Review and prospects of Dark Matter searches at CMS

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On behalf of CMS Collaboration

"New Physics with Exotic and Long-Lived Particles",

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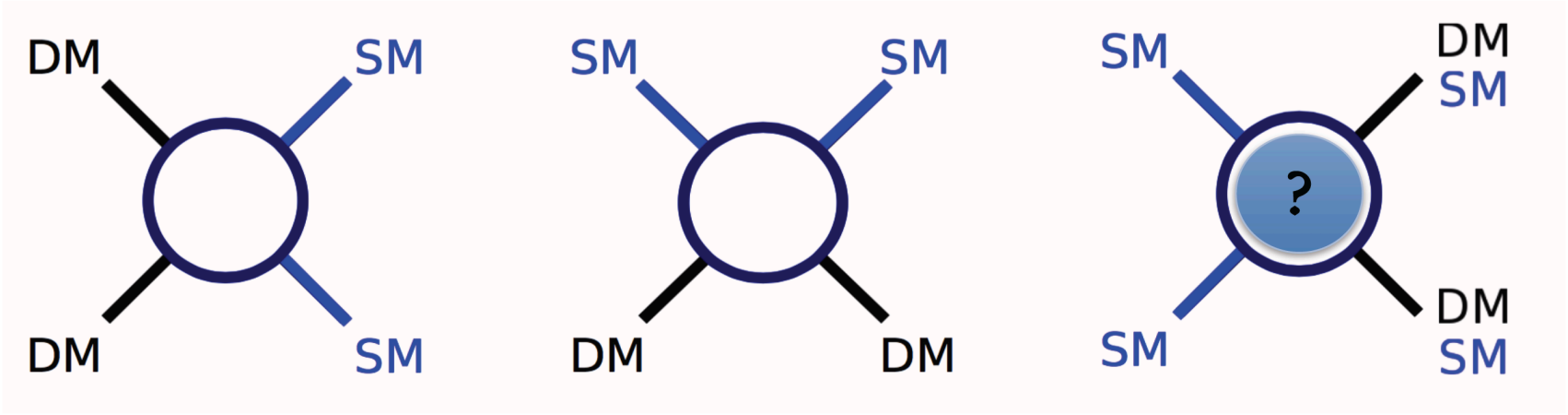
center for high energy physics

Indian Institute of Science, Bangalore, India

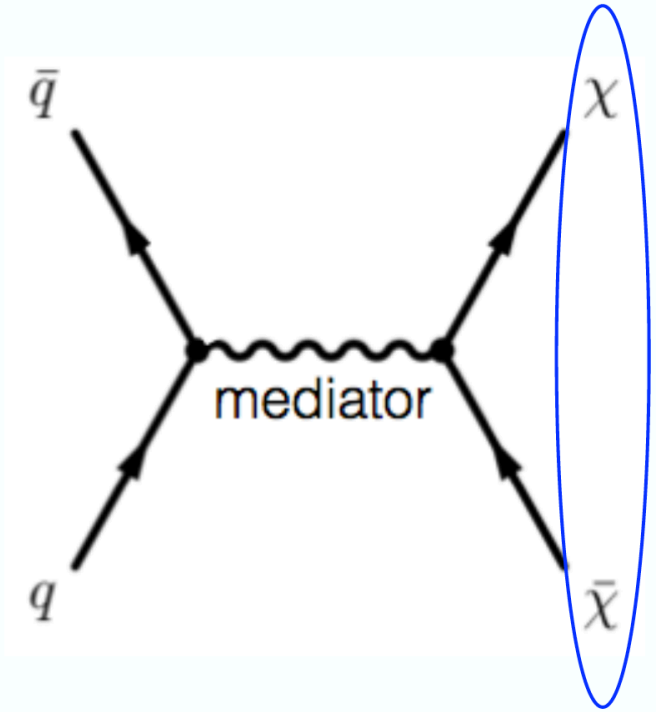
Dark Matter and its detection

- **Dark Matter (DM):**
  - Empirical evidence from astronomical observations
  - Interacts gravitationally, electrically and colour neutral and long lived
  - Most studied class of theories is Weakly Interacting Massive Particle (WIMP)
- **Detection/Searches (Complementary ways):**
  - Indirect Detection: detect annihilation of DM into known matter
  - Direct Detection: detect DM through its elastic scattering off nuclei
  - Particle Colliders: produce DM in high energy particle collisions
  - Indirect detection and Direct detection can discover DM with cosmological origin
  - Colliders can probe the dark interaction



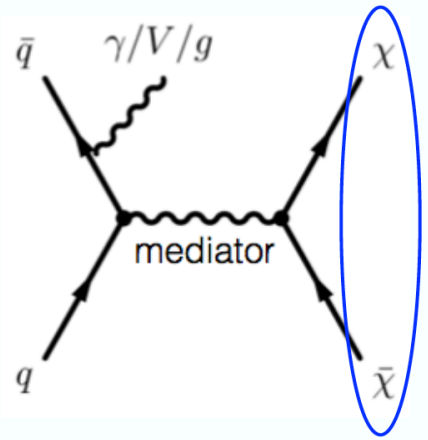
Indirect Detection Direct Detection Particle Colliders

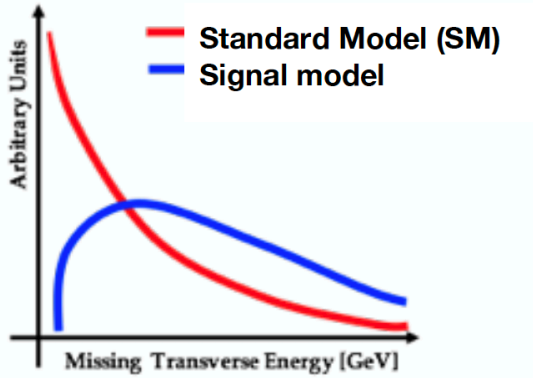
Dark Matter detection @LHC



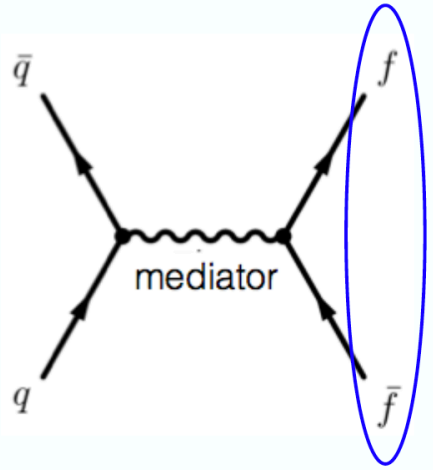
Dark Matter does not interact in detectors

Invisible searches

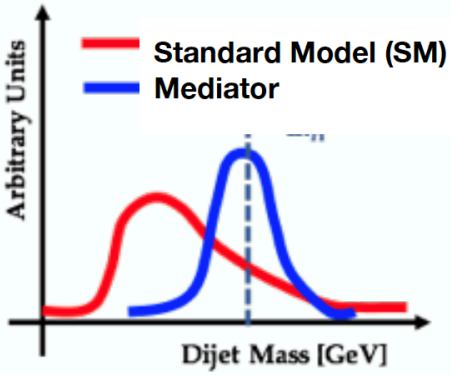




Tails of distributions



Visible searches



Bump hunt

Detection, Signatures & Interpretation of Dark Matter @LHC

- **Key observables:**
  - Invisible searches: Missing Transverse Energy from invisible Dark Matter particles (p_T^{miss})
  - Visible searches: Invariant mass for resonant production of mediator particles

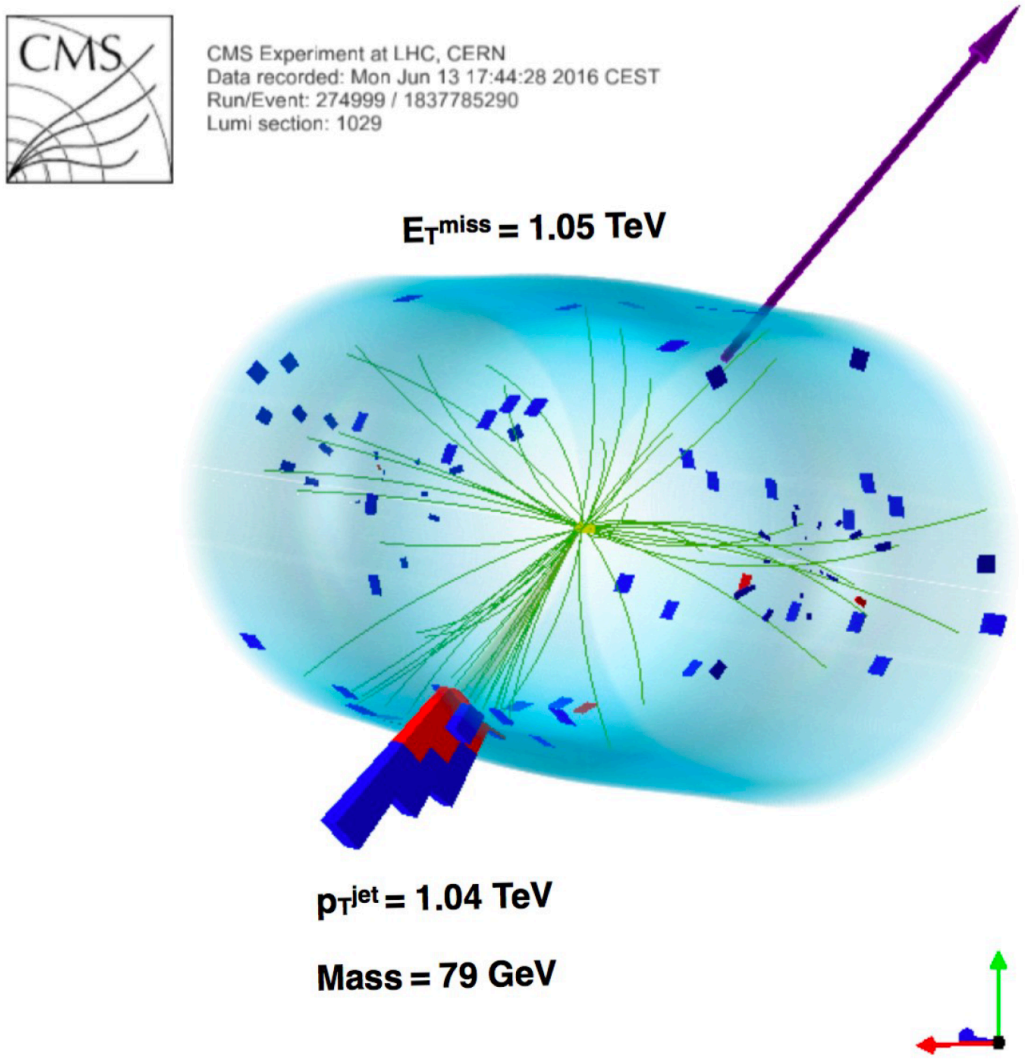
- **Wide range of Signatures:**
  - Invisible/mono-object
  - Visible/mediator
  - SUSY Decay chains
  - Long-lived particles
  - Hidden sector

- Representative/new results are covered in this talk

- **Interpretation:**
  - 13 TeV DM searches are now interpreted in standardized **Simplified Models**

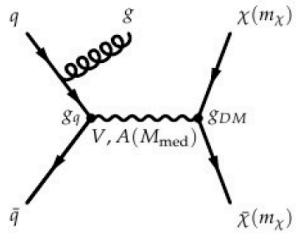
- **LHC DM Forum/Working Group:**
  - Benchmark models for interpretations
  - common basis to present LHC results wrt other LHC and non-LHC experiments
  - common basis for comparison of LHC DM searches to visible mediator searches

Invisible (mono-object) searches

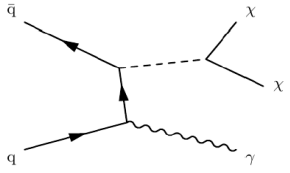


Dark Matter mono-object signatures @LHC

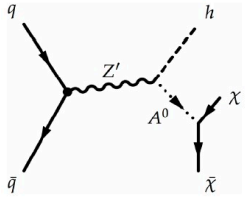
- Experimental signature is transverse momentum imbalance
- DM recoils against some visible object “X”
- This gives rise to the following signatures:



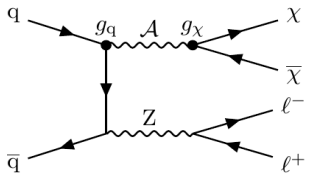
MonoJet

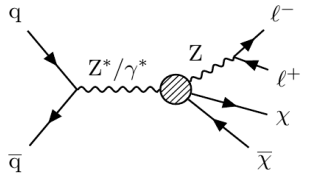


MonoPhoton

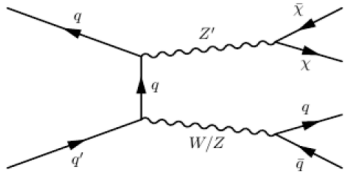


MonoHiggs

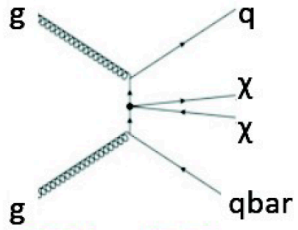




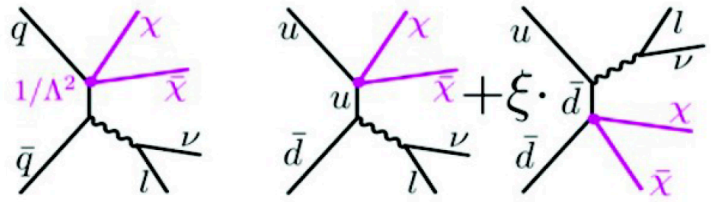
MonoZ (leptonic)



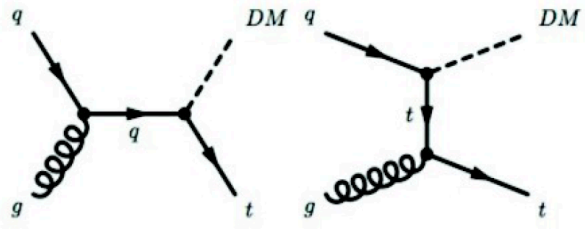
MonoW/Z (Hadronic)



BBbar /TTbar

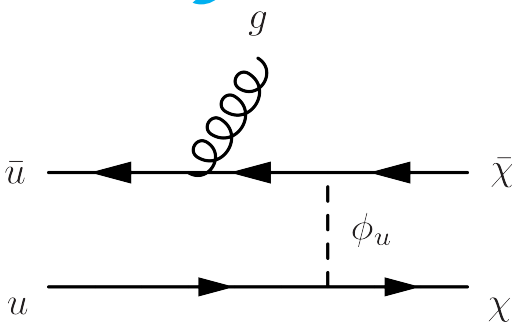


MonoW (monoLepton)

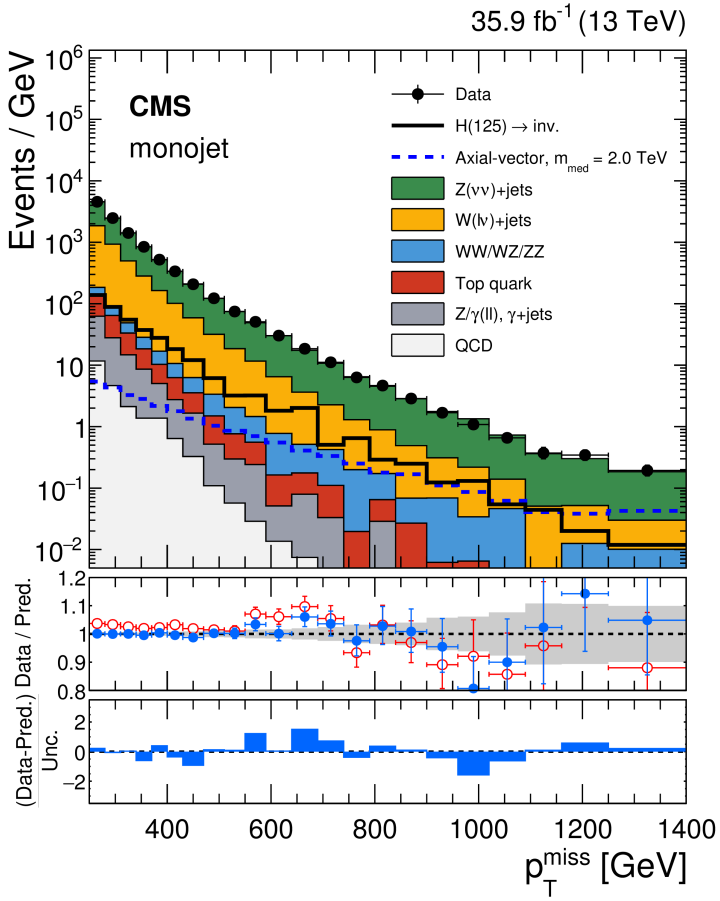


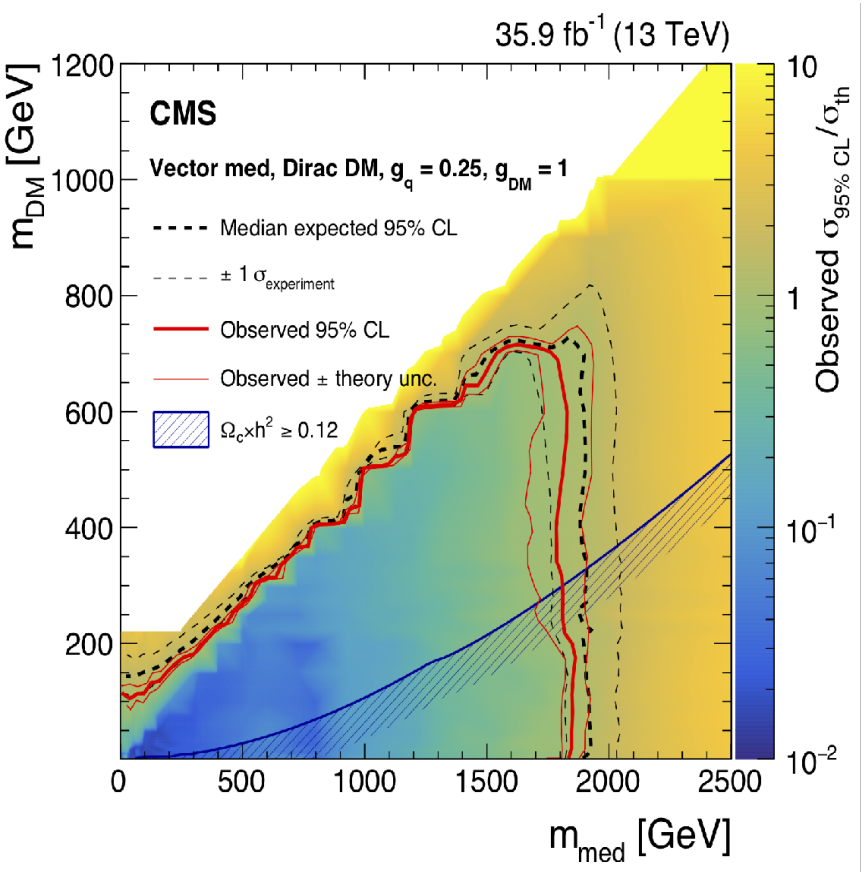
MonoTop

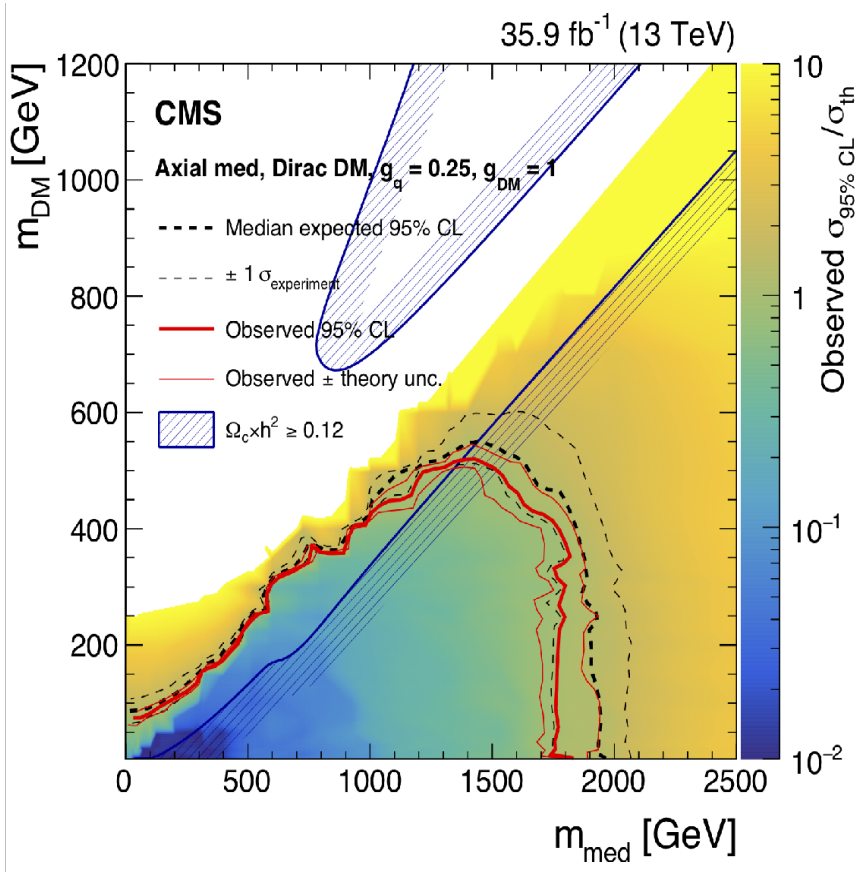
Mono-jet searches: p_T^{miss} + jet (1)



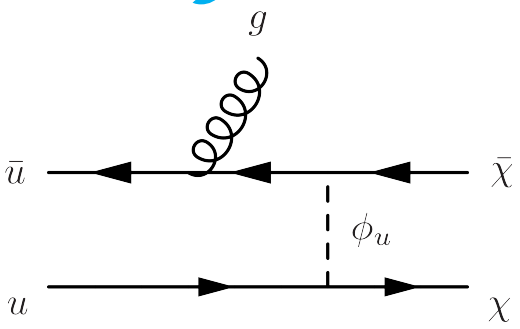
- [Phys. Rev. D 97 (2018) 092005]
- Mono-V (hadronic decays) also have similar reach as mono-jet
- Vector and axial-vector mediators with masses up to 1.8 TeV are excluded at 95% confidence level.



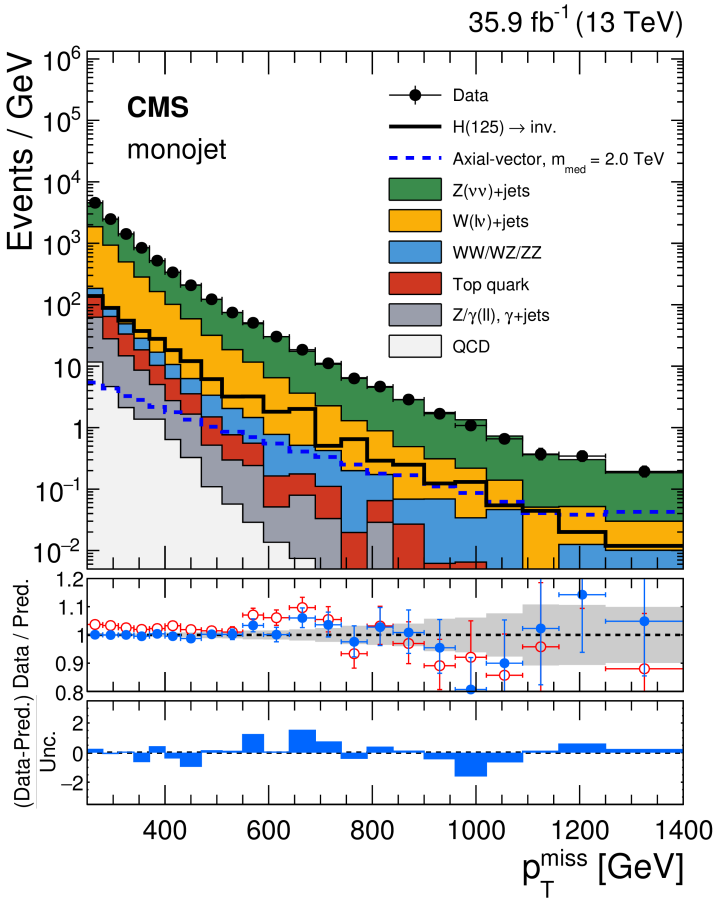


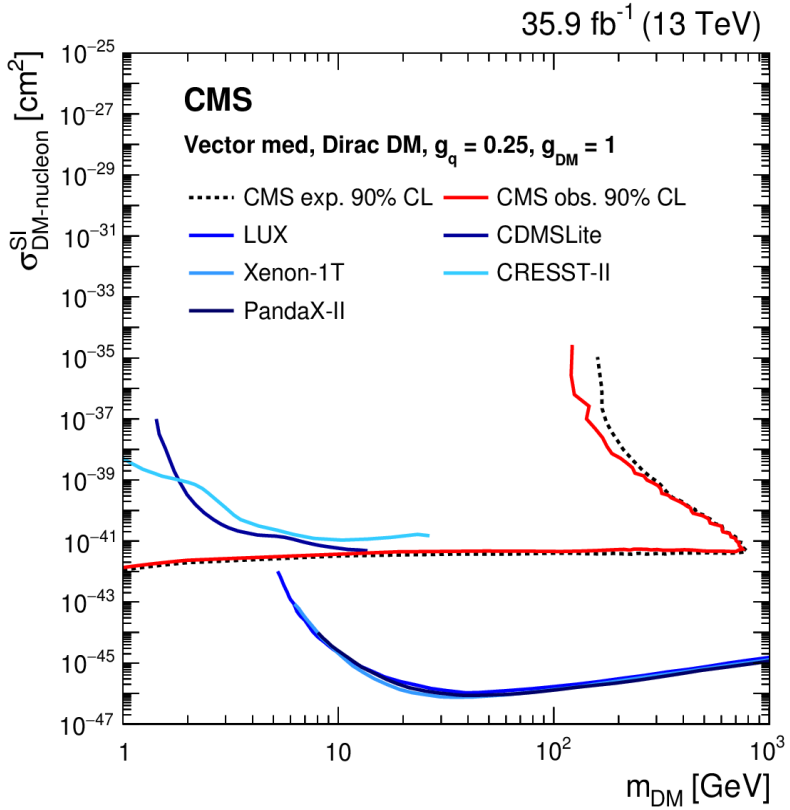


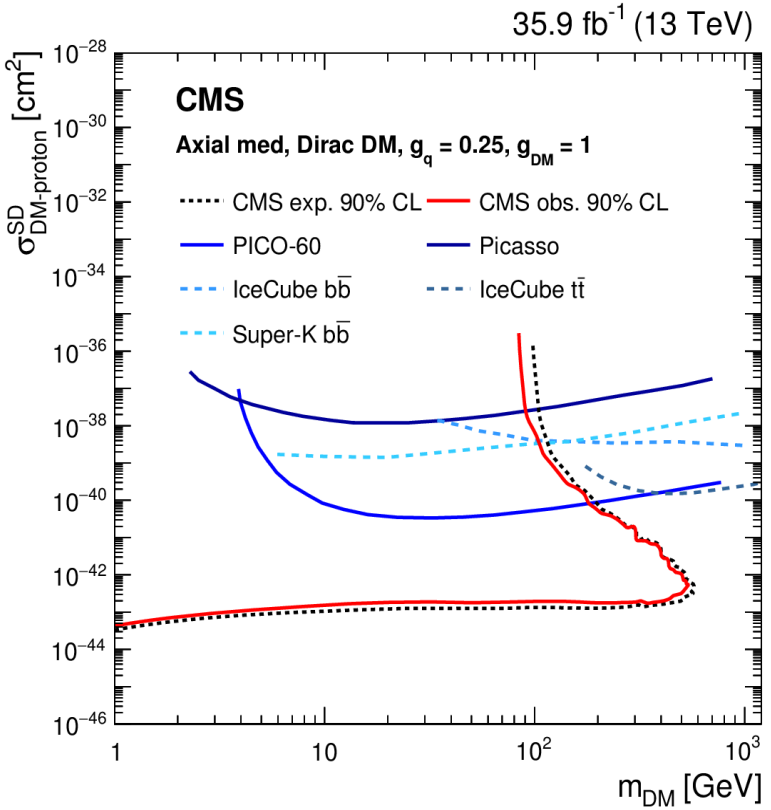
Mono-jet searches: p_T^{miss} + jet (2)



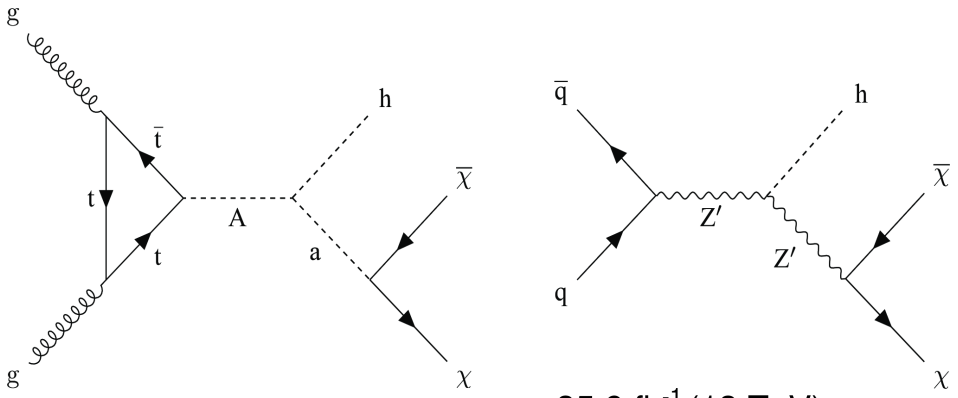
- [Phys. Rev. D 97 (2018) 092005]
- DM-Nucleon scattering: Exclusion limits at 90% CL in the m_{DM} vs. $\sigma^{SI/SD}$ plane for vector and axial-vector mediator models.
- Mono-jet searches have higher sensitivity at the lower m_{DM} for both the vector and axial-vector mediator models

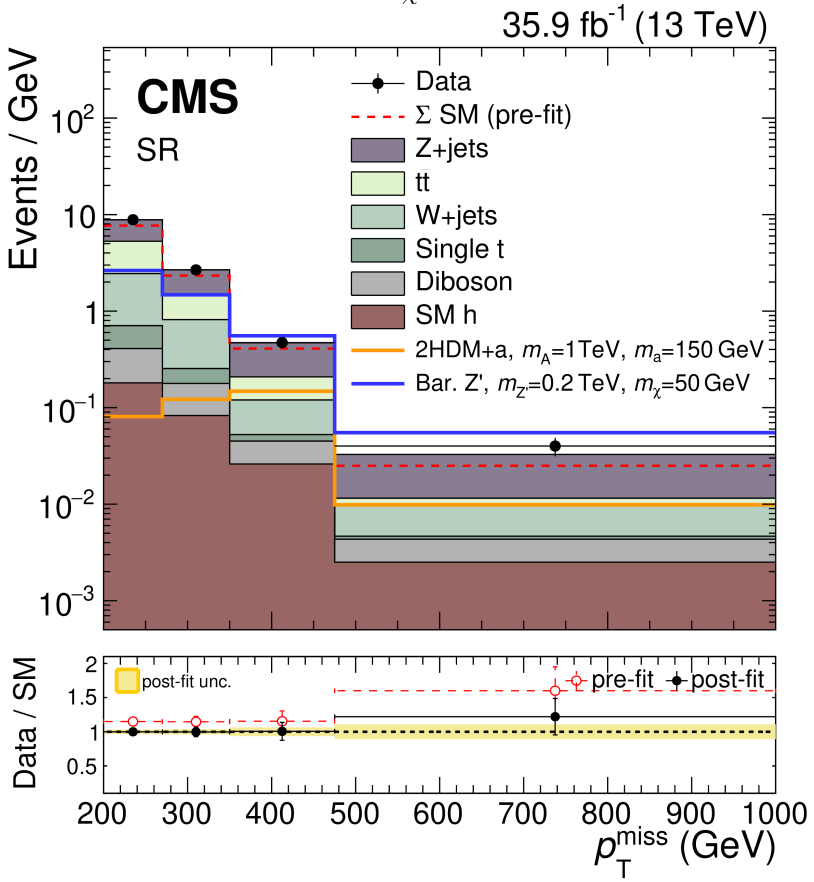




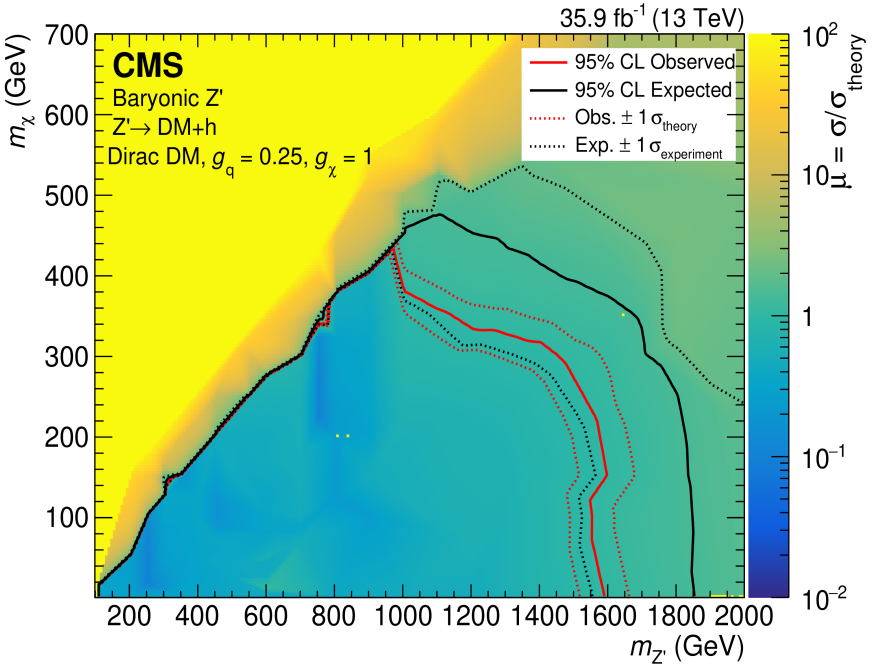


Mono-Higgs searches: p_T^{miss} + Higgs (→bb) (1)

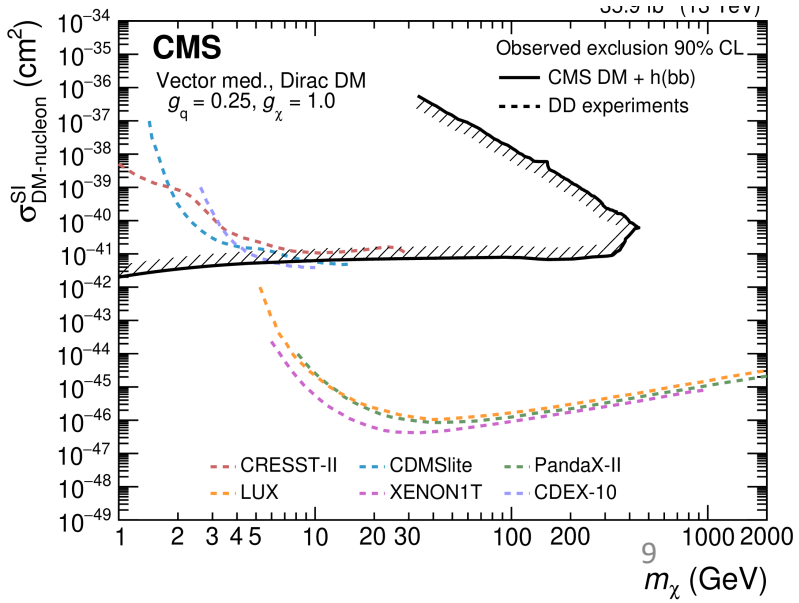




- Eur. Phys. J. C 79 (2019) 280
- For the baryonic Z' model,
- Z' boson masses up to 1.6 TeV are excluded for a DM mass of 1 GeV and
- DM masses up to 430 GeV are excluded for a Z' boson mass of 1.1 TeV.

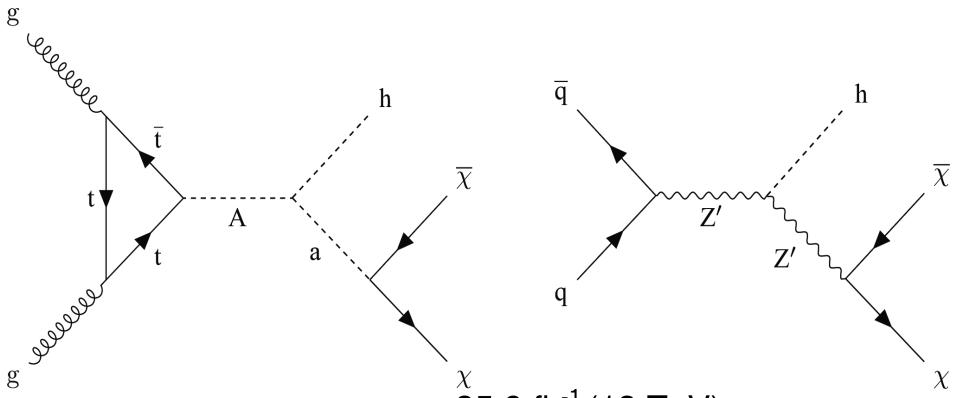


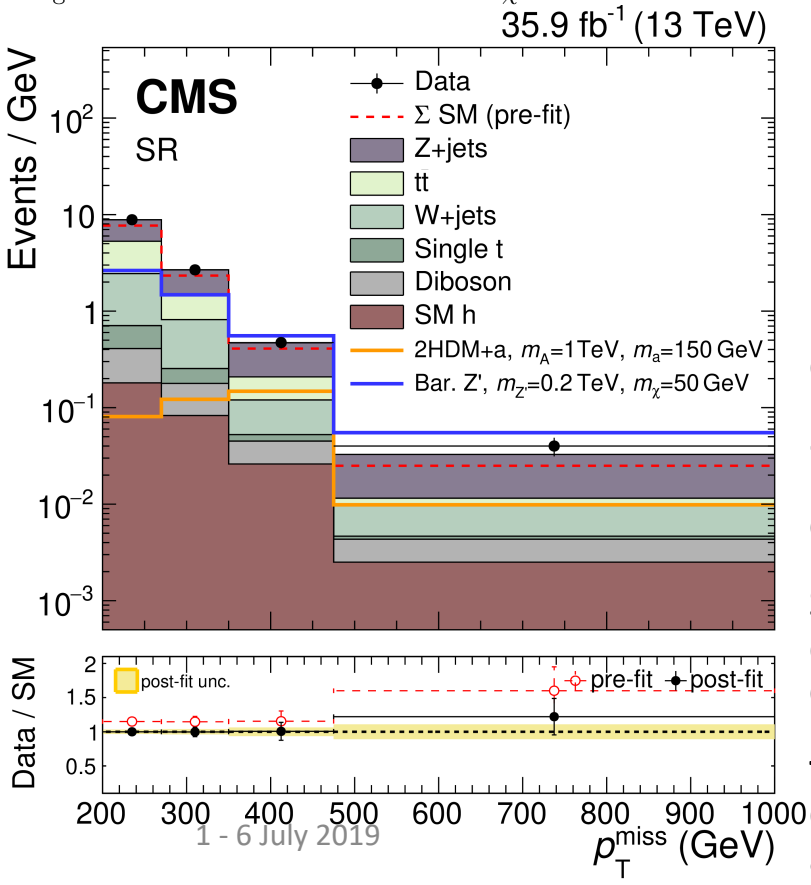
- The reinterpretation of the results for the baryonic Z' model in terms of an SI nucleon scattering cross section yields a **higher sensitivity for mχ < 5 GeV** than existing results from direct detection experiments, under the assumptions imposed by the model.

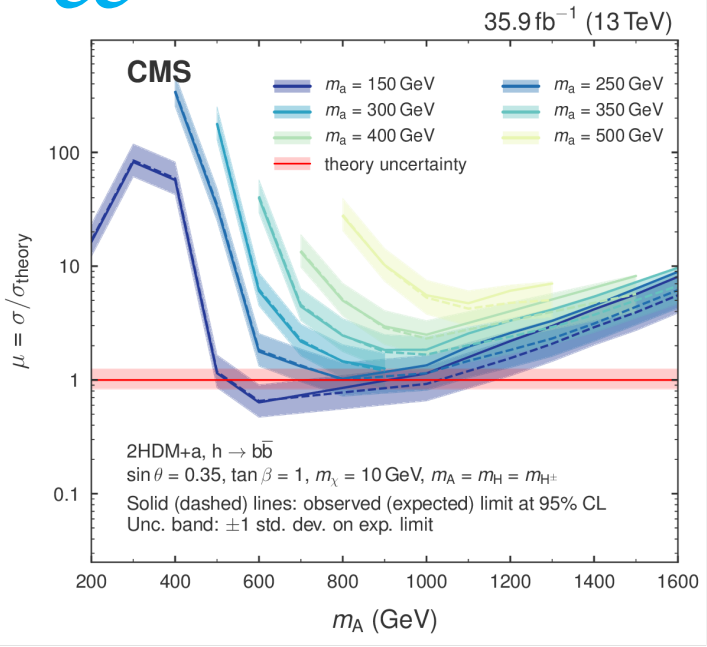


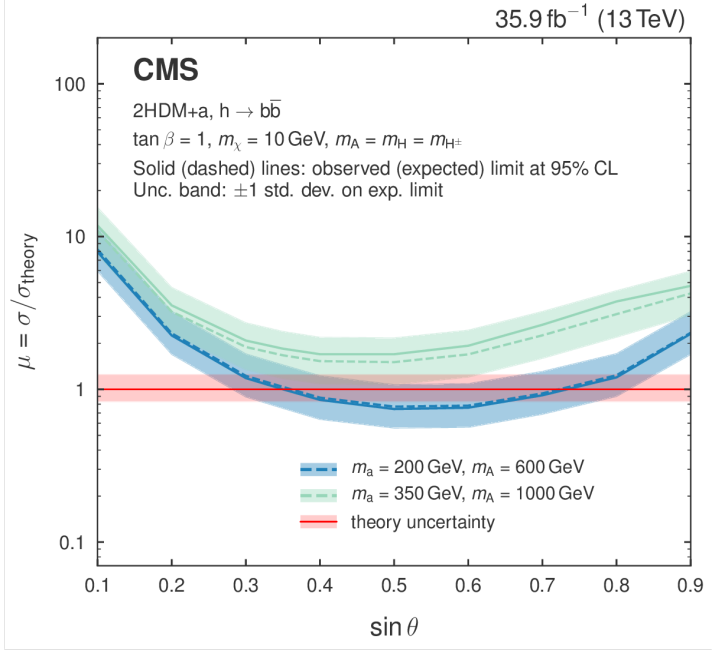
Mono-Higgs searches: p_T^{miss} + Higgs (→bb) (2)

Eur. Phys. J. C 79 (2019) 280







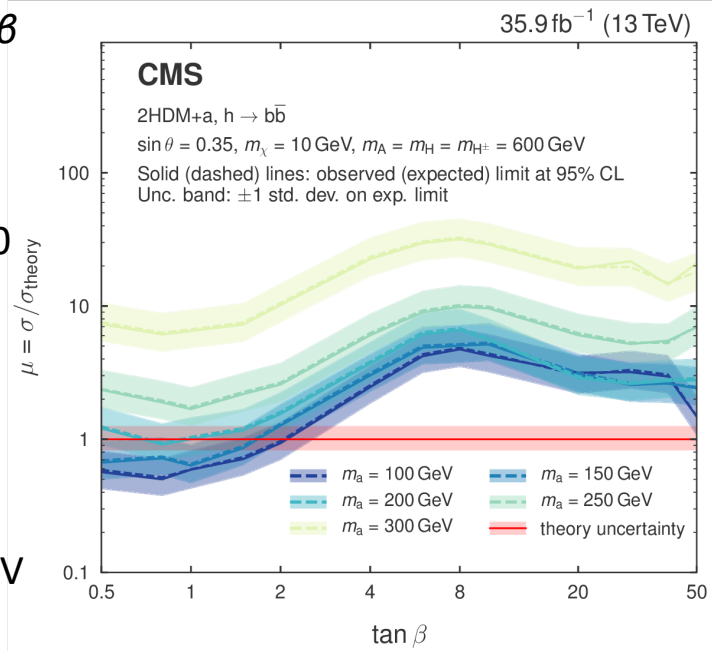


For the nominal choice of sinϑ and tanβ in the 2HDM+a model, the search excludes masses

500 <m_A< 900 GeV (*A* is the heavy pseudoscalar boson) assuming m_a= 150 GeV.

Scanning over sinϑ with tanβ = 1, exclude **0.35 < sinϑ < 0.75** for m_A= 600 GeV and m_a= 200 GeV.

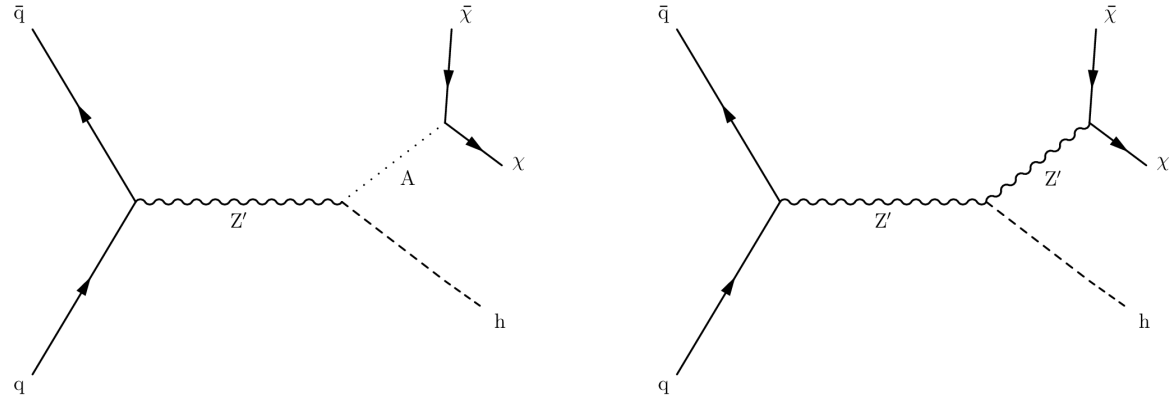
tanβ values between 0.5 and 2.0 are excluded for m_A= 600 GeV, m_a= 100 GeV and sinϑ=0.35



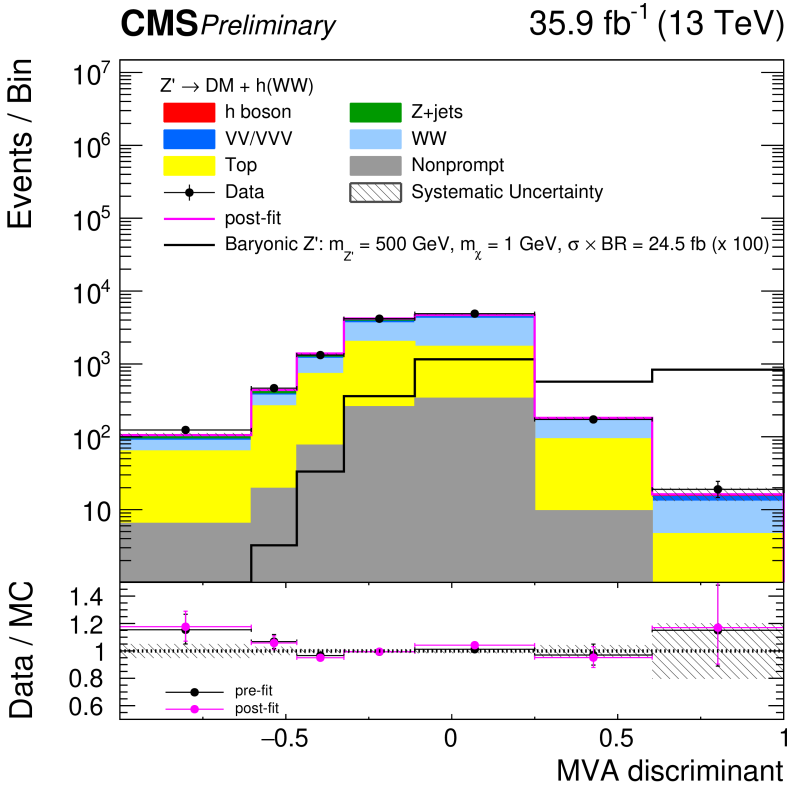
2HDM+a model is probed experimentally for the first time.

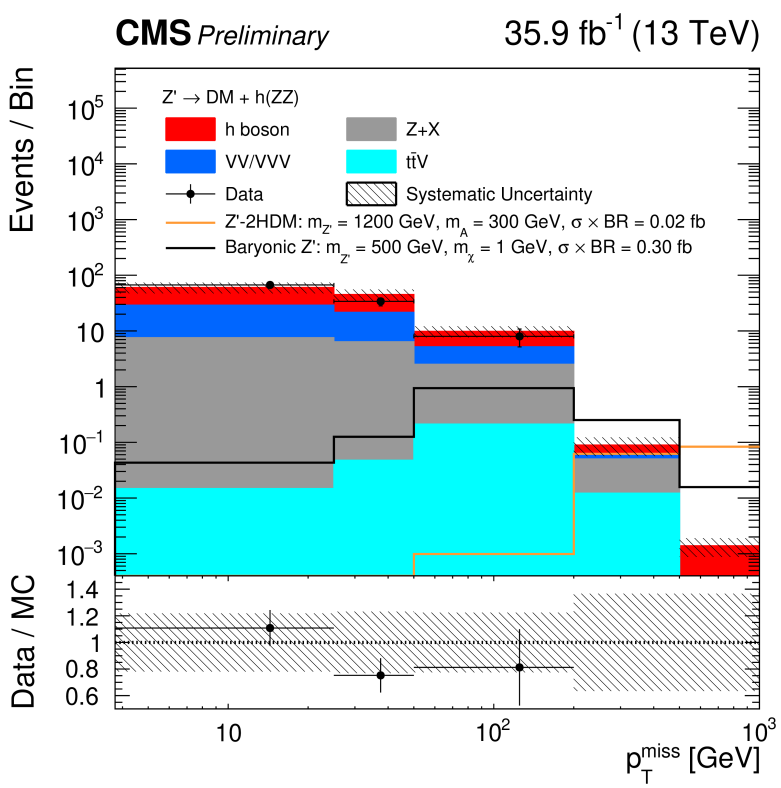
Combination of Mono-Higgs searches

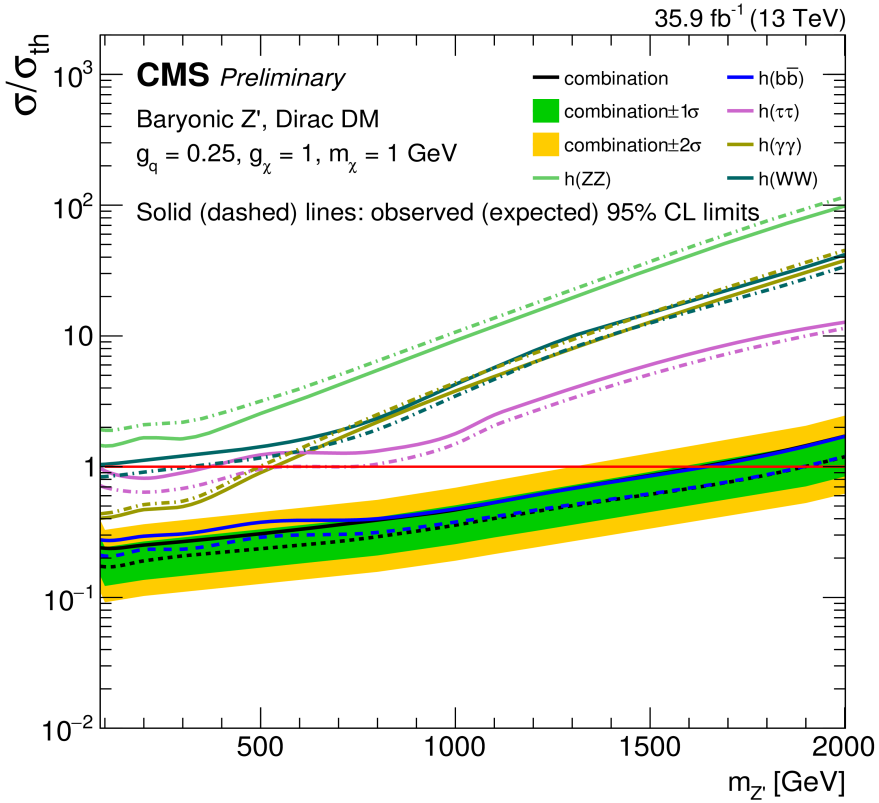
CMS-PAS-EXO-18-011



- Combination of Higgs channels (ττ, bb, γγ, WW, ZZ)
- First time search performed in H→WW and ZZ channels
- Most stringent limits on the parameters of Z'-2HDM and Baryonic Z' models
- Sensitivity driven by bb channel

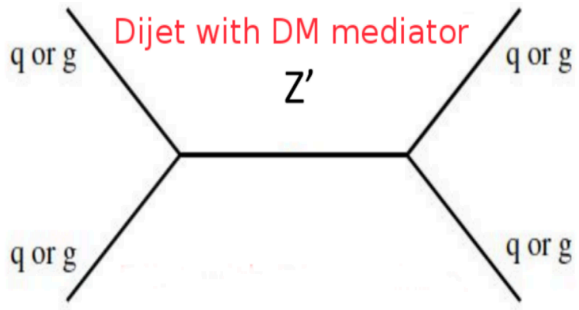






Mediator searches

Mediator of dark matter: Dijet searches



- DM mediator can decay to dijets or dark matter pairs
- Set limits on the DM mediator in the plane of DM mass vs. mediator mass
- Excluded region strongly depends on the chosen coupling and model scenario.

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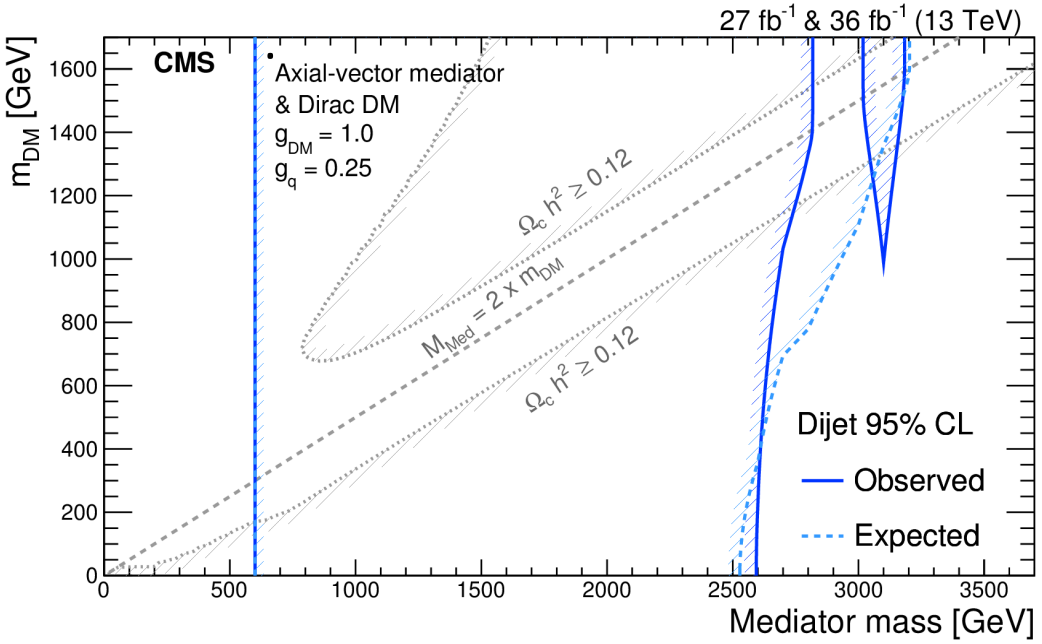
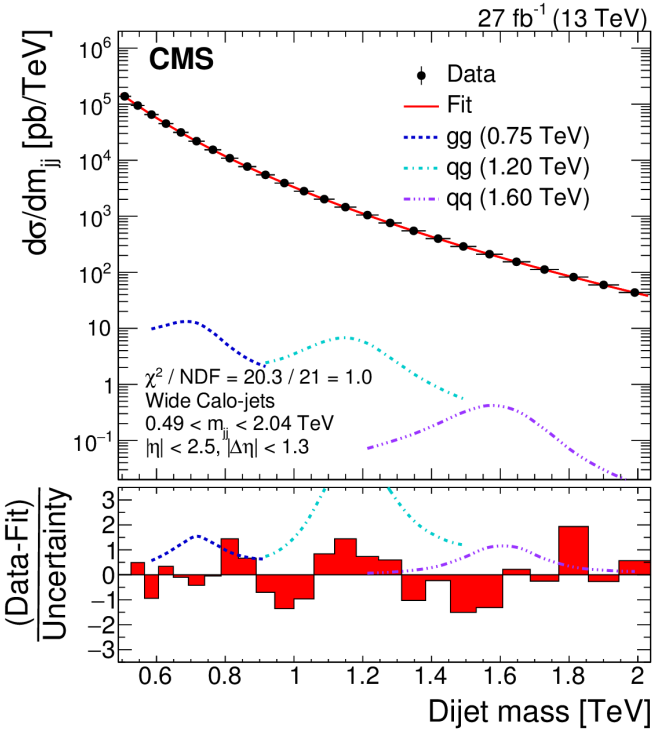
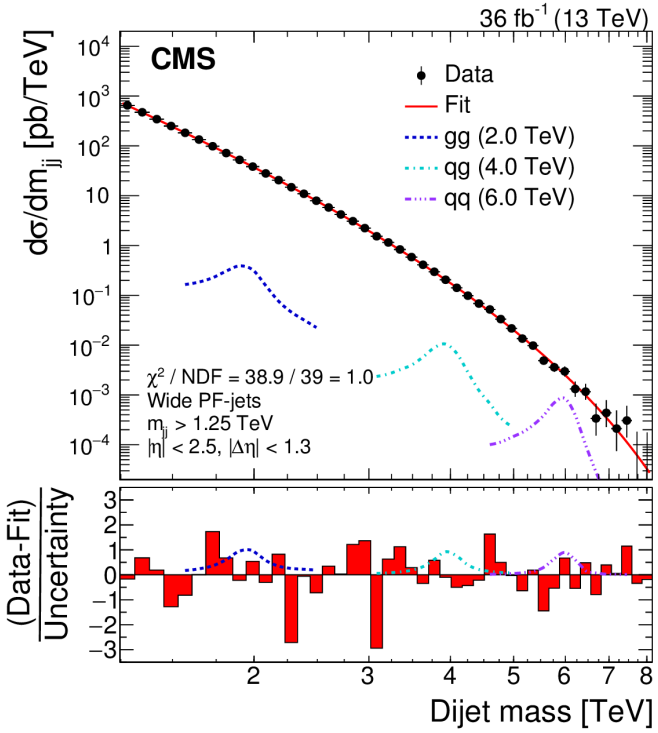
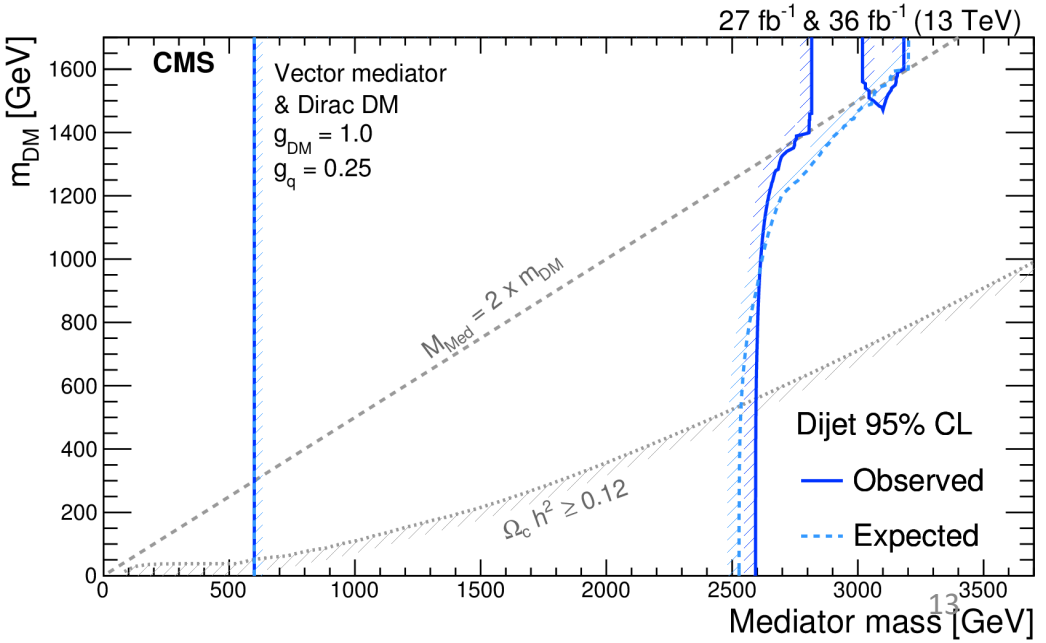
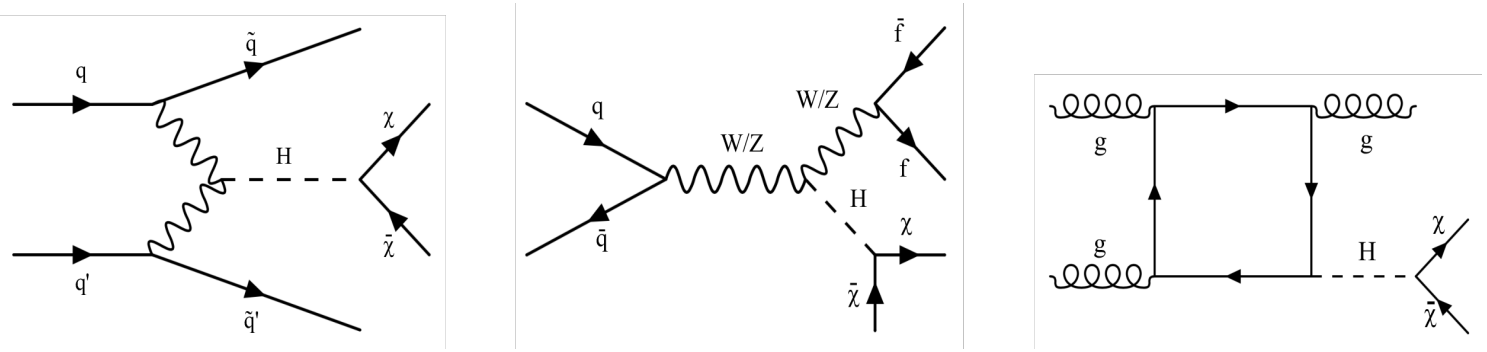








Higgs as a portal to dark matter



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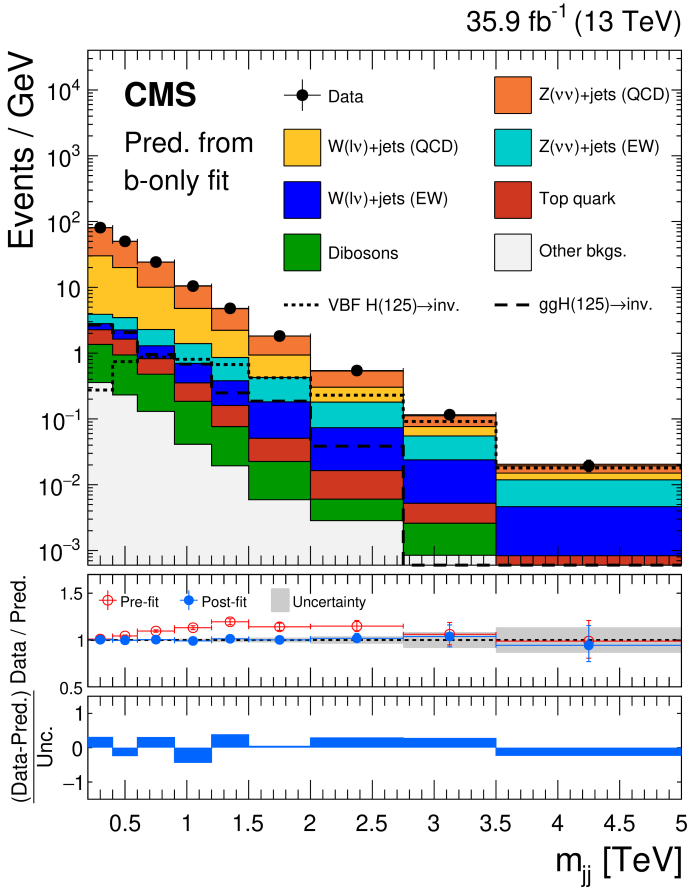
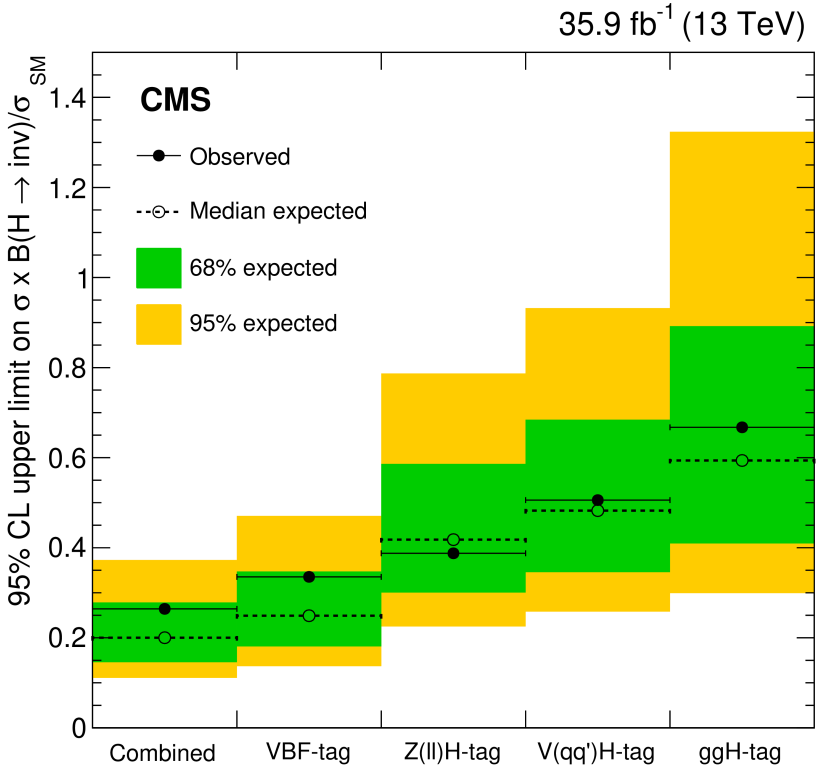
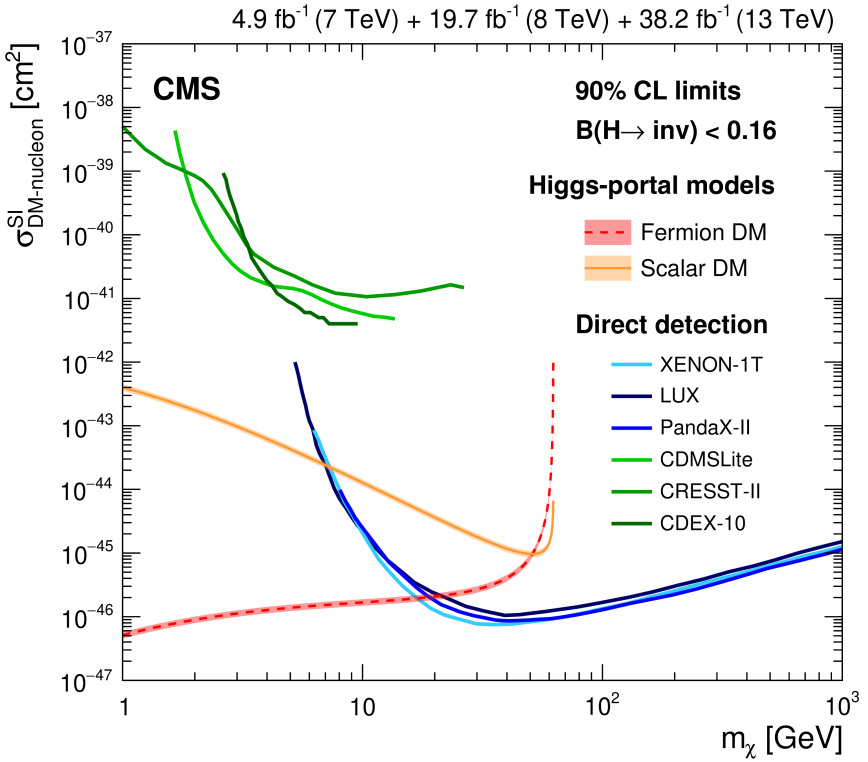
- Analyses targeted on specific production modes
  - Higgs → DM interpretations possible
- great progress recently, still room for more
- BR(H→inv) < 19% @95%CL
- limited to $m_{DM} < m_H / 2$
- LHC limits complementary to direct detection experiments.





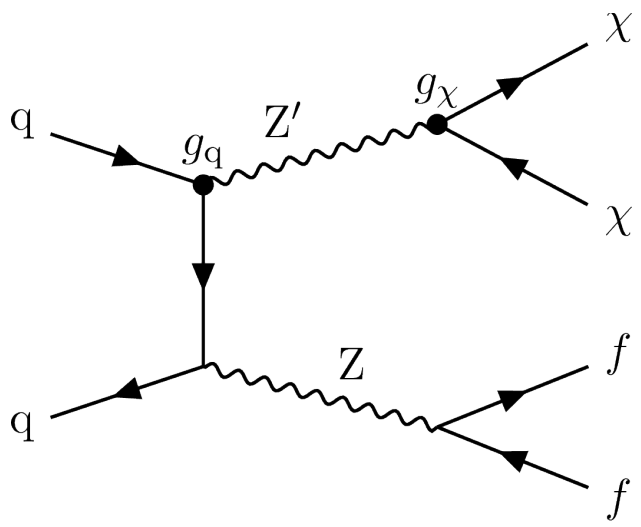


Future Prospects

The High Luminosity LHC Upgrade

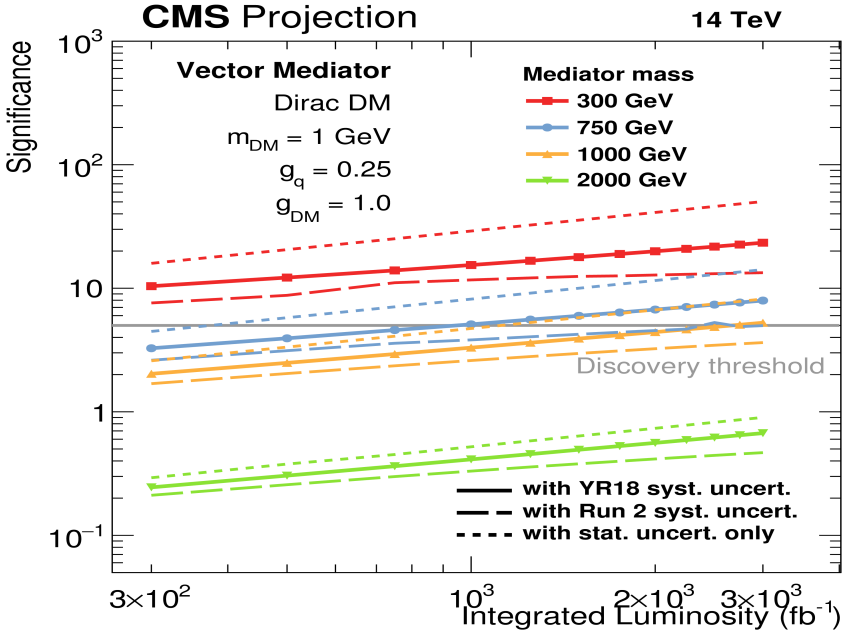
- The High Luminosity LHC (HL-LHC), approved project, represents the ultimate evolution of LHC machine performance
- Operation at up to instantaneous luminosity of $L = 7.5 \times 10^{34}$ Hz/cm^2 (LHC Run-II: 2×10^{34} Hz/cm^2) to collect up to 3000 fb^{-1} of integrated luminosity

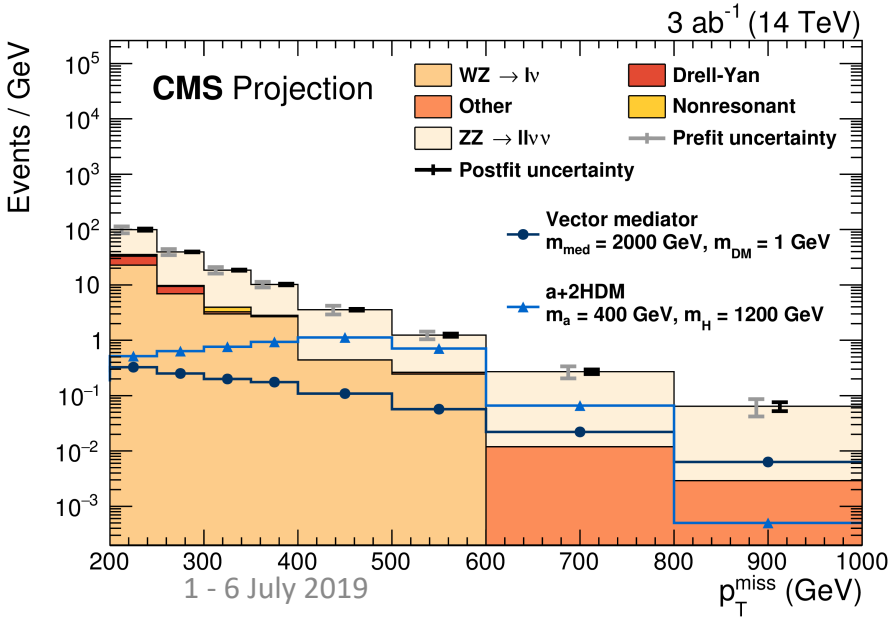
Projection of the Mono-Z search for dark matter to the HL-LHC

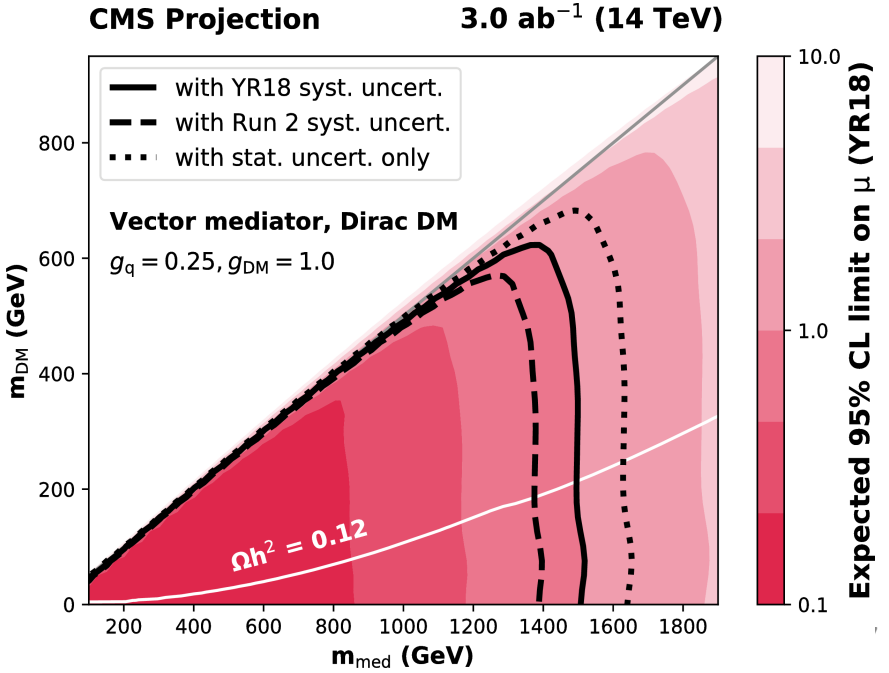


CMS-PAS-FTR-18-007

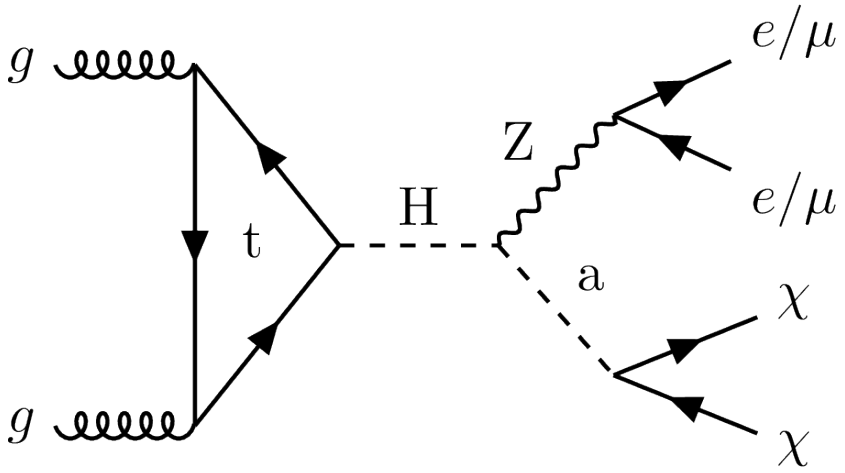
- Simplified model: minimal scenario with one new mediator boson Z' and one new DM Dirac fermion
- A signal with a mediator of mass 750 GeV could be discovered with 1 /ab, while a heavier mediator of 1 TeV would require 3 /ab.
- Assuming an integrated luminosity of 3 ab−1, it will be possible to probe vector-mediated DM production up to values of the mediator mass of approximately 1.5 TeV







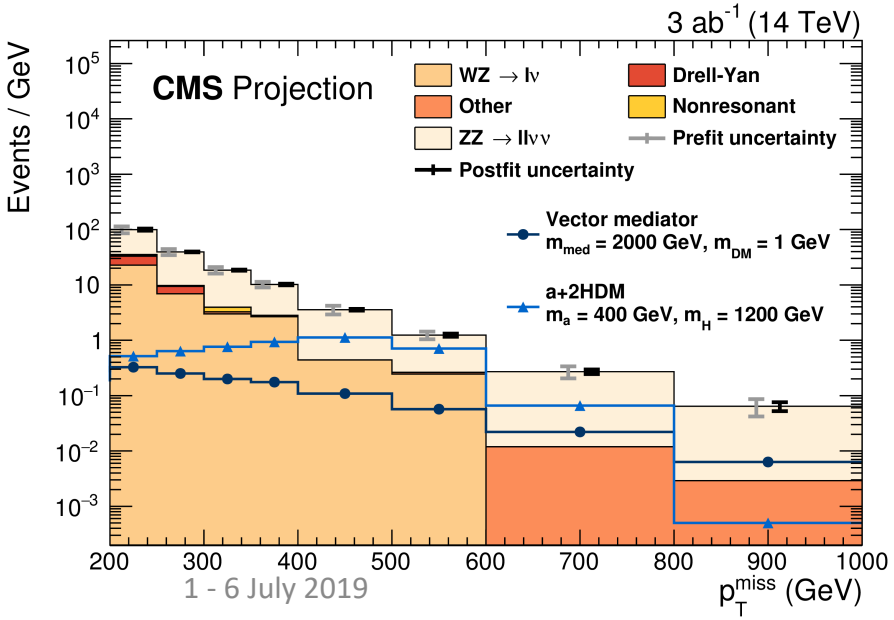
Projection of the Mono-Z search for dark matter to the HL-LHC

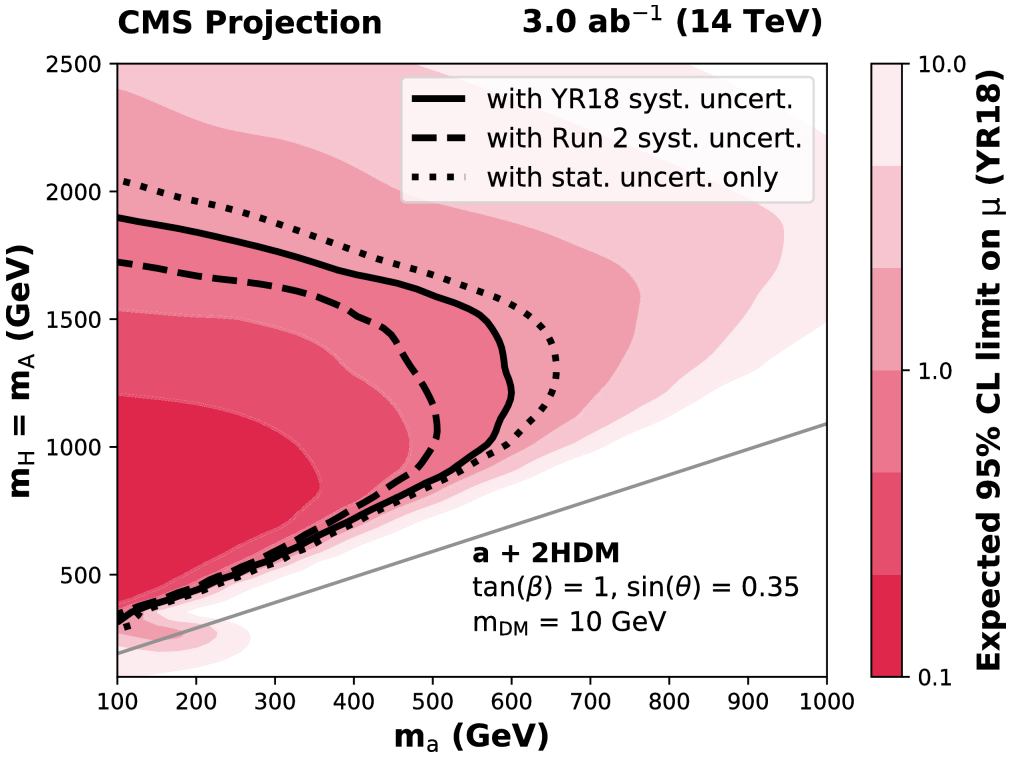


CMS-PAS-FTR-18-007

- 2HDM+a model: the DM particle candidate is a fermion that can couple to SM particles only through a spin-0, pseudoscalar mediator (a)

- In the 2HDM+a model, light pseudoscalar masses up to 600 GeV and heavy boson masses up to 1.9 TeV will be probed.





Summary

- Dark Matter searches at LHC are complementary to indirect and direct searches
- Broad search programme at the LHC
  - Wide variety of signatures (Invisible/visible/SUSY/Long lived etc)
  - No significant discrepancies wrt Standard Model predictions

- Future prospects:
  - Presented analyses is based on 2016 data
  - Full Run2 analysis are in progress
  - Projections to $3ab^{-1}$ at HL-LHC studied

Thanks