

# Dark matter searches from CMS

Laurent Thomas  
on behalf of the CMS Collaboration

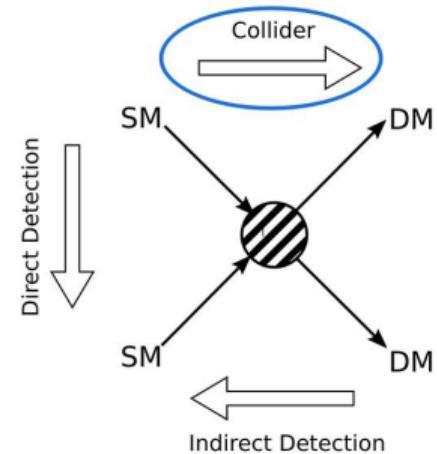
SUSY 2023

*University of Southampton*



# Introduction

- Possible production of dark matter at colliders offers a complementary approach to direct detection experiments and searches for annihilation decay products with telescopes.
- Many searches conducted at CMS since the LHC startup.  
→ Probing a large range of experimental signatures and theoretical models
- Will review a few recent results illustrating the broadness of this program.  
→ Impossible to give justice to all these searches in 15'.



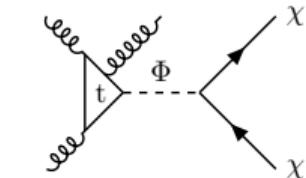
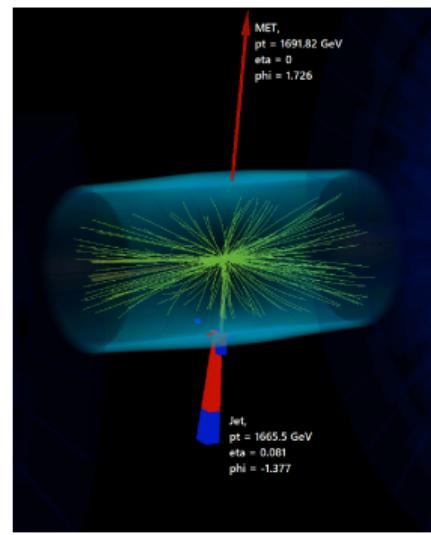
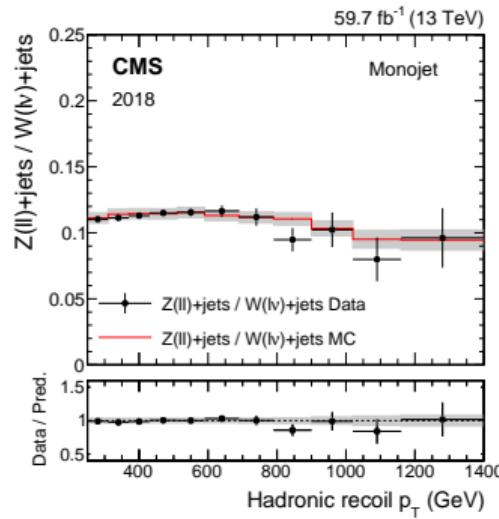
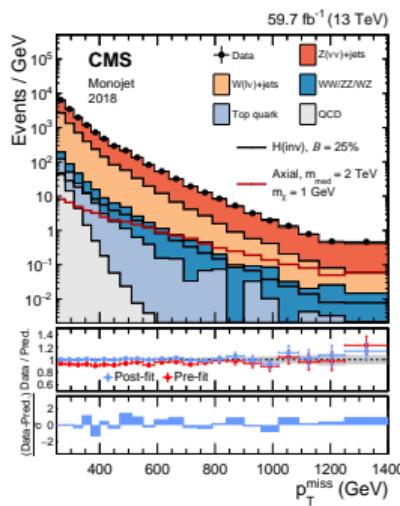
**Disclaimer: not covering SUSY focused searches.**

See K. Vellidis plenary and S. Bein, G. Salvi, P. Matorras Cuevas parallel talks.

[picture source](#)

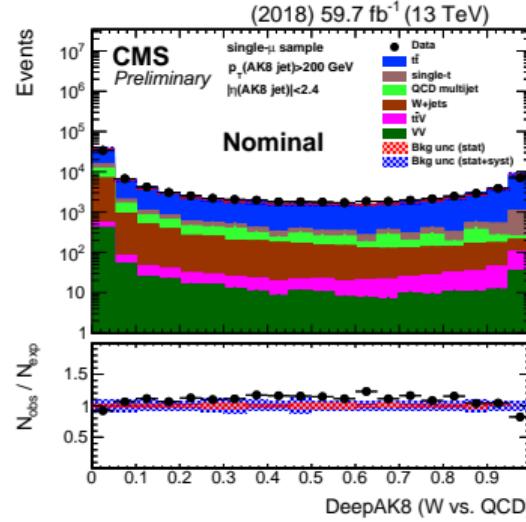
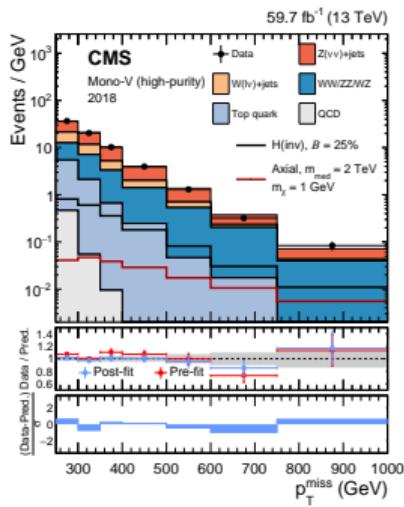
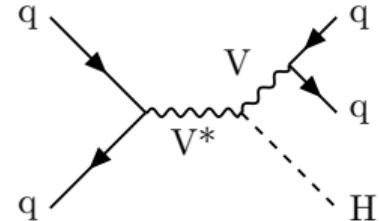
# Mono jet search (EXO-20-004)

- Looking for DM through events with a recoiling jet and high transverse momentum imbalance ( $p_T^{\text{miss}} > 250$  GeV).
- Signal extraction based on the  $p_T^{\text{miss}}$  distribution.
- Control regions with a leptonically decaying W/Z or a photon candidate
  - To constrain the main backgrounds ( $Z(\nu\nu)$  and  $W(l\nu)$  with a lost lepton) with the help of transfer factors derived from simulation.



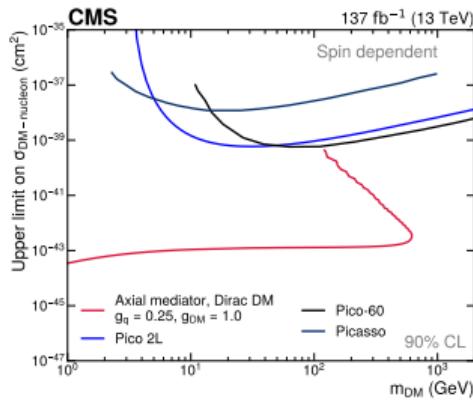
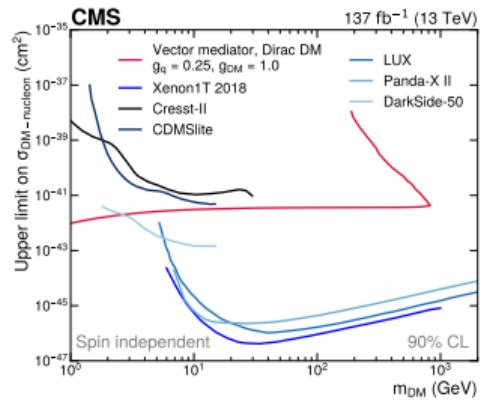
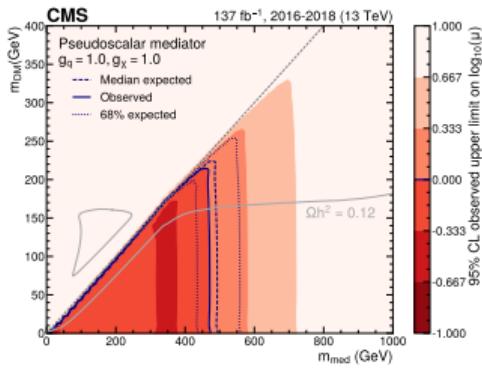
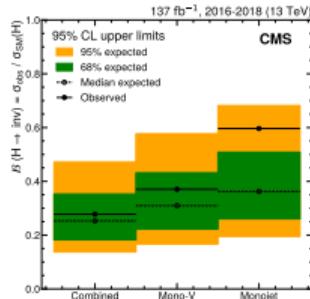
# Mono jet search: hadronic W/Z tagging ([EXO-20-004](#))

- Dedicated event categories for large radius jets consistent with a W/Z hadronic decay.
  - Generic ML taggers developed in the collaboration for this purpose.
  - Performances evaluated directly in data with semi-leptonic  $t\bar{t}$ .
- Benchmark process: invisible decay of the Higgs in the VH production mode.



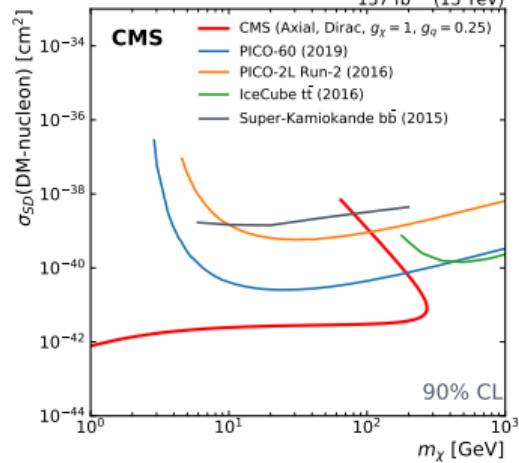
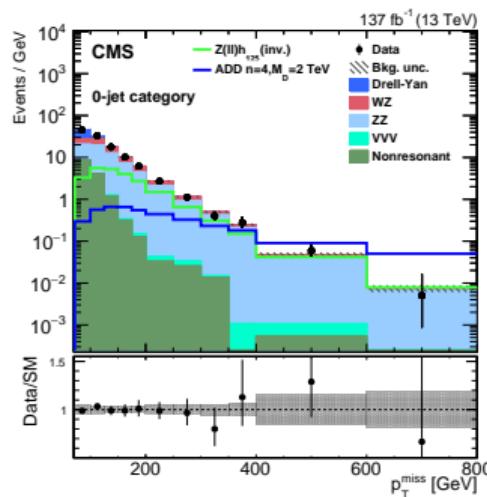
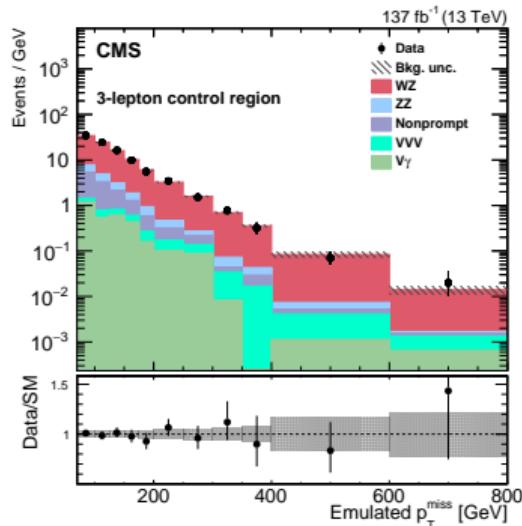
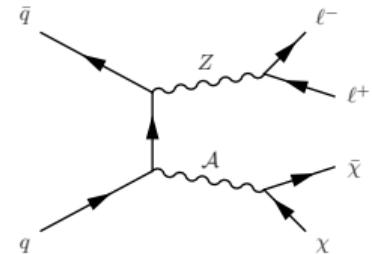
# Mono jet search: results (EXO-20-004)

- Upper limits set in the DM/mediator mass plane for various mediator spin hypotheses.
- Constraints competitive with direct searches, especially for axial-vector mediators.
- Exclude invisible Higgs branching ratio beyond 28 %.



# Mono Z(II) search (EXO-19-003)

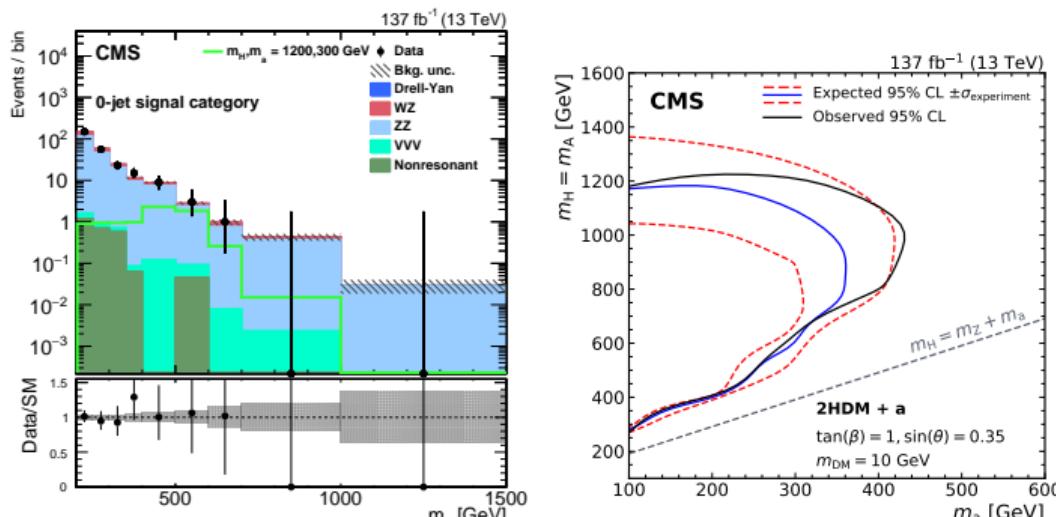
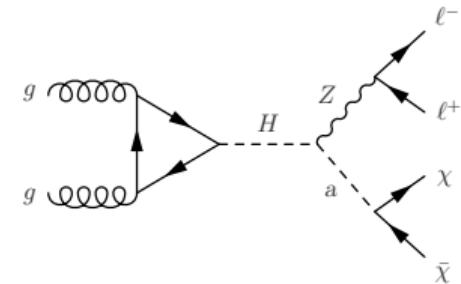
- Similar search as monojet, with a Z ( $ee/\mu\mu$ ) as the recoil.
- Allows to probe lower  $p_T^{miss}$  (down to 100 GeV).
- Control regions defined with 3 or 4 leptons to constrain WZ and ZZ backgrounds.
- Less sensitive than monojet to simple DM+mediator models.
- Similar sensitivity to Higgs invisible decay.



# Mono Z(II) search: 2HDM+a model ([EXO-19-003](#))

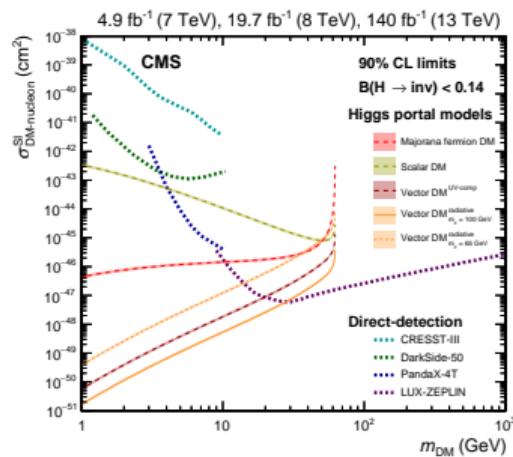
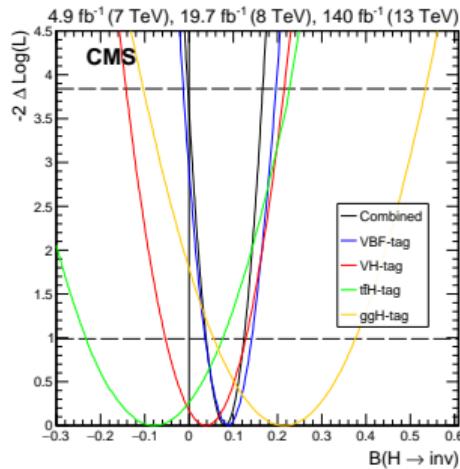
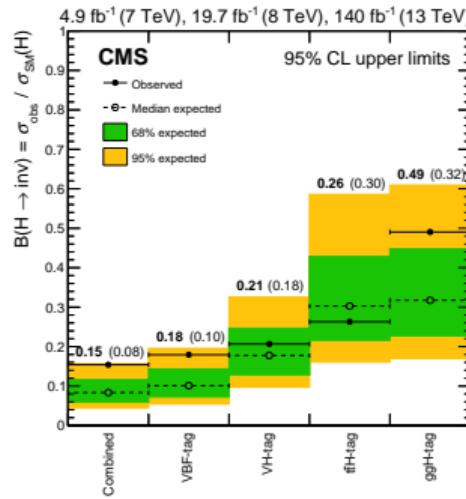
Two Higgs Doublet+a model:

- Usual Higgs doublet model:  
 $h$  (125 GeV),  $H$ ,  $H^\pm$ ,  $A$  and additional pseudoscalar,  $a$ , acting as mediator with DM.
- Possible resonant production of  $Z+a$  through  $H$  decay.
- Dedicated analysis performed using the  $Z+p_T^{\text{miss}}$  transverse mass.
- Analysis leading the sensitivity for this model.



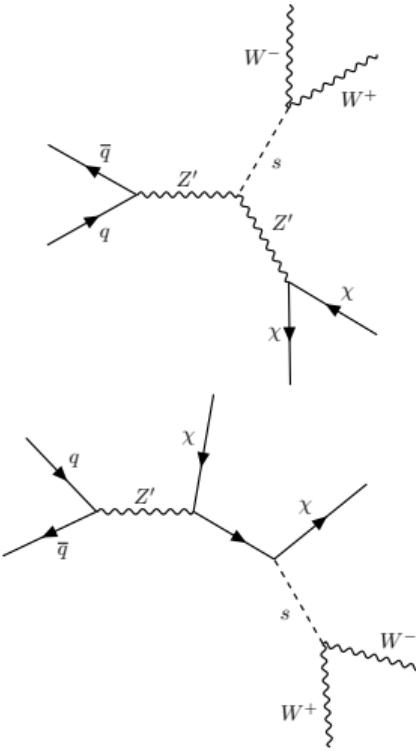
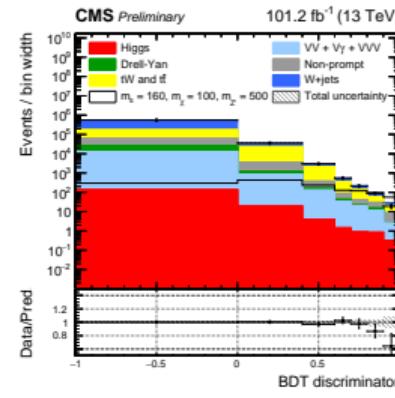
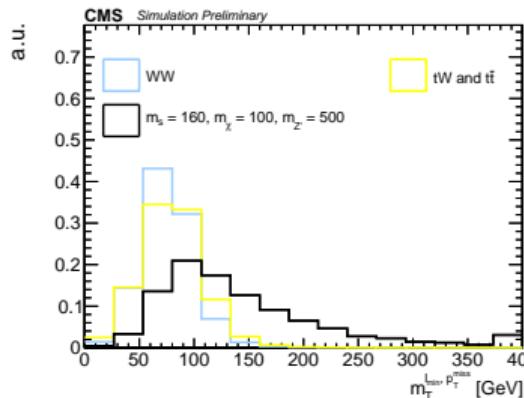
# Combination of Higgs invisible decay searches (HIG-21-007)

- Other production modes of the Higgs are also probed (VBF,  $t\bar{t}H$ ) and were recently combined.
- Exclude invisible Higgs branching ratio above 15%. (8% expected).
- Sensitivity driven by the VBF production.
- Competitive limits on DM-nuclei cross sections for DM masses below 10 GeV.



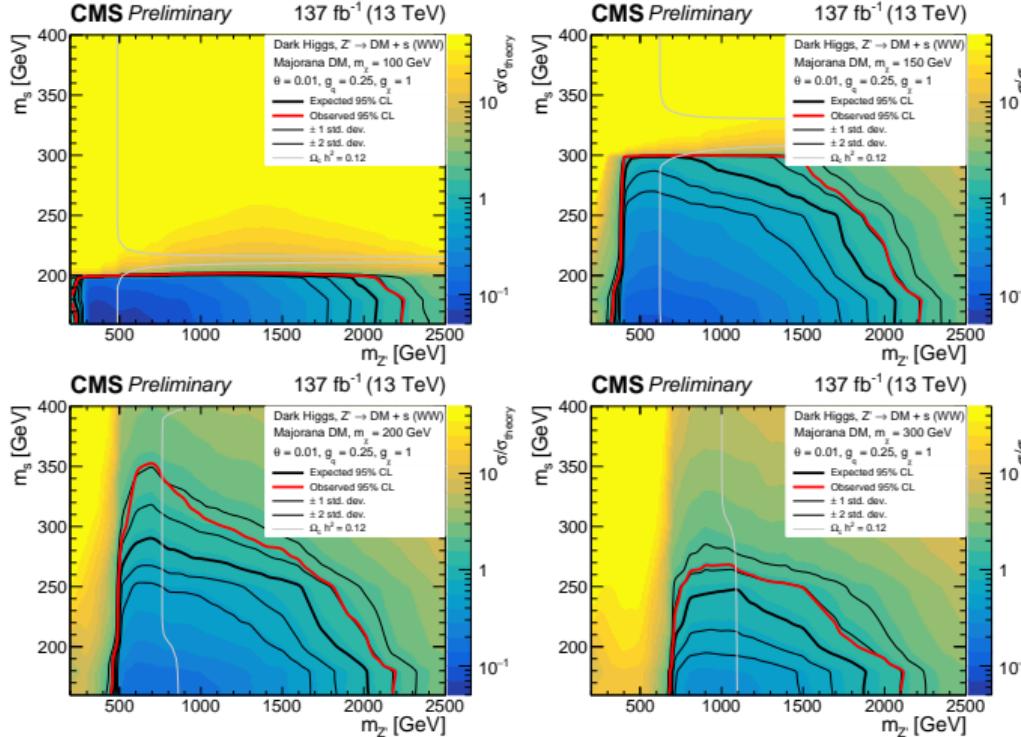
# DM produced with a pair of W bosons (EXO-21-012)

- A recently proposed scenario is the existence of a dark Higgs boson through which the DM particle acquires mass.
- A simple model consist of new U(1) symmetry, resulting in a dark Higgs singlet,  $s$ , and a massive  $Z'$ .
- For  $m_s > 160$  GeV, the dominant SM branching ratio is  $WW$ .
- Both dileptonic and semi-leptonic final states considered.
  - Dileptonic: various signal regions defined using the dilepton mass distribution ( $m_{ll}$ ), their  $\Delta R$  and the trailing lepton- $p_T^{\text{miss}}$  transverse mass ( $m_T^{l \text{ min}}, p_T^{\text{miss}}$ ).
  - Semi-leptonic: a BDT is built using 13 kinematic variables of the event.



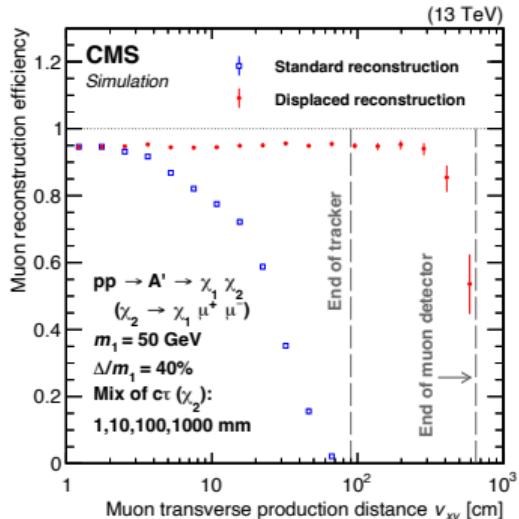
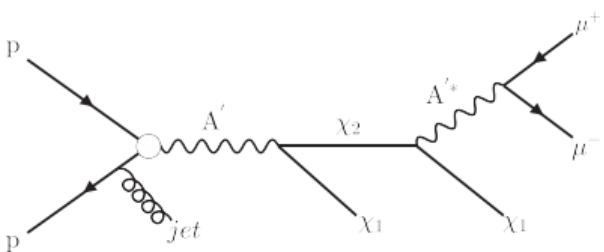
# DM produced with a pair of W bosons (EXO-21-012)

- Interpretation in terms of  $m_{Z'}$ ,  $m_s$  and  $m_{DM}$
- Kinematic threshold at  $m_s = 2 \times m_{DM}$



# Inelastic DM search with displaced muon pairs ([EXO-20-010](#))

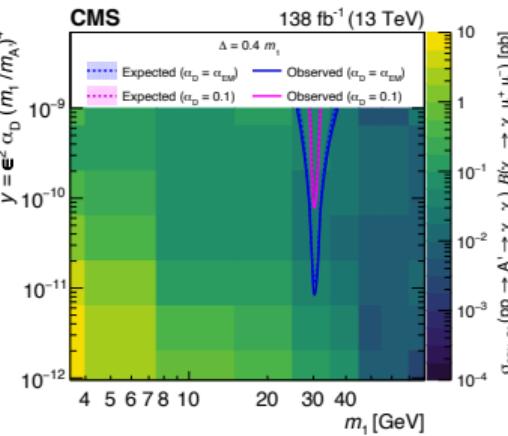
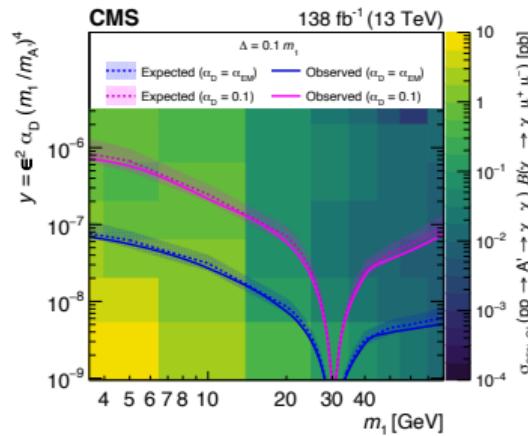
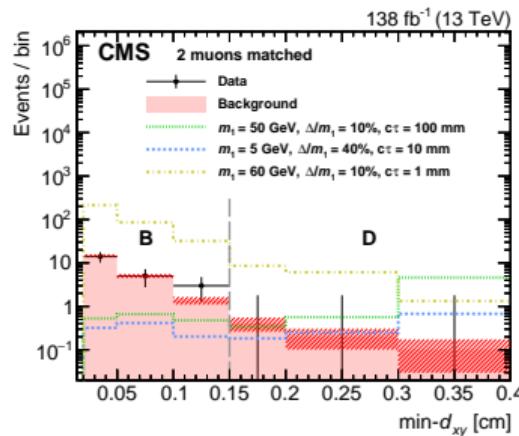
- Inelastic dark matter scenarios proposed to overcome the constraint from direct detection experiments.  
→ relic DM particles cannot scatter elastically off of nuclei.
- Simple model: dark photon  $A'$  from broken  $U(1)_D$  mixing with SM hypercharge  $Y$  and off-diagonal interactions with DM states  $(\chi_1, \chi_2)$ .
- Search for  $A'$  decay into a pair of DM and two muons with ISR jet for trigger/background reduction.
- Fundamental parameters:
  - $c\tau(\chi_2)$  (macroscopic)
  - $m_{A'}$  and  $m_1$  (benchmark:  $m'_A = 3 \times m_1$ )
  - $\Delta/m_1 = m_2 - m_1$  (benchmarks:  $\Delta/m_1=0.1, 0.4$ )
  - $\alpha_D$  (benchmarks: 0.1,  $\alpha_{EM}$ )



Dimuon final state:  
 large efficiency up to several meters of displacements with dedicated reco.

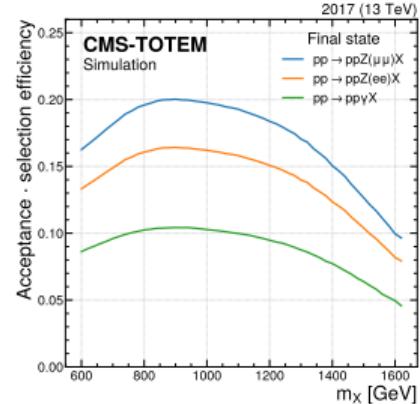
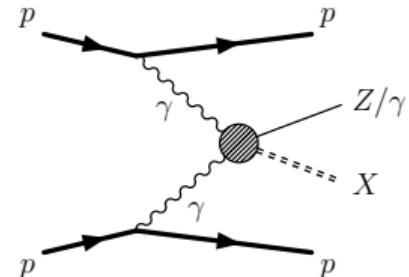
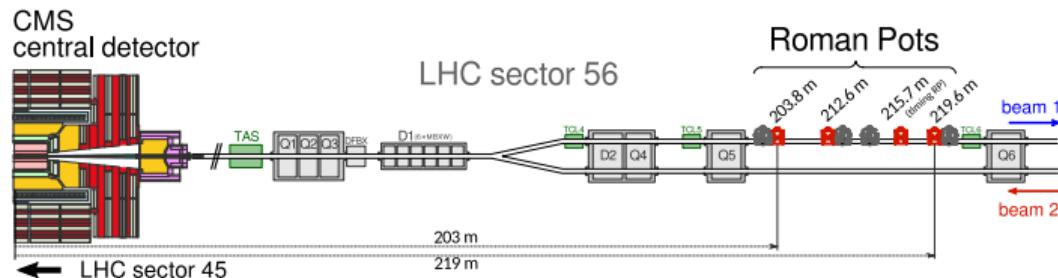
# Inelastic DM search with displaced muon pairs ([EXO-20-010](#))

- Three categories depending on the quality of the reconstructed muons.
- Background estimated from side band regions (“ABCD” method based on 2 uncorrelated variables: minimum transverse displacement ( $d_{xy}$ ) and isolation or  $\Delta\phi(\mu\mu, p_T^{\text{miss}})$ )
- Results interpreted as upper limit on  $\epsilon$  ( $A'/Y$  mixing).



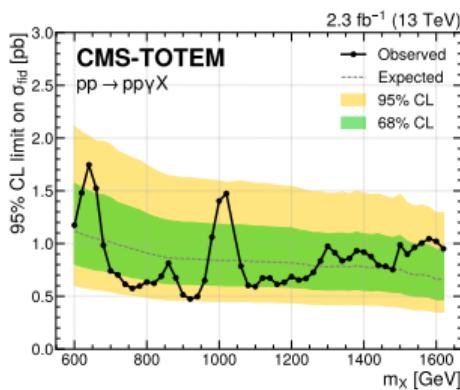
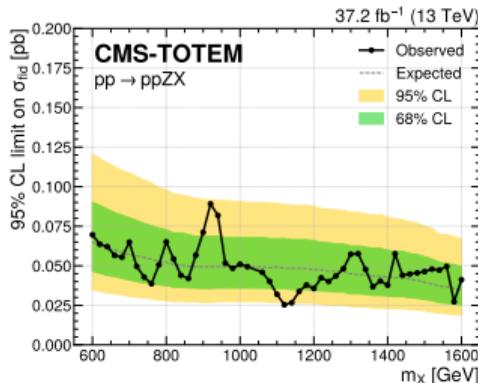
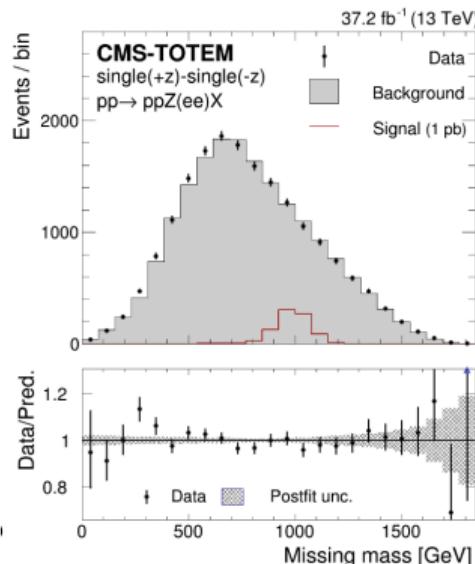
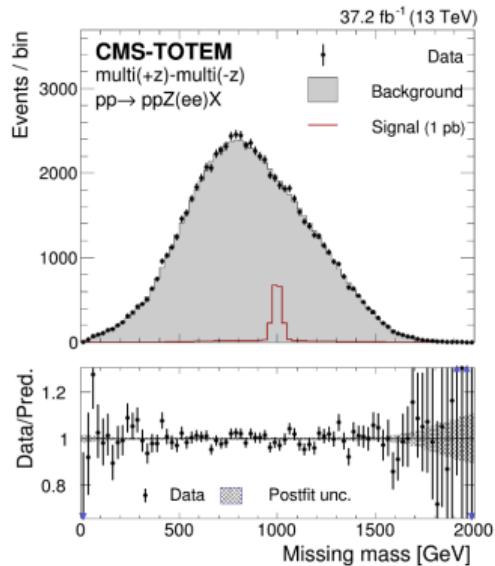
# Central exclusive production of $Z/\gamma + X$ ([EXO-19-009](#))

- Model independent search for  $pp \rightarrow pp + X + Z(ee/\mu\mu)$  or  $\gamma$ .
- Forward protons reconstructed with the CMS TOTEM precision proton spectrometer.
  - Array of Roman pots (tracking/timing stations) located 210m from the interaction point.
  - Large detection efficiency of intact protons with momentum loss  $\xi = \Delta p/p$  between 3 and 15%. (relative uncty: 6-10%)
  - The full kinematic of the central system is constrained.  
→ can reconstruct missing mass.
  - Sizeable acceptance in the 600-1600 GeV range.



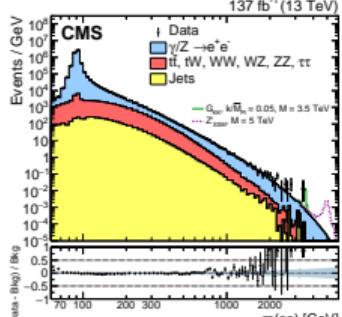
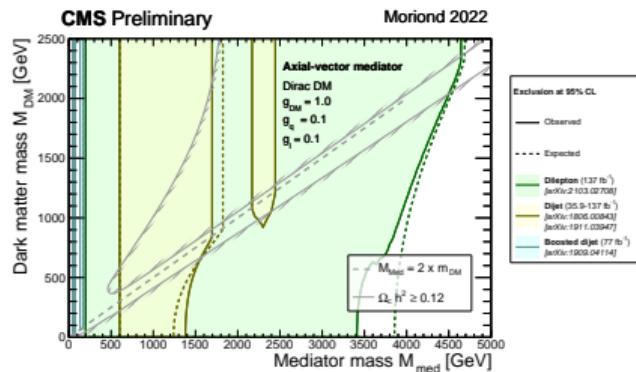
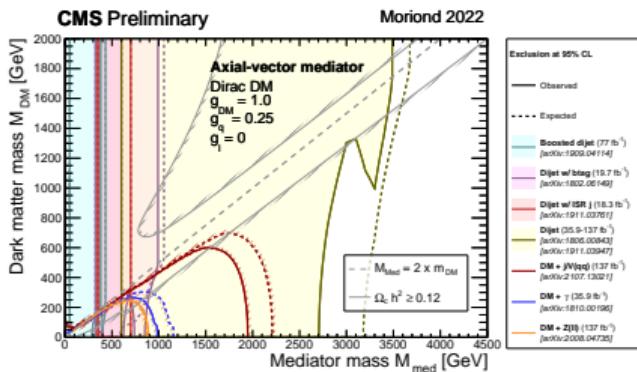
# Central exclusive production of $Z/\gamma + X$ (EXO-19-009)

- Event categories depending on the proton reconstruction quality (single/double station based).
- Background mostly from inclusive  $Z/\gamma$  production with pile up protons.
  - Data driven estimate by mixing  $Z/\gamma$  events with randomly selected pile up protons.
  - Validated with  $e\mu$  events.

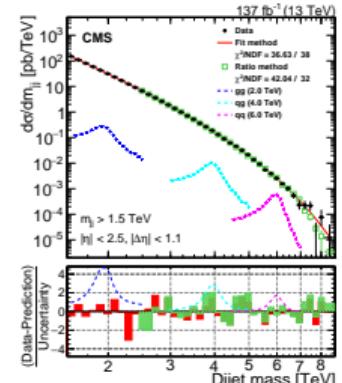


# Summary of DM/mediator exclusions

- A large variety of final states probed to look for DM and/or its mediator.
- Analyses presented above focus on final states with DM candidates in the final state.
- An alternative approach is to search for the mediator through its decays into Standard Model particles.
- For common choices of quark, leptons and DM couplings, can exclude mediator masses below several TeV.



(EXO-19-019)



(EXO-19-012)

## Summary

- CMS has a very rich program of searches for dark matter.
- It is continuously expanding with new models/final states being considered.
- No sign of dark matter so far...
- The next data may help us to shed light on its nature...

**Thank you for your attention.**