Prospects on HH production at the HL-LHC with the CMS experiment

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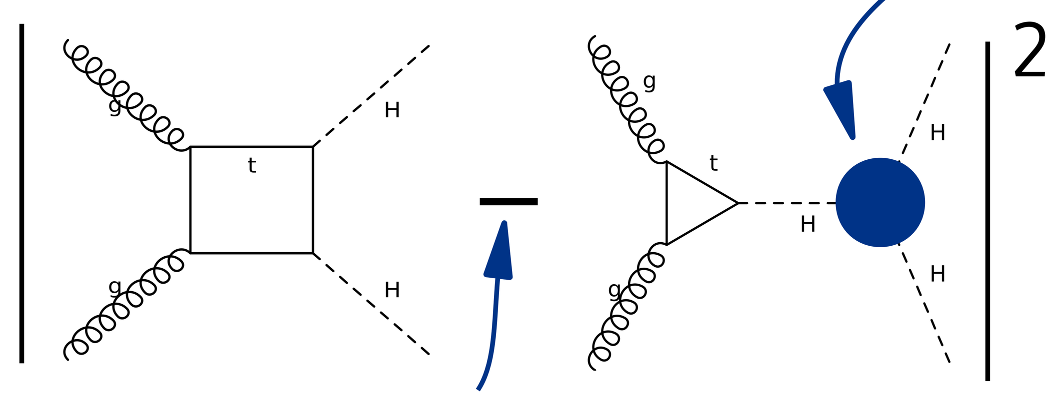
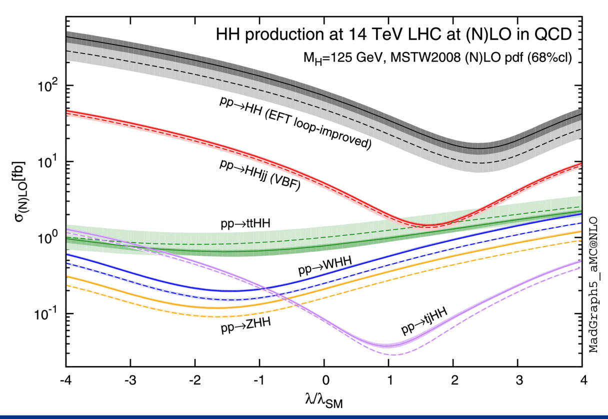
Double Higgs production

- Direct access to **Higgs self-coupling λ**
- Probe **scalar potential structure** !



- **Destructive interference**
  - → small cross-section : 40 fb @ 14 TeV
  - → strong variations if $\lambda \neq \lambda_{SM}$
- Dominated by gluon fusion :



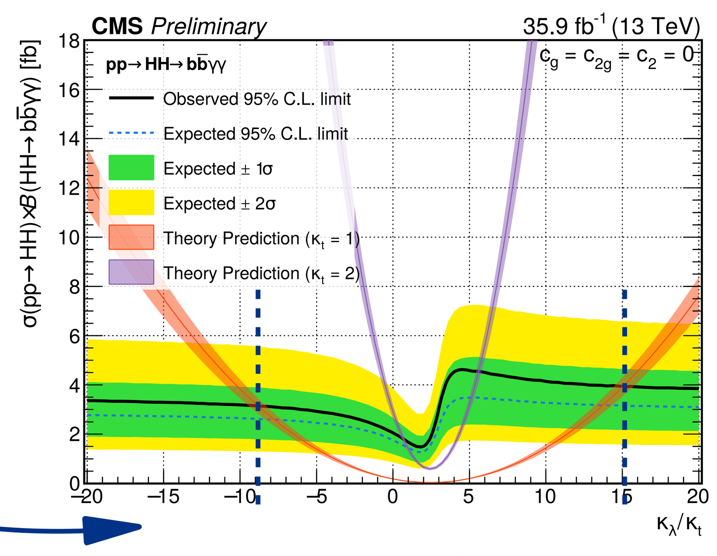
Current CMS double Higgs results

- Variety of final states probed
  - → maximise sensitivity
- Run I result : exp./obs. limit σ < 47/43 x σ_{SM}
- Run II : no excess seen, **limits on $\mu_r = \sigma/\sigma_{SM}$**

Final state	$b\bar{b}\gamma\gamma$[1]	$b\bar{b}\tau\tau$[1]	$b\bar{b}b\bar{b}$[2]	$b\bar{b}VV(l\nu l\nu)$[1]
Exp./obs.	16/19	25/30	308/342	89/79

- Search for **deviations from SM**

signal kinematics : dependence on $\kappa_\lambda = \lambda/\lambda_{SM}$

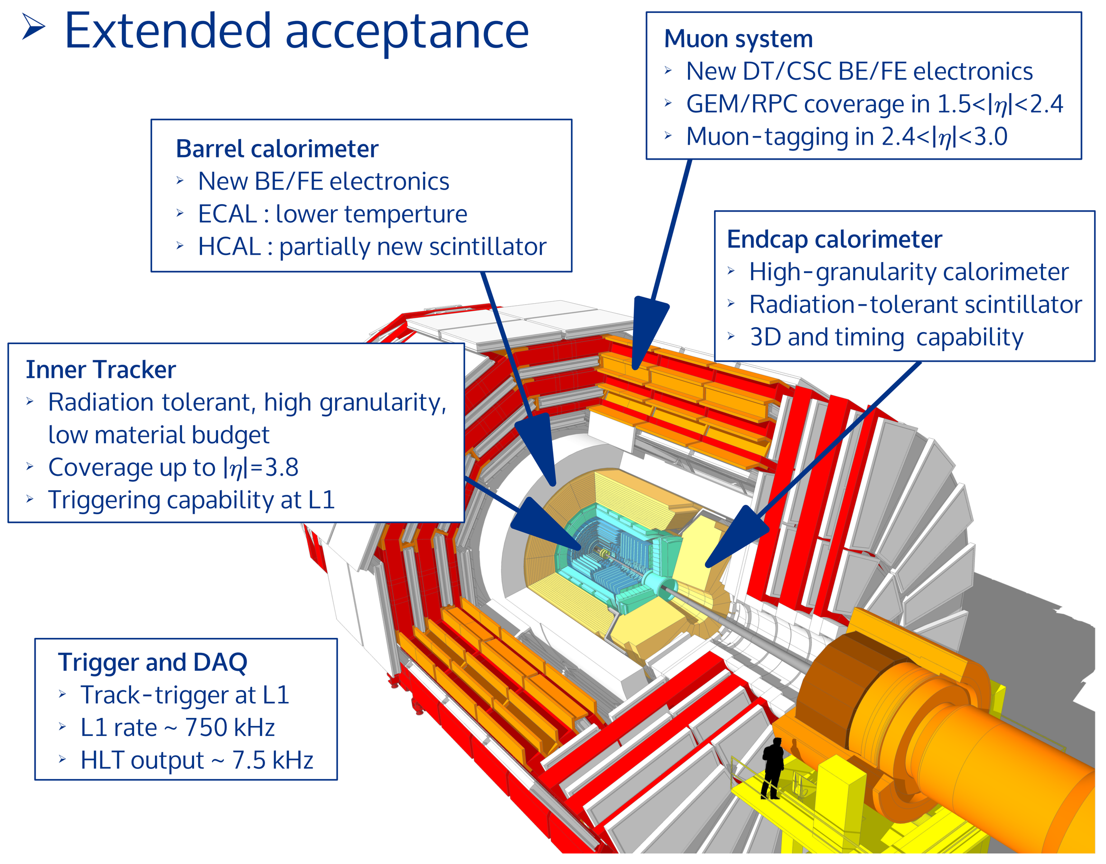


- Need **much more data** to constrain λ !

[1] 2016 data (35.9 fb⁻¹) / [2] 2015 data (2.3 fb⁻¹)

CMS Phase II Upgrade

- HL-LHC : 3000 fb^{-1} with L_{inst} ~ 5x10^{34}/cm^2/s
- Run I-II-III radiation damage
  - → new detector needed
- Maintain current performances despite <PU> ~ 140-200
- Extended acceptance

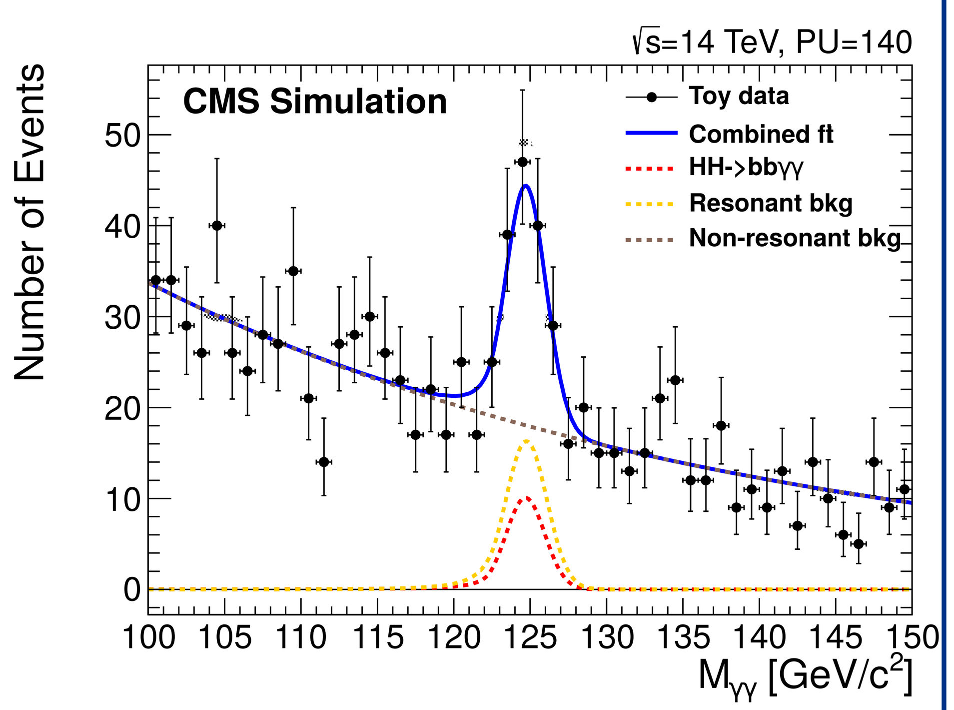


Dedicated upgrade studies

Follow upgrade **Technical Proposal (TP)** – <PU>=140, 3000 fb^{-1}

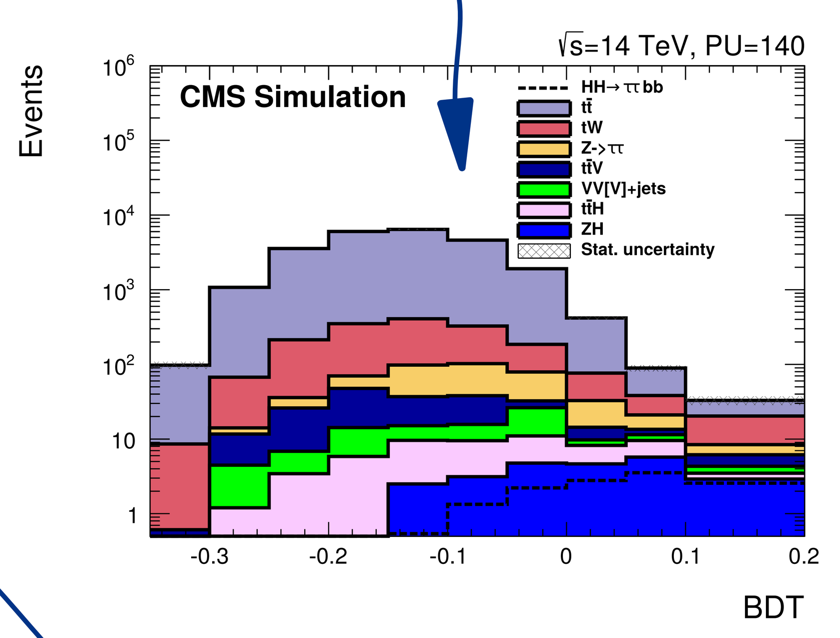
1) $b\bar{b}\gamma\gamma$ final state :

- Backgrounds : multijet + photons, $t\bar{t}(\gamma)$, single Higgs
- MC truth smeared & re-weighted
- 2D parametric fit on $M_{\gamma\gamma}$ vs. $M_{b\bar{b}}$
- **1.6 sigma** signal significance, **67 % precision** on σ_{HH}

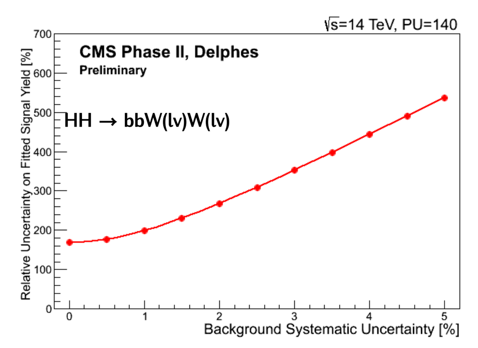


2) $b\bar{b}\tau\tau$ final state :

- Backgrounds : $t\bar{t}$(V), Z($\tau\tau$), VV, single Higgs, multijet assumed negligible
- DELPHES fast simulation tuned to full sim.
- Crucial : jet PU ID (E_T, $M_{\tau\tau}$ resolution), track-trigger
- Signal extraction : MT_2 variable ($\tau_{had}\tau_{had}$), BDT ($\tau_\mu\tau_{had}$)
- **0.9 sigma, 105 % precision** on σ_{HH}

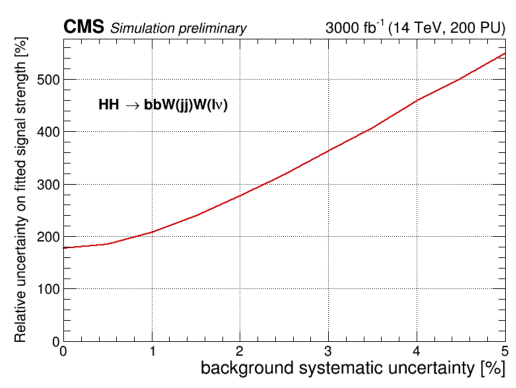


Combine $b\bar{b}\gamma\gamma$ and $b\bar{b}\tau\tau$:
1.9 sigma, 54 % prec. on σ_{HH}



3) $b\bar{b}VV$ final state (lνlν and lνjj):

- Only $t\bar{t}$ dominant background considered
- DELPHES simulation tuned to full sim.
- BDT (lνjj) and ANN (lνlν) discriminant
- Promising channels for combination



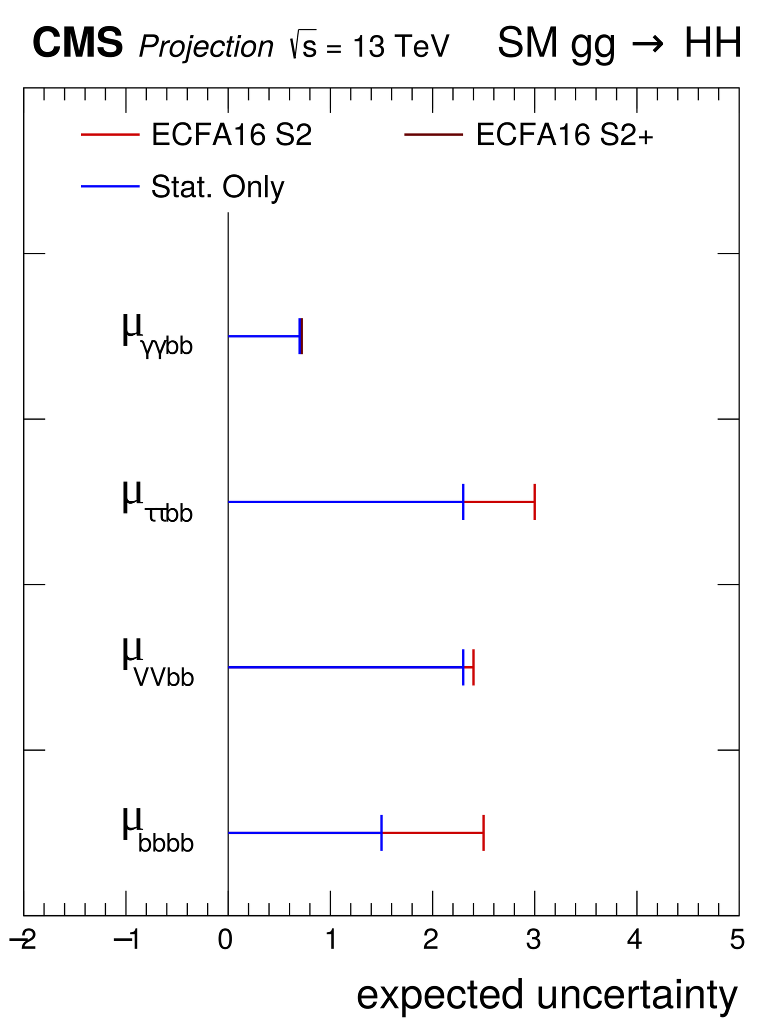
Extrapolation of Run II analyses

- Results on 2015 data @ 13 TeV (2.3-2.7 fb^{-1}) → projected to L_{int}=3000 fb^{-1}
- 13 → 14 TeV : σ_{HH} increase by 18 %, scale backgrounds same factor (pessimistic)
- Increased acceptance not considered (pessimistic)
- Scenarios assumed for systematic uncertainties :

1) « **Stat. only** » : scale yields with L_{int}; neglect systematics

2) « **ECFA16 S2** » :
- Theory uncertainties reduced by 50 %
- Experimental systematics :
  - → reduced with luminosity
  - → lower limit = estimated detector performances

3) « **ECFA16 S2+** » ($b\bar{b}\gamma\gamma$ only) :
- S2 + Impact of <PU>=200 & detector upgrades on photon performance (efficiency, resolution, fake rate) explicitly taken into account



Photon reconstruction :
- Majority of signal in Barrel
  - → performance similar to current detector
- Timing capabilities
  - → Vertex finding degradation (PU) mitigated
  - → Maintain $M_{\gamma\gamma}$ resolution

Channel	Median expected limits in μ_r ECFA16 S2	Median expected limits in μ_r Stat. Only	Z-value ECFA16 S2	Z-value Stat. Only	Uncertainty as fraction of μ_r = 1 ECFA16 S2	Uncertainty as fraction of μ_r = 1 Stat. Only
gg → HH → $\gamma\gamma$bb (S2+)	1.44	1.37	1.43	1.47	0.72	0.71
gg → HH → $\tau\tau$bb	5.2	3.9	0.39	0.53	2.6	1.9
gg → HH → VVbb (lνlν)	4.8	4.6	0.45	0.47	2.4	2.3
gg → HH → bbbb	7.0	2.9	0.39	0.67	2.5	1.5

Main backgrounds est. from data
→ Stat. uncertainty only (scaled with L)

Multijet bkg. from data → negligible stat. uncertainty
Lepton (incl. τ) uncertainties as of 2015
Differences with dedicated study :
- Multijet bkg. not explicitly rejected
- Signal extraction less aggressive

Conclusions

- Double Higgs production : Crucial channel at HL-LHC
- Dedicated studies, projections of existing analyses
  - → Estimate ultimate sensitivity & identify bottlenecks
- Even with 3000 fb^{-1}, observation challenging ! Will require :
  - Combination of several final states (new channels being considered)
  - Maximised signal acceptance
  - Keeping theory & experimental systematics in check

References

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