SEARCH FOR NEW RESONANCES

On Behalf of the ATLAS and CMS Collaborations

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NDM-2020

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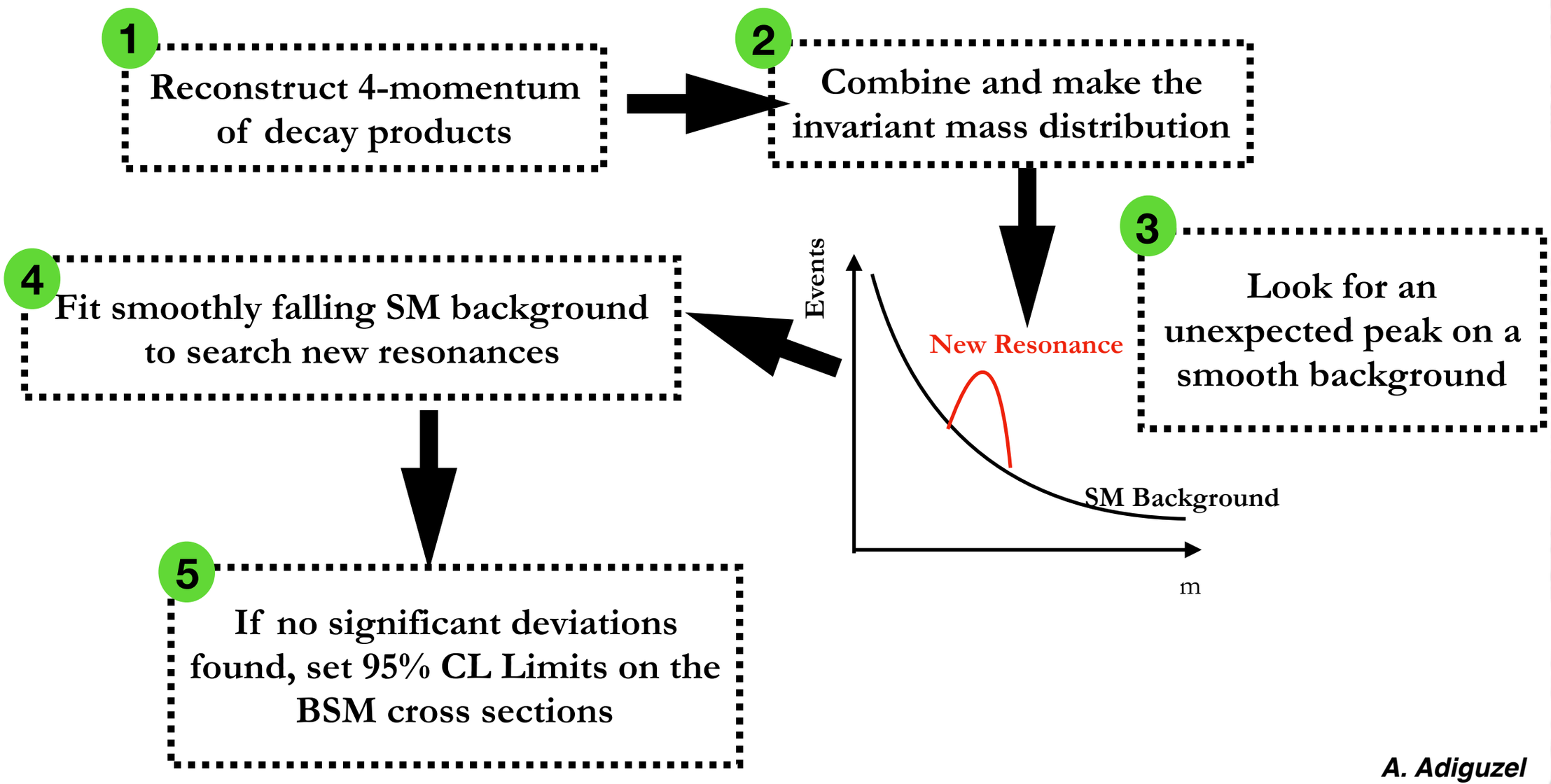
RESONANCES

- **Resonance searches** have been playing an **important role** in **HEP**
- Our understanding of physics is **incomplete**. There are **open questions …**
  - **New physics** theories have been proposed to explain these questions
    - **New resonances** appear in a variety of SM extensions (e.g. supersymmetry, grand unification models, extra dimensions …)
      - Looking for **new resonances** predicted by these models is a good way to test them
- **Resonance searches** are the classic **collider methodology** in searches for new particles and their excitations
  - The **majority** of exotics searches follow this methodology
    - **Try to infer the presence of a new particle by combining its decay products:**



NEW RESONANCE SEARCHES at ATLAS & CMS

- Great variety of **recent searches** for **new resonances in ATLAS & CMS**
  - No chance of covering everything here ….
  - Included in this presentation (**clickable link!**):

Hadronic final states:
- **Dijet/Dibjet (ATLAS in backup & CMS)**
- **Dijet+Lepton (ATLAS)**
- **Dijet+Photon (ATLAS)**
- **Dibjet+ISR (ATLAS & CMS in backup)**
- **Dijet+ISR (photon +jets) (ATLAS & CMS) in backup**
- **Pair-produced three-jets (CMS) in backup**
- **Diboson (ATLAS)**
- **TTbar (ATLAS in backup & CMS)**
- **HH to $b\bar{b}b\bar{b}$ (ATLAS)**
- **VLQ Searches (ATLAS & CMS) in backup**

Leptonic final states:
- **Dilepton (ATLAS)**
- **Excited lepton+2 jets+2 Lepton (CMS)**
- **Multilepton (CMS) in backup**
- **Lepton+missing energy (ATLAS & CMS in backup)**
- **W_R+heavy neutrino (ATLAS in backup & CMS)**
- **Long-lived particles (ATLAS)**
- **Heavy neutral leptons(ATLAS)**

Summary
ATLAS & CMS

- **Results are performed using ~36fb^{-1} / ~80fb^{-1} / ~140fb^{-1} of 13 TeV pp collision Run2 data**

HADRONIC FINAL STATES

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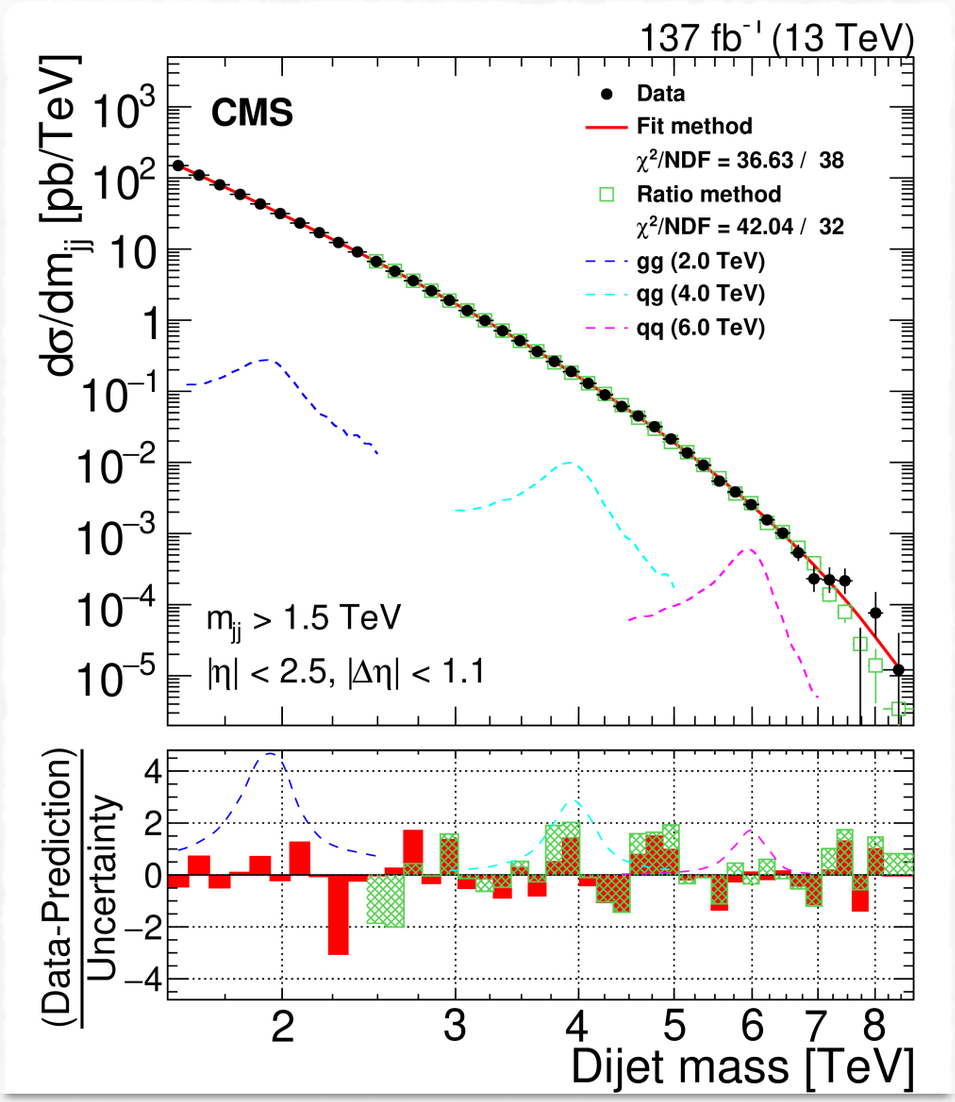
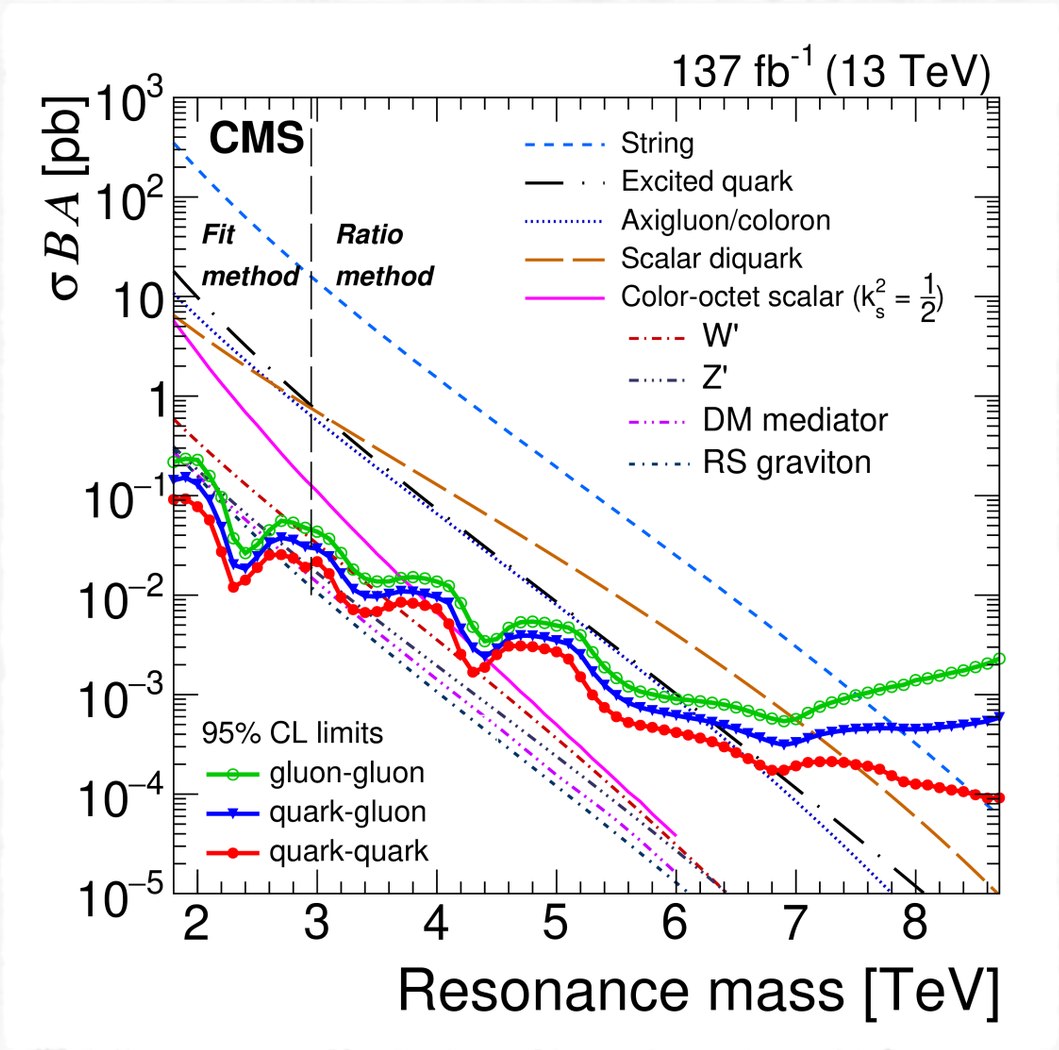
DIJET SEARCHES

- Narrow and broad resonances decaying to a pair of jets
- Full Run 2 data : 137 fb^{-1}
- Invariant mass of two 'wide' jets
  - Add jets (within $\Delta R < 1.1$) to leading/subleading jet
- **Background estimation : Ratio Method and Fit Method**
  - Ratio method: estimate background using m_{jj} distribution in CR defined by a $|\Delta\eta|$ sideband between two leading jets and valid from 2.4 TeV
  - Fit method: Fit mass spectrum with a parametric function and used for $m_{jj} > 1.5$ TeV





- Separate limits for different final states: qq, gg, qg
  - Dijets resonances shapes depending on the final state
  - The listed models are excluded between 1.8 TeV and the indicated mass limit by this analysis

ATLAS arXiv:1910.08447 Limit: q* with masses < 6.7 TeV using 139 fb^{-1}

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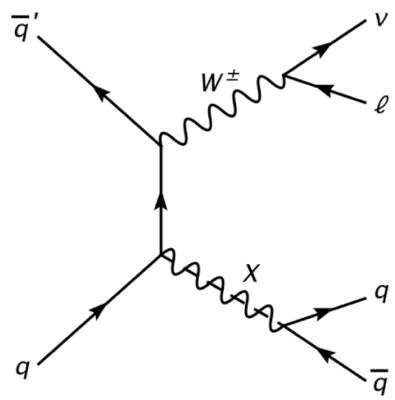
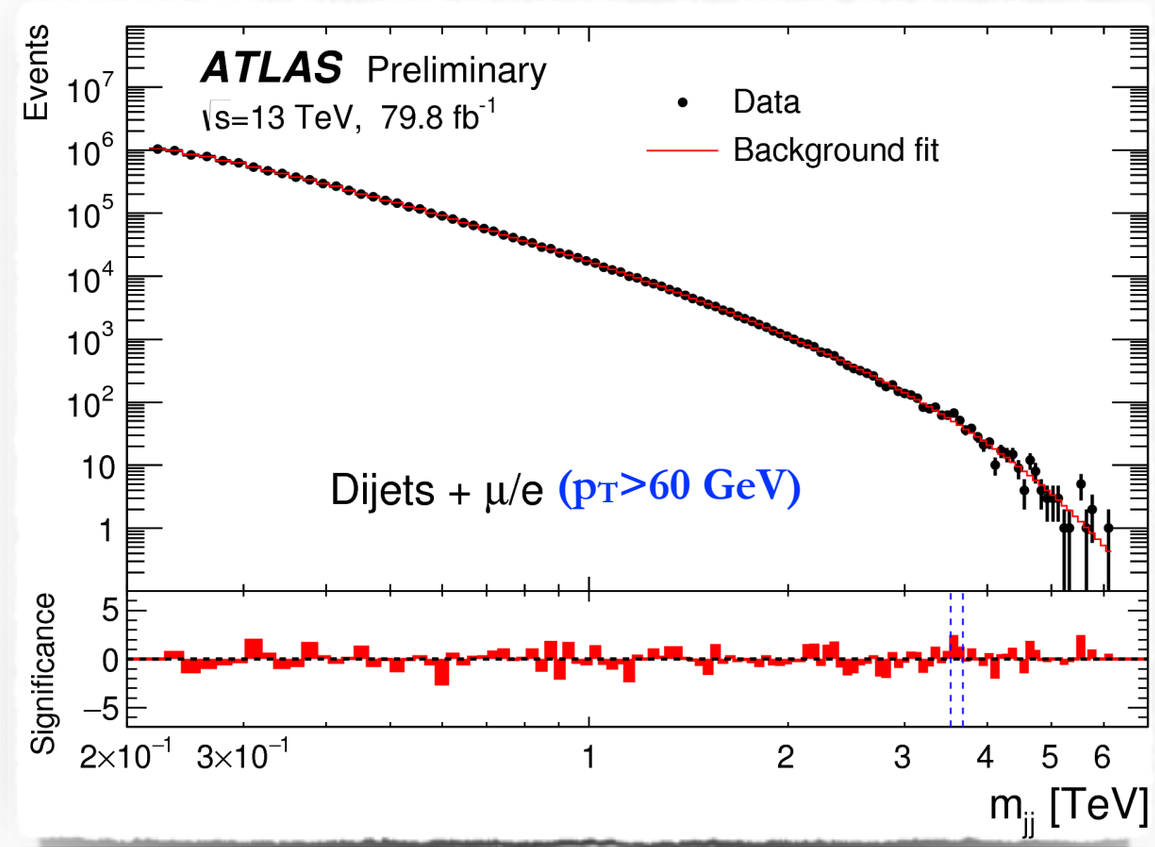
DIJET+LEPTON SEARCHES

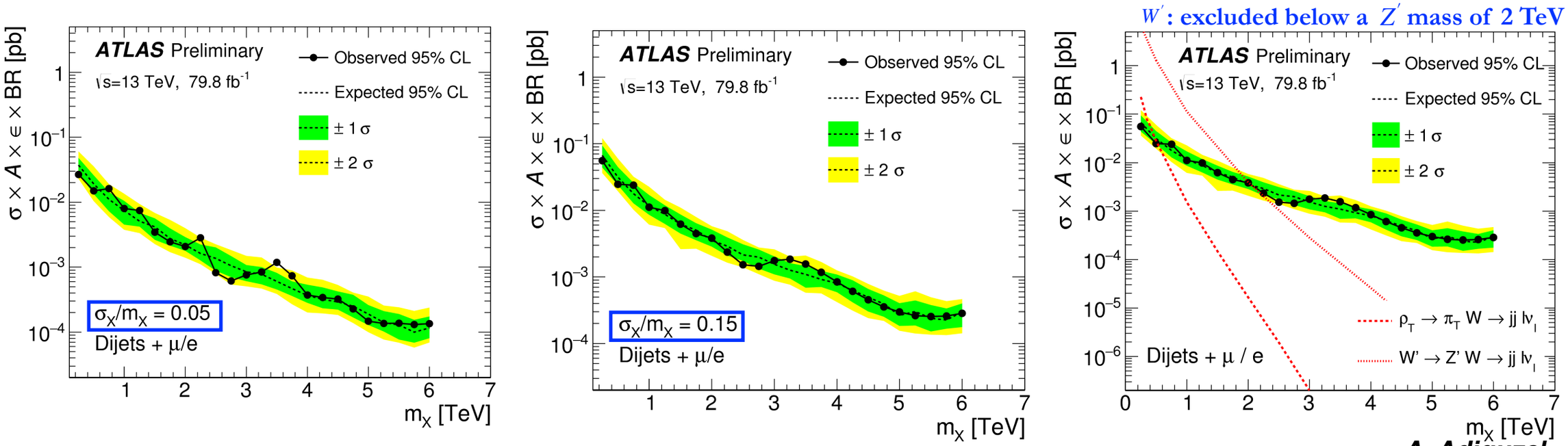


- Dijet resonances in events with identified leptons
- Use single lepton (electron or muon) trigger to extend m_{jj} sensitivity below 1 TeV
- Background modeled with a five parameter function and by using sliding window fit (SWIFT) procedure
- Data is compatible with SM expectation



- Limits on new resonances described by Gaussian signals

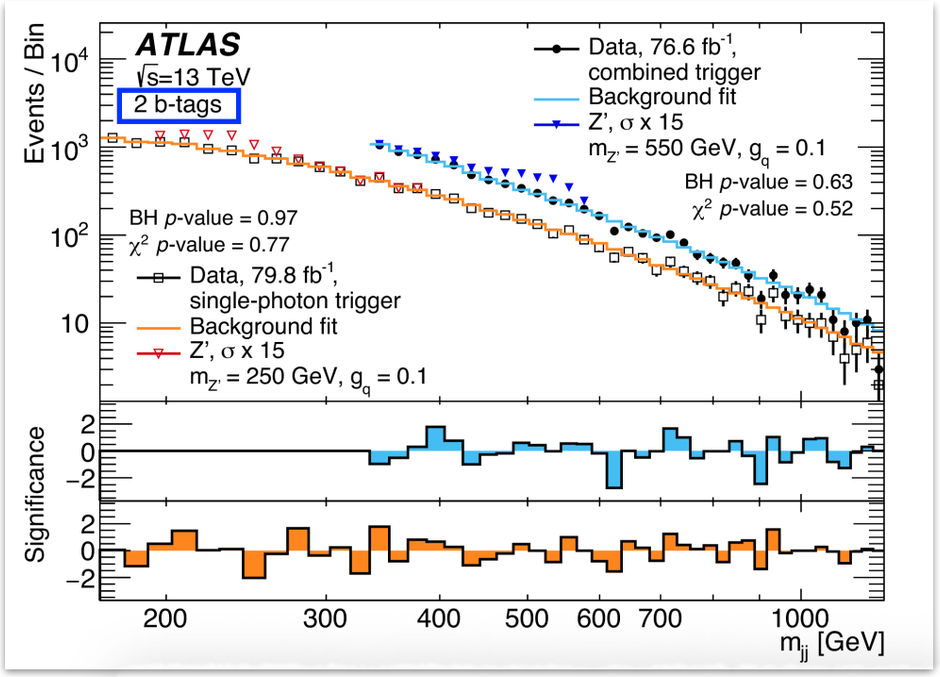
ρ_T : excluded below 0.5 TeV
W' : excluded below a Z' mass of 2 TeV

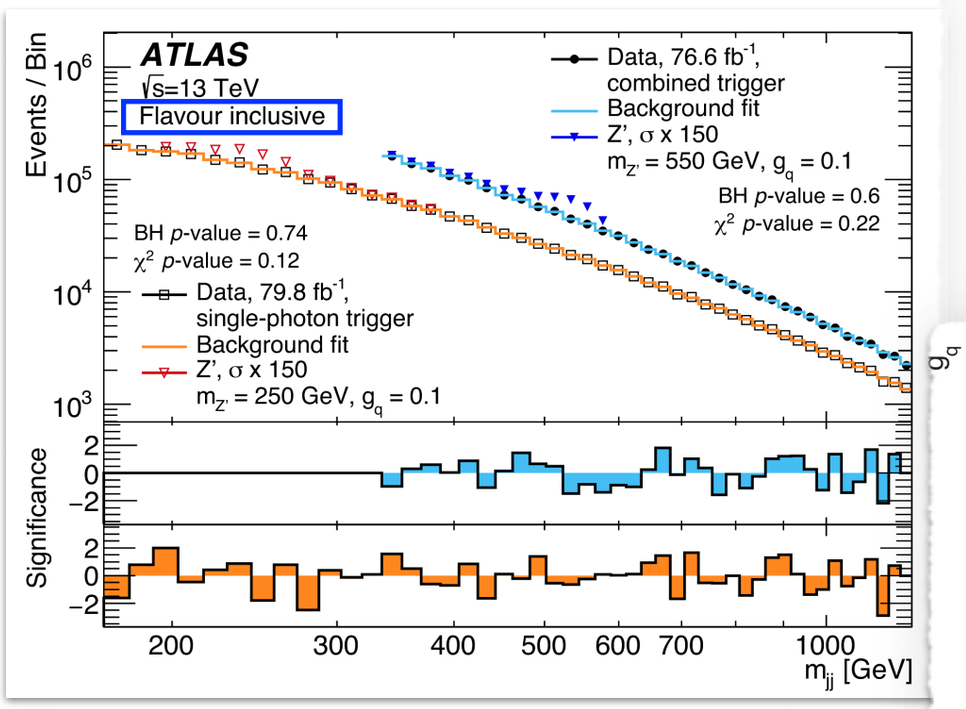


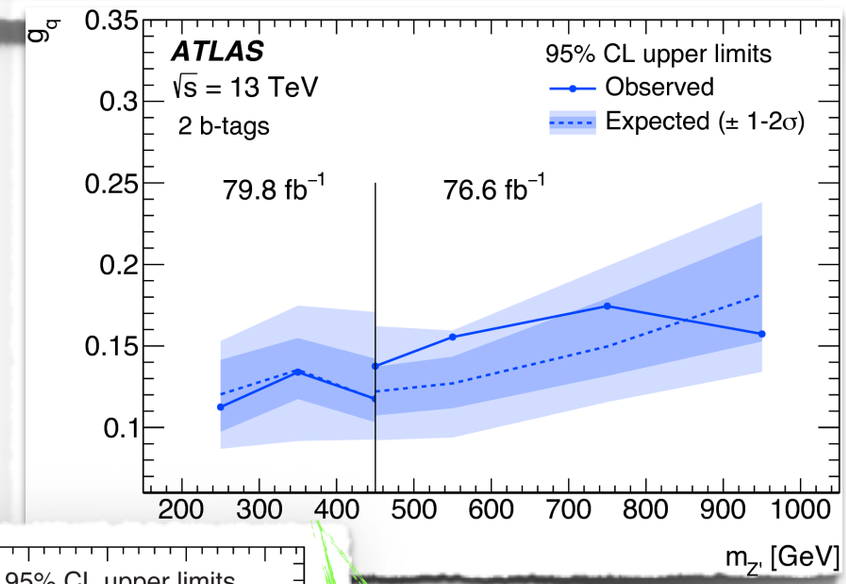
DIJET+PHOTON SEARCHES

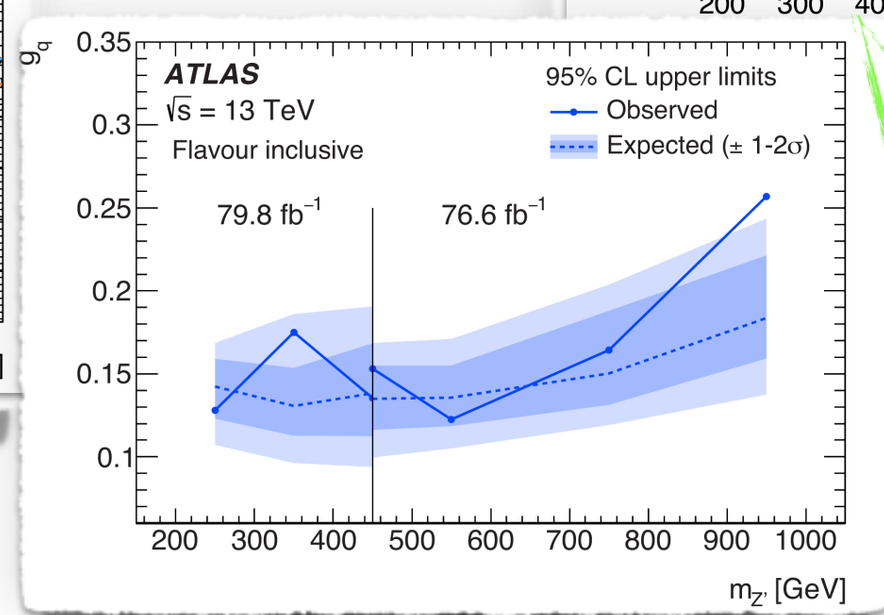
arxiv:1901.10917

- Low-dijet-mass events produced in association with a high transverse energy photon
- Use **single photon trigger** to lower the invariant mass threshold
  - Single photon trigger : search for resonances with masses from 225 GeV to 450 GeV
- **Combined trigger** : search for resonances with masses from 450 GeV to 1.1 TeV
- Sliding window estimate
- Events are separated into **four categories** for further analysis:
  - Flavour inclusive and 2-b tag selection
    - Combined trigger : m_{jj} > 335 GeV and single photon trigger: m_{jj} >169 GeV







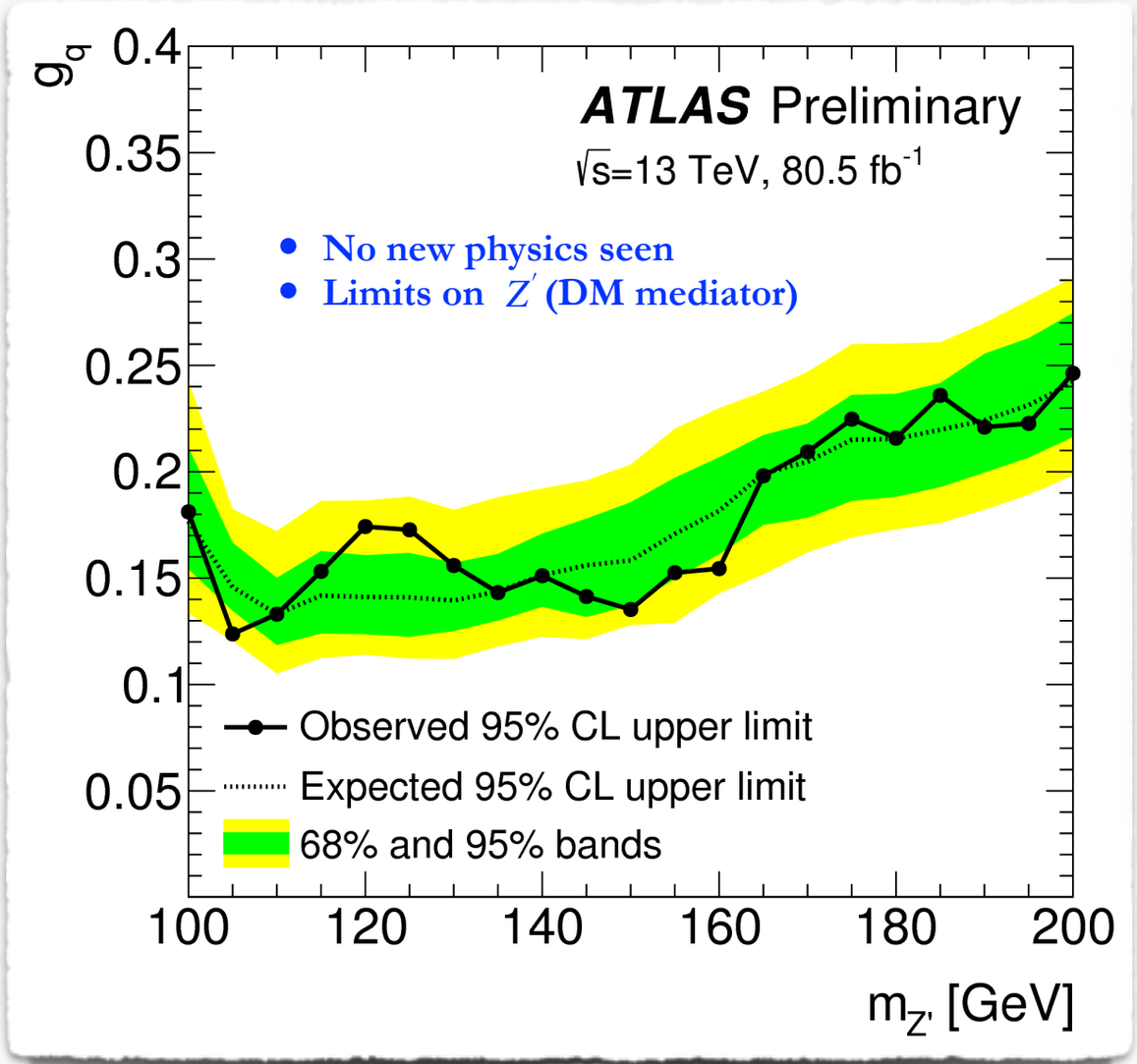


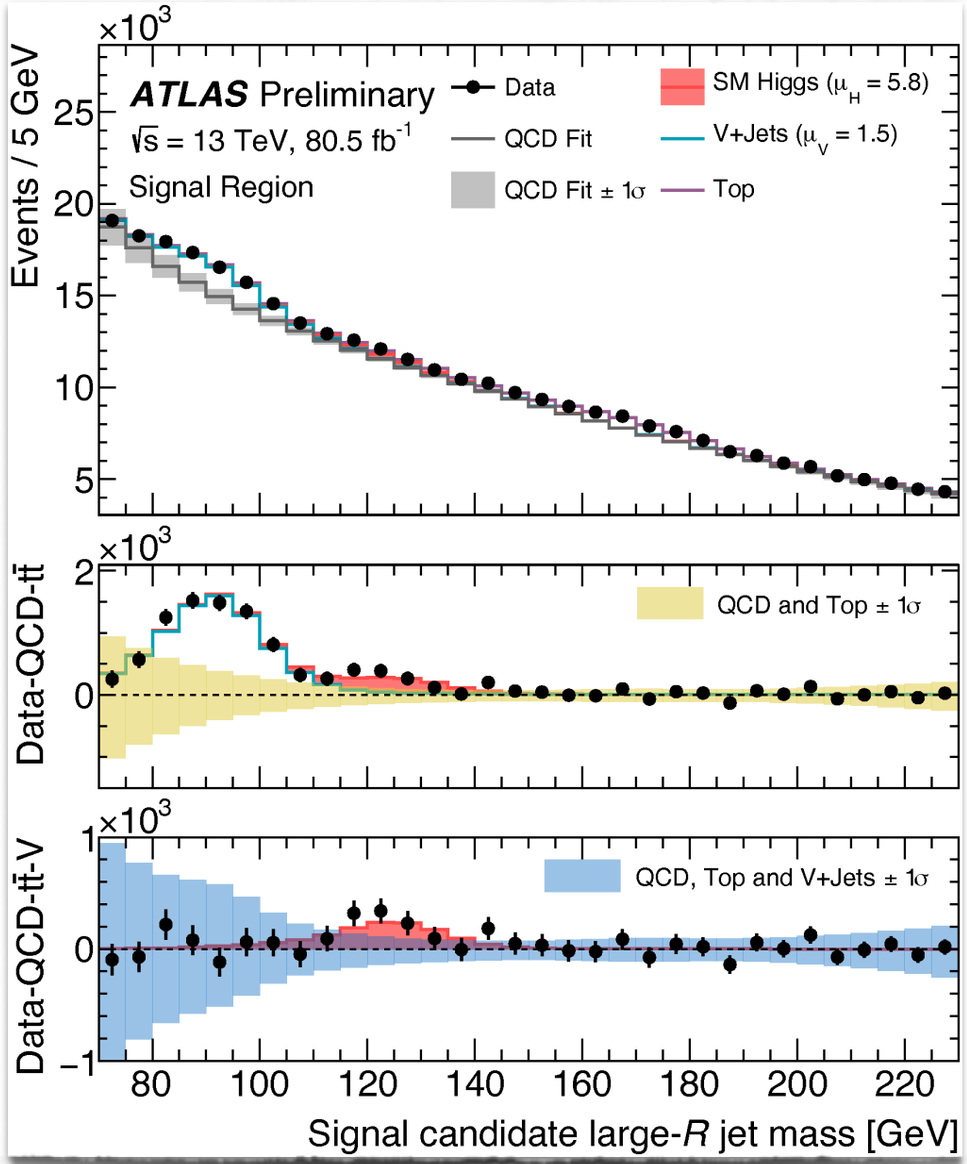
Limits on Z' axial-vector-dark-matter mediators as function of coupling

ATLAS-CONF-2018-052

DIBJETS+ ISR SEARCHES

- Search for boosted resonances decaying to two b-quarks and produced in association with a jet
- Search range in $70 < m_{jj} < 230$ GeV
  - Complementarity to dijet + photon search (2 b-tag region)
- QCD estimation:
  - Fit to data
  - Validation in CR with 0-btagged jets





CMS-EXO-17-024
Limit on:
$g_{q\phi}$: 3.9
g_{qA} : 2.5
using ~36 fb-1

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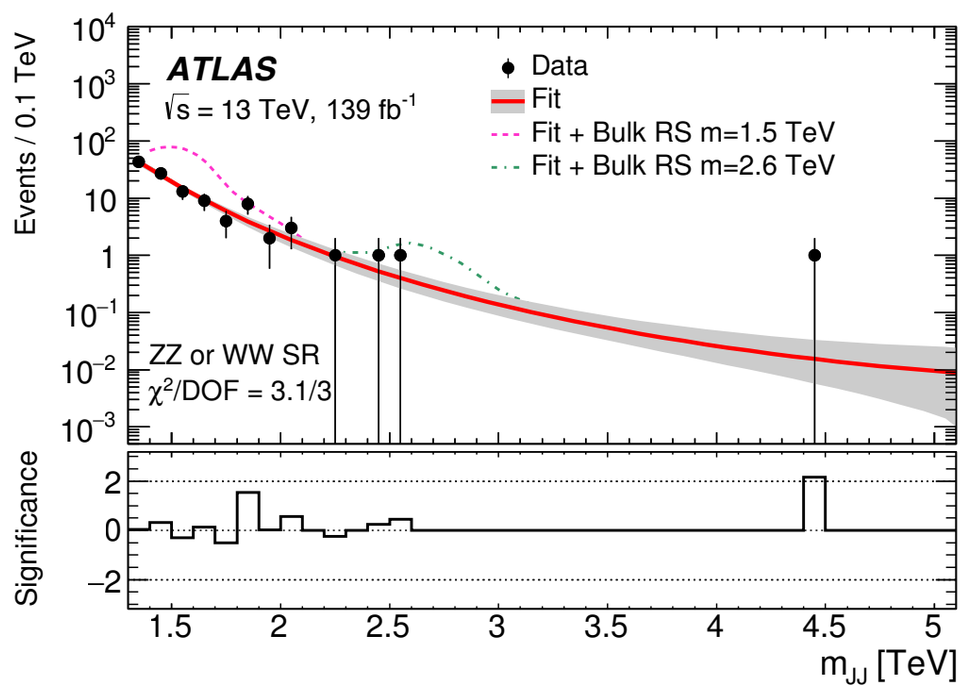
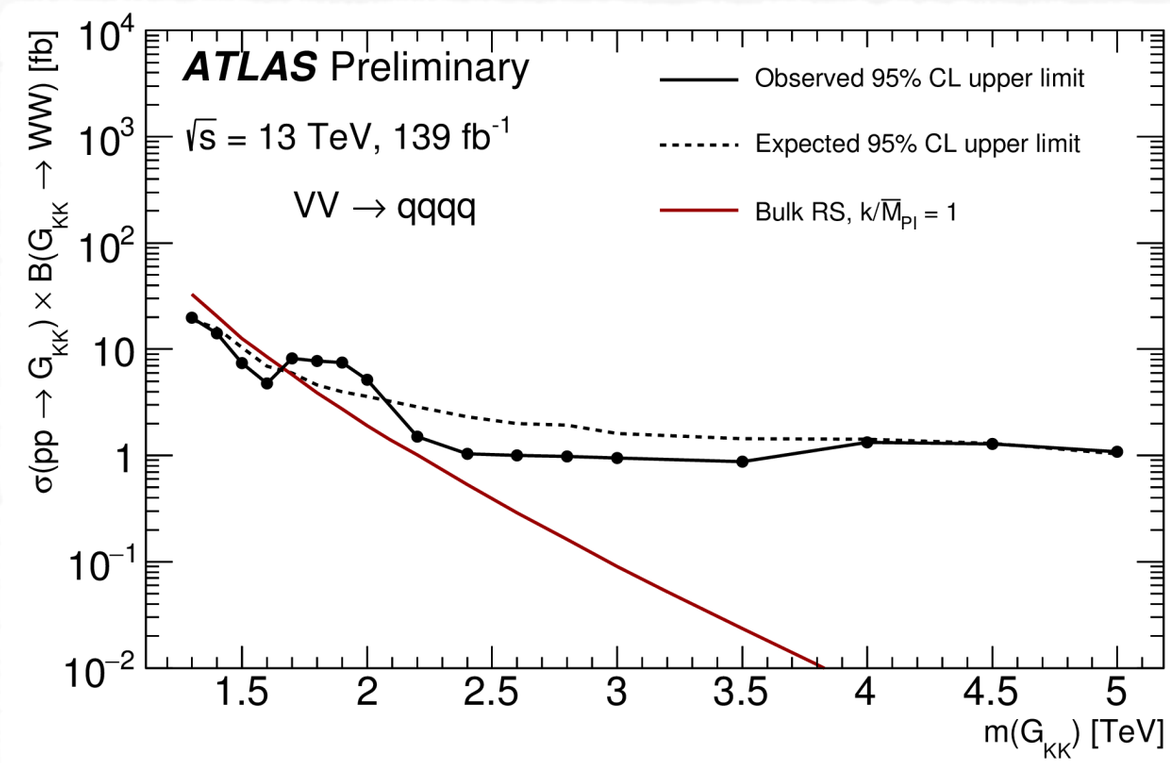
DIBOSON SEARCHES

arxiv:1906.08589v2

- There are models predicting heavy resonances decaying to SM W/Z bosons
  - Three specific benchmark models are used:
    - A spin-0 radion decaying into WW or ZZ
    - A spin-1 Heavy Vector Triplet Model provides signal such as $W' \rightarrow WZ / Z' \rightarrow WW$
    - A spin-2 graviton $G_{KK} \rightarrow WW \; or \; ZZ$, Kaluza-Klein modes of the Randall-Sundrum graviton
- Hadronic W/Z decays can be distinguished from gluon or quark initiated jets
- Similar strategy as di-jet search but boson tagging applied : a three-dimensional (jet mass, D_2, n_{trk}) tagger using TCC jets



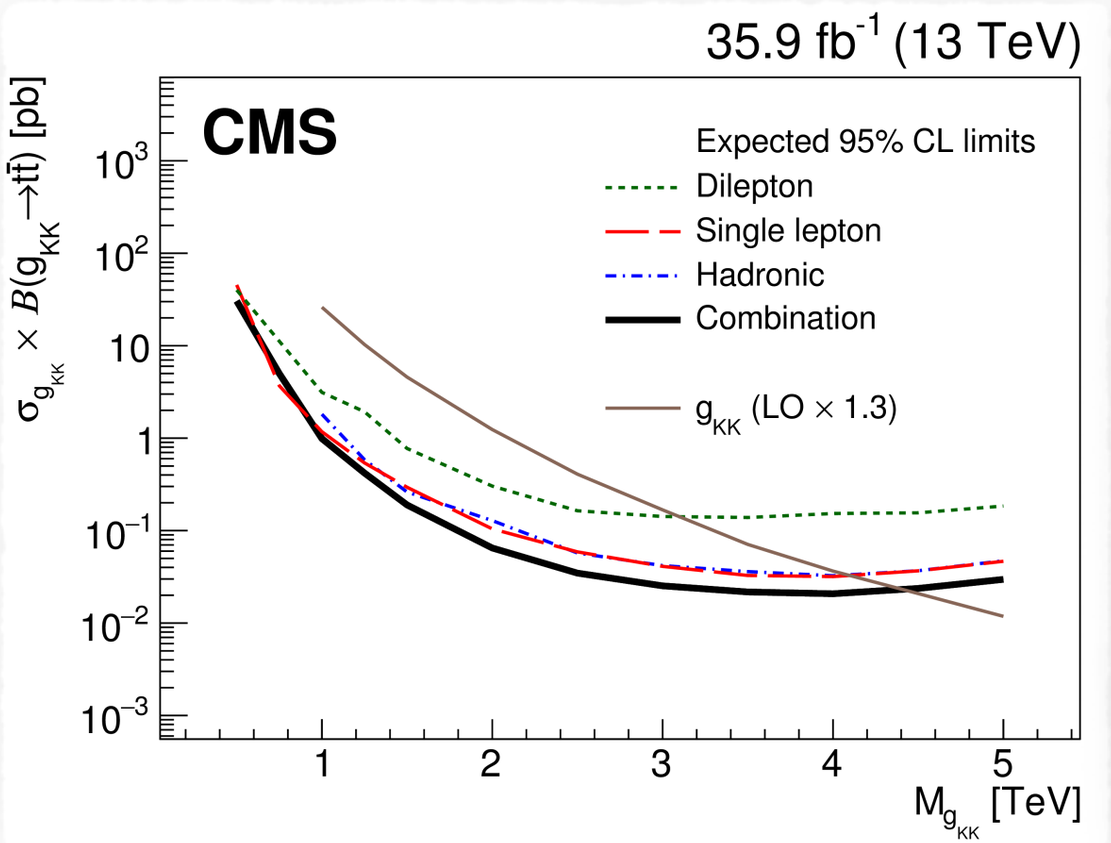


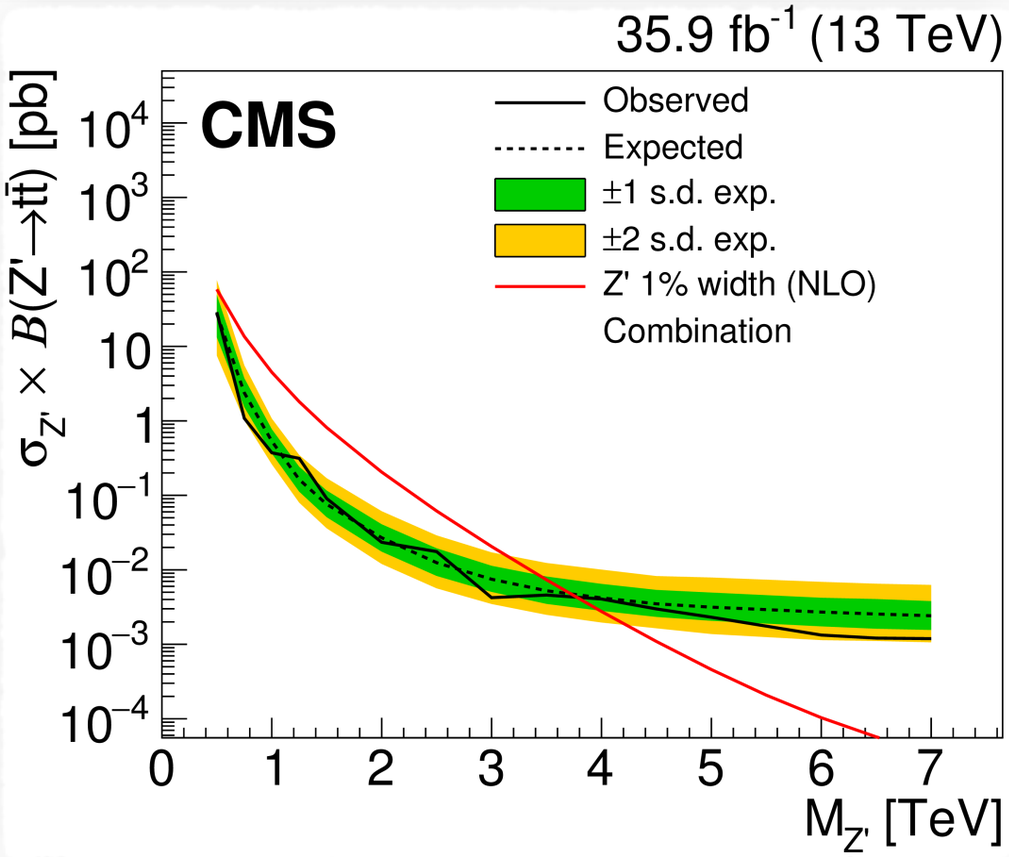
CMS-B2G-18-002
$G_{bulk} \rightarrow WW(ZZ)$: 20 (27) and 0.2 fb for resonance masses between 1.2 and 5.2 TeV, using ~ 80 fb^{-1}

- Data in agreement with the background expectations in all channels
- No significant excesses are observed
- Best results so far : production of a G_{kk} in the bulk RS model with $k/\overline{M}_{PI} = 1$ is excluded in the range 1.3 TeV-1.8 TeV, at the 95 % CL

TTBAR RESONANCES

- Full Hadronic channel provides the best sensitivity along with single lepton
- **The first search:** combines all three decay topologies of the ttbar system: dilepton, single lepton, and fully hadronic





Exclusions:

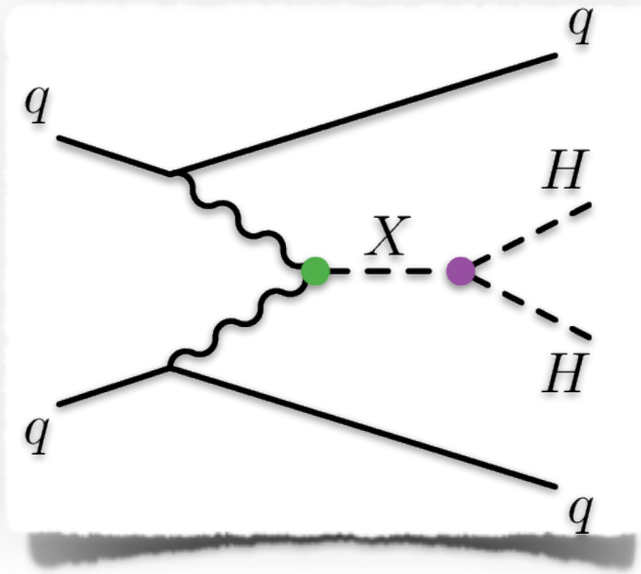
- Topcolor Z' model up to 3.8 (width of 1 %), 5.25 (width of 10 %), 6.65 (width of 30%)TeV

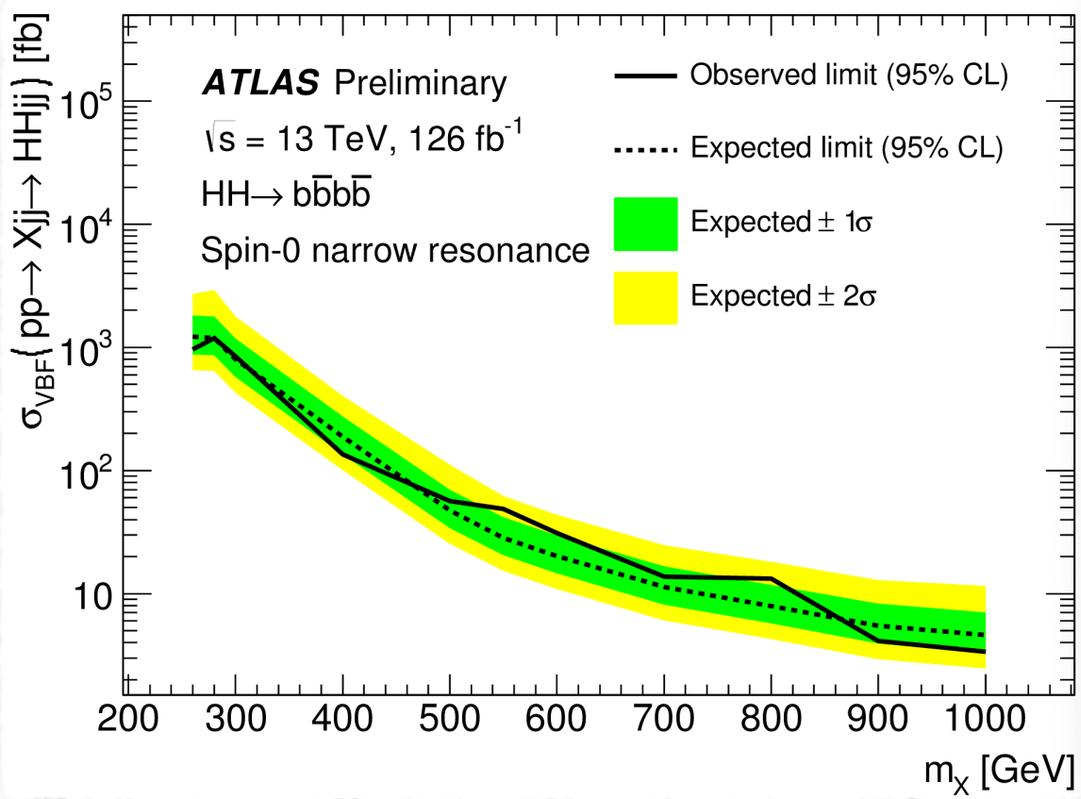
- KK gluon up to 4.55 TeV

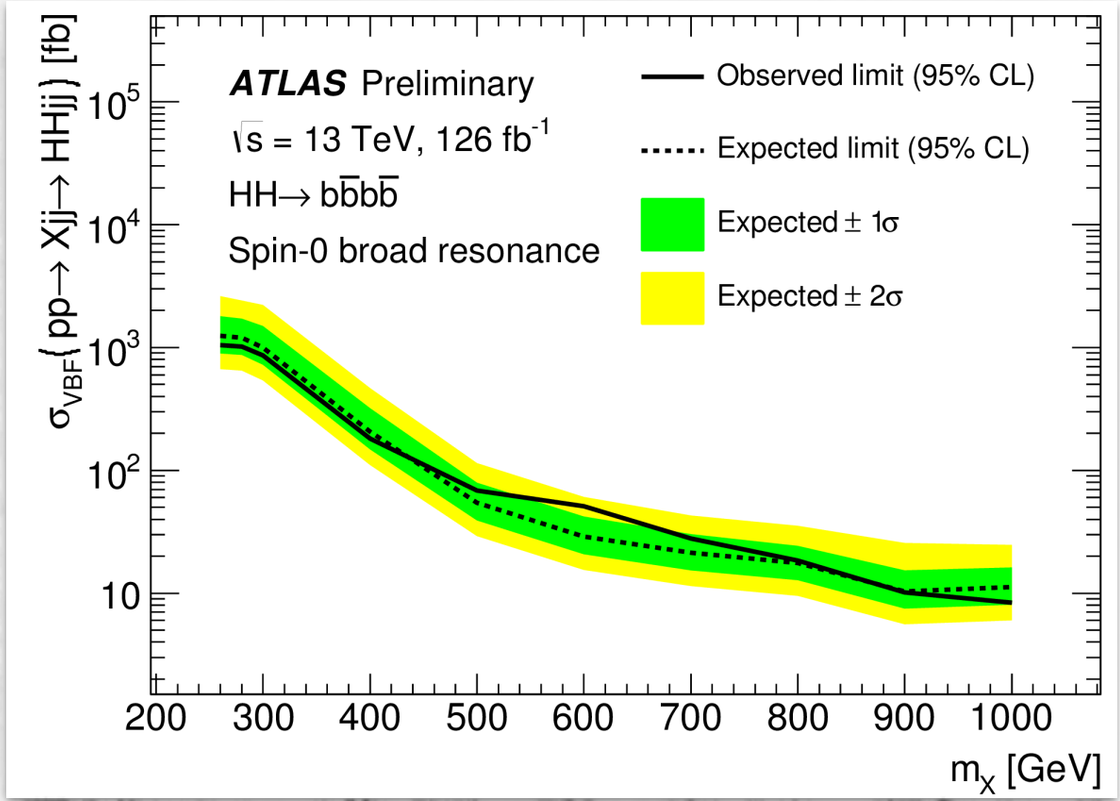
ATLAS
Phys. Rev. D 99 (2019) 092004
Limit on
Z' : 3.1-3.6 TeV
KK gluon : 3.4 TeV

SEARCH FOR THE $HH \to b\bar{b}b\bar{b}$ PROCESS via VECTOR BOSON FUSION

- Higgs boson pair production via vector boson fusion in the $b\bar{b}b\bar{b}$ final state using 126 fb^{-1}
- Limits on the production cross-section are set for a heavy scalar resonance in the context of an extended Higgs sector
- Used a combination of **b-jet triggers**
- **Dominate backgrounds:** multijet (modelled using data) and ttbar (modelled using simulation)
- No significant excess above the SM expectation
  - **The largest deviation from the background-only hypothesis is observed at 550 GeV with a local significance of 1.5 standard deviations**





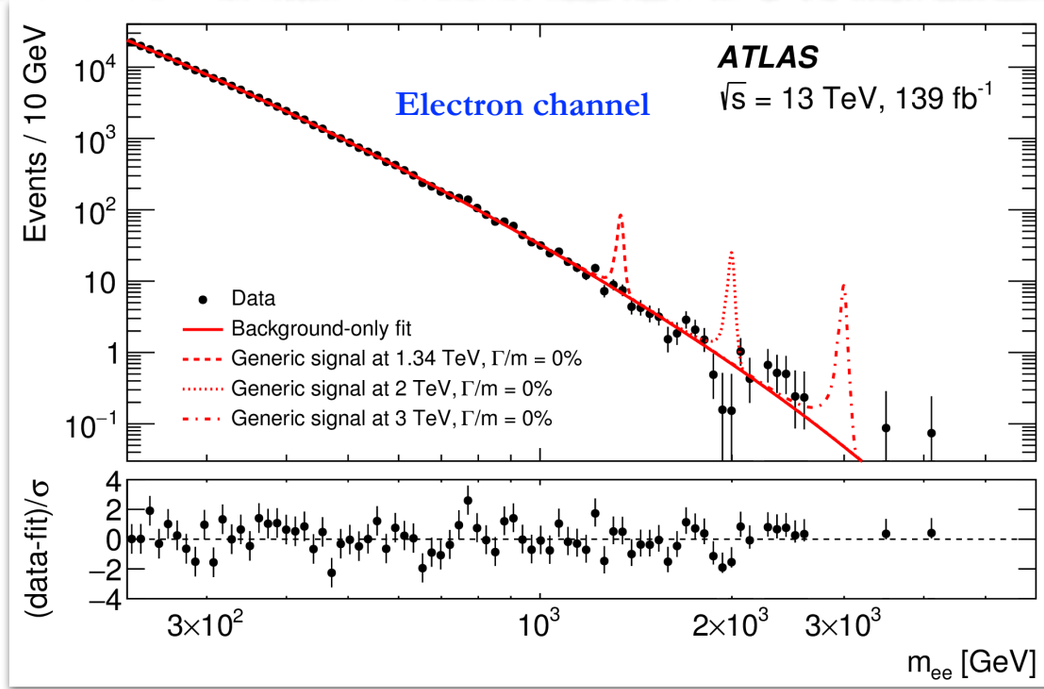


LEPTONIC FINAL STATES

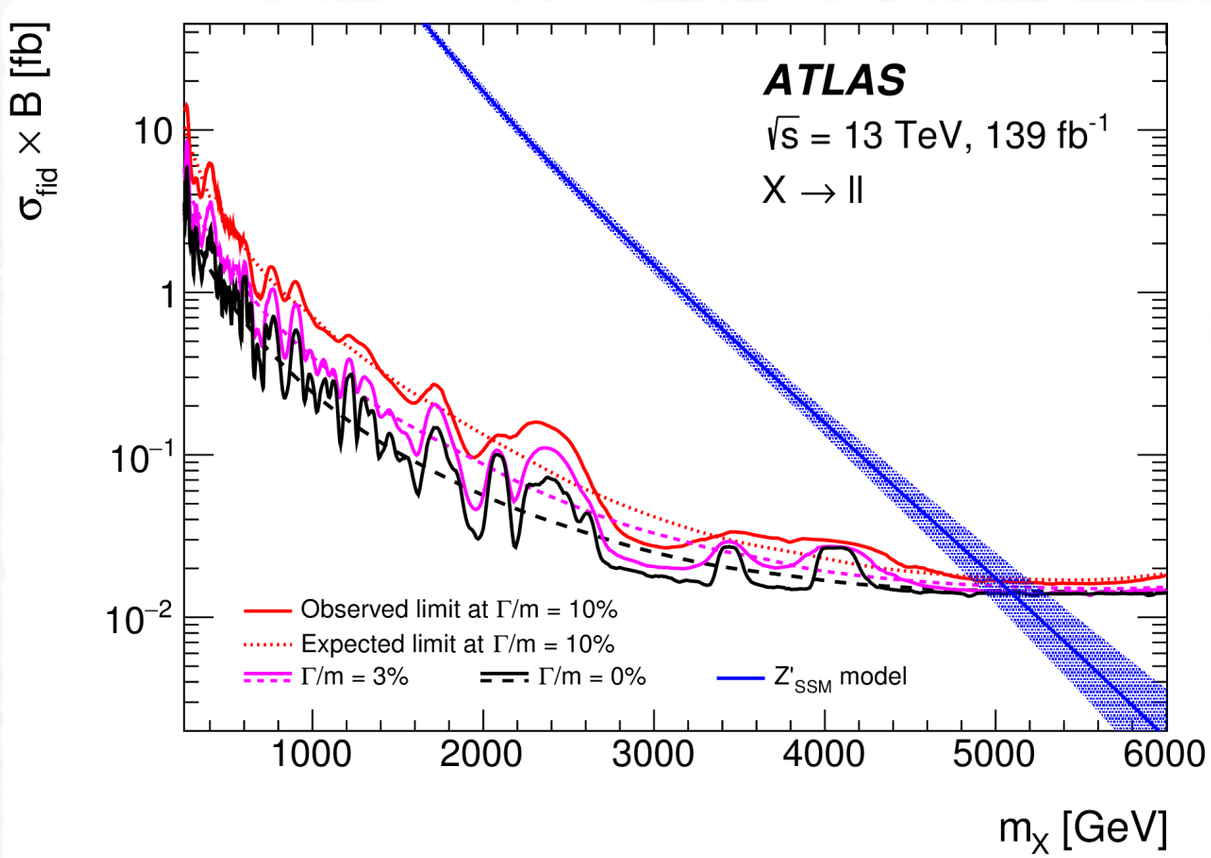
HIGH MASS DILEPTON RESONANCES

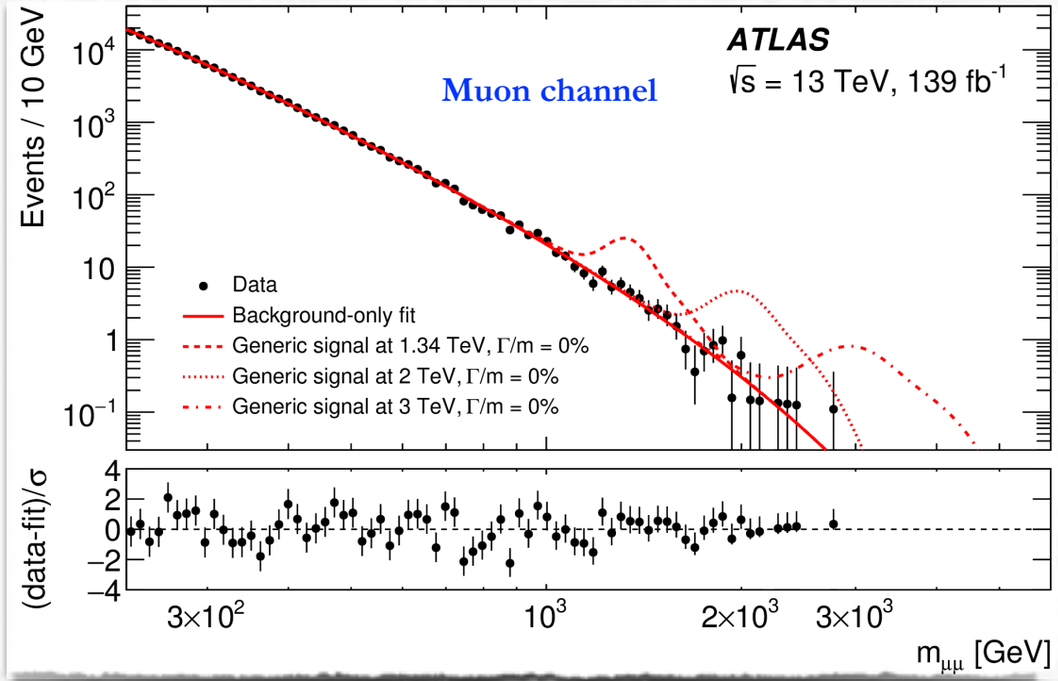
- Search for heavy resonances decaying to leptons
- Updated result with full Run 2 data
- m_{ll} > 225 GeV to go beyond the Z peak
- Fitting m_{ll} distribution by a smooth background parameterisation and BW $\oplus$ (Gauss + CB) function for the signal with given m_X, Γ_x :

$$f_{\ell\ell}(m_{\ell\ell}) = f_{\mathrm{BW},Z}(m_{\ell\ell}) \cdot \left(1 - x^c\right)^b \cdot x^{\sum_{i=0}^{3} p_i \log(x)^i}$$



✱ **Data are compatible with SM expectation**



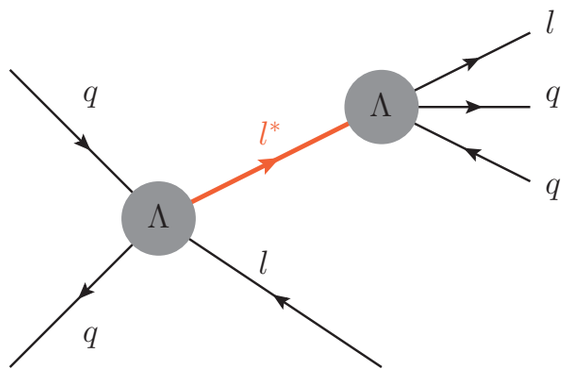


Model dependent $ee \oplus \mu\mu$ **limits:**

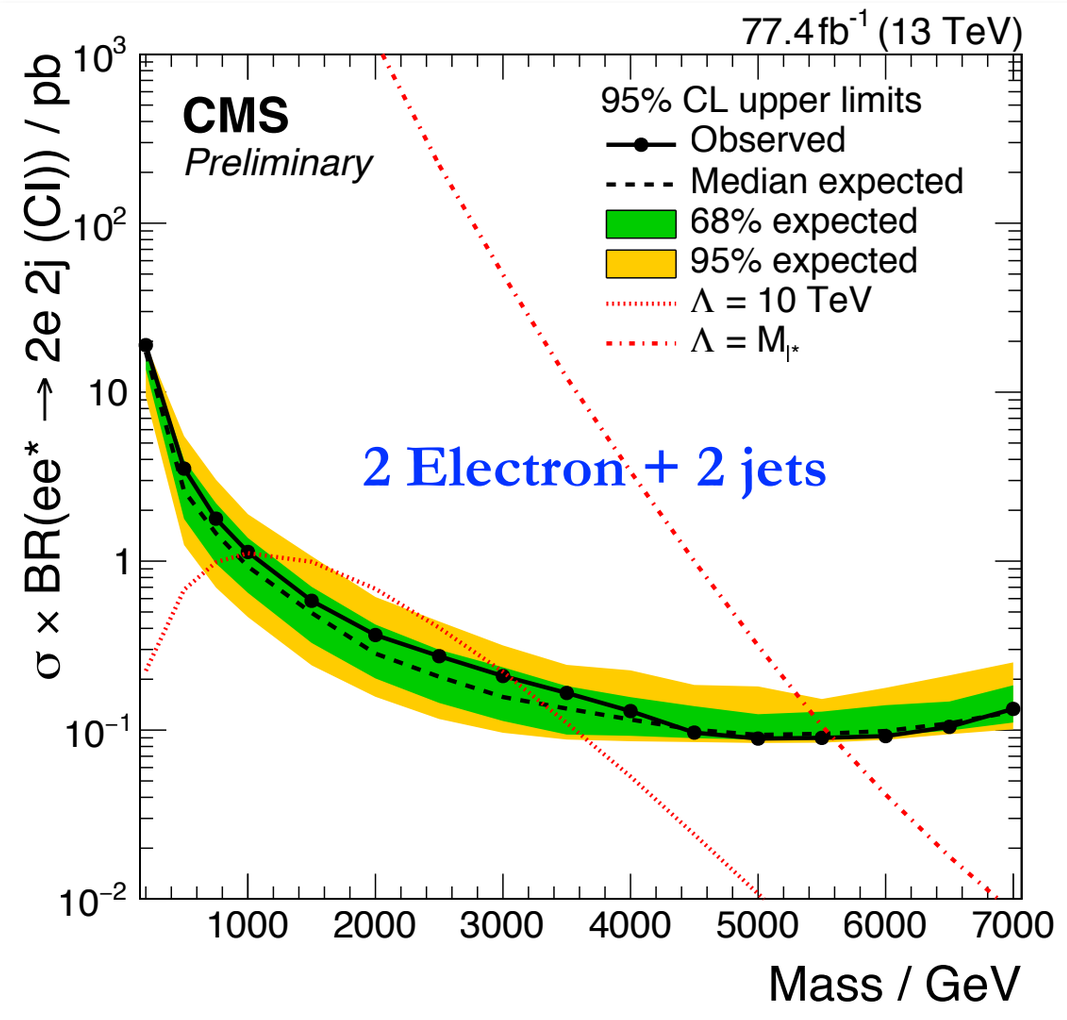
E_6 motivated bosons $Z'_{\psi,\chi}$: m_X > 4.5 and 4.8 TeV

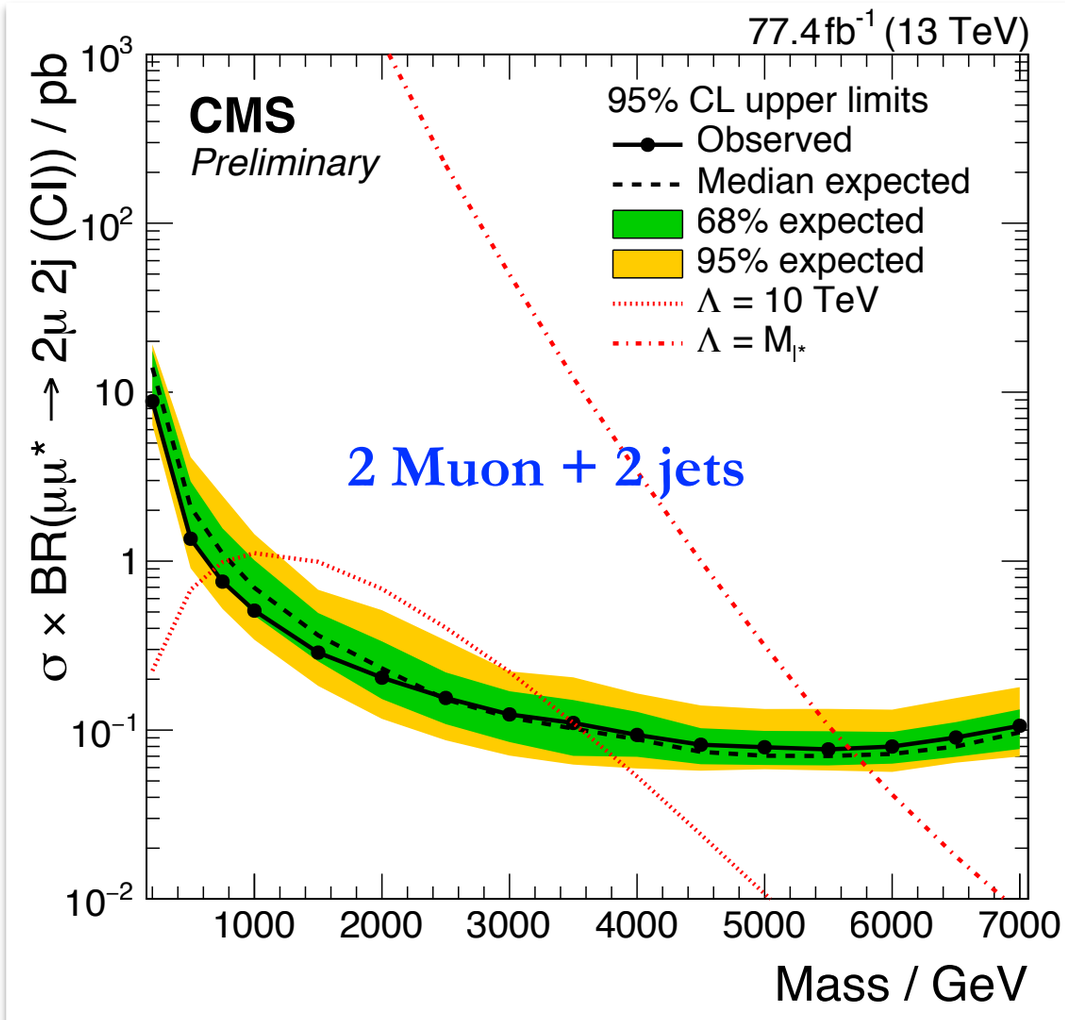
Z'_{SSM} : m_X > 5.1 TeV

SEARCH FOR EXCITED LEPTONS WITH TWO LEPTONS AND TWO JETS FINAL STATES



- Excited leptons decaying via contact interaction to 2 leptons and 2 jets
- No significant excess in either channel
  - Excited **electrons** (muons) up to masses of **5.6** (5.7) TeV are excluded





EXOT-2018-030

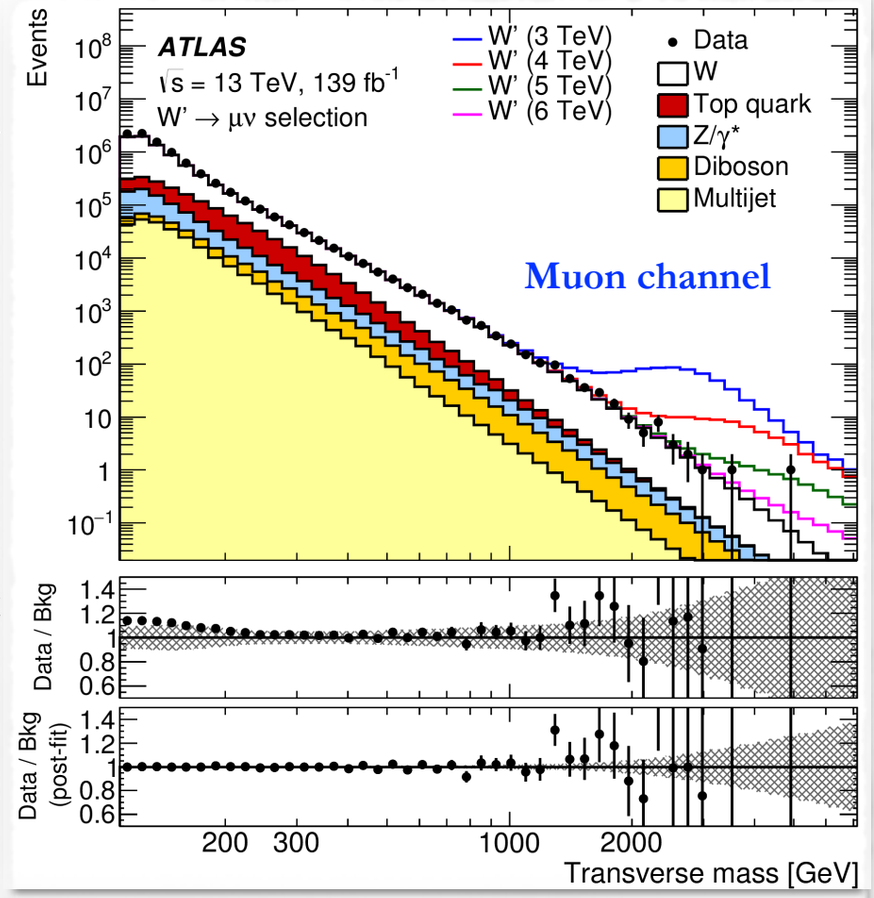
LEPTON AND MISSING TRANSVERSE ENERGY

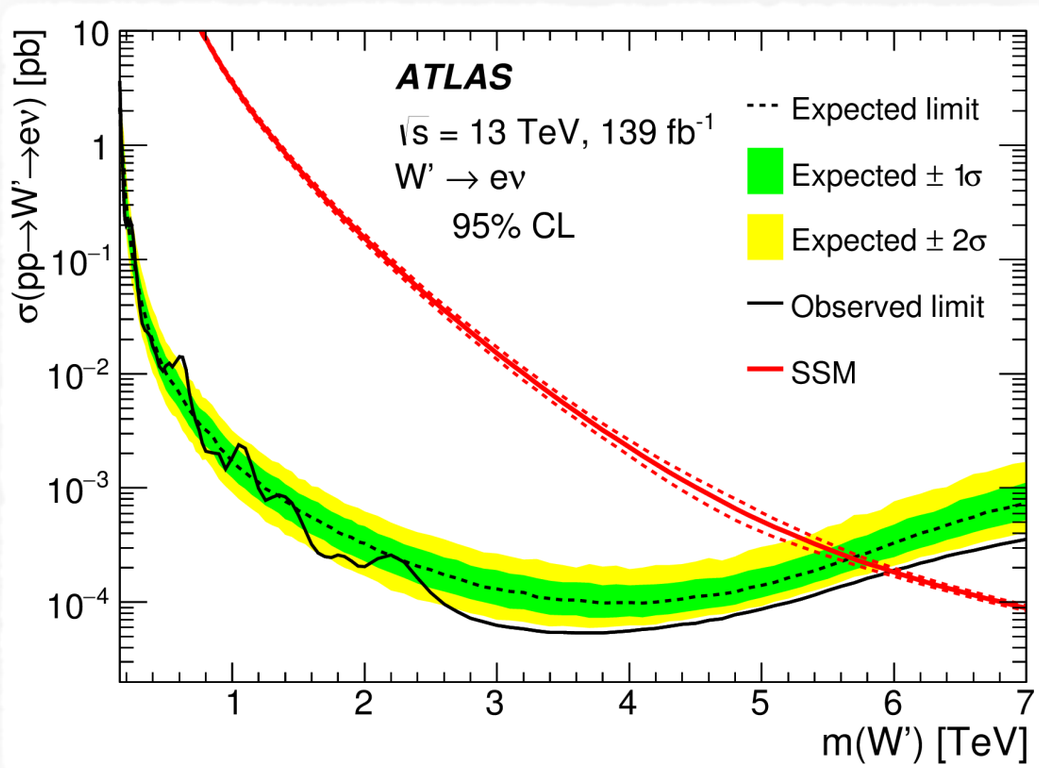
$W' \rightarrow e\nu/\mu\nu$

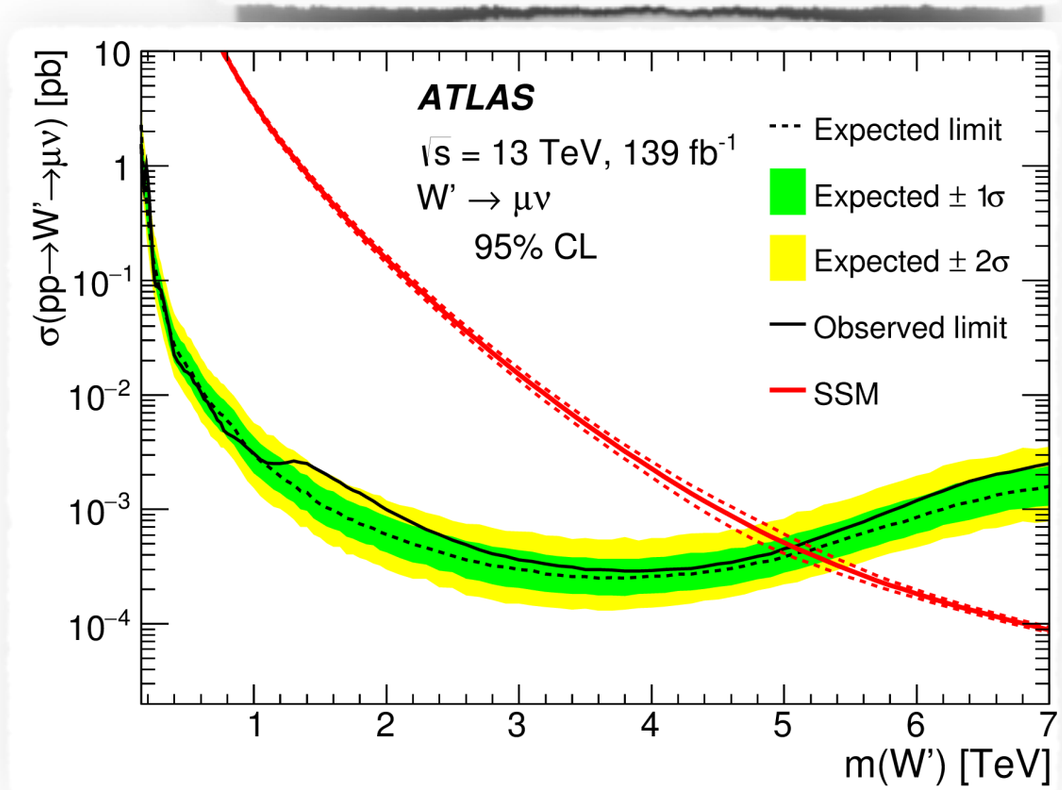
- A **heavy charged boson resonance** decaying into **charged lepton and a neutrino**
- Full Run 2 data : 2015 - 2018, corresponding to 139 fb^{-1}
- Selected events with **single-electron and single-muon triggers**
- The discriminating variable:

$$m_T = \sqrt{2\, p_T\, E_T^{miss}\, (1 - \cos\phi_{\ell\nu})}$$

- **No significant excess above the SM background**, upper limit on $\sigma \times B(W' \rightarrow l\nu)\ l = e, \mu$ are set at 95 % CL







CMS-EXO-16-033
CMS-EXO-17-008
Limit on W' :
e/mu : 4. 9 TeV
tau : 4.0 TeV
using 36 fb^{-1}

- ✱ Assuming SM couplings for the W' : $M_{W'} > 6.0\ (5.1)$ TeV in the electron and muon channels, respectively.
- ✱ $M_{W'} > 3.7$ TeV in the tau channel (using 36 fb^{-1})

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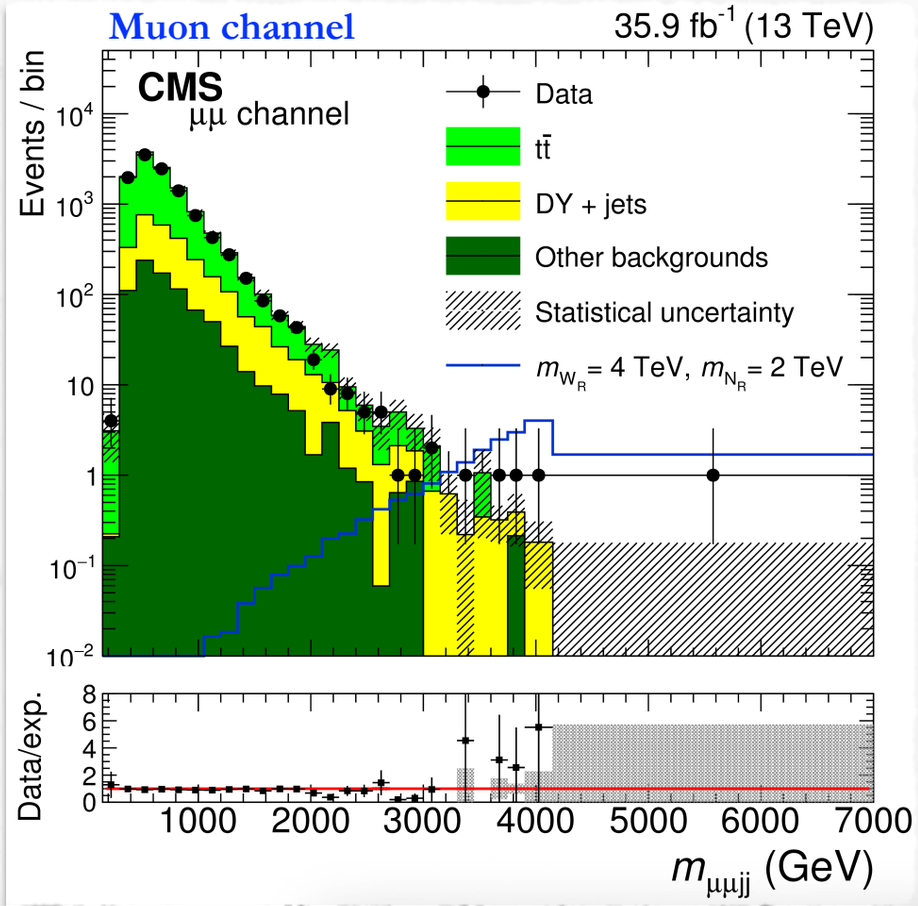
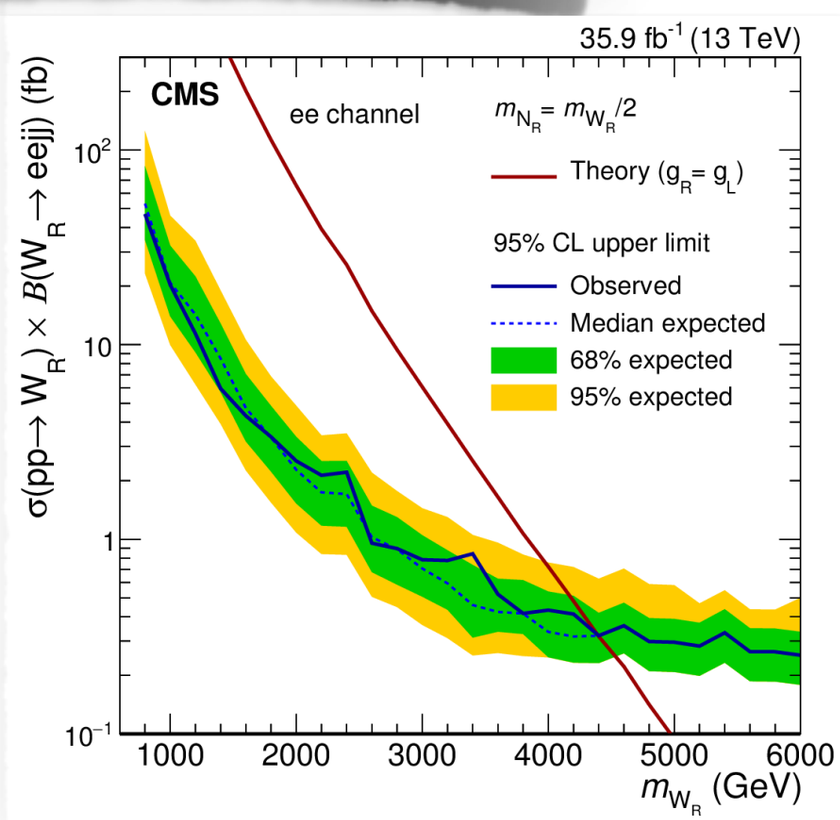
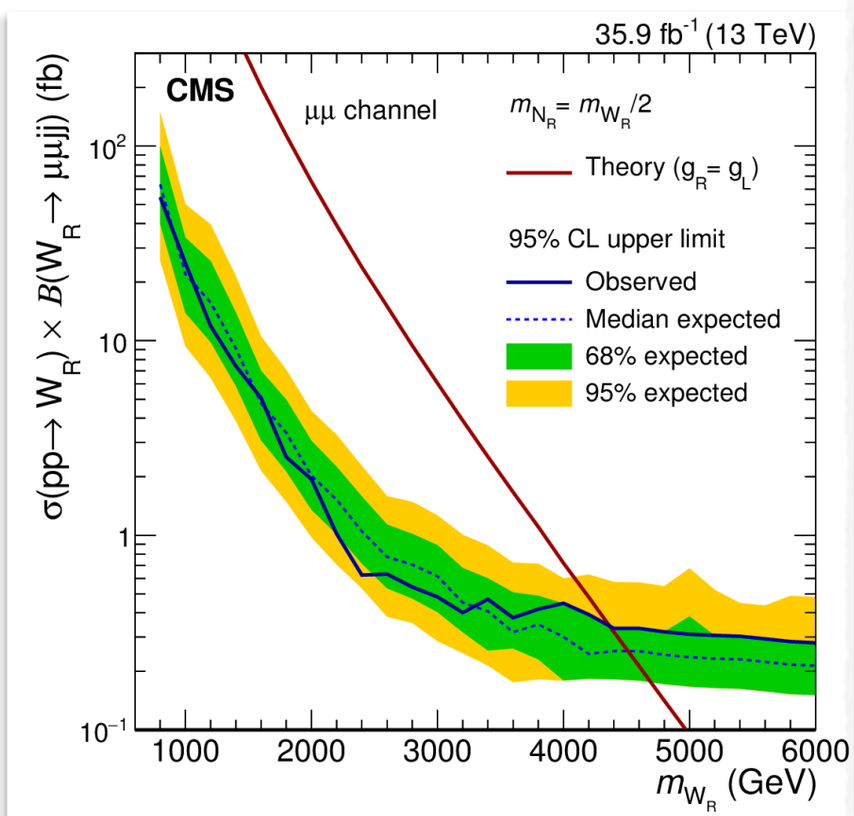
SEARCH FOR W_R and a HEAVY NEUTRINO



$$W_R \to \ell N_R \to \ell\ell W_R^* \to \ell\ell q\bar{q}', \ \ell = e \text{ or } \mu.$$

- Data in 2016, ~36 pb^{-1}
- Assuming that couplings are identical to those of the SM and that only one heavy neutrino flavor N_R contributes significantly to the W_R decay width
- Triggers:
  - **Electrons**: unprescaled double electron trigger
  - **Muons**: unprescaled single muon trigger
- No significant excess above SM expectation is seen
- **The region in the two-dimensional mass plane excluded at 95 % CL extends to** ~ $m_{W_R} = 4.4\ TeV$

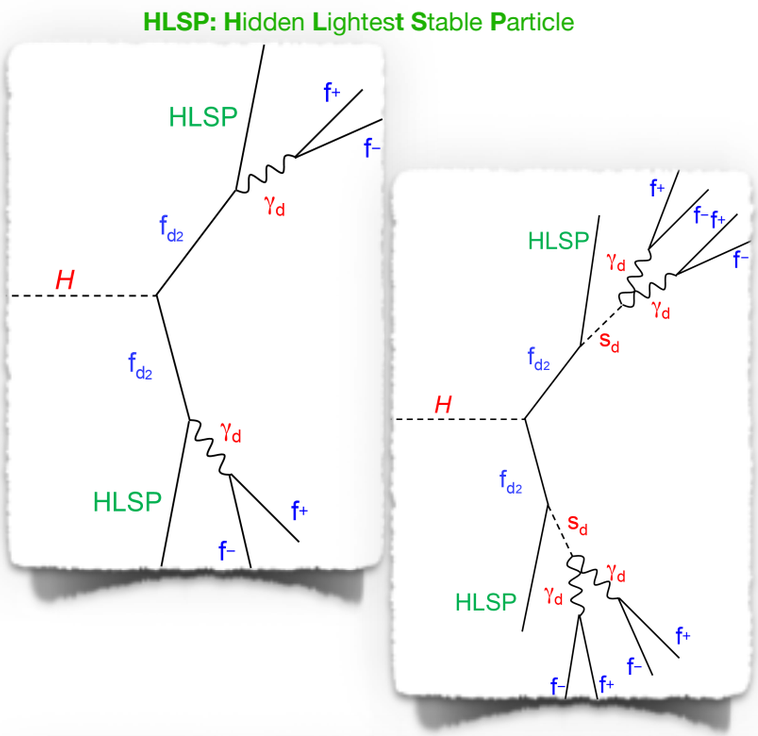




ATLAS
EXOT-2018-15
$m_{W_R} > 3.8 - 5\ TeV$ for
$m_{N_R} = 0.1 - 1.8\ TeV$
using 80 fb^{-1}

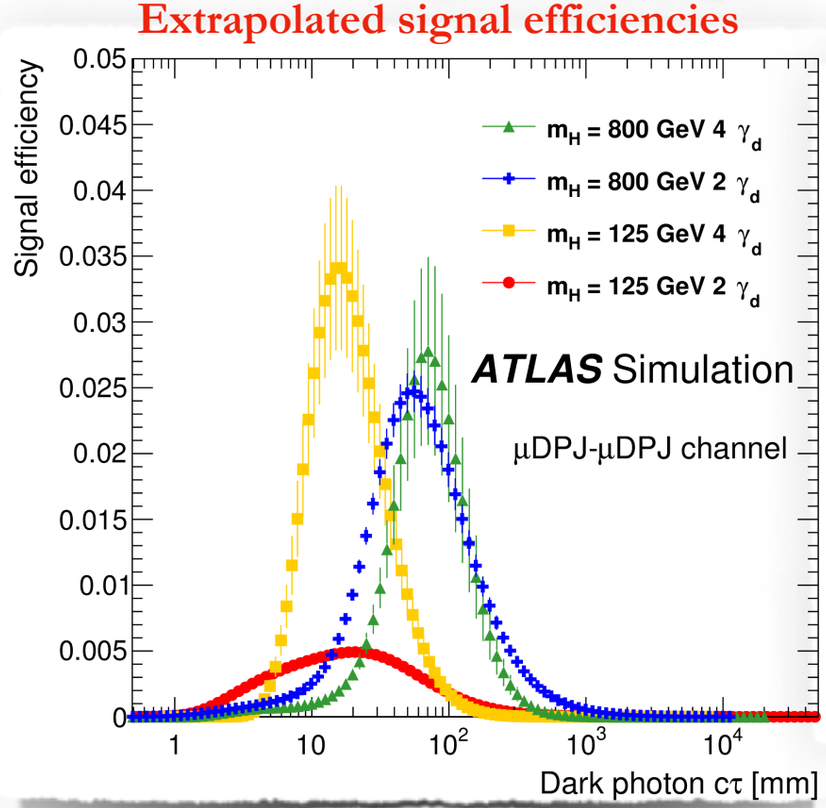
SEARCH FOR LONG-LIVED NEUTRAL PARTICLES

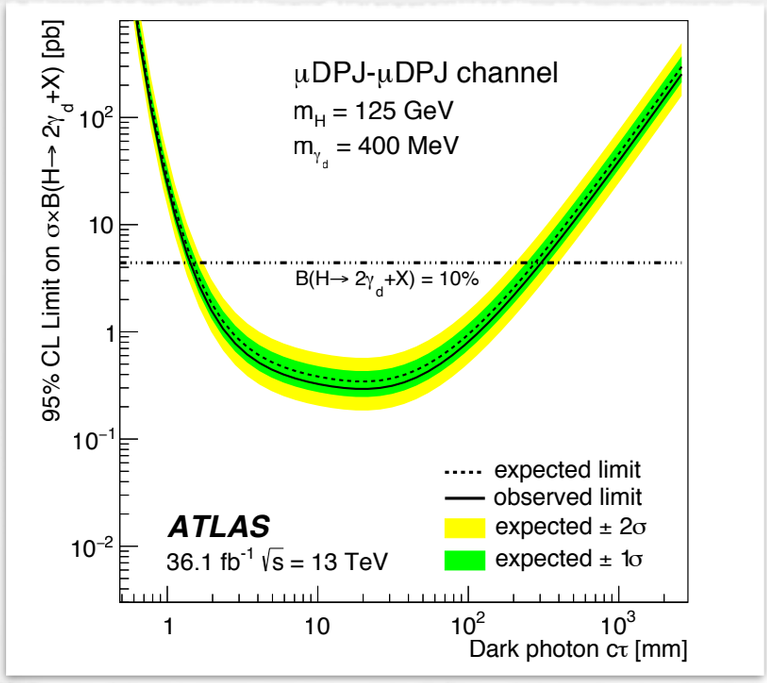
EXOT-2017-28

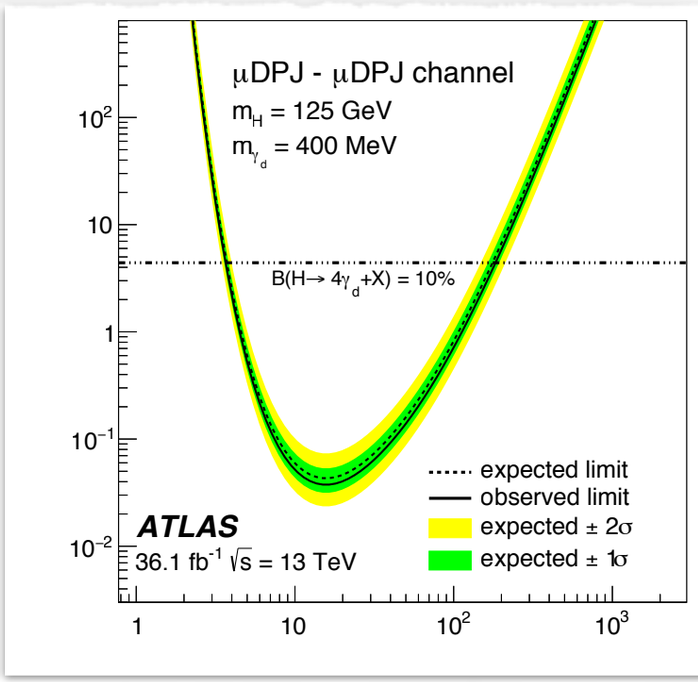


- Long-lived dark photons produced from the decay of a Higgs boson or heavy scalar boson and decaying into displaced collimated SM fermions
- Used the benchmark model : Falkowski-Ruderman-Volansky-Zupan (FRVZ)
  - f_{d_2} (dark fermion): produced via a Higgs Boson decay
  - **Two different cases:** the production of either two or four dark photons
- Backgrounds: Multi-jet events (main), W+jets, Z+jets, ttbar, single top-quark, WW, WZ, and ZZ events
- Two DPJ (dark-photon jet) classification:
  - muonic-DPJ **(μDPJ)** and hadronic-DPJ (hDPJ)
- Triggers: Two muon triggers and one calorimeter trigger

Extrapolated signal efficiencies







$\sigma x BR$ above 4 pb is excluded for a Higgs boson decaying into two dark photons for dark-photon decay lengths **between 1.5 mm and 307 mm.**

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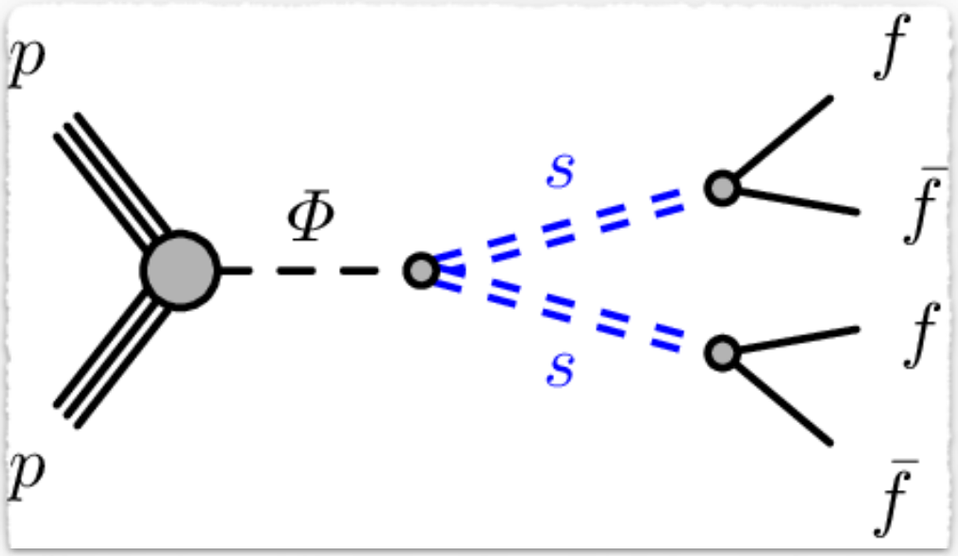
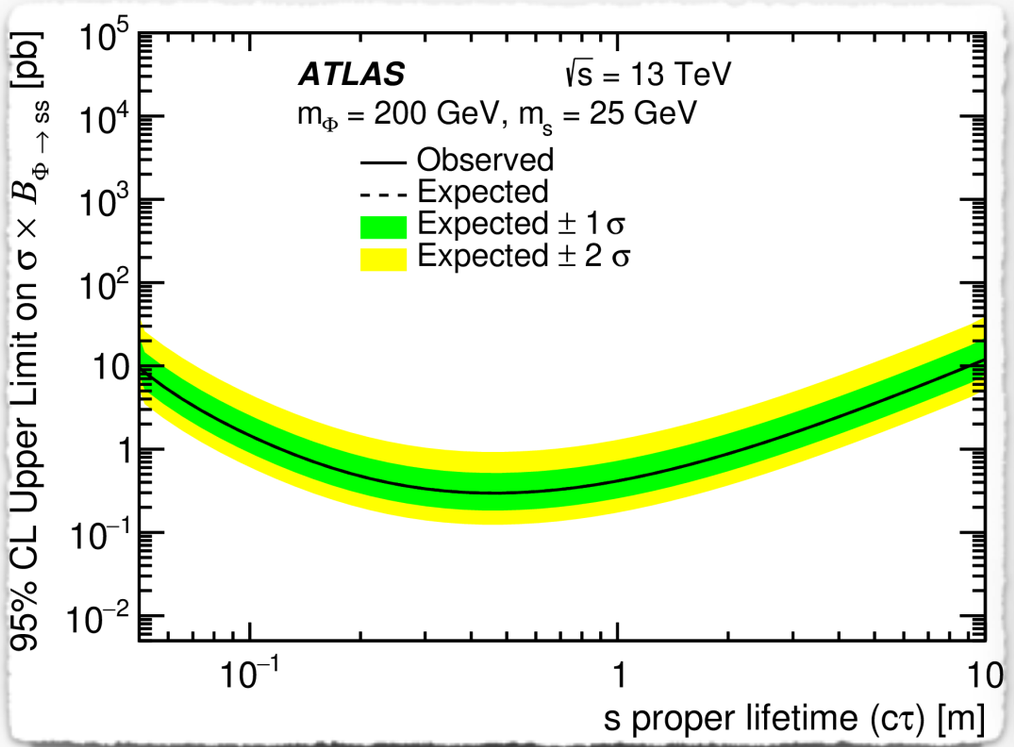
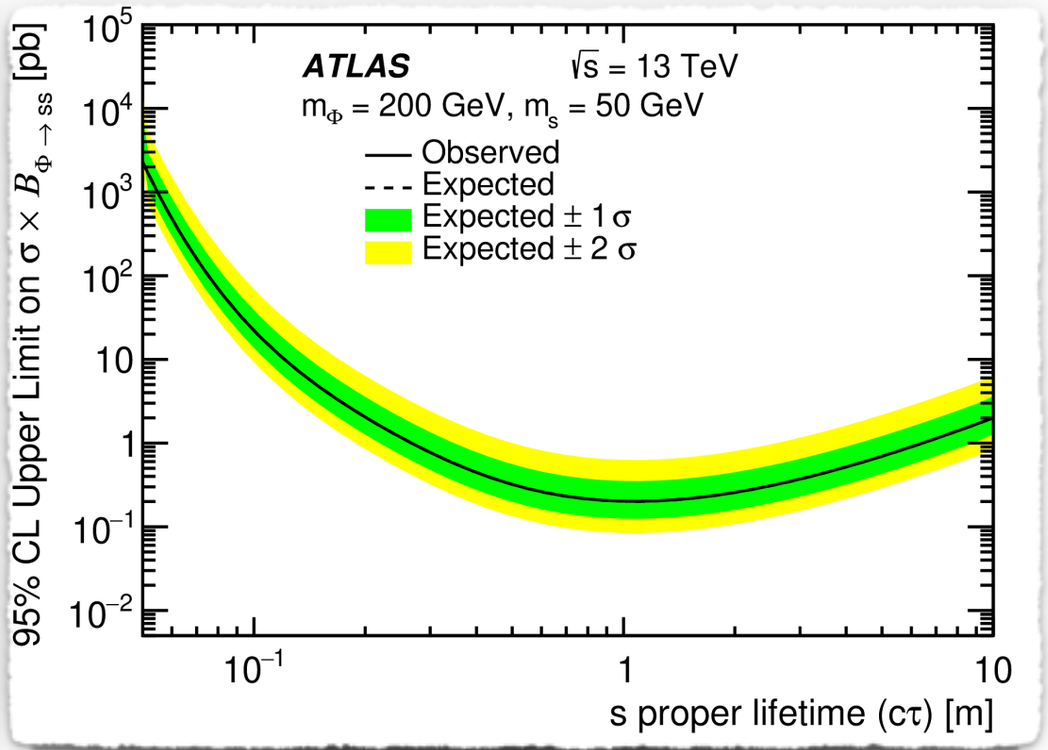
SEARCH FOR LONG-LIVED NEUTRAL PARTICLES



- Long-Lived neutral particles decaying into displaced hadronic jets using 33fb^{-1}
- Benchmark **Hidden Sector** (HS) models
- **Focus on the topology:** one long-lived particle decays in the **ID** and the other decays in the **MS**
- **Special techniques**
  - large-radius tracking and displaced vertex reconstruction algorithm
- Data driven background estimation method



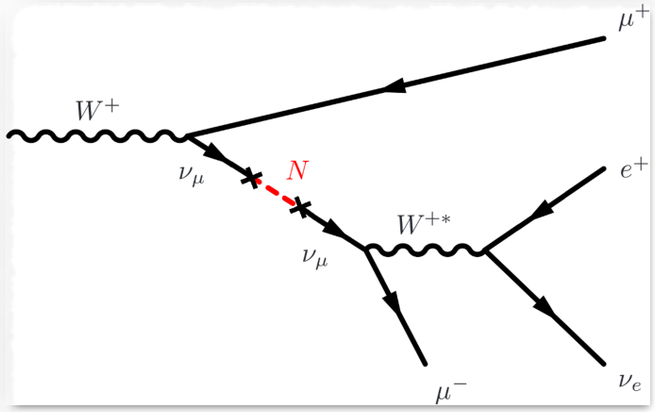


- A scalar mediator mass range from 125 to 1000 GeV, decaying to pairs of long-lived scalars mass range from 8 to 400 GeV
- Limits on the cross section times branching ratio for a **200 GeV Φ mass** decaying into long-lived scalars with masses of **25 and 50 GeV**

SEARCH FOR HEAVY NEUTRAL LEPTONS (HNLs)

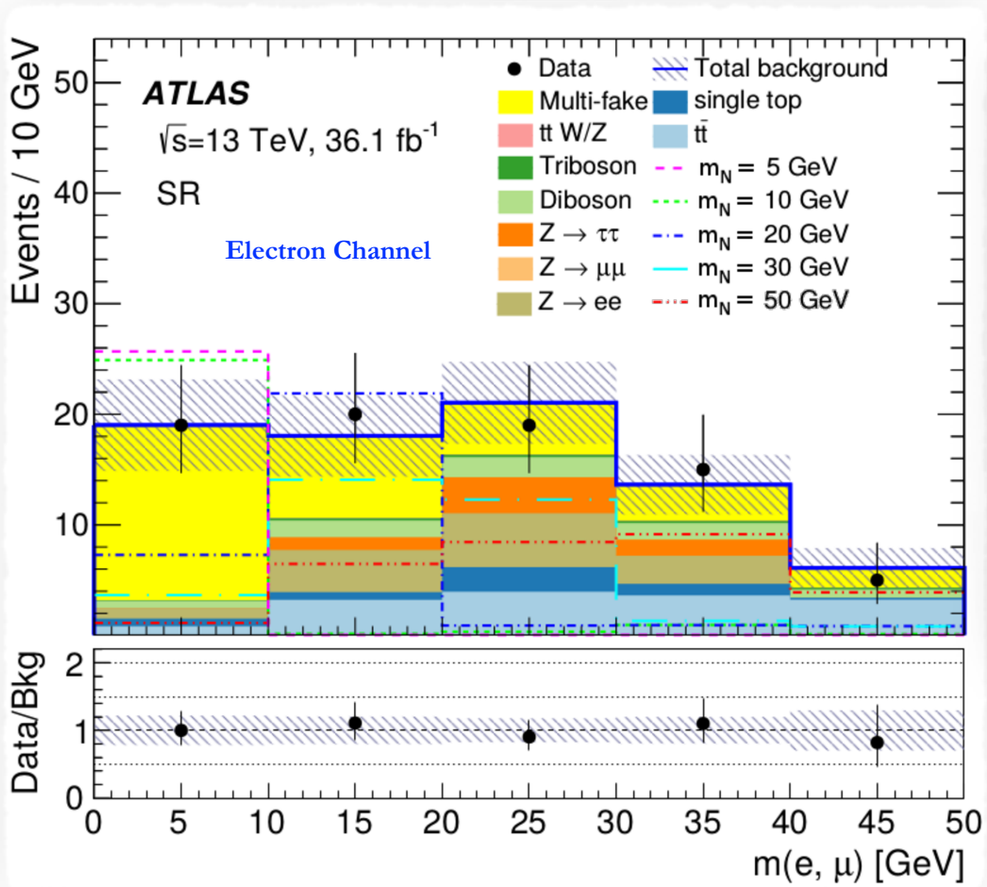
arXiv:1905.09787

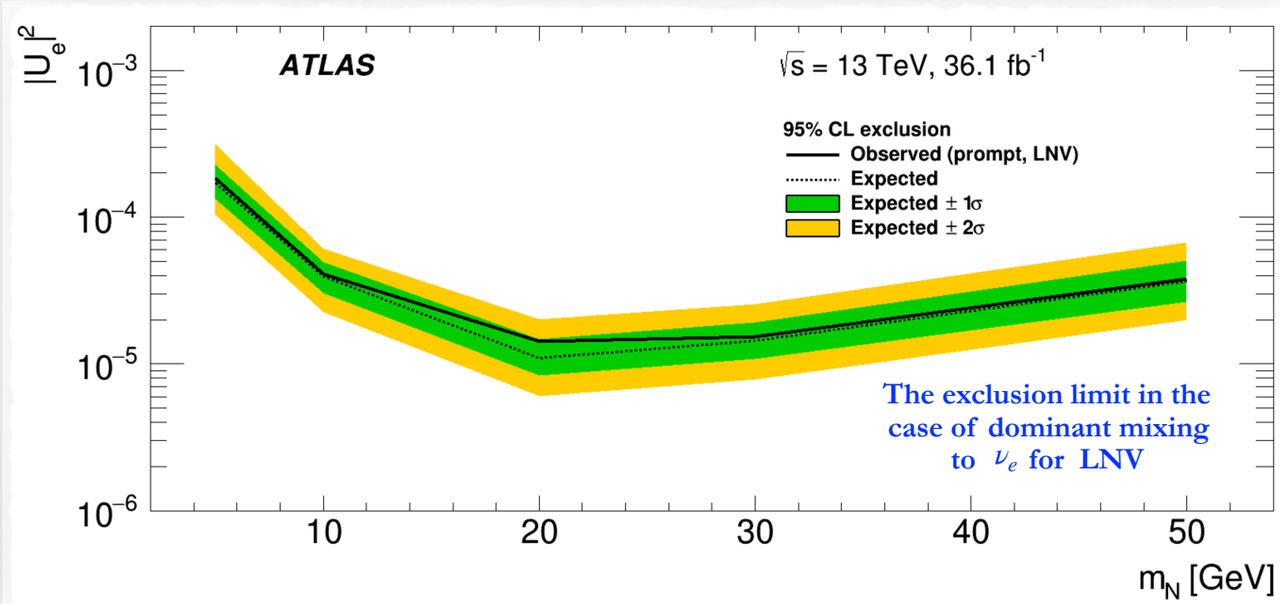
- Leptonic decays of W bosons are used **to search for HNLs**: produced through mixing with muon or electron neutrinos
- Both prompt and displaced leptonic decay signatures:
  - **Prompt**: 3 leptons (2mu1e or 2e1mu) produced at the IP with a veto on OSSF topologies
  - **Displaced**: comprises a prompt muon from the W decay and the requirement of a dilepton vertex (mumu or mue) displaced in the transverse plane by 4-300 mm from the IP



W boson production

$$\sigma(pp \to W) \cdot \mathcal{B}(W \to \ell N) = \sigma(pp \to W) \cdot \mathcal{B}(W \to \ell \nu) \cdot |U|^2 \left(1 - \frac{m_N^2}{m_W^2}\right)^2 \left(1 + \frac{m_N^2}{2m_W^2}\right).$$

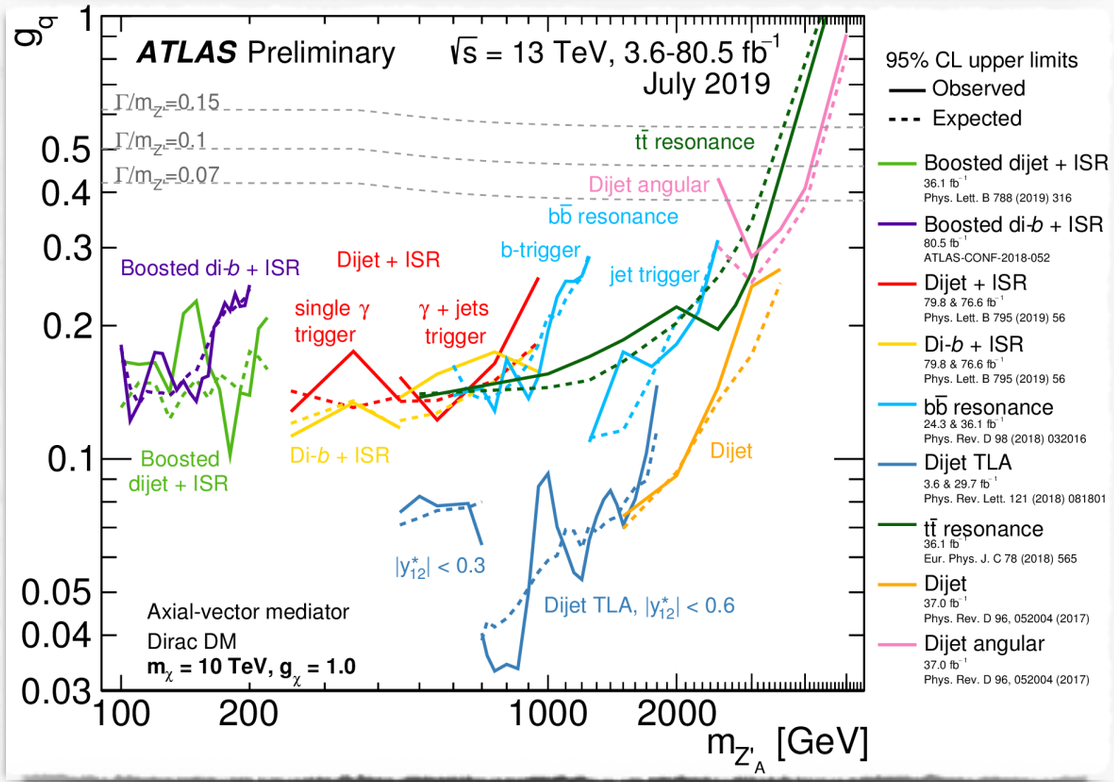


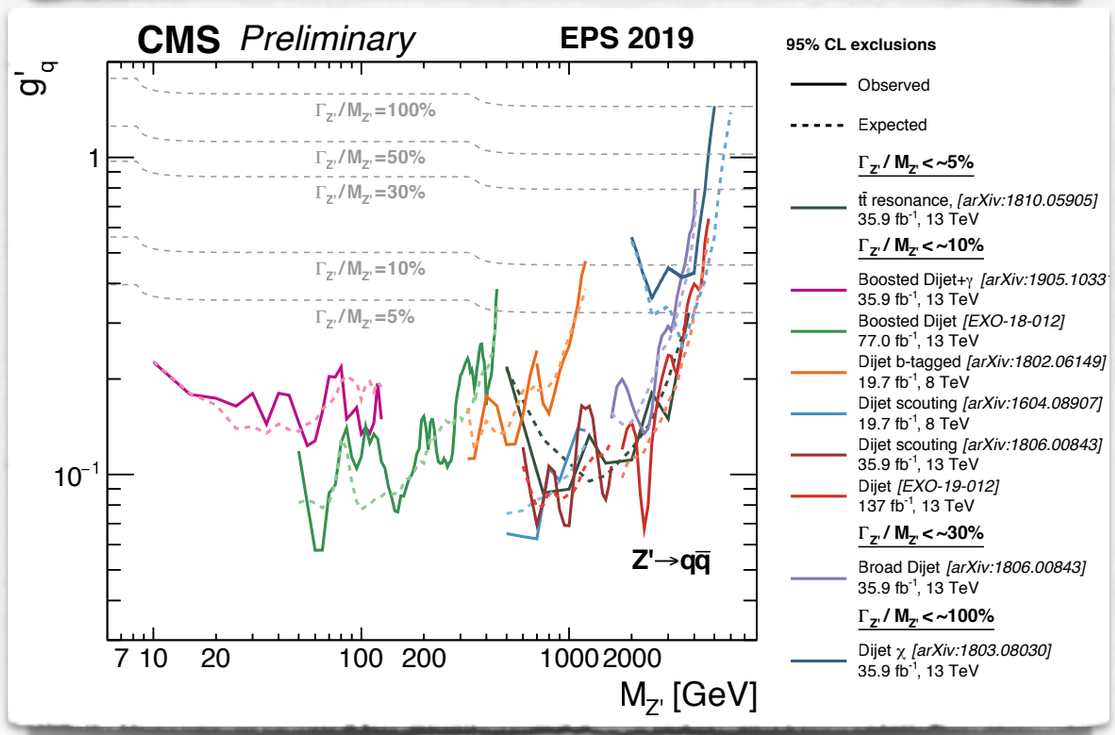


The search sets constraints on the HNL mixing to muon and electron neutrinos for HNL masses in the range 4.5 - 50 GeV

SUMMARY

- Not possible to cover everything here …
- Please feel free to examine the all results available from the experiments:
  - **ATLAS EXOTICS RESULTS [1]**
  - **CMS EXOTICA RESULTS [2]**
- ATLAS & CMS searches for BSM resonances in hadronic/leptonic final states utilised 36-139/fb of LHC Run-II pp data at $\sqrt{s} = 13\ TeV$
- No significant deviations from the SM background hypothesis so far
- Processing of the full LHC Run-II 139/fb data set is in progress
- Long Shutdown period
  - Have a chance to think and discuss more!
  - **Waiting for the integrated luminosity to increase and new techniques and ideas are very welcome :)**





THANKS!!!

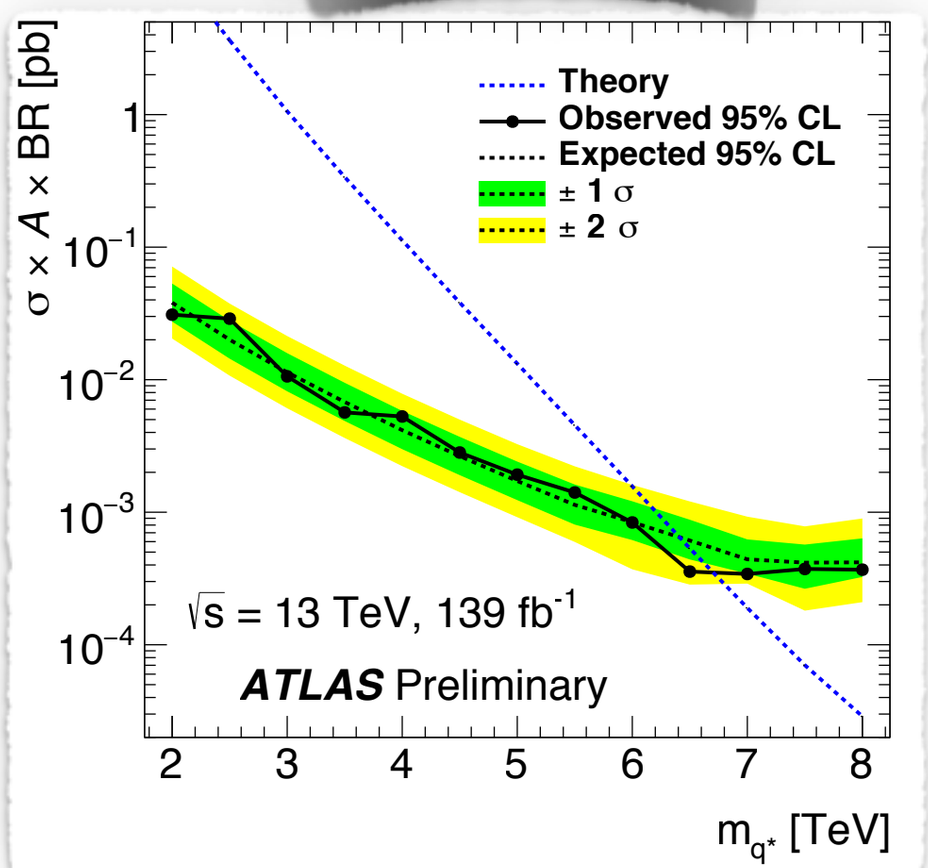
A. Adiguzel

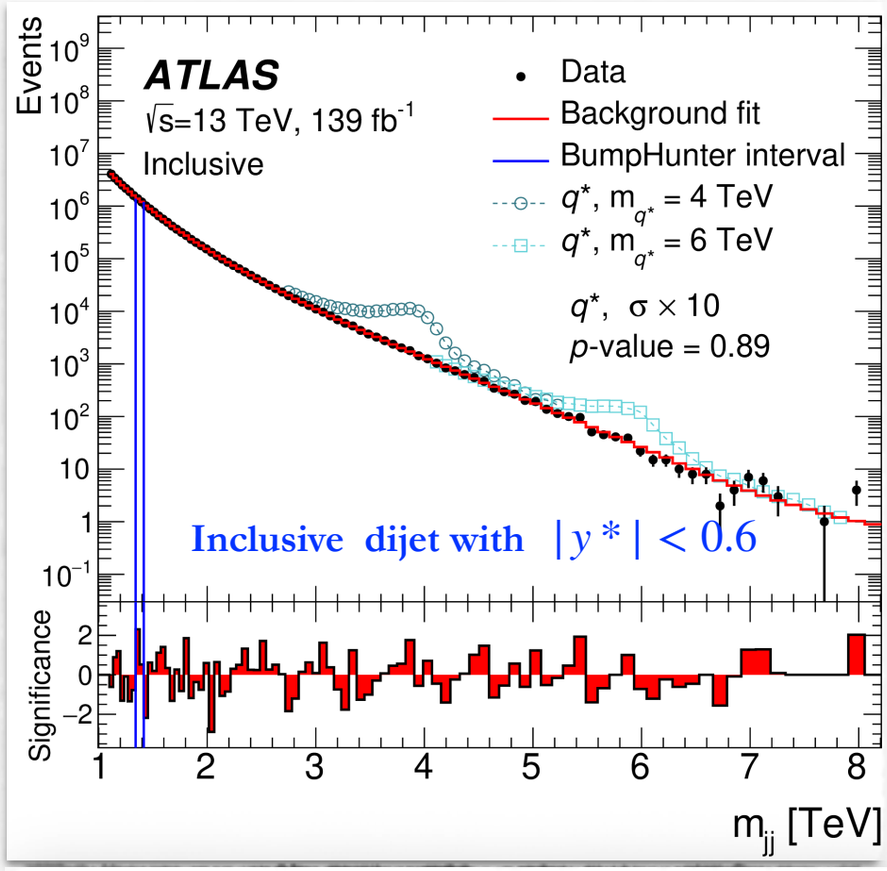
BACK UP

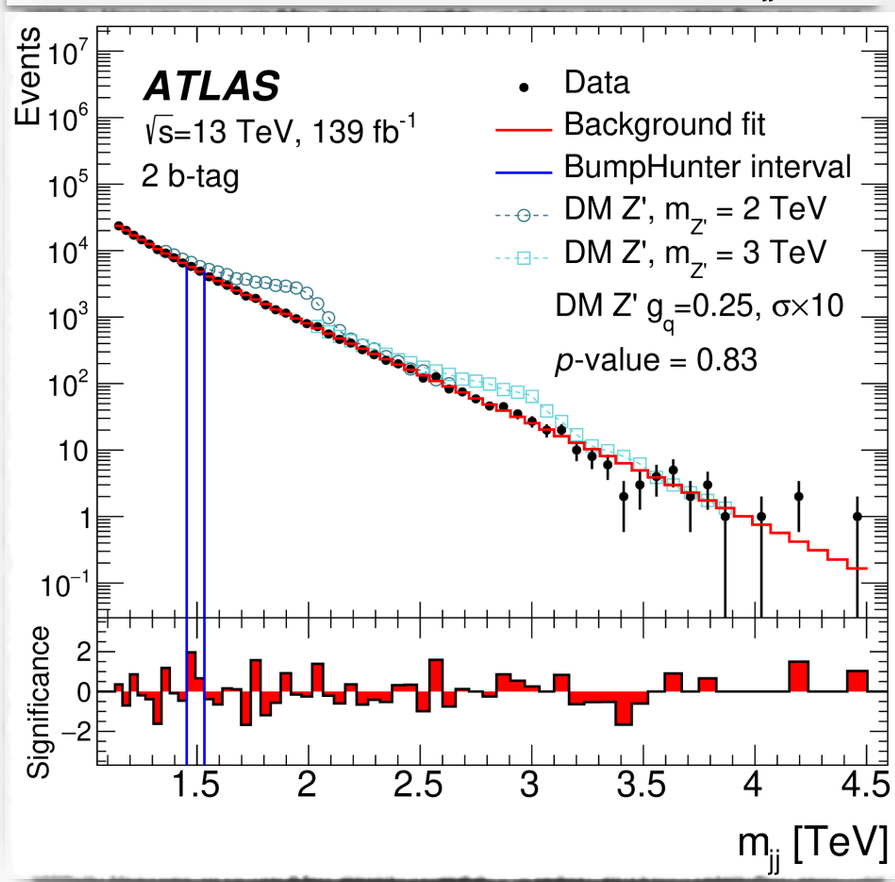
arXiv:1910.08447

DIJET/DIBJET SEARCHES

- New resonances decaying to a pair of jets
- Full Run 2 data : 2015 - 2018, corresponding to 139 fb^{-1}
- Collecting data with single jet trigger (p_T threshold 420 GeV)
- Probe high mass region
- Variable binning to reflect varying resolution
- Background estimate obtained using the sliding window-fit
- Data fitted with : $f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x}$



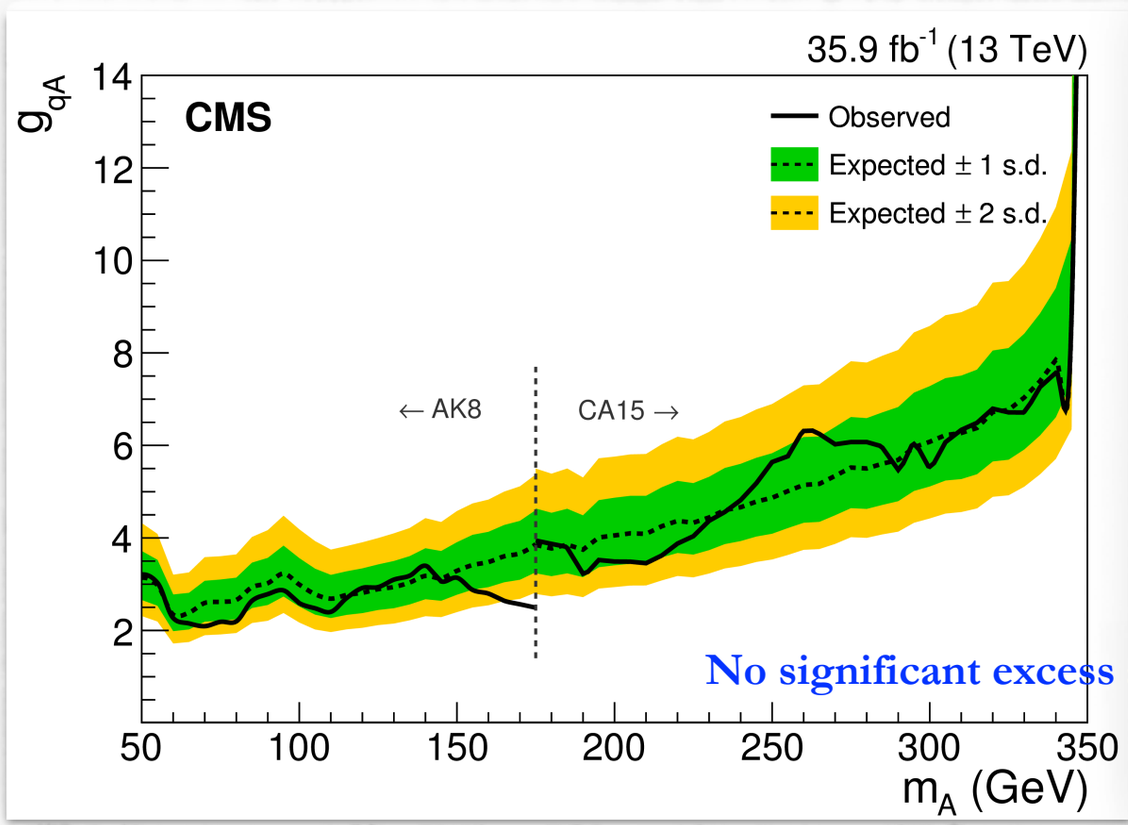


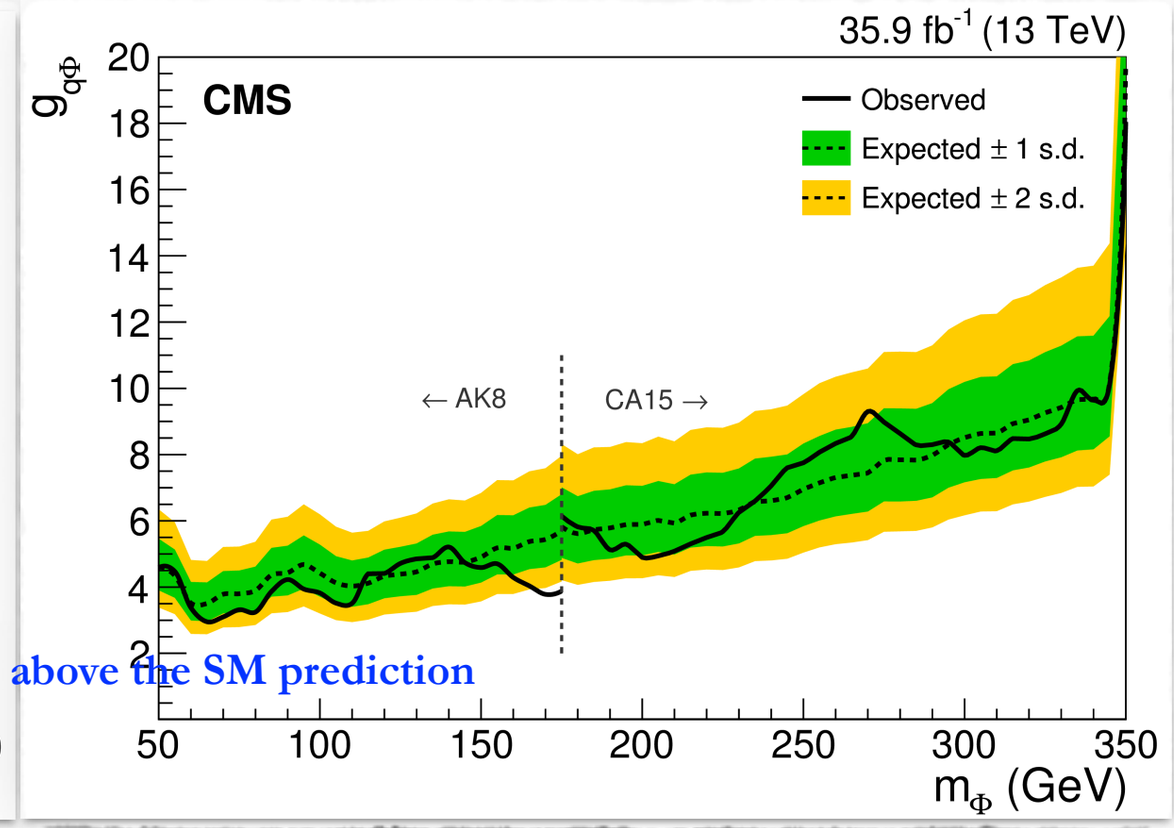


- Limits on Gaussian signal models
- No significant excesses found
  - **Excited quarks q*** with masses < **6.7 TeV** are excluded at 95% CL

DIBJETS+ ISR SEARCHES

- Narrow, low-mass, scalar and pseudoscalar resonances decaying to bottom quark-antiquark
- Two wide-jet algorithm considered:
  - anti-k_t R=0.8, better sensitivity at signal masses below 175 GeV
  - Cambridge-Aachen R=1.5, better sensitivity at higher masses
- Dedicated double b-tagger
  - Events failing the selection are used for the QCD estimation
- 11 p_T categories (six for AK8, five for CA15) defined
- Soft drop jet mass as discriminating variable





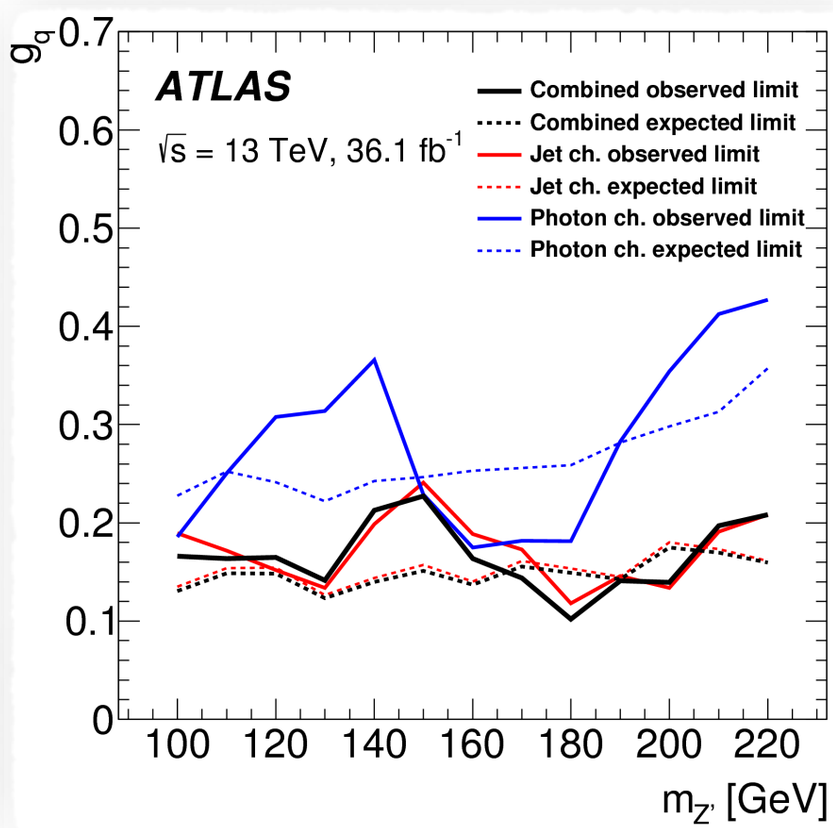
No significant excess above the SM prediction

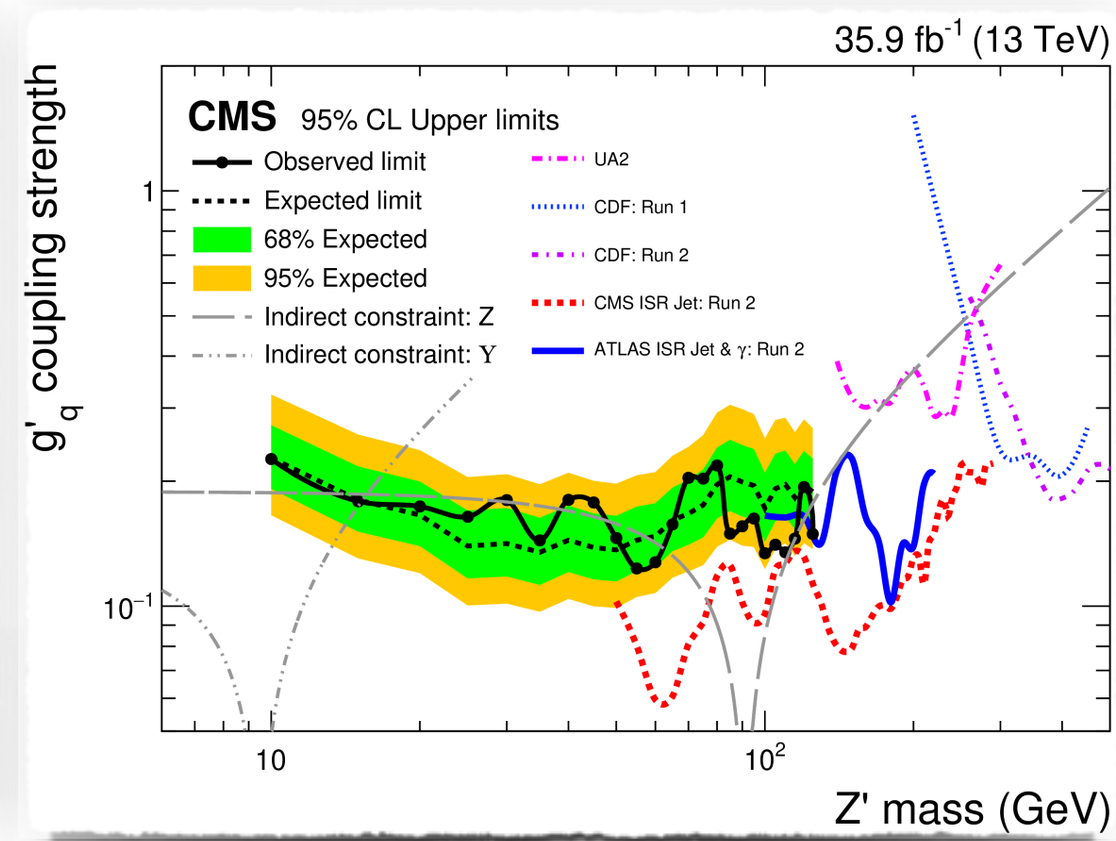
Upper limit on $g_{q\phi}(g_{qA})$ of 3.9(2.5)

DIJET+ ISR (Photon/Jets) SEARCHES

- A search for new light resonances decaying to pairs of quarks and produced in association with high-p_T photon or jet.
- Very similar techniques in all analyses
  - Search for an excess in m_{jj}
    - **ATLAS:** Photon trigger: $E_T > 155$ GeV ; jet trigger : $p_T > 450$ GeV - anti-k_t R= 0.4
    - **CMS:** One photon with $p_T > 175$ GeV; leading jet $p_T > 200$ GeV - anti-k_t R= 0.8
  - Limits on DM mediators
    - CMS results below 50 GeV are the first to be published in this range

ATLAS-EXOT-2017-01

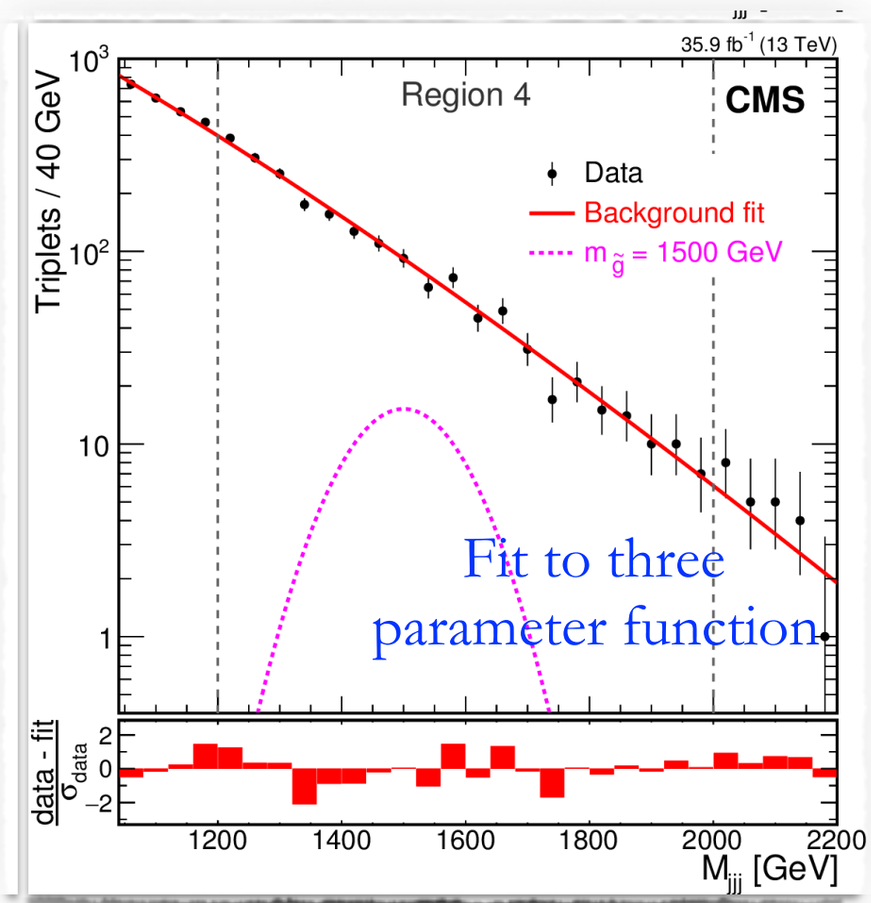


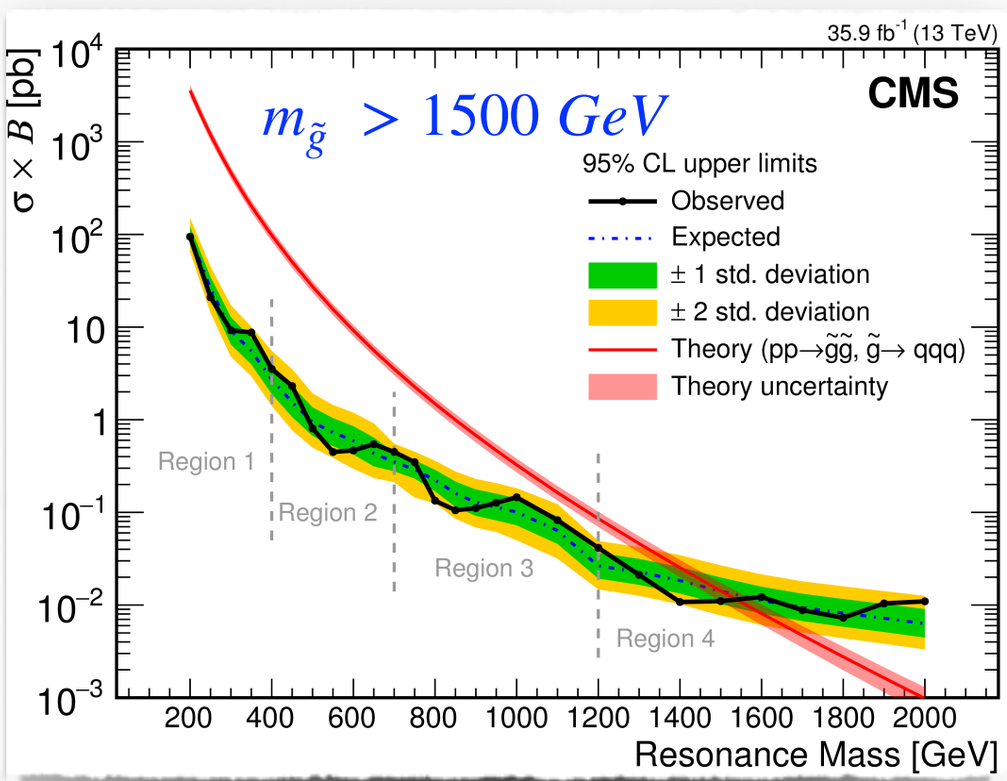


CMS-EXO-17-027

PAIR PRODUCED THREE-JET RESONANCES

- Performed for pair-produced resonances decaying into three jets
- Data 2016, ~36 pb^{-1}
- Gluino mass range (from 200 to 2000 GeV) is explored in four separate region:
  - Region 1: 200-400 GeV
  - Region 2: 400-700 GeV
  - Region 3: 700-1200 GeV
  - Region 4: 1200-2000 GeV
- Theoretical model : **RPV gluinos**
- Three sources of background : QCD multijets, fully hadronic decays of ttbar pairs and combinatorial background from signal events





- No significant excess
- Gluino masses below **1500 GeV** are excluded at 95% CL

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TTBAR RESONANCES

- General search for X→ ttbar resonances
- **Main backgrounds:**
  - SM ttbar and multijet
- **Benchmark models**
  - Topcolor assisted technicolor Z' (spin-1)
  - Randall-Sundrum (RS) model Kaluza Klein G (Spin=2)
  - DM mediator and KK gluon with different widths

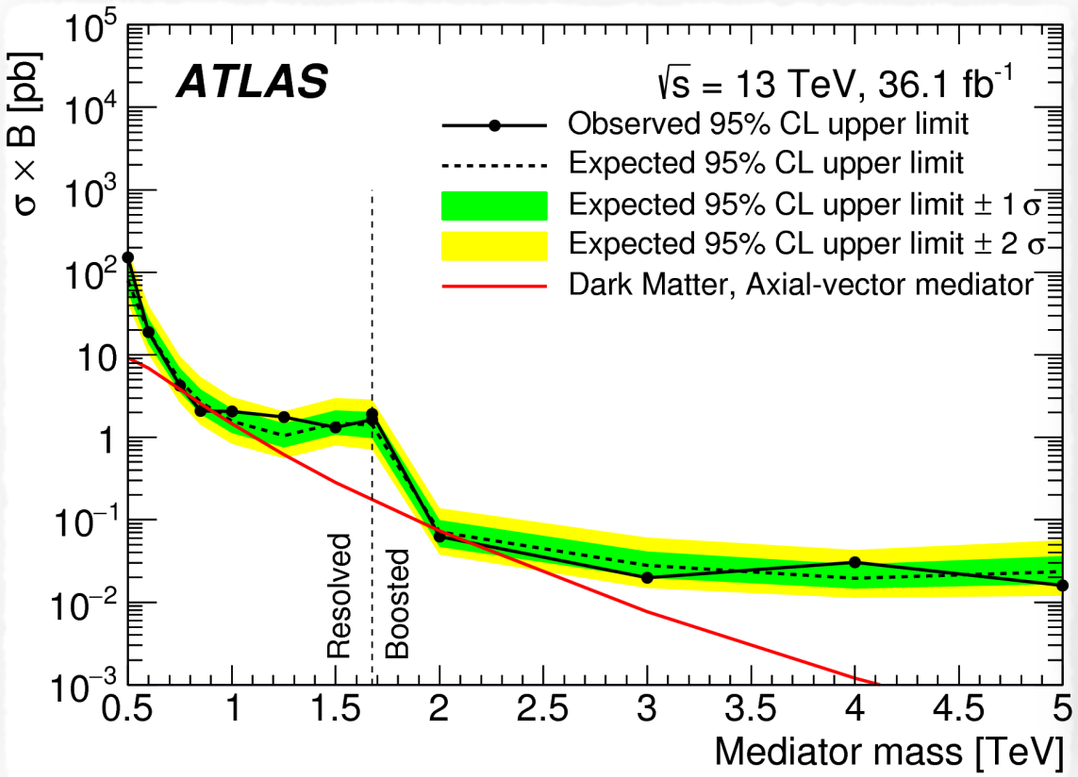
- **Mass categorisation:**
  - **Low mass**: multijet final state "resolved"
  - **High mass**: large-R jets (boosted)
- **Pair reconstruction:**
  - **Resolved**: buckets of tops algorithm, based on m_{top} and m_W
  - **Boosted**: top-tagging based on jet mass and jet substructure

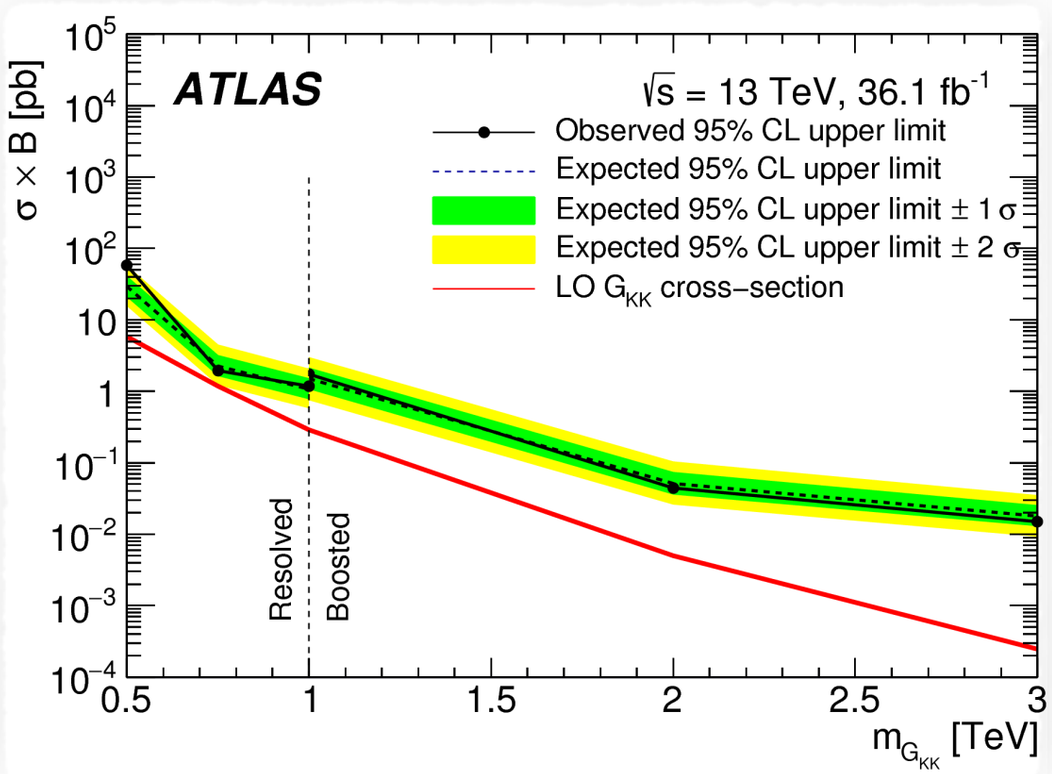
Exclusions:

- Technicolor Z' model up to 3.1-3.6 TeV

- Simplified DM mediators from 0.8 to 0.9 TeV and from 2.0 TeV to 2.2 TeV

- KK gluon up to 3.4 TeV depending on the decay width of the particles

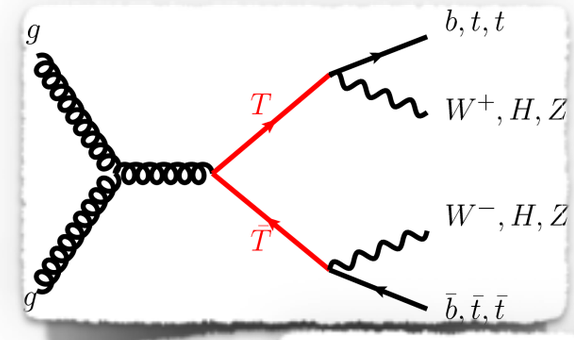


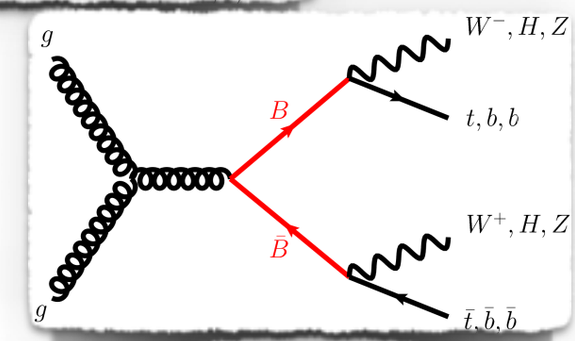


VECTOR-LIKE QUARKS COMBINATION

EXOT-2017-17

- Most searches assume that the VLQs couple/decay to SM particles (a boson and a 3rd generation quark)
- Rich phenomenology at the LHC — leptons, jets, lots of to quarks, and bottom quarks in the final state!



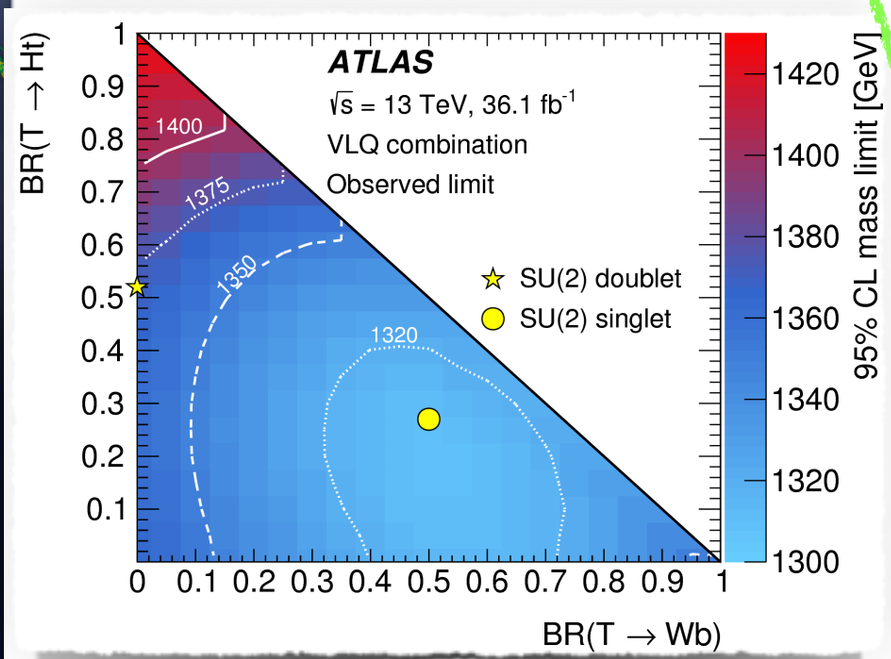


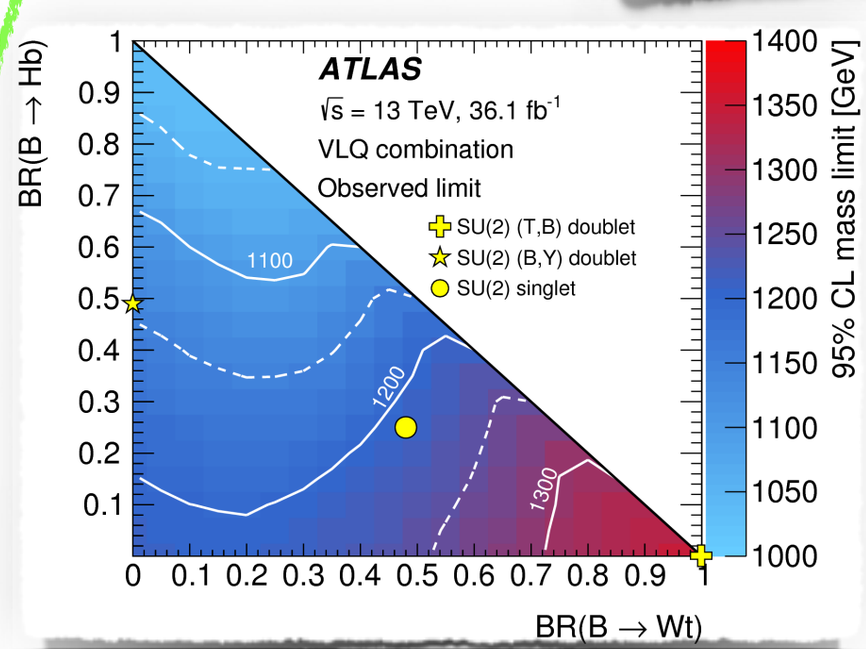
- A combination of the searches for pair-produced vector like partners is performed:
  - $T \rightarrow Zt/Wb/Ht$
  - $B \rightarrow Zb/Wt/Hb$
    - The branching ratio for each decay mode depends on the VLQ mass and weak-isospin quantum numbers

Multiple Channels

Analysis	$T\bar{T}$ decay	$B\bar{B}$ decay
$H(bb)t + X$ [16]	$HtH\bar{t}$	-
$W(\ell\nu)b + X$ [17]	$WbW\bar{b}$	-
$W(\ell\nu)t + X$ [18]	-	$WtW\bar{t}$
$Z(\nu\nu)t + X$ [19]	$ZtZ\bar{t}$	-
$Z(\ell\ell)t/b + X$ [20]	$ZtZ\bar{t}$	$ZbZ\bar{b}$
Tril./s.s. dilepton [21]	$HtH\bar{t}$	$WtW\bar{t}$
Fully hadronic [22]	$HtH\bar{t}$	$HbH\bar{b}$

- Combination significantly increases sensitivity
- Singlet T and B are excluded for $m_{T,B} < 1.31$ and 1.22 TeV
- For the (T,B) doublet, $m_{T,B} < 1.37$ TeV are excluded

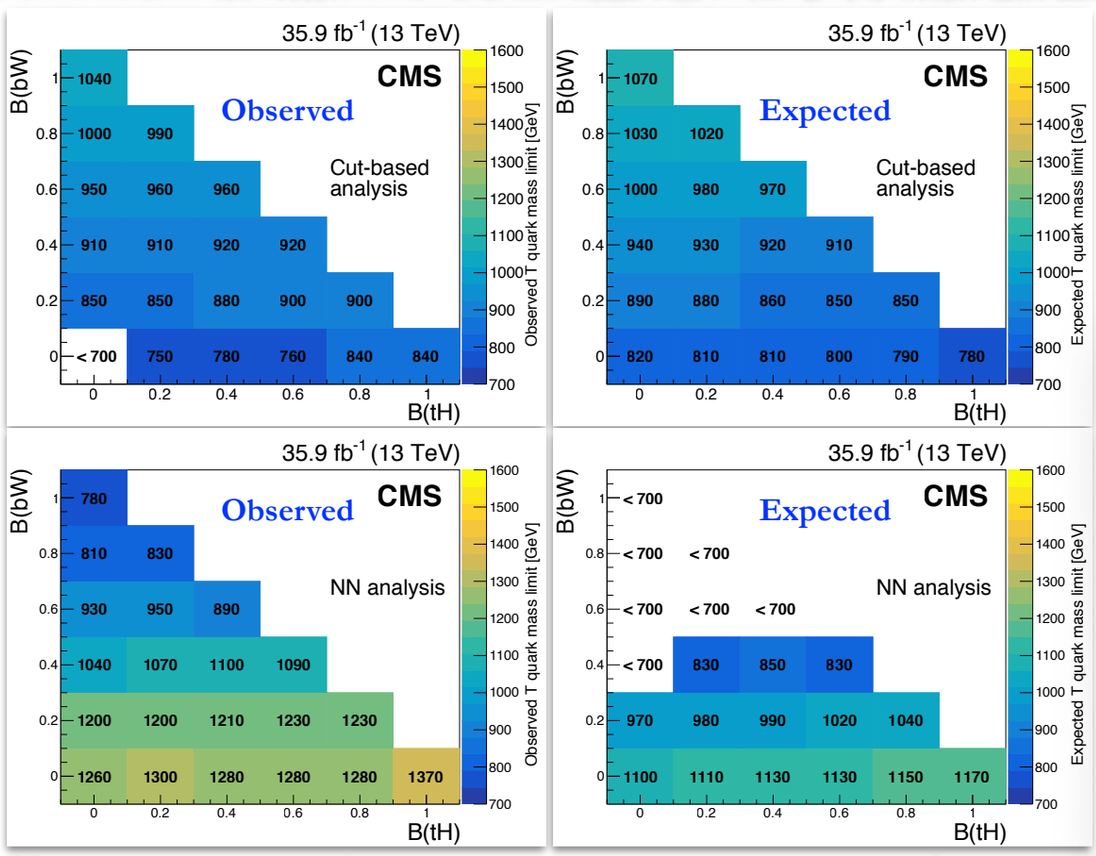




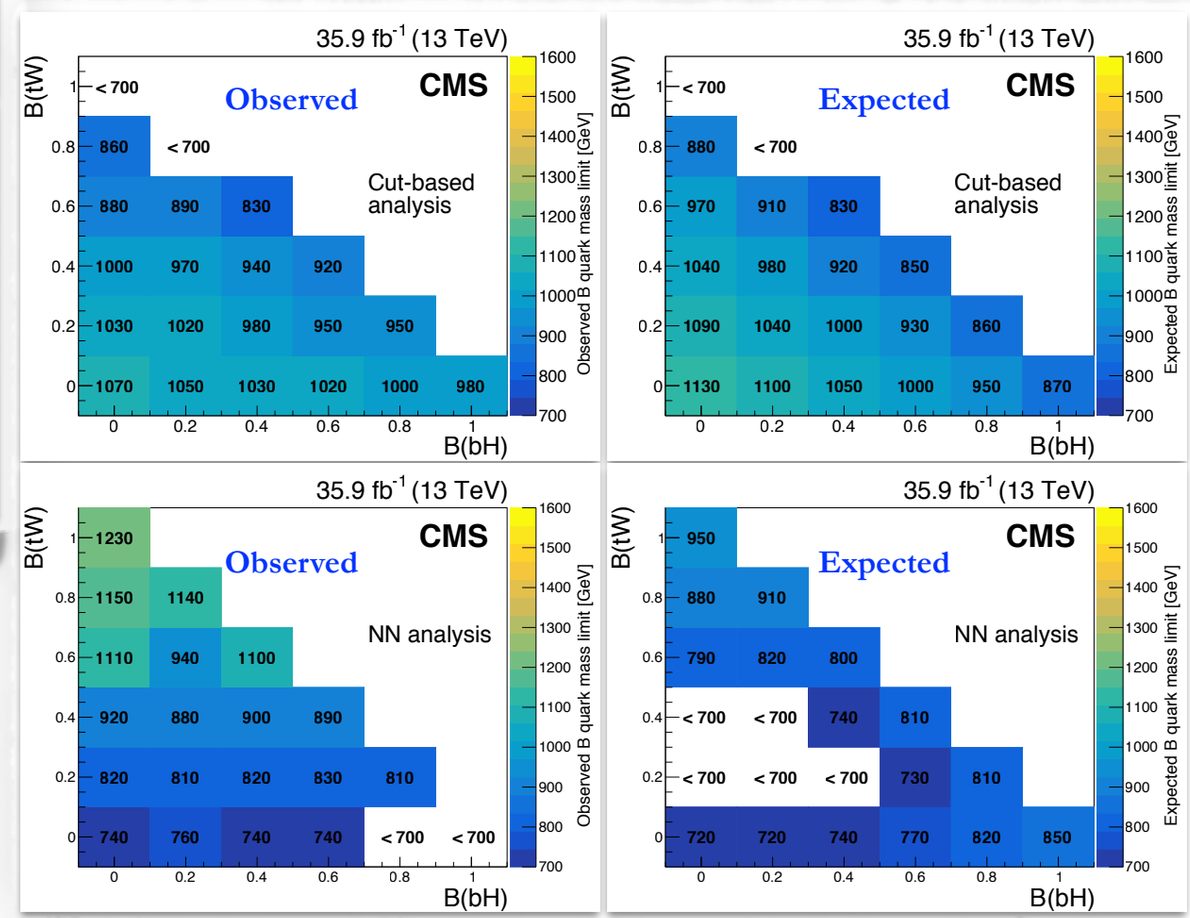
VECTOR-LIKE QUARKS COMBINATION

- The results two searches for pair production of vector-like T/B quarks in fully hadronic final states
- Two independent analysis — "Cut-Bases analysis" and "Neural network analysis"

Mass exclusion limits at 95 % CL for each combination of **B quark** branching fractions



Mass exclusion limits at 95 % CL for each combination of **T quark** branching fractions

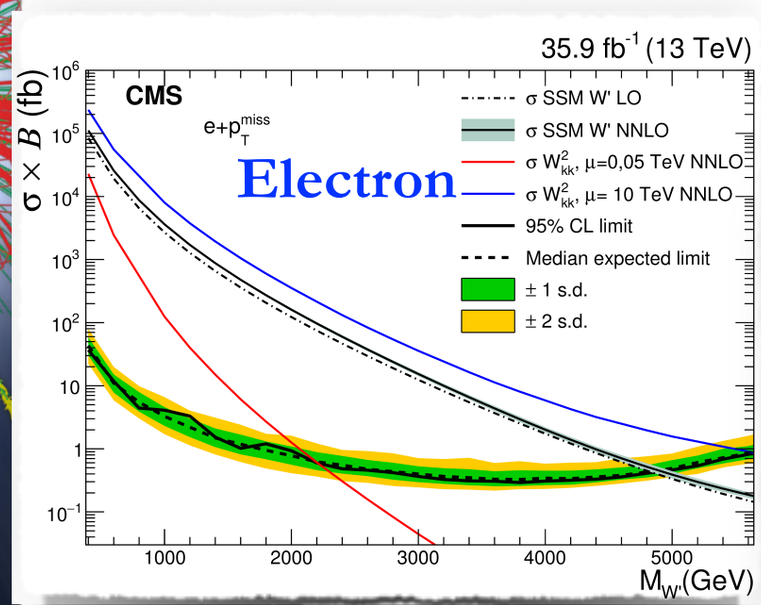


LEPTON AND MISSING TRANSVERSE ENERGY

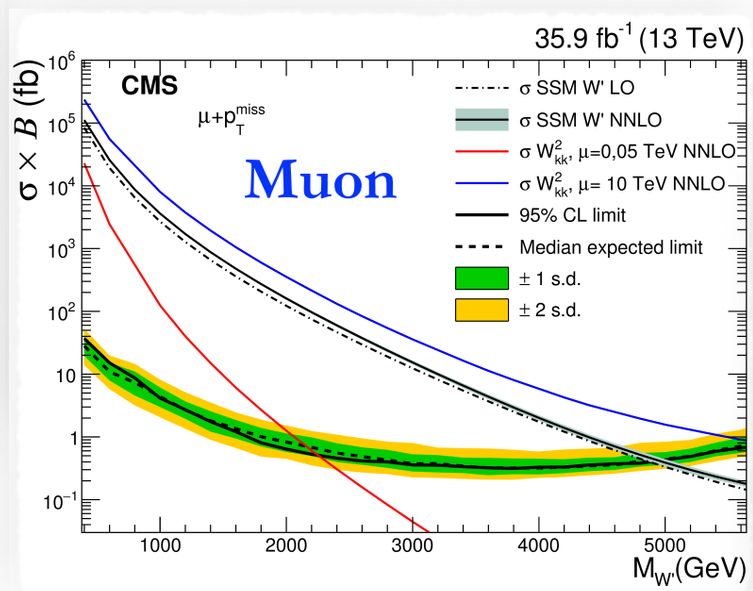
$W' \rightarrow e\nu/\mu\nu/\tau\nu$

- CMS-EXO-16-033 where $l = e, \mu$
- CMS-EXO-17-008 where $l = \tau$

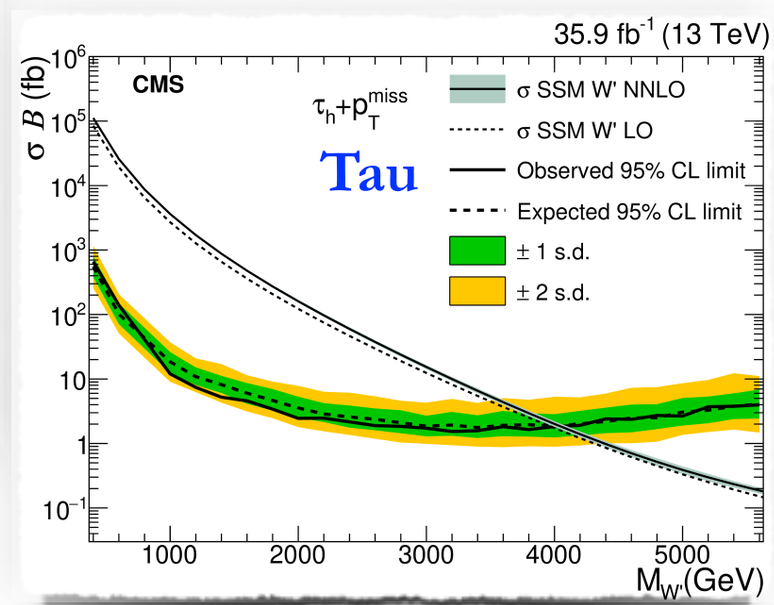
- Similar analysis strategies:
  - e/μ analysis: single $e/\mu/\gamma$ trigger
  - τ analysis: cross-trigger requiring a hadronic τ (τ_h) and $\not{E}_T$
  - e/μ are reconstructed in a similar way as in the dilepton search
  - Taus: only well-reconstructed and identified τ_h are considered
  - Final analysis variable : transverse mass $M_T(l, \not{E}_T)$



$W'_{SSM} > 4.9\ TeV$



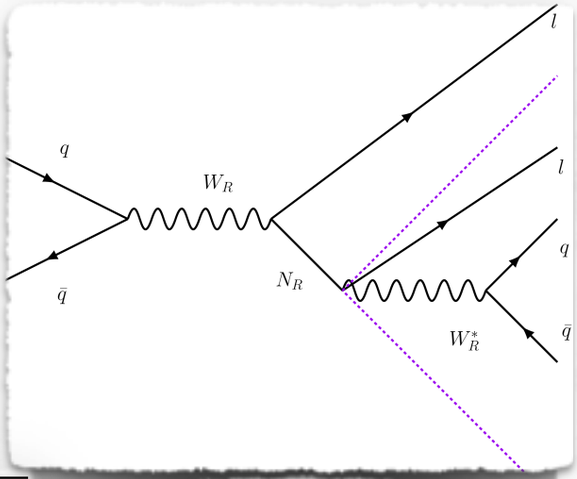
$W'_{SSM} > 4.9\ TeV$



$W'_{SSM} > 4.0\ TeV$

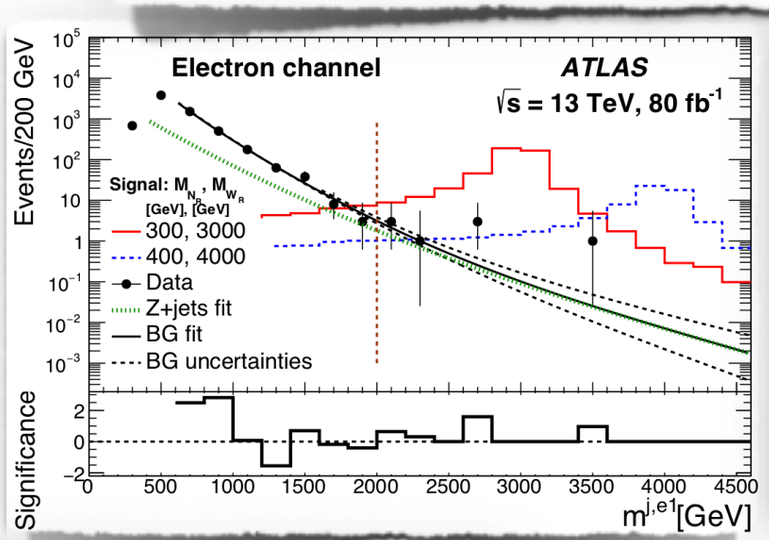
SEARCH FOR W_R and a HEAVY NEUTRINO

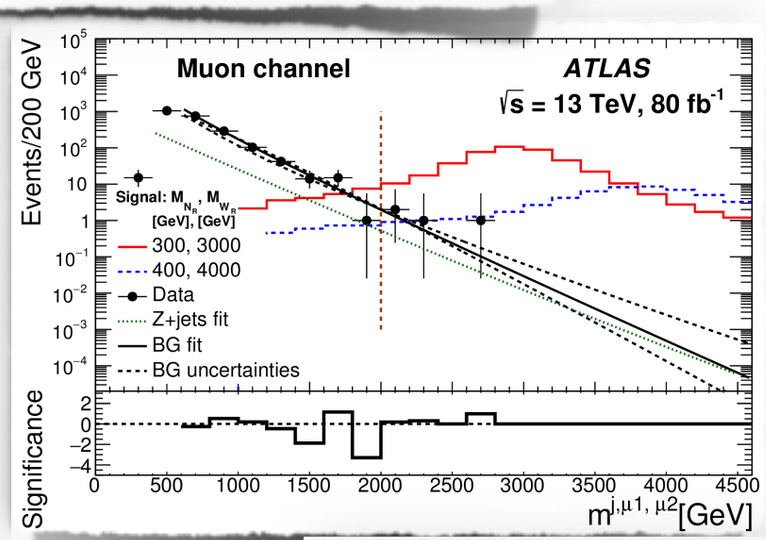
- **Left-Right Symmetric Model**:
  - Restores P-symmetry at a high energy
  - SM-singlet heavy neutrinos N_R
  - Heavy gauge boson W_R coupled to right-handed fermion currents
- $m_{N_R}/m_{W_R} \leq 0.1$:
  $W_R \rightarrow N_R l^{\pm}$ $(l = e, \mu)$,
  boosted $N_R \rightarrow l^{\pm} + large - R\ jet$



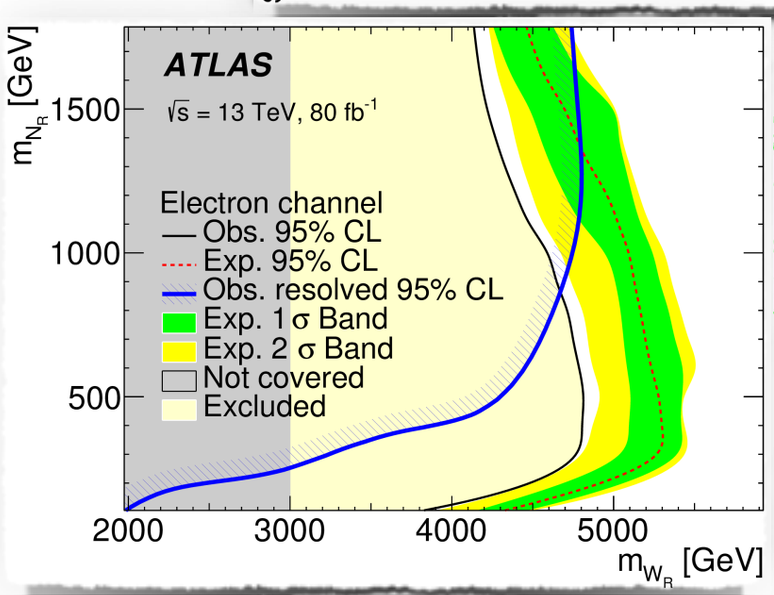
Region	Range of $m_{W_R}^{reco}$	Lepton flavour
Signal region (SR)	> 2 TeV	Same flavour
Control region (CR)	< 2 TeV	Same flavour
Validation region (VR)	All	Mixed flavour (leading: muon; subleading: electron)

ELECTRON





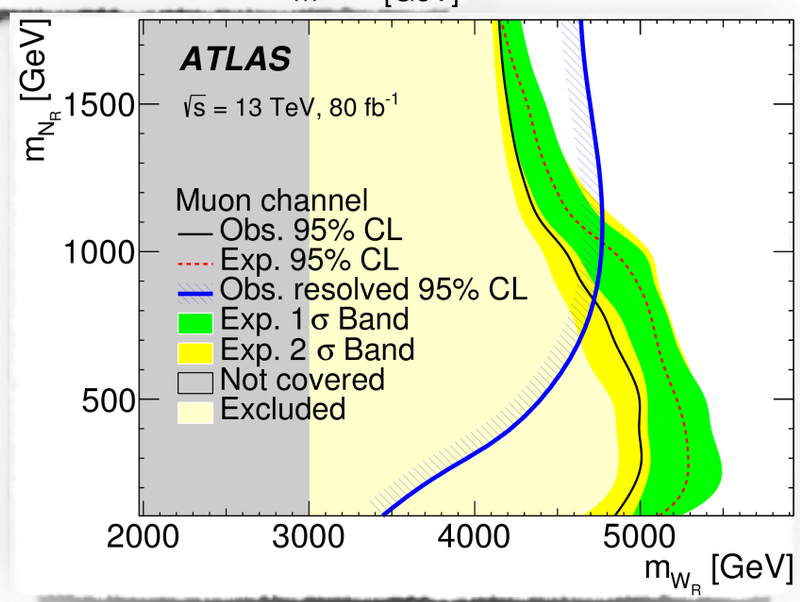
MUON



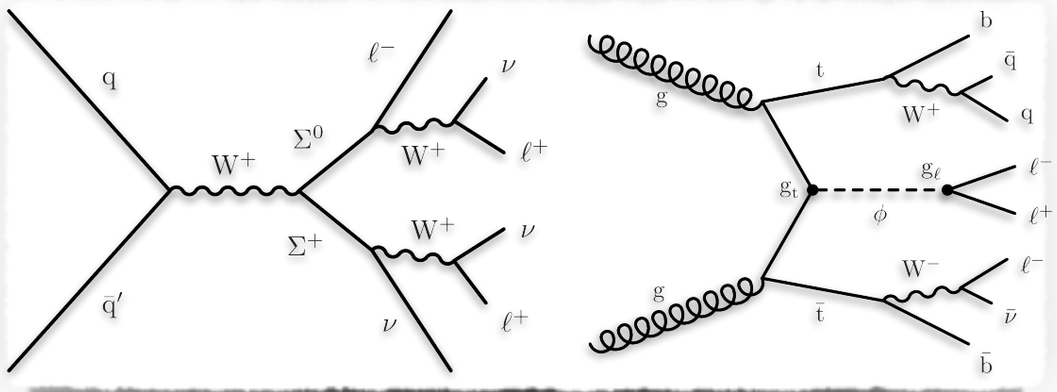
$m_{W_R} > 3.8 - 5\ TeV\ for$

$m_{N_R} = 0.1 - 1.8\ TeV$

$at\ CL = 95\ \%$



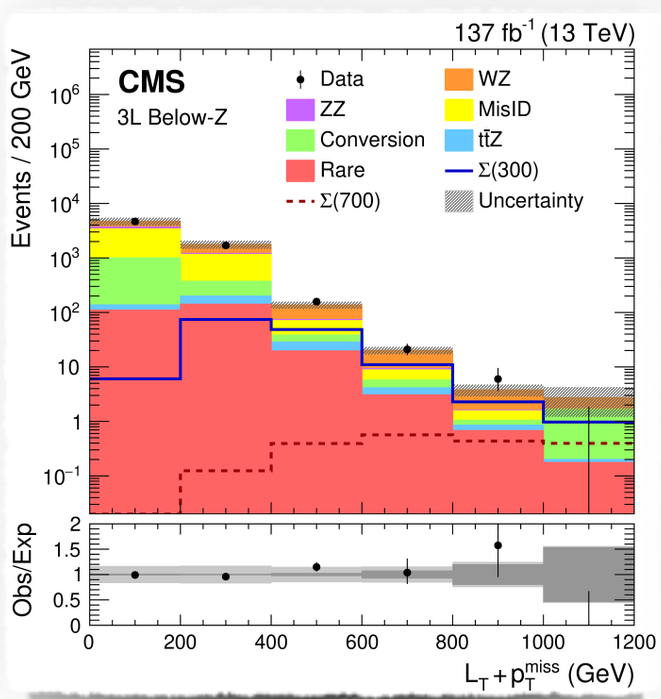
MULTILEPTON SEARCHES

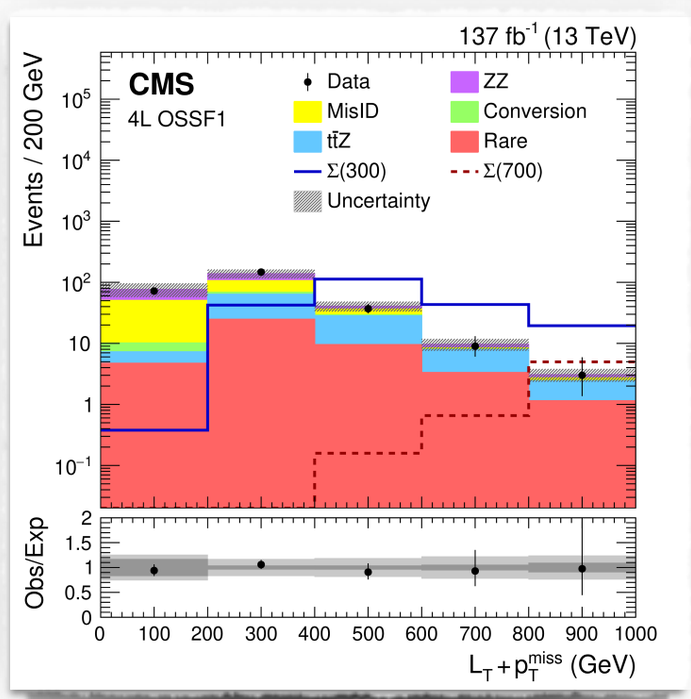


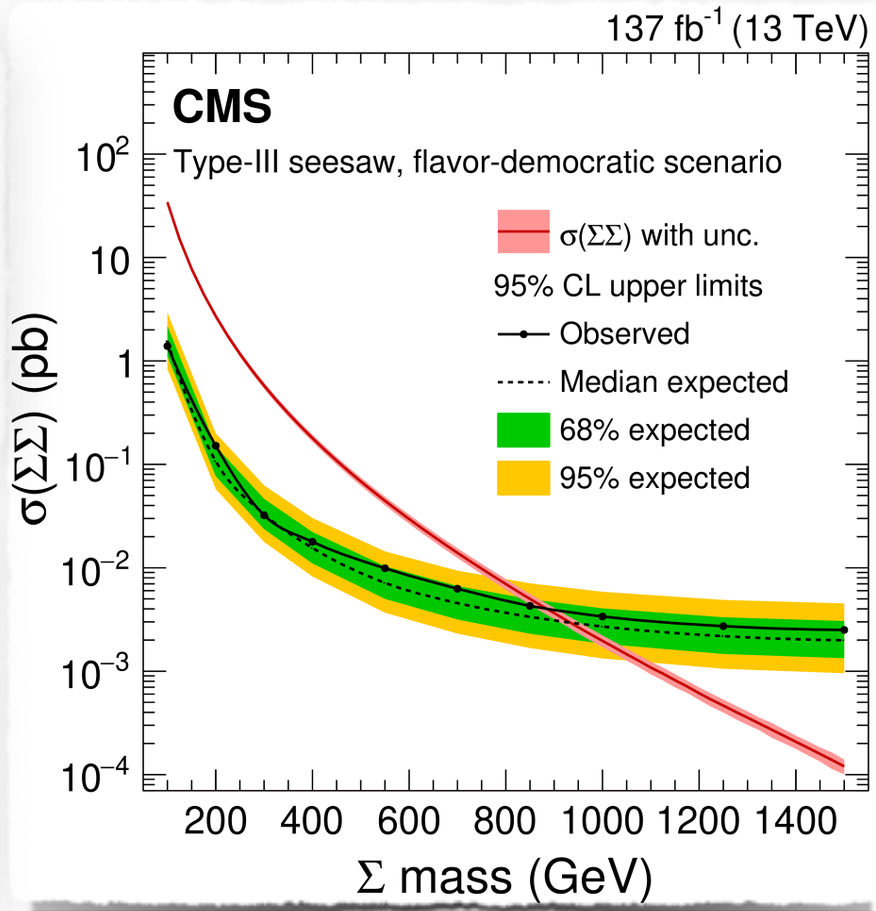
- Three or more electrons and muons in the final states
- Look for non-resonant excesses in the tails of the sum of lepton pTs+missing transverse momentum
- Observed data consistent with SM expectation

Multi lepton signal regions for the signal model: type-III seesaw

Label	$N_{leptons}$	N_{OSSF}	M_{OSSF} (GeV)	p_T^{miss} (GeV)	Variable and range (GeV)		Number of bins
3L below-Z	3	1	<76	—	$L_T+p_T^{miss}$	[0, 1200]	6
3L on-Z	3	1	76–106	>100	M_T	[0, 700]	7
3L above-Z	3	1	>106	—	$L_T+p_T^{miss}$	[0, 1600]	8
3L OSSF0	3	0	—	—	$L_T+p_T^{miss}$	[0, 1200]	6
4L OSSF0	≥4	0	—	—	$L_T+p_T^{miss}$	[0, 600]	2
4L OSSF1	≥4	1	—	—	$L_T+p_T^{miss}$	[0, 1000]	5
4L OSSF2	≥4	2	—	>100 if both pairs are on-Z	$L_T+p_T^{miss}$	[0, 1200]	6







* The results exclude heavy fermions of the type-III seesaw model for masses below **880 GeV** at 95 %

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2019

ATLAS Preliminary

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

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 – 4 j	Yes	36.1	M_D 7.7 TeV	$n = 2$	1711.03301
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	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 $\sum p_T$	≥ 1 e, μ	≥ 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 $G_{KK} \rightarrow \gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	1707.04147
	Bulk RS $G_{KK} \rightarrow WW/ZZ$	multi-channel			36.1	G_{KK} mass 2.3 TeV	$k/\overline{M}_{Pl} = 1.0$	1808.02380
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qqqq$	0 e, μ	2 J	–	139	G_{KK} mass 1.6 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2019-003
	Bulk RS $g_{KK} \rightarrow tt$	1 e, μ	≥ 1 b, $\geq$ 1J/2j	Yes	36.1	g_{KK} mass 3.8 TeV	$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 3 j	Yes	36.1	KK mass 1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \rightarrow tt) = 1$	1803.09678
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e, μ	–	–	139	Z' mass 5.1 TeV		1903.06248
	SSM $Z' \rightarrow \tau\tau$	2 τ	–	–	36.1	Z' mass 2.42 TeV		1709.07242
	Leptophobic $Z' \rightarrow bb$	–	2 b	–	36.1	Z' mass 2.1 TeV		1805.09299
	Leptophobic $Z' \rightarrow tt$	1 e, μ	≥ 1 b, $\geq$ 1J/2j	Yes	36.1	Z' mass 3.0 TeV	$\Gamma/m = 1\%$	1804.10823
	SSM $W' \rightarrow \ell\nu$	1 e, μ	–	Yes	139	W' mass 6.0 TeV		CERN-EP-2019-100
	SSM $W' \rightarrow \tau\nu$	1 τ	–	Yes	36.1	W' mass 3.7 TeV		1801.06992
	HVT $V' \rightarrow WZ \rightarrow qqqq$ model B	0 e, μ	2 J	–	139	V' mass 3.6 TeV	$g_V = 3$	ATLAS-CONF-2019-003
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	1712.06518
	LRSM $W_R \rightarrow tb$	multi-channel			36.1	W_R mass 3.25 TeV		1807.10473
	LRSM $W_R \rightarrow \mu N_R$	2 μ	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, μ	–	–	36.1	Λ 40.0 TeV	η_{LL}^-	1707.02424
	CI $tttt$	≥ 1 e, μ	≥ 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, μ	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, μ	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, μ	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
	Scalar reson. $\phi \rightarrow t\chi$ (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 τ	2 b	–	36.1	LQ_3^u mass 1.03 TeV	$\mathcal{B}(LQ_3^u \rightarrow b\tau) = 1$	1902.08103
	Scalar LQ 3rd gen	0-1 e, μ	2 b	Yes	36.1	LQ_3^d mass 970 GeV	$\mathcal{B}(LQ_3^d \rightarrow t\tau) = 0$	1902.08103
Heavy quarks	VLQ $TT \rightarrow Ht/Zt/Wb + X$	multi-channel			36.1	T mass 1.37 TeV	SU(2) doublet	1808.02343
	VLQ $BB \rightarrow Wt/Zb + X$	multi-channel			36.1	B mass 1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3}T_{5/3} \lvert T_{5/3} \rightarrow Wt + X$	2(SS)/$\geq$3 e, μ	$\geq$1 b, $\geq$1 j	Yes	36.1	$T_{5/3}$ mass 1.64 TeV	$\mathcal{B}(T_{5/3} \rightarrow Wt)$= 1, $c(T_{5/3}Wt)$= 1	1807.11883
	VLQ $Y \rightarrow Wb + X$	1 e, μ	≥ 1 b, ≥ 1j	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y \rightarrow Wb)$= 1, $c_R(Wb)$= 1	1812.07343
	VLQ $B \rightarrow Hb + X$	0 e, μ, 2 γ	≥ 1 b, ≥ 1j	Yes	79.8	B mass 1.21 TeV	κ_B= 0.5	ATLAS-CONF-2018-024
	VLQ $QQ \rightarrow WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \rightarrow qg$	–	2 j	–	139	q^* mass 6.7 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2019-007
	Excited quark $q^* \rightarrow q\gamma$	1 γ	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1709.10440
	Excited quark $b^* \rightarrow bg$	–	1 b, 1 j	–	36.1	b^* mass 2.6 TeV		1805.09299
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	Type III Seesaw	1 e, μ	≥ 2 j	Yes	79.8	N^0 mass 560 GeV		ATLAS-CONF-2018-020
	LRSM Majorana ν	2 μ	2 j	–	36.1	N_R mass 3.2 TeV	$m(W_R) = 4.1$ TeV, $g_L = g_R$	1809.11105
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	1710.09748
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \rightarrow \ell\tau) = 1$	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

10^{-1} 1 10 **Mass scale [TeV]**

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

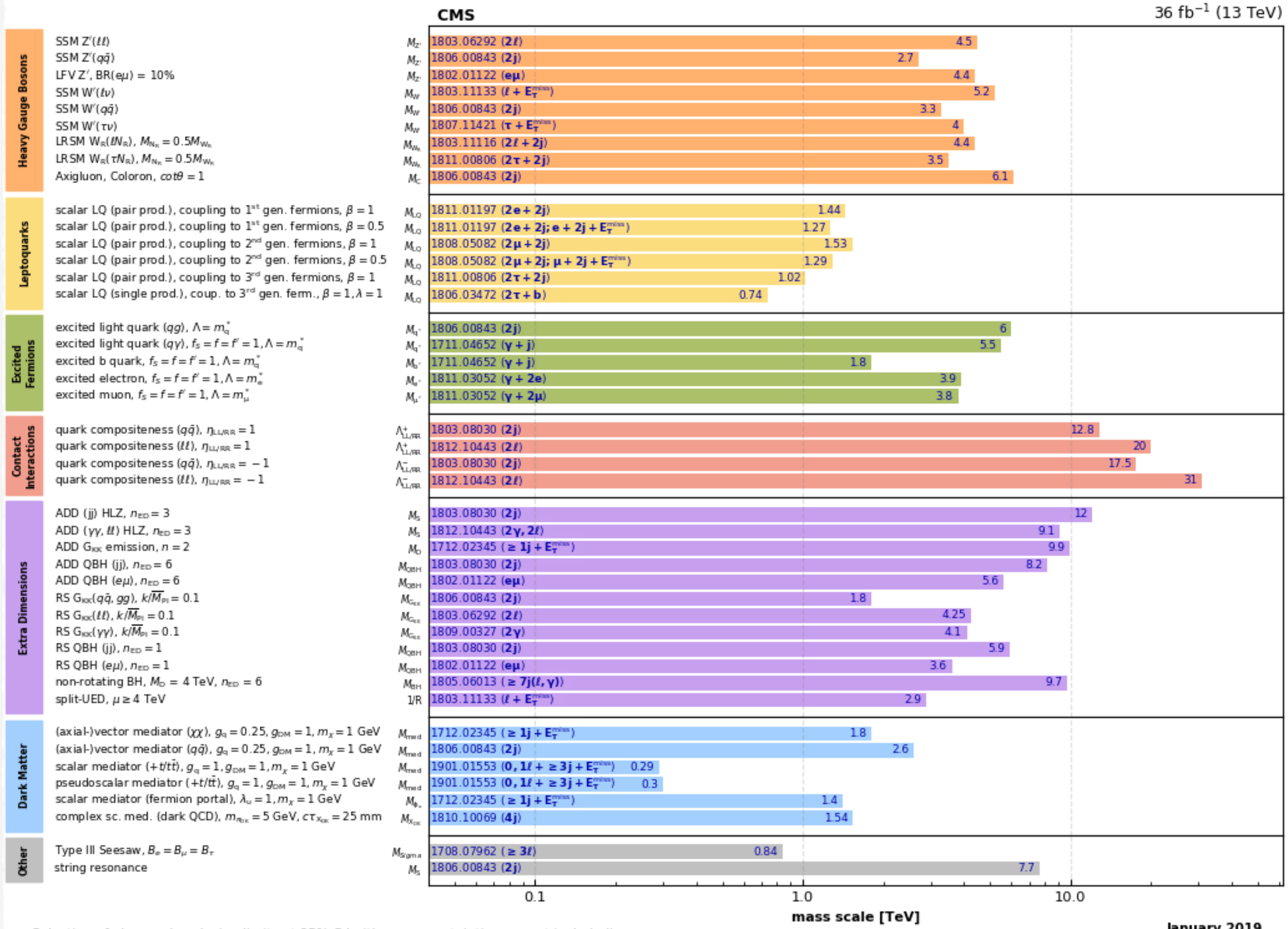
†Small-radius (large-radius) jets are denoted by the letter j (J).

✱ **Reach of ATLAS searches for new phenomena other than Supersymmetry. Only a representative selection of the available results is shown. Green bands indicate 8 TeV data results; yellow (orange) bands indicate 13 TeV data results with partial (full) dataset.**

A. Adiguzel

NDM-2020

Overview of CMS EXO results



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