

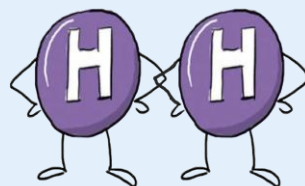


UNIVERSITÀ  
DEGLI STUDI DI BARI  
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# HH Searches Overview

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## Motivation:

**SM:**  $H$  production @ 13 TeV @LHC **56 pb** (NLO) &  $HH$  production @13 TeV @LHC **33 fb** (NNLO)

**BSM:** Anomalous couplings of the Higgs & New heavy resonances decaying to  $HH$

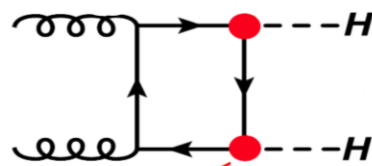
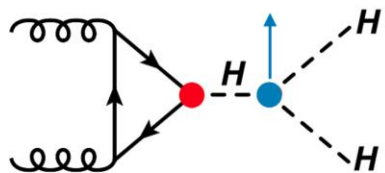
## Non-Resonant HH

### Enhance the HH production rate Via:-

- Modify Higgs boson self-coupling (SM free parameter to be constrained )
- Modify the Higgs-top Yukawa coupling
- New vertices

$$V(H) = \frac{1}{2}m_H^2 H^2 + \lambda_3 \nu H^3 + \frac{1}{4}\lambda_4 H^4 \quad \kappa_\lambda = \lambda_3/\lambda_3^{\text{SM}}$$

H-H self coupling



H-t Yukawa coupling

The HH non-resonance production provides the best channel to study the HH self-coupling / trilinear coupling modifier

$$\kappa_\lambda = \begin{cases} 1 & \text{(SM prediction)} \\ \neq 1 & \text{(BSM scenario)} \end{cases}$$

## Resonant HH

### Enhance the HH rate via New BSM bosons decaying to HH:-

#### RS model of the WED theories

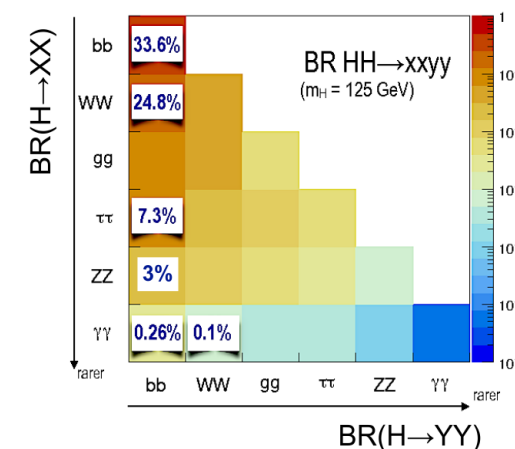
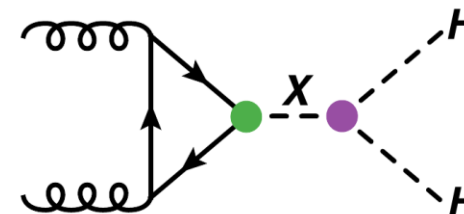
#### Spin-2 Graviton / Spin-0 Radion $\rightarrow HH$

- Introduce one extra compactified dimension
- Explain the gravity (not included in the SM)
- Explain the hierarchy between Gravity and atomic forces

#### SUSY / NMSSM

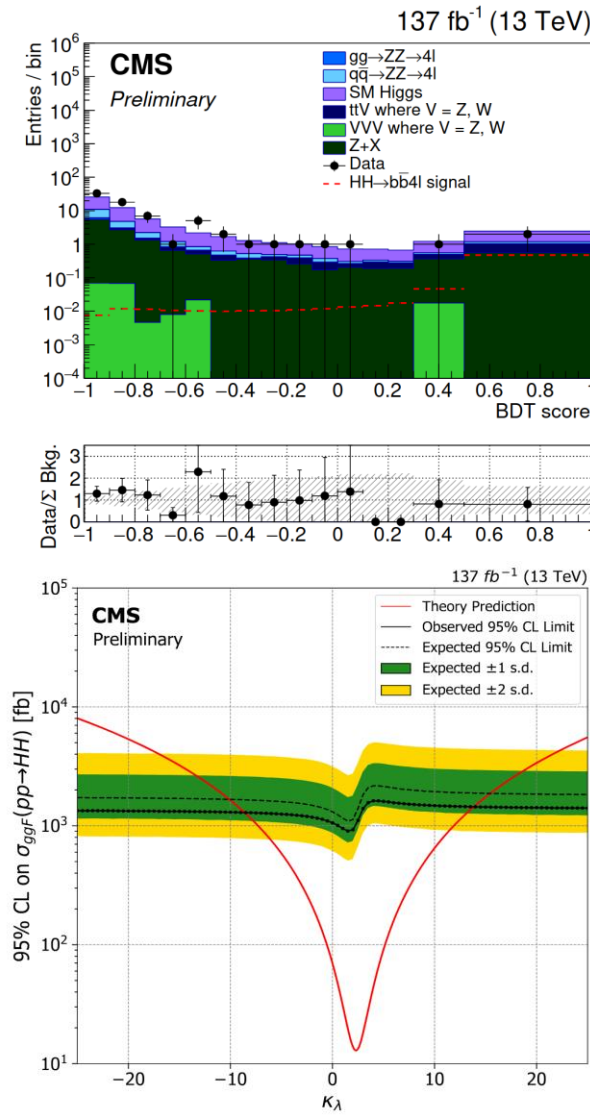
#### Additional heavy Higgs $H^0 \rightarrow HH$

- Introduce two Higgs doublets
- Gauge Coupling Unification (GUT)
- Dark Matter Candidate (WIMP)
- Solve the hierarchy problem

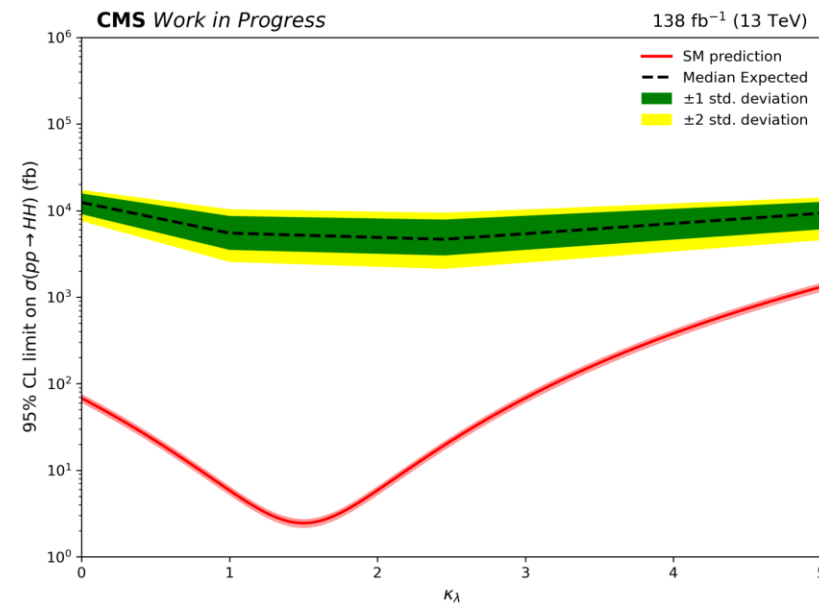


CMS-PAS-HIG-20-004

Run-II, 137 fb<sup>-1</sup>, 13 TeV  
HH→ bb4l



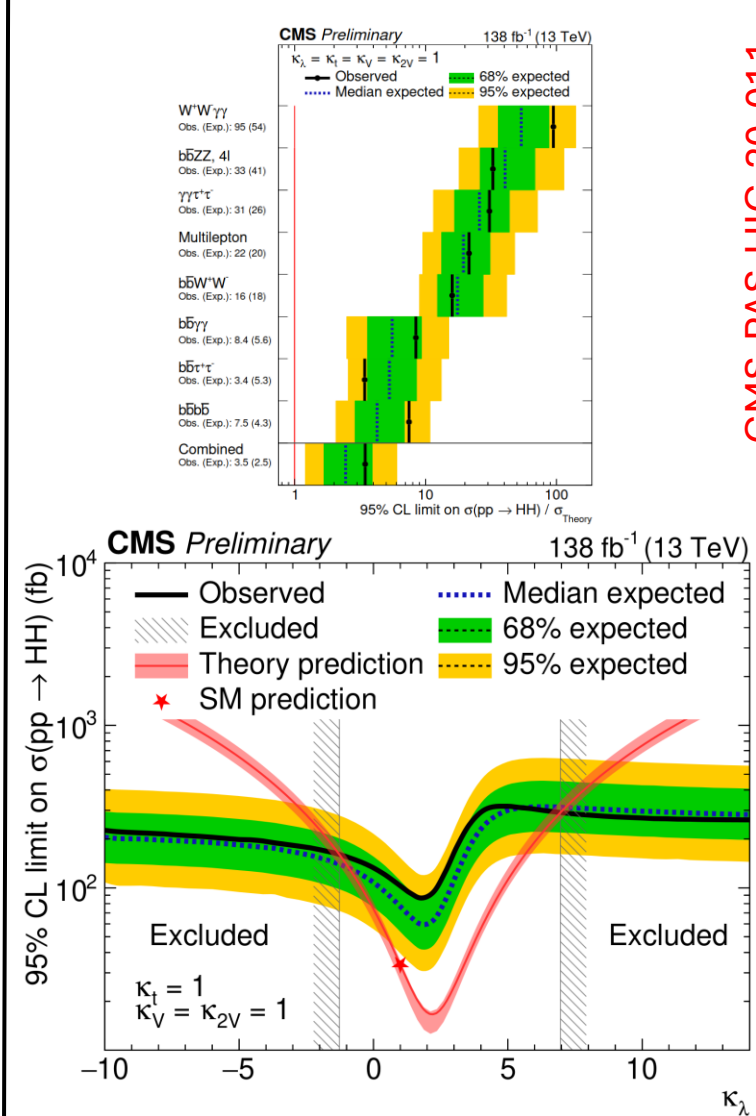
Run-II, 138 fb<sup>-1</sup>, 13 TeV  
HH→ bbμμ



Projection at future LHC runs  
HH→ bbμμ

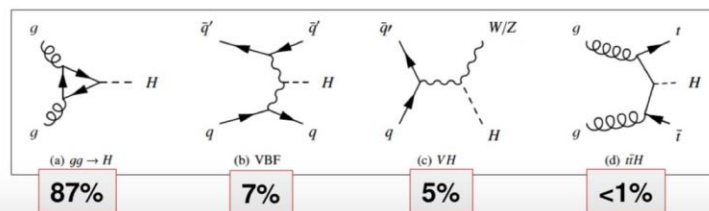
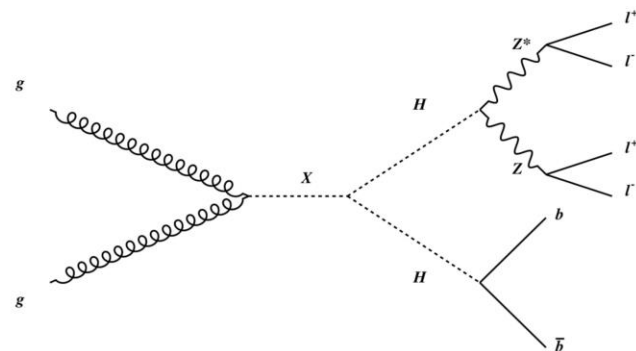
| Signal Strength ( $\mu$ )          | Run 2 combined (137 fb <sup>-1</sup> ) | Run 3 (500 fb <sup>-1</sup> ) | HL-LHC (3000 fb <sup>-1</sup> ) |
|------------------------------------|----------------------------------------|-------------------------------|---------------------------------|
| 2.5% quantile ( $\mu - 2\sigma$ )  | 84                                     | 44                            | 18                              |
| 16.0% quantile ( $\mu - 1\sigma$ ) | 116                                    | 61                            | 25                              |
| 50% quantile ( $\mu$ )             | 177                                    | 93                            | 38                              |
| 84% quantile ( $\mu + 1\sigma$ )   | 275                                    | 144                           | 59                              |
| 97.5% quantile ( $\mu + 2\sigma$ ) | 329                                    | 171                           | 70                              |

Run-II, 138 fb<sup>-1</sup>, 13 TeV  
HH→ different final state



CMS-PAS-HIG-20-011

Under **CMS review**: Search for resonant production of Higgs boson pairs decaying to four leptons and two b jets in pp collisions at  $\sqrt{s}=13$  TeV [CADI: B2G-25-002](#)



## Hypothesis & final state:

RS model of the WED theories

Spin-2 Graviton / Spin-0 Radion  $\rightarrow HH \rightarrow bb4l$

**Data sets:** CMS run-II UL dataset ( $\sim 137 \text{ fb}^{-1}$ )

## Analysis Strategy:

### 1- Event selection

$H \rightarrow ZZ \rightarrow 4l$  selection ( $M_H \pm 10 \text{ GeV}$ )

(Higgs group legacy strategy HIG-19-001)

$H \rightarrow bb$  from the highest B-tagged jets

### 2- background estimation

Irreducible background: MC estimation

$gg/VBF \rightarrow H, ZZ, VH, qqH, VVV$

Reducible backgrounds: data-driven estimation

$DY+\text{jets}, tt\text{jets}, WZ$

### 3- Validations in CRs

Data/MC comparison in 2 CR orthogonal to SR

$4l$  SB &  $4l+\text{jets}$  SB (agreement within the stat. uncer.)

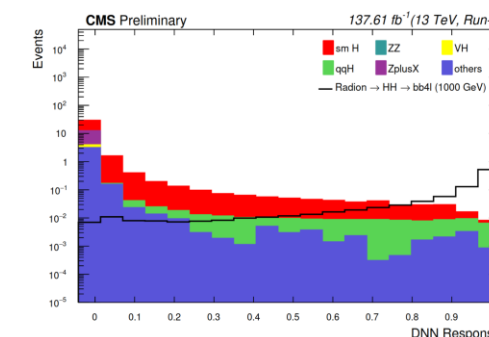
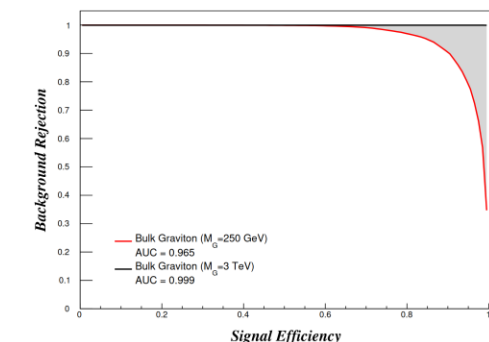
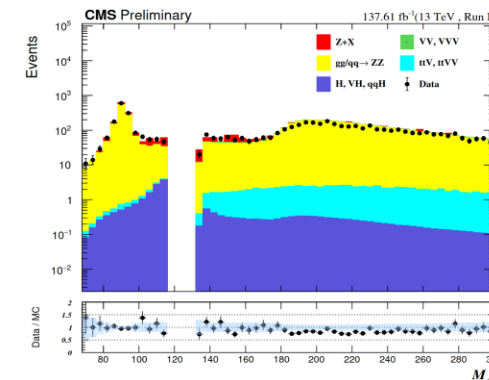
### 4- signal Vs. Background discrimination

Multivariate analysis based on DNN:

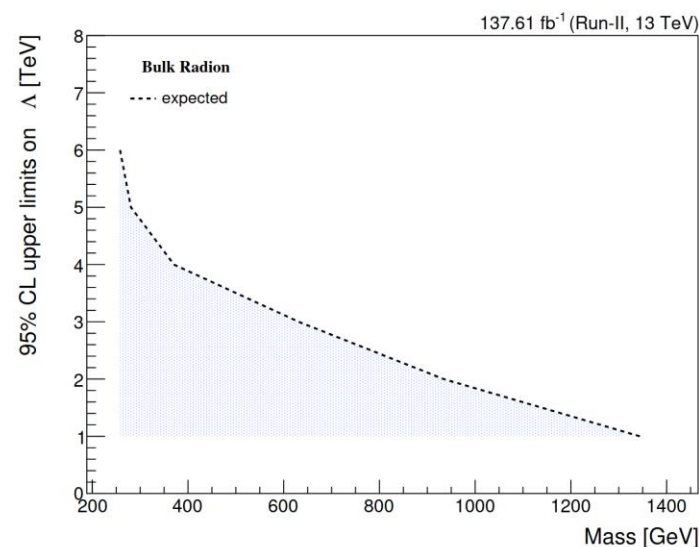
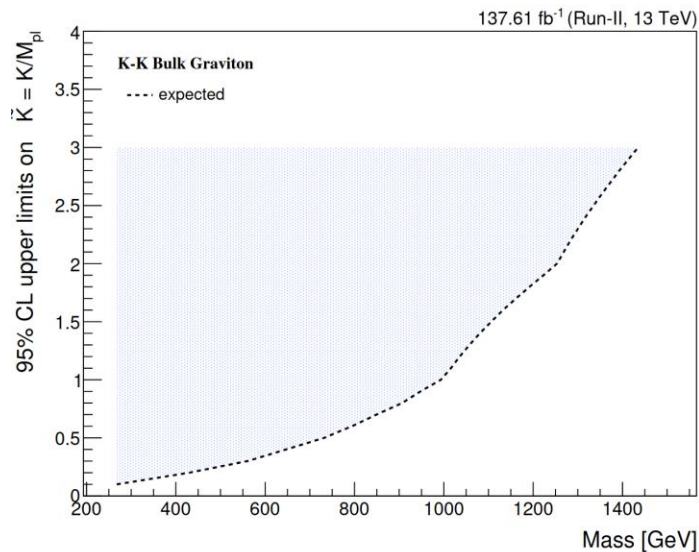
- optimization of the DNN using grid search
- training the DNN: 80% training & 20% testing
- application

### 5- Statistical interpretation

Maximum likelihood estimation

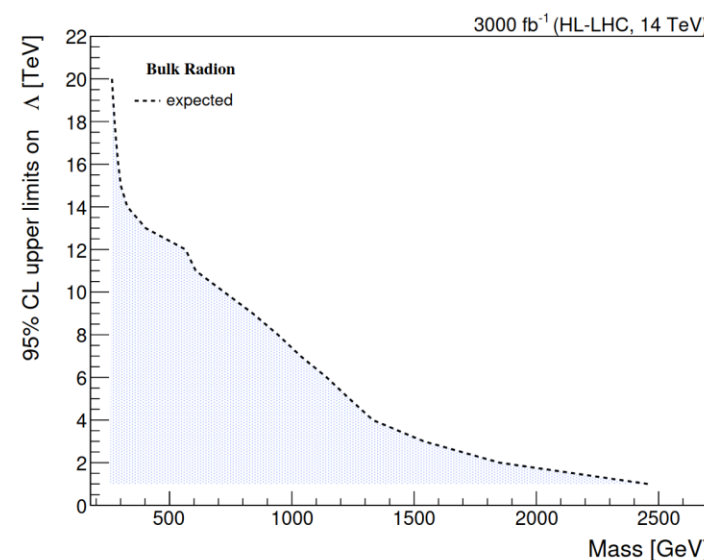
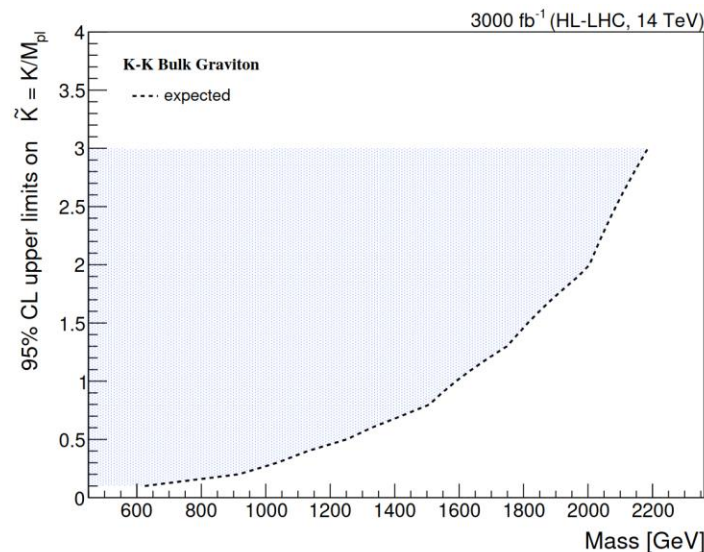


Run-II,  $138\text{ fb}^{-1}$ , 13 TeV  
HH  $\rightarrow$  bb4l

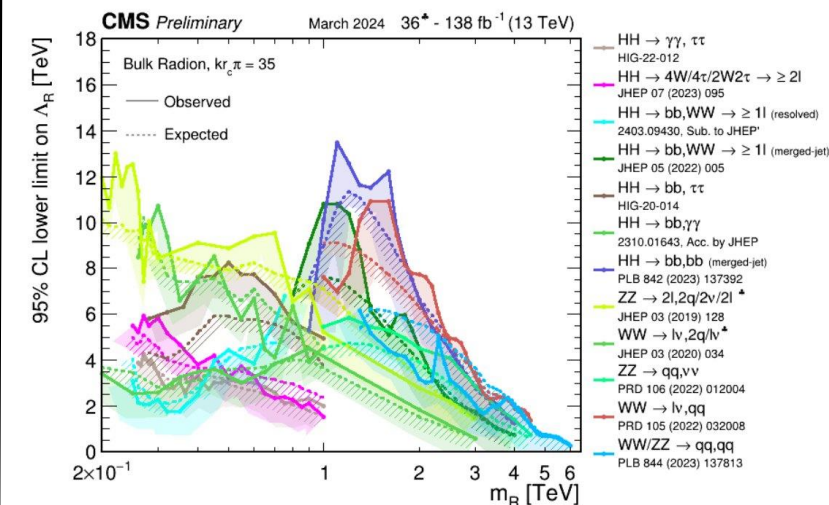
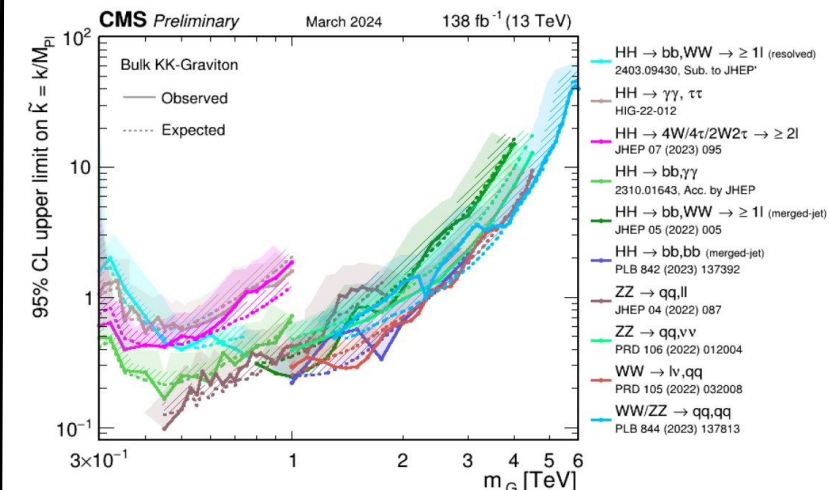


CMS-AN-2024/167

HL-LHC,  $3\text{ k fb}^{-1}$ , 14 TeV  
HH  $\rightarrow$  bb4l



Run-II,  $138\text{ fb}^{-1}$ , 13 TeV  
HH  $\rightarrow$  different final states



Physics Results B2G-2025(tiwiki)