

**Search for Dark Matter in events with missing
transverse momentum and a Higgs boson
decaying to two photons in pp collisions at
 $\sqrt{s} = 13$ TeV with the ATLAS detector**

[ATLAS-CONF-2020-054](#)

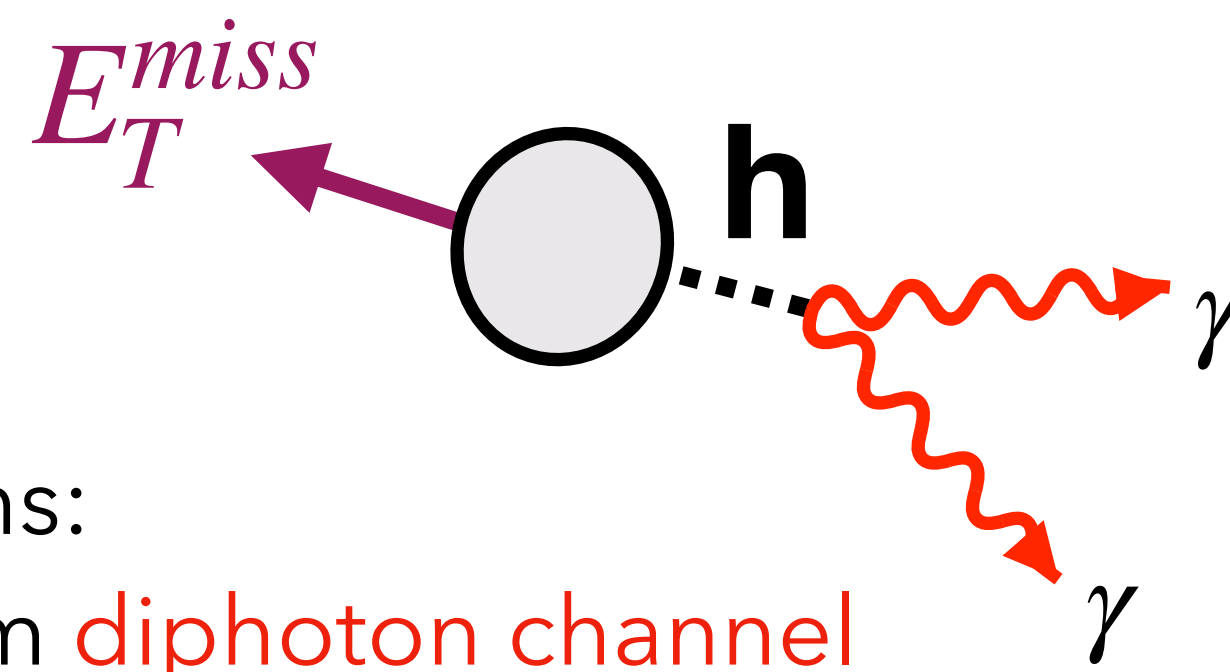
Moriond Electroweak 2021

26. 03. 2021

**Alexander Leopold, on behalf of the
ATLAS collaboration**



Motivation



The “Mono-Higgs” signature contains:

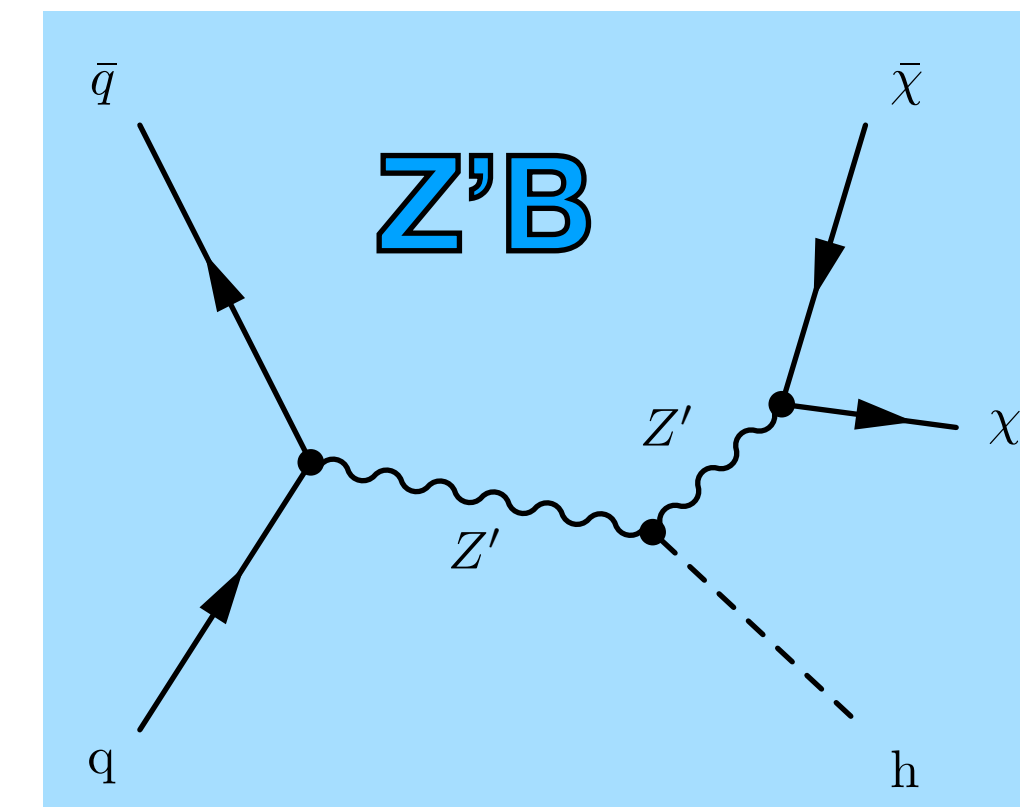
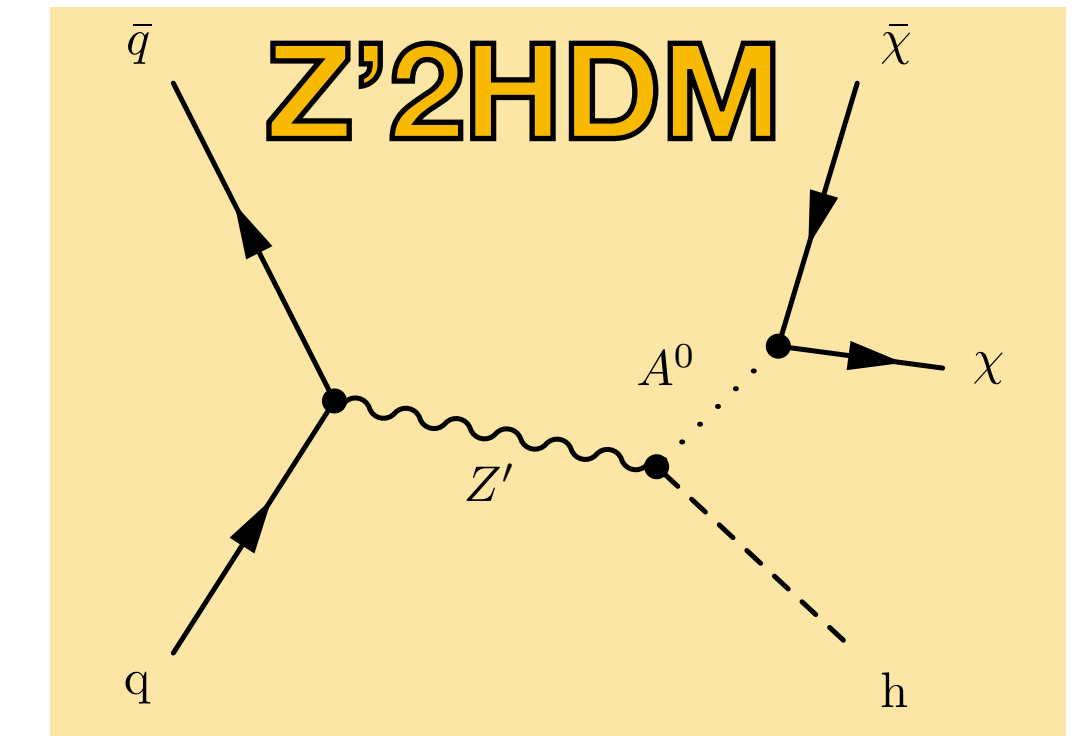
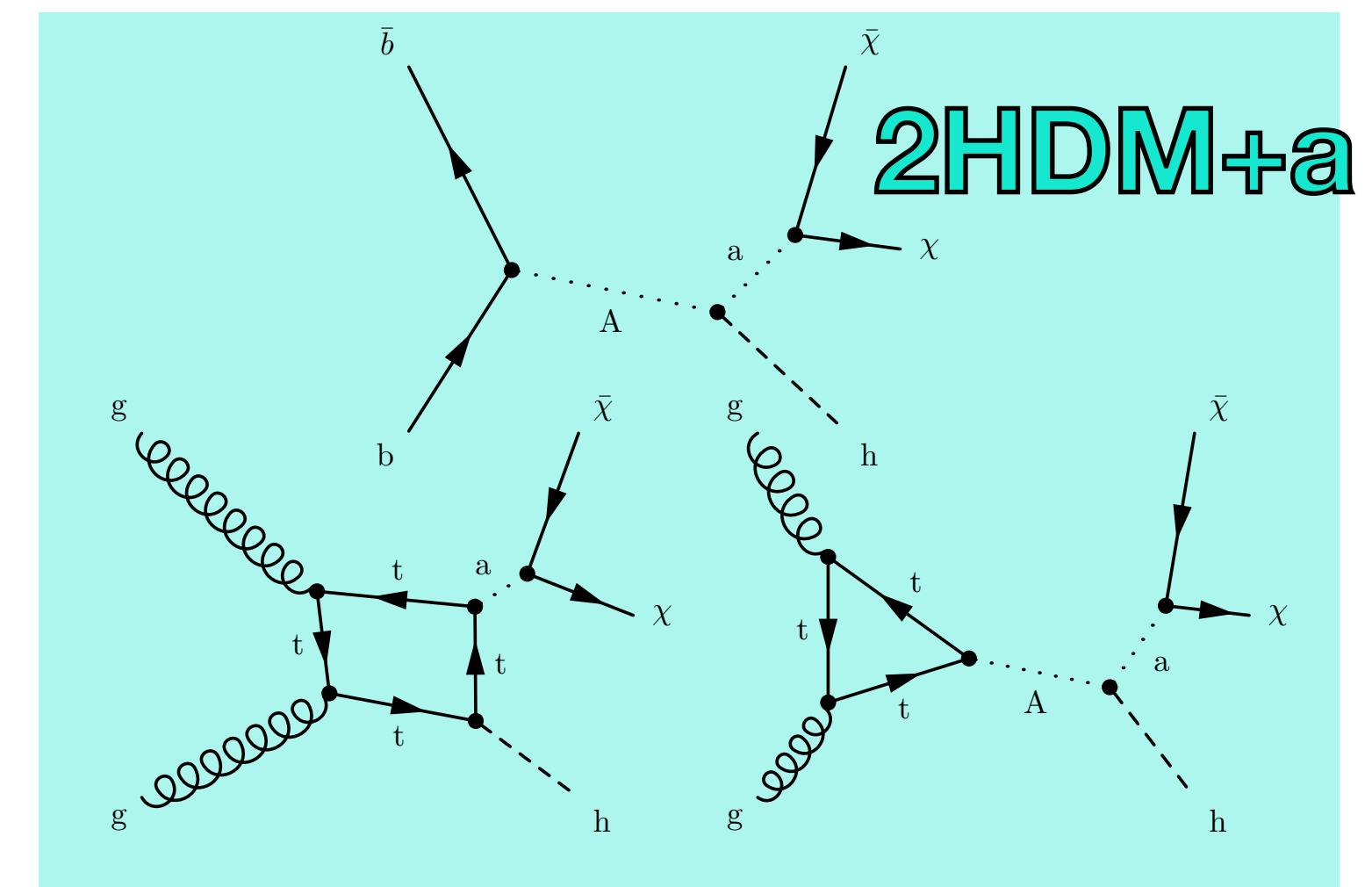
- ▶ a Higgs boson, reconstructed from **diphoton channel**
- ▶ DM particles recoil against diphoton system, don't leave any observable signal in the detector → **missing transverse momentum**

- Analysis profits from **diphoton trigger** (instead of E_T^{miss} trigger)
- Good sensitivity in the lower E_T^{miss} range
- Higgs ISR is Yukawa suppressed, allows to probe the hard scatter
- Uses full Run 2 data (139 fb⁻¹)
- Provides complementarity with $h(\rightarrow b\bar{b}) + E_T^{miss}$ channel (see Spyros' talk)

3 models considered in this analysis:

- ▶ a single model (**2HDM+a**) used for the signal category optimisation which is applied in *all* models
- ▶ Results also interpreted in **Z'2HDM** and **Z'B** model

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→ **Higgs boson h in all models assumed to have mass of 125 GeV!**

Analysis overview

Event pre-selection: 2 photons ($105 \leq m_{\gamma\gamma} \leq 160$ GeV) and

$E_T^{miss}(\text{diphoton VX}) > 90$ GeV

← *all objects reconstructed w.r.t. the diphoton vertex (VX)*

Background rejection cuts:

- $E_T^{miss}(\text{diphoton VX}) - E_T^{miss}(\text{hardest VX}) < 30$ GeV

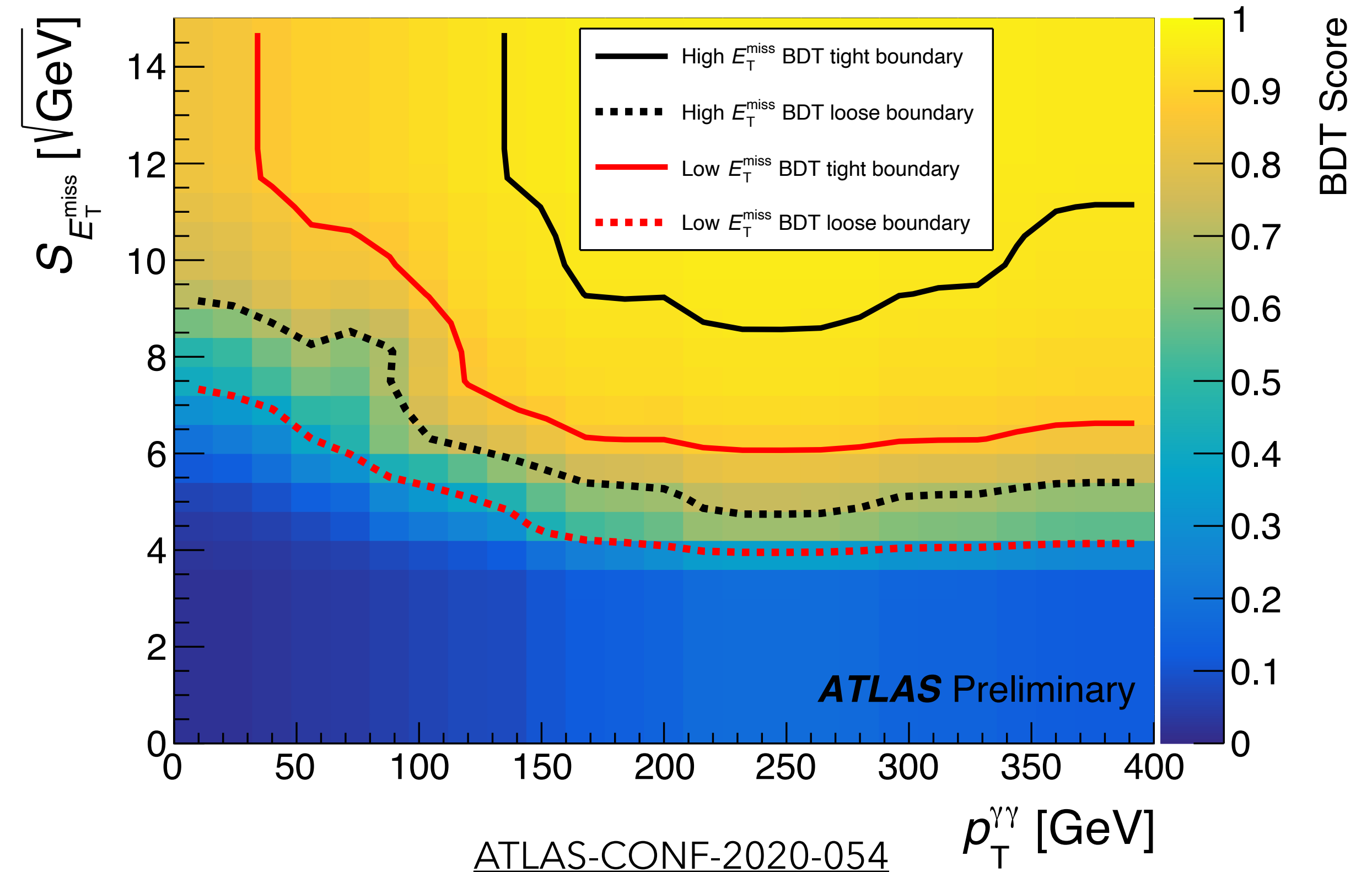
← *reject fake E_T^{miss}*

- electron & muon veto ← *reject $V\gamma$ and $V\gamma\gamma$ backgrounds*

Categorisation performed with BDT, using 2 input variables:

- $S_{E_T^{miss}} = E_T^{miss} / \sqrt{\sum E_T}$
- $p_T^{\gamma\gamma}$

Category	Category name	Selection
1	high E_T^{miss} , BDT tight	$E_T^{miss} > 150$ GeV, $0.950 < \text{BDT score} < 1$
2	high E_T^{miss} , BDT loose	$E_T^{miss} > 150$ GeV, $0.694 < \text{BDT score} < 0.950$
3	low E_T^{miss} , BDT tight	$E_T^{miss} < 150$ GeV, $0.864 < \text{BDT score} < 1$
4	low E_T^{miss} , BDT loose	$E_T^{miss} < 150$ GeV, $0.386 < \text{BDT score} < 0.864$



Results

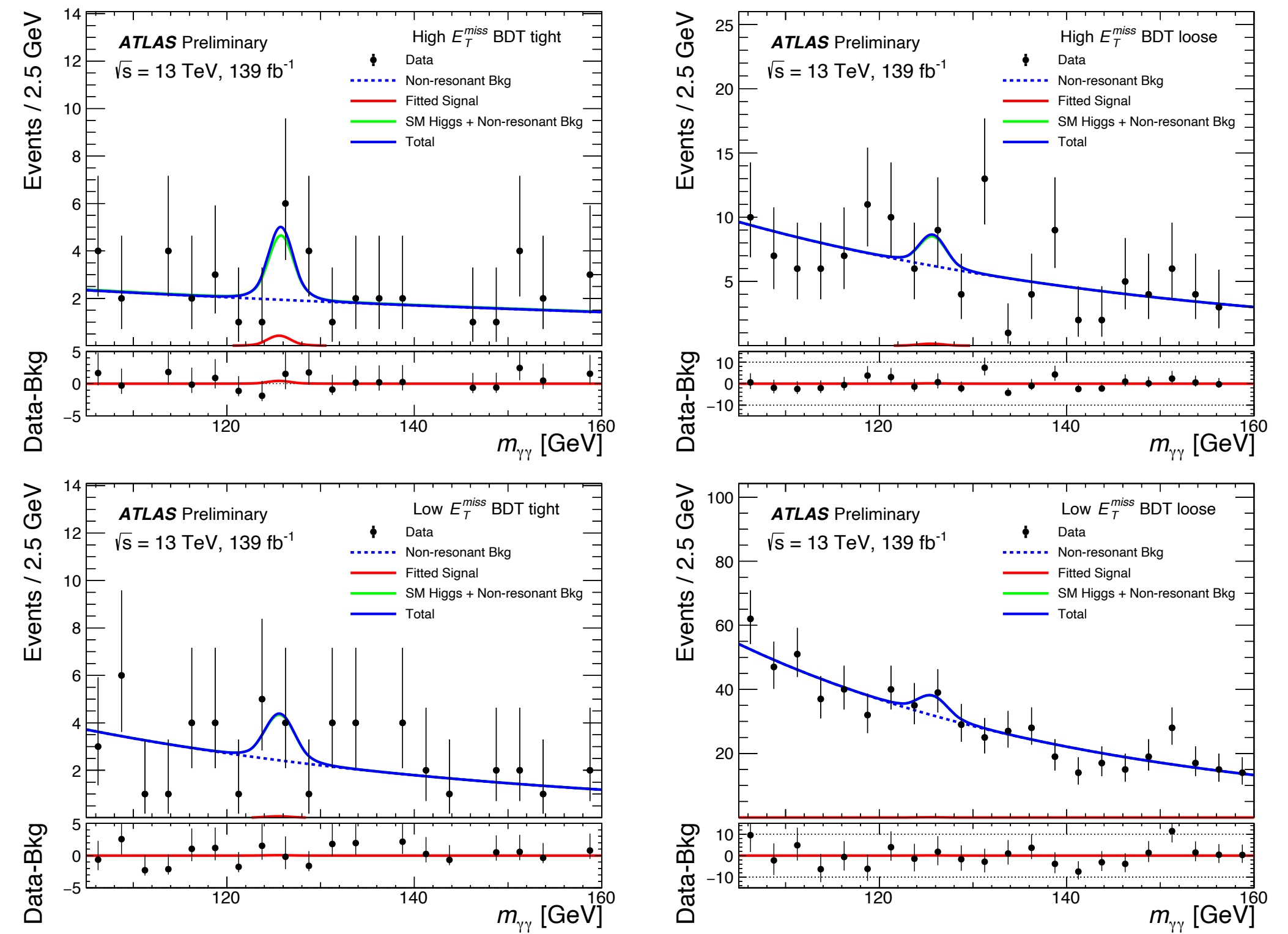
“SM Higgs” peak and signal: $m_{\gamma\gamma}$ shape modelled with double-sided Crystal Ball function (gaussian core and power laws in the tails)

Non-resonant BG modelled by smoothly falling function
 → based on MC templates, parameters estimated from data sidebands

($105 < m_{\gamma\gamma} < 120$ GeV, $130 < m_{\gamma\gamma} < 160$ GeV)

Unbinned maximum likelihood fit performed simultaneously on all 4 signal categories to extract the signal strength

→ *No significant excess above the SM prediction observed*



Post-fit event yields:

ATLAS-CONF-2020-054

Category	High E_T^{miss} BDT tight	High E_T^{miss} BDT loose	Low E_T^{miss} BDT tight	Low E_T^{miss} BDT loose
Data	12	29	11	143
Backgrounds				
SM Higgs boson	3.74 ± 0.25	3.40 ± 0.28	3.12 ± 0.23	9.9 ± 1.5
Non-resonant	7.8 ± 1.3	25.3 ± 2.3	9.8 ± 1.5	130 ± 5
Total	11.6 ± 1.3	28.7 ± 2.3	12.9 ± 1.5	140 ± 5
Z'_B model, $m_{Z'_B} = 1000$ GeV, $m_\chi = 50$ GeV				
Signal yields	0.7 ± 3.1	0.1 ± 0.6	0.1 ± 0.6	0.1 ± 0.6
Z' -2HDM model, $m_A = 800$ GeV and $m_\chi = 500$ GeV				
Signal yields	0.6 ± 3.1	0.1 ± 0.4	0.05 ± 0.26	0.03 ± 0.17
2HDM+a model, $m_A = 600$ GeV, $m_a = 200$ GeV, $\tan \beta = 1.0$, $\sin \theta = 0.35$				
Signal yields	0.6 ± 3.1	0.2 ± 1.2	0.1 ± 0.5	0.1 ± 0.7

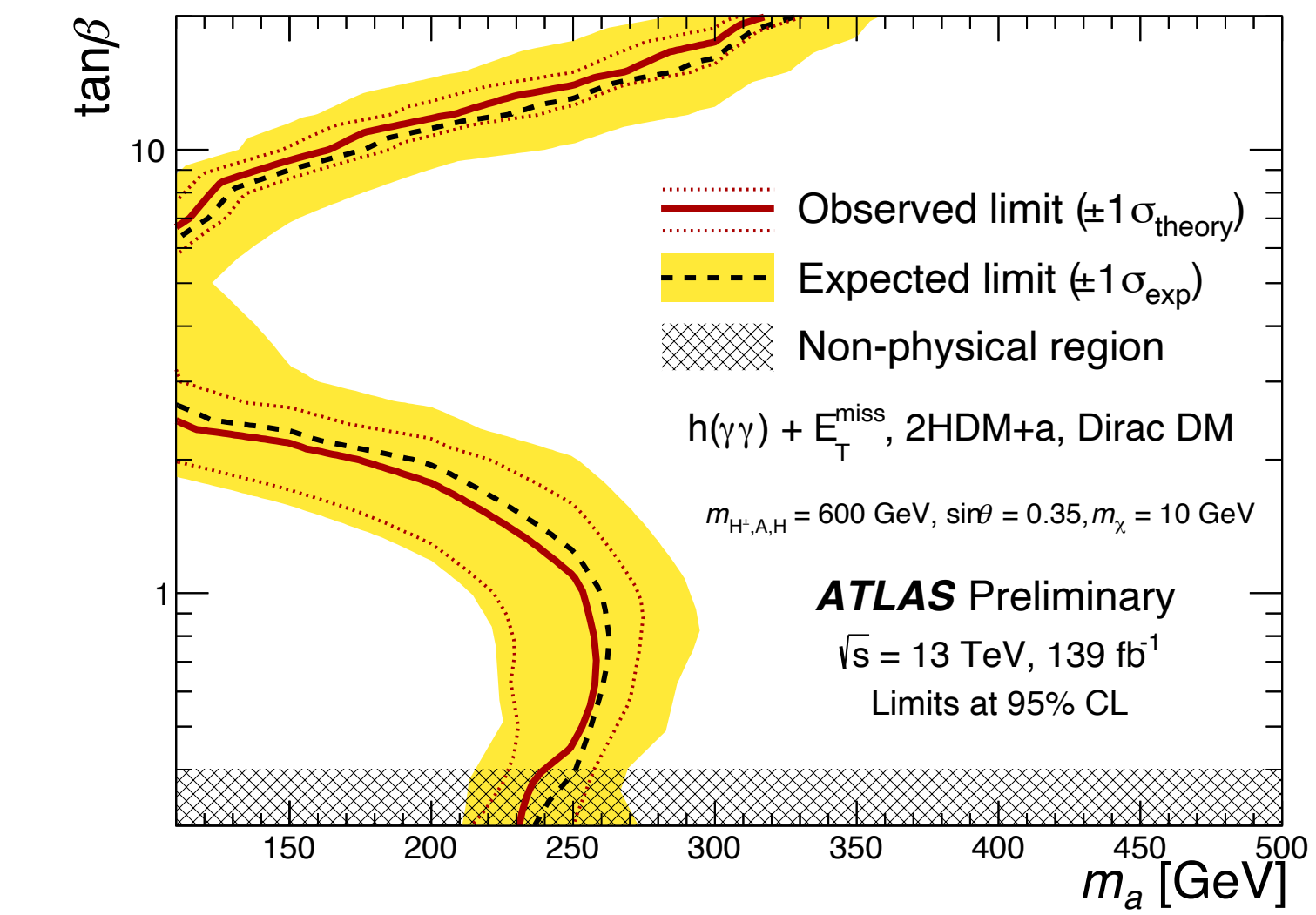
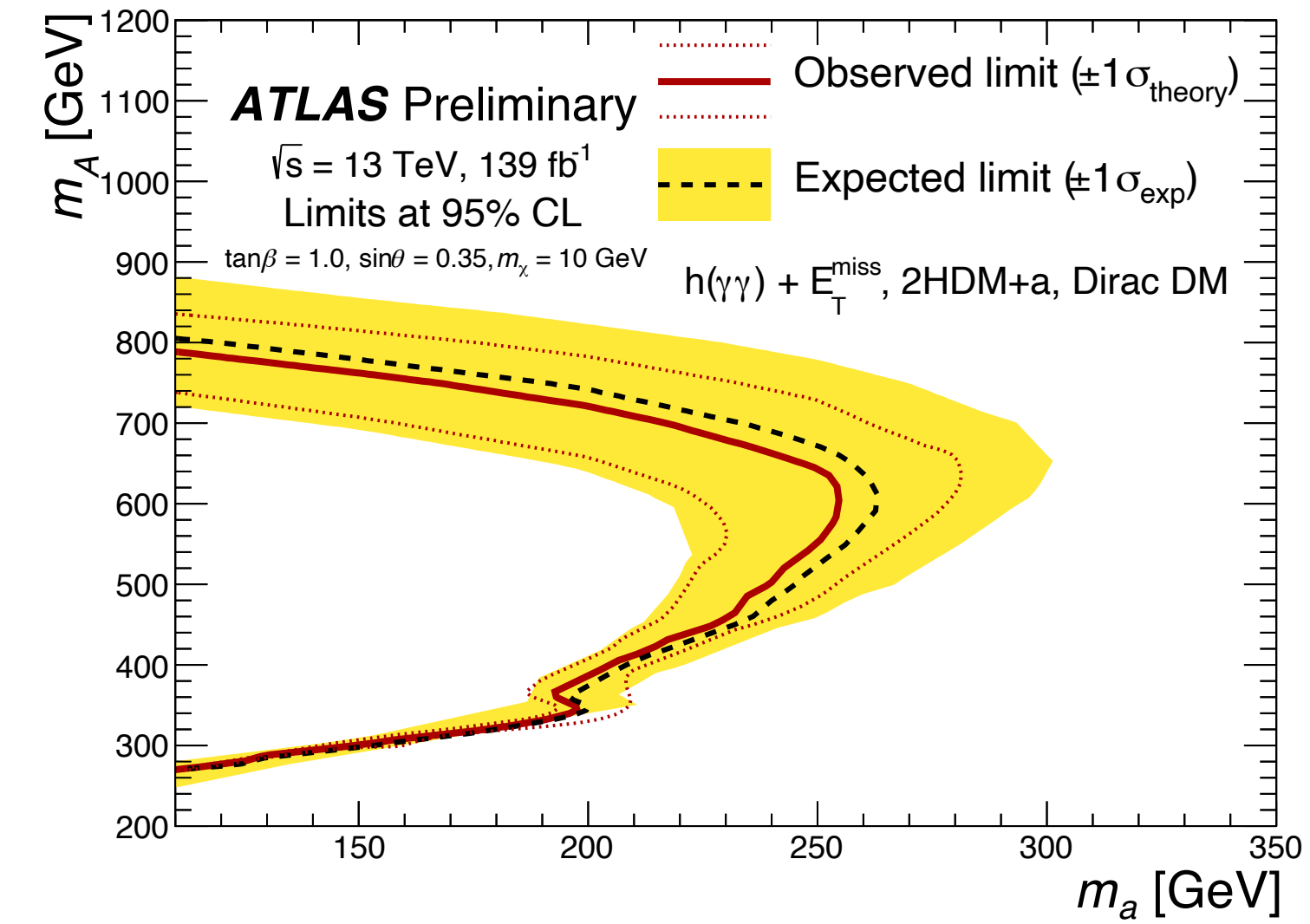
Interpretation

Results are interpreted in the framework of 95% CL upper limits on the cross sections times branching fraction of the considered models

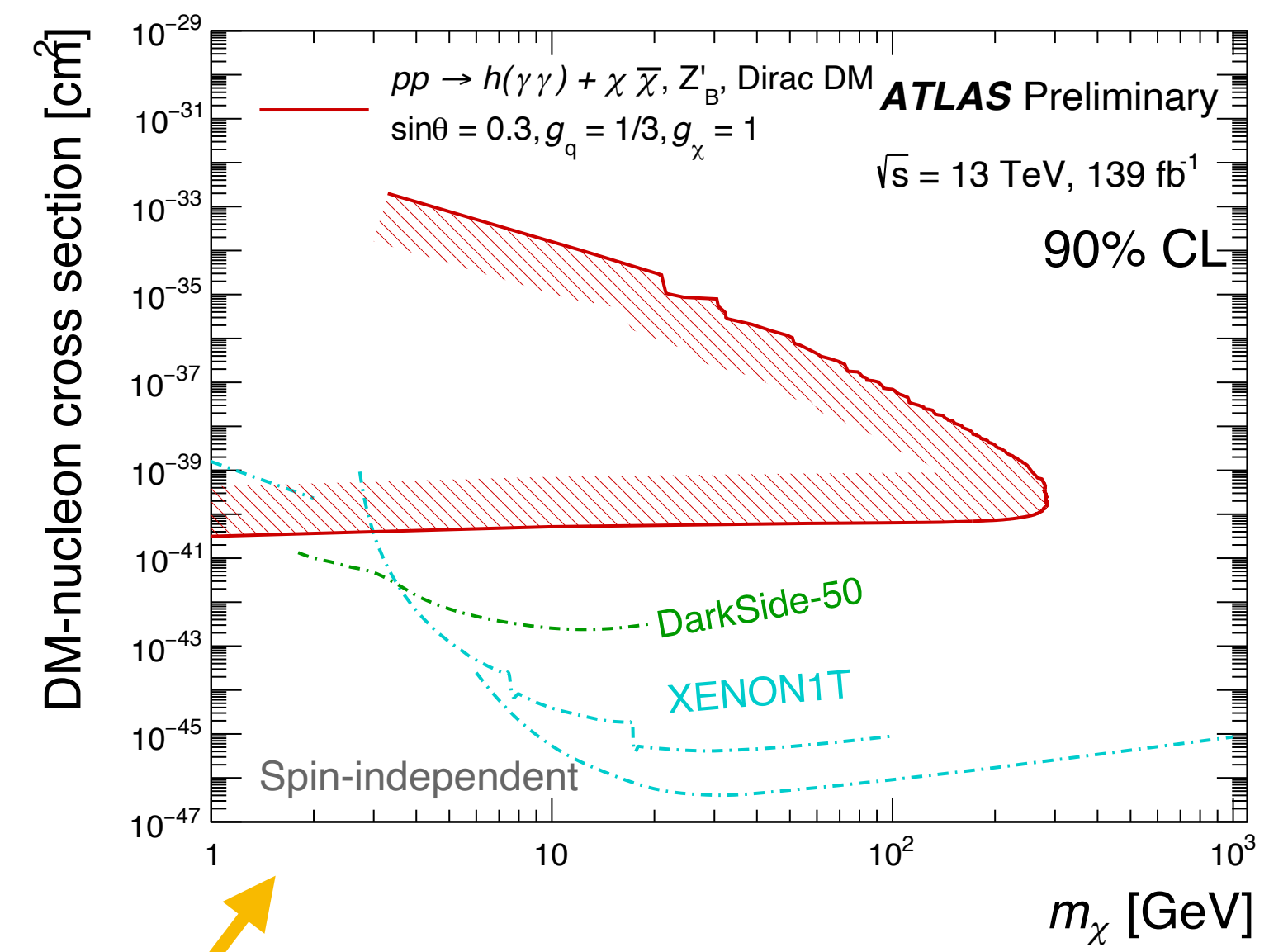
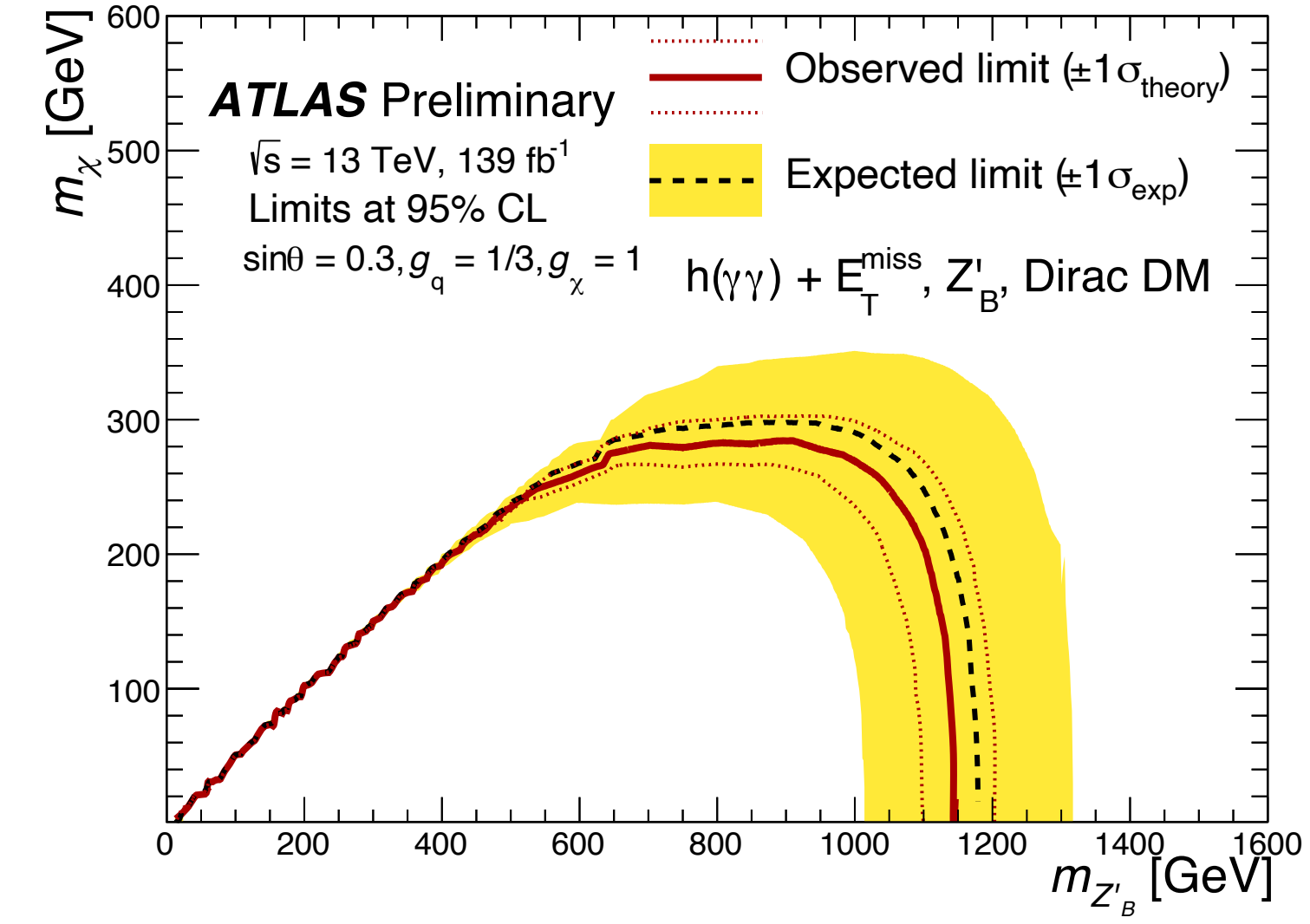
→ displayed as exclusion contours



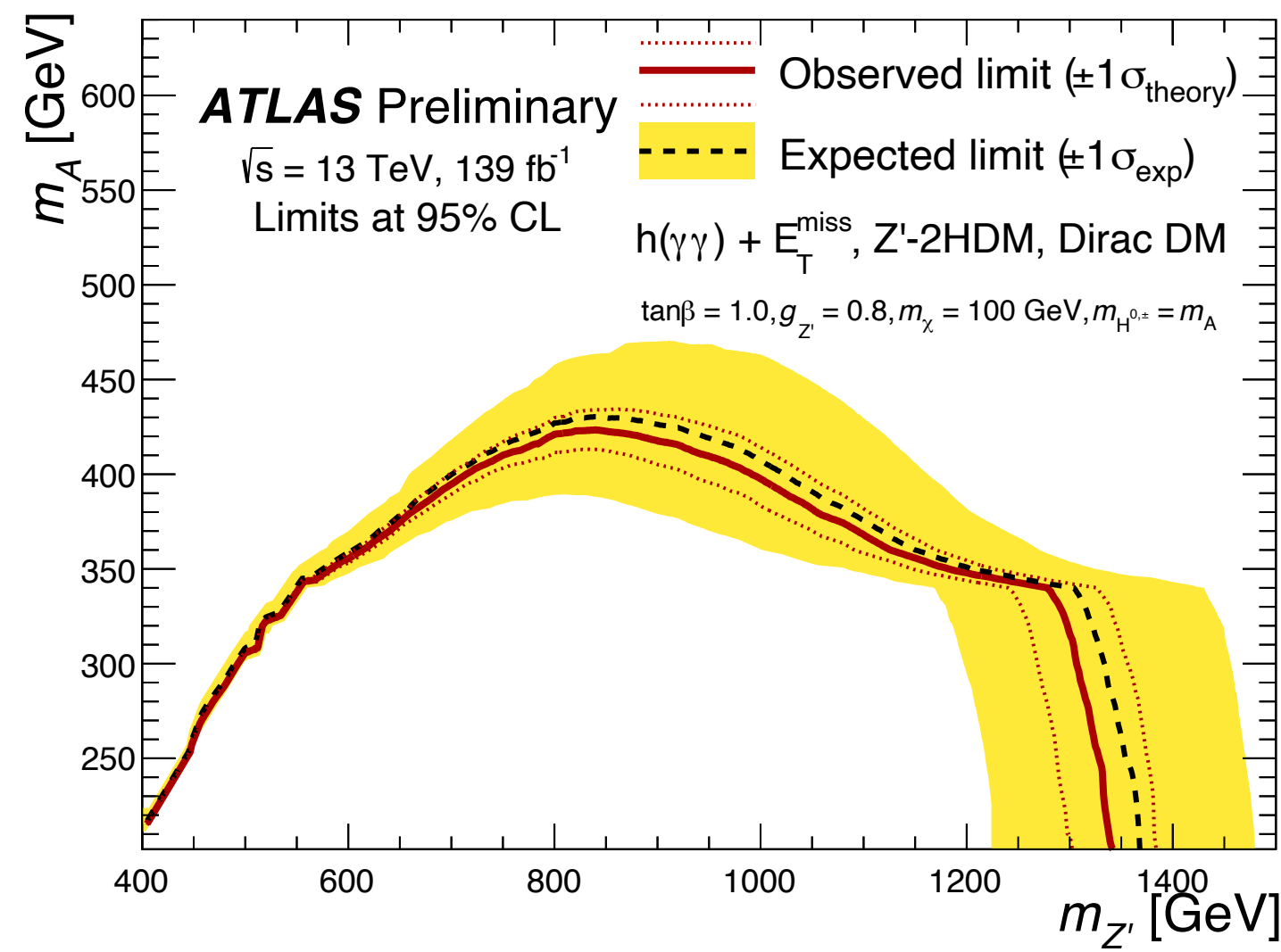
2HDM+a



Z'B



Z'2HDM



only valid for the specified model parameters!

BACKUP

$h \rightarrow \gamma\gamma$ “common” pre-selection

Trigger:

2015 - 2016: 2 loose photons (35 GeV, 25 GeV)

2017 - 2018: 2 *medium* photons (35 GeV, 25 GeV) \leftarrow keep trigger rates constant

- ≥ 1 Vertex reconstructed
- **2 photons** ($p_T > 25$ GeV) within $|\eta| < 2.37$, excluding $1.37 < |\eta| < 1.52$ (crack region)
- tight photon identification and isolation requirements
- (Sub) leading photon needs to pass $p_T/m_{\gamma\gamma} > 0.35(0.25)$ \leftarrow optimised for 125 GeV resonance
- found within $105 \leq m_{\gamma\gamma} \leq 160$ GeV

Jets:

- Particle flow jets
- $p_T > 25$ GeV, $|\eta| < 4.4$
- pileup suppression cuts

Electrons:

- $p_T > 10$ GeV, $|\eta| < 2.47$
- exclude crack region
- medium WP
- $|d_0|/\sigma_{d_0} < 5.0$, $|z_0| \sin \theta < 0.5$

Muons:

- $p_T > 10$ GeV, $|\eta| < 2.7$
- medium WP
- $|d_0|/\sigma_{d_0} < 3.0$, $|z_0| \sin \theta < 0.5$

Missing transverse momentum

(E_T^{miss}) :

- neg. vector sum of the transverse momenta of all hard object
- soft E_T^{miss} reconstructed from tracks

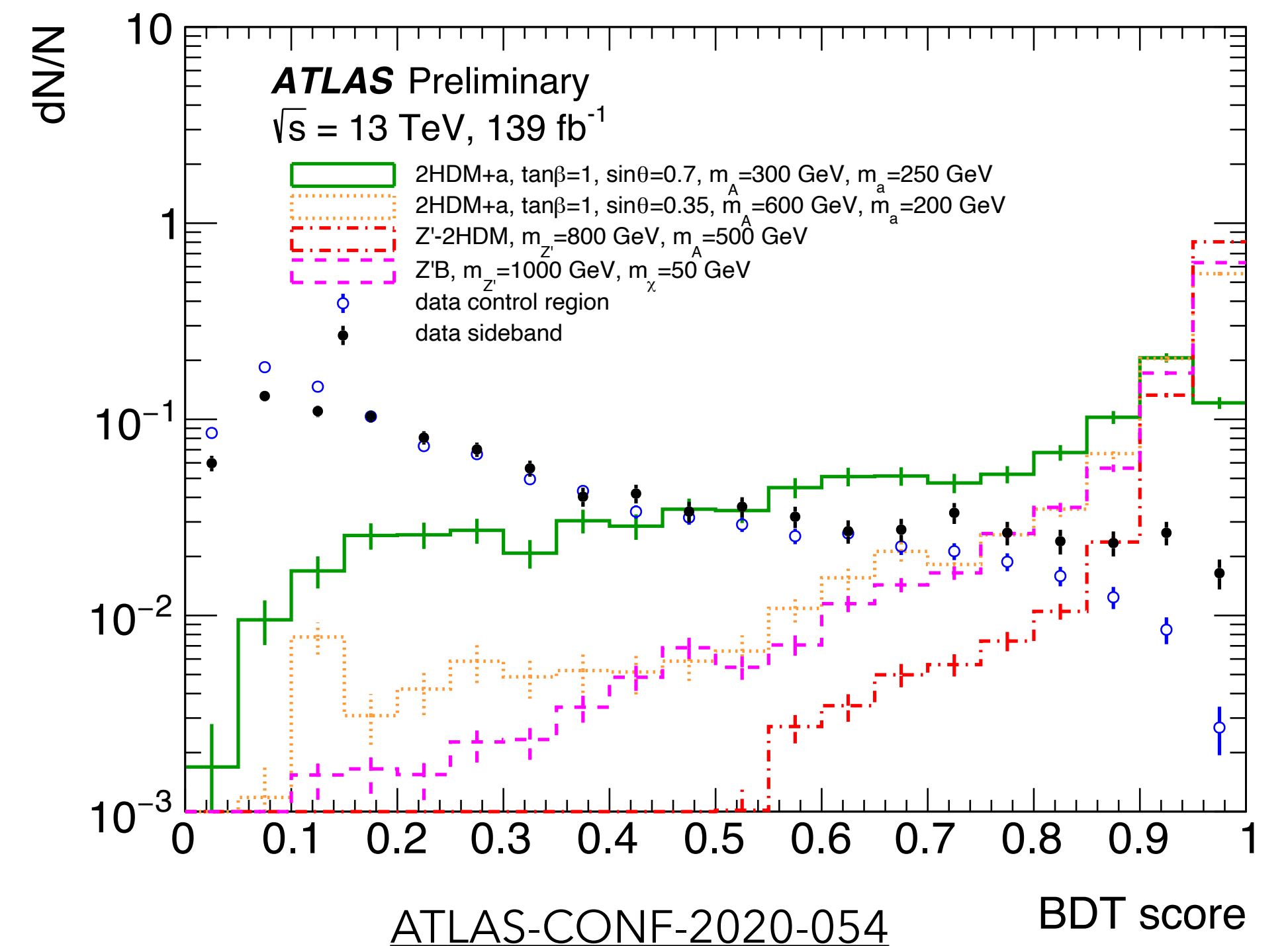
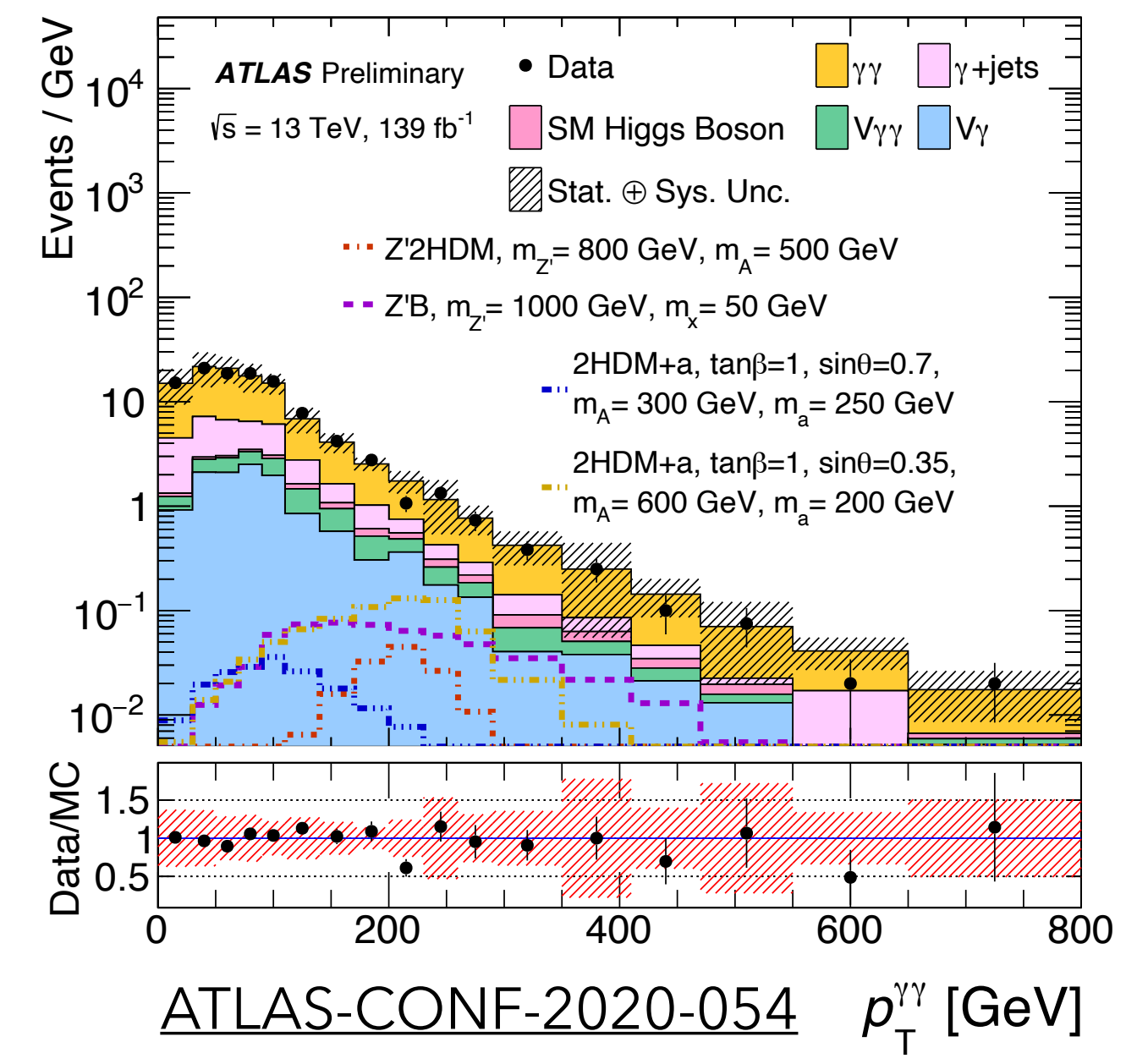
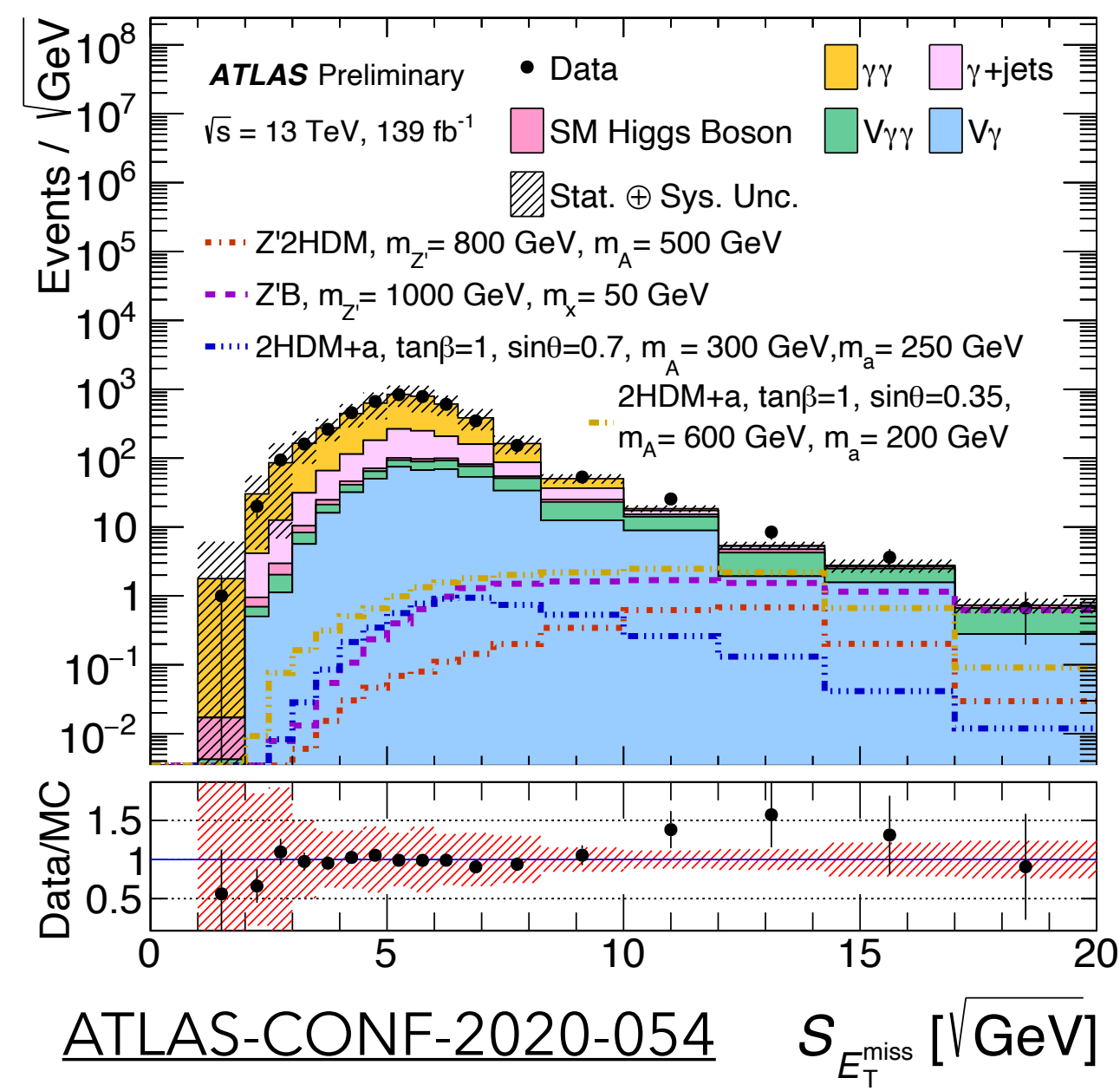
- Diphoton vertex: spatial resolution provided by granularity of EM calorimeter is used to improve the vertex selection in diphoton events (NN)

BDT training

Goal: train single BDT, retain good BG/
Signal separation power for all models
and parameter spaces

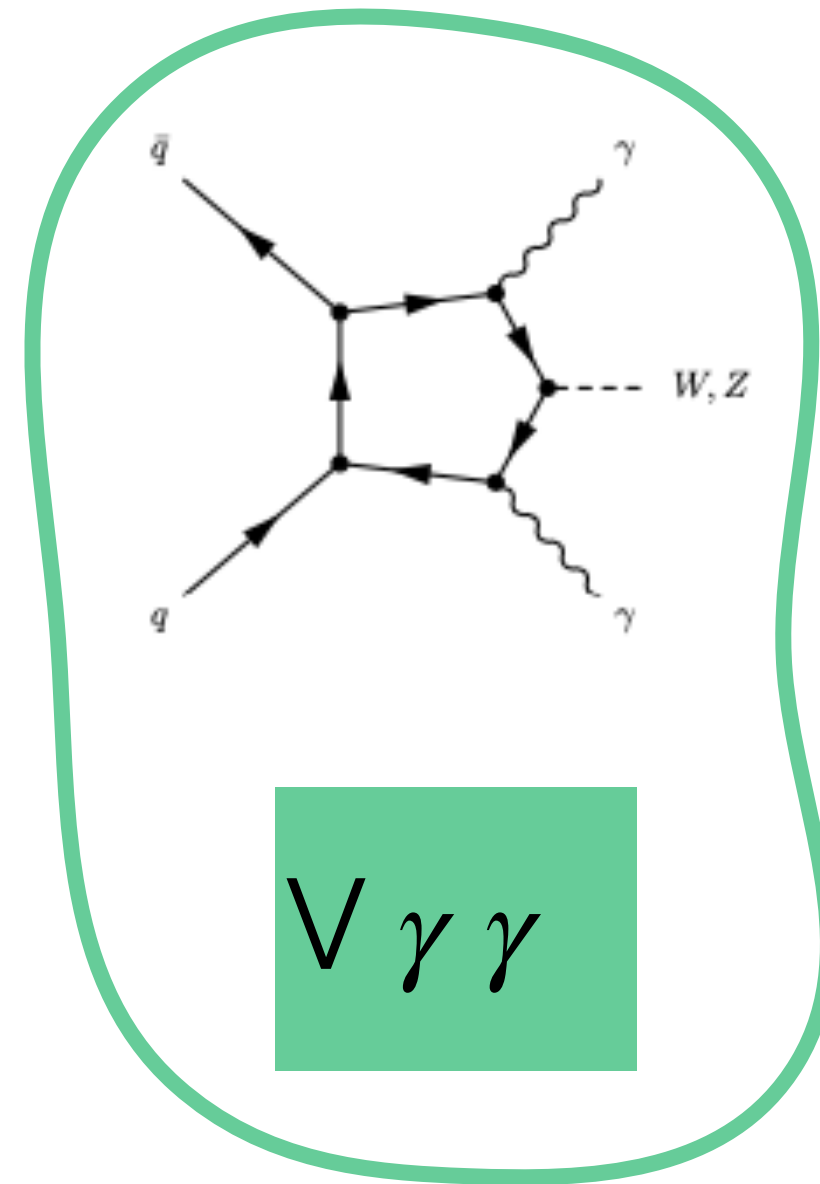
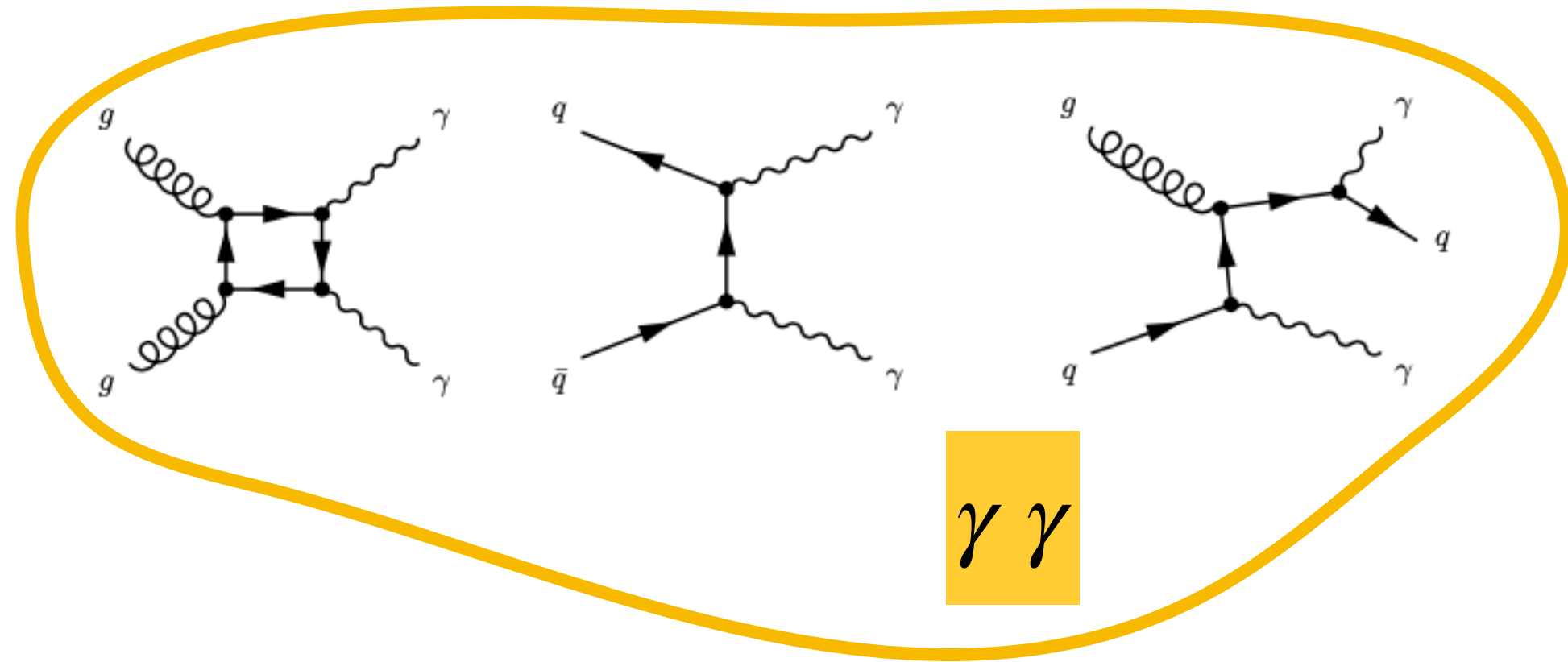
- ▶ Background: Data control region (NTI data, at least one photon fails tight ID or isolation req.)
- ▶ Signal: 2HDM+a *with low $-E_T^{miss}$ spectrum* ($\tan\beta=1, \sin\theta=0.7, m_A=300$ GeV, $m_a=250$ GeV)

⇒ “BG-like” signal chosen to exploit correlations low E_T^{miss} region with the BDT and preserve good sensitivity in the high E_T^{miss} region

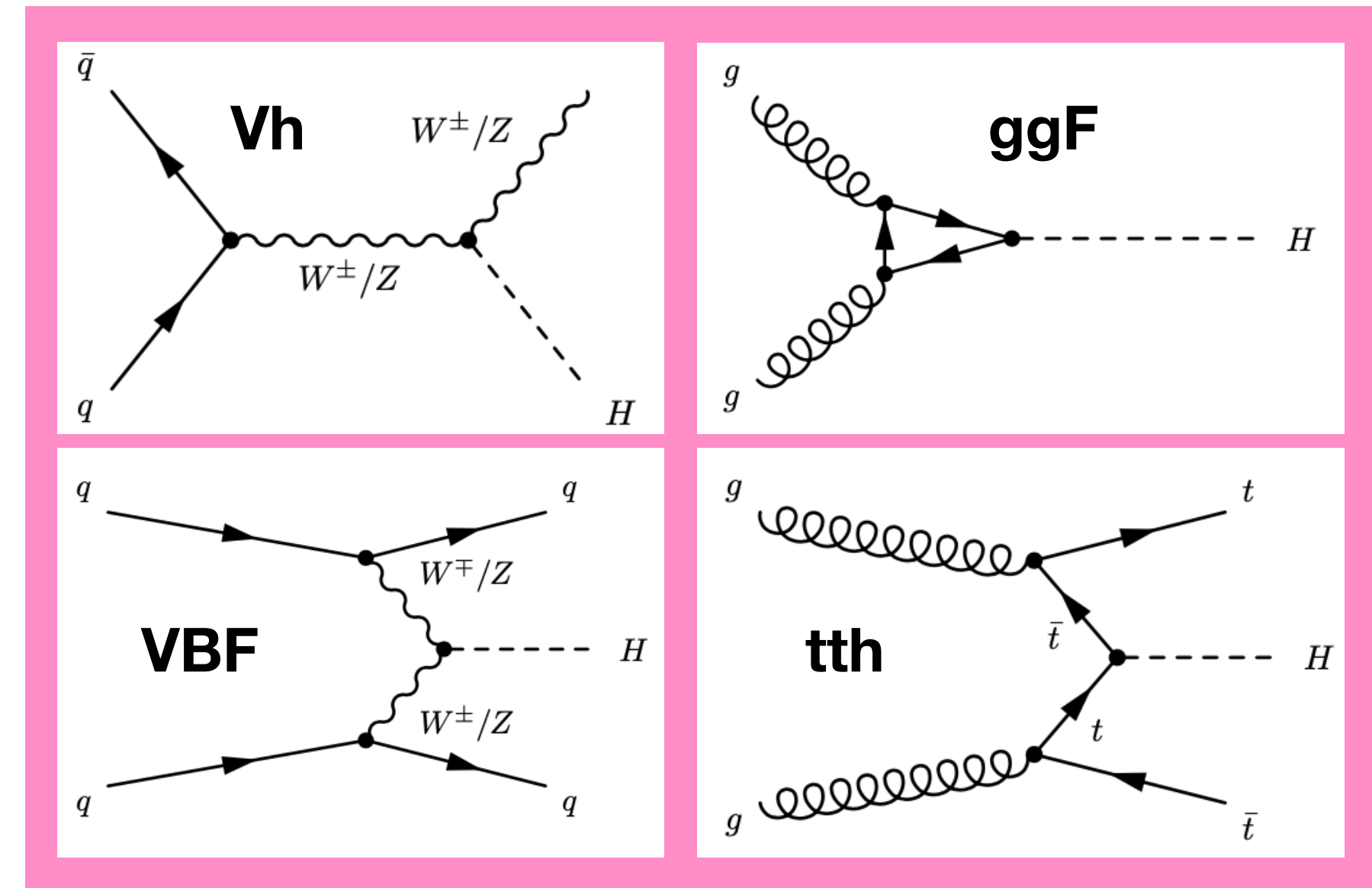


Backgrounds

non-resonant SM backgrounds



peaking SM backgrounds

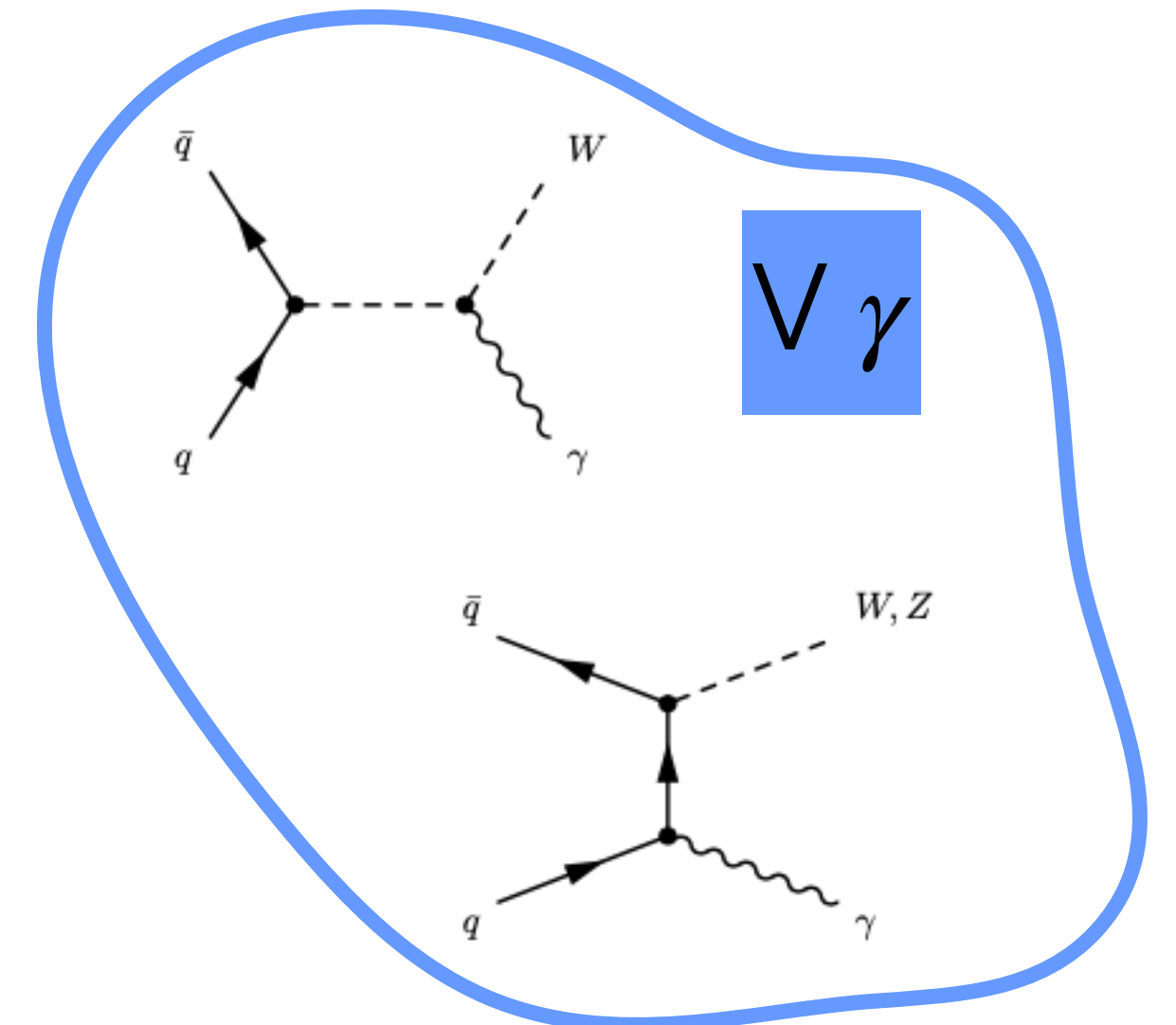
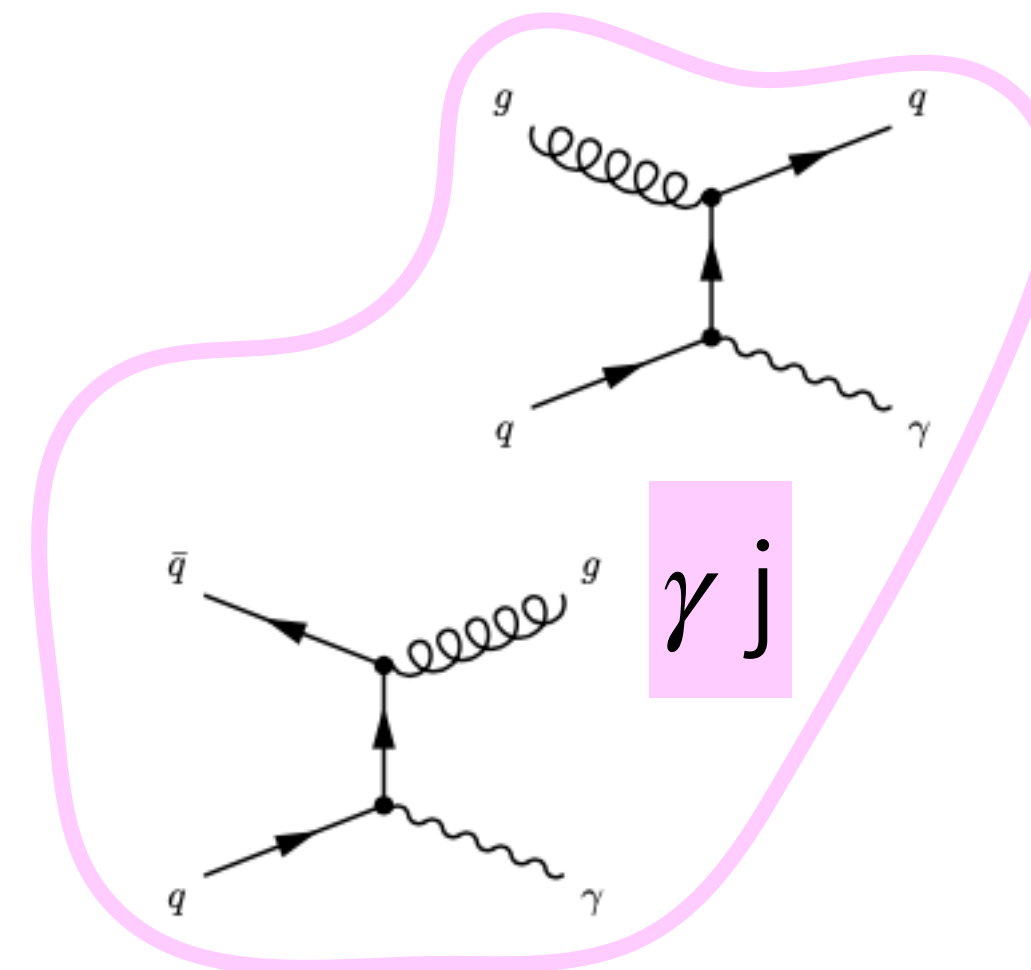


Irreducible backgrounds:

- events with two promptly produced photons

Reducible backgrounds:

- events that contain objects faking photon signatures (e.g. jets, electrons w/o a reconstructed track)
- γj obtained from control region, where one photon fails ID



Exp. and theor. uncertainties

Uncertainty on non-resonant background modelling
(S+B fit to B-only MC, “spurious signal”)

PU reweighting to obtain same profile in data and MC

Signal interpolation method concerns the limit setting only

QCD scale uncertainty: uncertainty on the cross-section from higher order terms

conversion of parton-level information to hadron-level (e.g. ISR&FSR parameters, modelling of UE, hadronization)

→ Table shows representative values for the impact on the most sensitive category (high E_T^{miss} , tight BDT)

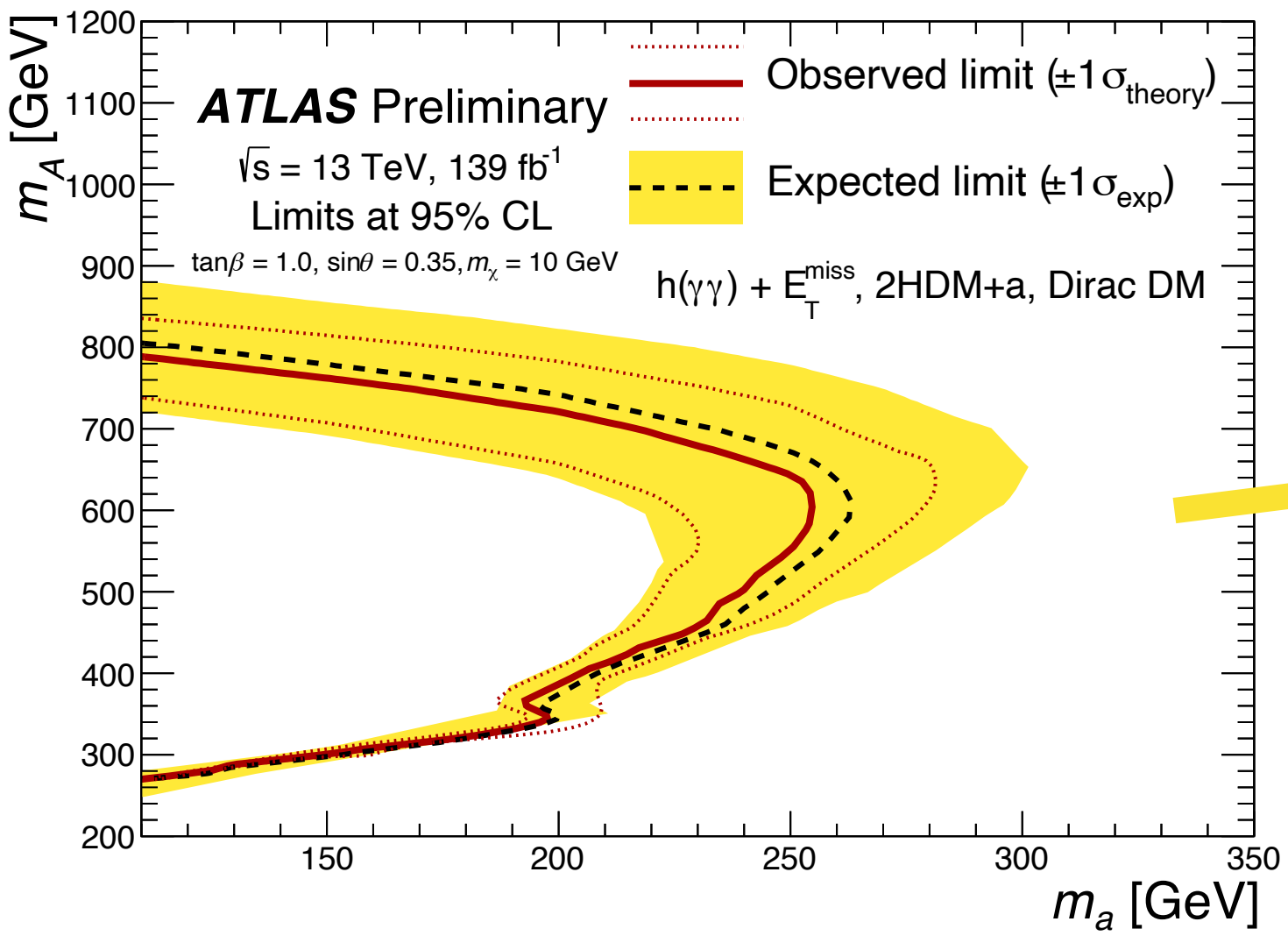
Factorisation & renormalisation scale and PDF+ α_s uncertainty on the signal cross sections are not included in the interpretation of the limits

Source	Signals [%]	Backgrounds [%]	
		SM Higgs boson	Non-resonant background
Experimental			
Luminosity	1.7	1.7	-
Trigger efficiency	1.0	1.0	-
Vertex selection (inclusive cat.)	0.01	0.01	-
Photon energy scale	1.0	1.2	-
Photon energy resolution	0.3	0.4	-
Photon identification efficiency	1.3	1.3	-
Photon isolation efficiency	1.3	1.4	-
ATLFASTII simulation	2.0	-	-
E_T^{miss} reconstruction and jet uncertainty	2.8	1.7	-
Pile-up reweighting	2.3	2.0	-
Signal efficiency interpolation	< 13	-	-
Non-resonant background modelling	-	-	6.8
Theoretical			
Factorization and renormalization scale in migration	1.3	3.5	-
PDF+ α_s in migration	1.2	1.0	-
Factorization and renormalization scale in cross section	-	2.8	-
PDF+ α_s in cross section	-	2.8	-
Multi-parton interactions, ISR/FSR, hadronization	3.0	3.0	-
$B(H \rightarrow \gamma\gamma)$	1.7	1.7	-

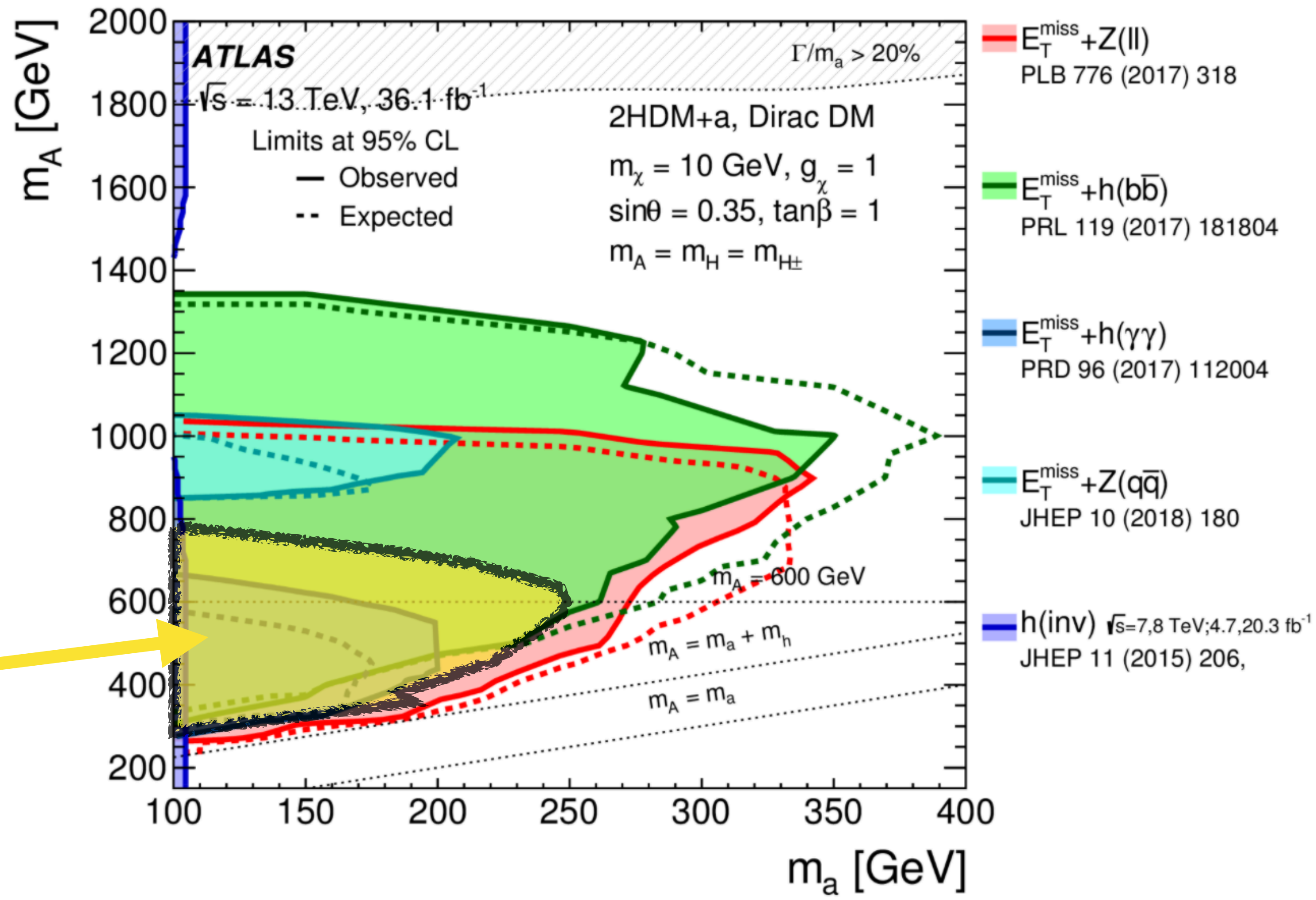
Previous results on 2HDM+a



Comparison with 36fb⁻¹ results



ATLAS-CONF-2020-054



JHEP 05 (2019) 142