Higgs results and prospects at ATLAS

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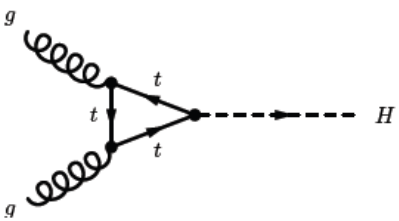
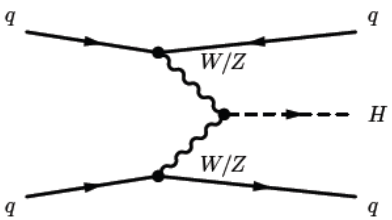
Introduction

- Introduction on Higgs production and decay at LHC
- Highlights on recent results from the ATLAS experiments
  - Bosonic final states and precision measurements
  - Recent updates on fermionic final states
  - An example of recent results on $H \rightarrow \tau\tau$, $H \rightarrow inv$
- Properties
  - Mass and spin
  - Couplings
- Future prospects on Higgs Physics at ATLAS
  - 300 fb^{-1} and 3000 fb^{-1} at 13-14 TeV
- Link to all ATLAS Higgs public results (RUN1 and Prospects):
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies

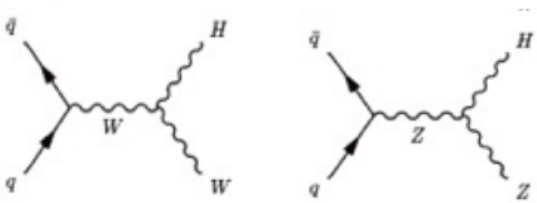
Higgs production and decay at LHC



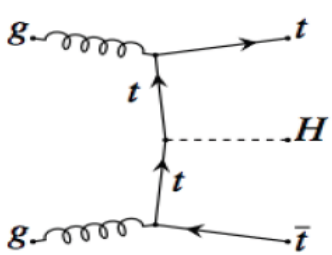
ggF: Main diagram (87%)
PDF+scale errors ~11%



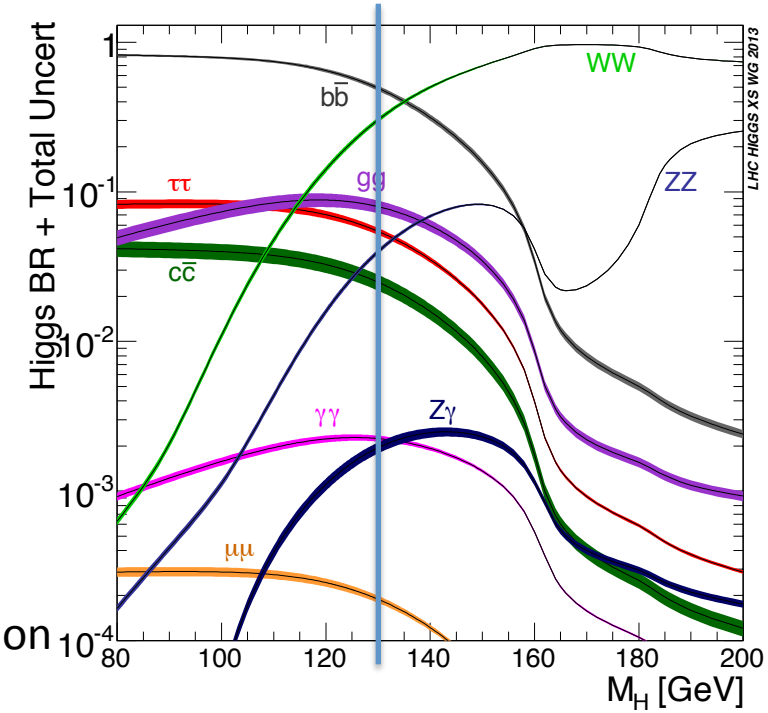
VBF: distinct signature
Contributes 7%
Error ~3%



VH: associated production
5% of total σ
Error ~3-4 %



ttH: associated production with ttbar
1% of total σ
Error ~12%



Exp events before selection, 8 TeV

Decay	Events / fb^{-1}
γγ	50
ZZ*(→4l)	3
WW(→lnln)	60
ττ	1500
bb (VH prod)	600

Highlights on recent Run 1 results

High precision channels

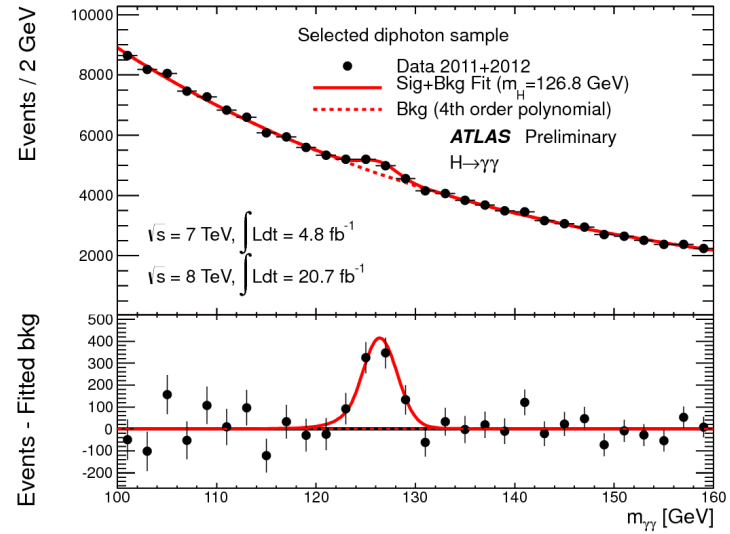
γγ and ZZ*→4l: full reconstruction of the final state
Measure mass and other properties

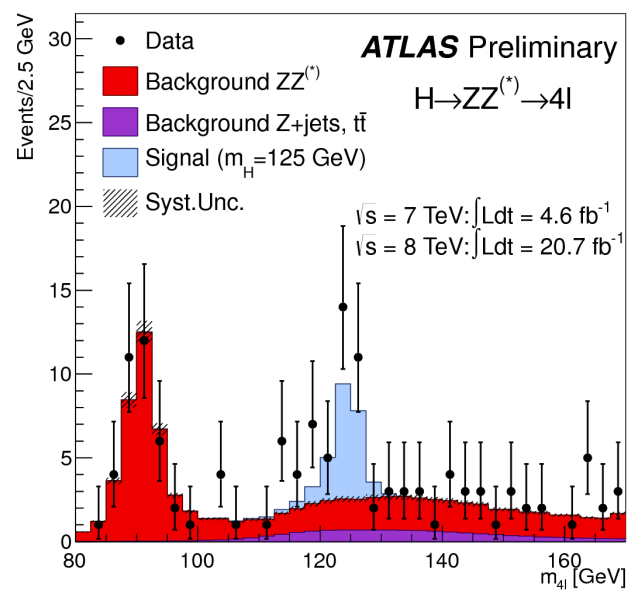
γγ:

- Two isolated, high ET and tight quality photons
- Irreducible background from γγ continuum
- Reducible γ-jet and di-jet, DY e+e-
- Event categorization based on signature and kinematics (S/B)

ZZ* →4l:

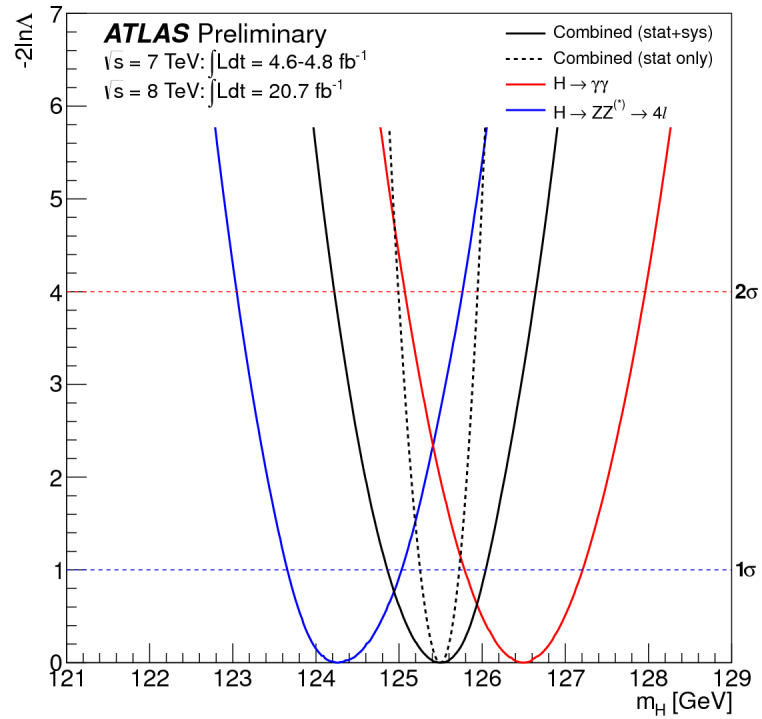
- Best S/B
- Main backgrounds from ZZ continuum (irreducible)
- Reducible Z+jets, ttbar

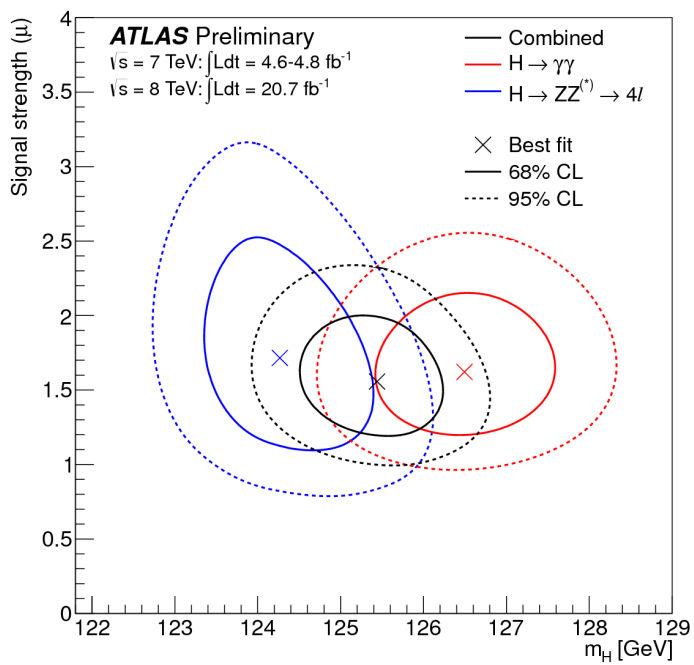




Mass combination

- Combination of the two high-precision channels
  - **$M_{\gamma\gamma}$=126.8 ±0.2 (stat) ±0.7 (syst) GeV**
  - **M_{4l}=124.3$^{+0.6}_{-0.5}$(stat)$^{+0.5}_{-0.3}$(syst) GeV**
  - Combined:
    M_H=125.5 ±0.2(stat) $^{+0.5}_{-0.6}$(syst) GeV





Combined fit of
ΔM_H=2.3$^{+0.6}_{-0.7}$(stat)±0.6 (syst) GeV

Masses compatibility at the 2.4 σ level

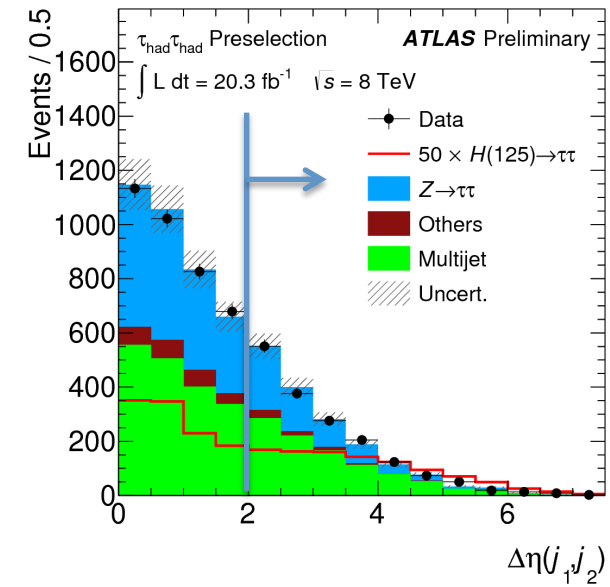
Main uncertainties are photon and electron energy scales

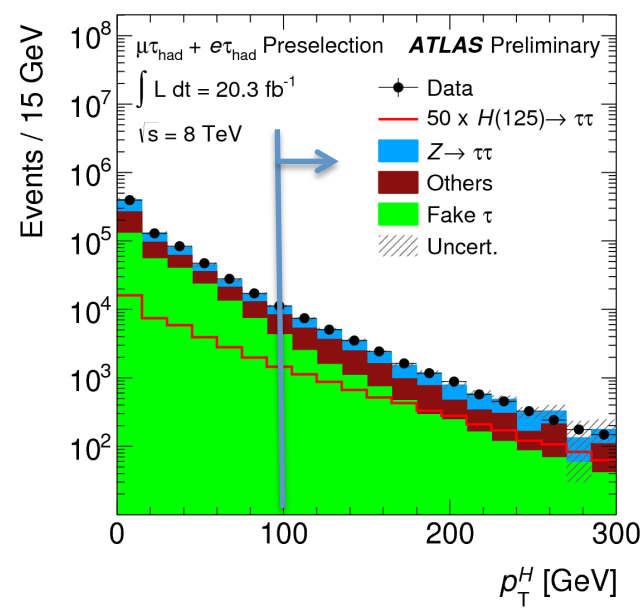
$H \rightarrow \tau\tau$

ATLAS-CONF-2013-108

- Results on 20.3 fb^{-1} of data at 8 TeV

$H \rightarrow \tau_{lep}\tau_{lep}$	$H \rightarrow \tau_{lep}\tau_{had}$	$H \rightarrow \tau_{had}\tau_{had}$
BR 12.4%	BR 45.6%	BR 42%
Very clean signature	Clean signature	Large multi-jet background





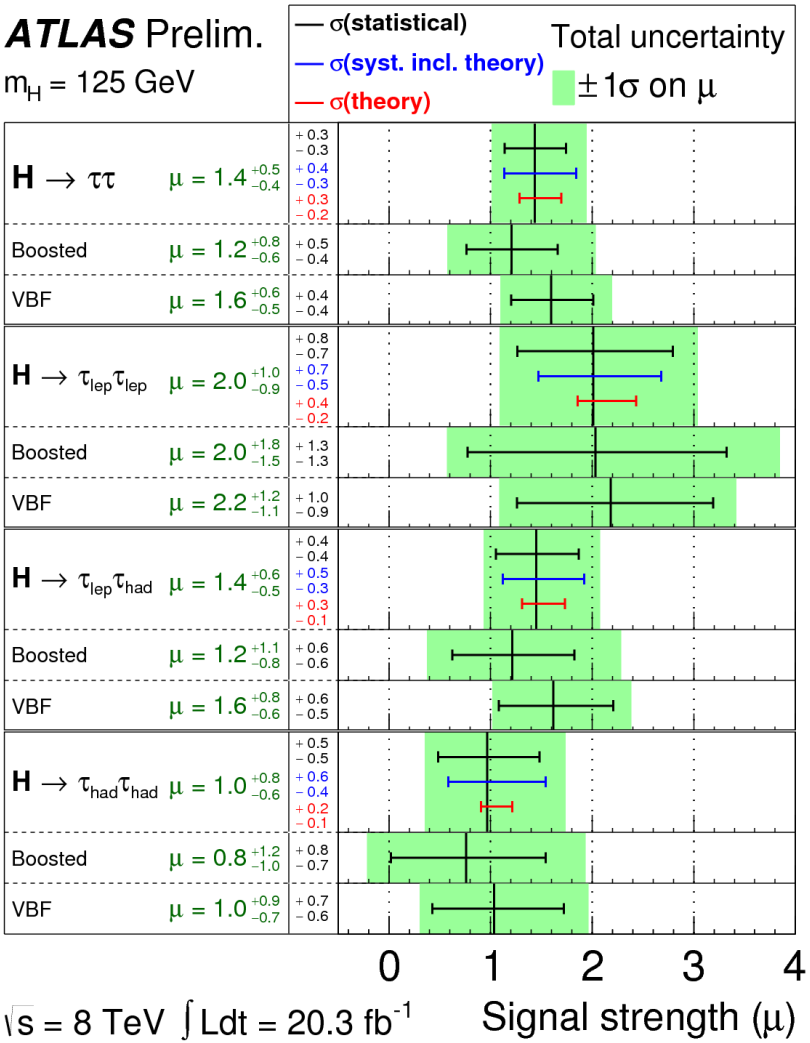
Two categories in each channel:

- **VBF:** two jets with $\Delta\eta(jj)$ separation
- **Boosted:** not-VBF and high pT H

Signal/background separation with multi-variate analysis

- One BDT for each category

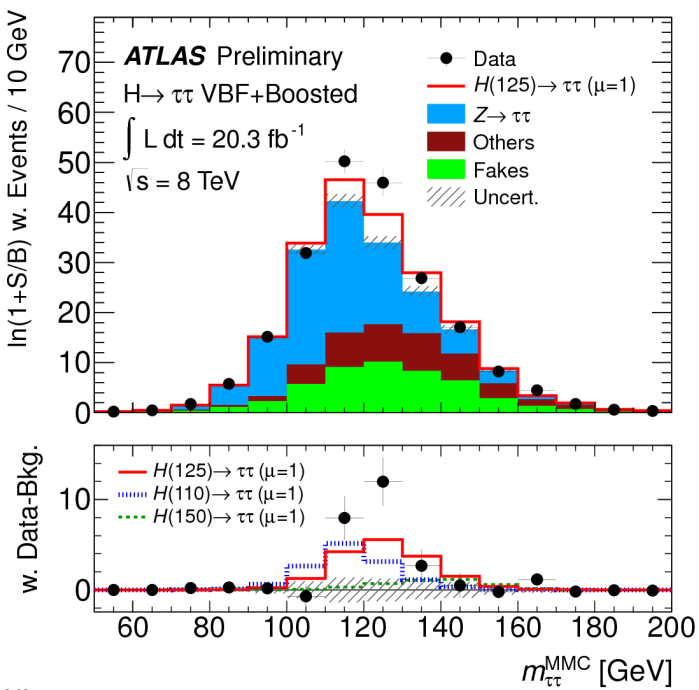
H→ττ : results



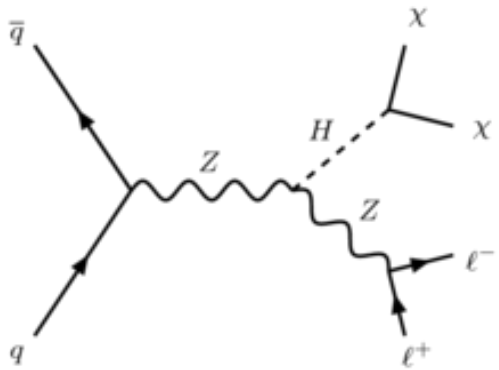
Expected significance @125 GeV **3.2 σ**
Observed significance: **4.1 σ**

First direct evidence of the Higgs boson decay to fermions

Signal strength $\mu=\sigma/\sigma_{SM}=1.4\ ^{+0.5}_{-0.4}$

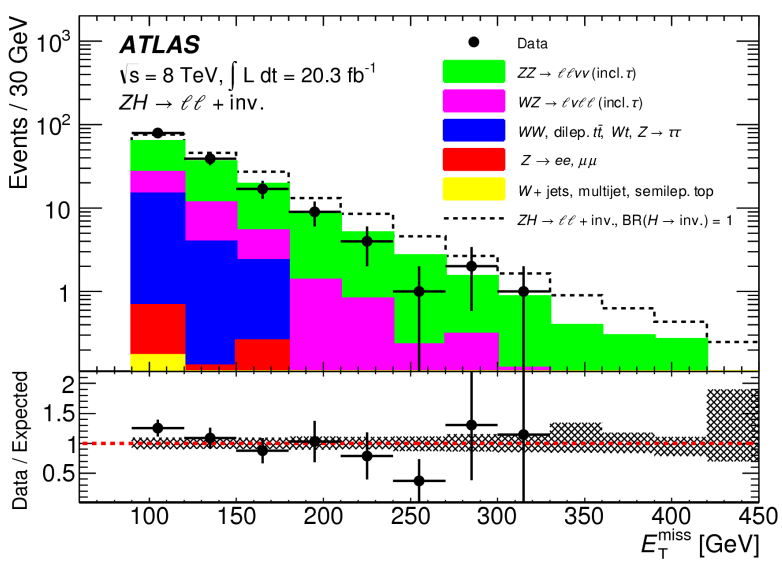


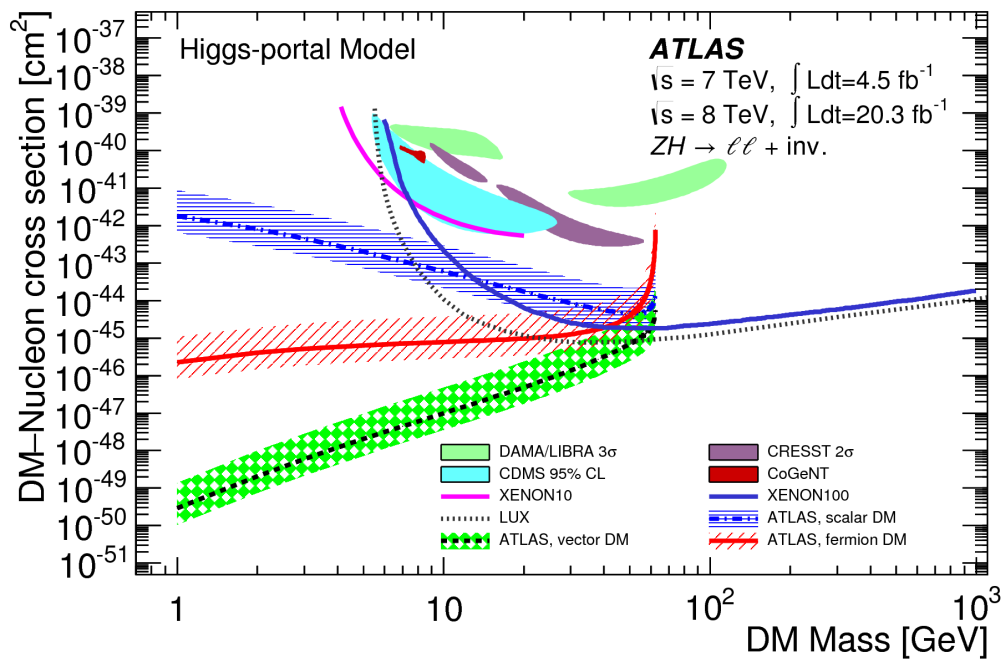
Search for invisible decays



- Look for invisible decay in associated production, with Z→ll
- Upper limits can be set on the invisible decay BR: BR < 75% @95% C.L. (expected 62%) assuming SM 125.5 GeV Higgs cross section
- The limit can be interpreted in the framework of the Higgs-portal DM scenario

arXiv:1402.3244v2 [hep-ex] 12 Mar 2014





Signal strengths, all channels and combined

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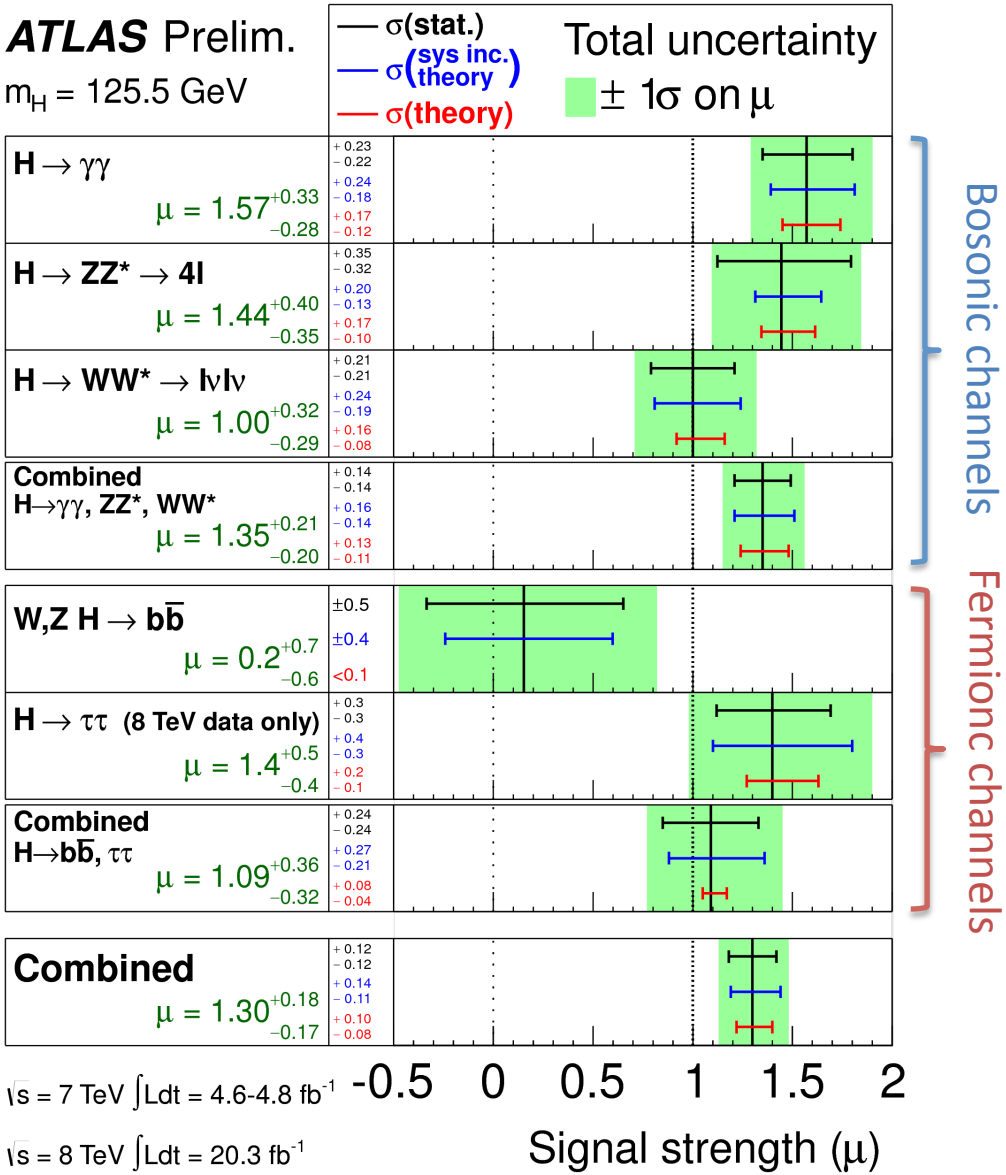

- Measure the ratio of the observed rate to the SM expectation
  $\mu=\sigma/\sigma_{SM}$
- At the combined mass M_H=125.5 GeV
- Ratio of the production cross sections fixed to the SM

- No significant deviation from 1 is observed

Combination of all channels, bosonic and fermionic:

$\mu=1.30^{+0.18}_{-0.17}$

Sensitivity to VBF production

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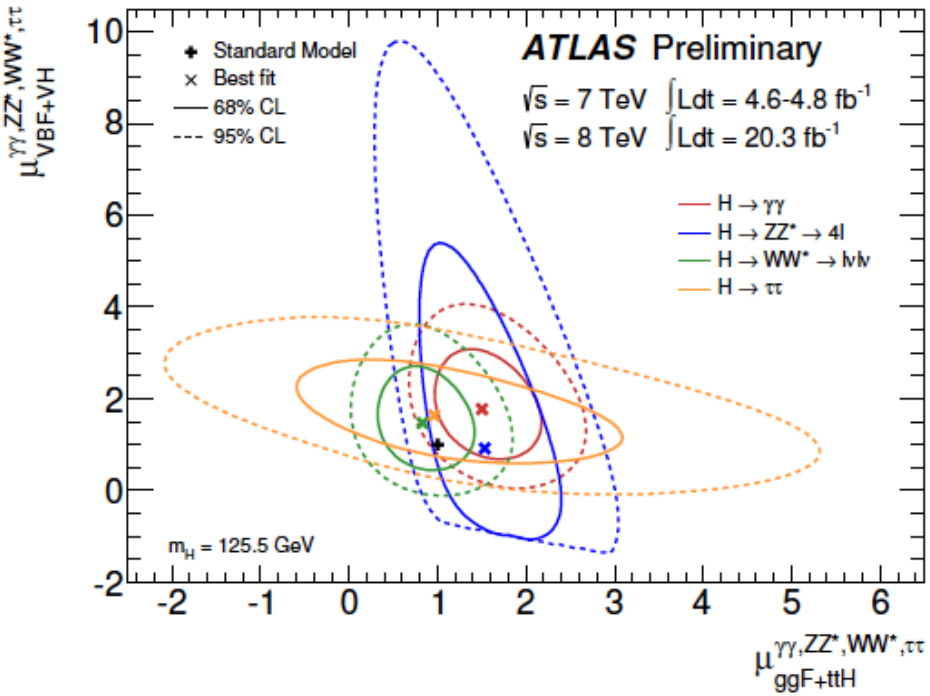
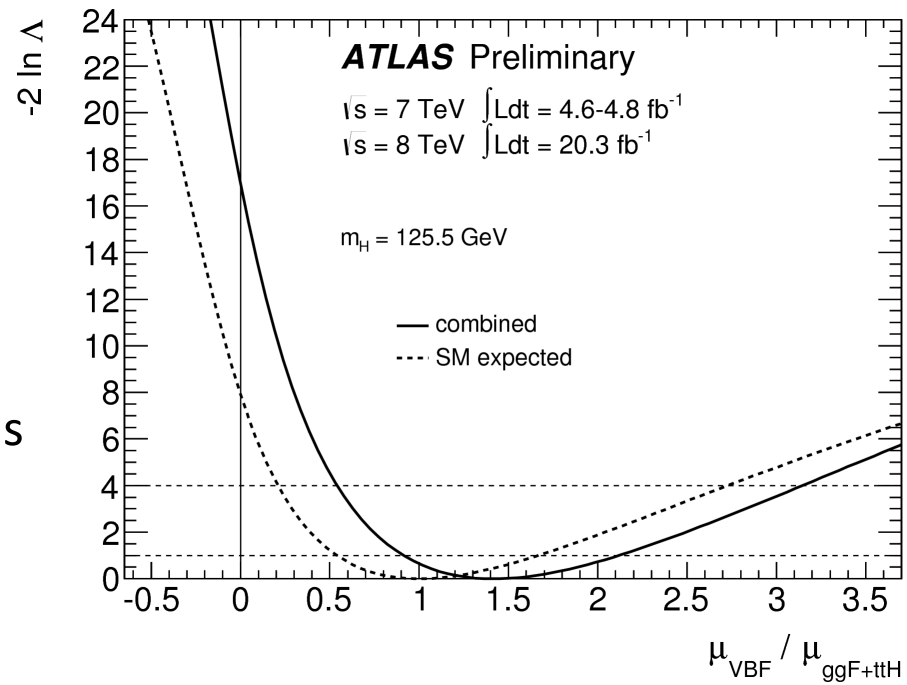


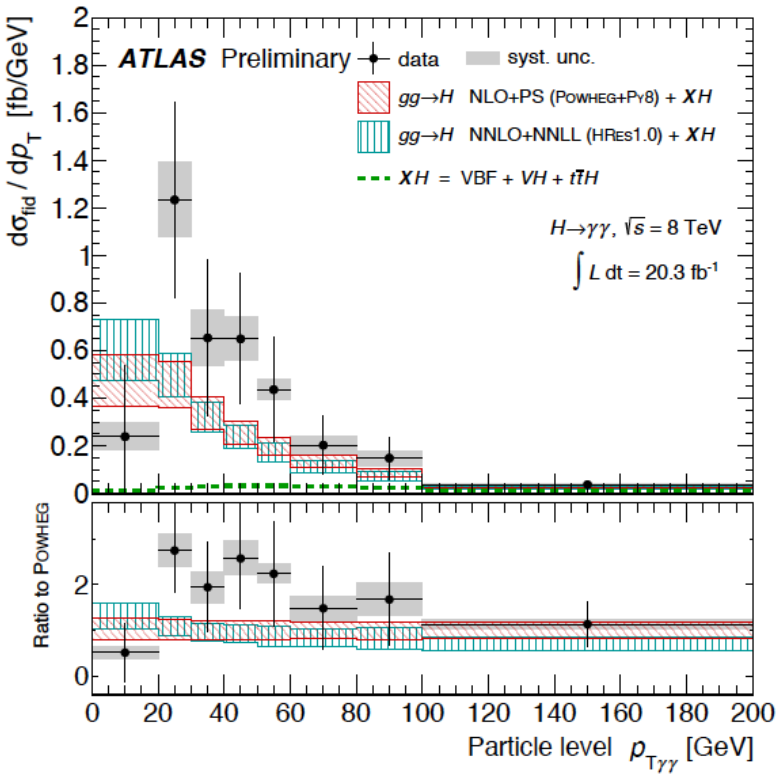
Fit of $\mu_{VBF}/\mu_{ggF+ttH}$ provides **4.1 σ** evidence of Higgs production via VBF

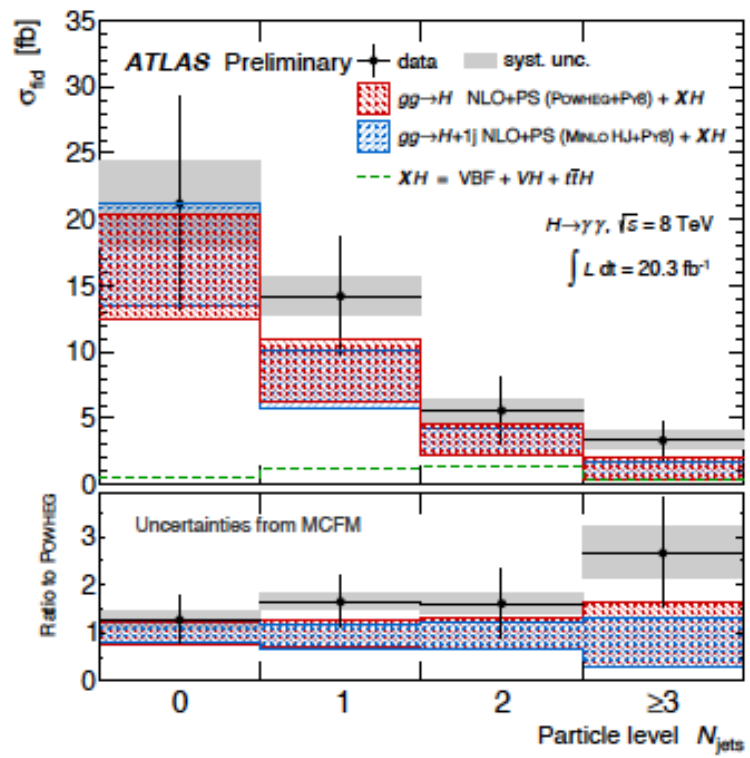


Combination of γγ, ZZ, WW and ττ channels

Differential cross sections

- Combined signal+background fits in **H→γγ** differential distributions
- Test distributions sensitive to higher-order corrections and different production mechanisms **($P^T_{\gamma\gamma}$, N_{jets})**
- Plus other interesting distributions (e.g. **|cos θ*|**)





- Within current statistics, no significant deviation from the SM found

More details in the poster by G. Mancini

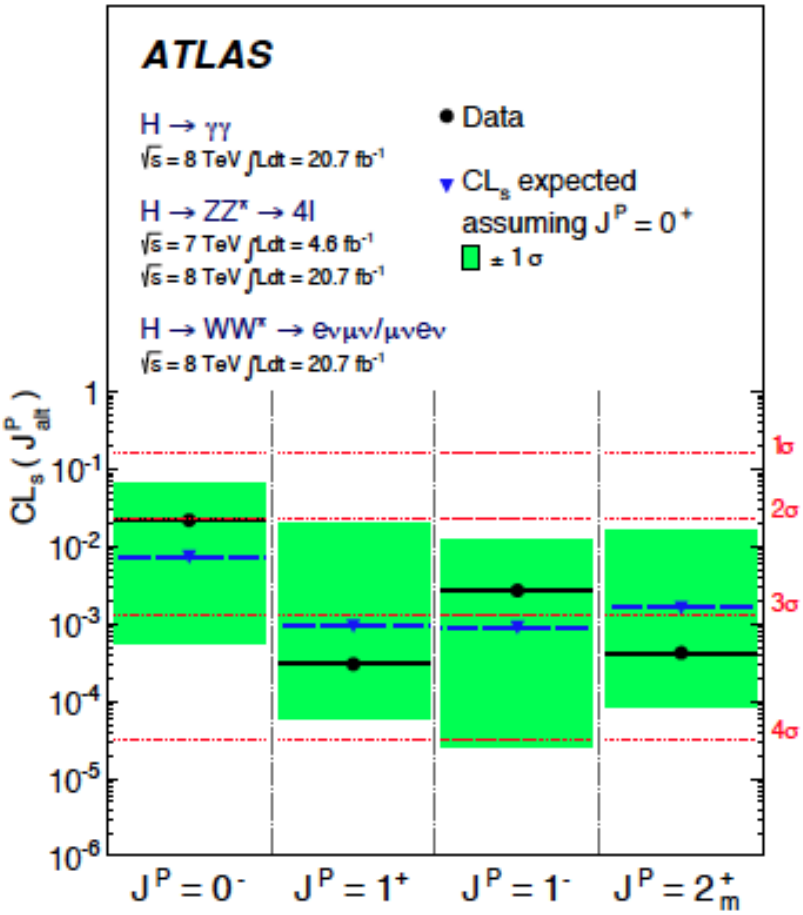
Spin and parity analyses

- Three channels combined to test different spin-parity hypotheses against SM 0+:
- $H \rightarrow ZZ^* \rightarrow 4l$:
  - Full reconstruction of the final state
    - Multi-variate analysis using five angles and masses of the two Z's
- $H \rightarrow \gamma\gamma$:
  - Fit of $|\cos\theta^*|$ γ angle w.r.t. the beam axis in the Collins-Soper frame (minize p_T effects)
- $H \rightarrow WW \rightarrow l\nu l\nu$
  - Multi-variate analysis with 4 discriminating variables (m_{ll}, $\Delta\phi_{ll}$, p_T^{ll}, m_T)

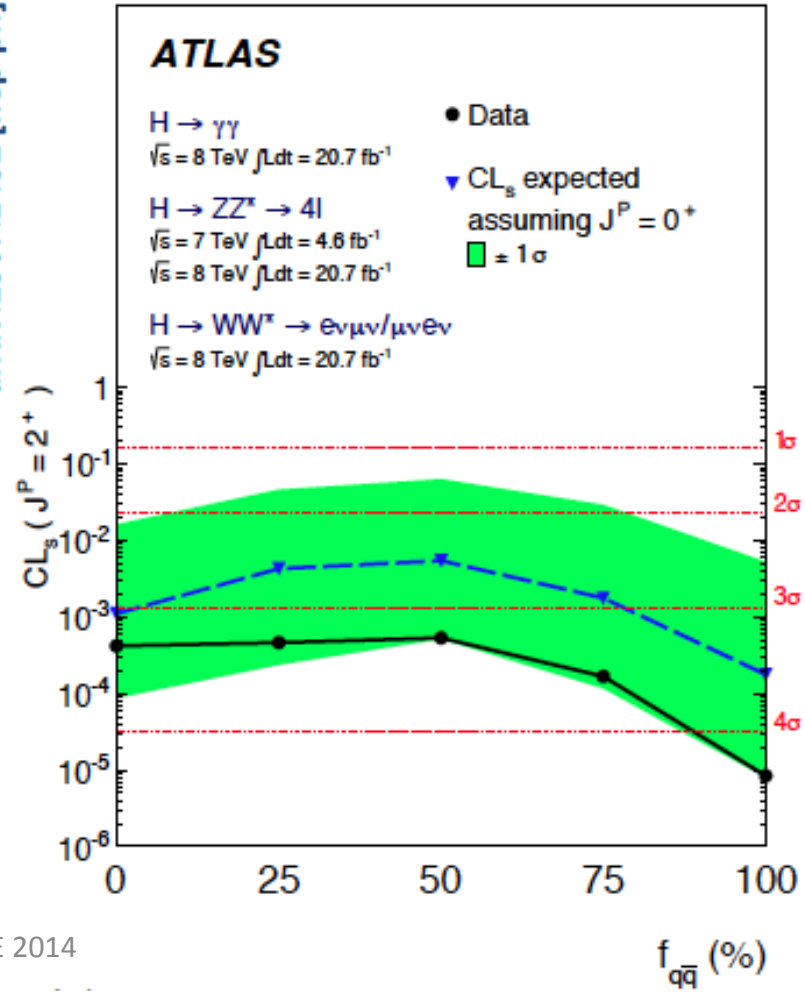
Spin and parity results

Expected / observed CL_S for the test of hypotheses alternative to the SM 0+
Green bands are the 68% expected exclusion range, given a 0+ signal
All channels combined

Scan of the qq production fraction for the 2+ case



arXiv:1307.1432 [hep-ph]



Couplings fit

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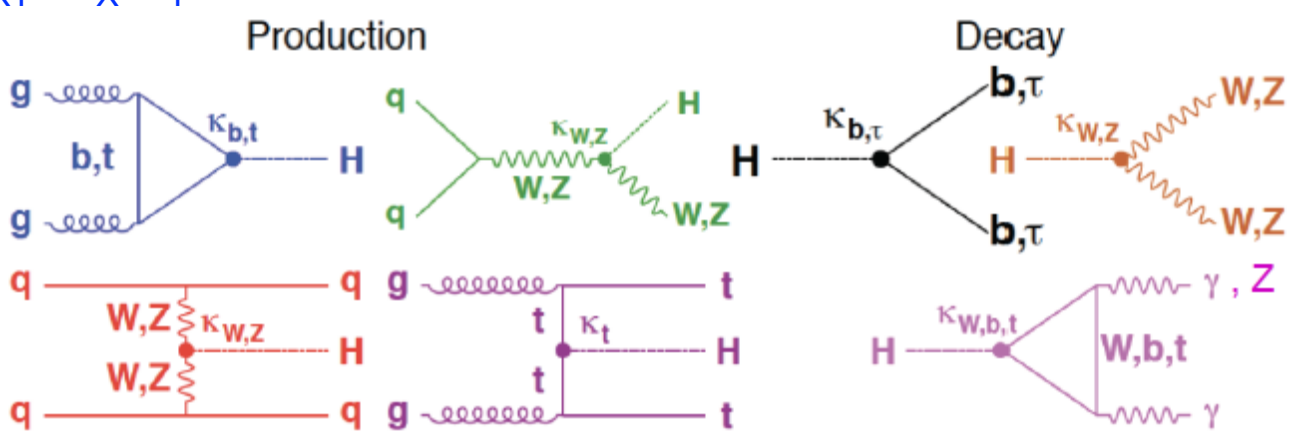
- Assume spin-0, CP-even coupling structure, in small-width approximation:
  - $\sigma(XX \rightarrow H) \bullet BR(H \rightarrow YY) \sim \Gamma_X \Gamma_Y / \Gamma_H$
- Fit deviations from the SM of the couplings strengths, assuming all observations come from the same resonance
- Assume a model, e.g. universal couplings to fermions, bosons:
  - $K_F = K_t, K_b, K_\tau$
  - $K_V = K_Z, K_W$
- Couplings scale ratios independent from assumptions on total width:
  - $\lambda_{XY} = K_X / K_Y$



Results

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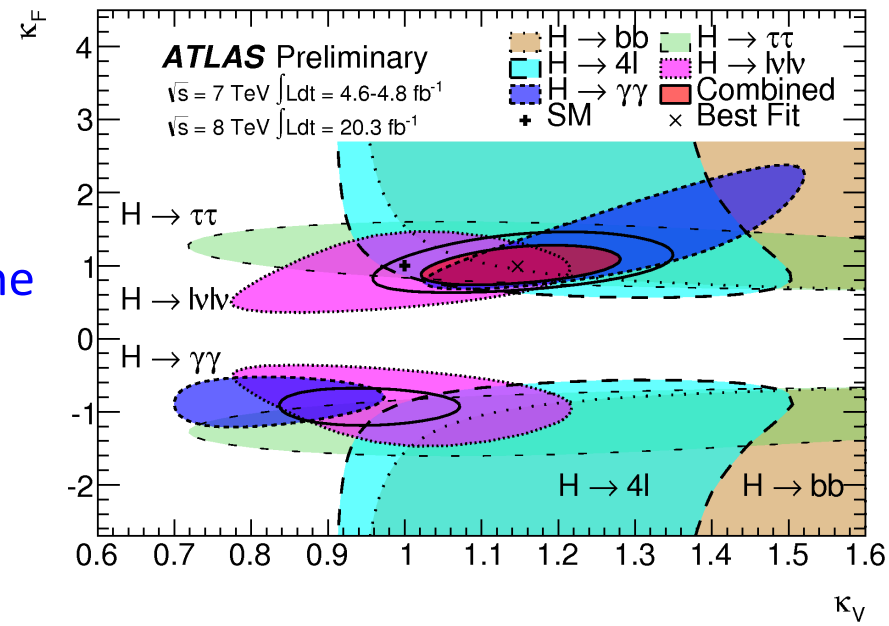
Fit of the universal vector bosons and fermion couplings (K_V, K_F)

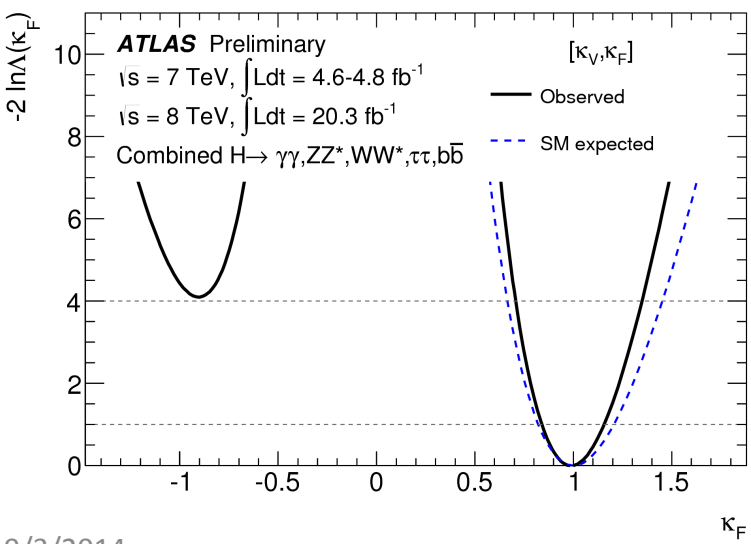
Sensitivity to the sign of K_F only from $H \rightarrow \gamma\gamma$

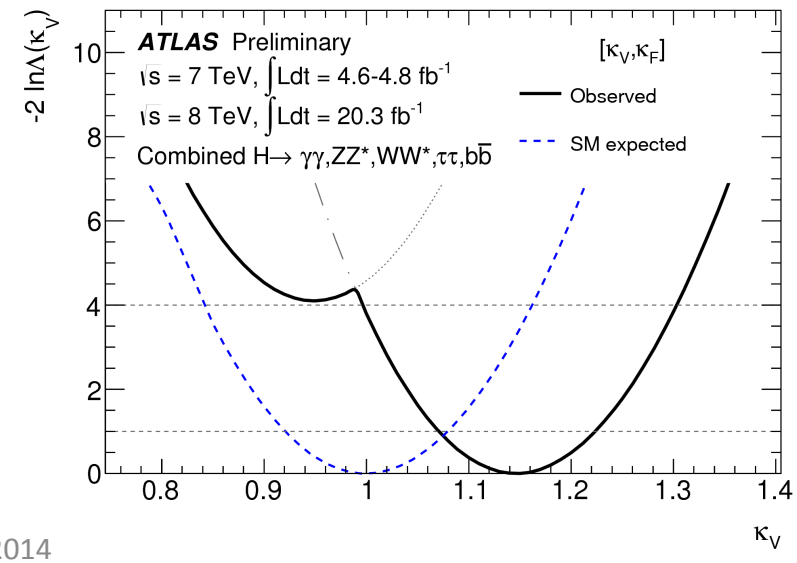
- Interference between W and t loops in the decay diagram

K_F=0 excluded at >5σ level

More details in the poster by A. Gabrielli



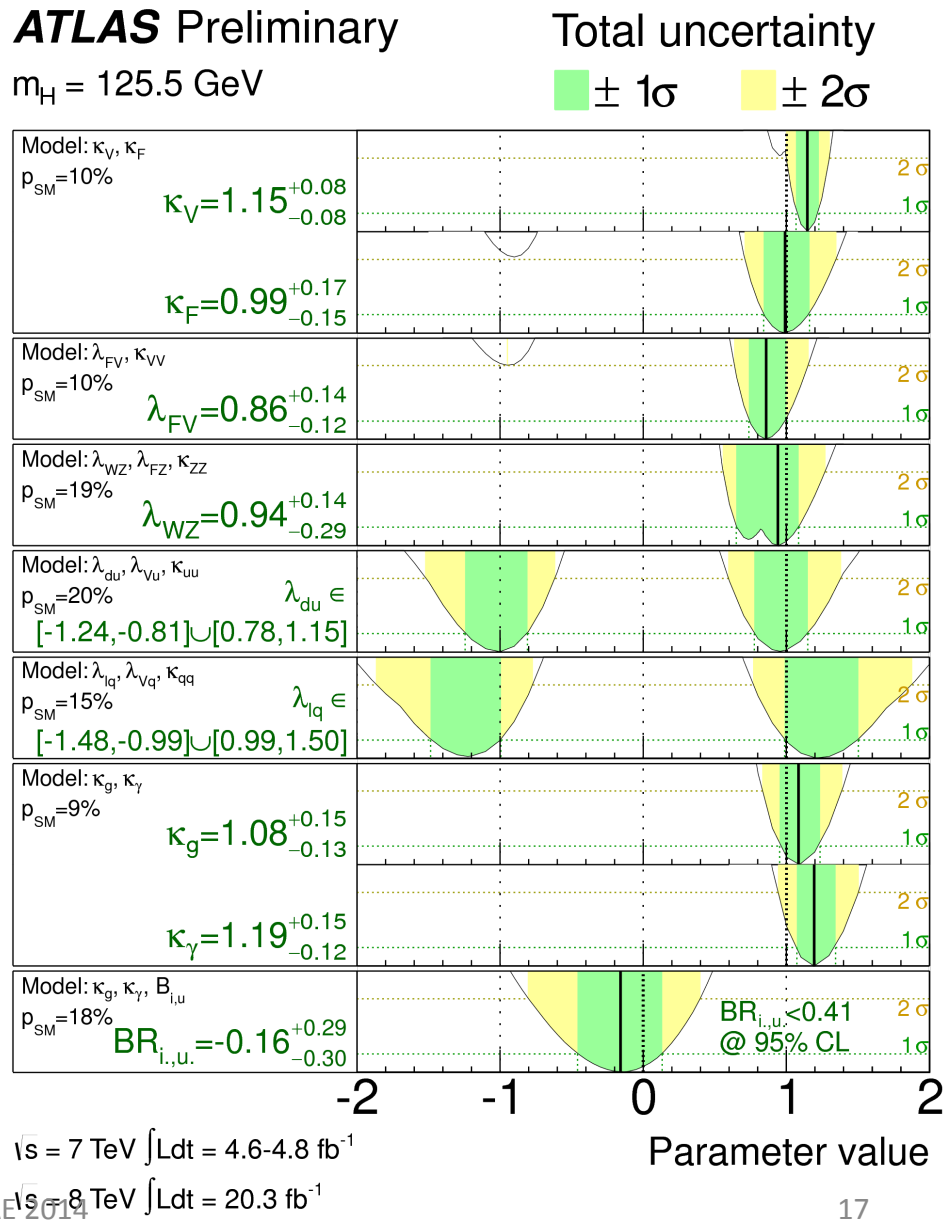




Couplings fit summary

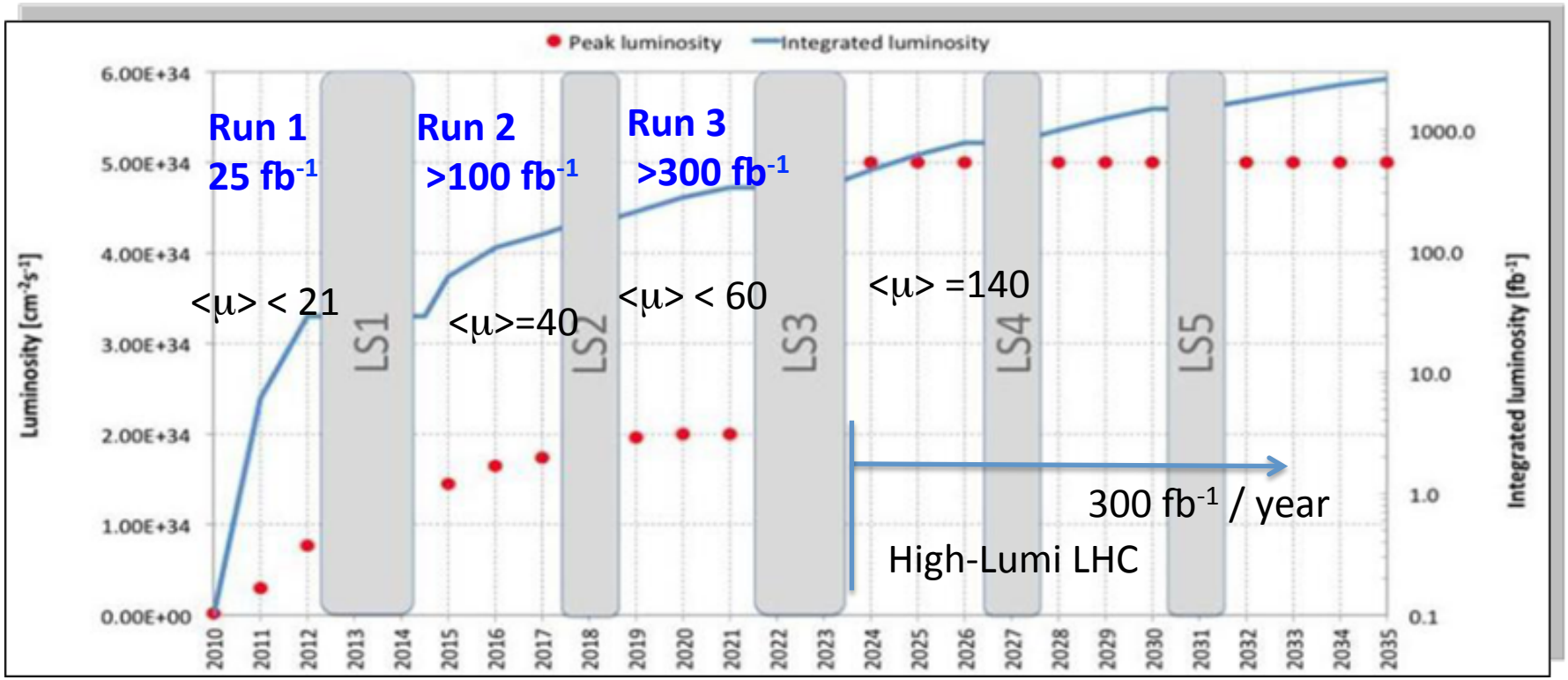
Results can be interpreted in different benchmark models:

- The K_V, K_F can be constrained at the ~10-15% level
- $\lambda_{WZ} = 0.94^{+0.14}_{-0.29}$
  - Model-independent Test of the custodial simmetry
- BR (inv. / undetected) < 0.41 @95% C.L.
- Recently added: fermionic channels
- All results are consistent with the SM



Prospects for the next runs

LHC Plans



Conditions at the start of Run 2 are defined:
$L=1.6*10^{34}$ cm^{-2}s^{-1}
(2508 bunches, 25 ns)

- Run1 7-8 TeV
- Run2 and Run3 data taking at 13-14 TeV
- <μ> is the average number of interactions per BC

Higgs Physics at 13-14 TeV

- Int lumi x10 and signal cross section x2.5
  - Precision measurements of Higgs production and decay rates, mass and couplings
  - Couplings tensor structure and CP-violating terms
  - Search for additional BSM Higgs
- ATLAS has built results projections for Run-2, Run-3, and HL-LHC
- Detector response via a parametrization derived from:
  - Run-1 fullsim samples with pileup up to $<\mu>=69$, updated with fullsim of the Phase-1 and Phase-2 detectors for $<\mu>$ up to 80-140.
- Analyses similar to Run-1, with some modification and optimization for higher lumi
- Details in the ECFA-Workshop documents:
  - ATLAS-PHYS-PUB-2013-13
    ATLAS-PHYS-PUB-2013-14

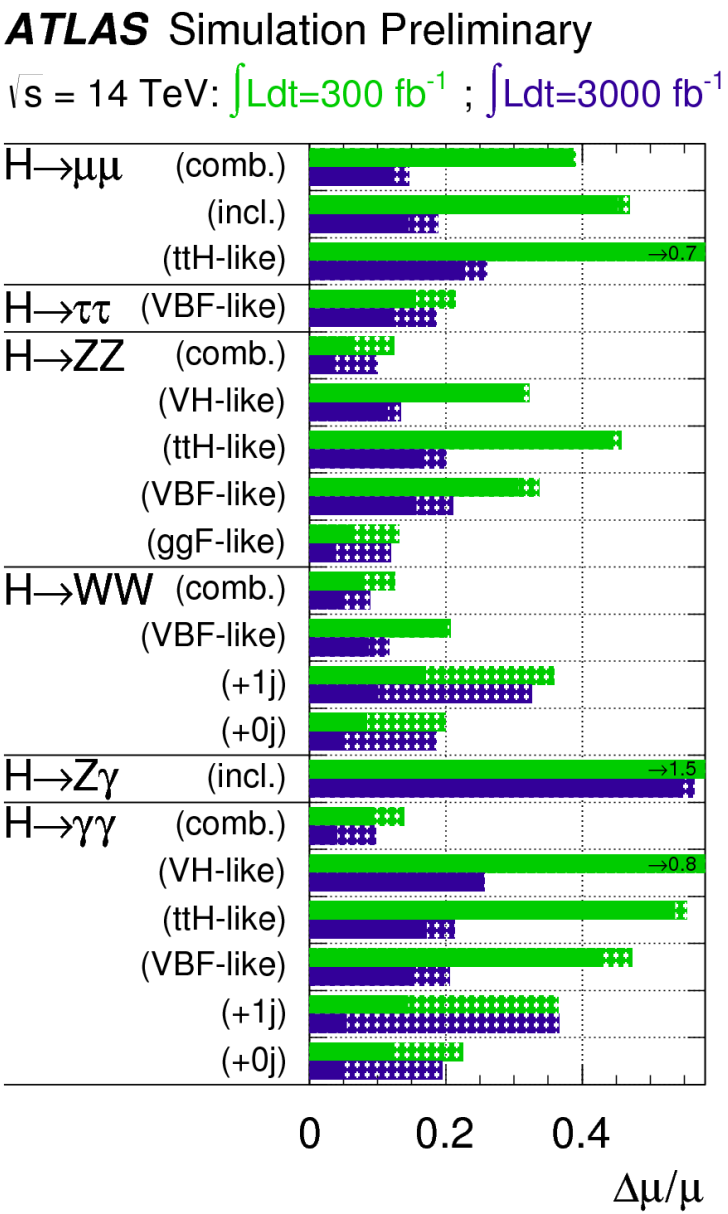
Signal strengths with 300 fb^{-1}

ECFA Workshop
ATLAS-PHYS-PUB-2013-014

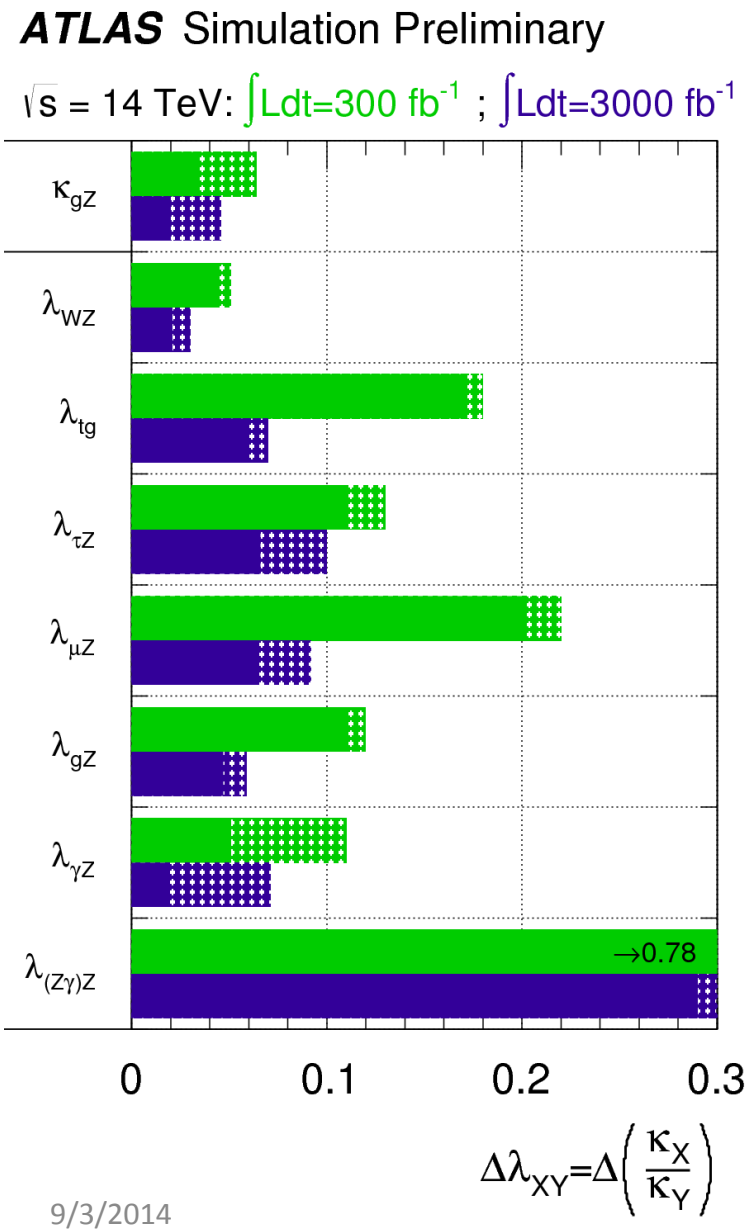
- Systematics as in Run 1, with and without theory errors

Relative errors on signal strenghts with 300 fb^{-1}

Channel	$\Delta\mu/\mu$ (%)	$\Delta\mu/\mu$ (%) (no th err)
$\gamma\gamma$	14	9
ZZ	12	6
WW	13	8
$\tau\tau$	22	16
$\mu\mu$	39	38
$Z\gamma$	147	145



Couplings ratios



Generic test of a fit to coupling ratios: $\lambda_{XY}=K_X/K_Y$

No assumption on the total width

Many theory and experimental uncertainties cancel in the ratio

Relative uncertainties range from 4 to 18% with 300 fb^{-1}

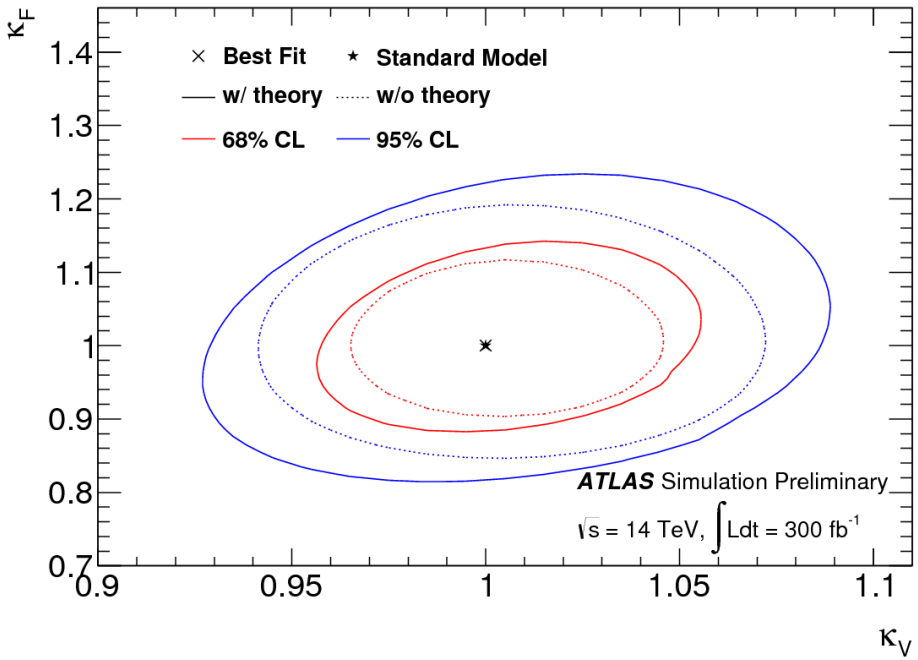
Improvement by more than a factor 2 with 3000 fb^{-1}

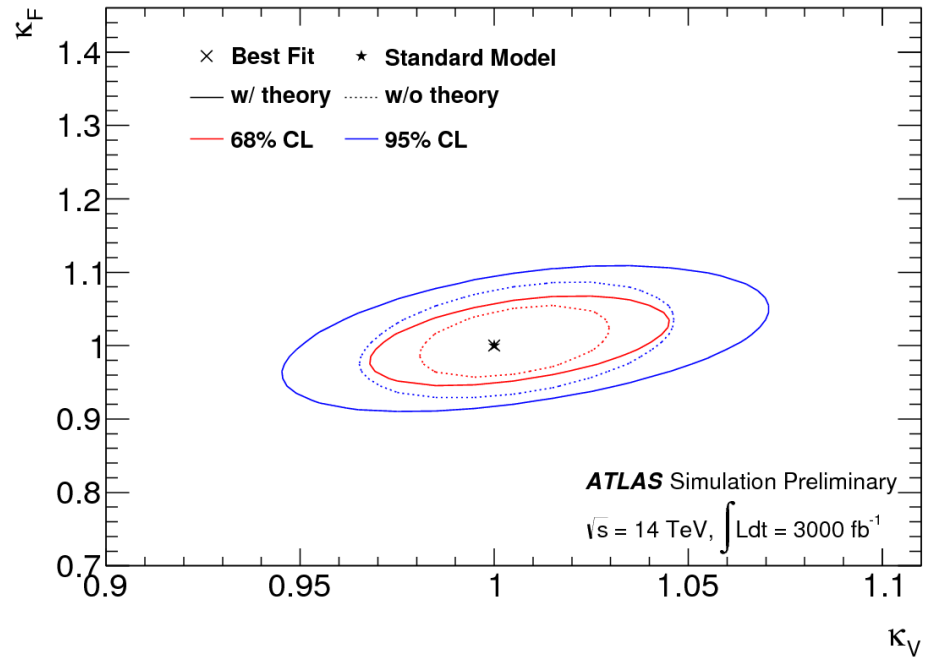
➔ Uncertainties from 1.5 to 9%

ATLAS-PHYS-PUB-2013-014
ECFA WS

Couplings prospects

ATLAS-PHYS-PUB-2013-014





- Fit of the universal couplings K_V, K_F
- About 5% - 10% precision reachable in the fit to fermions and vector bosons couplings
- **~2.5%** and **~7%** uncertainties on K_V, K_F with 300 fb^{-1}
- Becoming **~1.5%** and **~3%** with 3000 fb^{-1}

BSM extensions of the Higgs sector lead to ~1%-10% effects on the couplings (e.g. extra EW singlet, 2HDM)

Higgs couplings tensor structure

Most general amplitude describing a Spin-0 particle with arbitrary parity decay to vector bosons

$$A(X \to VV) = v^{-1}\left(g_1^{(0)} m_V^2 \epsilon_1^* \epsilon_2^* + g_2^{(0)} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + g_3^{(0)} f^{*(1),\mu\nu} f_{\mu\alpha}^{*(2)} \frac{q_\nu q^\alpha}{\Lambda^2} + g_4^{(0)} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}\right)$$

CP-even
SM tree level

CP-even
Loop-induced

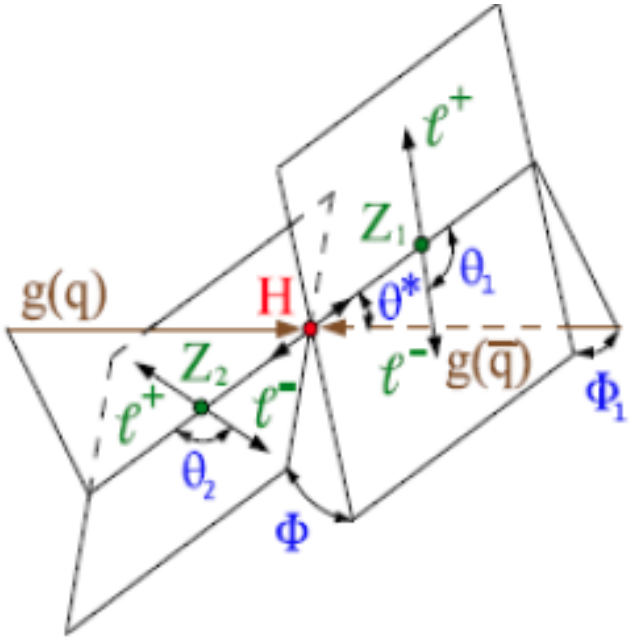
CP-even
Loop-induced

SM: g1=1 , test for anomalous CP admixtures

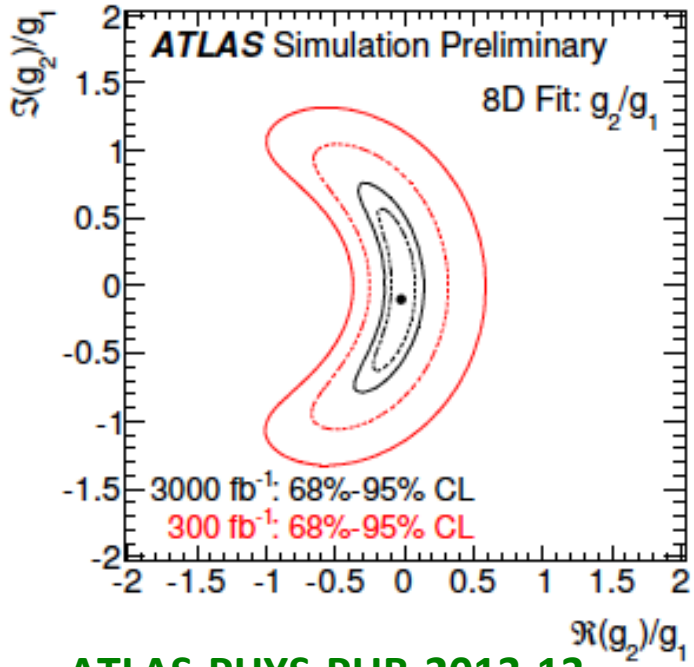
ME analysis of the coupling structure:

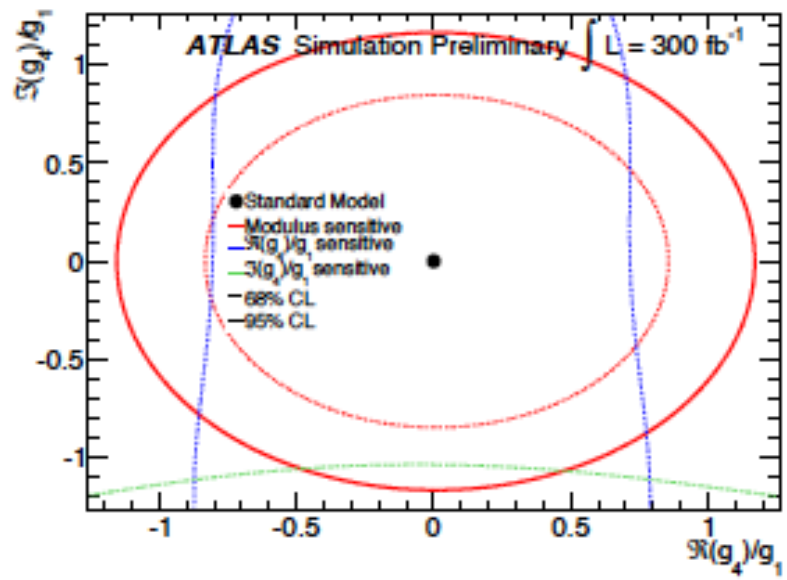
- Fit optimal ME ratios
- 8D fit of angular and mass variables

(see the posters by G. Grossi and G. Gustavino for more details)



CP mixing expected limits





ATLAS-PHYS-PUB-2013-13

Luminosity	$\lvert g_4\rvert/g_1$	$\Re(g_4)/g_1$	$\Im(g_4)/g_1$	$\lvert g_2\rvert/g_1$	$\Re(g_2)/g_1$	$\Im(g_2)/g_1$
300 fb^{-1}	1.03	(-1.01, 1.01)	(-1.02, 1.02)	1.39	(-0.88, 0.38)	(-1.13, 1.13)
3000 fb^{-1}	0.49	(-0.34, 0.26)	(-0.34, 0.48)	0.81	(-0.33, 0.11)	(-0.73, 0.75)

Expected 95% C.L. limits

Sensitivity to 10%-20% CP-violating admixture with Run2 – Run3

Factor 2-3 improvement with 3000 fb-1

Conclusions

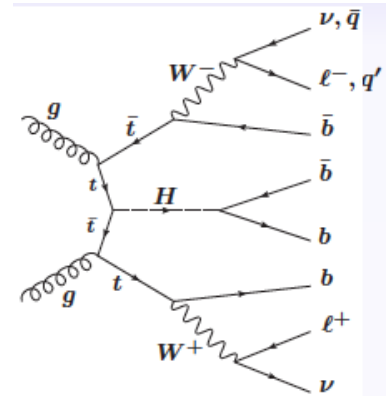
- Summary of the most recent Higgs results of the ATLAS experiment
  - First direct evidence of the Higgs decay to fermions in the $\tau\tau$ channel
  - Mass and couplings
  - Spin and parity
- Prospects for future LHC runs
  - With 300 fb^{-1} (3000 fb^{-1})
  - Constraints on couplings in various models
  - Limits on CP mixing couplings

Backup Slides

Search for ttH, H→bb

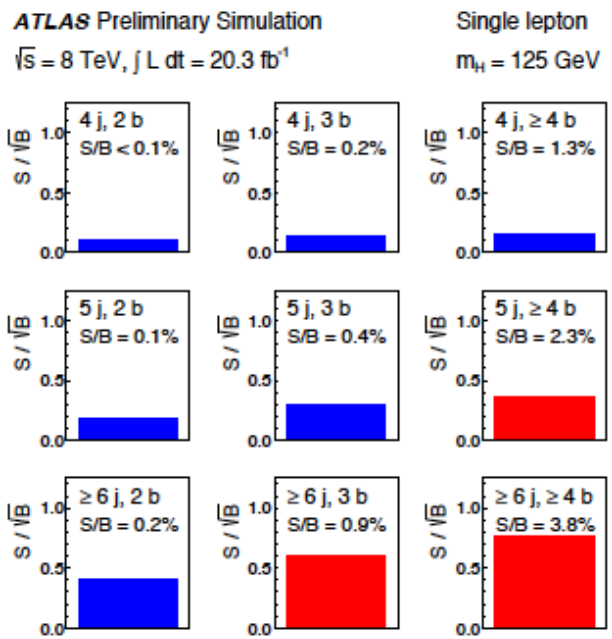
ATLAS-CONF-2014-011

- Direct measurement of the top-Higgs Yukawa coupling via ttH production
- Look at two final states:
  - l+jets: 1 e or μ and 4 to ≥6 jets and 2 to ≥4 b-jets
  - Di-lepton: 2 opposite-sign leptons (e,μ) and 2 to ≥4 jets and 2 to ≥4 b-jets

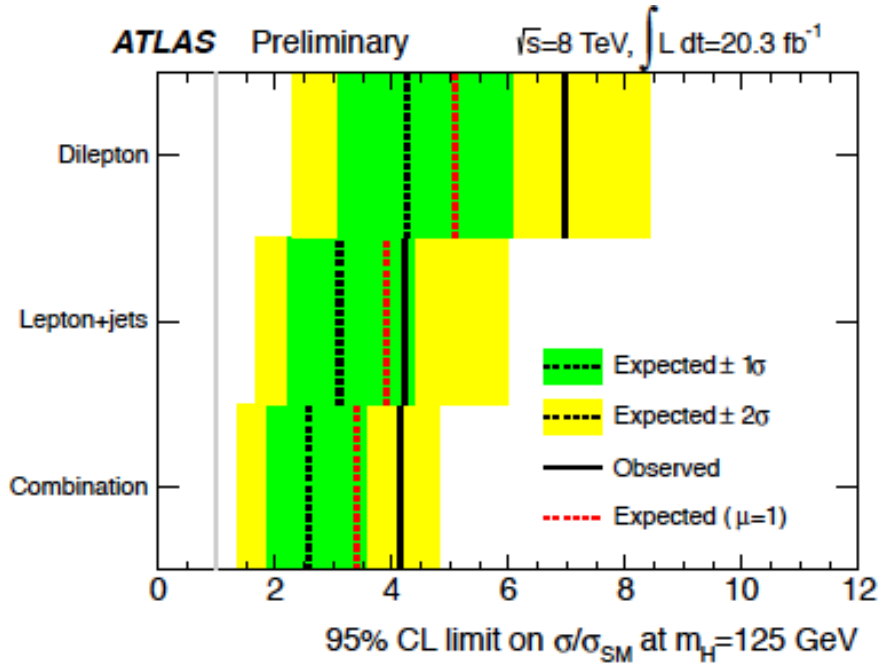


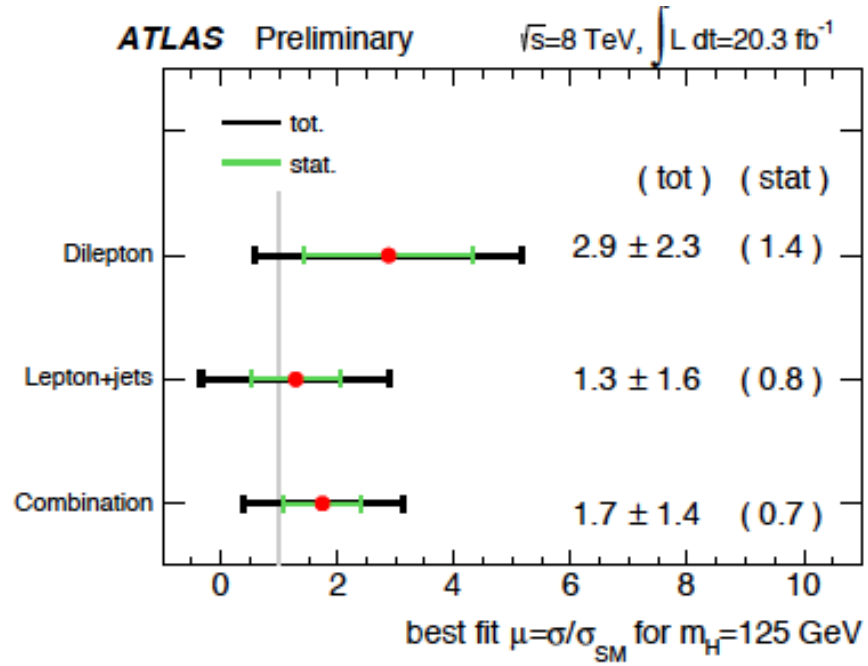
Cut-based selection for the signal

- Main background after the selection is ttbar+jets



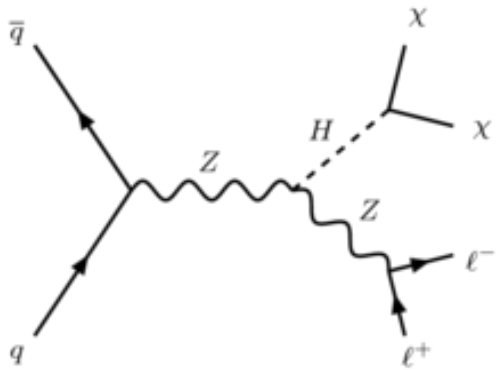
Results on ttH, H→bb





- 95% CL limit on σ/σ_{SM} is **4.1 observed, 2.6 expected**

Search for invisible decays



- Look for invisible decay in associated production, with Z→ll
- Upper limits can be set on the invisible decay BR: BR < 75% @95% C.L. (expected 62%) assuming SM 125.5 GeV Higgs
- The limit can be interpreted in the framework of the Higgs-portal DM scenario

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