Searches for dark matter at CMS in events with missing transverse energy

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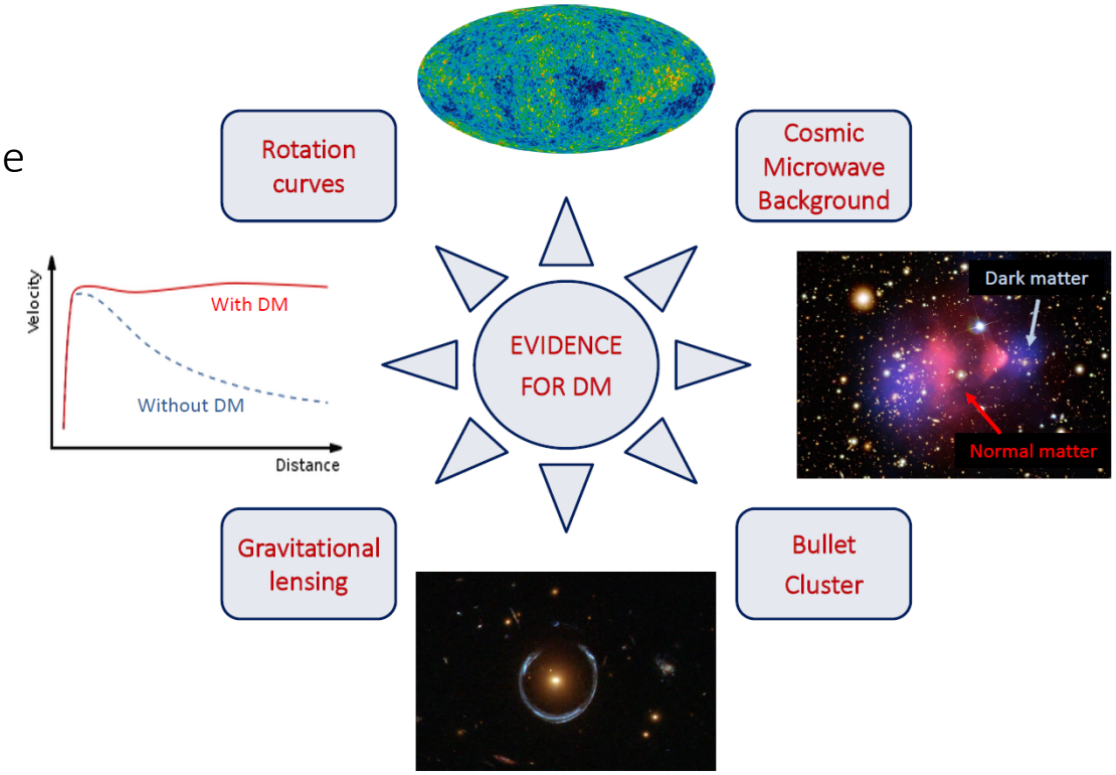
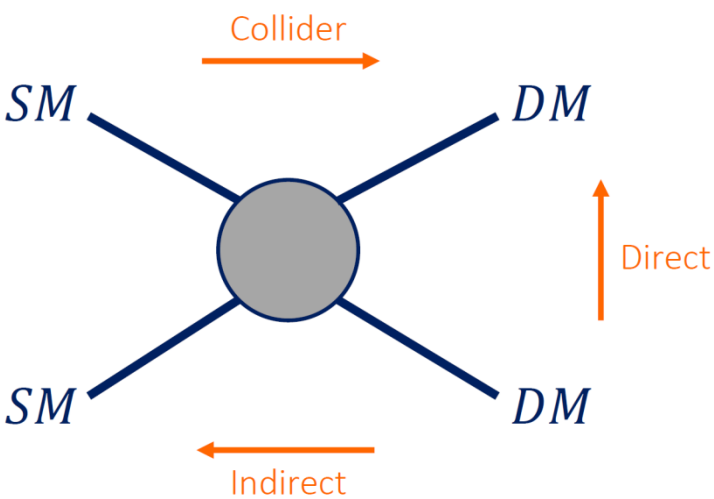
DIS2017 Birmingham

Introduction

- Dark matter constitutes ~26% of the energy content of the universe
- Many independent sources of evidence
- Its underlying nature is unknown. Requires new physics beyond the standard model





- Three complementary strategies for searching for DM
- Collider searches are particularly sensitive to light DM (<10 GeV) and spin dependent interactions

DM searches at LHC

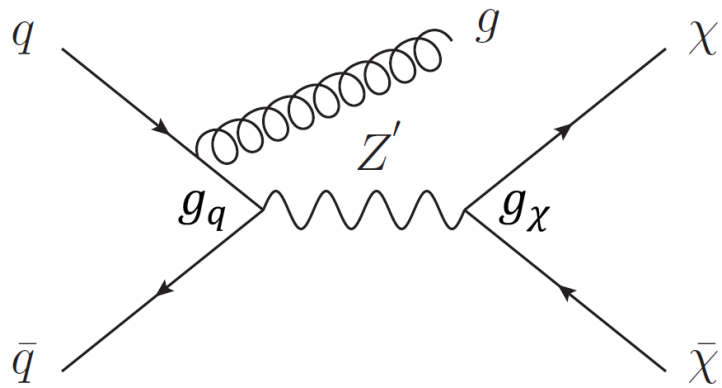
- Weakly interacting DM particles may be produced in high energy p-p collisions at the LHC

- DM at the LHC is detected through the missing transverse energy it creates in an event as it recoils against some object X (jet, photon, boson…)
  - "mono-X" or "MET+X" signatures

(*) ATLAS/CMS Dark Matter Forum 1507.00966

- Use simplified models* to interpret results
  - Pair-produced fermionic DM via a massive (vector, axial-vector, scalar, or pseudoscalar) boson
  - Minimal set of parameters

M_{med}	M_χ
g_q	g_χ

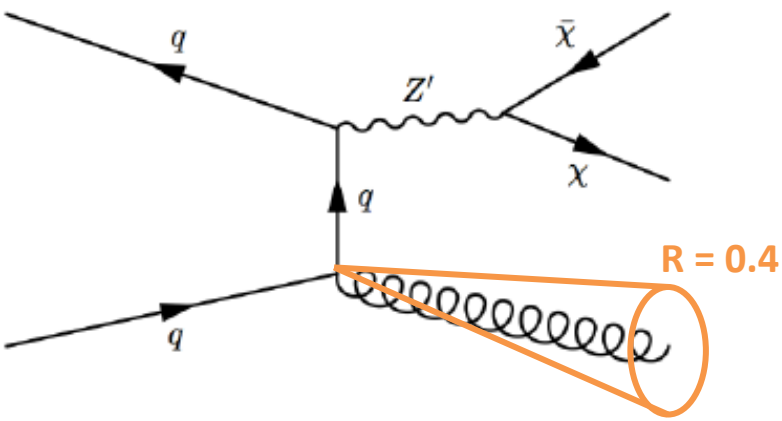


Mono-jet/Mono-V(had)

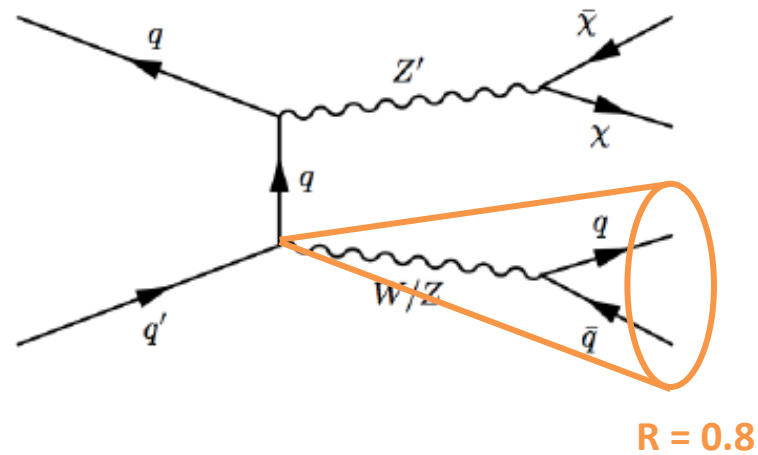
EXO-16-037
12.9 fb^{-1} (2016)

- Look for large MET, at least one high p_T jet, and veto leptons, photons and b-jets

mono-jet



mono-V



- <u>Mono-V:</u>
  - MET > 250 GeV
  - Leading AK8 jet p_T > 250 GeV, $|\eta| < 2.4$, mass $[m_W\text{-}15, m_Z\text{+}15]$, N-subjettiness $\tau_2/\tau_1 < 0.6$

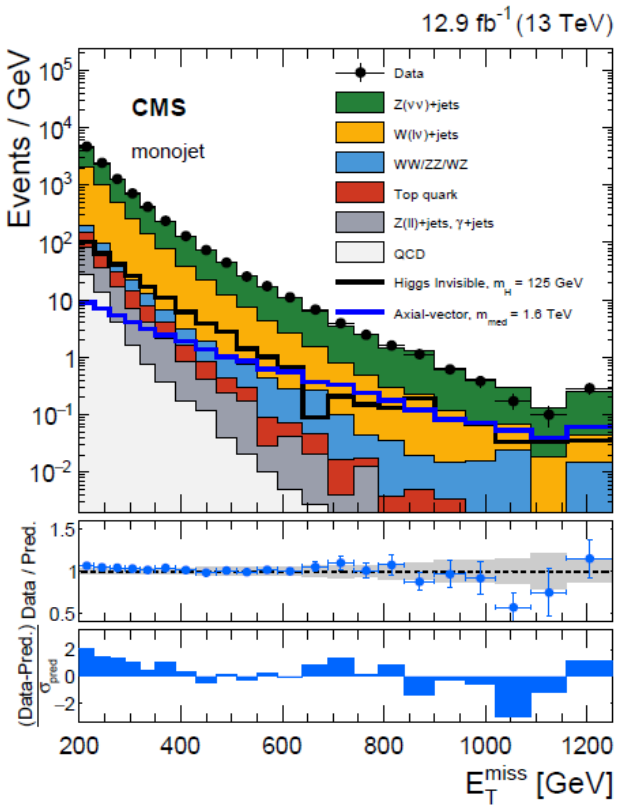
- <u>Mono-jet:</u>
  - MET > 200 GeV
  - Leading AK4 jet p_T > 100 GeV, $|\eta| < 2.5$

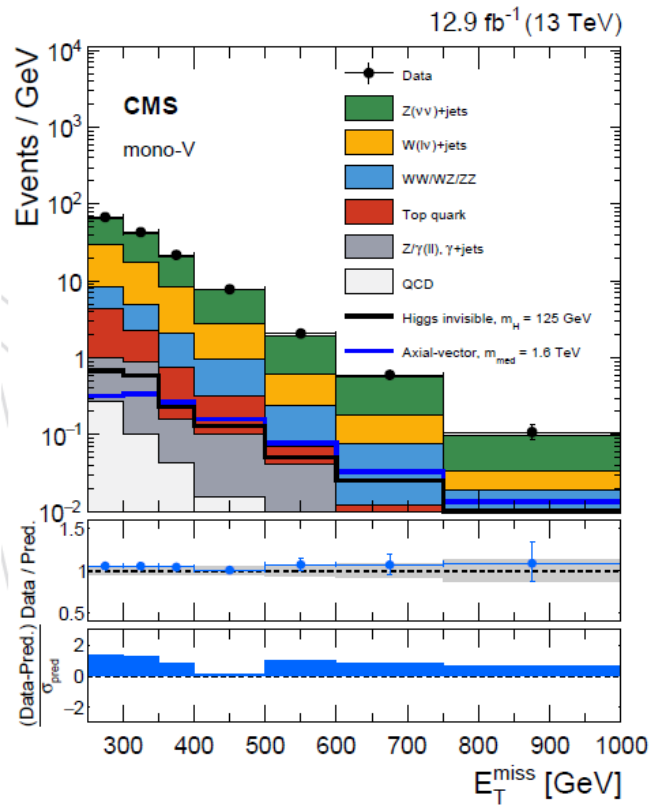
Mono-jet/Mono-V(had)

EXO-16-037
12.9 fb^{-1} (2016)

- Dominant background processes are Z(vv)+jets (60%) and W(lv)+jets (30%)
- Need precise estimation of these backgrounds
  - Use five control regions in data
    - Z(μμ)+jets, Z(ee)+jets, γ+jets to estimate Z
    - W(μν)+jets, W(eν)+jets to estimate W
- Estimate background and extract signal strength by performing a simultaneous fit over all mono-jet and mono-V control and signal regions

mono-jet



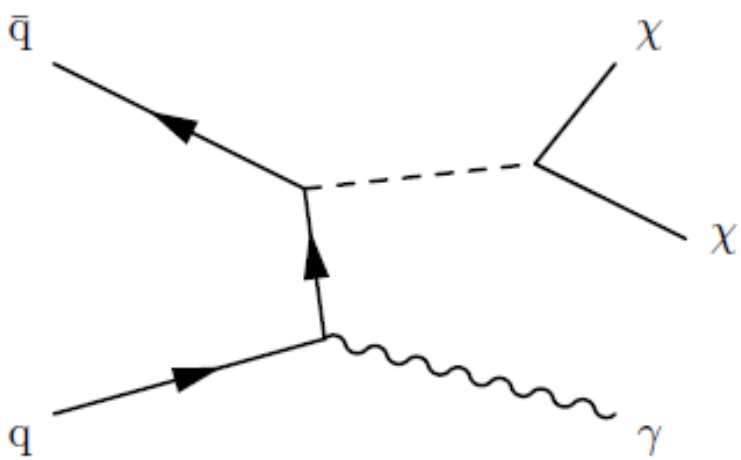


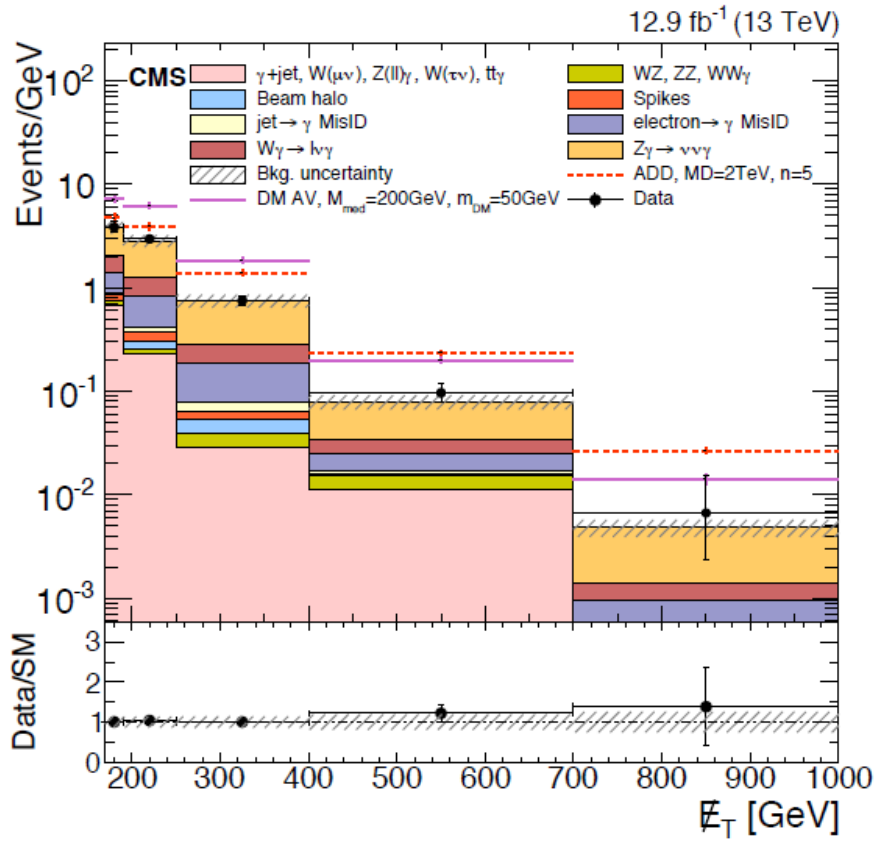
mono-V

Mono-photon

EXO-16-039
12.9 fb^{-1} (2016)

- Select events with a barrel photon with p_T > 175 GeV, MET > 170 GeV, veto leptons
- Dominant backgrounds are Z(νν)γ and W(lν)γ
  - Estimated using MC with NNLO QCD and NLO EWK corrections, and verified in control regions in data
- Cut-and-count analysis

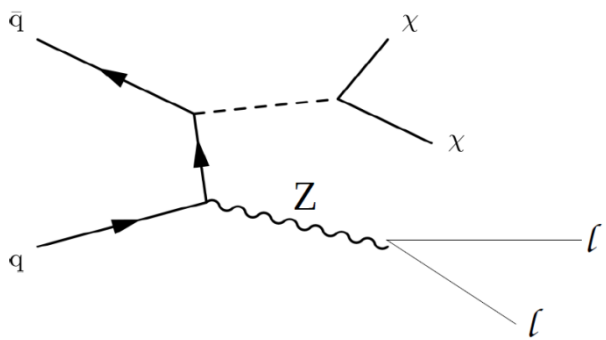




Mono-Z(ll)

EXO-16-038
12.9 fb^{-1} (2016)

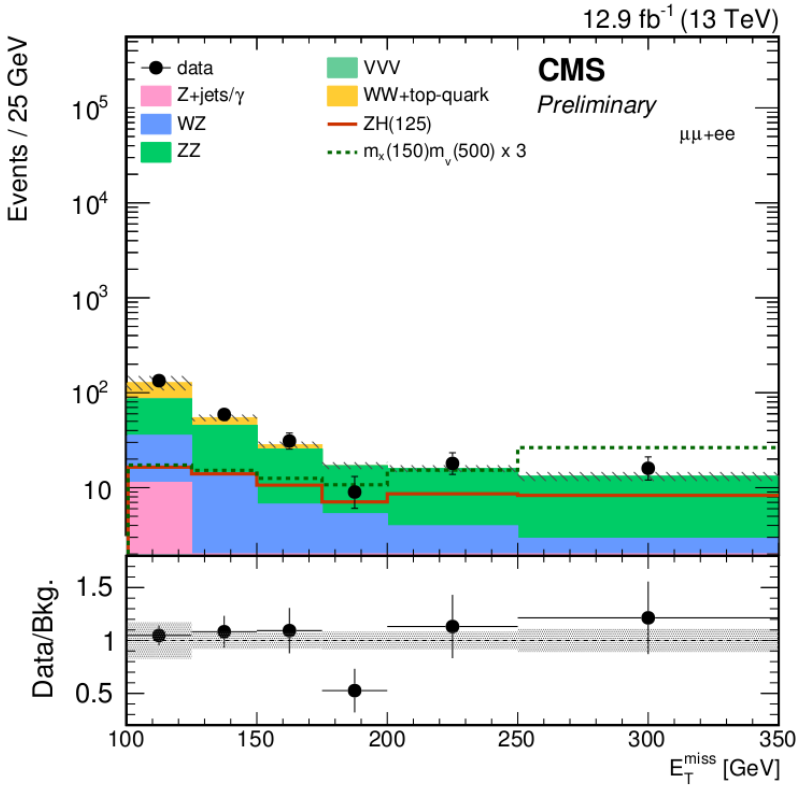
- Select events with ee/μμ within Z mass window, MET > 100 GeV, veto additional leptons, b-tagged jets and high p_T jets



- Dominant backgrounds are Z(ll)Z(νν) (60%) and Z(ll)W(lν) (25%)

- ZZ and ZW background estimated with MC simulation with higher order (NLO/NNLO) corrections

- Perform a binned fit to the MET shape



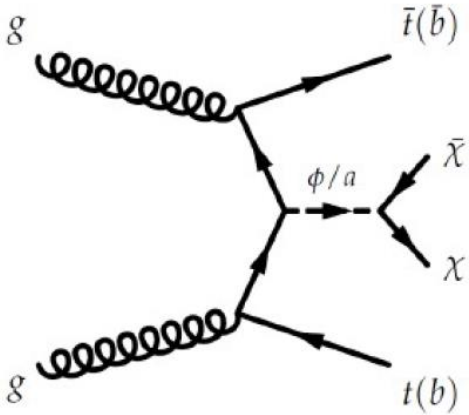
DM+tt/bb

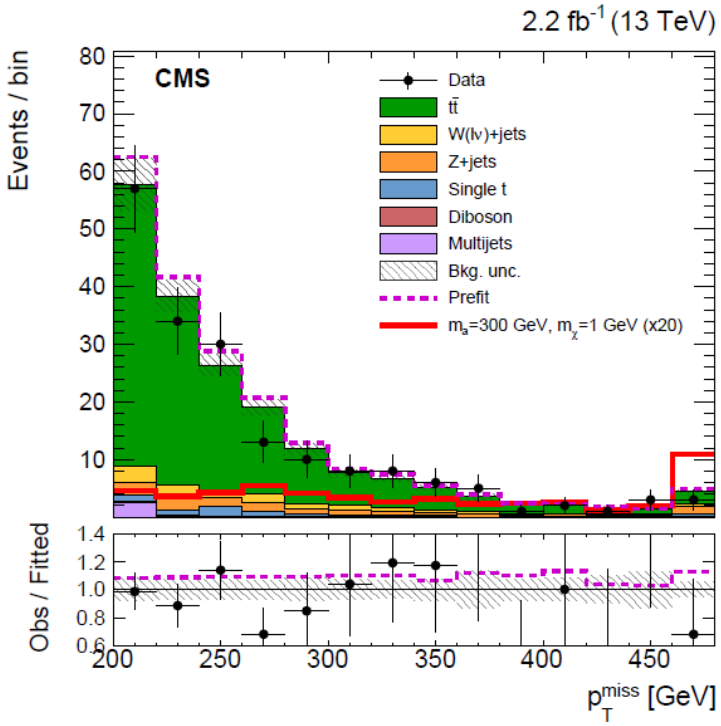
EXO-16-005
2.2 fb^{-1} (2015)

- Assuming minimal flavour violation, spin-0 (scalar and pseudoscalar) mediators couple to quarks with Yukawa structure → couple preferentially to heavy quarks

- 4 final states analysed: tt (hadronic, semileptonic, dileptonic) and bb

- <u>tt hadronic</u>
  - MET > 200 GeV
  - Multivariate top-tagger to identify hadronic top decays to 3 jets
    - Categorize by number of resolved top tags
  - Dominant background is tt(1l)





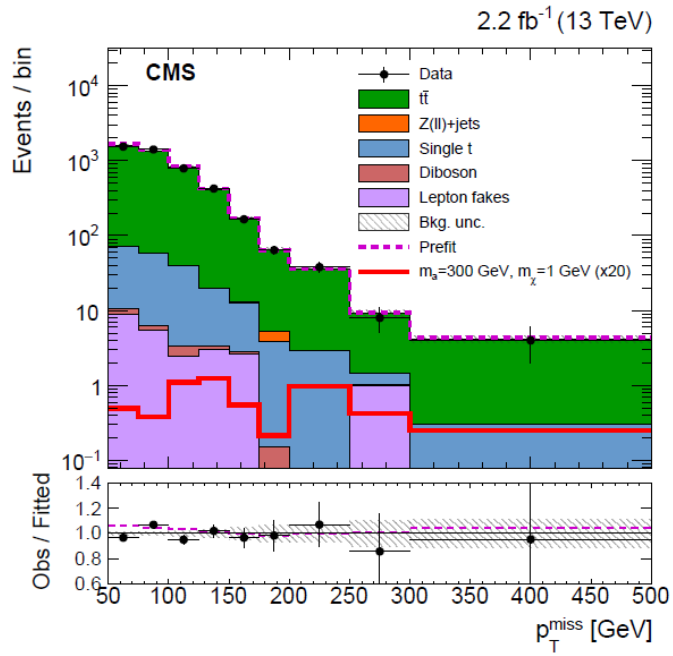
hadronic (2 top-tags)

DM+tt/bb

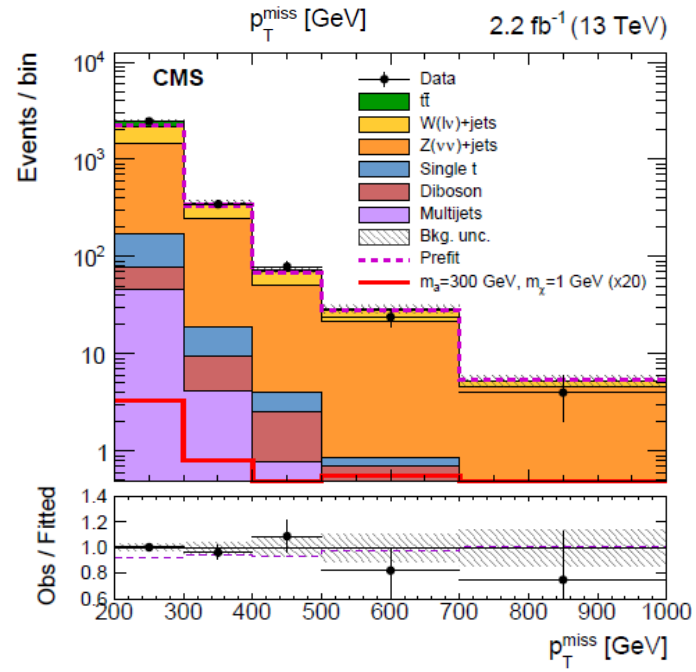
EXO-16-005
2.2 fb^{-1} (2015)

- <u>tt semileptonic</u>
  - MET > 160 GeV
  - Exactly one lepton (e or μ)
  - Dominant background is tt(2l)
- <u>tt dileptonic</u>
  - MET > 50 GeV
  - Exactly two leptons (ee, eμ, or μμ)
  - Dominant background is tt(2l)
- <u>bb</u>
  - MET > 200 GeV
  - >= 1 b-tagged jet
  - Dominant backgrounds are Z(vv)+jets, W(lv)+jets, tt(1l)
- Overlaps between channels are taken care of and a simultaneous fit over all channels is performed to extract limits on a combined DM+tt and DM+bb signal

dileptonic eμ



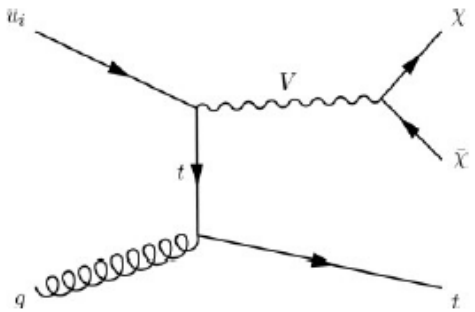
bb (1 b-tag)



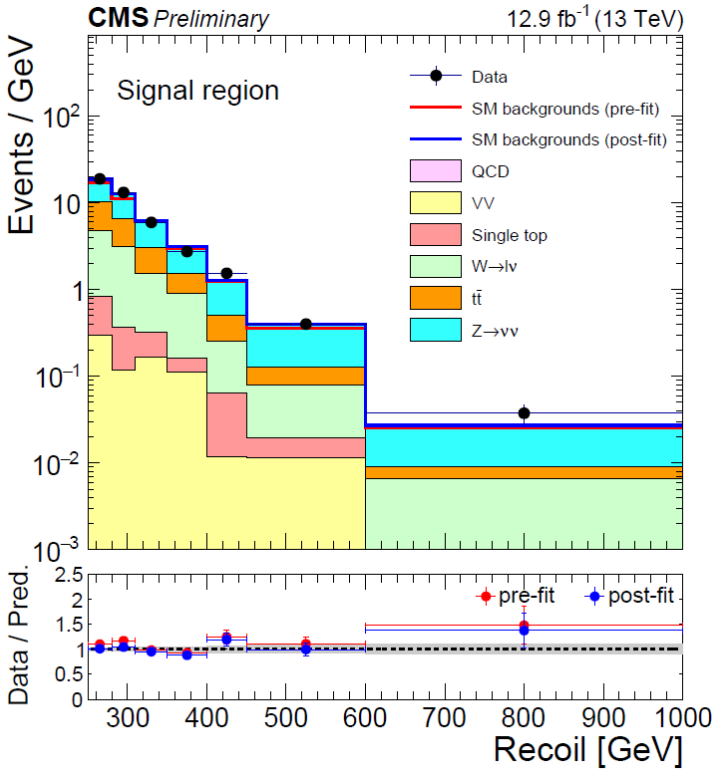
Mono-top

EXO-16-040
12.9 fb^{-1} (2016)

- Select events with MET > 250 GeV and a boosted hadronic top. Veto leptons, photons, and additional b-tagged jets
- Top-tagging: R=1.5, mass 110-210 GeV, τ_3/τ_2, subjet b-tag
- Dominant backgrounds are tt, Z(νν)+jets, and W(lν)+jets
  - Estimate with seven control regions in data
- MET shape analysis



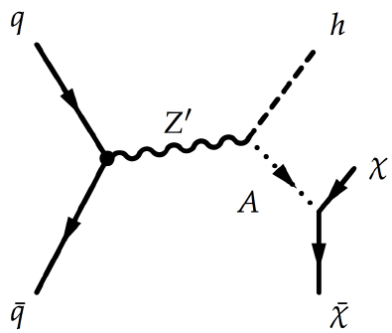
Flavor-changing Vector



Mono-Higgs(bb/γγ)

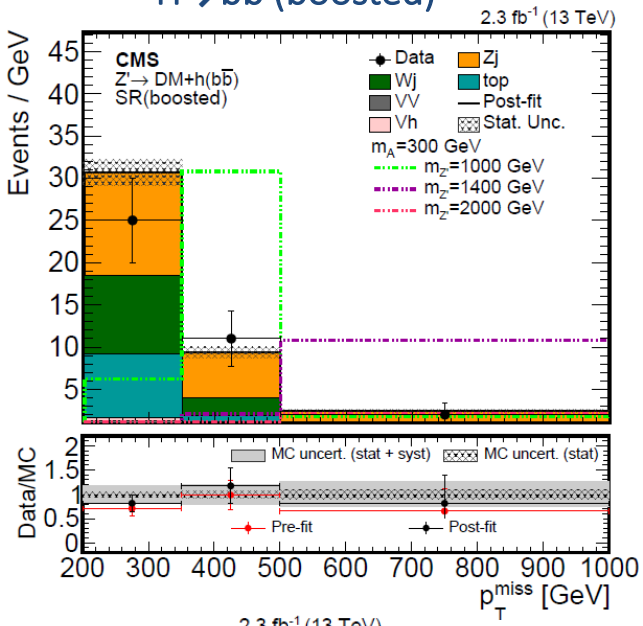
EXO-16-012
2.3 fb^{-1} (2015)

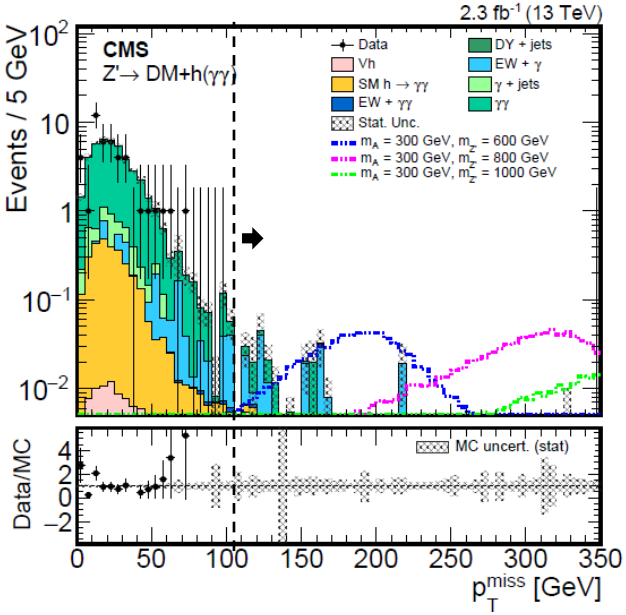
- Interpretation in the context of a 2HDM



- <u>H(bb)</u>
  - Two regimes of bb system
    - Resolved: 2 AK4 jets, p_T^{jj} > 150 GeV, MET > 170 GeV
    - Boosted: 1 AK8 jet, p_T^{j} > 200 GeV, MET > 200 GeV
  - 100 < m_{bb} < 150 GeV
  - Dominant backgrounds are Z(νν)+jets, W(lν)+jets, tt
    - Estimated with control regions in data
- <u>H(γγ)</u>
  - MET > 105 GeV
  - 120 < $m_{\gamma\gamma}$ < 130 GeV
  - Dominant backgrounds are γγ and γ+jets
    - Estimated with $m_{\gamma\gamma}$ sidebands

H→bb (boosted)





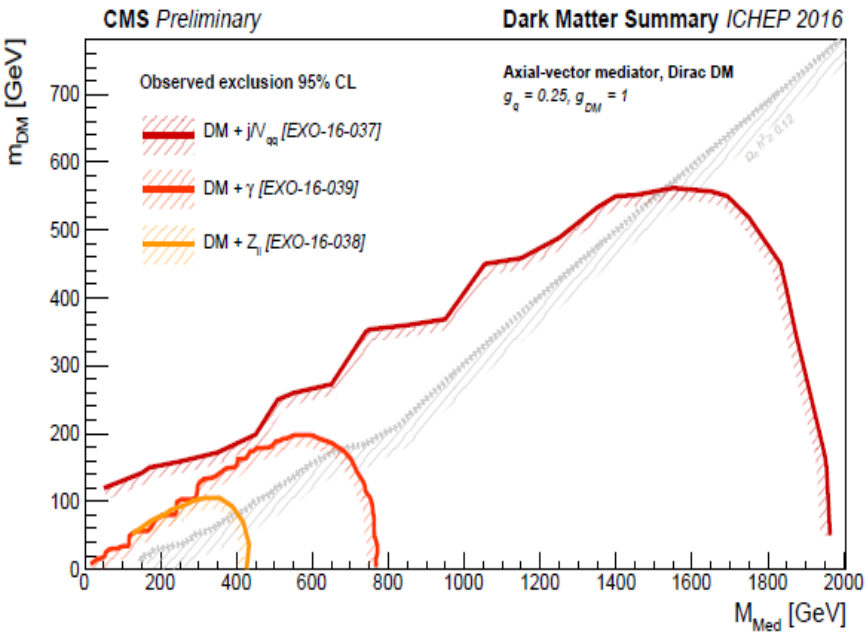
H→γγ

Spin-1 limits

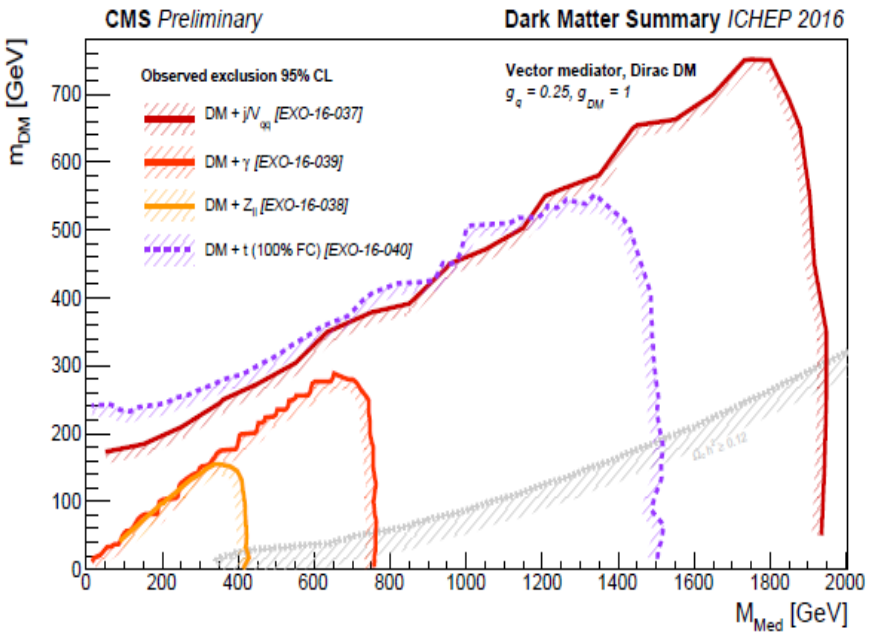
- 95% CL exclusion regions in the mediator-DM mass plane for different MET+X searches for spin-1 mediators

- Mediator couplings of $g_q = 0.25$, $g_{DM} = 1$

Axial-vector



Vector

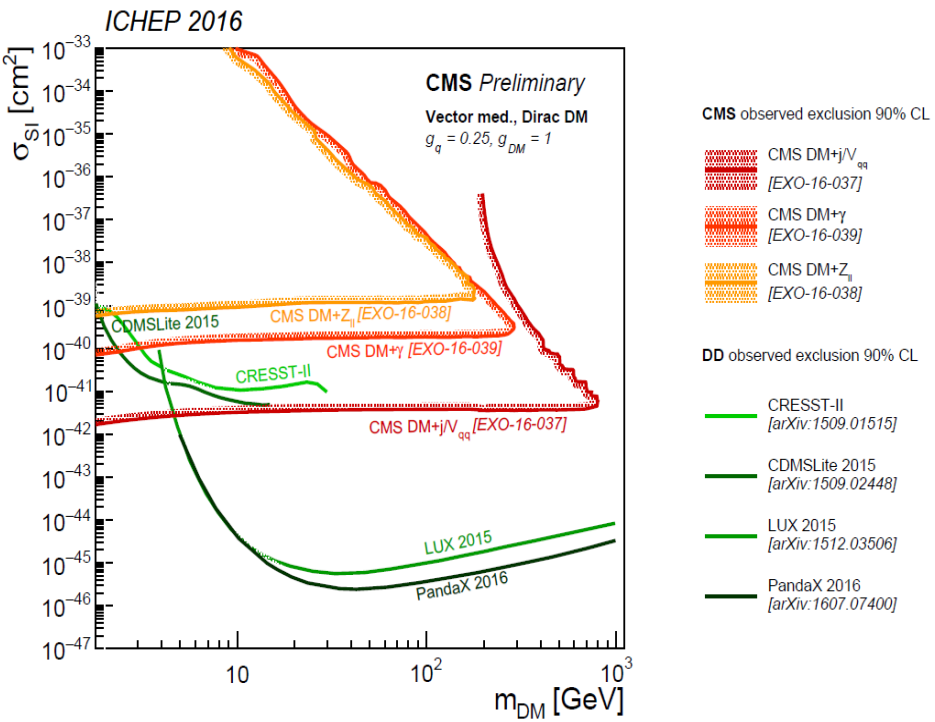


Spin-1 limits compared to DD

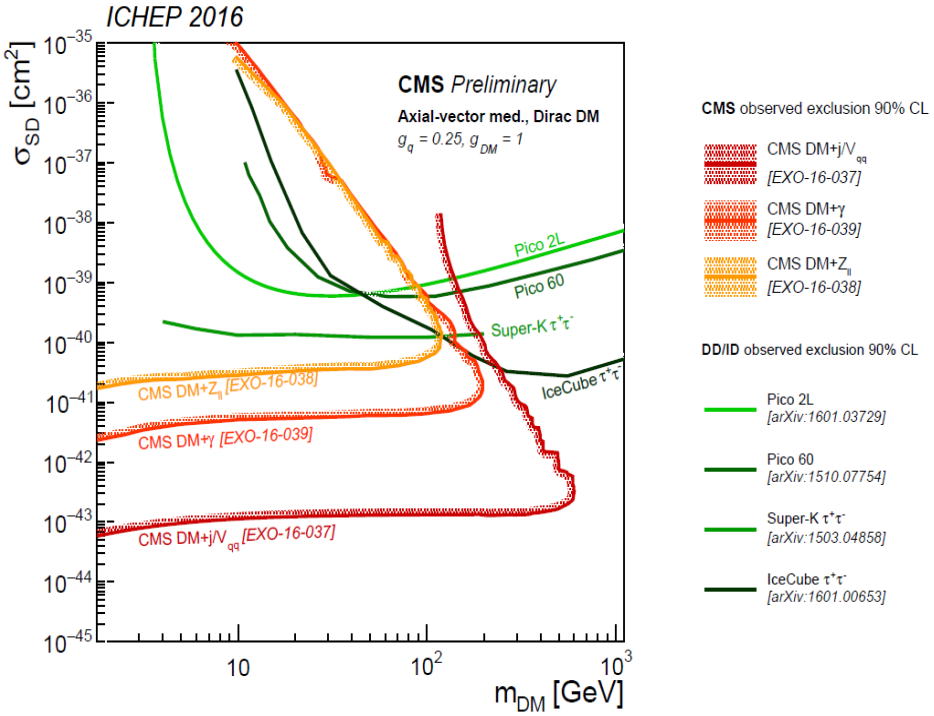
(*) LHC DM Working Group 1603.04156

- Comparison with direct detection experiments
- Convert collider limits on mediator and DM masses to a limit on DM-nucleon scattering cross section*
- Collider constraints most stringent at low m_{DM} and for σ_{SD}

Spin independent (vector)



Spin-dependent (axial-vector)

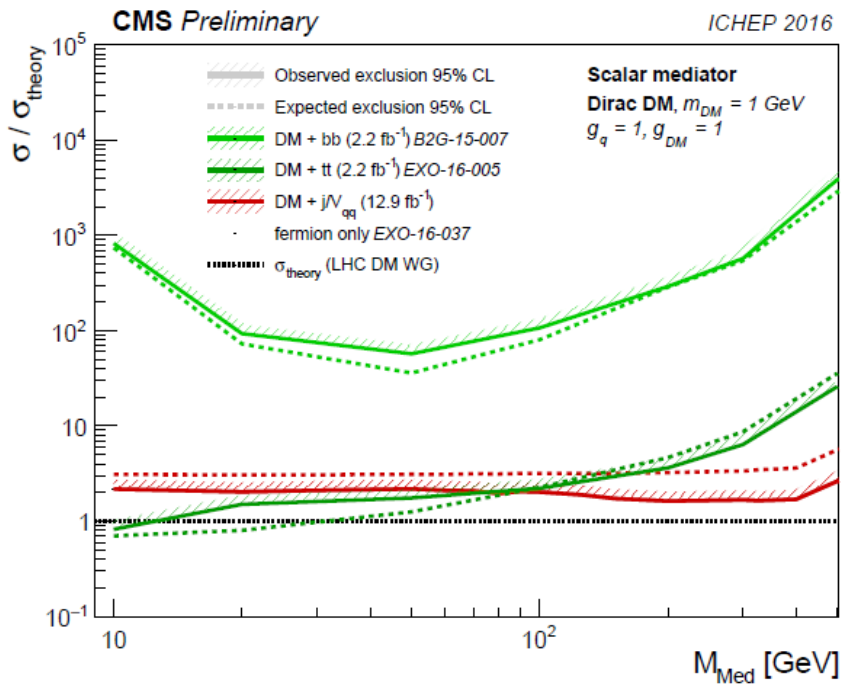


Spin-0 limits

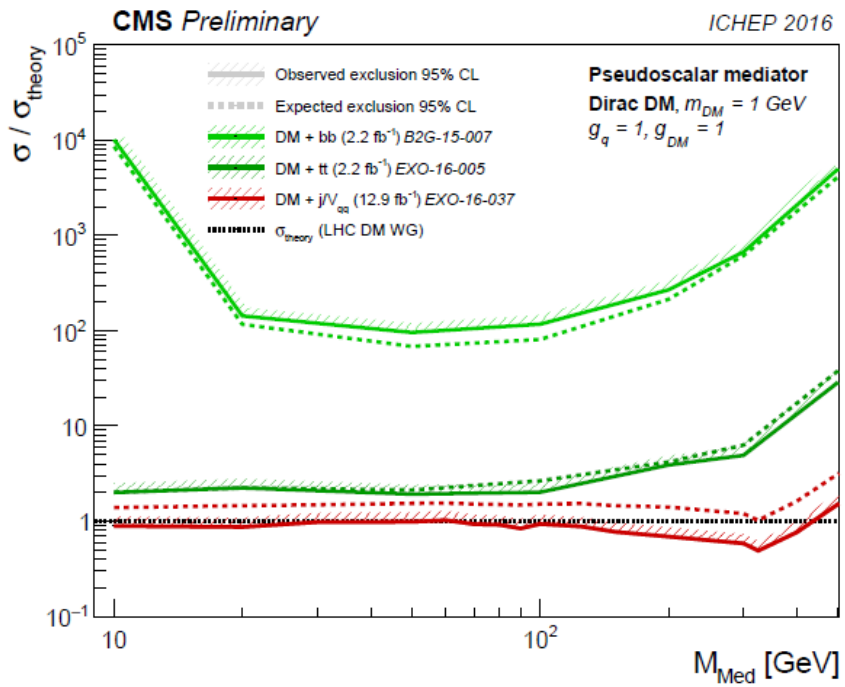
- 95% CL exclusion regions in the mediator-DM mass plane for different MET+X searches for spin-0 mediators

- Mediator couplings of $g_q = g_{DM} = 1$

Scalar



Pseudoscalar



Summary

- Searches for dark matter have been performed in various MET+X final states at CMS at $\sqrt{s}$ = 13 TeV
- No excess has been found yet and limits are set on a variety of simplified models
- LHC searches are complimentary to direct and indirect detection experiments
- Results with the full 2016 dataset (36 fb^{-1}) to come soon – stay tuned!

BACKUP

MET+X searches at CMS

X	Dataset	CMS Documentation
jet or V (had)	12.9 fb^{-1} (2016)	EXO-16-037
photon	12.9 fb^{-1} (2016)	EXO-16-039
Z (ll)	12.9 fb^{-1} (2016)	EXO-16-038
tt/bb	2.2 fb^{-1} (2015)	EXO-16-005
t (had)	12.9 fb^{-1} (2016)	EXO-16-040
Higgs ($\gamma\gamma$)	2.3 fb^{-1} (2015)	EXO-16-011
Higgs (bb)	2.3 fb^{-1} (2015)	EXO-16-012

Spin-0 limits compared to DD

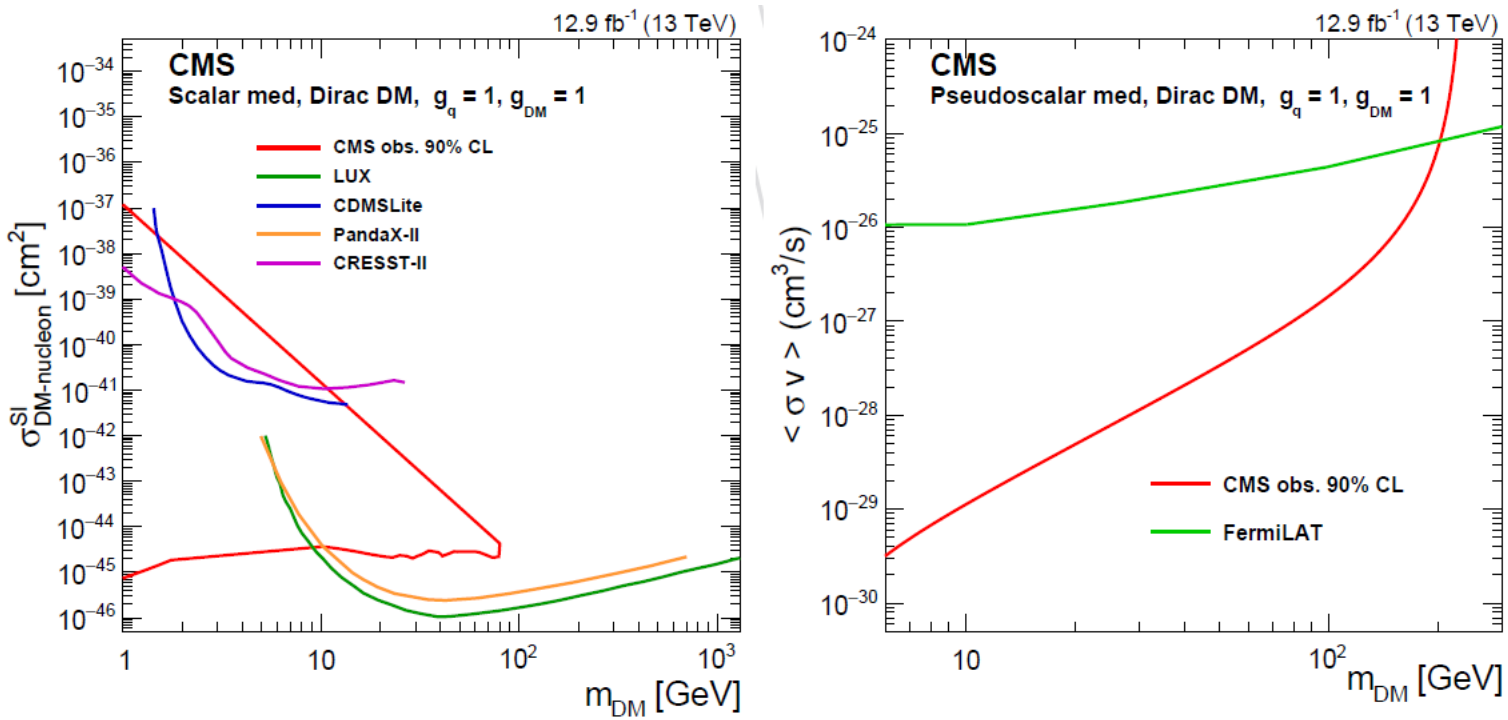


Figure 12: Exclusion limits at 90% CL in the m_{DM} vs. $\sigma_{SI/SD}$ plane for the scalar mediator model (left). The observed exclusion in this search (red line) is compared to the results from the CDMSLite [90], LUX [91], PandaX-II [92], and CRESST-II [93] experiments. For the pseudoscalar mediator (right), limits are compared to the the velocity-averaged DM annihilation cross section upper limits from Fermi–LAT [89]. There are no comparable limits from direct detection experiments as the scattering cross section between DM particles and SM quarks is suppressed at nonrelativistic velocities for a pseudoscalar mediator [98, 99].

Summary of largest excluded masses

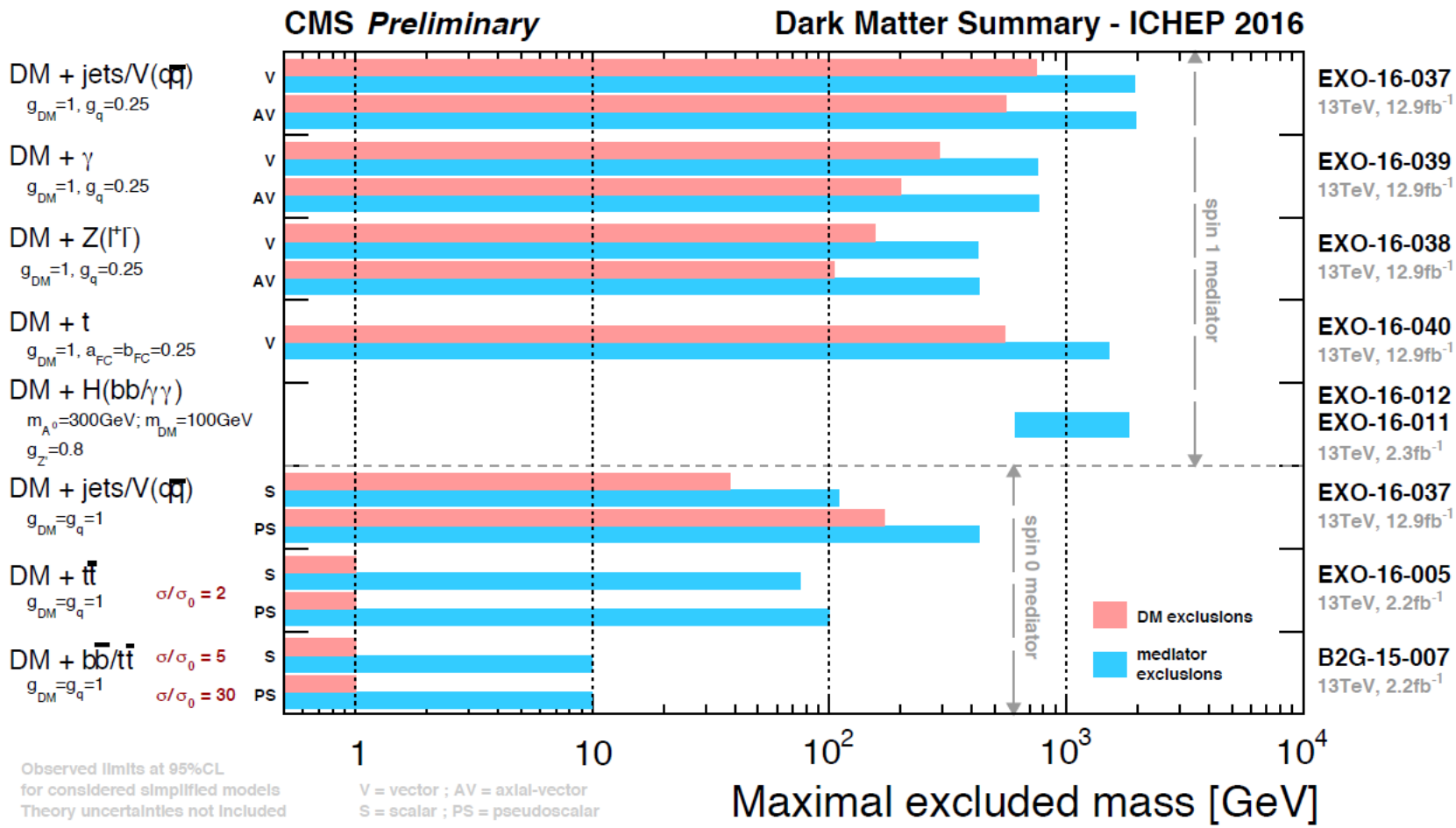


Figure 6. *Maximal/minimal reach of DM searches from CMS in mediator mass (blue bar) and DM mass (red bar). The limits represent 95% CL observed exclusions and they are only applicable to the model and coupling choices indicated next to the bars.*

Mono-Higgs(bb/γγ)

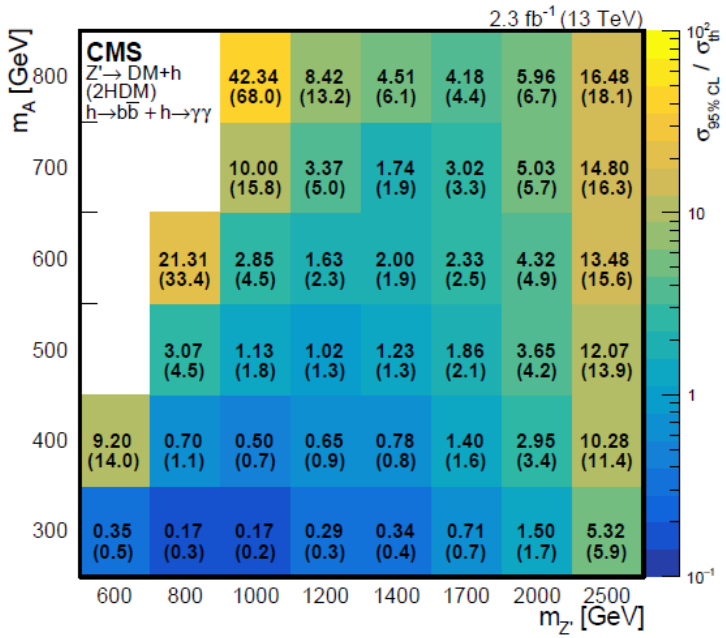


Figure 11: The observed (expected) 95% CL limit on the signal strength for the combination of $h \to \gamma\gamma$ and $h \to b\bar{b}$ decay channels for m_A = 300 - 800 GeV and m_A = 600 - 2500 GeV. The theoretical cross section is calculated using $g_{Z'} = 0.8$.