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SM Higgs prospects in ATLAS and CMS

G. Ortona (LLR) for the CMS and ATLAS collaborations

Outline

Introduction

Golden channels and coupling to bosons

- $H\rightarrow ZZ$, $H\rightarrow\gamma\gamma$, $H\rightarrow WW$

Yukawa couplings

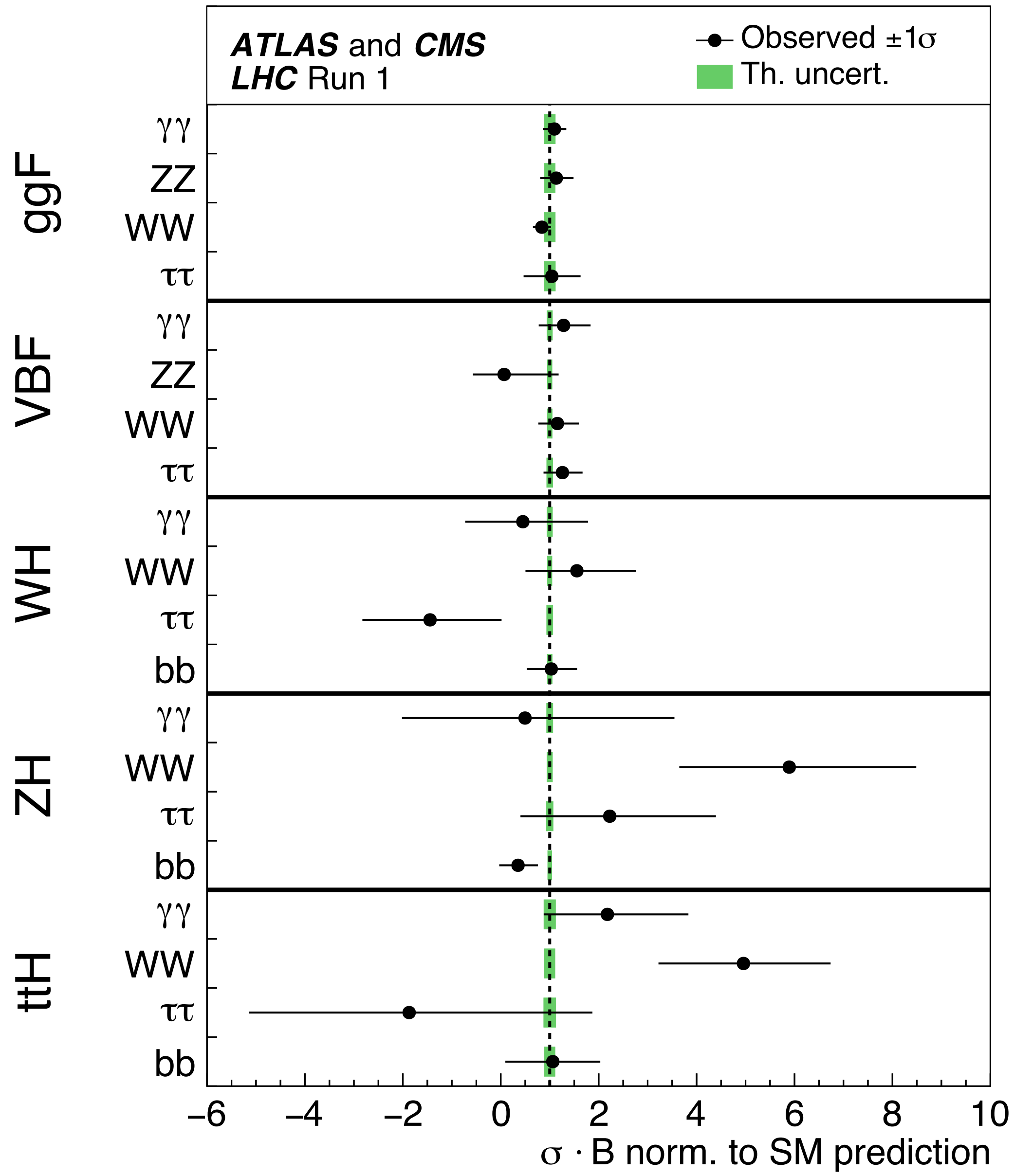
- bottom, taus, muons

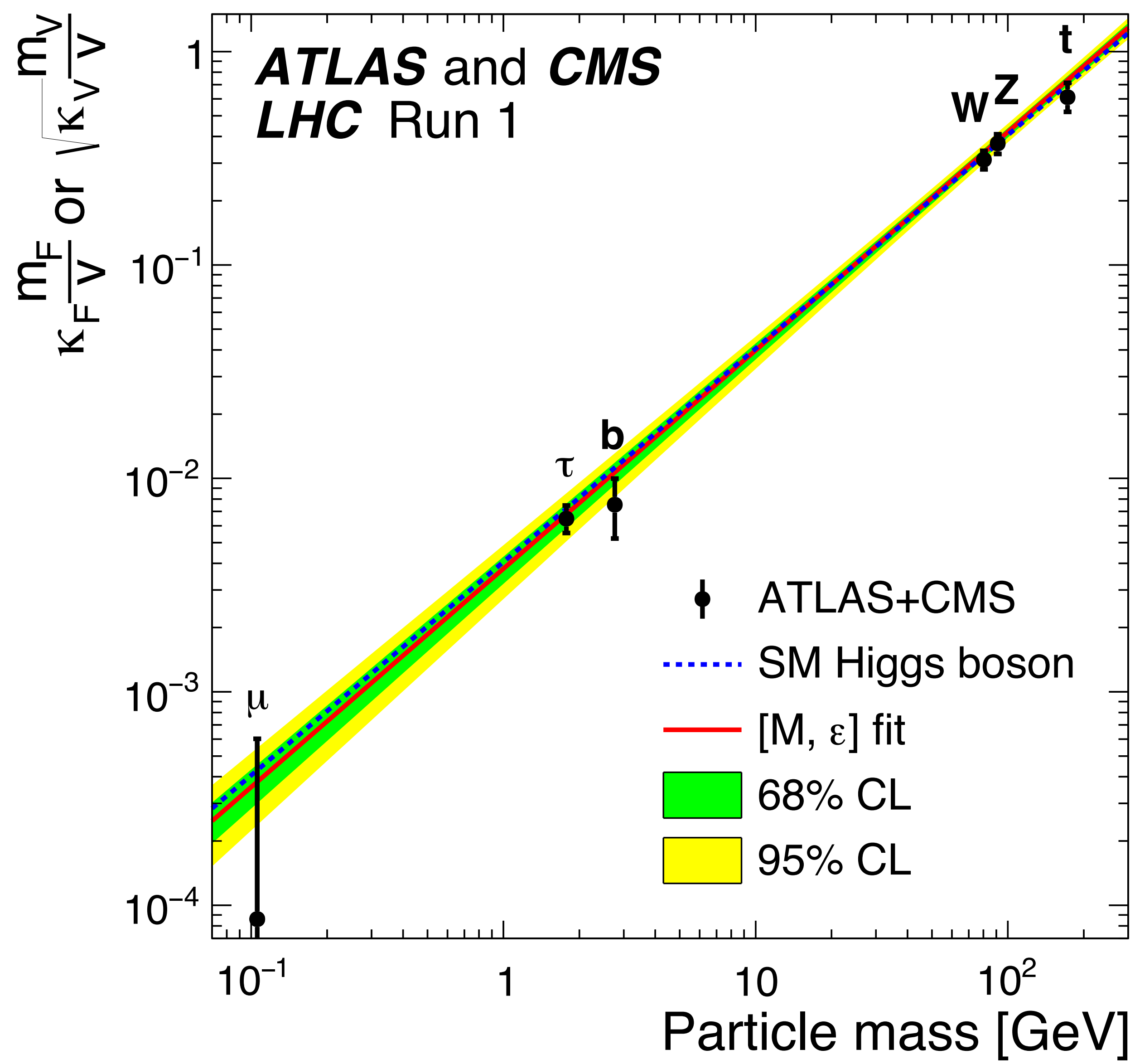
The big picture

- Overview of couplings and signal strengths for production and decay mode

Summary and conclusions

Where are we?





The existence of (at least one) Higgs boson well established

No deviations from SM so far

A few exceptions aside, we are not yet at the level of precision we need to probe small deviations from the SM and narrow down NP. For precision Higgs coupling we need HL/HE-LHC

Strategy

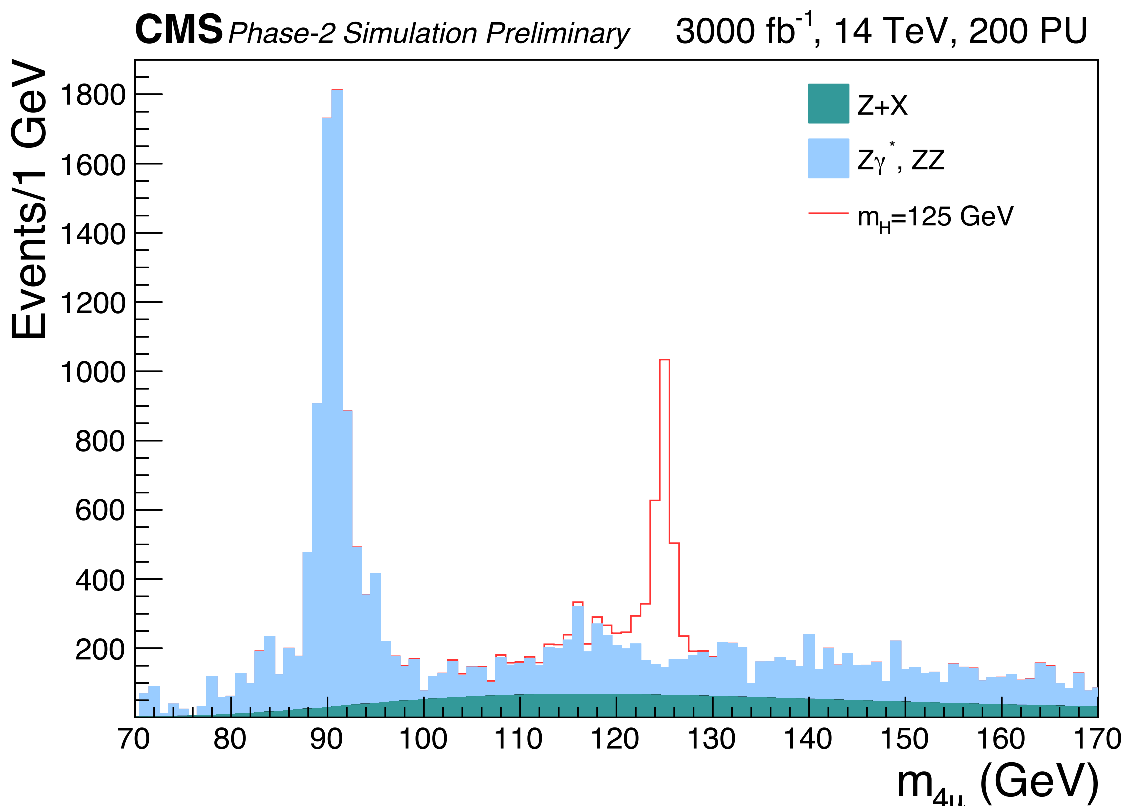
CMS extrapolation scenarios:

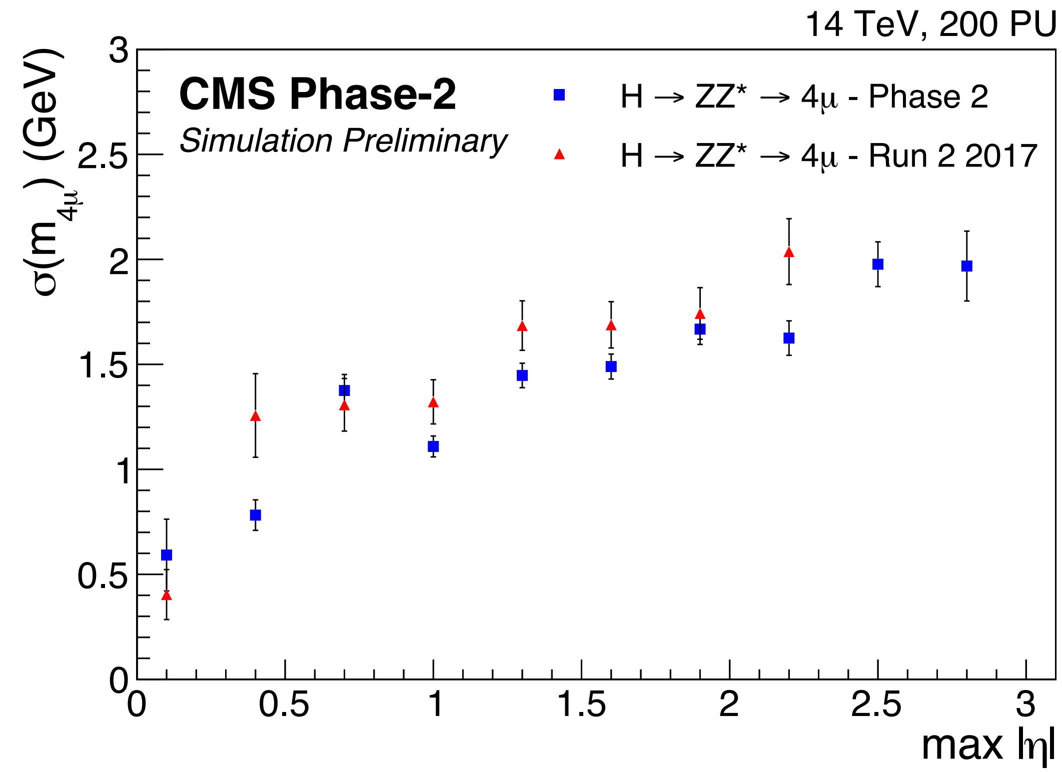
- S1: Systematic uncertainties constant, unchanged detector performances
- S2: Theoretical uncertainties scaled by 0.5, experimental uncertainties scaled by luminosity (until a floor)
- S1/S2+: Includes higher PU and detector upgrades effects

ATLAS extrapolation scenarios:

- Includes programmed detector upgrades, with extended η coverage of the tracker up to $|\eta|<4.0$ ("reference" scenario)
- PU and upgrades taken into account for projections
- Theoretical uncertainties scaled by 1, 0.5 or 0

Golden channels: ZZ



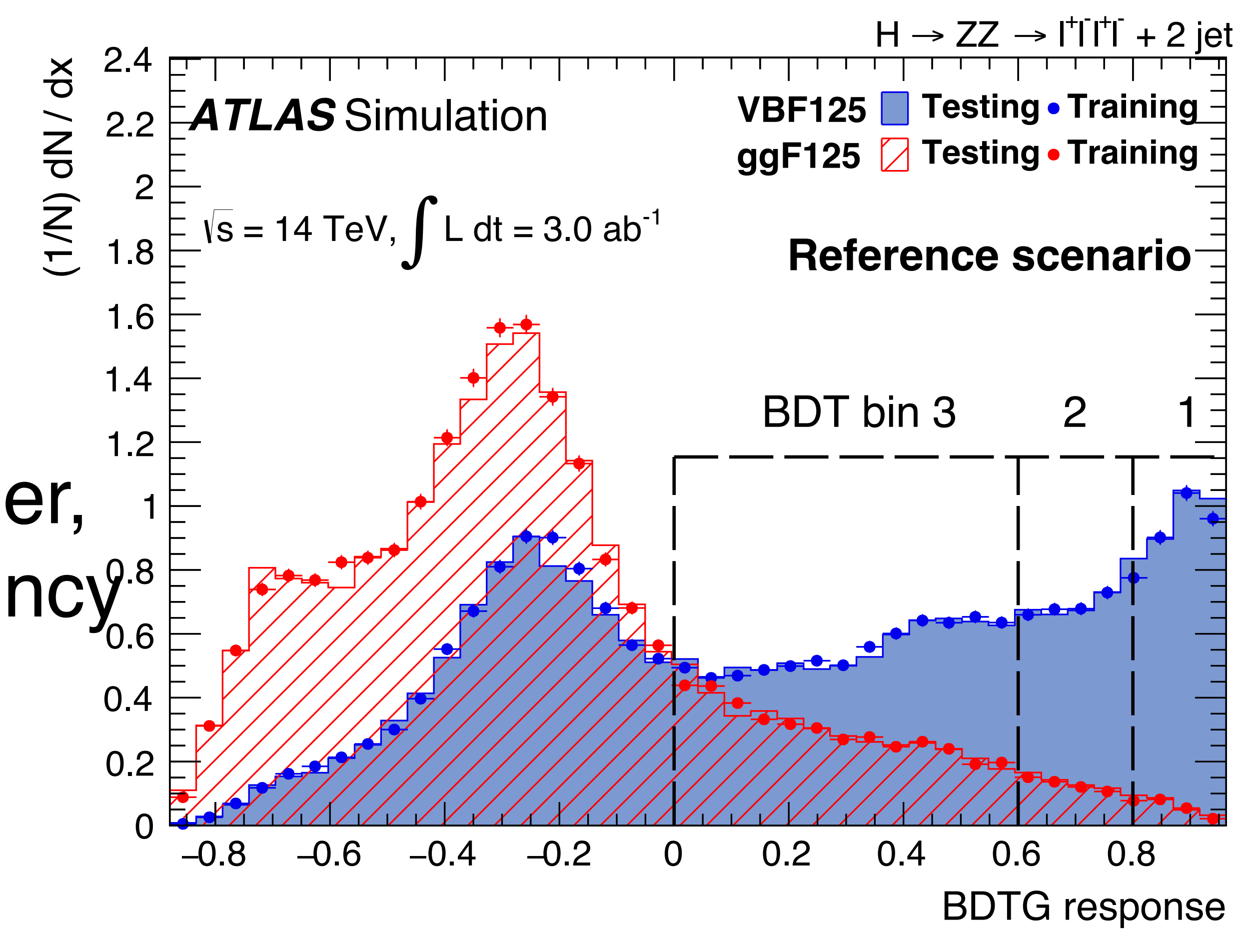


Main contributor to the H mass measurement at LHC-Run2

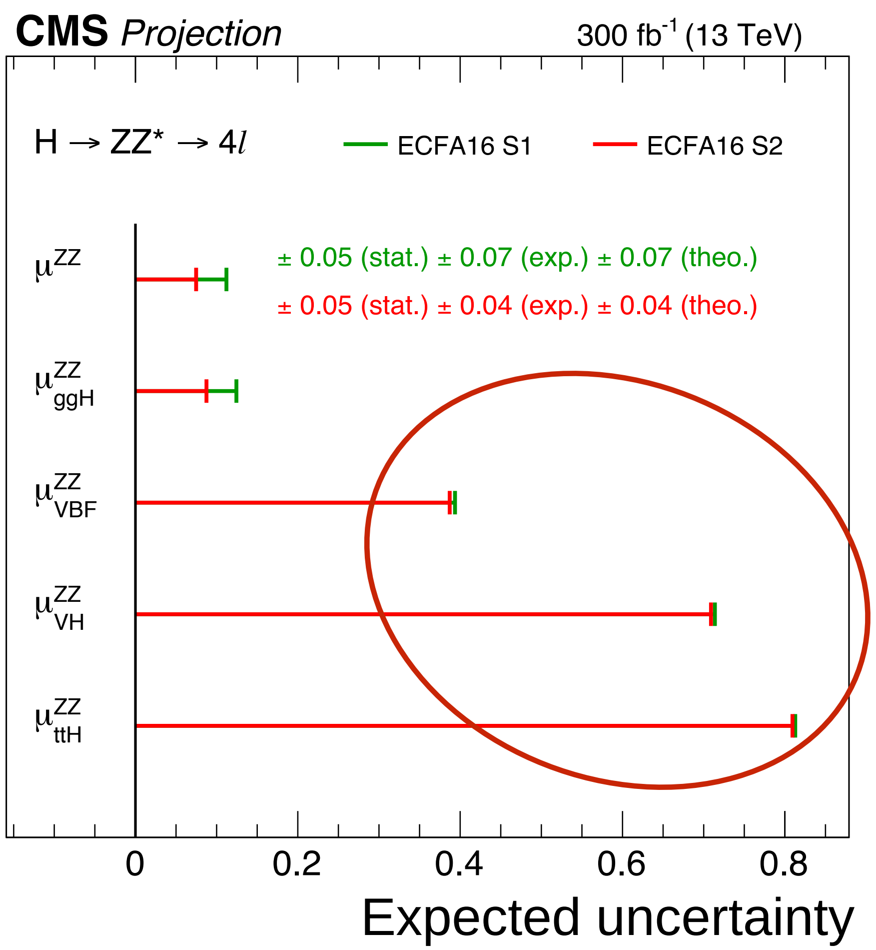
Upgraded detectors bring significant improvements:

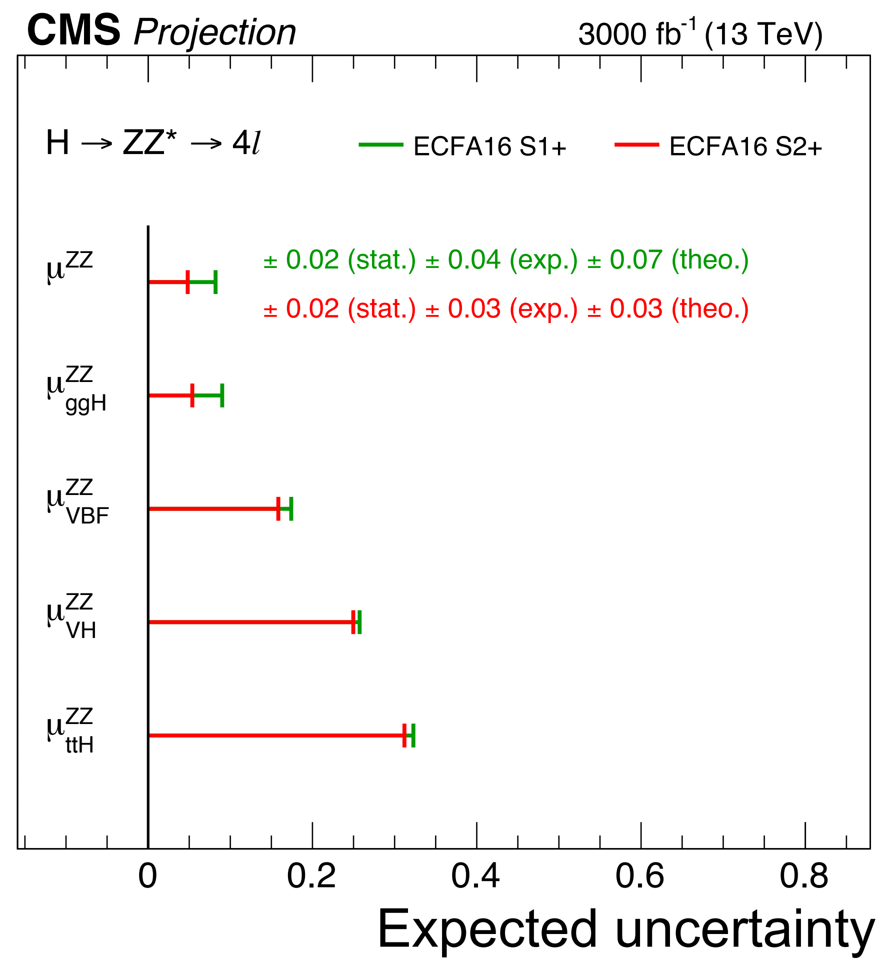
- Increased CMS/ATLAS tracker acceptances up to |η|<4, new EM trigger, improved μ triggers, higher reco efficiency and momentum resolution in Phase2

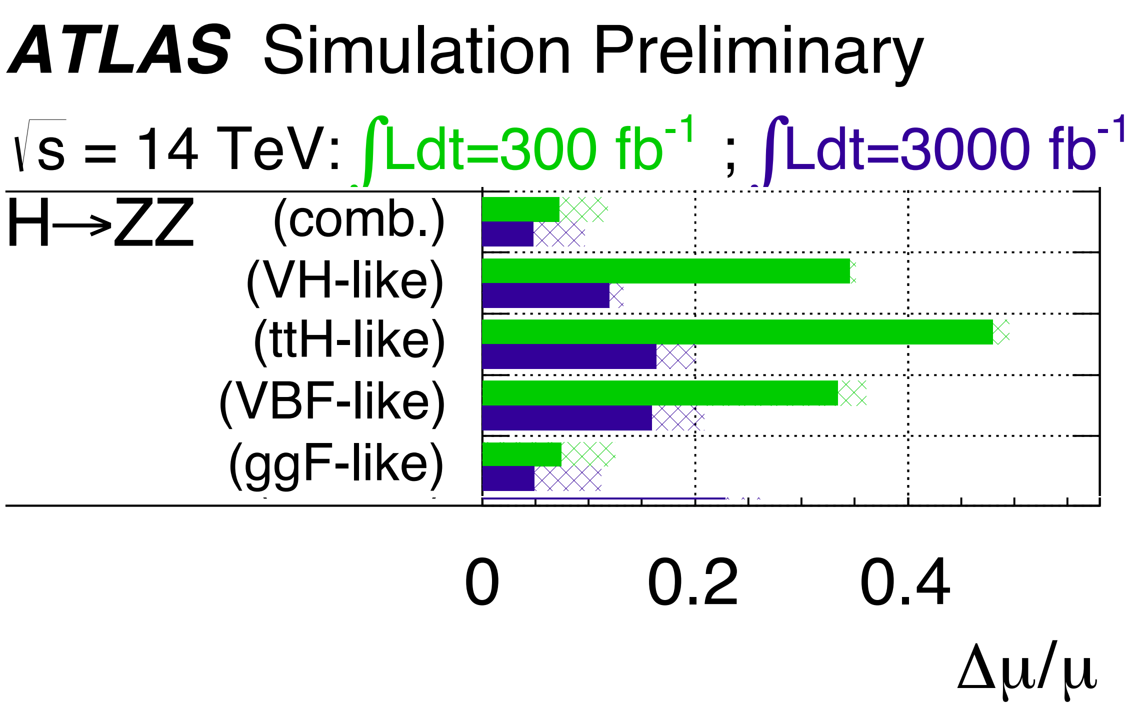
Strong sensitivity to ggH, and good (but limited) sensitivity to VBF and VH



ZZ: signal strengths



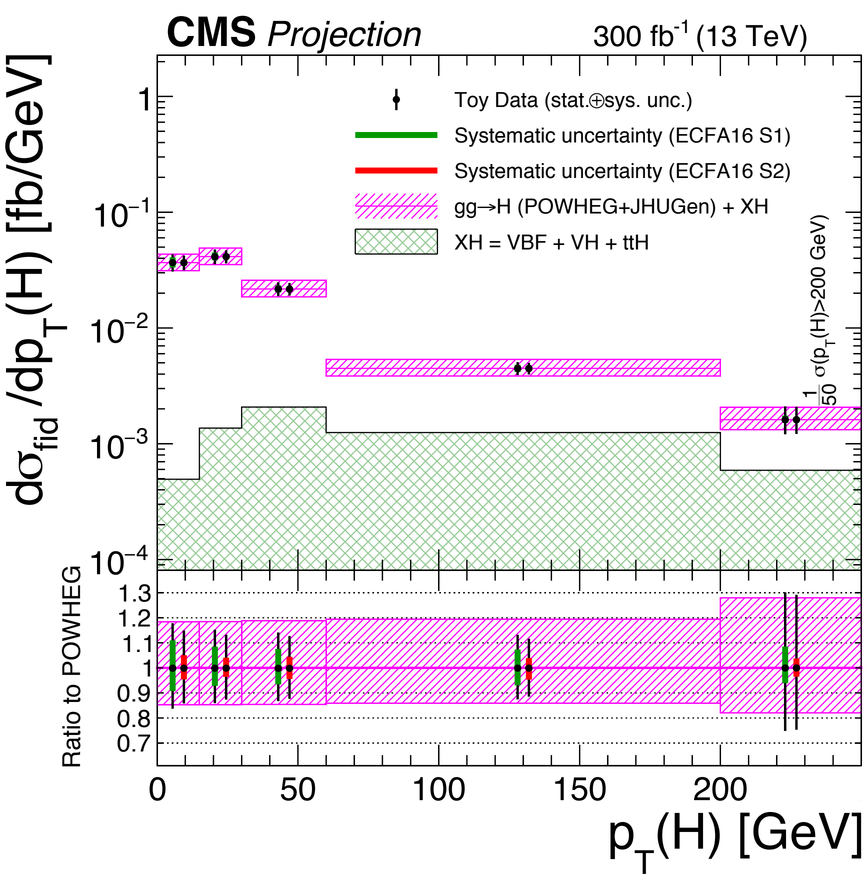


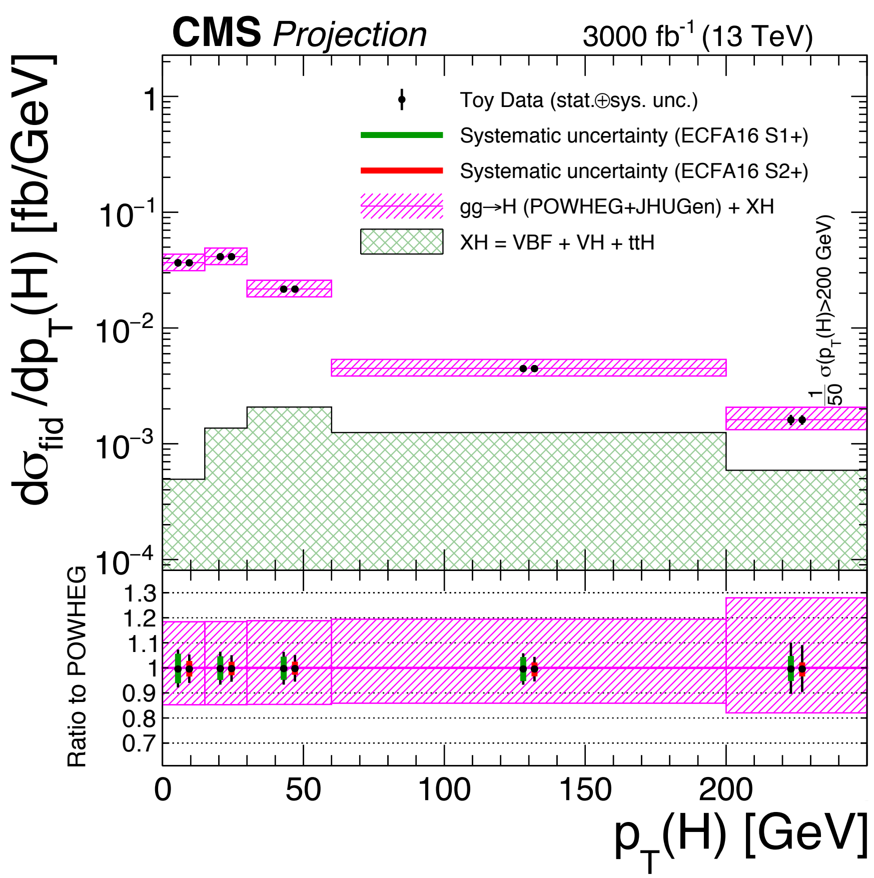


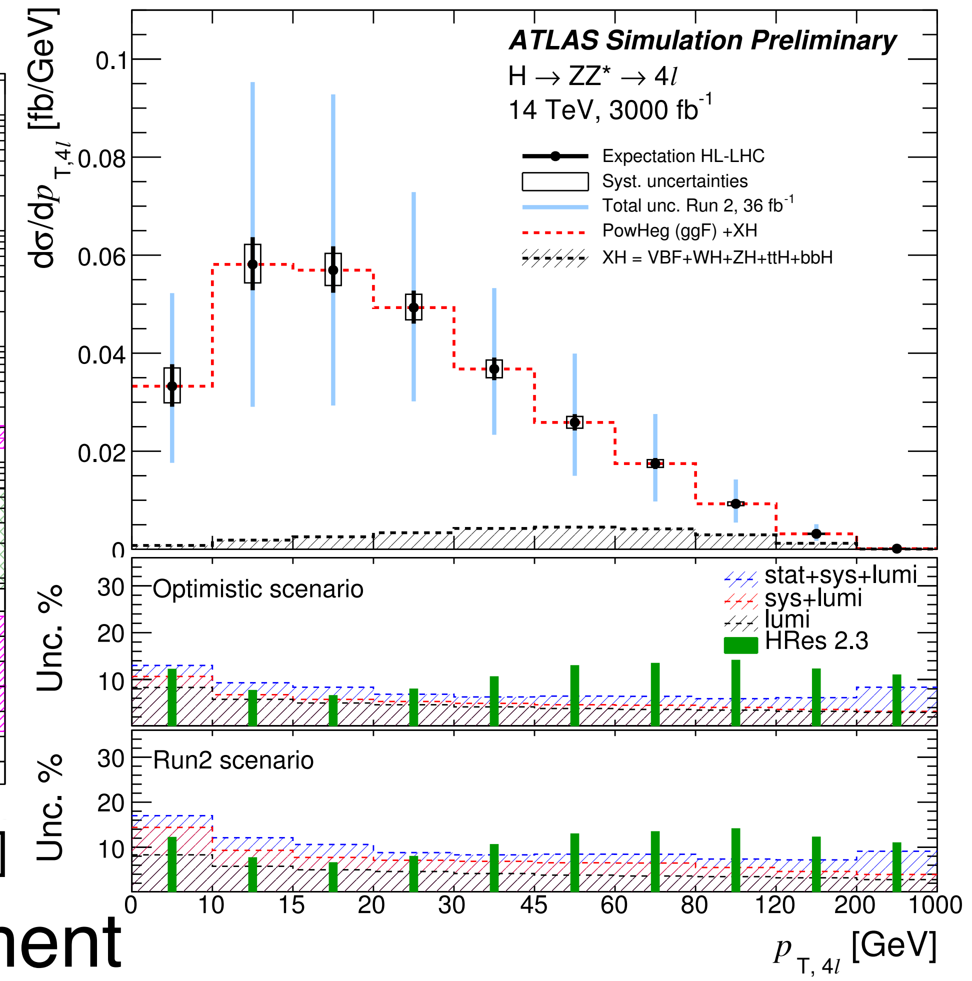
- Expected uncertainties below 15% (5% for gluon fusion) with 3 ab^{-1} for the signal strengths measurement

CMS-FTR-16-002

ZZ: Differential distributions







Measured in a fiducial phase space close to experiment acceptance

Statistical uncertainties are still dominating at high p_T even at 3 ab^{-1} (4-9%)

Improved signal modelling needed before 300 fb^{-1}

Some sensitivity to the shape at low (high) p_T:
gives sensitivity to k_b, k_c (k_t)

Important to extend coverage (bins, range, variables) in the future

Anomalous ZZ couplings

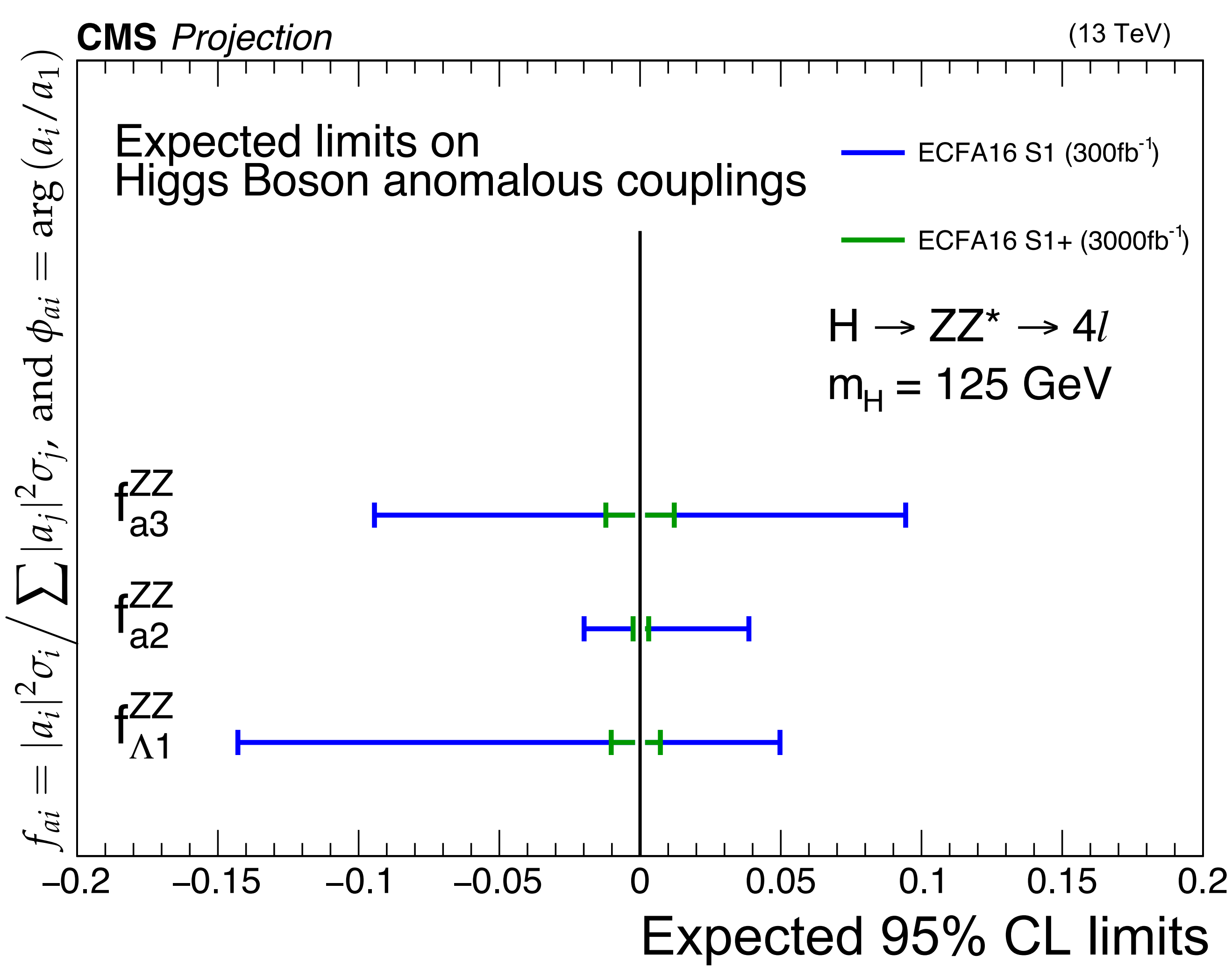
$$A(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_1^2 + \kappa_2^{\mathrm{VV}} q_2^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2}\right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}$$

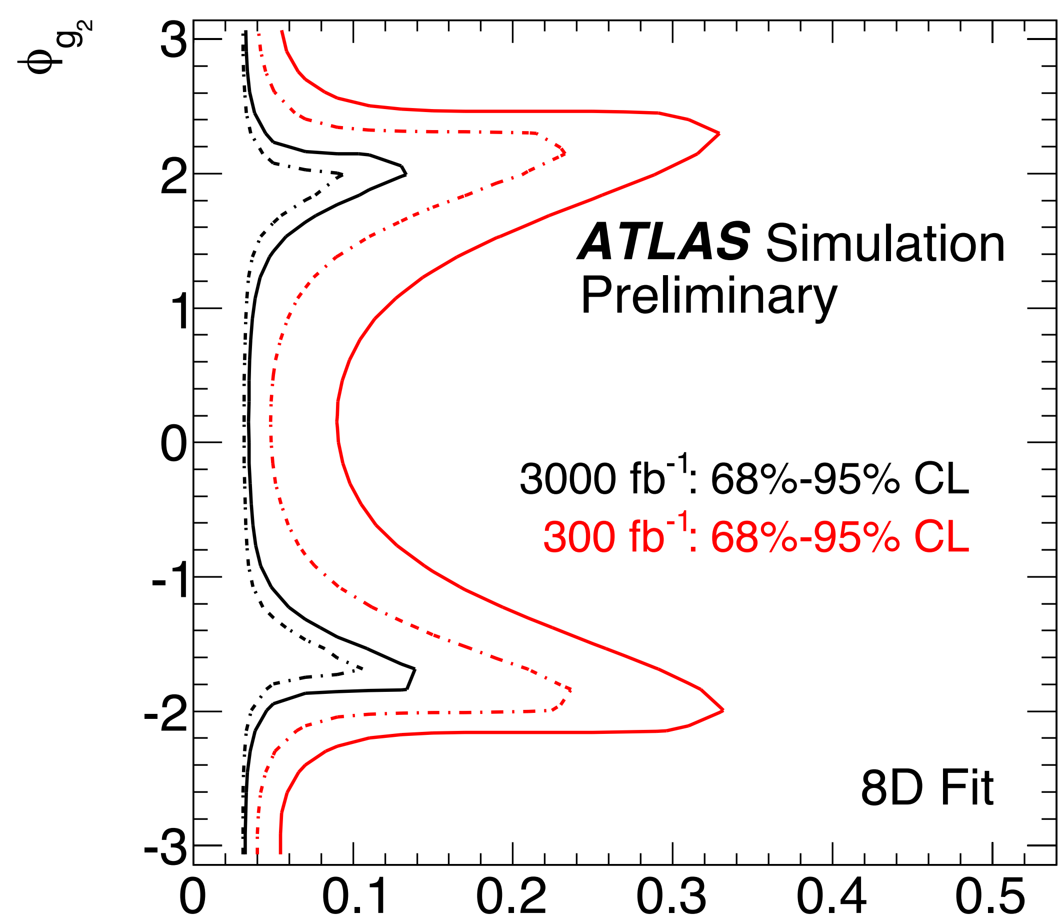
O(1%) precision on anomalous HVV couplings at HL-LHC

Different notations in CMS and ATLAS. Both probe tensor-structure and the CP violation in the H→VV coupling:

f_{a3} = fraction of CP violation; f_{g3} (f_{g4}) = fraction of CP-even(odd) contributions

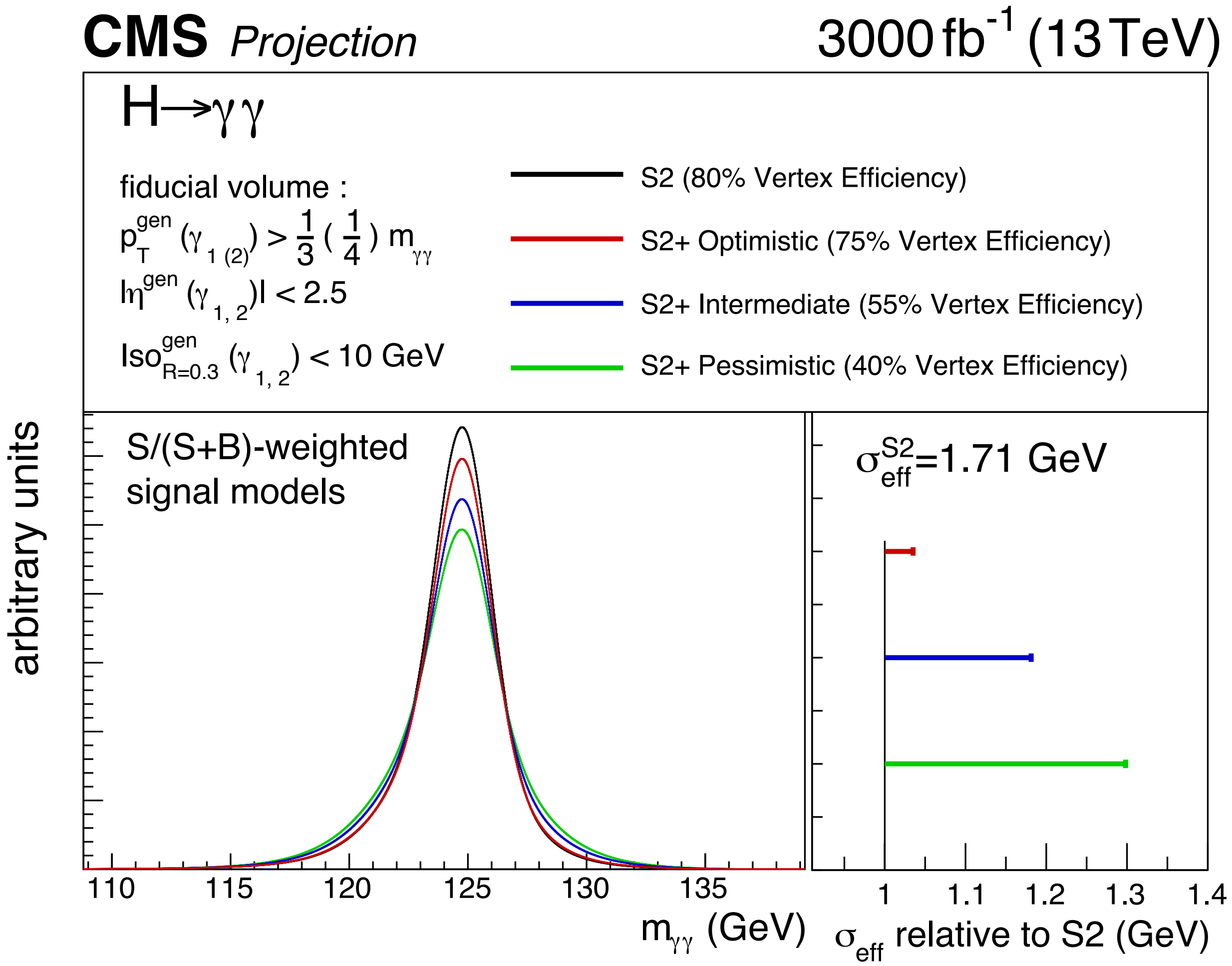
Significant improvement when including production-level information (HIG-17-011)

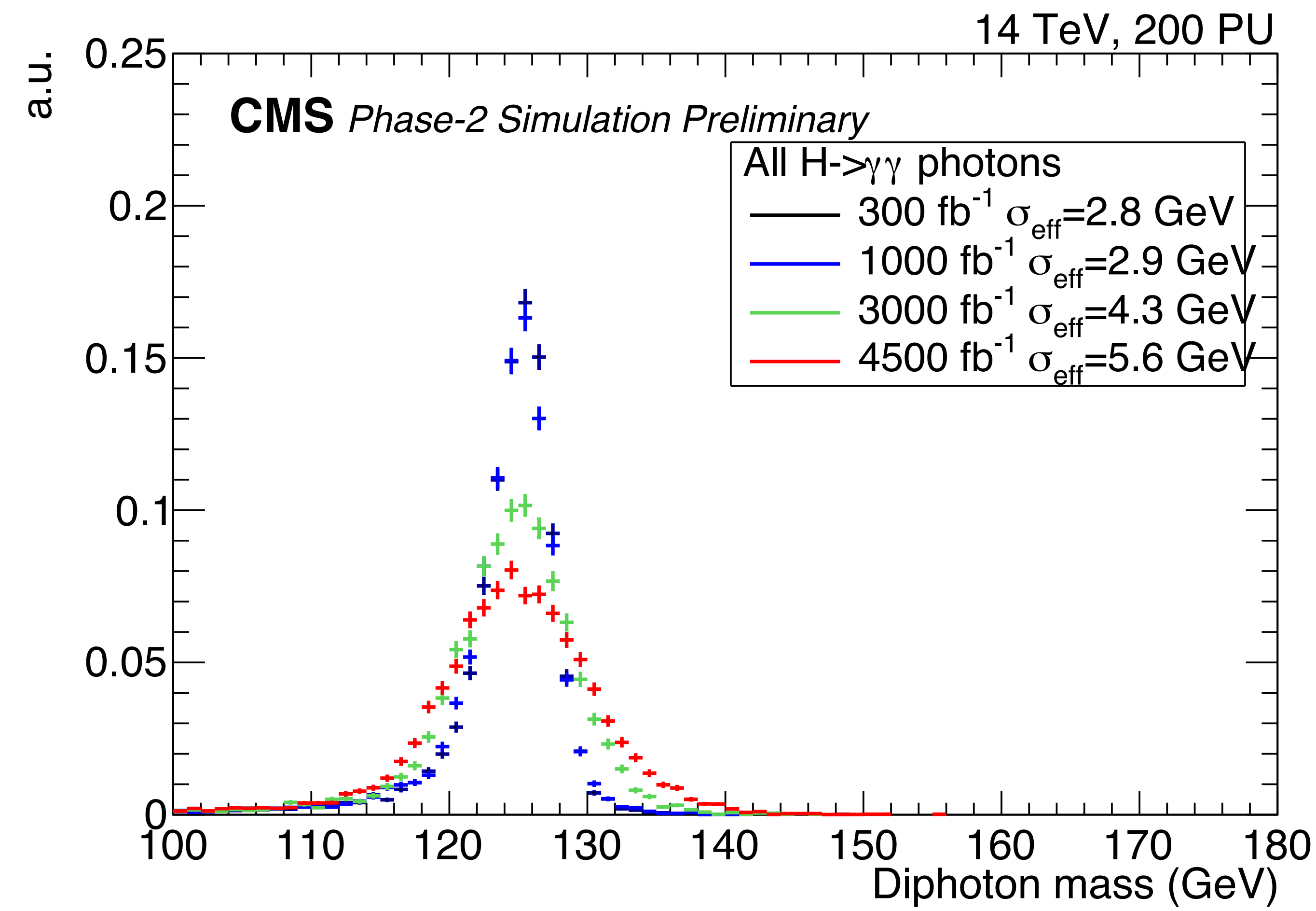




$a_1 = g_1 \frac{m_V^2}{m_H^2} + \frac{s}{m_H^2}\left(2g_2 + g_3 \frac{s}{\Lambda^2}\right)$; $a_2 = -\left(2g_2 + g_3 \frac{s}{\Lambda^2}\right)$; $a_3 = -2g_4$,

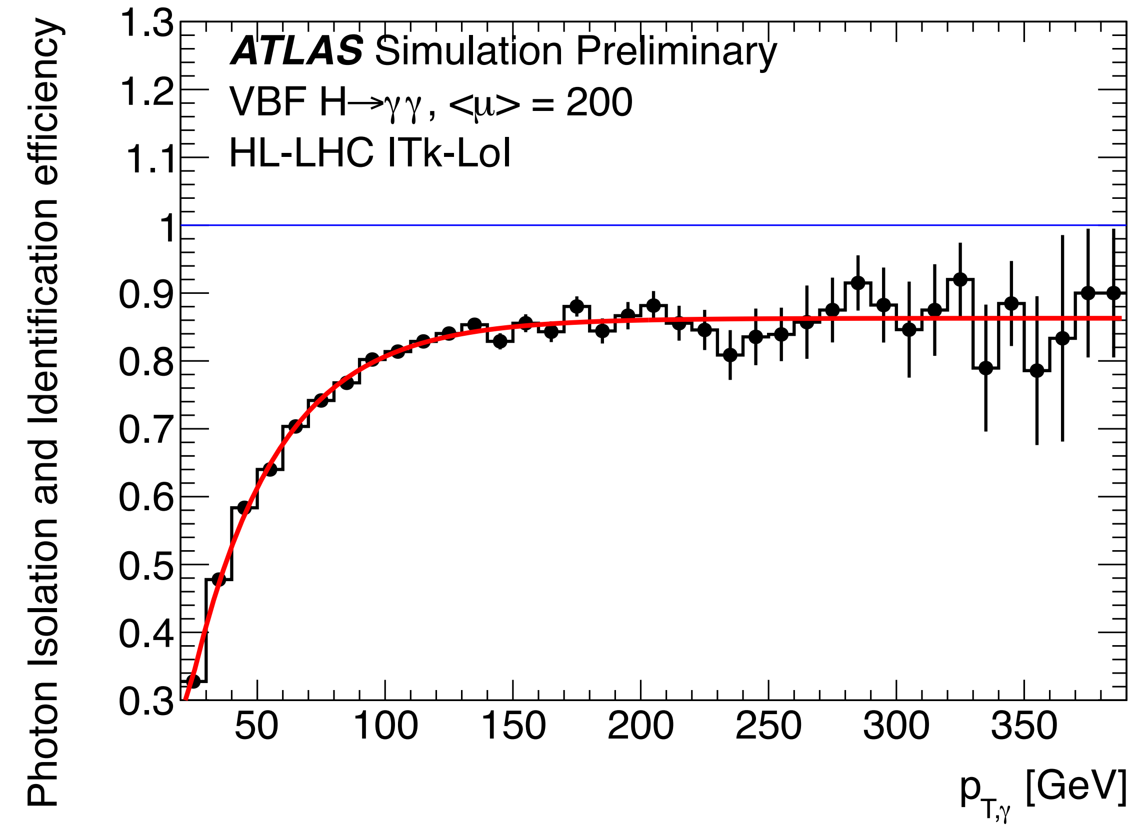
Golden channels: γγ



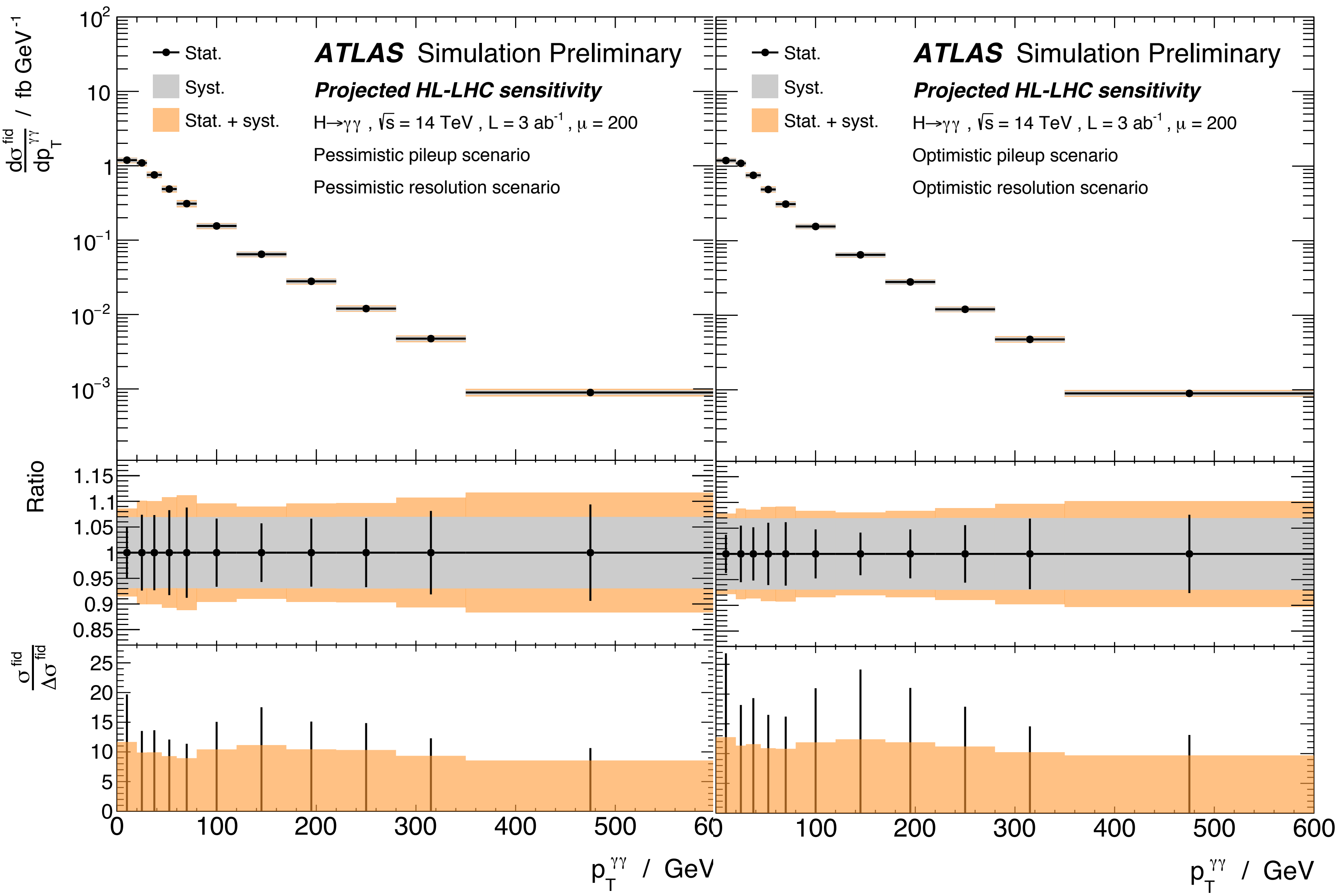


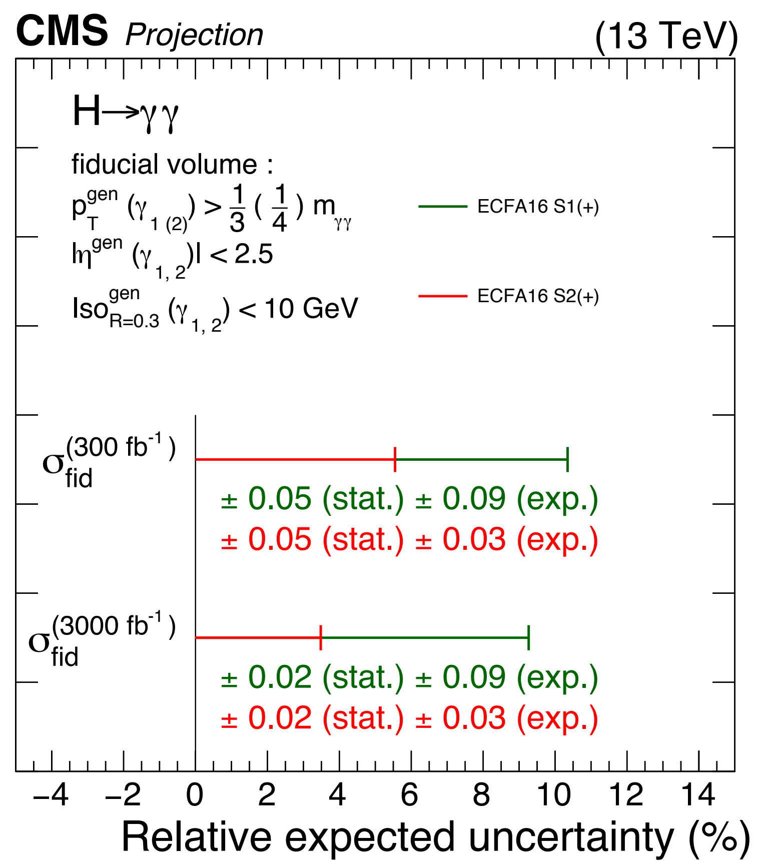
Resolution mostly driven by photon energy and vertexing resolutions

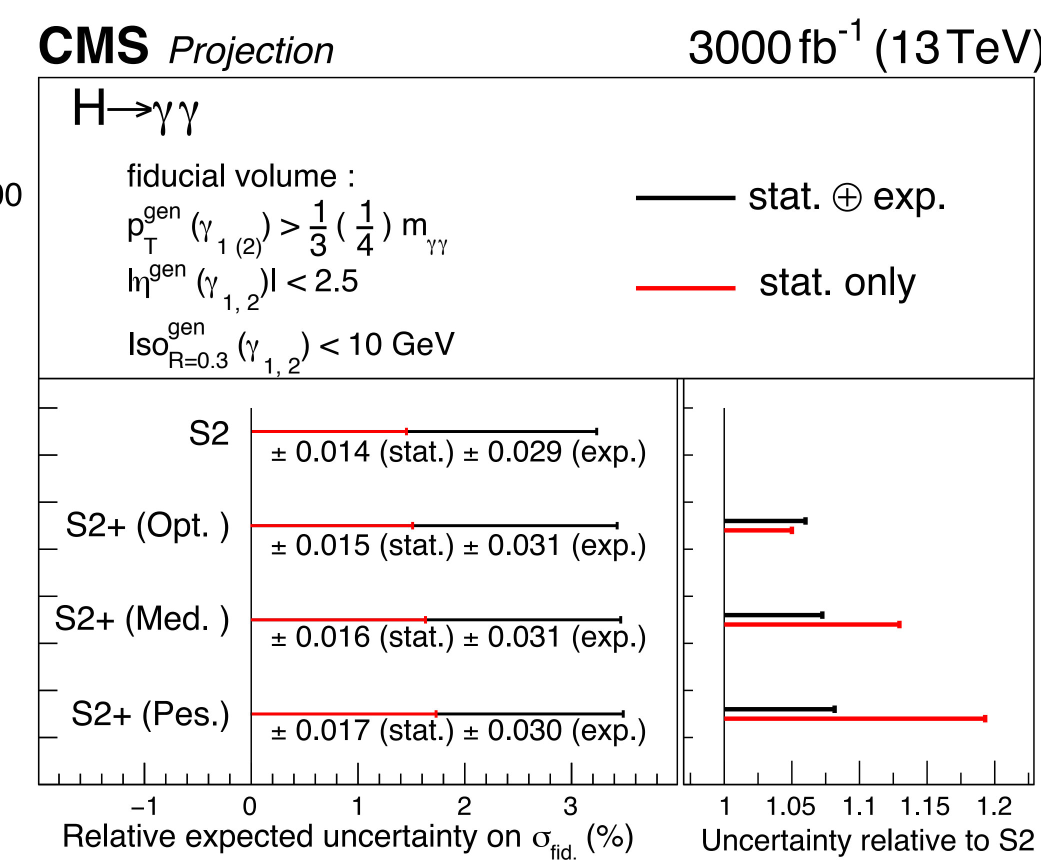
For the projections assumed reduced photon ID, vertex efficiency



γγ: cross section

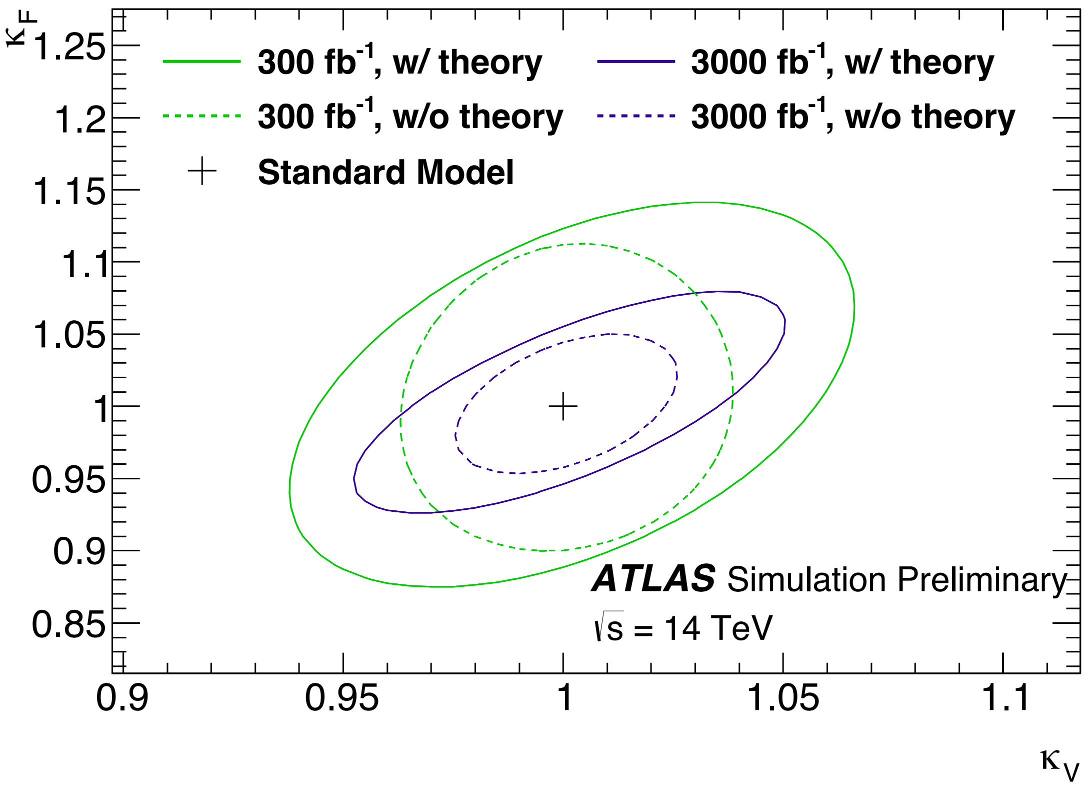


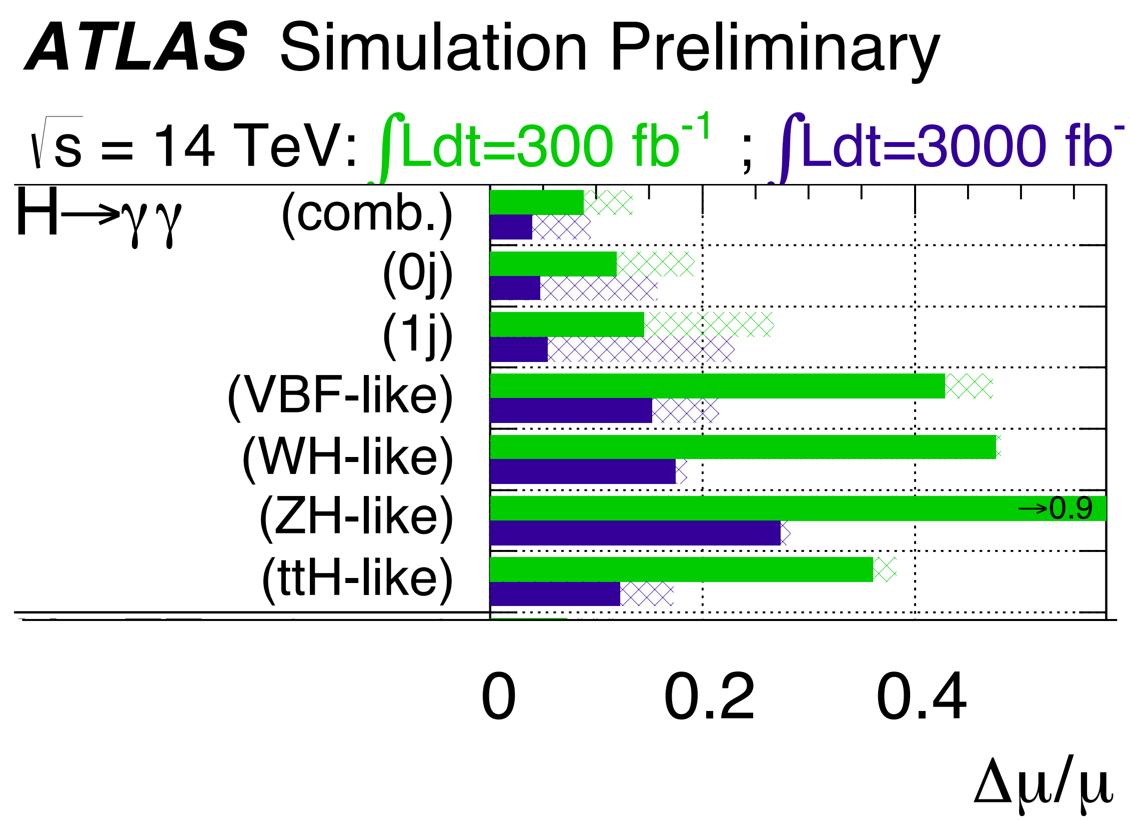




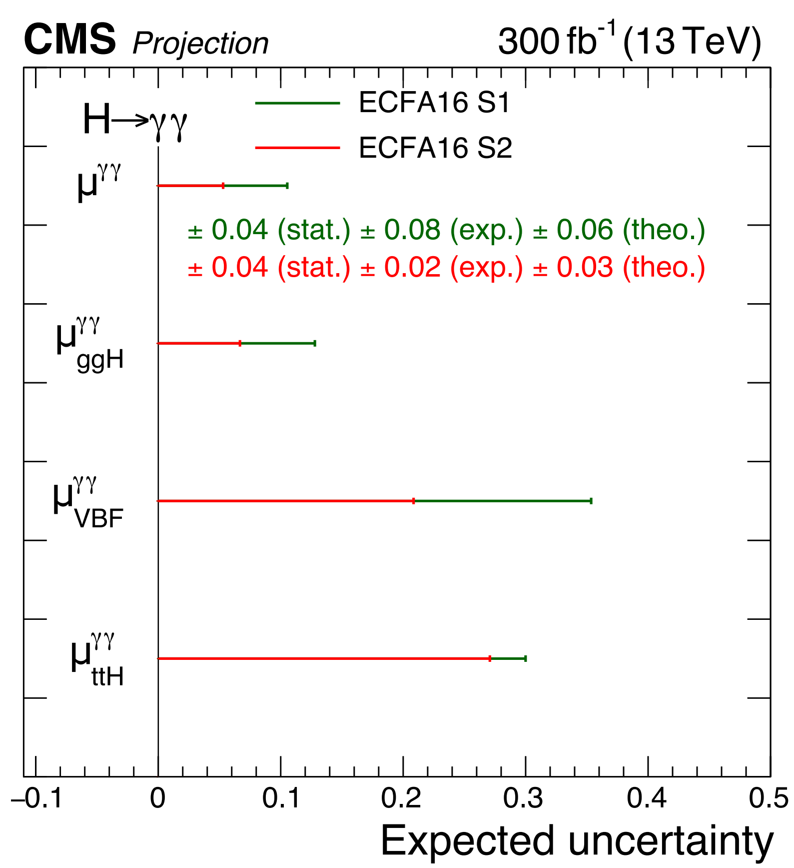
Fiducial cross-section measurement to be dominated by systematic uncertainties already at $300 fb^{-1}$

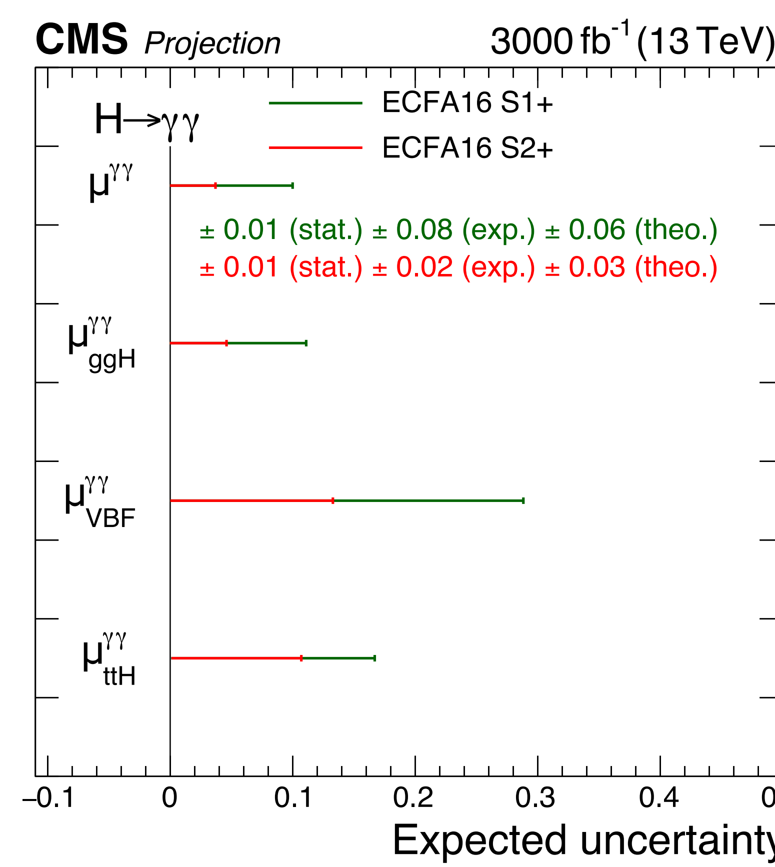
γγ: couplings





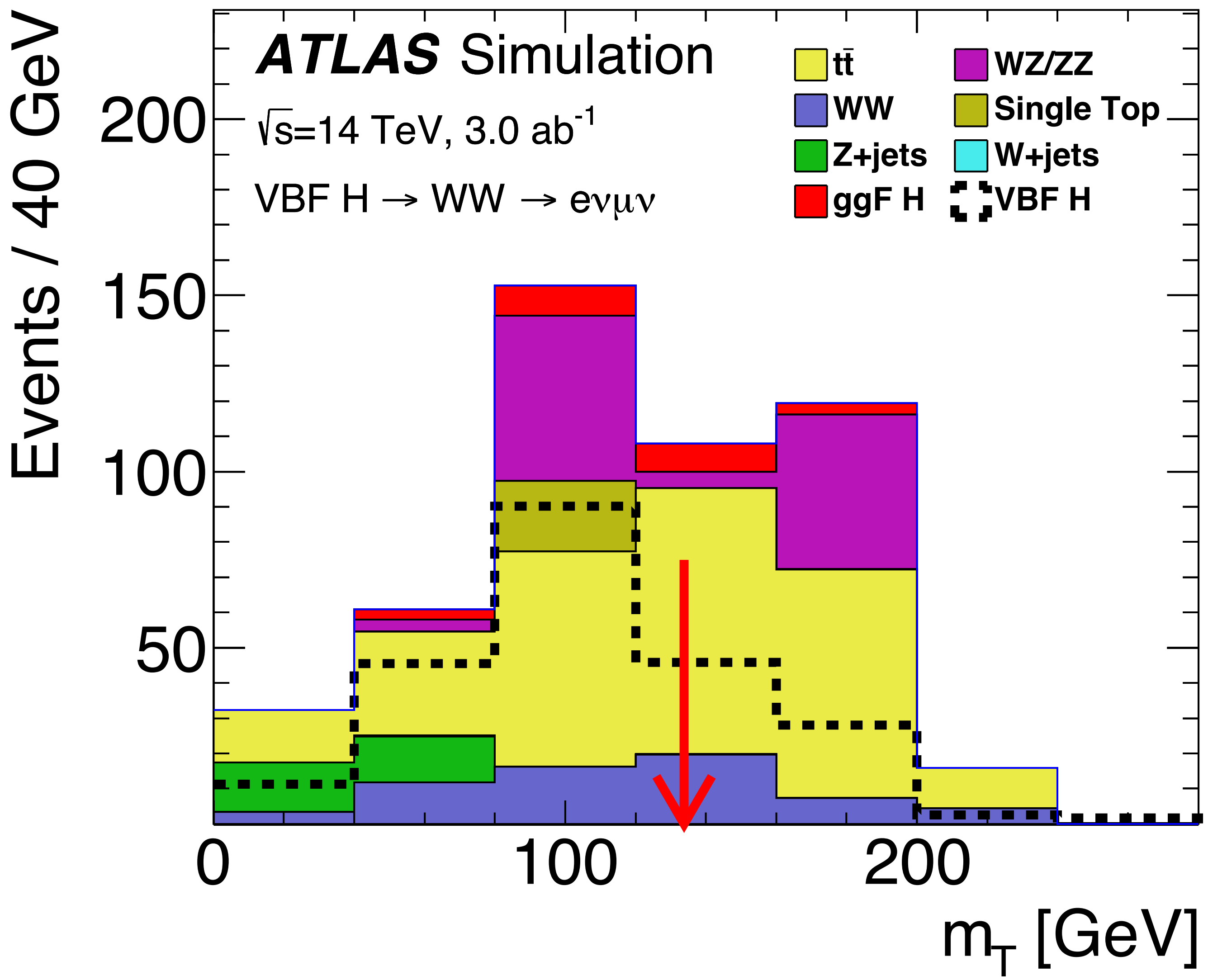
- Similar expected sensitivities between the two experiments
- Precision higher than 5-10%





(VBF)H→WW

ATL-PHYS-PUB-2016-018



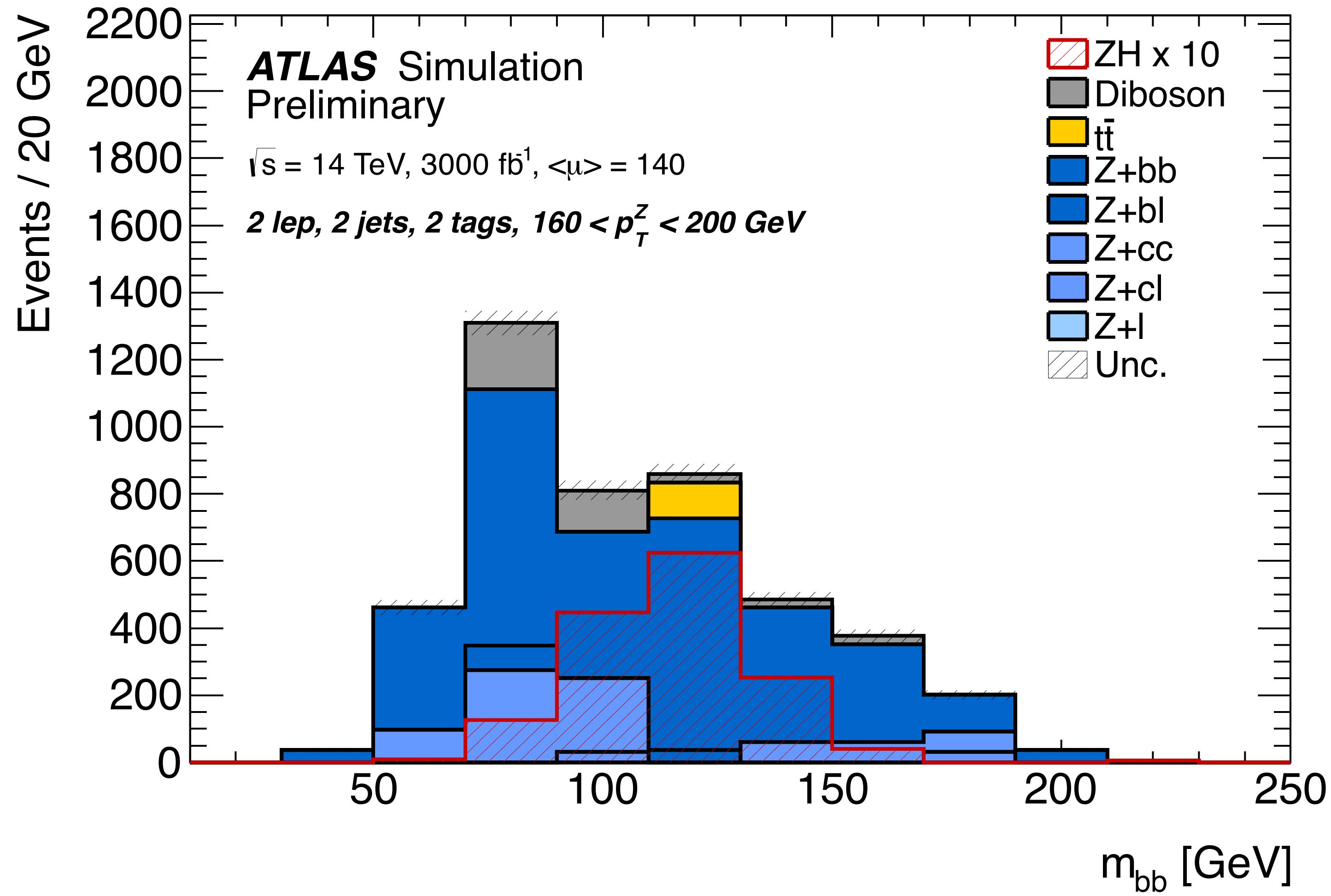
η acceptance important for signal efficiency (VBF topology)

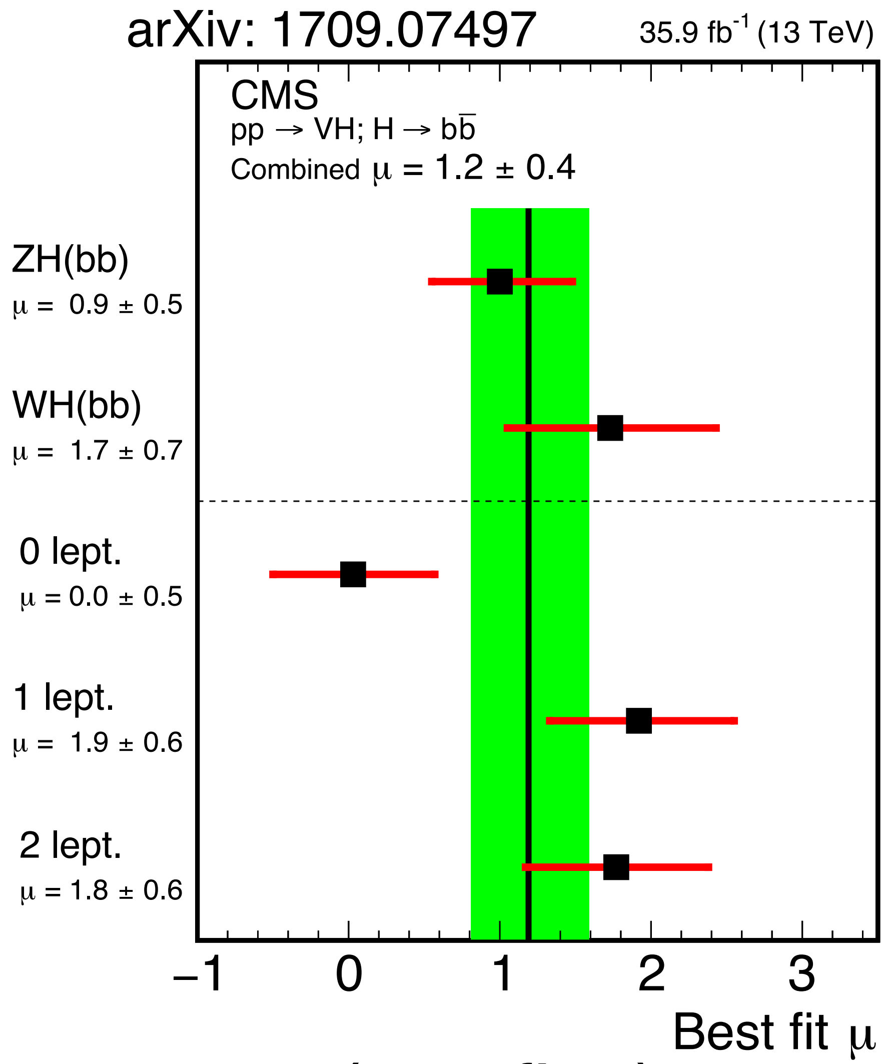
- 82% efficiency in |η|<4.0
- 26% in |η|<2.7

Even in worst case scenario we should be able to observe H→WW production

Scoping scenario	Δ_μ			Significance (σ)		
Signal unc.	Full	1/2	None	Full	1/2	None
Reference	0.20	0.16	0.14	5.7	7.1	8.0
Middle	0.25	0.21	0.20	4.4	5.2	5.4
Low	0.39	0.32	0.30	2.7	3.3	3.5

Yukawa couplings: bottom





Projections from Run1 legacy from ATLAS: from 3.9σ ($300fb^{-1}$) to 8.8σ ($3000fb^{-1}$). 15% uncertainty on the signal strength

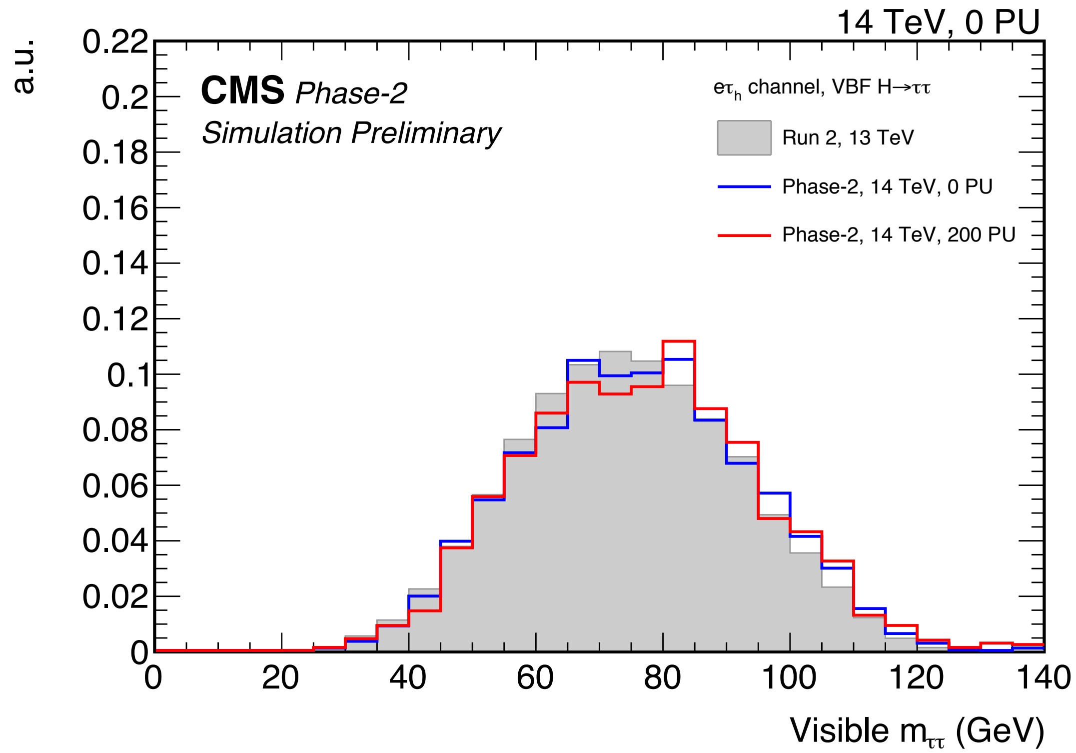
With current statistics, first evidence for (V)H→bb from CMS (3.3σ, arXiv: 1709.07497) and ATLAS (3.5σ, arXiv:1708.03299)

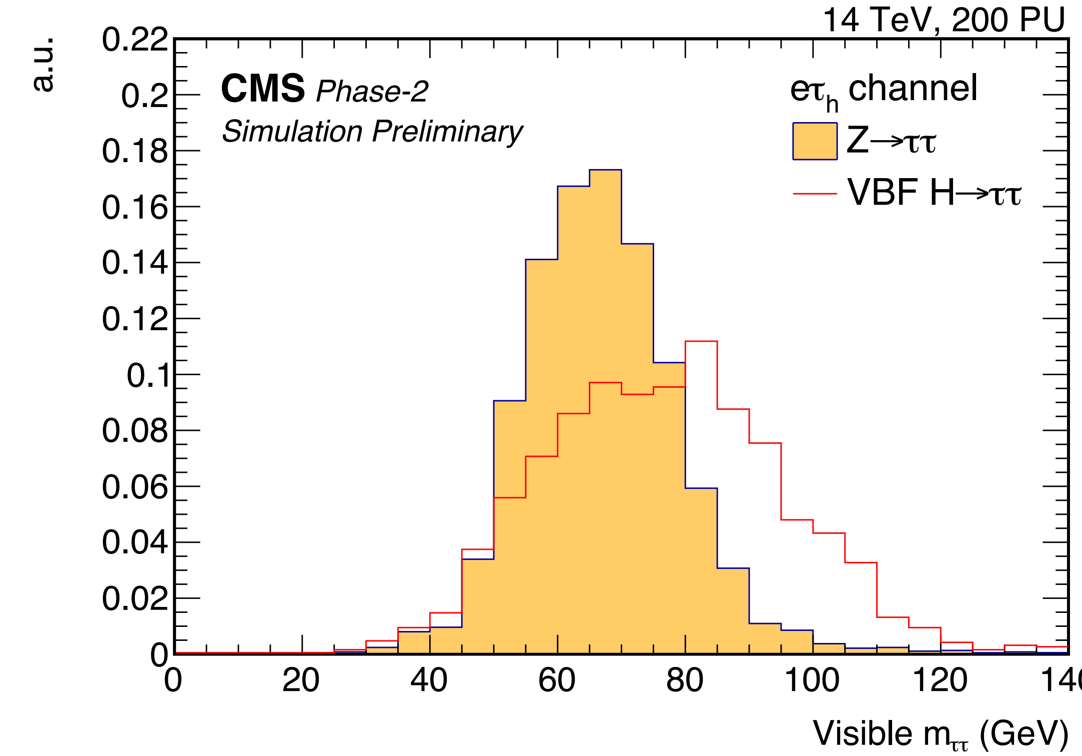
5-10% uncertainty from CMS projections from Run1

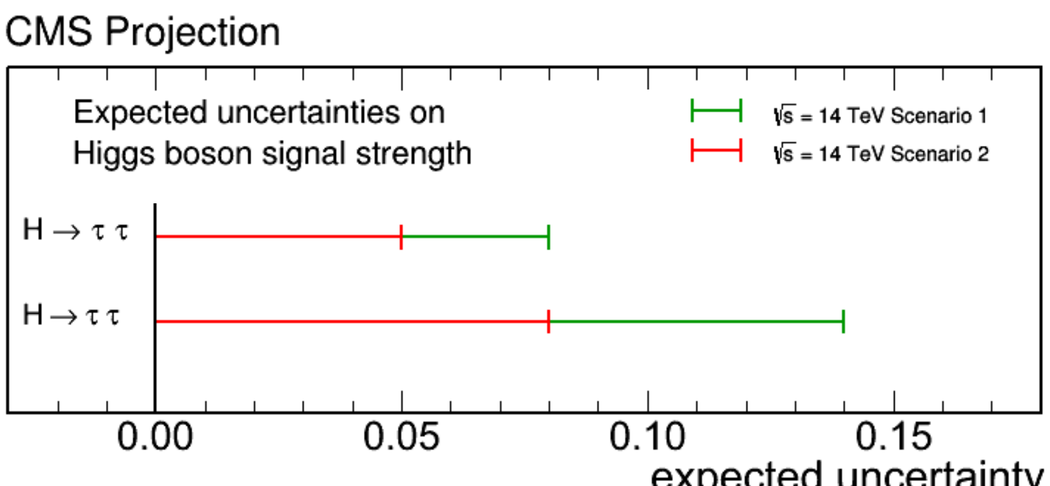
ggH→bb could probe high p_T region, can be within reach

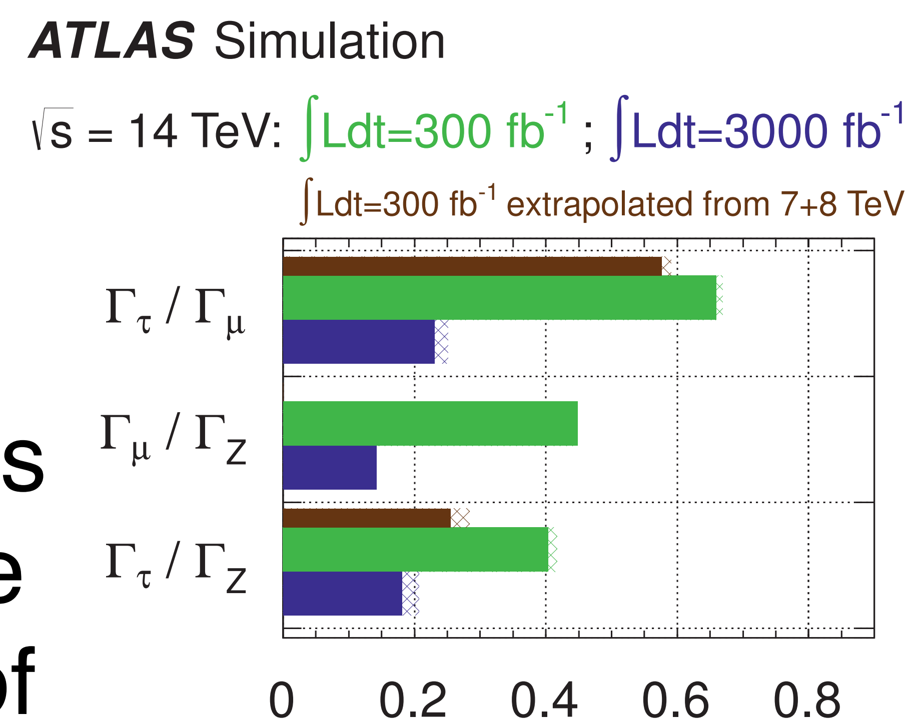
CMS-FTR-16-002
CMS-TDR-17-002
ATL-PHYS-PUB-2013-007

Yukawa couplings: taus









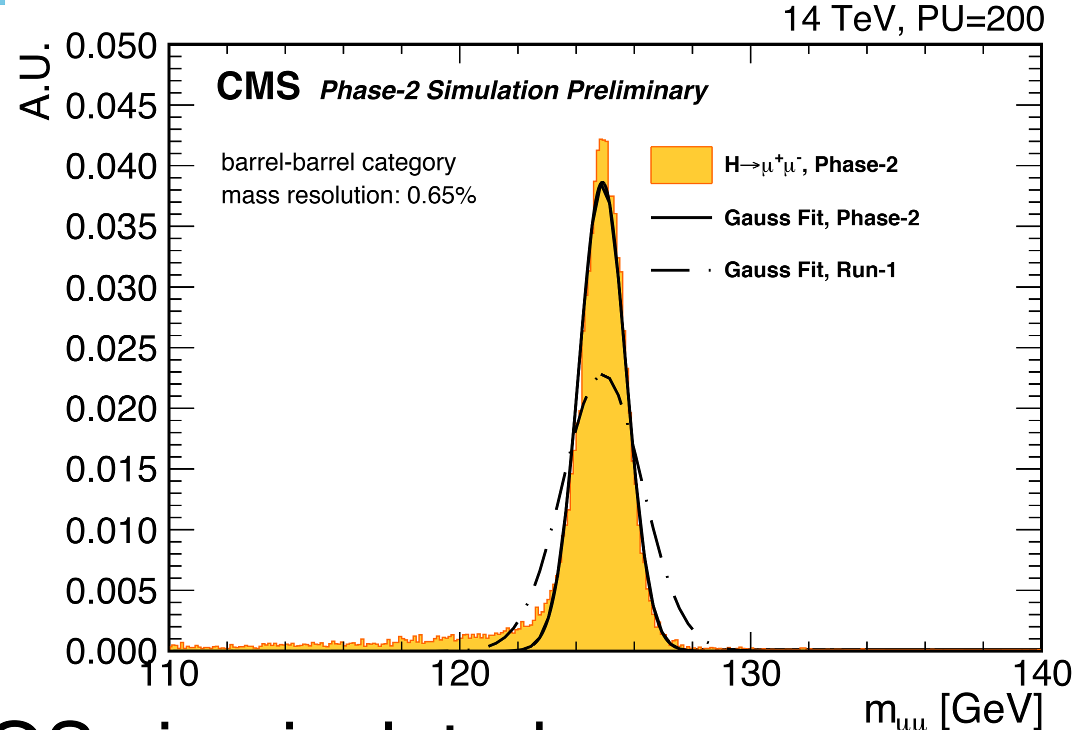
$$\frac{\Delta(\Gamma_X/\Gamma_Y)}{\Gamma_X/\Gamma_Y} \sim 2\frac{\Delta(\kappa_X/\kappa_Y)}{\kappa_X/\kappa_Y}$$

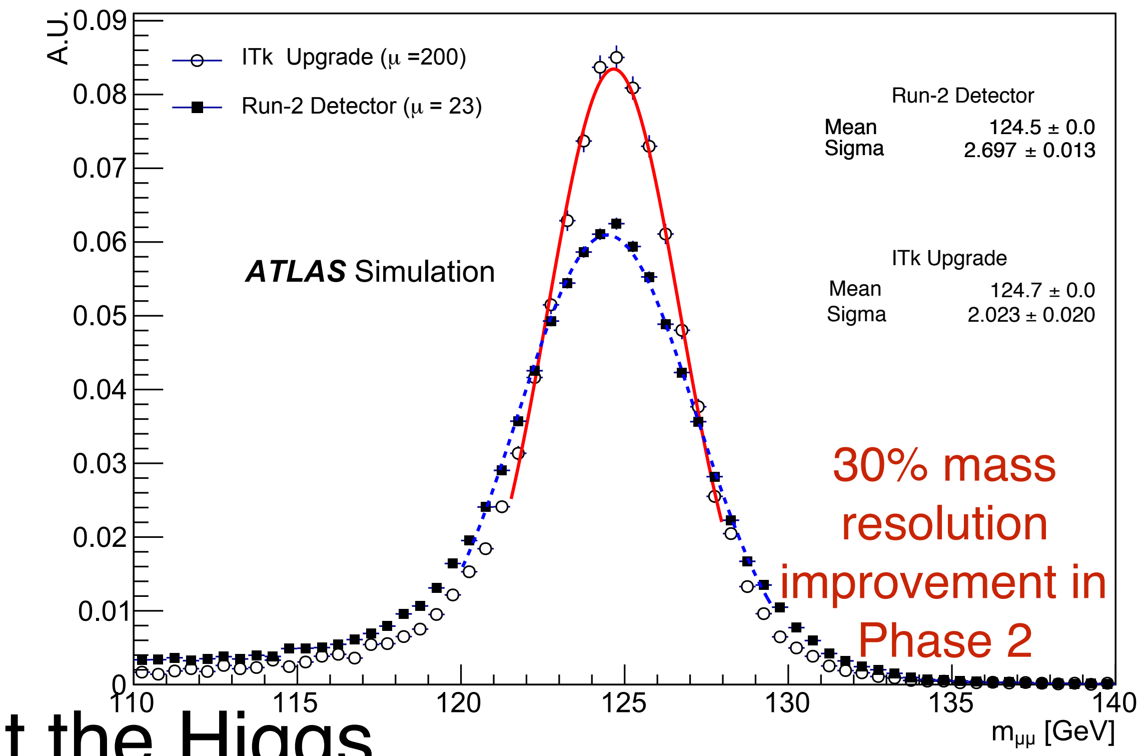
Reasonable separation of the H and Z peaks

Mass resolution at HL-LHC almost the same as in Run2, even when factoring in ageing of the detectors (1ab^{-1})

Precision at the 5-8% level (3 ab^{-1})

Yukawa couplings: muons

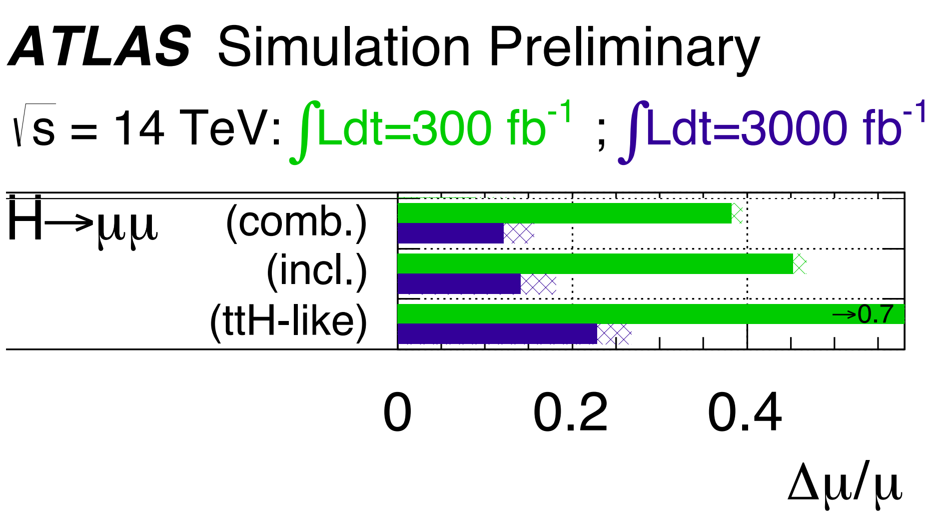


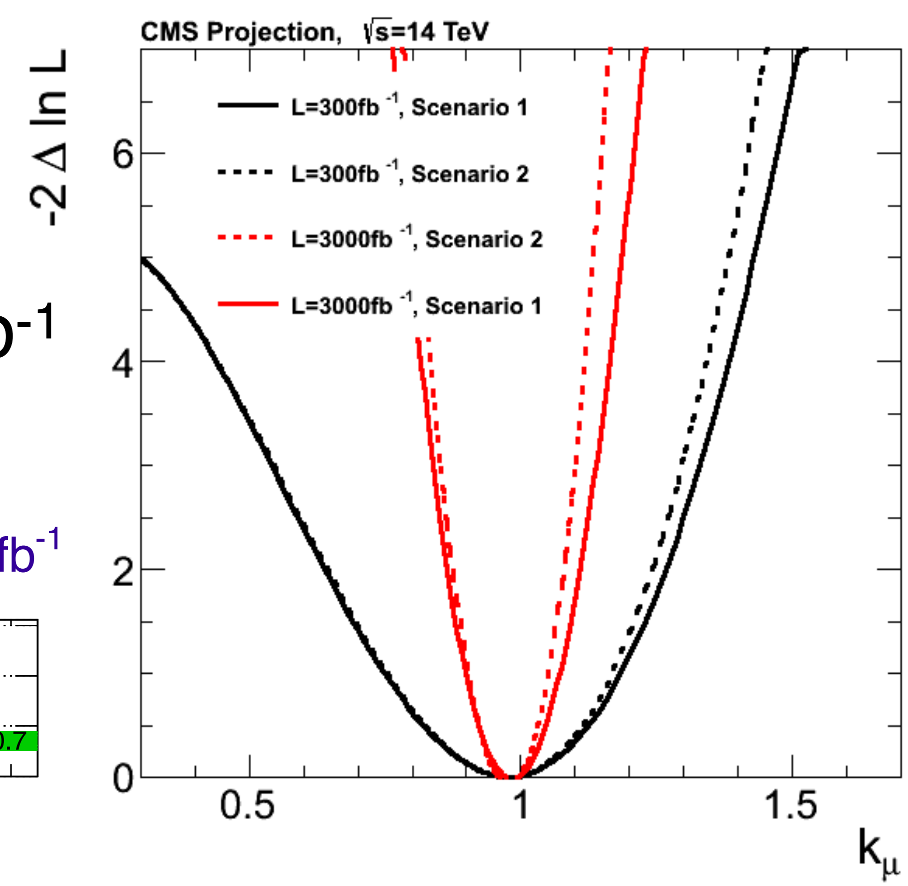


2 OS sign isolated muons, resonant peak at the Higgs mass, very clear signature

BR(H→μμ)=0.022. Only visible at HL-LHC

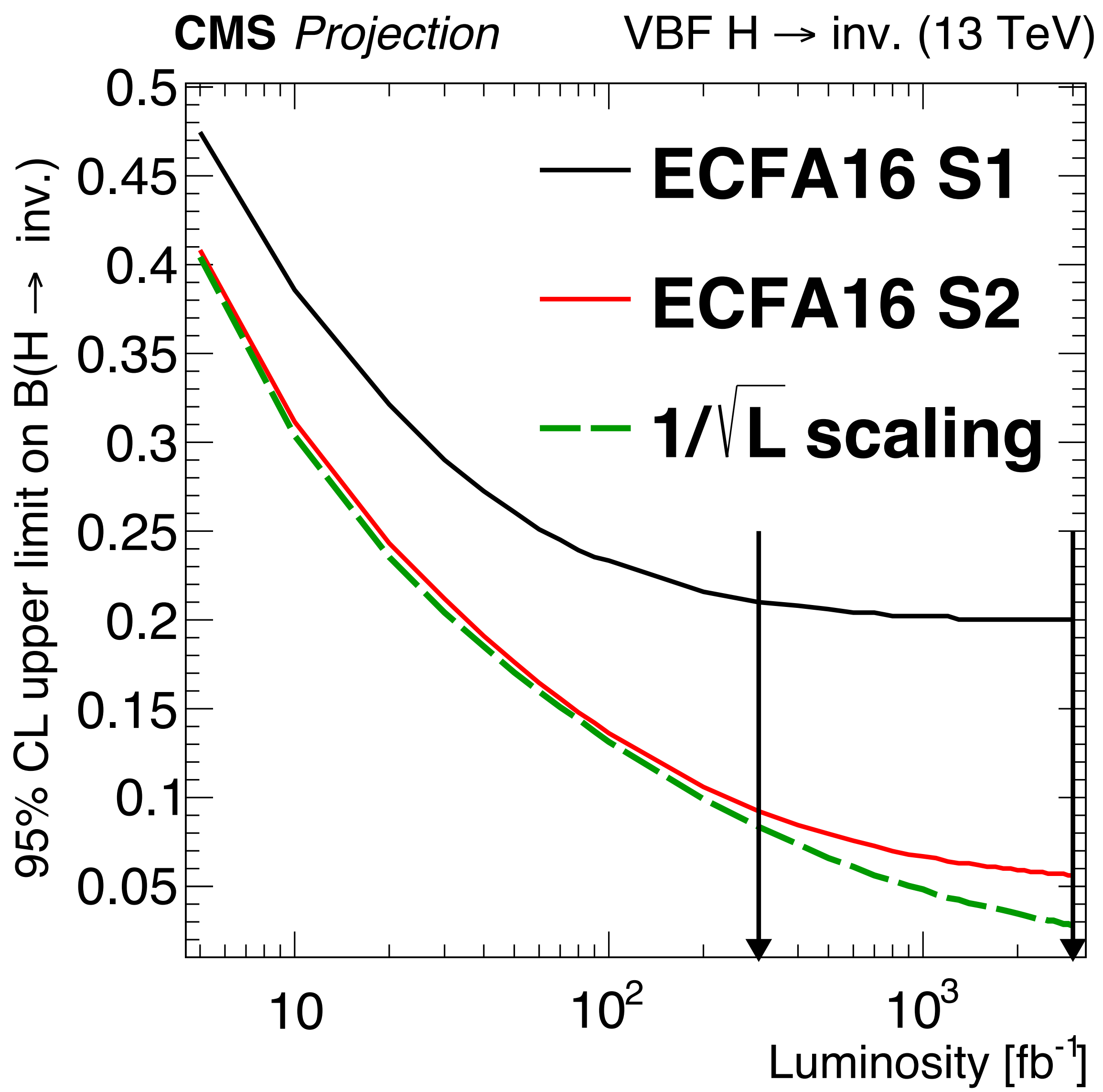
CMS and ATLAS projections from Run1:
40% (16%) signal strength precision at 300 (3000) fb^{-1}





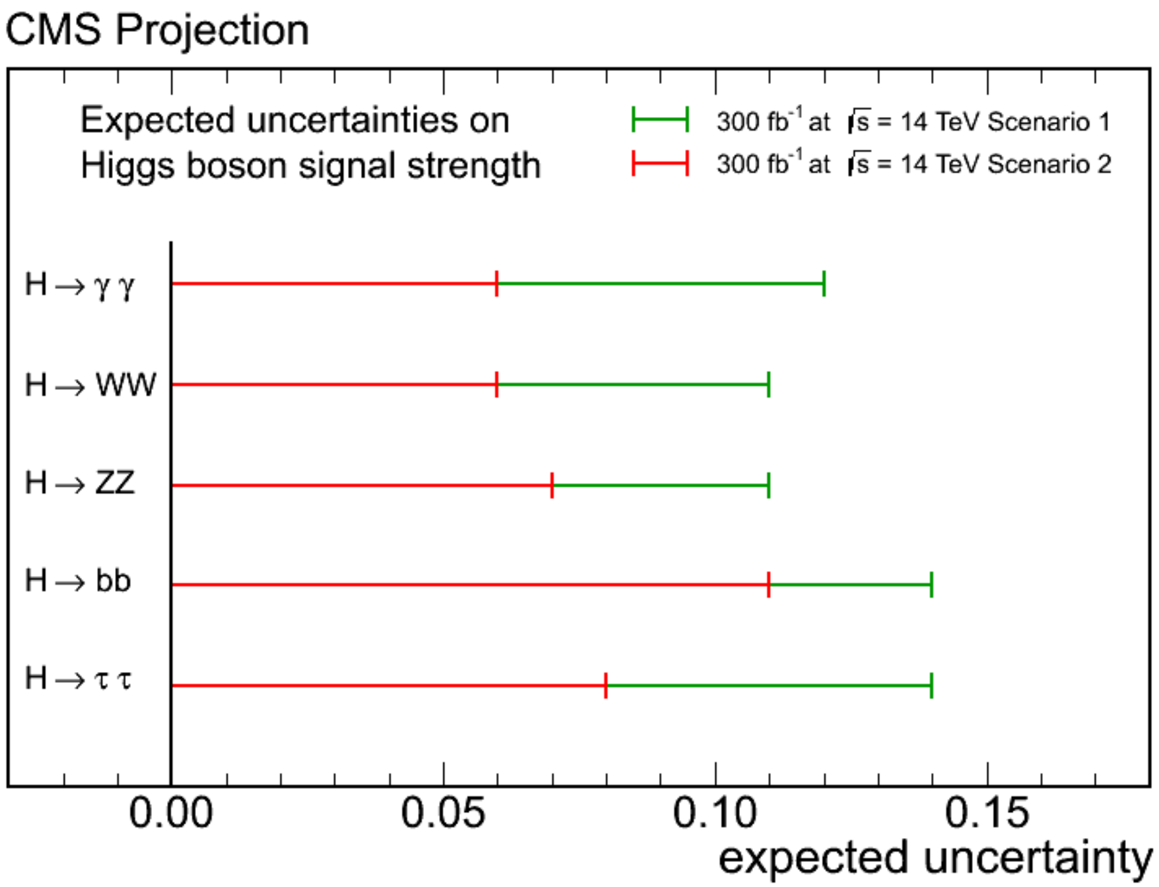
With Phase2 detector:
mass resolution <1%,
uncertainty on
H→μμ coupling <5%

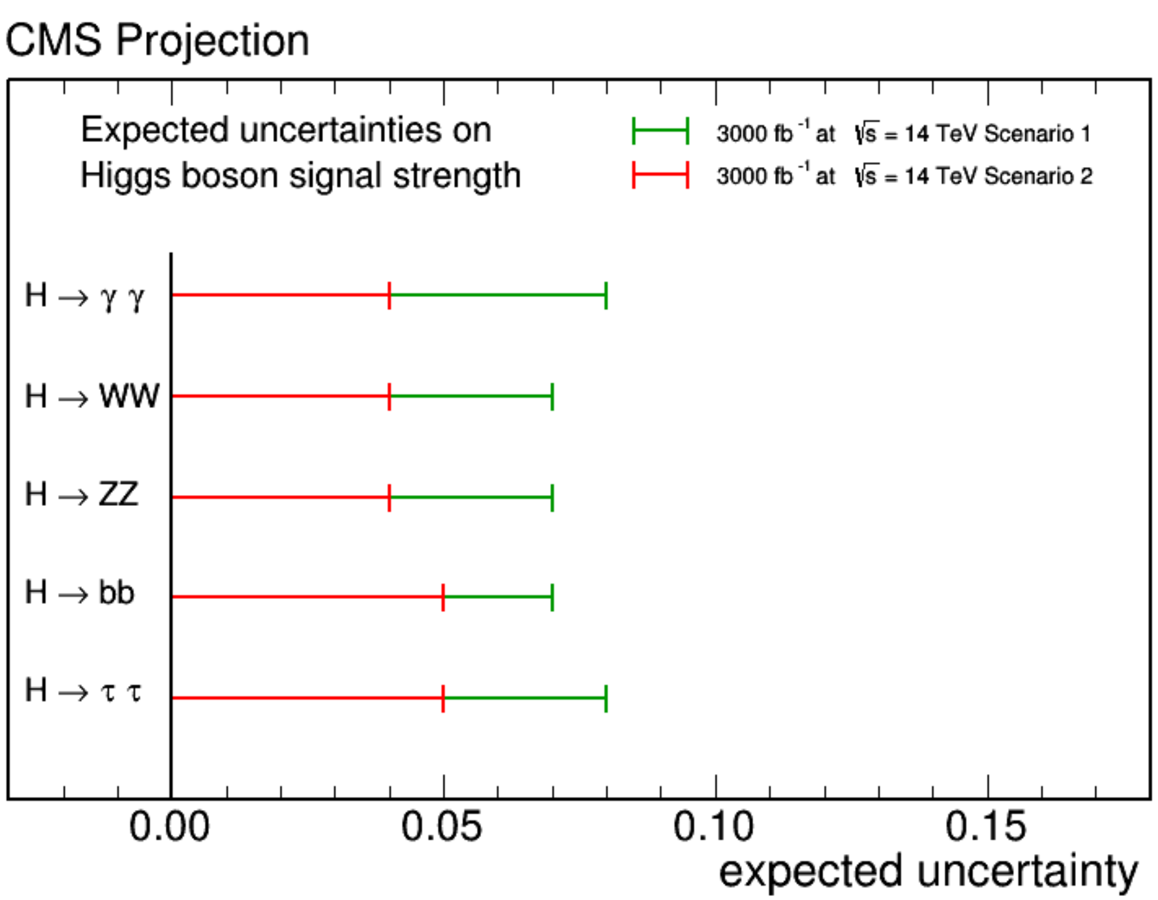
Higgs to invisible

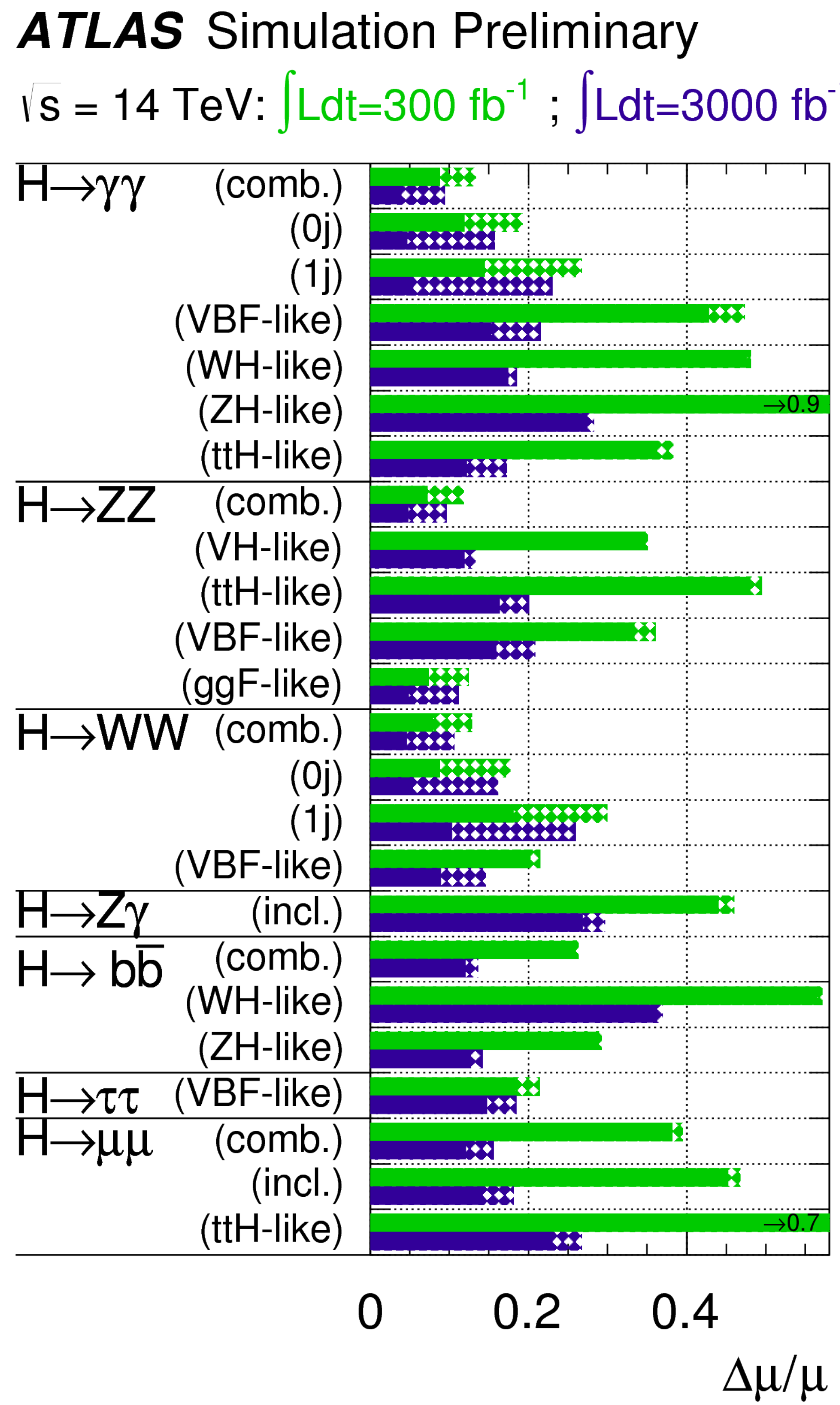


- Tight constraints could be set on NP and Higgs properties from H→invisible branching fraction (constrained to the ~10% level)

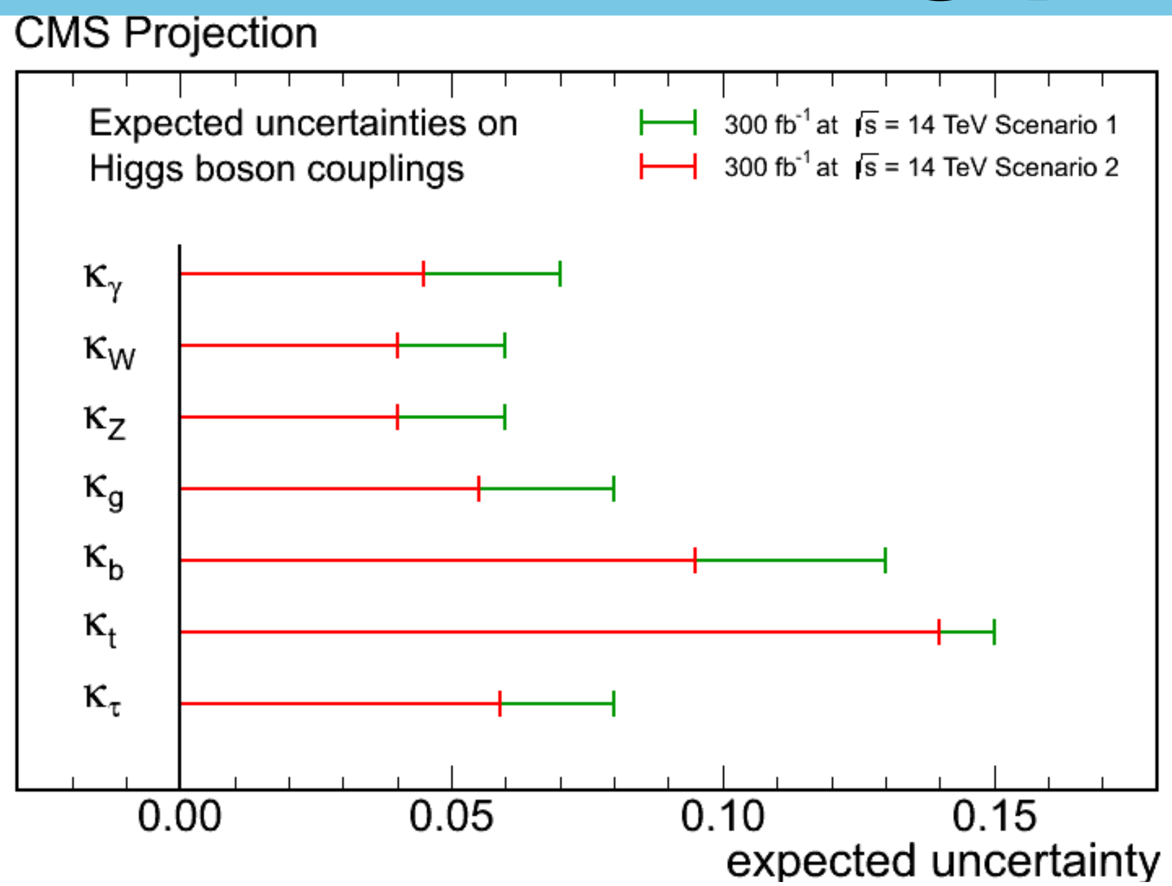
The big picture: μ

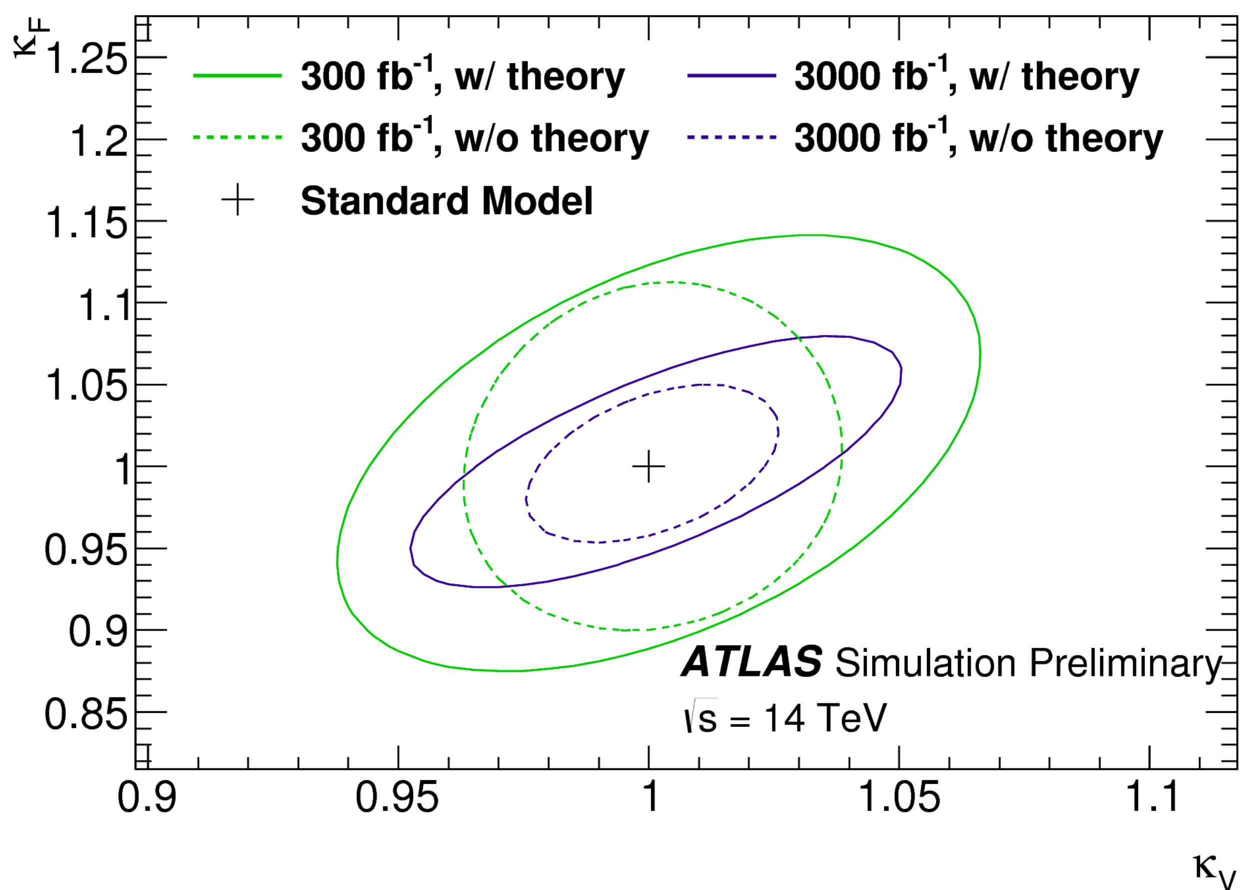


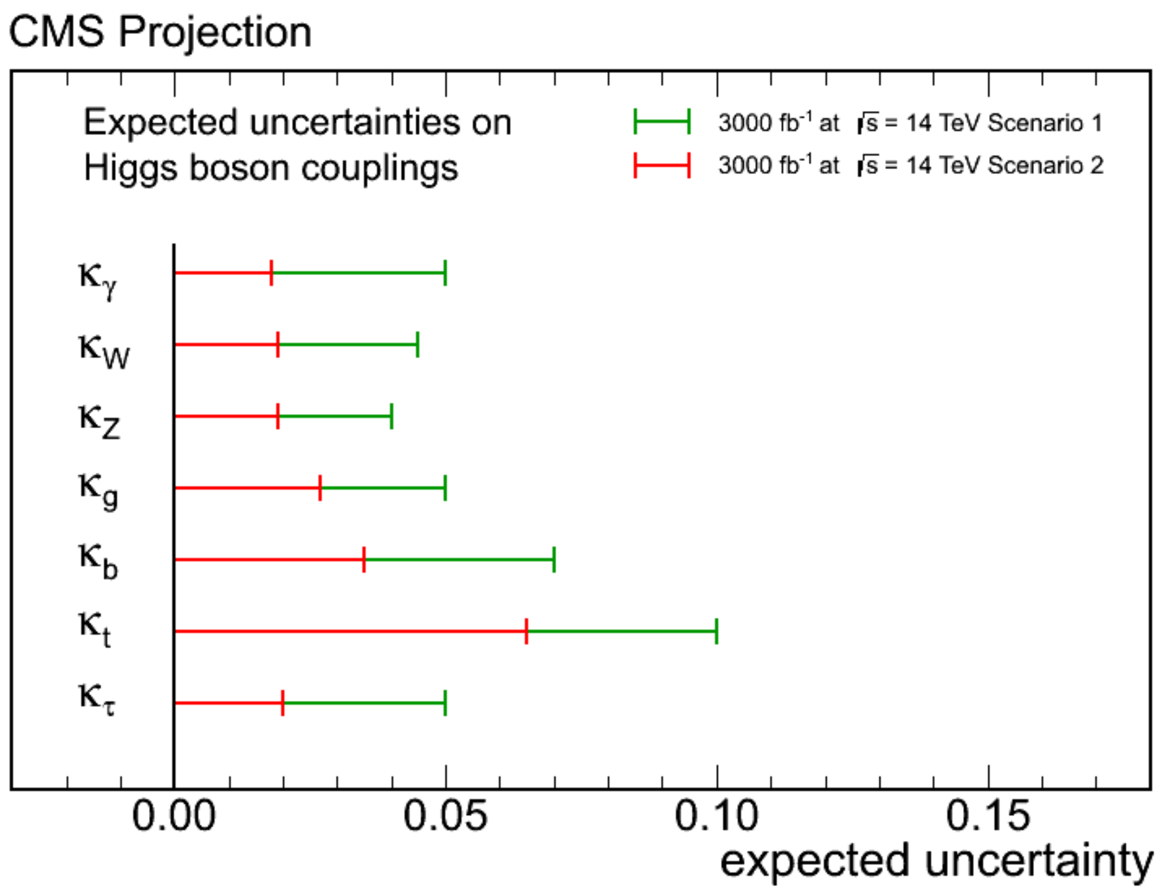




The big picture: couplings

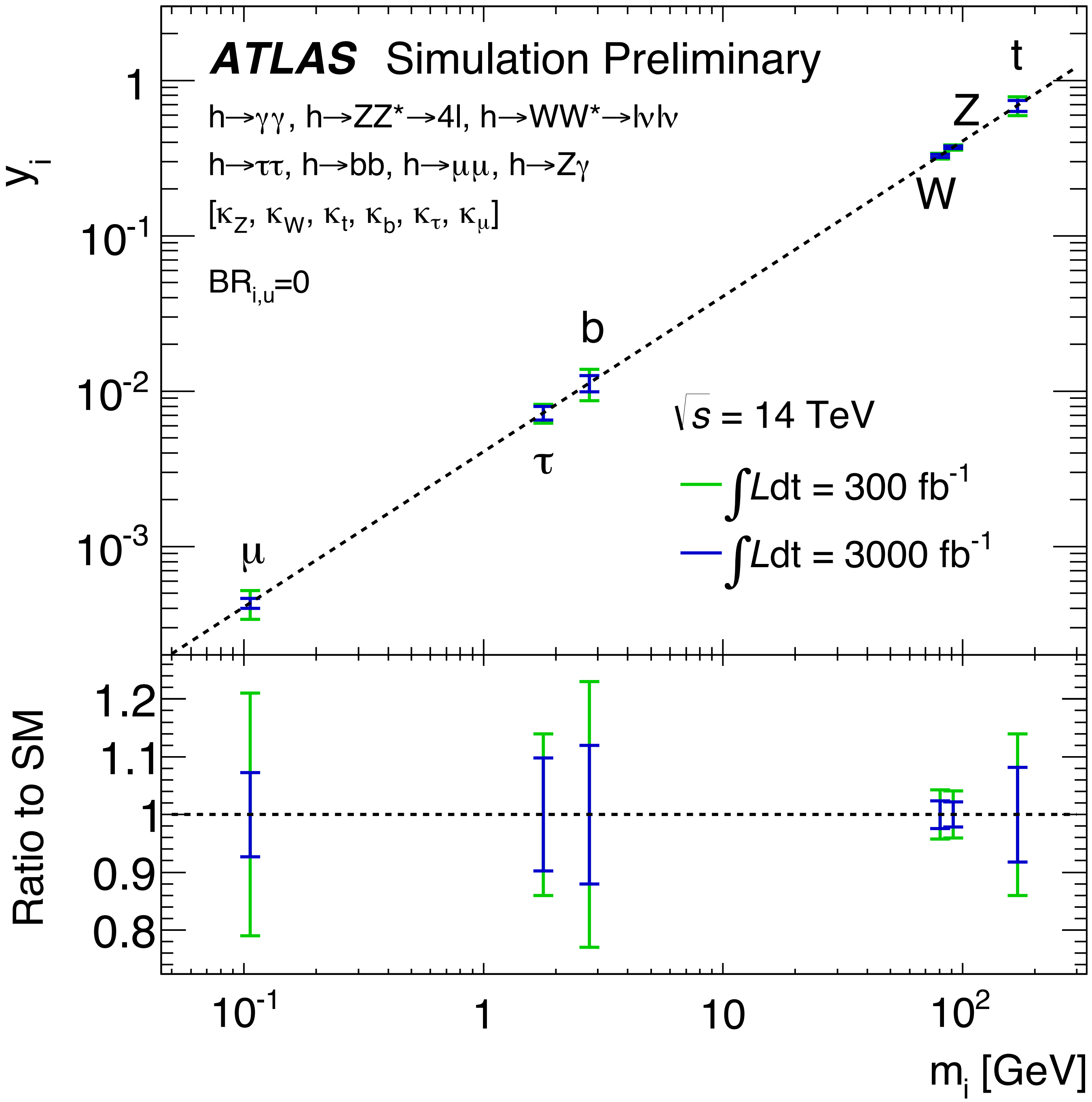


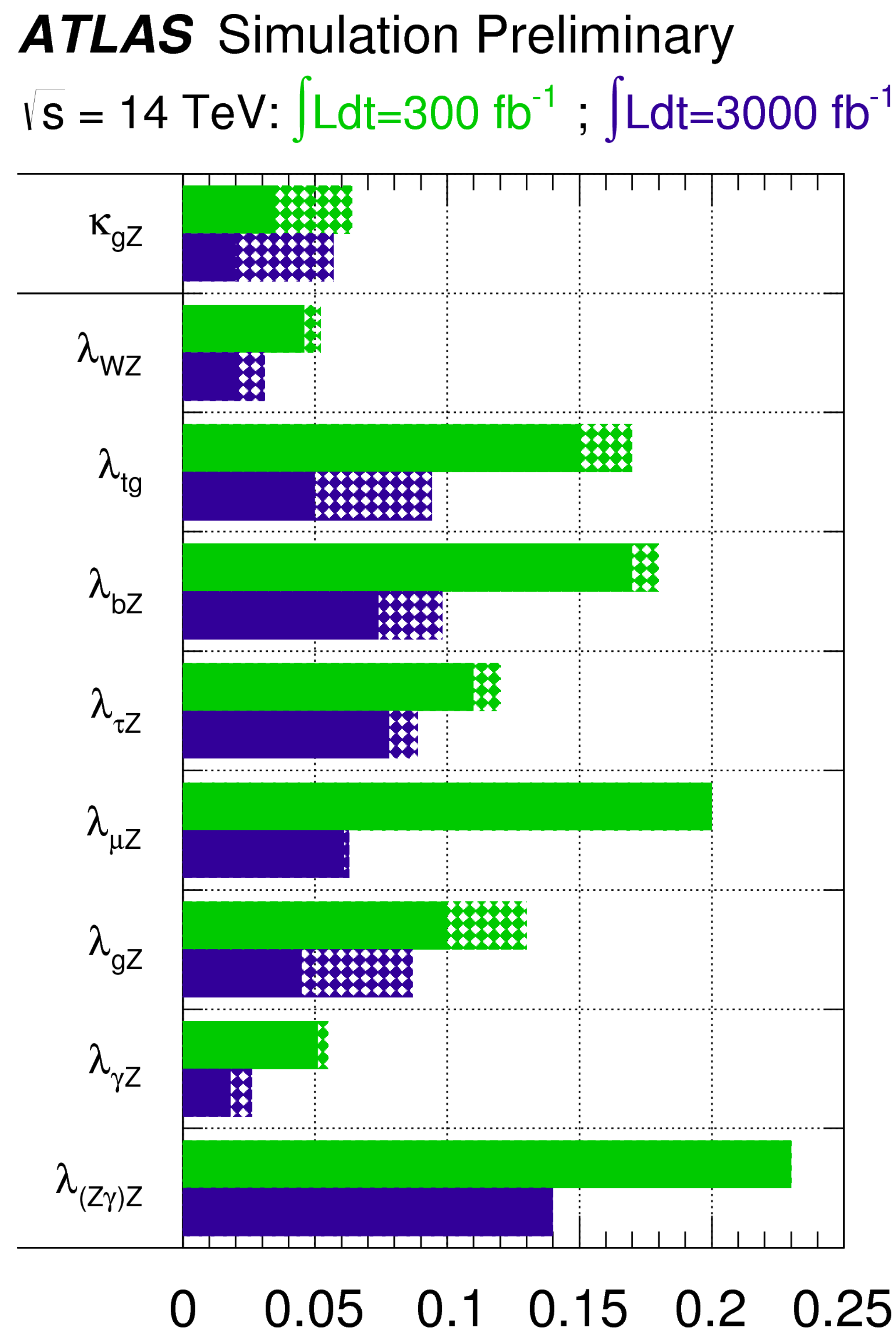




- Expected sensitivity on coupling modifiers ≲5% in all channels for 3 ab-1

Summary of results



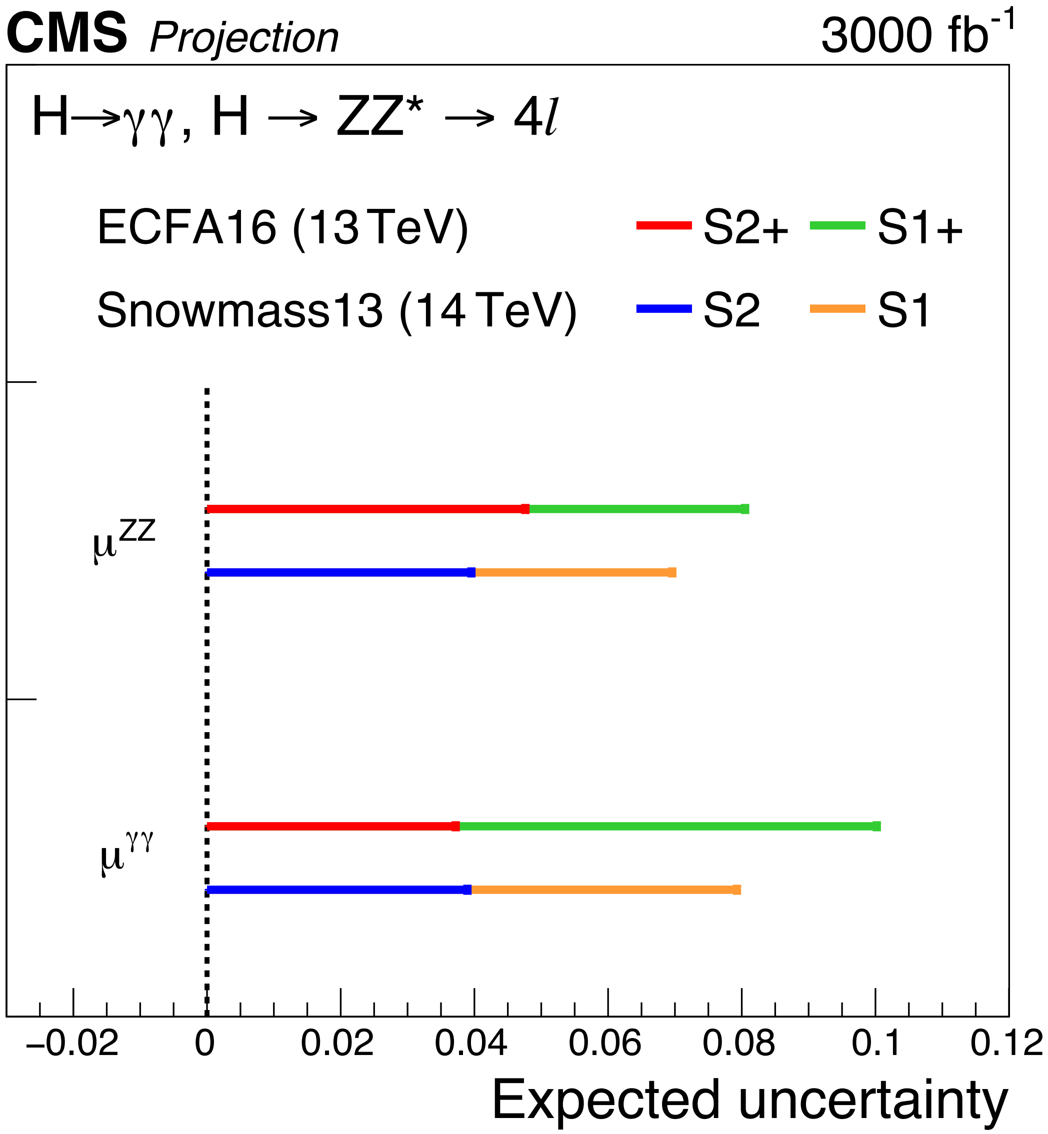


$\Delta\lambda_{XY}=\Delta(\frac{\kappa_X}{\kappa_Y})$

CMS *Preliminary* [S1,S2]

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]

Summary & Conclusions



Projections and studies were performed by the ATLAS and CMS collaborations from Run1/2 extrapolations or parametrised simulation

Potential to reach the percentage level in precision on the Higgs coupling modifiers and signal strengths

Covering most of the Higgs production and decay channels

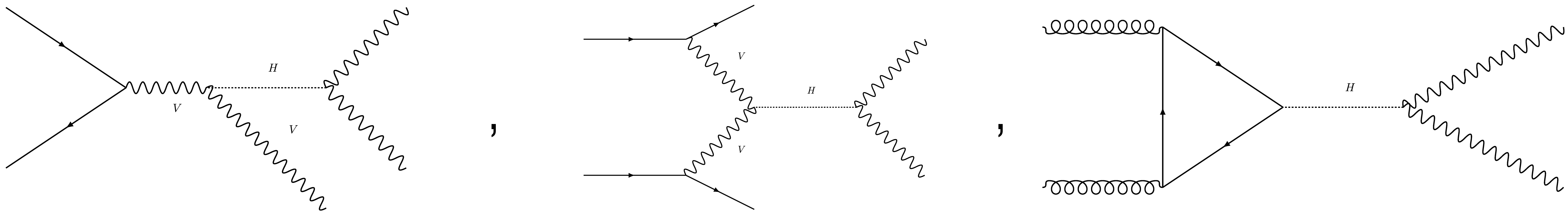
Latest projections confirm previous assumptions (Snowmass)

Recent improvement in Run2 analyses not yet propagated to HL-LHC projections

BACKUP

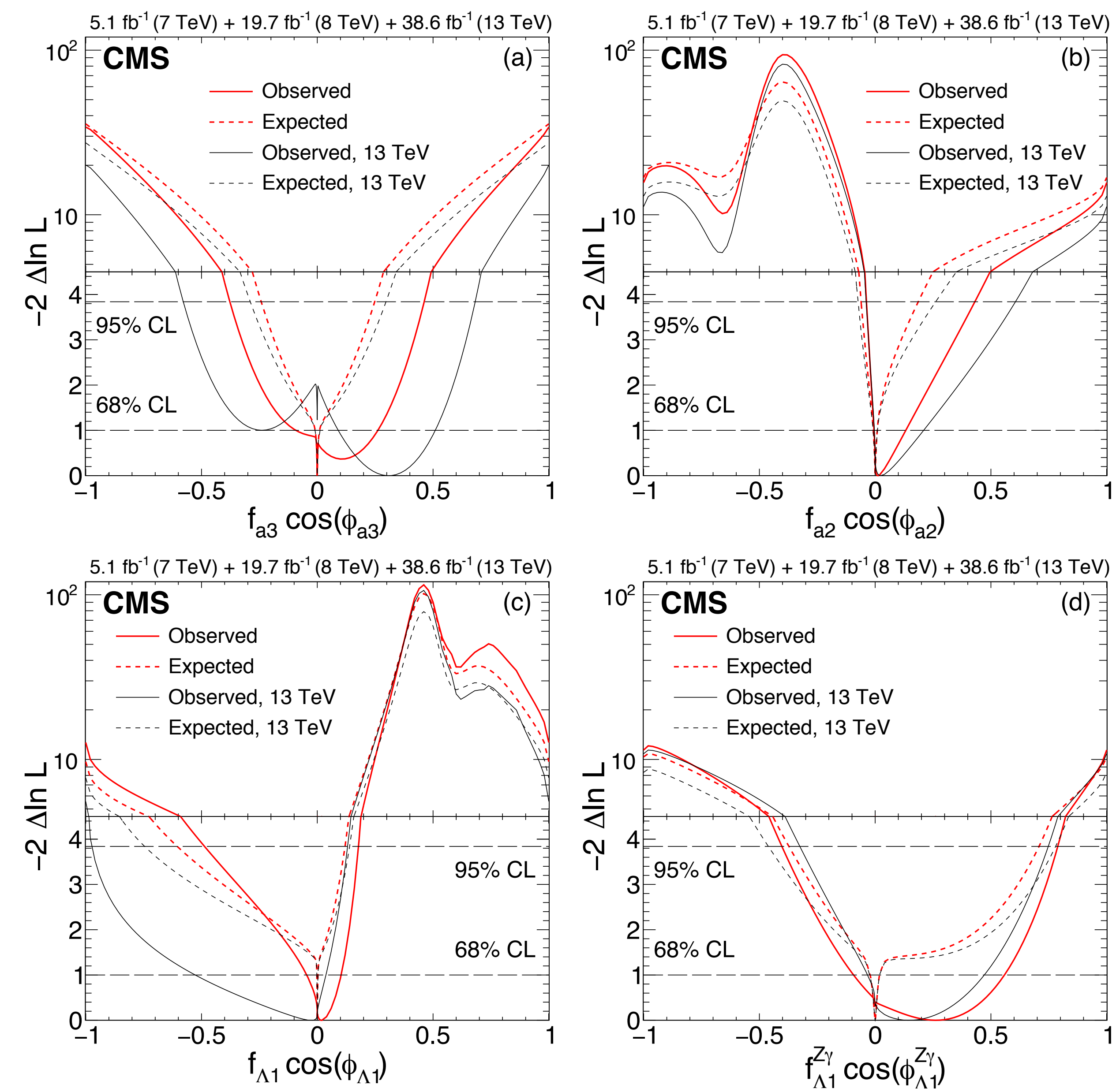
arXiv:1707.00541

Anomalous ZZ couplings

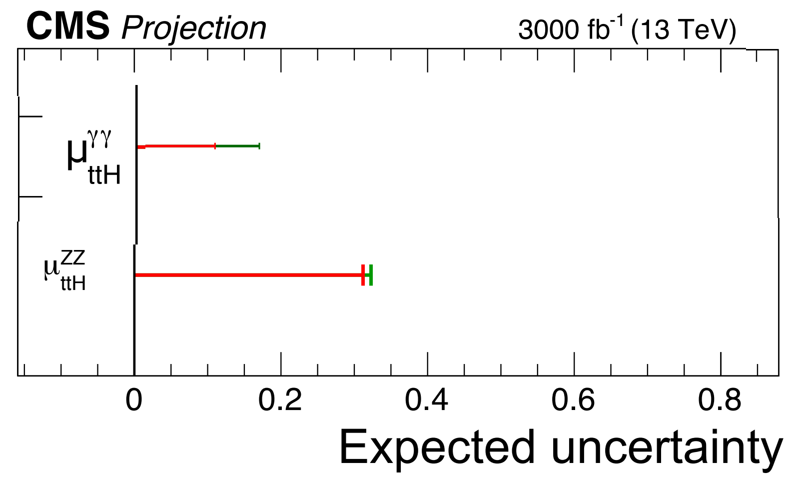


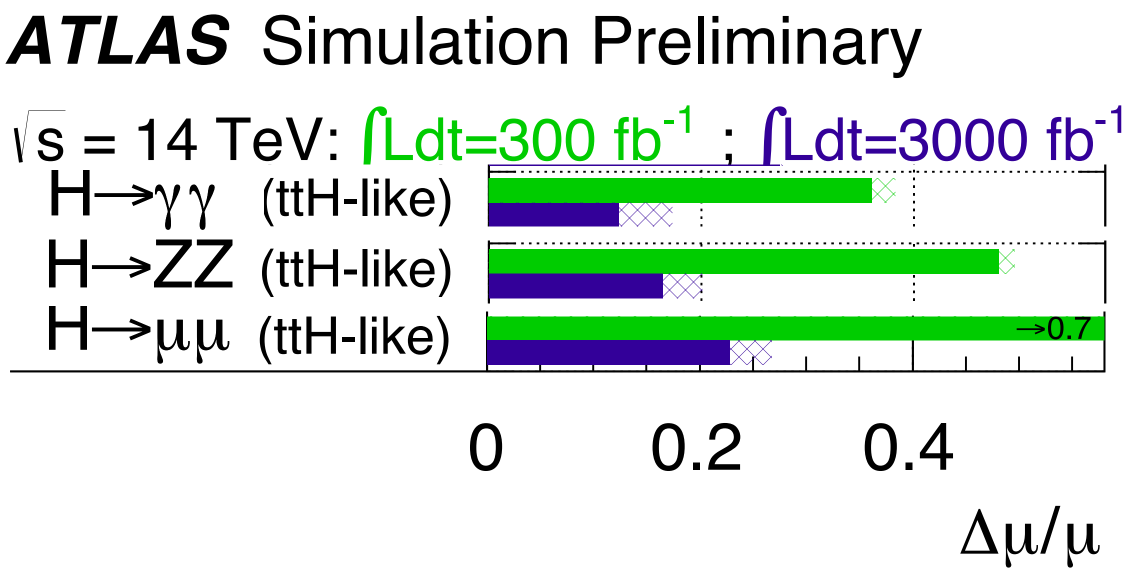
$$A(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_1^2 + \kappa_2^{\mathrm{VV}} q_2^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2}\right] m_{\mathrm{V}1}^2 \epsilon_{\mathrm{V}1}^* \epsilon_{\mathrm{V}2}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}$$

Recent CMS results (HIG-17-011) show that exploiting the production-level information can significantly improve the sensitivity to anomalous couplings towards 3000fb-1



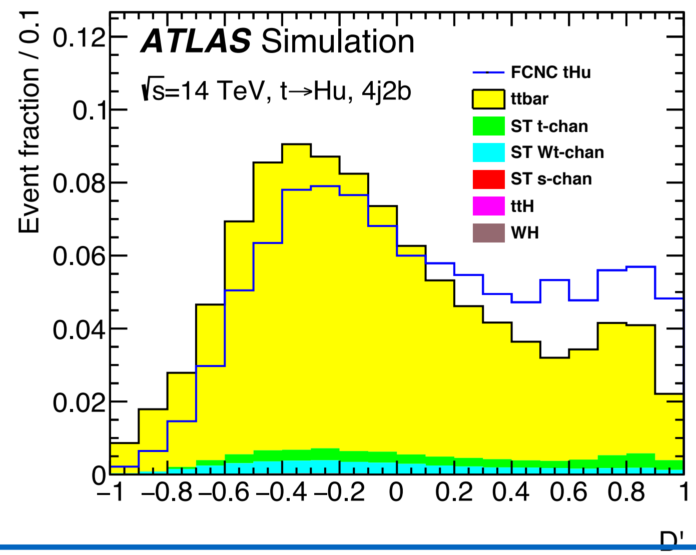
Yukawa couplings: top



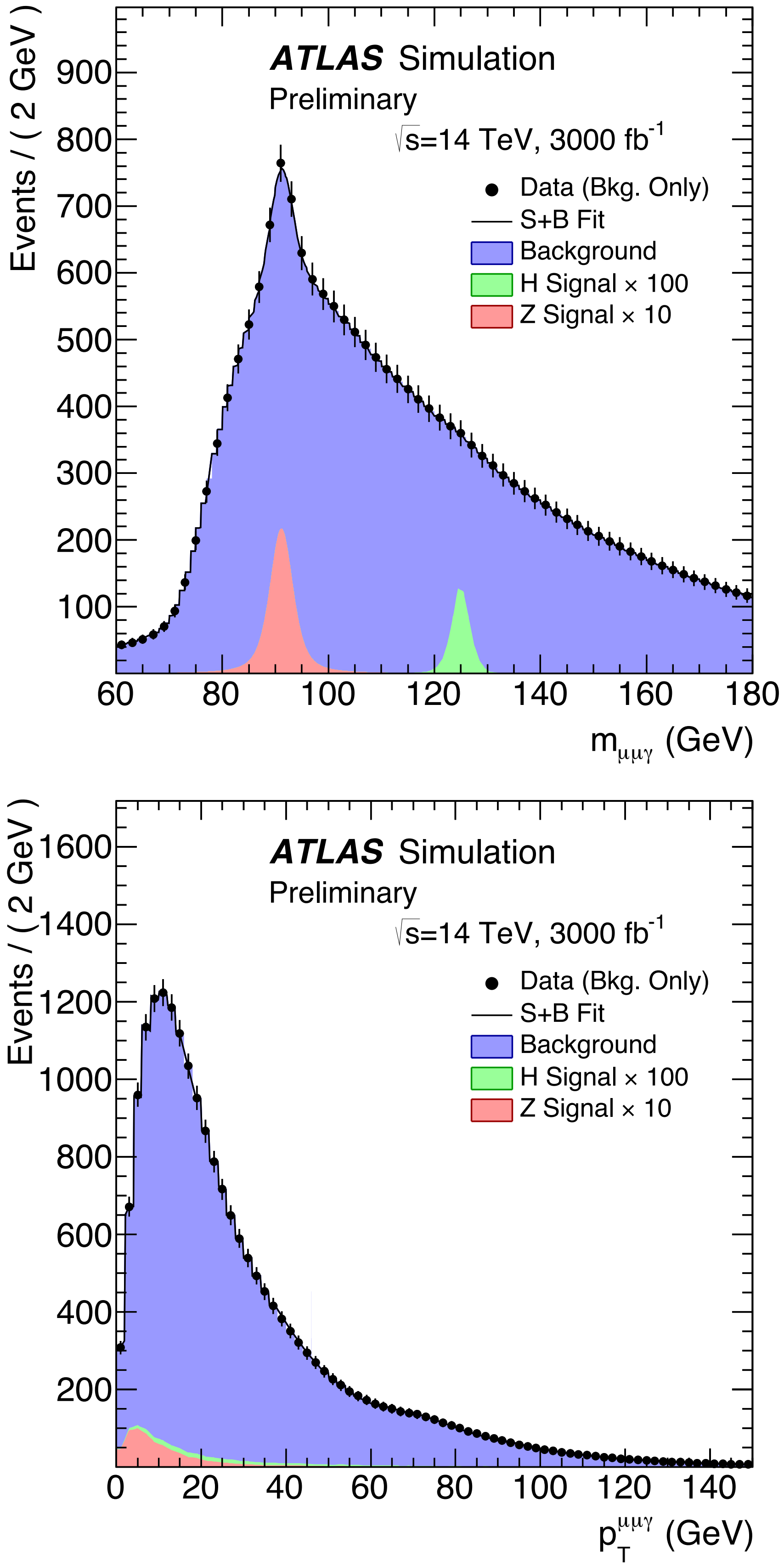


- Top Yukawa coupling can be measured from: ttH-like categories in H->gg, H->ZZ, H->mm
- And searches for ttH production, with different H decays

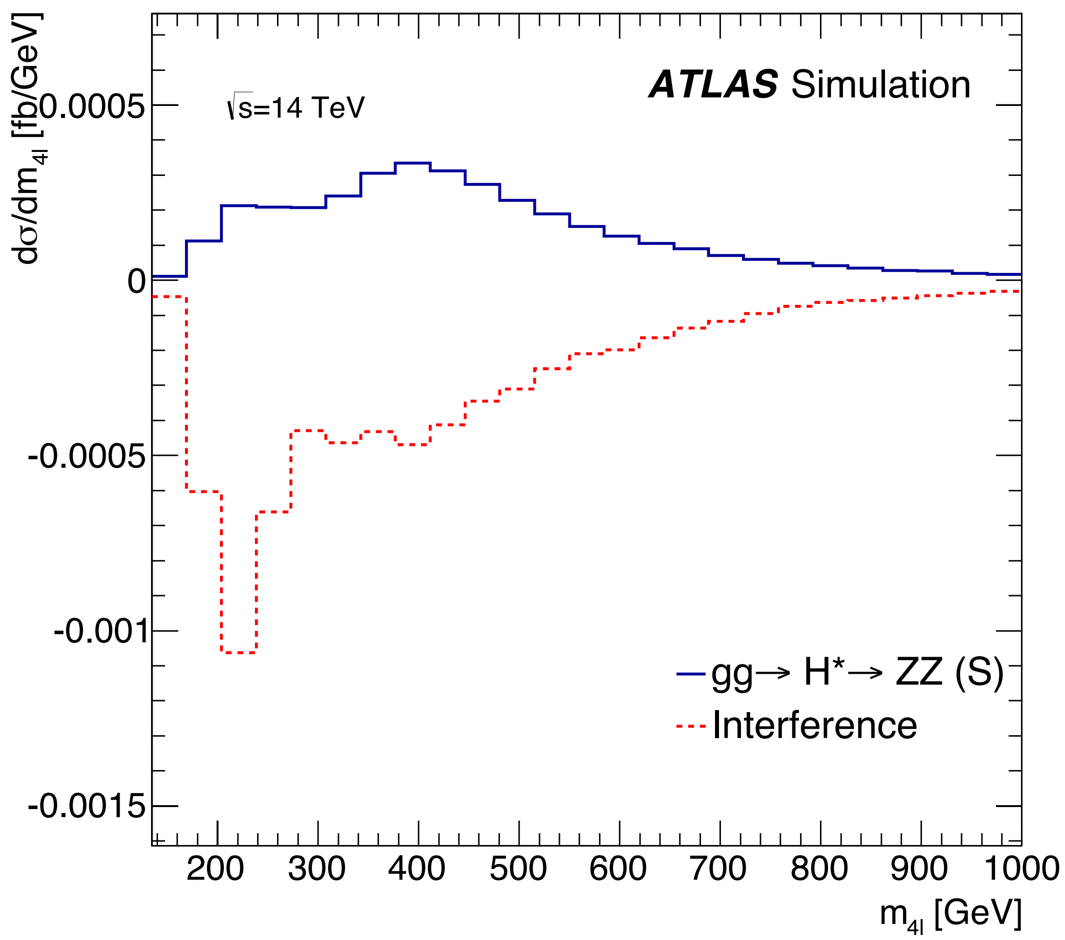
- tHq production can probe FCNC down to BR(t->Hq~10^{-4})

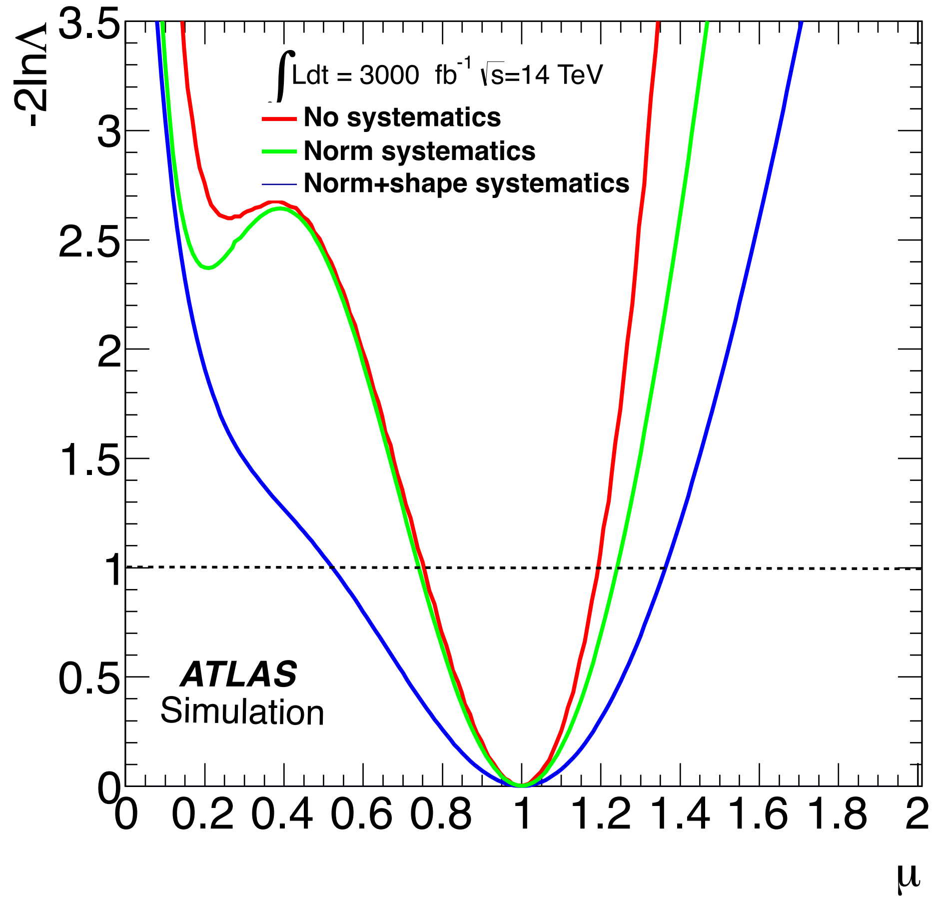


- ATLAS H->j/psi
- Very difficult to see it even at HL-LHC



ZZ: Higgs off-shell





- (Explain assumptions, RB*, mu->width etc.)
- If off-shell and on-shell couplings are the same, it is possible to translate the off-shell production in a measurement on the width
- With 3 ab^{-1}: 30-50% uncertainty: $\Gamma_H^{(L2)} = 4.2^{+1.5}_{-2.1}$ MeV (stat+sys).