Exotic searches at the LHC

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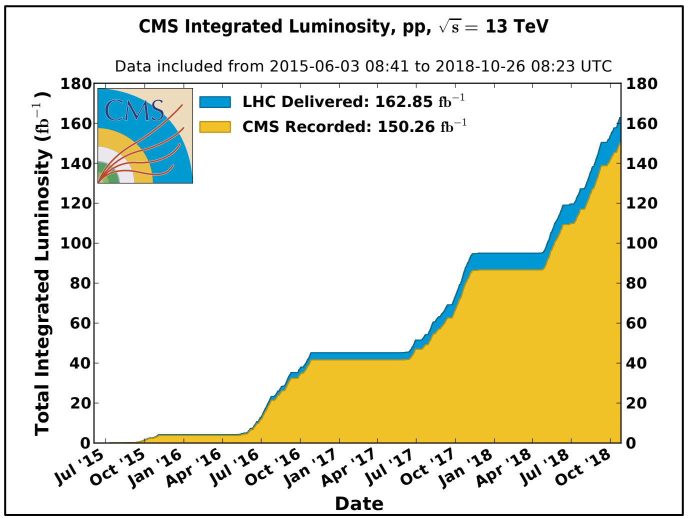
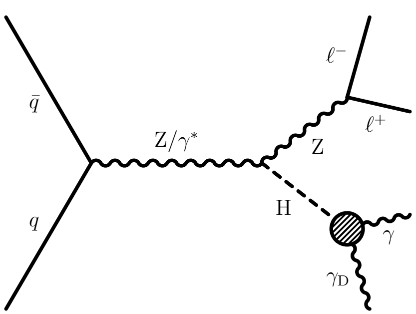
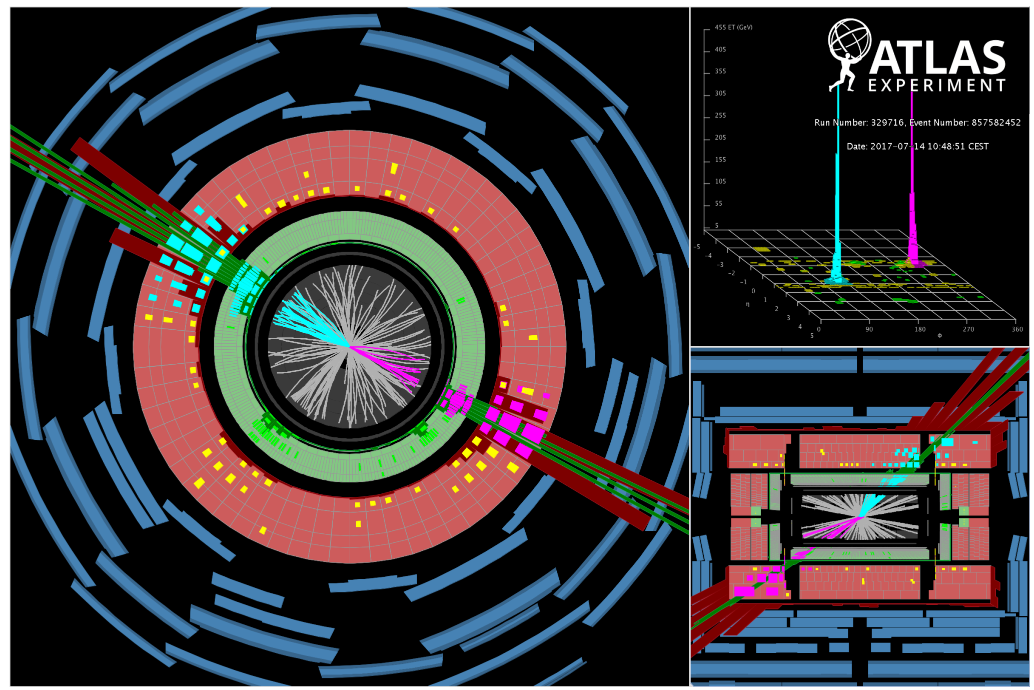
On behalf of the ATLAS, CMS, and LHCb collaborations

Introduction

- ✧ This talk presents recent results on searches for **physics beyond the Standard Model**
- ➢ Searches for BSM resonances.
- ➢ Dark sector: searches for dark matter and dark photons.
- ➢ Searches for BSM long-lived particles exploiting non-conventional signatures.







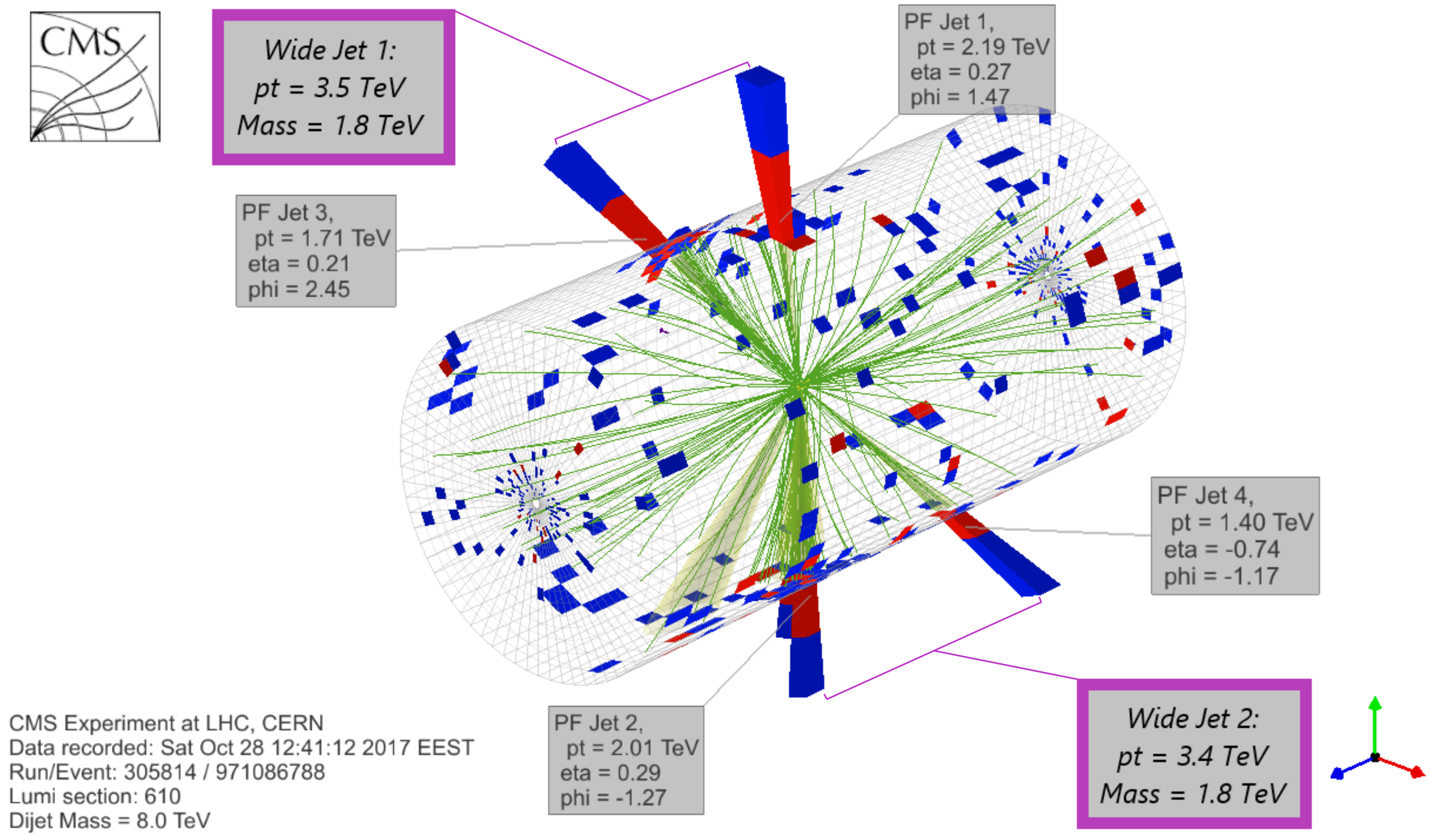
Resonances

Resonances: dijet

- The dijet signature is a very generic approach to searching for new exotic resonances.
- A number of theoretical models predict such a final state:

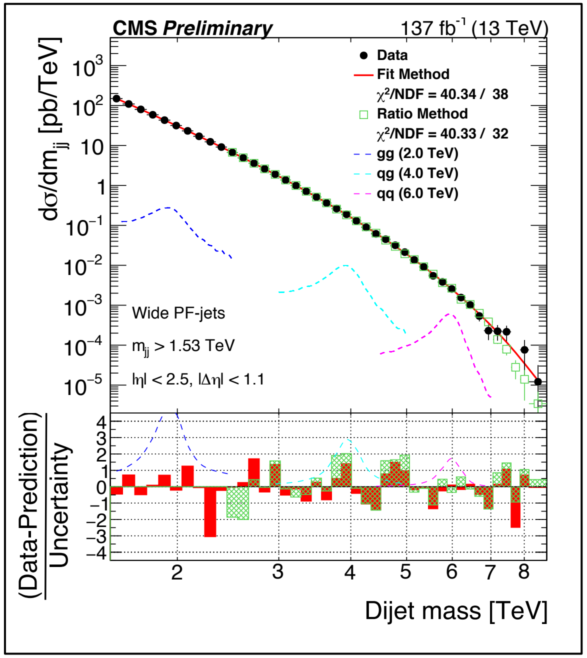
  string resonances (Regge excitations of q/g) ; scalar diquarks (GUT E6) ;

  quark compositeness ; RS gravitons ; DM mediators ; etc.



- Several CMS and ATLAS analyses target the generic dijet signature, as well as its variations.
- Most basic signature : high-mass dijet final state.

Resonances: dijet



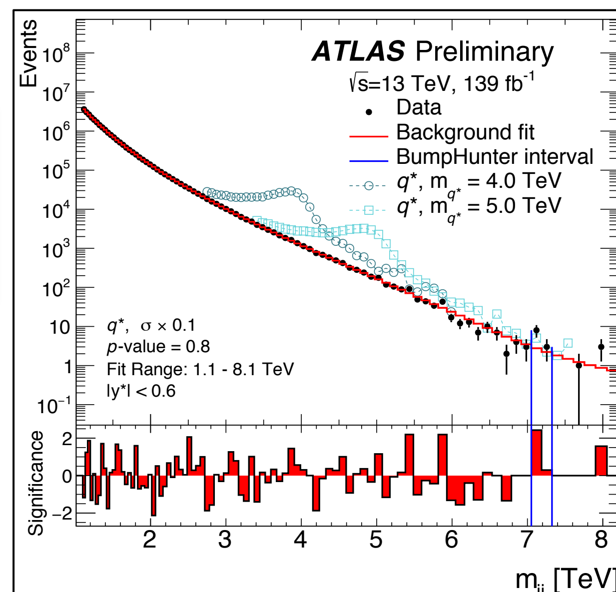
CMS-PAS-EXO-19-012
Paper under preparation

- **Trigger**: OR of { HT>1050 ; 1 jet pT > 550 GeV }
- For each of the 2 leading jets, surrounding jets (ΔR < 1.1) are grouped into "wide jets"
- This reduces the impact of **gluon FSR**.
- **Suppress t-channel** background : |Δη|<1.1

- ✧ **Background fitted** in 1.5 < mjj < 2.4 TeV
- Above 2.4 TeV : data-driven "**ratio method**" based on |Δη| control regions
- RM does not depend on the signal region, has smaller uncertainties, and higher significance for wider resonances.

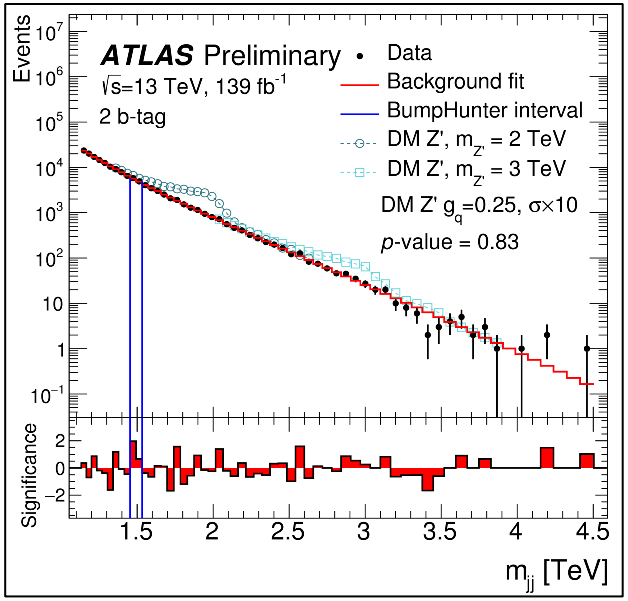
- **Trigger**: 1 jet pT > 420 GeV
- Jets: two leading jets pT > 150 GeV.
- Suppress t-channel : 0.5*|y1-y2| < 0.6
- Fit background to the data.

ATLAS-CONF-2019-007

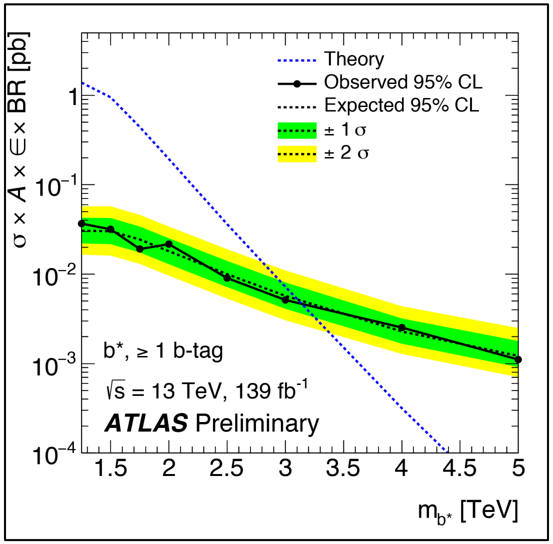


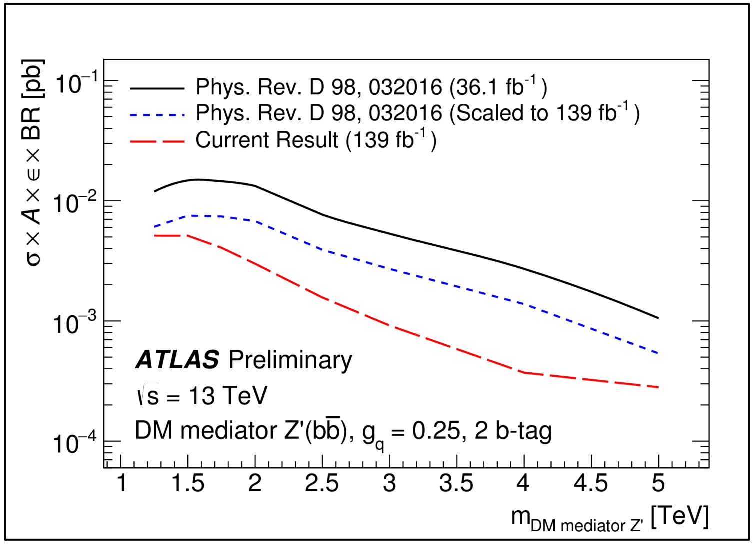
Resonances: bb

- Preliminary ATLAS results on the search for dijets from bb quarks, using full Run 2 data.
- Signal models: b*, DM Z’(bb), SSM, KK gravitons, etc.
- Adding categories: ≥1 b jet ; 2 b jets. Identification of b jets using a deep neural network (based on impact parameter of tracks and displaced vertices).



$1b$	b^*	3.2 TeV
$2b$	DM mediator Z' $g_q = 0.20$	2.8 TeV
	DM mediator Z', $g_q = 0.25$	2.9 TeV
	SSM Z',	2.7 TeV
	graviton, $k/\overline{M}_{PL} = 0.2$	2.8 TeV

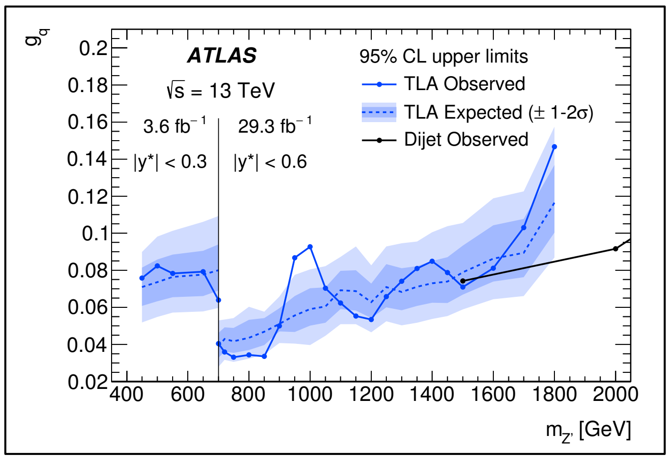




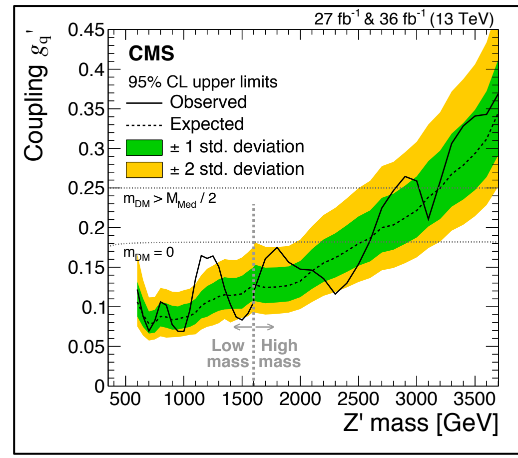
Low-mass resonances

- In order to search for **low-mass resonances**, the **trigger strategy** must be adapted wrt the high-mass analysis.
- **First option**: “data scouting” (CMS : *JHEP 08 (2018) 130*) / “trigger-level analysis” (ATLAS : *Phys. Rev. Lett. 121 (2018) 081801*)
- *Record a reduced event content & perform the analysis using trigger objects. Sensitive mass range: 450 − 1000 GeV.*
- **Second option**: exploit boosted dijets recoiling against **ISR** object
  - ISR photon/jet: ATLAS (*Phys. Lett. B 788 (2019) 316*). ISR photon: CMS (*arXiv:1905.10331*). ISR jet: CMS (*arXiv:1909.04114*)

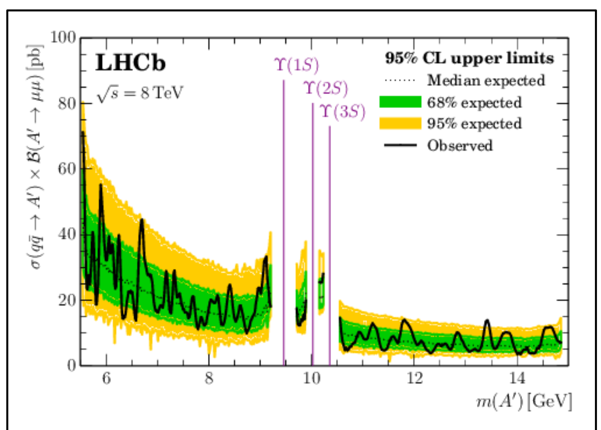
ATLAS Trigger-Level Analysis
Phys. Rev. Lett. 121 (2018) 081801

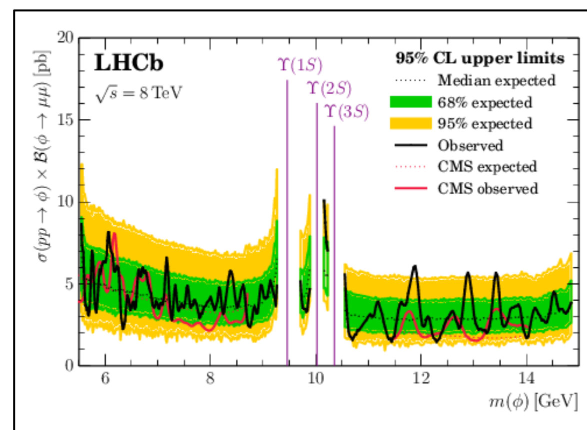


CMS Scouting
JHEP 08 (2018) 130



LHCb very low mass dimuon
JHEP 09 (2018) 147

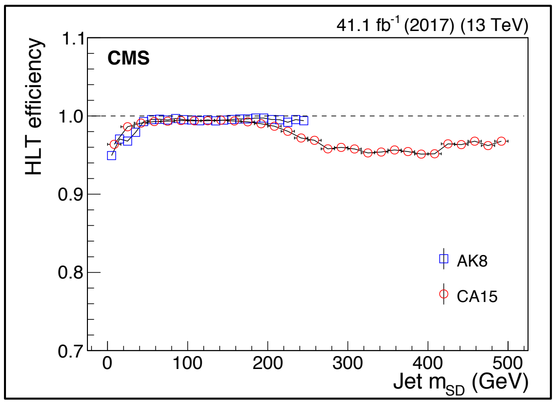


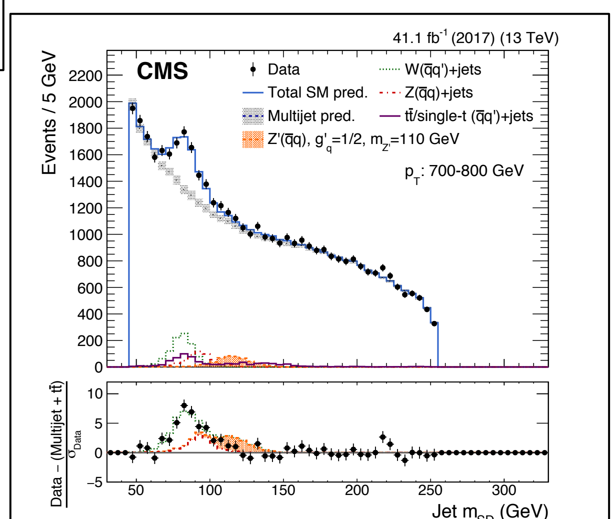


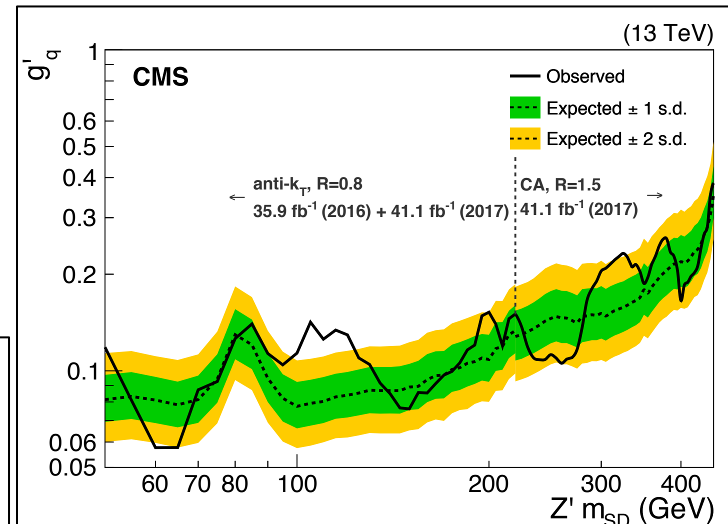
Low-mass resonances: boosted dijet

Search for a low-mass resonance recoiling against ISR jet then decaying into a boosted dijet

- ✧ **Trigger**: Anti-kT (R=0.8) jets. Trimming: recluster jet constituents into kT subjets (R=0.2) ; discard soft components (pT / pT(jet) < 0.03).
- ✧ **Offline jets:** Anti-kT R=0.8 for m < 175 GeV. Cambridge-Aachen R=1.5 above.
  - ➢ "**Soft drop**": cleans out soft and wide-angle radiation → reduces mass of QCD jets, but not W/Z/Z'
  - ➢ Jet substructure's consistency with 2 prongs is checked.
- ✧ **Dominant background**: QCD evaluated in data control regions (based on substructure variables).



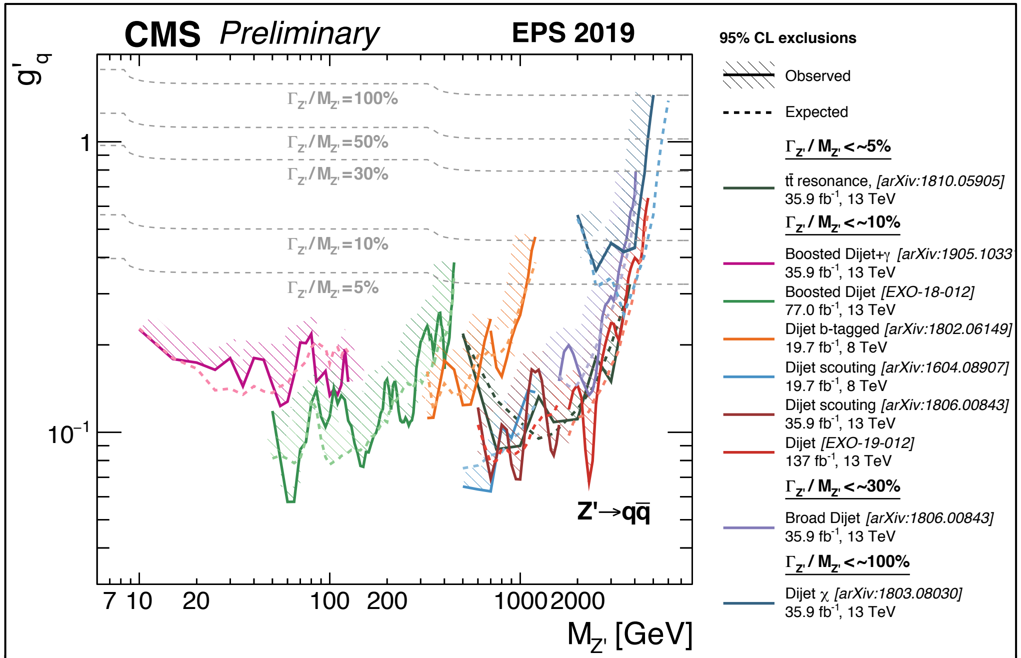


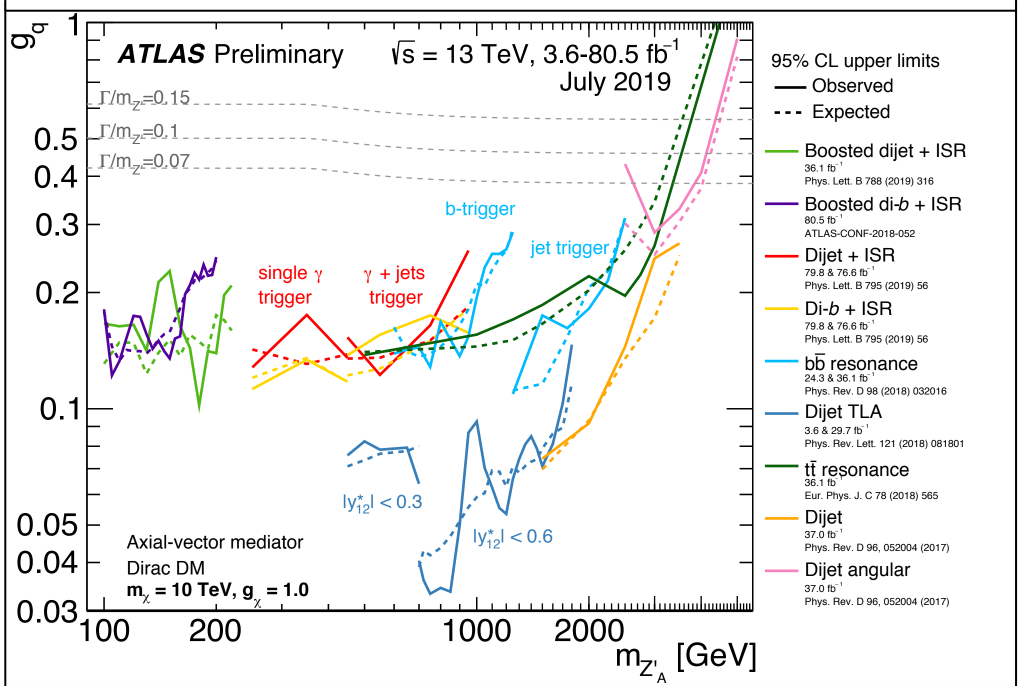


- ✧ **Upper limits on Z' − q coupling**
  - ➢ g' > 0.4 excluded for mZ' in 50 - 450 GeV
  - ➢ g' > 0.2 excluded for mZ' < 250 GeV
  - ➢ Most sensitive limits to date in 50 − 300 GeV
  - ➢ First direct limits for leptophobic Z' to wide jet, in the 300 − 450 GeV range.

arXiv:1909.04114
Submitted to PRD

Resonances: dijet summary





- **Limits range from 10 GeV** ($g'_q < 0.2$) **to 4.5 TeV** ($g'_q < 0.45$).

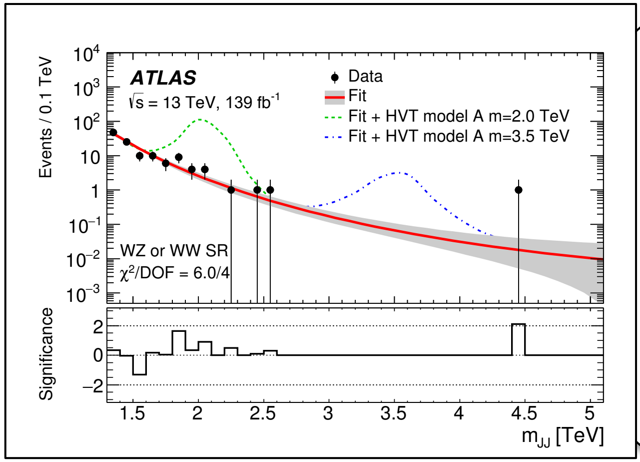
- Grey dashed lines: g'_q values at fixed values of $\Gamma_{Z'}/M_{Z'}$
- Broad dijet analysis: valid for $\Gamma_{Z'}/M_{Z'} \leq 5$ %
- Dijet χ analysis: valid for $\Gamma_{Z'}/M_{Z'} \leq 100$ %
- tt̄ analysis: valid for $\Gamma_{Z'}/M_{Z'} \leq 5$ %
- In all other analyses, the intrinsic width is assumed to be negligible compared to the experimental resolution.
  - They are valid for $\Gamma_{Z'}/M_{Z'} \leq 10$ %

- **Limits range from 100 GeV** ($g'_q < 0.2$) **to 5 TeV** ($g'_q < 0.9$)

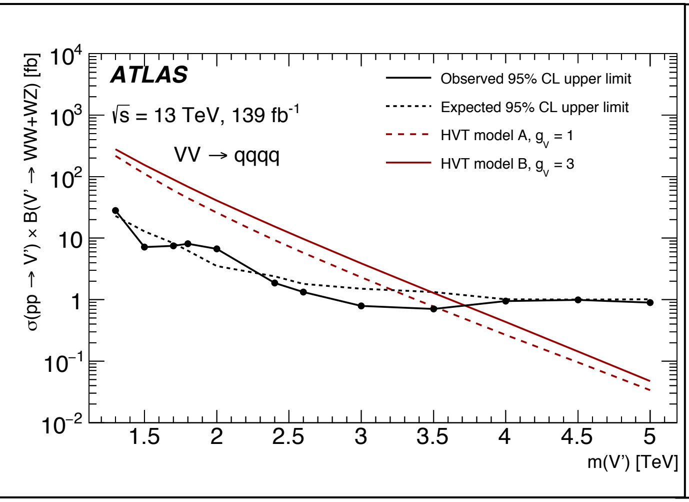
- TLA dijet $|y^*| < 0.6$: sensitive up to $\Gamma/m_{Z'} = 0.07$
- TLA dijet $|y^*| < 0.3$ & dijet + ISR : sensitive up to $\Gamma/m_{Z'} = 0.1$
- Dijet & di-b searches: sensitive up to $\Gamma/m_{Z'} = 0.15$
- Dijet angular analysis: sensitive up to $\Gamma/m_{Z'} = 0.50$
- tt̄ resonance: no limitation in sensitivity from $\Gamma/m_{Z'}$

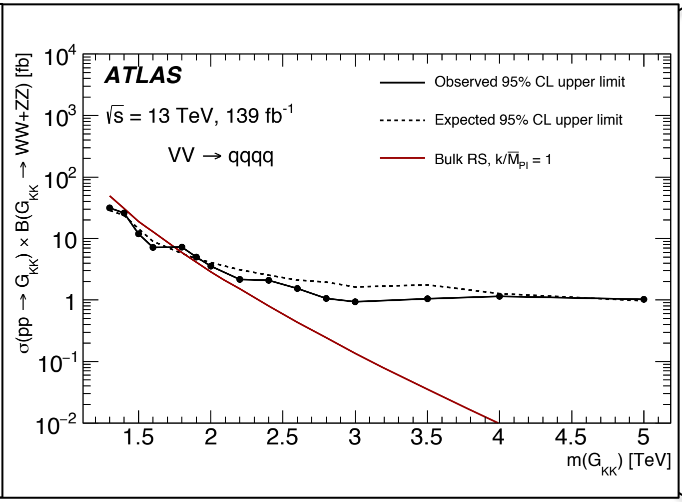
Resonances: diboson

- Dibosons
- Spin-0 radion decaying into WW or ZZ. Spin-1 HVT (W'→WZ ; Z'→WW). Spin-2 RS/KK graviton (WW, ZZ).
- Studying here two channels: V' → WW or WZ ; G_{KK} or radion → WW or ZZ.



- **Trigger**: 1 anti-kT (R=1.0) jet with pT > 420 to 440 GeV (from 2016 to 2018).
- **Offline jets**: anti-kT (R=1.0) jets. Trimming: discard soft subjets (pT / pT(jet) < 0.05).
- **Substructure** to identify boosted bosons: exploit jet mass and energy correlation functions.
- Check consistency with two prongs.
- Suppress further the QCD background by exploiting the charged hadron multiplicity.
- **Background** estimation: fit parametrised form to the dijet mass distribution. Model this parametric shape using 3 independent control regions.





Exclusion limits

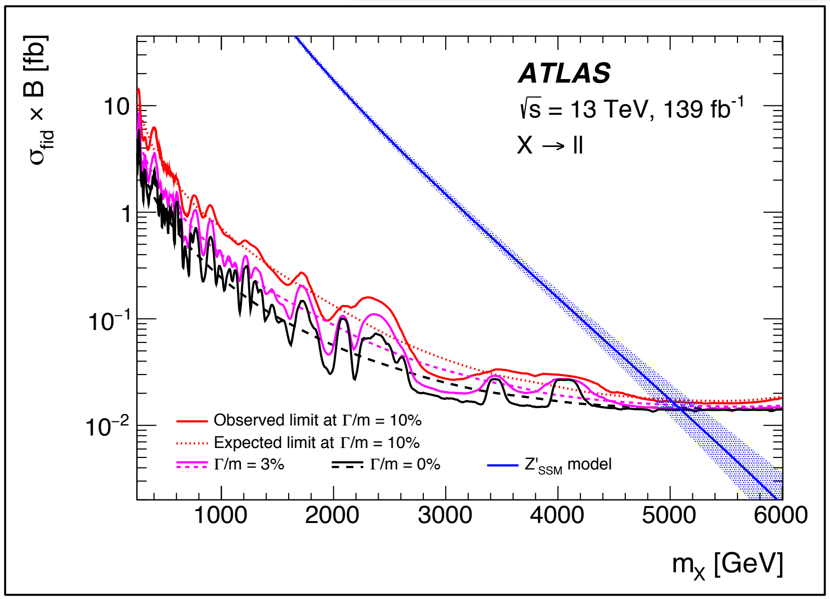
- WW+WZ in the **HVT** model **A** (gV = 1):
  1.3 < m(V') < **3.5** TeV
- WW+WZ in the **HVT** model **B** (gV = 3):
  1.3 < m(V') < **3.8** TeV
- Exclusion of $\mathbf{G_{KK}}$ in the **bulk RS** model (k/M_{Pl} = 1):
  1.3 < m(GKK) < **1.8** TeV

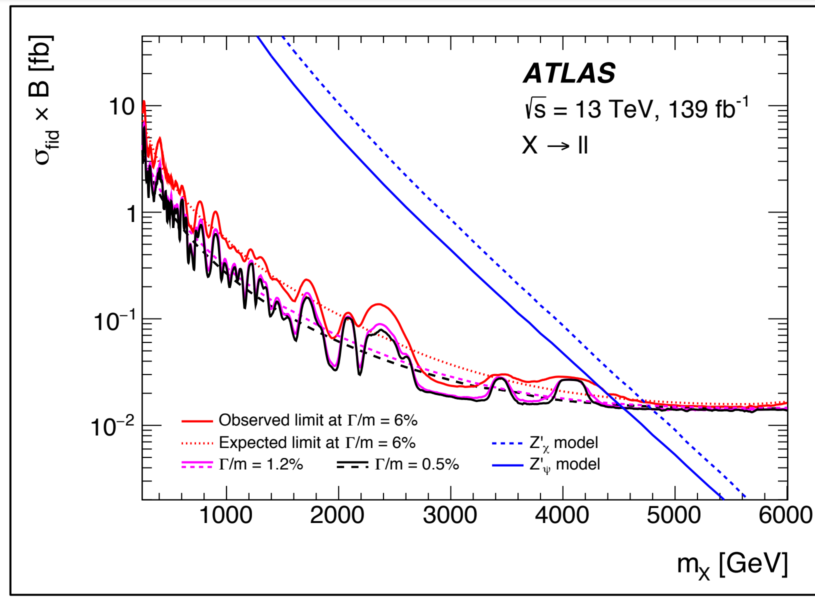
arXiv:1906.08589
Submitted to JHEP

Resonances: dilepton

- The dilepton signature is another generic approach to search for resonances, constraining a number of models:
- Spin 0: MSSM (BR(μμ) > BR(ee)).
- Spin 1 vector : Sequential Standard Model (SSM: Z' has same couplings to fermions as Z), E6 GUT (Z'_χ & Z'_ψ), Heavy Vector Triplet (HVT).
- Spin 2 : excited RS graviton

- Muon identification: dedicated high-pT working point (efficiency: 69% at 1 TeV).
- The background contribution to the invariant mass spectrum is fitted to the data using a functional form.
- Signal extraction → generic signal shape functions are used: non-relativistic Breit-Wigner functions of various widths convolved with the detector resolution.



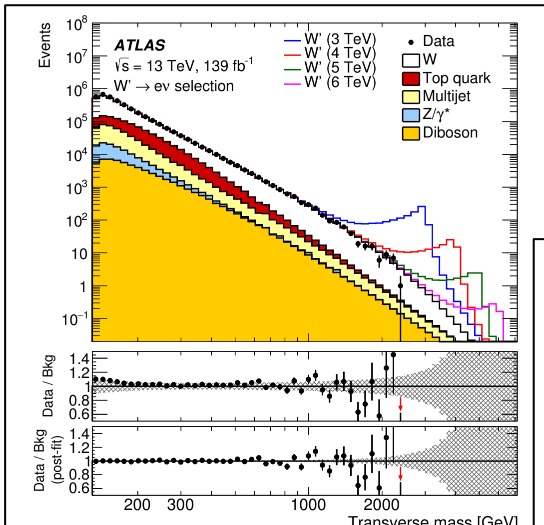


- Limits on the fiducial cross-section multiplied by the BR(ee, μμ) for generic resonances (relative width: 0-10%).
- **Most stringent limits** to date obtained on the $\mathbf{Z'_\psi}$ and $\mathbf{Z'_{SSM}}$ models: m($\mathbf{Z'_\psi}$) < **4.5** TeV m($\mathbf{Z'_{SSM}}$) < **5.1** TeV

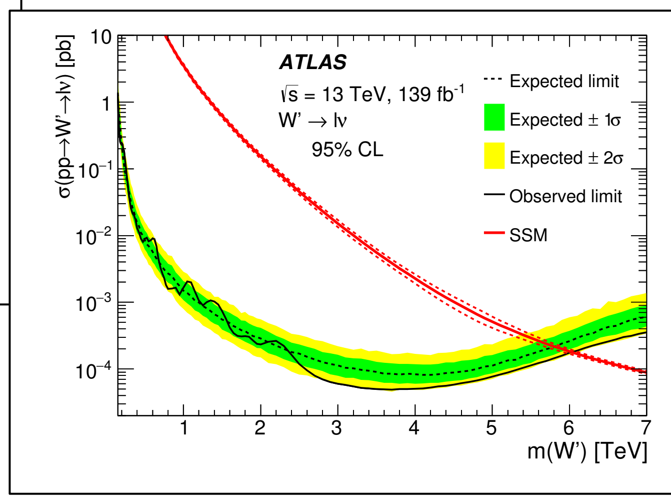
Phys. Lett. B 796 (2019) 68

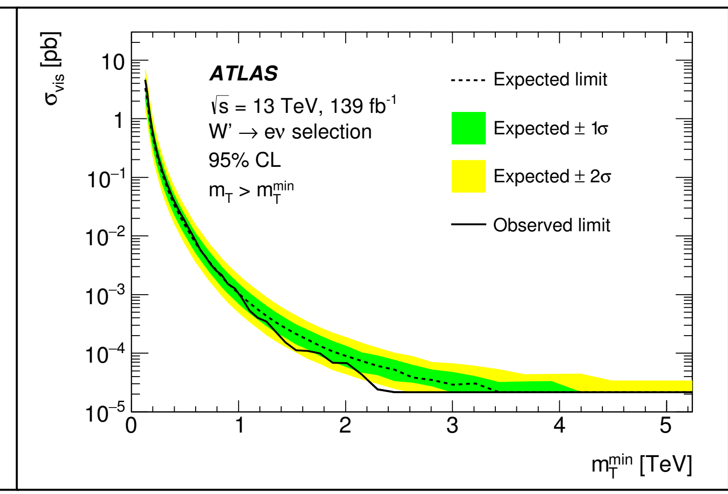
Resonances: lepton + MET

- Charged resonances are also explored by exploiting the lepton + missing transverse momentum channel.
- Instead of the dilepton invariant mass, the transverse mass of the lepton + MET system is analyzed.
- Limits on the SSM W' boson are obtained (SSM: W' → same couplings to fermions as W, suppressed couplings to bosons).
- Model-independent limits and constraints on generic fixed-width resonances are also produced, for reinterpretation purposes.



- QCD background: "matrix method" (evaluate jet to lepton fake rate in control regions) extrapolated to high m_T.
- Other backgrounds from MC (tt + VV extrapolated to high m_T).





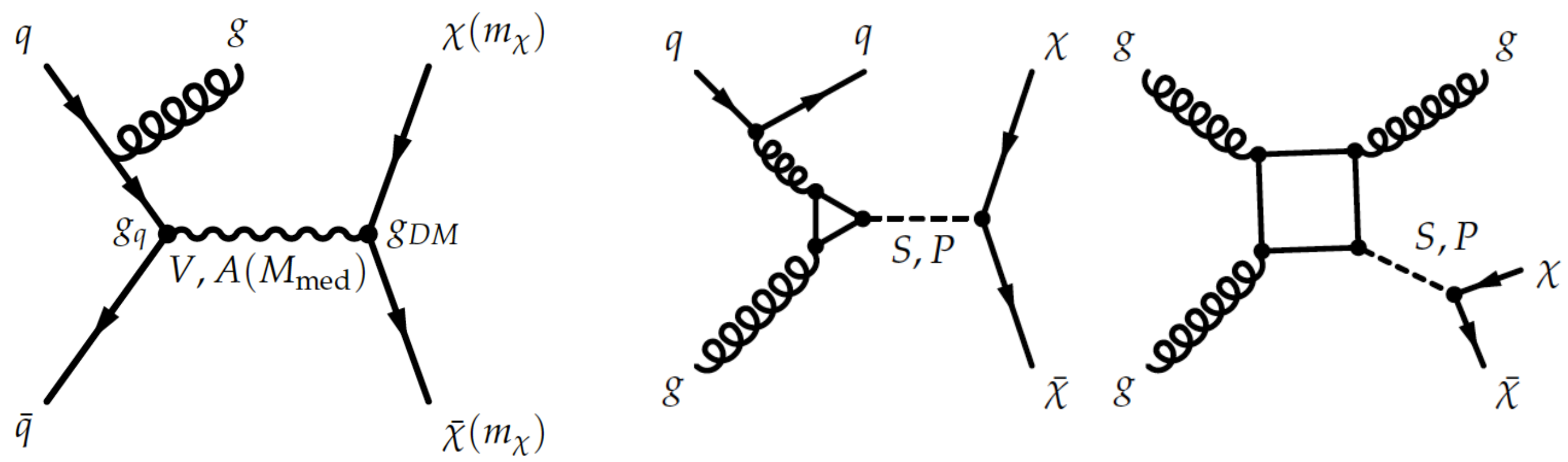
- Upper limits on **SSM W'** : masses up to **6 TeV** are excluded
- Model-independent **upper limits** in the **e** / μ channel (single m_T bin analysis):
  => from **4.6** / **15 pb** at **m_T^{min} = 130** / **110 GeV** to **22** (**22**) **ab** at high m_T^{min}

arXiv:1906.05609
Submitted to PRD

Dark Sector

Dark Matter searches

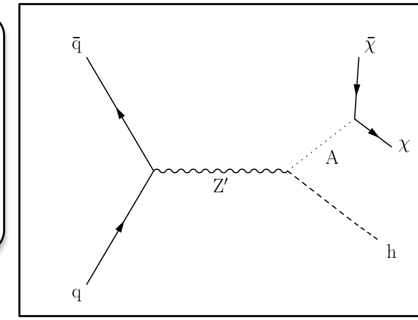
- **LHC searches** focus mostly on the pair production of Weakly Interacting Massive Particles (WIMPs)
- **Simplified models** are often used, involving a single mediator (Z') and a single type of WIMP (χ)



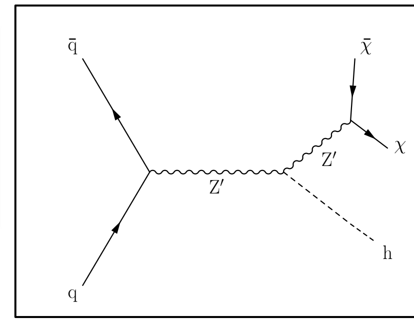
- **Mediator**: scalar/pseudo-scalar or vector/axial-vector, coupling to both SM and DM sectors
- **DM particle**: stable, neutral, weakly-interacting fermion
- **Parameters**: mediator mass and width ($m_{Z'}$, $\Gamma_{Z'}$) ; DM mass (m_χ) ; mediator couplings (g_q ; g_χ)

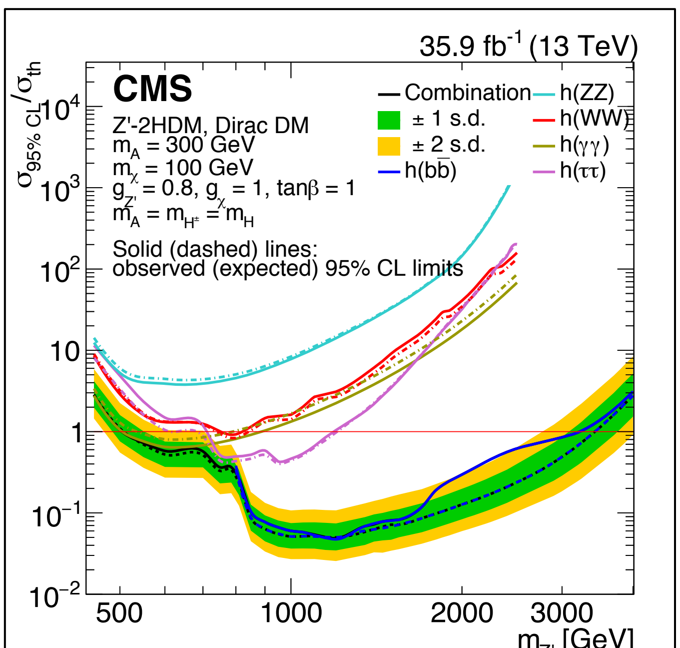
DM searches: mono-Higgs (CMS)

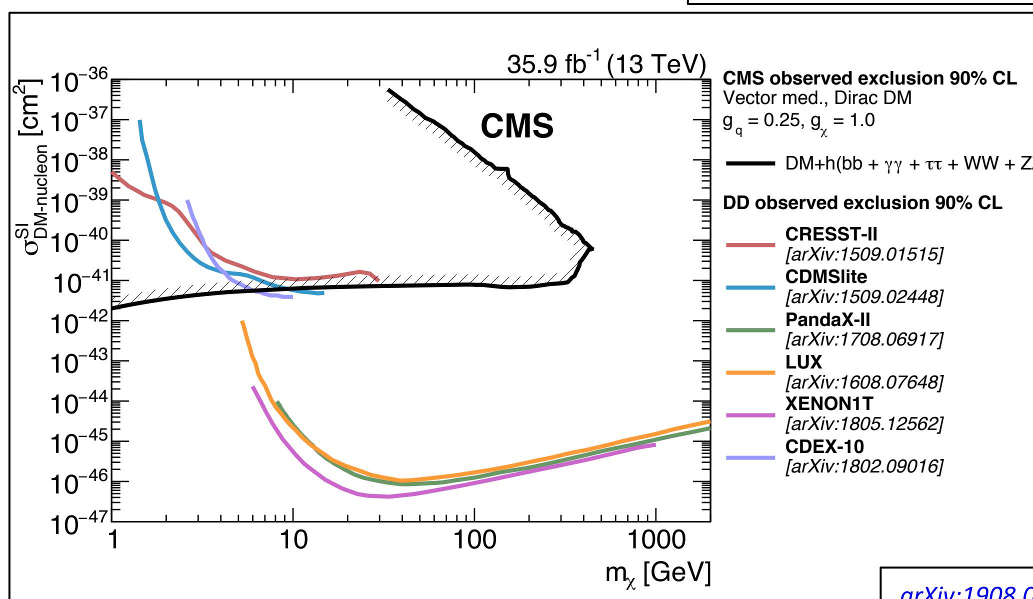
- **Search for DM particles produced in association with a Higgs boson** (arXiv:1908.01713).
- First search including mono-H(WW, ZZ) channels, combined with mono-H(bb, ττ, γγ).
- Two simplified models: Z'-2HDM ($U(1)_{Z'}$ extension) ; baryonic Z' (new baryonic number).
- Limits are reinterpreted in terms of DM-nucleon interaction cross section.



- Z'-2HDM: combination dominated by H(bb) at $m_{Z'}$ > 800 GeV. The gg, tt, WW channels provide the tightest constraints at lower mass.
- For the chosen set of parameters, the interaction cross section limits are more stringent than direct detection experiments for a DM mass between 1 and 5 GeV.



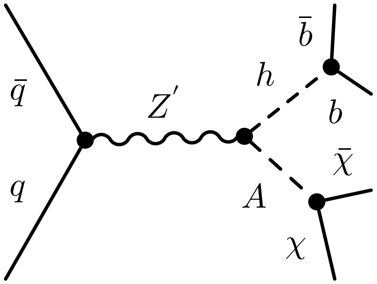


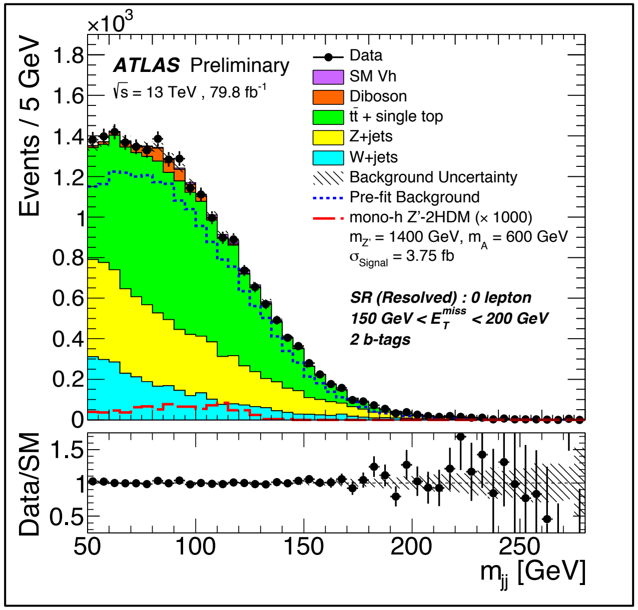


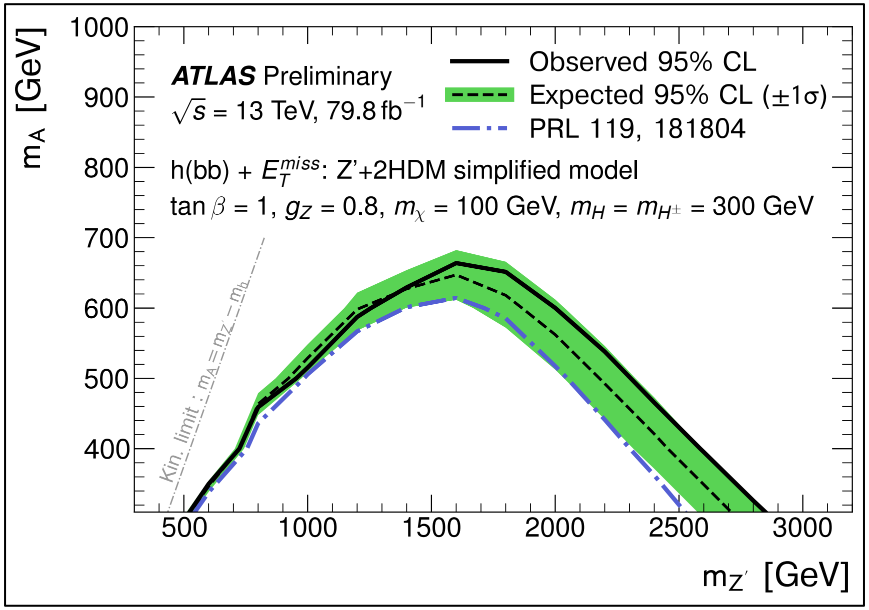
arXiv:1908.01713
Submitted to JHEP

DM searches: mono-H(bb) (ATLAS)

- ATLAS search for mono-H(bb) with 80 /fb. Interpretation in the context of the Z'-2HDM simplified model.
- Masses of the *Z'* are excluded up to 2.8TeV depending on the choices for other model parameters.

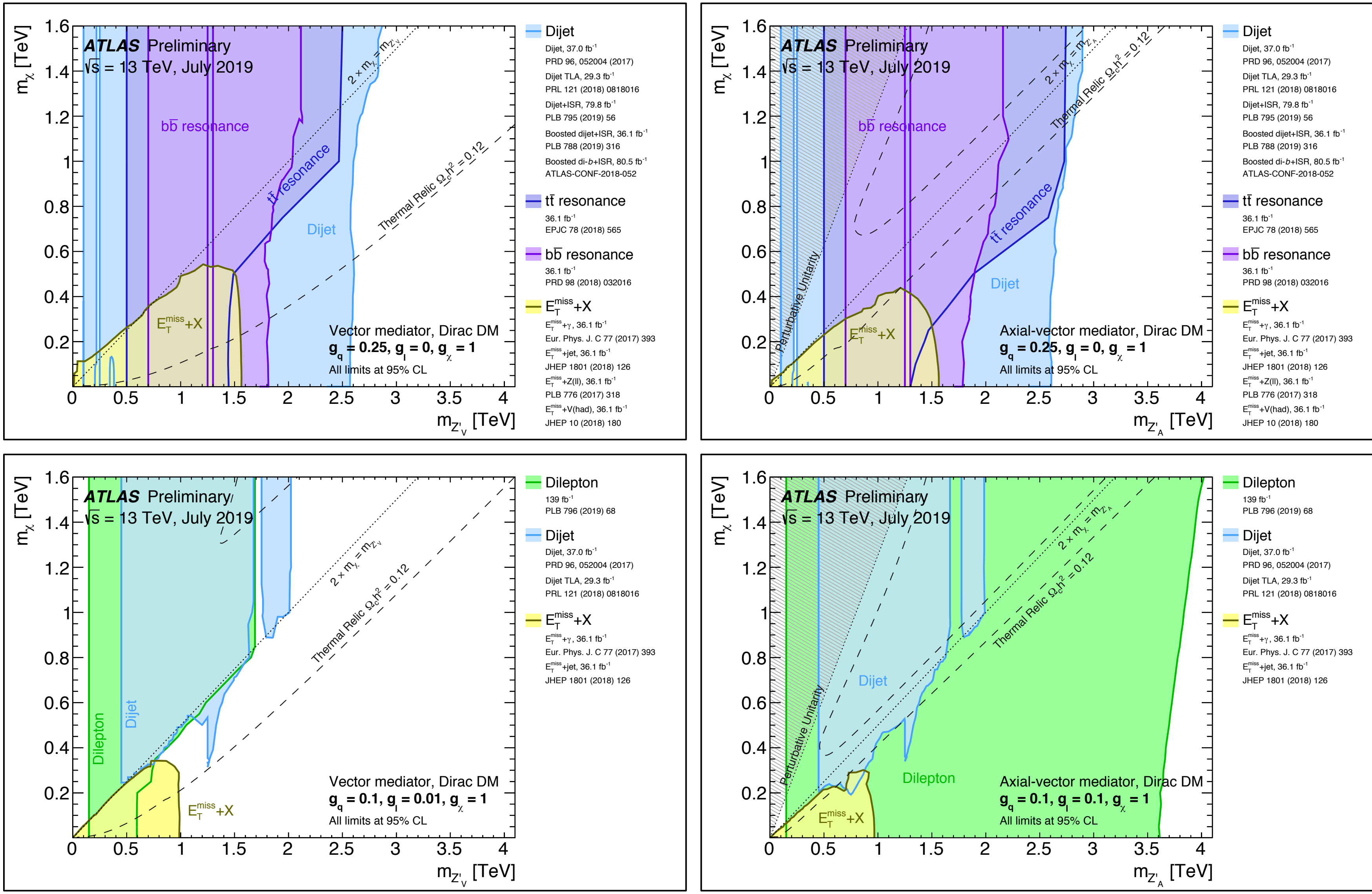






ATLAS_CONF_2018_039

DM searches summary: ATLAS



Masses of **leptophobic** (**leptophilic**) **vector** and **axial-vector** mediators between **200 GeV** and **2.5 TeV** (**3.5 TeV**), for coupling values g_q = 0.25 and g_χ = 1, and m = 1 TeV, are excluded at 95% CL.

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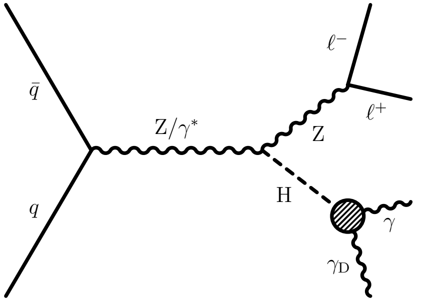
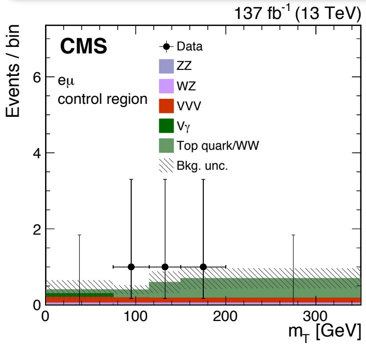
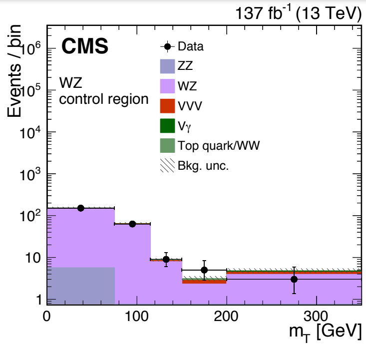
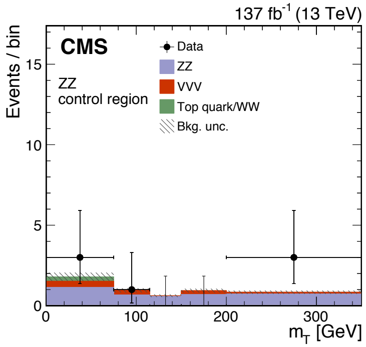
Dark photon searches (CMS)

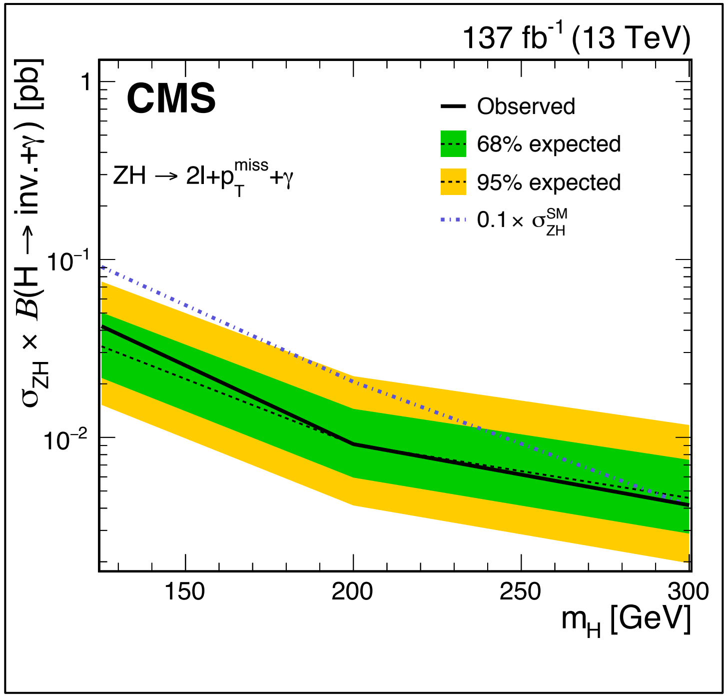
- **Search for a massless dark photon in ZH decays** (arXiv:1908.02699)
- It is however sensitive to BSM enhancements of the Higgs boson decay rate into an undetectable particle and a photon.
- It can also be used as a search for heavier Higgs bosons.











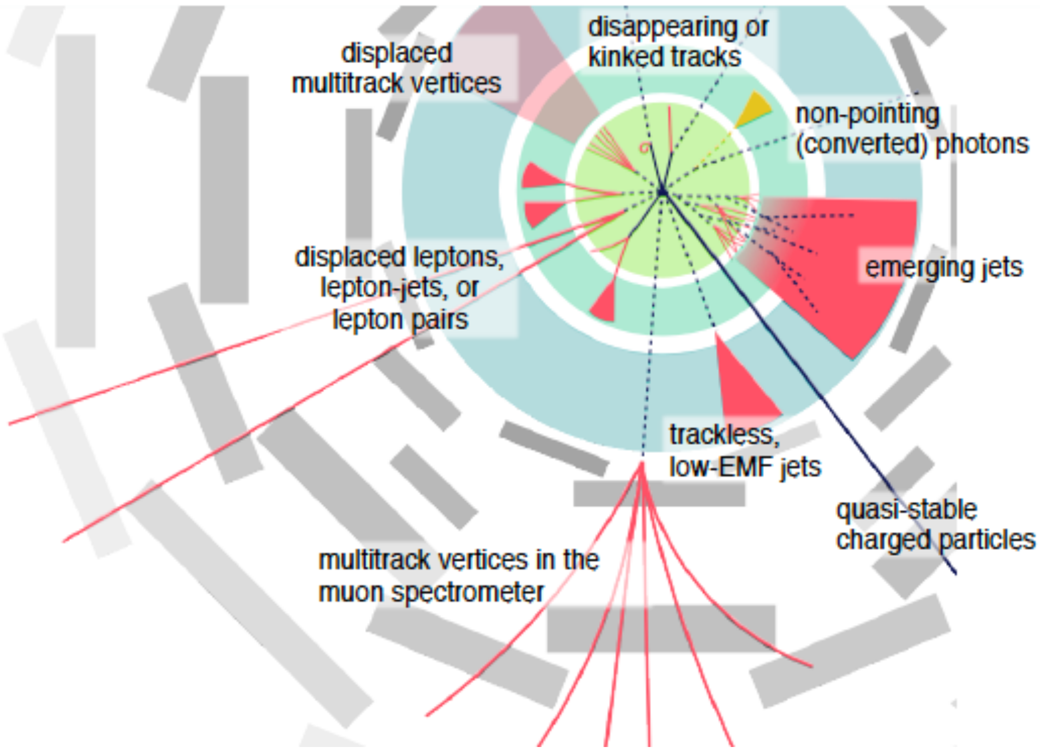
arXiv:1908.02699
Submitted to JHEP

- **Signature**: opposite-sign same-flavour dilepton compatible with a Z + large MET + isolated high-ET photon.
- WZ background suppressed by 3rd lepton veto. Top background suppressed by b-jet veto.
- Further topological requirement comparing the dilepton system to the (γ + MET) system suppress Zγ and Z+jets.
- Observed (expected) limit on **BR(H→inv + γ)** at m_H = 125 GeV : **4.6 (3.6) %**.

BSM Long-Lived Particles

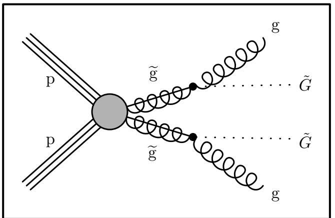
Long-Lived Particles

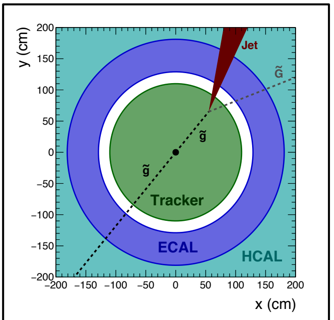
- Most LHC searches for new physics, which focus on prompt signatures, did not reveal any sign of exotic particles so far.
- An increasing number of atypical (non-prompt) signatures are analyzed as well in order to explore the long-lived particle (LLP) territory.
- Searches are categorized based on their signatures, that can by backed up by several theoretical models (including simplified models).



from LHC LLP white paper (arXiv:1903.04497)

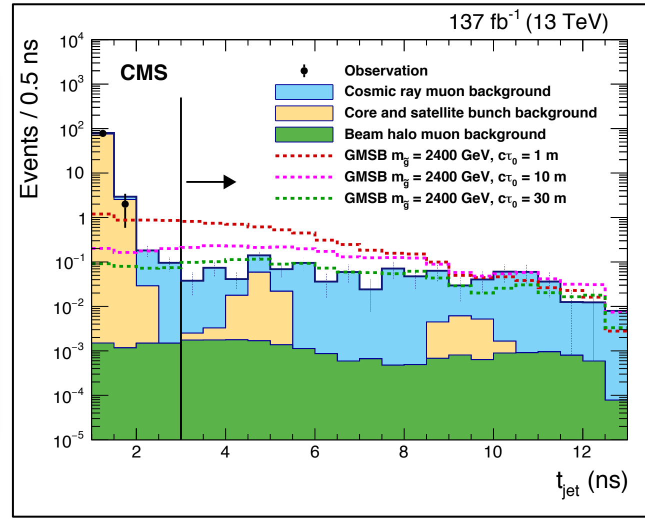
Displaced jet + MET (CMS)



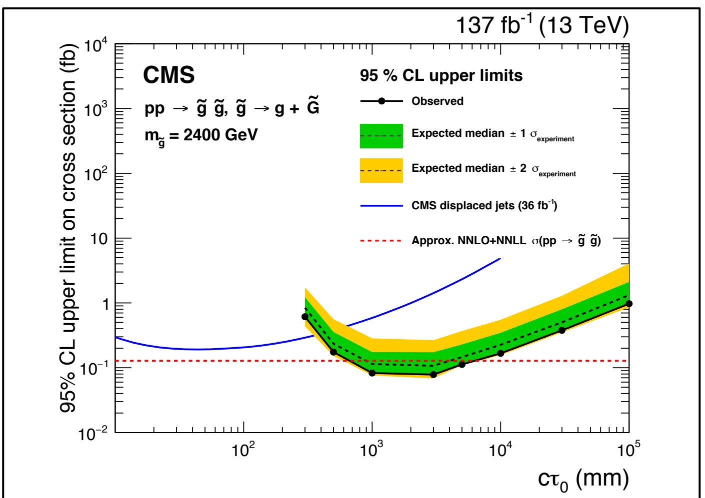


✧ **Final state : displaced jets and missing transverse momentum**

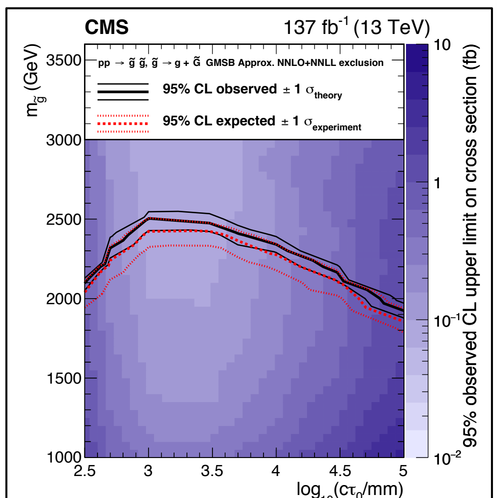
- GMSB SUSY model: $pp \rightarrow \tilde{g}(\tilde{G}g) + \tilde{g}(\tilde{G}g)$
- Pair-produced LL gluinos decay into gluons that form displaced jets, and gravitinos that escape the detector.
- CMS ECAL timing capabilities are exploited.
- Trigger: MET > 120 GeV & MHT > 120 GeV
- **Major backgrounds**: cosmic muons; ECAL timing tails from "core" LHC BX; activity from "satellite" BX; beam halo muons.



- **Jet selection**: various cuts (e.g. timing) suppress instrumental and beam backgrounds.
- **Event selection**: suppress MET instrumental/ beam contamination ; reject cosmic muons.
- **Background evaluation**: data-driven methods using control and validation regions based on noise-cleaning variables.



- 95% CL upper limit on $\sigma(pp \rightarrow \tilde{g}\,\tilde{g})$
- Blue line: results from **Phys. Rev. D 99, 032011**



- Limit in the (m_g ; $c\tau$) plane

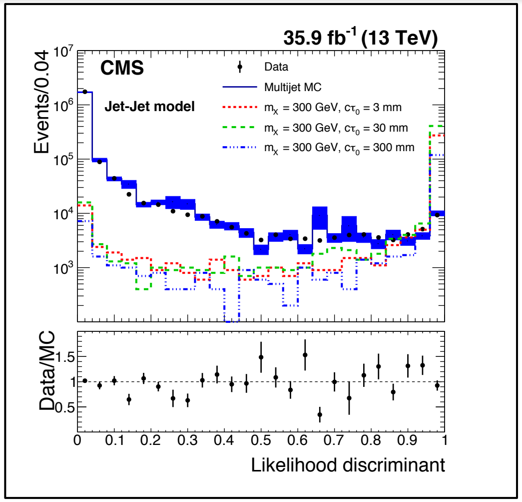
✧ **Results: exclusion limits**

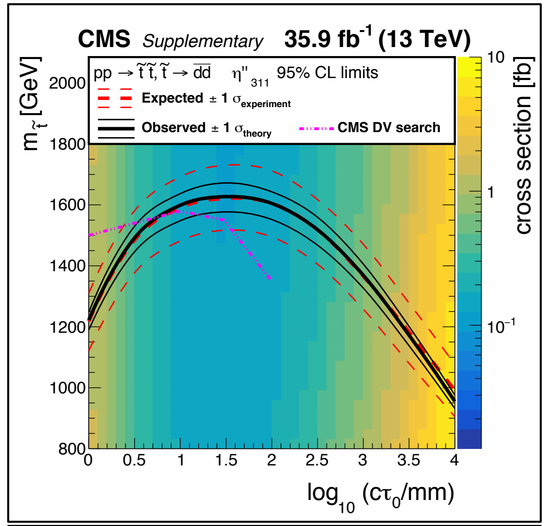
- **Gluino masses** up to **2100**, **2500**, and **1900** GeV are excluded at 95% CL for **cτ of 0.3, 1, and 100 m** (respectively)

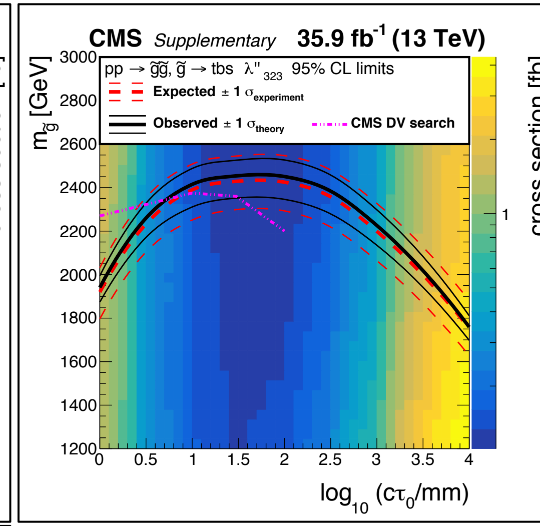
Phys. Lett. B 797 (2019) 134876

Displaced jets (CMS)

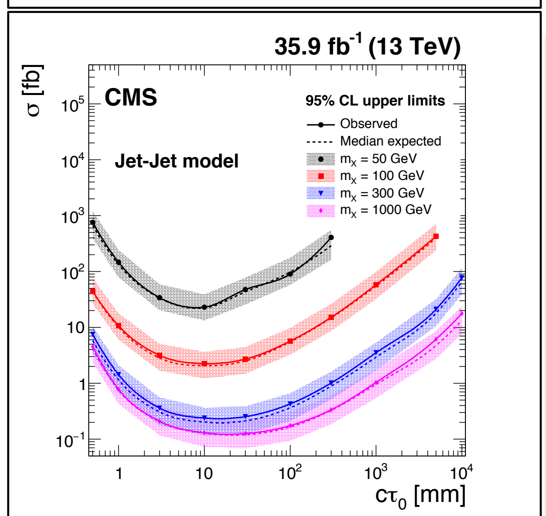
- **Search for LLP decaying into displaced jets**
  - Simplified model: pp → χ(qq) χ(qq)   where χ is a neutral LLP that decays into a quark-antiquark pair (u,d,c,s,b at equal BR)
  - Mass range: 5 – 3000 GeV   Decay length range: 1 mm – 10 m
  - Other models: GMSB SUSY ($pp \to \tilde{g}(\tilde{G}g) + \tilde{g}(\tilde{G}g)$) ; RPV SUSY ($\tilde{g}(tbs)$, $\tilde{t}(b\ell)$) ; dynamical RPV SUSY ($\tilde{t}(\overline{dd})$).







- **Trigger:** 2 jets (at most 1 prompt track and at least 1 displaced track) + HT
- Secondary vertices are fitted using displaced tracks associated with each dijet, they must verify χ^2, mass, and p_T conditions. An observable characterizing the dijet's prompt activity is also used.
- **Background evaluation**: likelihood discriminant based on the vertex track multiplicity and transvese displacement.



✧ **Results: 95% CL exclusion limits**

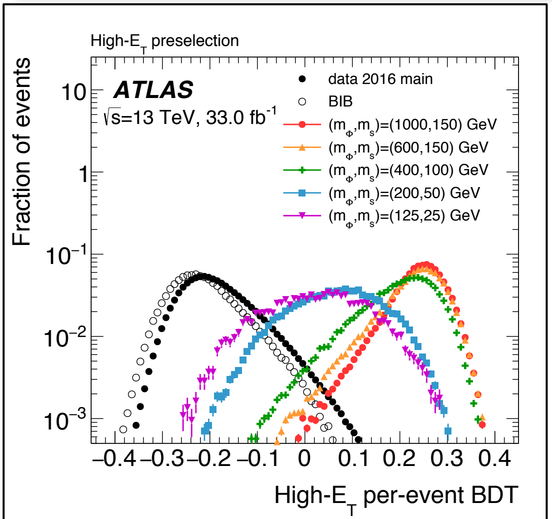
- **Simplified model** : upper limit of **0.2 fb** for **m_χ = 1000 GeV** and **cτ** between **3** and **130 mm**.

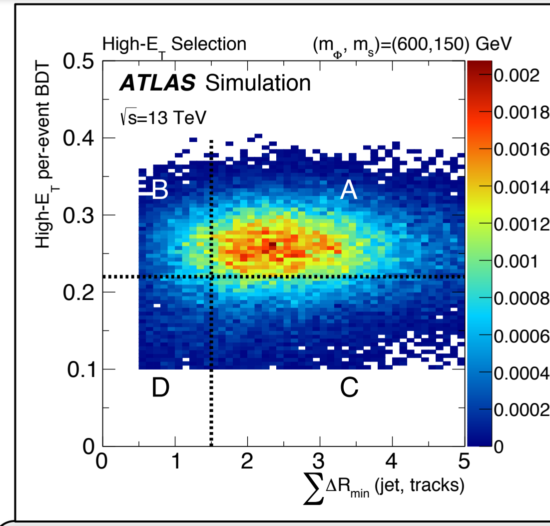
Model		Mass (GeV)	ct (mm)
GMSB	$\tilde{g}(\tilde{G}g)$	< 2300	20 - 110
RPV	$\tilde{g}(tbs)$	< 2400	10 - 250
RPV	$\tilde{t}(b\ell)$	< 1350	7 - 110
dRPV	$\tilde{t}(\overline{dd})$	< 1600	10 - 110

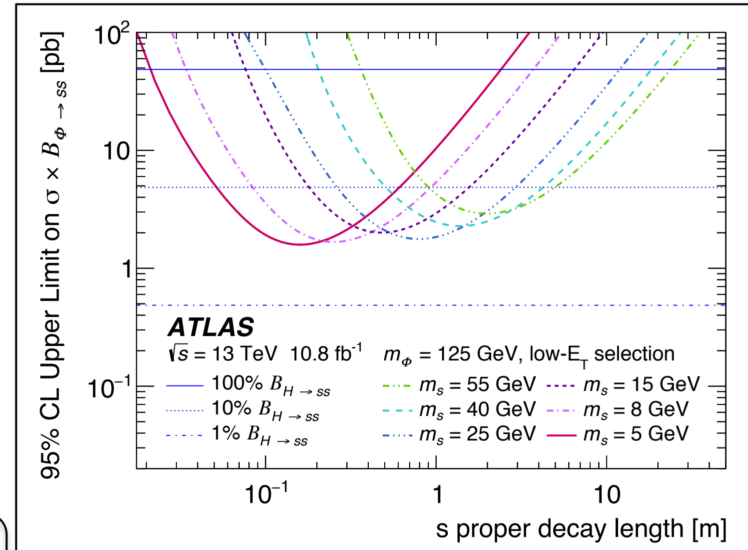
Phys. Rev. D 99 (2019) 032011. Note: DV = displaced vertices (Phys. Rev. D 98 (2018) 092011)

Displaced jets (ATLAS)

- **Search for neutral LLP decaying into displaced hadronic jets in the ATLAS calorimeter**
  - Simplified Hidden Sector model: neutral boson Φ (125 – 1000 GeV) + neutral scalar s (5 – 400 GeV) : Φ → s s → 4 fermions
  - Assuming BR(s → f) = BR(H_{125} → f) implies 85% of the decays are in the bb final state (for $m_s \geq 25$ GeV)
  - s(qq) decays into a single jet, narrower than SM ones, without any track, with a large E_{HAD} / E_{EM} ratio.







✧ **Trigger**: jets with topological conditions, noise cleaning, track veto, beam-induced background (BIB) removal.

✧ **Jet selection:**
- 1 multilayer perceptron to get decay positions (Lxy, Lz)
- multiclassifier BDT (signal, QCD, BIB).

✧ **Event selection:** BDT (BIB vs signal)

✧ **Background estimation**: ABCD method
- ∑ΔR: summed angular distance between each jet's axis and the closest track
- Per-event BDT value

✧ Accounts for non-zero signal contamination in control regions.
- *Fitting simultaneously signal and bkg*

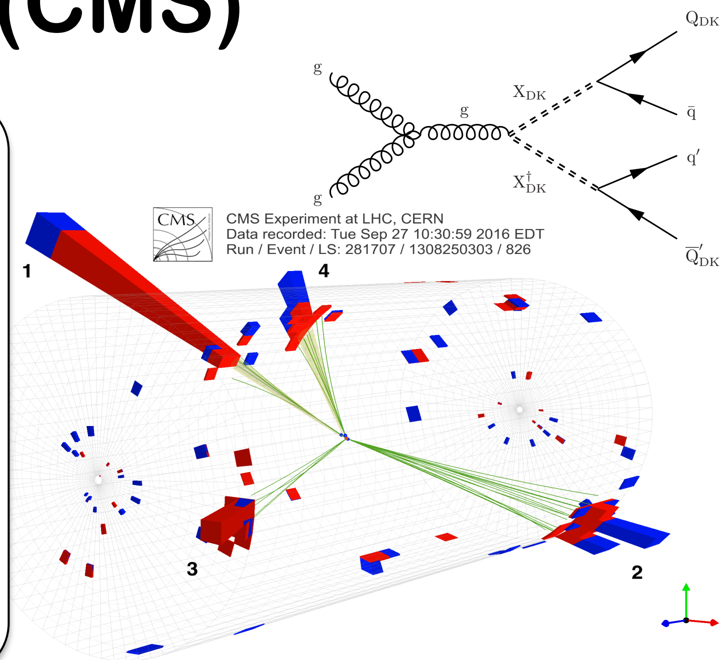
✧ Main source of uncertainty (25%).

✧ **Results: exclusion limits**
- 95% CL observed upper limit on σ(Φ) x BR(Φ→ss)
- Example plot above: assumes a mediator similar to the Higgs boson (ie m=125 GeV)
- Upper limit is divided by the ggH production cross section at 13 TeV (ie 48.58 pb).

Assuming **BR=10%**, LLPs (**m = 5 to 55 GeV**) are excluded in a **cτ** range of **5 cm to 5 m.**

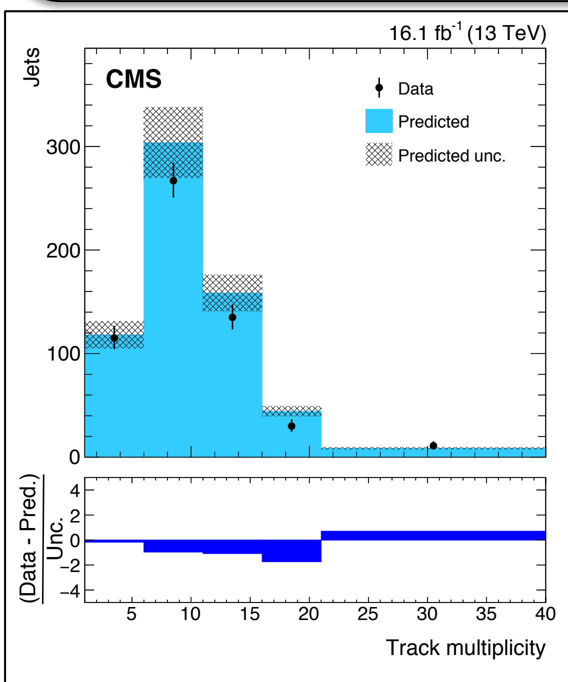
Eur. Phys. J. C 79 (2019) 481

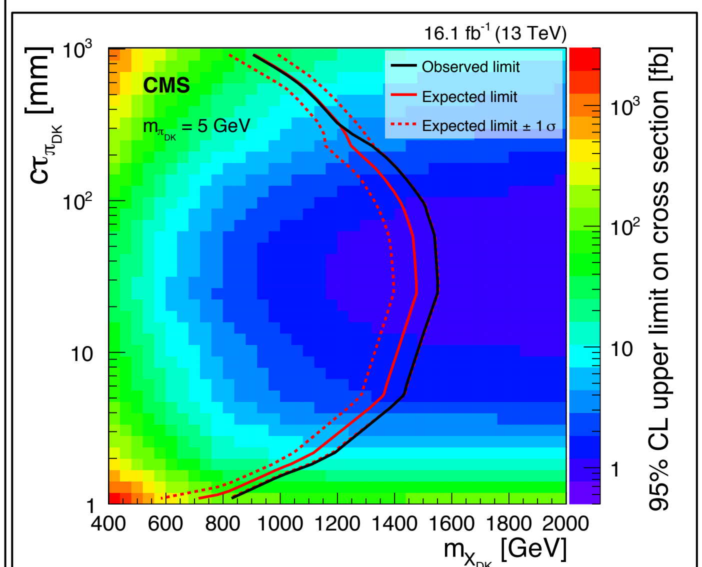
Emerging jets (CMS)



✧ Final state : prompt jets + emerging jets

- **Dark QCD** model: assumes DM is made of dark quarks (Q_{DK}) that interact with SM particles through a complex scalar mediator X_{DK}
- **Signature**: 2 jets from SM quarks + 2 jets from dark quarks (forming dark pions).
- The **emerging jet (EMJ) identification** makes use of observables based on the event's tracks topology and kinematics. Several sets of event selection criteria are defined. Each signal point is assigned the set that maximizes the significance.
- **Background evaluation**: evaluate the probability for a QCD (b, light) jet to pass the EMJ criteria (main source of uncertainty).





✧ Results: exclusion limits

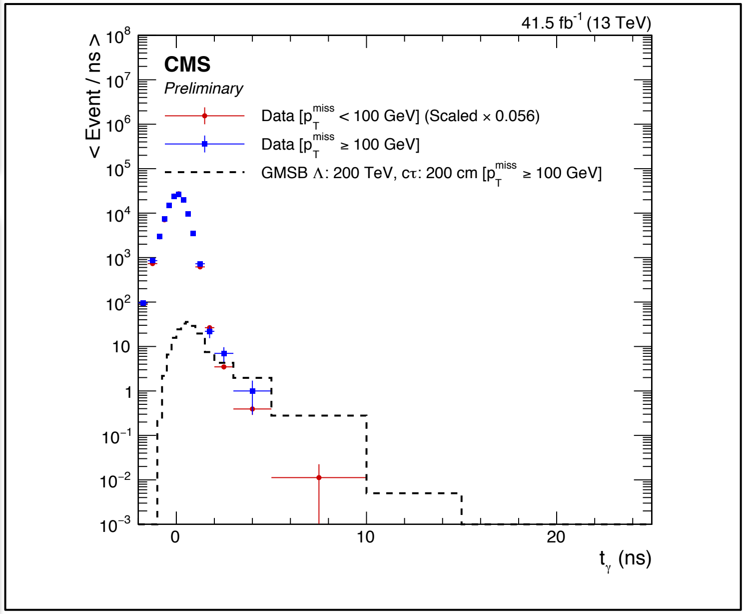
- For $M(X_{DK})$ in 400 − 1250 GeV : dark pions with cτ in 5 − 225 mm are excluded
- The excluded ct range is wider at lower $M(X_{DK})$ masses.
- The limit depends weakly on $M(Q_{DK})$ for values between 1 and 10 GeV.

JHEP 02 (2019) 179

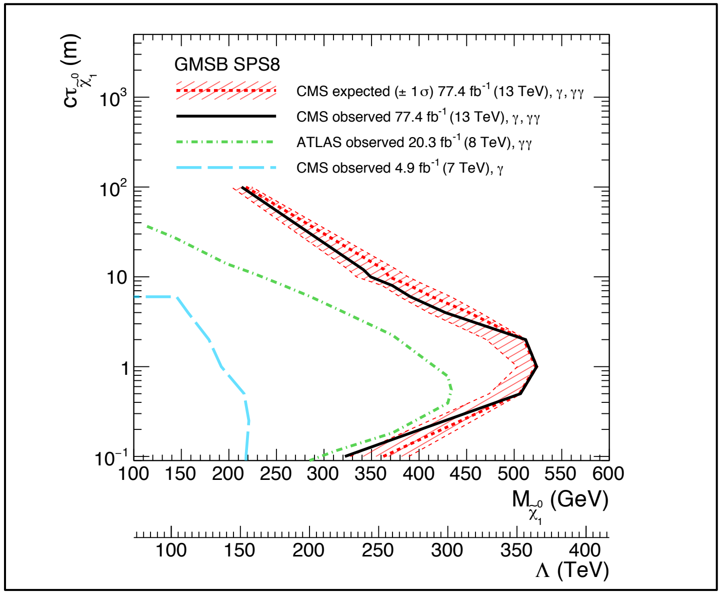
Delayed photons (CMS)

✧ **Search for LLPs decaying to photons**

- Benchmark model "Snowmass Points and Slopes 8 (SPS8)" (Eur. Phys. J. C 25 (2002) 113)
- **GMSB SUSY** model: decay chains producing long-lived neutralinos leading to final states with one or two photons, jets, and missing transverse momentum (MET).



- **Trigger**: diphoton (ET > 42, 25 GeV) in 2016. Dedicated delayed photon (more elliptical shower in the ECAL) + H_T algorithm in 2017.
- **Delayed photons**: out-of-time γ (seeded by ECAL deposits delayed by > 3 ns).
- **Event** : ≥ 1 central (|η|<1.444) photon (pT > 70 GeV) + delayed ID requirement. ≥3 jets. HT > 400 GeV in 2017 (efficient region of the 2017 trigger).
- **Background estimation**: ABCD method using MET and t_γ criteria (main uncertainty).



✧ **Results: exclusion limits**

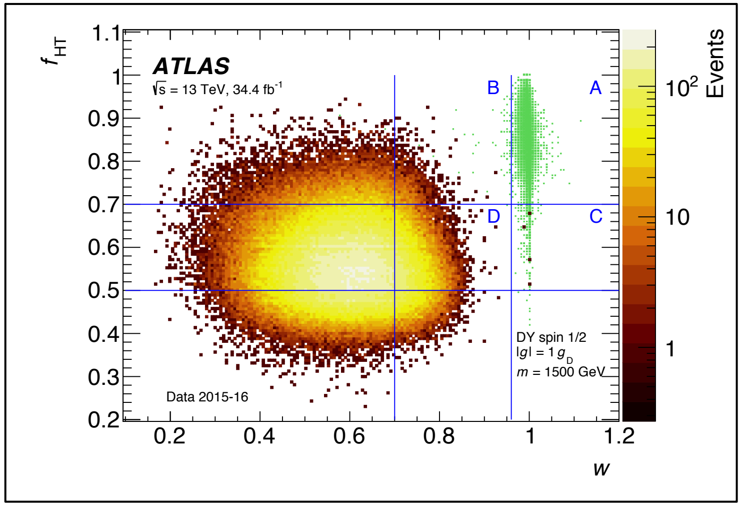
- For neutralino cτ of 10, 10^2, 10^3, 10^4 cm, masses up to 320, 525, 360, 215 GeV are excluded at 95% CL, respectively.
- The previous best limits are extended by about one order of magnitude in the neutralino proper decay length.
- The mass reach is improved by about 100 GeV.

arXiv:1909.06166
Submitted to PRD

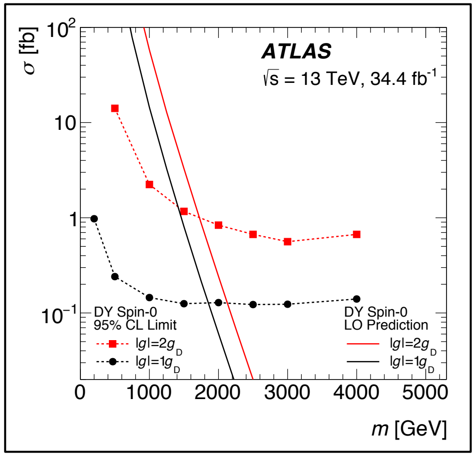
Monopoles & high-electric charge objects

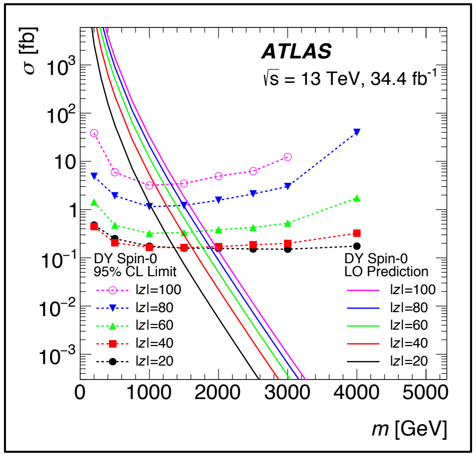
✧ **Search for magnetic monopoles and high-electric charge objects (ATLAS)**

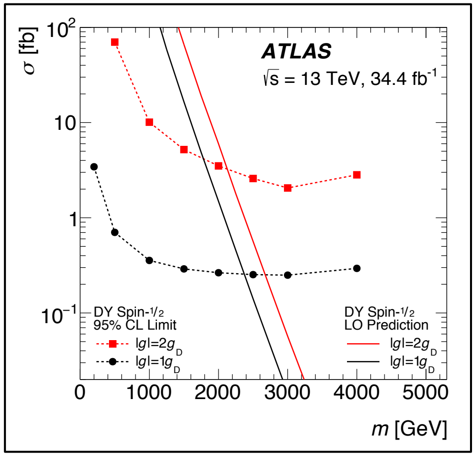
- Dirac's magnetic monopole description explains electric charge quantization
- Some extensions of the SM predict monopole masses accessible at the LHC.
- High-ionization signature that is also expected with stable High-Electric Charge Objects (HECOs).

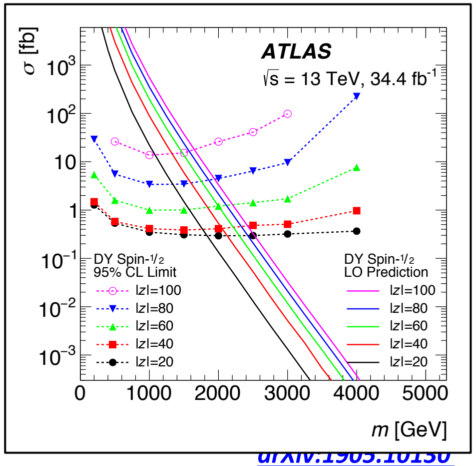


- **Trigger**: L1 → total $E_T \geq 22$ GeV in the electromagnetic calorimeter (ECAL). HLT → "high-threshold" (≥ 2 keV / 6 keV) hits in the transition radiation tracker + veto based on energy deposit in hadronic calorimeter.
- **Event selection**: 1 candidate with a topological cluster in the electromagnetic calorimeter. 2 selection variables are defined: fraction of tracker hits in a given window ; energy dispersion in the cluster.
- **Backgrounds**: overlapping charged particles; tracker or ECAL noise; high-energy electrons.





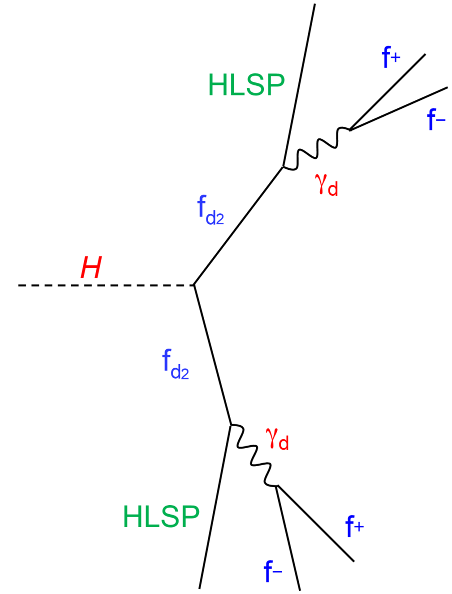




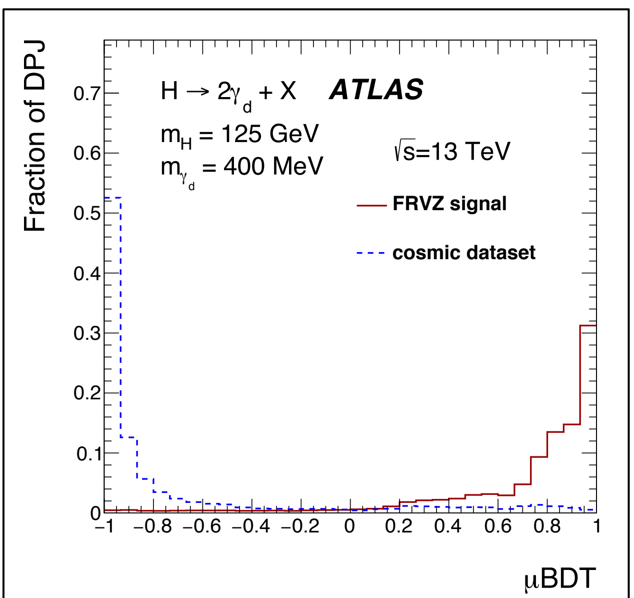
arXiv:1905.10130
Submitted to PRL

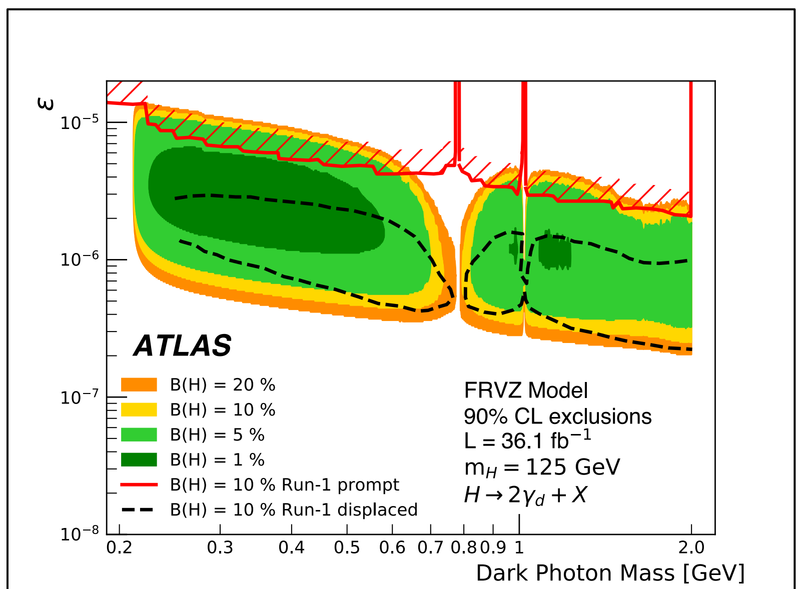
Collimated leptons & light hadrons (ATLAS)

✧ **Light neutral LLPs decaying into collimated leptons and light hadrons.**
- Dark photon model in which a hidden sector is connected to the SM through Higgs portal.
- Benchmark model: Falkowski–Ruderman–Volansky–Zupan (FRVZ).
- Small-mass γ_D → collimated photons or hadrons → "dark photon jet" (DPJ)



- **Muon trigger:** triple-muon (purely based on muon detectors) + non-prompt collimated muon.
- **Calorimeter trigger** : targeting narrow jets produced mostly within the hadronic calorimeter + beam-induced background cleaning.
- **Event selection**: based on the definition of two classes of DPJs. Muonic: Cambridge-Aachen clustering (R=0.4) of muons (BDT to suppress cosmic background). Hadronic: BDT to suppress QCD jets.
- **Main background**: QCD multijets, evaluated through ABCD method based on DPJ isolation and opening angle between DPJs.



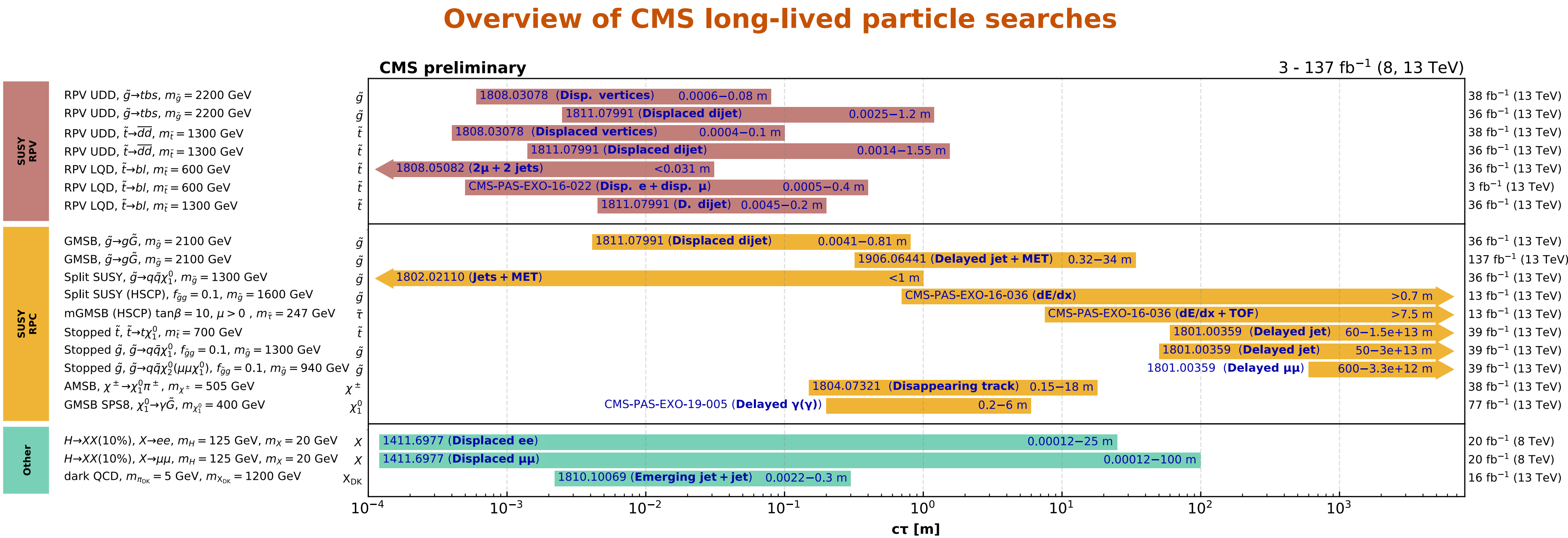


✧ **Results: exclusion limits**

Upper limit on
$\sigma(H) \times BR(H \rightarrow \gamma_D \gamma_D)$:
4 pb for $c\tau$ in 1.5 – 307 mm.

arXiv:1909.01246
Submitted to EPJC

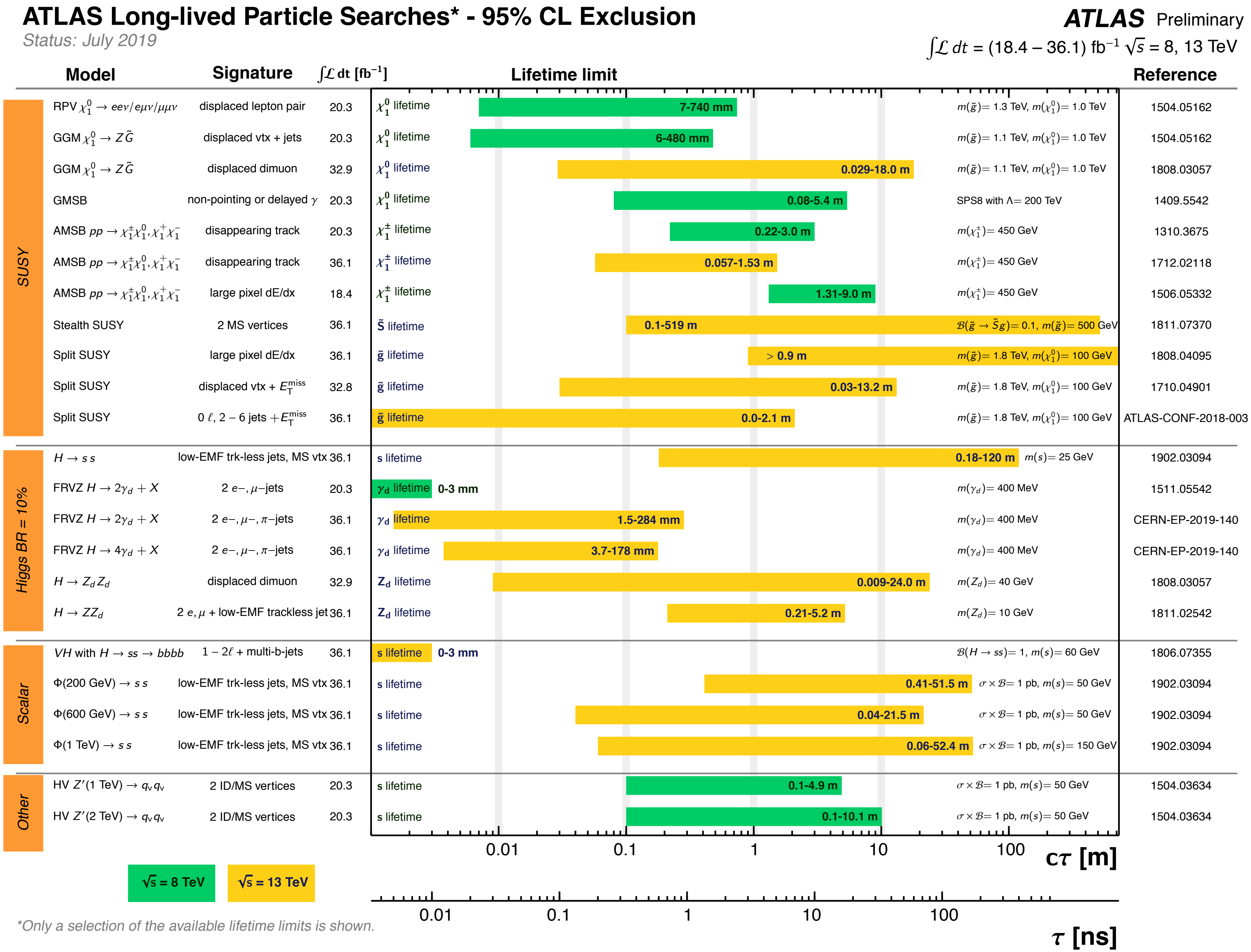
LLPs : CMS summary plot



July 2019

Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.

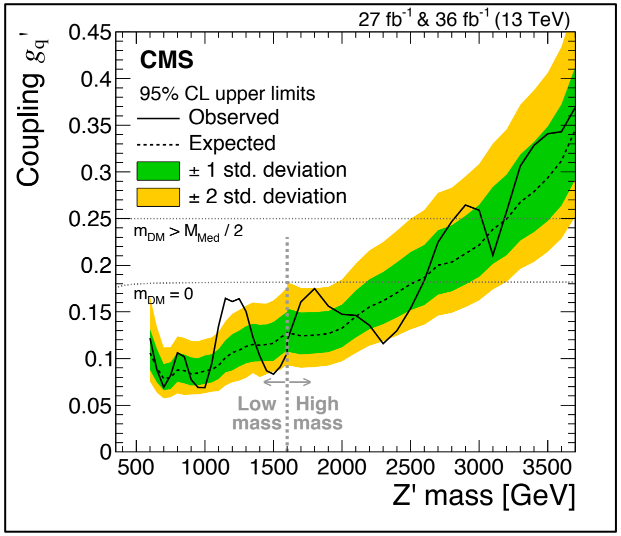
LLPs : ATLAS summary plot

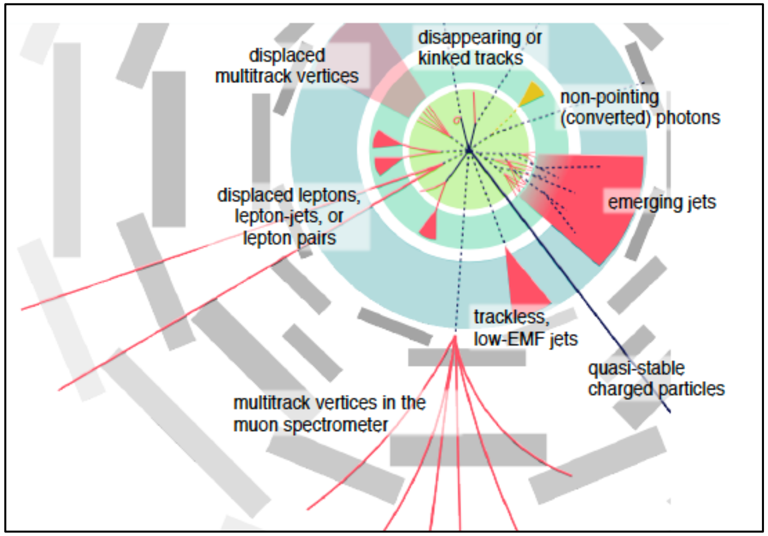


Conclusion

Conclusion

- Searches for new physics at the LHC are providing progressively tighter constraints, thanks to:
  - developing or strengthening evolved online and offline approaches (e.g. trigger-level analysis, jet substructure, background fitting methods, etc) ;
  - exploring non-conventional signatures ;
  - analyzing an increasing integrated luminosity.





- A number of searches for new physics have been performed with the full Run-2 data set.
- Novel signatures have been explored with a partial data set and updates with full data are under way.

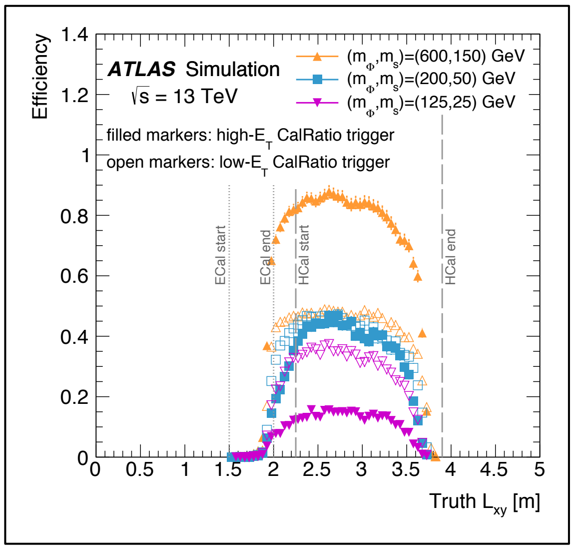
Thanks for your attention

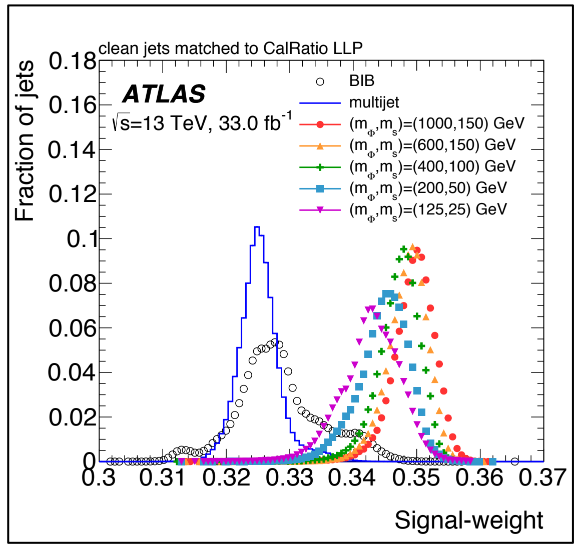
BACKUP

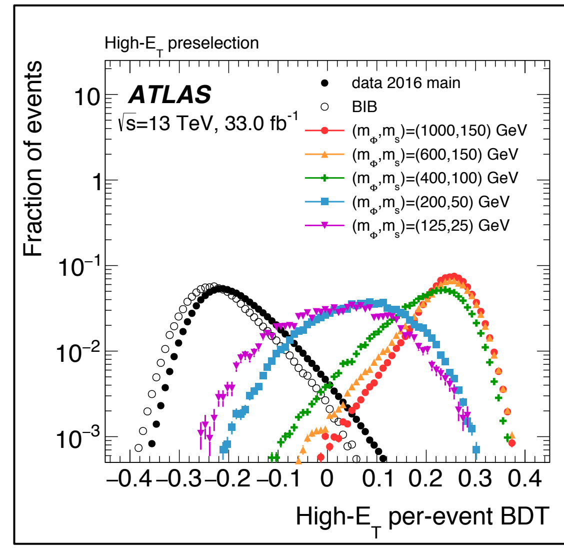
LLPs : displaced jets

Eur. Phys. J. C 79 (2019) 481

- **Search for neutral LLP decaying into displaced hadronic jets in the ATLAS calorimeter**
  - Simplified Hidden Sector model: neutral boson mediator Φ (125 − 1000 GeV) + neutral scalar s (5 − 400 GeV)
  - Decay chain: $\Phi \rightarrow s\, s \rightarrow 4$ fermions
  - Assuming BR(s $\rightarrow$ f) = BR($H_{125} \rightarrow$ f) implies 85% of the decays are in the bb final state (for $m_s \geq 25$ GeV)
  - Assuming s decays within calorimeters: s(qq) forms a single jet, narrower than SM ones, without any track, with a large E_{HAD} / E_{EM} ratio.







Trigger : 2 complementary algorithms
- **L1** “high-ET” : 2 jets ET>60 GeV
- **L1** “low-ET” : 2 jet ET>30 GeV + ECAL/ HCAL **topological** condition
- **HLT** : anti-kT (0.4) jet ET>30 GeV, dedicated jet **cleaning**, **track veto**, $\mathbf{E_{HAD}}$ **/** $\mathbf{E_{EM}}$ condition, beam-induced background (**BIB**) removal
- *BIB + cosmic datasets for bkg studies.*

✧ **Jet identification** : multilayer perceptron
- **Input:** jet energy fraction in each ECAL/ HCAL layer
- **Output**: longitudinal and radial decay positions Lxy and Lz

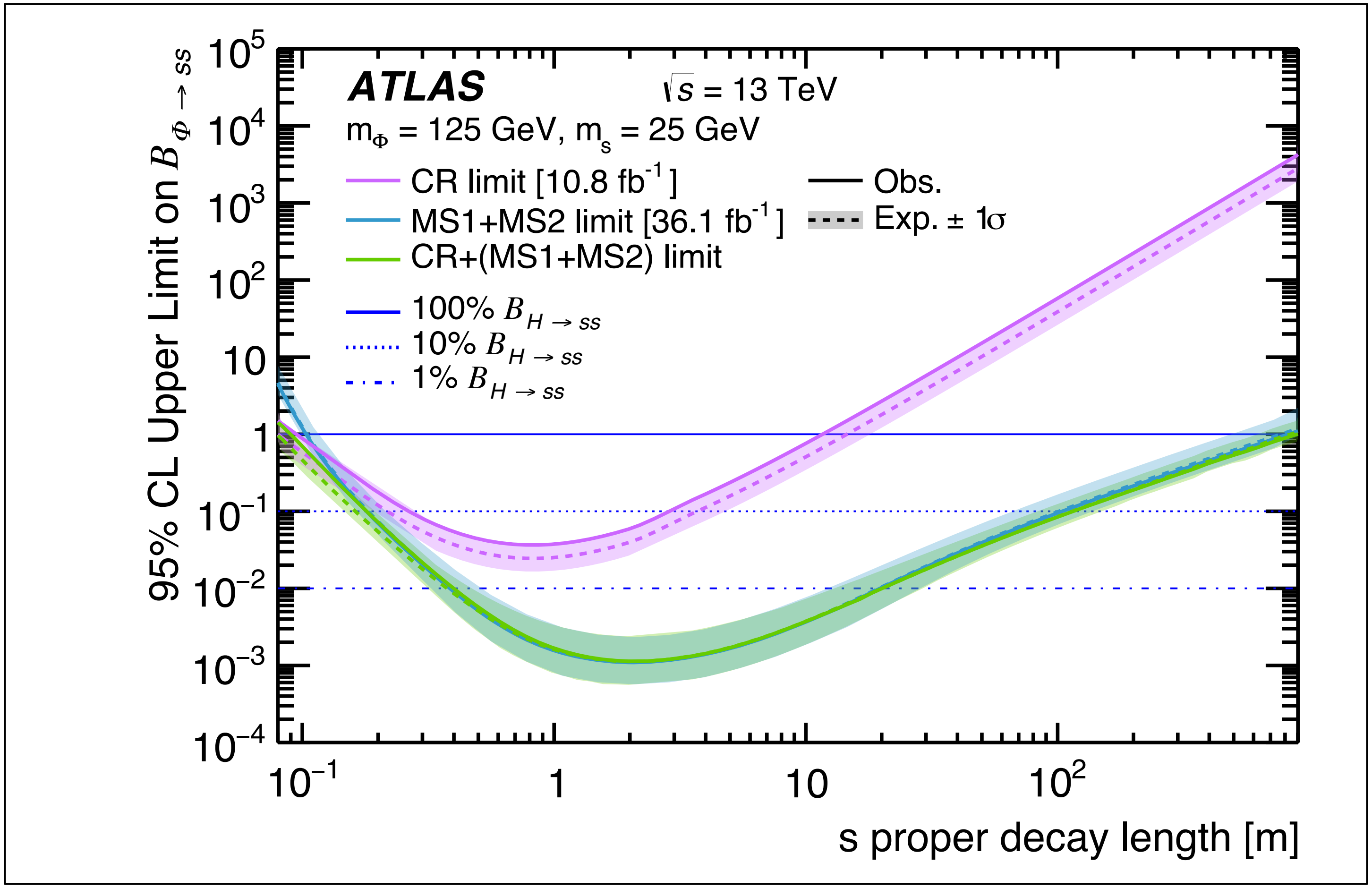
✧ **Jet selection:** per-jet BDT separating jets in 3 classes: signal, multijet, BIB.
- Uses track and jet variables, Lxy, Lz.

Event selection: per-event BDT
- **Input:** per-jet weight of the 2 most signal-like and the 2 most BIB-like jets. HTmiss / HT. ΔR(signal jets).
- **Output**: discriminator between BIB and signal events.

LLPs : displaced jets

Eur. Phys. J. C 79 (2019) 481

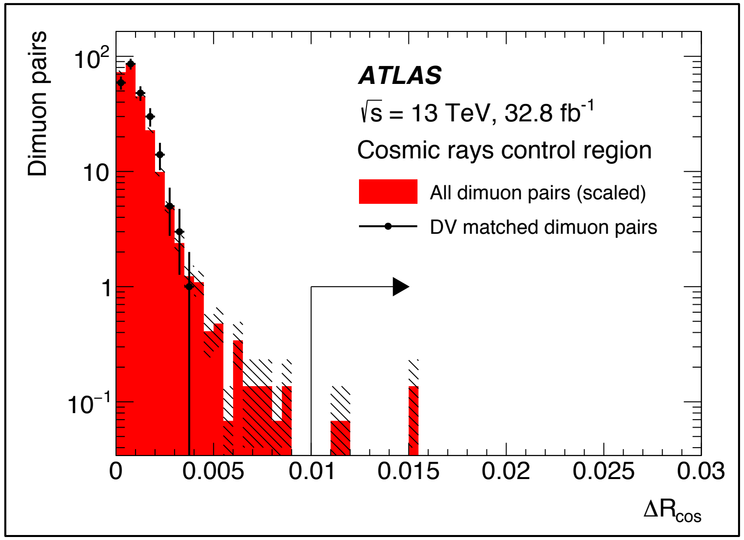
➢ **Search for neutral LLP decaying into displaced hadronic jets in the ATLAS calorimeter**



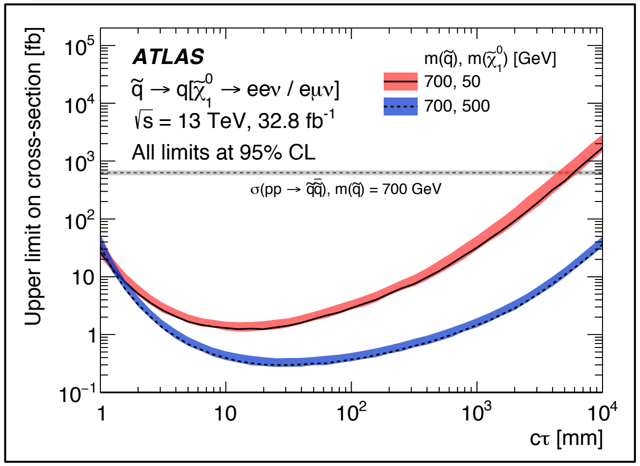
Displaced dilepton vertices (ATLAS)

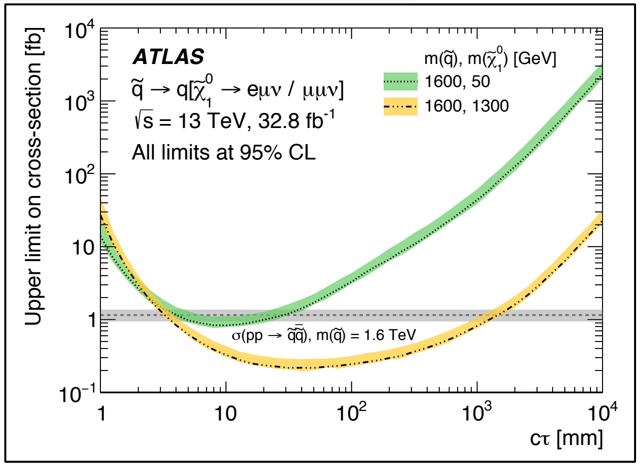
✧ Search for LLPs decaying into dileptons

- Simplified RPV SUSY: squark pair decaying into LL neutralinos, each of them leading to an opposite-sign dilepton and a neutrino.
- Toy model: LL Z' to dilepton.
- These two models are chosen to represent 2-body and 3-body scenarios.



- **Trigger**: single displaced muon ; single and double photon (to select efficiently displaced electrons).
- **Event selection**: dedicated tracking and displaced vertex (DV) reconstruction algorithms are exploited. Requirements on DV transverse displacement. Lepton reconstruction using displaced tracks.
- **Main background**: cosmic muons mimicking displaced dimuons. Rejected using dimuon topological variable.



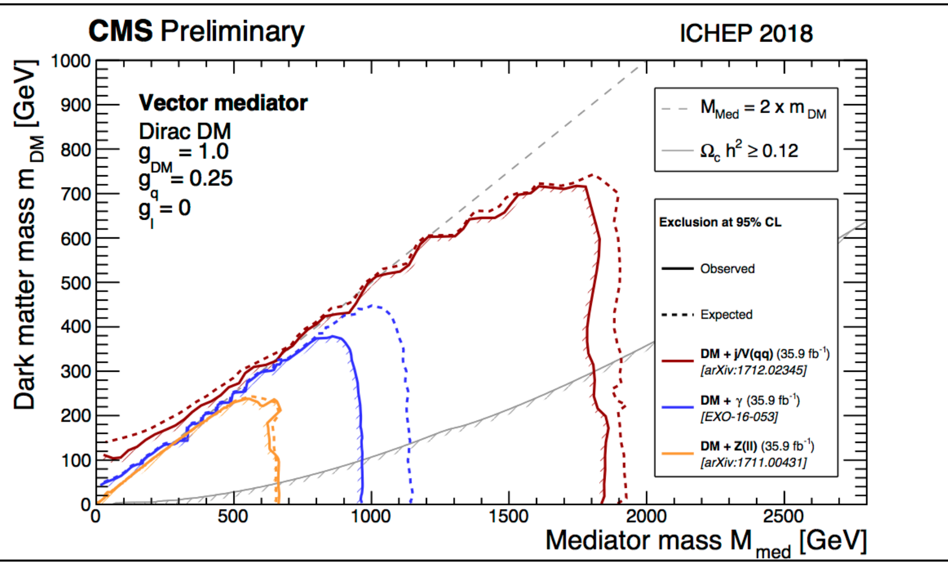


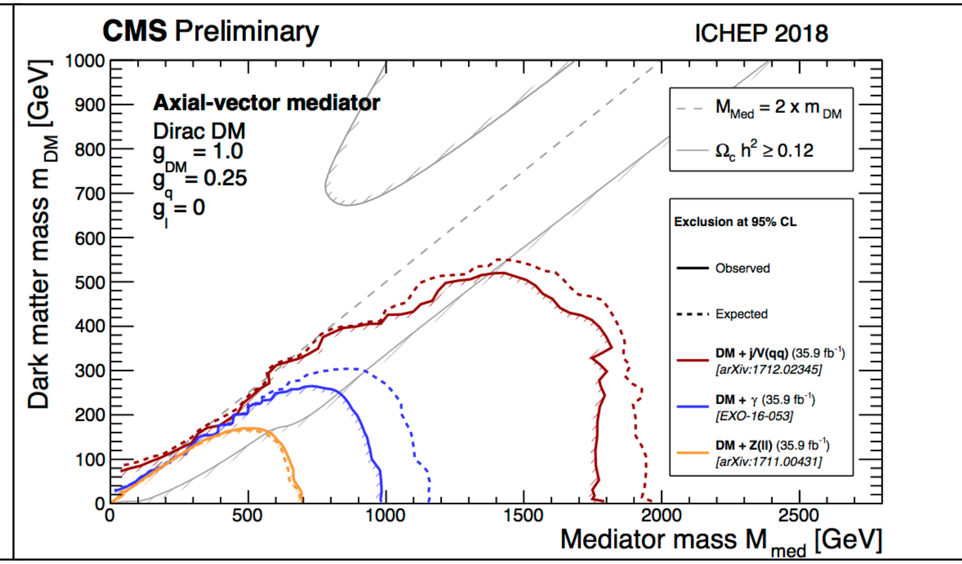
✧ Results: exclusion limits

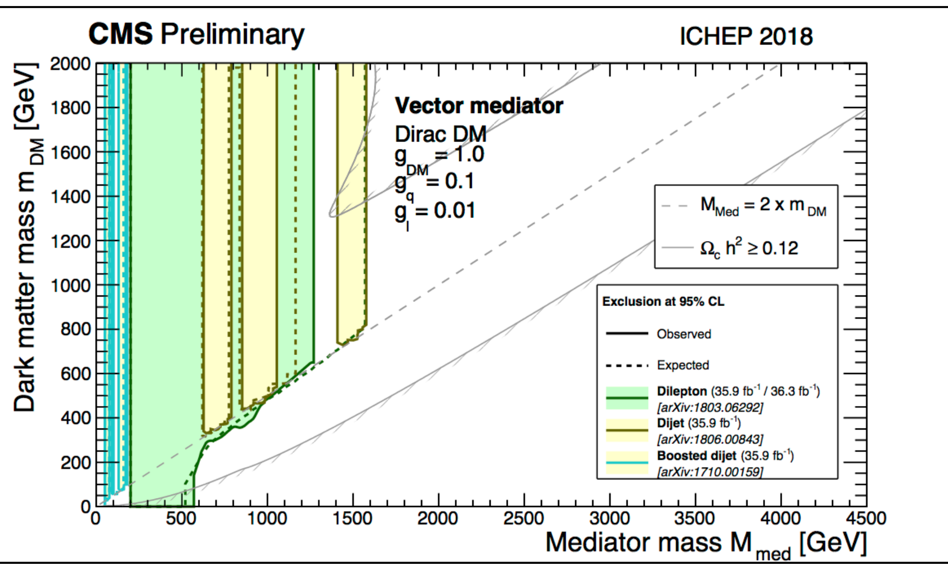
- For a 700 GeV squark, neutralinos with masses of 50–500 GeV and cτ of 1 mm to 6 m are excluded.
- For a 1.6 TeV squark, neutralinos with a mass of 1.3 TeV and cτ of 3 mm to 1 m are excluded.

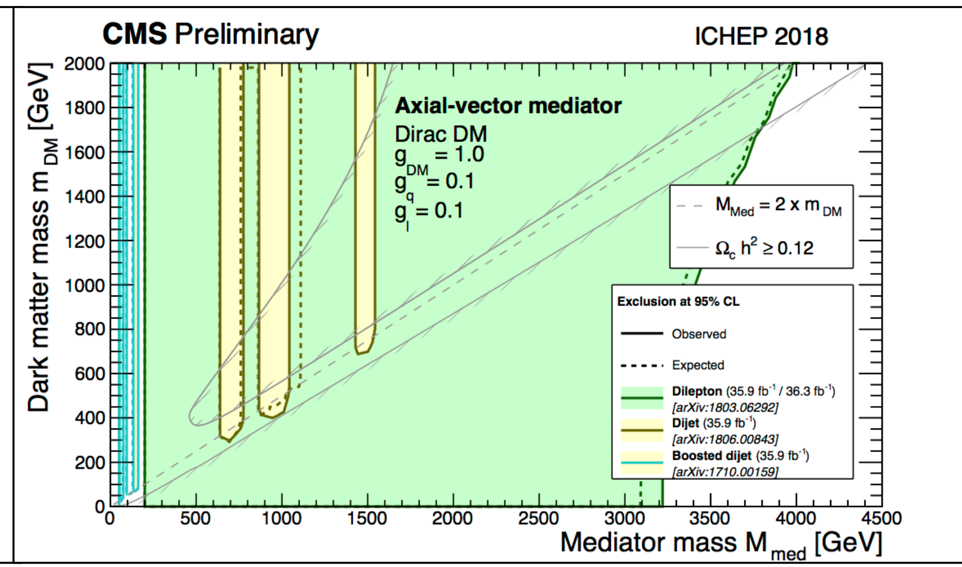
arXiv:1907.10037
Submitted to PLB

DM searches summary: CMS









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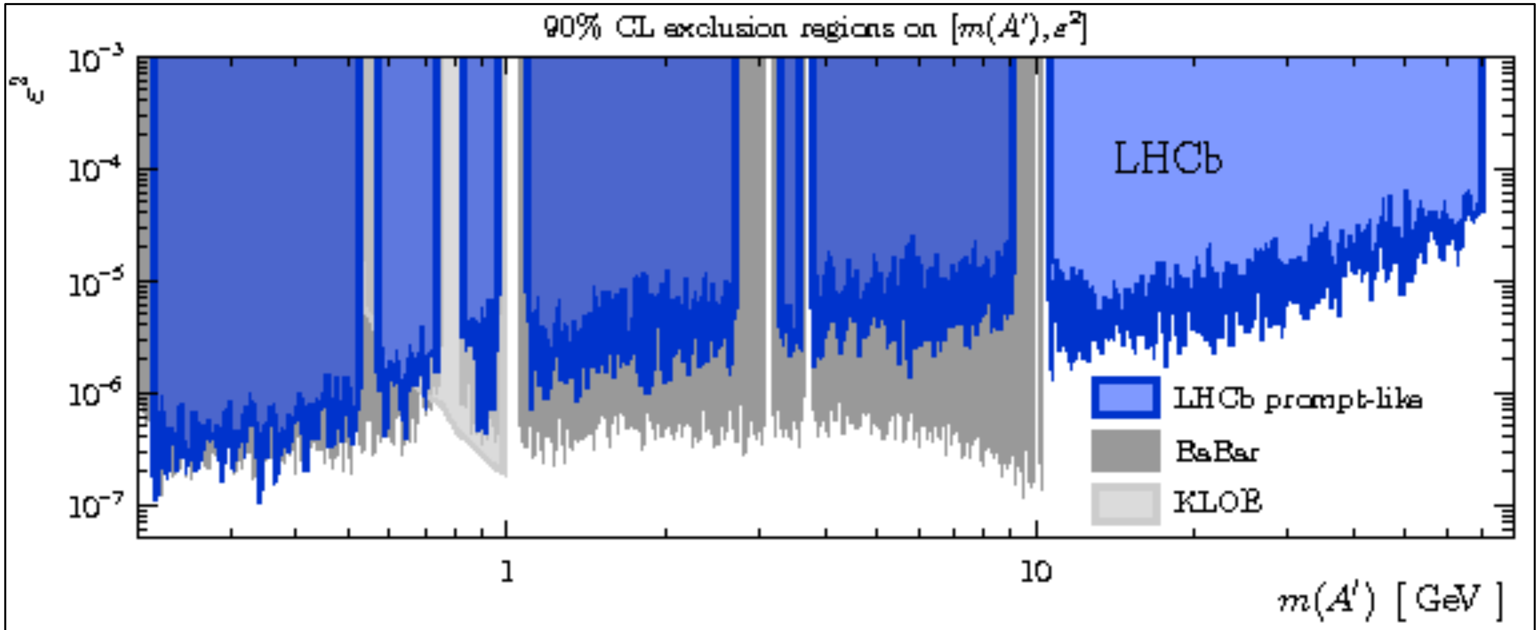
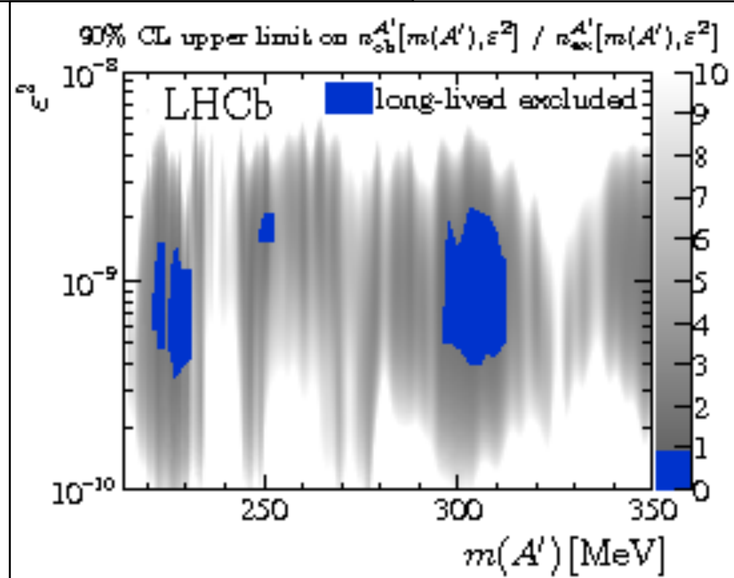
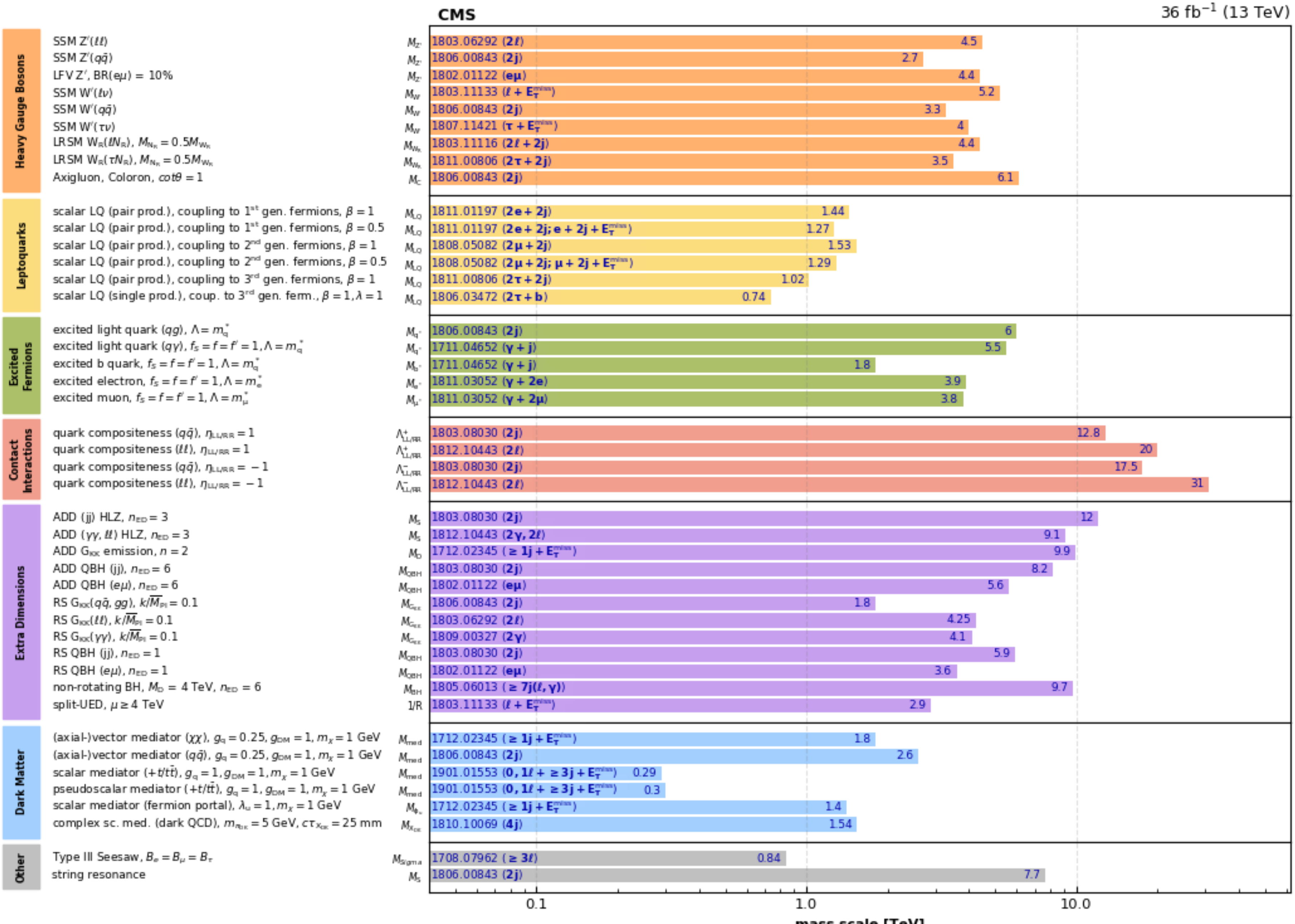
Dark photon searches (LHCb)

- **Search for prompt or long-lived dark photons in the dimuon final state** ([*Phys. Rev. Lett.* 120 (2018) 061801](#))



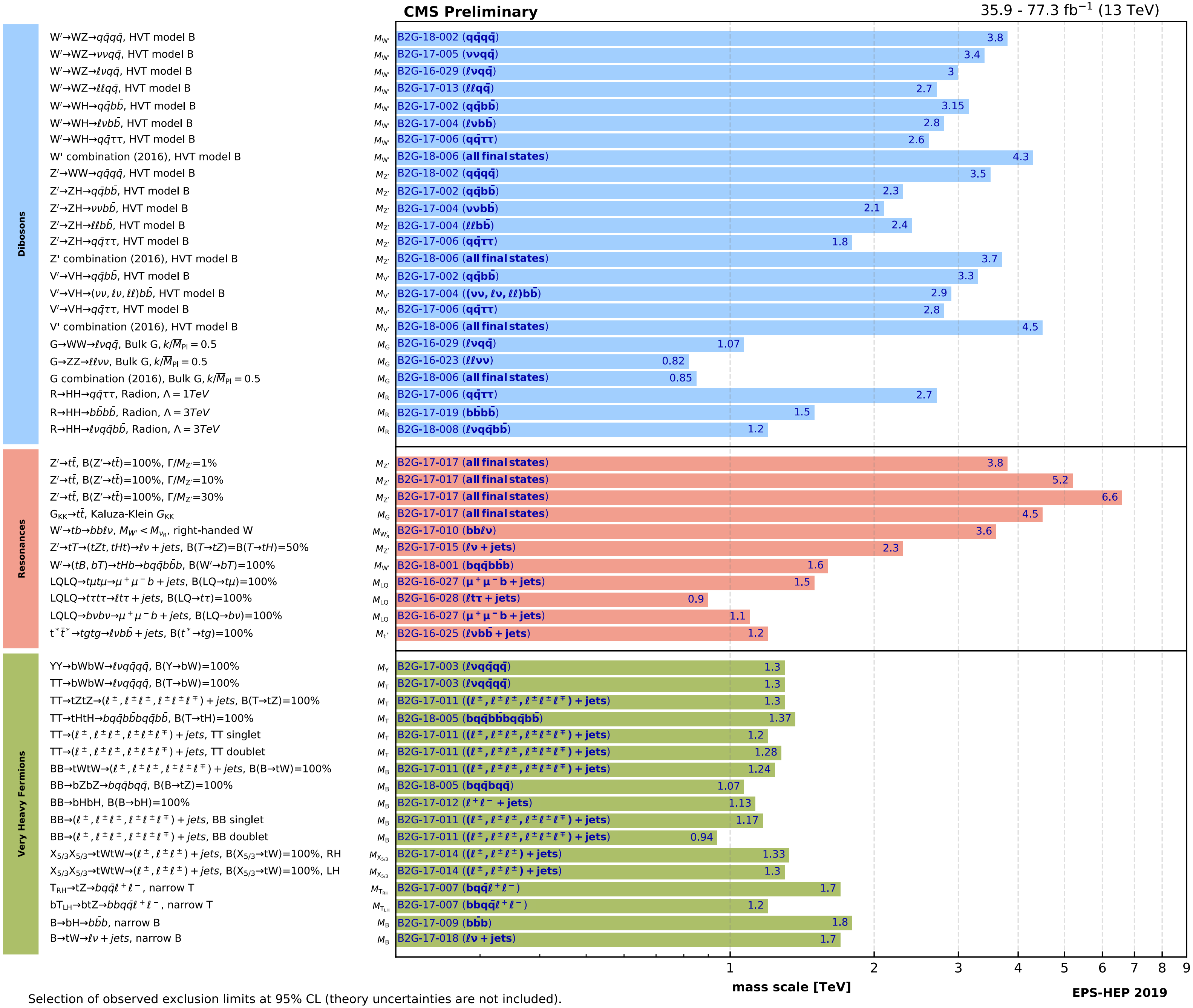


Overview of CMS EXO results



Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).

Overview of CMS B2G results



Selection of observed exclusion limits at 95% CL (theory uncertainties are not included).

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2019

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 139)\ \text{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt [\text{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	$0\ e, \mu$	$1-4$ j	Yes	36.1	M_D 7.7 TeV	$n = 2$	1711.03301
	ADD non-resonant $\gamma\gamma$	$2\ \gamma$	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	1707.04147
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09127
	ADD BH high $\sum p_T$	$\geq 1\ e, \mu$	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	$2\ \gamma$	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	1707.04147
	Bulk RS $G_{KK} \to WW/ZZ$	multi-channel			36.1	G_{KK} mass 2.3 TeV	$k/\overline{M}_{Pl} = 1.0$	1808.02380
	Bulk RS $G_{KK} \to WW \to qqqq$	$0\ e, \mu$	2 J	–	139	G_{KK} mass 1.6 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2019-003
	Bulk RS $g_{KK} \to tt$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	36.1	g_{KK} mass 3.8 TeV	$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	$1\ e, \mu$	≥ 2 b, ≥ 3 j	Yes	36.1	KK mass 1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	1803.09678
Gauge bosons	SSM $Z' \to \ell\ell$	$2\ e, \mu$	–	–	139	Z' mass 5.1 TeV		1903.06248
	SSM $Z' \to \tau\tau$	$2\ \tau$	–	–	36.1	Z' mass 2.42 TeV		1709.07242
	Leptophobic $Z' \to bb$	–	2 b	–	36.1	Z' mass 2.1 TeV		1805.09299
	Leptophobic $Z' \to tt$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	36.1	Z' mass 3.0 TeV	$\Gamma/m = 1\%$	1804.10823
	SSM $W' \to \ell\nu$	$1\ e, \mu$	–	Yes	139	W' mass 6.0 TeV		CERN-EP-2019-100
	SSM $W' \to \tau\nu$	$1\ \tau$	–	Yes	36.1	W' mass 3.7 TeV		1801.06992
	HVT $V' \to WZ \to qqqq$ model B	$0\ e, \mu$	2 J	–	139	V' mass 3.6 TeV	$g_V = 3$	ATLAS-CONF-2019-003
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	1712.06518
	LRSM $W_R \to tb$	multi-channel			36.1	W_R mass 3.25 TeV		1807.10473
	LRSM $W_R \to \mu N_R$	$2\ \mu$	1 J	–	80	W_R mass 5.0 TeV	$m(N_R) = 0.5$ TeV, $g_L = g_R$	1904.12679
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV	η_{LL}^-	1703.09127
	CI $\ell\ell qq$	$2\ e, \mu$	–	–	36.1	Λ 40.0 TeV	η_{LL}^-	1707.02424
	CI $tttt$	$\geq 1\ e,\mu$	≥ 1 b, ≥ 1 j	Yes	36.1	Λ 2.57 TeV	$\lvert C_{4t} \rvert = 4\pi$	1811.02305
DM	Axial-vector mediator (Dirac DM)	$0\ e, \mu$	$1-4$ j	Yes	36.1	m_{med} 1.55 TeV	g_q=0.25, g_χ=1.0, $m(\chi) = 1$ GeV	1711.03301
	Colored scalar mediator (Dirac DM)	$0\ e, \mu$	$1-4$ j	Yes	36.1	m_{med} 1.67 TeV	g=1.0, $m(\chi) = 1$ GeV	1711.03301
	$VV_{\chi\chi}$ EFT (Dirac DM)	$0\ e, \mu$	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
	Scalar reson. $\phi \to t\chi$ (Dirac DM)	0-1 e, μ	1 b, 0-1 J	Yes	36.1	m_ϕ 3.4 TeV	$y = 0.4$, $\lambda = 0.2$, $m(\chi) = 10$ GeV	1812.09743
LQ	Scalar LQ 1st gen	1,2 e	≥ 2 j	Yes	36.1	LQ mass 1.4 TeV	$\beta = 1$	1902.00377
	Scalar LQ 2nd gen	1,2 μ	≥ 2 j	Yes	36.1	LQ mass 1.56 TeV	$\beta = 1$	1902.00377
	Scalar LQ 3rd gen	$2\ \tau$	2 b	–	36.1	LQ_3^u mass 1.03 TeV	$\mathcal{B}(LQ_3^u \to b\tau) = 1$	1902.08103
	Scalar LQ 3rd gen	0-1 e, μ	2 b	Yes	36.1	LQ_3^d mass 970 GeV	$\mathcal{B}(LQ_3^d \to t\tau) = 0$	1902.08103
Heavy quarks	VLQ $TT \to Ht/Zt/Wb + X$	multi-channel			36.1	T mass 1.37 TeV	SU(2) doublet	1808.02343
	VLQ $BB \to Wt/Zb + X$	multi-channel			36.1	B mass 1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3} T_{5/3} \vert T_{5/3} \to Wt + X$	2(SS)/$\geq 3\ e,\mu$	≥ 1 b, ≥ 1 j	Yes	36.1	$T_{5/3}$ mass 1.64 TeV	$\mathcal{B}(T_{5/3} \to Wt)$= 1, $c(T_{5/3}Wt)$= 1	1807.11883
	VLQ $Y \to Wb + X$	$1\ e, \mu$	≥ 1 b, ≥ 1j	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y \to Wb)$= 1, $c_R(Wb)$= 1	1812.07343
	VLQ $B \to Hb + X$	$0\ e,\mu$, $2\ \gamma$	≥ 1 b, ≥ 1j	Yes	79.8	B mass 1.21 TeV	κ_B= 0.5	ATLAS-CONF-2018-024
	VLQ $QQ \to WqWq$	$1\ e, \mu$	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	139	q^* mass 6.7 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2019-007
	Excited quark $q^* \to q\gamma$	$1\ \gamma$	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1709.10440
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	36.1	b^* mass 2.6 TeV		1805.09299
	Excited lepton ℓ^*	$3\ e, \mu$	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	$3\ e, \mu, \tau$	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	Type III Seesaw	$1\ e, \mu$	≥ 2 j	Yes	79.8	N^0 mass 560 GeV		ATLAS-CONF-2018-020
	LRSM Majorana ν	$2\ \mu$	2 j	–	36.1	N_R mass 3.2 TeV	$m(W_R) = 4.1$ TeV, $g_L = g_R$	1809.11105
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	1710.09748
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	$3\ e, \mu, \tau$	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Multi-charged particles	–	–	–	36.1	multi-charged particle mass 1.22 TeV	DY production, $\lvert q \rvert = 5e$	1812.03673
	Magnetic monopoles	–	–	–	34.4	monopole mass 2.37 TeV	DY production, $\lvert g \rvert = 1g_D$, spin 1/2	1905.10130

$\sqrt{s}$ = 8 TeV | $\sqrt{s}$ = 13 TeV partial data | $\sqrt{s}$ = 13 TeV full data

Mass scale [TeV]: 10^{-1}, 1, 10

*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

Useful links

Summary plots from ATLAS Exotics:
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/

Summary plots from CMS Exotica:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryPlotsEXO13TeV