MITP Topical Workshop, "Electroweak Precision Physics from Beta Decays to the Z Pole"
Mainz, October 24-28, 2022

Overview of collider searches (and opportunities)

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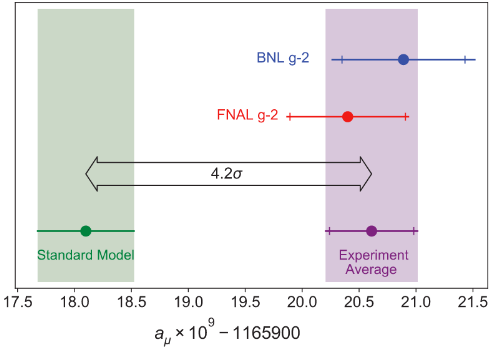
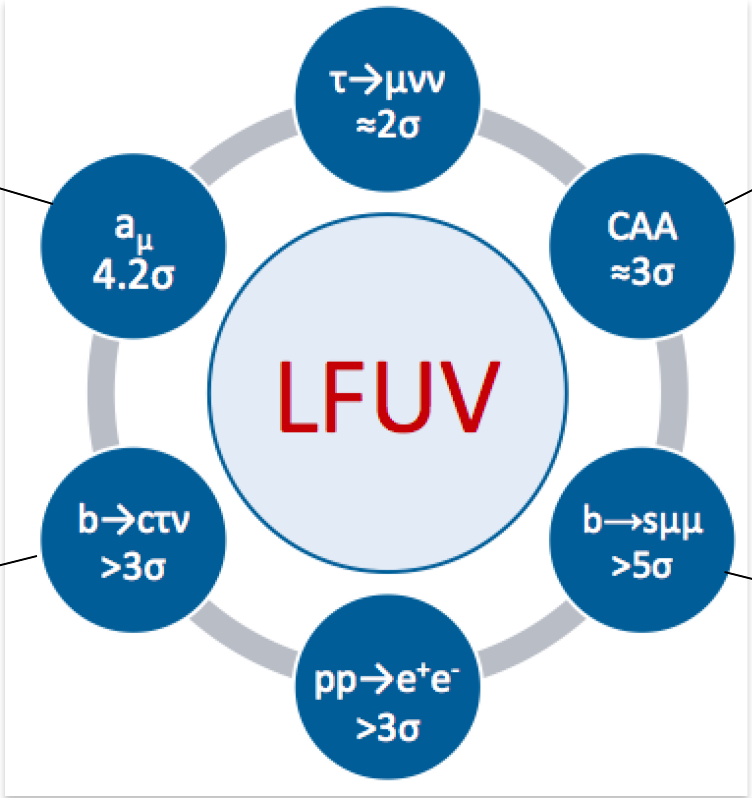
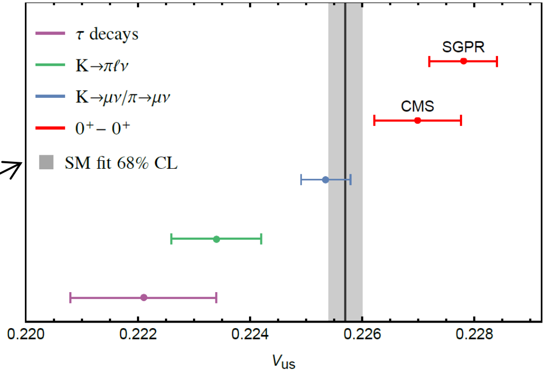
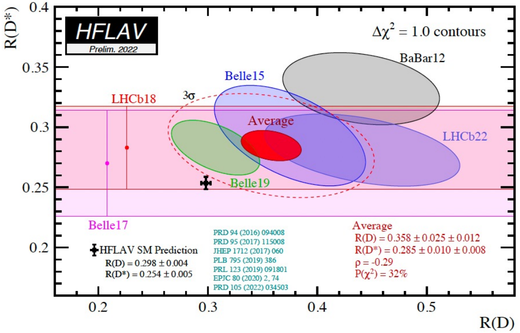
Hints for LFUV

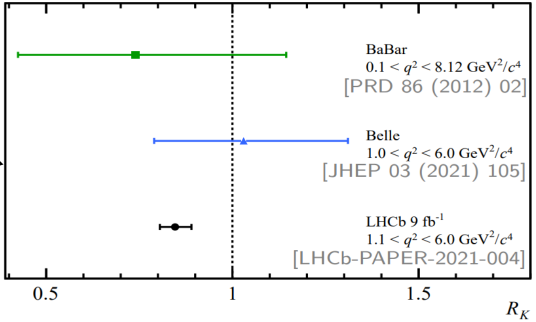








UPDATED!



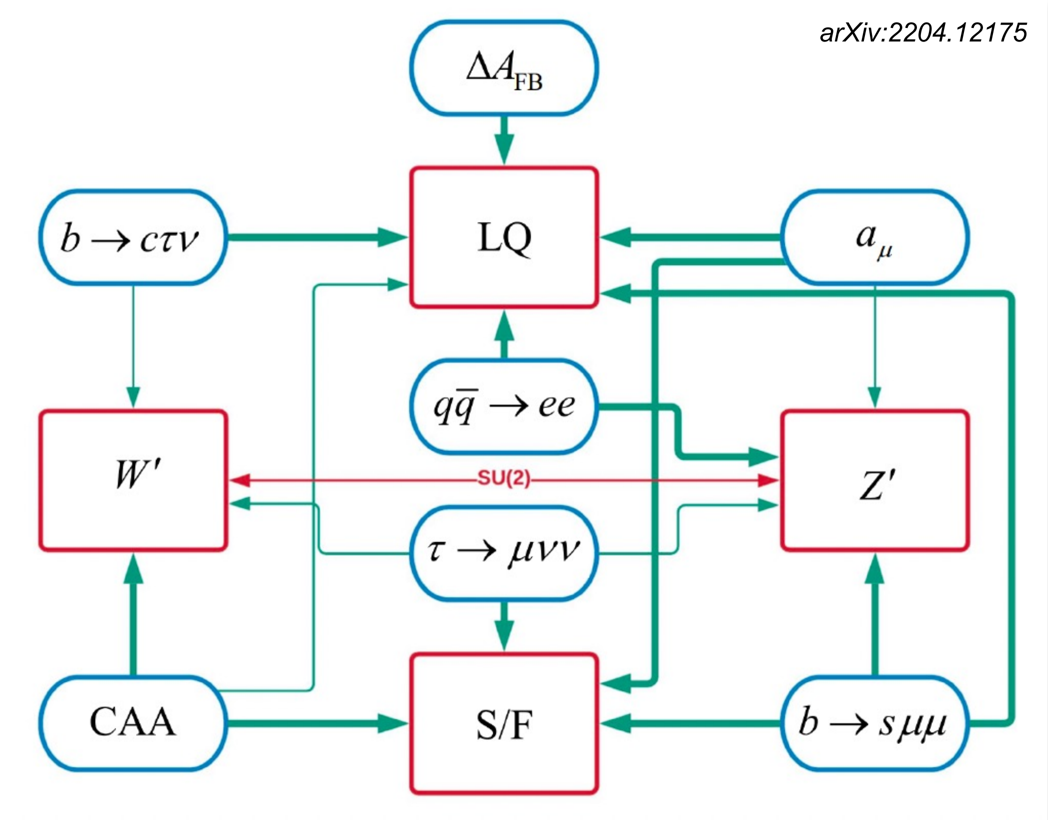
Also: $R(K^*)$, P_5', $B_s \to \mu\mu$, $B_s \to \mu\mu\phi$

Credit: A. Crivellin

Possible new physics explanations

- Hundreds of phenomenological papers proposing explanations.
- Successful explanations need to satisfy many constraints.
- A large fraction of models involve particles already being searched in ATLAS and CMS.
  - **How well are we doing?**
  - **What are we missing?**

Not discussing models where explanation is driven by new scalars or SUSY particles



Light resonances

Light leptophilic vectors/scalars: phenomenology

Anomaly scorecard

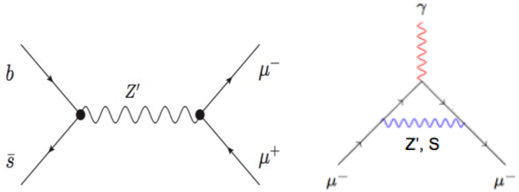
R(K) R(K*)

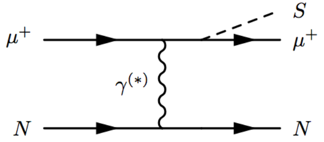
R(D) R(D*)

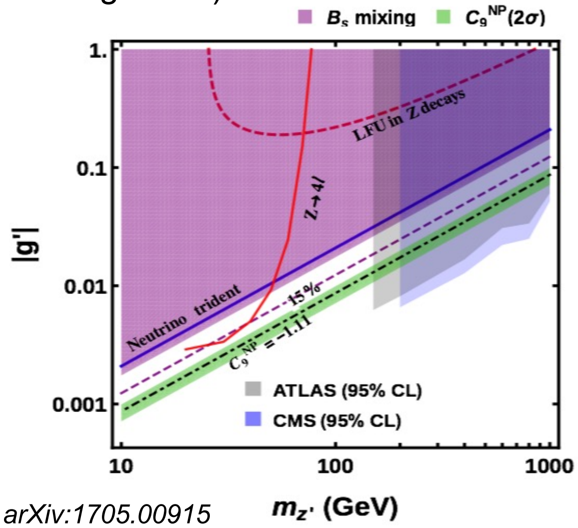
a_μ

Other

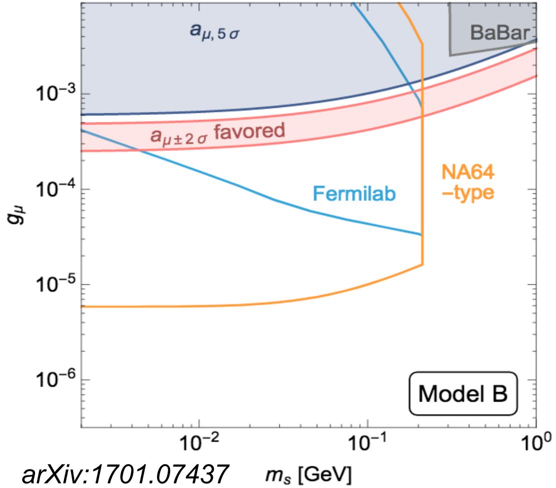
- Flavored light vectors and (pseudo-)scalars appear in many SM extensions that explain R(K), R(K*) (for masses >10 GeV) and a_μ.
- A Z' associated with the spontaneously broken $U(1)_{L\mu-L\tau}$ symmetry only interacts with the second and third generation of leptons at tree level ➔ challenging at a hadron collider.
- For $M_{Z'/S}$>5 GeV can perform searches at the LHC.
- For lighter Z'/S can use fixed target experiments (very light scalars can be long-lived!).







arXiv:1705.00915



arXiv:1701.07437

Light resonances: current program

Anomaly scorecard

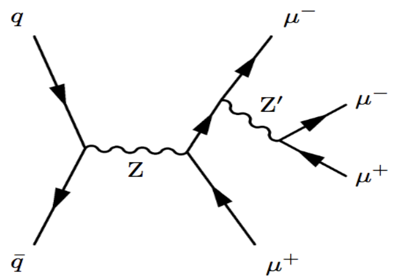
R(K) R(K*)

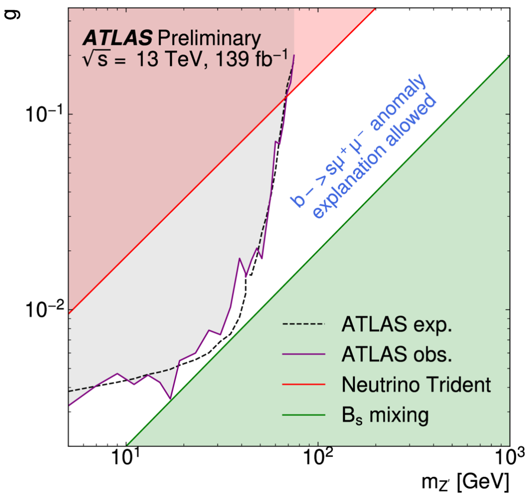
R(D) R(D*)

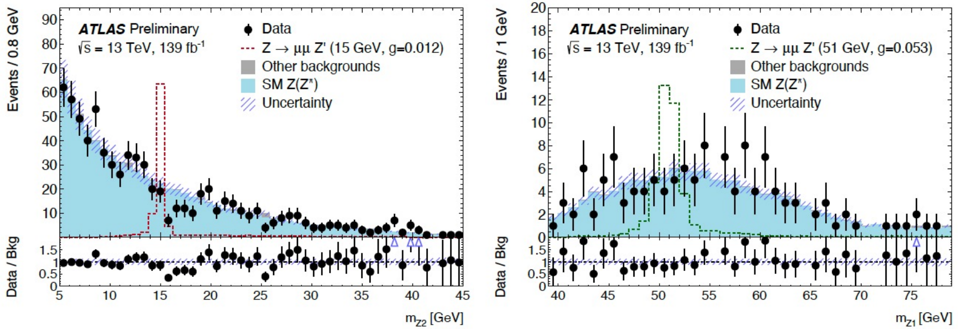
a_μ

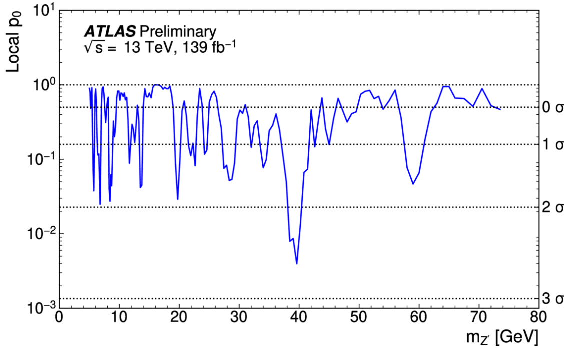
Other

- For ~5 GeV< $M_{Z'}$< M_Z perform searches in Z→4μ.









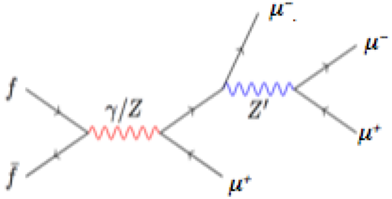
[ATLAS-CONF-2022-041]()

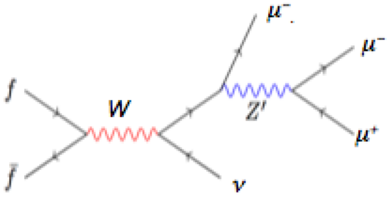
Light resonances: opportunities

Anomaly scorecard

- R(K) R(K*)
- R(D) R(D*)
- a_μ
- Other

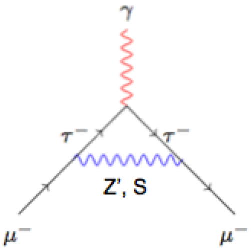
- Searches for $\gamma^{(*)}/Z^{(*)} \rightarrow 4\mu$ and $W^{(*)} \rightarrow 3\mu + E_T^{miss}$ to go above M_Z.

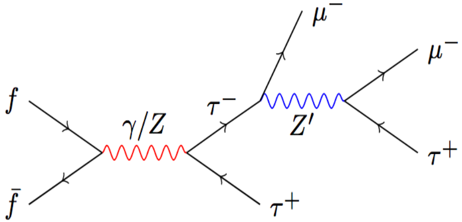


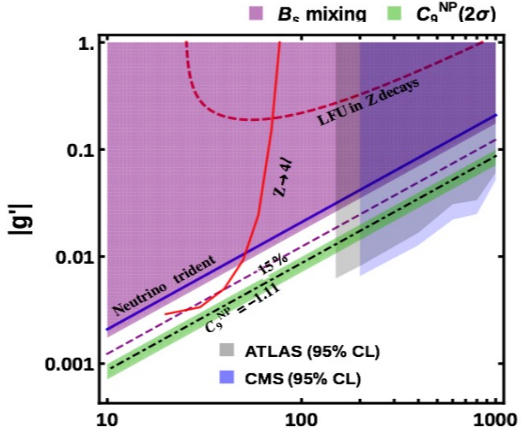


- Other explanations of a_μ involve e.g. flavor-violating vectors or scalars.

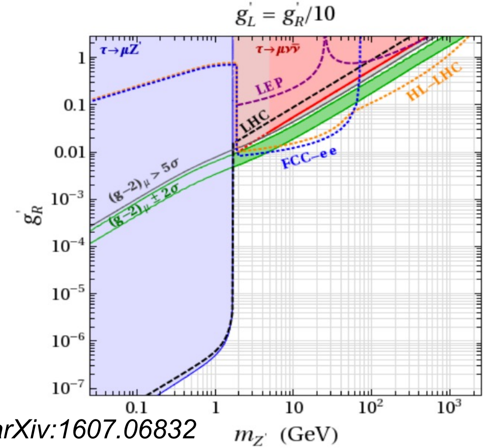
  ➔ New dedicated multilepton search involving taus at higher masses!







arXiv:1705.00915

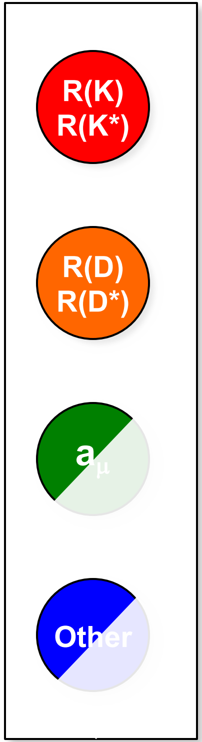


arXiv:1607.06832

Heavy resonances

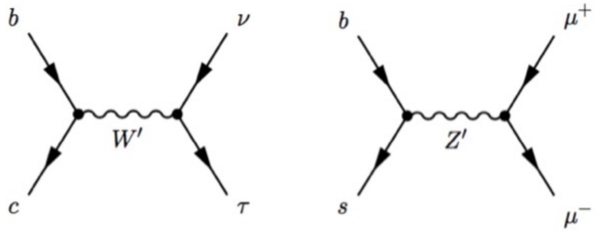
Heavy vector particles: phenomenology

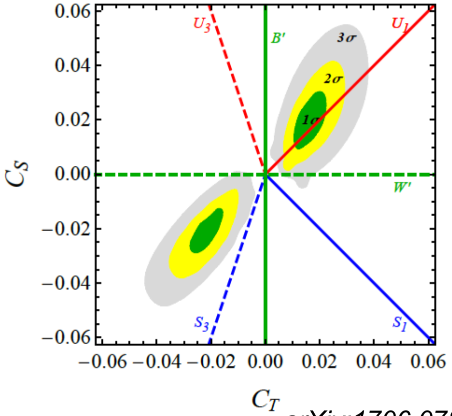
Anomaly scorecard



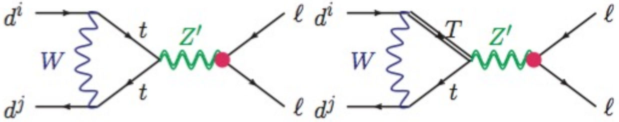
- B-anomalies can be explained with new heavy W' and Z' bosons with LH couplings to fermions. A heavy W'/ LFV Z' can also explain the CA/a_μ anomaly (*arXiv:2005.13542*).
- Many models, with different flavor structure, predict very different cross sections and decay rates to SM particles.

  ➔ decays to 3[rd] generation quarks and 2[nd]/3[rd] generation leptons relevant!
- Flavor-violating couplings to quarks can also be generated without new sources of flavor violation via loops:

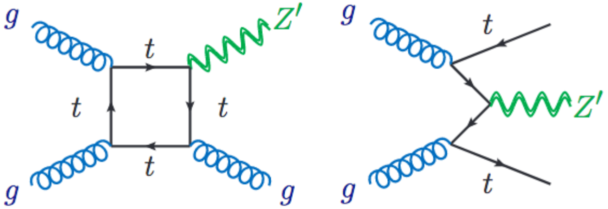


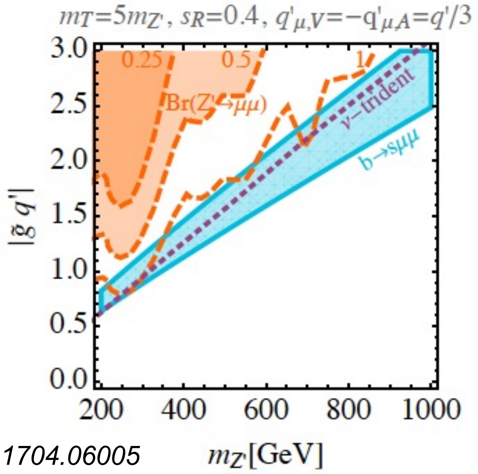


arXiv:1706.07808



Most relevant production modes:

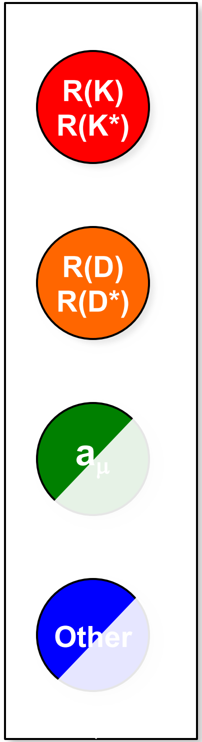




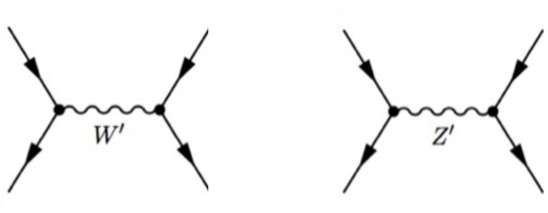
arXiv:1704.06005

Heavy vector particles: current program

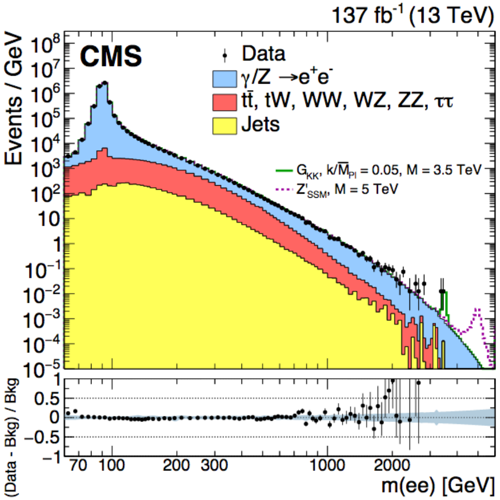
Anomaly scorecard



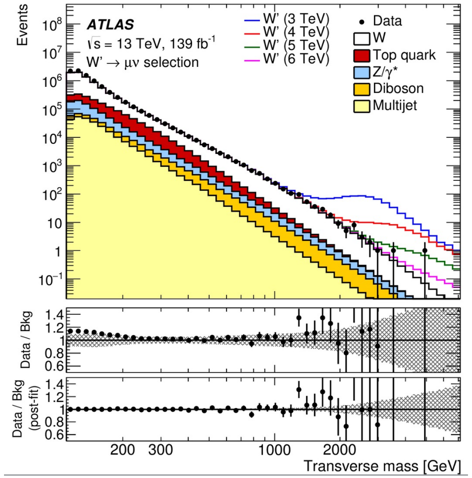
- Broad program of inclusive searches for dilepton, dijet, and tb/tt resonances



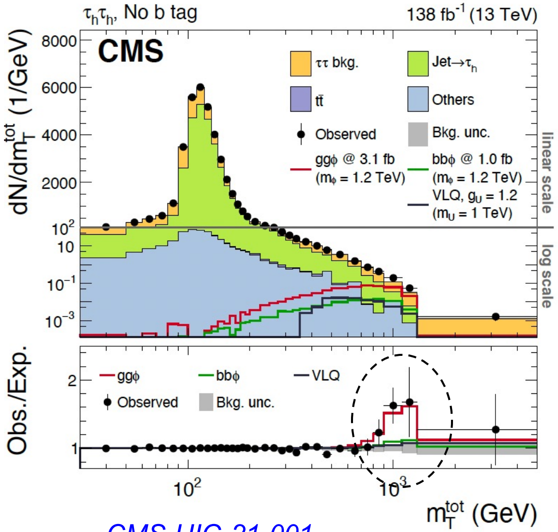
Also LFV Z' searches



[CMS-EXO-19-019]



[EXOT-2018-30]



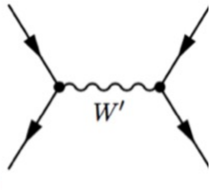
[CMS-HIG-21-001]

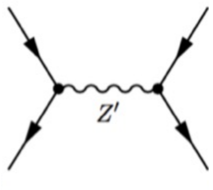
Heavy vector particles: current program

Anomaly scorecard

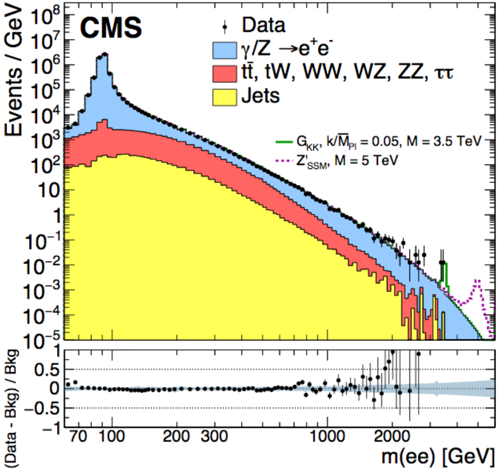
- R(K) R(K*)
- R(D) R(D*)
- a_μ
- Other

- Broad program of inclusive searches for dilepton, dijet, and tb/tt resonances

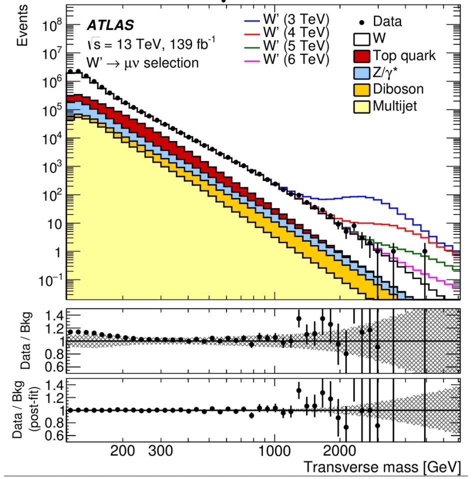




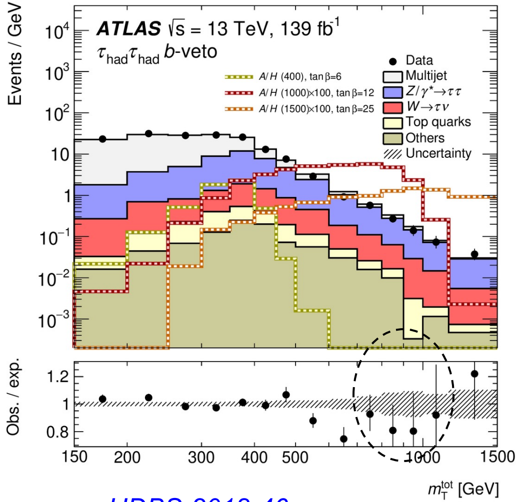
ee



$\mu\nu$



$\tau\tau$



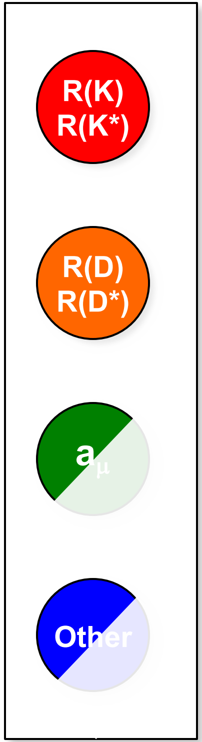
CMS-EXO-19-019

EXOT-2018-30

HDBS-2018-46

Heavy vector particles: current program

Anomaly scorecard



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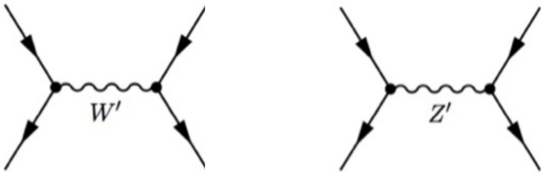

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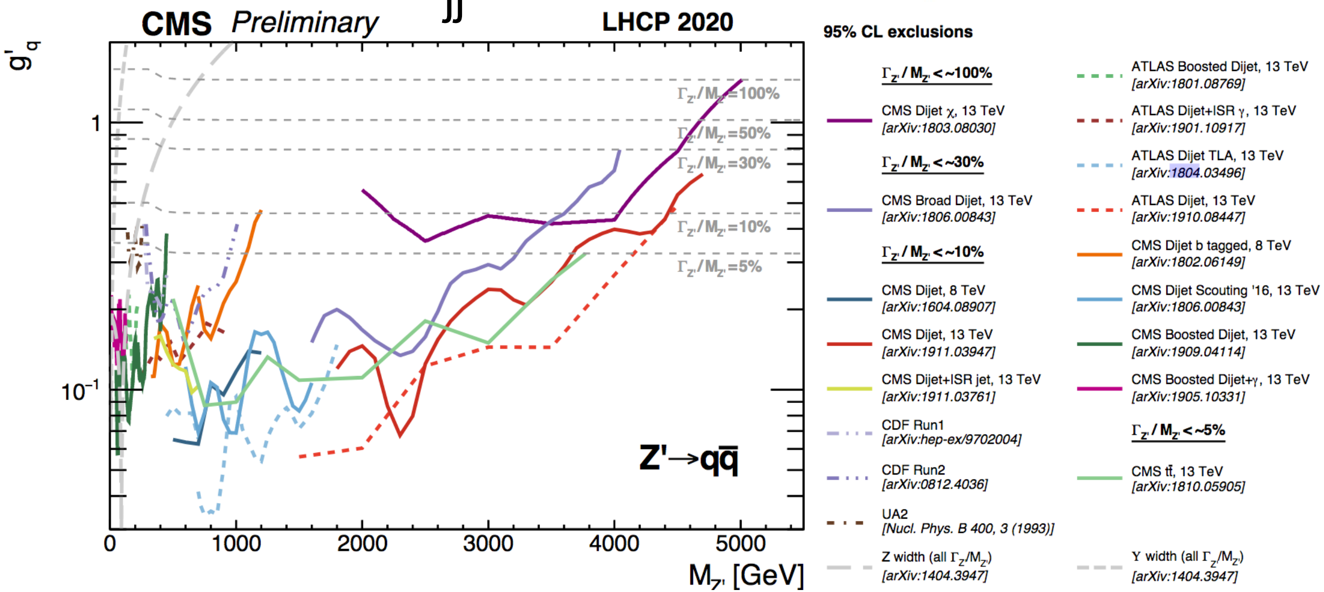
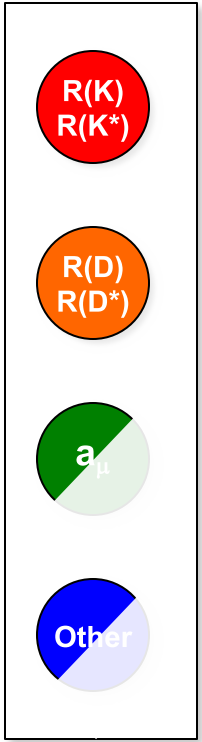


Heavy vector particles: current program

Anomaly scorecard



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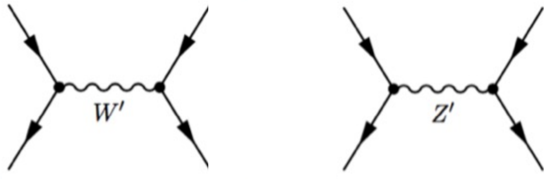

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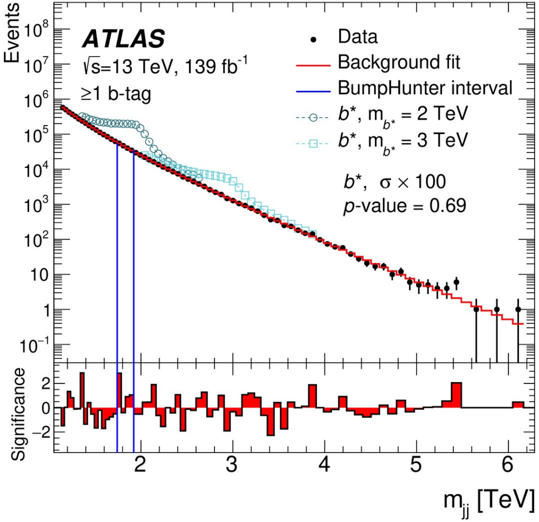

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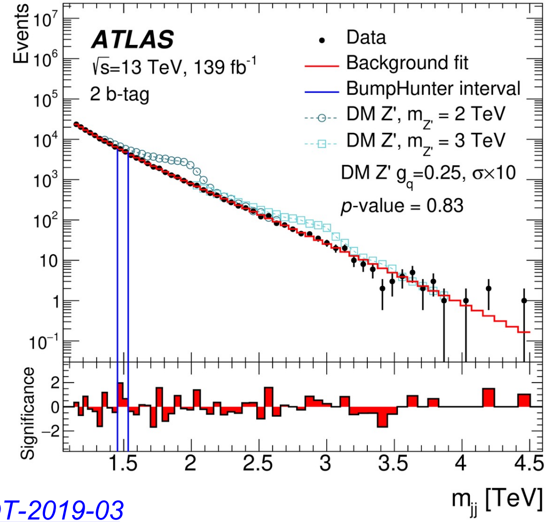
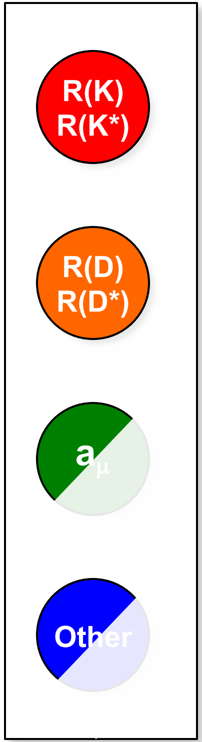


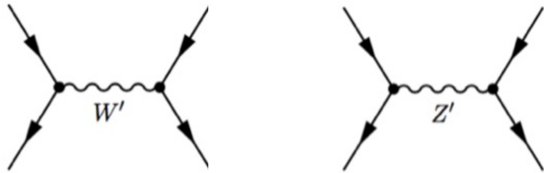
[EXOT-2019-03]

Heavy vector particles: current program

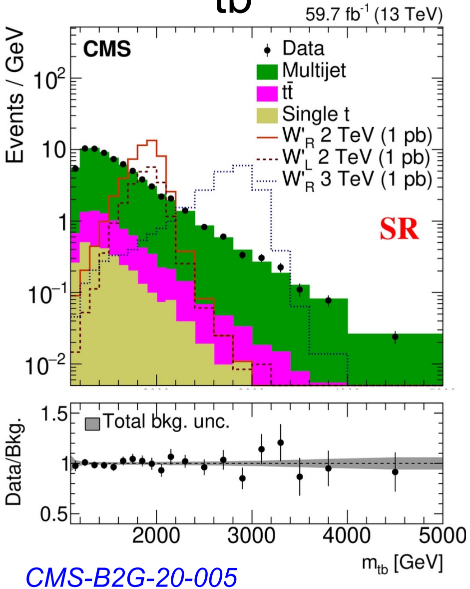
Anomaly scorecard



- Broad program of inclusive searches for dilepton, dijet, and tt/tb resonances

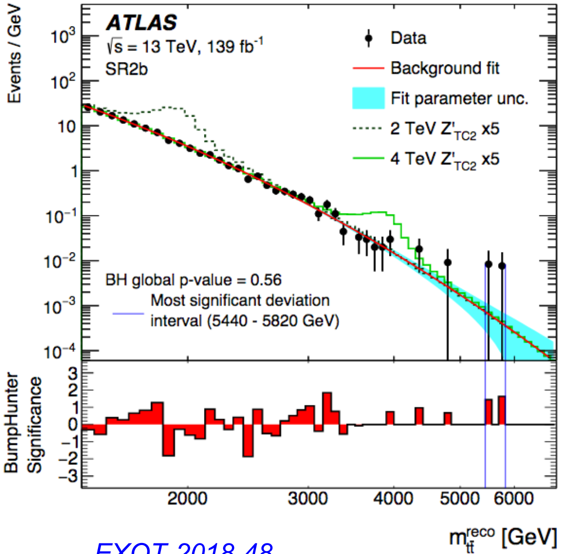


tb



[CMS-B2G-20-005]

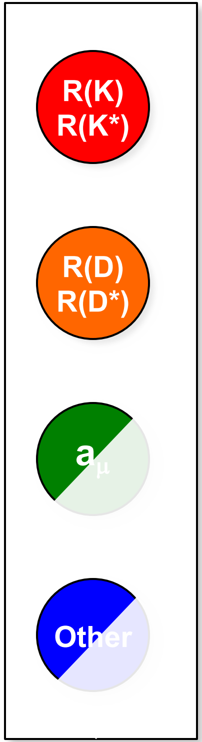
tt



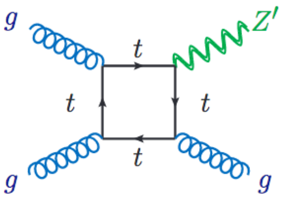
[EXOT-2018-48]

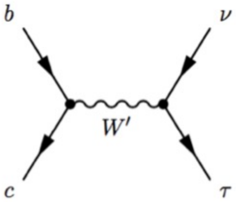
Heavy vector particles: opportunities

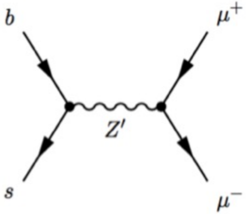
Anomaly scorecard

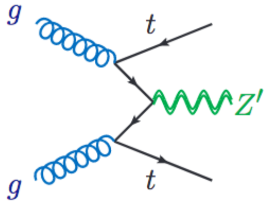


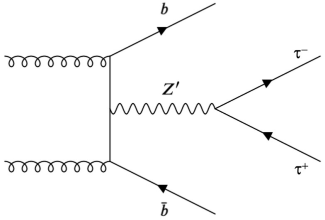
- Extend program to exclusive final states!

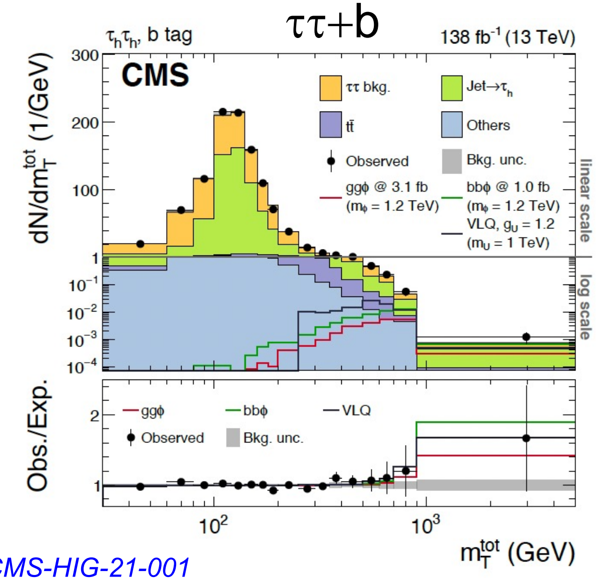


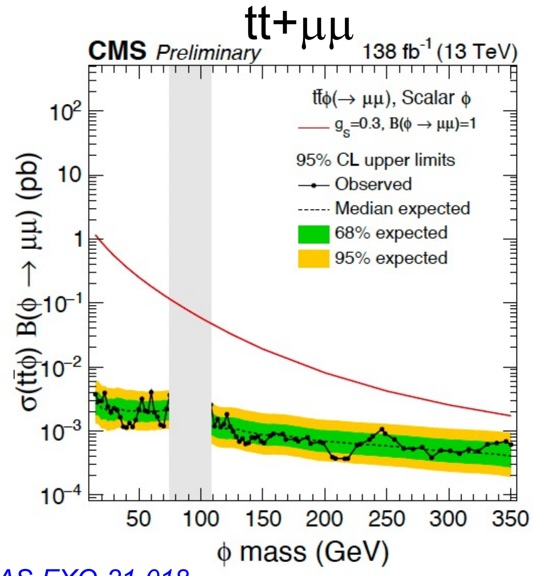










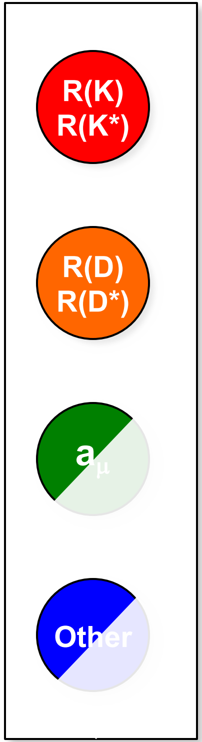


CMS-HIG-21-001

CMS-PAS-EXO-21-018

Heavy vector particles: opportunities

Anomaly scorecard



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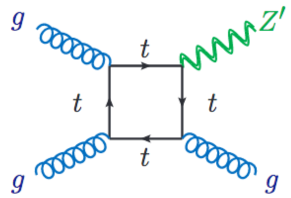
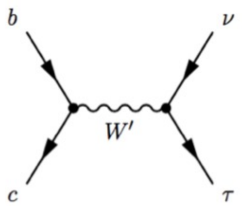
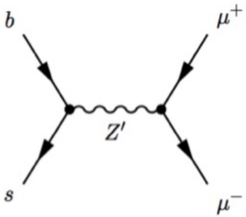
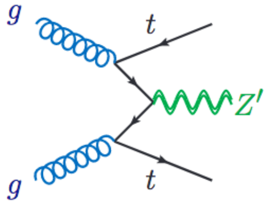


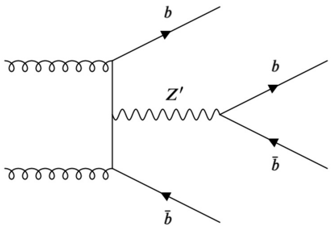


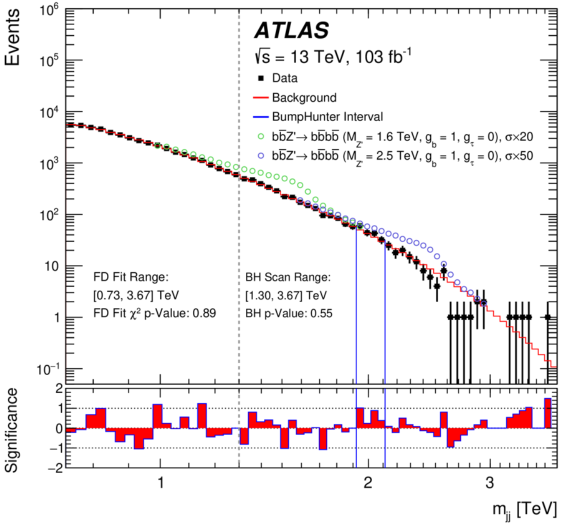


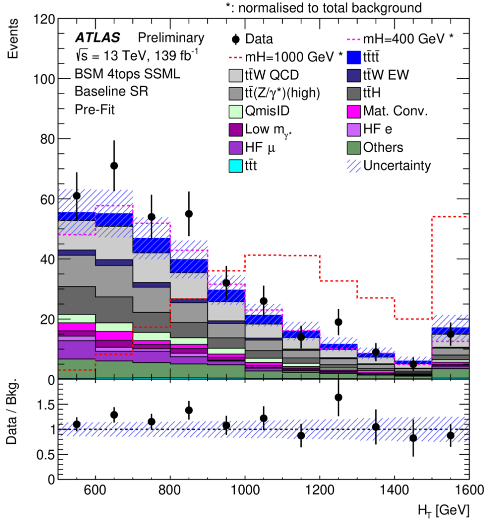


3b

4t







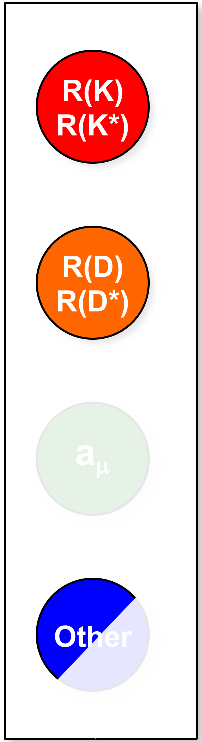
[EXOT-2018-09](#)

[ATLAS-CONF-2022-008](#)

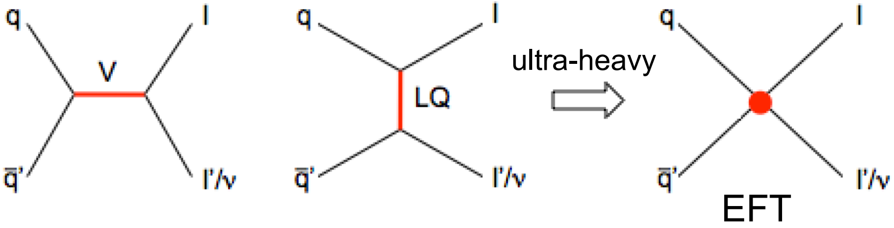
High-p_T tails

Non-resonant dileptons: phenomenology

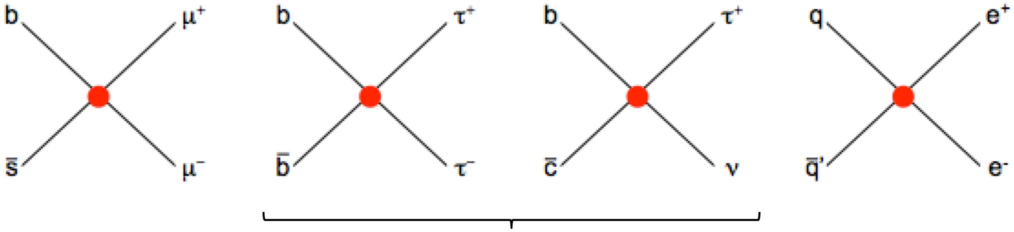
Anomaly scorecard



- Over a wide range of parameter space consistent with several anomalies, the relevant particles are very heavy and/or wide
  ➔ non-resonant production dominates.



- Some of the relevant processes:

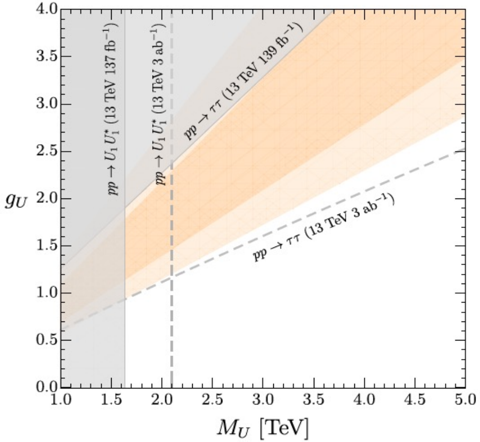


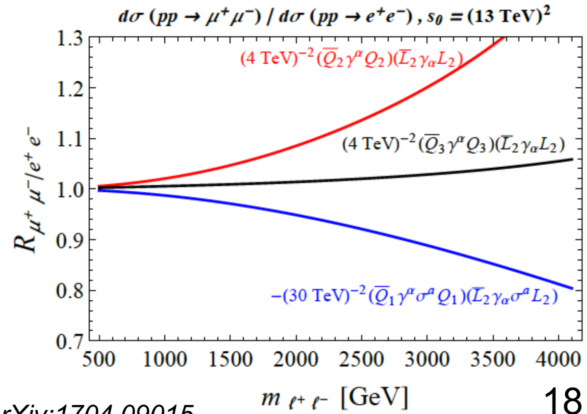
R(K), R(K*)

R(D), R(D*)

CA anomaly

arXiv:2103.16558

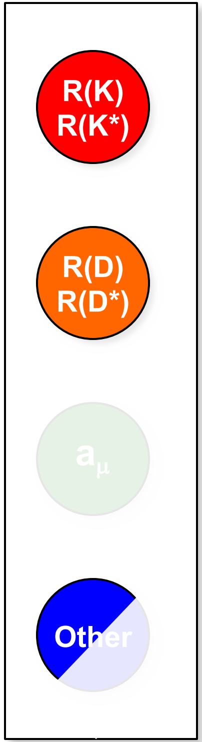




arXiv:1704.09015

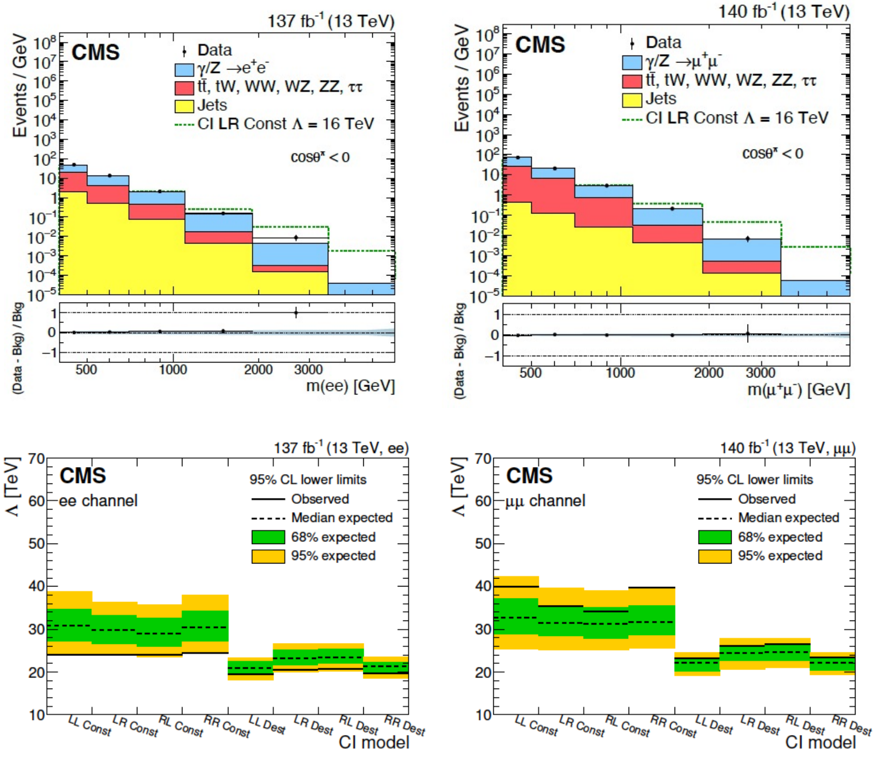
Non-resonant dileptons: current program

Anomaly scorecard



$$\mathcal{L}_{q\ell} = \frac{g^2_{\text{contact}}}{\Lambda^2}\Big[\eta_{LL}(\overline{q}_L\gamma^\mu q_L)(\overline{\ell}_L\gamma_\mu\ell_L) + \eta_{RR}(\overline{q}_R\gamma^\mu q_R)(\overline{\ell}_R\gamma_\mu\ell_R)$$
$$+\eta_{LR}(\overline{q}_L\gamma^\mu q_L)(\overline{\ell}_R\gamma_\mu\ell_R) + \eta_{RL}(\overline{q}_R\gamma^\mu q_R)(\overline{\ell}_L\gamma_\mu\ell_L)\Big],$$

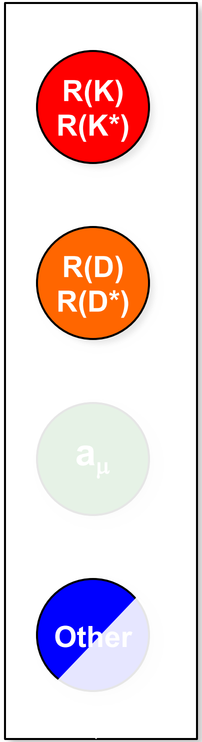
- Non-resonant inclusive ee, $\mu\mu$ searches published.
  - Slight excess in ee channel seen by CMS



CMS-EXO-19-019

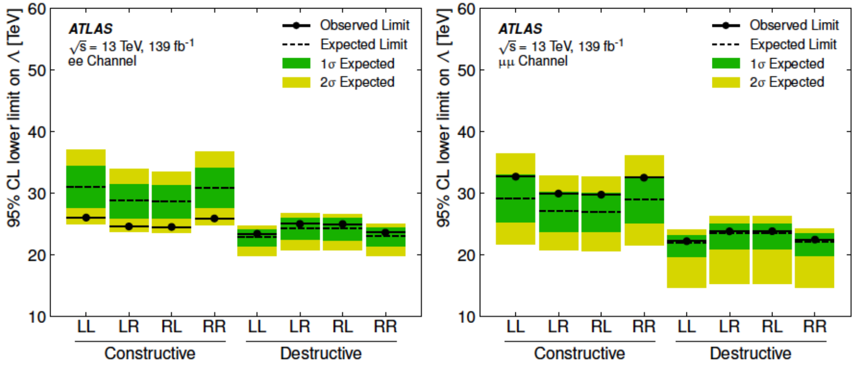
Non-resonant dileptons: current program

Anomaly scorecard

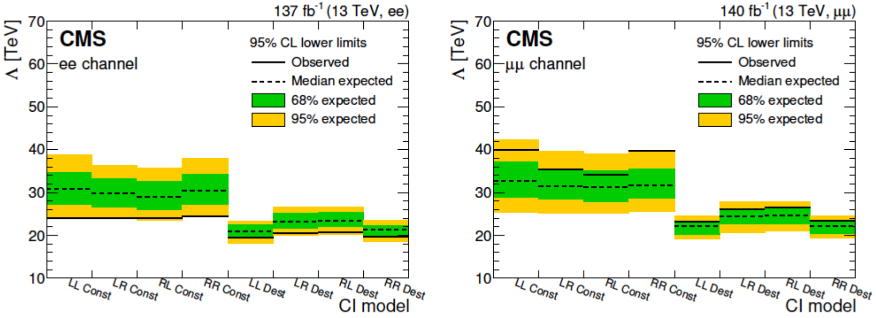


$$\mathcal{L}_{q\ell} = \frac{g^2_{\text{contact}}}{\Lambda^2}\Big[\eta_{\text{LL}}(\overline{q}_{\text{L}}\gamma^\mu q_{\text{L}})(\overline{\ell}_{\text{L}}\gamma_\mu \ell_{\text{L}}) + \eta_{\text{RR}}(\overline{q}_{\text{R}}\gamma^\mu q_{\text{R}})(\overline{\ell}_{\text{R}}\gamma_\mu \ell_{\text{R}})$$
$$+\eta_{\text{LR}}(\overline{q}_{\text{L}}\gamma^\mu q_{\text{L}})(\overline{\ell}_{\text{R}}\gamma_\mu \ell_{\text{R}}) + \eta_{\text{RL}}(\overline{q}_{\text{R}}\gamma^\mu q_{\text{R}})(\overline{\ell}_{\text{L}}\gamma_\mu \ell_{\text{L}})\Big],$$

- Non-resonant inclusive ee, μμ searches published.
  - Slight excess in ee channel seen by CMS and ATLAS.



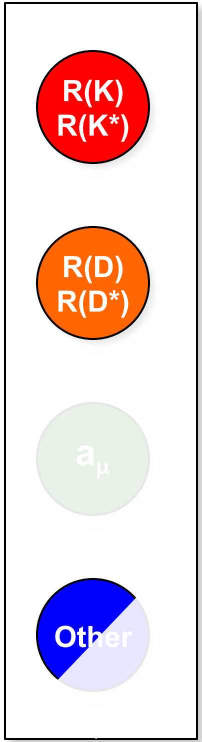
EXOT-2019-16



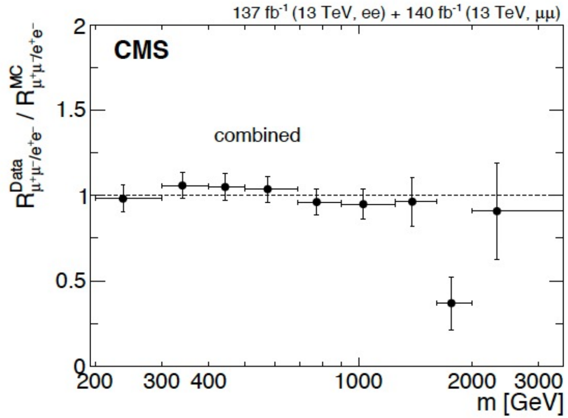
CMS-EXO-19-019

Non-resonant dileptons: current program

Anomaly scorecard



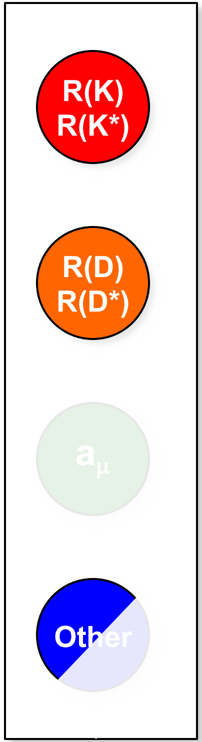
- Unfolded spectra and LFUV ratio test also obtained by CMS.
  - $R_{\mu\mu/ee}$ normalized to 1 in 200-400 GeV m_{ll} region.
  - Compatibility with $R_{\mu\mu/ee}$=1 hypothesis for m_{ll}>400 GeV: ~2.3σ.



CMS-EXO-19-019

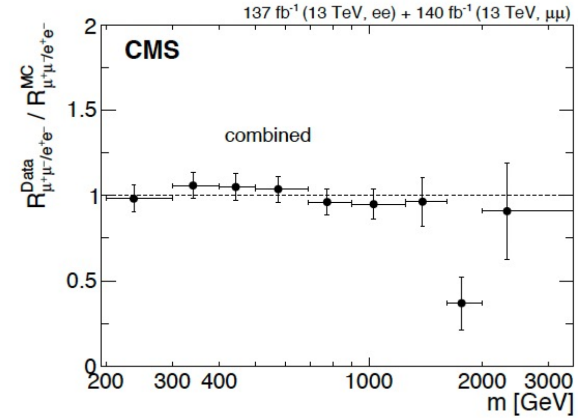
Non-resonant dileptons: current program

Anomaly scorecard

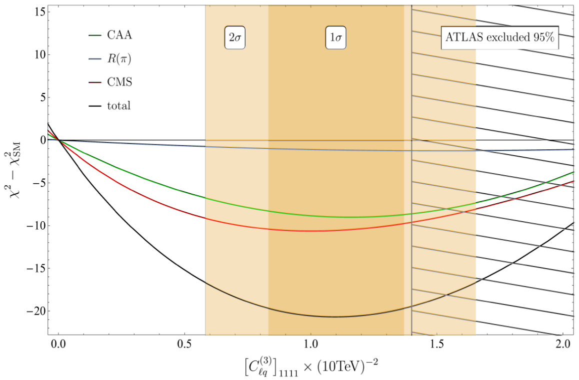


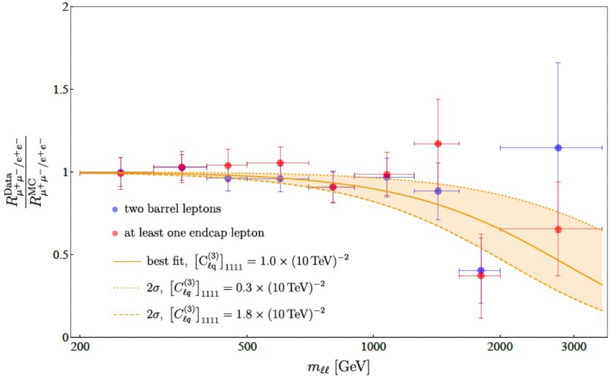
- Unfolded spectra and LFUV ratio test also obtained by CMS.
  - $R_{\mu\mu/ee}$ normalized to 1 in 200-400 GeV m_{ll} region.
  - Compatibility with $R_{\mu\mu/ee}$=1 hypothesis for m_{ll}>400 GeV: ~2.3σ.
  - Can be explained, along with the CAA anomaly, by this operator:

$$[Q^{(3)}_{\ell q}]_{1111} = (\bar{\ell}_1\gamma^\mu\sigma^I\ell_1)(\bar{q}_1\gamma_\mu\sigma^I q_1)$$



[CMS-EXO-19-019]

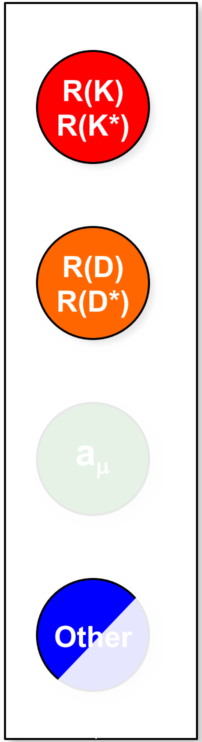




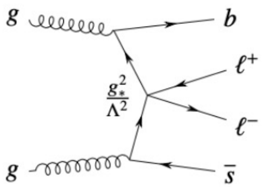
arXiv:2103.12003

Non-resonant dileptons: current program

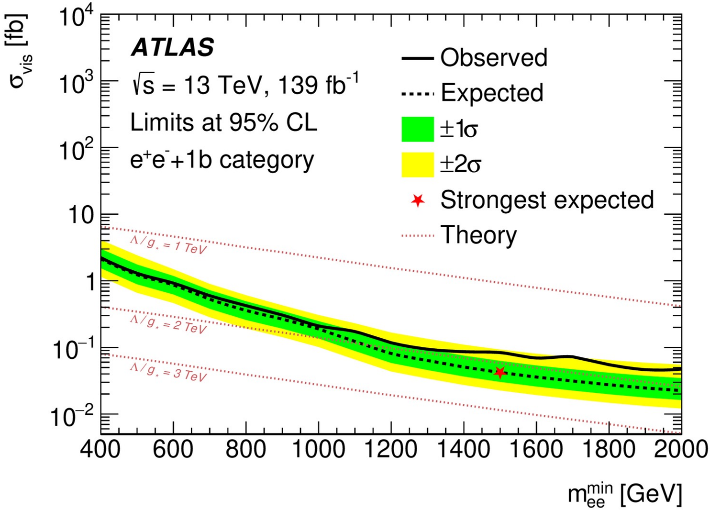
Anomaly scorecard

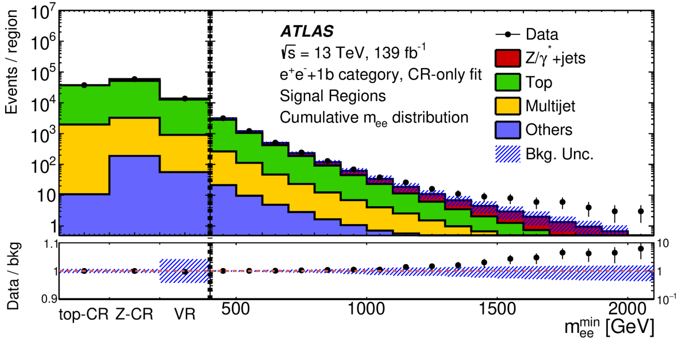


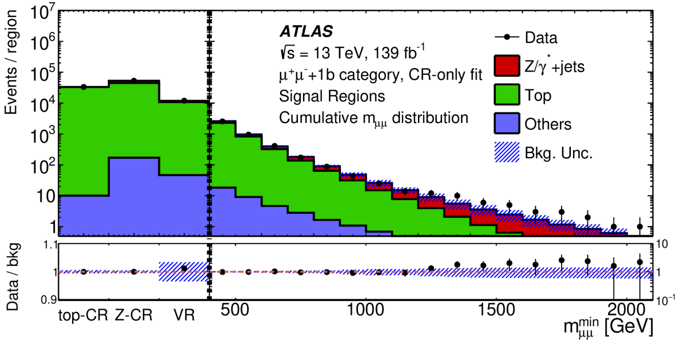
- First search for bsll CI recently completed by ATLAS:



- Largest deviation in ee+1b category for m_{ee}^{min}>1.6 TeV: 2.6σ local (1.5σ global).



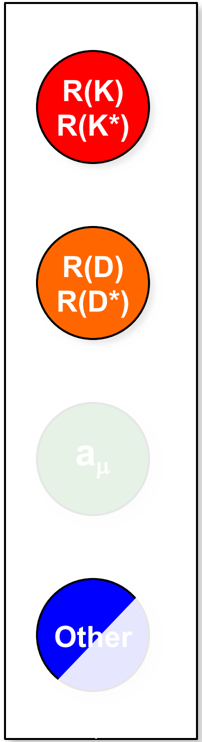




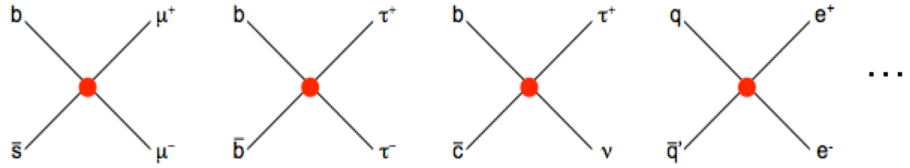
EXOT-2018-16

Non-resonant dileptons: opportunities

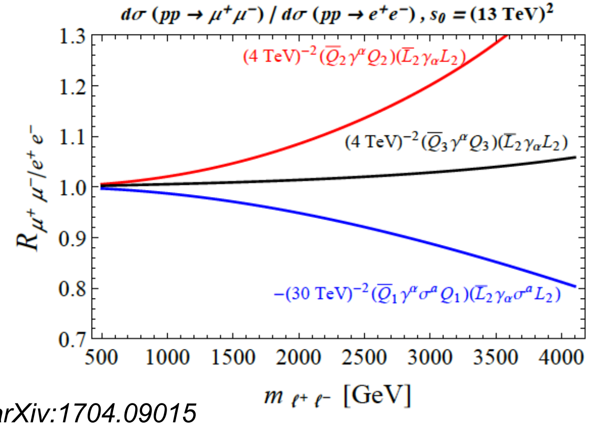
Anomaly scorecard



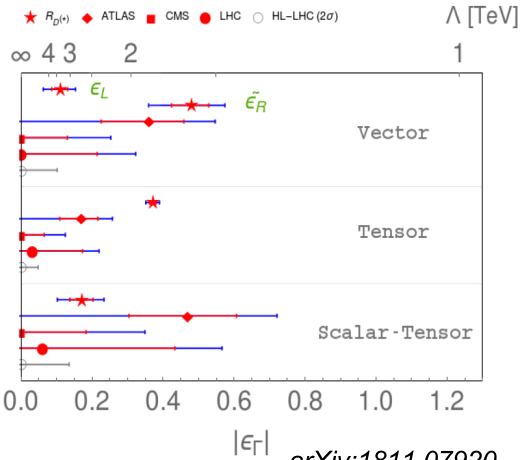
- Develop broad program of non-resonant dilepton searches (ee, μμ, ττ, eν, μν, τν), both in inclusive and exclusive (e.g. 0b, ≥1b) final states.



- Unfolded dilepton mass spectra and LFU ratio tests.



arXiv:1704.09015



arXiv:1811.07920

Leptoquarks

Vector leptoquarks: phenomenology

Anomaly scorecard

R(K) R(K*)

R(D) R(D*)

a_μ

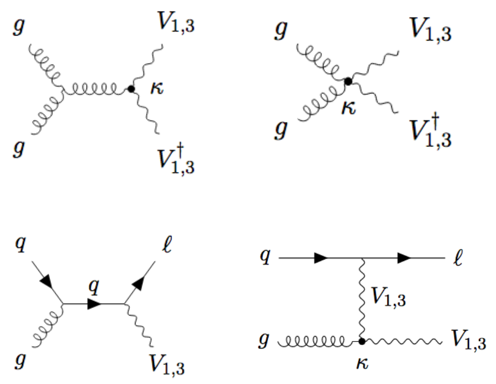
Other

- Predicted by Pati-Salam lepton-quark unification models (gauge origin) and composite Higgs models. Typical mass ~few TeV.

- Resonant production in pairs or singly.

  Enhanced cross section if of gauge origin in the case of vector LQs.

  Non-resonant production relevant, particularly at high mass, if large coupling.



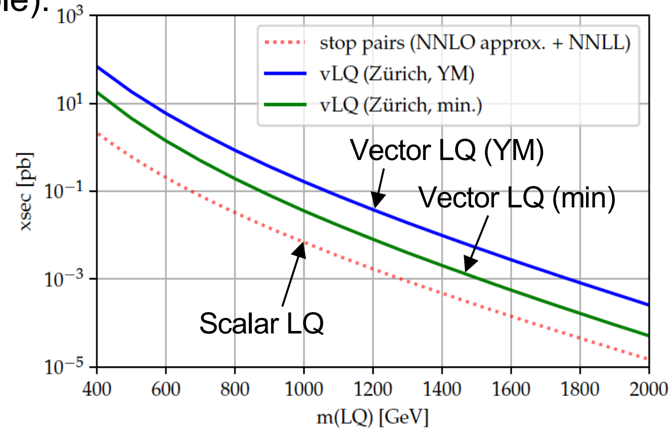
- Single-particle explanation of B anomalies: V_1 (V_3 also possible).
- Dominant decay if only explaining R(K), R(K*):

  $V_1^{+2/3} \rightarrow b\mu,\ t\nu$

  $V_3^{-1/3} \rightarrow b\nu$

  $V_3^{+2/3} \rightarrow b\mu,\ t\nu$

  $V_3^{+5/3} \rightarrow t\mu$

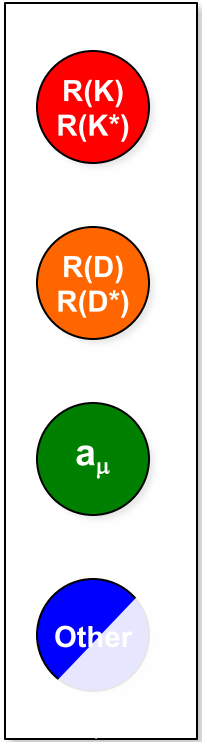


If also explaining R(D), R(D*), couplings to τ dominate.

Need a broad program!

Scalar leptoquarks: phenomenology

Anomaly scorecard



- Predicted by composite Higgs models (as pNGBs) or GUTs. Typical mass ~1 TeV.

- Most successful models involve at least two LQs:
  - S_1 and S_3 (e.g. *arXiv:1912.04224*)
  - R_2 and S_3 (e.g. *arXiv:1806.05689*)
  - Another possibility: S_1 and singlet ϕ^+ (e.g. *arXiv:2104.05730*)
    - Can also explain a_μ and the CA anomaly.
    - But large masses for S_1 and ϕ^+ preferred (multi-TeV).

- Decay modes directly related to the B anomalies:

$S_1^{-1/3} \rightarrow b\nu,\ c\tau \Rightarrow$ R(D), R(D*) $\Leftarrow$ $R_2^{+2/3} \rightarrow b\tau,\ c\nu$

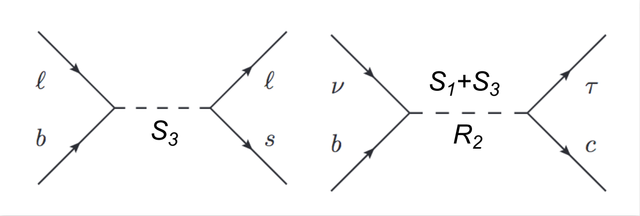
$R_2^{+5/3} \rightarrow t\tau,\ c\tau$

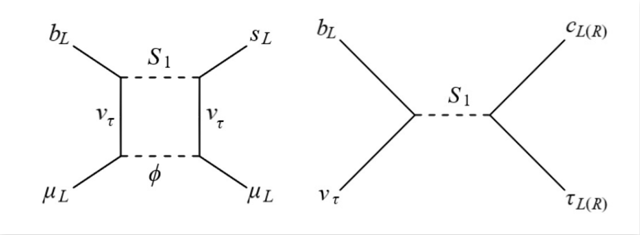
$S_3^{+2/3} \rightarrow t\nu$

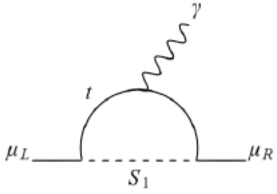
$S_3^{-1/3} \rightarrow b\nu,\ t\mu$

$S_3^{-4/3} \rightarrow b\mu \Rightarrow$ R(K), R(K*)

However, other decay modes may actually dominate (e.g. $S_3^{-4/3} \rightarrow b\tau^-$) if similar hierarchies as in SM quark Yukawas hold ($\lambda_{b\tau} > \lambda_{b\mu}$).







Need a broad program!

Leptoquarks: current program

Anomaly scorecard

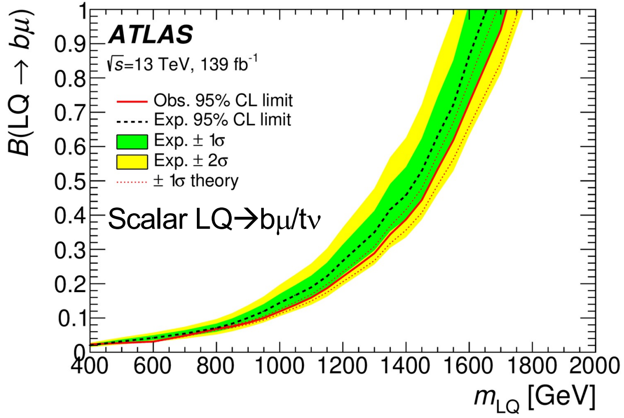
- R(K) R(K*)
- R(D) R(D*)
- a_μ
- Other

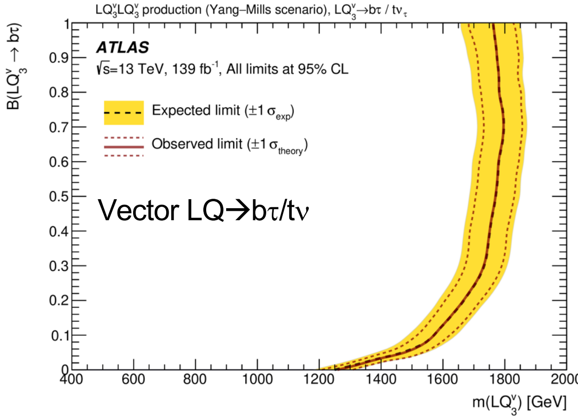
- Broad program of searches for pair-production underway.

	u, d, s	c	b	t
νν	X		X	X
νl			X	
ll	X	X	X	X
ντ			X	
ττ	X		X	X

- Typical mass exclusions:
  - LQ_S: ~1.0-1.7 TeV depending on search/benchmark
  - LQ_V: ~ LQ_S limit + 0.4 TeV

EXOT-2019-13





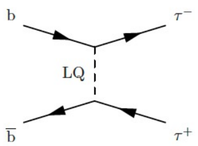
SUSY-2019-18

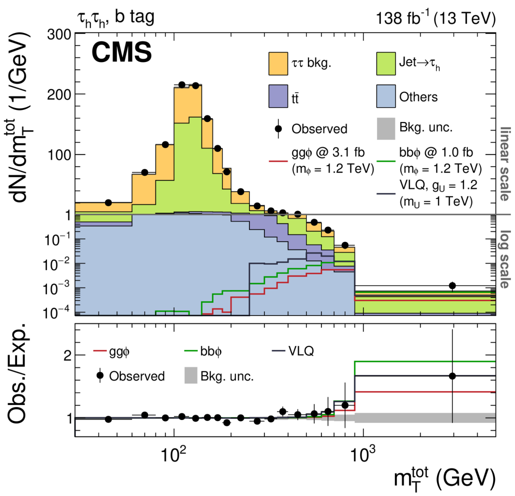
Leptoquarks: current program

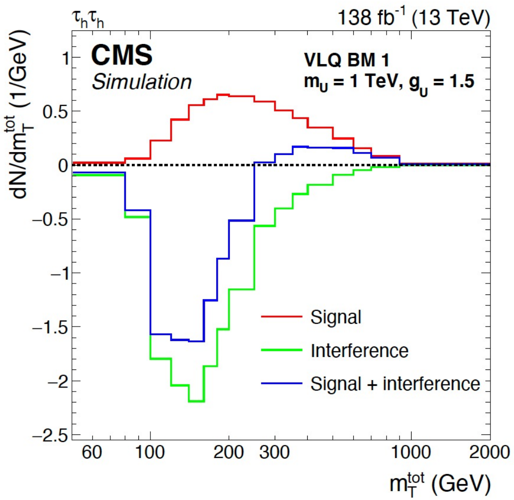
Anomaly scorecard

- R(K) R(K*)
- R(D) R(D*)
- a_μ
- Other

- Growing program of single LQ searches: l+LQ(→bl) (l=e,μ,τ), τ+LQ(→bν), ν+LQ(→bτ), ν+LQ(→cτ).
- Also considering non-resonant production. Interference with SM background can be relevant!



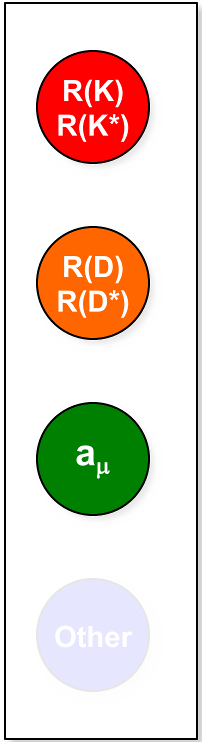




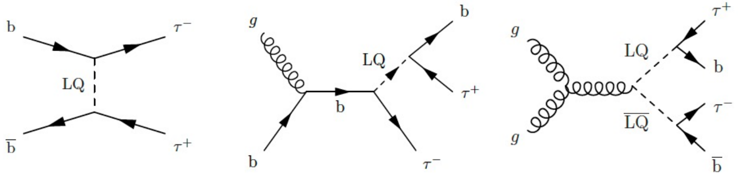
CMS-HIG-21-001

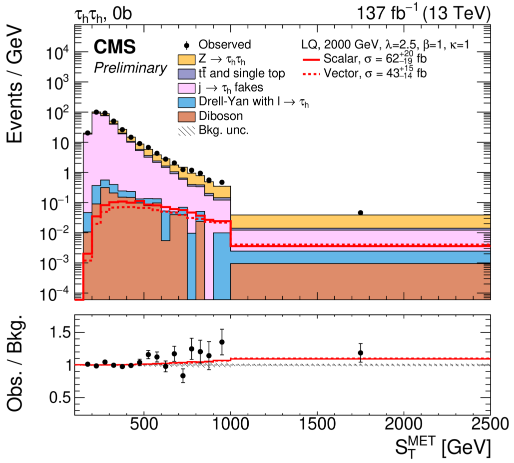
Leptoquarks: current program

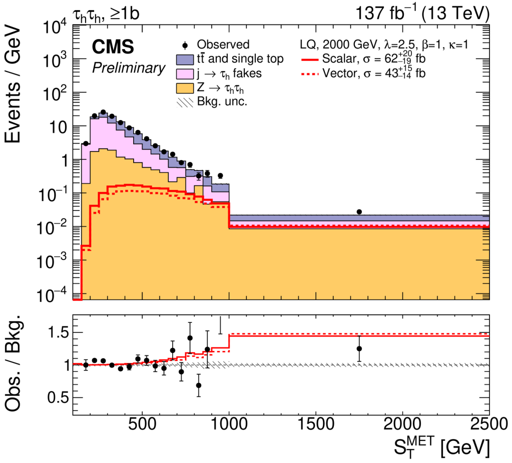
Anomaly scorecard



- Growing program of single LQ searches: l+LQ(→bl) (l=e,μ,τ), τ+LQ(→bν), ν+LQ(→bτ), ν+LQ(→cτ).
- Also considering non-resonant production. Interference with SM background can be relevant!







CMS-PAS-EXO-19-016

Leptoquarks: current program

Anomaly scorecard

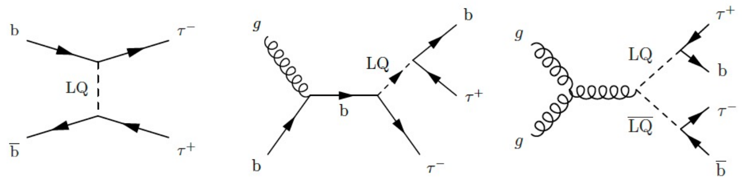
R(K)
R(K*)

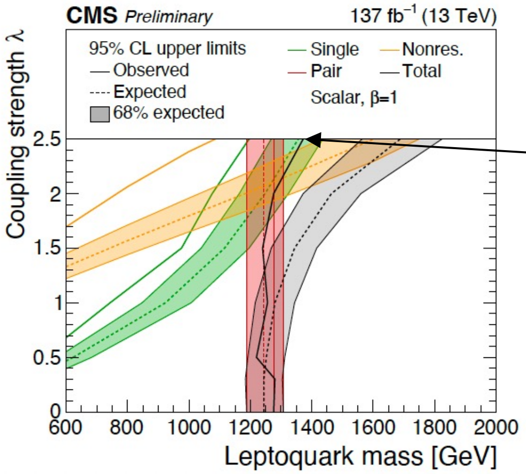
R(D)
R(D*)

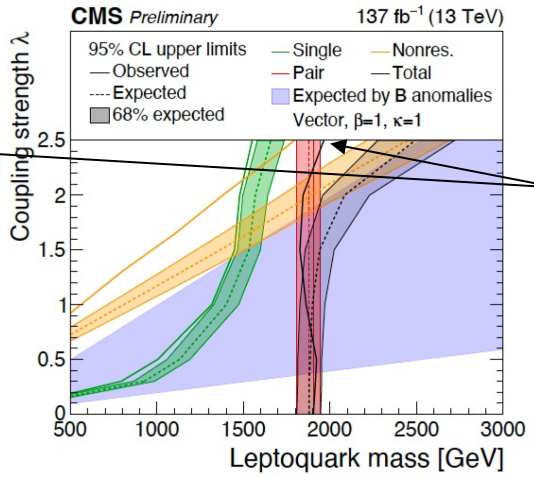
a_μ

Other

- Growing program of single LQ searches: l+LQ(→bl) (l=e,μ,τ), τ+LQ(→bν), ν+LQ(→bτ), ν+LQ(→cτ).
- Also considering non-resonant production. Interference with SM background can be relevant!







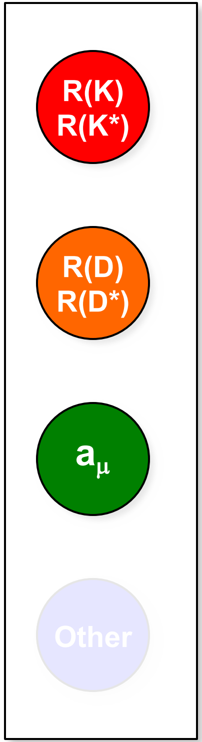
~3.4σ excess at m_{LQ}=2 TeV, λ=2.5

Potentially exciting!!
ATLAS result soon!

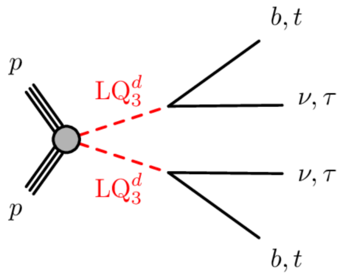
CMS-PAS-EXO-19-016

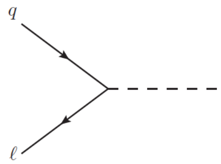
Leptoquarks: opportunities

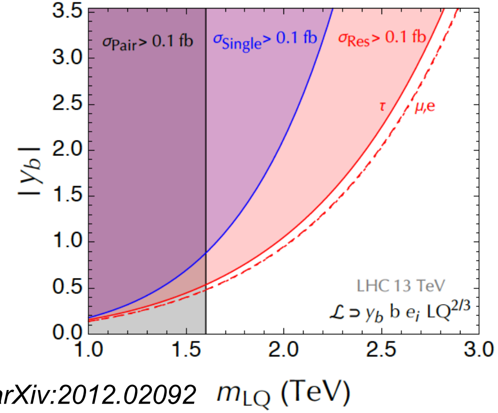
Anomaly scorecard



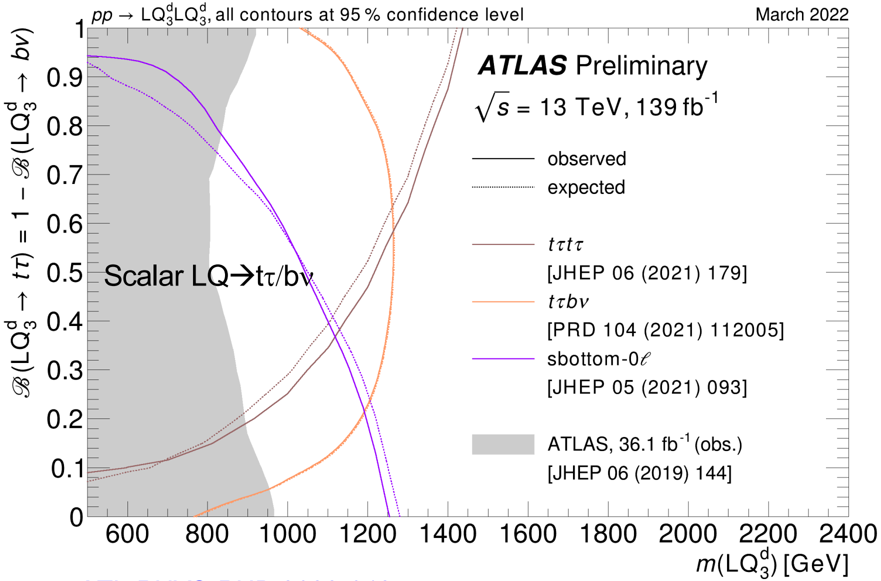
- More sophisticated analyses for:
  - Pair production
  - Single production
  - Non-resonant production
  - Combinations!
- Explore single resonant production







arXiv:2012.02092

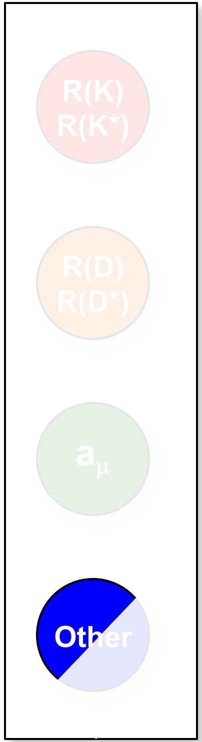


ATL-PHYS-PUB-2022-012

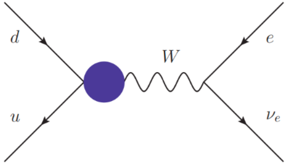
Vector-like quarks

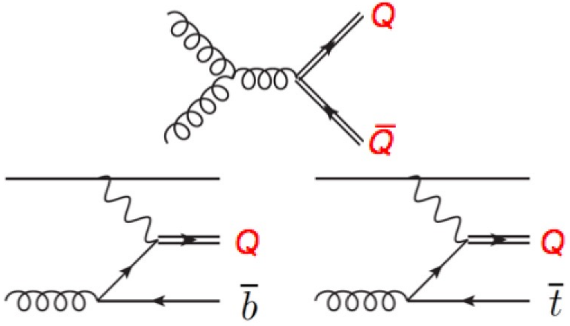
Vector-like quarks: phenomenology

Anomaly scorecard

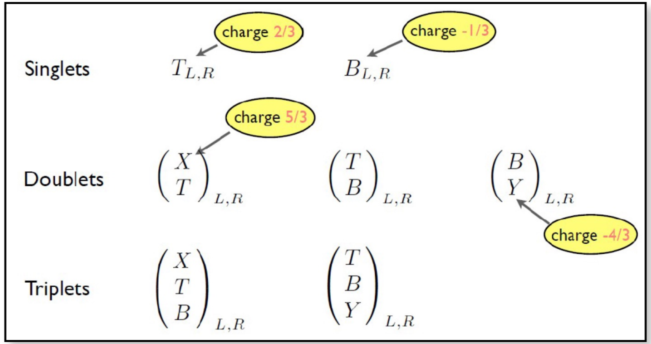


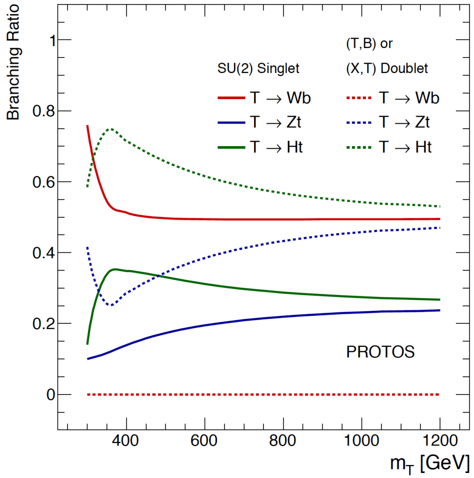
- Predicted in Composite Higgs models and other UV-complete constructions. Typical mass ~O(TeV).
- Can explain CA anomaly.





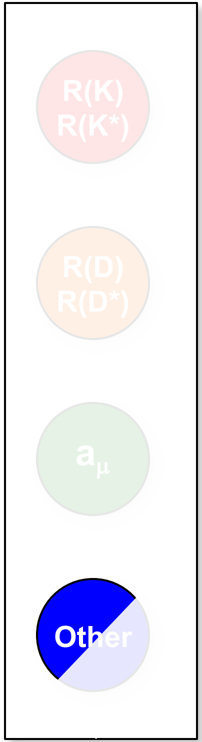
- Production: in pairs via QCD, singly via EW.
- Decay: Q→Wq, Zq, Hq, all with sizable BR
- VLQs typically assumed to mix preferentially with 3rd generation quarks.



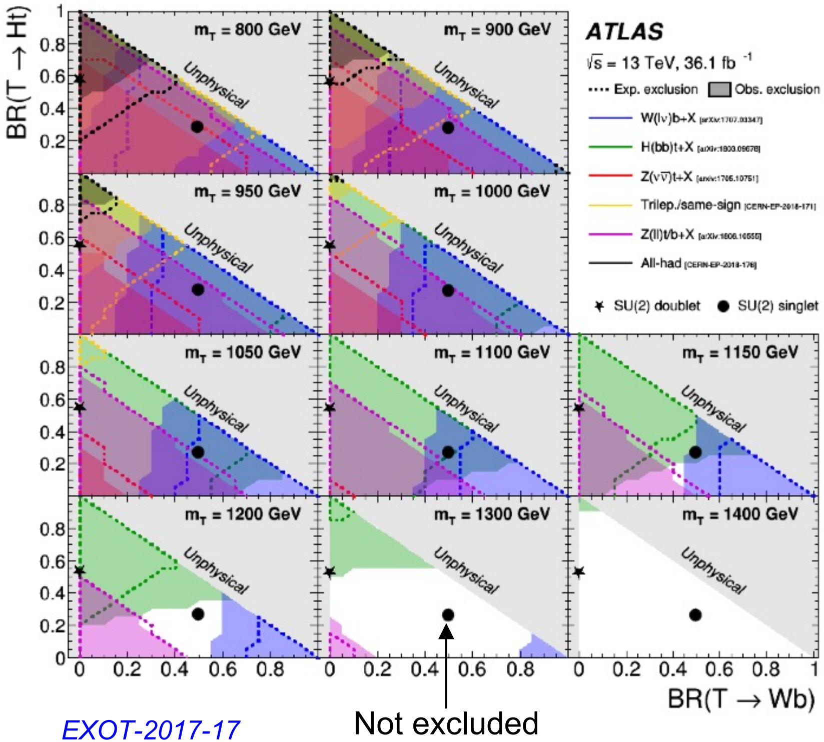


Vector-like quarks: current program

Anomaly scorecard



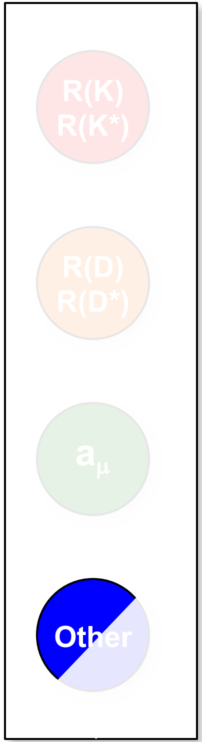
- Broad program of searches for pair production of VLQs preferentially coupled to 3rd generation quarks with partial Run 2 data (36 fb^{-1}).
- Combinations can lead to significant improvements in sensitivity.



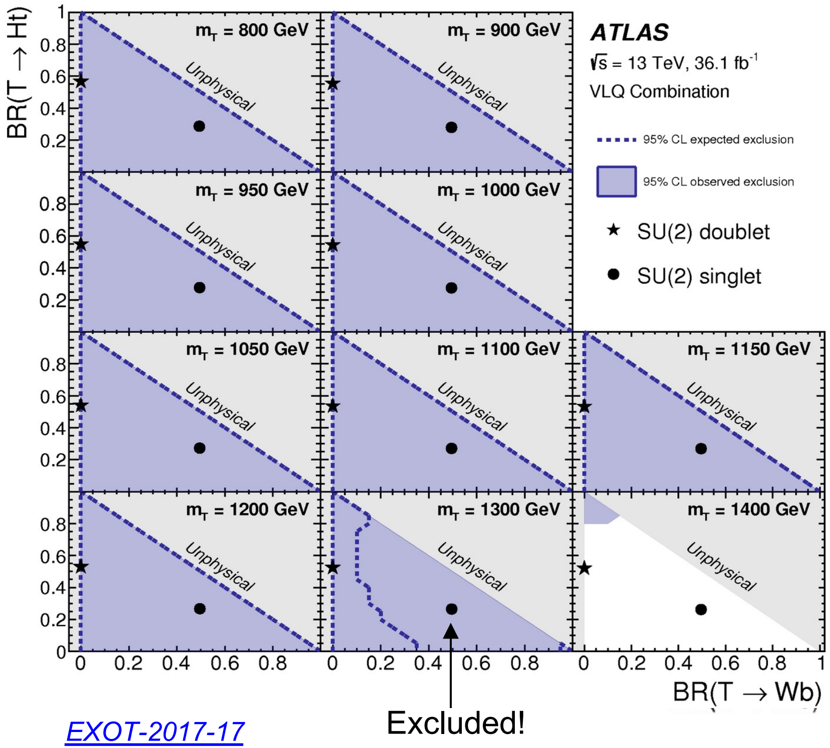
[EXOT-2017-17]

Vector-like quarks: current program

Anomaly scorecard



- Broad program of searches for pair production of VLQs preferentially coupled to 3rd generation quarks with partial Run 2 data (36 fb^{-1}).
- Combinations can lead to significant improvements in sensitivity.



VLT (VLB) masses below 1.3 (1.0) TeV excluded for any combination of BRs.

EXOT-2017-17

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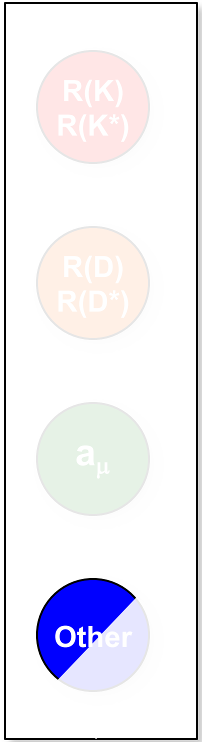
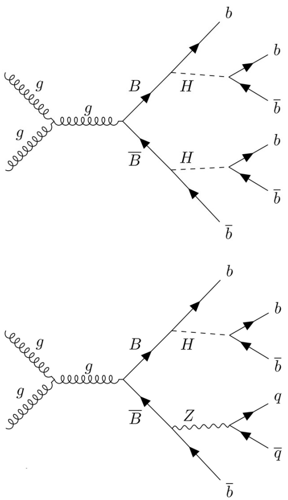
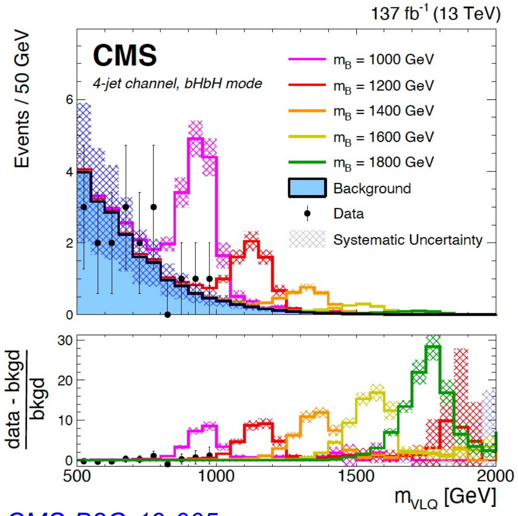
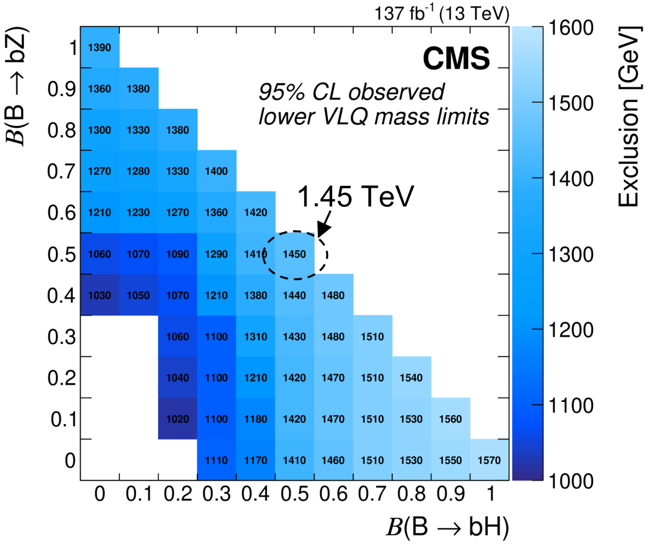


- Broad program of searches for pair production of VLQs preferentially coupled to 3rd generation quarks with partial Run 2 data (36 fb^{-1}).
- Combinations can lead to significant improvements in sensitivity.
- Full Run 2 program underway. Individual searches now have comparable/better sensitivity than partial Run 2 combination:
  - x4 larger integrated luminosity
  - Improved experimental techniques (e.g. boosted object tagging).



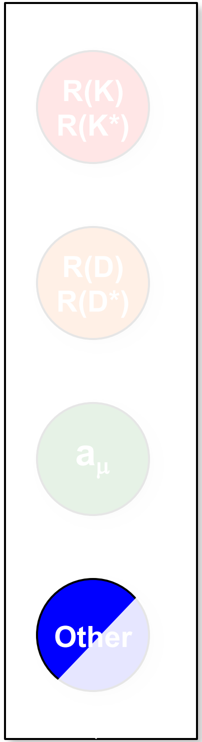




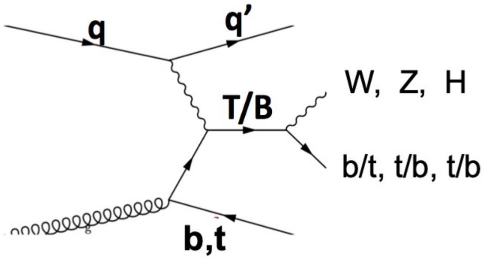
[CMS-B2G-19-005](CMS-B2G-19-005)

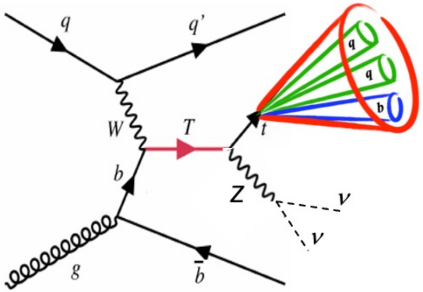
Vector-like quarks: current program

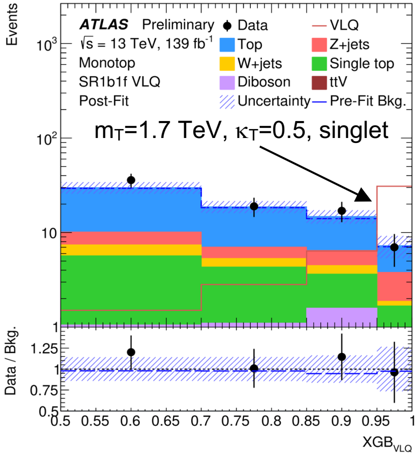
Anomaly scorecard

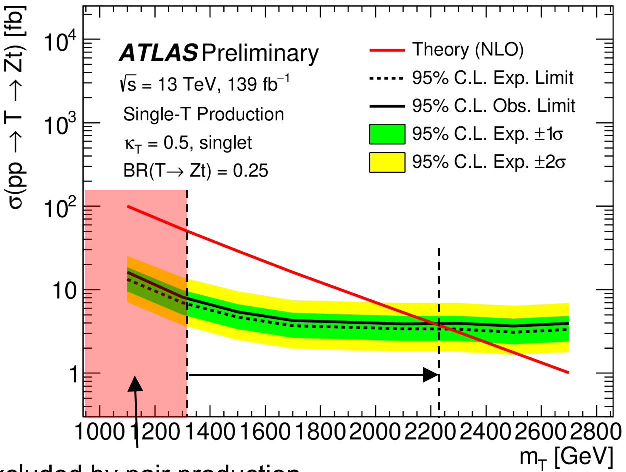


- Similarly broad program of searches for single production, again focusing on preferential couplings to 3rd generation quarks.
- Powerful handles against backgrounds:
  - Forward jet tagging
  - Boosted object tagging
  - VLQ mass reconstruction
- More complex interpretations (mass- and coupling-dependent).
- Highest sensitivity achieved for singlet representations.







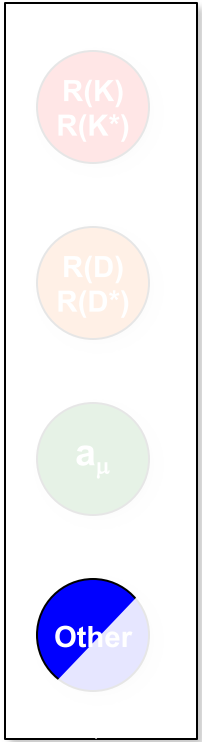


Excluded by pair production

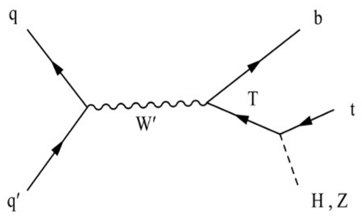
[ATLAS-CONF-2022-036]

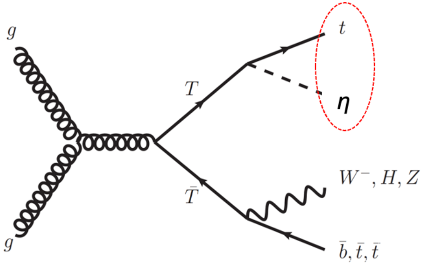
Vector-like quarks: opportunities

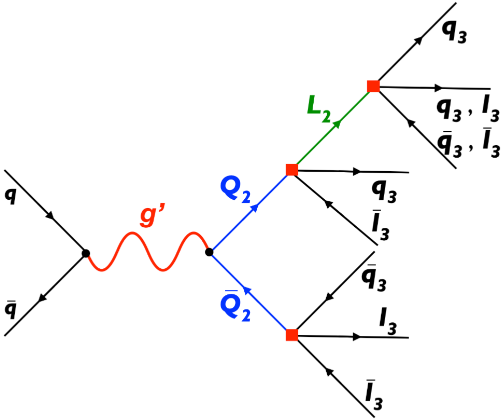
Anomaly scorecard



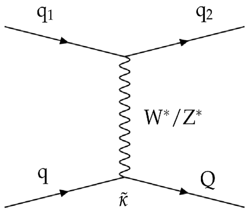
- Non-standard production: e.g. via W'/Z'.
- Non-standard decay modes: e.g. Q→q+η, η CP-odd scalar; 3-body final states as in 4321 model, etc.

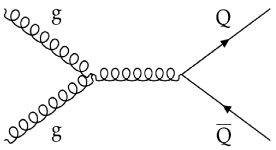




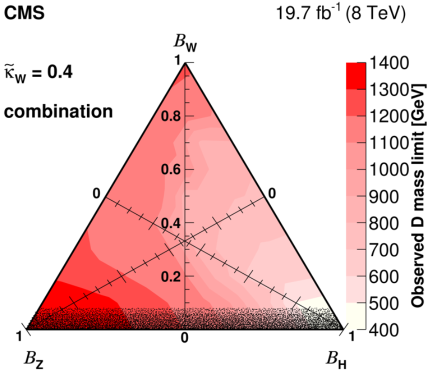


- VLQs preferentially coupled to light-quark generations. Most recent search by CMS in Run 1!





Production	Channel
Single (electroweak)	$Dq \to Wqq$
	$Dq \to Zqq$
Pair (strong)	$Q\bar{Q} \to WqWq$
	$Q\bar{Q} \to WqZq$
	$Q\bar{Q} \to WqHq$
	$Q\bar{Q} \to ZqZq$
	$Q\bar{Q} \to ZqHq$

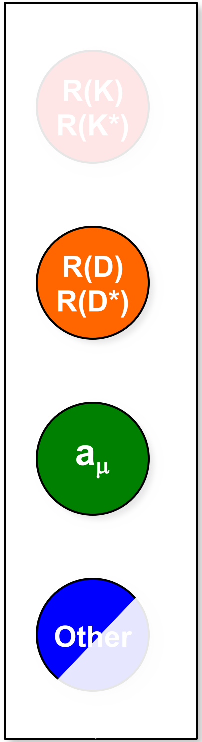


CMS-B2G-12-016

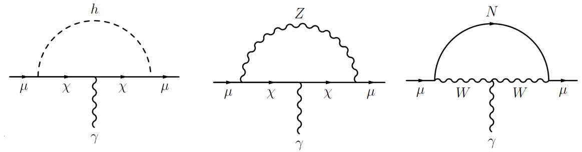
Vector-like leptons

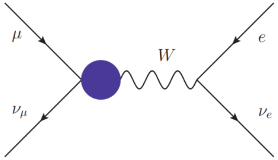
Vector-like leptons

Anomaly scorecard

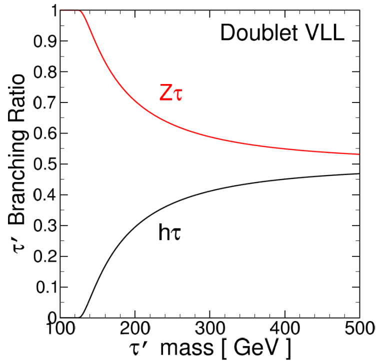


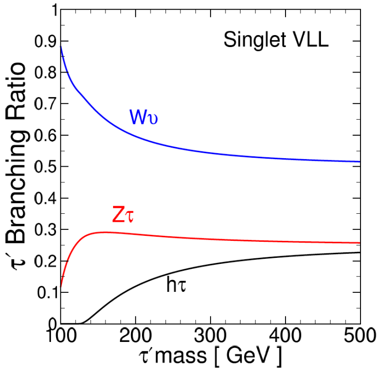
- Predicted in Composite Higgs models and other UV-complete constructions. Typical mass O(TeV).
- Can explain R(K), R(K*) (via loop effects), a_μ, and/or CA anomalies.



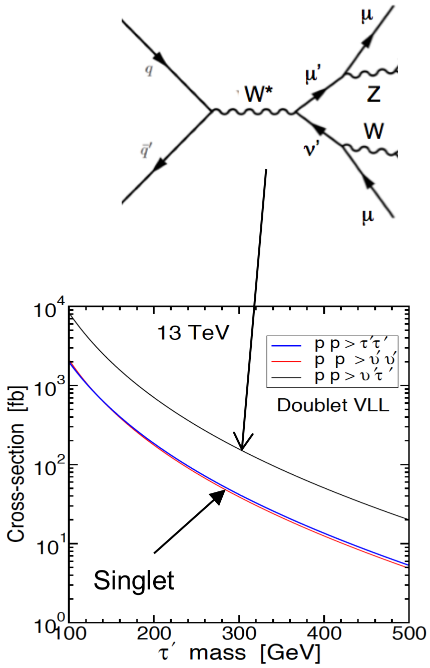


- DY pair production dominant (via W* and/or Z/γ*).
- Typically CC (l'→Wν, ν'→Wl) and/or NC decays (l'→Z/Hl), depending on the SU(2)$_L$ representation.





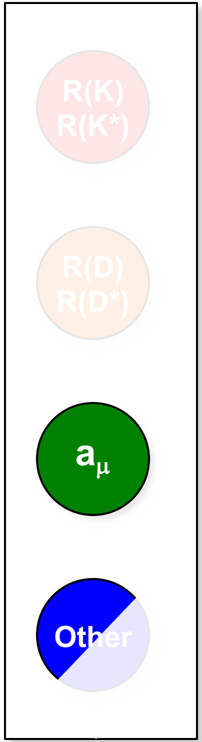
arXiv:1510.03456



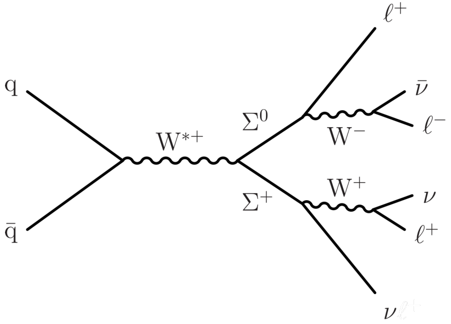
arXiv:1510.03456

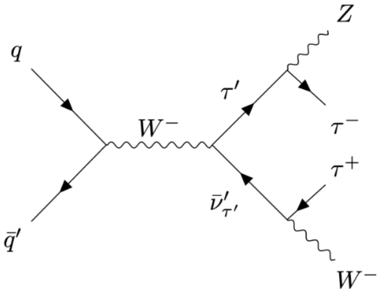
Vector-like leptons: current program

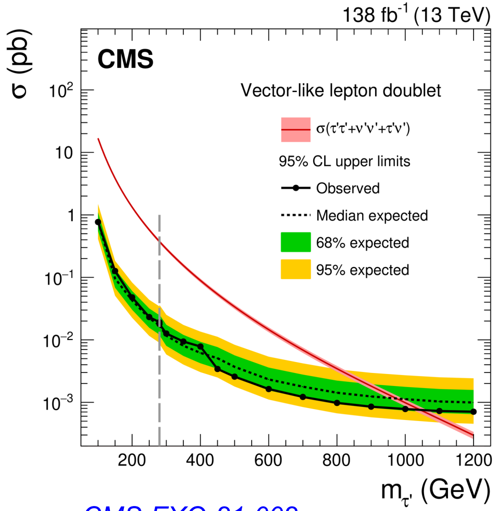
Anomaly scorecard



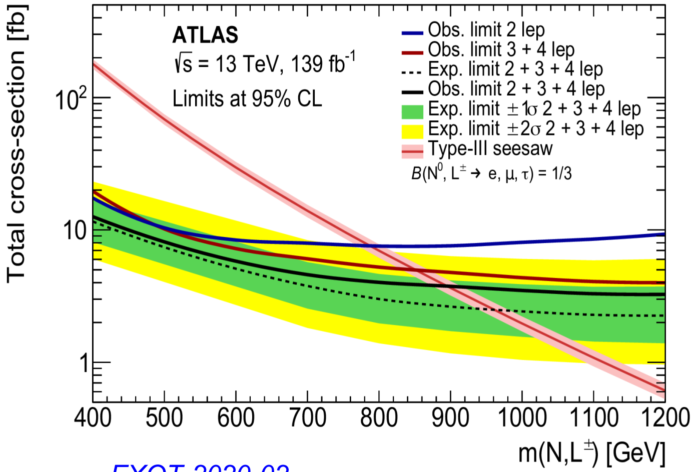
- Most advanced searches target multilepton final states (2l, 3l, 4l), but are not optimized for vector-like electrons/muons:
  - Type-III seesaw heavy-lepton multiplet (flavor democratic scenario)
  - Vector-like taus in the doublet and singlet scenarios







[CMS-EXO-21-002]



[EXOT-2020-02]

Vector-like leptons: current program

Anomaly scorecard

R(K) R(K*)

R(D) R(D*)

a_μ

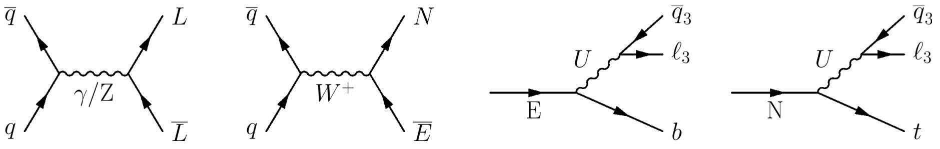
Other

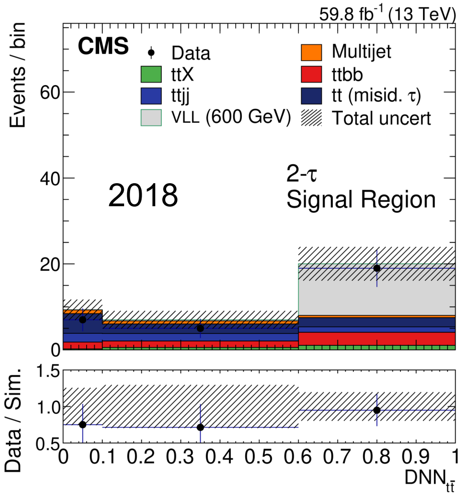
- Recent CMS search for the VLLs appearing in the 4321 model.
- Complex cascades giving heavy-flavored multilepton+multijet final states.

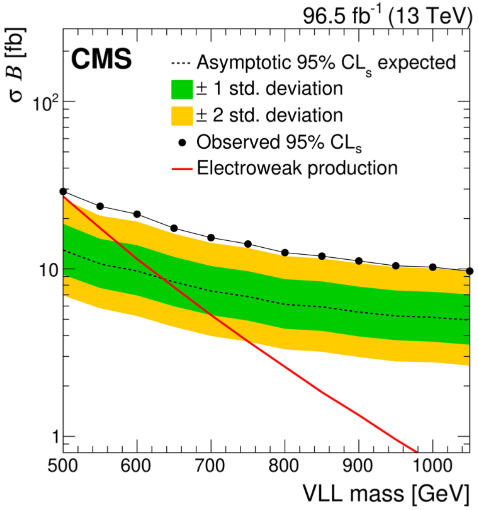
Tau multiplicity	VLL production + decay mode	Final state
0 τ	$\mathrm{EE} \to \mathrm{b}(\mathrm{t}\nu_\tau)\mathrm{b}(\mathrm{t}\nu_\tau)$	$4\mathrm{b} + 4\mathrm{j} + 2\nu_\tau$
	$\mathrm{EN} \to \mathrm{b}(\mathrm{t}\nu_\tau)\mathrm{t}(\mathrm{t}\nu_\tau)$	$4\mathrm{b} + 6\mathrm{j} + 2\nu_\tau$
	$\mathrm{NN} \to \mathrm{t}(\mathrm{t}\nu_\tau)\mathrm{t}(\mathrm{t}\nu_\tau)$	$4\mathrm{b} + 8\mathrm{j} + 2\nu_\tau$
1 τ	$\mathrm{EE} \to \mathrm{b}(\mathrm{b}\tau)\mathrm{b}(\mathrm{t}\nu_\tau)$	$4\mathrm{b} + 2\mathrm{j} + \tau + \nu_\tau$
	$\mathrm{EN} \to \mathrm{b}(\mathrm{t}\nu_\tau)\mathrm{t}(\mathrm{b}\tau)$	$4\mathrm{b} + 4\mathrm{j} + \tau + \nu_\tau$
	$\mathrm{EN} \to \mathrm{b}(\mathrm{b}\tau)\mathrm{t}(\mathrm{t}\nu_\tau)$	$4\mathrm{b} + 4\mathrm{j} + \tau + \nu_\tau$
	$\mathrm{NN} \to \mathrm{t}(\mathrm{b}\tau)\mathrm{t}(\mathrm{t}\nu_\tau)$	$4\mathrm{b} + 6\mathrm{j} + \tau + \nu_\tau$
2 τ	$\mathrm{EE} \to \mathrm{b}(\mathrm{b}\tau)\mathrm{b}(\mathrm{b}\tau)$	$4\mathrm{b} + 2\tau$
	$\mathrm{EN} \to \mathrm{b}(\mathrm{b}\tau)\mathrm{t}(\mathrm{b}\tau)$	$4\mathrm{b} + 2\mathrm{j} + 2\tau$
	$\mathrm{NN} \to \mathrm{t}(\mathrm{b}\tau)\mathrm{t}(\mathrm{b}\tau)$	$4\mathrm{b} + 4\mathrm{j} + 2\tau$

Obs significance VLL (600 GeV):

	2017	2018	Combination
0-τ	0	0	0
1-τ	1.44	1.65	1.93
2-τ	0.83	2.04	2.26
1+2-τ	1.63	2.55	2.88
0+1+2-τ	1.38	2.57	2.83



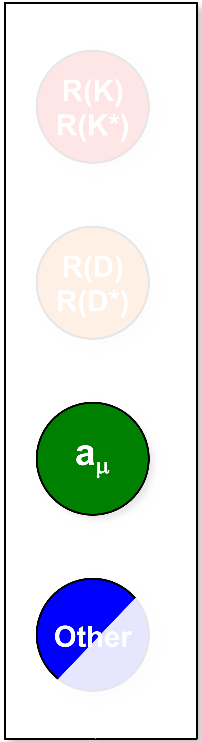




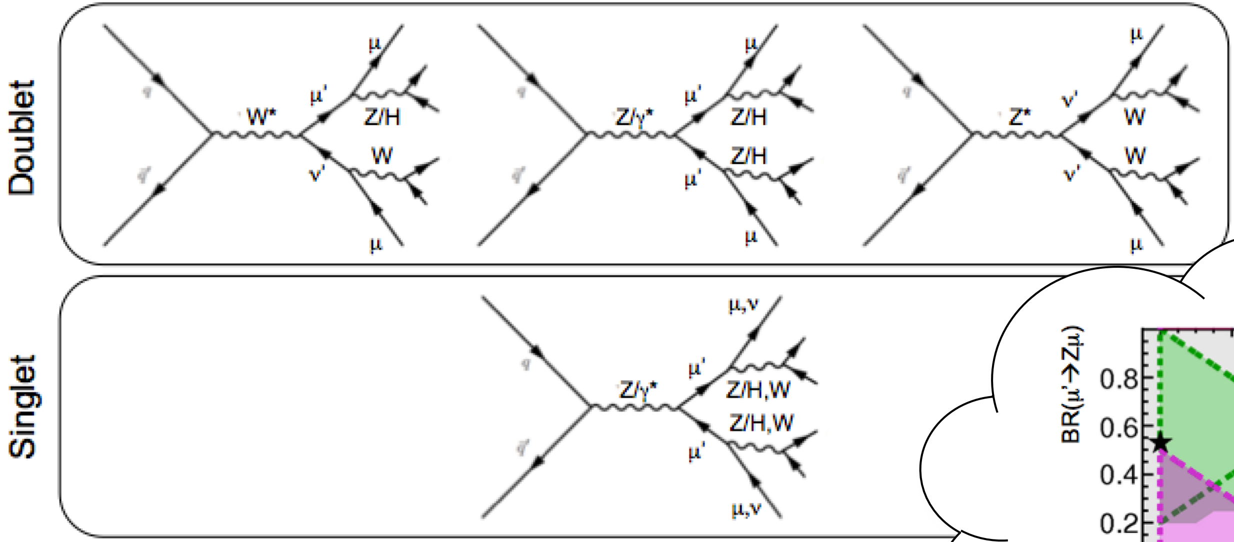
CMS-B2G-21-004

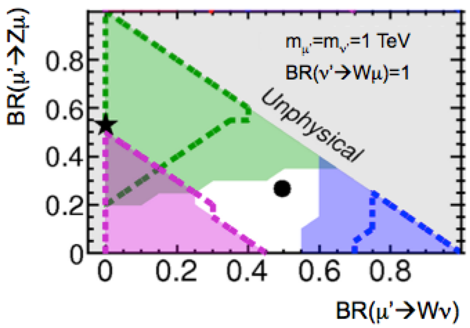
Vector-like leptons: opportunities

Anomaly scorecard



- Develop optimized searches for the three different vector-like lepton flavors separately. Given the small production cross section, must optimally exploit broad range of possible signatures (including hadronic W/Z/H decays!):

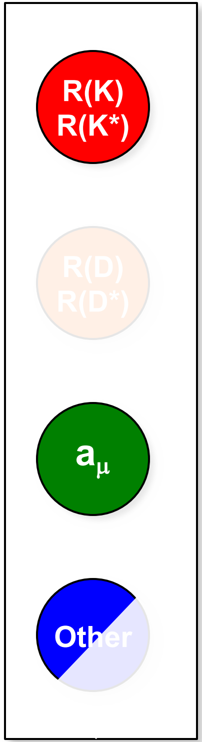




Program should reach similar level of sophistication as for vector-like quarks!

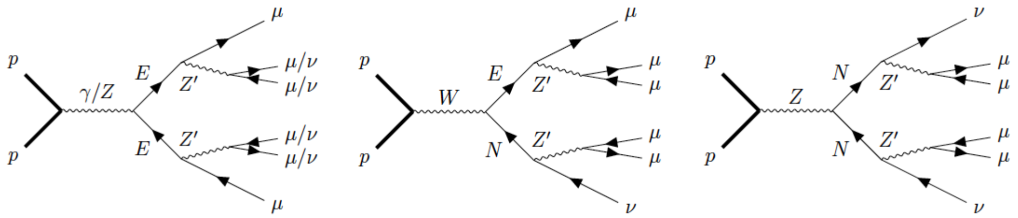
Vector-like leptons: opportunities

Anomaly scorecard

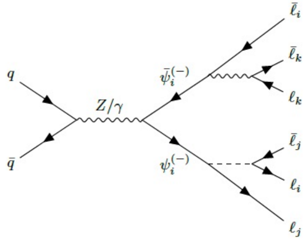


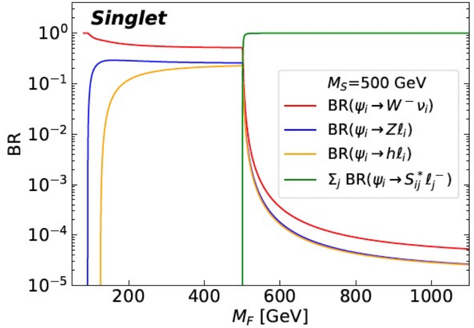
- Develop optimized searches for the three different vector-like lepton flavors separately. Given the small production cross section, must optimally exploit broad range of possible signatures (including hadronic W/Z/H decays!):
- Consider other novel production/decay modes.

  E.g. Simplified model with VLLs (to address a_μ) and a Z' (to address R(K), R(K*)): e.g. *arXiv:2104.04461*



  E.g. Flavourful vector-like leptons decaying into flavor-violating scalars: e.g. *arXiv:2011.12964*



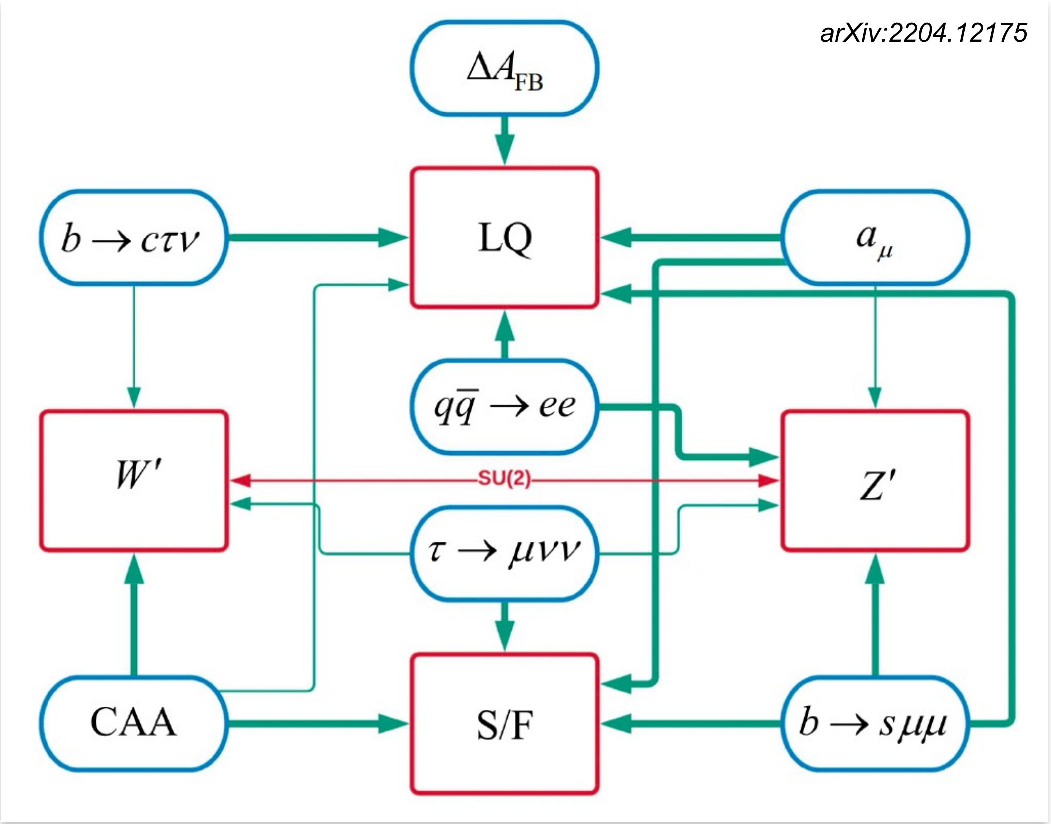


➔ Analyze ≥4l events split by lepton flavor!

Conclusions

- The picture painted by LFUV anomalies is exciting, but also quite confusing!
  More experimental information is needed.

- We have a broad search program probing relevant theory parameter space that can explain current anomalies.
  ➔ Long-term program with real potential for discovery!
  …But there are many areas where we need to improve to make sure we leave no stone unturned.



Conclusions

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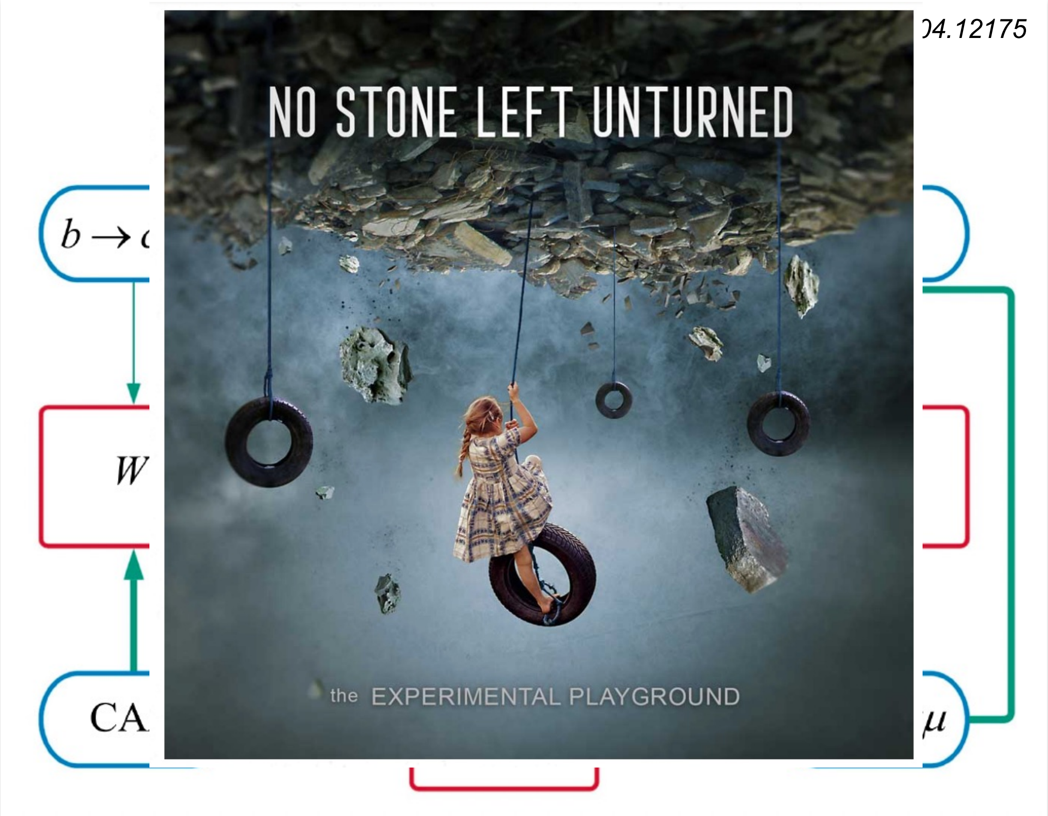
- We have a broad search program probing relevant theory parameter space that can explain current anomalies.
  ➔ Long-term program with real potential for discovery!
  …But there are many areas where we need to improve to make sure we leave no stone unturned.

- The landscape to be probed is vast, and the available resources/time limited.

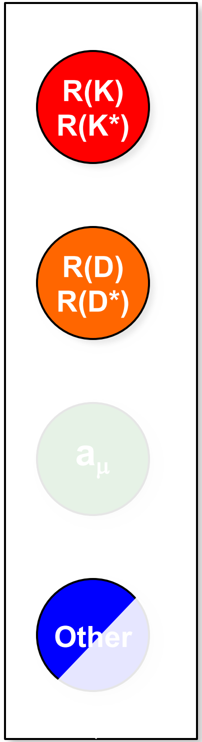
A vibrant theory-experiment interplay critical to sort this out!



Backup

Non-resonant dileptons: current program

Anomaly scorecard

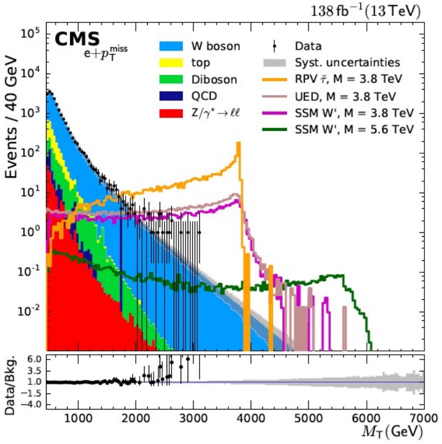


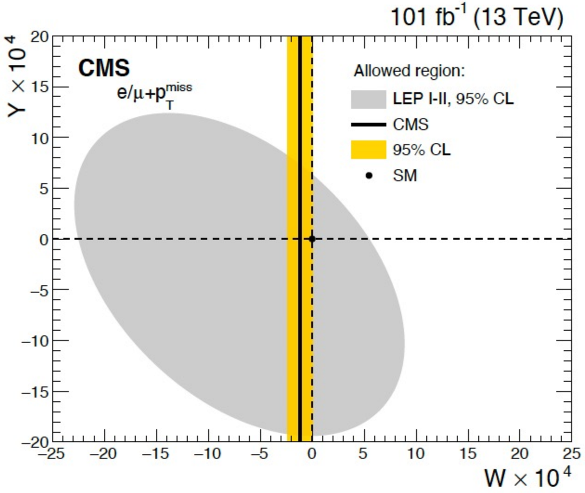
- Inclusive searches for lepton+MET completed by both ATLAS and CMS.
- Non-resonant interpretation only available from CMS as constraint on the oblique W parameter.

Modification of W-boson propagator:

$$\left|\frac{P_W}{P_W^{(0)}}\right|^2 = \left(1 + \frac{(2t^2-1)W}{1-t^2} + \frac{t^2 Y}{1-t^2} - \frac{W(q^2-m_W^2)}{m_W^2}\right)^2$$

$t=\tan\theta_W$





CMS-EXO-19-017