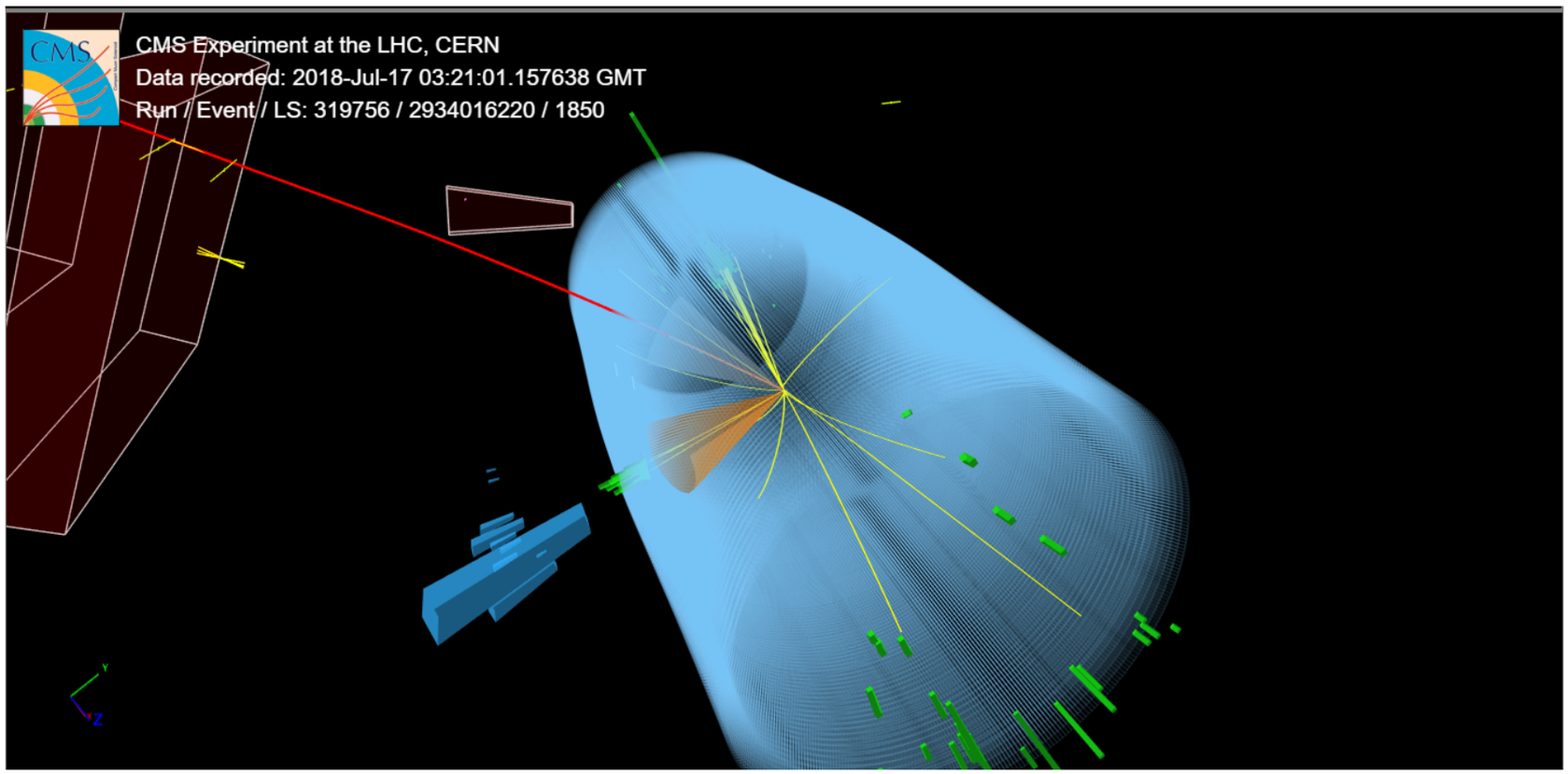
Imperial College London

Summary of the NMSSM subgroup activities



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The NMSSM subgroup

- Conveners:
  - Theory: Ulrich Ellwanger (Orsay), Maggie Muhlleitner (KIT), Nausheen Shah (Wayne)
  - ATLAS: Nikolaos Rompotis (Liverpool)
  - CMS: Daniel Winterbottom (Imperial College)
- Contact email: lhc-higgs-nmssm-convener@cern.ch
- Twiki page: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWGNMSSM

Areas of interest

- NMSSM = MSSM + singlet

MSSM

A, H, h, H+, H-

NMSSM

a, h′

- Focus of the subgroup has been on signatures unique to NMSSM wrt MSSM

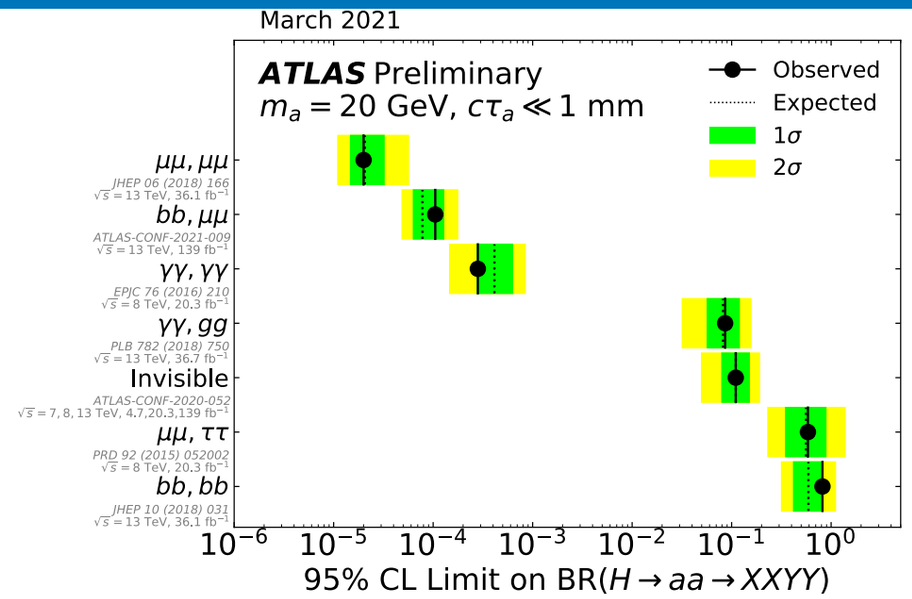
- Not to say that MSSM-orientated final states are not also interesting

- At beginning of the LHC NMSSM related searched we orientated towards light pseudo-scalar searches e.g $h_{SM} \rightarrow aa$ (h_{SM} is observed SM-like 125 GeV state)

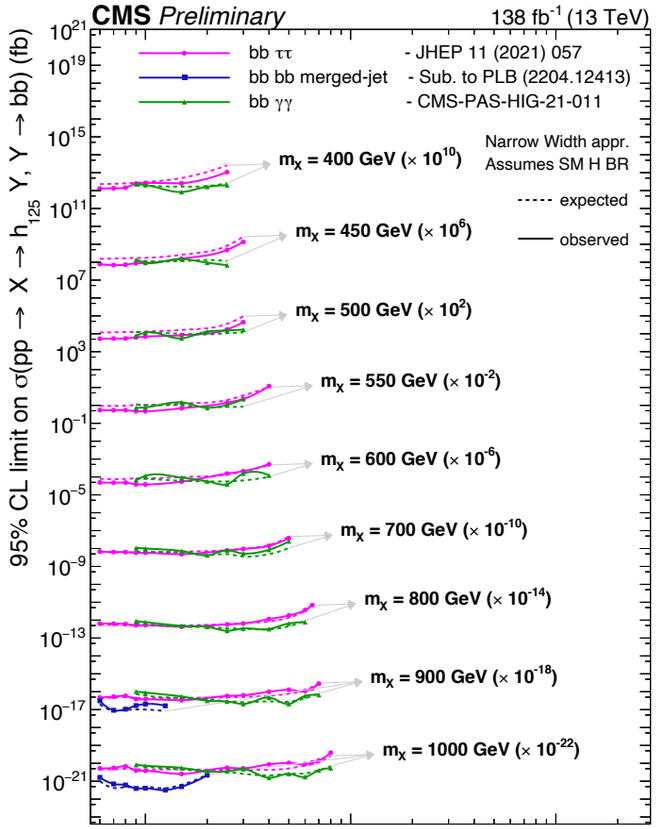
- For last few years focus has shifted towards multi-Higgs final states e.g $H \rightarrow h_s h_{SM}$ / $A \rightarrow a_s h_{SM}$ - I will refer to these as $X \rightarrow Yh$ in the following

Previous experimental results

- Many previous searches for $h_{SM} \rightarrow aa$ by CMS and ATLAS, e.g:
  - ATLAS: aa→bbμμ : ATLAS-HDBS-2021-03
  - CMS aa→bbττ/bbμμ: CMS-HIG-22-007 (NEW!)
  - + many more
- Now several searches for X→Yh by CMS and ATLAS in various final states
  - CMS Yh→bbττ: CMS-HIG-20-014
  - CMS Yh→4b: B2G-21-003
  - CMS Yh→bbɣɣ: CMS-HIG-21-011
  - ATLAS Yh→ττVV: ATLAS-HDBS-2022-44 (NEW!)



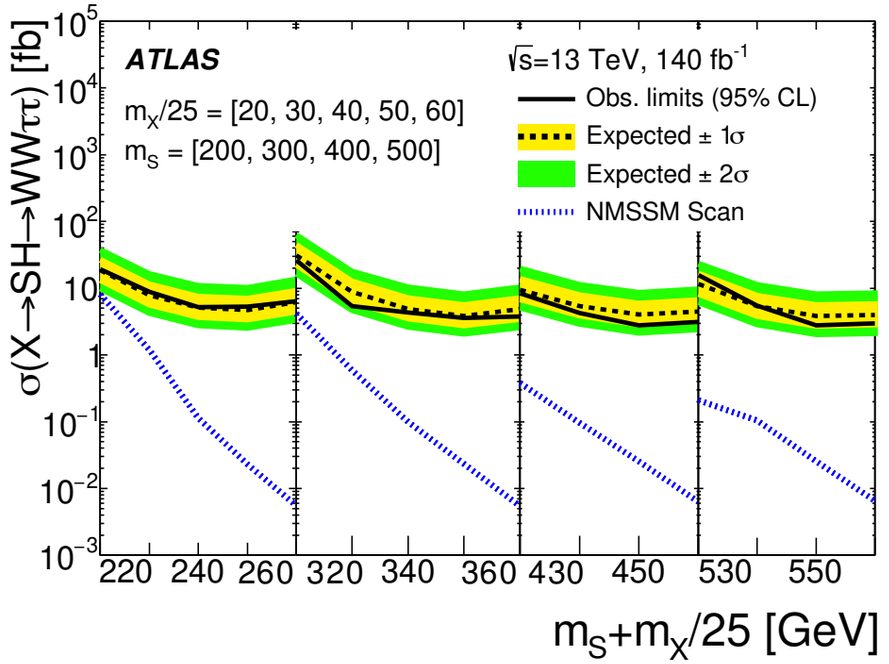
ATLAS h→aa summary plot from here

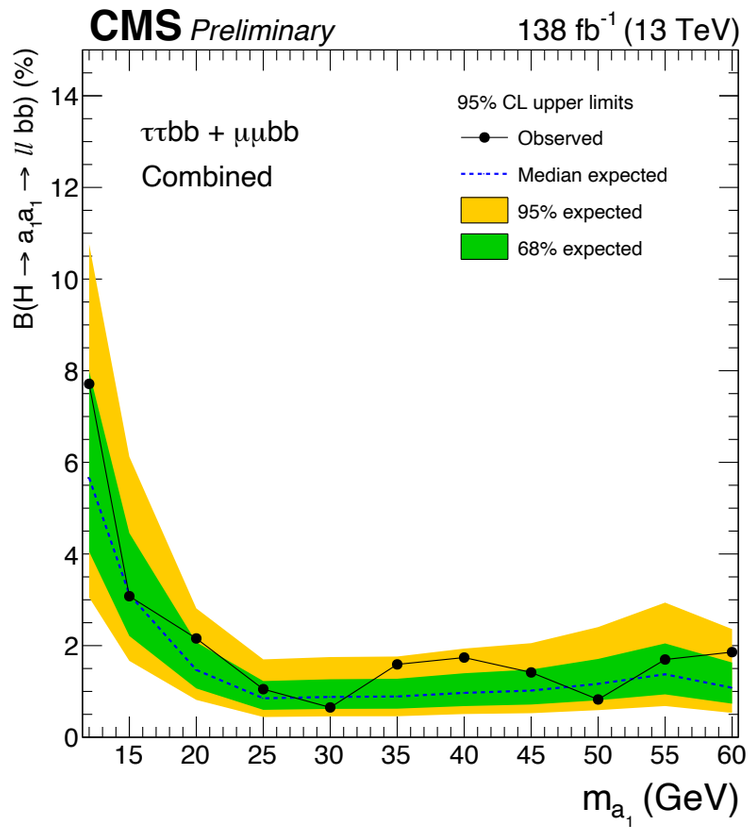


CMS X→Yh summary plot from here

New experimental results

- Two new experimental results since the last workshop:
- ATLAS search for $X \rightarrow Yh \rightarrow VV\tau\tau$
- CMS search for $h_{SM} \rightarrow aa \rightarrow bb\tau\tau$/ bbμμ
- We will have dedicated talks in the parallel session on Wednesday morning about both of these analyses





NMSSM “benchmarks”

- MSSM-style benchmarking is not possible for NMSSM phase-space as it is too complicated for a set of useful simple benchmarks

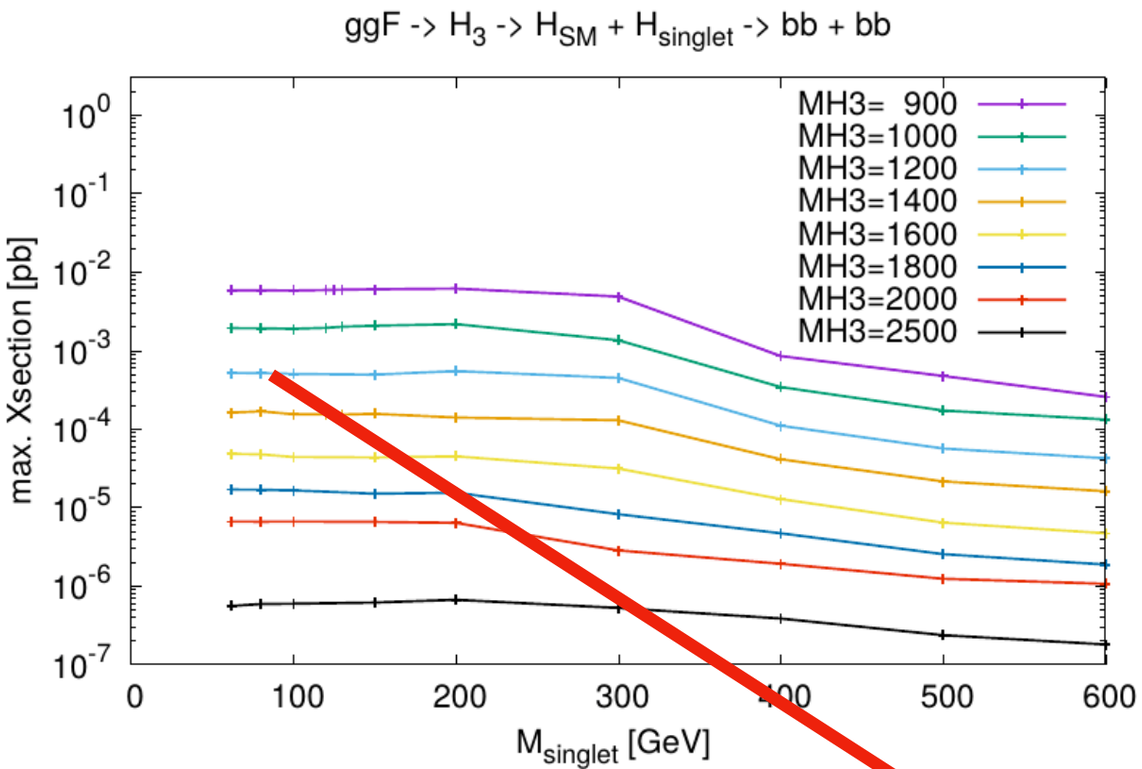
- Instead the group produce maximum allowed cross-section times branching ratios for specific signatures

- The are obtained by tuning the parameters within ranges allowed by various phenomenological constraints to maximise the cross-section

- Constraints include: Mass and couplings of SM-like Higgs boson, BSM searches at LHC and LEP, B-physics, Dark-matter direct detection

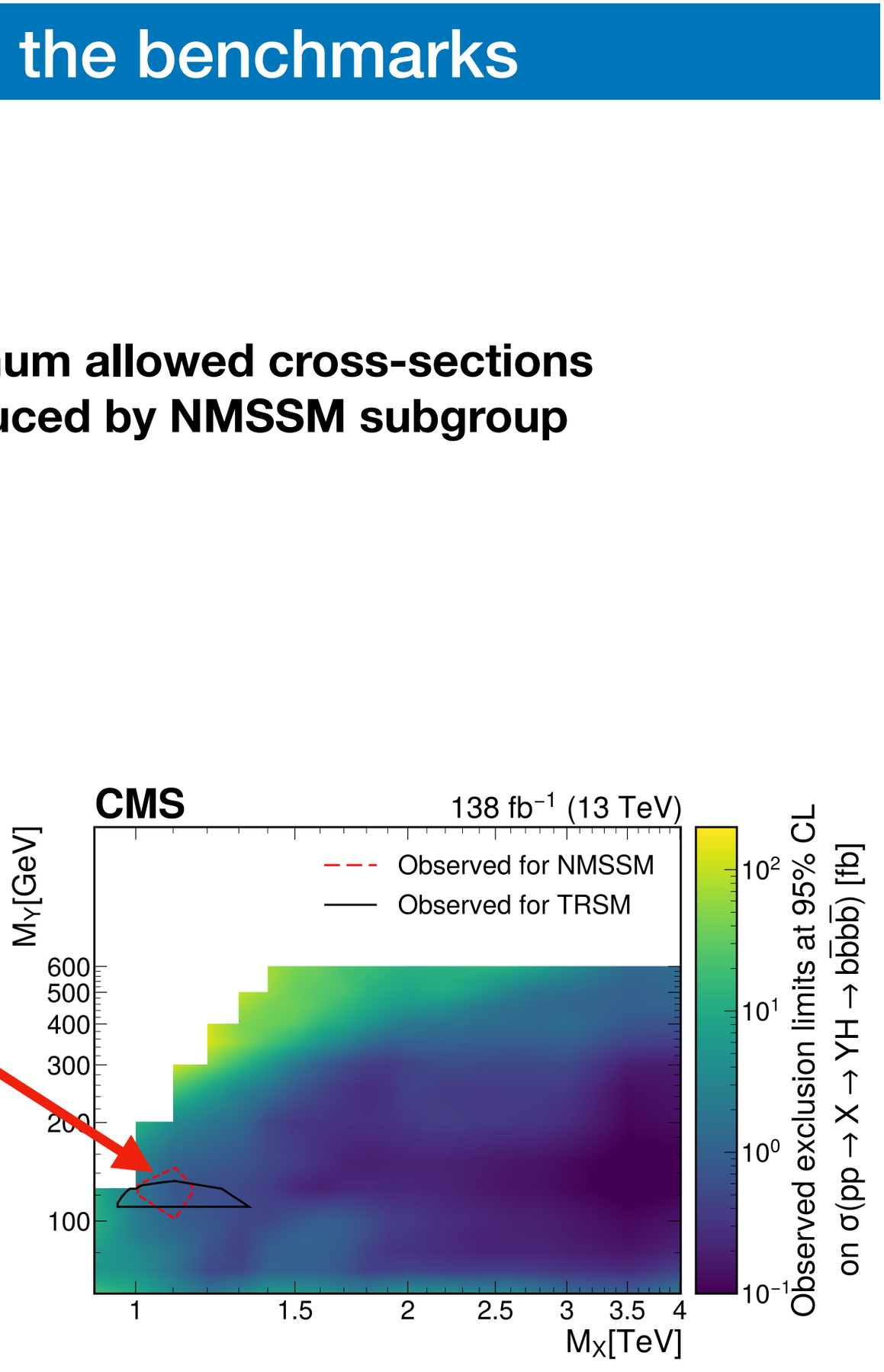
- More details in arxiv:2203.05049: “Benchmark Planes for Higgs-to-Higgs Decays in the NMSSM”, U. Ellwanger, C. Hugonie

How experiments use the benchmarks



Maximum allowed cross-sections produced by NMSSM subgroup

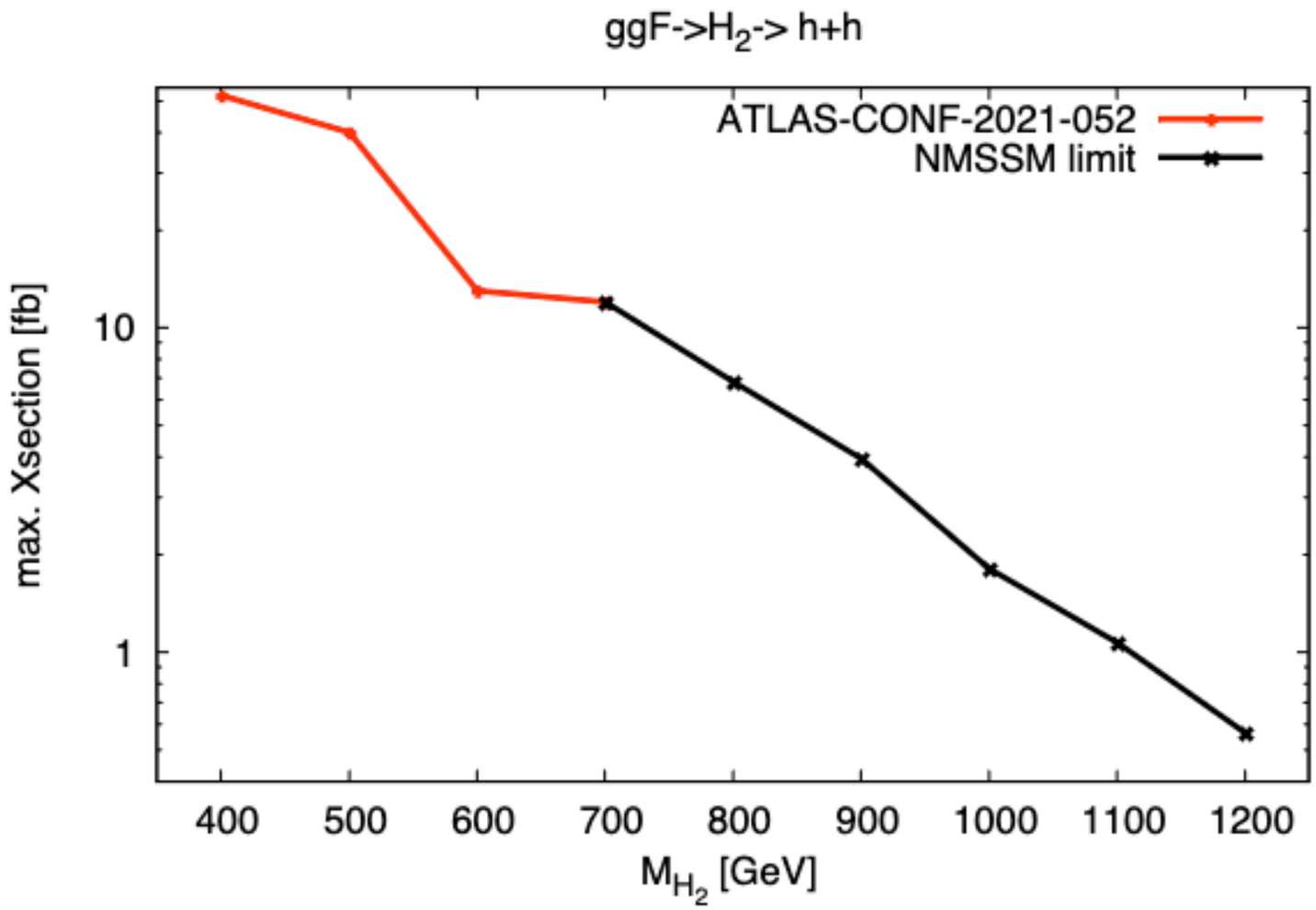
Experimental analyses check if observed limits extend below max-allowed XSs regions where the XSs are “excluded” are indicated in the plot



Other benchmarks

- Maximum-allowed cross-sections also produced for X→Yh for other channels: 4b, bbττ, bbɣɣ, ττɣɣ and VVττ

- Maximum allowed cross-sections also computed for the H→hh channel



References for benchmarks

- We had some complaints from theory-side that experimentalists were not referencing the benchmarks properly in the publications

- From the experimental-side this was explained to be due to a lack of a citable source - twiki pages cannot be cited under ATLAS/CMS publication rules!

- To fix this issue we are working on producing a public LHCHWG note for the NMSSM subgroup

- Analyses are reminded to cite arxiv:2203.05049 in the meantime, and should cite NMSSMTools

Requests from experimentalists

1. Use a clearer versioning for benchmarks to account for experimental limits that are used to maximise XSs being updated in time

   - We try to make it clear which version of NMSSMTools is used to determine the XSs, and by knowing the version one can look upon the constrains in https://www.lupm.univ-montp2.fr/users/nmssm/history.html

2. Would like to have XSs that do not include the BR of the SM-like Higgs (so that different channels with same Y final state can be combined)

   - We are looking into how best to achieve this. There may be some technical issue due to how the XSs are determined but at least it should be possible by rescaling the XSs such that they correspond to the SM-values for the SM-like Higgs BRs

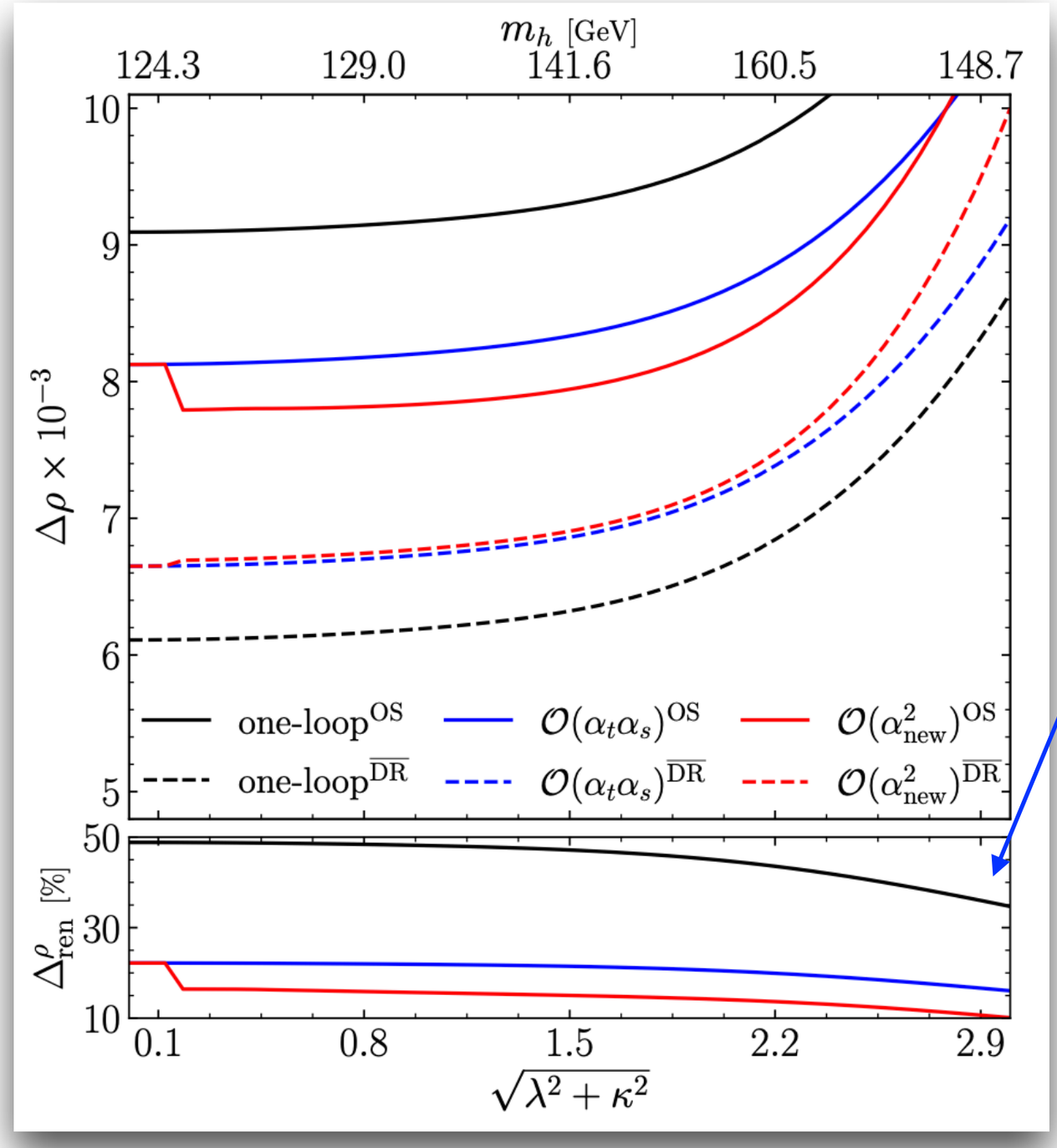
3. Use finer grids for cross-sections (help reduce interpolation effects)

4. Produce XSs for more Y final states

For points 3 and 4, these are possible but represent a considerable amount of works we ask experimentalists to make specific requests (e.g final-states / mass-points) to minimise the amount of work

Further developments on the theory side

- $O((\alpha_t+\alpha_\lambda+\alpha_\kappa)^2+\alpha_t\alpha_s)\equiv O(\alpha_{new}^2)$ corrections to the ρ parameter and to M_W in the Complex NMSSM



[Dao,Gabelmann,Mühlleitner,'23]

ρ Parameter:

- 2-loop corrections are significant

- theory uncertainty (through renorm. / scheme variation) reduced at 2-loop:

one-loop: 55%

$O(\alpha_t\alpha_s)$: 22%

$O(\alpha_{new}^2)$: 16%

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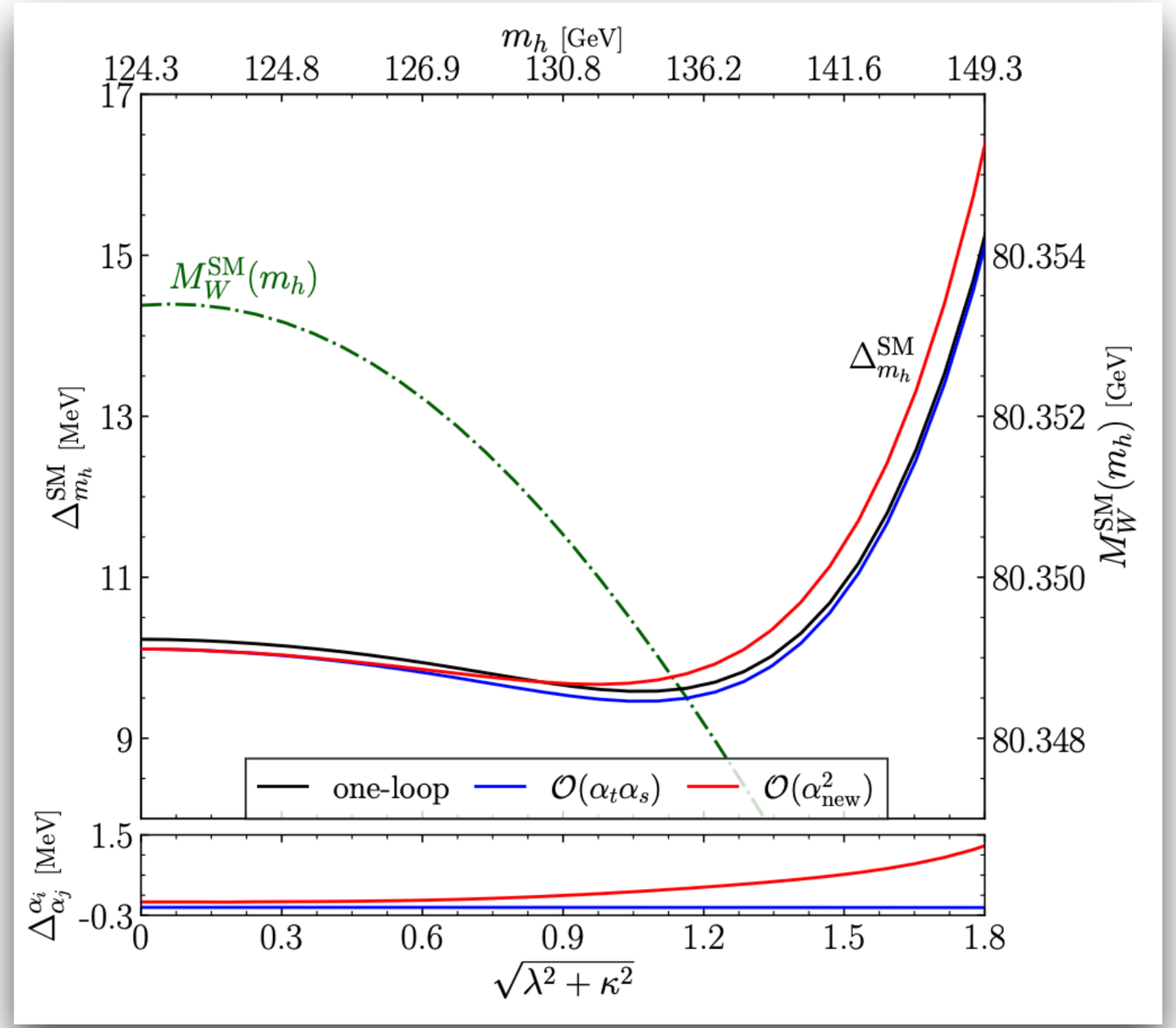

[Dao,Gabelmann,Mühlleitner,'23]

Corrections to M_W:

$$\Delta_{m_h}^{\rm SM} = M_W^{\rm NMSSM} - M_W^{\rm SM}(m_h)$$
$$\Delta_{\alpha_j}^{\alpha_i} = M_W^{(\alpha_i)} - M_W^{(\alpha_j)}.$$

2-loop effects of O(few MeV) smaller than parametric uncertainties

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- New results implemented in NMSSMCALC 5.2

```
#
BLOCK MODSEL  # Model selection
     3     1   # complex NMSSM
     5     2   # CP-violating
     6     4   # loop level 1: one 2: two O(alpha_t alpha_s) 3: two O(alpha_t alpha_s + alpha_t^2) 4: two O
alpha_s)
     7     3   # for top/stop sector: 1: DRbar scheme no gauge running; 2: DRbar w/ gauge running 3: OS sch
     8     0   # 0: MHpm as Input, 1: Alambda as Input
    10     0   # 0: no EDMs calculated (default), 1: EDMs calculated, 2: detailed output
    11     1   # 0: no AMMs calculated (default), 1: AMMs calculated, 2: detailed output
    12     0   # 0: no effective HHH couplings calculated,  1: effective HHH couplings calculated
    13     1   # 0: no loop-corrected W-mass calculated,  1: loop-corrected W-mass calculated in OS scheme
BLOCK WMASS
# W mass prediction in the on-shell scheme
  1  0     8.03534512E+01   # W mass in the SM using MH=MHSUSY
  1  1     8.03583622E+01   # W mass in the NMSSM at 1-loop
  1  2     8.03575596E+01   # W mass in the NMSSM at 2-loop QCD
  1  3     8.03574004E+01   # W mass in the NMSSM at 2-loop EW
BLOCK DeltaRhoDR
  1  1     6.03734989E-03     6.08820800E-03   # DeltaRho in the SM and NMSSM at 1-loop
  1  2     5.74333243E-03     6.94365826E-03   # DeltaRho in the SM and NMSSM at 2-loop QCD
  1  3     5.54099741E-03     6.92252224E-03   # DeltaRho in the SM and NMSSM at 2-loop EW
BLOCK DeltaRhoOS
  1  1     8.91664978E-03     8.97379729E-03   # DeltaRho in the SM and NMSSM at 1-loop
  1  2     7.94823690E-03     7.99184215E-03   # DeltaRho in the SM and NMSSM at 2-loop QCD
  1  3     7.61293754E-03     7.65385045E-03   # DeltaRho in the SM and NMSSM at 2-loop EW
```

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```
#
BLOCK MODSEL  # Model s
     3     1    # comple
     5     2    # CP-vio
     6     4    # loop l                                    ha_s + alpha_t^2) 4: two O
alpha_s)
     7     3    # for to                                    w/ gauge running 3: OS sch
     8     0    # 0: MHp
    10     0    # 0: no                                     output
    11     1    # 0: no                                     output
    12     0    # 0: no                                     lings calculated
    13     1    # 0: no loop-corrected W mass calculated, 1: loop-corrected W mass calculated in OS scheme
BLOCK WMASS
# W mass prediction in the on-shell scheme
  1  0     8.03534512E+01   # W mass in the SM using MH=MHSUSY
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```

Comparison of calculations for M_W, M_h, muon anomalous magnetic moment in NMSSMCALC w/ NMSSMTools, FlexibleSUSY, SARAH/SPheno: good agreement provided that input parameters and renormalization scales are treated in the same way

Summary

- The NMSSM subgroup is providing theory predictions for the NMSSM in the form of maximally allowed cross-section times branching ratios

- Recent CMS and ATLAS analyses are using these inputs to compare their experimental limits to the most optimistic scenarios

- More cross-sections can be provided for different final states and mass points but experimentalists should contact us to discuss their needs as they are not trivial to produce

- New 2-loop corrections to the ρ parameter and M_W now derived and included in NMSSMCALC