

Searches for BSM Higgs at the LHC

Hyunyoung Kim On behalf of the ATLAS and CMS collaborations



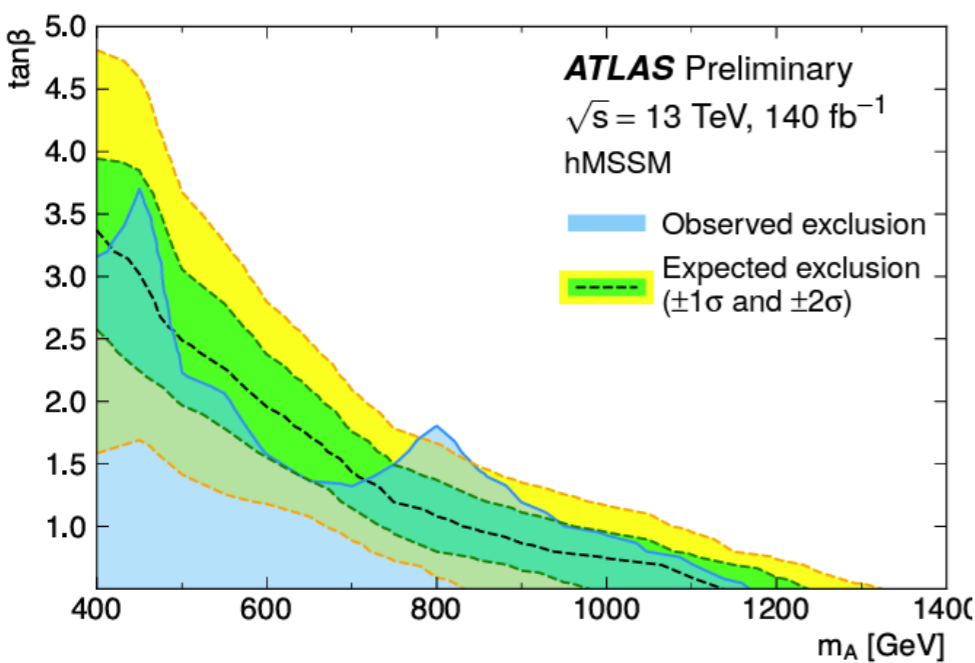
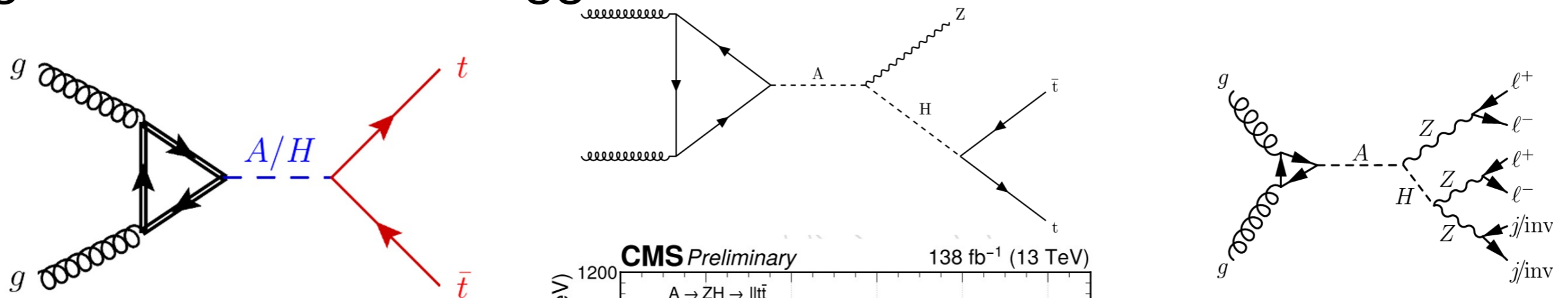
Mitchell Conference 2024
May 23 2024

Introduction

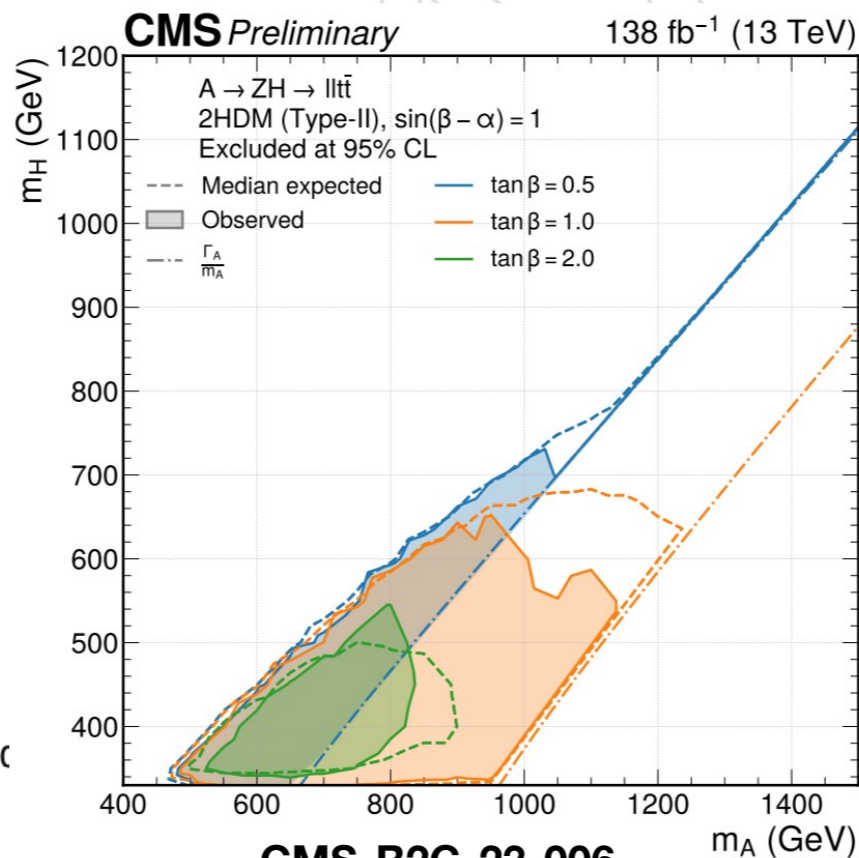
- Two Higgs Doublet Model (2HDM): Introduces two Higgs doublets instead of one.
 - Predictions: Five Higgs bosons:
 - Two neutral CP-even (**h**, **H**)
 - One neutral CP-odd (**A**)
 - Two charged (**H⁺**, **H⁻**)
- 2HDM + S: Extends 2HDM by adding a singlet scalar (S).
 - Predictions: 2HDM + Two additional neutral bosons:
 - 1 CP-odd (**a₁**)
 - 1 CP-even (**a₂**)
 - Implications: Richer phenomenology with potential for new exotic decay channels.
- Exotic Decays of (Pseudo-) Scalar Particles:
 - Decays into new particles: The Higgs bosons might decay into unknown particles, such as dark matter candidates or other new states.

2HDM Results

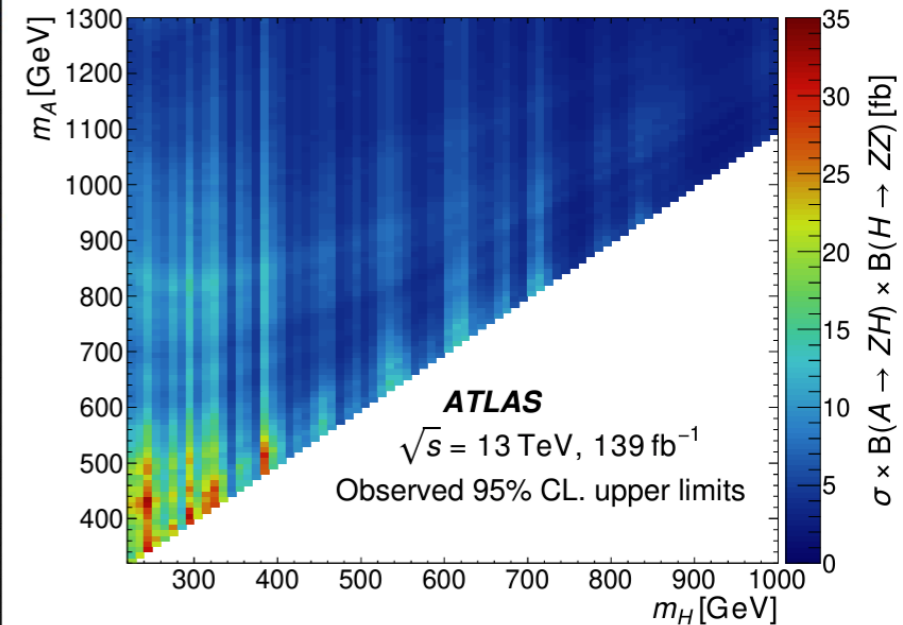
Expansions of the SM Higgs sector may introduce extra fields that generate additional Higgs bosons.



ATLAS-CONF-2024-001



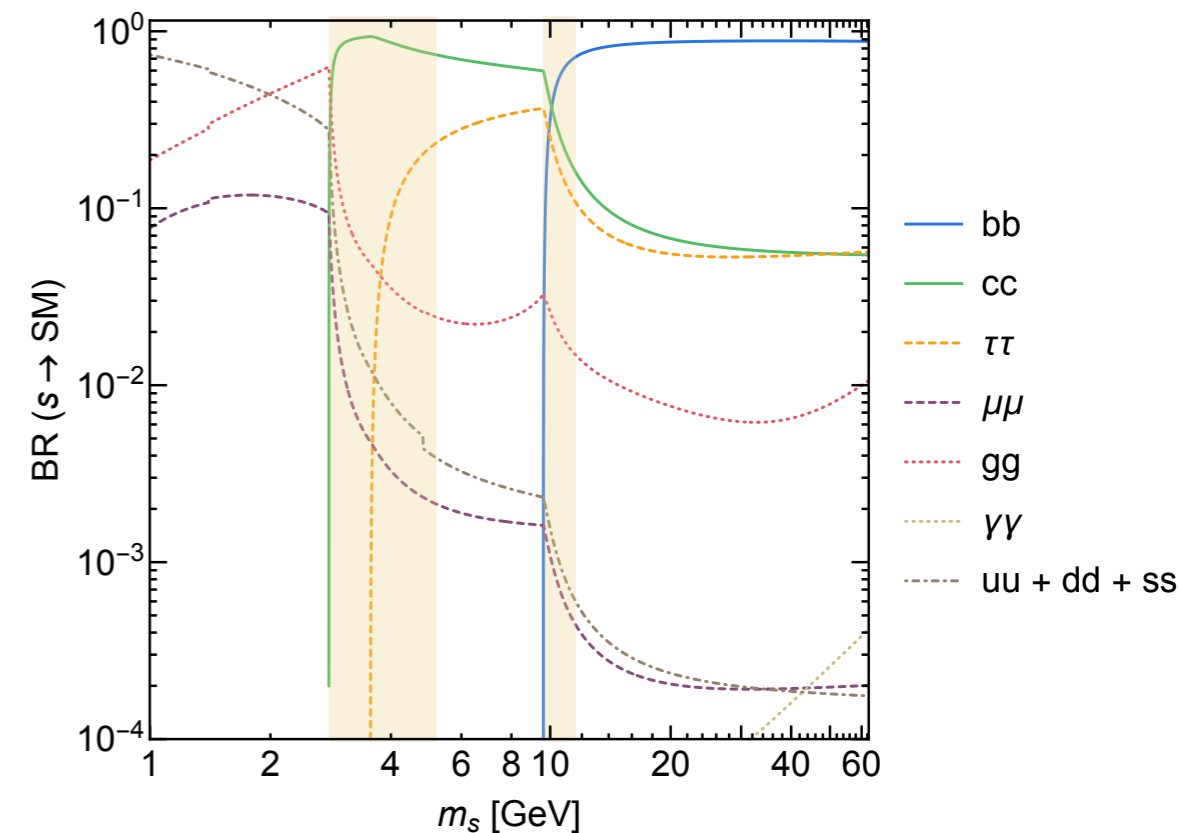
CMS-B2G-23-006



<https://arxiv.org/abs/2401.04742>

Exotic Higgs Decay

- Various models for physics beyond the SM predict the existence of new (pseudo-) scalar particles, a , including: Axion-like particles and Extended Higgs sector
 - $H \rightarrow Za$: Kinematically allowed for $m_a < 33.8$ GeV
 - $H \rightarrow aa$: Kinematically allowed for $m_a < 62.5$ GeV
- Experimental characteristics of H and a decays depend strongly on m_a



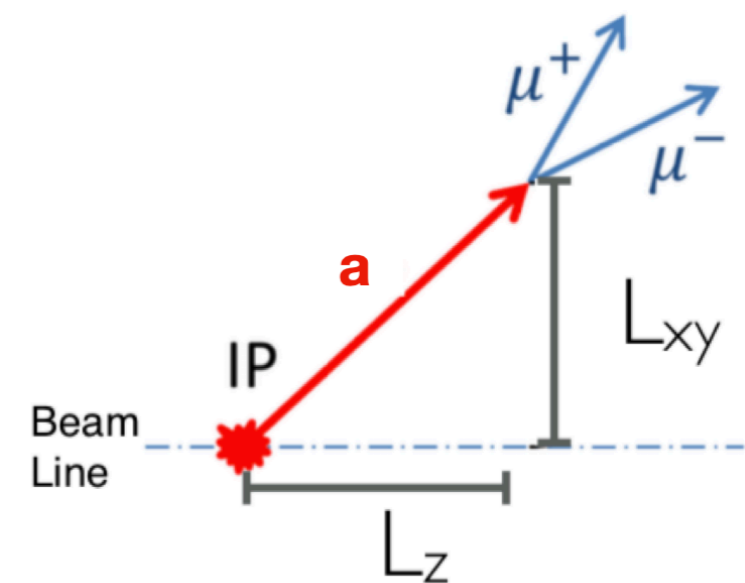
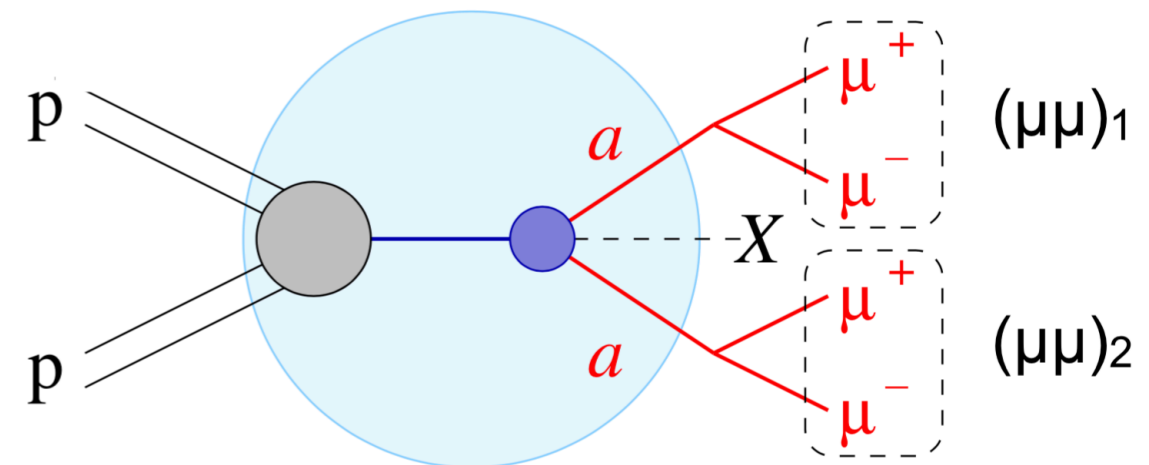
[Phys. Rev. D90.075004\(2014\)](#)

https://indico.in2p3.fr/event/32664/timetable/?view=standard_numbered#119-rare-higgs-decays-in-atlas

Model Independent Search

CMS-HIG-21-004

- Model independent search uses the 4 muons final state
- Prompt or long-lived two particles decay to two dimuon pairs
- The identical invariant mass for each dimuon pairs
- Result can be interpreted in many models with similar signature
- Three Higgs portal and one Vector portal benchmarking models (4 in 1 analysis)
- Large mass coverage 0.21 – 60 GeV and $c\tau < 100$ mm

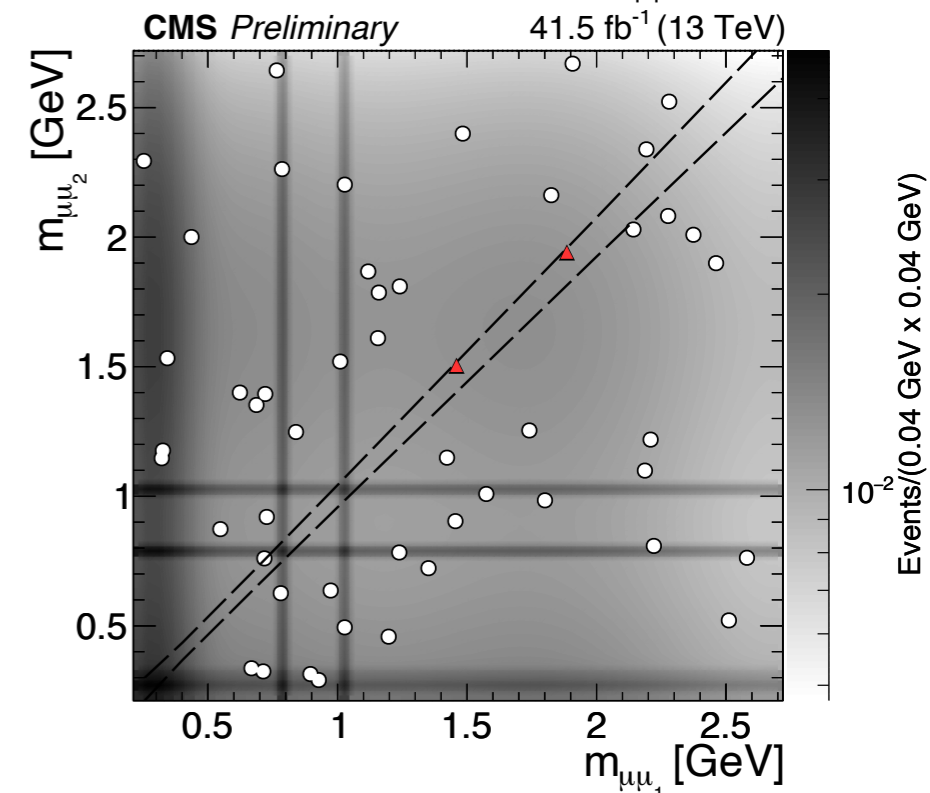
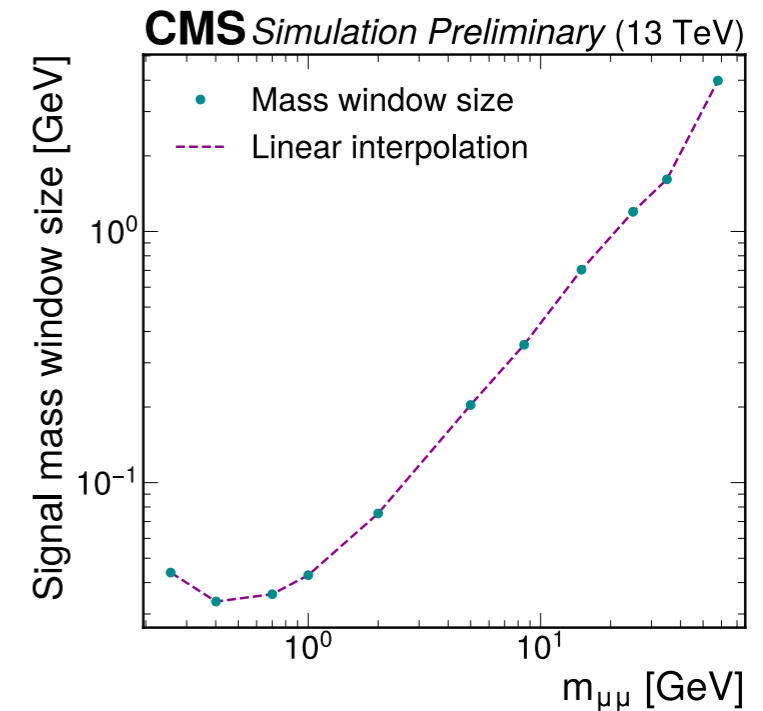


Analysis Strategy

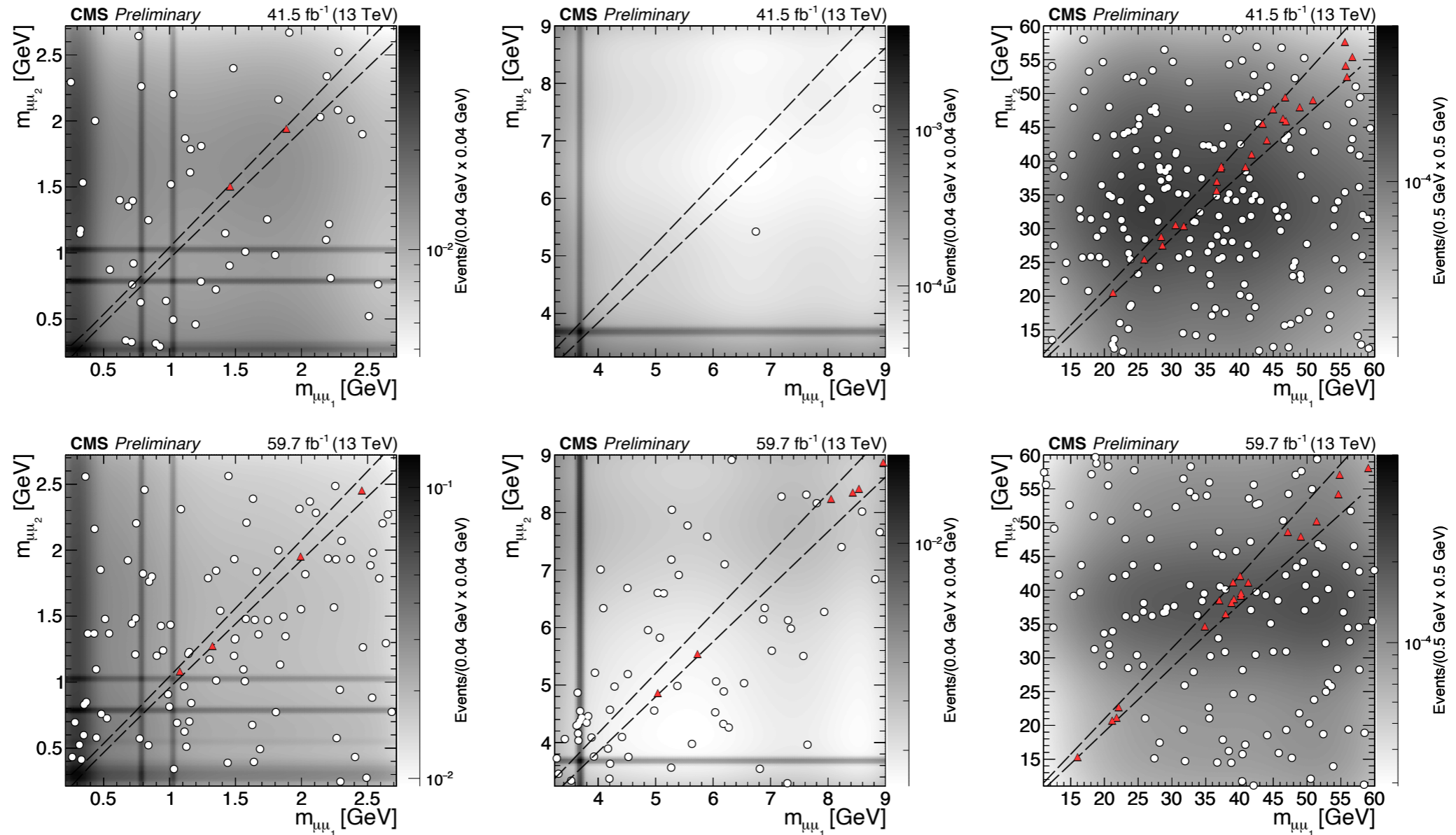
- Get a 2D background PDF of m_1 and m_2 from the signal-like events (three muons events)
- Integrated the PDF density of the signal region (SR) and control region (CR)

- $$\frac{I_{SR}}{I_{CR}} \times N_{CR} = N_B$$

- Calculate the model independent limit then the result is interpreted in each benchmark model



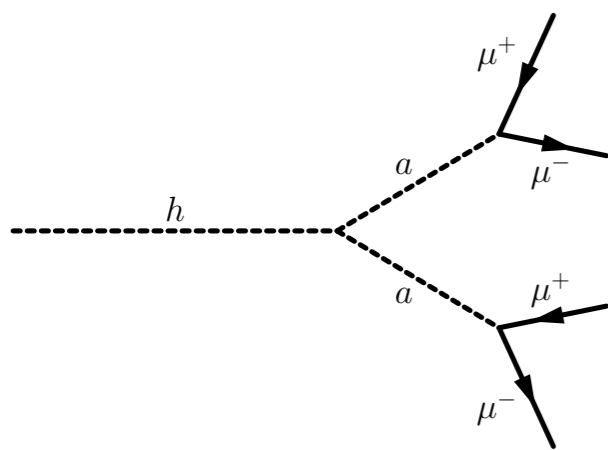
Background Estimation



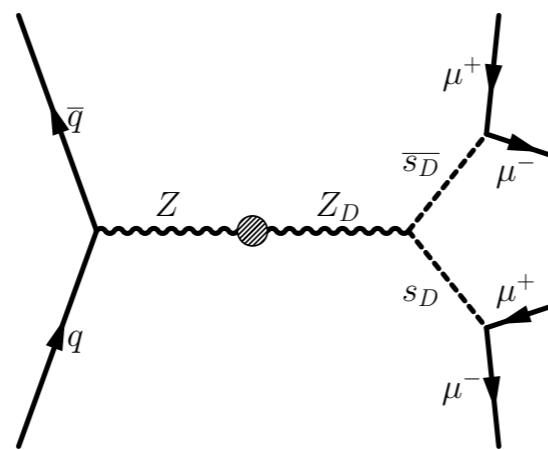
CMS-HIG-21-004

Region	Quantity	Year 2017	2018
Below J/ψ	Exp. events in SR	2.62 ± 0.32 (stat) ± 0.14 (syst)	4.34 ± 0.44 (stat) ± 0.18 (syst)
	Obs. events in SR	2	4
Above J/ψ , Below Υ	Exp. events in SR	0.19 ± 0.14 (stat) ± 0.01 (syst)	6.16 ± 0.76 (stat) ± 0.09 (syst)
	Obs. events in SR	0	6
Above Υ	Exp. events in SR	18.10 ± 1.23 (stat) ± 4.49 (syst)	13.81 ± 1.16 (stat) ± 5.39 (syst)
	Obs. events in SR	24	20

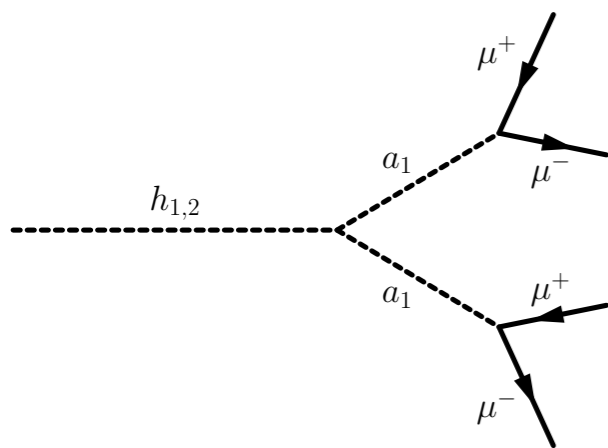
Benchmark Models



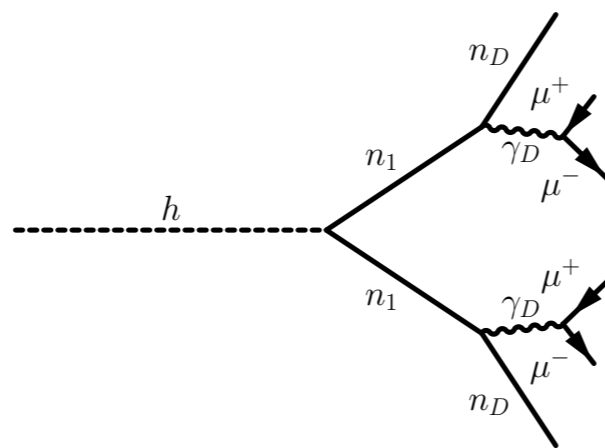
ALP



Vector Portal



NMSSM



Dark SUSY

- ALP:
$$\sum_{d \leq 5} \sum_{i=1}^{N_d} \frac{C_i}{\Lambda^{d-4}} O_i^{(d)}$$

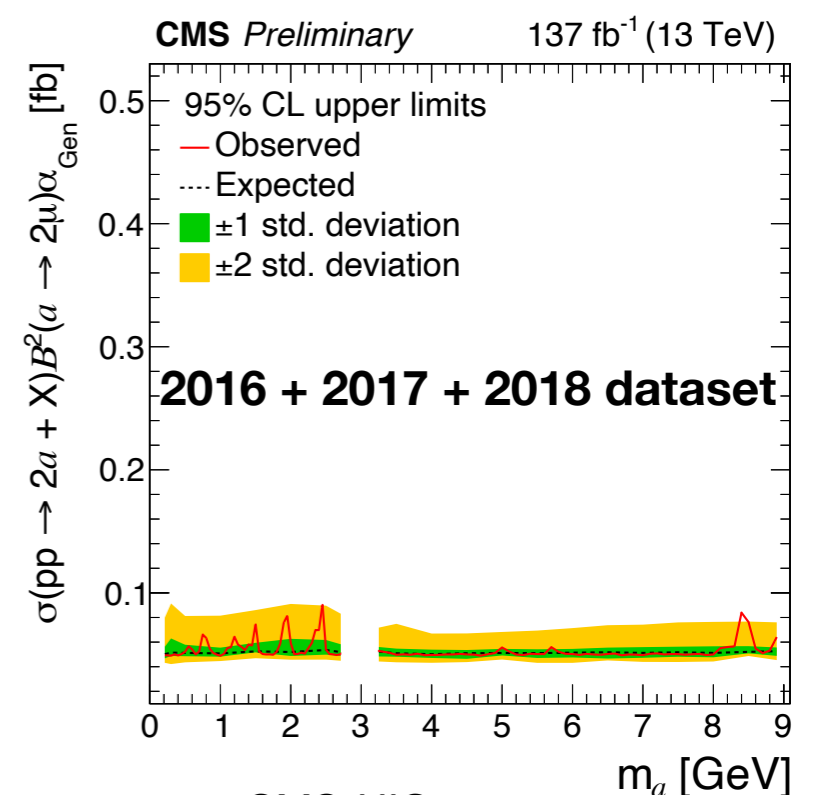
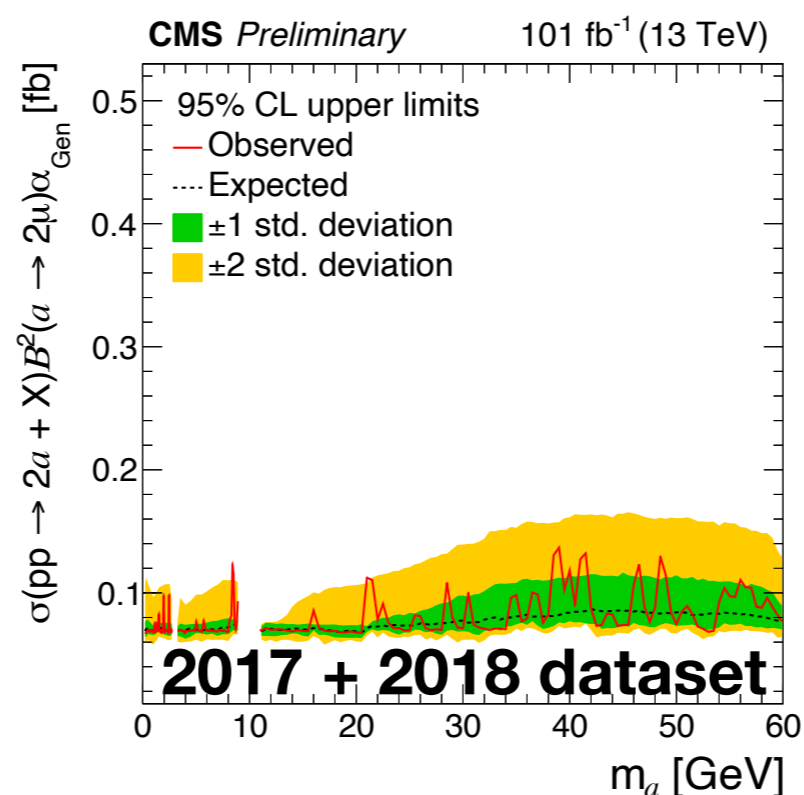
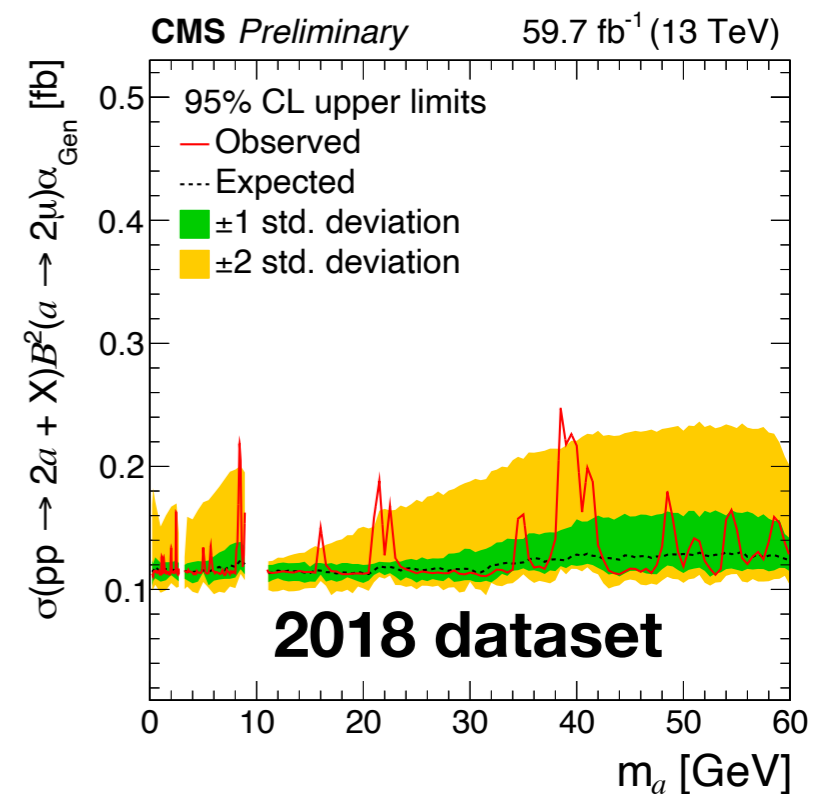
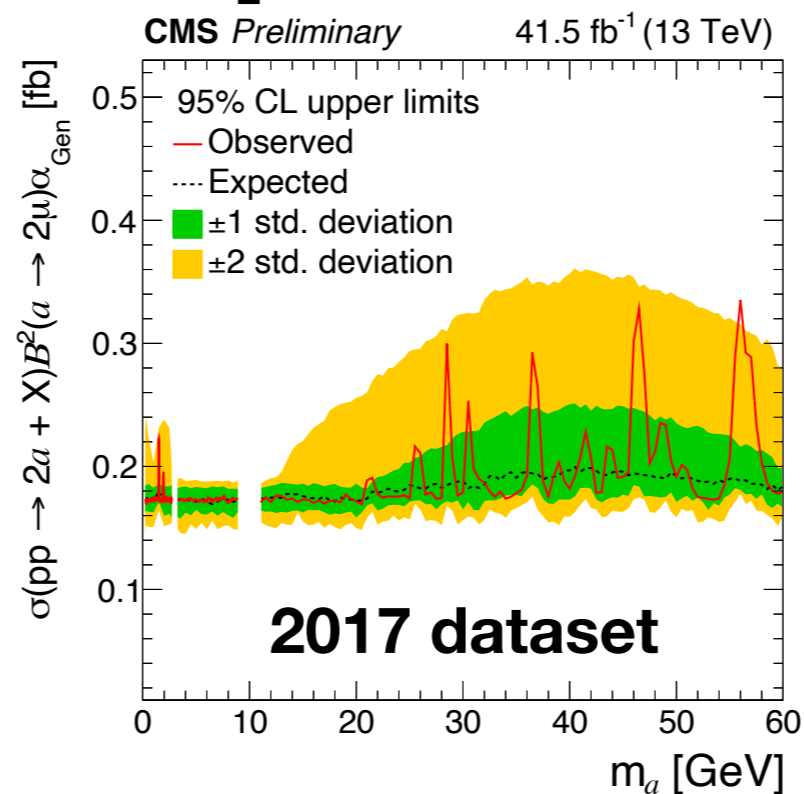
- Vector Portal:
$$\frac{1}{4} \hat{X}_{\mu\nu} \hat{X}^{\mu\nu} + \frac{\epsilon}{2} \hat{X}_{\mu\nu} \hat{B}^{\mu\nu}$$

- NMSSM:
$$\lambda \hat{S} \hat{H}_u \hat{H}_d + \frac{\kappa}{3} \hat{S}^3$$

- Dark SUSY:
$$\frac{\epsilon}{2} F_{\mu\nu}^Y F_D^{\mu\nu}$$

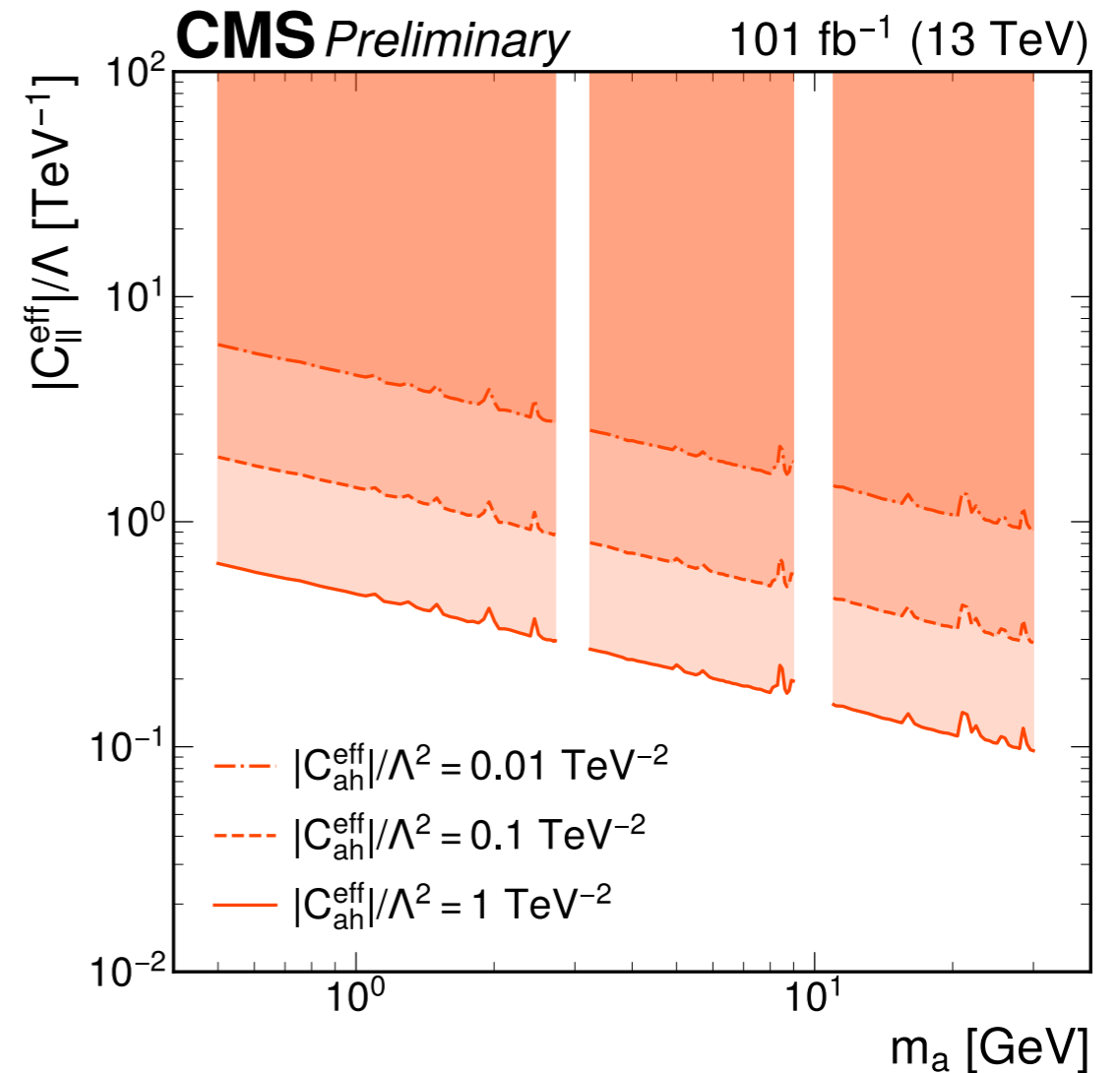
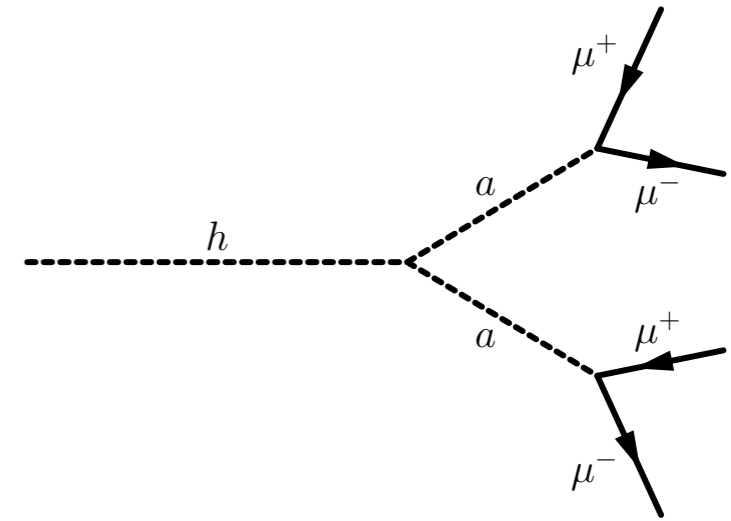
Model Independent Limits

- The 2017 dataset includes only prompt events
- The 2018 dataset includes both prompt and long-lived events
- The 2017+2018 dataset is interpreted using only the prompt signal
- The 2016+2017+2018 dataset is analyzed up to 9 GeV and is interpreted using only the prompt signal



ALP

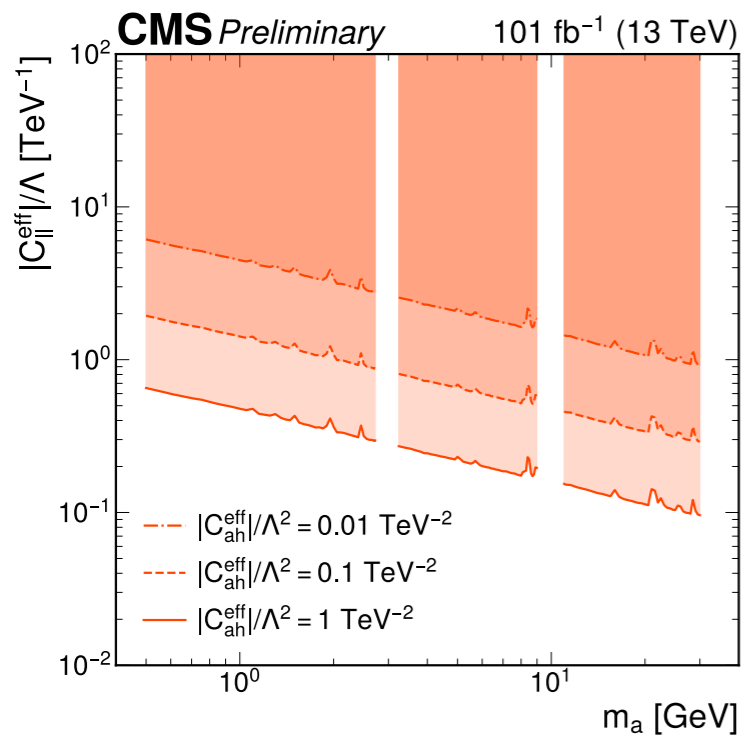
- Axion-like particle (ALP) model:
 $pp \rightarrow h \rightarrow 2a \rightarrow 4\mu$
- axion-like particle, decay to leptons (partial width far smaller than detector resolution)
- Λ : new physics scale, characteristic scale of global symmetry breaking (MC default: 1 TeV)
- C_{ah}^{eff} : effective coupling between the ALP and the SM Higgs boson
- C_{ll}^{eff} : effective coupling between the ALP and SM leptons



CMS-HIG-21-004

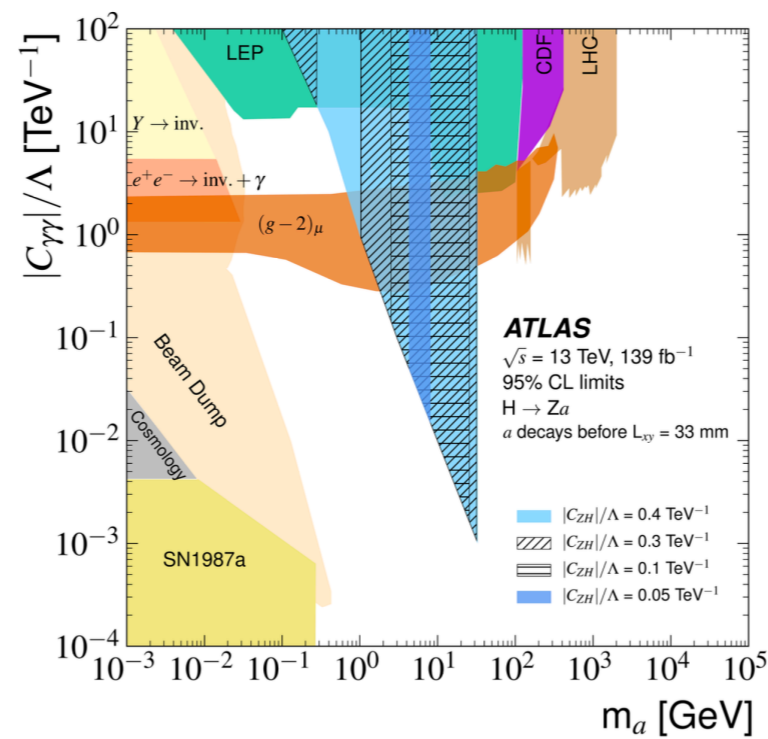
ALP Results

$$H \rightarrow 2a \rightarrow 4\mu$$

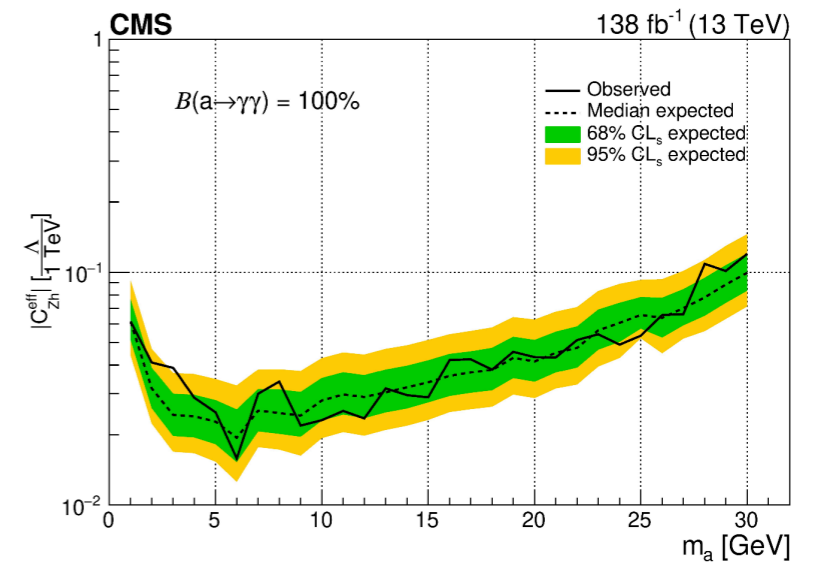


CMS-HIG-21-004

$$H \rightarrow Za, a \rightarrow \gamma\gamma$$



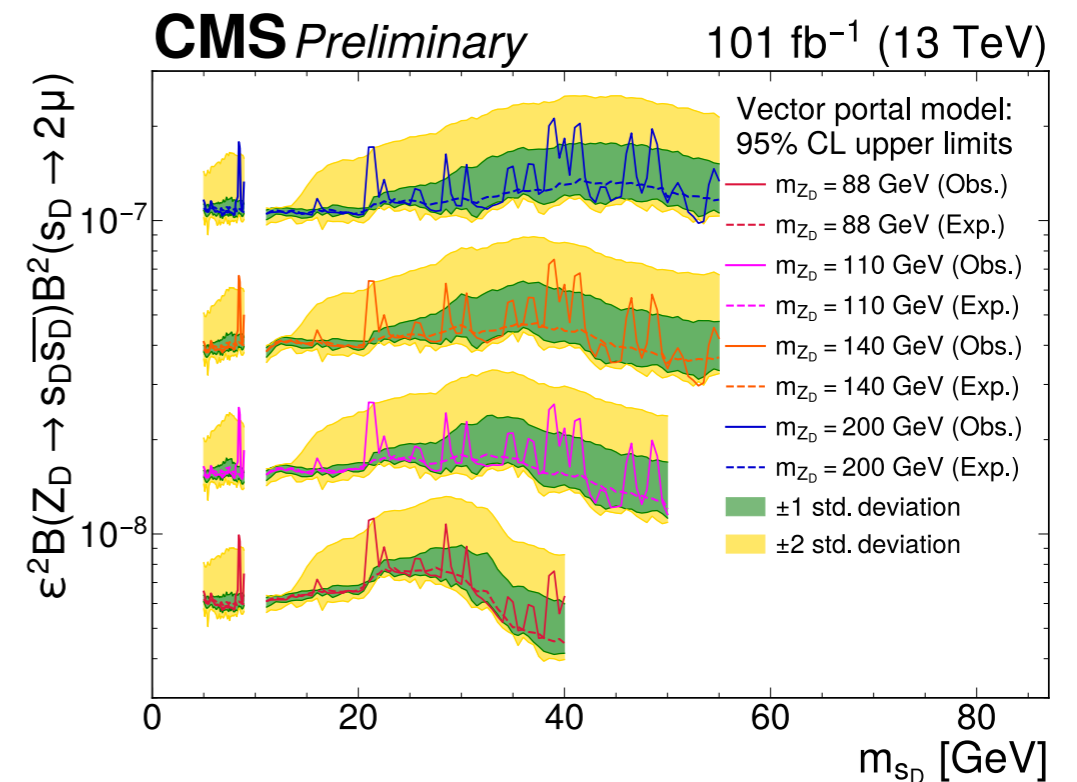
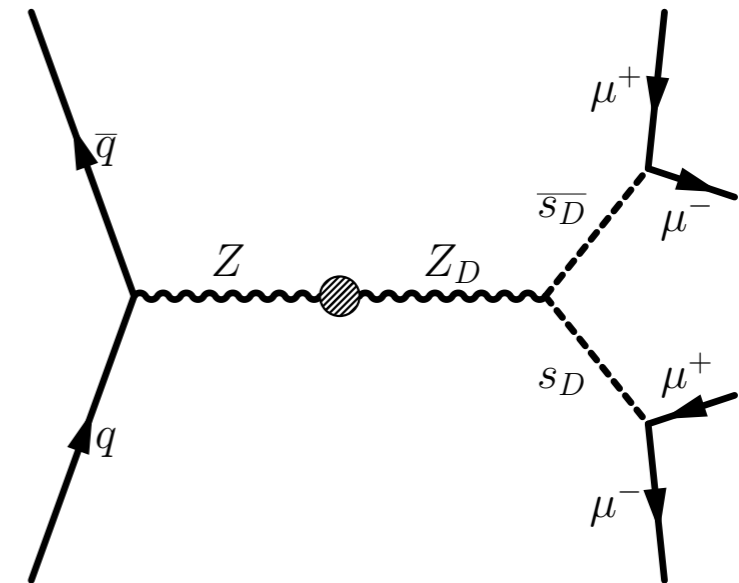
Phys. Lett. B 848 (2024) 138536



Phys. Lett. B 852 (2024) 138582

Vector Portal

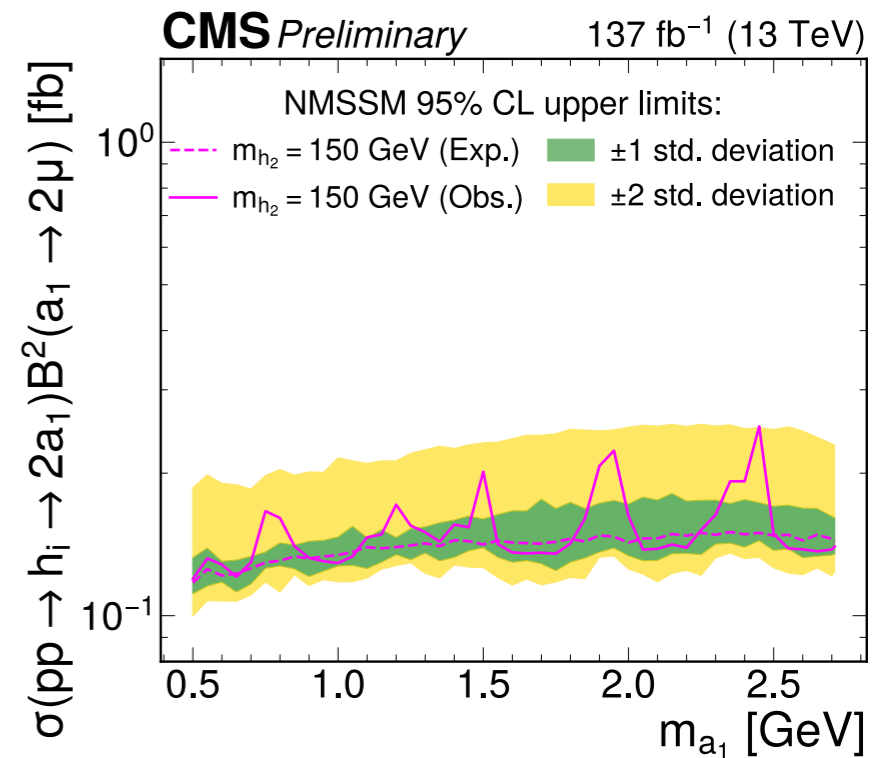
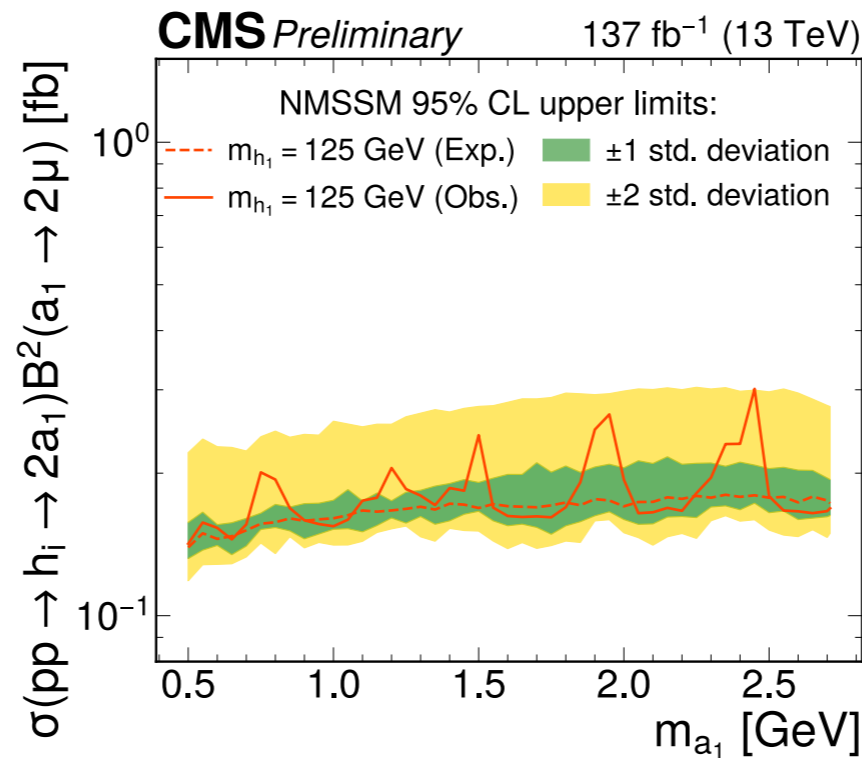
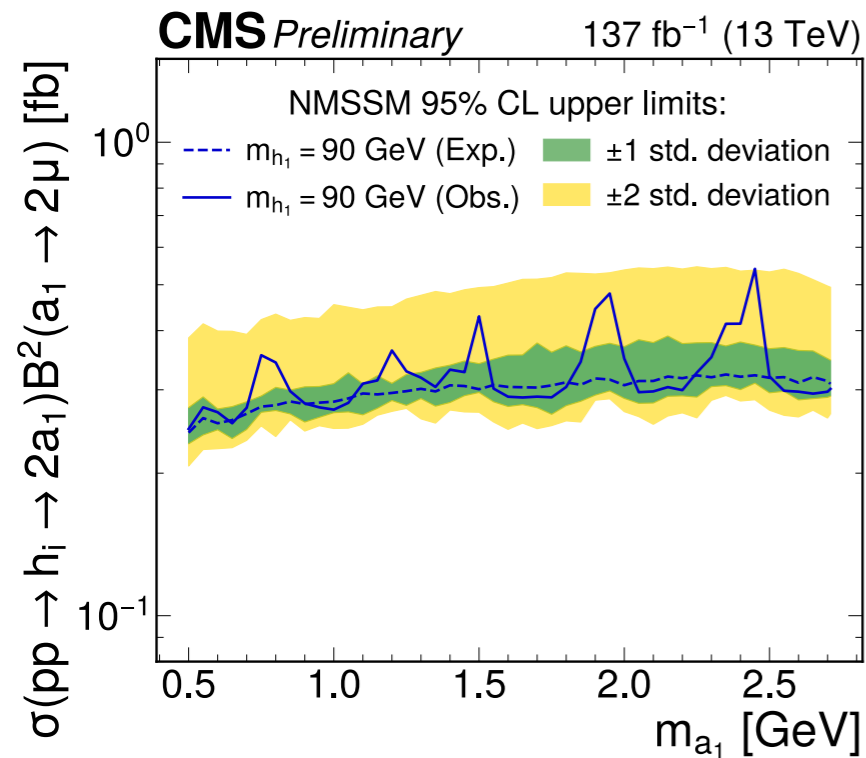
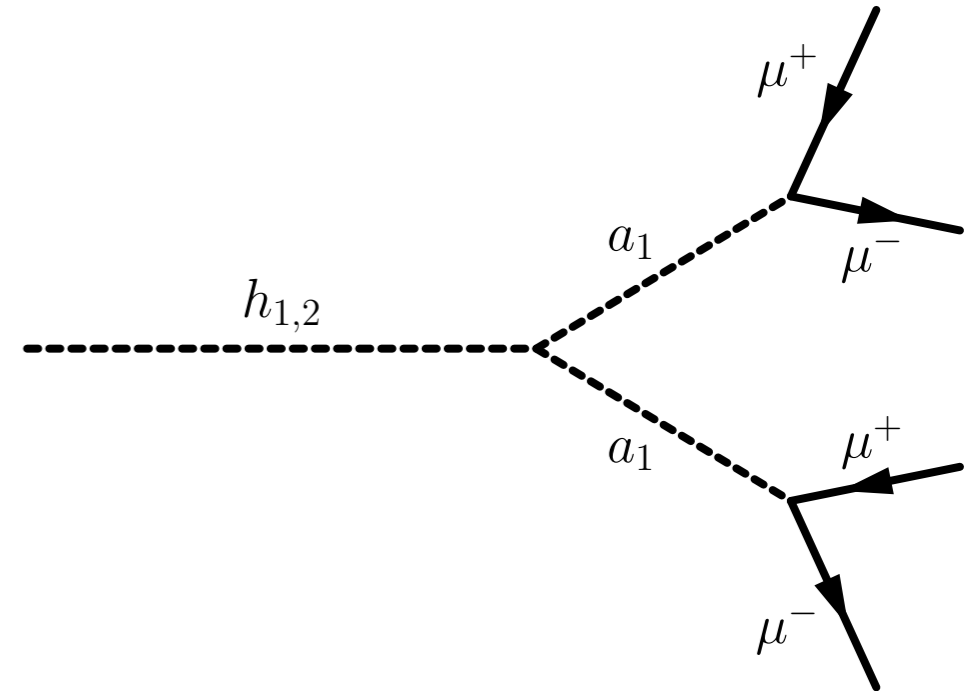
- Dark matter particle produced via non-Higgs portal
- Spin-1 mediator: dark vector boson Z_D , kinetic mixing with SM Z boson, decay to dark scalar s_D



CMS-HIG-21-004

NMSSM

- Predicts multiple CP-even Higgs h_1 and h_2
- Also predicts CP-odd Higgs (a_1): could couple to SM leptons

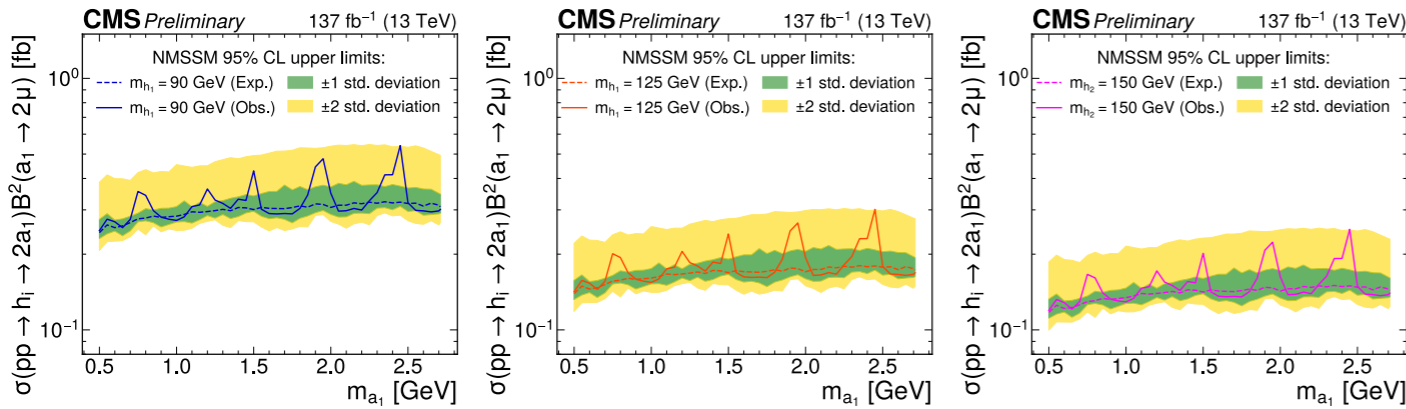


CMS-HIG-21-004

The Mitchell Conference

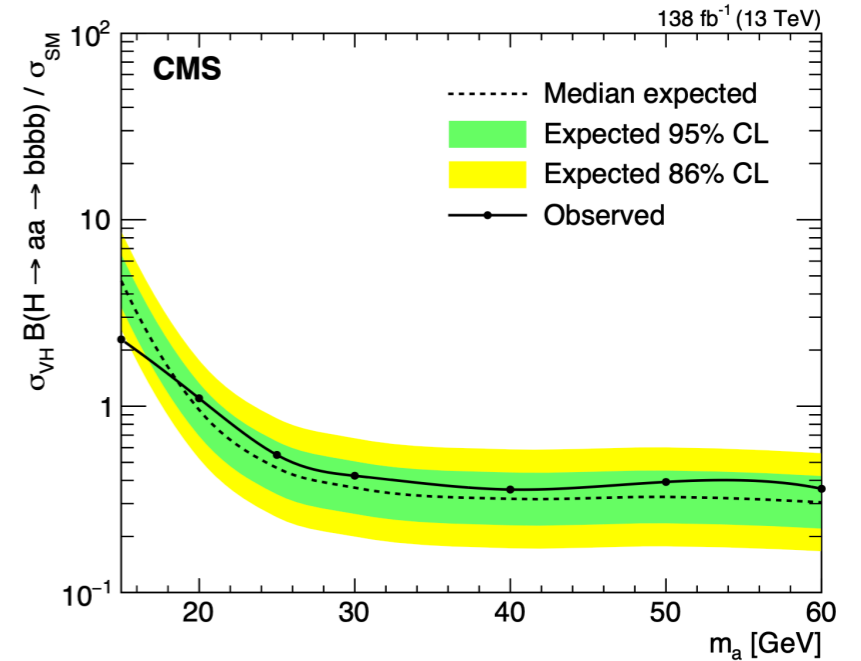
2HDM + S Results

$H \rightarrow 2a \rightarrow 4\mu$

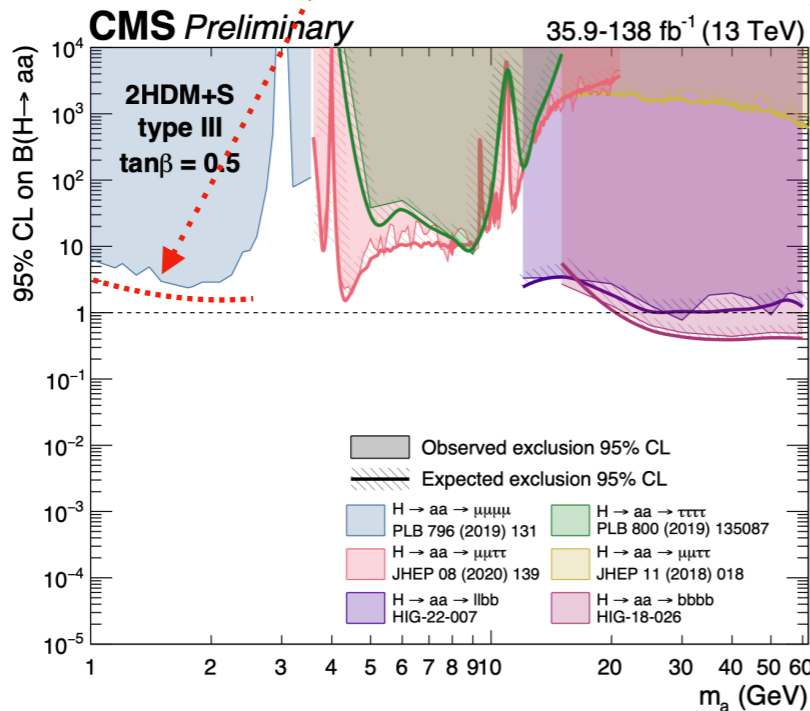


CMS-HIG-21-004

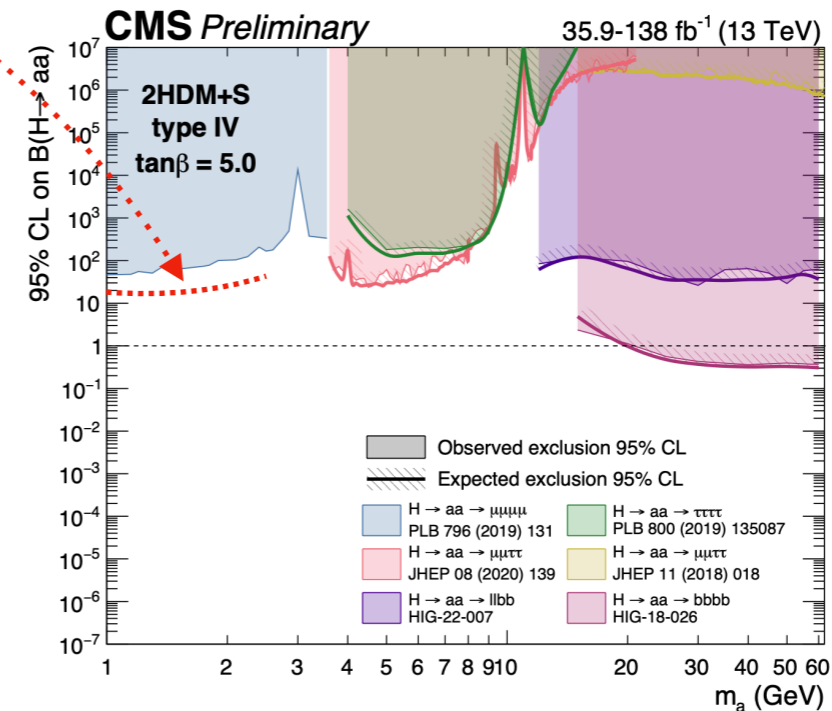
$H \rightarrow 2a \rightarrow 4b$



<https://arxiv.org/abs/2403.10341>

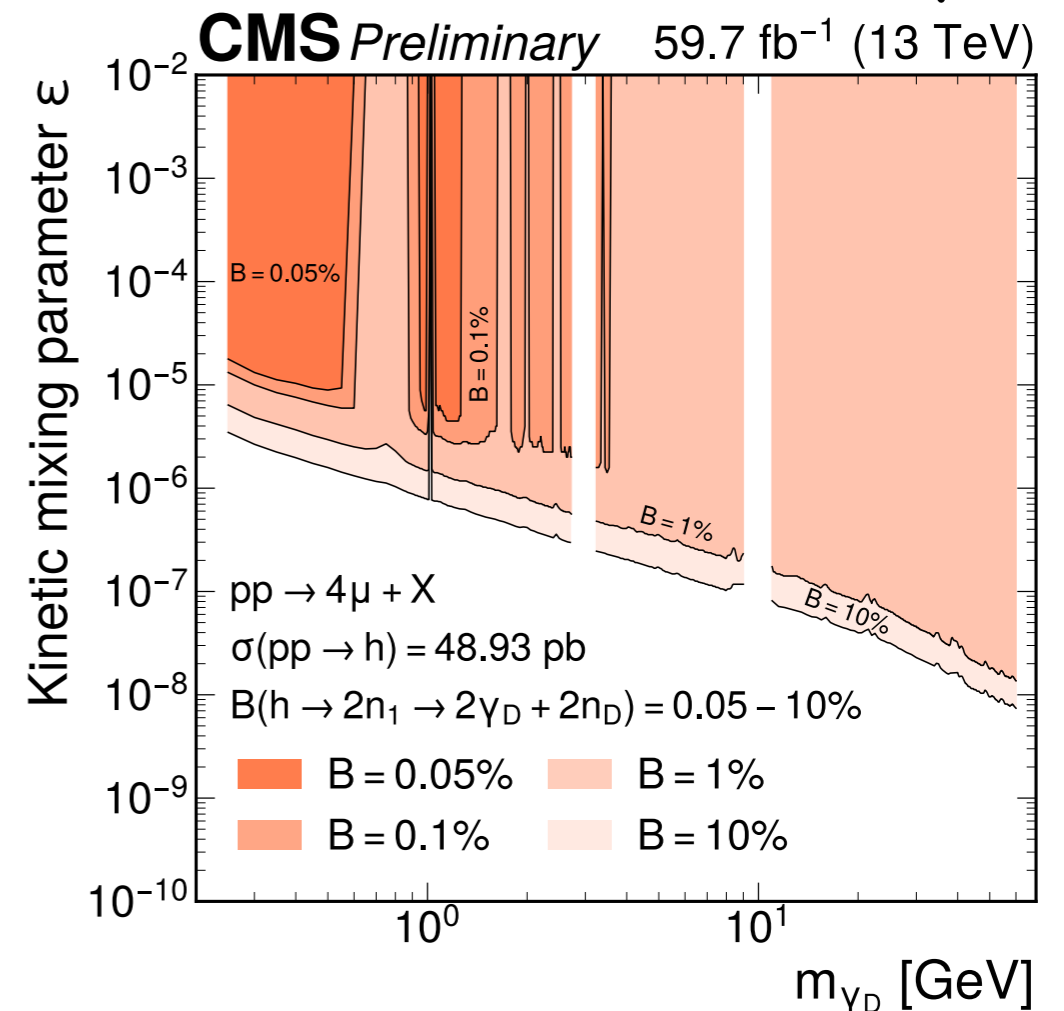
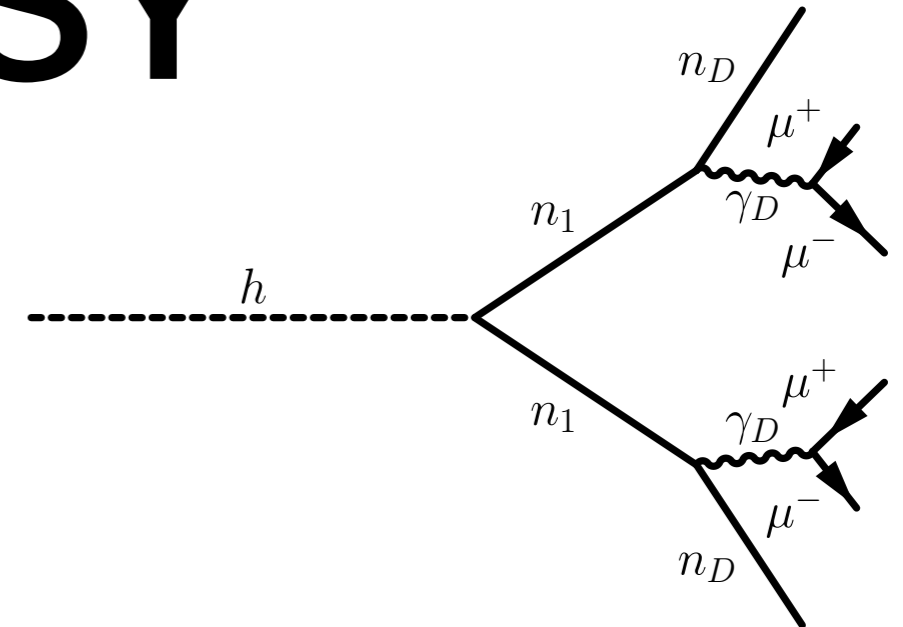


CMS TWiki



Dark SUSY

- MSSM + Dark Sector
- $pp \rightarrow h \rightarrow 2n_1, n_1 \rightarrow n_D + \gamma_D, \gamma_D \rightarrow \mu^+ \mu^-$
- n_1 : lightest neutralino from MSSM
- n_D : dark neutralino
- γ_D : dark photon from broken $U(1)_D$ symmetry



Summary

- The full Run 2 ATLAS and CMS BSM Higgs searches are presented in terms of 2HDM (+ S) and exotic decays.
- A large amount of phase space remains available for exploring extended Higgs sectors.
- Looking forward to more Run 2 and first Run 3 results on searches for BSM Higgs.