A detailed map of *Higgs boson interactions* ten years after the discovery

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on behalf of the
ATLAS & CMS collaborations

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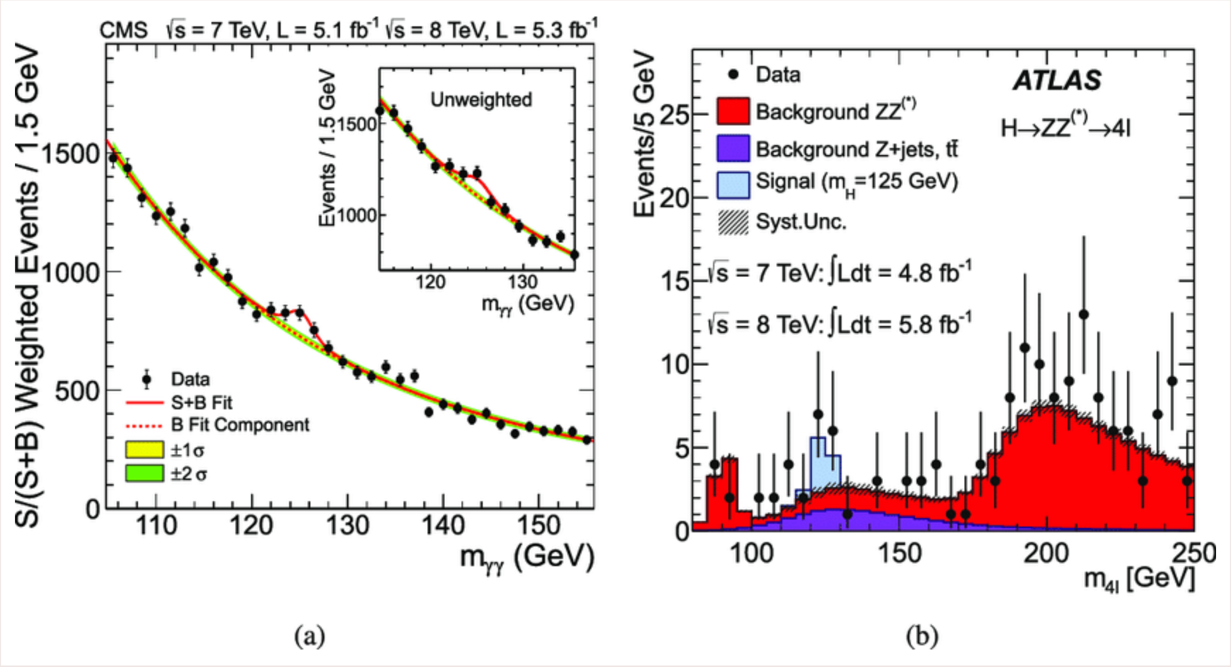
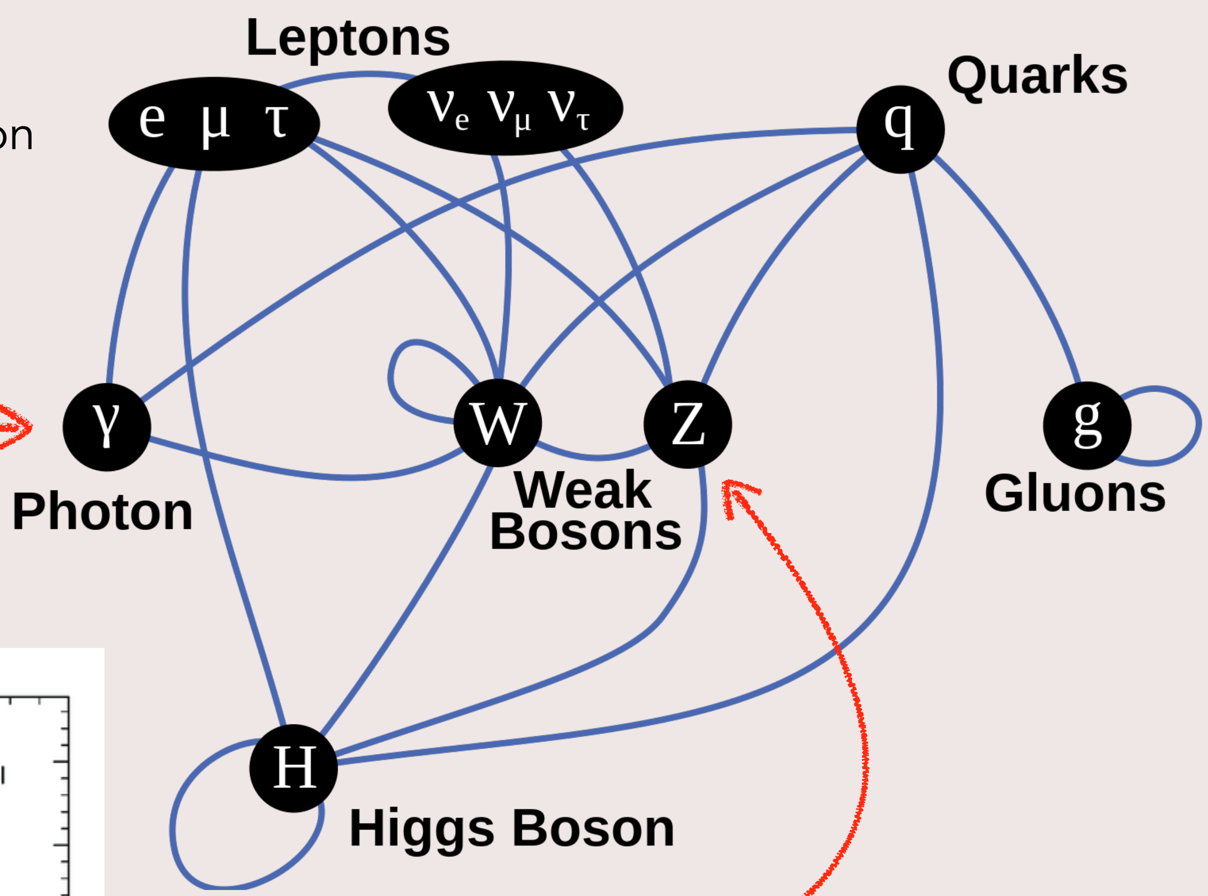
Introduction

- Higgs boson couples to all massive particles
  - Only particle that distinguishes between fermion generations

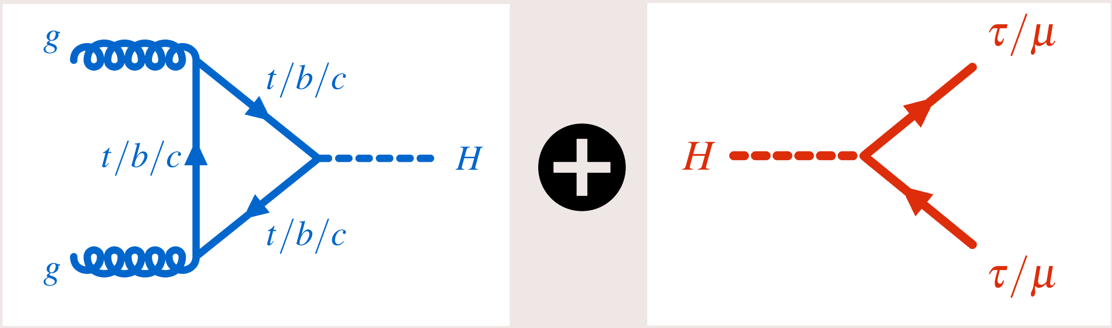
- At the time of the discovery, we knew very little about the Higgs boson





Higgs at the LHC

- Experimentally, we have access to two main things:
  - How many Higgs bosons were **produced** (and how)
    - Based on characteristics of production mode
  - How those Higgs bosons **decayed**



- Production and decay rates contain a lot of information about the Higgs boson (and beyond?)
  - Sensitive to couplings
  - Any deviations we find could be signs of NP
  - The constraints we can place can be re-interpreted as constraints on BSM scenarios
  - Kinematic dependence of these processes can be quite sensitive to BSM effects

- Over 30 separate measurements per experiment; rates varying over several orders of magnitude

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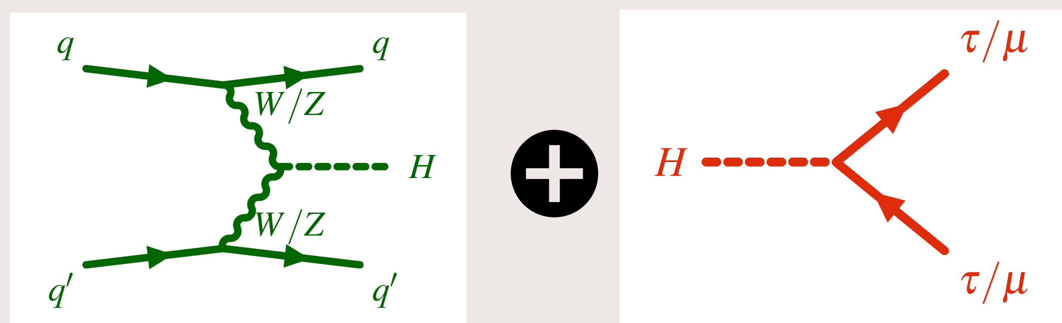

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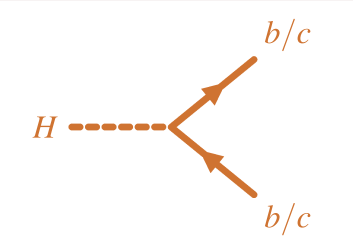
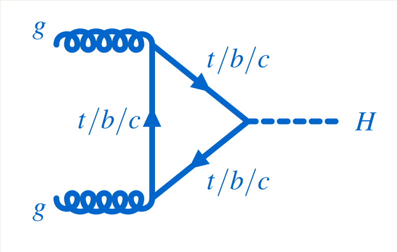
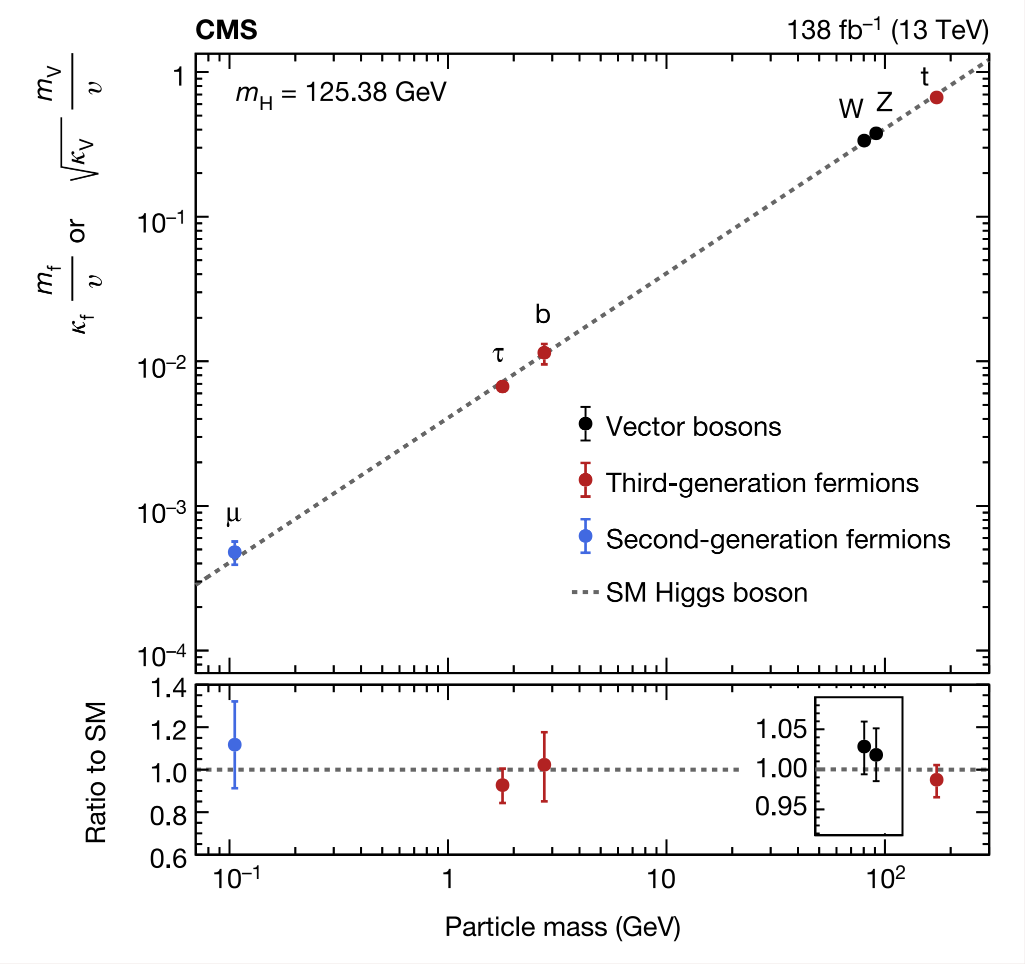
Combination

- Combining all production and decay mode measurements is where this becomes really interesting…
- Let's use the example of Higgs couplings to *b* quarks
  - The *b* quark is fairly heavy (strong coupling) but lighter than the Higgs so accessible as a decay product
  - Easiest way to study it is to look at this decay:



  - However, there's also:





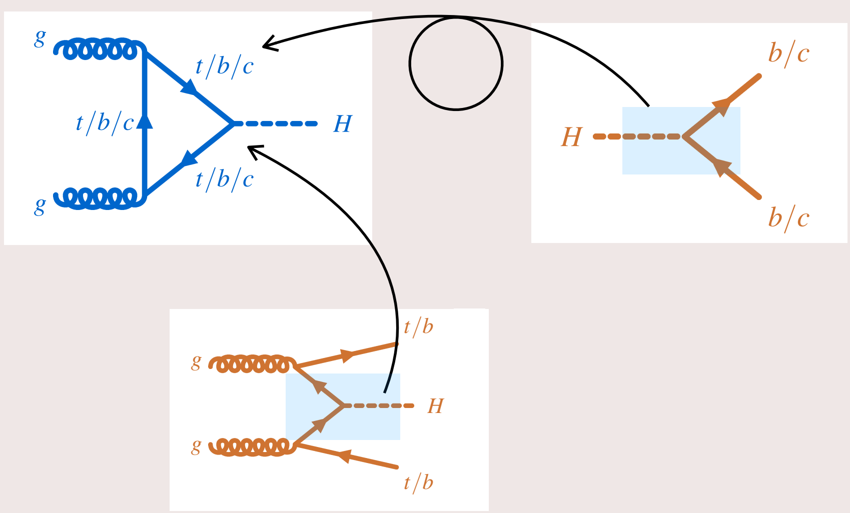
  - Together: more precise measurement of coupling (can take advantage of strengths of each!)

Higgs couplings

Best picture we have to date of the Higgs boson and its interactions with other particles

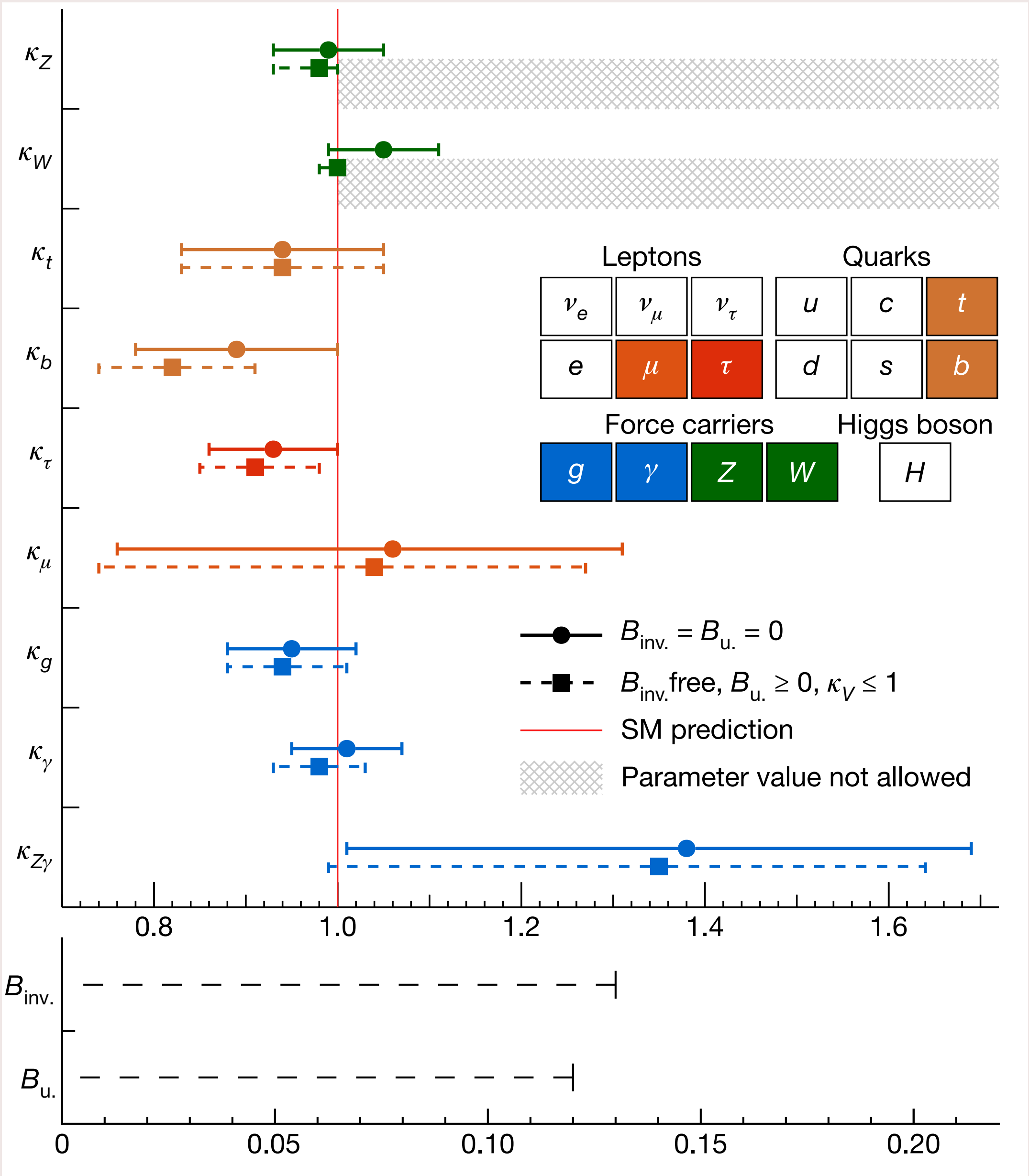
- Together, gives more precise measurement of coupling (current precision: 5% on vector boson couplings, 7-12% for fermion couplings) and total Higgs production rate (current precision: 6%)
  - Established coupling to bosons, top/bottom-type fermions, third (and hints of second) generation

- Are loop processes consistent with SM-only? *(Yes*)*



- Is there any way there could be other particles that couple to the Higgs? *(Yes, e.g. invisible particles could account for at most ~13% of Higgs decays*)*
- Are measurements consistent with assumption of only one Higgs boson? *(Yes*)*

**Within our current experimental precision/techniques*



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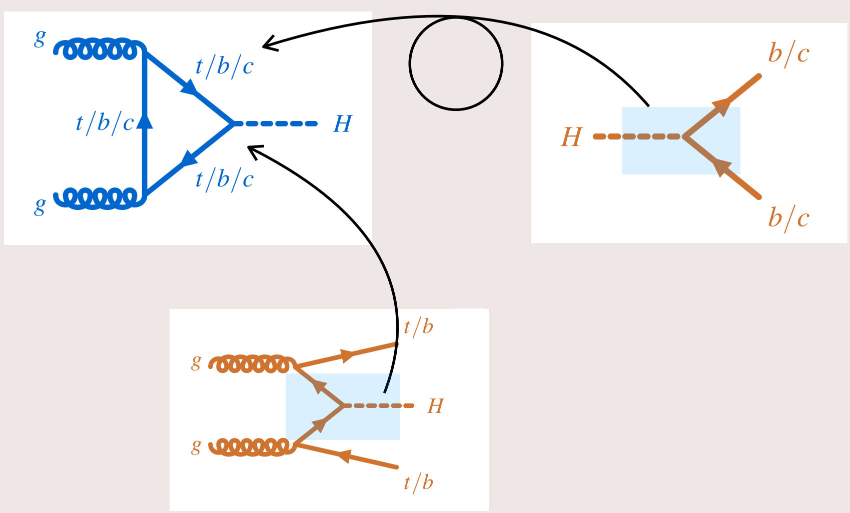

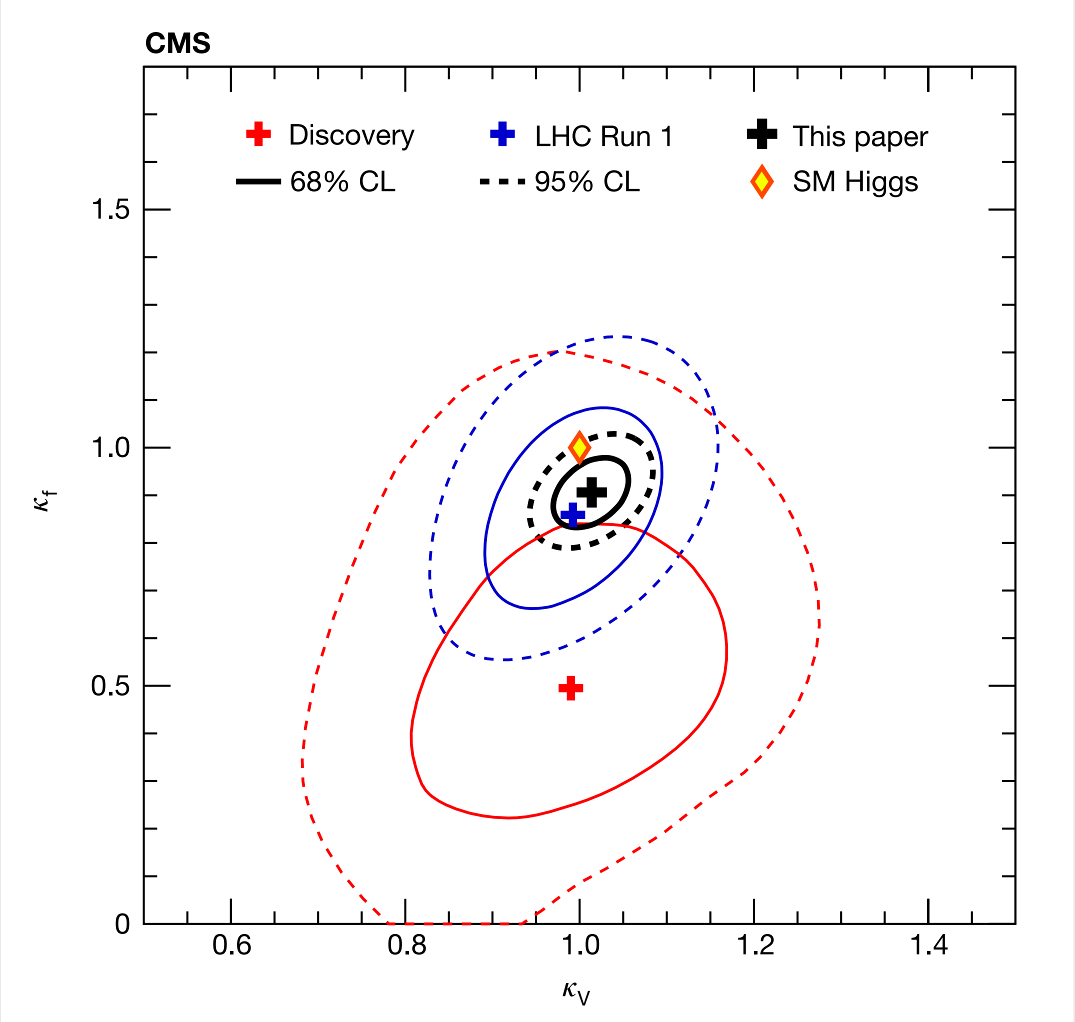

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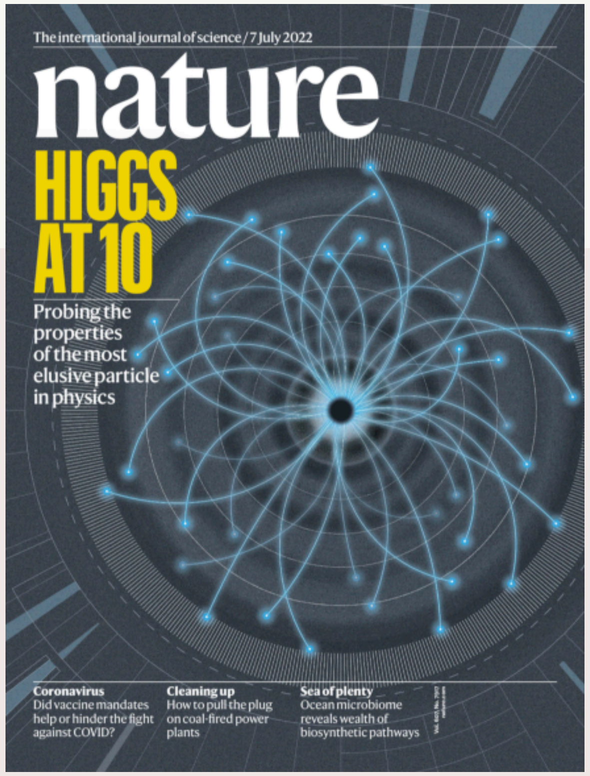
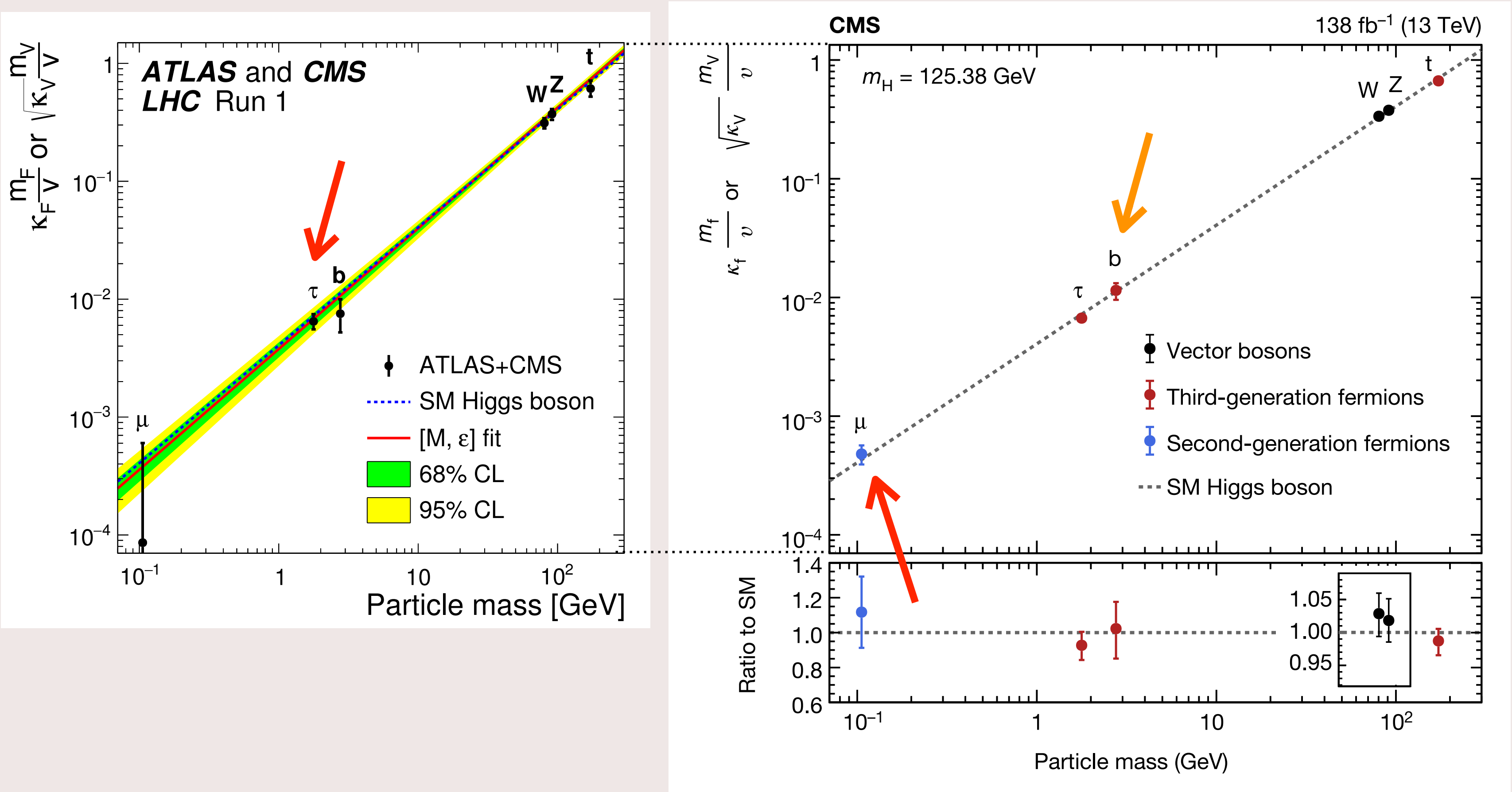
Conclusion



- A particle consistent with the Higgs boson was discovered 10 years ago by the ATLAS and CMS Collaborations
  - Early measurements had large (statistical) uncertainties
  - Many properties untested, lots of phase space available for BSM
- **10 years later:**
  - Precise measurement of Higgs production cross-sections and decay rates
    - Observation of all main LHC production processes: ggF, VBF, WH, ZH, $t\bar{t}H + tH$
    - Increased precision on $H \to \gamma\gamma$, ZZ, $W^{\pm}W^{\mp}$, $\tau^{+}\tau^{-}$, observation of $H \to b\bar{b}$, $\geq 2\sigma$ on $H \to \mu\mu$, $Z\gamma$
  - Interpretation of results in terms of couplings to other particles (κ framework)
  - Study of kinematic properties of Higgs production processes (STXS framework)
  - Study of Higgs self-coupling
- Presented in two separate publications in Nature (ATLAS, CMS)

Run 1 → Run 2

- The LHC recently finished its second run
    - ~30 times more Higgs bosons than in Run 1 (9M per experiment, but only about 0.03% are experimentally accessible)
- In most cases results improved by much more than expected
    - Improvements in all areas: particle reconstruction/identification/calibration, analysis design, machine learning, theory predictions, …
    - Extensive involvement from us not just in the combination but also in all of these areas!
- Much more knowledge about the Higgs boson + significantly tighter constraints on BSM



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