Exotics and BSM in ATLAS and CMS (non DM searches)

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supported in part by NCN grant 2014/15/B/ST2/03998

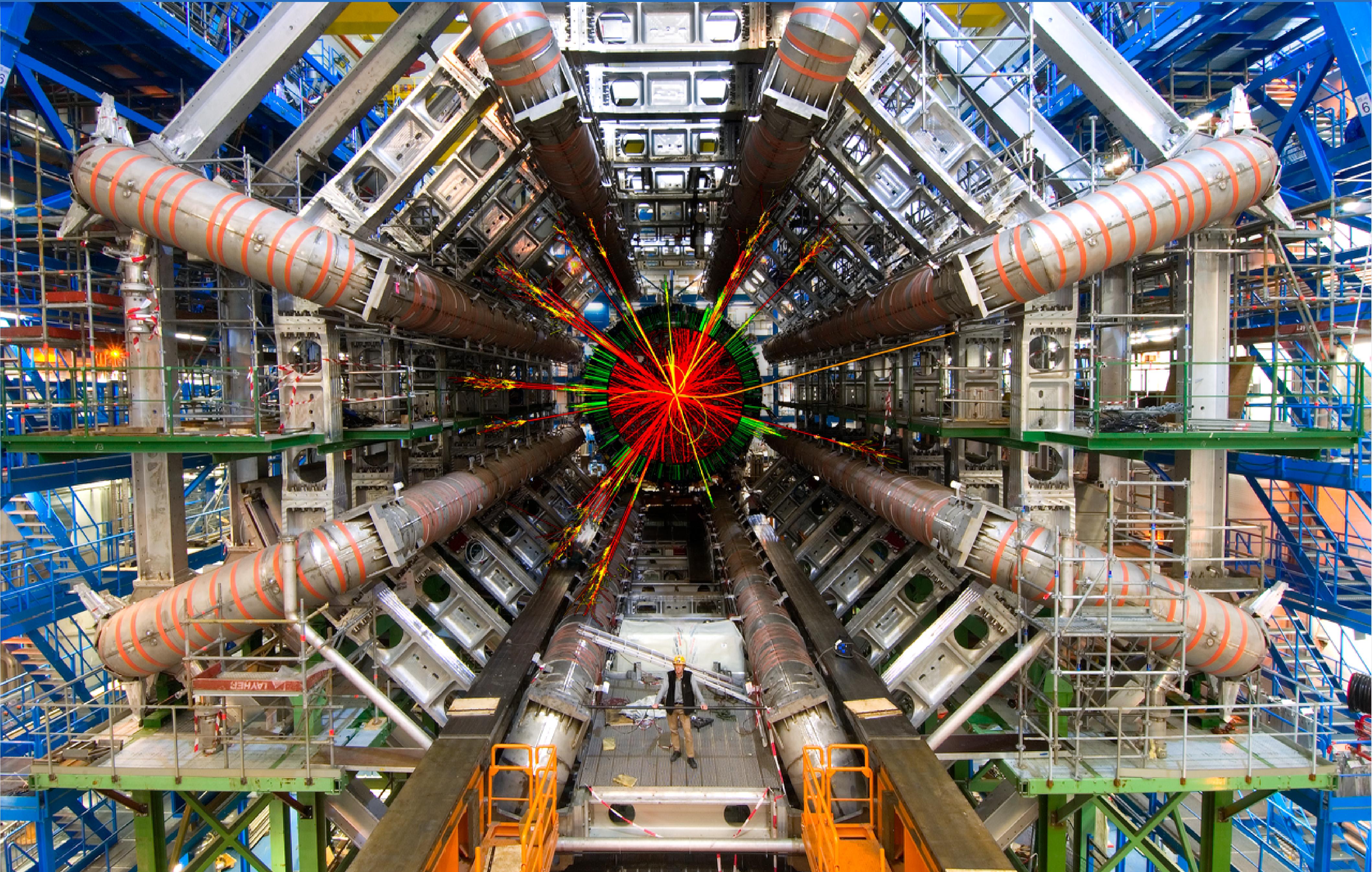
OUTLINE
- What is exotic @ LHC (introduction)
- Some examples of recent exotica searches
  - → prompt
  - → long lived
- Conclusions

CORFU2018

Corfu Summer Institute 2018: Workshop
on the Standard Model and Beyond

Corfu, Mon Repos, 7/09/2018

microscopic black hole candidate
ATLAS in the time of construction



CMS – Compact Muon Solenoid

Topological searches:

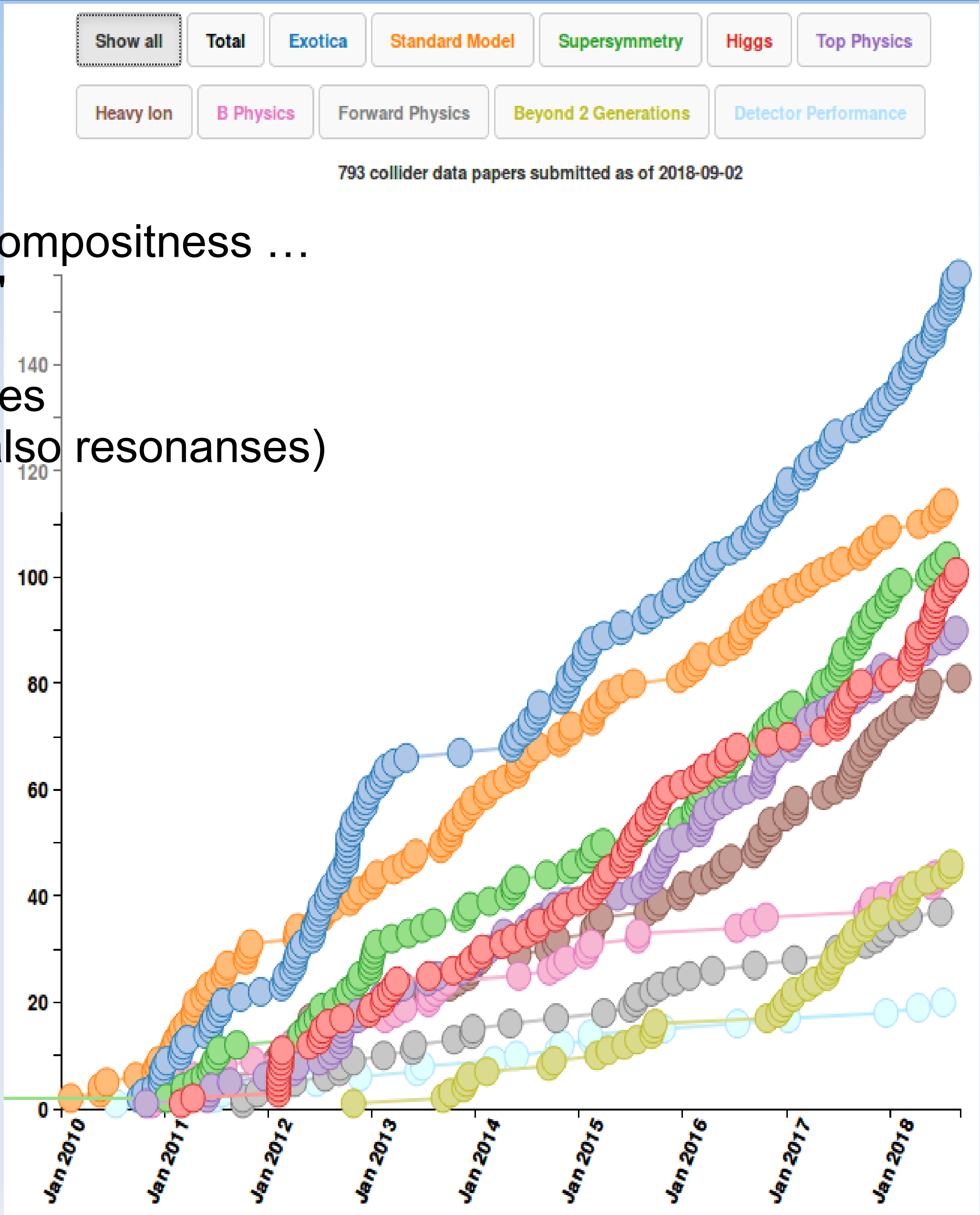
- Resonances (dijets, dileptons, diphotons)
  → Z', RS gravitons, compositness …
- Single lepton + MET → leptonic decays of W'
- Leptons and jets → leptoquarks
- Multiobject topologies → microscopic black holes
- Mono - ”something visible” → dark matter (← also resonanses)
- ...

At the SUSY – Exotica border

- RPV SUSY (more on the SUSY side)
- Long-Lived Particles (LLP)
- Many topologies with jets and leptons are common for SUSY and Exotica
- ...

EXOTICA *par excellence*

- ...



793 collider data papers submitted as of 2018-09-02

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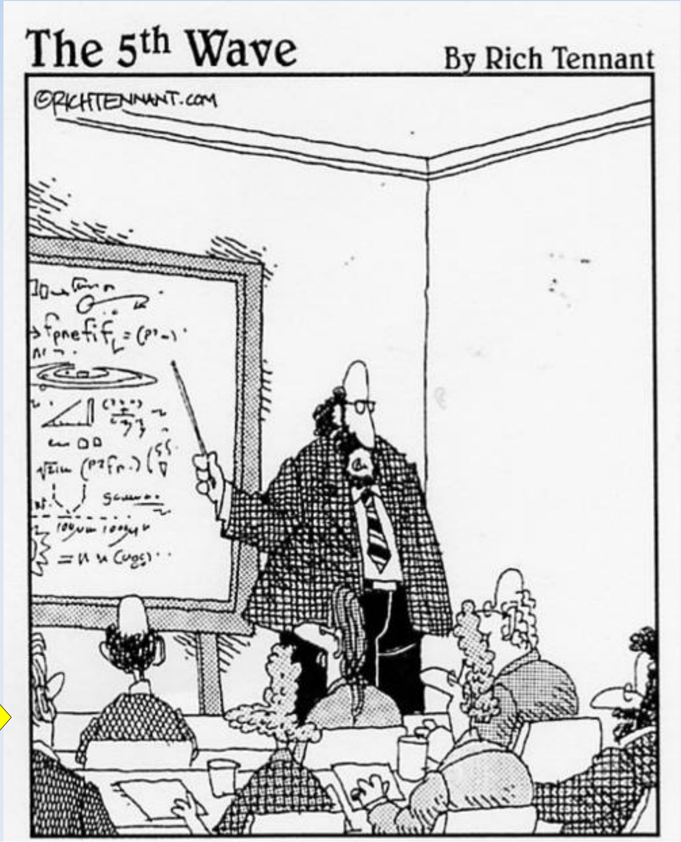
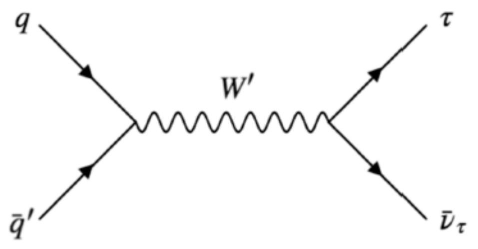
EXOTICA *par excellence*
- ...

In short:
we search for everything,
maybe except
'doesn't matter'.



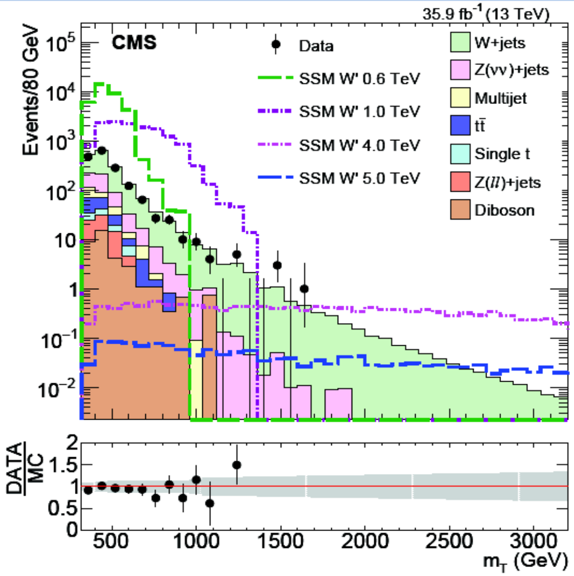
“After the discovery of ‘antimatter’ and ‘dark matter’, we have just confirmed the existence of ‘doesn’t matter’, which does not have any influence on the Universe whatsoever.”



High mass $\tau\nu$ rezonances

CMS-EXO-17-008, (arXiv:1807.11421, Jul 2018) **ATLAS: PRL 120, 161802 (Jan2018)**

Both experiments use hadronic decyas of tau leptons and transverse mass m_T.



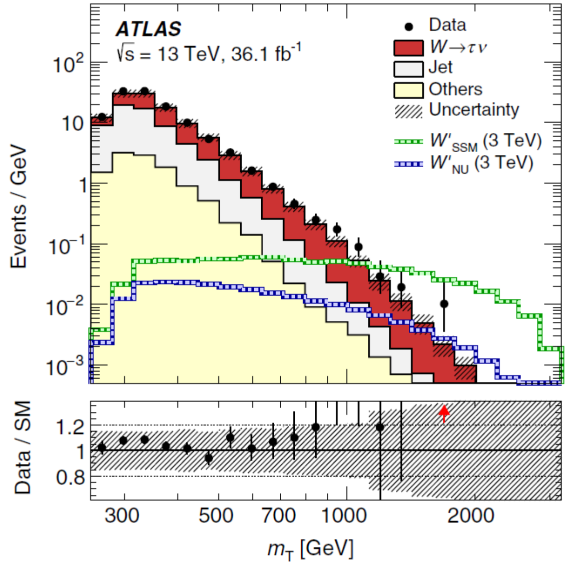
$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\tau} p_{\mathrm{T}}^{\mathrm{miss}} [1 - \cos \Delta\phi(\vec{p}_{\mathrm{T}}^{\,\tau}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})]}$$

CMS trigger (selection):
p_T^{miss} > 90 (200) GeV
p_T tau_h > 50 (80) GeV

ATLAS trigger:
E_T^{miss} > 70, 90, 110 GeV
select.: MET > 150 GeV

For missing transverse momentum **CMS** uses p_T^{miss} , whereas ATLAS uses E_T^{miss}. Hereafter I will use MET for both experiments.

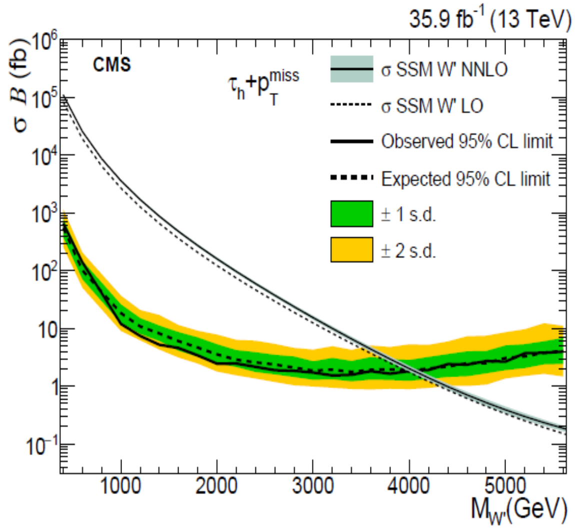
Genuine tau background was simulated.



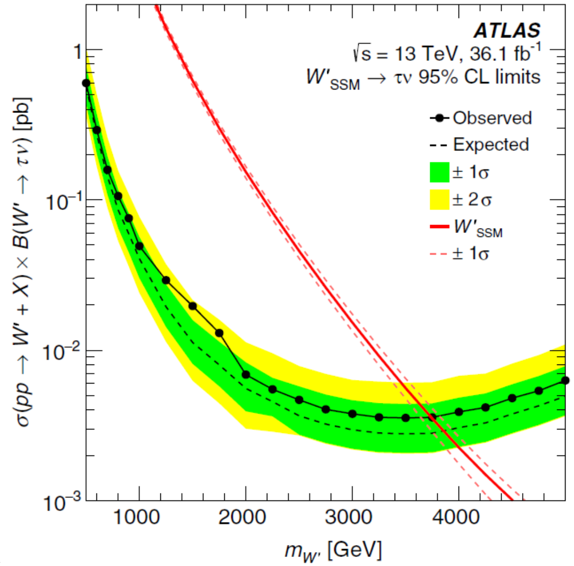
CMS: jet misid. is simulated but verified using Z → mu mu with muons removed.

ATLAS: jet misid is estimated using three control regions (CR) such that in CR1 and CR3 taus are 'weaker', whereas in CR2 and CR3: MET < 100 GeV

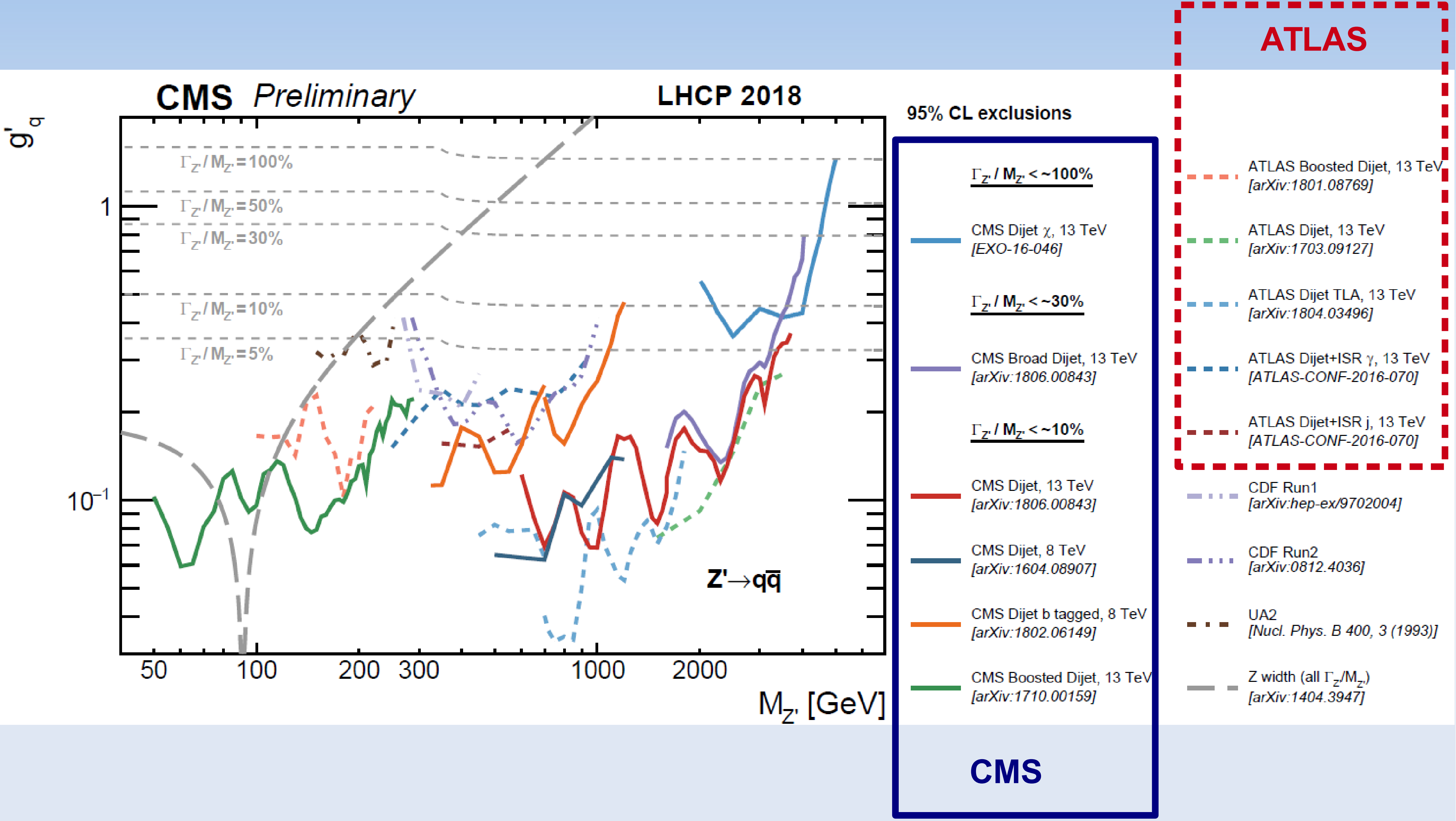
$N_{jet} = N_{CR1} N_{CR2} / N_{CR3}$

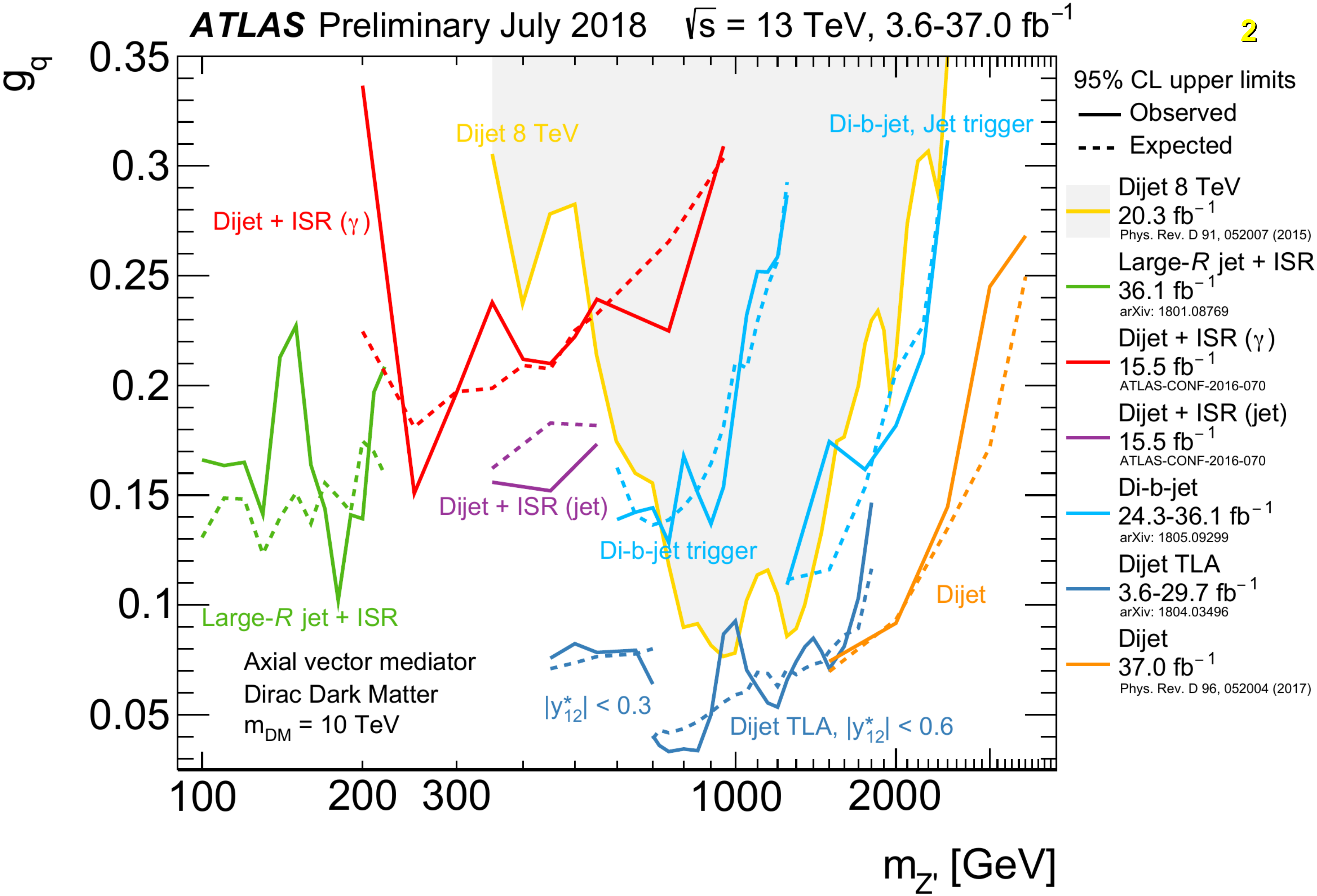


No significant excesses in m_T distributions.
Almost identical limits on W' mass set.



Z' → q qbar summary




ATLAS Preliminary July 2018 √s = 13 TeV, 3.6-37.0 fb^{-1}
g_q
0.35
0.3
0.25
0.2
0.15
0.1
0.05
100
200
300
1000
2000
$m_{Z'}$ [GeV]
Dijet 8 TeV
Di-b-jet, Jet trigger
Dijet + ISR (γ)
Dijet + ISR (jet)
Di-b-jet trigger
Large-R jet + ISR
Dijet
Axial vector mediator
Dirac Dark Matter
m_{DM} = 10 TeV
$|y^*_{12}| < 0.3$
Dijet TLA, $|y^*_{12}| < 0.6$
95% CL upper limits
Observed
Expected
Dijet 8 TeV
20.3 fb^{-1}
Phys. Rev. D 91, 052007 (2015)
Large-R jet + ISR
36.1 fb^{-1}
arXiv: 1801.08769
Dijet + ISR (γ)
15.5 fb^{-1}
ATLAS-CONF-2016-070
Dijet + ISR (jet)
15.5 fb^{-1}
ATLAS-CONF-2016-070
Di-b-jet
24.3-36.1 fb^{-1}
arXiv: 1805.09299
Dijet TLA
3.6-29.7 fb^{-1}
arXiv: 1804.03496
Dijet
37.0 fb^{-1}
Phys. Rev. D 96, 052004 (2017)

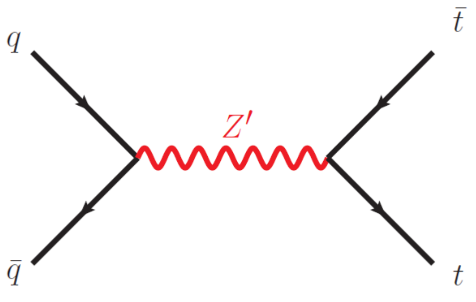
Search for **heavy particles** decaying into **top-quark pairs** using lepton-plus-jets events in p–p coll. at sqrt(s) = 13 TeV with the **ATLAS** detector (arXiv:1804.10823, Apr 2018)

Search for **resonant $t\bar{t}$** production in p-p collisions at sqrt(s) = 13 TeV (**CMS** PAS B2G-17-017, Jun 2018)

Model independent search for a resonant excess in $t\bar{t}$ system mass.
The main background is non resonant $t\bar{t}$ production.

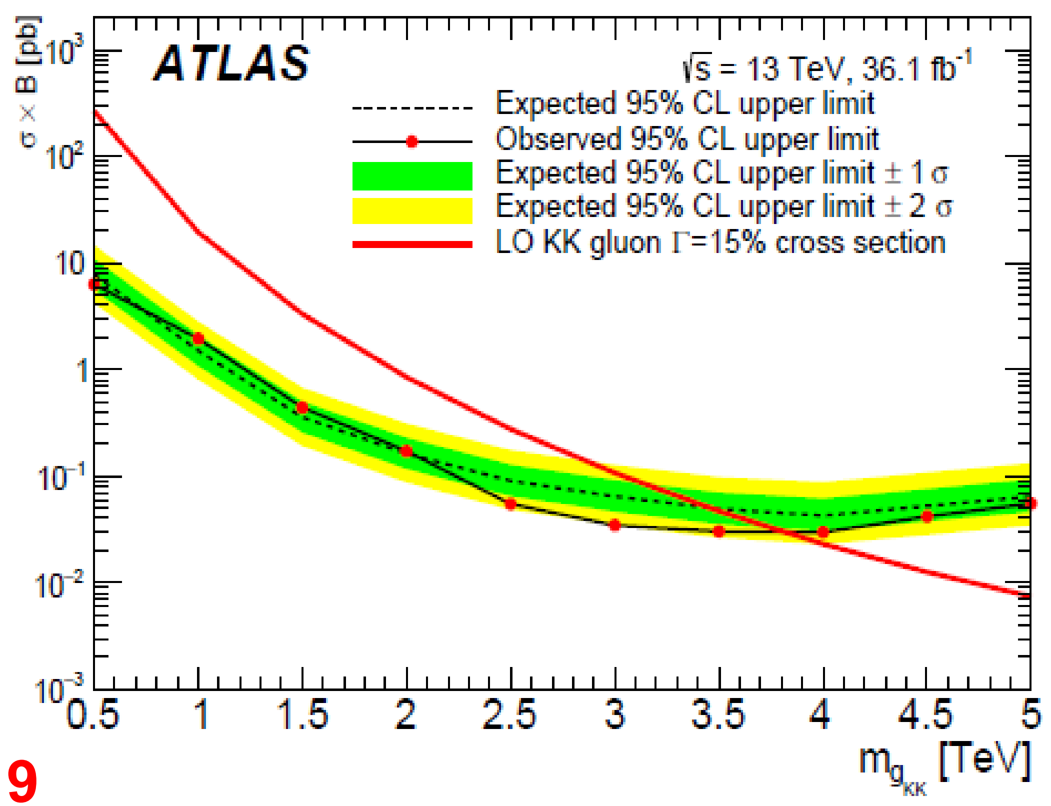
ATLAS:
lepton-plus-jet channels only.
Resolved and boosted t systems selections.

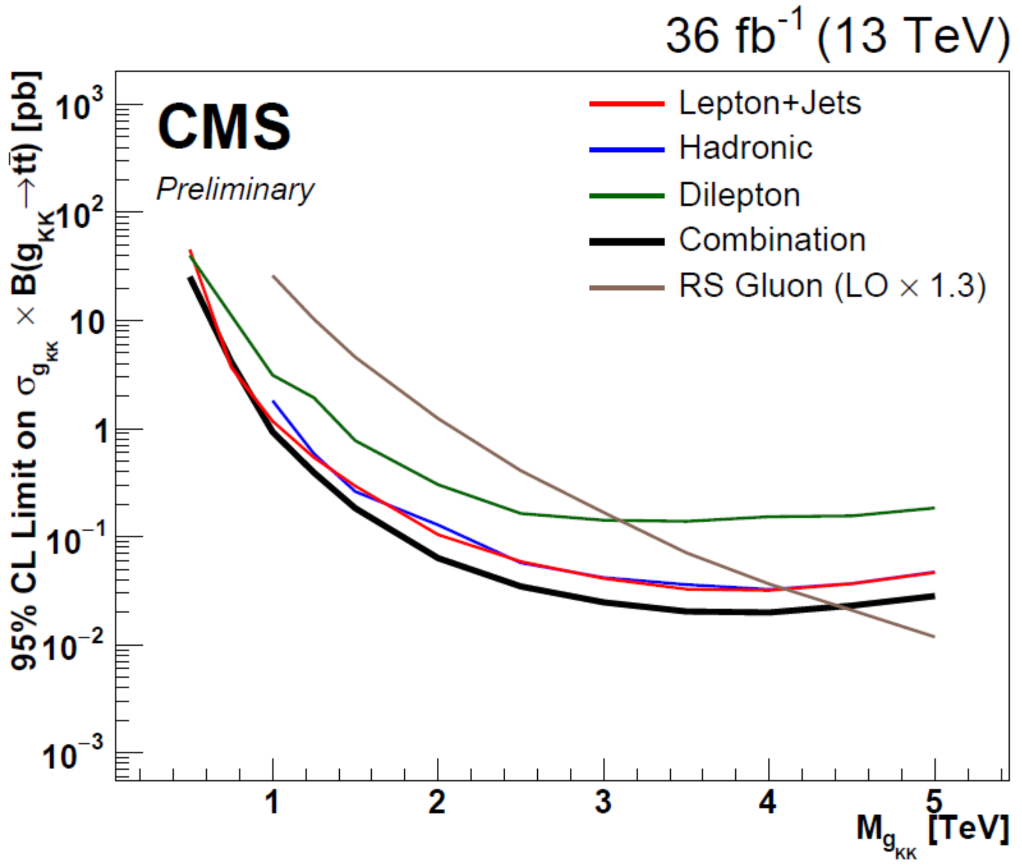
Backgrounds: $t\bar{t}$ from MC,
W+jets & multi-jet from data.



CMS:
leptons-plus-jet, lepton-lepton & full hadronic selections.

Backgrounds: $t\bar{t}$ from MC,
data-driven for non $t\bar{t}$ multijet

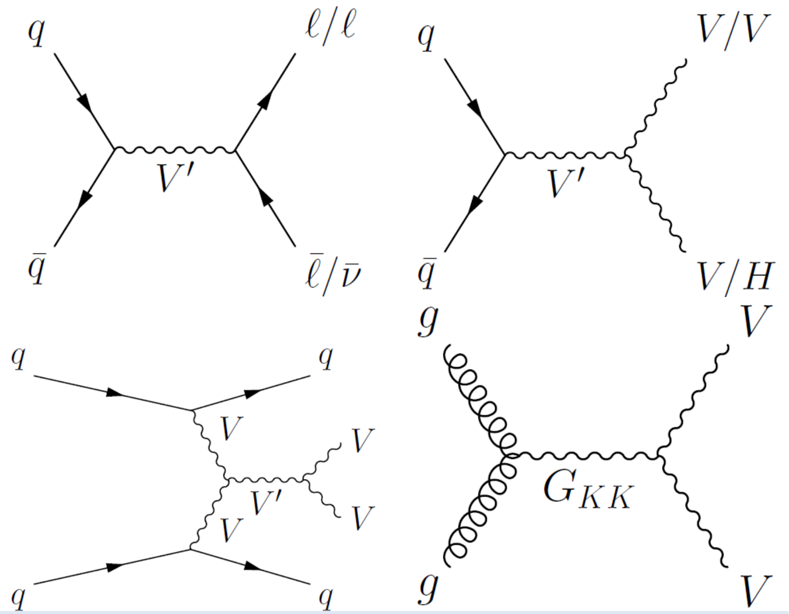


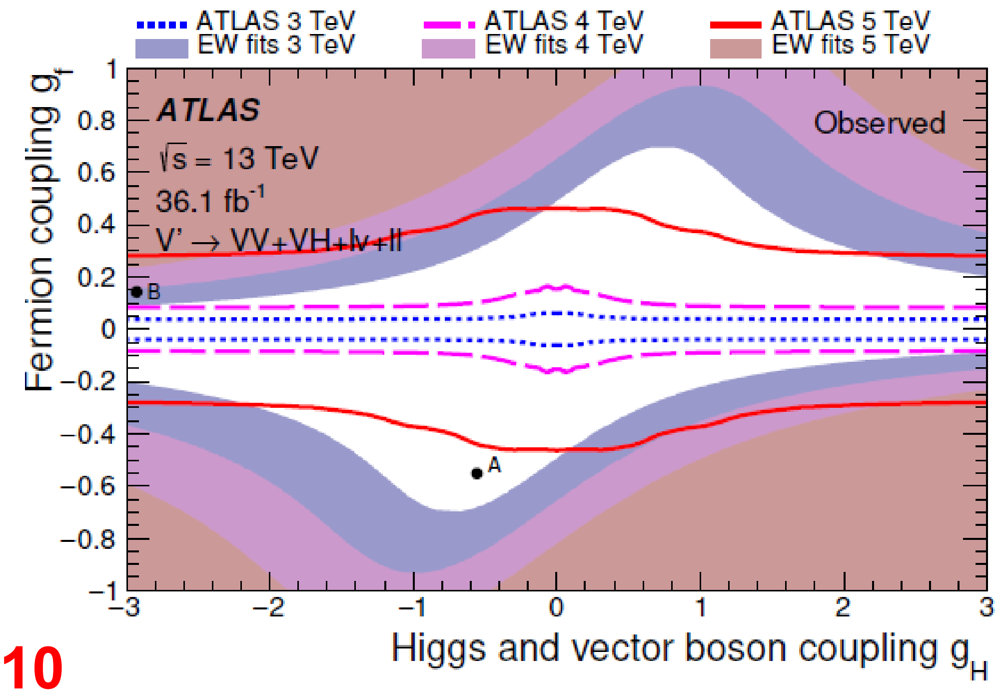


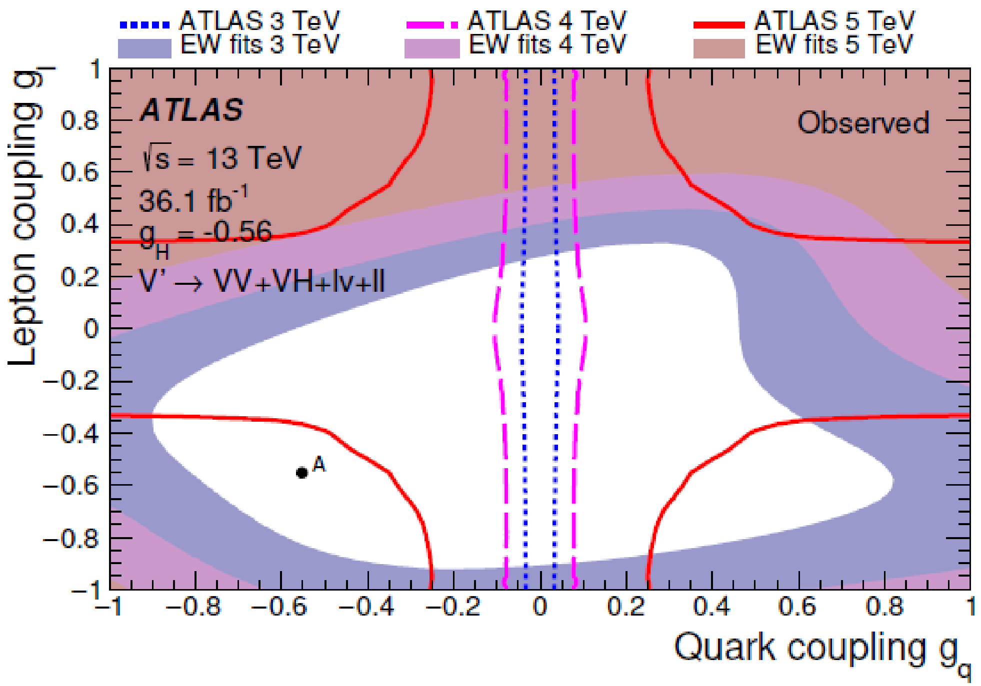
Combination of searches for heavy resonances decaying into bosonic and leptonic final state using 36 fb-1 of pp collision data at sqrt(s) 13 TeV with the ATLAS detector (arXiv:1808.02380, Aug 2018)

10 ATLAS analyses combined.
Channels taken into account: WZ → *qqqq*, *ℓvqq*, *ℓvℓℓ;*
WW → *qqqq*, *ℓvqq*, *ℓvℓv; ZZ* → *qqqq*, *ℓℓqq*, *vvqq*, *ℓℓvv*, *ℓℓℓℓ;*
WH → *qqbb*, *ℓvbb; ZH* →*qqbb*, *vvbb*, *ℓℓbb*,
and the lepton–antilepton channels: *ℓℓ*, *ℓv*.

Results interpreted (among others) in the heavy vector triplet (HVT) model. Several **one dimensional limits on x-sections** and **two dimensional limits on coupling strenghts** presented.

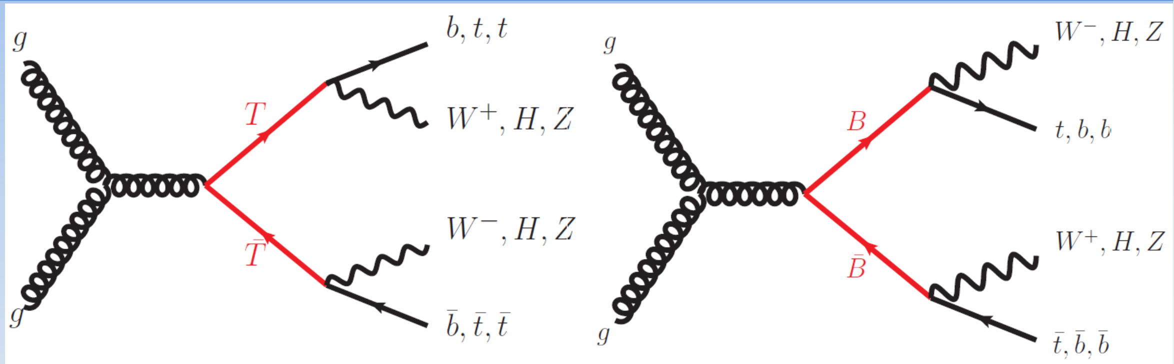


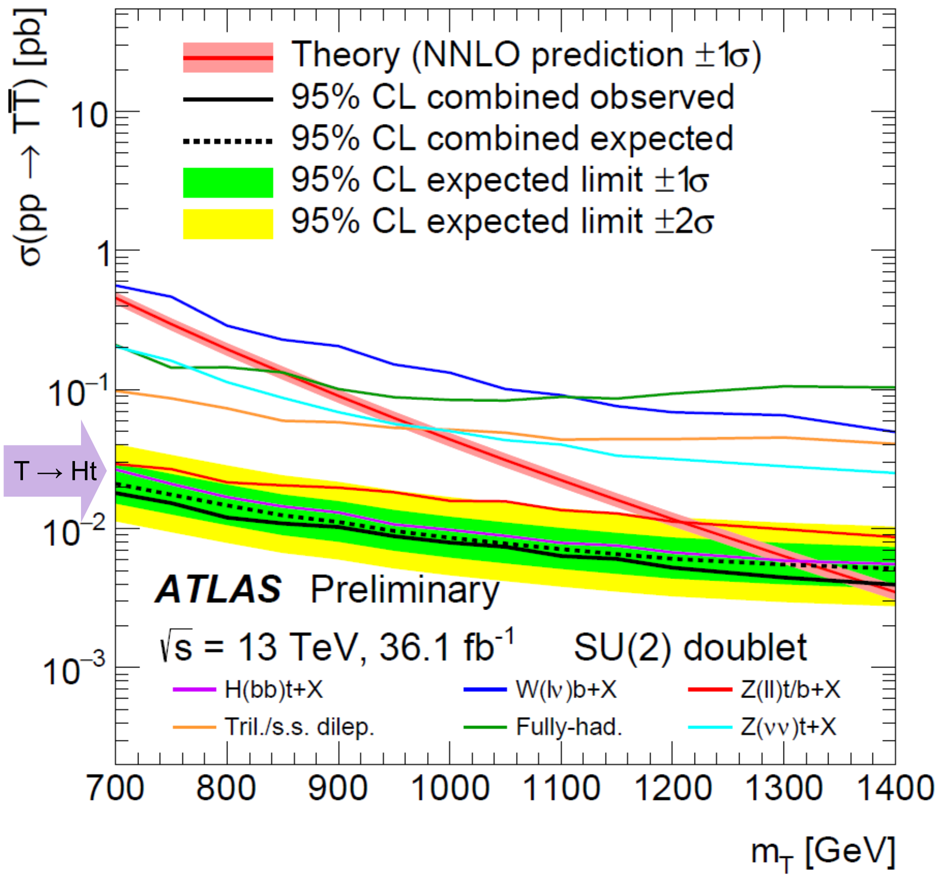


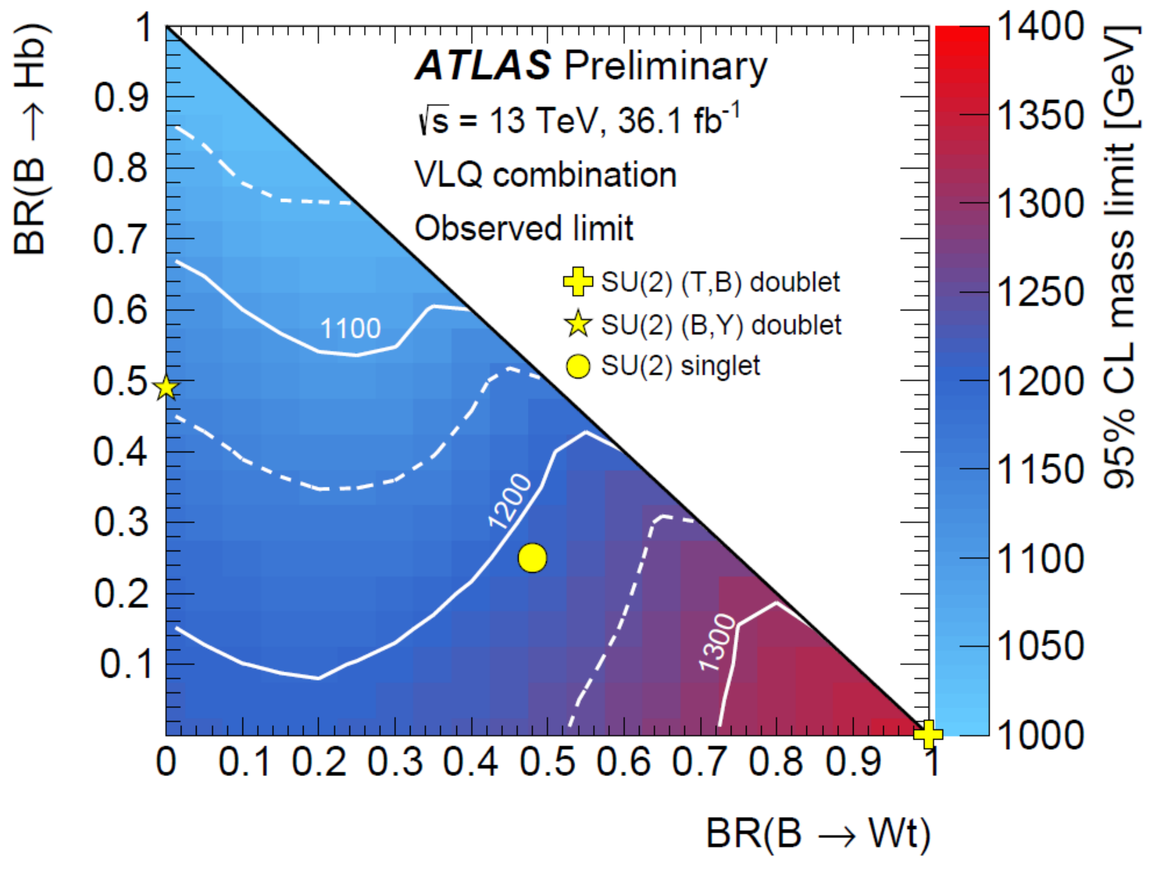


Combination of the searches for pair-produced vector-like partners (VLPs) of the third generation quarks at sqrt(s) 13 TeV with the ATLAS detector (ATLAS-CONF-2018-032, Jul 2018)

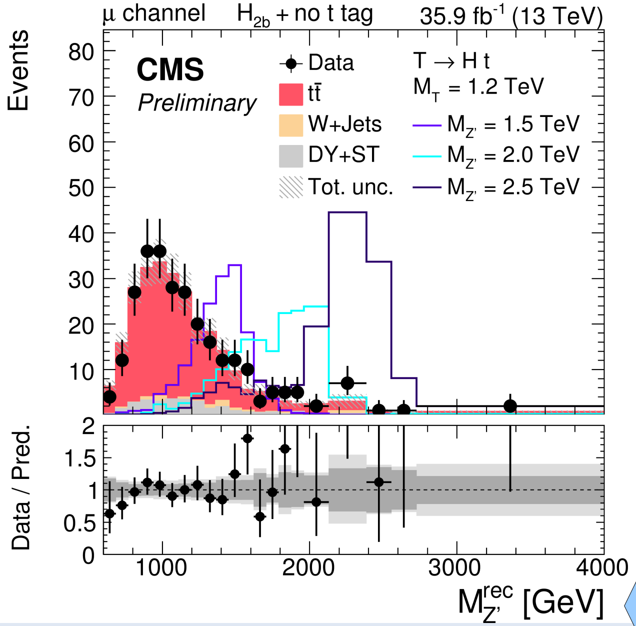
Seven recent ATLAS analyses combined.
(Similar to some of them done also by the CMS)

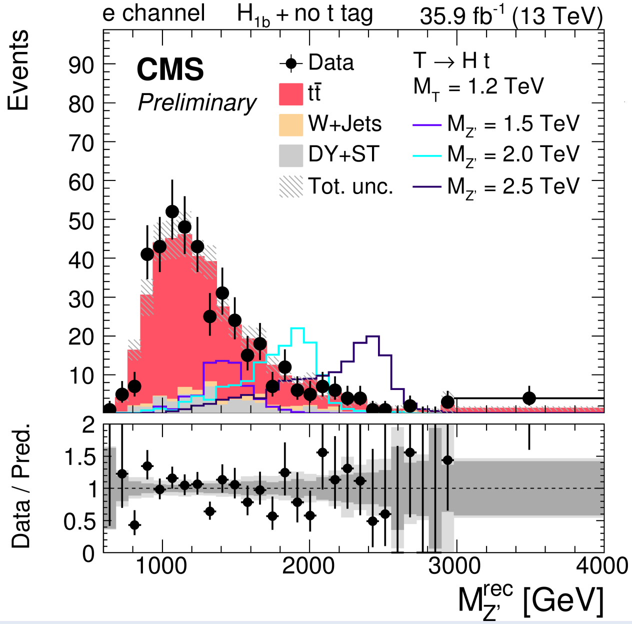






Search for a heavy resonance decaying to a top quark and a vector-like top quark (VLQ) in the lepton+jets final state (CMS PAS B2G-17-015)



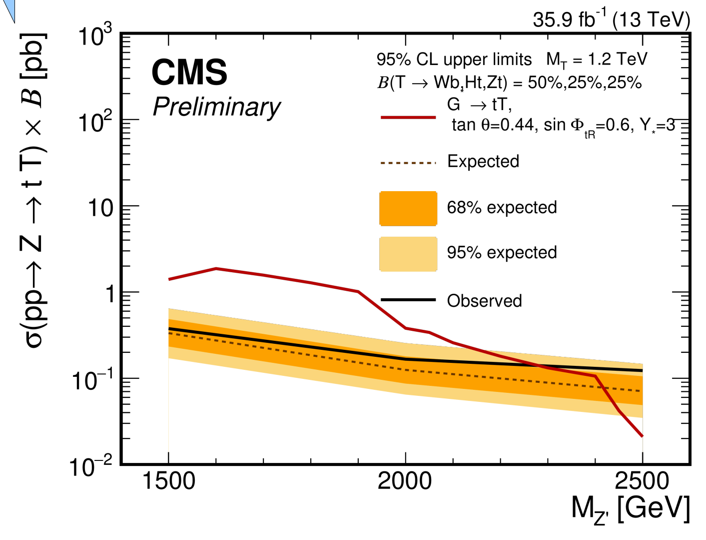


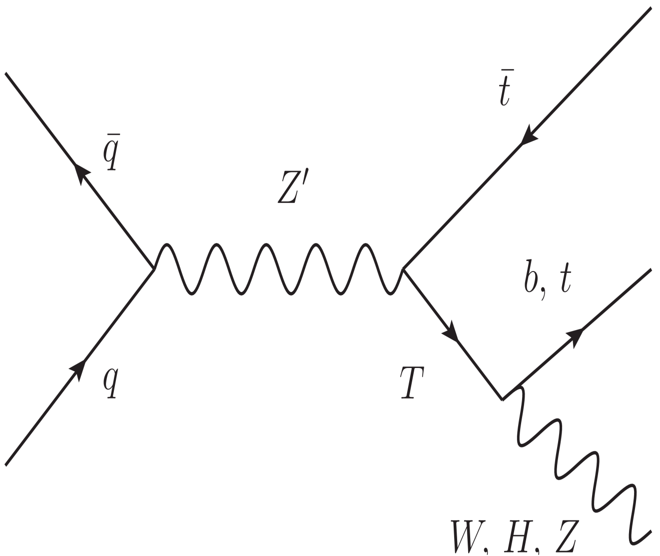
Final topologies are tHt, tZt, tWt.
Search optimized for tHt and tZt.
Exactly one t → lepton+MET+jets.

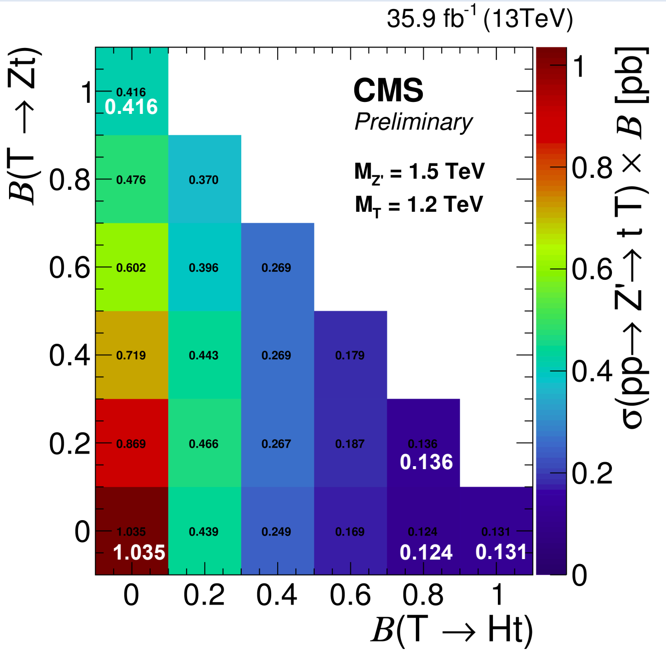
Single lepton triggers used.
mu+jets channel and e+jets channel

Bosted jet topologies. Z/W tagger, H taggers (H_{2b}, H_{1b}) and t tagger.
Soft drop jet mass and subjettiness in use.

Z' reco mass is taken from the best combination of reconstructed objects.
2 x 6 SR in total







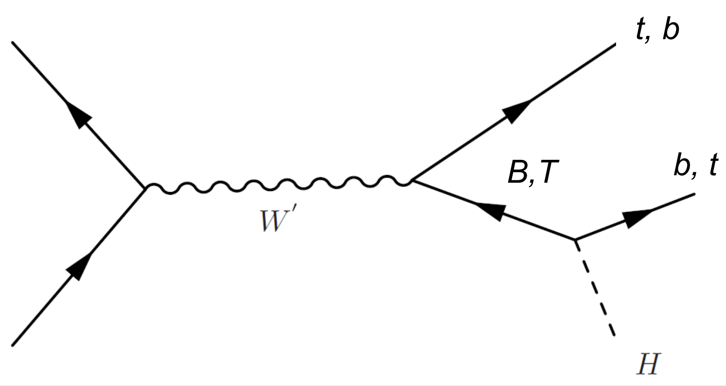
Search for a W' boson decaying to a vector-like quark (VLQ) and a top or bottom quark in the all-jets final state (CMS PAS B2G-18-001)

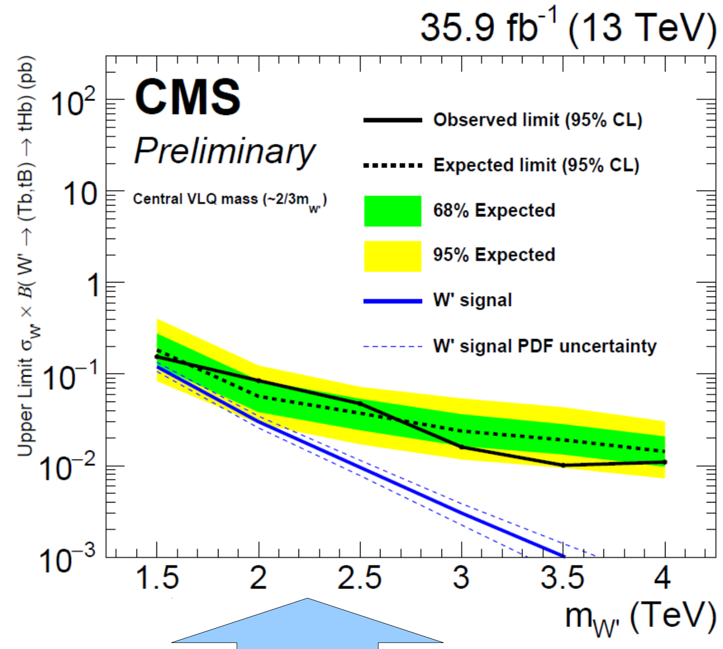
An inclusive search for W' → tHb.

Top and Higgs boosted.

Trigger: $H_T > 800, 900$ GeV
or wide (AK8) jet $p_T > 400$ GeV

The search variable is $\mathbf{m_{tHb}}$ mass.





The primary **background**:
QCD multijet production
is derived from data using control regions CR1-CR3.

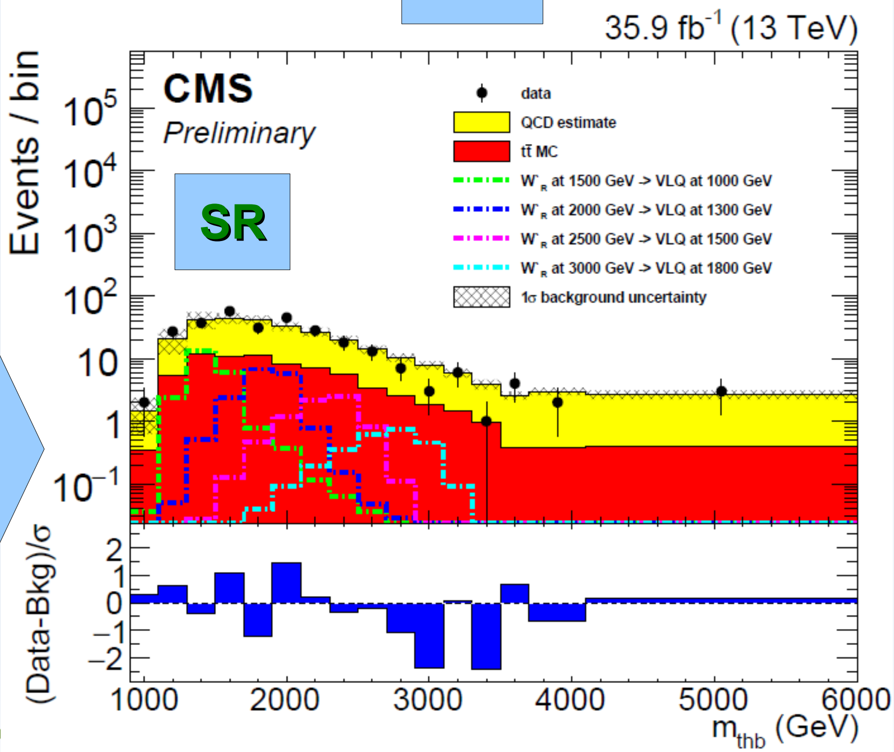
Applicability and versatility of the background estimate is tested using **validation regions** CR4-CR7.

selection

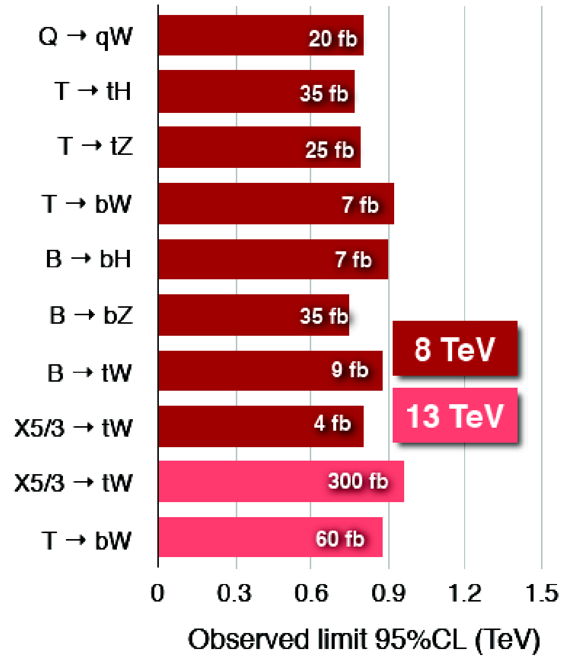
backg. estimate

backg. validation

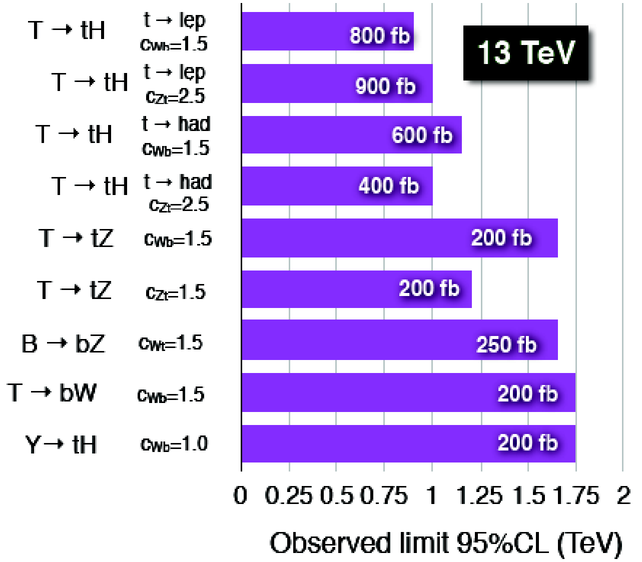
	t jet	H jet	b jet
SR >>>>>>	tag	tag	tag
est. CR1	antitag	antitag	tag
est. CR2	antitag	tag	tag
est. CR3	tag	antitag	tag
val. CR4	tag	tag	antitag
val. CR5	antitag	antitag	antitag
val. CR6	antitag	tag	antitag
val. CR7	tag	antitag	antitag



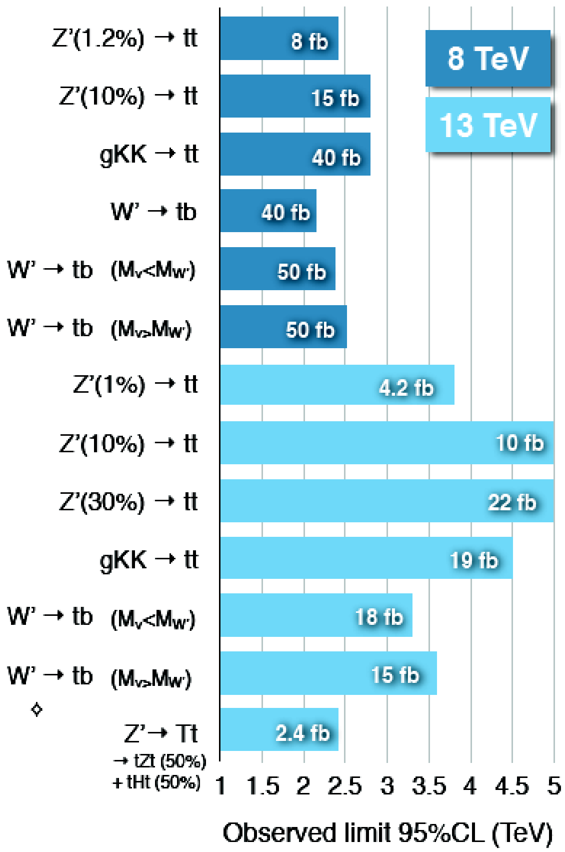
Vector-like quark pair production



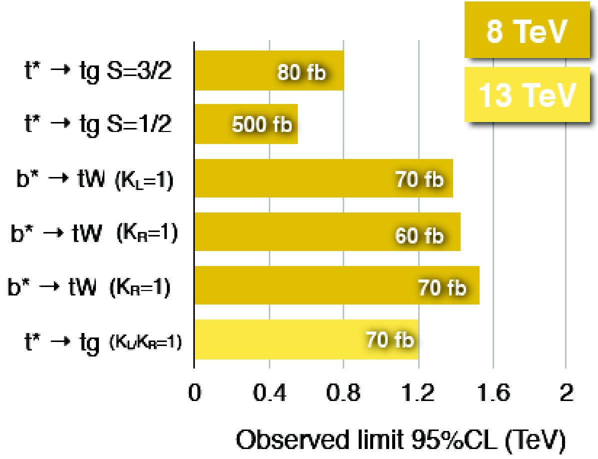
Vector-like quark single production



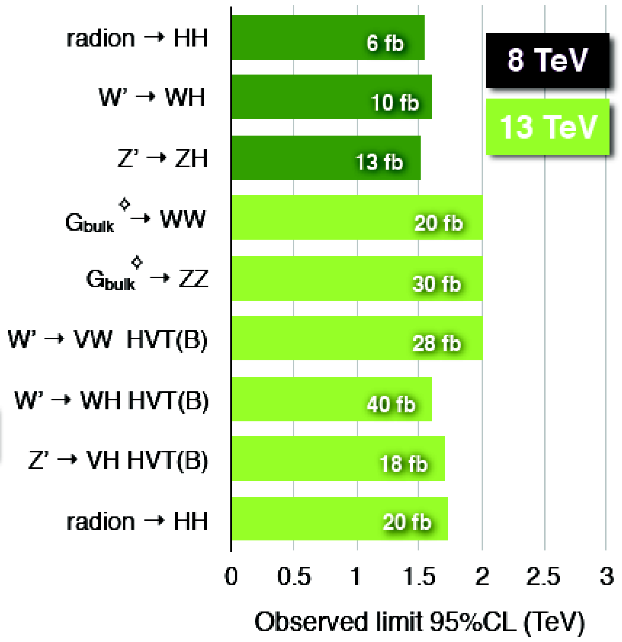
Resonances to heavy quarks



Excited quarks

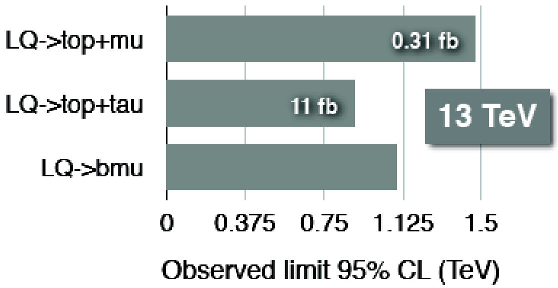


Resonances to dibosons



◊model-independent

Leptoquarks



CMS

B2G

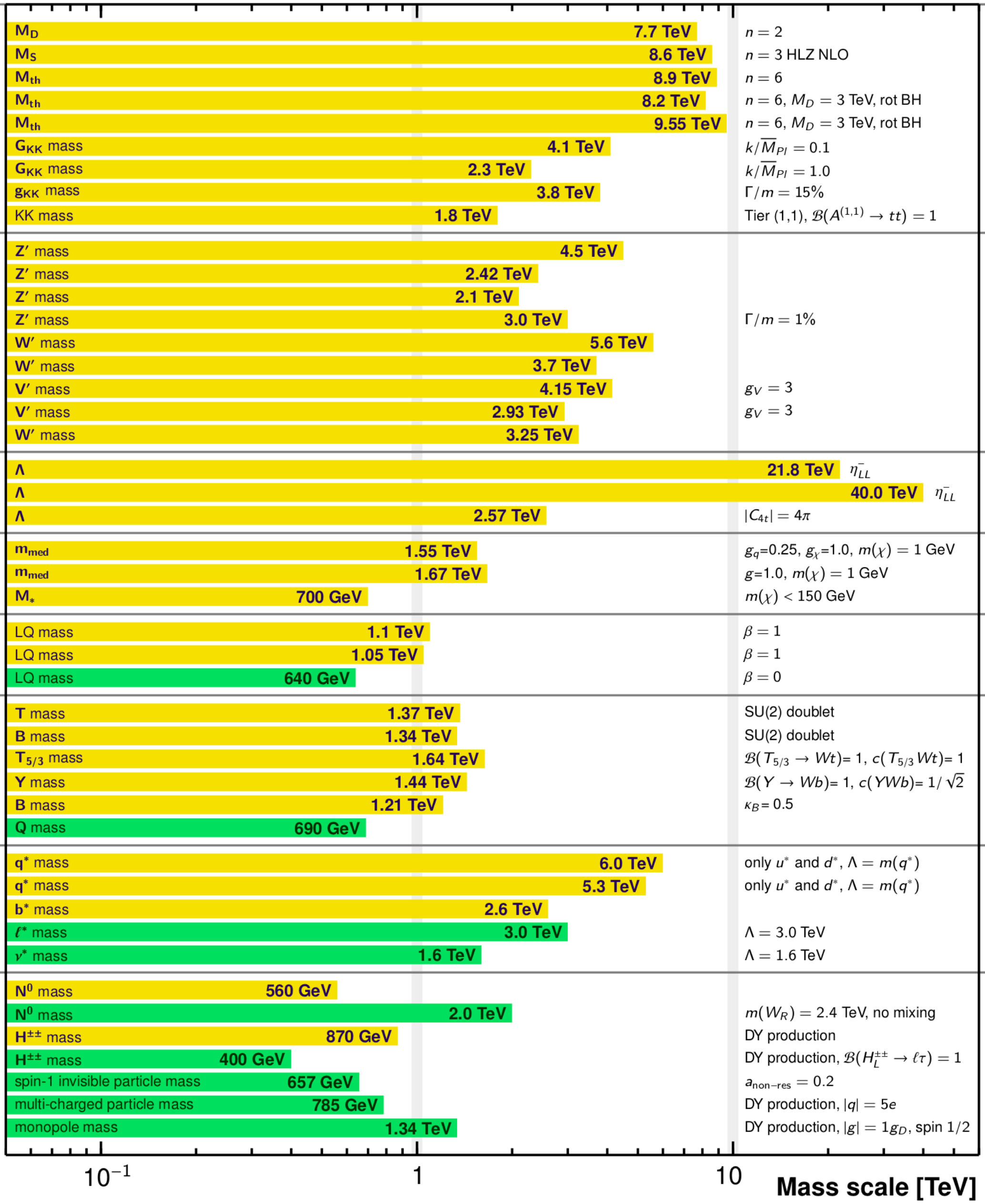
new physics searches with heavy SM particles

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2018

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 79.8)$ 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, 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 $G_{KK} \to \gamma\gamma$	2 γ	–	–	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	$k/\overline{M}_{Pl} = 1.0$	CERN-EP-2018-179
	Bulk RS $g_{KK} \to tt$	1 e, μ	≥ 1 b, ≥ 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), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	1803.09678
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	36.1	🟨 Z' mass 4.5 TeV		1707.02424
	SSM $Z' \to \tau\tau$	2 τ	–	–	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, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	🟨 Z' mass 3.0 TeV	$\Gamma/m = 1\%$	1804.10823
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	79.8	🟨 W' mass 5.6 TeV		ATLAS-CONF-2018-017
	SSM $W' \to \tau\nu$	1 τ	–	Yes	36.1	🟨 W' mass 3.7 TeV		1801.06992
	HVT $V' \to WV \to qqqq$ model B	0 e, μ	2 J	–	79.8	🟨 V' mass 4.15 TeV	$g_V = 3$	ATLAS-CONF-2018-016
	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' mass 3.25 TeV		CERN-EP-2018-142
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 $tttt$	$\geq$1 e,μ	$\geq$1 b, $\geq$1 j	Yes	36.1	🟨 Λ 2.57 TeV	$\lvert C_{4t} \rvert = 4\pi$	CERN-EP-2018-174
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
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	🟨 LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	🟨 LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	$\geq$1 b, $\geq$3 j	Yes	20.3	🟩 LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht/Zt/Wb + X$	multi-channel			36.1	🟨 T mass 1.37 TeV	SU(2) doublet	ATLAS-CONF-2018-032
	VLQ $BB \to Wt/Zb + X$	multi-channel			36.1	🟨 B mass 1.34 TeV	SU(2) doublet	ATLAS-CONF-2018-032
	VLQ $T_{5/3} T_{5/3} \vert T_{5/3} \to Wt + X$	2(SS)/$\geq$3 e,μ	$\geq$1 b, $\geq$1 j	Yes	36.1	🟨 $T_{5/3}$ mass 1.64 TeV	$\mathcal{B}(T_{5/3} \to Wt)$= 1, $c(T_{5/3} Wt)$= 1	CERN-EP-2018-171
	VLQ $Y \to Wb + X$	1 e, μ	≥ 1 b, ≥ 1j	Yes	3.2	🟨 Y mass 1.44 TeV	$\mathcal{B}(Y \to Wb)$= 1, $c(YWb)$= $1/\sqrt{2}$	ATLAS-CONF-2016-072
	VLQ $B \to Hb + X$	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 $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	🟩 Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	37.0	🟨 q^* mass 6.0 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1703.09127
	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	36.7	🟨 q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1709.10440
	Excited quark $b^* \to bg$	–	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 e, μ	2 j	–	20.3	🟩 N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	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, μ, τ	–	–	20.3	🟩 $H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	🟩 spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	🟩 multi-charged particle mass 785 GeV	DY production, $\lvert q \rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	🟩 monopole mass 1.34 TeV	DY production, $\lvert g \rvert = 1 g_D$, spin 1/2	1509.08059

🟩 $\sqrt{s}$ = 8 TeV 🟨 $\sqrt{s}$ = 13 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).

A strategy for a general search for new phenomena using data-derived signal regions and its application within the ATLAS experiment (arXiv:1807.07447, Jul 2018)

1

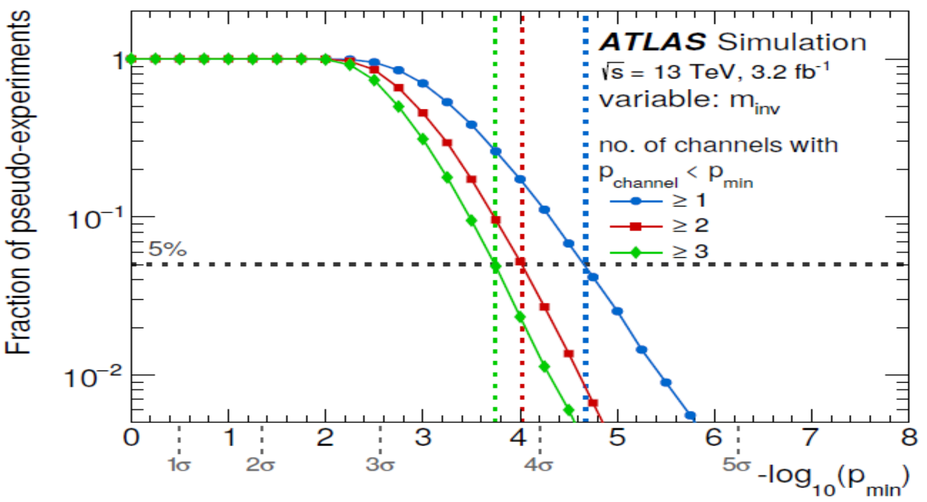
1. Data selection & MC simulation
2. Systematic uncertainties & validation
3. Sensitive variables & search algorithm

$$p_0 = 2 \cdot \min\left[P(n \leq N_{\mathrm{obs}}),\ P(n \geq N_{\mathrm{obs}})\right]$$

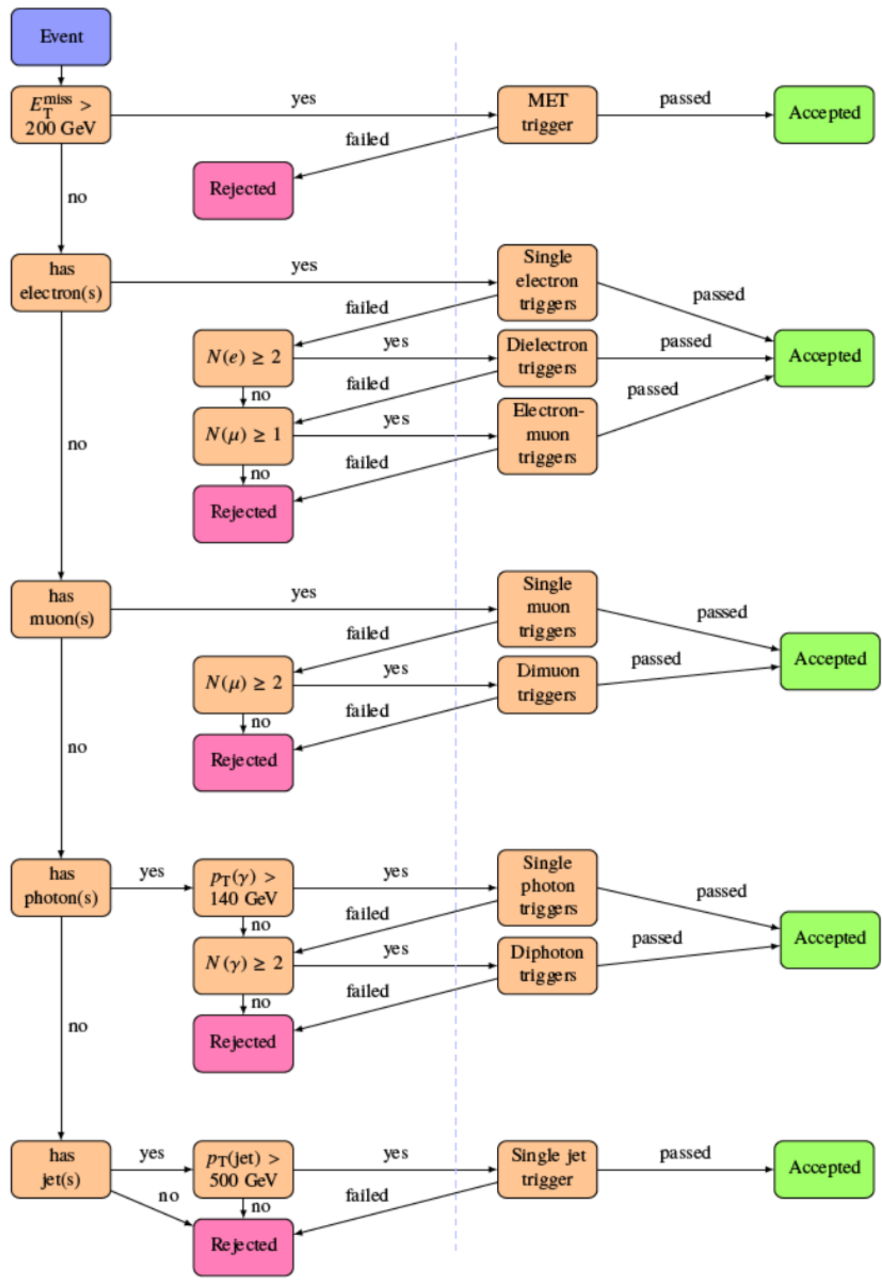
$$P(n \leq N_{\mathrm{obs}}) = \int_0^{\infty} \mathrm{d}x\, G(x; N_{\mathrm{SM}}, \delta N_{\mathrm{SM}}) \cdot \sum_{n=0}^{N_{\mathrm{obs}}} \frac{e^{-x} x^n}{n!} + \int_{-\infty}^{0} \mathrm{d}x\, G(x; N_{\mathrm{SM}}, \delta N_{\mathrm{SM}})$$

$$P(n \geq N_{\mathrm{obs}}) = \int_0^{\infty} \mathrm{d}x\, G(x; N_{\mathrm{SM}}, \delta N_{\mathrm{SM}}) \cdot \sum_{n=N_{\mathrm{obs}}}^{\infty} \frac{e^{-x} x^n}{n!}$$

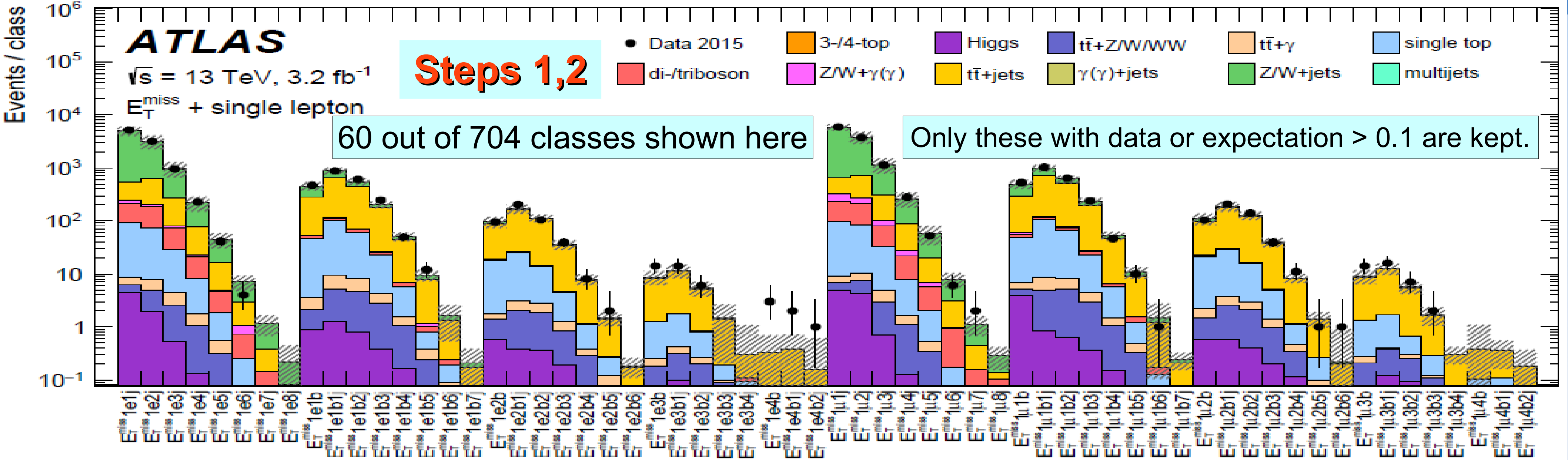
4. Generation of pseudo-experiments



5. Evaluation of the sensitivity
6. Results (**no significant deviations found**)
7. (only in the case of $P_{\mathrm{exp;i}}$ < 5%):
   Dedicated analysis of deviation



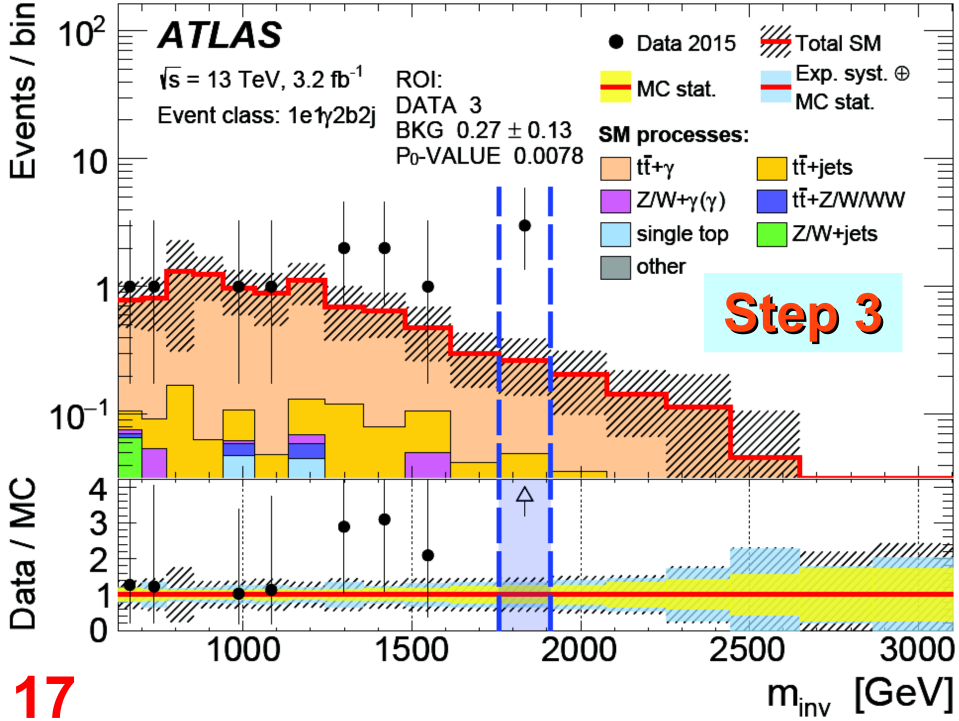
A strategy for a general search for new phenomena using data-derived signal regions and its application within the ATLAS experiment (arXiv:1807.07447, Jul 2018)



Steps 1,2

60 out of 704 classes shown here

Only these with data or expectation > 0.1 are kept.



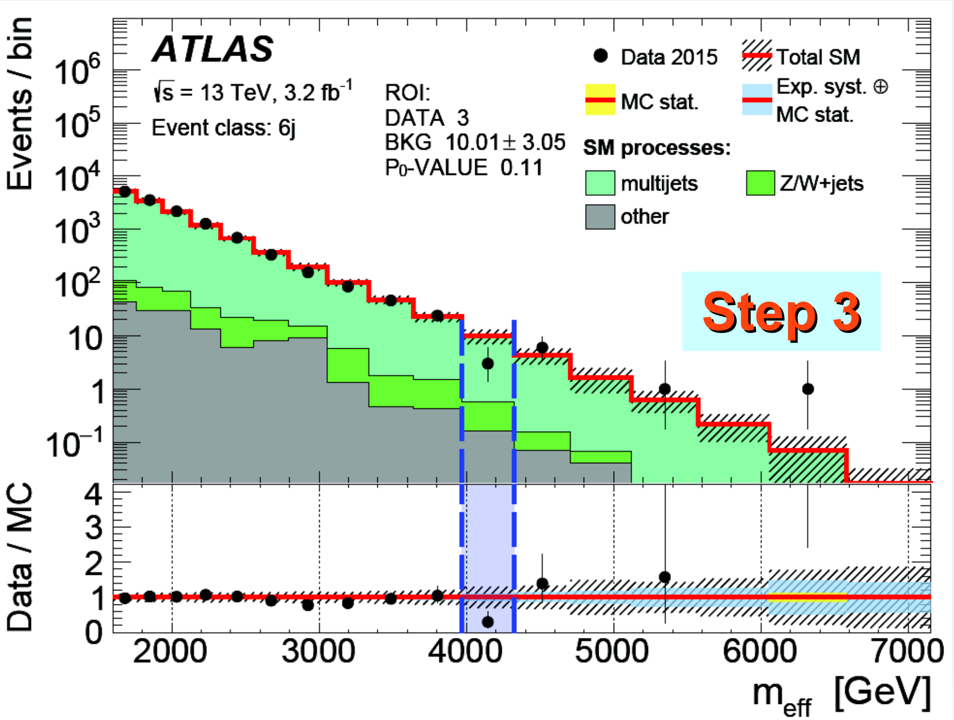
Step 3

36936 independ. bins

518320 contiguous regions

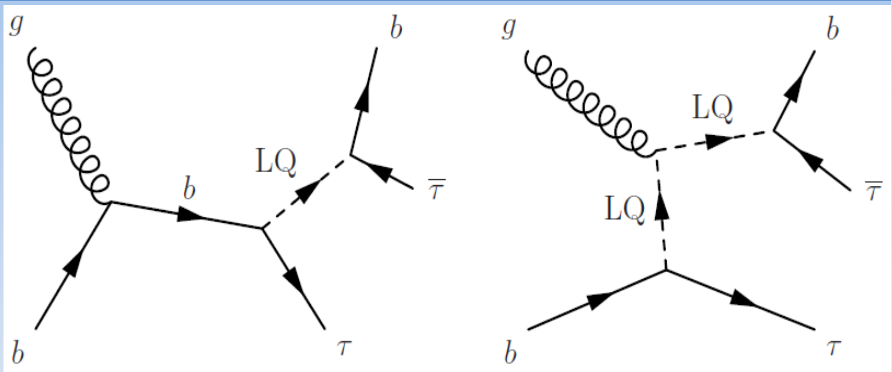
examples of such regions ← are → shown

blue bins



Step 3

Search for a singly produced third-generation scalar **leptoquark** decaying to a **tau** lepton and a **bottom** quark in proton-proton collisions at sqrt(s) = 13 TeV (**CMS** → doi:10.1007/JHEP07(2018)115, Jul 2018)

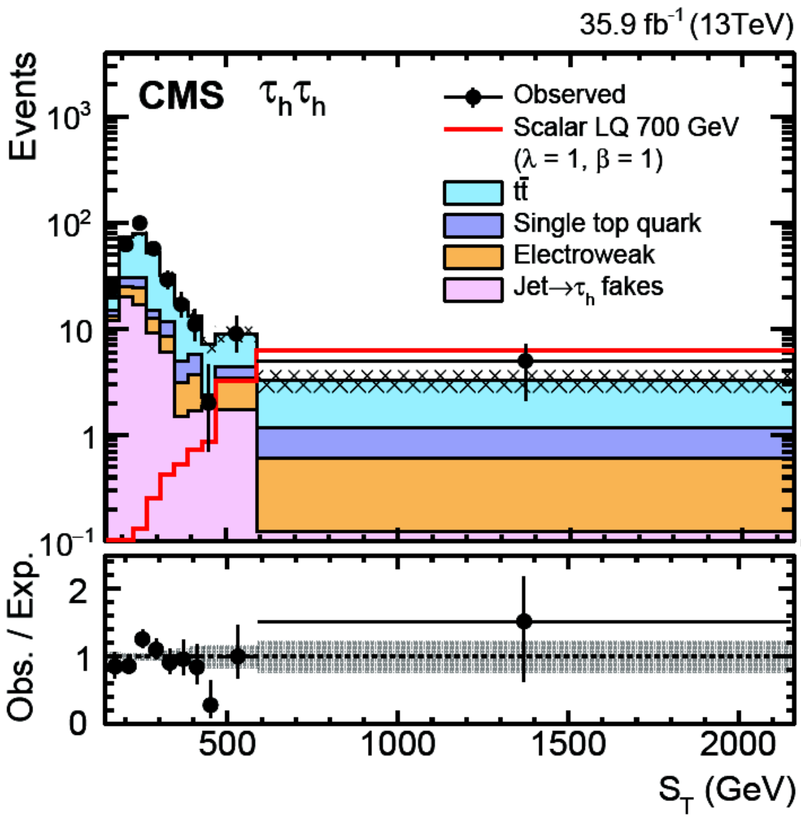


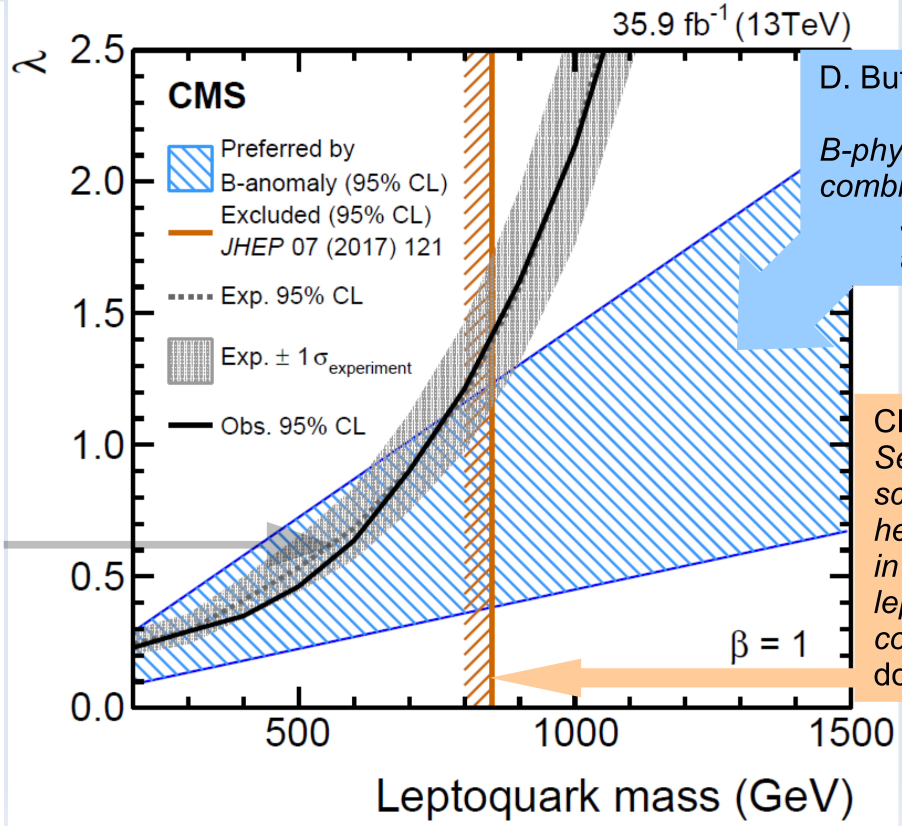
Trigger: isolated electrons, muons and tau candidates

$e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$ channels

At lest one hard b-tagged jet required.

Dominant background in all channels is $t\bar{t}$ production.
Additional backgrounds are W+jets, Z+jets, diboson, single top and QCD multijet events.





D. Buttazzo, A. Greljo, G. Isidori and D. Marzocca, *B-physics anomalies: a guide to combined explanations*, JHEP 11 (2017)044, arXiv:1706.07808.

CMS collaboration, *Search for third-generation scalar leptoquarks and heavy right-handed neutrinos in final states with two tau leptons and two jets in p-p collisions at sqrt(s) = 13 TeV* doi:10.1007/JHEP07(2017)121

Aren't long lived creatures interesting?

Motivation for LLP

- various SUSY scenarios:
  - gravitino DM
  - RPV
  - Split SUSY
  - [. . .]
- "hidden valley"
- [. . .]

BSM with
new symmetry,
weak coupling,
kinematic constraint,
potential barrier

Mary River Turtle with algae on its head © Chris Van Wyk

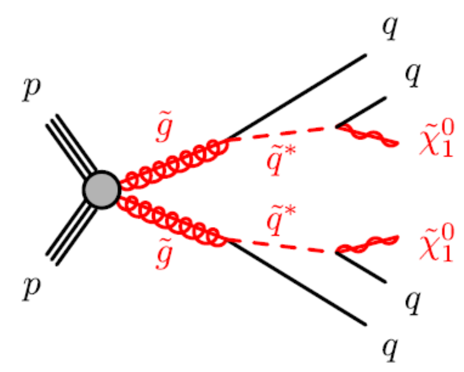
LLP with displaced vertices (DV)

1

ATLAS: Phys. Rev. D **97**,052012 (Mar 2018)

CMS-EXO-17-018
(arXiv:1808.03078, Aug 2018)

These analyses are similar in using displaced vertices, but focused on different signals.



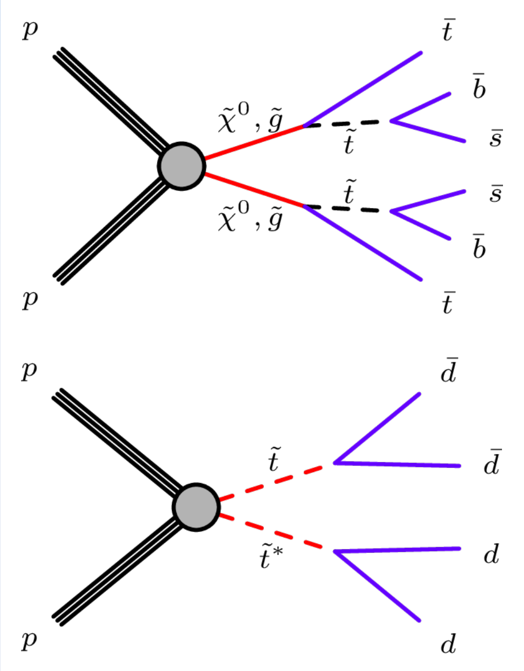
The ATLAS search is motivated by Split SUSY.

Large MET is expected and used for trigger and selection.

Final selection (SR):
MET > 250 GeV
at least one good DV with mass **m_{DV} > 10 GeV**
and number of assoicated tracks **$n_{trk} \geq 5$**

An additional *large radius tracking* (LRT) in use.

Only instrumental background is expected:
A) hadronic interactions
B) merged vertices
C) accidental crossing of vertices & tracks
Background estimated using
CRs with lower m_{DV} , n_{trk}.

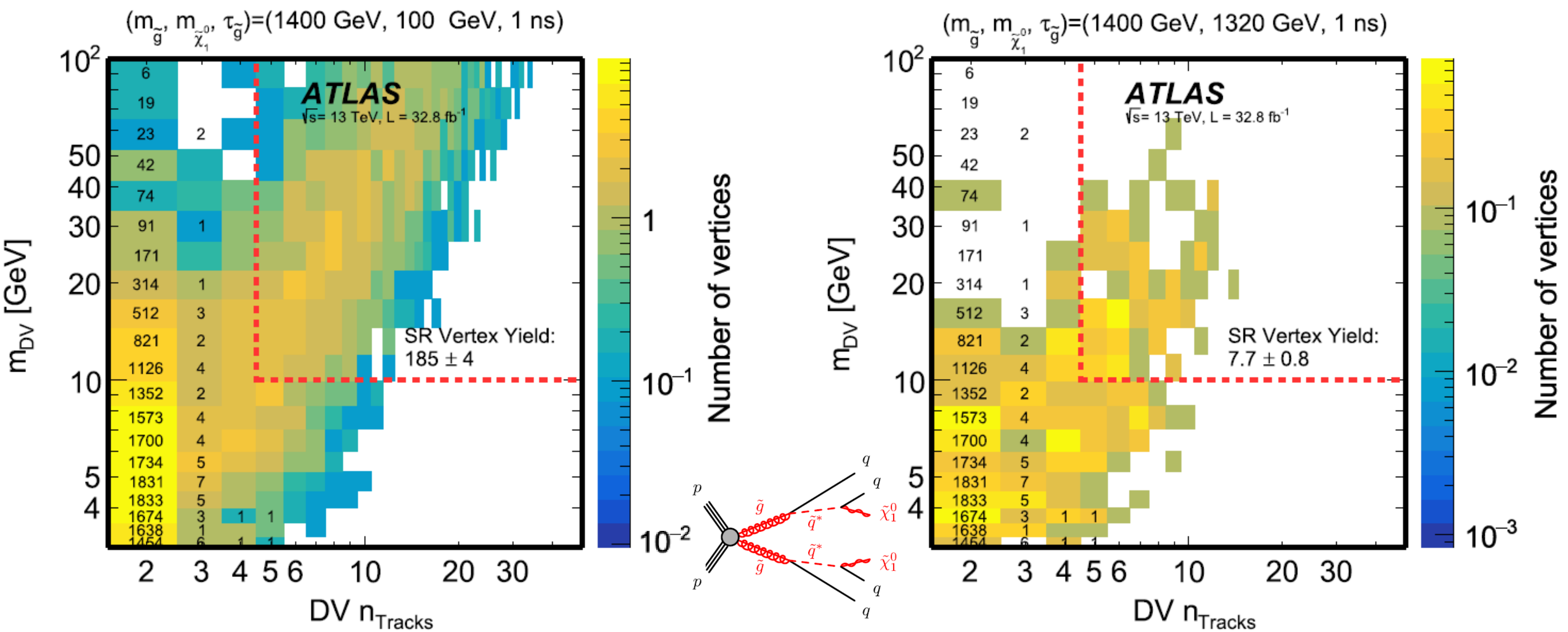


The CMS search is motivated by RPV SUSY.

No MET but large number of hard jets is expected.

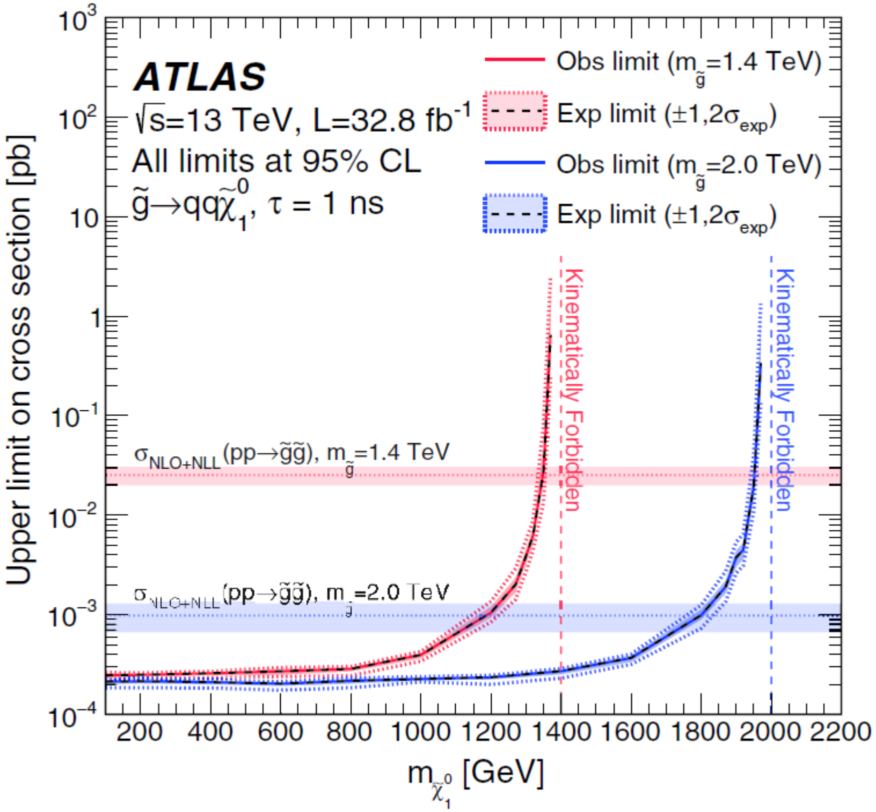
For trigger (selection)
H_T > 800, 900 (1000) GeV
(H_T is the scalar sum of hard jets transverse momenta)

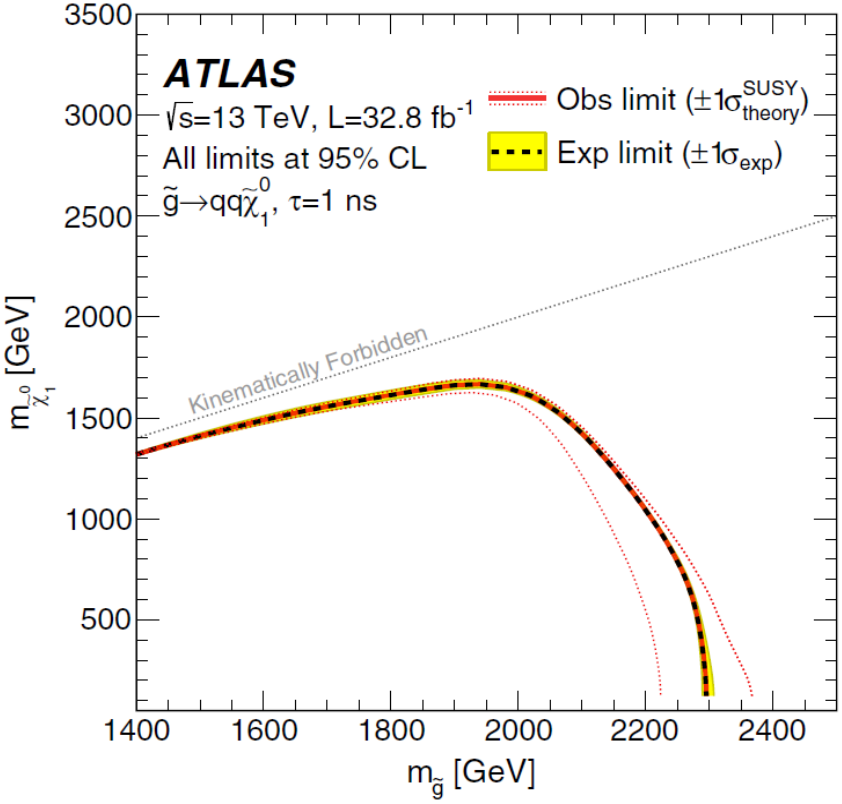
Only **DV** vertices **inside beam pipe** are considered.
In the search two such vertices are required in each event. **In the signal region not less than 5 tracks** per vertex are required. Vertices with fewer number of tracks form CRs. Background templates are constructed using events with single vertex.



LLP with displaced vertices

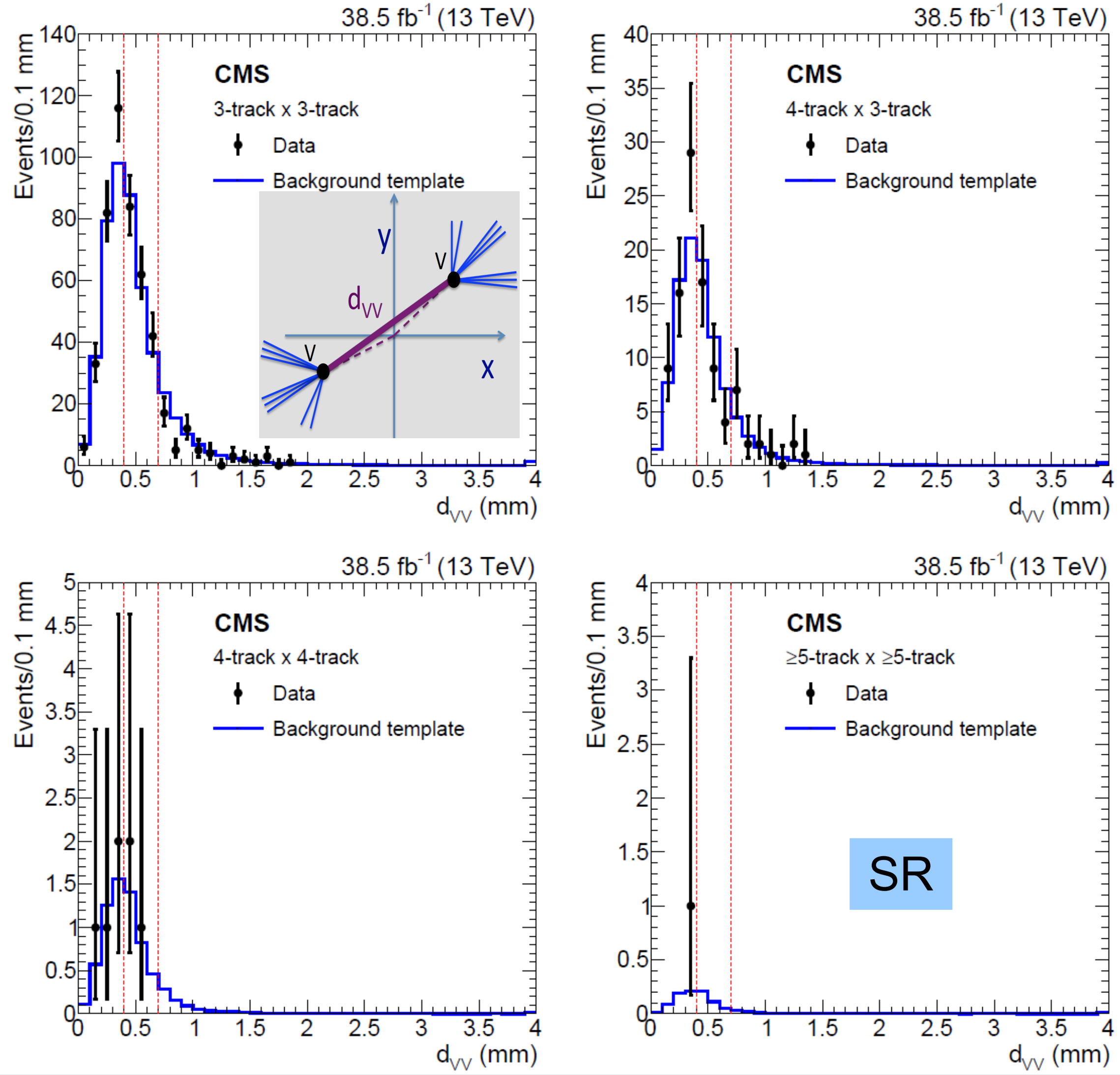
ATLAS results

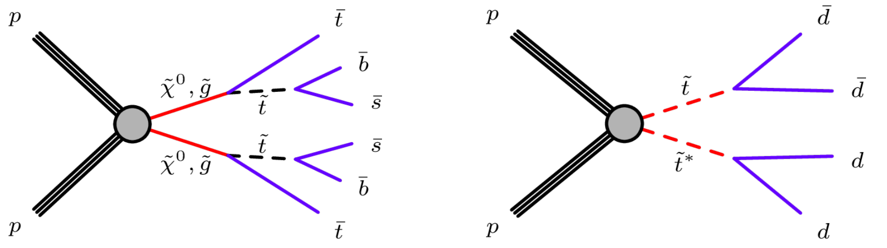


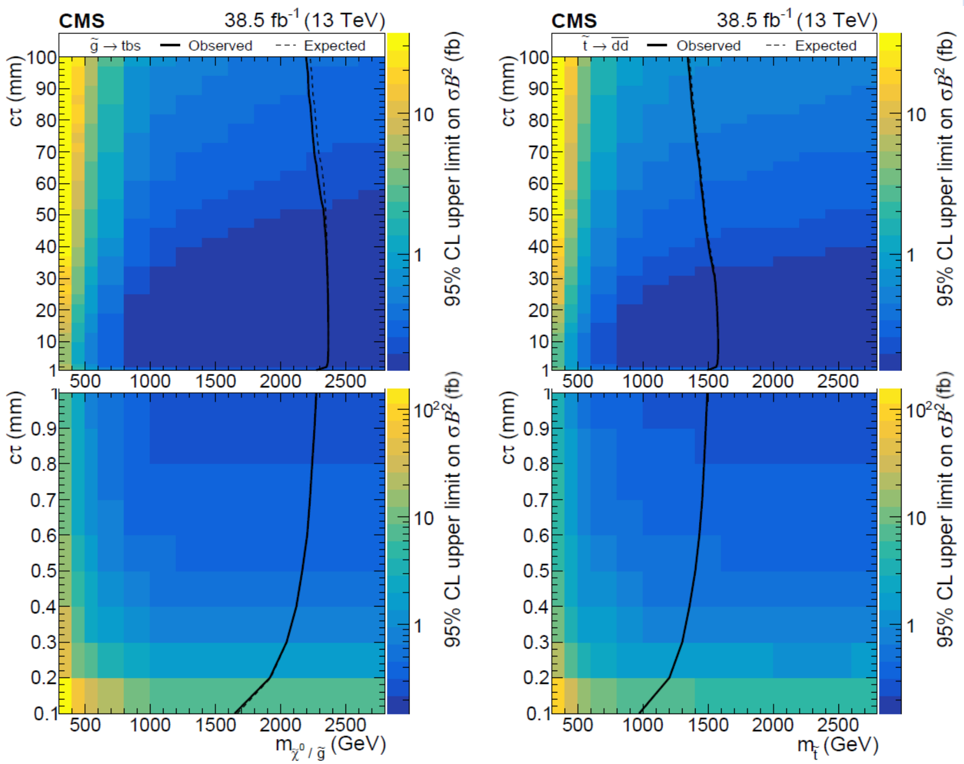


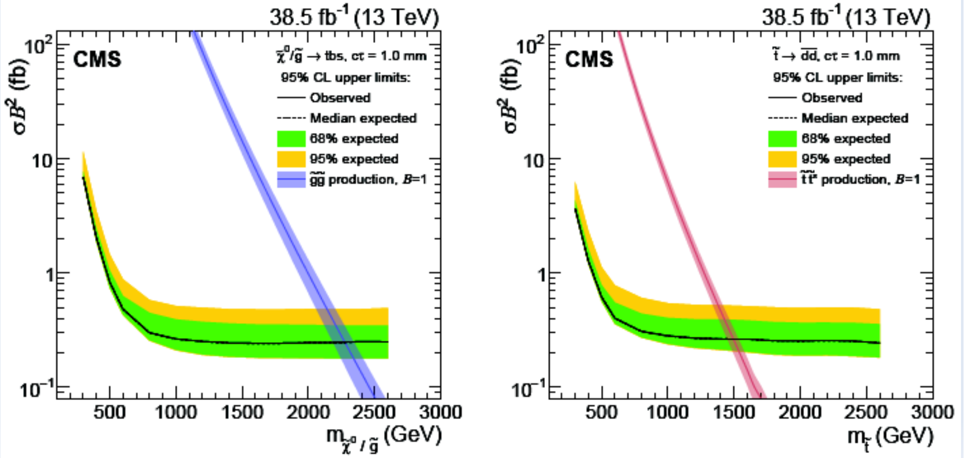
LLP with displaced vertices
CMS results

3

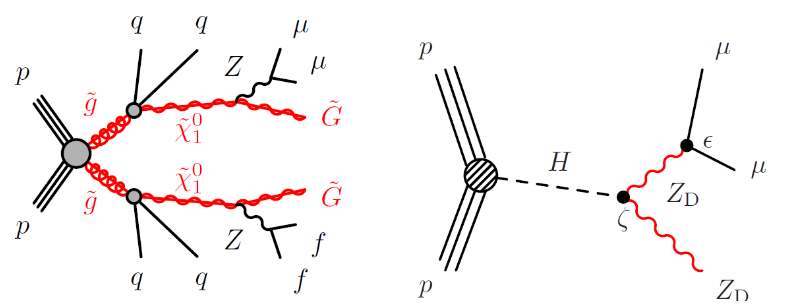








Search for long-lived particles in final states with **displaced dimuon vertices** in pp collisions at sqrt(s) = 13 TeV with the **ATLAS** detector (arXiv:1808.03057, Aug 2018)



Trigger: OR of: MET, 1, 2, 3 muon(s).

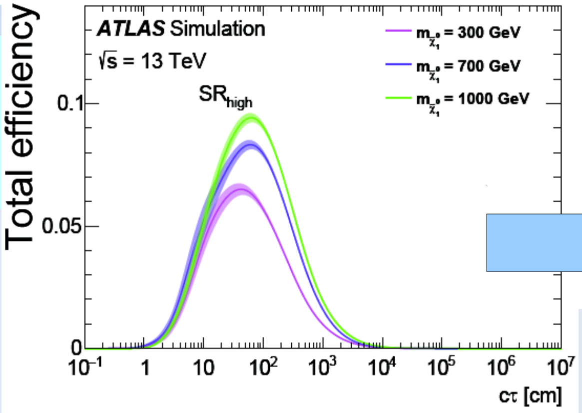
$SR_{low,high}$: pair of isolated OS MSonly.

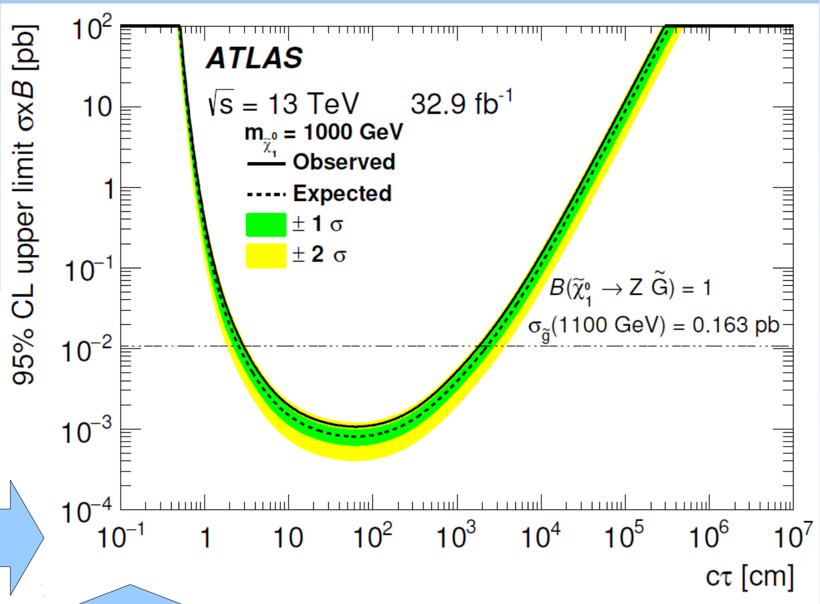
Comprehensive data-driven background estimate.

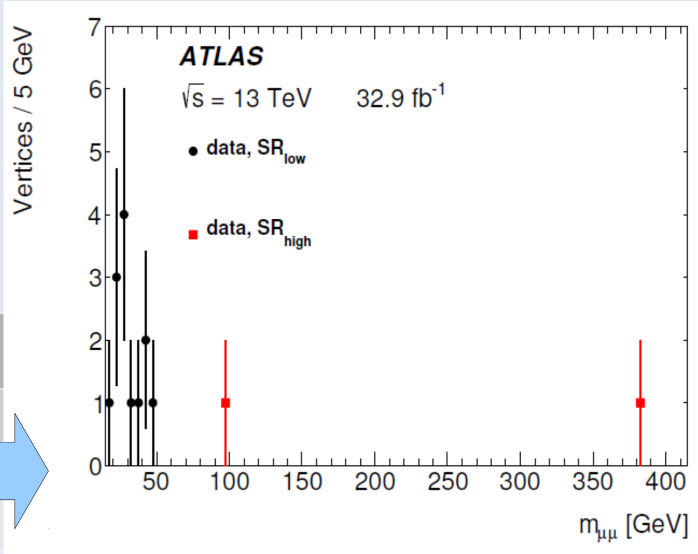
- MSonly & MScomb muons
- OS & SS pair of muons
- isolated vs non-isolated
- pairs with or without T boost

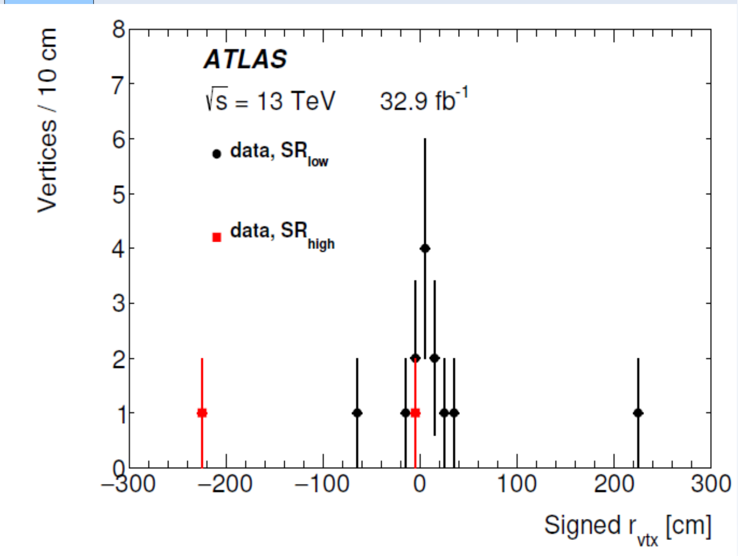
The main background is from accidental pairing.

	bckg. est.	observed
SR_{low}	13.8 ± 4.9	15
SR_{high}	$0.50^{+1.42}_{-0.07}$	2









Search for decays of stopped exotic long-lived particles produced in proton-proton collisions at sqrt(s) = 13 TeV (CMS: doi:10.1007/JHEP05(2018)127, Aug 2018)

1

Two searches for stopped LLPs that decay out of time:

→ **hadronic decays** detected in the calorimeters

→ **decays to muon pairs** detected in the muon system

LLP decays during empty BXs, dedicated triggers select events at least 2 BXs away from any proton bunches.

calo-jet ← signatures → **pair of muons**

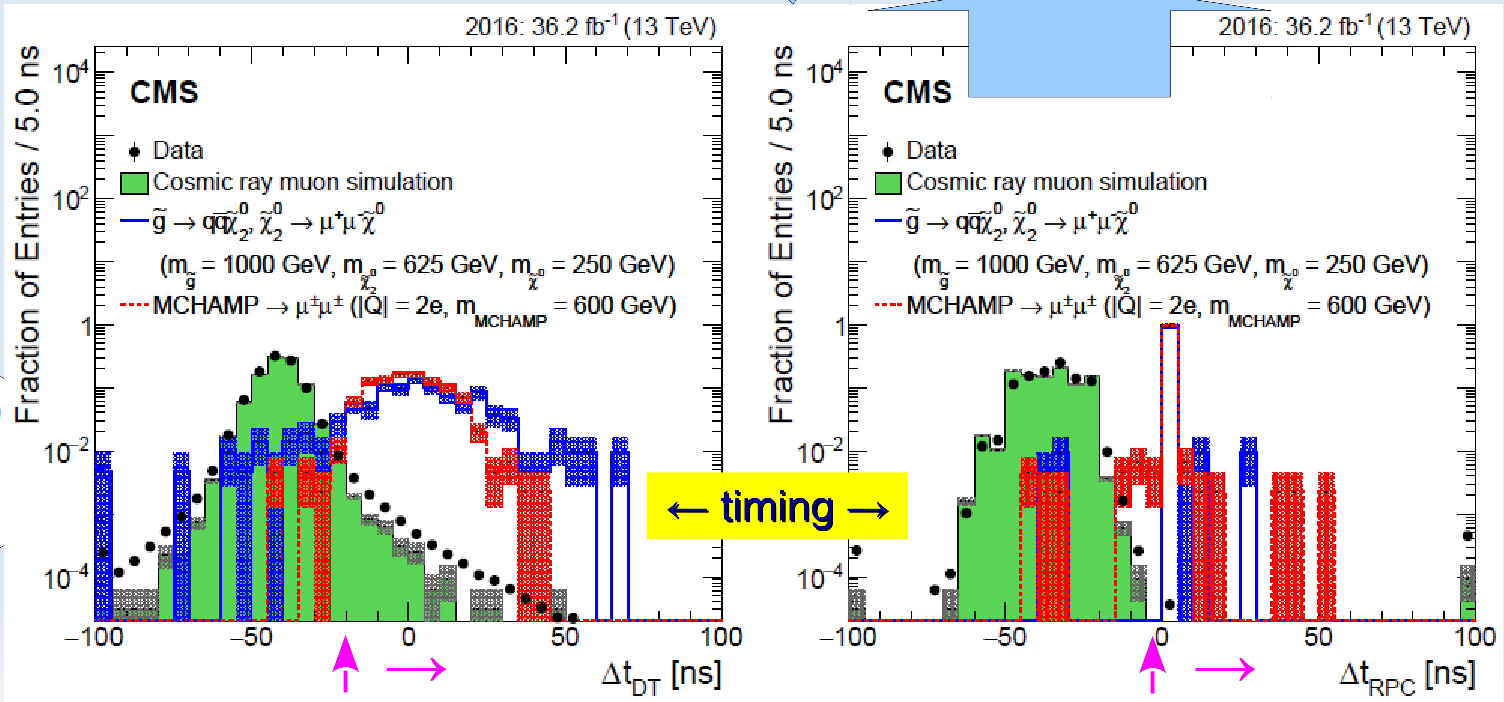
2- and 3-body stopped gluino (stop) decays

LHC period	Trigger livetime [hrs]	HCAL noise	Cosmic ray muons	Beam halo	Total background	observed
2015	135	$0.4^{+2.9}_{-0.4}$	2.6 ± 0.9	1.1 ± 0.1	$4.1^{+3.0}_{-1.0}$ (6.2)	4
2016	586	$0.0^{+9.8}_{-0.0}$	8.8 ± 3.1	2.6 ± 0.2	$11.4^{+10.3}_{-3.1}$ (17.4)	13

residual background in the **calorimetric search**

muon search

predicted	observed
0.04±0.03	0
0.40±0.50	0



← timing →

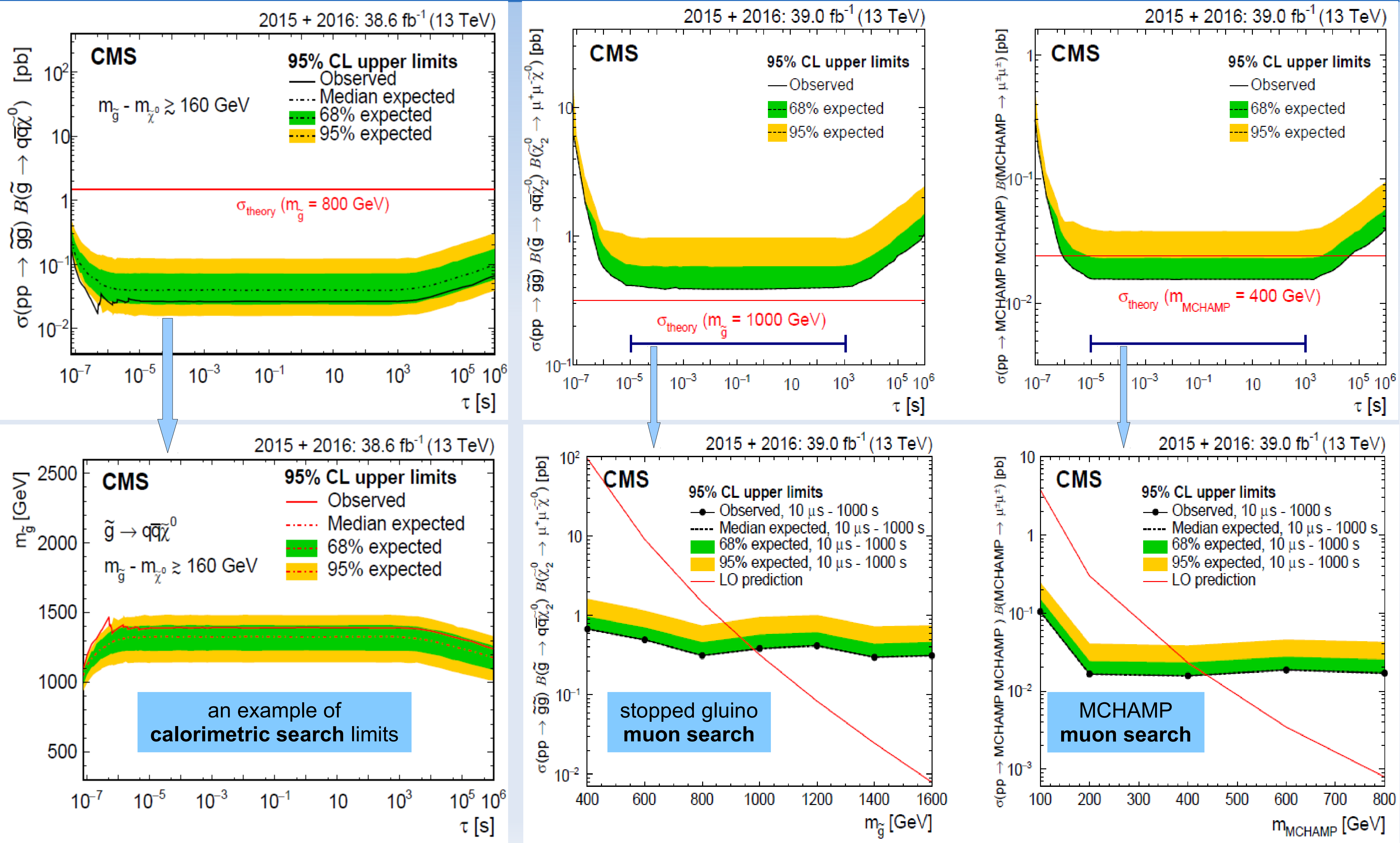
$\tilde{g} \to q\bar{q}\tilde{\chi}^0_2, \tilde{\chi}^0_2 \to \mu^+\mu^-\tilde{\chi}^0$

MCHAMP → $\mu^\pm\mu^\pm$

Search for decays of stopped exotic long-lived particles produced in proton-proton collisions at sqrt(s) = 13 TeV

(**CMS**: doi:10.1007/JHEP05(2018)127, **Aug 2018**)

2



an example of **calorimetric search** limits

stopped gluino **muon search**

MCHAMP **muon search**

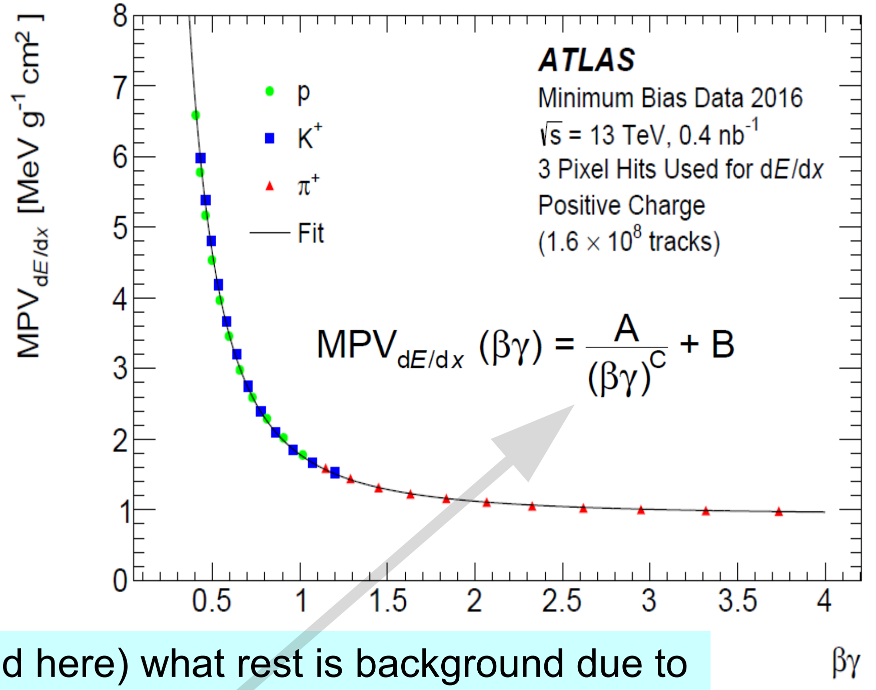
Search for **heavy charged long-lived** particles in proton–proton collisions at sqrt(s) = 13 TeV using an **ionisation measurement** with the **ATLAS** detector (arXiv:1808.04095, Aug 2018)

1

The search for gluinos (R-hadrons) is performed in two separate signal regions: **stable and metastable**.
The main difference is that **metastable candidates are required to not be seen in the muon system**.
Heavy gluinos are to be recognized by their **higher specific ionisation** in (four) pixel layers of the tracker.

The MET trigger with threshold varied from 70 to 110 GeV is used.

Events are selected by requiring (offline) MET > 170 GeV.
Candidates must have $p_T > 50$ GeV, $p > 150$ GeV, $|\eta| < 2$ and $\mathrm{MPV}_{dE/dx} > 1.8$ MeV cm²/g (which is roughly equivalent to $\beta\gamma < 0.9$)



After suppression of several types of background (not to be described here) what rest is background due to
– multiple sampling from Landau tail of specific ionisation,
– overlapping particles *etc*.

The background is fully estimated from data.
A template for momentum distribution in SR is obtained from *p*-CR with inverted $\mathrm{MPV}_{dE/dx}$ cut.
The d*E*/dx distribution (in several *p* bins) is obtained from d*E*/dx-CR with inverted MET cut.
Finally, a validation (VR) region is constructed by requiring $50 < p < 150$ GeV.

The search variable is the mass $m=p/(\beta\gamma)$ where **$\beta\gamma$** is obtained using the equation shown in the figure.

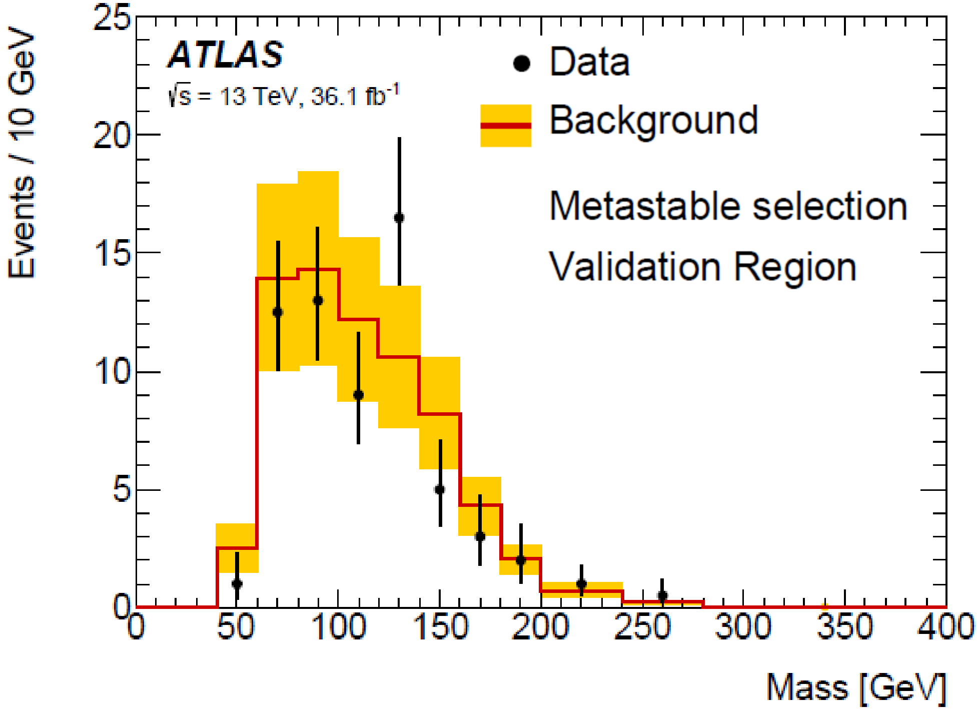
The background estimate is normalized to data in the region $m < 160$ GeV before the high ionisation cut is applied.

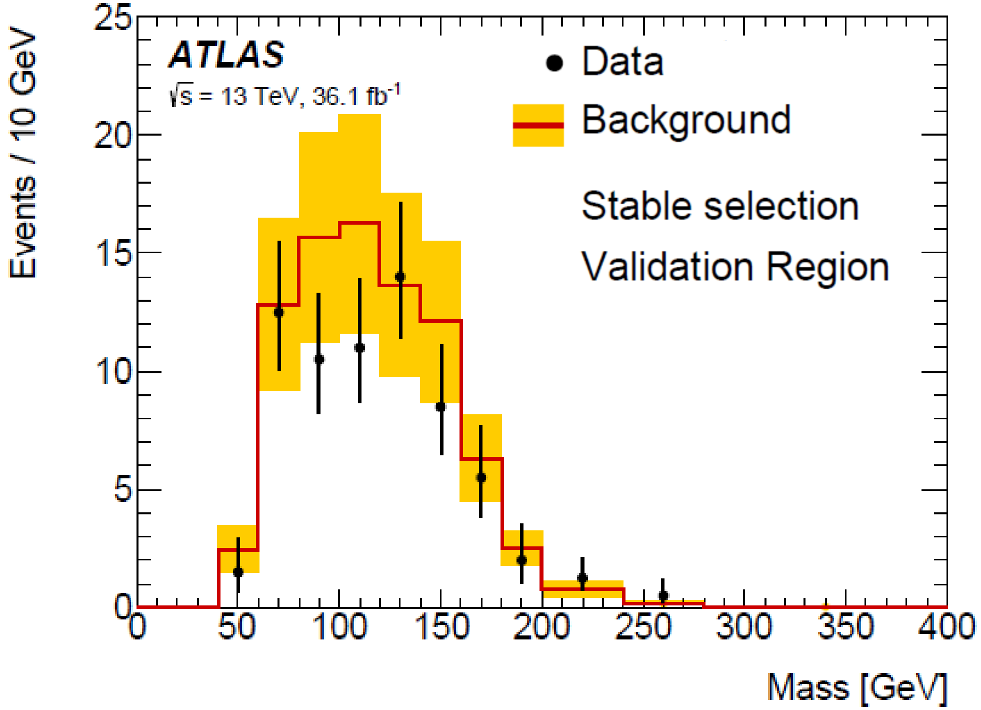
Search for **heavy charged long-lived** particles in proton–proton collisions at sqrt(s) = 13 TeV using an **ionisation measurement** with the **ATLAS** detector (arXiv:1808.04095, Aug 2018)

2

Table 1: Summary of the different selection requirements applied to the signal region (SR), the validation region (VR), and the control regions (CR).

	SR	VR	p-CR		d$E/$dx-CR	
			for SR	for VR	for SR	for VR
Track Momentum [GeV]	>150	50–150	>150	50–150	>150	50–150
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	>170		>170		<170	
Ionisation [MeV g^{-1} cm^2]	>1.8		<1.8		–	

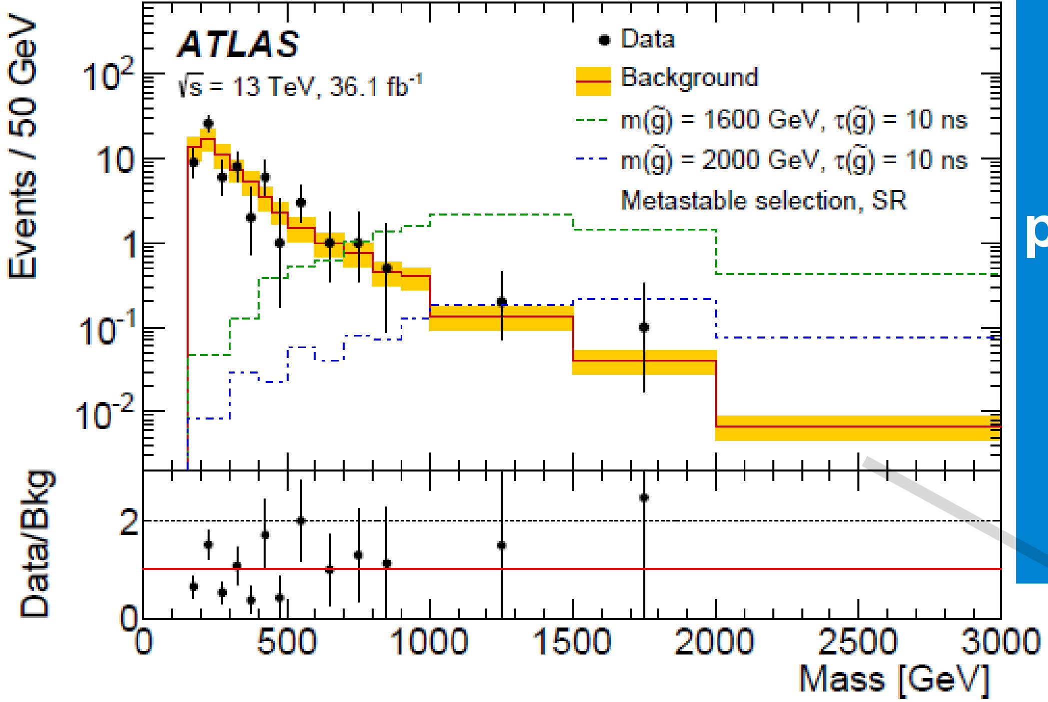




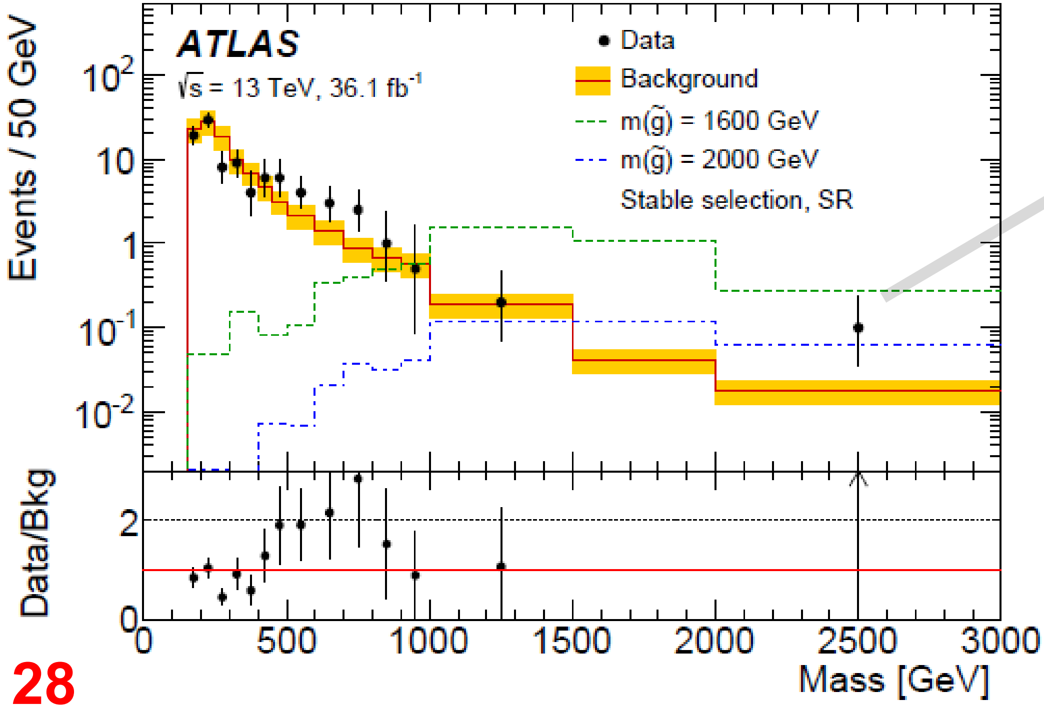
Search for **heavy charged long-lived** particles in proton–proton collisions at sqrt(s) = 13 TeV using an **ionisation measurement** with the **ATLAS** detector

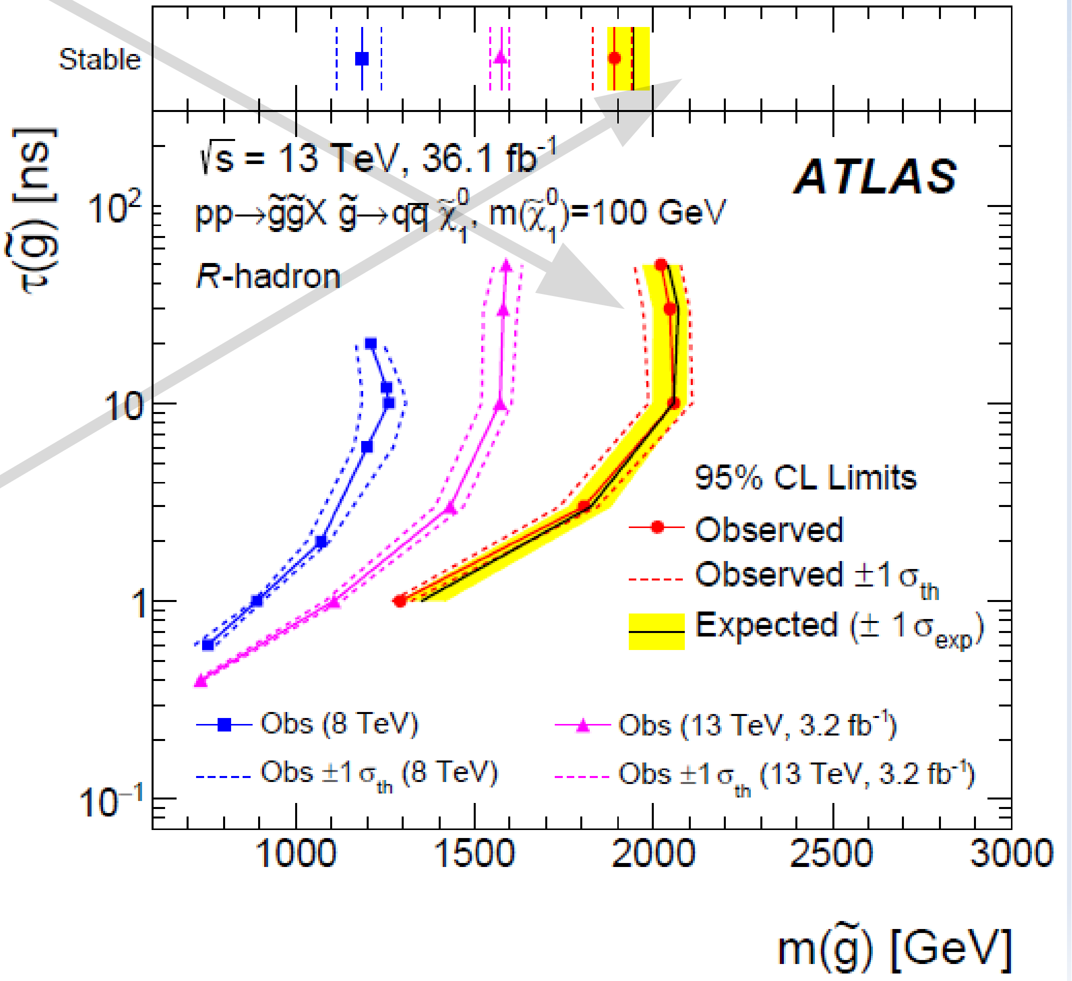
(arXiv:1808.04095, Aug 2018)

3

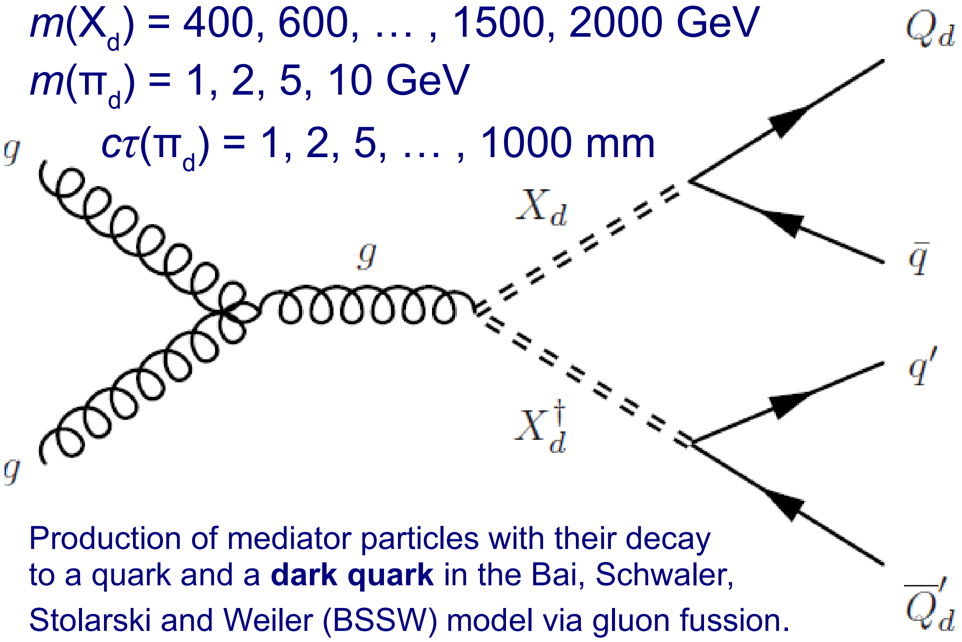


Results



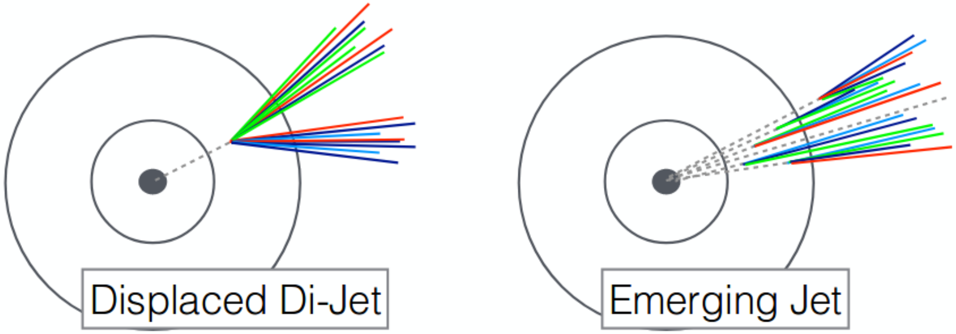


Search for new particles decaying to a jet and an **emerging jet**
(**CMS** PAS EXO-18-001, June 2018)



$m(X_d)$ = 400, 600, … , 1500, 2000 GeV
$m(\pi_d)$ = 1, 2, 5, 10 GeV
$c\tau(\pi_d)$ = 1, 2, 5, … , 1000 mm

Production of mediator particles with their decay to a quark and a **dark quark** in the Bai, Schwaler, Stolarski and Weiler (BSSW) model via gluon fussion.



Dark quarks hadronize under **dark QCD**. Dark hadrons decay via mediator to SM quarks giving emerging jet(s) signature.

$$c\tau \approx 80\,\mathrm{mm}\left(\frac{1}{\kappa^4}\right)\left(\frac{2\,\mathrm{GeV}}{f_{\pi_\mathrm{d}}}\right)^2\left(\frac{100\,\mathrm{MeV}}{m_{down}}\right)^2\left(\frac{2\,\mathrm{GeV}}{m_{\pi_\mathrm{d}}}\right)\left(\frac{m_{\mathrm{X_d}}}{1\,\mathrm{TeV}}\right)^4$$

Trigger: H_T > 900 GeV

Emerging jet candidates:
$|\eta|$ < 2, tracks of good quality with p_T > 1GeV and within R=0.4

Signature: multiple tracks with large impact parameter (IP).

→ **$\langle IP_{2D}\rangle$,** the median of unsigned transverse IP
→ $PU_{dz} = |z_{PV} - z_{trk}|$
→ $D_N = \mathrm{sqrt}\{(PU_{dz} / 0.01\mathrm{cm})^2 + IP_{sig}{}^2\}$,
where IP_{sig} is transverse IP significance
→ α_{3D} , a fraction of a scalar sum of p_T corresponding to tracks passing D_N selection

Optimized sets of requiremnts for emerging jets

	Set number	PU_{dz} (<)	D_N (<)	$\langle IP_{2D}\rangle$ (>) [cm]	α_{3D} (<)
emerging	EMJ-1	2.5	4	0.05	0.25
	EMJ-2	4.0	4	0.10	0.25
	EMJ-3	4.0	20	0.25	0.25
	EMJ-4	2.5	4	0.10	0.25
	EMJ-5	2.5	20	0.05	0.25
	EMJ-6	2.5	10	0.05	0.25
QCD	EMJ-7	2.5	4	0.05	0.40
	EMJ-8	4.0	20	0.10	0.50

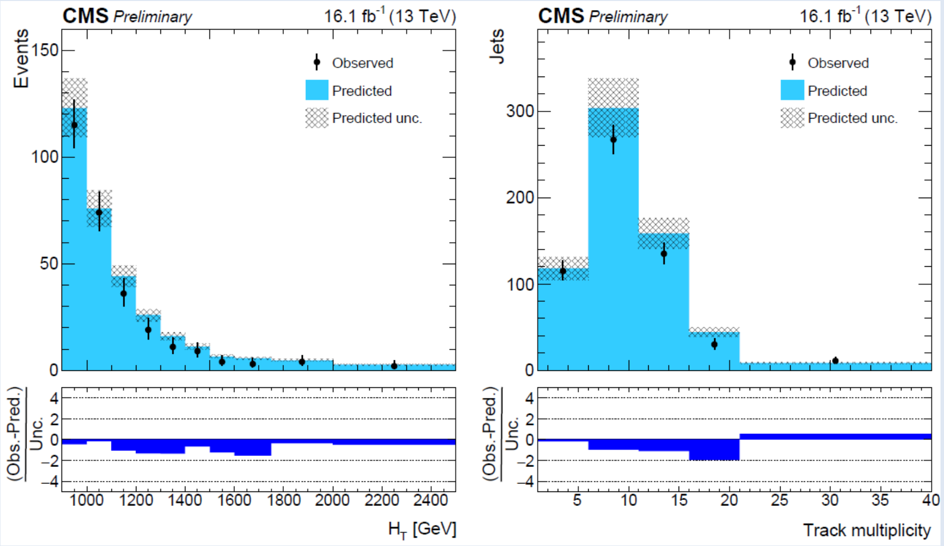
Search for new particles decaying to a jet and an emerging jet
(CMS PAS EXO-18-001, June 2018)

Optimized selection sets

Set number	H_T	$p_{T,1}$	$p_{T,2}$	$p_{T,3}$	$p_{T,4}$	p_T^{miss}	$n_{em}(\geq)$	EMJ set	no. models
1	900	225	100	100	100	0	2	1	12
2	900	225	100	100	100	0	2	2	2
3	900	225	100	100	100	200	1	3	96
4	1100	275	250	150	150	0	2	1	49
5	1000	250	150	100	100	0	2	4	41
6	1000	250	150	100	100	0	2	5	33
7	1200	300	250	200	150	0	2	6	103
8	900	225	100	100	100	0	2	7	QCD-enhanced
9	900	225	100	100	100	200	1	8	

Set number	Expected	Observed
1	$168 \pm 15\,(\text{syst}_1) \pm 5\,(\text{syst}_2)$	131
2	$31.8 \pm 5.0\,(\text{syst}_1) \pm 1.4\,(\text{syst}_2)$	47
3	$19.4 \pm 7.0\,(\text{syst}_1) \pm 5.5\,(\text{syst}_2)$	20
4	$22.5 \pm 2.5\,(\text{syst}_1) \pm 1.5\,(\text{syst}_2)$	16
5	$13.9 \pm 1.9\,(\text{syst}_1) \pm 0.6\,(\text{syst}_2)$	14
6	$9.4 \pm 2.0\,(\text{syst}_1) \pm 0.3\,(\text{syst}_2)$	11
7	$4.40 \pm 0.84\,(\text{syst}_1) \pm 0.28\,(\text{syst}_2)$	2

backg. est.



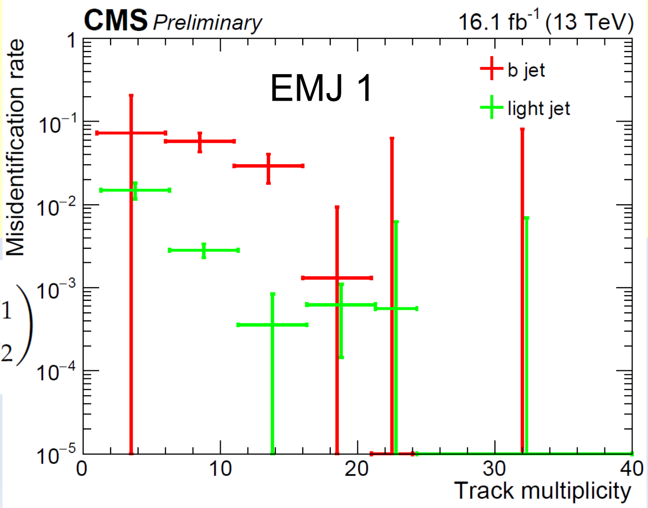
Probability of misidentification of jet as an emerging one depends on the flavor (b-jets are mach more vulnerable) and track multiplicity.

The misid rate is measured as a function of multiplicity using events triggered by $p_T > 165$ GeV photon.

Two subsamples: b-enriched and b-suppressed.

The b quark fraction of each is detrmined by a fit of simulated templates.

Finally:



$$\begin{pmatrix}\epsilon_{fb}\\ \epsilon_{fl}\end{pmatrix} = \begin{pmatrix}\frac{1-f_{b2}}{f_{b1}-f_{b2}} & \frac{-(1-f_{b1})}{f_{b1}-f_{b2}}\\ \frac{-f_{b2}}{f_{b1}-f_{b2}} & \frac{f_{b1}}{f_{b1}-f_{b2}}\end{pmatrix}\begin{pmatrix}\epsilon_{f1}\\ \epsilon_{f2}\end{pmatrix}$$

Background estimate verified by simulation, and validated in QCD enhanced samples
(selection set 8 is shown above)

Search for new particles decaying to a jet and an emerging jet

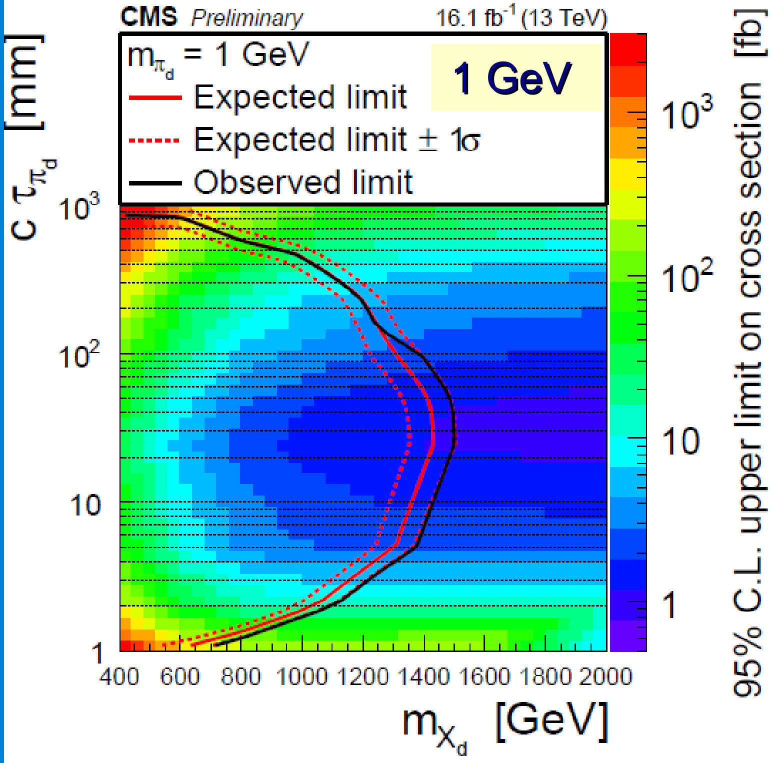
(CMS PAS EXO-18-001, June 2018)

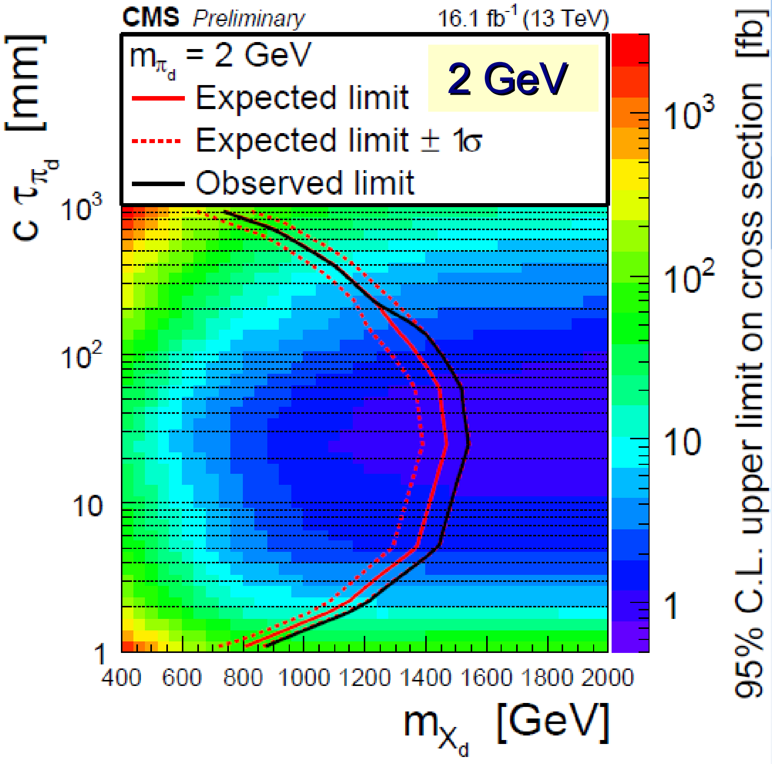
3

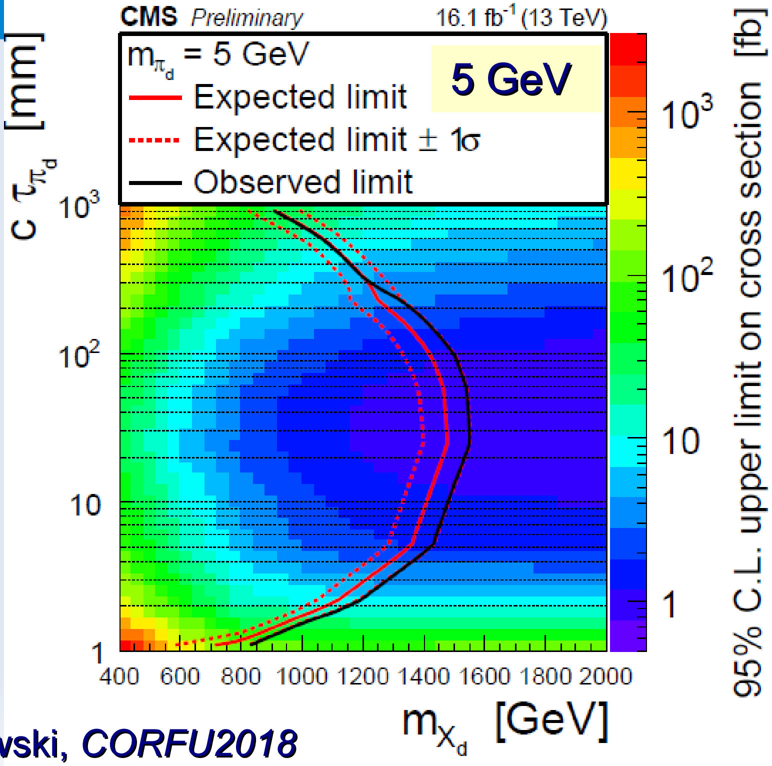
Results

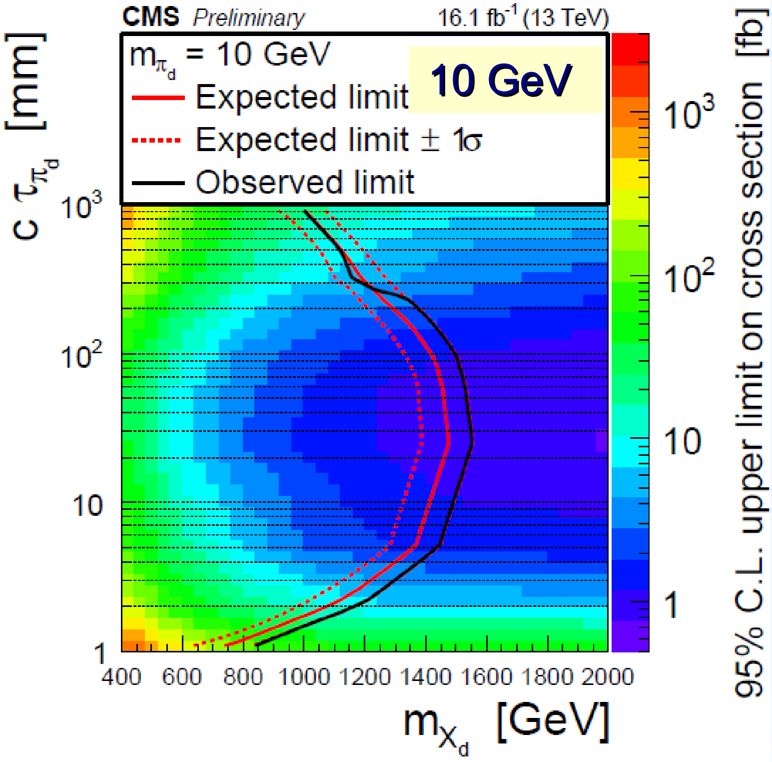
No statistaticaly significant excess found.

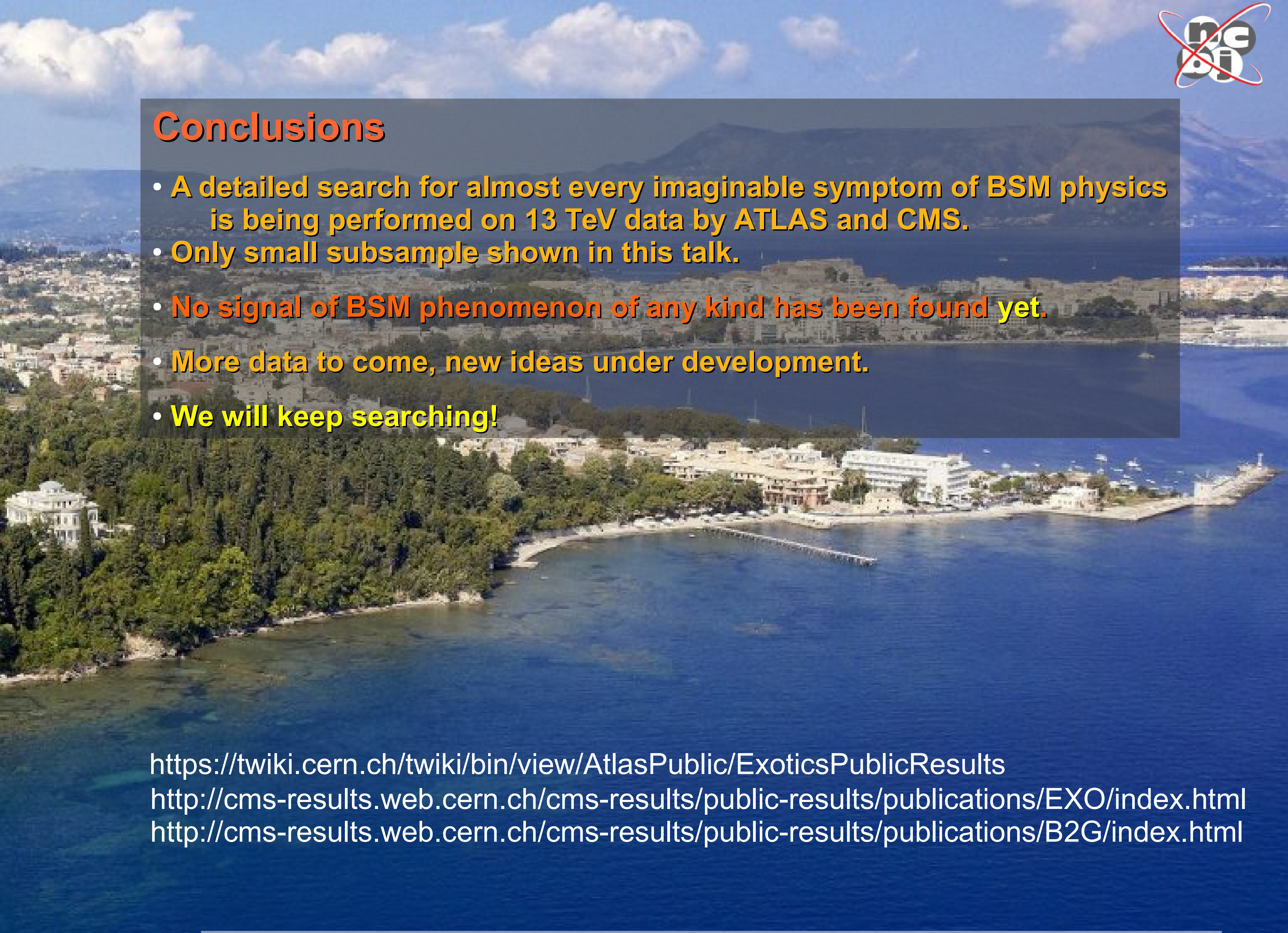
dark pion lifetime versus mediator mass X-sec limits for 4 masses of dark pion











Conclusions

- A detailed search for almost every imaginable symptom of BSM physics is being performed on 13 TeV data by ATLAS and CMS.
- Only small subsample shown in this talk.
- No signal of BSM phenomenon of any kind has been found yet.
- More data to come, new ideas under development.
- **We will keep searching!**

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html
http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G/index.html