Searches for Dark Matter with CMS at 13 TeV

Claudia-Elisabeth Wulz
Institute of High Energy Physics, Vienna
CMS Collaboration

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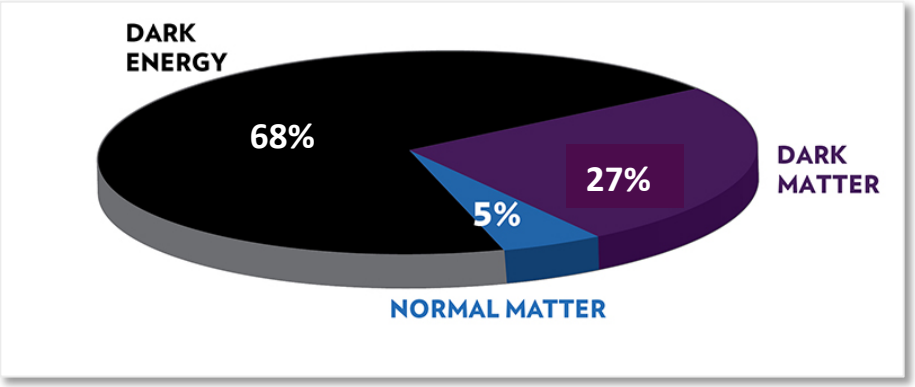
Lake Louise Winter Institute

Dark Matter Searches

Dark Matter (DM) could be produced at the LHC, directly or through decays (LSP in SUSY cascades, Higgs portal).

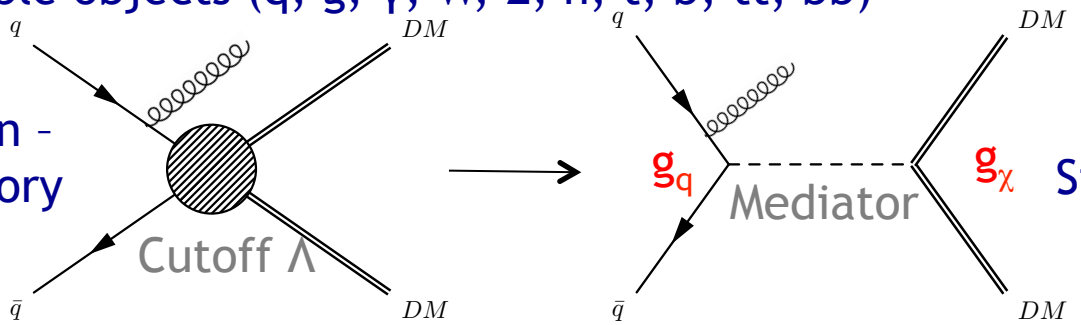


Collider searches:

- complementary to direct and indirect searches
- best for low DM masses and spin-dependent couplings

Direct production: only detectable as missing transverse momentum in association with additional, visible objects (q, g, γ, W, Z, h, t, b, $t\bar{t}$, $b\bar{b}$)

Contact interaction – effective field theory



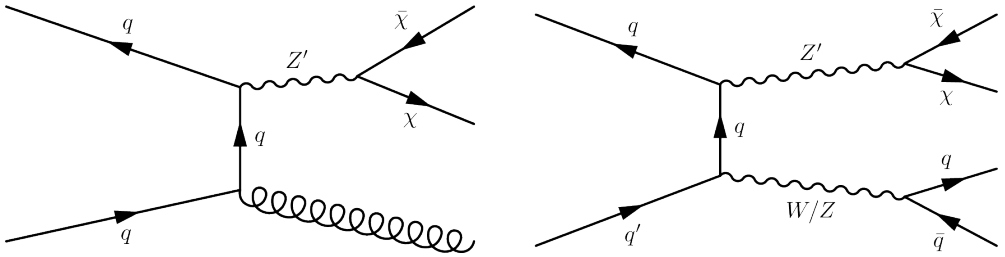
Simplified models

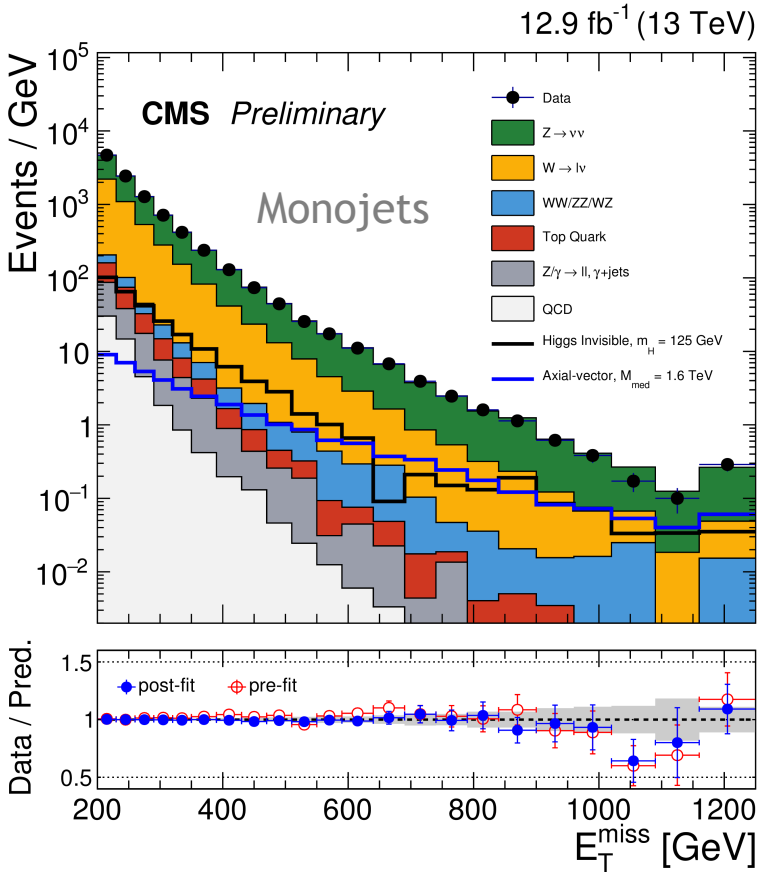
Simplified models less model-dependent than UV-complete models (SUSY etc.)
DM parameters: DM and mediator masses, couplings, type of mediator (scalar, pseudoscalar, vector, axial-vector, tensor).

e.g. *ATLAS/CMS DM Forum, arXiv 1603.04156 (2016)*

Monojets and hadronically decaying mono-V

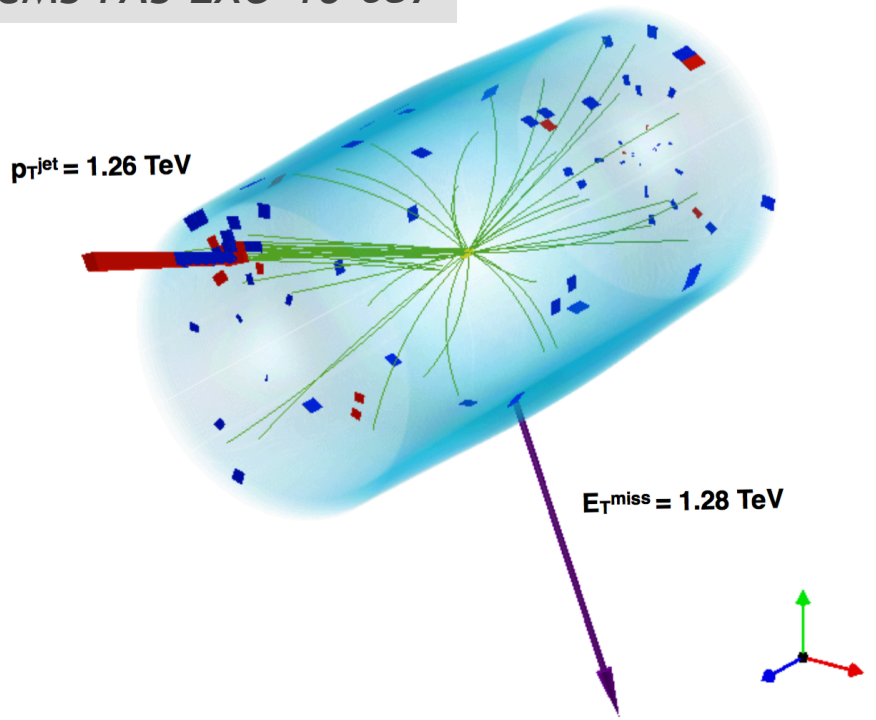
Backgrounds:
Z(νν)+jets (irreducible) dominates
W(lν)+jets: lepton veto
$t\bar{t}$: b-jet veto
QCD multijets: angular cuts





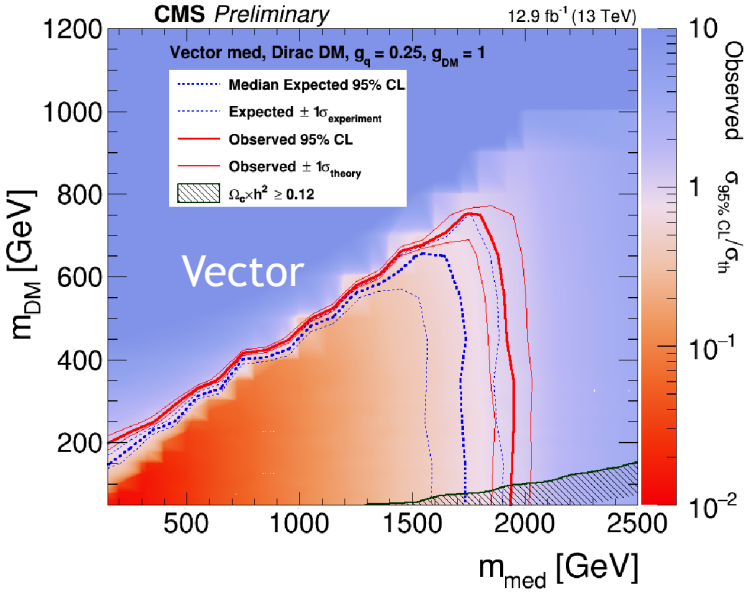
Examples: spin-1 mediator (V, AV)

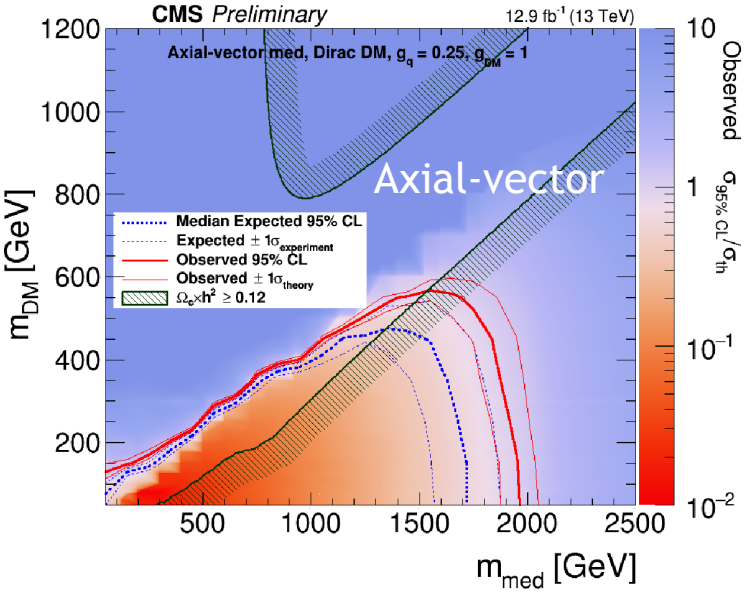
CMS-PAS-EXO-16-037

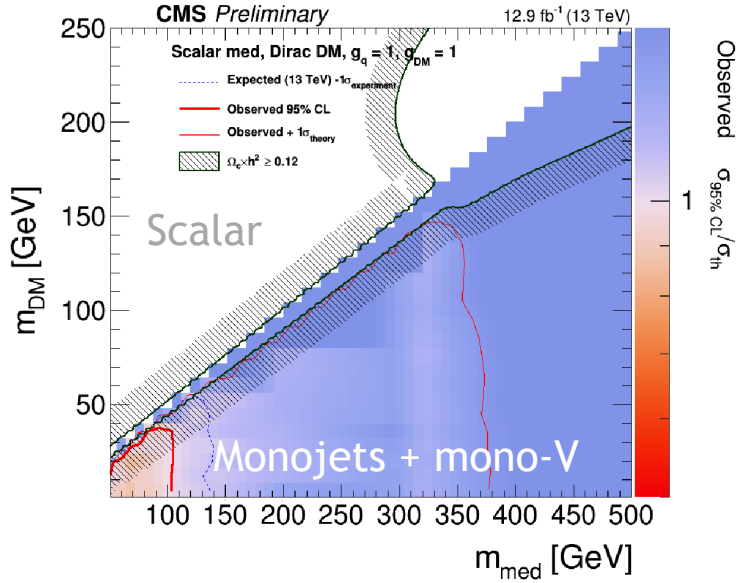


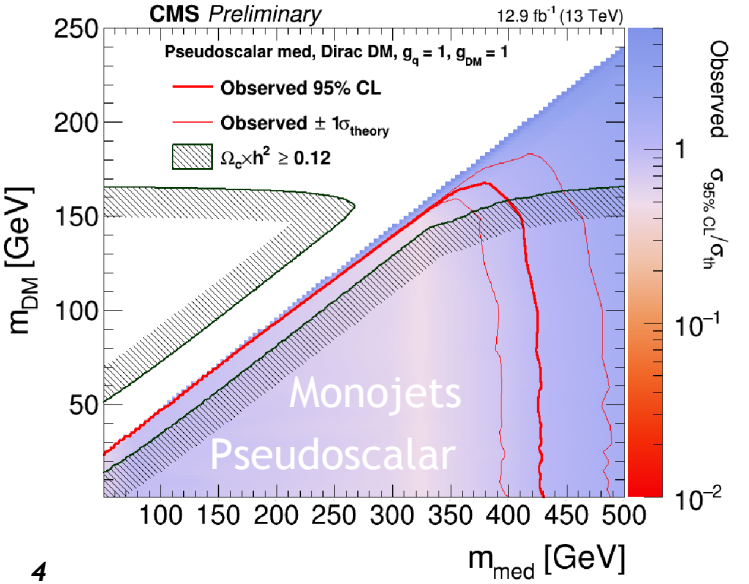
Monojets and hadronically decaying mono-V

Interpretation in terms of simplified model (g_{DM} = 1)





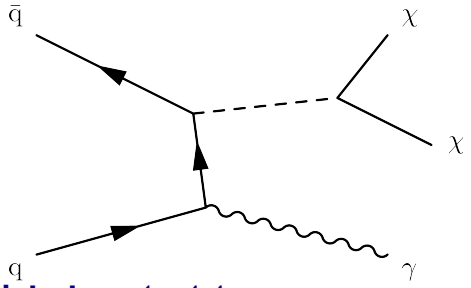




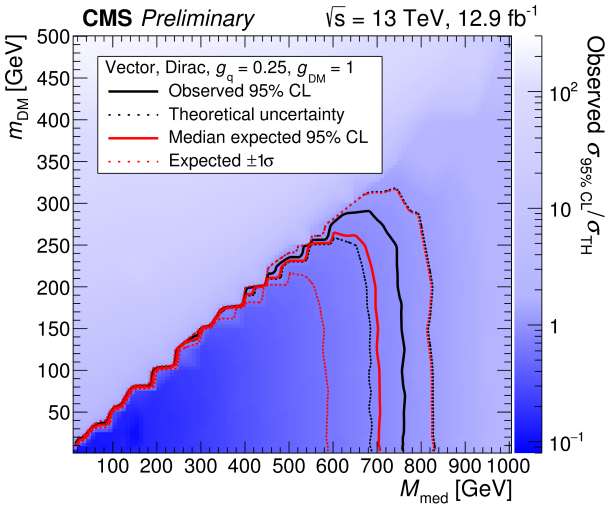
Monophotons

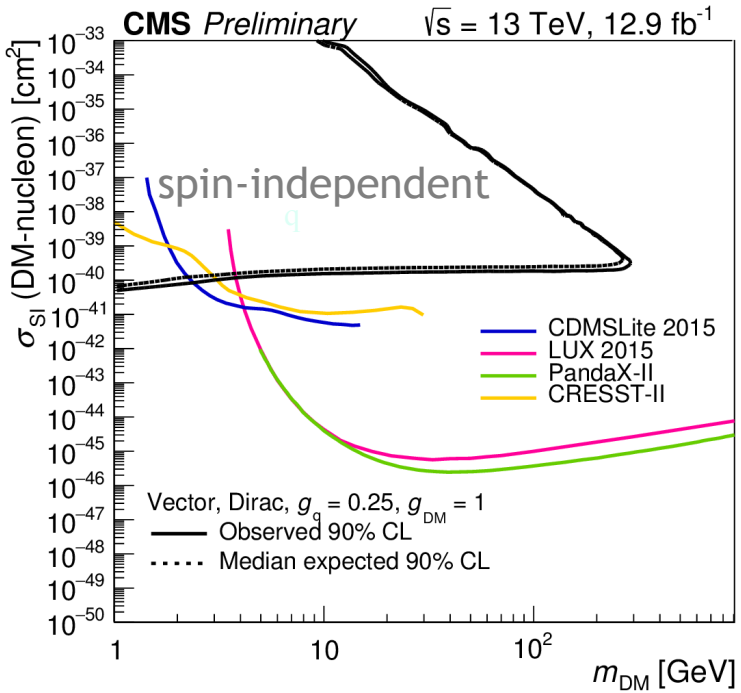
Cleaner than monojet channel, but less sensitive

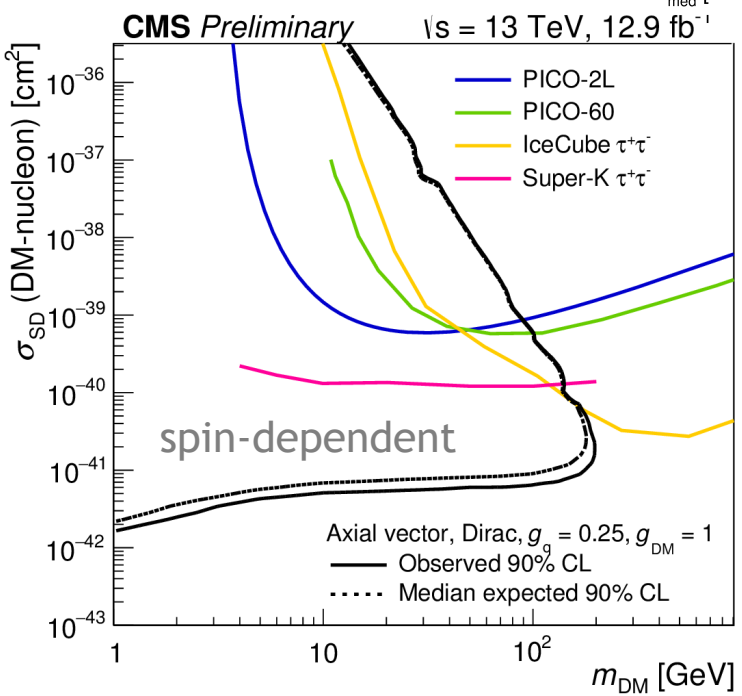
CMS-PAS-EXO-16-039



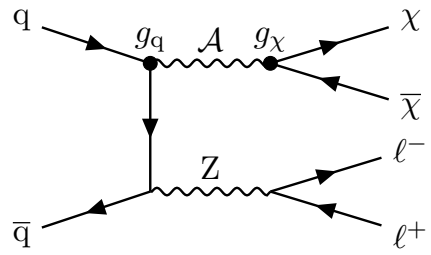
Event selection:
single γ with E_T > 175 GeV and |η| ≤ 1.44
E_T^{miss} > 170 GeV

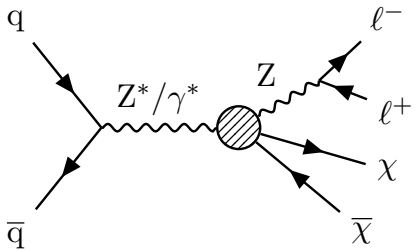


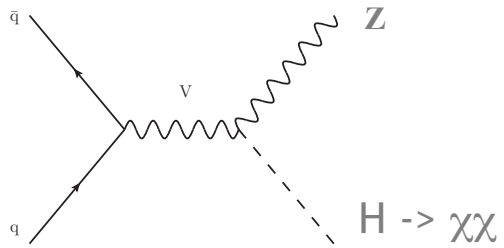




Mono-Z decaying to leptons (electrons, muons)

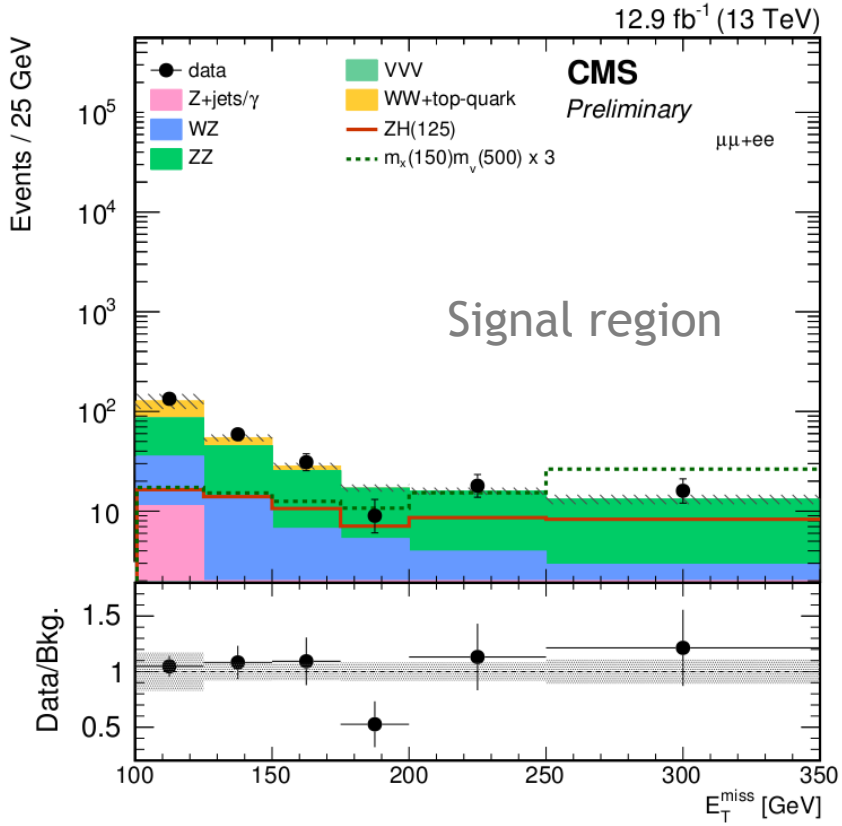




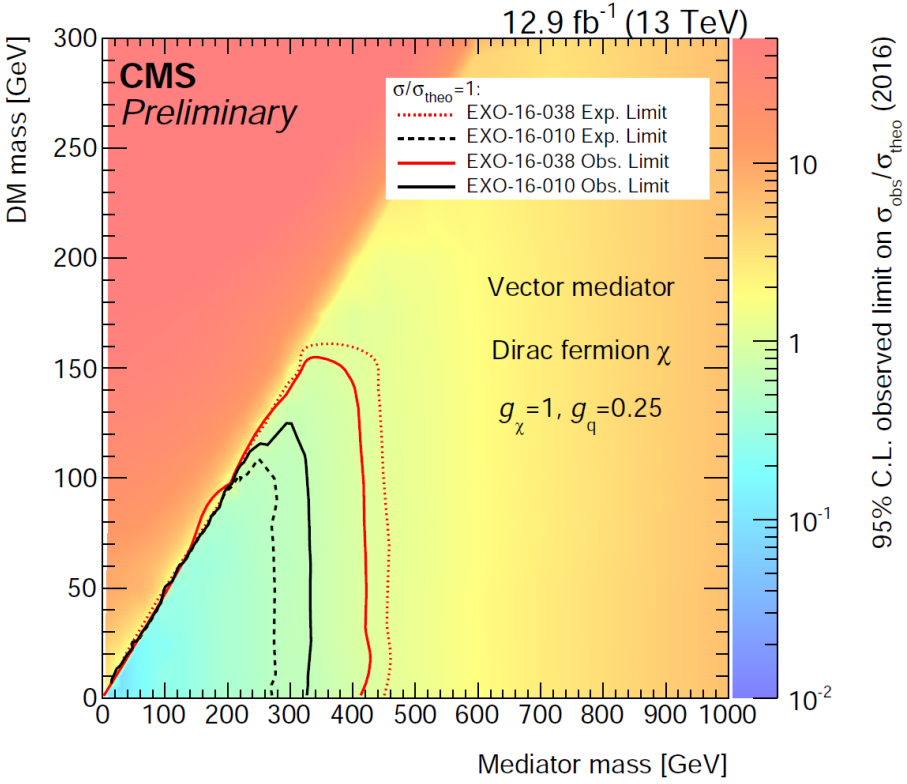


Observed B(H->invisible): < 0.86

CMS-PAS-EXO-16-038, 16-010



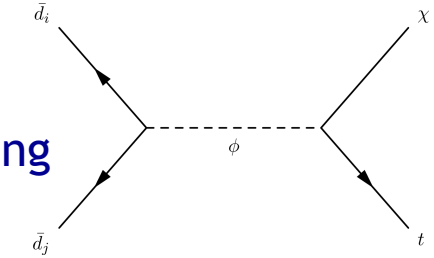
Comparison of 2015/2016 analyses



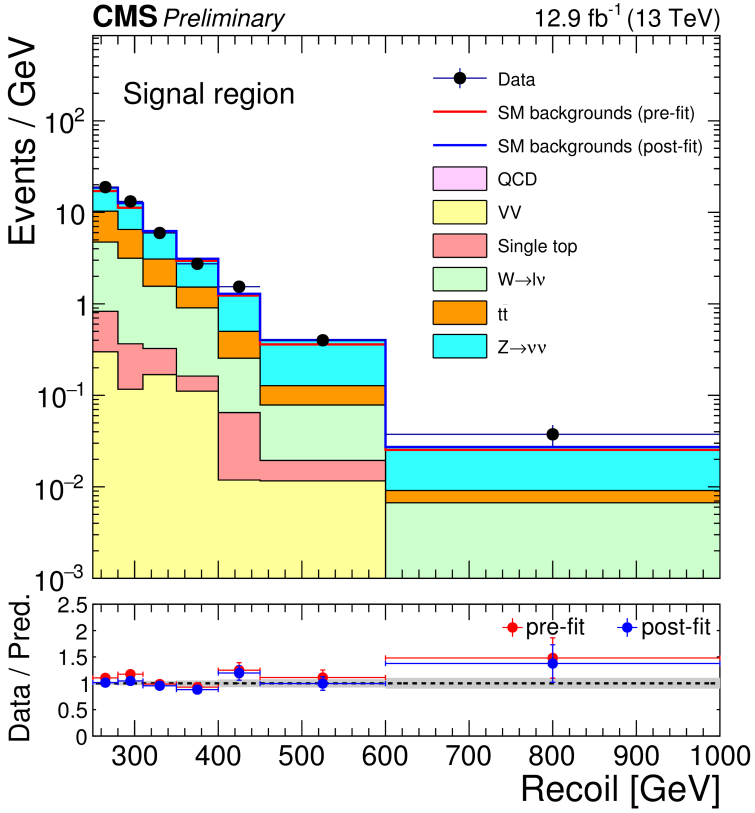
Boosted hadronically decaying monotops

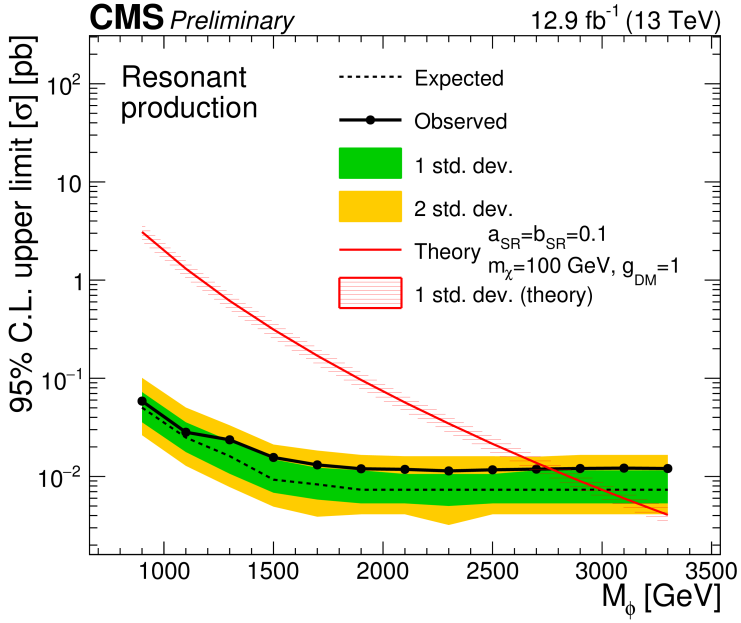
Events with hadronically decaying W from t selected. q-χ couplings in scalar interactions could be enhanced for heavy flavors.

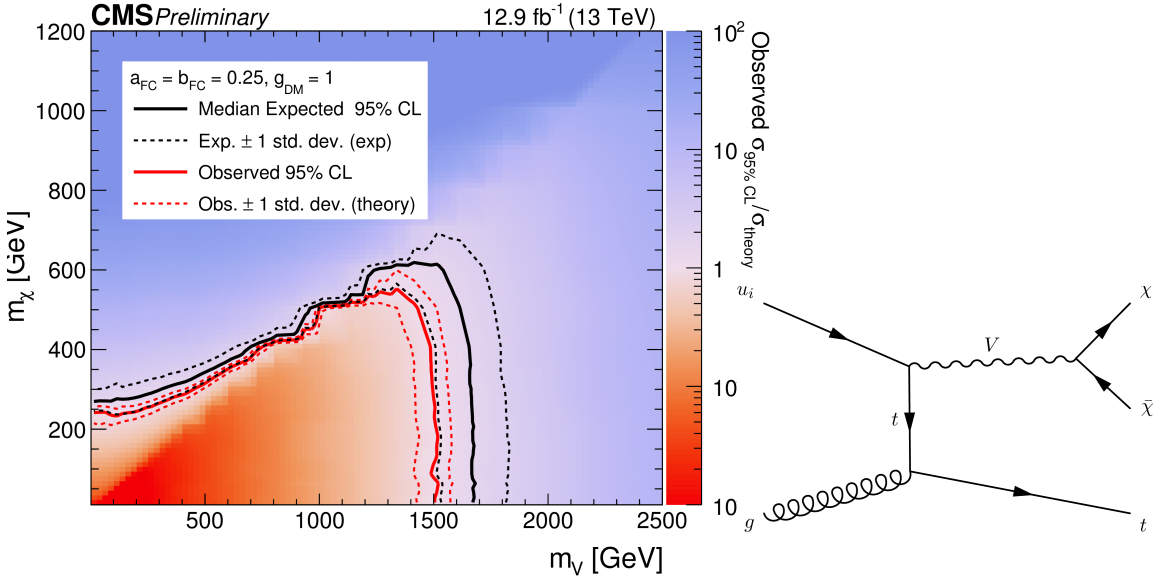
DM signal searched by fitting E_T^{miss} distribution in signal region, assuming background-only hypothesis



CMS-PAS-EXO-16-040



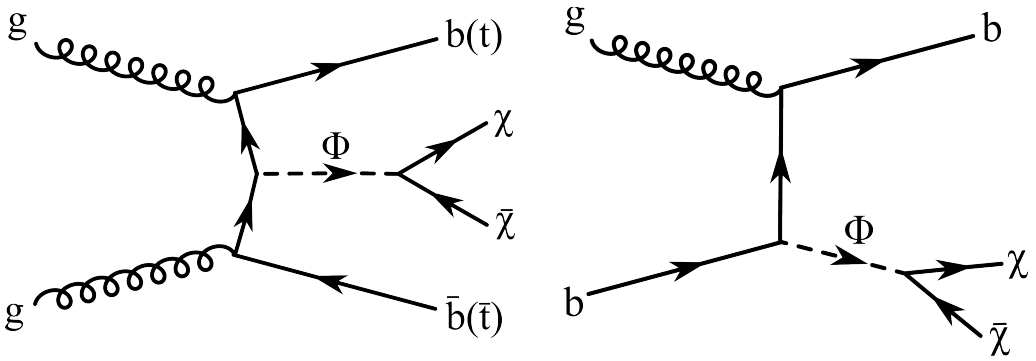


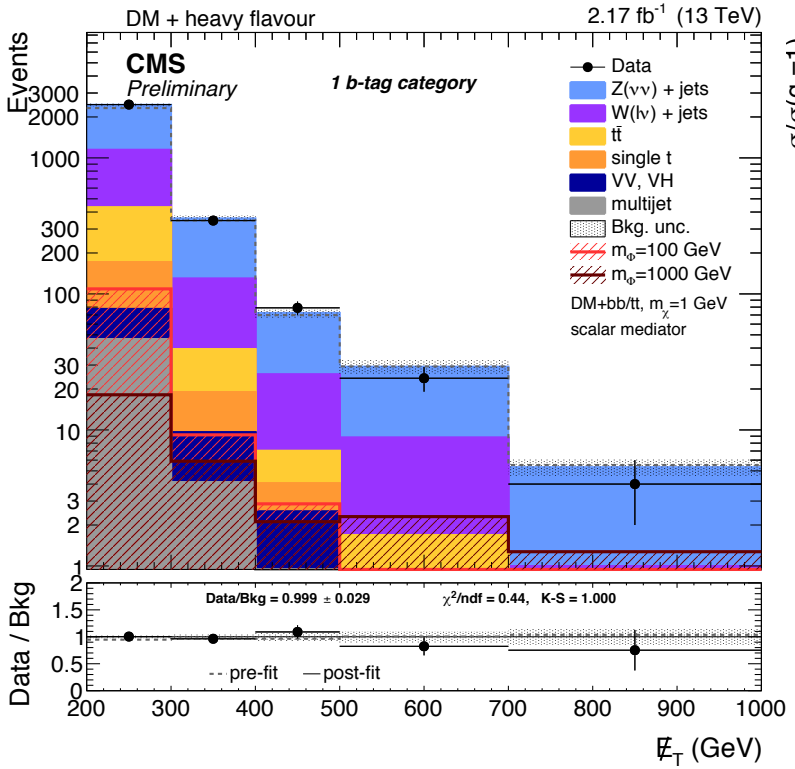


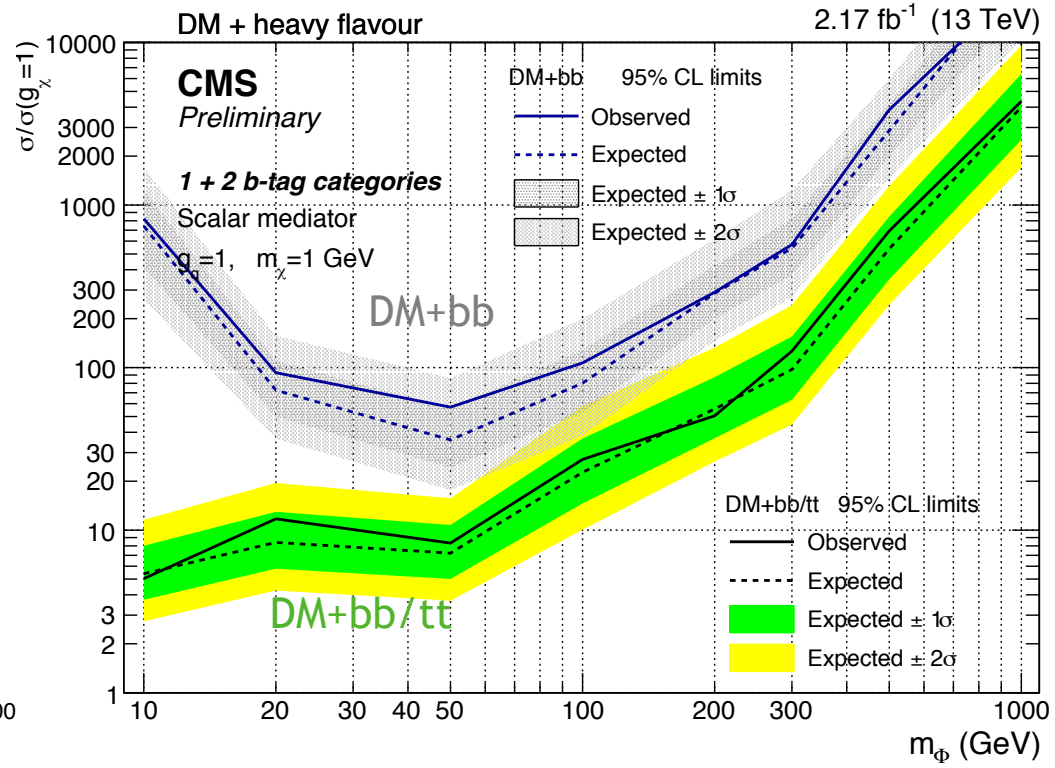
Dark Matter in association with b quarks

Signature: b (1 or 2) + E_T^{miss}
This analysis is sensitive also to DM production processes in association with t quarks, which decay to b's.

CMS-PAS-B2G-15-007



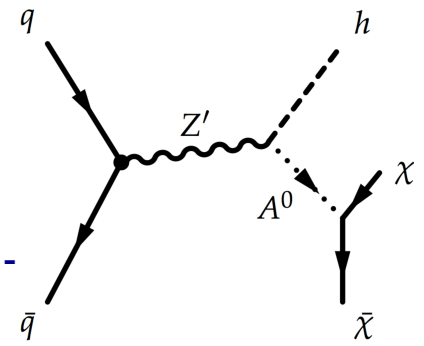




Mediator-DM couplings down to 5 x $\sigma/\sigma(g_{DM}=1)$ for a scalar mediator are excluded.

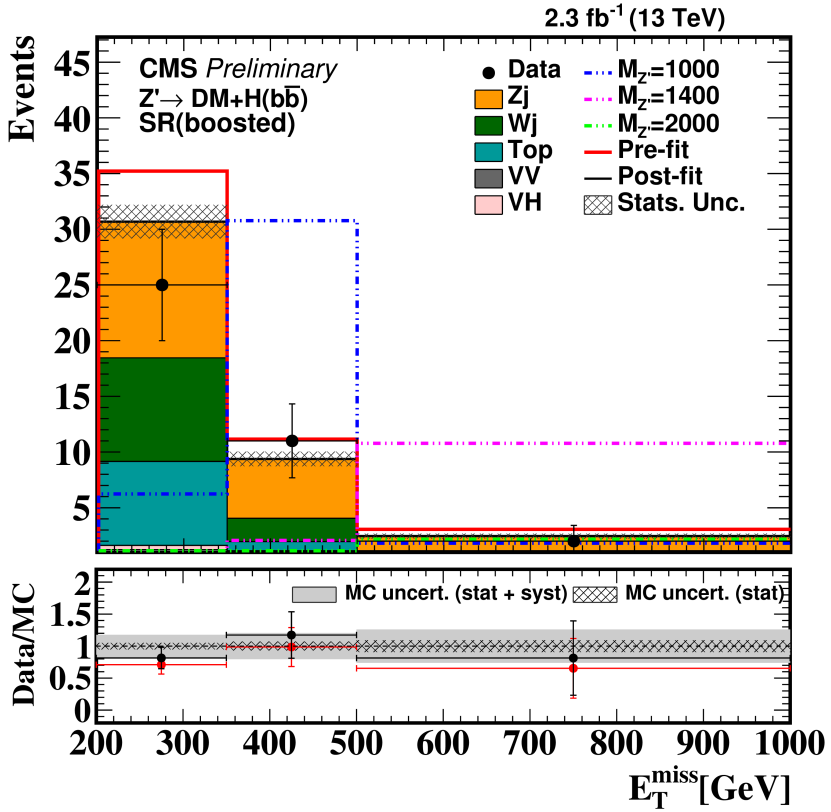
Dark Matter in association with H -> bb

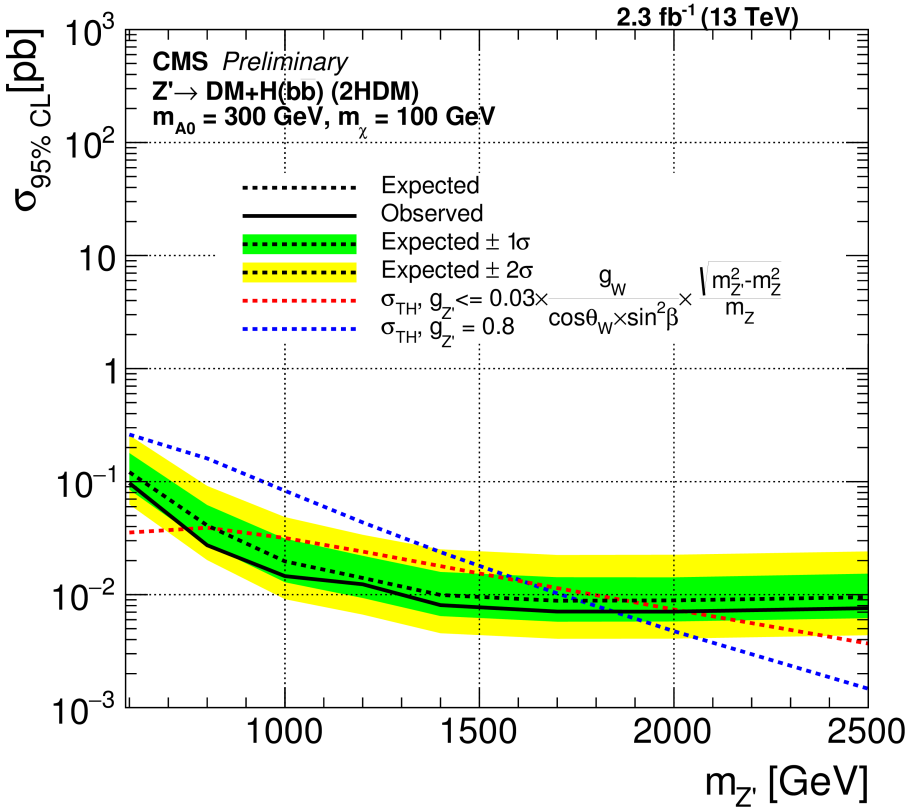
CMS-PAS-EXO-16-012



2H-doublet-model with invisibly decaying pseudoscalar A^0
doi:10.1007/JHEP06(2014)078

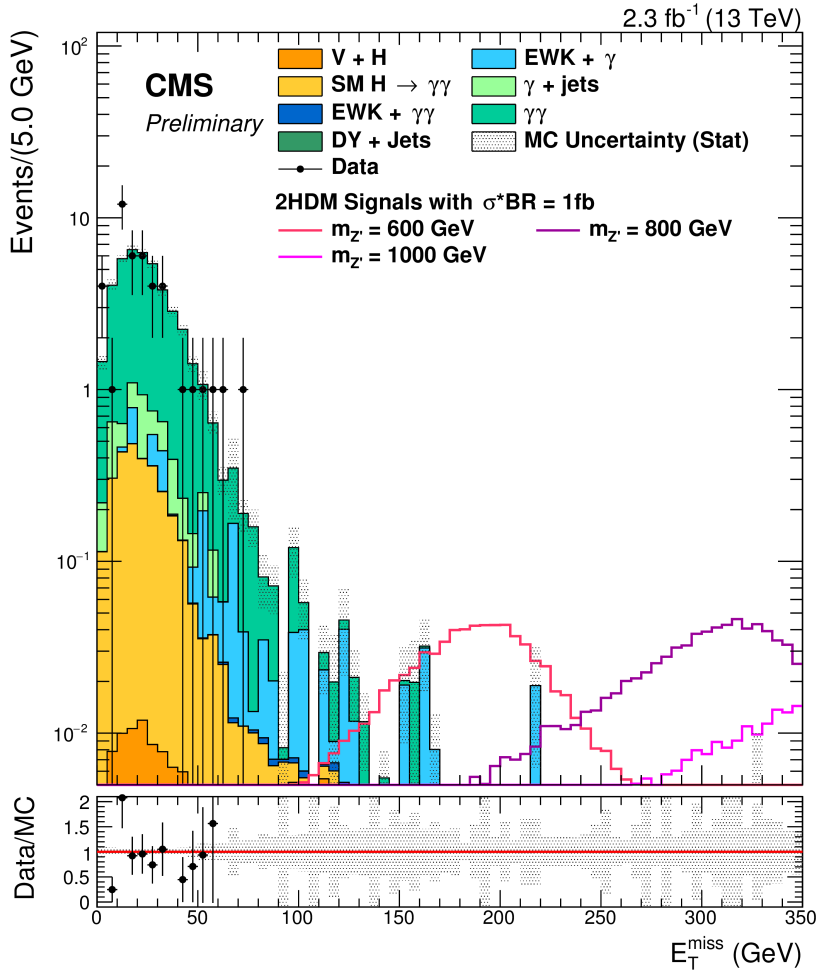
Event selection dependent on p_T: H reconstructed from 2 small- or 1 large-radius jet – resolved and boosted topologies.



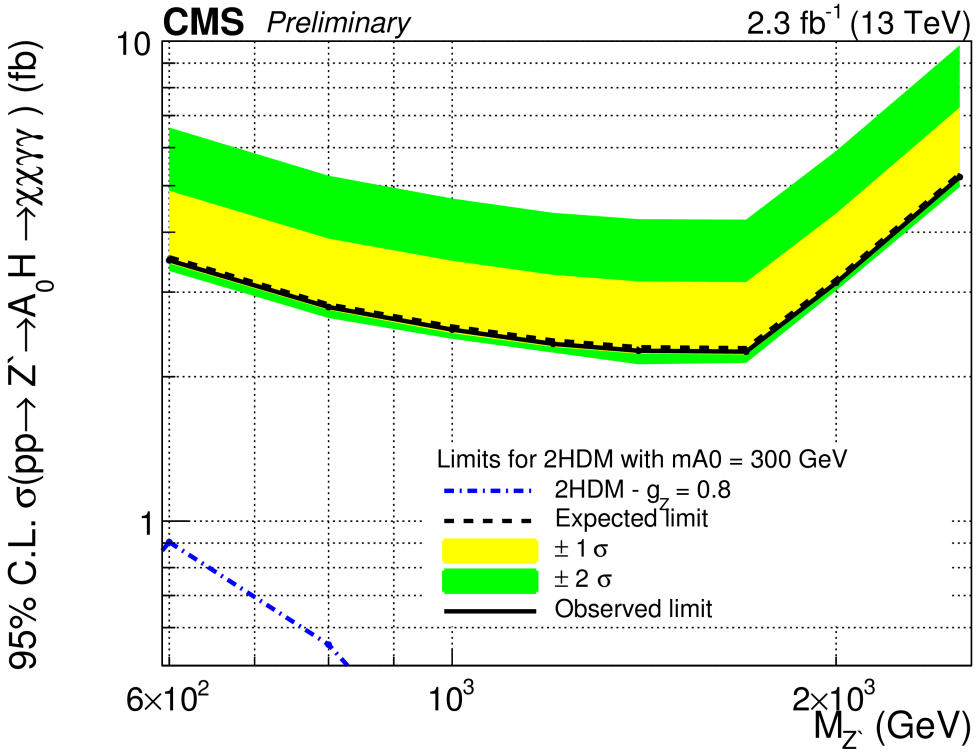


Dark Matter in association with H -> γγ

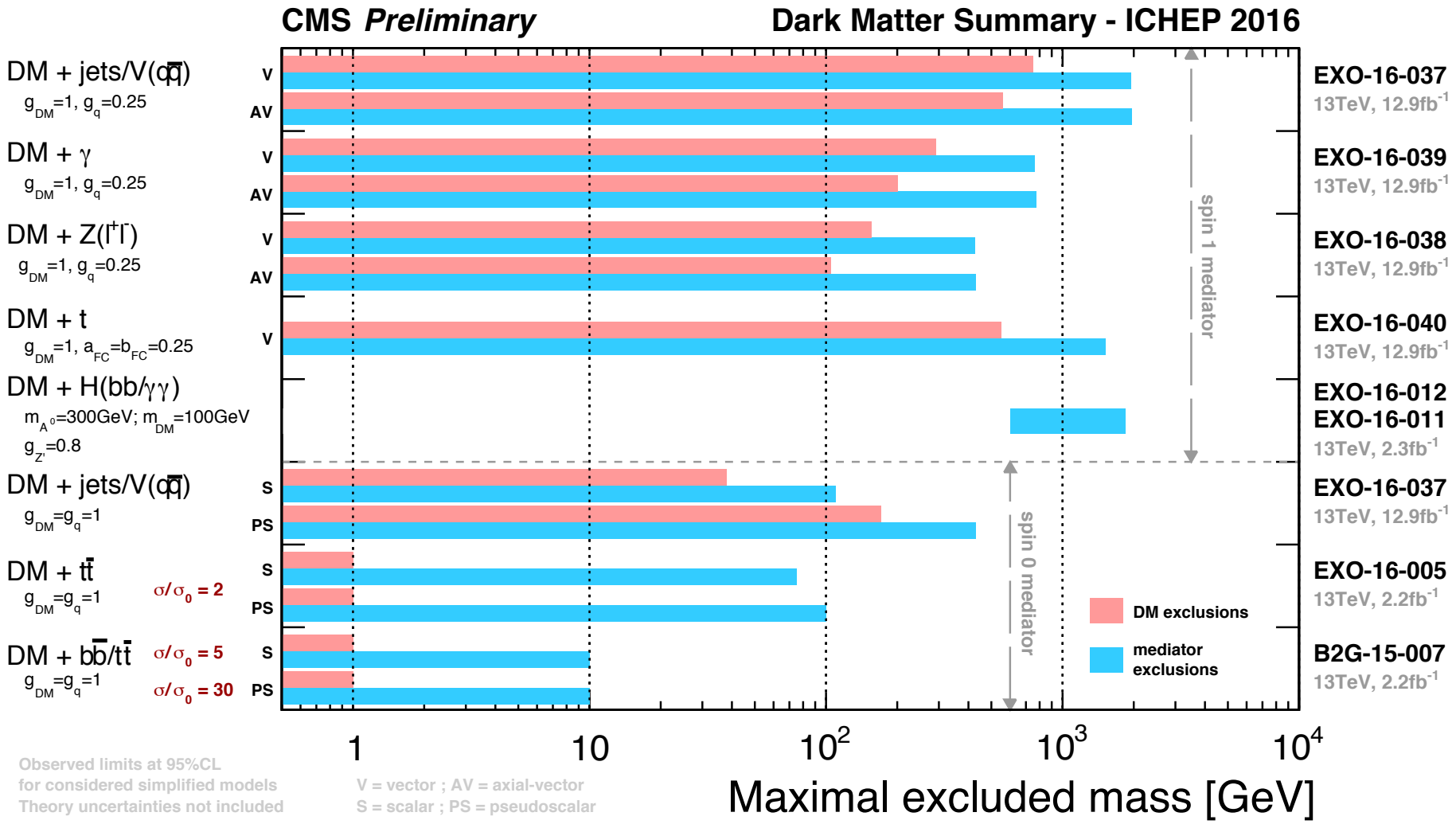
Same 2-HDM as for H -> bb.
Event selection:
2 photon candidates with kinematic requirements on $p_T/m_{\gamma\gamma}$, $m_{\gamma\gamma}$, E_T^{miss}



CMS-PAS-EXO-16-011



Dark Matter Mass Limits



Conclusions

- CMS has recently studied dark matter signatures with $\sqrt{s}$ = 13 TeV data and has derived limits as no excesses have been found.

- Simplified models are replacing EFT approach for Run 2 searches.

- If WIMP dark matter is not confirmed soon other scenarios such as SIMP dark matter might also be studied.

- In any case, we have to be open to all kinds of dark matter searches (WIMP, SIMP, axions, …) across different types of experiments – colliders, direct detection, indirect detection, and specialized experiments.

- Lots of data are still to come before the next LHC shutdown, so stay tuned!

BACKUP

Dark Matter Bibliography

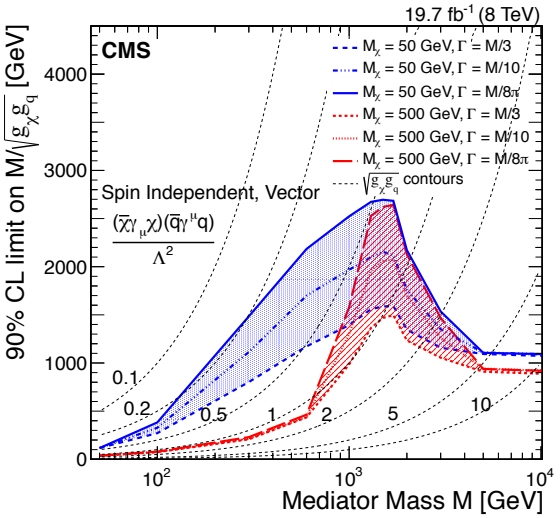
- Monojets: EXO-16-037, EXO-15-003 ($\sqrt{s}$ = 13 TeV), EXO-12-048 ($\sqrt{s}$ = 8 TeV)
- Dijets: EXO-16-013?, EXO-16-032, EXO-14-004 (8 TeV, razor)
- Monophotons: EXO-16-039, EXO-12-047 (8 TeV)
- Mono-Z: EXO-16-010, EXO-16-038, EXO-12-054 (8 TeV)
- Mono-W: EXO-16-013, EXO-16-037, EXO-12-060 (8 TeV)
- MET + top: EXO-16-017, EXO-16-040, B2G-14-004, B2G-13-004, B2G-12-022 (8 TeV)
- MET + tt: EXO-16-005, EXO-16-028
- MET + Higgs: EXO-16-011, EXO-16-012
- Associated b quarks: B2G-15-007 (13 TeV)

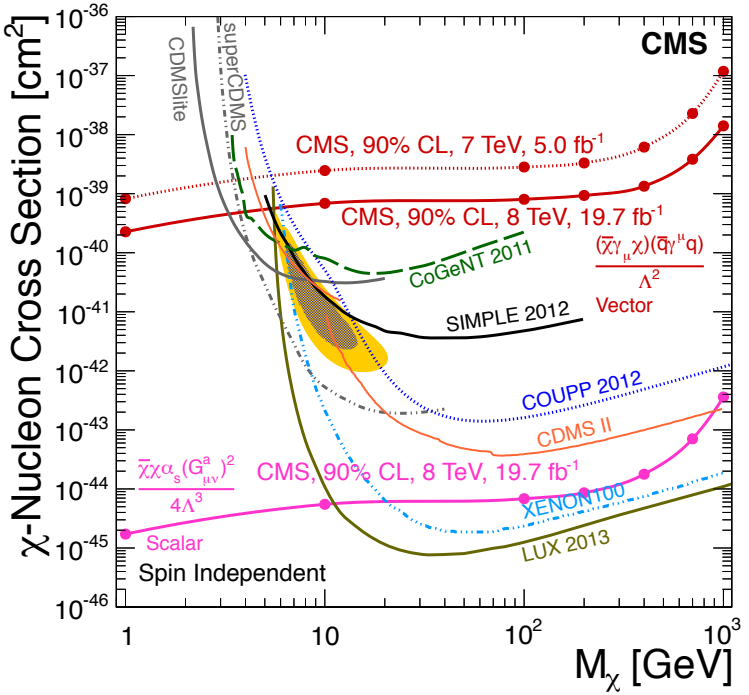
http://cms-results.web.cern.ch/cms-results/public-results/publications

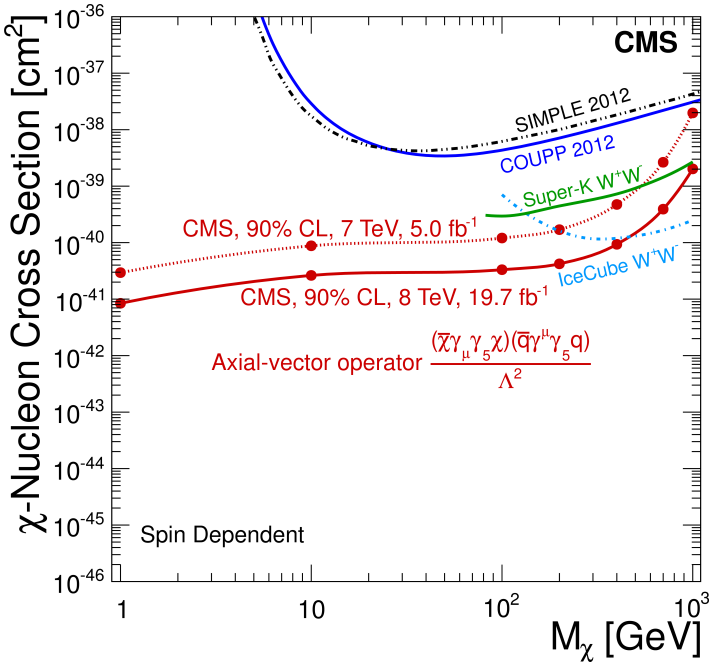
Dark Matter Searches - Monojets

CMS-EXO-12-048, EPJC 75 (2015) 235

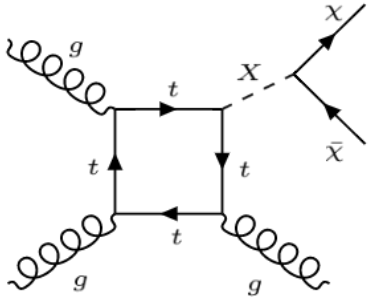
Data sample:
19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV, 5.0 fb^{-1} at $\sqrt{s}$ = 7 TeV
Background:
Z(νν) estimated from Z(μμ) control sample,
$t\bar{t}$ and QCD multijets removed by excluding events with more than 2 jets with p_T > 30 GeV

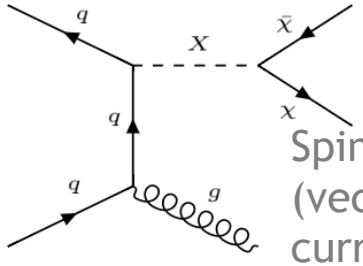






Dark Matter Searches - Monojets

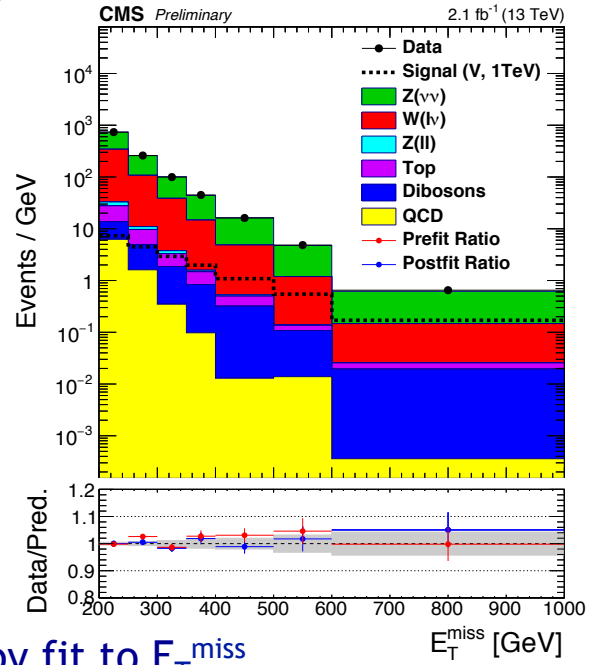




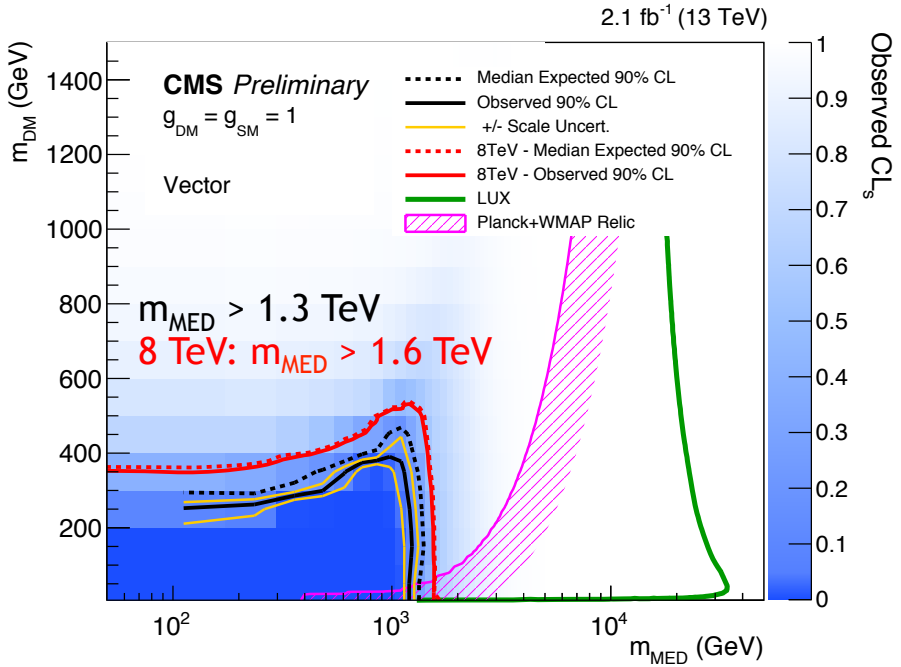
Spin-1 mediator X (vector or axial-vector current)

Spin-0 mediator X (scalar or pseudoscalar current)

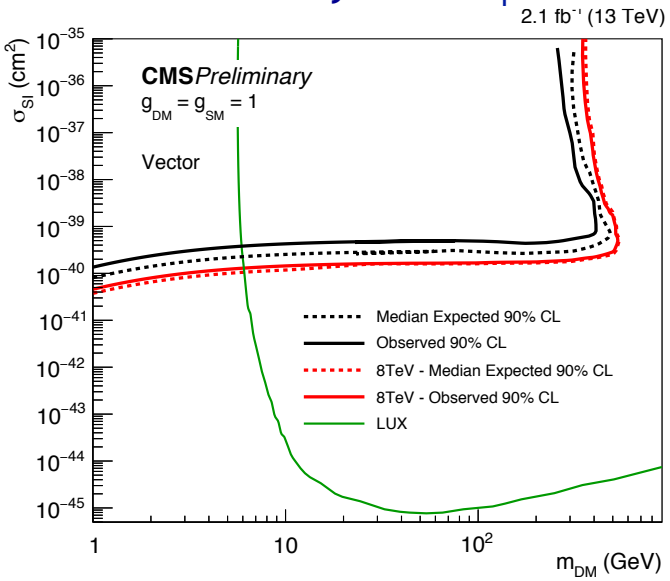
CMS-EXO-15-003



Event selection: ≥ 1 jets with E_T > 100 GeV, E_T^{miss} > 200 GeV
Data sample: 2.1 fb^{-1} at √s = 13 TeV



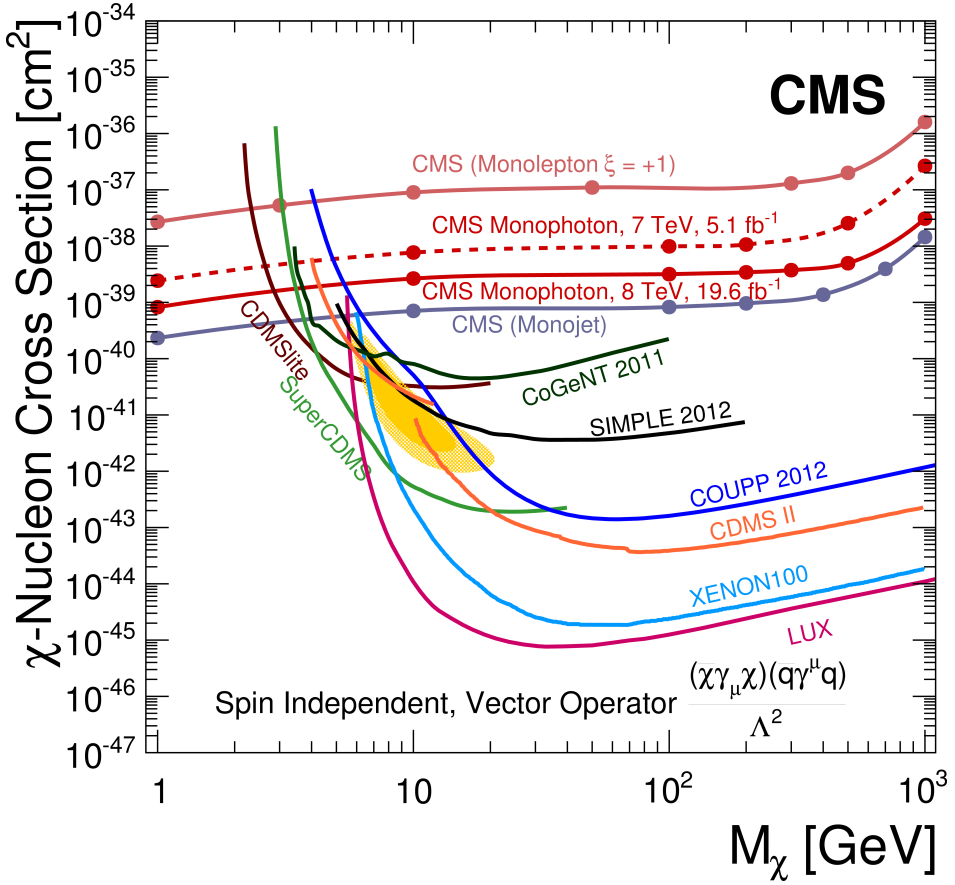
DM signal extracted by fit to E_T^{miss}

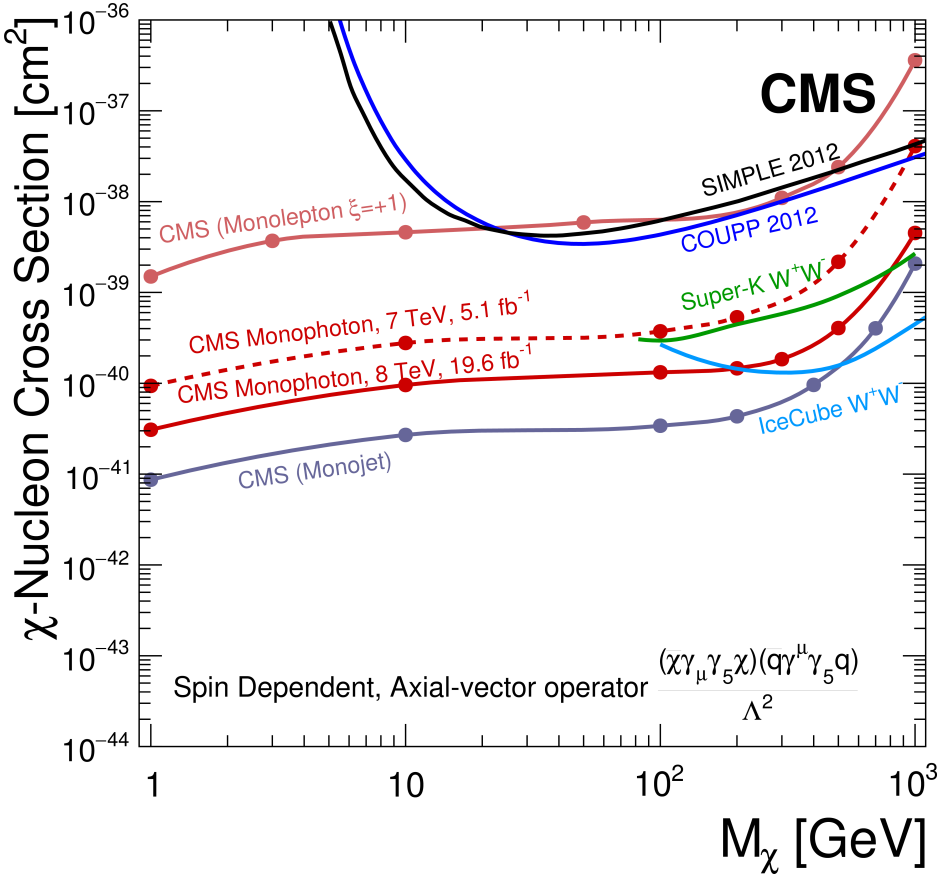


Dark Matter Searches - Monophotons

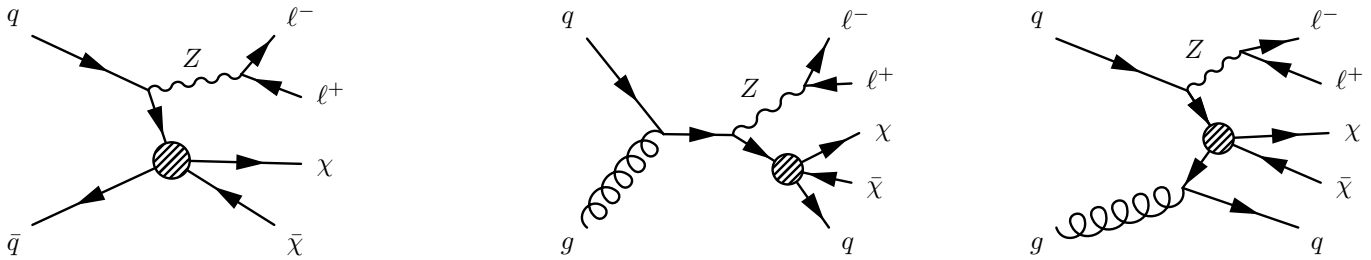
CMS-EXO-12-047, PLB 755 (2016)102

Data sample: 19.6 fb^{-1} at $\sqrt{s}$ = 8 TeV, 5.1 fb^{-1} at $\sqrt{s}$ = 7 TeV
Event selection: single photon with E_T > 145 GeV and $|\eta| \leq 1.44$, E_T^{miss} > 140 GeV



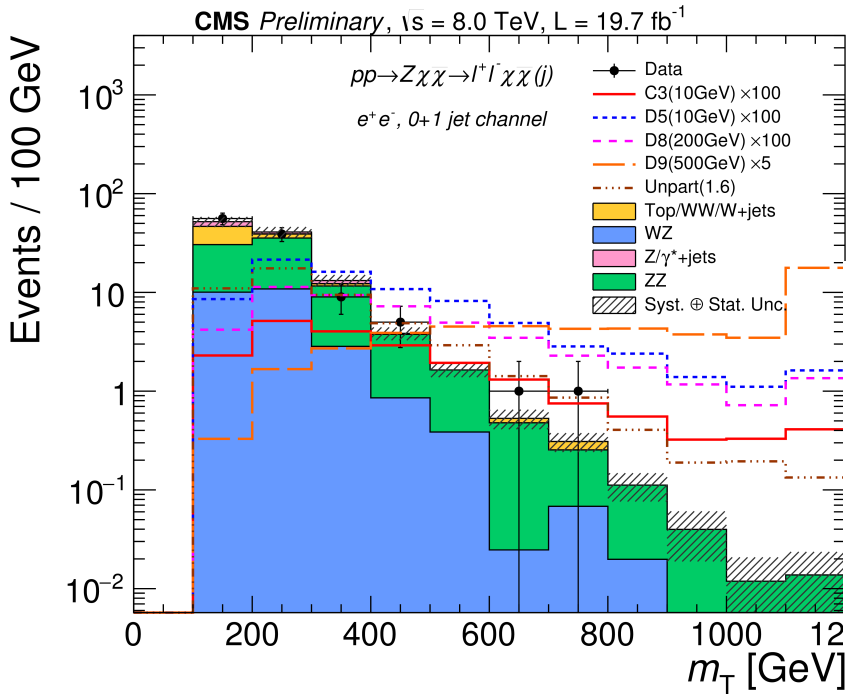


Dark Matter Searches - Mono-Z



Event selection: 2 isolated, opposite-charge e/μ each with p_T > 20 GeV and invariant mass compatible with Z, no additional e/μ with p_T > 20 GeV, dilepton p_T > 50 GeV, no b-tagged jet

CMS-EXO-12-054



Operators for Dirac fermion (D) or complex scalar (C) DM coupling to SM quarks, Λ being the coupling scale of interactions between DM and quarks:

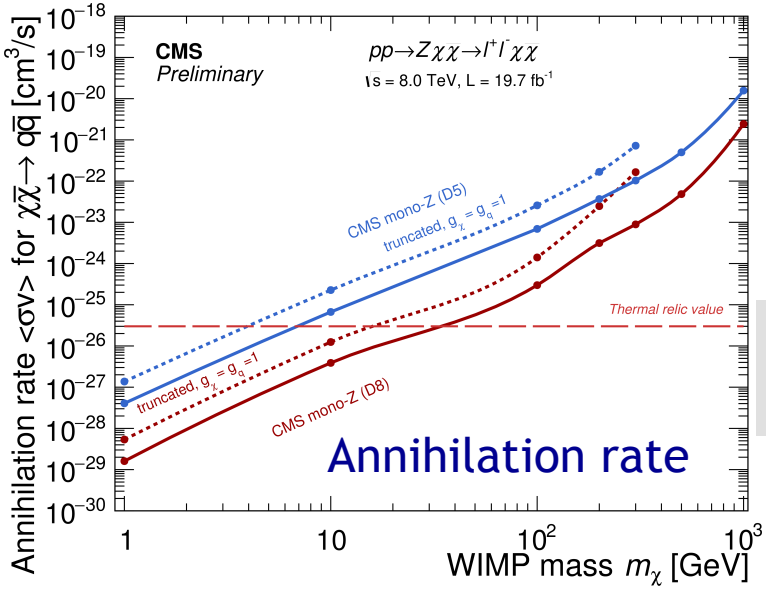
Vector coupling, spin-independent (D5): $\frac{\bar{\chi}\gamma^{\mu}\chi\bar{q}\gamma_{\mu}q}{\Lambda^2}$

Axial-Vector coupling, spin-dependent (D8): $\frac{\bar{\chi}\gamma^{\mu}\gamma^{5}\chi\bar{q}\gamma_{\mu}\gamma^{5}q}{\Lambda^2}$

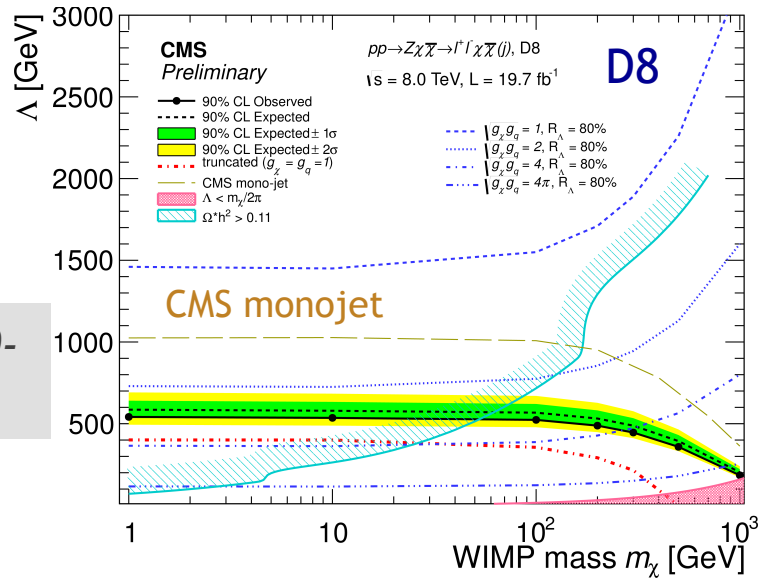
Tensor coupling, spin-dependent (D9): $\frac{\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q}{\Lambda^2}$

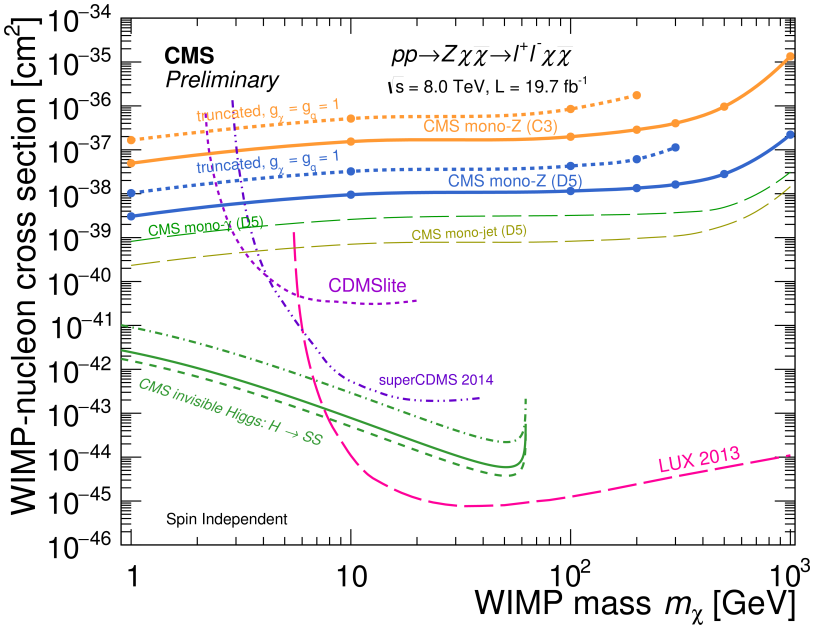
Vector coupling, spin-independent (C3): $\frac{\chi^{\dagger}\overleftrightarrow{\partial}_{\mu}\chi\bar{q}\gamma^{\mu}q}{\Lambda^2}$

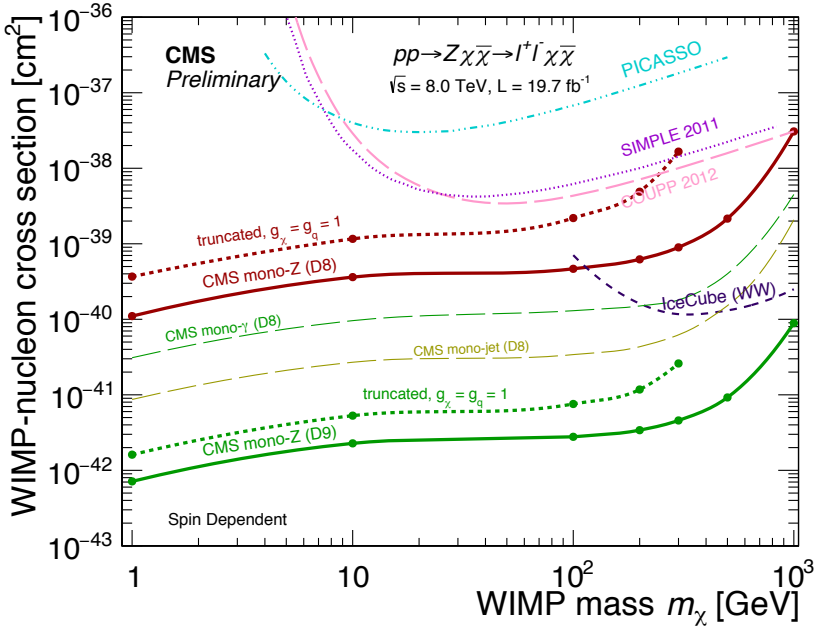
Dark Matter Searches - Mono-Z



CMS-EXO-12-054

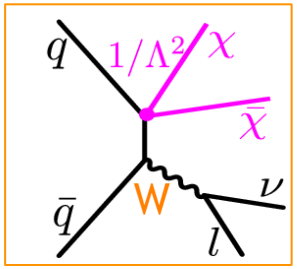




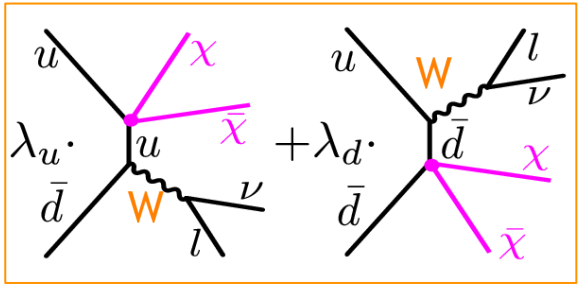


Dark Matter Searches - Mono-W

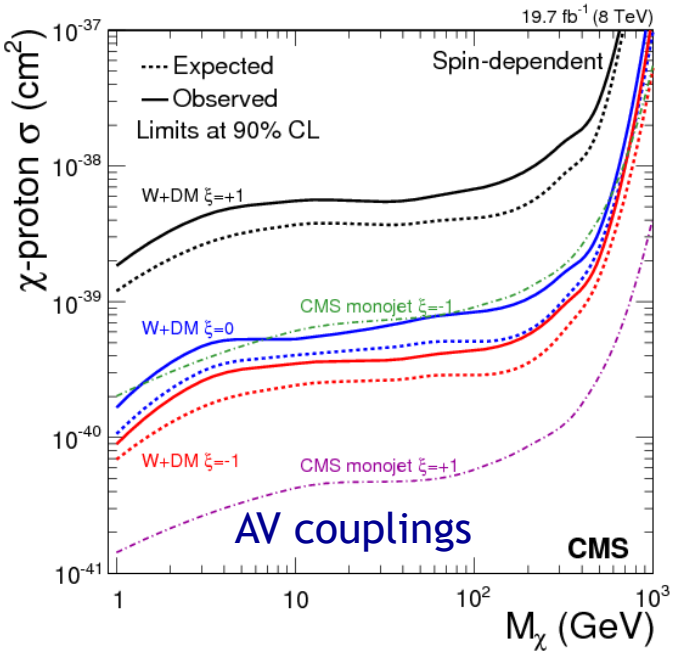
Dark matter interpretation of W' analysis

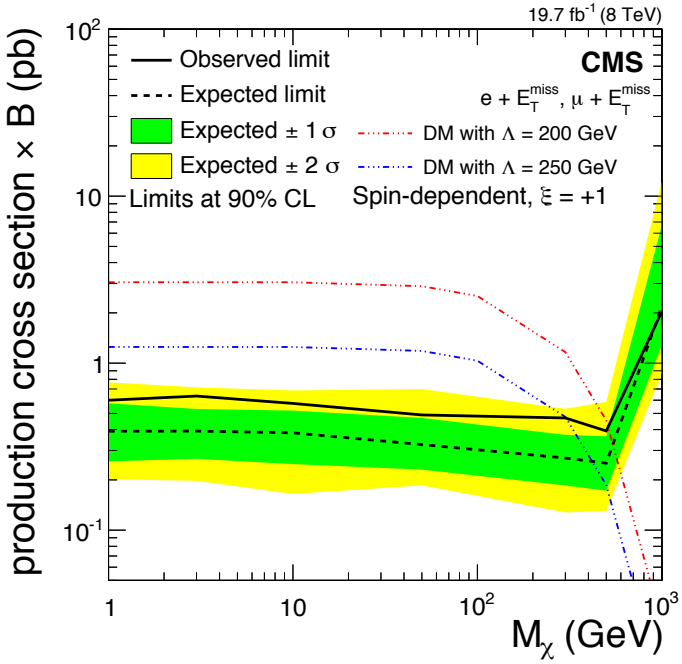


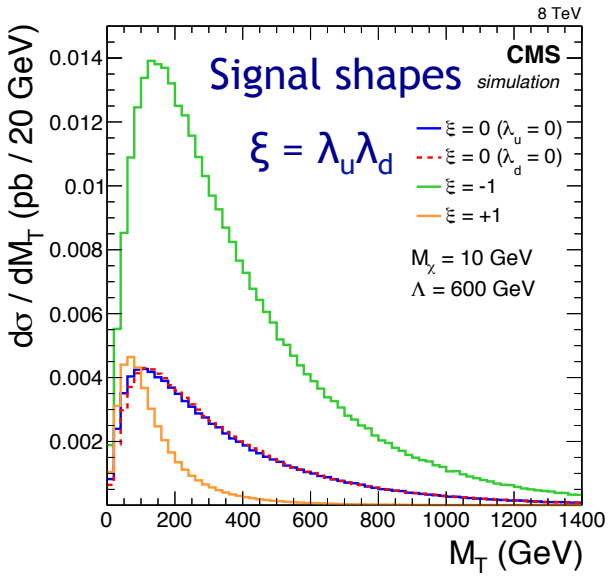
DM interference



Data sample: 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV
Event selection: prompt or non-prompt (from τ) single e or μ and E_T^{miss}
Advantages over monojet and mono-γ channels: lower SM background and trigger lepton







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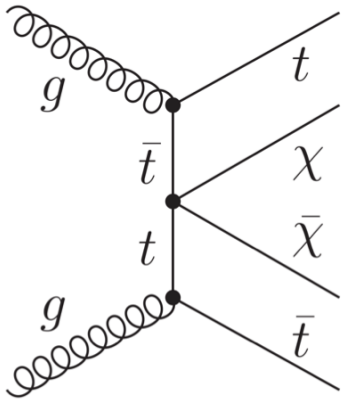
Dark Matter Searches - Top Pairs

q-χ couplings for heavy flavors enhanced in scalar interactions



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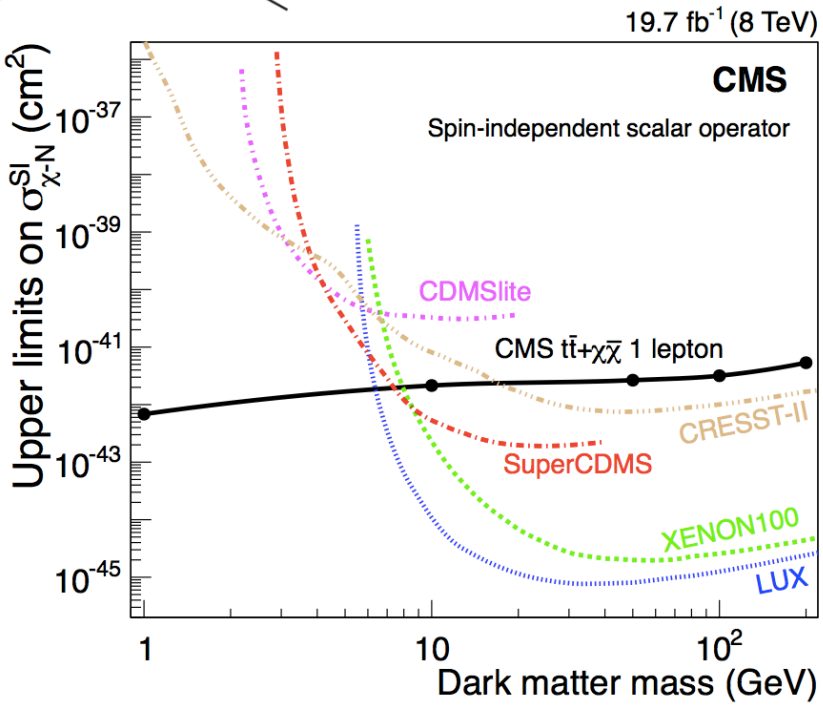
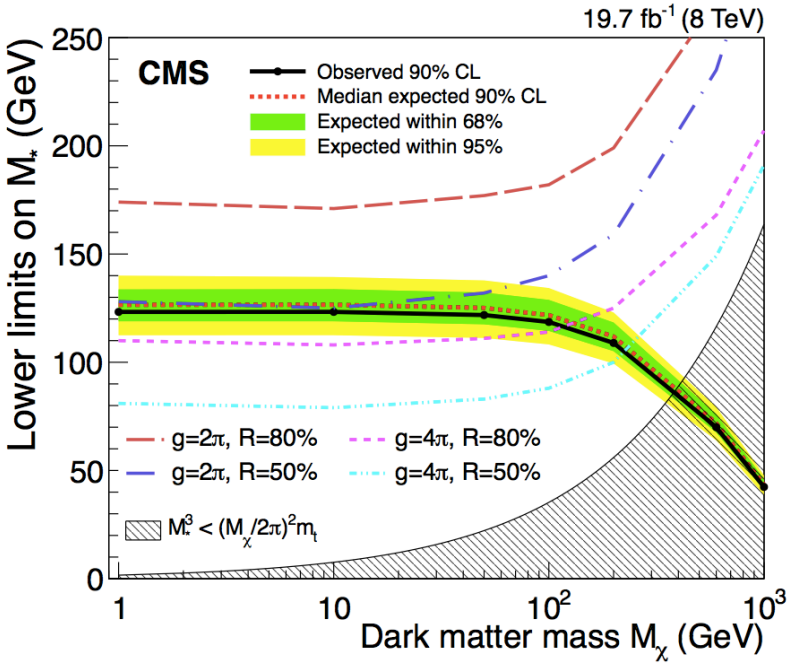
$tt + E_t^{miss}$ signature:
single lepton with jets, at least 1 b-tagged





M_*: scale of the interaction