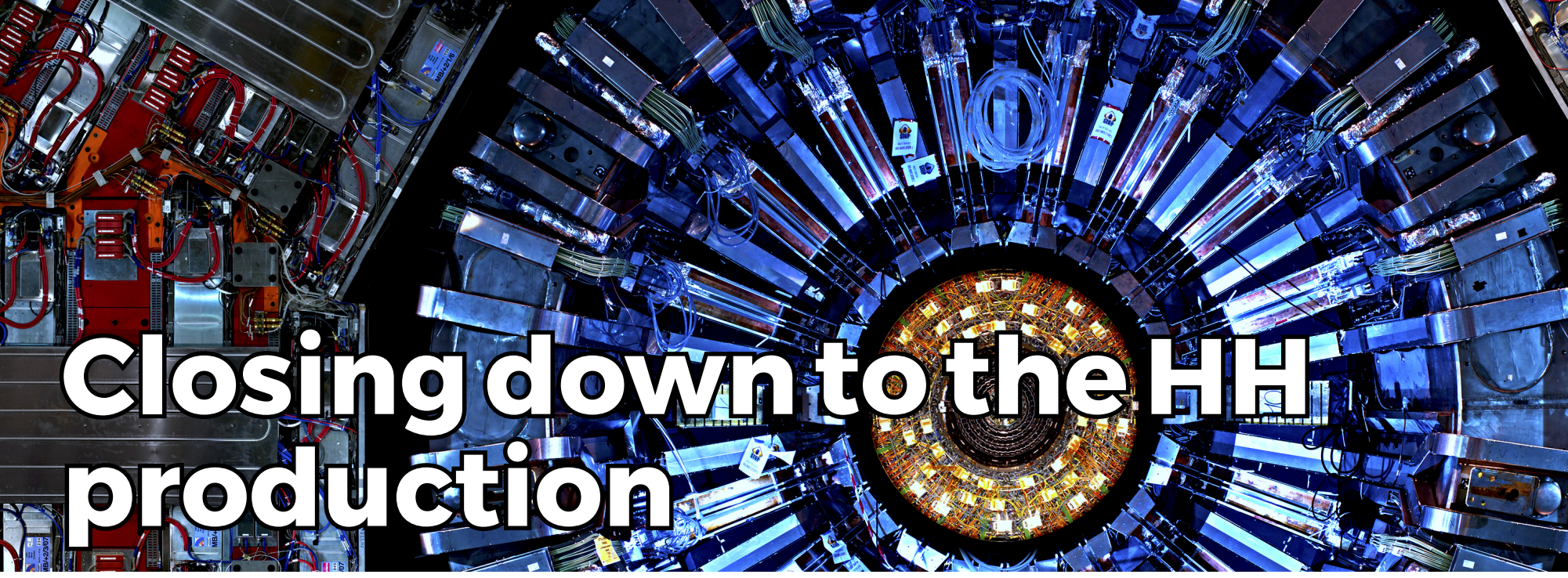

# Closing down to the HH production


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*École polytechnique*

**on behalf of the CMS Collaboration**


*Higgs Hunting*
*July 25, 2018*

# HH production

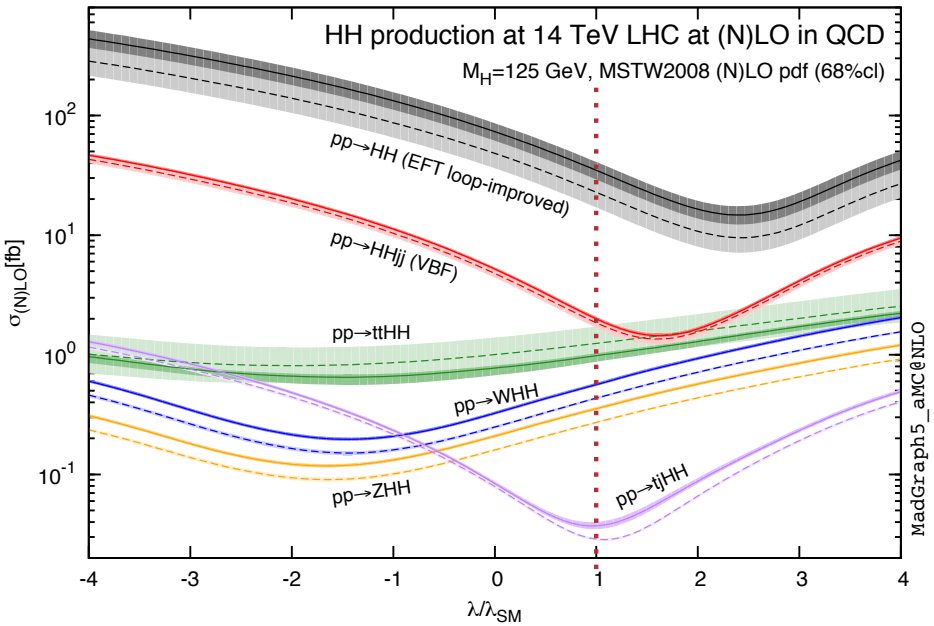
(see Lisa Borgonovi's talk in this conference)

- Unique probe of the Higgs mechanism
  - allows measurement of the Higgs self-coupling $\lambda$
  - it brings information on the shape of the Higgs potential

## Non-resonant searches

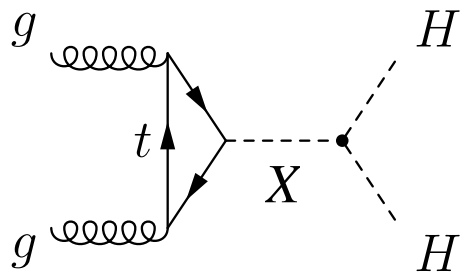
Process predicted by the SM

BSM effects can result in anomalous couplings (enhanced cross section)




## Resonant searches

Predicted by several extensions of the SM



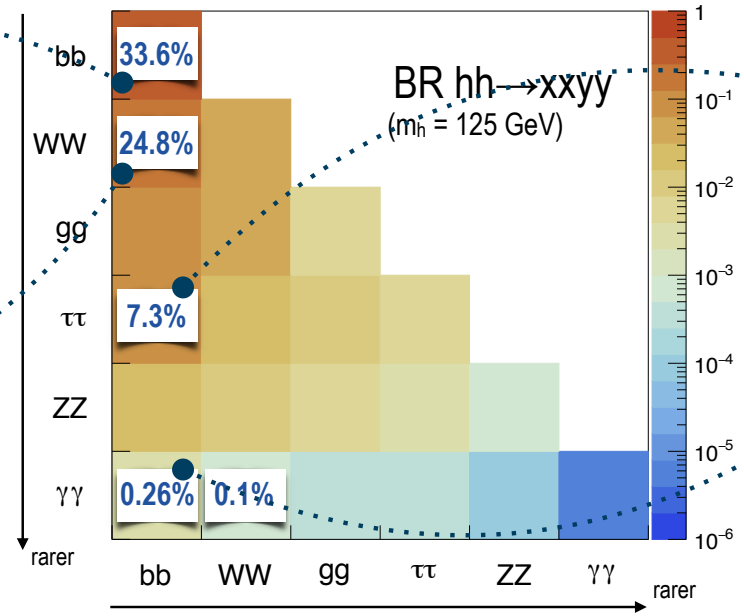

- MSSM/2HDM
- Singlet model
- Warped Extra Dimensions
- CP-even spin-0 or spin-2 particles predicted

# HH combination on 2016 data

**Dominant production mode**: gluon-gluon Fusion ($\sigma_{HH} \sim 33$ fb at 13 TeV)

**bbbb**
largest BR, large QCD and $t\bar{t}$ contamination

**bbWW**
large BR, large $t\bar{t}$ contamination




**bbττ**
good **compromise** between BR and purity

**bbγγ**
low branching ratio, high purity

- Trade-off between BR and purity
- coverage of different phase spaces
- different sensitivity in different mass ranges

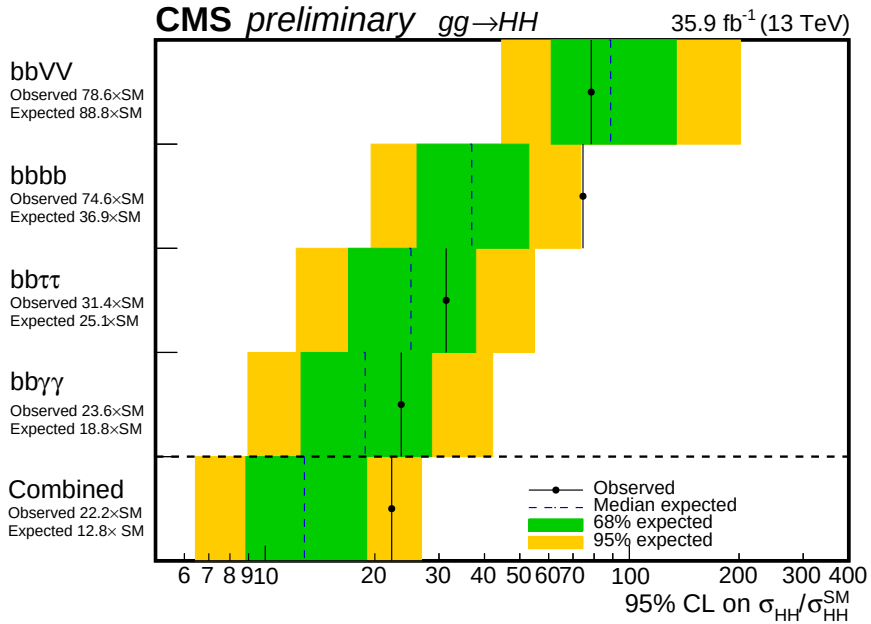
All channels are complementary, a lot to gain by combining

**Combination** performed with 35.9 $fb^{-1}$

CMS PAS HIG-17-030

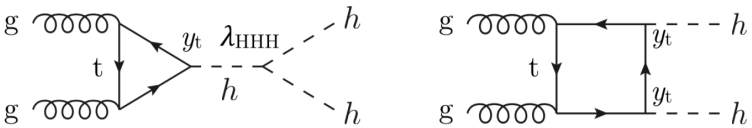
# Results: non-resonant exclusion

CMS PAS HIG-17-030



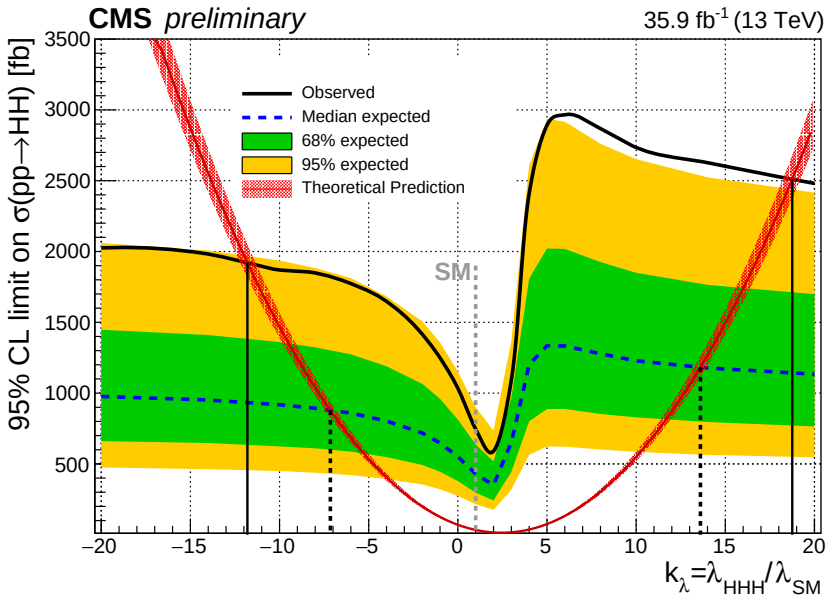

- SM exclusion:
  - Run I combination obs (exp) limit: 43 (46)$\times\sigma_{SM}$
  - most sensitive: bbγγ; bbττ
  - combined: 22 (13)$\times\sigma_{SM}$
  - the combination of channels brings a significant improvement over bbγγ alone

- Scan in function of $k_\lambda = \lambda/\lambda_{SM}$
  - affected by the interference between different diagrams



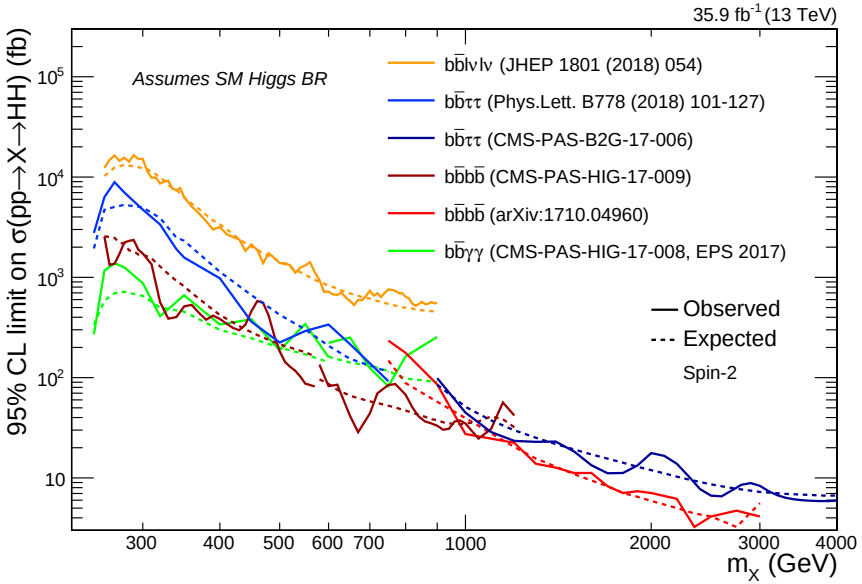

  - obs (exp) constraints:

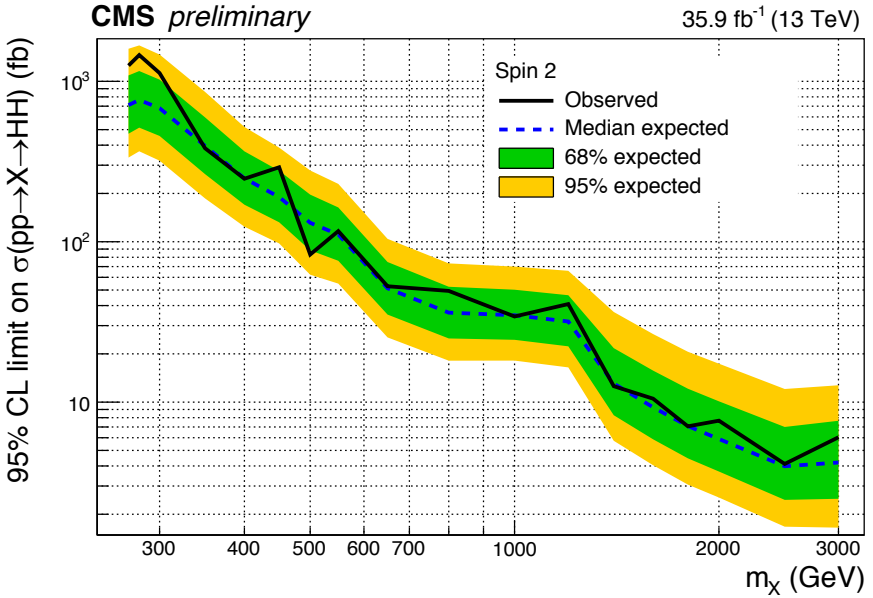
$-11.8 < k_\lambda < 18.8\ (-7.1 < k_\lambda < 13.6)$



# Results: resonant searches

## Different sensitivities in different regions




CMS PAS HIG-17-030

- Limits for spin-2 (graviton) CP-even particles interpretation
- narrow width resonance hypothesis

# Chasing down

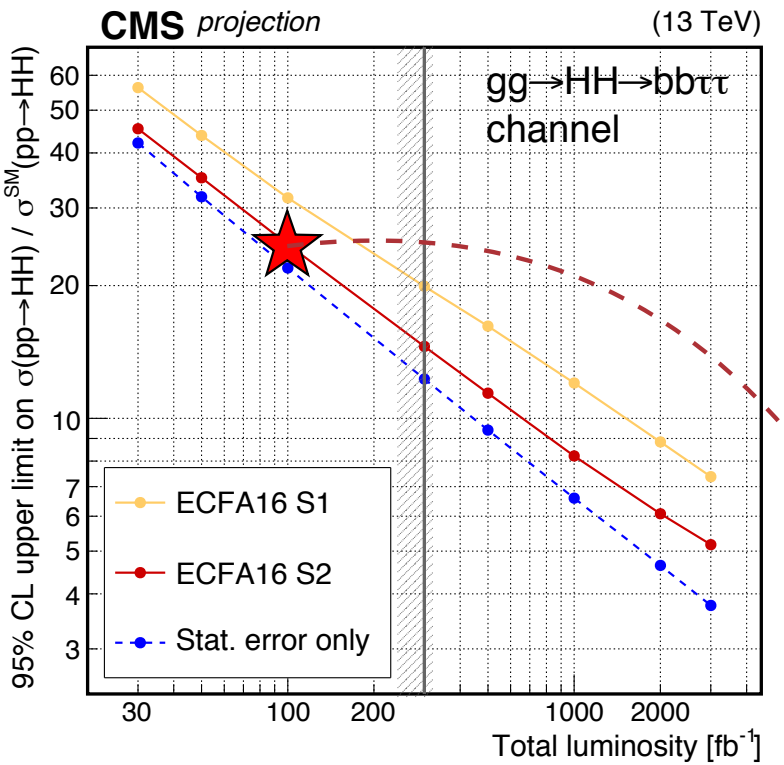
CMS PAS FTR-16-002

- Getting closer to observation of SM Higgs pair production:

  $22\ (13) \times \sigma_{SM}$ with $35.9\ \text{fb}^{-1}$

  - the single analyses are constantly improving
  - full Run II statistics: $\sim 150\ \text{fb}^{-1}$
- Observation out of reach for Run II, but **promising for HL-LHC** ($\sim 3000\ \text{fb}^{-1}$)

**Projection using 2015 data at 13 TeV**




$bb\tau\tau$ already overperformed the projected results

- result: $25 \times \sigma_{SM}$ with $35.9\ \text{fb}^{-1}$
- projection: $25 \times \sigma_{SM}$ with $100\ \text{fb}^{-1}$

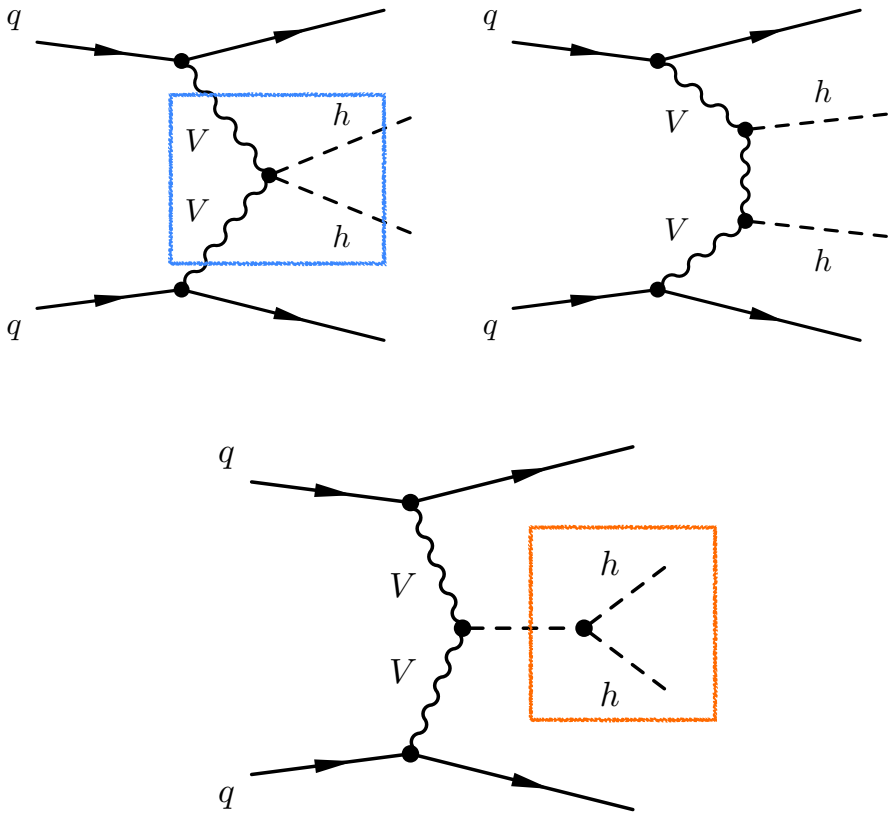
- results to be updated (Yellow Report 2018)

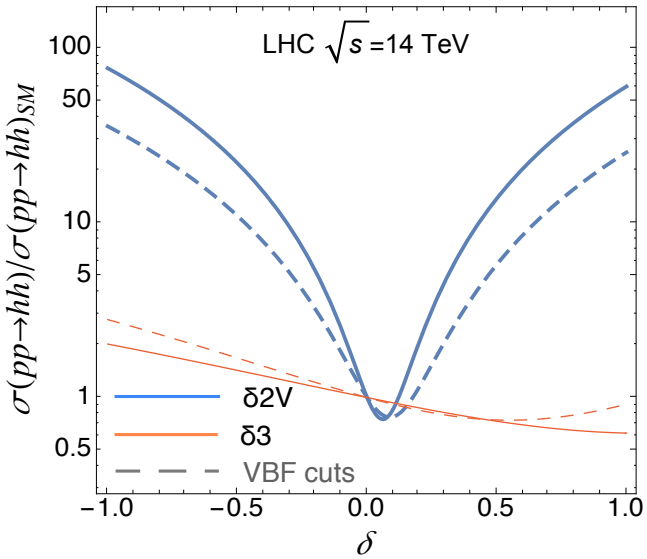
# Perspectives: production modes

arXiv:1401.7340

VBF HH production cross section is $\sim 2$ fb at $\sqrt{s} = 13$ TeV

- $\sigma_{ggF} \sim 20 \times \sigma_{VBF}$
- VBF category in bb$\gamma\gamma$ and planned for bb$\tau\tau$
- in addition to $\lambda_3$, can constrain $\lambda_{2V}$ (= $\lambda_V^2$ in the SM)




- **high sensitivity on $\lambda_{2V}$**: $\sigma/\sigma_{SM}$ up to 50 for $|\delta_{2V}| \sim 1$
  - $\delta = \lambda/\lambda_{SM} - 1$

# Conclusion

- Non-resonant and resonant Higgs pair production searches are performed in different channels
- Different channels have different sensitivities
  - The combination of channels brings a significant improvement
- The analyses with 2016 data performed better than the existing predictions
  - Combination of 2016 data: obs (exp) 22 (13)$\times\sigma_{SM}$ with 35.9 fb$^{-1}$
- The observation of the SM Higgs pair production is within reach of HL-LHC
  - Will we manage to extract the self-coupling?

# References

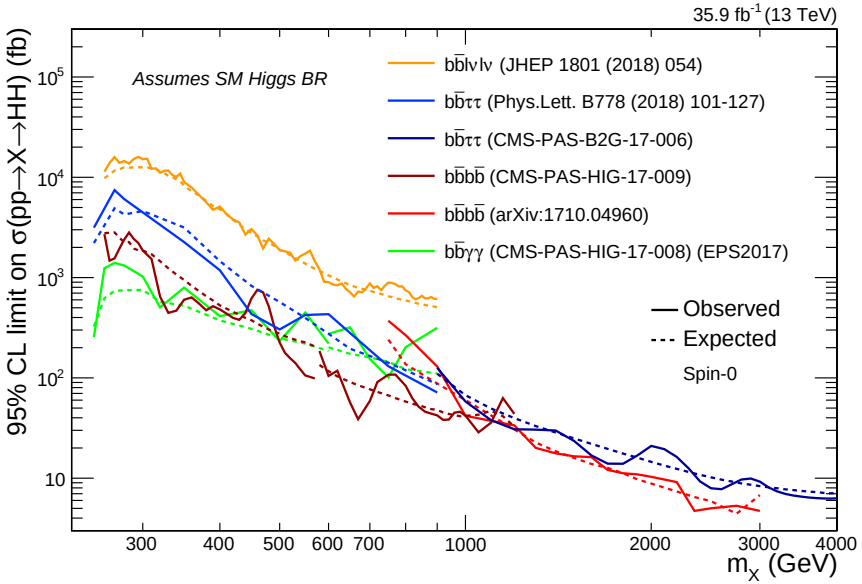
*Analyses included in the HH combination*:

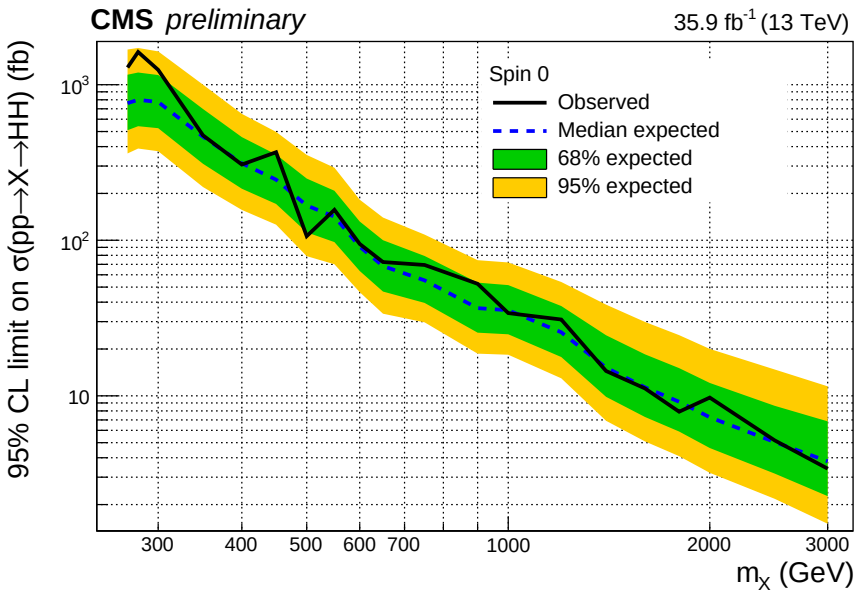
| | |
|---|---|
| bbVV($2\ell 2\nu$) | JHEP01(2018)054 |
| bb$\gamma\gamma$ low mass, non-resonant | CMS PAS HIG-17-008 |
| bb$\tau\tau$ low mass, non-resonant | PLB778(2018) |
| bb$\tau\tau$ high mass | CMS PAS B2G-17-006 |
| 4b low mass | CMS PAS HIG-17-009 |
| boosted 4b topologies | CMS PAS B2G-17-019 |
| 4b high mass | CMS PAS B2G-16-026 |
| 4b non-resonant | CMS PAS HIG-17-017 |

# Backup

# Results: resonant searches

## Different sensitivities in different regions




CMS PAS HIG-17-030

- Limits for spin-0 (radion) CP-even particles interpretation
- narrow width resonance hypothesis

# Systematics

| | |
|---|---|
| Triggers | no triggers in common, uncorrelated |
| Lepton and photon efficiencies | fully correlated for channels using the same objects (i.e. in bbVV, bb$\tau\tau$) |
| b-tag efficiencies | dominated by the misidentification rate of heavy flavour jets and b-tagging scale factors<br>• correlated across bbVV, bb$\tau\tau$, bb$\gamma\gamma$, res bbbb<br>• uncorrelated for non-res bbbb |
| Jet energy scale | uncertainties divided in 28 different sources<br>• all the sources are considered in the bbVV analysis<br>• for each source, effect on the yield is estimated in bb$\gamma\gamma$ and bb$\tau\tau$ and treated as correlated<br>• the residual shape effect is negligible and treated as uncorrelated<br>• bbbb uncorrelated |

Largest impact:

| | |
|---|---|
| bb$\tau\tau$ | $\tau$ energy scale (10%) |
| bb$\gamma\gamma$ | signal shape (5%) |
| bbbb | event yield fluctuations in the most sensitive BDT bins and overall background normalization (10%) |