Searches for BSM single Higgs bosons at the LHC (ATLAS + CMS)

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on behalf of the ATLAS and CMS Collaborations

Rencontres de Moriond, Electroweak Interactions &

Unified Theories 2026

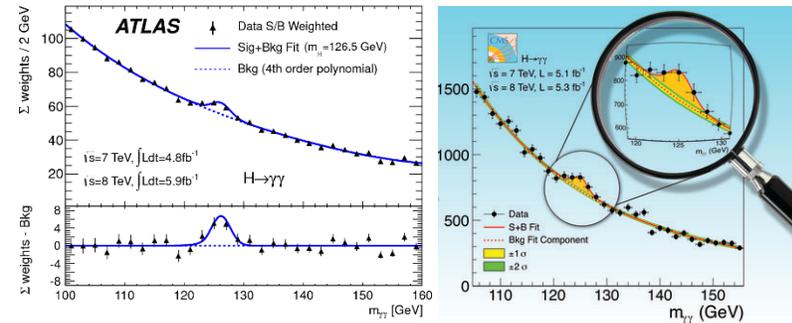Hotel Planibel, LA THUILE (IT), March 21 2026

Introduction

- We found one scalar boson in 2012....

- Why do we still look for others?

- Many BSM theories allow additional (pseudo) scalar bosons!

This talk: Five recent (<1year) or NEW searches for BSM single Higgs bosons from ATLAS and CMS

What is a 'BSM single Higgs boson'? Either singly-produced, or produced in association with H_{125}:

- 'Dark' Higgs H_D (CMS) or s (ATLAS) model: A 2-mediator (Z', H_D /s) DM model capable of reproducing the observed relic density

    - $H_D \rightarrow bb$ (50-150 GeV) CMS-PAS-SUS-23-013

    - $Z'^* \rightarrow Z'+s \rightarrow \chi\chi + bb$ (30-150 GeV) ATLAS PRL 134 (2025) 121801

    - $Z'^* \rightarrow Z'+s \rightarrow \chi\chi + H_{125} H_{125}$ (250-400 GeV) ATLAS JHEP 09 (2025) 067 *New!*

- Additional scalars A, H in IDM: $Z^* \rightarrow AH \rightarrow Z^*HH \rightarrow HH\ell\ell$ (m_H={60-180}, m_A- m_H={20-100} GeV) CMS-PAS-NPS-25-002

- Additional spin-0/spin-1 resonances: $X \rightarrow ZZ$ or $Z' \rightarrow ZH \rightarrow bb\tau\tau$ ($m_{X/Z'}$={200 GeV-6 TeV}) CMS-PAS-B2G-25-004 *New!*

Bonus: *New!* Updated summaries from CMS/ATLAS!!

Conclusion and perspectives

Acknowledgements

Please see other talks involving BSM Higgs boson searches:
- Searches for low-mass resonances in ATLAS and CMS: C. Collard 18/03
- Searches for new physics with photons in ATLAS and CMS: A. Agapitos 19/03
- Searches for new physics at high object masses A. Malara 19/03
- Searches for other exotica in ATLAS and CMS C. Koraka 19/03
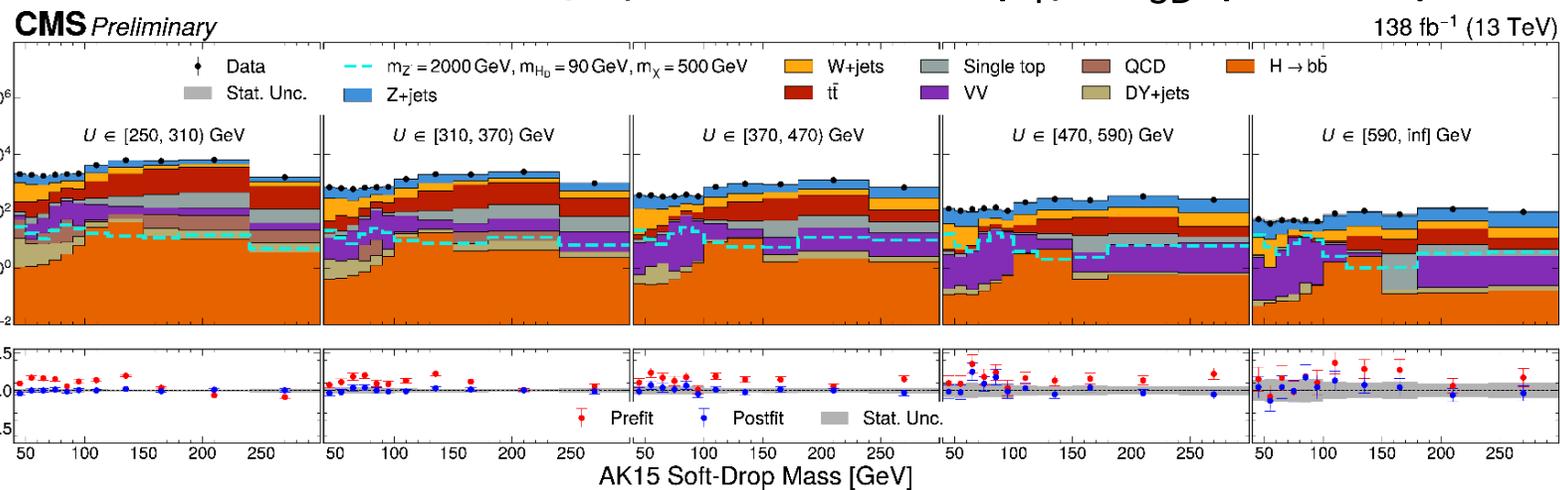- Multiple-Higgs searches at ATLAS and CMS in ATLAS and CMS. V. Dao 21/03
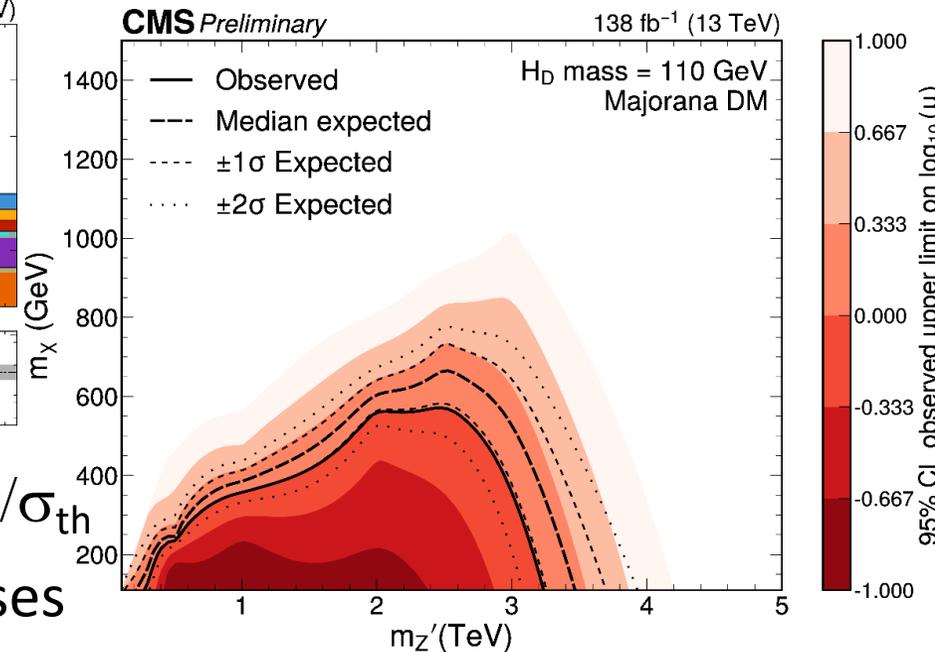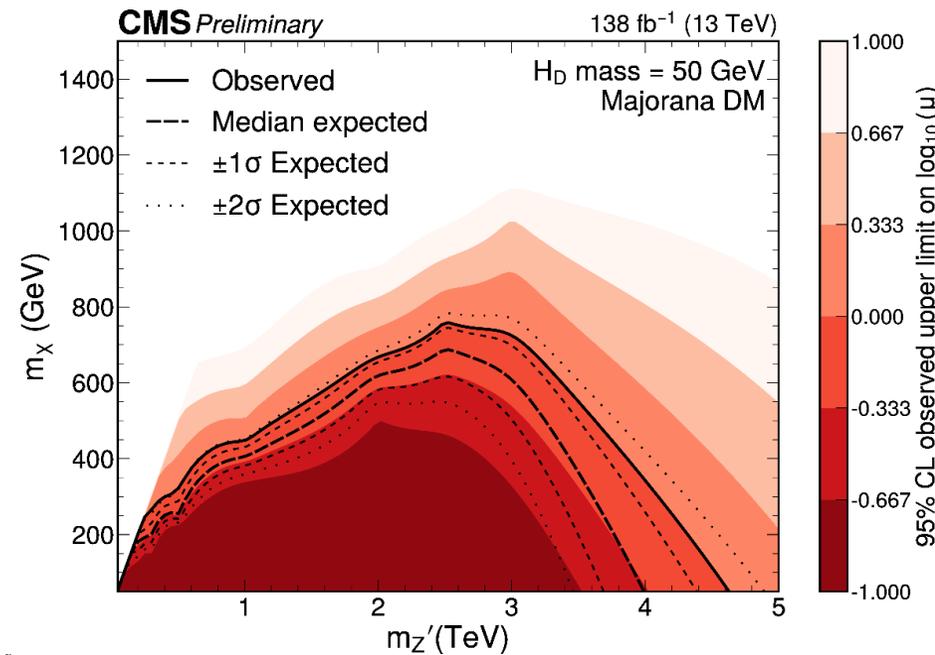
'Dark' Higgs $H_D \rightarrow bb$ (50-150 GeV)
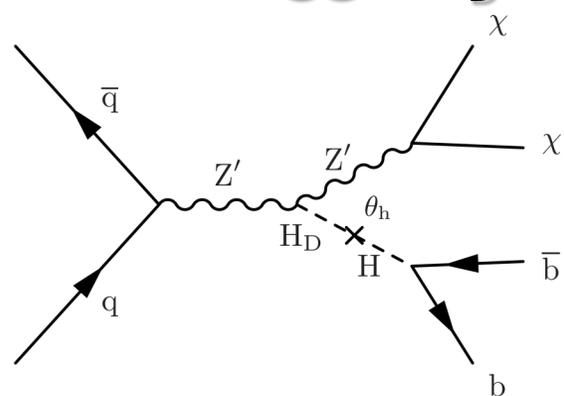
- DM Z' produced with H_D mixing w/H_{125} (θ_h)

- Signature: Large Et_{miss} + $H_{125} \rightarrow bb$

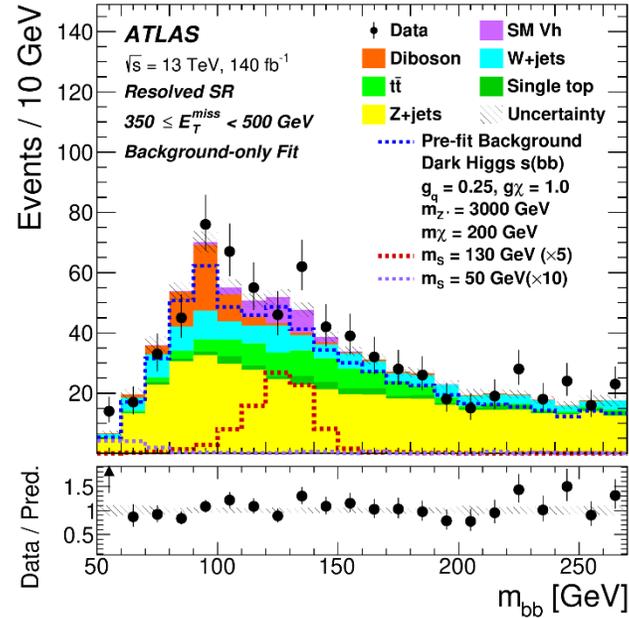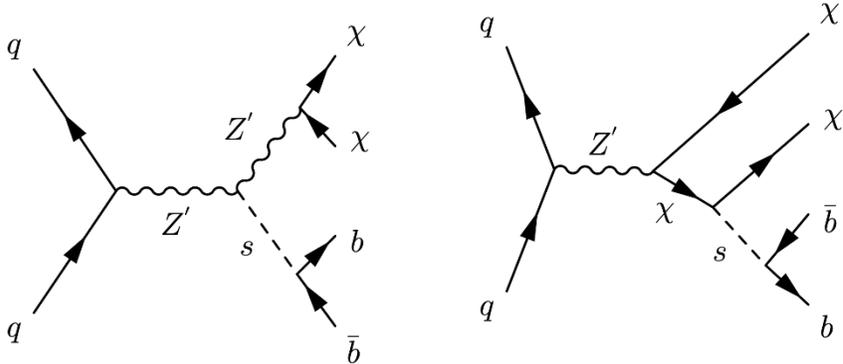- Major backgrounds: V+jets, ttbar, single t

- SR, 7 CR defined in {U(non-hadronic p_T), m_{SD} phase space

- Max joint LH over SR + CR to model background/extract $\mu = \sigma/\sigma_{th}$

- 95% CL limits on μ in { $m_{Z'}$-m_χ} phase space: Exclude Z' masses between 2.5-4.5 TeV (depending on m_{HD})
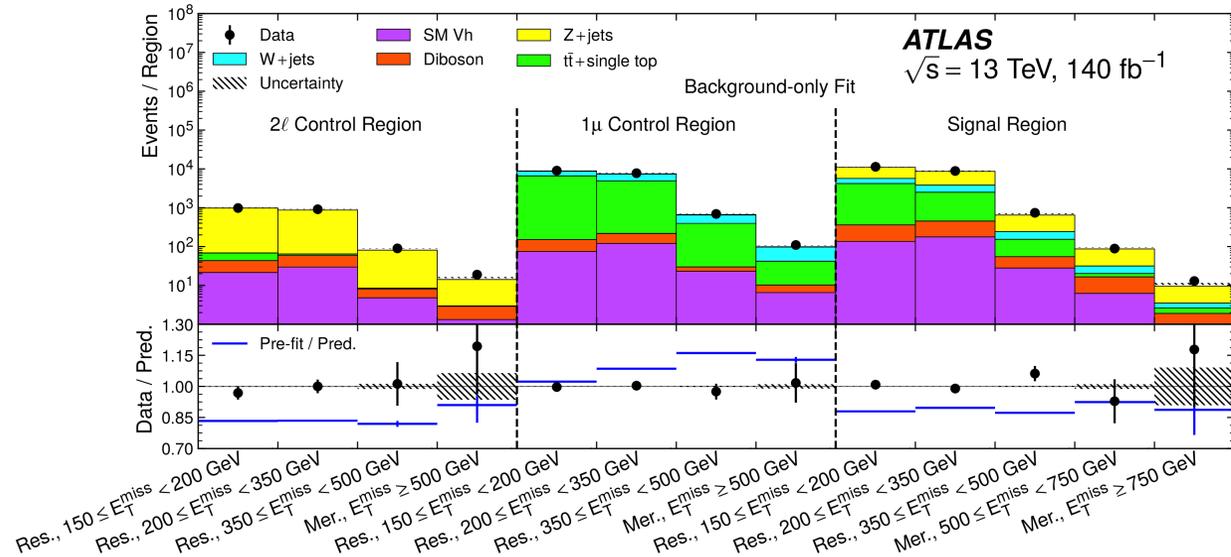
'Dark' Higgs s from Z'*→Z'+s→χχ + bb (30-150 GeV)

- Signature: merged (m_s<50 GeV) or resolved (m_s>70 GeV) bb system, m_{bb} binned in $E_{t\,miss}$

- Backgrounds from tt and V+jets

- Access lower m_s with $E_{t\,miss}$ trigger and dedicated merged-bjet (large R) tagger

- 1-μ and 2ℓ CR for V+jets modeling➔Simultaneous ML fit to m_{bb} (SR) or event yields (CR)

- Most significant uncertainties (% of total): Data statistics (75-80%), large-R bjet tagger calibration (20-47%)

'Dark' Higgs s from Z'*→Z'+s→χχ + bb (30-150 GeV)

- Scenario 2: Z'-χ coupling floats to match the relic density

- Largest deviations for m_s~50, 130 GeV
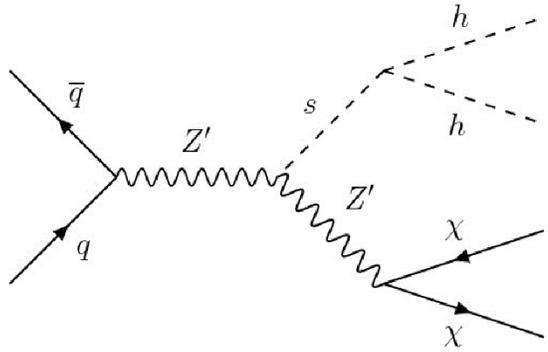
- $m_{Z'}$<4.5 TeV excluded for m_s =75 GeV
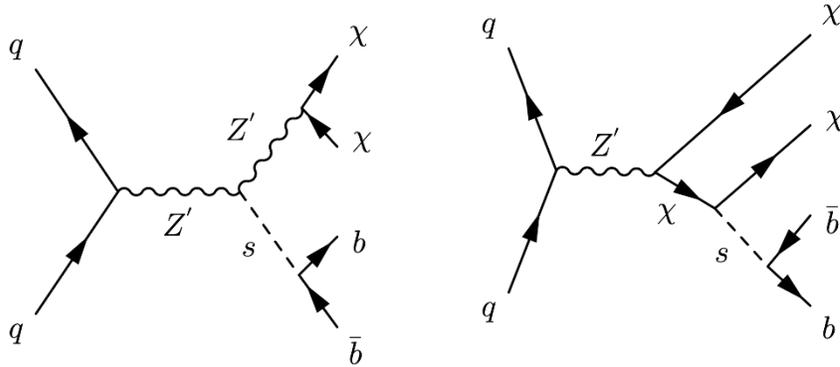
- Exclusions in {m_s, $m_{Z'}$} plane: Scenario 1: Z'-χ (DM) coupling fixed (comparable to CMS analysis)

- $m_{Z'}$<3.4 TeV excluded for m_s =70 GeV
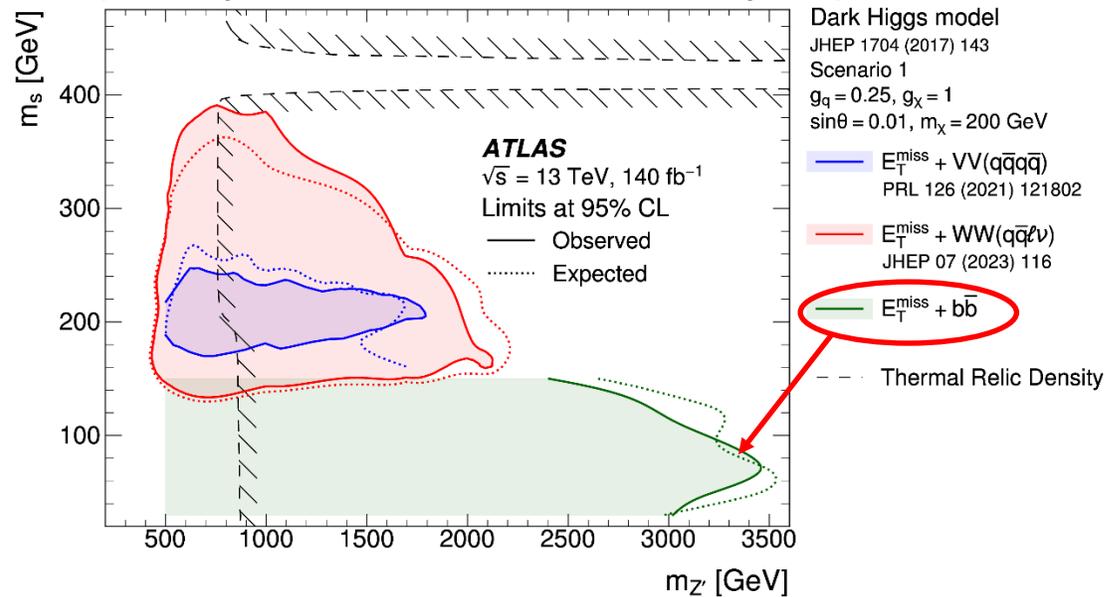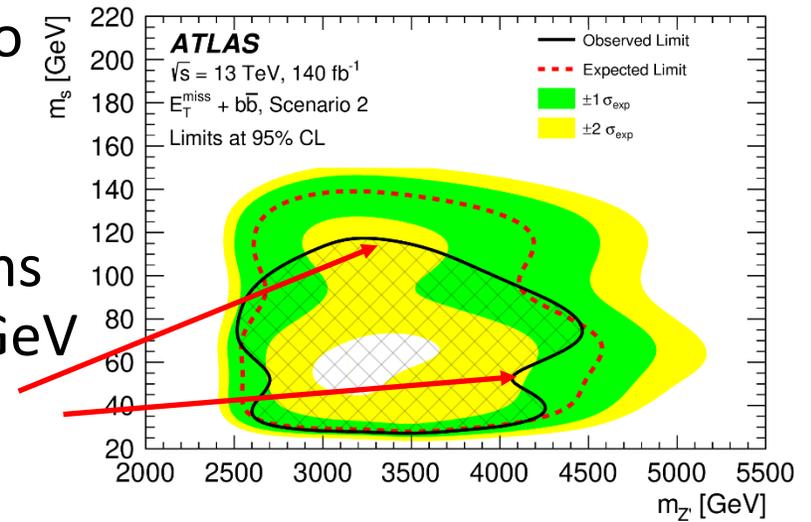
- Scenario 3: m_s =70 GeV (max sensitivity)

- Exclusion in {m_χ, $m_{Z'}$} plane: $m_{Z'}$<4.8 TeV

'Dark' Higgs s from $Z'^* \to Z' + s \to \chi\chi + H_{125} H_{125}$ (250-400 GeV)

JHEP 09 (2025) 067

- Exclusions in $\{m_s, m_{Z'}\}$ plane: Scenario 1: Z'-χ (DM) coupling fixed

Dark Higgs model
JHEP 04 (2017) 143
$g_q = 0.25$, $g_\chi = 1$
$\sin\theta = 0.01$, $m_\chi = 200$ GeV

ATLAS
$\sqrt{s}$ = 13 TeV, 140 fb^{-1}
Limits at 95% CL
— Observed
⋯ Expected

E_T^{miss} + VV($q\bar{q}q\bar{q}$)
PRL 126 (2021) 121802

E_T^{miss} + WW($q\bar{q}\ell\nu$)
JHEP 07 (2023) 116

E_T^{miss} + $b\bar{b}$
PRL 134 (2025) 121801

E_T^{miss} + hh($b\bar{b}b\bar{b}$)

Thermal Relic Density
$\Omega_c h^2 \geq 0.12$

- Exclude m_s = {250-400 GeV} for 500 < $m_{Z'}$ < 2.3 TeV

(Background plot, top)
ATLAS
$\sqrt{s}$ = 13 TeV, 140 fb^{-1}
Background-only fit
Preselection
— ·— $m(s, Z')$=(385, 1400) GeV
— — $m(s, Z')$=(310, 2100) GeV
Data, $t\bar{t}$ + light, $t\bar{t}$ + ≥1b, $t\bar{t}$ + ≥1c, Single Top, Z+jets, W+jets, $t\bar{t}$ + X, Diboson, Total SM
Events / 0.05
Data / Pred.
CR, VR, SR
NN score

(Limit plot, bottom)
ATLAS
$\sqrt{s}$ = 13 TeV, 140 fb^{-1}
Limits at 95% CL
— Observed
— — Expected
$\pm 1\sigma_{exp}$
$g_q = 0.25$, $g_\chi = 1$,
$\sin\theta = 0.01$, $m_\chi = 200$ GeV
$m_s = 2m_h$
m_s [GeV]
$m_{Z'}$ [GeV]

- Signature: 3- or 4-bjets + $E_{t_{miss}}$, bb system merged (m_{bjet} >100 GeV) or resolved

- Backgrounds from tt and Z+jets

- Kinematic NN>0.95

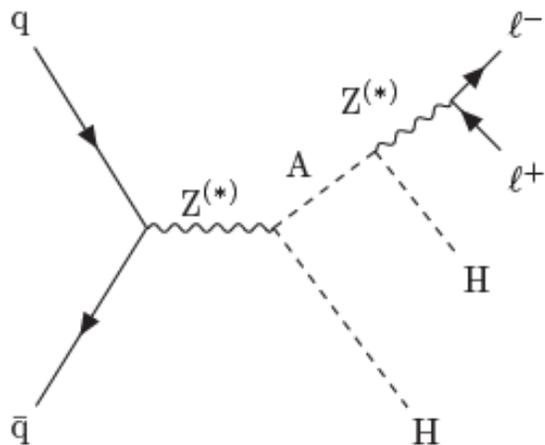- Simultaneous LH fits in 8 SR m_{HH} bins + 3CR (n_b, $m_T^b{}_{min}$) +1CR (Z→μμ)

  - Most significant uncertainties (% of total): Data statistics (95%), single t modeling/σ (18%), MC statistics (17%)

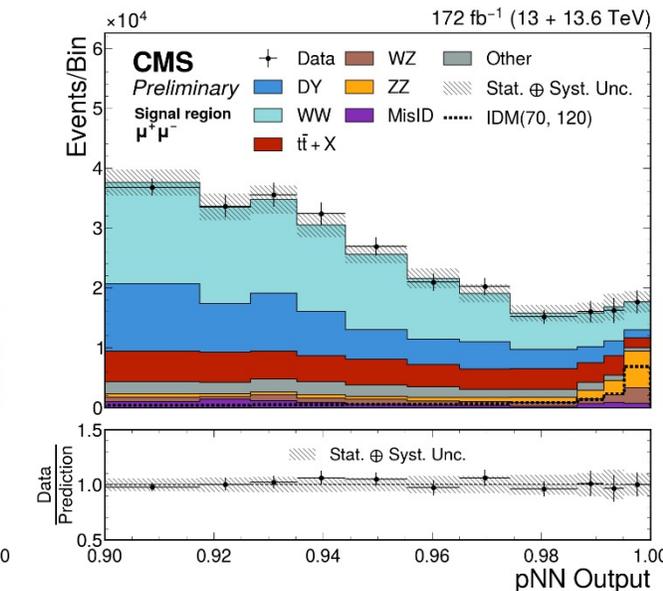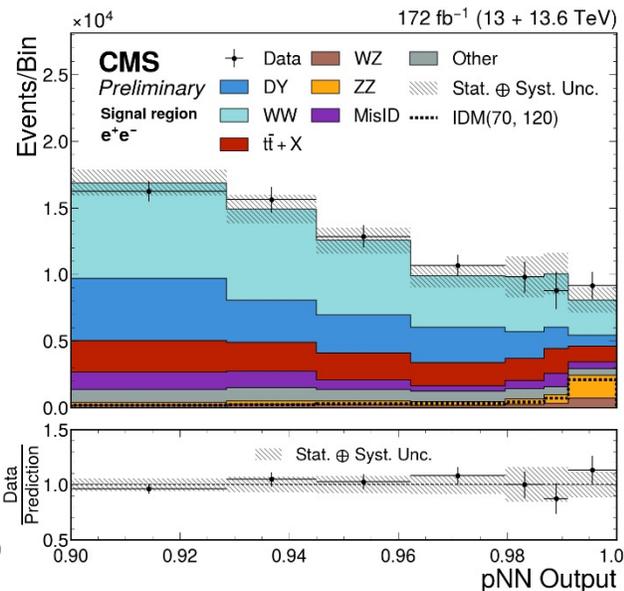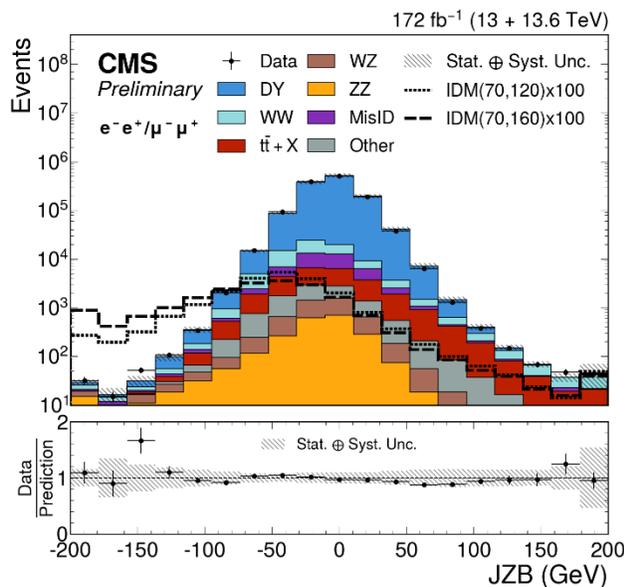# $Z^* \rightarrow AH \rightarrow Z^*HH \rightarrow HH\ell\ell$ (m_H={60-180}, m_A- m_H={20-100} GeV) IDM Run 2 + Run 3 (2022)

New!

- **IDM (Inert Doublet Model):** 2HDM w/unbroken Z_2 symmetry $\rightarrow$ 4 additional scalars: H^{+-} + bosophilic A, H (**stable** DM candidate)

- Signature: Di-e or di-μ pair + E_{tmiss}

- PNN: Kinematical, transverse mass and jet-Z balance variables

- Major backgrounds after PNN>0.9 : Diboson, ttbar

- Simultaneous binned Max LH fit over SR +7 CR to PNN output or dilepton $p_T \rightarrow$ model background/extract μ

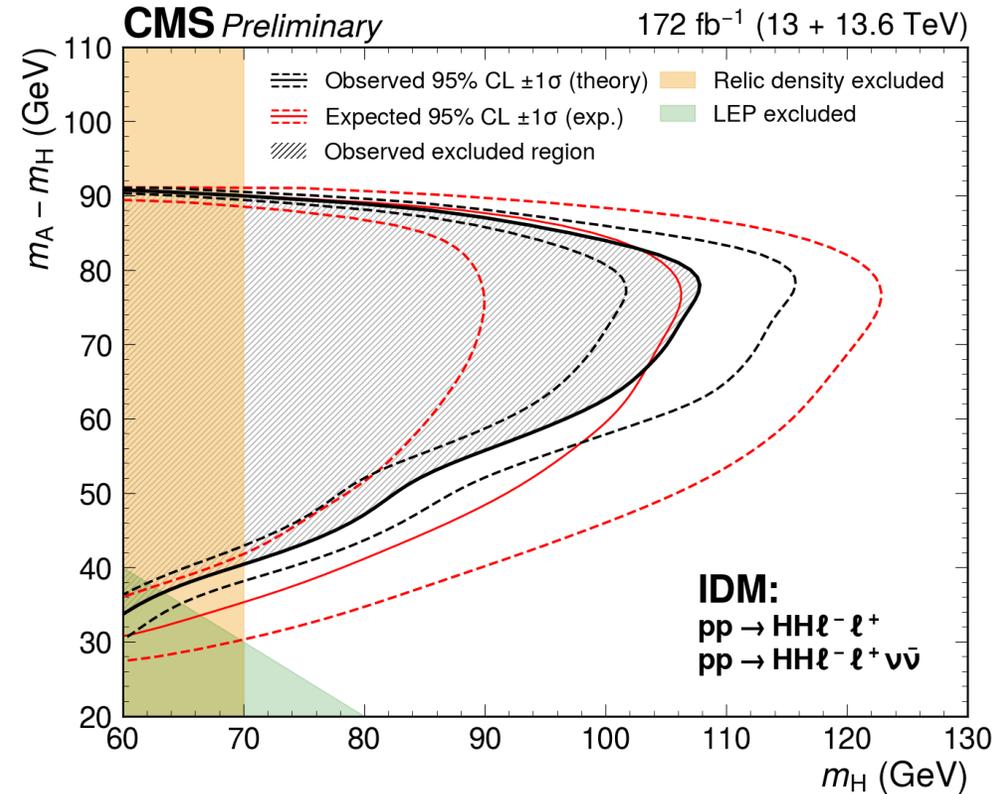# Z*→AH→Z*HH→HHℓℓ (m_H={60-180}, m_A- m_H={20-100} GeV) IDM Run 2 + Run 3 (2022)

New!
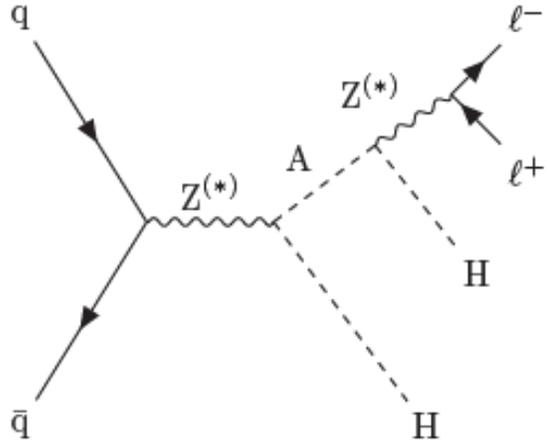
- Largely statistics-limited, but most important systematic uncertainties on μ: MC statistics + jet calibration

CMS *Preliminary*   172 fb⁻¹ (13 + 13.6 TeV)

- 95% CL observed limits on m_H and m_A in { (m_A-$m_H)$, m_H} phase space: Exclude m_H<108 GeV for m_A- m_H =78 GeV, and m_A- m_H ={35,90 GeV} for m_H=60 GeV
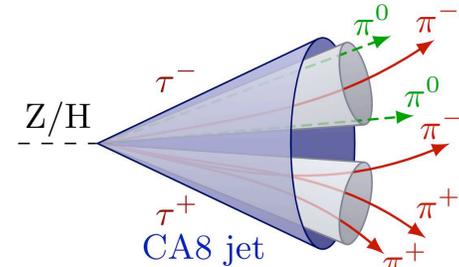
- First limits on m_H and m_A in IDM Model obtained by a dedicated search w/collision data

- Significant extension of constraints from previous direct/indirect measurements and DM searches: lower E_{tmiss} requirements
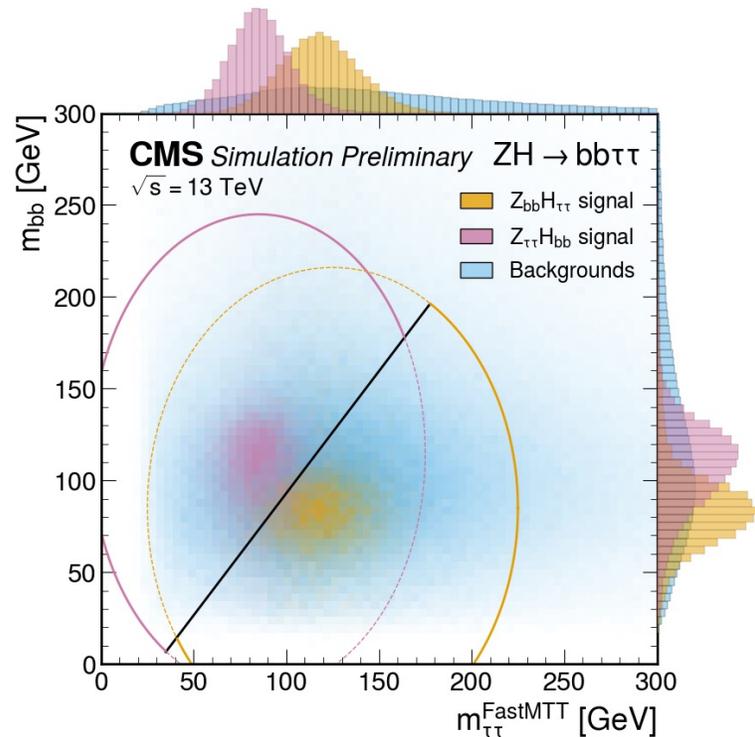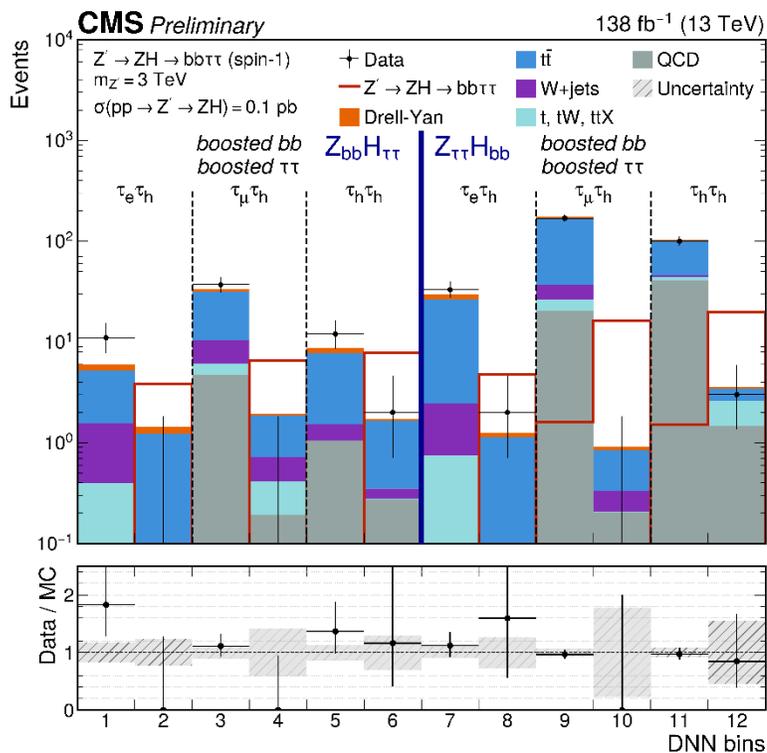
X →ZZ or Z'→ZH→bbττ ($m_{X/Z'}=\{200\ \text{GeV-6 TeV}\}$)

New!

Spin 0

Spin 1
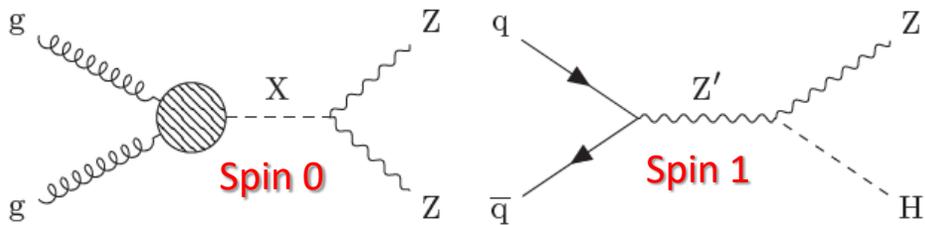
- bbττ final state, 12 categories: $\{\tau_\mu\tau_h,\ \tau_e\tau_h,\ \tau_h\tau_h\}$ X {bb/ττ system boosted/resolved}➡87.6% of possible ττ decays

- Primary backgrounds: ttbar, DY, QCD

- Dedicated reconstruction for boosted ττ pairs (m_X> 1 TeV): identification of subjets within large-radius jets to re-seed τ_h reconstruction

- Elliptical selection in $\{m_{bb}-m_{\tau\tau}\}$ plane, ε_{sig}>90%

- Diagonal selection to separate $Z_{bb}H_{\tau\tau}$ and $Z_{\tau\tau}H_{bb}$

- Signal extraction: Binned Max LH fit to output distribution of PNN with DNN architecture
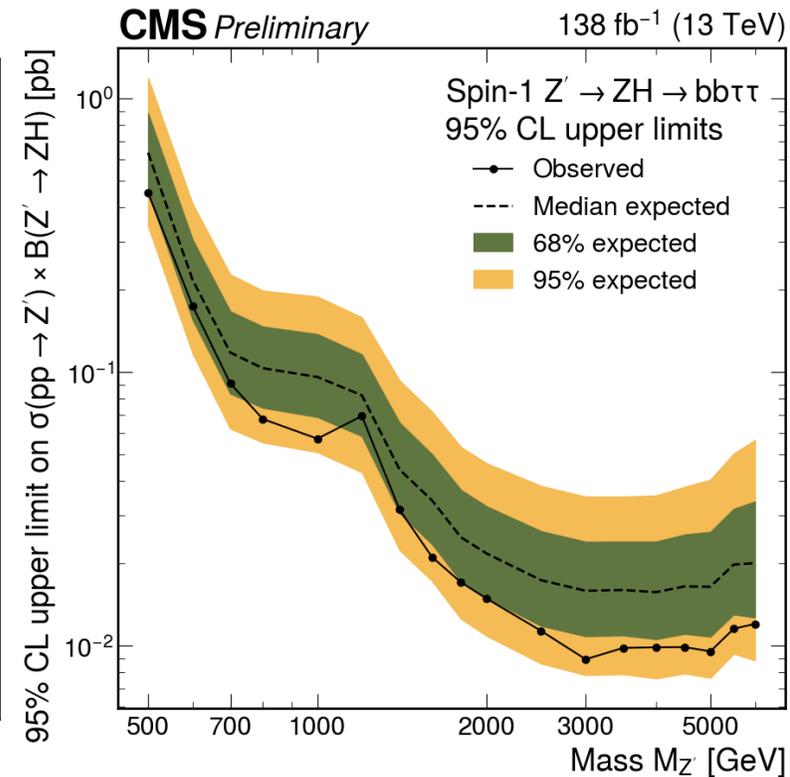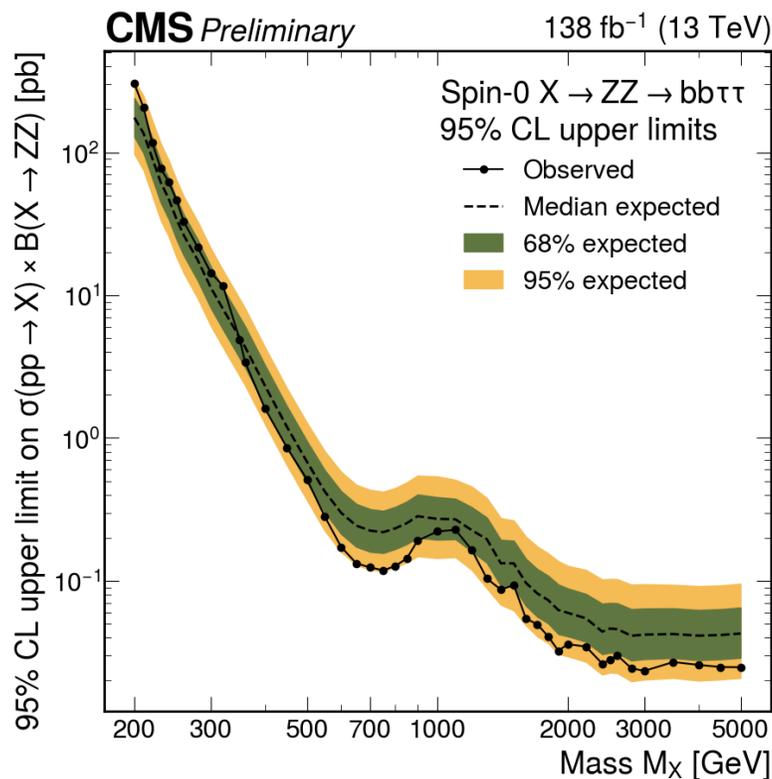
X →ZZ or Z' →ZH→bbττ (m$_{X/Z'}$={200 GeV-6 TeV})

New!

Spin 0

Spin 1
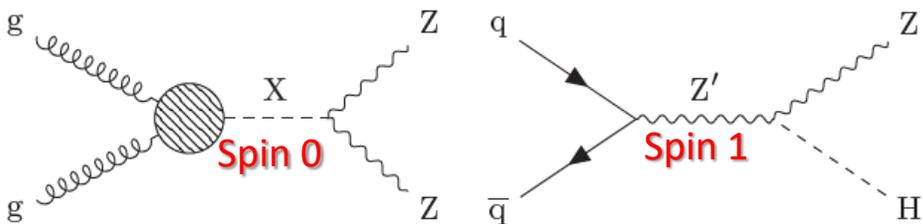
- 95% CL observed limits on
  - σ(X→ZZ) between 300pb-24fb
  - σ(Z'→ZH) between 0.4pb-12fb

- Dominant systematic uncertainties: DY and ttbar theoretical predictions, MC statistics, b-tagging efficiencies
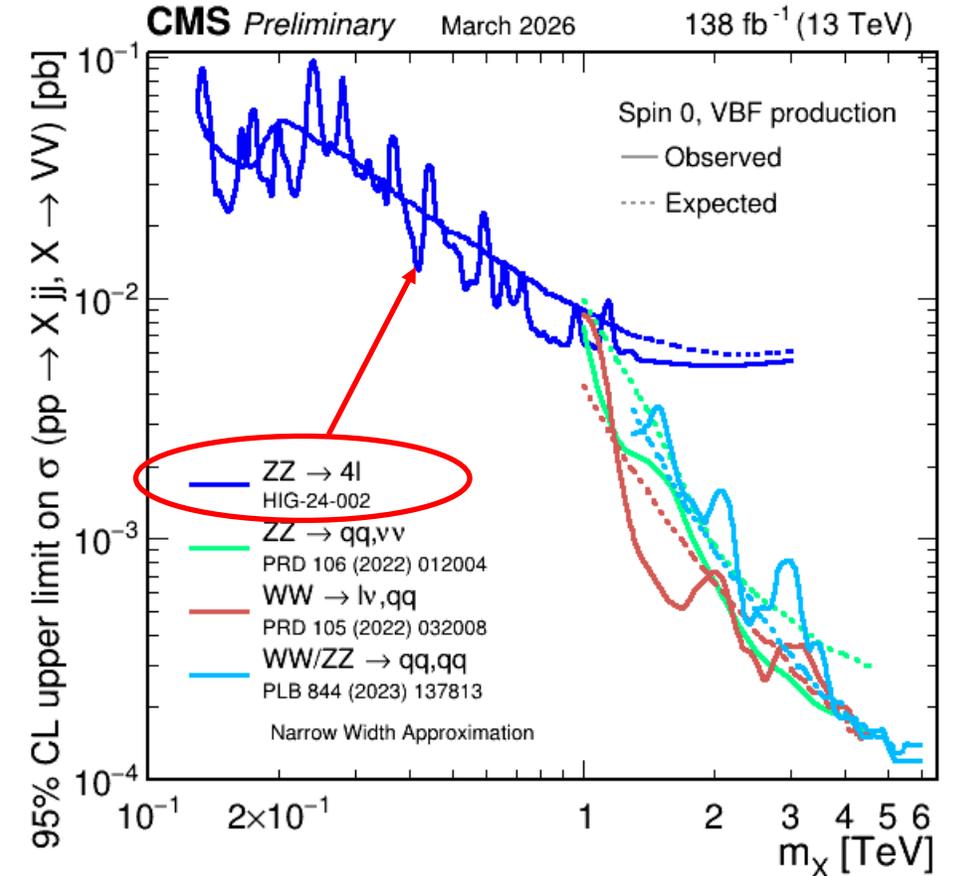
- **First analysis targeting ZZ,ZH→bbττ final state**

CMS *Preliminary*   138 fb⁻¹ (13 TeV)

Spin-0 X → ZZ → bbττ
95% CL upper limits
- Observed
- Median expected
- 68% expected
- 95% expected

95% CL upper limit on σ(pp → X) × B(X → ZZ) [pb]

Mass M$_X$ [GeV]

CMS *Preliminary*   138 fb⁻¹ (13 TeV)

Spin-1 Z' → ZH → bbττ
95% CL upper limits
- Observed
- Median expected
- 68% expected
- 95% expected

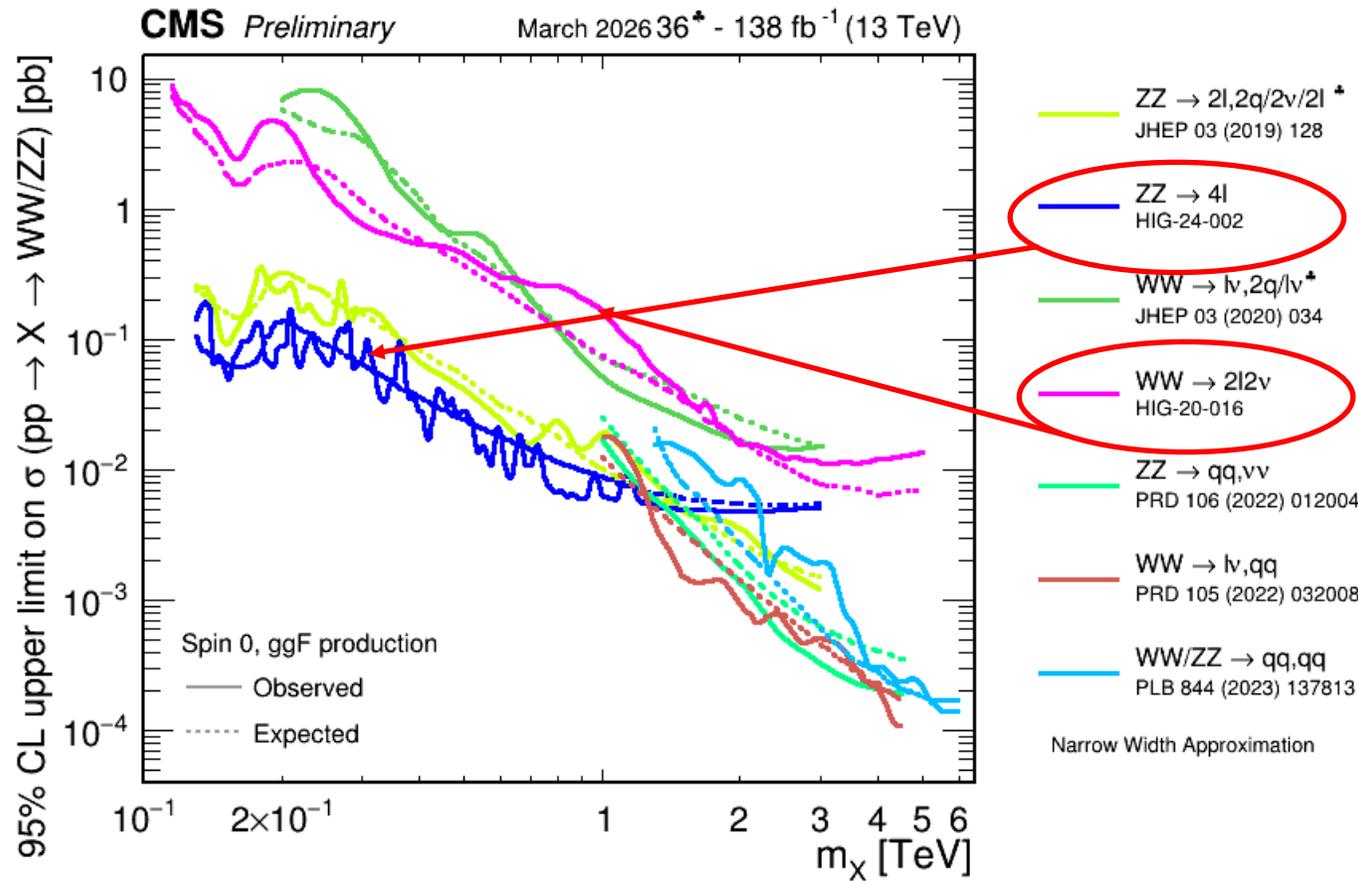95% CL upper limit on σ(pp → Z') × B(Z' → ZH) [pb]

Mass M$_{Z'}$ [GeV]

New Run 2 Summaries: Spin 0 X →VV

New!

- ggF production

- VBF production

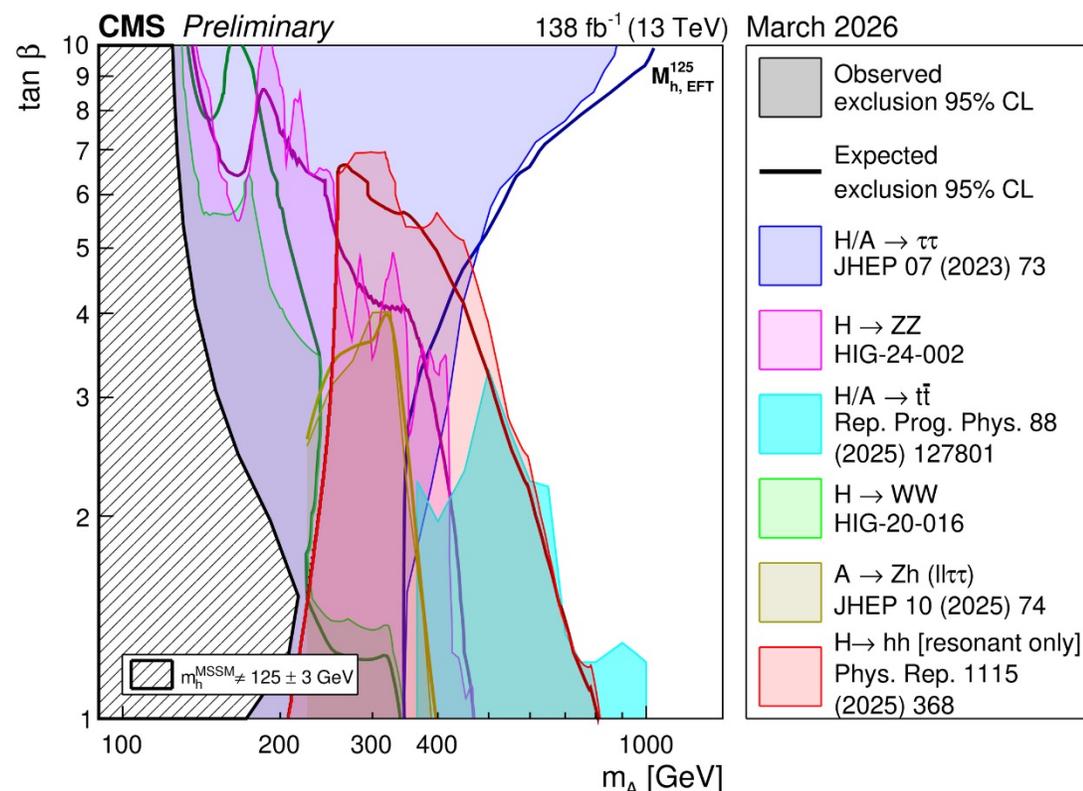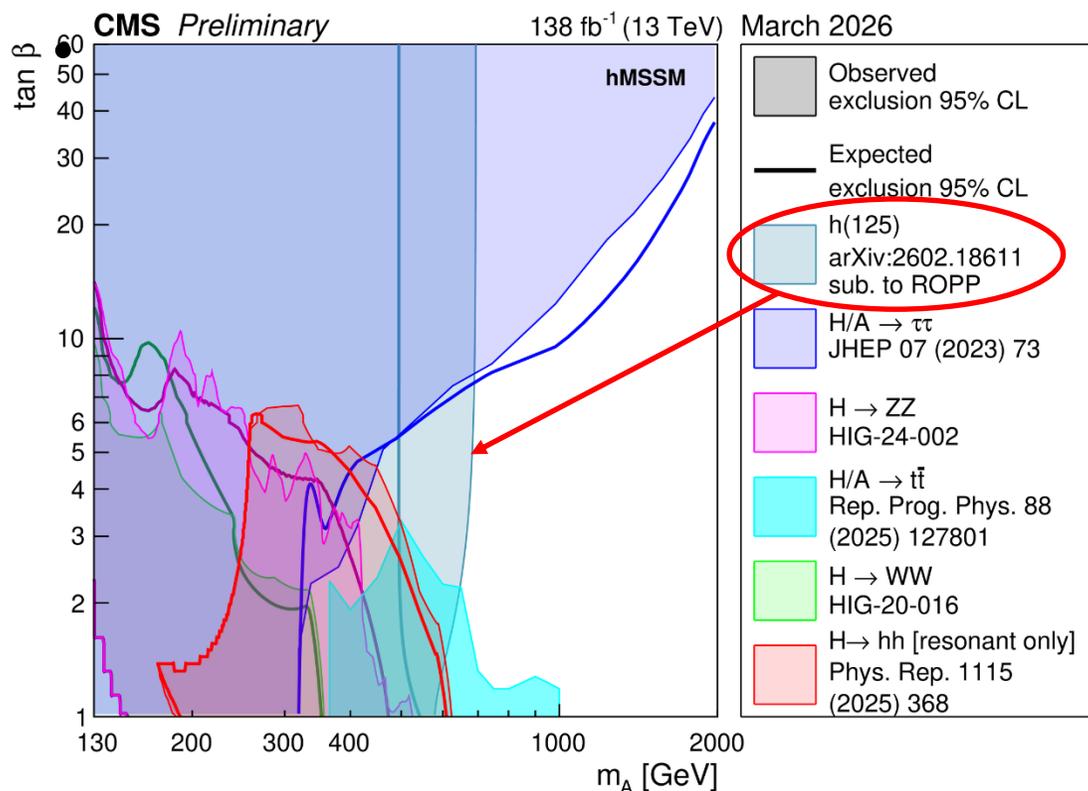- 95% CL observed limits, new analyses added

New Summaries: Spin 0, MSSM reinterpretations

New!

- hMSSM: $h=H_{125}$, $M_S \sim 1\,TeV$, Higgs sector describable by $\{\tan\beta, m_A\}$, and h phenomenology by couplings to V, t, b: Include latest H_{125} combination

- M_h^{125} EFT scenario: Heavy superparticles→production/ decay of MSSM Higgs bosons little affected by them, extends M_h^{125} scenario to low $\tan\beta$

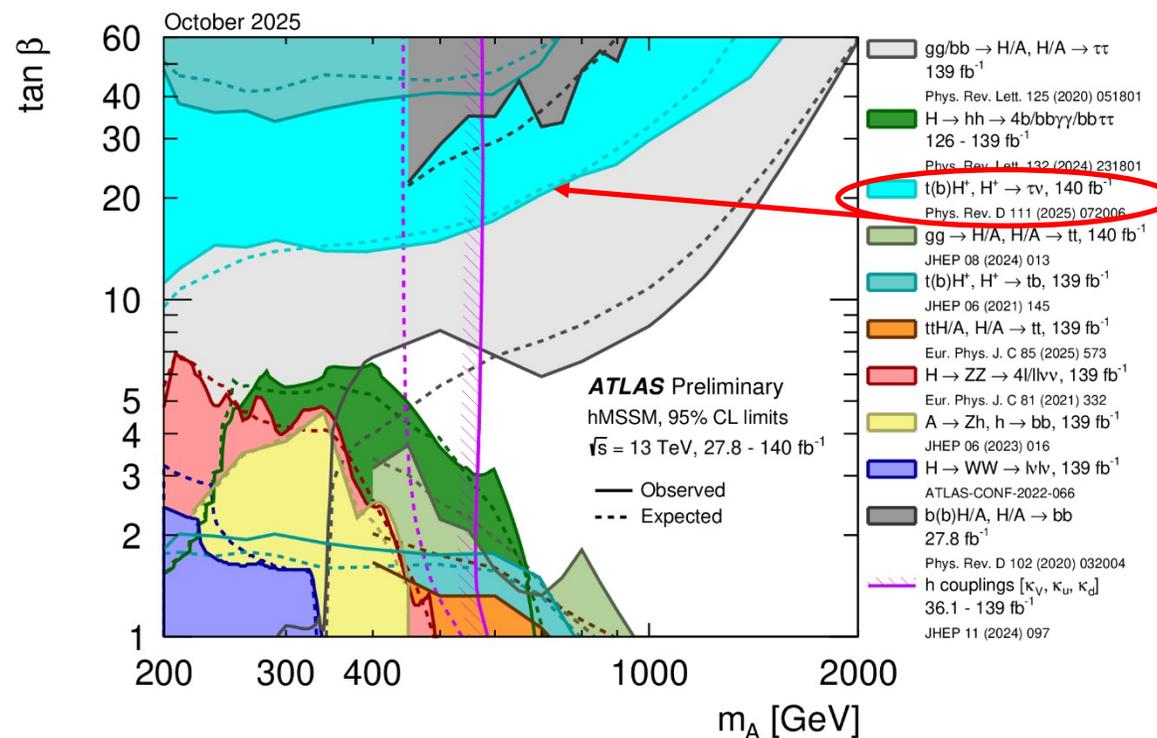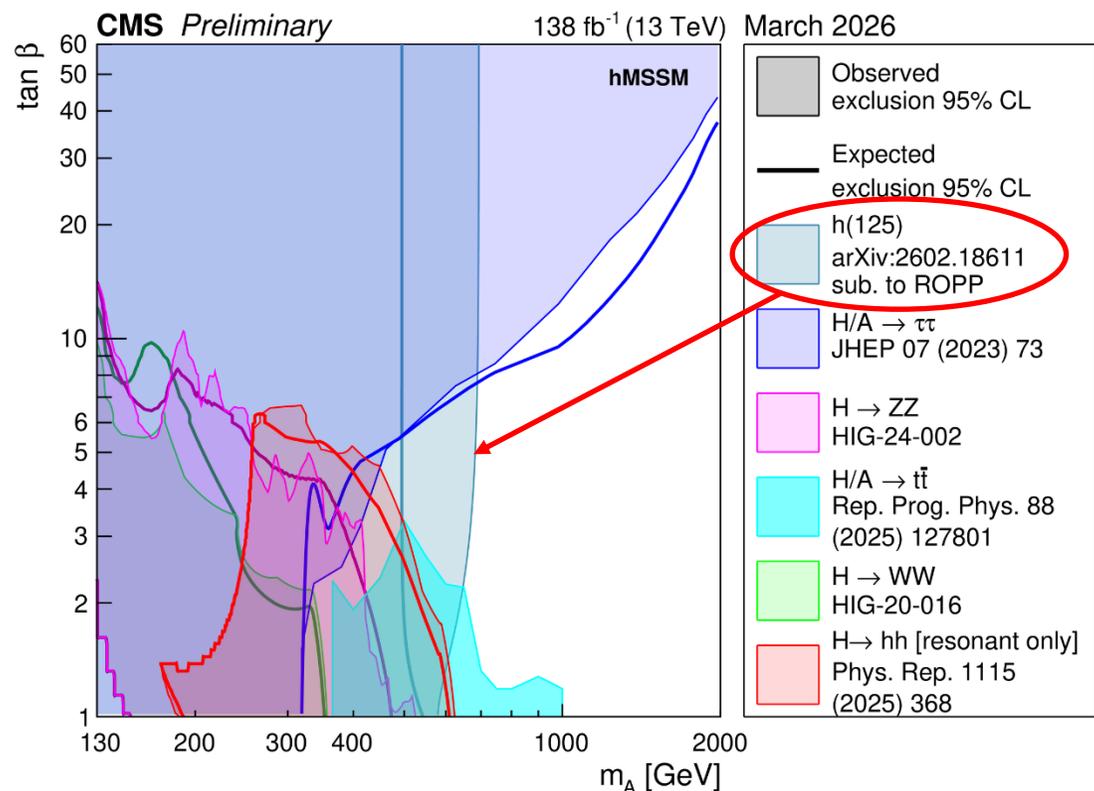- 95% CL observed limits for m_A versus $\tan\beta$

New Summaries: Spin 0, MSSM reinterpretations

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- hMSSM: $h = H_{125}$, $M_S \sim 1\,TeV$, Higgs sector describable by $\{\tan\beta, m_A\}$, and h phenomenology by couplings to V, t, b

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

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2025-042/ includes new $H^+ \to \tau\nu$ result
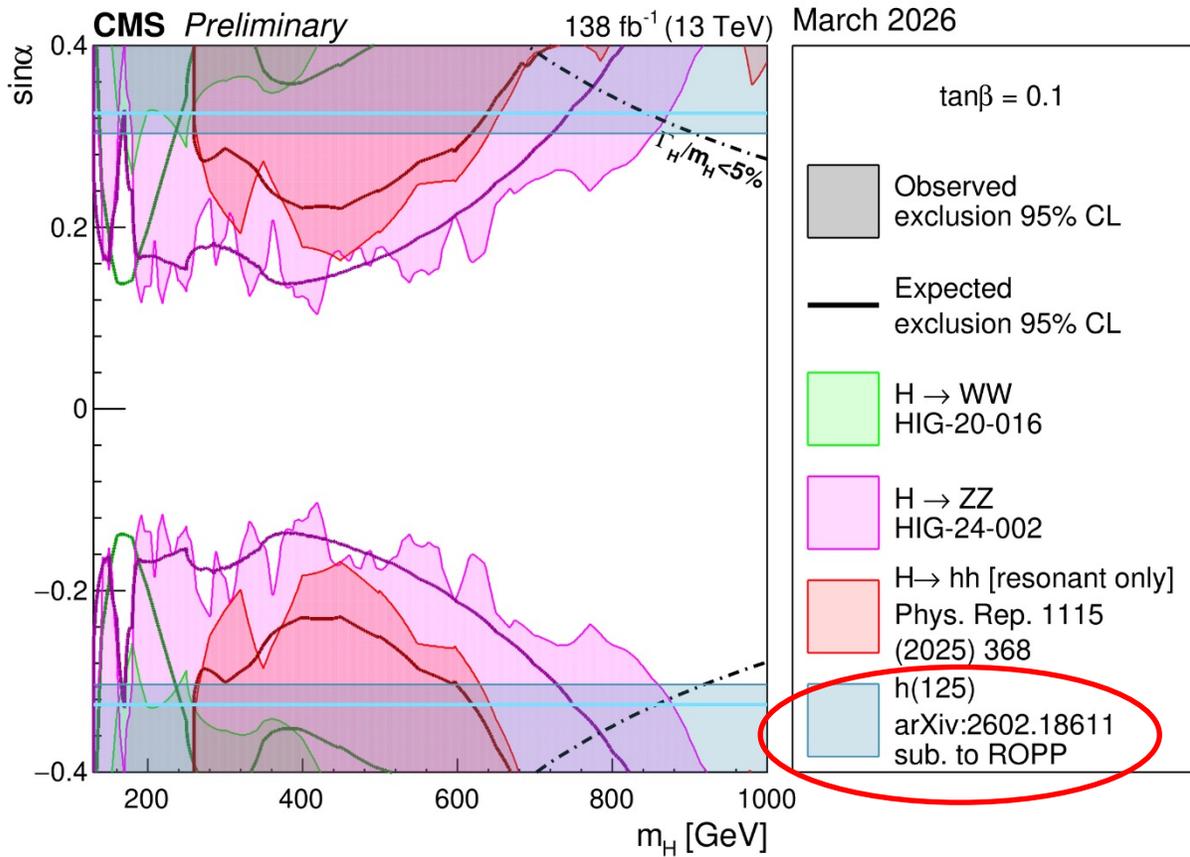

- 95% CL observed limits for m_A versus $\tan\beta$

New Summaries: Spin-0, SM + singlet reinterpretation

New!

- 95% CL observed limits for sinα versus m_H in the SM+ singlet Higgs extension

- tanβ=0.1

- tanβ=4
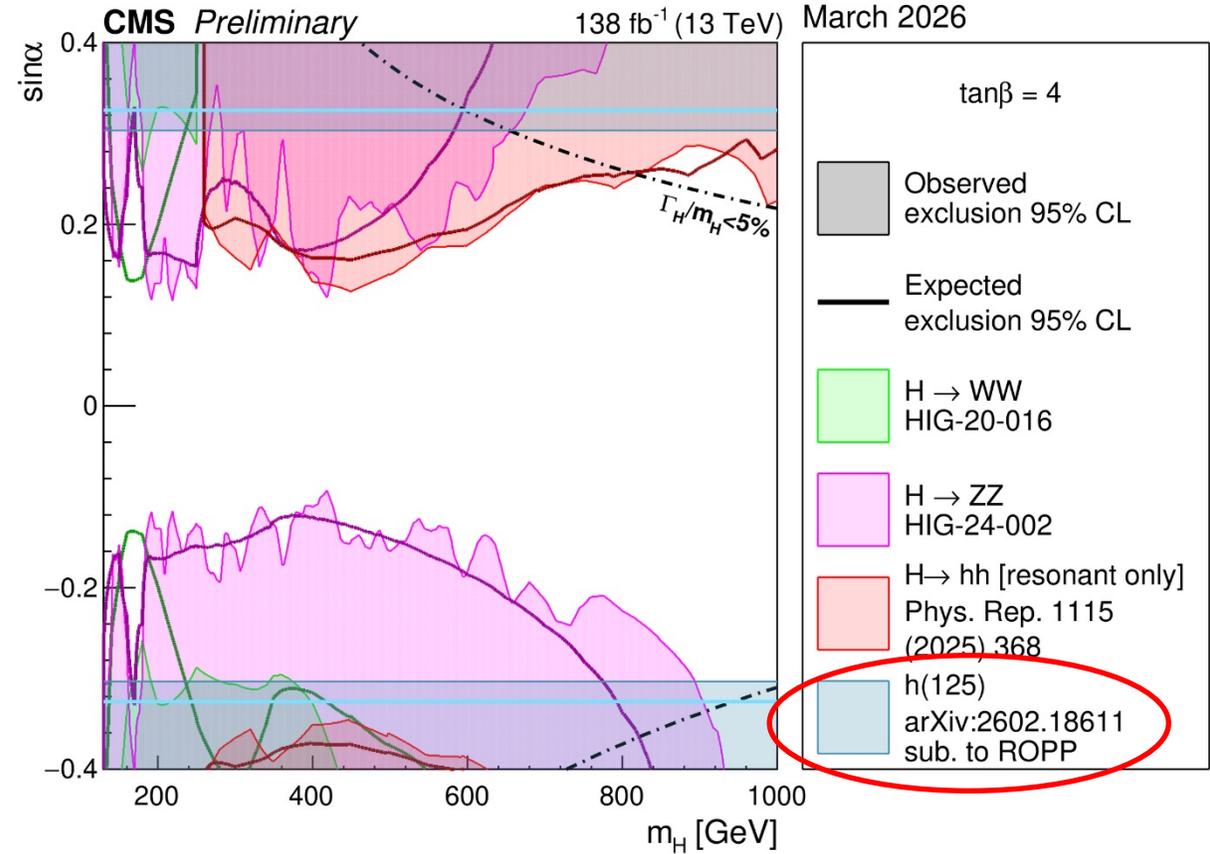
- Include latest H_{125} combination, several other tanβ values available
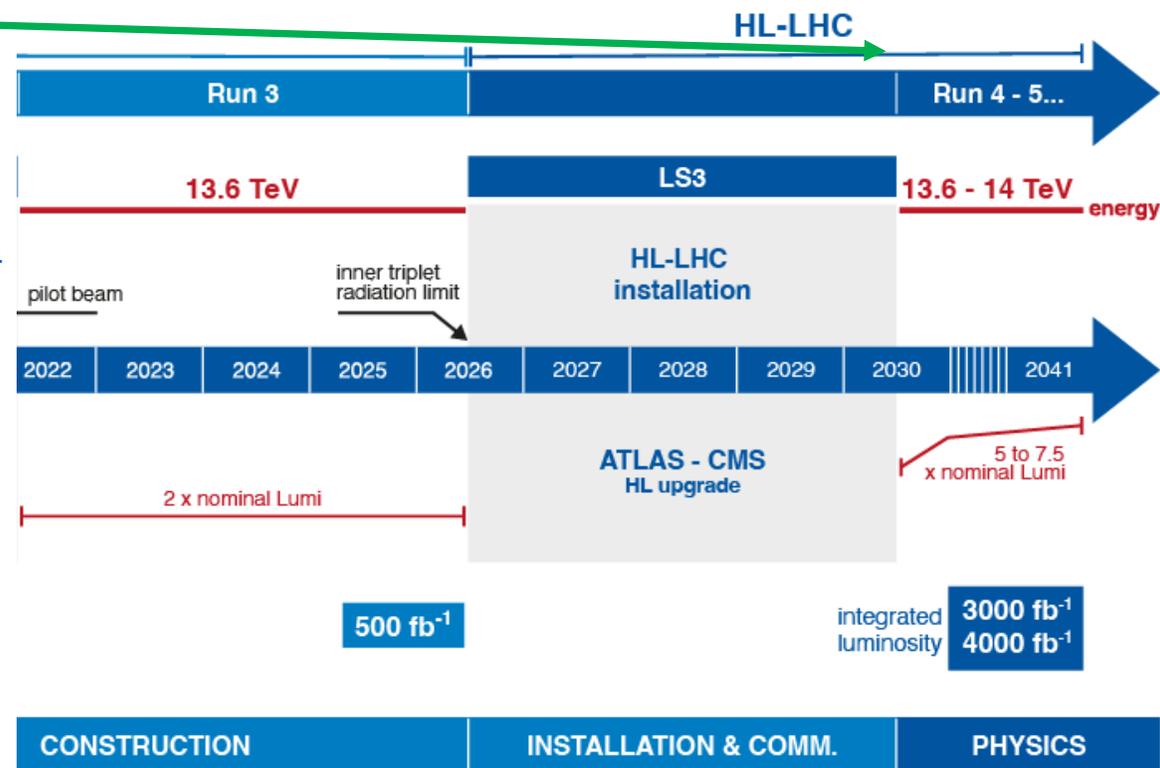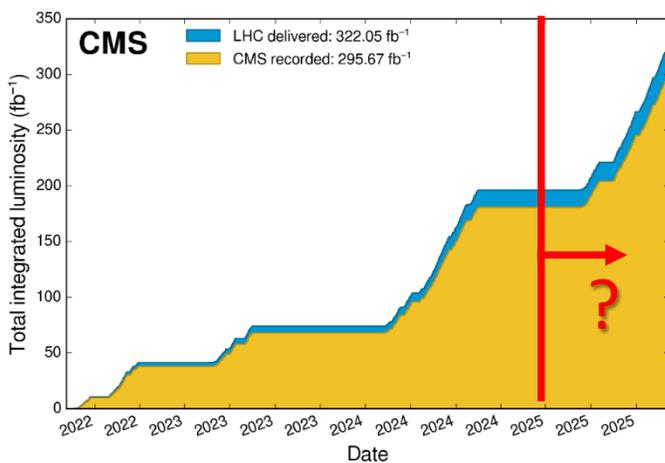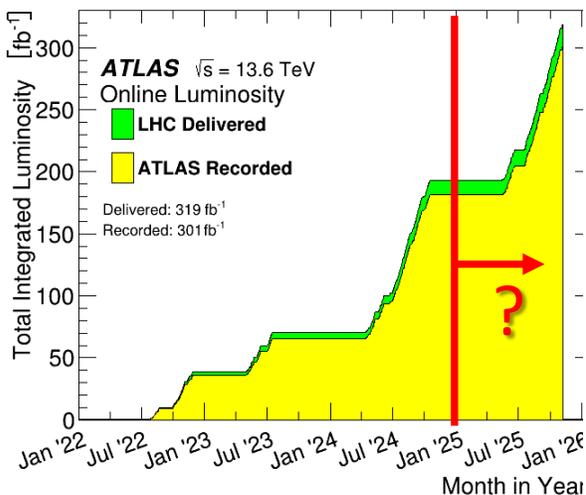
Conclusions and Perspectives

- No evidence for additional single BSM Higgs bosons found so far by CMS and ATLAS.

- Presented 4 results from Full LHC Run 2 data set + 1 including early Run 3 data (2022)

- Run 3 is almost over….but not the data analysis!

- Hope for ~350fb⁻¹➔ ~50% (>=2025) largely unexplored for the moment!

- HL-LHC starts ~2030, expect 3ab⁻¹

- Overall, still plenty of discovery potential at LHC!

https://twiki.cern.ch/twiki/bin/view/CMSPublic/
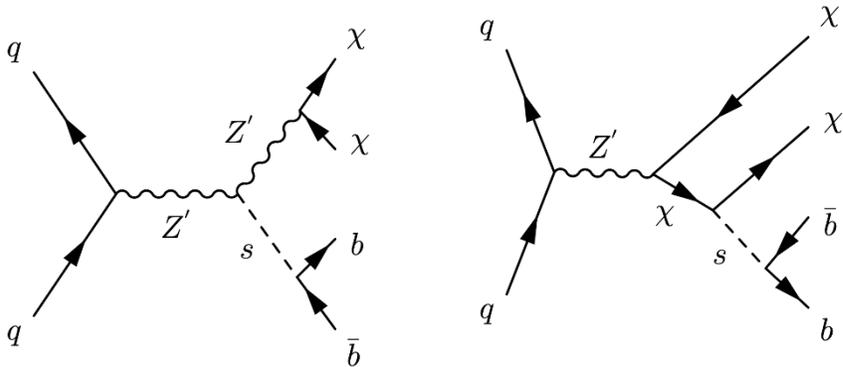LumiPublicResults#Multi_year_summary_proton_proton

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/
LuminosityPublicResultsRun3

https://hilumilhc.web.cern.ch/content/hl-lhc-project Jan 2025

Acknowledgements

16

Backup

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- 1- and 2μ CR for V+jets modeling➜Simultaneous ML fit to m_{bb} (SR) or event yields (CR)

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