

2HDM $PZ2H$ model study for $t\bar{t}+DM$

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Model details

- 2HDM w/ additional PS mediator ([arXiv: 1701.07427](#) / [UFO](#))
 - M_h scalar Higgs (h1)
 - M_H heavier scalar Higgs (h2)
 - M_A pseudoscalar Higgs (h3)
 - $M_{H^{\pm}}$ charged Higgs (hc)
 - M_a additional CP-odd weak eigenstate not present in nominal 2HDMs (h4)
- More model parameters
 - α mixing angle between neutral CP-even weak eigenstates (H and h)
 - θ mixing angle between neutral CP-odd weak eigenstates (A and a)
 - $\tan\beta$ ratio of Higgs VEVs
 - M_{DM} Dirac fermion WIMP
- Important: working in alignment/decoupling limit where $\alpha = \beta - \pi/2$ so $\sin(\beta - \alpha)=1$
 - ➔ h couples to massive EWK gauge bosons with SM h coupling strengths

$t\bar{t} + \text{DM}$ in context of model

- Study $t\bar{t} + \chi\bar{\chi}$ process at LO (generate $p p \rightarrow x d \bar{x} d \bar{t} t$) using MG5
 - Determine what, if any, kinematic dependence on tuneable model parameters

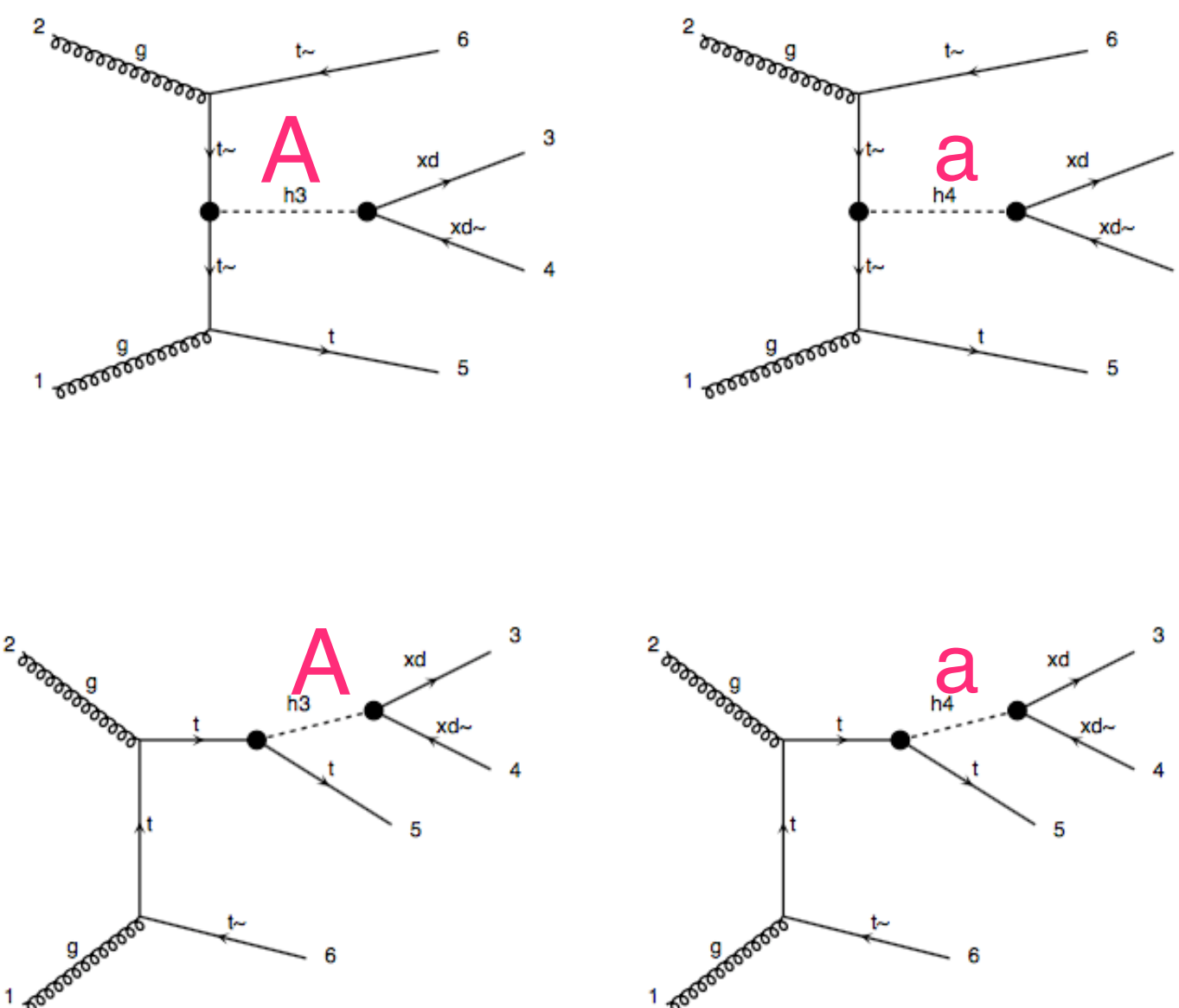
$\sin\theta, \tan\beta, M_a, M_A, M_H, M_{H^{\pm}}, M_h$

- Initially, investigate baseline scenarios inspired by 1701.07427

- **Case 1:** Scan over M_a , and keep
 $\sin\theta=0.7071, M_H=M_{H^{\pm}}=750, M_h=125, M_A=500, \tan\beta=1$
- **Case 2:** Scan over M_A , and keep
 $\sin\theta=0.7071, M_H=M_{H^{\pm}}=750, M_h=125, M_a=500, \tan\beta=1$
- **Case 3:** Scan over $\sin\theta$ for some M_a , and keep
 $M_H=M_{H^{\pm}}=750, M_h=125, M_A=500, \tan\beta=1$
- **Case 4:** Scan over $\tan\beta$, and keep
 $\sin\theta=0.7071, M_H=M_{H^{\pm}}=750, M_h=125, M_A=500, M_a=100$

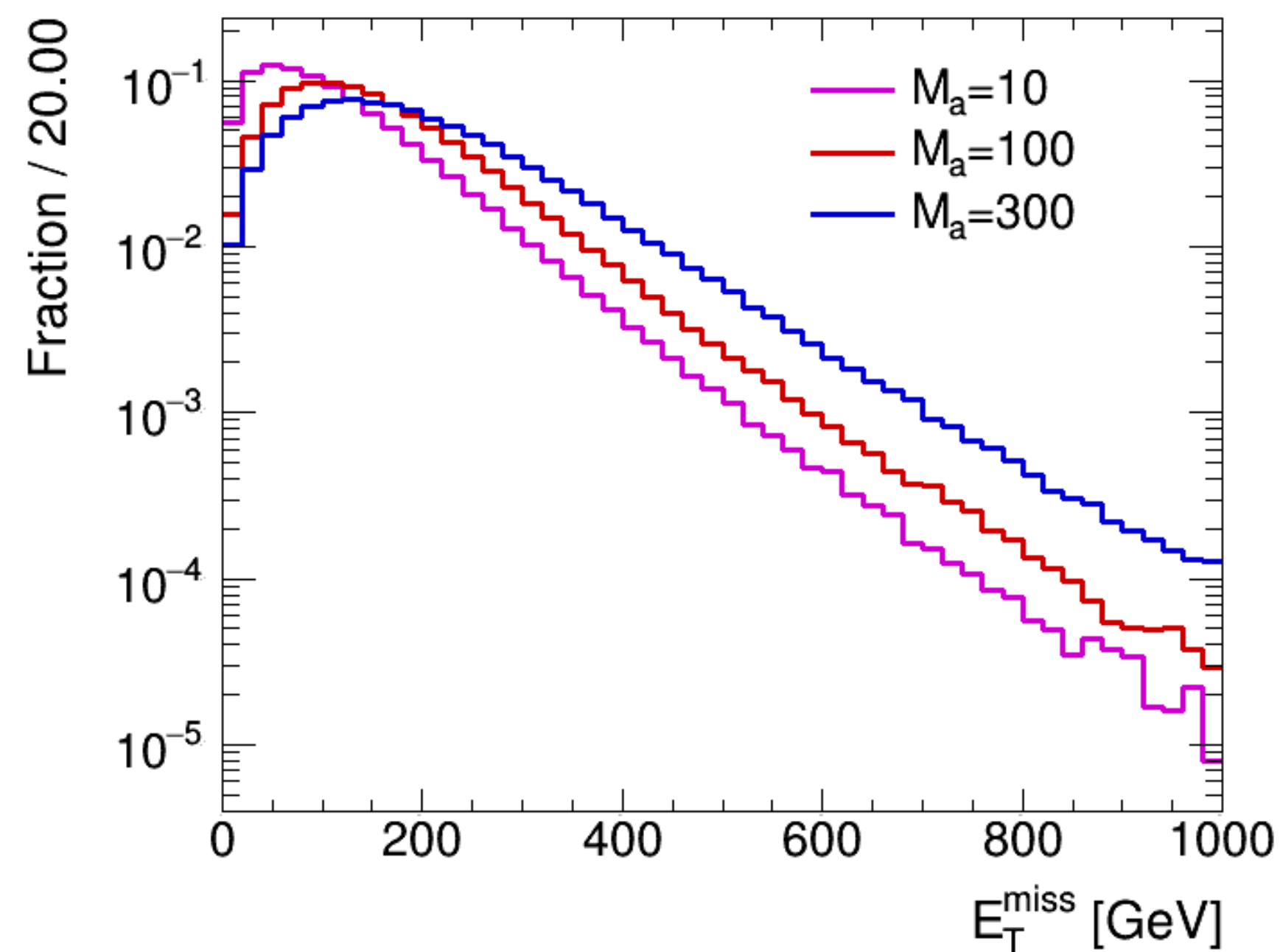
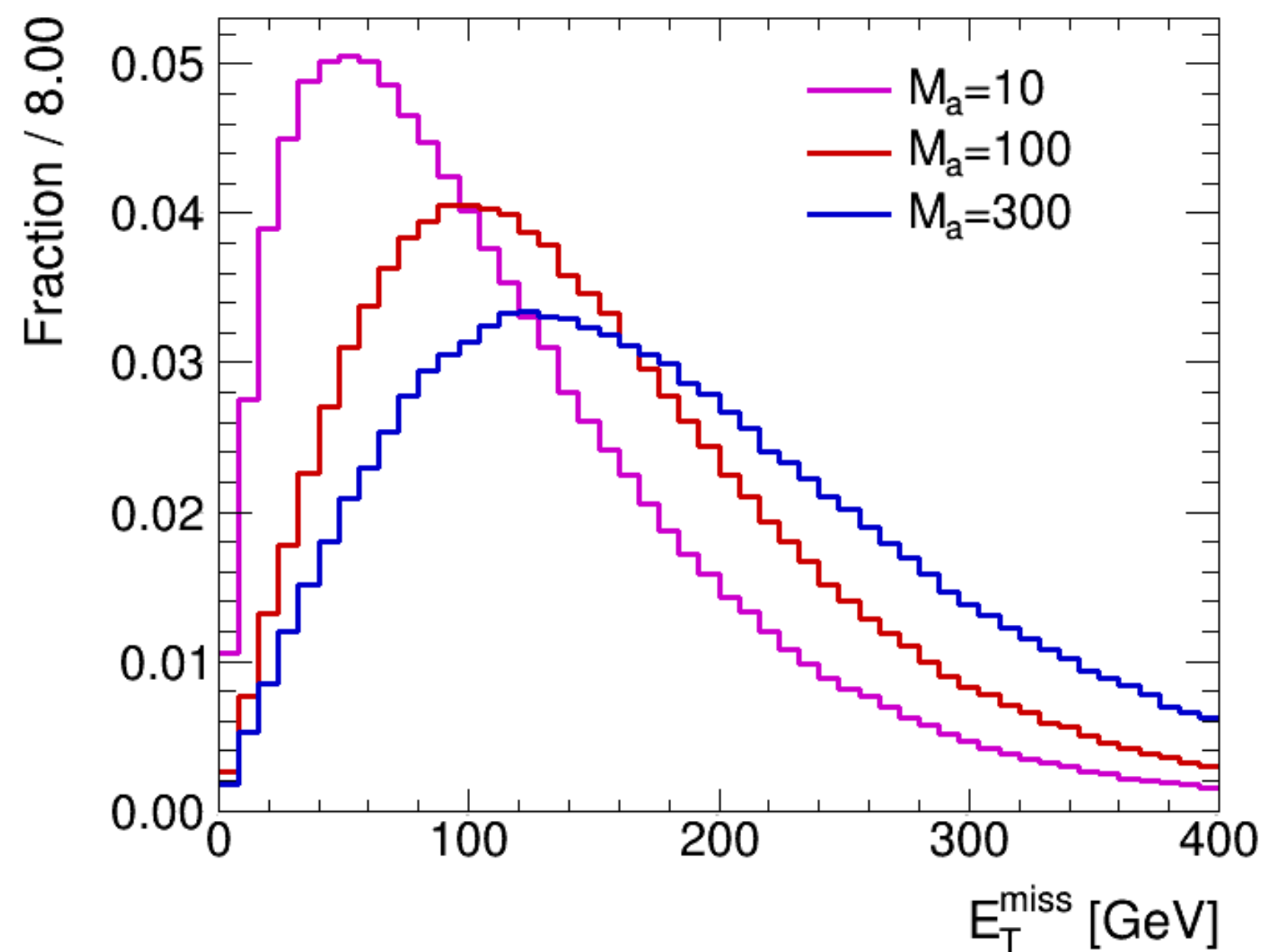
- PDF set used: NNPDF30_lo_as_0130_nf_4

Example diagrams generated



Case 1: Scan M_a

$\sin\theta=0.7071$, $M_H=M_{H^\pm}=750$, $M_h=125$, $M_A=500$, $\tan\beta=1$, $M_{DM}=1$

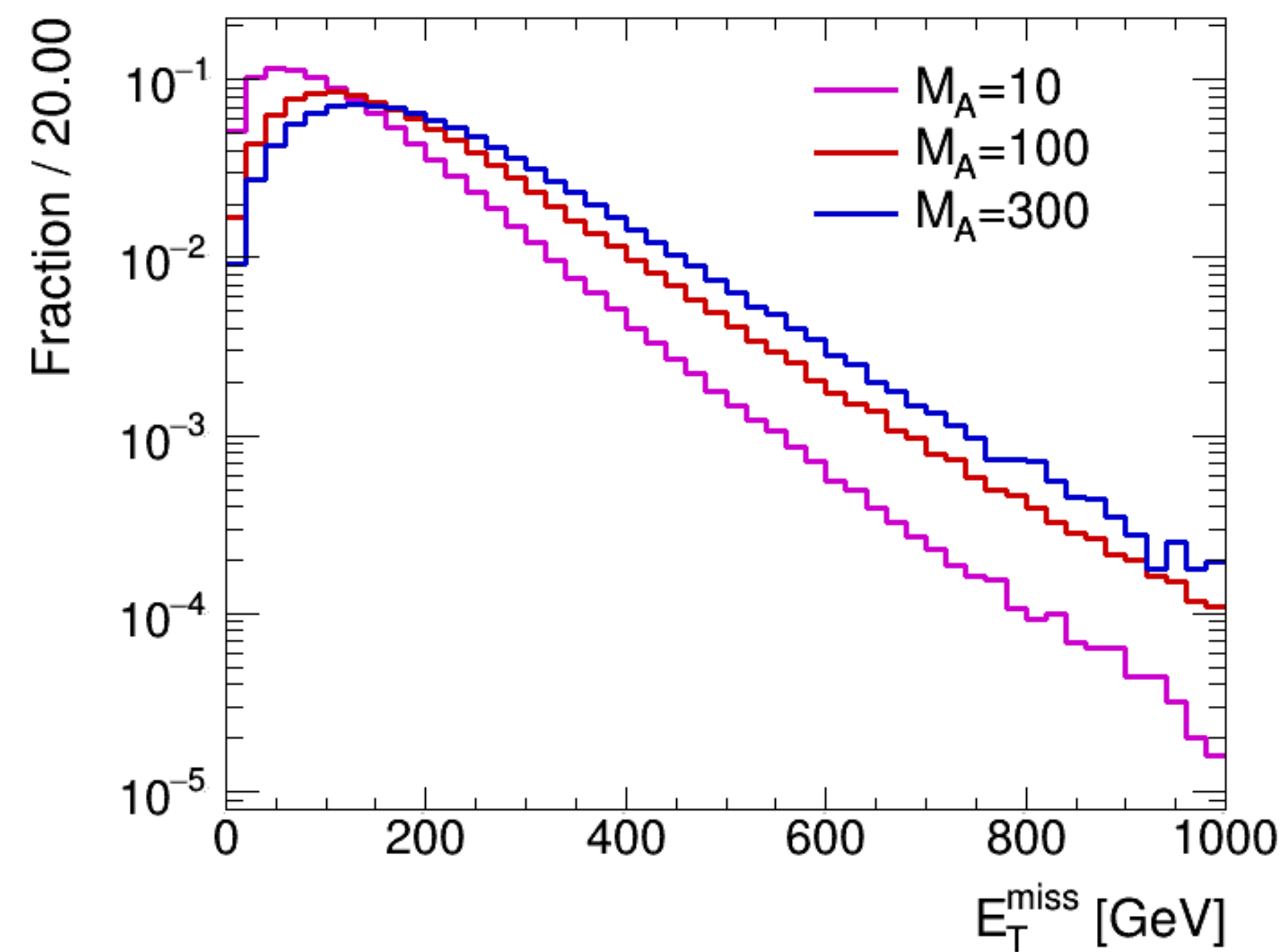
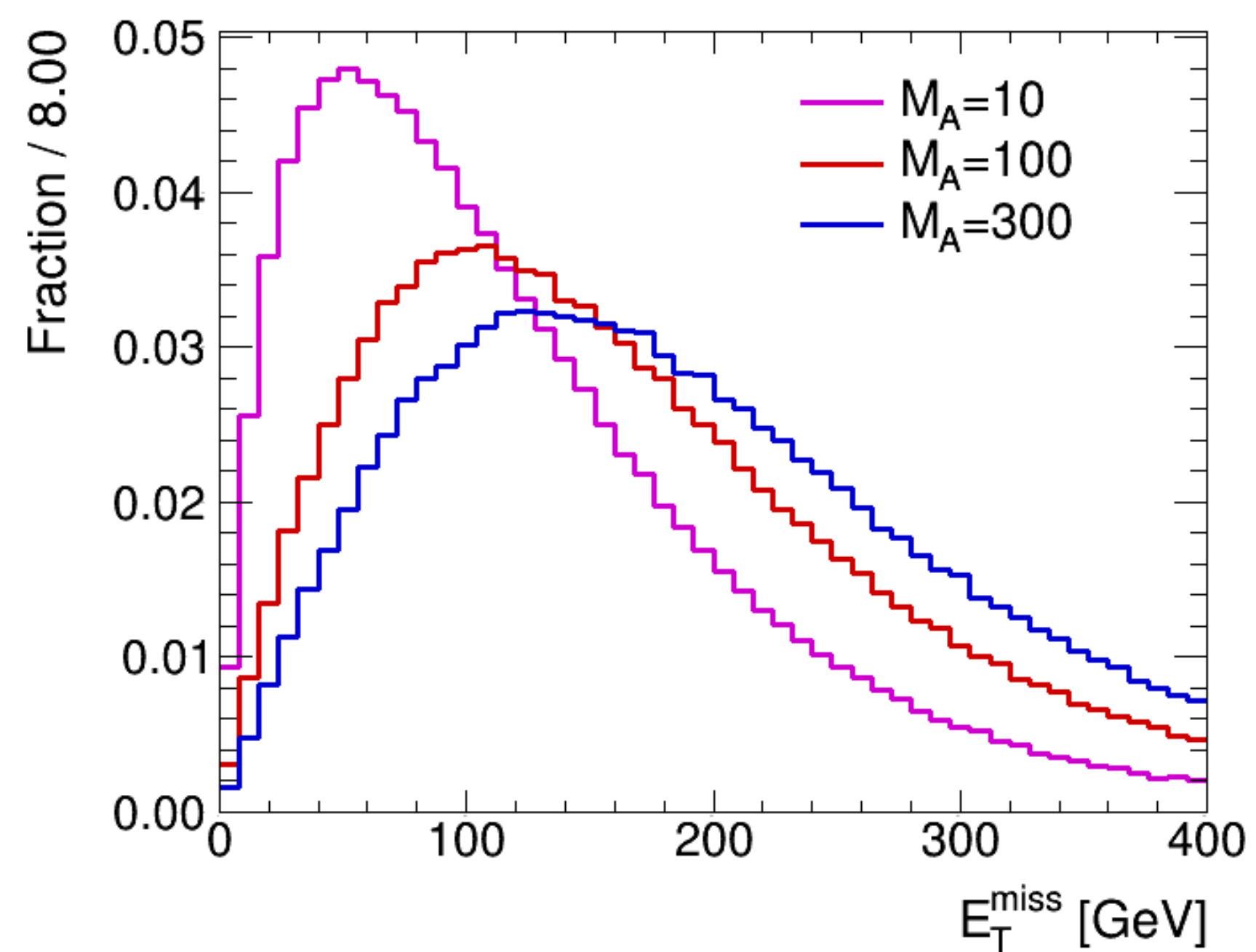


Harder MET spectrum with heavier M_a

- Mediator widths are calculated in MG5 (DECAY set to AUTO)
- $E_T^{\text{miss}} = \text{gen-level } p_T \text{ of DMs produced}$

Case 2: Scan M_A

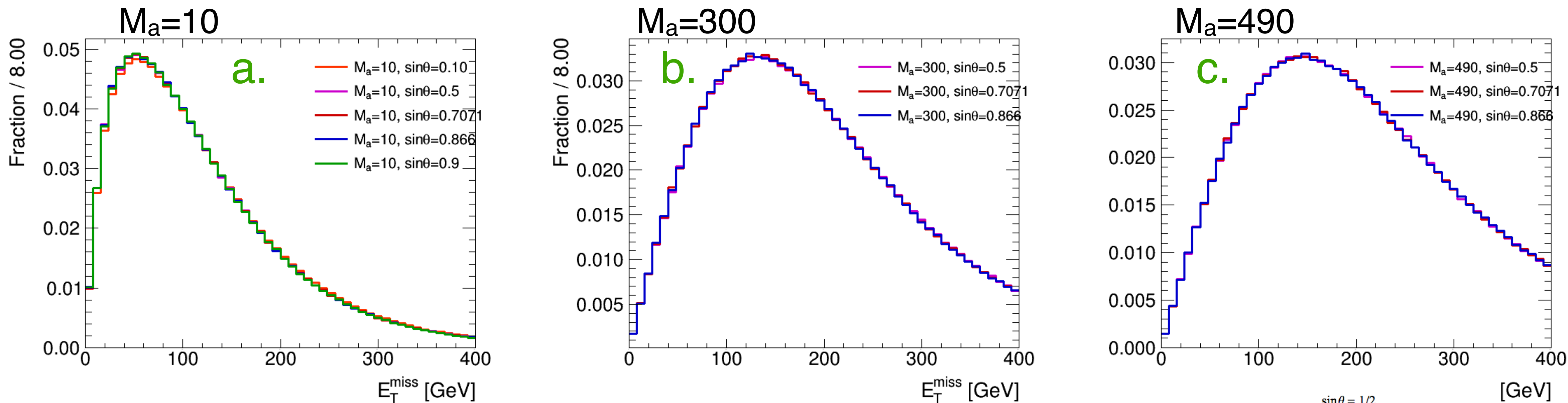
$\sin\theta=0.7071$, $M_H=M_{H^\pm}=750$, $M_h=125$, $M_a=500$, $\tan\beta=1$, $M_{DM}=1$



MET has similar dependence on M_A as on M_a

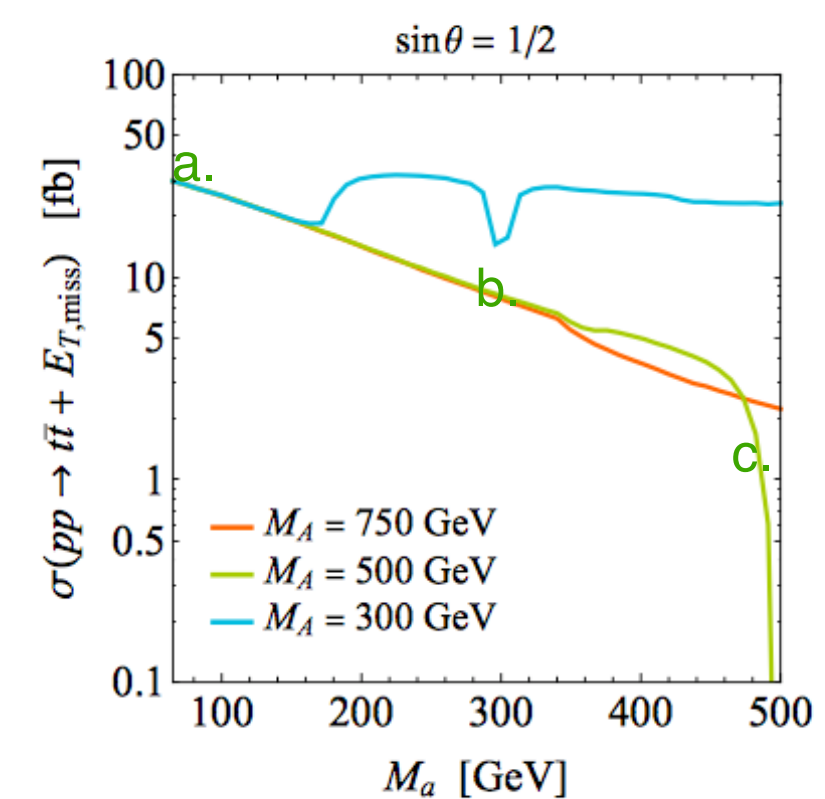
Case 3: Scan $\sin\theta$ for some M_a

$M_H=M_{H^\pm}=750$, $M_h=125$, $M_A=500$, $\tan\beta=1$, $M_{DM}=1$



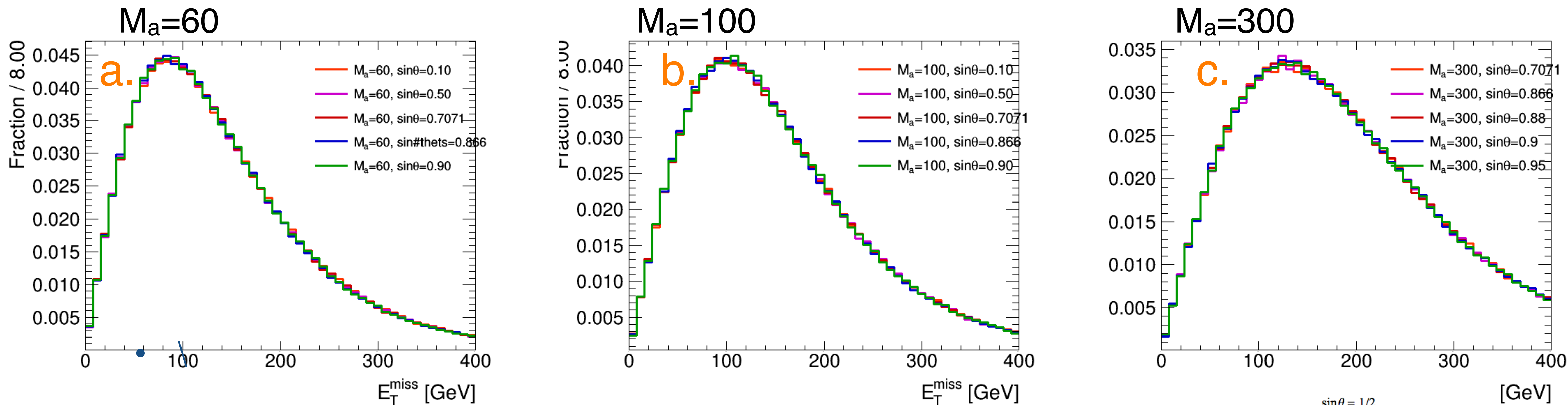
MET has no dependence on $\sin\theta$, but cross sections do change

- Generated LO diagrams are symmetric wrt exchange mediator (a/A)
- $\Gamma(A \rightarrow \chi\bar{\chi}) \propto \sin^2\theta$ and $\Gamma(a \rightarrow \chi\bar{\chi}) \propto \cos^2\theta$



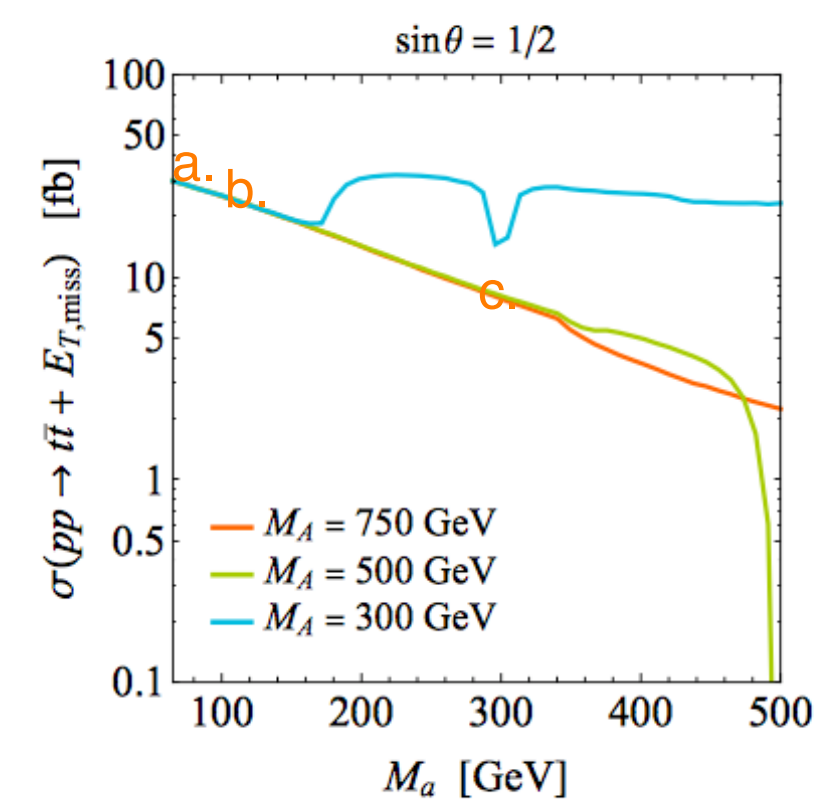
Case 3 cont'd: Scan $\sin\theta$ for some M_a

$M_H=M_{H^\pm}=750$, $M_h=125$, $M_A=750$, $\tan\beta=1$, $M_{DM}=1$



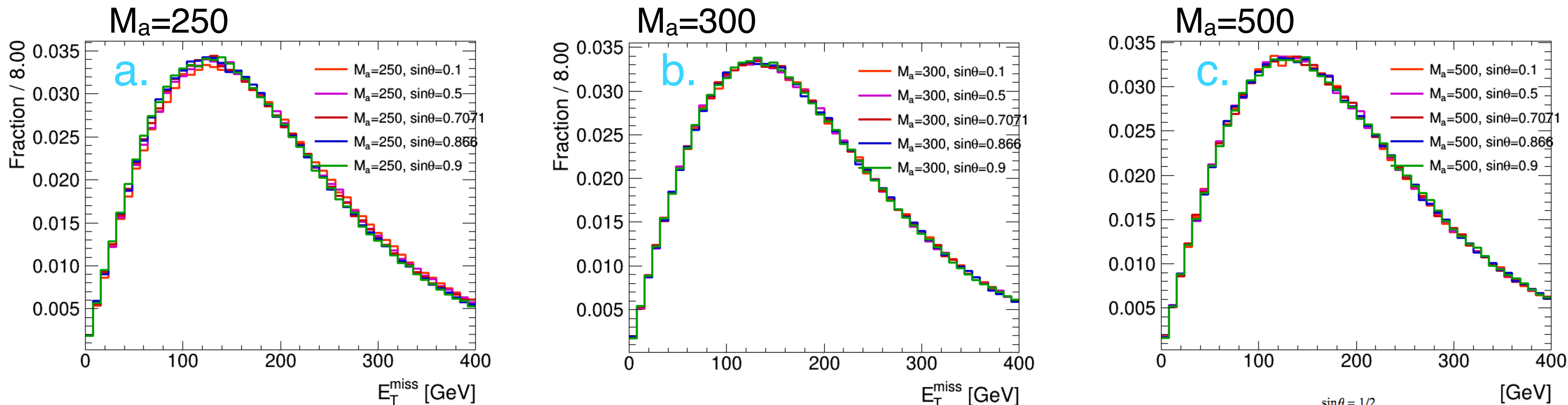
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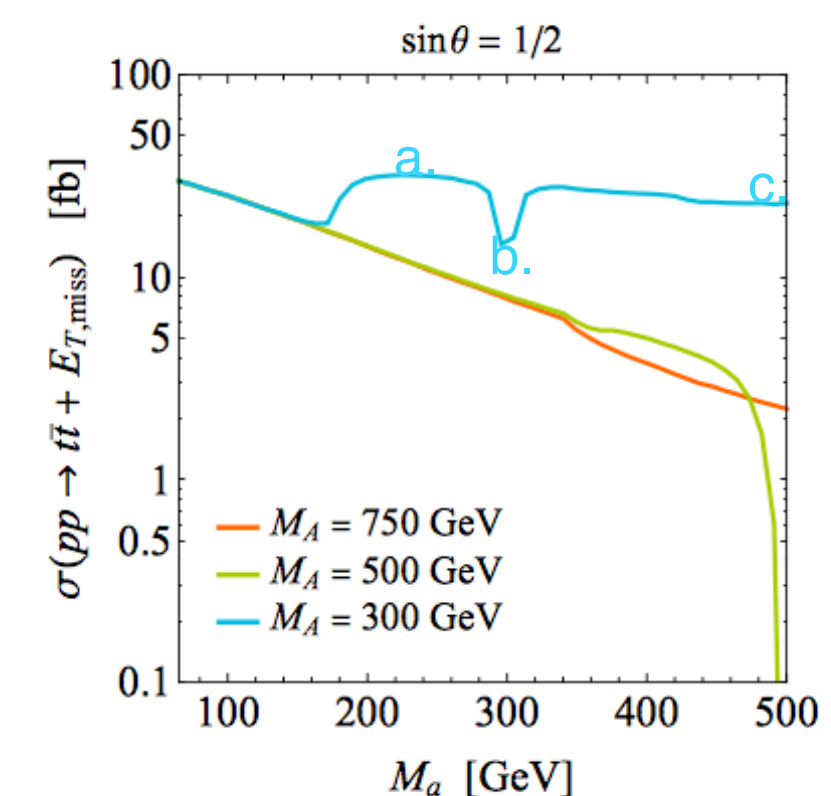


Case 3 cont'd: Scan $\sin\theta$ for some M_a

$M_H=M_{H^\pm}=750$, $M_h=125$, $M_A=300$, $\tan\beta=1$, $M_{DM}=1$

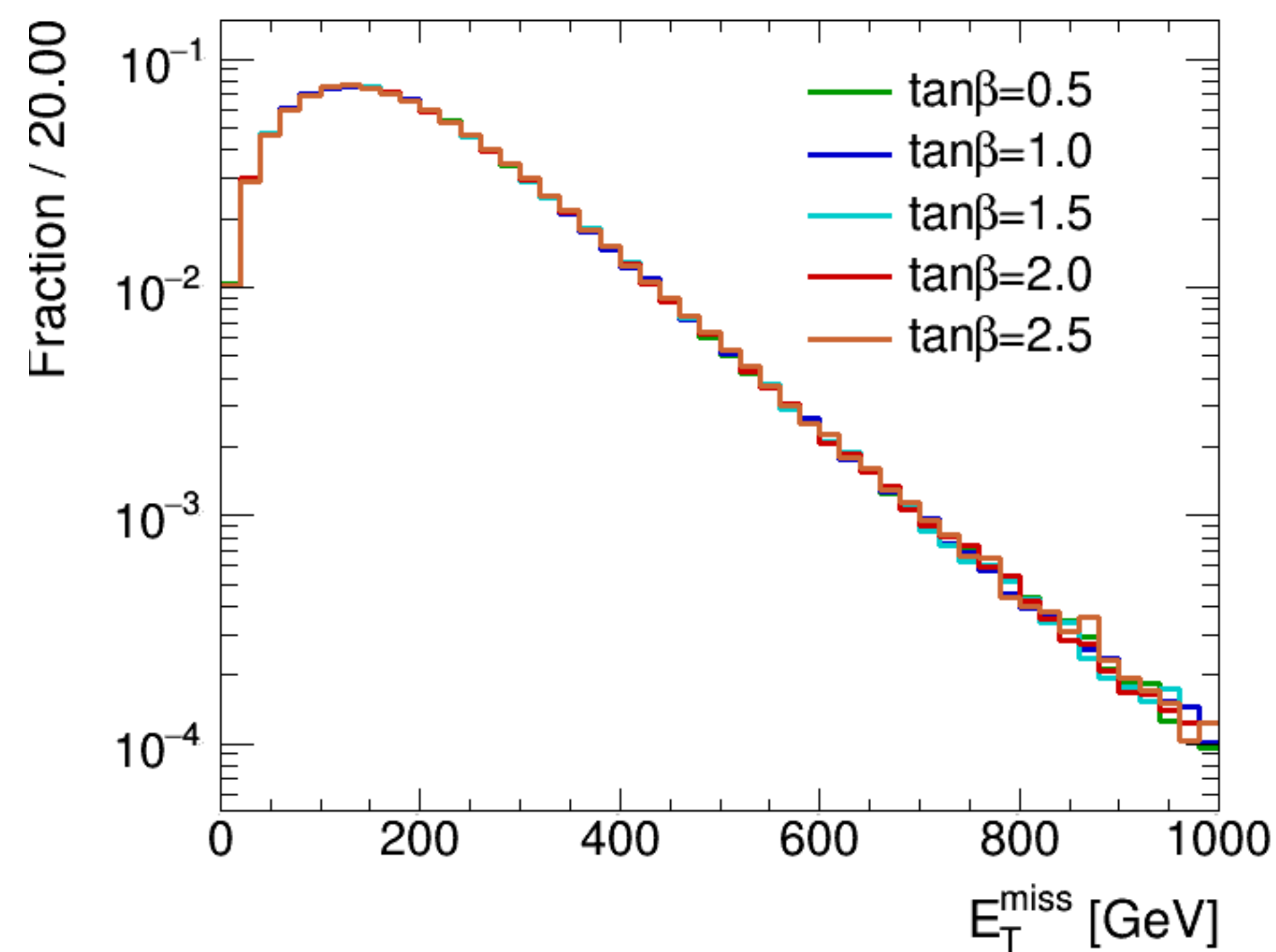
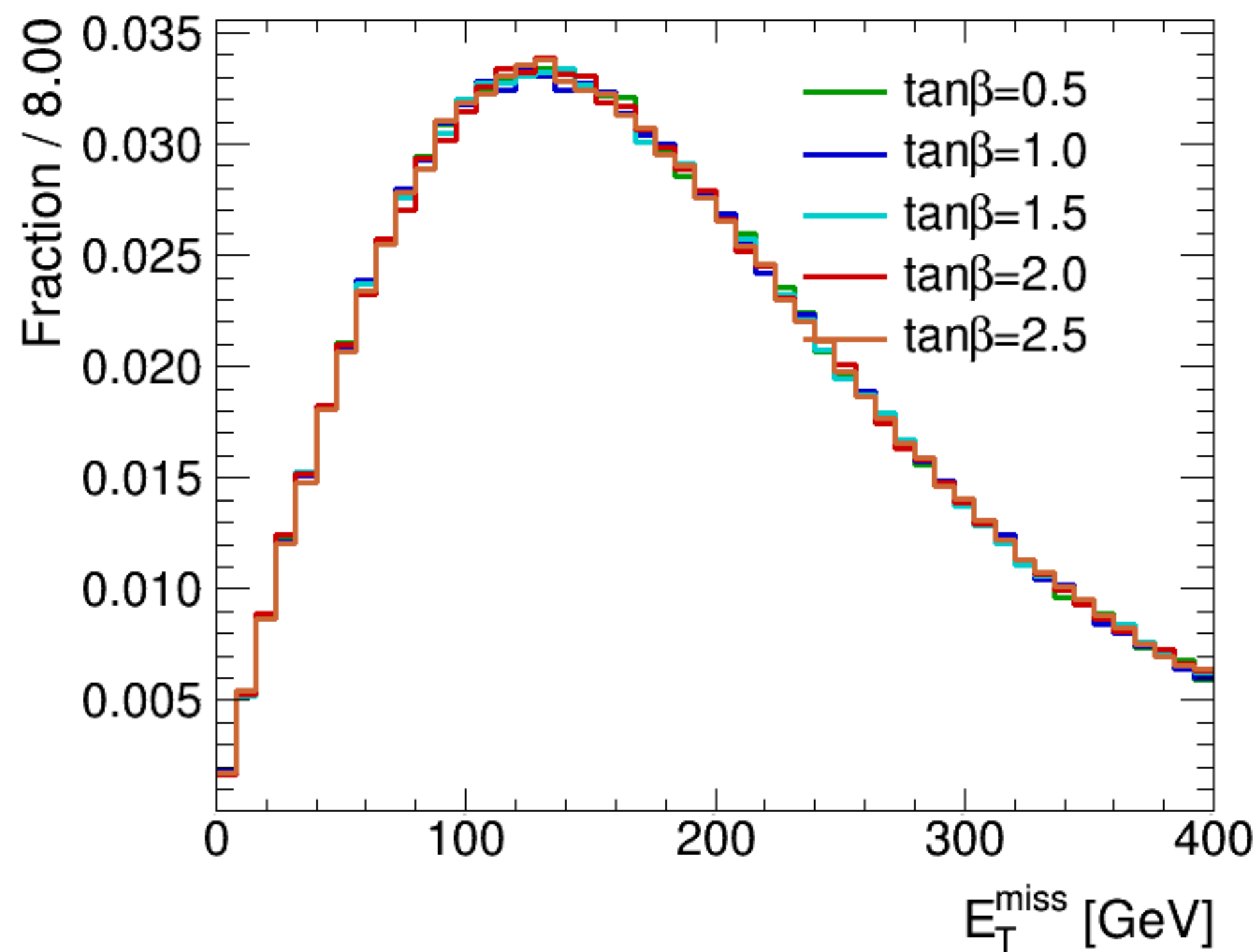


- Constructive and destructive interference occurs near $M_a \sim M_A - M_h \sim 175$ and $M_a \sim M_A$ ($A \rightarrow ah$ dominates over $A \rightarrow \chi\bar{\chi}$)
- Inclusive cross-sections confirm $\sigma_a \sim 3\sigma_b$ and $\sigma_c \sim 2.5\sigma_b$ from 1701.07427



Case 4: Scan $\tan\beta$

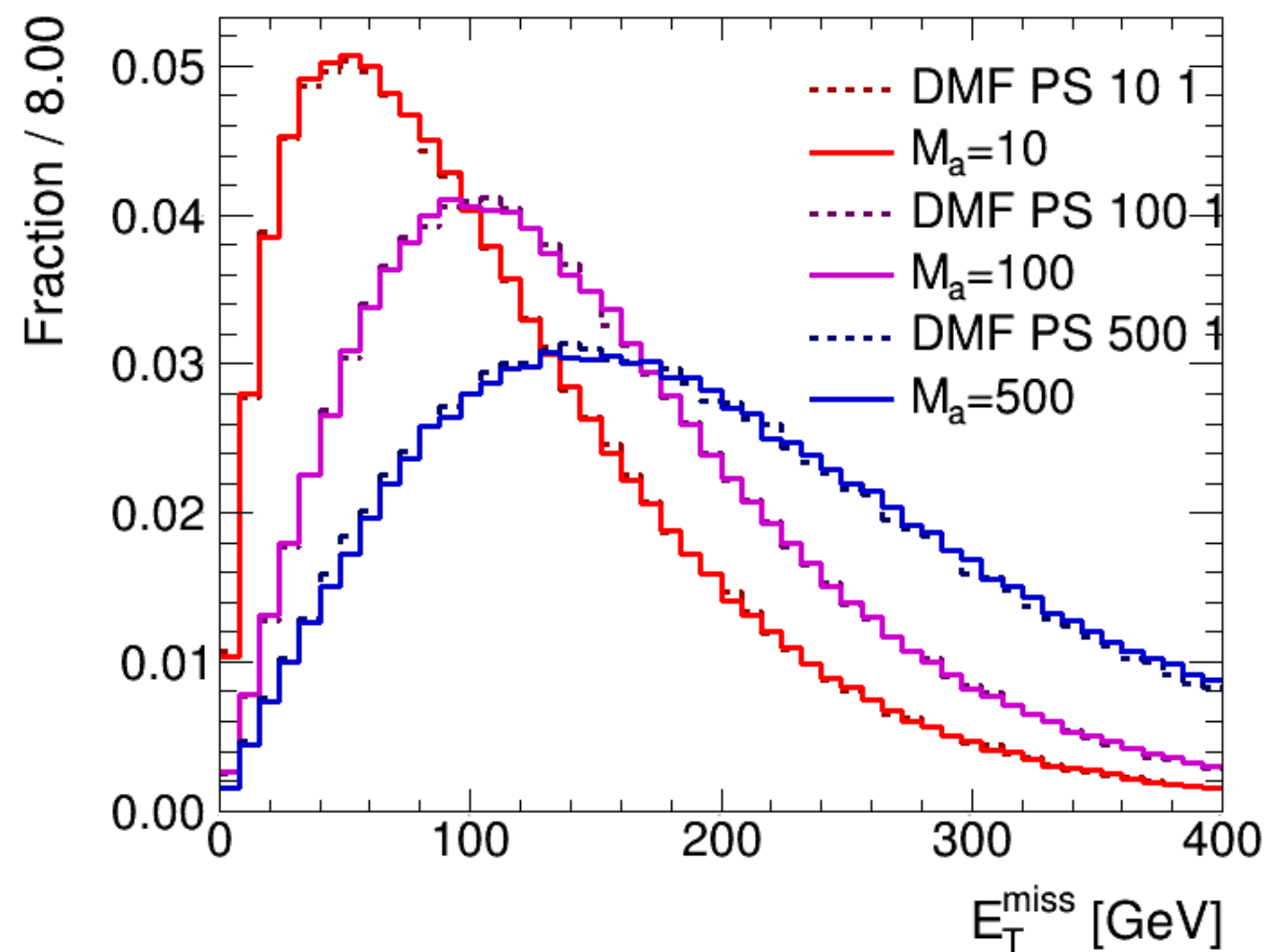
$\sin\theta=0.7071$, $M_H=M_{H^\pm}=750$, $M_h=125$, $M_A=750$, $M_a=300$, $M_{DM}=1$



MET has no dependence on $\tan\beta$

Compare with simplified models

2HDM parameters: $\sin\theta=0.7071$, $M_H=M_{H^\pm}=750$, $M_h=125$, $M_A=750$, $M_{DM}=1$



- Comparison with DMF pseudoscalar simplified models where $g_q = g_{DM} = 1$ and $M_{DM} = 1$ show same kinematics as 2HDM model for $M_{MED}=M_a$
- For $M_A > M_a$ inclusive cross-sections scale as $\sigma_{2HDM} \sim 0.5\sigma_{DMF}$

$$\frac{\sigma(pp \rightarrow t\bar{t} + E_T^{miss})}{\sigma(pp \rightarrow t\bar{t} + E_T^{miss})_{DMF}} \simeq \left[\frac{y_\chi \sin\theta}{g_\chi g_q \tan\beta} \right]^2$$

M_{MED}/M_a [GeV]	σ_{2HDM} [pb]	σ_{DMF} [pb]
10	0.220	0.446
100	0.098	0.194
500	0.0035	0.0056

Conclusions

- Kinematic dependence: harder MET spectra with increasing M_a/M_A
 - Kinematics are similar but not identical when swapping M_a and M_A (case 1 v. case 2)
- No dependence of kinematics on variation of $\sin\theta$ or $\tan\beta$
 - Diagrams generated for $t\bar{t}+\chi\bar{\chi}$ are symmetric wrt A ($h3$) and a ($h4$)
 - Cross sections do change
- Same kinematic dependence as DMF PS model ($M_{DM} = g_q = g_{DM} = 1$) for 2HDM where $M_a = M_{med}$ from DMF
 - Straightforward scaling between model cross sections is confirmed for $M_A > M_a$