LHCHWG3: BSM Higgs

With input from the excellent subgroup talks yesterday

WG3 convenors:
Abdollah Mohammadi (University of Wisconsin)
Jana Schaarschmidt (University of Washington)
Shufang Su (University of Arizona)
Zhen Liu (University of Minnesota)
Jan Steggemann (EPFL and ETH Zurich) (outgoing)

LHCHWG Meeting November 2021

WG3: Group Overview and Contacts

Twiki: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG3

- **MSSM** ATLAS: Tim Barklow, CMS: Afiq Anuar,
  Theory: Michael Spira, Pietro Slavich, Emanuele Bagnaschi
- **Extended Higgs (Neutral and Charged)**
  ATLAS: Lidija Zivkovic, Nikos Rompotis, CMS: Mariarosaria d'Alfonso, Santeri Laurila,
  Theory: Tania Robens, Rui Santos, Shufang Su
- **Exotic Higgs Decays** ATLAS: Verena Martinez, CMS: Georgia Karapostoli, LHCb:
  Lorenzo Sestino,Theory: Brian Shuve, Matthias Konig
- **NMSSM** ATLAS: Nikos Rompotis, CMS: Daniel Winterbottom,
  Theory: Ulrich Ellwanger, Margarete Mühlleitner, Nausheen Shah
- **bbH** ATLAS: Tim Barklow, CMS: Chayanit Asawatangtrakuldee,
  Theory: Michael Spira, Marius Wiesemann

Mandate:

- Develop benchmark scenarios for interpreting Higgs searches in BSM models
- Identify missing signatures and assess the feasibility of new Higgs searches
- Develop/maintain/combine tools for the calculation of physical observables
- Ensure a correct description of theory issues in experimental publications

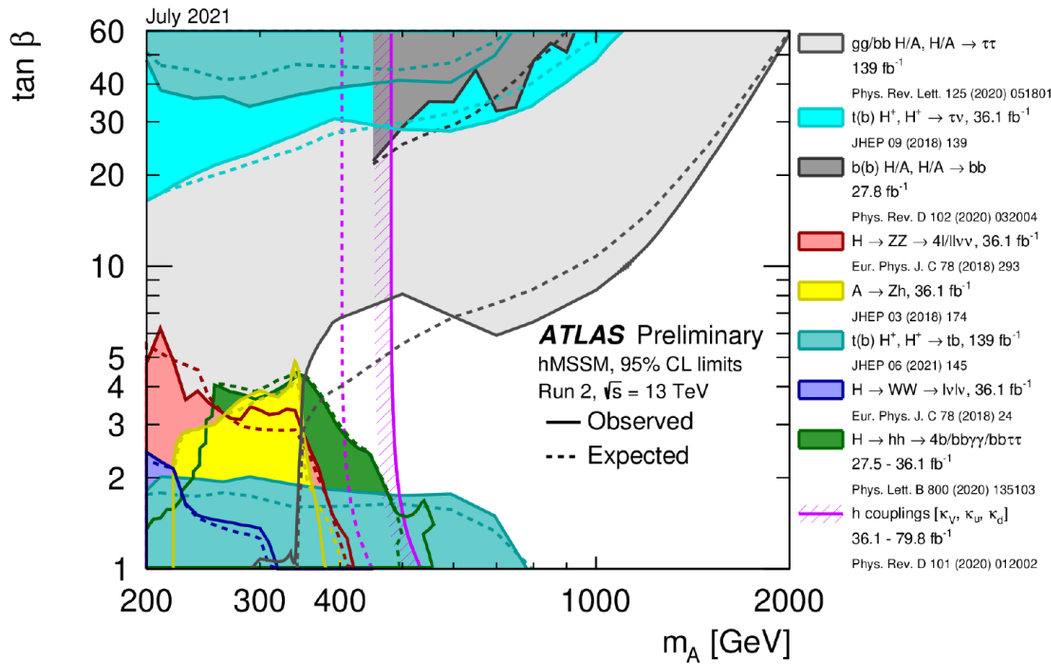
MSSM

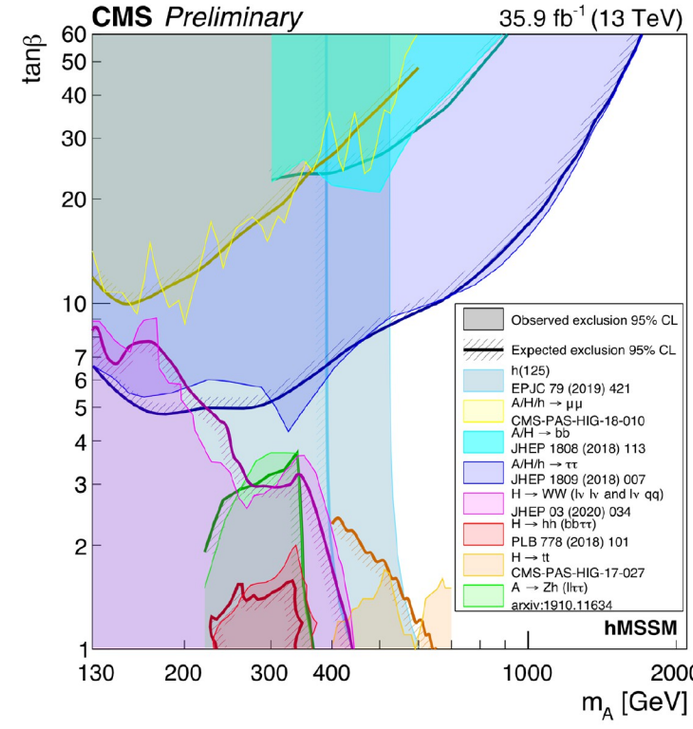
- Group provides benchmarks scenarios and recommendations for MSSM interpretations
- **Twiki:** https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWGMSSMNeutral
- The benchmarks have evolved with time, especially since the Higgs discovery
- **Currently supported and recommended benchmarks:**

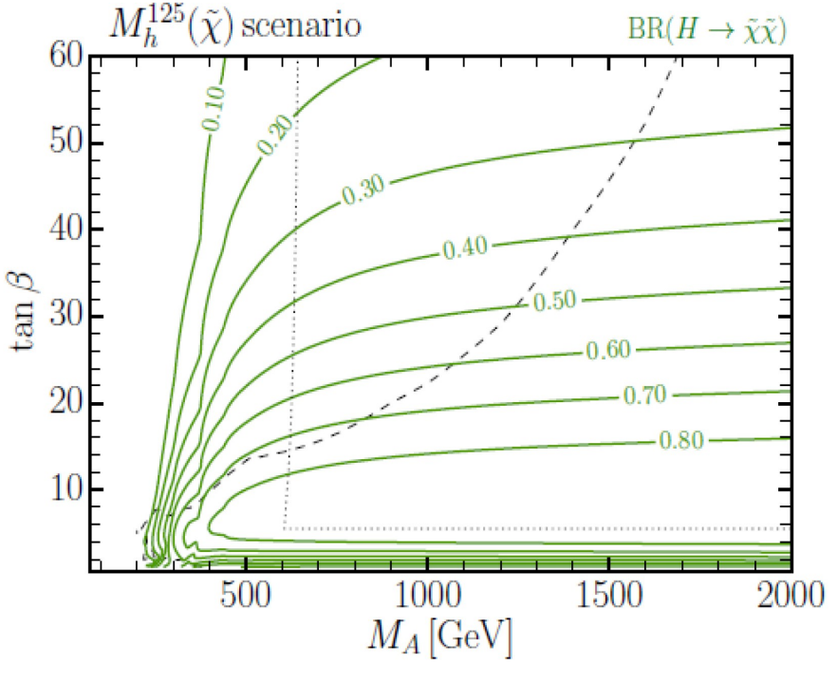
  - mh125 scenarios (1808.07542)
    Mh125, Mh125($\widetilde{\chi}$), Mh125($\widetilde{\tau}$), MH125(alignment), Mh125(alignment), $Mh_1$125(CPV)
  - μ<0 scenarios (2005.14536)
  - low tanβ EFT scenarios (1901.05933)
  - hMSSM (1307.5205)

- Latest activity: **Public Note draft** https://cds.cern.ch/record/2791954/
  to document the setup for the root files and their use. Comments are welcome!
- ROOT files will be released on Zenodo in the future
- Latest updates described in talk by Emanuele (p6) (updated tools, additional information)
- Also work ongoing to release recommendations for **Higgs pT reweighting**

MSSM







- Lots of MSSM results, covering huge parameter space
- Largely uncovered is „wedge“ region around tanβ~7 where cross section has a minimum and decay of the heavy Higgs bosons to SM particles is suppressed.
- Specific scenarios feature enhanced rates of Higgs decays to SUSY

→ Huge motivation to search for heavy Higgs decays to SUSY particles, but there are no experimental results :(

- Subgroup plans to provide information on SUSY decays to SM particles for each scenario

Extended Higgs

- Provides recommendations and benchmarks for a broad range of models:

  2HDM (in many variants: CP conserving or CP-violating, BGL, Inert, Fermiophobic, ...),
  also 3HDM, Georgi-Machacek, and other models, for charged and neutral Higgses

- Extensive discussion of benchmarks provided in YR4

- Group has expertise on a huge number of tools for cross section, BR and particle spectra calculations (see Rui's review at a previous LHCHWG meeting)

- Responsible to provide recommendations for the production of charged Higgs (for light, intermediate or heavy mass)

- Also addresses issues of width and interference effects.

Twiki: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG3EX

Mailing list: lhc-higgs-neutral-extended-scalars@cern.ch
(don't get confused, this group contains charged Higgs too!)

Extended Higgs

- The extended Higgs subgroup held 2 public subgroup meetings in 2021, with 28 diverse talks:

  https://indico.cern.ch/event/1050919/

  https://indico.cern.ch/event/1091117/

- This series of meetings will continue! Subscribe to the mailing list to get the announcements

- Current focus is mainly on 3 topics:

  - **Overlooked signatures**

    In particular: $pp \rightarrow H^{\pm} + h_{bsm}$ in various final states ($W + 4\gamma$ / 4τ / $4b$ / $2\mu 2\tau$, ...)

  - **Width and interference effects in BSM searches**

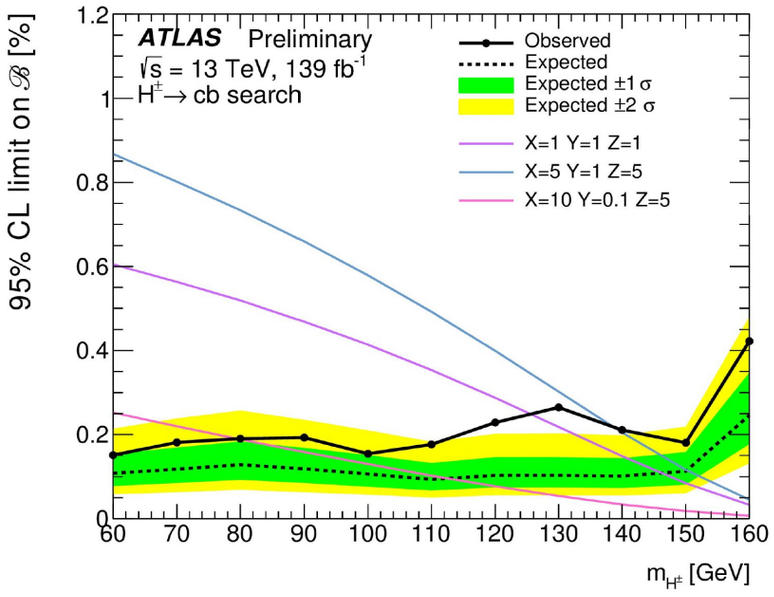
    Important topic, often neglected in searches by simply assuming generic narrow-wdith models

  - **Recasts**

    This entails reaching out to the LHC reinterpretation forum and learning from the expertise from SUSY and Exotics searches

Extended Higgs

$H^+ \rightarrow cb$:



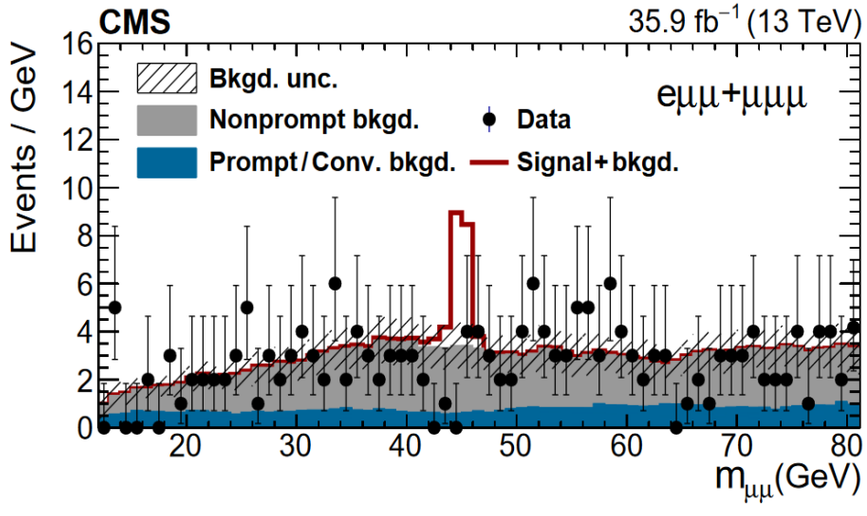
There were discussions yesterday about the **H^+ in the intermediate mass range** (mH^+~mtop, tbH and $t \rightarrow bH^+$ production modes interfere)

Public results on that from ATLAS and CMS only for $H^+ \rightarrow \tau\nu$ channel

Recommendations were released in 2016/17:
https://arxiv.org/abs/1607.05291 (Degrande et al)

Total cross sections at NLO, but differential cross sections at LO

$H^+ \rightarrow Wa$, $a \rightarrow \mu\mu$:



Theorists encourage searches for $H^+ \rightarrow W + h_{bsm}$

„the forgotten channel“ (https://arxiv.org/abs/2103.07484)

h_{bsm} can be heavy. In the available public results from ATLAS and CMS $H^+ \rightarrow Wa$, and a is light and decays to two muons.

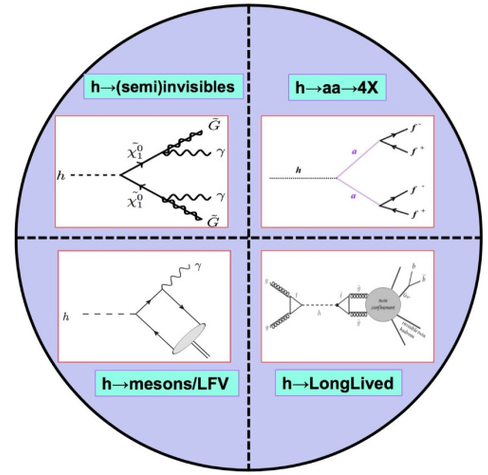
Exotic Higgs Decays

- **Twiki:** https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGExoticDecay

- Goal of this group is to provide recommendations for H(125) decays to BSM states

- **Sub-domains:**

  - Prompt exotic decays
  - Long-lived exotic decays
  - Invisible Higgs Decays
  - Lepton Flavor Violation
  - Rare Decays



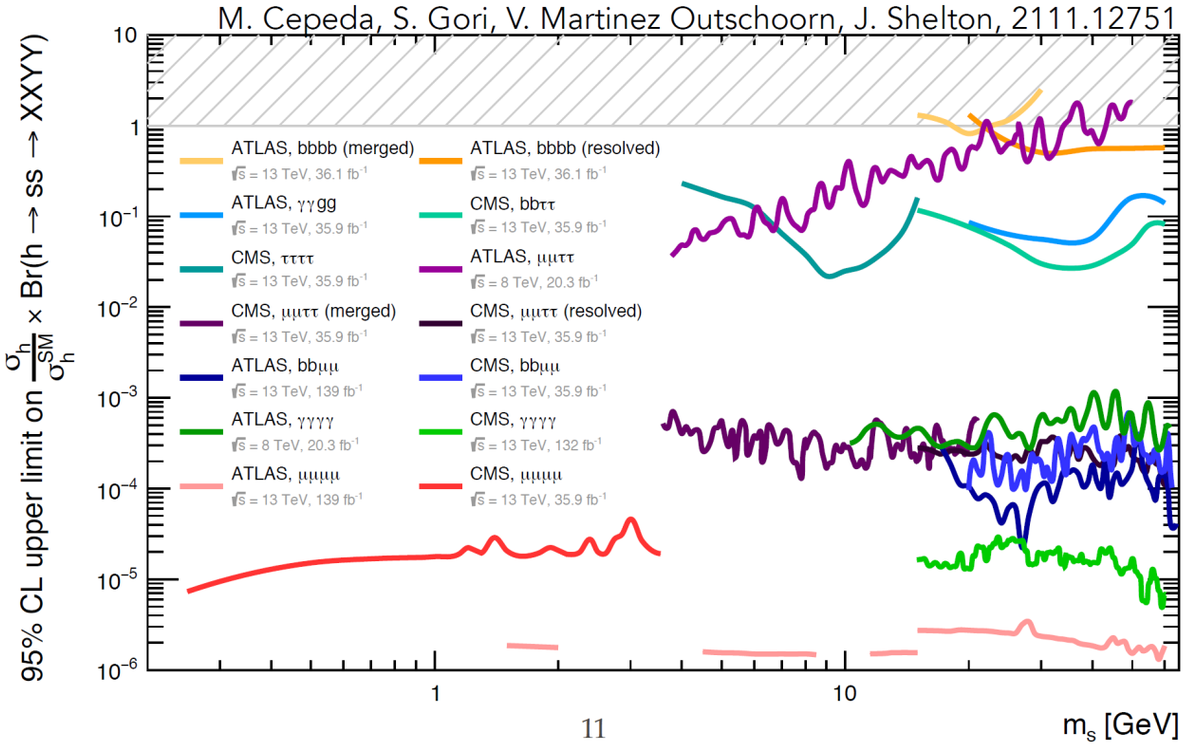
- **New ideas/developments:**

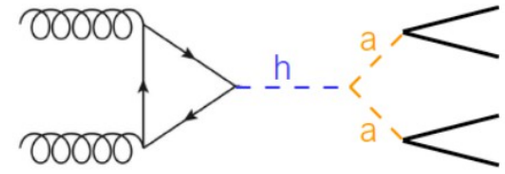
  - New benchmarks for hidden sectors and „dark showers“ (number of dark particles, non-isolated from each other) (2103.01238)
  - Higgs decays leading to soft unclustered energy patterns („SUEP“) (eg. 1612.00850)

- **Tasks of the subgroup:**

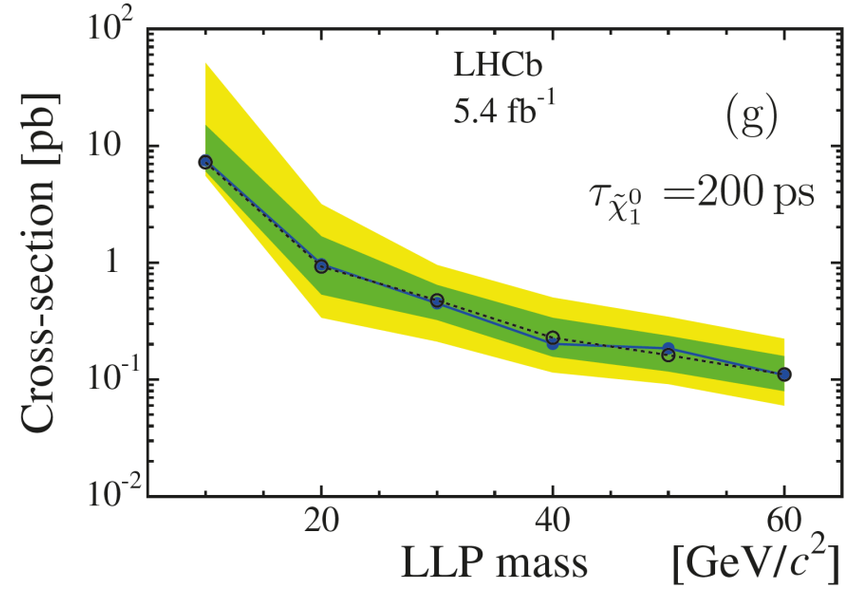
  - Benchmarks for ALPs to photon/gluon decays, and for semi-visible decays (ff+MET) (ongoing)
  - Improved calculation of decays of Higgs to mesons or vector bosons (ongoing)
  - Reinterpretation of prompt decays to LLP scenarios (planned)

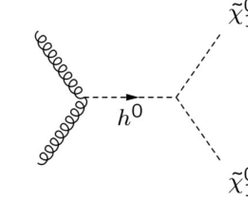
Exotic Higgs Decays





H → 2 LLPs → muon + 2q 2110.07293





Gaps in the experimental searches:

- Fully hadronic decays (eg. H → gggg/ggbb, …)
- Semi-visible decays
- J/Ψ and Υ regions (difficult)
- Cascade decays
- Long-lived particles in final states with lepton/photons, or low pT signatures

bbH

- Since SM cross section is small (talk), the group evolved from a cross group to a BSM subgroup
  bbH is an important production mechanism for type-II models like the MSSM, and other BSM models

- A large number of **experimental results** available from ATLAS and CMS, eg.
  Search for bH→bbb (ATLAS, CMS), A/H→ττ (ATLAS, CMS), A/H→μμ (ATLAS, CMS)

- Information on previous group activities from earlier LHCHWG talks by Abdollah and Marius

- **Twiki page with state-of-the-art recommendations:**
  https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWGBBH

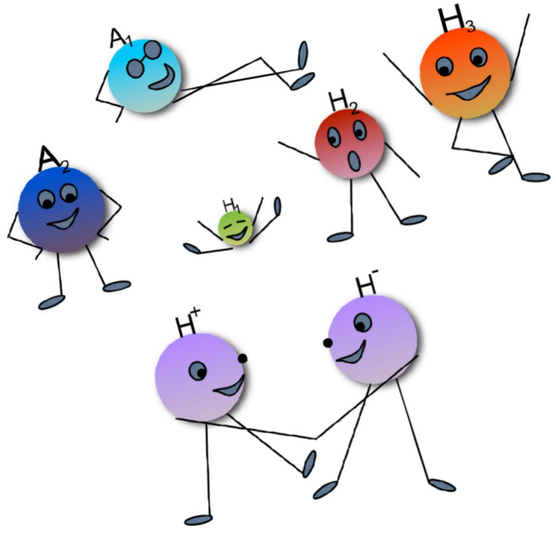
  It contains a lot of useful information, eg.
  - best possible predictions for bbH production (merging 4FS NLO with 5FS NNLO calculation)
  - Information on bbH generators (ie. the matching of 4FS NLO calculation to parton showers)

- Extensive theoretical documentation in YR4 available

- No active developments ongoing, but the group remains as a **„point of contact“** for specific questions: lhc-higgs-bbh-convener.cern.ch

- One possible direction forward is the calculation of NLO interference effects between different BSM Higgs bosons and between signal and background with identical final states, but this cannot be done before new NLO calculations become available

NMSSM



Twiki: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWGNMSSM

Next-to-MSSM
2 complex Higgs doublets + complex singlet field

7 Higgs bosons: H_1, H_2, H_3, A_1, A_2, H^+, H^-

Theoretically well motivated (eg. solves the μ–problem)

However, experiments rarely target specific NMSSM signatures

Recent progress in the NMSSM fixed order spectrum calculations reported in talk by M. Mühlleitner

- computation of $((a_t+a_\lambda+a_\kappa)^2)$ corrections to CP-violating NMSSM Higgs masses at zero external momentum, in the gaugeless limit, in mixed OS-DRbar renormalisation scheme

- Regularisation of IR divergences

- New corrections are implemented in NMSSMCALC

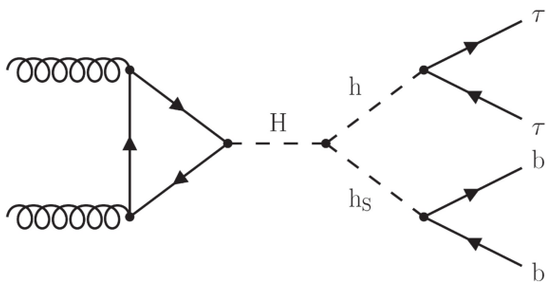
- Corrections are a few percent and slightly reduce theory uncertainty

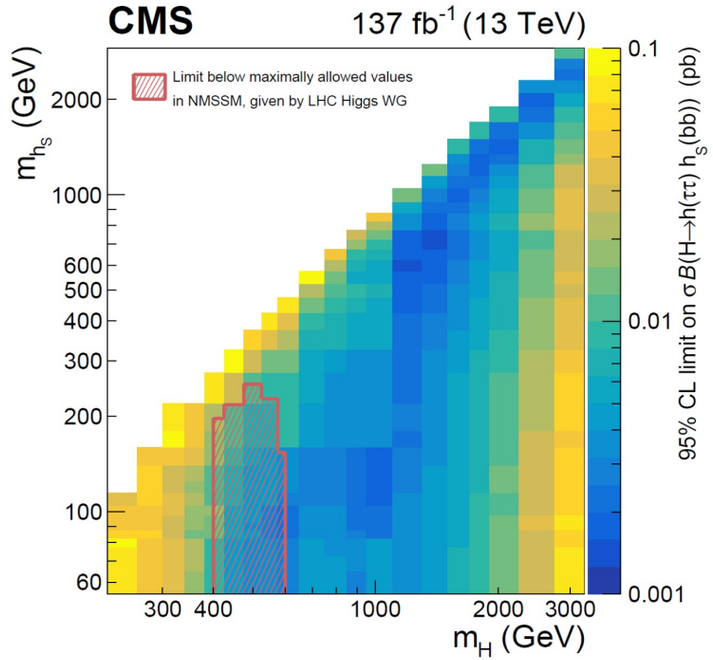
- Large impact on Higgs mixing, ie. they affect the Higgs couplings to SM particles

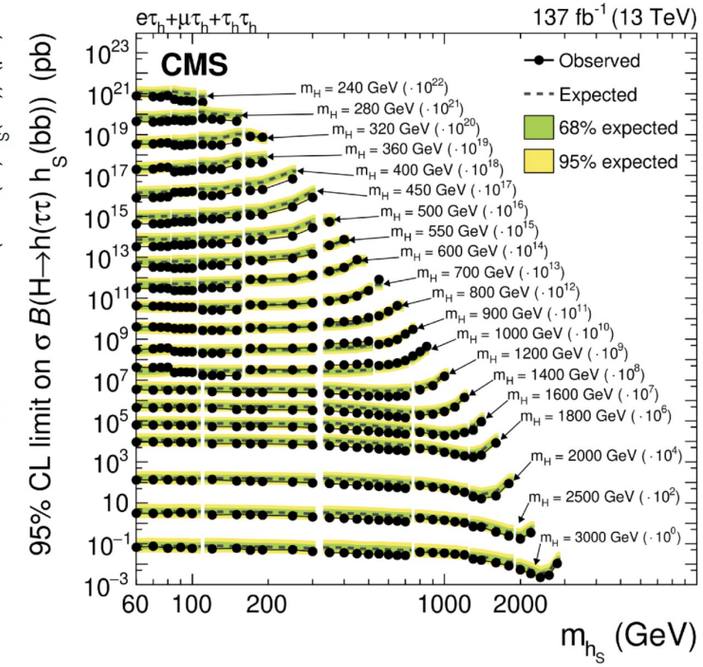
NMSSM: $H_1 \rightarrow h_2 h_3$

CMS search for $H \rightarrow h_s + h_{125} \rightarrow bb\tau\tau$

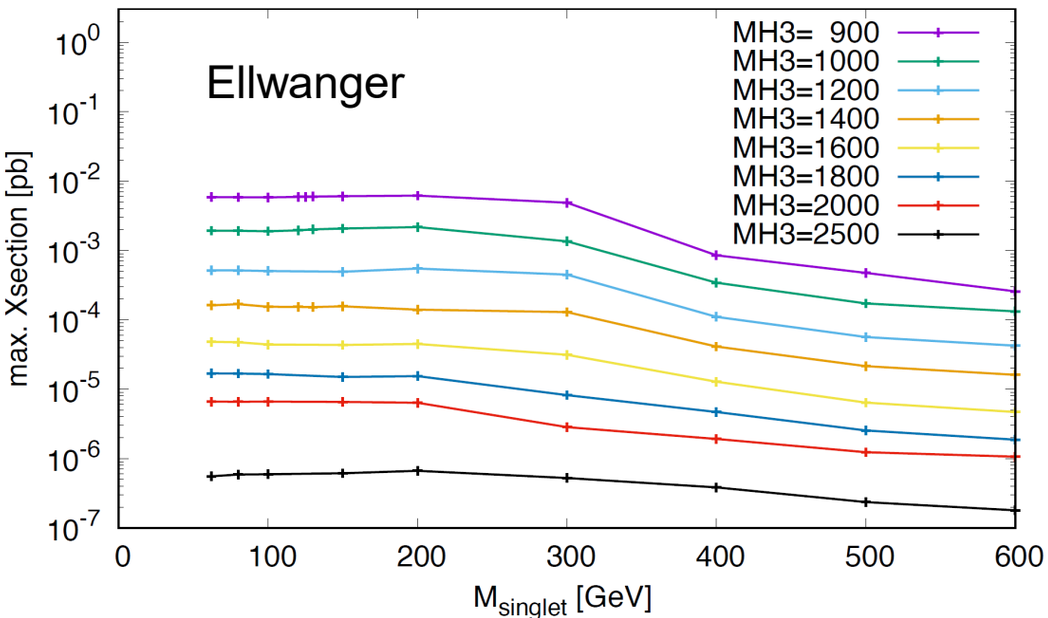
H is a new heavy Higgs (240-3000 GeV),
Hs is a new lighter Higgs
(60-2800 GeV),
H125 is the observed Higgs







ggF -> H_3 -> H_{SM} + $H_{singlet}$ -> bb + bb



Huge opportunity here

DiHiggs searches are popular, and can be used to constrain the NMSSM !

(or discover BSM physics – but that's not garanteed)

Experimentalist need to move on from $H \rightarrow h_{125} h_{125}$ and consider asymmetric decays

Acknowledging Contributions to WG3

- We started a **record of all previous (sub-)convenors**:

WG3 Conveners		Subgroup Conveners									
		Exotic Higgs Decays		Extended Higgs Sector		MSSM		NMSSM		bbH	
Zhen Liu	2019-Current	Lorenzo Sestini	2017-Current	Rui Santos	2015-Current	Michael Spira	2010-Current	Nikos Rompotis	2018-Current	Michael Spira	2014-Current
Jan Steggemann	2020-Current	Georgia Karapostoli	2020-Current	Santeri Laurila	2021-Current	Pietro Slavich	2012-Current	Nausheen R. Shah	2019-Current	Marius Wiesemann	2014-Current
Jana Schaarschmidt	2021-Current	Brian Shuve	2020-Current	Tania Robens	2021-Current	Timothy Barklow	2019-Current	Timothy Barklow	2021-Current	Abdollah Mohammadi	2019-Current
Shufang Su	2021-Current	Matthias Konig	2020-Current	Nikos Rompotis	2021-Current	Artur Gottmann	2020-Current	Afiq Anuar	2021-Current	Timothy Barklow	2021-Current
Pietro Slavich	2017-2021	Verena Martinez	2021-Current	Jana Schaarschmidt	2016-2020	Emanuele Bagnaschi	2020-Current	Eric Feng	Previous	Lei Zhang	2019-2021
Anna Goussiou	2018-2020	Jesse Shelton	2013-2020	Jan Steggemann	2019-2021	Andrew Gilbert	2017-2020	David Strom	Previous		
Stefania Gori	2017-2019	Cecile Caillol	2017-2020	Mariarosaria d'Alfonso	2021-2021	Guillermo Hamity	2017-2019	Rachel Yohei	Previous		
Liron Barak	Previous	Ljiljana Morvaj	2018-2020	Lidija Zivkovic	2019-2021	Allison McCarn	Previous	Ullrich Ellwanger	Current		
Nikos Rompotis	Previous	Zhen Liu	2017-2019	Healther Logan	2015-2021	Stefan Liebler	Previous	Maggie Mühlleitner	Current		
Roger Wolf	Previous	Stefania Gori	2013-2017	Shufang Su	2015-2021	Rebecca Lane	Previous	Florian Staub	Previous		
Ian Low	Previous	Abdollah Mohammadi	2015-2017	Ulrich Ellwanger	2015-2021	Daniel Winterbottom	Previous	Abideh Jafari	Previous		
Maggie Mühlleitner	Previous	Shikma Bressler	Previous	Xiaohu Sun	Previous						
David Sperka	Previous	Abdollah Mohammadi	Previous	Raffaele Gerosa	Previous						
Mario Pelliccioni	Previous	Roger Caminal	Previous	Martin Flechl	Previous						
				Maria Ubiali	Previous						
				Marco Zaro	Previous						
				Xiangyang Ju	Previous						

- We also write **supporting letters** highlighting exceptional contributions than can aid in applications (signed by all WG3 convenors)

→ With such efforts, we acknowledge past efforts and also hope to encourage future engagements in the WG3, to keep the community alive

- We encourage **public subgroup meetings**, where people can come and present their work
  Excellent example: Extended Higgs subgroup meetings, which received a lot of interest.

- Encourage writing LHCHWG Official Reports (More information on LHCHWG documentation)

Summary & Plans

- Continue our progresses on MSSM, NMSSM, 2HDM;
  strengthen our established experiment–theory connections
- Continue with organized discussions on extended Higgs physics,
  also inviting contributions from newcomers
- (potentially) Expand the WG3 expertise and organize discussions on Dark Sector
  and BSM Higgs
- (potentially) Establish a connection to the LHC BSM reinterpretation forum
- Make ourselves visible at Snowmass?
- Very open to requests from experiments (benchmarks, recommendations, …),
  but also support requests from theorists to experiments (ie. publishing likelihoods etc.)
- Need to start preparing for LHC Run-3 change of energy, many recommendations
  need to be updated