Higgs prospects at HL-LHC

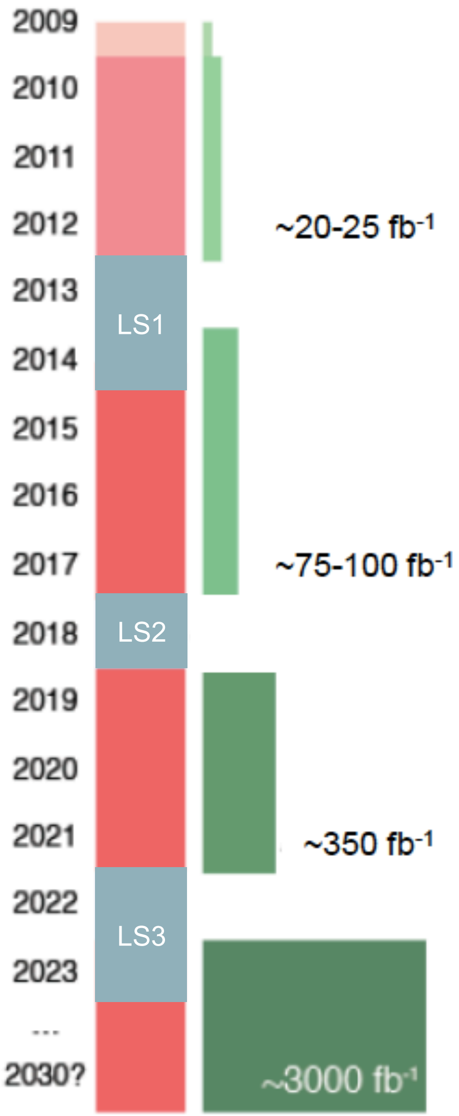
Nikos Konstantinidis (UCL)
On behalf of the ATLAS and CMS Collaborations

EPS HEP Conference, Stockholm, 20/07/2013

Outline

- HL-LHC: timelines, targets and assumptions
- Higgs properties
  - Rare Higgs processes
  - Couplings to fermions and bosons
  - Self-couplings
- Vector boson scattering
- Conclusions

The HL-LHC programme



More details on LHC upgrades in plenary talk by Mike Lamont and in several parallel sessions

- Start at 2024 after a ~2-year shutdown (LS3)
  - LHC: new IR magnets, crab cavities, …
- LHC peak luminosity: ~5e34$cm^{-2}s^{-1}$
  - ~140 pp collisions per bunch crossing
- Collect ~250-300fb^{-1}/year for a total of ~3000fb^{-1} per experiment by the early 2030s
- An ambitious programme of detector upgrades proposed by ATLAS and CMS to maintain/improve current performance
  - In trigger, offline reconstruction, identification of physics objects
  - Also to address key experimental systematics that would limit in particular the Higgs studies

Assumptions and projections

- Projections use realistic/conservative assumptions about detector performance at HL-LHC and the evolution of systematic uncertainties
  - Impressive progress in minimizing the impact of pile-up during 2012
  - In 2012, <μ> up to ~35; extrapolation to <μ>~140 not huge

- ATLAS performed generator-level studies, applying resolution and efficiency parameterisation functions for the HL-LHC conditions
  - With realistic/conservative assumptions for the effects of pile-up
    - E.g. full sim. studies of b-tagging with tracker upgrade now show better performance

- CMS extrapolate current results with different assumptions
  (1) Pessimistic: experimental and theory systematics as of today
  (2) Optimistic: experimental systematics scale as $1/\sqrt{L}$, theory systematics halved

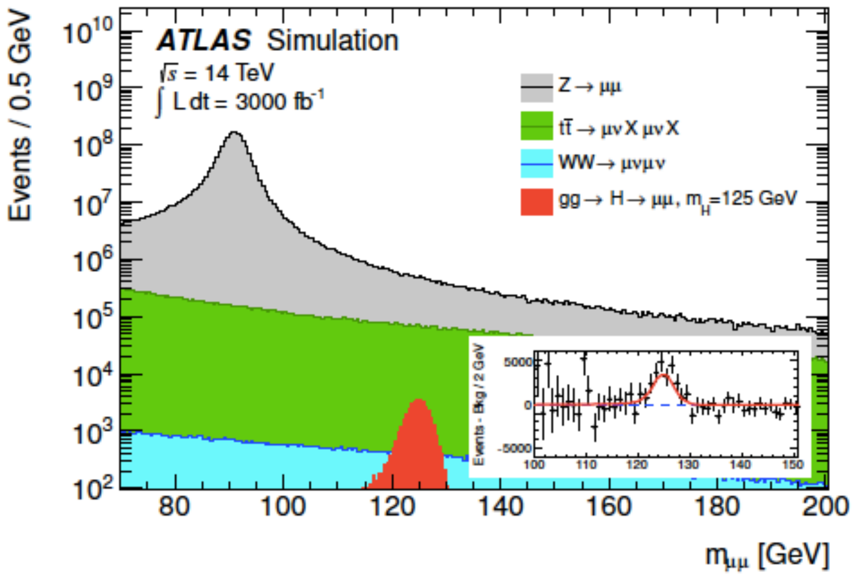
- Past experience: projections almost invariably proved conservative!

Rare Higgs processes

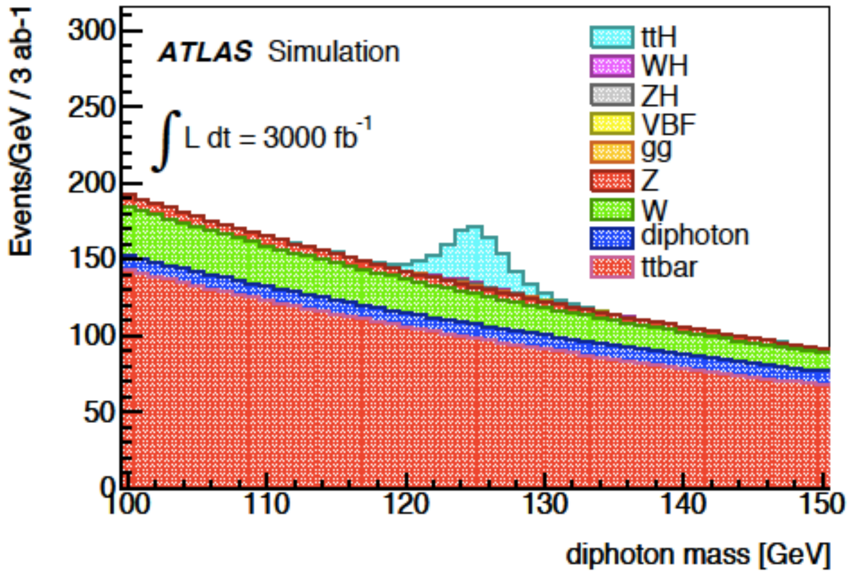
- H→μμ
  - ATLAS finds ~2σ with 300fb^{-1} and ~6σ with 3000fb^{-1}
  - CMS should achieve similar sensitivity
- ttH, H→μμ (ATLAS)
  - Involves only fermion couplings
  - Only ~30 events in 3000fb-1, but very pure: s/b~1
- ttH, H→γγ (ATLAS)
  - Another rare, but relatively pure process (s/b~20%)
  - Important probe of top Yukawa coupling

H→μμ

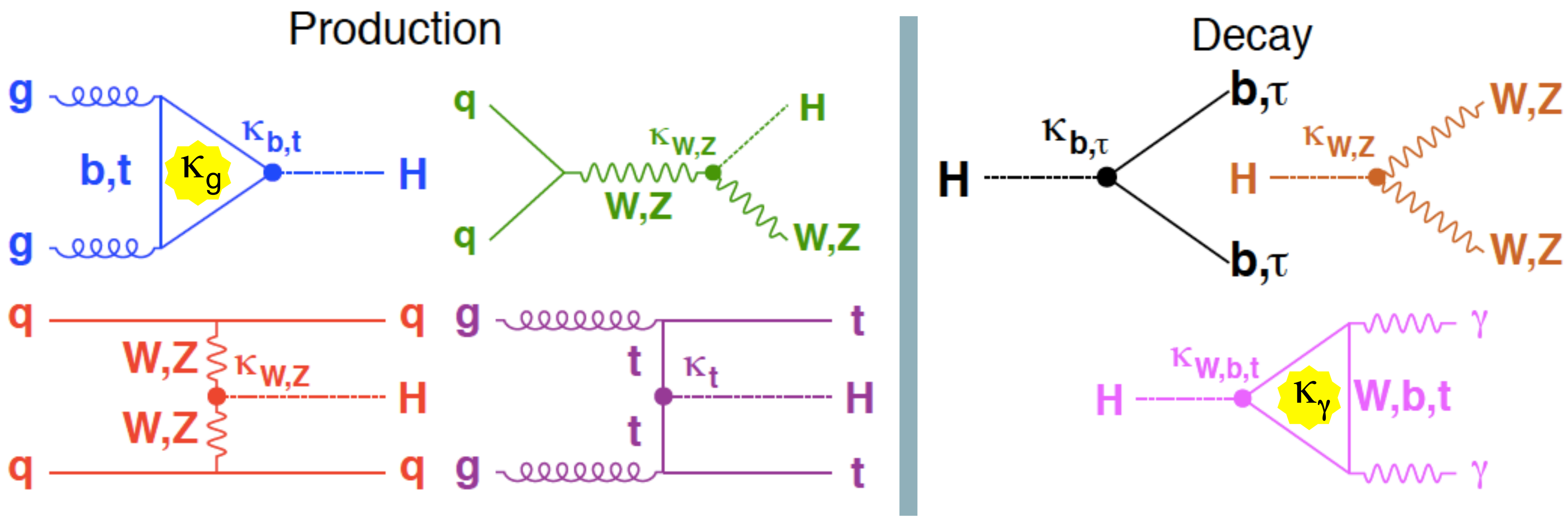
CERN-LHCC-2012-022



ttH, H→γγ

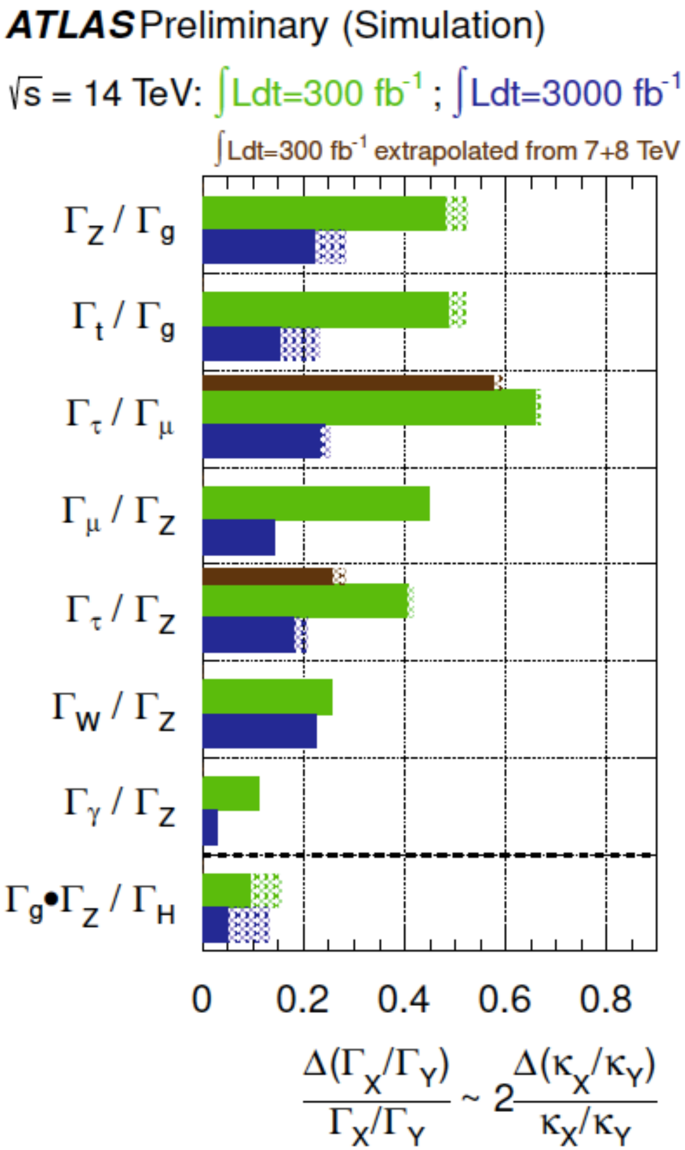


- At the LHC, only possible to measure σxBR's
  - Expressed as ratio to the SM values: $\mu=(\sigma \times BR)/(\sigma \times BR)_{SM}$
- Ratios of partial widths can be derived without any model assumptions
- Interpretation in terms of couplings is model dependent
  - Expressed in terms of scale factors, κ, wrt SM values; $\Gamma_X/\Gamma_Y \sim (\kappa_X/\kappa_Y)^2$



Couplings – ATLAS

CERN-LHCC-2012-022



Minimal fit: only two coupling scale factors, κ_F for fermions and κ_V for vector bosons

- No BSM contributions in either loops or in the total Higgs width

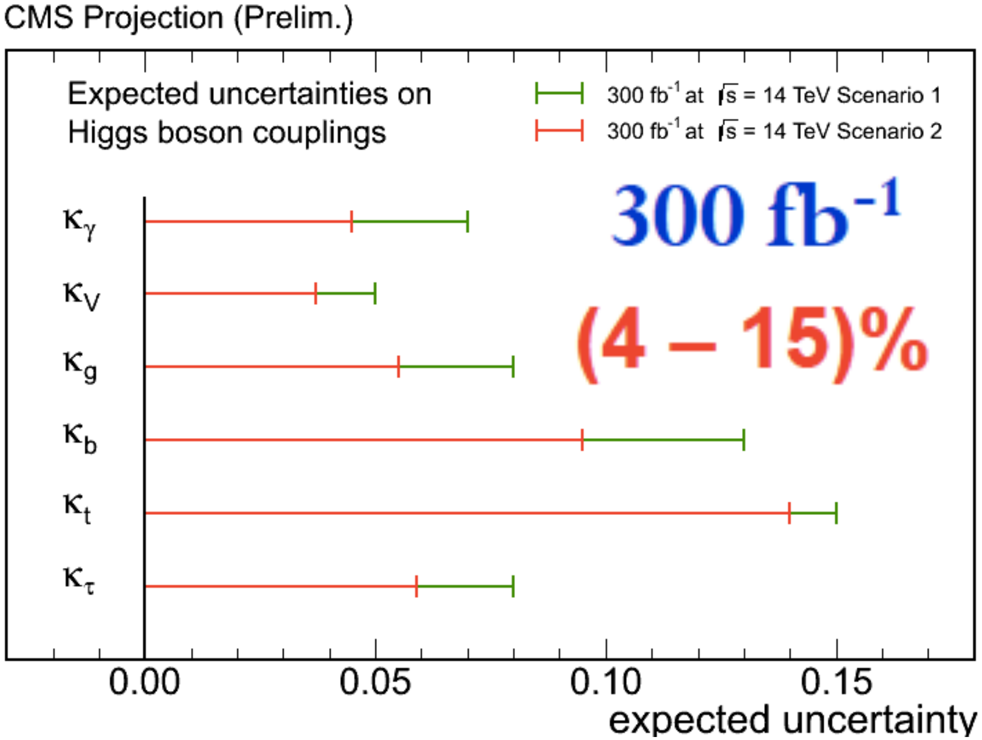
Sensitivity without (with) theory uncertainties:

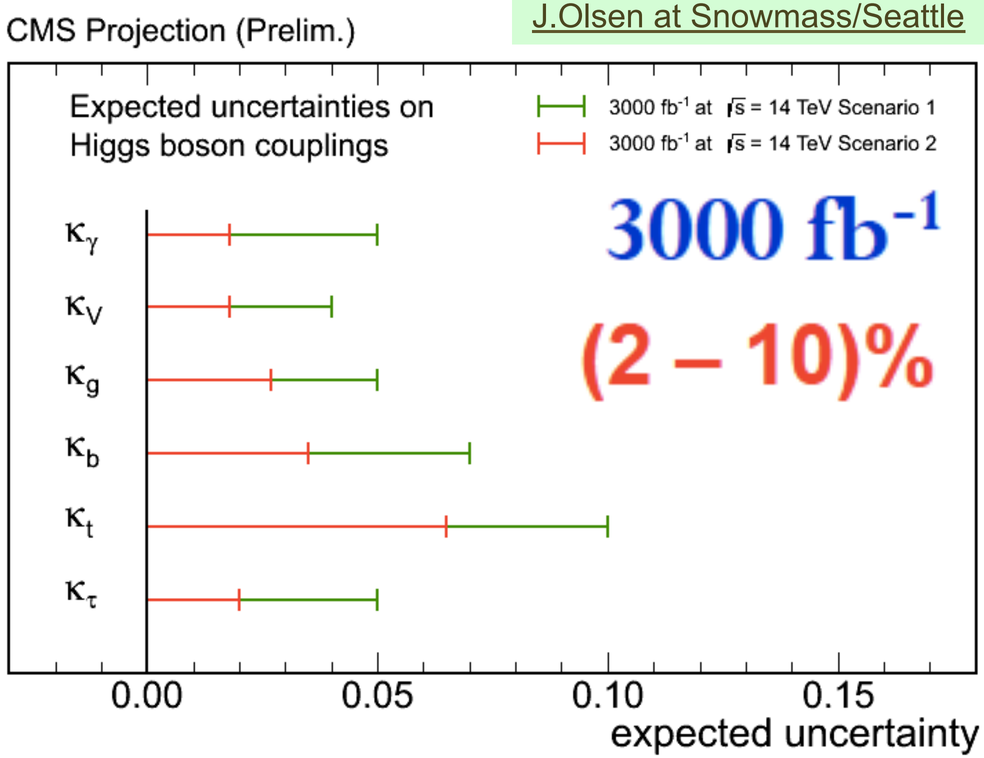
ATLAS	300 fb^{-1}	3000 fb^{-1}
κ_V	3.0 % (5.6 %)	1.9 % (4.5 %)
κ_F	8.9 % (10 %)	3.6 % (5.9 %)

A big improvement, esp. on κ_F, with 3000fb^{-1} provided the theory uncertainties are reduced!

Couplings – CMS

J.Olsen at Snowmass/Seattle



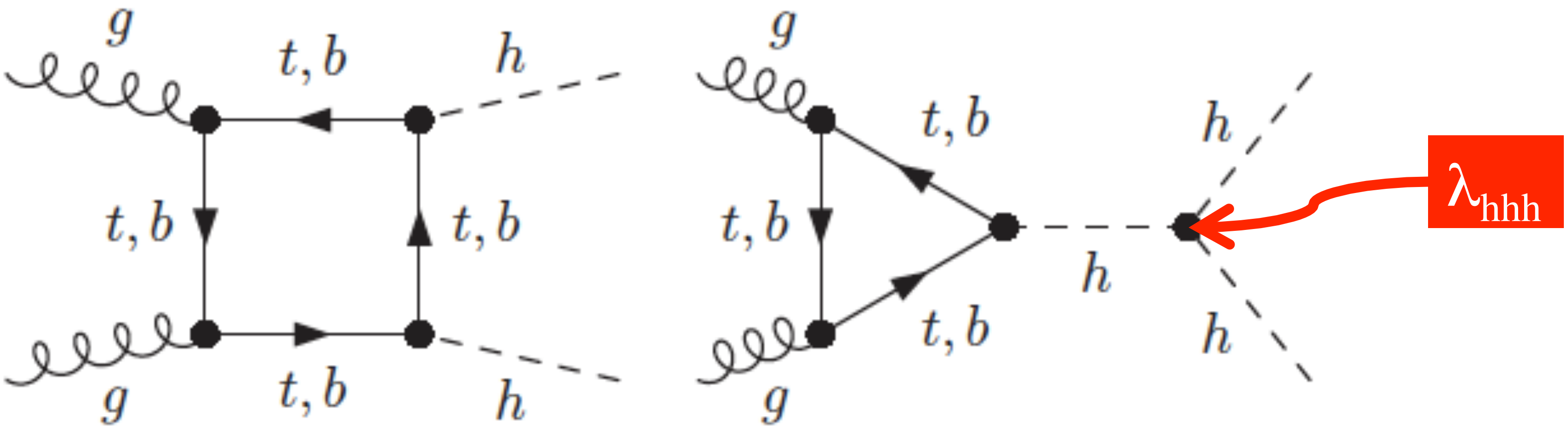


Numbers in brackets are % uncertainties on coupling deviations for [scenario 2, scenario 1]

L (fb^{-1})	κ_γ	κ_V	κ_g	κ_b	κ_t	κ_τ
300	[5, 7]	[4, 5]	[6, 8]	[10, 13]	[14, 15]	[6, 8]
3000	[2, 5]	[2, 3]	[3, 5]	[4, 7]	[7, 10]	[2, 5]

Ultimately, combined ATLAS+CMS precision down to a few %.

Higgs self-coupling

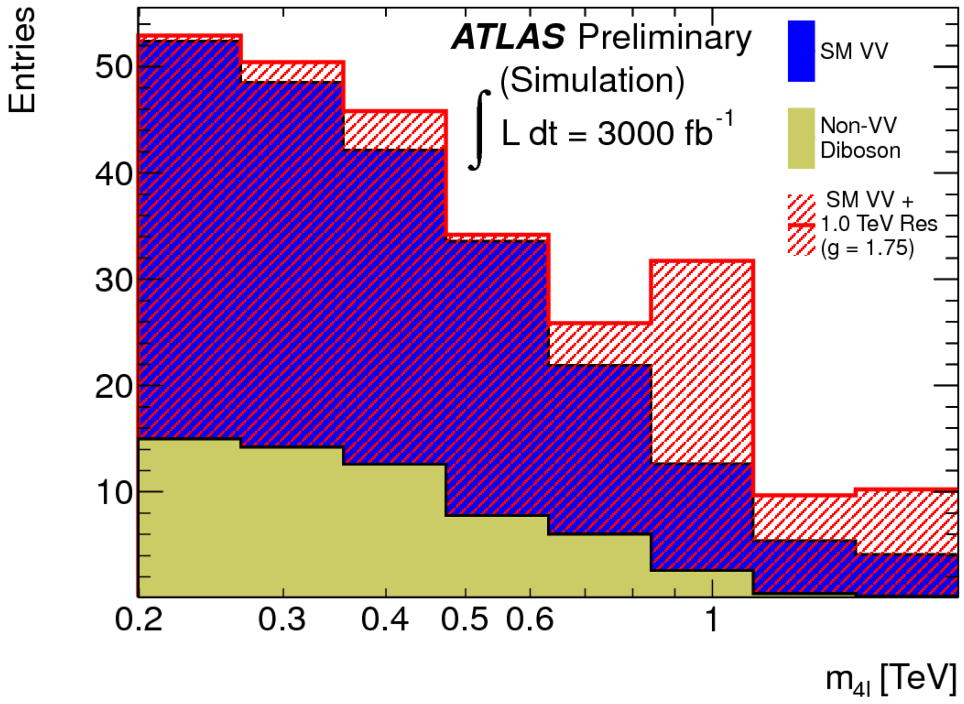


- Arguably, the most challenging measurement at the LHC!
  - Look for Higgs-pair production; destructive interference with diagrams not containing the self-coupling vertex λ_{hhh}
  - For $\lambda_{HHH}/\lambda_{HHH}^{SM}$ = 0/1/2, the cross section is 71/34/16fb
- Preliminary ATLAS studies indicate that hh→bbγγ is promising
  - σxBR~0.1fb, backgrounds are largely Xh(h→γγ) and continuum bbγγ
  - Additional signal channels under study, e.g. bbττ
  - New set of results to appear at the ECFA HL-LHC workshop in October
- A measurement by ATLAS+CMS with 3000fb^{-1} may be possible

Vector Boson Scattering

CERN-LHCC-2012-022

- Crucial test of EWSB dynamics and the nature of the Higgs
- Big gains in sensitivity with 3000fb^{-1}
  - ZZ→4leptons: low backgrounds, clear peak in m_{4l}, high sensitivity
    - Factor ~3 improvement in measuring the SM σxBR
    - Increased sensitivity to models predicting TeV-scale resonances



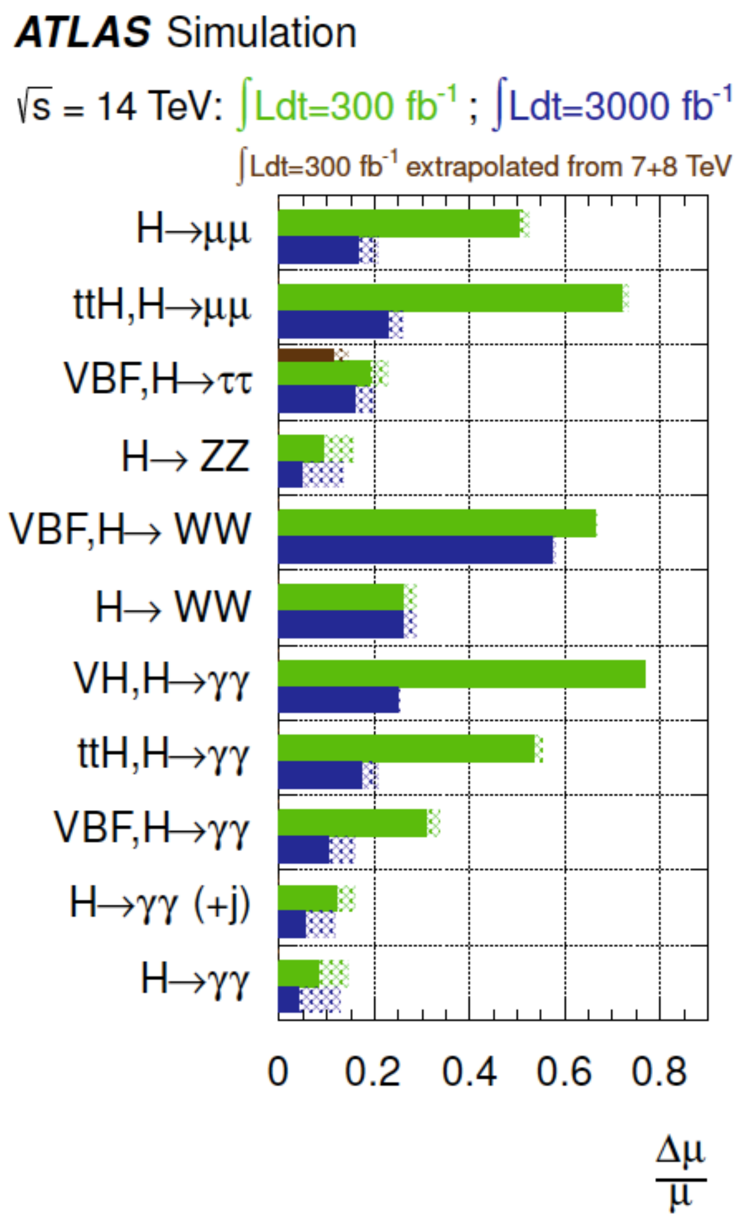
model	300 fb^{-1}	3000 fb^{-1}
$m_{resonance}$ = 500 GeV, g = 1.0	2.4σ	7.5σ
$m_{resonance}$ = 1 TeV, g = 1.75	1.7σ	5.5σ
$m_{resonance}$ = 1 TeV, g = 2.5	3.0σ	9.4σ

Conclusions

- Great prospects for pinning down the properties of the 125GeV Higgs boson at the HL-LHC with 3000fb^{-1} per experiment
  - Studies and projections indicate ~few % precision in all fermion and vector boson couplings
- Input from the theory community vital
  - Theory uncertainties will quickly become an important limiting factor
- Vector Boson Scattering, direct searches for BSM partners of the Higgs and BSM interpretation of results are all very crucial for elucidating the path beyond the Standard Model

Back up slides

- $\mu=(\sigma \times BR)/(\sigma \times BR)_{SM}$



μ uncertainties at 300fb^{-1}

Channel	Uncertainty on mu value with 300 fb^{-1} [%]			
	Experimental only		Experimental + theory	
	ATLAS	CMS	ATLAS	CMS
$\gamma\gamma$	8	5	15	15
ZZ	9	8	16	11
WW (1)	26	9	29	14
$\tau\tau$ (2)	11	9	15	11
$\tau\tau$	19	9	23	11

(1) ATLAS uncertainty based on old result

(2) ATLAS uncertainty extrapolated with CMS approach

CP violation in Higgs sector (ATLAS)

$$A(X \to VV) \sim \left(a_1 M_X^2 g_{\mu\nu} + a_2 (q_1 + q_2)_\mu (q_1 + q_2)_\nu + a_3 \varepsilon_{\mu\nu\alpha\beta} q_1^\alpha q_2^\beta\right) \varepsilon_1^{*\mu} \varepsilon_2^{*\nu}$$

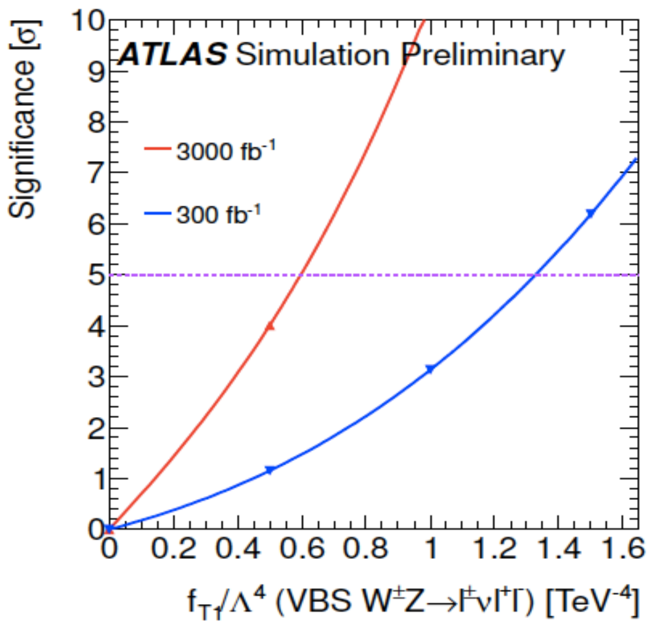
- HZZ amplitude can have CP-even & CP-odd terms: CP violation

Significance for various a_3

Integrated Luminosity	Signal (S) and Background (B)	$6 + 6i$	$6i$	$4 + 4i$
100 fb^{-1}	$S = 158; B = 110$	3.0	2.4	2.2
200 fb^{-1}	$S = 316; B = 220$	4.2	3.3	3.1
300 fb^{-1}	$S = 474; B = 330$	5.2	4.1	3.8

3000fb^{-1} would give sensitivity to much smaller levels of CP violation.

ATL-PHYS-PUB-2013-006

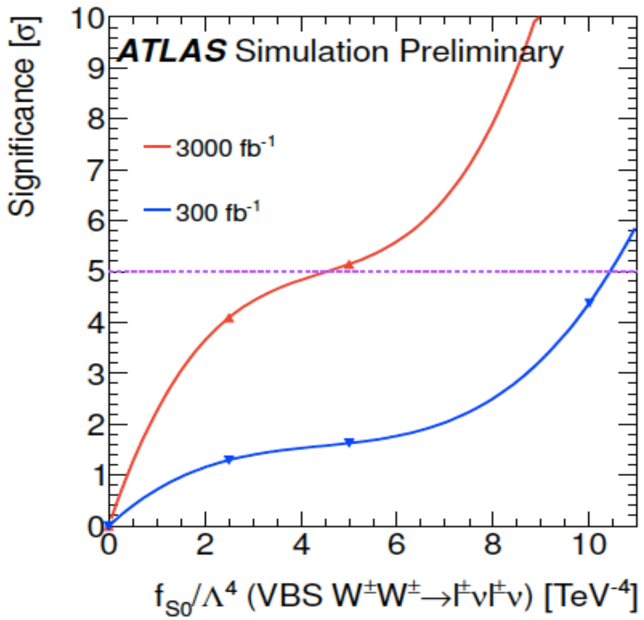


New physics parametrised in terms of higher-dimension, gauge-invariant terrms:

$$\mathcal{L}_{T,1} = \frac{f_{T1}}{\Lambda^4} \mathrm{Tr}[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}] \times \mathrm{Tr}[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}]$$

5σ sensitivity

	300 fb^{-1}	3000 fb^{-1}
f_{T1}/Λ^4	1.3 TeV^{-4}	0.6 TeV^{-4}



$$\mathcal{L}_{S,0} = \frac{f_{S0}}{\Lambda^4} [(D_\mu\phi)^\dagger D_\nu\phi)] \times [(D^\mu\phi)^\dagger D^\nu\phi)]$$

5σ sensitivity

model	300 fb^{-1}	3 ab^{-1}
f_{S0}/Λ^4	10 TeV^{-4}	4.5 TeV^{-4}