Dark Matter at the LHC

LHC days in Split

September 17th-22nd, Split

Pablo Martínez Ruiz del Árbol

On behalf of the CMS, ATLAS and LHCb Collaborations

Instituto de Física de Cantabria

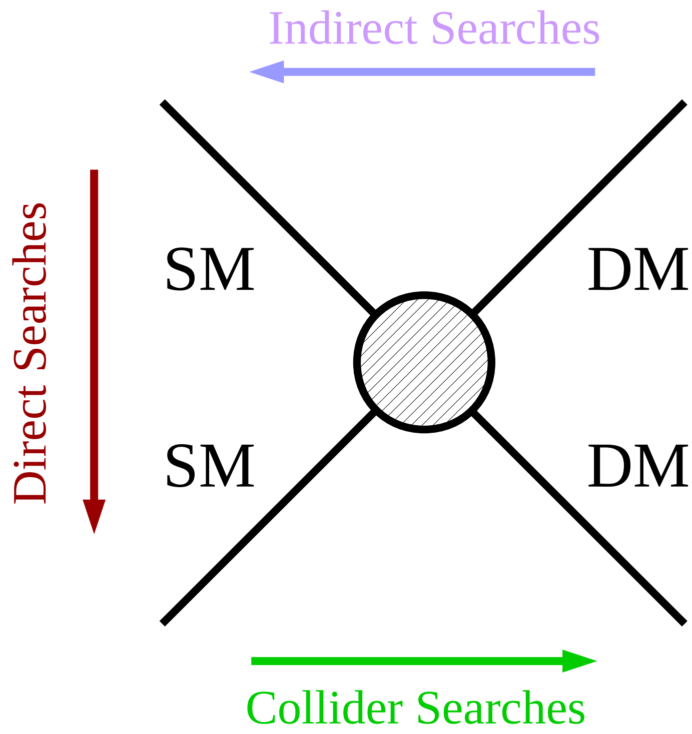
CMS Compact Muon Solenoid

ATLAS EXPERIMENT

LHCb

Dark Matter searches in colliders

- The nature of **Dark Matter** (DM) remains nowadays one of the misteries of the universe.
- If DM interacts beyond gravity we should observe **new phenomena** in various experiments.
- A very week interaction might require **all of them** to provide an observation or discovery.



- Disclaimer: Showing just a selection/summary of results, use the links for more information.

The LHC: a marvellous machine

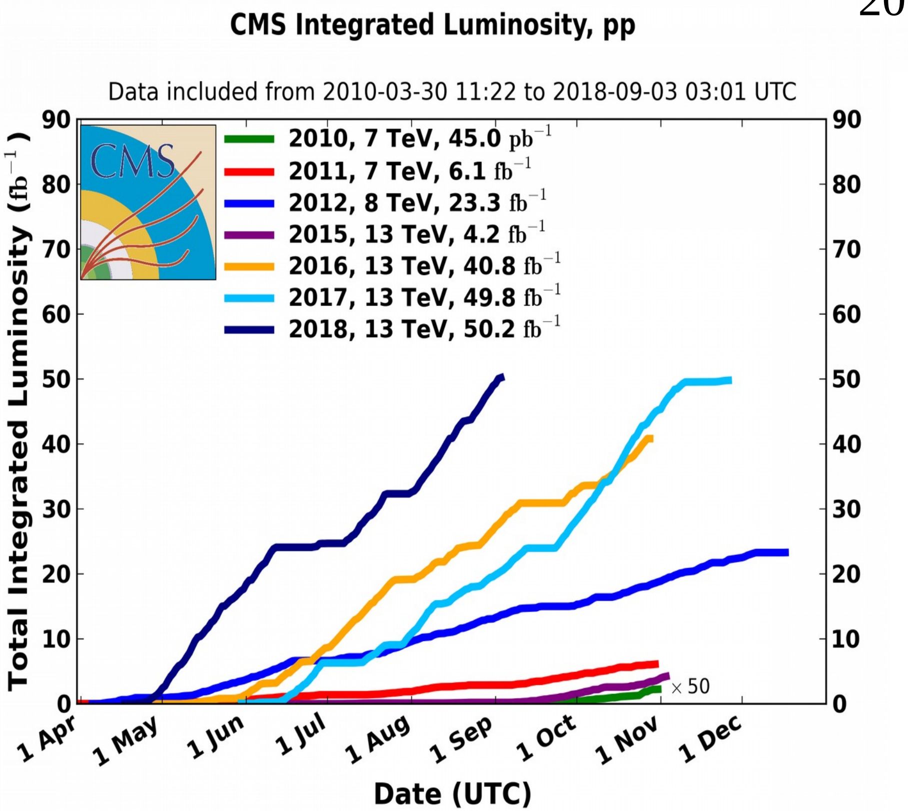
- The LHC has shown a superb performance since the beginning of the data taking in 2010.

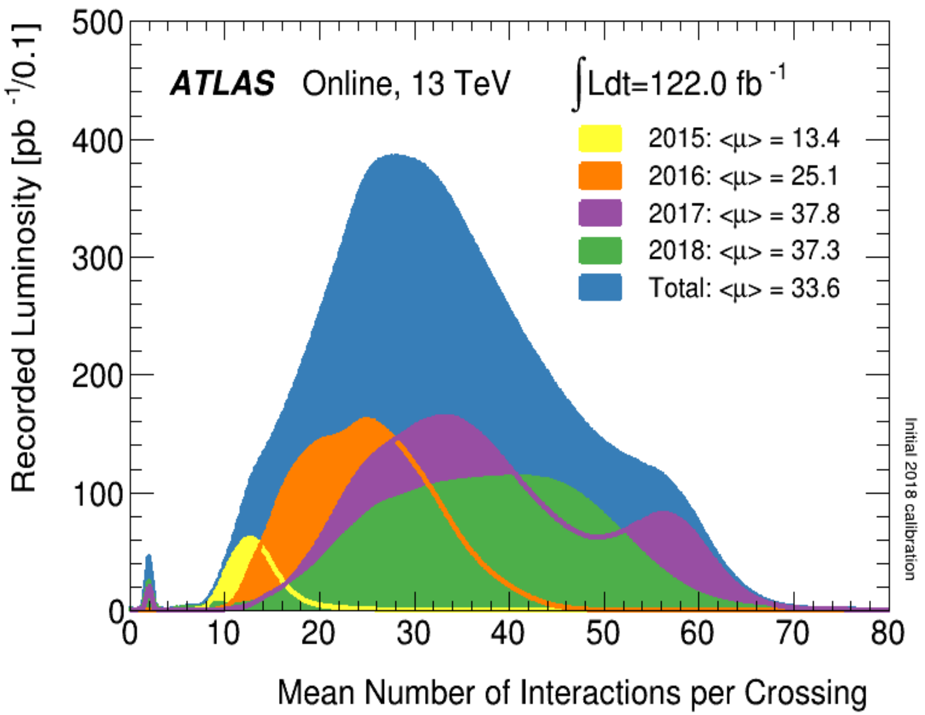
Run 1 (√s = 7-8 TeV)

2010-2012 ~ 30 fb^{-1}

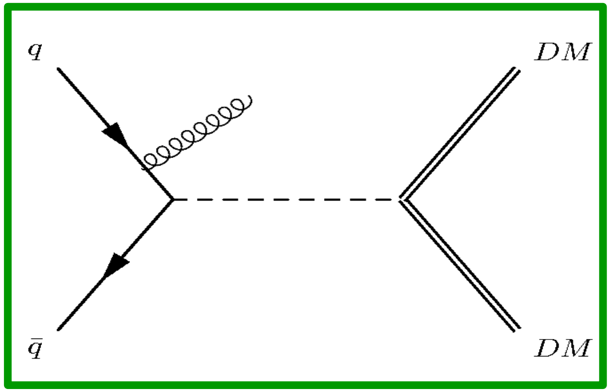
Run 2 (√s = 13 TeV) In this talk

2015 ~ 4 fb^{-1} 2016 ~ 40 fb^{-1} 2017 ~ 50 fb^{-1}
2018 ~ 50 fb^{-1}(expect 60 fb^{-1})



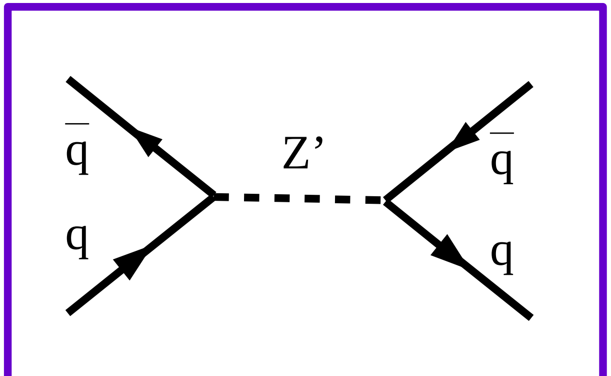


Looking for DM at colliders



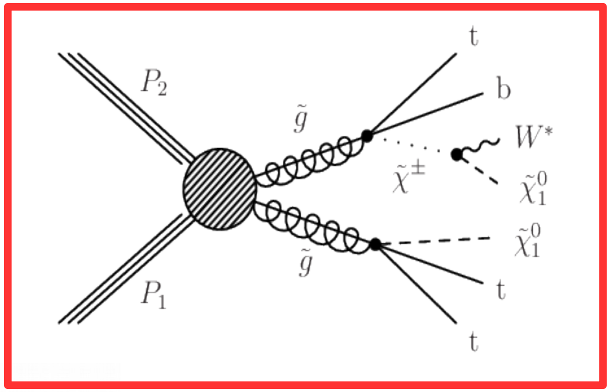
Direct production of DM

- SM object back-to-back to the missing momentum.
- Mono-X searches: DM + ISR gluons, photons, W, Z and H.
- DM in association with heavy flavour (top, top-antitop, bb).



Mediator resonances and offshell.

- A mediator decaying finally into SM products.
- Dijet resonances: low and high mass, narrow and broad.
- Dimuon mass spectra: dark photons.

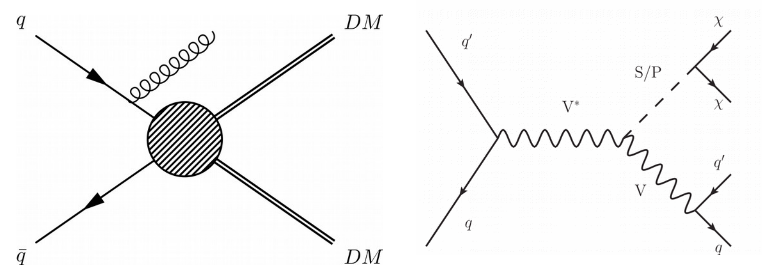


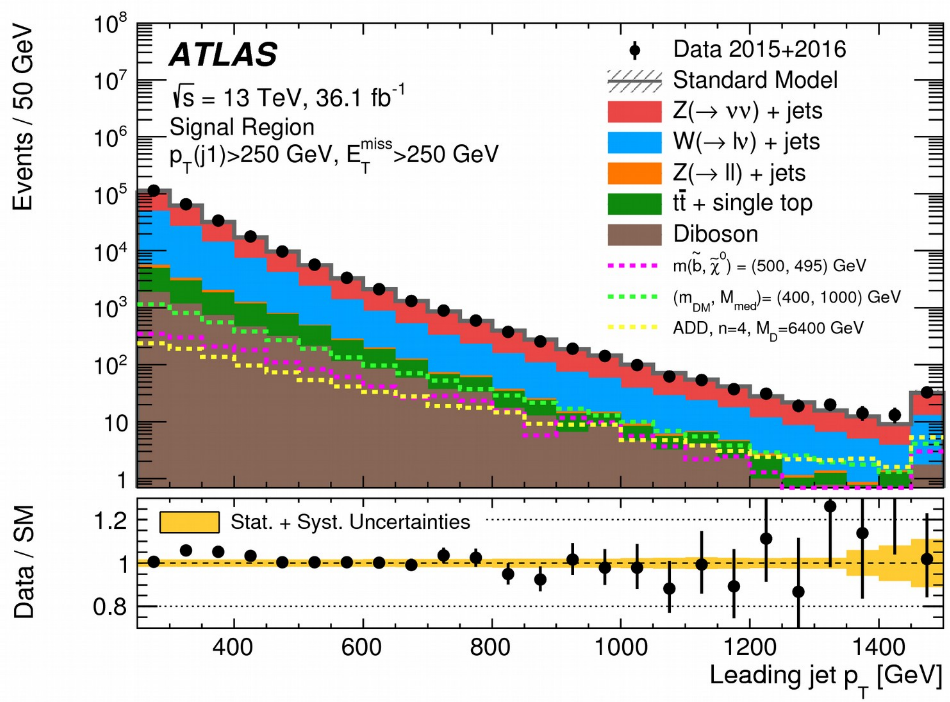
Long decay chains: SUSY like

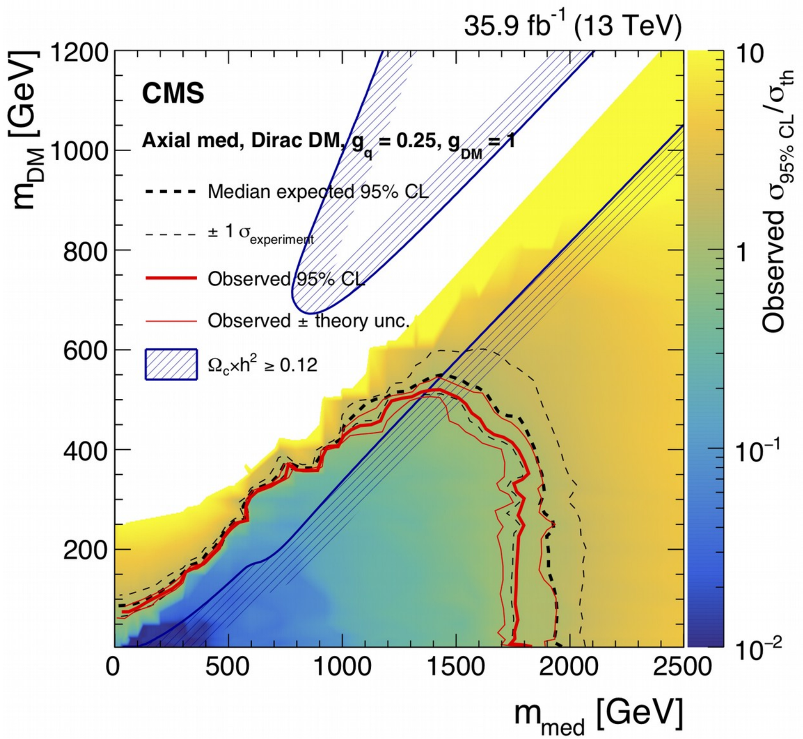
- R-parity conserved → DM candidate with SM products.
- Strong production: gluinos, squarks, stops.
- EWK production: chargino/neutralino, sleptons, staus.

Monojet signatures: gluon, Z, and W

- DM produced in association with one gluon, W, or Z decaying hadronically.
- Jet back-to-back with missing momentum.
- Typical backgrounds are $Z(\rightarrow \nu\nu)$+jets and W+jets.
- Use of AK4 and AK8 jets (for boosted W and Z).





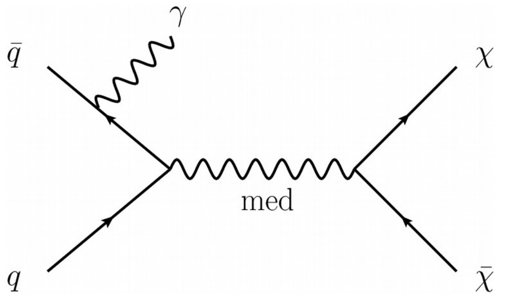


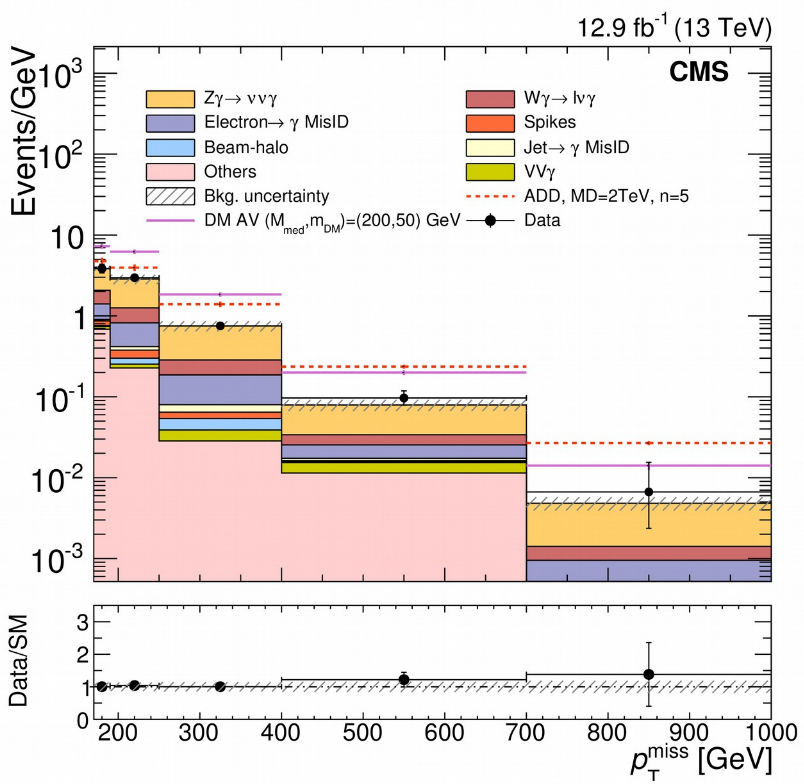
JHEP01(2018)126

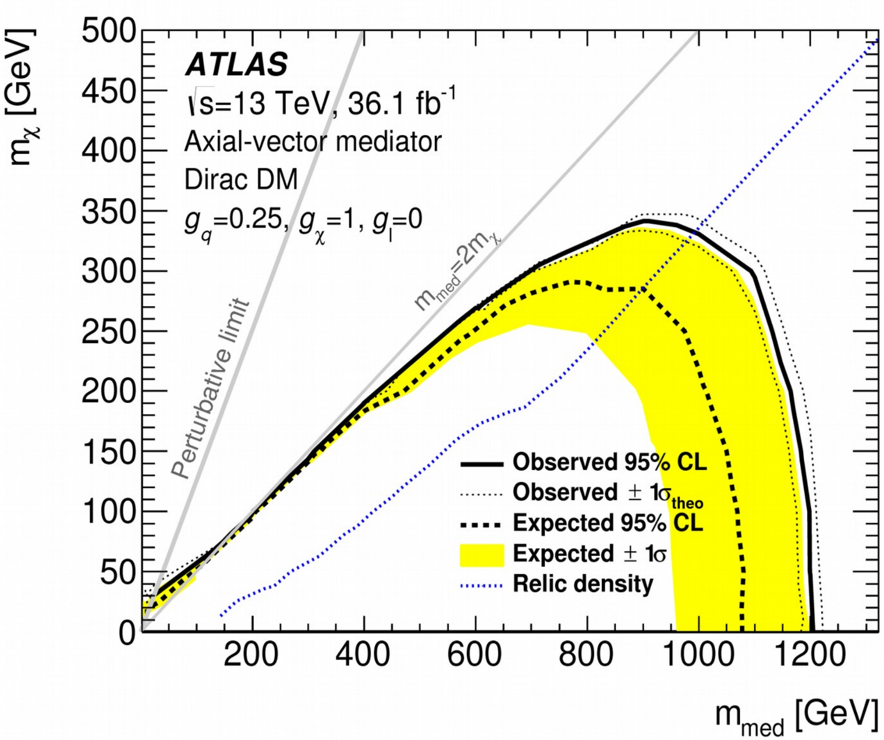
PhysRevD.97.092005

Mono photon signatures

- DM produced in association with one very energetic photon.
- Similar to previous search but with photon instead of jet.
- Main backgrounds are Z(→υυ)+gamma and W(→ lυ)+gamma.





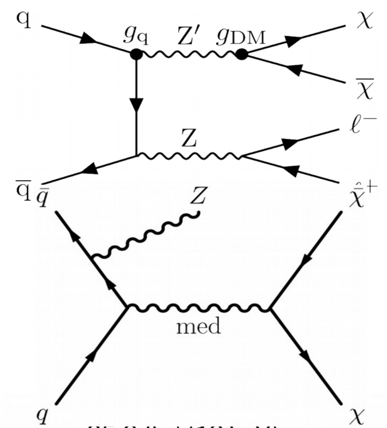


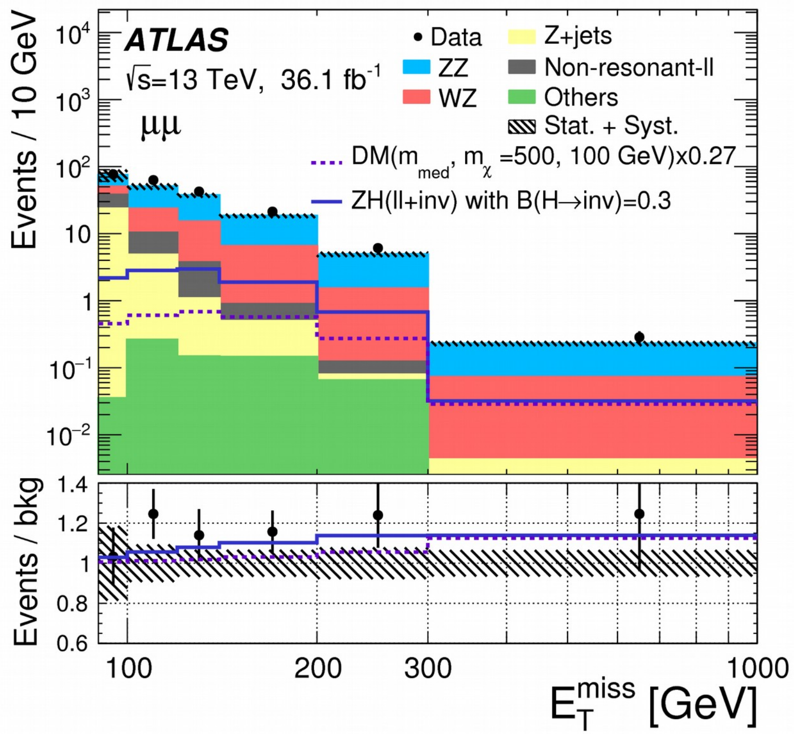
JHEP10(2017)073

epjc/s10052-017-4965-8

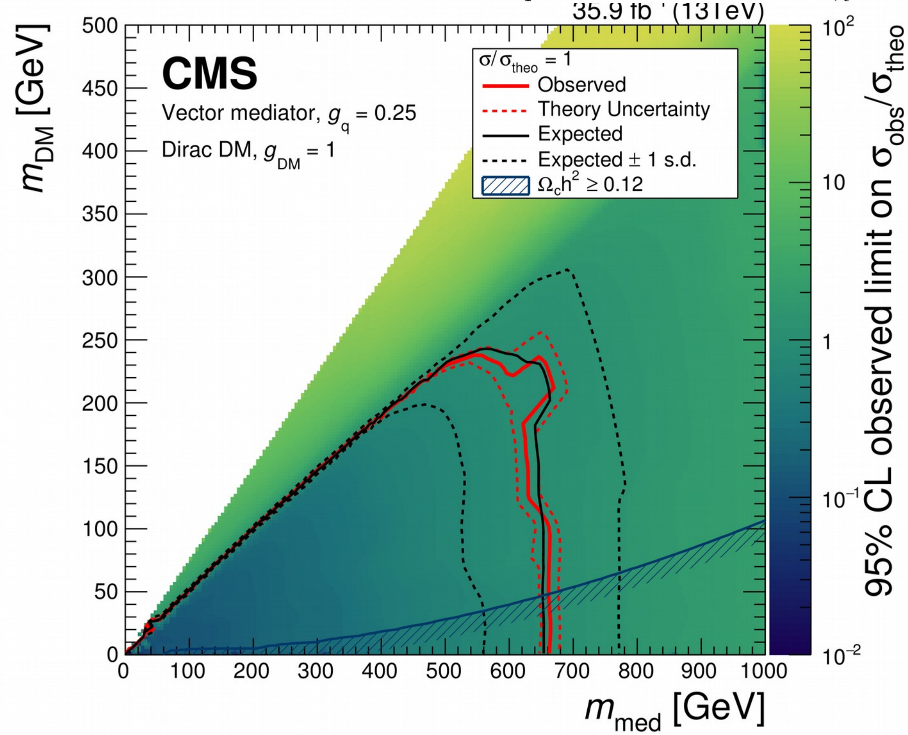
Mono Z in the dilepton channel

- DM produced in association with a Z boson decaying into leptons.
- Main backgrounds ZZ(→ υυ) and WZ(→ ll) contributions.
- Constraint to the Z mass reduces the non-resonant lepton background.
- Able to use lepton triggers → lower MET thresholds.





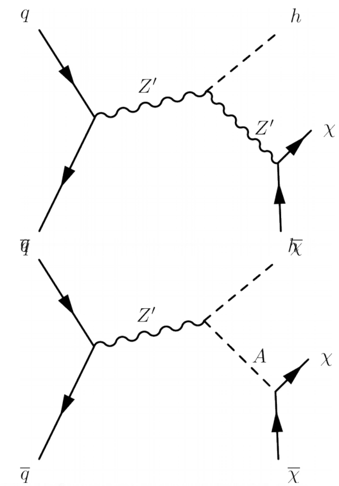
PLB 776 (2017) 318

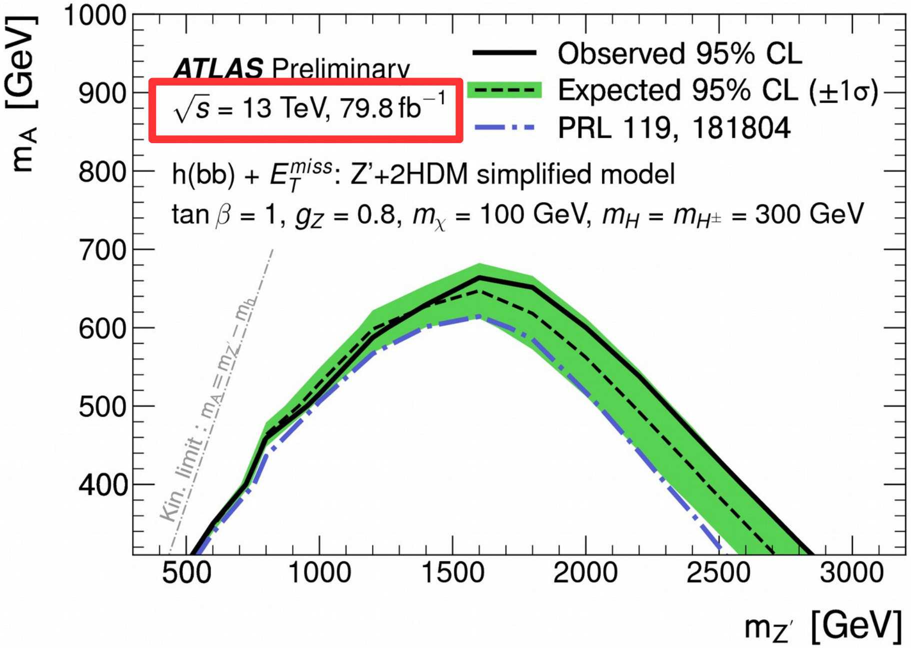


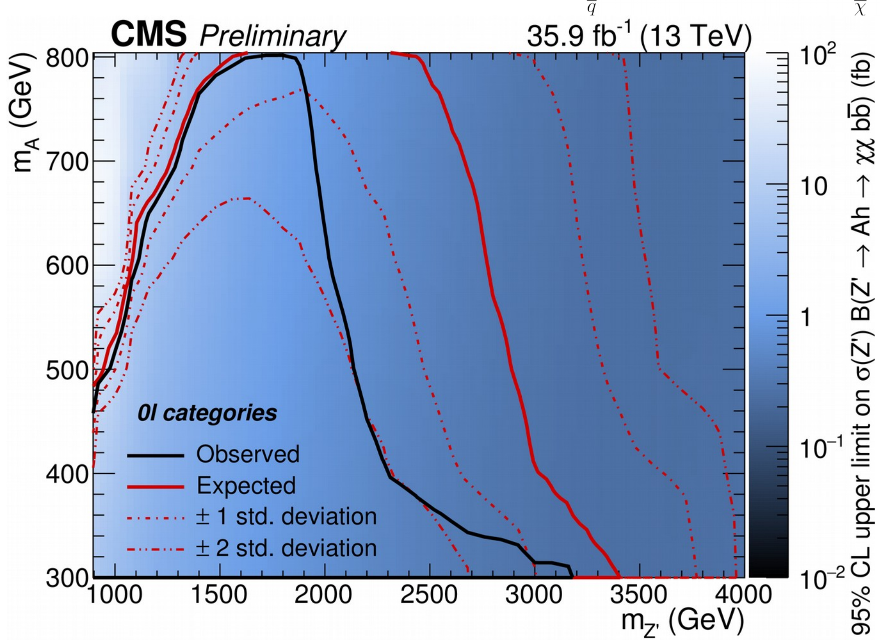
epjc/s10052-018-5740-1

Mono Higgs signatures

- DM produced in association with a Higgs boson.
- Several analysis according to decay: H → bb, ττ, γγ, WW (soon).
- Imposing constraint on the mass of the Higgs boson.
- Dominated by H → bb where backgrounds are Z(nunu) and W(lnu) + jets.
- Interpreted in the 2HDM and Z' barionic models.





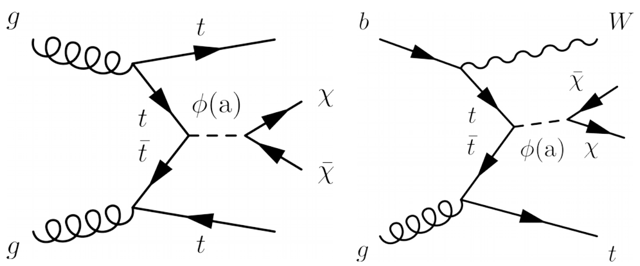


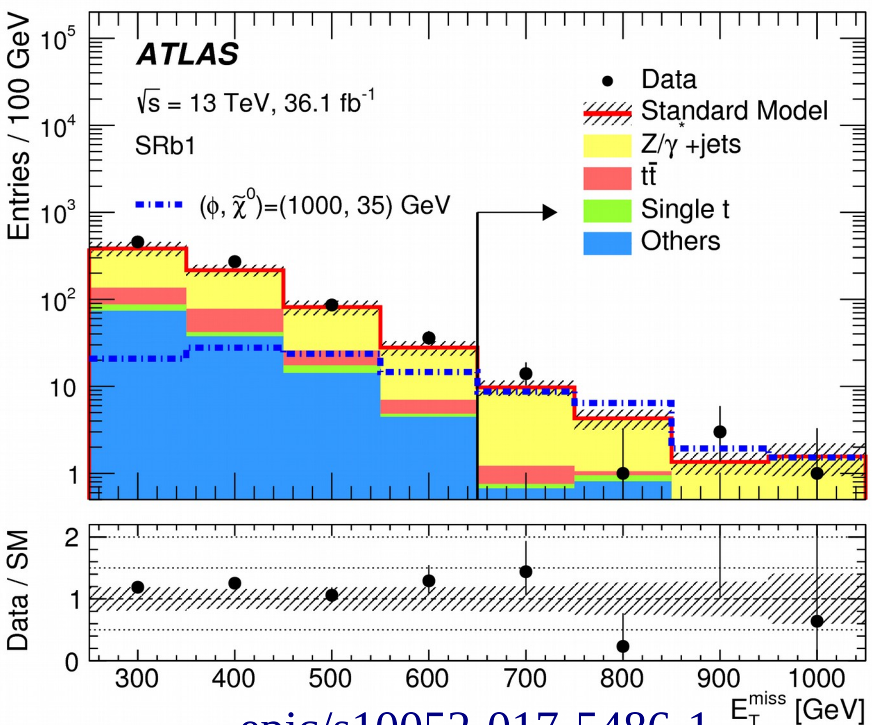
ATLAS-CONF-2018-039

CMS-PAS-B2G-17-004

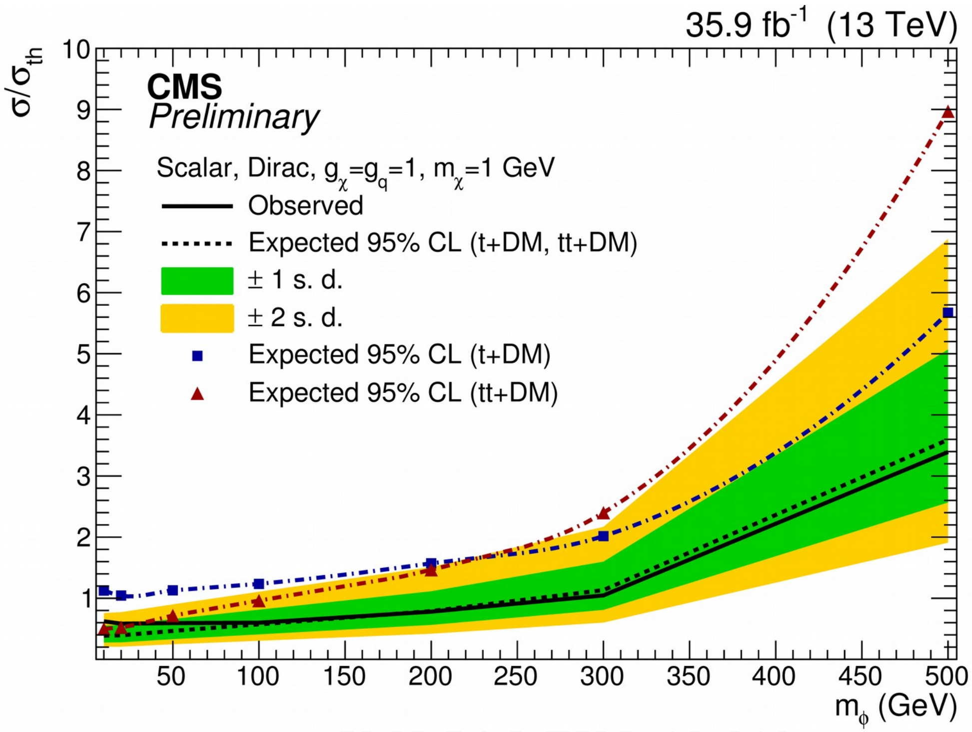
DM in association with 1(2) top(s)

- DM produced in association with pairs of top or single top.
- Exploring the different top decays: 0, 1, and 2 leptons.
- Interpreted in terms of scalar and pseudoscalar mediators.
- Exclusion of scalar mediators up to 250 GeV approximately.





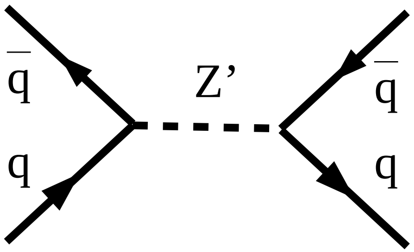
epjc/s10052-017-5486-1



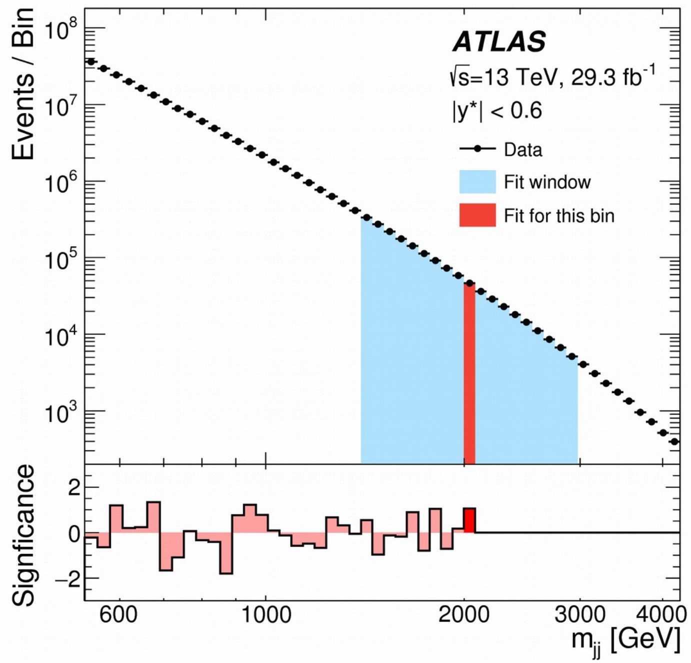
CMS-PAS-EXO-18-010
arXiv:1807.06522

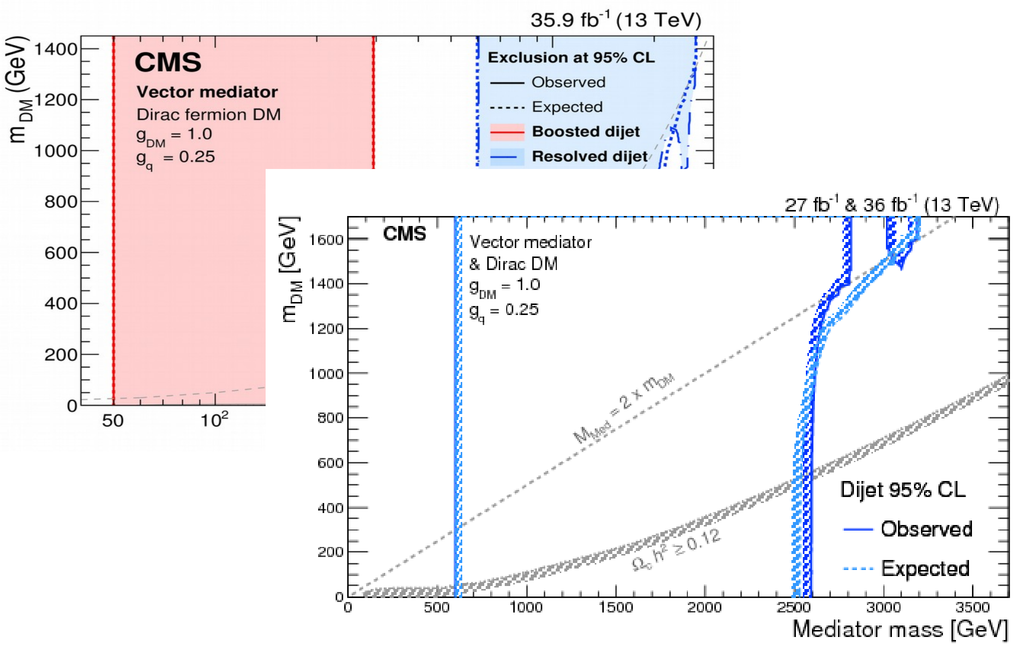
Dijet resonances

- Dijet resonances provide a powerful handle to constrain DM interaction cross section.
- Background is SM QCD: fitting signal shapes over a background model.
- Exploring low and high masses with narrow and broad resonances.
- Low mass analysis using trigger objects to reduce pt thresholds.



JHEP01820189097



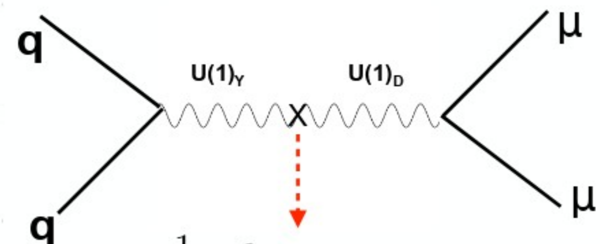


PhysRevLett.121.081801

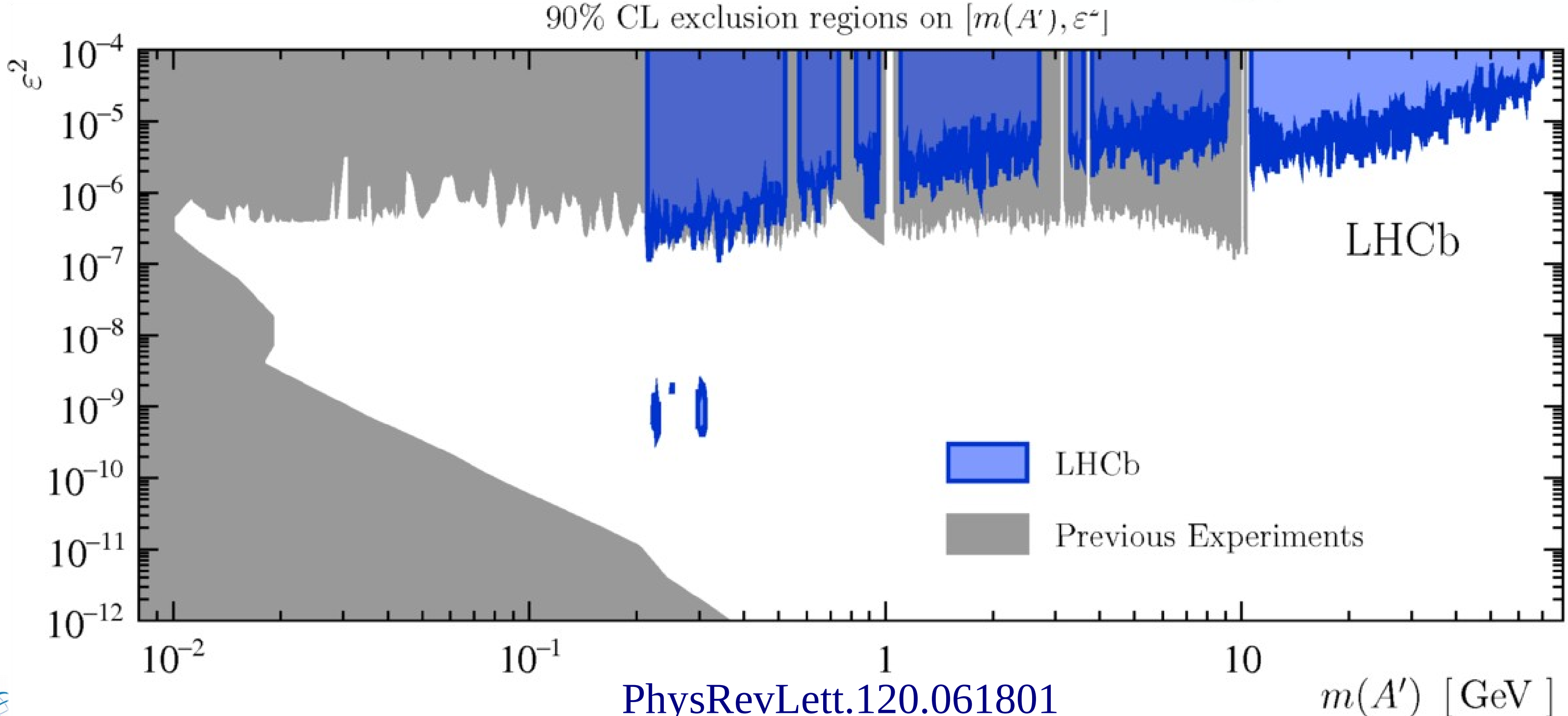
arXiv:1806.00843

DM dark photons

- Search for kinetic mixing with the offshell photon in the dimuon channels.
- Analysis with 1.6 fb^{-1} at 13 TeV.
- First limits above 10 GeV on m(A').
- Also a displaced search with lower pt muon thresholds.



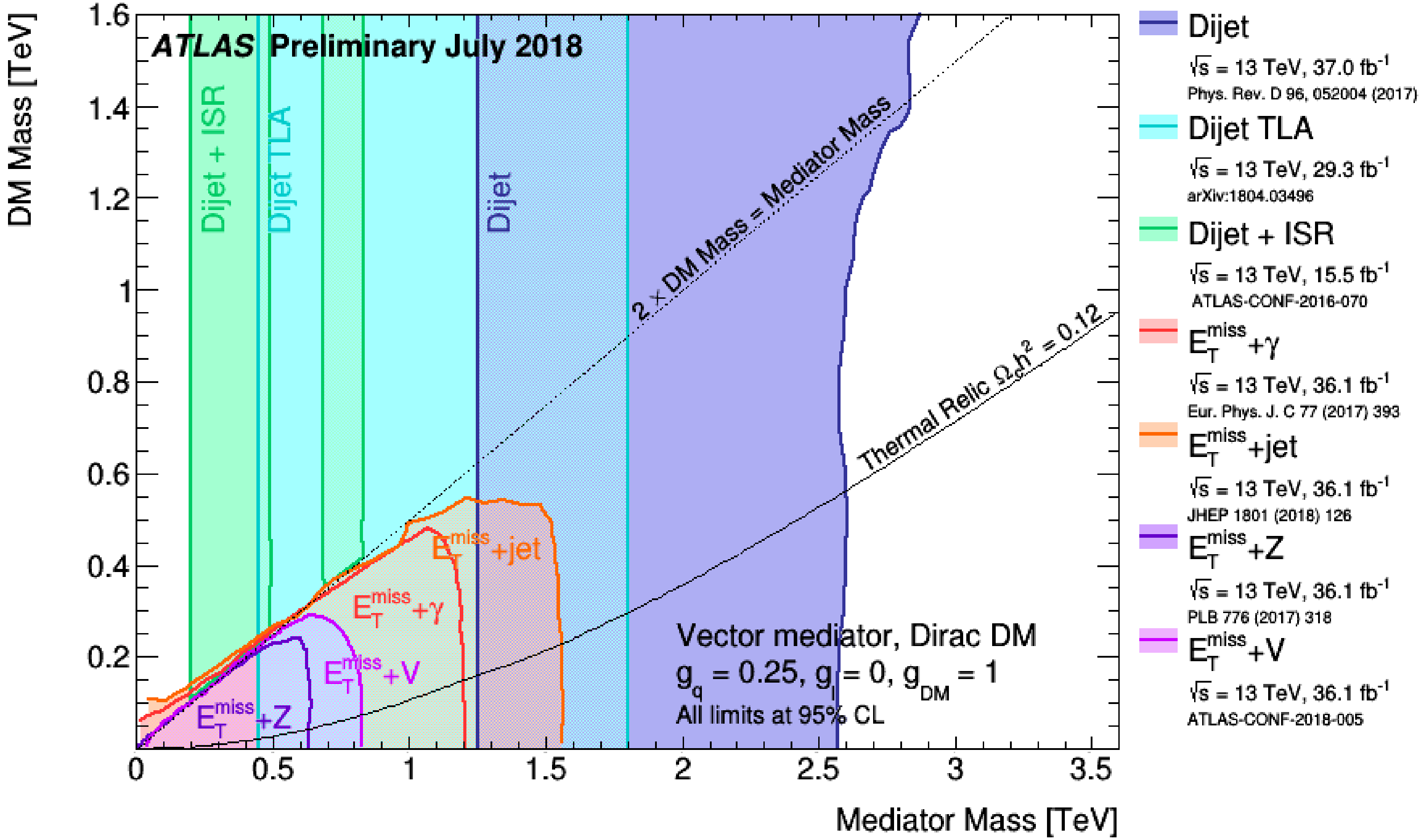
$$\frac{1}{2}\frac{\epsilon}{\cos\theta}\hat{Z}_{D\mu\nu}\hat{B}^{\mu\nu}$$



PhysRevLett.120.061801

Putting all together

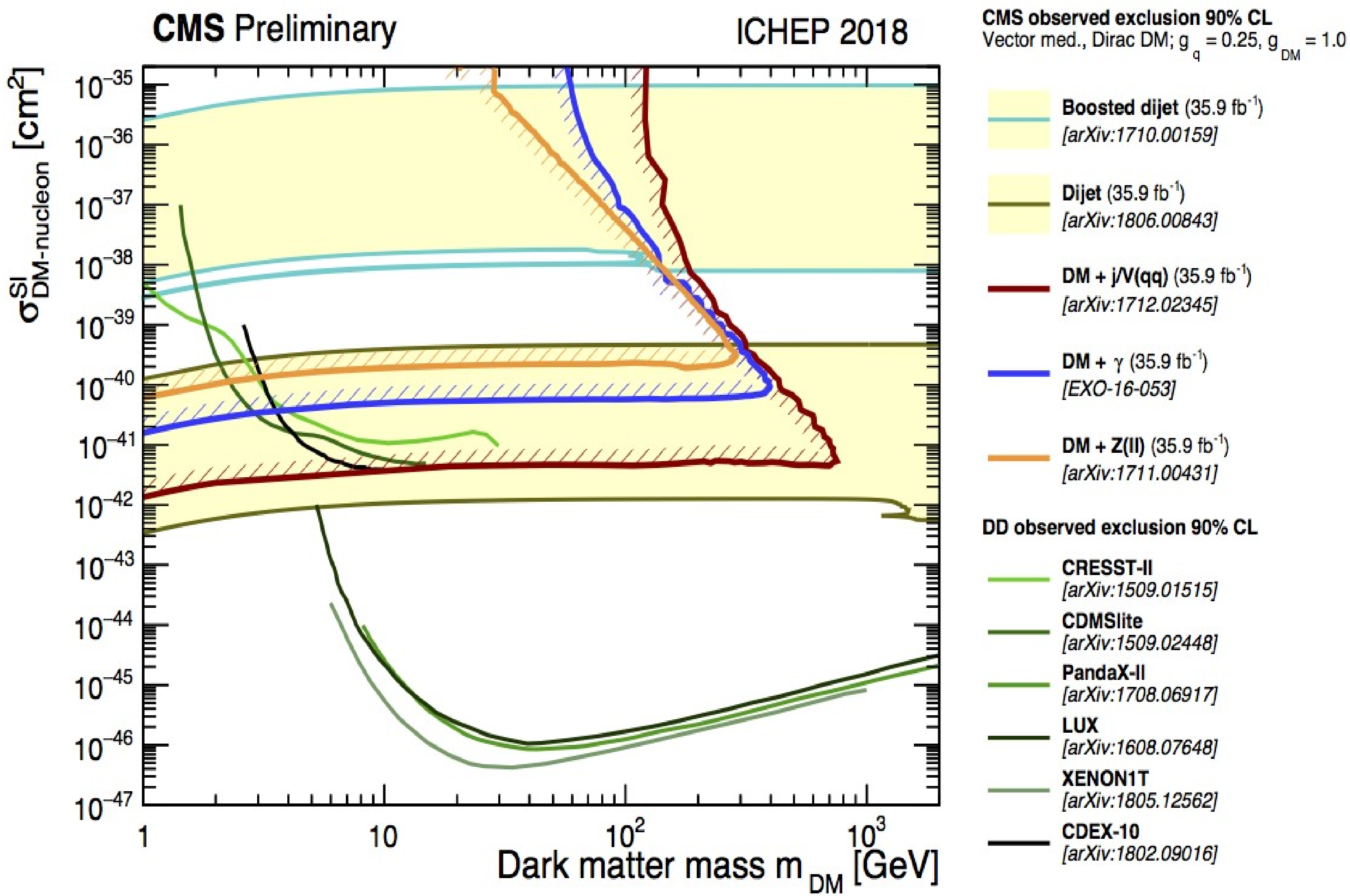
- Dijet resonances dominates the exclusion for both vector and axial-vector mediators.
- Both vector and axial-vector mediators excluded up to ~ 2.5 TeV.



Check backup for axial-vector results.

Comparison with other experiments

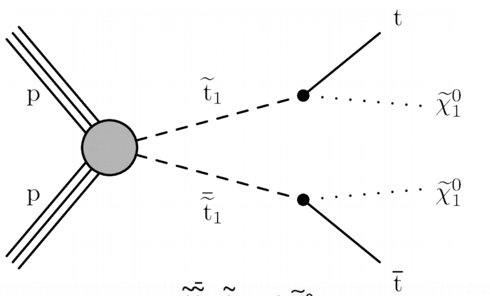
- Fixing the limits on the couplings allows to translate xsections into DM production xsections.

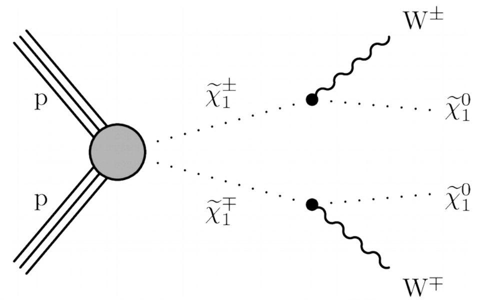


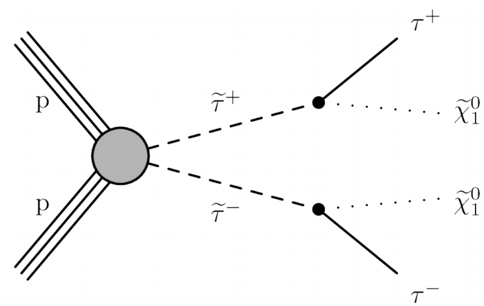
Check backup for scalar and axial-vector results.

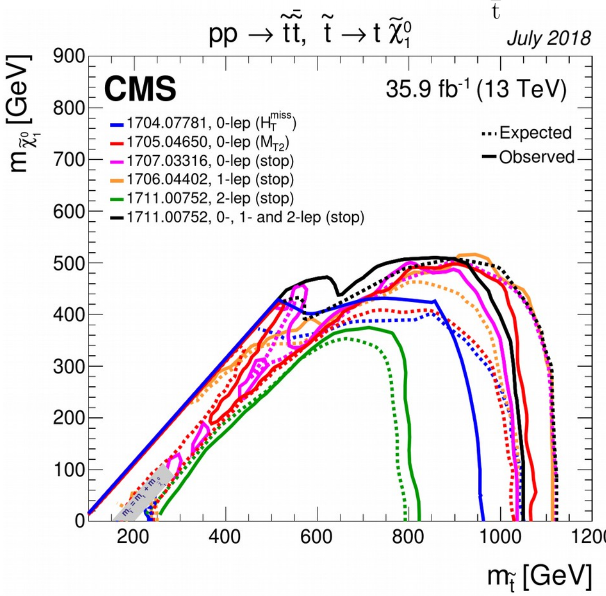
SUSY-like results

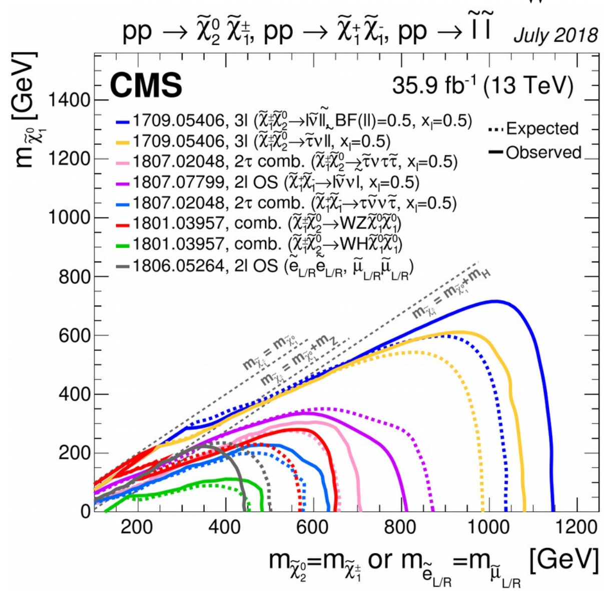
- Assuming R-parity is conserved SUSY models provide candidates for DM (LSP).
- Experiments have a quite large program of SUSY searches in many different topologies.
- MET is still a key ingredient but in these searches there are also many SM particles. .

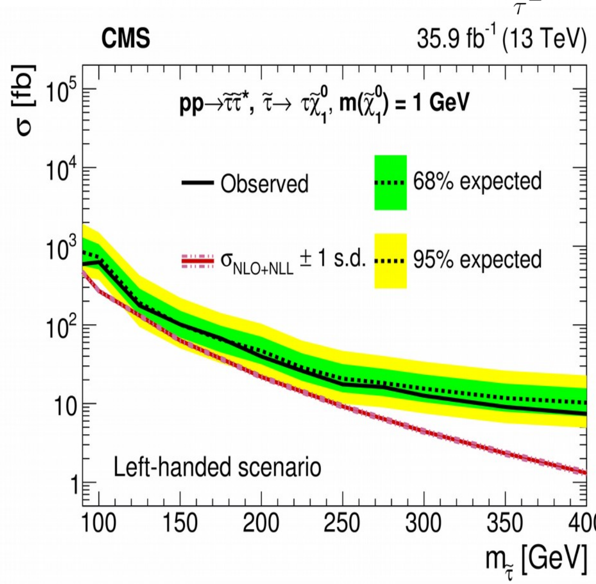






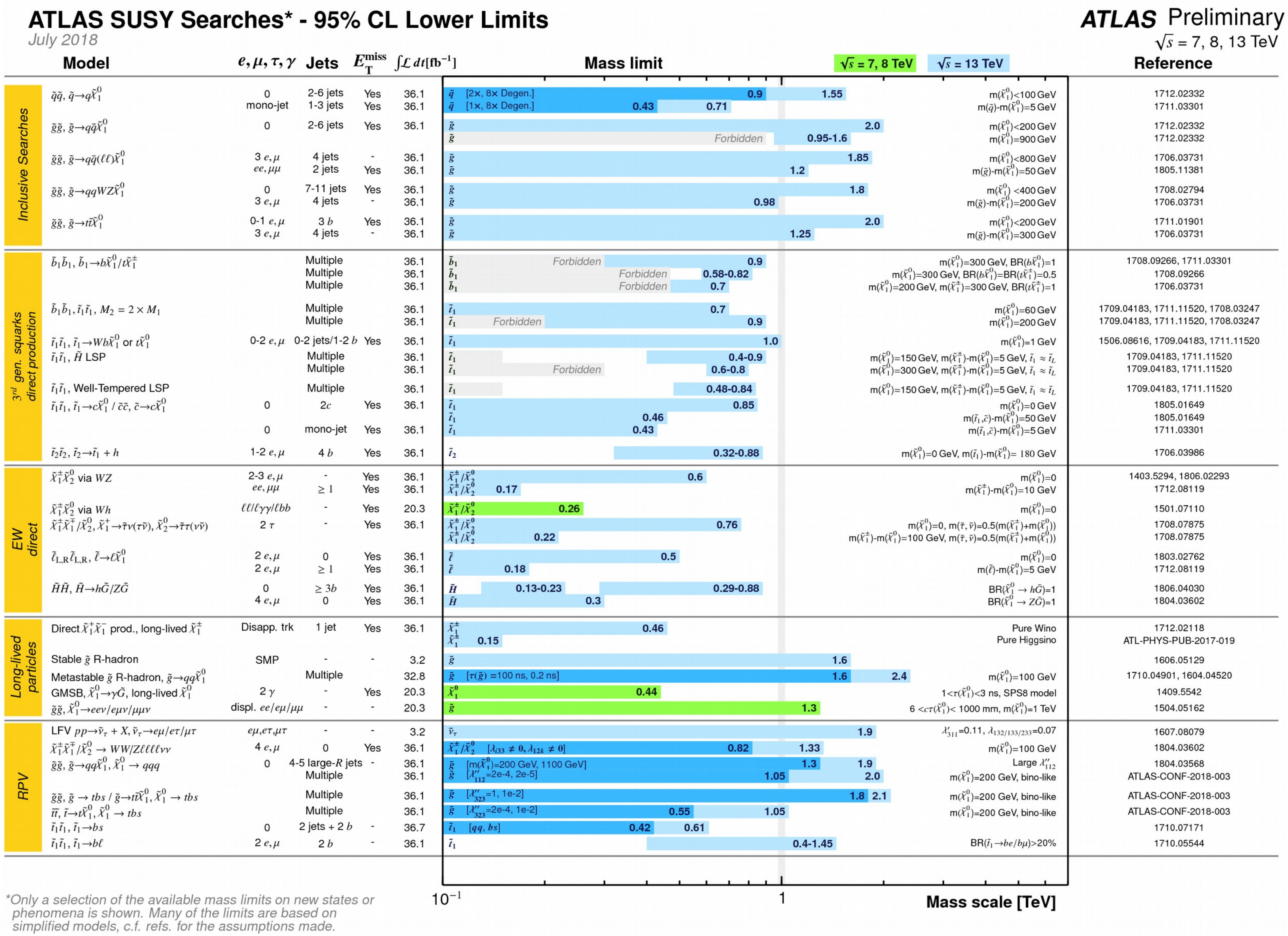






arXiv:1807.02048

SUSY results



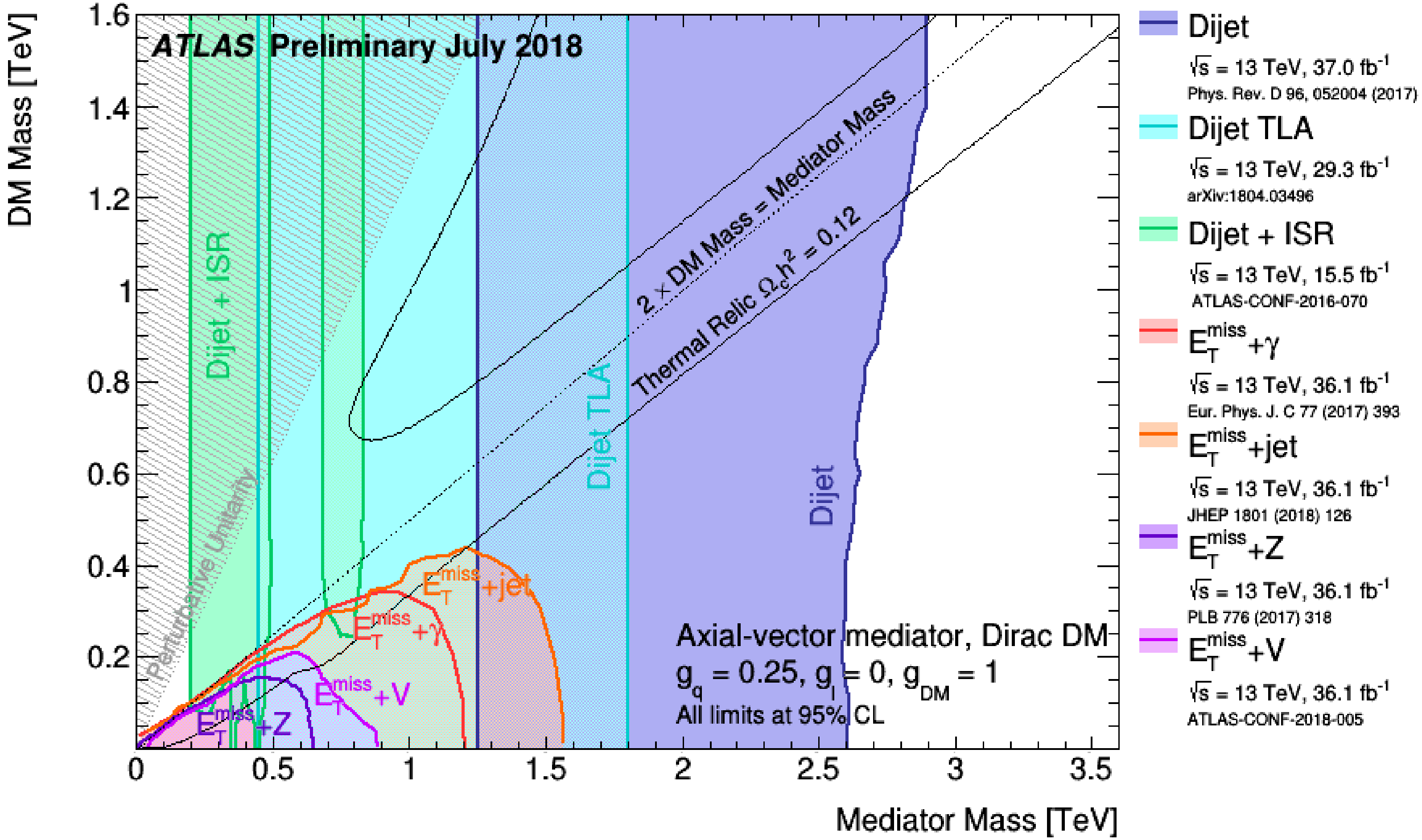
Conclusions

- The experiments at the LHC have very broad and ambitious DM search program.
- This is possible thanks to the superb performance of the LHC machine.
  - Run 2 will end up with up to 150 fb^{-1} most of it still to be analyzed.
- Unfortunately no evidence of a signal found so far.
- But increasing luminosity will allow better limits in the time to come (or discovery!).
  - Specially for vector and axial-vector mediator models.
- Interest is also turning now on searches for long-lived particles.
  - This kind of tolopologies require dedicated reconstruction techniques.
- A lot of new results will come in the next months. Stay tuned!

Backup

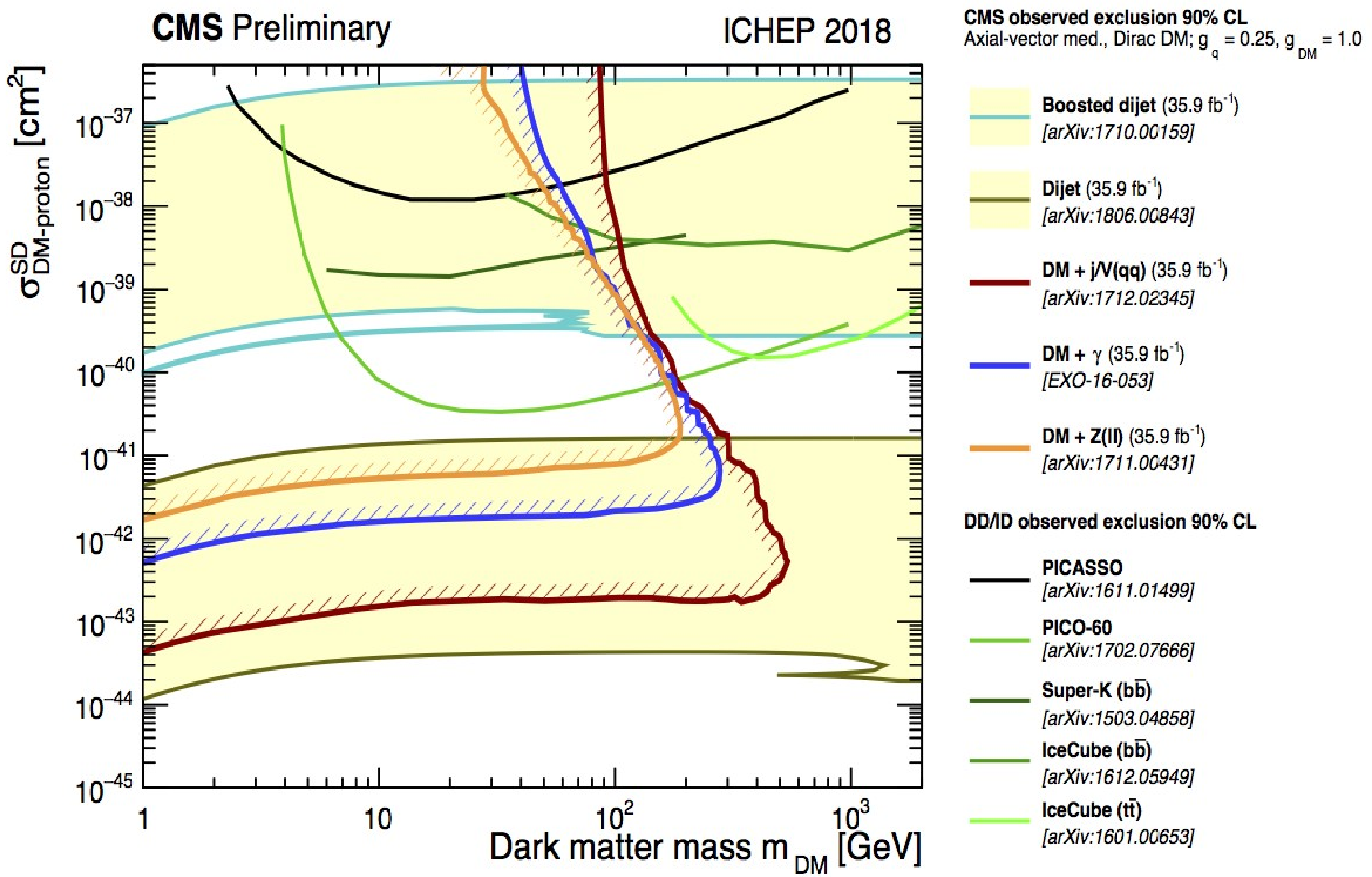
Putting all together

- Dijet resonances dominates the exclusion for both vector and axial-vector mediators.
- Both vector and axial-vector mediators excluded up to ~ 2.5 TeV.



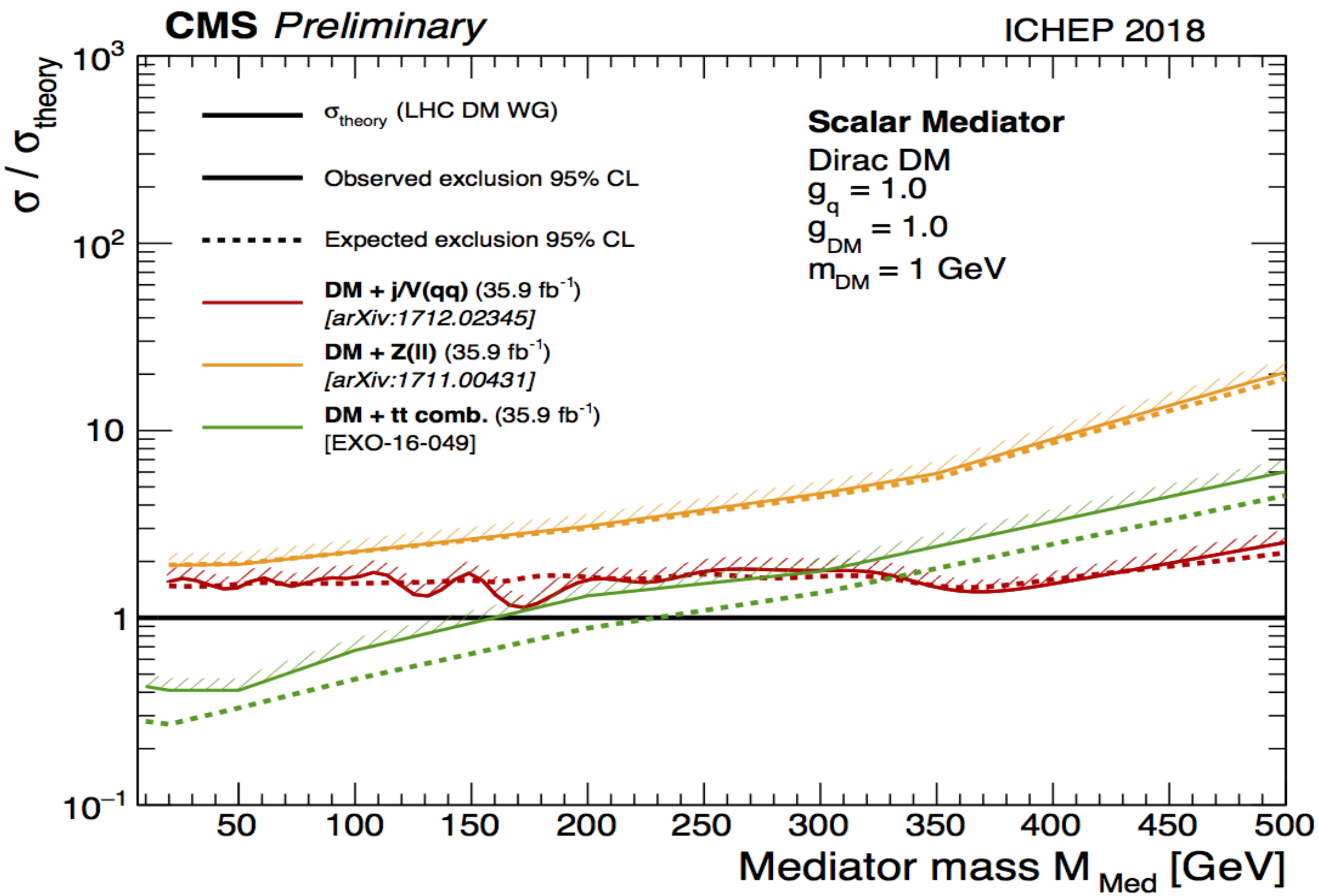
Comparison with other experiments

- Fixing the limits on the couplings allows to translate xsections into DM production xsections.



Comparison with other experiments

- Fixing the limits on the couplings allows to translate xsections into DM production xsections.



Comparison with other experiments

- Fixing the limits on the couplings allows to translate xsections into DM production xsections.