High mass Higgs boson searches at CMS

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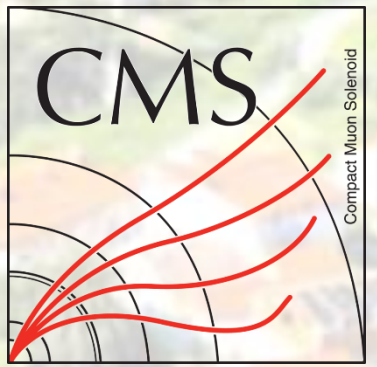
On behalf of the CMS Collaboration



LHC Days 2024

30/09/2024

Introduction

Why search for new high mass Higgs bosons?

The Standard Model does not explain everything

- The asymmetry between matter and anti-matter
- The gravitational interaction
- Dark matter and dark energy
- The neutrino oscillation

Is there a solution to fix these issues?

Models including theories with extended Higgs sectors proposing heavy scalar particles

- Minimal Super-symmetry Standard Model (MSSM): two-Higgs-doublet models (2HDM)
- Next-to-minimal extensions (NMSSM): 2HDM + Singlet, Higgs triplet, ...

This presentation covers three of the last CMS high mass Higgs boson searches

$X \rightarrow HH/YH \rightarrow \gamma\gamma\tau\tau$

CMS-PAS-HIG-22-012

- NMSSM
- Neutral scalar Higgs boson (X)

$A \rightarrow ZH \rightarrow ll\tau\tau$

CMS-PAS-HIG-22-004

- Model-independent & MSSM
- Neutral pseudoscalar Higgs boson (A)

$X \rightarrow ZZ \rightarrow 4l$

CMS-PAS-HIG-24-002

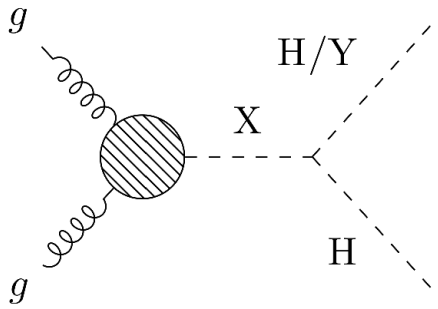
- Model-independent
- Neutral scalar Higgs boson (X)
- Golden channel

$X \rightarrow HH/YH \rightarrow \gamma\gamma\tau\tau$

Analysis Strategy

$X \rightarrow HH/YH \rightarrow \gamma\gamma\tau\tau$

Both resonant & non-resonant production modes are considered



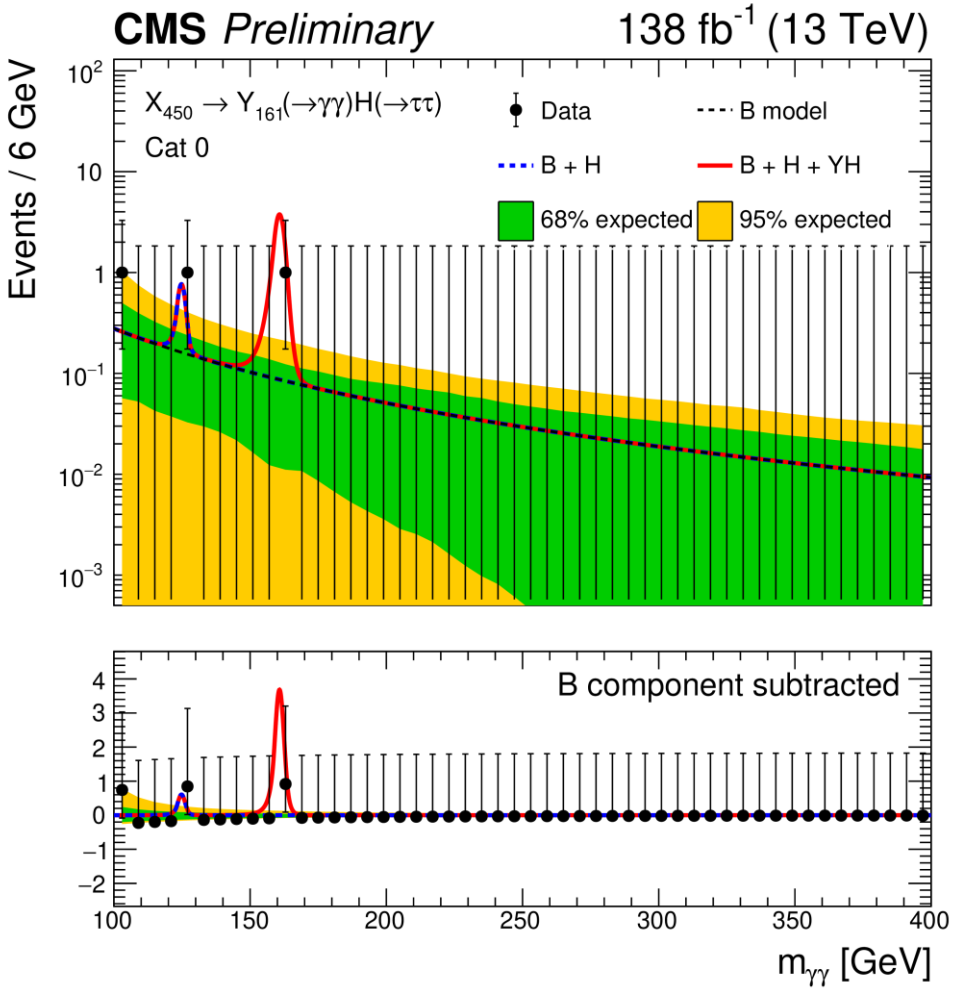
Event selection and categorization

- **Trigger:** on γγ
- **Selection:** *2 good photons, and at least 1 τ candidate*
- **Categorization:** *8 categories based on the lepton flavor*

Observable of interest: $m_{\gamma\gamma}$

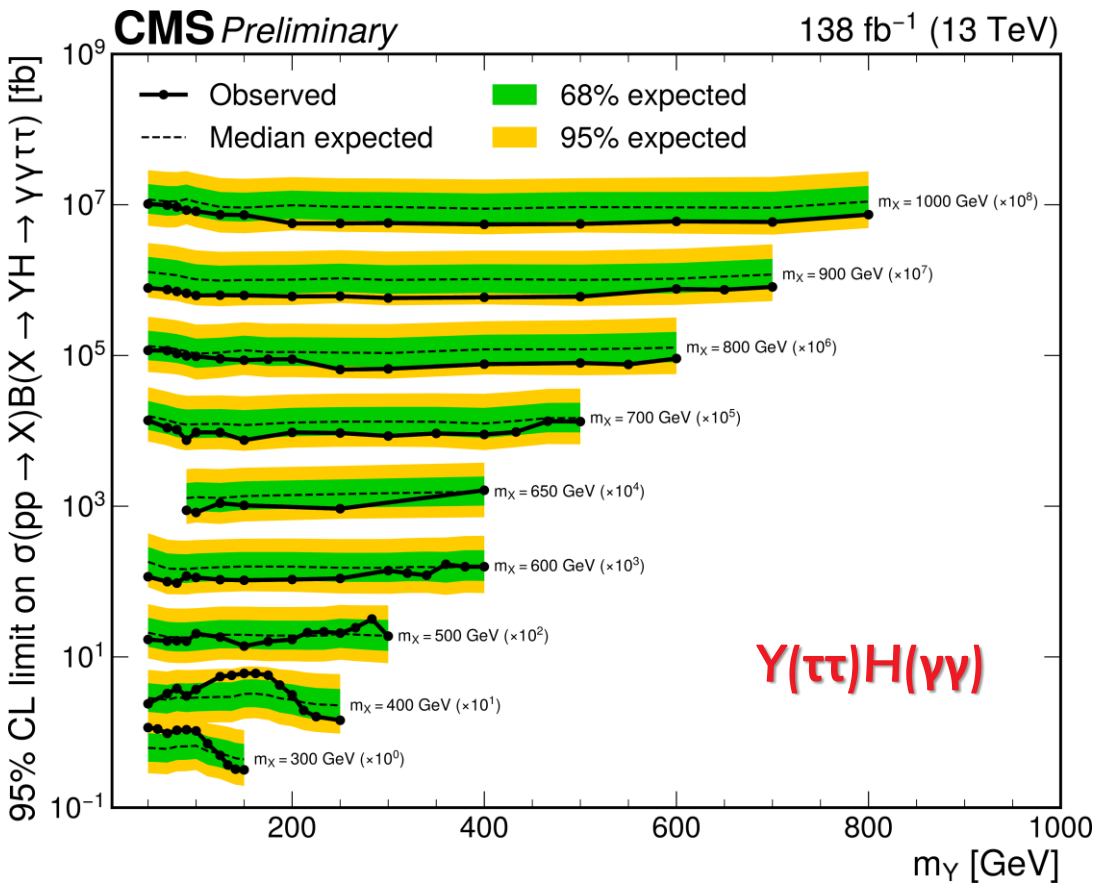
Process modelling

- Signals: double crystal ball functions (DCB) on $m_{\gamma\gamma}$
- Single Higgs boson: DCB on $m_{\gamma\gamma}$
- **Continuum backgrounds**: *smooth functions*
- **Drell-Yan (DY) background:** *ABCD method*

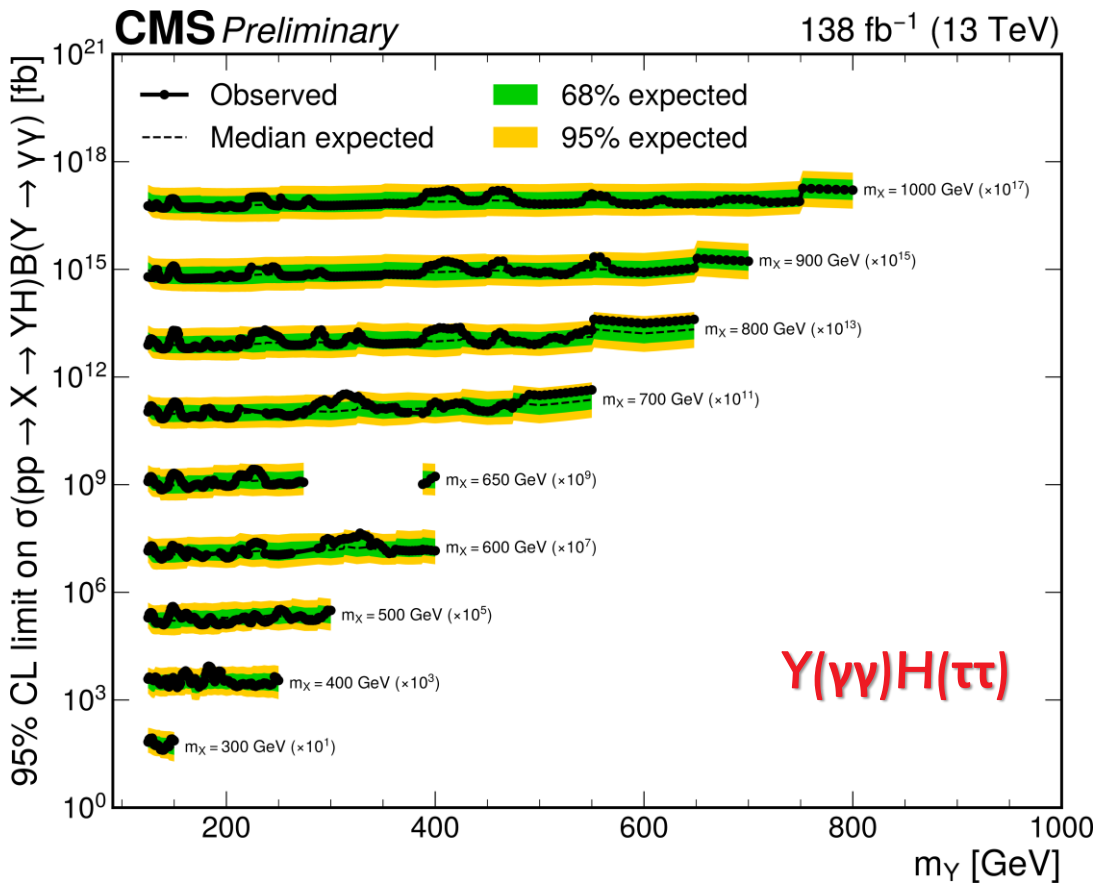


Results

$X \rightarrow HH/YH \rightarrow \gamma\gamma\tau\tau$



m_X



Highest significance at (m_X, m_Y)=(320, 60) GeV
Local: 2.6 σ
Global: 2.2 σ

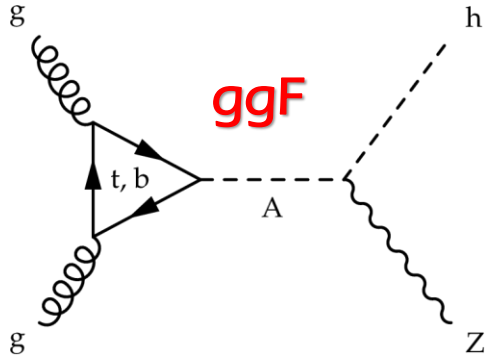
Highest significance at (m_X, m_Y)=(450, 161) GeV
Local: 3.2 σ
Global: 0.3 σ

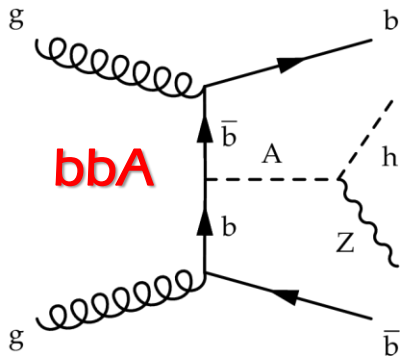
$A \rightarrow ZH \rightarrow ll\tau\tau$

Analysis Strategy

$A \rightarrow ZH \rightarrow ll\tau\tau$

Two production modes are considered:





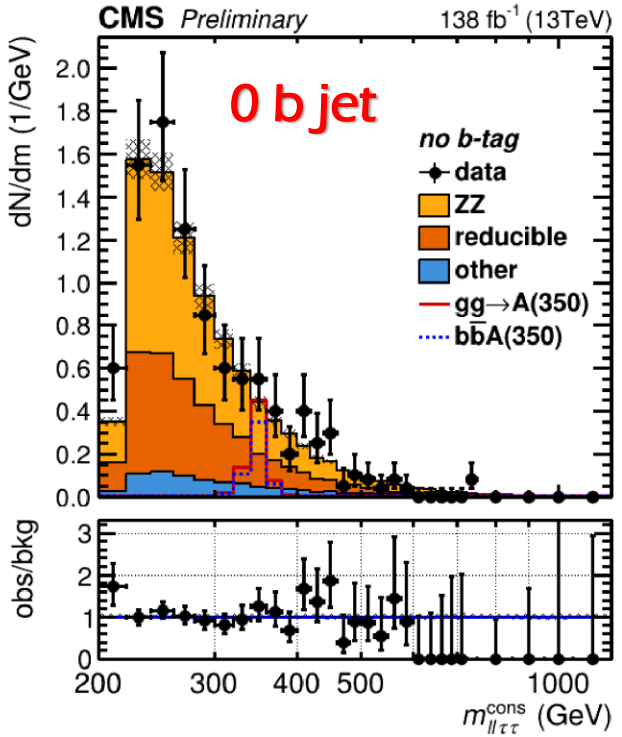
Event selection and categorization

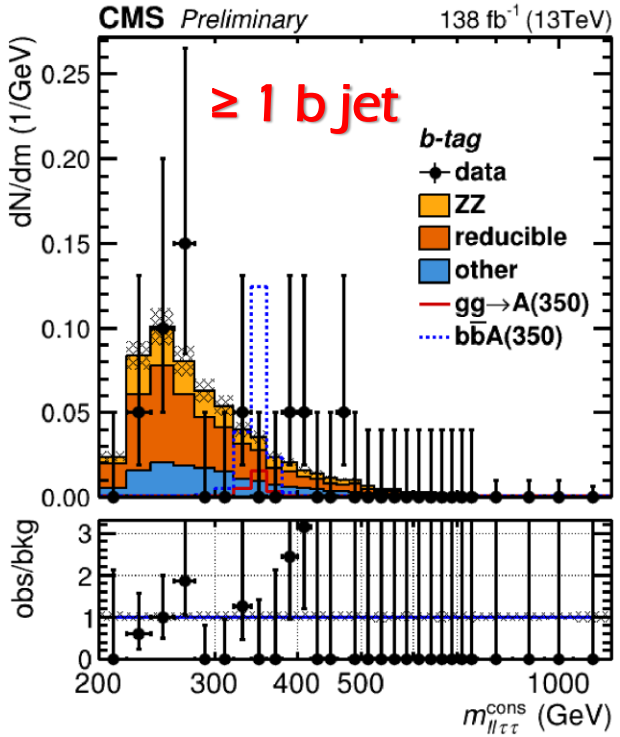
- **Trigger:** Single e/μ triggers on $Z \rightarrow ll$ (l = e/μ)
- **Selection:** Select leptons (e, μ, hadronic τ) in order to build the Z and H candidate
- **Categorization:** 2 categories

Observable of interest: $M_{ll\tau\tau}$

Process modelling

- Signals: from MC
- Irreducible backgrounds: from MC
- Reducible backgrounds: estimated from a data-driven method

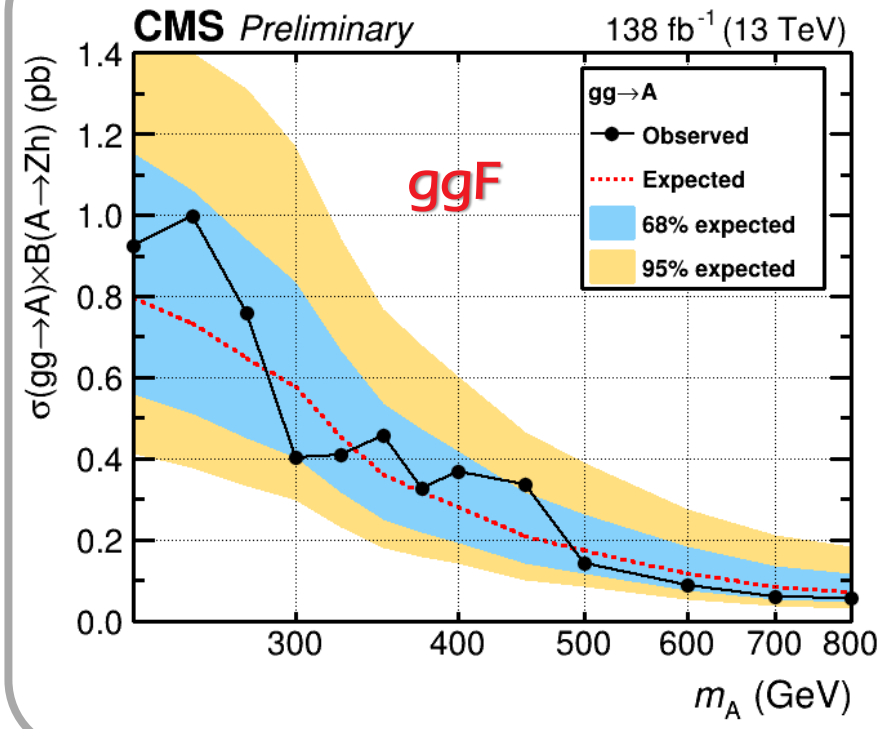


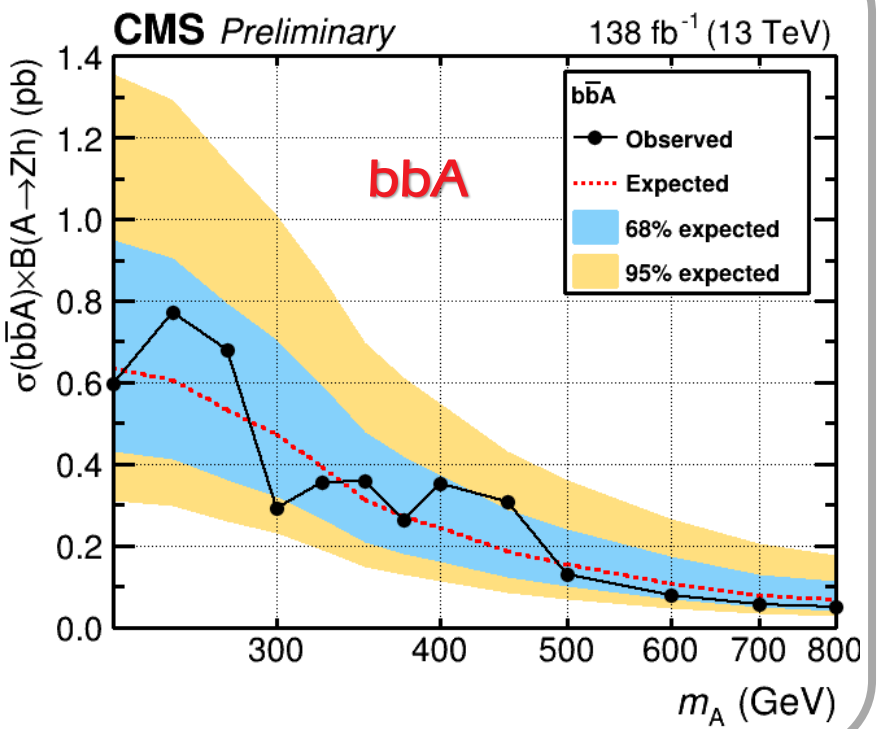


Results

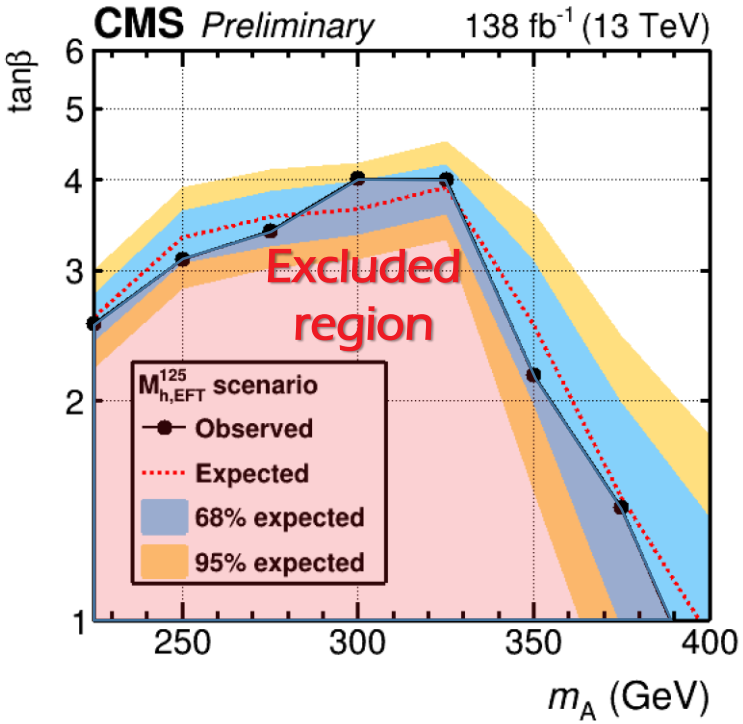
$A \rightarrow ZH \rightarrow ll\tau\tau$

Model-independent





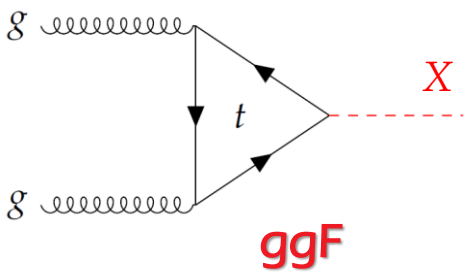
MSSM

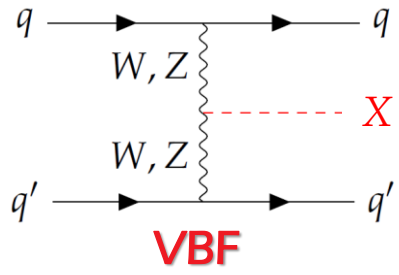


No excess observed

$$X \rightarrow ZZ \rightarrow 4l$$

Two production mechanisms are considered:





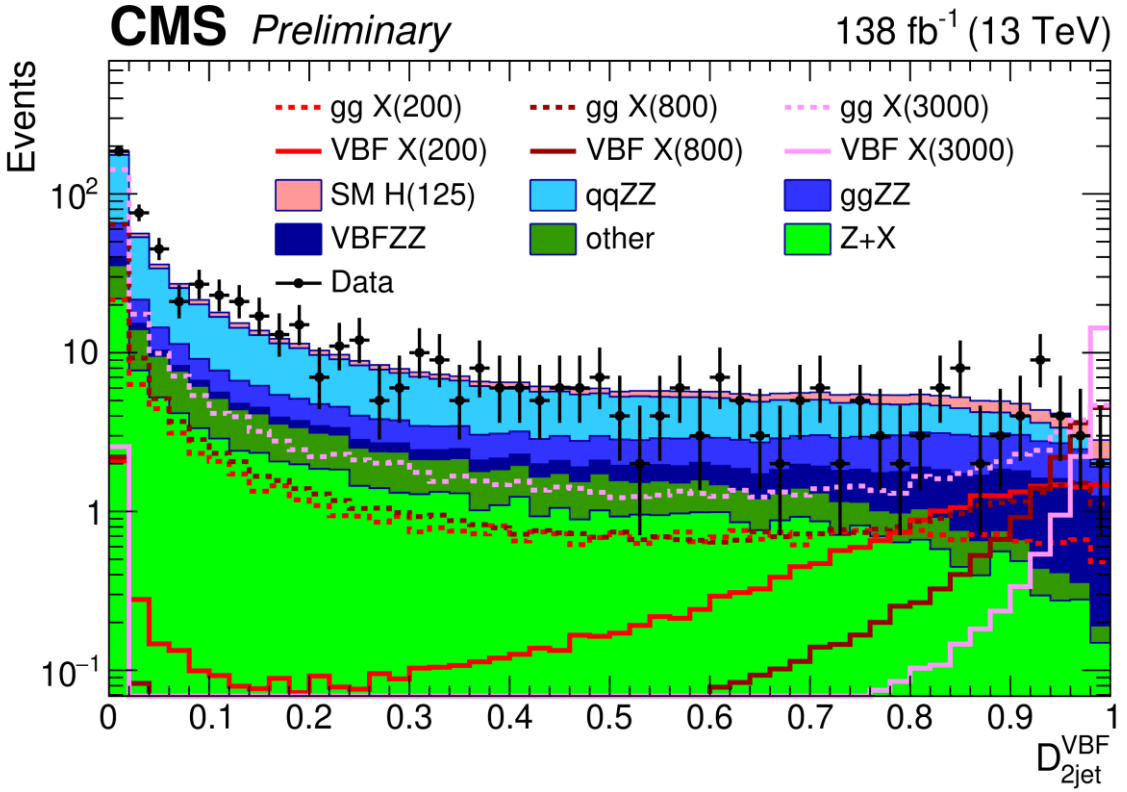
Event selection

- **Trigger:** on 1, 2 or 3 leptons
- **Selection:** e and μ in order to build Z candidates, and then the ZZ candidate

Event categorization

Two categories mutually exclusive targeting ggF and VBF based on jet kinematics and $\mathcal{D}_{2jets}^{VBF}$ computed from the Matrix Element Likelihood Approach (MELA)

$$\mathcal{D}_{2jets}^{VBF} = \left[1 + \frac{\mathcal{P}_{HJJ}(\vec{\Omega}^{H+JJ}|m_{4l})}{\mathcal{P}_{VBF}(\vec{\Omega}^{H+JJ}|m_{4l})}\right]^{-1}$$

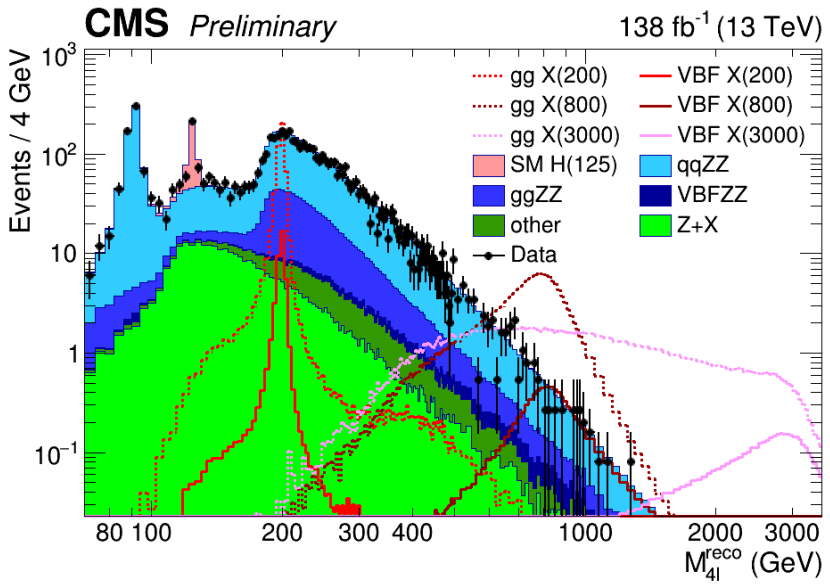


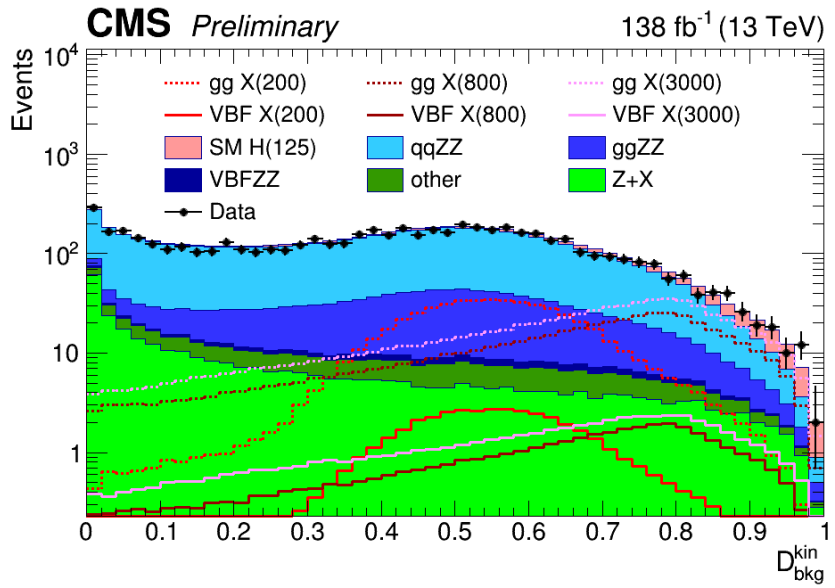
Analysis Strategy

$X \rightarrow ZZ \rightarrow 4l$

Observables of interest:
M_{4l}^{reco} and $\mathcal{D}_{bkg}^{kin}$

$$\mathcal{D}_{bkg}^{kin} = \left[1 + \frac{\mathcal{P}_{bkg}^{qq}(\vec{\Omega}^{H\to 4l}|m_{4l})}{\mathcal{P}_{sig}^{gg}(\vec{\Omega}^{H\to 4l}|m_{4l})}\right]^{-1}$$



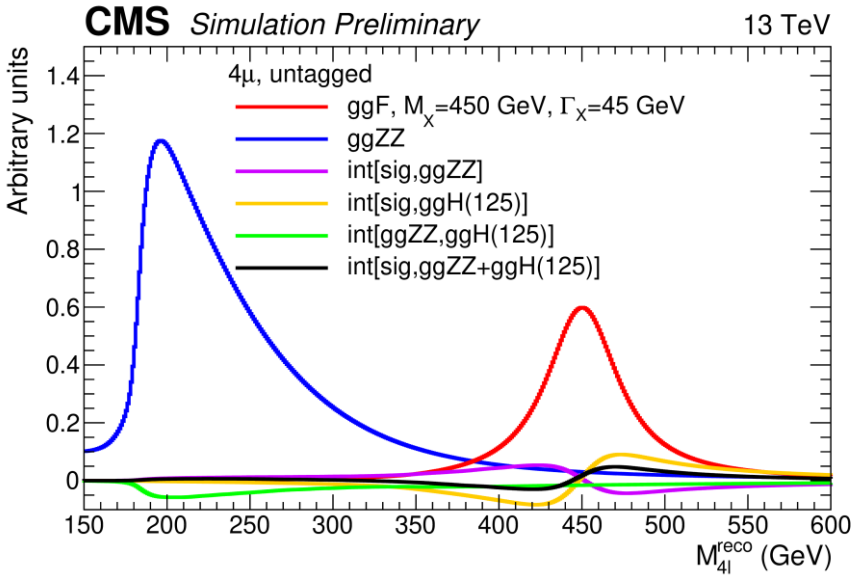


Parametric process modelling

- Signals: from MC, as a function of M_{4l}^{reco} and $\mathcal{D}_{bkg}^{kin}$, and parameterized as:

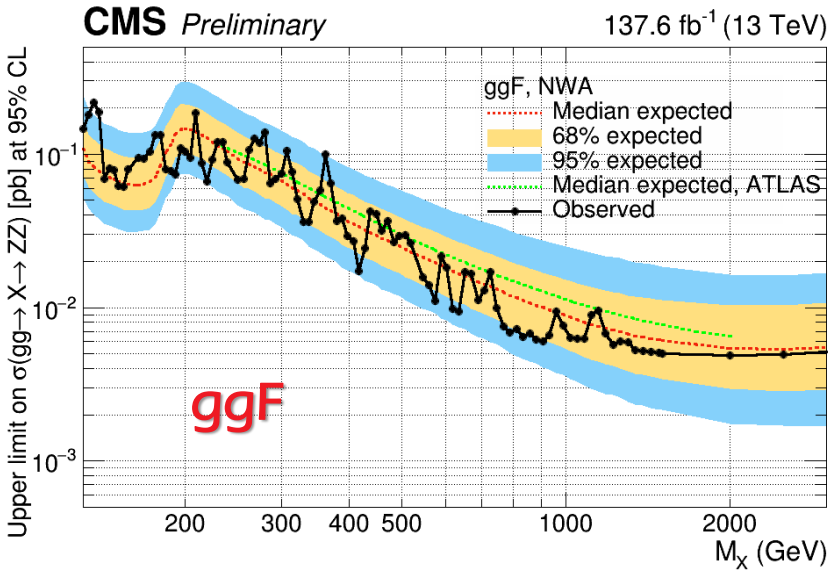
  Signal = ((analytic lineshape × efficiency) ⊗ resolution) × 2D template

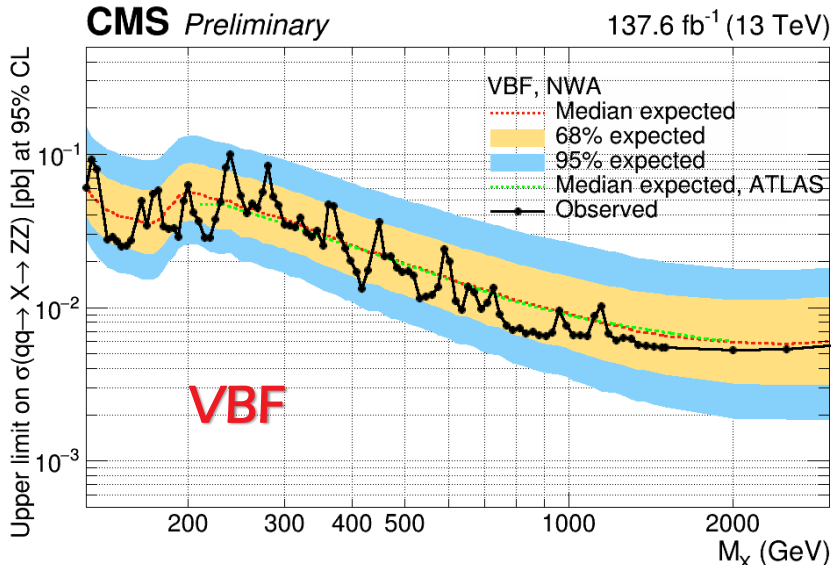
- Irreducible backgrounds: from MC
- Reducible backgrounds: from a data-driven method
- Interferences: amplitudes from signal, backgrounds; phases from generators and kinematics



Results – Narrow width

$X \rightarrow ZZ \rightarrow 4l$

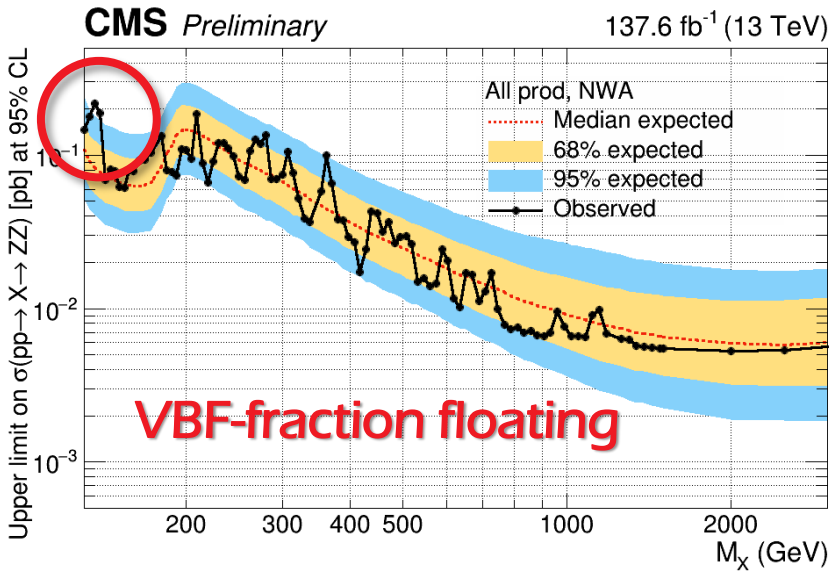


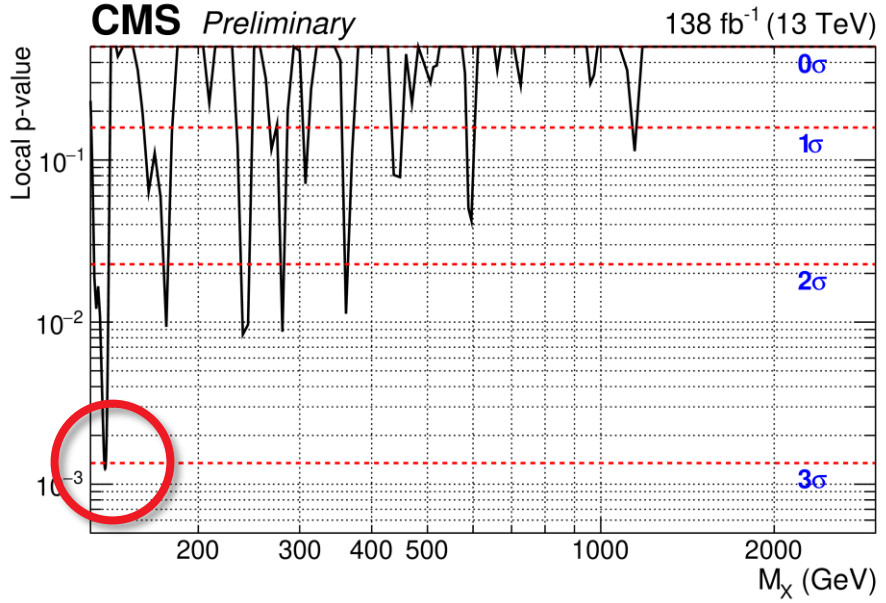


Highest significance reached at 137.8 GeV

Local: 3.02 σ

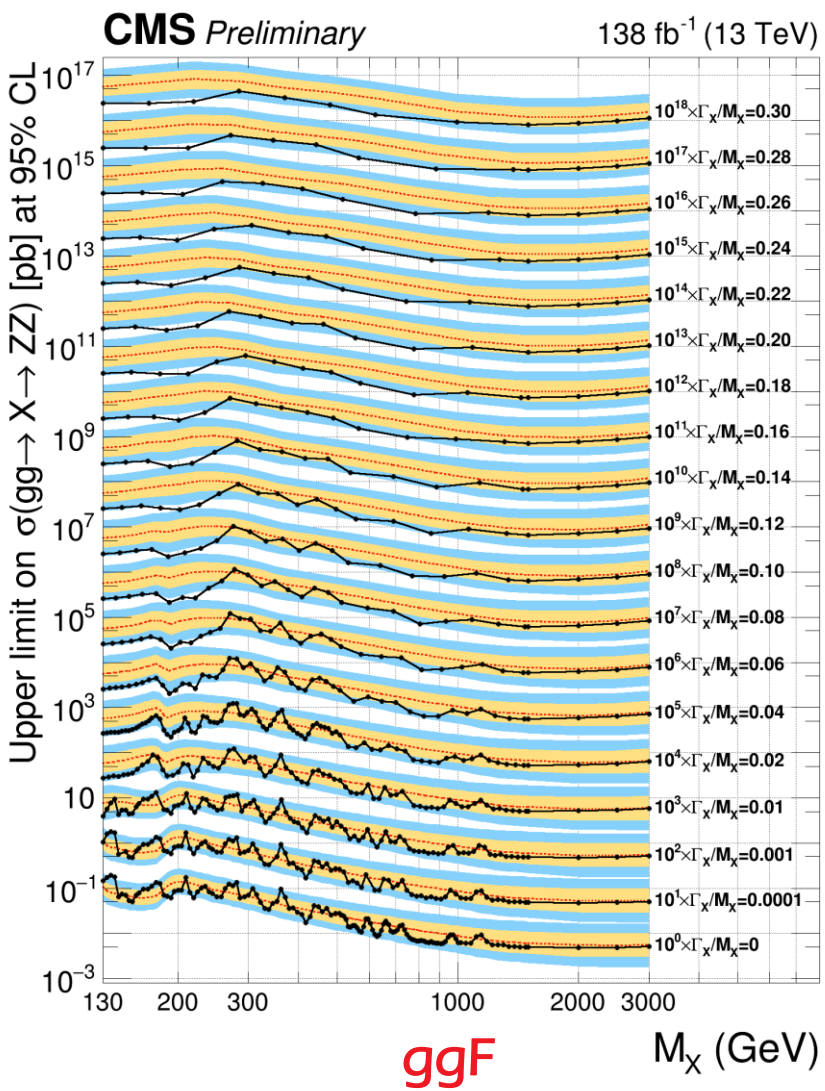
Global: 1.85 σ





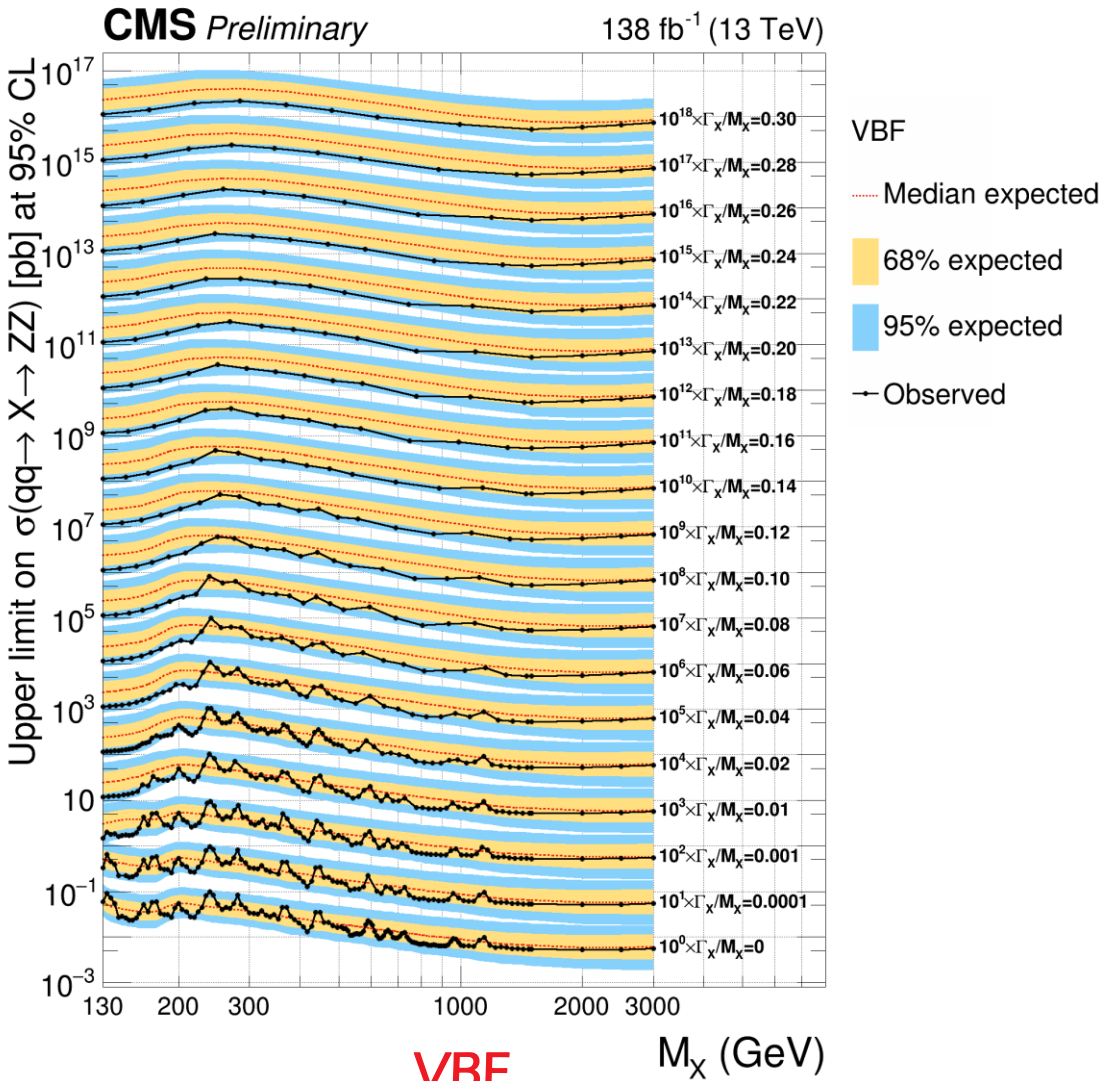
Results – Varying width

$X \rightarrow ZZ \rightarrow 4l$



ggF

$\frac{\Gamma_X}{M_X}$



VBF

No excess observed

Conclusion

Some of the last published results on searches for high mass Higgs bosons

- Scalar $X \rightarrow HH/YH \rightarrow \gamma\gamma\tau\tau$
- Pseudoscalar $A \rightarrow ZH \rightarrow ll\tau\tau$
- Scalar $X \rightarrow ZZ \rightarrow 4l$

No significant excess is observed

What can be done now?

- Some measurements can be improved with machine learning technics
- Significant improvements are expected with LHC Run 3 and HL-LHC with increased statistics

Thank you for your attention