Jon Butterworth, Martin Habedank, Priscilla Pani

DESY.

2HDMa & Contur

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

HUMBOLDT-UNIVERSITÄT ZU BERLIN

[→source]

Overall picture

general topic of my PhD project: search for
Dark Matter in signatures with jets

➔ →MET+jet search perfect match
("Search for new phenomena in events with an energetic jet and large missing transverse momentum using the ATLAS detector")
but: "inconvenient" schedule for me
(→paper about to be published)

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("Unfolded p_T^{miss}+jets differential cross-section measurement")
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Priscilla very experienced with **2HDM+pseudoscalar model**

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tool for “exploring the sensitivity of unfolded collider measurements to BSM models”

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what you're probably going to hear from me in the future

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what I'm going to talk about today

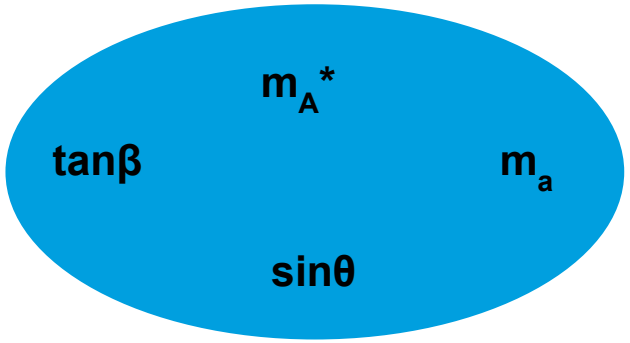
what you're probably going to hear from me in the future

2HDM+a model

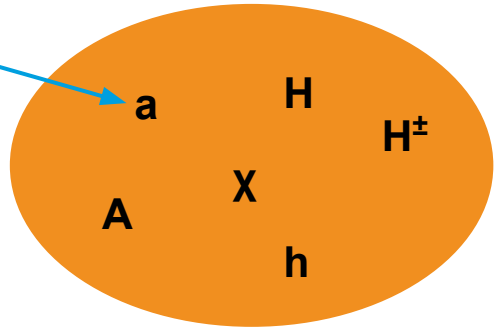
Two-Higgs-doublet model with a pseudoscalar mediator

- pseudoscalar mediator that couples to DM and SM particles
- additional second Higgs doublet (→"2HDM")
  - to avoid strong constrains by Higgs boson couplings
  - ratio of vacuum expectation values: tanβ
- mediator-SM coupling through mixing of mediator and second Higgs doublet
  - a-A mixing angle: sinθ

Parameters



Particles



* we usually fix $m_{H\pm}=m_H=m_A$

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Contur - Constraints On New Theories Using Rivet

Contur in general

- LHC precision measurements largely model-independent
- provided as Rivet routines
- most measurements in agreement with SM

➔ use those as pure SM-background for BSM model scans

disadvantages

- not as fast or sensitive as dedicated searches
- cannot claim discovery

advantages

- can cover broad range of signatures and models
- can set limits on New Physics and indicate where (not) to investigate further

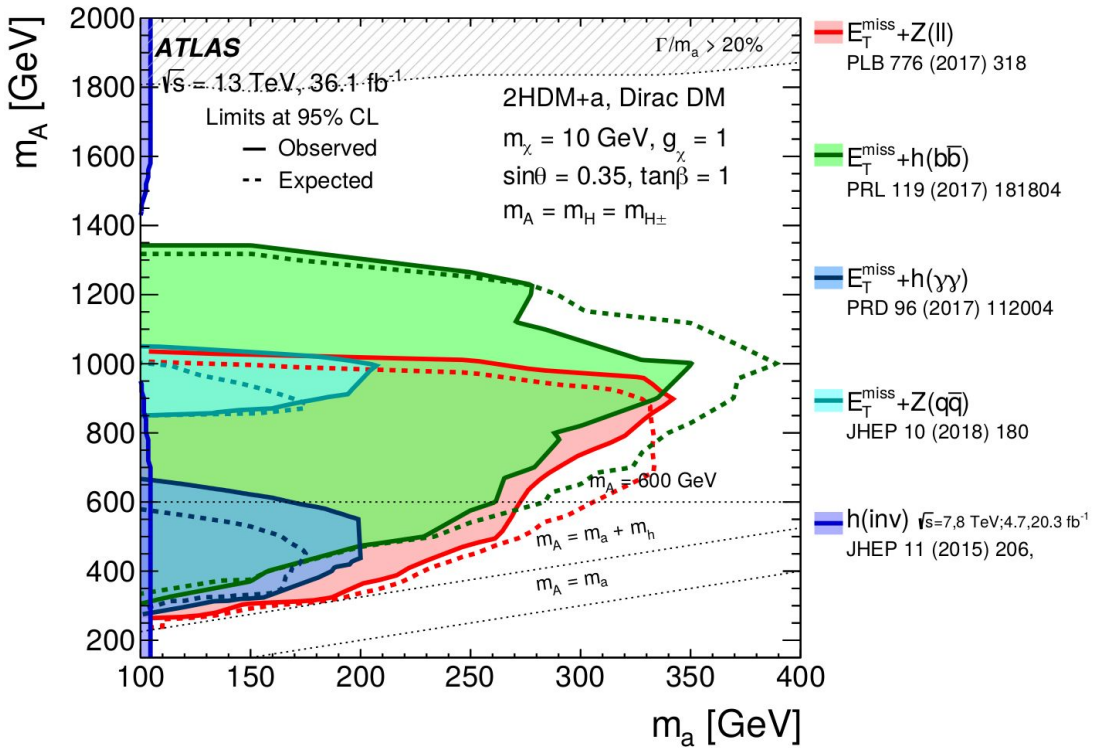
→paper →webpage →code

Starting point - ATLAS limit

chosen parameter region:

- $m_A = m_{H\pm} = m_H$
- $m_\chi = 10$ GeV
- $\sin\theta = 0.35$
- $\sin(\beta-\alpha) = 1 \rightarrow$ alignment limit (lightest mass eigenstate has SM Higgs couplings)
- $\tan\beta = 1$

m_A-m_a scan



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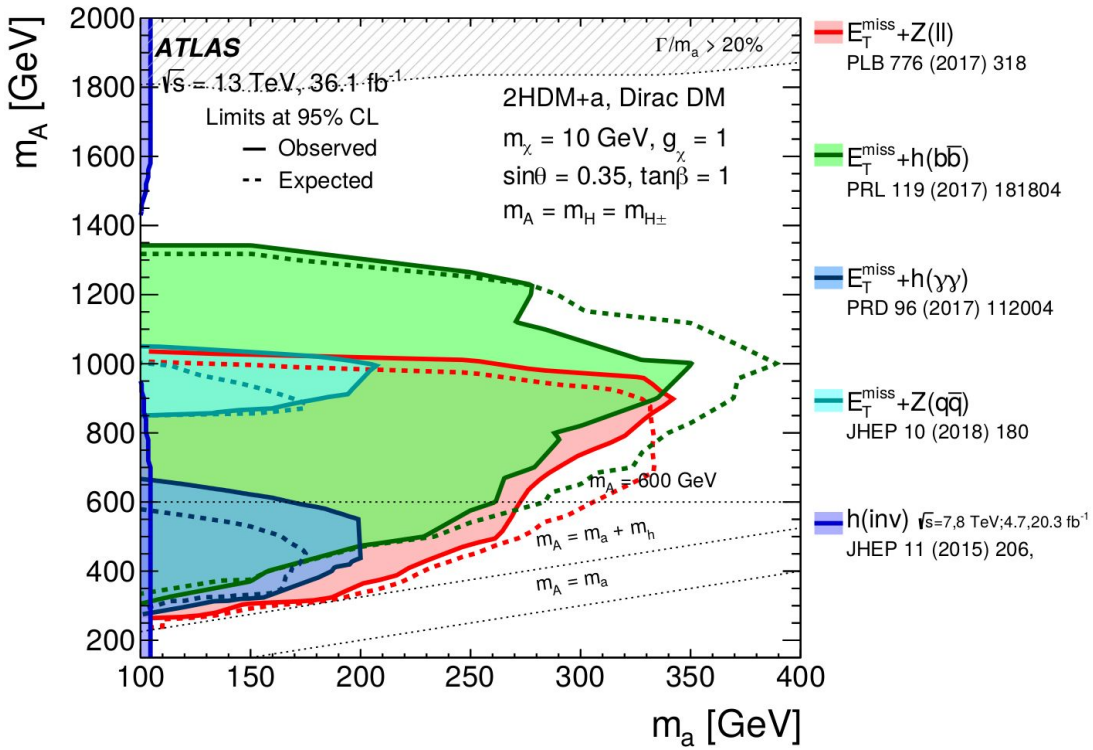
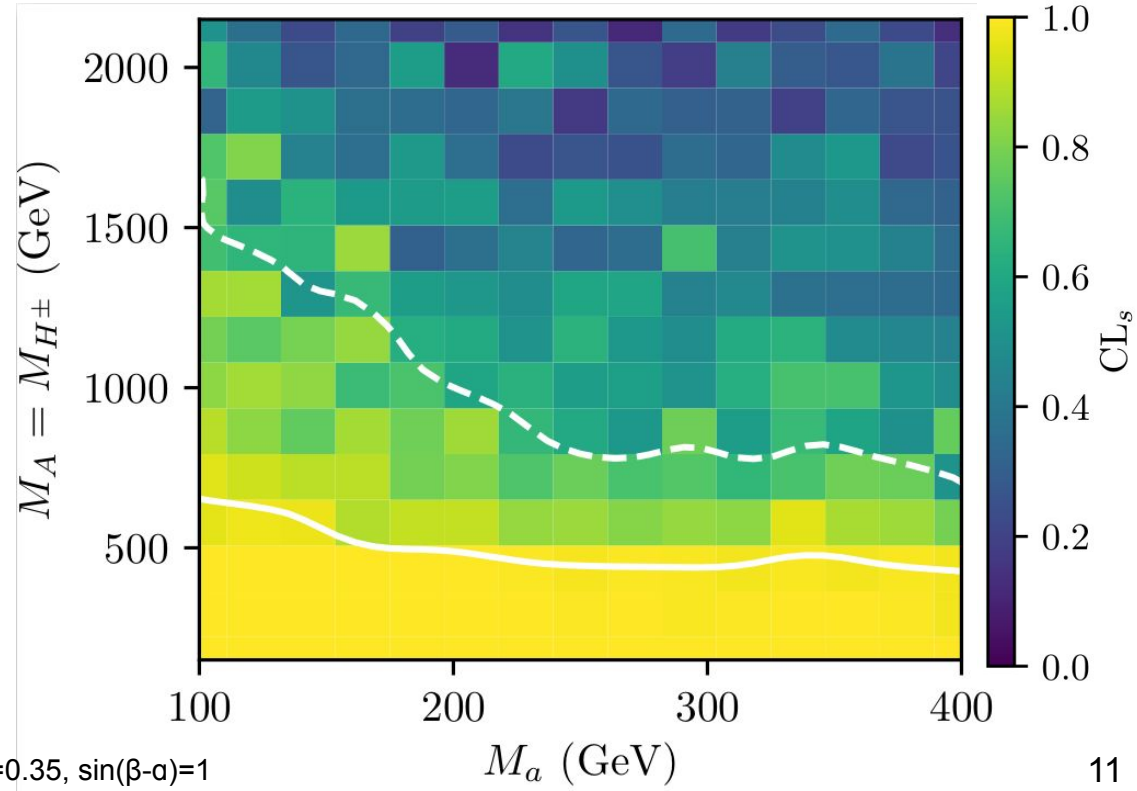
Contur results - m_A scan

1. generate BSM events with →Herwig
2. check where significant number of events would have entered fiducial phase of LHC measurements
   ➔ Contur

m_A-m_a scan





JHEP05(2019)142 tanβ = 1, $m_A = m_{H\pm} = m_H$, m_χ=10 GeV, sinθ=0.35, sin(β-α)=1

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dedicated searches

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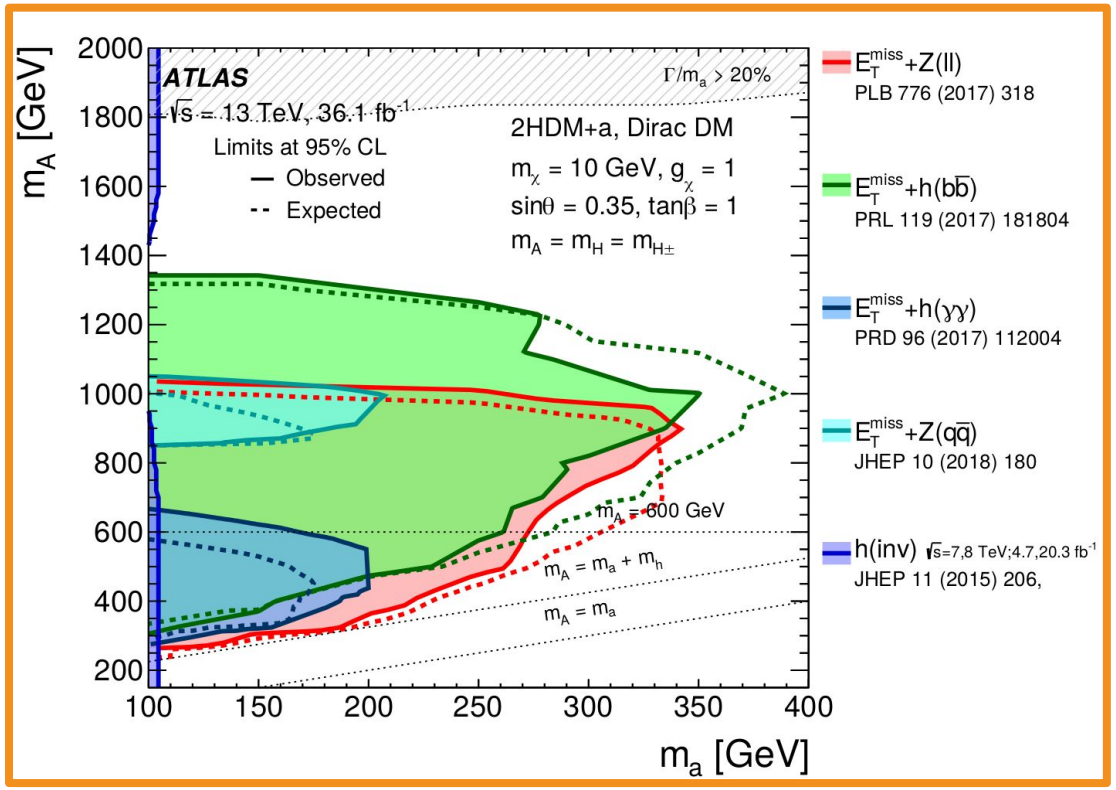

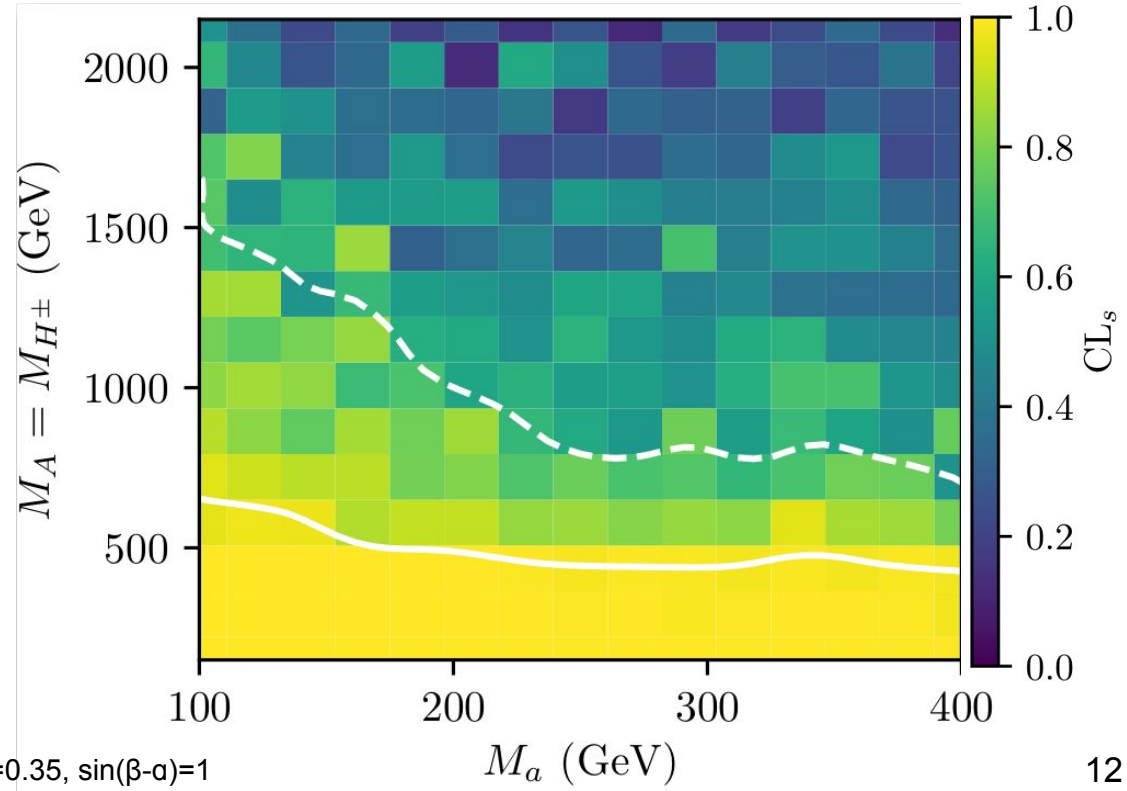

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Contur results - m_A scan

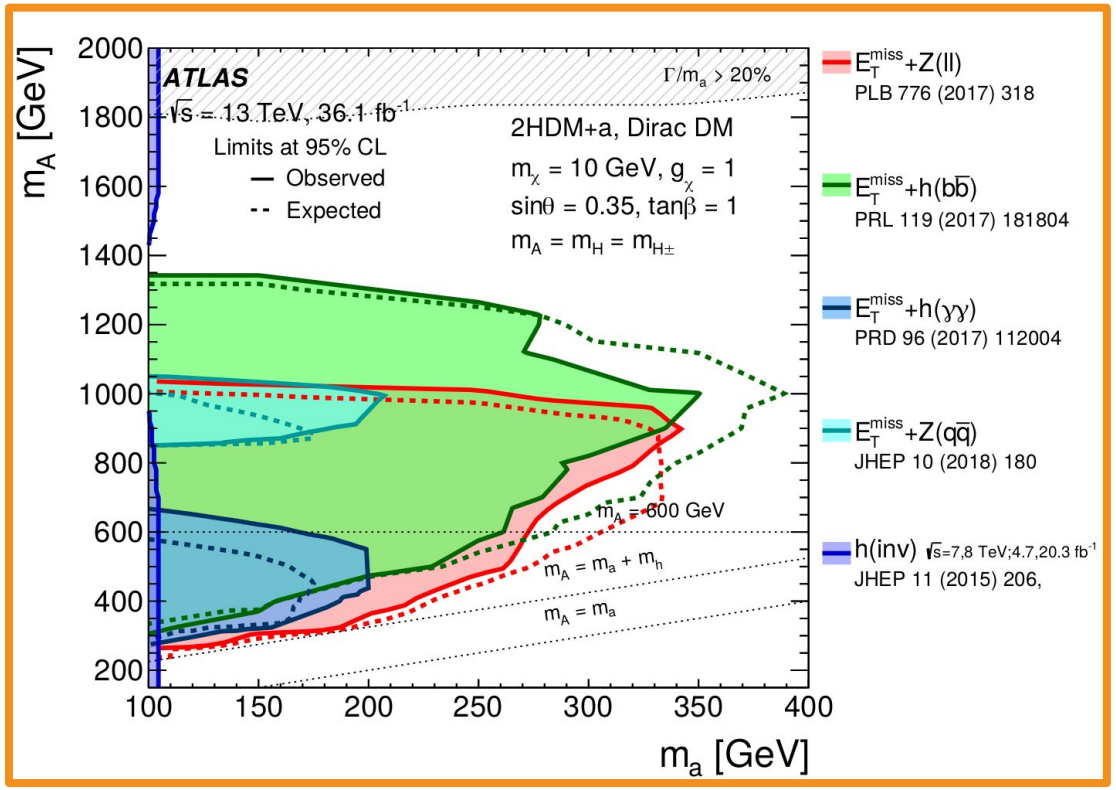
1. generate BSM events with →Herwig
2. check where significant number of events would have entered fiducial phase of LHC measurements

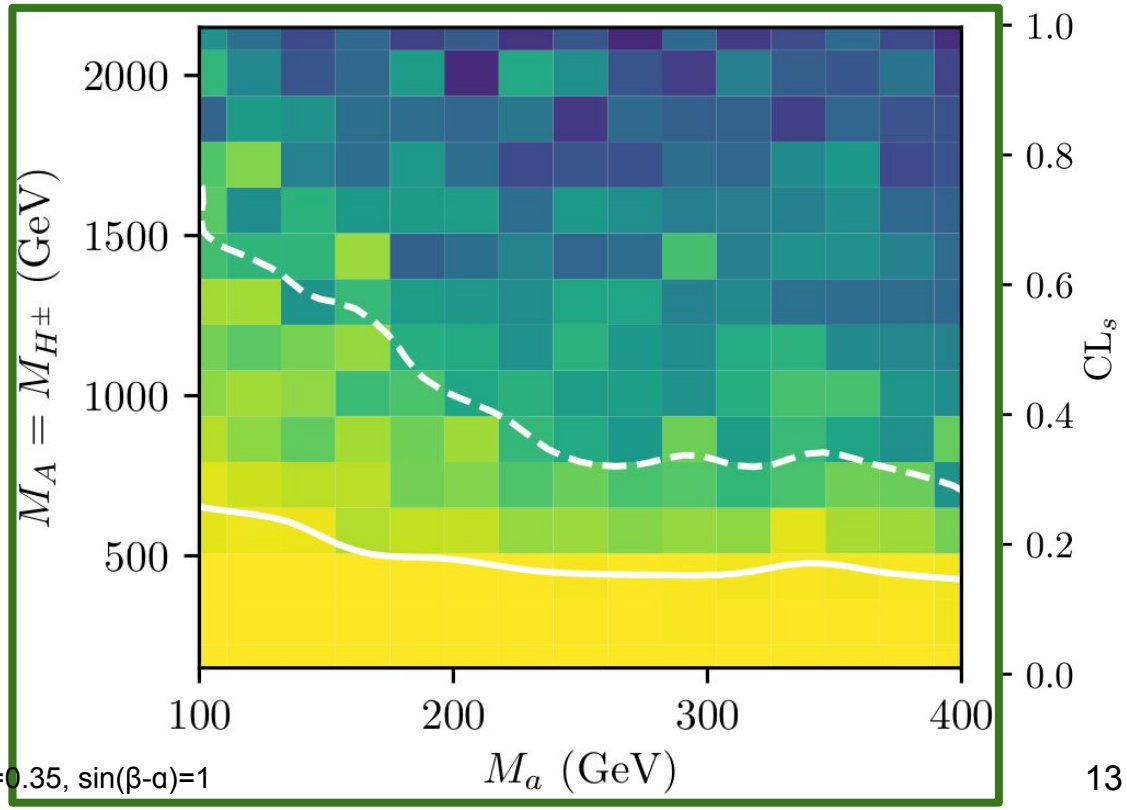
   ➔ Contur

dedicated searches

“only” measurements

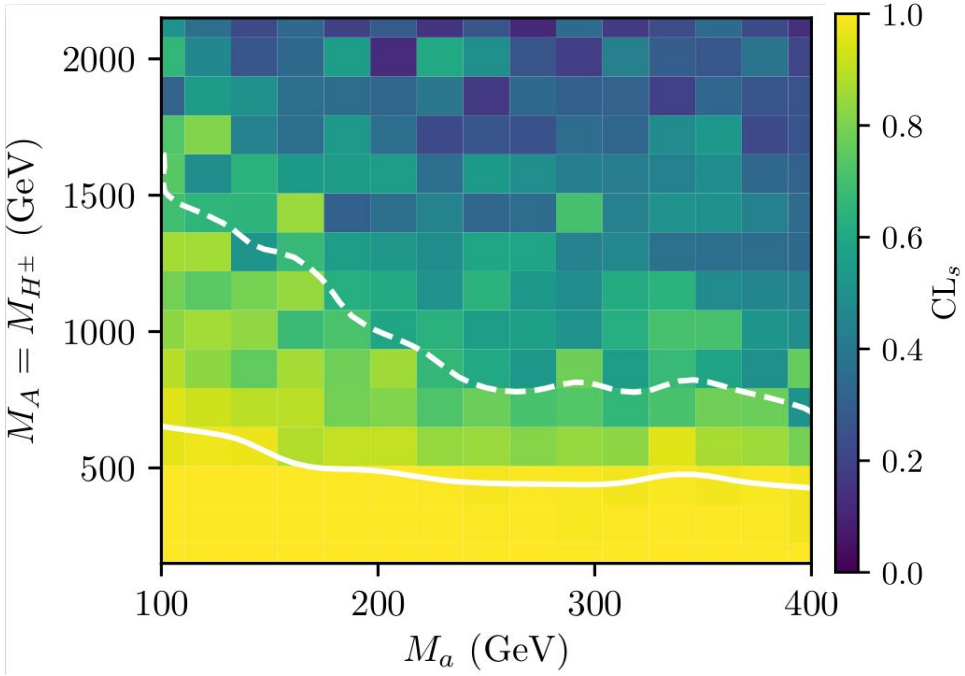
m_A-m_a scan



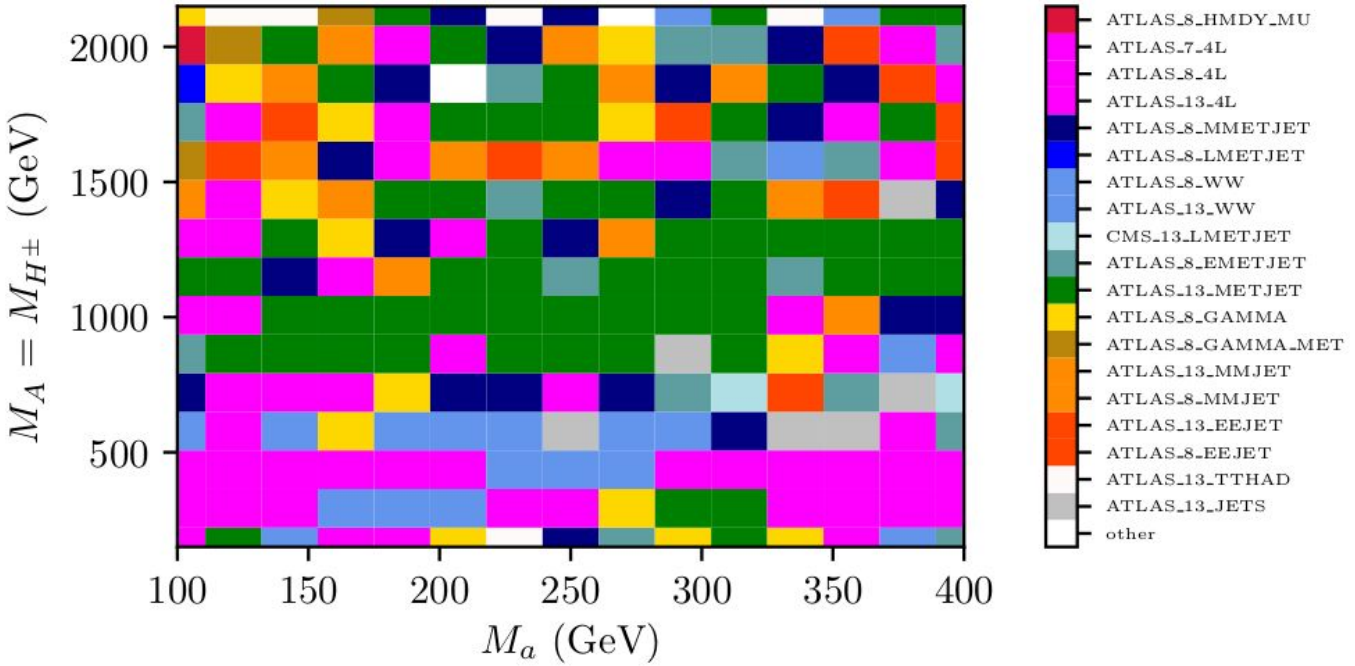


JHEP05(2019)142 tanβ = 1, $m_A = m_{H\pm} = m_H$, m_χ=10 GeV, sinθ=0.35, sin(β-α)=1

m_A scan - contributing measurements



dominant pools *



* Note: Not analyses are listed here but *pools*, a Contur specific grouping of analyses with similar signatures

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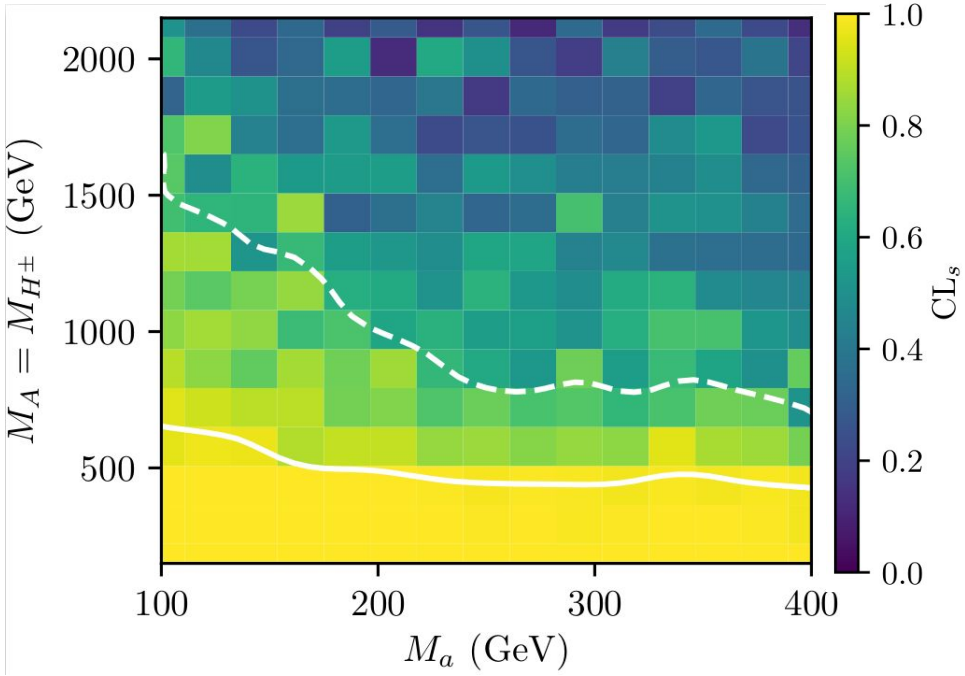

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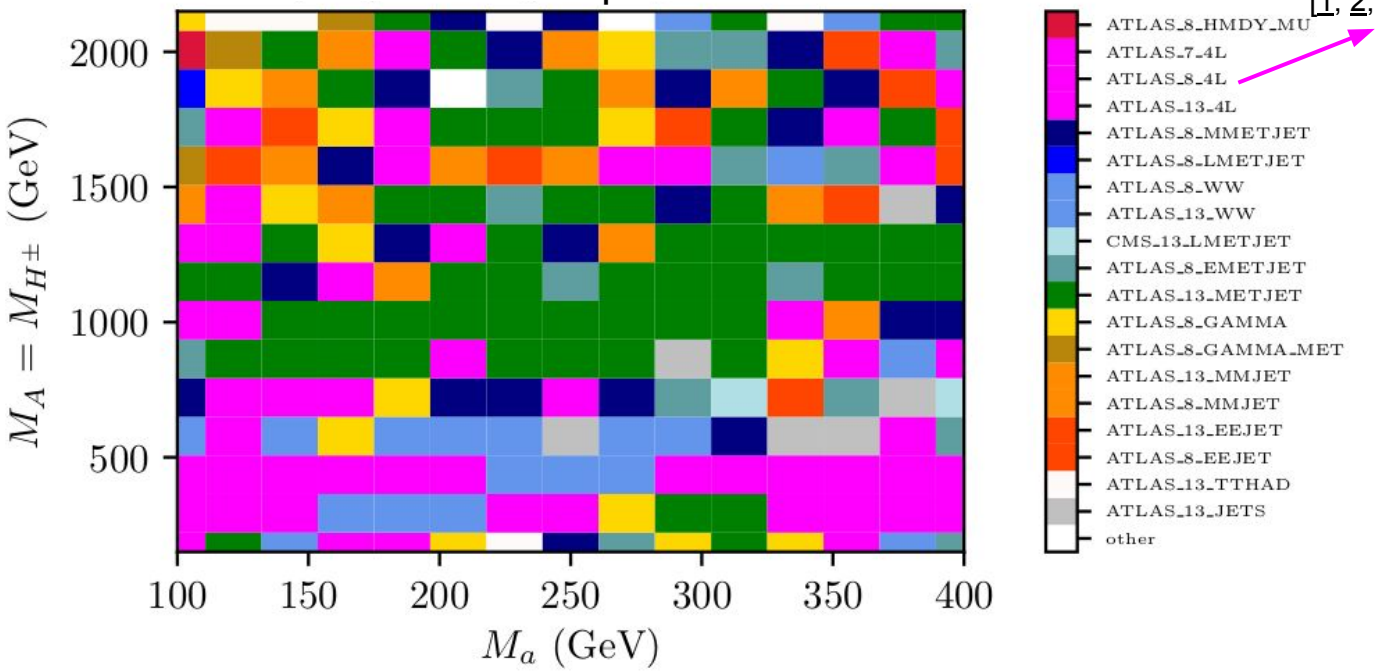

4-lepton production cross-section at 7, 8, 13 TeV with ATLAS [1, 2, 3, 4, 5]

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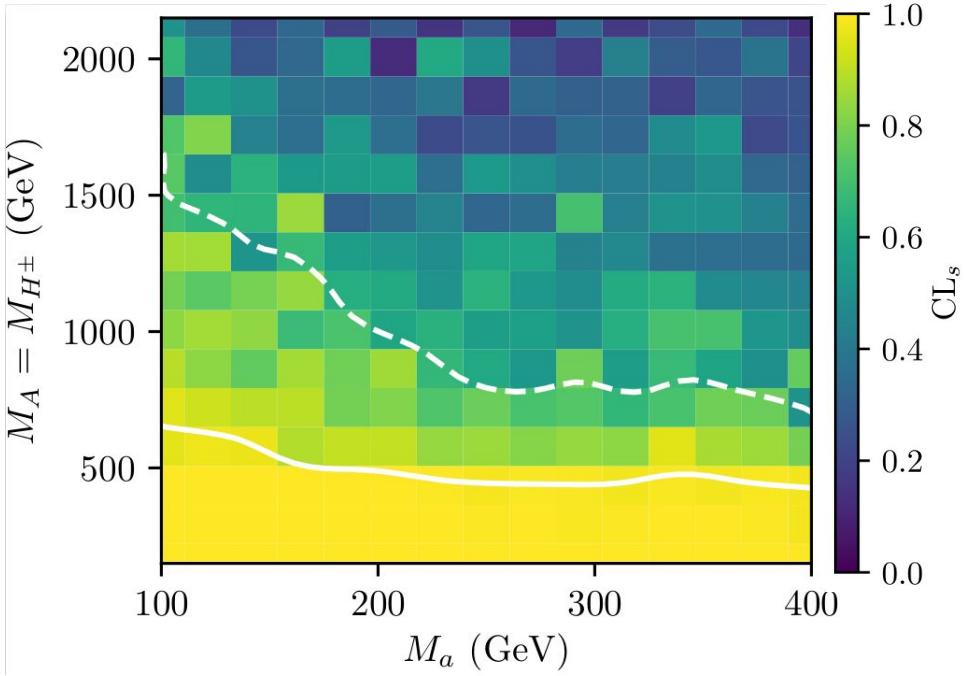

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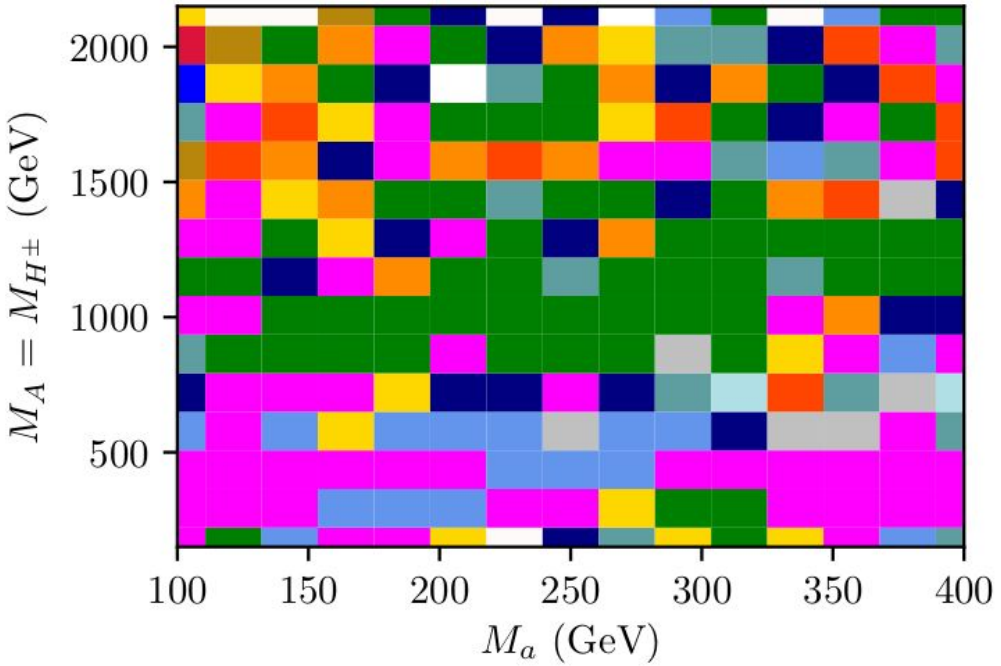

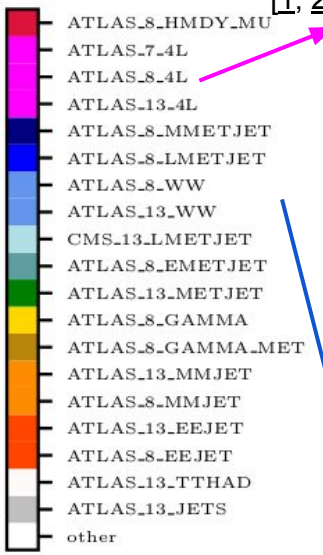

4-lepton production cross-section at 7, 8, 13 TeV with ATLAS [1, 2, 3, 4, 5]

WW(W) measurements at 8, 13 TeV with ATLAS [1, 2, 3, 4]

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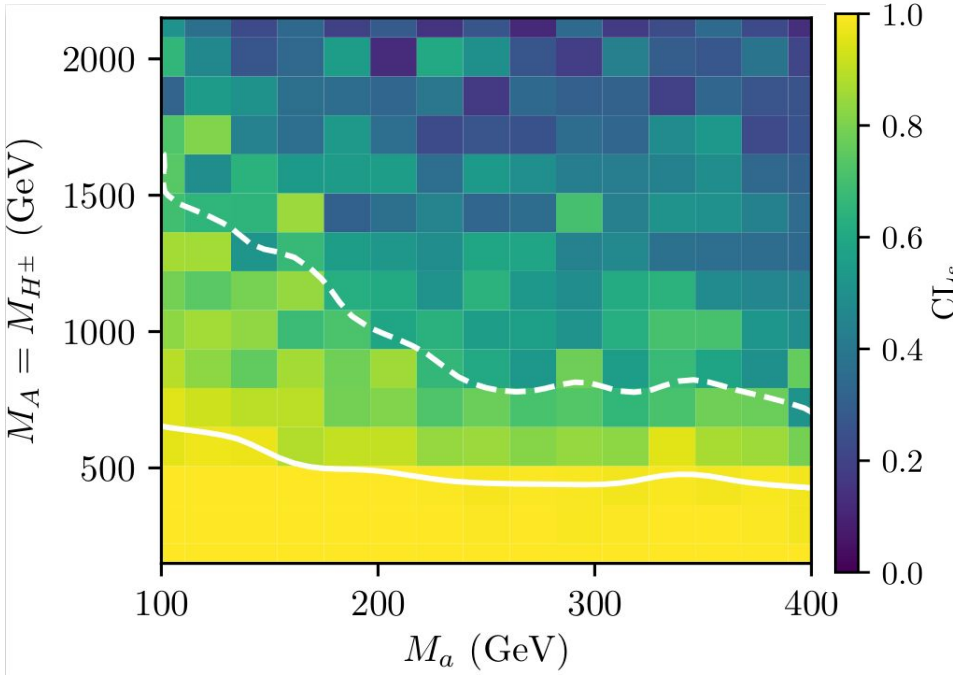

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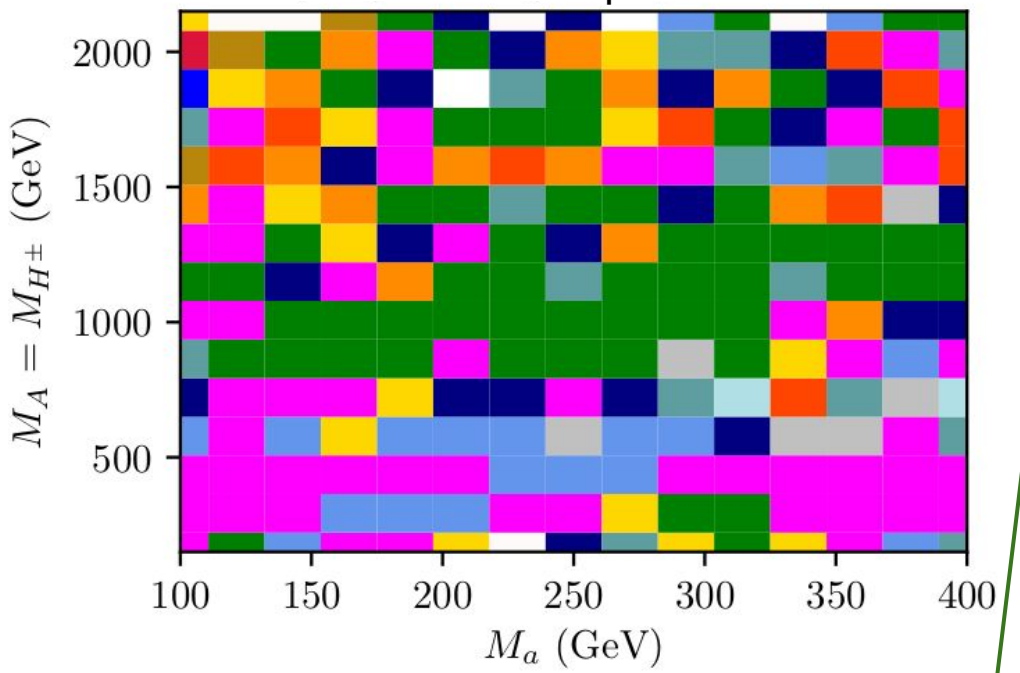

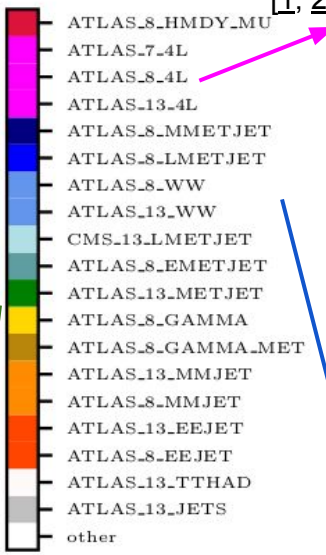

4-lepton production cross-section at 7, 8, 13 TeV with ATLAS [1, 2, 3, 4, 5]

WW(W) measurements at 8, 13 TeV with ATLAS [1, 2, 3, 4]

p_T^{miss}+jets cross section measurements at 13 TeV with ATLAS [1], 0-lepton SUSY search at 13 TeV with ATLAS [2]

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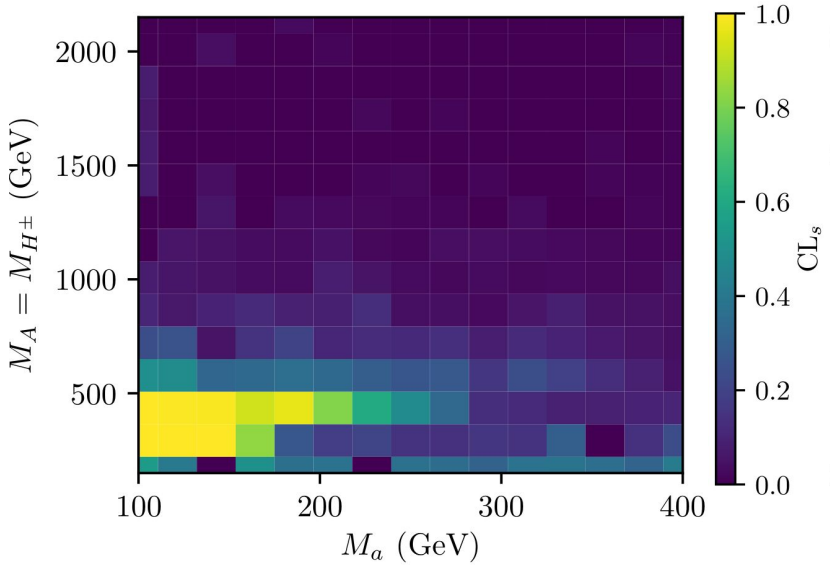
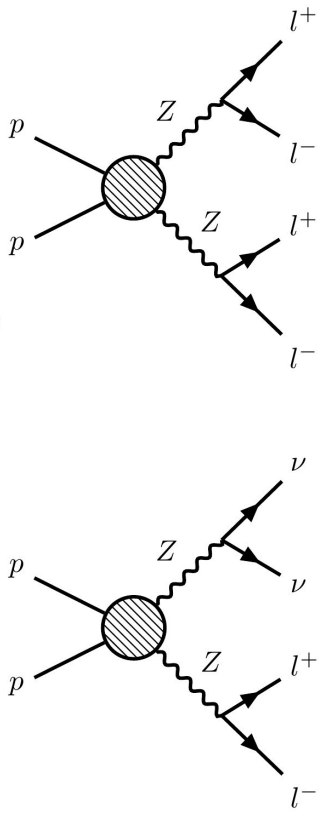
$\tan\beta = 1$, $m_A = m_{H\pm} = m_H$, m_χ=10 GeV, $\sin\theta$=0.35, $\sin(\beta-\alpha)$=1

m_A scan - exemplary explanation of sensitivity



ATLAS: Measurement of ZZ production @ 7 TeV



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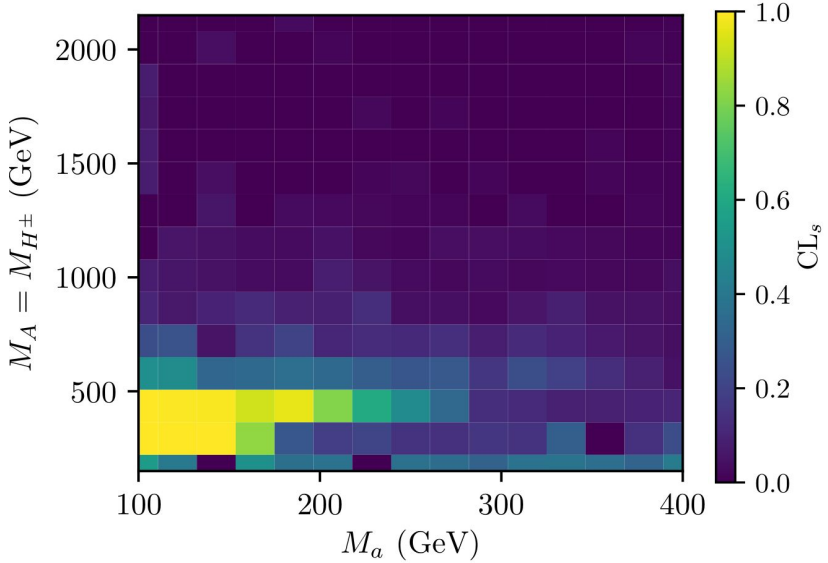

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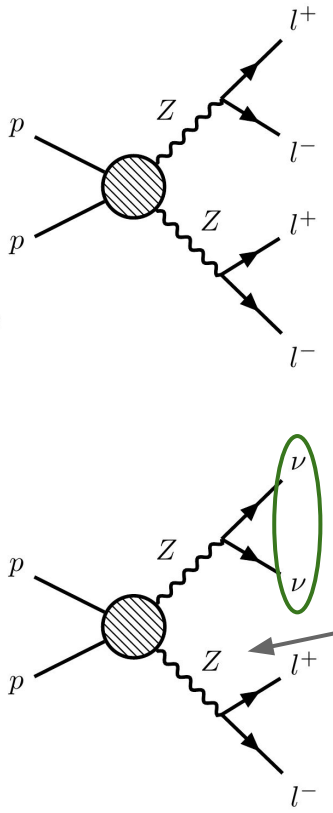
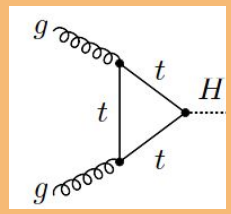
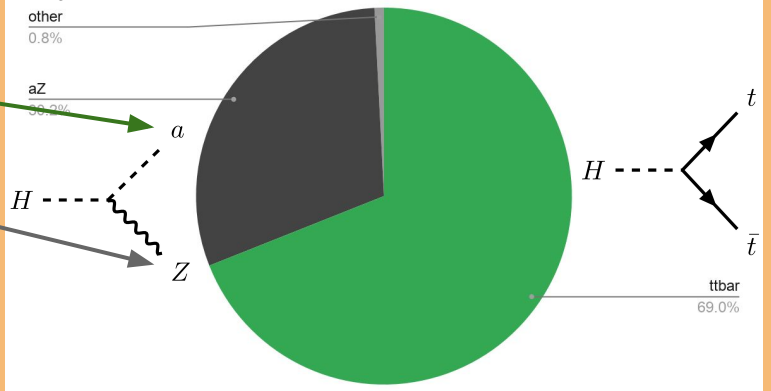


MET
+
Z

heavy CP-even Higgs (H) production:



heavy CP-even Higgs (H) decay:
(m_a=100 GeV, m_A=435 GeV)



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Contur results - m_A scan

chosen parameter region:

- $m_A = m_{H\pm} = m_H$
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- $\sin(\beta-\alpha) = 1$ → alignment limit (lightest mass eigenstate has SM Higgs couplings)
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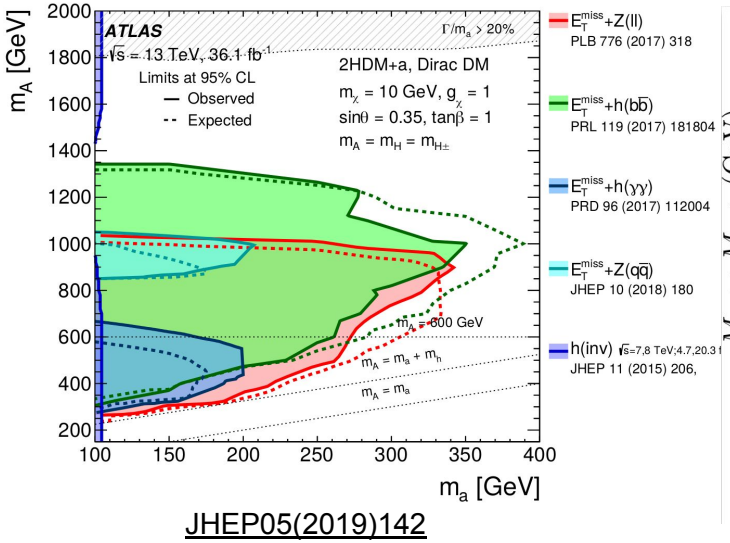

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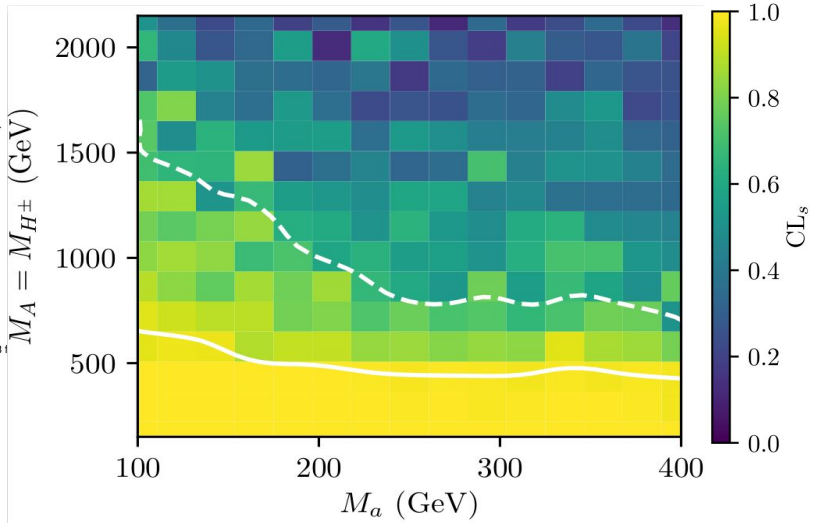
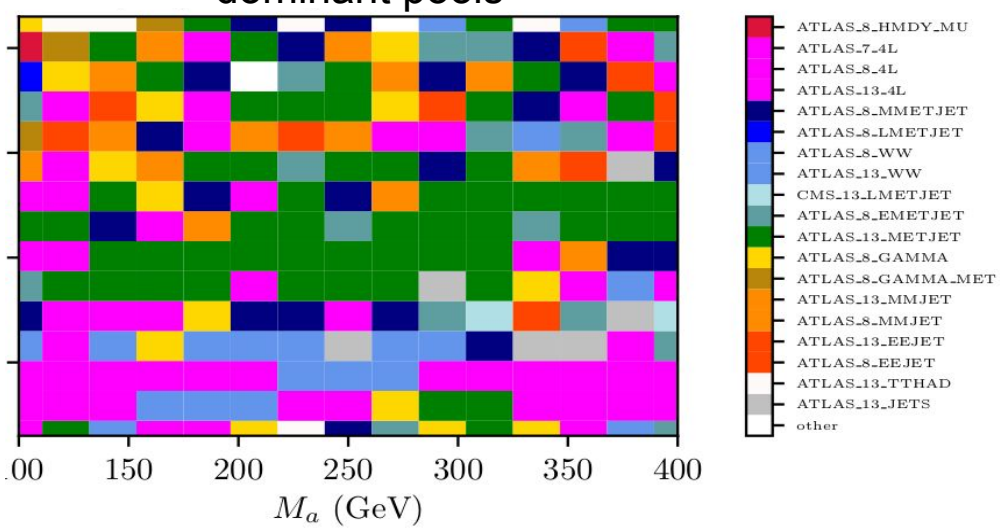


dominant pools

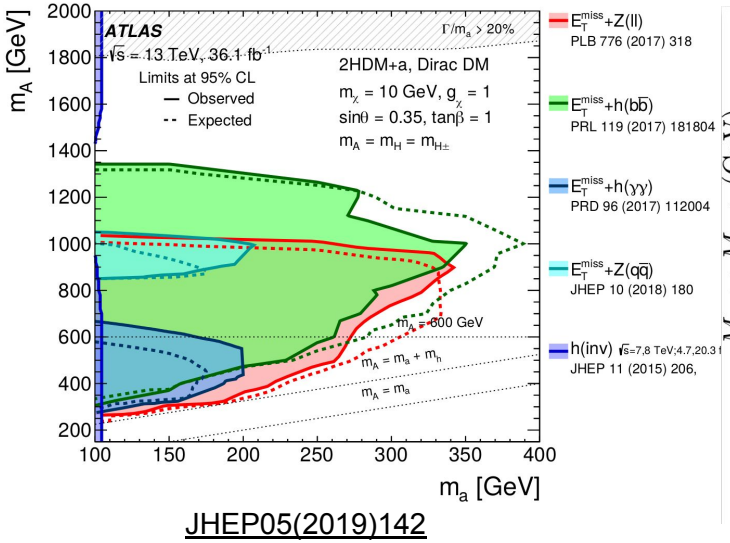


up to here →Les Houches 2019 proceedings

Contur results - m_A scan

chosen parameter region:

- $m_A = m_{H\pm} = m_H$
- m_χ=10 GeV
- ~~sinθ=0.35~~ → **sinθ=0.70**
- sin(β-α)=1 → alignment limit (lightest mass eigenstate has SM Higgs couplings)
- tanβ = 1



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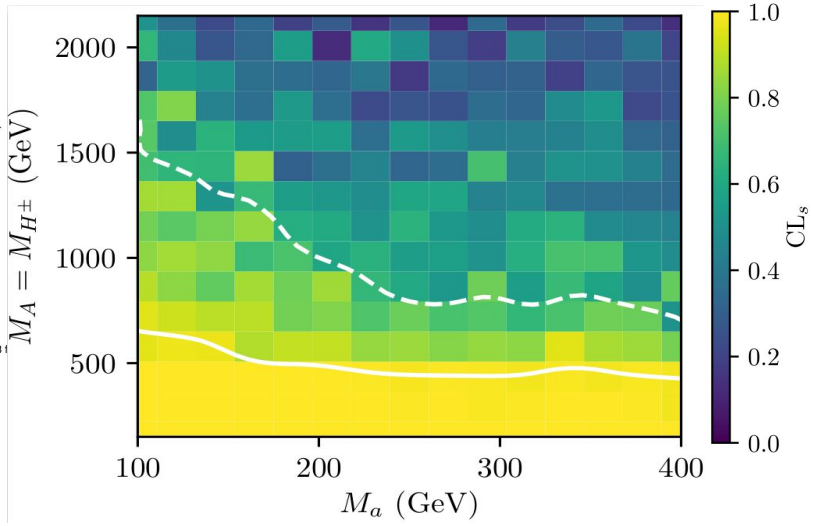

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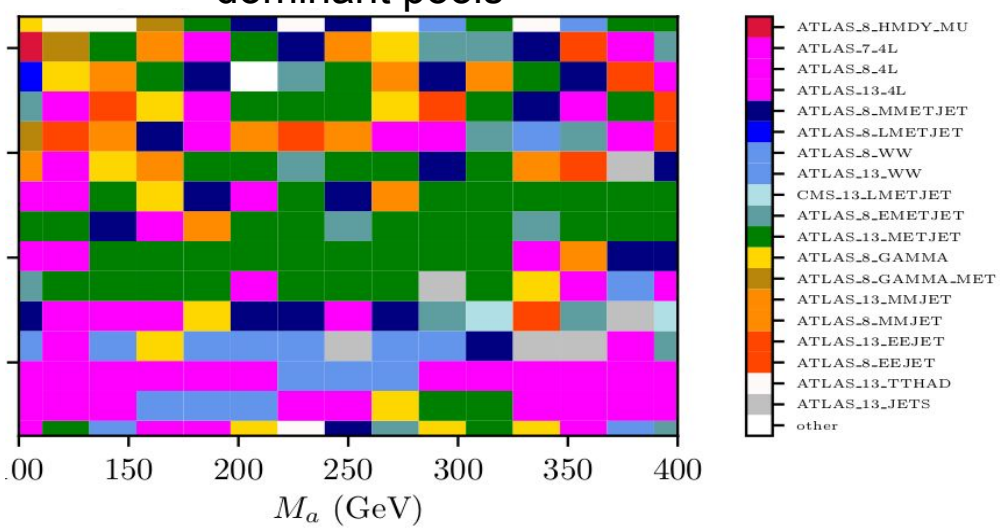

What do we expect for larger sinθ?

$$L \supset \sum_{f=t,b,\tau} x_f \cdot f\bar{f}\,(A\cos\theta - a\sin\theta) + w_x \chi\bar{\chi}(A\sin\theta - a\cos\theta)$$

$$\Gamma(a \to gg) \propto \sin^2\theta$$

sinθ=0.70: “maximum mixing”

- ➔ for t, b, τ, g: coupling to *a* increases, coupling to *A* decreases → production cross section of *a* increases
- ➔ for DM: coupling to *a* decreases, coupling to *A* increases

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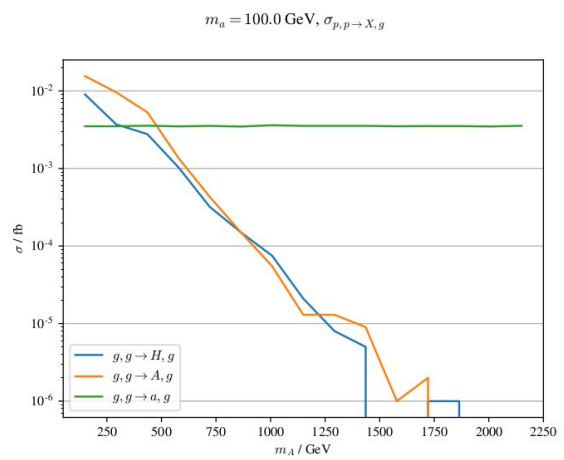
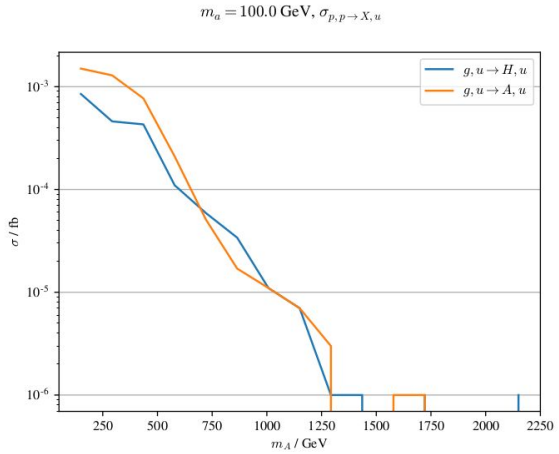
xsec(g+X)

xsec(u+X)

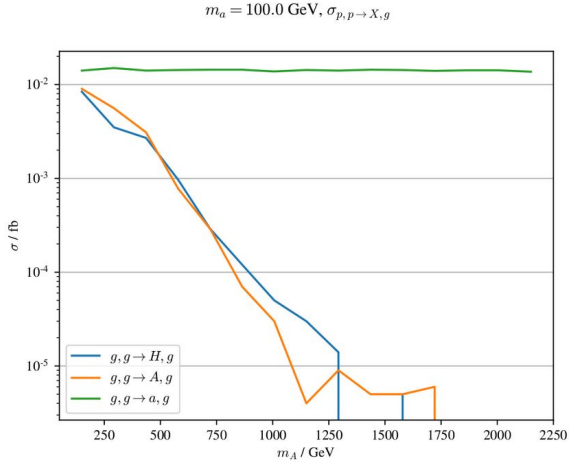
sinθ=0.35

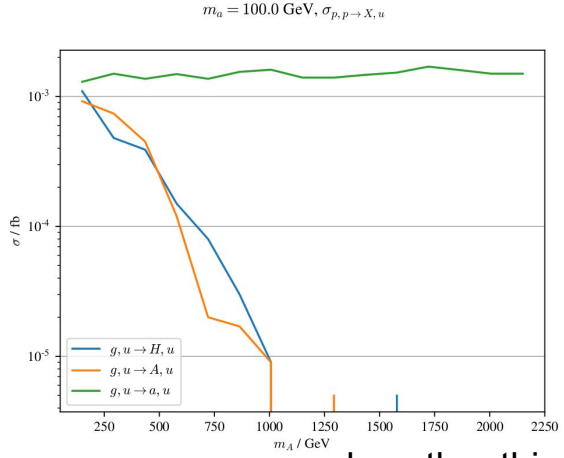
m_a = 100GeV





sinθ=0.70



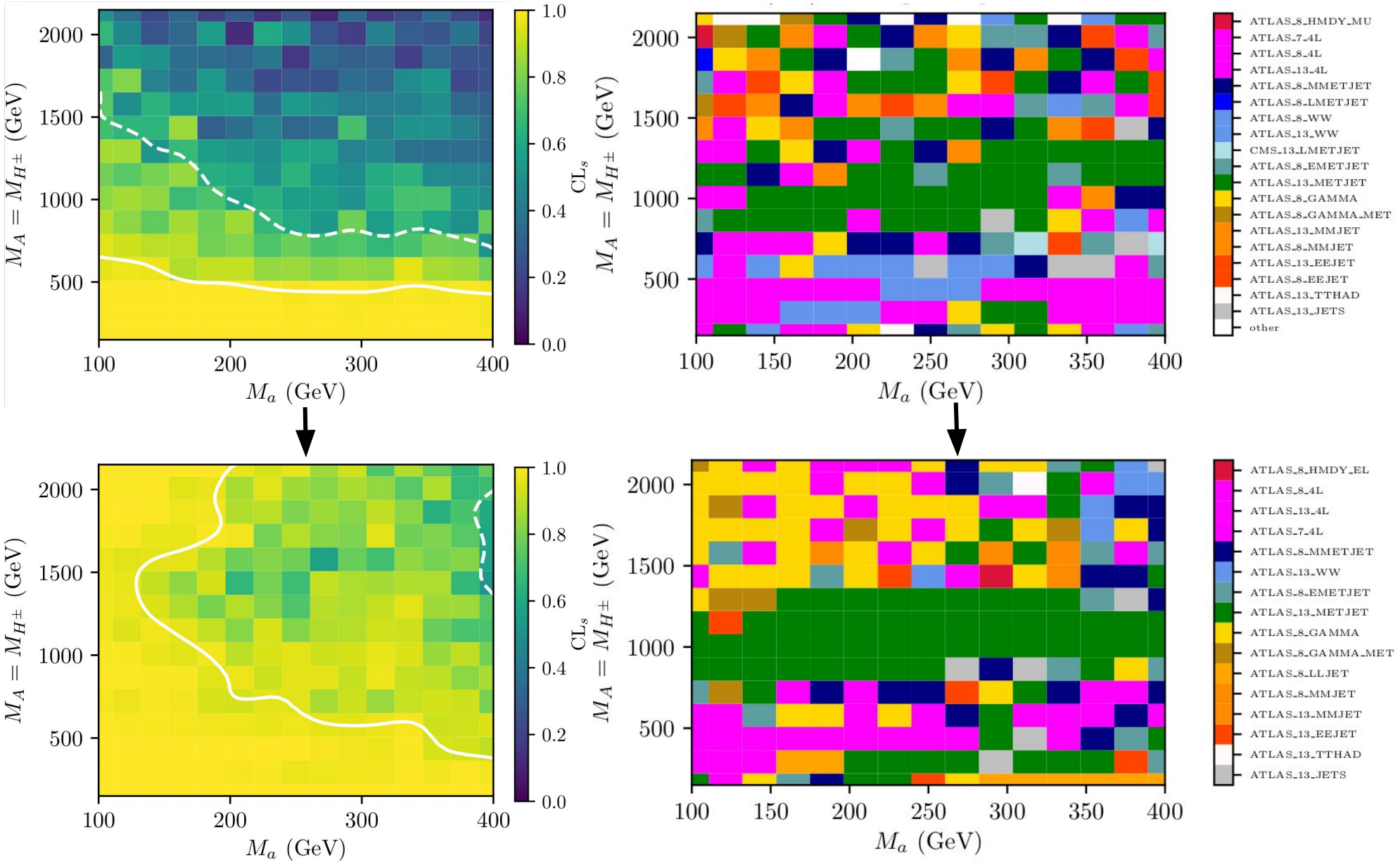


also other things change → later

What do we get?

sinθ=0.35

sinθ=0.70



sensitivity massively increased, as expected ✓ can we find out more about this?

ATLAS_7_4L

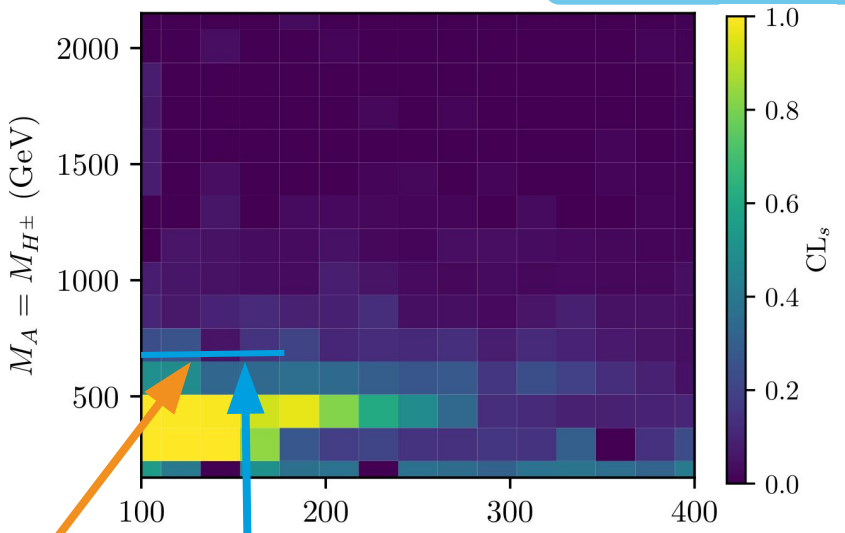
ATLAS_2012_I1203852

signature:
$ZZ^{(*)} \rightarrow 4l$
$ZZ^{(*)} \rightarrow 2l+MET$

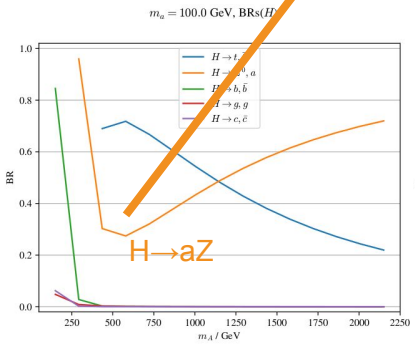
sinθ=0.35

most important process: H→a(χχ)Z

sinθ=0.70

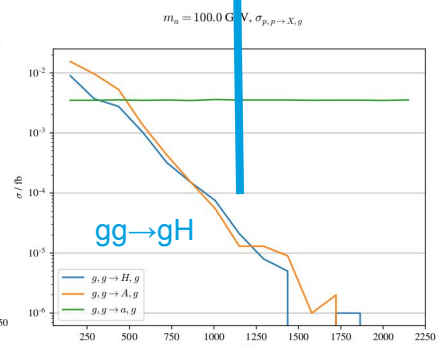


BRs(H), m_a=100GeV



m_A

xsec(g+X), m_a=100GeV



m_A

ATLAS_7_4L

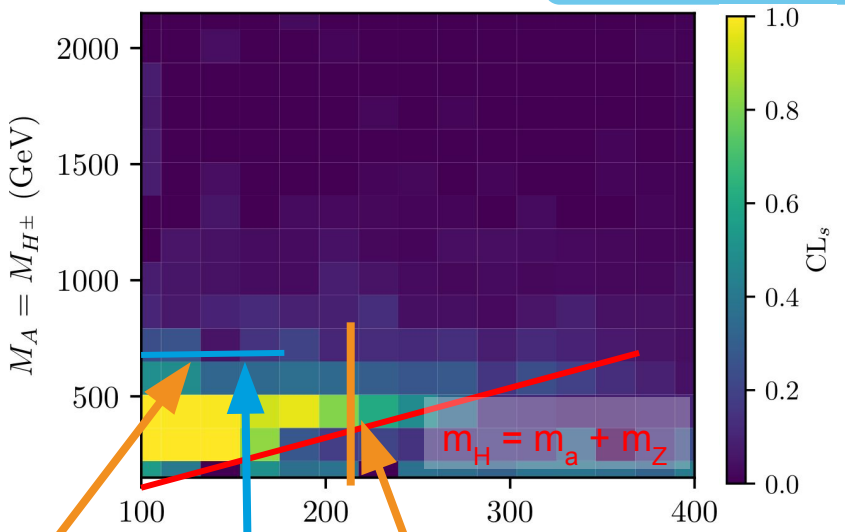
ATLAS_2012_I1203852

signature:
$ZZ^{(*)} \rightarrow 4l$
$ZZ^{(*)} \rightarrow 2l+MET$

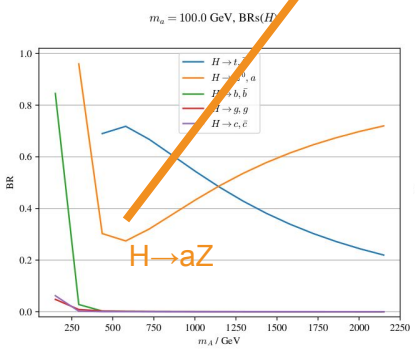
sinθ=0.35

most important process: H→a(χχ)Z

sinθ=0.70

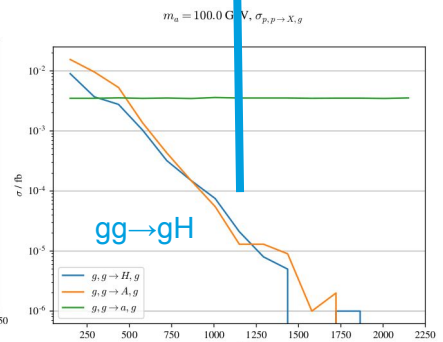


BRs(H), m$_a$=100GeV



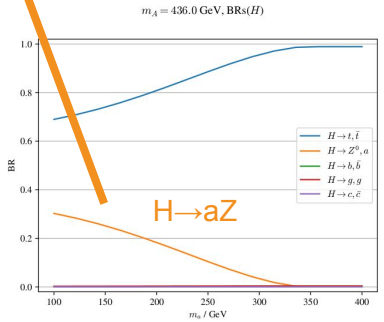
m$_A$

xsec(g+X), m$_a$=100GeV



m$_A$

BRs(H), m$_A$=436 GeV



m$_a$

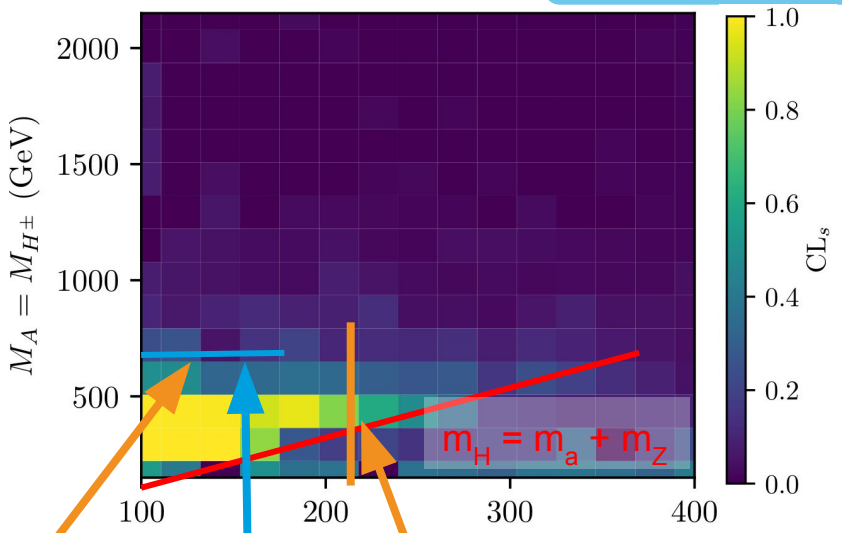
ATLAS_7_4L

ATLAS_2012_I1203852

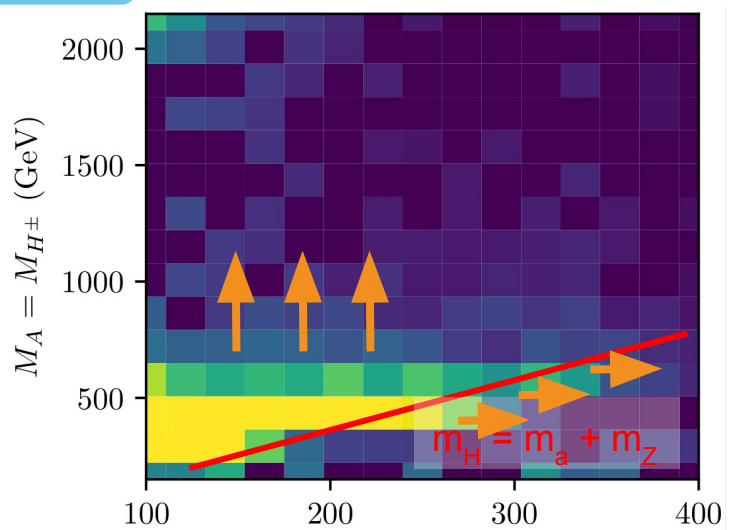
signature:
$ZZ^{(*)} \rightarrow 4l$
$ZZ^{(*)} \rightarrow 2l+MET$

most important process: $H \rightarrow a(\chi\chi)Z$

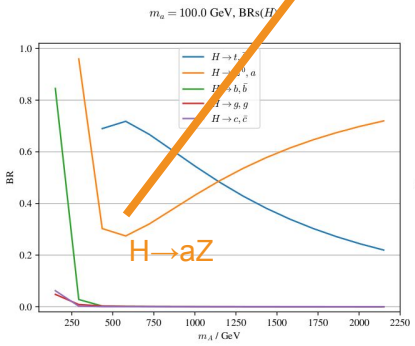
sinθ=0.35



sinθ=0.70

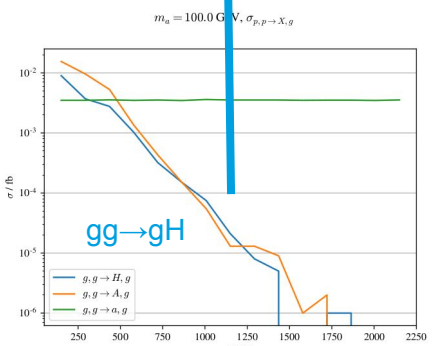


BRs(H), m_a=100GeV



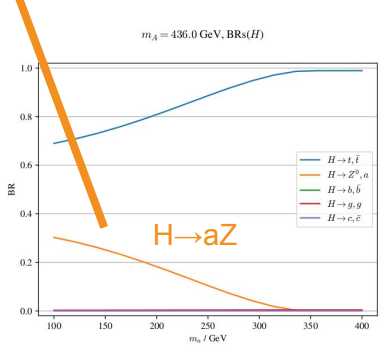
m_A

xsec(g+X), m_a=100GeV



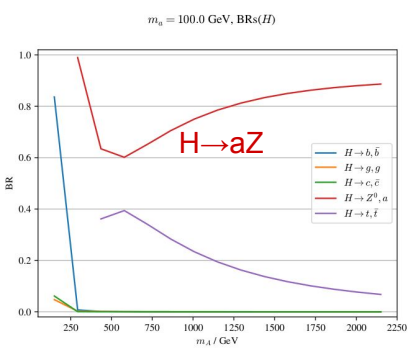
m_A

BRs(H), m_A=436 GeV



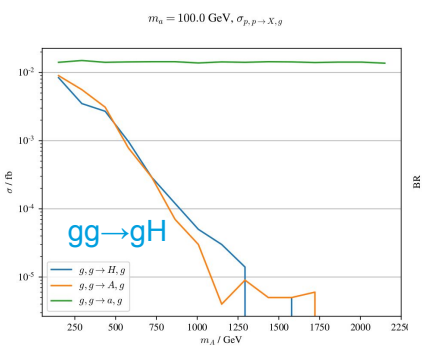
m_a

BRs(H), m_a=100GeV



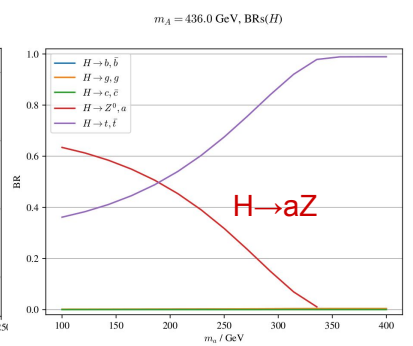
m_A

xsec(g+X), m_a=100GeV



m_A

BRs(H), m_A=436GeV

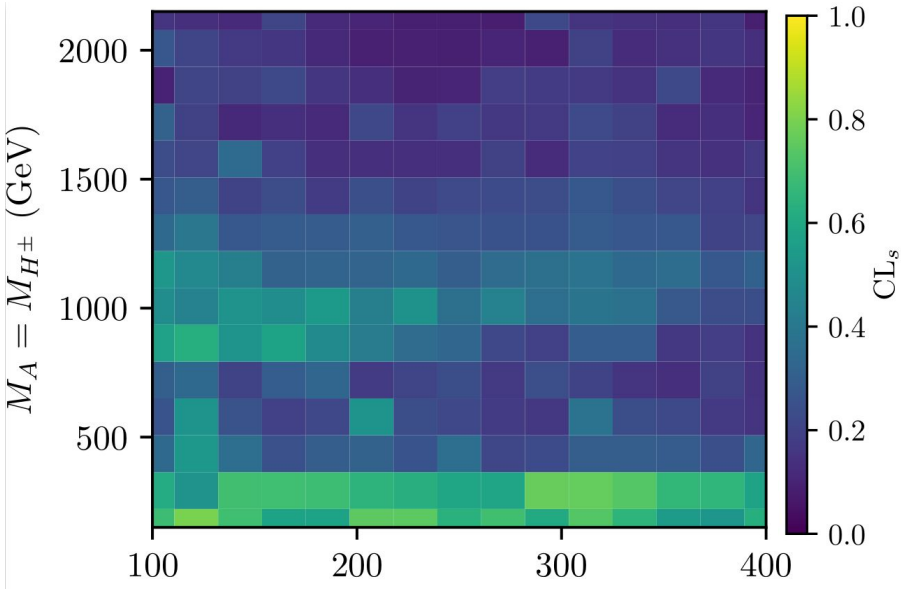


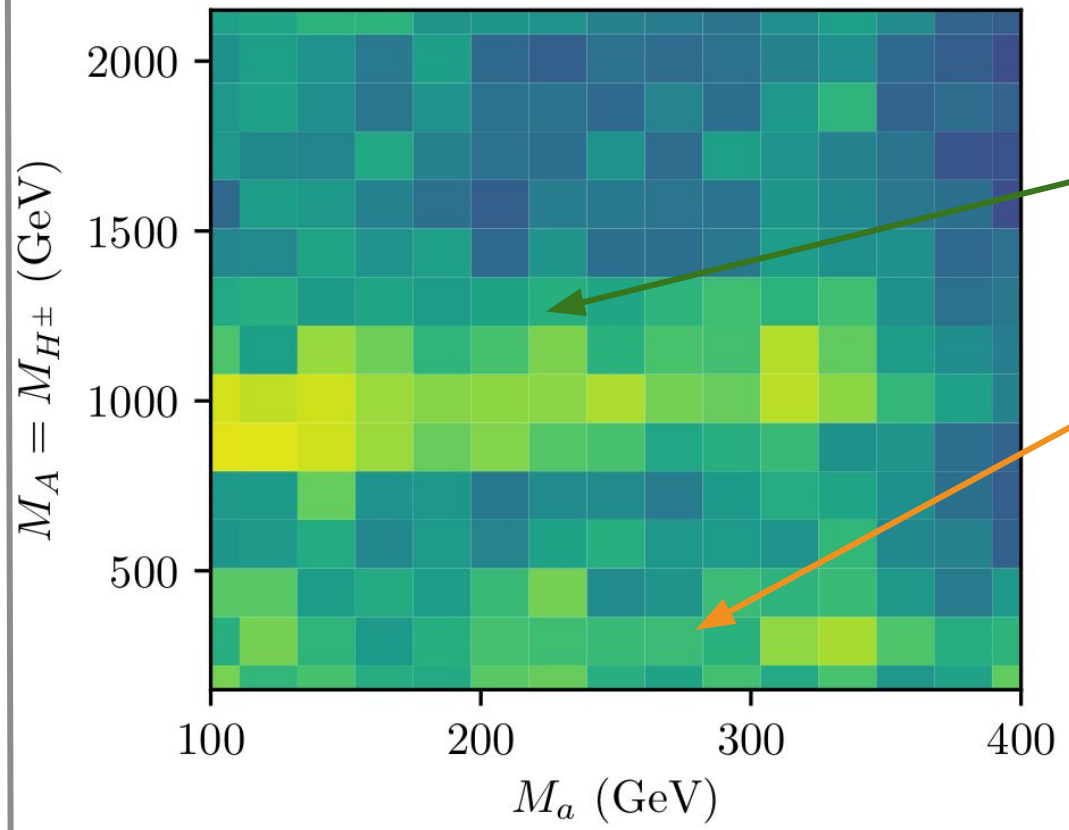
m_a

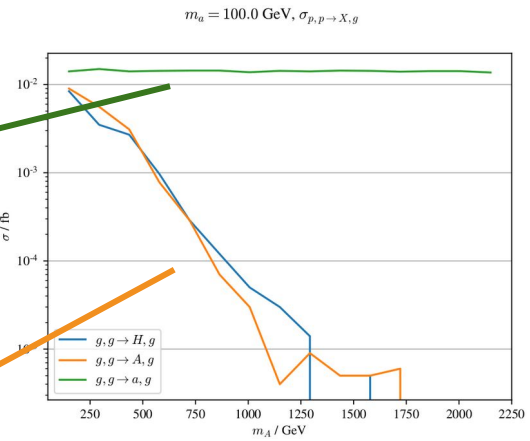
ATLAS_13_METJET

ATLAS_2016_I1458270
(0-lepton SUSY)

sinθ=0.35





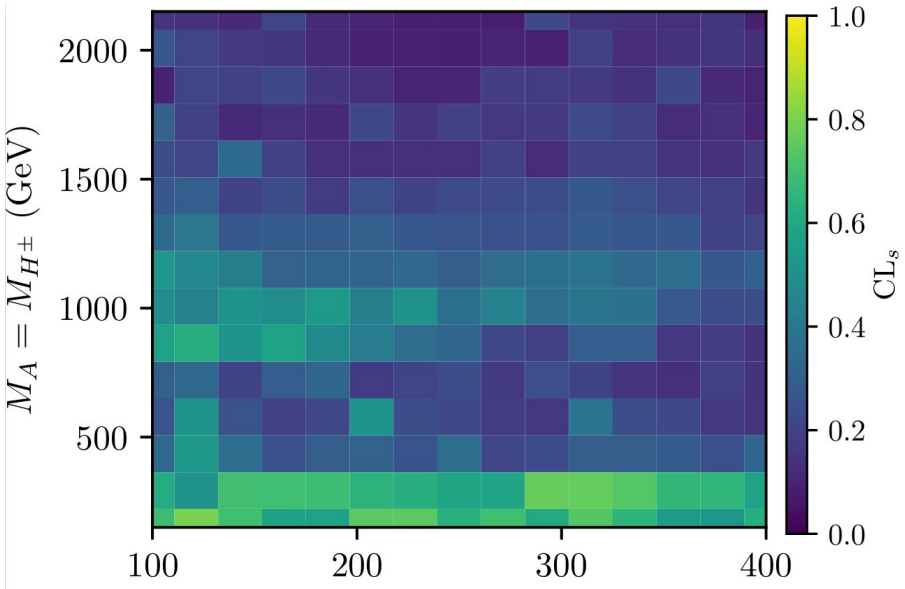


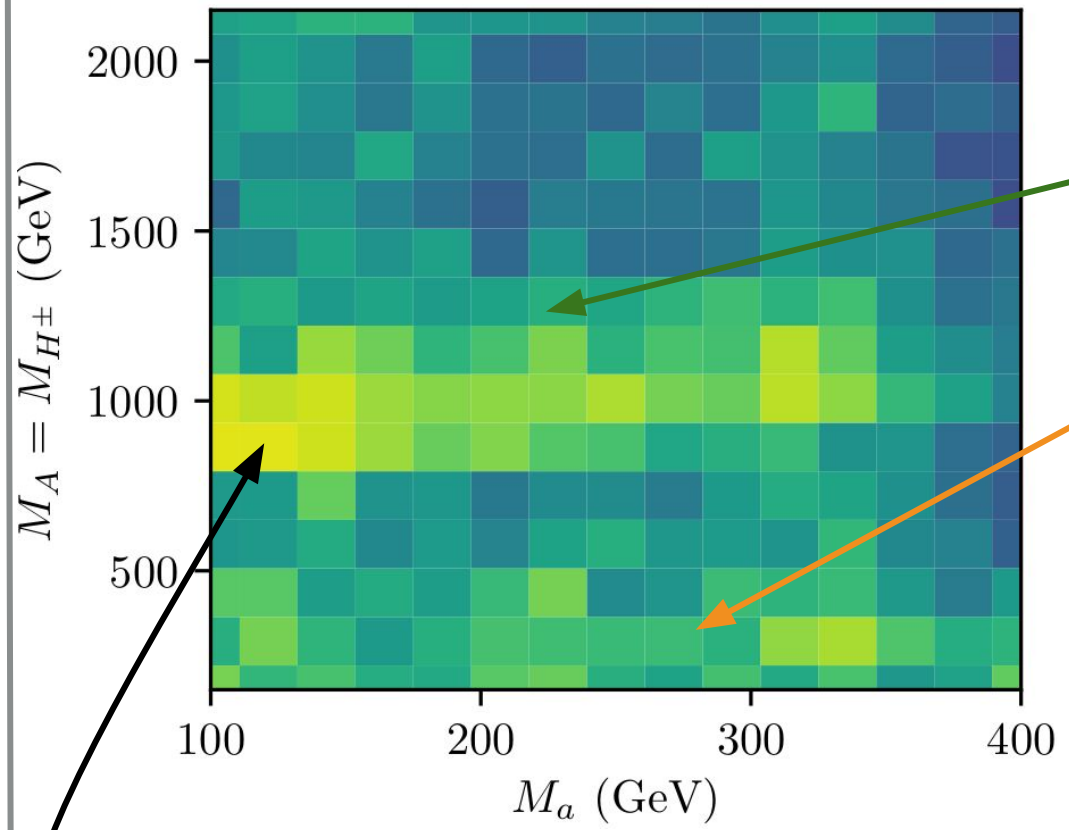
MET+jet from gg→gA, gg→ga everywhere

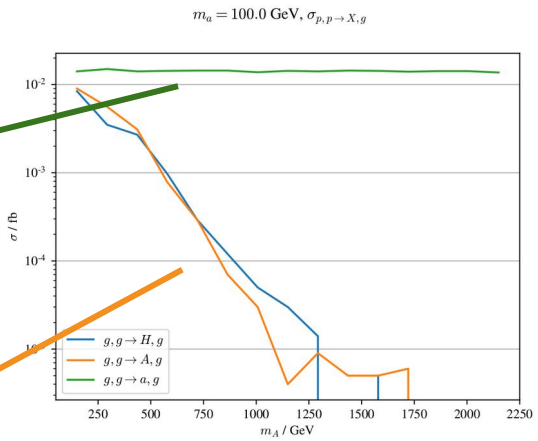
ATLAS_13_METJET

ATLAS_2016_I1458270
(0-lepton SUSY)

sinθ=0.35

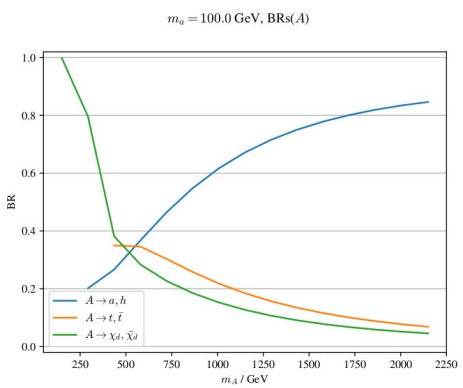




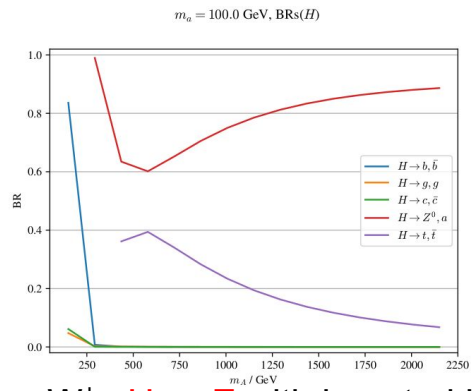


MET+jet from gg→gA, gg→ga everywhere

=



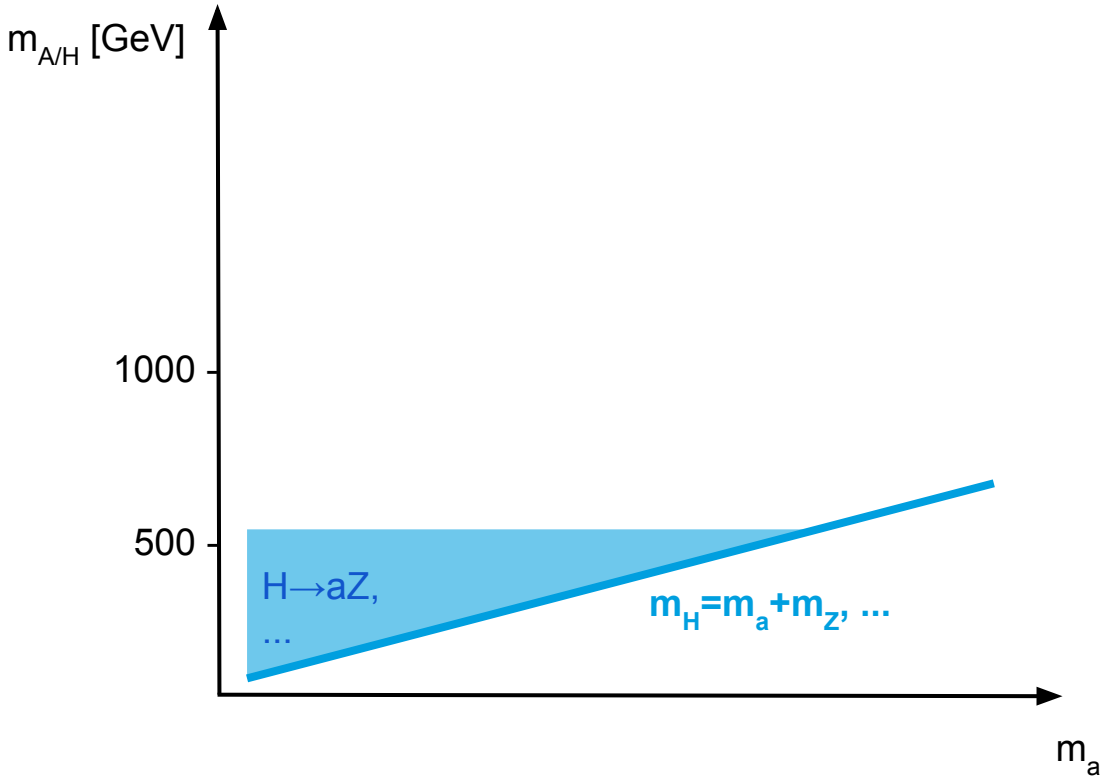
+



+

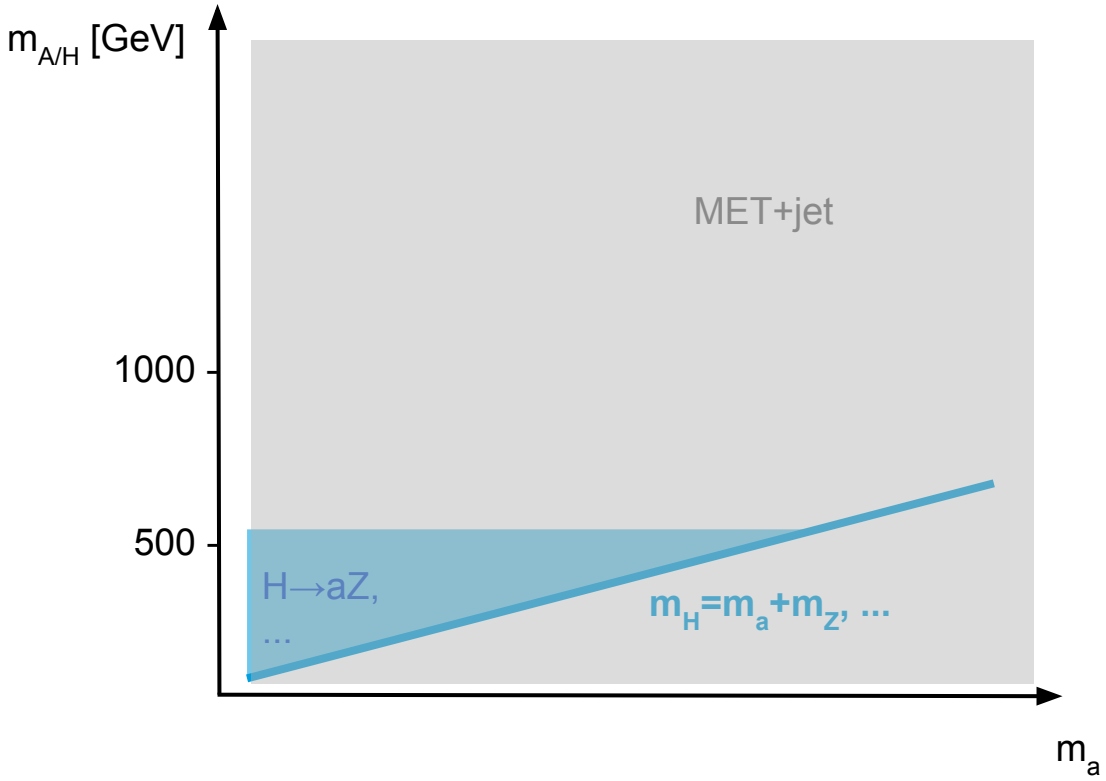
but also A→ ah(bb), H±→ aW±, H→aZ with boosted jets

Summary of sinθ=0.70 changes



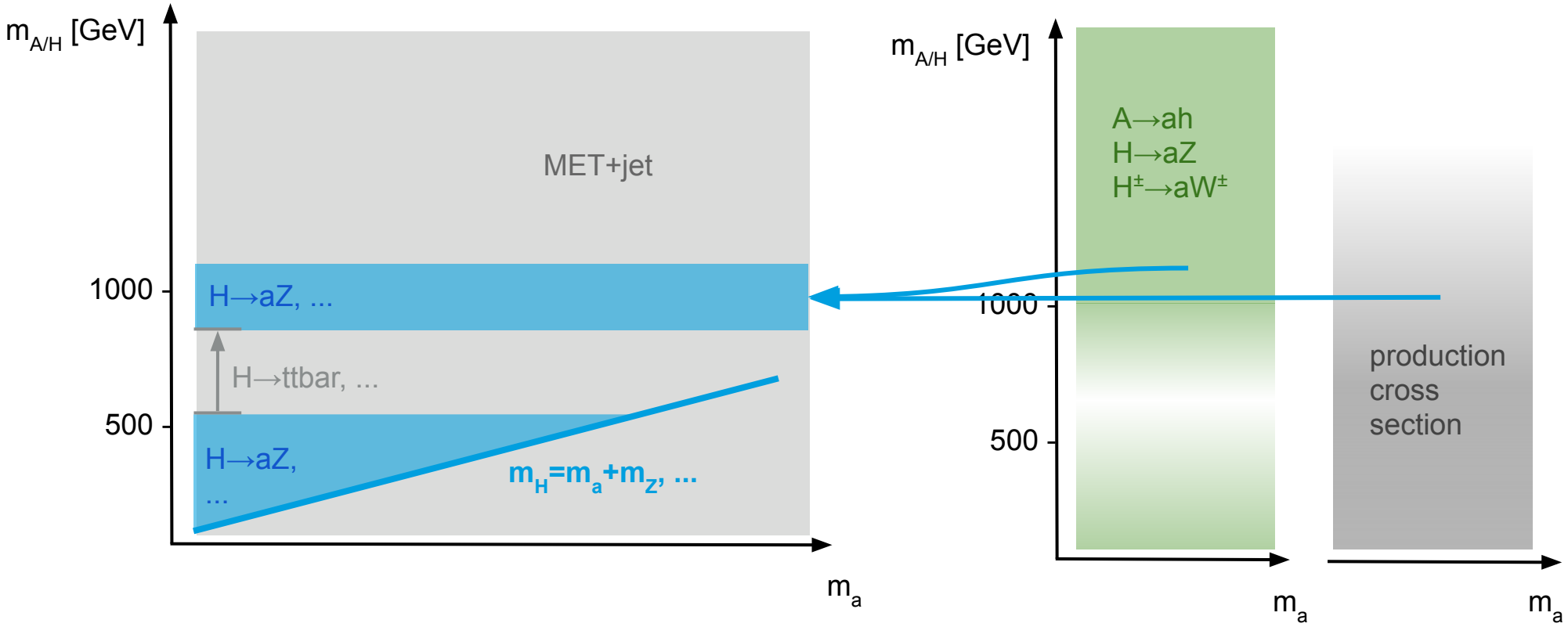
schematic, not for scale (duh!)

Summary of sinθ=0.70 changes



schematic, not for scale (duh!)

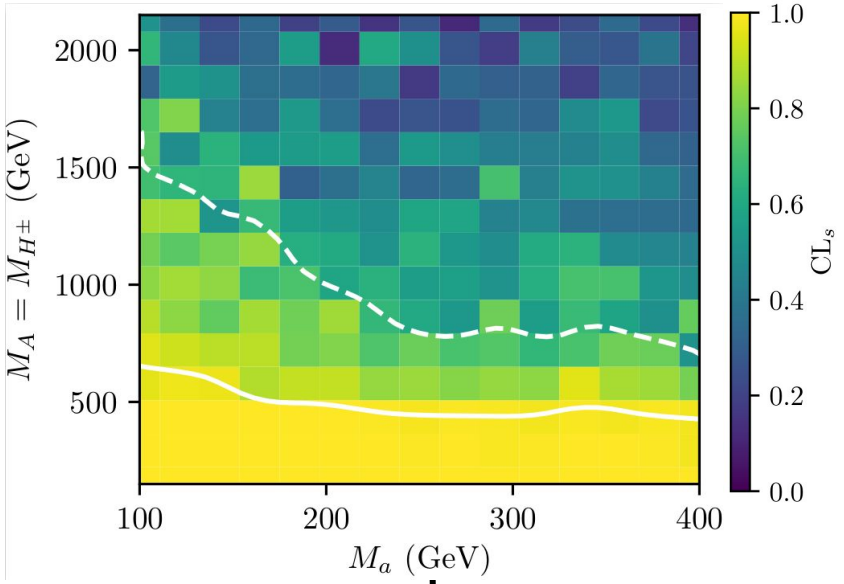
Summary of sinθ=0.70 changes



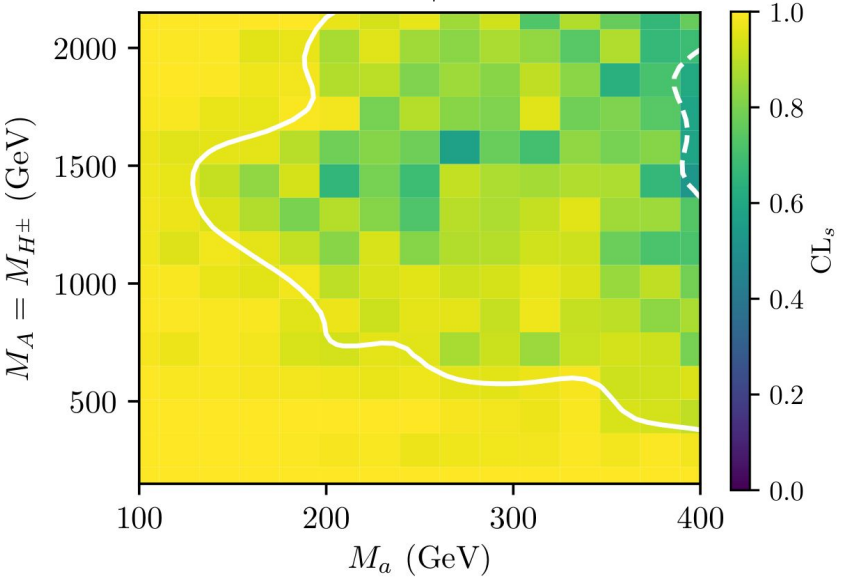
schematic, not for scale (duh!)

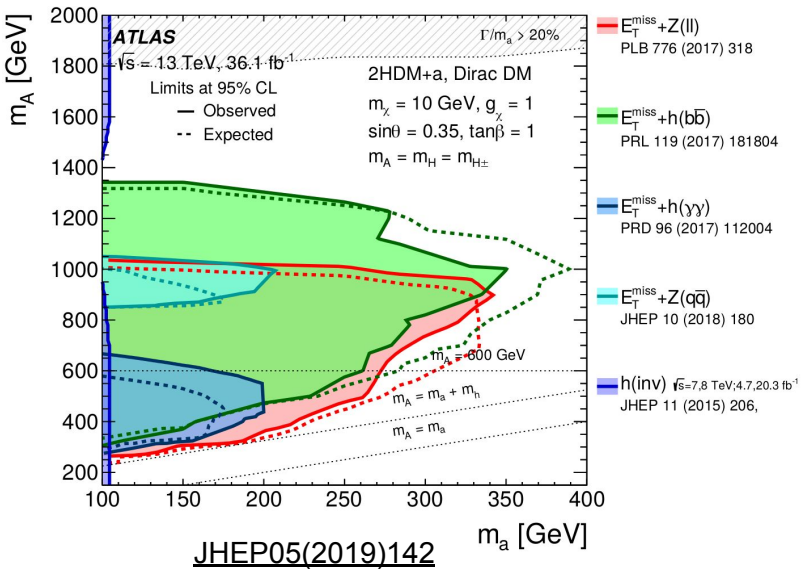
Summary

sinθ=0.35



sinθ=0.70





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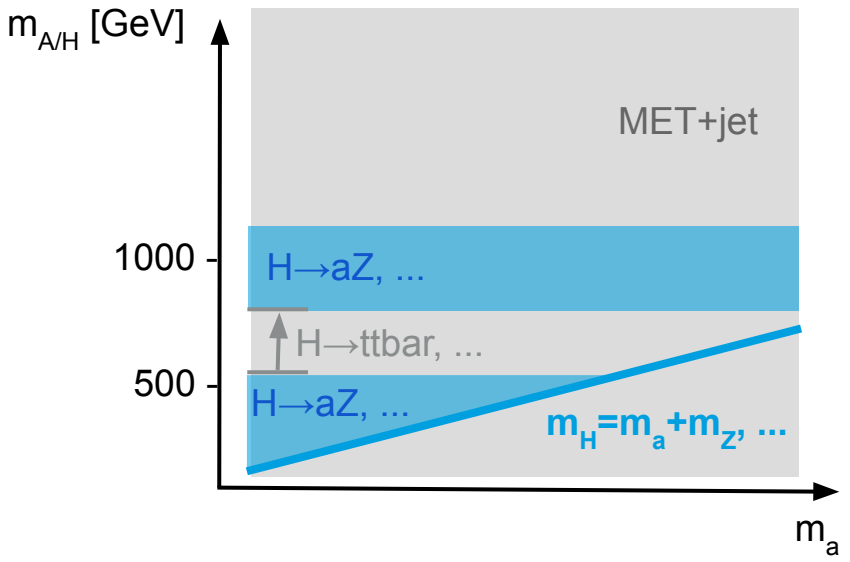


Caveats

1. roughly speaking:
   $\sin\theta \uparrow \Rightarrow$ particle width $\Gamma \uparrow$
   $m_{A,H} \uparrow \Rightarrow$ particle width $\Gamma \uparrow$

$\sin\theta$	$m_A(\Gamma = 20\%\ m_A)$
0.35	2 TeV
0.70	1 TeV

   so we have to take $\sin\theta=0.70$ results with a grain of salt (the higher m_A, the more) as **narrow-width approximation** becomes imprecise
2. Herwig doesn't support **2→3 processes**
   → right now implementing interface between MadGraph & Contur to investigate impact of 2→3 processes

The End

Backup

ATLAS_8_GAMMA

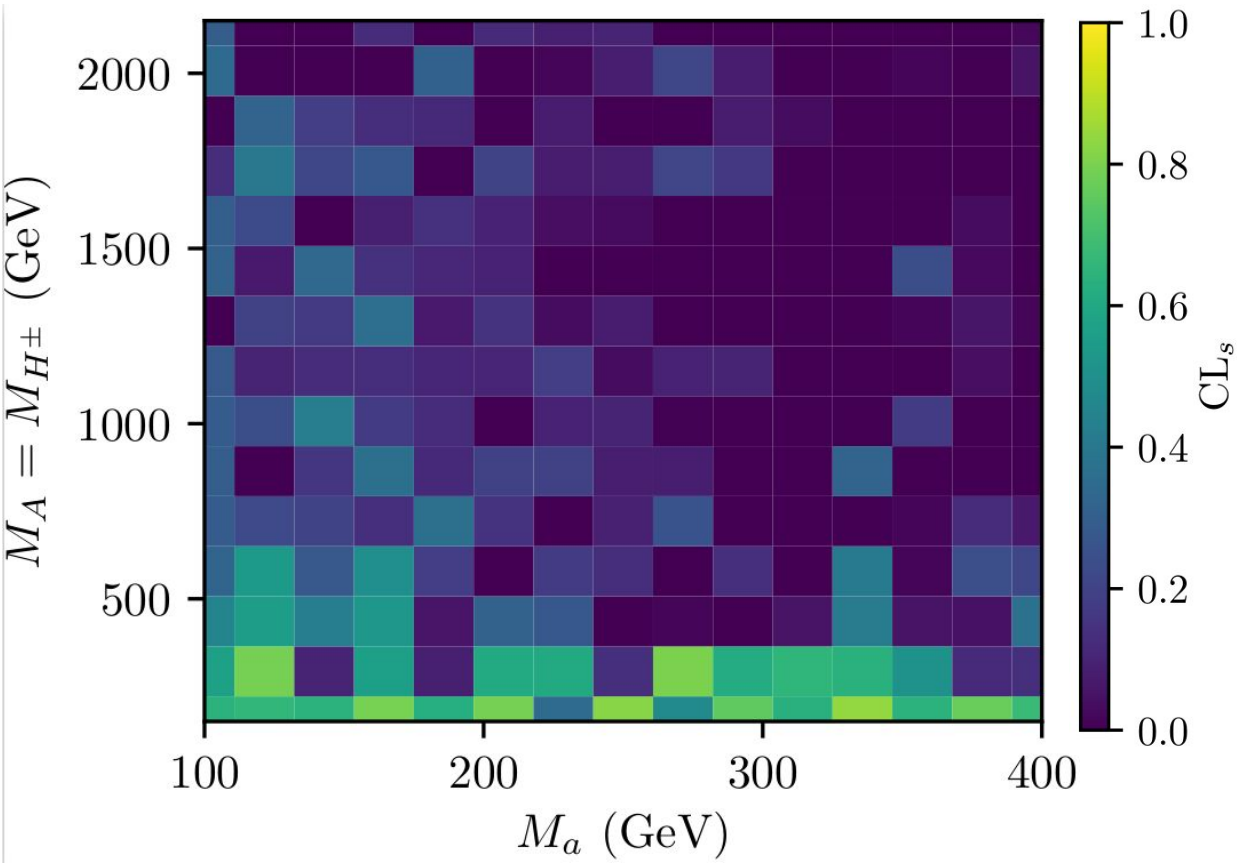
ATLAS_2014_I1306615

signtature: h→γγ

$g_{haa} \propto x \cdot (M_A^2 - M_a^2) \cdot sin^2\theta + y \cdot cos^2\theta$

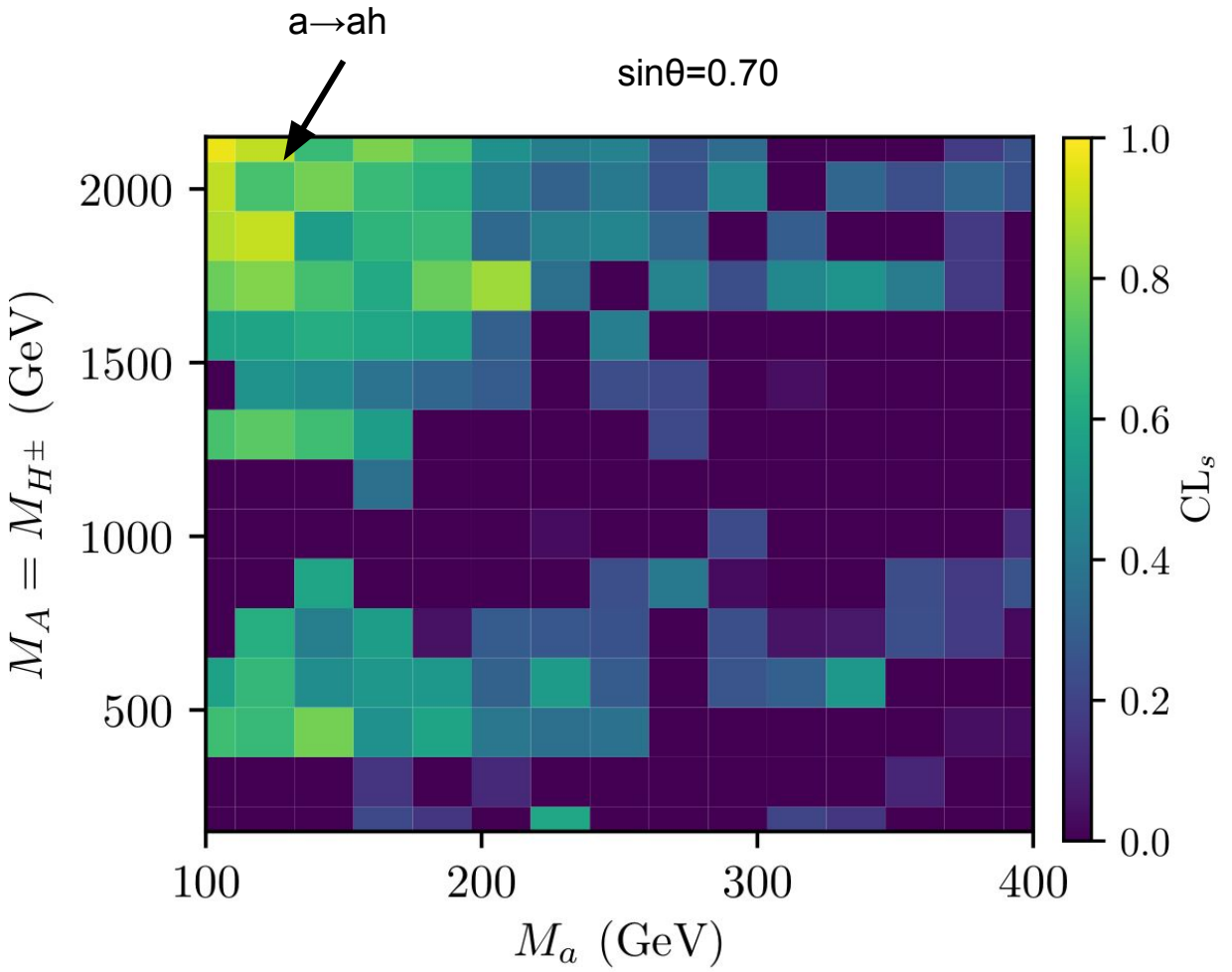
→ coupling ∝sin²θ; increase with higher m_A-m_a mass difference

sinθ=0.35



a→ah

sinθ=0.70



Charged Higgs

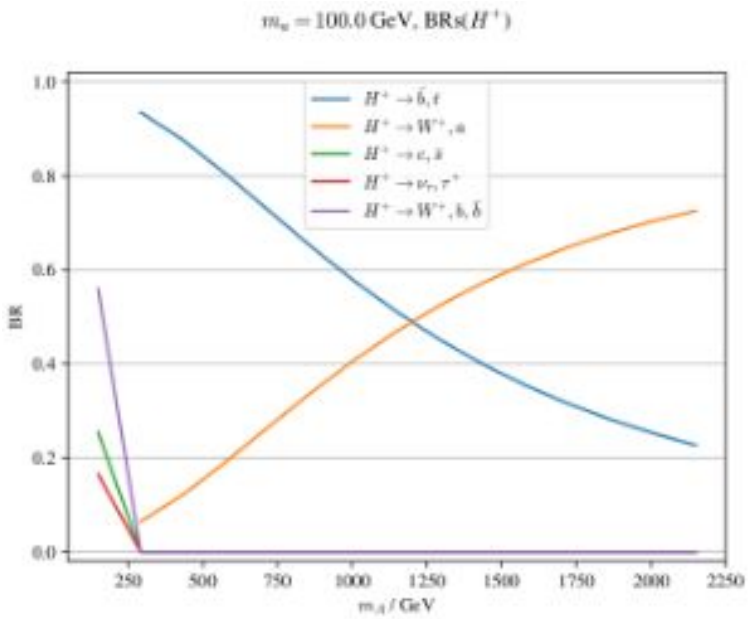
$$\Gamma(H^{\pm} \to aW^{\pm}) \propto \sin^2\theta$$

→ branching ratio increases
→ charged Higgs can become important for lower tanβ or not become important at all

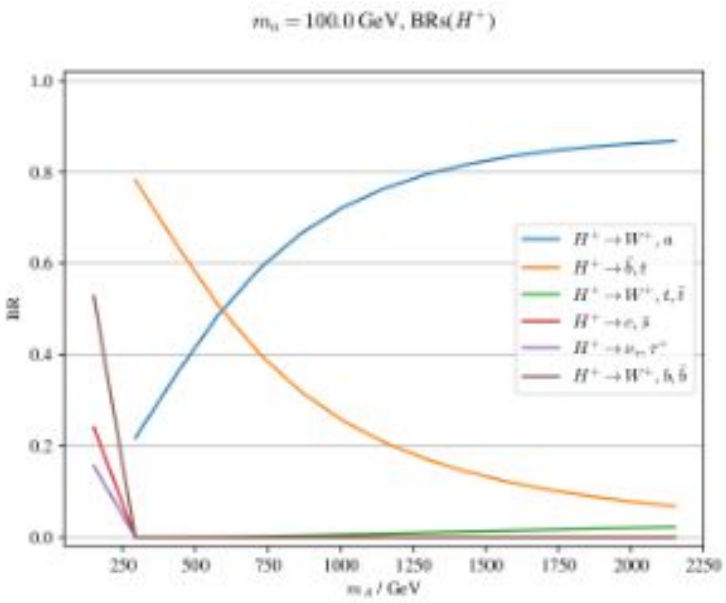
m_a=100GeV

BRs($H^{\pm}$)

sinθ=0.35



sinθ=0.70



Heavy CP-even Higgs H

$$\Gamma(H \to aZ) \propto \sin^2\theta$$

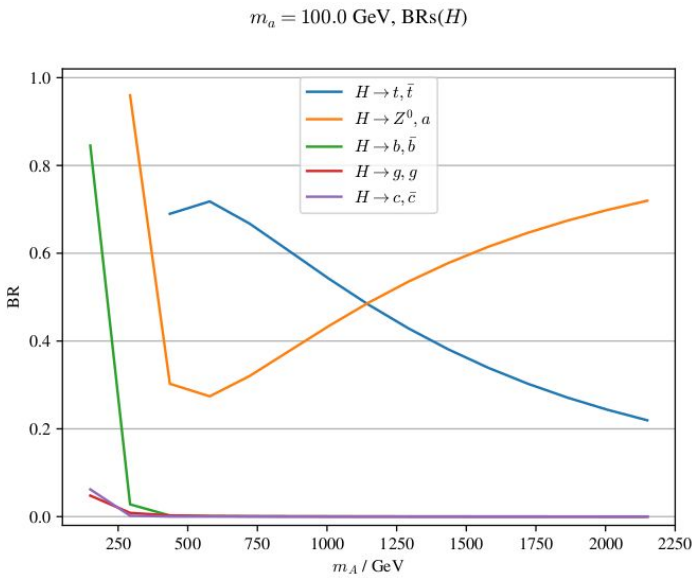
→ branching ratio increases

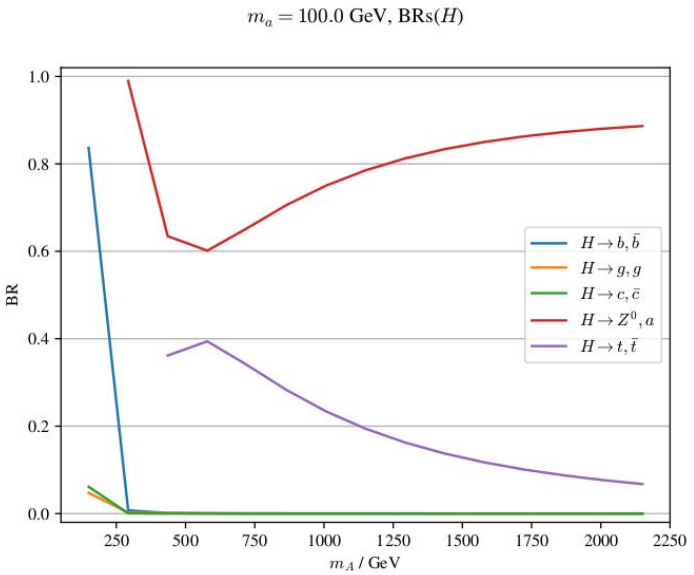
BRs(H)

sinθ=0.35

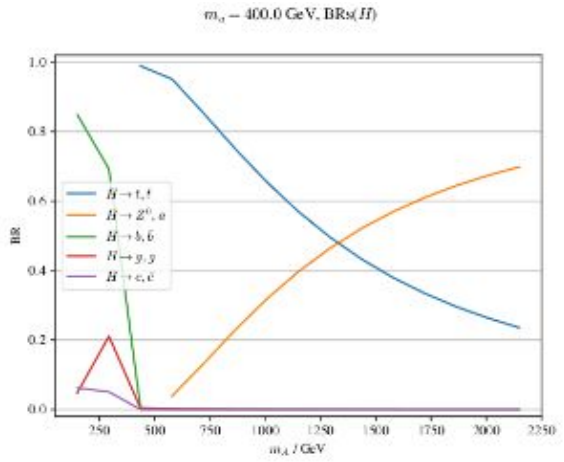
sinθ=0.70

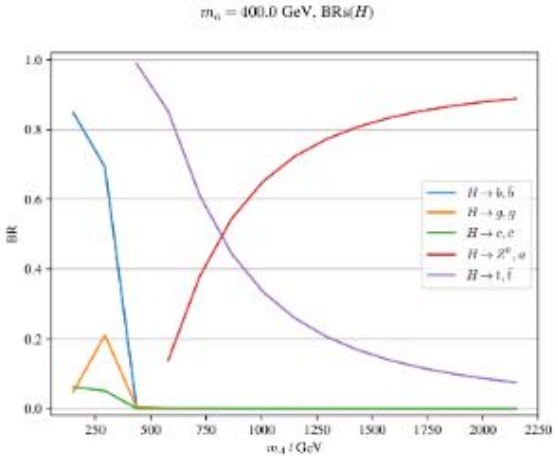
m_a=100GeV





m_a=400GeV





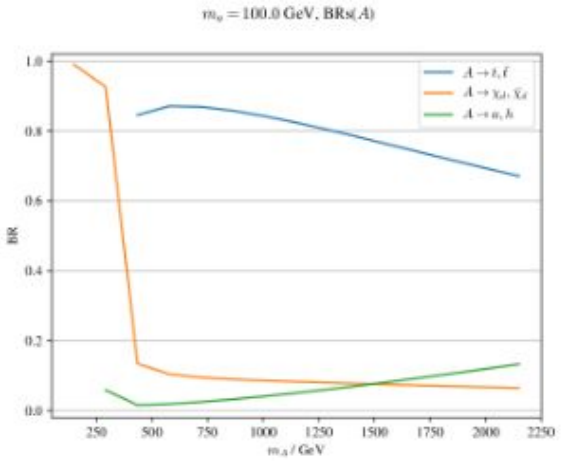
Heavy CP-odd Higgs A

$$\Gamma(A \to ah) \propto (m_A^2 - m_a^2) \sin\theta \cos\theta$$

m_a=100GeV

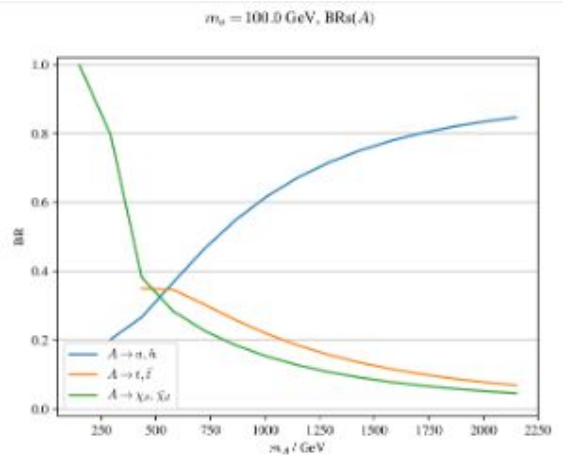
sinθ=0.35

BRs(A)



sinθ=0.70

BRs(A)



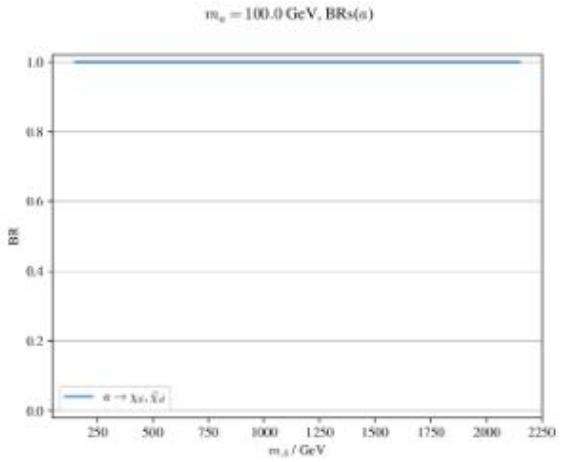
Coupling to fermions - branching ratios

$$L \supset \sum_{f=t,b,\tau} x_f \cdot f\bar{f}\,(A\cos\theta - a\sin\theta) + w_x \chi\bar{\chi}(A\sin\theta - a\cos\theta)$$

→ for low ma: coupling to t not possible → a→$\chi\chi$ still dominates

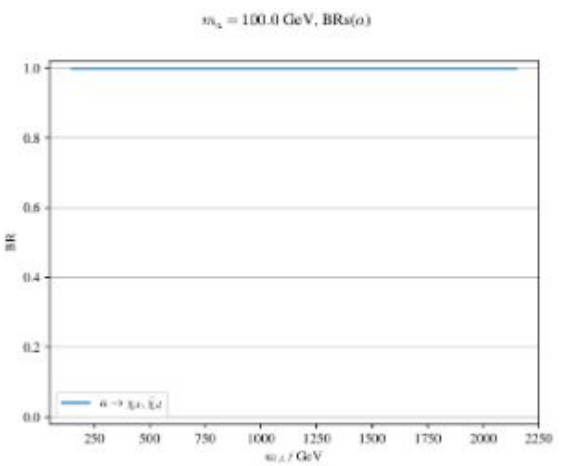
sinθ=0.35

BRs(a)

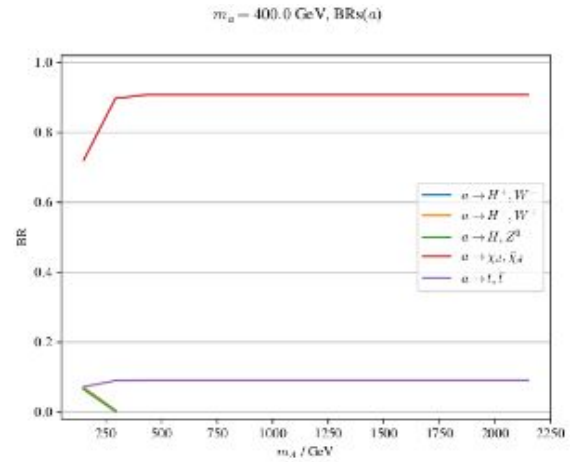


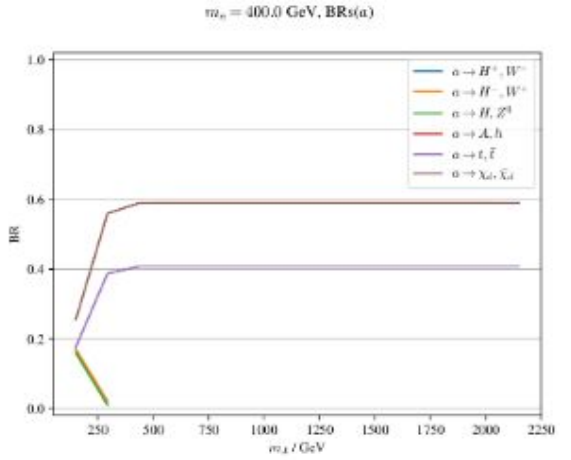
sinθ=0.70

BRs(a)



m_a=100GeV





m_a=400GeV