Search for dark matter at CMS

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On behalf of CMS collaboration

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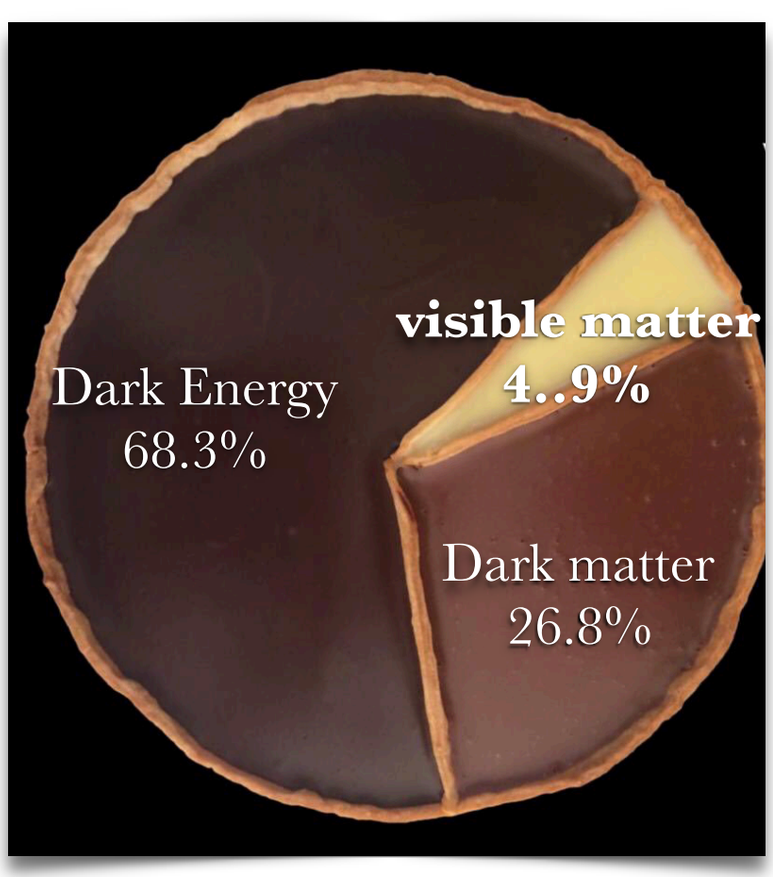
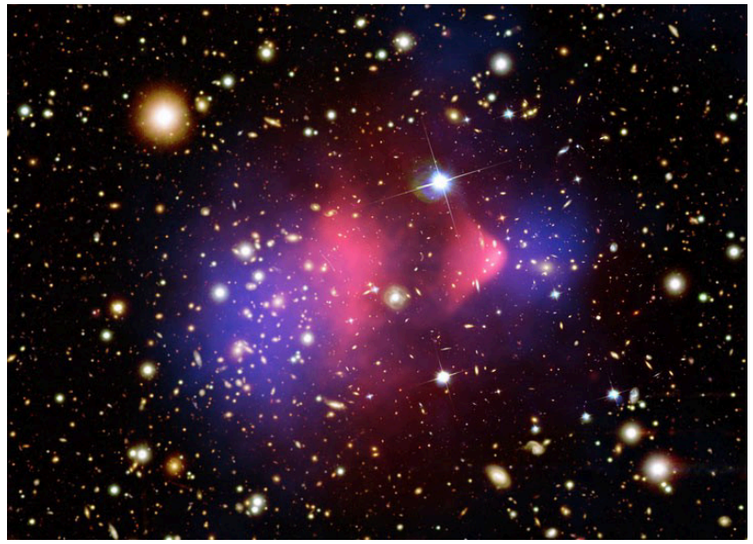
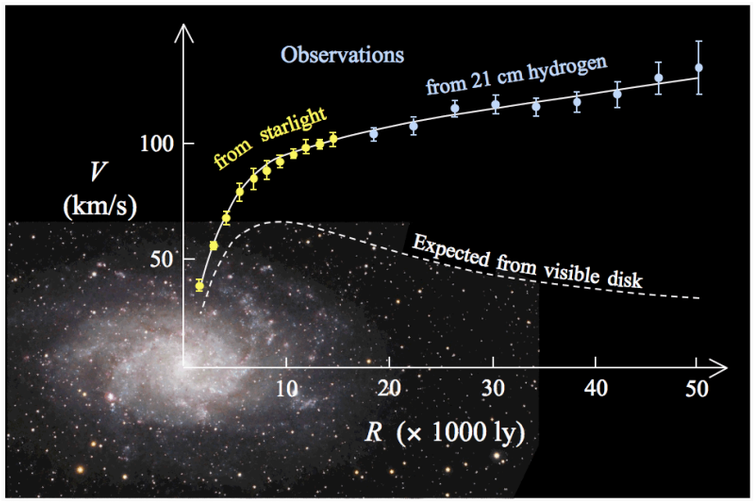
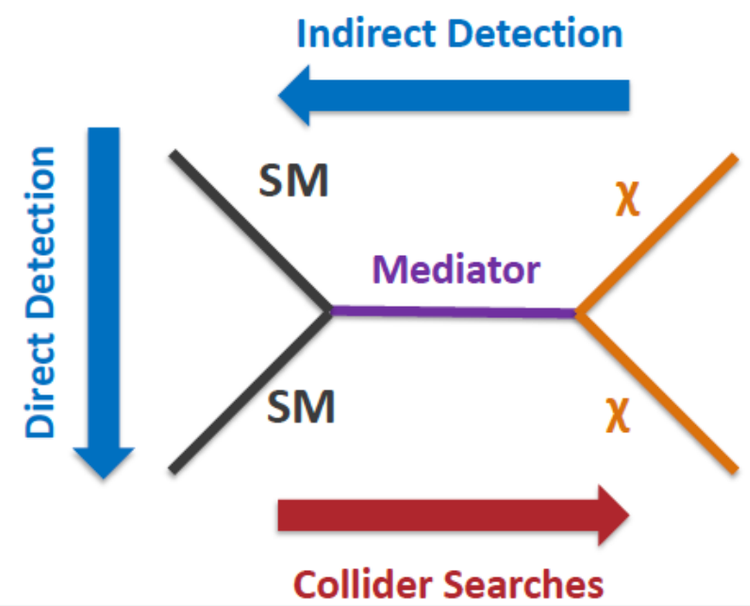


Dark Matter

- ☑ **Why search for dark matter (DM)?**
  - ☐ Multiple evidences from astronomical observations.
- ☑ **What do we know about DM?**
  - ☐ Interacts gravitationally
  - ☐ electrically neutral
- ☑ **What to look for in collider experiments?**
  - ☐ One of the most favourite DM candidate is weakly interacting massive particle (WIMP).
- ☑ Collider searches compliment evidence from direct and indirect detection.

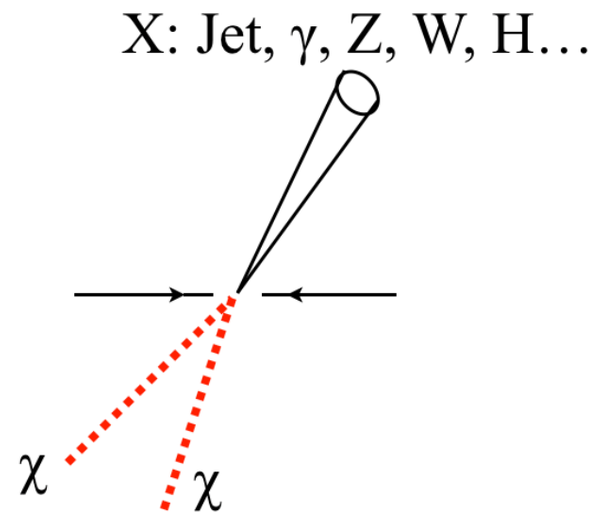




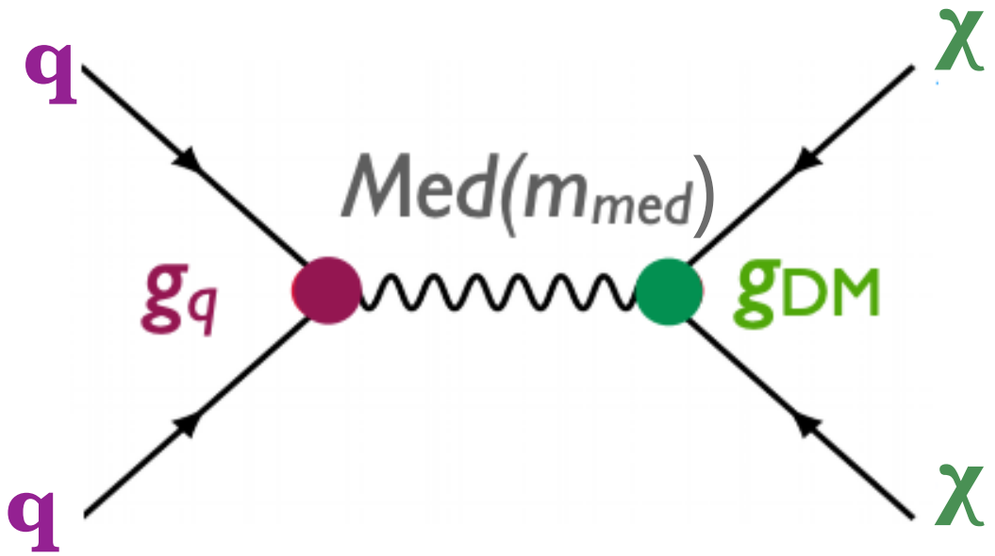


Simplified DM models

- ☑ CMS has very rich dark matter search program.
  - ☐ most common search is to look for the invisible dark matter produced in association with well understood SM particle(s) (dubbed as mono-X).
- ☑ Dark matter production described using "simplified models".
  - ☐ DM particle couples SM via a mediator
  - ☐ s-channel mediators
- ☑ Main parameters:
  - ☐ Spin/Parity of mediator
  - ☐ couplings g_q and g_{med}
  - ☐ Mediator and DM mass

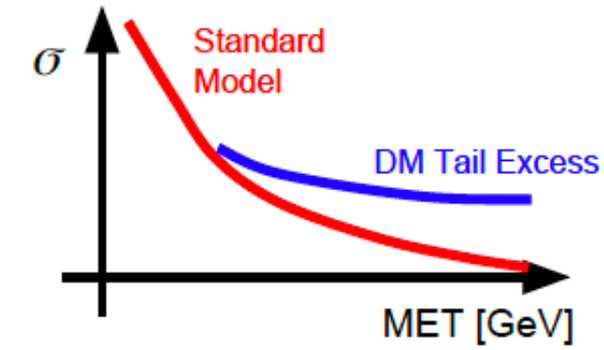


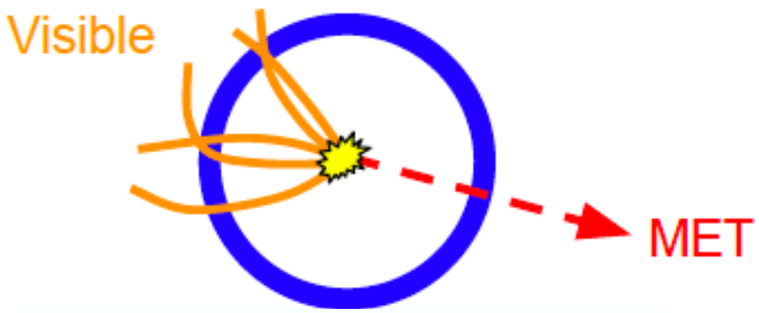
	vector	axial-vector
spin-1	$g_q \sum_q V_\mu \bar{q}\gamma^\mu q$	$g_q \sum_q A_\mu \bar{q}\gamma^\mu\gamma^5 q$
spin-0	scalar: $g_q \frac{\phi}{\sqrt{2}} \sum_f y_f \bar{f} f$	pseudoscalar: $g_q \frac{iA}{\sqrt{2}} \sum_f y_f \bar{f}\gamma^5 f$

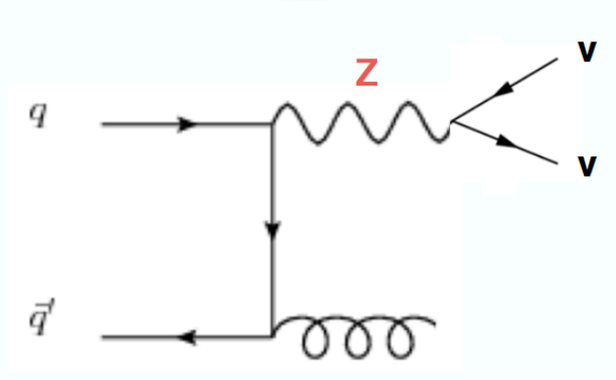


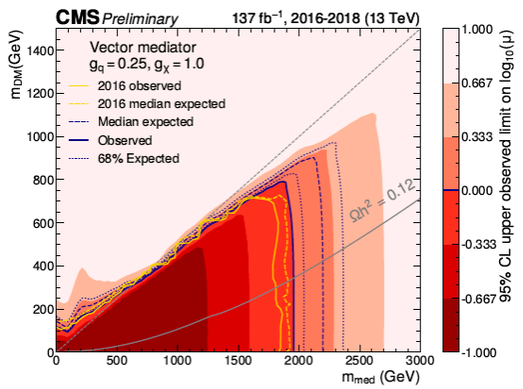
General Strategy

- ☑ Similar strategy is used by many mono-X searches.
  - search for excess of events in the MET tails.
  - select events with X (veto all other objects to reduce the SM backgrounds
  - measure the dominating backgrounds using dedicated control regions (to correct for simulation normalisation and/or shapes)
  - Constrain/exclude the phase space of a given simplified model.









List of analyses

The dark matter search programme at CMS is very vast.
Only a small set of analyses are chosen for today.

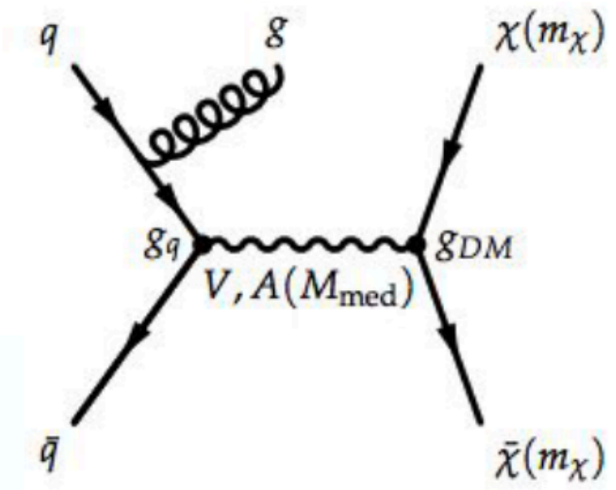
Analysis	Dataset	Document
mono-jet/V	137 fb^{-1}	EXO-20-004
dark-h WW	137 fb^{-1}	EXO-20-013
mono-Z(ll)	137 fb^{-1}	EPJC 81 (2021) 13
mono-Higgs combination	36 fb^{-1}	JHEP 03 (2020) 25

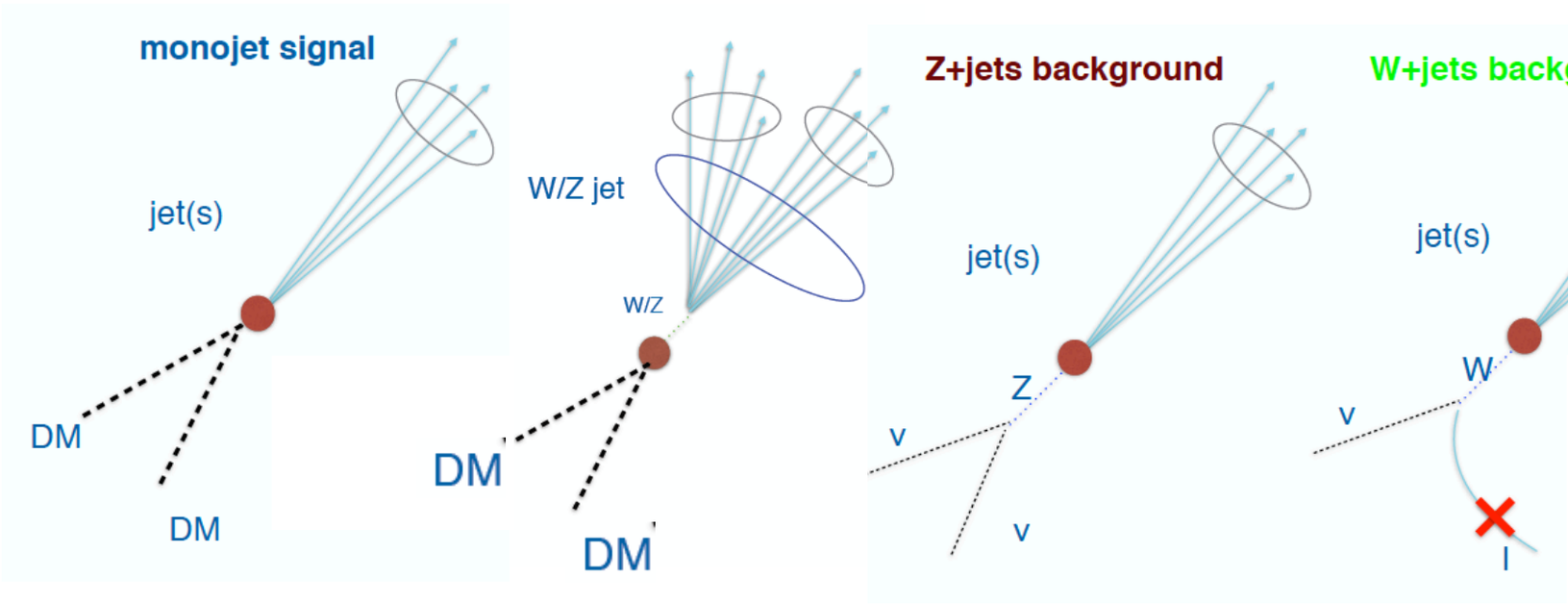
For full list of Dark matter searches

mono-jet/V

☑ Detector signature: **high p_T jet** and **nothing else**

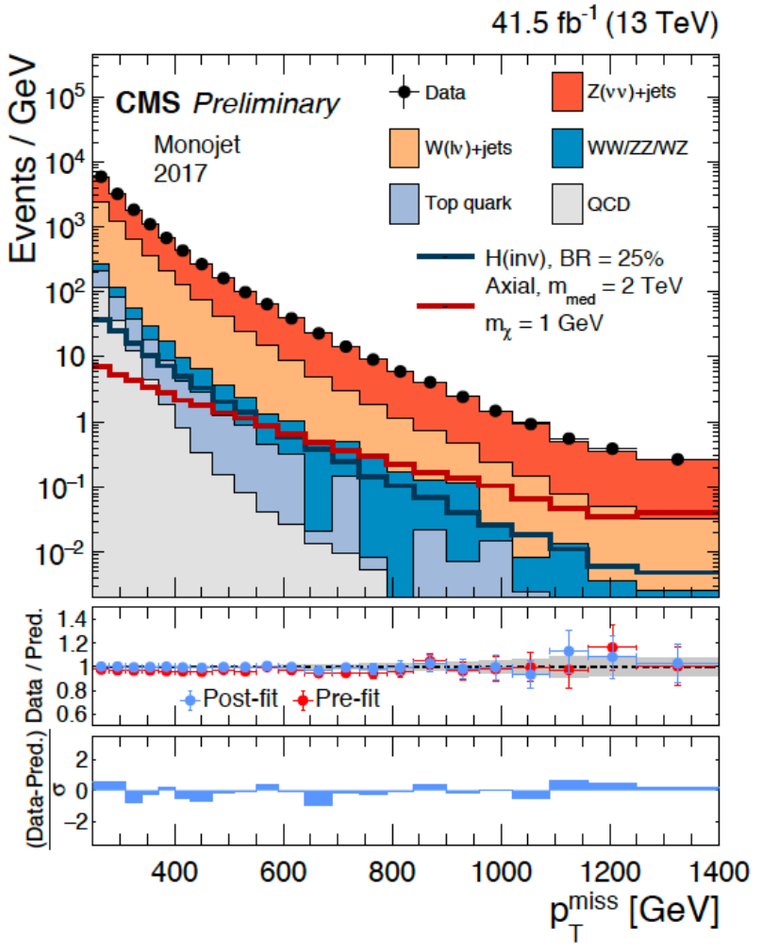
☑ Major backgrounds: Zνν+jets, W+jets





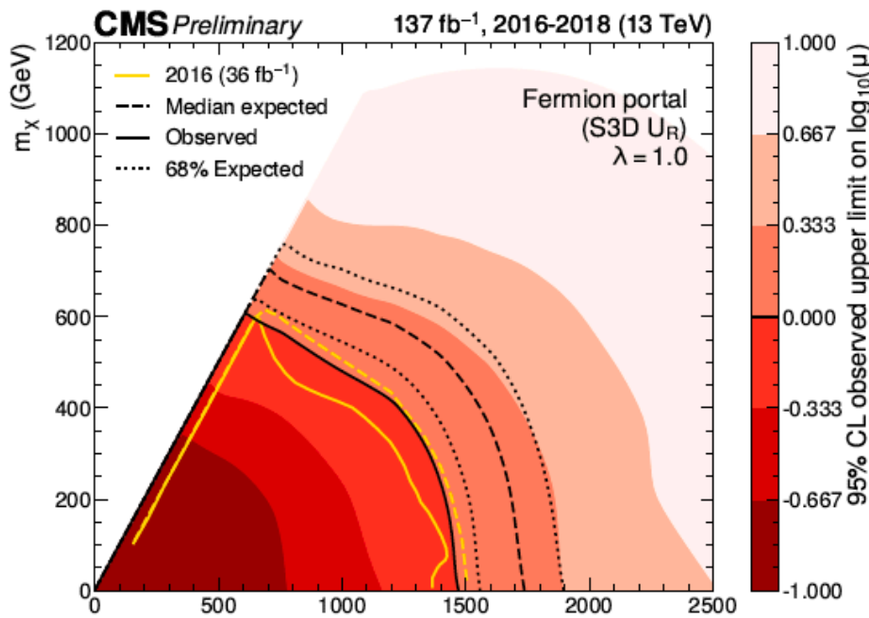
mono-jet: 1 AK4 jet
mono-V: Boosted V reconstructed as 1 AK8 jet.
mono-V subdivided into 2 sub-categories based on the purity

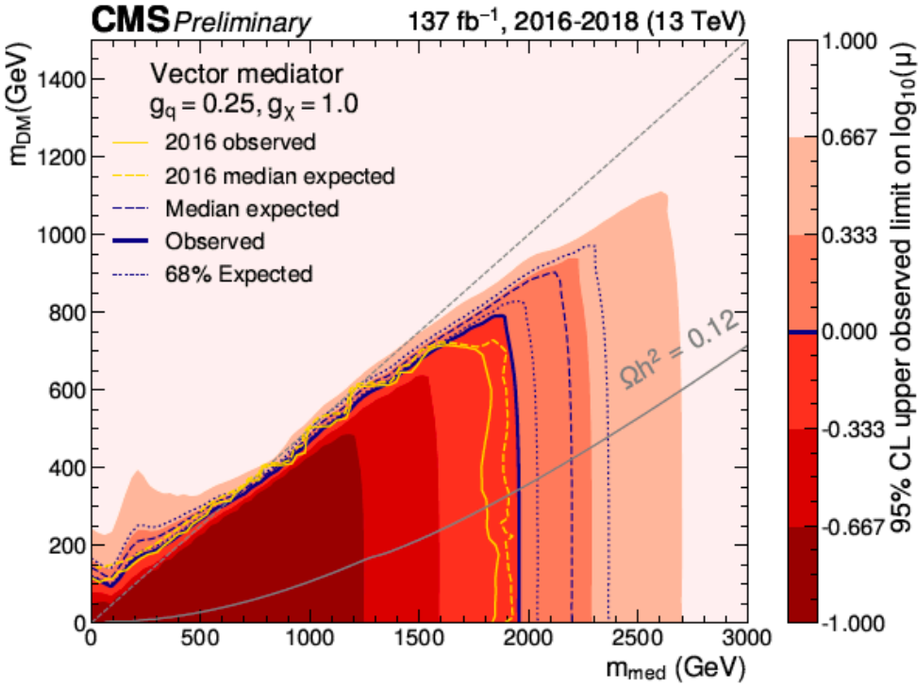
simultaneous fit of signal region with γ, 1e/μ, 2e/μ control regions. Normalisation and shape extracted via binned transfer factors from simulation are constrained, within theory and experimental uncertainties.

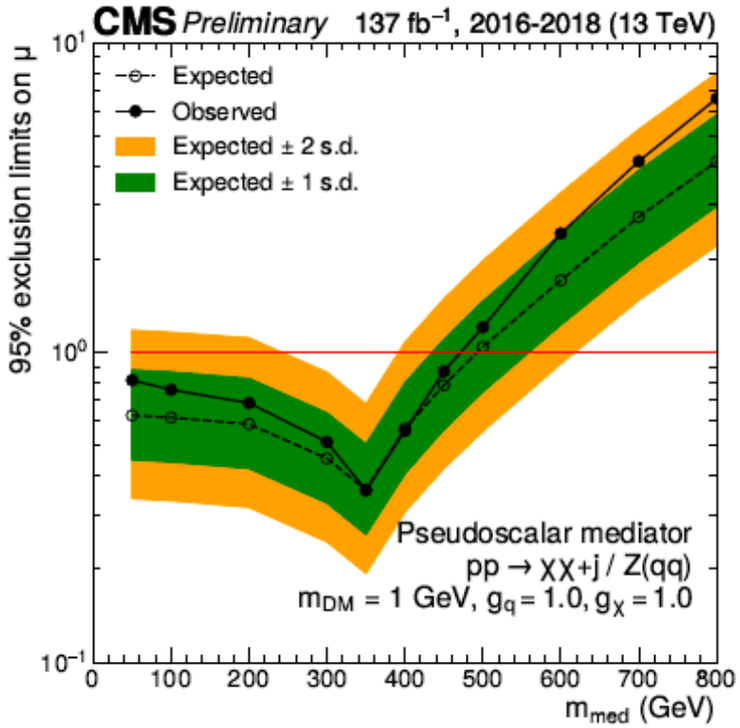


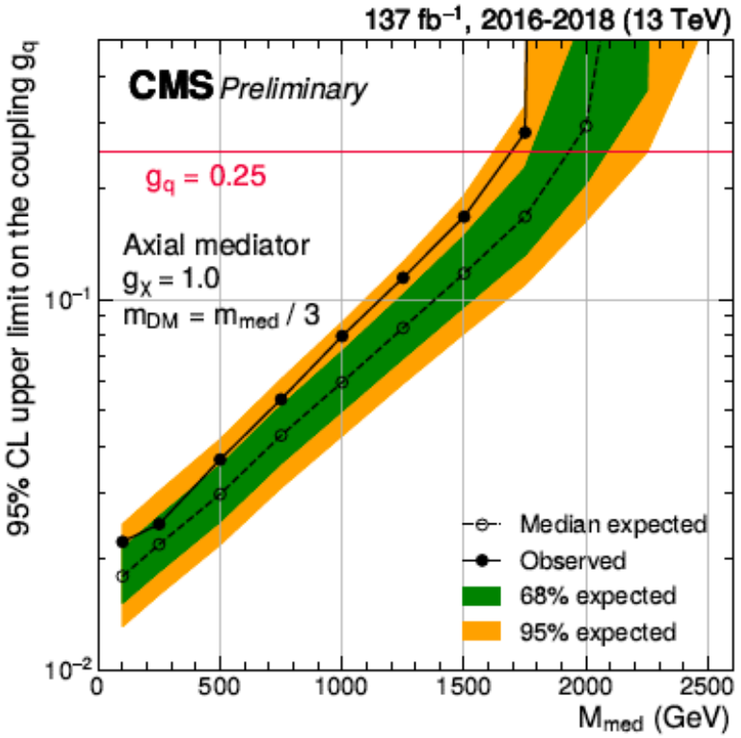
mono-jet/V

- ☑ The results are interpreted for Vector, Axial mediator and Fermion portal models.
- ☑ Vector mediator: excluded $m_{med} < 1.95$ TeV.
- ☑ Pseudo-scalar mediator: excluded $m_{med} < 460$ GeV.
- ☑ Fermion Portal: $m_{med} < 1.5$ TeV is excluded



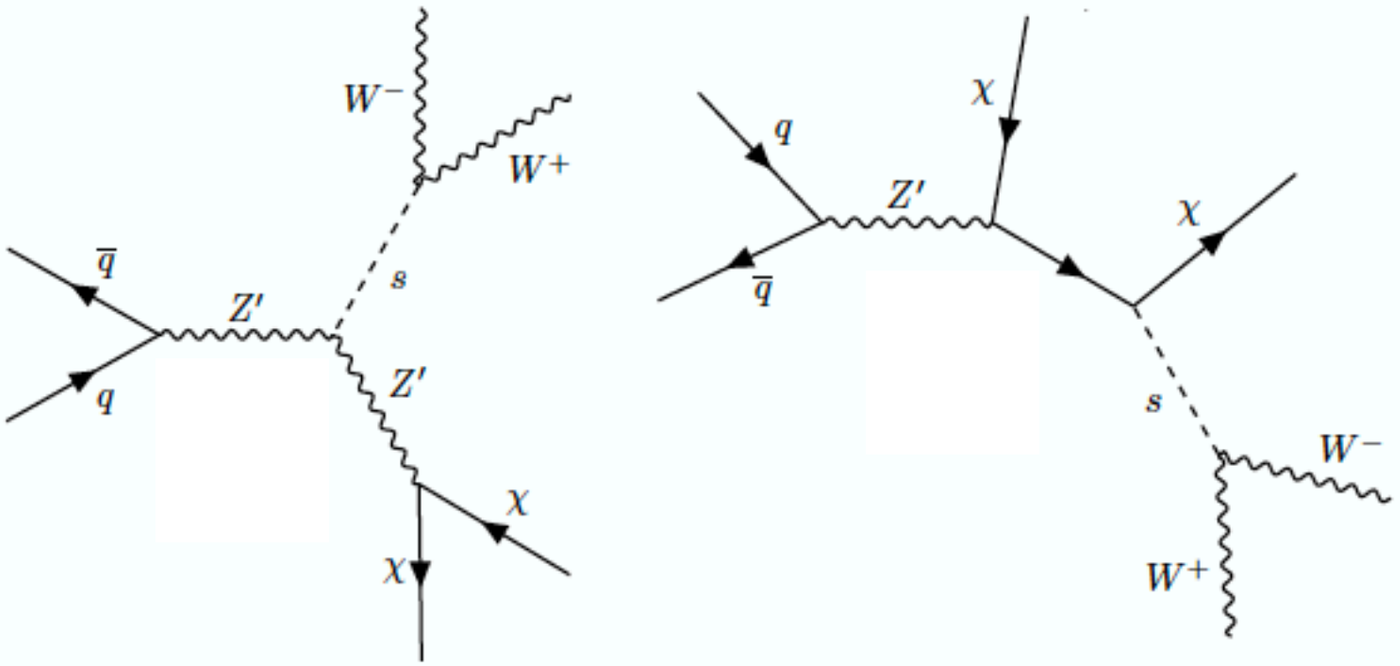


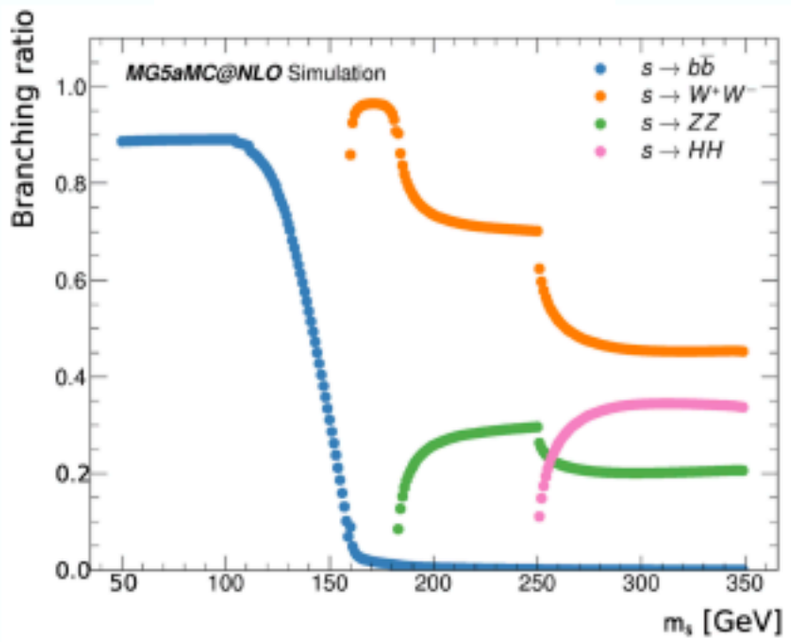




Dark Higgs boson (WW) + MET

- Dark Higgs boson model: Dark Matter particle acquire mass through their interaction with a dark Higgs boson (paper).

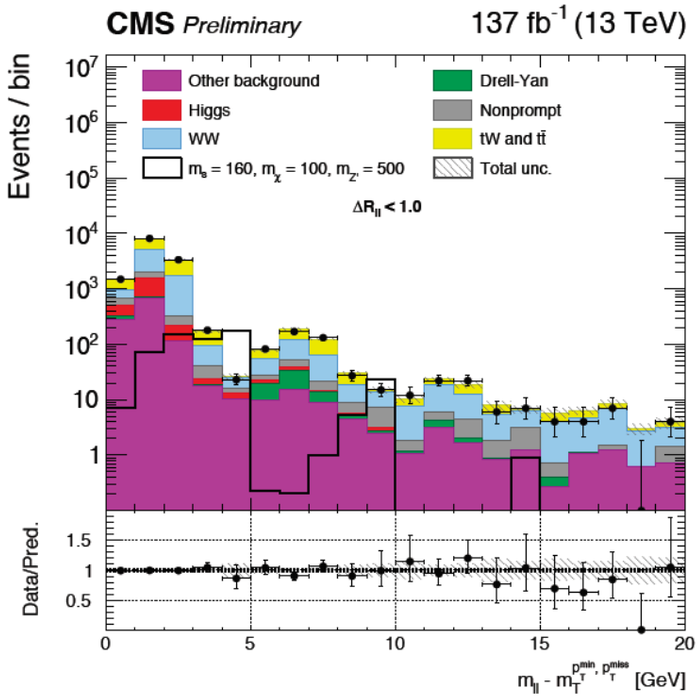


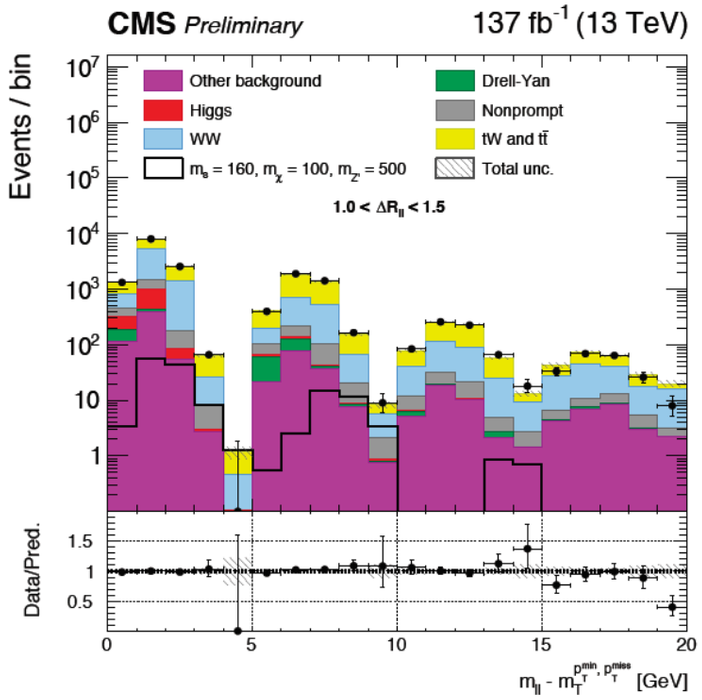


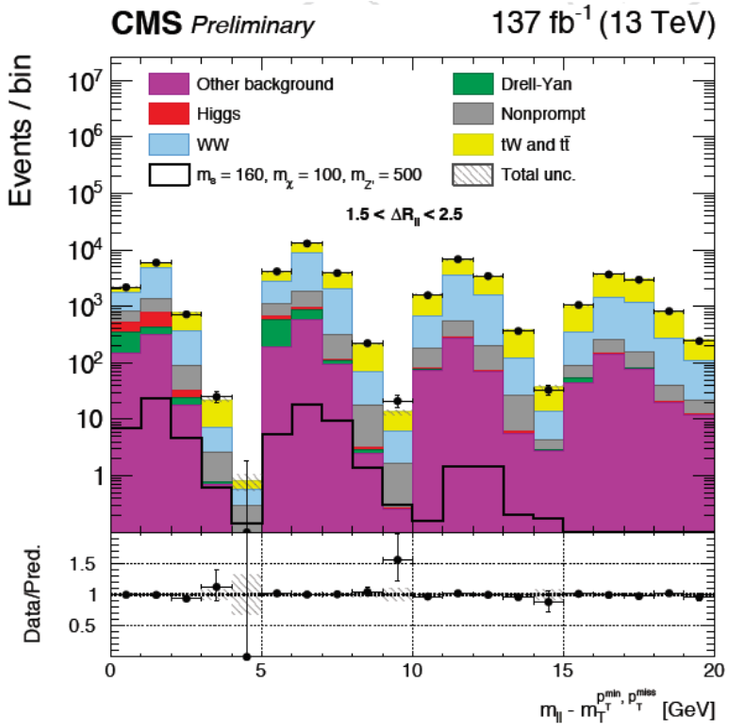
- WW decay mode dominates for m_s>160 GeV.
- s→WW search performed for the first time in fully leptonic final state.
- Final state: 2 opposite signed isolated leptons with large MET ⇨ Select signal like events using single electron/muon, double electron/muon triggers.
- Major backgrounds:
  - Non-prompt leptons: estimated using data, tight to loose method.
  - WW, Top and Z→ττ rate estimated from dedicated control region and shape is derived from simulation.

Dark Higgs boson (WW) + MET

3-dimensional fit performed using ΔR, m_{ll} and m_T

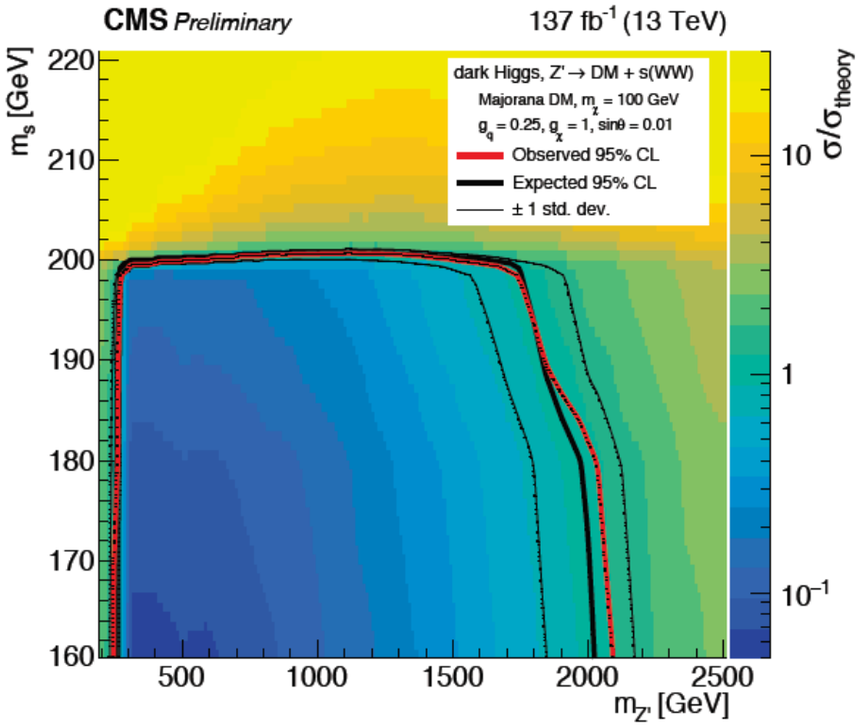


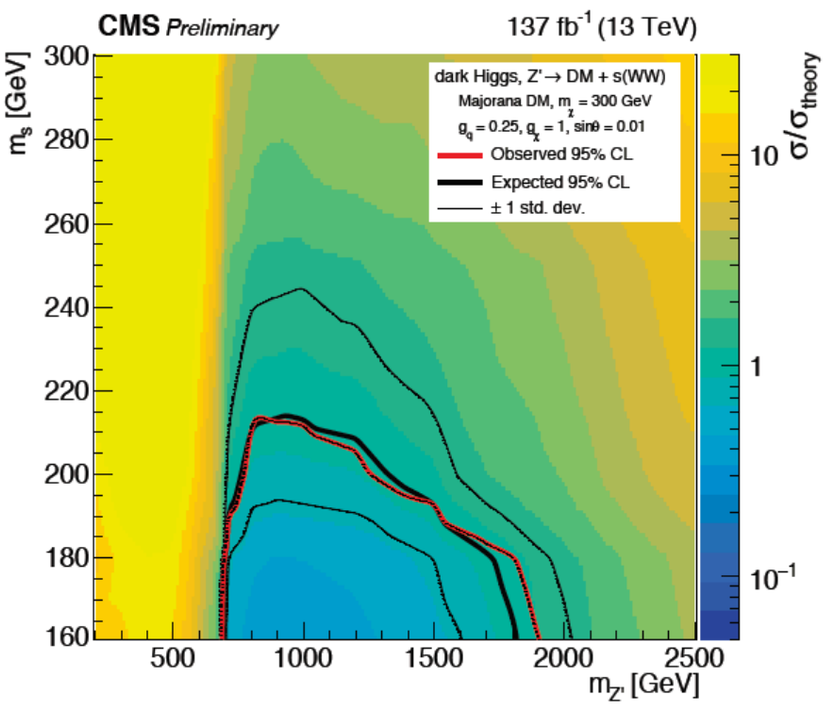




—No significant excess of events observed.

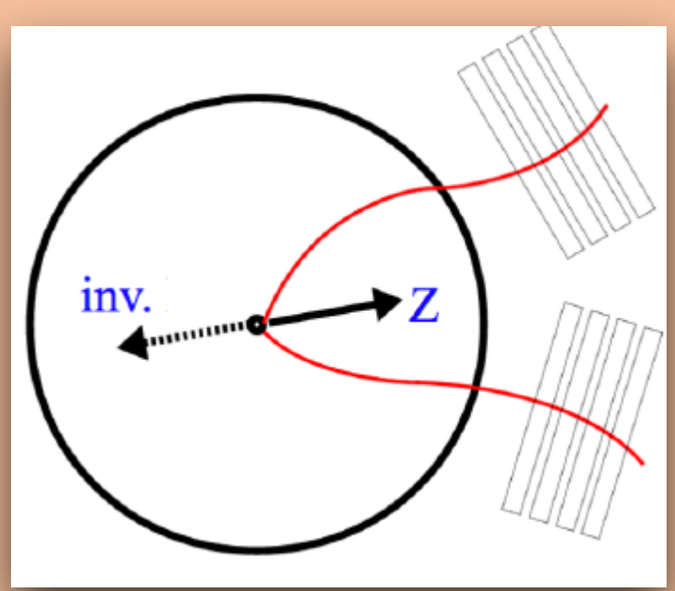
—most stringent limit for mχ=150 GeV





mono-Z(→ ll)

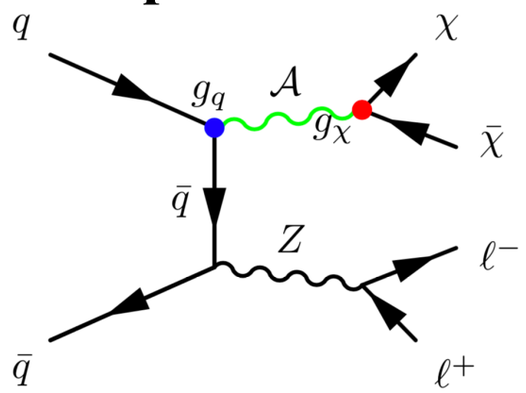
Search for dark matter in mono-Z (ll) final state



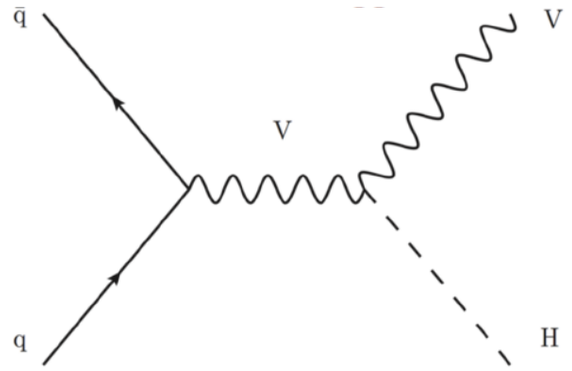
many interpretation from one analysis, DM, Higgs → invisible, Extra dimensions, Unparticle.

- ☑ Major background: WZ, ZZ, non-resonant, and DY+jets.
- ☑ Dedicated control region for each one of them.

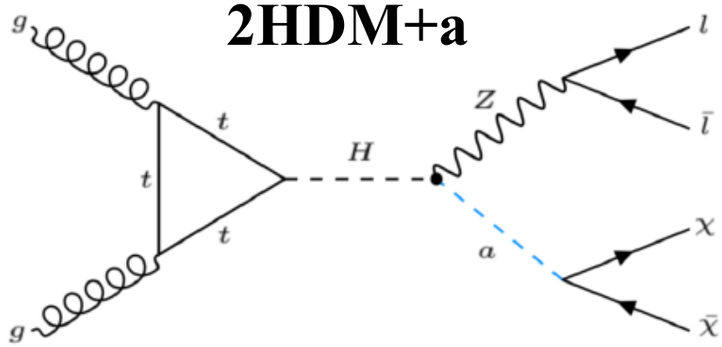
Simplified DM



Higgs → invisible



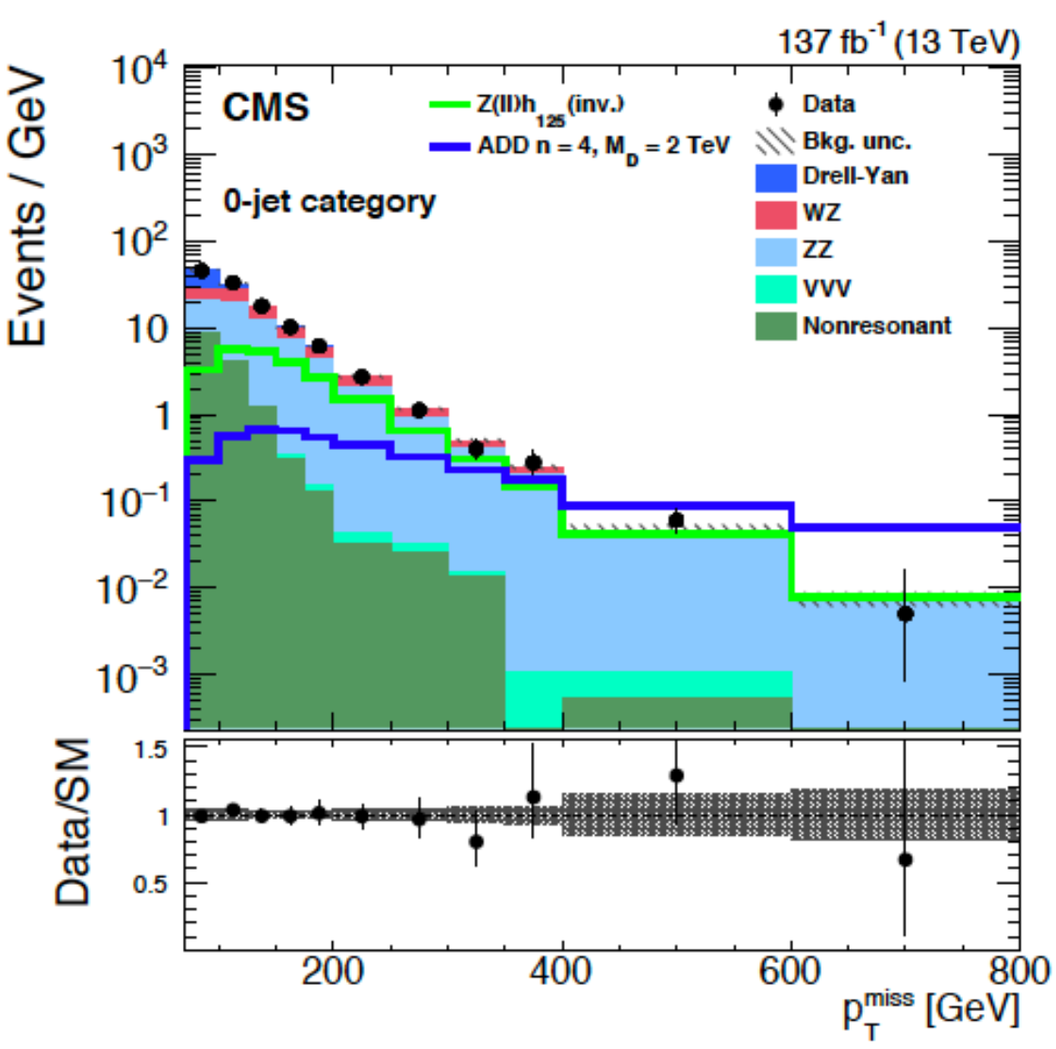
2HDM+a

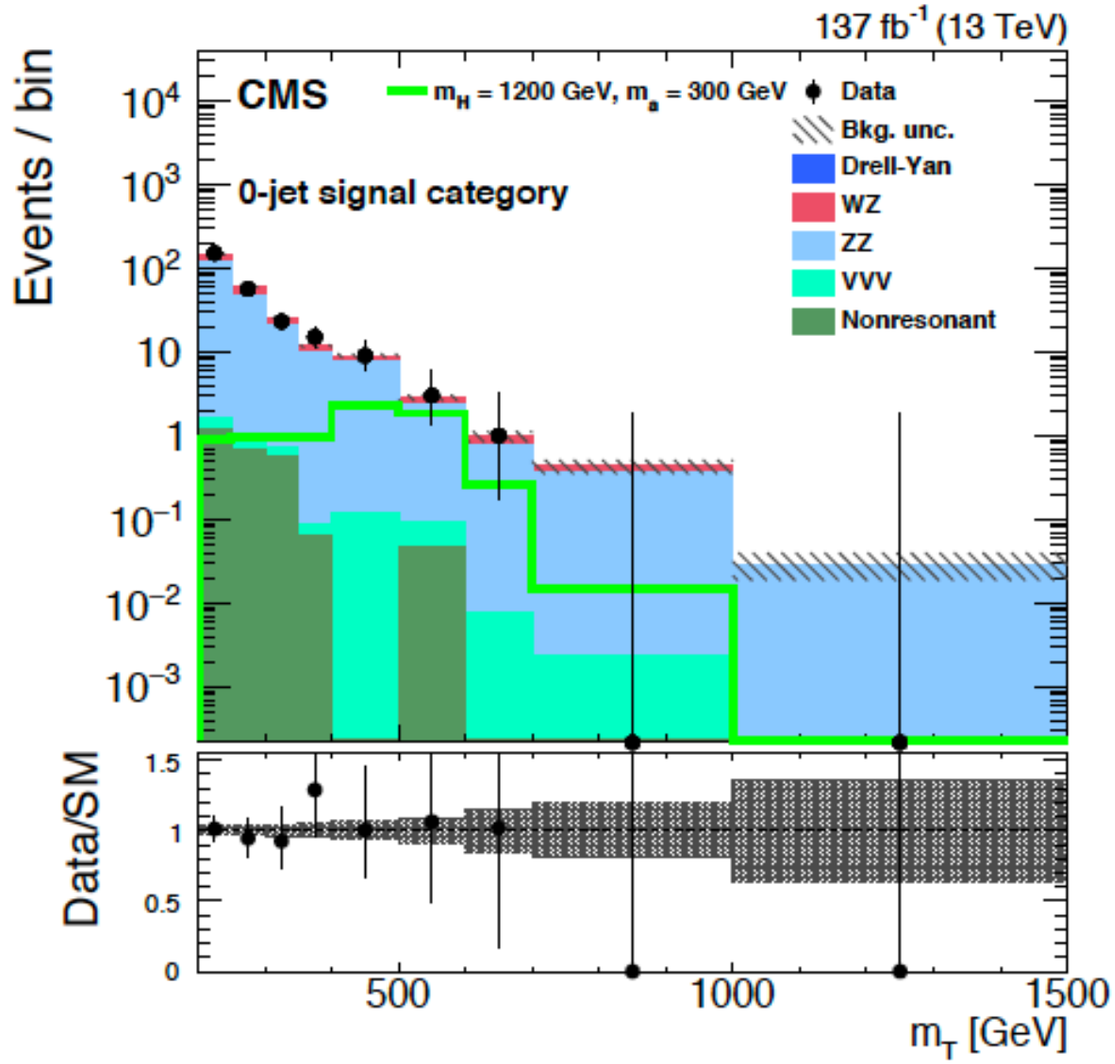


Quantity	Requirement	Target backgrounds
N_ℓ	=2 with additional lepton veto	WZ, VVV
p_T^ℓ	>25/20 GeV for leading/subleading	Multijet
Dilepton mass	$\lvert m_{\ell\ell} - m_Z \rvert < 15$ GeV	WW, top quark
Number of jets	≤1 jet with $p_T^j > 30$ GeV	DY, top quark, VVV
$p_T^{\ell\ell}$	>60 GeV	DY
b tagging veto	0 b-tagged jet with $p_T > 30$ GeV	Top quark, VVV
τ lepton veto	0 τ_h cand. with $p_T^\tau > 18$ GeV	WZ
$\Delta\phi(\vec{p}_T^{\,j}, \vec{p}_T^{\,miss})$	>0.5 radians	DY, WZ
$\Delta\phi(\vec{p}_T^{\,\ell\ell}, \vec{p}_T^{\,miss})$	>2.6 radians	DY
$\lvert p_T^{miss} - p_T^{\ell\ell} \rvert / p_T^{\ell\ell}$	<0.4	DY
$\Delta R_{\ell\ell}$	<1.8	WW, top quark
p_T^{miss} (all but 2HDM+a)	>100 GeV	DY, WW, top quark
p_T^{miss} (2HDM+a only)	>80 GeV	DY, WW, top quark
m_T (2HDM+a only)	>200 GeV	DY, WW, ZZ, top quark

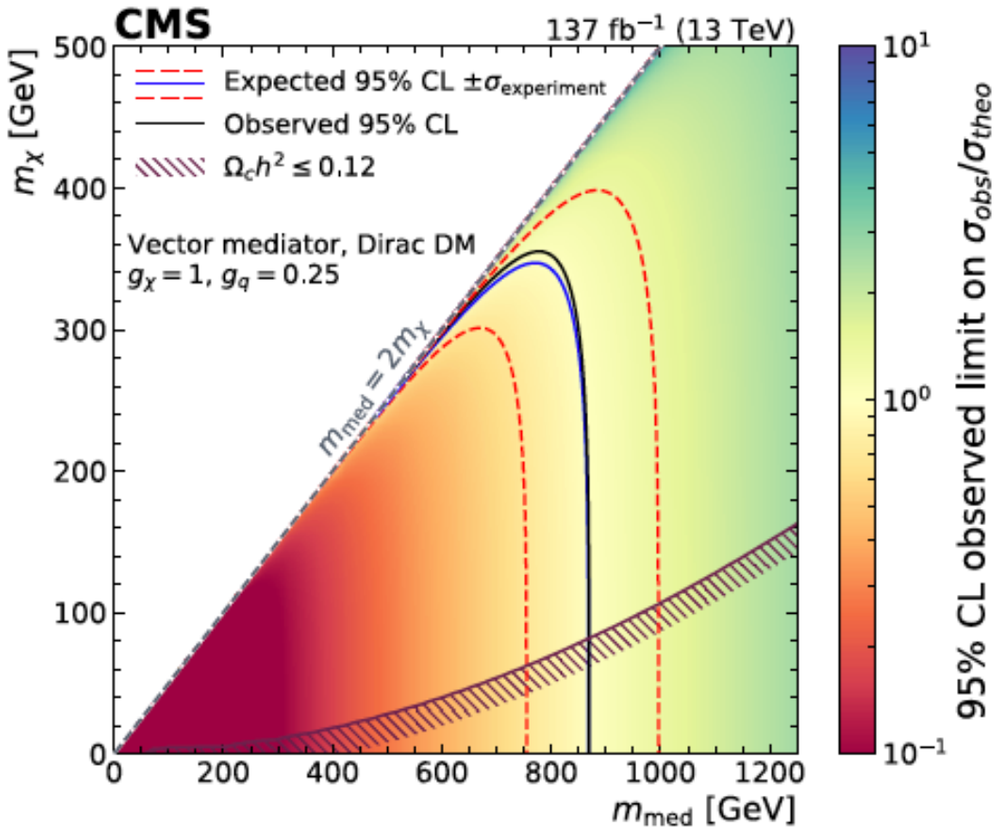
mono-Z(→ ll)

- ☑ Analysis divided in 0 and1 jet category to increase the sensitivity.
- ☑ Simultaneous fit of CR and SR to constraint major backgrounds.
- ☑ MET used as sensitive variable except for the 2HDM+a interpretation.
  - ☑ m_T is used to reconstruct the Jacobian peak.



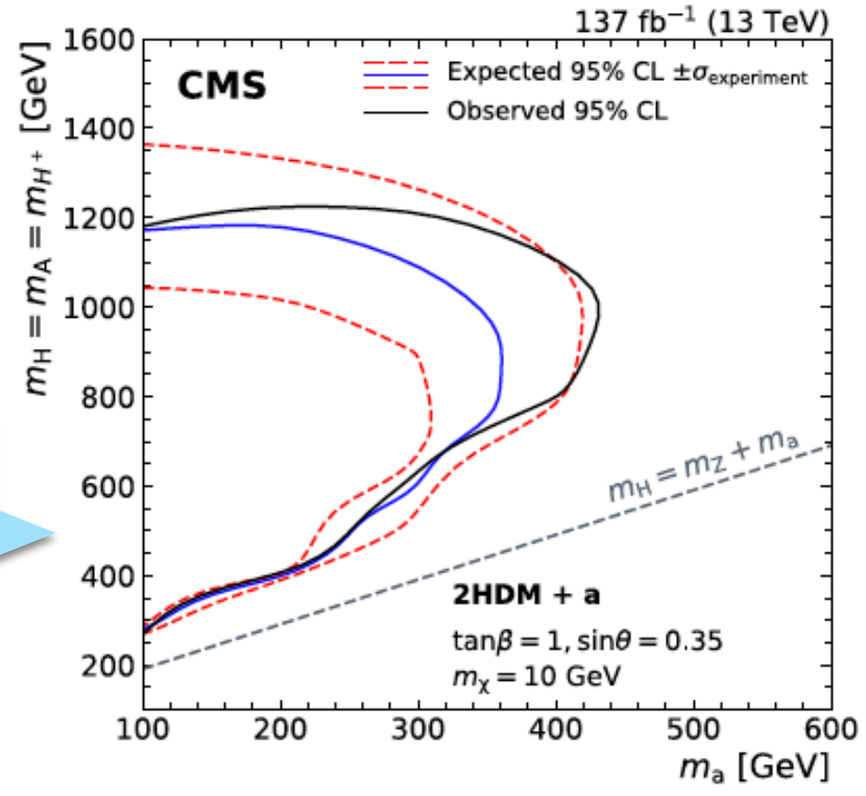


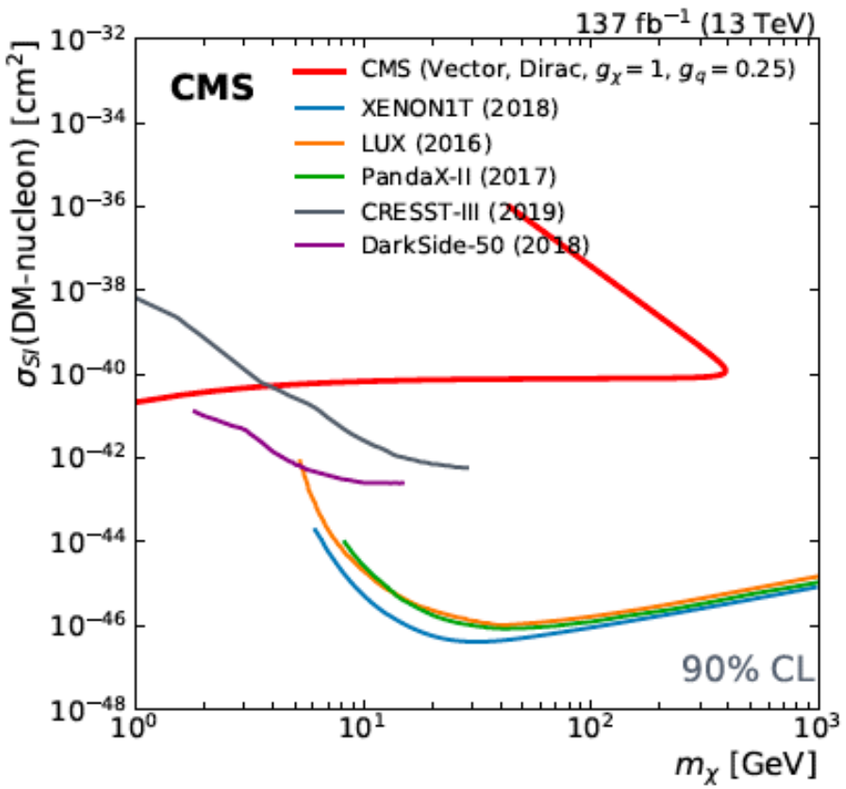
mono-Z(→ ll)



95% CL upper limit on m_{med} vs m_χ plane

95% CL upper limit on m_a vs m_A plane





90% CL upper limit on spin independent DM-nucleon production cross-section vs m_χ

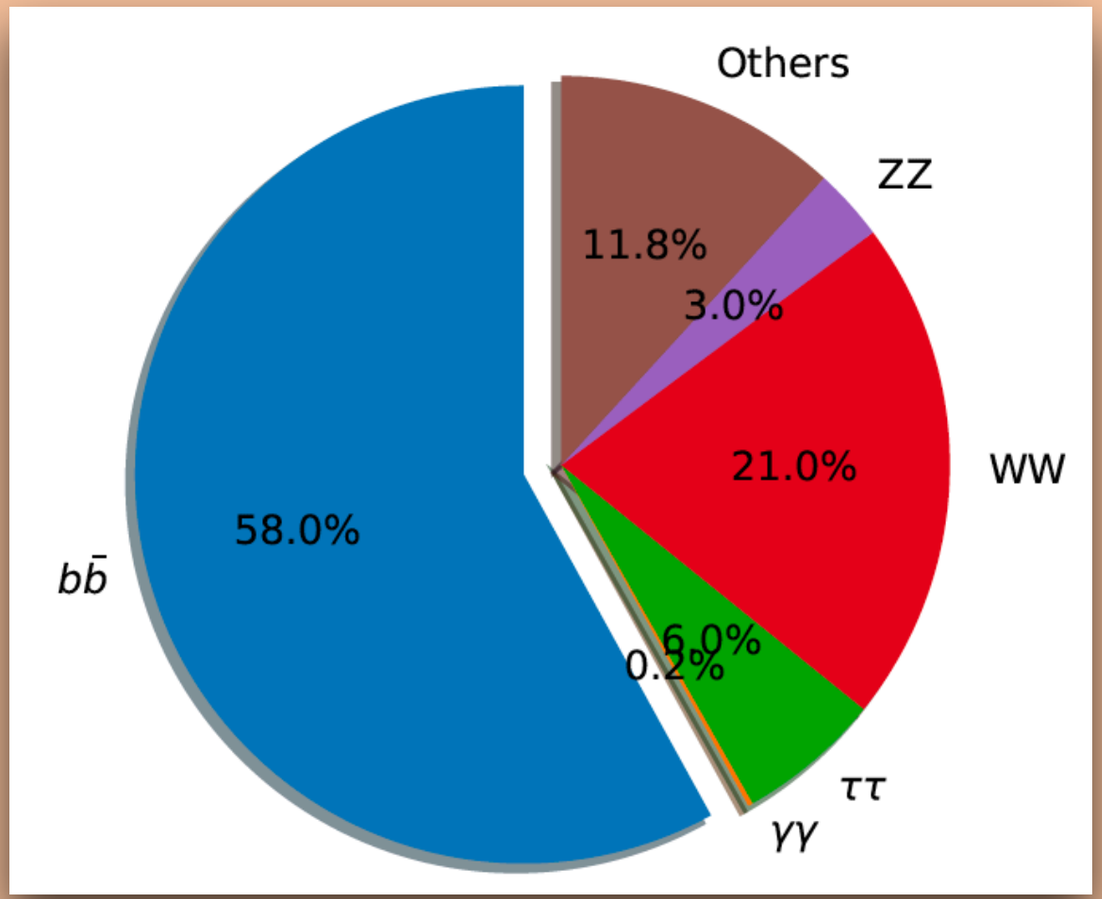
Results also interpreted as an upper limit on B(H→invisible) assuming SM Higgs boson m_H = 125 GeV production.

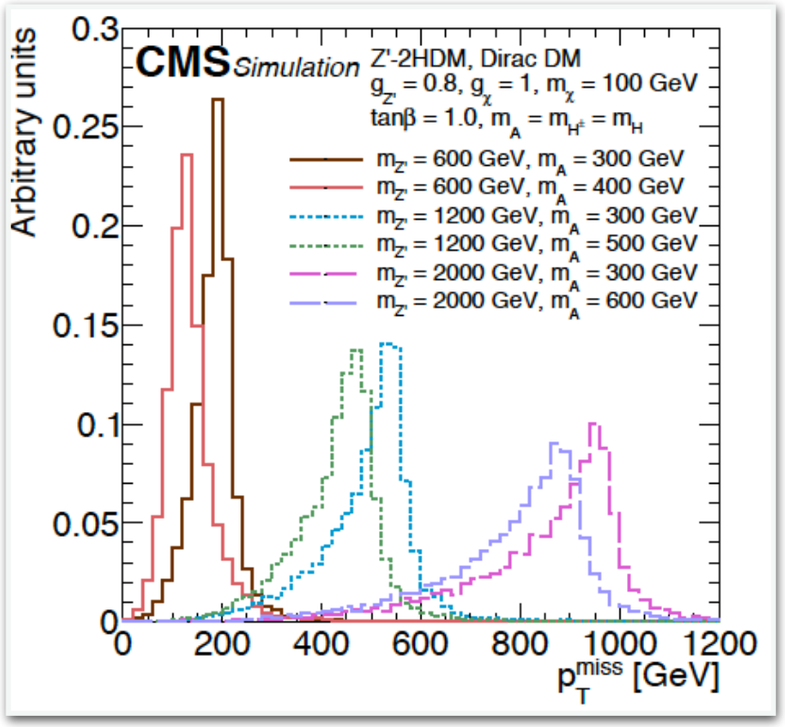
Obs 95% upper limit on B(H→invisible) is 29%

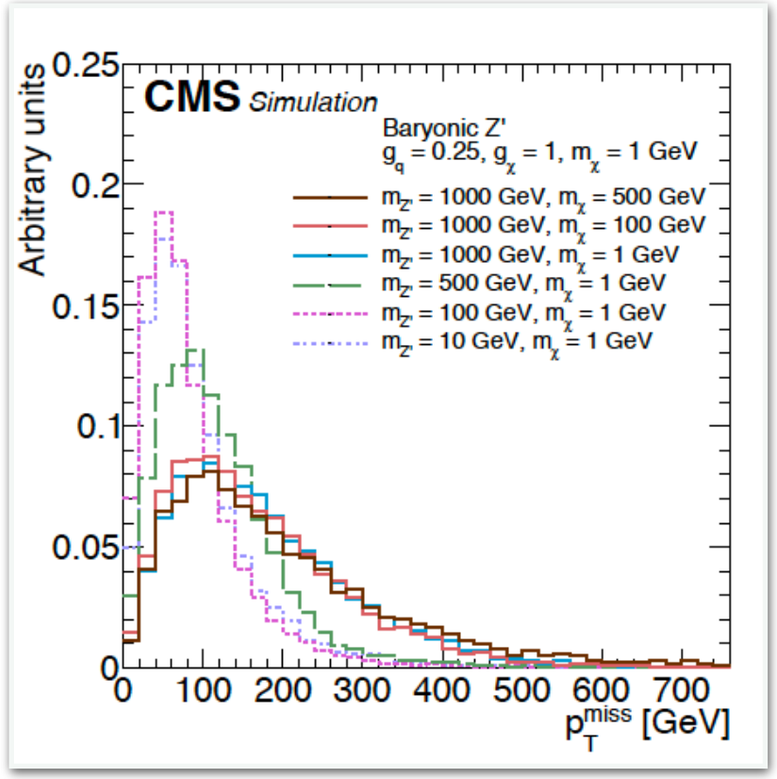
mono-Higgs

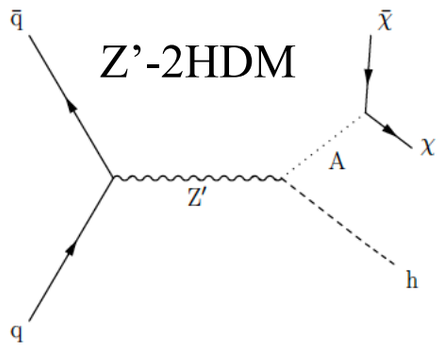
Search for dark matter in mono-Higgs final state

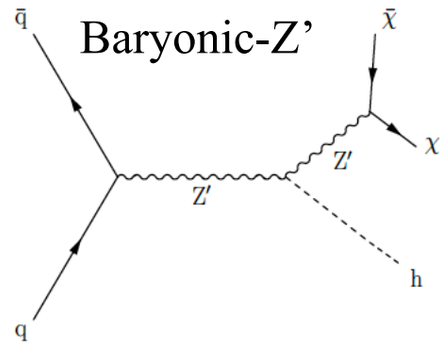
Higgs boson decay branching ratio

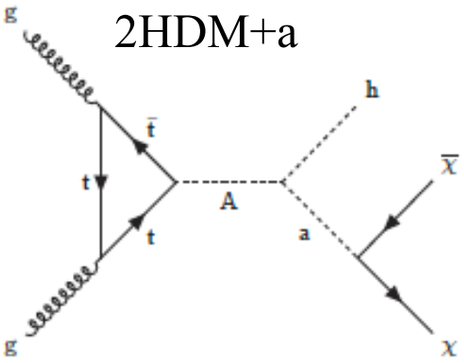




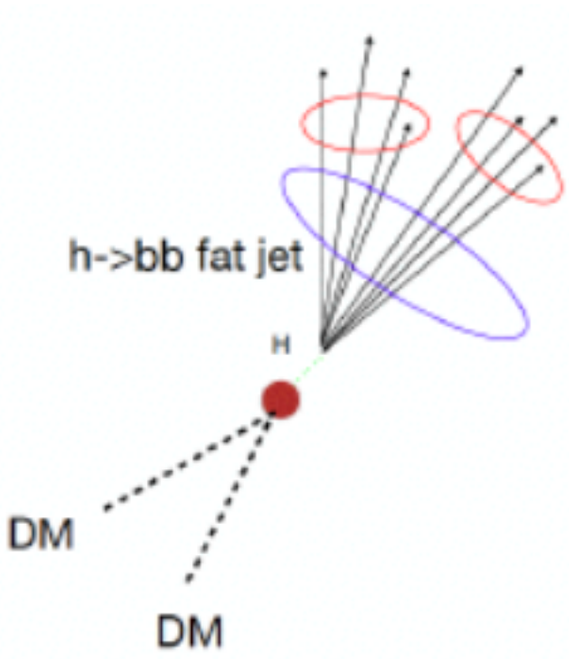








mono-Higgs

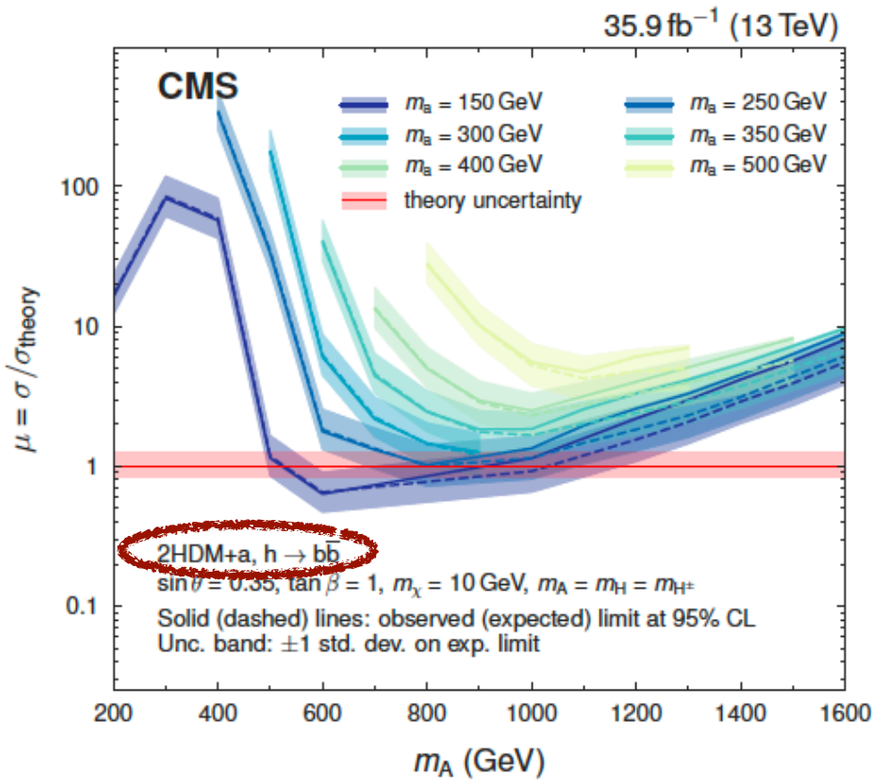


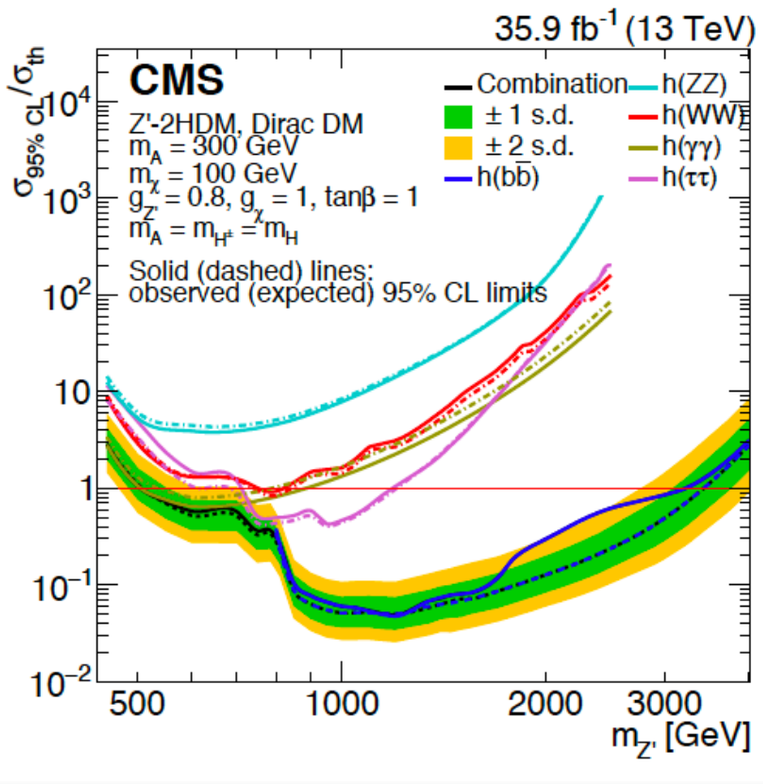
H→bb	most sensitive

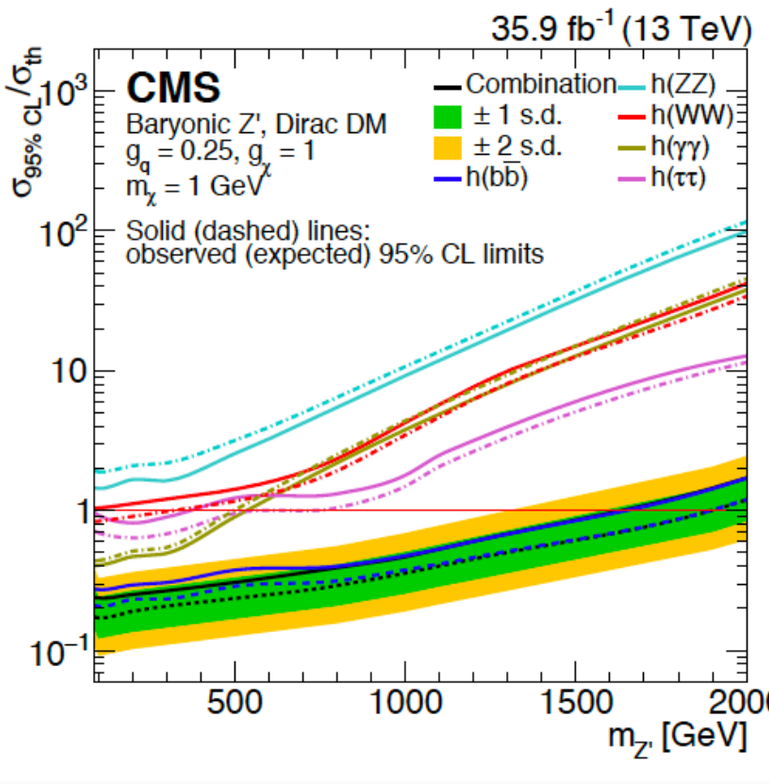
2HDM+a	CA15 jets
Baryonic-Z’	CA15 jets
Z’-2HDM	AK8 jets

Decay channel	Final state or category
$h \to bb$	AK8 jet (Z′-2HDM) CA15 jet (Baryonic Z′)
$h \to \gamma\gamma$	$p_T^{miss} \in 50$–$130\,GeV$ $p_T^{miss} > 130\,GeV$
$h \to \tau\tau$	$\tau_h\tau_h$ $\mu\tau_h$ $e\tau_h$
$h \to WW$	$e\nu\mu\nu$
$h \to ZZ$	$4e$ 4μ $2e2\mu$

Final states orthogonal to each other





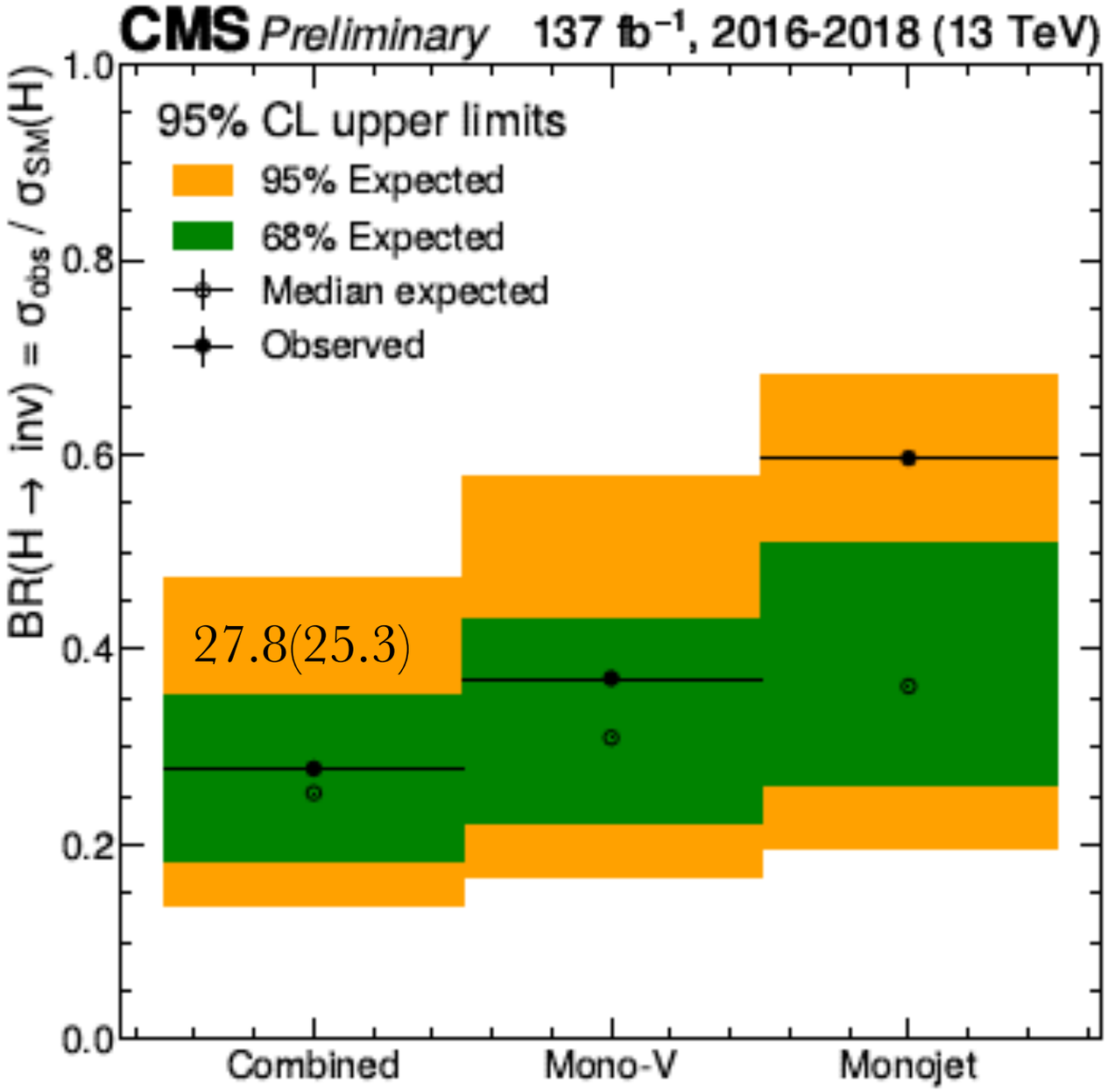


Summary

- ☑ Showcasing the recent selected dark matter searches from CMS.
- ☑ A wide variety of dark matter search analyses have already been performed.
  - ☐ MET based signatures are key to DM search at CMS.
  - ☐ constraints the production of DM at LHC.
  - ☐ Many full Run-2 DM analyses are still in progress.
- ☑ <u>Stay tuned for new results.</u>

Backup slides

H Inv from monoJ



mono-Higgs combination

Source	h → bb		h → γγ	h → ττ	h → WW	h → ZZ
	Z′-2HDM	Baryonic Z′				
AK4 jet b tagging	3–11%	Uncorr. (3–4%)	—	4%	Shape (1%)	1%
AK4 jet b mistag		Shape (5–7%)	—	2–5%	Shape (1%)	—
e ident. efficiency	4%	2%	—	2%	Shape (2%)	2.5–9.0%
μ ident. efficiency	4%	2%	—	2%	Shape (2%)	2.5–9.0%
τ_h ident. efficiency	3%	3%	—	4.5%	Shape (1%)	—
e energy scale	1%	—	—	—	Shape (1%)	3%
μ energy scale	1%	—	—	—	Shape (1%)	0.4%
JES	—	Uncorr. (4%)	—	Shape (<10%)	Shape (3%)	2–3%
Int. luminosity	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
Signal (PDF, scales)	0.3–9.0%	0.3–9.0%	0.3–9.0%	0.3–9.0%	0.3–9.0%	0.3–9.0%