WG3 BSM Higgs Outlook and Plans

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Introduction

The subgroup twiki with detailed information:

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

- MSSM
- nMSSM
- Extended Higgs (Charged and Neutral)
- Exotic Higgs
- bbH/bH

MSSM

Tim Barklow
Afiq Anuar
Emanuele Bagnaschi
Michael Spira

Mostly taken from Emanuele's talk

The goal of this subgroup is:

- To clarify theoretical aspects important for experimental studies
- To provide benchmark scenarios to be used by experimental collaborations
- To discuss possible future developments on probing the MSSM H sector at the LHC

MSSM tasks accomplished

Task	Status	Timescale ↑
Update of the ROOT files to the latest HDECAY version	Complete	July 2022
Update of the ROOT files to the latest HDECAY version	Complete	December 2021
Update of the ROOT files with new quantities (e.g. trilinear self-coupling of the SM-like Higgs)	Complete	December 2021
Update of the hMSSM ROOT file to the same cross-section setup of the other scenarios	Complete	December 2021
Release of the ROOT files on Zenodo	Complete	December 2021
Public note describing the ROOT files setup	Complete	December 2021
Update of the ROOT files of EFT scenarios with the inclusion of the SM predictions	Complete	July 2021
Release ROOT files for mh125 variants with negative μ	Complete	December 2020
Update of the ROOT files (SM BRs, **HDECAY** update, **FeynHiggs** proper version)	Complete	December 2020
Provide updated ROOT files for end RunII analyses	Complete	End 2018
Provide benchmark scenario for low $\tan\beta$ using EFT approach	Complete	End 2018
Provide new MSSM benchmark scenarios	Complete	Sept 2018
Update SM parameters for MSSM calculations to be consistent with YR recommendations for SM calculations	Complete	Sept 2018

Most notably:

- The group published a note on “Benchmark Scenarios for MSSM Higgs-Boson Searches at the LHC” for 8, 13, and 14 TeV XS in 6 (mh125) + 6 scenarios (https://cds.cern.ch/record/2791954/)
- Versioning of the Zenodo record is used – please cite the exact version that you use in your study

MSSM tasks in progress/planned

Task	Status	Timescale ↑
Keep an eye on potentially missing signatures	In progress	Continuous
WG support to the release of experimental likelihoods	In progress	Continuous
Prioritize channels according to importance for end of LHC run2/3 or HL-LHC	In progress	Continuous
A/H decay to SUSY states and corresponding ROOT files	Planned	2023
Higgs $p_{\perp}^{\phi}$ public note	Planned	2023
Provide description and common tool for BSM Higgs $p_{\perp}^{\phi}$ calculation @ NLO+PS precision for gluon fusion	Planned	2023
Include 13.6 TeV cross sections in the ROOT files	In progress	Early 2023
Switch to PDF4LHC21 for the cross sections in the ROOT files	In progress	Early 2023

Main efforts:

- ❑ Provide the cross-section at 13.6 TeV
- ❑ Update the cross-section root files with new PDF4LHC21
- ❑ Present a separate set of root file with different BRs for different SUSY channels(Currently, all BRs to SUSY are summed in a single histogram)
- ❑ Provide description and common tool for BSM Higgs P_T^{ϕ} calculation

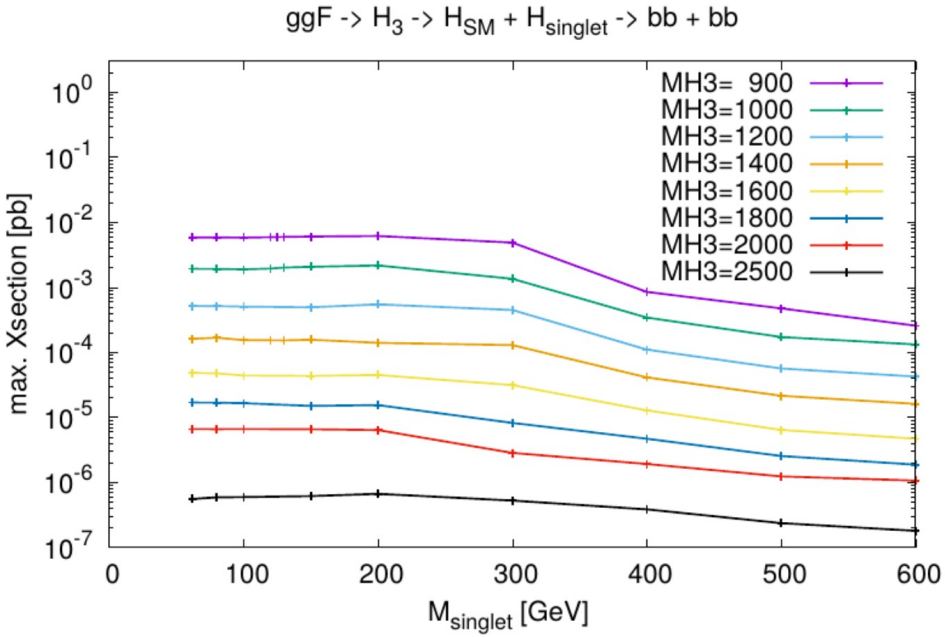
nMSSM

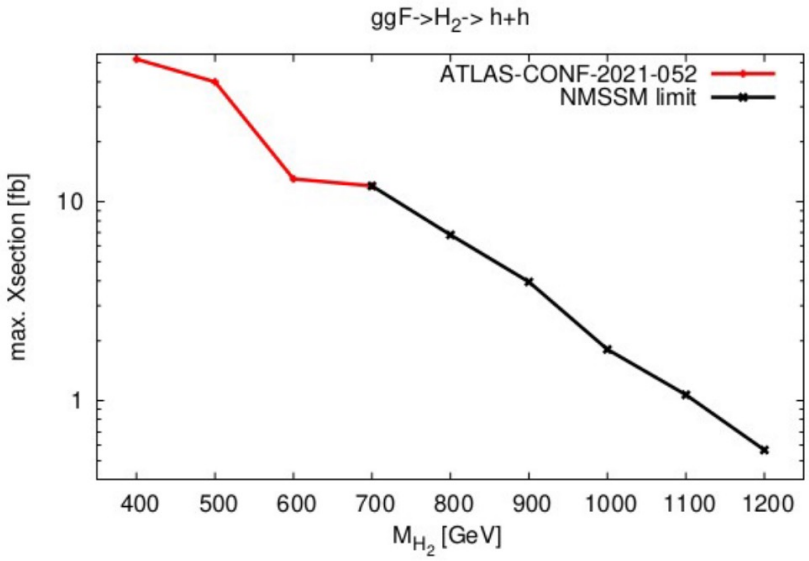
Nikos Rompotis
Daniel Winterbottom
Ulrich Ellwagner
Margarete Mühlleitner
Nausheen Shah

Mostly taken from Nikolaos's talk

- Over the past years the group plan has gradually transitioned from providing benchmark scenarios (similar to MSSM) to maximum XS times BR for specific signatures.
- More focus on multiHiggs final state & cascade-like signatures than just light pseudoscalar Higgs bosons

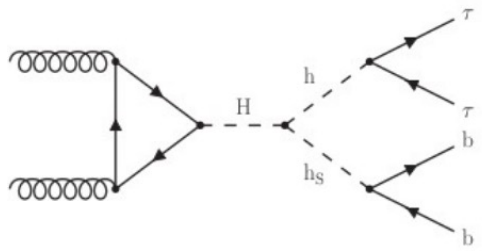
Some benchmark examples (and results)

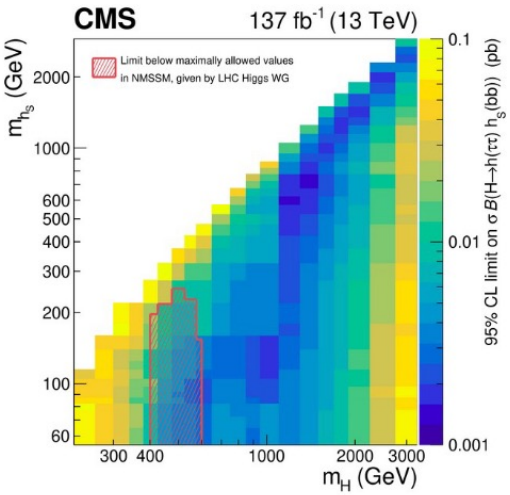




A broad class of searches have been performed already by experimentalists:

- di-H125 results
- Light particles
  - Boosted di-photon resonances (10–70 GeV)
- multi-Higgs results / cascades

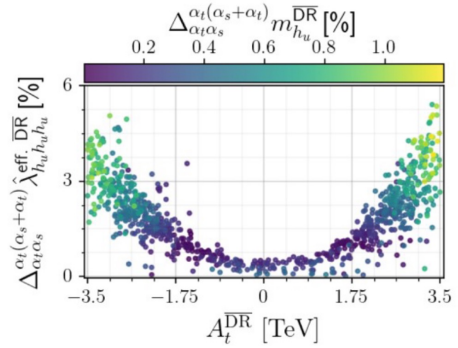


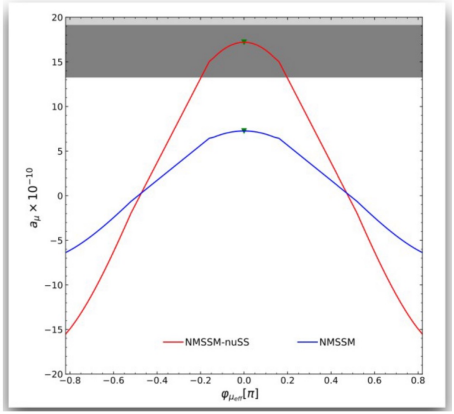


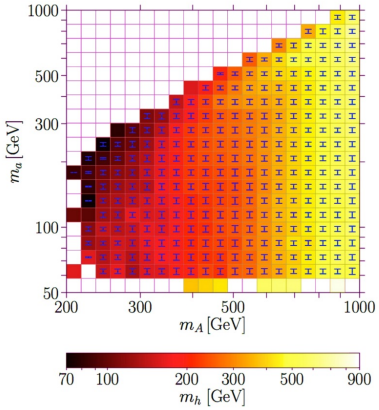
Recent updates from theory

- Calculating the $O(\alpha_t^2)$ corrections to the trilinear Higgs self-coupling
  - correction at the order of a few percent and is correlated to the mass correction
- Investigates the CP- violating NMSSM with and w/o an inverse seesaw (ISS) mechanism. Computed one loop SUSY contribution to AMM
  - The effects of the extended (s)neutrino sector on the muon AMM and on the mass of the SM-like Higgs boson can be significant.
- NMSSMTools scans with consistent h125 pheno

[Borschensky,Dao,Gabelmann,MM,Rzehak,'22]







Outlook

- Experimenters are encouraged to contact nMSSM conveners if they think they can use the provided numbers
- The twiki benchmarks are just examples of possibilities and more points can be produced or more signatures can be explored upon request

Lidija Zivkovic
Nikos Rompotis
Mariarosaria d'Alfonso
Santeri Laurila
Tania Robens
Rui Santos

Extended Scalars

Mostly taken from Tania's talk

- 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

Extended Higgs sector

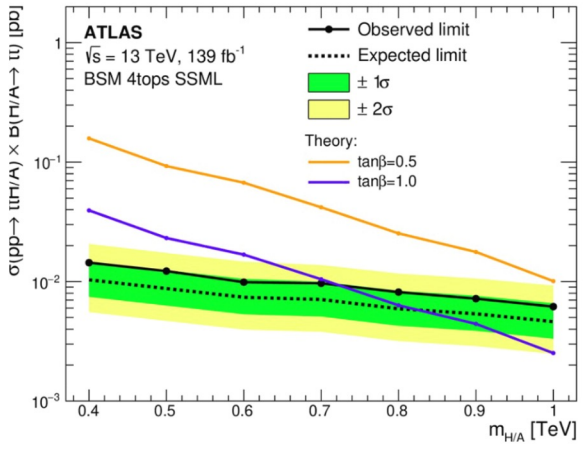
- Recent group activities has been on:
  - Overlooked signatures
    - Encouraging experientalist to look for unexplored signatures i.e. $gg \rightarrow H_{sm} \rightarrow Z^{*}a \rightarrow Z^{*}Z^{*}h$
  - Width and interference effects in BSM searches
  - Recasts
  - CPV
- The group hold 4 meetings over the last year with around 50 talks over the 5 days.
  - Next meeting is 11.1.2023 (save the dates and subscribe to their mailing list if you are interested)
  - Goal is to study CPV in models with extended Higgs sectors. The results will appear in a white paper or CERN report

Experimental results

- Several new results from ATLAS and CMS

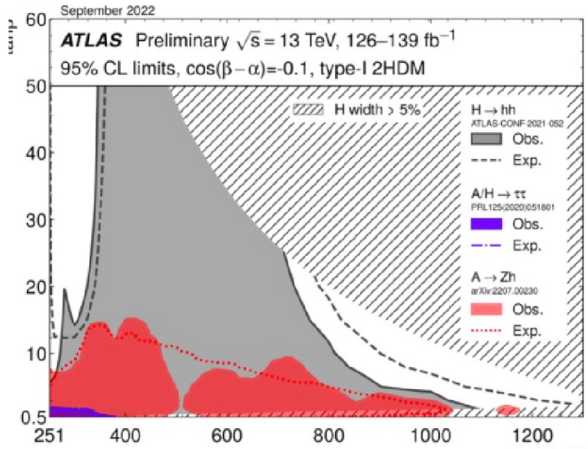
ttA/H → tt

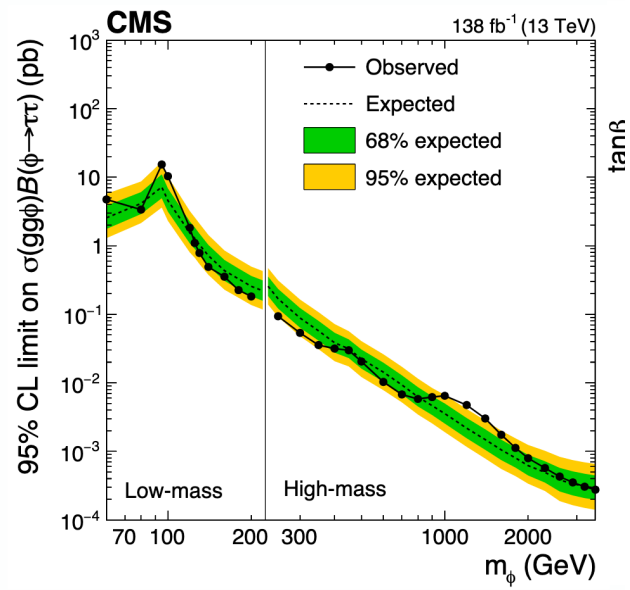
EXOT-2019-26



ATL-PHYS-PUB-2022-043

(Sept 2022) 2HDM



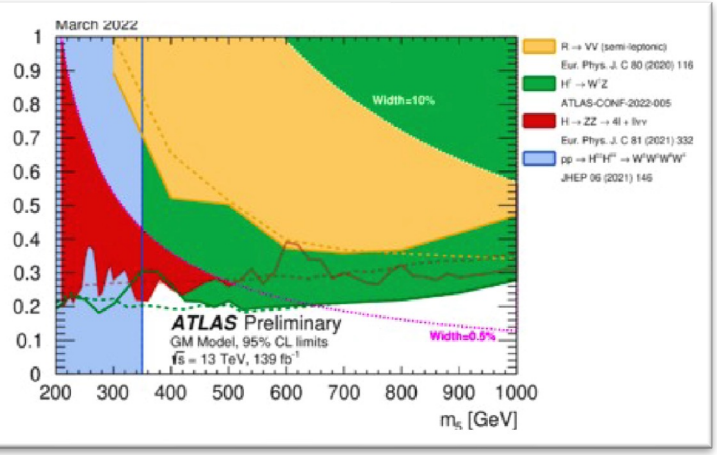


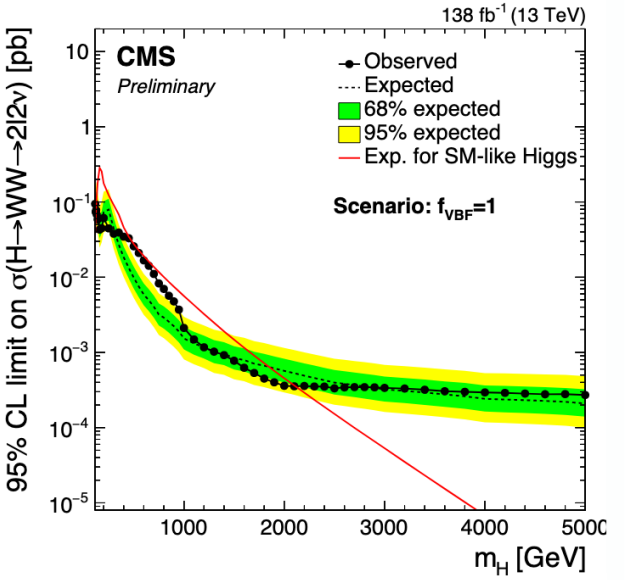
- Overlay plots

ATL-PHYS-PUB-2022-008

(March 2022)

Georgi-Machacek





Outlook & plans

- Continue meetings with the following topics:
  - Overlooked signatures
  - Width and interference effects in BSM searches
  - Recasts
  - CPV
- Update experiments on latest theory calculations and tools
  - make sure that channels that *also* belong to this subgroup (as e.g. H → V V′) are modelled according to state of the art
- Investigate in more detail width, interference, ...
- Propagate further insights of LHC Reinterpretation Forum
- Provide maximal cross sections for novel final states (as e.g. done for CERN-EP-2022-034, CMS-PAS-HIG-21-011)
- update of cross sections for Run 3 center-of-mass energy
- also many common topics with HH cross-group ⇒ cross-talk

Verena Martinez
Alexis Kalogeropoulos
Brian Shuve
Matthias Konig

Exotic Higgs Decays

Mostly taken from Rafael's talk

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

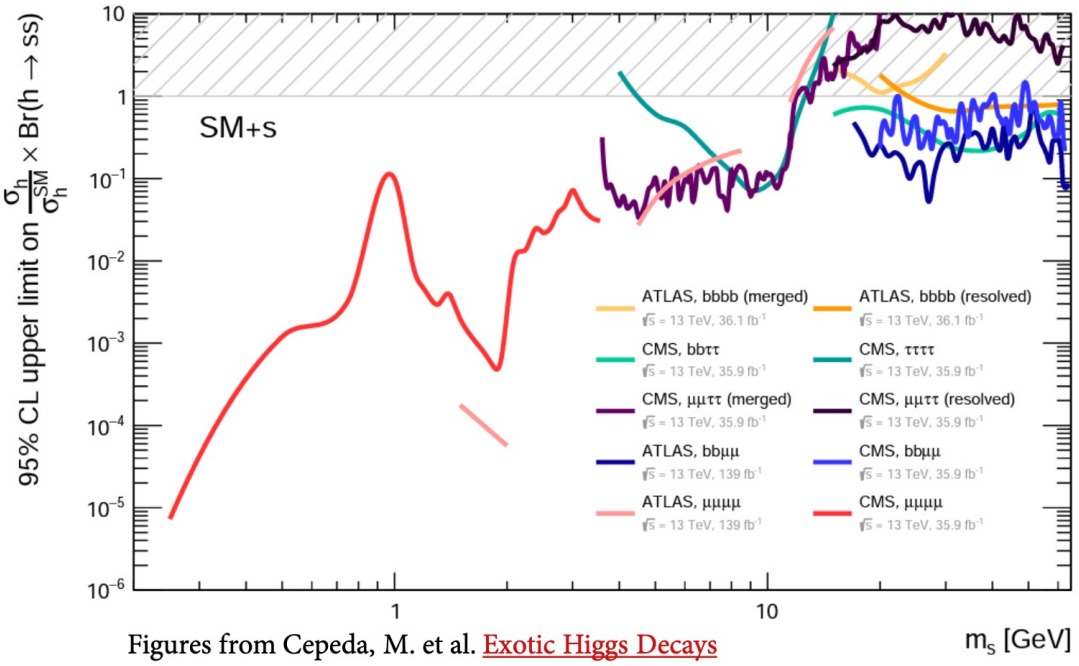
H→aa

$H \to aa, a \to XX, a \to YY$

XX / YY	ee	$\mu\mu$	$\tau\tau$	bb	gg	$\gamma\gamma$
ee						
$\mu\mu$						
$\tau\tau$						
bb						
gg						
$\gamma\gamma$						

CMS	Full Run 2
	Partial Run 2
ATLAS EXPERIMENT	Full Run 2
	Partial Run 2

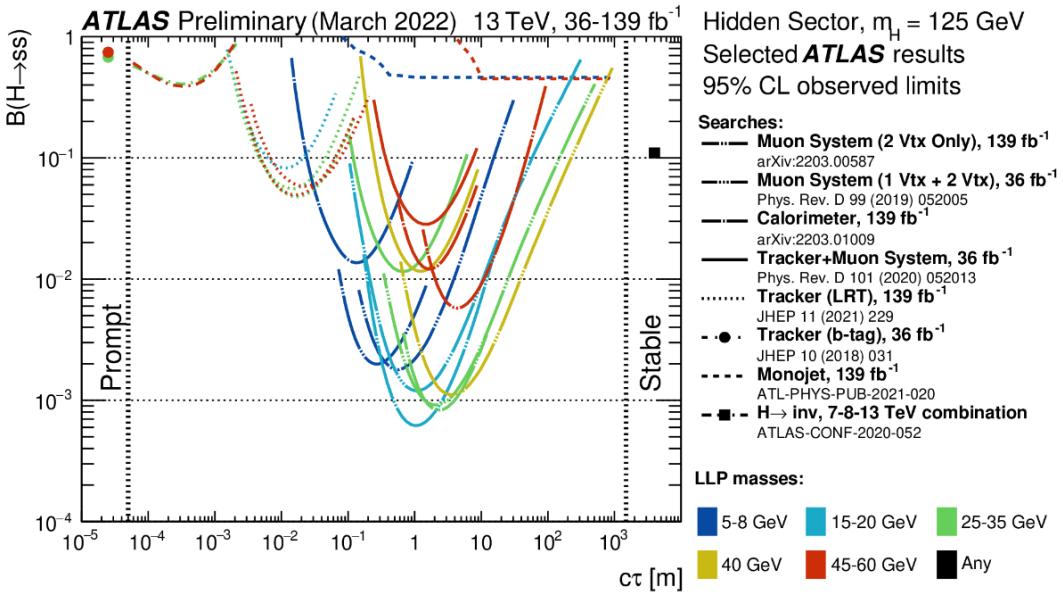
Interpreting result in SM+s model

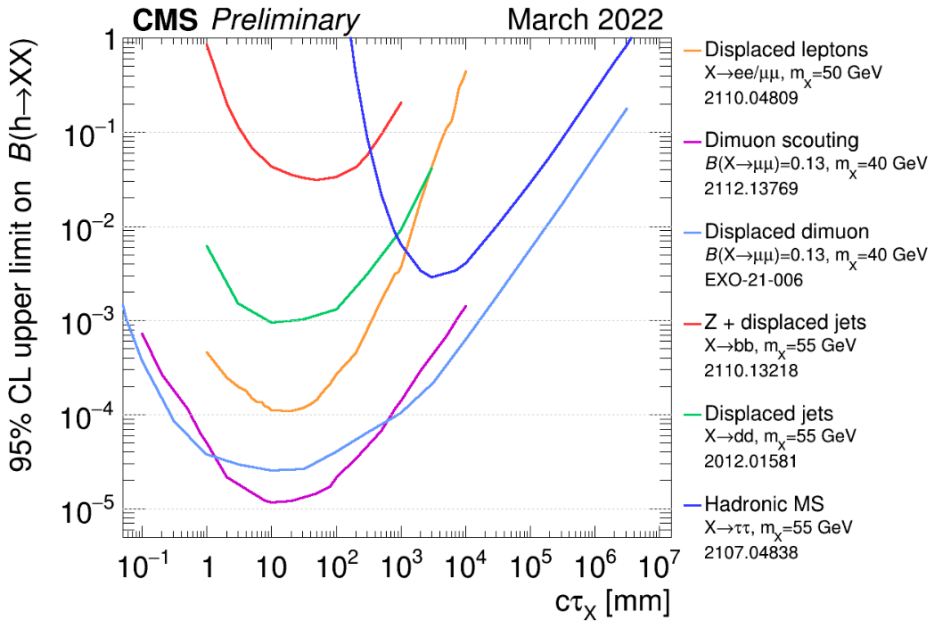


Figures from Cepeda, M. et al. Exotic Higgs Decays

- Many unexplored channels, mass spectrum ranges, and production modes.
- More challenging signatures require dedicated taggers/identifications (ongoing)
- Results with mass lese than 25 GeV can be interpreted in strong first order EW phase transition models (2203.08206)
- Signatures with unequal (pseudo)scalar mass could be explored as well.

H→LongLived

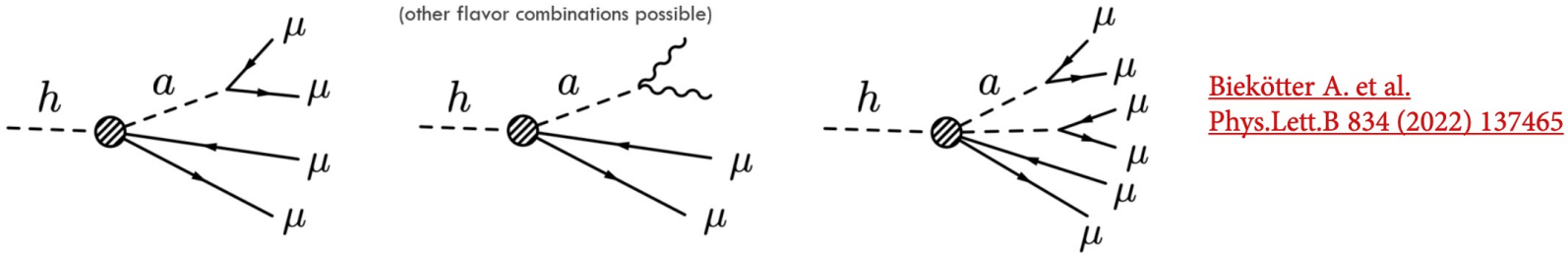




- Challenging signatures, as neither ATLAS nor CMS were initially designed optimally to look for these signatures. On the other hands these signatures are SM-background free!
- Experimental searches rely on many different techniques depending on cτ
- New timing detectors for Phase II can help exploring these signatures more precisely

Other Exotic Higgs decays

- Search for Higgs rare decays to mesons are ongoing (talk by R. Ward)
- Improved calculation of decays of Higgs to mesons/vector bosons (ongoing)
- Flavour-violating 125-GeV Higgs decays are important and have explored so far. One can extend that search to flavor-violating decays of the low-mass scalar [Evans et al, arXiv:1910.07533]
- Higgs to invisible search remains very important part of the exotic Higgs decays introducing Higgs boson as a portal to Dark Matter
- Higher dimension ALP operators can allow $H \to aff$ and $H \to aaff$ Signal can be probed via multi-lepton searches. Here a recast of the CMS $Z_d\, Z_d \to 4\ell$ search



Biekötter A. et al. Phys.Lett.B 834 (2022) 137465

- Providing benchmarks for ALPs to photon/gluon decays, and for semi-visible decays (ff+MET) (ongoing)
- Reinterpretation of prompt decays to LLP scenarios (planned)

Tim Barklow
Chayanit Asawatangtrakuldee
Michael Spira
Marius Wiesemann

bbH

Mostly taken from Chayanit's talk

- Goal is to provide inclusive and exclusive cross-sections for bbH production and MC generation tools
- The group remains as a “point of contact“ for specific questions

Run II summary

Channel	ATLAS	CMS
H/A → ττ	**139 fb^{-1} Phys. Rev. Lett. 125 (2020) 051801**	**138 fb^{-1} arXiv:2208.02717**
H/A → bb	28 fb^{-1} Phys. Rev. D 102 (2020) 032004	36 fb^{-1} JHEP 08 (2018) 113
H/A → μμ	36 fb^{-1} JHEP 07 (2019) 117	36 fb^{-1} Phys. Lett. B 798 (2019) 134992
A → Zh	**139 fb^{-1} arXiv:2207.00230 (Z → ℓℓ/νν, h → bb)**	36 fb^{-1} EPJC 79 (2019) 564 (Z → ℓℓ/νν, h → bb) 36 fb^{-1} JHEP 03 (2020) 065 (Z → ℓℓ, h → ττ)
A → ZH H → ZA	**139 fb^{-1} EPJC 81 (2021) 396 (Z → ℓℓ, H → bb and WW)**	36 fb^{-1} JHEP 03 (2020) 055 (Z → ℓℓ, A/H → bb)

bbH

- Generation of bbh @NLO and calculation of the XS @NLO are both important as bbH is an important irreducible background for HH->bbH
- Currently, there is no NLO generator for bbH for the yt^2
- The NLO calculation leads to ~ 100% uncertainty mostly due to the yt^2 contribution
- A solution to reduce such uncertainty would be developing NLO+PS generator for the yt^2 contribution or full bbH NLO process
- There could be other EWK corrections leading to additional sources of uncertainties due to the interference between gg->HH and gg->bbH, but to realize them better, first we need an NLO generator for bbH
  - More time and person power is needed to accomplish these studies

Summary and Outlook

- Ongoing effort in all of the WG3 to strengthen our established experiment–theory connections
- Continue with organizing topical meetings. Has mostly been in Extended Higgs sector, but other subgroups can follow the same path. i.e. In the past here has been regular Exotic Higgs Decay workshops.
- As more data are being collected during LHC Run III, we need to provide cross-section for new 13.6 TeV(ongoing), update recommendation, …
- Need to work on publishing the tools, so
  - Other members of the groups can use the tools and become productive/helpful
  - The knowledge would not be lost, in case the main proponents leave the field

Back Up