Search for heavy scalar resonances in the 4-lepton final state at 13 TeV

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Why new resonances?

The Standard Model (SM) has weaknesses

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Theories beyond the SM (BSM) try to strengthen it

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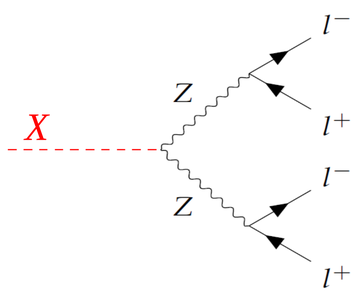
New resonances are predicted

- **Additional Higgs bosons:**
  - extended Higgs sector
  - supersymmetry
- **Radion / graviton :**
  - warped extra dimension

GOIDEN CHANNEL: ZZ→4l

- Great S/B ratio for the SM Higgs boson
- High efficiency and good resolution of e, μ
- Well modelling of the background processes



Misidentification rate of leptons measured in **Z+1 lepton** regions; applied to **Z+2 lepton** regions orthogonal to the signal region.

Data-driven method

Analysis strategy

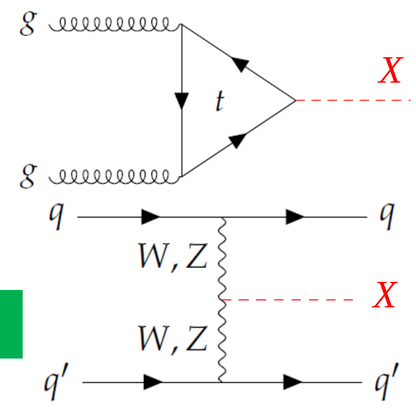
Use the **Run 2** dataset from the **CMS** detector, with $\mathcal{L} \approx 138\ \mathrm{fb}^{-1}$

Two production mechanisms:

- **gluon fusion** and **vector boson fusion**

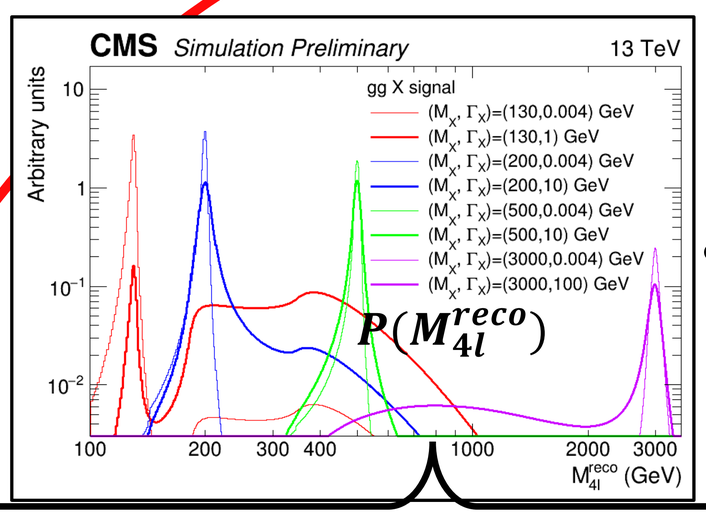
Three parameters: M_X, Γ_X, f_{VBF}

Model independent search !



Signal modeling

$$P\left(M_{4l}^{reco}, D_{bkg}^{kin}\right) =$$



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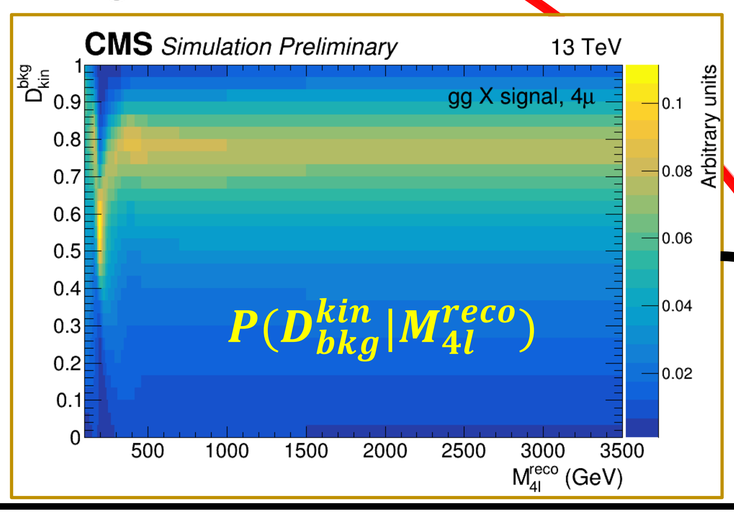

$$\left(\text{Analytical lineshape } P\left(M_{4l}^{gen}|M_X,\Gamma_X\right) = \sigma\left(M_{4l}^{gen}\right)\cdot\frac{2M_{4l}^{gen}M_X}{\left[\left(M_{4l}^{gen}\right)^2 - M_X^2\right]^2 + (M_X\Gamma_X)^2}\right) \cdot \left(\text{Signal efficiency } \mathrm{Eff}\left(M_{4l}^{gen}\right) = \frac{\text{selected events}}{\text{generated events}}\right) \otimes \left(\text{Mass resolution } R\left(M_{4l}^{reco}|M_{4l}^{gen}\right) \text{ Double crystal ball function}\right)$$

Trigger selection: single/double/triple-lepton

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Event selection:
4 leptons with ID and ISO
2 Z boson candidates
1 ZZ candidate
3 final state: **4μ, 4e, 2e2μ**

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Categorization:
ggF, VBF categories based on the VBF Jets and D_{2jet}^{VBF}

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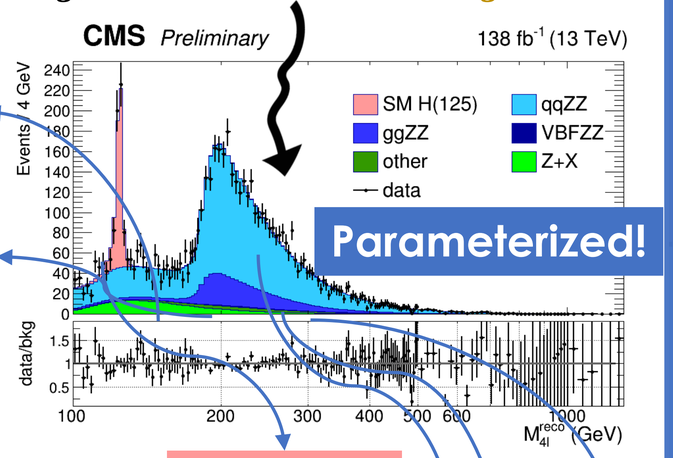
Matrix Element Likelihood Approach (MELA): provide kinematic discriminants: D_{bkg}^{kin}, D_{2jet}^{VBF}

Background modeling

$$P\left(M_{4l}^{reco}, D_{bkg}^{kin}\right) = P(M_{4l}^{reco}) \cdot P(D_{bkg}^{kin}|M_{4l}^{reco})$$



Parameterized!

MC

The same approach as signals

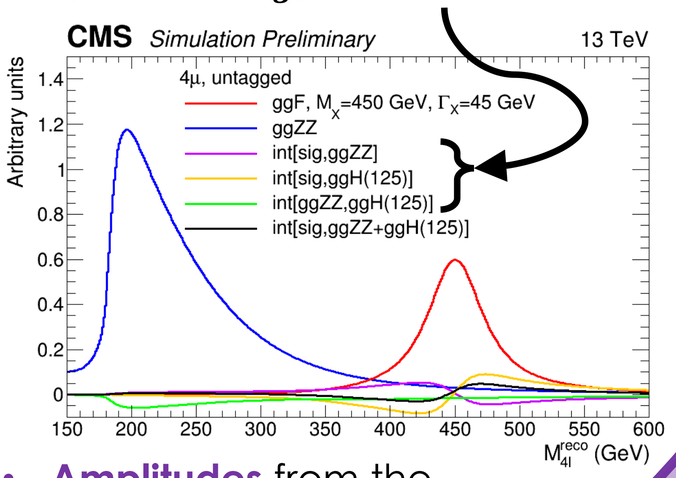
MC

MC

MC

Interference modeling

$$P\left(M_{4l}^{reco}, D_{bkg}^{kin}\right) = P(M_{4l}^{reco}) \cdot P(D_{bkg}^{kin}|M_{4l}^{reco})$$



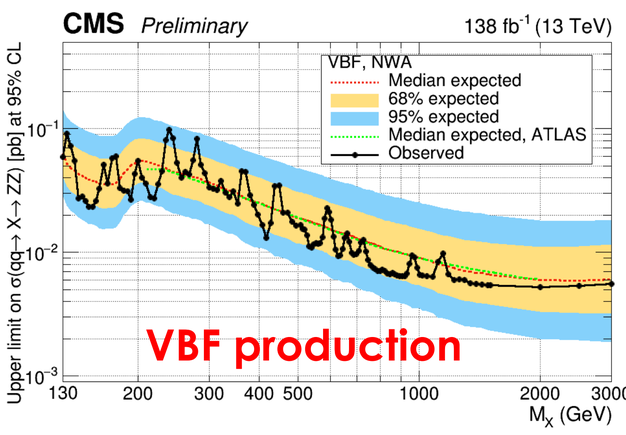
- **Amplitudes** from the interferencing processes
- **Phases** from kinematics and generators

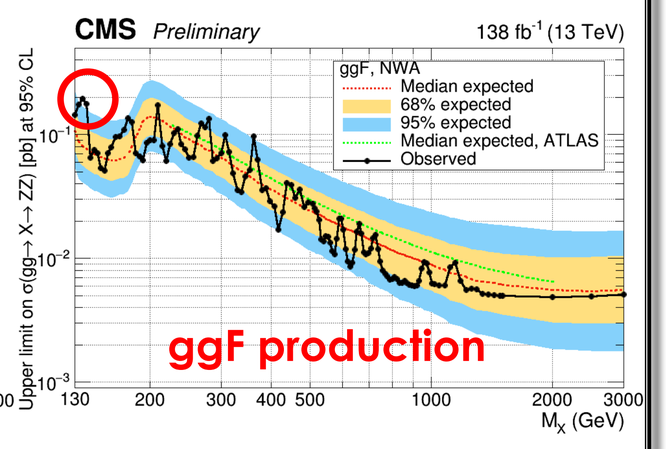
Results

Statistical methods

- Extended unbinned likelihood fit
- Systematic uncertainties as nuisance parameters
- Upper limits of the cross section of $pp \to X \to ZZ$ as a function of M_X, Γ_X, f_{VBF}

Narrow width assumption



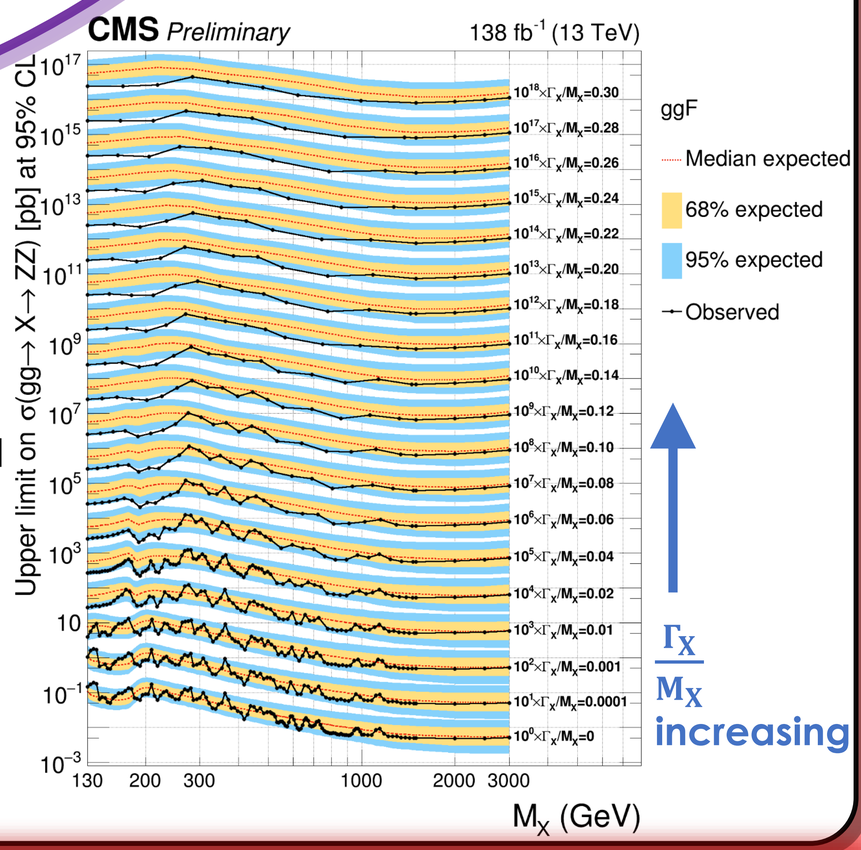


- Observed results mostly within the ±1 standard deviation band.
- Excess at around **138 GeV**: **local 3.02 σ; global 1.85 σ**
- Competitive with the ATLAS results !

Various width assumptions

- Scan not just M_X but also Γ_X/M_X.
- Γ_X/M_X from 0 to 30%

ggF production



- Up and down cross of data at low widths.
- Get smeared and flattened as the width increases.
- **No additional excess observed.**

Conclusion

Based on 138 fb^{-1} data collected by the CMS detector, searches for scalar resonances decaying to four leptons presented. No significant excess is observed, and upper limits on the cross section are computed within a large phase space.