HH and Scalar+H resonant searches at the HL-LHC

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Lepton-Photon 2025

On behalf of the CMS Collaboration

28 August 2025

Outline

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- HL-LHC Projection Methodology
- $X \rightarrow HH$ Projections, Results, Exclusions
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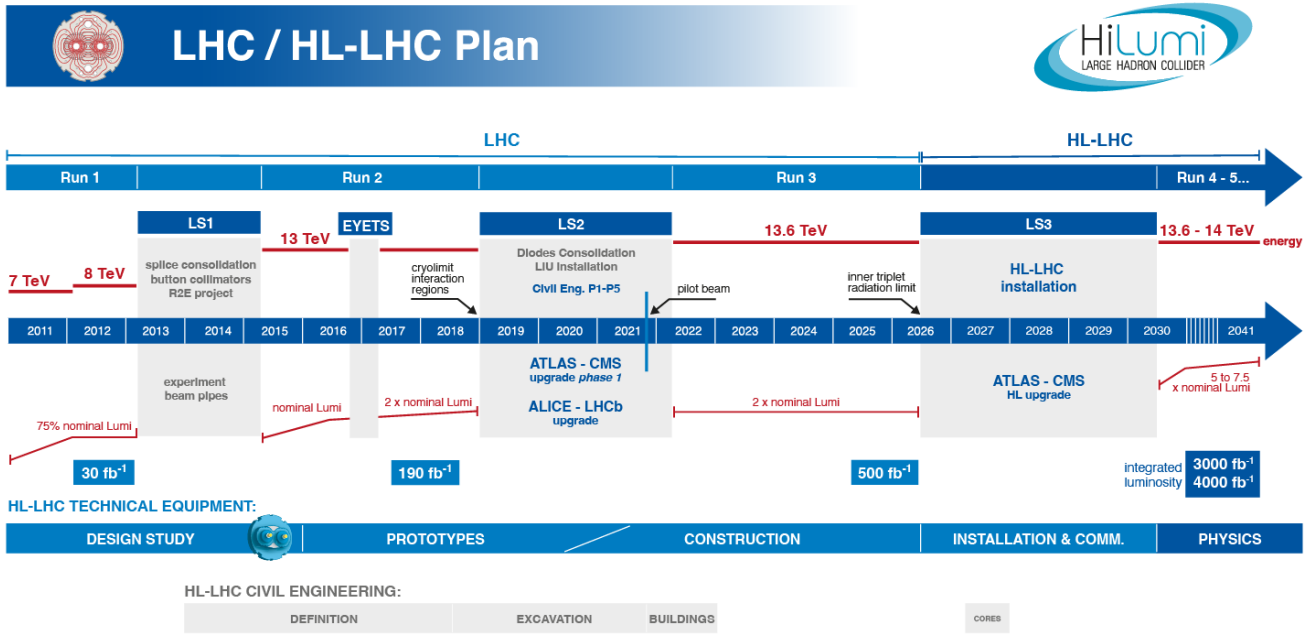
- Summary

High Luminosity LHC (HL-LHC)

- HL-LHC baseline (ultimate) stats
  - 14 TeV center-of-mass energy
  - 140 (200) pile up
  - 3000fb-1 (4000fb-1) integrated luminosity over lifetime

- Many upgrades across CMS to prepare for HL-LHC
  - Major improvements to online and offline event reconstruction software to exploit upgraded detector abilities

- As X to HH or YH are among the most relevant searches at the HL-LHC, projection studies are important to —
  - Motivate ongoing hardware and software upgrade
  - Provide an estimate of sensitivity to relevant BSM theories that can be achieved with the HL-LHC

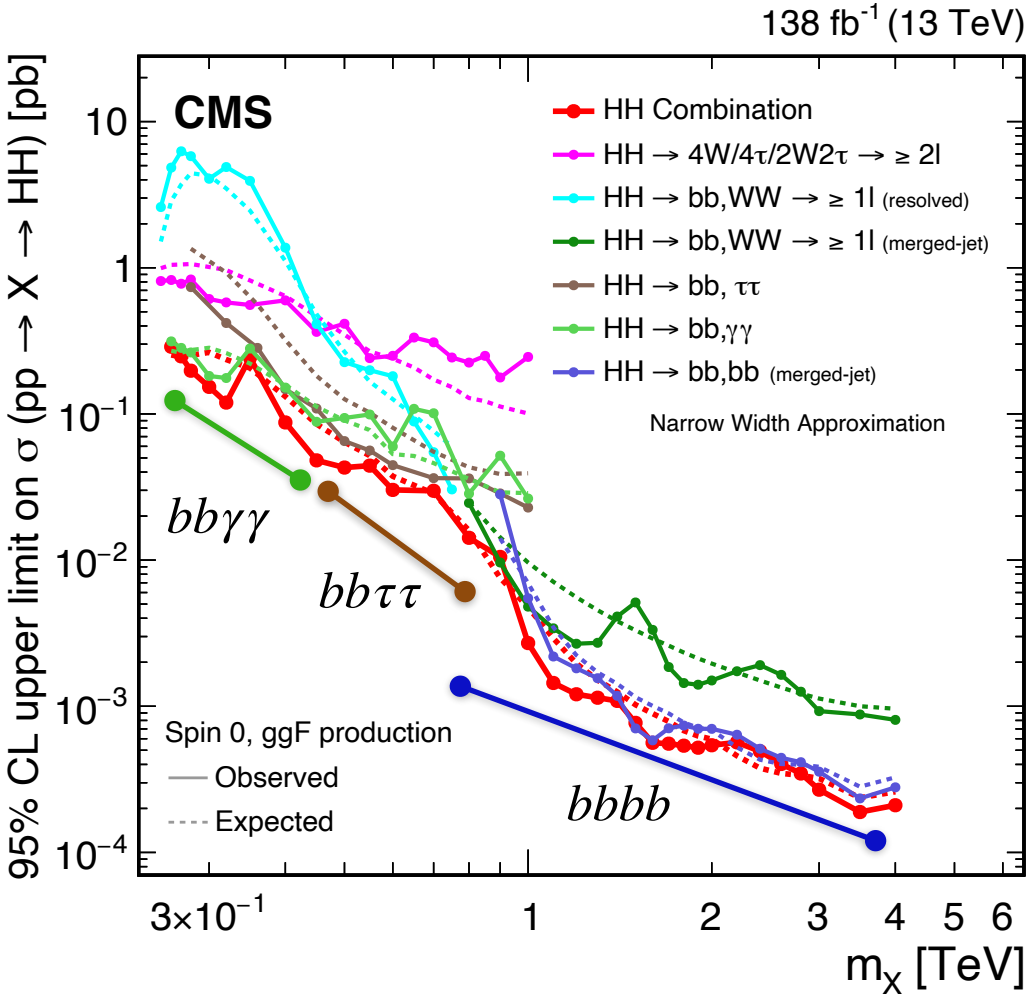


HL-LHC Projection Methodology

TEXAS A&M UNIVERSITY

- Using the most sensitive CMS Run 2 channels ($bb\gamma\gamma$, $bb\tau\tau$, and $bbbb$), HL-LHC Projections are made
  - Projected to an integrated luminosity of 3000fb^{-1}
  - Signal cross sections are scaled to center-of-mass energy of 14 TeV

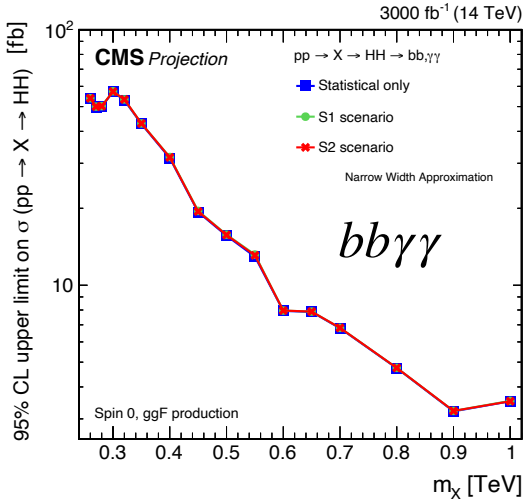
- Upgraded CMS detector is assumed to have comparable efficiency and resolution on physics objects as Run 2
  - Experimental sensitivity for HL-LHC is derived in 3 scenarios
    - All systematic uncertainties are assumed to be the same as Run 2 (conservative)
    - Theory uncertainties are halved, while experimental uncertainties are set according to [CERN Yellow Report 2019-007]
    - Statistical uncertainties only

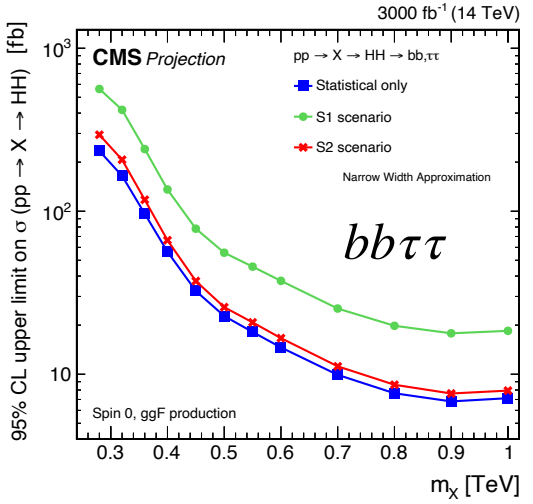


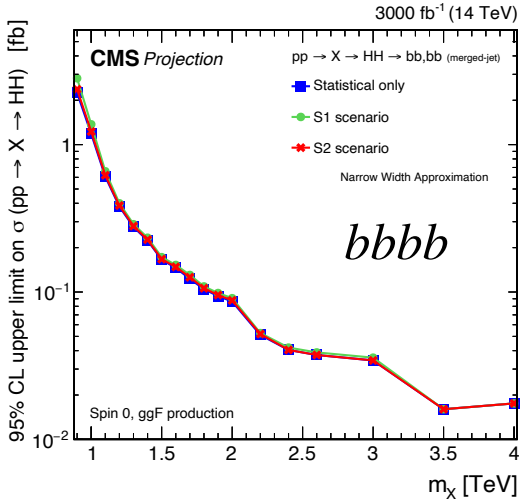
$X \rightarrow HH$ Projections

- 3 channels considered are projected to 3000fb^{-1} and showed with 3 systematic uncertainty scenarios

- $HH \rightarrow bb\gamma\gamma$
  - Overall impact of systematic uncertainties is below 1% due to small uncertainty on the background modeling
- $HH \rightarrow bb\tau\tau$
  - Largest S1 (Run 2 uncertainties) impact due to limited size in MC simulation used for background estimation
  - Largest S2 (CERN Yellow Report uncertainties) impact due to efficiencies of b-jet and τ identification and misidentification
- $HH \rightarrow bbbb$ boosted
  - Overall impact of uncertainties is small as analysis is limited by statistical uncertainty in data

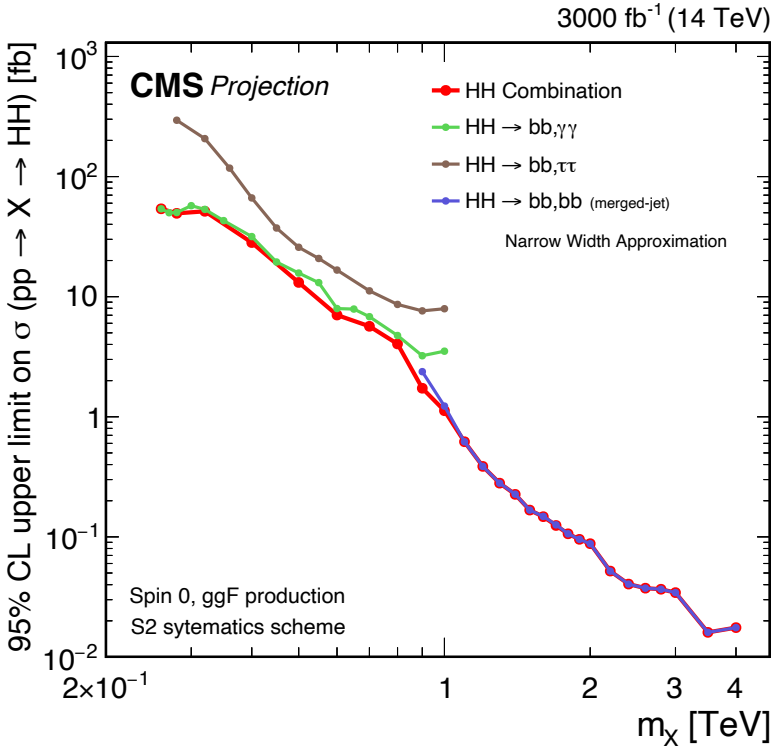


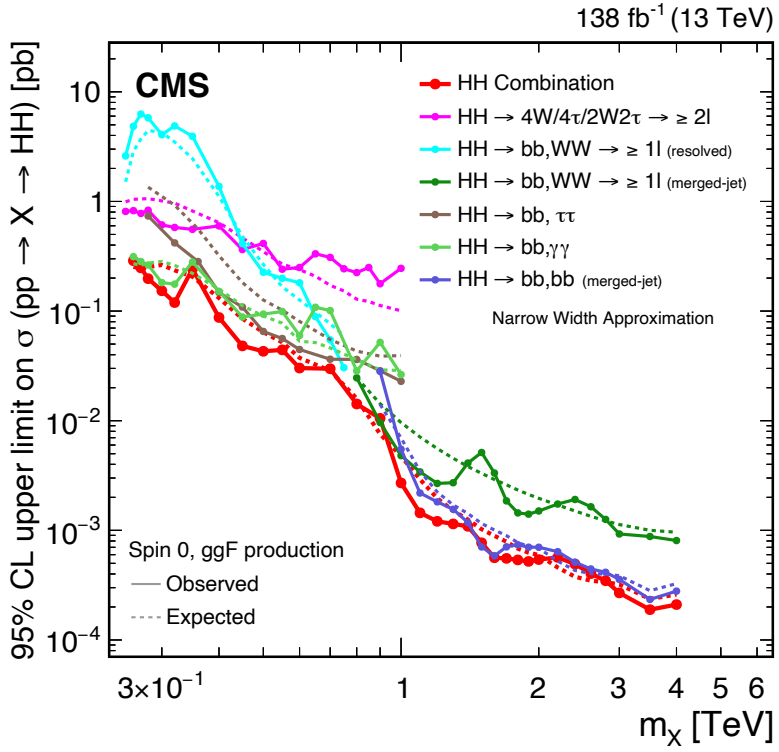




$X \rightarrow HH$ Combination

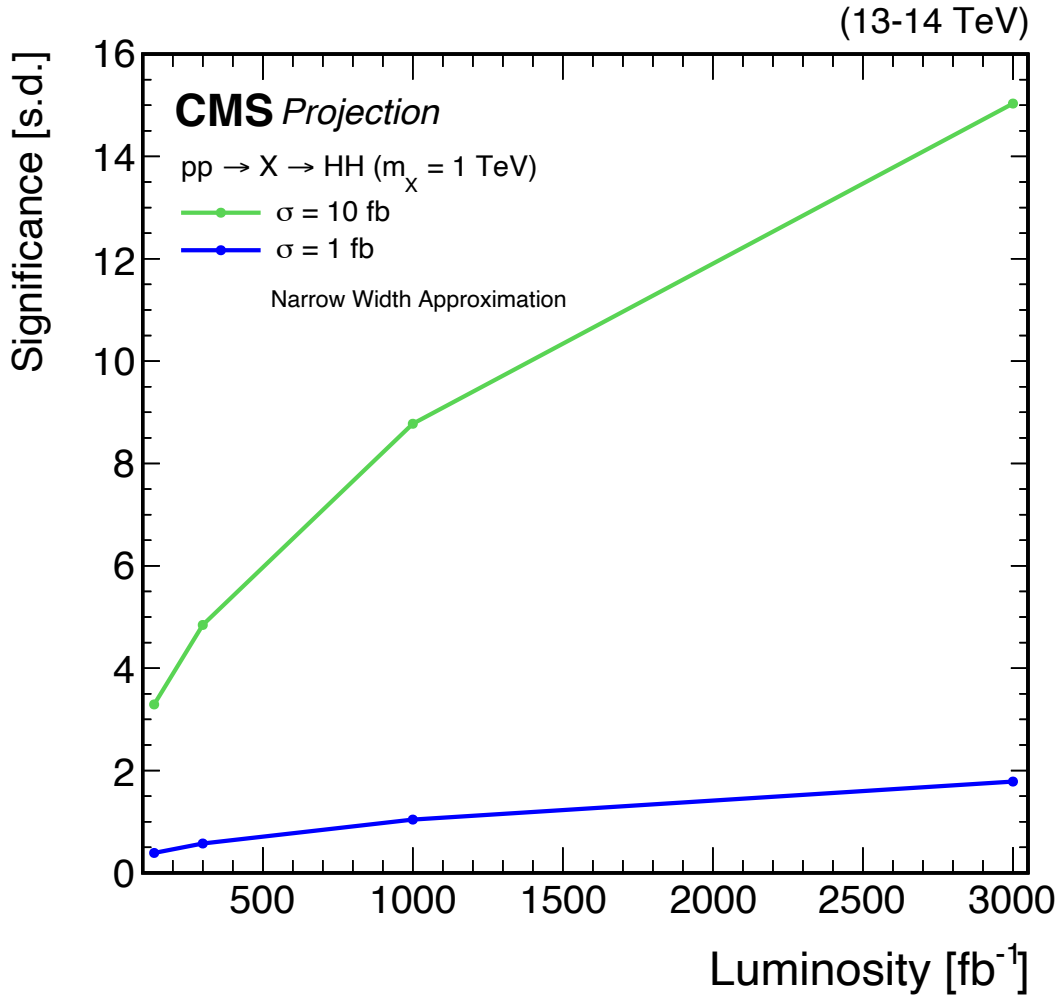
- Combination of HL-LHC Projections
  - Low mass combination dominated by $bb\gamma\gamma$ channel
  - High mass only considers $bbbb$ channel
  - Due to both having low impact from systematic uncertainties, differences between 3 scenarios are small
- Comparison to Run 2 Upper Limits
  - HL-LHC Combination sets upper limits between 50 fb and 0.02 fb
  - Run 2 Combination sets upper limits between 200 fb and 0.2 fb





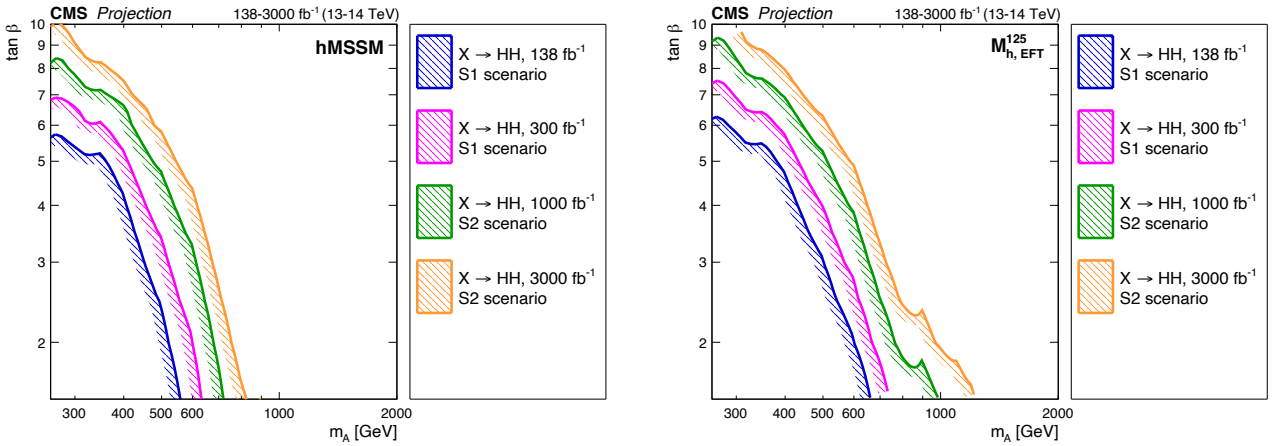
$X \rightarrow HH$ Discovery Significance

- Expected significance for the discovery for a X with mass 1TeV with two different cross sections is shown as a function of integrated luminosity
  - Based on 3 channels considered, projection shows a resonance with cross section of 10fb would yield 4.8 standard deviations at 300fb^{-1}, indicating possible with the combination of Run 3 and Run 2
  - A cross section of 3fb would reach 5 standard deviations with 3000fb^{-1}

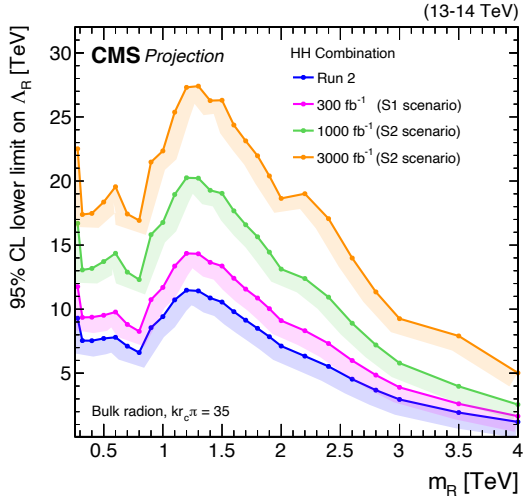


$X \rightarrow HH$ Model Exclusion Zones

- As integrated luminosity increases, we project the exclusion changes of 3 models
  - Minimal Super Symmetric Model, Warped Extra Dimensions bulk, Singlet
  - Checked at 300fb^{-1}, 1000fb^{-1}, 3000fb^{-1}
  - Run 2 uncertainty scenario is used for Run 2 and 300fb^{-1} results
  - HL uncertainty scenario is used for 1000fb^{-1} and 3000fb^{-1} results



- Minimal Super Symmetric Model
  - hMSSM model and $M_{h,\text{EFT}}^{125}$ benchmark
  - Exclusion contours in the $(\tan\beta, m_A)$ plane
- Warped Extra Dimensions Bulk Scenario
  - Lower limit on the bulk radion ultraviolet cutoff parameter (Λ_R)
  - Exclusion contours in the (Λ_R, m_R) plane



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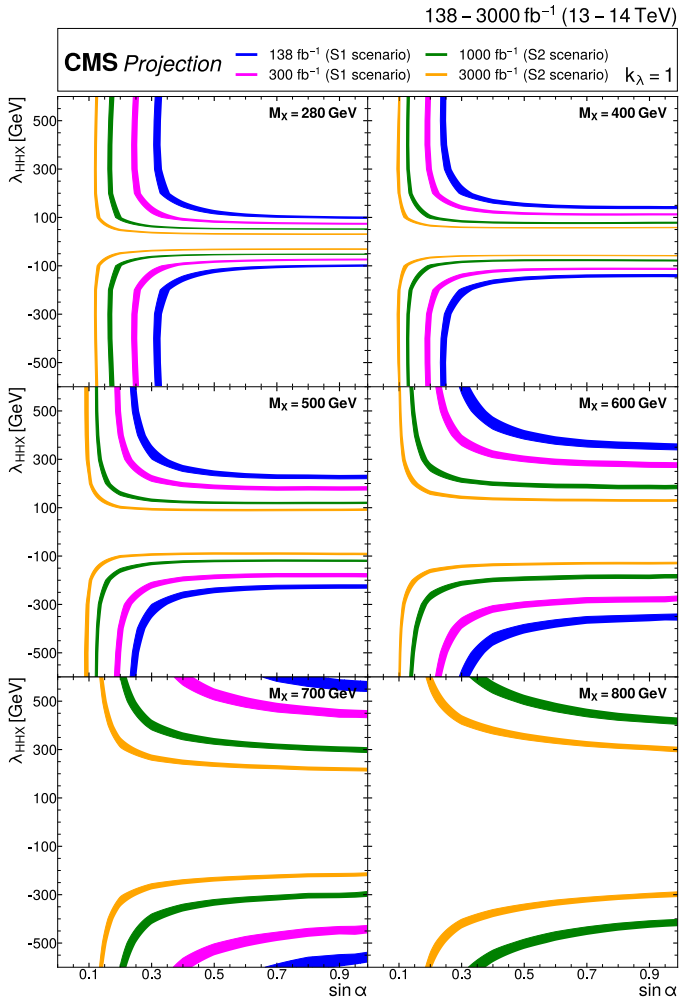
  - HL uncertainty scenario is used for 1000fb^{-1} and 3000fb^{-1} results

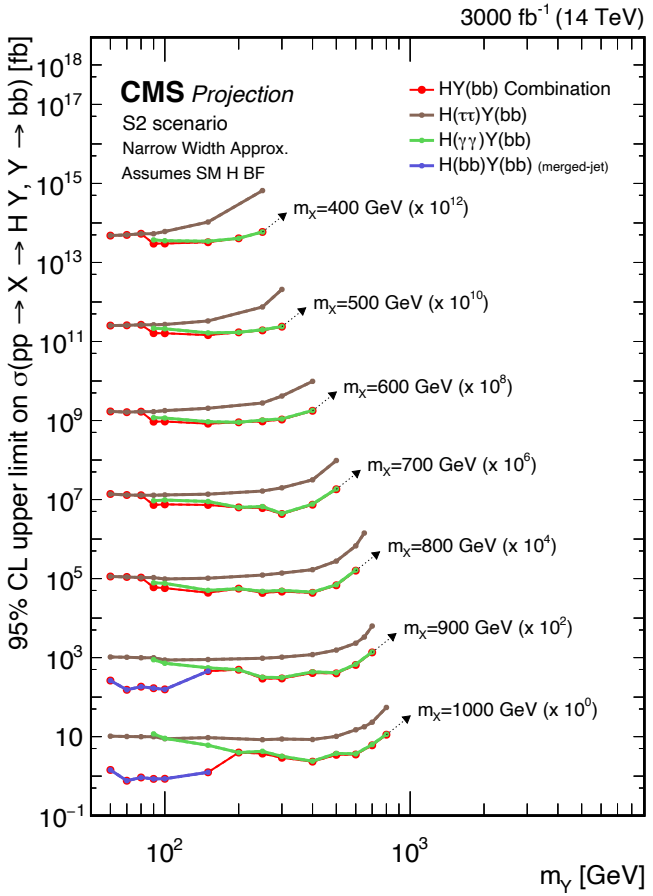
- Singlet Scenario
  - $k_\lambda = 1$ real-singlet model
  - Exclusion contours in the $(\lambda_{HHX}, \sin\alpha)$ plane

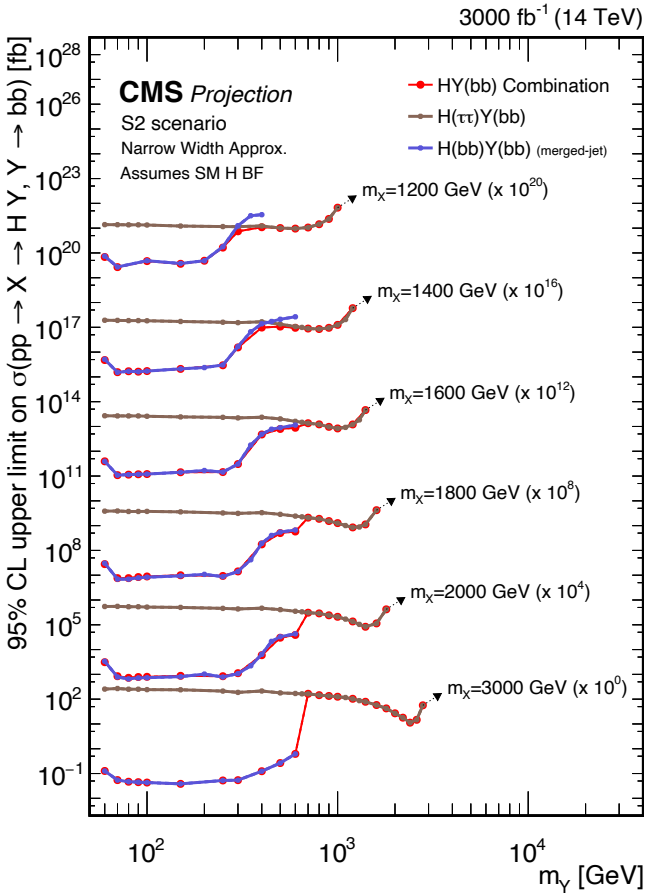


$X \rightarrow YH$ Projections

- Similarly, the same 3 channels are shown and projected to 3000fb^{-1}
  - Uncertainty scenarios are similar to results from $X \rightarrow HH$ projections
  - With $X \rightarrow YH$ we create a more dynamic phase space for channel behavior

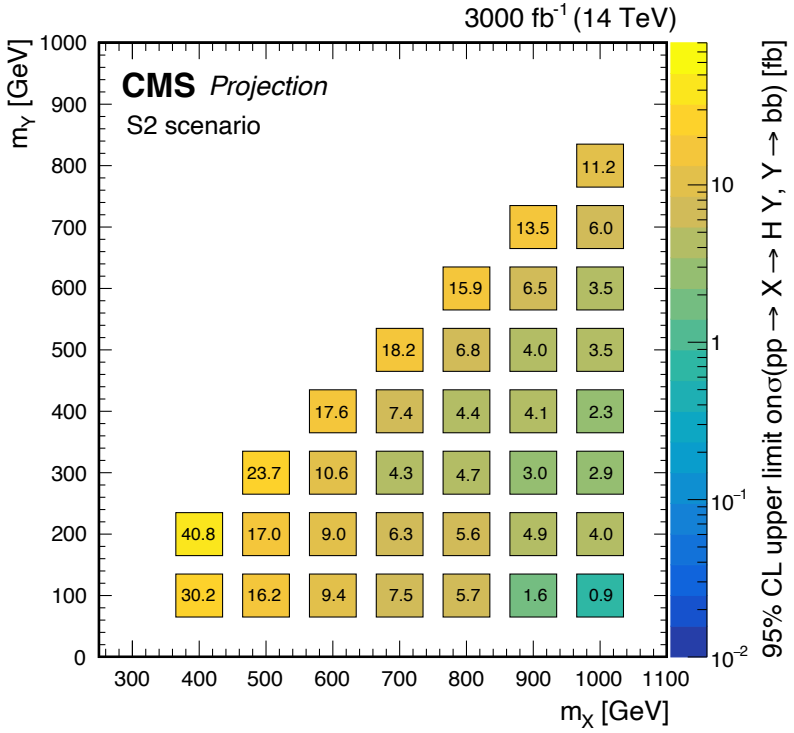
- $YH \rightarrow bb\gamma\gamma$
  - Useful to probe phase space with large m_Y/m_X as Y particle has low transverse momentum
- $YH \rightarrow bb\tau\tau$
  - Intermediate m_Y/m_X region shows comparable sensitivity with $bb\gamma\gamma$ and equal weight in the combination
- $YH \rightarrow bbbb$ boosted
  - Useful to probe phase space with small m_Y/m_X as Y particle receives a large Lorentz boost, utilizing boosted $bbbb$ topology of the merged jet

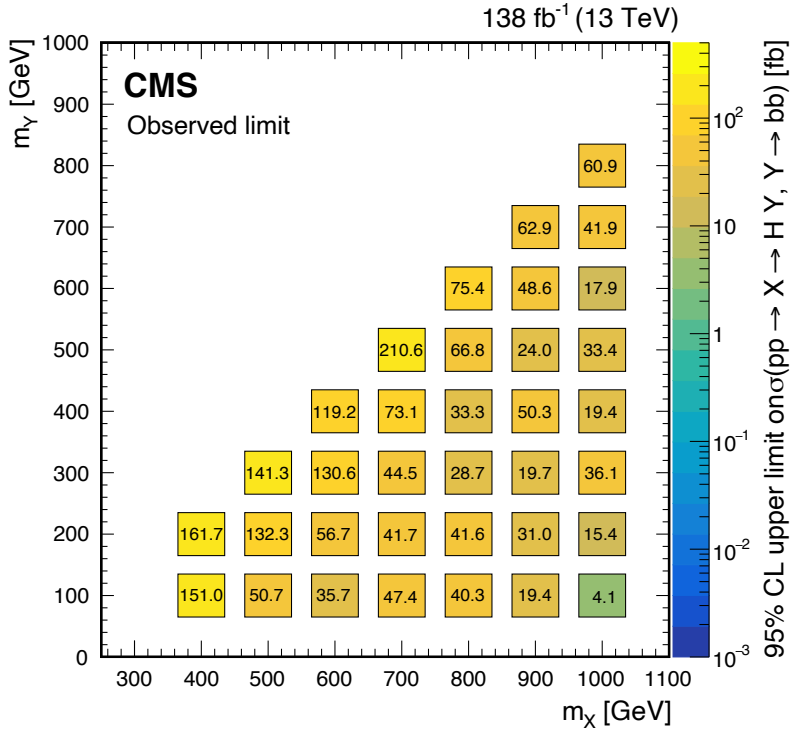




$X \rightarrow YH$ Combination

- Selected bins from the YH phase space are used to display the upper limits compared to Run 2
  - Improvement is clear compared to Run 2 combination

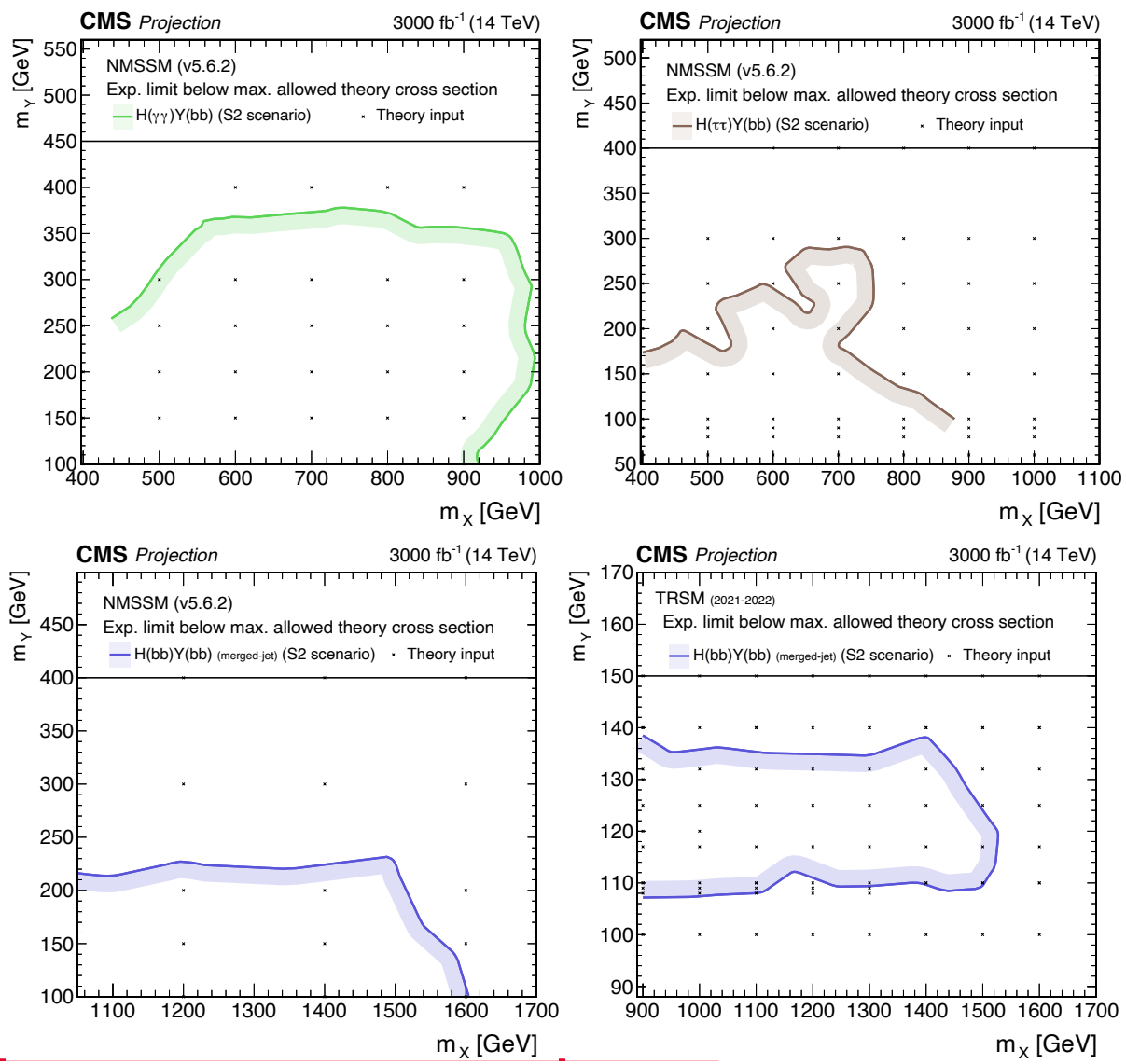




$X \rightarrow YH$ Model Exclusion Zones

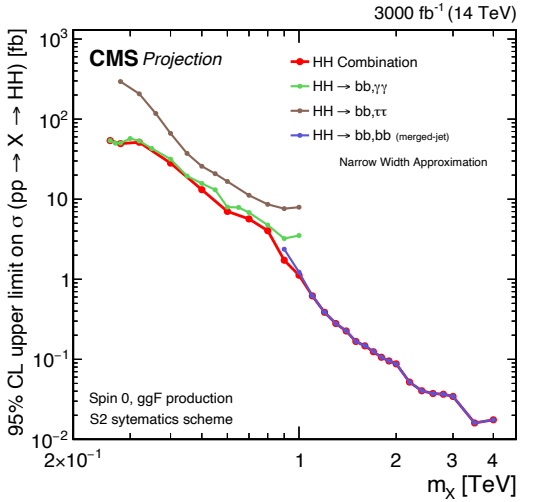
- Next-to Minimal Super Symmetric Model
  - Compare maximally allowed cross sections with the projections from 3000fb^{-1}
  - Projections show large exclusion area
    - $Y(bb)H(\gamma\gamma)$ —
      $500 < m_X < 1000\text{GeV}$
      $100 < m_Y < 350\text{GeV}$
    - $Y(bb)H(bb)$ —
      $1100 < m_X < 1500\text{GeV}$
      $m_Y < 200\text{GeV}$

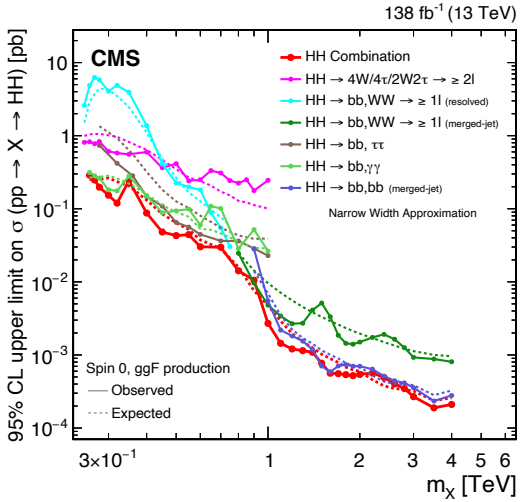
- Two Real Singlet Model (TRSM)
  - Similarly compare maximally allowed cross section to projections
  - $Y(bb)H(bb)$ —
    $900 < m_X < 1500\text{GeV}$
    $110 < m_Y < 135\text{GeV}$

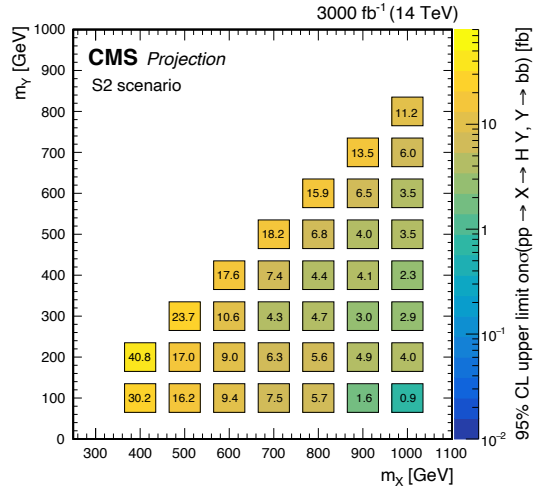


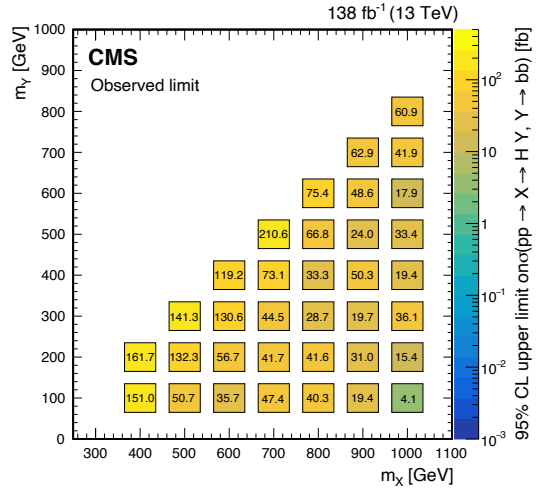
Summary

- Shown HH and YH projected results with datasets of size 300, 1000, and 3000fb^{-1}
  - 3000fb^{-1} corresponding to the baseline HL-LHC scenario over its lifetime
- Combination of projections show upper limits of X range from 50fb at M_X 250GeV to nearly 0.01fb at M_X 4TeV
- $X \rightarrow HH$ exclusion zones are shown for the MSSM, WED, and Singlet models at 4 working points for integrated luminosity
- $X \rightarrow YH$ exclusion zones are shown for the NMSSM and TRSM models compared to their maximally allowed cross sections
- Overall HL-LHC projections show strong results in all 3 channels investigated









Backup

https://www.sciencedirect.com/science/article/pii/S0370157324003223?via=ihub