Higgs - BSM aspects

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Overview

- *Possible* discussion topics over the next 10 days - split into two parts
- “Precision”
  - Trilinear and quadrilinear Higgs couplings
  - Constraining the CP structure of the Higgs couplings
  - Higgs & EFT
  - Characterizing Higgs boson production and decay
  - Lepton flavour violation in the Higgs sector
- “Novelties”
  - Exotic decays of the 125 GeV Higgs boson
  - Additional Higgs bosons at low/high mass: uncovered parameter space
  - Naturalness:
    - Gaps in searches for traditional models (SUSY, compositeness)
    - Searches for cosmological triggers (new Higgs bosons and v-like leptons)
    - Unexpected signatures of naturalness

Overview

- *Possible* discussion topics over the next 10 days - split into two parts
- “Precision”
  - Trilinear and quadrilinear Higgs couplings

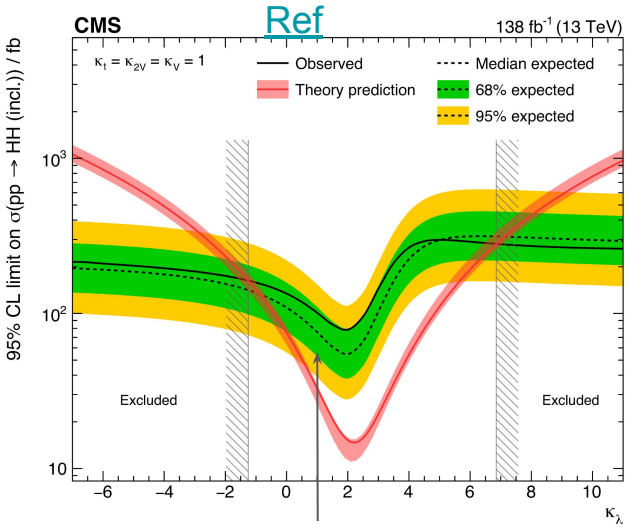
These are just possible starting points for discussion - we’re looking forward to your ideas!

- Naturalness:
  - Gaps in searches for traditional models (SUSY, compositeness)
  - Searches for cosmological triggers (new Higgs bosons and v-like leptons)
  - Unexpected signatures of naturalness

Trilinear & quadrilinear Higgs couplings

Experiments constraining $\kappa_\lambda = \lambda_3/\lambda_3^{SM}$ through HH production…

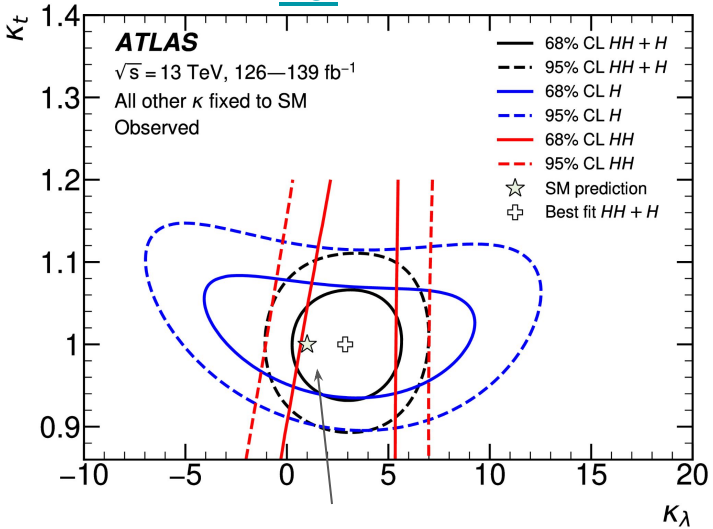
Ref



SM

… and through H and HH production

Ref



SM

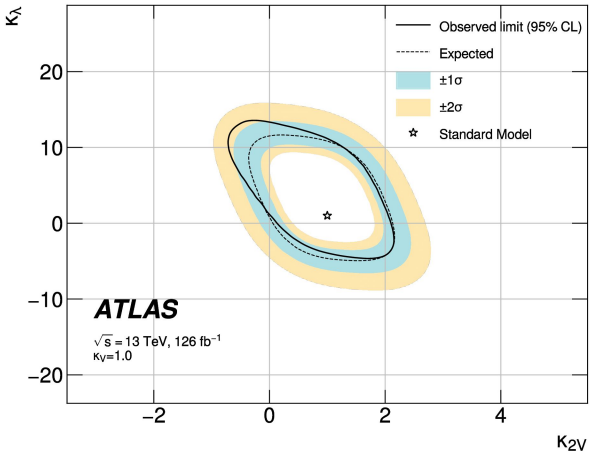
λ3 contributions to other (SM) processes ?

λ4 <> HHH → not for a while; what else can we do?

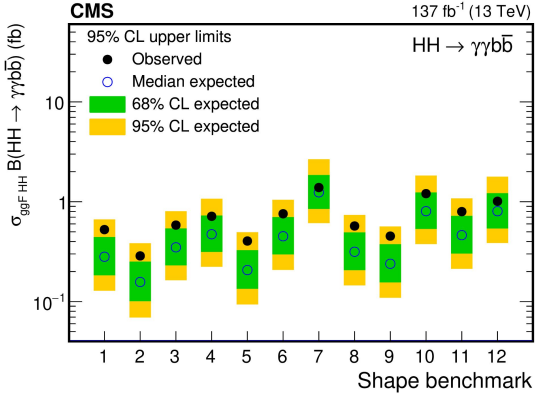
Probing non-SM values of λ? (e.g. different κλ dependence of subdominant HH production modes - anywhere else?)

…

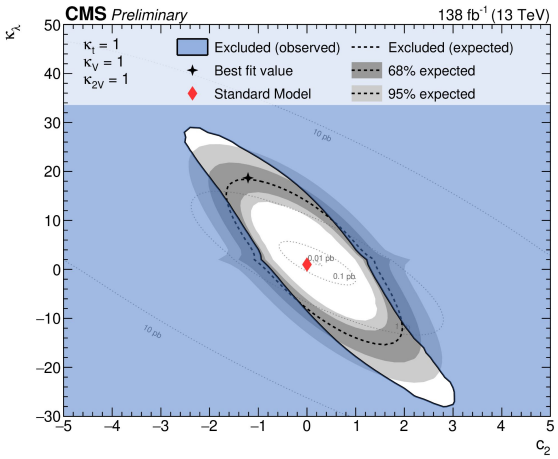
Di-Higgs: other couplings



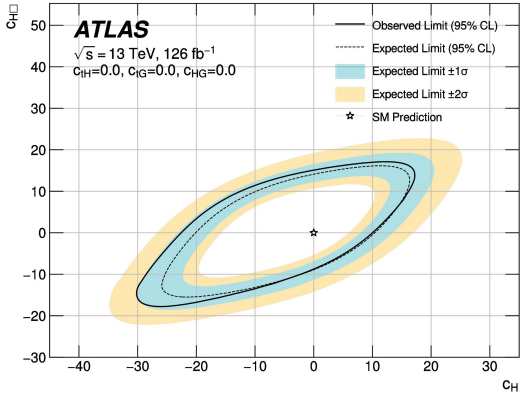
Interpretations in the parameter space κ_λ, κ_t, κ_V, κ_{2V}, c_2



EFT benchmark scenario limits & SMEFT interpretations

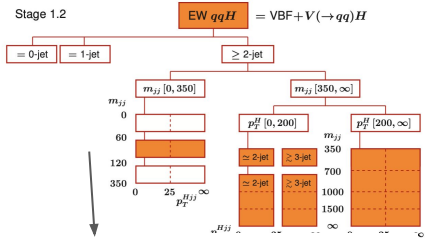


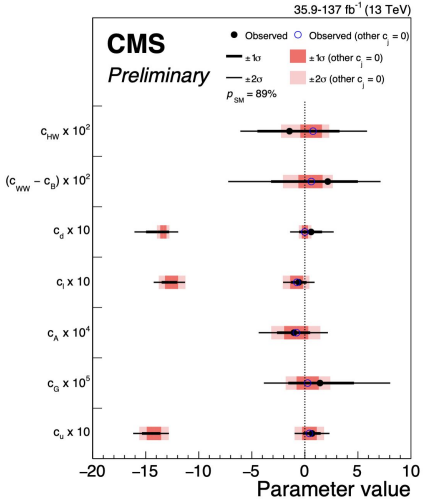
Can we go beyond this?



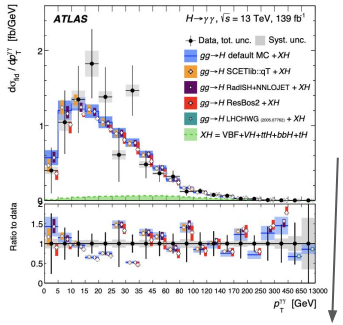
Higgs & EFT

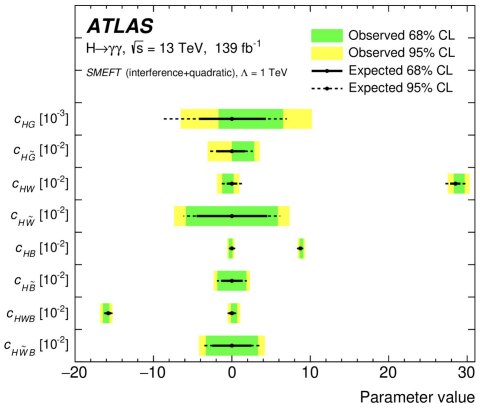
STXS, differential measurements, and…



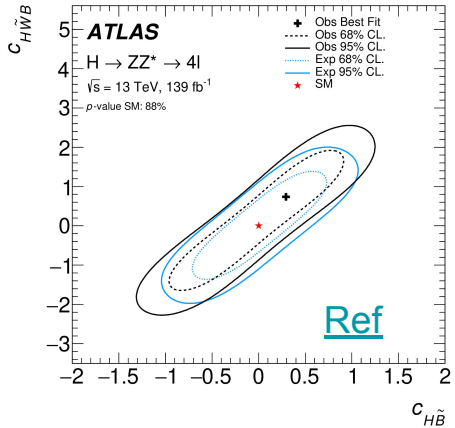


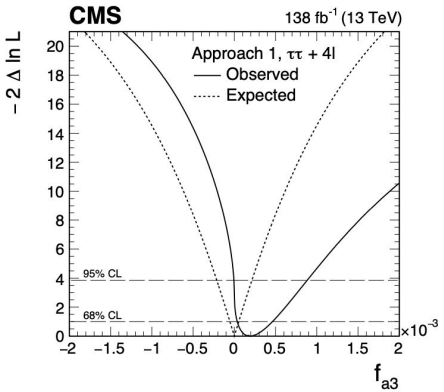
NB: converging on SMEFT with common (LHCWG) parameterization





…dedicated direct interpretations





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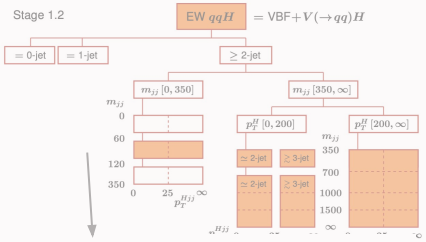
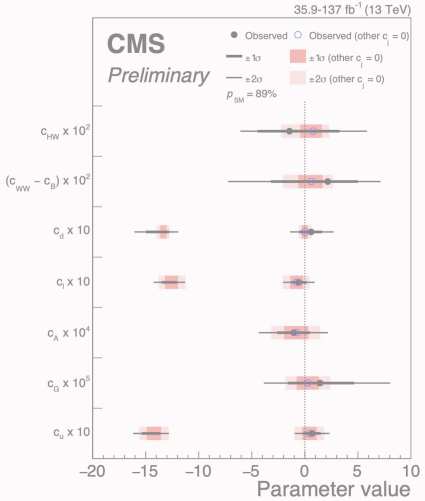
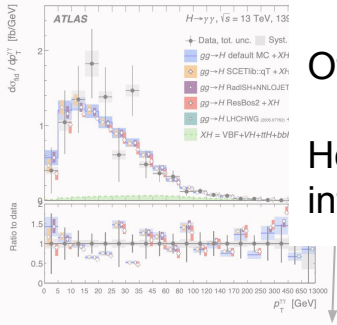
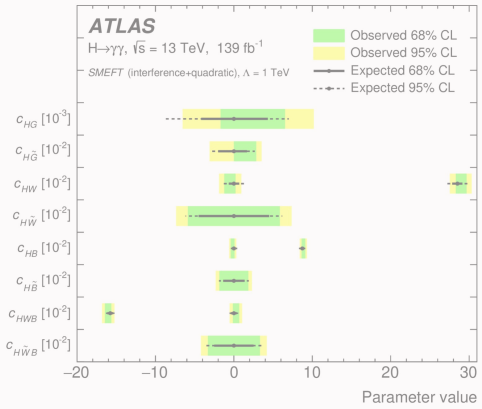






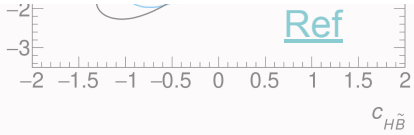


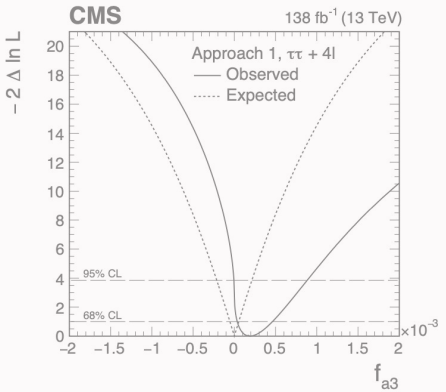
NB: converging on SMEFT with common (LHCWG) parameterization

Is STXS sufficient for this purpose?

Other distributions to be measured?

How to benefit from dedicated interpretations (reusability)?



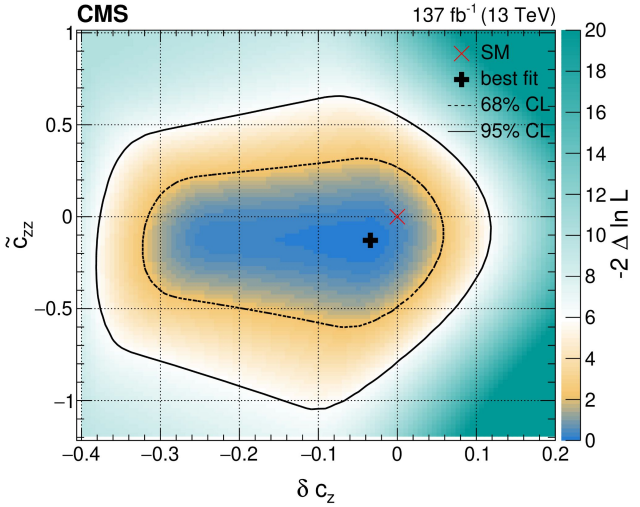


Higgs: CP structure

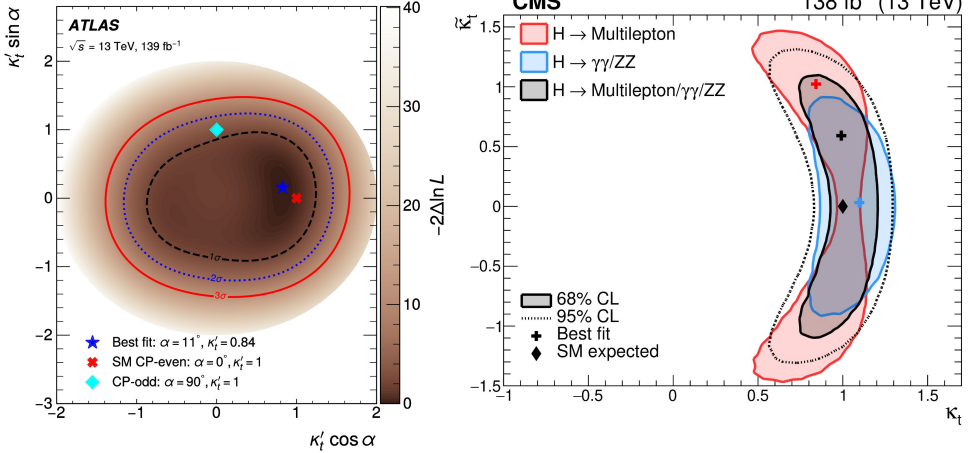
Probed in ttH, Hττ, Hgg, HVV couplings

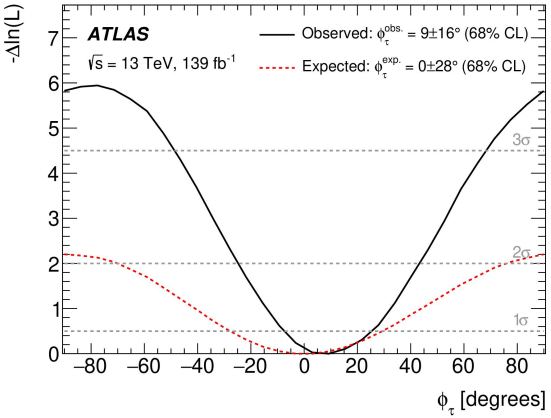
- Mapping to BSM models?
- Re-usability?

HVV



ttH

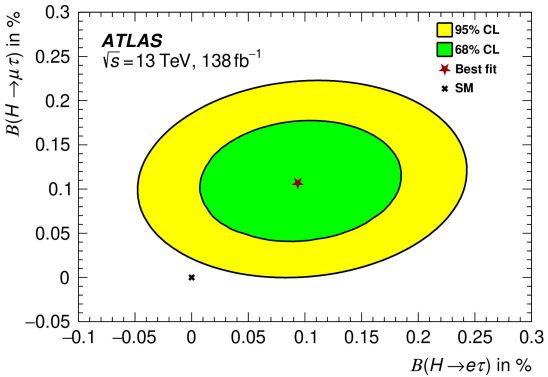


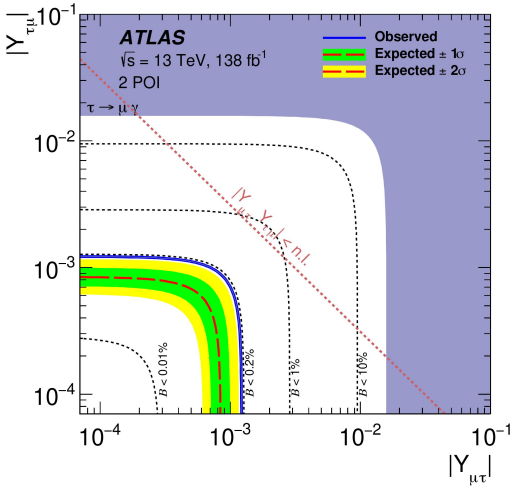


Hττ

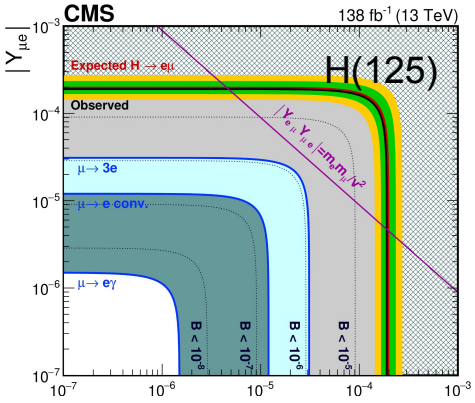
Lepton flavour violation in the Higgs sector

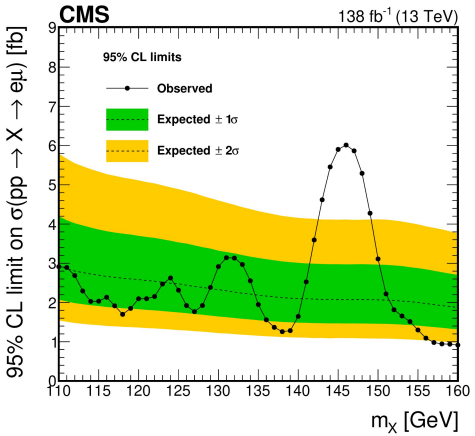
Searches for H(125)→eτ, μτ





Searches for H→eμ





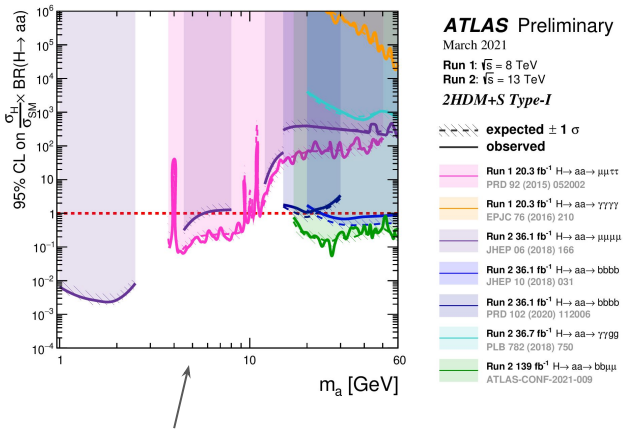
Both experiments cover H→μτ,eμ,eτ (not just at 125 GeV!)

- Model interpretations?

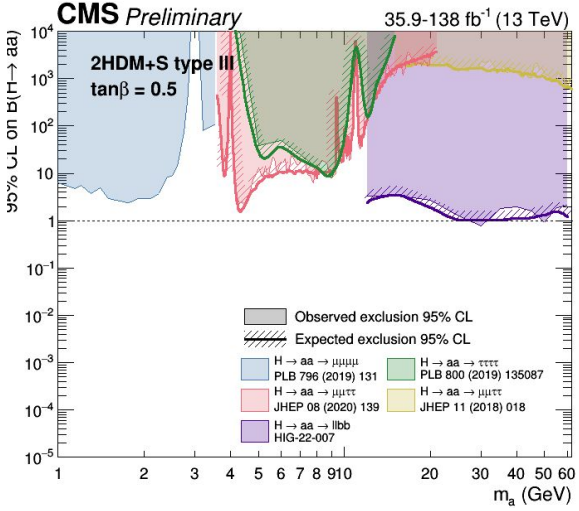
- Putting together different constraints?

Exotic Higgs boson decays

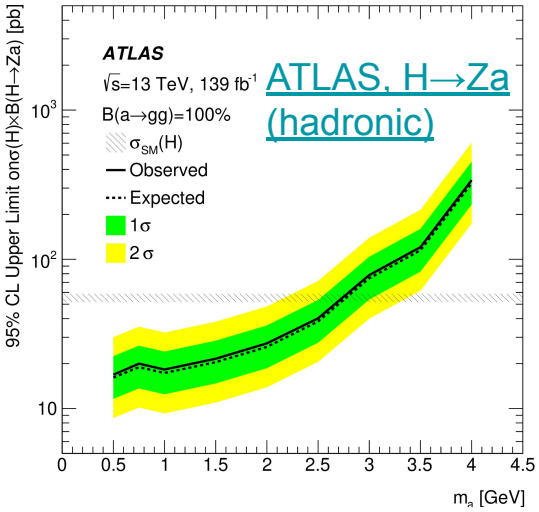
- Just some examples of what's studied in the experiments.



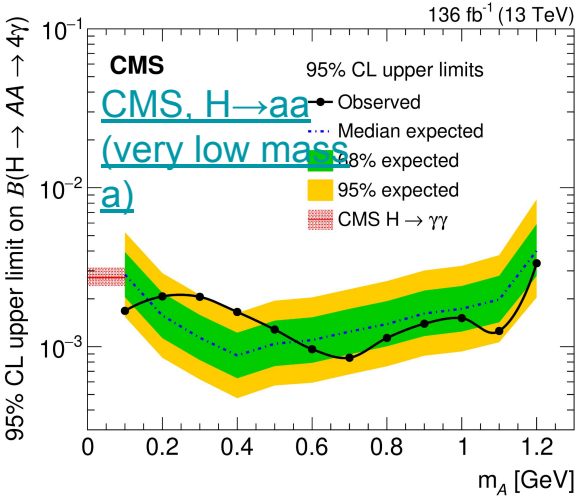
ATLAS 2HDM+S type I summary



CMS 2HDM+S (type II) summary



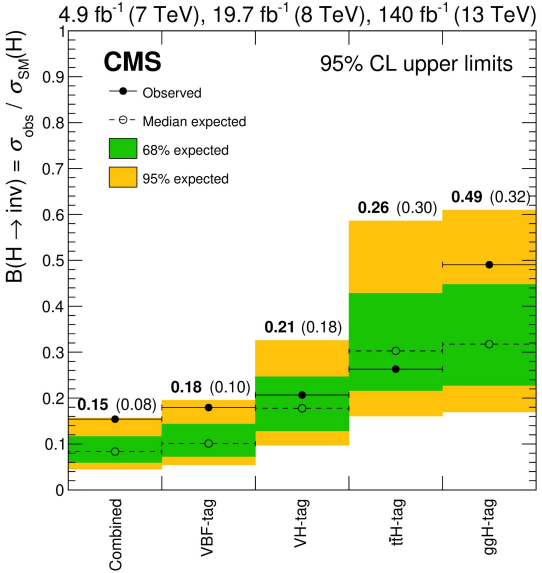
ATLAS, H→Za (hadronic)



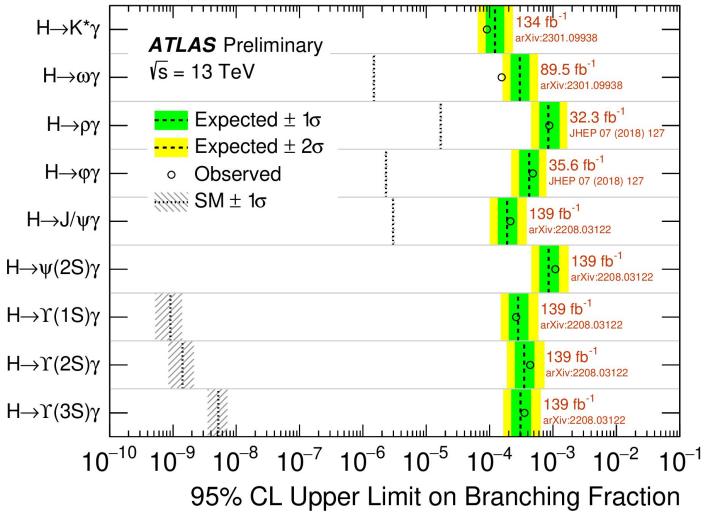
CMS, H→aa (very low mass a)

Exotic Higgs boson decays

- … Some more examples of what's studied in the



H→invis. (w/ DM interpretations)

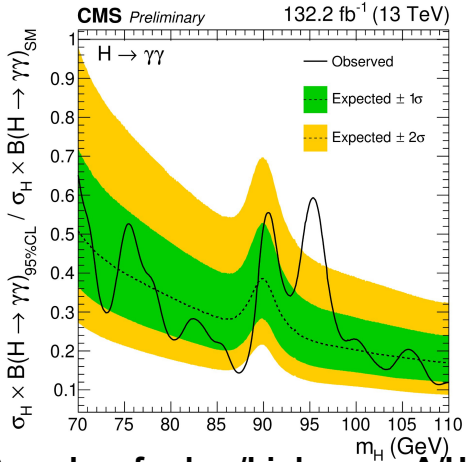


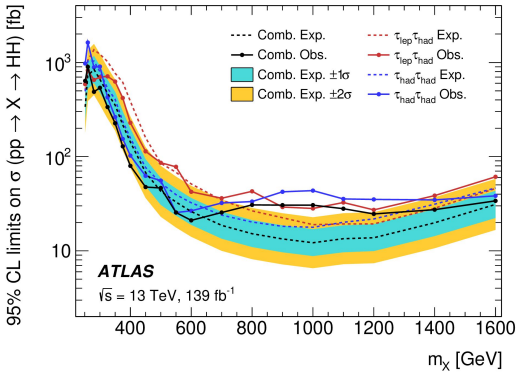
H→Meson+γ summary

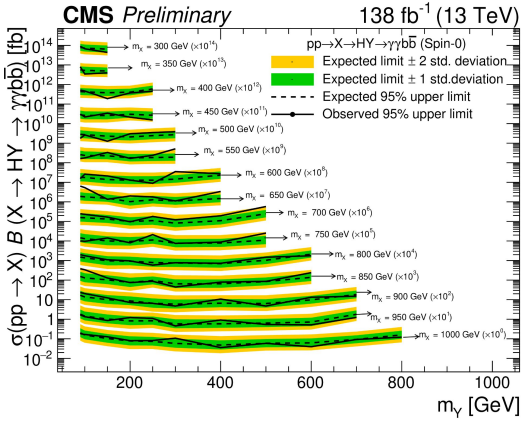
Not all the searches interpreted in a specific model → something to be gained?

Missing interesting channels?

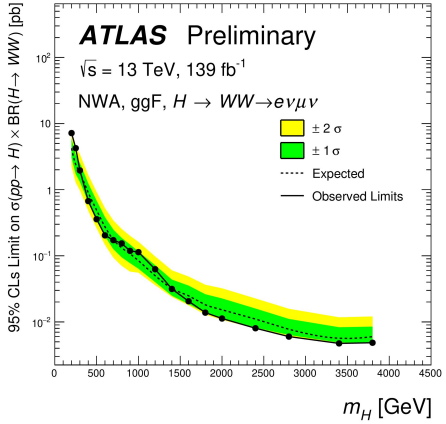
Searches for additional Higgs bosons



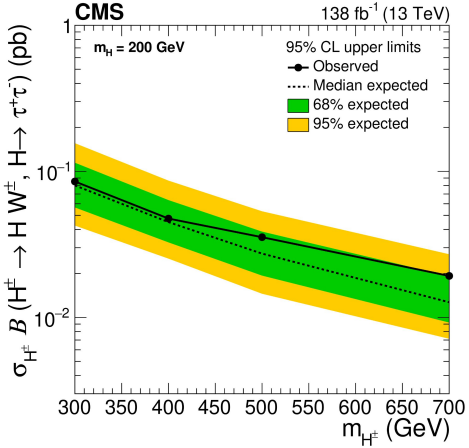




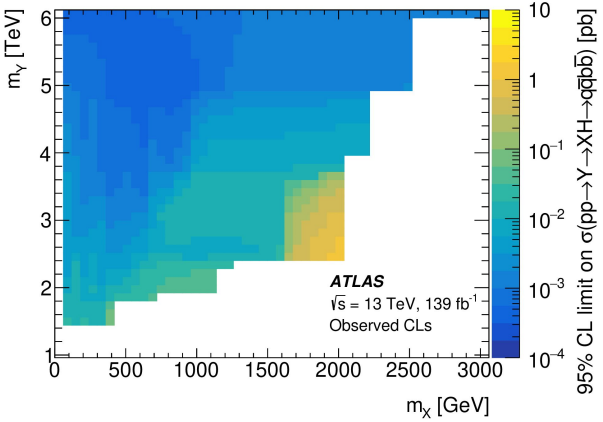
Searches for low/high mass A/H in 'SM' Higgs decay channels



Searches for X->H(125)H(125)

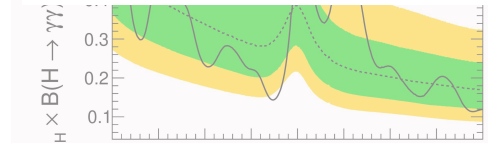


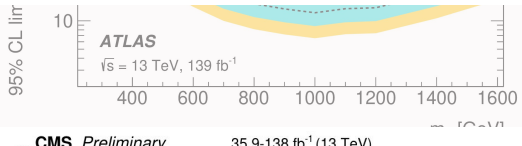
X->H(125)Y searches

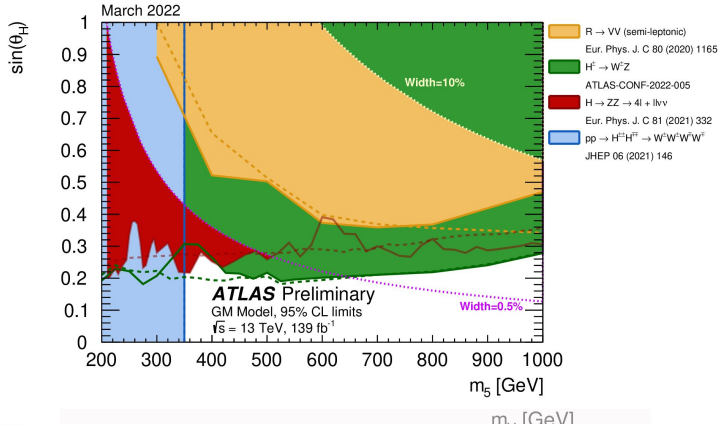


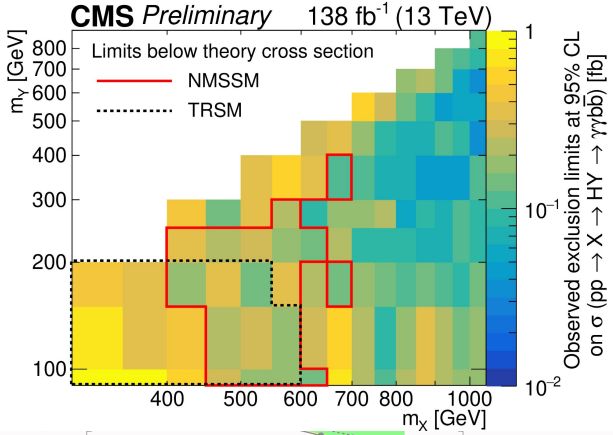
Searches for additional Higgs bosons

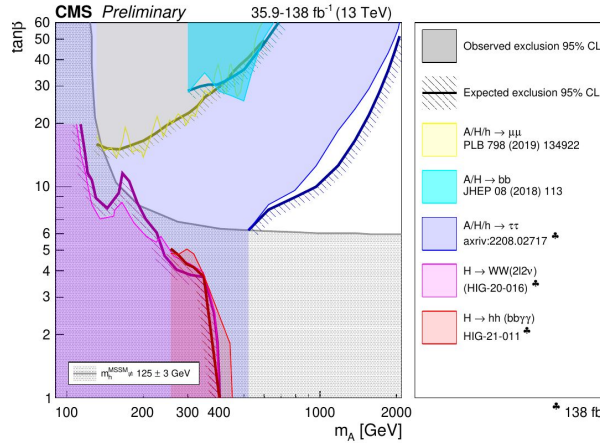
Only a snapshot of the experimental search programme for additional Higgs bosons
- Are we missing any phase space?
- Model interpretations: do not have benchmarks for all models
- Information provided by experiments: enough?

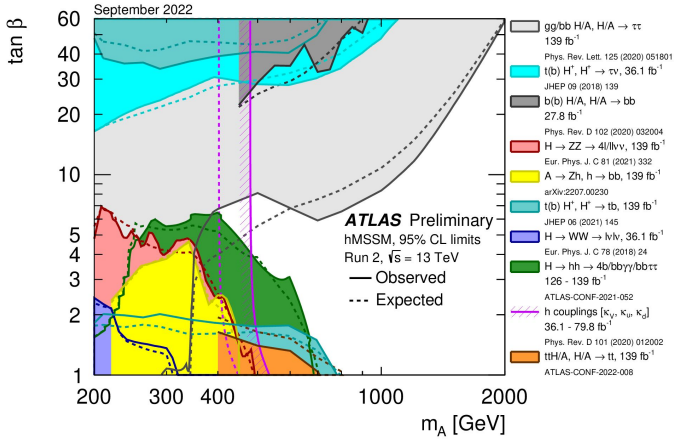


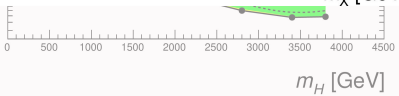


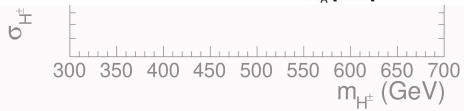












Dissemination of experimental results

Digitized information (usually) available:

- Measured value + interval, or limits
- Covariance matrix
- Rivet routine
- Profiled likelihood (multidimensional if needed) or simplified likelihood
- Efficiencies/acceptances
- …

Sufficient?

Sufficiently easy to find and use?

Higgs Mass Squared

$$m_h^2 |H|^2$$

WEAK FORCE, STRUCTURE OF NUCLEI, COMPLEX CHEMISTRY, …

SYMMETRY-BASED ESTIMATE

$$m_h^2 \sim \frac{y_t^2 M_{\rm Pl}^2}{16\pi^2}$$

Symmetry~10^{34} Experiment

ASSUMPTIONS (=SOLUTIONS)

The Higgs mass is ultimately calculable

No new symmetries exist below the Planck scale

We have extrapolated the Planck mass from low energy measurements

We have implicitly treated quantum gravity as an ordinary quantum field theory where high energy particles can leave only very specific imprints at low energy.

The Higgs mass is ultimately calculable

The best theory of quantum gravity that we have (string theory) has this property and we do not know of any options that do not have it.

Food for discussion (#0): Do you dare to try?

No new symmetries exist below the Planck scale

Relaxing this assumption leads to our favorite explanations: supersymmetry and scale invariance (compositness). However …

No new symmetries exist below the Planck scale

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Food for discussion (#1): Where are we with experimental bounds?

1. Translate simplified models results to “natural SUSY” parameter space
2. And to natural composite top partners parameter space (Rattazzi, Matsedonskyi, Wulzer, et al.)
3. How about WIMPs?

We have extrapolated the Planck mass from low energy measurements

Relaxing this assumption leads to large extra dimensions (not warped) or models with large number of particles. The qualitative expectation of new physics close to the Higgs mass remains

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Food for discussion (#2): Where are we with experimental bounds and phenomenological calculations?

ASSUMPTIONS (=SOLUTIONS)

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Food for discussion (#3): How theoretically crazy is it to relax the assumption?

1. UV/IR Mixing: the only concrete model (Craig, Koren) breaks Lorentz at O(1)
2. Quantum gravity as a phase correction to the S-matrix makes sense in 2D (Dubovsky, Gorbenko, Mirbabayi). Any remote possibility of generalizing to 4D?

Food for discussion (#4): What else?

1. Non-invertible symmetries in 2D can explain apparent tunings of relevant operators. Any hope it might it teach us something about 4D?
2. ….

Food for discussion (#5): What about the Multiverse?

Currently it's the most concrete explanation that we have besides a new symmetry

It can have signatures testable at HL-LHC and future colliders (trigger operators)

Summary

- Still lots to do in the BSM Higgs sector

- Looking forward to hearing your ideas and the discussions over the next days!