Combined Measurements of the Properties of the Higgs Boson Using the ATLAS Detector

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on behalf of the ATLAS Collaboration

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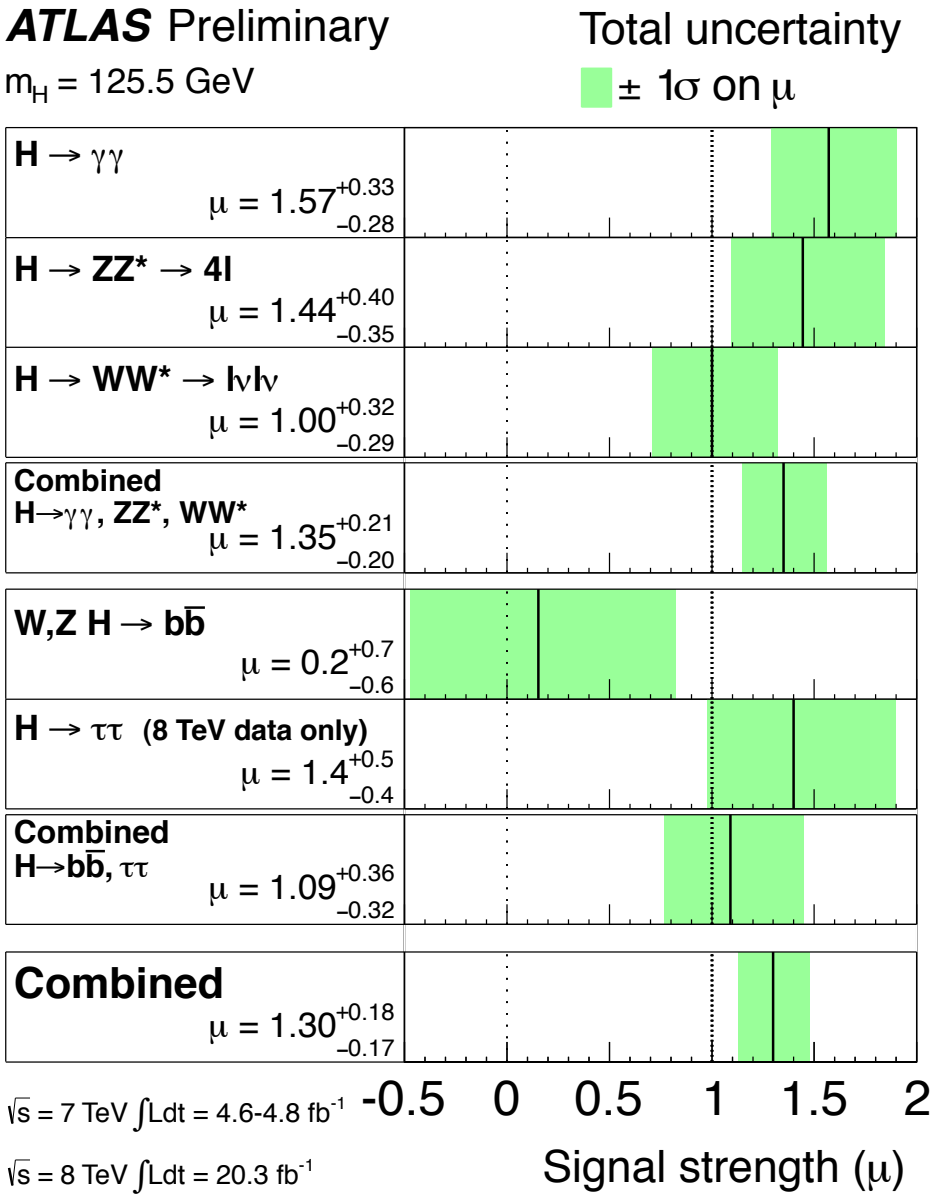
Coupling Measurements

Combine ATLAS measurements, for detailed descriptions of Higgs couplings.

Five decay channels.
4.6-4.8/fb at 7 TeV
20.3/fb at 8 TeV.

Now with fermions!

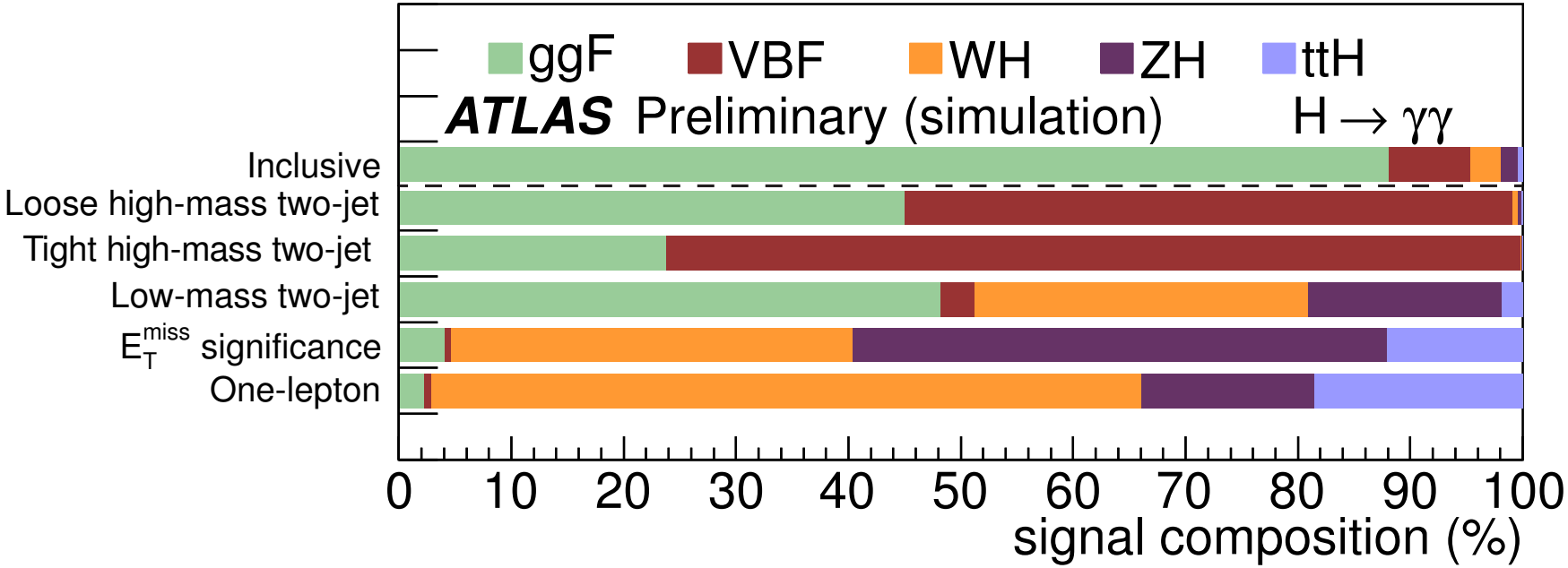
ATLAS-CONF-2014-009



Analysis Categories

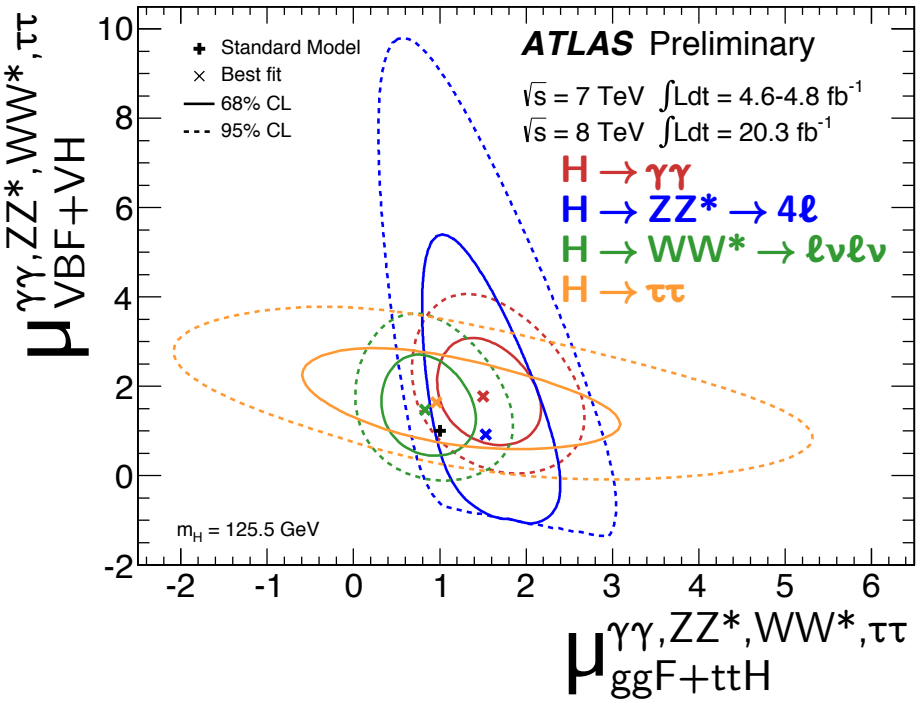
Channel	Decay	Production Tagging
$h \to \gamma\gamma$	-	VBF, ℓ, $\not{E}_T$, 2-jet VH.
$h \to ZZ^*$	4ℓ	VBF, ℓ
$h \to WW^*$	$\ell\nu\ell\nu$	0-jet, 1-jet, 2-jet VBF
$V(h \to bb)$	$Z \to \nu\nu$, $W \to \ell\nu$, $Z \to \ell\ell$	-
$h \to \tau\tau$ (2012)	$\tau_{\text{lep}}\tau_{\text{lep}}$, $\tau_{\text{lep}}\tau_{\text{had}}$, $\tau_{\text{had}}\tau_{\text{had}}$	Boosted ggh, VBF

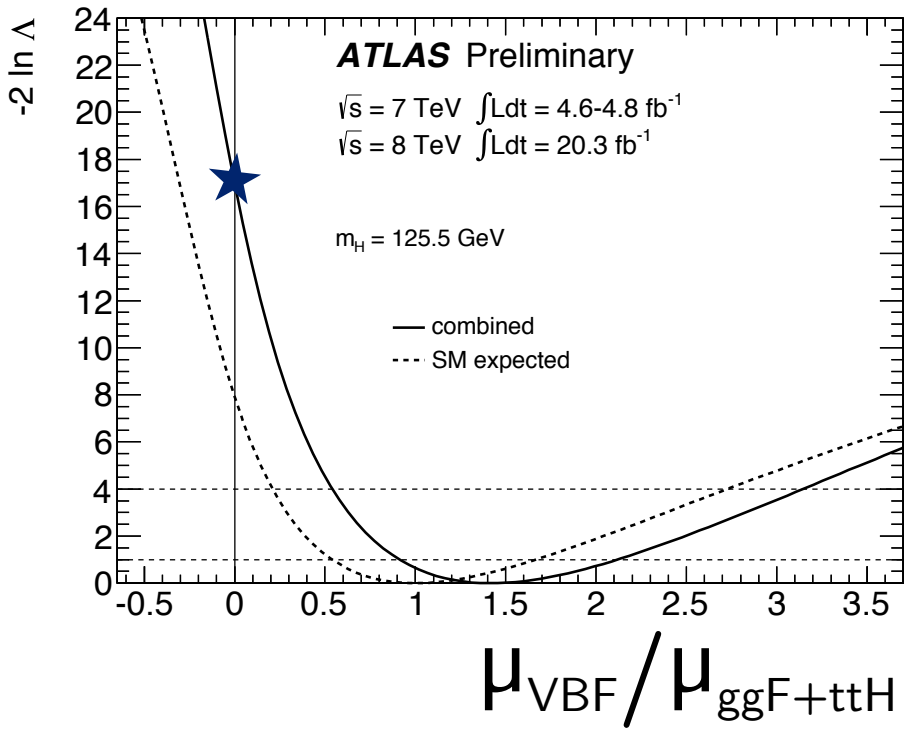
Example: Tagged Categories in $h \to \gamma\gamma$



Production Modes

- Split by production mode: **VBF + Vh** type v. **ggh + tth** (left).
- **4.1σ evidence** of VBF production (right)!



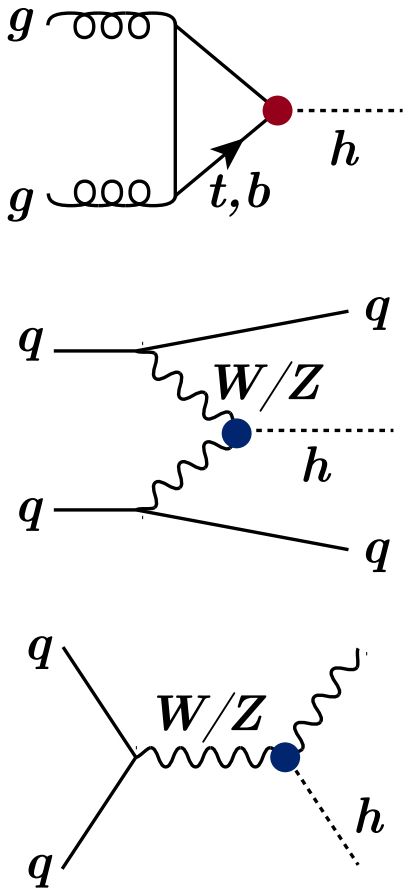


Coupling Fits

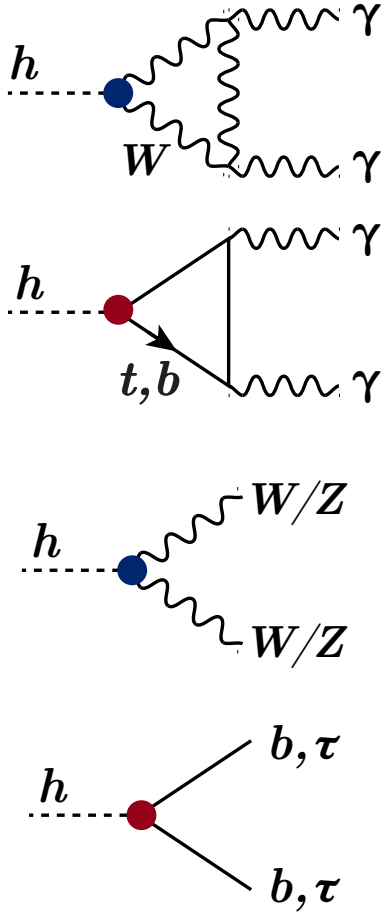
Factorizing

- Production Modes
- **Fermions** v. **Bosons**
- Up v. Down
- Leptons v. Quarks
- W v. Z: Custodial Sym.
- Photon, Gluon Loops
- Unobs. or Invisible

Production Modes



Decays



Methodology

- Define multipliers $\boldsymbol{\kappa}$ for each coupling: κ_γ, κ_V, κ_ℓ, etc.
  - **SM is $\boldsymbol{\kappa \equiv 1}$; non-SM is $\boldsymbol{\kappa \neq 1}$.**
- For each derivation, set appropriate terms equal.
  - e.g., $\kappa_f = \kappa_b = \kappa_t = \kappa_\tau$ and $\kappa_V = \kappa_W = \kappa_Z$
- Assume LO SM-like to fit for couplings.
  - Example: loop to photons contains interference:

$$\kappa_\gamma^2 \equiv 1.59\kappa_W^2 - 0.66\kappa_W\kappa_t + 0.07\kappa_t^2$$

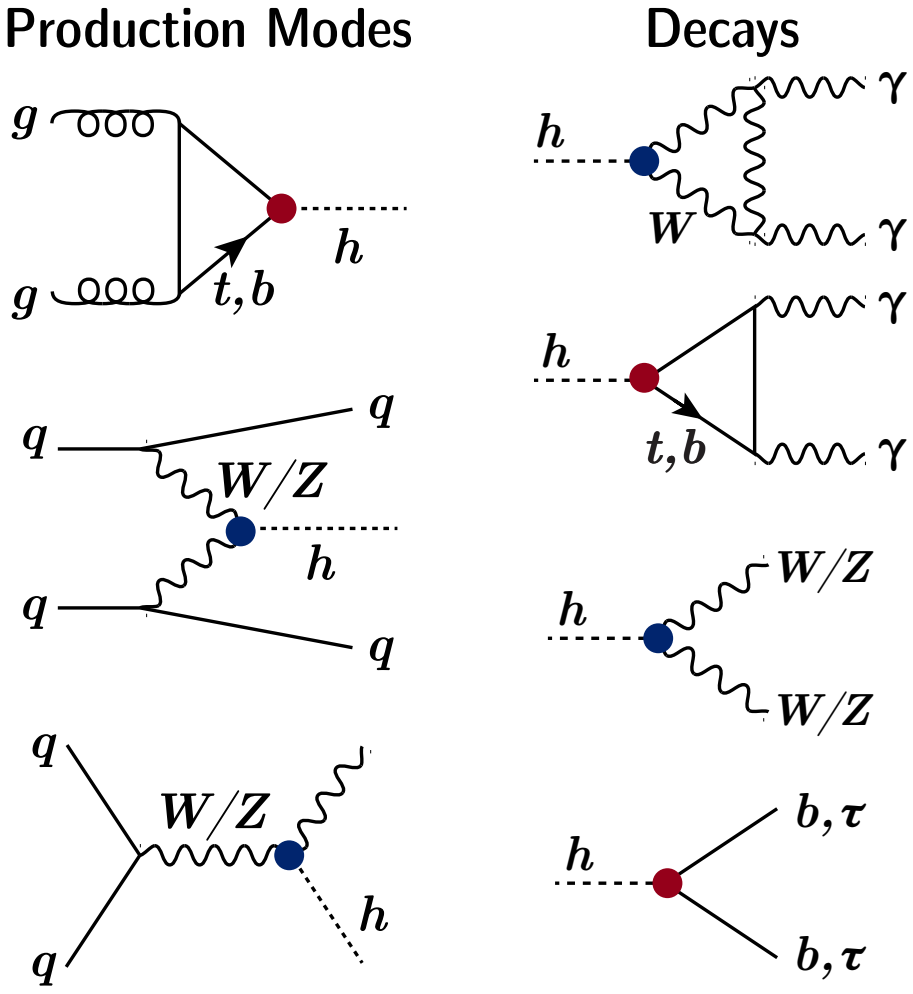
- Maximize likelihood ratio, for parameter(s) of interest $\boldsymbol{\alpha}$ and NPs $\boldsymbol{\theta}$:

$$\boldsymbol{\Lambda(\alpha) = \frac{\mathcal{L}(\alpha, \hat{\hat{\theta}}(\alpha))}{\mathcal{L}(\hat{\alpha}, \hat{\theta})}}$$

Coupling to Fermions v. Vector Bosons

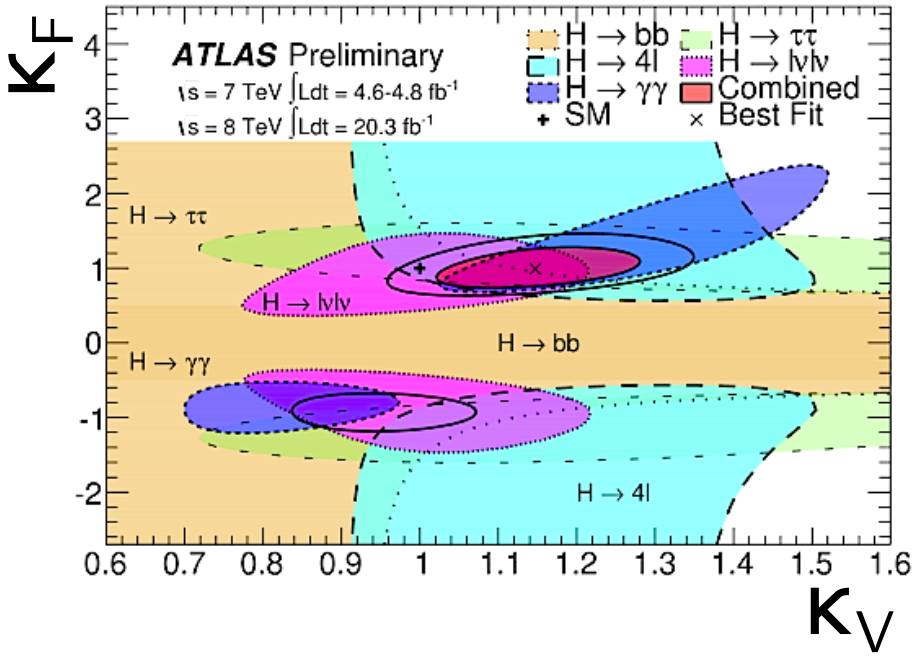
$$\kappa_V = \kappa_W = \kappa_Z$$
$$\kappa_F = \kappa_t = \kappa_b = \kappa_\tau$$

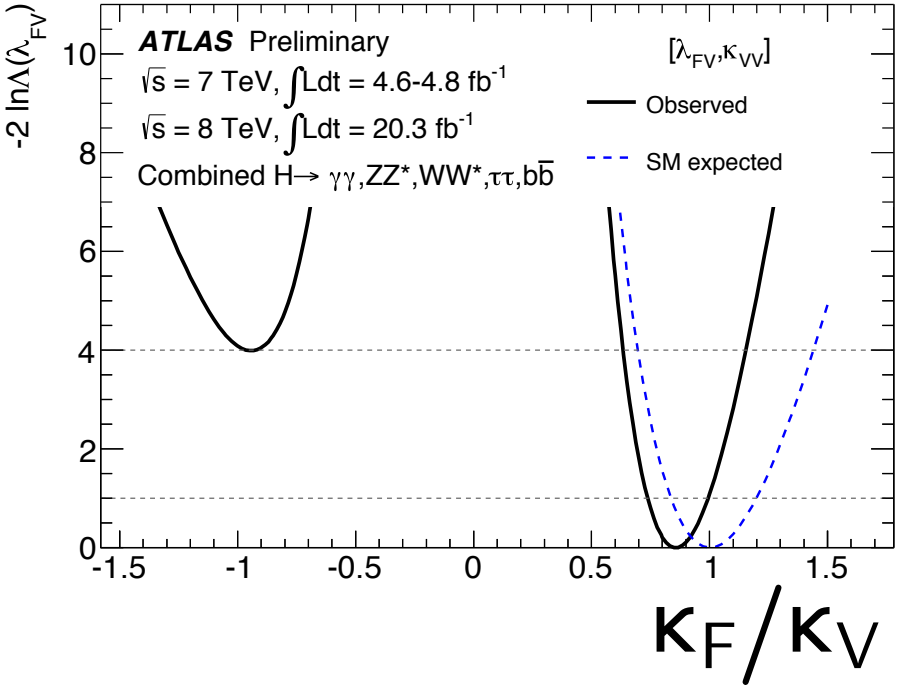
- Normalization profiled in fit.



Coupling to Fermions v. Vector Bosons

- Gluon fusion: coupling to fermions. ✓
  - Strong $\kappa_F > 0$ from bosonic modes. So why measure $h \to ff$?





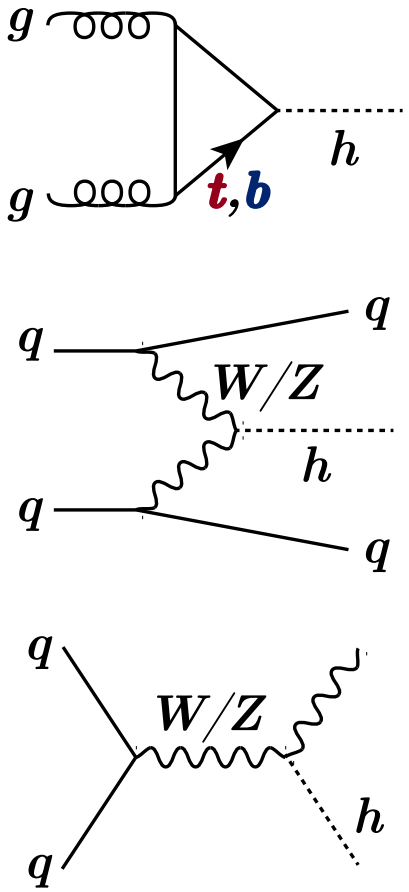
Couplings to Up v. Down Type

- Need $h \to \tau\tau$ and $h \to bb$ to split types of fermions.

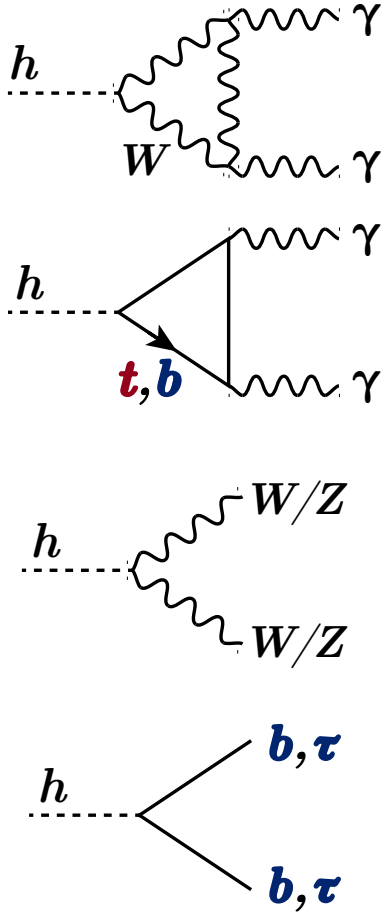
$$\kappa_u = \kappa_t$$
$$\kappa_d = \kappa_b = \kappa_\tau$$

- Normalization and vector type couplings profiled.
- Quark v. leptons in backup.

Production Modes



Decays

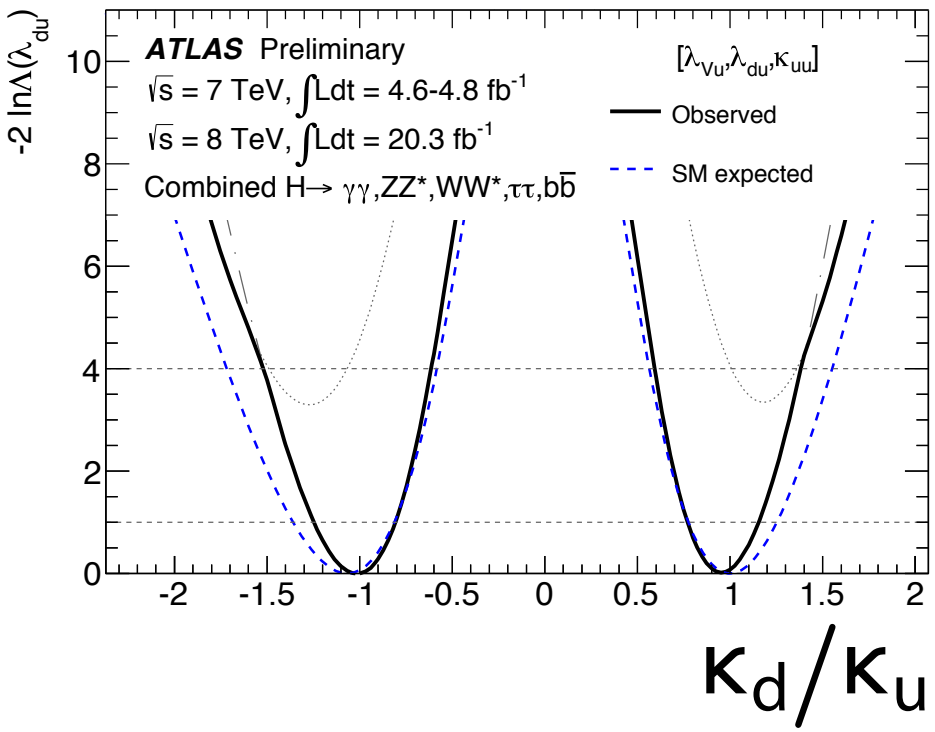


Couplings to Up v. Down Type

Many two-Higgs doublet models split fermionic couplings to the Higgs among up/down type.

- Total width is down-type dominated.
- Also affords check of Higgs couplings v. mass!

No sensitivity to the sign – but couplings look good!

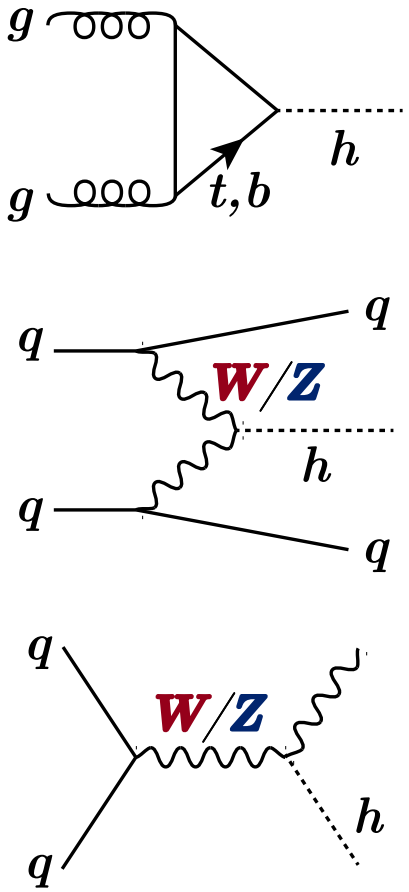


Custodial Symmetry

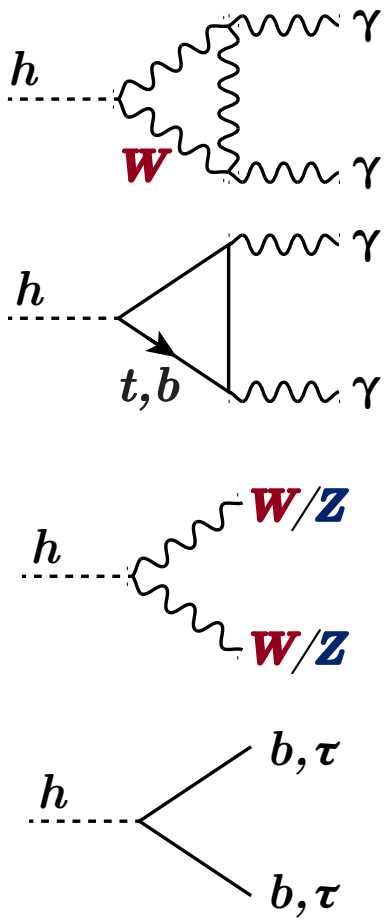
κ_W v. κ_Z

- Direct inputs $h \to WW$, $h \to ZZ$, and Vh production.
- Also constrained by VBF (3/4 W fusion, 1/4 Z fusion); and W loop in $h \to \gamma\gamma$.
- Normalization and fermionic couplings profiled.

Production Modes



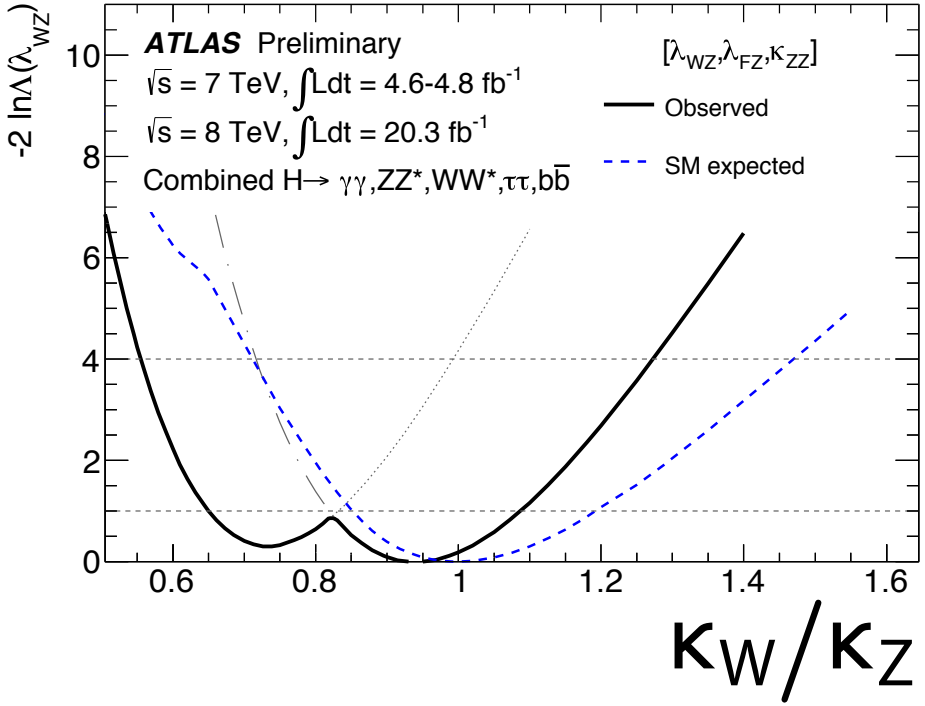
Decays



Custodial Symmetry

Custodial symmetry well-measured at LEP: confirm in the Higgs sector!

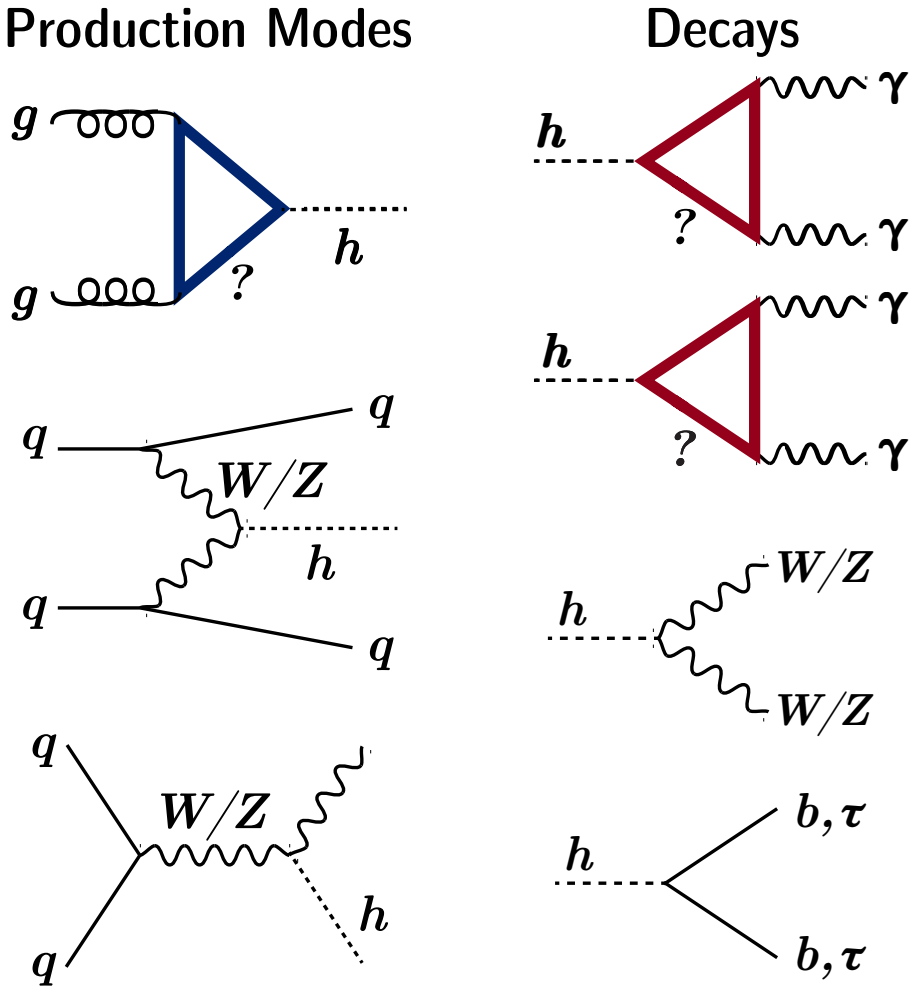
$$\kappa_W/\kappa_Z = 0.94^{+0.14}_{-0.29}$$



Additional Particles in the Loops

κ_g **v.** κ_γ

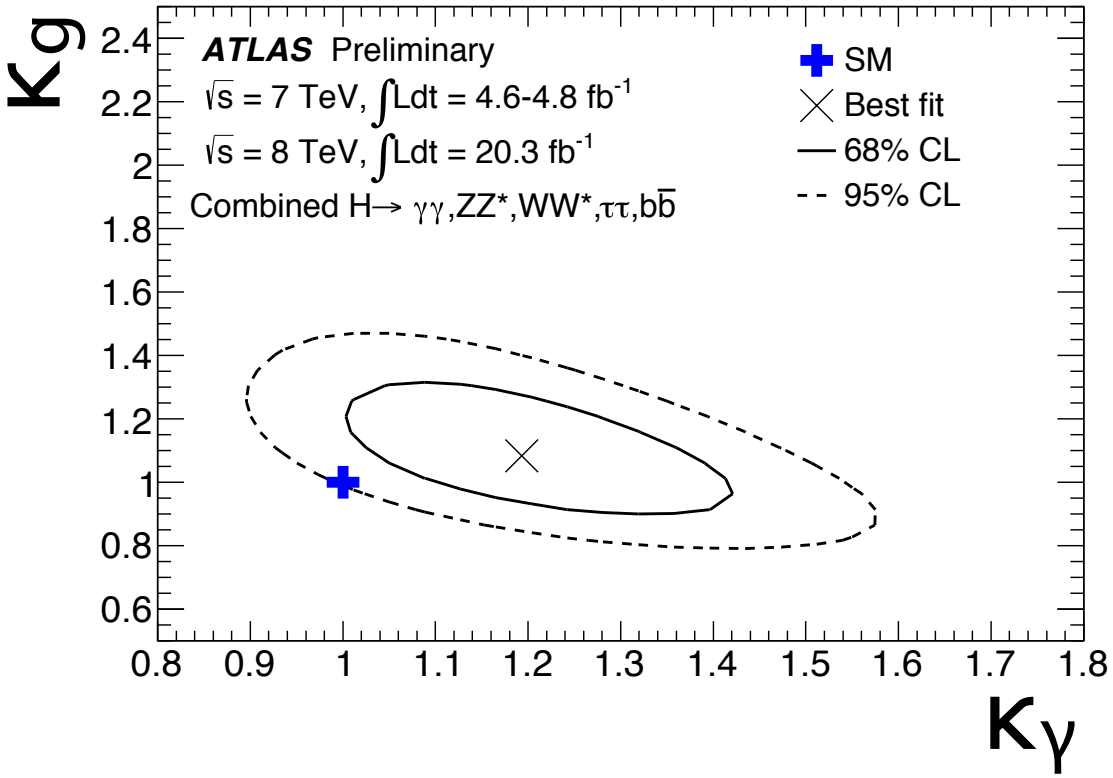
- Assume only SM contributions to width.

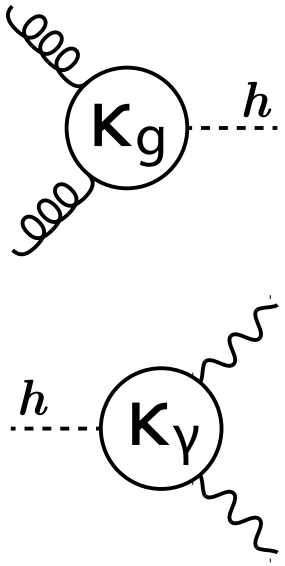


Additional Particles in the Loops

Scalings κ_g and κ_γ: loops with colored or charged particles.

- No hints of higher scale particles, additional scalars, etc.



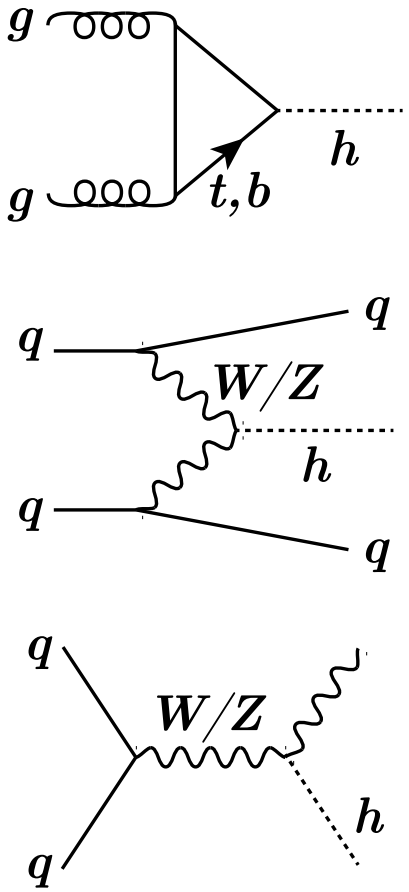


Indirect Limit on Invisible or Unobserved Decays

- Same fit for κ_g, κ_γ, but float the observed width:

$$\boxed{1 - \mathcal{B}(\text{inv., unobs.})}$$

Production Modes

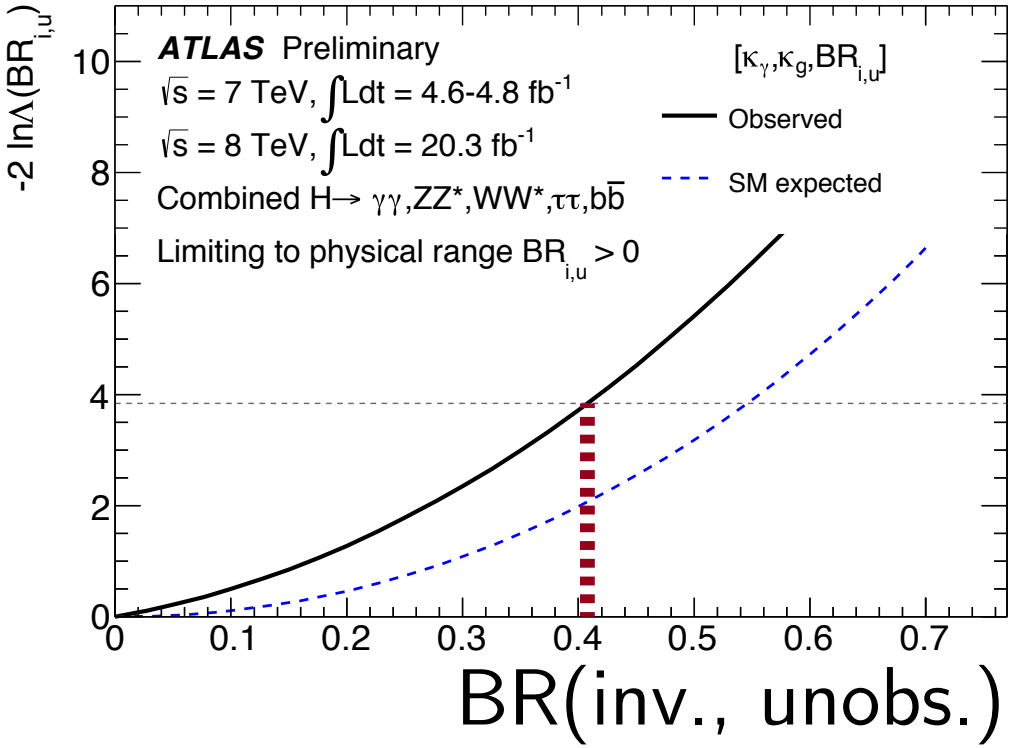


Decays

Indirect Limit on Invisible or Unobserved Decays

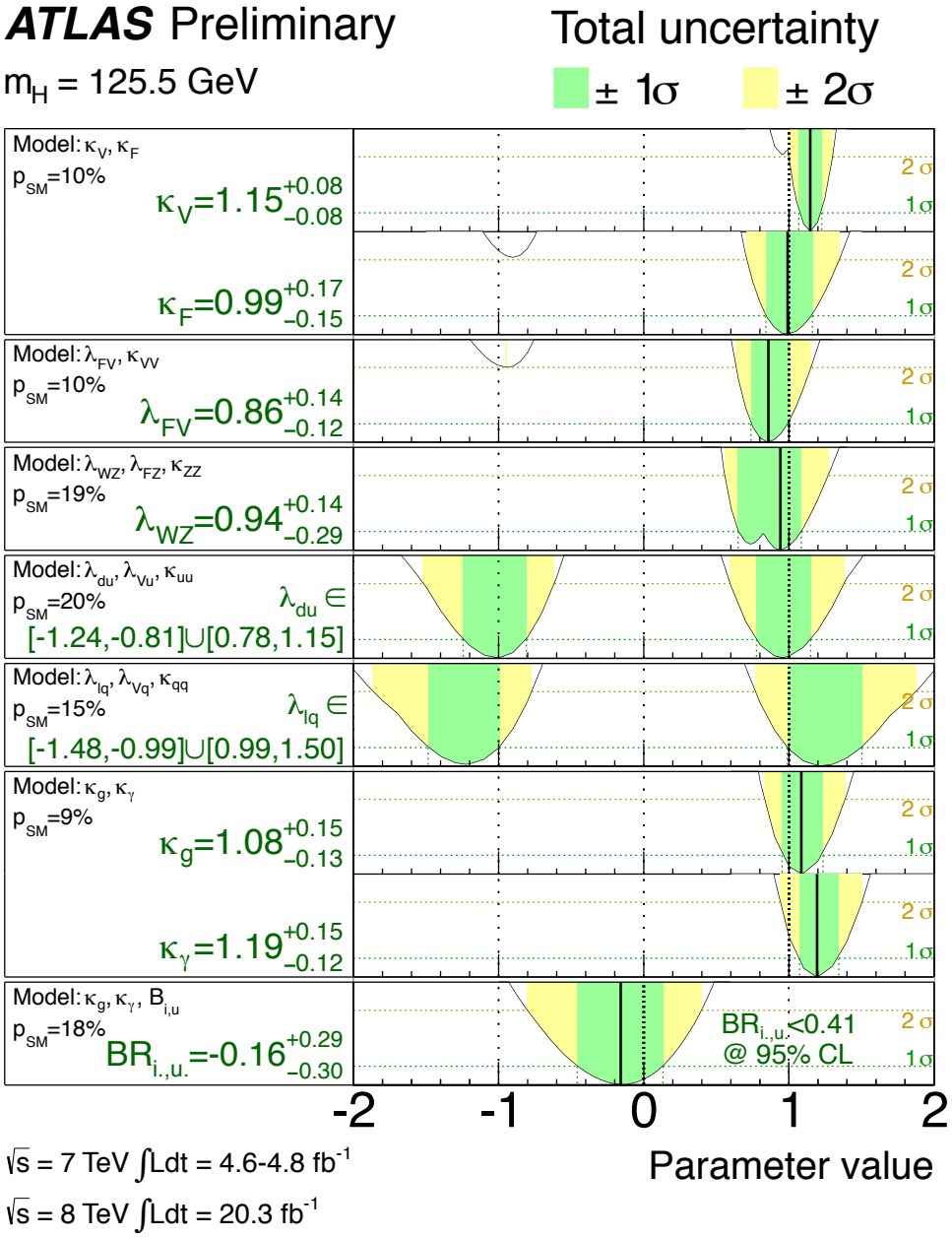
$$\mathcal{B}(\textbf{inv., unobs.}) < \textbf{0.41 at 95\% CL}$$

- Combination with $Z(H \to \text{inv.})$ search gives $\mathcal{B}(\text{inv.}) < 0.37$.*



* **ATLAS-CONF-2014-010**

Good Agreement to SM in All Observables



Couplings to Vector Bosons

Couplings to Fermions

Ratio of κ_F/κ_V

Custodial Symmetry

SUSY?

Additional Particles in the Loops

Unobserved or Invisible Width

Bonus

Quark v. Lepton Couplings