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

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on behalf of the ATLAS Collaboration

3rd International Conference on New Frontiers in Physics
Crete, August 2nd, 2014

Introduction

Indirect search for beyond-Standard-Model Higgs physics,
using measurements of the production and decay rates
of the 125 GeV Higgs particle.

- Probe of the SM prediction on the mass scaling of Higgs couplings.

Limits are set for the following models:

- Minimal Composite Higgs Models (MCHM)
- Additional electroweak singlet models
- Two-Higgs-Doublet Models (2HDMs)
- A simplified Minimal Supersymmetric Standard Model (MSSM)
- A Higgs portal to dark matter

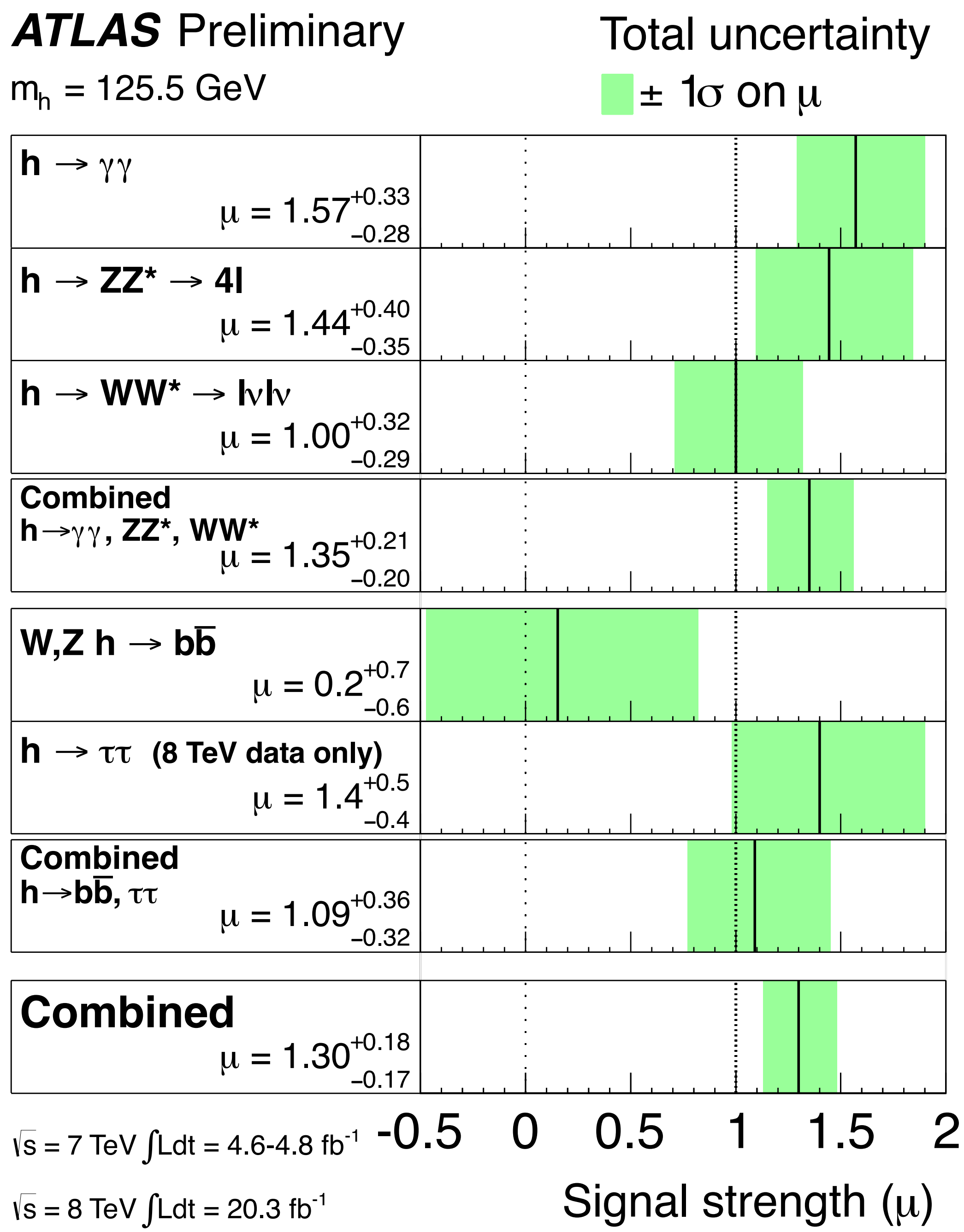
Input

ATLAS proton-proton collision data

- 4.8 fb^{-1} at $\sqrt{s}$ = 7 TeV
- 20.3 fb^{-1} at $\sqrt{s}$ = 8 TeV

Production and decay rates measurements in the following decay channels:

- $h \to \gamma\gamma$
- $h \to ZZ^* \to 4\ell$
- $h \to WW^* \to \ell\nu\ell\nu$
- $h \to \tau\tau$
- $h \to b\bar{b}$
- Upper limits on the rate for $Zh \to \ell\ell + E_{\mathrm{T}}^{\mathrm{miss}}$



Procedure

Confidence intervals and limits based on the profile likelihood ratio test statistic

$$t_{\alpha} = -2 \ln \Lambda(\alpha), \qquad \Lambda(\alpha) = \frac{L(\alpha\,, \hat{\hat{\theta}}(\alpha))}{L(\hat{\alpha}, \hat{\theta})}$$

Couplings parametrized using scale factors κ_i
relative to the SM values for m_h = 125.5 GeV.

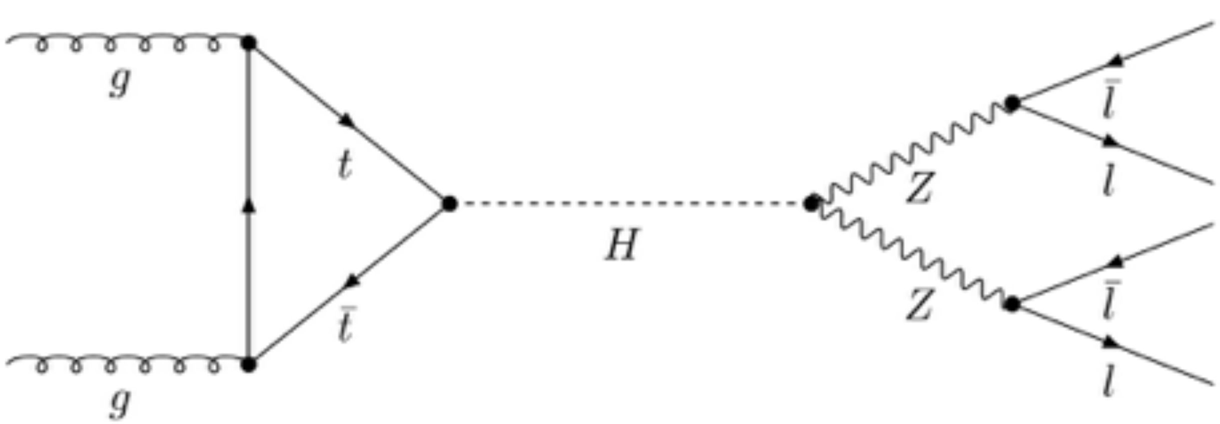
$$\kappa_i = \frac{g_i}{g_{i,SM}}$$

Process rates are parametrized as functions of κ_i
for example for $gg \to h \to ZZ^* \to 4\ell$

SM: $\kappa_i = 1$

$$\mu = \frac{\sigma \times \mathrm{BR}}{(\sigma \times \mathrm{BR})_{\mathrm{SM}}} = \frac{\kappa_g^2 \cdot \kappa_Z^2}{\kappa_h^2}$$

$$\kappa_h^2 = \sum_i \kappa_i^2 \mathrm{BR}_i$$



Mass Scaling of Couplings

Probe of the mass dependence of the Higgs boson couplings to other particles.

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

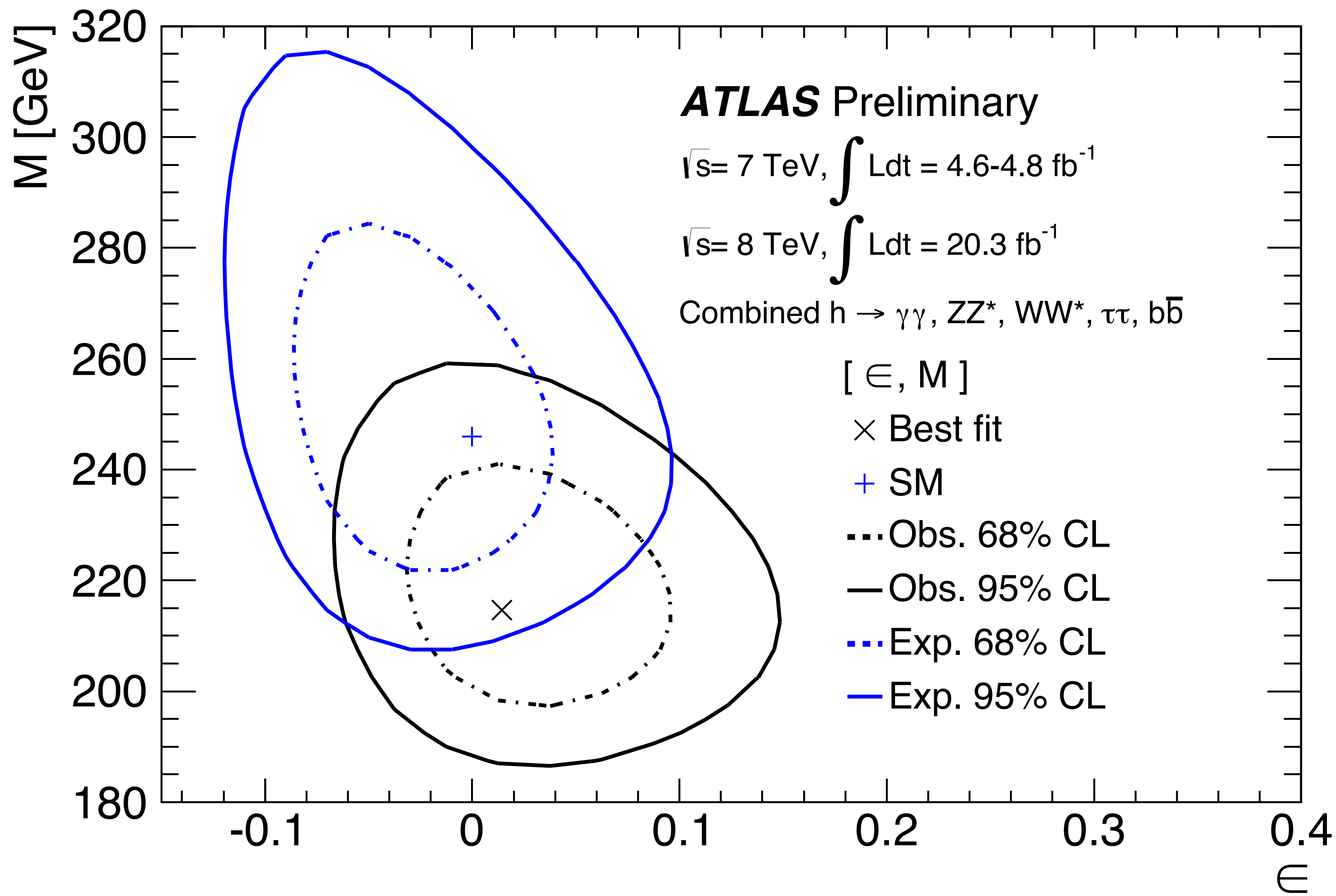
$v \approx 246$ GeV is the vacuum expectation value in the SM

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

Coupling measurements used:

κ_Z	$0.95^{+0.24}_{-0.19}$
κ_W	$0.68^{+0.30}_{-0.14}$
κ_t	$[-0.80, -0.50] \cup [0.61, 0.80]$
κ_b	$[-0.7, 0.7]$
κ_τ	$[-1.15, -0.67] \cup [0.67, 1.14]$

Mass Scaling of Couplings



Best fit compatible with the SM within 1.5 σ

Minimal Composite Higgs Model (MCHM)

In this model the Higgs boson is a composite, pseudo-Nambu-Goldstone boson rather than an elementary particle.

Couplings modified as a function of the Higgs boson compositeness scale f

$$\xi = v^2/f^2$$

SM: $f = \infty$
$\xi = 0$

MCHM4:

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

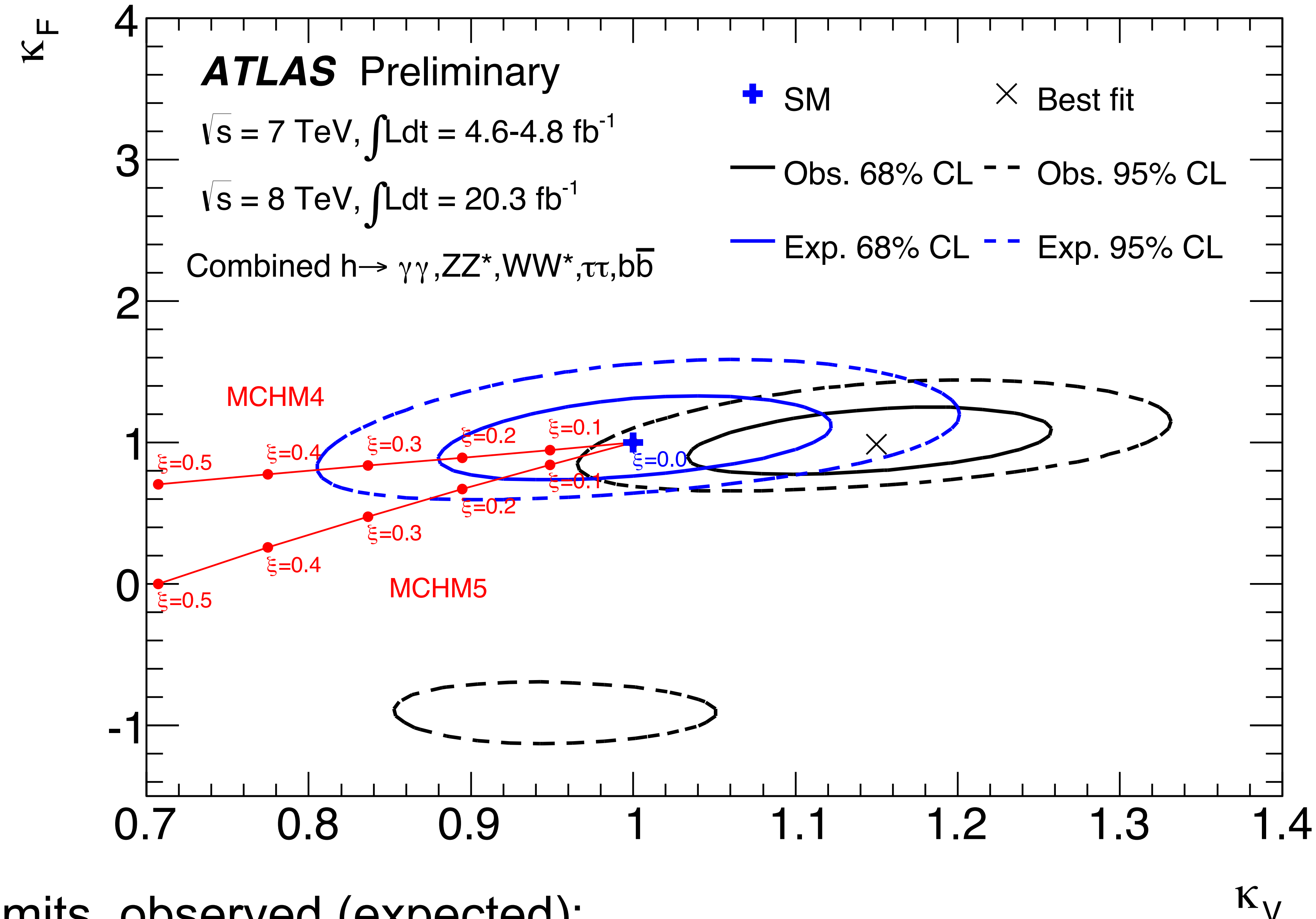
MCHM5:

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

$$\kappa_F = \frac{1-2\xi}{\sqrt{1-\xi}}.$$

μ_h	$1.30^{+0.18}_{-0.17}$
$\kappa = \sqrt{\mu_h}$	$1.14^{+0.09}_{-0.08}$
κ_V	1.15 ± 0.08
κ_F	$0.99^{+0.17}_{-0.15}$

Minimal Composite Higgs Model (MCHM)



95% CL limits, observed (expected):

MCHM4: $\xi < 0.12$ (0.29)

f > 710 GeV (460 GeV)

MCHM5: $\xi < 0.15$ (0.20)

f > 640 GeV (550 GeV)

Additional Electroweak Singlet

The addition of an EW singlet field results in two CP-even Higgs bosons *h* and *H*, with reduced signal strength by scale factors κ and κ'

$$\kappa^2 + \kappa'^2 = 1.$$

$$\mu_h = \frac{\sigma_h \times \mathrm{BR}_h}{(\sigma_h \times \mathrm{BR}_h)_{\mathrm{SM}}} = \kappa^2 \qquad \mu_H = \frac{\sigma_H \times \mathrm{BR}_H}{(\sigma_H \times \mathrm{BR}_H)_{\mathrm{SM}}} = \kappa'^2 (1 - \mathrm{BR}_{H,\mathrm{new}})$$

$$\kappa'^2 = 1 - \mu_h$$

μ_h	$1.30^{+0.18}_{-0.17}$
$\kappa = \sqrt{\mu_h}$	$1.14^{+0.09}_{-0.08}$

Additional Electroweak Singlet

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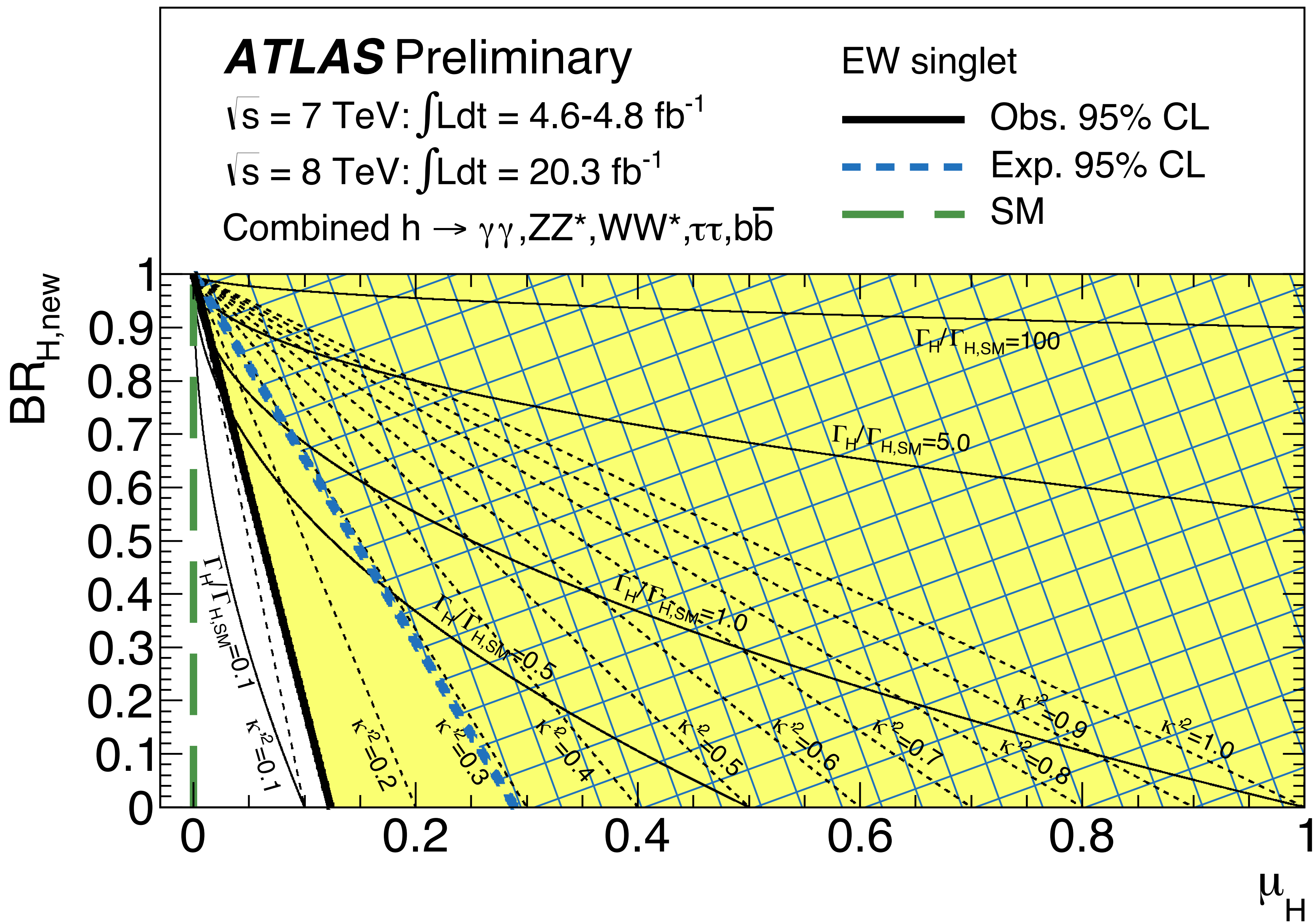


Two-Higgs-Doublet Model

SM Higgs sector is extended by an additional doublet.

2HDMs predict the existence of 5 Higgs bosons:

- 2 neutral CP-even bosons h and H,
- 1 neutral CP-odd boson A,
- 2 charged bosons $H^{\pm}$

Assuming CP conservation

2 Higgs doublets vacuum expectation values, v1 and v2

$$\tan\beta \equiv v_2/v_1 \qquad v_1^2 + v_2^2 = v^2 \approx (246\ \mathrm{GeV})^2$$

α: mixing angle of the two neutral CP-even Higgs states.

The couplings of the 2 neutral CP-even Higgs bosons to vector bosons are:

$$\begin{aligned} g_{hVV}^{\mathrm{2HDM}}/g_{hVV}^{\mathrm{SM}} &= \sin(\beta-\alpha) \\ g_{HVV}^{\mathrm{2HDM}}/g_{HVV}^{\mathrm{SM}} &= \cos(\beta-\alpha) \end{aligned}$$

Two-Higgs-Doublet Model

Type I: “Fermiophobic”

one doublet couple to vector bosons
the other to fermions

Type II: “MSSM-like”

one doublet couples to up-type quarks
the other to d-type quarks and leptons

Type III: “Lepton-specific”

the Higgs boson couple to quarks as type I
to leptons as type II

Type IV: “Flipped”

type III flipped

Coupling scale factor	Type I	Type II	Type III	Type IV
κ_V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
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	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$

2-Higgs-Doublet Model

ATLAS Preliminary

$\sqrt{s}$ = 7 TeV: $\int Ldt$ = 4.6-4.8 fb^{-1}

$\sqrt{s}$ = 8 TeV: $\int Ldt$ = 20.3 fb^{-1}

Combined $h \rightarrow \gamma\gamma, ZZ^*, WW^*$

$h \rightarrow \tau\tau, b\bar{b}$

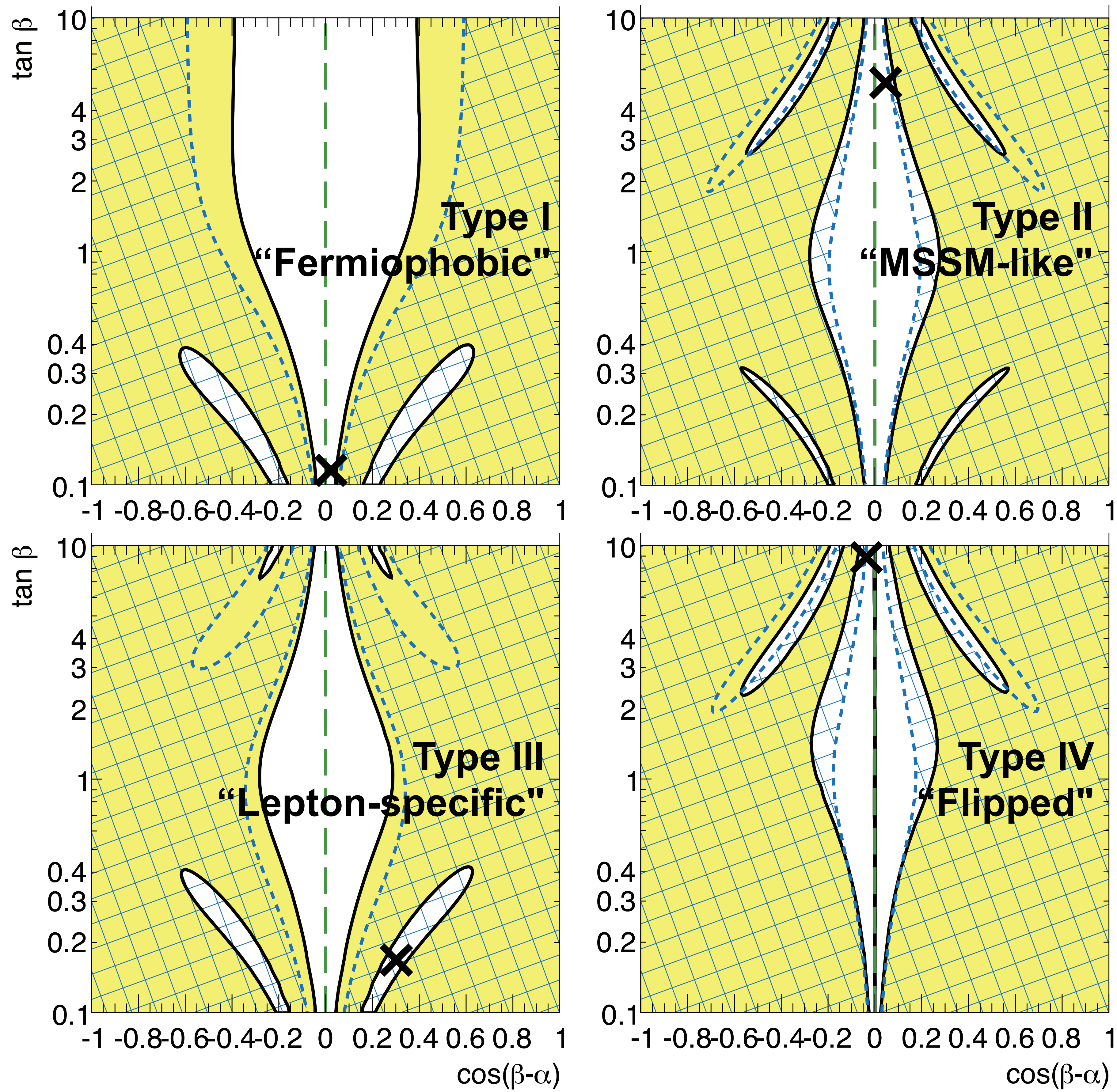
2HDM

Obs. 95% CL

Best fit

Exp. 95% CL

SM

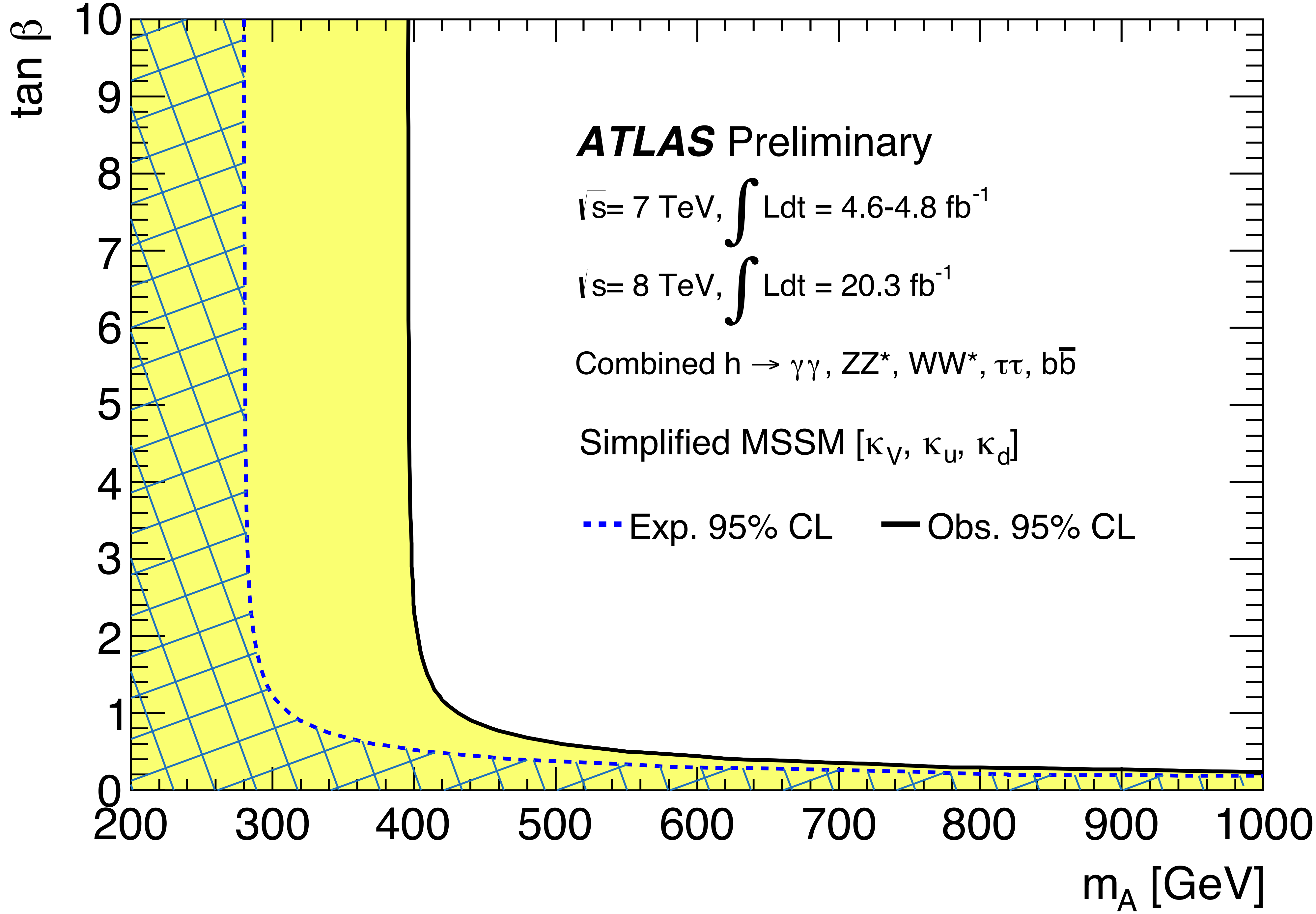


Simplified MSSM

The couplings can be determined from the mass mixing matrix of the neutral CP-even Higgs states, as a function of m_A and $\tan\beta$

$\lambda_{Vu} = \kappa_V/\kappa_u$	$1.21^{+0.24}_{-0.26}$
$\kappa_{uu} = \kappa_u^2/\kappa_h$	$0.86^{+0.41}_{-0.21}$
$\lambda_{du} = \kappa_d/\kappa_u$	$[-1.24, -0.81] \cup [0.78, 1.15]$

Simplified MSSM



Higgs Portal to Dark Matter

Many “Higgs portal” models introduce an additional weakly-interacting massive particle (WIMP)

κ_h^2 is a function of the branching ratio of the Higgs to invisible final states $\mathrm{BR}_{\mathrm{inv}}$

$$\kappa_h^2 = \Gamma_h/\Gamma_{h,\mathrm{SM}} = \sum_i \kappa_i^2/(1 - \mathrm{BR}_{\mathrm{inv}})$$

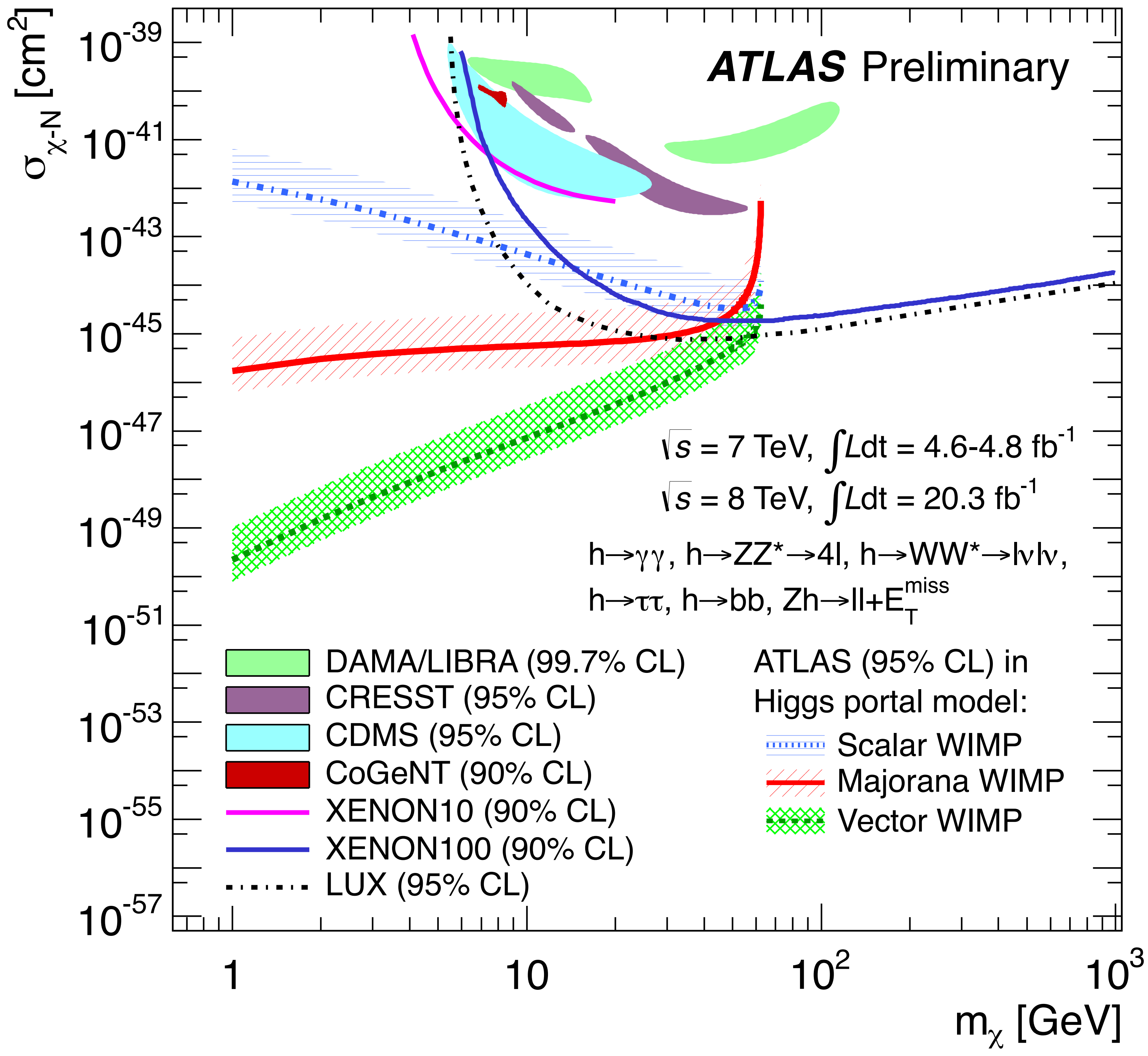
$\mathrm{BR}_{\mathrm{inv}}$ measured:

- without the limits on $Zh \to \ell\ell + E_{\mathrm{T}}^{\mathrm{miss}}$ $\quad -0.16^{+0.29}_{-0.30}$
- considering the limits on $Zh \to \ell\ell + E_{\mathrm{T}}^{\mathrm{miss}}$ $\quad -0.02 \pm 0.20$

95% CL limits, observed (expected): $\mathrm{BR}_{\mathrm{inv}} < 0.37\ (0.39)$

Higgs Portal to Dark Matter

Coupling re-parametrized in terms of the cross section for scattering between the WIMP and nucleons via Higgs boson exchange, $\sigma_{\chi - N}$



Conclusions

- No evidence for physics beyond the Standard Model is observed.
- The mass dependence of the couplings is consistent with the predictions for a SM Higgs boson.
- Constraints are set on various beyond-Standard-Model theories.
- More data is needed! Coming next year.

References

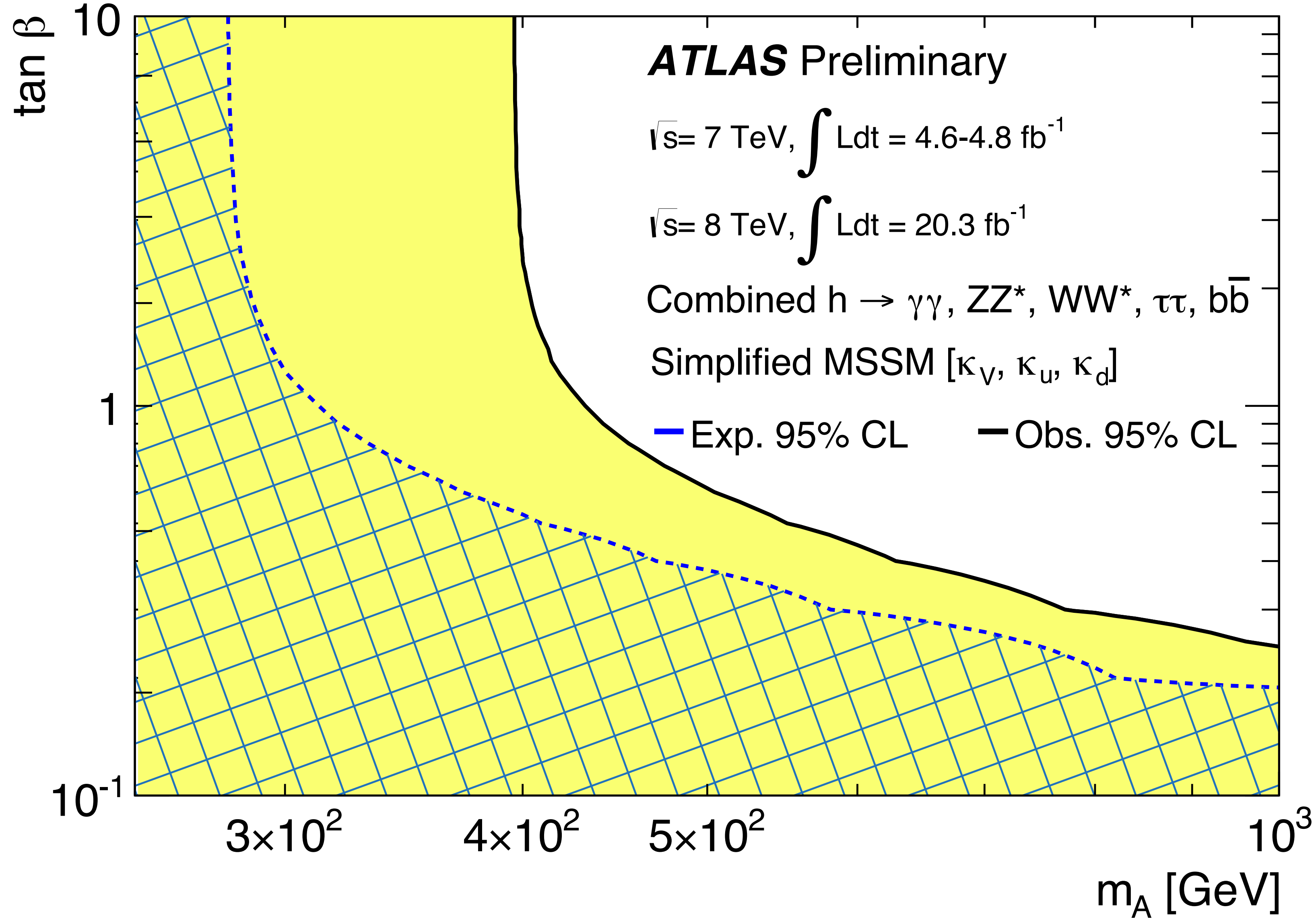
- ATLAS Collaboration, *Updated coupling measurements of the Higgs boson with the ATLAS detector using up to 25/fb of proton-proton collision data*, ATLAS-CONF-2014-009 (2014).
- ATLAS Collaboration, *Constraints on New Phenomena via Higgs Coupling Measurements with the ATLAS Detector*, ATLAS-CONF-2014-010 (2014).

Backup

Simplified MSSM

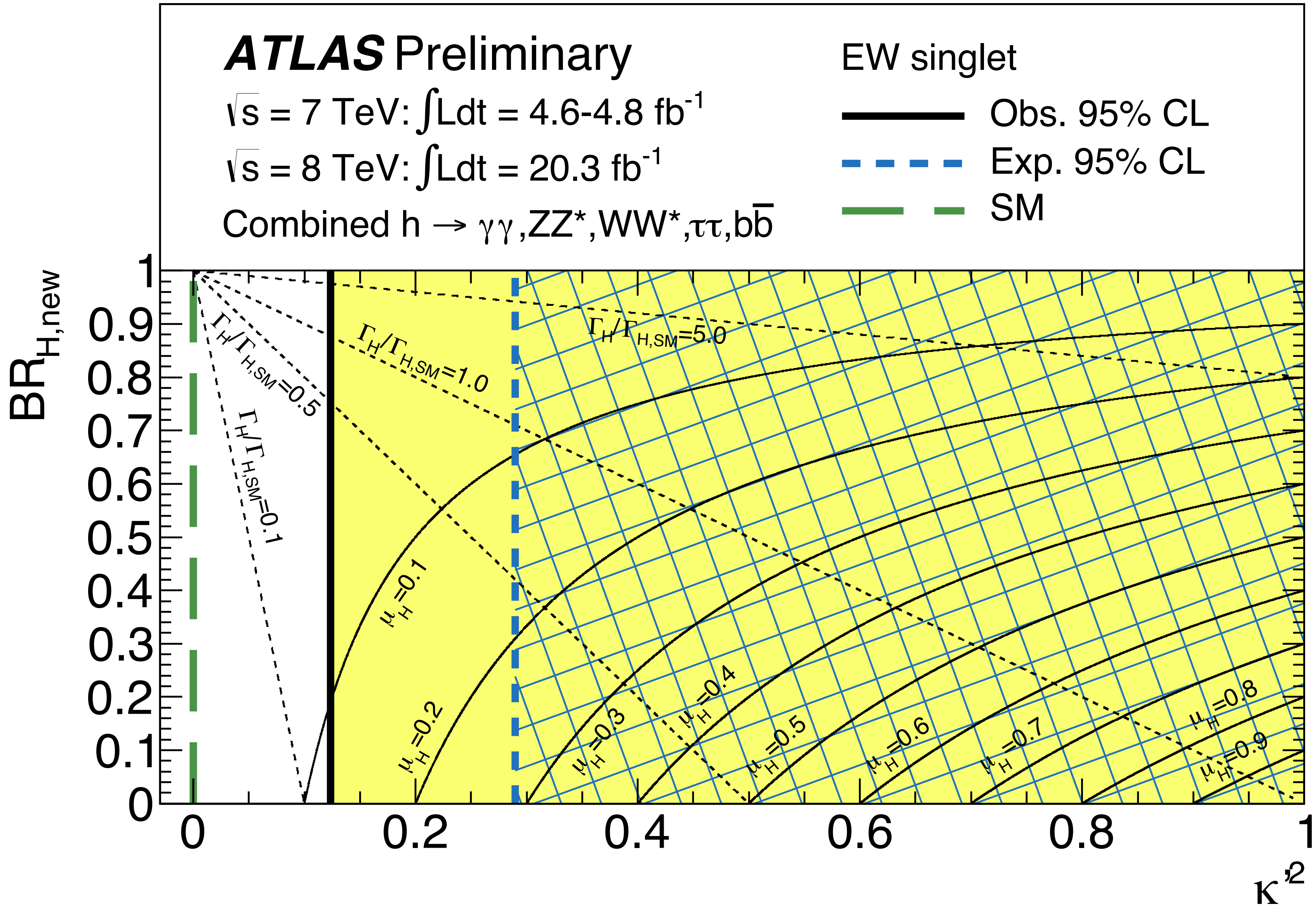
Regions of the (tan β - mA) plane excluded

Logarithmic scale



Additional Electroweak Singlet

Regions of the ($BR_{H,new}$, κ'^2) plane excluded



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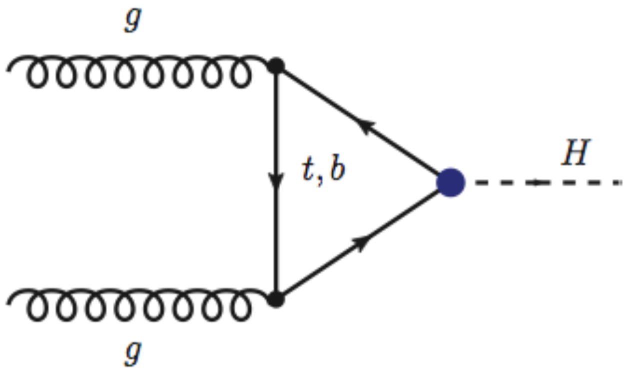
type III flipped

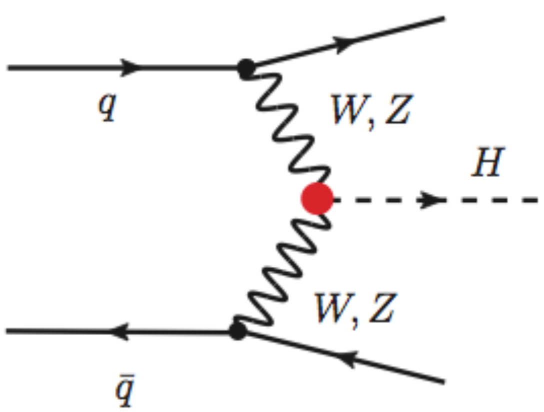
κ_V	1.15 ± 0.08
κ_F	$0.99^{+0.17}_{-0.15}$
$\lambda_{Vu} = \kappa_V/\kappa_u$	$1.21^{+0.24}_{-0.26}$
$\kappa_{uu} = \kappa_u^2/\kappa_h$	$0.86^{+0.41}_{-0.21}$
$\lambda_{du} = \kappa_d/\kappa_u$	$[-1.24, -0.81] \cup [0.78, 1.15]$
$\lambda_{Vq} = \kappa_V/\kappa_q$	$1.27^{+0.23}_{-0.20}$
$\kappa_{qq} = \kappa_q^2/\kappa_h$	$0.82^{+0.23}_{-0.19}$
$\lambda_{lq} = \kappa_l/\kappa_q$	$[-1.48, -0.99] \cup [0.99, 1.50]$

Coupling framework

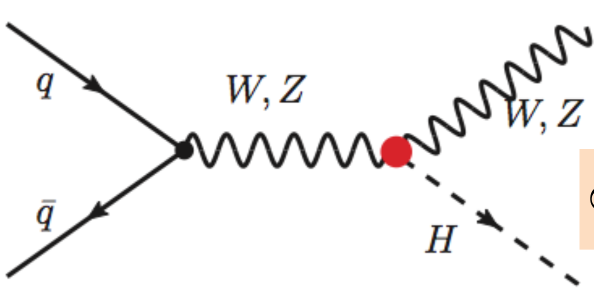
Production



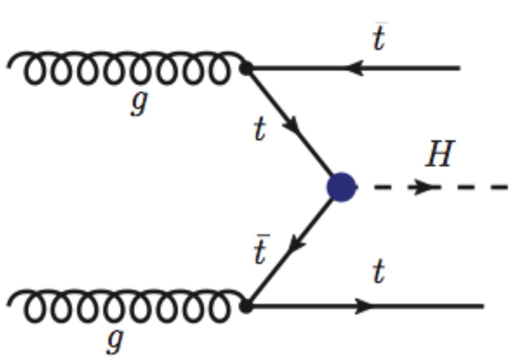
$$\propto \kappa_g^2 = 1.06\kappa_t^2 - 0.07\kappa_t\kappa_b + 0.01\kappa_b^2$$



$\propto \kappa_V^2$

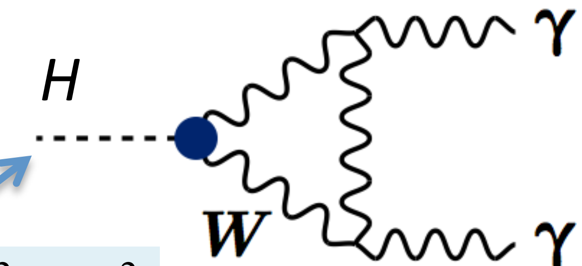


$\propto \kappa_V^2$

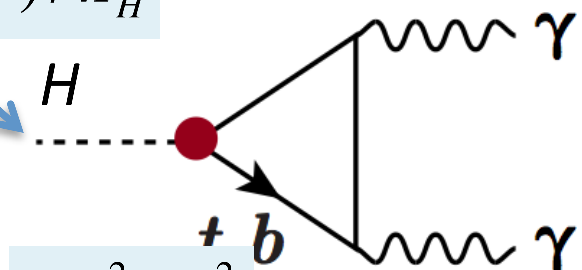


$\propto \kappa_t^2$

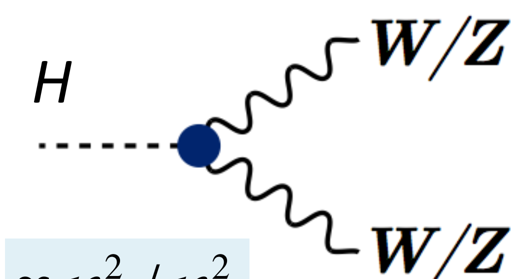
Decay



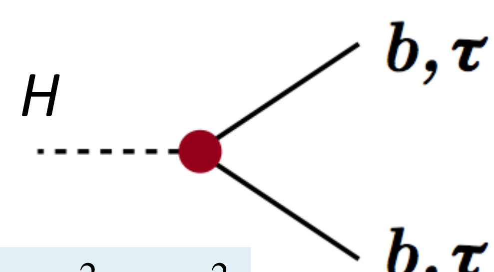
$$\propto \kappa_\gamma^2 / \kappa_H^2 = (1.59\kappa_W^2 - 0.66\kappa_W\kappa_t + 0.07\kappa_t^2)/\kappa_H^2$$



$\propto \kappa_V^2 / \kappa_H^2$



$\propto \kappa_V^2 / \kappa_H^2$



$\propto \kappa_{b,\tau}^2 / \kappa_H^2$

$$\sigma(ggF) \times BR(H \to \gamma\gamma) \sim \frac{\kappa_F^2 . \kappa_\gamma^2(\kappa_F, \kappa_F, \kappa_F, \kappa_V)}{0.75\kappa_F^2 + 0.25\kappa_V^2}$$

$$\sigma(VBF) \times BR(H \to \gamma\gamma) \sim \frac{\kappa_V^2 . \kappa_\gamma^2(\kappa_F, \kappa_F, \kappa_F, \kappa_V)}{0.75\kappa_F^2 + 0.25\kappa_V^2}$$

$$\sigma(ggF) \times BR(H \to WW, ZZ) \sim \frac{\kappa_F^2 . \kappa_V^2}{0.75\kappa_F^2 + 0.25\kappa_V^2}$$

$$\sigma(VBF) \times BR(H \to WW, ZZ) \sim \frac{\kappa_V^2 . \kappa_V^2}{0.75\kappa_F^2 + 0.25\kappa_V^2}$$

$$\sigma(VBF, VH) \times BR(H \to \tau\tau, bb) \sim \frac{\kappa_V^2 . \kappa_F^2}{0.75\kappa_F^2 + 0.25\kappa_V^2}$$

Slide from N. Andari's presentation at Higgs Hunting 2014

Higgs Portal to Dark Matter

Many “Higgs portal” models introduce an additional weakly-interacting massive particle (WIMP)

κ_h^2 is a function of the branching ratio of the Higgs to invisible final states BR_{inv}

$$\kappa_h^2 = \Gamma_h/\Gamma_{h,\mathrm{SM}} = \sum_i \kappa_i^2/(1 - \mathrm{BR}_{\mathrm{inv}})$$

Effective couplings to photons and gluons are introduced to absorb the possible contributions of new particles through loops

κ_g	$1.00^{+0.23}_{-0.16}$
κ_γ	$1.17^{+0.16}_{-0.13}$