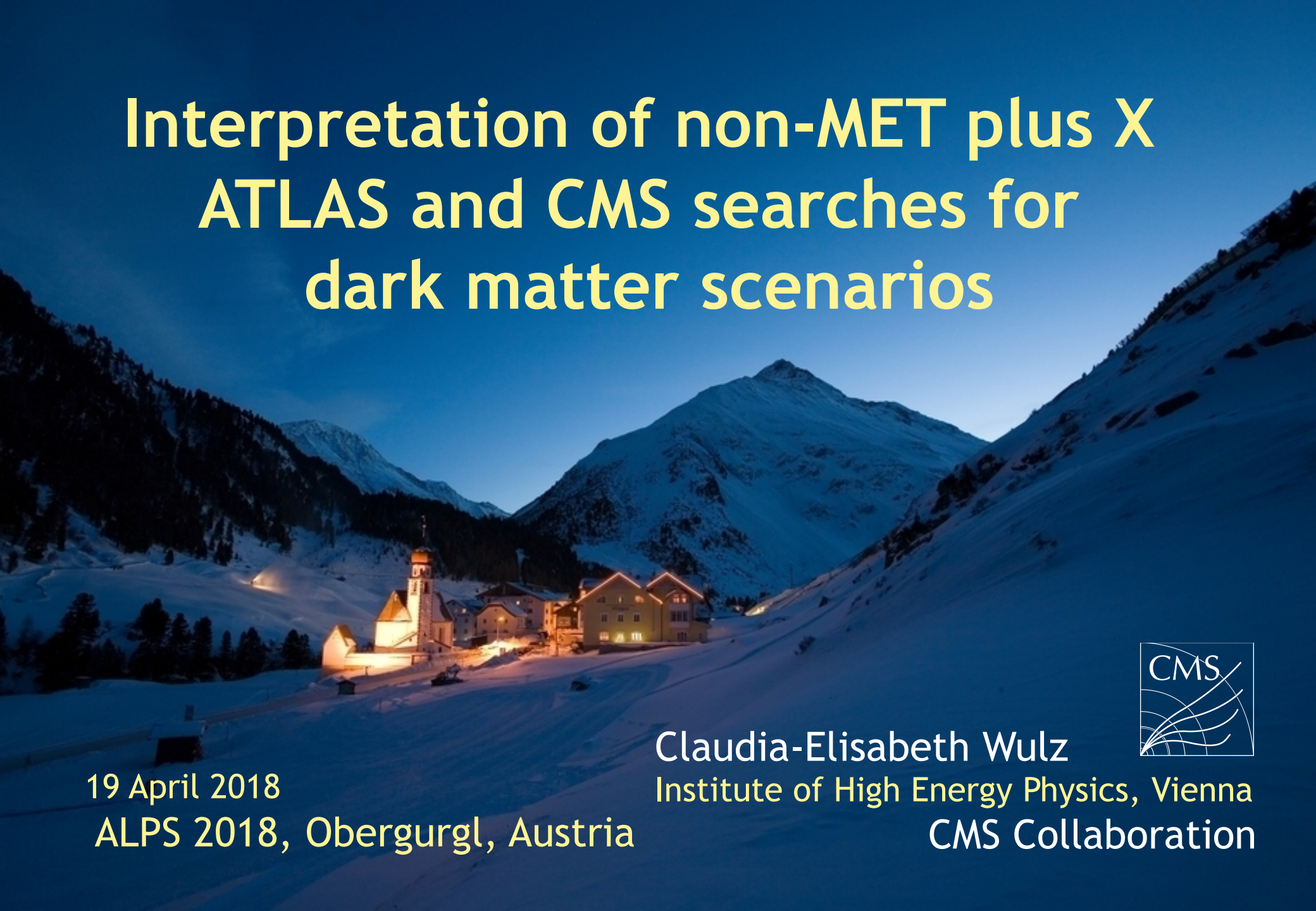
Interpretation of non-MET plus X ATLAS and CMS searches for dark matter scenarios



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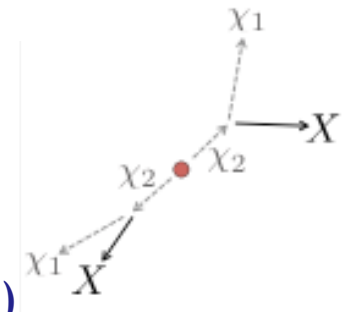
19 April 2018
ALPS 2018, Obergurgl, Austria

Dark Matter searches in non-MET channels

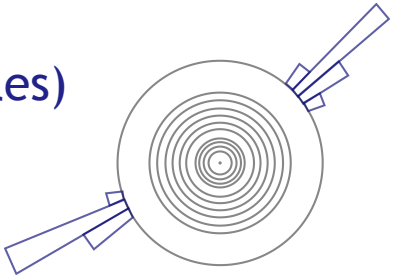
At colliders:

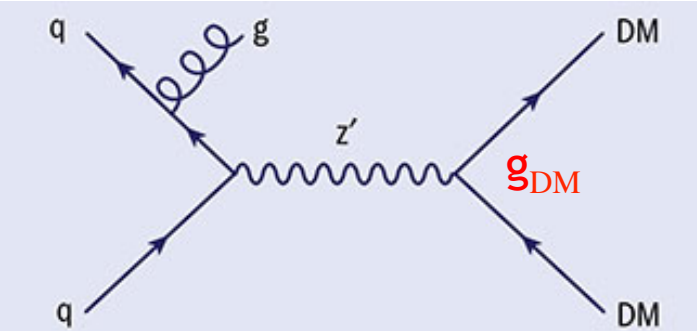
- dark matter (DM) searches conventionally target WIMPs in channels with missing transverse energy (MET)
  - "mono-X" searches (X = q, g, γ, W, Z, h, t, tt, bb, …)
  - displaced DM (long-lived particles, e.g. χ_2 from heph-ph 1704.06515)
- dilepton and dijet non-MET searches extend discovery range
- trackless jets targeting SIMPs (strongly interacting DM particles)

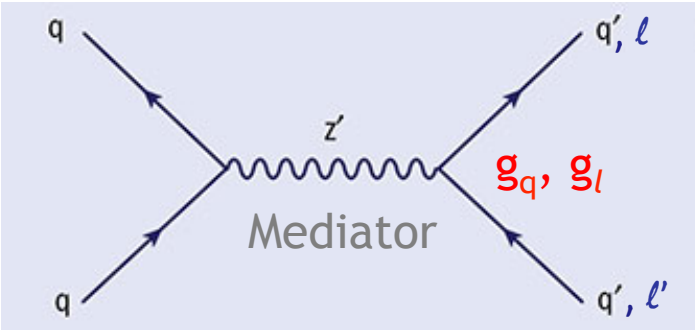


Production at the LHC:

- through decays, e.g. LSP in SUSY cascades
- direct, e.g. through Higgs or Z' portal







DM parameters: DM particle and mediator masses, couplings, type of interaction (scalar, pseudoscalar, vector, axial-vector, tensor)

Dileptons in model with spin-1 mediator

CMS search for high-mass vector or axial vector SM-DM mediator

CMS-EXO-16-047
hep-ex 1803.06292

5 parameters define production/decay rates of mediator and event kinematics: m_{DM}, m_{Med}, g_{DM}, g_l, g_q

Benchmark couplings illustrating complementary strengths of dilepton/dijet analyses:

- vector mediator: $g_{DM} = 1$, $g_q = 0.1$, $g_l = 0.01$
- axial-vector mediator: $g_{DM} = 1$, $g_q = g_l = 0.1$

Electron selection:

- isolated electromagnetic clusters with $p_T > 35$ GeV and $|\eta| < 1.44$ or $1.57 < |\eta| < 2.50$
- at least one electron must be in barrel region to reduce QCD background
- dielectrons need not be oppositely charged

Muon selection:

- isolated muon tracks with $p_T > 50$ GeV and $|\eta| < 2.4$

Backgrounds: estimated from simulation (except fake leptons from QCD jets)

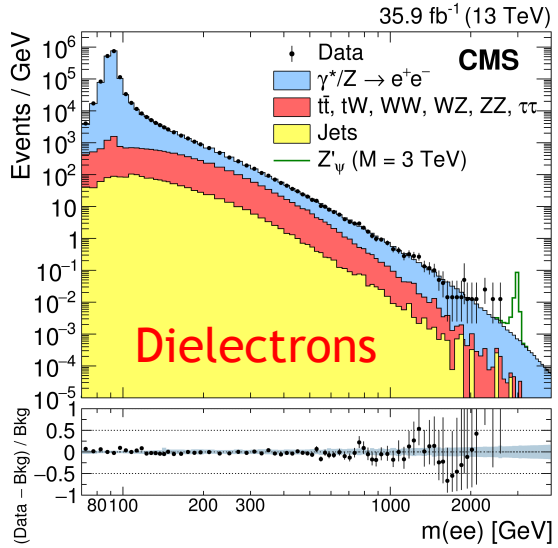
Drell-Yan (dominant)

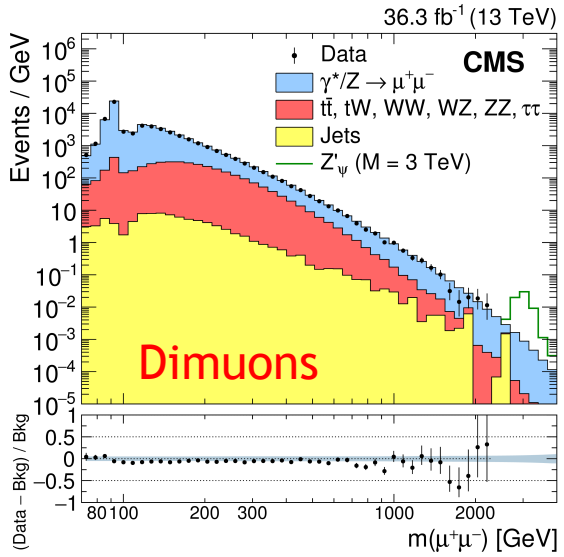
Photons radiated from incoming protons $\gamma\gamma \rightarrow l^+l^-$ (included in DY NNLO K-factor)

Leptons from tt, tW, WW, WZ, ZZ, $\tau^+\tau^-$

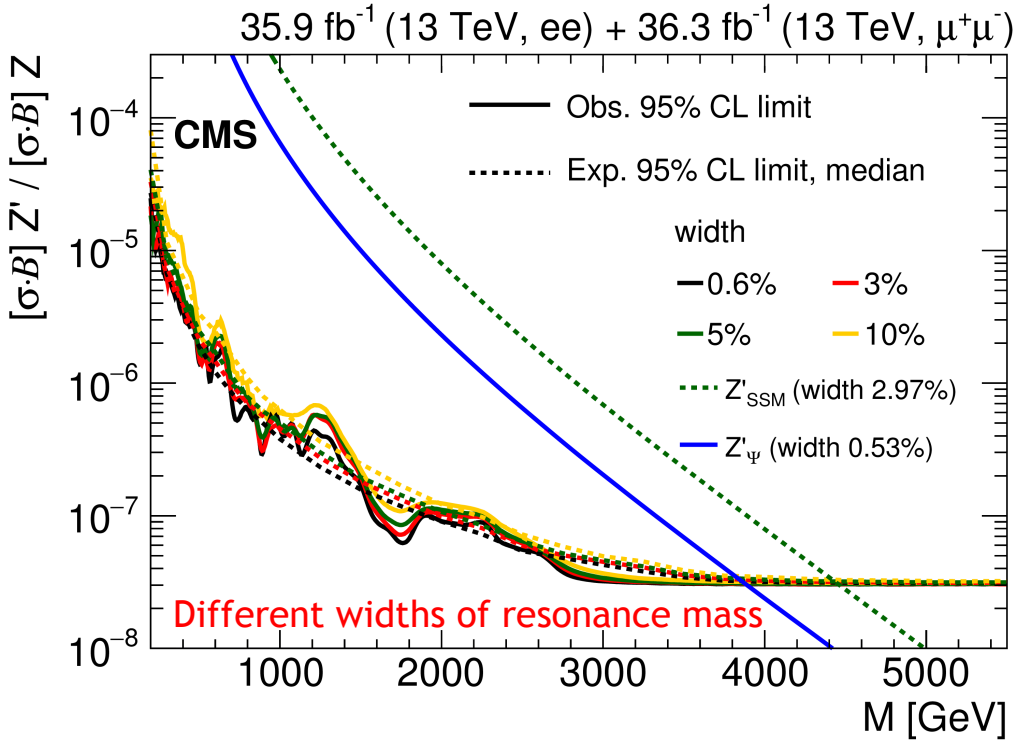
QCD jets faking leptons

Dileptons in model with spin-1 mediator





CMS-EXO-16-047, hep-ex 1803.06292



Z' production cross section x branching fraction relative to Z boson

Z' mass limits: $M(Z'_{SSM}) > 4.5$ TeV, $M(Z'_\psi) > 3.9$ TeV

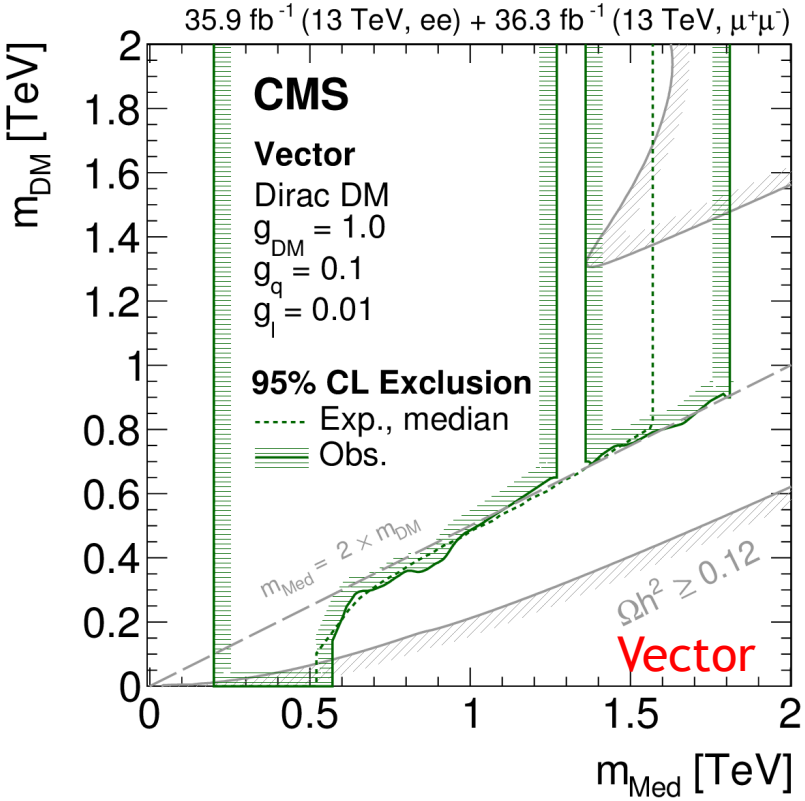
Similar limits have been obtained by ATLAS

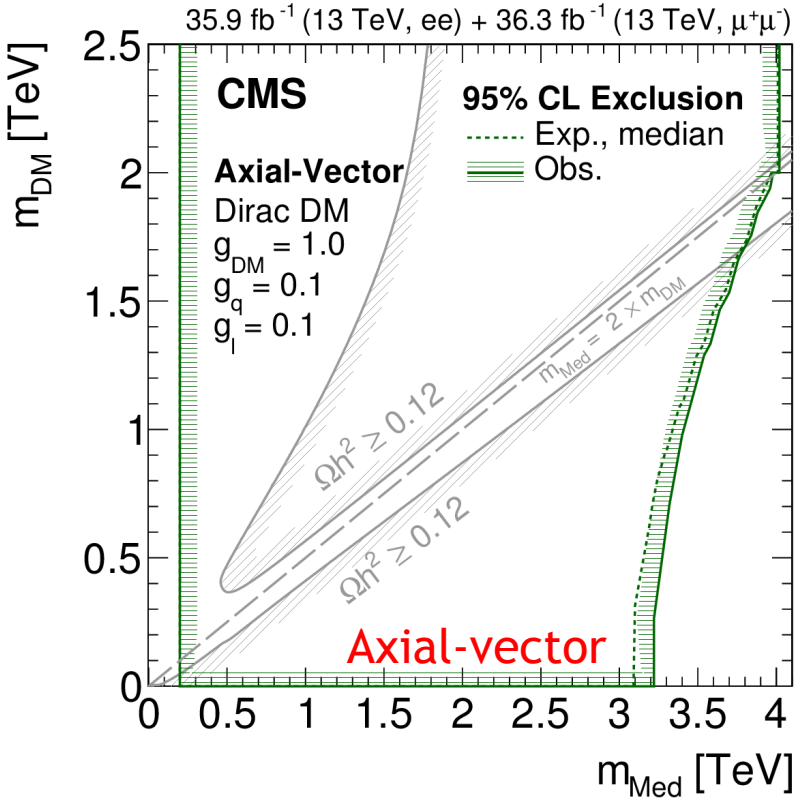
hep-ex 1707.02424

Dileptons in model with spin-1 mediator

CMS-EXO-16-047, hep-ex 1803.06292

$m_{DM} > m_{Med}/2$: mediator cannot decay to DM, leptonic branching fraction sizable
Vector -> small lepton branching fraction limits sensitivity to $m_{DM} > m_{Med}/2$
- interesting range to probe, almost inaccessible to MET searches
Axial-vector -> sizeable leptonic couplings, exclusion also possible for $m_{DM} < m_{Med}/2$





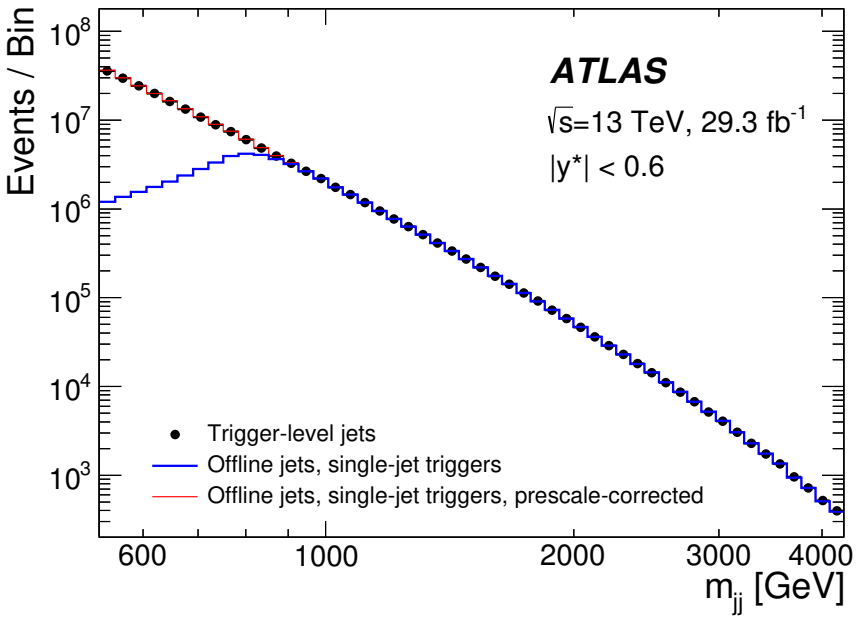
95% confidence level exclusions on the masses of the DM particle and its mediator

Dijet analyses

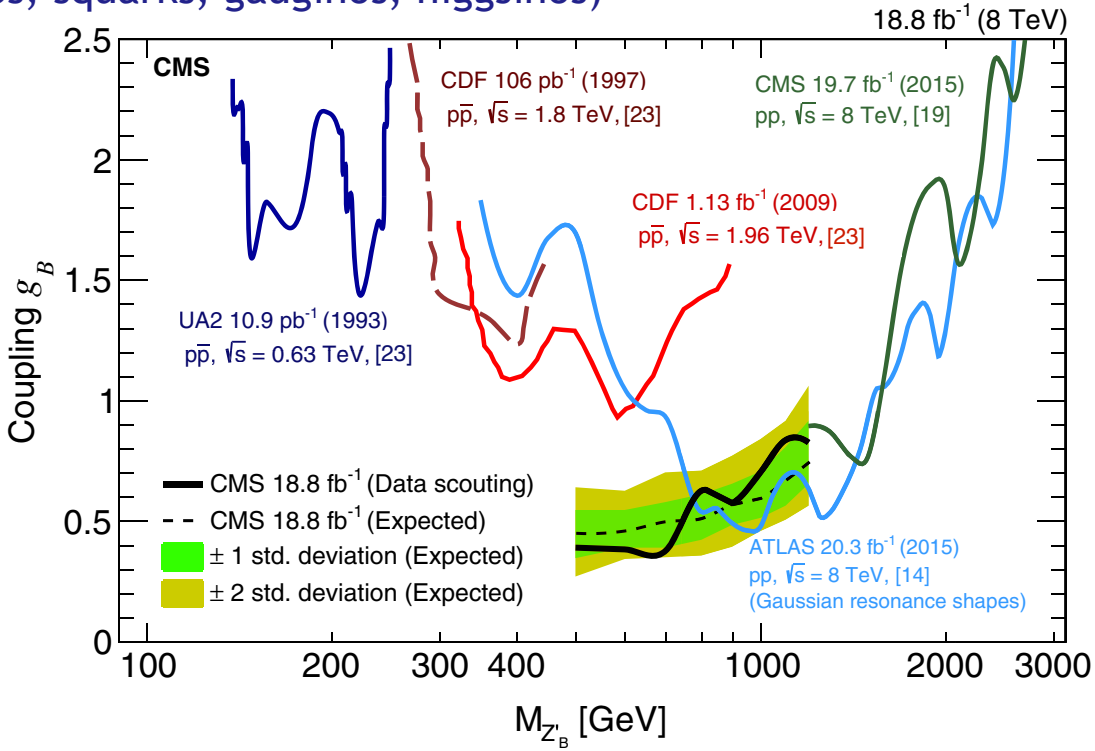
Novelties:

- low-mass mediator regions accessible
  - angular distributions
  - data scouting / trigger-level jets (online HLT reconstruction, reduced event format -> low trigger rates, no offline reconstruction)

Note: R-parity conserving SUSY searches also part of LHC DM search program, covering wide range of light mediator scenarios (gluinos, squarks, gauginos, higgsinos)



hep-ex 1804.03496



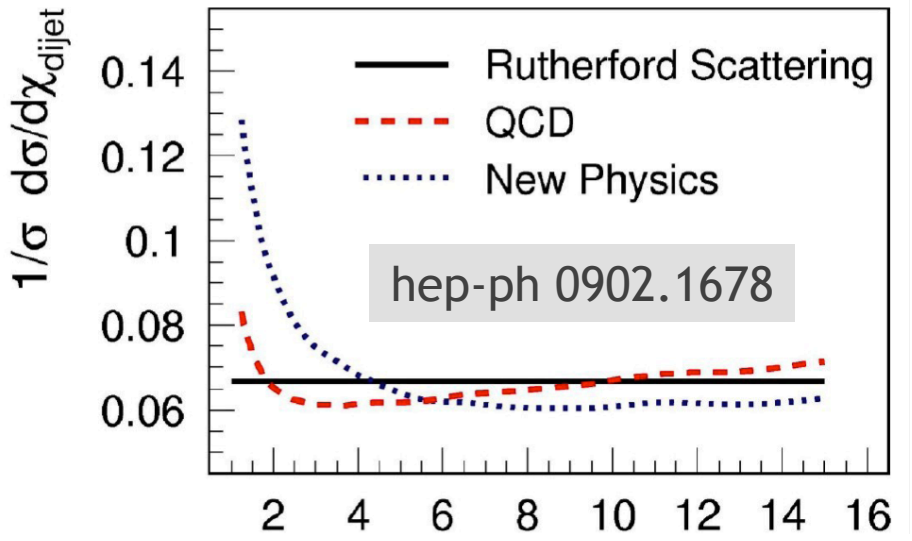
hep-ex 1604.08907

Dijet angular analysis

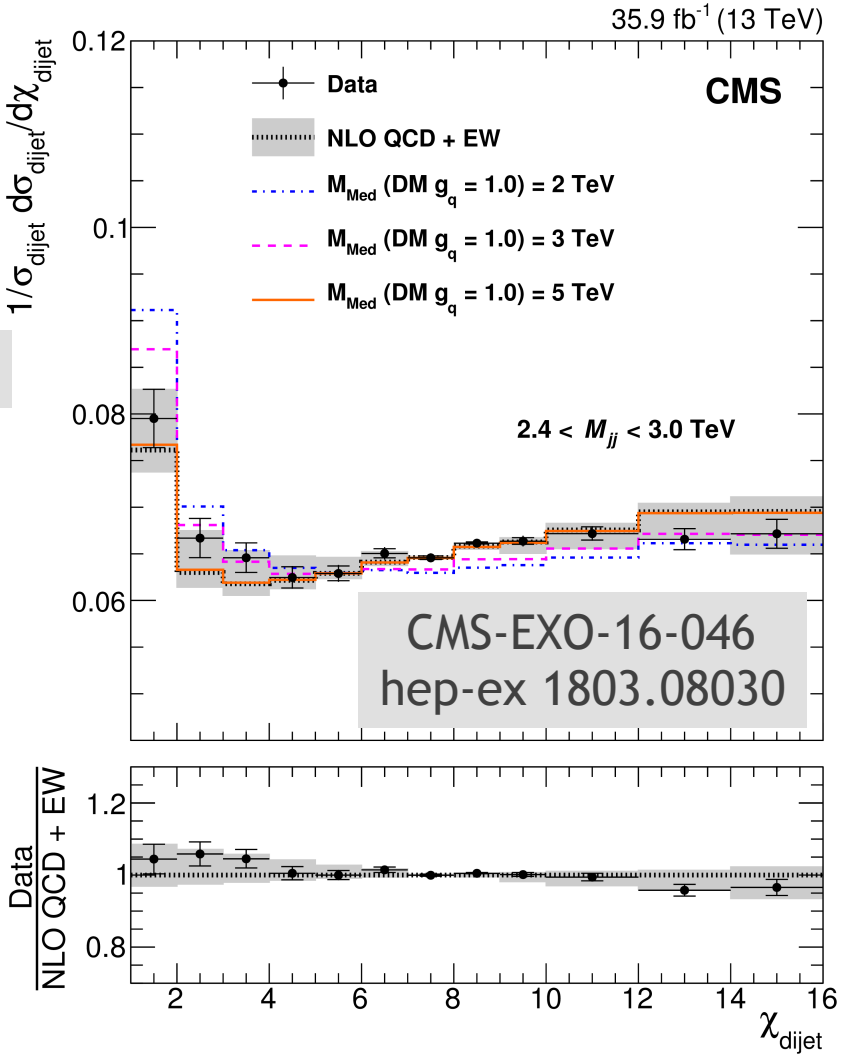
Angular distributions

- sensitive to wide resonances or non-resonant production, in contrast to standard dijet searches
- sensitive to dynamics of scattering process without strong dependence on PDFs

Simplified model: relative width of spin-1 mediator increases with g_q hep-ex 1603.04156

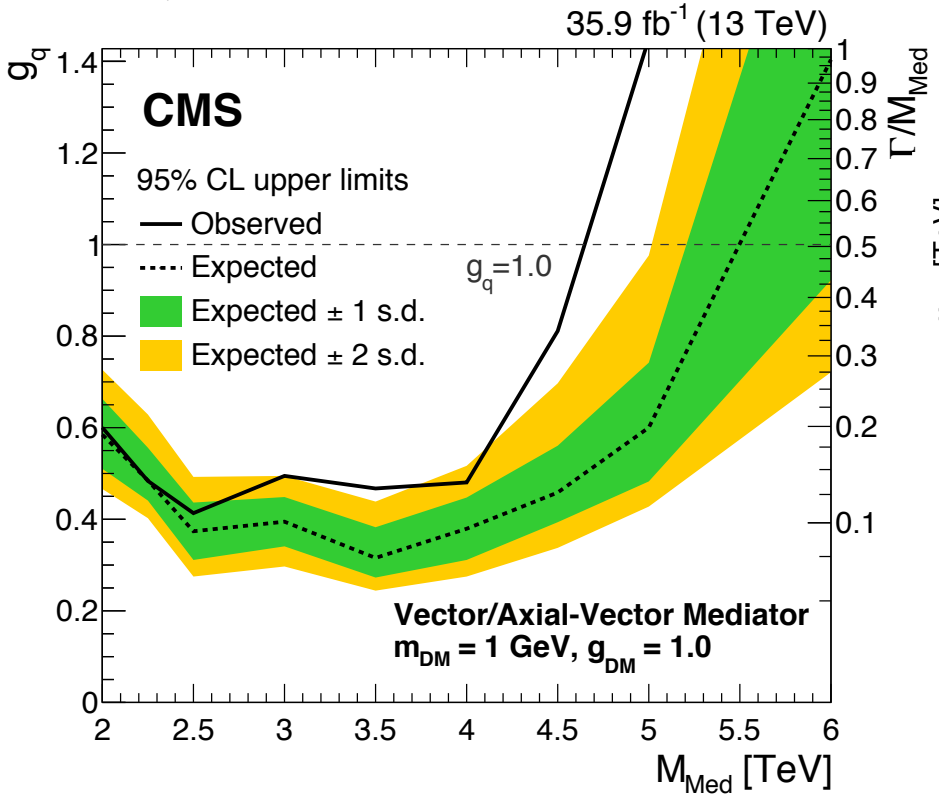


$$\chi_{dijet} = \exp(|y_1 - y_2|) = \frac{1 + cos\theta^*}{1 - cos\theta^*}$$

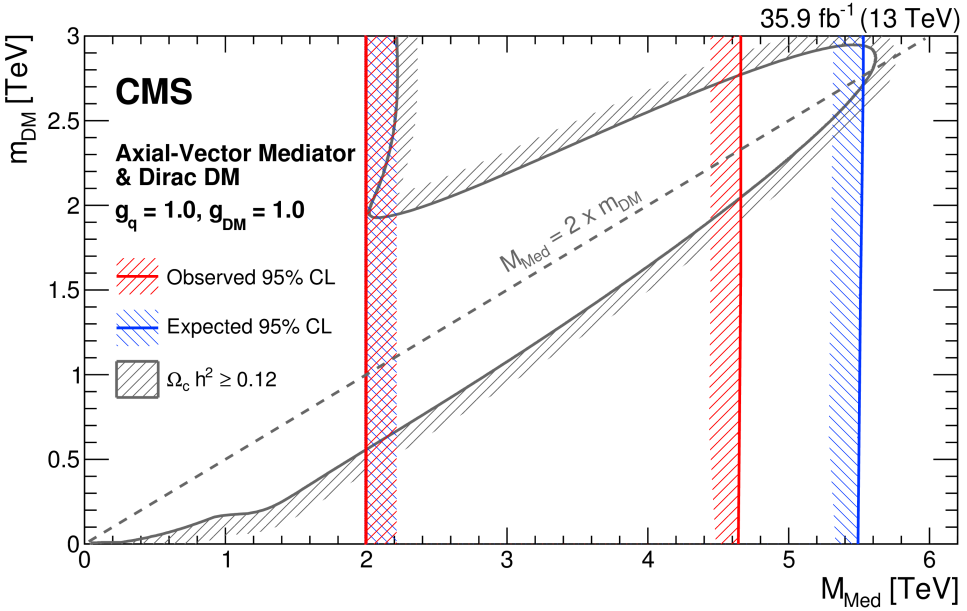


Dijet angular analysis

For the first time, lower limits between 2.0 and 4.6 TeV are set on the mass of a dark matter mediator for vector / axial-vector mediators, for universal quark couplings $g_q \geq 1$. This region is not accessible in narrow dijet resonance searches, because sensitivity fades away at $g_q > 0.45$ (widths in q decay channel increase to > 10%). Limit degradation above 4 TeV / $g_q > 0.5$: acceptance for high-mass resonances decreases as function of width. Exclusion almost independent from m_{DM} as total width dominated by width of q decay channel.



CMS-EXO-16-046
hep-ex 1803.08030



Low-mass dijet analysis (450 – 1800 GeV)

hep-ex 1804.03496

Event selection:
- 2 samples: L1 jet with E_T > 100 GeV (29.3 fb^{-1}), L1 jet with E_T > 75 GeV (3.6 fb^{-1})
- at least 2 trigger-level jets with p_T > 85 GeV, |η| < 2.8
- leading trigger-level jet must have p_T > 220 / 185 GeV (E_T > 100 / 75 GeV)
- cuts on $y^* = (y_1-y_2)/2$, depending on m_{jj} range and sample

Backgrounds:
SM dijet production, estimated from data using new sliding-window fit:
- fit spectra in smaller windows instead of entire mass range
- fitted functional form is evaluated at centre of a window, which slides in 1-bin steps
- estimates in each bin collated to form final background estimate
- function used for each bin is the one that yields best χ^2 over full fitted m_{jj} range

For this analysis, 3 functional forms have been used, with $x = m_{jj}/\sqrt{s}$

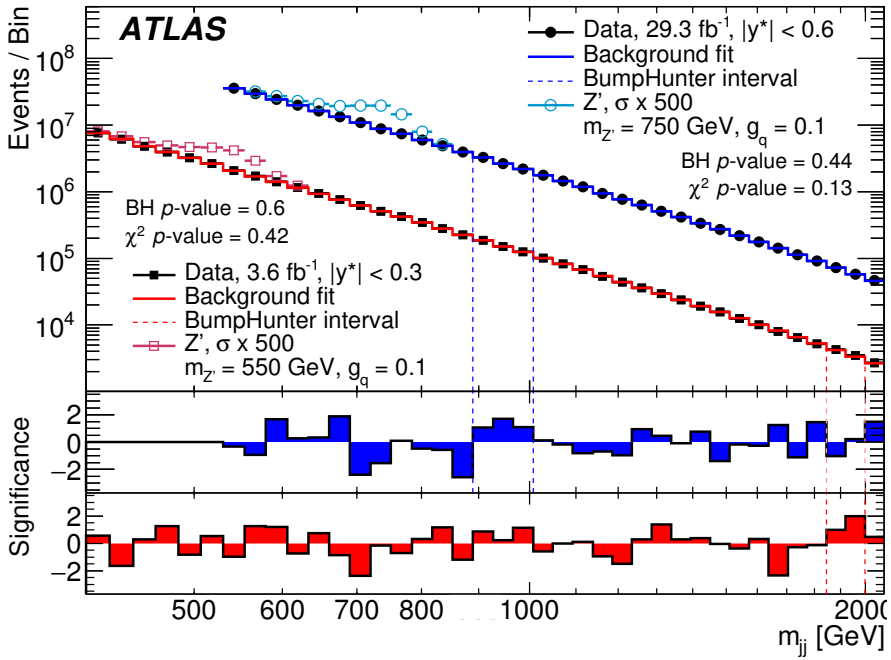
$$f_1(x) = p_1(1-x)^{p_2} x^{p_3+p_4 \ln x+p_5 \ln x^2}$$
$$f_2(x) = p_1(1-x)^{p_2} x^{p_3+p_5 \ln x^2}$$
$$f_3(x) = \frac{p_1}{x^{p_2}} e^{-p_3 x-p_4 x}$$

Low-mass dijet analysis (450 – 1800 GeV)

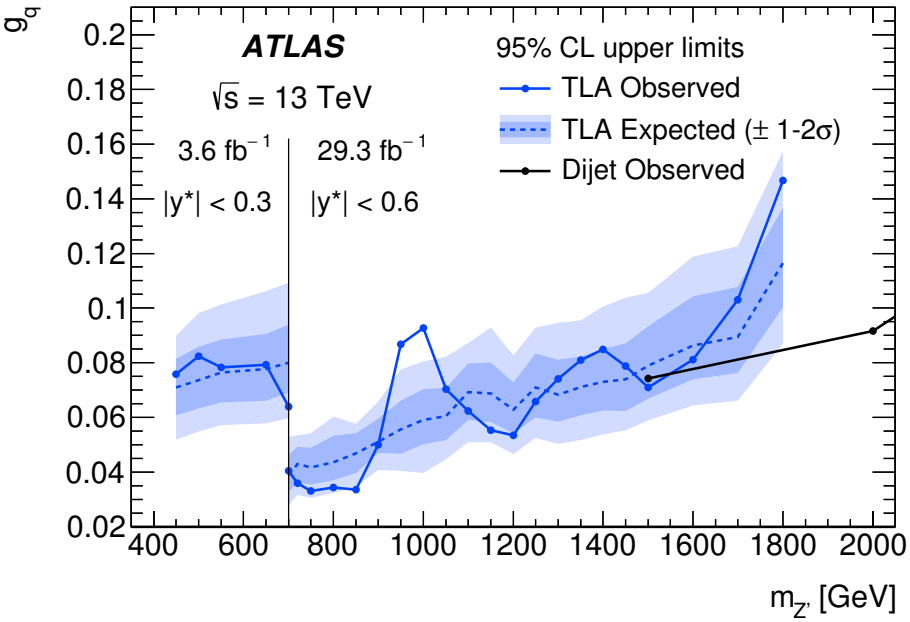
hep-ex 1804.03496

Bump hunter

- qualifies the statistical significance of any localized excess
- if p-value < 0.01 signal region blinded before calculating background



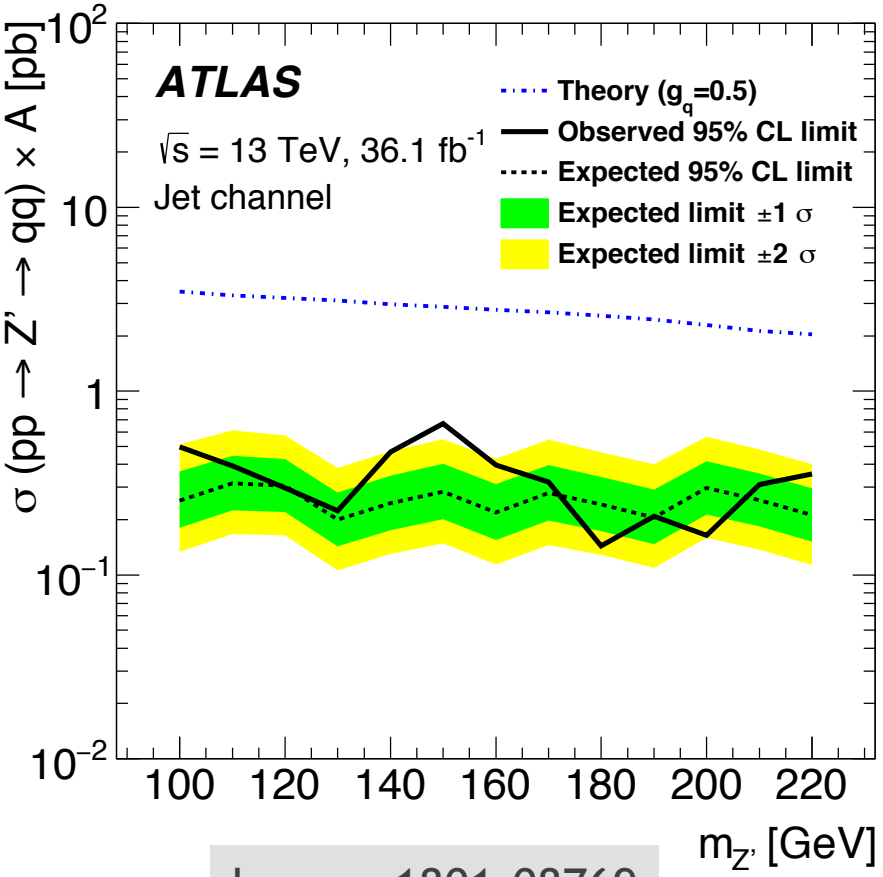
g$_q$ vs m$_{Z'}$, for trigger-level analysis and dijet analysis



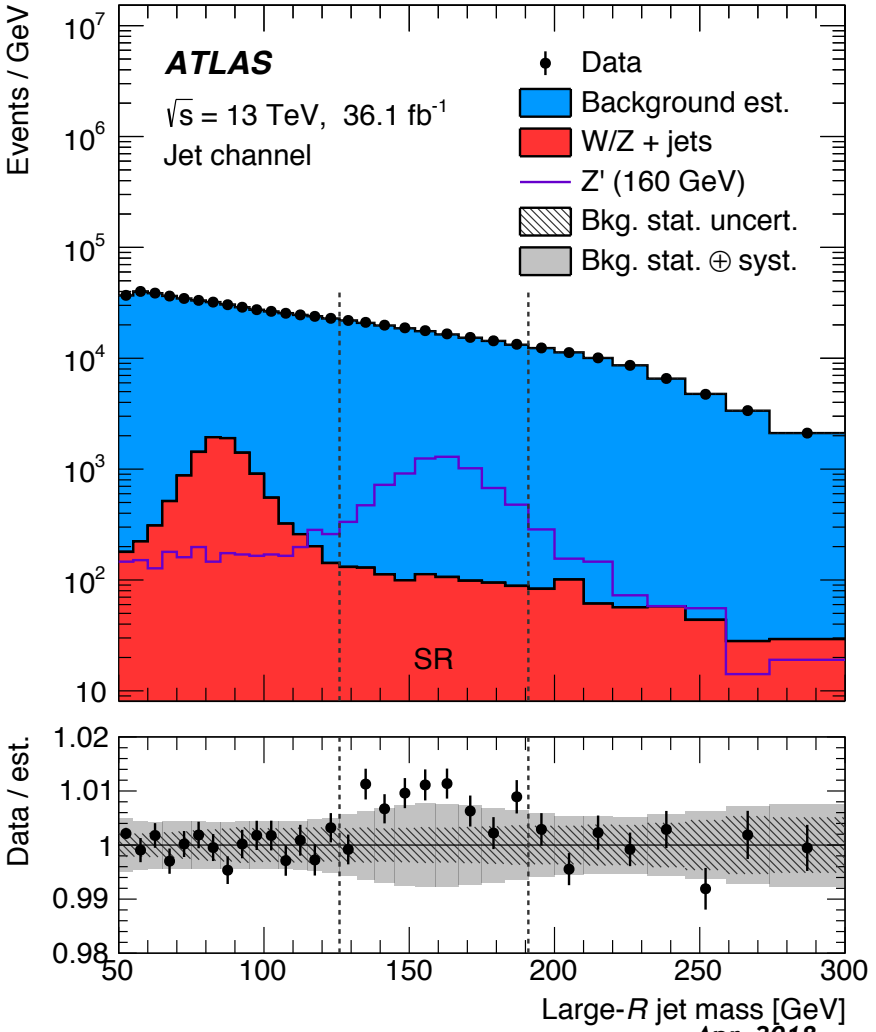
Low-mass dijet analysis with boosted dijets

Signal: boosted dijet with jet or photon from ISR

- decay products from DM mediator are collimated (merged large-R jet)
- use jet substructure techniques to identify quark pair (e.g. N-subjettiness τ_{21})
- can trigger on ISR jet or photon



hep-ex 1801.08769

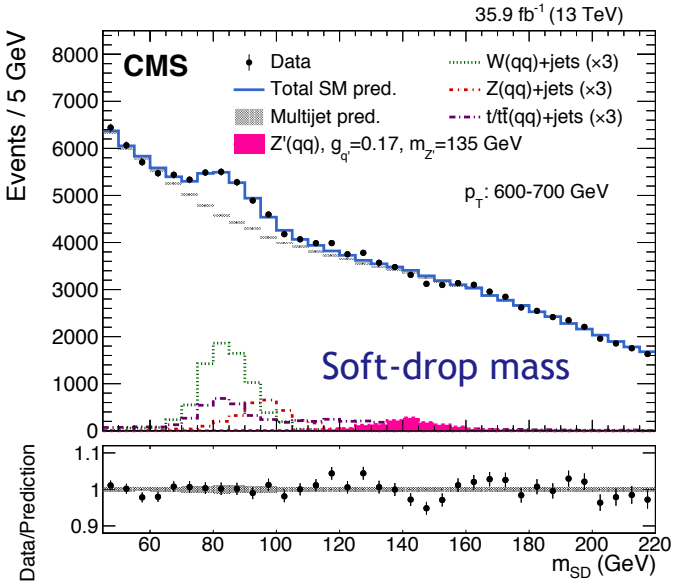


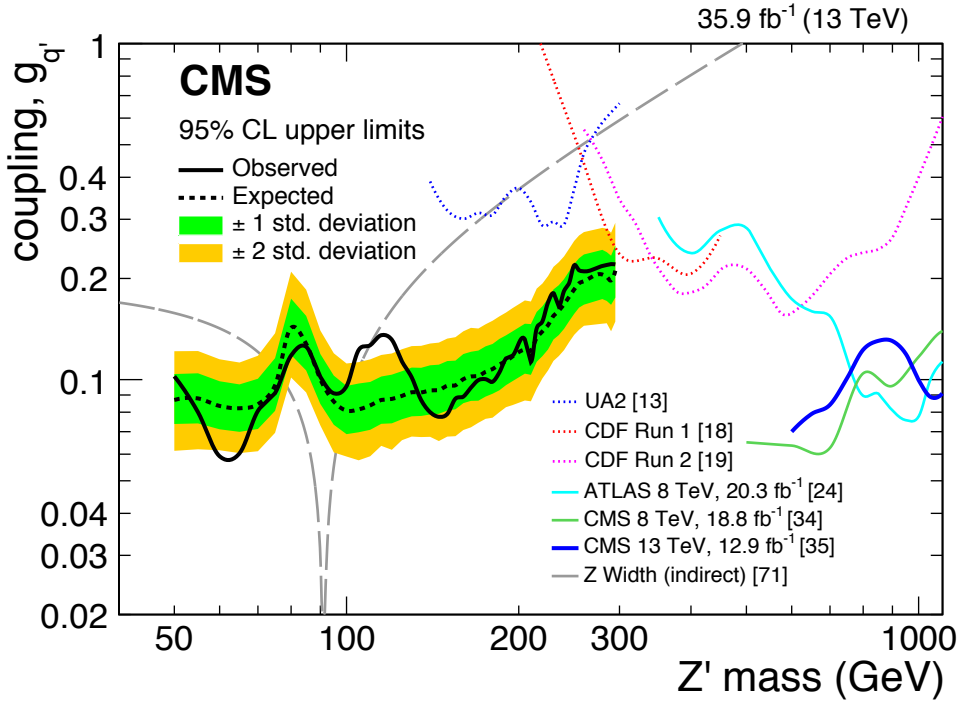
Low-mass dijet analysis with boosted dijets

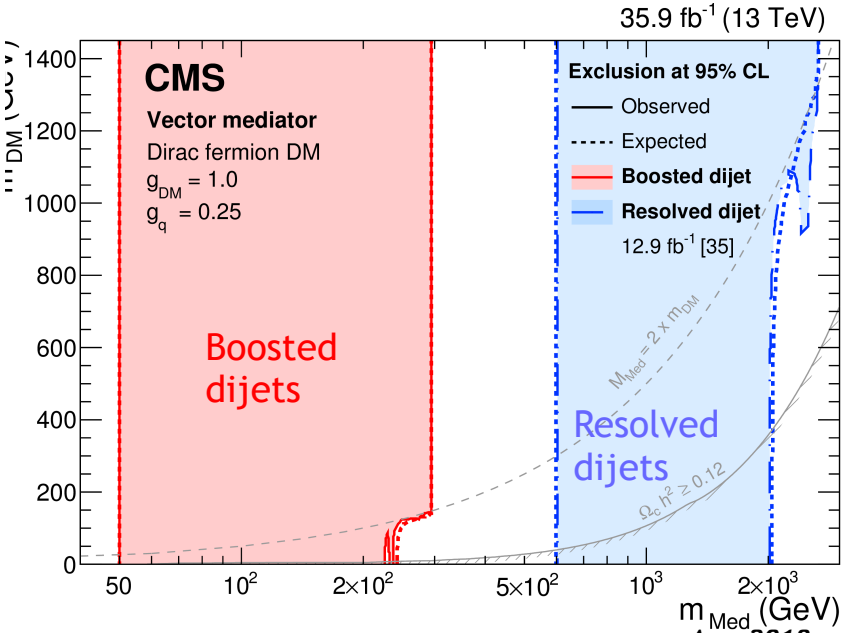
The limits constrain simplified models of dark matter production involving a mediator interacting between quarks and dark matter particles through a vector or axial-vector current.

Search region extended for the first time to masses below 100 GeV.

CMS-EXO-17-001, hep-ex 1710.00159

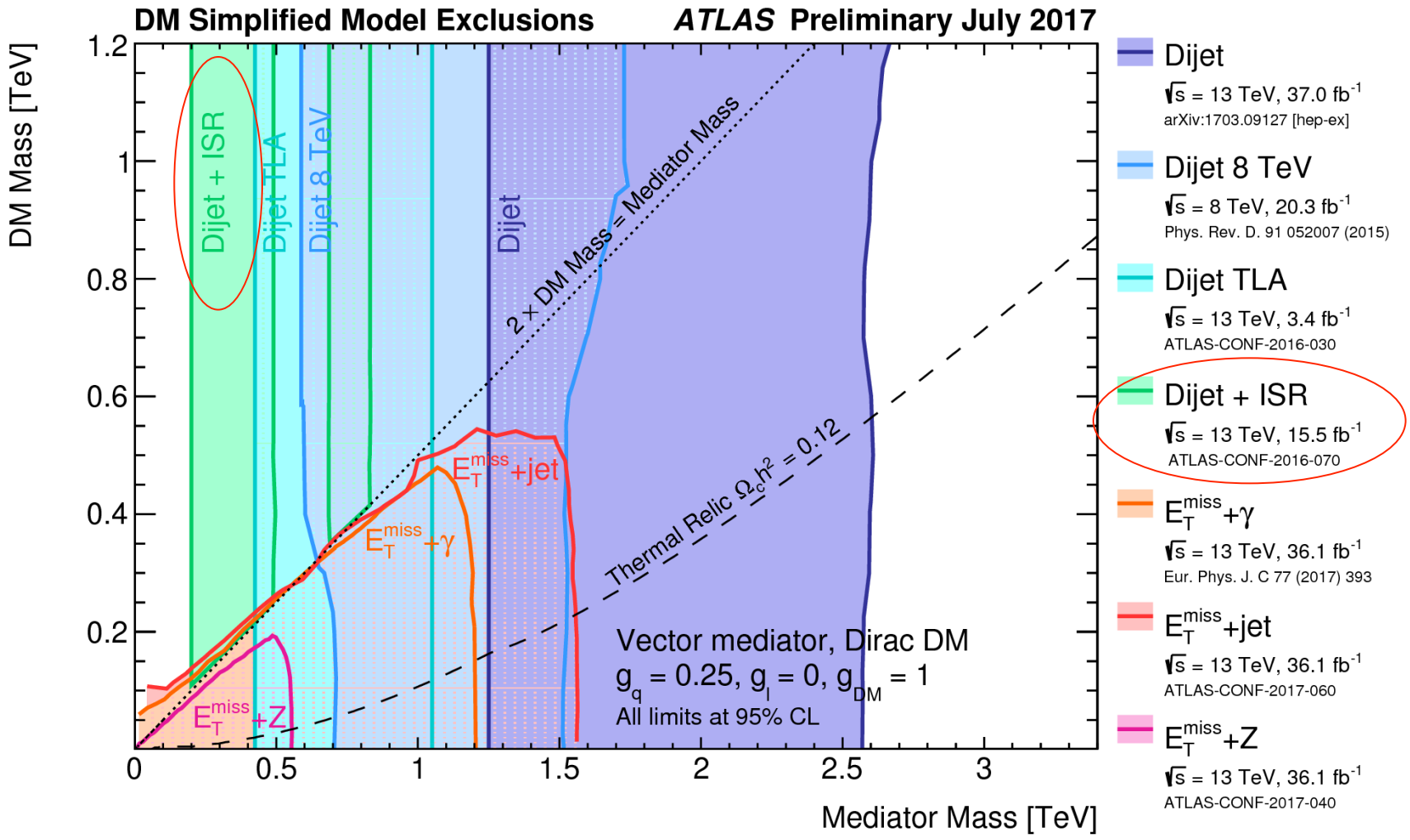






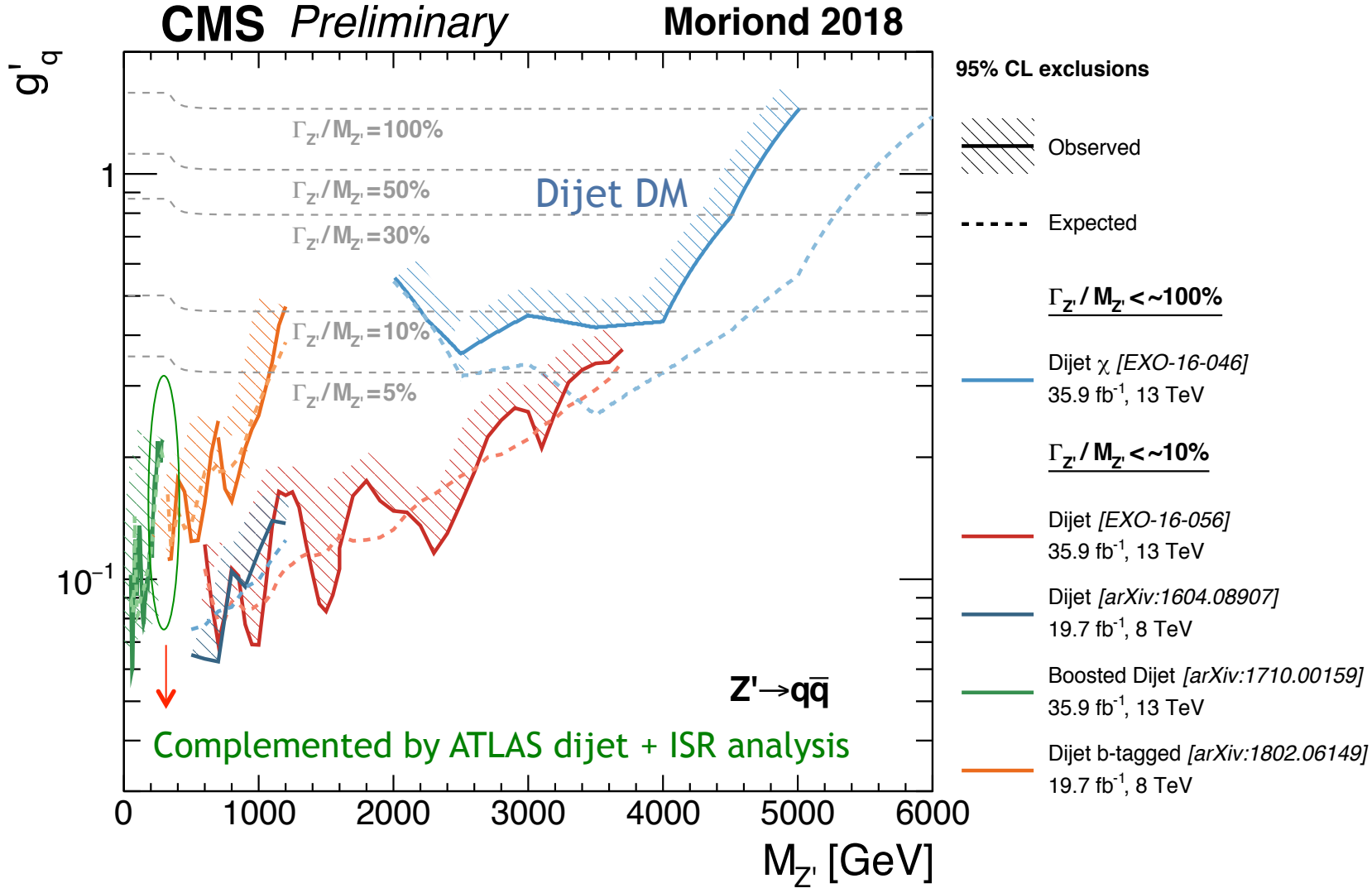
ATLAS DM exclusion

Gap 300-500 GeV filled by dijet + ISR analysis



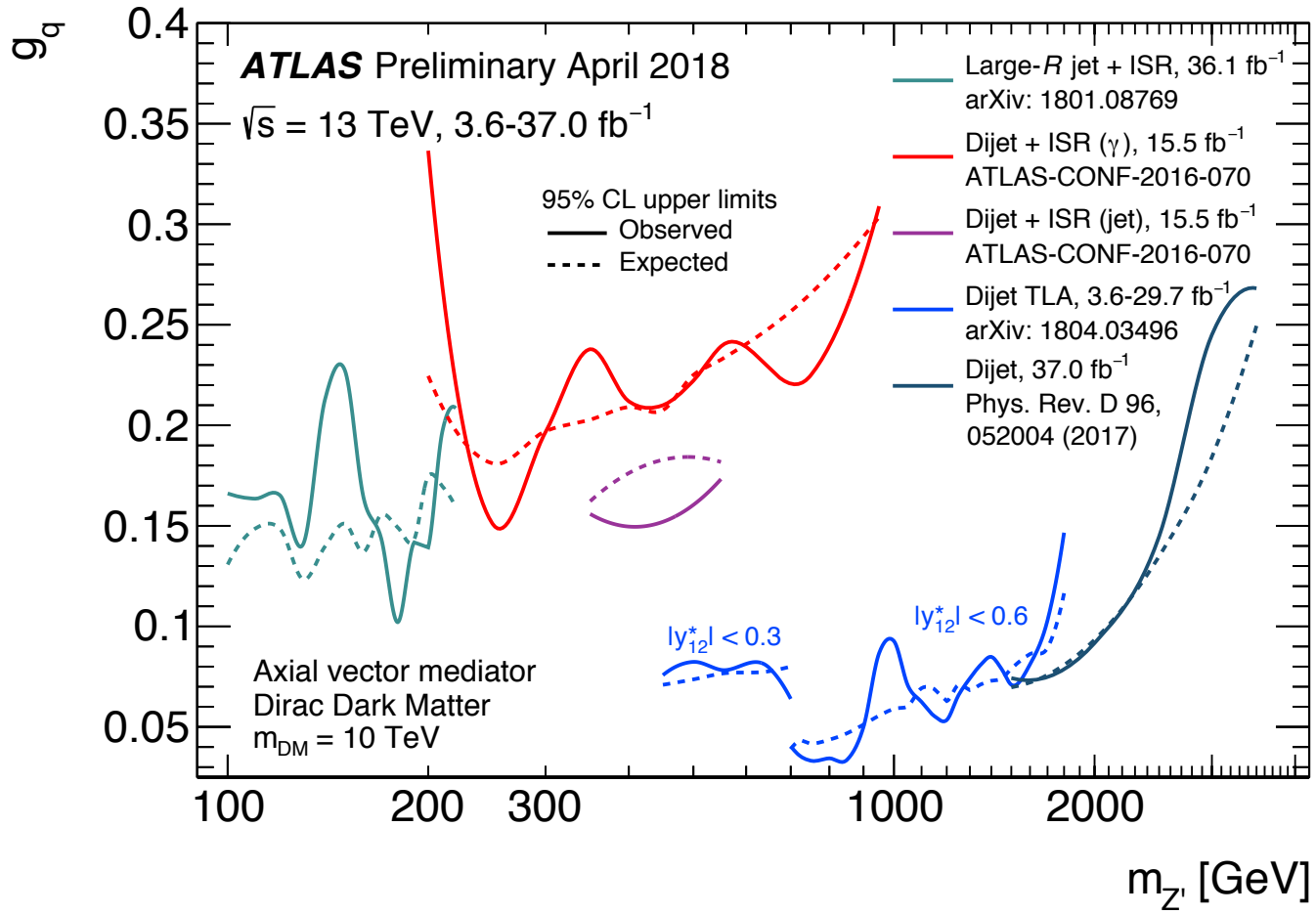
CMS DM summary

CMS limits on universal coupling between leptophobic Z' boson and quarks



ATLAS DM summary

ATLAS limits on universal coupling between leptophobic Z' boson and quarks



Conclusions

- ATLAS and CMS have studied dark matter signatures without missing transverse energy and have derived limits as no significant excesses have been found.

- Dijet and dilepton signatures have been exploited.

- Dijet angular distributions extend reach.

- Further signatures without missing transverse energy such as trackless jets or displaced objects are being studied.

- Lots of data are still to come before the next LHC shutdown, so stay tuned!

BACKUP

Bibliography

ATLAS

- Low-mass dijet resonances: hep-ex 1804.03496 (older 1703.09127)
- Dilepton resonances: hep-ex 1707.02424

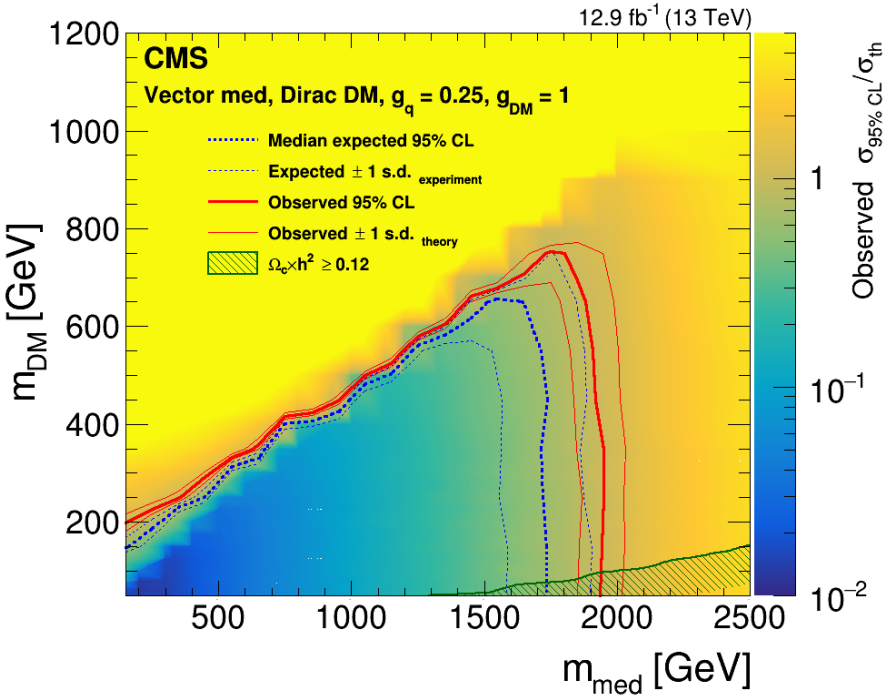
CMS

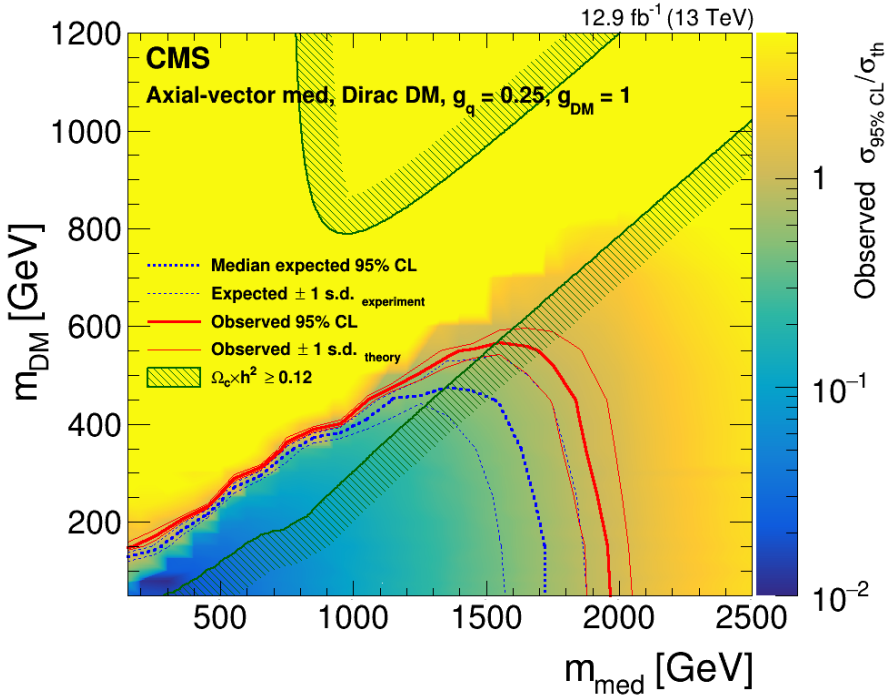
- Dijet resonances (high- and low-mass): EXO-17-001 (hep-ex 1710.00159) (older EXO-16-032)
- Dijet angular distributions: EXO-16-046 (hep-ex 1803.08030)
- Dilepton resonances: EXO-16-047 (hep-ex 1803.06292)
- Trackless jets: EXO-17-010 (not public yet)

https://twiki.cern.ch/twiki/bin/view/AtlasPublic

http://cms-results.web.cern.ch/cms-results/public-results/publications

MET search for spin-1 mediator





SUSY models with long-lived particles

- Gauge-mediated SUSY, where gravitino is LSP and DM candidate (gravitino decay is displaced)
- Split SUSY, with e.g. lightest neutralino is DM candidate (decay of gluino proceeds via an off-shell quark at high mass and is hence displaced
- Models with pure wino-LSP (such as AMSB) or pure higgsino-LSP (the small mass splittings result in macroscopic decay distances)
- SUSY with DM in hidden sector and non-thermal production of DM (the typically small coupling to the hidden sector can make the decay to the hidden sector displaced)