UCLouvain

Higgs21

Searches for resonant and non-resonant Higgs boson pair production in the four bottom quark final state at 13 TeV

Angela Taliercio on behalf of **CMS collaboration**

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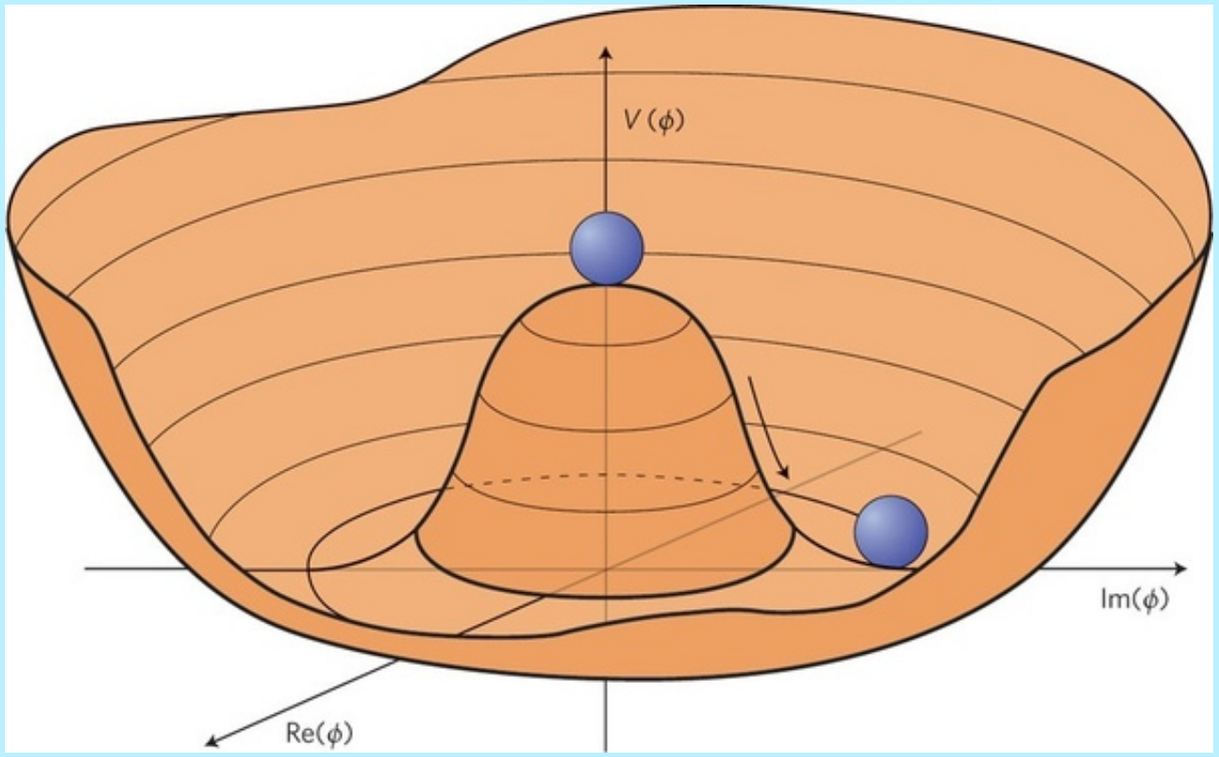
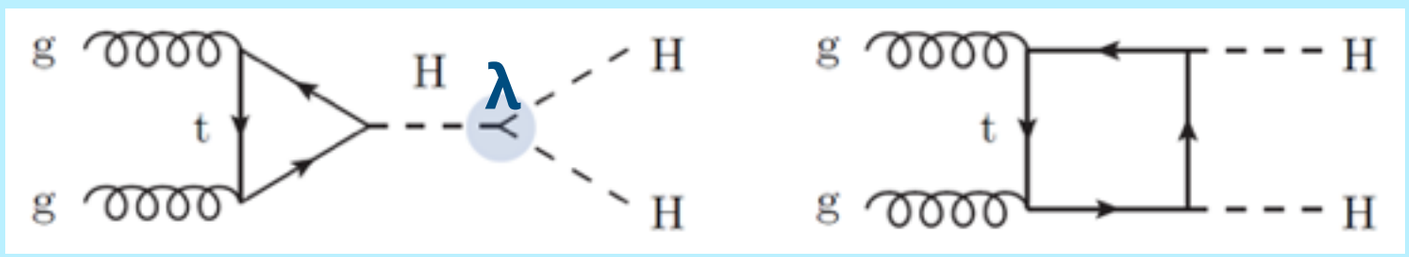
Introduction: search for double Higgs boson production

- In Standard Model destructive interference of triangle and box contributions → tiny cross section → Experimentally very challenging
- The direct measure of λ is a strong test of the SM prediction (λ~0.13 from theoretical SM prediction)

Higgs potential





[Eq 1]

$$V\left(\phi^{\dagger}\phi\right) = \mu^{2}\phi^{\dagger}\phi + \lambda\left(\phi^{\dagger}\phi\right)^{2}$$

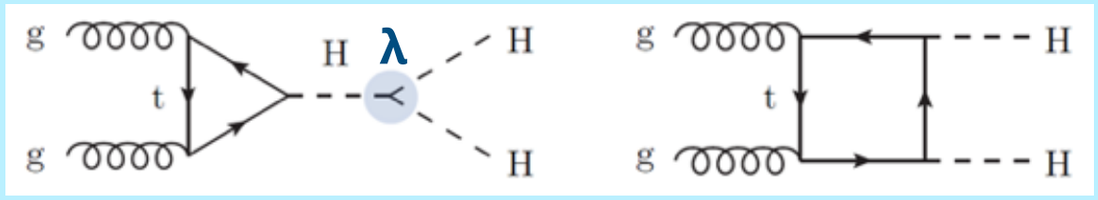
$$\sigma_{SM}^{HH} = 31.05^{+5\%}_{-7\%}\ \text{fb}\ (\text{scale} \oplus \text{PDF} \oplus \alpha_S \oplus \text{m}_t)$$ [1]

Since $\sigma_{HH}^2 \propto \lambda$, it is possible to measure λ through the cross section of the double Higgs production

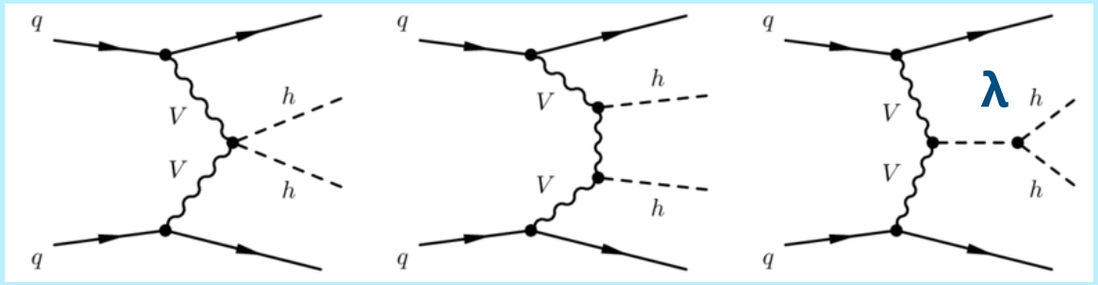
[1] https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGHH#Current_recommendations_for_di_H

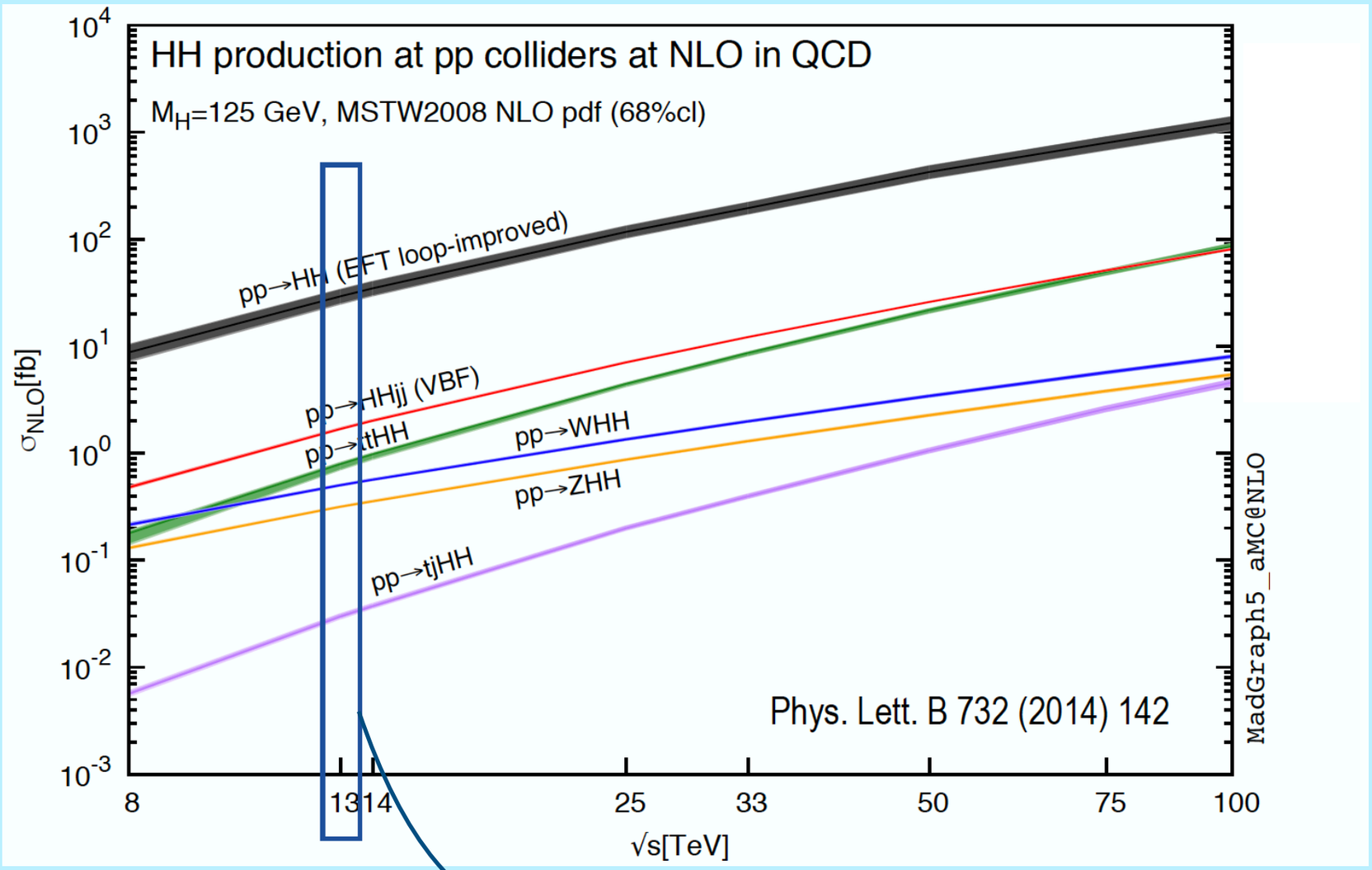
Introduction: HH production in the SM

HH gluon-gluon fusion production



HH VBF fusion production





- **Gluon fusion:** dominant production mode

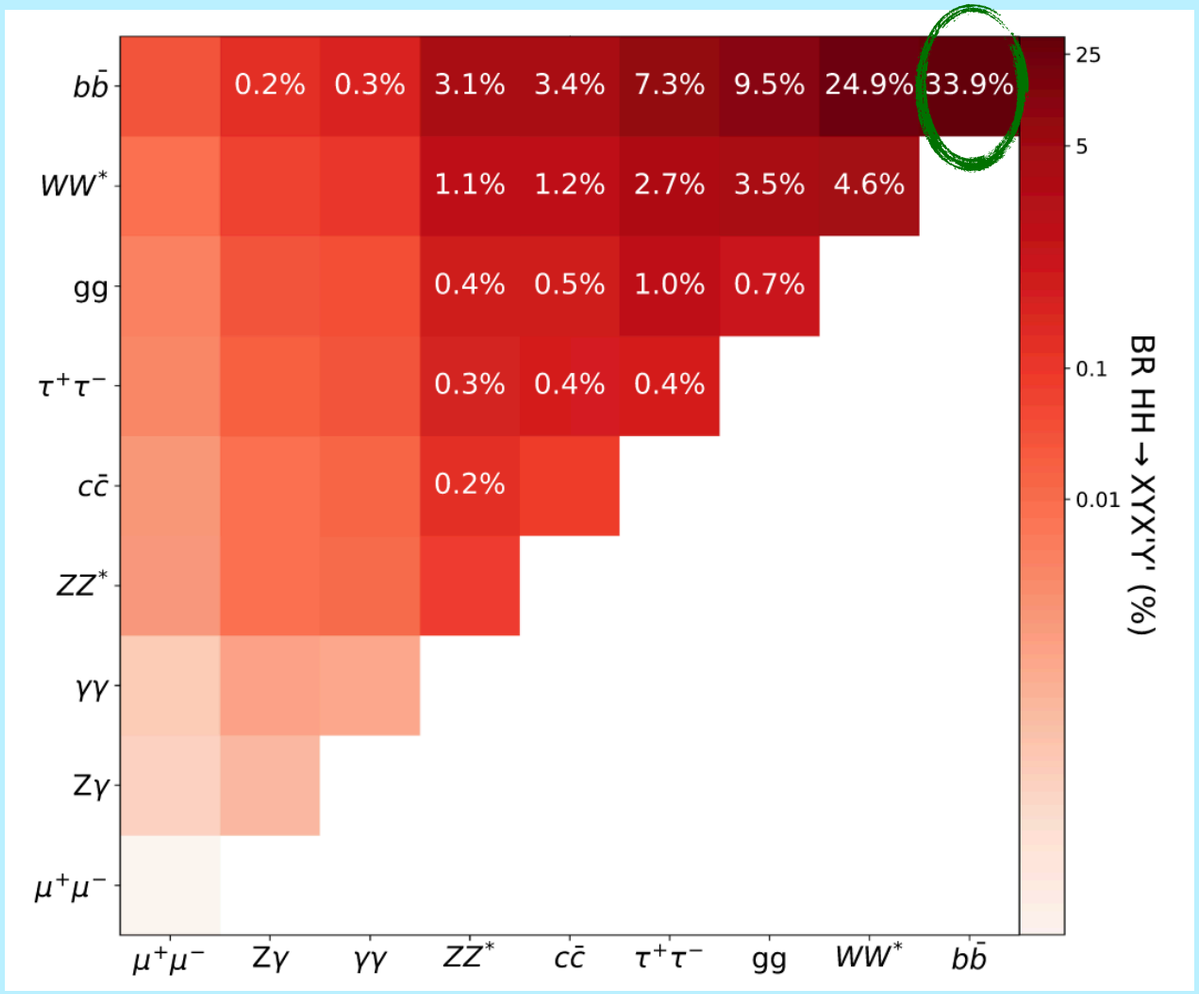
- **Large destructive interference → tiny cross section**

http://cds.cern.ch/record/2692014

HH searches in CMS

HH decay modes being explored using the **2016 data (36 fb^{-1})**:

- HH→4b
- HH→bb$\gamma\gamma$
- HH→bb$\tau\tau$
- HH→bbVV (V=Z,W)



- **2016 combination results**

95% CL limit on non-resonant HH production signal strength:

- **Observed: 22.2**
- **Expected: 12.8**

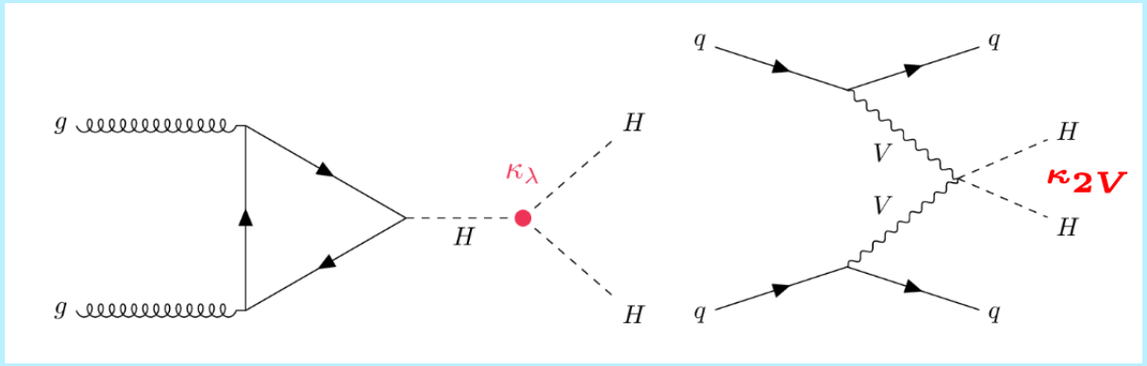
Constrain on k_λ:

- **Observed: $-11.8 < k_\lambda < 18.8$**
- **Expected: $-7.1 < k_\lambda < 13.6$**

RunII HH combination ongoing!

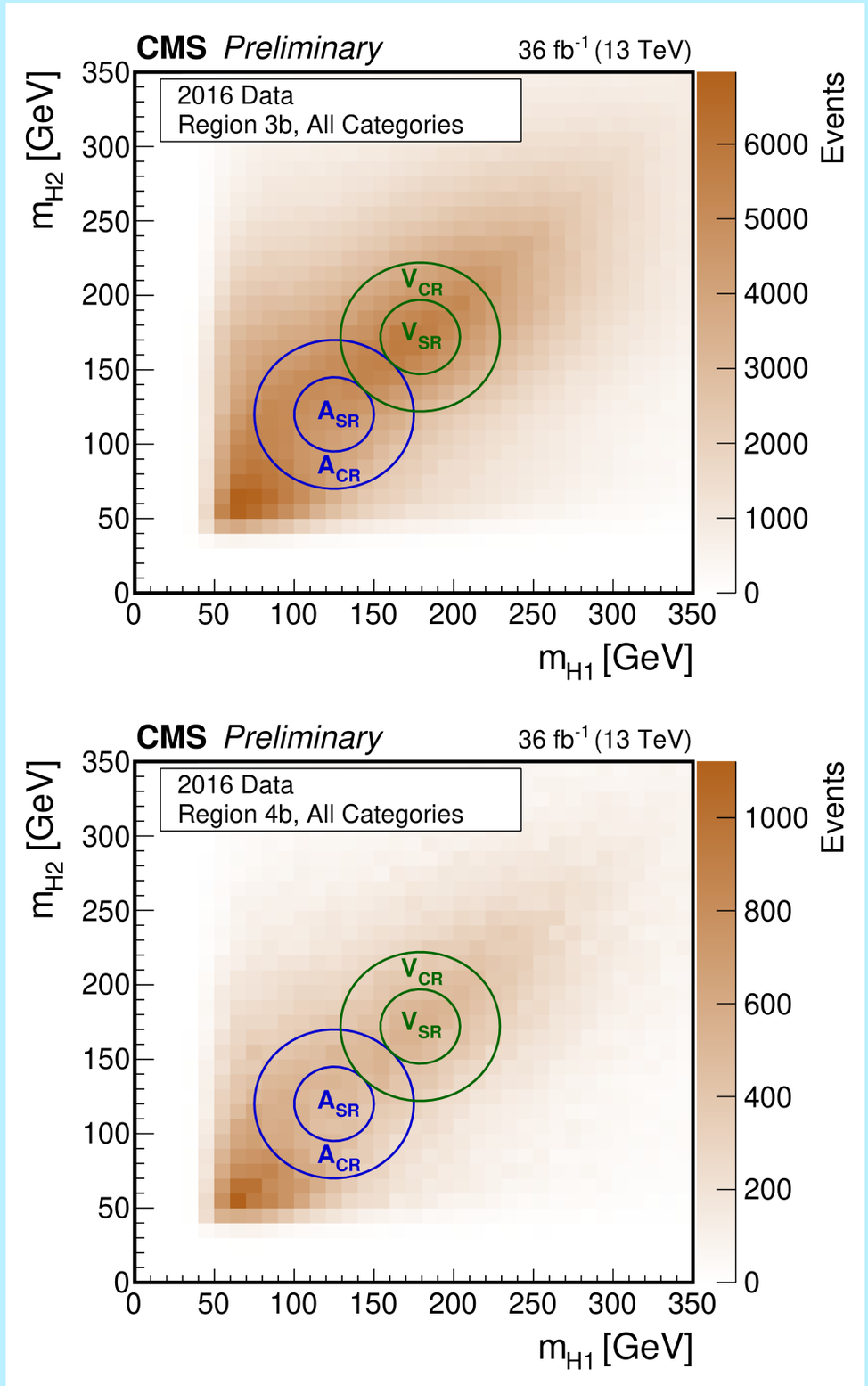
HH → 4b: analysis strategy

- Targeting Higgs self coupling and VVHH coupling:
  - **gluon-gluon fusion and VBF categories**



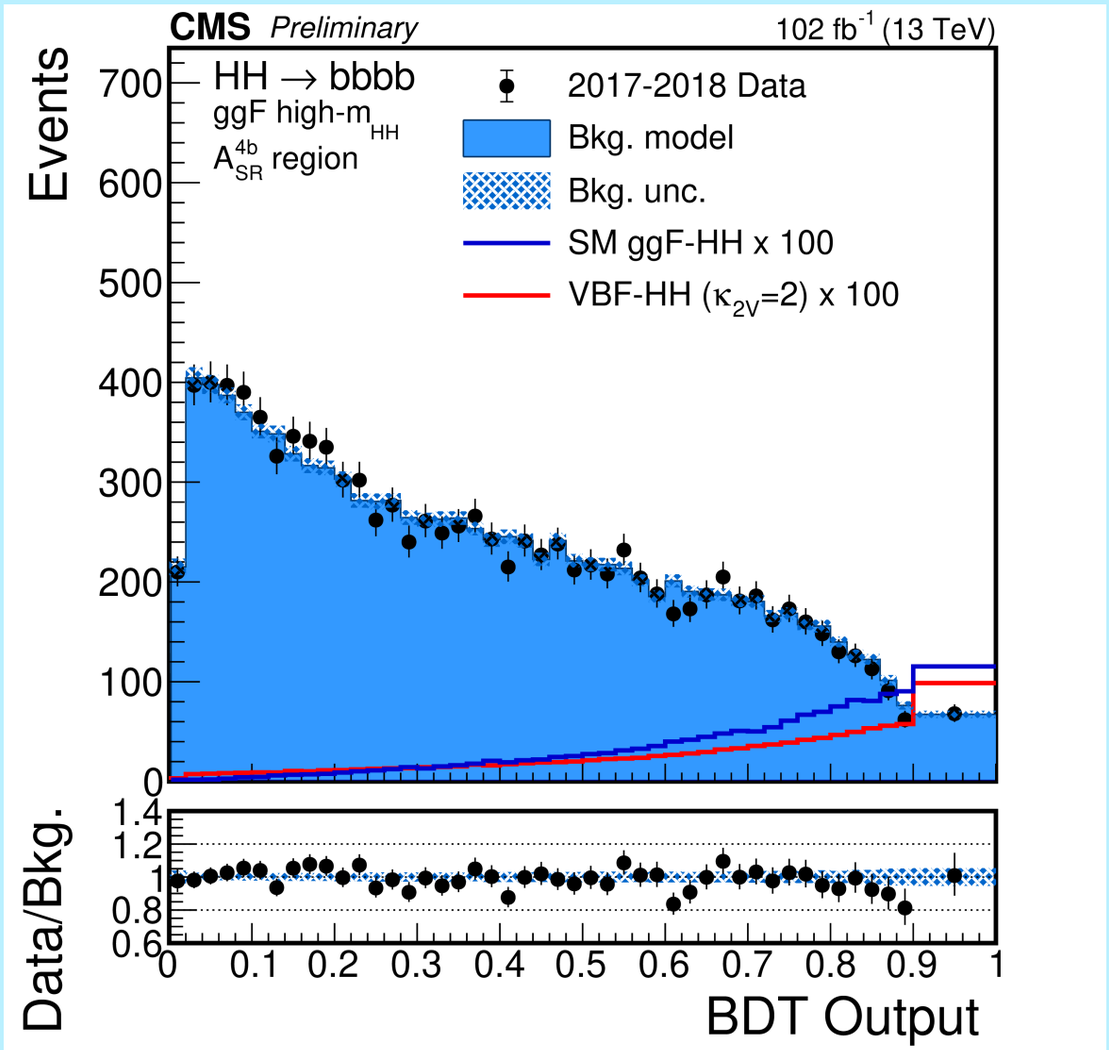
- The highest source of background is QCD and tt:
  - background estimated from data

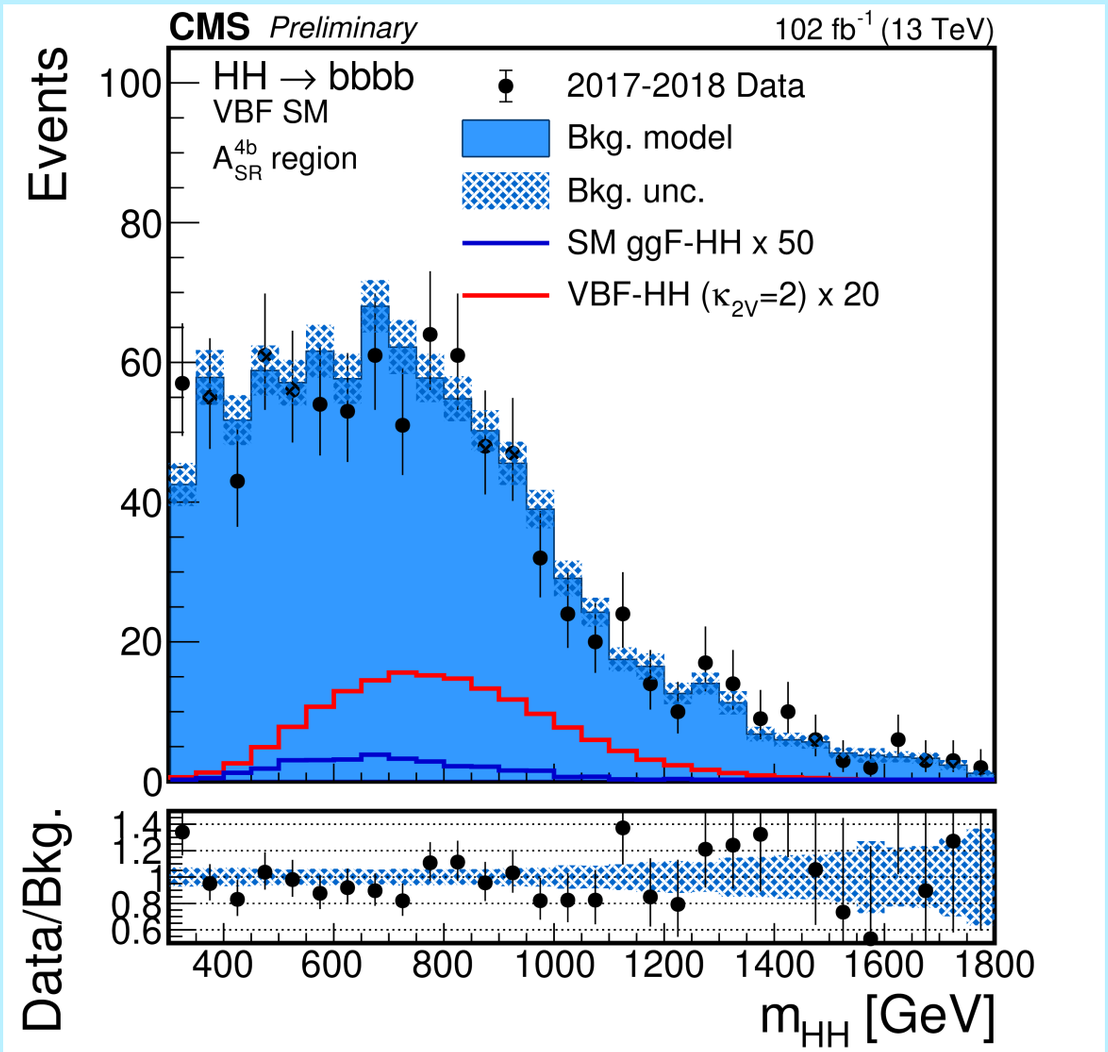
- **Signal and control regions, are divided in 4b and 3b region** → the b-jet candidate with the lowest DeepJet output to satisfy (or fail) the medium working point



HH → 4b: analysis strategy

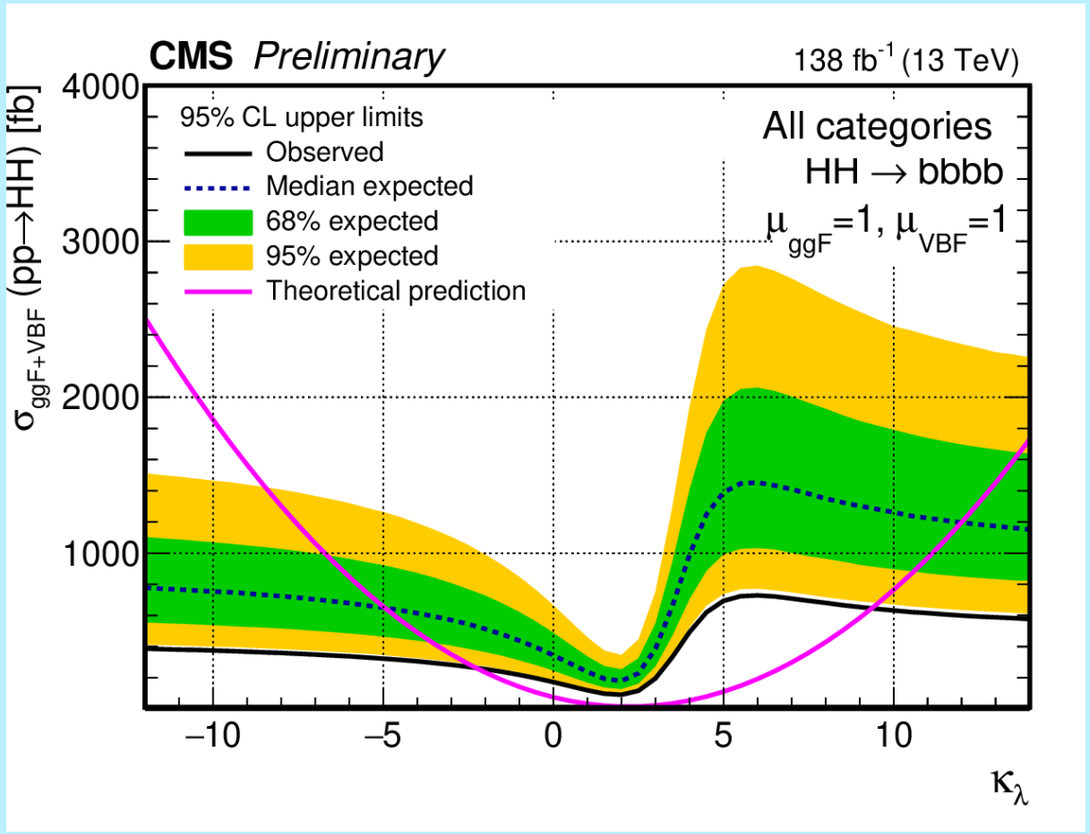
- Background events in the A_{4bSR} region are modelled from events in the A_{3bSR} region: BDT is trained in the A_{4bCR} and A_{3bCR} regions, and applied to events in A_{3bSR} to model A_{4bSR}
- Another BDT is trained to separate from the signal the weighted A_{3bSR} background events

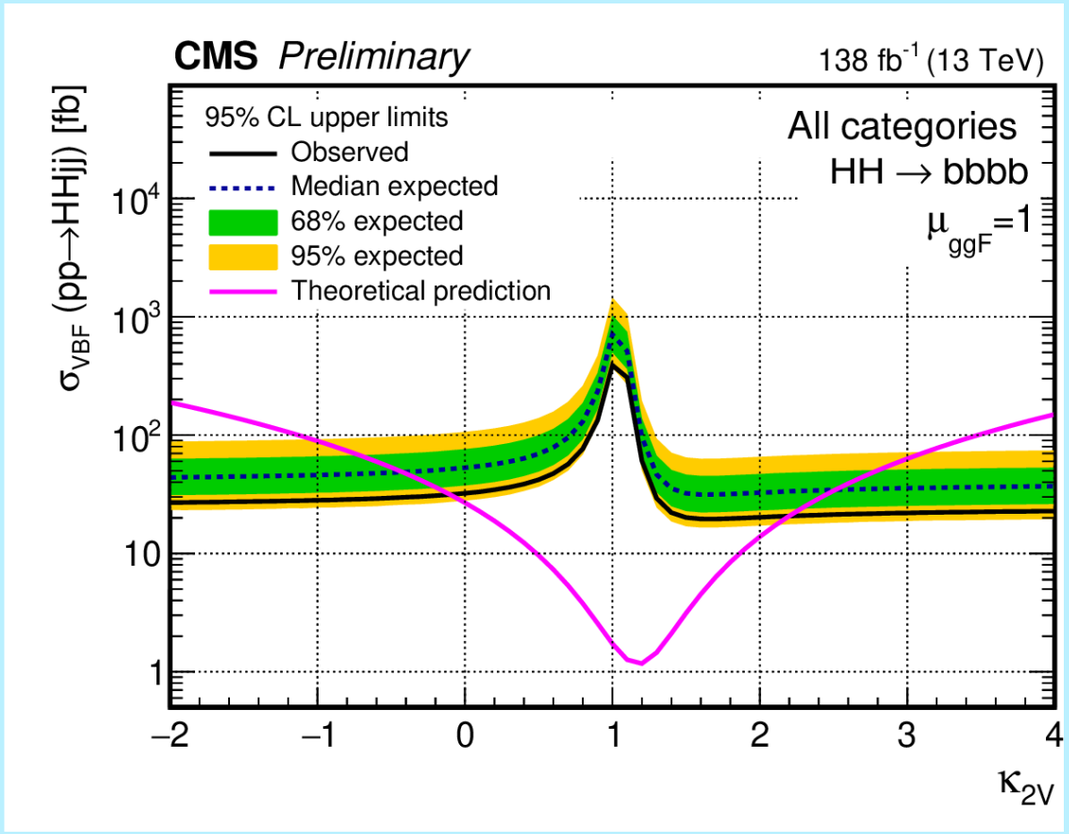




HH → 4b: results

- A binned maximum likelihood fit is simultaneously performed in the four categories (depending on the mass of HH and on the production process) to extract the results



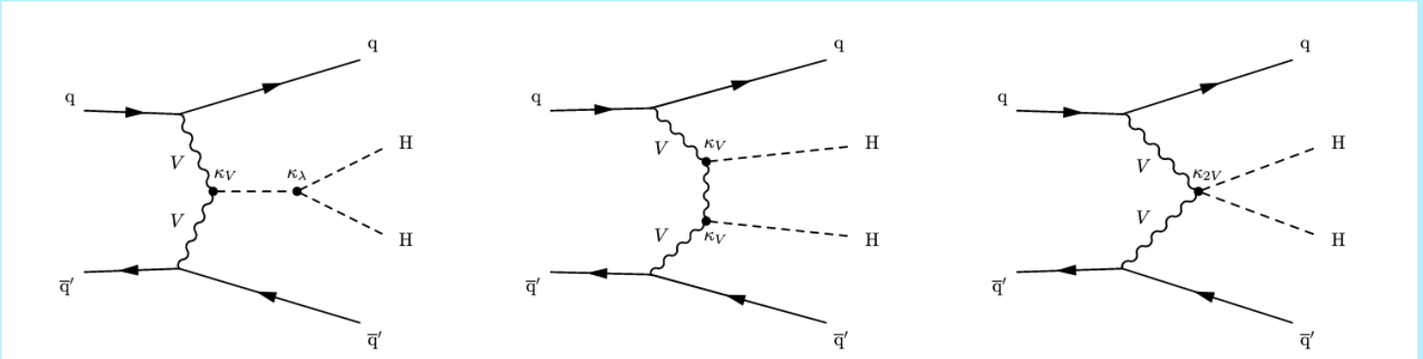


Results:

- upper limit on the cross section → σ(pp →HH →4b) < 3.6 (7.3) × SM obs. (exp.)
- κ_λ constraint → $-2.3 < \kappa_\lambda < 9.4$ $(-5.0 < \kappa_\lambda < 12.0)$
- κ_{2V} constraint → $-0.1 < \kappa_{2V} < 2.2$ $(-0.4 < \kappa_{2V} < 2.5)$

HH → 4b boosted: analysis strategy

- Results on the k_v and k_{2v} couplings:
  - **VBF specific category - high sensitivity on κ_{2V} coupling**



- main backgrounds: QCD and tt estimated from CRs and MC

- The main challenge is the efficient reconstruction of H→bb:
  - **first analysis to apply the ParticleNet classifier**

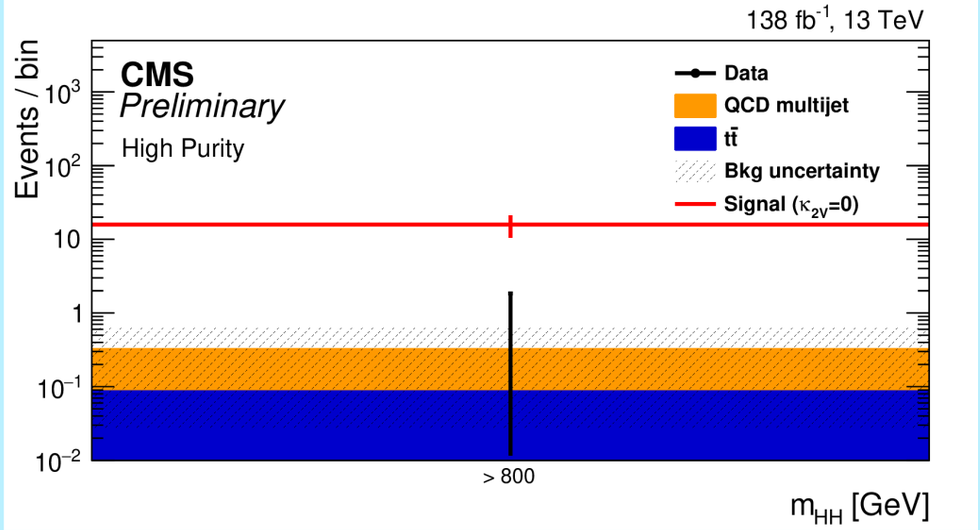
HH → 4b boosted: analysis strategy

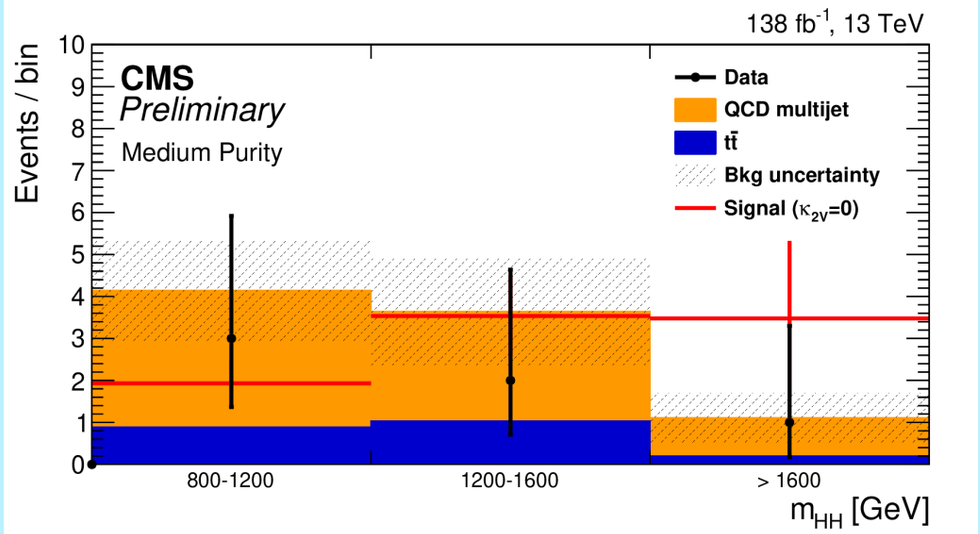
The main challenge is the efficient reconstruction of H→bb:
first analysis to apply the ParticleNet classifier

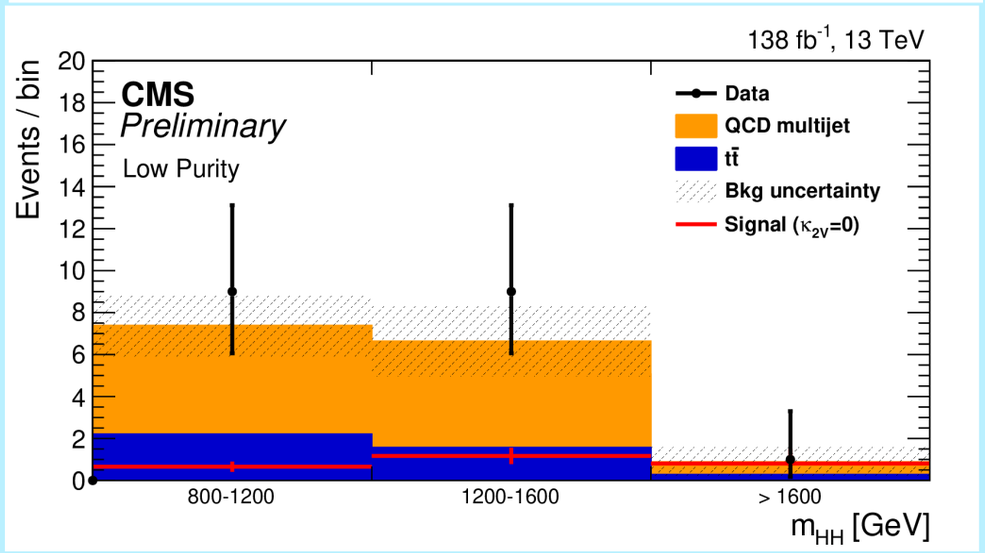
assigning a number of output scores for each jet, corresponding to the probability that the jet is induced by a given process

Discriminate between large-radius jets from genuine H →bb decays and those from QCD multijet processes → **3 categories are defined**: high - medium - low purity

Highest sensitivity to κ_{2V} coupling

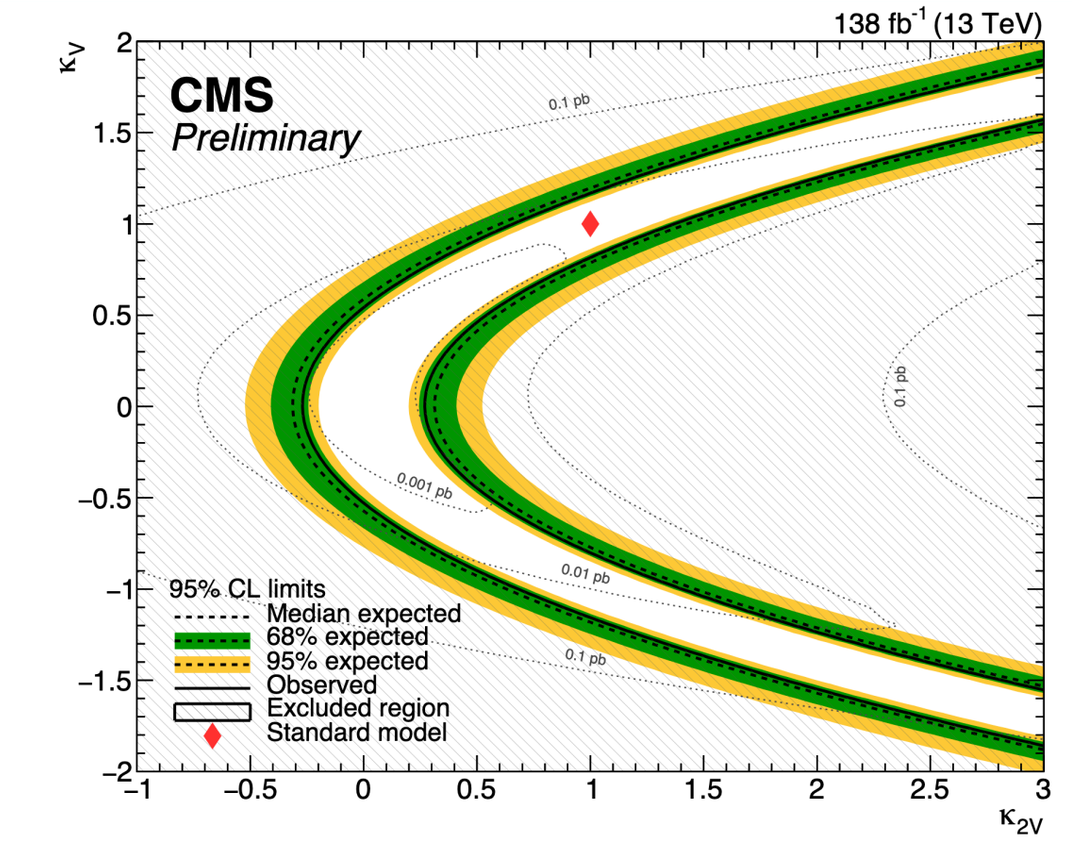


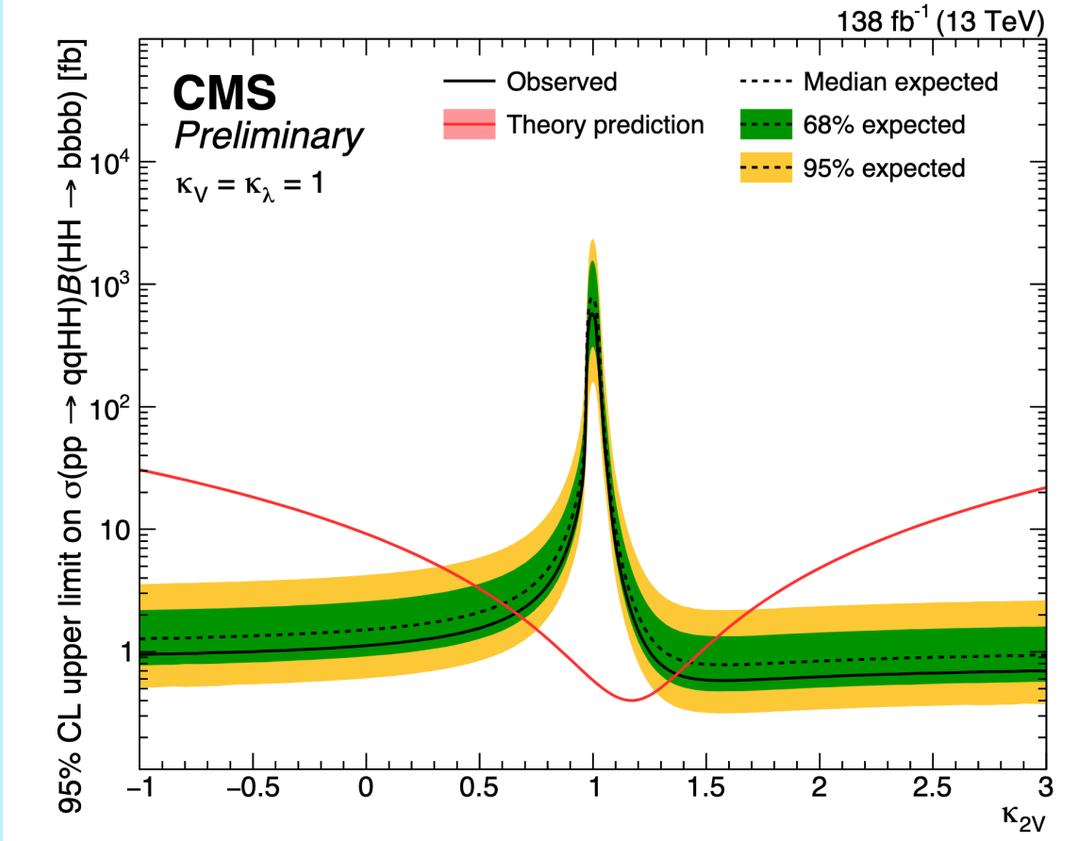




HH → 4b boosted: results

- A binned maximum-likelihood fit using the m_{HH} templates is performed simultaneously with all SR and CR event categories



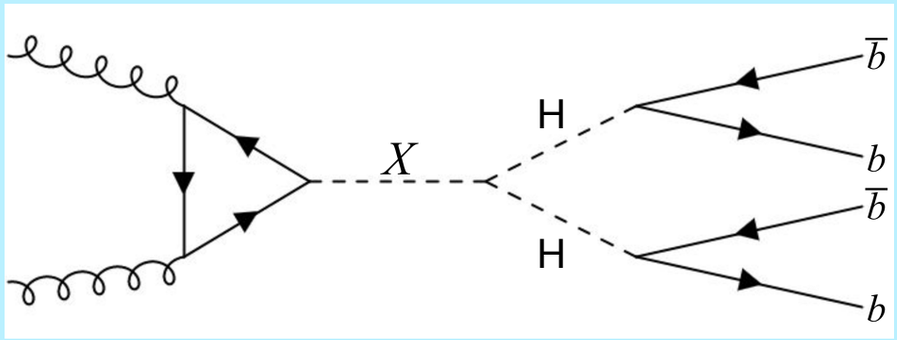


Results:

- κ_{2V} constraint → $0.6 < \kappa_{2V} < 1.4$ (obs. and exp.) at 95% CL
- $\kappa_{2V} = 0$ excluded at more than 95% CL for $\kappa_V > 0.5$ and all other $\kappa = 1$

X → HH → 4b: analysis strategy

- Massive BSM resonance X that then decays to a Higgs boson pair (X → HH)



- BSM scenarios that predict the existence of resonances (models with a warped extra dimension):
  - **spin-0 radion**
  - **spin-2 first Kaluza–Klein** (KK) excitation of the **graviton**

- multijet production and tt +jets backgrounds → estimated in data

X → HH → 4b: analysis strategy

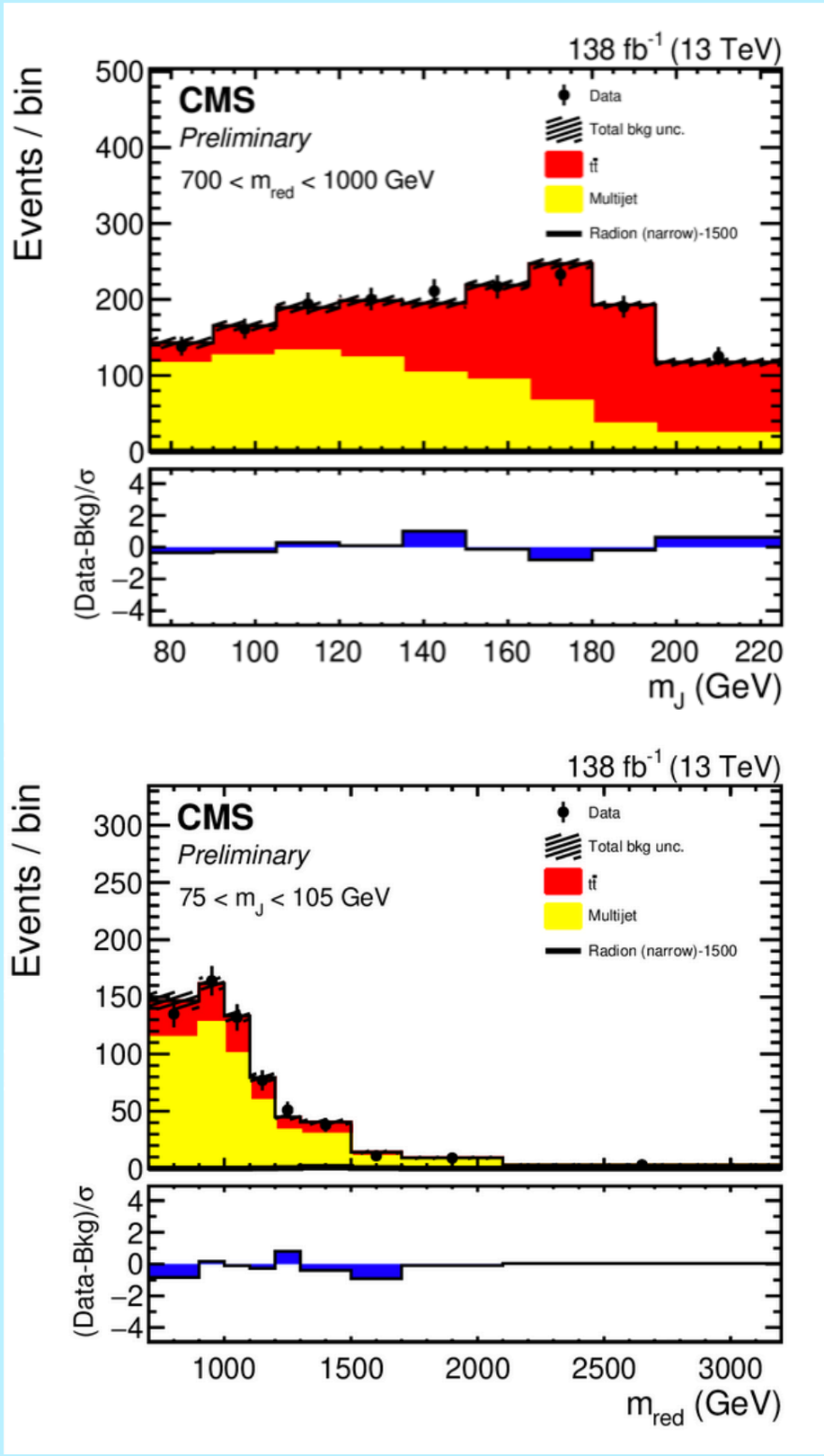
- H-tagged DNN for resolved and semiresolved topology:
  - reduced mass:

$$m_{\text{red}} \equiv m_{\text{JJ}} - (m_{\text{J}} - m_{\text{H}}) - (m_{\text{J}_2} - m_{\text{H}})$$

  - m_J m_{J2}: masses of the leading and subleading H-tagged jets

- The reduced mass is used to reduce the fluctuations caused by jet energy and mass resolutions

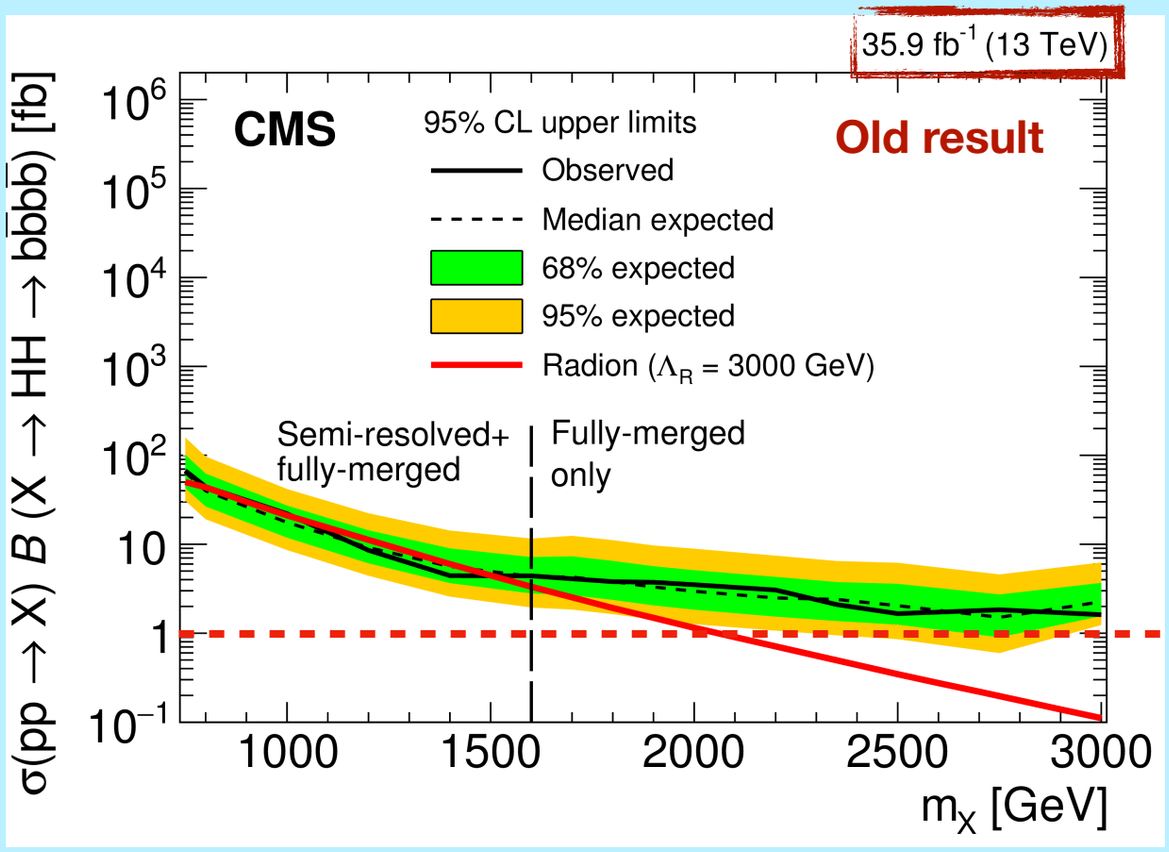
- **8–10% improvement in the dijet mass resolution**

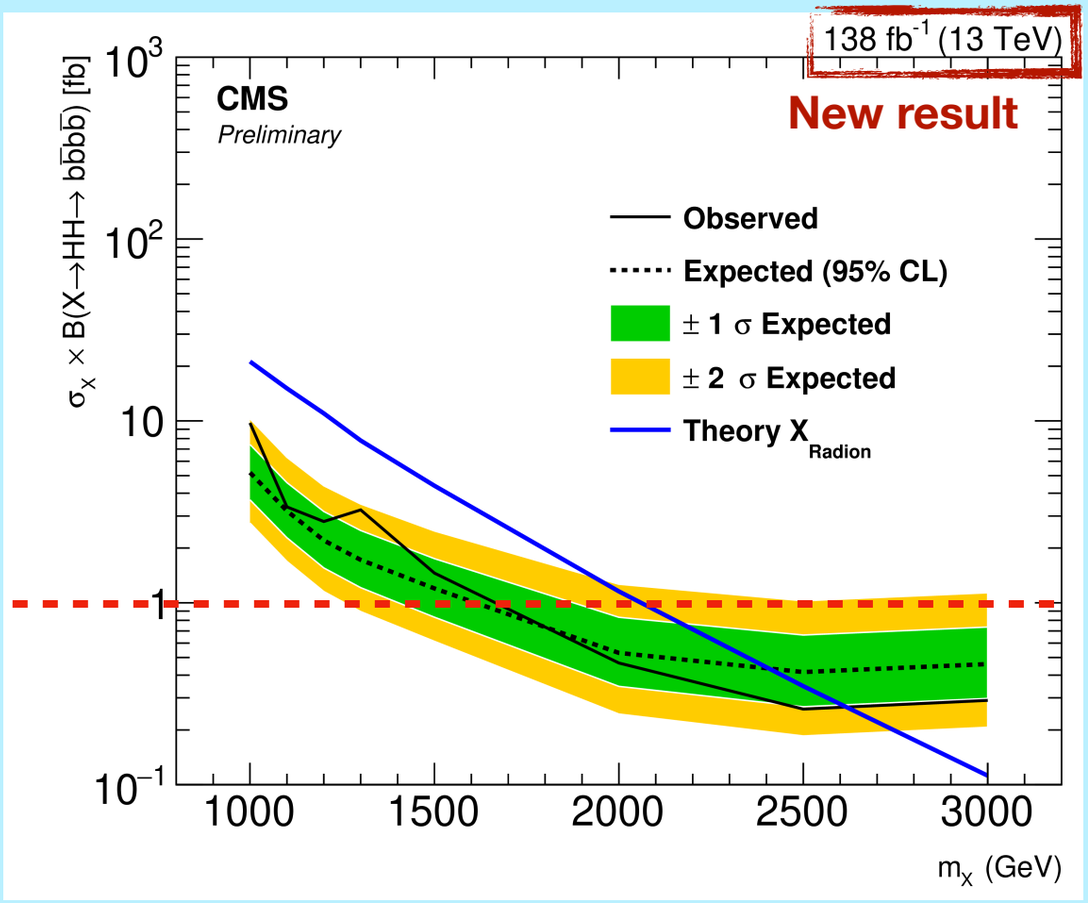


X → HH → 4b: results

- A likelihood fit to data is used to test the signal hypothesis

- Background model is constructed as a sum of the individual background contributions using a Poisson distribution for each bin of the (m_J, m_{red})





The upper limits range from on the cross section for the mass range 1–3 TeV:

- **4.94 to 0.19 fb for the bulk graviton**
- **9.74 to 0.29 fb for the radion**

Summary

Di-Higgs production investigation in 4b final state:

Advantage

- largest branching ratio

Disadvantage

- large QCD background → background model techniques based on DNN crucial

Several topologies:

- HH → bbbb **sensitive to HH non resonant cross section**
- HH → bbbb boosted **sensitive to HHVV coupling**
- X → HH → bbbb **sensitive to BSM spin 0 or spin 2 gravitons**