Updated studies for Higgs measurements LHCb and CMS

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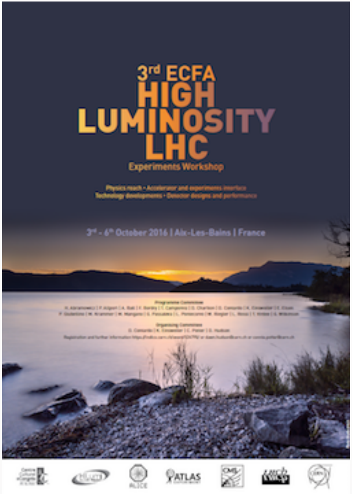
ECFA High Luminosity LHC Experiments - 2016

Outline

- **CMS results**
  - **Introduction**
  - **SM Higgs projections:**
    - $H \rightarrow \gamma\gamma$
    - $H \rightarrow ZZ$
  - **Double Higgs projections**
    - $HH \rightarrow bb\gamma\gamma$
    - $HH \rightarrow bbbb$
    - $HH \rightarrow bb\tau\tau$
    - $HH \rightarrow bbWW$
    - $HH \rightarrow bbWW$ Phase II study
  - **BSM Higgs projections**
    - $H \rightarrow \tau\tau$
    - $H \rightarrow inv.$
- **LHCb results**
- **Summary**



CMS Results

Introduction

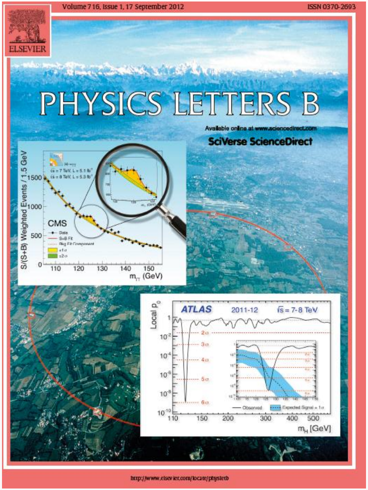
From the discovery machine to the Higgs factory

High Luminosity-LHC:

- Precision measurements
- Rare decays and couplings
- HH production - Higgs self-coupling

Performance studies at 3000 fb^{-1}:

- Projections from current analyses
- Studies using the CMS upgraded detector simulated with Delphes



Higgs physics & upgraded detector

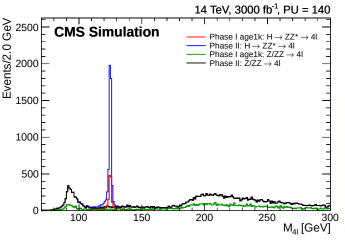
The expected performance of the CMS upgrades is described in the following documents:

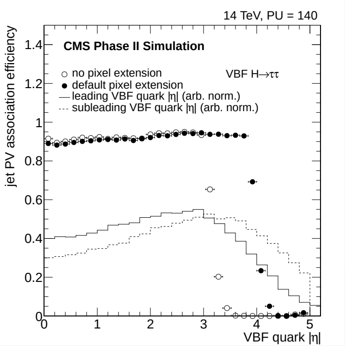
- **LHCC-P-008**
- **LHCC-G-165**

Studies from these documents are taken into account to define the projection scenarios presented here

Higgs studies show the gain in:

- Performance
- Extended coverage





Extrapolation strategy

Public results are extrapolated to larger data sets 300 and 3000 fb^{-1}. In order to summarize the future physics potential of the CMS detector at the HL-LHC, extrapolations are presented under different uncertainty scenarios:

- **S1** All systematic uncertainties are kept constant with integrated luminosity. The performance of the CMS detector is assumed to be the unchanged with respect to the reference analysis
- **S1+** All systematic uncertainties are kept constant with integrated luminosity. The effects of higher pileup conditions and detector upgrades on the future performance of CMS are taken into account
- **S2** Theoretical uncertainties scaled down by a factor 1/2, while experimental systematic uncertainties are scaled down by the square root of the integrated luminosity until they reach a defined lower limit based on estimates of the achievable accuracy with the upgraded detector. The effects of higher pileup conditions and detector upgrades on the future performance of CMS are not taken into account
- **S2+** Theoretical uncertainties scaled down by a factor 1/2, while experimental systematic uncertainties are scaled down by the square root of the integrated luminosity until they reach a defined lower limit based on estimates of the achievable accuracy with the upgraded detector. The effects of higher pileup conditions and detector upgrades on the future performance of CMS are taken into account

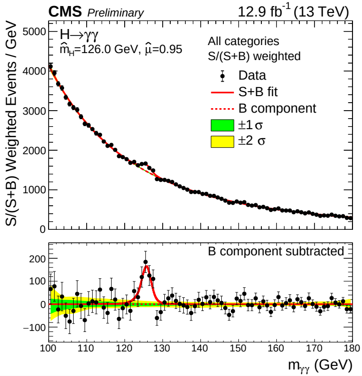
Extrapolation strategy

Public results are extrapolated to larger data sets 300 and 3000 fb^{-1}. In order to summarize the future physics potential of the CMS detector at the HL-LHC, extrapolations are presented under different uncertainty scenarios:

	systematics unchanged	exp. sys. scaled* $1/\sqrt{L}$	theo. sys. scaled 1/2	high PU effects
ECFA16 S1	✓	✗	✗	✗
ECFA16 S1+	✓	✗	✗	✓
ECFA16 S2	✗	✓	✓	✗
ECFA16 S2+	✗	✓	✓	✓

(*) until they reach a defined lower limit based on estimates of the achievable accuracy with the upgraded detector.

Higgs properties in the H$\rightarrow \gamma\gamma$ channel using **12.9 fb^{-1}** of data at 13 TeV



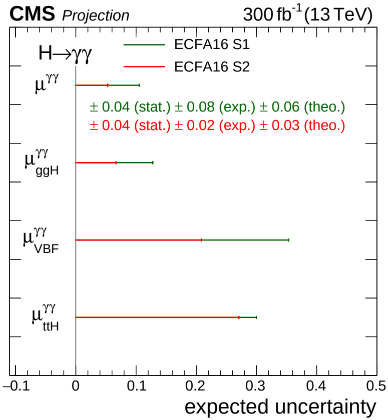
Selected measurements have been projected to 300 (3000) fb^{-1}:

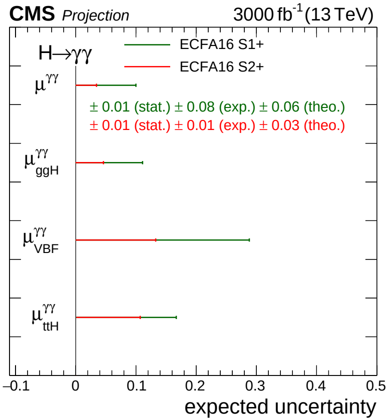
- Signal strength per production mode
- Fiducial cross section measurement

For 3000 fb^{-1}, the effect of high pileup and detector performance are considered (based on LHCC-P-008):

- The beamspot is simulated to be ∼5cm
- Vertex identification reduced from 80% to 40%
- Photon ID efficiency decreased by 2.3% (10%) in EB (EE)

$H \to \gamma\gamma$ - Signal strength





Extrapolation to 300 fb^{-1}

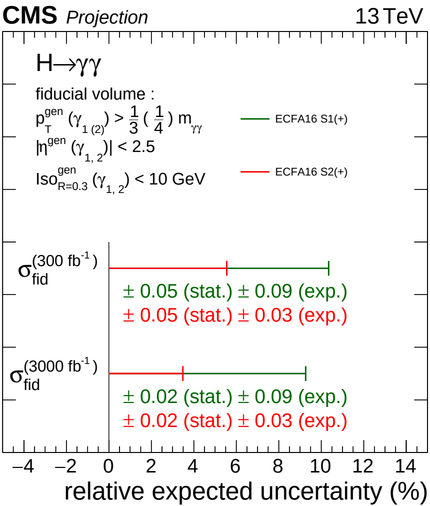
Extrapolation to 3000 fb^{-1}

$H \to \gamma\gamma$ - Fiducial cross section

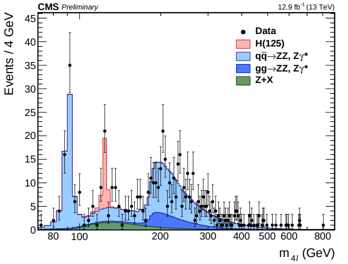
Projected relative uncertainty for the $H \to \gamma\gamma$ fiducial cross section (σ_{fid})

Fiducial volume defined on generator-level quantities

Theoretical uncertainty on the signal cross section decoupled



Higgs properties in the $H \to ZZ$ channel using **12.9 fb^{-1}** of data at 13 TeV



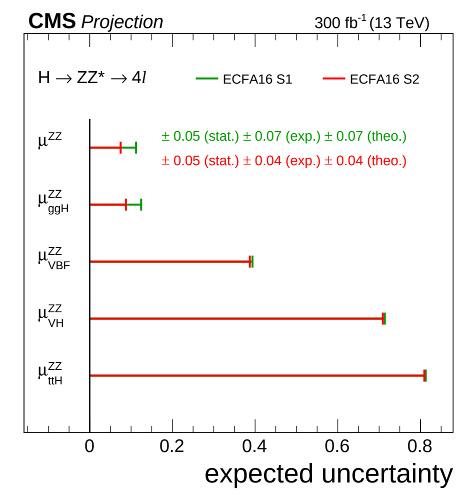
Selected measurements have been projected to 300 (3000) fb^{-1}:

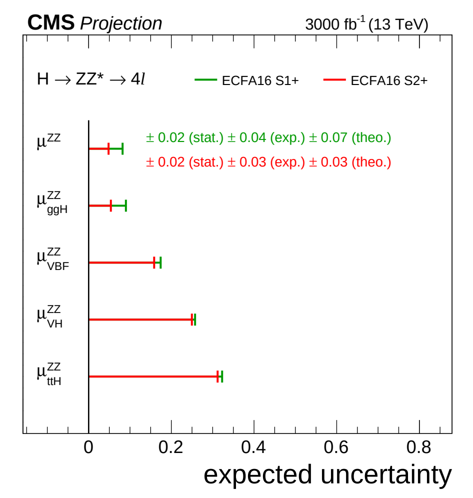
- Signal strength per production mode
- Differential cross section for $p_T(H)$
- Constraints on anomalous couplings

For 3000 fb^{-1}, the effect of high pileup is considered (based on LHCC-P-008):

- Lepton efficiency
- Misidentification rates

H → ZZ - Signal Strength

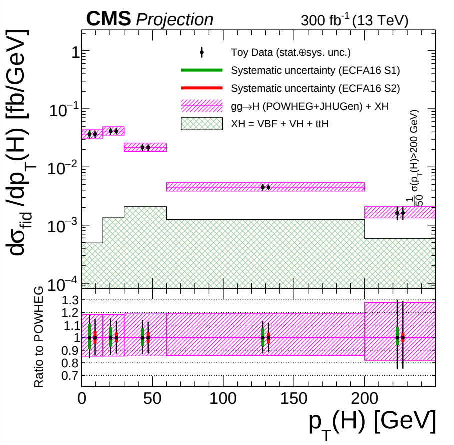


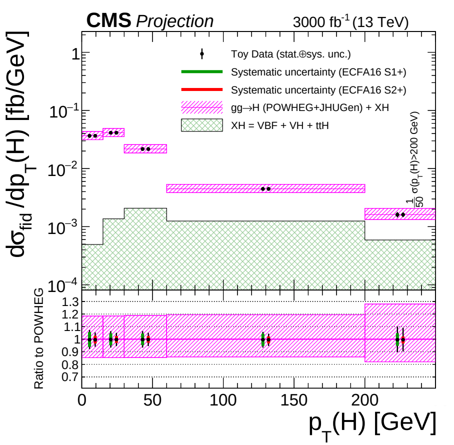


Extrapolation to 300 fb^{-1}

Extrapolation to 3000 fb^{-1}

H → ZZ - Differential $p_T(H)$ Cross Section





Extrapolation to 300 fb^{-1} **Extrapolation to 3000 fb^{-1}**

H → ZZ - Anomalous couplings

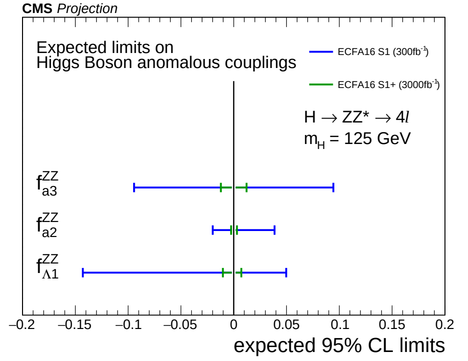
Generic decay amplitude of $H \to ZZ$ for spin-0 particle:

$$A(H \to VV) \sim \left[a_1 - e^{i\phi_{\Lambda Q}} \frac{(q_{V1}+q_{V2})^2}{\Lambda_Q^2} - e^{i\phi_{\Lambda 1}} \frac{(q_{V1}^2+q_{V2}^2)}{\Lambda_1^2}\right] m_V^2 \epsilon_1^* \epsilon_2^* + a_2 f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3 f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}$$

- Test for anomalous HZZ couplings a_i:

$$f_{ai} = \frac{|a_i|^2\sigma_i}{\sum_j |a_j|^2\sigma_j},\ \phi_{ai} = \tan^{-1}(a_i/a_1)$$

- Interference contribution becomes more dominant at smaller values of $f_{ai} \times \cos(\phi_{ai})$



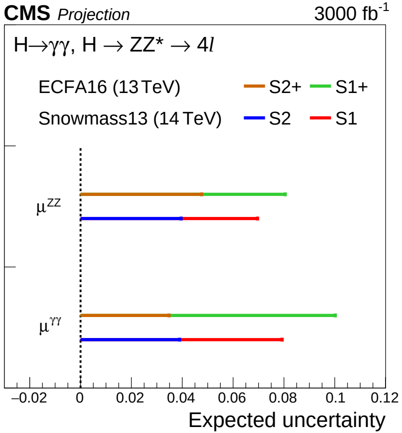
Comparison with previous results (Snowmass13)

ECFA16 vs Snowmass13

Snowmass assumptions:

- Energy from 8 TeV to 14 TeV
- Theory uncertainties from YR3
- S2 scenario does not include any lower bound when scaling down the experimental uncertainties

ECFA16 theory uncertainties from YR4 (ducument in preparation)

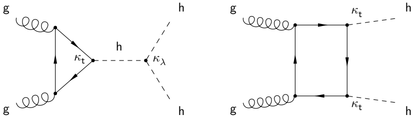


Higgs boson Pair Production

Next milestone in Higgs physics

Access to the H **self-coupling** λ

- Scalar potential structure



- Very low production cross section
  - Destructive interference
  - $\sigma(\mathbf{pp} \rightarrow \mathbf{HH})^{\mathbf{SM}}_{\mathbf{NNLO+NNLL}} = \mathbf{33.45\ fb}$ (@ 13TeV)

Four results at 13 TeV:

- $HH \rightarrow bb\gamma\gamma$ **CMS-PAS-HIG-16-032**
- $HH \rightarrow bbbb$ **CMS-PAS-HIG-16-026**
- $HH \rightarrow bb\tau\tau$ **CMS-PAS-HIG-16-012**
- $HH \rightarrow bbWW \rightarrow bbl\nu l\nu$ **CMS-PAS-HIG-16-024**

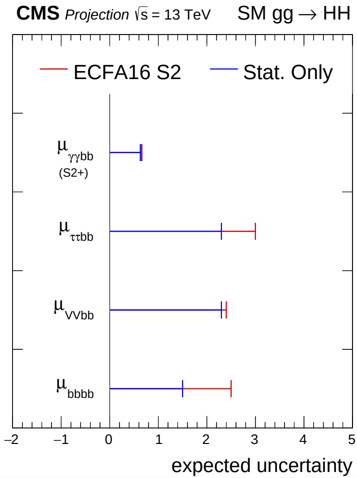
Higgs boson Pair Production

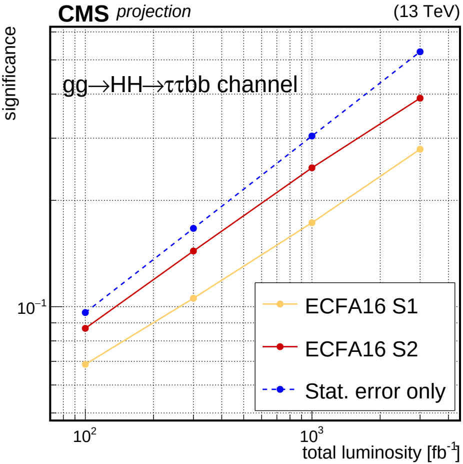
Projections from public analyses using 2015 data at 13 TeV

Channel	Median expected limits in μ_r			Z-value			Uncertainty as fraction of $\mu_r = 1$		
	ECFA16		Stat.	ECFA16		Stat.	ECFA16		Stat.
	S1	S2	Only	S1	S2	Only	S1	S2	Only
$gg \to HH \to \gamma\gamma bb$ (S1+/S2+)	1.3	1.3	1.3	1.6	1.6	1.6	0.64	0.64	0.64
$gg \to HH \to \tau\tau bb$	7.4	5.2	3.9	0.28	0.39	0.53	3.7	2.6	1.9
$gg \to HH \to VVbb$		4.8	4.6		0.45	0.47		2.4	2.3
$gg \to HH \to bbbb$		7.0	2.9		0.39	0.67		2.5	1.5

Results compatible with previous studies assuming the HL-LHC conditions **CMS-PAS-FTR-15-002**

Higgs boson Pair Production





HH $\rightarrow$ bbWW $\rightarrow$ bbjjlν in Phase II

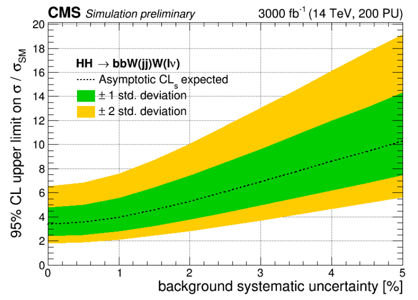
Study based on **Delphes** simulation of the **upgraded CMS detector**

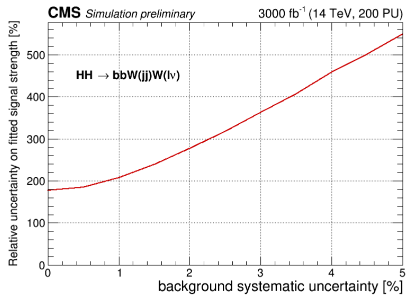
- Energy: 14 TeV
- Pile up 200
- Integrated luminosity: 3000 fb^{-1}

Analysis features:

- Only background considered: $t\bar{t}$
- Signal optimisation via BDT

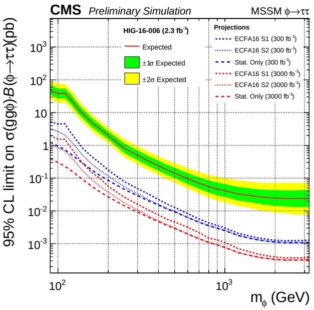
Similar performance compared to previous studies on HH $\rightarrow$ bbWW $\rightarrow$ $bbl\nu l\nu$ (CMS-PAS-FTR-15-002)

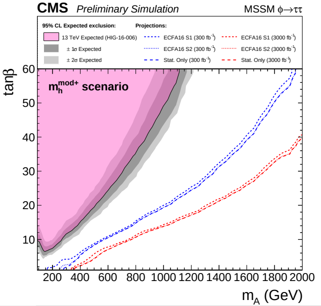




Search using 2.3 fb^{-1} of data at 13 TeV

- One of the most sensitive channels for constraining extended Higgs sectors
- Cross sections limits:
  - $gg(\phi \rightarrow \tau\tau)$
  - $bb(\phi \rightarrow \tau\tau)$
- Model dependent limits:
  - $\mathbf{m}^{\mathbf{mod}+}$ benchmark
- Sensitivity at high m_A still dominated by statistics





ECFA16 S1 (300 fb^{-1})	ECFA16 S1 (3000 fb^{-1})
ECFA16 S2 (300 fb^{-1})	ECFA16 S2 (3000 fb^{-1})
Stat. Only (300 fb^{-1})	Stat. Only (3000 fb^{-1})

VBF H $\rightarrow$ inv.

CMS-PAS-HIG-16-016

Search using **2.3 fb^{-1}** of data at 13 TeV

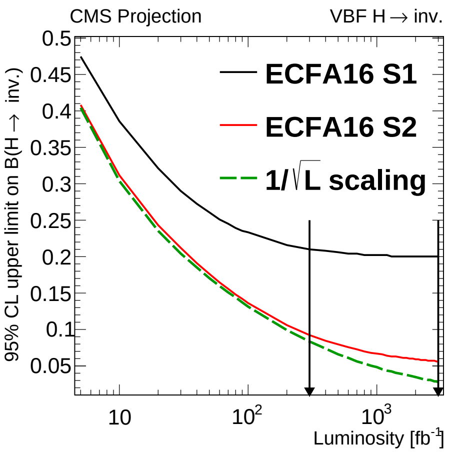
Main backgrounds:

- $Z(\nu\nu)$+ jets
- $W(l\nu)$ + jets
- QCD multijet

Current expected limits:

- BR(H $\rightarrow$ inv.) < 0.63

Expected 95% CL upper limits on BR(H $\rightarrow$ inv.) as a function of luminosity



	ECFA16 S1	ECFA16 S2	$1/\sqrt{L}$ scaling
300 fb^{-1}	0.210	0.092	0.084
3000 fb^{-1}	0.200	0.056	0.028

LHCb Results

LHCb Strategy

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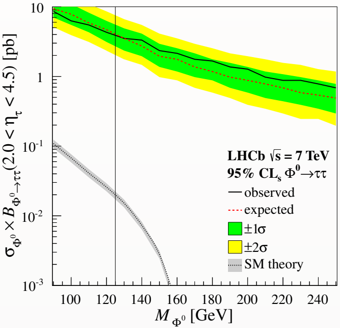
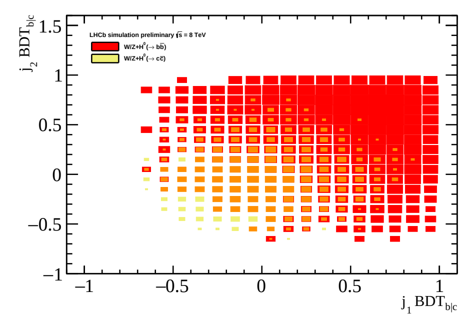
- **Disadvantages**
  - lower luminosity
  - reduced acceptance, $\lesssim 5\%$
  - not a hermetic detector
  - ECAL saturation

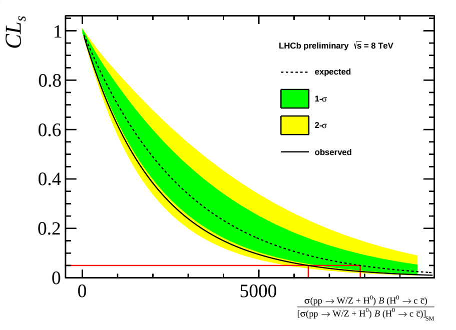


- **Advantages**
  - very flexible trigger
  - low pile-up
  - particle ID
  - excellent secondary vertex resolution
  - complementary forward region
- **LHCb should focus on channels which utilize strengths**
  - exclusive final states requiring PID and/or secondary vertices
  - inclusive *c* and *b*-jet final states

- **new** limits set with 1.98 fb^{-1} of data at $\sqrt{s} = 8$ TeV
  - two heavy flavor tagged jets, one or two muons or electrons
  - approximate pseudorapidity $2 < \eta < 4$

$$\sigma(pp \to Z/W + H) \times \mathcal{BF}(H[b\bar{b}]) < 1.6\ \mathrm{pb}\ (\times 50\ \mathrm{SM})$$
$$\sigma(pp \to Z/W + H) \times \mathcal{BF}(H[c\bar{c}]) < 9.4\ \mathrm{pb}\ (\times 6400\ \mathrm{SM})$$





Summary

CMS:

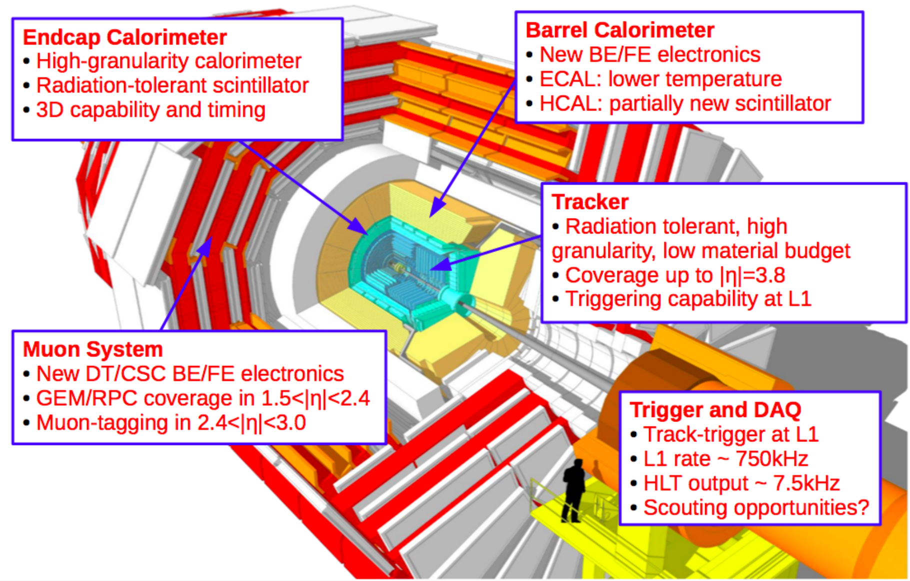
- Projections for 300/3000 fb^{-1} using 13 TeV analyses and studies based on Delphes simulation of the upgraded CMS detector have been shown **(CMS DP-2016/064)**
  - Properties measured with uncertainties at percent level
  - Access to HH production
- Additional studies with more detailed description of the upgraded detector will be performed in the coming months

LHCb:

- Identification of the upgrade strengths
- Focus on final states with c and b-jets

Backup Slides

CMS Phase II Upgrades



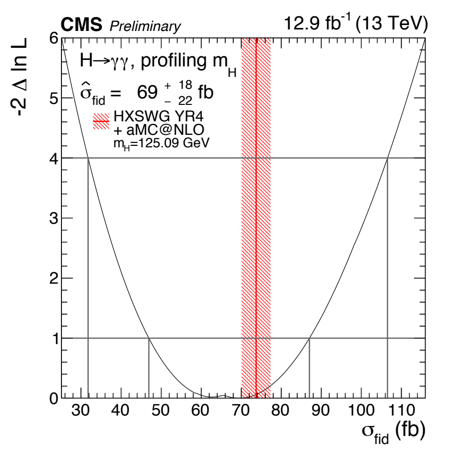
Extrapolation strategy - Naming

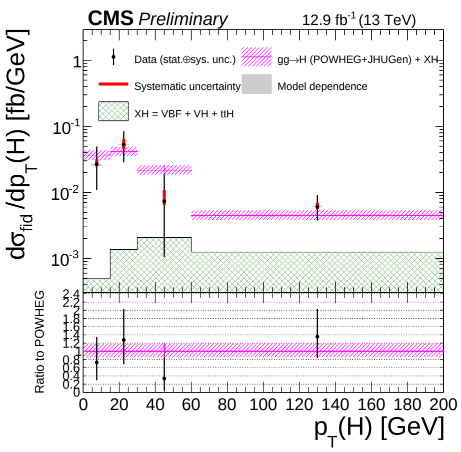
Projections from run II (13 TeV) results are labeled as ECFA16 uncertainty scenario:

- **ECFA16 S1**
- **ECFA16 S1+**
- **ECFA16 S2**
- **ECFA16 S2+**

Comparison with Snowmass results:
Previous extrapolations from 8 TeV analyses to 14 TeV are presented for comparison in some results and labeled as Snowmass13 uncertainty scenario. In this case S2 does not include any lower bound when scaling down the experimental uncertainties.
e.g. **Snowmass13 S2**

Fidutial σ





Resonant HH $\rightarrow$ bbbb production

Table 5: Projection of the sensitivity to the resonant HH production at 3 ab^{-1} expected to be collected during the HL-LHC program. The projections are based on 13 TeV analysis performed with data collected in 2015. The 95% CL expected limits are provided for different spin-0 resonances masses assuming: preliminary analysis from 2015; Scenario 2 - reduced systematic uncertainties taking advantage of a larger data sample and upgraded detector; no systematic uncertainties. For each resonant mass the value of the mass scale $\Lambda_R = \sqrt{6} \exp[-kl] \overline{M}_{Pl}$ excluded at 95% CL is also provided.

m_X(TeV)	Median expected limits on σ (fb)			$\sigma_R(\Lambda_R = 1\,\text{TeV})$ (fb)	Λ_R (TeV) excluded
	2.3 fb^{-1}	ECFA16 S2+	Stat. Only		
0.3	2990	46	41	7130	13
0.7	129.4	7.3	3.4	584	8.9
1.0	81.5	4.4	2.4	190	6.6