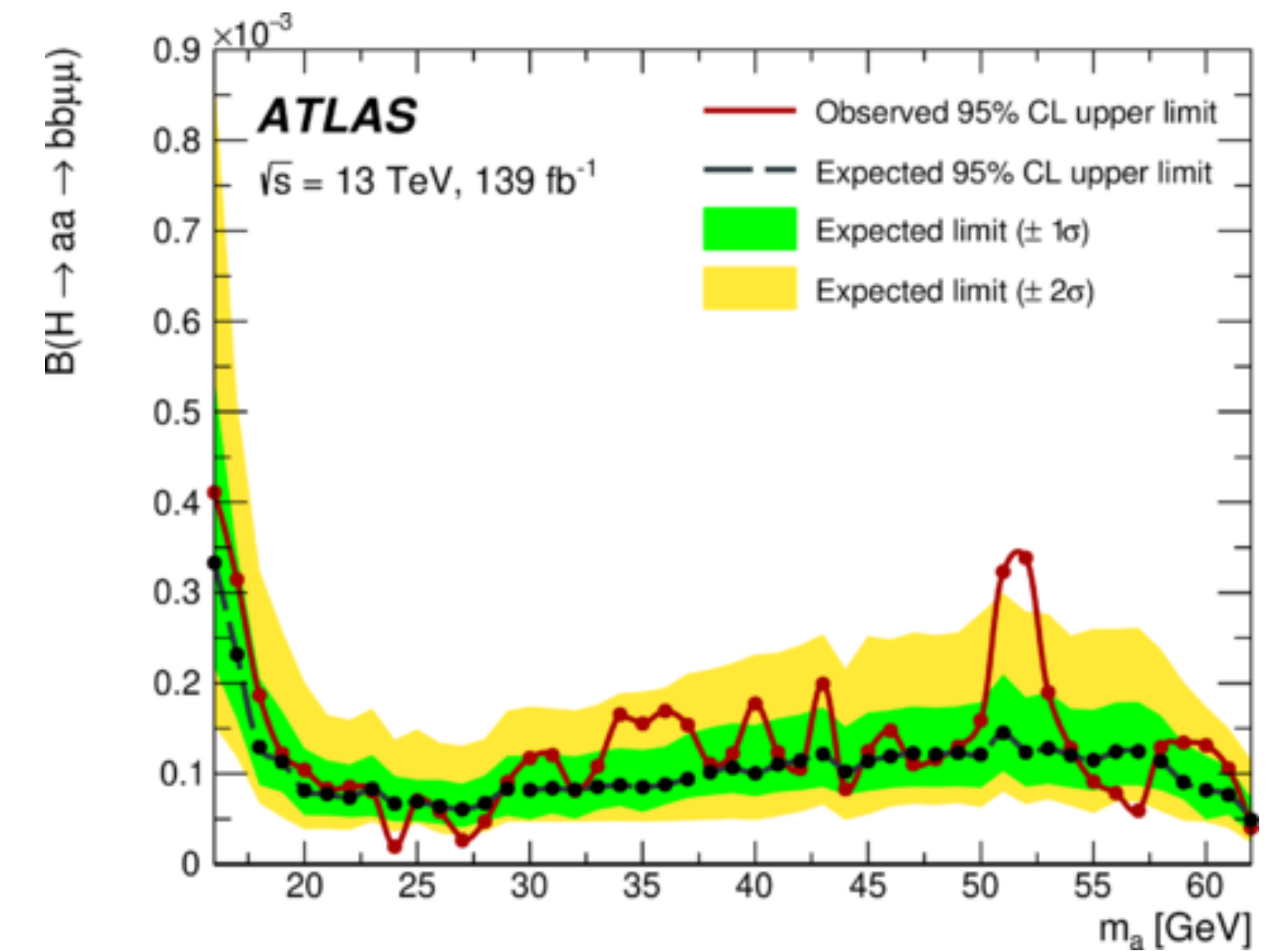
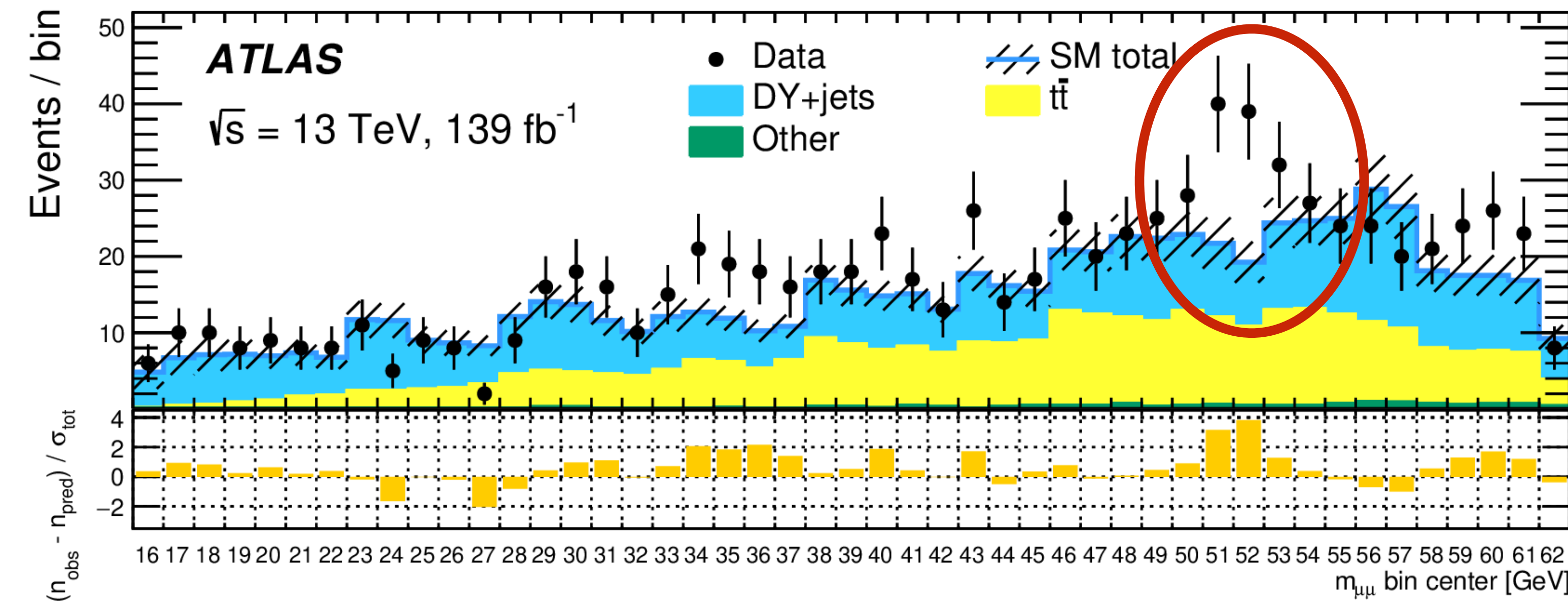
Searches for axion-like particle in $2b$ (fit distribution) 2μ (trigger) final state:

- Kinematic likelihood fit (KLM) used to constrain the m_{bb} to the $m_{\mu\mu}$ mass
 - Improve b-jet resolution maximising the likelihood
 - Cut on the KLM score (L^{\max}) to select best $m_{\mu\mu} \sim m_{bb}$ events
- Bump hunt over the $m_{\mu\mu}$ invariant mass distribution



$H \rightarrow 2a \rightarrow 2b2\mu$

Search for a narrow resonance in the $m_{\mu\mu}$ spectrum ($16\text{GeV} < m_{\mu\mu} < 62\text{GeV}$) and train BDTs to separate the signal from the DY and $t\bar{t}$ backgrounds



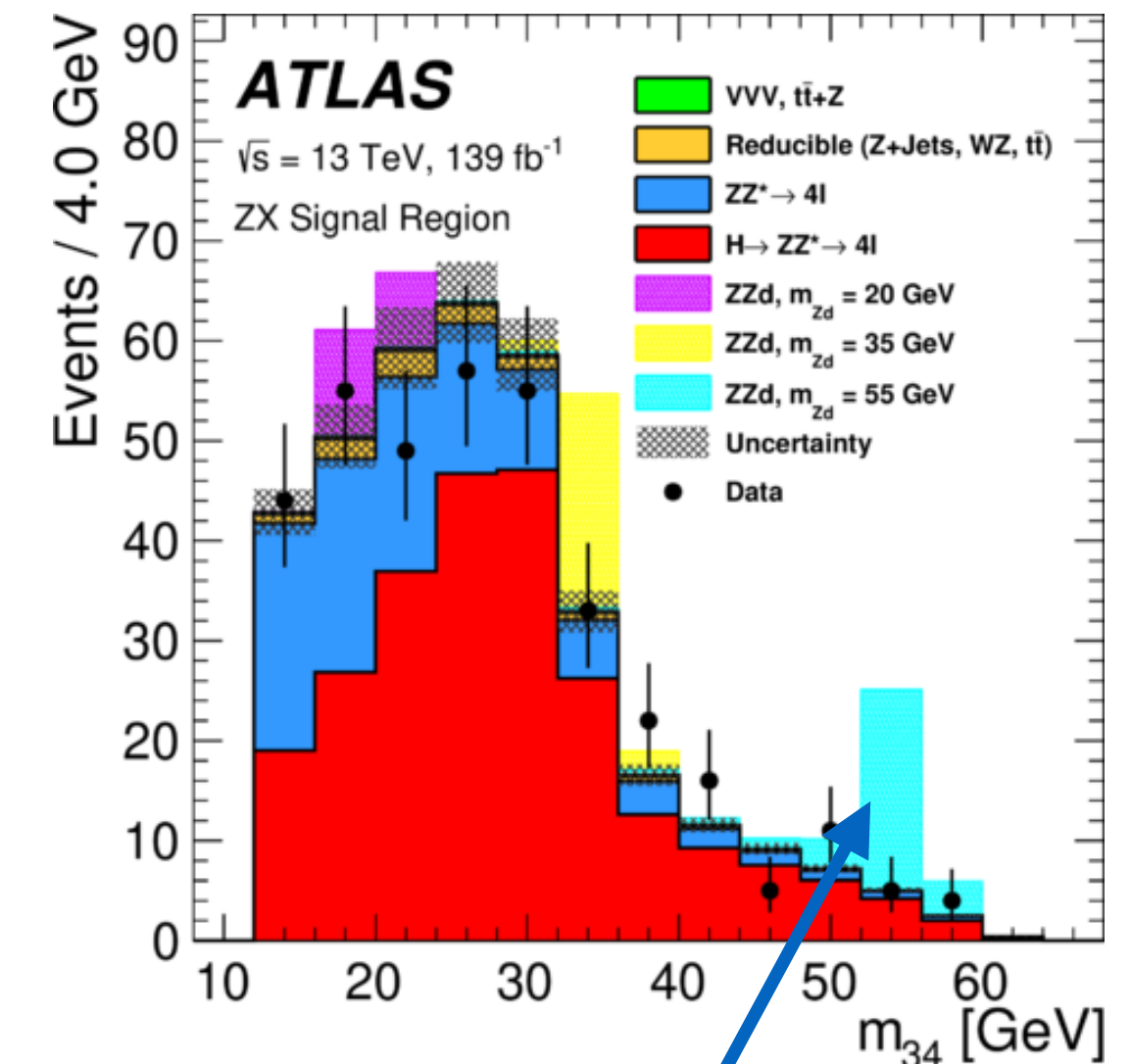
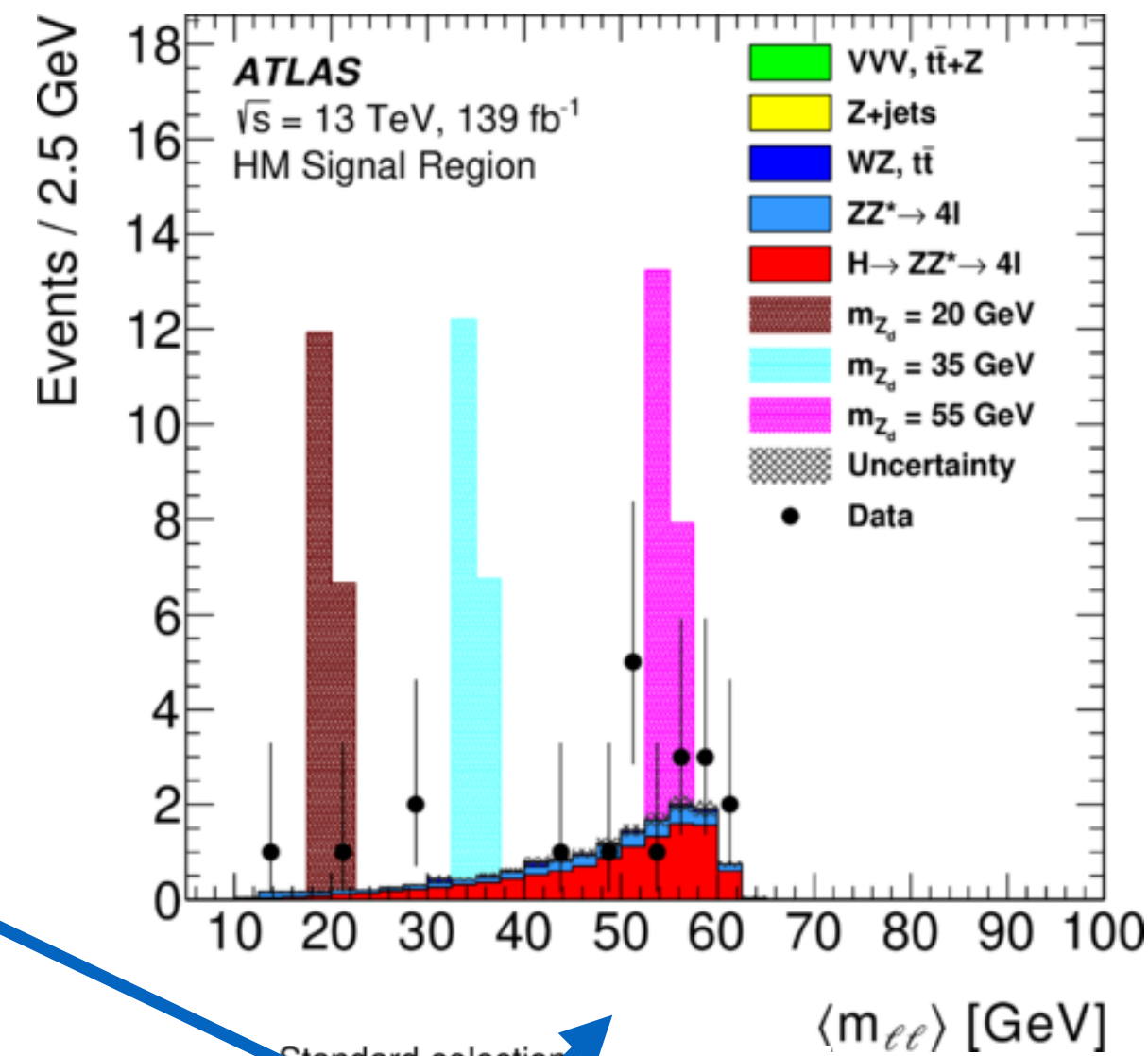
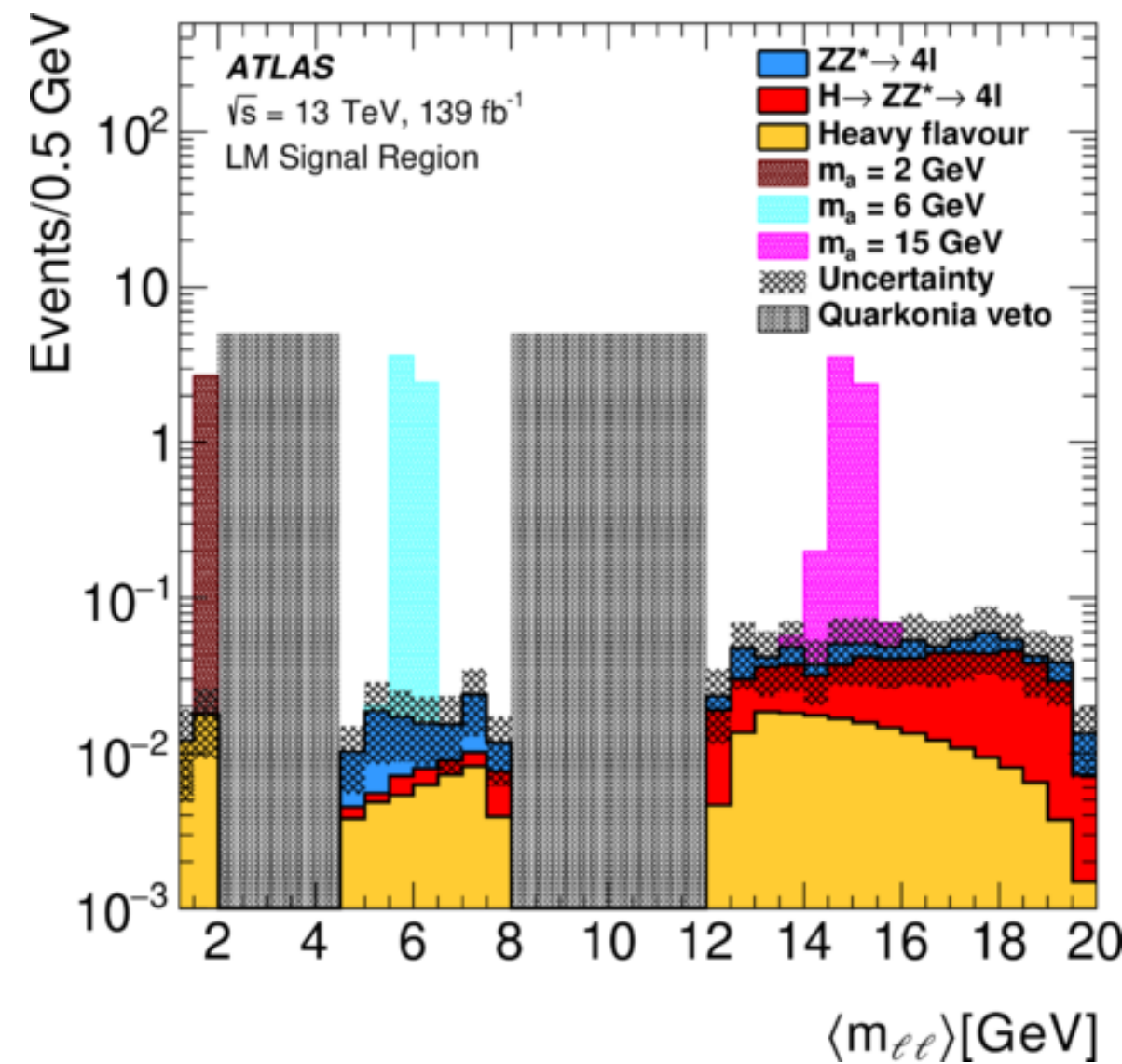
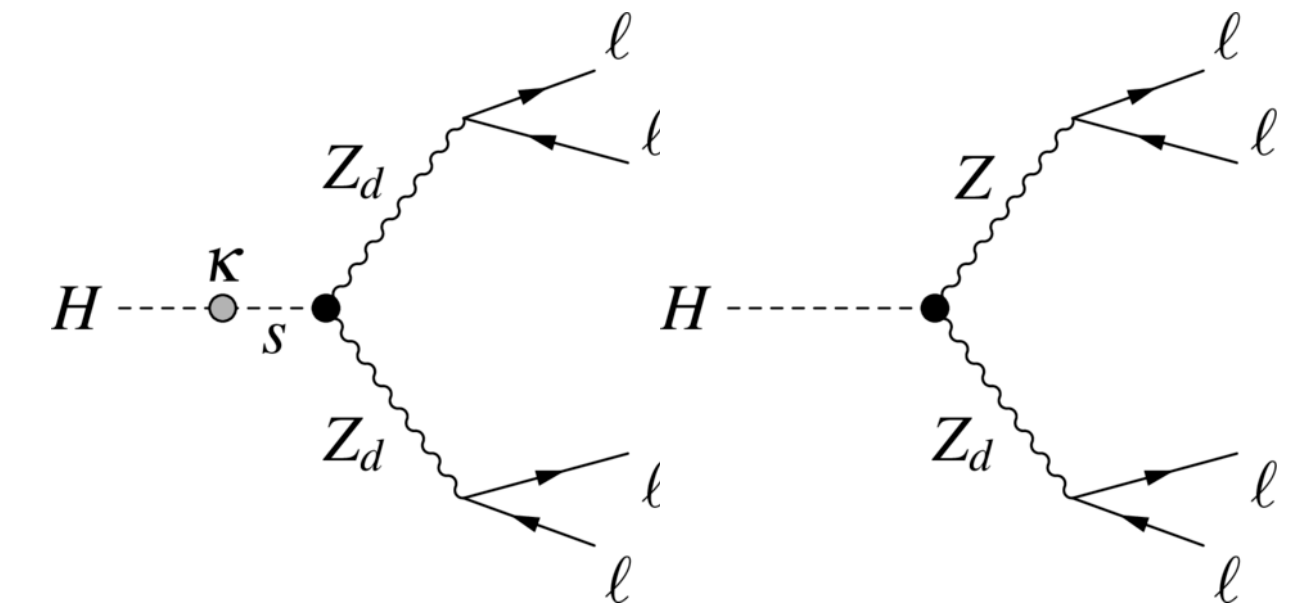
m_a 52 GeV:
local sig 3.27 sigma
global sig 1.67 sigma

H → XX/ZX → 4l

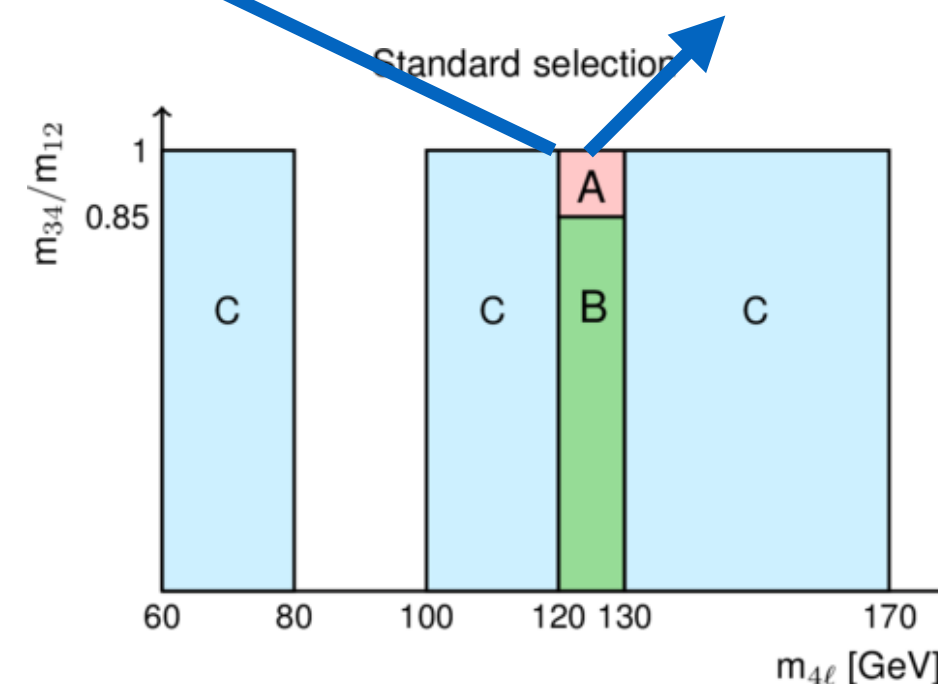
Search for exotic decays of the Higgs in four lepton final states:

- High-mass $15\text{GeV} < m_X < 60\text{GeV}$ (e/ μ)
- Low-mass $1\text{GeV} < m_X < 15\text{GeV}$ (μ -only)
- ZX $15\text{GeV} < m_X < 55\text{GeV}$ (e/ μ)

Mix of MC template and data-driven estimates for fakes and normalisation



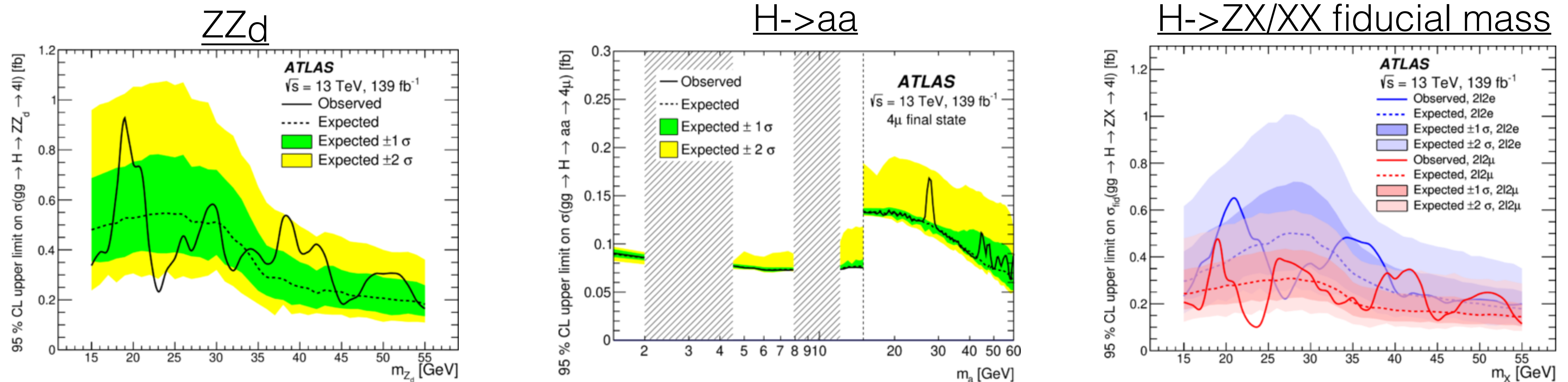
Four-lepton invariant mass compatible with Higgs Boson mass



Scan di-lepton invariant mass distribution for excess

H \rightarrow XX/ZX \rightarrow 4l

Results are very versatile and limits on the fiducial mass can be interpreted in many different dark sector interpretations: HAHM, coupling parameter κ , kinematic mixing, mass mixing, 2HDM+S in different Yukawa couplings

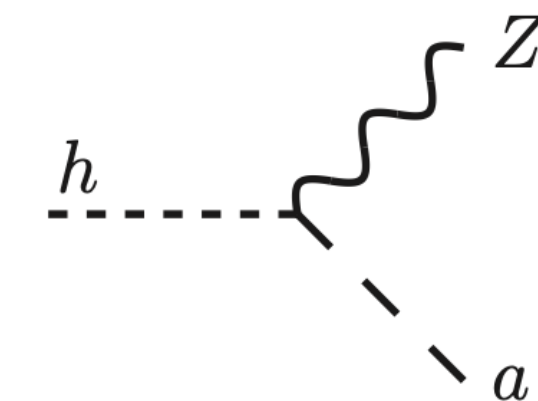
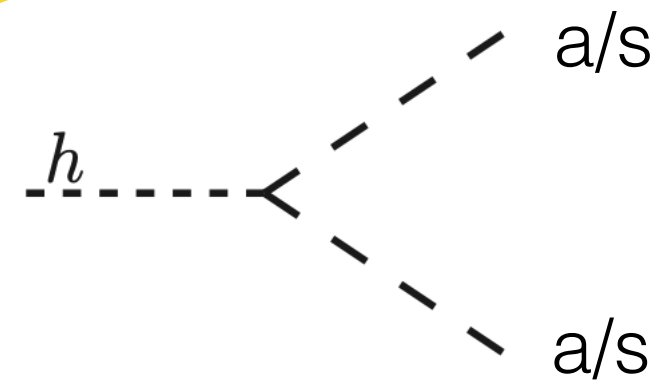


No significant excess observed, largest deviation in high-mass region at 28 GeV (local sig 2.5 σ)

Higgs-BSM searches for ALP

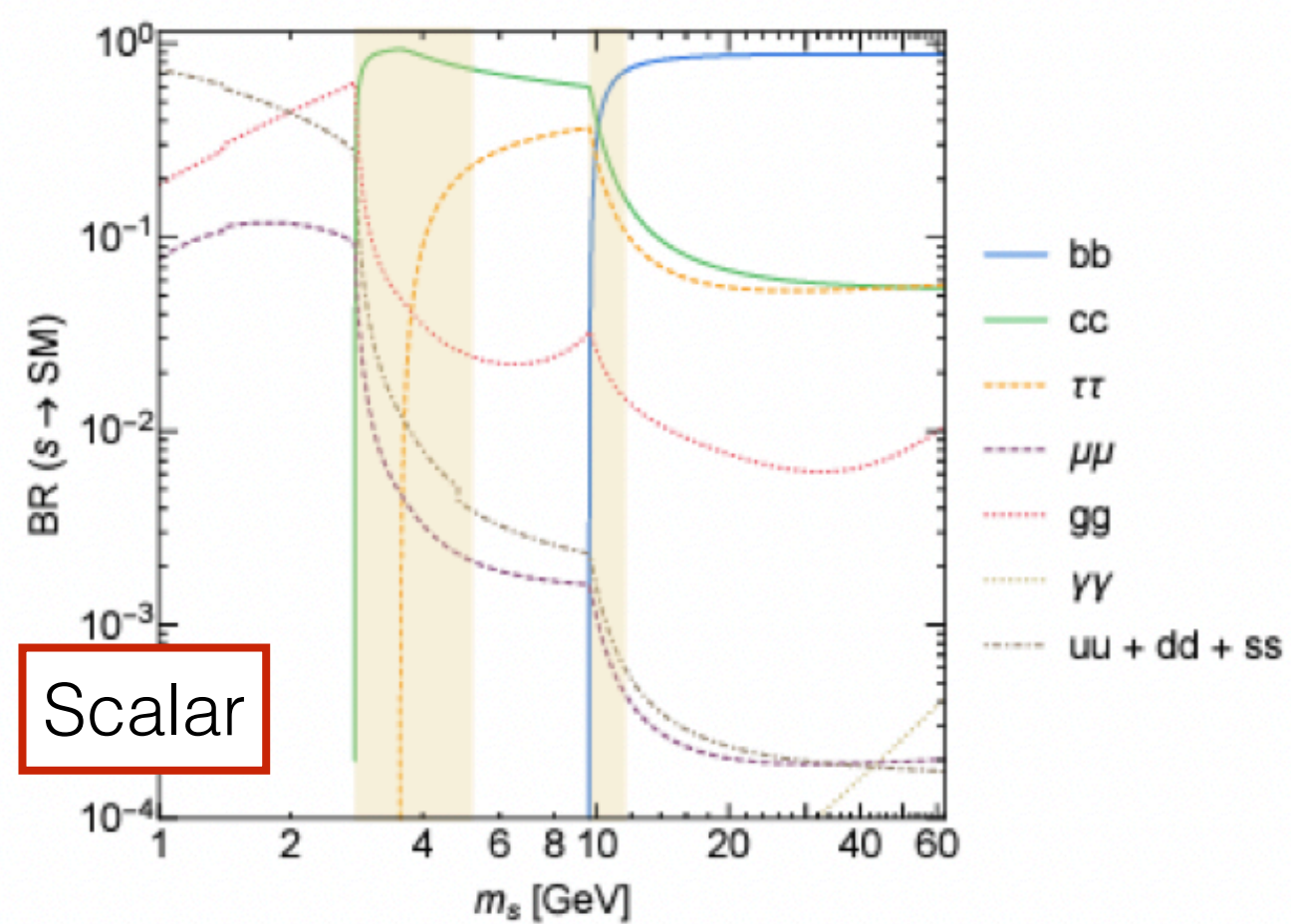
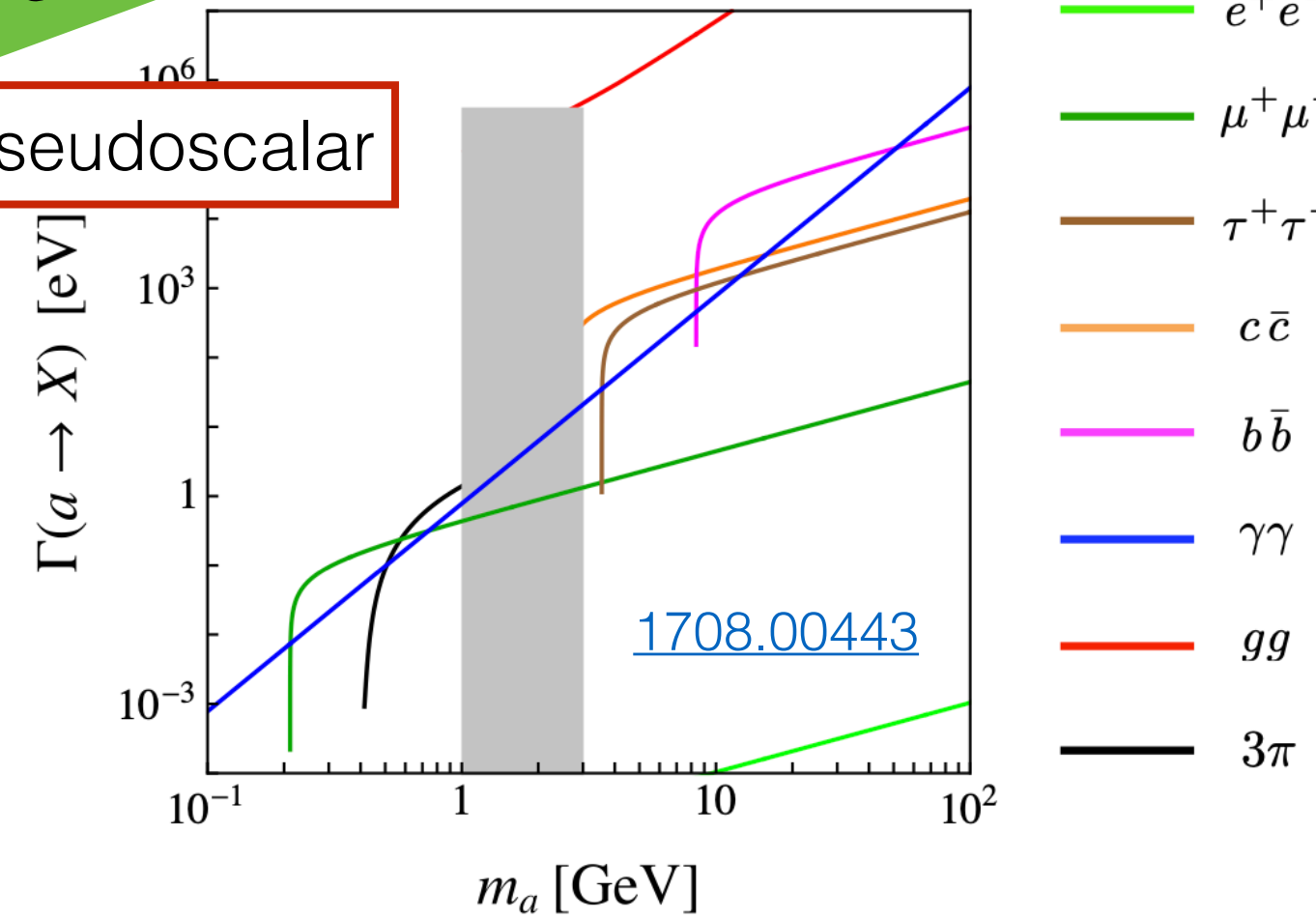
Explore Higgs BSM decays to probe hidden sectors, searching for light pseudo-scalar portals (axions/ALPs)

Production

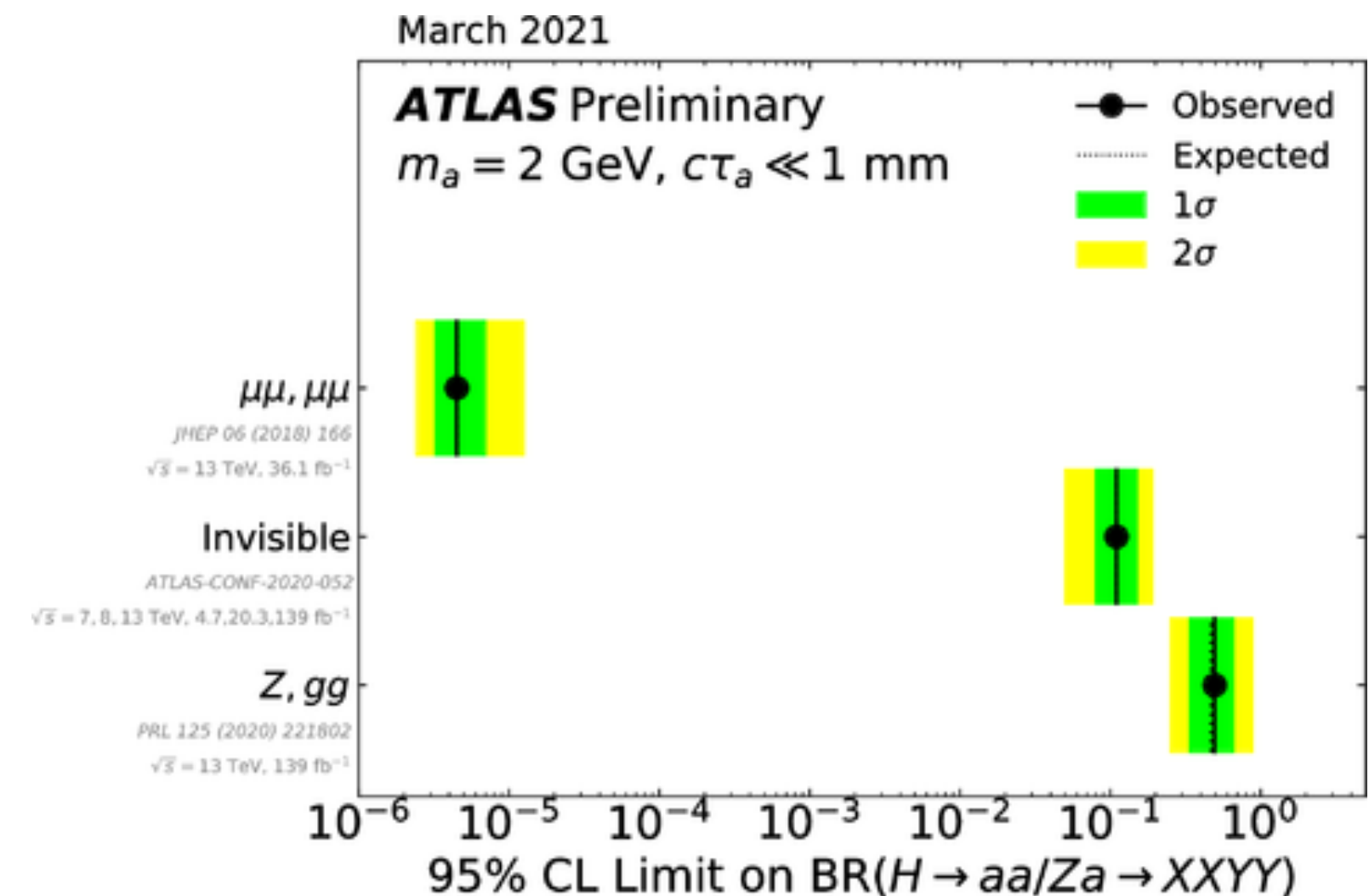
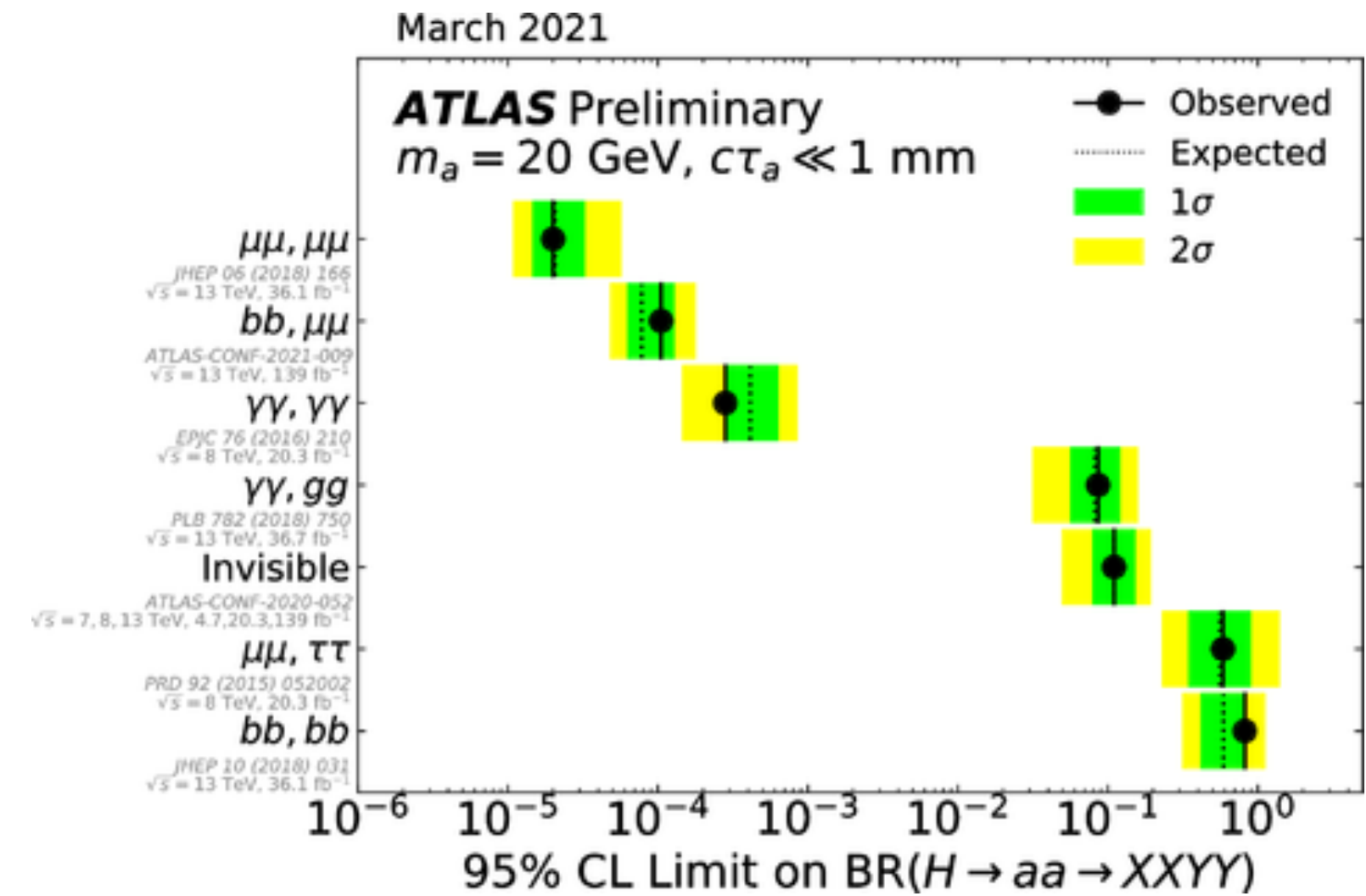


Decays

Pseudoscalar



Scalar

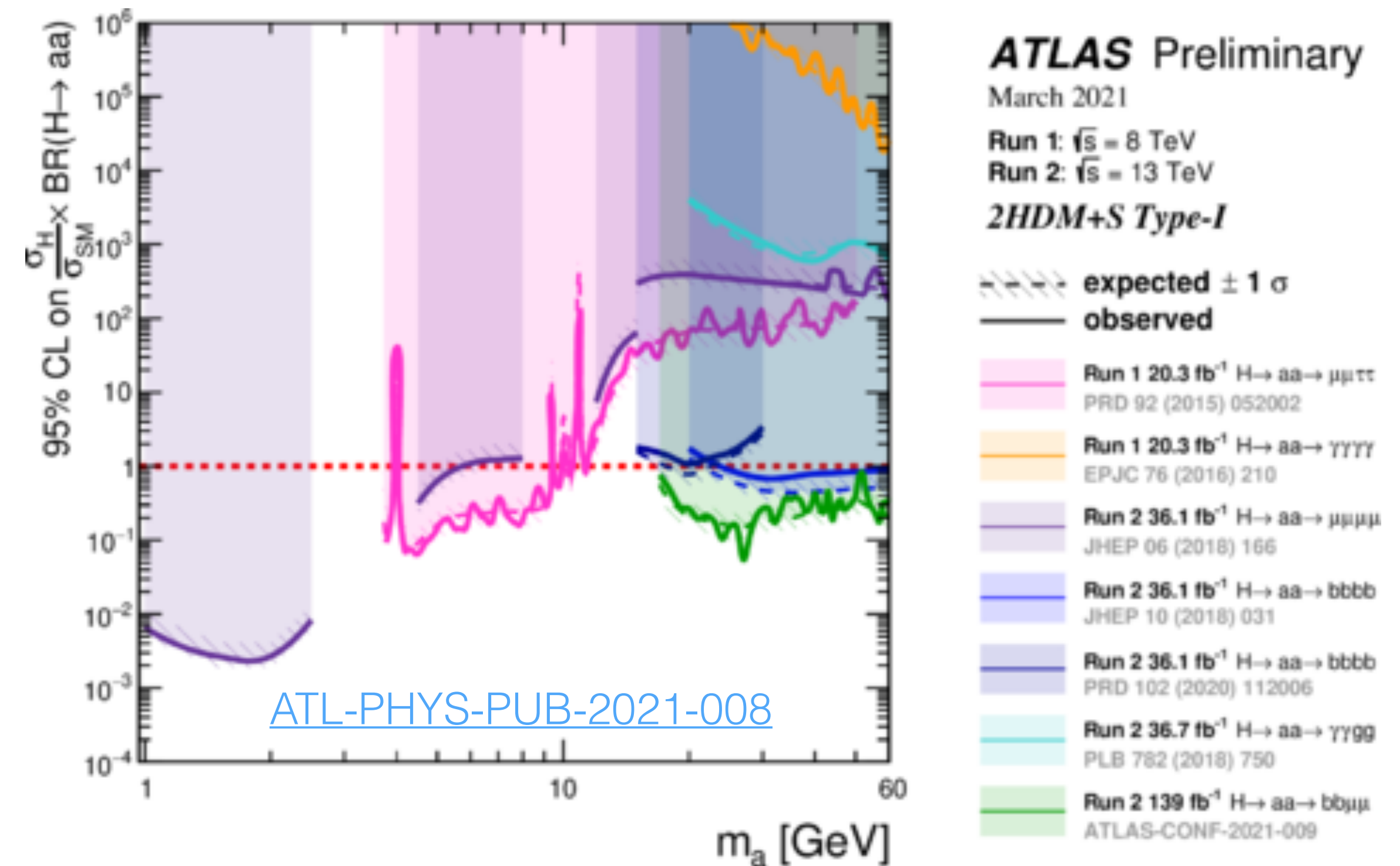


Decay rates for a NP scale at 1 TeV and effective coefficients set to 1

Summary

New searches for Higgs BSM decays at ATLAS using full Run-2 dataset have been presented, mainly focusing on LFV and Hidden Sectors

- Higgs invisible decays not yet fully constraint ([ATLAS-CONF-2021-053](#)): $\text{BR}(H \rightarrow \text{invisible}/\text{undetected}) < \sim 10\%$. Plenty of room for BSM physics
- Few interesting deviations that need to be verified with Run3 dataset
- Run3 and the updated detector offer a unique opportunity to access smaller cross-sections and unexplored channels

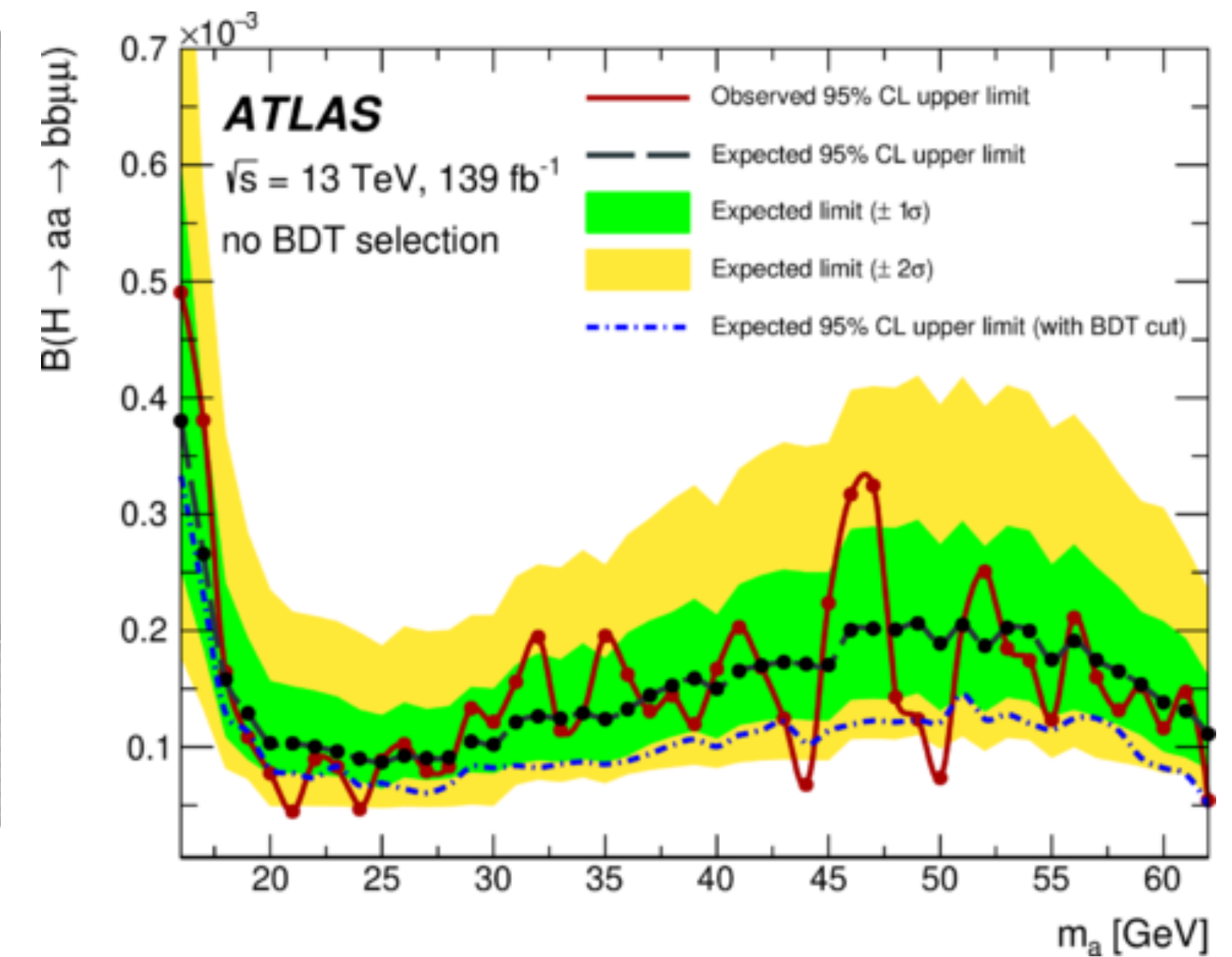
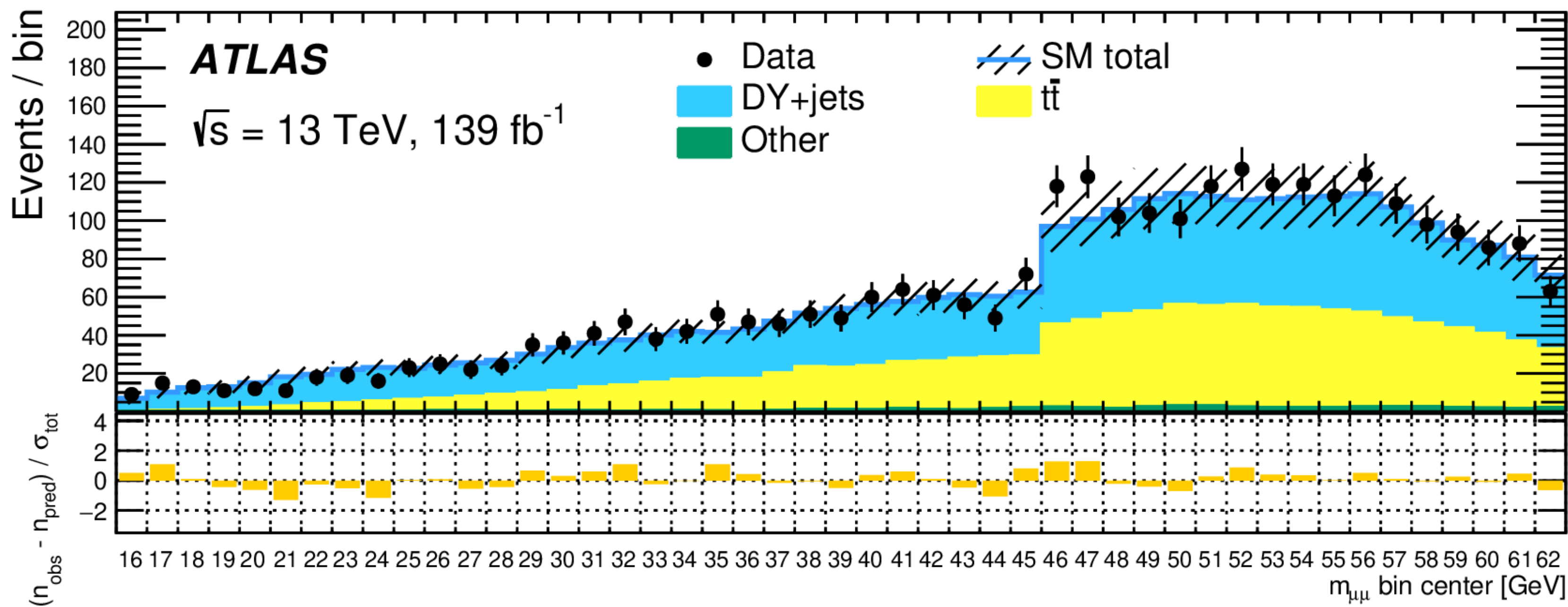


BACKUP

$H \rightarrow 2a \rightarrow 2b2\mu$

[HDBS-2021-03](#)

Results also provided without the BDT cut, no significant excess



m_a 52 GeV:
local sig 3.27 sigma
global sig 1.67 sigma