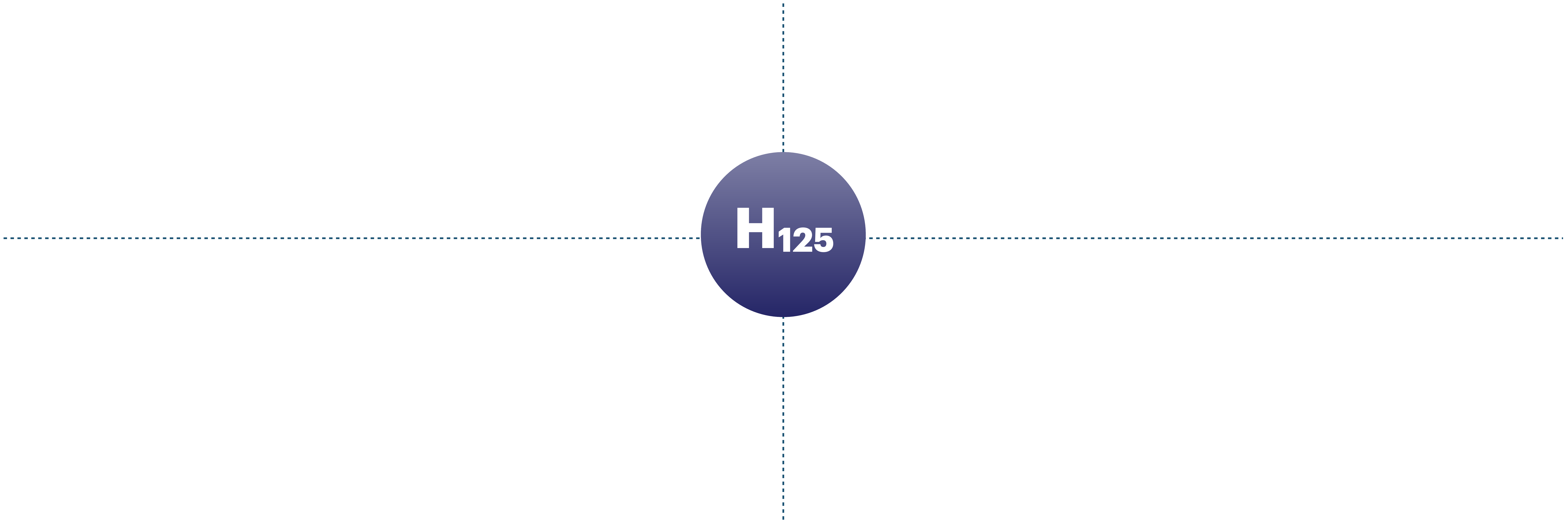
The Higgs boson in searches for physics beyond the Standard Model

Roberto Salerno
on behalf of the ATLAS and CMS Collaborations

The role of H in searches for BSM

Few examples

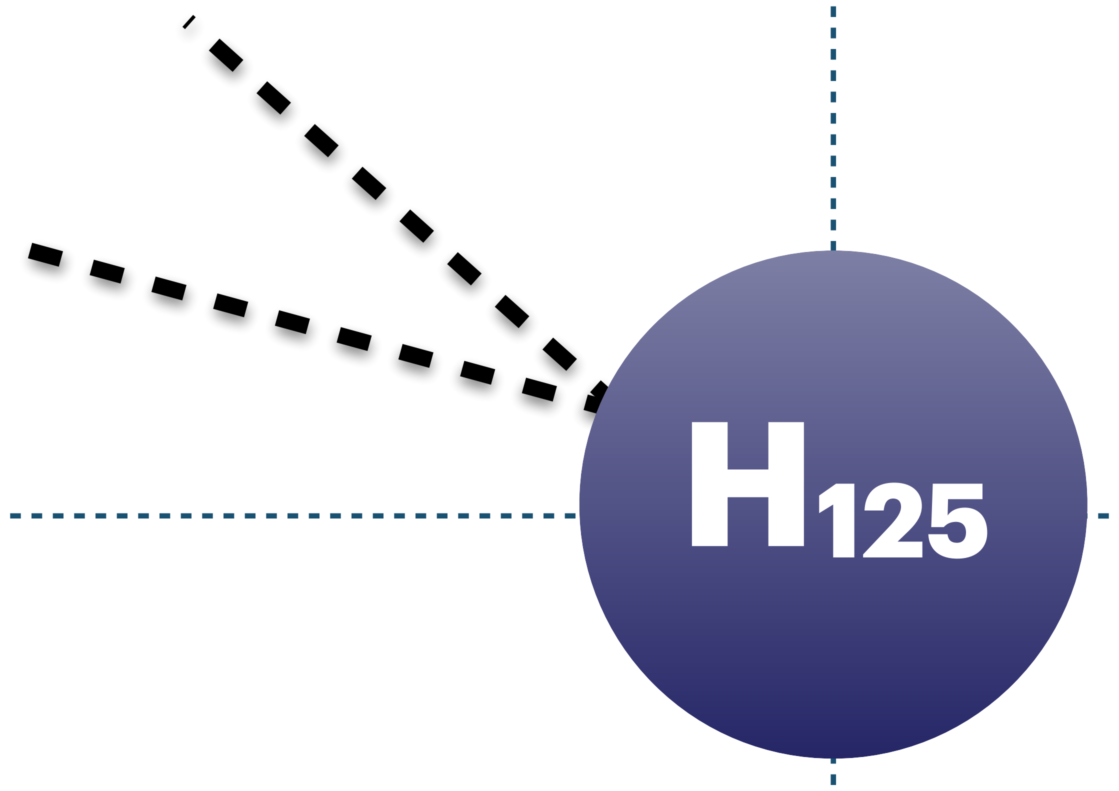


The role of H in searches for BSM

Few examples

invisible decay

H_{125} invisible
and undetected decays



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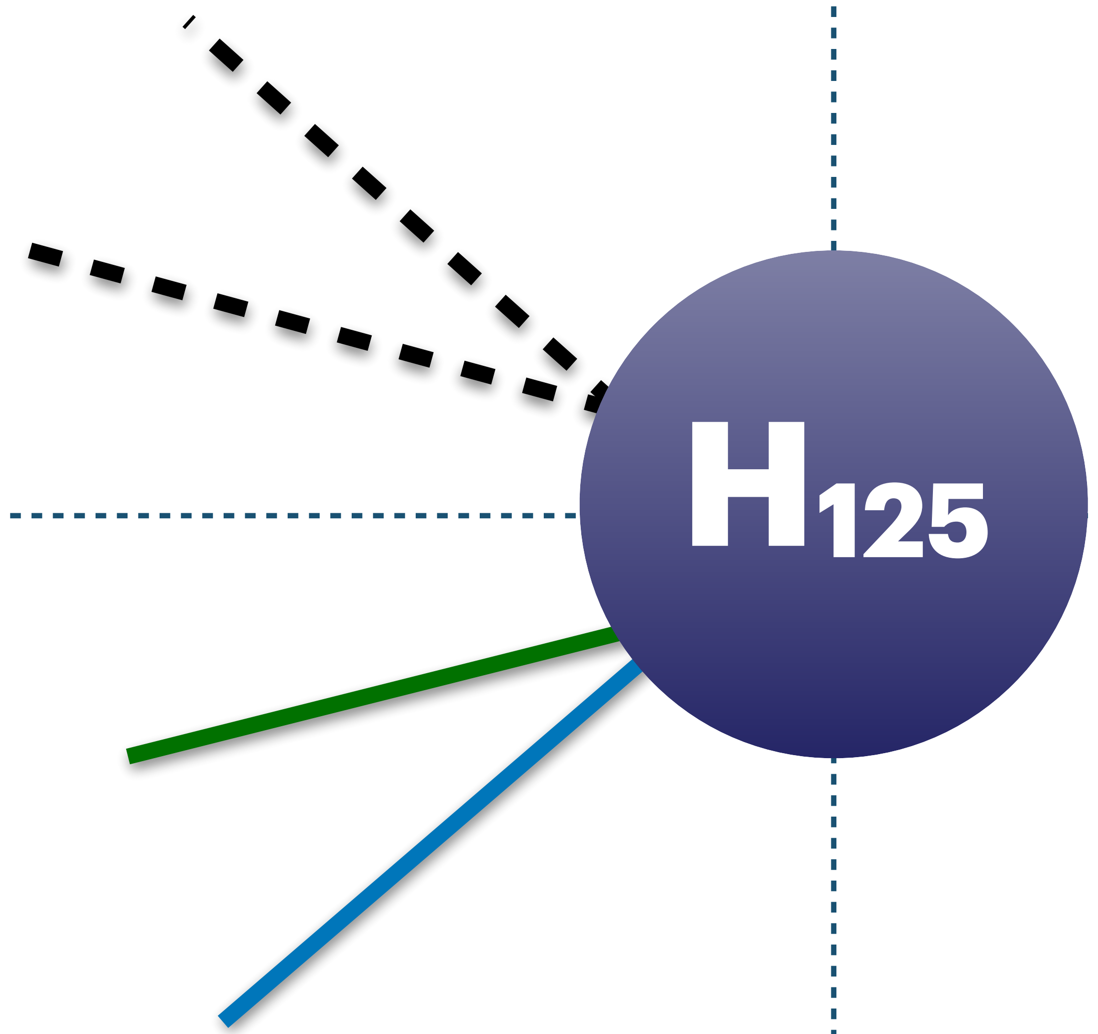

flavour violating decays

H_{125} flavour violating
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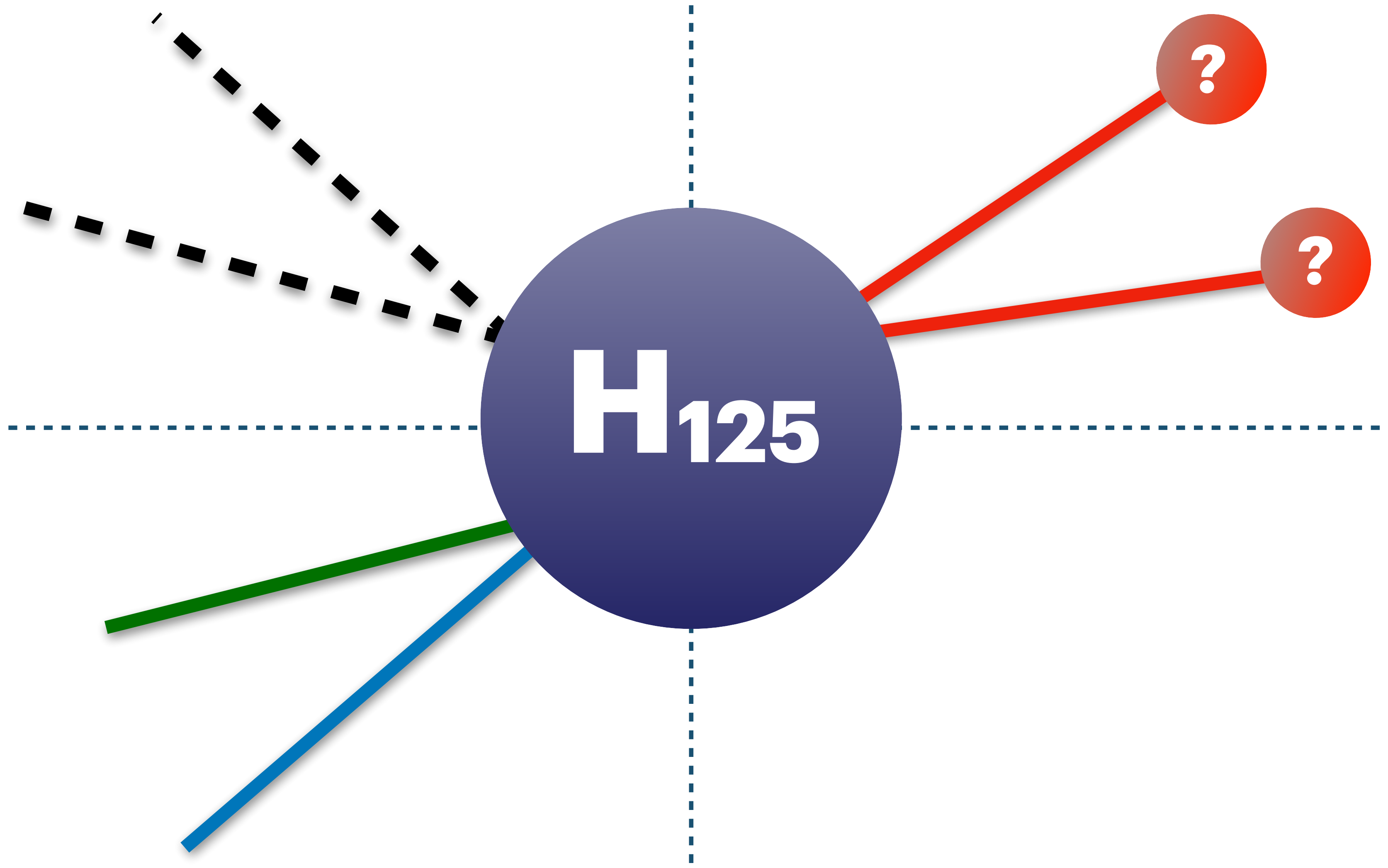

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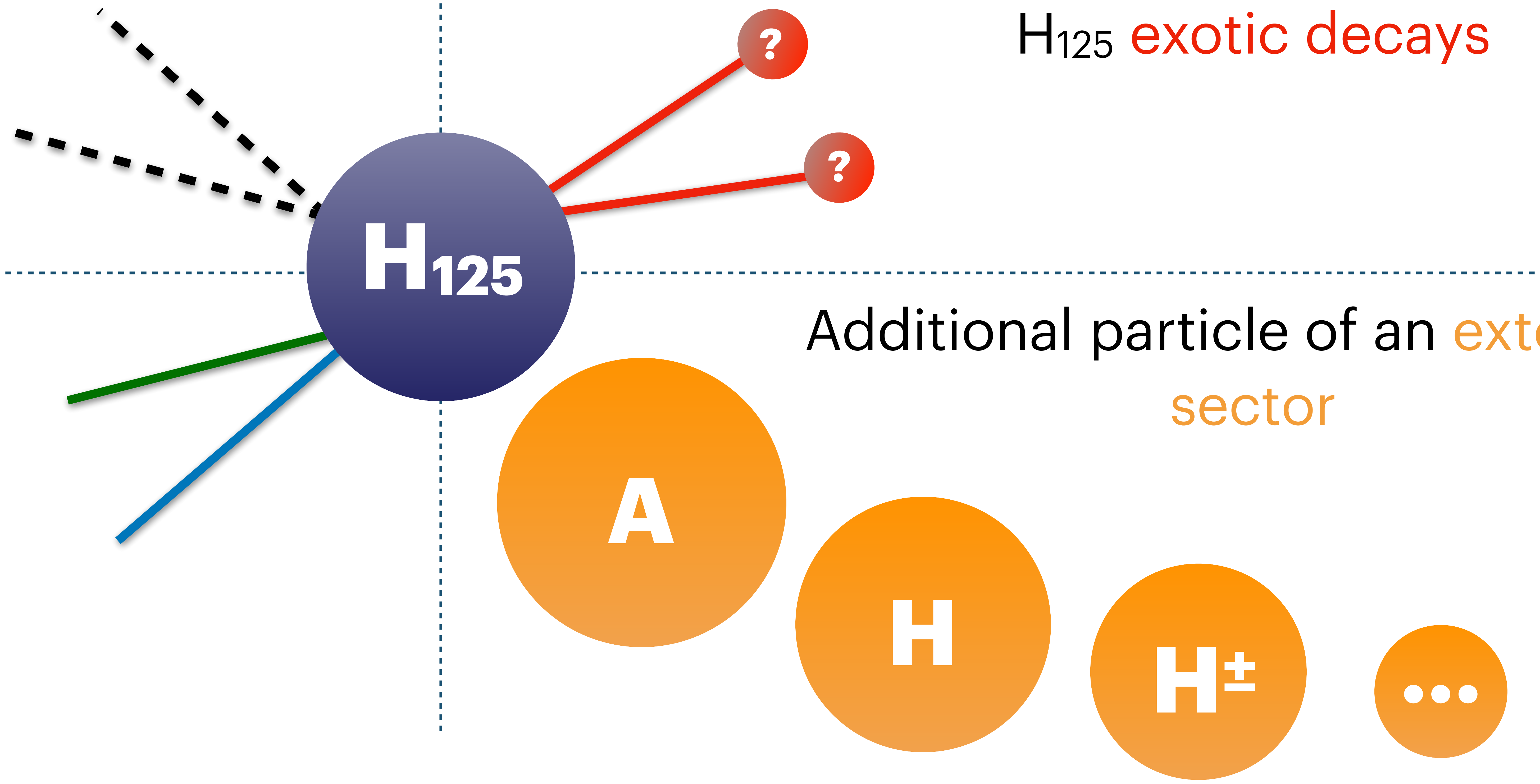

H_{125} exotic decays

exotic decays

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flavour violating decays

Additional particle of an extended
sector

extended sector

The role of H in searches for BSM

Few examples

Very large physics program pursued by both ATLAS and CMS!
It is impossible to cover everything, I will show the diversity and complementary of few analyses.

Higgs boson to invisible decay

The expected SM H branching fraction to invisible decay ($\mathscr{B}_{\text{inv}}$) is 0.12% due to $H \to ZZ^* \to \nu\bar{\nu}\nu\bar{\nu}$

Several BSM scenario ⇒ anomalous and sizeable values, $\mathscr{B}_{\text{inv}}$ is significantly enhanced.

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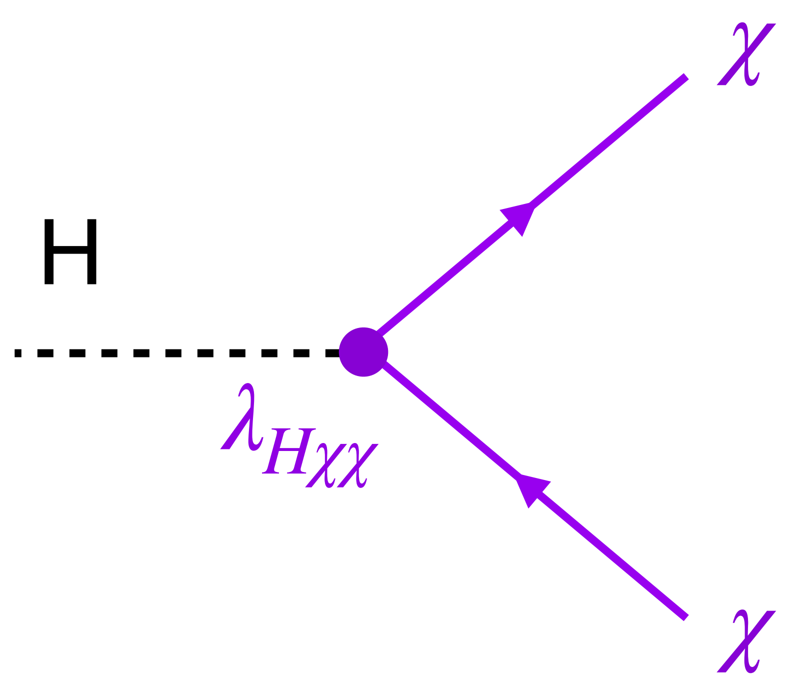
In one class of models H decay in a pair of stable WIMPs.
They represent a simple extension of the SM to provide a Dark Matter (DM) candidate and are able to predict the observed relic DM density via s-channel $\chi\chi \to f\bar{f}$ annihilation.



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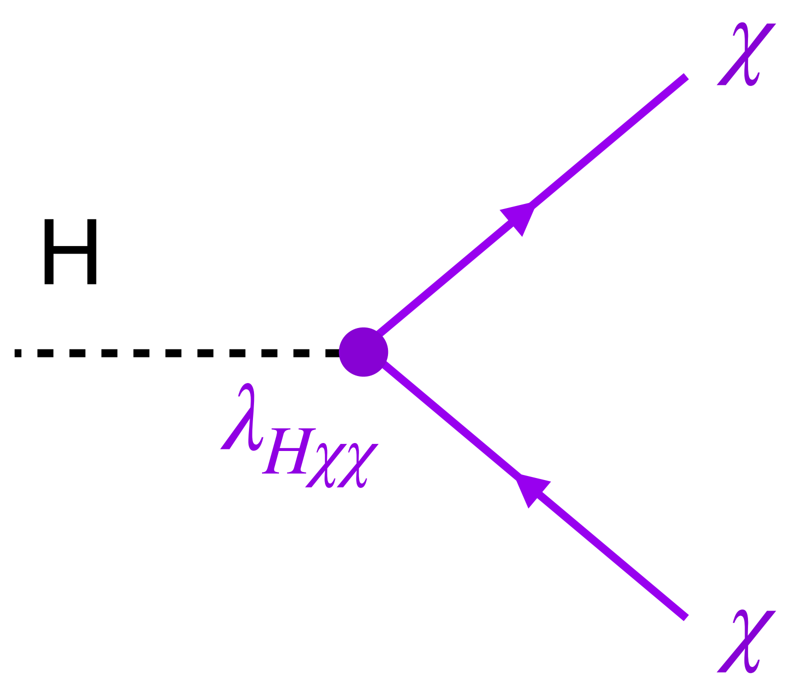
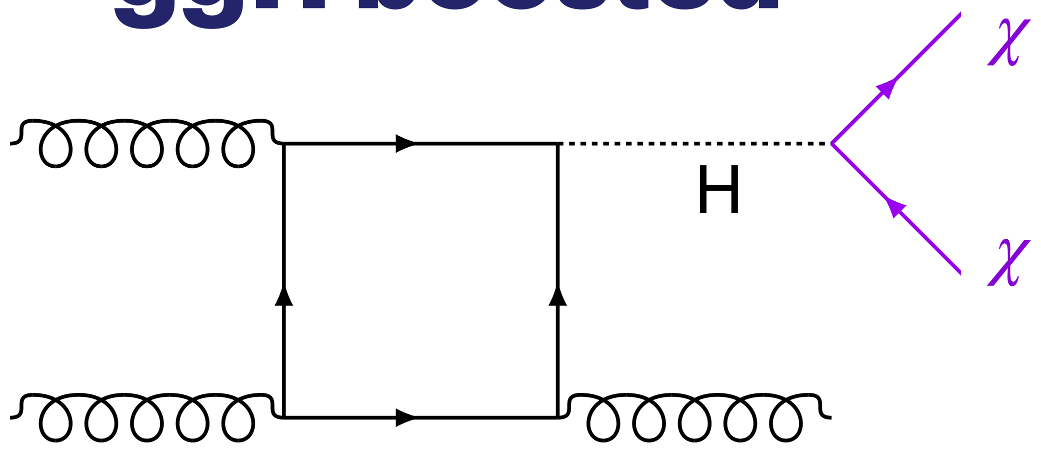


The solution of the DM problem could be found within the Higgs sector.

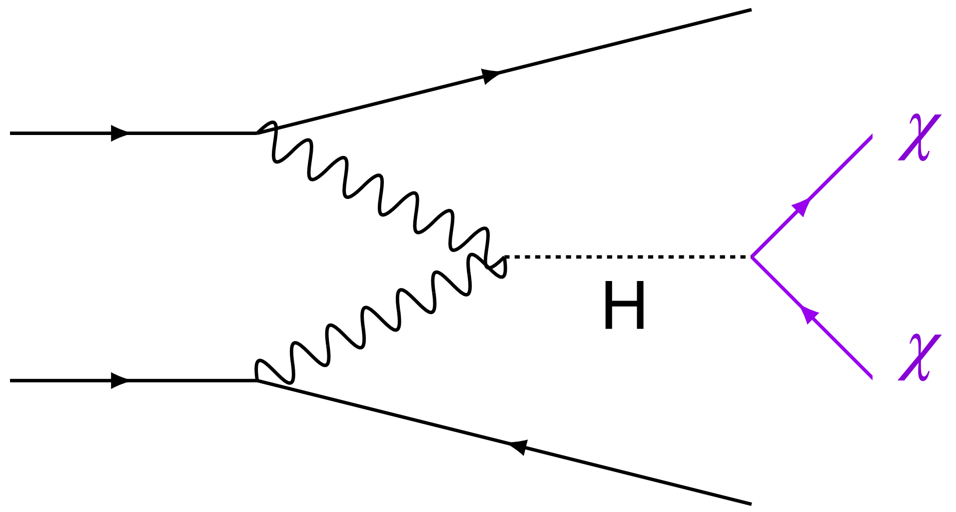
Common signature : significant missing transverse momentum from the Higgs boson decay.
Identify the event : profit of visible particles recoiling against the Higgs boson.

Search for Higgs boson to invisible decay

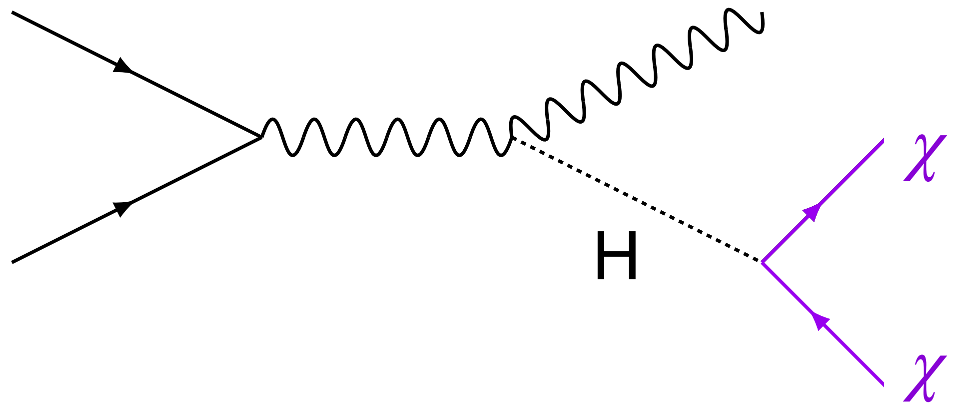
ggH boosted



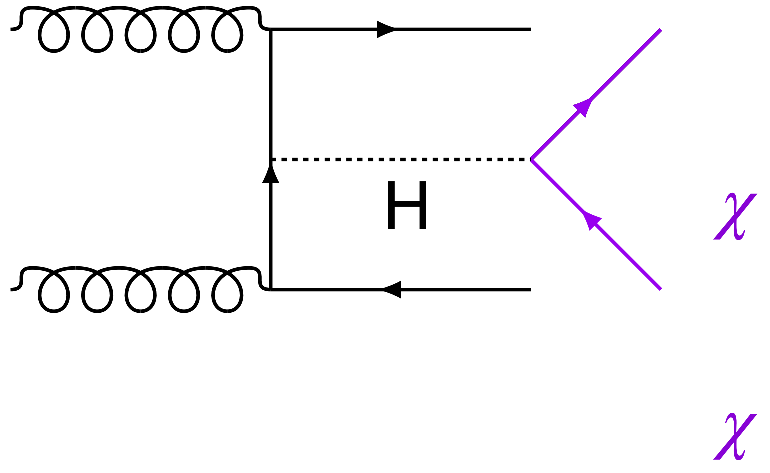
VBF



Associated production



ttH



ATLAS and CMS probe all production mechanisms

Run2 analyses

	ggH boosted	VBF	Associated production	ttH
ATLAS	Phys.Rev.D 103 (2021) 11, 112006	arXiv:2202.07953 Eur.Phys.J.C 82 (2022) 2, 105	Phys.Lett.B 829 (2022) 137066	ATLAS-CONF-2022-007
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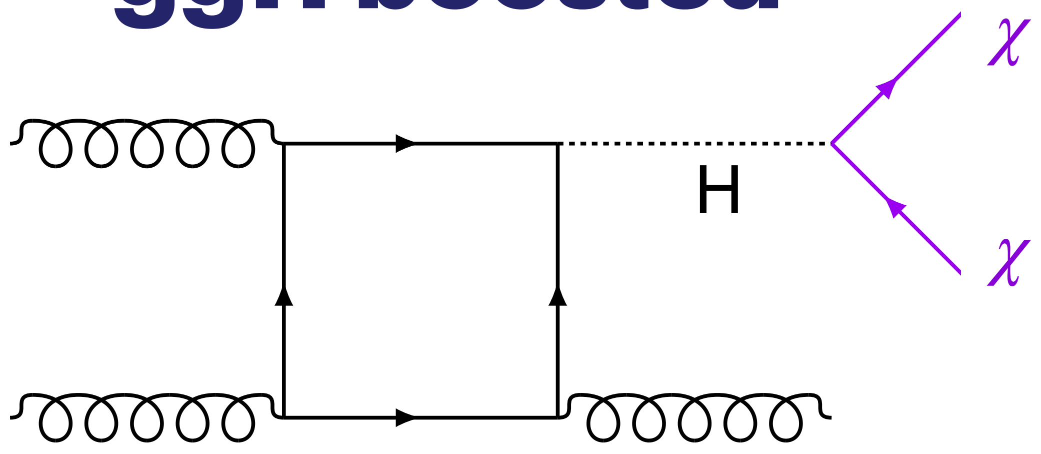
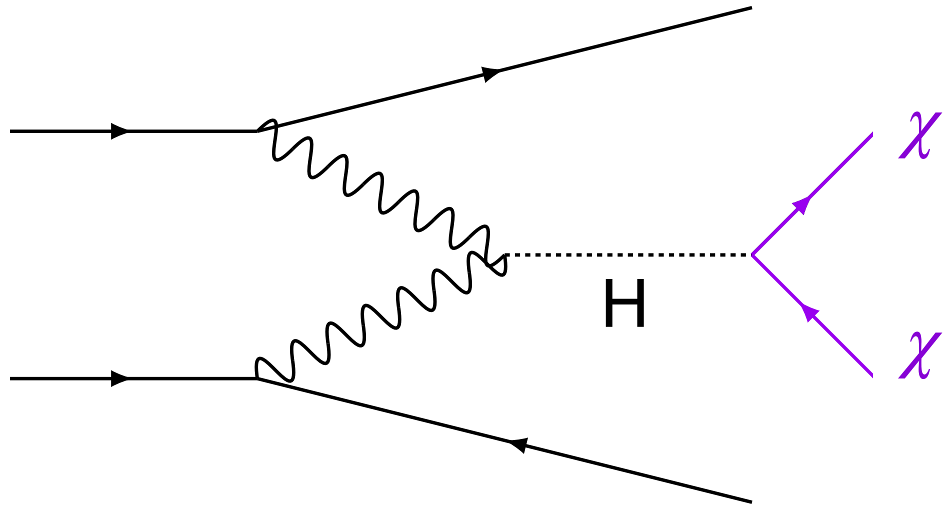


VBF



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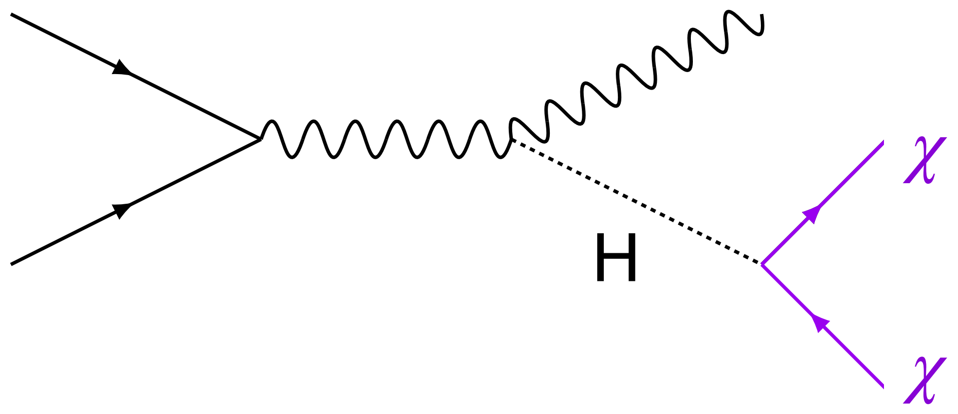
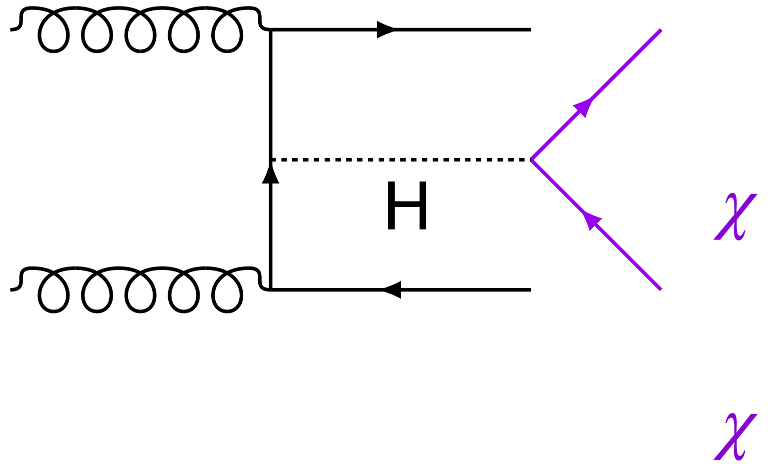


ttH



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The VBF production mechanism drives the overall sensitivity in the direct search for invisible decays of the Higgs boson, thanks to its large production cross section and **distinctive event topology**

VBF Higgs boson to invisible decay

arXiv:2202.07953

Phys.Rev.D 105 (2022) 092007

Strategy

2 jets with large angular separation $\Delta\eta_{jj}$ and large invariant mass m_{jj}

Veto on other objects (leptons/photons)

High missing transverse momentum (trigger constraint) → reject QCD

Low $|\Delta\phi_{jj}|$ → reject QCD

⇒ Main remaining backgrounds: $Z(\nu\nu) + \text{jets}$ and $W(l\nu) + \text{jets}$ (strong and VBF productions)

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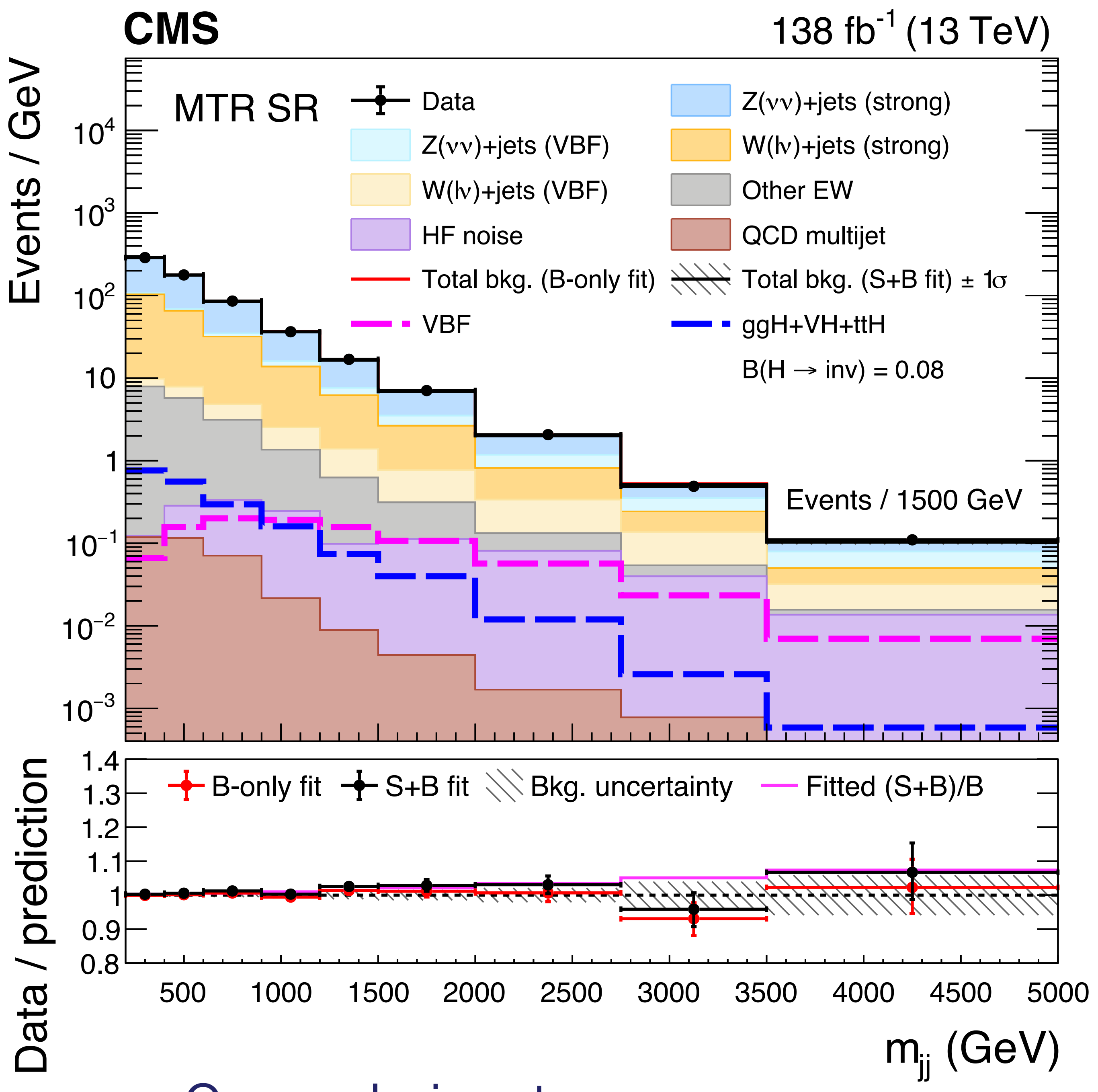

One analysis category

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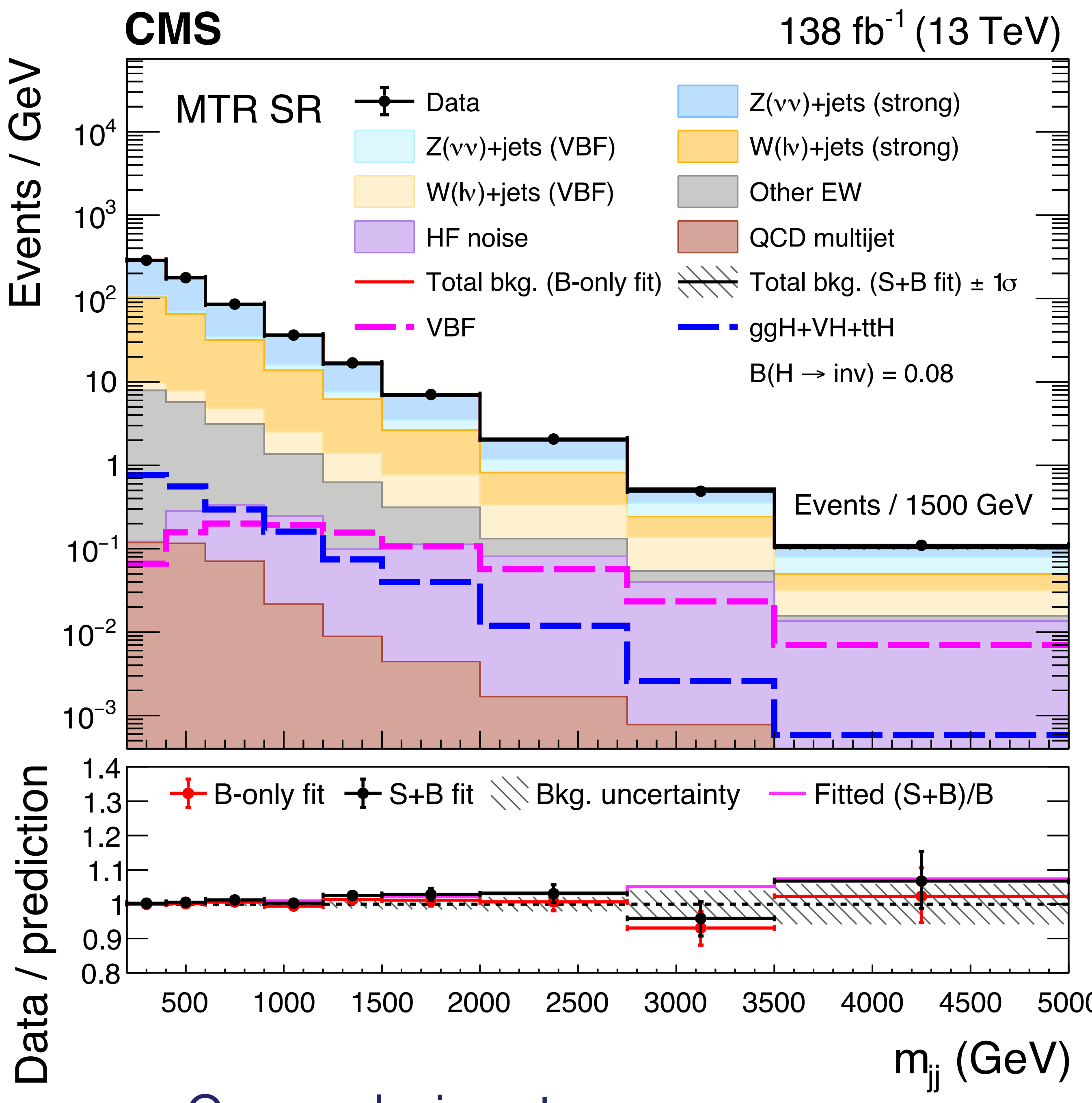

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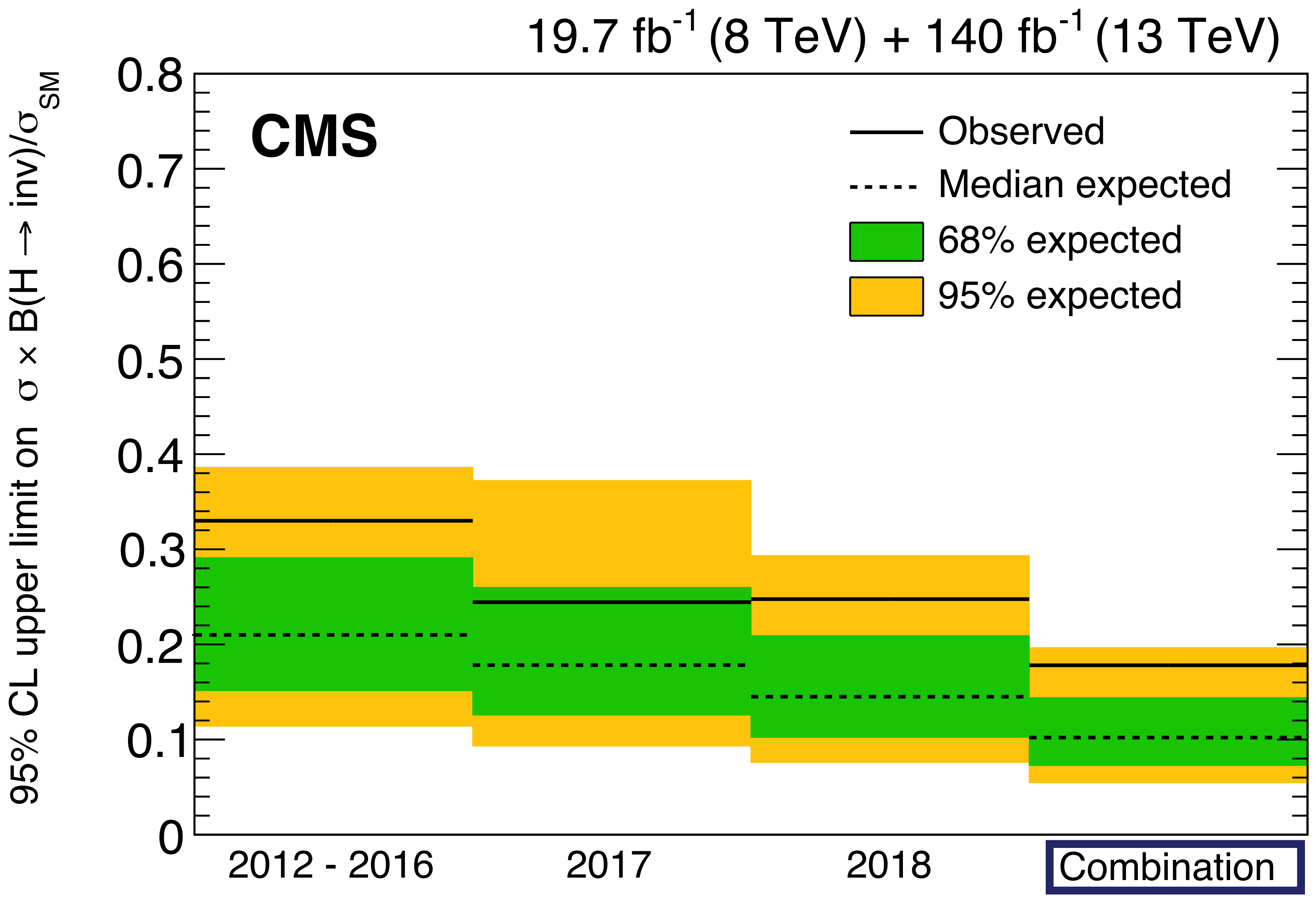


Results

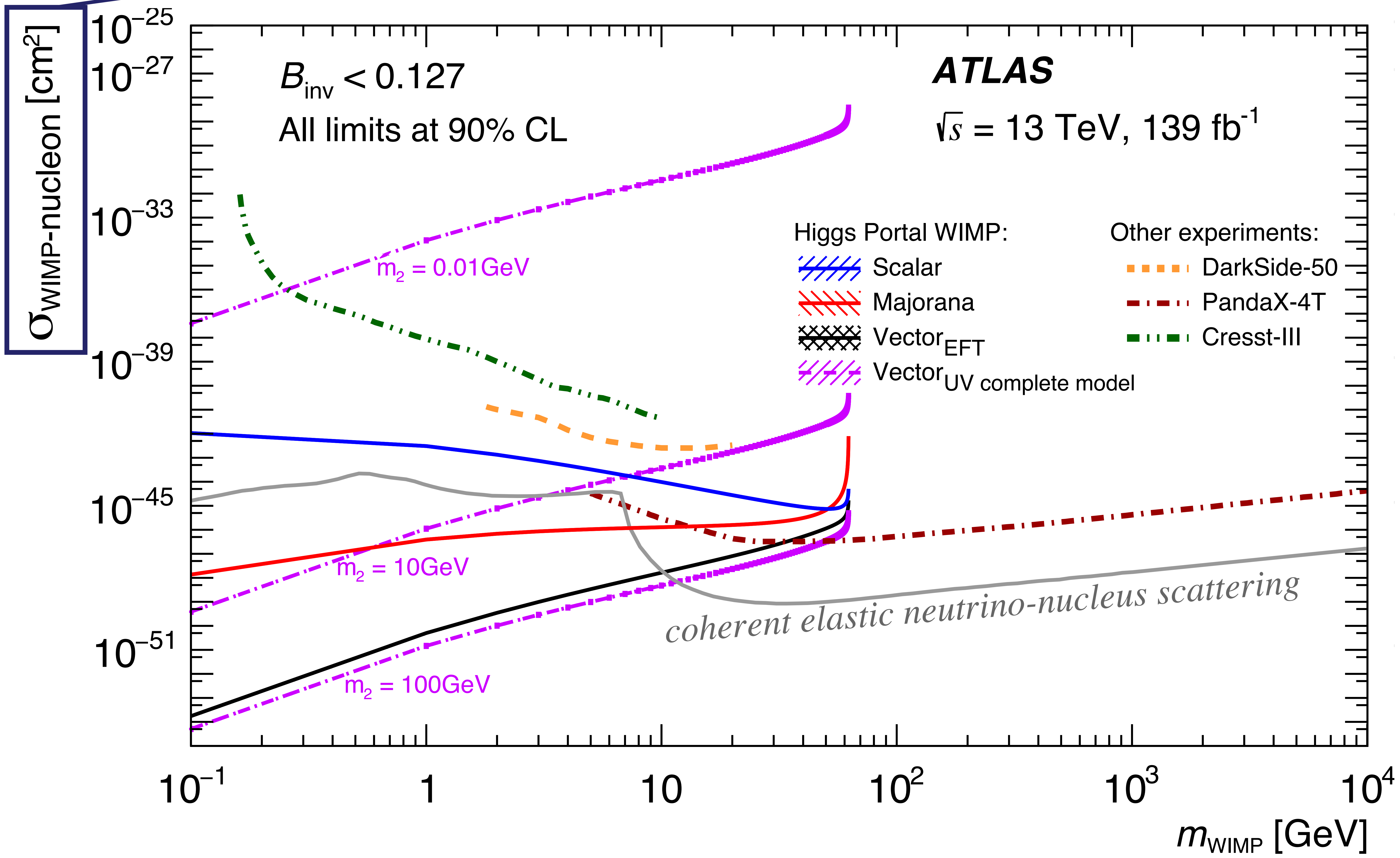
	obs(ext) UL on $\mathscr{B}_{\text{inv}}$
ATLAS	0.145(0.103)
CMS	0.18(0.10)

Interpretations

arXiv:2202.07953

Phys.Rev.D 105 (2022) 092007

Upper limits on the spin-independent **WIMP–nucleon cross section**



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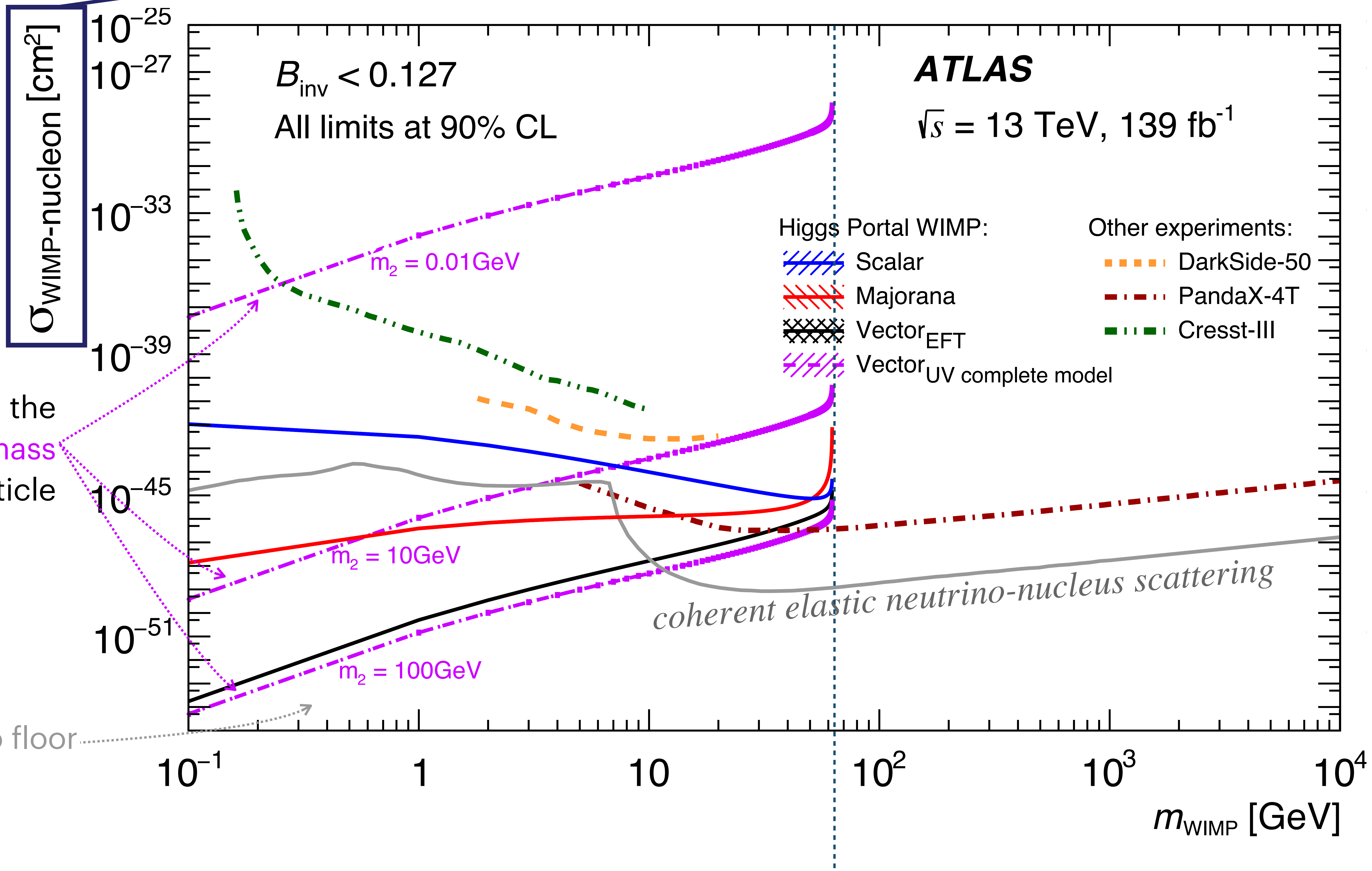

For the vector$_{\text{UV}}$ models, the dependence on the mass m_2, new scalar particle

Down in the neutrino floor

Kinematical threshold

$m_{\text{WIMP}} = m_{\text{DM}} = m_{H/2}$ = 62.5 GeV

Outperforms direct searches experiments for low m_{DM}

Lepton-Flavour Violating decays

$H \to e\mu/\mu\tau/e\tau$ are forbidden in the SM but takes place through the LFV Yukawa couplings $Y_{ij} \neq (m_i/v)\delta_{ij}$ arising in two Higgs doublet models, extra dimensions, models with flavor symmetries, models of compositeness, …

$$\begin{pmatrix} Y_{ee} & Y_{e\mu} & Y_{e\tau} \\ & Y_{\mu\mu} & Y_{\mu\tau} \\ & & Y_{\tau\tau} \end{pmatrix}$$

Lepton-Flavour Violating decays

Phys.Rev.D 104 (2022) 032013

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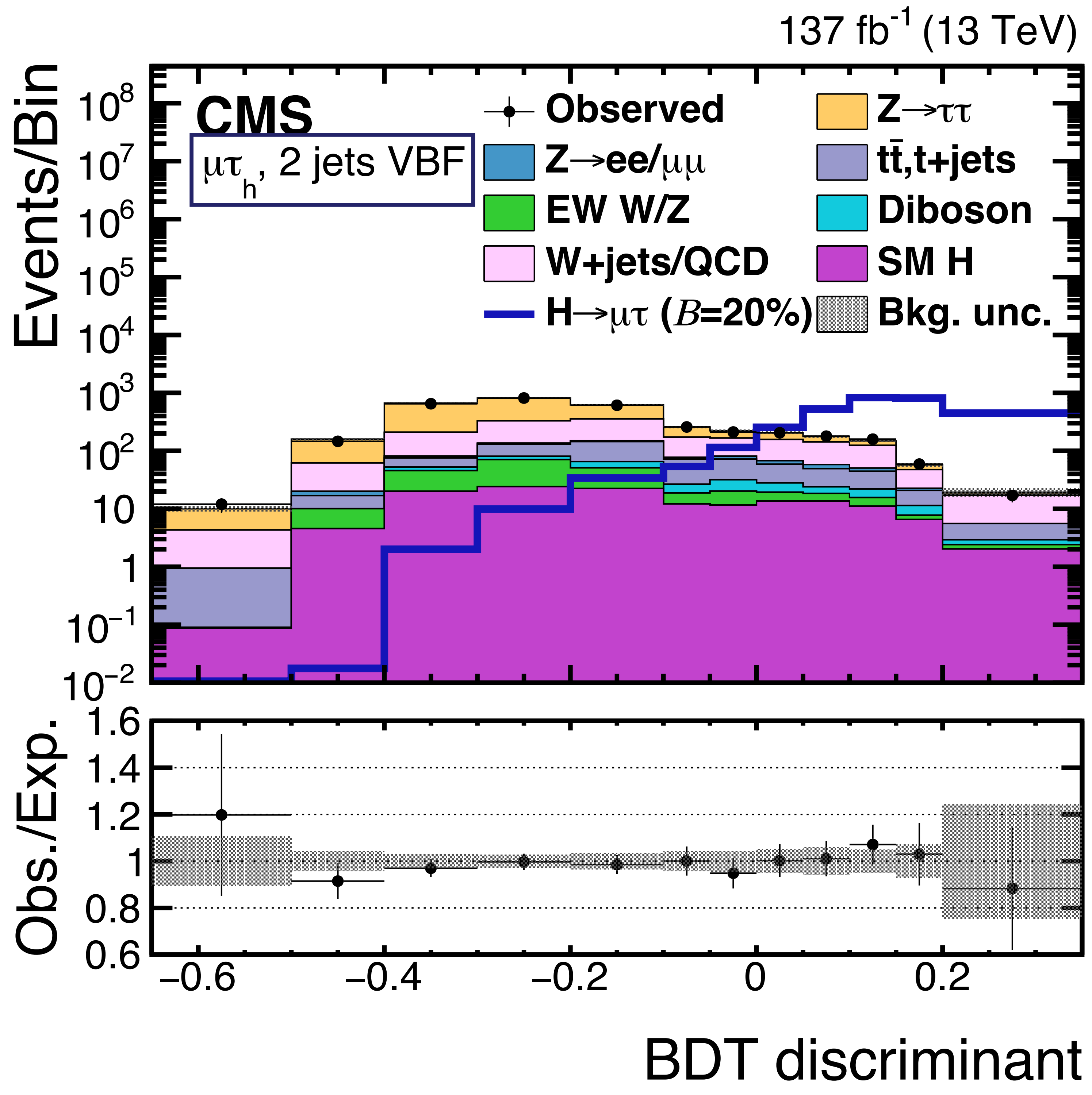
Focus on $Y_{e\tau}$ and $Y_{\mu\tau}$ ($Y_{e\mu}$ strongly constrained by $\mu \to e\gamma$)



Channels: $e\tau_h$, $e\tau_\mu$, $\mu\tau_h$, $\mu\tau_e$

Jet categories: 0j, 1j, 2j (ggH), VBF

BDTs to discriminate signal

Joint fit to BDT outputs

Most sensitive category

Lepton-Flavour Violating decays

Phys.Rev.D 104 (2022) 032013

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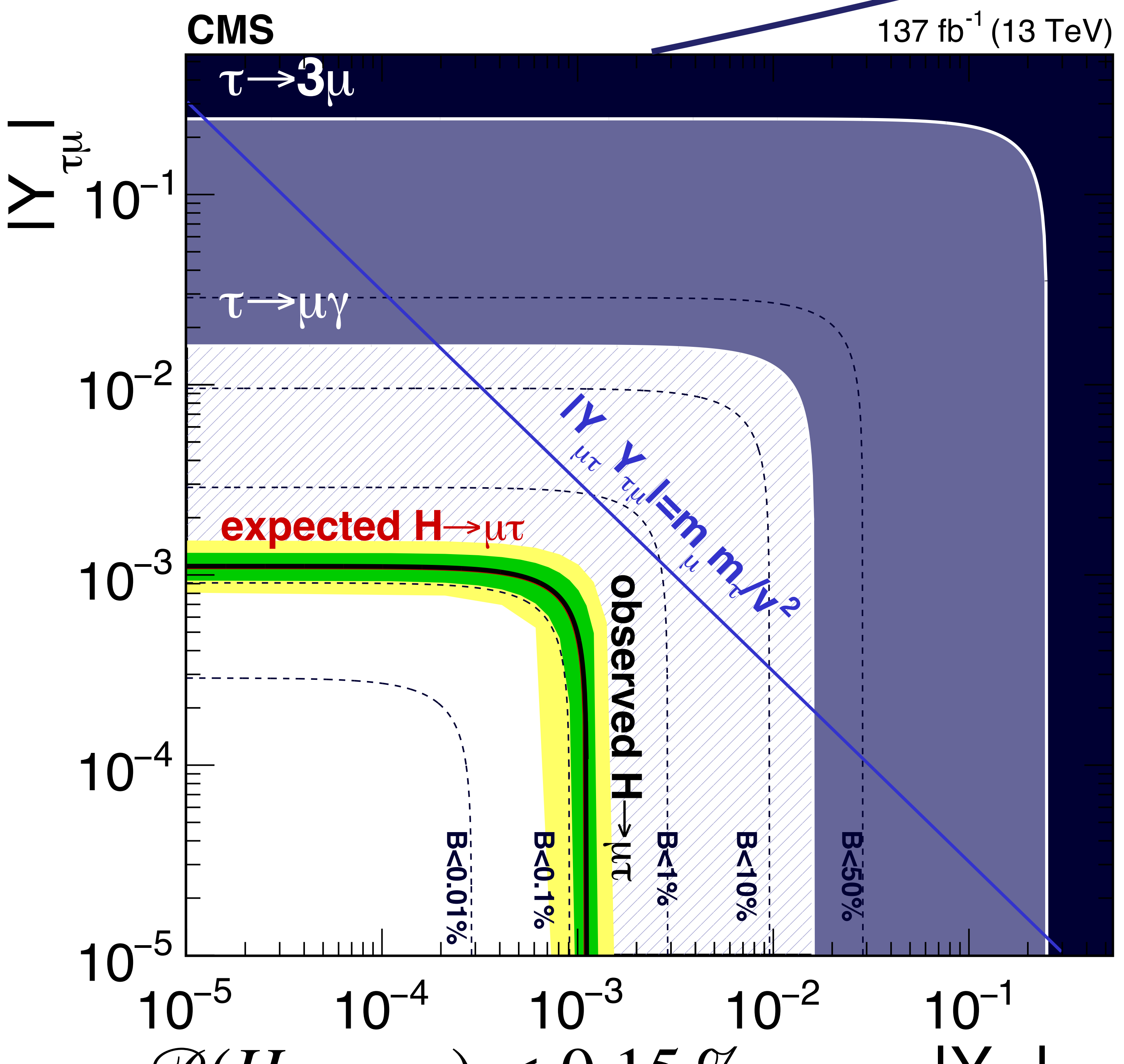
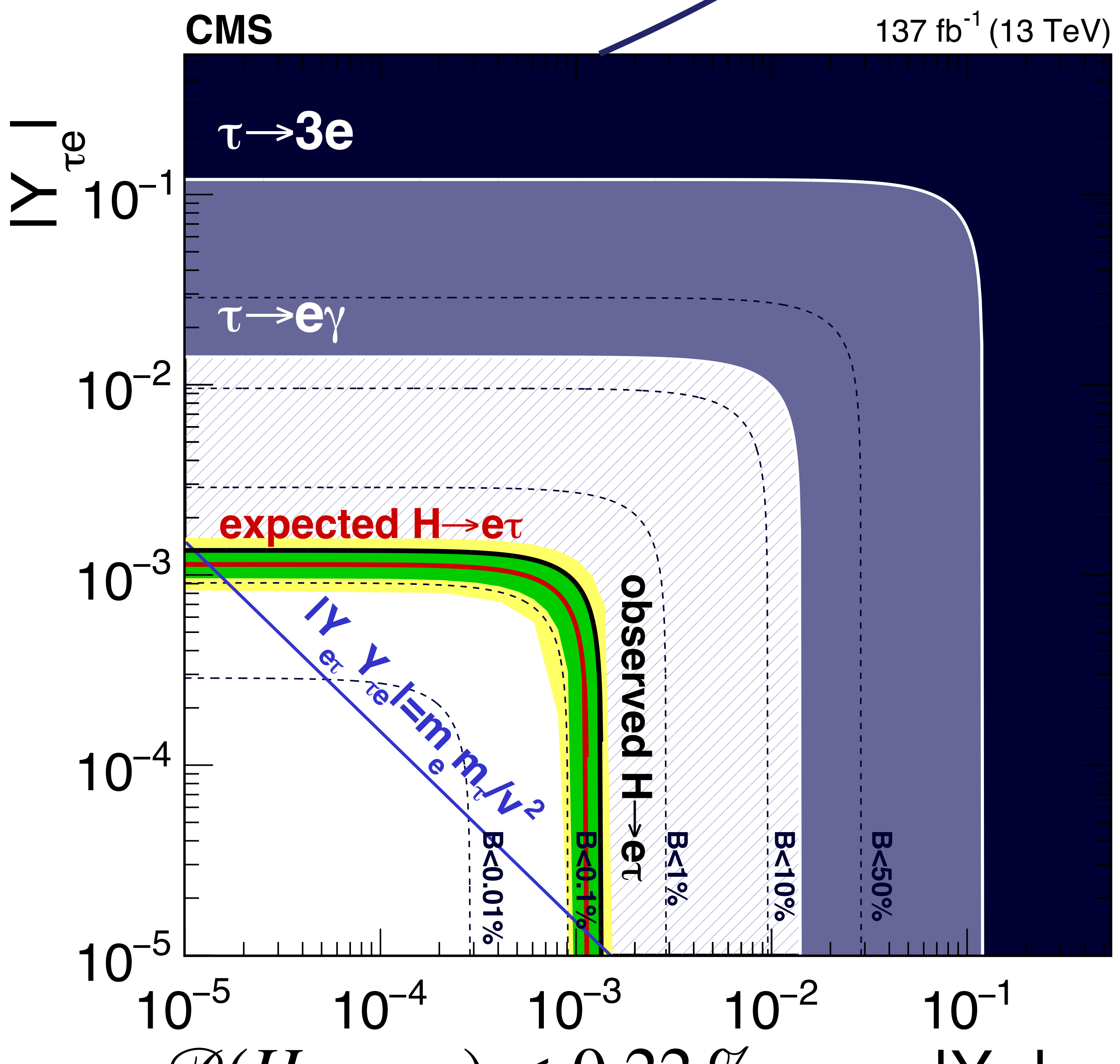
Focus on $Y_{e\tau}$ and $Y_{\mu\tau}$ ($Y_{e\mu}$ strongly constrained by $\mu \to e\gamma$)

The upper limits on $\mathscr{B}(H \to e\tau)$ and $\mathscr{B}(H \to \mu\tau)$ are used to put constraints on $Y_{e\tau}$ and $Y_{\mu\tau}$

Better than constraints from other experiments and for $Y_{\mu\tau}$ within the naturalness limit $|Y_{\mu\tau}Y_{\tau\mu}| < \frac{m_\mu m_\tau}{v^2}$



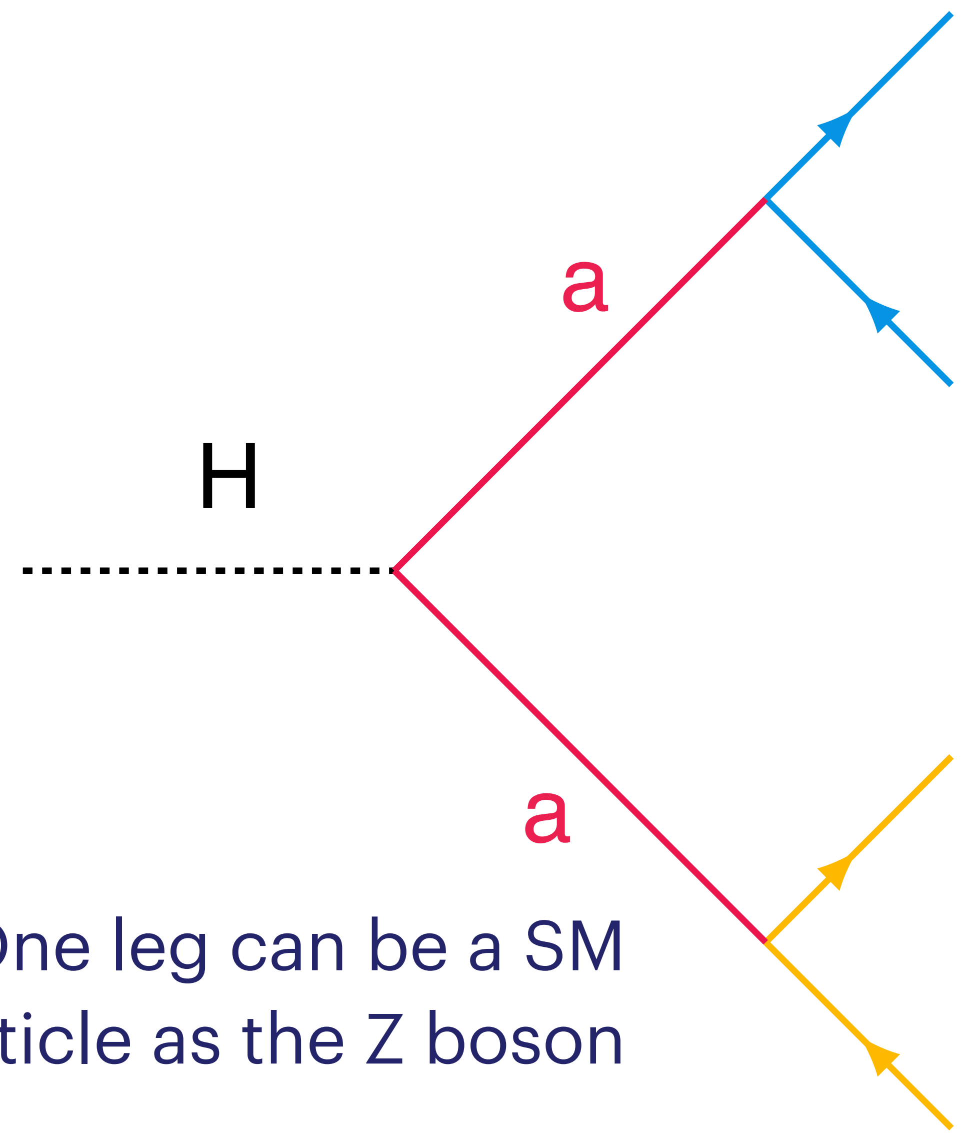
$\mathscr{B}(H \to \mu\tau) < 0.15\,\%$



$\mathscr{B}(H \to e\tau) < 0.22\,\%$

Higgs boson exotic decays

Some extensions[1] to the SM include Higgs boson decays via one or two hypothetical on-shell new (pseudo)scalar(s) decaying to a pair of SM particles.



One leg can be a SM particle as the Z boson

[1] additional SM-neutral singlet model, minimal composite Higgs models, two-Higgs-doublet-like models, next-to-minimal supersymmetric standard models, axion-like particle models, hidden abelian Higgs models, ….

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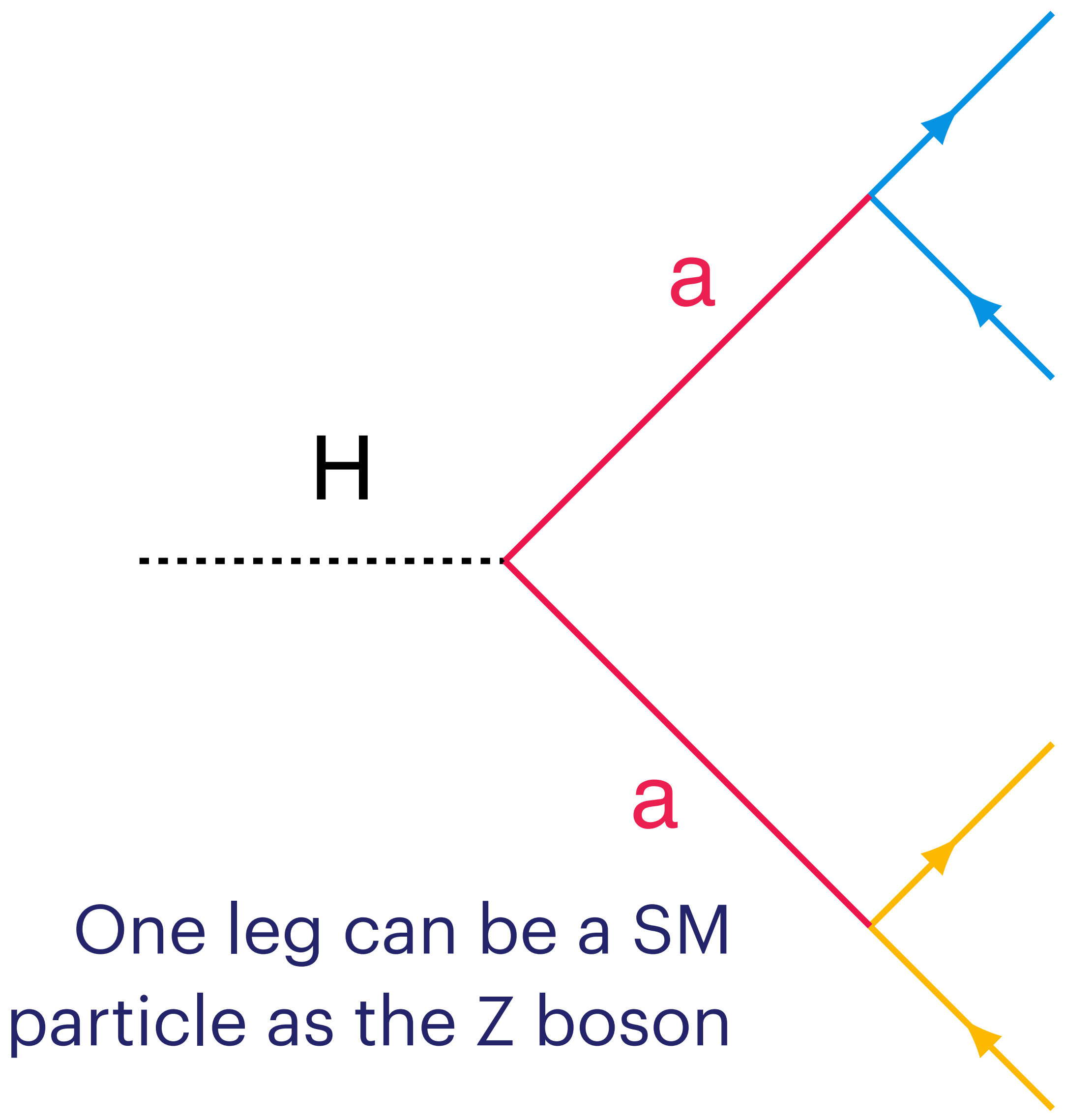
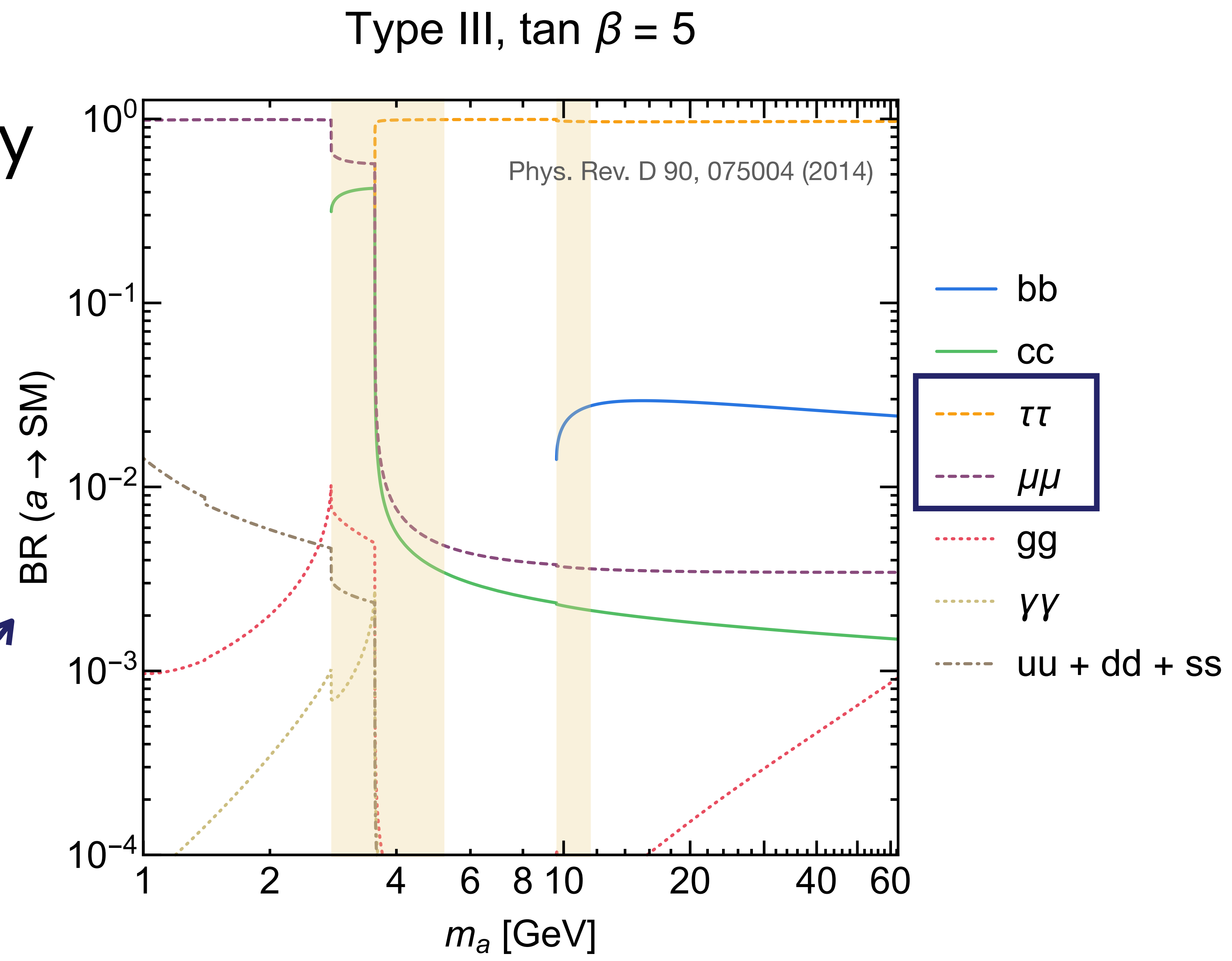


If kinematically allowed a → bb generally dominates, but other decays may also be significant depending on the model.

As example



Searches down to 15–20 GeV have resolved final states, below that, **decay products start to merge**.

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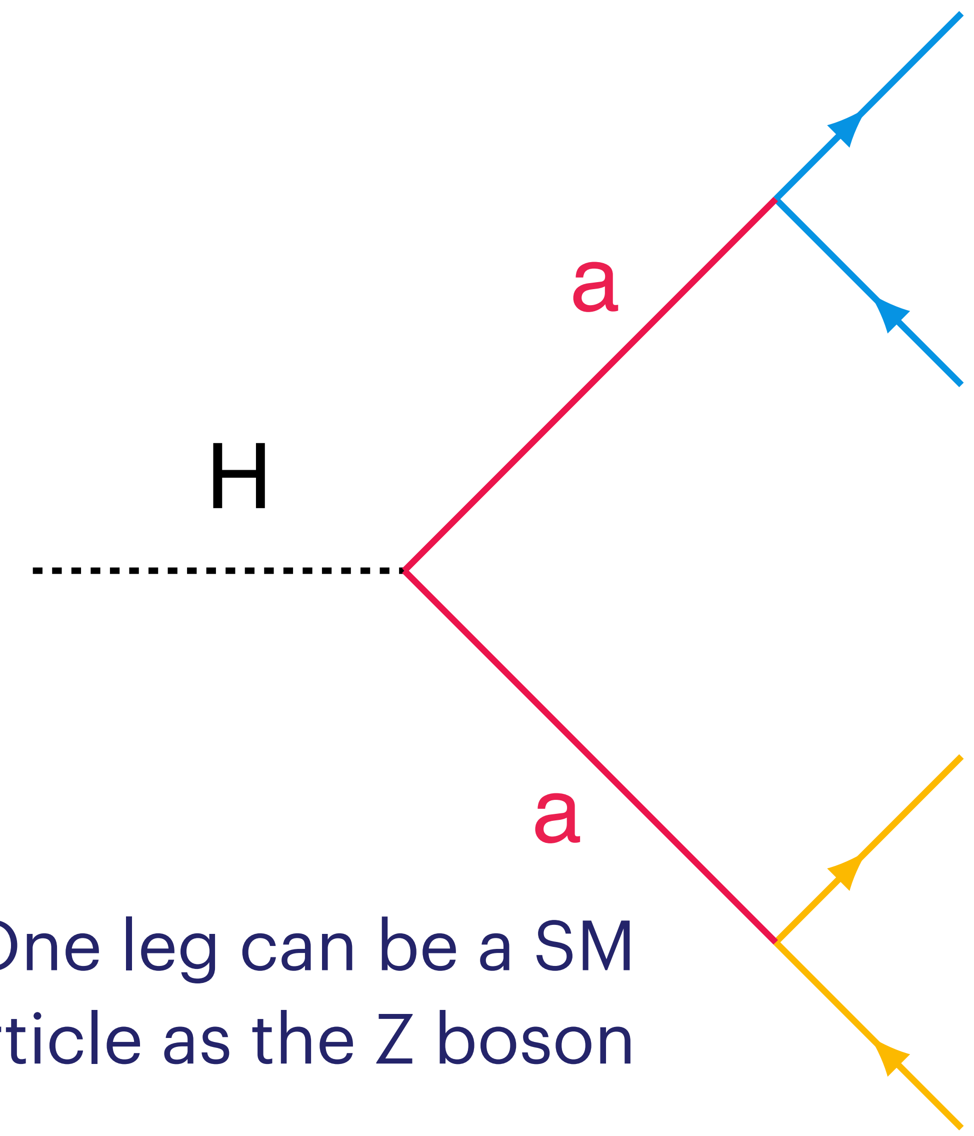

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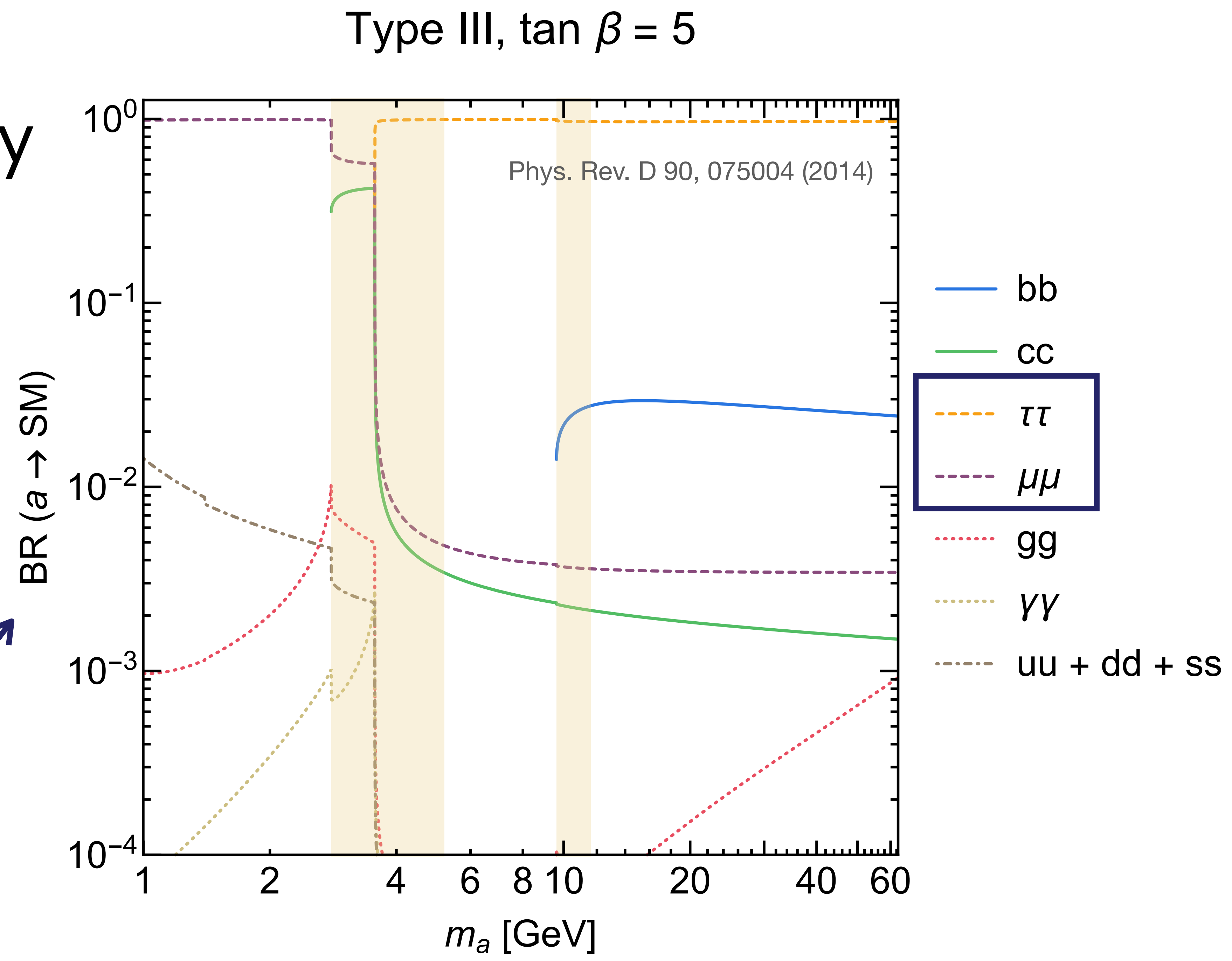

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ATLAS and CMS have produced many results on various final states using the LHC Run2 data.

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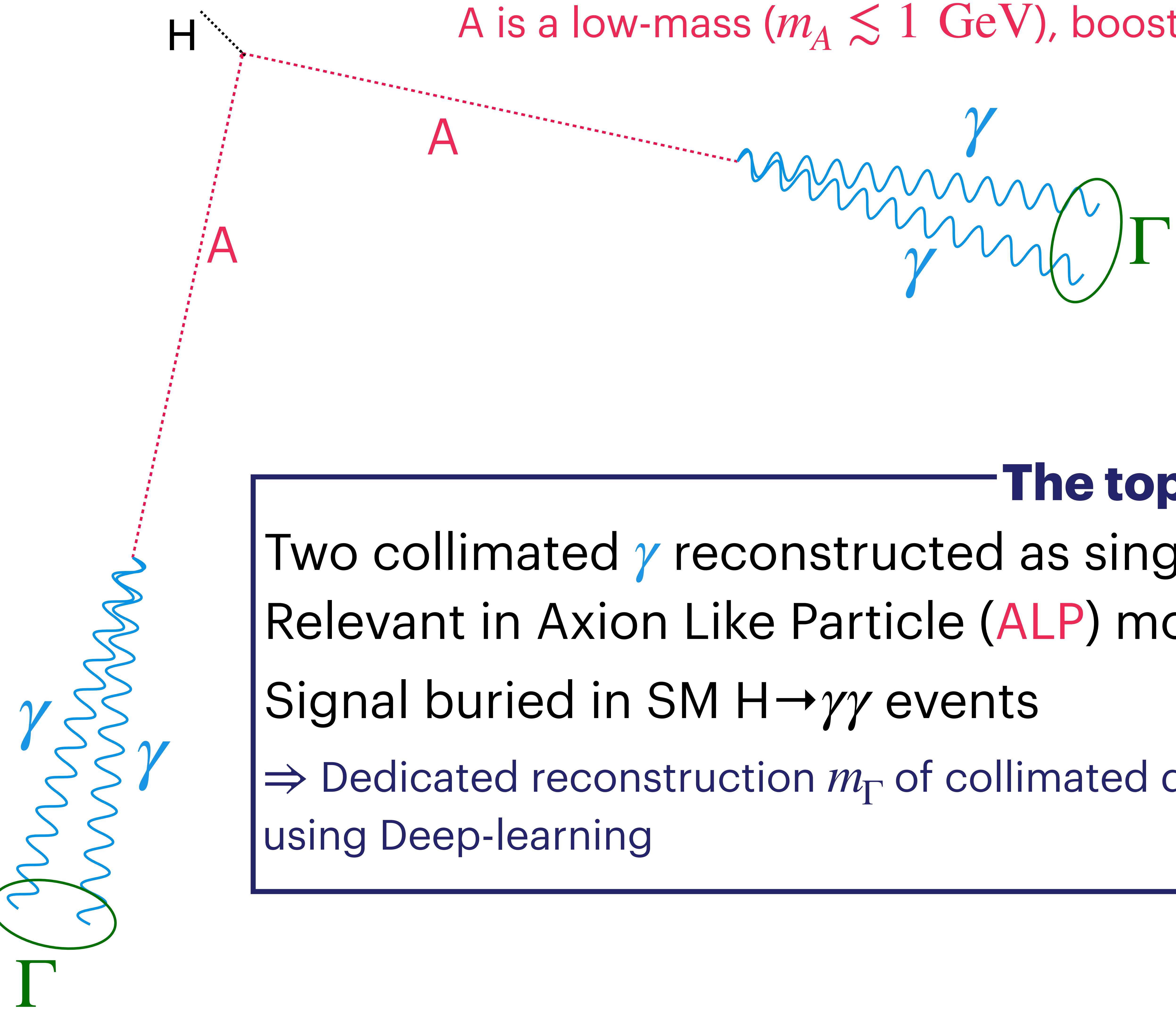
$H \to AA \to 4\gamma$

A is a low-mass ($m_A \lesssim 1$ GeV), boosted scalar



The topology

Two collimated γ reconstructed as single Γ

Relevant in Axion Like Particle (ALP) model

Signal buried in SM $H \to \gamma\gamma$ events

⇒ Dedicated reconstruction m_Γ of collimated di-γ using Deep-learning

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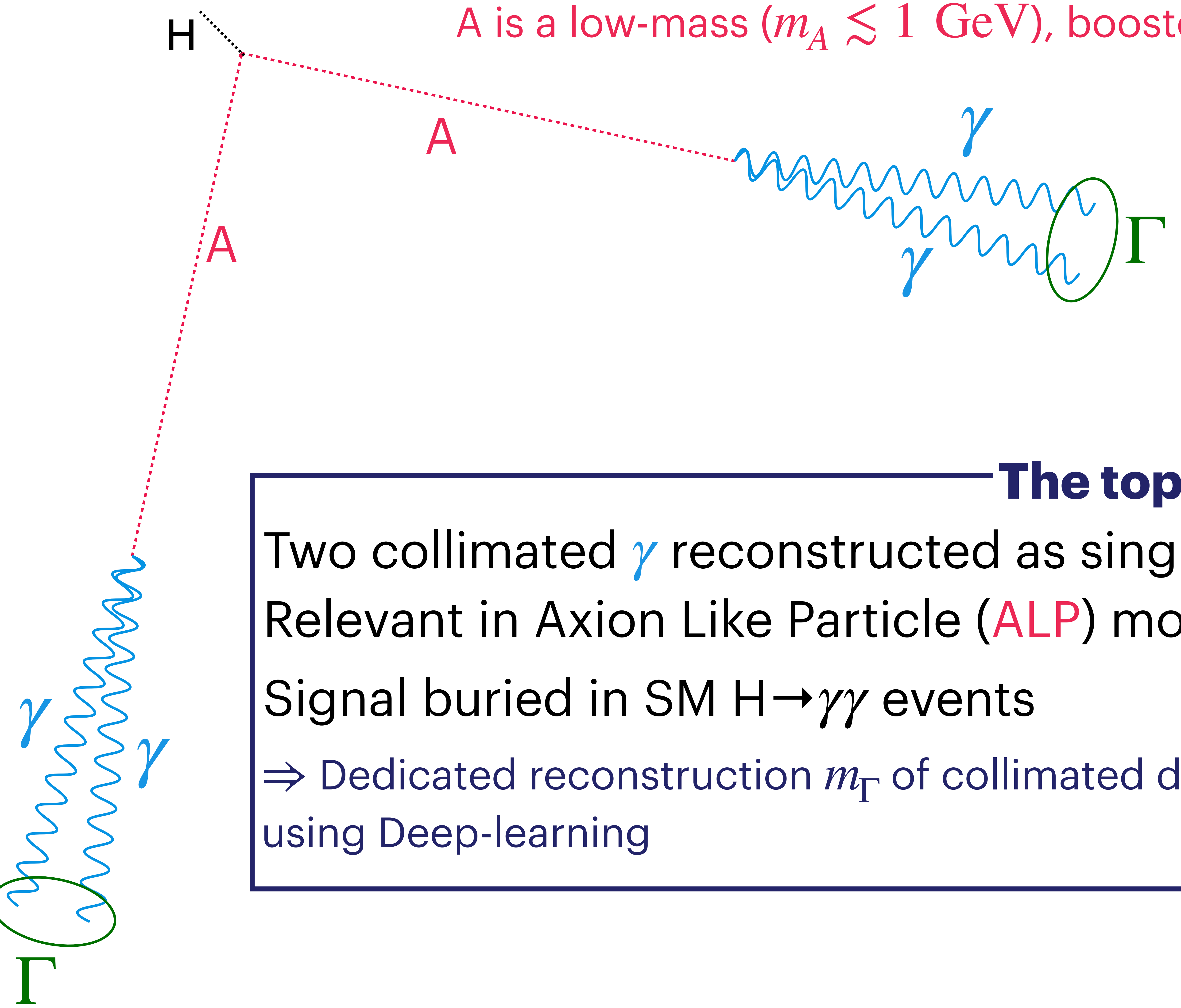

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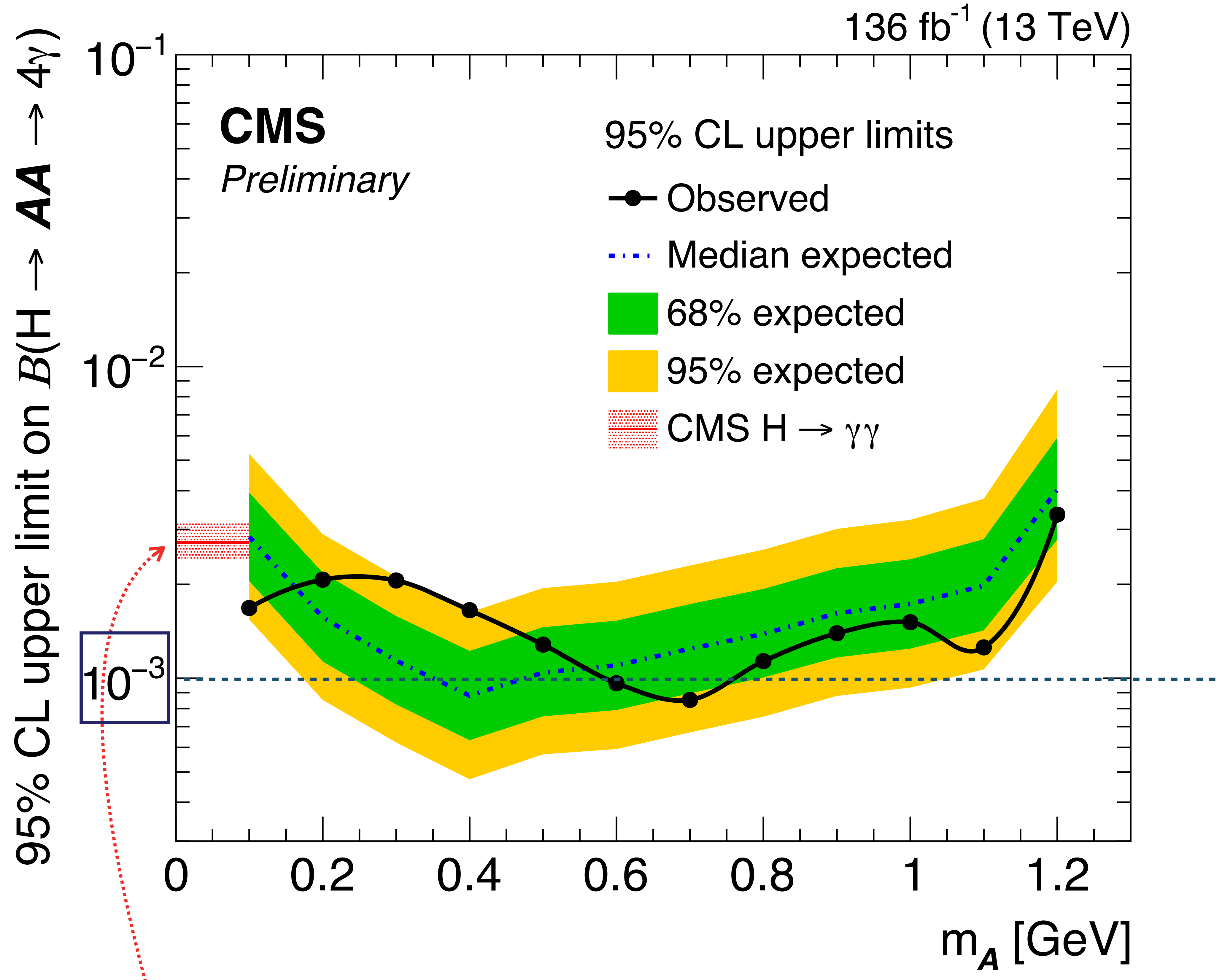
Upper limits on the branching fraction $\mathscr{B}(H \rightarrow AA \rightarrow 4\gamma)$



Upper bound provided by SM $H \rightarrow \gamma\gamma$

$H \rightarrow ZZ_d/Z_dZ_d/ss/aa \rightarrow 4\ell$

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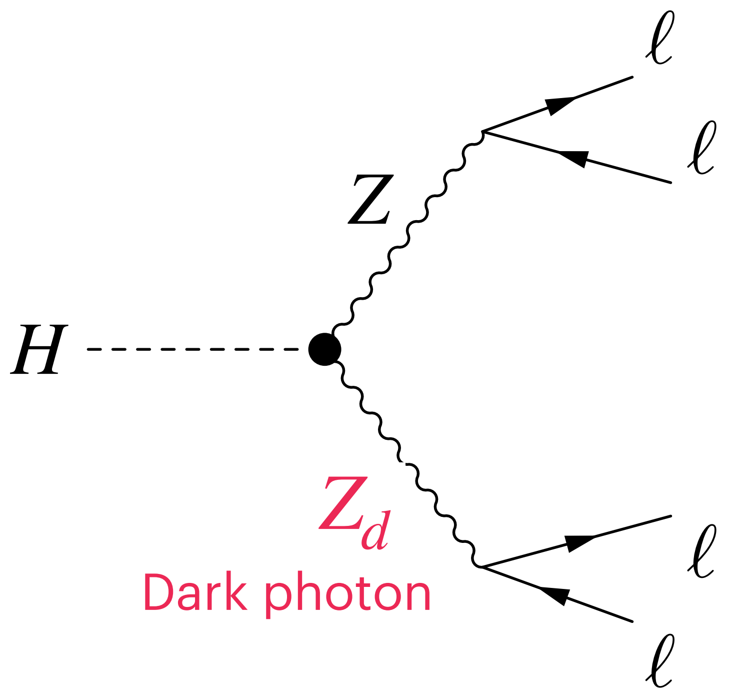
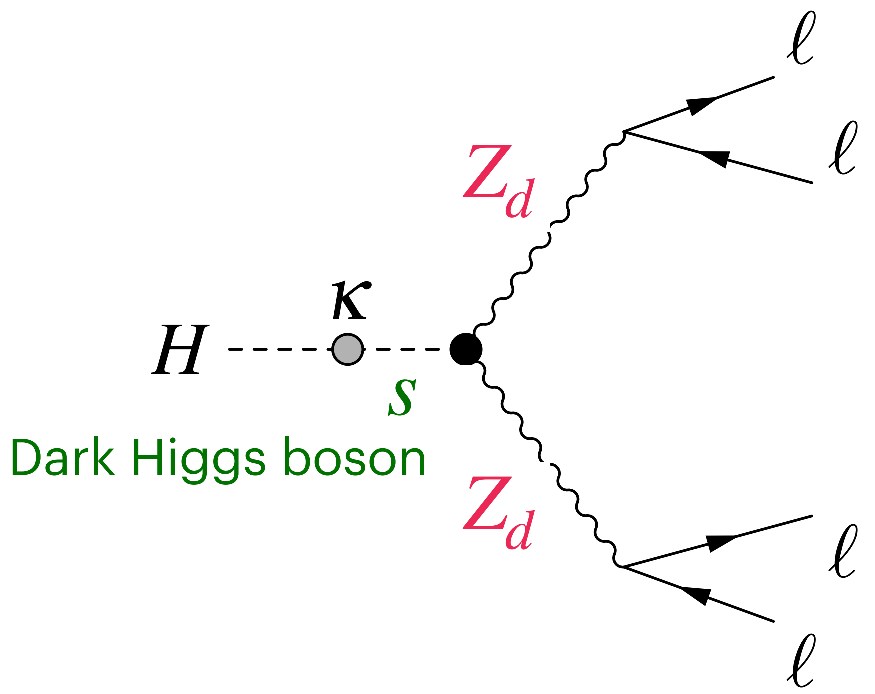
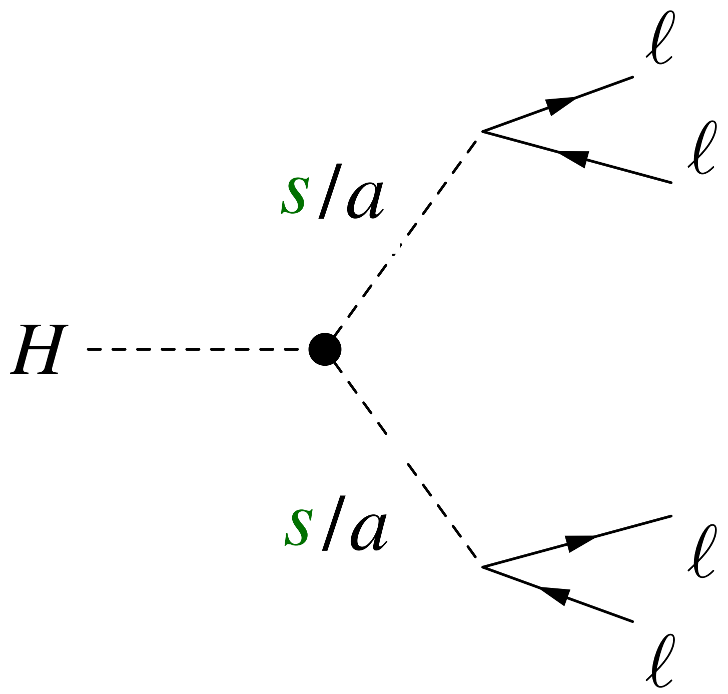
Results in this final state can be interpreted various theoretical models



U(1) gauge theory mixes with SM hypercharge



U (1) is broken by a hidden-sector Higgs mechanism



Extended Higgs sector

$H \to ZZ_d / Z_d Z_d / ss / aa \to 4\ell$

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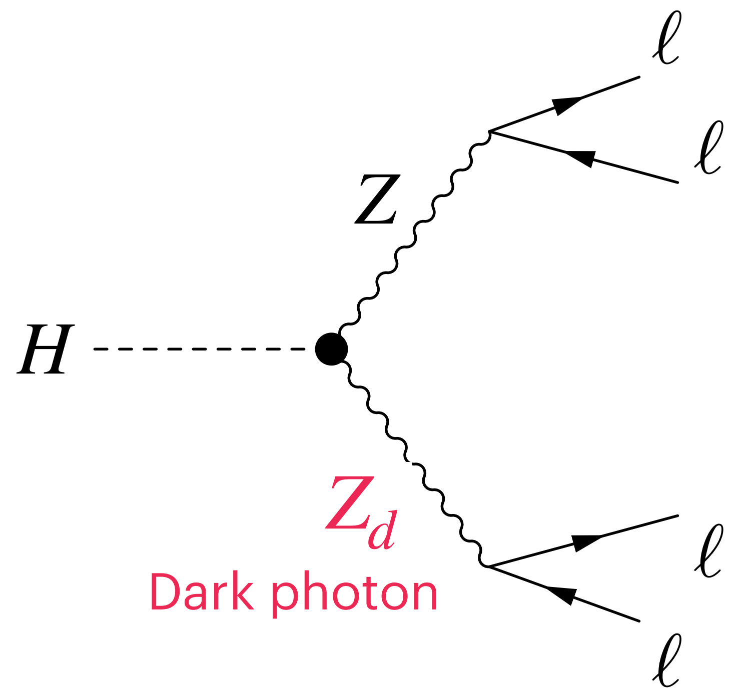

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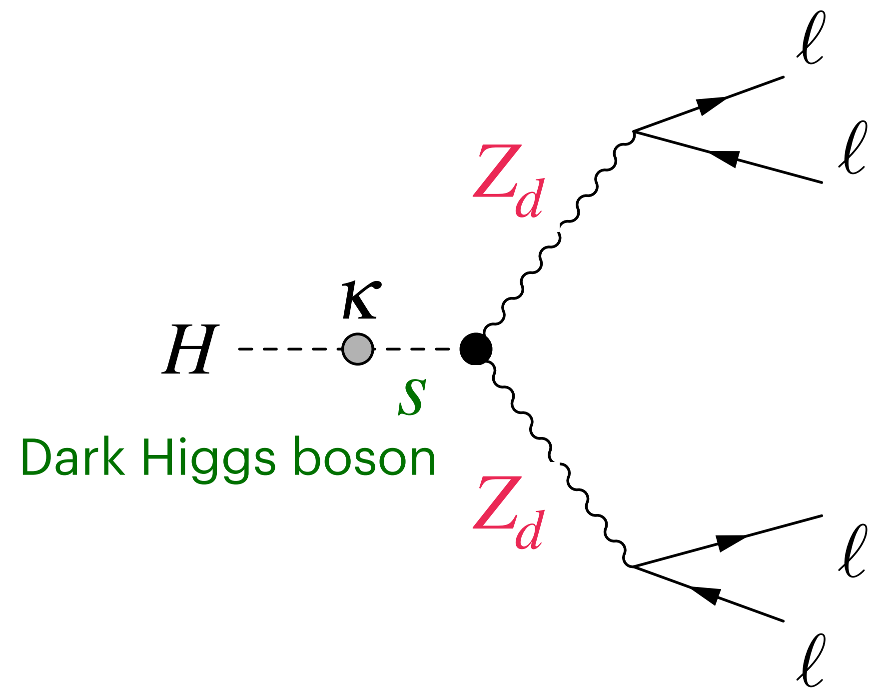

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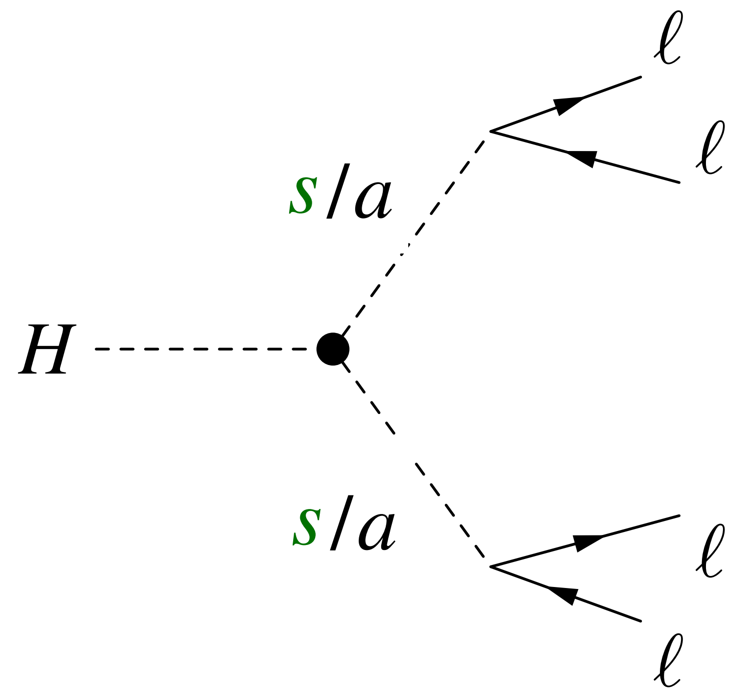

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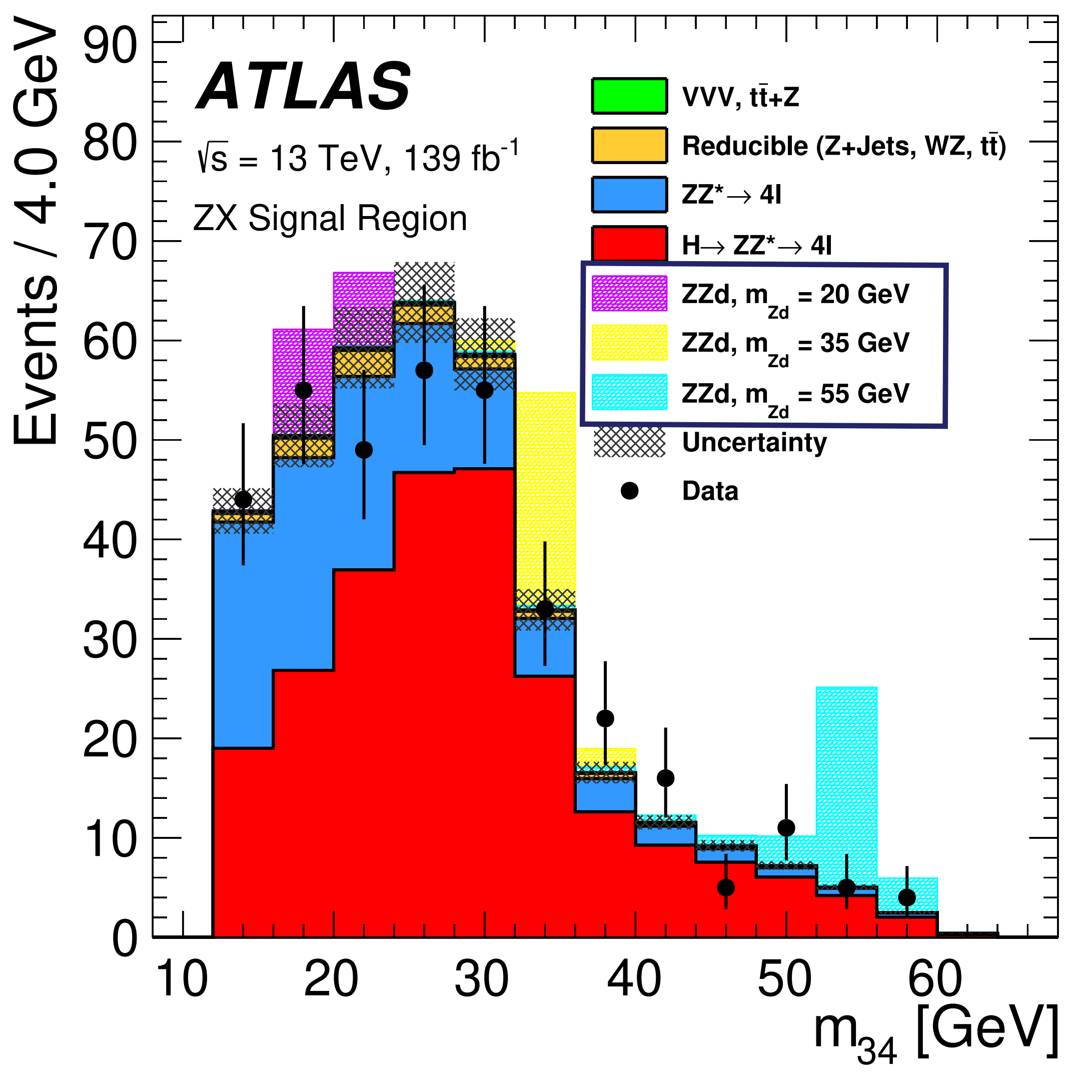
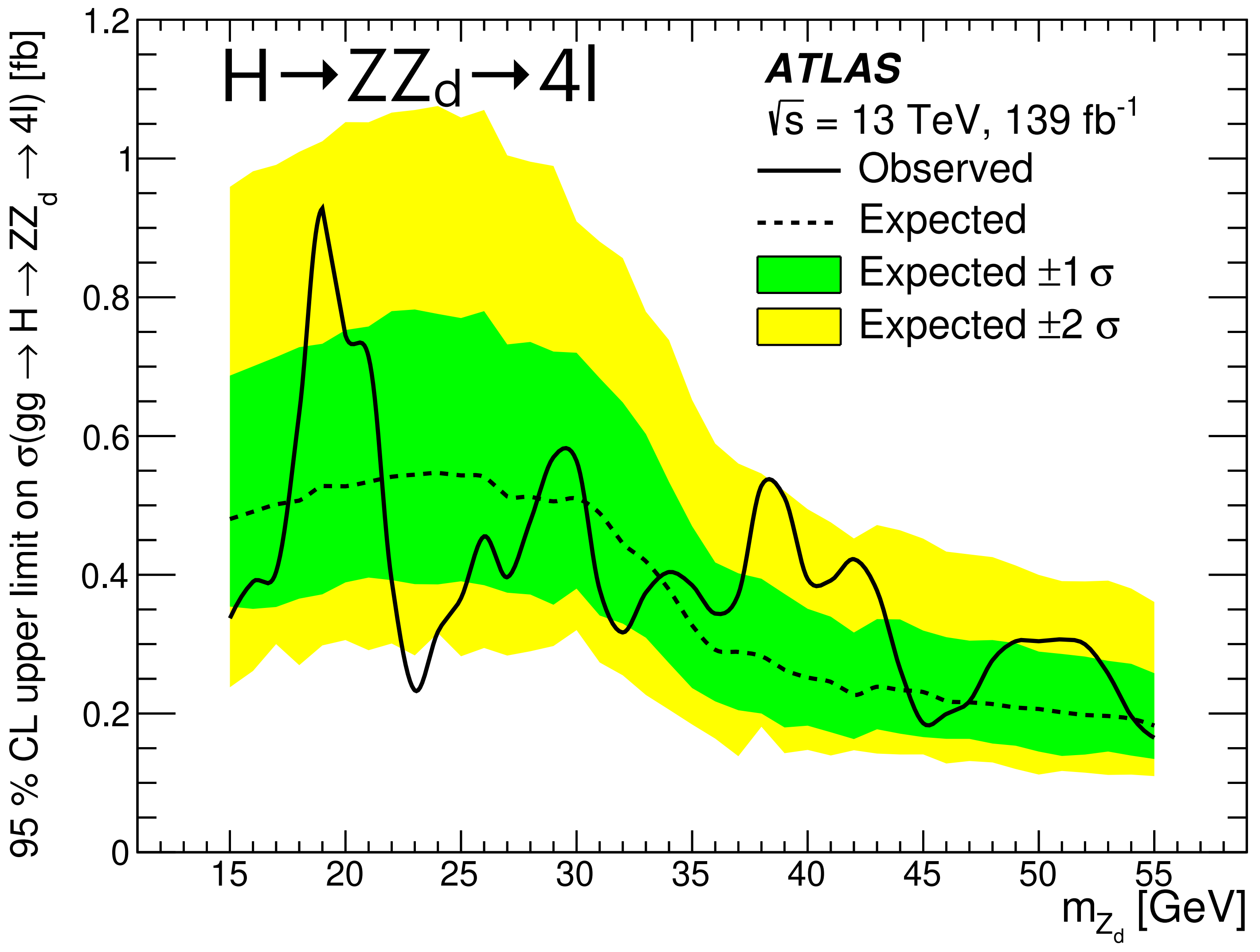


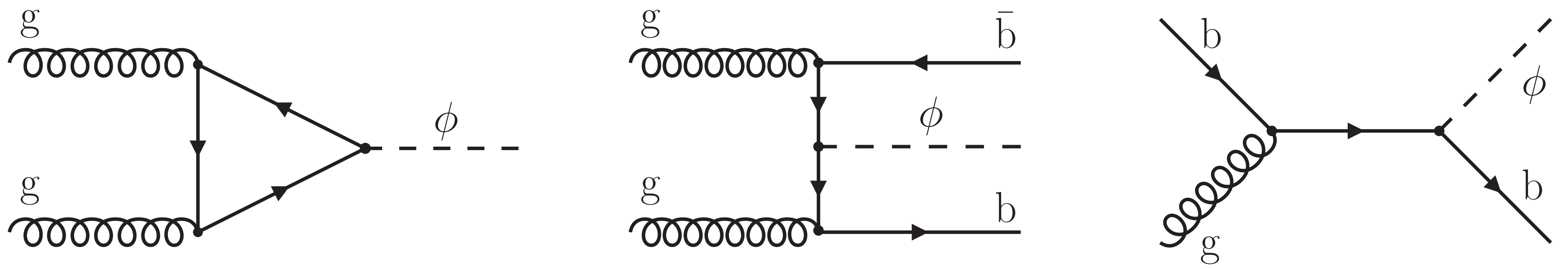


Also model-independent fiducial cross section limits

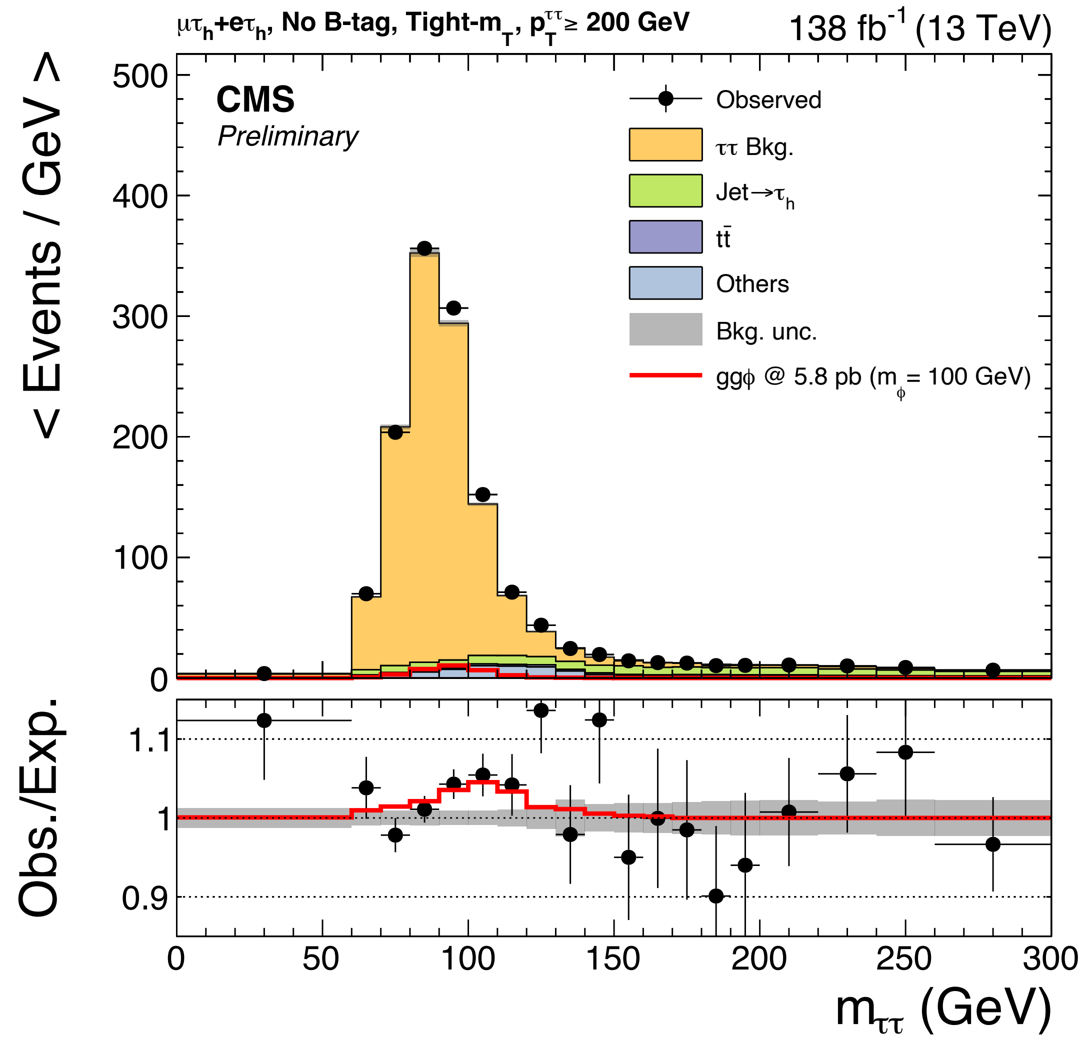
A/H→ττ

CMS PAS HIG-21-001

4 ττ final states ($\tau_h\tau_h$, $\mu\tau_h$, $e\tau_h$, $e\mu$)
b-tag/no b-tag category



Fit $m_{\tau\tau}$
in various Higgs p_T categories

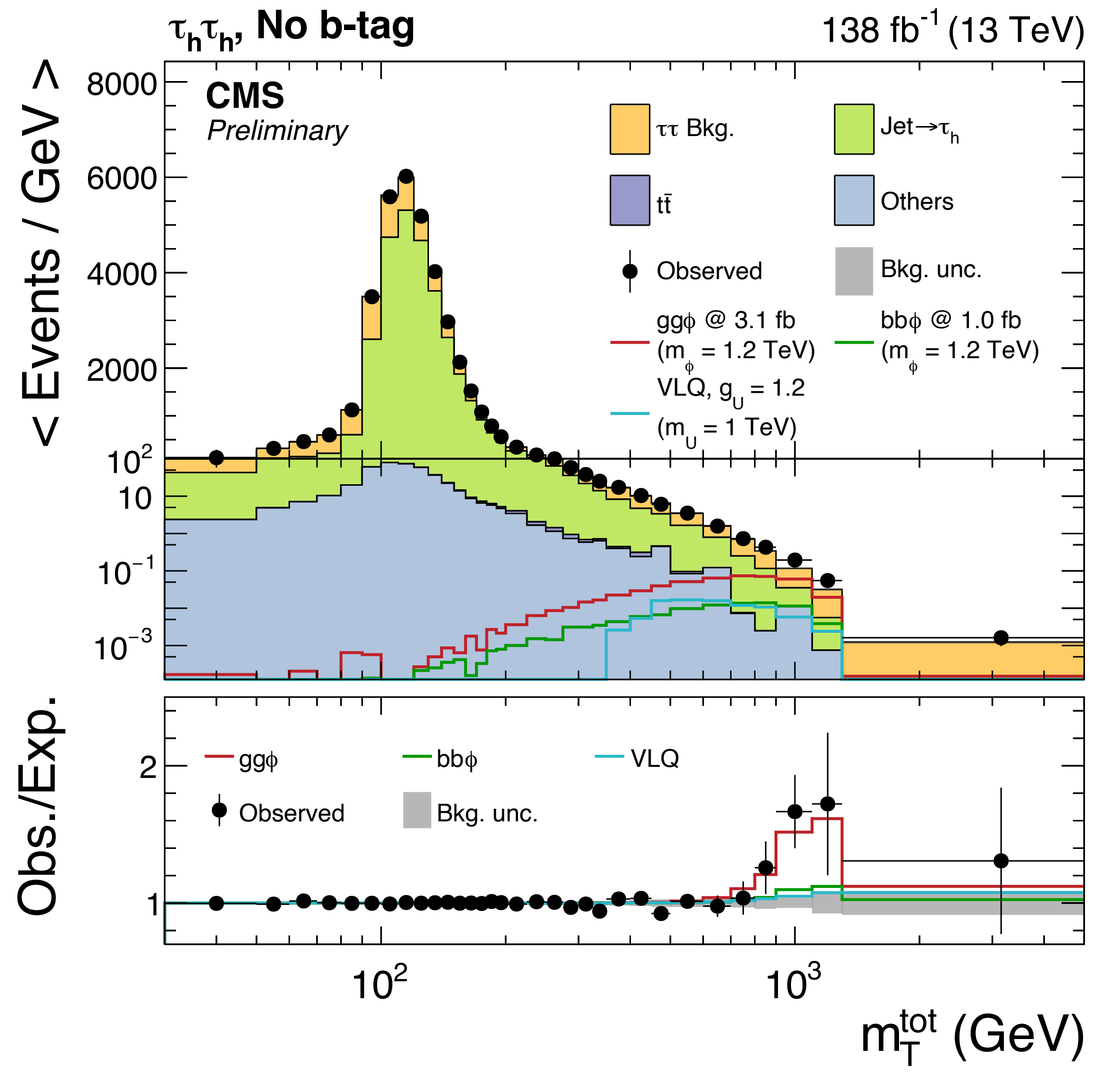


Low-mass analysis

$m_\phi < 250$ GeV

High-mass analysis

$m_\phi > 250$ GeV



Fit transverse mass variable
Few m_T categories

A/H→ττ

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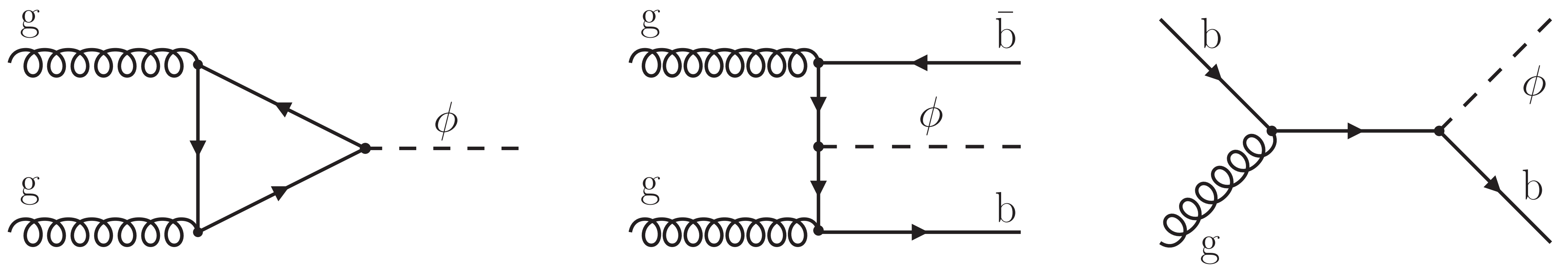
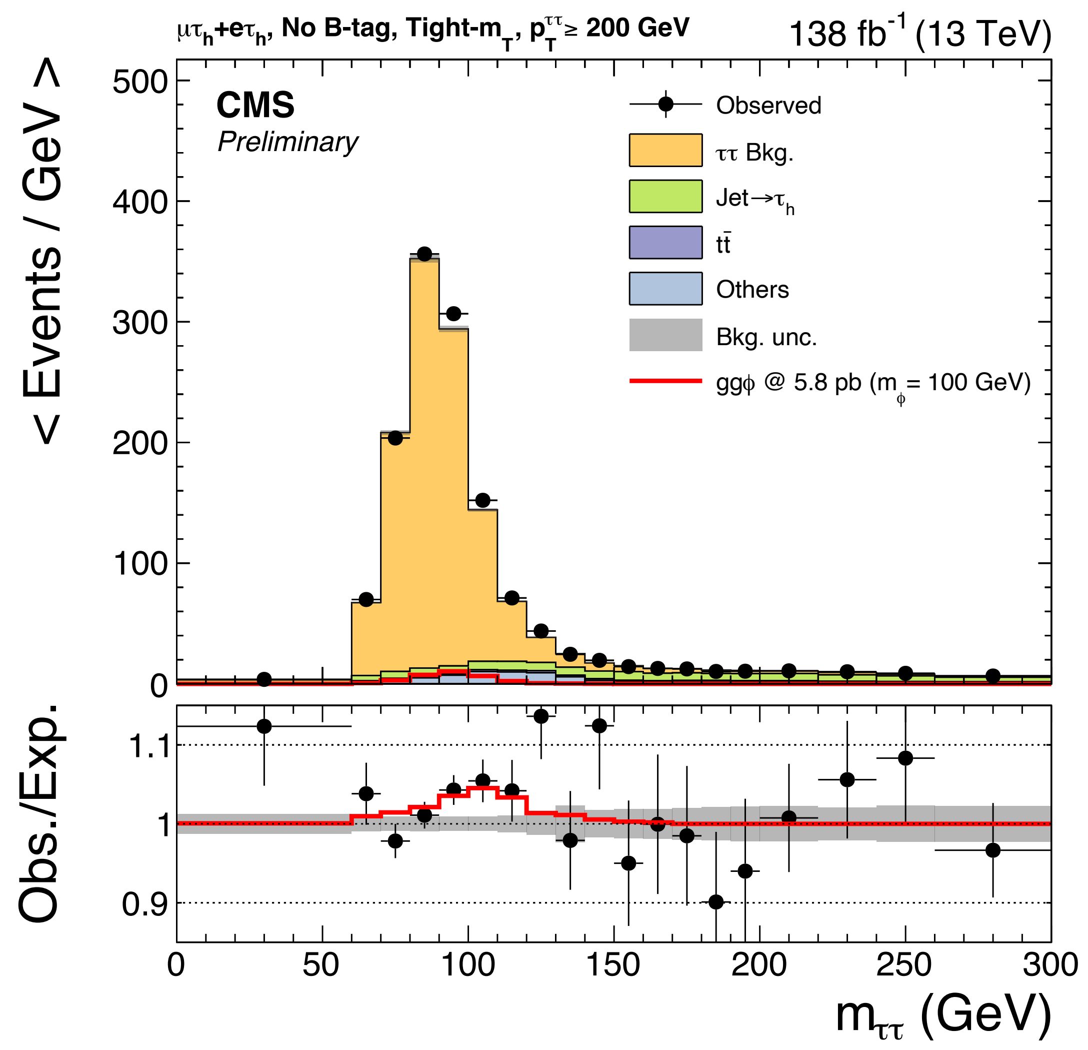
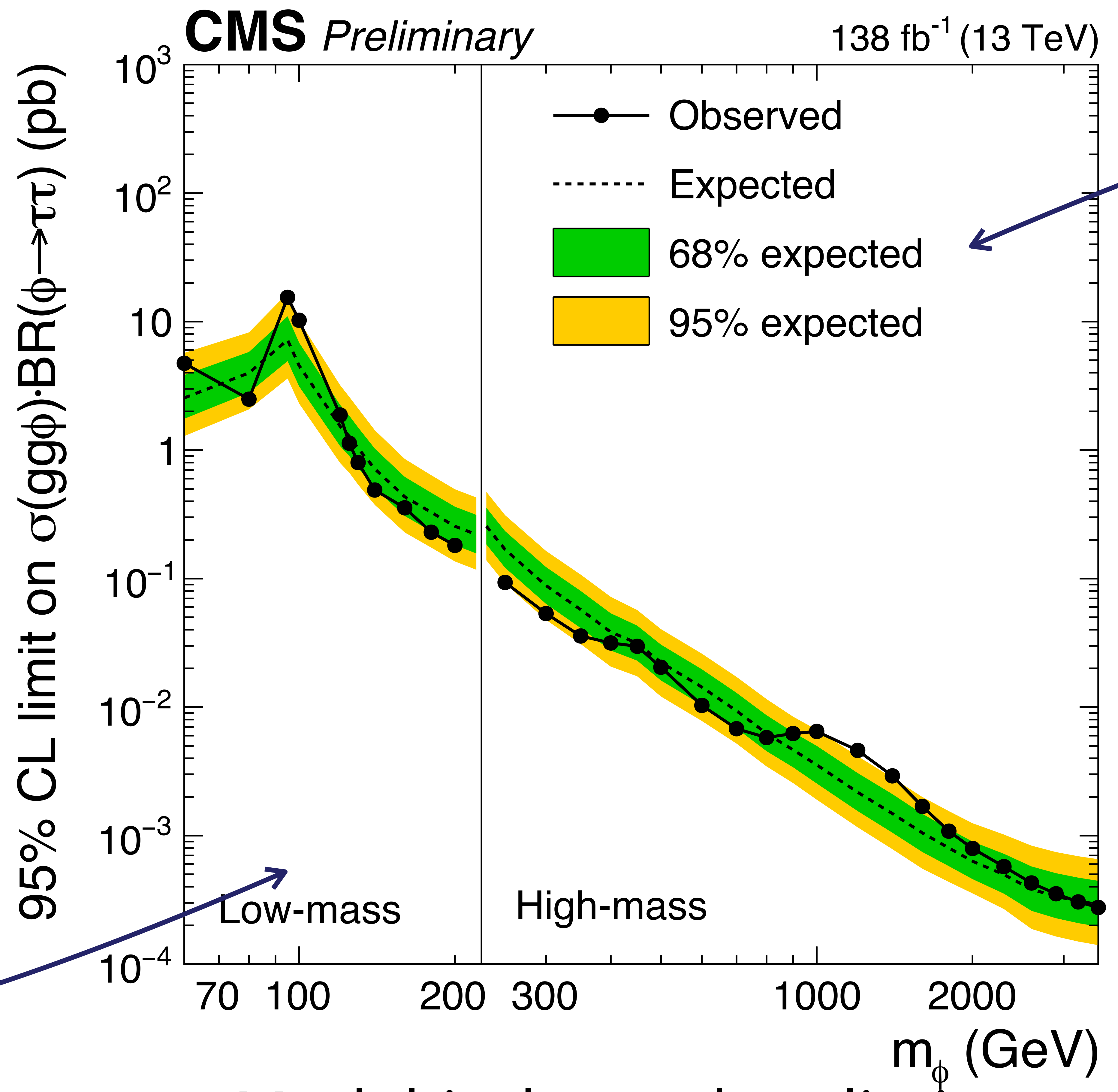


Fit $m_{\tau\tau}$
in various Higgs p_T categories

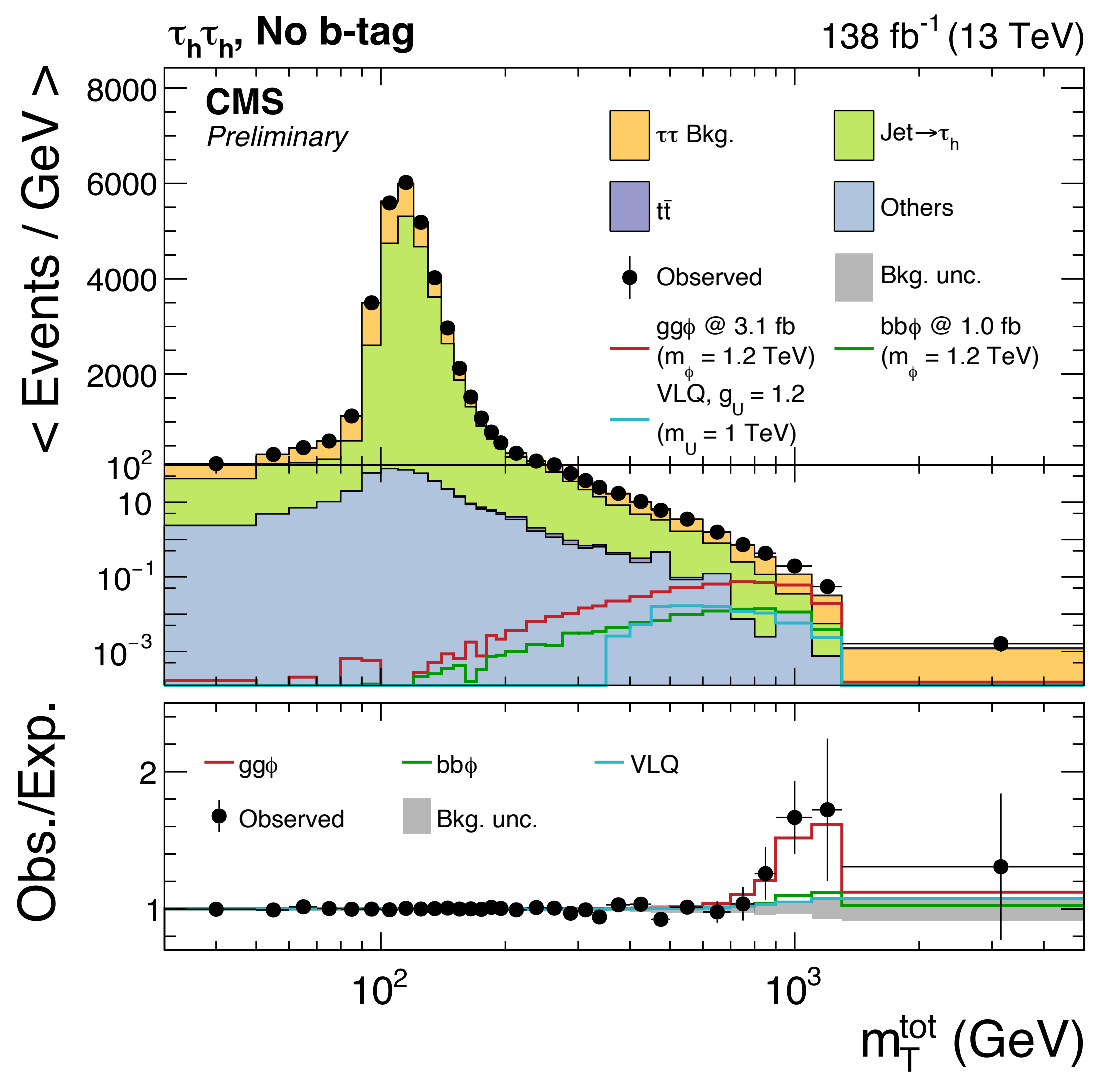


Low-mass analysis
$m_\phi < 250$ GeV



Model-independent limits
on $\sigma(gg\phi)$ and $\sigma(bb\phi)$

High-mass analysis
$m_\phi > 250$ GeV

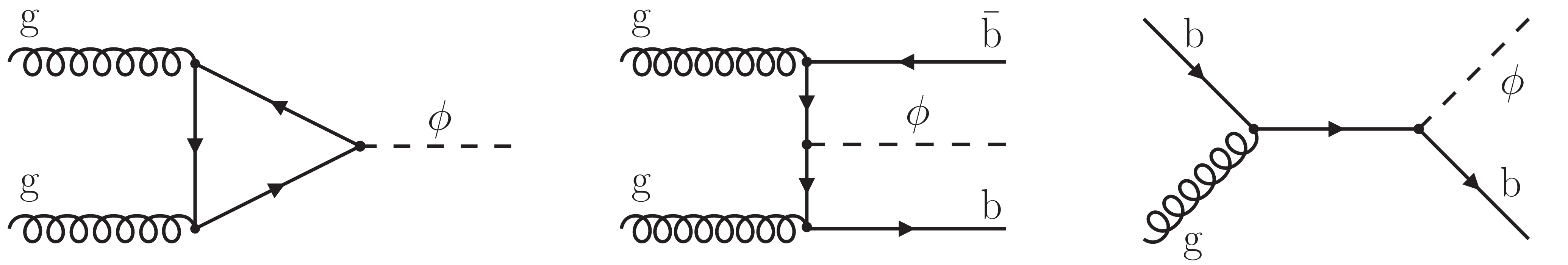


Fit transverse mass variable
Few m_T categories

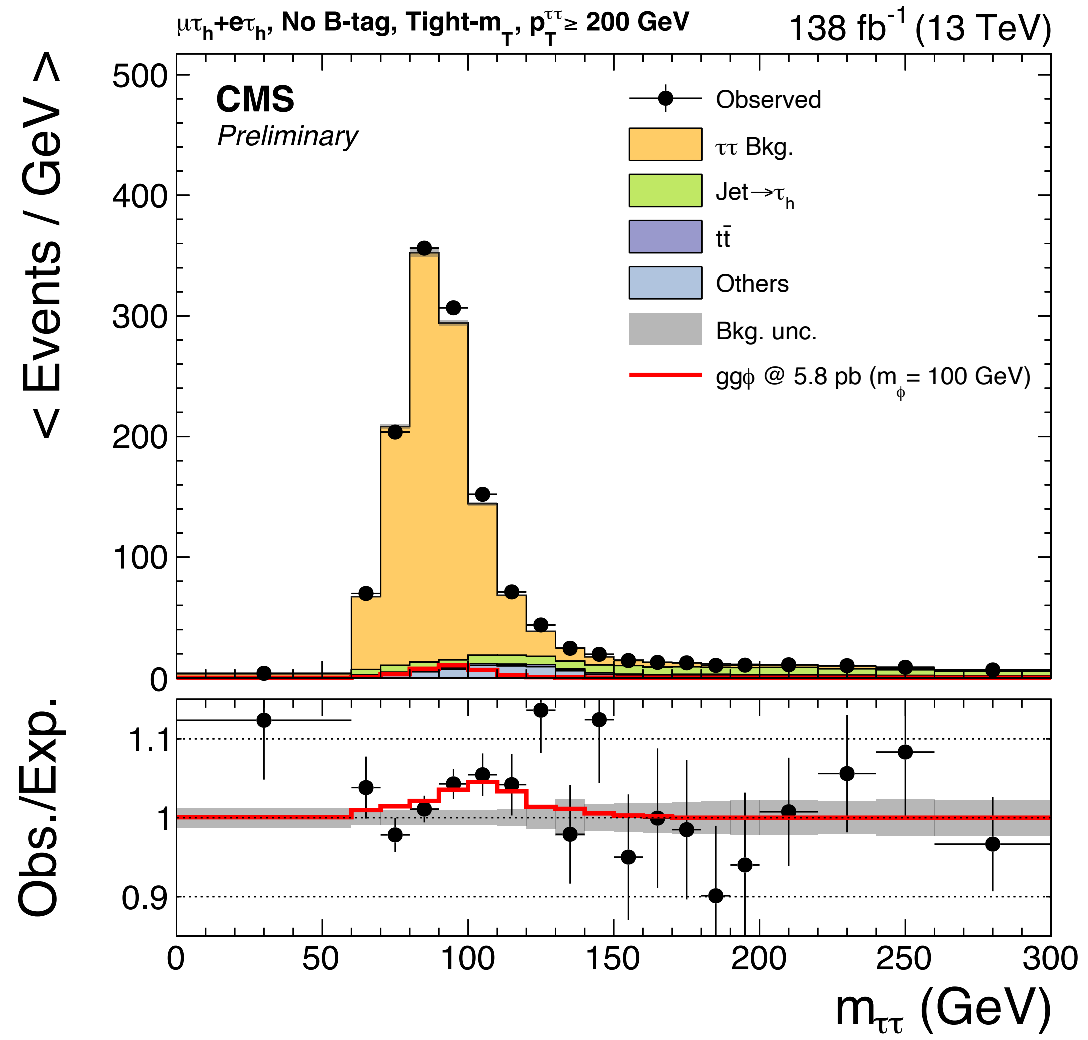
$A/H \rightarrow \tau\tau$

CMS PAS HIG-21-001

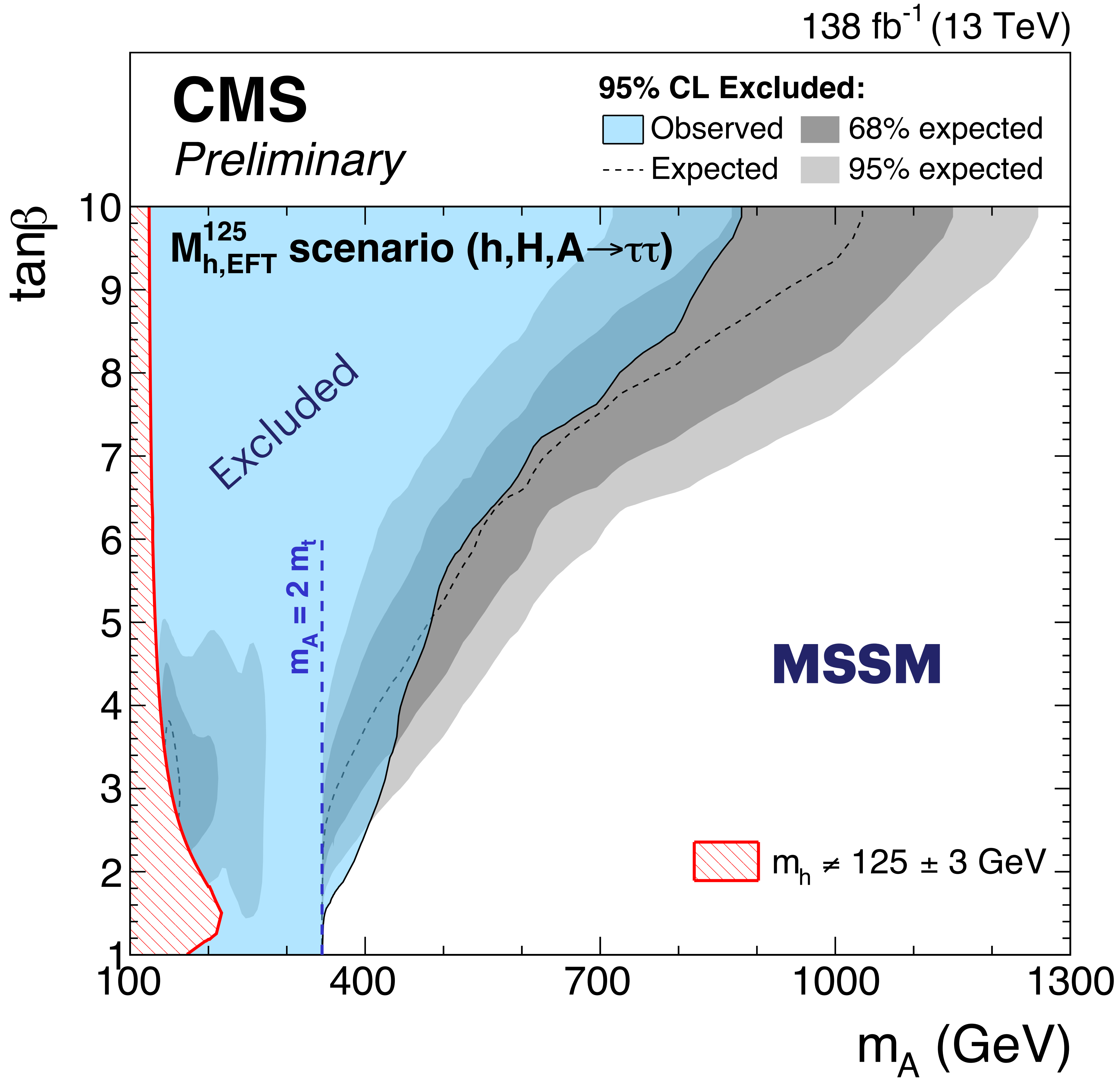
4 ττ final states ($\tau_h\tau_h$, $\mu\tau_h$, $e\tau_h$, $e\mu$)
b-tag/no b-tag category



Fit $m_{\tau\tau}$
in various Higgs p_T categories

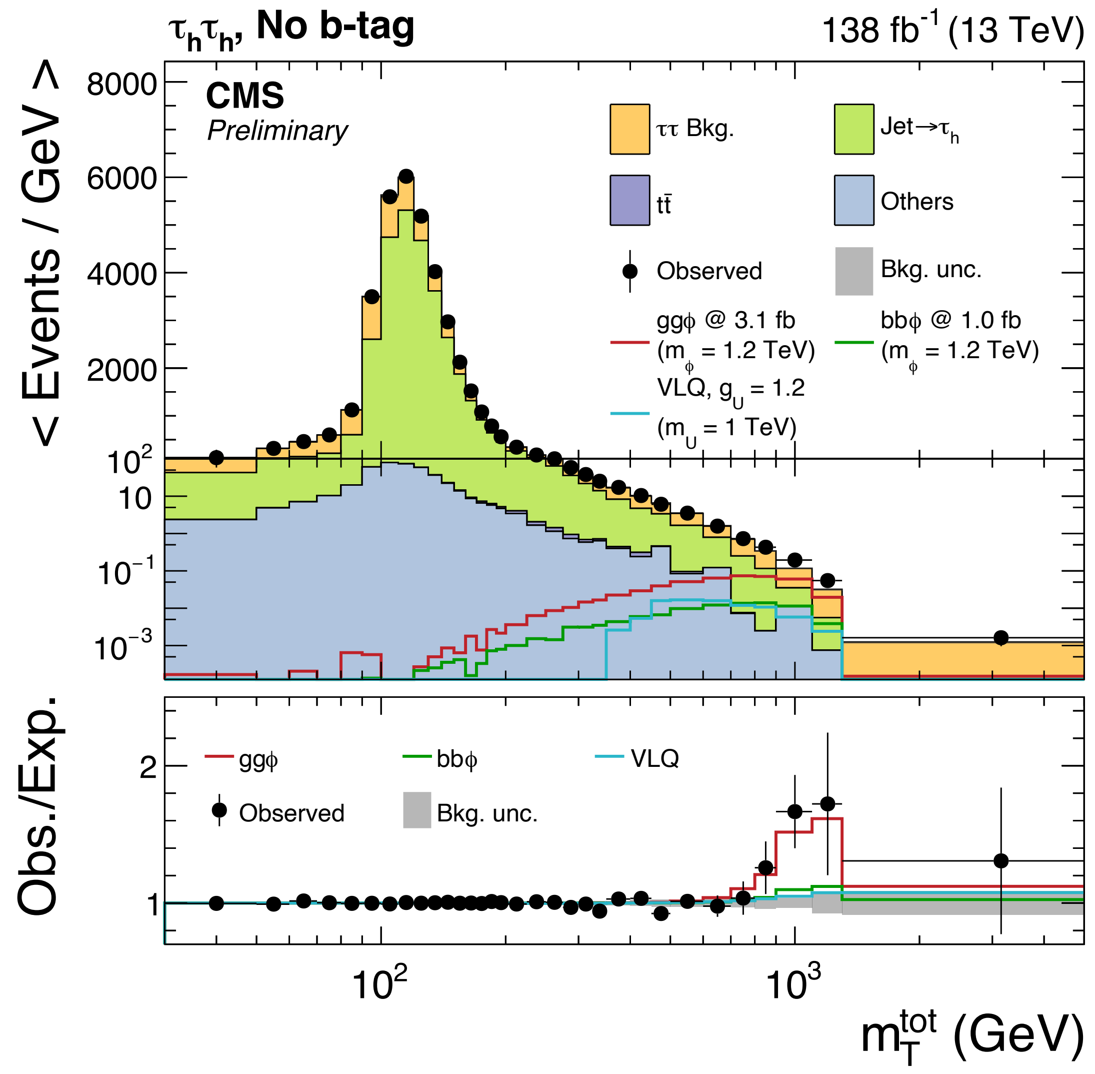


Low-mass analysis
$m_\phi < 250$ GeV



Model dependent limits
on various scenarios

High-mass analysis
$m_\phi > 250$ GeV



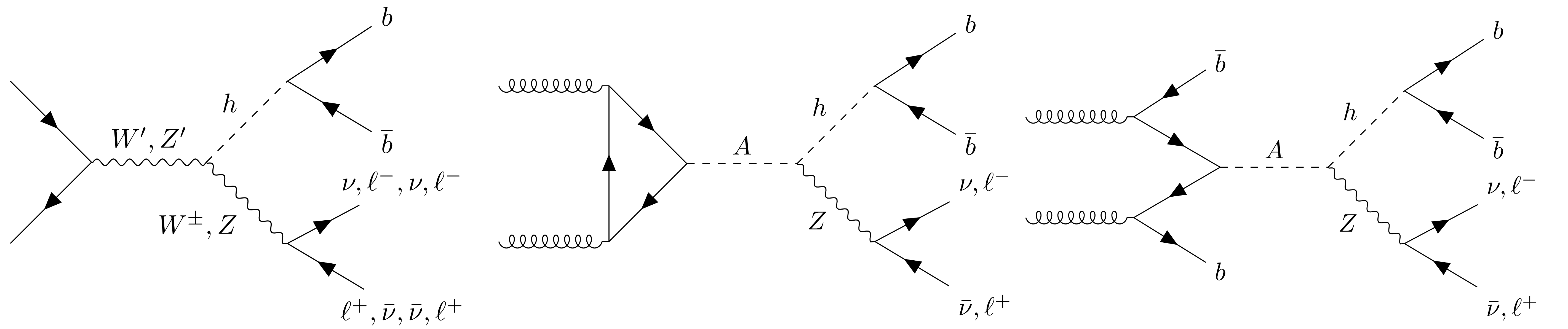
Fit transverse mass variable
Few m_T categories

W′/Z′/A→Vh125

HDBS-2020-19

Phys. Rev. D 105 (2022) 032008

Eur. Phys. J. C 81 (2021) 688

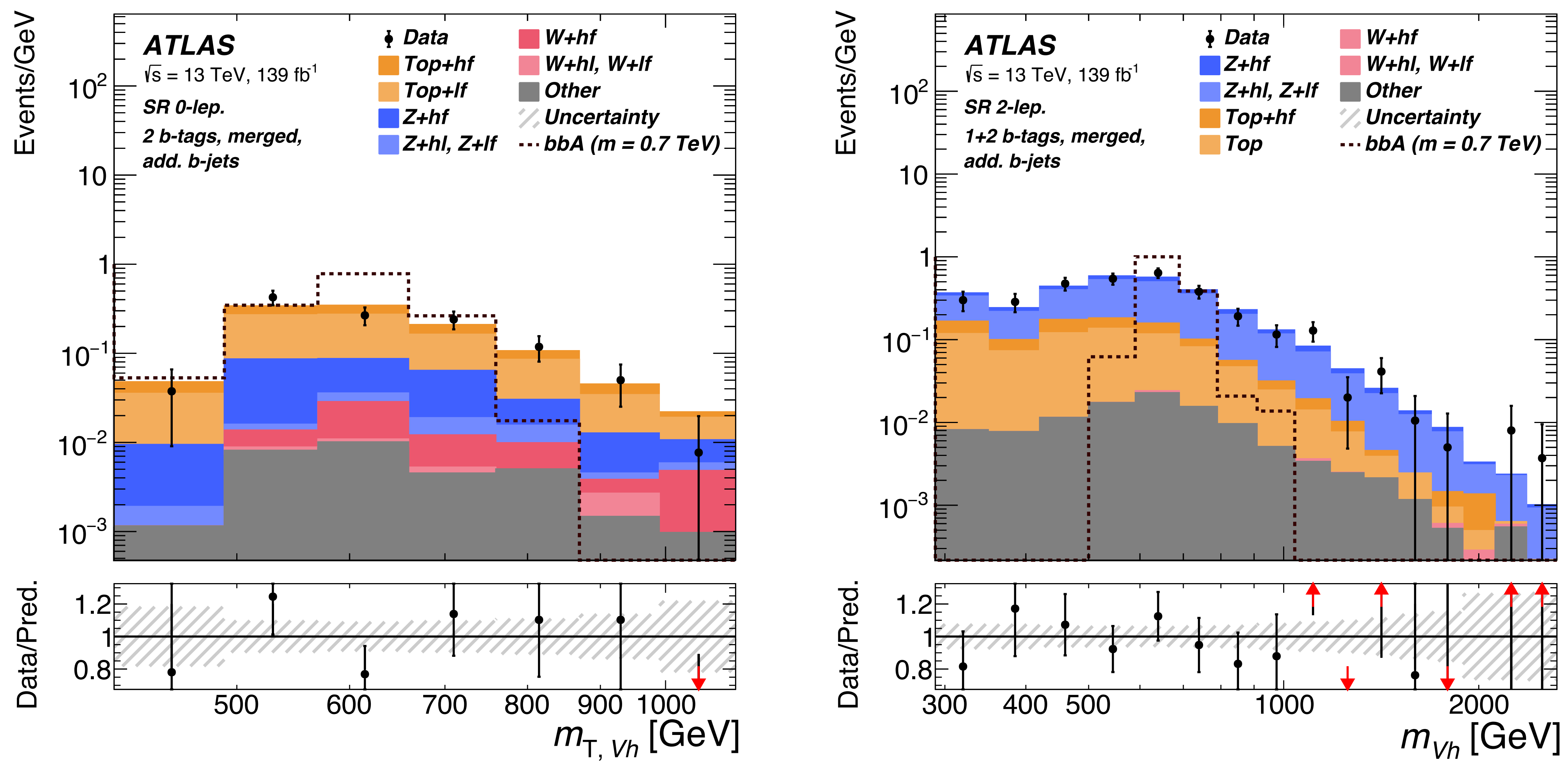


Strategy

0-, 1-, and 2-lepton channels

b-tag jet categories (merged and resolved)

Fit either $m_{T,VH}$ or m_{VH}



W′/Z′/A→Vh125

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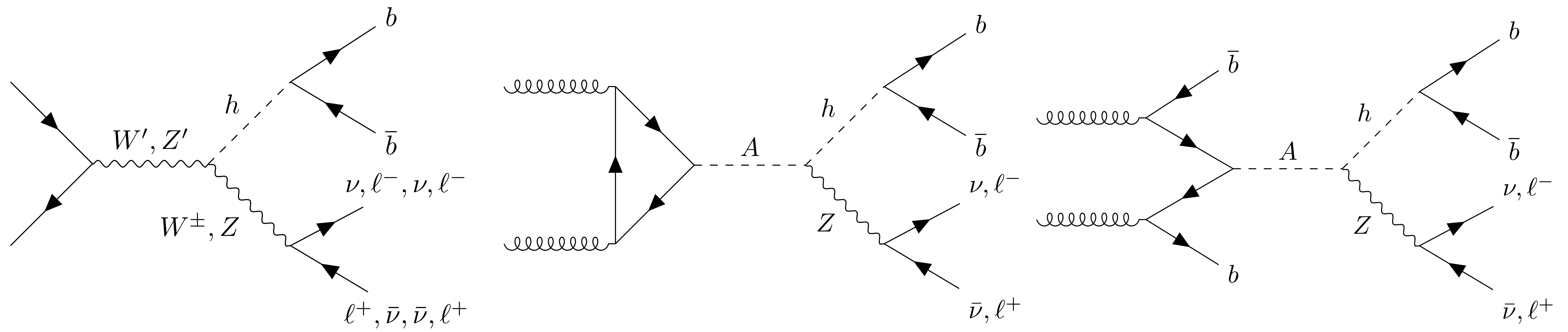

Strategy

0-, 1-, and 2-lepton channels

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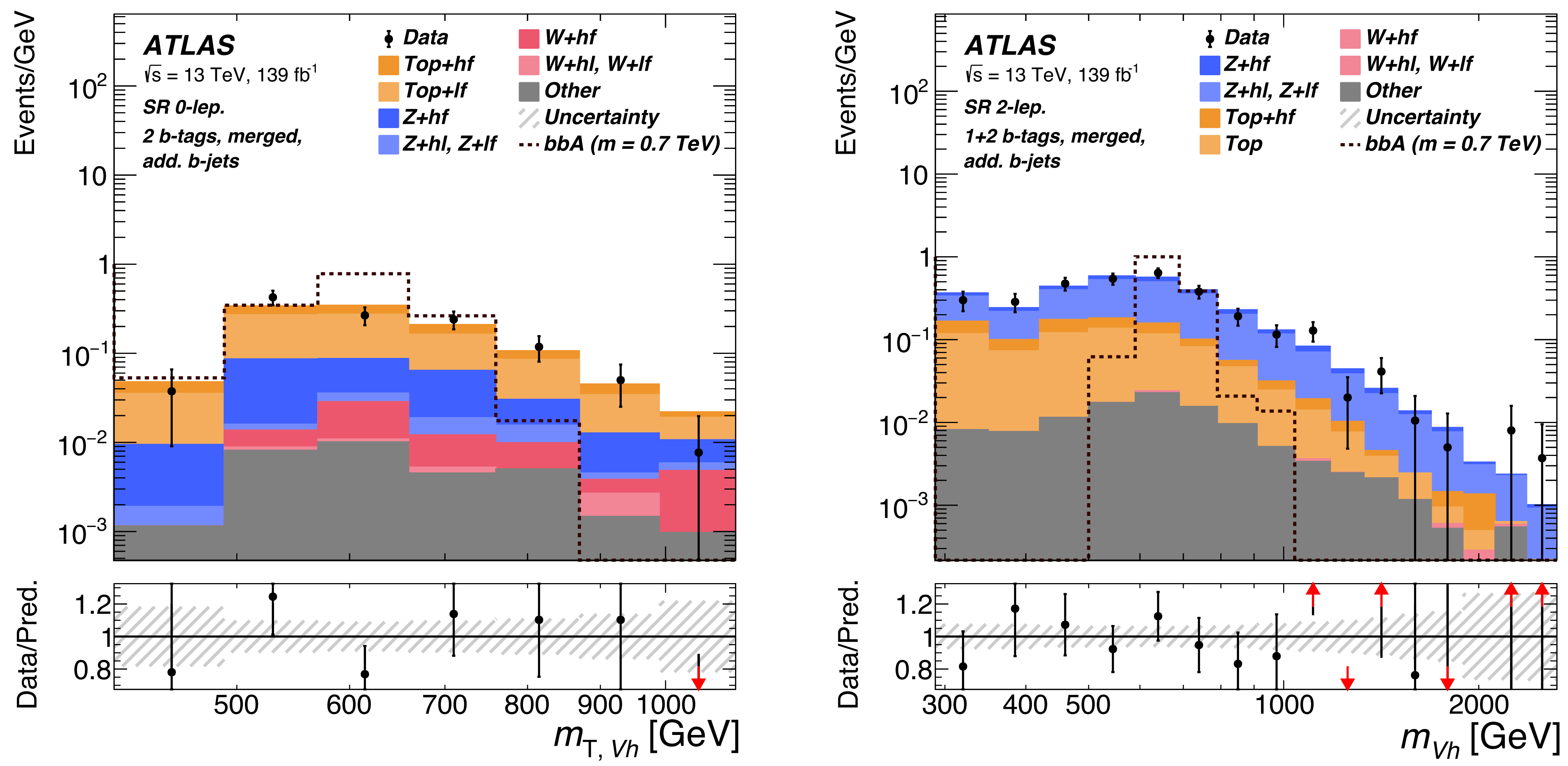

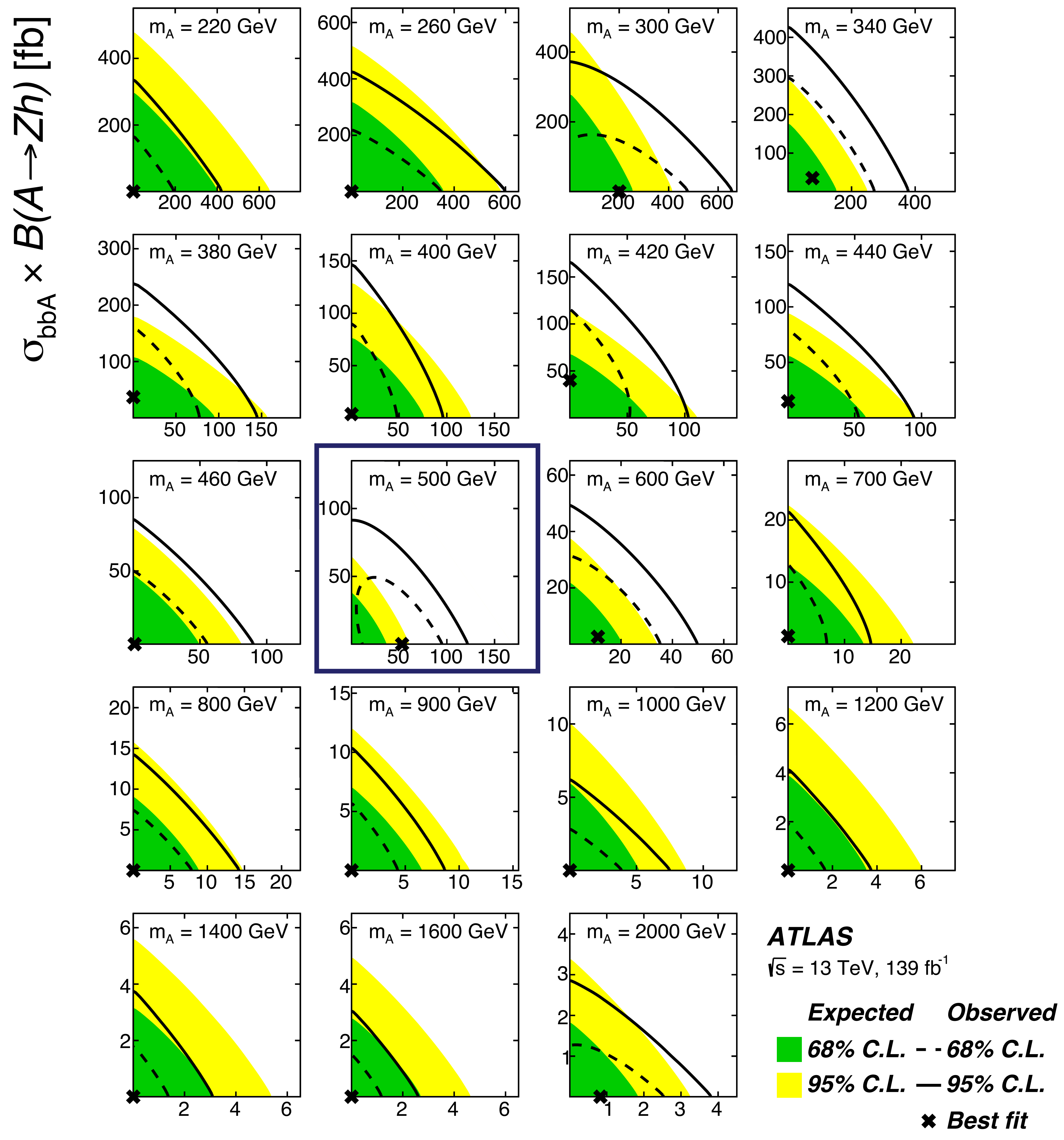

2d LL scan of b-associated production cross section vs gluon-gluon fusion production cross section

Conclusions

Ten years after its discovery, the Higgs boson plays a fondamental role in searches for physics beyond the Standard Model from studying its properties through probing for invisible, forbidden, and exotic decays to searching for additional particles part of a possible extended Higgs sector.

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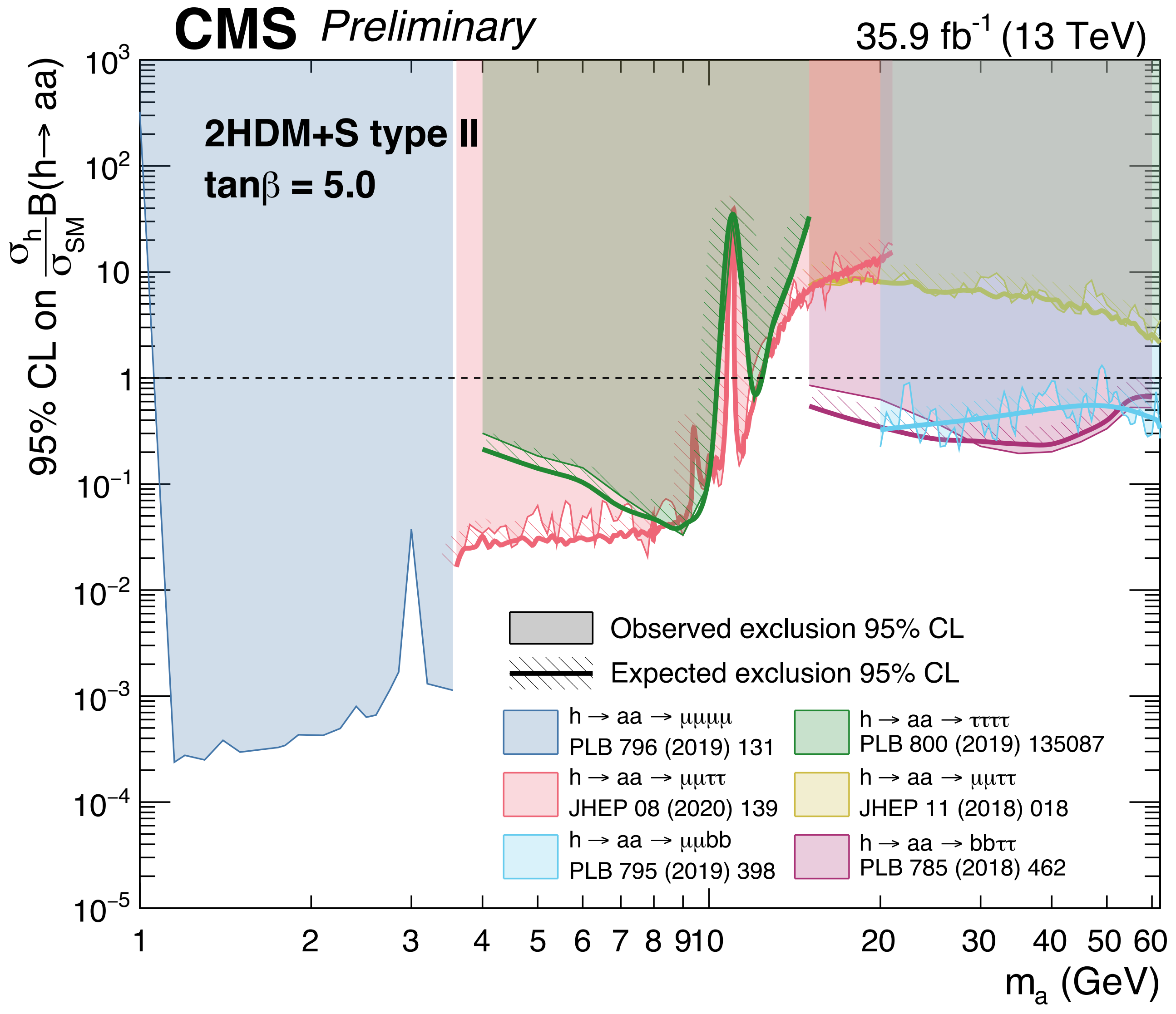
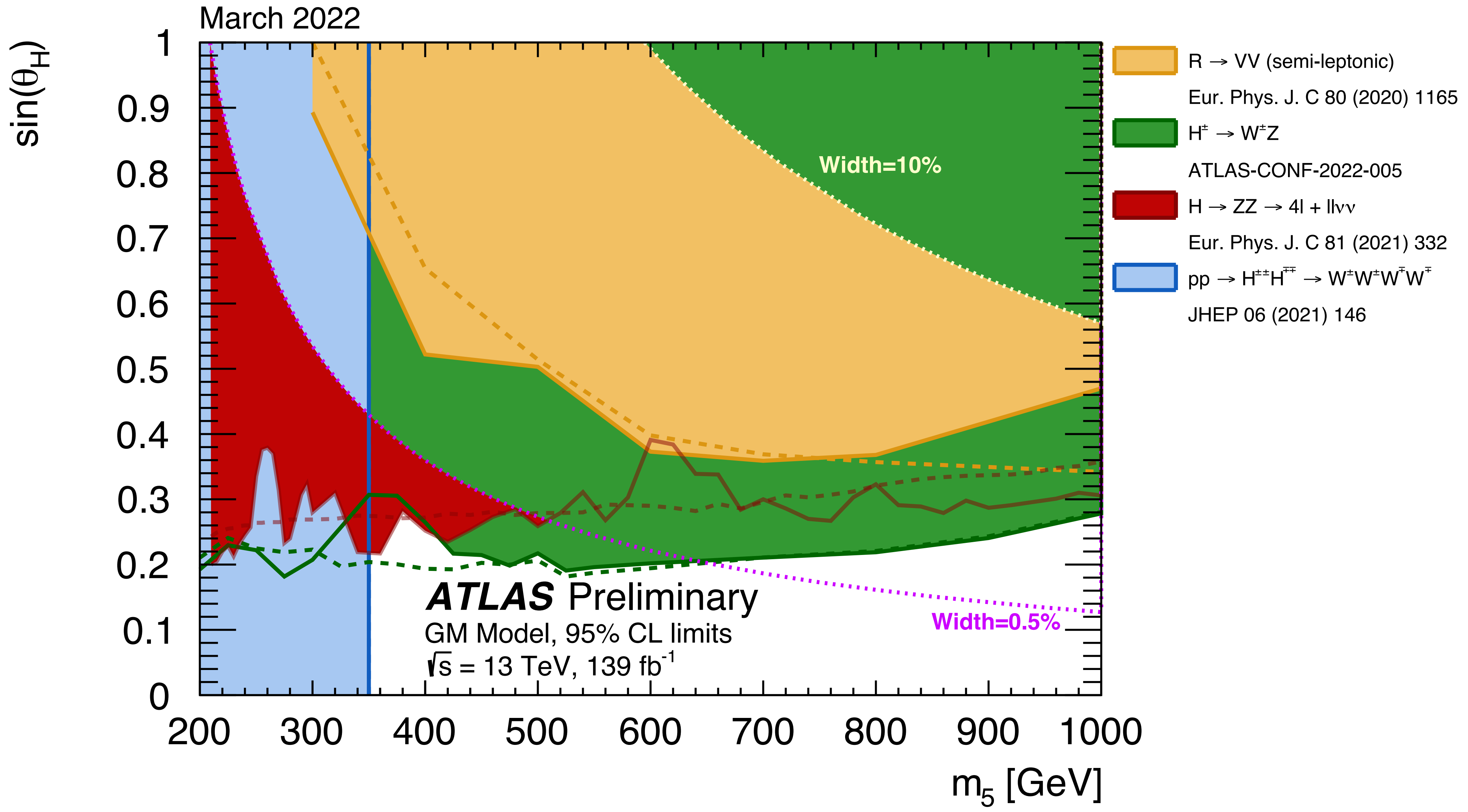
Ten years after its discovery, the Higgs boson plays a fondamental role in searches for physics beyond the Standard Model from studying its properties through probing for invisible, forbidden, and exotic decays to searching for additional particles part of a possible extended Higgs sector.

A very large physics program on all these topics is pursued by ATLAS and CMS!

invisible decay flavour violating decays exotic decays extended sector … … …





More results on ATLAS Higgs HDBS CMS HIG EXO B2G physics analysis groups webpages