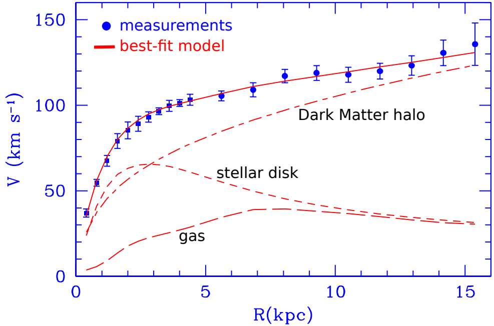
Searches for dark matter with CMS

International Conference on High Energy Physics 2024

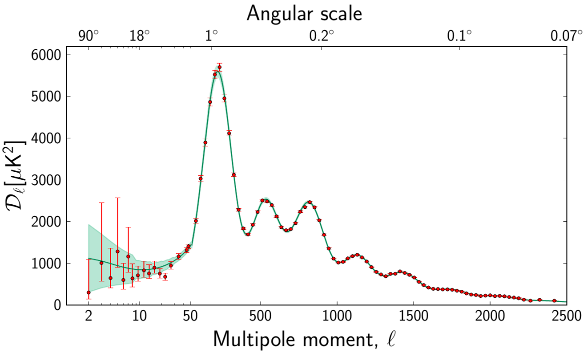
M. Waßmer on behalf of the CMS collaboration | July, 19th

Motivation

Astrophysical and cosmological observations motivate the existence of dark matter.



Adapted from: Corbelli, Saluci. *Mon. Not. Roy. Astron. Soc.* 311 (2000)



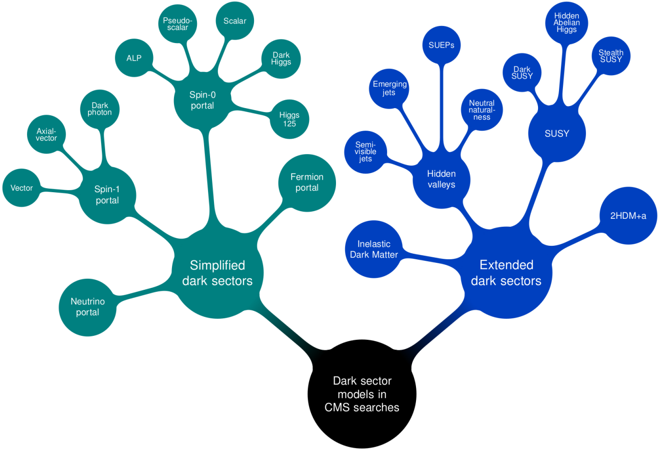
Astron. Astrophys. 571 (2014)

Largest part of matter in the universe is cold dark matter (DM). No suitable DM candidate available in the standard model (SM) of particle physics.

Types of dark matter/sector searches at CMS

Simplified dark sectors:

- DM candidate
- mediator/portal (MED) connects DM with SM
- invisible searches: MED→DM, mono-X
- visible searches: MED→SM, visible resonances



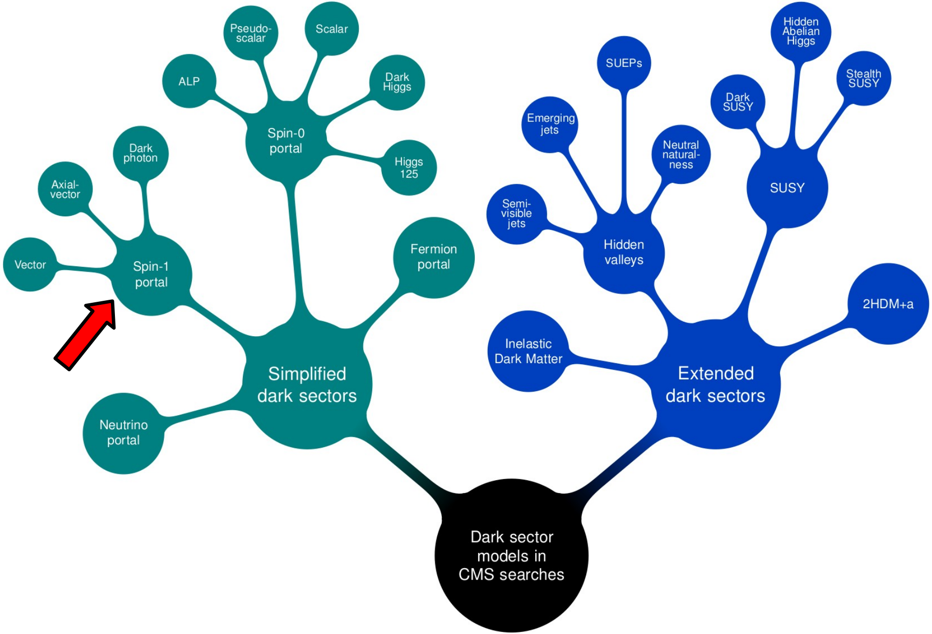
Extended dark sectors:

- more complex UV complete models
- additional mediators
- more new particles
- new interactions
- complex/rich final states

CMS-EXO-23-005

extensive and new review paper by CMS

check it out


Dark sector models in CMS searches
Simplified dark sectors
Spin-1 portal
Vector
Axial-vector
Dark photon
Spin-0 portal
ALP
Pseudo-scalar
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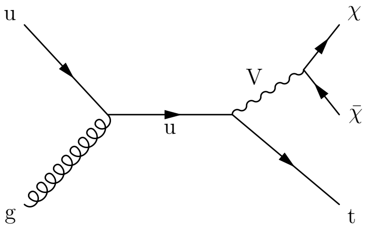
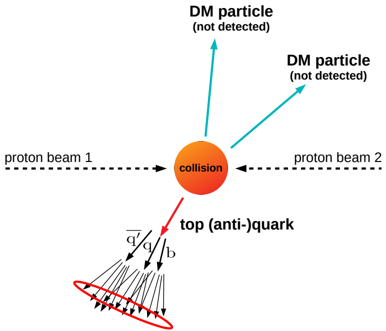
Dark Higgs
Higgs 125
Fermion portal
Neutrino portal
Extended dark sectors
Inelastic Dark Matter
Hidden valleys
Semi-visible jets
Emerging jets
SUEPs
Neutral natural-ness
SUSY
Dark SUSY
Hidden Abelian Higgs
Stealth SUSY
2HDM+a

Search for new physics with a mono-top signature

CMS-PAS-SUS-23-004

- spin-1 portal realized in a simplified model [1, 2]
- vector or axial-vector coupling of the mediator V
- Dirac-type DM candidate χ (WIMP)
- $\not{E}_T$ + top quark (mono-top) at tree level via flavor-changing neutral current (FCNC)
- up-top production mode favored by parton density functions at LHC

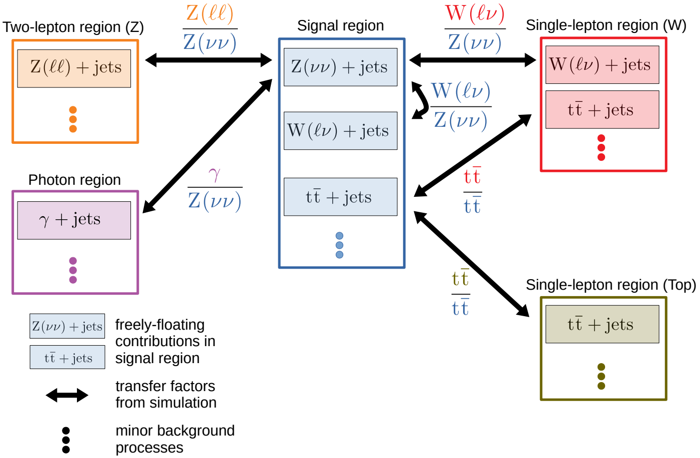




Search for new physics with a mono-top signature

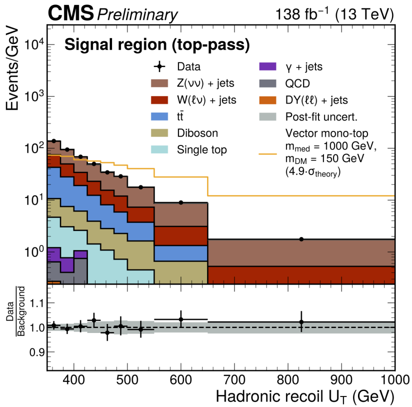
- only consider hadronic top quark decay
- cluster top decay products into a fat-jet
- ML-based discriminator (particleNet [3]): top-jets vs. QCD-jets
- hadronic recoil as observable
- control regions (CRs) based on number of leptons and b-tags
- robust statistical model using transfer factors

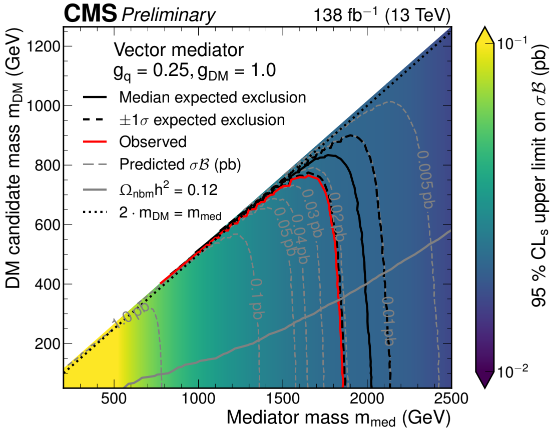
⇒ estimate main backgrounds in signal region (SR) from data in CRs



CMS-PAS-SUS-23-004

Search for new physics with a mono-top signature

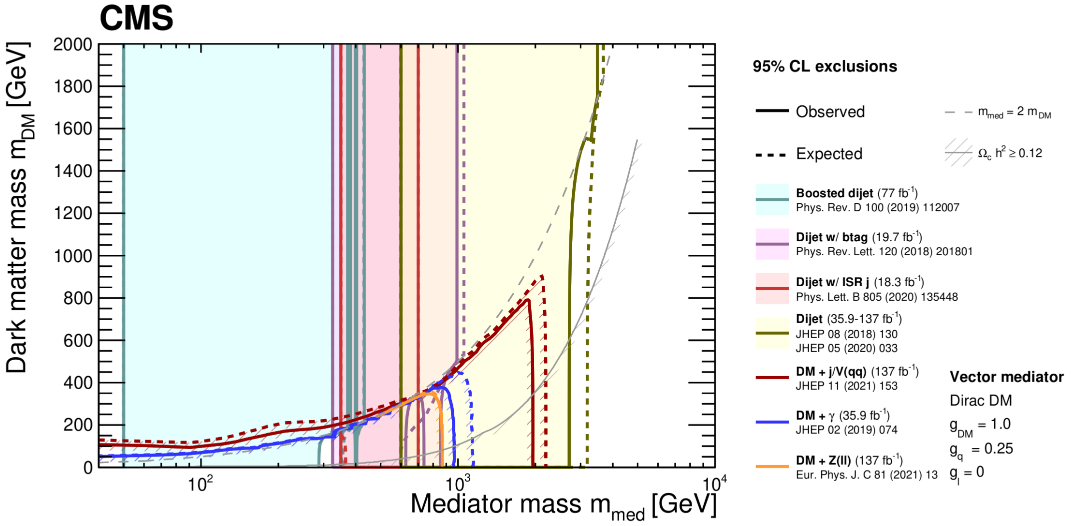




CMS-PAS-SUS-23-004

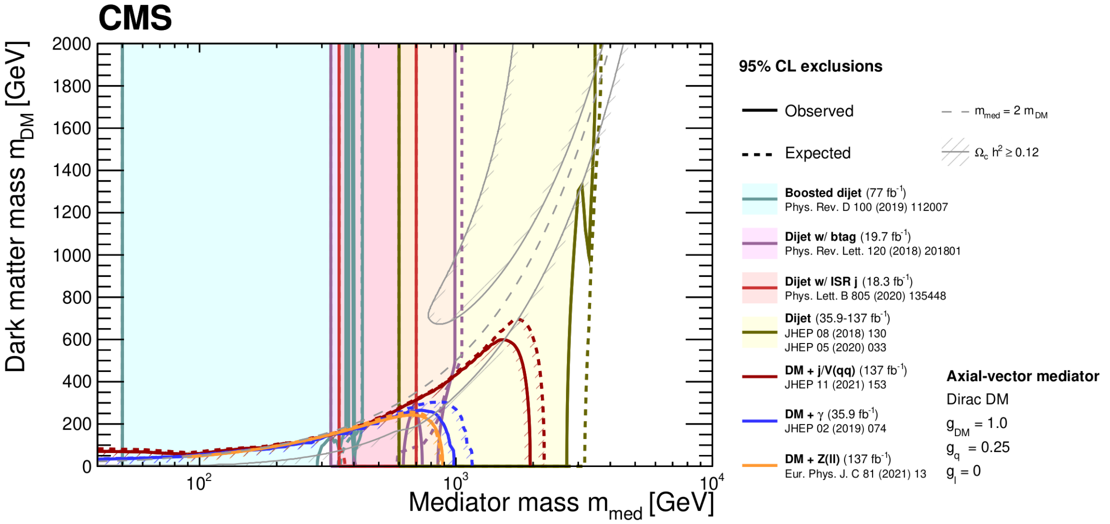
Most stringent exclusion limits for (axial) vector coupled dark matter production via an up-top FCNC to date.

Summary of spin-1 simplified models (vector)



March 2024, CMS-EXO Public Results

Summary of spin-1 simplified models (axial-vector)



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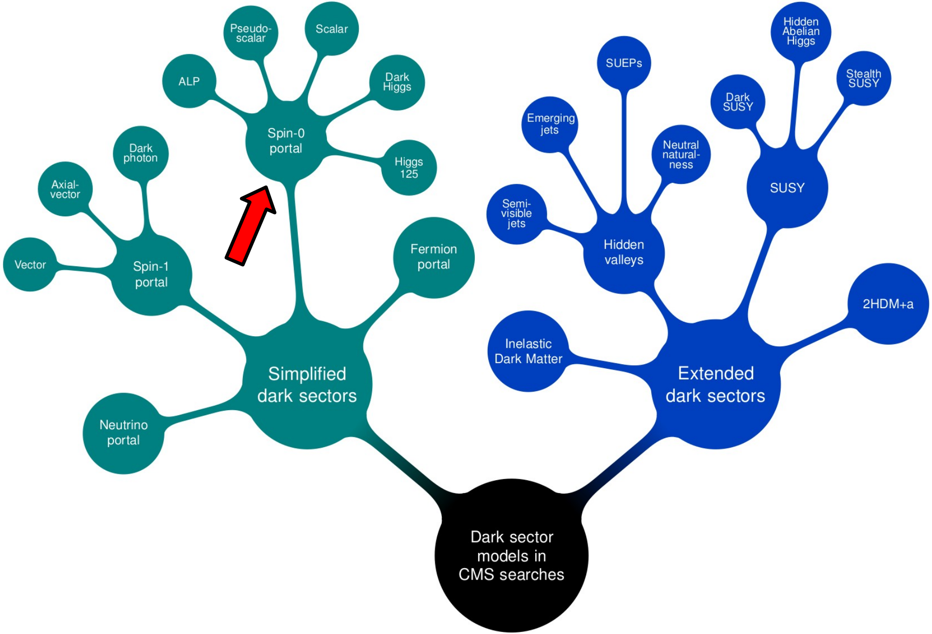
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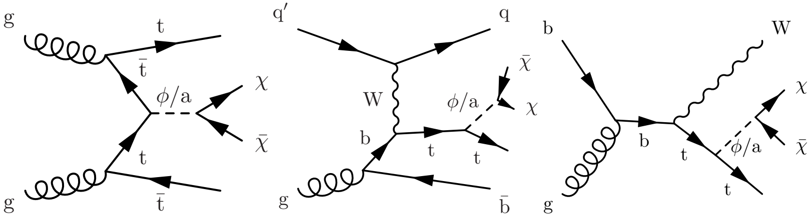
Dark sector models in CMS searches

DM produced with a single top quark or a top quark pair

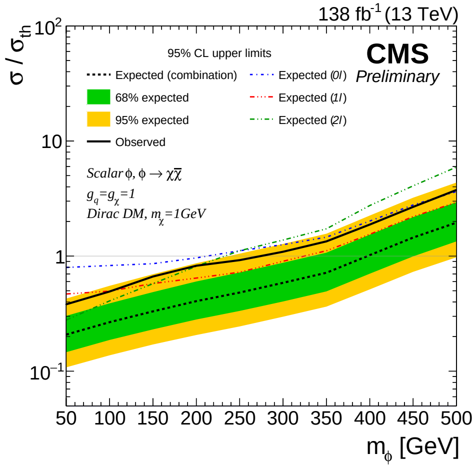
CMS-PAS-EXO-22-014

- spin-0 portal realized in a simplified model [2, 4, 5, 6]
- scalar (ϕ) or pseudo scalar (a) mediator, Dirac-type DM candidate (χ)
- fermion (f) coupling of ϕ/a of Yukawa-type, i.e., Higgs-boson-like couplings $\propto m_f$
- SM couplings preferrably to heavy third generation quarks (top and bottom quark)
- no mixing with SM Higgs boson assumed (while mixing exists in dark Higgs models)
- sensitive final states $t\bar{t} + \chi\bar{\chi}$ and $t/\bar{t} + \chi\bar{\chi}$
- $t\bar{t} + \chi\bar{\chi}$ also explored in top squark search CMS-SUS-20-002



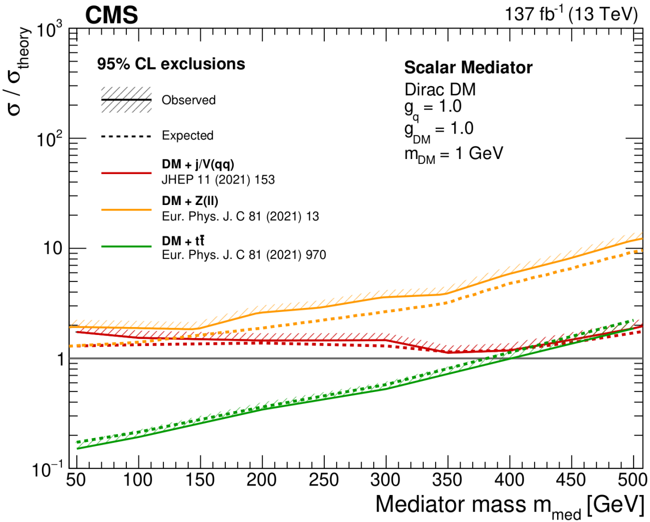
DM produced with a single top quark or a top quark pair

- search in all lepton multiplicity channels (0l, 1l, 2l) with full run 2 data
- $t\bar{t} + \chi\bar{\chi}$ and $t/\bar{t} + \chi\bar{\chi}$ categories according to b-tag multiplicity
- further categorization using forward jet-multiplicity for t- and tW-channel modes of $t/\bar{t} + \chi\bar{\chi}$
- hadronic recoil as observable in 0l & 1l channels
- neutral network discriminant in 2l channel
- control regions to improve background process estimations in signal regions
- signal-like excess with $< 2\sigma$ significance



CMS-PAS-EXO-22-014

Summary of spin-0 simplified models (scalar)



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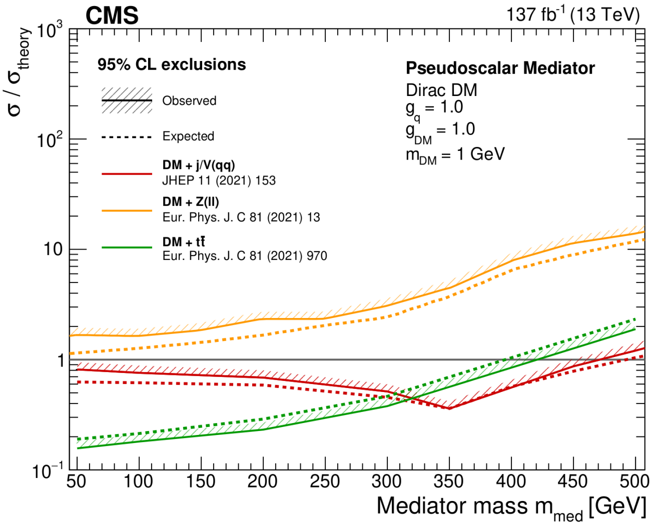
Summary of spin-0 simplified models (pseudoscalar)



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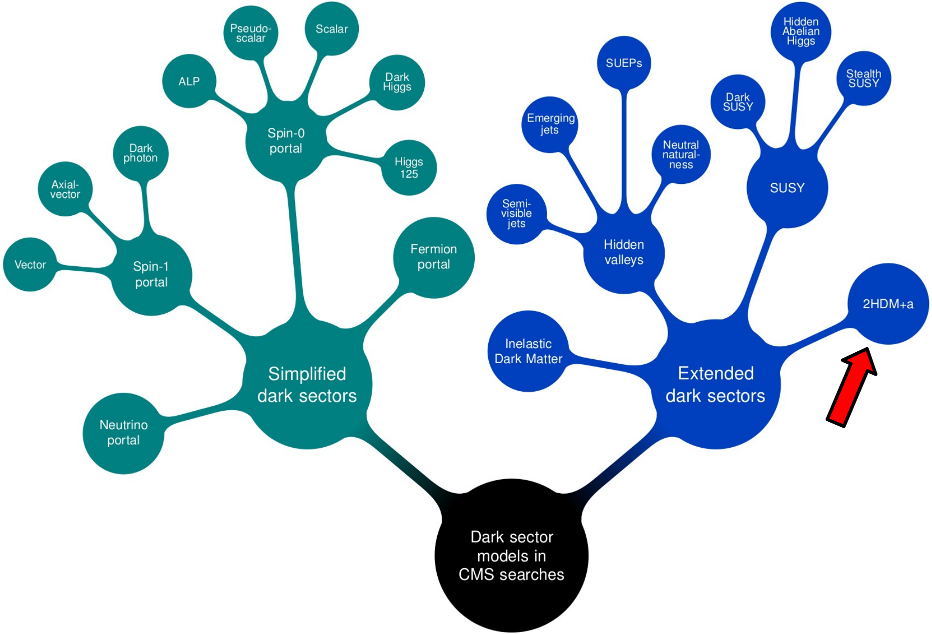

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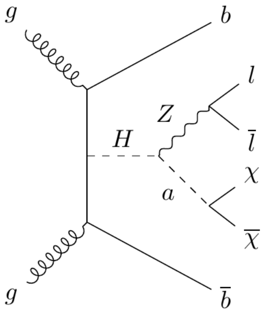
Search for DM with b-quark and lepton pairs

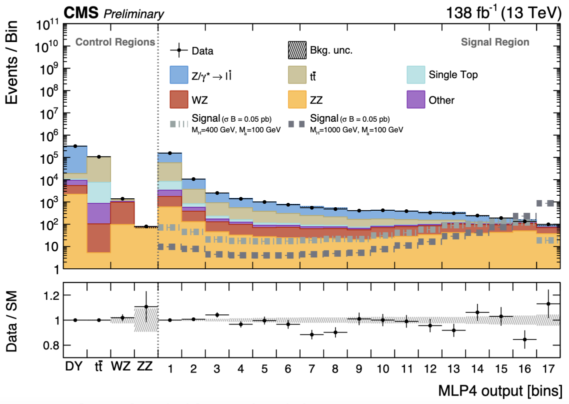
CMS-PAS-SUS-23-018

- pseudoscalar *a* links SM and DM → avoids DM-nucleon constraints from direct detection experiments
- Fermi-LAT gamma-ray excess [7] hypothesized to originate from $\chi\bar{\chi} \rightarrow b\bar{b}$ [8, 9, 10]
- 2HDM model + additional portal pseudoscalar (2HDM+*a*) naturally allows pseudoscalar link between SM and DM and can produce couplings favoring b quarks [11]
- possible production of $b\bar{b}$, DM candidates in association with a Z boson
- search for significant $\not{E}_T$, a dilepton pair, and a pair of b-jets



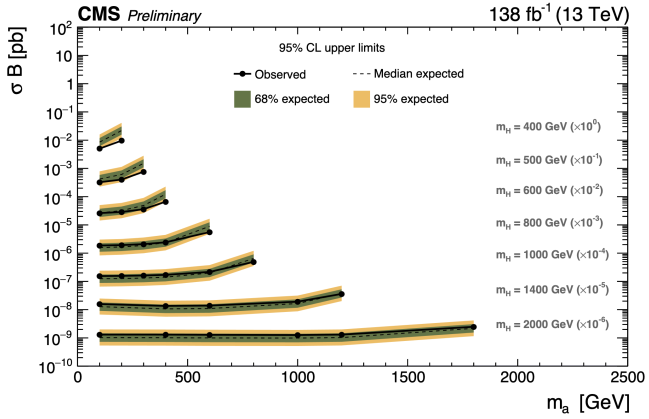
Search for DM with b-quark and lepton pairs

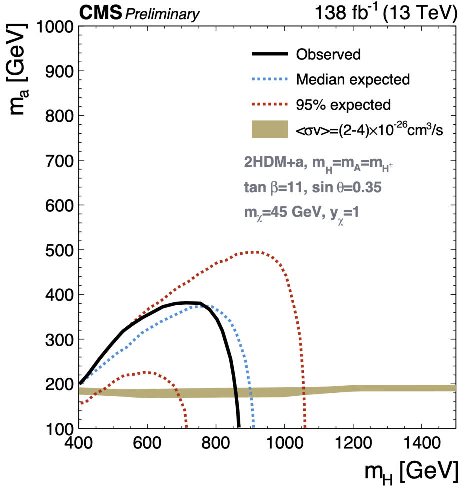
- largest backgrounds: Drell-Yan, $t\bar{t}$ (DL), single top, diboson
- baseline selection using leptons, b-tag multiplicity, $\not{E}_T$ and analytical $t\bar{t}$ (DL) reconstruction
- neural network (MLP) to further discriminate signal from remaining backgrounds
- neural network output used to create bins of low and high sensitivity
- overall normalization of major background processes freely-floating and constrained from dedicated CRs



CMS-PAS-SUS-23-018

Search for DM with b-quark and lepton pairs



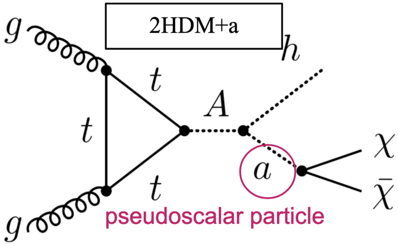


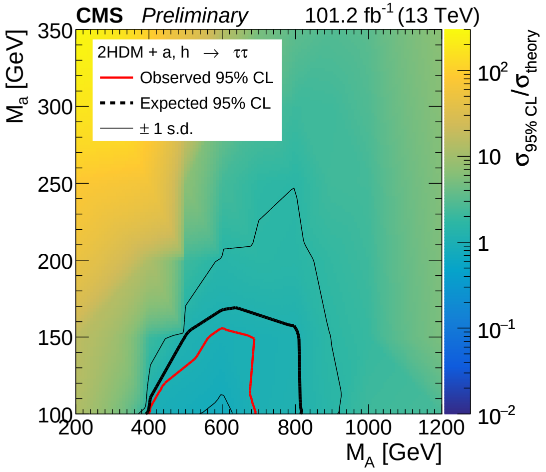
CMS-PAS-SUS-23-018

Search for DM in association with a Higgs boson ($\to \tau\tau$)

CMS-PAS-SUS-23-012

- production of a SM Higgs boson decaying to two τ leptons in association with a DM pair
- another signature possible in 2HDM+a
- selection: significant E_T^{miss}, a di-τ pair compatible with SM Higgs boson mass, no additonal leptons or b-tagged jets, and large total transverse mass





Summary

- wide variety of dark matter searches at CMS ranging from
  - simplified models and simple dark sectors to extended dark sectors
  - simple final states to more complex ones and new signatures
- new data collection and reconstruction techniques e.g. scouting and parking (not shown in this talk)
- detailed/extensive review of CMS dark sector searches: CMS-EXO-23-005
- so far no significant dark matter signal found
- more data, higher center-of-mass energy, refined analysis techniques, and detector upgrades will push sensitivity further in the future

Thank you for your attention.
Keep your eyes open for new results!

References I

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References II

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