Constraints on new phenomena through Higgs coupling measurements with the ATLAS detector

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references and background information

Update of ATLAS-CONF-2014-010 (Moriond 2014): https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2014-010/

Based on SM Higgs coupling paper

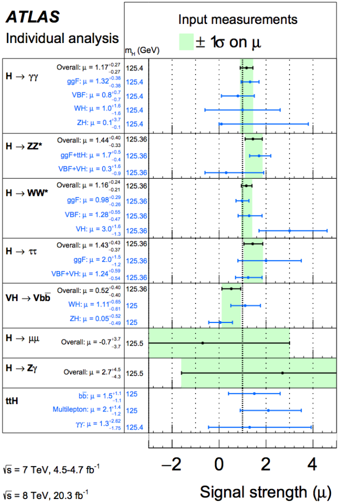
Using 7 and 8 TeV data

Mass measured: $m_H = 125.36$ GeV

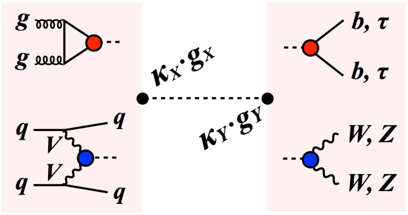
Global signal strength measured: $\mu = 1.18^{+0/15}_{-0.14}$

Couplings of the Higgs boson to fermions and vector bosons depend on parameters of the BSM theory to be probed

- Measurement of H boson coupling strengths
- $H \to$ *invisible*



framework



Production X Decay Y

Narrow width approximation

$\sigma x BR(i \rightarrow H \rightarrow f) = \frac{\sigma_X \cdot \Gamma_Y}{\Gamma_H}$

Production	Decay	Width
$\kappa_X^2 = \frac{\sigma_X}{\sigma_X^{SM}}$	$\kappa_Y^2 = \frac{\Gamma_Y}{\Gamma_Y^{SM}}$	$\kappa_H^2 = \frac{\sum \kappa_Y \Gamma_Y^{SM}}{\Gamma_H^{SM}}$

$\mu = \frac{N_{obs}}{N_{exp}} = \frac{\kappa_X^2 \cdot \kappa_Y^2}{\kappa_H^2}$

- Deviations from SM Higgs parametrised using scaling factors κ (SM: $\kappa = 1$)
- Couplings are then re-expressed in terms of BSM parameters in each model
- Fit all κ simultaneously (assume fixed Γ_H)
- Interference in H $\rightarrow \gamma\gamma$, gg$\rightarrow$H, ... which can cause some sign-ambiguities

Mass scaling

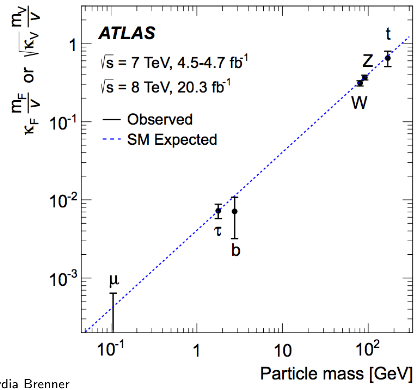
Parameterise vector and fermion couplings via mass scaling deviation ϵ and M (vev)

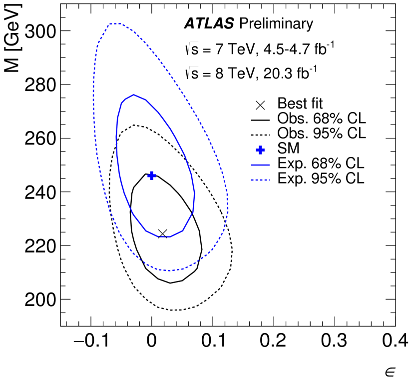
$$\kappa_{V,j} = v\frac{m_{V,j}^{2\epsilon}}{M^{1+2\epsilon}},\ \kappa_{f,j} = v\frac{m_{f,j}^{\epsilon}}{M^{1+\epsilon}}$$

SM: $\epsilon = 0,\ M = v$

$\epsilon = 0.018 \pm 0.039$ (obs)
$\epsilon = 0.000 \pm 0.042$ (exp)

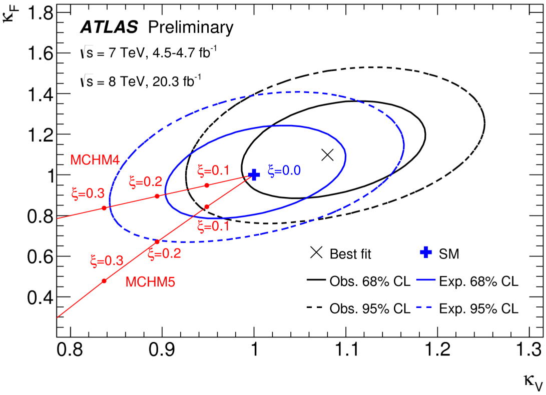
$M = 224^{+14}_{-12}$ (obs)
$M = 246^{+19}_{-16}$ (exp)





Higgs boson compositeness

- Higgs as a composite, pseudo Nambu-Goldstone boson could resolve hierarchy problem
- Modifications to tree-level couplings as a function of compositeness scale f in different minimal composite Higgs models
- $\xi = v^2/f^2$ where f is the Higgs compositeness scale
- SM: $\xi \to 0, f \to \inf$

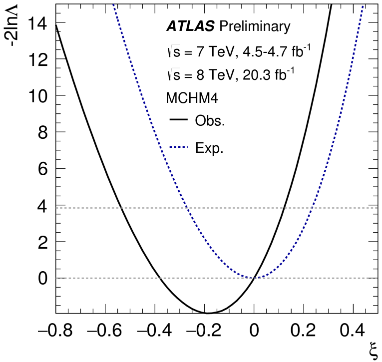


Minimal Composite Higgs Model (MCHM)

Model	Observed	Expected
MCHM4	> 710 GeV	> 510 GeV
MCHM5	> 780 GeV	> 600 GeV

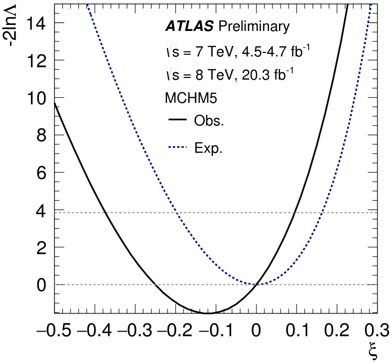
MCHM4

$\kappa_V = \kappa_F = \sqrt{1-\xi}$



MCHM5

$\kappa_V = \sqrt{1-\xi}, \kappa_F = (1-2\xi)/\sqrt{1-\xi}$



Additional electroweak singlet

- Simplest extension of the SM Higgs sector: heavy, real singlet
- Spontaneous symmetry breaking: two CP-even Higgs bosons

Light Higgs h

- SM decay modes
- $\mu_h = \frac{\sigma_h \times BR_h}{(\sigma_h \times BR_h)_{SM}} = \kappa^2$

Heavy Higgs H

- New non-SM decay modes such as $H \to hh$, parametrised by $BR_{H,new}$
- $\mu_H = \frac{\sigma_H \times BR_H}{(\sigma_H \times BR_H)_{SM}} = \kappa'^2(1 - BR_{H,new})$

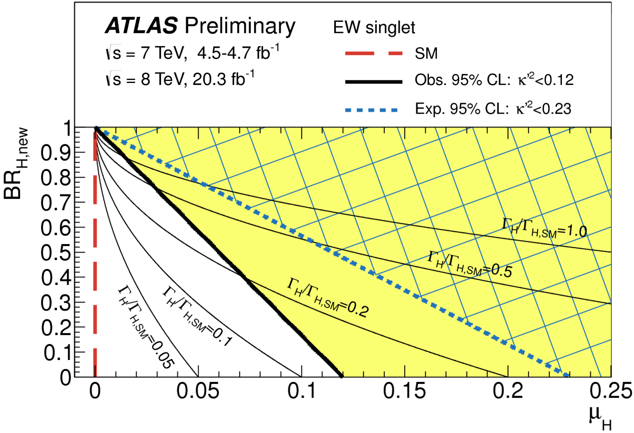
Coupling of Higgs to SM particles for h and H proportional to SM couplings, but reduced by κ and κ', implying $\kappa^2 + \kappa'^2 = 1$

Indirect constraint on heavy Higgs boson coupling from signal strength of light boson: $\kappa'^2 = 1 - \mu_h$

Additional electroweak singlet

Light Higgs signal strength (ignoring boundary): $\mu_h = 1.18 \pm 1.15$

Coupling	Observed	Expected
κ'^2	< 0.12	< 0.23



Two Higgs doublet models

- Additional EW doublet
- Five Higgs bosons: two CP-even bosons h and H,one neutral CP-odd boson A, two charged bosons $H^{\pm}$
- Discovered particle is the light CP-even neutral Higgs boson h
- Described by six parameters: the four masses, the ratio of the vacuum expectation values ($tan\beta = \frac{v_1}{v_2}$) and the mixing angle α of the two neutral, CP-even Higgs states.
- Gauge invariance fixes couplings of the two neutral, CP-even Higgs bosons to vector bosons: $\frac{g_{hVV}^{2HDM}}{g_{hVV}^{SM}} = sin(\beta - \alpha)$, $\frac{g_{HVV}^{2HDM}}{g_{HVV}^{SM}} = cos(\beta - \alpha)$
- Four 2HDM types

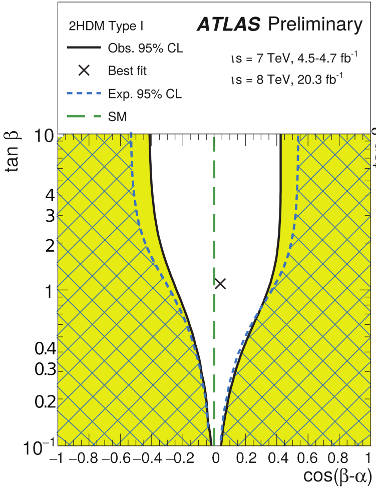
Coupling	Type I	Type II	Lepton specific	Flipped
κ_u	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
κ_d	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
κ_ℓ	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$

2HDM: Type I and II

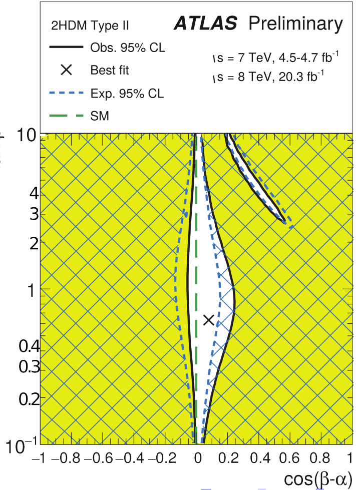
- Data prefers SM alignment limit at $cos(\beta - \alpha) = 0$

Inverted sign of the coupling to down-type fermions causes wing.

THDM-I



THDM-II

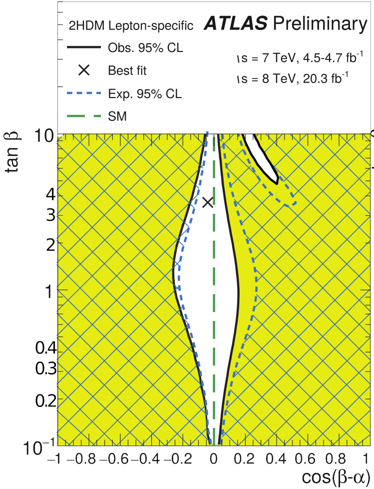


2HDM: Lepton-specific and Flipped

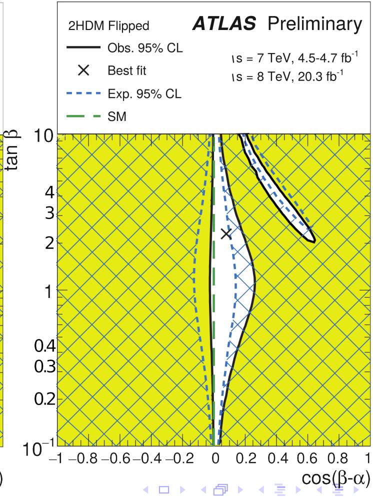
- Data prefers SM alignment limit at $cos(\beta - \alpha) = 0$

Inverted sign of the coupling to leptons or bottom quarks causes wings.

Lepton-specific



Flipped



Simplified MSSM

- Supersymmetry provides a natural solution to the hierarchy problem and Dark Matter

The made assumptions are:

- Simplified means the same decay modes as for the SM Higgs boson
  - No Higgs boson decays to supersymmetric particles, heavy Higgs boson decays to lighter ones
- Neglecting loop corrections from stops in gluon fusion production and di-photon decays
- Assume universality of the down-type fermion couplings: $\kappa_b = \kappa_\tau$
- Measured Higgs mass used to express couplings (k_V, k_u, k_d) in terms of m_A and $tan\beta$: $\kappa_b = \kappa_\tau = \kappa_\mu$

Simplified MSSM

Indirect limit from Higgs couplings only:

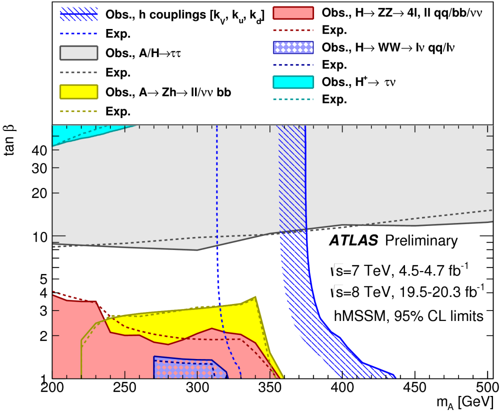
- For $1 < tan\beta < 50$, $m_A > 370$ GeV (290 GeV) at 95% CL
- hMSSM not valid below $tan\beta < 1$

Overlay of direct and indirect limits

$$\kappa_V = \frac{s_d(m_A, tan\beta) + tan\beta\, s_u(m_A, tan\beta)}{\sqrt{1 + tan^2\beta}}$$

$$\kappa_u = s_u(m_A, tan\beta)\frac{\sqrt{1 + tan^2\beta}}{tan\beta}$$

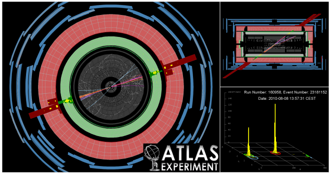
$$\kappa_d = s_d(m_A, tan\beta)\sqrt{1 + tan^2\beta}$$



Higgs to invisible

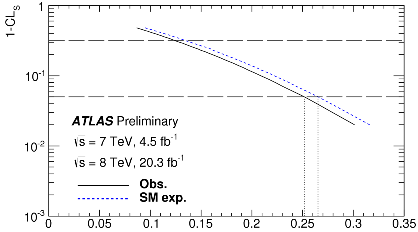
Direct searches via Missing E_T:

- VBF, h → inv. *ATLAS-CONF-2015-004*
- Z(ll)h(inv) *PRL 112, 201802 (2014)*
- V(jj)h(inv) *arXiv:1504.04324*



Limits set on BR(h → inv)

	Observed	-2σ	-1σ	Expected	$+1\sigma$	$+2\sigma$
VBF h	0.28	0.17	0.23	0.31	0.44	0.60
Z(→ll)h	0.75	0.33	0.45	0.62	0.86	1.19
Z(→jj)h	0.78	0.46	0.62	0.86	1.19	1.60
Combined Results	0.25	0.14	0.19	0.27	0.37	0.50

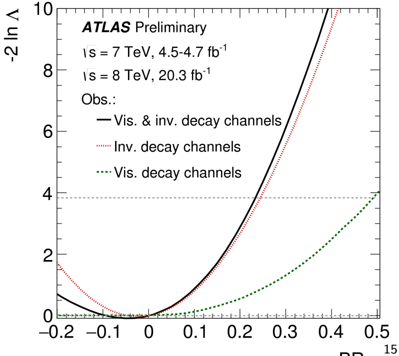


Combination visible and invisible

- Direct searches assume $\kappa_i = 1$
- Coupling assumes κ_v and κ_F

	best-fit obs	best-fit exp	$+2\sigma$ obs	$+2\sigma$ exp	95% CL obs	95% CL exp
baseline combination	-0.045	0	0.219	0.226	0.173	0.221
Direct searches only ($\kappa_i = 1$)	-0.022	0	0.259	0.257	0.238	0.252
Coupling measurements only (κ_V,κ_F,κ_γ,κ_g,$\kappa_{Z\gamma}$),($\kappa_V < 1$)	-	-	-	-	0.27	0.39

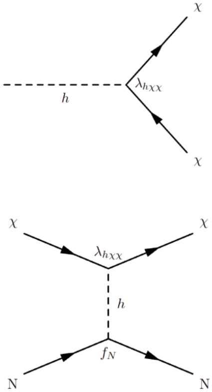
$$\Gamma_H(\kappa_i, BRinv) = \kappa_H(\kappa_i) * \frac{\Gamma_{SM}(H)}{1-BRinv}$$

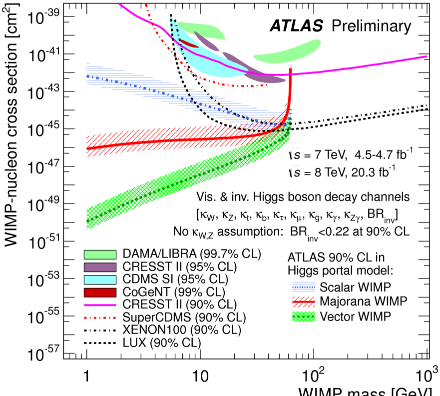


Higgs portal model

- Higgs portal model includes dark matter WIMP coupling to Higgs boson
- Set limit on BR_{inv} which are translated to the WIMP nucleon scattering cross-section
- Spin dependent; scalar, majorana or vector.

In Higgs Portal model, ATLAS limits are stringent for light ($m_\chi < m_{h/2}$) WIMPs



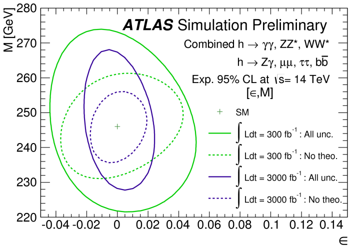


Summary and outlook

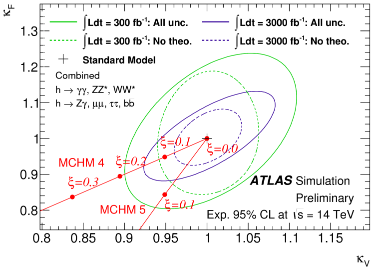
- Run-1 measurement of ATLAS of Higgs coupling strengths and indirect searches for invisible Higgs decays result in picture consistent with the SM Higgs boson within the present uncertainties.
- Interpretation of these measurements in various BSM models results in constraints on various BSM model parameters.
- Enhanced Higgs production in Run-2 and beyond will significantly improve these Higgs property measurements in the next years, that will result in more stringent limits on BSM physics.

Prospects are:

Mass scaling

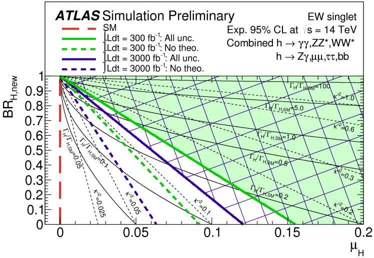


MCHM

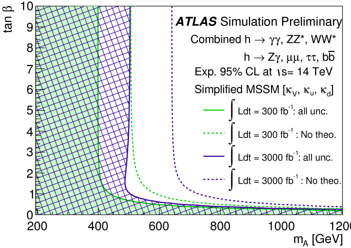


Summary and outlook

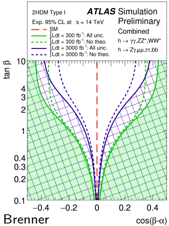
EW singlet



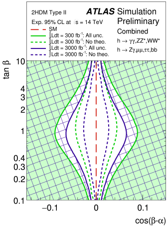
hMSSM



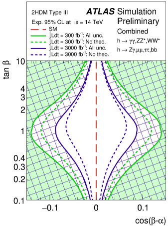
Type-I



Type-II



Lepton Specific



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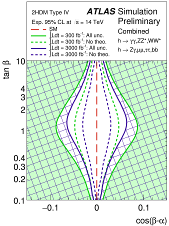

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Main differences with respect to Moriond 2014 CONF are

- Split of Zh associated production into gg→Zh (loop) and qq→Zh (tree level)
- Tree-level interference of single top associated production th
- Theoretical uncertainties updated to reflect latest LHXSWG recommendations
- Correlations of BR uncertainties couplings so neglected
  - Important only for HL-LHC where uncertainties much smaller, particularly on vector boson couplings