UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

ATLAS EXPERIMENT

HL-LHC

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(UTFSM)

On behalf of the ATLAS and CMS collaborations

Higgs Couplings 2017

Institute for Theoretical Physics

Heidelberg University, November 6-10, 2017

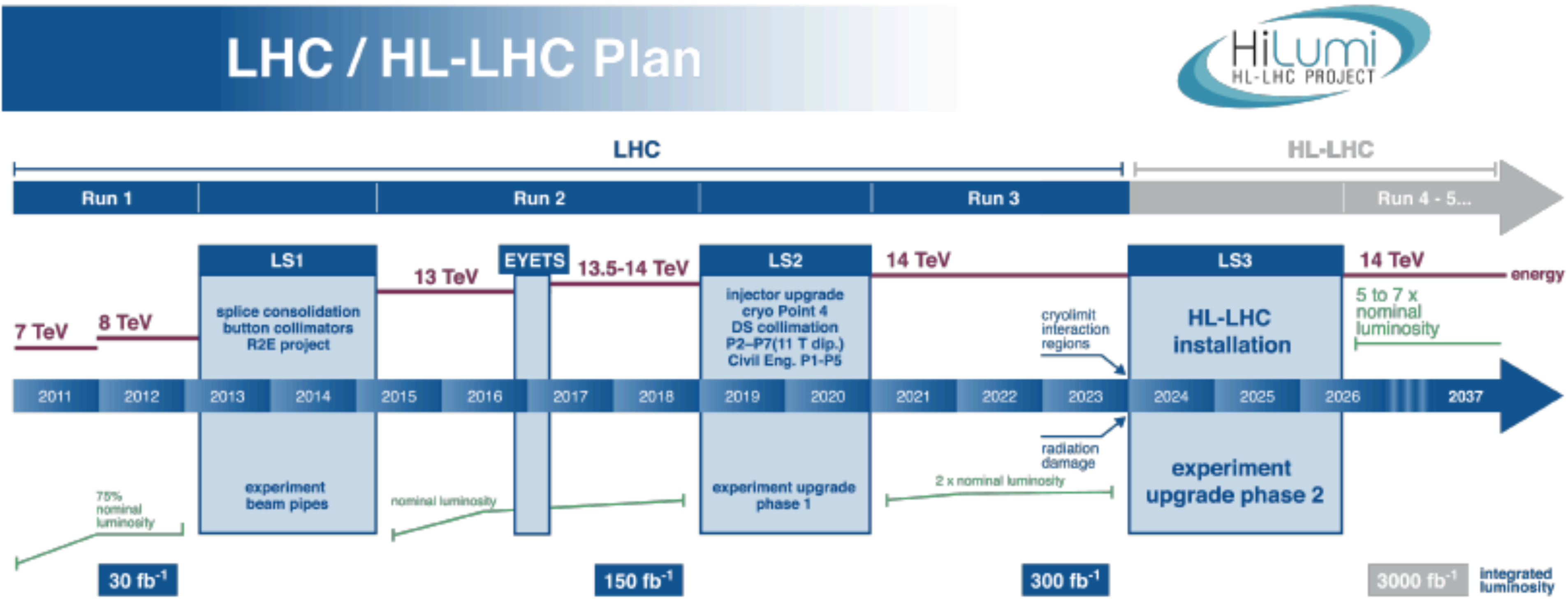
CCTVal

CMS

Outline

- HL-LHC Introduction
- Higgs prospects for:
  - Individual decay channels
  - Combined couplings (global analysis)
  - BR(Higgs $\rightarrow$ inv)
  - Higgs Width
  - Higgs pair production
- Conclusions

The roadmap to the HL-LHC

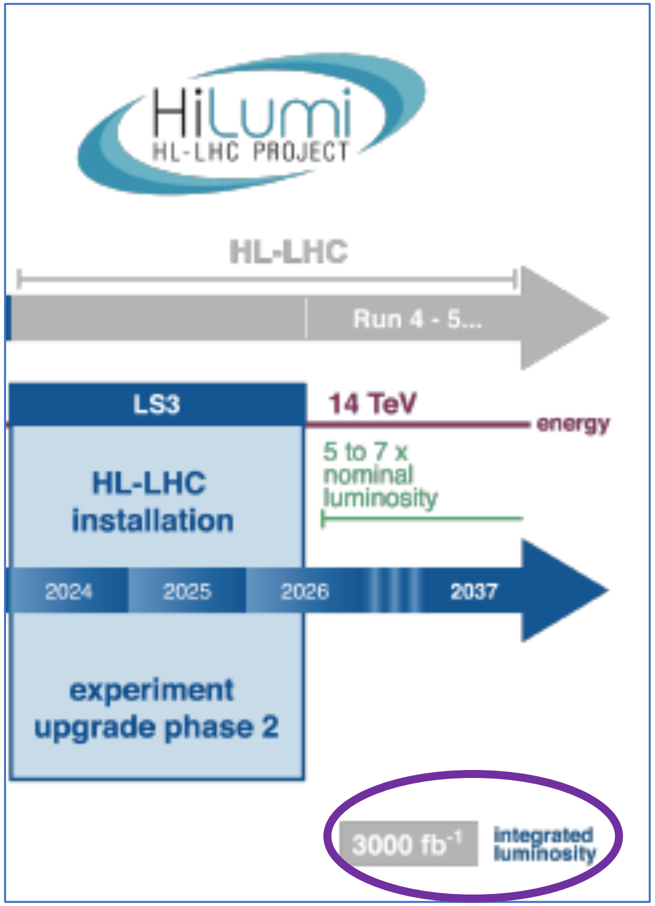


Plan to extend the LHC physics program to study the Higgs boson properties and to maximize new physics discovery potential.

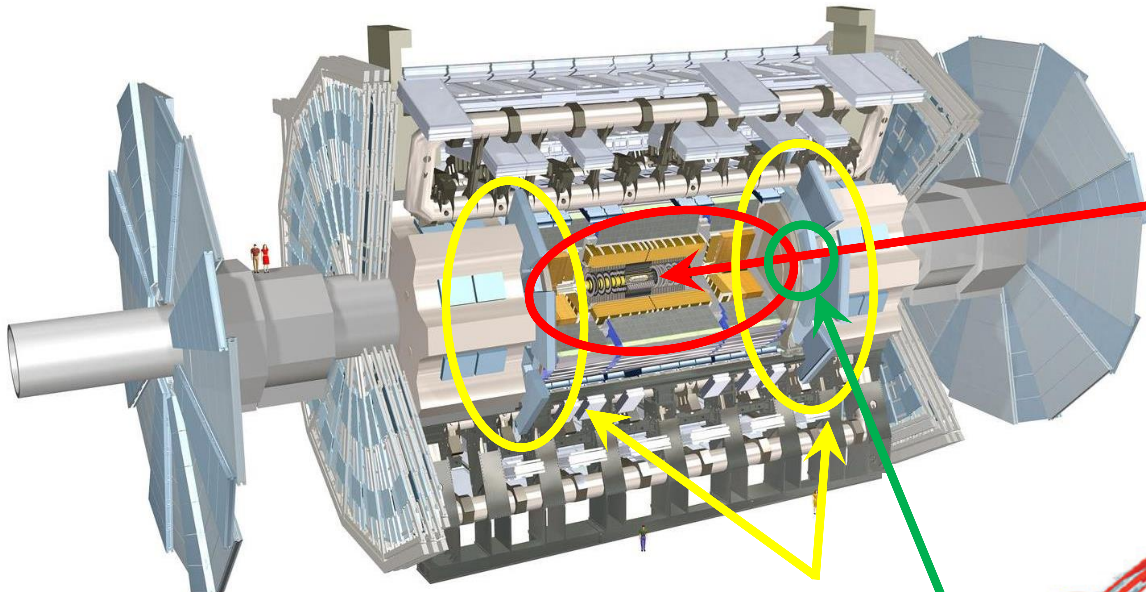
The roadmap to the HL-LHC

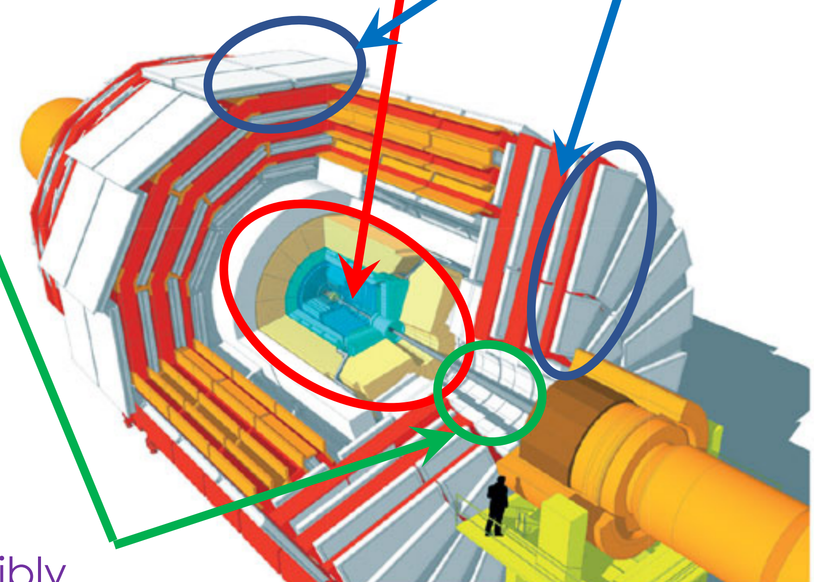
HL-LHC Upgrade plan with respect to the original LHC design

- ❑ ***x10*** more delivered integrated luminosity *(3000 fb^{-1})*
- ❑ ***x5 - x7.5*** nominal instantaneous luminosity
- ❑ Expect *140-200* p-p interactions per bunch crossing
- ❑ Detector systems will be upgrated to cope with unprecedented high pile-up conditions and event rate while keeping performance



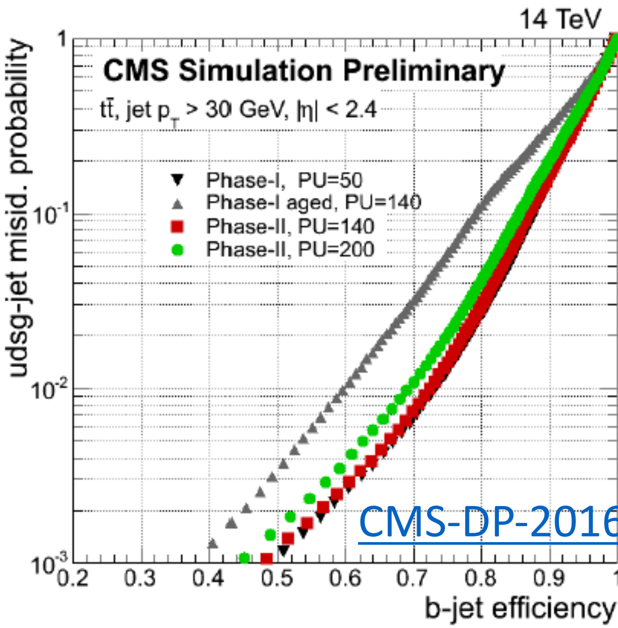
Detector upgrades in a nutshell





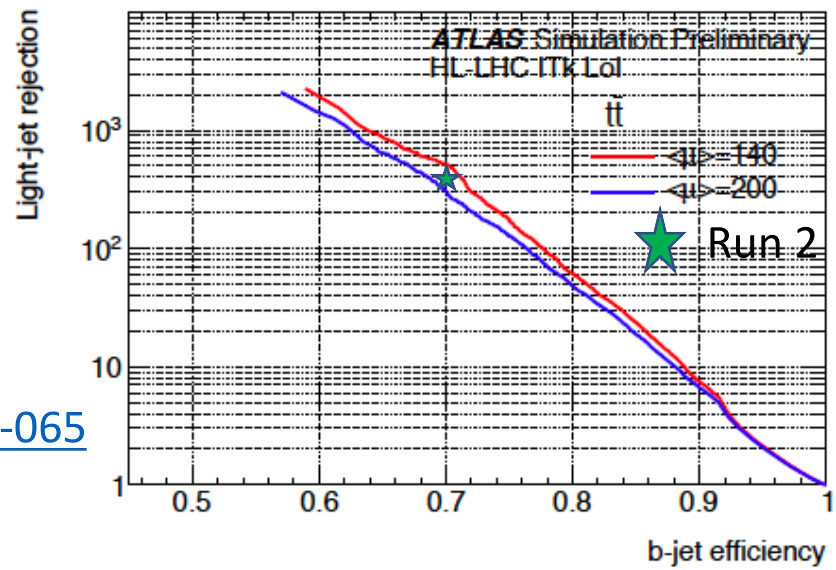
- Trigger updates
  i. Possibly a new level of hardware trigger (ATLAS)
  ii. Information from tracking at L0/L1
  iii. New inner barrel trigger chambers MS
- New calorimeter and muon system FE electronics (CMS & ATLAS)
- Possibly new high granularity timing detectors

Detector performance highlights



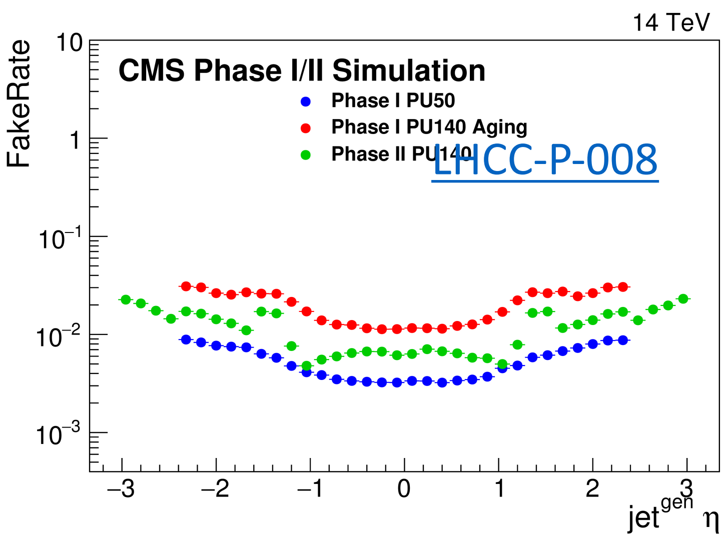
CMS-DP-2016-065

ATL-PHYS-PUB-2016-026

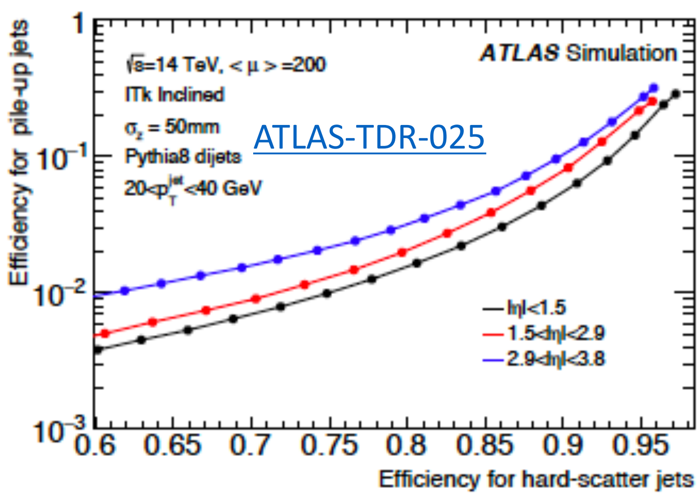


Light-jet rejection better with the upgraded detectors

Compared to Run II



LHCC-P-008



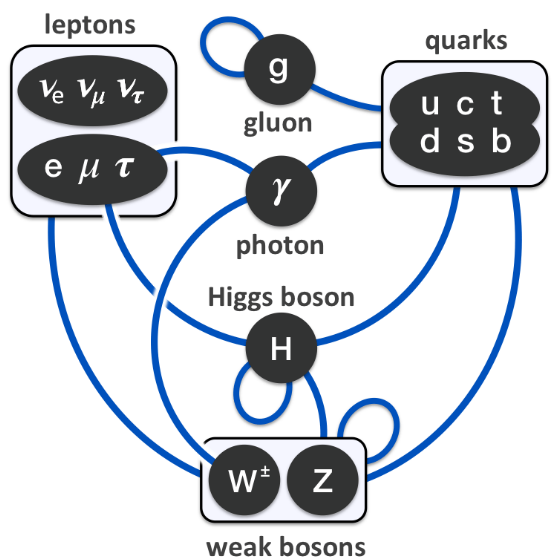
ATLAS-TDR-025

Extended tracker to $|\eta| < 4$
Achieve good pile-up jet and fake-tau rejections

HL-LHC Higgs Physics Program

- Observe and measure full set (accessible) of production & decay modes of the Higgs
- Measure Higgs boson couplings to leptons and bosons with high precision
- Look for possible deviations from the SM in the Higgs sector (or elsewhere)
- Measure Higgs differential cross section observables (estimations for the HL-LHC are ongoing)
- Constrain significatively triple-Higgs coupling constant (λ_{hhh})
- Observe Higgs pair-production

A long road ahead toward Higgs coupling precision era



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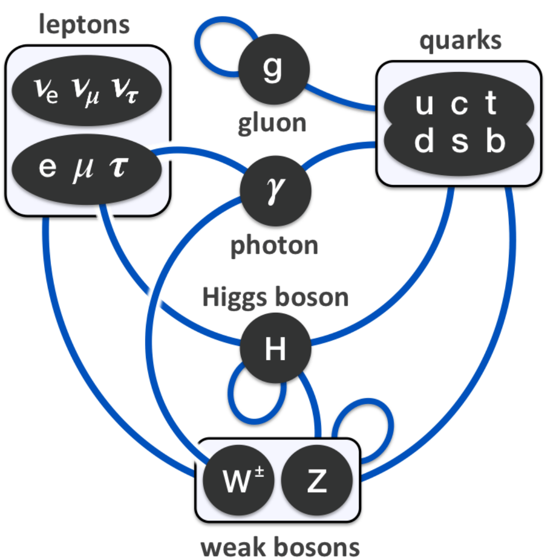

HL-LHC Higgs Physics Program

Covered in **this talk**

- Observe and measure full set (accessible) of production & decay modes of the Higgs ✓
- Measure Higgs boson couplings to leptons and bosons with high precision ✓
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- Constrain significatively triple-Higgs coupling constant (λ_{hhh}) ✓
- Observe Higgs pair-production ✓

Performance assumptions

Claim: Upgraded detectors will keep or improve current performance

- **ATLAS:**

  — Scale signal and backgrounds yields of current analyses

  — Similar performance of the upgraded detector to the current detector under Run 2 (or Run 1) conditions, full systematic uncertainties unless otherwise stated (exp+th)

  — Efficiency, resolution and fake rate functions taken from full simulation applied to generator level physics objects

- **CMS:**

  — Scale signal and backgrounds yields of current analyses

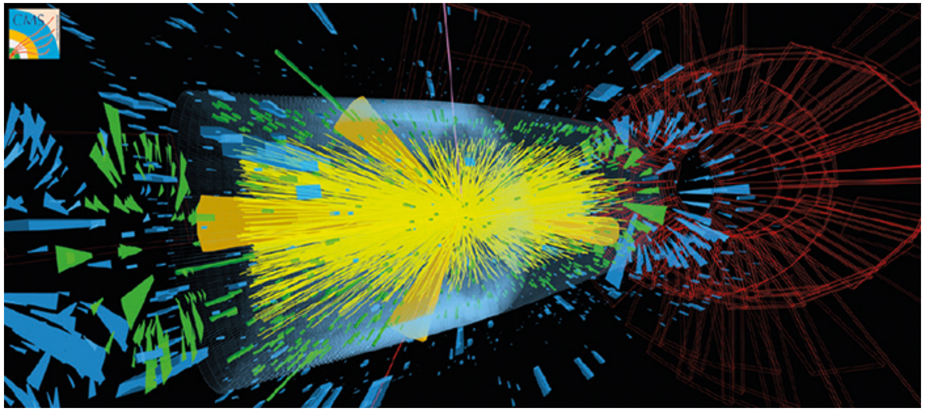
  — Two scenarios for systematic uncertainties

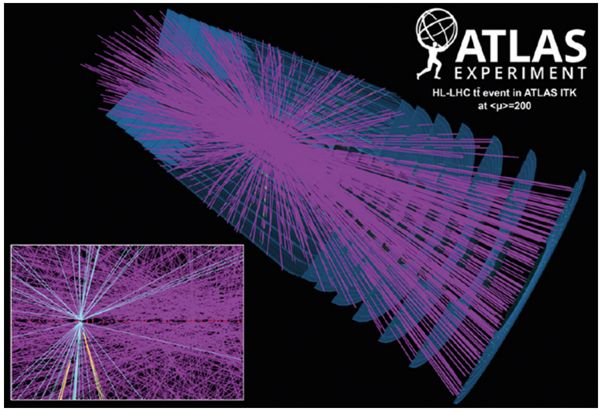
  Scenario 1(S1): Systematic uncertainties remain the same

  Scenario 2(S2): Theoretical uncertainties scaled by ½, other systematic uncertainties scaled by $1/\sqrt{L}$

  ECFA 2016

  Scenario 1+(S1+) and 2+(S2+): Same as S1and S2 but including upgraded detector performance and pile-up conditions using DELPHES fast simulation code





Performance assumptions

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— Similar performance of the upgraded detector to the current detector under Run 2 (or Run 1) conditions, full systematic uncertainties unless otherwise stated (exp+th)

— Efficiency, resolution and fake rate functions taken from full simulation applied to generator level physics objects. ← **Default approach used by ATLAS, unless otherwise stated**

- **CMS:**

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— Two scenarios for systematic uncertainties

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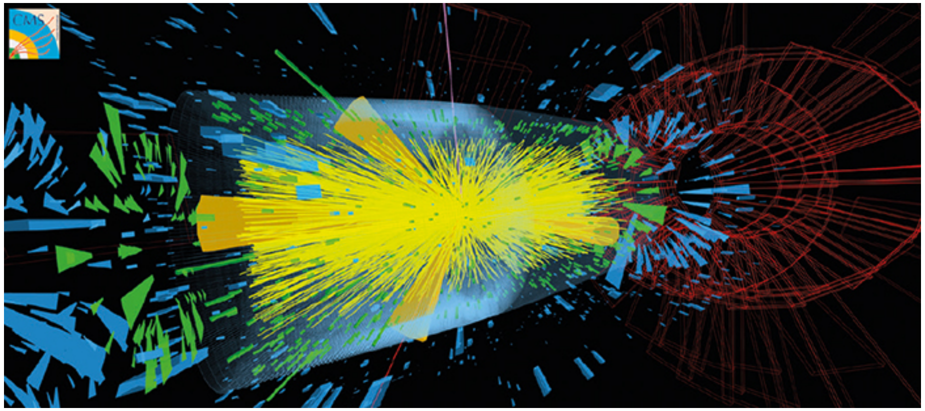
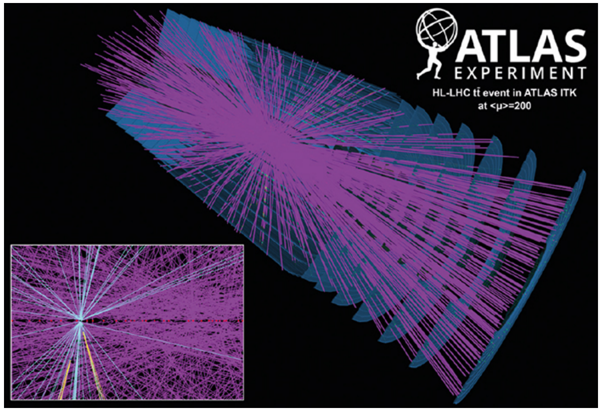
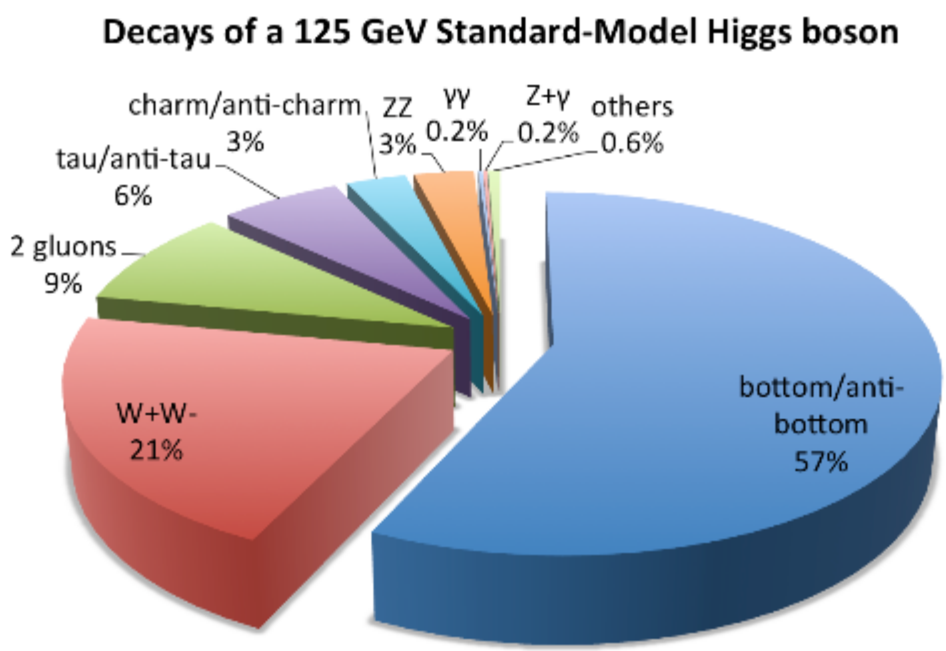




Individual decay channels



$H \rightarrow \gamma\gamma$

- ATLAS Expects observation of ttH with 8.2 σ significance

ATLAS	$t\bar{t}H$	WH	ZH	VBF
Significance	8.2	4.2	3.7	3.8

- Last CMS result find 10/4% (Scenarios S1+/2+) uncertainty on signal strength.

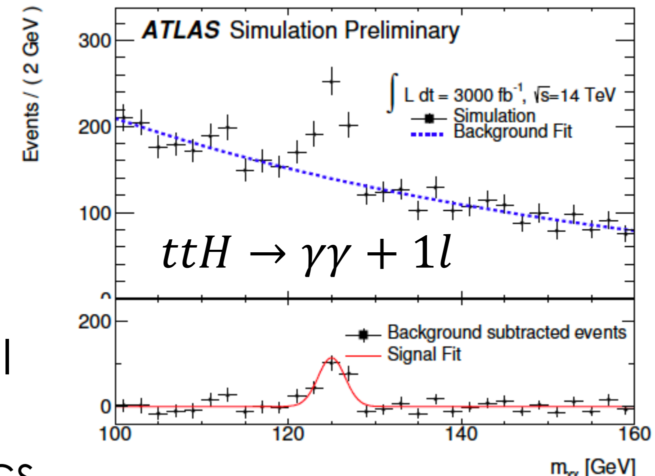
- Run II CMS result using 36.1 fb^{-1} of data on overall $\Delta\mu$ uncertainty is at 14% level already. Can go more differential to exploit the full HL-LHC statistics

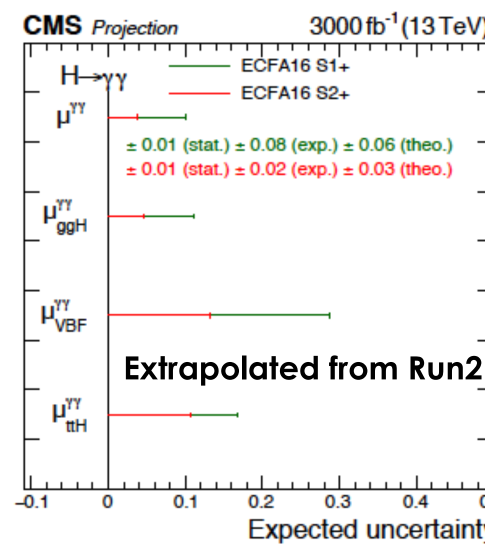
	$\Delta\hat{\mu}/\hat{\mu}$ (%)			
Production mode	Total	Statistical	Experimental	Theoretical
$t\bar{t}H$	$^{+21}_{-17}$	$^{+13}_{-12}$	$^{+5}_{-4}$	$^{+17}_{-11}$
WH	$^{+26}_{-25}$	$^{+21}_{-20}$	$^{+13}_{-12}$	$^{+10}_{-8}$
ZH	$^{+35}_{-31}$	$^{+32}_{-29}$	$^{+7}_{-7}$	$^{+12}_{-8}$
ggF	$^{+19}_{-14}$	$^{+3}_{-3}$	$^{+1}_{-1}$	$^{+19}_{-14}$
VBF	$^{+29}_{-29}$	$^{+18}_{-18}$	$^{+1}_{-1}$	$^{+23}_{-23}$

Uncertainties dominated by statistics and theory

ATL-PHYS-PUB-2014-012

Run 1 di-photon Trigger efficiency and mass resolution





FTR-16-002-pas

$H \to ZZ^* \to 4l$

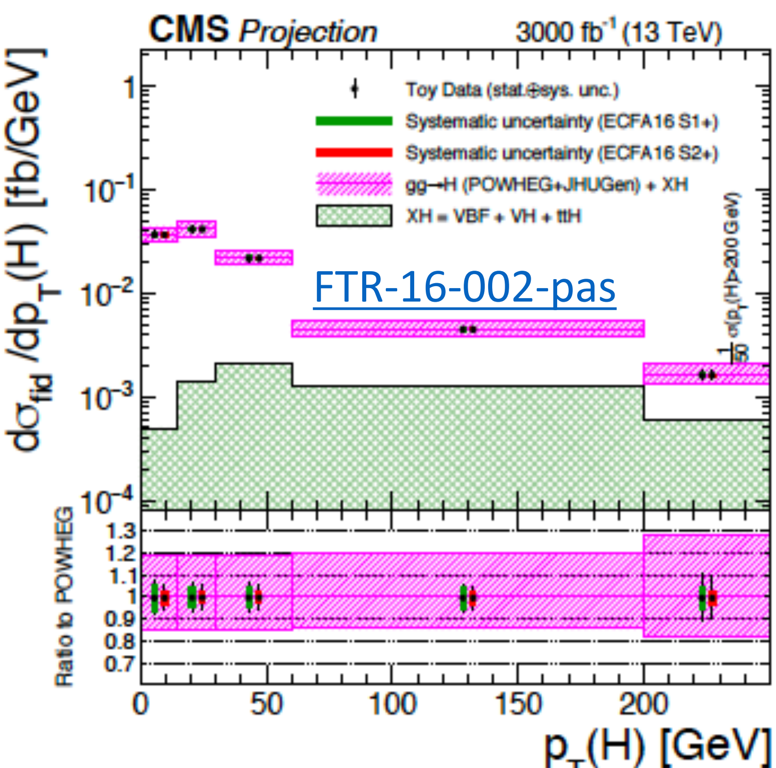
ATL-PHYS-PUB-2016-008

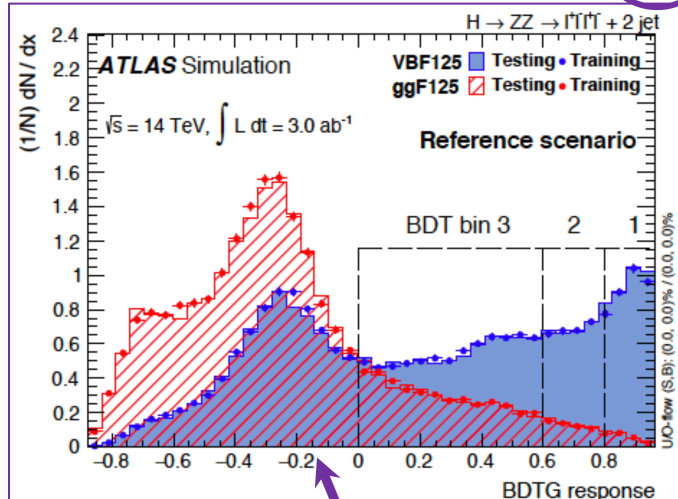
Extra discrimination of VBF against ggF H->ZZ Using 3 BDT signal regions

6% reduction wrt to previous result

ATLAS	Statistical uncertainty only			
Scoping scenario	VBF + $2j$ events	ggF + $2j$ events	Z_0 (VBF vs. ggF)	$\Delta\mu/\mu$
Reference	237 (206)	324 (159)	11.4	±0.134

- Very pure signal, sensitive to the 5 production modes
- Only sensitive to ttH at HL-LHC
- CMS expects 8/5% in S1+/S2+ on μ uncertainty
- CMS differential studies show that statistics will be a limiting factor even for HL-LHC in the High $p_T(H)$ region





ATLAS	3000 fb^{-1}			
ggF	0.131	0.025	0.040	0.124
VBF	0.371	0.187	0.225	0.226
WH	0.390	0.375	0.061	0.085
ZH	0.532	0.526	0.038	0.073
$t\bar{t}H$	0.224	0.184	0.034	0.120
Combined	0.100	0.016	0.036	0.093

$M_{jj} > 130$ GeV, $p_t > 30$ GeV
Jet tracking extended to $|\eta| < 4.0$, leptons within $|\eta| < 2.4$

ATL-PHYS-PUB-2014-012

HZZ - Anomalous couplings

$$A(H \to ZZ) \sim \left(\left(a_1 m_Z^2 + \frac{k_1 q_1^2 + k_2 q_2^2}{\Lambda_1^2} \right) \epsilon_1^* \epsilon_2^* + a_2 f_{\mu\nu}^{*(1)} f^{(2),\mu\nu} + a_3 f_{\mu\nu}^{*(1)} \tilde{f}^{(2),\mu\nu} \right)$$

CP-even

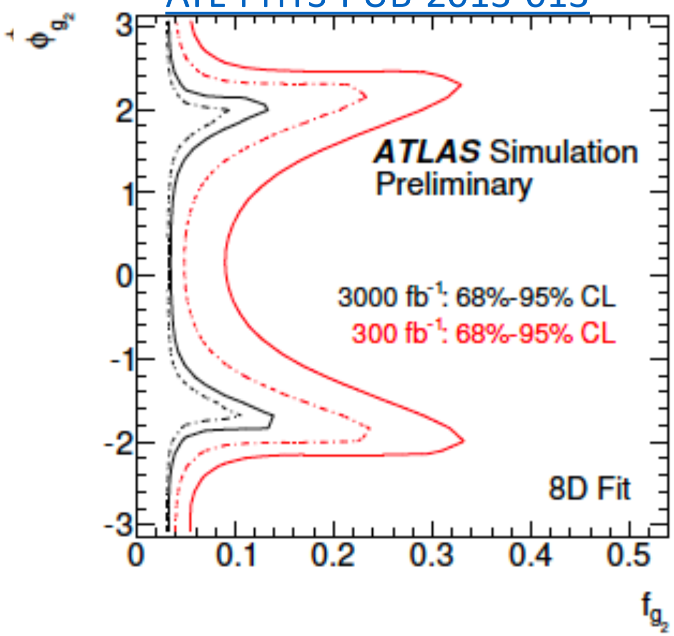
CP-odd

- a_1,a_2 couplings depend on non-SM CP-even coupling g_2
- CP-odd (even) couplings, can be strongly constrained with ATLAS 10% (3.7%) and CMS (S1+) 1.5% (<1%) HL-LHC data
- Different parametrization and fit model used in each case

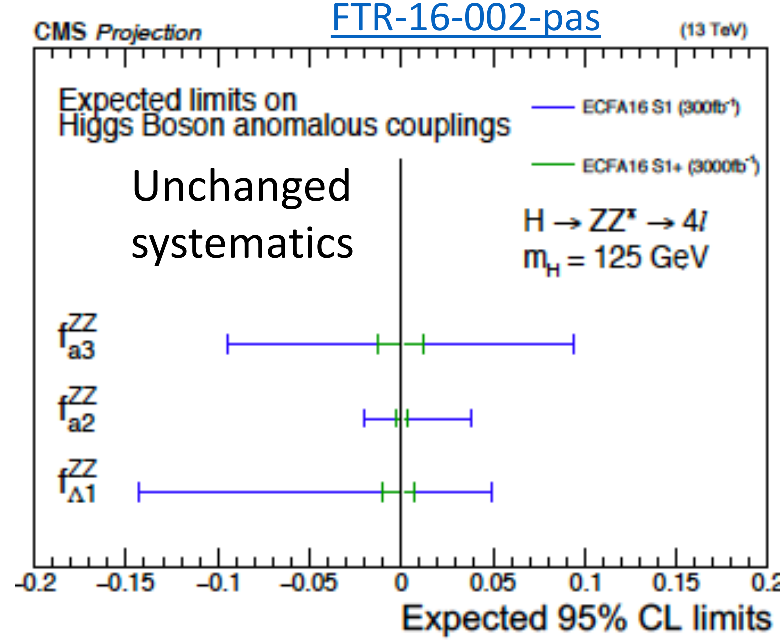
$$f_{g_i} = \frac{|g_i|^2 \sigma_i}{|g_1|^2 \sigma_1 + |g_2|^2 \sigma_2 + |g_4|^2 \sigma_4};$$

$$\phi_{g_i} = \arg\left(\frac{g_i}{g_1}\right)$$

ATL-PHYS-PUB-2013-013

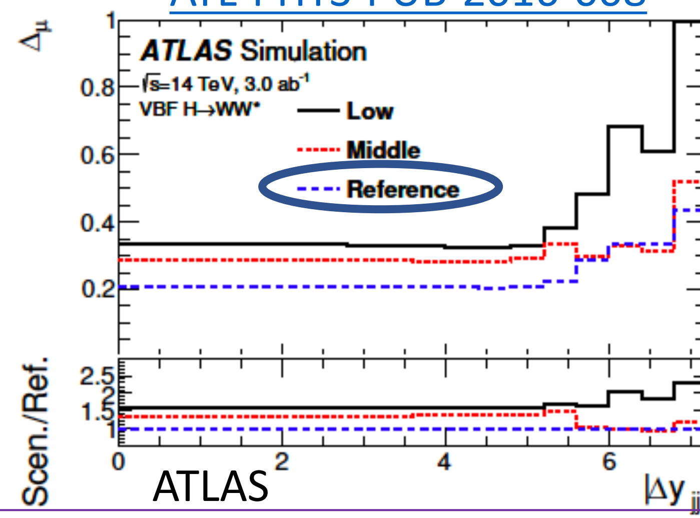


FTR-16-002-pas



$H \rightarrow WW^* \rightarrow l\nu l\nu$

ATL-PHYS-PUB-2016-008

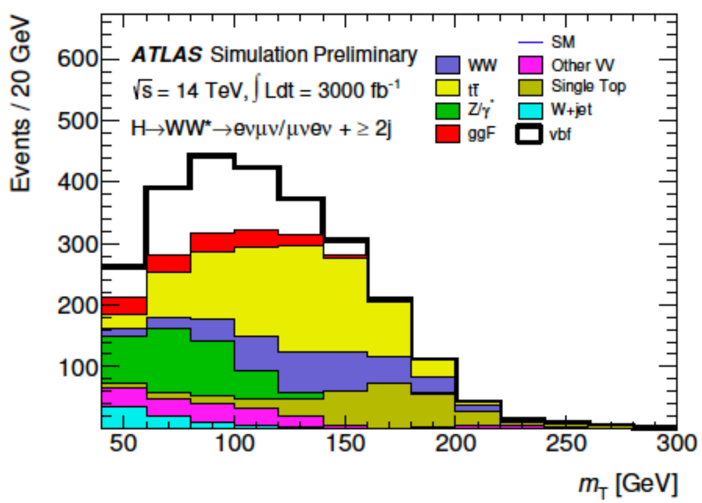


- Increase in ttbar rate and pile-up conditions degrade sensitivity
- Channel dominated by exp & theory syst uncert
- CMS expects 7/4% (scenarios 1/2) on μ uncertainty

CMS arxiv:1307.7135

Analysis revisited for the scoping reference scenario no sensitivity lost

Scoping scenario Signal unc.	ATLAS Δ_μ Full	1/2	None	Significance (σ) Full	1/2	None
Reference	0.20	0.16	0.14	5.7	7.1	8.0



0,1 and ≥2 jets categories for ggF and VBF production modes

ATLAS	μ_{ggF}	μ_{VBF}	$\mu_{ggF+VBF}$
3000 fb^{-1}	$1^{+0.16}_{-0.14}$	$1^{+0.15}_{-0.15}$	$1^{+0.10}_{-0.09}$

ATL-PHYS-PUB-2014-012

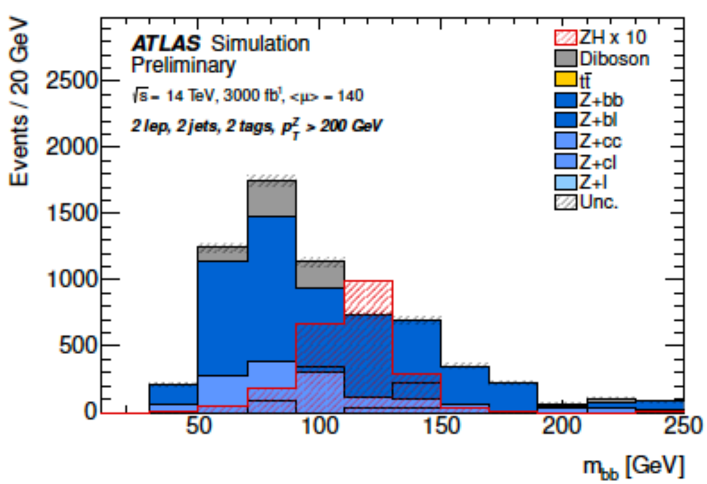
$H \to bb$

ATL-PHYS-PUB-2014-011

- Expected sensitivity would reach 8.8σ with an uncertainty on μ of 14%
- Improved b-tagging efficiency wrt to previous result & MVA sig-bkg separation
- 1+2 lepton signal categories combined

CMS arxiv:1307.7135

- CMS expects 7/5% (scenarios 1/2) on μ uncertainty



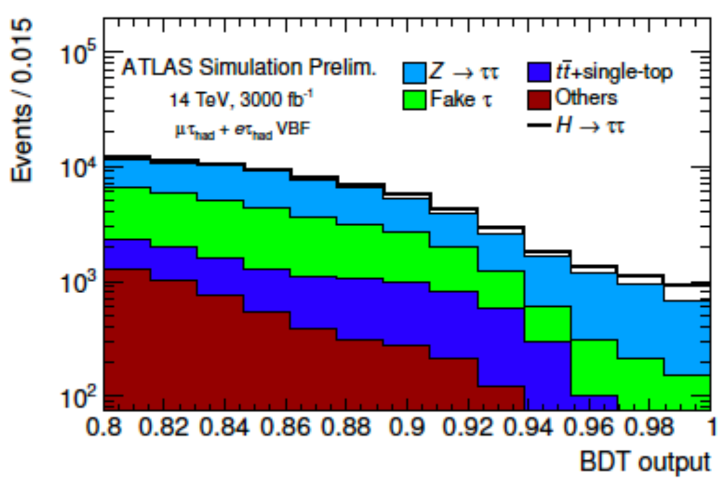
$H \to \tau\tau$

ATL-PHYS-PUB-2014-018

- ATLAS VBF $\tau_{lep}\tau_{had}$ 8-24% uncerainty on μ is found depending on f-jet pile-up rejection eff 50%-90%
- Projection based on Run1 analysis same MC and MVA technique
- Embedding pile-up jets on 2012 data, degrade MET and MMC res

CMS arxiv:1307.7135

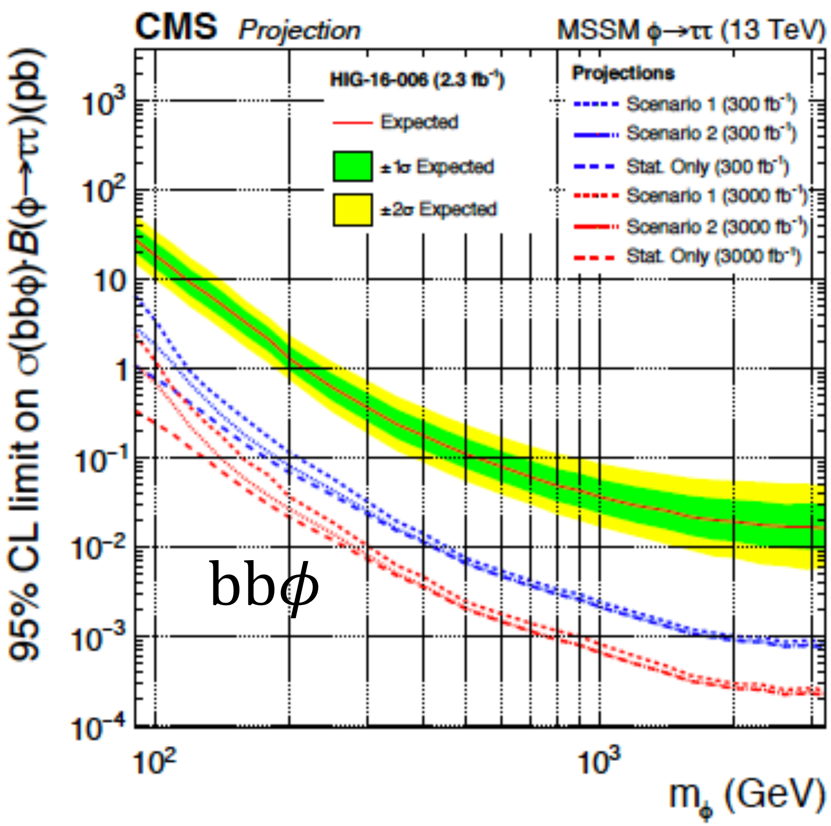
- CMS expects 8/5% in scenarios 1/2 including several channels

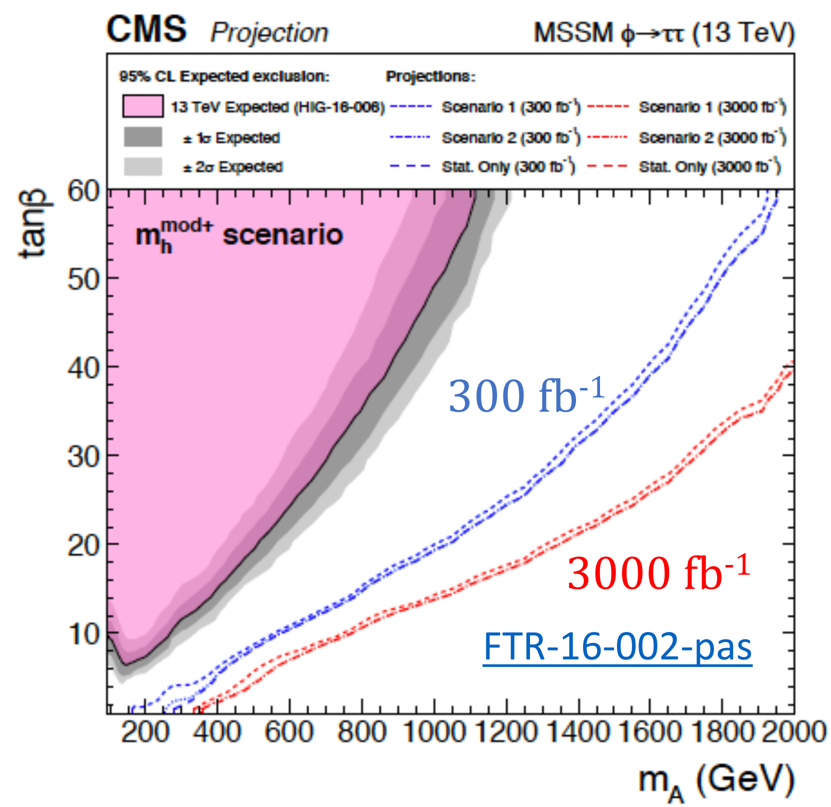


$H \rightarrow \tau\tau$ (MSSM Limits)

- One of the most sensitive channels for constraining extended Higgs models
- Cross section limits on ggF and bb associated production

- Model dependent limits on m_h^{mod+} scenario (Lightest CP-even Higgs is the SM Higgs)
- Sensitivity at high m_A still dominated by statistics

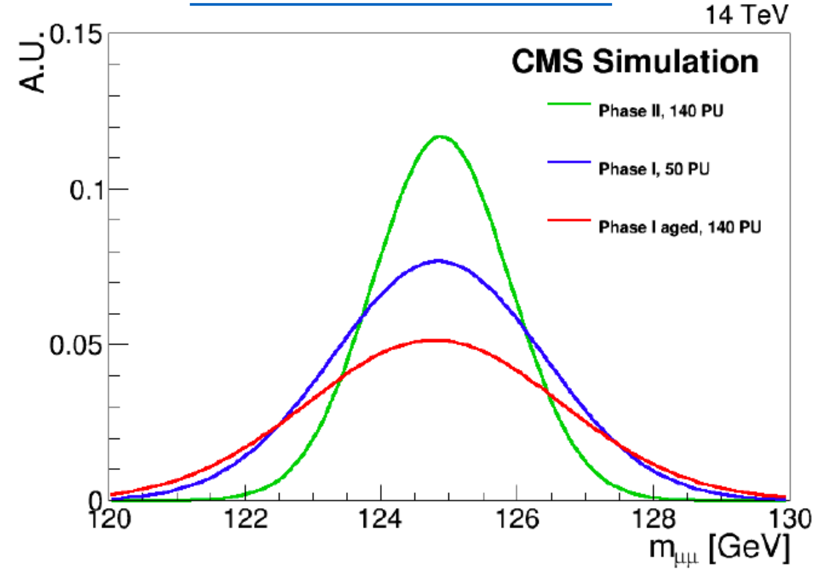




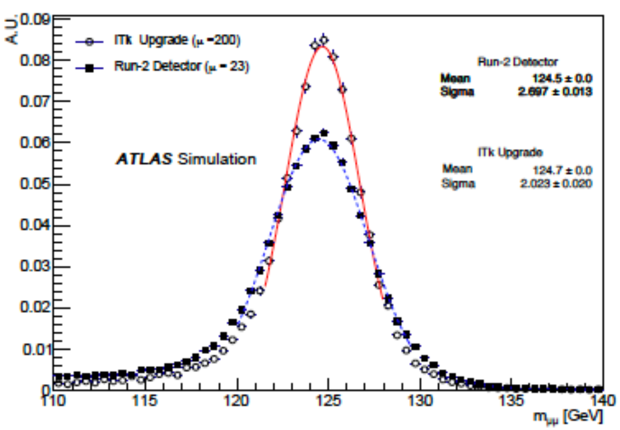
$H \to \mu\mu$

- Sensitive to second generation coupling
- CMS expects 7.9σ @ 3ab^{-1} and 5σ @ 1.2 ab^{-1} Uncertainty on μ 20/14% for scenarios 1/2
- ATLAS expects 7σ @ 3ab^{-1} and 21% uncertainty on μ
- ttH production should be visible

CERN-LHCC-2015-010

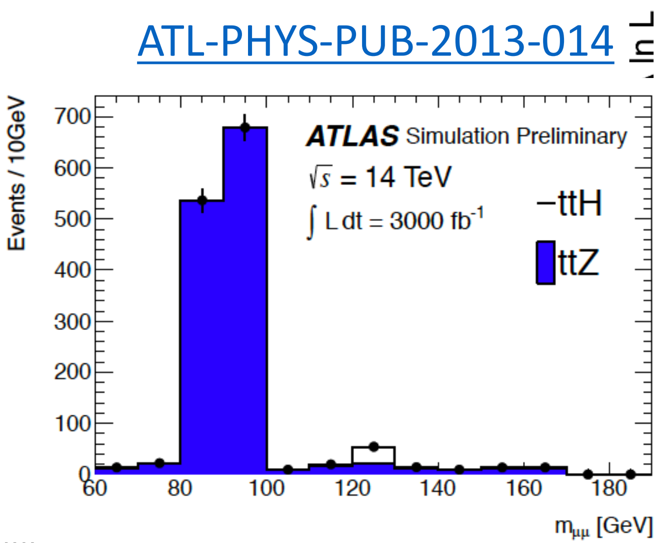


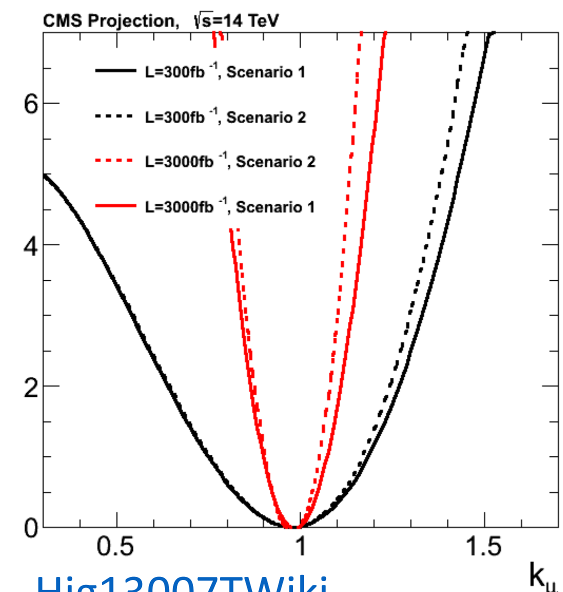
ATLAS-TDR-025



Expected resolution on $m_{\mu\mu}$ better than Run II

ATL-PHYS-PUB-2013-014





Hig13007TWiki

$H \to Z\gamma$

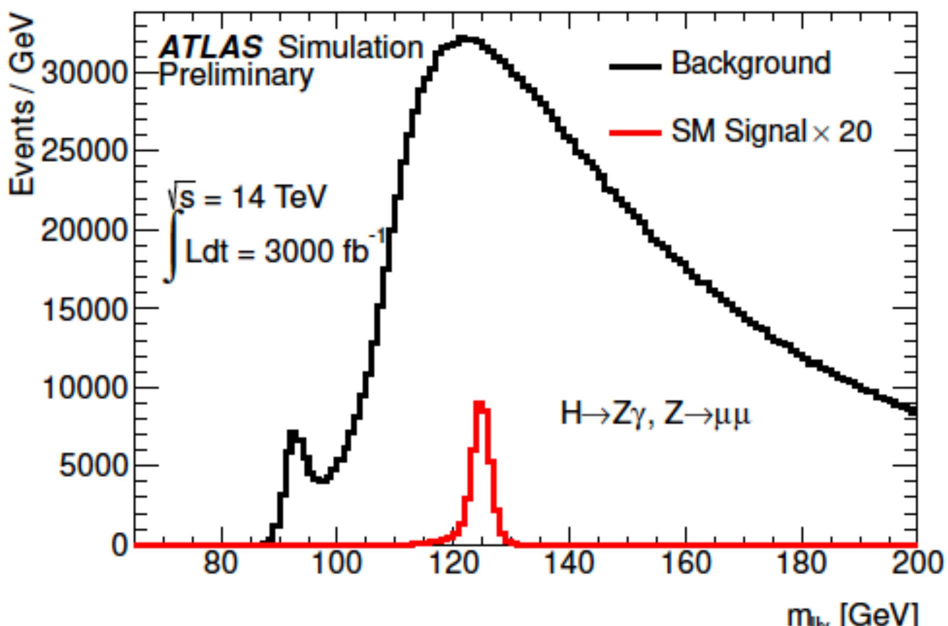
- ATLAS expects to reach a sensitivity of 3.9σ with $3ab^{-1}$
- Error on μ dominated by stats and mass resolution syst.

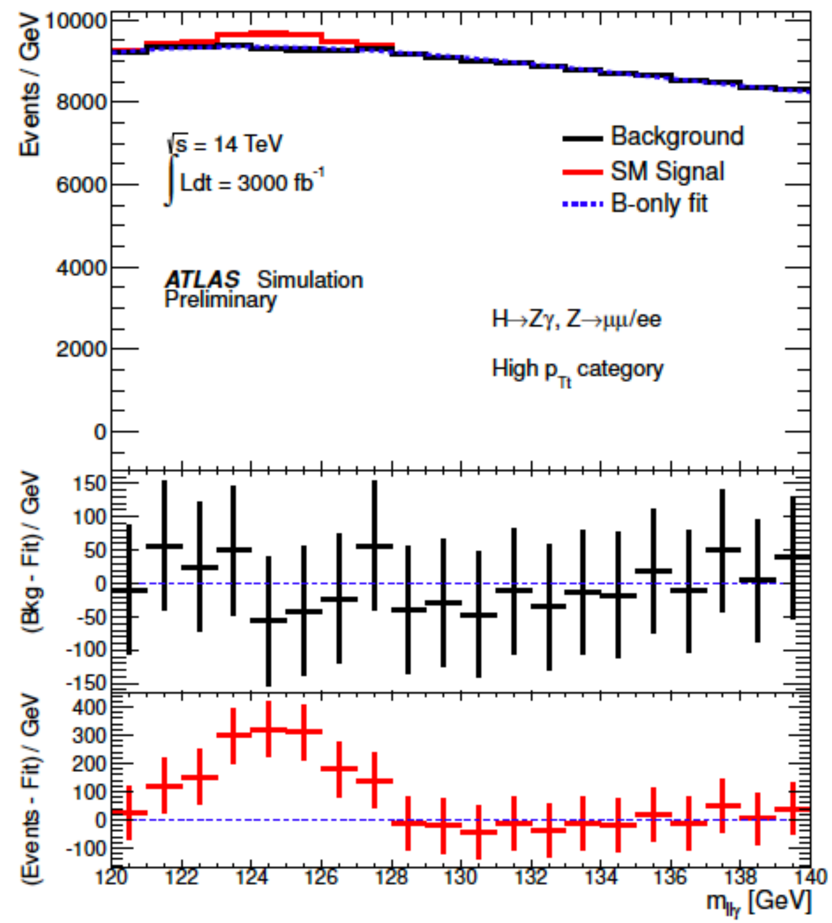
$$1.00^{+0.25}_{-0.26}(stat.)^{+0.17}_{-0.15}(sys.)$$

- CMS expects 24/20 % in Scenarios 1/2 on μ uncertainty

Current RunII ATLAS result:
[arxiv:1708.00212]
Upper limit of 6.6xSM
CMS RunI result is ~ 10xSM
[arxiv:1307.5515]

[ATL-PHYS-PUB-2014-006]



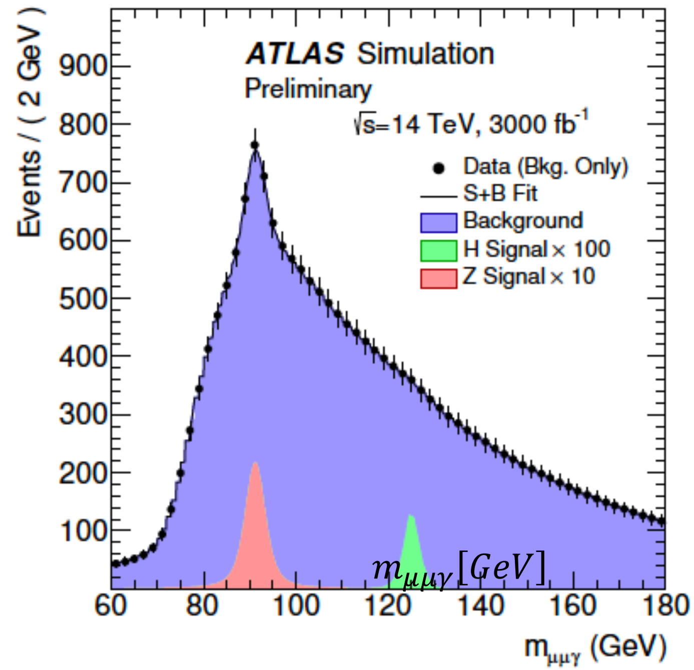


Other rare processes

$H \rightarrow J/\psi\gamma$

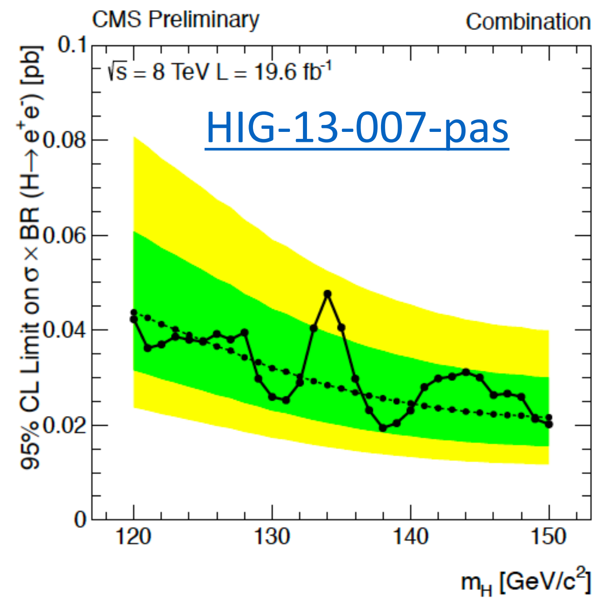
- Sensible to H-cc coupling
- Uncertainty of 2-5 % in the background estimation.
- ATLAS reaches a sensitivity of 15 x SM value
- Several improvements possible

ATL-PHYS-PUB-2015-043



$H \rightarrow ee$

- Run I limit by CMS, its observation would reveal departure from SM Higgs (SM BR~$5x10^{-9}$)
- Ratio for σxBR limit for $H \rightarrow ee\ and\ H \rightarrow \mu\mu$ is 1.4

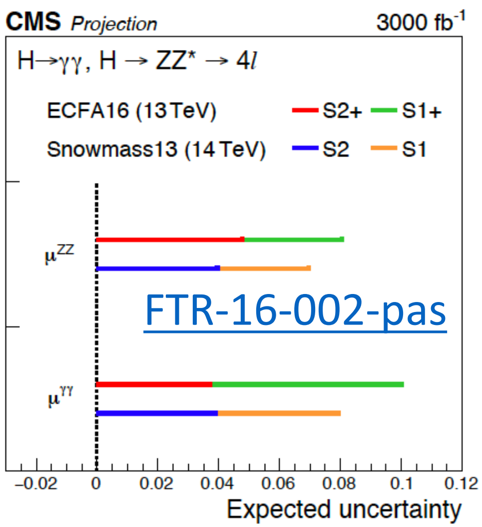


No projections yet for other rare decays

H→$\phi\gamma$(2.3x10^{-6}), H→$\rho\gamma$(1.68x10^{-5}) or H→$\Upsilon\gamma$(9x10^{-9})

Signal strength precision

- Significatively more precision than @ 300 fb^{-1}
- ATLAS assume full and no theory sys
- CMS theory sys/2 and scale sys with $1/\sqrt{L}$



FTR-16-002-pas

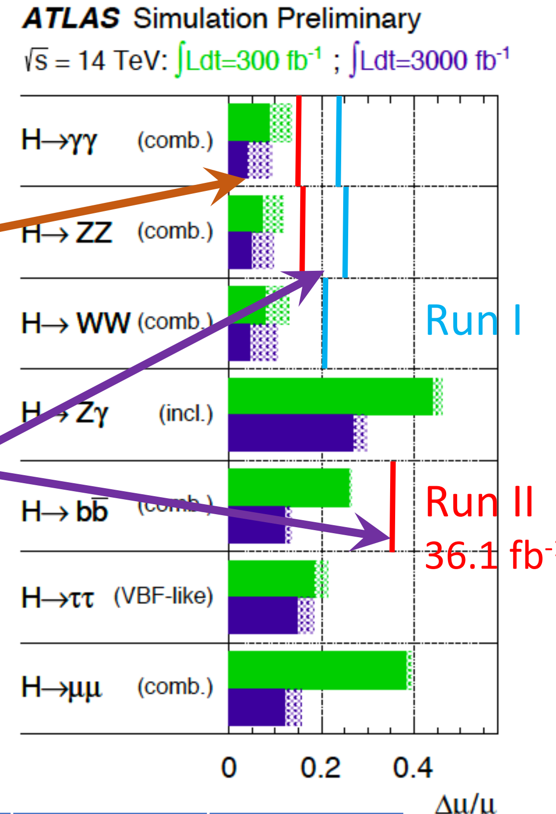
Arxiv:1307.7135

Dashed area corresponds to theory systematics

Run I and II results already quite good !

ATLAS: Do not include improved detector designs or improvements in analysis techniques

ATL-PHYS-PUB-2014-016



	$\gamma\gamma$	WW	ZZ	bb	$\tau\tau$	$Z\gamma$	$\mu\mu$
CMS*	[4,8]	[4,7]	[4,7]	[5,7]	[5,8]	[20,24]	[20,24]
ATLAS	[4,9]	[5,11]	[4,9]	[12,14]	[15,19]	[27,30]	[12,16]

CMS
inv.
[17, 28]
[6, 17]

* CMS global fit doesn't include ECFA 2016 updated ZZ and $\gamma\gamma$ results

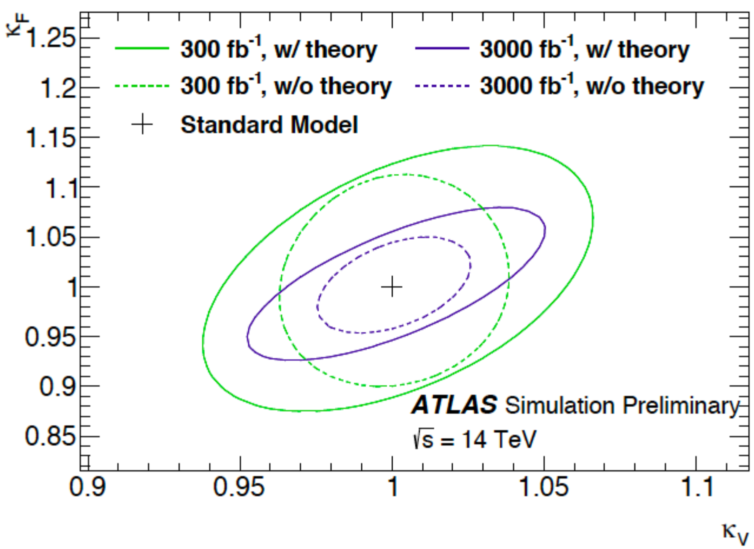
Couplings

- Total width assumed to be sum of components (ATLAS).
- Up to a factor of 2 times more precise than with 300 fb^{-1}
- Rather old results

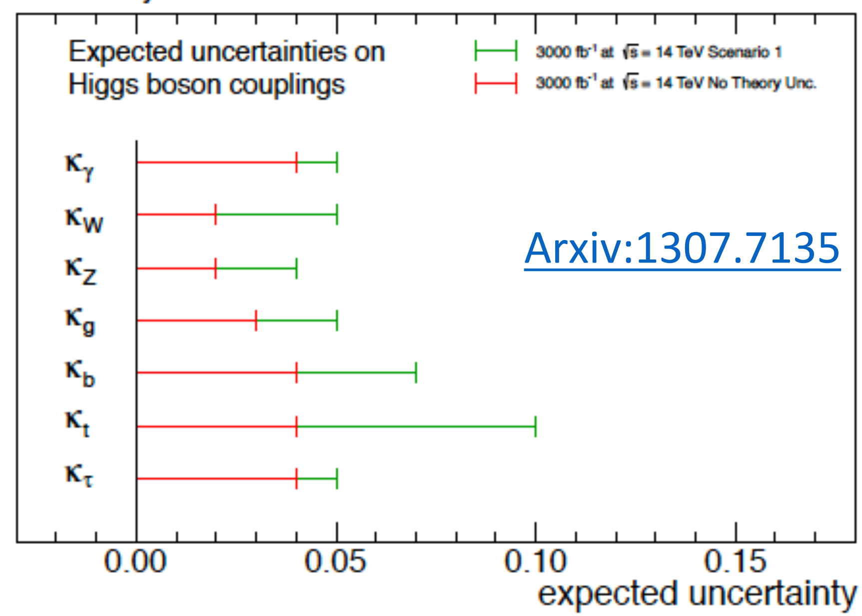
$$\frac{\sigma \cdot B\,(gg \to H \to \gamma\gamma)}{\sigma_{\rm SM}(gg \to H)\cdot B_{\rm SM}(H \to \gamma\gamma)} = \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

$$\kappa_H = \sum_{H\to j} \frac{\kappa_j^2 \Gamma_j^{SM}}{\Gamma_H^{SM}}$$

ATL-PHYS-PUB-2014-016



CMS Projection



Arxiv:1307.7135

	k_γ	k_W	k_Z	k_g	k_b	k_t	k_τ	$k_{Z\gamma}$	k_μ
CMS*	[2,5]	[2,5]	[2,4]	[3,5]	[4,7]	[7,10]	[2,5]	[10,12]	[8,8]
ATLAS	[4,5]	[4,5]	[4,4]	[9,5]	[10,12]	[8,11]	[9,10]	[14,14]	[7,8]

CMS

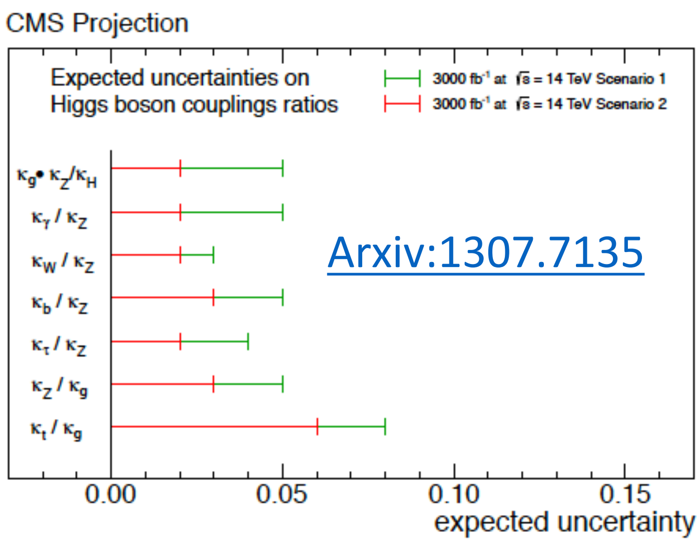
BR_{SM}
[14, 18]
[7, 11]

* CMS global fit doesn't include ECFA 2016 updated ZZ and $\gamma\gamma$ results

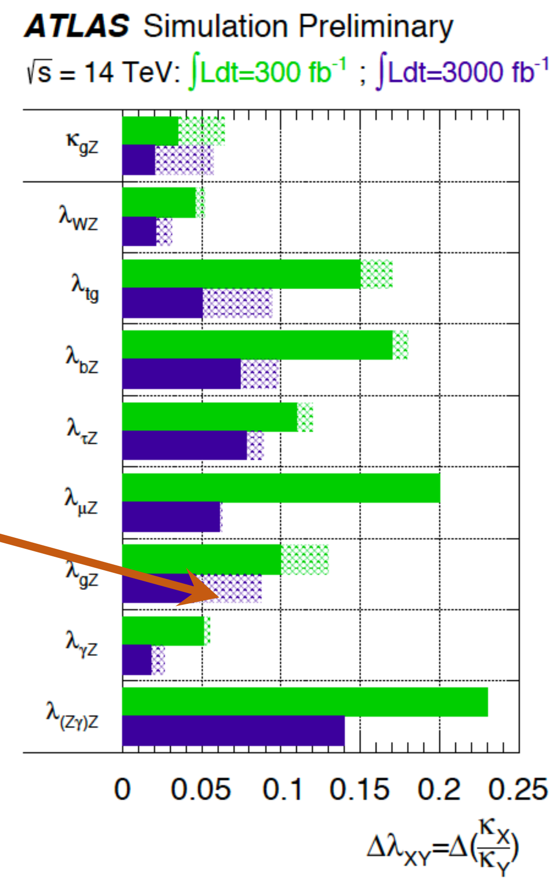
Coupling ratios

ATL-PHYS-PUB-2014-016

- Most generic model, remove the assumption on the total width
- Only ratios of the coupling scale factors could be determined at the LHC



Dashed area corresponds to theory systematics



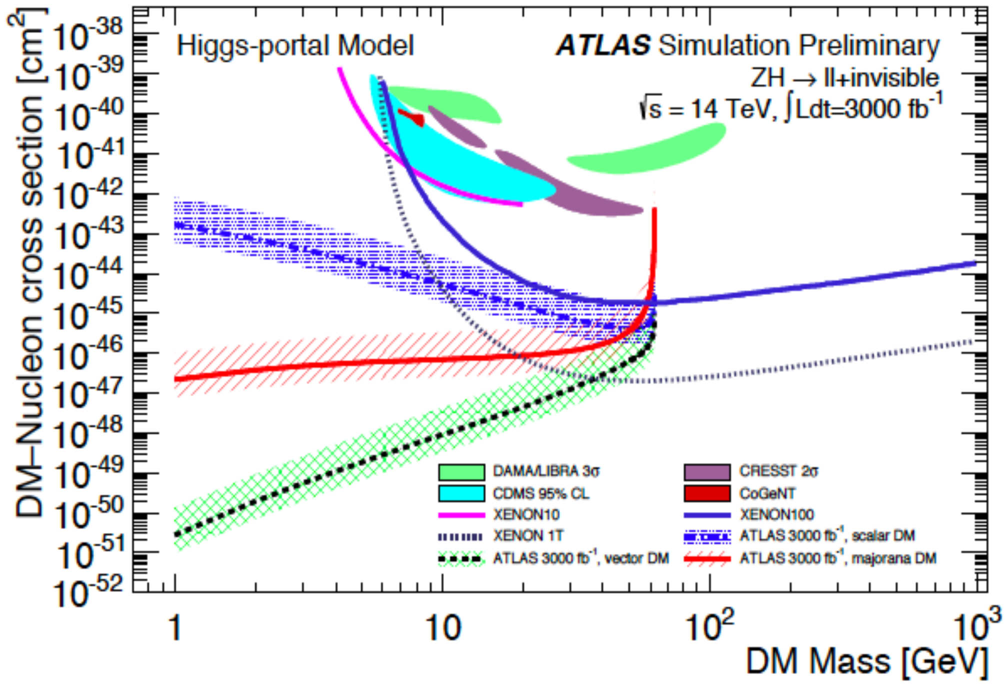
* CMS global fit doesn't include ECFA 2016 updated ZZ and $\gamma\gamma$ results

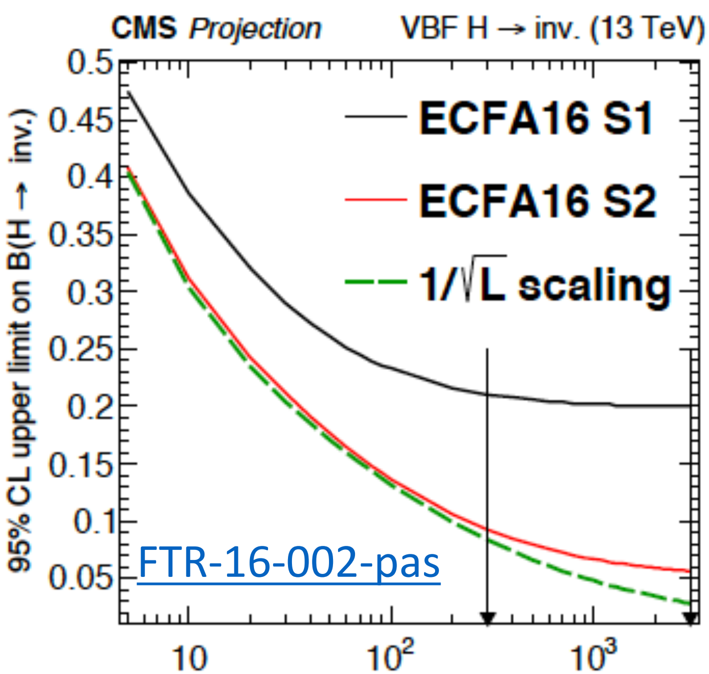
	$k_g \cdot k_Z/k_H$	k_γ/k_Z	k_W/k_Z	k_b/k_Z	k_τ/k_Z	k_g/k_Z	k_t/k_g	k_μ/k_Z	$k_{Z\gamma}/k_Z$
CMS*	[2,5]	[2,5]	[2,3]	[3,5]	[2,4]	[3,5]	[6,8]	[7,8]	[12,12]
ATLAS	[2,6]	[2,3]	[2,3]	[7,10]	[8,9]	[5,9]	[5,9]	[6,6]	[14,14]

ZH→ℓℓ + inv

ATL-PHYS-PUB-2013-014

- Direct search for invisible branching fraction
- Complements indirect limit determined from global analysis
- CMS expects ~20/5% upper limit on the inv-BR (S1/S2+)
- DM couplings to Higgs $h\chi\chi$





ATLAS

BR($H\rightarrow$inv.) limits at 95% (90%) CL	300 fb^{-1}	3000 fb^{-1}
Realistic scenario	23% (19%)	8.0% (6.7%)
Conservative scenario	32% (27%)	16% (13%)

CMS

	ECFA2016 (S1)	ECFA2016 (S2+)	ECFA2016 (S2)
300 fb^{-1}	0.210	0.092	0.084
3000 fb^{-1}	0.200	0.056	0.028

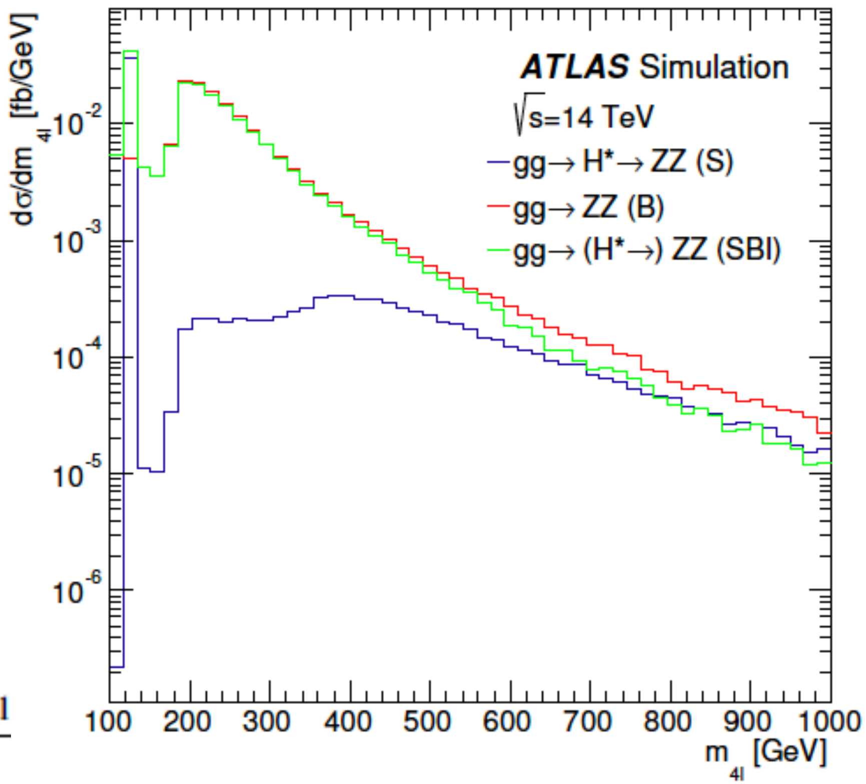
$\mathscr{H}$ Width

$$\mu_{\text{off-shell}}(\hat{s}) \equiv \frac{\sigma^{gg\to H^*\to VV}_{\text{off-shell}}(\hat{s})}{\sigma^{gg\to H^*\to VV}_{\text{off-shell, SM}}(\hat{s})} = \kappa^2_{g,\text{off-shell}}(\hat{s}) \cdot \kappa^2_{V,\text{off-shell}}(\hat{s})$$

- A key ingredient for the global κ analysis
- The total width of the Higgs boson can be measured (set upper limits) at the LHC comparing on-shell and off-shell production of H→ZZ
- ATLAS result indicates that under a number of assumptions, the SM Higgs boson width can be estimated with a systematic uncertainty of ~2 MeV at the HL-LHC

$$\Gamma_H^{(L2)} = 4.2^{+1.5}_{-2.1}\ \text{MeV (stat+sys)}.$$

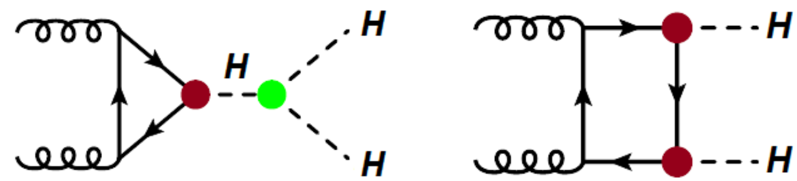
ATL-PHYS-PUB-2015-024



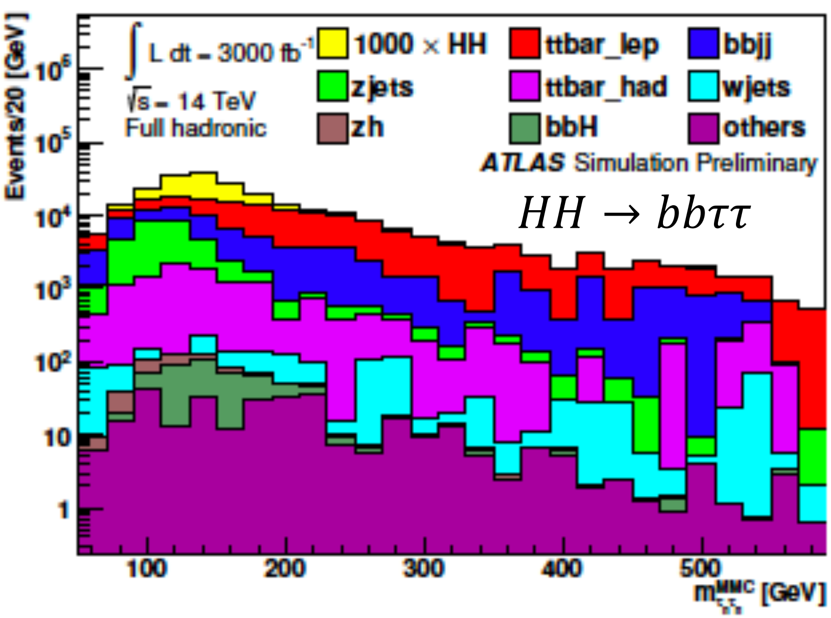
$$\mu_{\text{on-shell}} = \frac{\sigma^{gg\to H\to ZZ}_{\text{on-shell}}}{\sigma^{gg\to H\to ZZ}_{\text{on-shell, SM}}} = \frac{\kappa^2_{g,\text{on-shell}} \cdot \kappa^2_{Z,\text{on-shell}}}{\Gamma_H/\Gamma_H^{SM}}$$

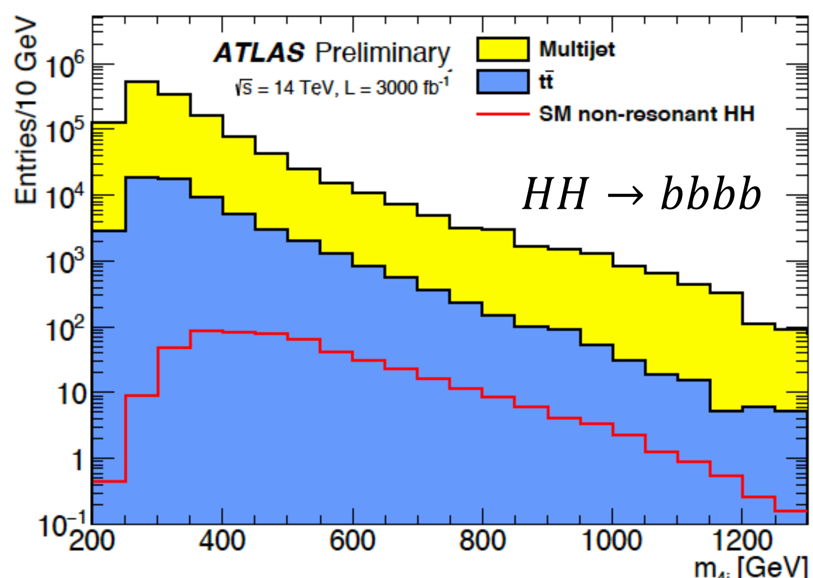
Higgs pair production (λ_{HHH})

- Very challenging measurement
- Sensible to the triple Higgs coupling
- Very small production cross section in the SM make this process only accessible at HL-LHC
- QCD and ttbar backgrounds are huge



Decay Channel	Branching Ratio	Total Yield (3000 fb^{-1})
$b\bar{b} + b\bar{b}$	33%	4.1×10^4
$b\bar{b} + W^+W^-$	25%	3.1×10^4
$b\bar{b} + \tau^+\tau^-$	7.4%	9.0×10^3
$W^+W^- + \tau^+\tau^-$	5.4%	6.6×10^3
$ZZ + b\bar{b}$	3.1%	3.8×10^3
$ZZ + W^+W^-$	1.2%	1.4×10^3
$\gamma\gamma + b\bar{b}$	0.3%	3.3×10^2
$\gamma\gamma + \gamma\gamma$	0.0010%	1



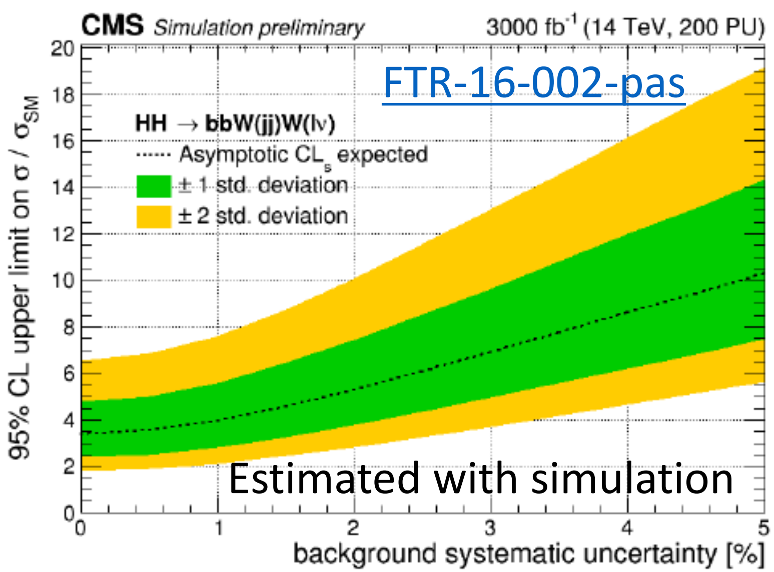


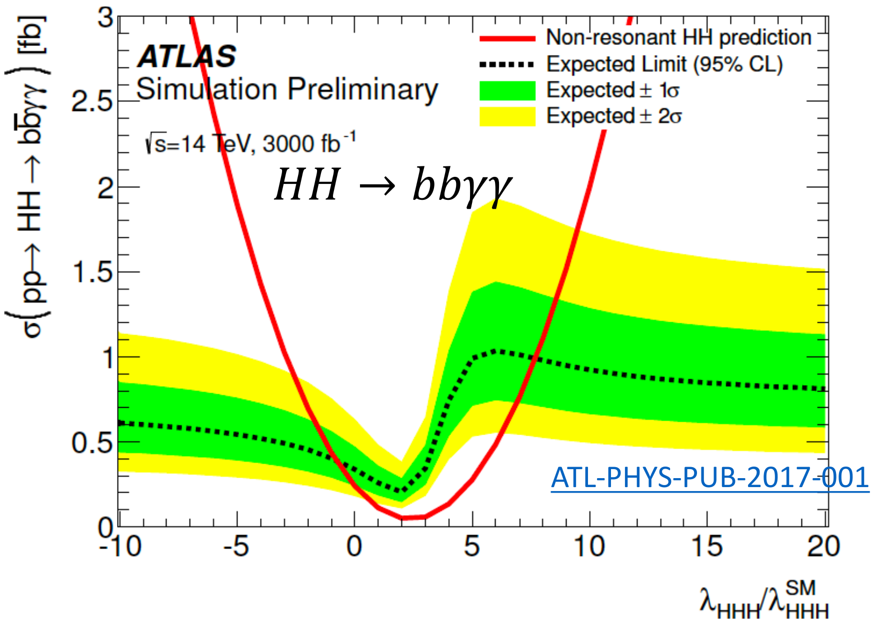
Higgs pair production (λ_{HHH})

- ATLAS uses parametrized performance on MC samples (except 4b) to put limits on κ_λ, CMS uses Run2 extrapolations to estimate sensitivity (expept bbW(jj)W(lν))
- Combination of projections planned for 2018, current expected comb. sensitivity below 2σ

Channel ATLAS	Sensitivity/ Exclusion Limit
HH→bb$\tau\tau$ ATL-PHYS-PUB-2015-046	0.6 σ (combined) / -4.3 < $\lambda_{HHH}/\lambda_{SM}$ < 12
HH→bbbb **(Run2 extrap)** ATL-PHYS-PUB-2016-024	/ -3.5< $\lambda_{HHH}/\lambda_{SM}$ <11
HH→bb$\gamma\gamma$ ATL-PHYS-PUB-2017-001	1.05 σ / -0.8< $\lambda_{HHH}/\lambda_{SM}$ <7.7
ttHH→ttbbbb ATL-PHYS-PUB-2016-023	0.35σ /

Channel **CMS**	Median expected limits in μ_r		Z-value		Uncertainty as fraction of $\mu_r = 1$	
	ECFA16 S2	Stat. Only	ECFA16 S2	Stat. Only	ECFA16 S2	Stat. Only
$gg \to HH \to \gamma\gamma bb$ (S2+)	1.44	1.37	1.43	1.47	0.72	0.71
$gg \to HH \to \tau\tau bb$	5.2	3.9	0.39	0.53	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





Conclusions

- The ATLAS and CMS upgraded detectors with HL-LHC data will be able to probe Higgs couplings deviations w.r.t. SM with a precision of a few percents

- The ATLAS and CMS upgraded detectors with HL-LHC data will be able to measure rare Higgs decay modes as $H \rightarrow \mu\mu$ or $H \rightarrow Z\gamma$ and ttH production mode in all 5 main H decay modes

- Higgs pair production is an important topic for HL-LHC and the experiments are trying to use as many final states as possible to attack HH from different angles

- New results will come out from current TDR studies and implementation of recent Run2 analysis tools

7 th International Conference on High Energy Physics in the LHC era

8-12 January 2018, Universidad Técnica Federico Santa María, Valparaíso, Chile

Dedicated to the memory of
Lev Lipatov

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Dark Matter Searches — Non Perturbative QCD
Astroparticle Physics — Hadron Structure
Neutrino Physics — High Energy QCD
Future Experiments — Particle Detectors
Instrumentation — Beyond the Standard Model Physics
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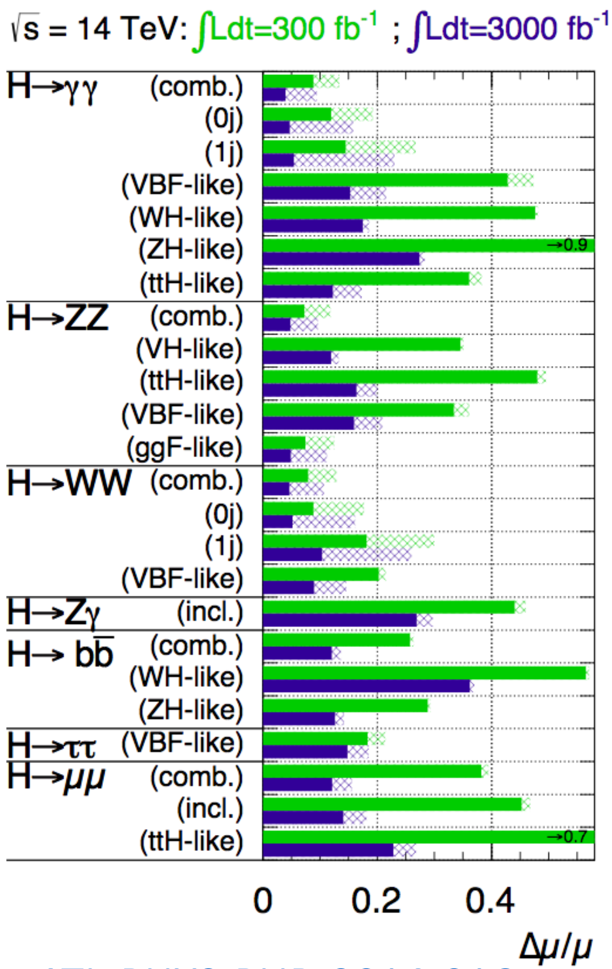
https://indico.cern.ch/e/hep2018

Backup

Expected Higgs signal strength uncertainties per channel

Extrapolated from Run1



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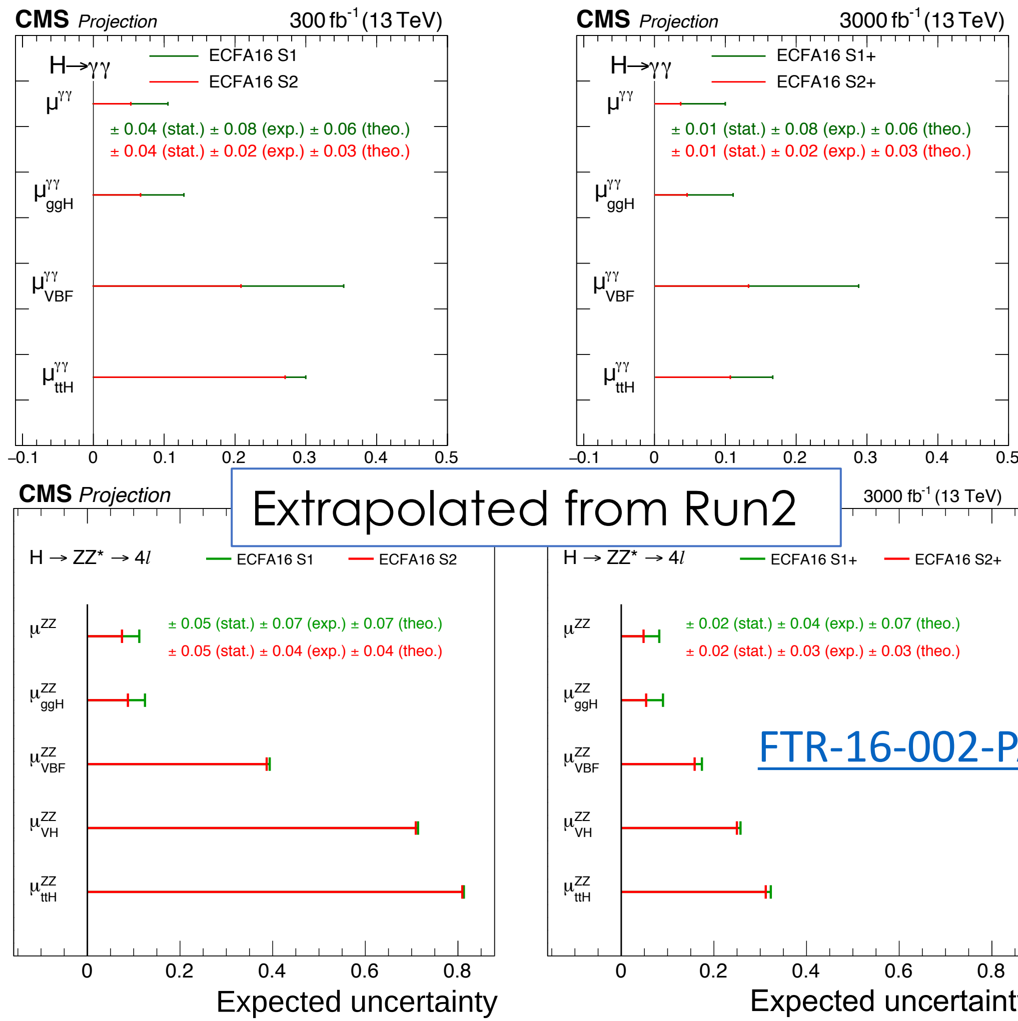
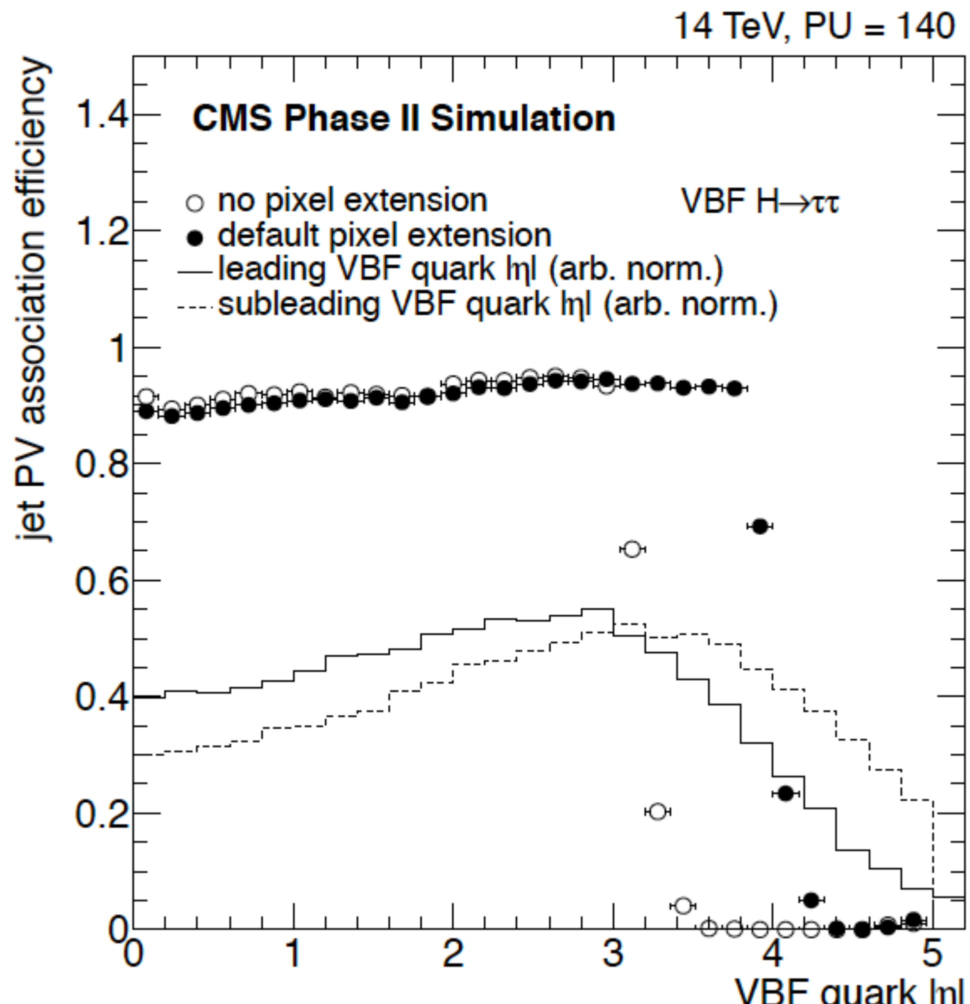
Extrapolated from Run2

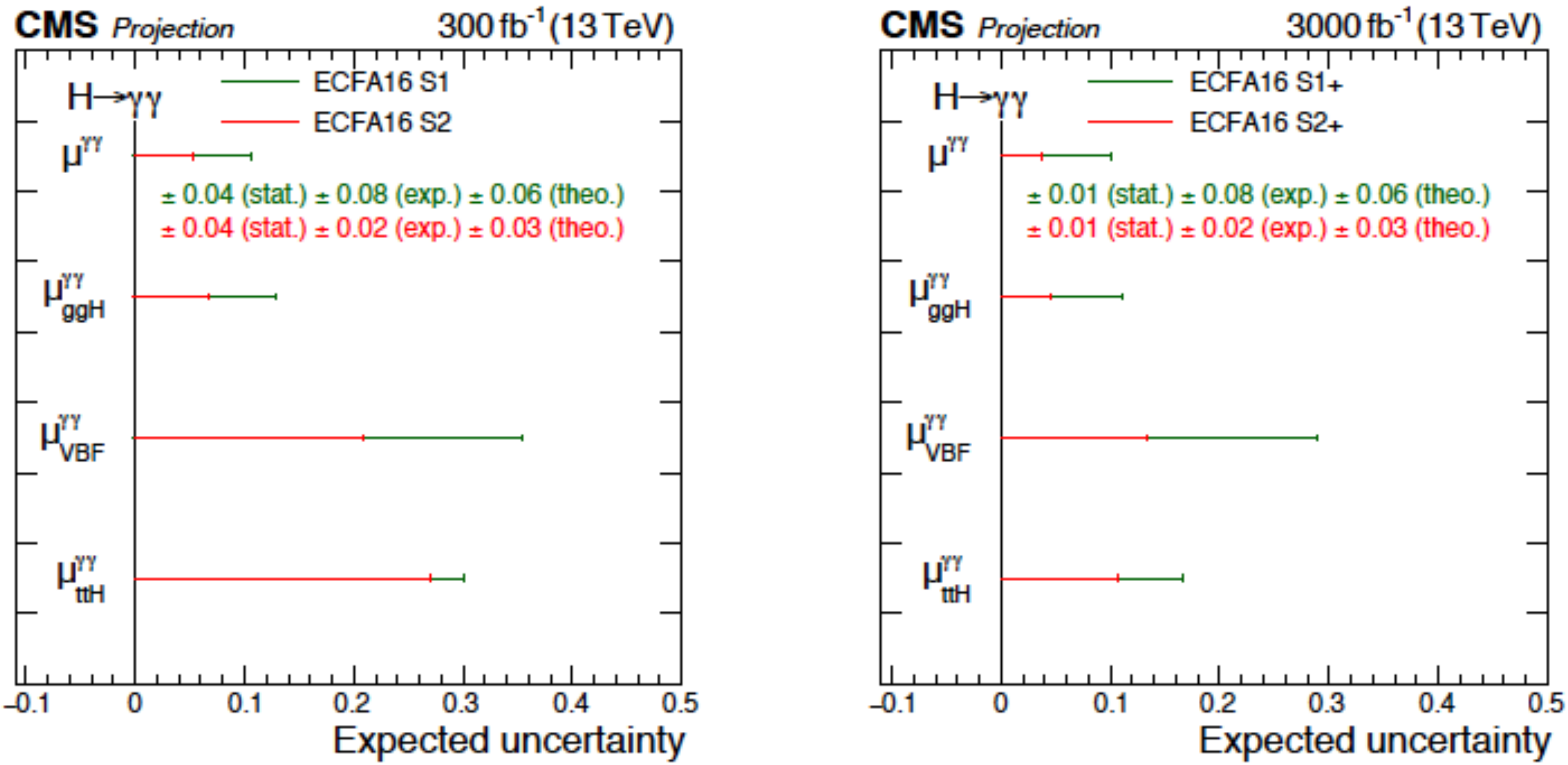


(a) (b)

FTR-16-002-PAS

Main CMS Detector Upgrades

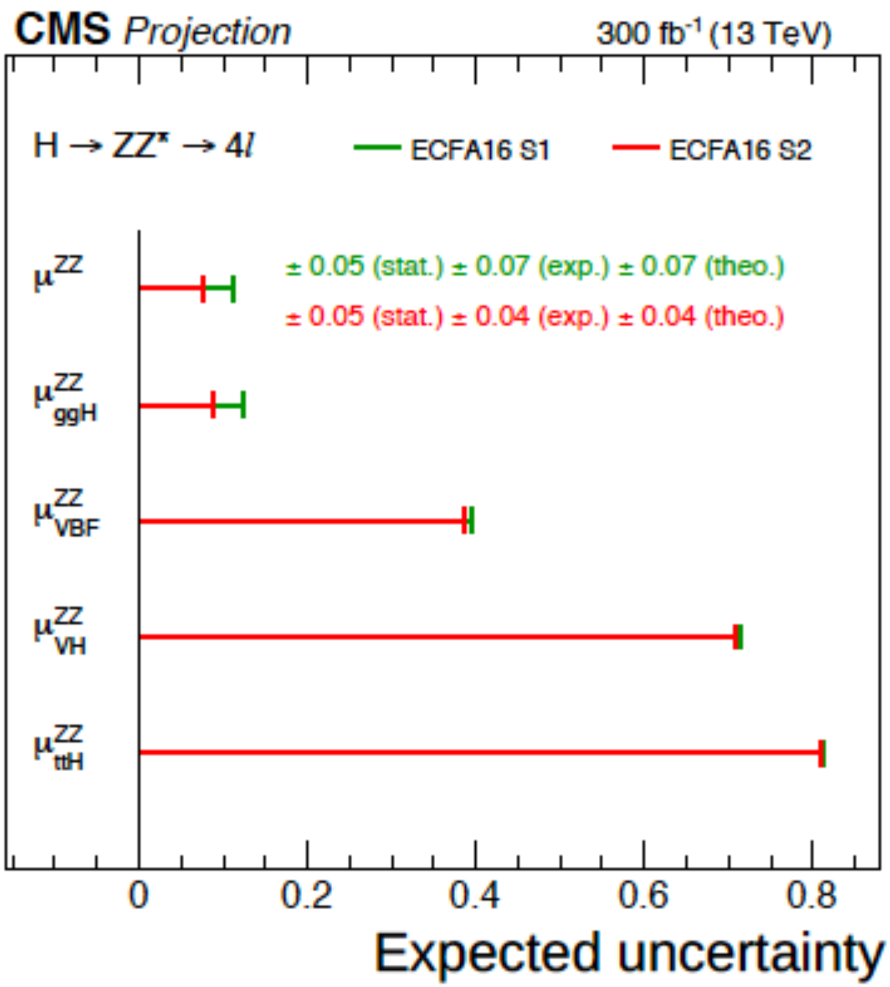


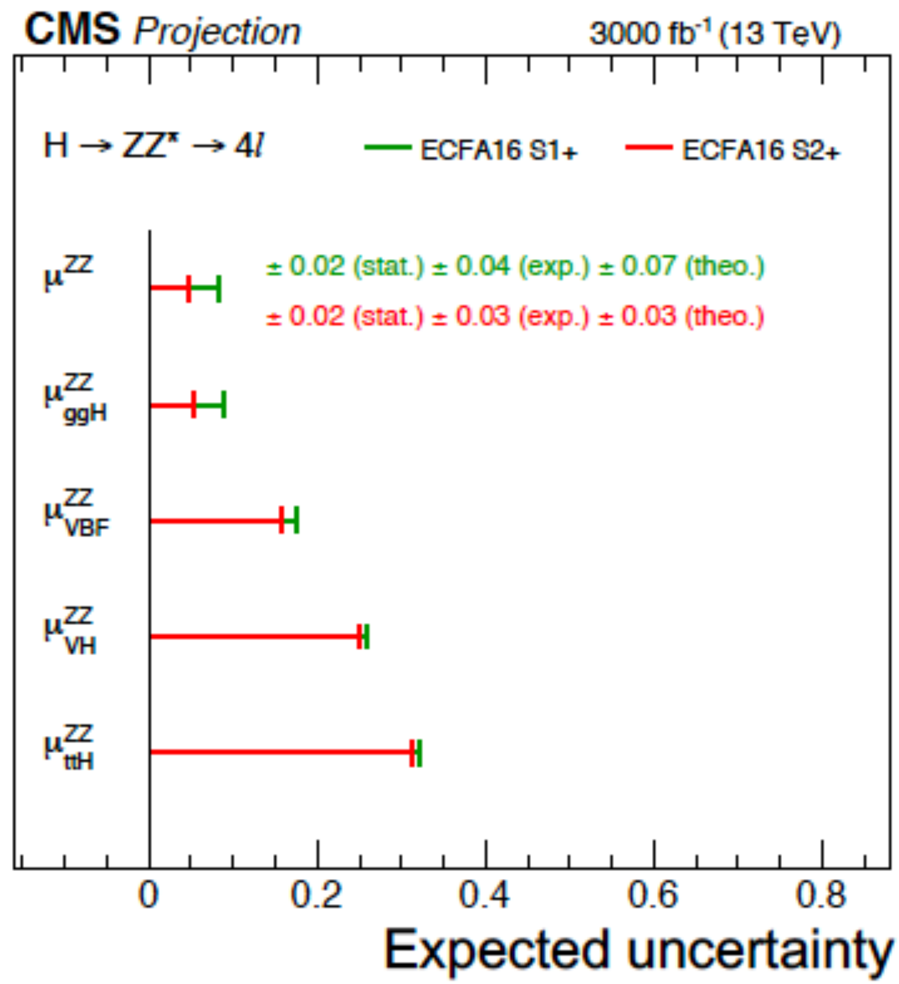

CMS Projection
300 fb-1 (13 TeV)
H→γγ
ECFA16 S1
ECFA16 S2
μγγ
± 0.04 (stat.) ± 0.08 (exp.) ± 0.06 (theo.)
± 0.04 (stat.) ± 0.02 (exp.) ± 0.03 (theo.)
μγγ ggH
μγγ VBF
μγγ ttH
–0.1 0 0.1 0.2 0.3 0.4 0.5
Expected uncertainty
CMS Projection
3000 fb-1 (13 TeV)
H→γγ
ECFA16 S1+
ECFA16 S2+
μγγ
± 0.01 (stat.) ± 0.08 (exp.) ± 0.06 (theo.)
± 0.01 (stat.) ± 0.02 (exp.) ± 0.03 (theo.)
μγγ ggH
μγγ VBF
μγγ ttH
–0.1 0 0.1 0.2 0.3 0.4 0.5
Expected uncertainty

Projected uncertainty in the $H \rightarrow \gamma\gamma$ signal strength (%)				
	300 fb^{-1}		3000 fb^{-1}	
	ECFA16 S1	ECFA16 S2	ECFA16 S1+	ECFA16 S2+
$\mu^{\gamma\gamma}_{ggH}$	13	7	11	5
$\mu^{\gamma\gamma}_{VBF}$	35	21	29	13
$\mu^{\gamma\gamma}_{ttH}$	30	27	17	11
3 $\mu^{\gamma\gamma}$	11	5	10	4
	(stat.) ± (exp.) ± (theo.)			
$\mu^{\gamma\gamma}$	$4 \pm 8 \pm 6$	$4 \pm 2 \pm 3$	$1 \pm 8 \pm 6$	$1 \pm 2 \pm 3$

Projected uncertainty in $H \to ZZ$ signal strength (%)				
	300 fb^{-1}		3000 fb^{-1}	
	ECFA16 S1	ECFA16 S2	ECFA16 S1+	ECFA16 S2+
μ^{ZZ}_{ggH}	12	9	9	5
μ^{ZZ}_{VBF}	39	39	17	16
μ^{ZZ}_{VH}	71	71	26	25
μ^{ZZ}_{ttH}	81	81	32	31
μ^{ZZ}	11	7	8	5

	(stat.) $\pm$ (exp.) $\pm$ (theo.)			
$\mu^{\gamma\gamma}$	$5 \pm 7 \pm 7$	$5 \pm 4 \pm 4$	$2 \pm 4 \pm 7$	$2 \pm 3 \pm 3$


CMS Projection
300 fb-1 (13 TeV)
H → ZZ* → 4l
ECFA16 S1
ECFA16 S2
± 0.05 (stat.) ± 0.07 (exp.) ± 0.07 (theo.)
± 0.05 (stat.) ± 0.04 (exp.) ± 0.04 (theo.)
μ^ZZ
μ^ZZ_ggH
μ^ZZ_VBF
μ^ZZ_VH
μ^ZZ_ttH
0
0.2
0.4
0.6
0.8
Expected uncertainty


CMS Projection
3000 fb-1 (13 TeV)
H → ZZ* → 4l
ECFA16 S1+
ECFA16 S2+
± 0.02 (stat.) ± 0.04 (exp.) ± 0.07 (theo.)
± 0.02 (stat.) ± 0.03 (exp.) ± 0.03 (theo.)
μ^ZZ
μ^ZZ_ggH
μ^ZZ_VBF
μ^ZZ_VH
μ^ZZ_ttH
0
0.2
0.4
0.6
0.8
Expected uncertainty

H decay	prod. tag	exclusive final states	cat.	res.	ref.
$\gamma\gamma$	untagged	$\gamma\gamma$ (4 diphoton classes)	4	1-2%	[6]
	VBF-tag	$\gamma\gamma + (jj)_{\mathrm{VBF}}$	2	<1.5%	
	VH-tag	$\gamma\gamma$ + (e, μ, MET)	3	<1.5%	
	ttH-tag	$\gamma\gamma$ (lep. and had. top decay)	2	<1.5%	[23]
$ZZ \to 4\ell$	$N_{\mathrm{jet}} < 2$	4e, 4μ, $2e2\mu$	3	1-2%	[7]
	$N_{\mathrm{jet}} \geq 2$		3		
$WW \to \ell\nu\ell\nu$	0/1-jets	(DF or SF dileptons) $\times$ (0 or 1 jets)	4	20%	[8]
	VBF-tag	$\ell\nu\ell\nu + (jj)_{\mathrm{VBF}}$ (DF or SF dileptons)	2	20%	[24]
	WH-tag	$3\ell 3\nu$ (same-sign SF and otherwise)	2		[25]
$\tau\tau$	0/1-jet	(eτ_h, $\mu\tau_h$, eμ, $\mu\mu$)$\times$ (low or high p_T^τ)	16	15%	[10]
	1-jet	$\tau_h\tau_h$	1		
	VBF-tag	(eτ_h, $\mu\tau_h$, eμ, $\mu\mu$, $\tau_h\tau_h$) $+ (jj)_{\mathrm{VBF}}$	5		
	ZH-tag	(ee, $\mu\mu$) $\times$ ($\tau_h\tau_h$, eτ_h, $\mu\tau_h$, eμ)	8		[26]
	WH-tag	$\tau_h\mu\mu$, τ_heμ, e$\tau_h\tau_h$, $\mu\tau_h\tau_h$	4		
bb	VH-tag	($\nu\nu$, ee, $\mu\mu$, eν, $\mu\nu$ with 2 b-jets)$\times$x	13	10%	[27]
	ttH-tag	(ℓ with 4, 5 or $\geq$6 jets) $\times$ (3 or $\geq$4 b-tags);	6		[28]
		(ℓ with 6 jets with 2 b-tags); ($\ell\ell$ with 2 or $\geq$3 b-jets)	3		
$Z\gamma$	inclusive	(ee, $\mu\mu$) $\times$ (γ)	2		[29]
$\mu\mu$	0/1-jets	$\mu\mu$	12	1-2%	[30–32]
	VBF-tag	$\mu\mu + (jj)_{\mathrm{VBF}}$	3		
invisible	ZH-tag	(ee, $\mu\mu$) $\times$ (MET)	2		[21]

Table 3: Precision on the measurements of κ_γ, κ_W, κ_Z, κ_g, κ_b, κ_t and κ_τ. These values are obtained at $\sqrt{s} = 14$ TeV using an integrated dataset of 300 and 3000 fb^{-1}. Numbers in brackets are % uncertainties on couplings for [Scenario 2, Scenario 1] as described in the text. For the fit including the possibility of Higgs boson decays to BSM particles d the 95% CL on the branching fraction is given.

L (fb^{-1})	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	$\kappa_{\mu\mu}$	BR_{SM}
300	[5, 7]	[4, 6]	[4, 6]	[6, 8]	[10, 13]	[14, 15]	[6, 8]	[41, 41]	[23, 23]	[14, 18]
3000	[2, 5]	[2, 5]	[2, 4]	[3, 5]	[4, 7]	[7, 10]	[2, 5]	[10, 12]	[8, 8]	[7, 11]

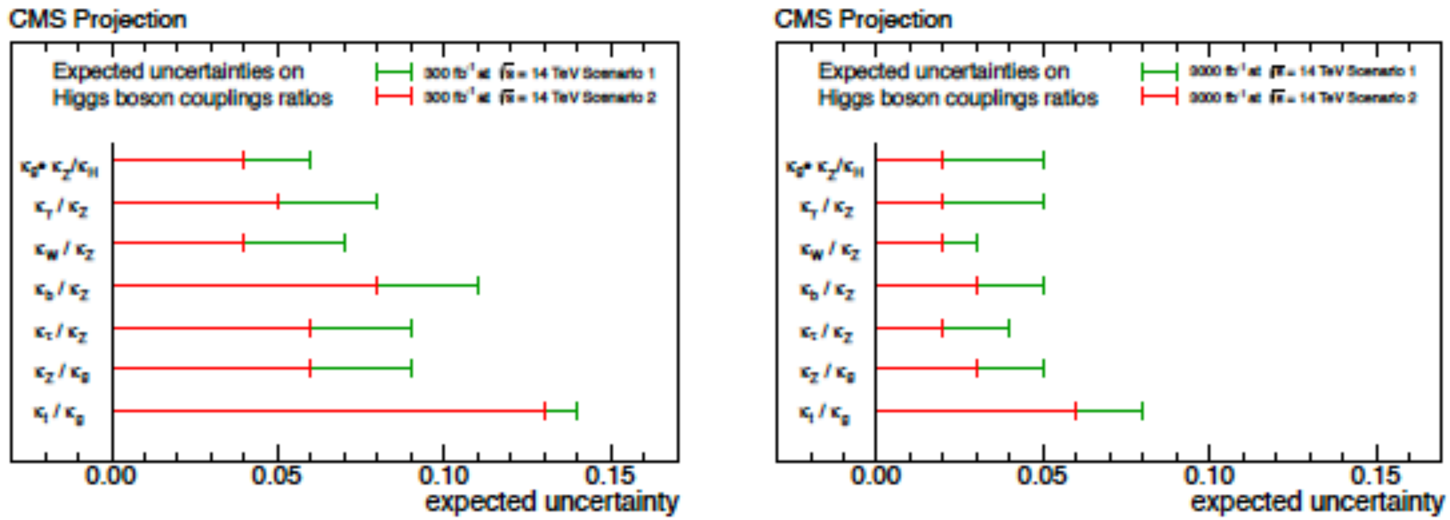


Figure 14: Estimated precision on the measurements of ratios of Higgs boson couplings (plot shows ratio of partial width. It will be replaced by a plot of ratio of couplings by the time of the pre-approval. Uncertainties are 1/2). The projections assume $\sqrt{s} = 14$ TeV and an integrated dataset of 300 fb^{-1} (left) and 3000 fb^{-1} (right). The projections are obtained with the two uncertainty scenarios described in the text.

Main ATLAS Detector Upgrades

Table 1: Brief Description of the Detector Scenarios

Name	Cost (MCHF)	Tracking η coverage	Quality of b-jet identif.
Reference	275	4.0	Excellent
Middle	230	3.2	Good
Low	200	2.7	Satisfactory