June 20, 2017
DM WG meeting

Mono-Z report on 2HDM+Pseudoscalar model

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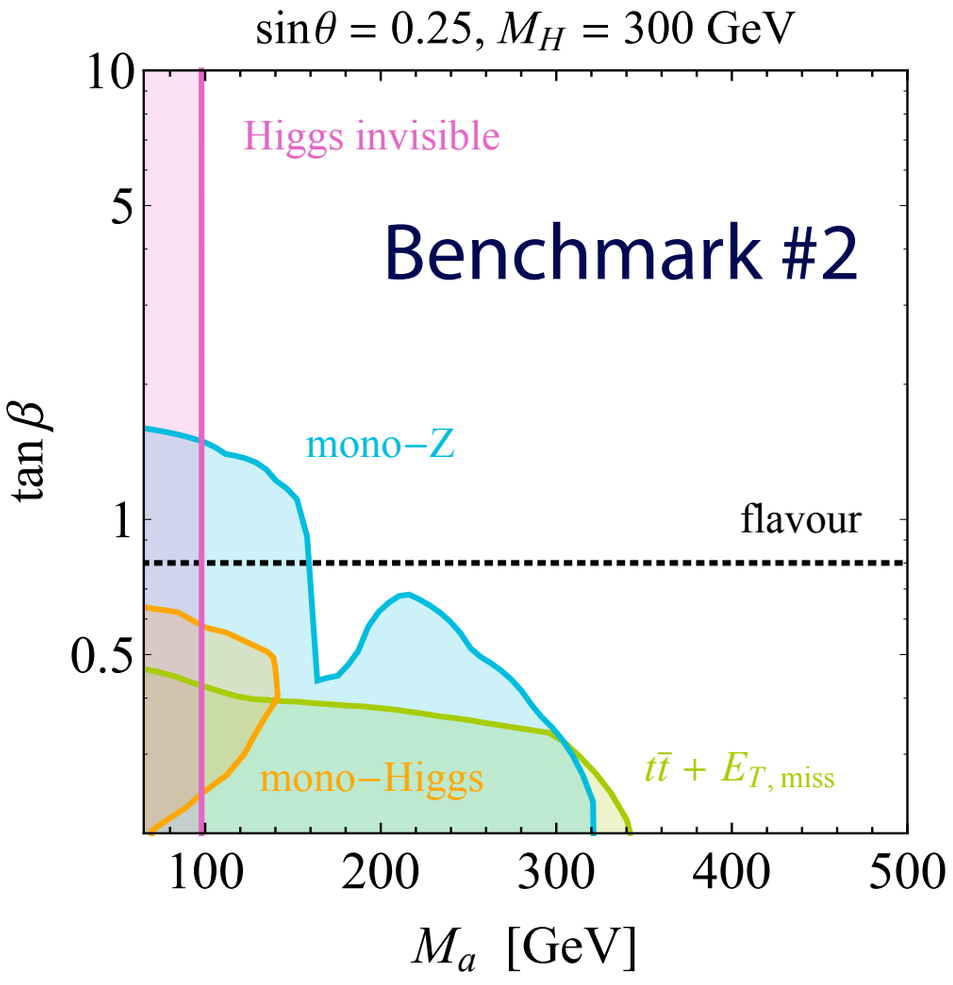
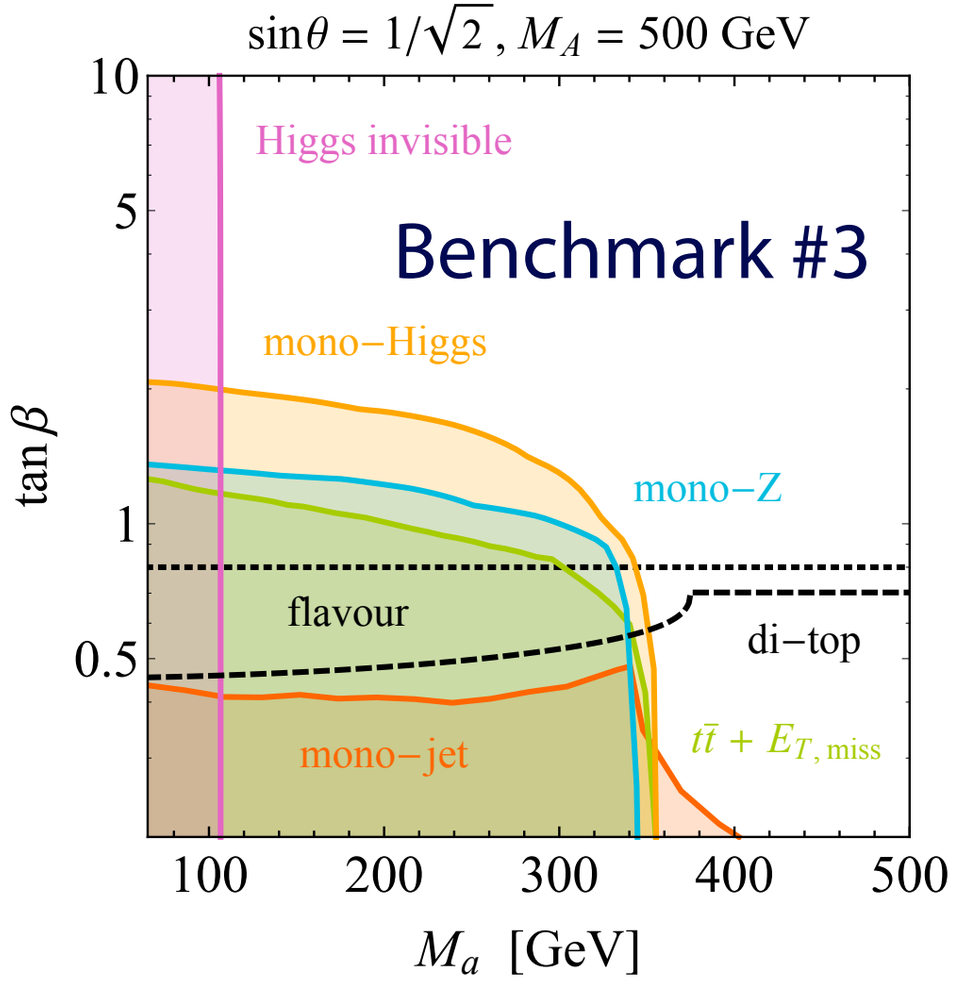
(University of Tokyo)

Mono-Z for 2HDM+a Model

Sensitive probe to the 2HDM+a model in large parameter space





Today's report :

- Preliminary sensitivity scan in tanβ vs m(a) grid for mono-Z
- Complementarity between mono-H and mono-Z
- Limits in tanβ vs m(a) evaluated from acceptance in m(A) vs m(a) grid

Preliminary Grid Scan

Estimate mono-Z sensitivity in tanβ vs m(a) grid for MC request

- Both $Z \rightarrow qq$ and $Z \rightarrow ll$ studied
- Only resolved selection used (selections cuts listed in backup for $Z \rightarrow qq$)
- lam3 = 0 for $Z \rightarrow qq$, = 0.258 for $Z \rightarrow ll$
  - — no big difference between 0 and 0.258 for $Z \rightarrow qq$ (see backup)

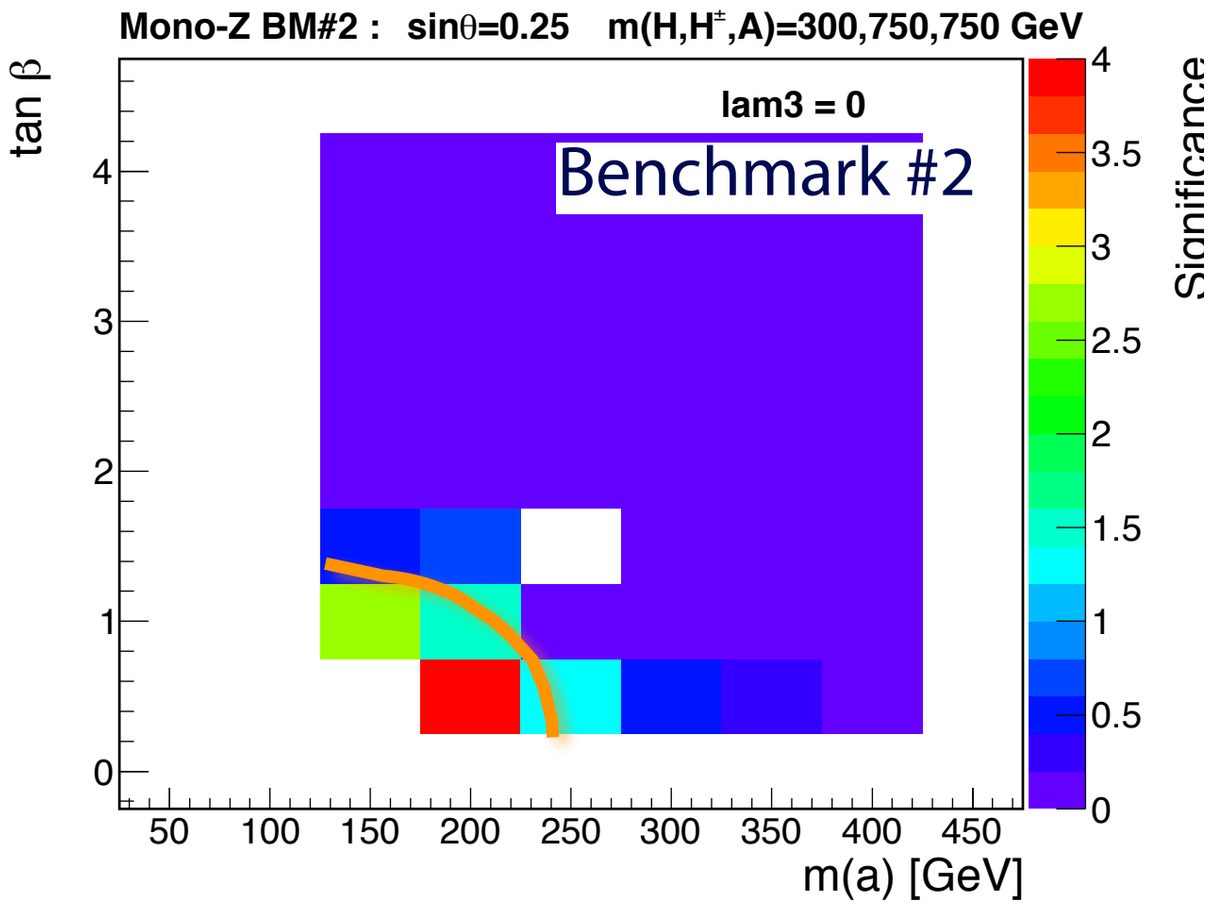
Scan performed by calculating significance defined as $S/\sqrt{B}$

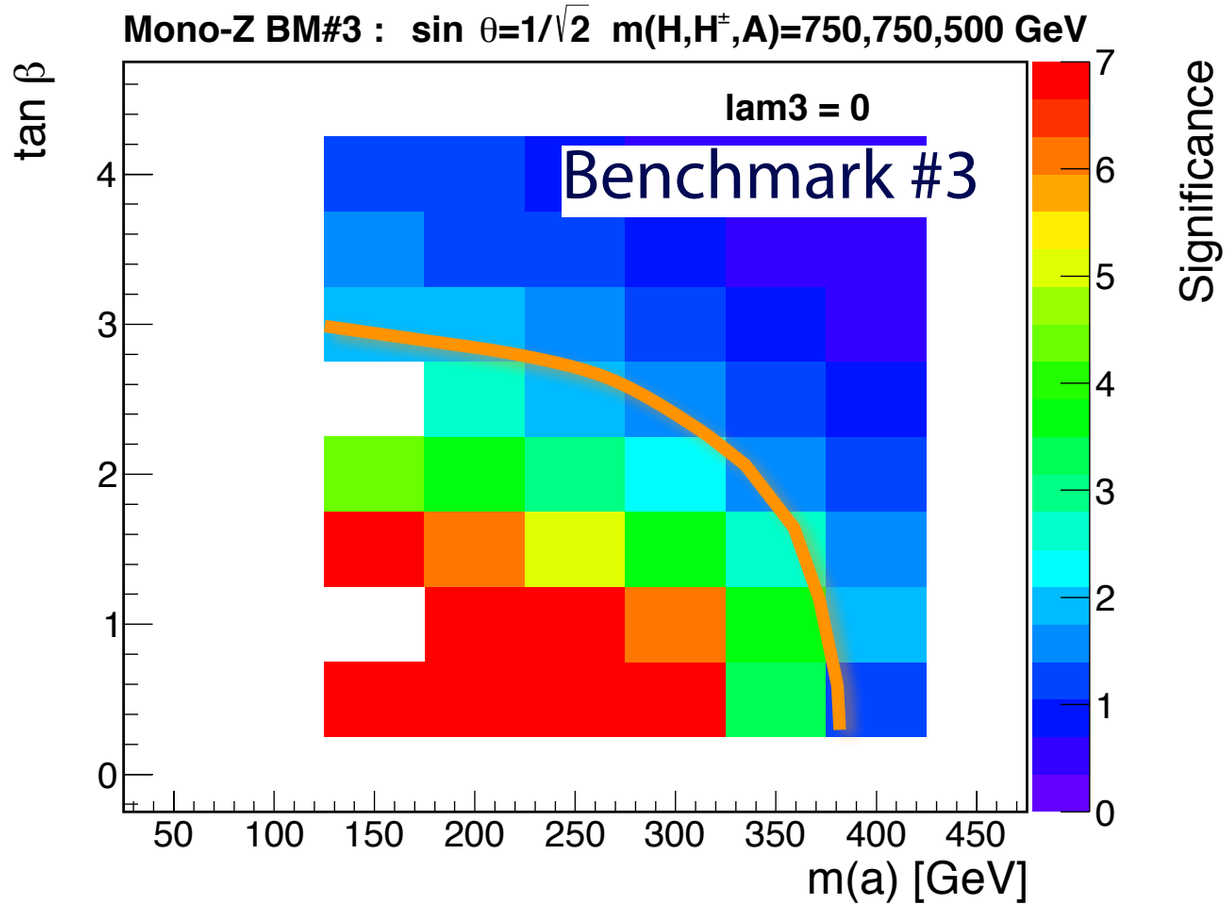
- $Z \rightarrow \nu\nu$+jets ($ZZ \rightarrow llvv$) sample used as background for $Z \rightarrow qq$ (ll)
- Scaled by factor 2 to account for other backgrounds, e.g, top, W+jets
- Significance = $\sqrt{\sum_i (S_i/\sqrt{B_i+\Delta B_i})^2}$ where i runs over E_T^{miss} bin
- Draw contour at ~2σ significance for exclusion

ΔB = stat ⊕ 20% syst

tanβ vs m(a) Grid

Mono-Z(qq) at 36 fb^{-1}

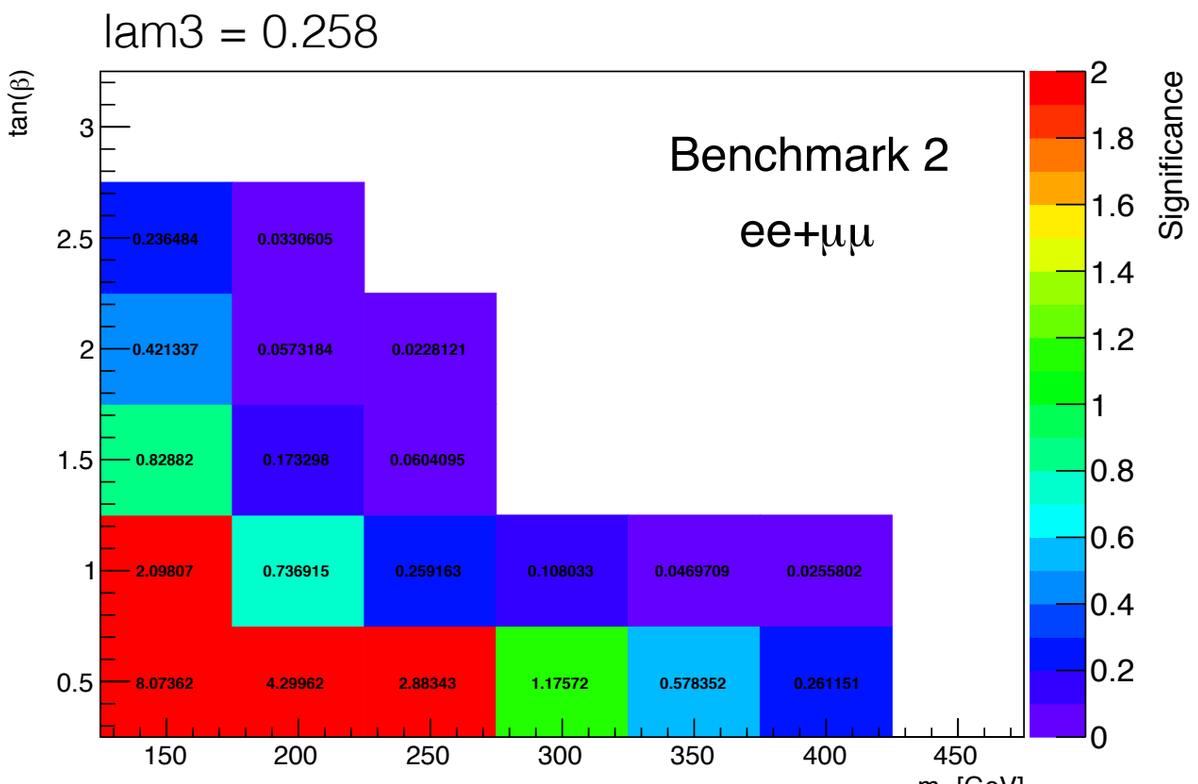


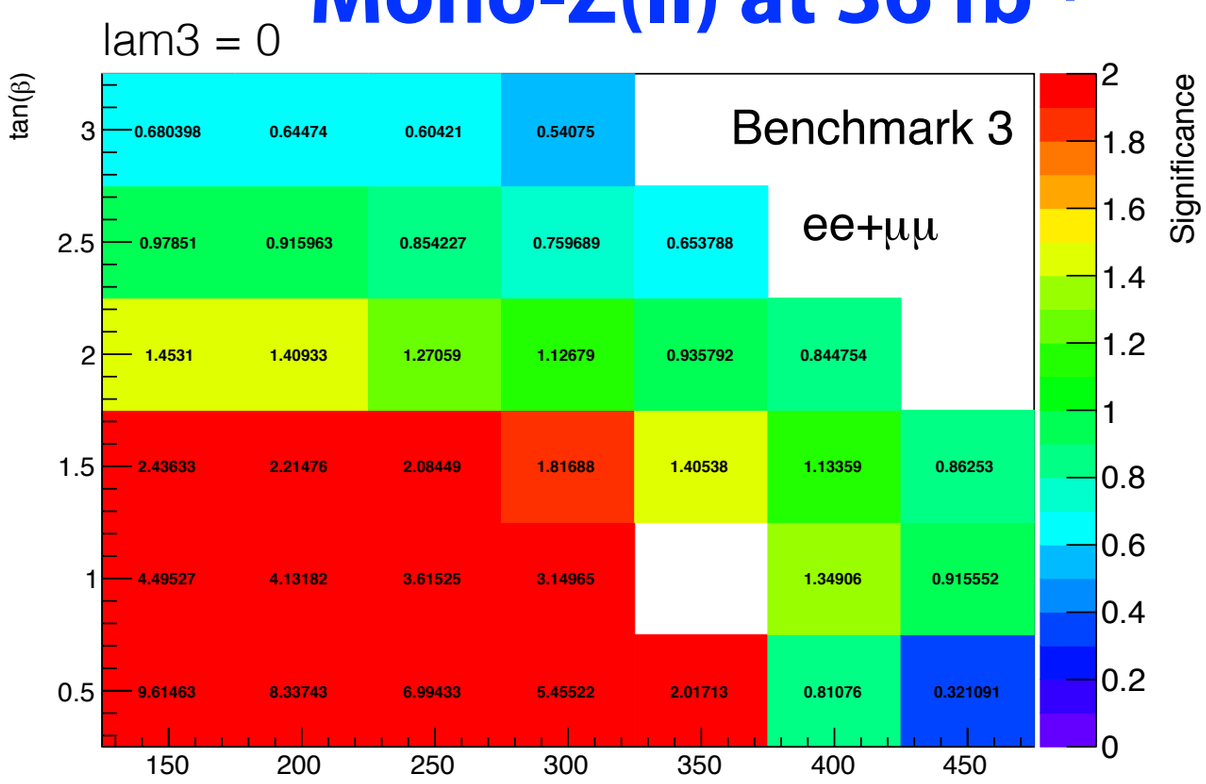


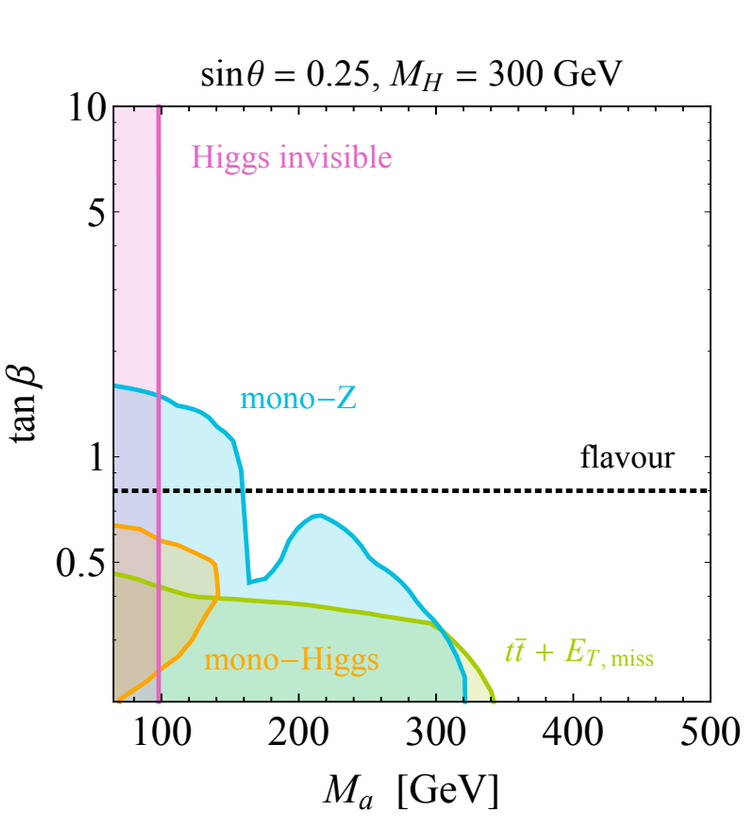
tanβ vs m(a) Grid

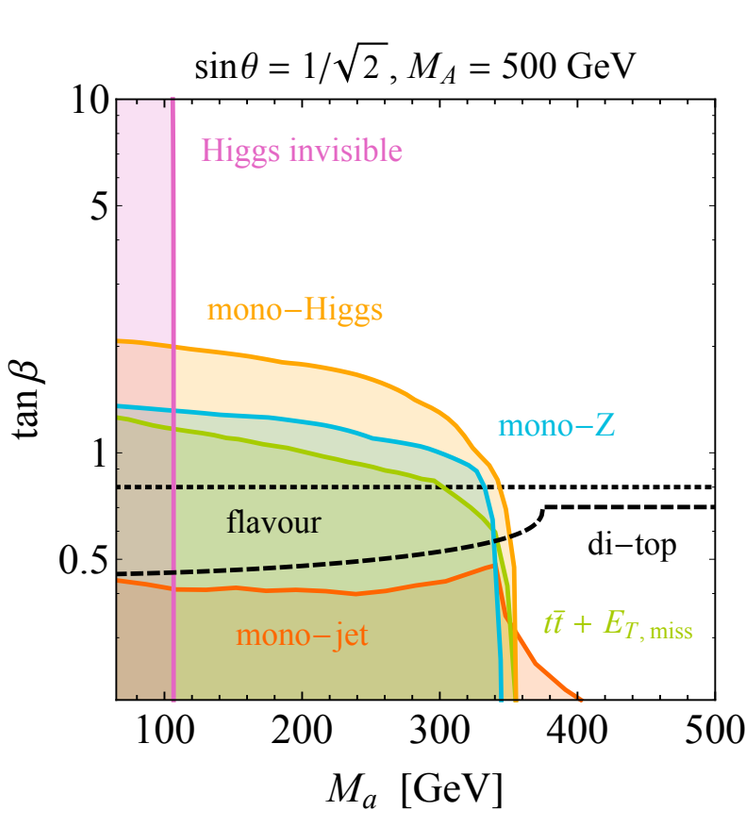
C. Anelli, K. Hamano, A. Elliot

Mono-Z(ll) at 36 fb^{-1}









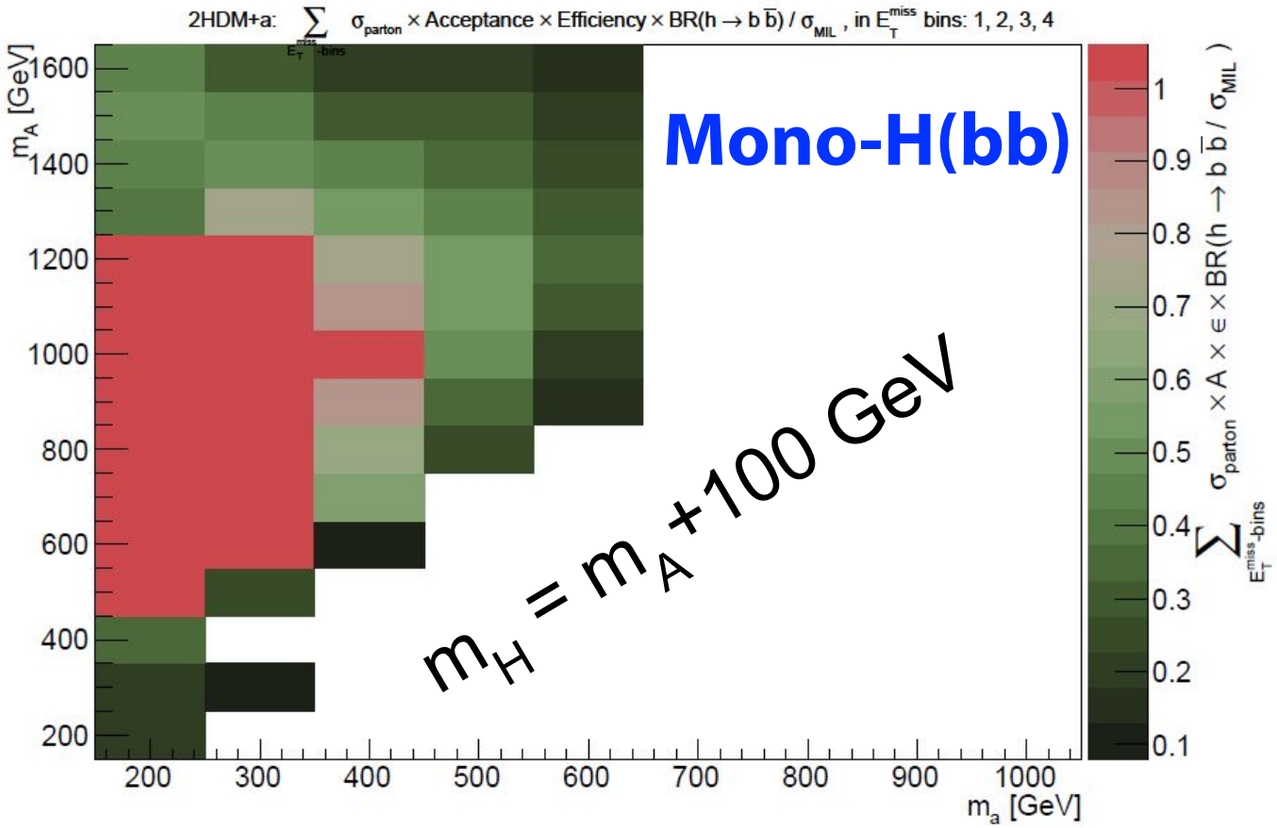
Mono-Z(ll) sensitivity confirmed to be consistent with that in the paper

m(A) vs m(a) Grid

L. Henkelmann, O. Brandt

m(A) vs m(a) grid proposed for Mono-H at the last meeting

- other parameter choice :
  - $\sin\theta = 0.35$, $\tan\beta = 1$
  - $m_X = 1$ GeV, $y_X = 1$
  - **$m(H) = m(A) + 100$ GeV**
    → preferred choice for mono-H



Comparison with Mono-H

L. Henkelmann, O. Brandt

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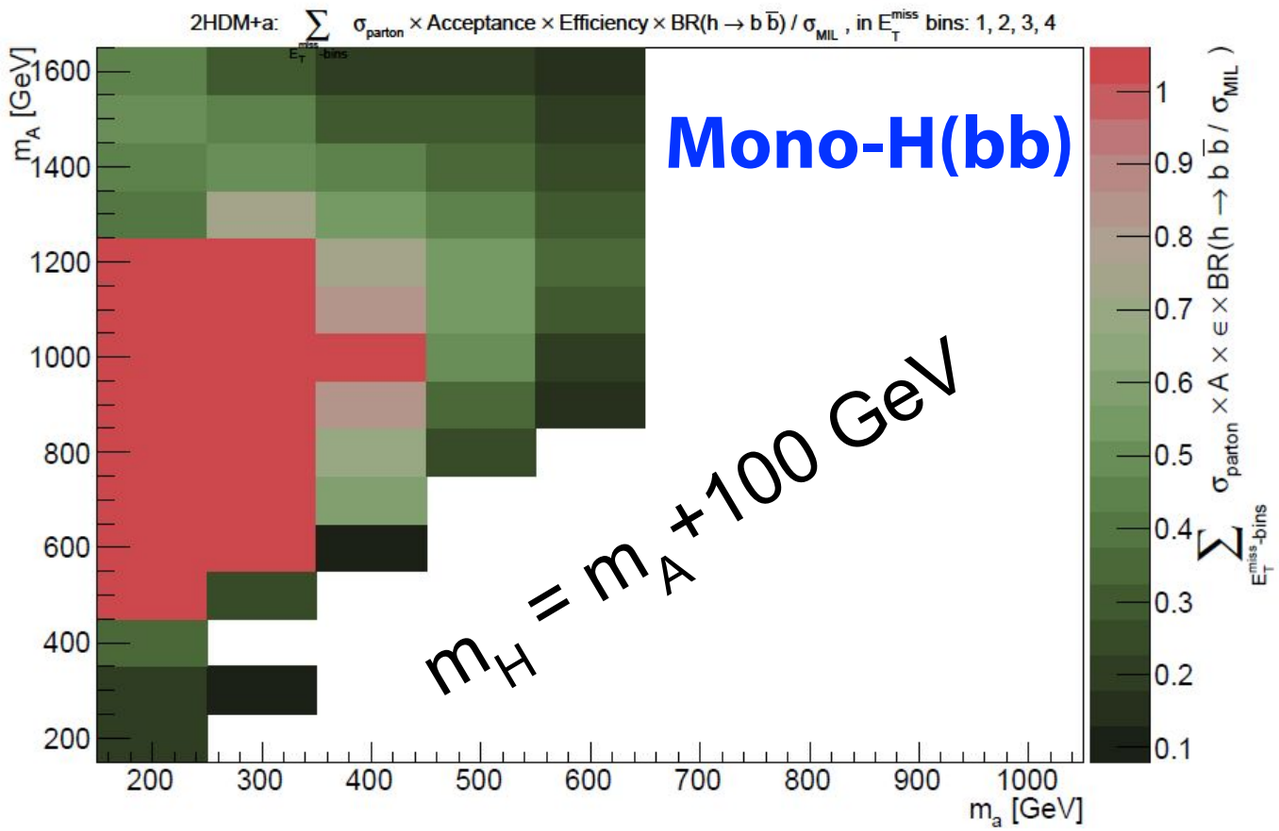
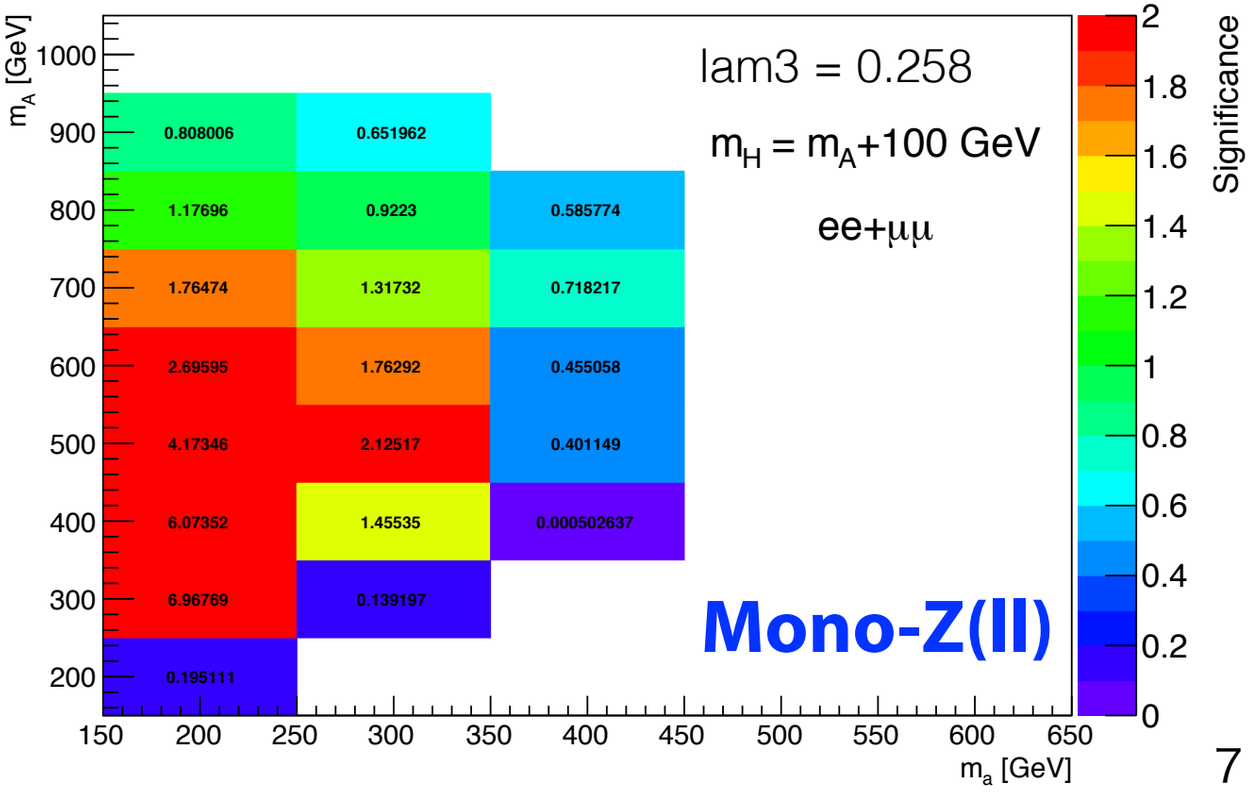
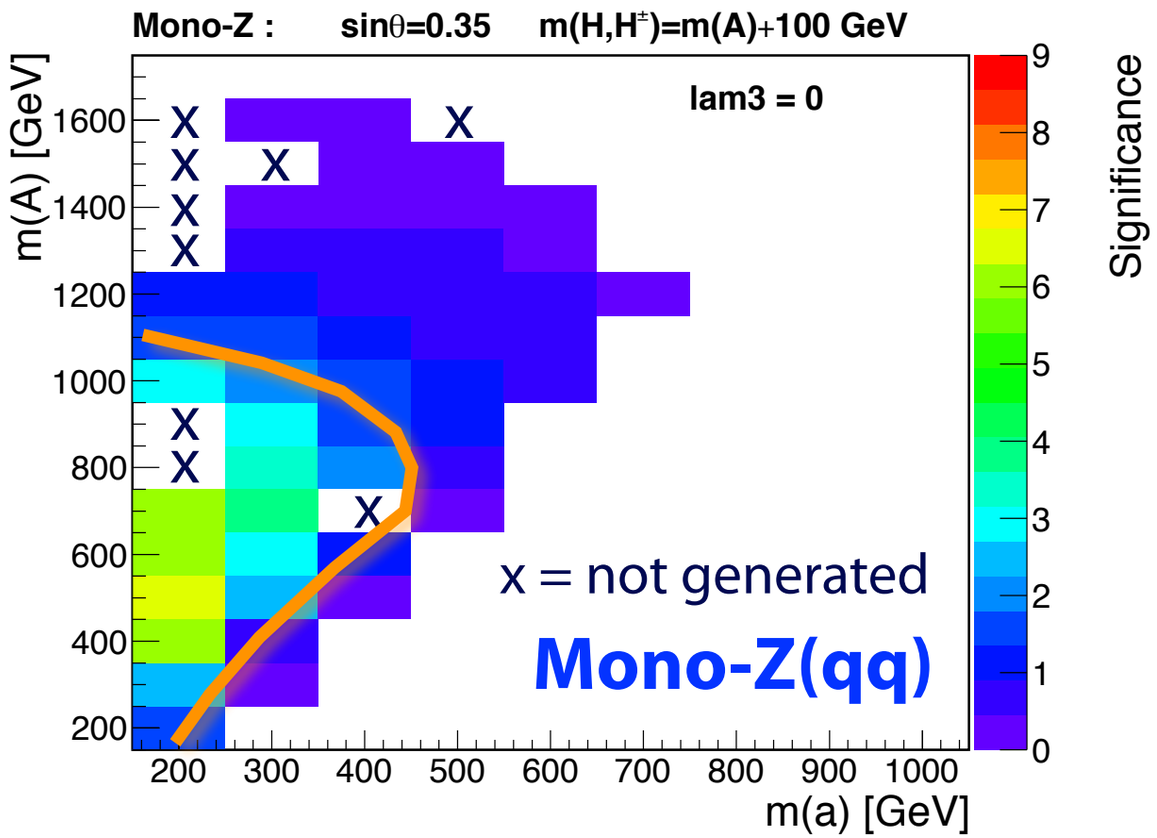


C. Anelli, K. Hamano, A. Elliot





Comparison with Mono-H

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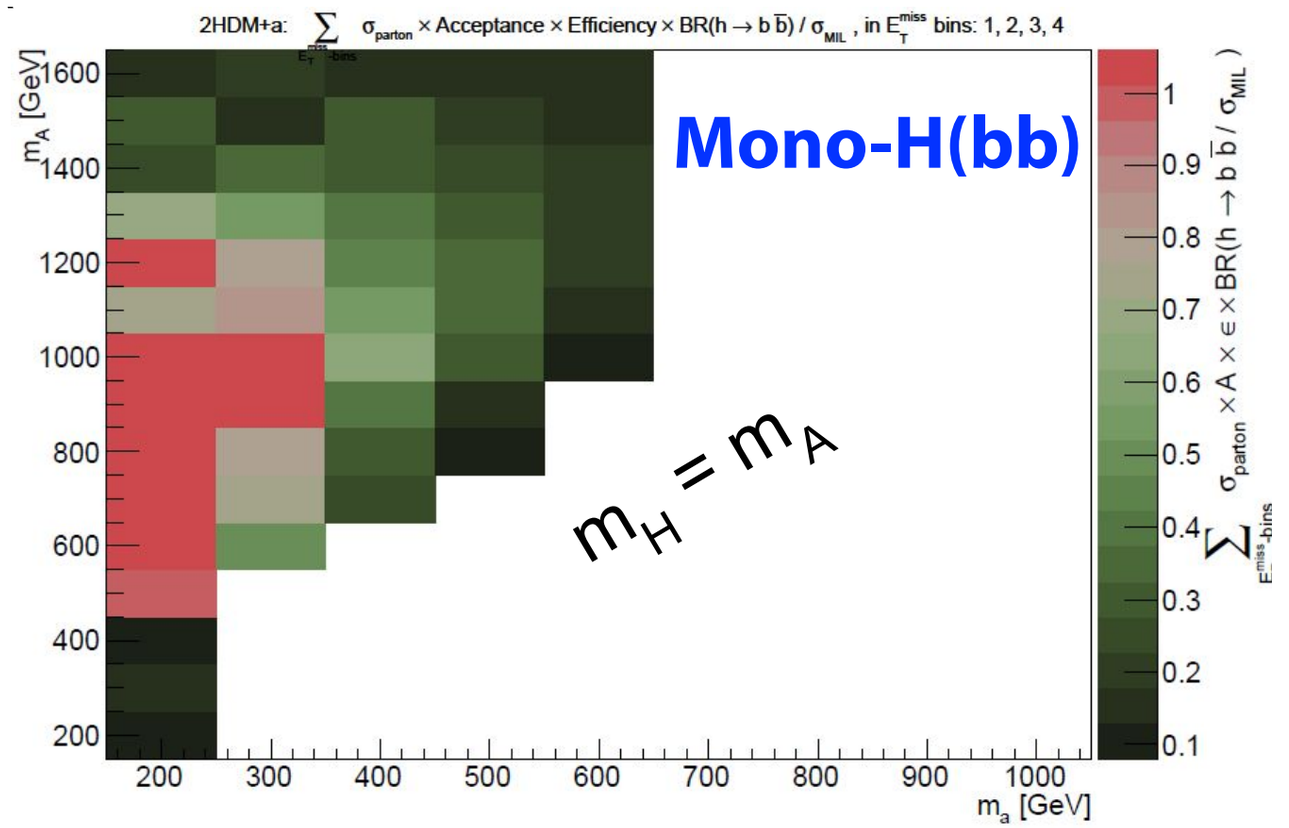
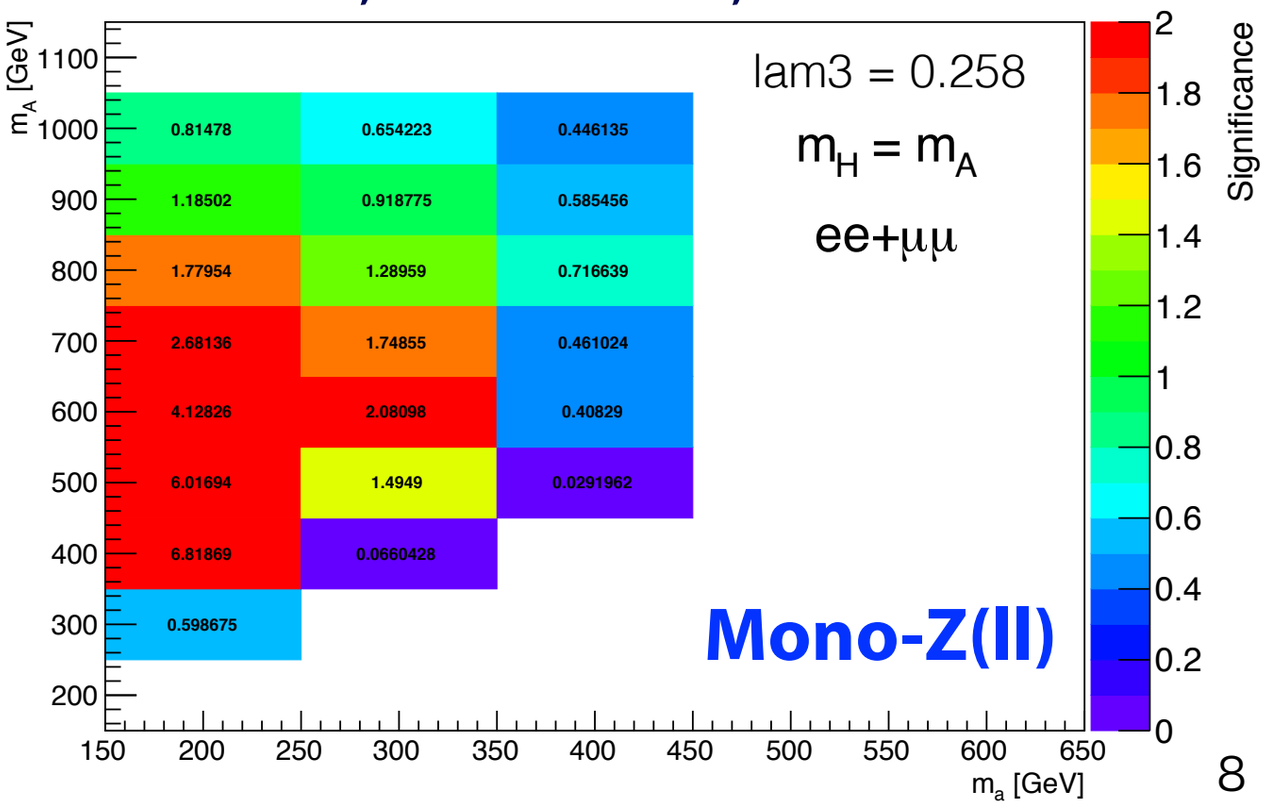
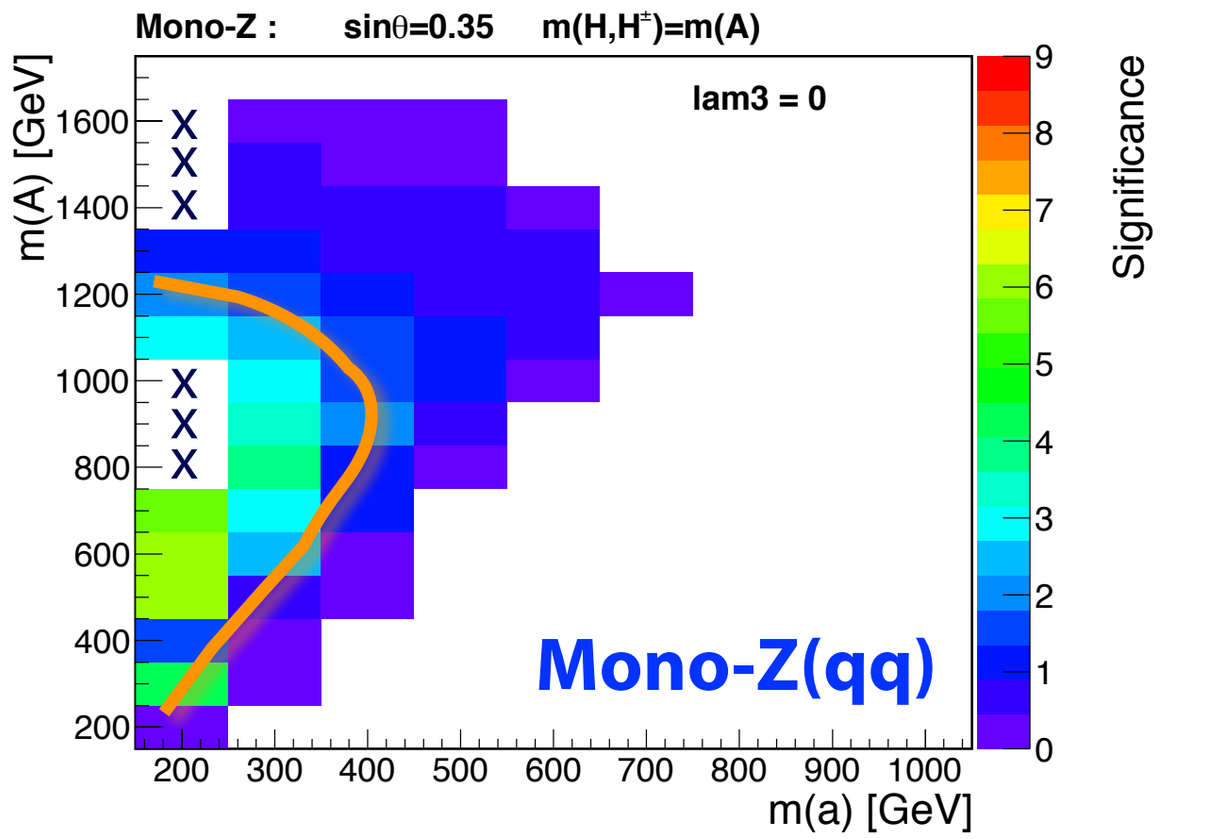
m(A) vs m(a) grid proposed for Mono-H at the last meeting

- other parameter choice :
  - $\sin\theta = 0.35$, $\tan\beta = 1$
  - $m_X = 1$ GeV, $y_X = 1$
  - **m(H) = m(A)**
    → current preference?



C. Anelli, K. Hamano, A. Elliot



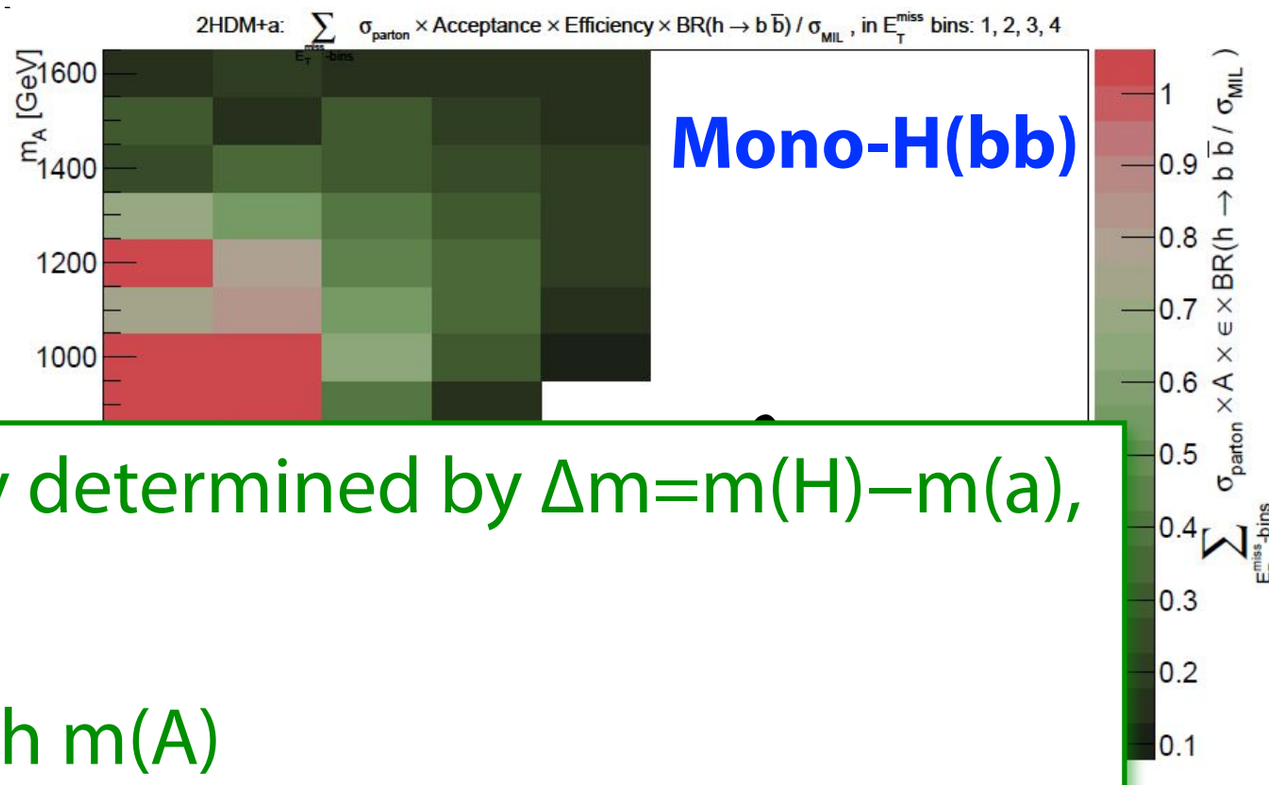


Comparison with Mono-H

L. Henkelmann,
O. Brandt

m(A) vs m(a) grid proposed for Mono-H at the last meeting

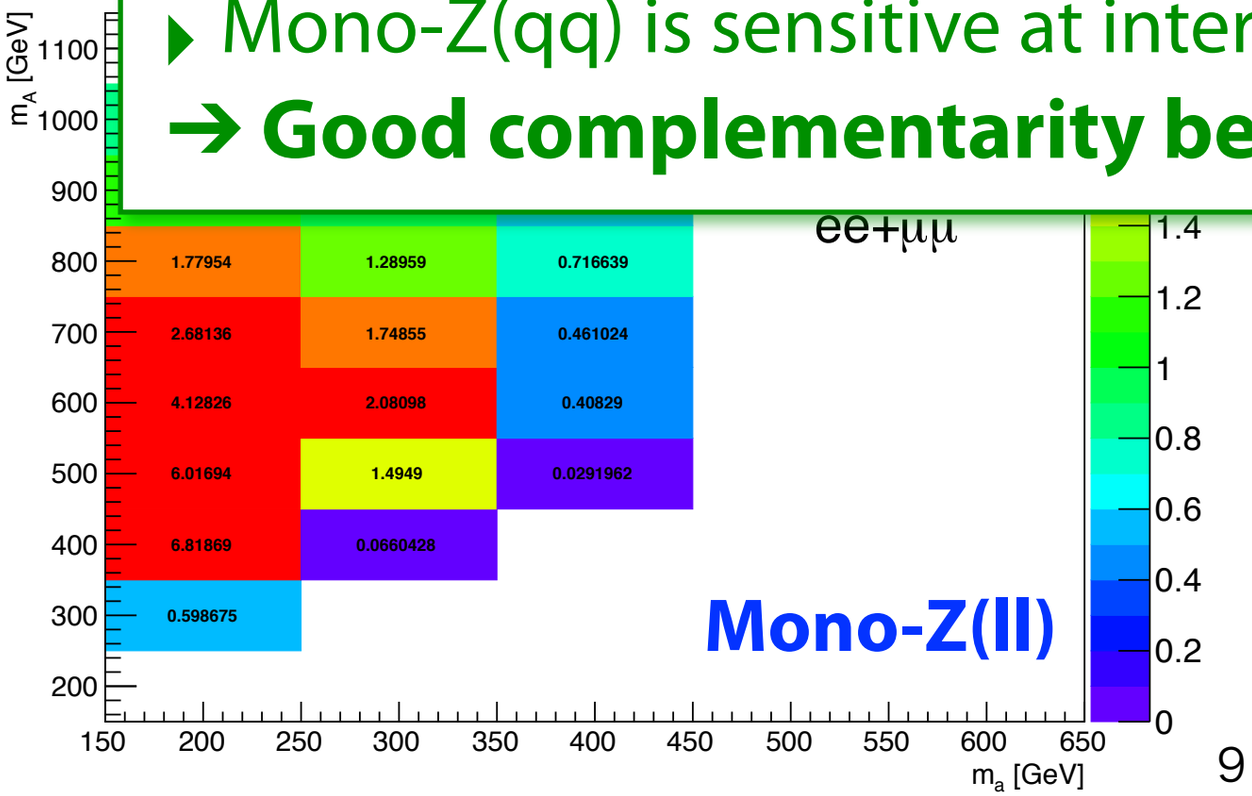
- other parameter choice :
  - $\sin\theta = 0.35$, $\tan\beta = 1$
  - [illegible]

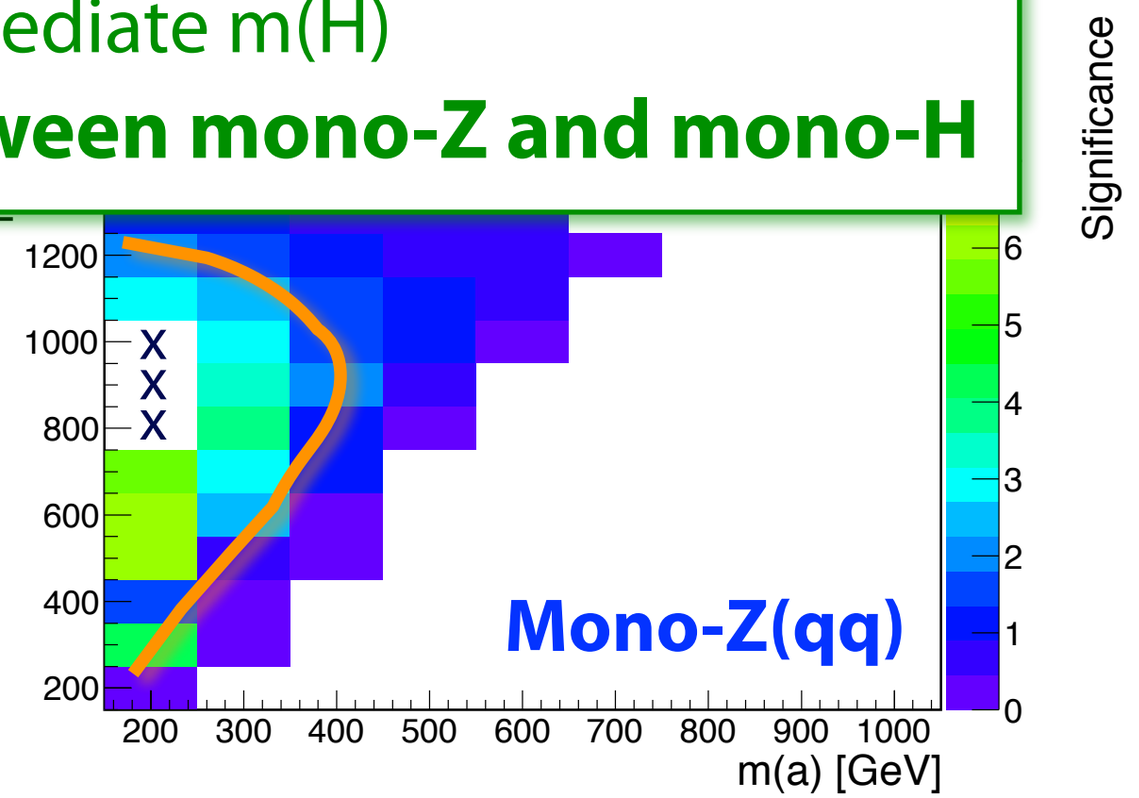


Mono-Z signal sensitivity largely determined by Δm=m(H)–m(a), not m(H)–m(A)

- Mono-H(bb) is sensitive at high m(A)
- Mono-Z(ll) is sensitive at low m(H)
- Mono-Z(qq) is sensitive at intermediate m(H)

➔ Good complementarity between mono-Z and mono-H

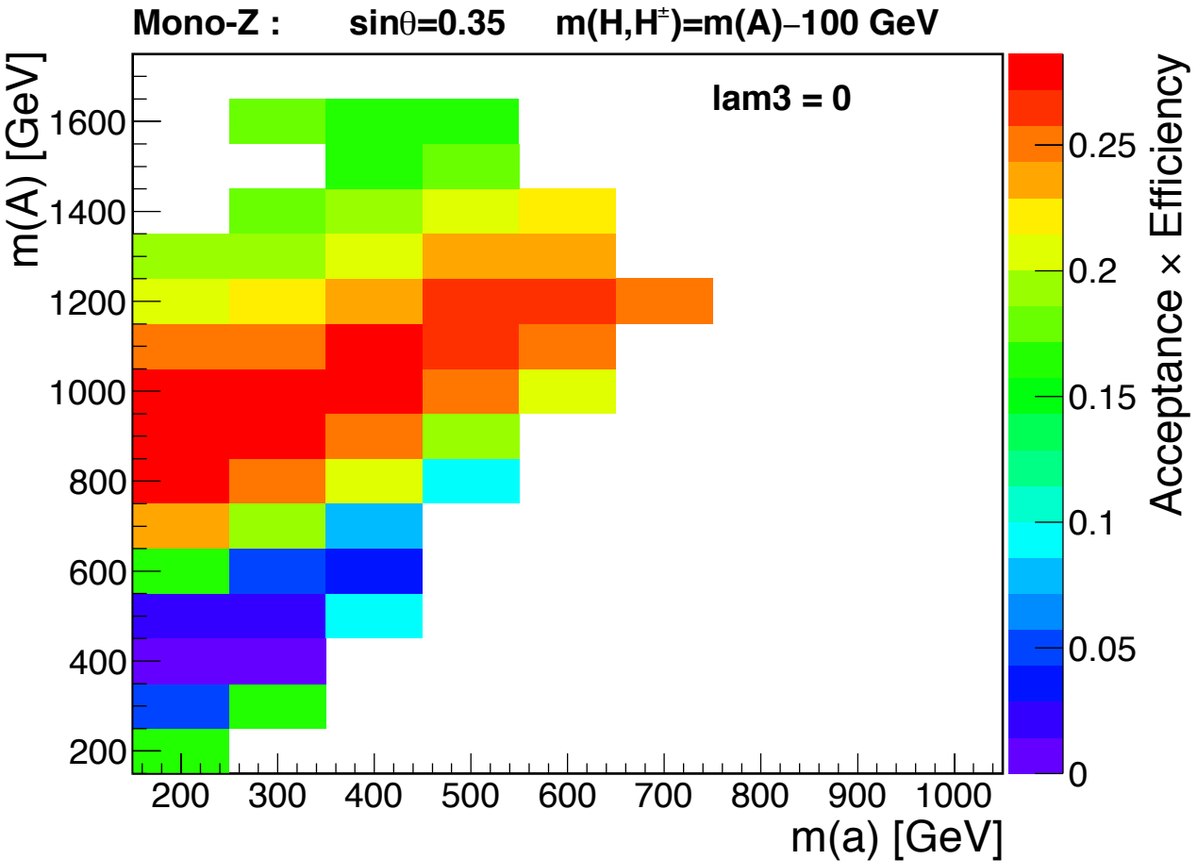




Mono-Z Acceptance

Mono-Z(qq)

- m(A) vs m(a) grid
- m(H)=m(A)–100 GeV



acceptance gets minimum(maximum)
when Δm = m(H)–m(a) ~ 0(600) GeV

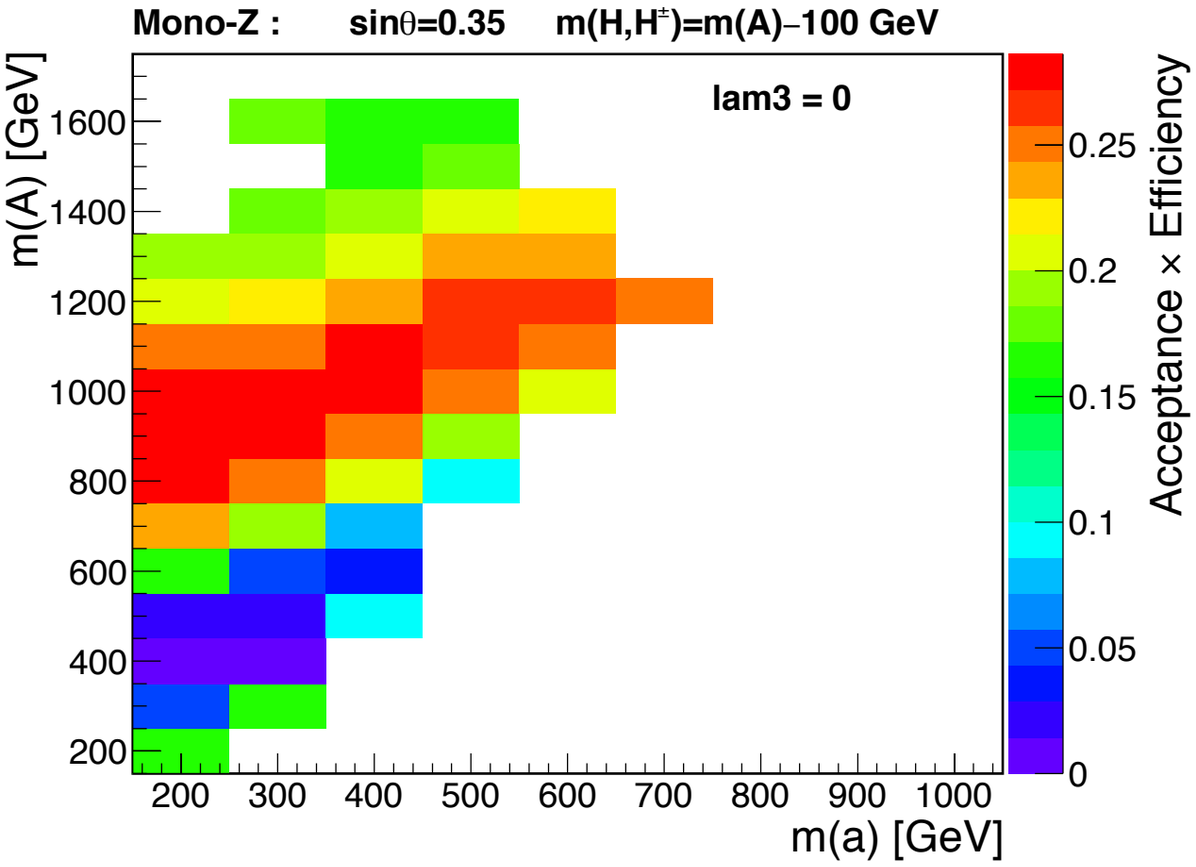
Acceptance varies significantly with mass difference Δm = m(H)–m(a)

➔ Kinematic properties of the mono-Z signal is characterized by Δm

Mono-Z Acceptance

Mono-Z(qq)

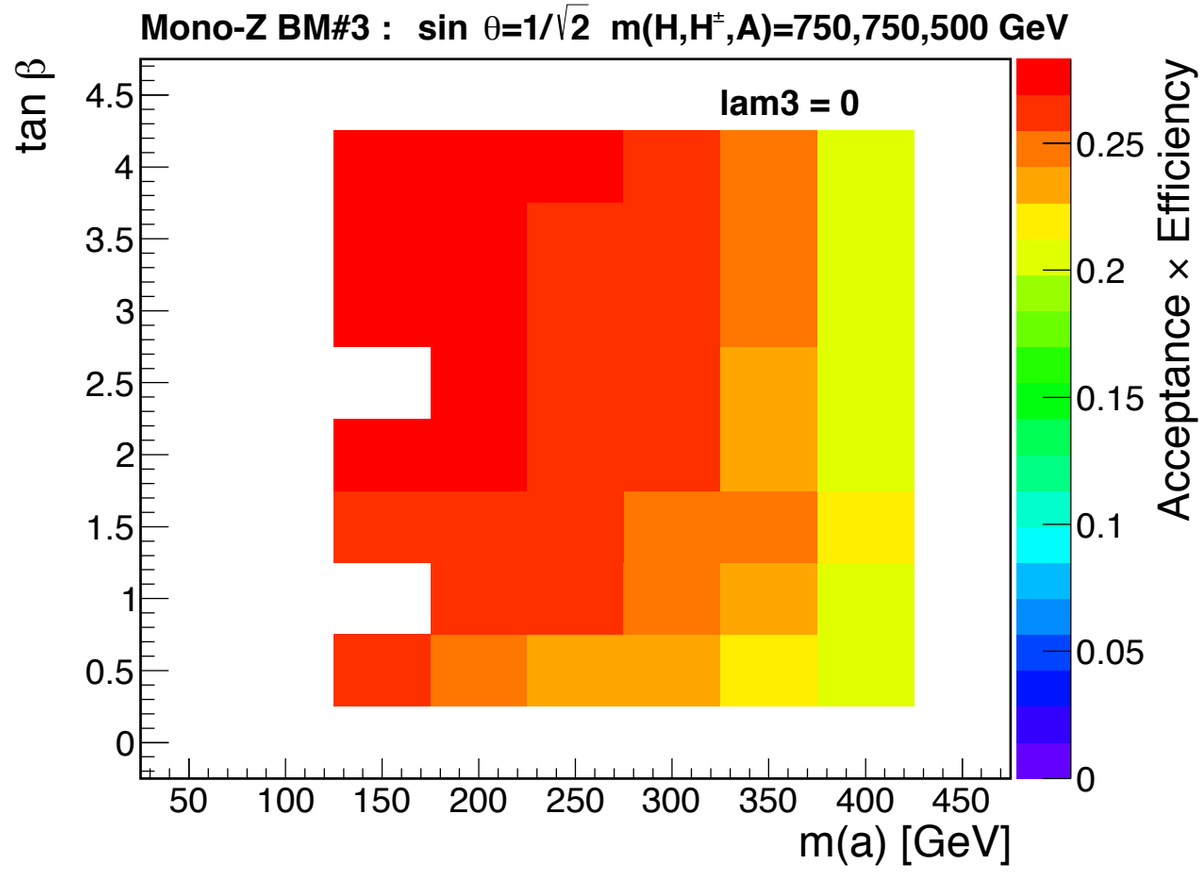
- m(A) vs m(a) grid
- m(H)=m(A)−100 GeV



acceptance gets minimum(maximum)
when Δm = m(H)−m(a) ~ 0(600) GeV

Benchmark #3

- tanβ vs m(a) grid
- m(H)=750 GeV, m(A)=500 GeV

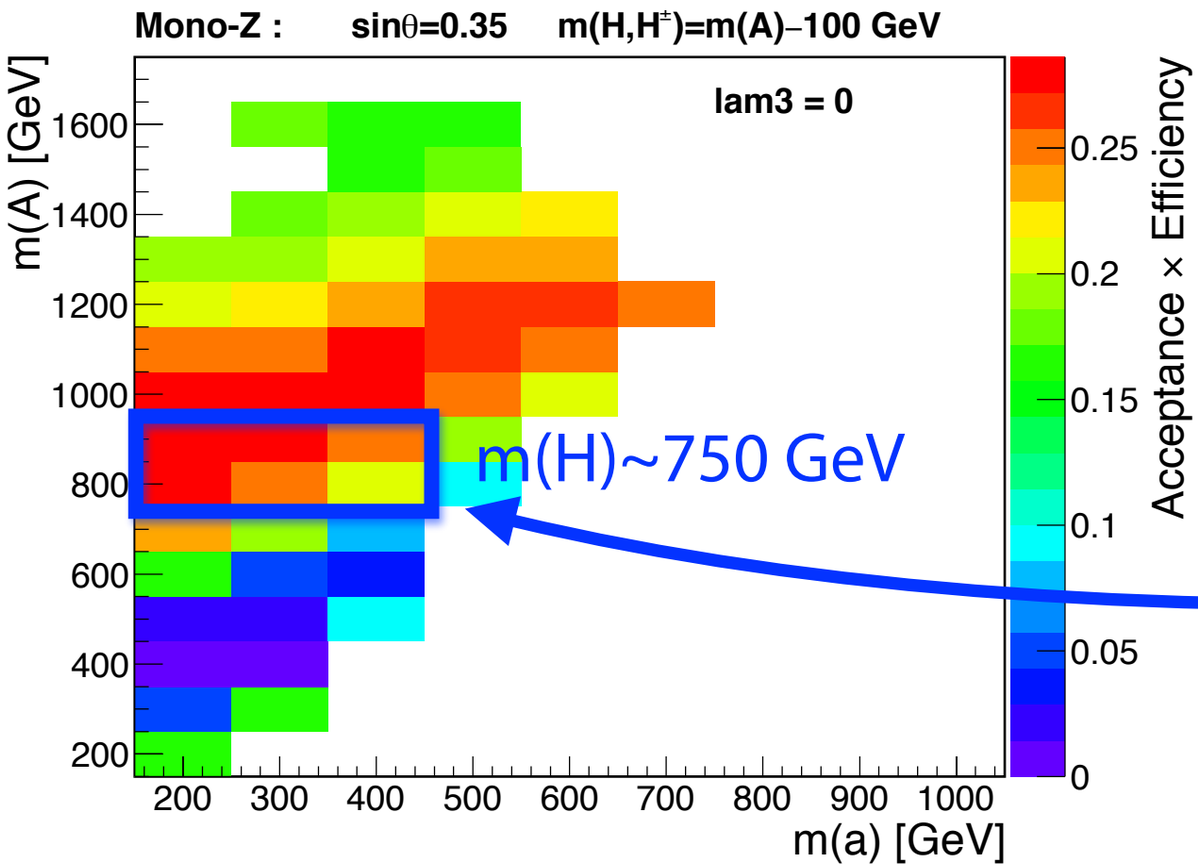


m(a) dependence changes at low tanβ

Mono-Z Acceptance

Mono-Z(qq)

- m(A) vs m(a) grid
- m(H)=m(A)−100 GeV



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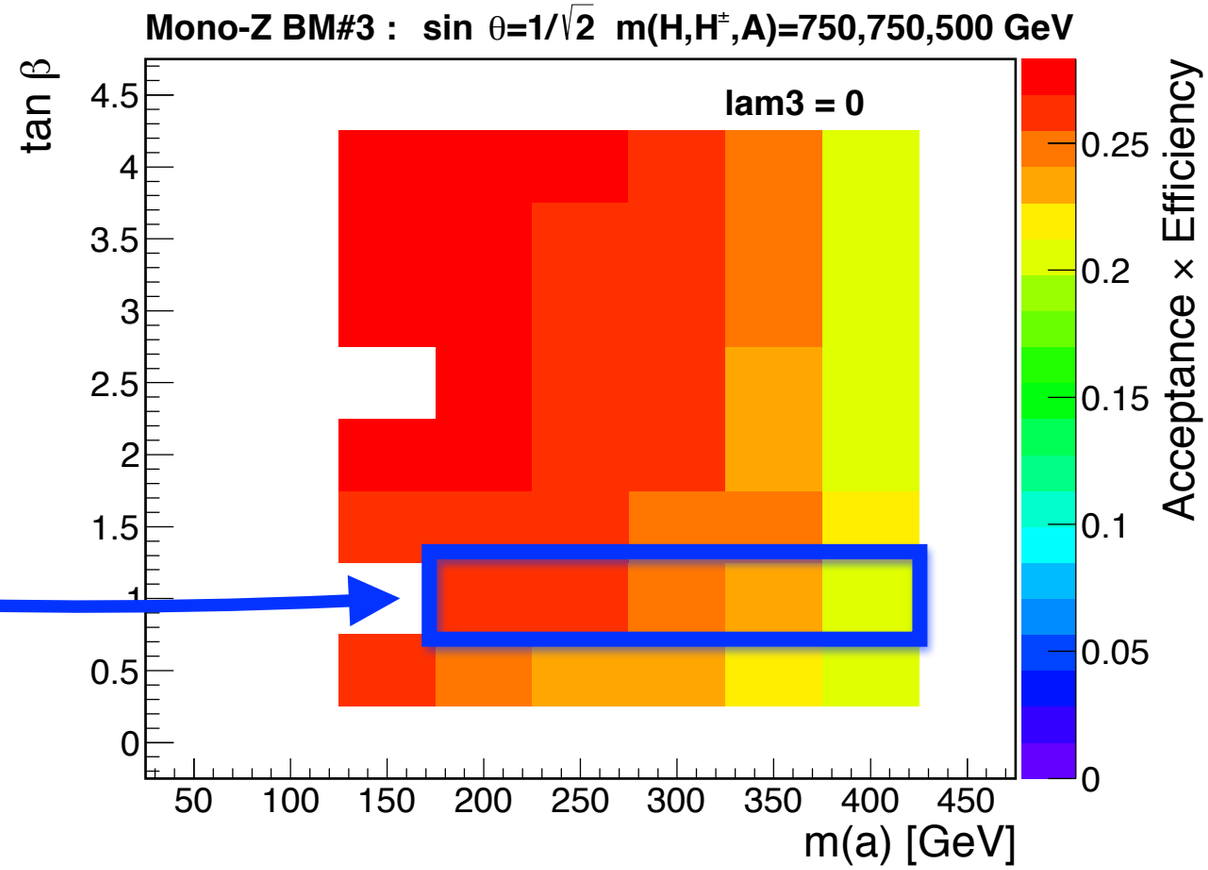
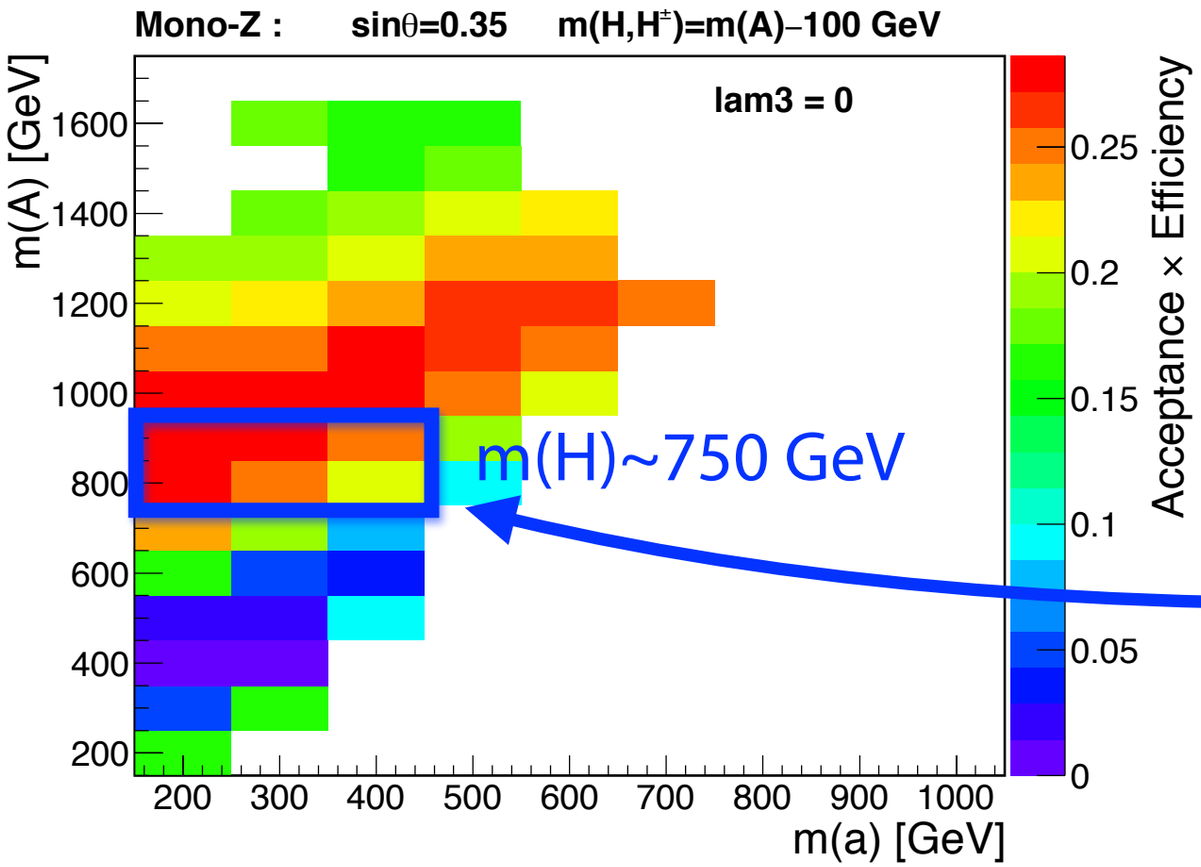


m(a) dependence changes at low tanβ

Mono-Z Acceptance

Mono-Z(qq)

- m(A) vs m(a) grid
- m(H)=m(A)−100 GeV



acceptance gets minimum(maximum)
when Δm = m(H)−m(a) ~ 0(600) GeV

Benchmark #3

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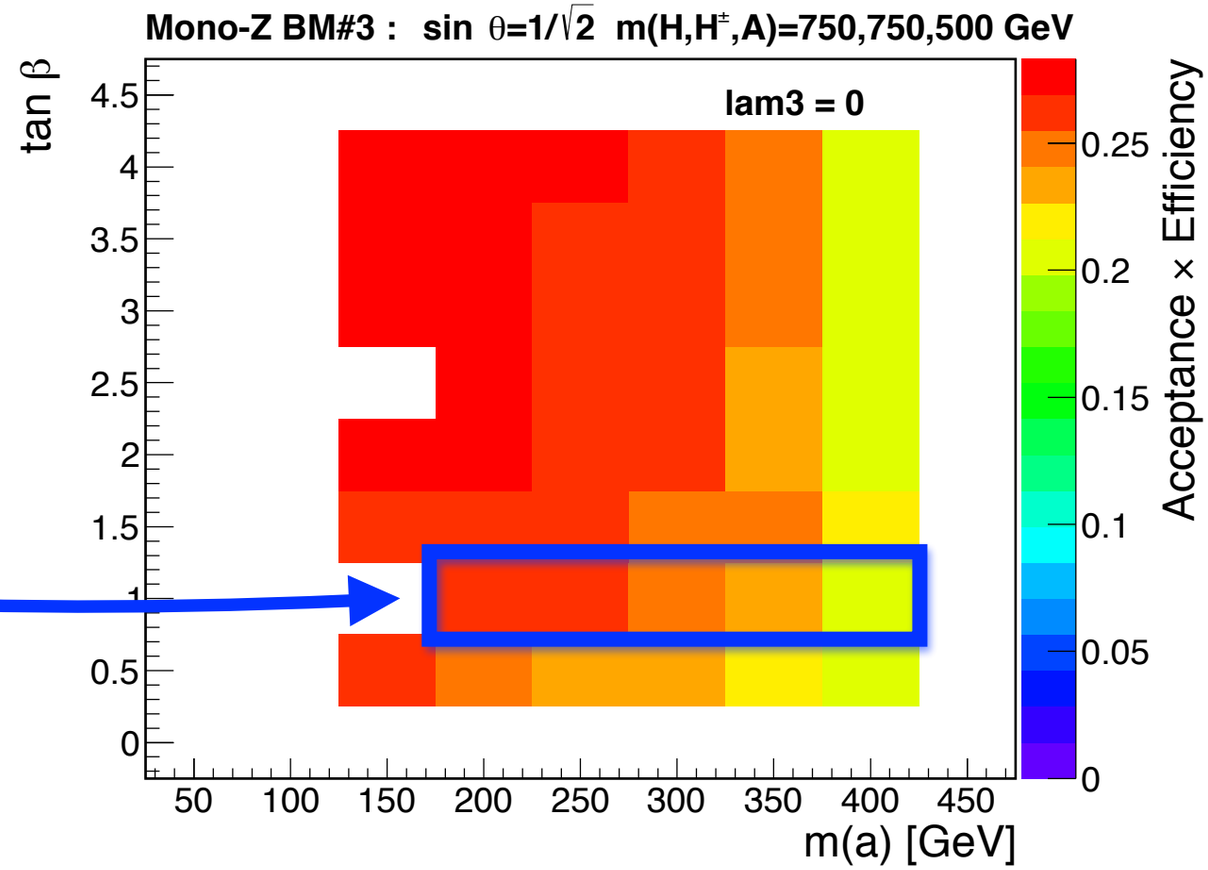


m(a) dependence changes at low tanβ

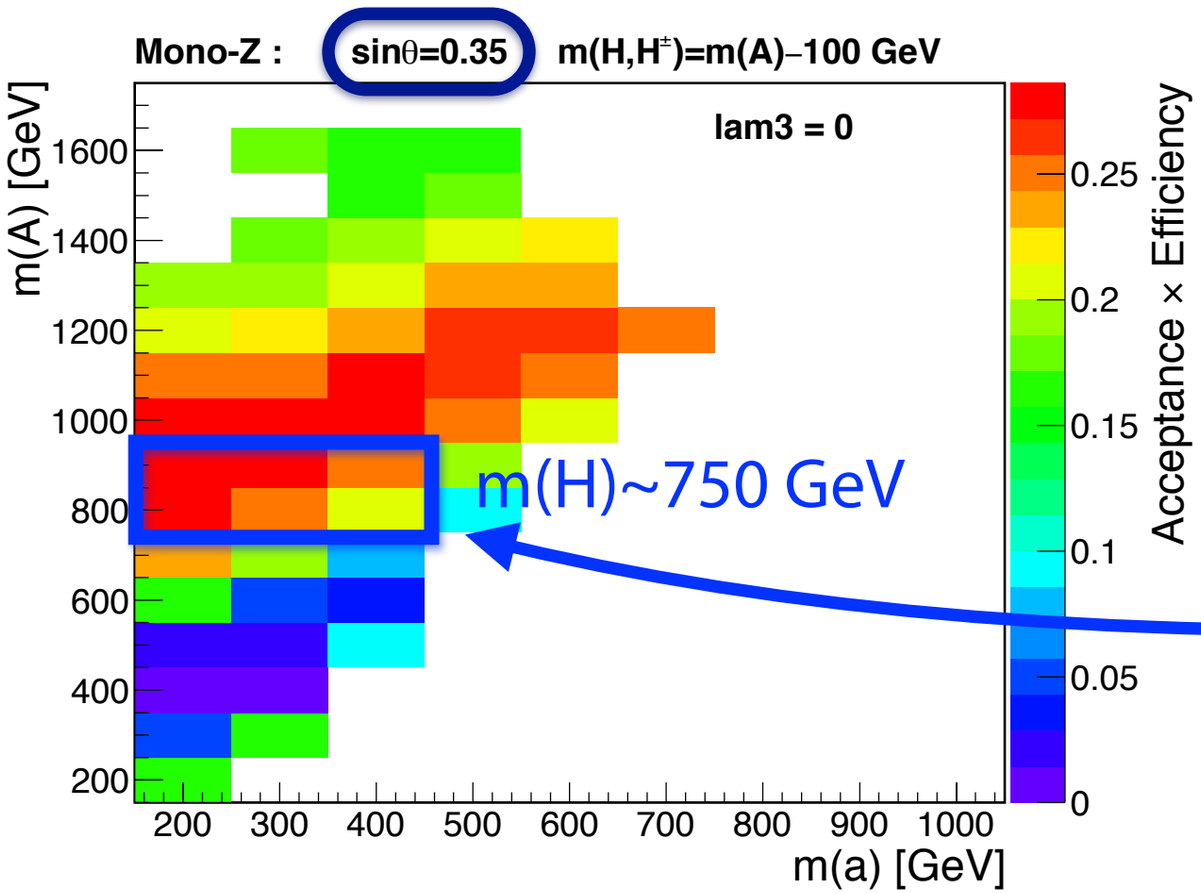
Similar acceptance when Δm=m(H)−m(a) is similar

➔ Extract limit in tanβ vs m(a) grid from acceptance in m(A) vs m(a)?

Mono-Z Acceptance

Mono-Z(qq)

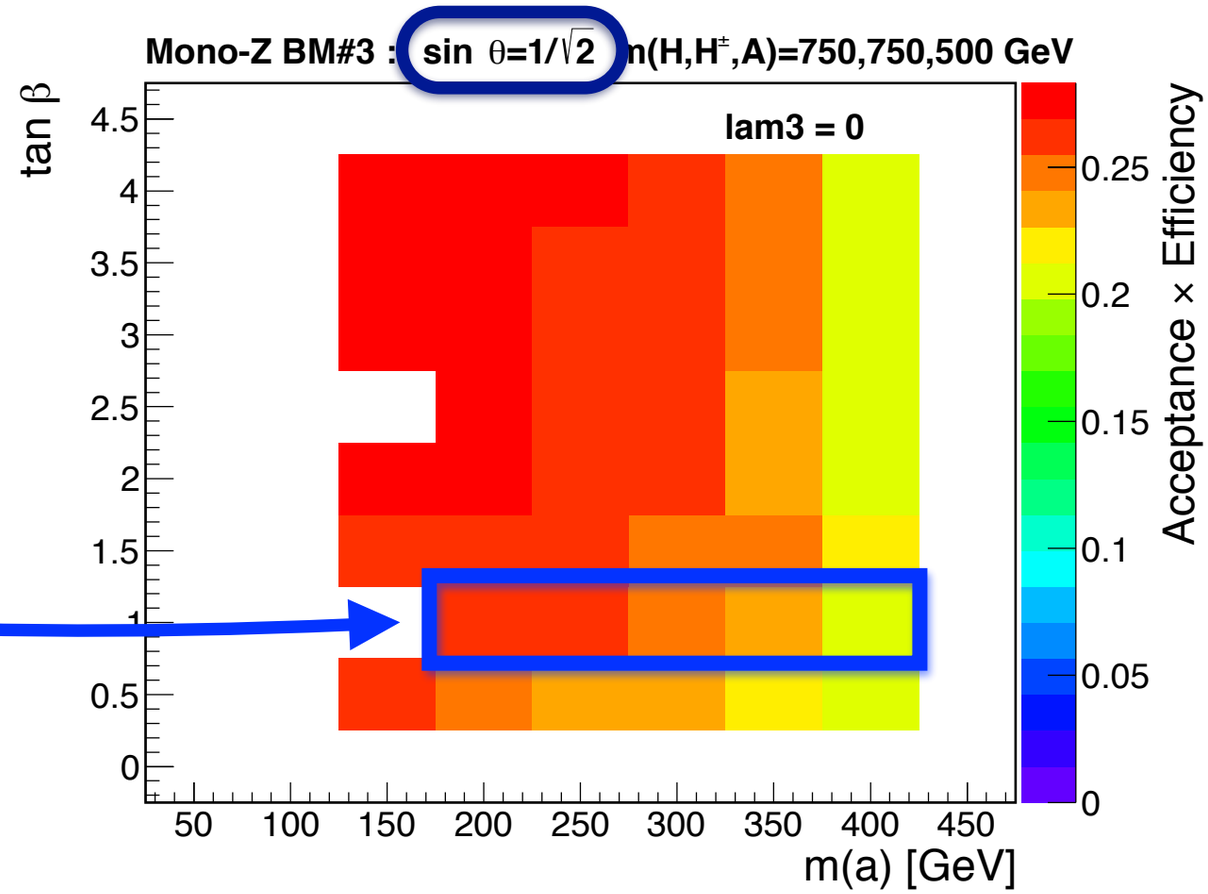
- m(A) vs m(a) grid
- m(H)=m(A)−100 GeV



acceptance gets minimum(maximum)
when Δm = m(H)−m(a) ~ 0(600) GeV

Benchmark #3

- tanβ vs m(a) grid
- m(H)=750 GeV, m(A)=500 GeV



m(a) dependence changes at low tanβ

Similar acceptance when Δm=m(H)−m(a) is similar

➔ Extract limit in tanβ vs m(a) grid from acceptance in m(A) vs m(a)?

Check on sinθ dependence in backup

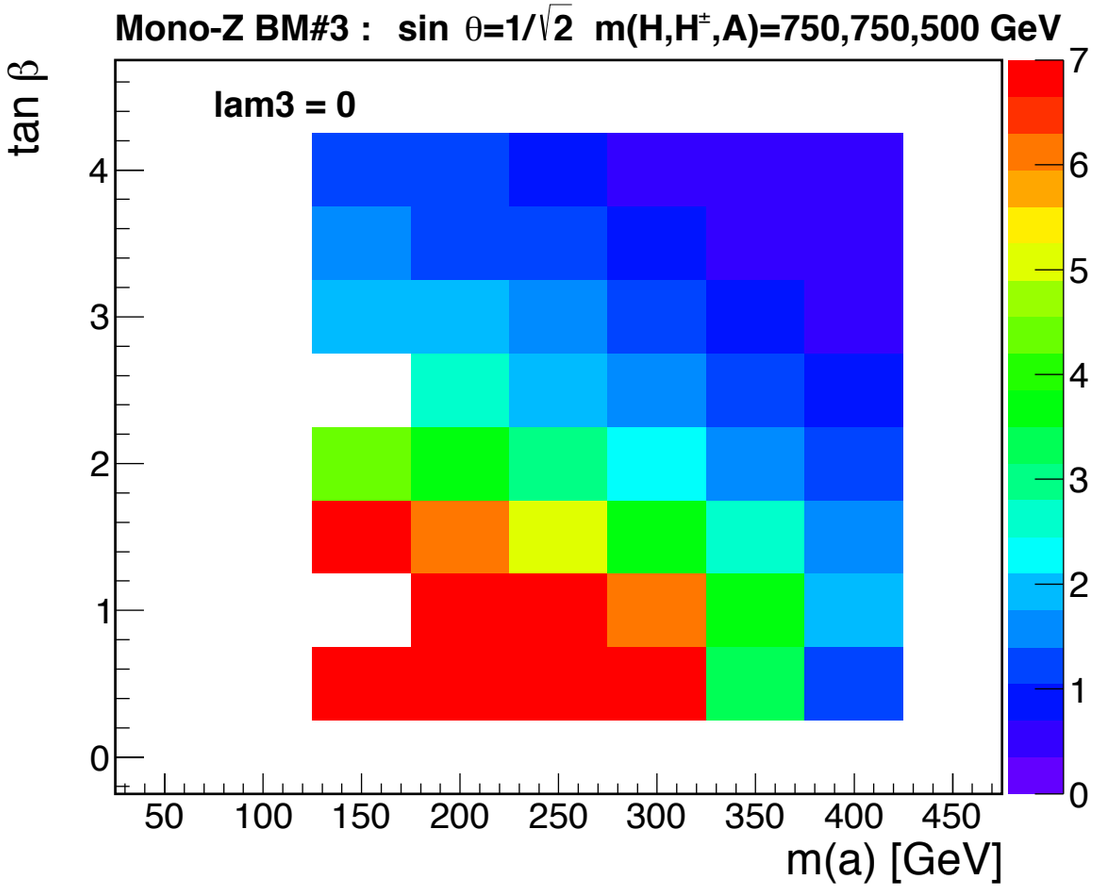
Sensitivity for Benchmark #3

Evaluate significance using acceptance in m(H) vs m(a) grid

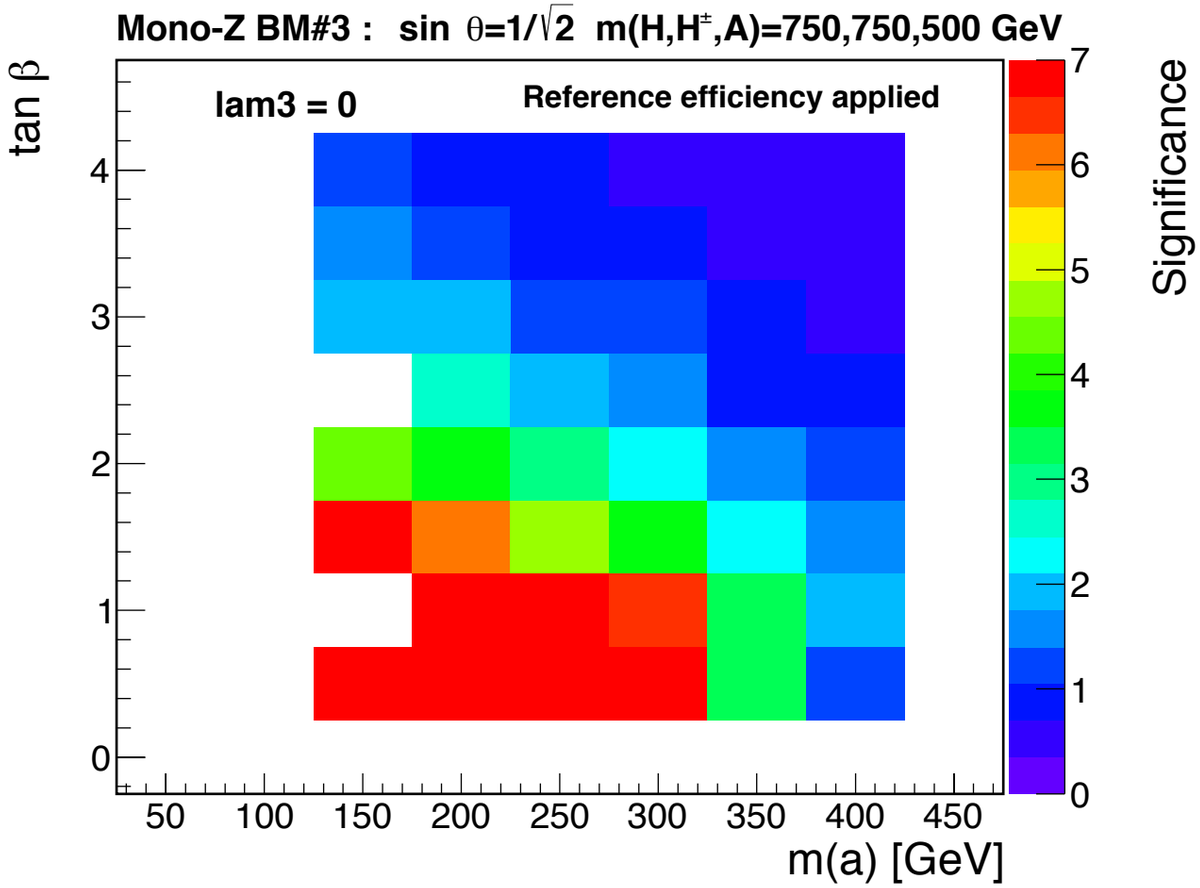
Mono-Z(qq)

- Benchmark #3
- m(H)=750 GeV, m(A)=500 GeV

Significance calculated directly



Significance calculated* using acceptance in m(A) vs m(a) grid



* No tanβ dependence considered

Sensitivity for Benchmark #3

Evaluate significance using acceptance in m(H) vs m(a) grid

Mono-Z(qq)

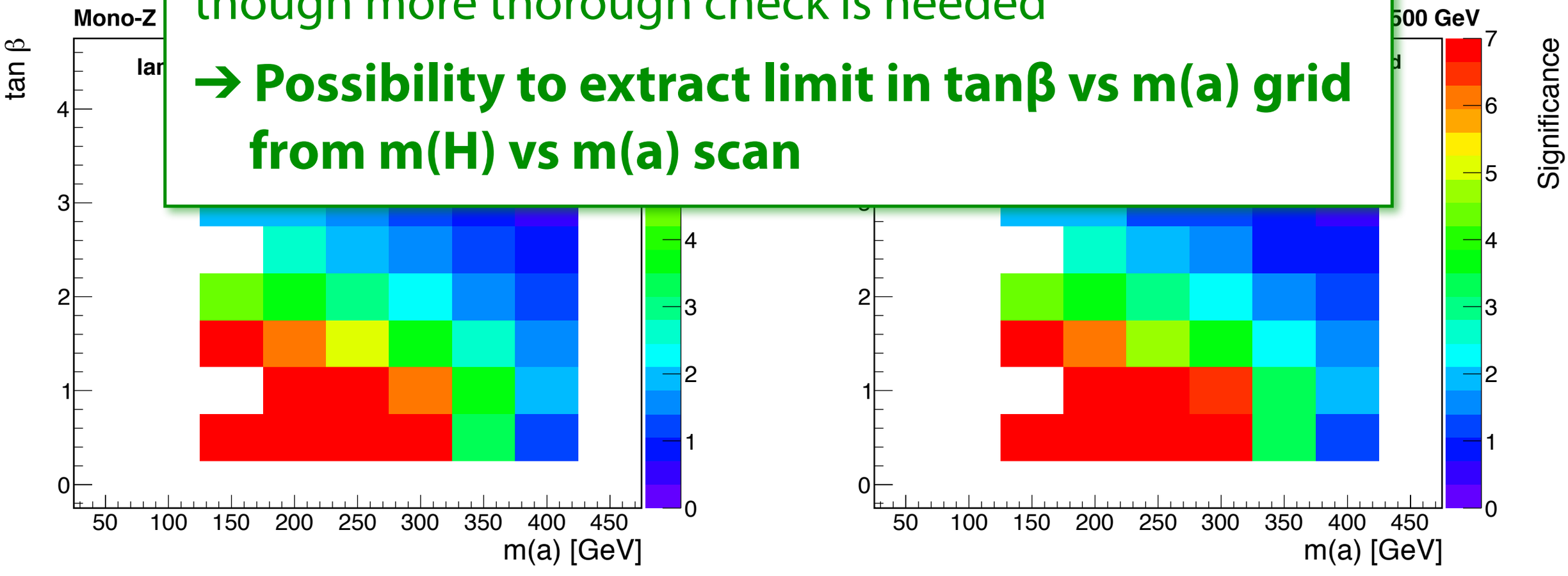
- Benchmark #3
- m(H)=750 GeV, m(A)=500 GeV

Significance calculated directly

Significance calculated* using grid

Consistent results obtained from the two approaches, though more thorough check is needed

➔ Possibility to extract limit in tanβ vs m(a) grid from m(H) vs m(a) scan

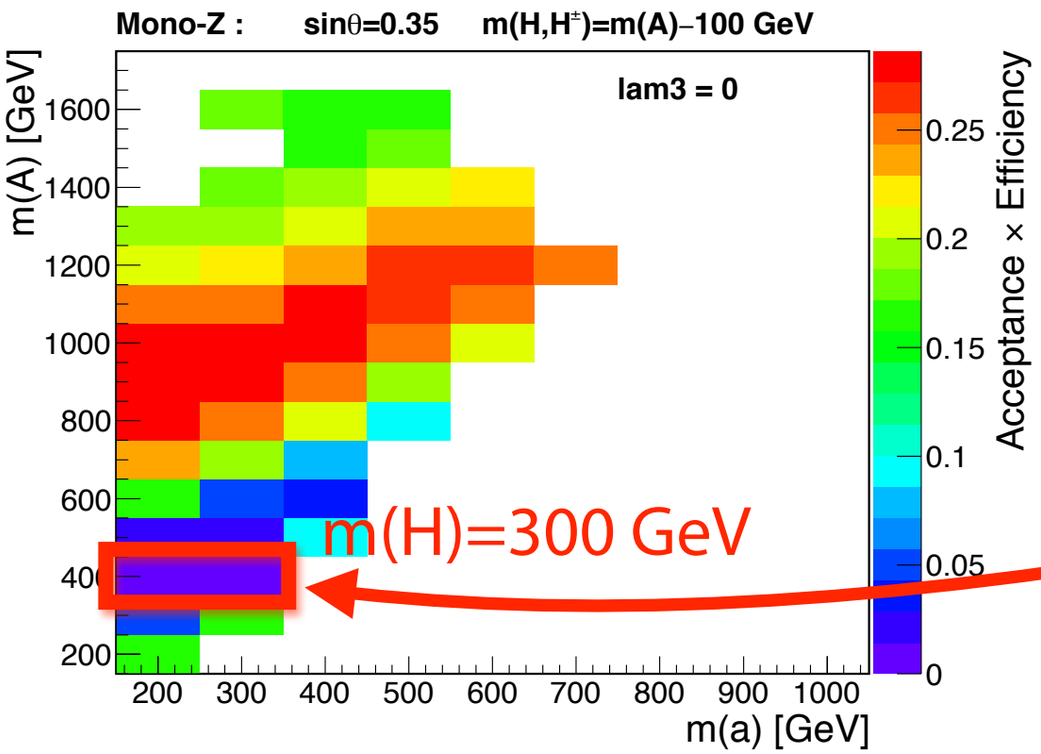


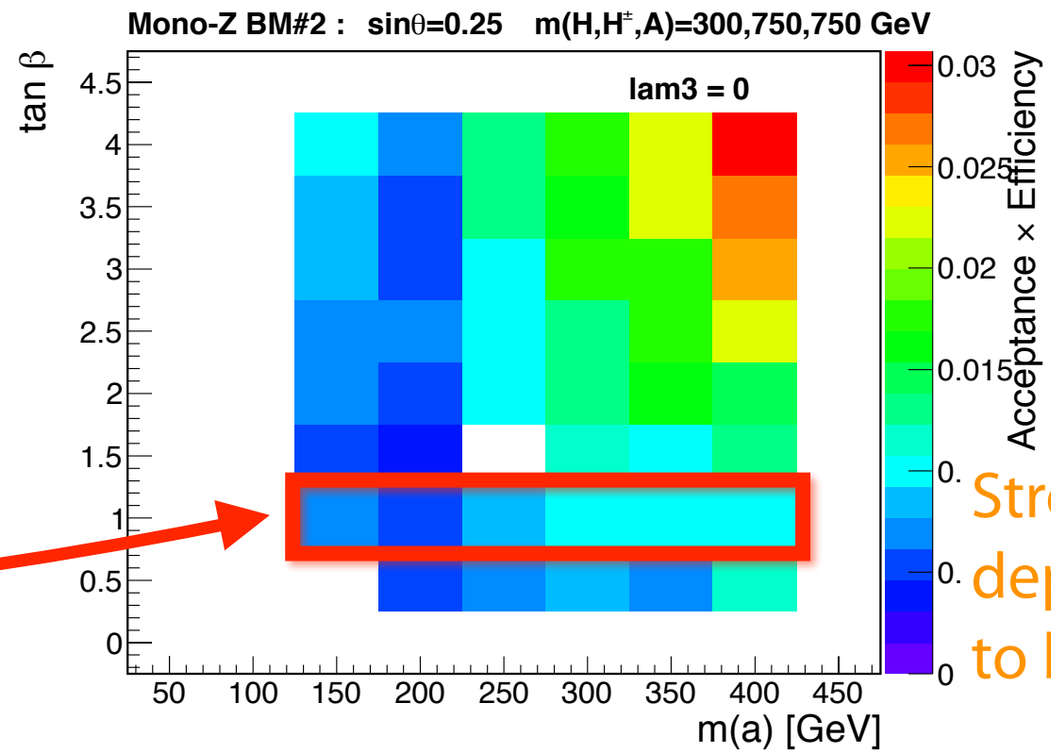
* No tanβ dependence considered

Sensitivity for Benchmark #2

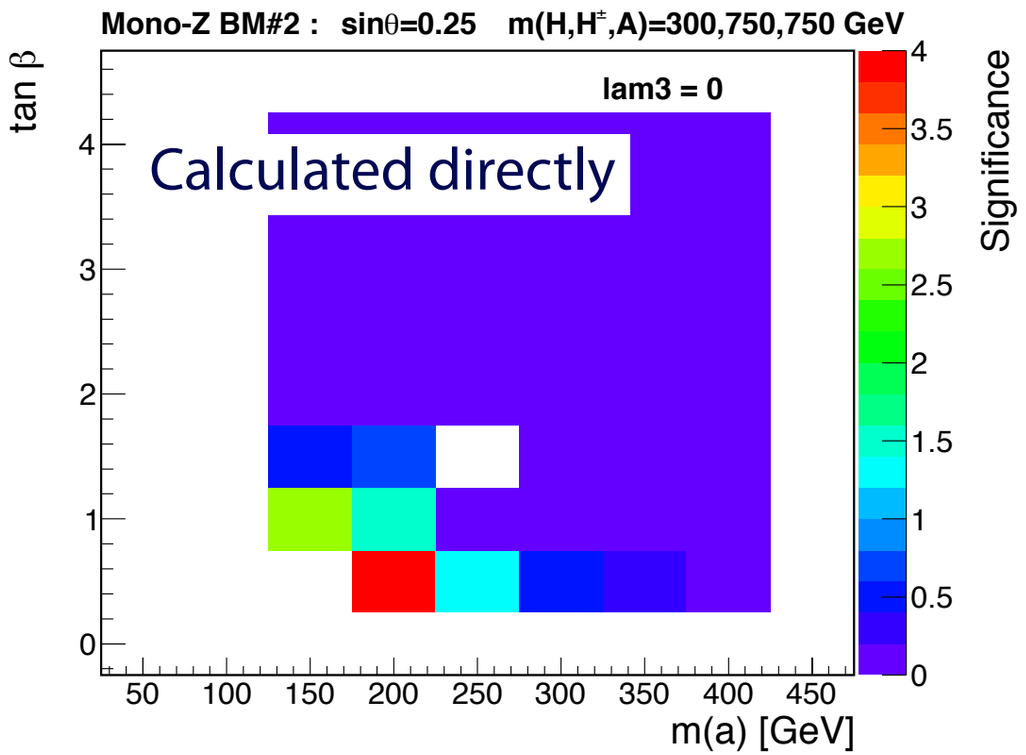
Evaluate significance using acceptance in m(H) vs m(a) grid

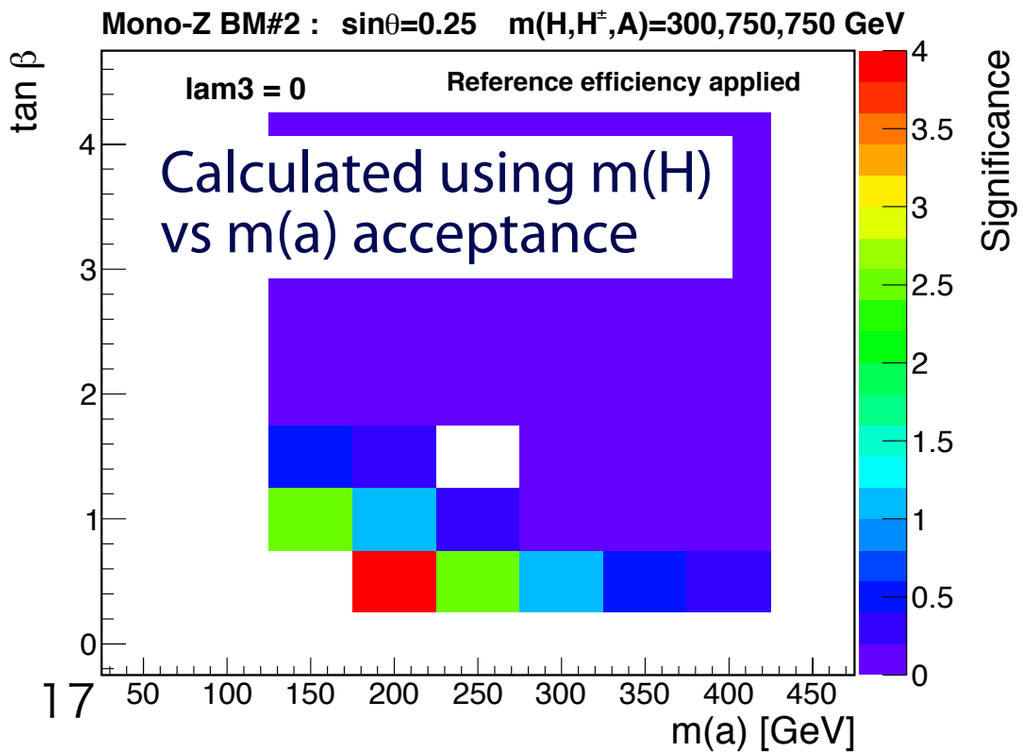
Mono-Z(qq)





Strong tanβ dependence to be checked





Mono-Z Acceptance

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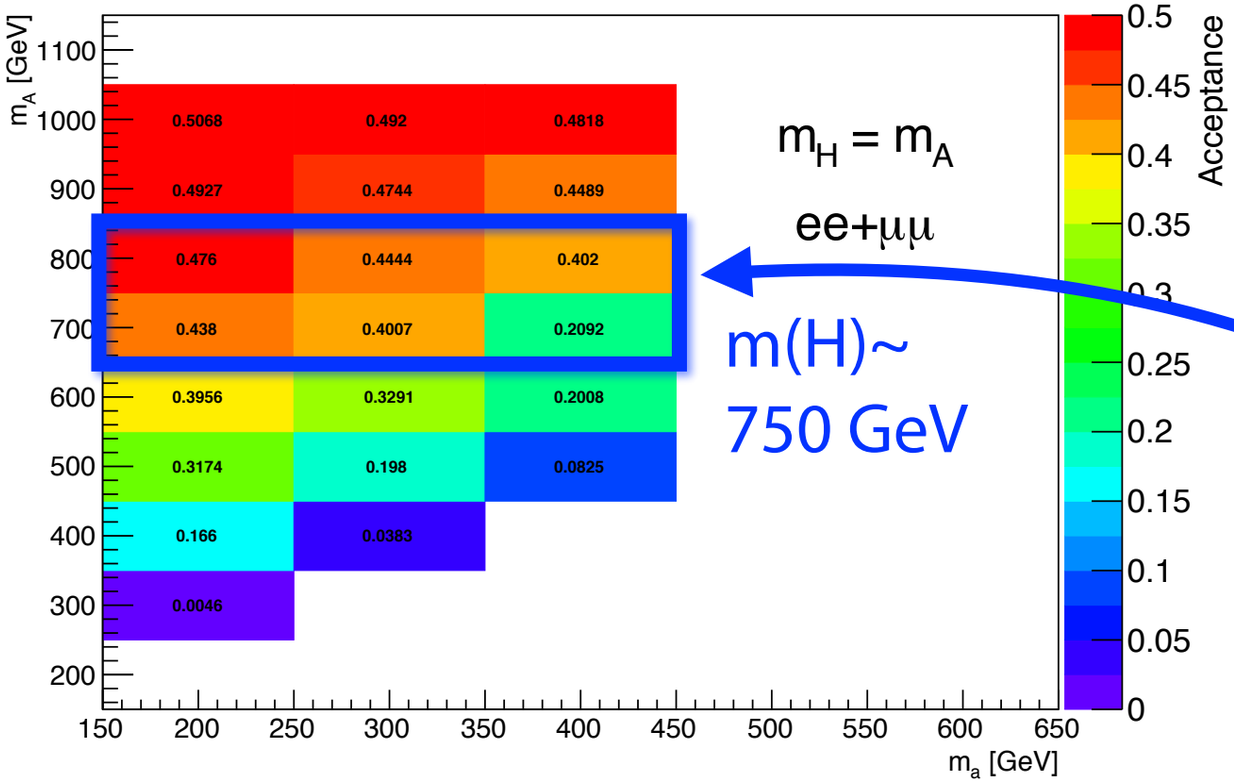
Mono-Z(ll)

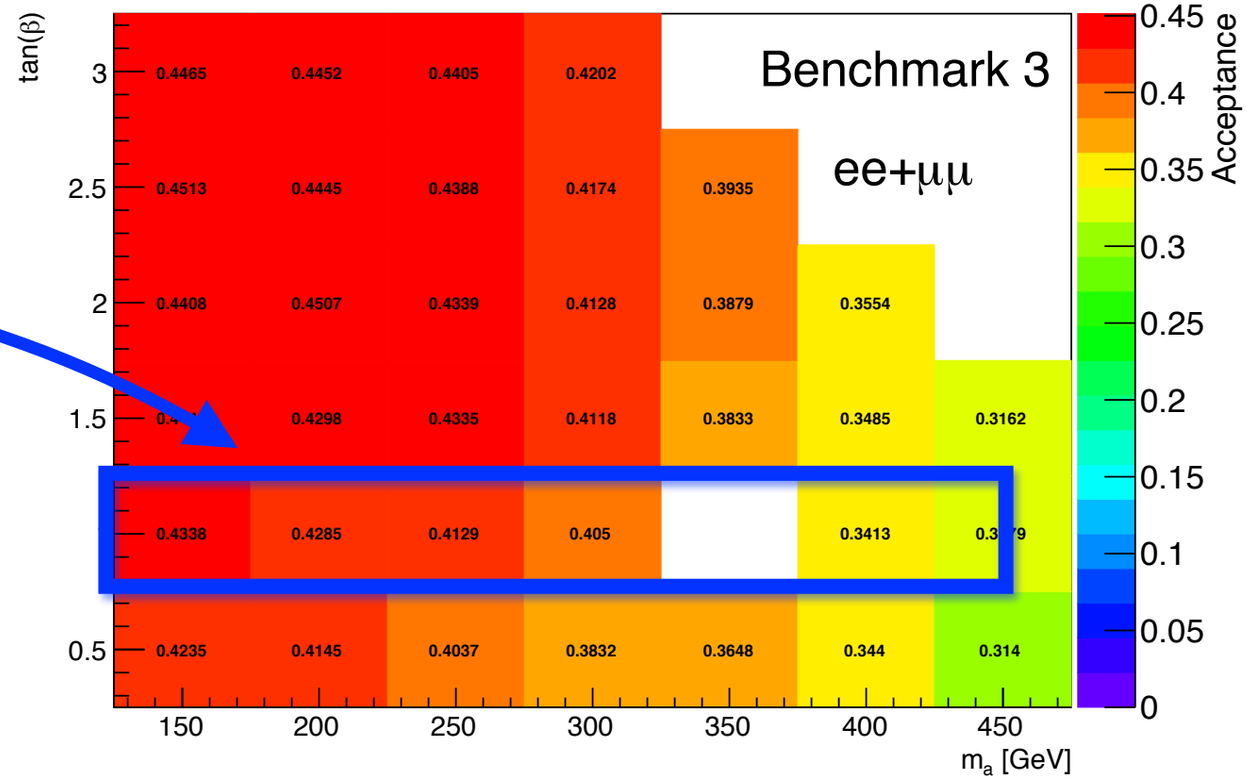
- m(A) vs m(a) grid
- m(H)=m(A)



acceptance gets minimum(maximum)
when Δm = m(H)−m(a) ~ 0(700) GeV

Benchmark #3

- tanβ vs m(a) grid
- m(H)=750 GeV, m(A)=500 GeV



m(a) dependence changes at low tanβ

Z→ll acceptance also mainly determined by Δm = m(H)−m(a)

Indicates that the same approach could work for Z→ll

E_T^{miss} vs Δm checked in backup

Summary

- Performed sensitivity scan for mono-Z in tanβ vs m(a) grid
- Compared mono-Z sensitivity with mono-H(bb) in m(A) vs m(a) grid
  ➔ Observed good complementarity
- Kinematic properties of mono-Z signal characterized by Δm = m(H)–m(a)
  ➔ Acceptance largely determined by Δm, not m(H)–m(A)

For grid scan :

- m(H) vs m(a) grid can cover wide range of kinematic properties
- Acceptance for a given m(H) in m(H) vs m(a) grid could be used to set limit in tanβ vs m(a) grid (*in the region where there is no strong tanβ or sinθ dependence*) if fiducial limit is provided
  ➔ under investigation
- If this works, it could be sufficient to have limit in two grids:
  - m(H) vs m(a) with m(H) = m(A)?
  - tanβ vs m(a) for benchmark #3

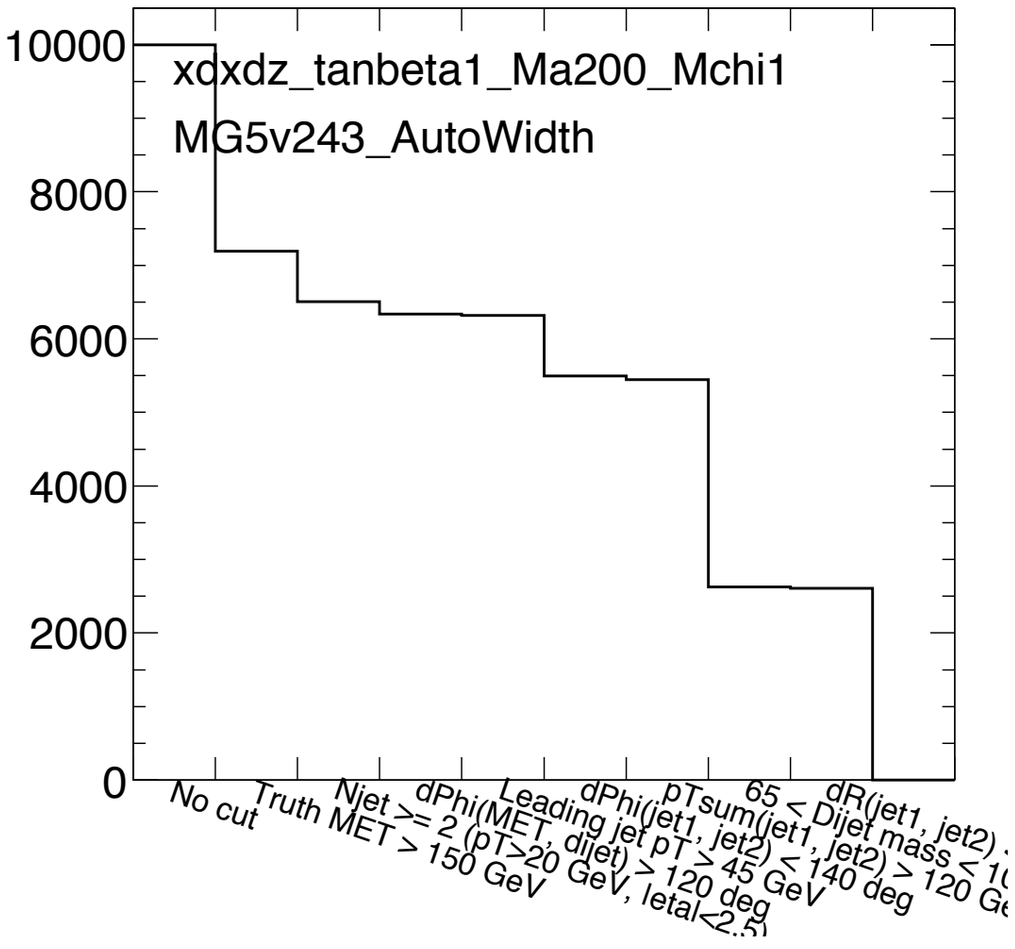
  to get constraint on other scenarios

Backup

Benchmark #3

Selections motivated by PLB 763 (2016) 251

- Truth monoZ cut 26% efficiency

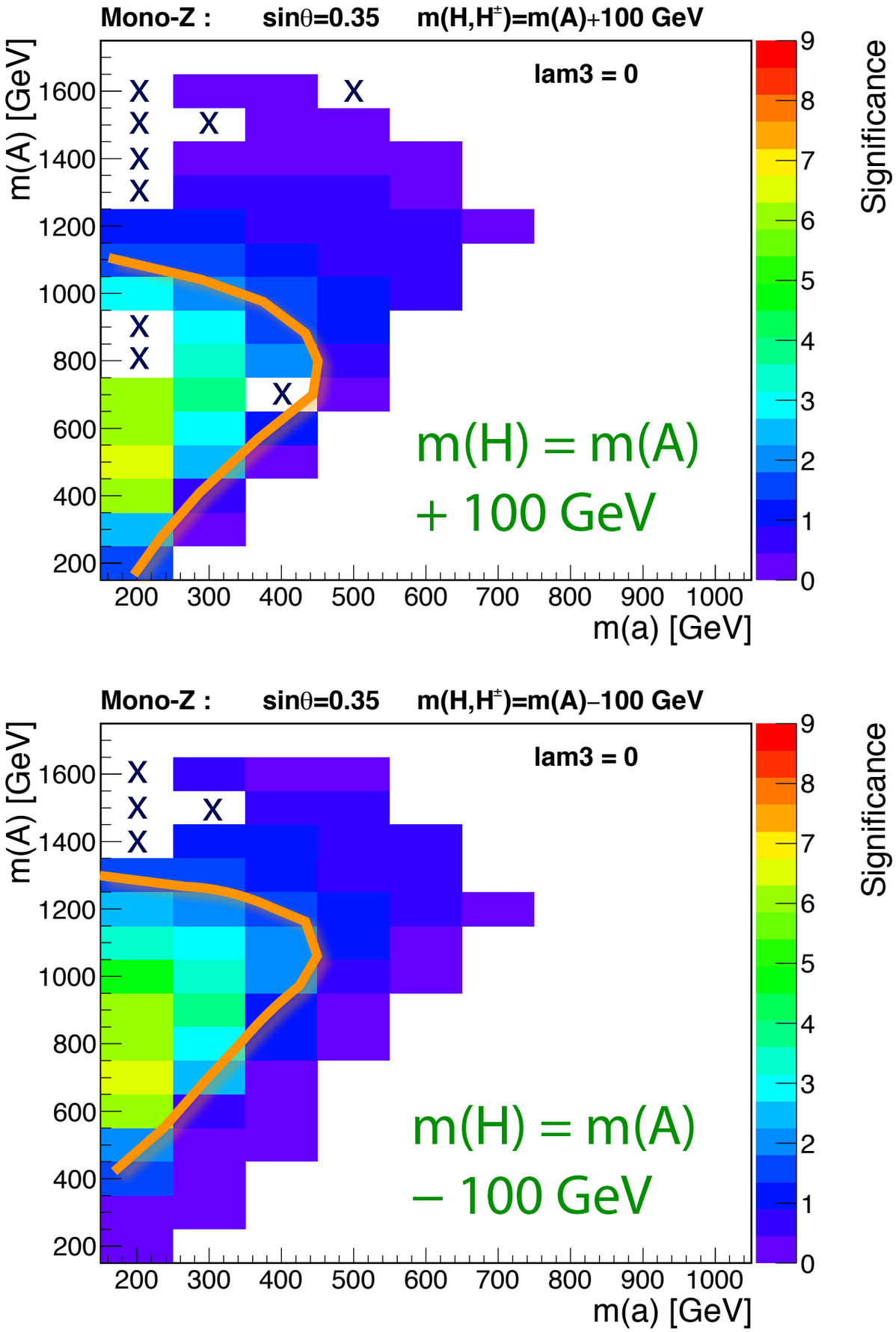


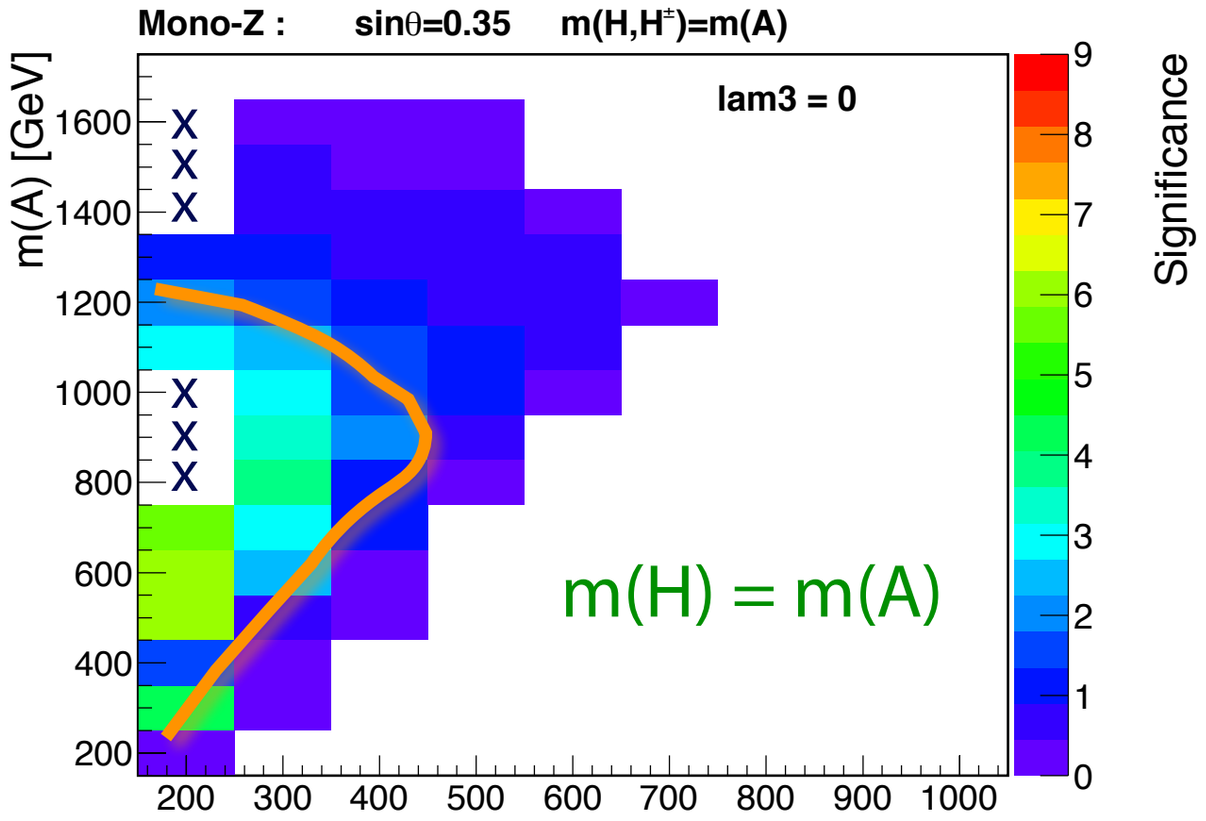
Resolved selections for Mono-Z

- Truth MET > 150 GeV
- Njet ≥ 2 (pT > 20 GeV, eta < 2.5)
- dPhi(MET, dijet) > 120 deg
- Leading jet pT > 45 GeV
- dPhi(jet1, jet2) < 140 deg
- pTsum(jet1, jet2) > 120 GeV (Njet $= 2$) or pTsum(jet1, jet2, jet3) > 150 GeV (Njet ≥ 3)
- $65 <$ Dijet mass < 105 GeV
- dR(jet1, jet2) < 1.4

➔ Truth mono-Z cut efficiency ~ 26%

Mono-Z sensitivity at 36 fb^{-1}

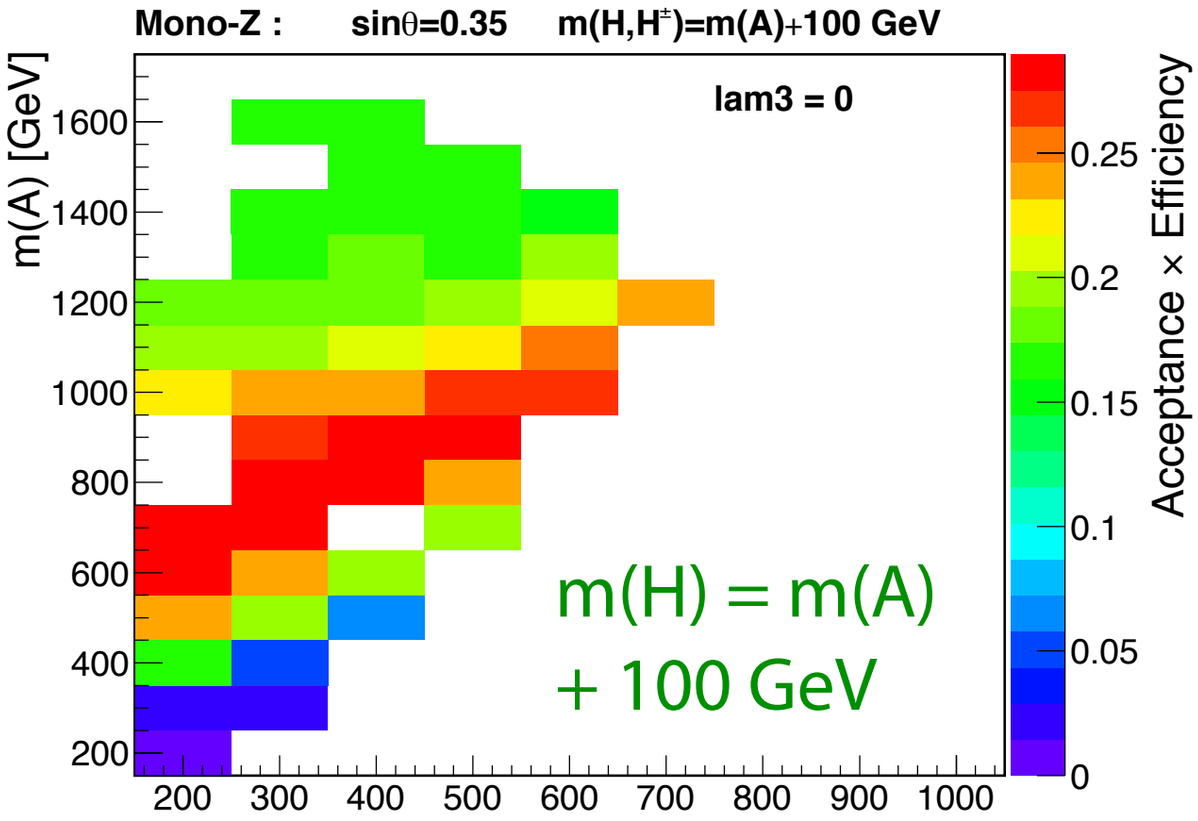


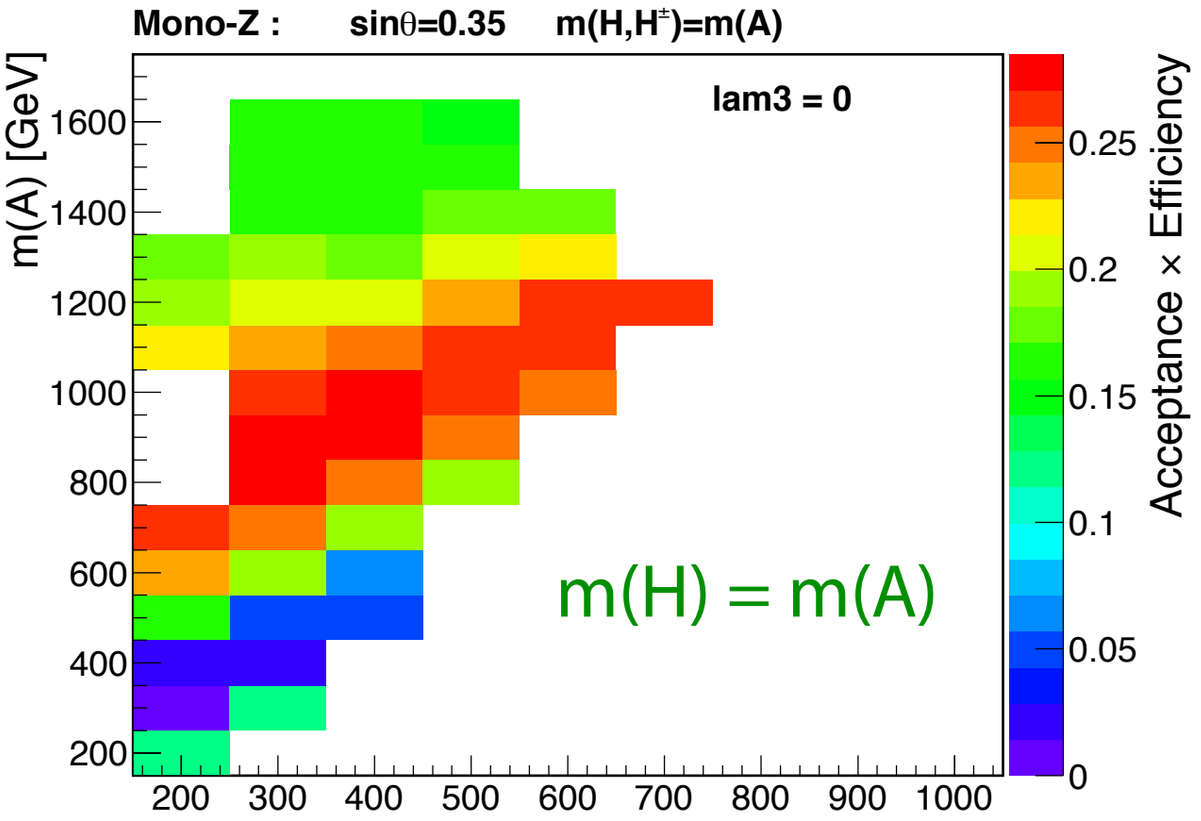


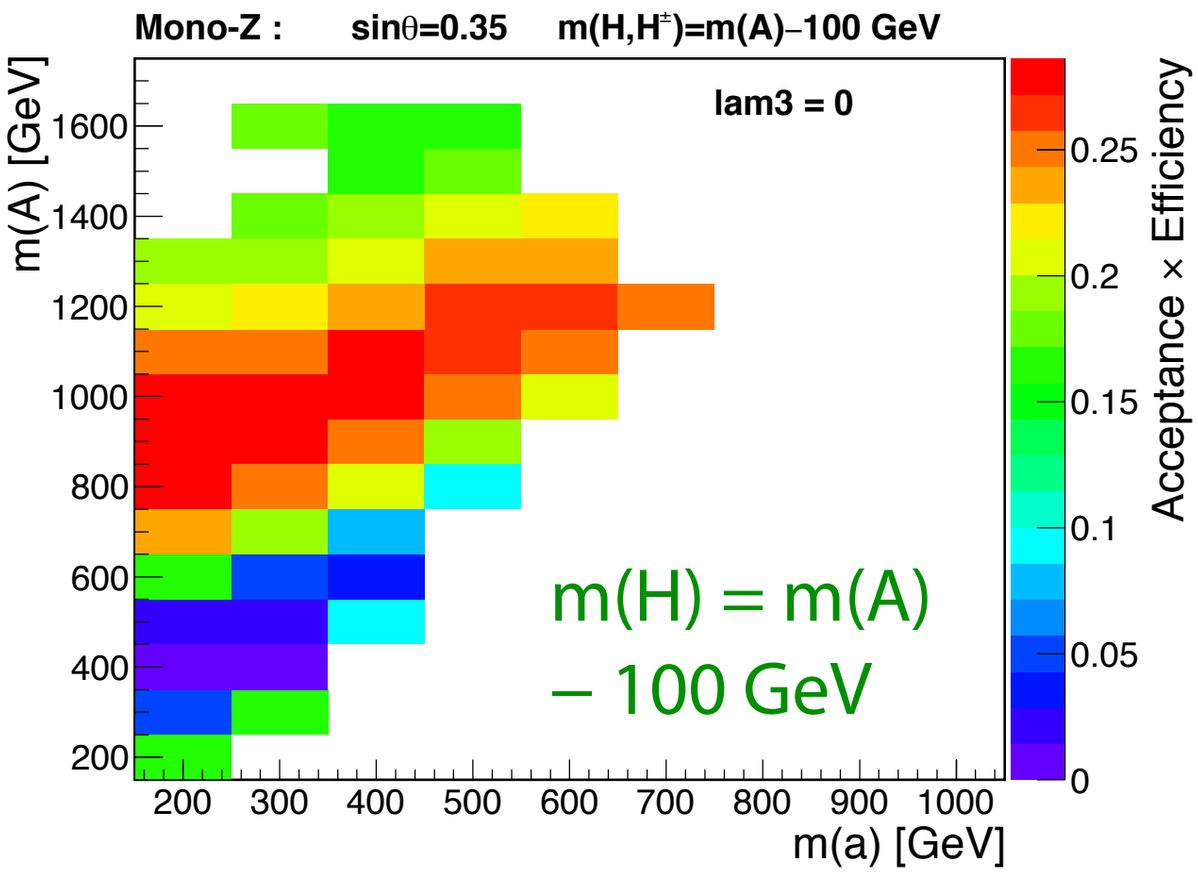
m(H)–m(A) Dependence

- Sensitive region for mono-Z is mostly determined by m(H)
- Shifted along m(A) when changing m(H) relative to m(A)

Mono-Z Acceptance







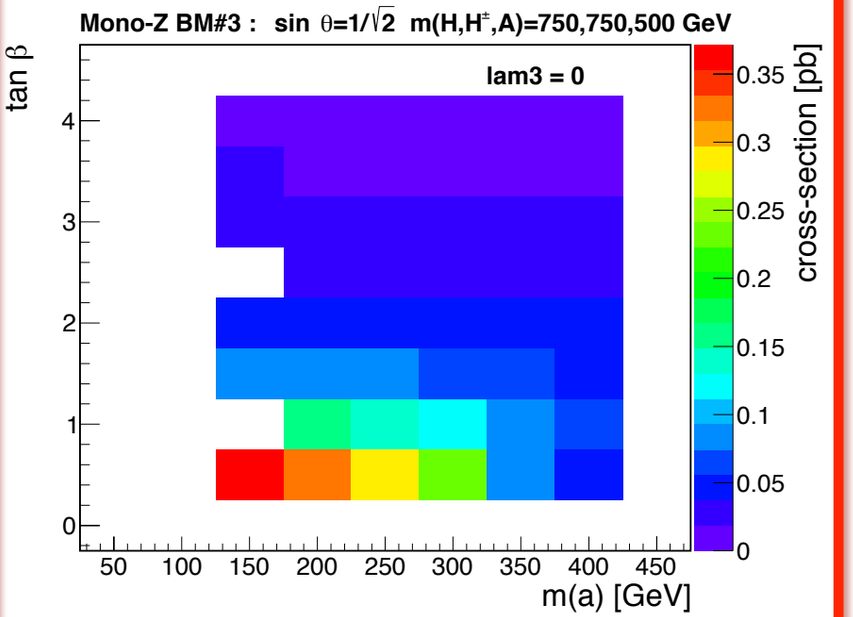
m(H)−m(A) Dependence

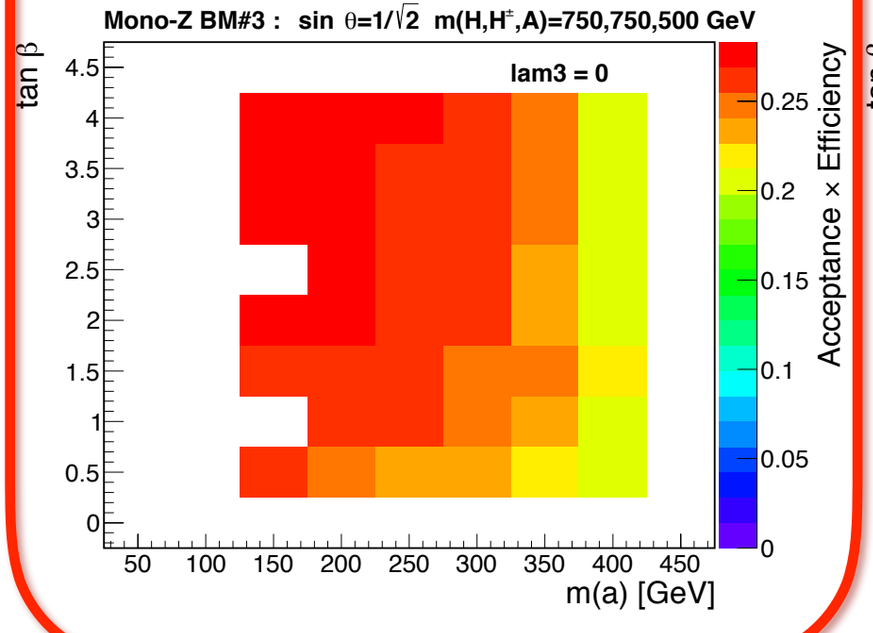
- Acceptance is mostly determined by Δm=m(H)−m(a)
- Less sensitive to m(H)−m(A)
  → Vacuum stability issue becomes less relevant

lam3 Parameter Check

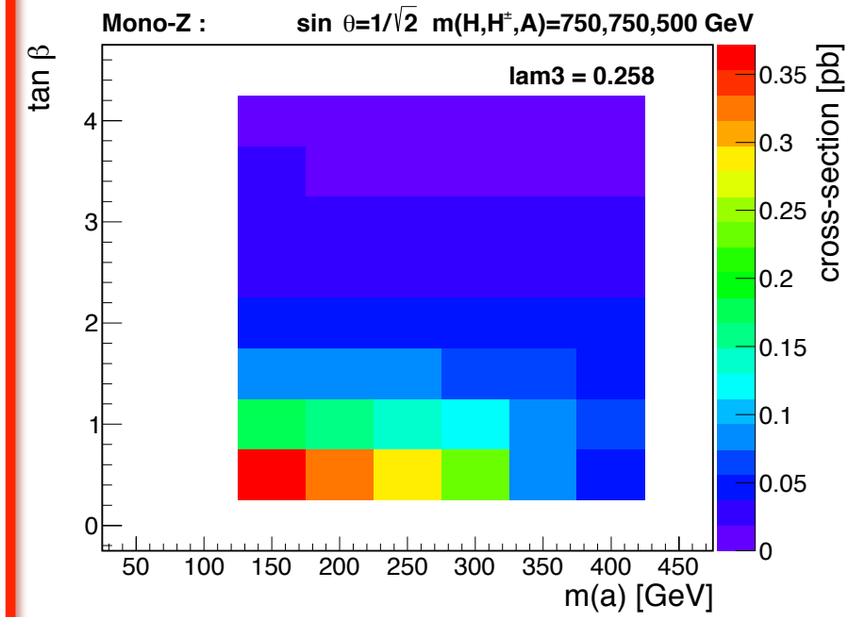
m(H) fixed to 750 GeV

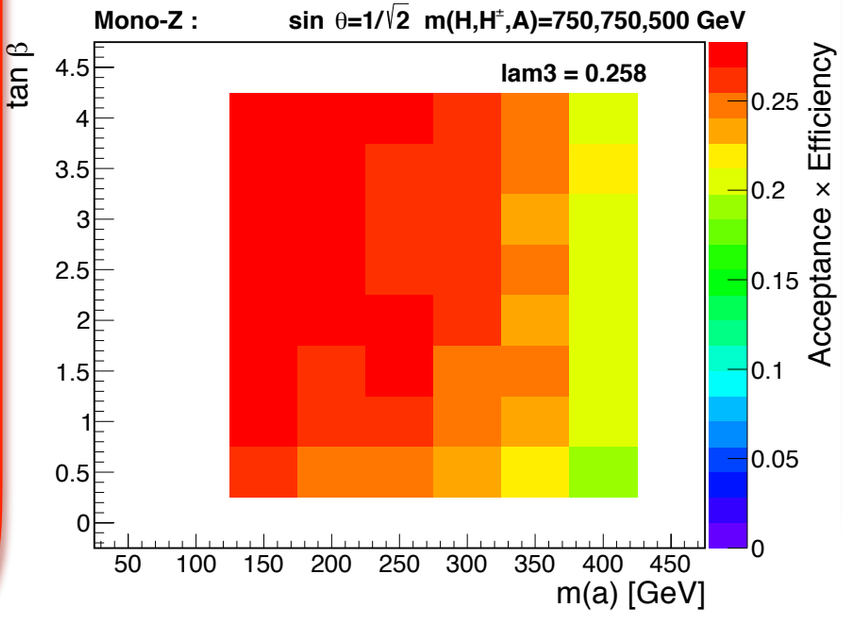
lam3=0
m(A)=500GeV



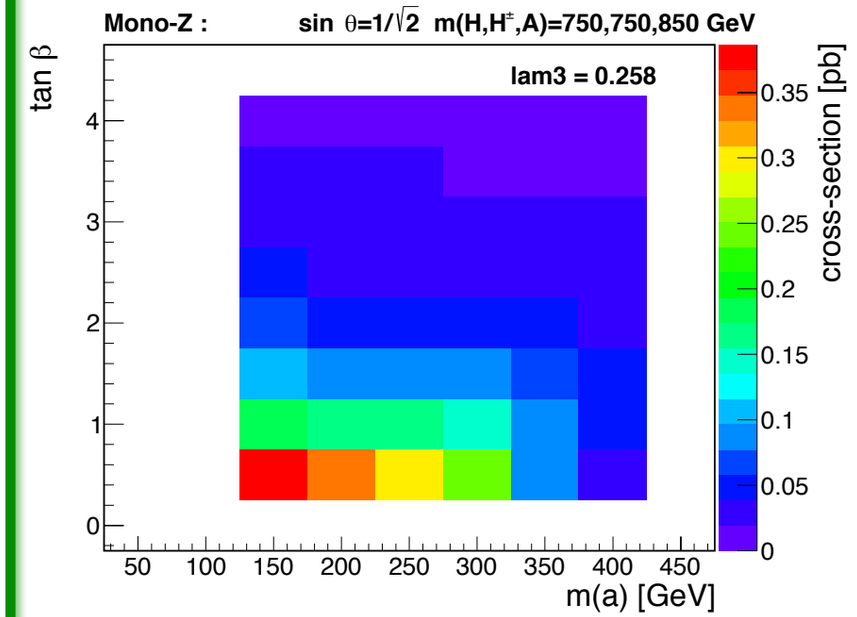


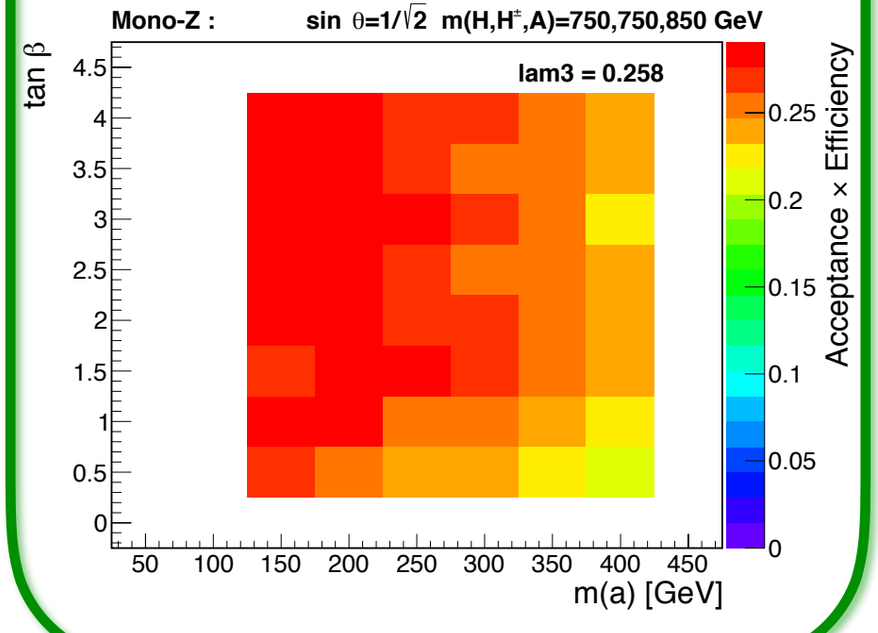
lam3=0.258
m(A)=500GeV





lam3=0.258
m(A)=850GeV





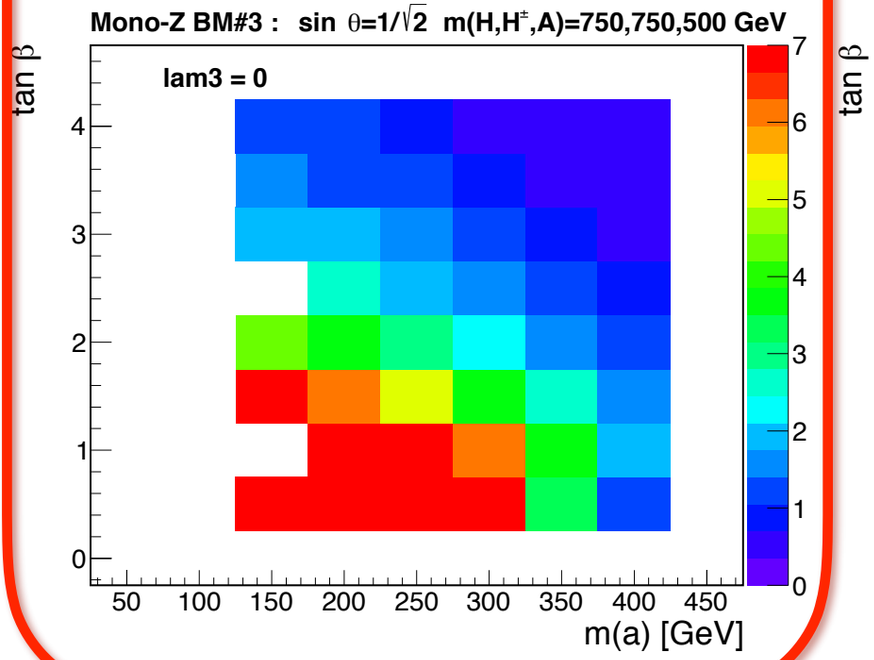
➔ Benchmark #3 in paper

➔ Recommended setting

lam3 Parameter Check

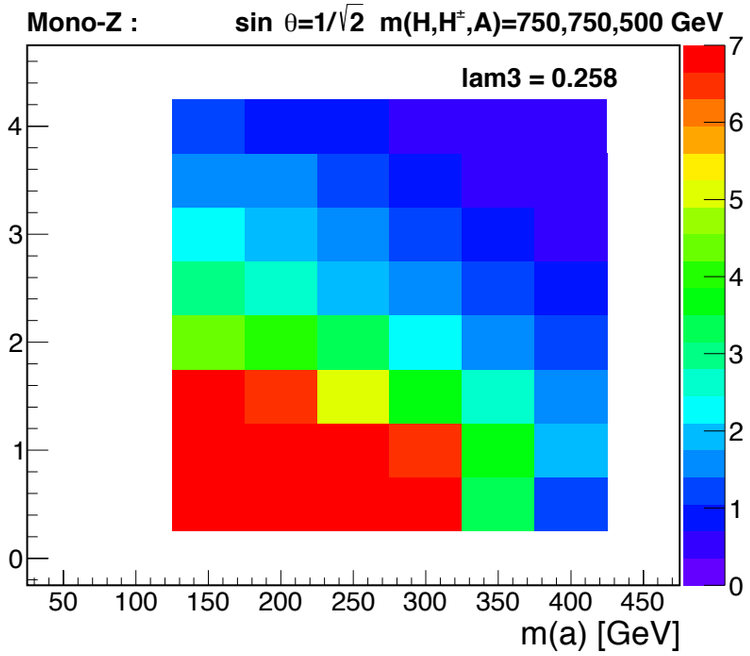
m(H) fixed to 750 GeV

lam3=0
m(A)=500GeV

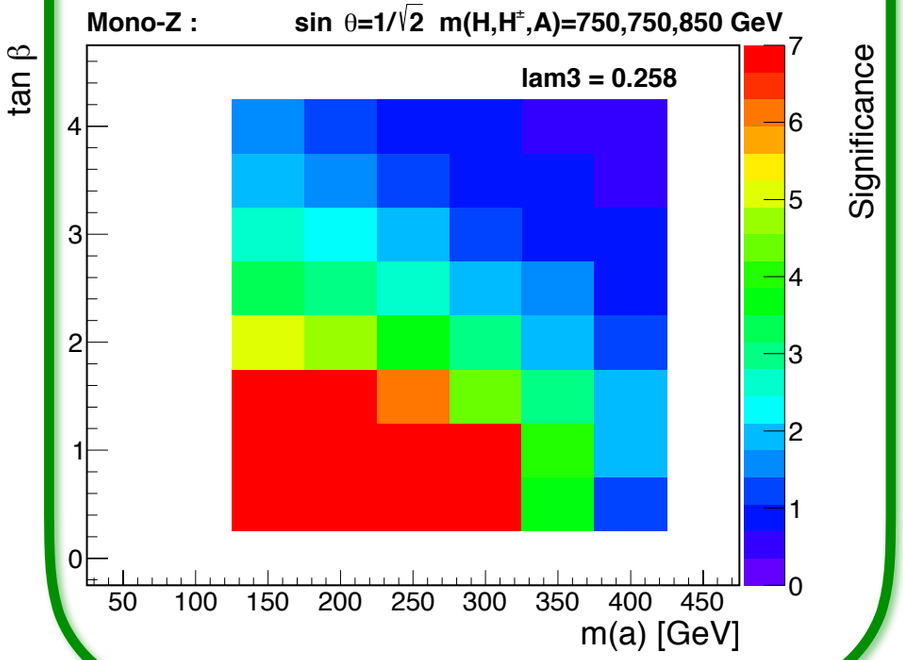


→ Benchmark #3 in paper

lam3=0.258
m(A)=500GeV



lam3=0.258
m(A)=850GeV



→ Recommended setting

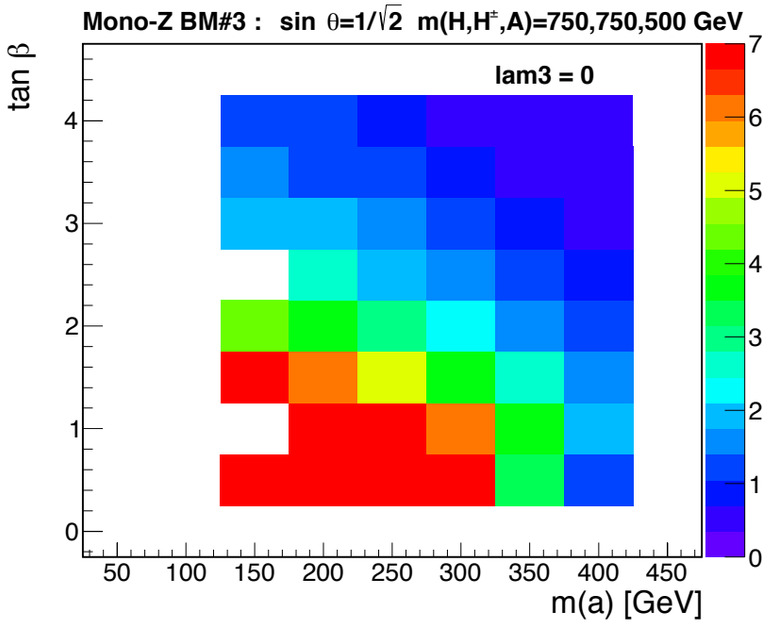
Slightly increased sensitivity with increased cross sections for recommended setting

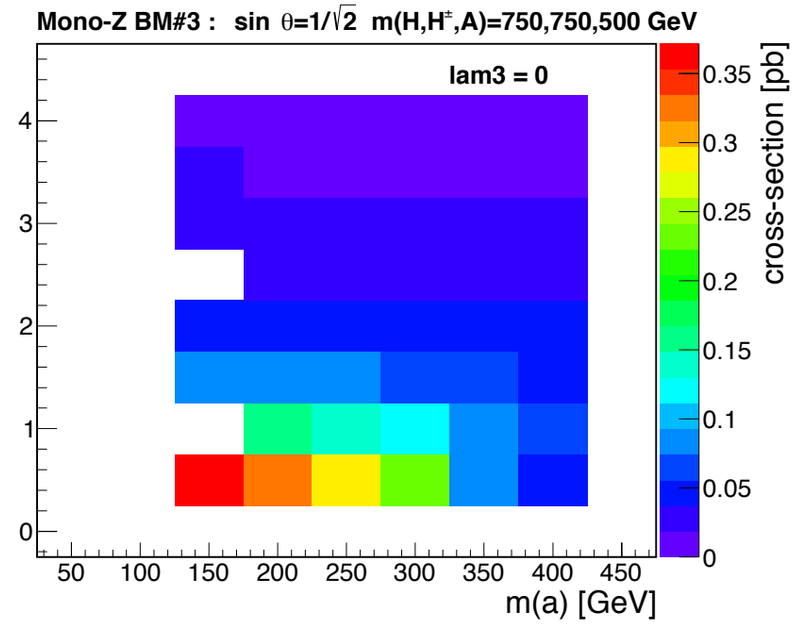
Mixing Angle Dependence

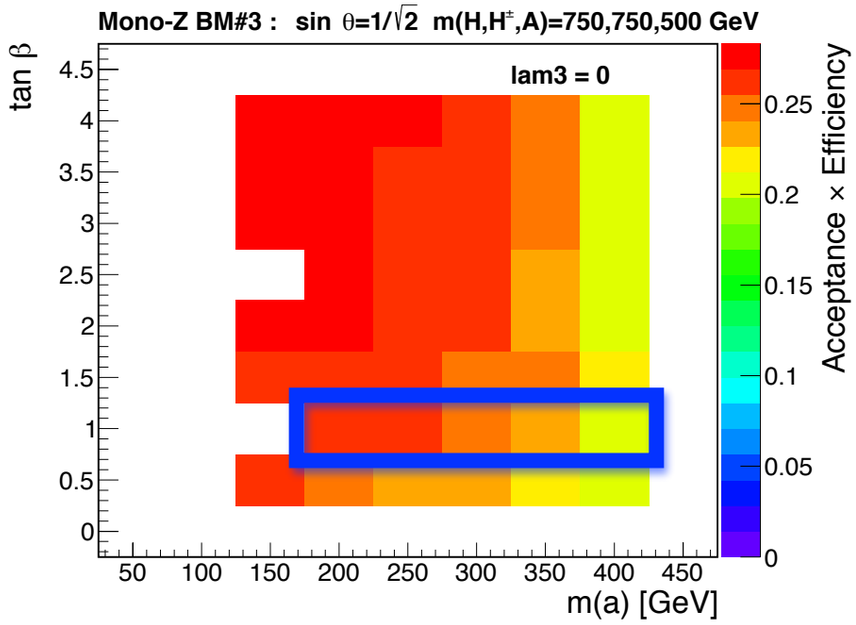
Benchmark #3

- tanβ vs m(a) grid
- m(H)=750 GeV, m(A)=500 GeV

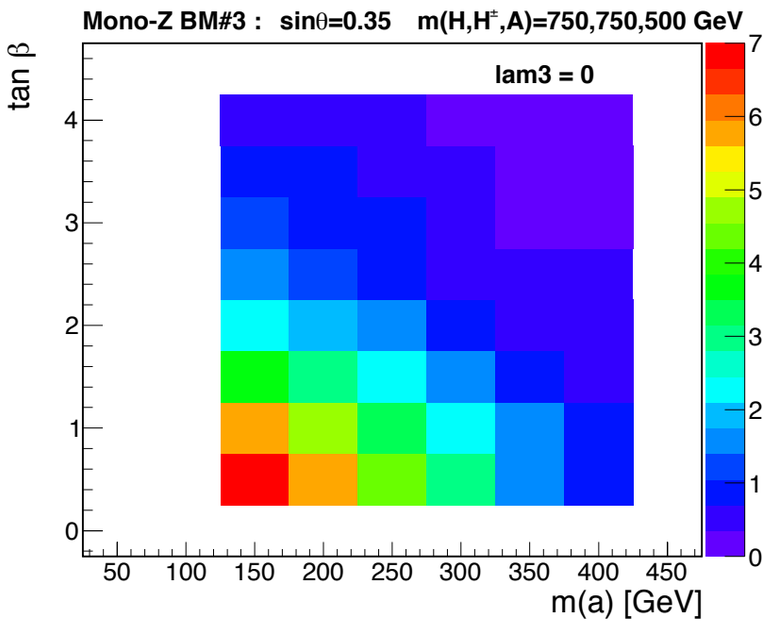
$\sin\theta = 1/\sqrt{2}$

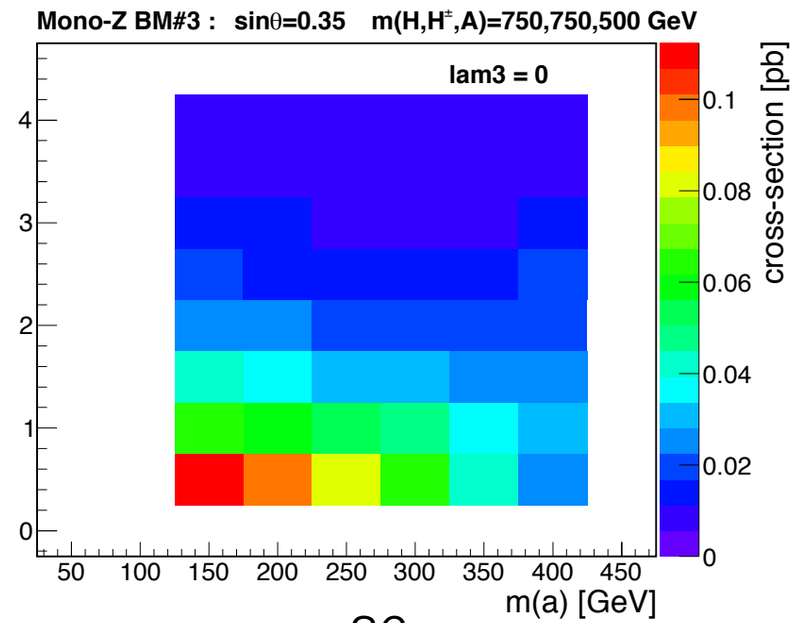


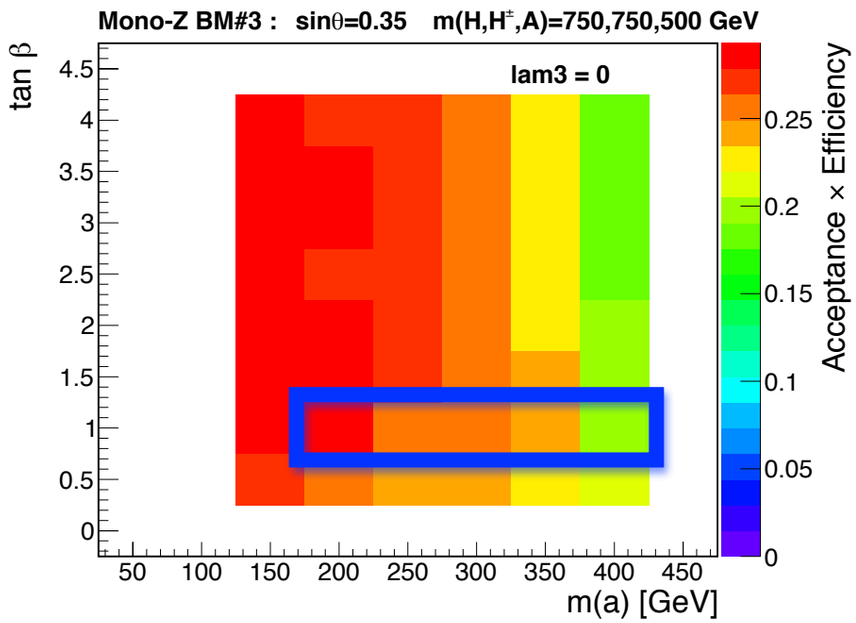




$\sin\theta = 0.35$



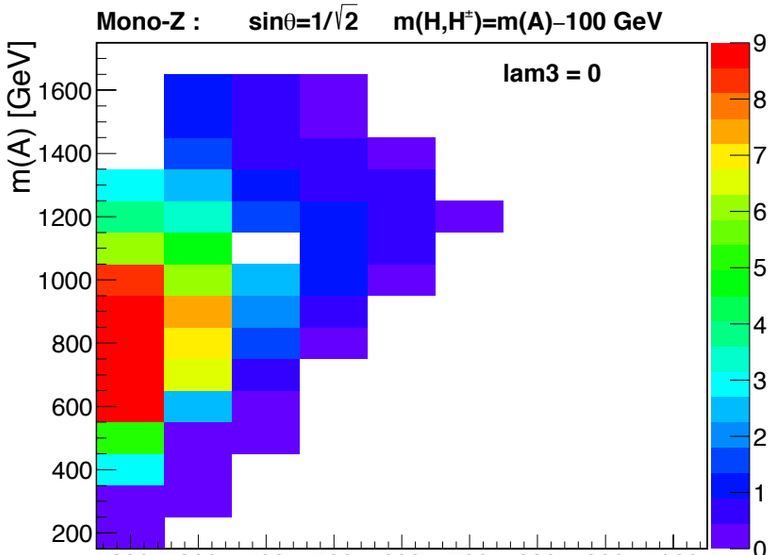


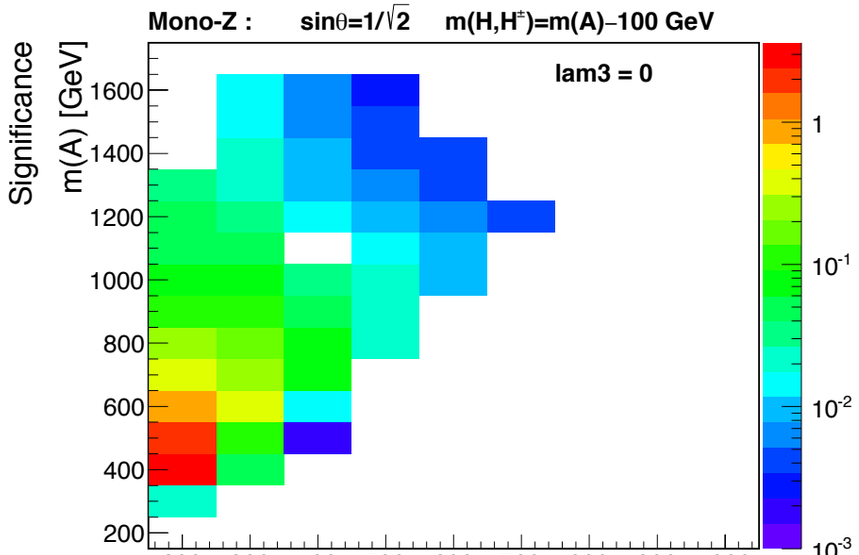


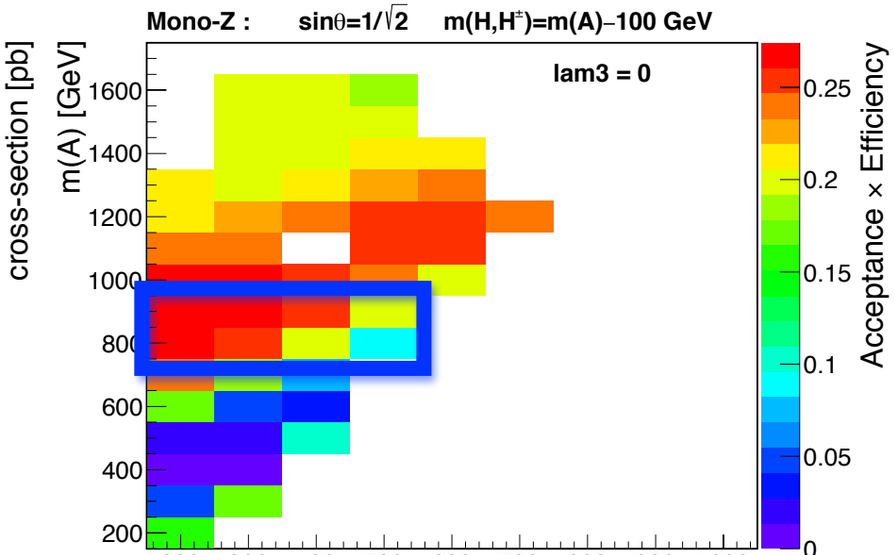
Mixing Angle Dependence

- m(A) vs m(a) grid
- m(H)=m(A)−100 GeV

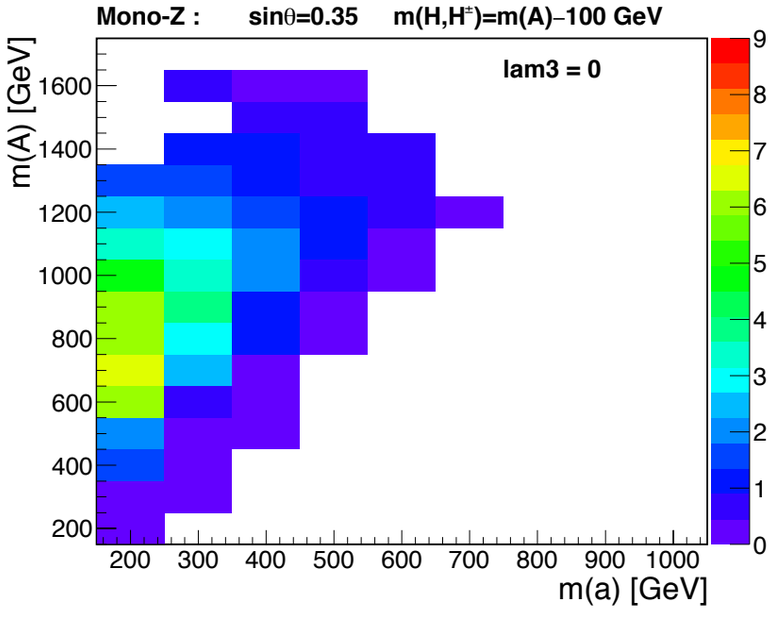
$\sin\theta = 1/\sqrt{2}$

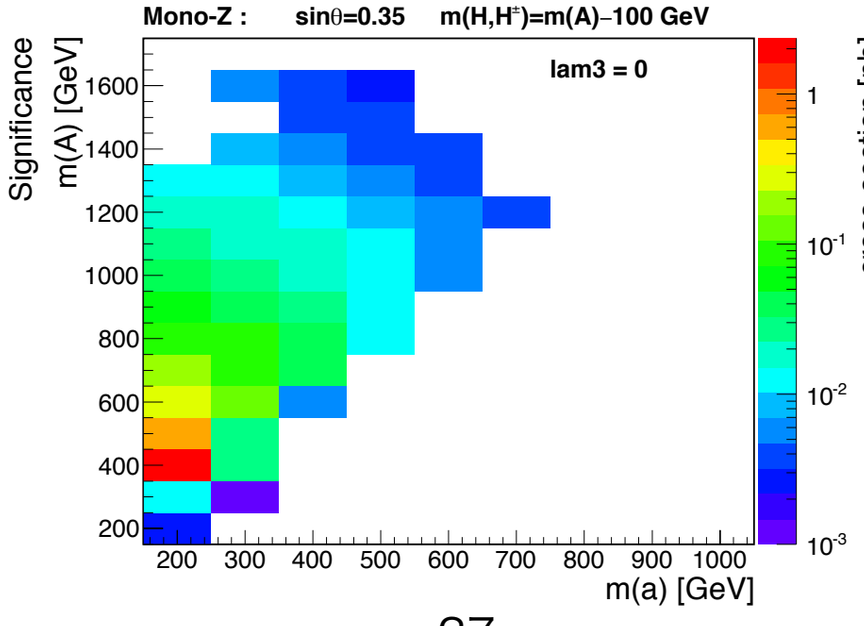


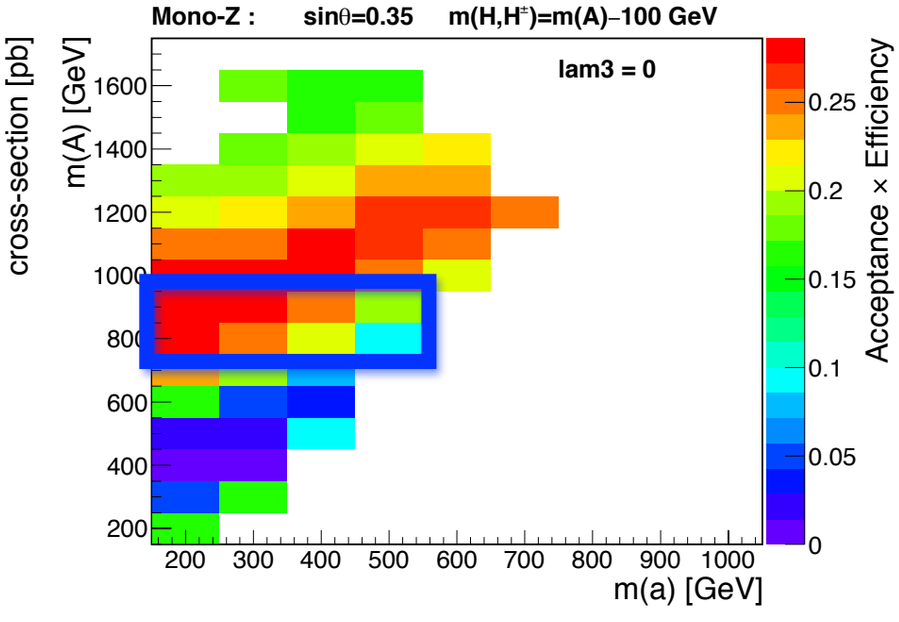




$\sin\theta = 0.35$

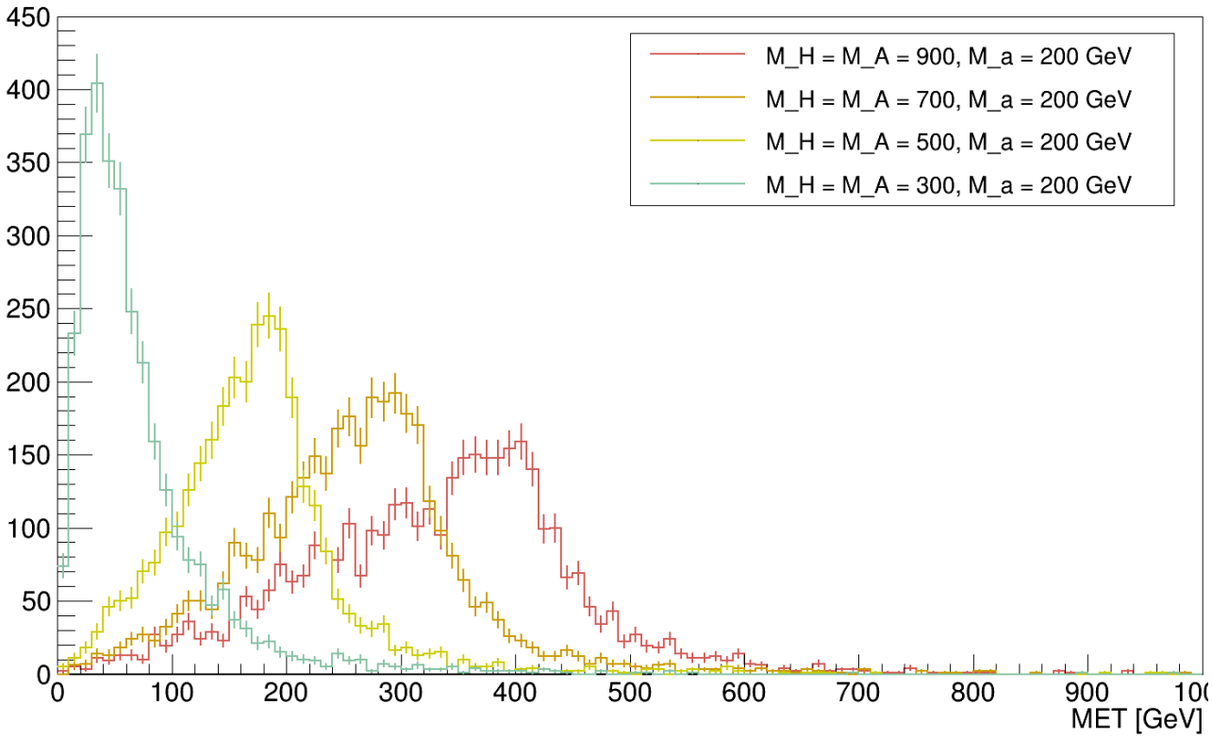


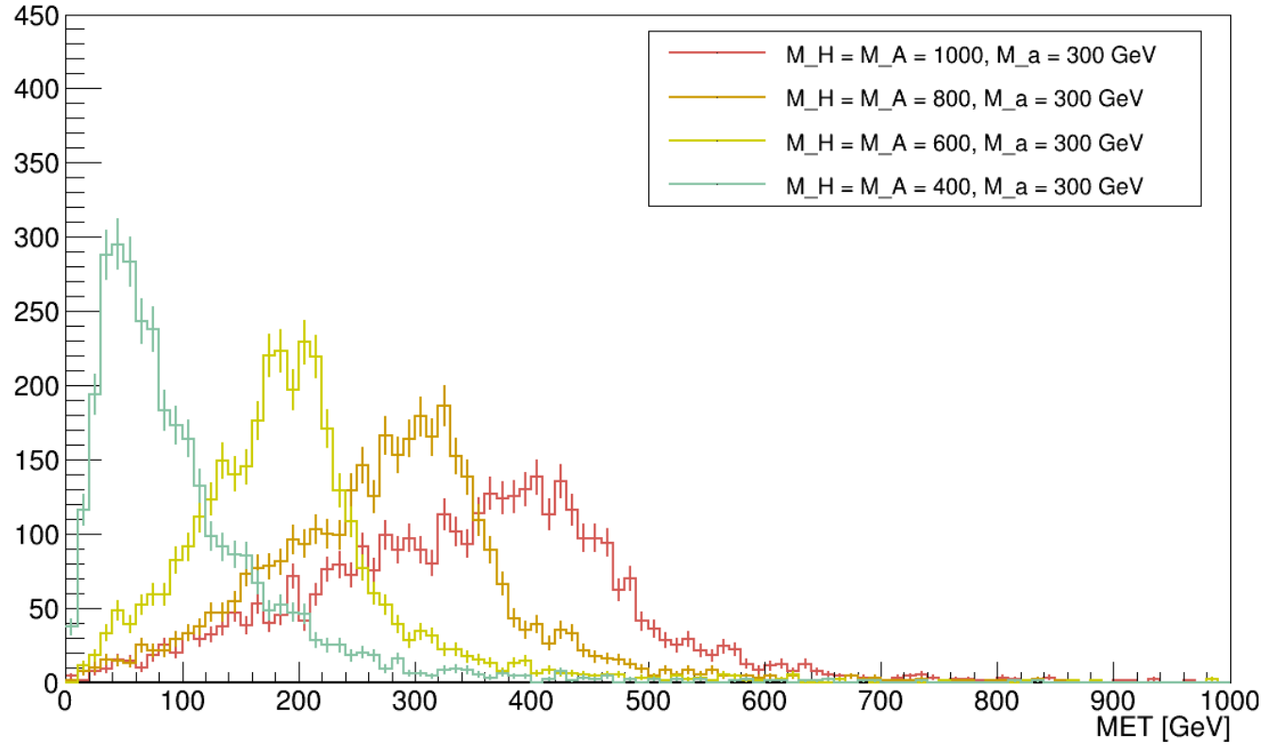




MET Distribution

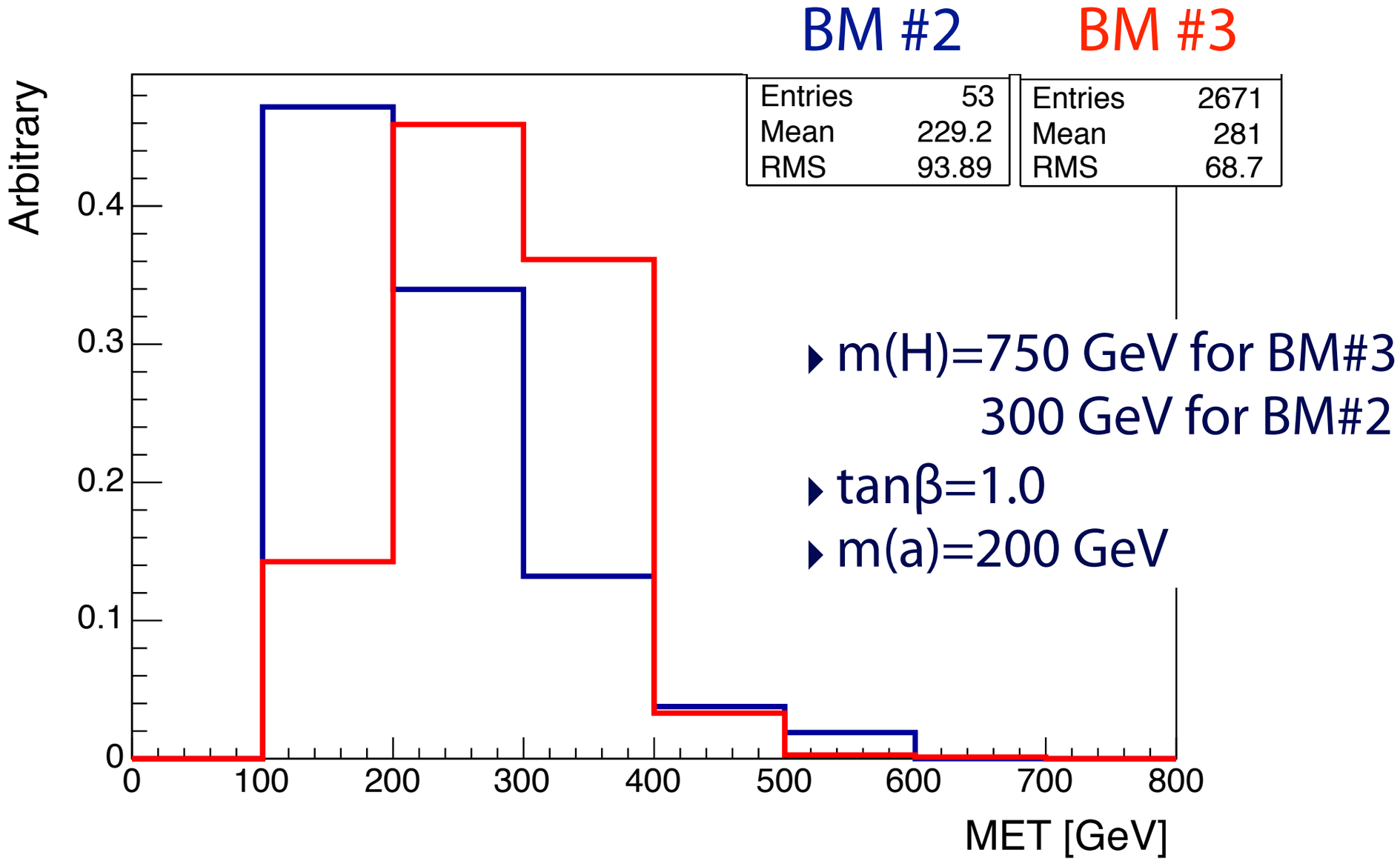
MET distribution for the pseudoscalar 2HDM





MET shape and acceptance depends on mainly on **(mH - ma):**
(mH - ma) =100, 300, 500, 700 for values of ma = 200 and ma = 300

mH = mHc = mA, sin(θ) = 0.35, tan(β) = 1, lam3 = 0.258


BM #2
BM #3
Entries 53
Mean 229.2
RMS 93.89
Entries 2671
Mean 281
RMS 68.7
m(H)=750 GeV for BM#3
300 GeV for BM#2
tanβ=1.0
m(a)=200 GeV
Arbitrary
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
700
800
MET [GeV]