H(125) BSM aspects and searches for new scalar bosons

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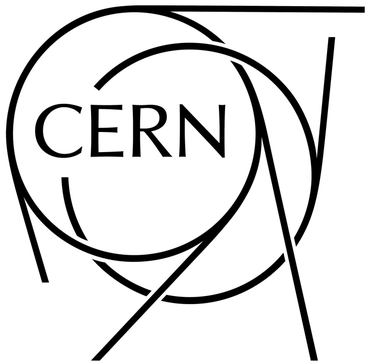
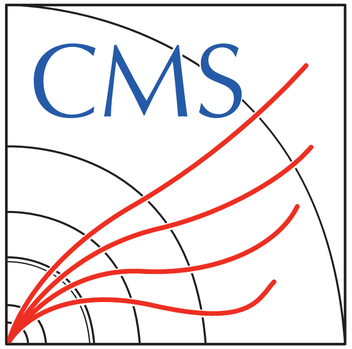
On behalf of the CMS Collaboration

HH2026: Higgs Hunting 2026 Workshop

16-18 Sep 2026, Orsay / Paris

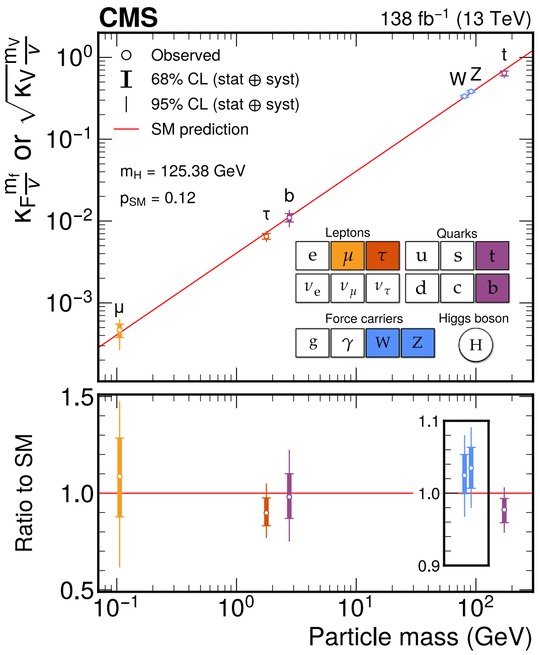




Why look beyond the SM Higgs?

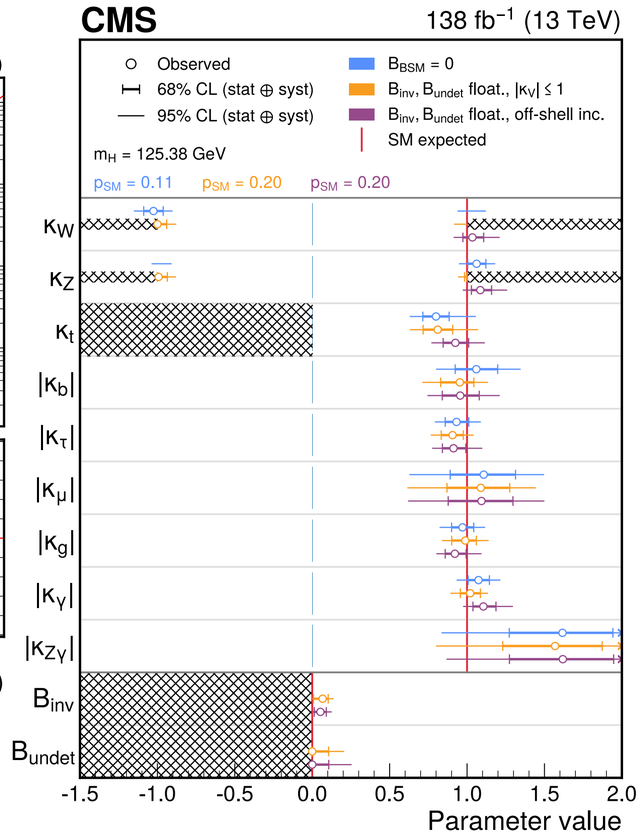
SM-like H(125) → room for BSM decays → extended scalar sector

- The Higgs boson remains the only fundamental scalar particle observed
- Higgs couplings are increasingly SM-like, but sizeable BSM branching fractions remain allowed



H(125) couplings: increasingly SM-like

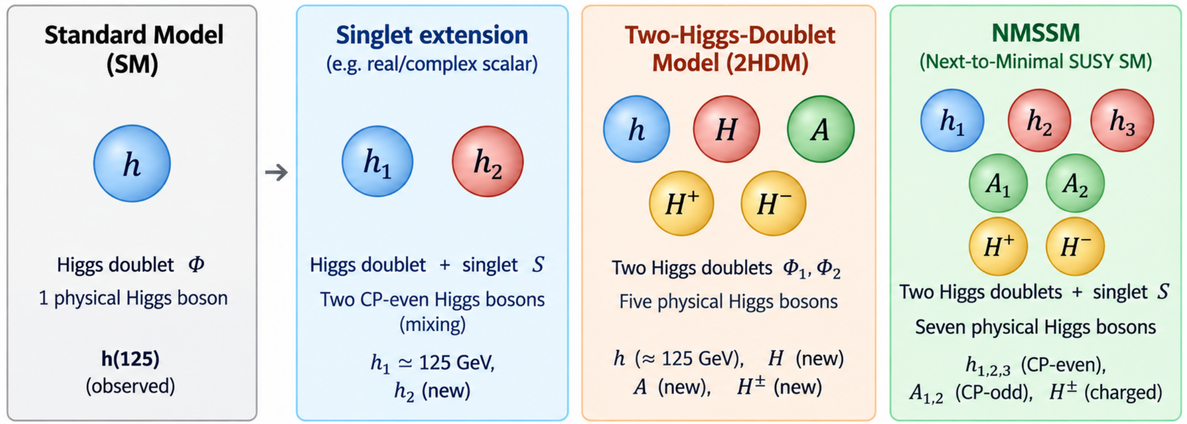
arXiv: 2602.18611



Yet O(10%) BSM branching fractions remain possible

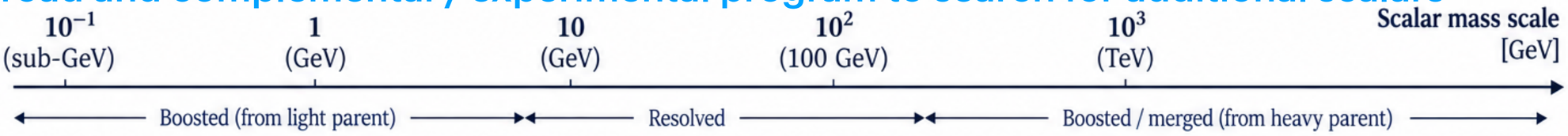
Indirect constraints on B(H→undetected):
<16% [CMS] and <12% [ATLAS]

- A SM-like H(125) can coexist with additional scalars



The scalar search program

A broad and complementary experimental program to search for additional scalars



H(125) decays as a portal

Exotic Higgs decays to new light states

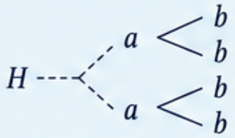
$H \to SS$
very light scalars ($m_S \lesssim$ few GeV)

e.g. $H \to SS \to 2\mu 2h$ (prompt or displaced)

$H \to aa$
light pseudoscalars ($m_a \sim 1 - 60$ GeV)

e.g. $H \to aa \to 2\mu 2\tau, 4\tau$ (low masses, boosted)

$H \to aa \to 4b$
$m_a \sim 10 - 60$ GeV

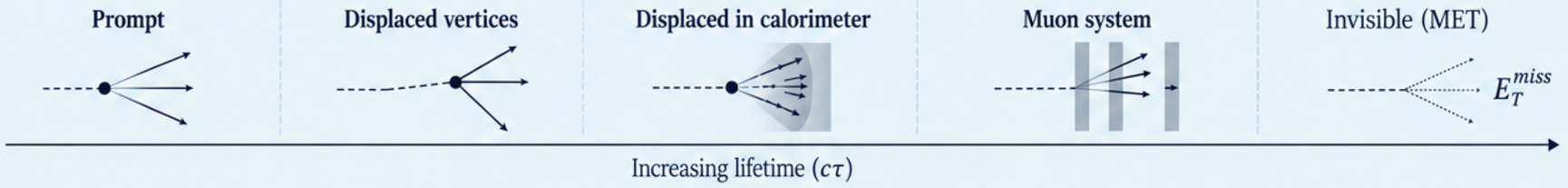


resolved ↔ boosted (transition region)

$m_H/2$ (≈ 62.5 GeV)

Hidden sectors and long lifetimes

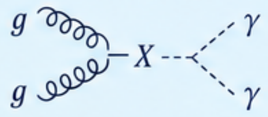
Complementary signatures for the same underlying models



Direct production of additional Higgs/ scalar states

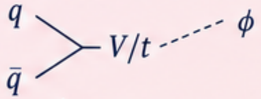
Resonant and non-resonant searches

Low-mass scalar
$X \to \gamma\gamma$
(≈ 70 – 110 GeV)



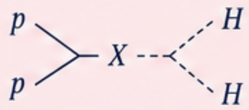
e.g. ggH, VBF, VH, ttH

Associated production
$W\phi, Z\phi, t\bar{t}\phi$
(≈ 15 – 350 GeV)



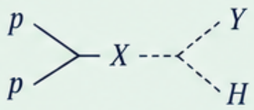
$\phi \to ee, \mu\mu, \tau\tau$
(multilepton final states)

$X \to HH$



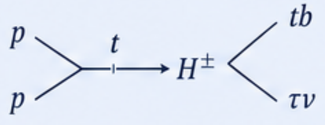
HH decays:
$bb\tau\tau$, $WW\gamma\gamma$, 4b, $bb\gamma\gamma$, …

$X \to YH$



HY decays:
$\gamma\gamma bb$, 4b, bb4q, bbZZ, $\tau\tau bb$, …

Charged Higgs $H^\pm$



$tH^\pm, H^\pm \to tb, \tau\nu$
Complementary probe of extended Higgs sectors

Searching for additional light scalars

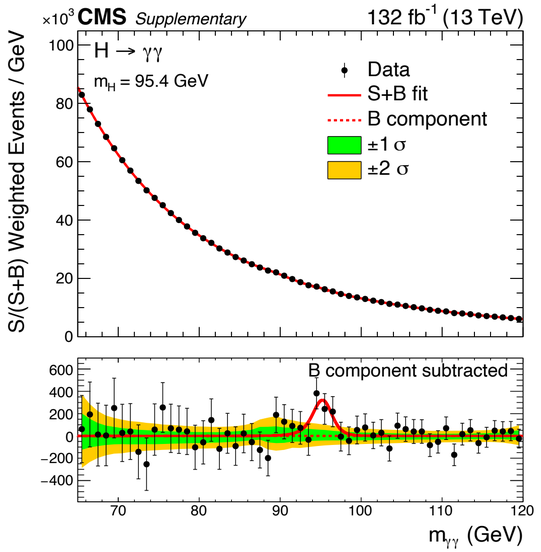
Still room below 125 GeV

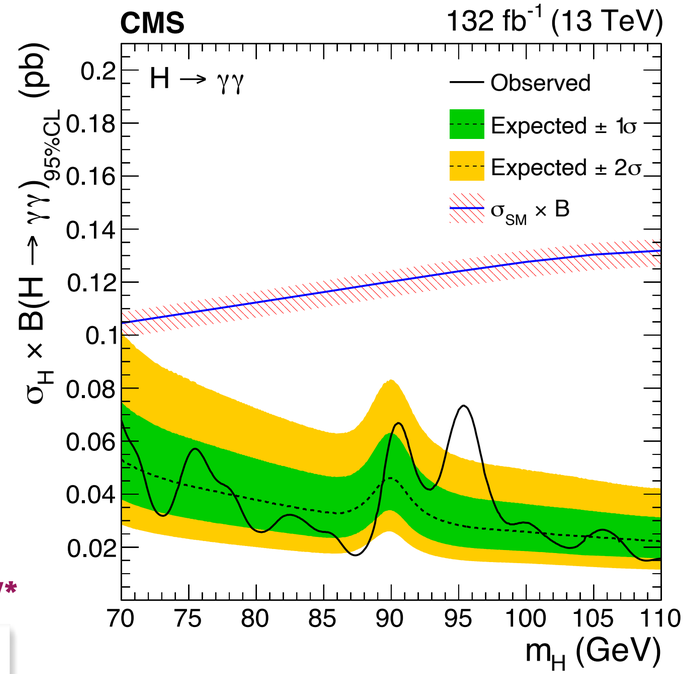
Phys. Rev. D 110 (2024) 012013

CMS H→γγ , full Run2 — 132 fb⁻¹

Phys. Lett. B 860 (2025) 139067

- Search for an additional SM-like scalar: 70<m_H<110 GeV
- Dedicated low-mass selection; categories target ggH, VBF, VH and ttH production
- Signal extracted from fits to the $m_{\gamma\gamma}$ spectrum
- 95% CL limits: $\sigma_H \times B(H\to\gamma\gamma)$ = 15–73 fb





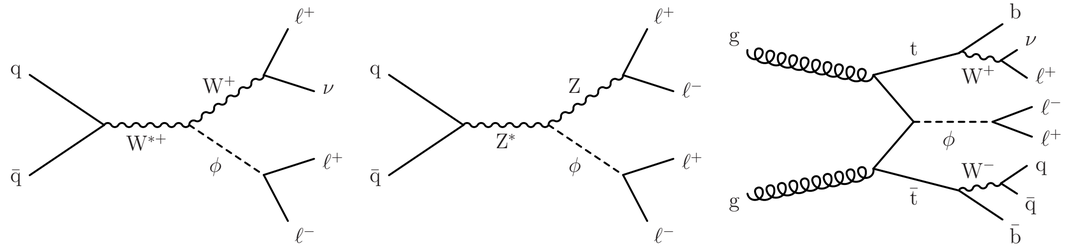
Largest deviation at m_H=95.4 GeV*

$2.9\sigma(\text{local}) \rightarrow 1.3\sigma(\text{global})$

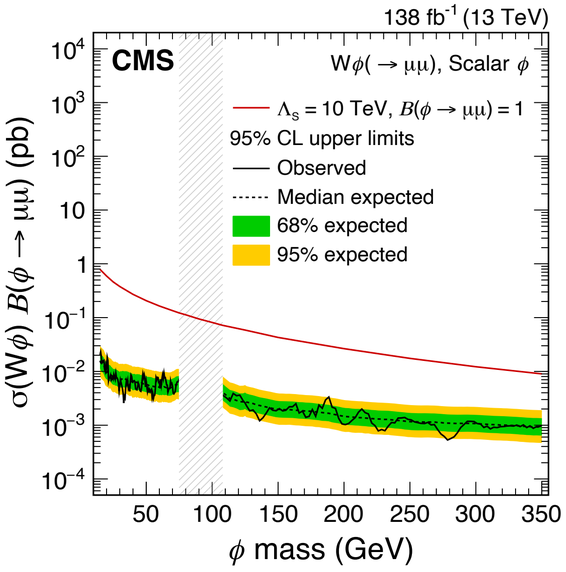
*Full Run-2 result retains this feature at 95.4 GeV seen in earlier combination

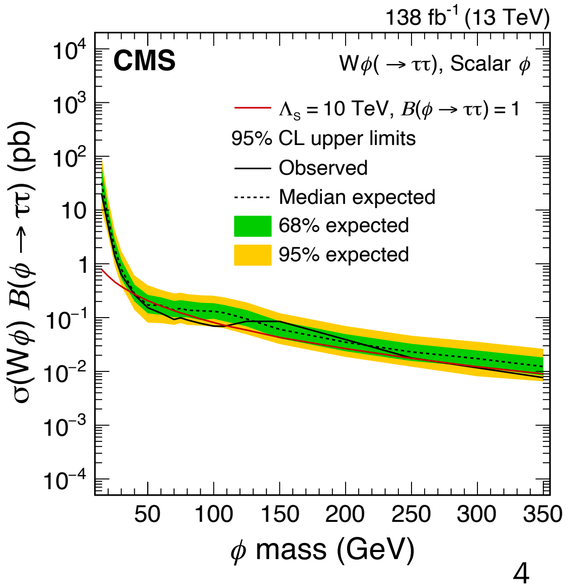
Associated production Wϕ,Zϕ,tt̄ϕ + multileptons with ϕ→ℓℓ , full Run2 — 138 fb⁻¹

- Scalar or pseudoscalar ϕ, ϕ→ee,μμ,ττ



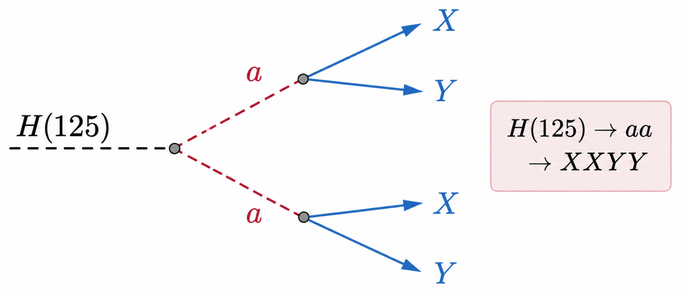
- 15<m_ϕ<350 GeV, 3ℓ / 4ℓ final states
- Search for a localized resonance in $\mathbf{m_{\ell\ell}}$





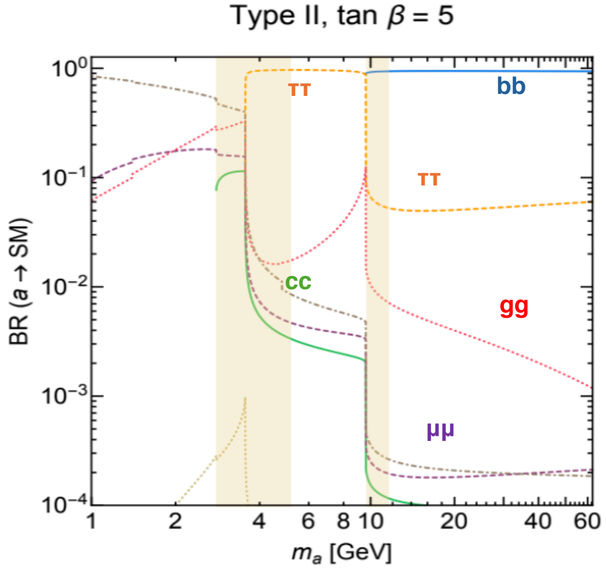
$H^{125} \rightarrow$ light scalars

A broad experimental program

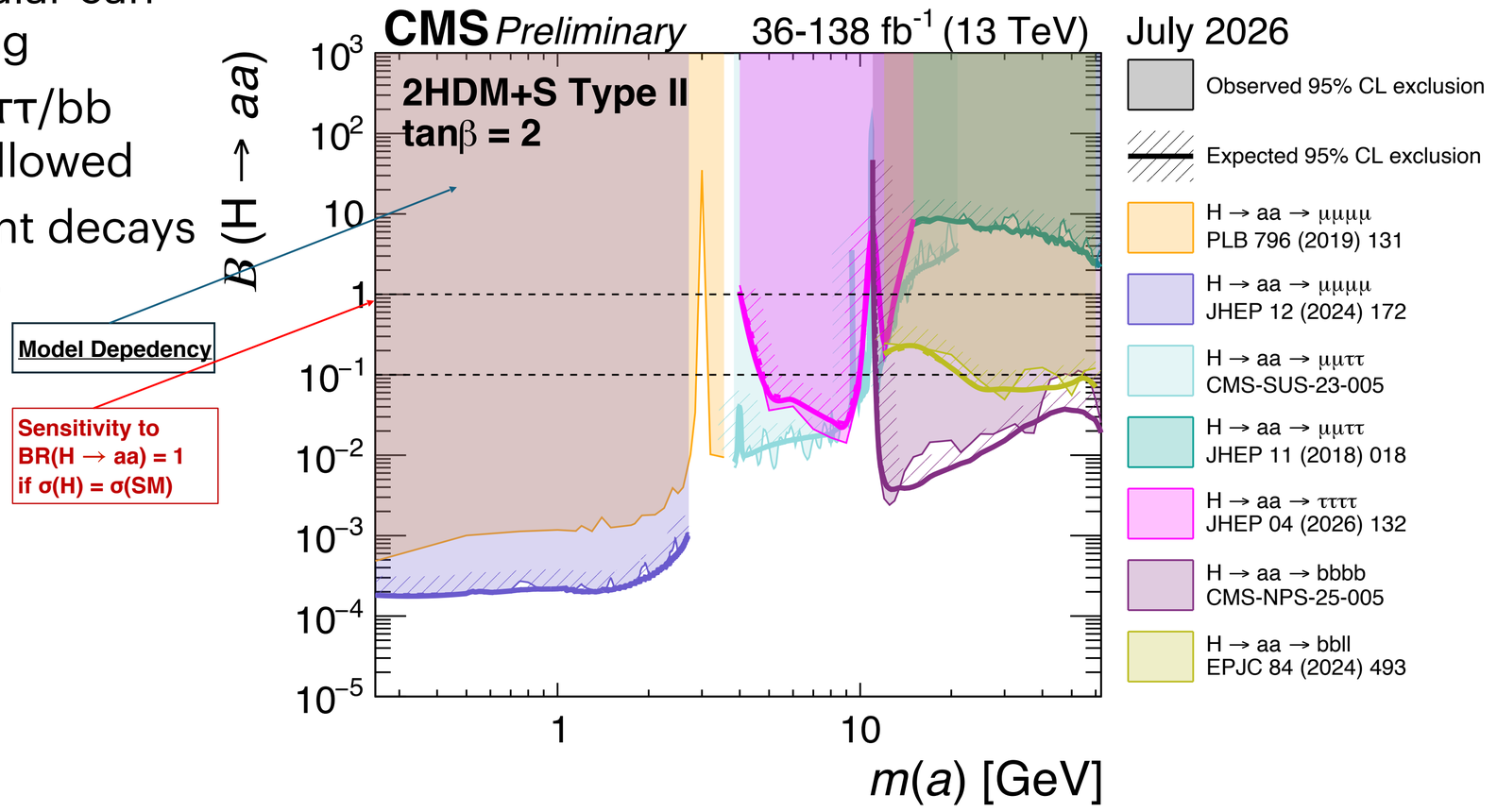


H→aa : a benchmark for extended Higgs sectors

- A light singlet-like (pseudo-)scalar can couple to H(125) through mixing
- For Yukawa-like couplings, a→ττ/bb dominate once kinematically allowed
- Different m_a regimes → different decays and reconstruction techniques



One topology — many experimental signatures



https://cms-summary-searches.docs.cern.ch/2HDM_S/

Fully boosted H→aa→4b

CMS-PAS-NPS-25-005

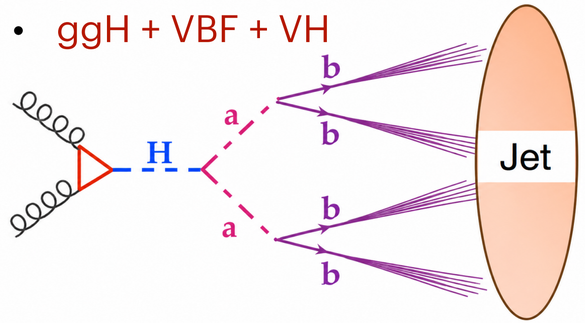
NEW result: CMS-PAS-NPS-25-005

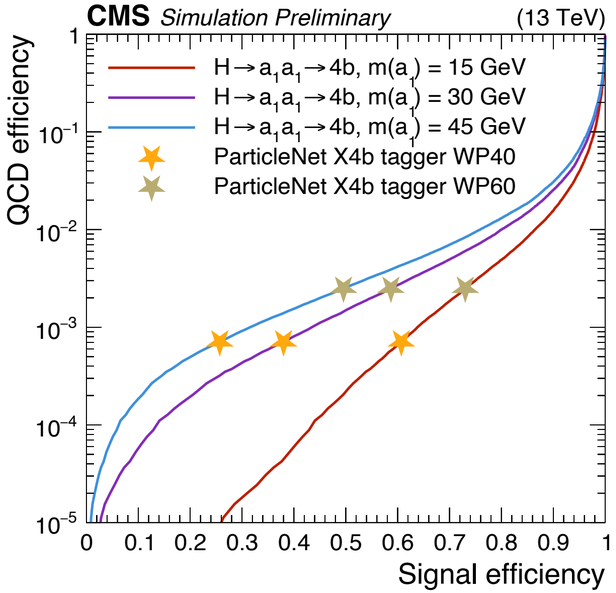
Addresses regime where resolved 4b reconstruction looses efficiency

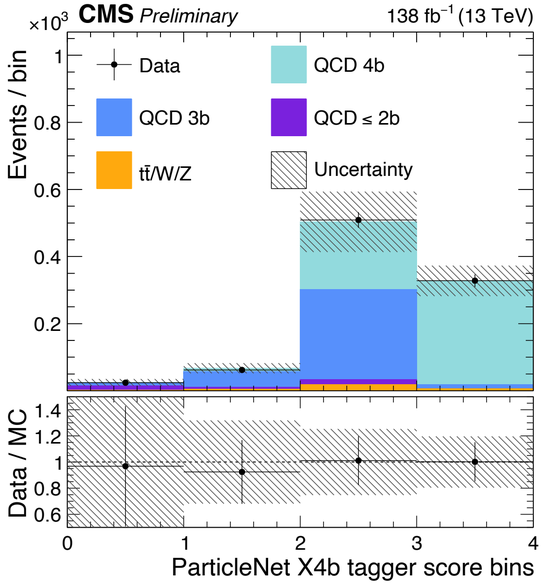
- Dedicated ParticleNet AK8-based "X4b tagger"
- Simultaneous regression of parent (m_H) and daughter (m_a) mass
- Data-driven QCD background modelling:
  - events failing tight X4b define the control regions
  - transfer factors parameterized in m_H^{reg} ,m_{a1}^{reg}
- Signal extracted in (m_H^{reg} ,m_{a1}^{reg}) with 2DAlphabet fit

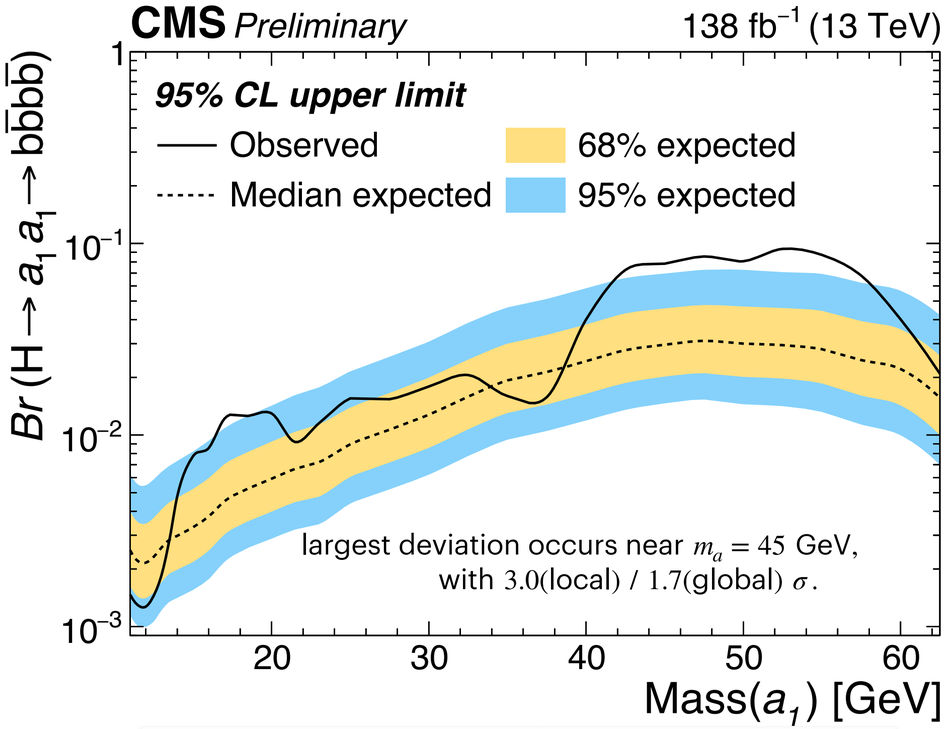
4 b quarks → 1 AK8 jet

- $p_T(H)$ > 250 GeV
- ggH + VBF + VH









BR($H \to aa \to 4b$) ≈ 0.13% – 9.4 % (obs.)

~ 10 × improvement over previous searches

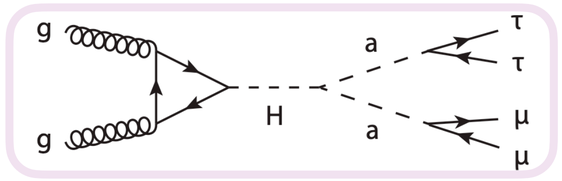
Other recent H→aa results

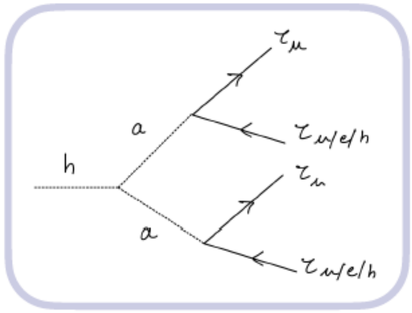
CMS-PAS-SUS-23-005 | CMS-SUS-24-002, JHEP 04 (2026) 132

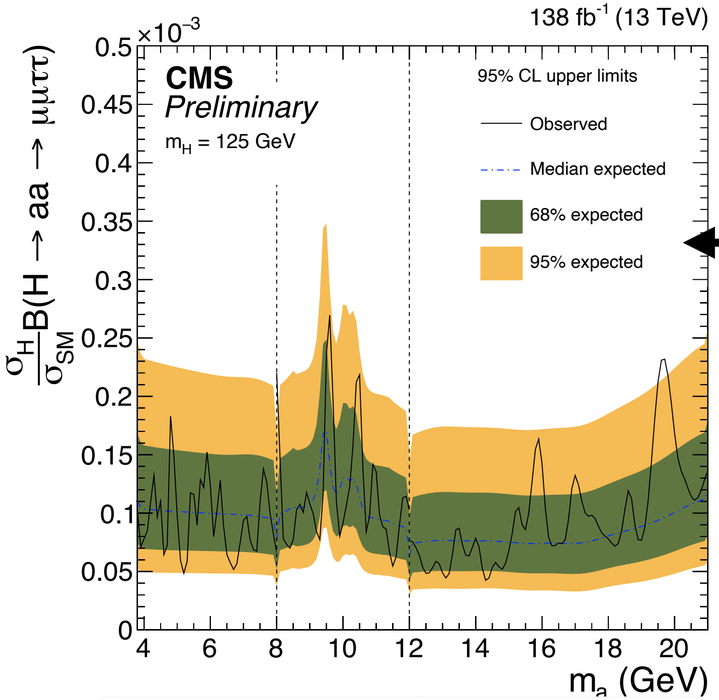
CMS-NPS-25-003, arXiv:2605.19144

H—>aa—>2μ2τ, h—>aa—>4τ, h—>$\phi_1\phi_2$—>2b2τ/4b2τ

- At lower masses, *tau* and *muon* final states — and asymmetric scalar decays — give us complementary access to regions where 4b cannot reach.







Boosted 2μ2τ

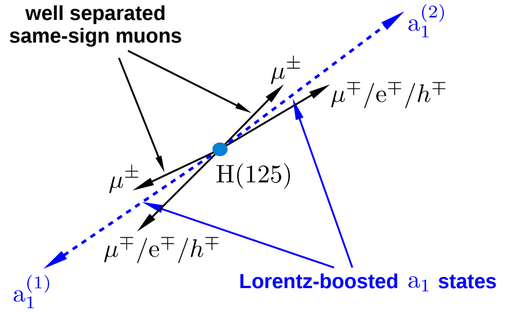
- Accessing very light a

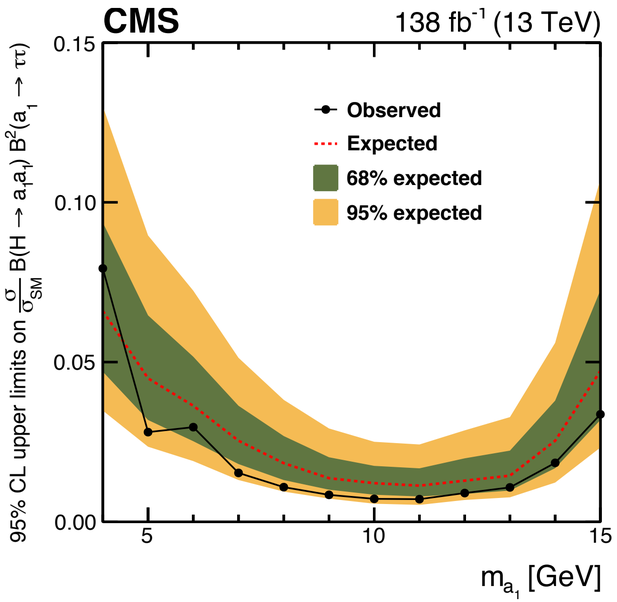
H→aa→4τ/2τ2μ

- Extending the low-mass τ coverage
- complementary 4τ, 2μ2τ sensitivity

$BR(H \to aa \to 2\mu 2\tau) \approx 5 \cdot 10^{-5} - 3 \cdot 10^{-4}$

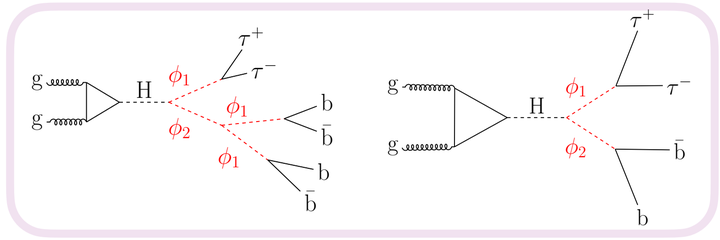
for m_a between 3.6 and 21 GeV

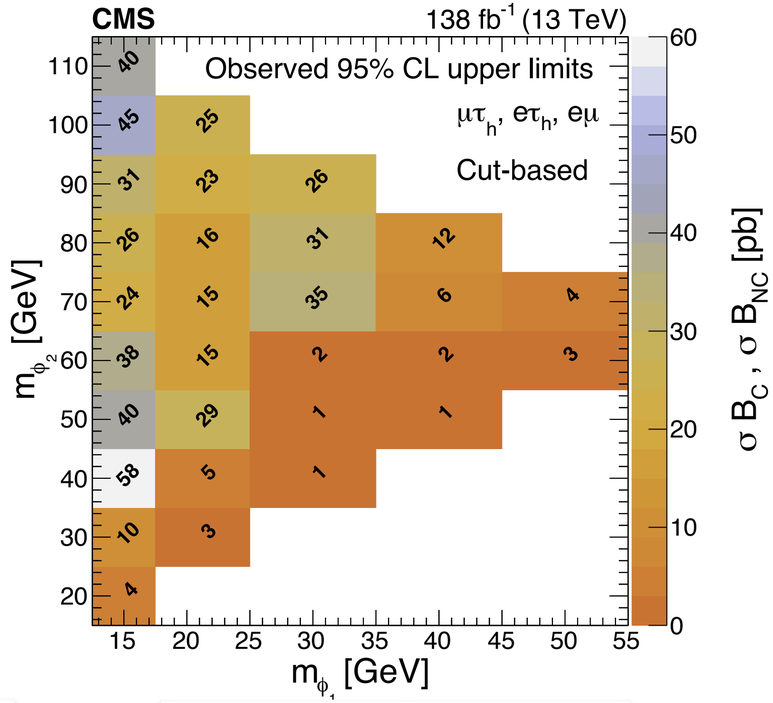




$BR(H \to aa) \cdot BR^2(a \to 2\tau) \approx 0.007 - 0.079$

H→ $\phi_1\phi_2$ →2b2τ/4b2τ

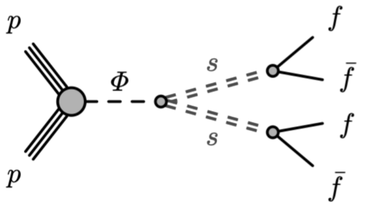




$\sigma \cdot B \approx 5 \cdot 0.9 - 36.8$ pb (obs.)

Higgs portals to hidden sectors

Beyond prompt decays ↔ displaced / dark sector



Common Physics Origin —> many exotic Higgs scenarios introduce new light scalar states

- h→ss and h→aa
- couple weakly to the Standard Model through the Higgs portal

- As the coupling decreases: prompt decays gradually evolve into
  - **displaced decays, LLP signatures**
  - detector-stable particles
- without changing the underlying model.

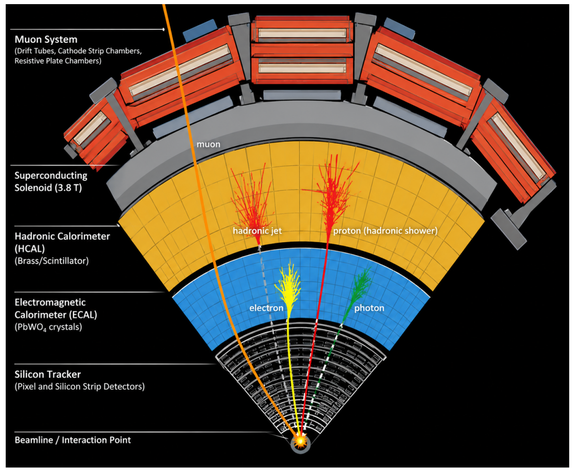
COMPLEMENTARY EXPERIMENTAL COVERAGE

Lifetime regime	Experimental signature
Prompt ($c\tau < 1$ mm)	Standard exotic Higgs searches
Tracker LLPs	Displaced vertices, displaced b jets
Calorimeter LLPs	Delayed hadronic showers
Muon-system LLPs	Displaced clusters
Very long-lived	Invisible / MET signatures

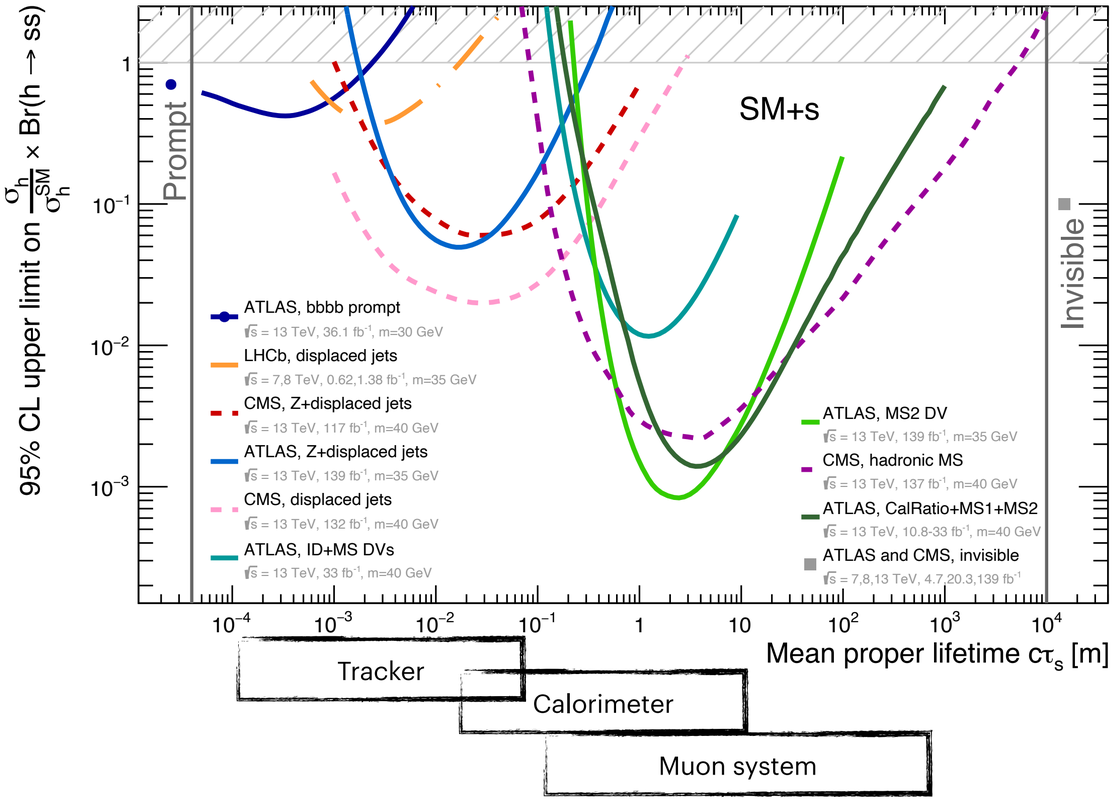
Prompt searches →

Higgs measurements →

1% →

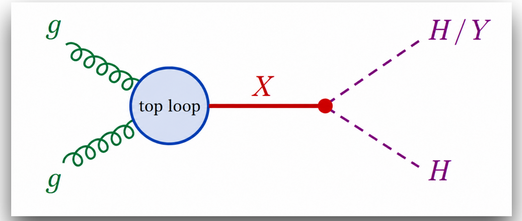


arXiv:2111.12751



Additional scalars at higher mass

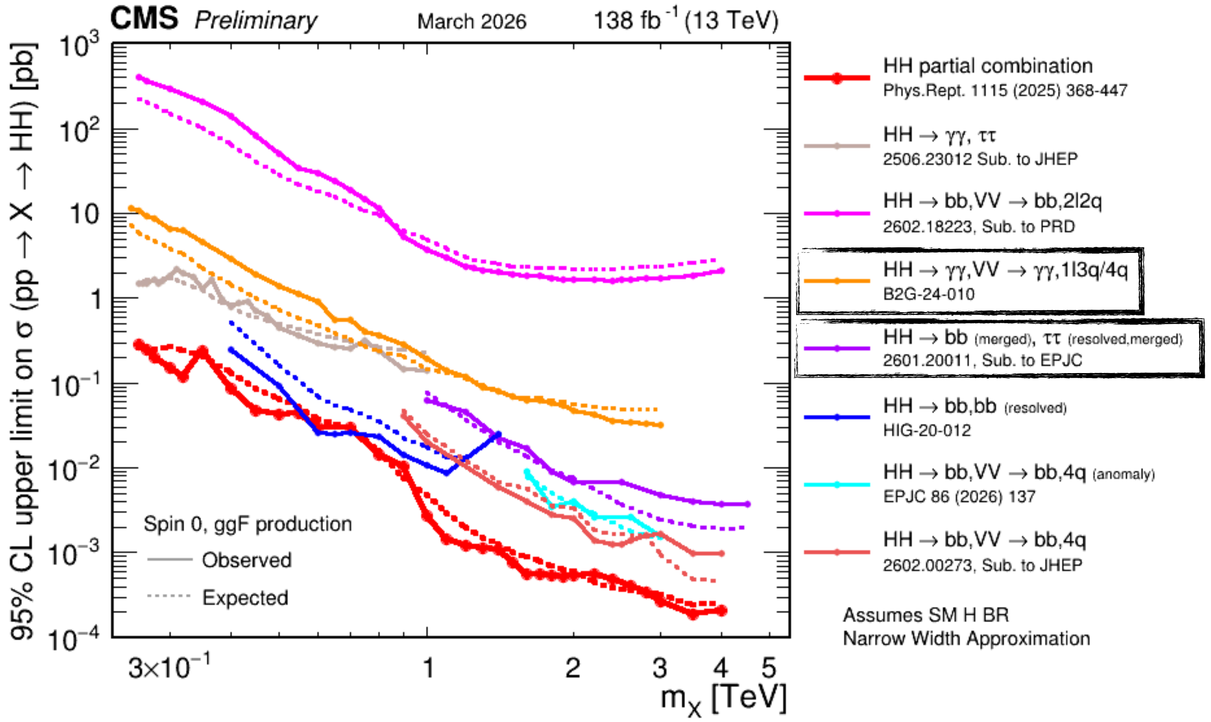
Two complementary resonance topologies: X→HH, X→YH



Resonant scalar searches X→HH and X→YH:

- Motivated by warped-extra-dimensional models, 2HDM/NMSSM and generic spin-0/spin-2 scenarios;
- Run 2 searches span roughly **200 GeV–6 TeV** depending on the channel

TODAY'S RESULTS
• **HH→WWγγ** (CMS-PAS-B2G-24-010): first LHC result incl. fully hadronic mode; improves comb. at higher mass
• **HH→bbττ** (CMS-B2G-24-014, arXiv:2601.20011): CMS boosted, 1-4.5 TeV; best limits for mX > 1.4 GeV; contributes to combination
• **X→YH→bbγγ** (CMS-B2G-24-001, arXiv:2508.11494): standalone result, outside HH combination
• **X→YH→bb4q** (CMS-B2G-23-007,arXiv:2602.00273): first LHC all-hadronic bbVV result
• **X→YH→4b** (arXiv:2605.02848; CMS-HIG-20-012): contributes to YH combination (bbγγ, bbττ, 4b)
• ~~**X→ZZ/ZH** (B2G-25-004): diboson resonant search, outside HH combination; first search in bbττ~~

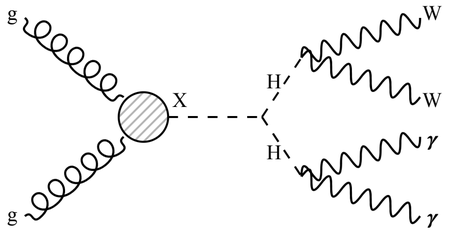


CMS-PAS-B2G-24-010

Additional scalars at higher mass

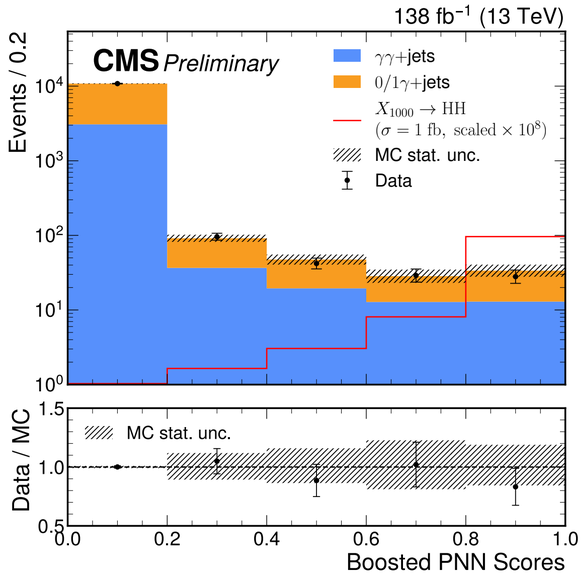
Resonant X→HH: WWγγ

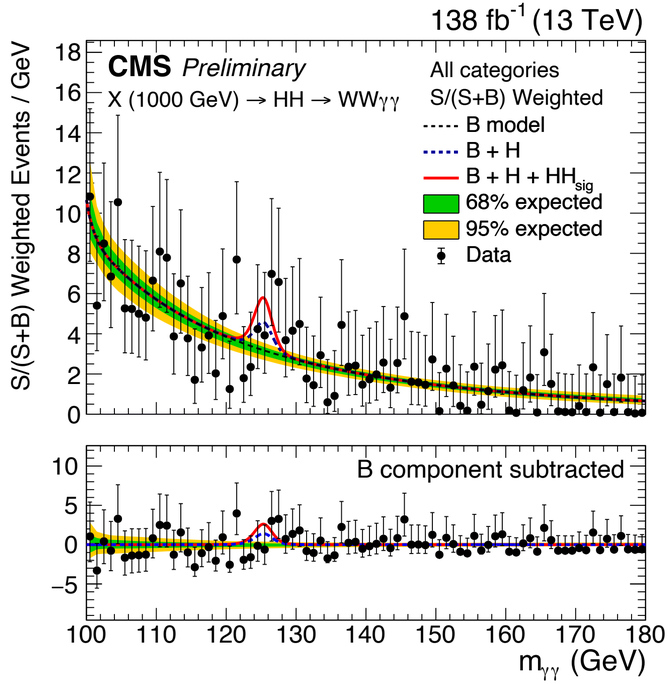
X→HH→WWγγ:
First search incl. fully hadronic WW + boosted topologies

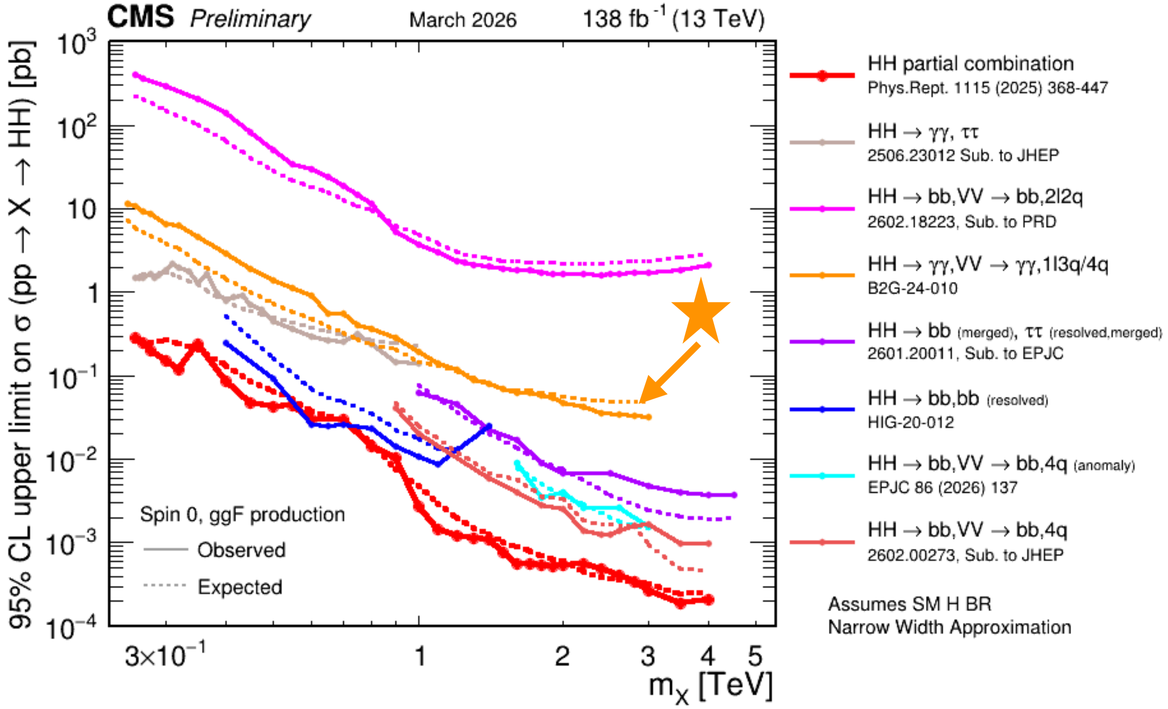


Resolved → boosted reconstruction with increasing mX:

- H→WW→4q reconstructed as one 3–4 prong AK8 jet at high-boost
  - using ParticleNet and ParticleTransformer jet tagging
- mass-dependent PNN categorization for resolved and boosted regimes
- Signal extracted from simultaneous fits to $m_{\gamma\gamma}$







arXiv:2601.20011, CMS-B2G-24-014

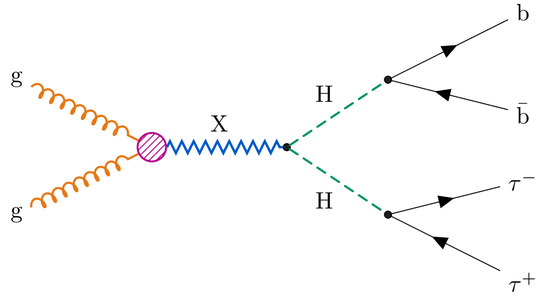
Additional scalars at higher mass

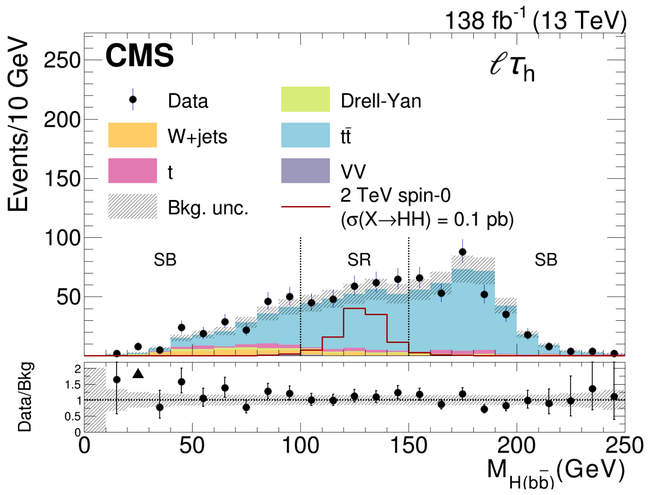
Resonant X→HH: boosted bbττ

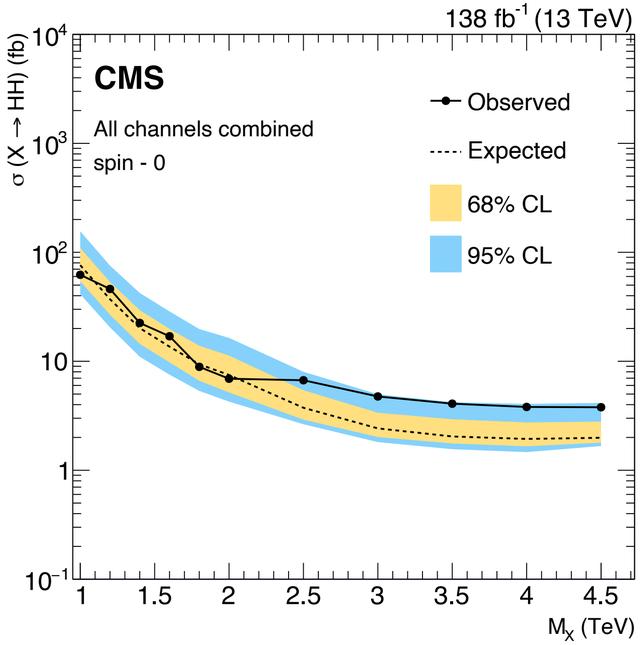
NEW boosted HH→bbττ:
most sensitive LHC limits in mass range of 1.4 to 4.5 TeV

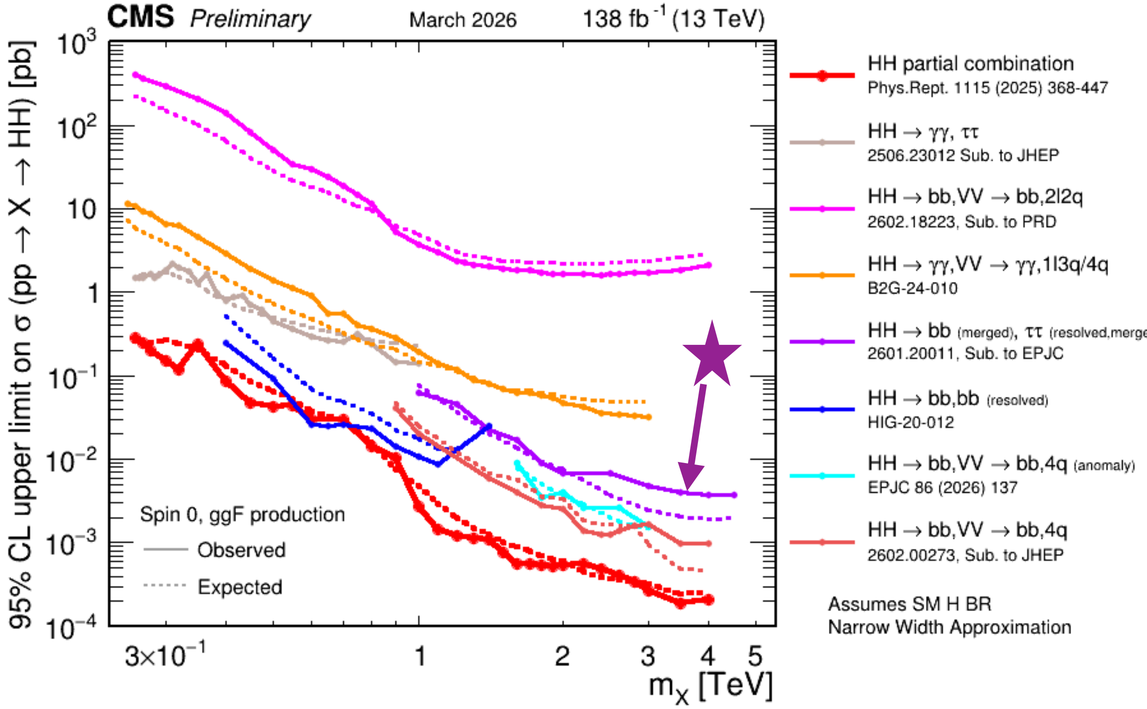
Dedicated reconstruction for highly boosted H→bb and H→ττ:

- H→bb: **single AK8 jet**, ParticleNet **bb tag + mass regression**
- H→ττ: overlapping τ's recovered with dedicated **boosted**-τ reconstruction + BOOSTEDDEEPTAU
- $m_{\tau\tau}$ reconstructed with **FastMTT**; X reconstructed from H(bb)+H(ττ)
- Final search uses the reconstructed m_X spectrum in $\tau_h\,\tau_h$ and $\ell\tau_h$









Scalar cascades: X→YH

B2G-24-001 / JHEP 12 (2025) 178

B2G-23-007 / JHEP 08 (2026) 050

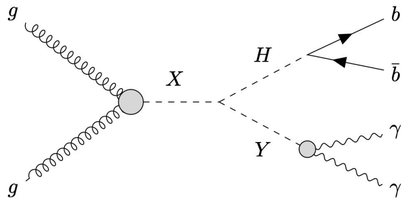
New daughter scalar + second unknown mass: γγbb, bb4q, 4b

Resonant X→YH scalar searches:

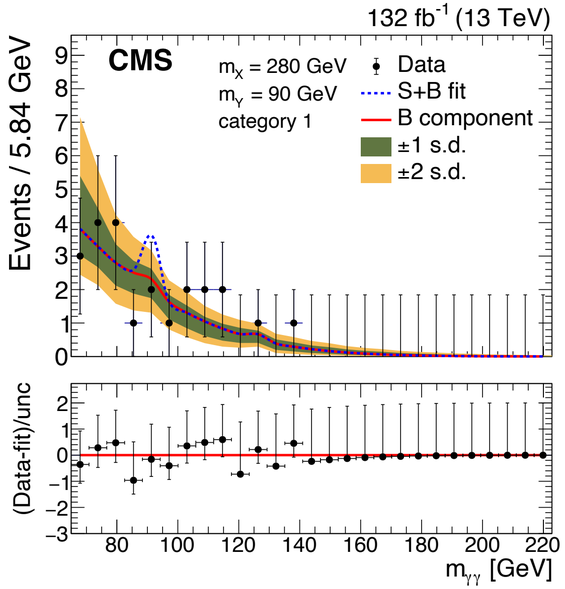
- experimentally and conceptually different from HH.

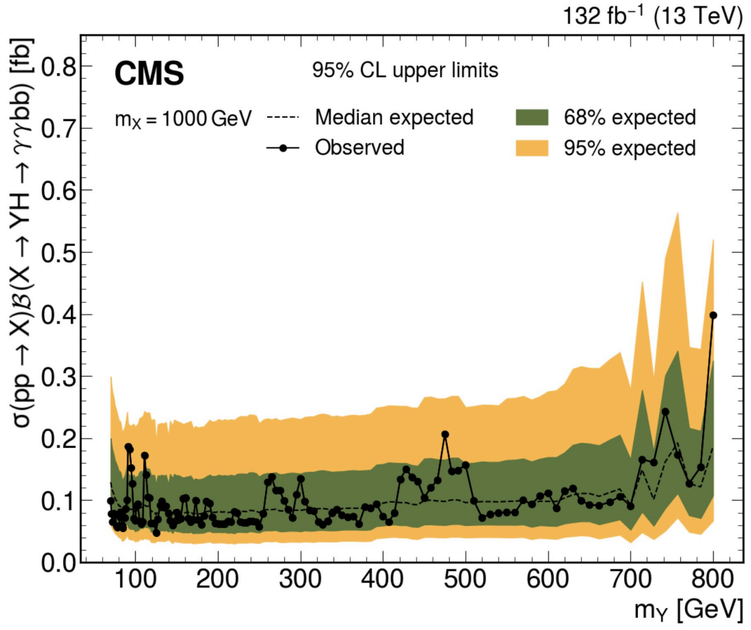
X→YH→γγbb

CMS scans mX from 240 GeV —1 TeV and mY from 70 to 800 GeV



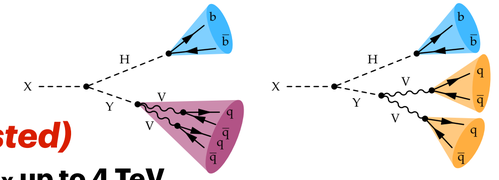
There is an interesting CMS feature:
local excess 3.3σ (global 0.65σ) at (m_X; m_Y) = (300; 77) GeV

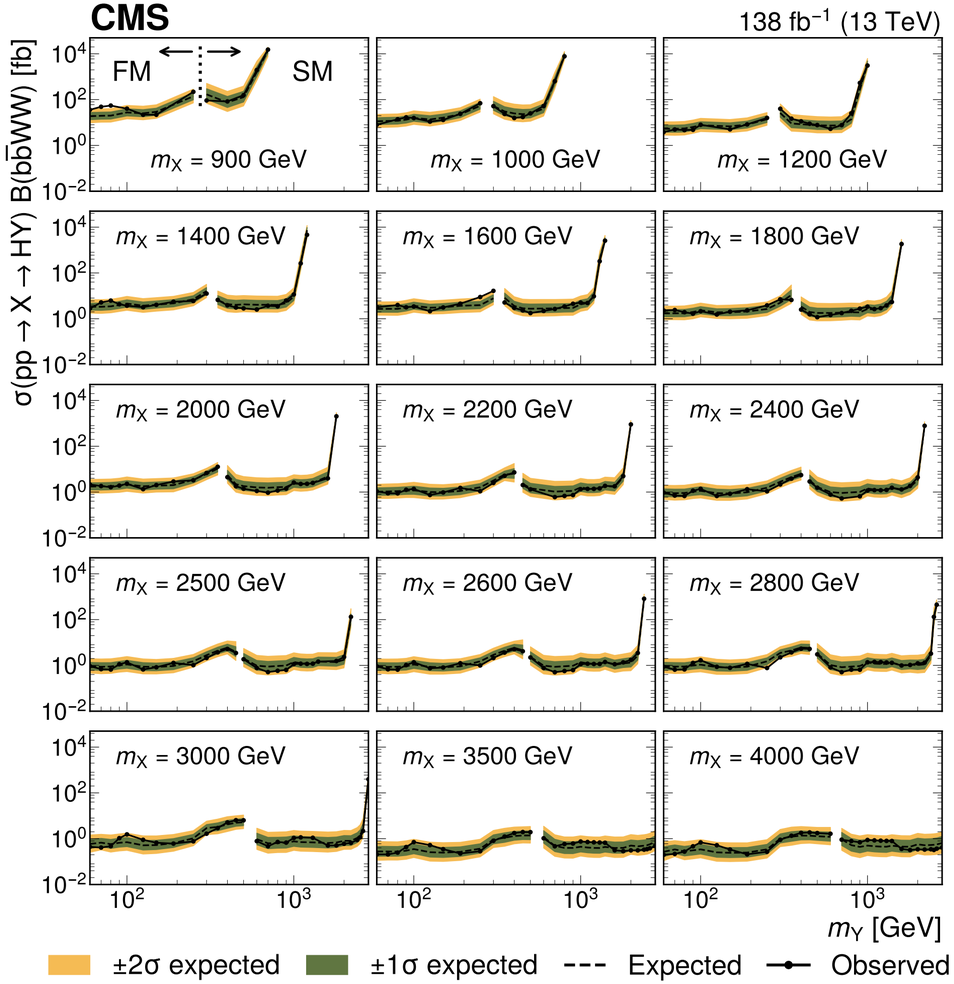




X—>YH—> bb (4q) (boosted)

high-mass boosted regime → m_X up to 4 TeV





Scalar cascades: X→YH

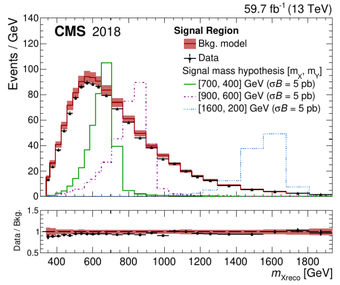
arXiv:2605.02848; CMS-HIG-20-012

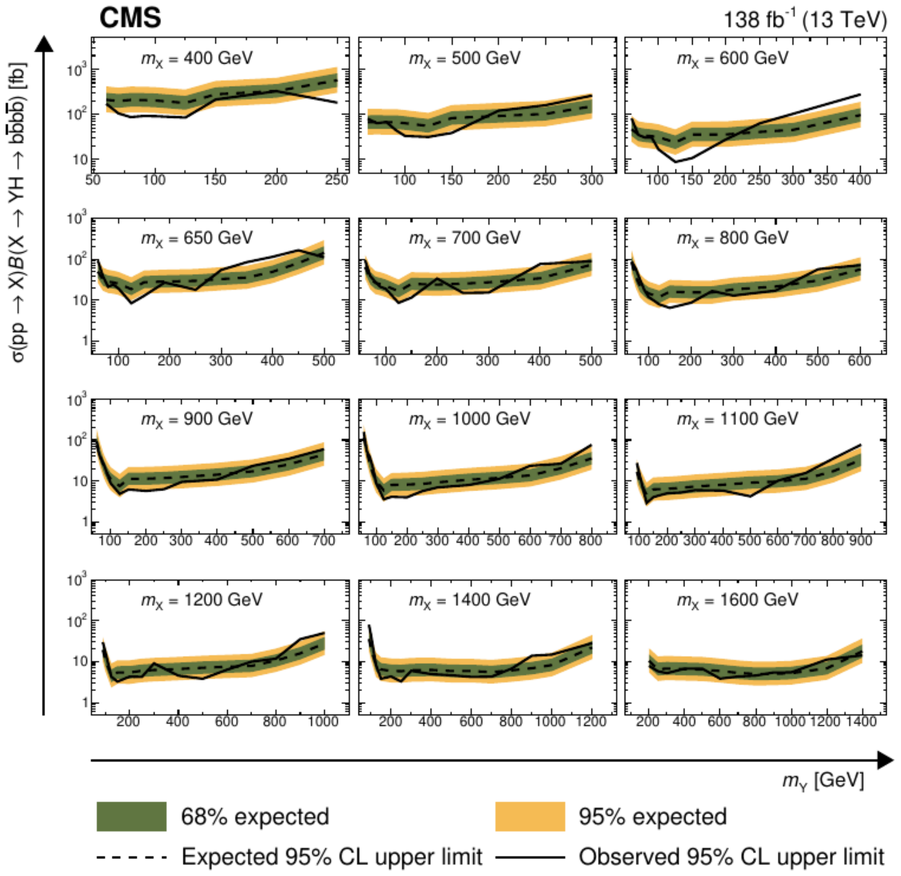
CMS-PAS-B2G-24-019

X→YH→4b

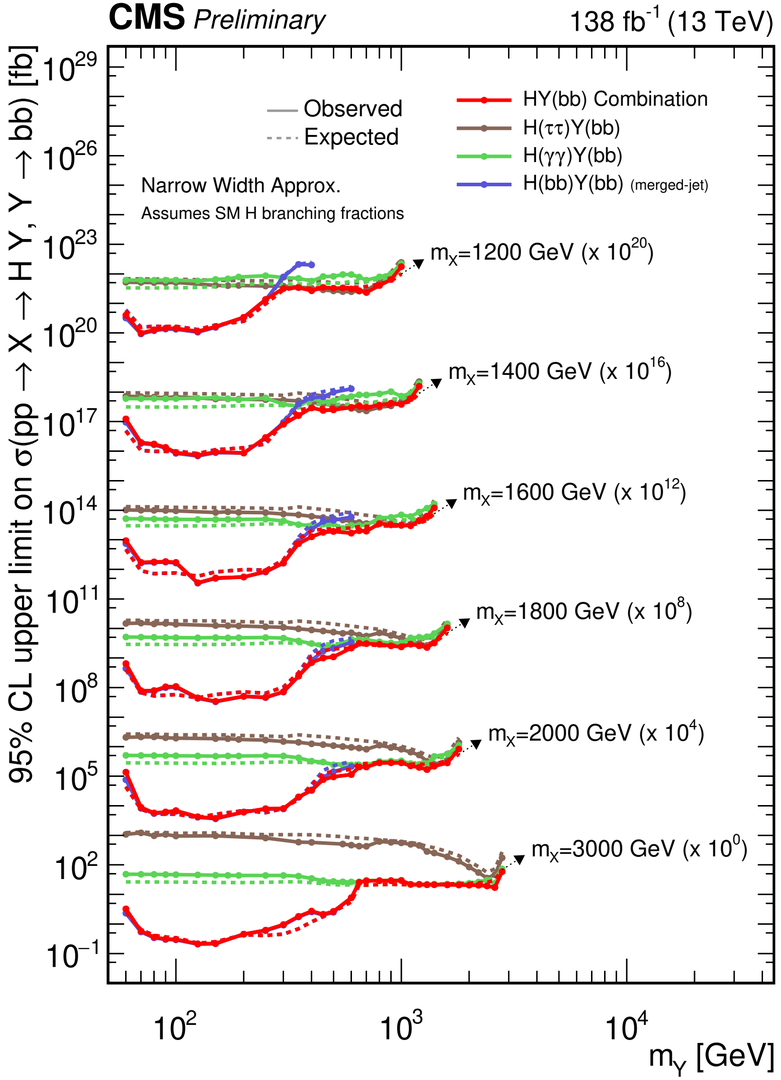
m_X = 0.4—1,6 TeV, m_Y = 0.06—1,4 TeV

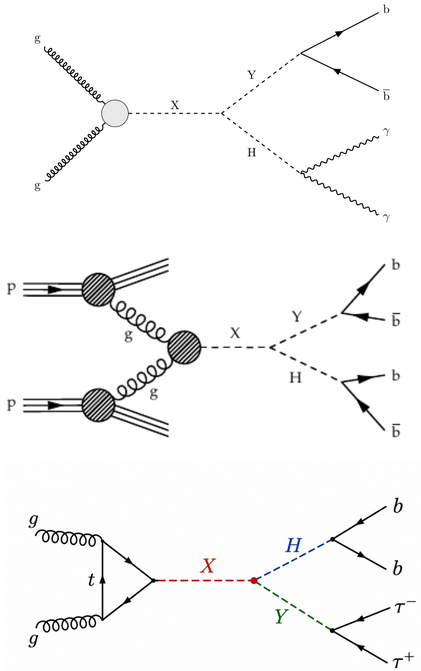
Largest deviation:
3.47σ local / 2.44σ global
at (m_X, m_Y) = 600, 400) GeV





And there is an even newer CMS combination of three X→HY(bb) channels: **diphoton+bb**, **4b**, and **ττ+bb**





bbγγ provides the leading individual sensitivity at high mY over broad mX ranges

Summary & outlook

The scalar sector remains wide open

Exotic decays of H(125)

- *light-scalar searches* now reach sub-percent to few-percent BR in favorable regions
- Fully *boosted H→aa→4b*: 0.13–9.4% upper limits on BR observed for m_a = 11–62.5 GeV
- *prompt → displaced → invisible searches* extend coverage over many orders of magnitude in lifetime

Direct searches span additional scalars: GeV → multi-TeV resonances

- *Resonant X→HH*: boosted bbττ reaches **m_X = 4.5 TeV**, with best sensitivity above 1.4 TeV.
- *X→YH*: searches cover 2D (m_X, m_Y) space, with m_X reaching about **4 TeV** in boosted channels.
- largest CMS features shown today:
  - *3.3σ local → 0.65σ global* in **bbγγ**, and
  - *3.47σ local → 2.44σ global* in **4b**

Run 2 → Run 3 (→ HL-LHC)

- More data + new triggers + ML-driven reconstruction are opening qualitatively new signatures.

No compelling departure from the SM yet — but we are far from having exhausted the scalar sector!

Back ups

The BSM Higgs Landscape

BSM Higgs searches expand beyond H—>aa

BSM physics predicts new scalars and/or hidden sectors

- Prompt, invisible (h→χχ), LLP, dark-sector decays

Prompt exotic decays	Dark-sector signatures	Heavy Resonances	Invisible signatures
$h \to aa$ $a \to bb, \tau\tau, \mu\mu, \gamma\gamma, ..$	$h \to \gamma_d\gamma_d$ $h \to ss$	$X \to HH$ $X \to YH$ with $Y = W, Z, A, H$	$h \to \chi\chi$
Extended scalar sectors NMSSM 2HDM+S Singlet extensions	Hidden valleys Dark photons Long-lived particles Semi-visible decays	Heavy Higgs bosons Resonant HH production Extended scalar sectors	Higgs portal dark matter bb+MET γ+H(bb)+MET

Exotic Higgs program is broader than h—>aa alone

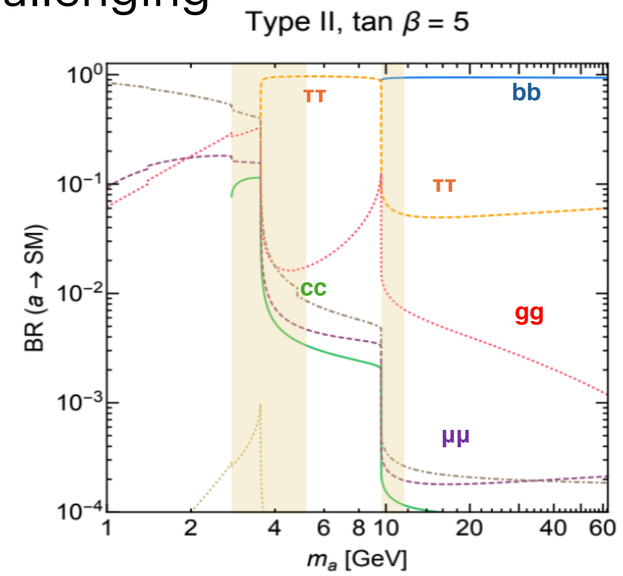
- Exploring the scalar sector: h —> aa/ss, h—> $\gamma_d\gamma_d$, X—>HH and X—>YH topologies.
- Different final states dominate in different mass regions — no single analysis covers the full parameter space!

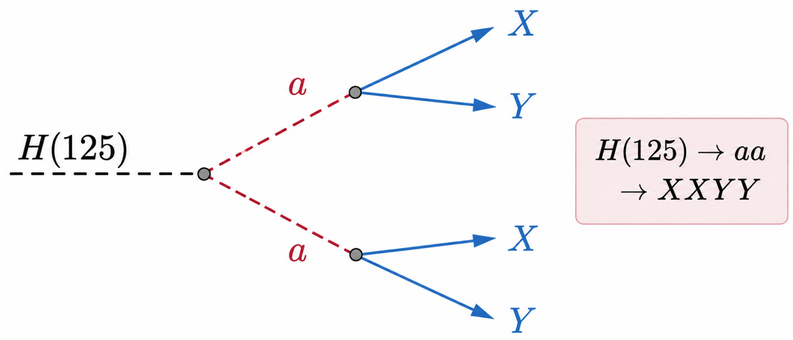
$H^{125} \rightarrow$ light scalars

A broad experimental program

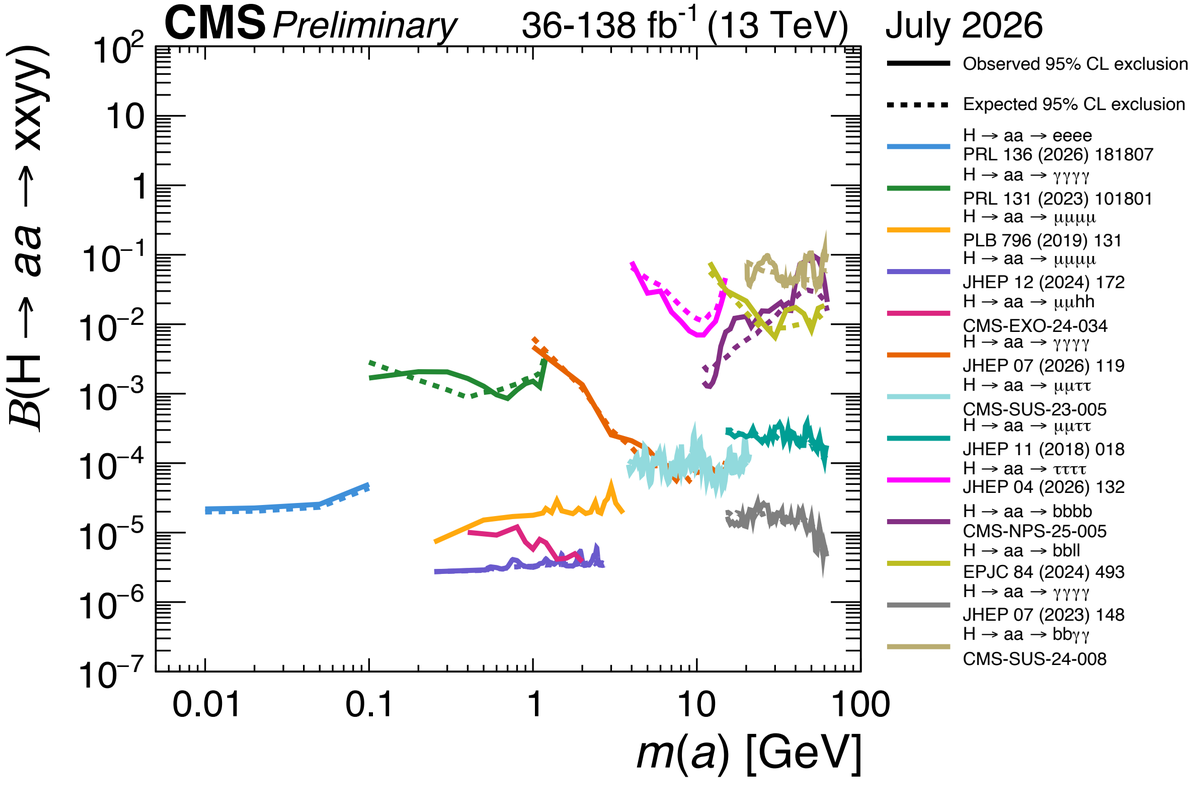
H→aa searches inspired by 2HDM + S

- Mediator is a singlet (pseudo)scalar
  - Inherits Yukawa-like couplings from mixing with H doublets→ proportional to mass
- Large BR to b's/τ's, but experimentally challenging





Model independent limits on BR(H—>aa)

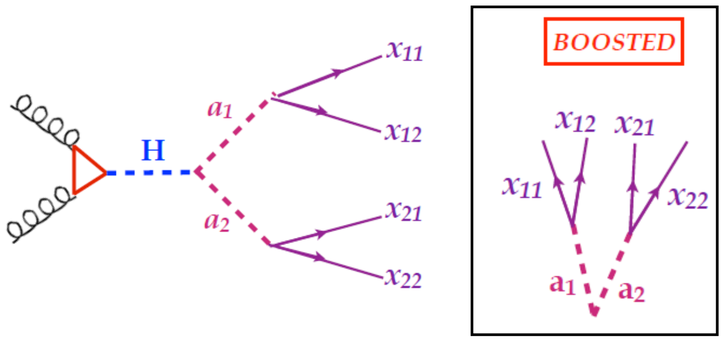


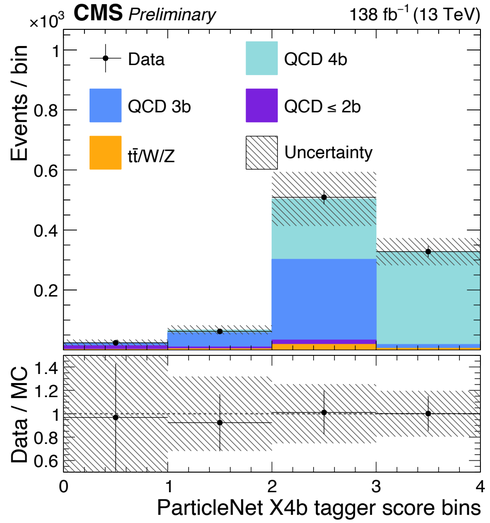
https://cms-summary-searches.docs.cern.ch/

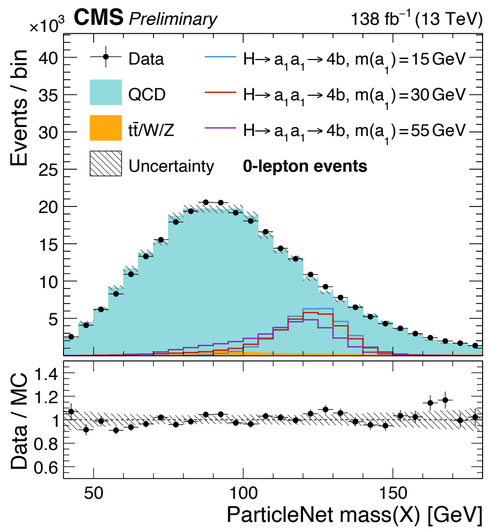
Fully boosted H→aa→4b

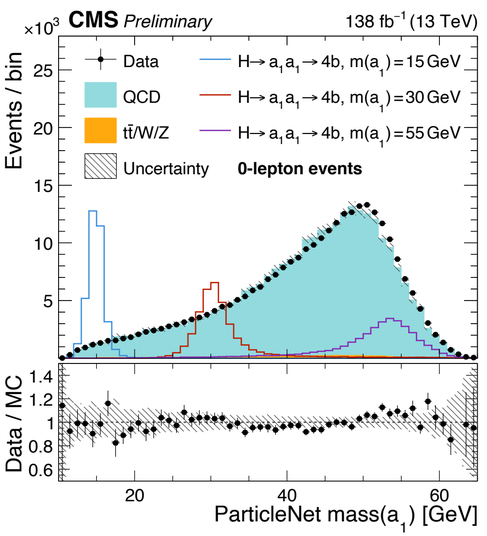
Accessing the difficult low-mass regime

- Fully boosted H→a1a1→4b provides strongest constraints to date on prompt a1→bb decays for all m(a1) in 11 – 62.5 GeV.
- **Entire H→aa→4b decay reconstructed inside a single large-radius AK8 jet**
  - ParticleNet AK8 mass regression and boosted categories
  - Simultaneous regression of: m_H, m_a









Data-driven background modelling

- QCD estimated directly from data
- Events failing a tight X4b requirement define the control region
- Transfer factors parameterized in: (regressed m_H , regressed m_a)
- Signal extracted using a simultaneous 2DAlphabet fit

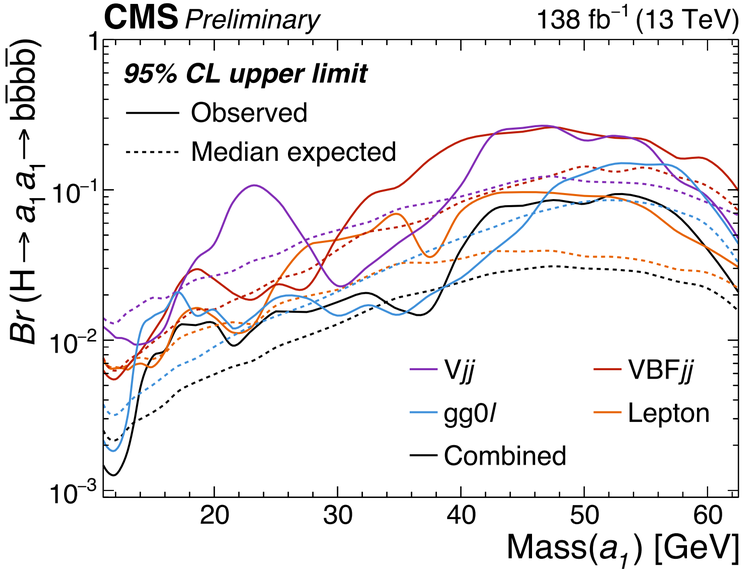
Fully boosted H→aa→4b

CMS NPS-25-005

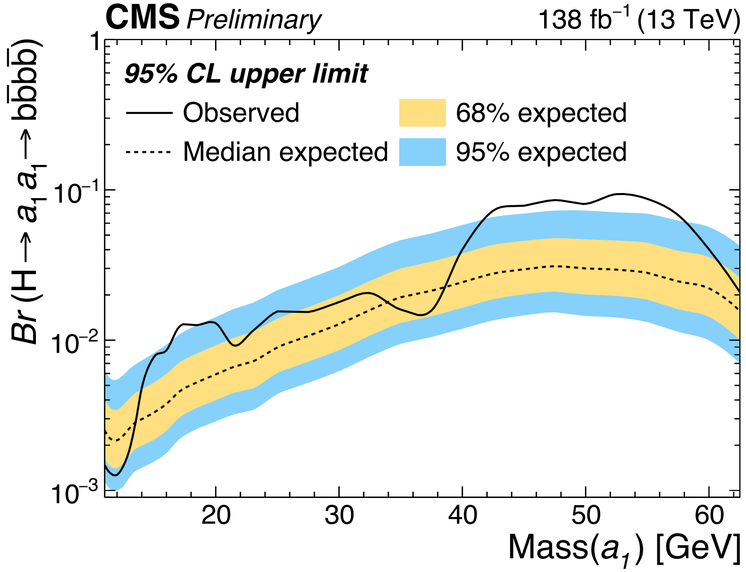
Limits stronger than ATLAS ZH Run 2 (0l and 2l) with custom AK8 bb-tagging for m_a < 30 GeV.

- Direct synergy with Run-3 boosted bb reconstruction developments

Expected limits:
BR(H→aa→4b) ≈ 0.22–3.1%



~10 × improvement over previous searches



- H produced with $p_T(H)$ > 250 GeV
- Uses all major Higgs production modes (ggH, VBF, VH)

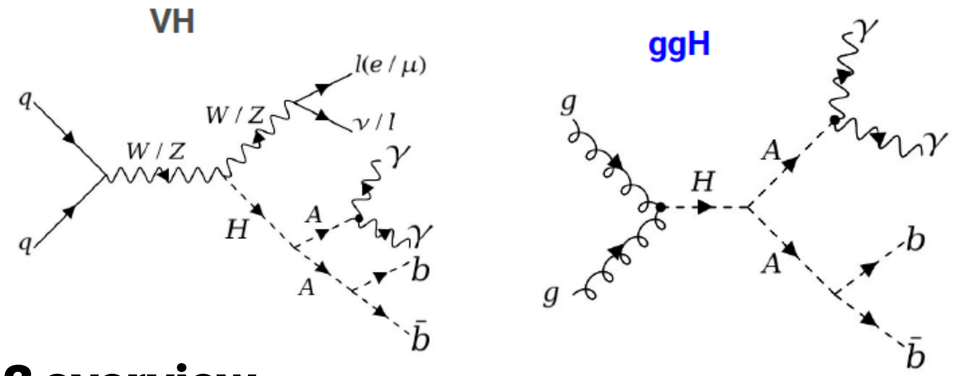
Addresses a regime where:

- standard resolved approaches loose efficiency
- jet substructure becomes the dominant handle

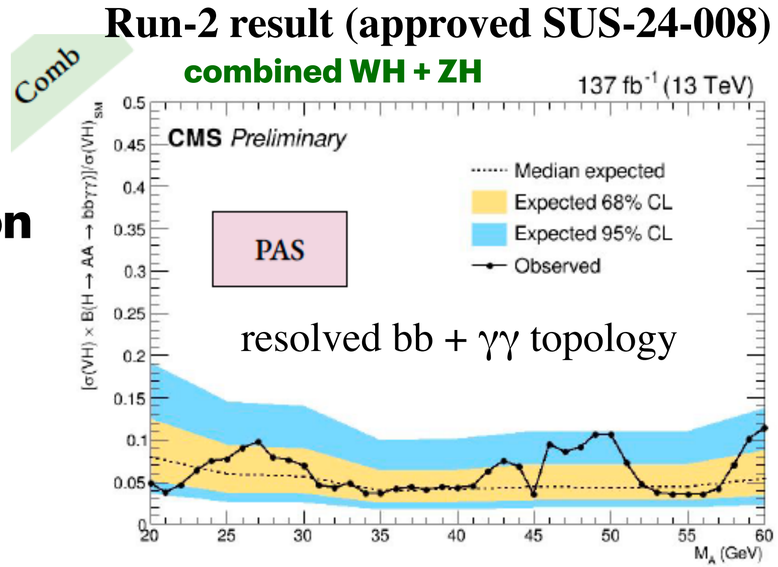
bbγγ Analysis Synergies

From Run 2 VH search to a broader Run 3 program

Excellent diphoton mass resolution complements bb reconstruction

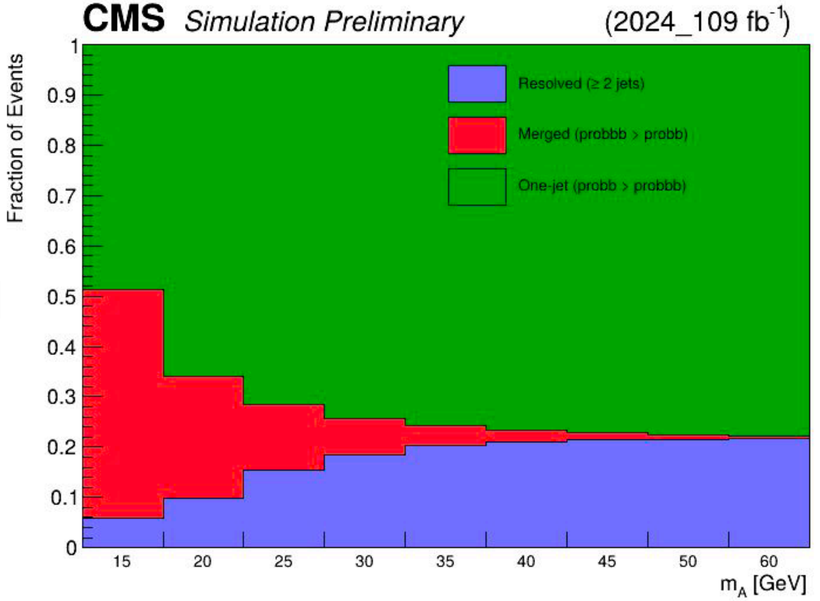


H→AA→bbγγ

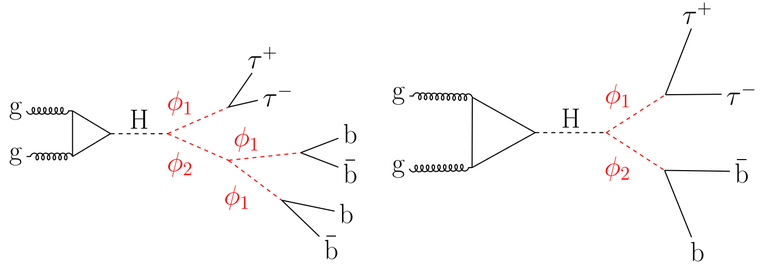


Run 3 overview

- retain VH sensitivity — add ggH production for the first time — significantly increase signal yield
- exploit HiggsDNA + FlashggFinalFits workflow
- Shared boosted topology reconstruction with 4b analyses. Shared challenges:
  - b-tagging uncertainties dominate sensitivity
  - low-mass bb reconstruction — boosted A→bb reconstruction



bbττ / 4b2τ Analyses

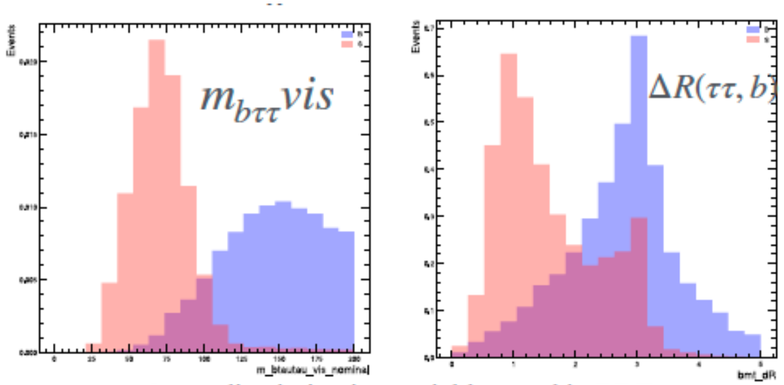


CMS NPS-25-003

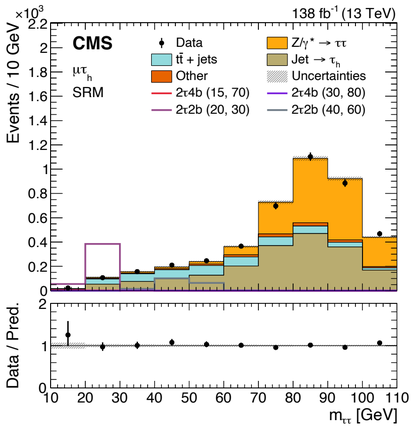
Asymmetric TRSM-inspired scalar scenarios $H \to h_1 h_2$ with $h_1 \neq h_2$

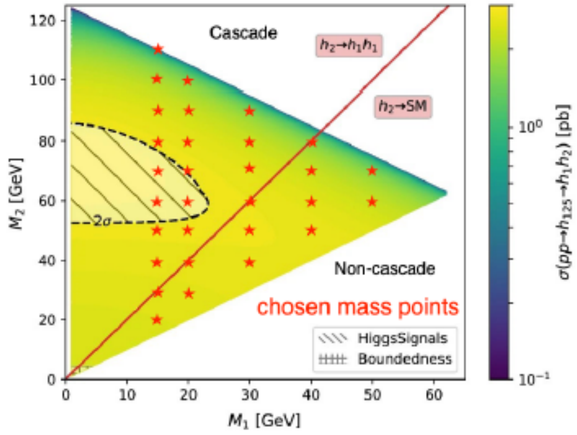
Analysis strategy:

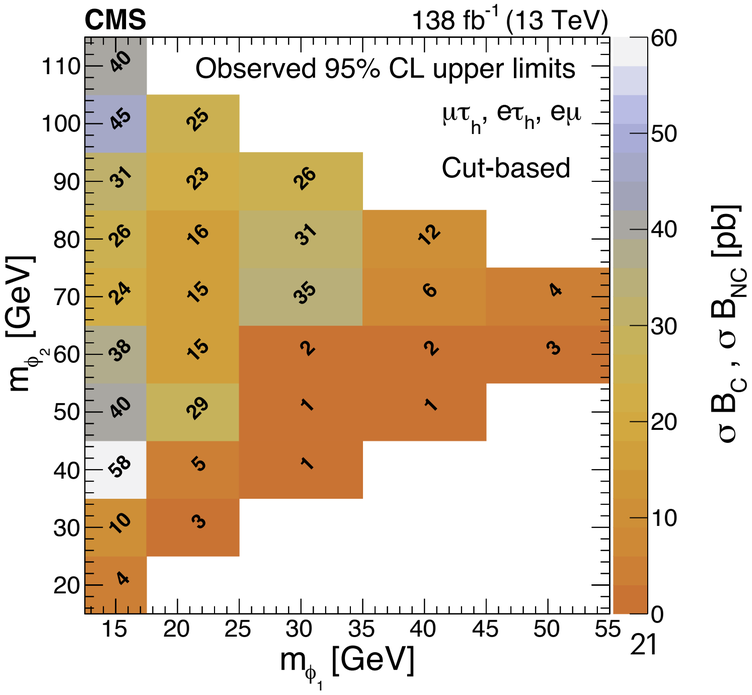
- Full Run-2 UL dataset. Channels: μτh, eτh, eμ in ggH and VBF
- Events split in basis of invariant mass of visible ττ and leading b-jet
- Strong use of BDT categorization of dedicated SRs and SVFit reconstruction of $m_{\tau\tau}$



Some discriminating variables used in BDT







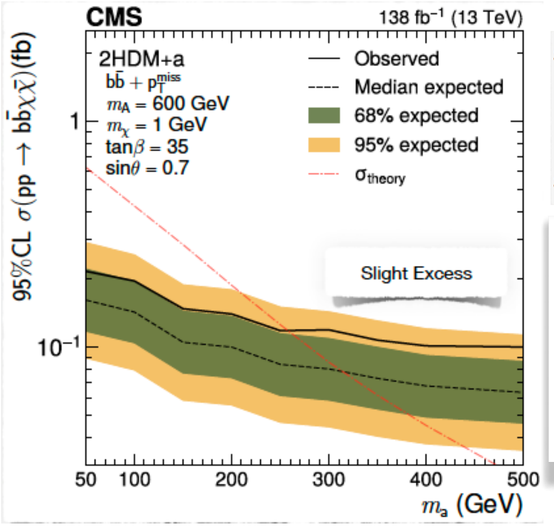
- Complementary to bbγγ: exploits the dominant b-quark decay mode of the light scalar while leveraging τ-trigger acceptance; sensitivity is driven by b-tagging performance and low-mass bb reconstruction.
- Natural complementarity with 4b analyses in branching-ratio coverage (but cleaner final state)

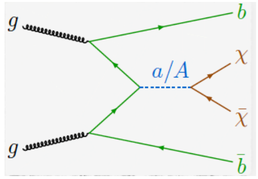
bb+MET signatures

Connecting Exotic Higgs, Dark Matter and EW SUSY searches

bb+MET

- Target: $pp \to b\bar{b} + \chi\chi$ within the type-II 2HDM+a framework. Key features:
  - pseudo-scalar mediator a/A, dark matter pair produces MET
  - bb final state provides maximal sensitivity at large tanβ

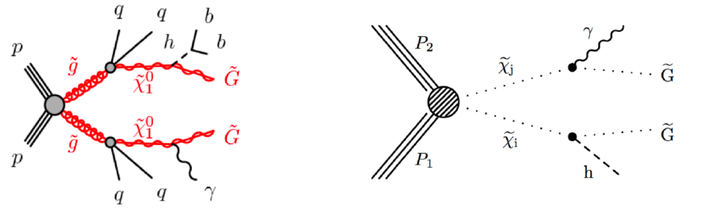


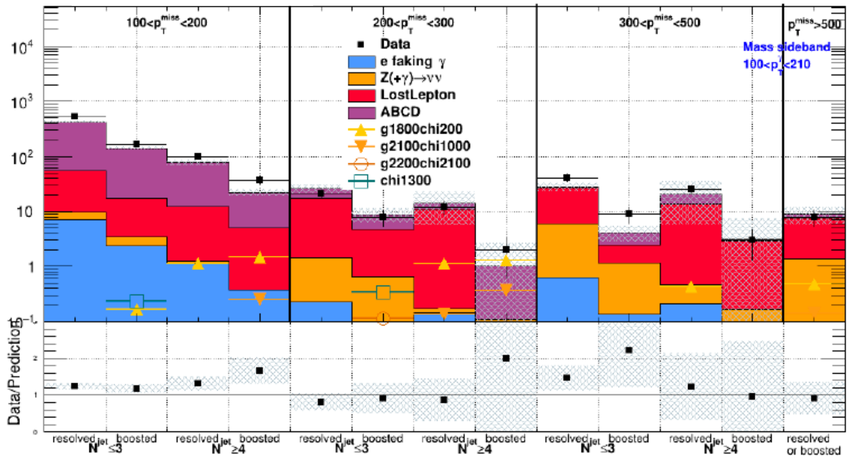


Run-2 CMS excluded mediators up to m_a ~260GeV
(mild excess at higher masses motivating the Run-3 extension)

γ + H(bb) + MET

- Gauge-mediated SUSY search: $\tilde{\chi}_1^0 \to h + \tilde{G}$, with $h \to b\bar{b}$
  - Signature: γ + H(bb) + p_T^{miss}
- Analysis simultaneously exploits:
  - resolved Higgs (AK4), boosted Higgs candidates (AK8)
  - MET-based signal regions
- ParticleNet and DeepFlavour strategies reused
- Shared MET and trigger systematics with SUSY analyses





Additional scalars at higher mass

CMS-PAS-B2G-24-010

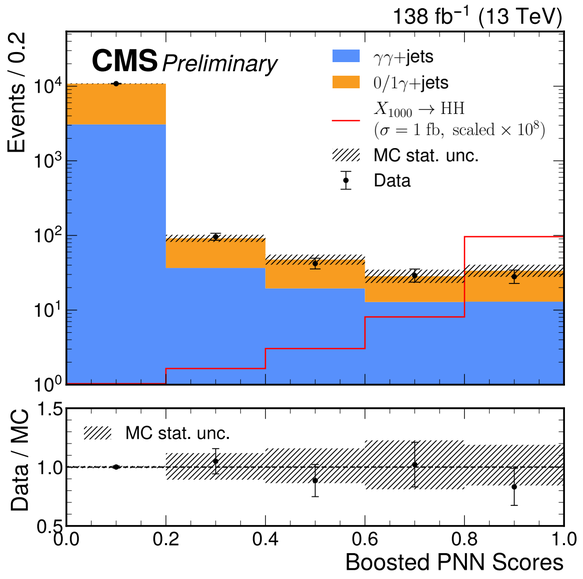
arXiv:2601.20011, CMS-B2G-24-014

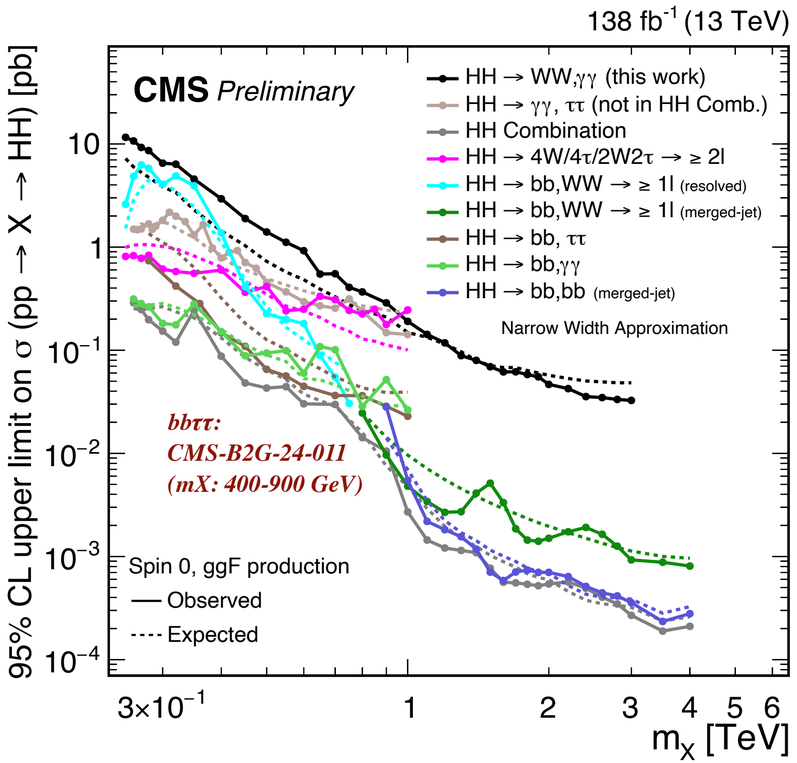
Resonant X→HH: WWγγ, boosted bbττ

- Extended scalar sectors can produce **resonant Higgs-pair production**, enhancing HH well above the non-resonant SM rate.

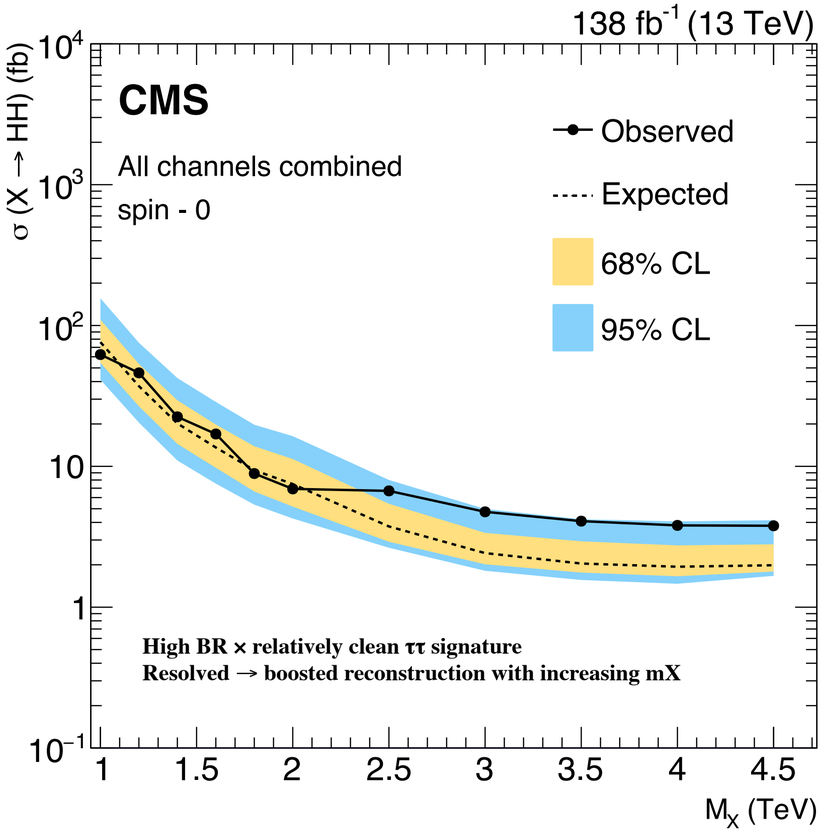
HH→WWγγ:
competitive in the intermediate mass region

— First LHC search incl. fully hadronic and boosted WW topology
— Leverages H → γγ mass resolution





NEW boosted HH→bbττ:
most sensitive LHC limits in mass range of 1.4 to 4.5 TeV



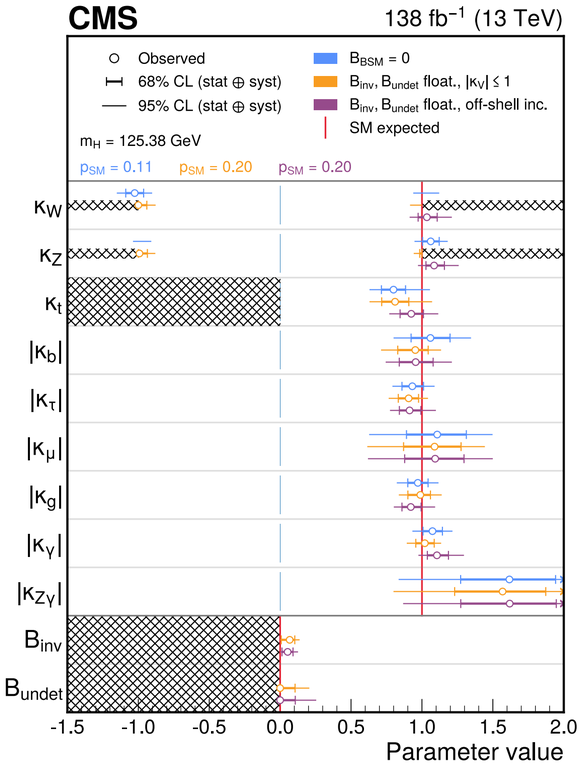
Constraints Beyond Direct Searches

Flavor, LEP, Higgs couplings, EW precision

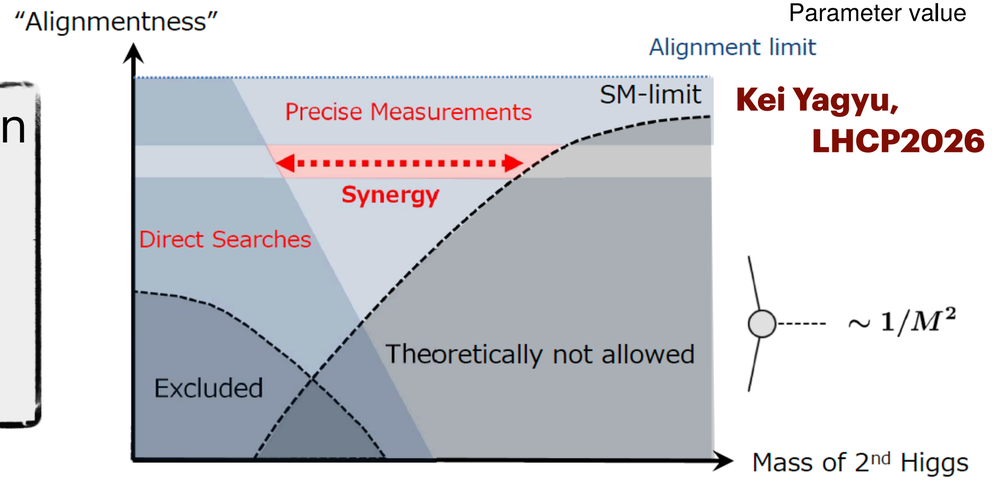
Direct searches are only one projection of the extended Higgs sector.

Complementary constraints:

- LEP / EW precision: Z width, charged Higgs limits, mW, ρ parameter
- Flavour: b→sγ, Bs→μμ, B-mixing; especially powerful in Type-II-like models
- Higgs couplings: h(125) alignment, exotic BR fraction, loop-level deviations
- Theory consistency: perturbativity, unitarity, vacuum stability, mass splittings



- Even when no new scalar is directly observed, precision measurements restrict the same parameter space.
- **For exotic Higgs searches**, direct limits should increasingly be interpreted together with Higgs-coupling, flavour, LEP and EW precision constraints.



Kei Yagyu, LHCP2026