Recent BSM Higgs Searches at CMS & ATLAS

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University of California Davis
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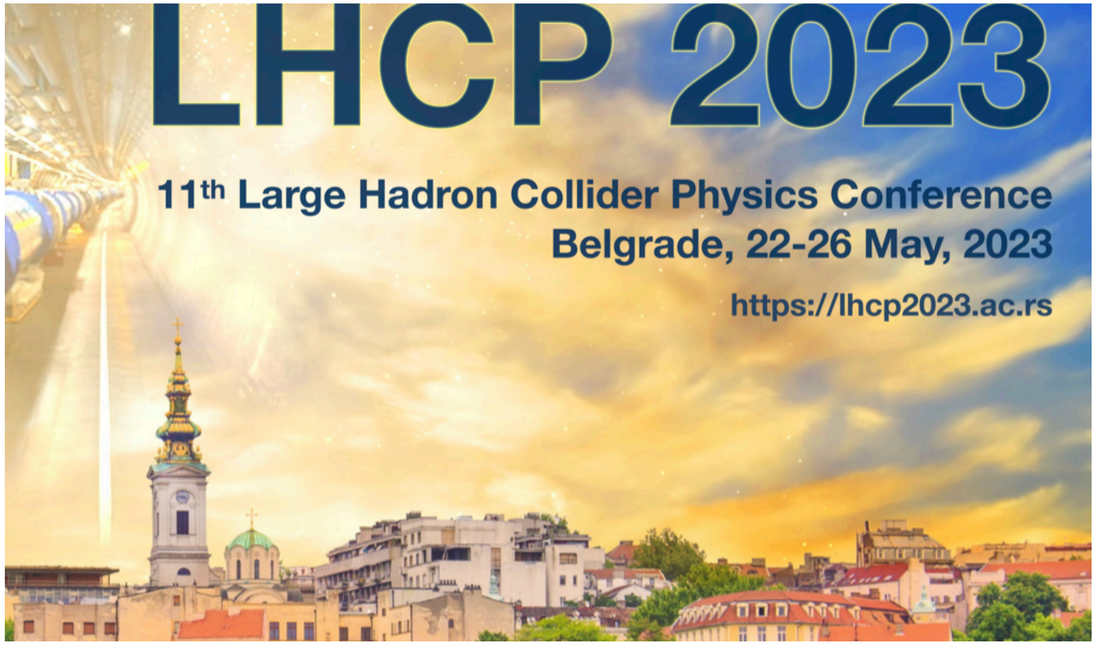


LHCP 2023, Belgrade, Serbia, 26 May, 2023

Higgs Status: This week @ LHCP!

- SM measurements: σ, Br, μ, κ, …
- BSM searches/theory: 2HDM(+S), Heavy, Light, EFT, …

Exotic production and decays of the 125 GeV Higgs - ATLAS ¶
Speaker: Rocky Bala Garg (Stanford University (US))

Exotic production and decays of the 125 GeV Higgs - CMS
Speaker: Pallabi Das (Princeton University (US))

Higgs/Top/EWK and Global EFT results at ATLAS
Speaker: Eleonora Rossi (University of Oxford (GB))

Higgs/Top/EWK and Global EFT results at CMS
Speaker: Davide Valsecchi (ETH Zurich (CH))

Measurement of Higgs boson production and properties
Speaker: Chiara Arcangeletti (INFN e Laboratori Nazionali di Frascati (IT))

Search for rare/BSM Higgs boson decays and BSM Higgs sector
Speaker: Maxwell Chertok (University of California Davis (US))

Higgs boson production in association with top quark at ATLAS
Speaker: Valentina Vecchio (University of Manchester)

Higgs boson production in association with top quark at CMS
Speaker: Clara Ramon Alvarez (Universidad de Oviedo (ES))

Higgs probes of top contact interactions and their interplay with Higgs self-coupling
Speaker: Stefano Di Noi (Università di Padova and INFN, Sezione di Padova)

Higgs boson couplings at ATLAS	*Luca Fiorini*
Belgrade, Serbia	11:30 - 11:45
Higgs couplings at CMS	*Fabio Monti*
Belgrade, Serbia	11:47 - 12:02
Amplitudes as observables for Higgs at colliders	*Spencer Chang*
Belgrade, Serbia	12:04 - 12:19
Higgs boson fiducial differential cross section measurements at CMS	*Vukasin Milosevic*
Belgrade, Serbia	12:21 - 12:36
Higgs boson fiducial differential cross section measurements at ATLAS	*Roberto Di Nardo*
Belgrade, Serbia	12:38 - 12:53
Higgs Yukawa CP and baryon asymmetry	*Marco Menen*
Belgrade, Serbia	12:55 - 13:10
Higgs boson rare production and decay at ATLAS and CMS	*Toyoko Orimoto*
Belgrade, Serbia	13:12 - 13:27

Testing BSM with the Higgs
Speaker: Gauthier Durieux (CERN)

Precision Higgs Physics ¶
Speaker: Robert Valentin Harlander (Rheinisch Westfaelische Tech. Hoch. (DE))

Theory overview of Offshell Taskforce
Speaker: Eleni Vryonidou (University of Manchester (GB))

Higgs boson mass, width, CP and anomalous couplings measurements at CMS
Speaker: Li Yuan (Beihang University (CN))

Higgs boson mass, width, CP and anomalous couplings measurements at ATLAS
Speaker: Bo Liu (Chinese Academy of Sciences (CN))

Higgs couplings at future colliders
Speaker: Patrick Meade

Non-resonant HH production and Higgs self-coupling at ATLAS
Speaker: Rachel Jordan Hyneman (SLAC National Accelerator Laboratory (US))

Non-resonant HH production and Higgs self-coupling at CMS
Speaker: Saswati Nandan (National Institute of Chemical Physics and Biophysics (EE))

Precise SMEFT predictions for di-Higgs production
Speaker: Jannis Lang

G. Giudice

Every problem of the SM originates from Higgs interactions

$$\mathcal{L} = \lambda H \psi \bar{\psi} + \mu^2 |H|^2 - \lambda |H|^4 - V_0$$

flavour — naturalness — stability — C.C.

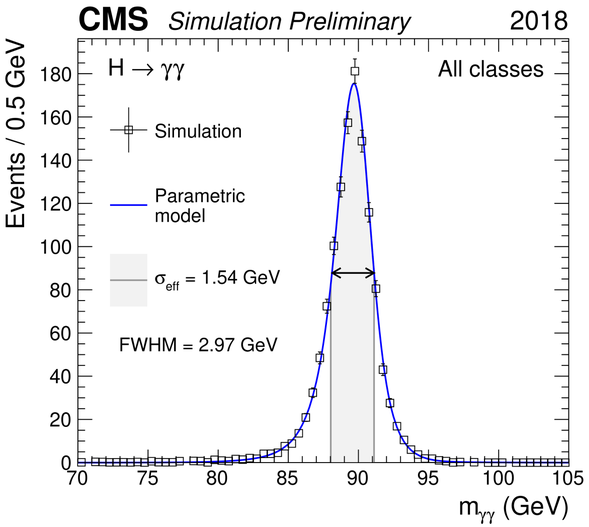
Summary of Newest Results

Low mass H → $\gamma\gamma$	CMS
H → invisible	ATLAS CMS
Heavy H	ATLAS
Searches for HH or HS	ATLAS CMS
LFV H → $\ell\tau$, eμ	ATLAS CMS
Light pseudoscalars	ATLAS CMS(2)
H → meson + γ	ATLAS

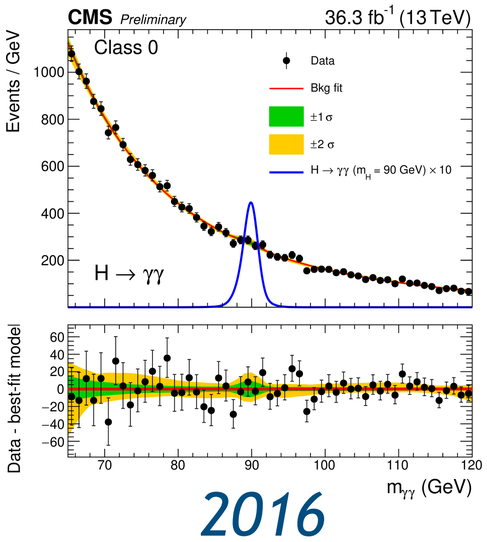
BSM Searches for H → $\gamma\gamma$

CMS H → $\gamma\gamma$ Search CMS PAS HIG-20-002

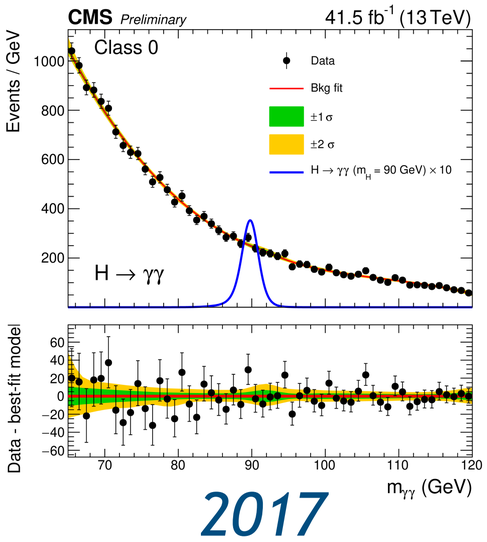
- Search for narrow-width SM-like Higgs in the diphoton channel, 70 < M($\gamma\gamma$) < 110 GeV
- Previous CMS result showed mild excess at 95 GeV, follow up with full Run 2 data!
- Primary challenges: sufficient trigger efficiency, Z → ee background rejection



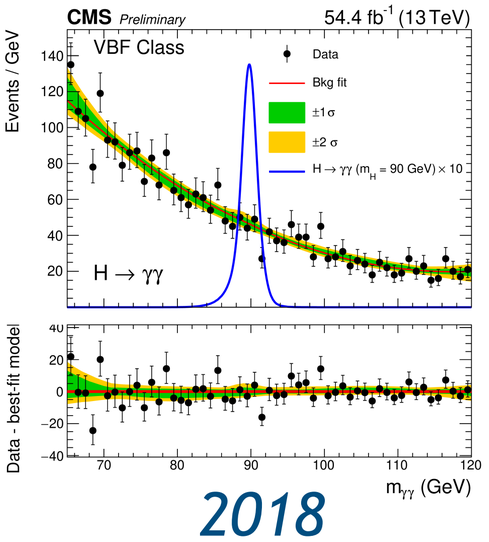
- Diphoton trigger, with pT > 30,18 GeV
  - 2016 only: 2 paths: 1. Barrel only, 2. Barrel+Endcap, with additional shower shape requirements
  - Trigger requirements limit search to M($\gamma\gamma$) > 70 GeV
- Reconstruction-level classes: VBF (2017 and 2018 only), Class 0, 1, 2. Class 0 has highest exp. sensitivity



2016



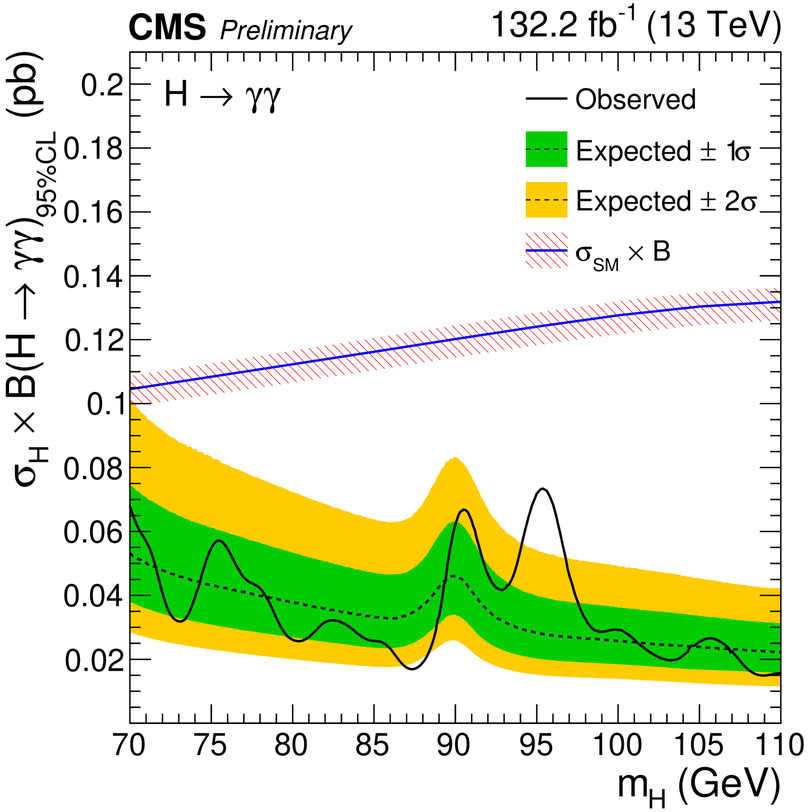
2017

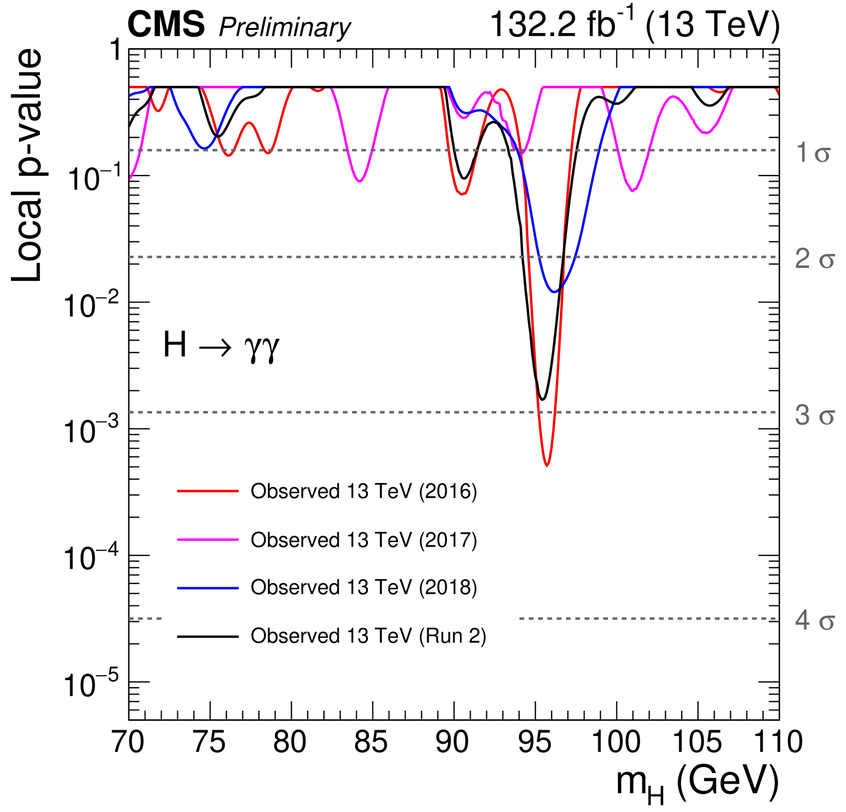


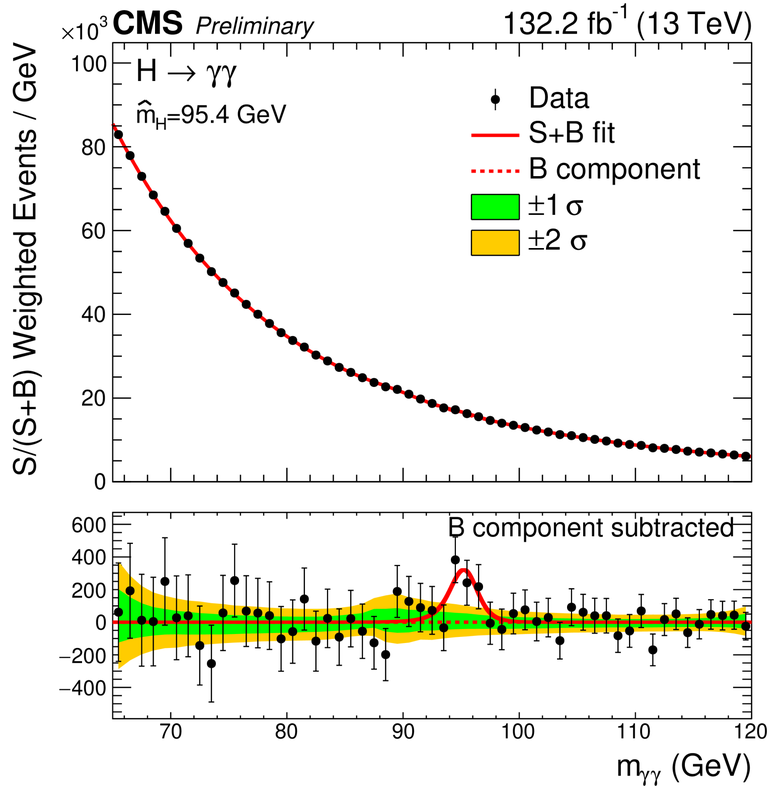
2018

CMS H → γγ Search CMS PAS HIG-20-002

- Small excess seen in all production modes: ggH+ttH, VBF, VH







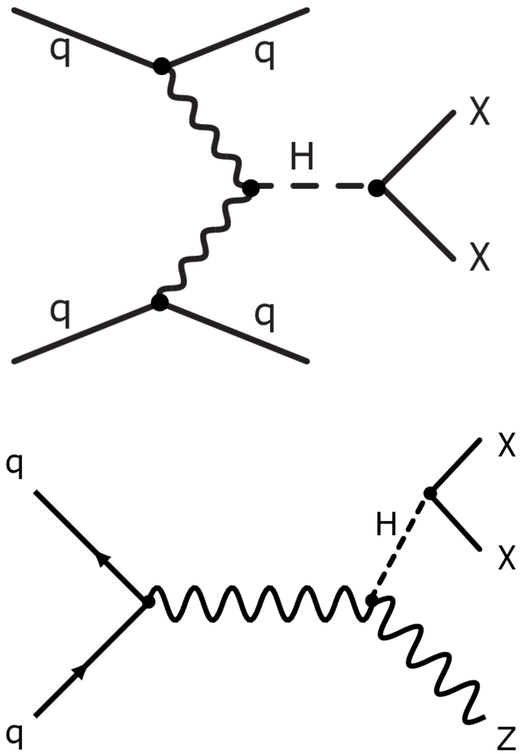
Local/global significance: 2.9σ/1.3σ @ 95.4 GeV

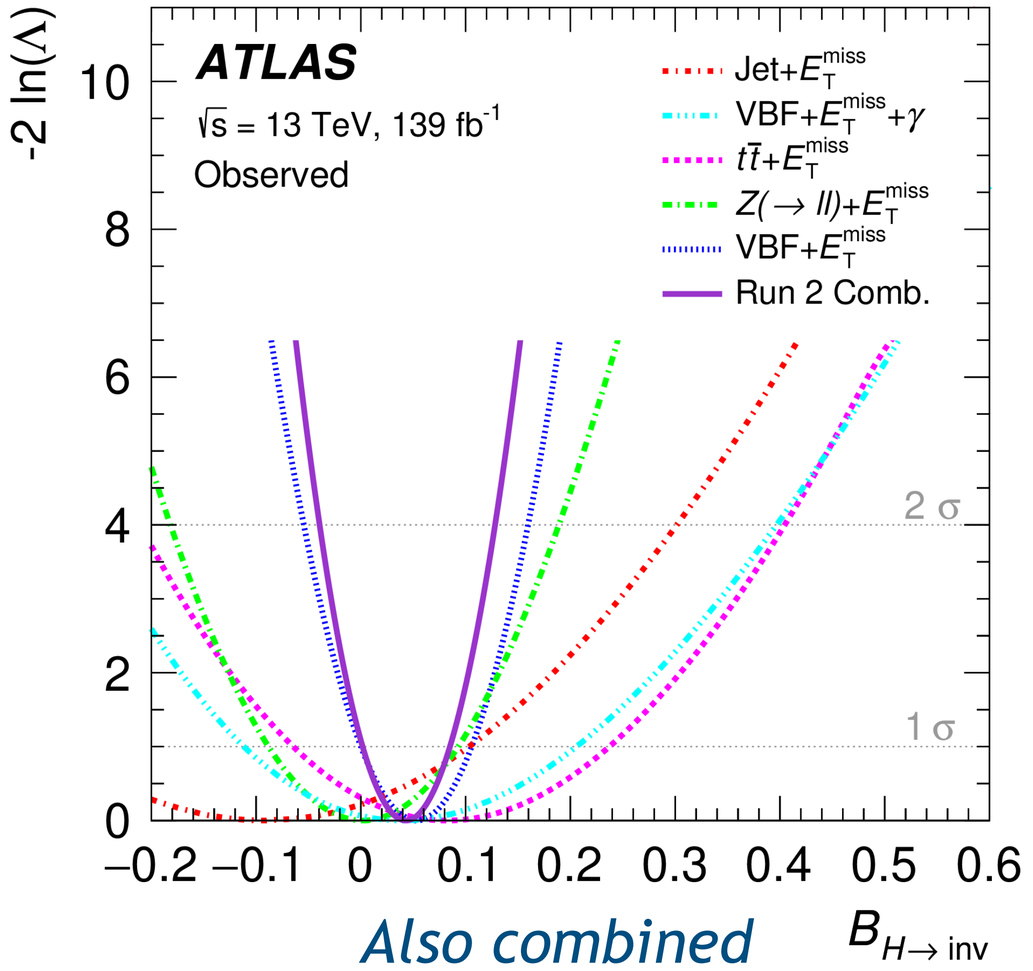
Previous CMS analysis: 2.8σ/1.3σ @ 95.3 GeV

H → invisible final states

ATLAS H → Invisible arXiv:2301.10731v1

- Higgs → Dark Matter! Invisible (→ MET), so measure and interpret accompanying visible particles
- New combination of results:
  - VBF + MET
  - Z + MET
  - tt + MET
  - VBF + MET + γ
  - Jet + MET

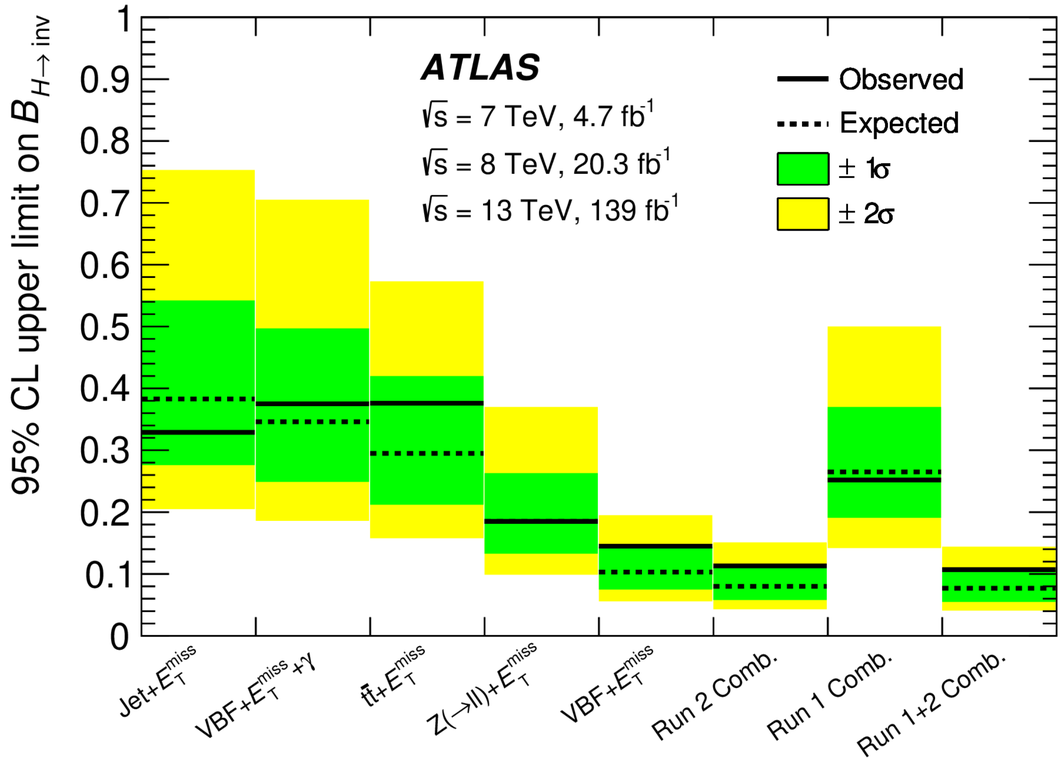




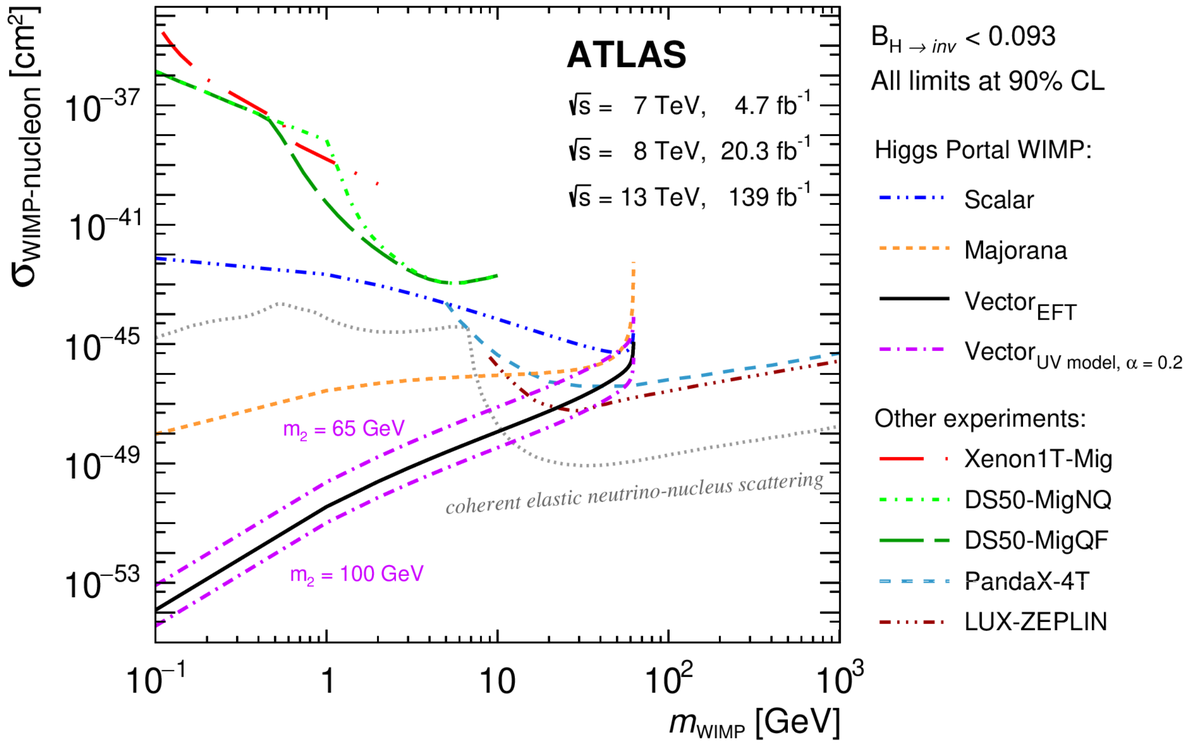
Also combined with Run 1 results

ATLAS H → Invisible arXiv:2301.10731v1

- VBF+MET most sensitive channel. Slight excess observed: Br @ 95% CL < 0.145(0.103) obs(exp)



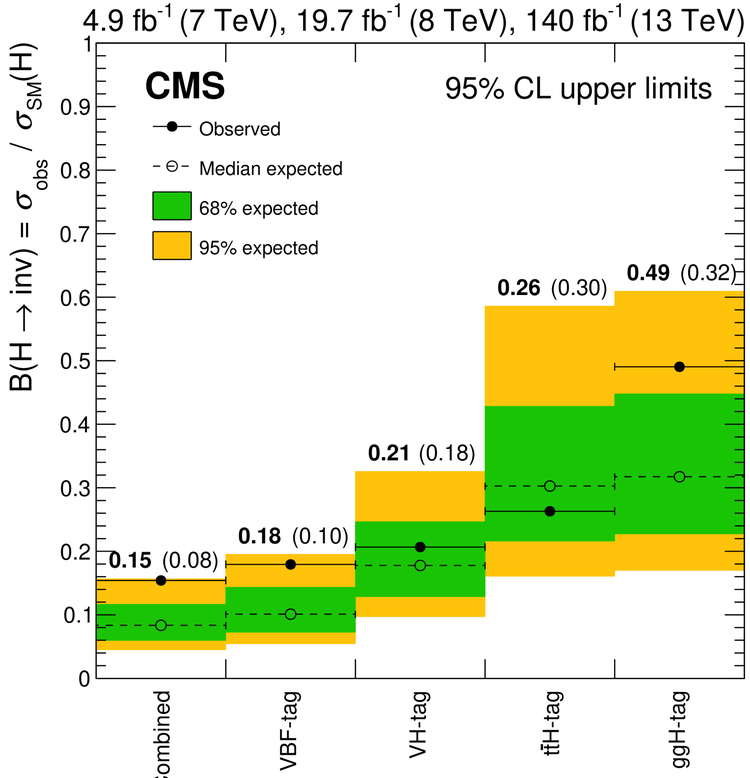
Run 1+2 combined: 0.107 (0.077)

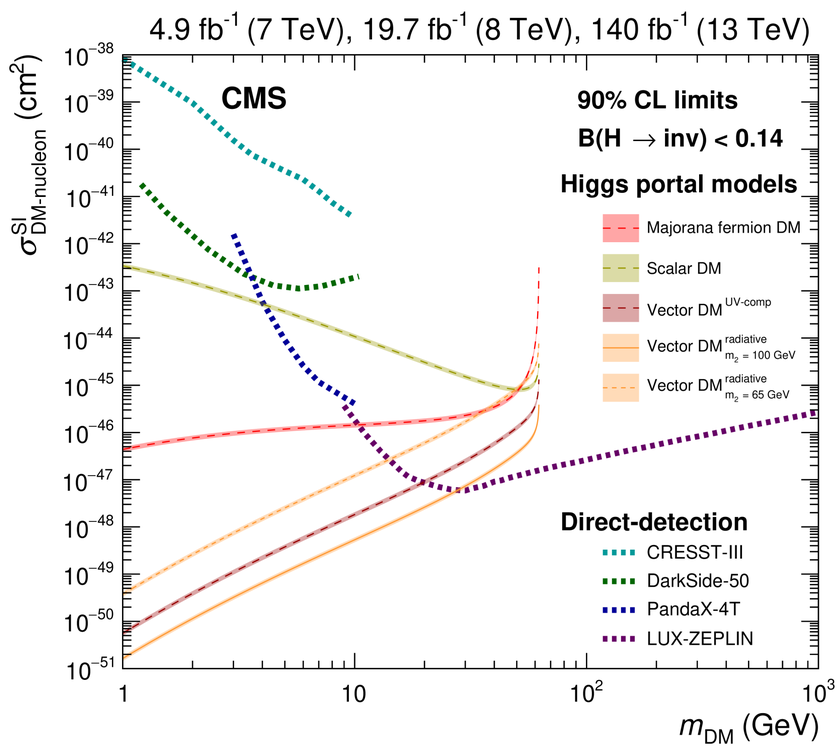


Higgs portal: m_2 = dark Higgs mass

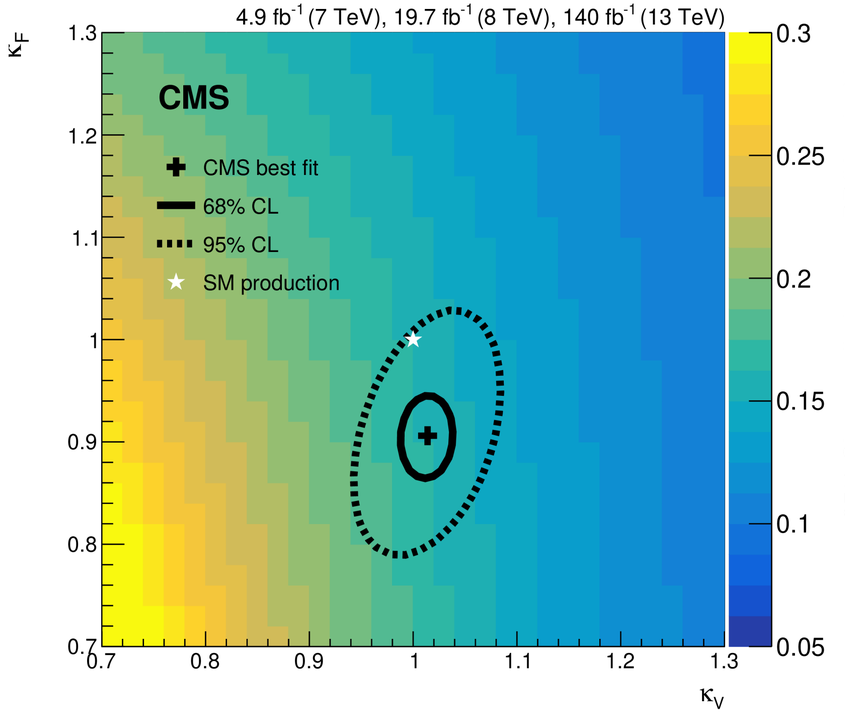
CMS H → Invisible arXiv:2303.01214v1

- New: ttH+MET, combine with previous (VH production)
  - BGs: Z→ inv, EWK → lost leptons
- AK8 Jet mass (PUPPI PF with SD plus Deep AK8) separates high-pT t or V decays from q/g fragmentation
  - @ pT > 400 GeV, t quark tag eff ~ 28% with 1% QCD mistag rate





coupling-strength modifier plane

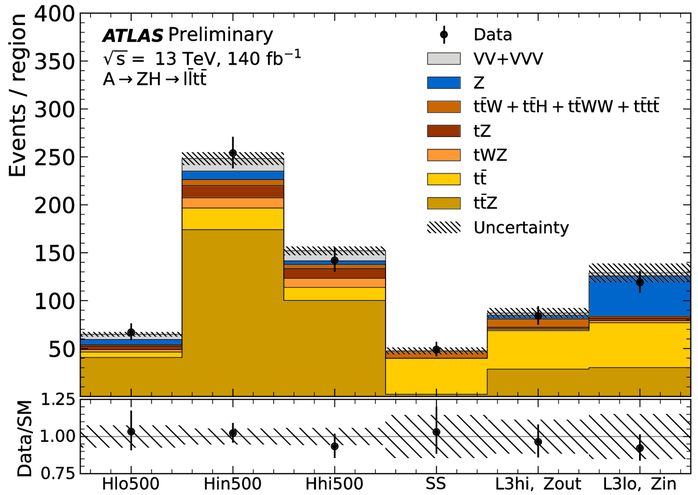


Run 1+2 combined: 0.15 (0.08)

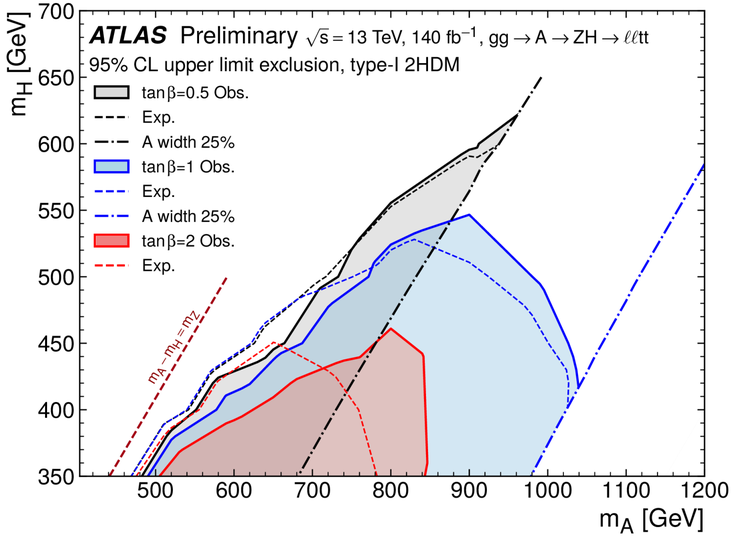
Heavy Higgs Searches

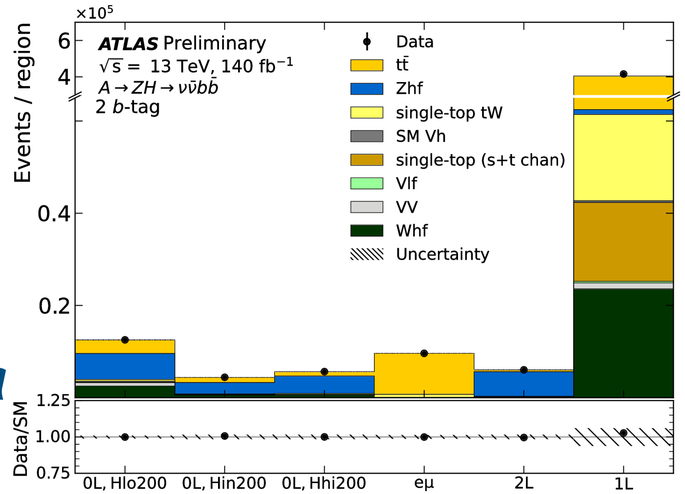
ATLAS A → H (heavy) + Z ATLAS-CONF-2023-034

- 2HDM, baryogenesis: $M_A > M_H$
- Consider mass ranges:
  - M_A > 800 GeV
  - $M_H > 2*M_{top} = 350$ GeV
- Channels:
  - tt$\ell\ell$: leptons+b's+jets
  - bb$\nu\nu$: complementary, DM search for heavy H → bb + MET

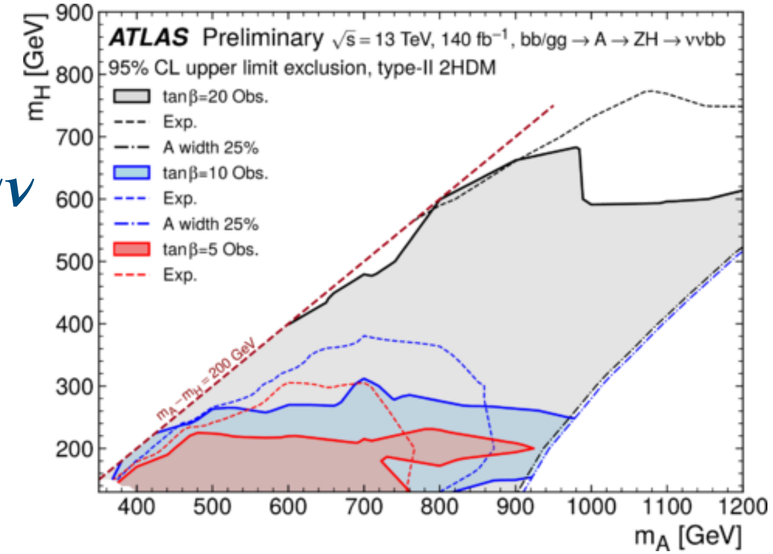


ttℓℓ

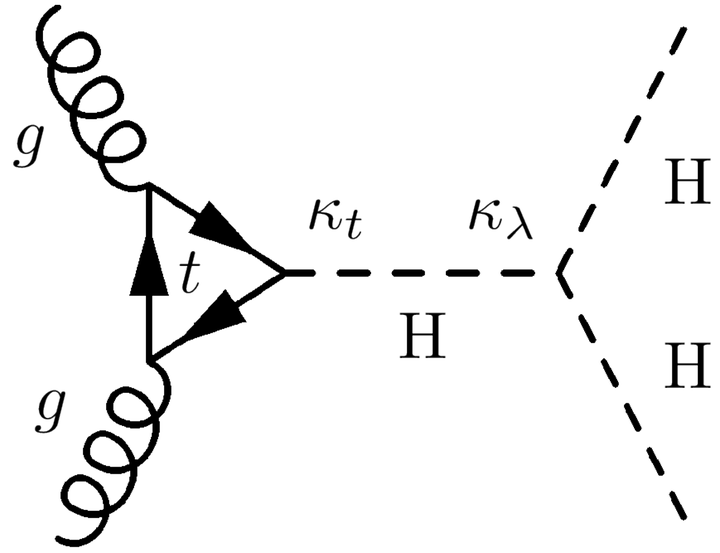


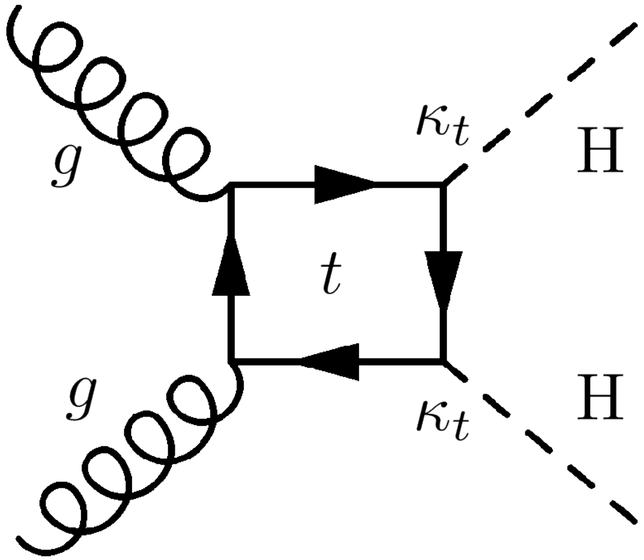


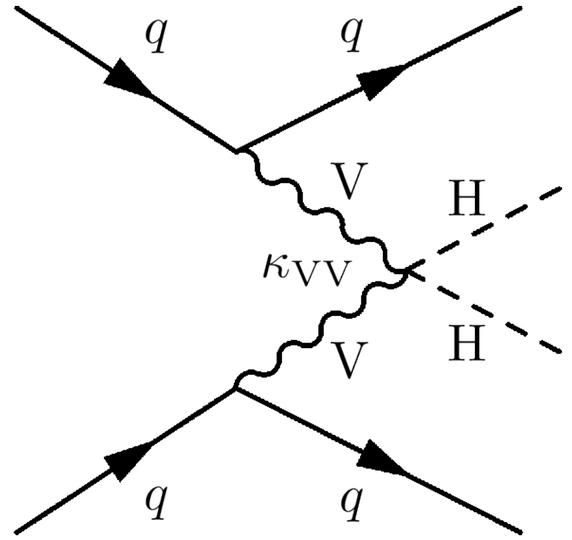
bbνν



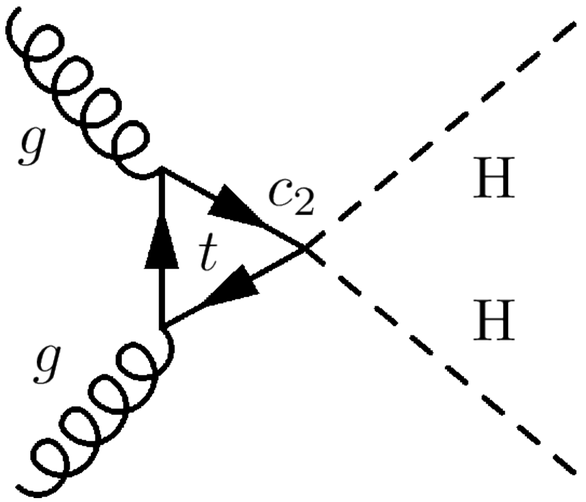
bg only fits to data
upper: ttℓℓ
lower: bbνν

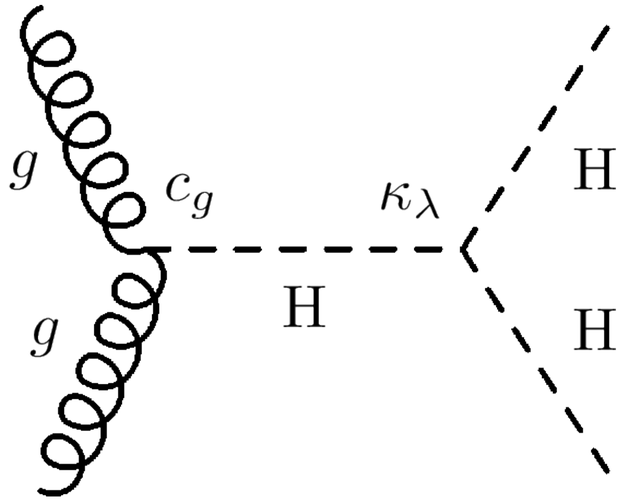


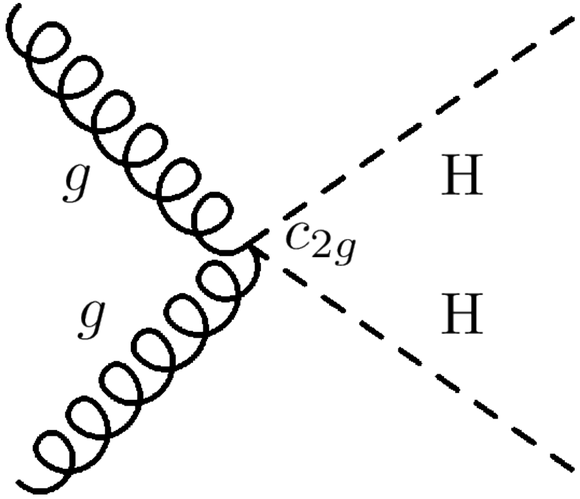




Searches for HH Production



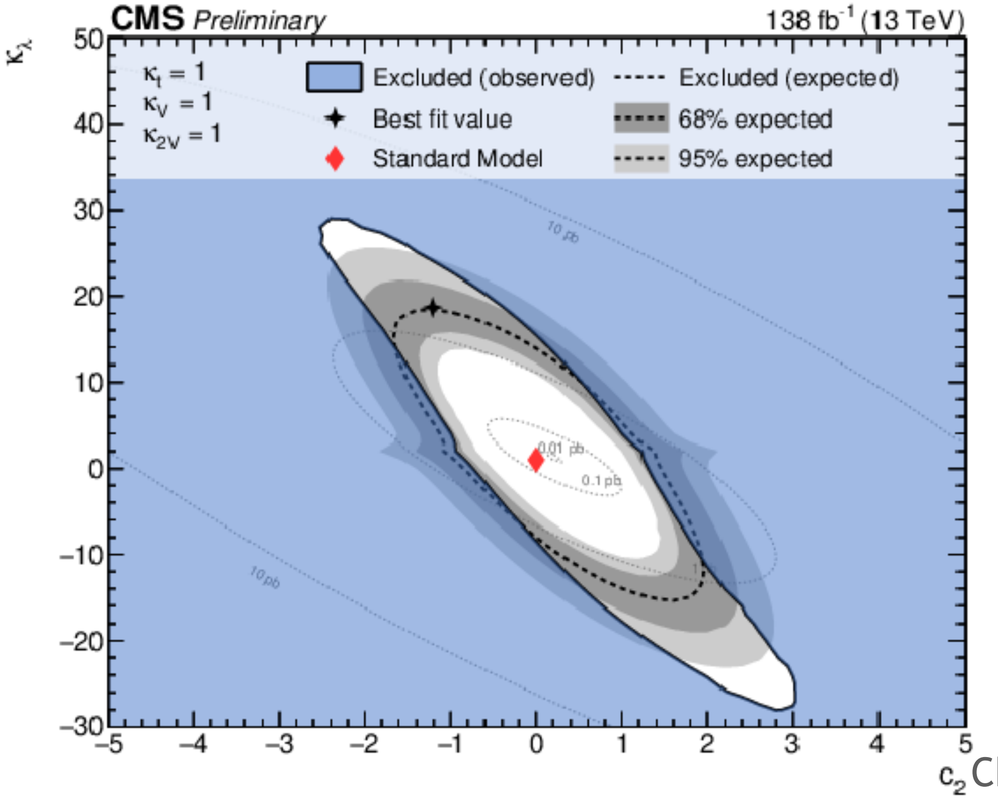




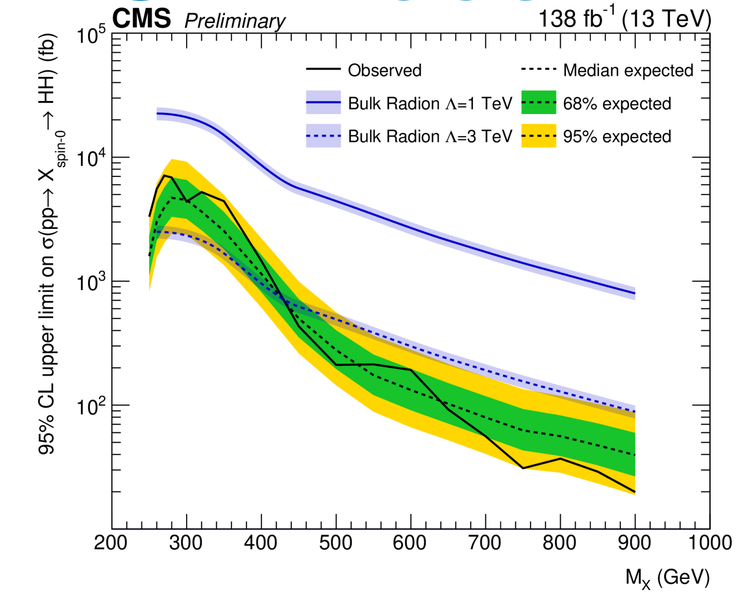
CMS HH Search

CMS PAS HIG-21-005

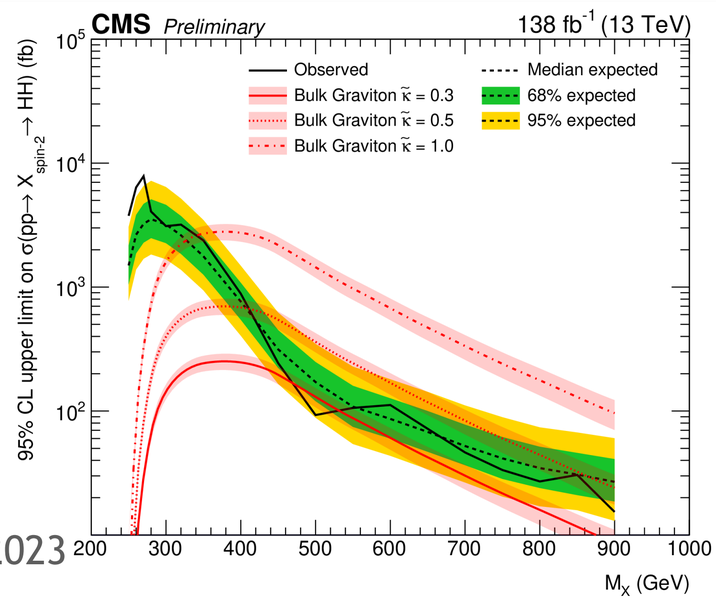
- Non-resonant: Study SM couplings and check for deviations
- HH → bb + WW
- Require at least one W → $\ell\nu$
- Resonant production search for exotic heavy states
  - 250 < M_X < 900 GeV, Spin 0, 2



Radion

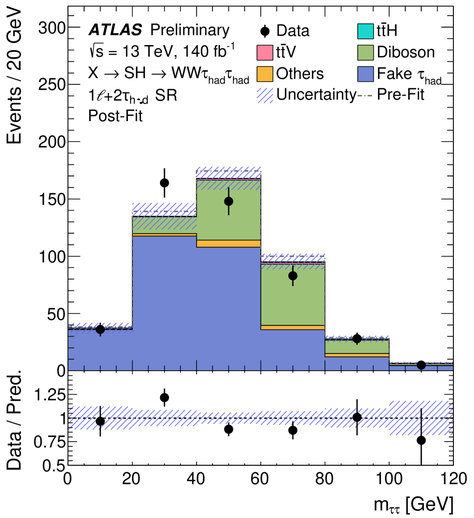


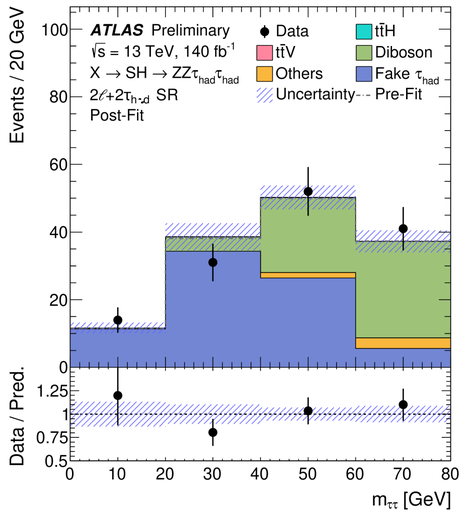
Graviton

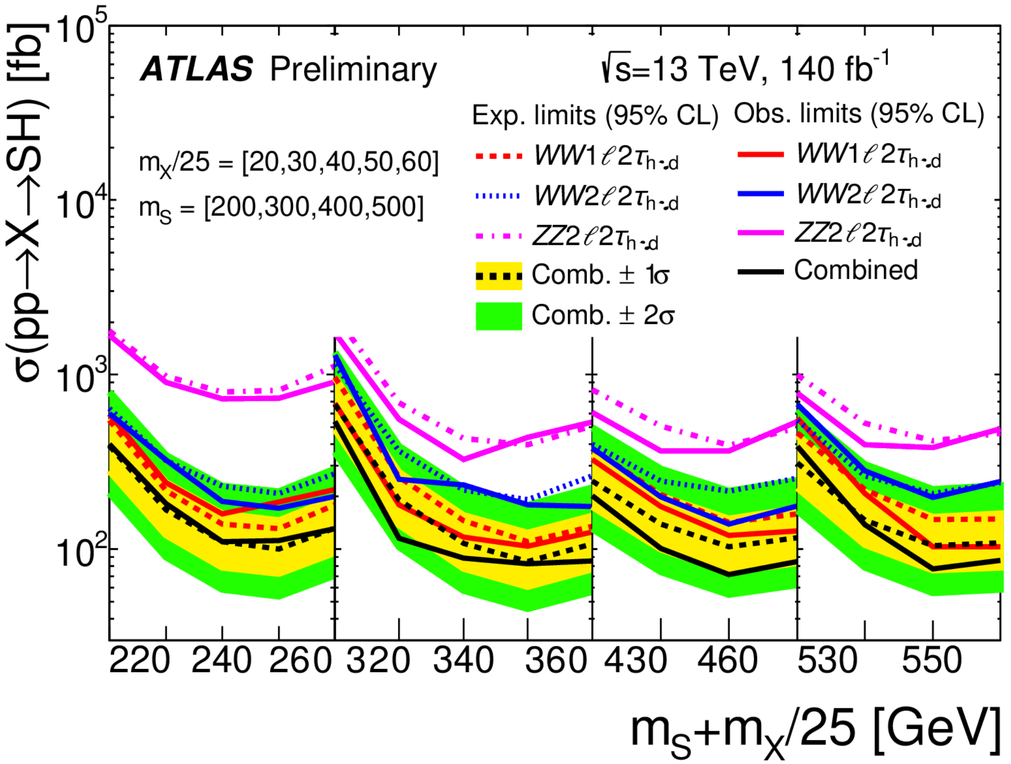


ATLAS X → S H ATLAS-CONF-2023-031

- Search for heavy scalar X decaying to SM Higgs plus singlet (S)
- Appearing in 2HDM+S, nMSSM
  - X mass: 500 - 1500 GeV
  - S mass: 200 - 500 GeV
- Require:
  - H → ττ → $\tau_{had}\tau_{had}$
  - S → VV →1 or 2 ℓ(=e,μ)
- BDT uses kinematics to separate signal from BG
- Fake τ_{had} measured from DD using CR techniques





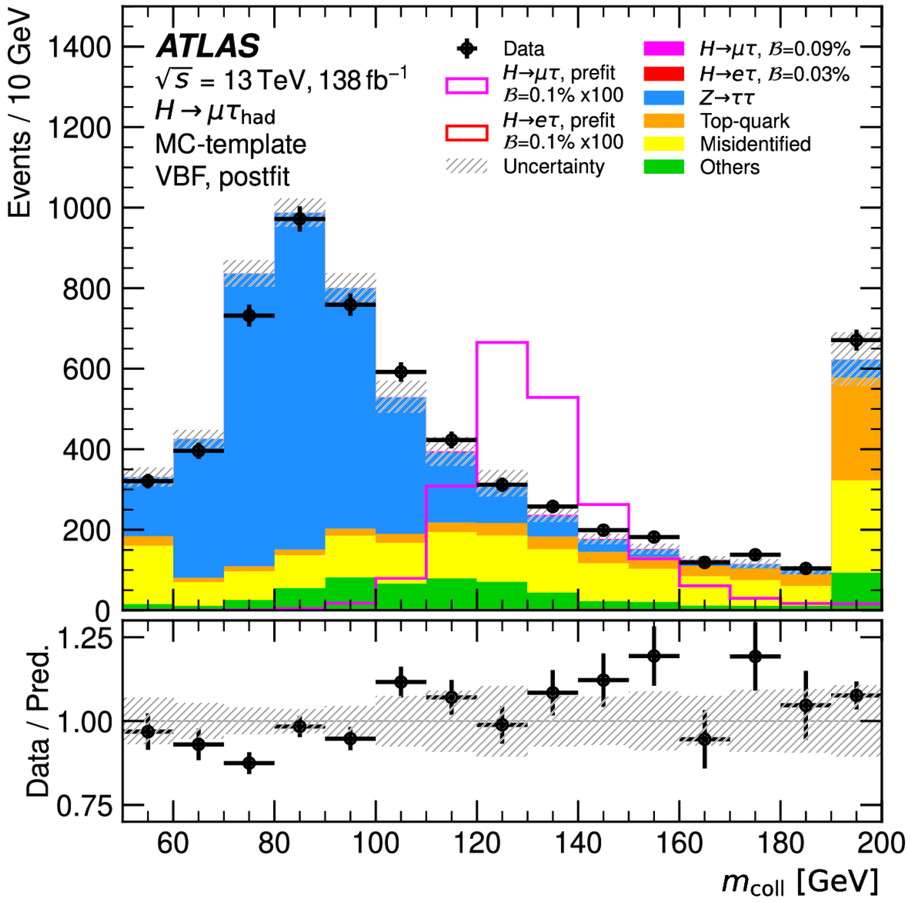


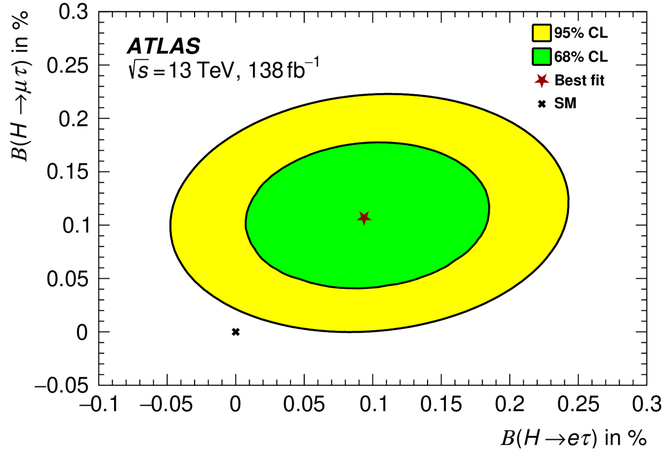
resulting upper limits @ 95% CL range: 72 - 542 fb

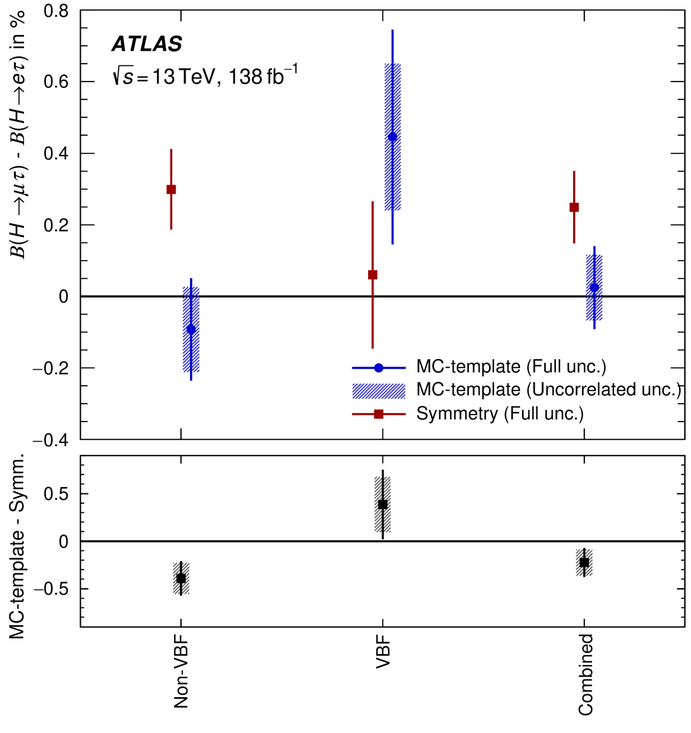
H → decays with LFV final states

ATLAS H → eτ, μτ arXiv:2302.05225v1

- Motivation: ν mixing, flavor anomalies
- BSM: 2HDM, CHM, flavor symmetries, etc.
- Include all tau decays
- Independent BG methods:
  - MC templates using DD normalization
  - Flavor symmetry e ↔ μ

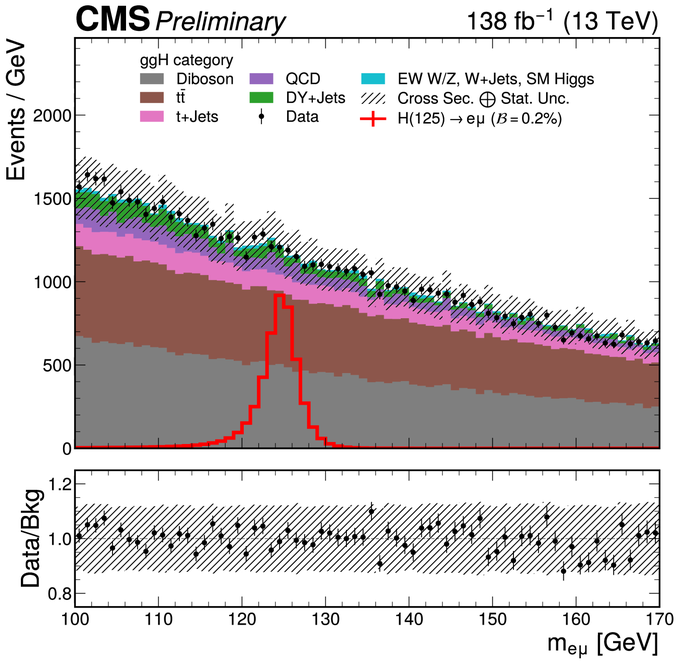


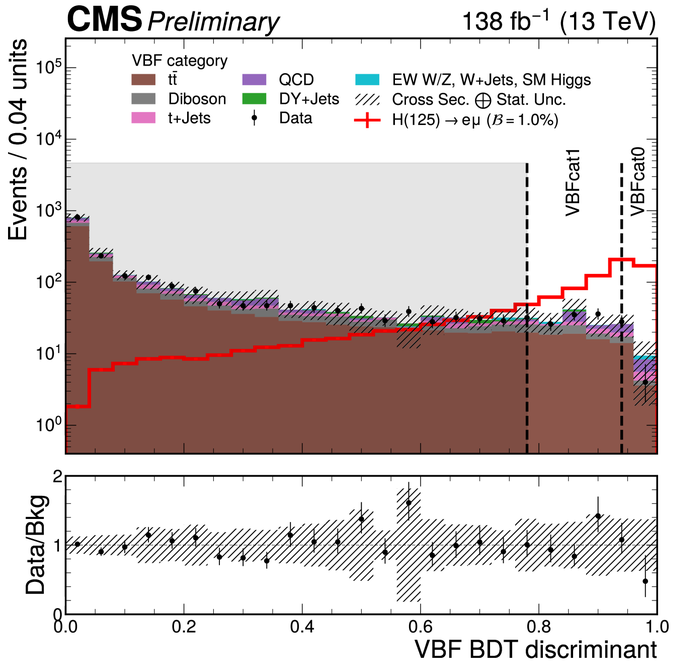


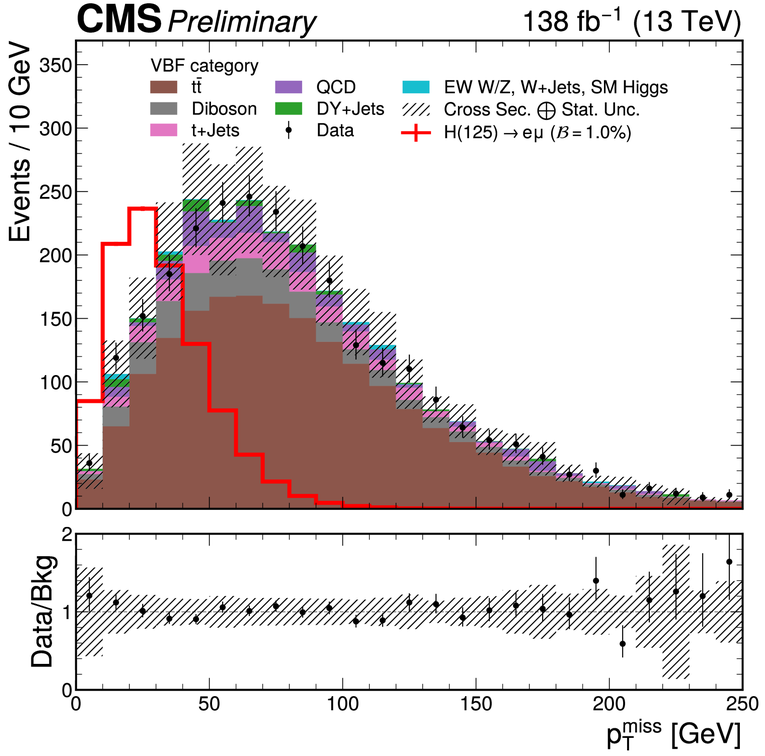


CMS $H \to e^{\pm}\mu^{\mp}$ Search PAS HIG-22-002

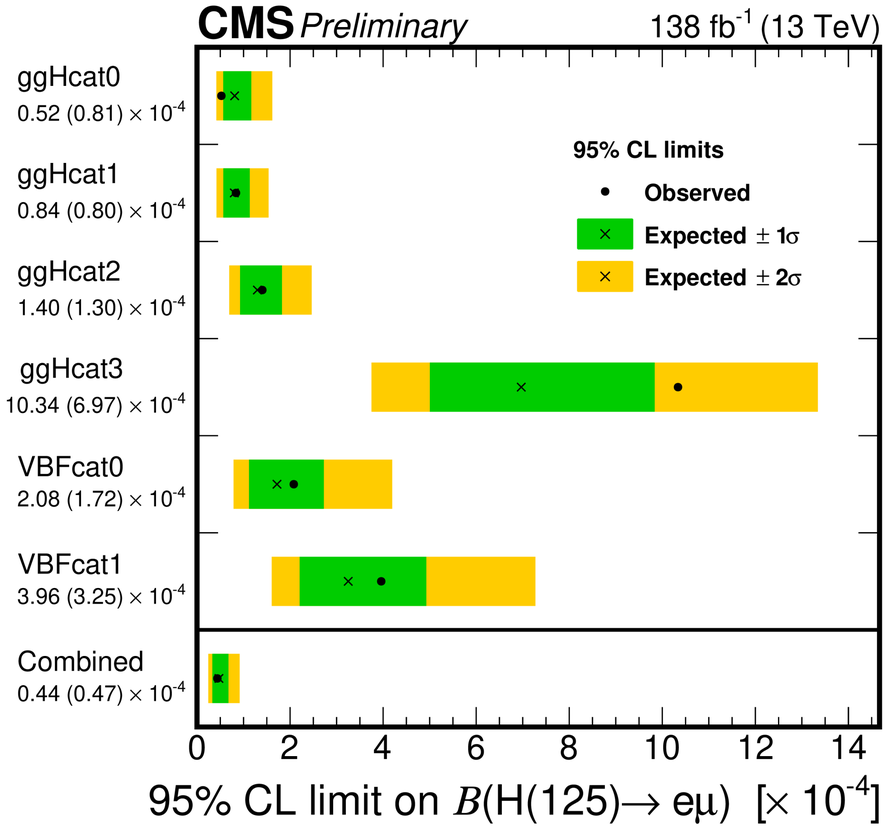
- Search considers both the “SM” Higgs and a BSM Higgs:
  - 110 GeV < M(H), M(X) < 160 GeV
  - range below $2M_W$ important for constraining 2HDM Type-III models
  - Look for peak over smoothly falling BG from tt, WW, Z+jets

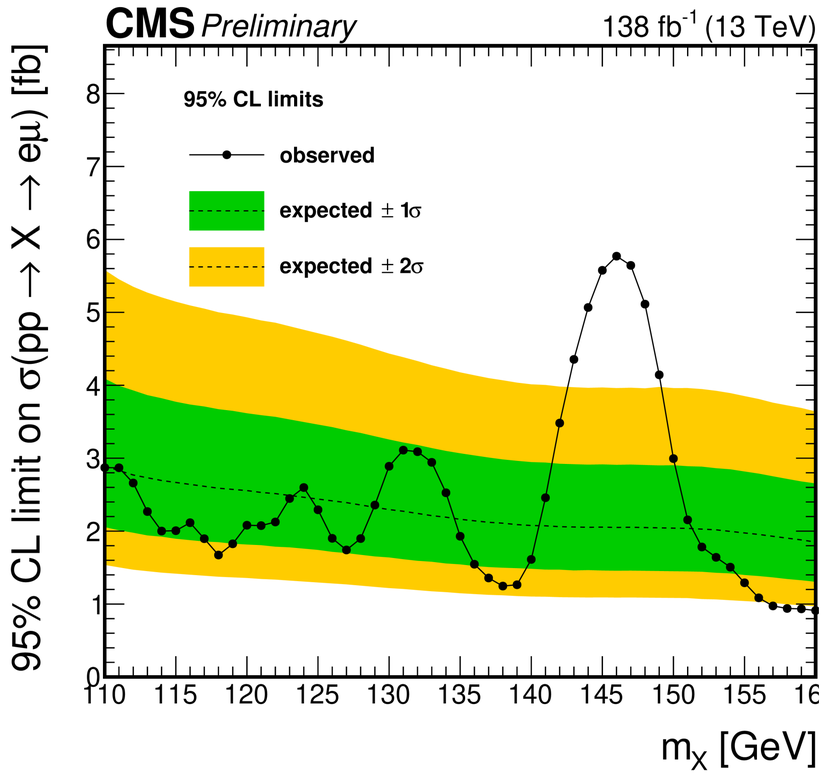


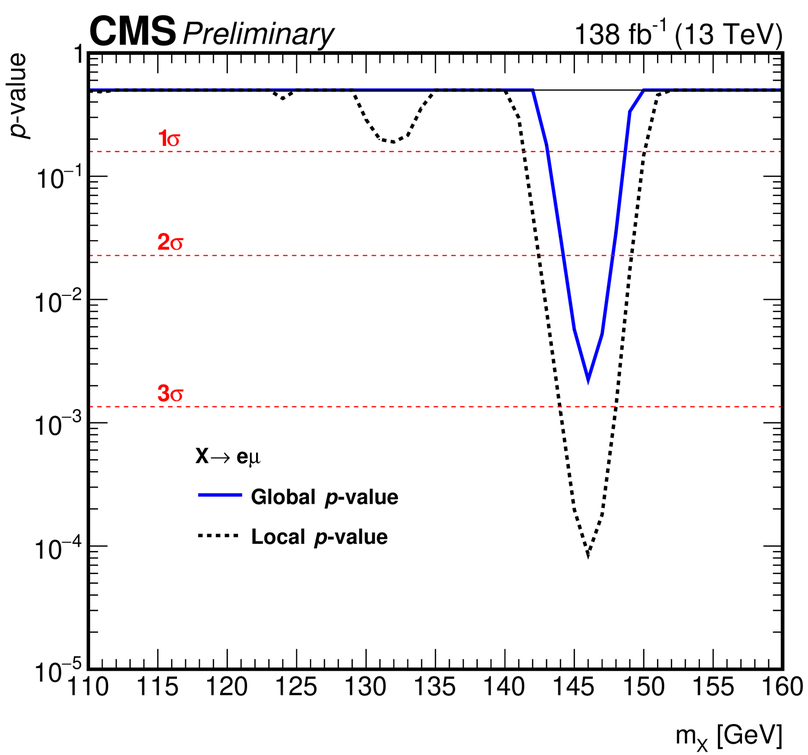




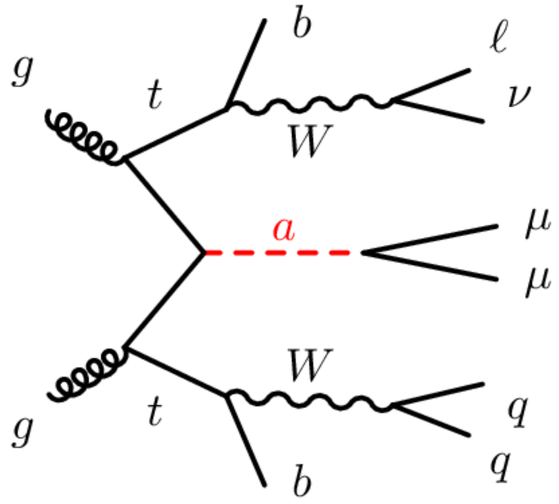
CMS H → e±μ∓ Search PAS HIG-22-002



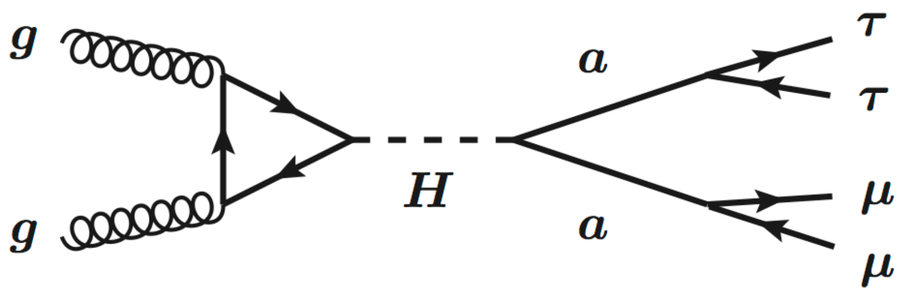




B(H125 → eμ) < 4.4 obs (4.7 exp) x 10-5



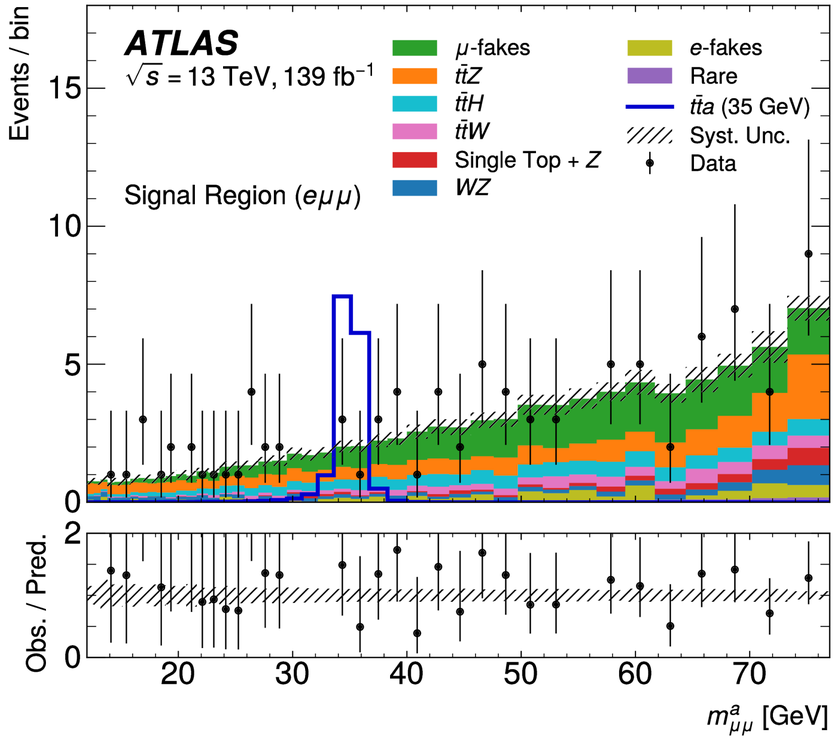
Searches for light pseudoscalar Higgs Bosons

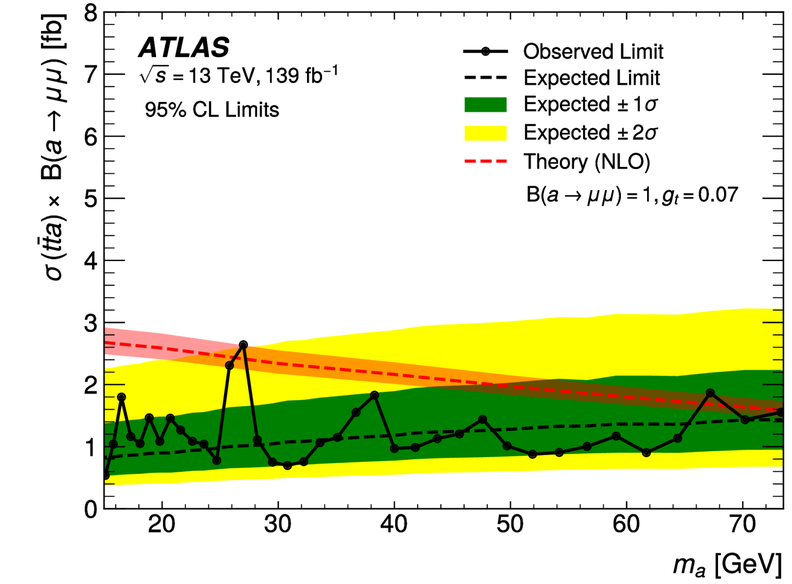


ATLAS Searches for light pseudoscalars with ttbar

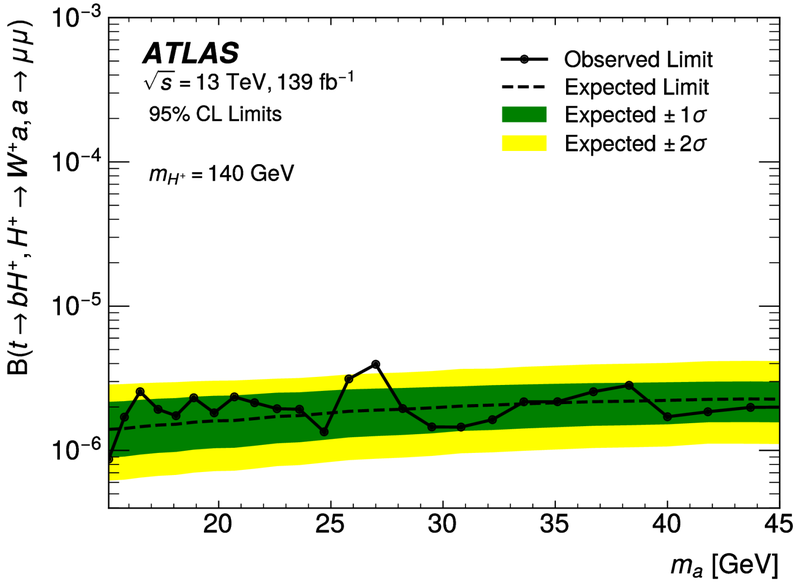
arXiv:2304.14247v1

- Two searches:
  - tta production
  - tt with t → H+ b, H+ → W+ a, a → μμ
- light "a" motivation:
  - 2HDM+S, NMSSM,
  - explain galactic γ emission excess!?
- a → μμ provides clean signature
- Search probes:
  - 15 < m(a) < 72 GeV
  - 120 < m(H±) < 160 GeV





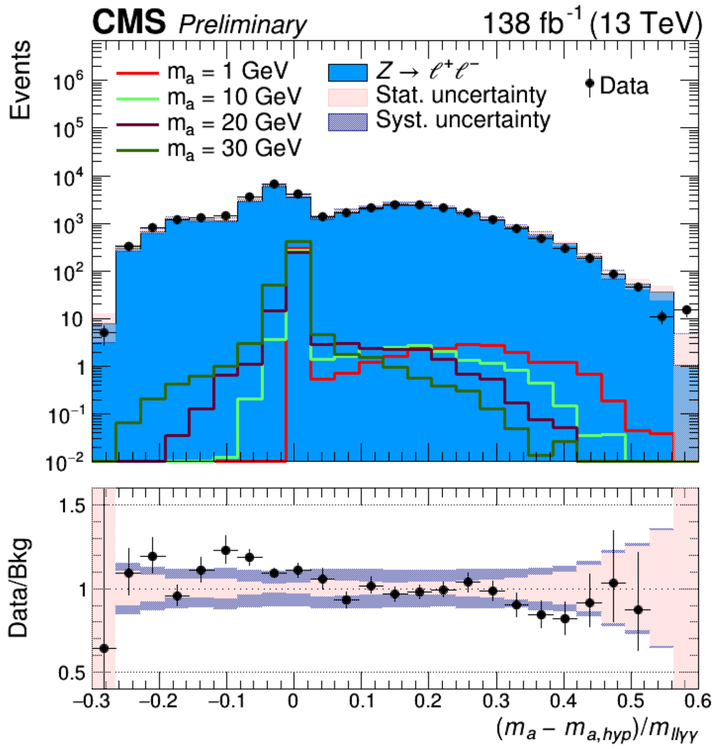
tta



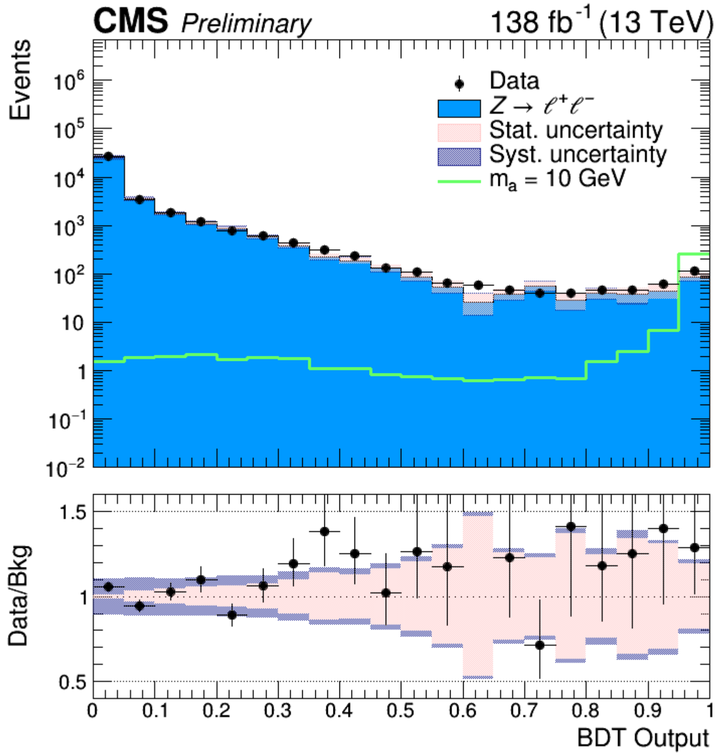
H±

CMS H → Za, with a → $\gamma\gamma$ CMS-PAS-HIG-22-003

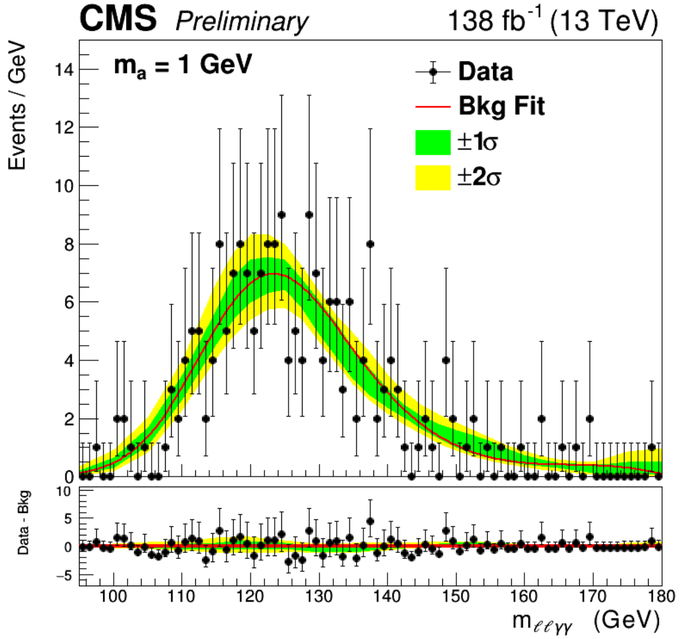
- Signature: Za → $\ell\ell\gamma\gamma$
- Consider 1 < m(a) < 30 GeV
- Apply to ALPs models

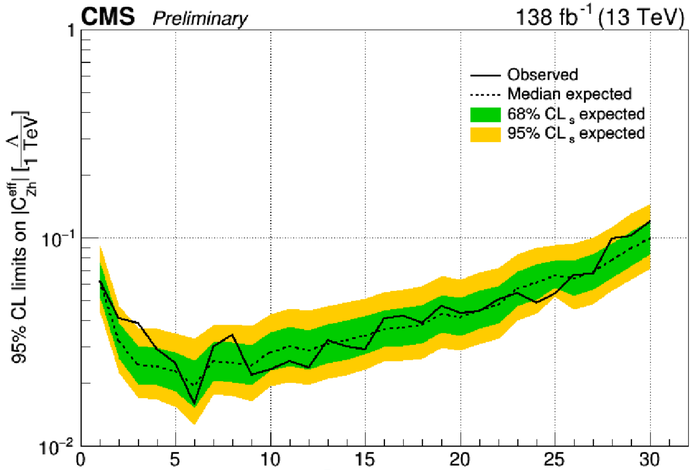


input to BDT,
others include photon variables



BDT Output m(a) = 10 GeV

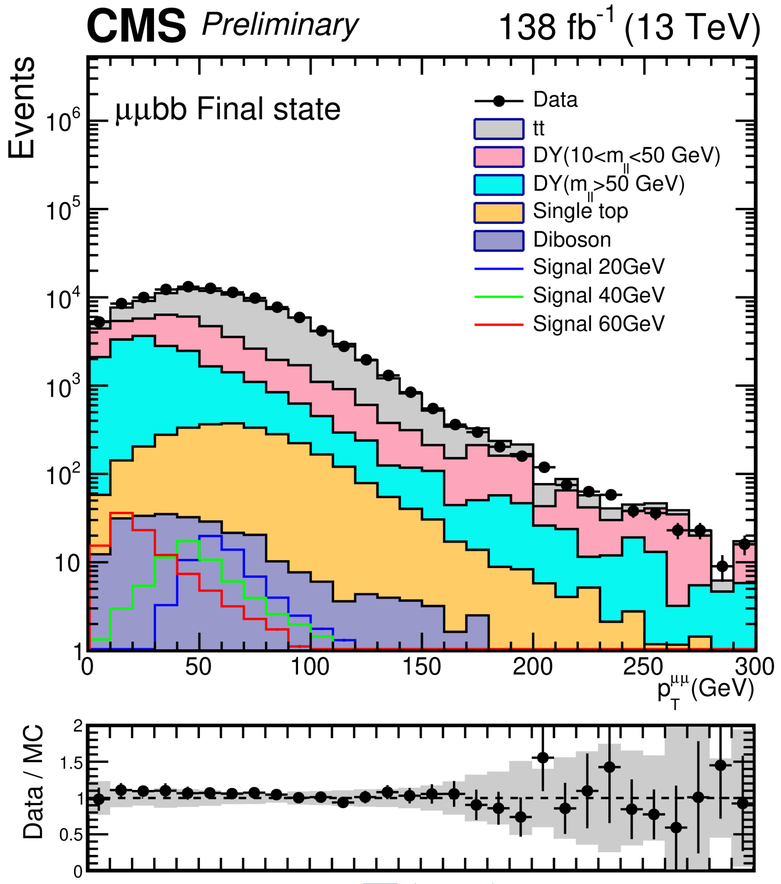




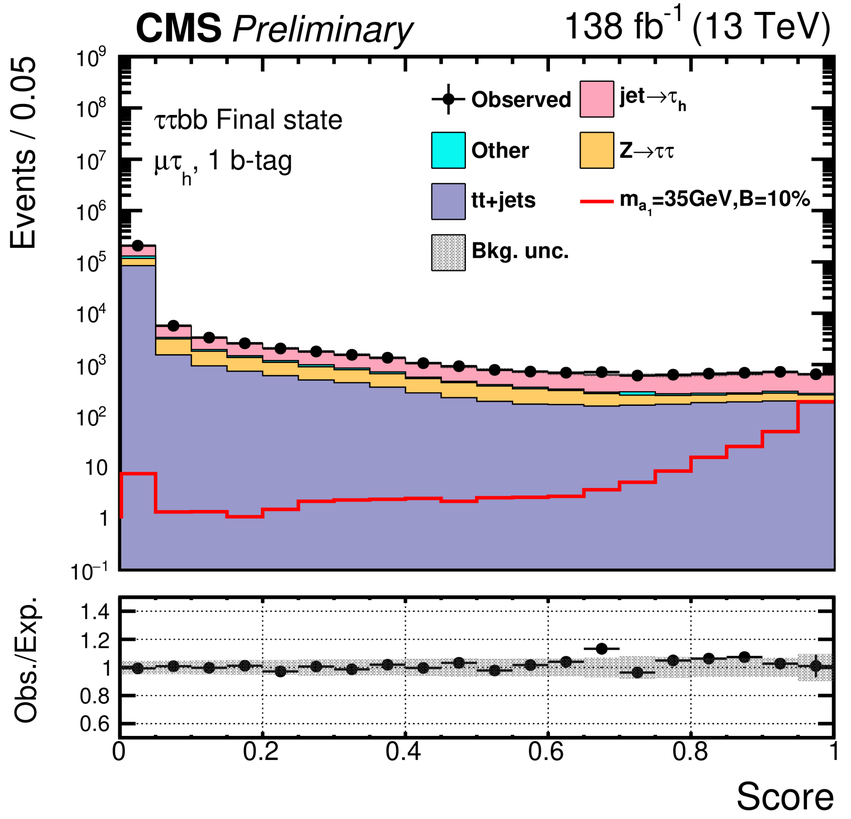
ALPs coupling to ZH

CMS H → aa → μμbb, ττbb CMS-PAS-HIG-22-007

- Yukawa couplings: a→ bb maximal when kinematically allowed, a → ττ is next, …
- 2HDM+S:
  - Type II: B(aa→ ττbb) ~ 10%
  - Type IV: ~ 50%
- Di-tau decays: eμ,eτ$_h$, μτ$_h$
- τ$_h$ reconstructed with HPS;
  - j → τ$_h$ mis-id performed with DD methods.
- BGs: tt, DY, diboson

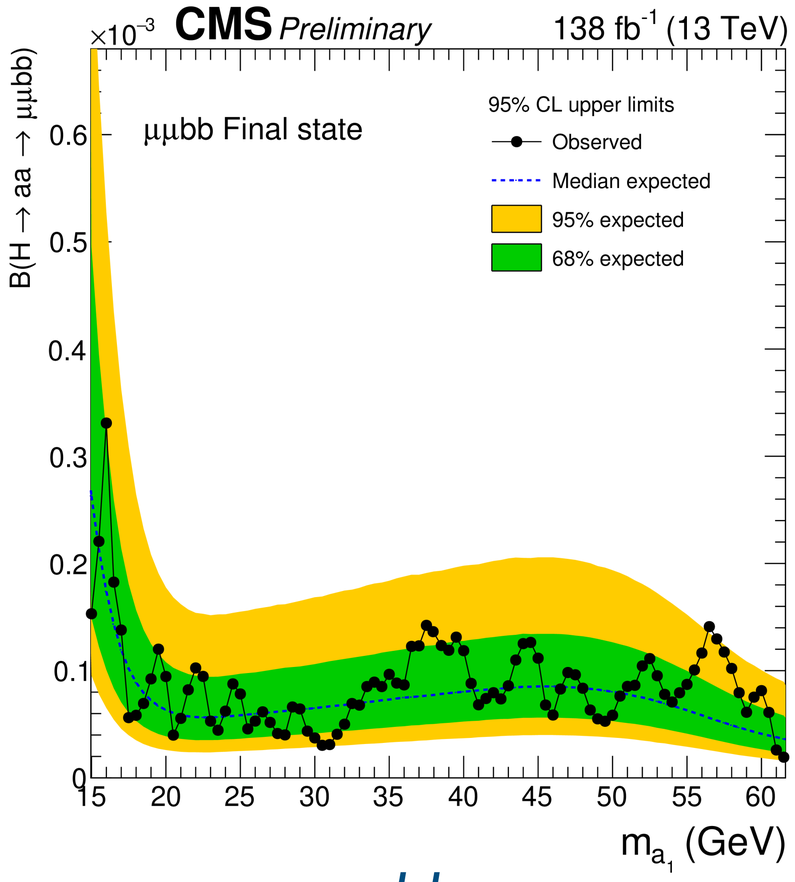


pT(μμ)

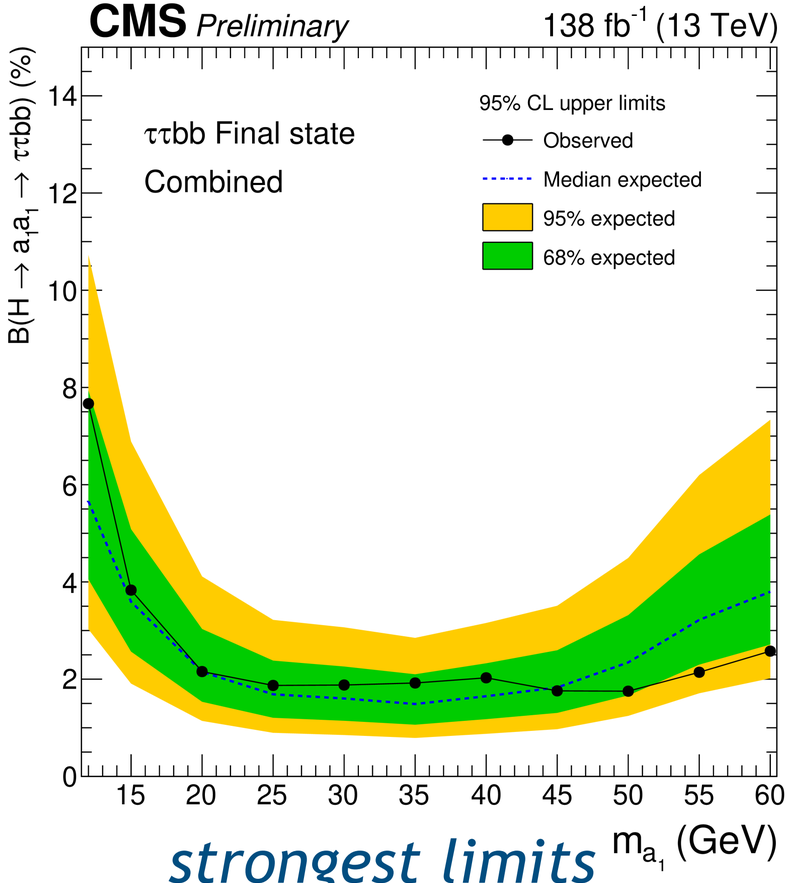


DNN Score

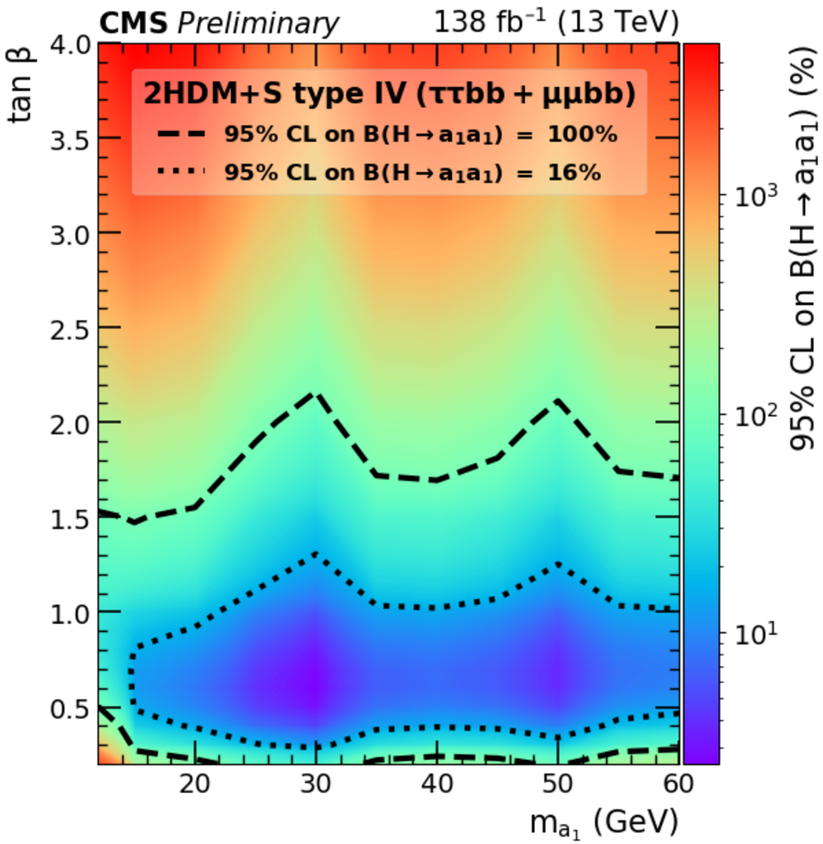
CMS H → aa → μμbb, ττbb CMS-PAS-HIG-22-007



μμbb

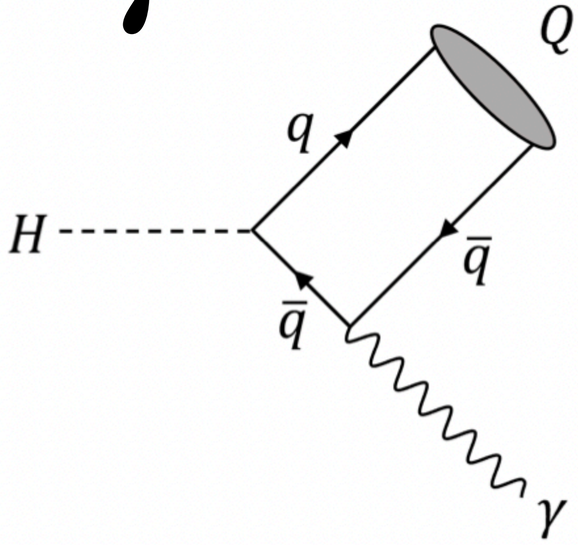


strongest limits from μτh channel

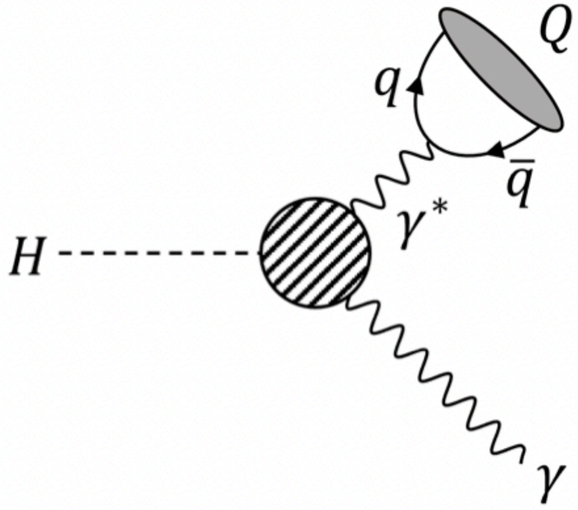


2HDM+S limits

H → meson + γ



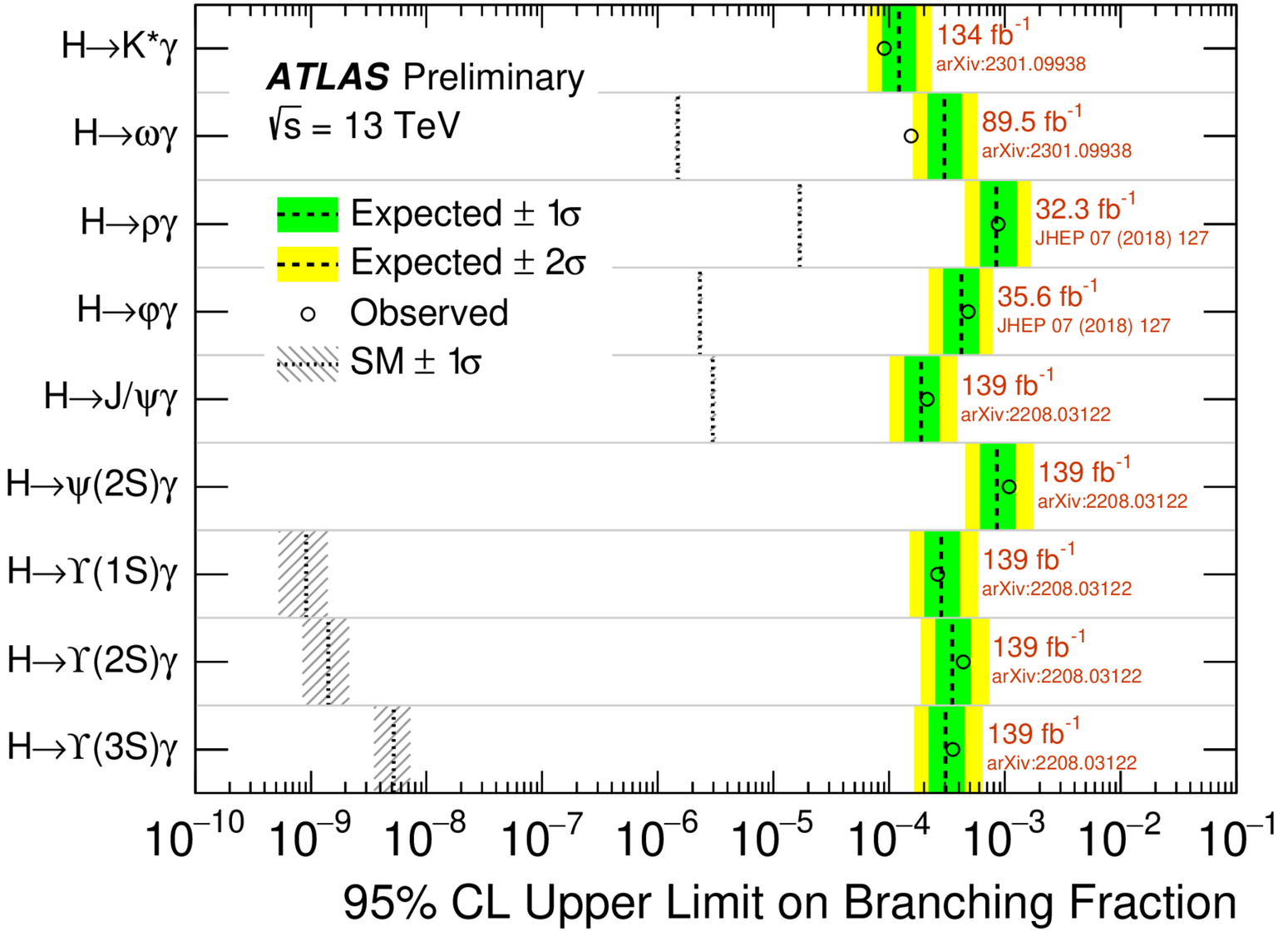
(a) Direct amplitude



(b) Indirect amplitude

ATLAS H → meson + γ ATL-PHYS-PUB-2023-004

- Unique approach to study Higgs couplings to light flavor
- Signatures:
  - K$\pi\gamma$, 3$\pi\gamma$, 2$\pi\gamma$, KKγ, $\mu\mu\gamma$ …
- SM predictions are tiny



Conclusions

Conclusions

- Large data sets at 13 TeV from Run 2 with excellent ATLAS and CMS detectors provide unprecedented search reach for BSM Higgs signals. 12 new results shown!
  - tl;dr : no BSM discoveries so far ;)
- The two collaborations have methodically improved search strategy and parameter space considered as the data sets have increased. Now ubiquitous:
  - Advanced and varied ML techniques
  - Combination of channels
- Observed bumps and wiggles will be vigorously probed with additional Run 3 data in advance of HL-LHC, which promises another 10X data at 14 TeV.