2HDM+a mono-h: Signal Grid

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on behalf of the ATLAS mono-h(bb) and mono-h(yy) groups

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ATLAS EXPERIMENT

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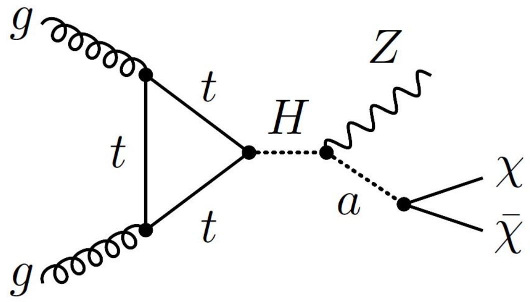
2 Higgs-Doublet Model with Pseudoscalar Dark Matter Mediator

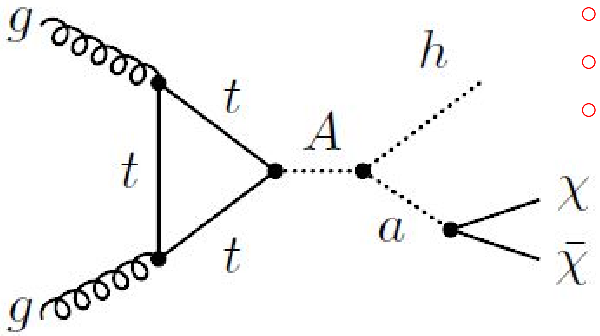
2 Higgs-Doublet Model (2HDM) ….

- SM has only one Higgs doublet
- 5 proper bosons
  - SM like scalar boson: h
  - heavy neutral scalar: H
  - heavy charged scalars: H^{+-}
  - pseudoscalar A_0
    - couples to SM particles

…. with Dark Matter Mediator (+a)

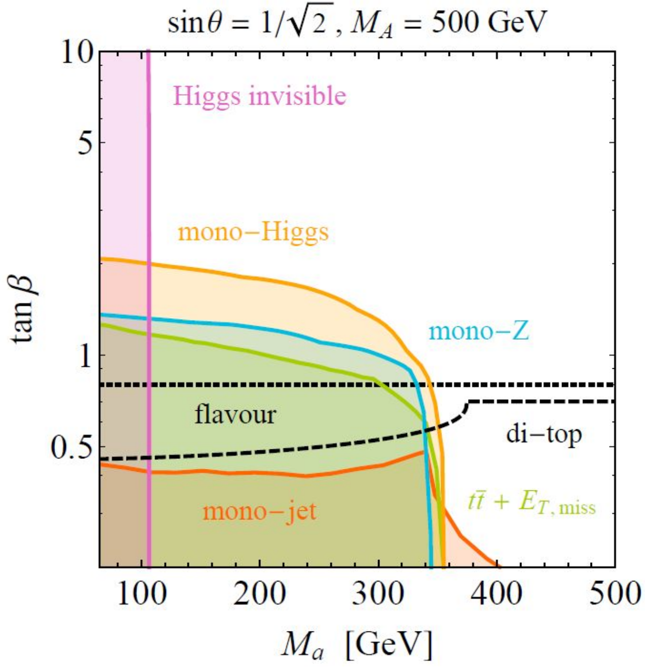
- pseudoscalar a_0
  - couples to fermionic Dark Matter (DM) particle
- a_0 and A_0 mix into mass-eigenstates a and A
- After mixing:
  - 2 pseudoscalars: a and A
  - both couple to DM
  - both couple to SM particles

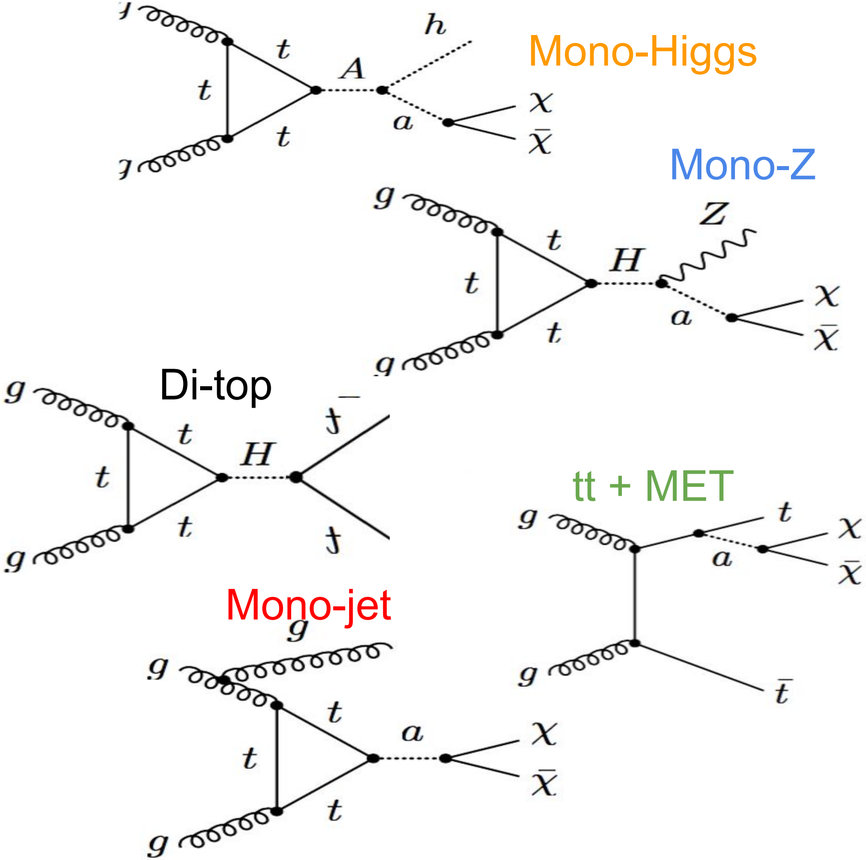




https://arxiv.org/abs/1701.07427

2HDM+a: Diverse palette of signatures





The interplay is experimentally exciting!

2HDM+a Parameters

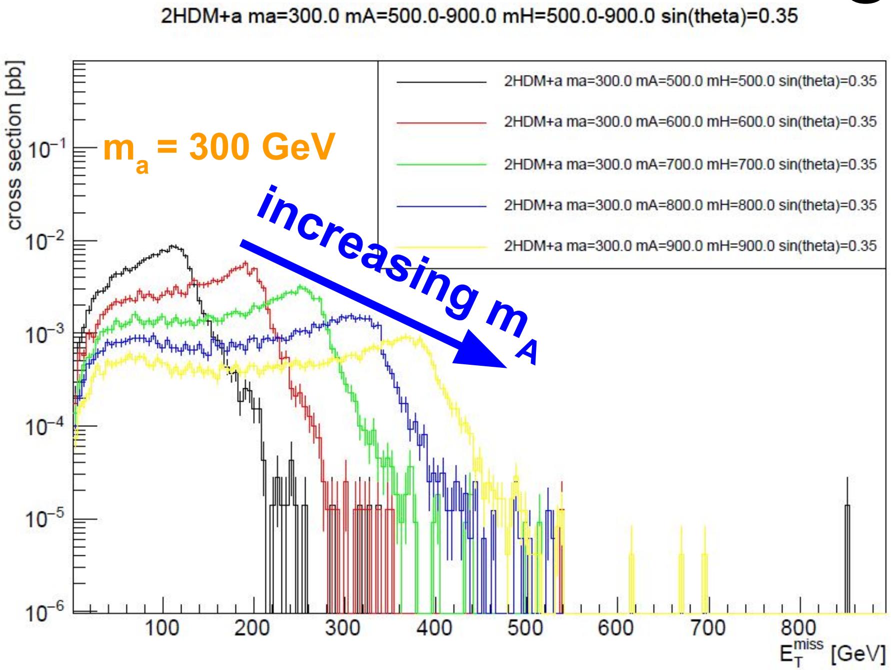
- 2HDM + pseudoscalar DM-mediators a, A
- parameters of interest:
  - m_a,m_A : DM mediator masses
  - m_H= m_{H+-} : heavy neutral (charged) scalar mass
  - tan(β): ratio of vacuum expectation values
  - sin(θ) : a-A mixing angle
  - $λ_3$, $λ_{P1}$,$λ_{P2}$: quartic scalar couplings
  - $y_χ$: DM Yukawa-coupling to a and A
  - $m_χ$: DM particle mass

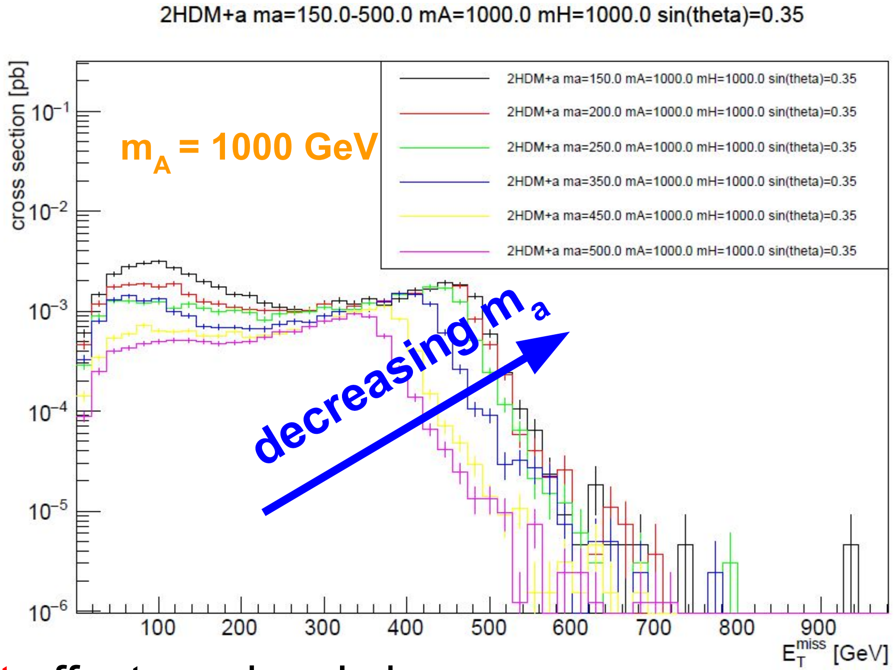
dominate mono-h kinematics

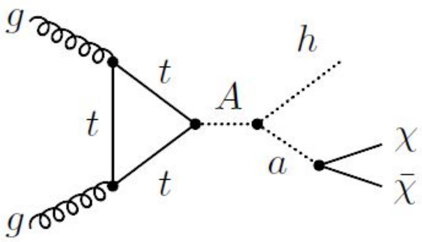
influence mono-h kinematics

change mono-h cross-sections

mono-h: Signal Kinematics

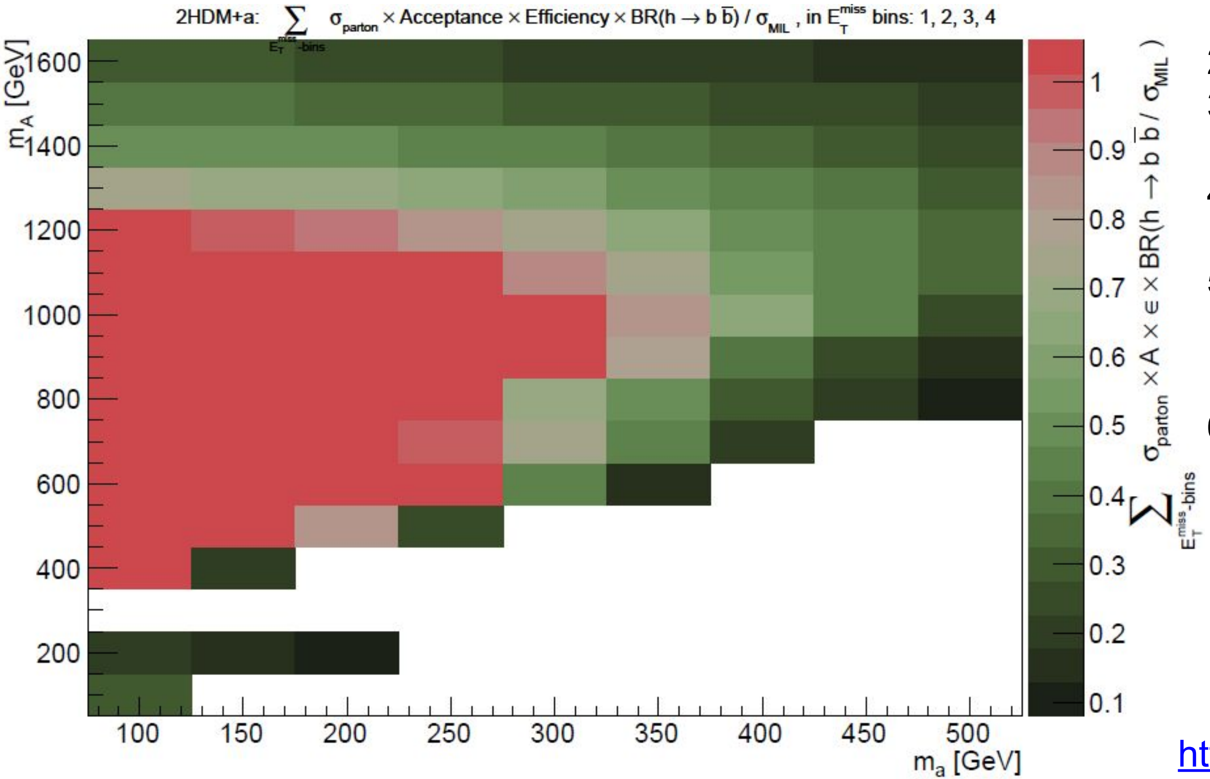






- m_a and m_A dominant effect on signal shape
  - ⇒ make signal grid a mass grid

Estimate mono-h(bb) Signal Sensitivity

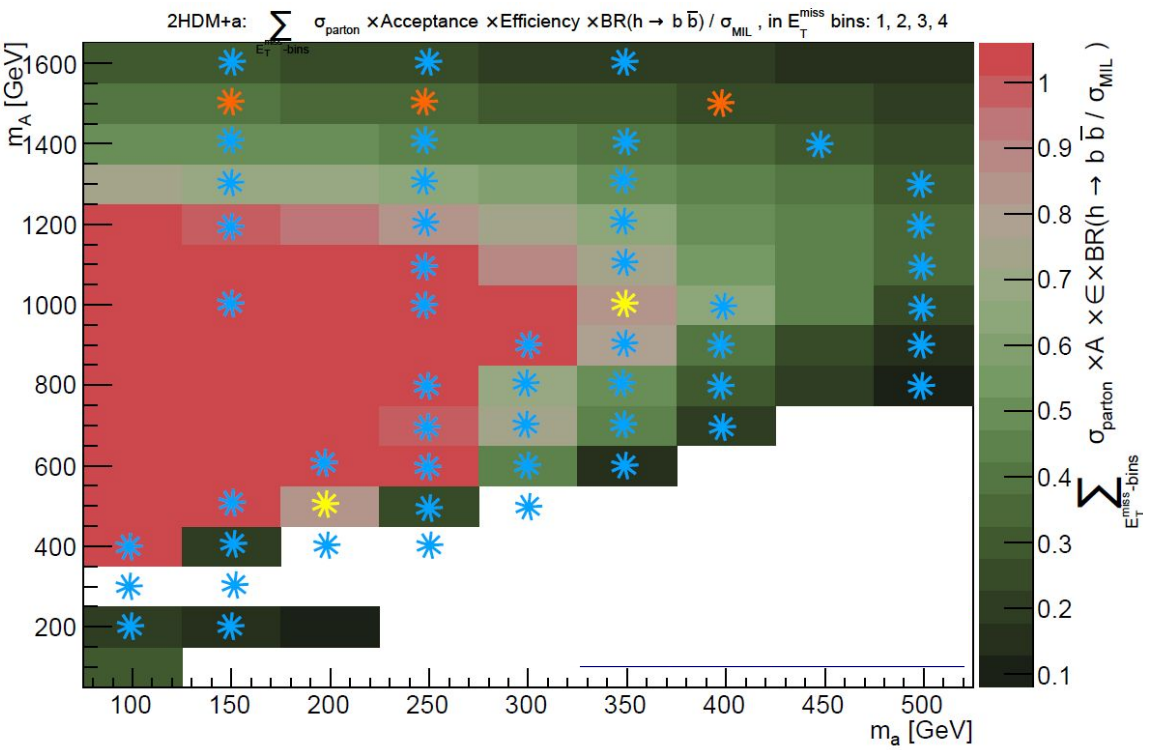


1. simulate parton-level x-sec
2. bin into 4 MET bins
3. multiply (bin-by-bin) with Acceptance x Efficiency
4. multiply with SM h→bb branching ratio
5. divide (bin-by-bin) by observed upper limit on σ(h(→bb) + MET)
6. sum over 4 MET bins

Range in E_T^{miss}/GeV	$\sigma^{obs}_{vis,h+DM}$ [fb]	$\sigma^{exp}_{vis,h+DM}$ [fb]	$\mathcal{A} \times \varepsilon$ %
[150, 200)	19.1	$18.3^{+7.2}_{-5.1}$	15
[200, 350)	13.1	$10.5^{+4.1}_{-2.9}$	35
[350, 500)	2.4	$1.7^{+0.7}_{-0.5}$	40
[500, ∞)	1.7	$1.8^{+0.7}_{-0.5}$	55

https://arxiv.org/abs/1707.01302

The mono-h(bb) mass Grid



52 samples

mono-h(bb) Grid: Parameter Choice

- **parameters of interest**:
  - m_a,m_A : scan
  - m_H= m_{H+-}: = m_A (⇒ also scanned)
  - tan(β) = 1
  - sin(θ) = 0.35
  - $\lambda_3 = \lambda_{P1} = \lambda_{P2} = 3$
  - $y_\chi = 1$
  - m_χ = 1 GeV

⇒ kinematically diverse set of signals

⇒ complementarity of signatures:

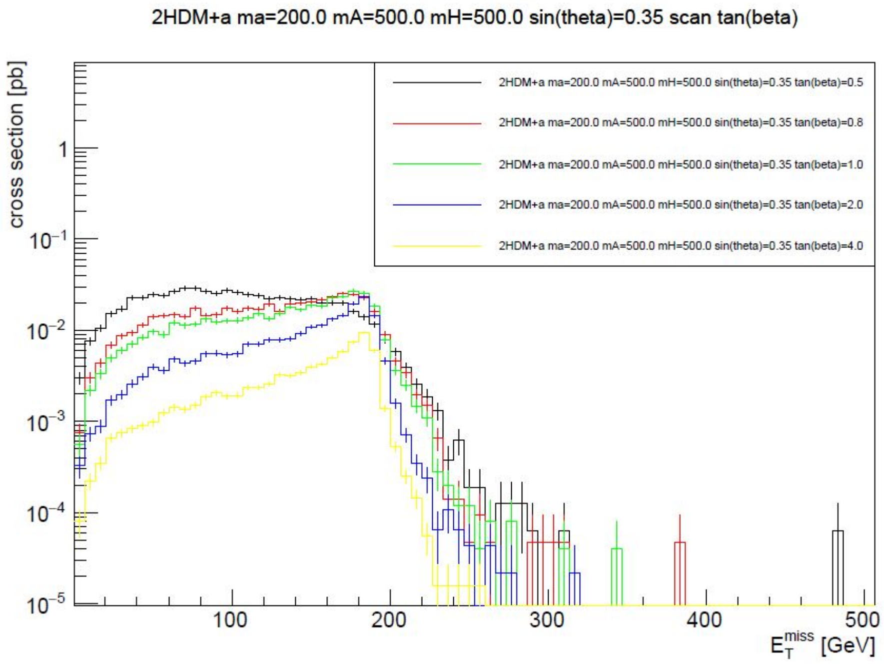
→ mono-h(bb)

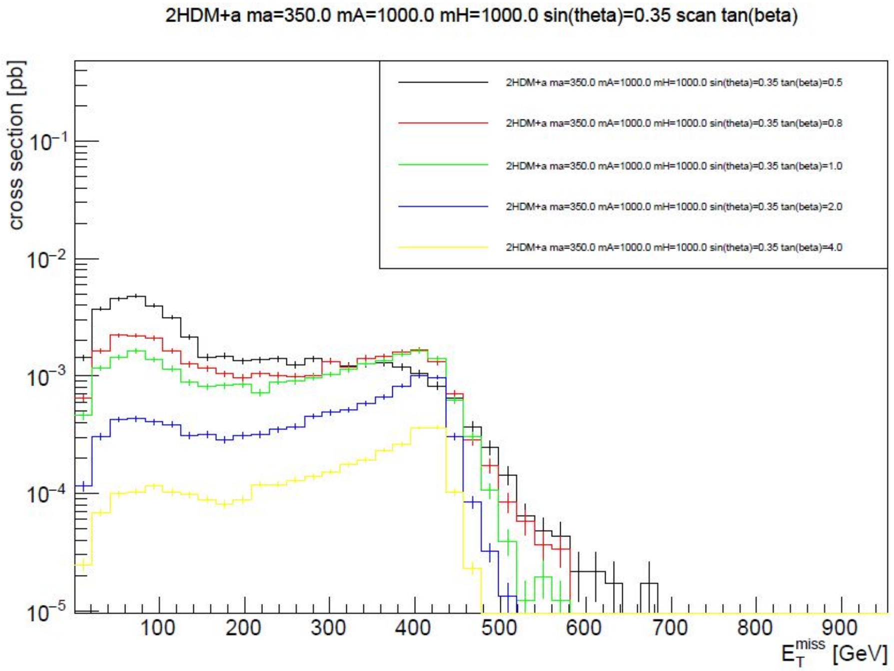
→ mono-h(yy)

→ mono-Z(ll)

→ mono-V(qq)

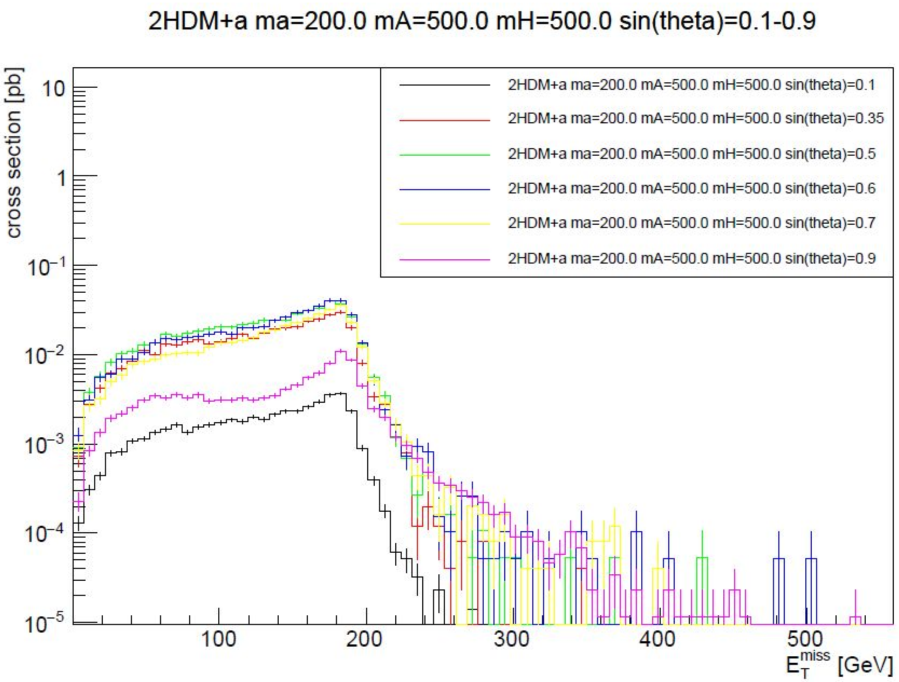
mono-h: tan(β)

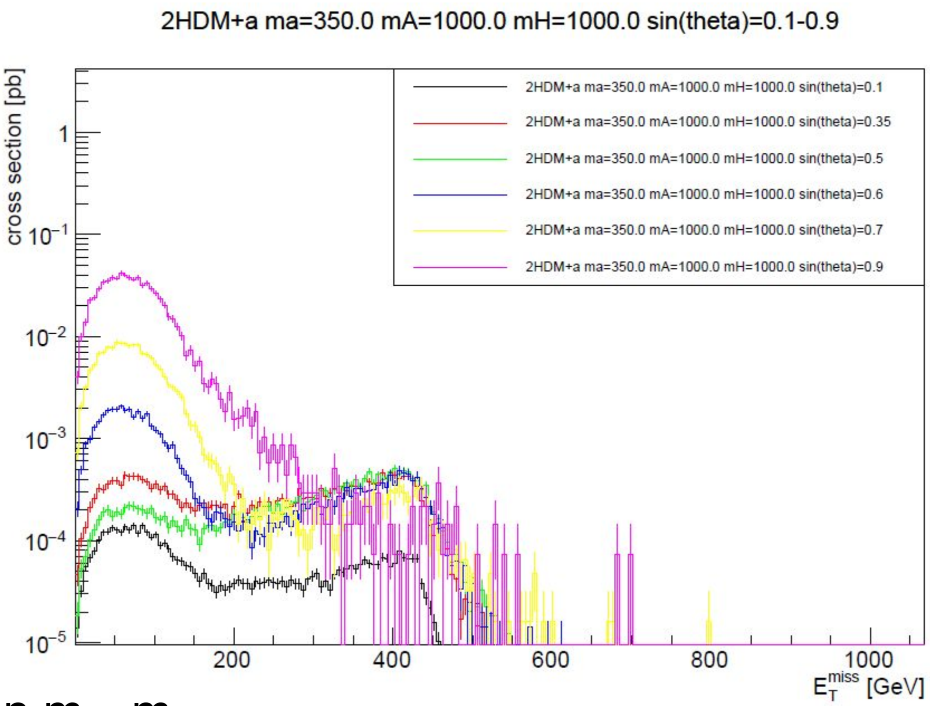




- less strong dependence than m_A, m_a
- non-trivial shape dependence

mono-h: sin(θ)





- less strong dependence than m_A, m_a
- non-trivial shape dependence

mono-h(bb) Grid: Parameter Choice

- **parameters of interest**:
  - m_a, m_A : scan
  - $m_H = m_{H+-}$: = m_A (⇒ also scanned)
  - tan(β) = 1
    - scan in ma, tan(β) for one m_A
  - sin(θ) = 0.35
    - scan at two mass points
  - $\lambda_3 = \lambda_{P1} = \lambda_{P2} = 3$
  - $y_\chi = 1$
  - $m_\chi = 1$ GeV

⇒ kinematically diverse set of signals

⇒ complementarity of signatures:

→ mono-h(bb)

→ mono-h(yy)

→ mono-Z(ll)

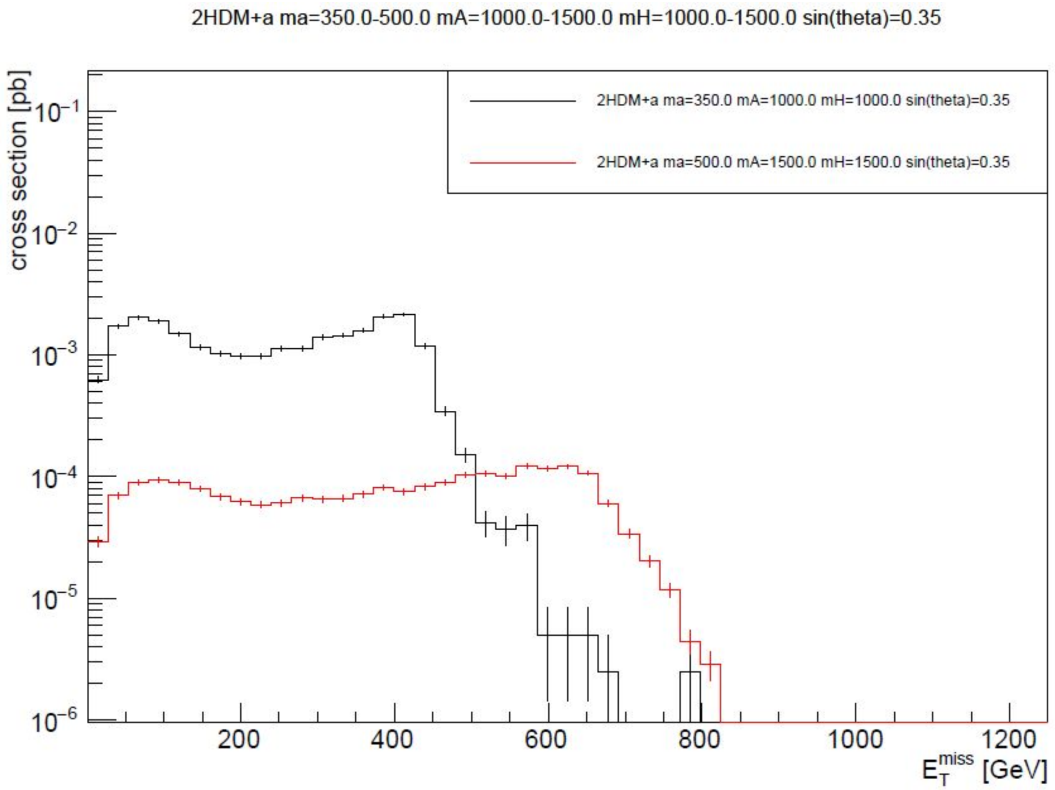
→ mono-V(qq)

Summary

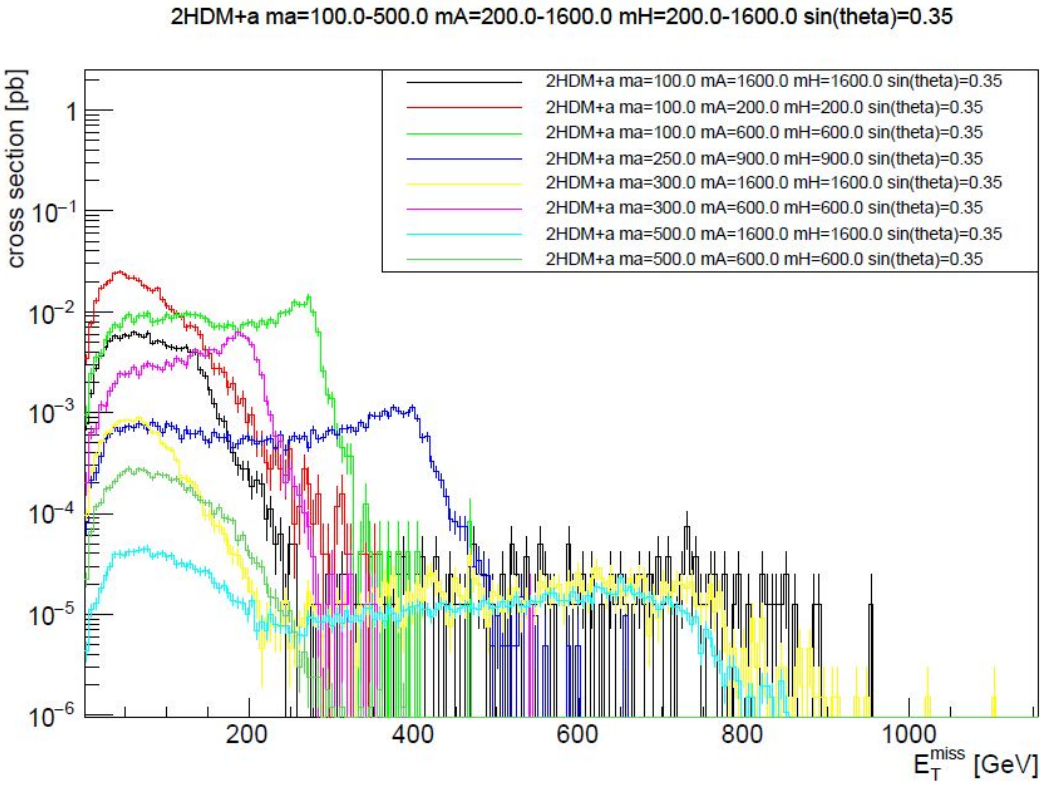
- **choice of parameters:**
  - m_a, m_A : scan
  - $m_H = m_{H+-} == m_A$
  - $\tan(\beta) = 1$
    - 1 2D scan
  - $\sin(\theta) = 0.35$
    - 2 1D scans
  - $\lambda_3, \lambda_{P1}, \lambda_{P2} = 3$
  - $y_\chi = 1$
  - $m_\chi = 1$ GeV

Backup

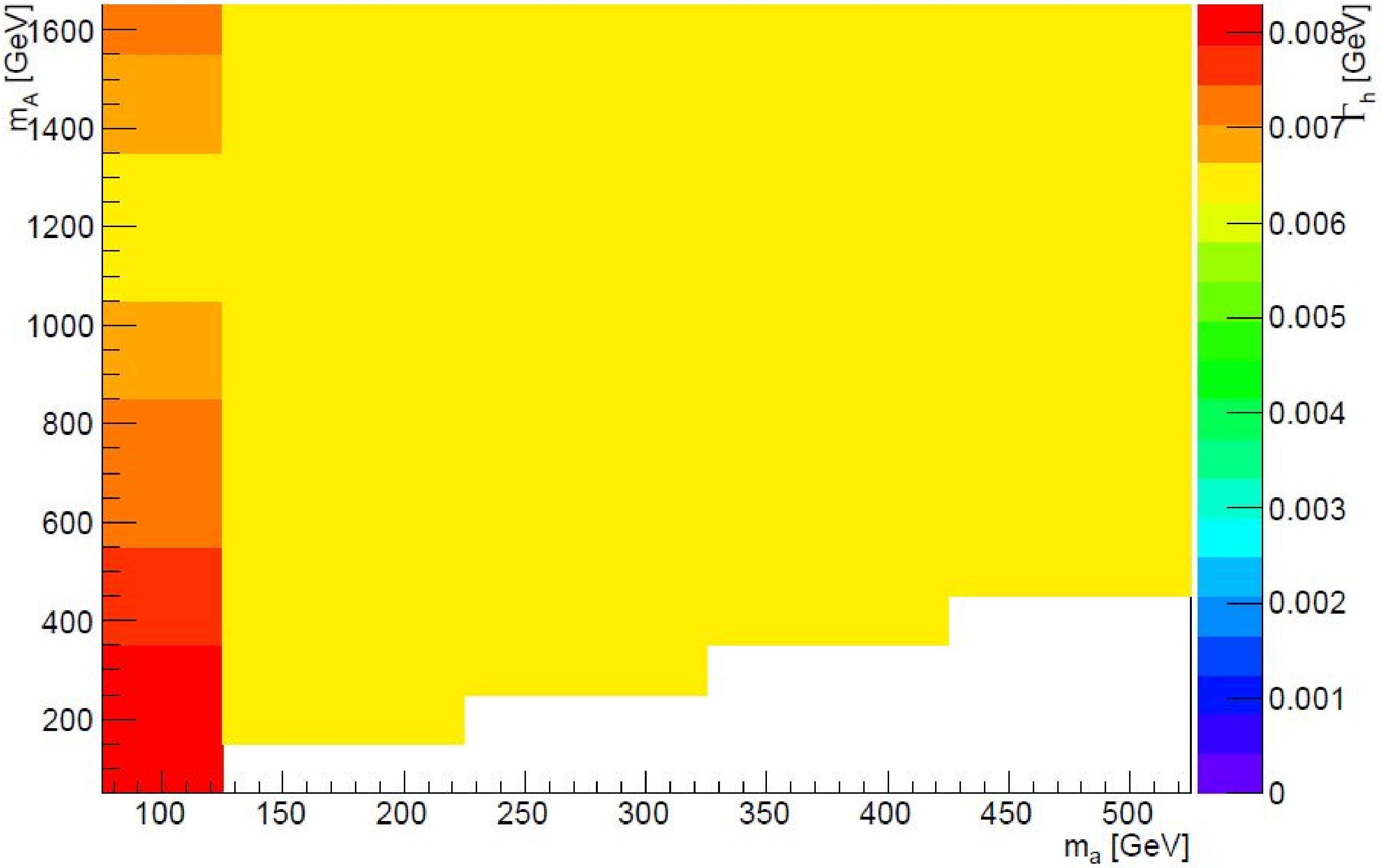
mono-h(yy) MET-spectra of base samples



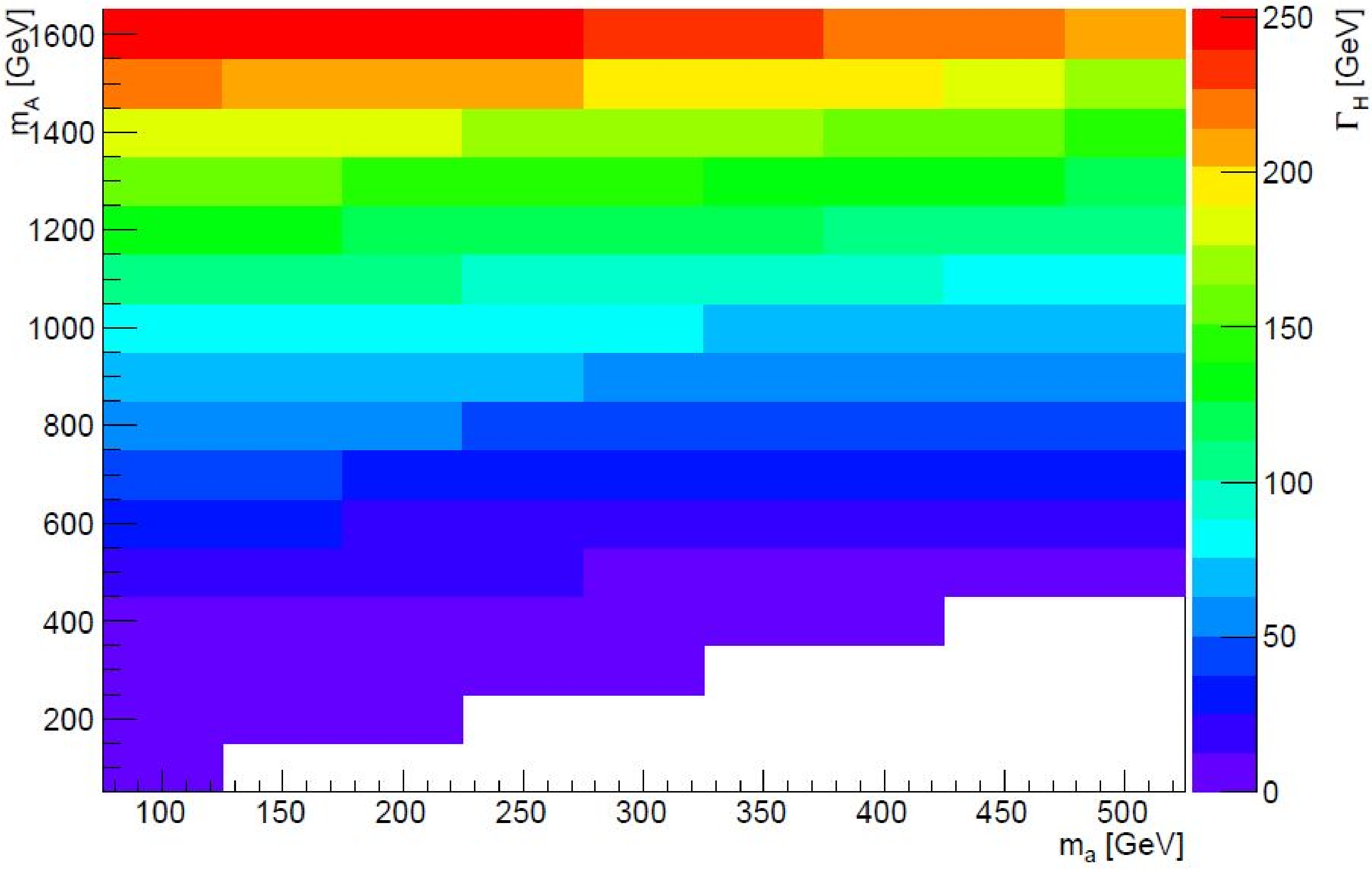
mono-h(yy) MET-spectra of validation samples

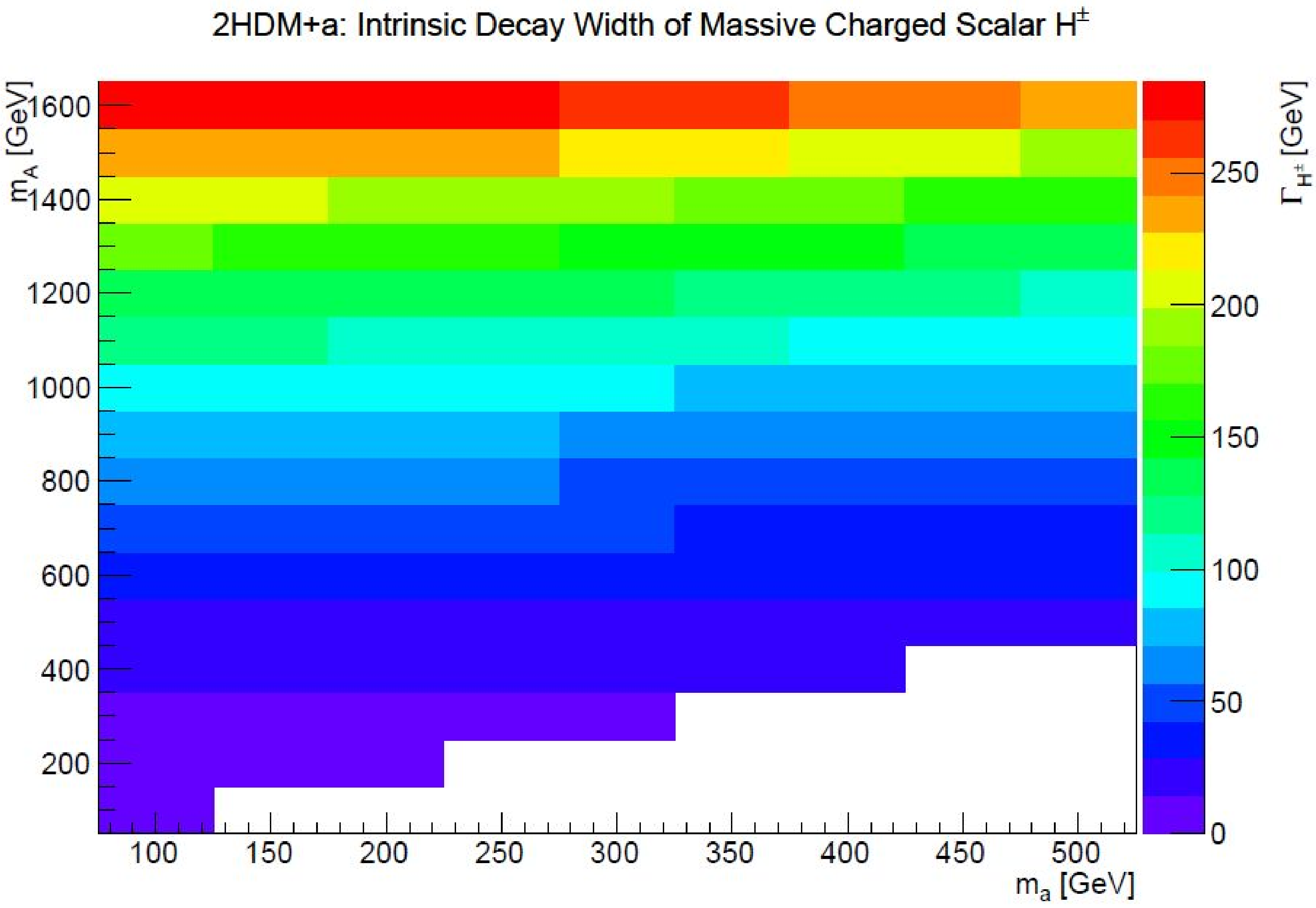


2HDM+a: Intrinsic Decay Width of Light Scalar h



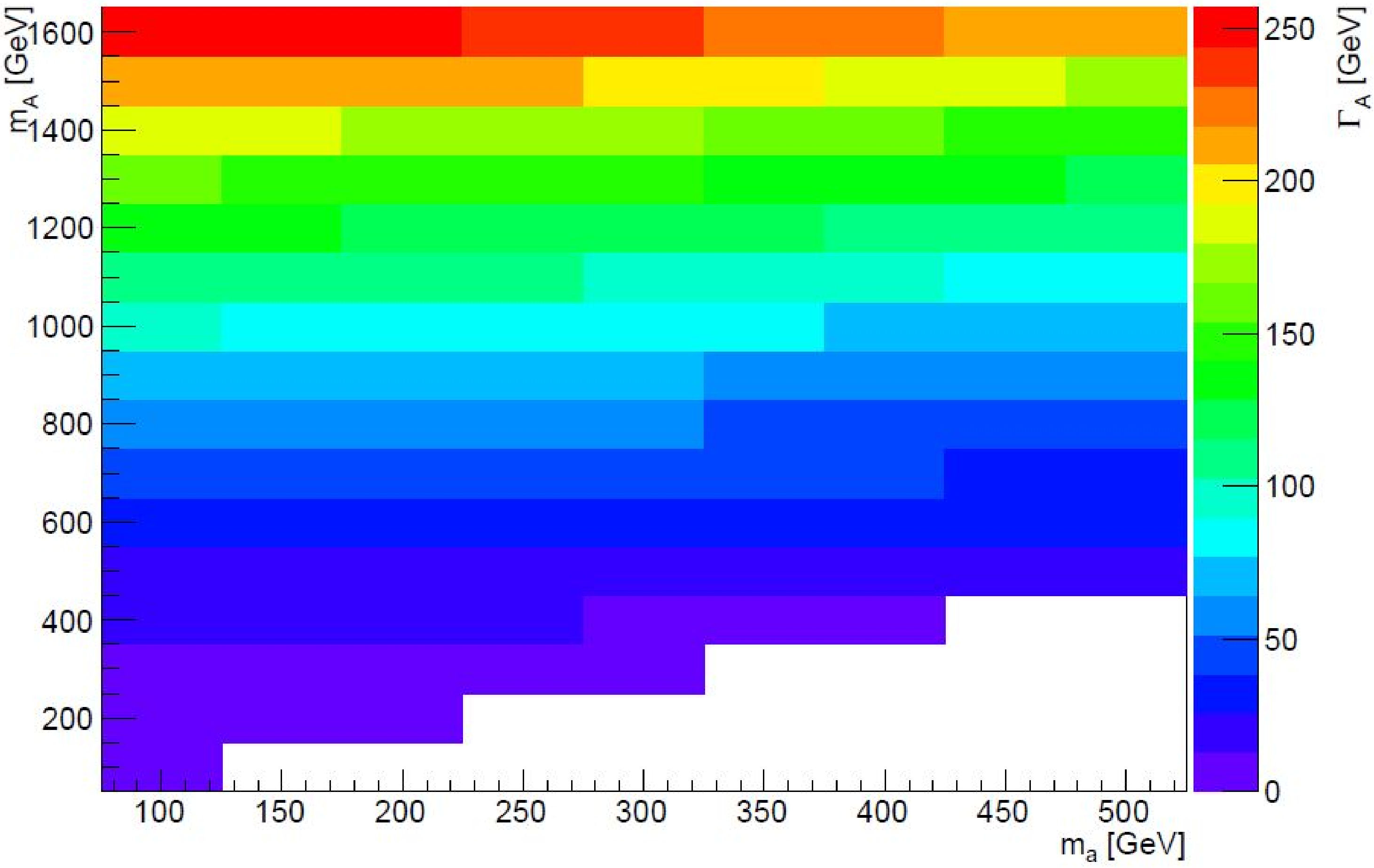
2HDM+a: Intrinsic Decay Width of Heavy Scalar H

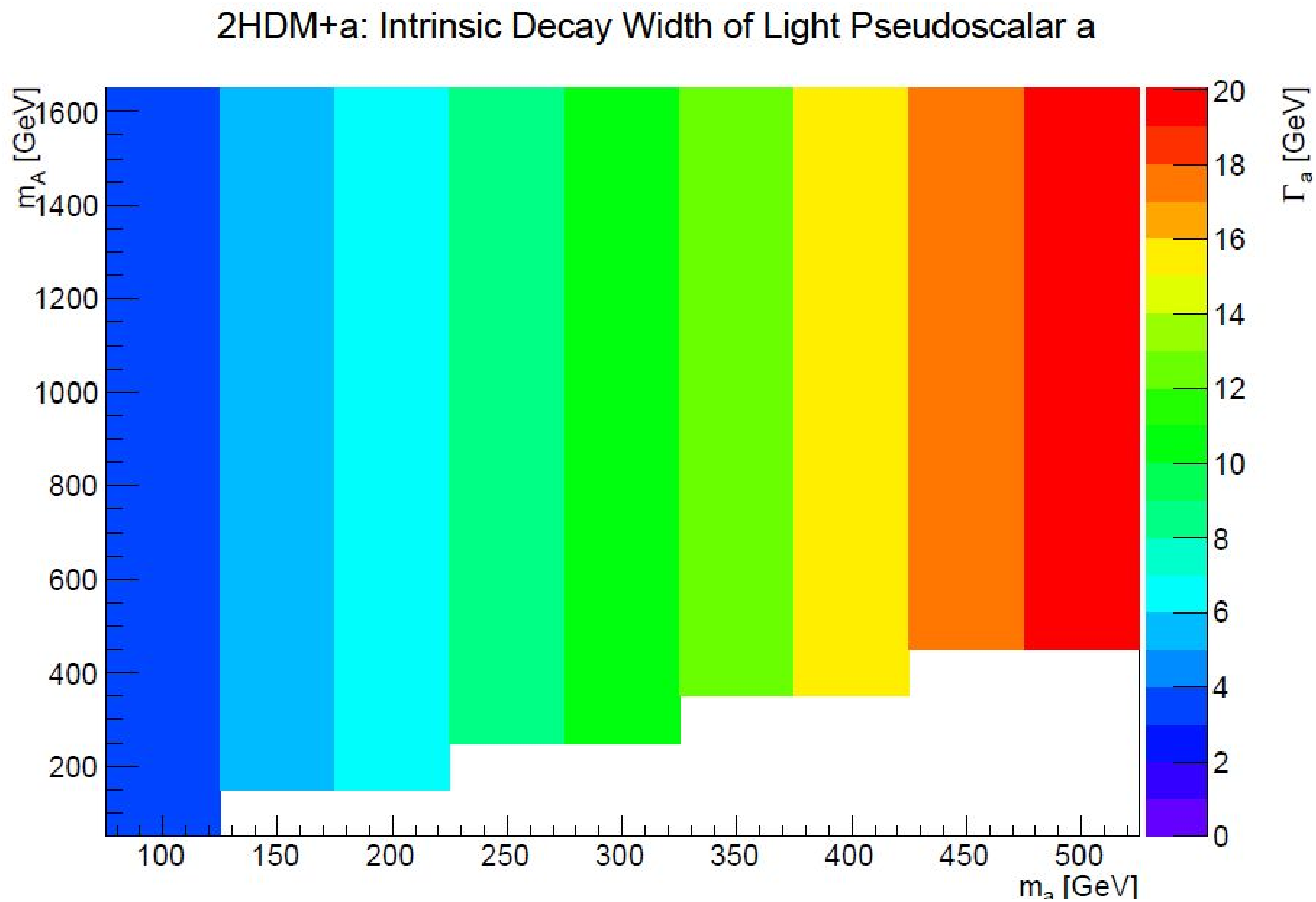




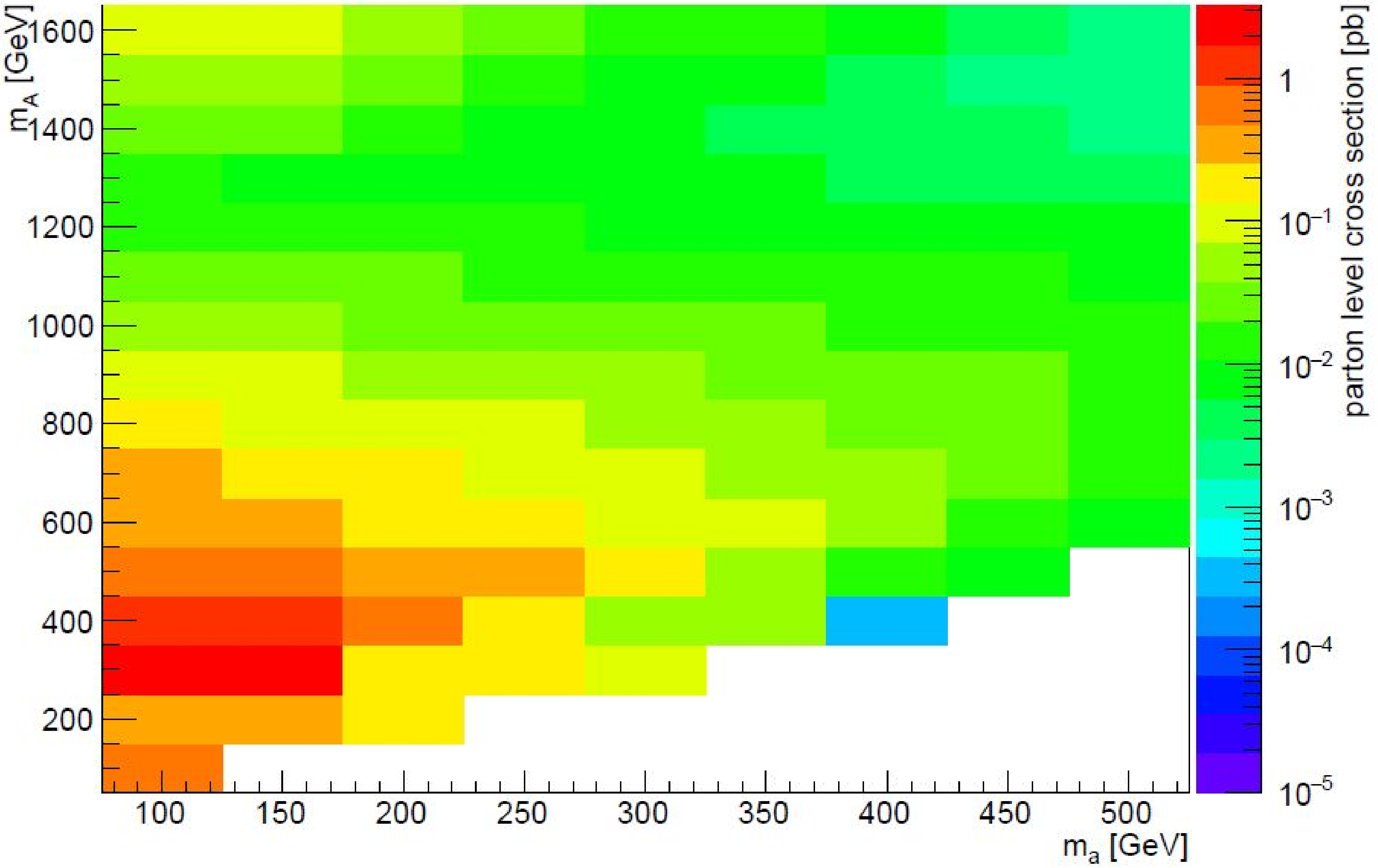
2HDM+a: Intrinsic Decay Width of Massive Charged Scalar H±
m_A [GeV]
1600
1400
1200
1000
800
600
400
200
100
150
200
250
300
350
400
450
500
m_a [GeV]
Γ_H± [GeV]
250
200
150
100
50
0

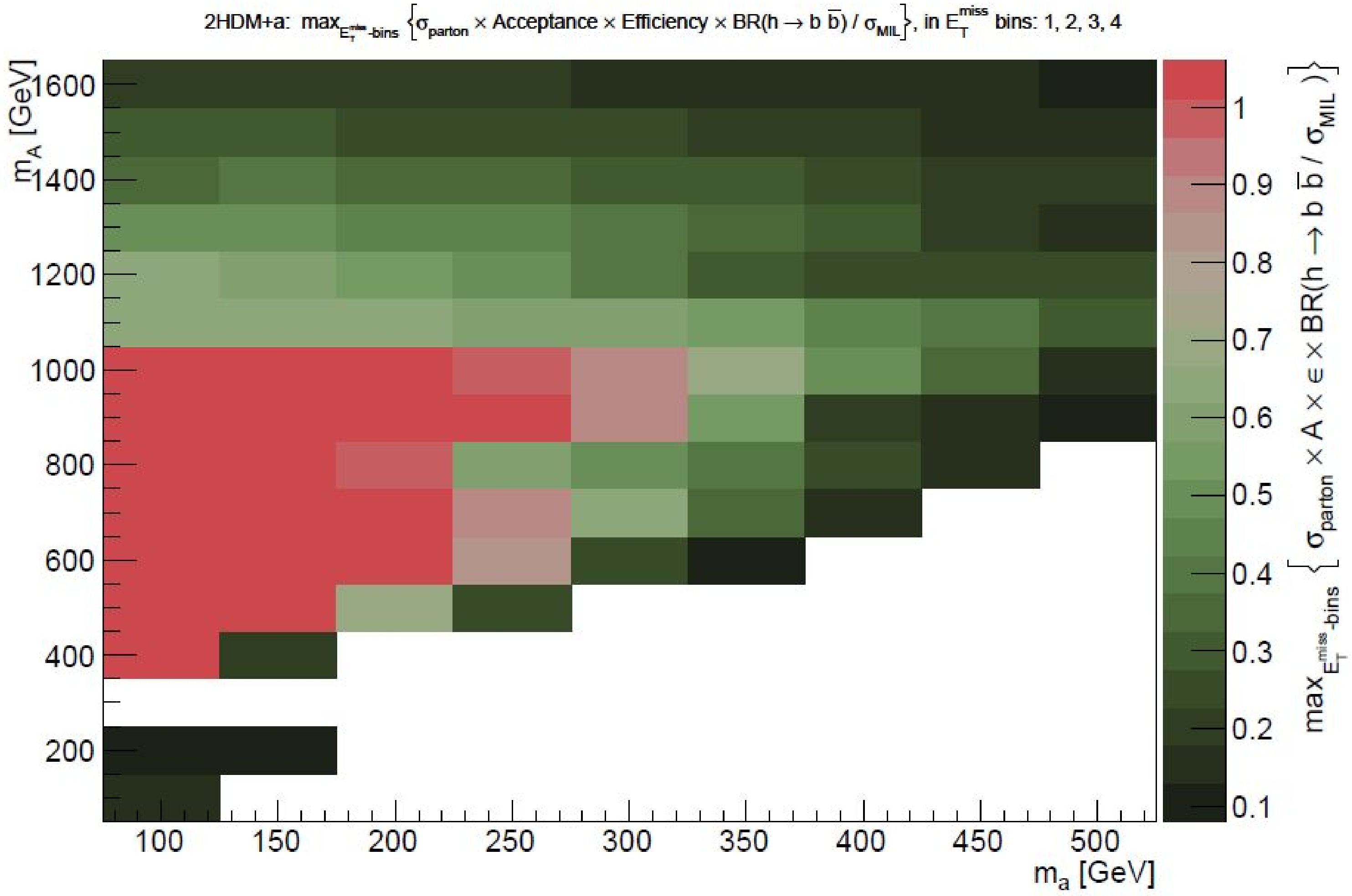
2HDM+a: Intrinsic Decay Width of Heavy Pseudoscalar A



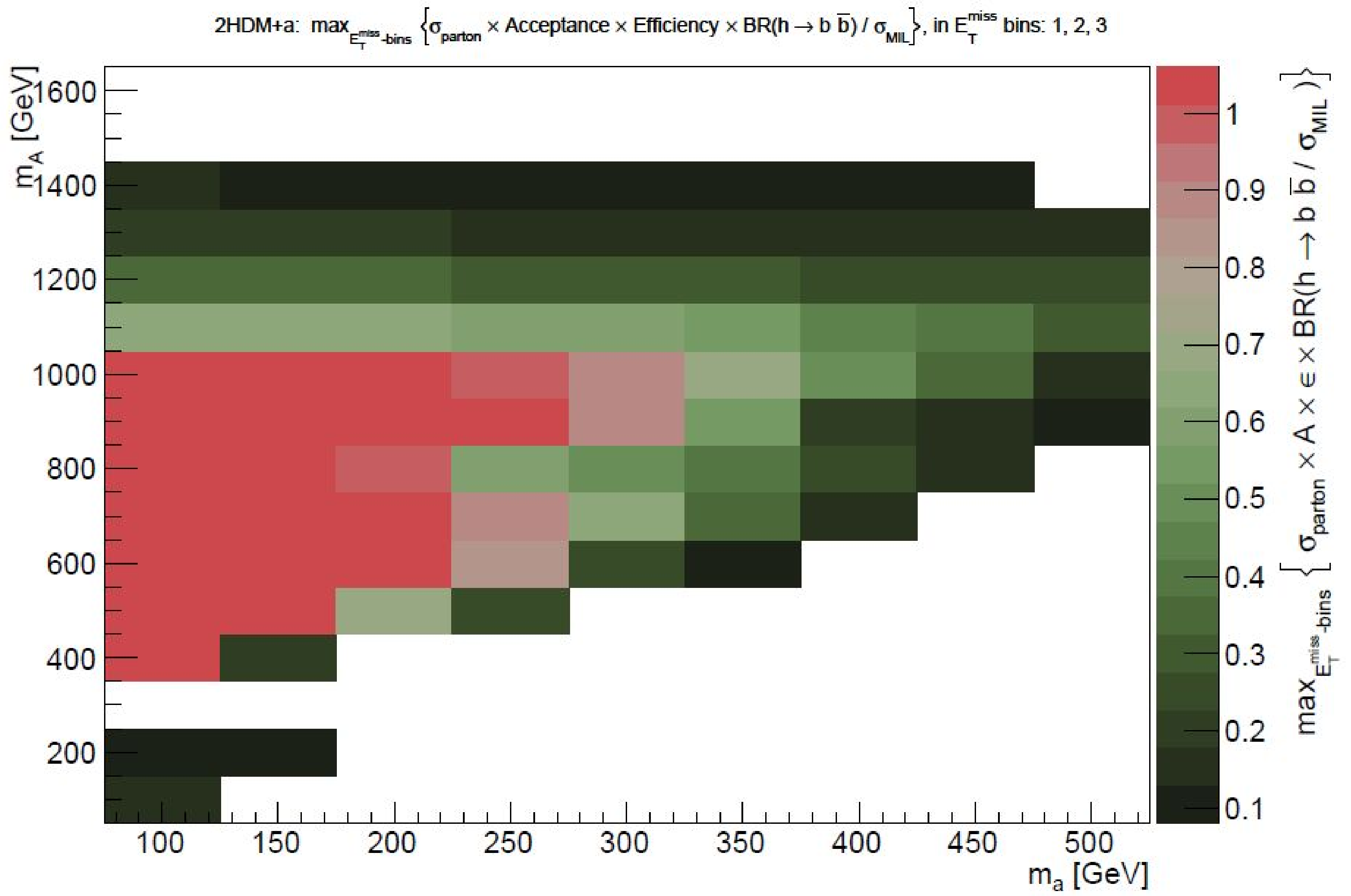

2HDM+a: Intrinsic Decay Width of Light Pseudoscalar a
m_A [GeV]
1600
1400
1200
1000
800
600
400
200
100
150
200
250
300
350
400
450
500
m_a [GeV]
Γ_a [GeV]
20
18
16
14
12
10
8
6
4
2
0

2HDM+a: parton level cross section

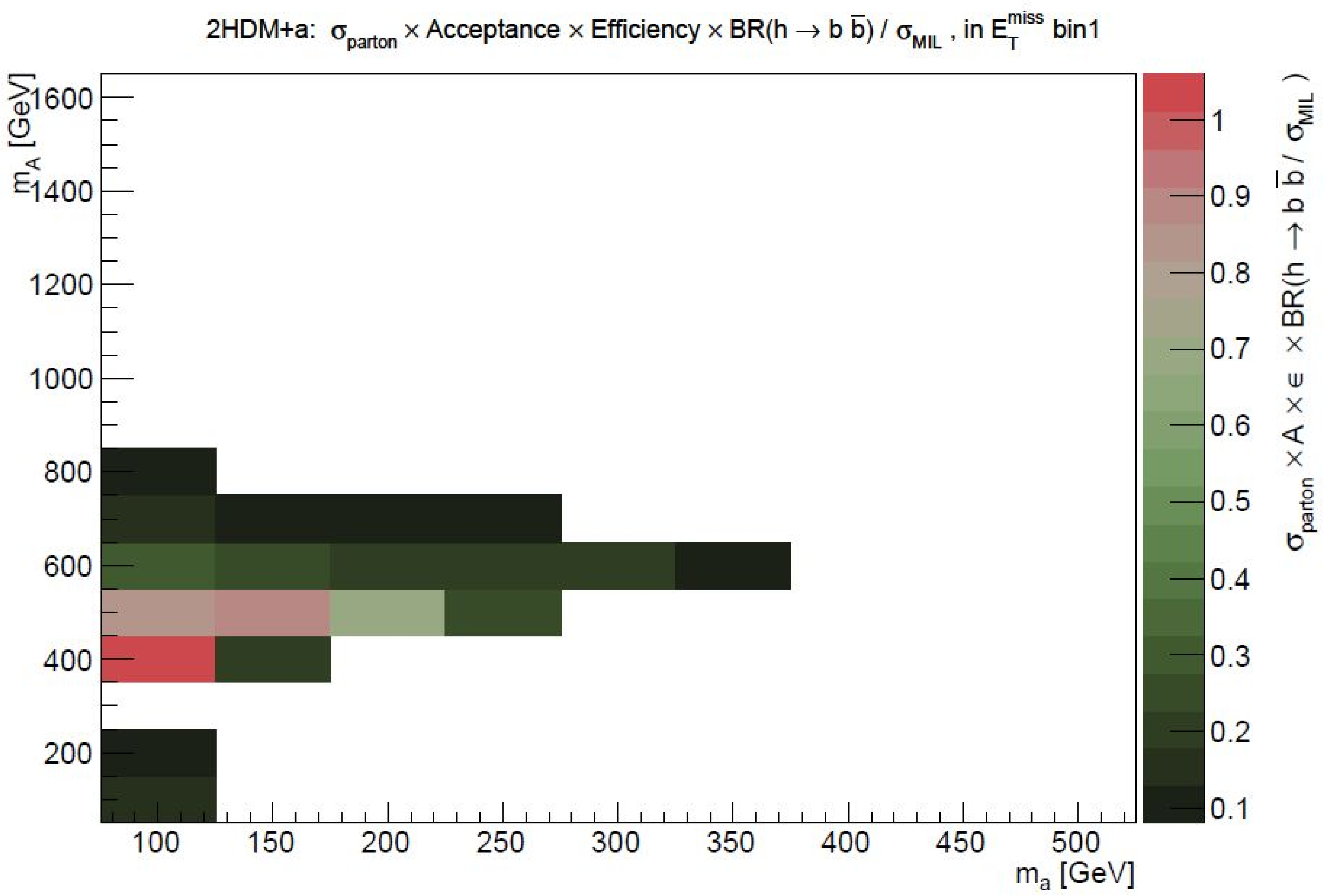




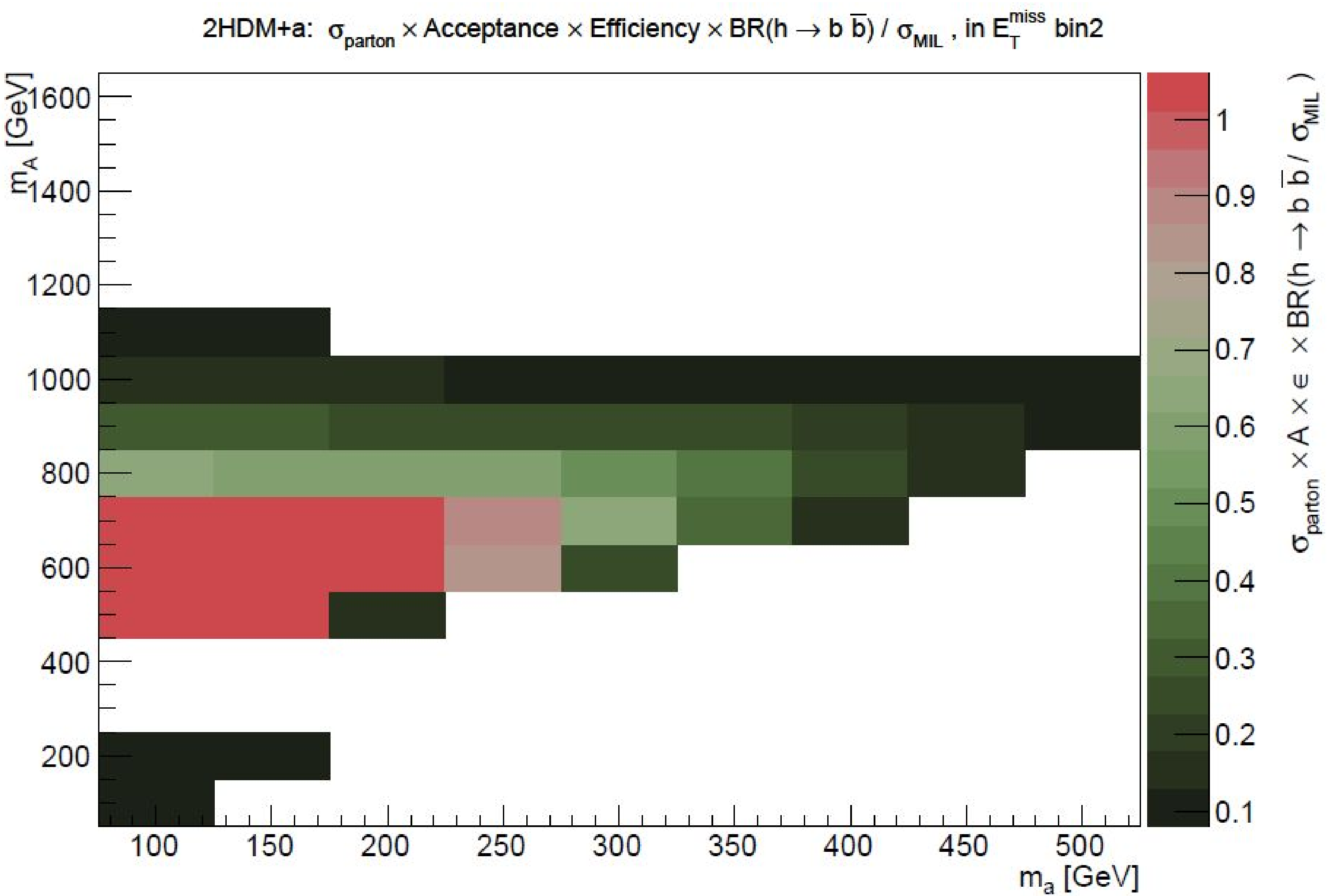
2HDM+a: $\max_{E_T^{miss}\text{-bins}} \{\sigma_{parton} \times \text{Acceptance} \times \text{Efficiency} \times BR(h \to b\bar{b}) / \sigma_{MIL}\}$, in E_T^{miss} bins: 1, 2, 3, 4
m_A [GeV]
1600
1400
1200
1000
800
600
400
200
100
150
200
250
300
350
400
450
500
m_a [GeV]
$\max_{E_T^{miss}\text{-bins}} \{\sigma_{parton} \times A \times \epsilon \times BR(h \to b\bar{b}) / \sigma_{MIL}\}$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1



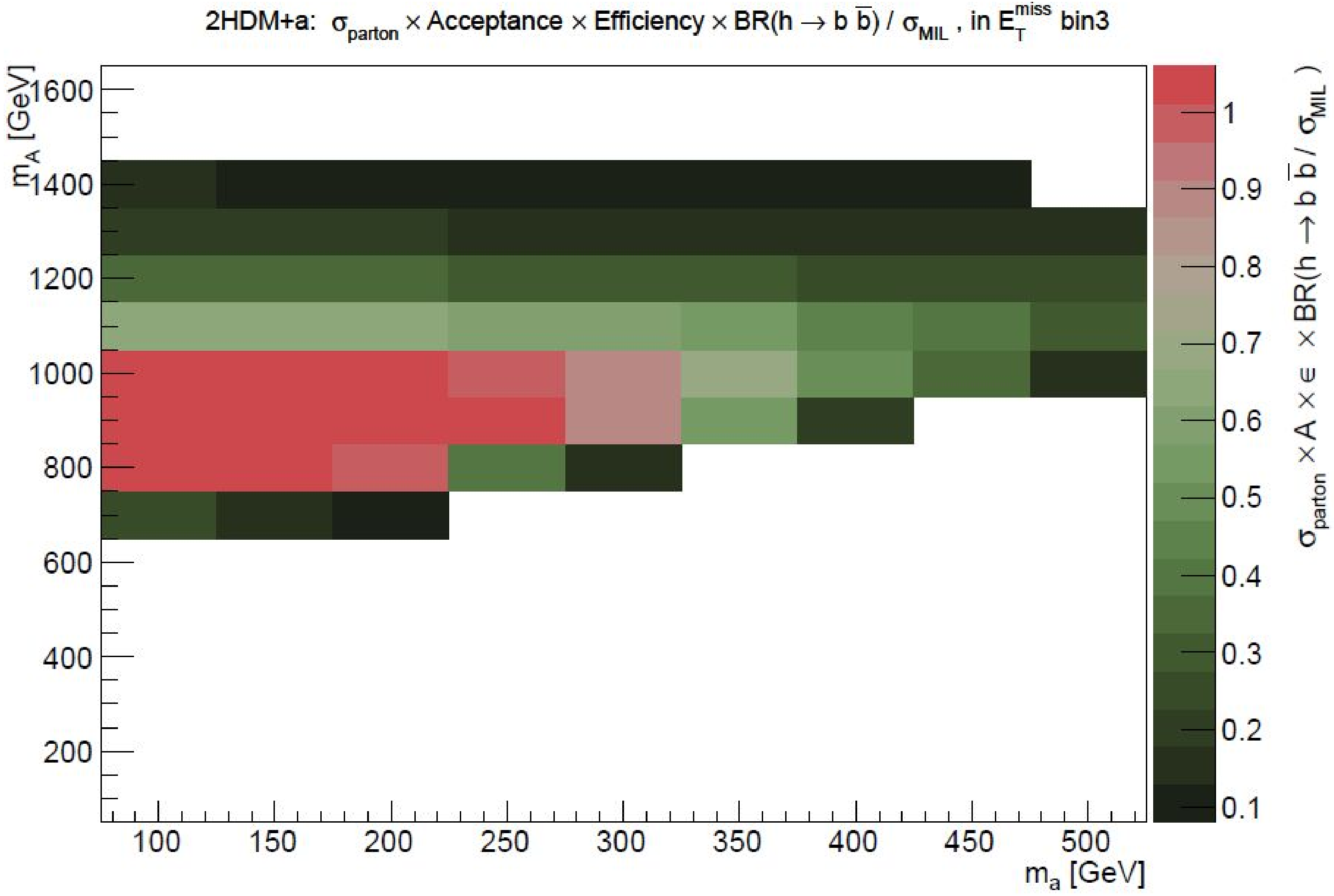
2HDM+a: max$_{E_T^{miss}\text{-bins}}$ {σ_{parton} × Acceptance × Efficiency × BR(h → b $\bar{b}$) / σ_{MIL}}, in E_T^{miss} bins: 1, 2, 3
m_A [GeV]
1600
1400
1200
1000
800
600
400
200
100
150
200
250
300
350
400
450
500
m_a [GeV]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
max$_{E_T^{miss}\text{-bins}}$ {σ_{parton} × A × ∈ × BR(h → b $\bar{b}$ / σ_{MIL})}



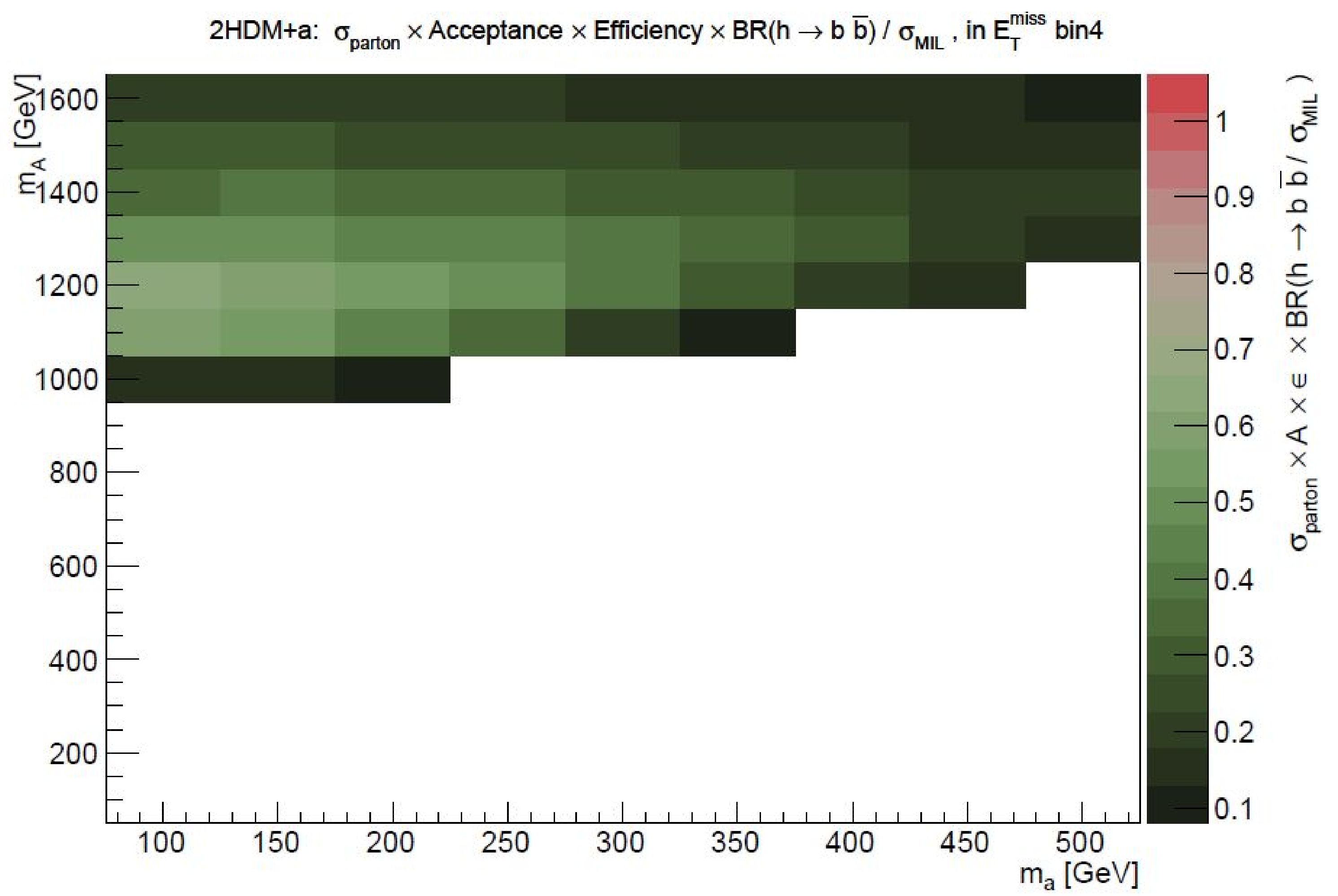
2HDM+a: $\sigma_{parton} \times$ Acceptance $\times$ Efficiency $\times$ BR($h \rightarrow b\bar{b}$) / σ_{MIL} , in E_T^{miss} bin1
m_A [GeV]
1600
1400
1200
1000
800
600
400
200
100
150
200
250
300
350
400
450
500
m_a [GeV]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
$\sigma_{parton} \times A \times \epsilon \times BR(h \rightarrow b\bar{b} / \sigma_{MIL})$



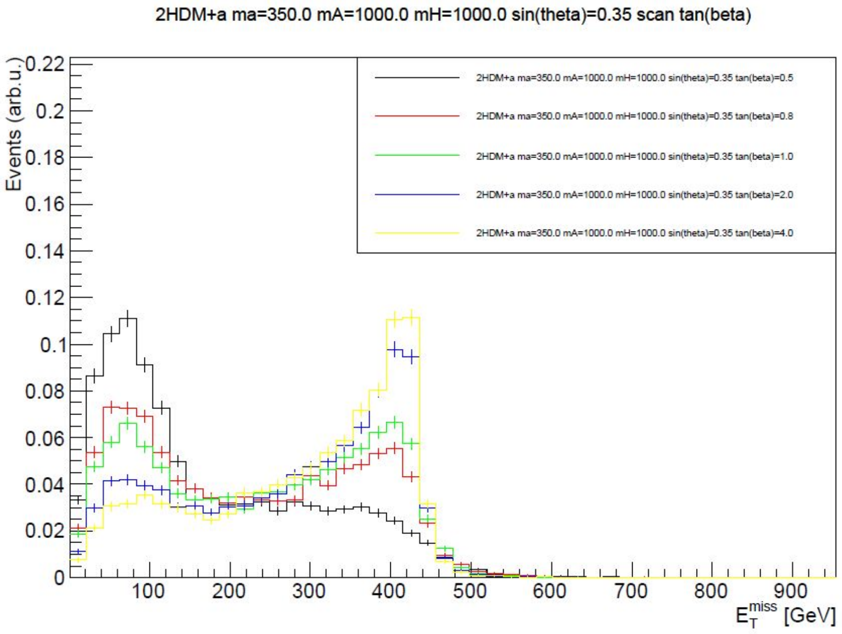
2HDM+a: σ_{parton} × Acceptance × Efficiency × BR(h → b $\bar{b}$) / σ_{MIL} , in E_T^{miss} bin2
m_A [GeV]
1600
1400
1200
1000
800
600
400
200
100
150
200
250
300
350
400
450
500
m_a [GeV]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
σ_{parton} × A × ∊ × BR(h → b $\bar{b}$ / σ_{MIL})

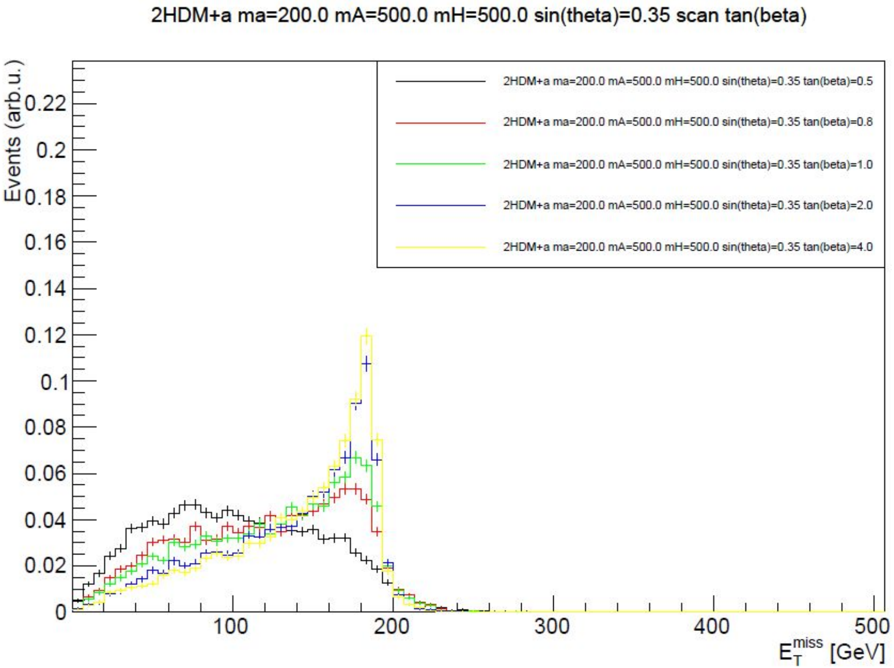


2HDM+a: $\sigma_{parton} \times$ Acceptance $\times$ Efficiency $\times$ BR($h \to b\bar{b}$) / σ_{MIL} , in E_T^{miss} bin3
m_A [GeV]
1600
1400
1200
1000
800
600
400
200
100
150
200
250
300
350
400
450
500
m_a [GeV]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
$\sigma_{parton} \times A \times \epsilon \times$ BR($h \to b\bar{b}$ / σ_{MIL})

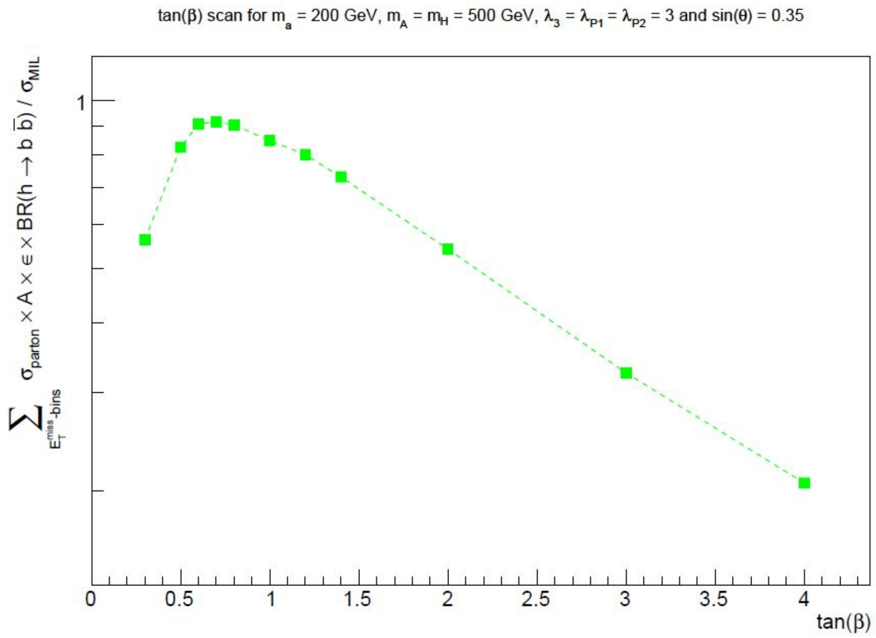

2HDM+a: σ_{parton} × Acceptance × Efficiency × BR(h → b $\bar{b}$) / σ_{MIL} , in E_T^{miss} bin4
m_A [GeV]
1600
1400
1200
1000
800
600
400
200
100
150
200
250
300
350
400
450
500
m_a [GeV]
σ_{parton} × A × ε × BR(h → b $\bar{b}$ / σ_{MIL})
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

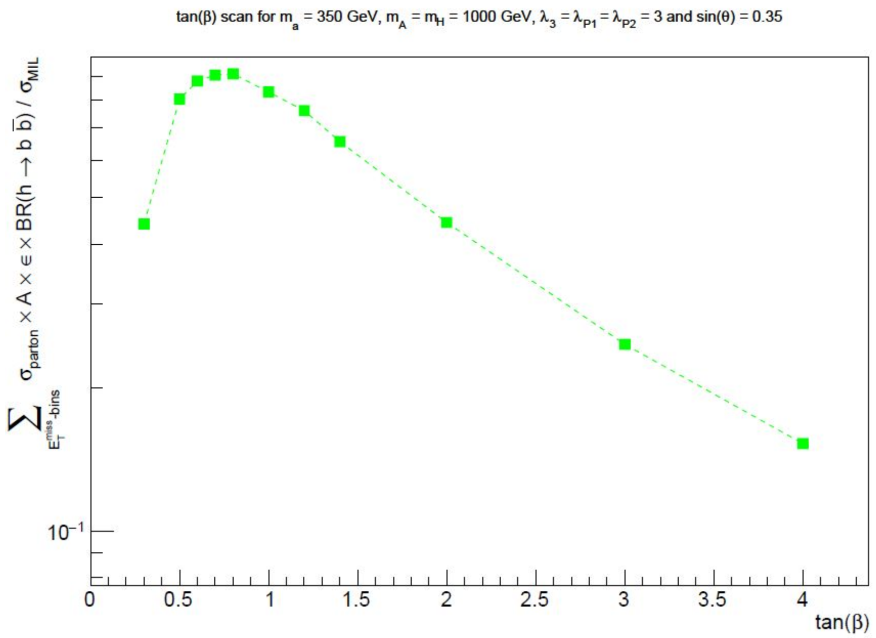
mono-h: tan(β), normalised to 1



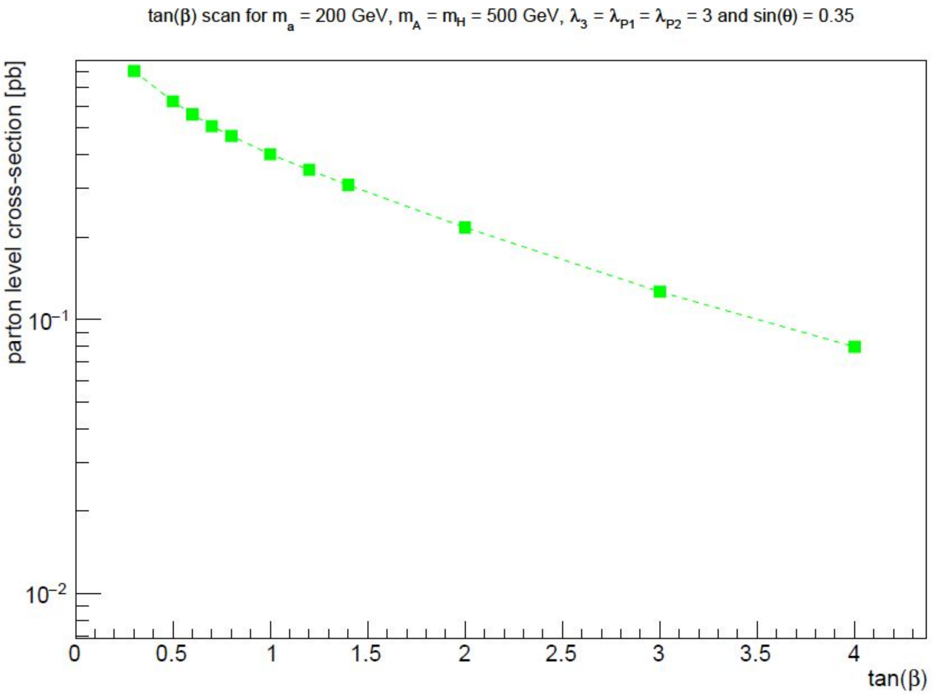


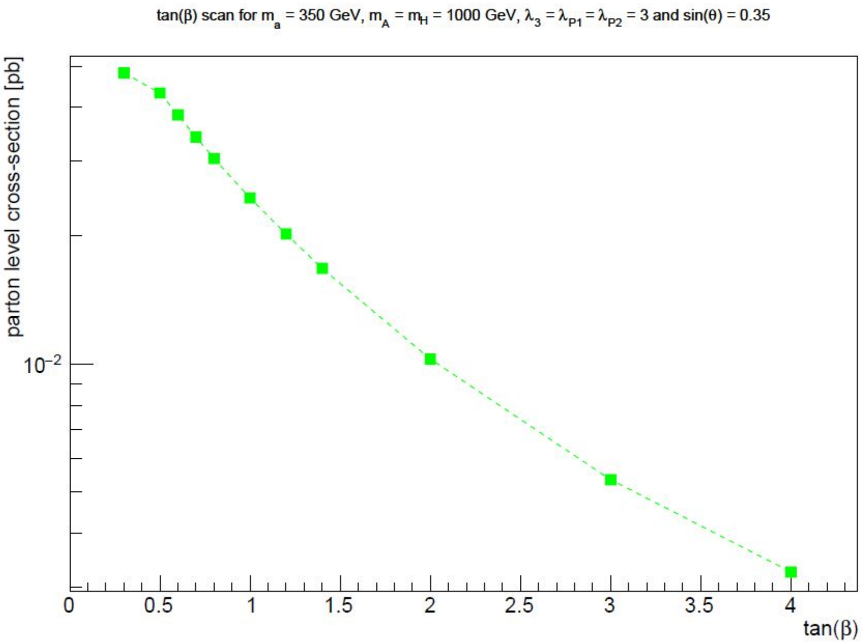
mono-h(bb): tan(β) sensitivity



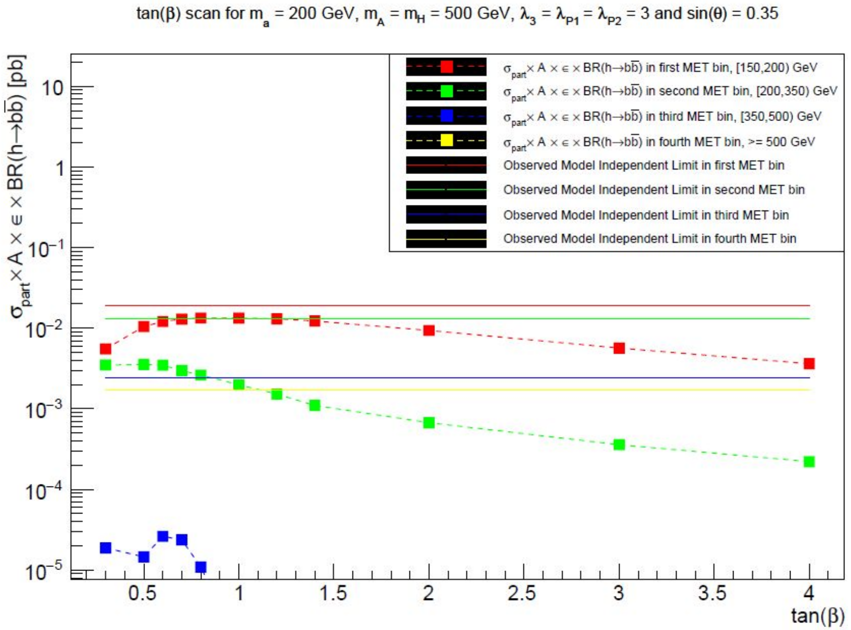


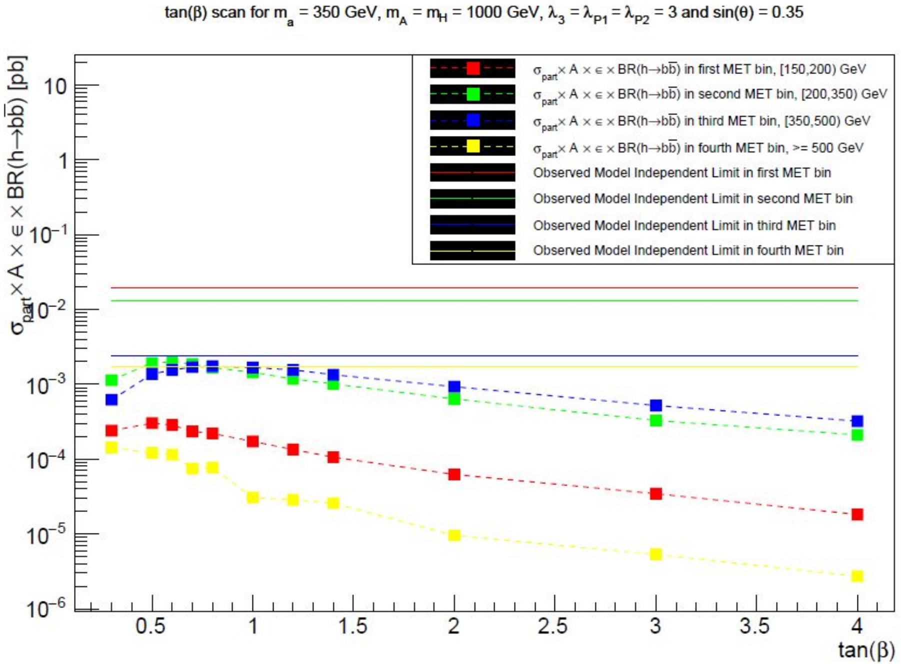
mono-h: tan(β): parton level cross-section



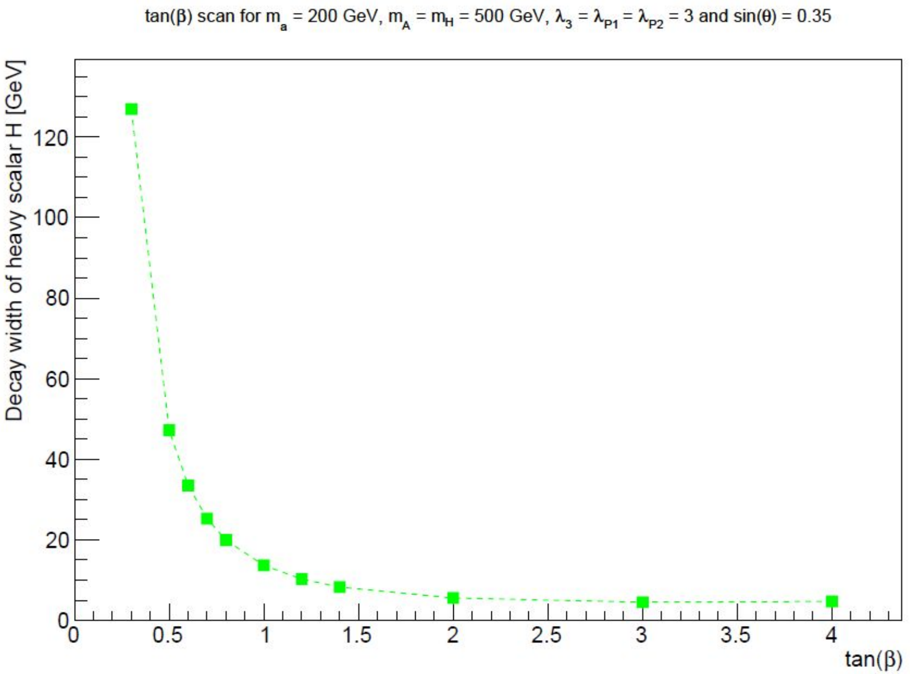


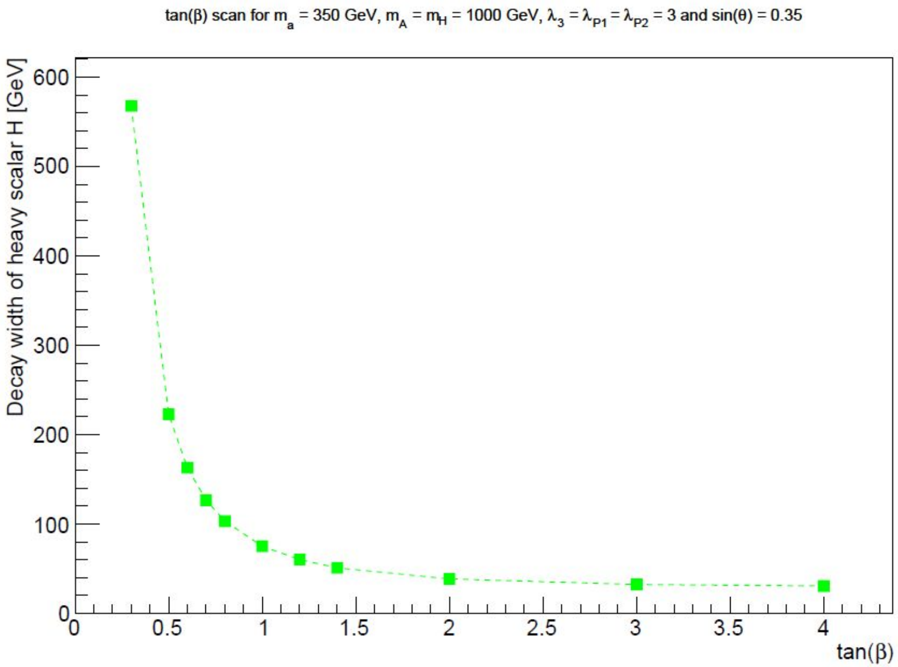
mono-h(bb): tan(β): bin-wise MIL-comparison



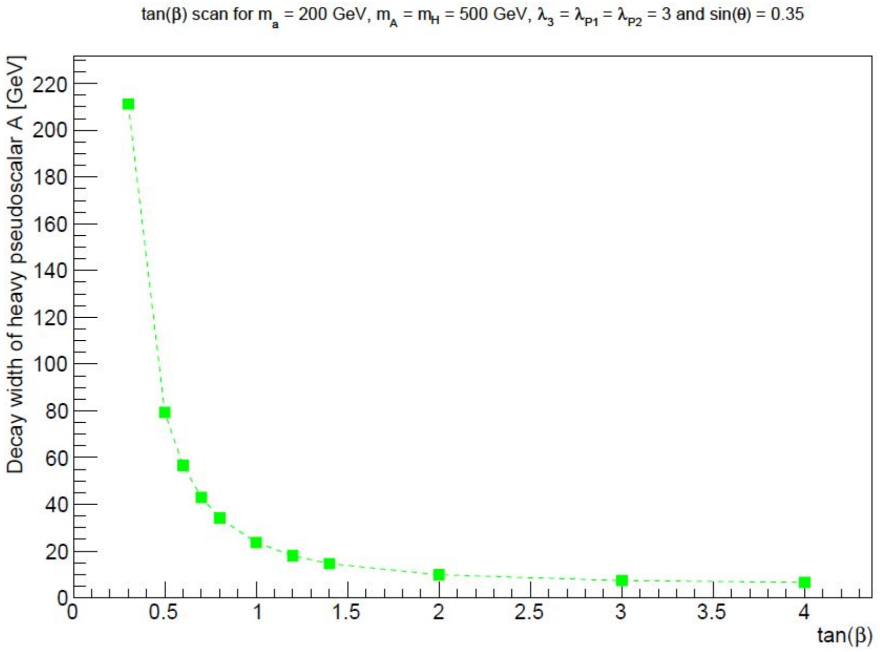


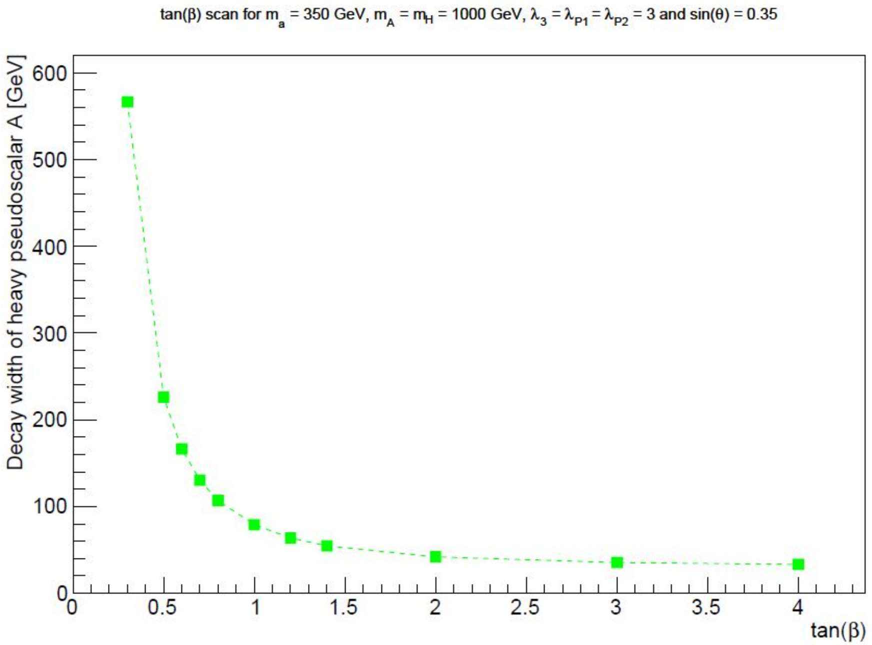
mono-h: tan(β): width of H



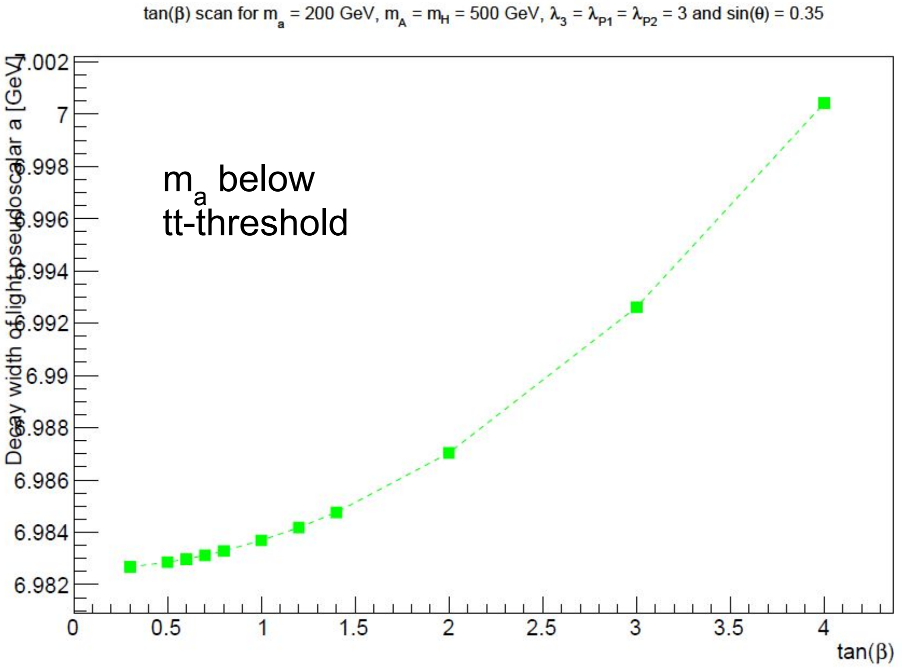


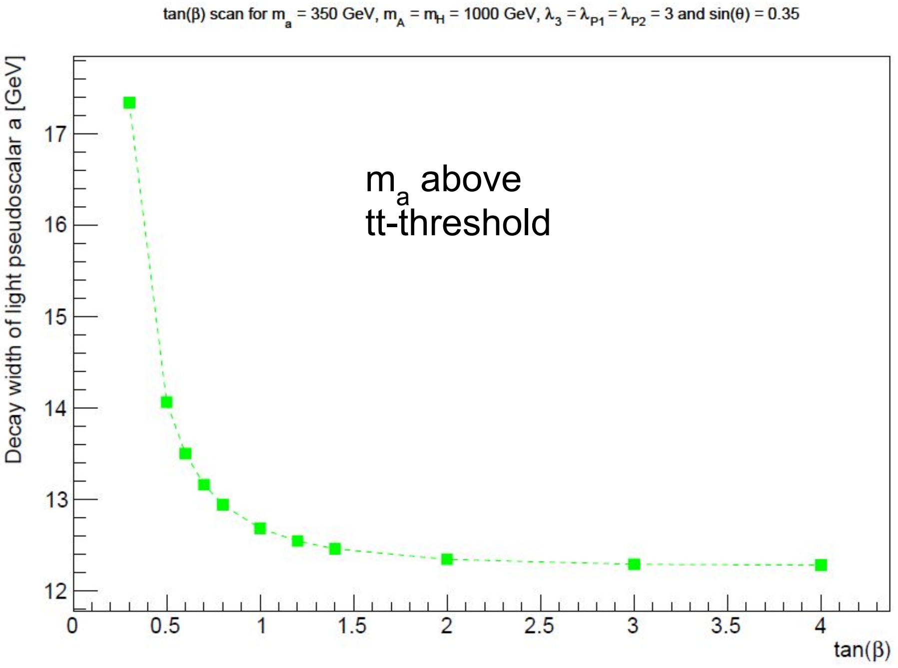
mono-h: tan(β): width of A



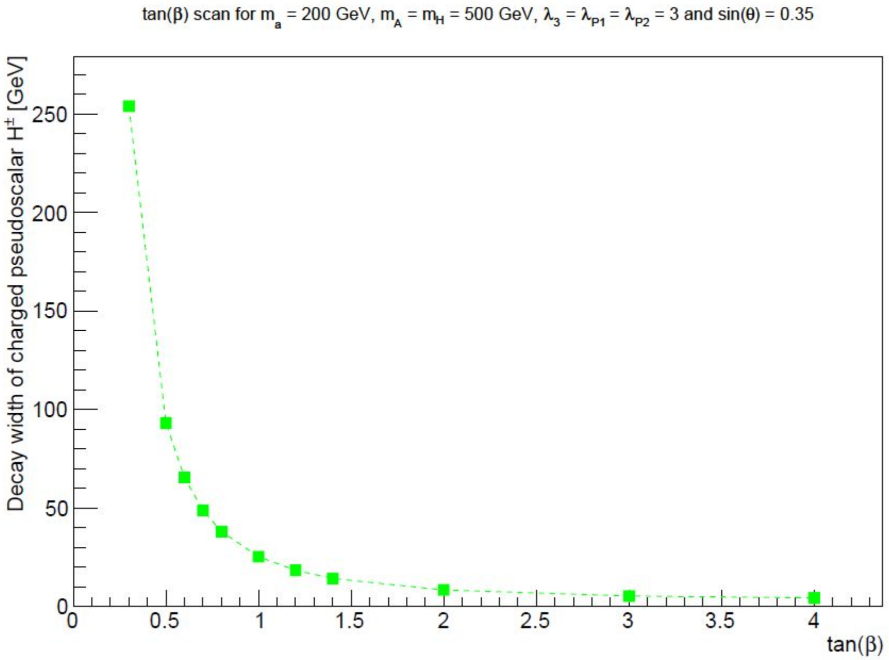


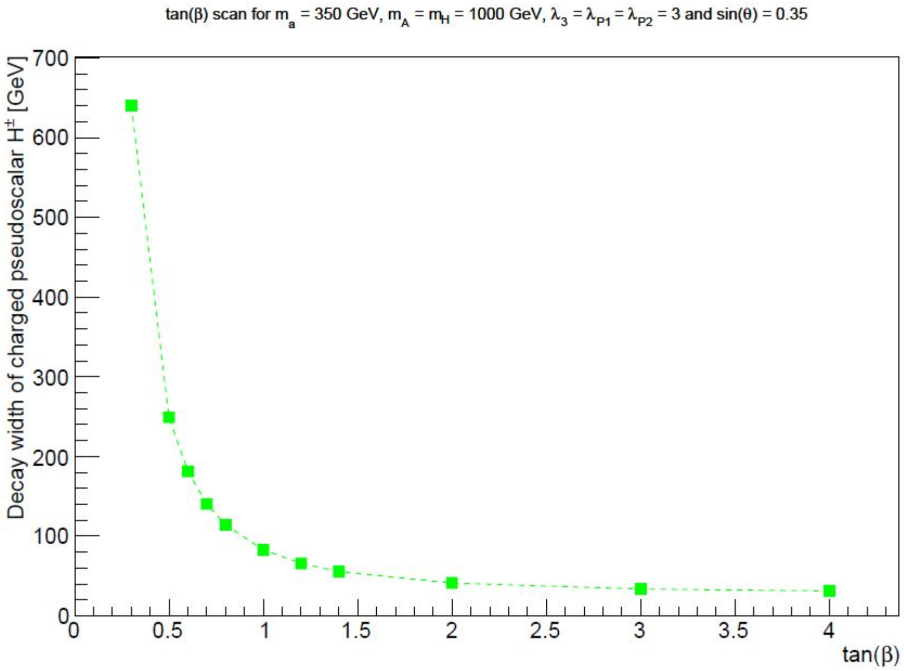
mono-h: tan(β): width of a



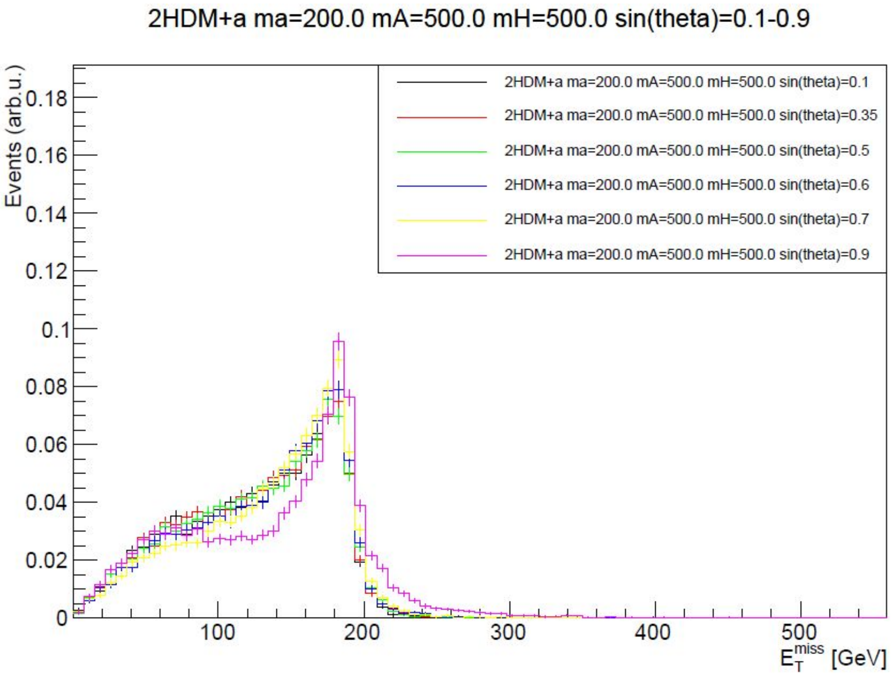


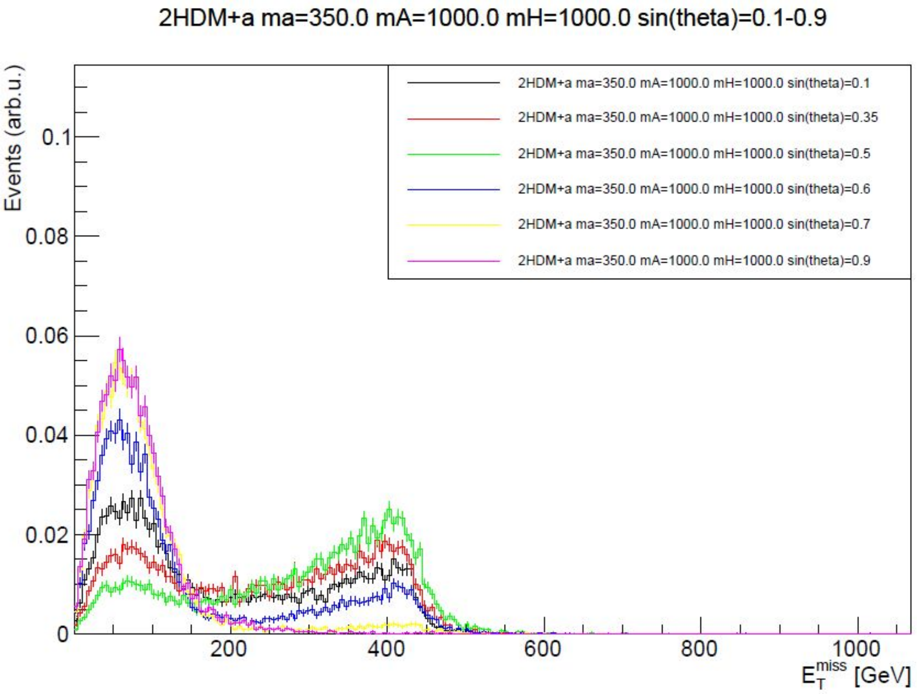
mono-h: tan(β): width of H^{+-}



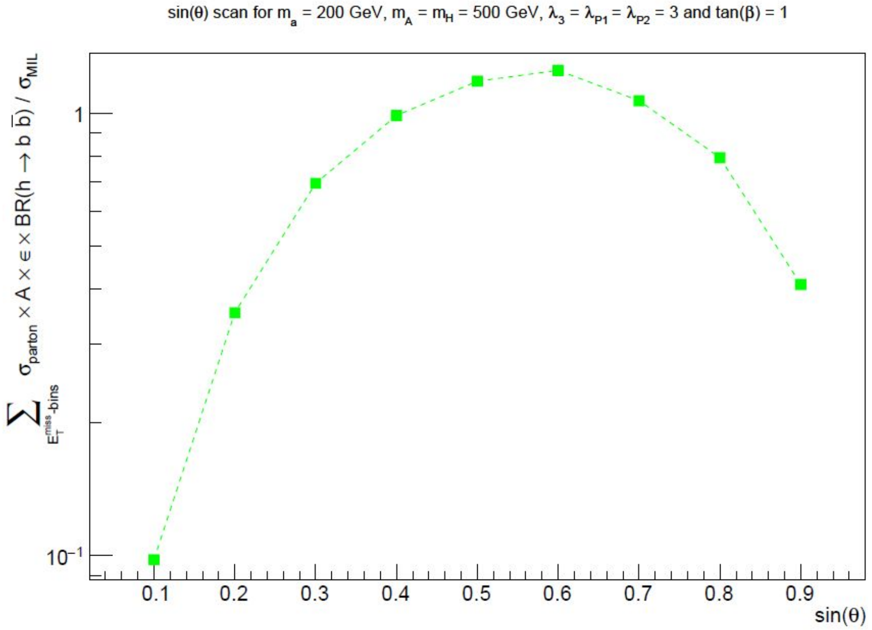


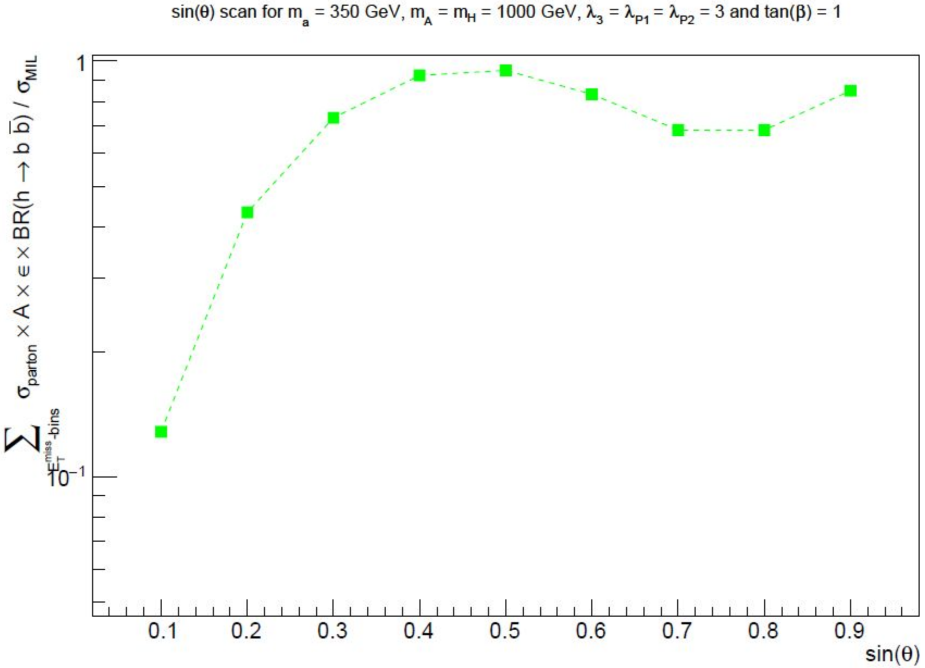
mono-h: sin(θ), normalised to 1



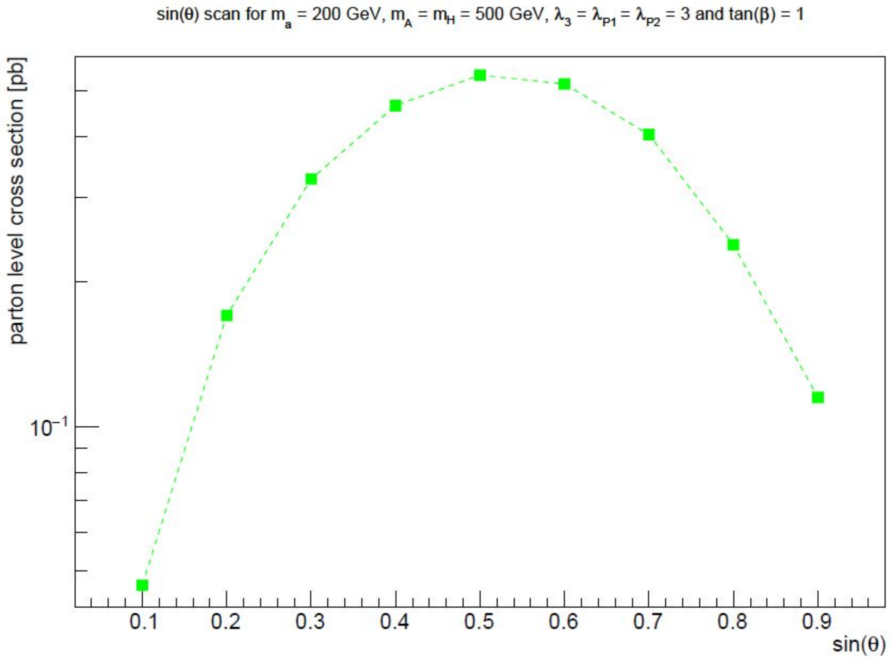


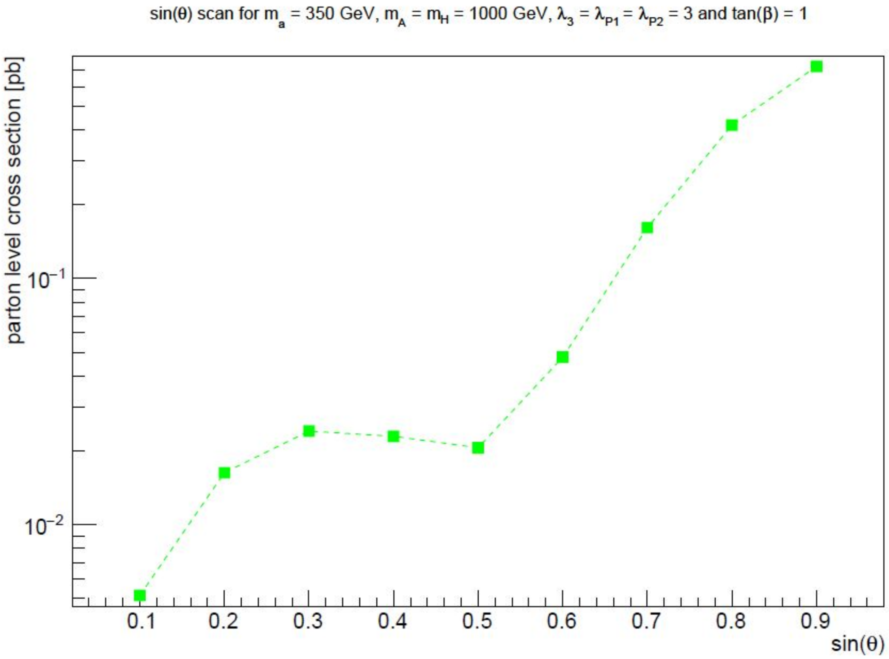
mono-h(bb): sin(θ) sensitivity



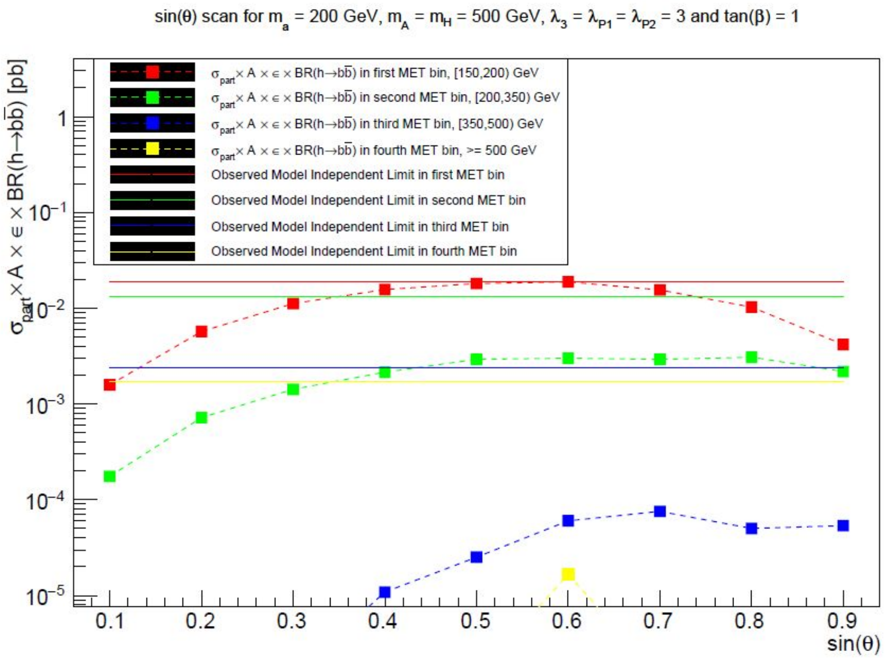


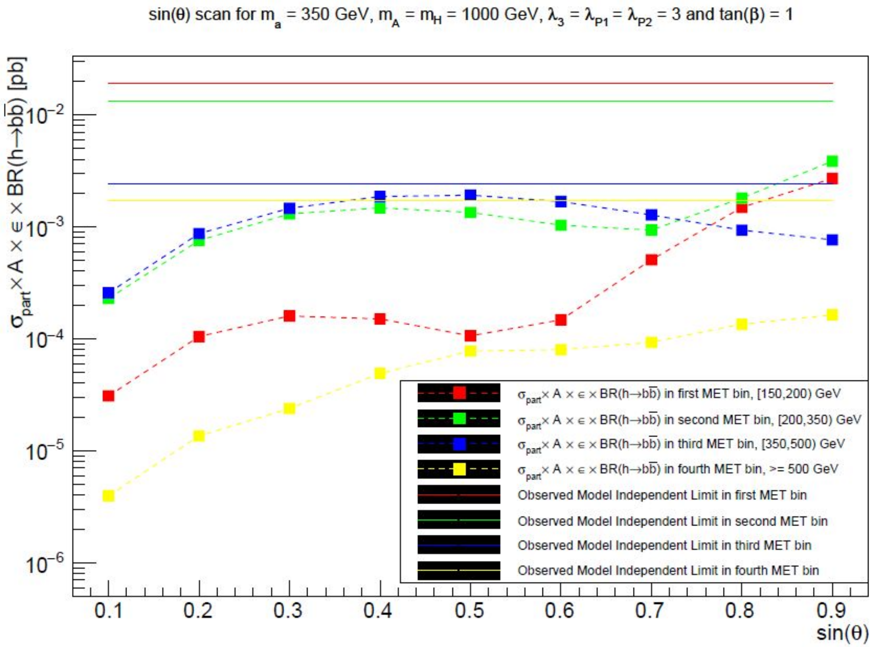
mono-h: sin(θ): parton level cross-section



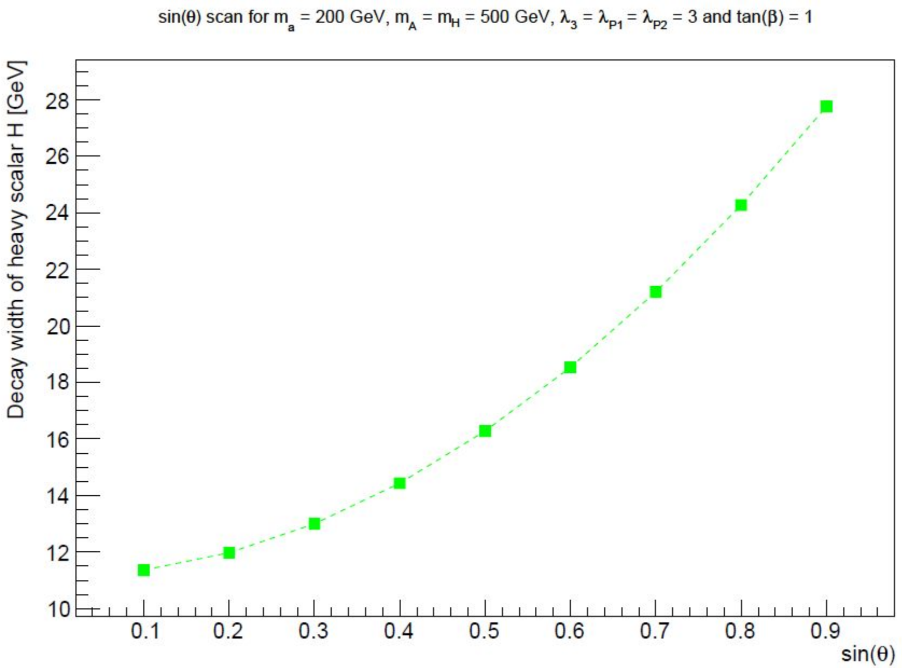


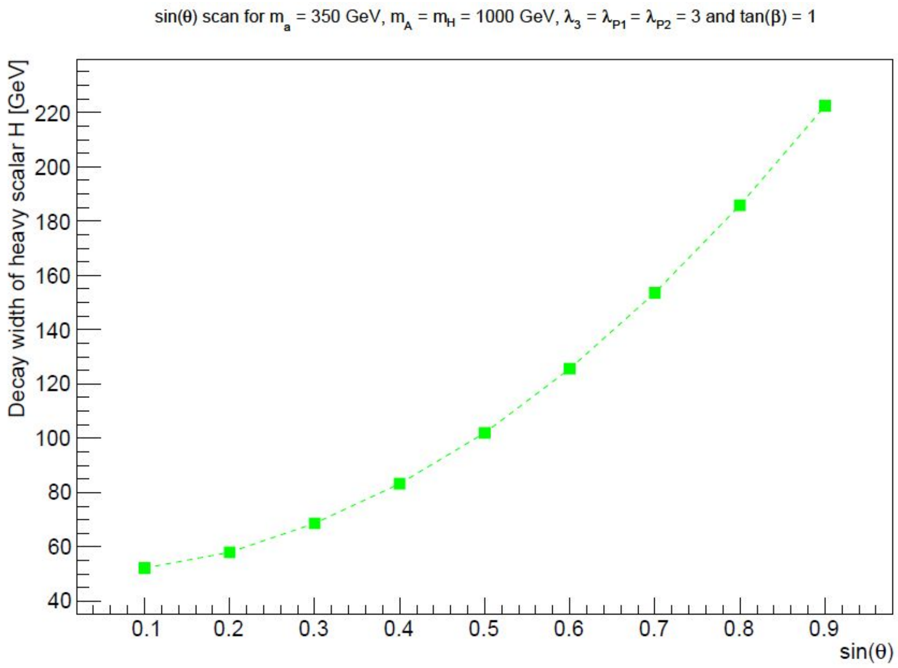
mono-h(bb): sin(θ): bin-wise MIL-comparison



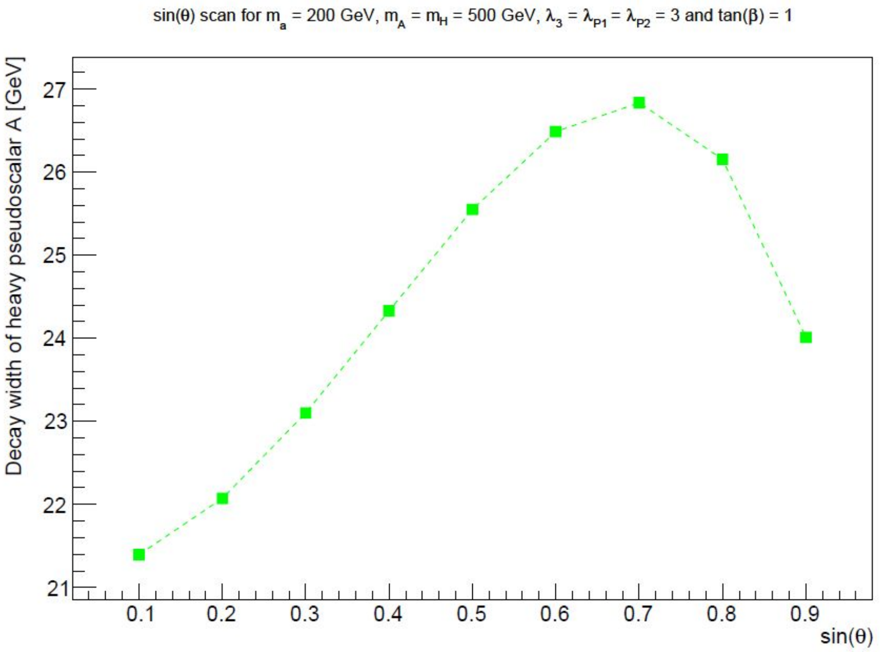


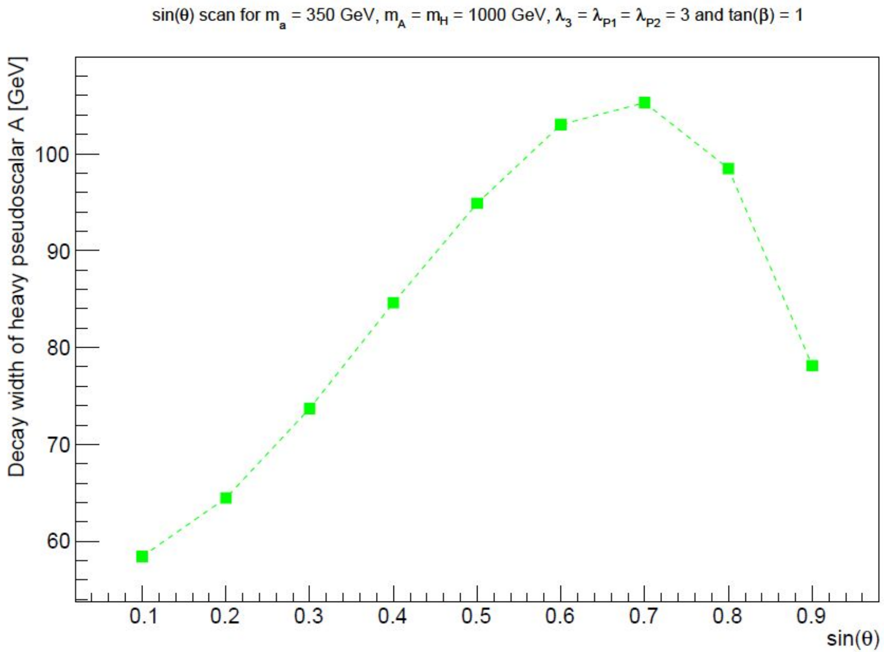
mono-h: sin(θ): width of H



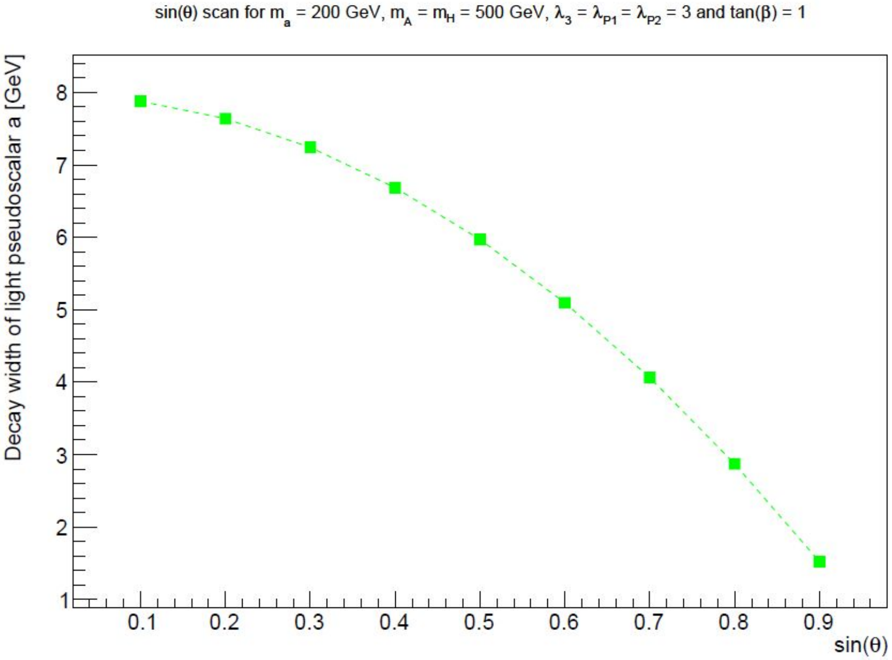


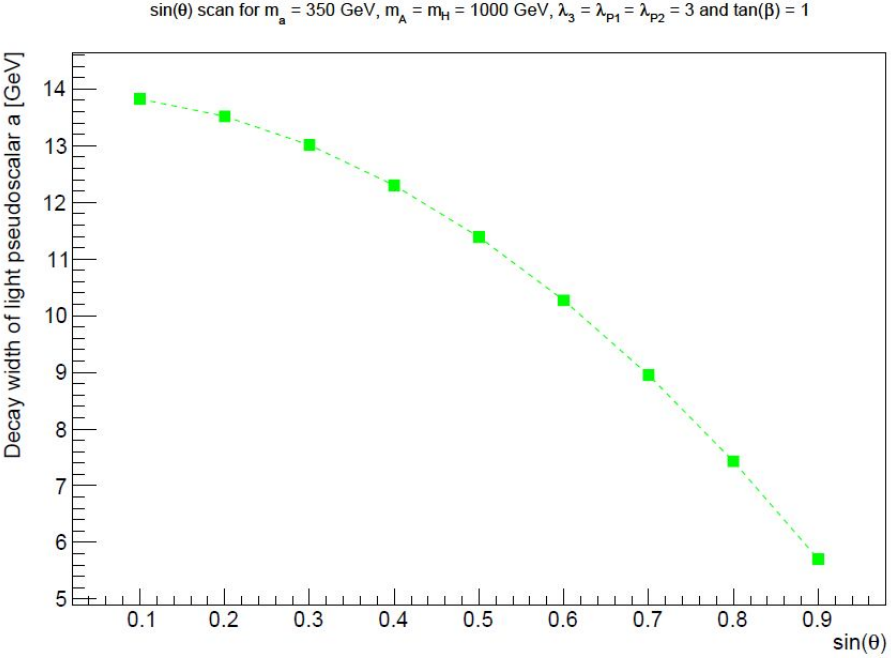
mono-h: $\sin(\theta)$: width of A





mono-h: sin(θ): width of a





mono-h: sin(θ): width of H^{+-}