h(→bb) associated dark matter search at ATLAS

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DESY

Mono-Higgs

- Experimental signature of DM search at collider:

  - X+MET (call Mono-X)
  - X can be W/Z, jet, γ etc.

- The discovery of the SM Higgs boson provides a new way to probe DM: h + MET (Mono-Higgs)

- Higgs unlikely from an ISR, so the Mono-Higgs would give direct insight into DM coupling to SM particles.

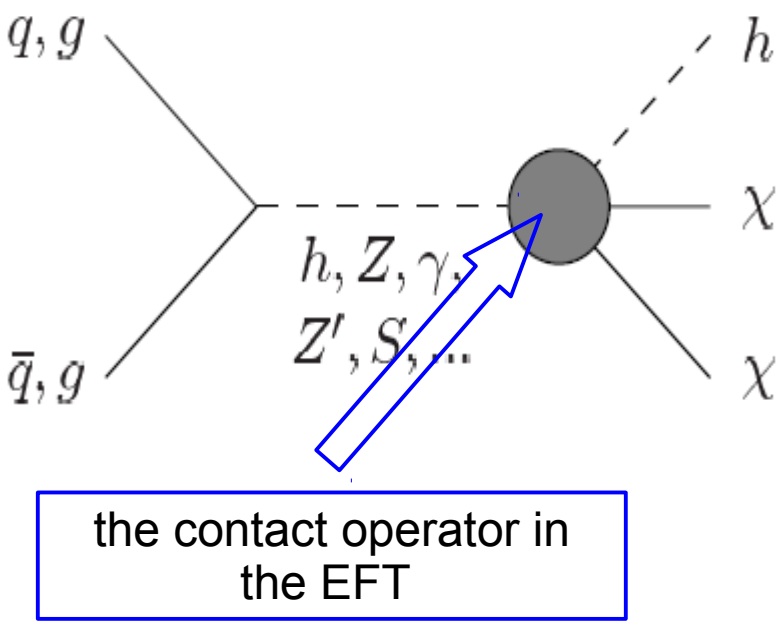
- Not very hard could imagine that h(→bb)+DM can have the best sensitivity, even though it is more complicated:

  - compare the already performed SM Higgs searches that have the same final states as h+DM: Zh→MET+γγ vs. Zh→MET+bb. MET+bb is better

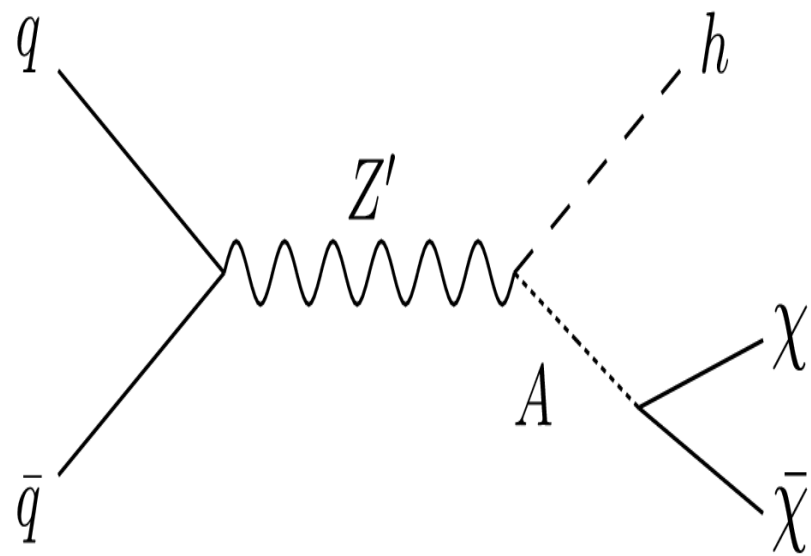
  - h(→bb)+DM can even explore the very high MET regions where the two jets are merging together, using jet-substructure techniques. Note very high MET regions are very important for some models

DM Models

- **EFT Model**
  - introduces different non-renormalizable operators that generate DM
  - more model-independent

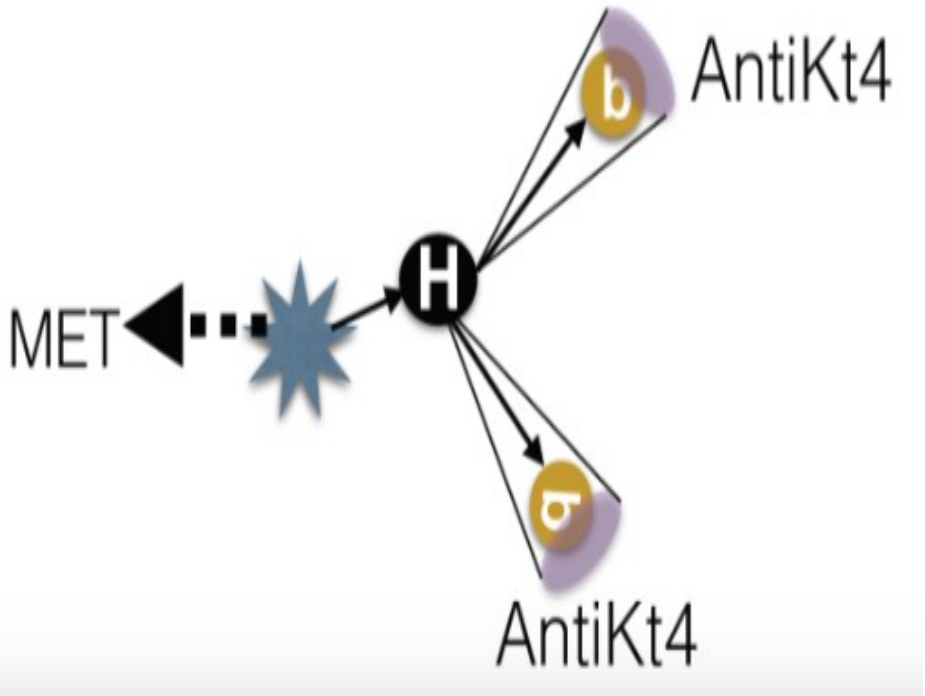


- **Simplified Model**
  - have a minimal number of renormalizable interactions and hence explicitly include the particles at higher masses
  - more model-dependent
  - Z'-2HDM used in this paper

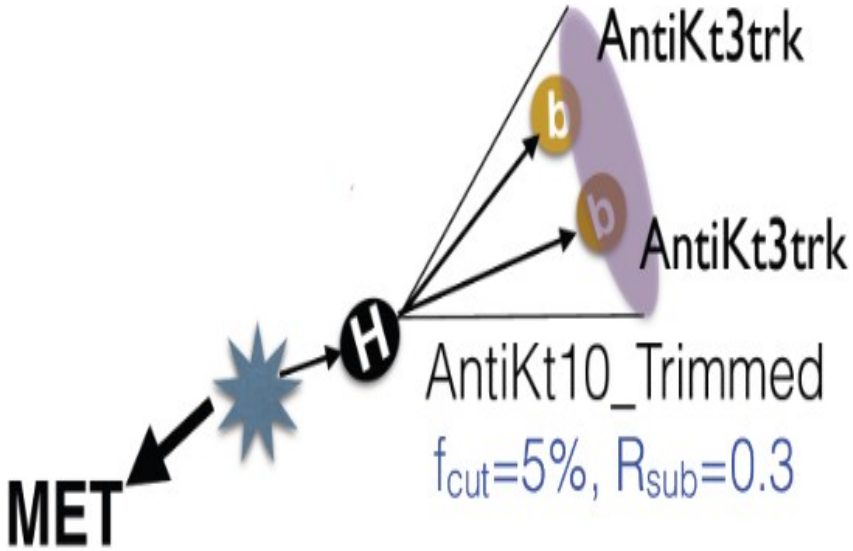


Resolved and Boosted Analysis

- Resolved R=0.4 cone-size jets, and they are well separated
- Mainly for low MET region



- In high MET region the jet activities are tending to merge together
- R=1.0 fat-jets used to recover signal acceptance
  - do b-tagging on the sub track-jets inside the fat-jets



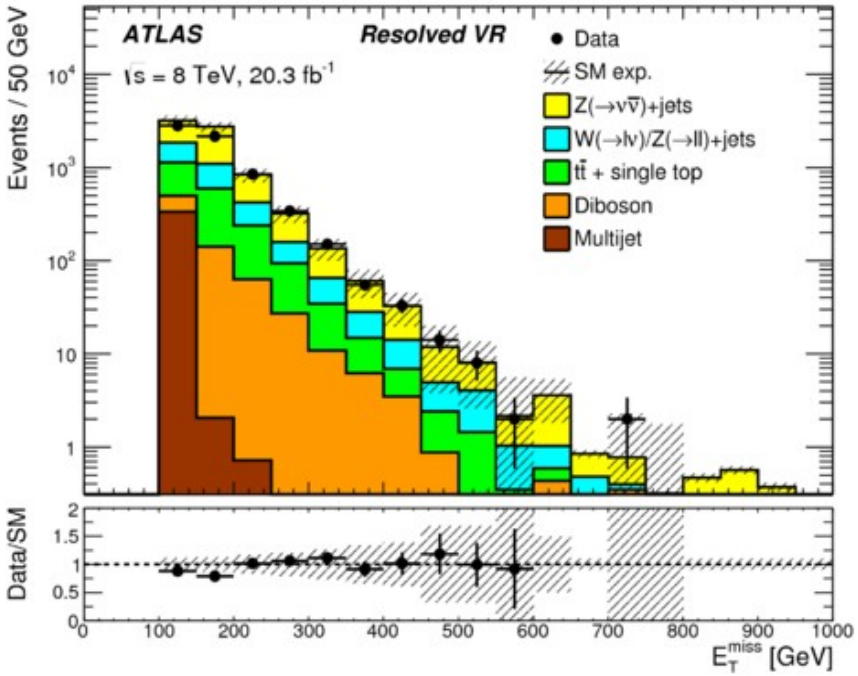
Selections

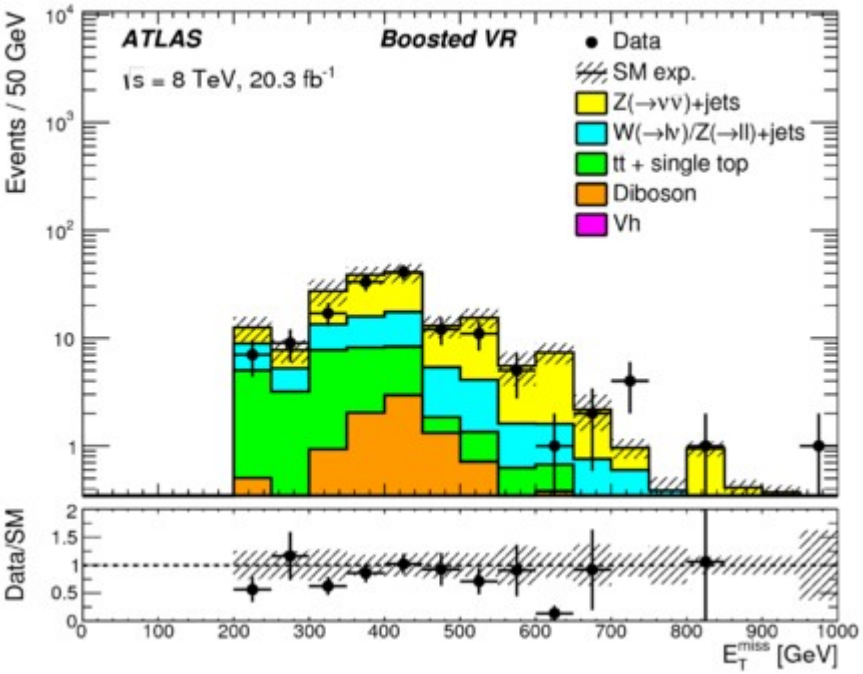
	Resolved	Boosted
$\Delta\phi_{\min}(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, j_i)$	> 1.0	> 1.0
Jet multiplicity	$2 \leq n_j \leq 3$	$n_J \geq 1$ $n_{j^{\mathrm{trk}}} \geq 2$
b-jet (60% eff.) p_{T}	$p_{\mathrm{T}}^{b_1} > 100$ GeV	-
b-jet multiplicity	$n_b \geq 2$ (60% eff.)	$n_{b^{\mathrm{trk}}} = 2$ (70% eff.)
Jet p_{T}	$p_{\mathrm{T}}^{b_2} > 60$ GeV when $n_j = 3$ $p_{\mathrm{T}}^{j_2} > 100$ GeV when $n_j = 3$	$p_{\mathrm{T}}^{J_1} > 350$ GeV
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})$	-	$< \pi/2$
Dijet separation	$\Delta R(j_1, j_2) < 1.5$	-
Invariant mass	90 GeV $\leq m_{b_1 b_2} \leq 150$ GeV	90 GeV $\leq m_{J_1} \leq 150$ GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 150, 200, 300, or 400 GeV	> 300 or 400 GeV

- Both analysis use sliding MET window strategy
  - look for the MET cut having the best sensitivity

Background Component

- Let's use the regions that are most close to the signal-regions to show the components
  - At least 1 b-tagged; resolved: Mjj ∉ [60-150] GeV, boosted: M(J) ∉ [90-150] GeV





- Dominated background:Z(→vv) + jets, then W+jets, ttbar, di-bosons

Z(→νν) + jets and QCD Estimation

- **Transfer function** to data-driven Zνν+jets from γ+jets/Z→μμ+jets (which we can obtain high purity control-regions); MET in γ+jets/Z→μμ+jets is rebuilt without the leading γ/μs:

$$Z\nu\nu_{bkg} = (Data - Bkg_{MC})_{\gamma+jetsCR} \boxed{\frac{Z\nu\nu_{MC}}{\gamma + jets_{MC}}}$$

  - Z→μμ+jets for MET < 200 GeV, γ+jets for MET>200 GeV

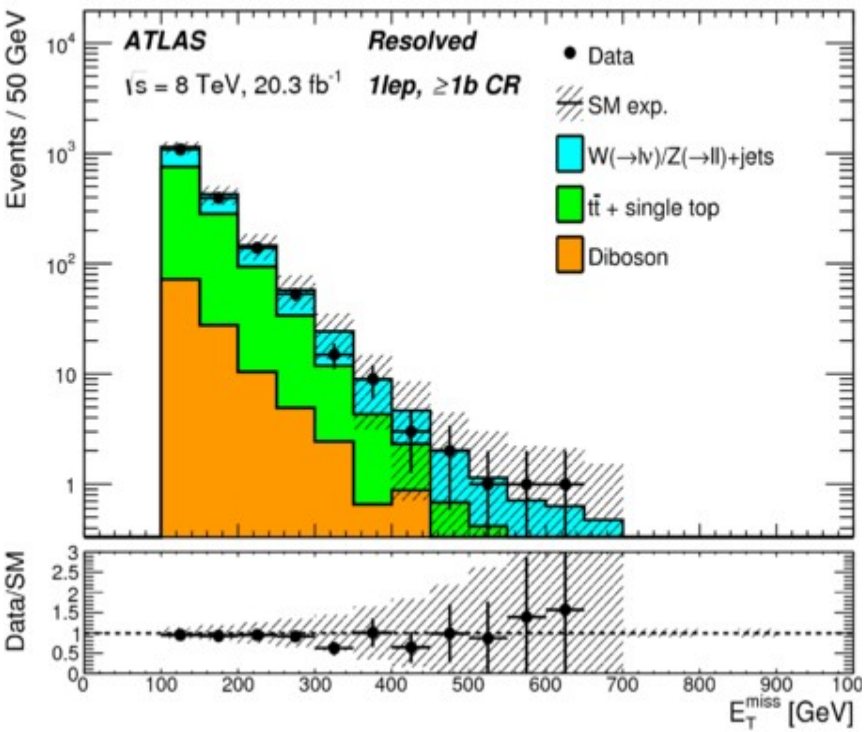
  - TF: center calue is from fitting at 0-btag selection stage, uncertainty from MC and variation at different selection stages.

- **QCD:**

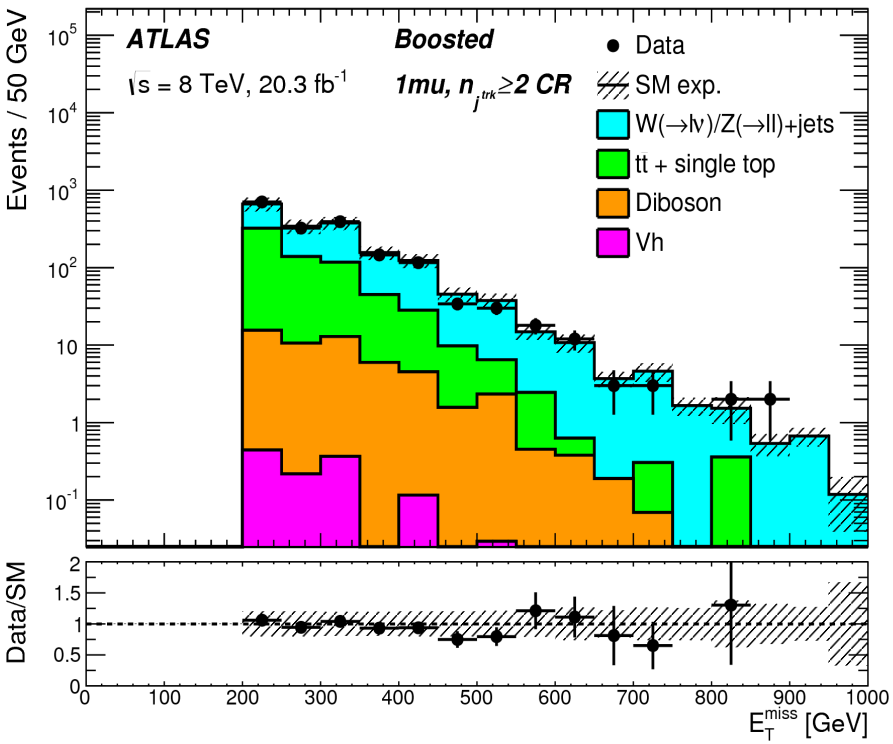
  - Resolved channel: jet smearing method. Smear jet from QCD control region into signal region, to mimic the high MET
  - Boosted channel: ABCD, base on two uncorrelated variables
  - Small in both cases, especially for boosted channel

W+jets and ttbar

- **Resolved**



- **Boosted**



- Shape from simulation, normalization from fitting to data
- Plots are after fitting, good agreement

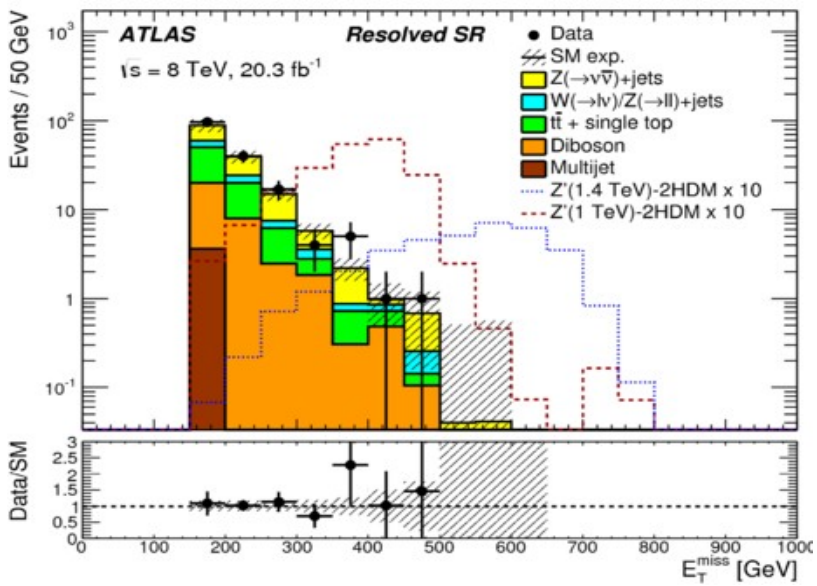
Uncertainties

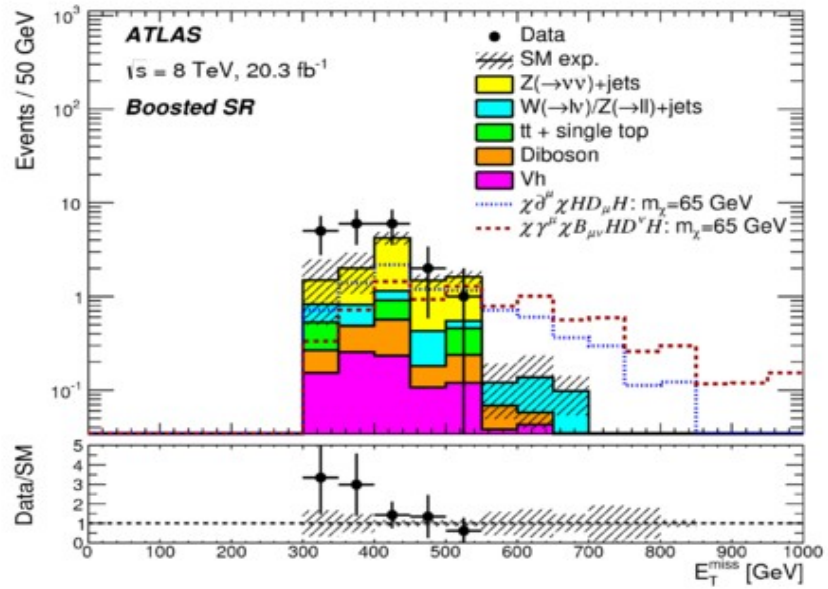
	Resolved (%)		Boosted (%)	
	Z'-2HDM	Total Background	EFT	Total Background
b-tagging	14	6–10	13	5.3
JES(small+large-R)	2.4	1.8–2.8	3.0	2.2–8.5
JER(small+large-R)	0.6	3.5–5.4	1.0	1.5–4.6
JMS(large-R)	-	-	1.0–2.5	1.3
JMR(large-R)	-	-	2.0	1.6
JVF (small-R)	0.7	0.5–0.9	1.1	0.2–0.6
$E_{\mathrm{T}}^{\mathrm{miss}}$ resolution/scale	0.0	< 0.2	0.5	0.1–0.8
Pileup	0.3	0.1	0.1–1.7	2.4
Cross-section	10	6.0–11	10	7.6–8.1
PDF and α_{s}	3.8–7.0	2.9	2.0–21	1.8
$Z(\nu\bar{\nu})$ transfer function	-	1.4–2.7	-	5.4–5.8
Total syst.	18–19	10–16	13–25	13–14

- For signals, dominated uncertainties are from b-tagging and theory
- For backgrounds, several uncertainties are similarly important

Final Yields & Plots

	Resolved				Boosted	
E_T^{miss}	> 150 GeV	> 200 GeV	> 300 GeV	> 400 GeV	> 300 GeV	> 400 GeV
$Z(\rightarrow \nu\bar{\nu})$+jets	48 ± 32	21 ± 5	2.9 ± 1.1	0.3 ± 0.3	7.0 ± 2.0	5.2 ± 1.6
Multijet	3.7 ± 3.1	0.02 ± 0.02	–	–	$< 0.0 \pm 0.1$	$< 0.0 \pm 0.1$
$t\bar{t}$ & single-top	48 ± 10	17 ± 3.8	1.6 ± 0.5	0.3 ± 0.1	0.8 ± 0.5	0.6 ± 0.4
W+jets & Z+jets	15 ± 3.4	6.2 ± 1.5	1.1 ± 0.3	0.3 ± 0.1	1.4 ± 0.7	0.8 ± 0.4
Diboson	29.4 ± 7.5	13.2 ± 3.8	2.8 ± 1.0	0.6 ± 0.3	0.9 ± 0.5	0.6 ± 0.3
$Vh(bb)$	5.0 ± 0.7	4.2 ± 0.6	1.0 ± 0.2	0.3 ± 0.1	1.0 ± 0.2	0.6 ± 0.1
Total background	148 ± 30	62 ± 7.5	9.4 ± 1.8	1.7 ± 0.5	11.2 ± 2.3	7.7 ± 1.7
Data	164	68	11	2	20	9





•Small excess (~2σ) in the boosted channel. LEE checked, not very signal-like.

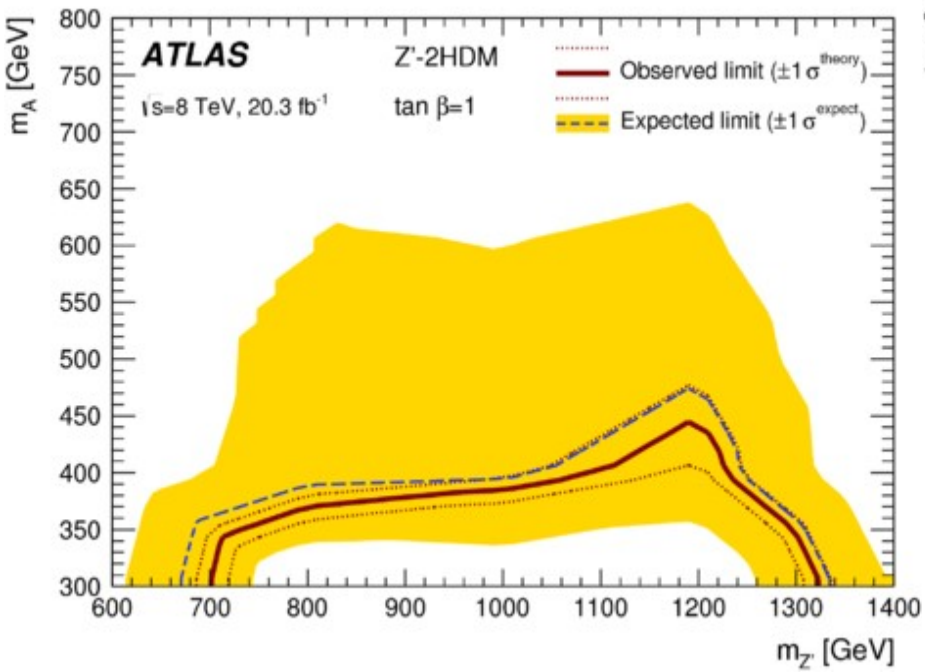
Model-independent upper limits

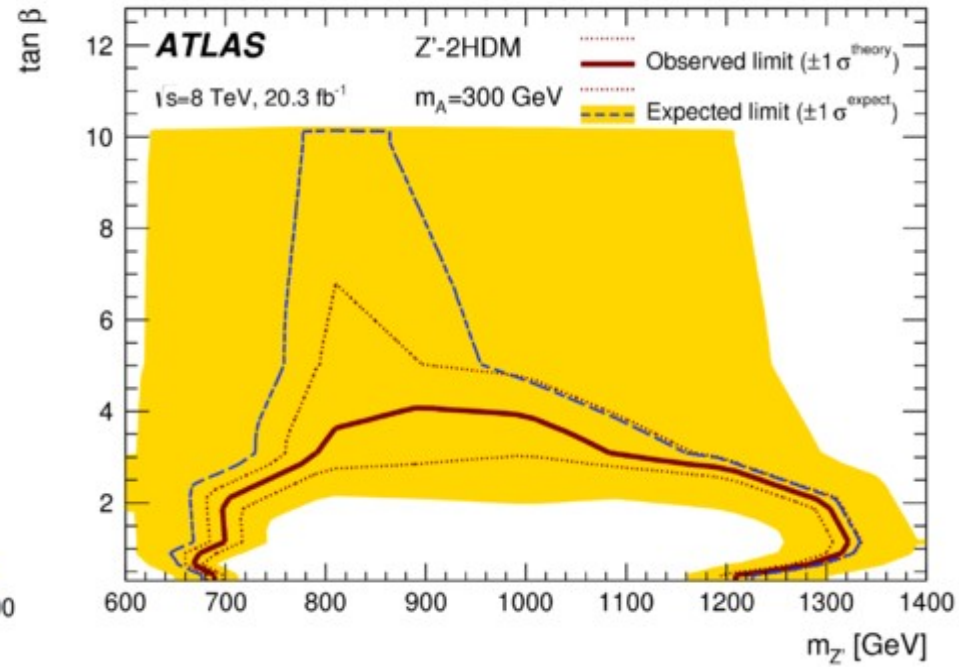
	E_T^{miss}	N_{obs}	N_{bkgd}	$\langle\sigma_{vis}\rangle^{95}_{obs}$[fb]	$N_{BSM}{}^{95}_{obs}$	$N_{BSM}{}^{95}_{exp}$	$p(s=0)$
Resolved	> 150 GeV	164	148	3.6	74	63^{+22}_{-14}	0.31
	> 200 GeV	68	62	1.3	27	$21^{+8.4}_{-3.9}$	0.28
	> 300 GeV	11	9.4	0.49	9.9	$8.2^{+3.4}_{-1.9}$	0.31
	> 400 GeV	2	1.7	0.24	4.8	$4.7^{+1.6}_{-1.0}$	0.39
Boosted	> 300 GeV	20	11.2	0.90	18	$9.9^{+4.2}_{-2.9}$	0.03
	> 400 GeV	9	7.7	0.43	8.8	$7.7^{+3.3}_{-2.0}$	0.37

- Counting limit-setting (no signal shape used) ⇒ Model-independent
- σ_vis = N_obs/Lumi.
- Model-independent limit numbers may provide useful information for theorists and others

Interpretation (Resolved Analysis)

- The interpretation is focusing on Simplified Model





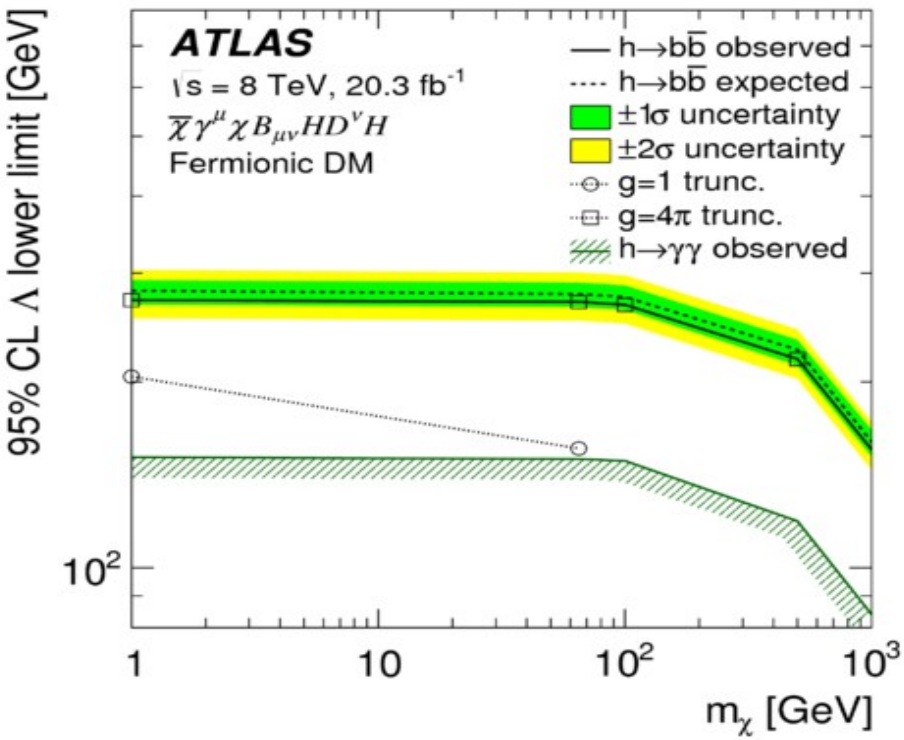
- A – Z' plane. Exclude mZ' from 700 - 1300 GeV for mA < 350 GeV

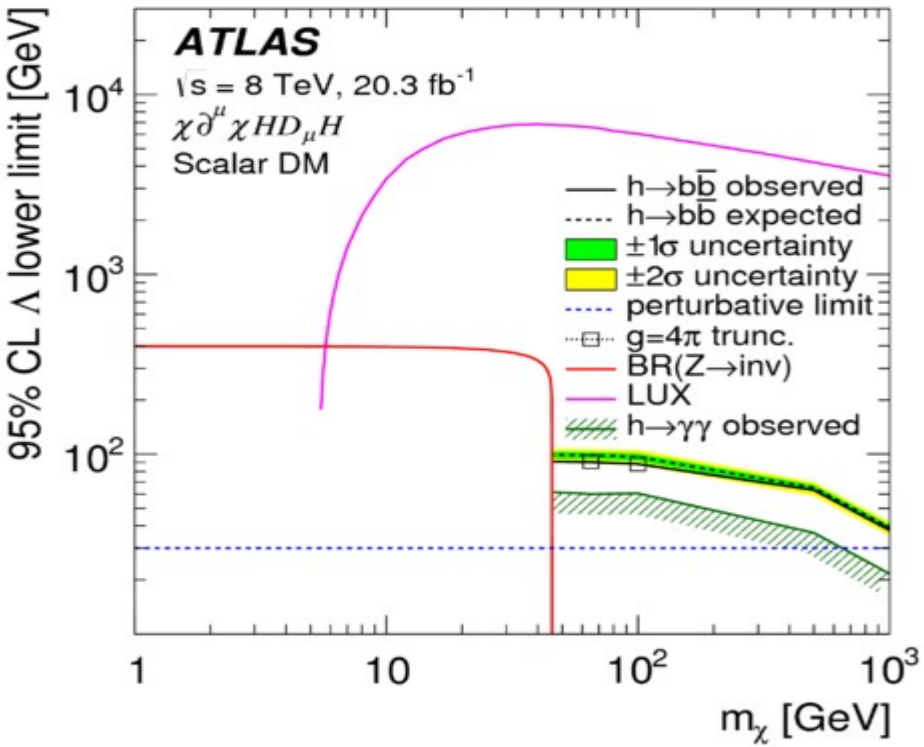
- tanβ>=0.3: perturbative requirement
- tanβ <10: direct searches for A
- Exclude mZ'=700-1300GeV for tanβ <2

- Alignment limit (α=β-π/2) used here where h is SM-like

Interpretation (Boosted Analysis)

- The interpretation is focusing on EFT Model





- Truncation is used to make the validity of EFT (momentum transferred < mass of the heavy mediator)
- Direct comparison between Mono-h(→γγ) and Mono-h(→bb) on the plots

Summary

- Present new DM search of ATLAS: mono-Higgs (→bb)
- Two channels: resolved (Z'-2HDM) & boosted (EFT)
- Exclusion limits set in both (mZ', mA0) and (mZ', tanβ) 2-D parameter spaces for Z'-2HDM model

Also set limits on Λ(λ) for different EFT operators

- a few times stronger than mono-h(γγ) which is also published
- Model-independent upper limit numbers provided