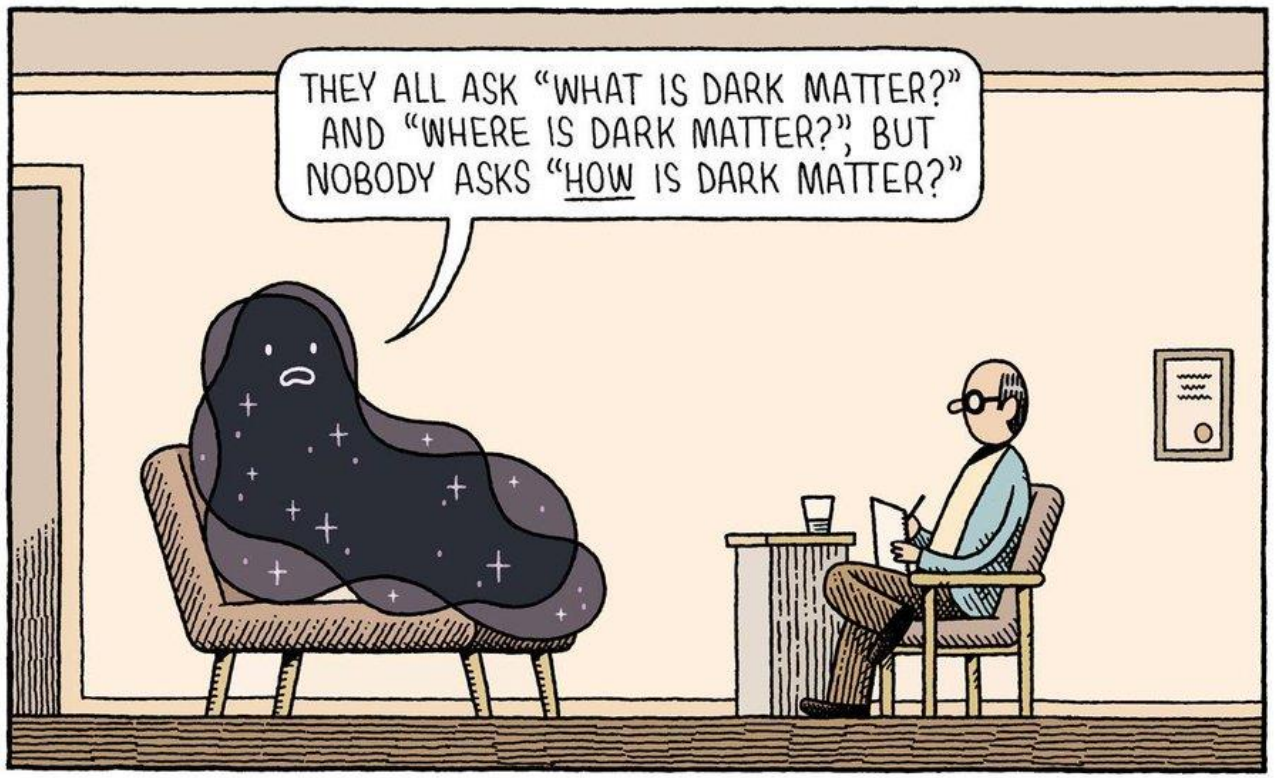


Searches for DM with CMS experiment

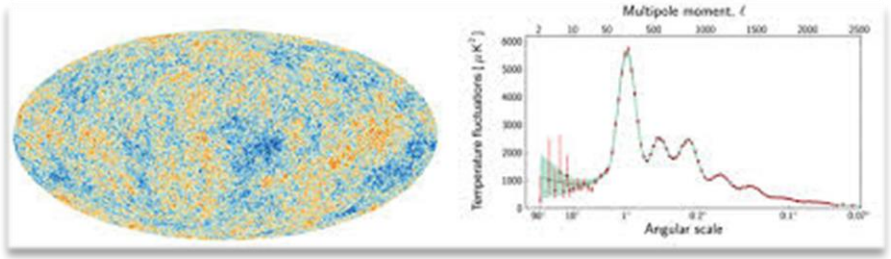
A. Cagnotta for CMS collaboration

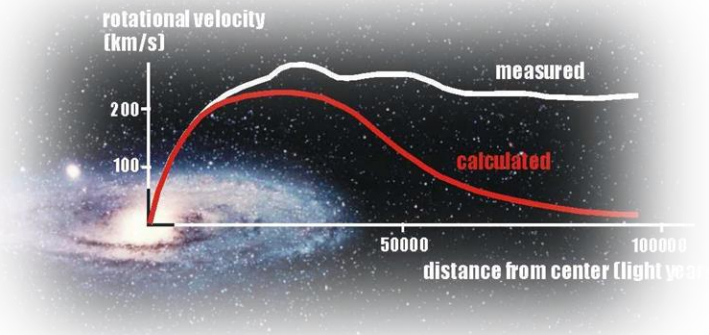
Contents

- Introduction to Dark Matter problem
- Phenomenology
- Latest CMS results
  - Search for dark matter produced in association with a single top quark or a top quark pair in proton-proton collisions at √s= 13 TeV
  - Search for dark matter produced in association with a pair of bottom quarks in proton-proton collisions at √s= 13 TeV
  - Search for dark matter particles in W+W− events with transverse momentum imbalance in proton-proton collisions at √s= 13 TeV
  - Search for new physics with emerging jets in proton-proton collisions at √s= 13 TeV

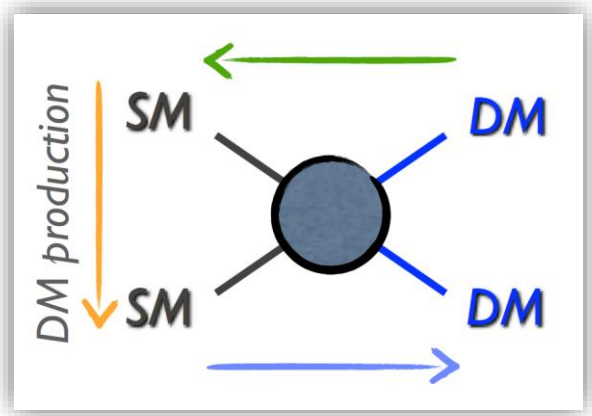
Introduction

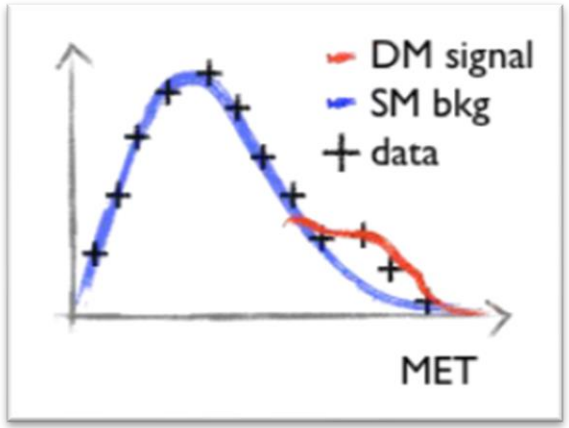
- Dark Matter evidence from astrophysical observation
  - interact gravitationally
  - no information about its nature





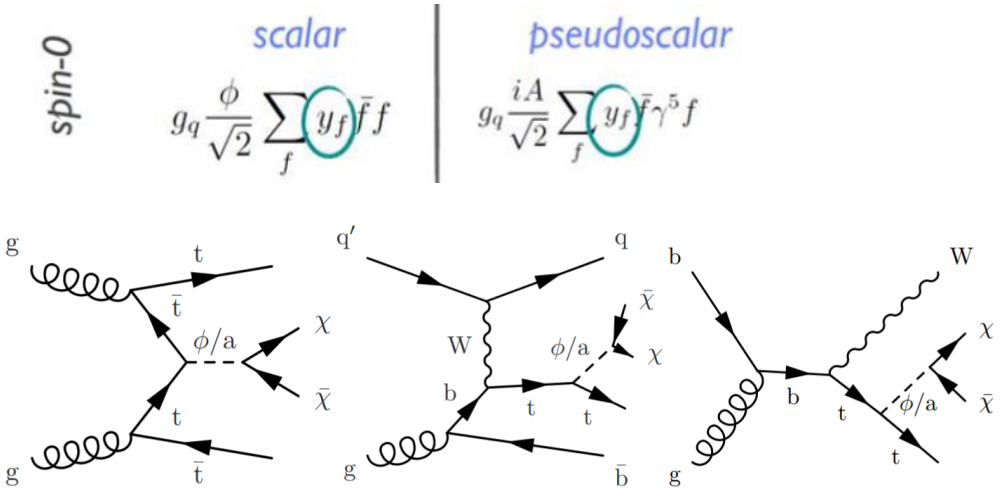
- Signatures at colliders
  - assume week interaction with SM particles
  - DM appears as an excess of events in MET tail wrt to SM



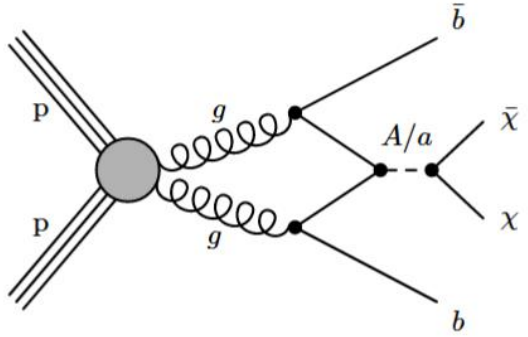


Phenomenology

- **Simplified models** [link]
  - minimal SM extensions
  - couplings prioritize **third generation**
  - new scalar (pseudoscalar) boson ϕ(a) interacting with SM fermions and DM particles (χ)
  - 4 additional parameters (m_{χ}, $m_{\phi(a)}$, g_q, g_{χ})

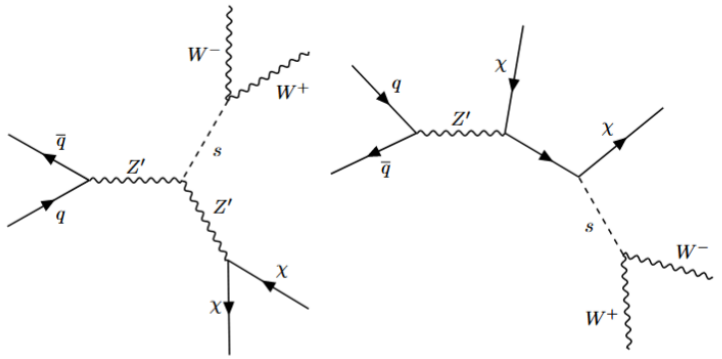


- **2Higgs-Doublet-Model *(2HDM)* + *a*** [link]
  - couplings prioritize **third generation**
  - the model contains a scalar Higgs boson, a pair of charged Higgs bosons (H±), a heavy scalar boson (H), a heavy pseudoscalar boson (A), and a light pseudoscalar mediator (a)
  - 5 free parameters in the model considered in the next slides (m_A, m_a, m_{χ}, sinθ, tanβ)

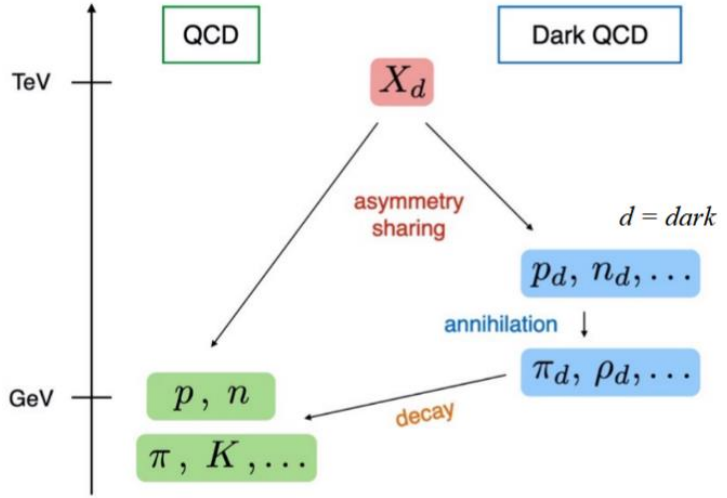


Phenomenology

- **Dark Higgs model** [link]
  - DM mass generated via Higgs mechanism in the dark sector
    - dark Higgs boson **s**
    - **Z'** gauge boson
  - DM χ is a majorana particle
    - singlet under U(1) gauge group
    - coupling between Z', s, DM χ

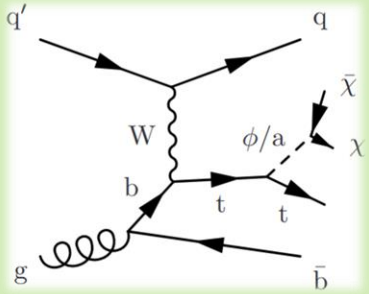
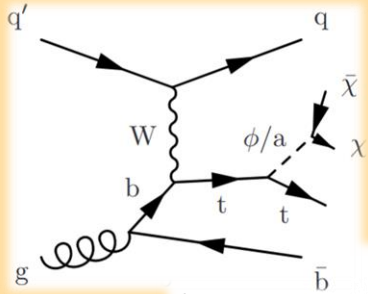
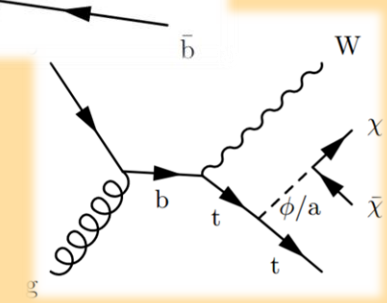
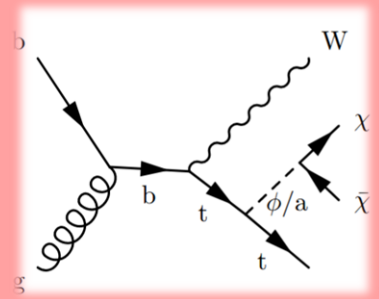
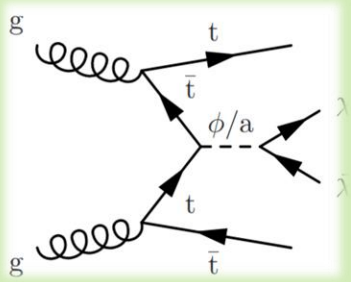
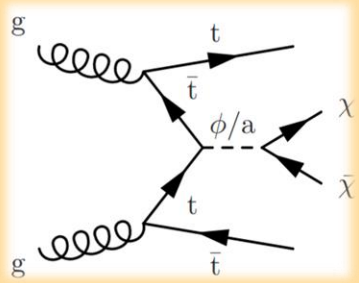
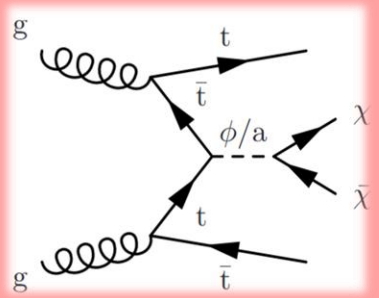


- **Emerging jets theory** [link]
  - dark sector → QCD-like non-abelian gauge symmetry SU(N_{color}^{dark})
  - dark fermions Q_{dark} interact with SM quarks through a scalar mediator X_{dark} coupling $\kappa_{i\alpha}$
  - the dark fermions hadronized in dark baryons and meson and the lightest object is the good DM candidate
  - Two version considered of this model
    - unflavored, only Yukawa coupling to d quark is non-negligible
    - flavor-aligned, multiple Yukawa couplings have non-negligible value



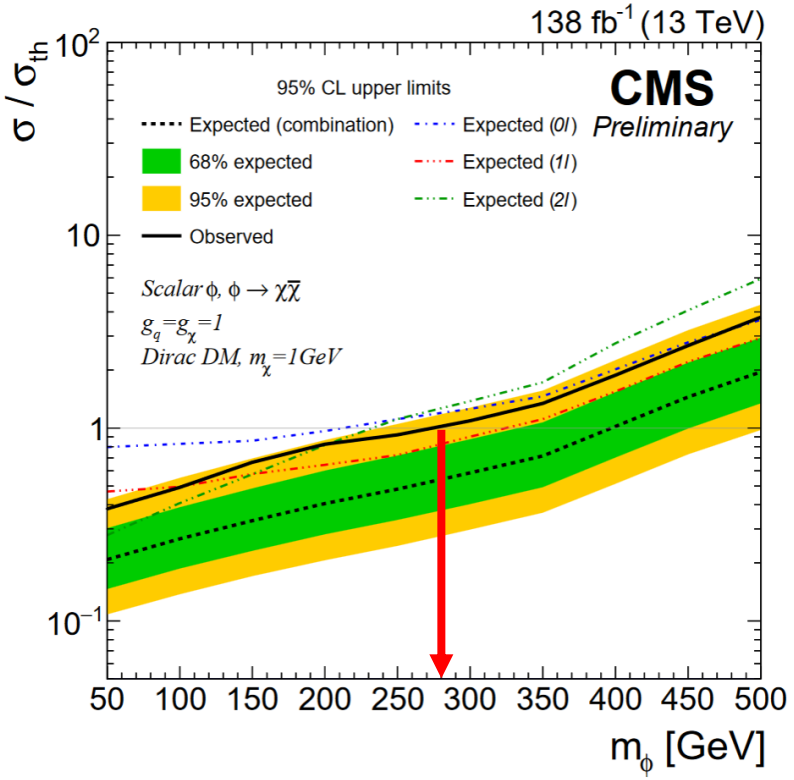
DM production with top quarks [CMS-EXO-22-014]

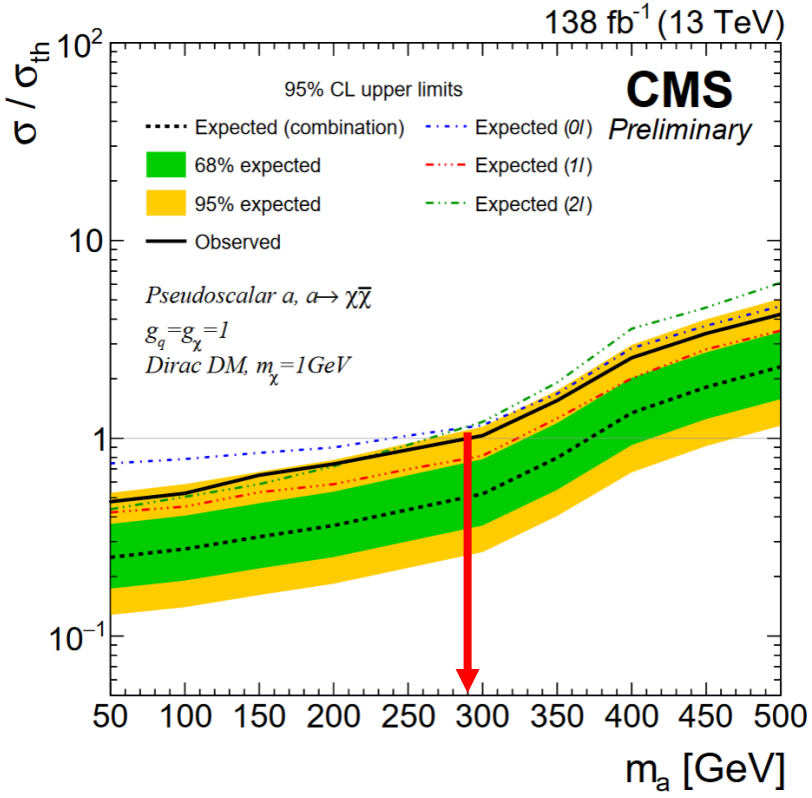
- Simplified Model → 3 final states considered

	All Hadronic	SingleLepton	DiLepton
= 1 b – jet	 b, W(j,j)	 b, W(l,ν) j,j [l,ν]  b, W(l,ν) [b, W(j,j)]	 l,ν b, W(l,ν)
≥ 2 b – jet	 b, W(j,j) b, W(j,j)	 b, W(j,j) b, W(l,ν)	 b, W(l,ν) b, W(l,ν)

DM production with top quarks

- Results interpreted in terms of signal model for scalar and pseudoscalar mediator masses between 50 and 500 GeV, with $m_x = 1$ GeV and $g_q = g_X = 1$
- A signal-like excess is observed in data. Because the signal kinematics are not very sensitive to the mass of the mediator, this excess is consistent with all mediator mass hypotheses
- **Excluded** mediator mass below **280(290) GeV** for the **scalar(pseudoscalar) mediator**

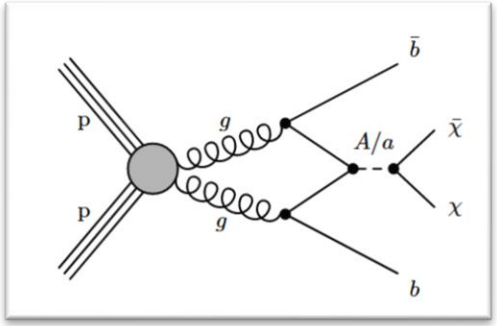


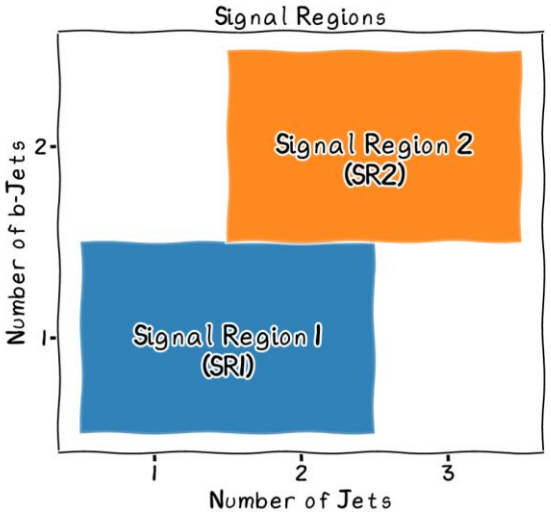


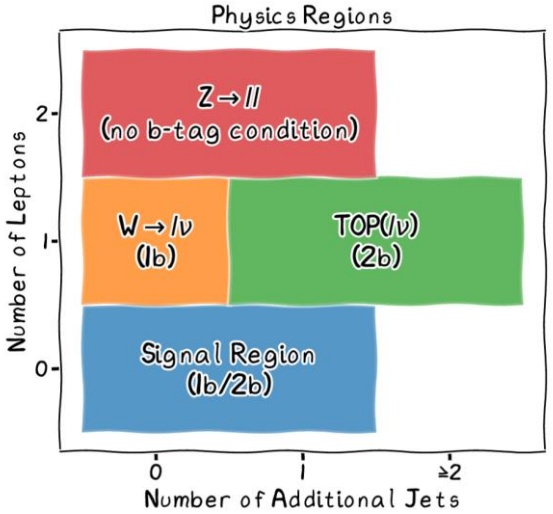
DM production in association with a pair of b quarks

CMS-SUS-23-008

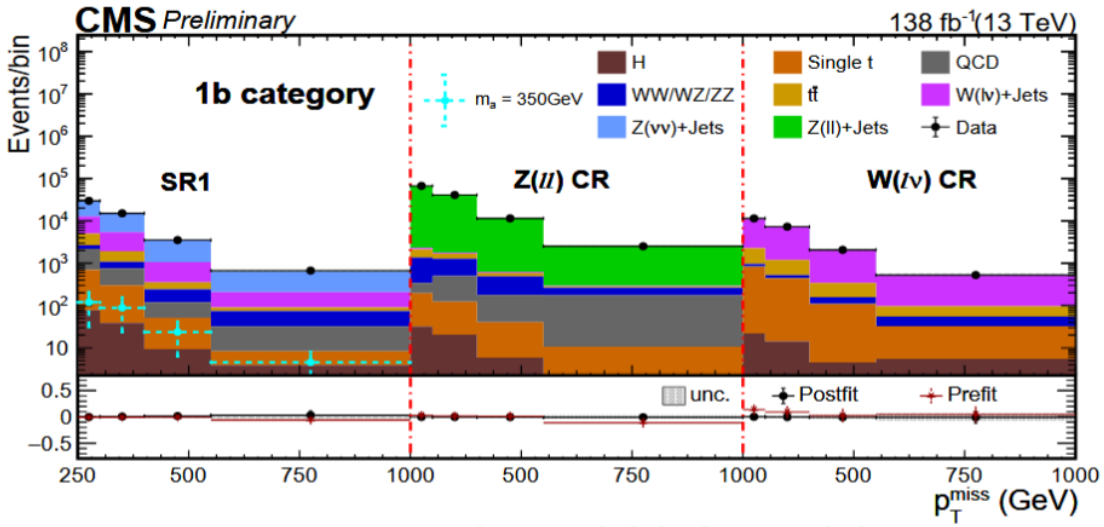
- 2HDM+a scenario
- Event selection
  - SR1, 1b-jet final state
  - SR2, 2b-jet final state

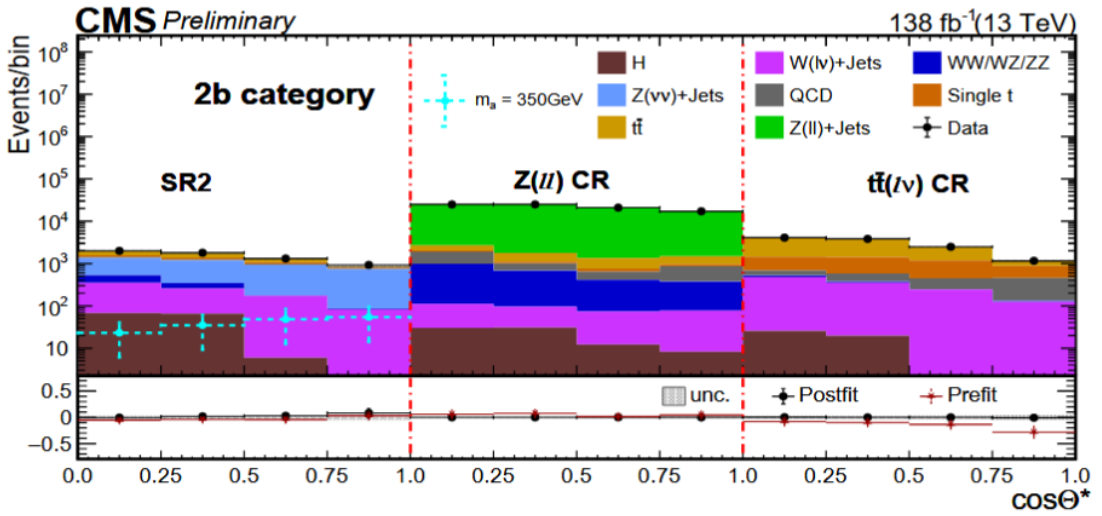






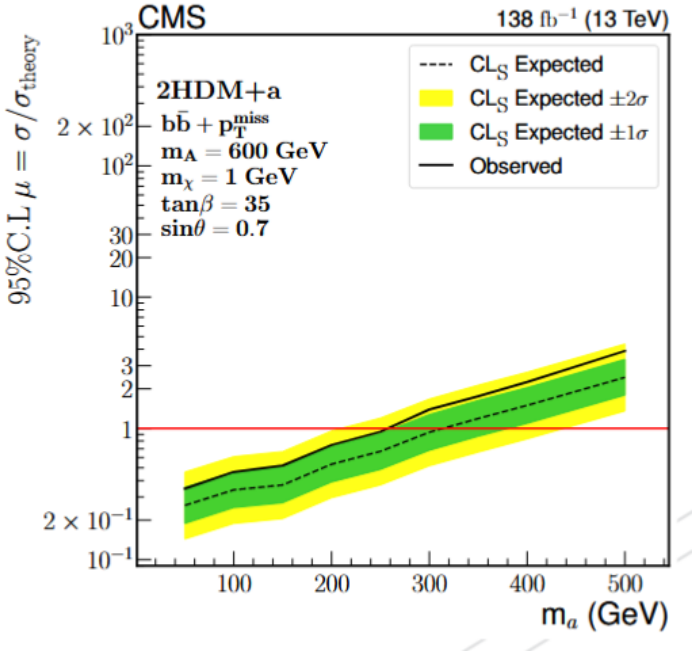
$$\cos\Theta^* = \left|\tanh\left(\frac{\eta_{Jet1} - \eta_{Jet2}}{2}\right)\right|$$

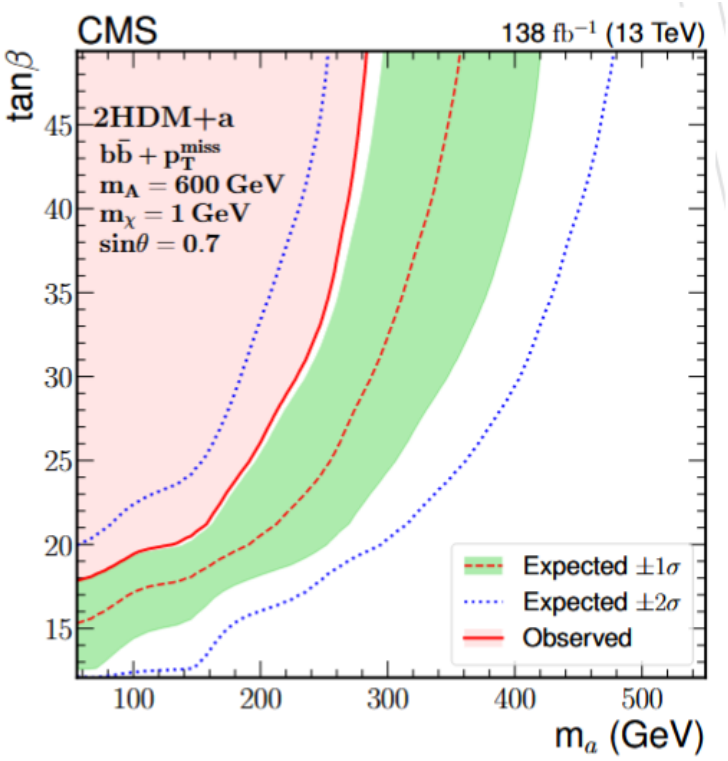


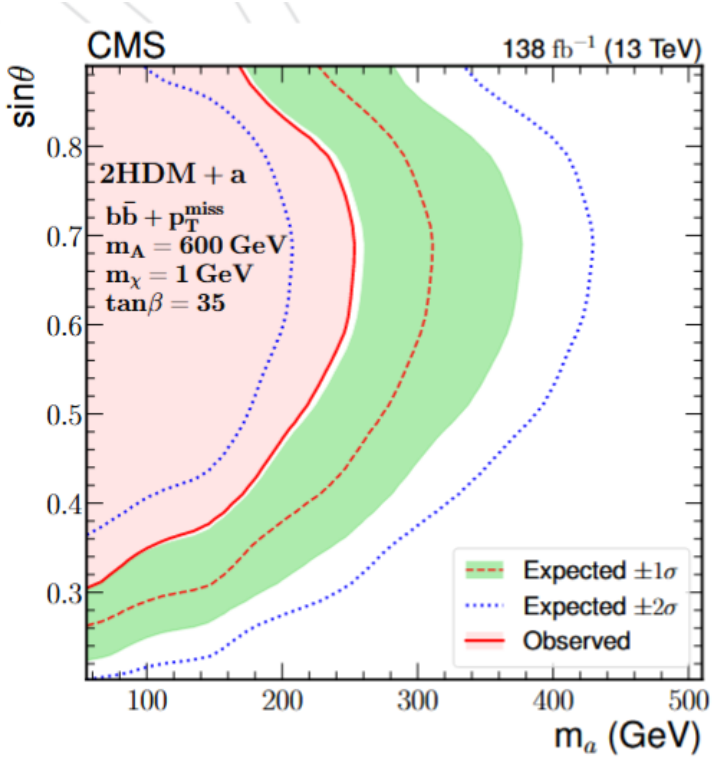


DM production in association with a pair of b quark

- The observed exclusion range on the m_a particle is up to 260 GeV for $\tan\beta = 35$, $\sin\theta = 0.7$, and $m_A = 600$ GeV
- 2D exclusion plot for m_a- $\tan\beta$ and m_a- $\sin\theta$





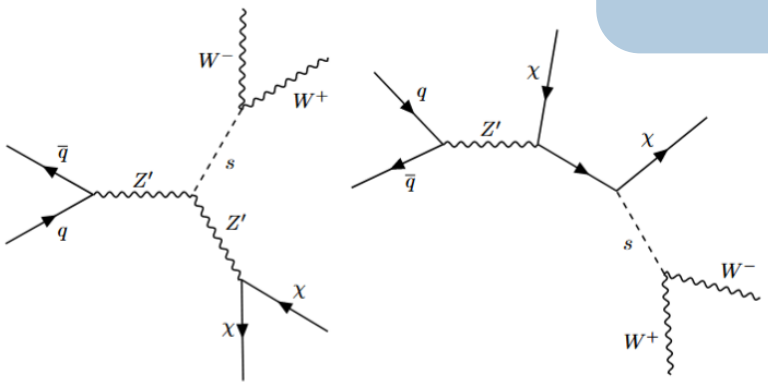


Dark Higgs (WW) + MET

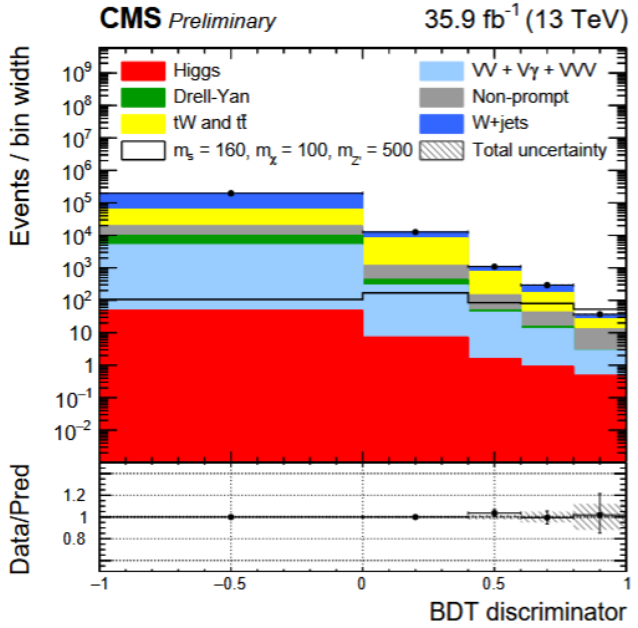
CMS-EXO-21-012

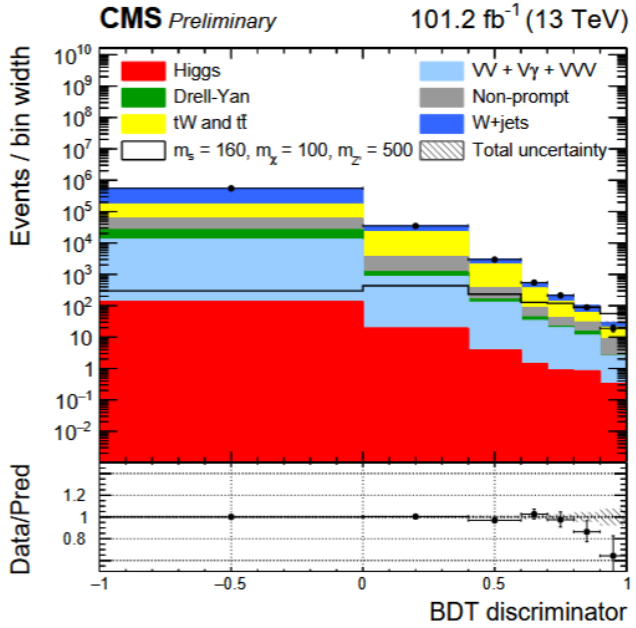
First Dark Higgs search at CMS

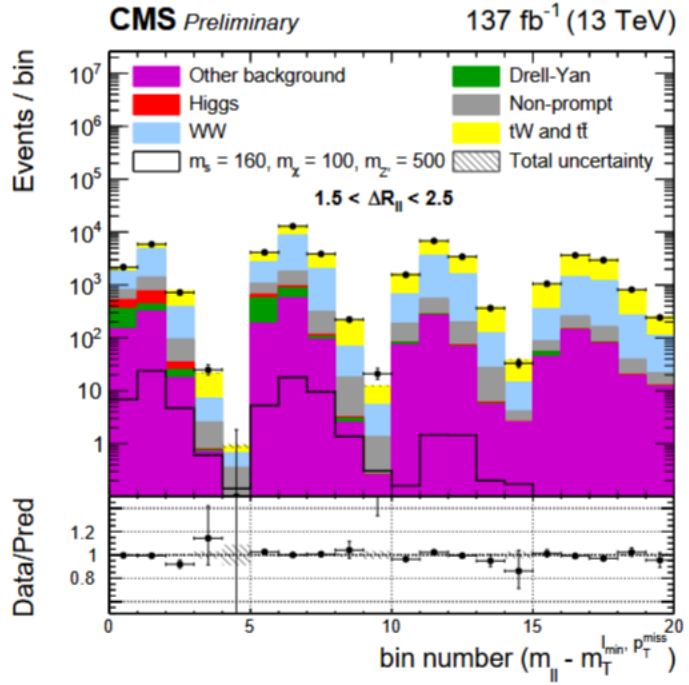
- Final state : s→ WW + MET p_T
  - WW → 2l2ν di-leptonic
  - WW → lνqq′ semi-leptonic



$$m_{\mathrm{T}}^{\ell\,\mathrm{min},p_{\mathrm{T}}^{\mathrm{miss}}} = \sqrt{2p_{\mathrm{T}}^{\ell\,\mathrm{min}}\,p_{\mathrm{T}}^{\mathrm{miss}}\left[1-\cos\Delta\phi(\vec{p}_{\mathrm{T}}^{\ell\,\mathrm{min}},\vec{p}_{\mathrm{T}}^{\mathrm{miss}})\right]},$$

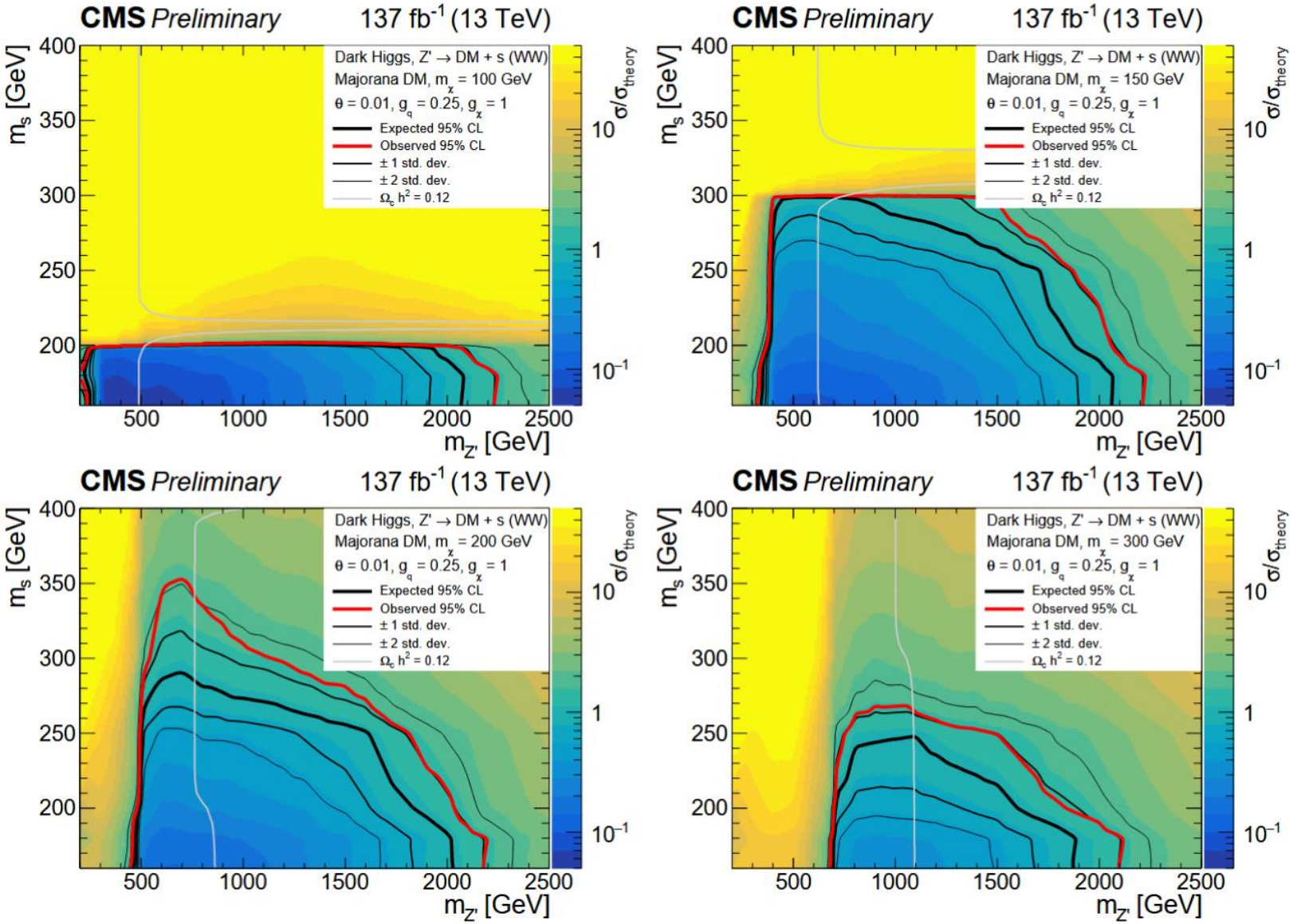






Dark Higgs (WW) + MET

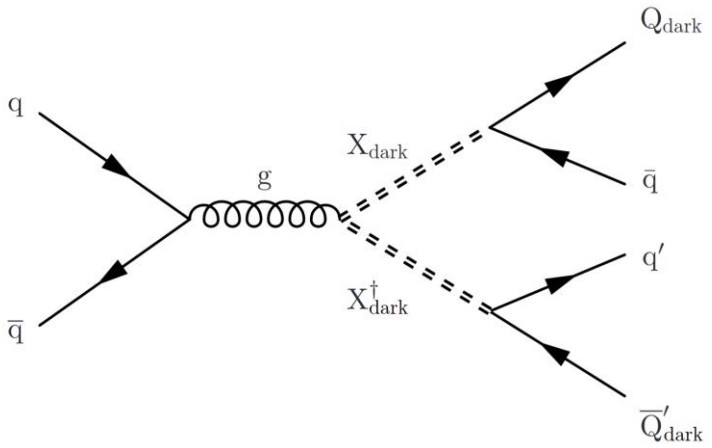
- Extended the search to a wider DM mass range, up to 300 GeV
- The most stringent limit is set for a $\mathbf{m_{DM}=200GeV}$, excluding m_s up to 350 GeV at $m_{Z'}$ of 700 GeV, and up to $m_{Z'} \approx 2200$ GeV for a $m_s = 160$ GeV.

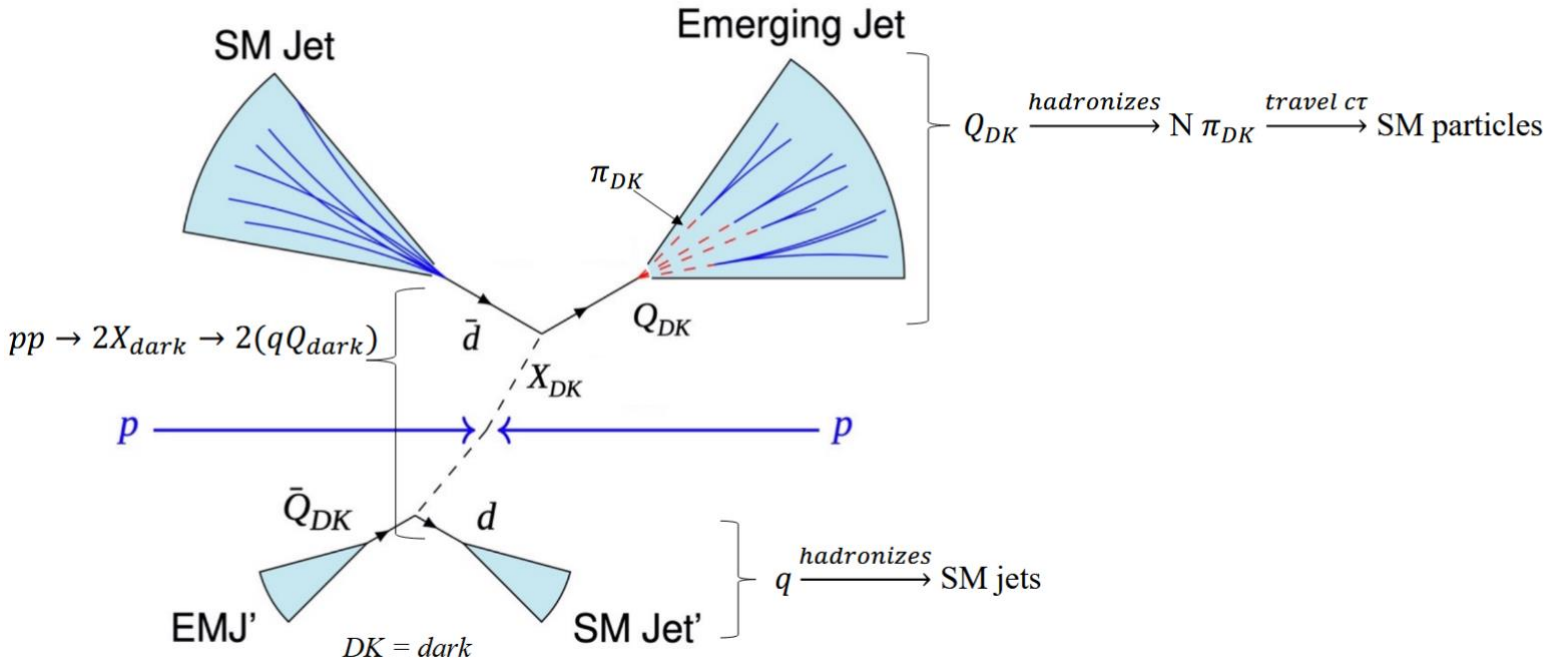


Emerging Jets

CMS-EXO-22-015

- Final state
  - High Hadron Transverse ($\mathbf{H_T}$)
  - **4 high-p_T jets**
- 2 methods used in both QCD-like DM scenarios
  - Model-generic → easily re-interpretable
  - Graph Neural Network → Higher sensitivity





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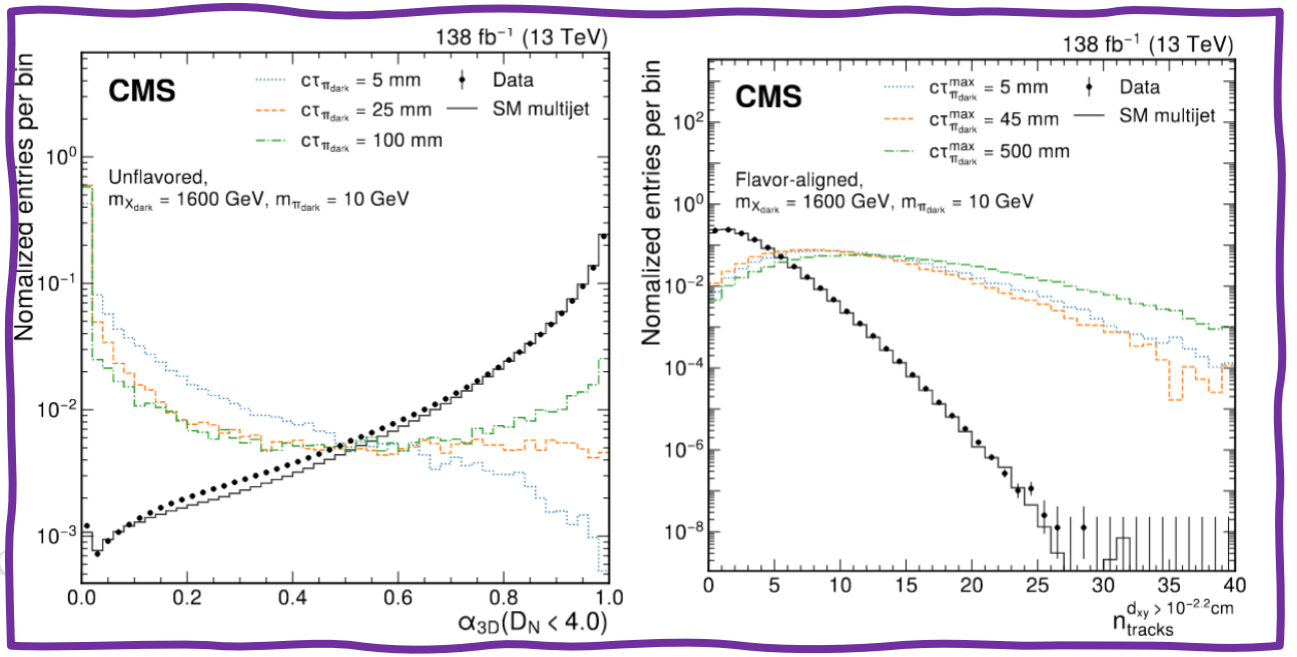
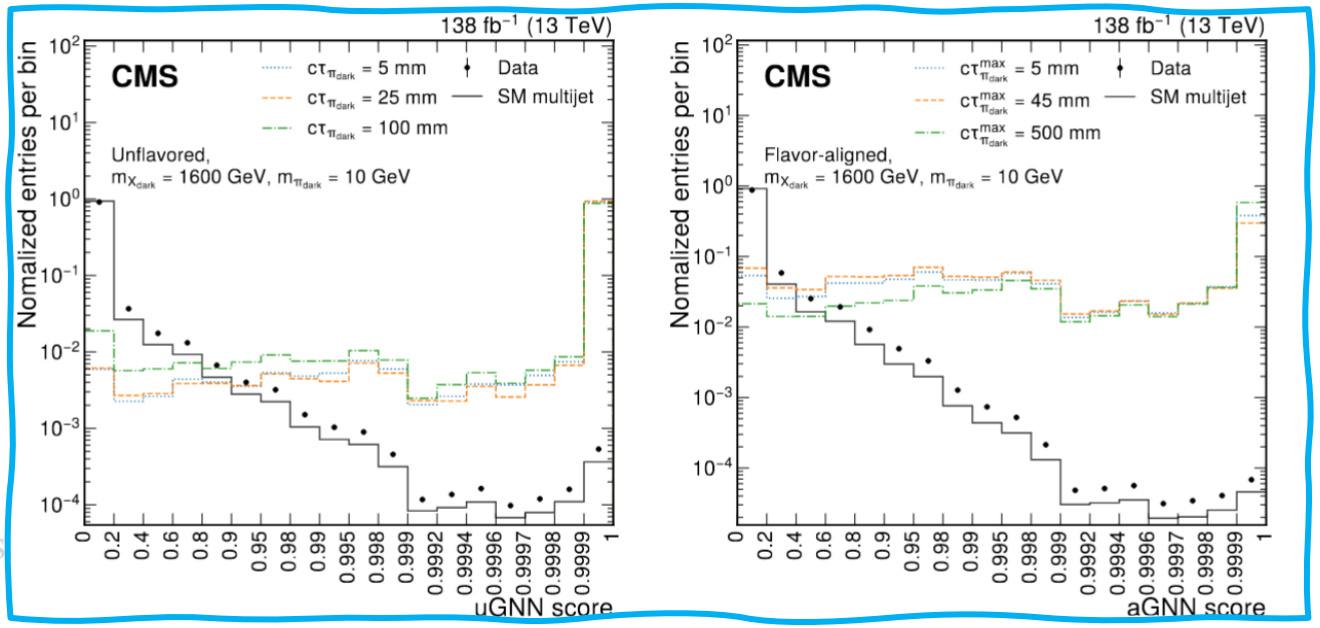
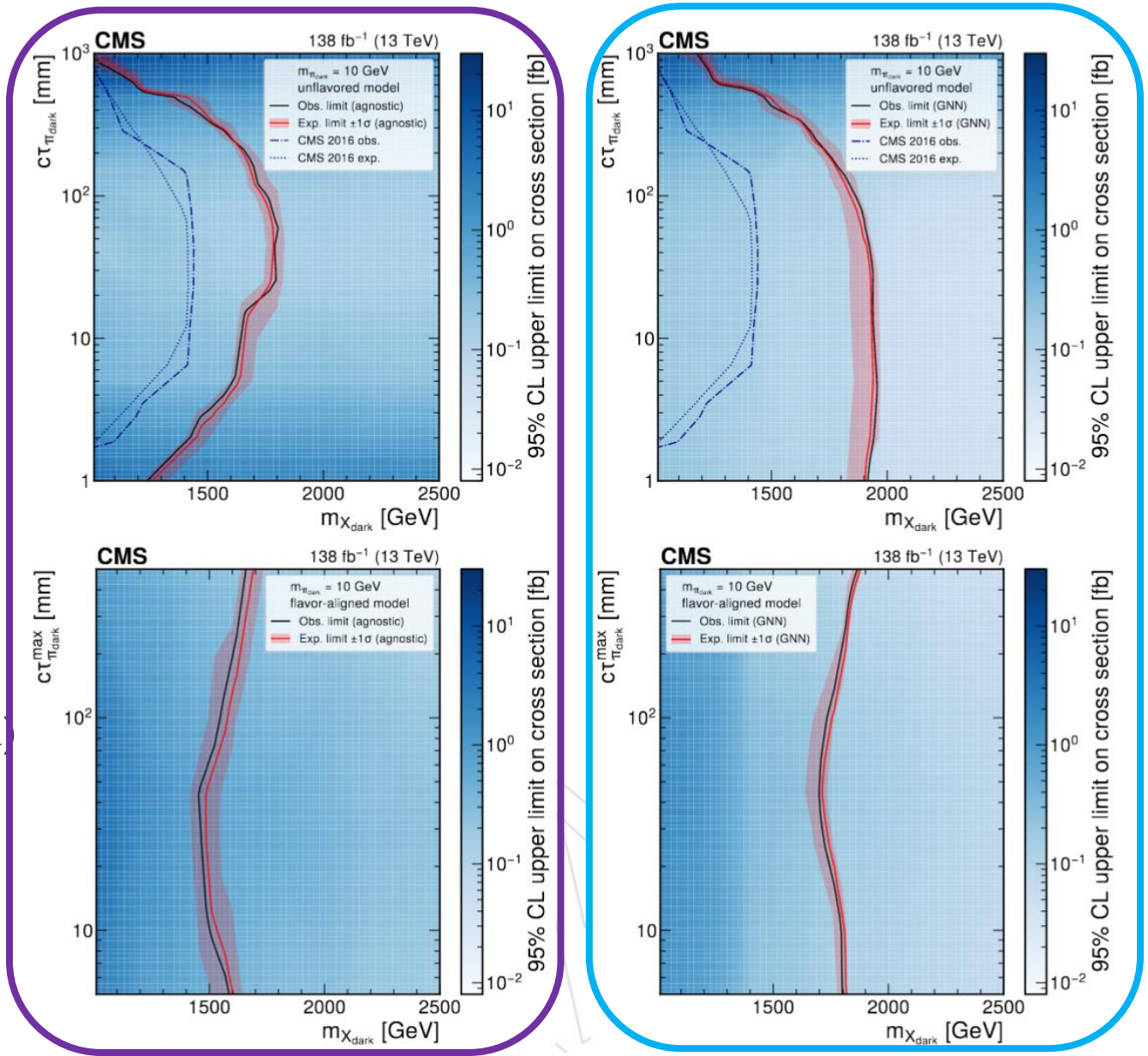




Emerging Jets

- Results are presented for unflavored and flavor-aligned scenario for **Model-generic** and **Graph Neural Network** methods
- In the 2D plane
  - dark pion lifetime
  - X_{dark} mass
- No excess found. Excluded
  - m(X_{dark}) up to 1950GeV (unflavored)
  - m(X_{dark}) up to 1850GeV (flavored-aligned)



Conclusion

- Four different searches of DM production at collider has been presented, targeting 4 different models
  - **Simplified model**, excluded mediator mass up to 280(290)GeV
  - **2HDM+a**, excluded up to 260 GeV for m_a (with $\tan\beta = 35$, $\sin\theta = 0.7$, and $m_A = 600$ GeV)
  - **Dark Higgs** (first CMS search), extended DM mass range up to 300GeV, excluded m_s up to 350 GeV and $m_{Z'}$ up to 2200GeV
  - **QCD-like DM**, explored unflavored and flavor-aligned scenarios with two different methods optimized for each coupling scenario
- No significant excess found so far. More results coming soon, including data from Run3

Conclusion

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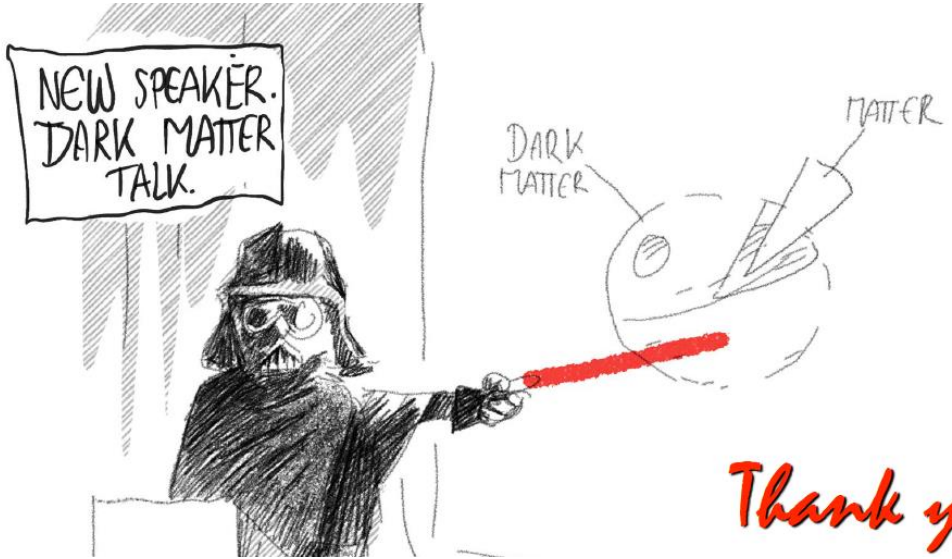

Thank you!