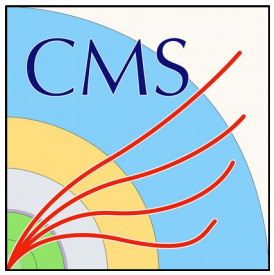
Search for di-Higgs production with 36 fb^{-1} of LHC data

Elisabeth Petit

on behalf of the ATLAS and CMS collaborations

LPSC Grenoble

Laboratoire de Physique Subatomique et de Cosmologie



26th International Conference on Supersymmetry and Unification of Fundamental Interactions

Barcelona, Spain

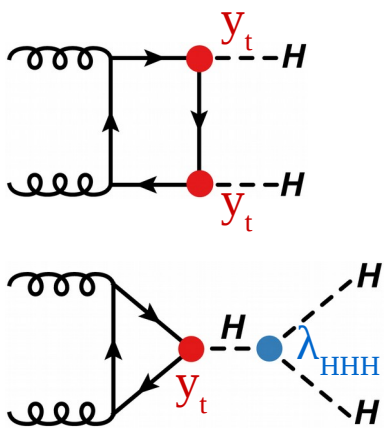
25th of July 2018

Double-Higgs production

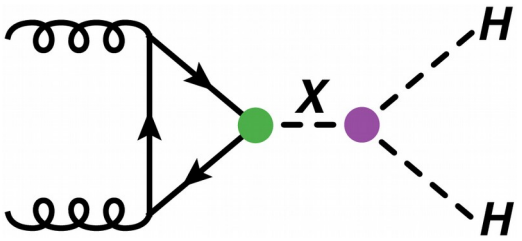
- Higgs self-coupling fundamental parameter of the SM

$$V(\Phi)=\frac{1}{2}\mu^2\Phi^2+\frac{1}{4}\lambda\Phi^4=\underbrace{\lambda v^2 h}_{\text{mass term}}+\underbrace{\lambda v h^3+\frac{1}{4}\lambda h^4}_{\text{self-coupling terms}}$$

- Rare process of the SM
  - destructive interference
  - $\sigma(gg\rightarrow HH)$ = 33 fb $\approx$ 1‰*$\sigma(gg\rightarrow H)$
  - BSM contribution can modify the Higgs boson coupling parameters and enhance the HH cross section

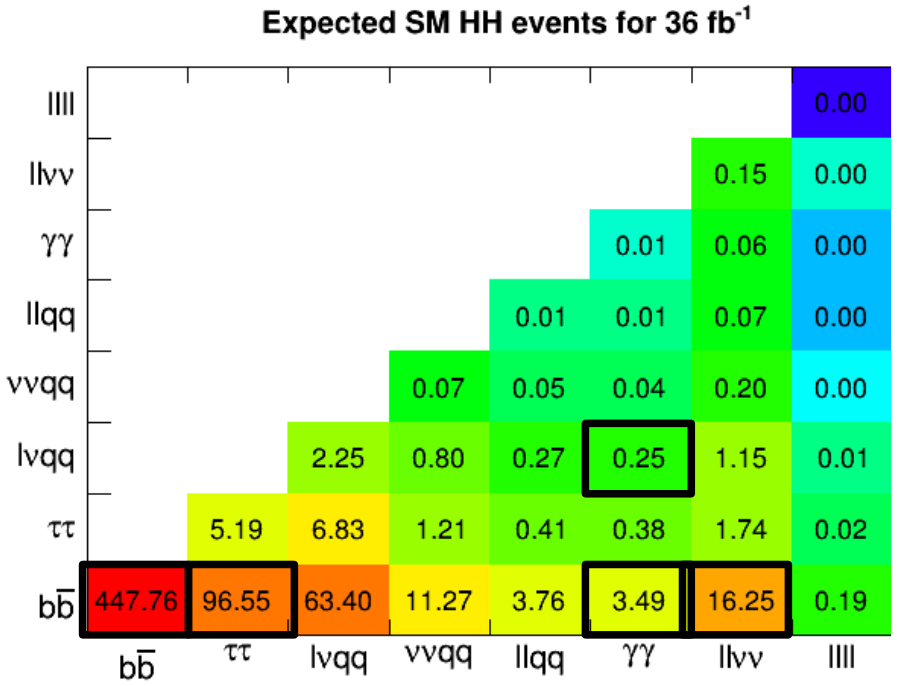


- Resonant production:
  - new heavy intermediate particle
  - KK graviton, radion, heavy Higgs bosons (2HDM), etc



Final states and Run-2 searches

- Channels considered:

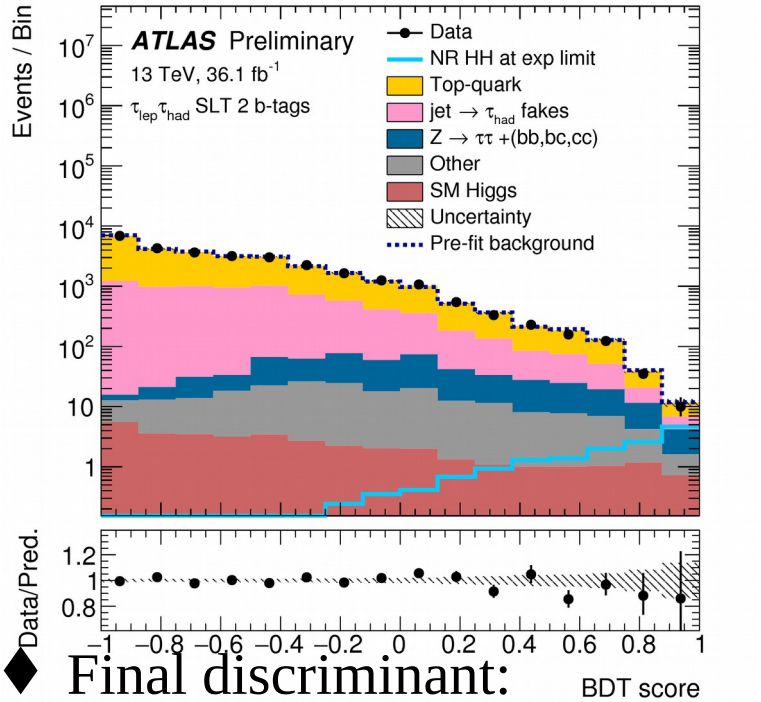


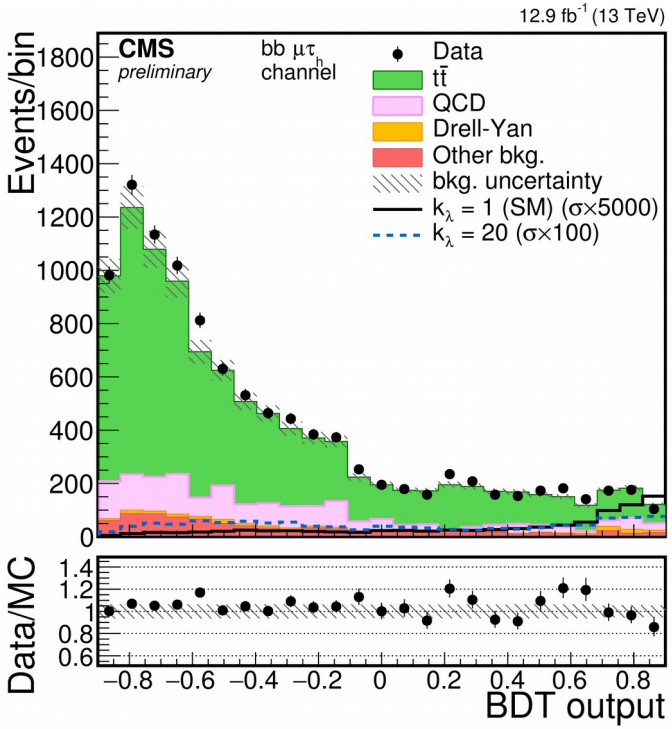
	ATLAS	CMS
$b\bar{b}\tau\tau$	CERN-EP-2018-164 (public soon) new	1707.02909 CMS-PAS-B2G-17-006
$b\bar{b}\gamma\gamma$	1807.04873	1806.00408
$b\bar{b}b\bar{b}$	1804.06174	1806.03548 new CMS-PAS-B2G-17-019 PAS-HIG-17-017
$b\bar{b}l\nu l\nu$		1708.04188
$l\nu qq\gamma\gamma$	1807.08567	
combination		PAS-HIG-17-030 new

- Presented today: analyses with ~36 fb^{-1} of data recorded in 2015-2016
- General analysis strategy:
  - candidate mass consistent with SM Higgs boson
  - small angular separation between b-jets ⇒ boosted regime above ~1 TeV
  - multivariate methods to reject background

$b\bar{b}\tau\tau$ channel

- Sizeable BR, relatively small background
- 2 b-jets + $\tau_{lep}\tau_{had}$ or $\tau_{had}\tau_{had}$
  - including boosted τ and b-jet for CMS
- BDT for resonant and non-resonant signal
  - new ATLAS: on non-resonant + each resonant mass point
  - CMS: resonant mass < or > 350 GeV

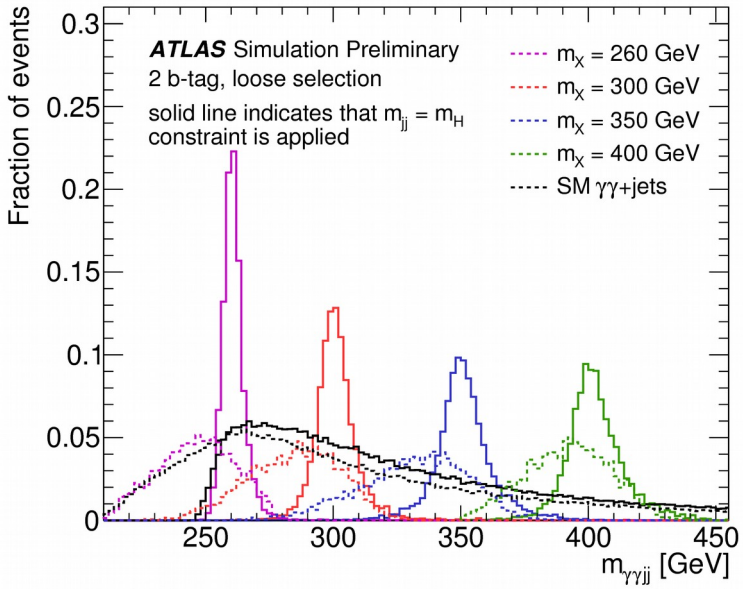




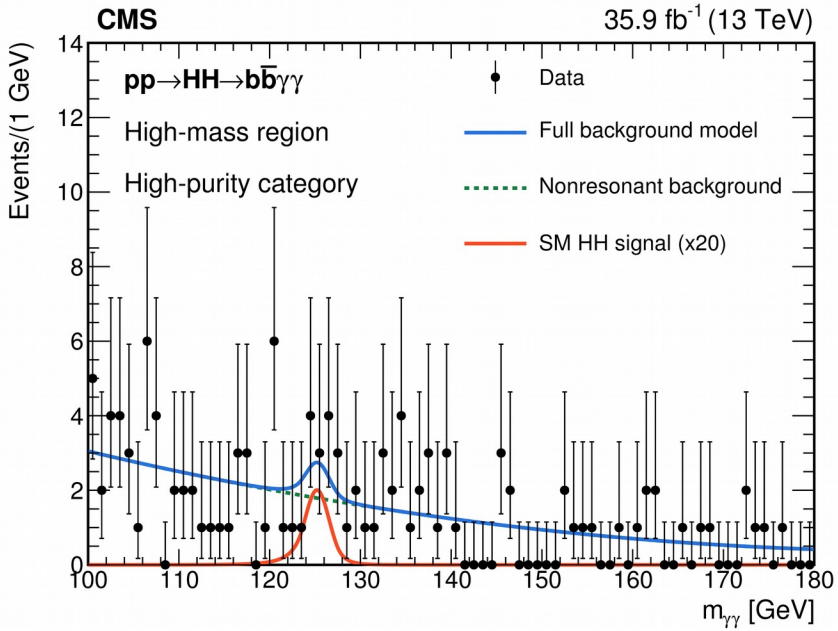
- Final discriminant:
  - BDT output (ATLAS)
  - modified m_{HH} for resonant, m_{T2} for non-resonant (CMS)

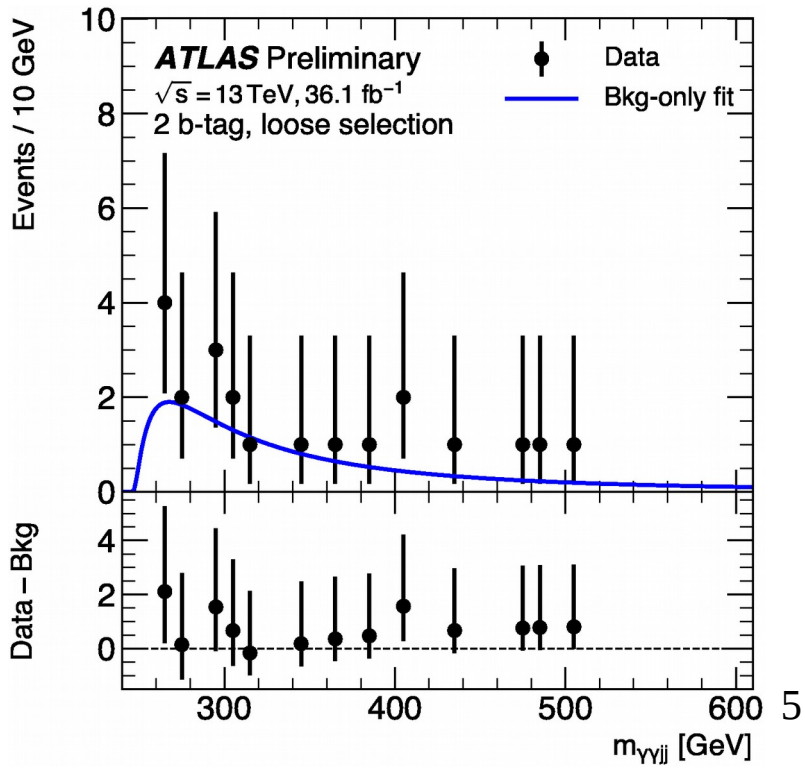
$b\bar{b}\gamma\gamma$ channel

- Small BR, good diphoton resolution, relatively small background
- 1 or 2 b-jets and two photons
  - corrected mass for resonant search
  - BDT selection (CMS)



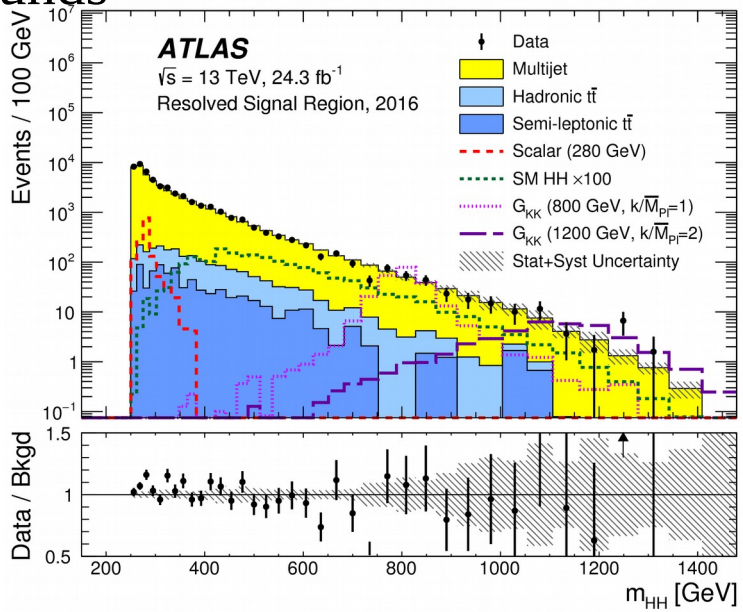
- Extraction of signal from parametric fits to:
  - $m_{\gamma\gamma}$ or $m_{\gamma\gamma jj}$ (ATLAS), $m_{\gamma\gamma} \times m_{jj}$ (CMS)





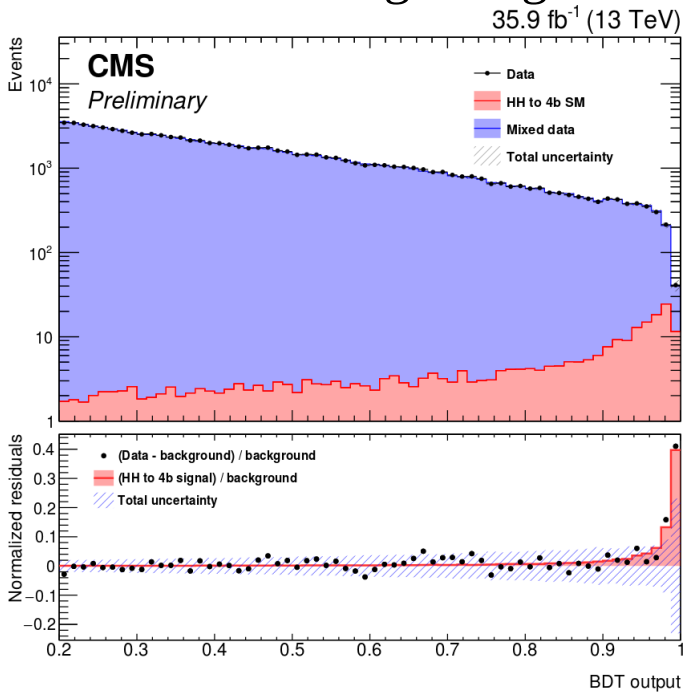
$b\bar{b}b\bar{b}$ channel

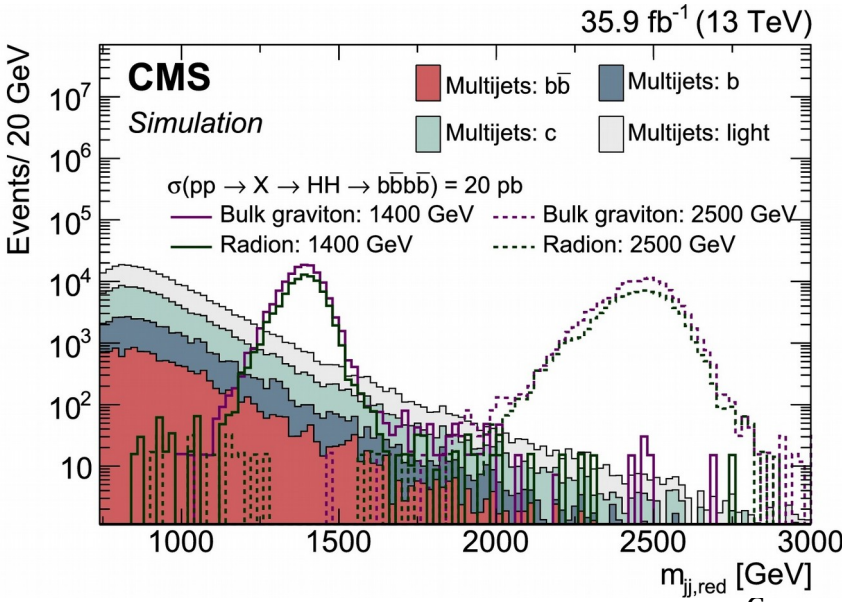
- Largest BR, large QCD multijets and $t\bar{t}$ backgrounds
- Large use of boosting techniques
  - 4 resolved b-jets: ~250-1200 GeV
  - semi-resolved (CMS): 750-~2000 GeV
  - 2 boosted b-jets: ~750-3000 GeV



- New result targeting non-resonant production:
  - new data-driven technique to provide samples for BDT training + bkg BDT shape

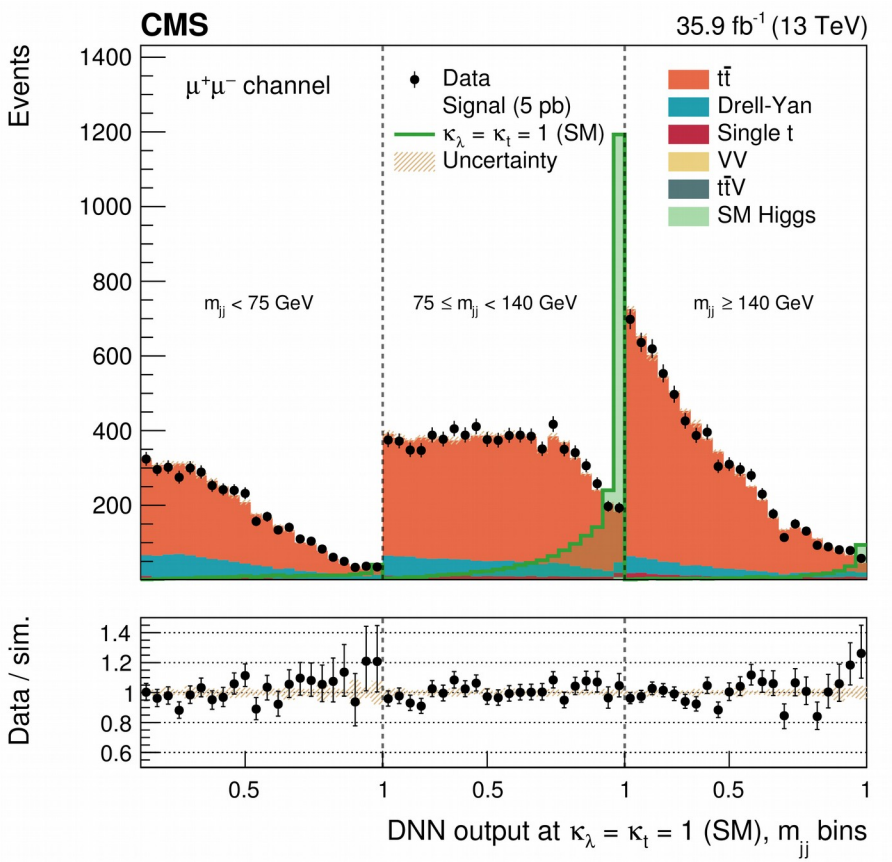
new



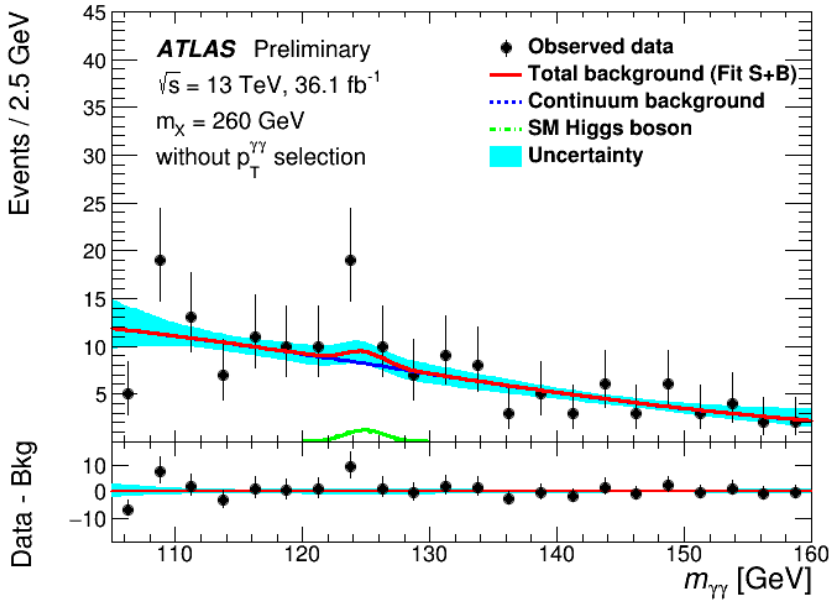


$b\bar{b}l\nu l\nu$ and $l\nu qq\gamma\gamma$ channels

- $b\bar{b}VV(\rightarrow l l \nu\nu)$: large BR, large bkg
- Two opposite sign leptons, two small-R b-tagged jets,
  $12 < m_{ll} < m_Z - 15$ GeV
- Neural network training + output used as discriminating variable

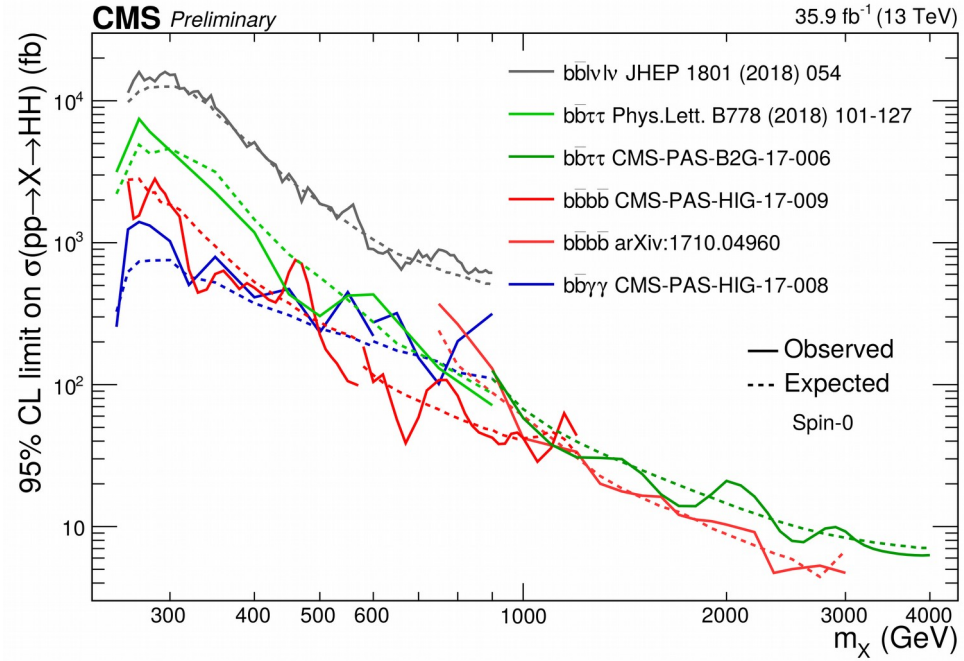


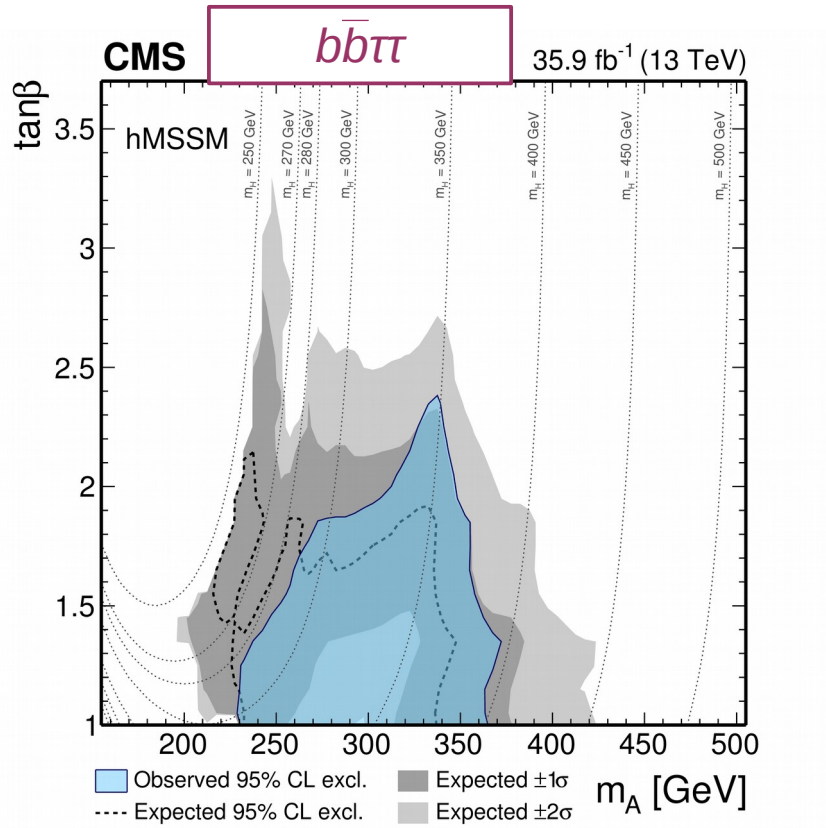
- $\gamma\gamma WW(\rightarrow l\nu qq)$: small BR, good diphoton resolution
- Two photons, one lepton (e or μ), two jets and no b-tagged jets
  - $p_T^{\gamma\gamma} > 100$ GeV for non-resonant and resonant search for mx > 400 GeV



Results for resonant HH

- Limit set on spin-0 (THDM, hMSSM) and spin-2 processes (graviton, radion, ...):
  - complementarity of the different channels and analysis techniques (resolved/boosted), combination in back-up
  - no significant excess

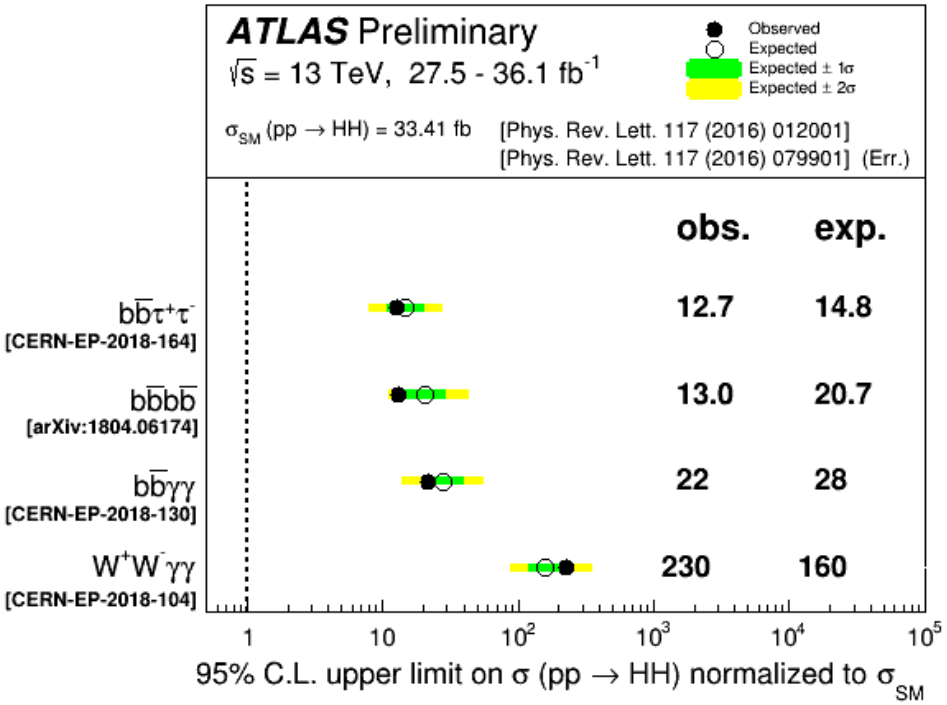


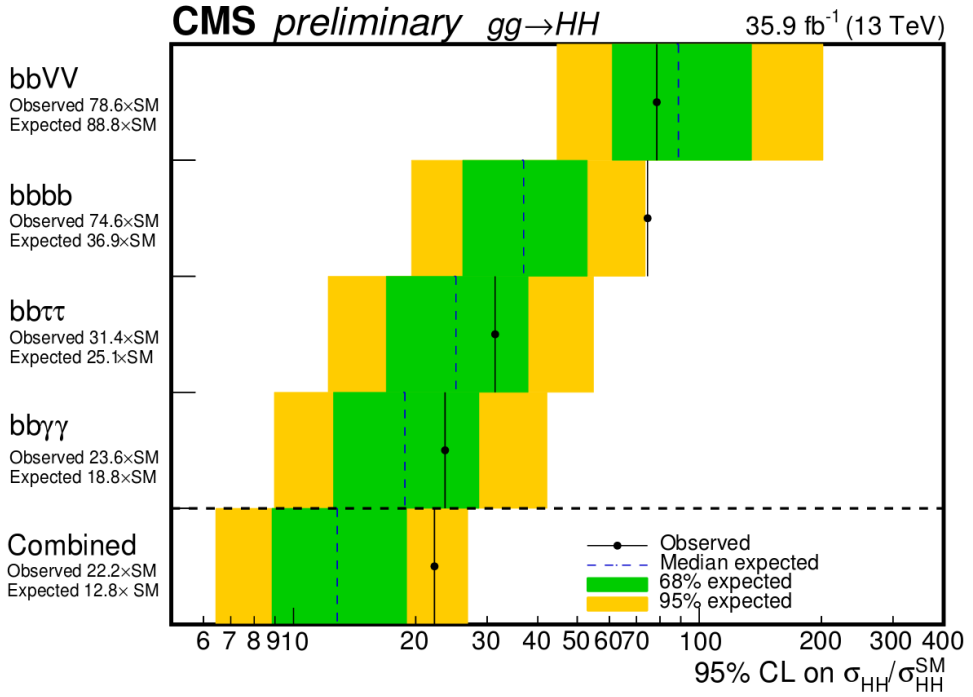


- Interpretation in hMSSM model
  - CP-even lighter scalar = h (125 GeV Higgs boson)
  - CP-even heavier scalar = H
  - CP-odd scalar = A

Results for non-resonant HH (1)

- Summary of limits on σ/σ_{SM}: new



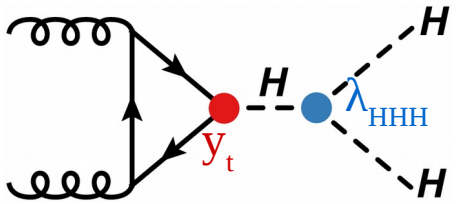


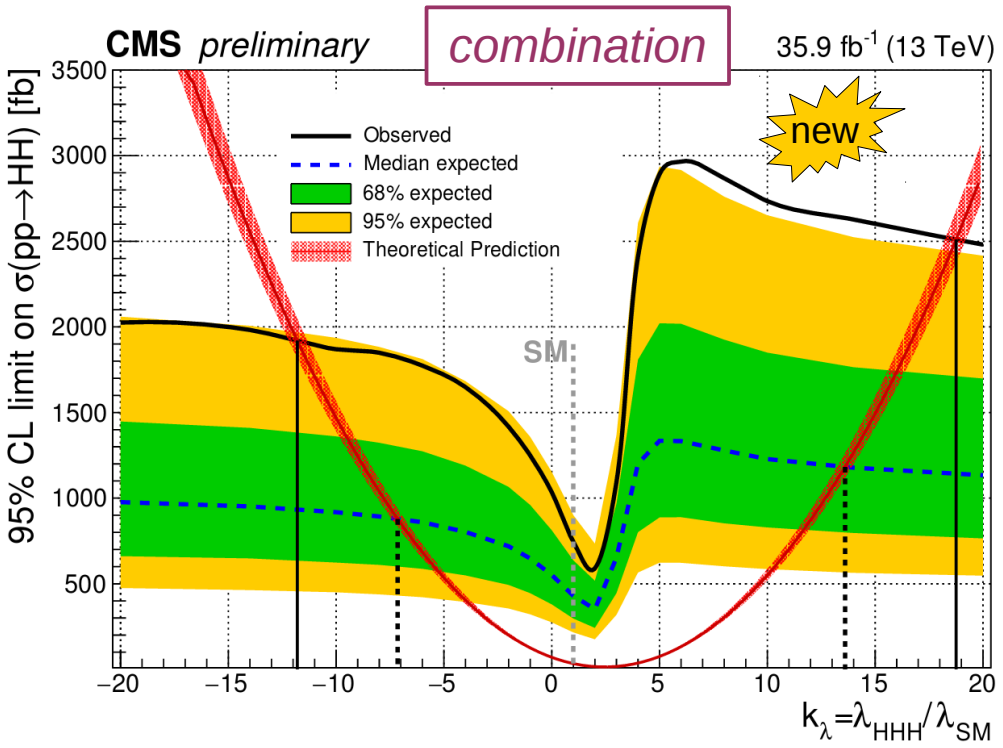
- Combined results: O(10*SM)
  - most sensitive channels: $b\bar{b}\tau\tau$, $b\bar{b}\gamma\gamma$, $b\bar{b}b\bar{b}$
  - difference of sensitivity between experiments ⇒ room for improvement

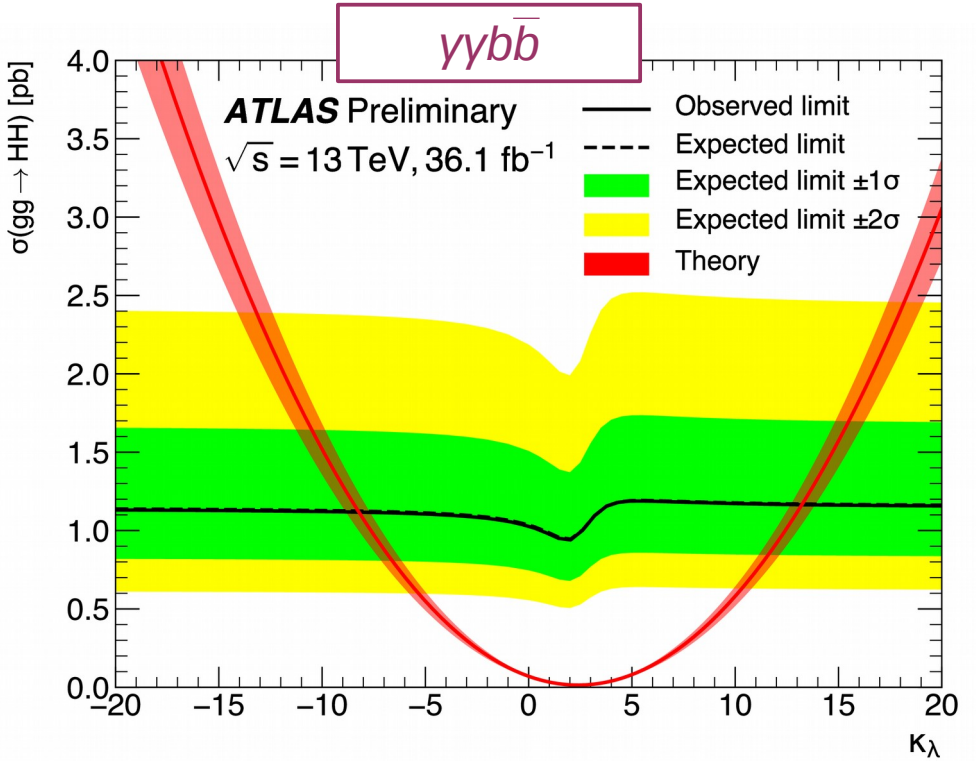
	expected limit on σ/σ_{SM}	
	ATLAS	CMS
bbττ	15	25
bbγγ	28	19
bbbb	21	37
bbllνν	-	89
lνqqγγ	160	
combination		13

Results for non-resonant HH (2)

- Limit on anomalous couplings: $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH,SM}$







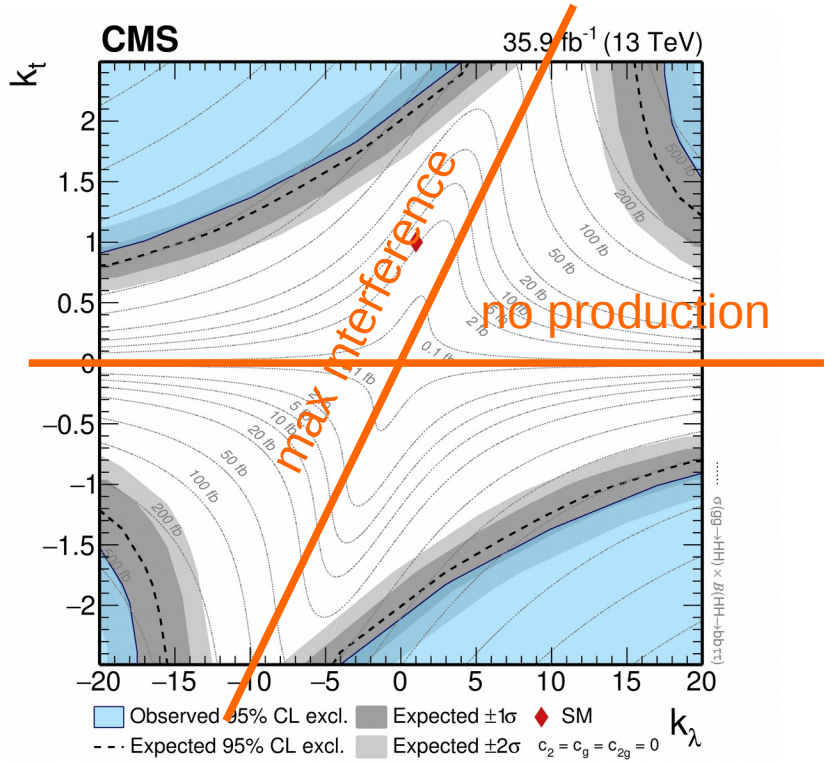
- Current limit: ~-7 < κ_λ < 14

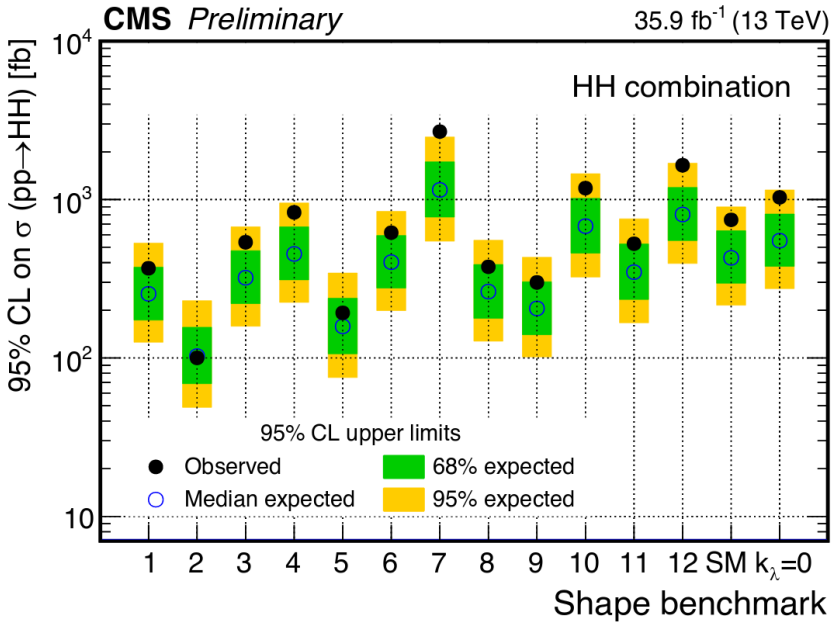
Results for non-resonant HH (3)

- EFT approach:

$$\mathcal{L}_h = \frac{1}{2}\partial_\mu h \partial^\mu h - \frac{1}{2}m_h^2 h^2 - \kappa_\lambda \lambda_{SM} v\, h^3 - \frac{m_t}{v}(v + \kappa_t h + \frac{c_2}{v} h\, h)\,(\bar{t_L} t_R + h.c.) + \frac{1}{4}\frac{\alpha_s}{3\pi v}(c_g h - \frac{c_{2g}}{2v} h\, h)\, G^{\mu\nu} G_{\mu\nu}$$

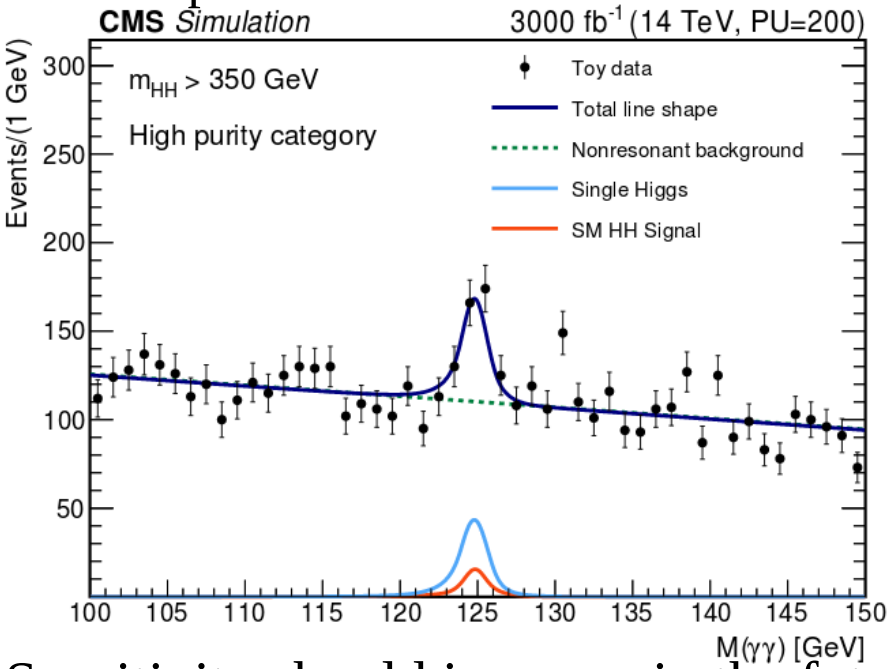
- Limit in κ_λ-κ_t plane:
- Interpretation with benchmark points (1507.02245):

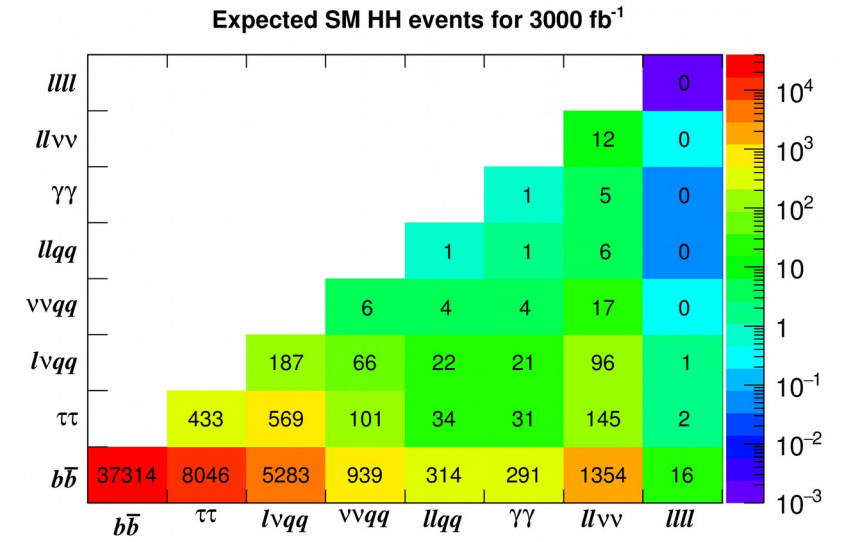


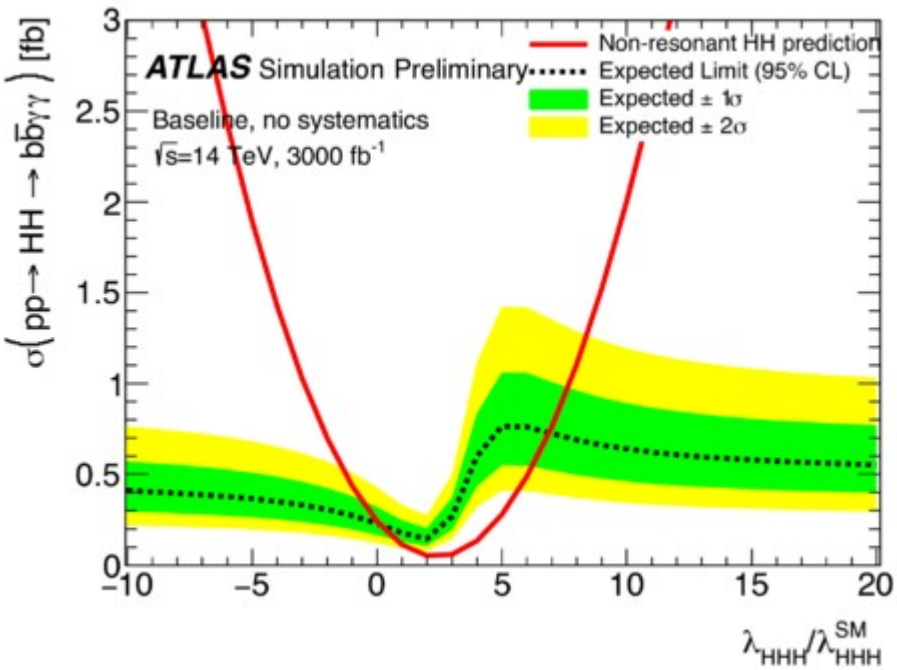


HL-LHC prospects

- 3000 fb^{-1} /experiment in 2035
- Currently best expected limit from $b\bar{b}\gamma\gamma$ channel: $0 < \kappa_\lambda < 7$
  - competitive limit from $b\bar{b}\tau\tau$



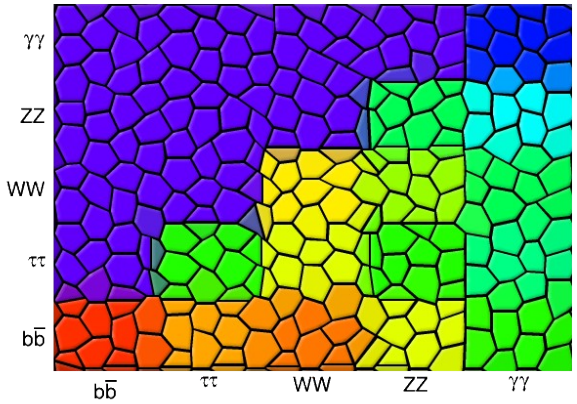




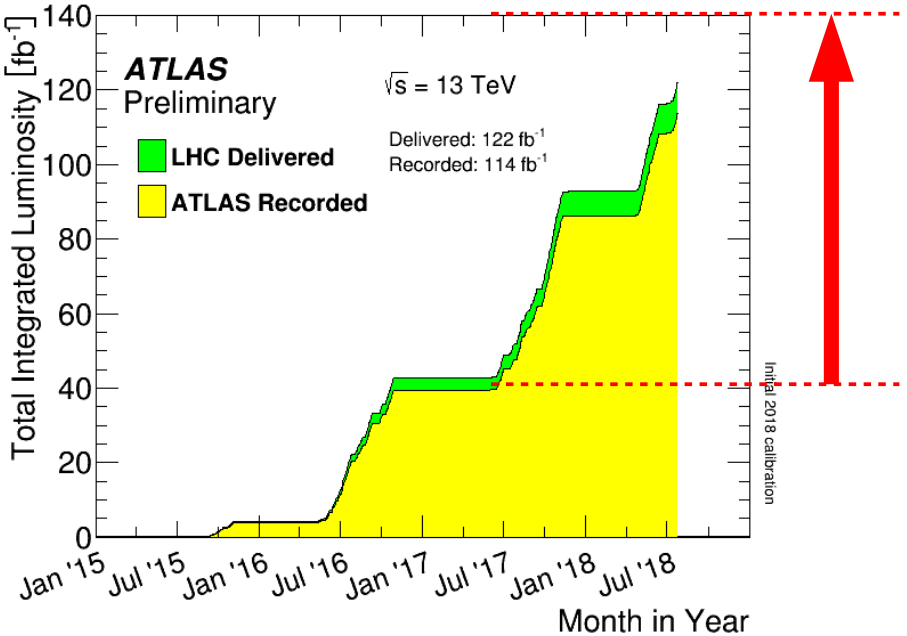
- Sensitivity should improve in the future:
  - better understanding of phase-2 detectors, improved physics object reconstruction
  - improve analysis strategy
  - combination of channels and experiments
- CERN Yellow Report foreseen end of 2018

Conclusion

- Di-Higgs searches based on ~36 fb^{-1} of LHC Run-2 data
  - several final states studied: $b\bar{b}b\bar{b}$, $b\bar{b}\gamma\gamma$, $b\bar{b}\tau\tau$, etc
  - improved sensitivity using boosted technologies and machine learning
- No significant excess observed in resonance search
- No excess in non-resonant production, limit ~10*SM



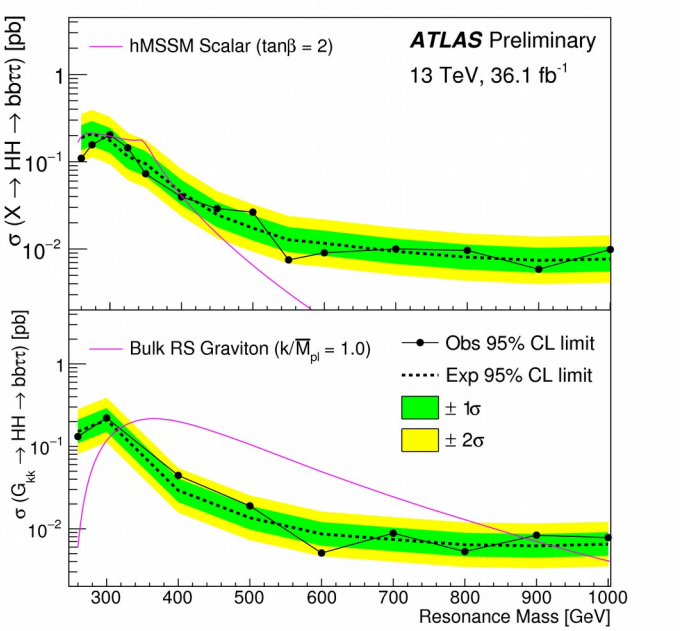
- Expected integrated luminosity by the end of Run-2: ~150 fb^{-1}
  - evidence of SM di-Higgs production and precise measurement of Higgs potential for HL-LHC

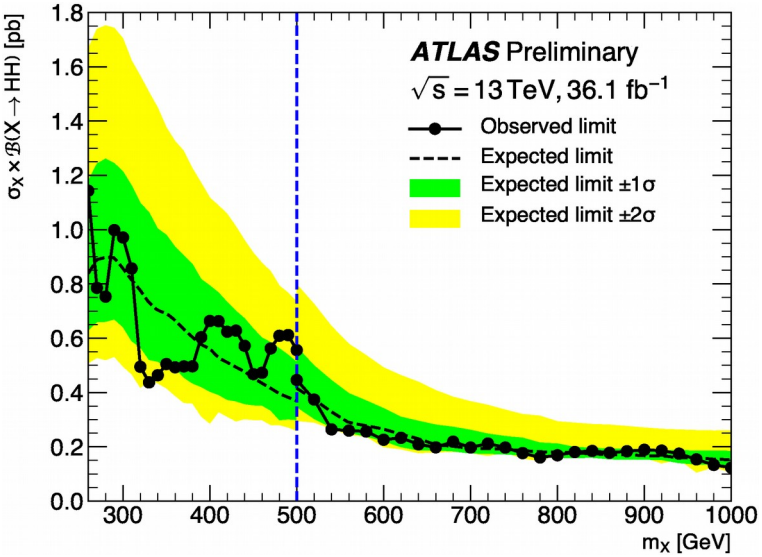


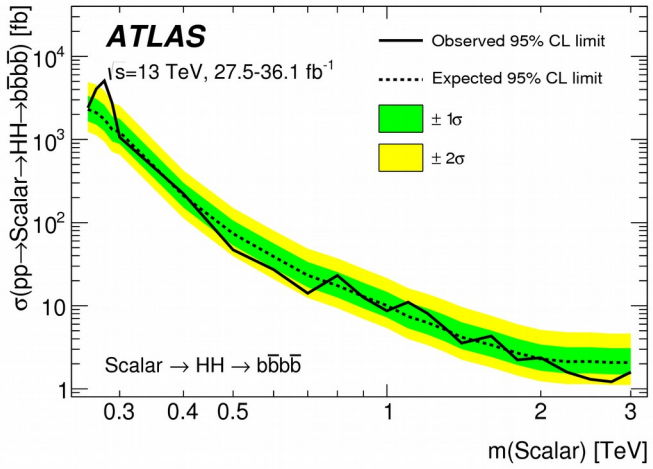
Back-up

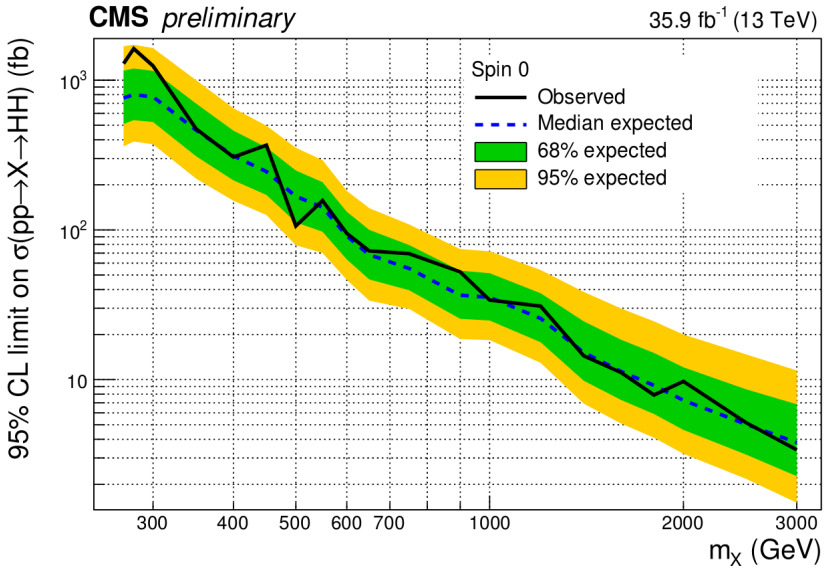
Results for resonant HH

- Limit set on spin-0 (2HDM, hMSSM) and spin-2 processes (graviton, radion, ...):





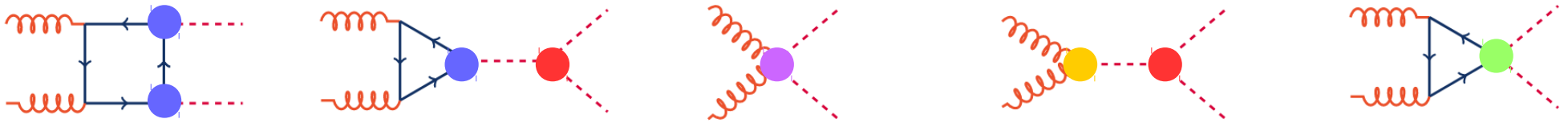




EFT approach

- From JHEP04(2016)126

$$\mathcal{L}_h = \frac{1}{2}\partial_\mu h \partial^\mu h - \frac{1}{2}m_h^2 h^2 - \kappa_\lambda \lambda_{SM} v\, h^3 - \frac{m_t}{v}(v + \kappa_t h + \frac{c_2}{v} h\, h)\,(\bar{t_L} t_R + h.c.) + \frac{1}{4}\frac{\alpha_s}{3\pi v}(c_g h - \frac{c_{2g}}{2v} h\, h)\, G^{\mu\nu} G_{\mu\nu}$$



- 12 benchmark points:

Benchmark	κ_λ	κ_t	c_2	c_g	c_{2g}
1	7.5	1.0	-1.0	0.0	0.0
2	1.0	1.0	0.5	-0.8	0.6
3	1.0	1.0	-1.5	0.0	-0.8
4	-3.5	1.5	-3.0	0.0	0.0
5	1.0	1.0	0.0	0.8	-1
6	2.4	1.0	0.0	0.2	-0.2
7	5.0	1.0	0.0	0.2	-0.2
8	15.0	1.0	0.0	-1	1
9	1.0	1.0	1.0	-0.6	0.6
10	10.0	1.5	-1.0	0.0	0.0
11	2.4	1.0	0.0	1	-1
12	15.0	1.0	1.0	0.0	0.0
SM	1.0	1.0	0.0	0.0	0.0