The Higgs as a Tool for Discovery

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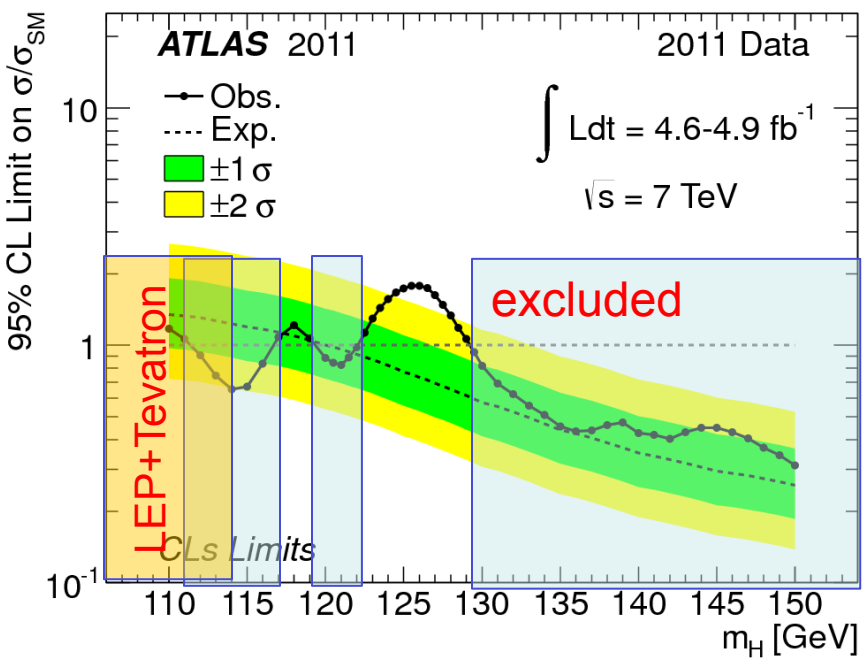
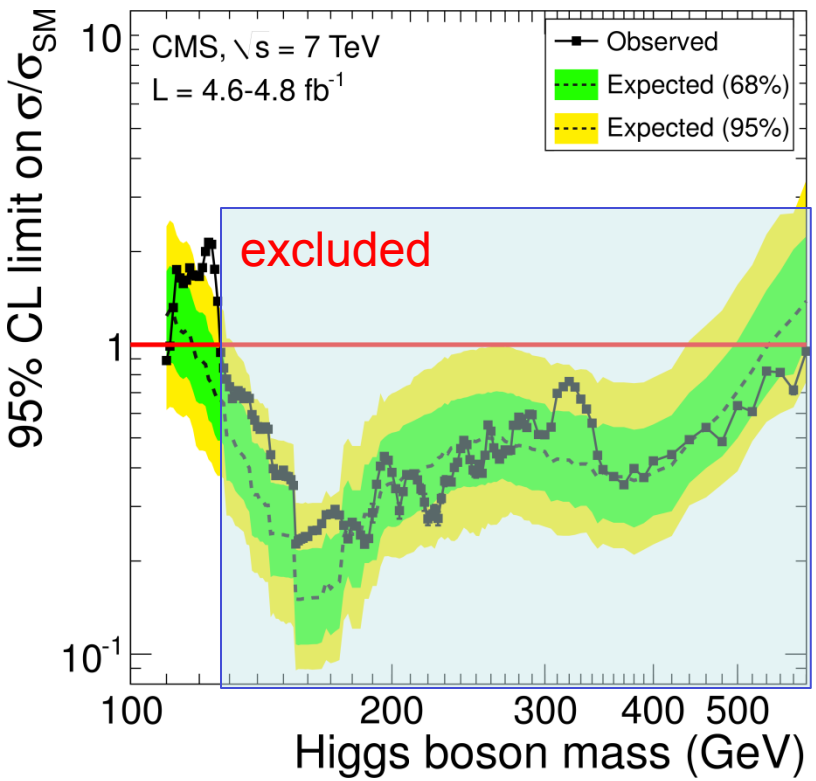
SLAC

The Evasive Higgs Boson

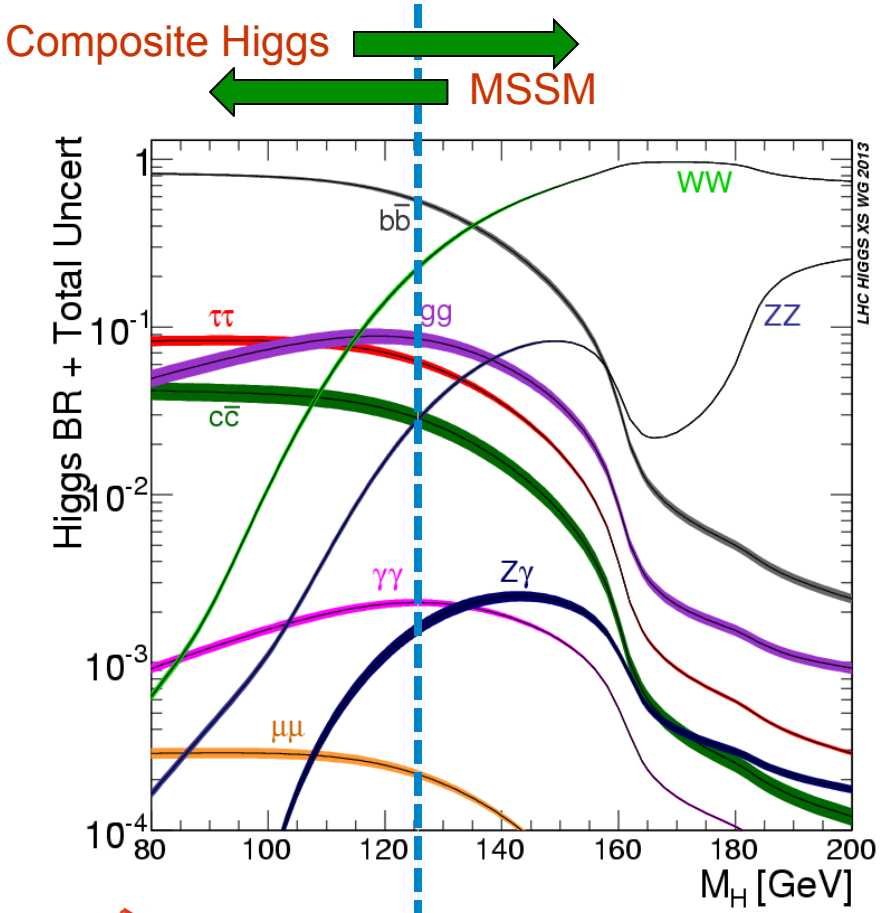
Mar/2012





Resisted detection until we turned over the last stone…

Higgs at a Vantage Point



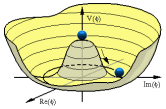
125 GeV mass: curiously balanced with democratic access to many decay channels ➡ A tool box of many gadgets…

Higgs the Massenger

Higgs is 'responsible' for the masses in the SM:

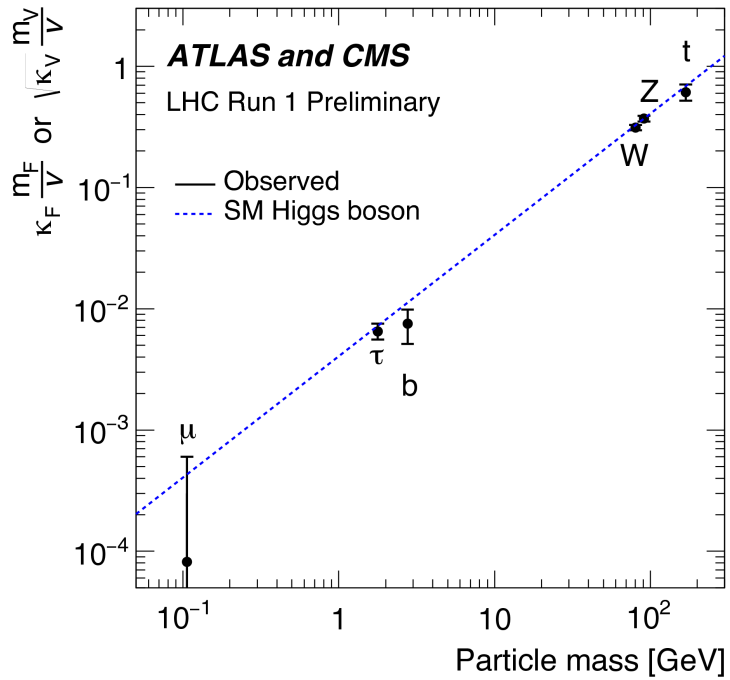
- W/Z masses and Higgs self coupling:

  $|D_\mu \phi|^2 - V(\phi)$



- Fermion masses as Yukawa couplings:

  $y_{ij} \Psi_{iL} \phi \Psi_{jR} + h.c.$



Only known BSM phenomenon is Dark Matter with gravitational interactions coupled to mass.

Couplings:

$hVV \sim 2M_V^2/v$

$hff \sim M_f/v$

➡ **Higgs portal to Dark Matter**

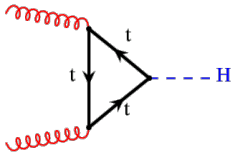
Higgs and BSM Discovery Prospects

- Higgs production and decays
  - Precision measurements to detect deviations from the SM.
  - Unexpected Higgs decay modes.
- New heavy particles decaying to Higgs
  - A new tool for distinctively tagging the source of new physics.
- Higgs can be plural ?

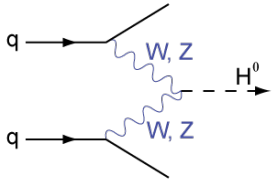
Disclaimer: A limited personal view on a few topics as a prelude to the more serious discussions in the Higgs session

Higgs Production at pp Colliders

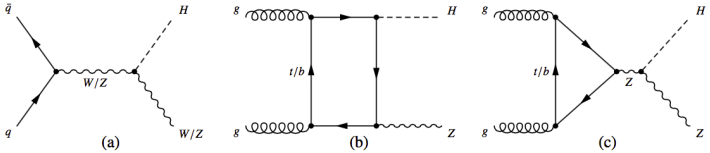
ggF: gluon-gluon Fusion



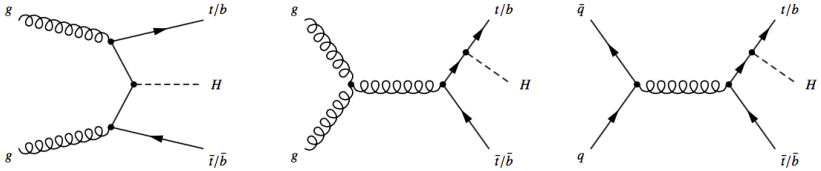
VBF: Vector Boson Fusion

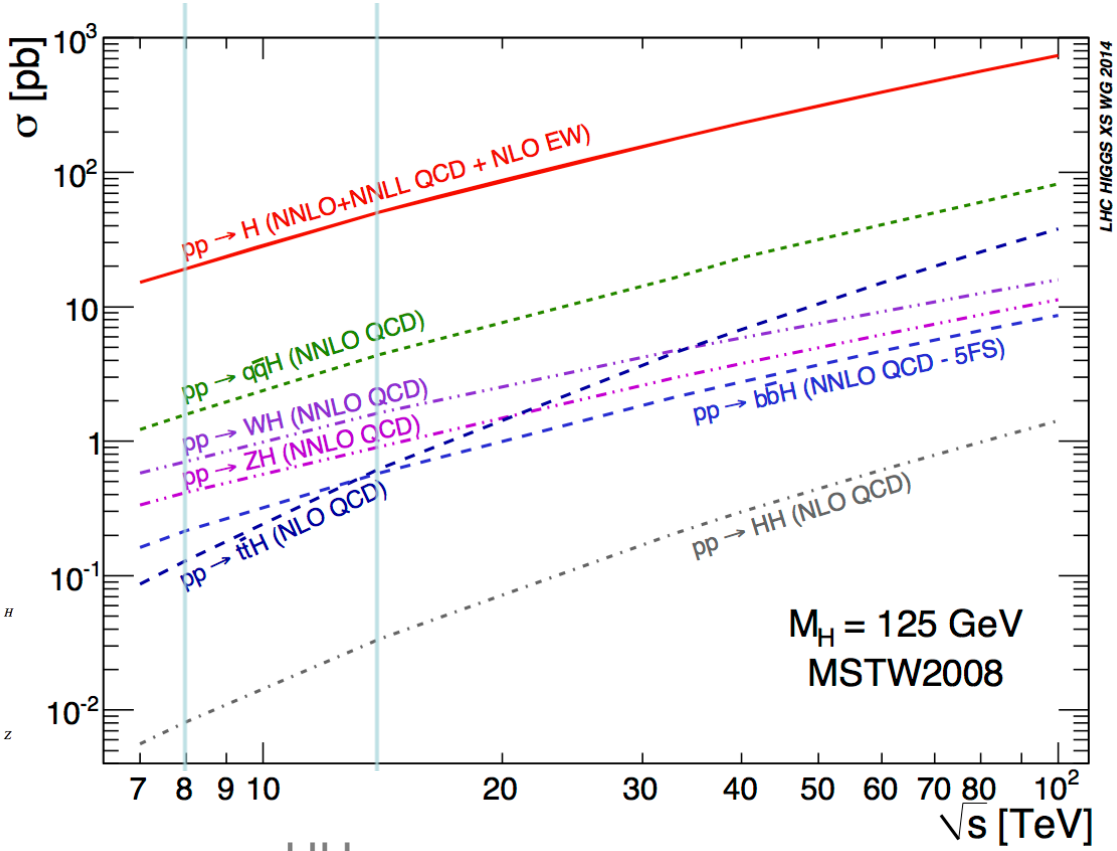


VH: W/Z + H

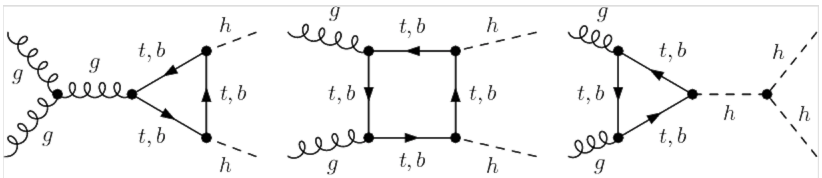


ttH: tt+H (bb+H)





HH:



Higgs Couplings @ LHC

- Measurements at LHC are products of initial production cross section and final state decay BR
  - Signal strength:

$$\mu_i^f = \frac{\sigma_i \cdot \mathrm{BR}^f}{(\sigma_i)_{\mathrm{SM}} \cdot (\mathrm{BR}^f)_{\mathrm{SM}}} = \mu_i \times \mu^f$$

  - Assume no-BSM contribution and bundle unmeasured modes with closest measured relative, can extract individual μ_i, μ^f from combining measurements.
- Coupling Modifier (κ-framework) to propagate same coupling deviation in all measurements
  - Production or decay variation $\kappa_j^2 = \sigma_j / \sigma_j^{\mathrm{SM}}$ or $\kappa_j^2 = \Gamma^j / \Gamma_{\mathrm{SM}}^j$
  - Measurements vary as

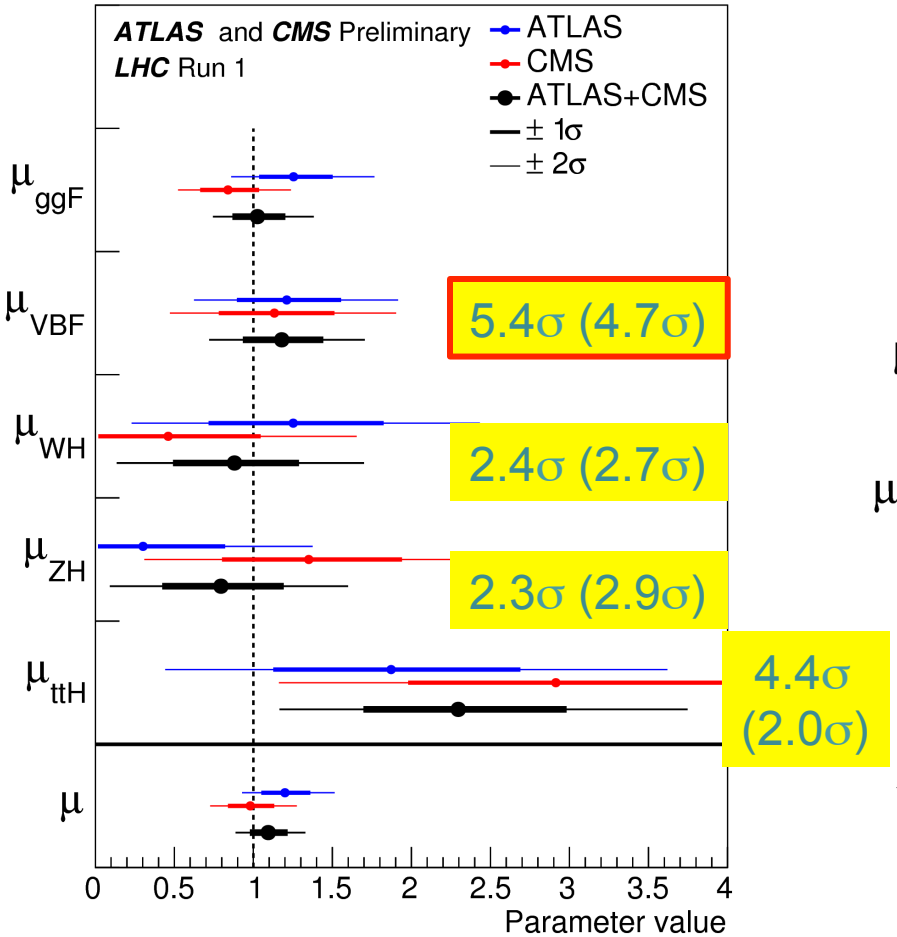
$$\sigma_i \cdot \mathrm{BR}^f = \frac{\sigma_i(\vec{\kappa}) \cdot \Gamma^f(\vec{\kappa})}{\Gamma_{\mathrm{H}}}$$

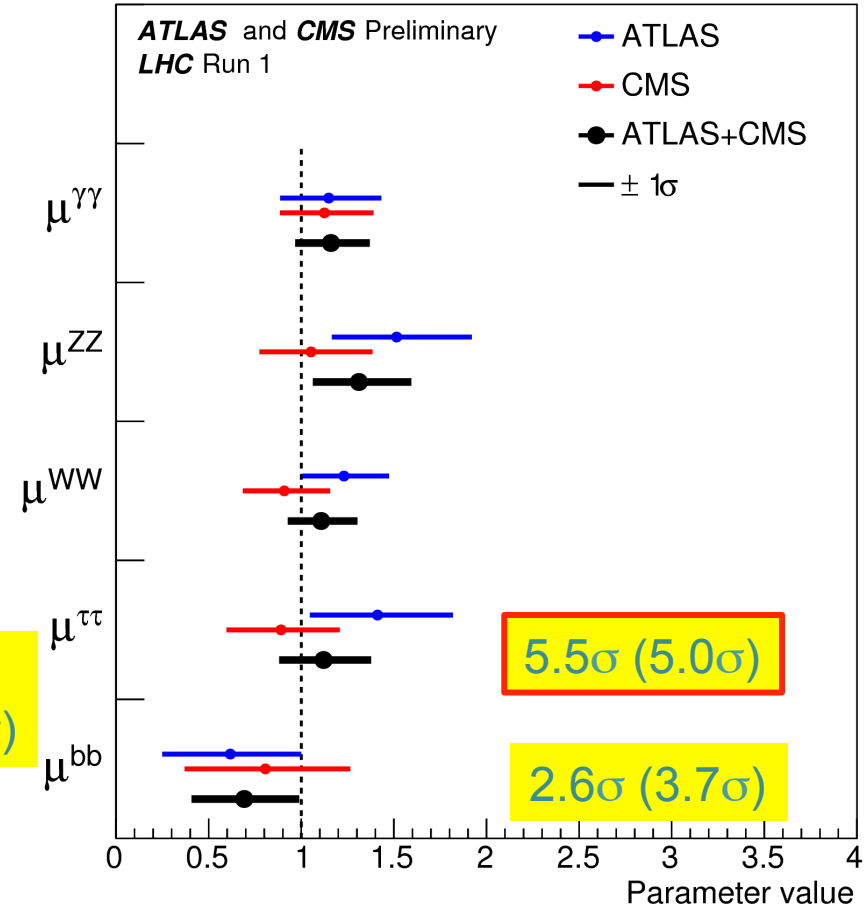
and allowing

$$\Gamma_{\mathrm{H}} = \frac{\kappa_H^2 \cdot \Gamma_H^{\mathrm{SM}}}{1 - \mathrm{BR}_{\mathrm{BSM}}}$$

Production/Decay Signal Strengths

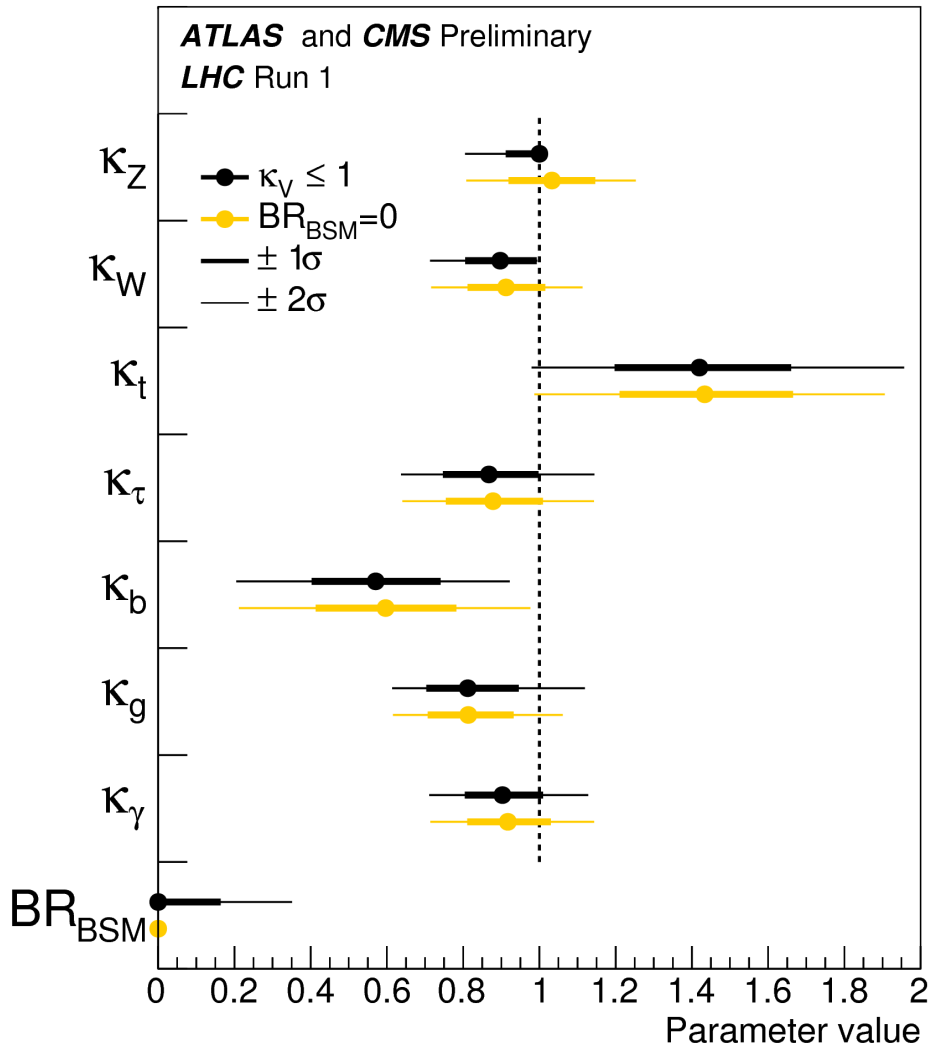
Observed (expected) significance





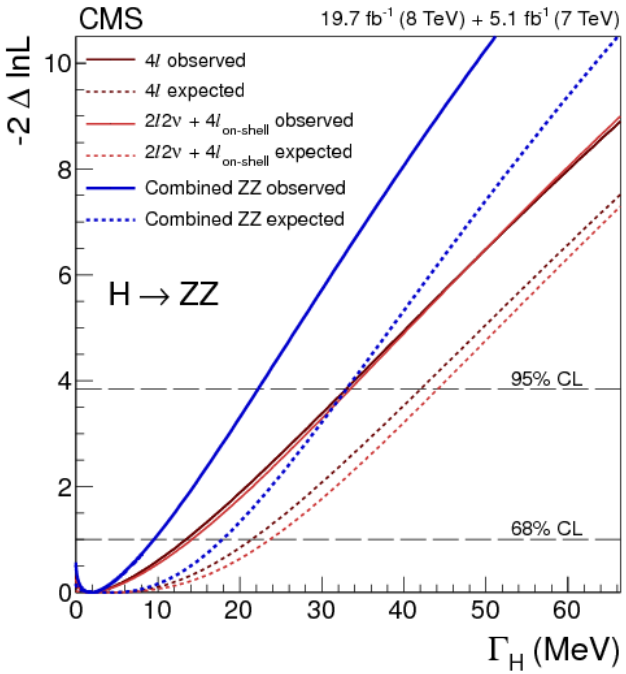
Unfolded Higgs Couplings

- Still remarkably consistent with the SM, but plenty room for surprises.
- Current frontier is at the fermionic couplings.
- ttH and VBF production modes are gaining attention.



More Higgs Properties

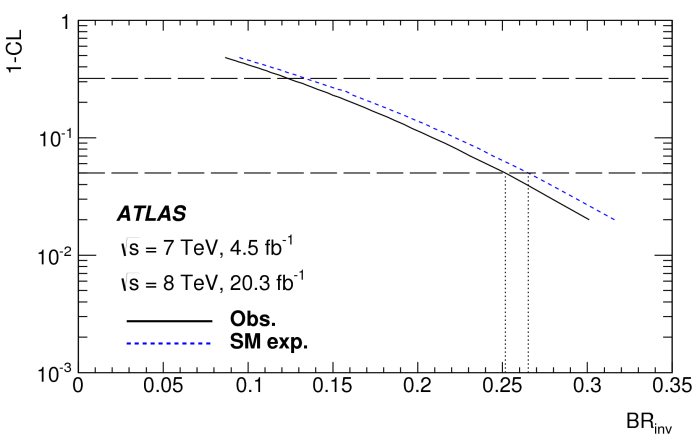
- $M_h = 125.09 \pm 0.21_{stat} \pm 0.11_{sys}$ GeV
  => <0.2% precision !
- Spin=2 excluded at >99.9% CL.
- CMS used off-shell Higgs production and decays to ZZ->4l final state to constrain Higgs width Γ_H < 26-46 MeV depending on potential BSM physics energy scales (SM ~4 MeV).

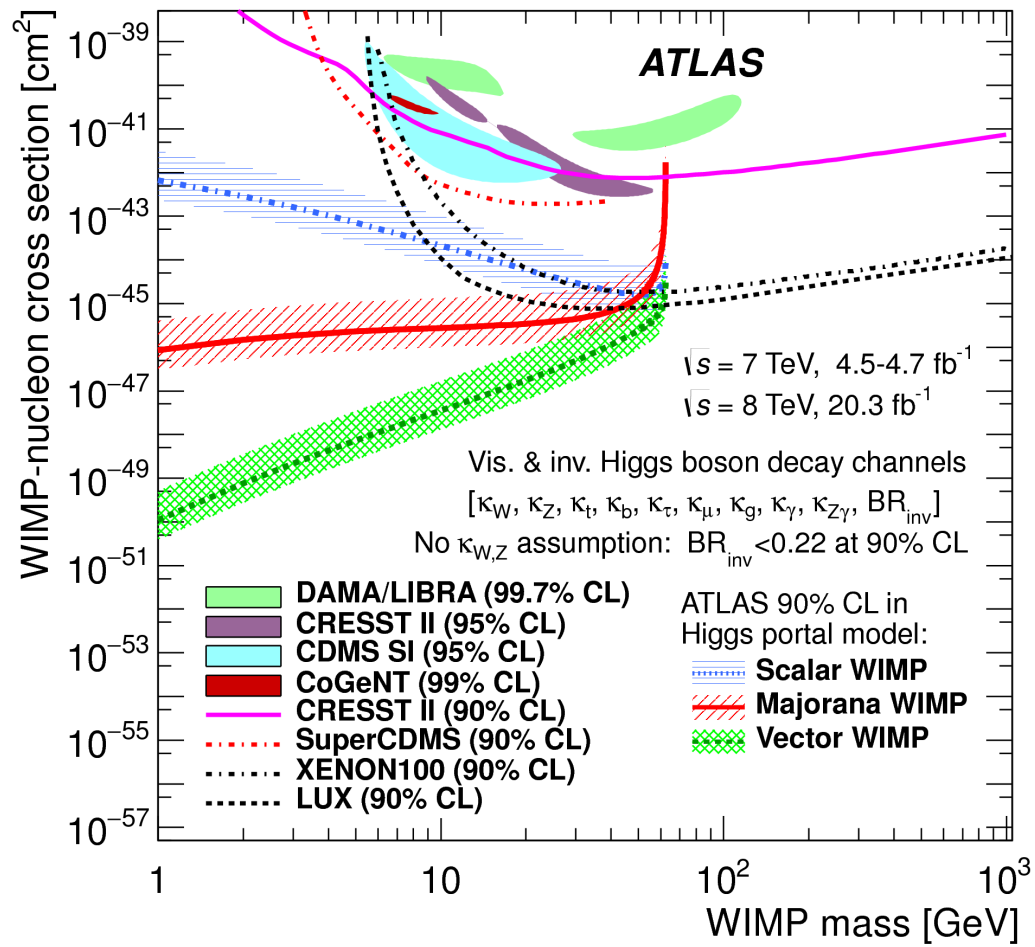


Searches for H->Invisible

Direct search for invisible H decays from ZH and VBF production, combined with visible mode measurements.

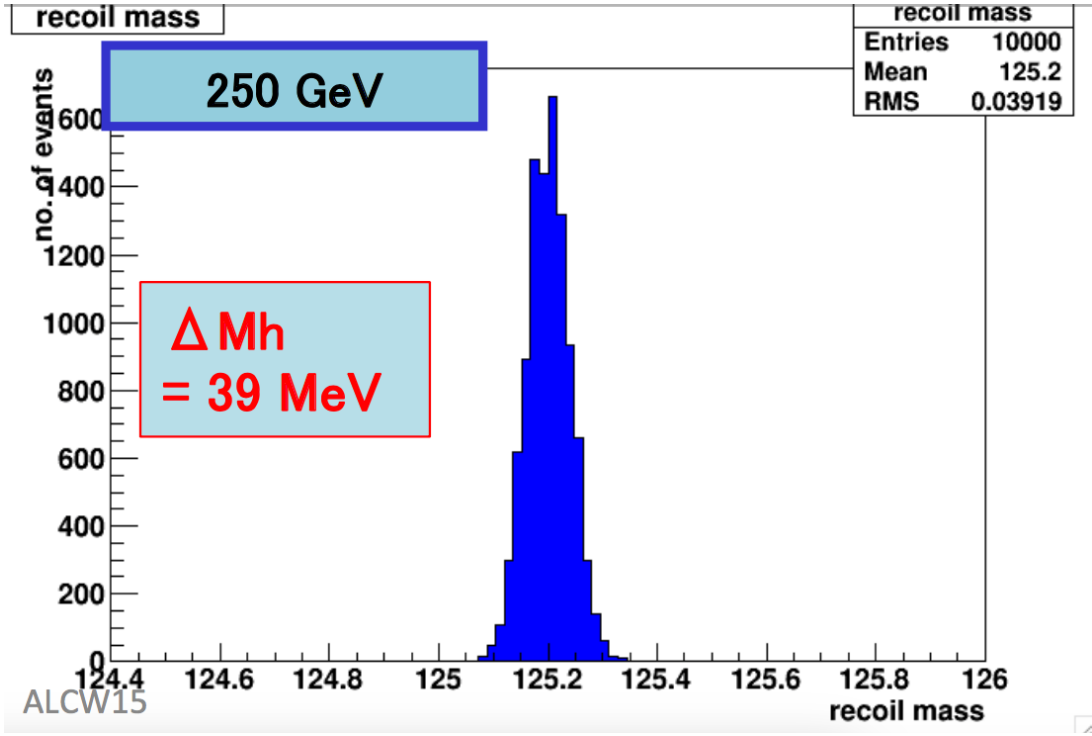
BR(inv)<23% at 95% CL





Future e^+e^- Higgs Factories

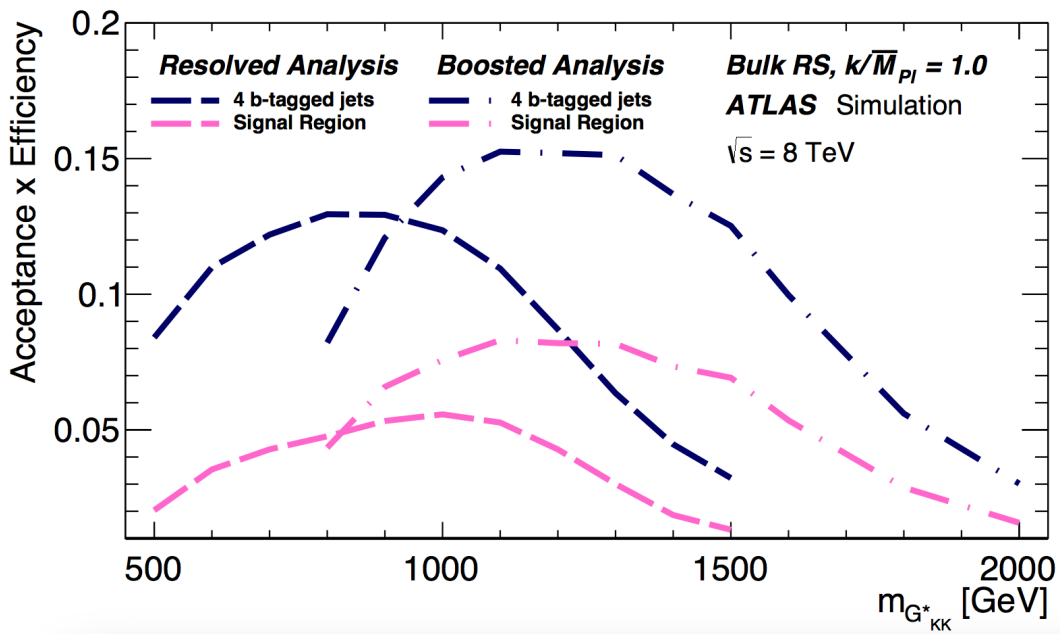
- Absolute BR measurements with high resolution Z+h recoil.
- Much cleaner environment for exploring the hadronic modes to utilize all statistics.
- Unique reach for h->cc.



ILD simulation

Higgs as a tool for exotic searches

- Models for New Physics models with heavy particles often have decays modes containing Higgs – a new physics signature.
- As a hi-Pt tagging tool, high BR modes such as bb becomes more important.
- For very high mass object decaying of Higgs, the boosted topology is a distinctive new environment.

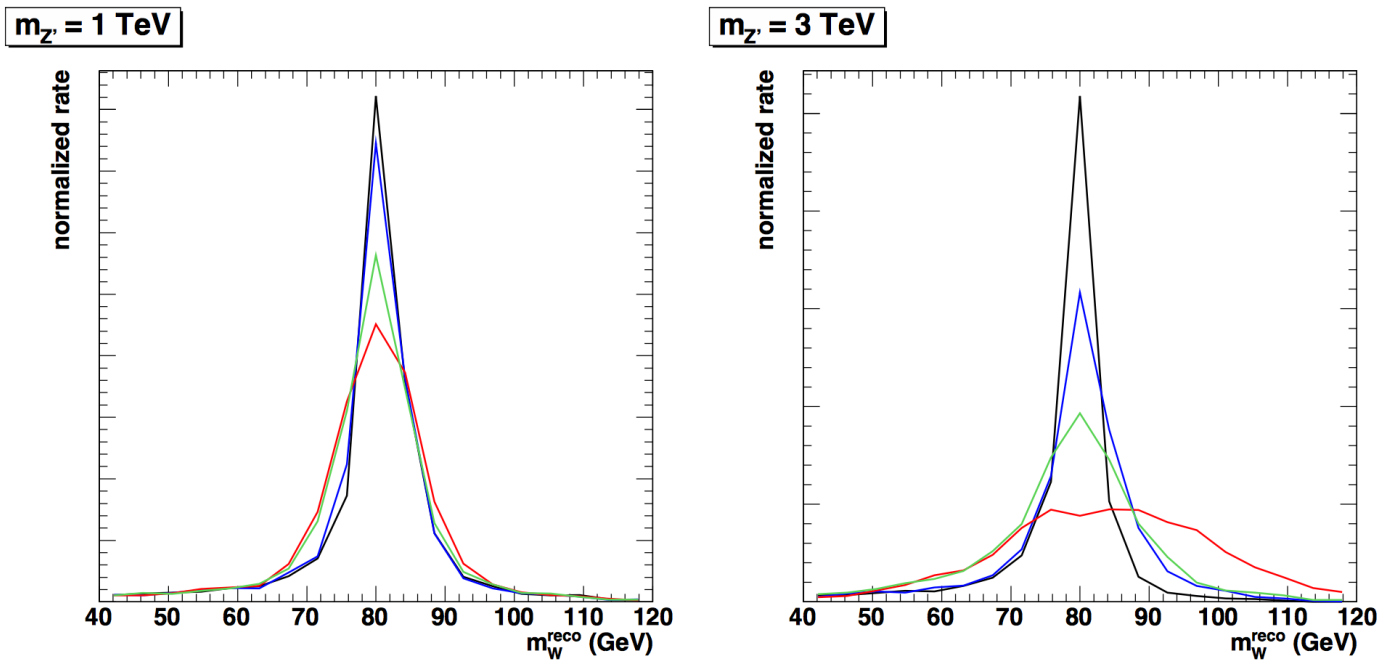


ATLAS X->hh->bbbb (Run 1)

Challenges of very boosted regime

Katz, Son, Tweedie ArXiV 1010.5253

- Truth particle
- Ideal E-flow
- Rescaled ECAL
- Pure HCAL



- Calorimeter granularity concerns. Supplement with tracking ?
- Tracking granularity OK for TeV jets ? Merging hits, fakes, efficiency in jet core ? Can Pt resolution be improved ?
- B, D hadrons decay beyond first layer(s) of pixel.

Higgs Physics and HL-LHC Detector Upgrade

- Lepton ID:
  - Preserving low trigger Pt threshold - L1 Track trigger
  - Forward tracking and other coverage improvements.
- Forward jets
  - Fast timing or very forward tracking to suppress pileup for preserving forward jet tagging (VBF)
- Tracker Upgrade:
  - Granularity for improved tracking at very high Pt jet core ?
  - Improved Pt resolution ?
  - Charm tagging ?
- Trigger:
  - Track trigger for leptons, b-tag, tau …
  - Missing Et trigger in high pileup environment