



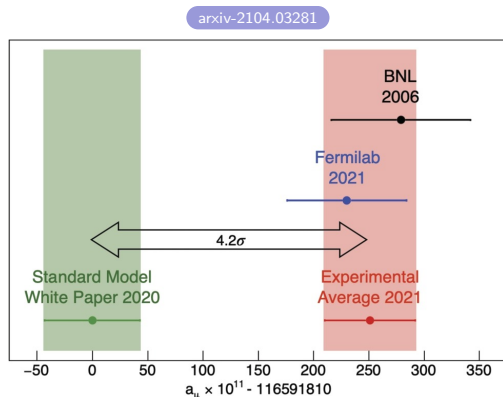
Exotics (non-SUSY) searches at the LHC

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CLHCP 2022

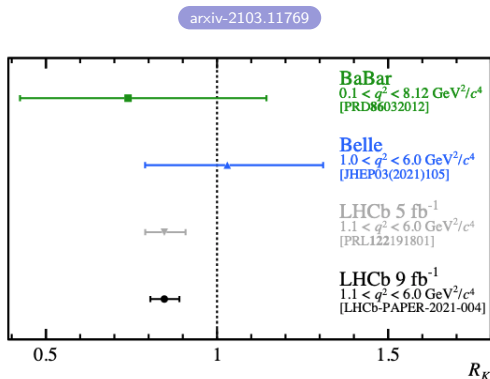


- The Standard Model (SM) *fails* to explain/leave several opened questions:
 - Lepton Flavour Violation (LFV), like in neutrino oscillation
 - Muon anomalous magnetic moment ($g-2$)
 - Anomalies in B-physics: $R_D^{(*)}$ and $R_K^{(*)}$
 - Dark matter in the universe
 - Many Others ...
- All these opens to a new plethora of searches for physics Beyond Standard Model (BSM)



$$a_\mu^{SM} = 116591810(43) \times 10^{-11}$$

$$a_\mu^{exp} = 116592061(41) \times 10^{-11}$$



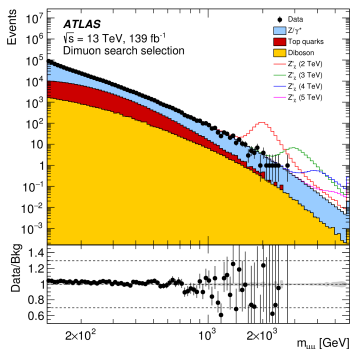
3.1 σ discrepancy with respect to SM

Main techniques to search for BSM



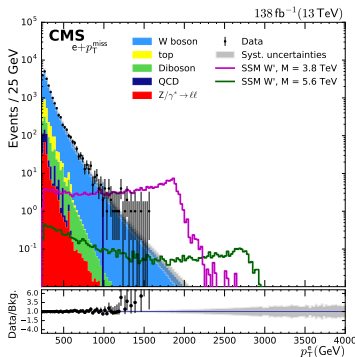
- At LHC, several data analyses using Run1/Run2 datasets are trying to search for BSM
- Possible to test several signal hypothesis and tune models
- Possible to develop new object reconstruction and machine learning algorithms

Bump Hunting



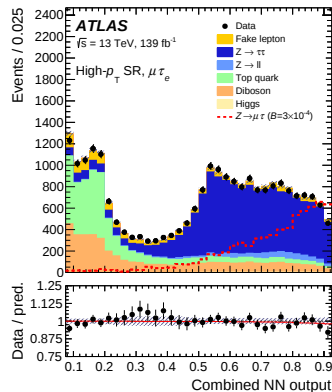
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Excess at high p_T regime



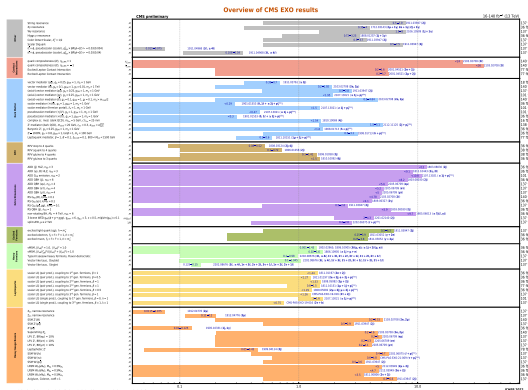
JHEP 07 (2022) 067

MVA



Phys. Rev. Lett. 127 (2021) 271801

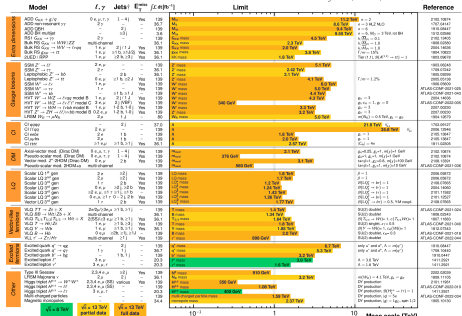
- Exotics searches covers a large variety of possible final states and signal models
 - New fermions and gauge bosons
 - Additional Higgs boson and di-Higgs production
 - Leptoquarks
 - Long-lived particles
 - Many Others ...
- Results scan over a wide range of mass at the TeV scale
- Next slides will highlight some of the current results trying to span over different searches method/fields



ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

Status: July 2022

ATLAS Preliminary $\sqrt{s} = 13\text{ TeV}$

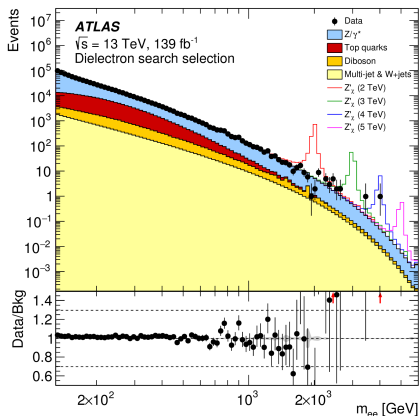


*Only a selection of the available mass limits on new states or phenomena is shown.

*Small values (large redshift) are denoted by the letter 'J'.

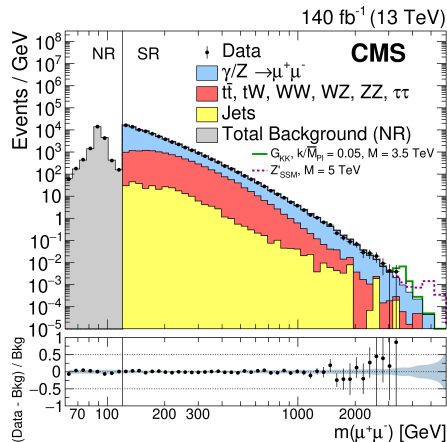
- Search for heavy resonances decaying into 2 electrons/muons
- Allow to test several models/resonance with different spin (0,1,2)

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Model	Lower limits on $m_{Z'}$ [TeV]					
	ee		$\mu\mu$		$\ell\ell$	
	obs	exp	obs	exp	obs	exp
Z'_{ψ}	4.1	4.3	4.0	4.0	4.5	4.5
Z'_{χ}	4.6	4.6	4.2	4.2	4.8	4.8
Z'_{SSM}	4.9	4.9	4.5	4.5	5.1	5.1

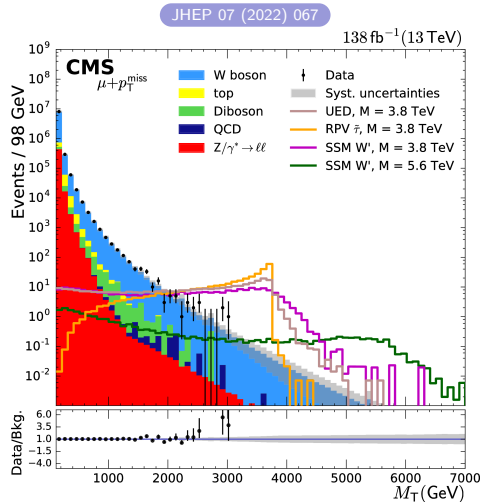
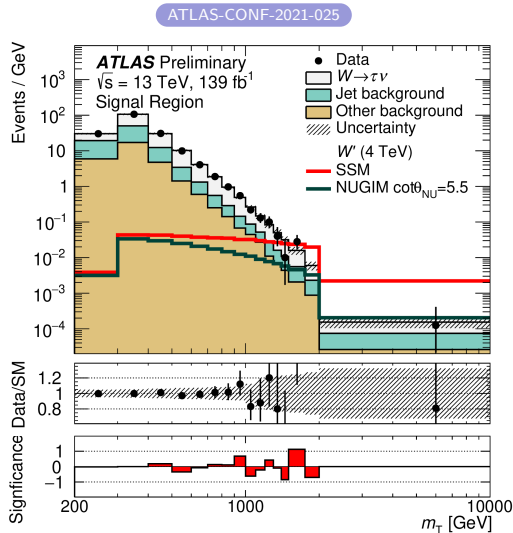
arXiv:arXiv:2103.02708



Channel	Z'_{SSM}		Z'_{ψ}	
	Obs. [TeV]	Exp. [TeV]	Obs. [TeV]	Exp. [TeV]
ee	4.72	4.72	4.11	4.13
$\mu\mu$	4.89	4.90	4.29	4.30
$ee + \mu\mu$	5.15	5.14	4.56	4.55

- New resonances excluded up to mass of $\simeq 5$ TeV

- Search for excess in the high M_T regime considering all leptonic final states
- Allow to test several models like Sequential SM, Universal Extra Dimensions



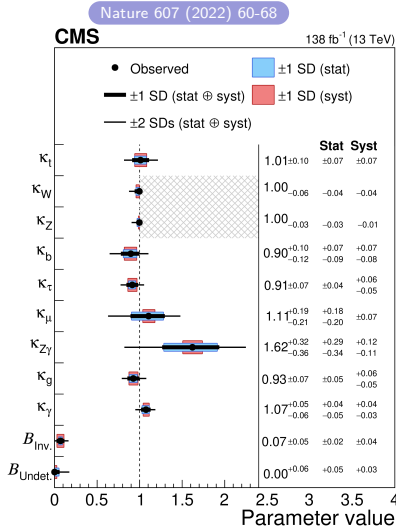
Channel	$M_{W'}$ lower limit (TeV)	
	Observed	Expected
Electron	5.4	5.3
Muon	5.6	5.5
Combination	5.7	5.6

- W' excluded up to mass of $\simeq 5 \text{ TeV}$

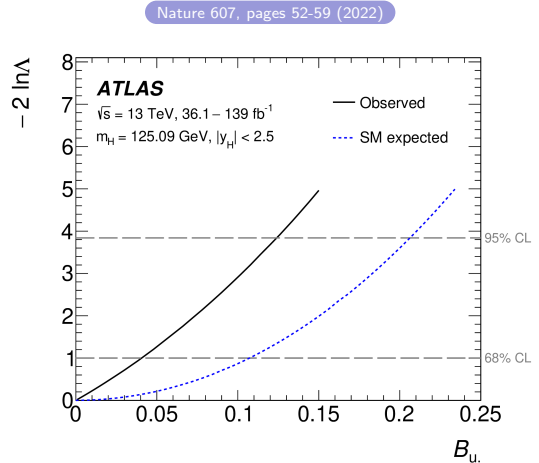
Higgs combination measurement



- This year it's the 10th year after the Higgs boson discovery in 2012
- Both ATLAS and CMS published Higgs combination measurements setting limits to invisible/undetected Higgs boson decays
- However, we can consider exotic and invisible Higgs decays to probe new physics



$B_{inv.} < 0.16$, $B_{un.} < 0.16$ at 95% CL

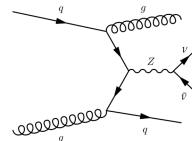
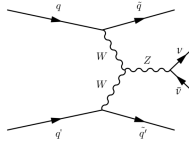
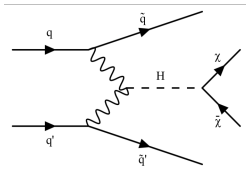


$B_{inv.} < 0.13$ (0.08 exp), $B_{un.} < 0.12$ (0.21 exp.) at 95% CL

H → invisible in VBF final state

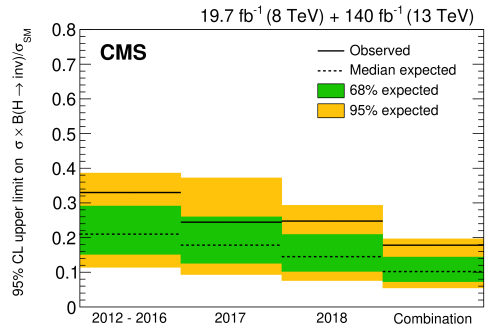
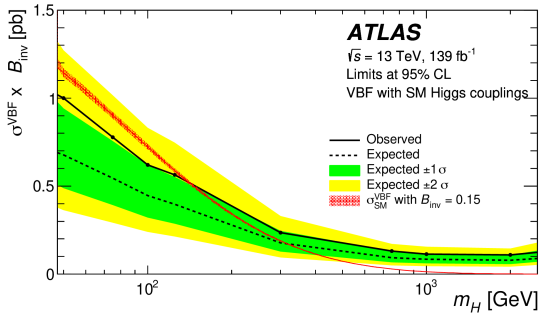


- VBF Higgs boson production most sensitive channel to search for H → invisible
- Main background from strong and electroweak Z+jets production
- (ATLAS) Results interpreted for Higgs boson as a portal to dark matter



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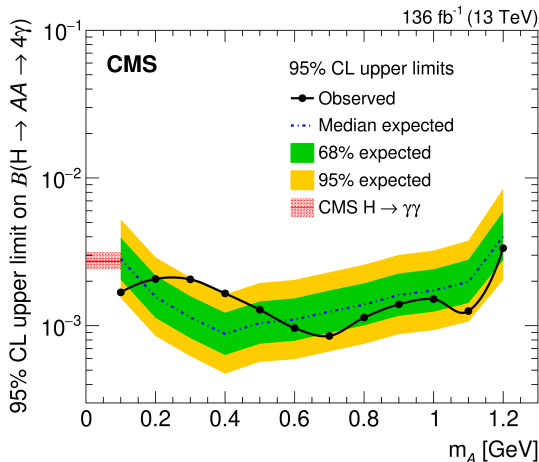
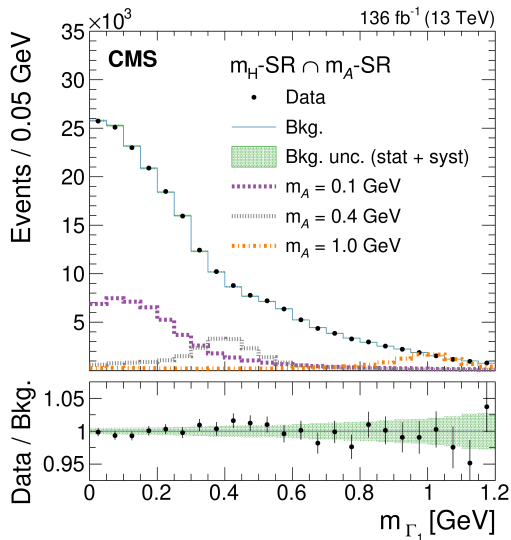
Phys. Rev. D 105 (2022) 092007



$B_{\text{inv.}} < 0.15$ (0.10 exp.) at 95% CL

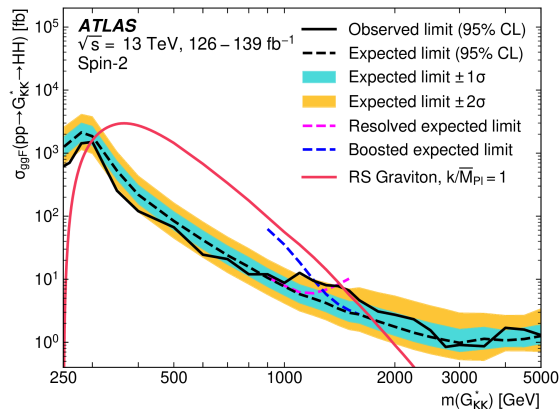
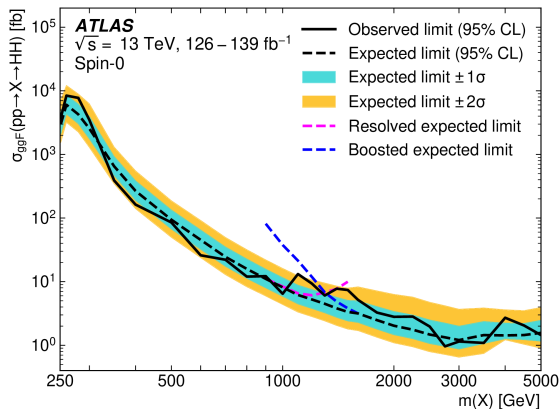
$B_{\text{inv.}} < 0.18$ (0.10 exp.) at 95% CL

- Look for two collimated photons reconstructed as Γ
- Main background from SM $H \rightarrow \gamma\gamma$ and QCD/ γ +jets



- No excess observed in $\mu\text{S+B}$ fit of Γ distributions $\rightarrow$ set limits on exotics Higgs decay $B(H \rightarrow \mathcal{A}\mathcal{A} \rightarrow 4\gamma) \epsilon [0.9, 3.3] \times 10^{-3}$ at 95% CL for $0.1 \text{ GeV} < M_A < 1.2 \text{ GeV}$

- Considering spin-0 and spin-2 benchmark signal models
 - corresponds to resonant HH production via gluon-fusion
- Analysis performed in *Resolved* and *Boosted* regime:
 - *Resolved* for $M_X \in [250, 1500]$ GeV, using anti-Kt 0.4 jets
 - *Boosted* for $M_X \in [0.9, 5]$ TeV, using largeR jets



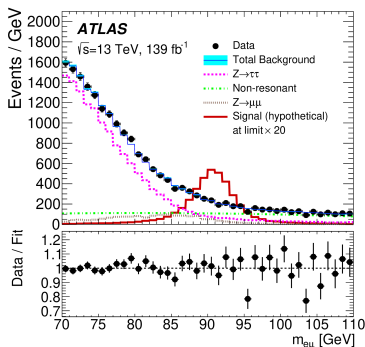
- Bulk Randall-Sundrum model excluded for graviton masses $298 \text{ GeV} < M < 1460 \text{ GeV}$

- Lepton Flavour conservation often violated in BSM theories
- Search for LFV in Z decay:
 - peak around the Z mass in the $Z \rightarrow e\mu$ final state
 - fit MVA score in the final states involving τ leptons

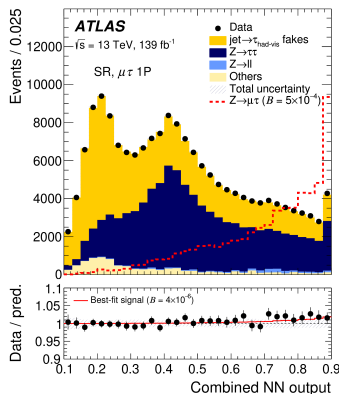
$$Z \rightarrow e\mu$$

$$Z \rightarrow l\tau_{had}$$

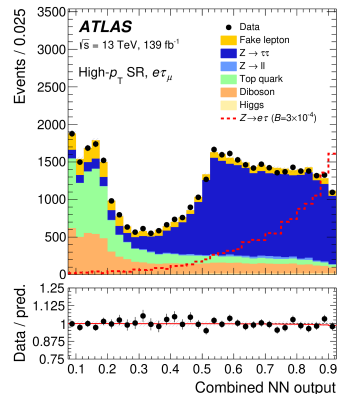
$$Z \rightarrow l\tau_{lep}$$



arXiv:2204.10783



Nature Phys. 17 (2021) 819



Phys. Rev. Lett. 127 (2021) 271801

- $\mathcal{B}(Z \rightarrow e\mu) < 2.62 \times 10^{-7}$ at 95% CL
- $\mathcal{B}(Z \rightarrow e\tau) < 5 \times 10^{-6}$, $\mathcal{B}(Z \rightarrow \mu\tau) < 6.5 \times 10^{-6}$ at 95% CL
- All these results are the most stringent limits to date for LFV search in Z decay

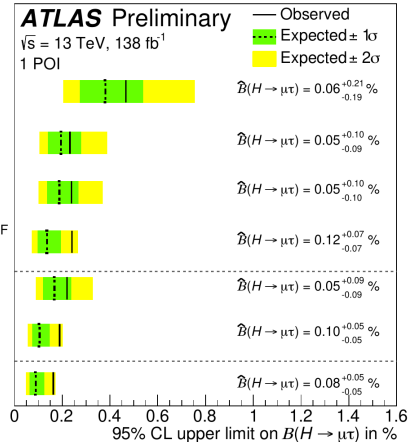
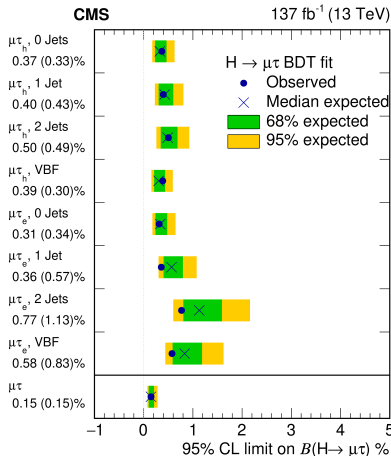
LFV search in $H \rightarrow l\tau$ final state



- Search in both leptonic and hadronic τ decay final state
- Use MVA discriminant to enhance signal over background and extract results

Phys. Rev. D 104 (2021) 032013

ATLAS-CONF-2022-060



Obs. (Exp) $\mathcal{B}(H \rightarrow e\tau) < 0.22(0.16)\%$

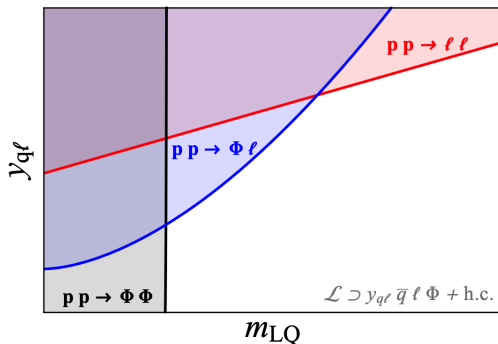
Obs. (Exp) $\mathcal{B}(H \rightarrow \mu\tau) < 0.15(0.15)\%$

Obs. (Exp) $\mathcal{B}(H \rightarrow e\tau) < 0.19(0.11)\%$

Obs. (Exp) $\mathcal{B}(H \rightarrow e\tau) < 0.18(0.09)\%$

- Results can be interpreted as limits for non-diagonal Yukawa coupling matrix elements

- LQs can explain deviations from lepton flavour universality from the SM in B-physics
 - Predicted in many BSM scenarios and decay to lepton-quark pairs
 - Carry color charge, fractional electric charge and non-zero baryon and lepton number
- The LQ cross section depends not only depends on the mass of LQ but also on the Yukawa coupling(λ)

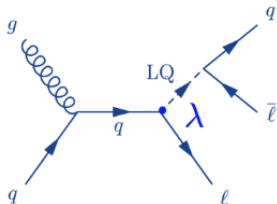


Arxiv-1801.07641

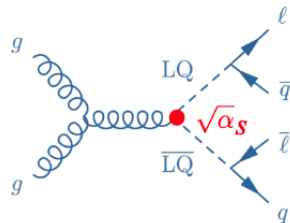
Spin	$3B + L$	$SU(3)_c$	$SU(2)_W$	$U(1)_Y$	Allowed coupling
0	-2	$\bar{3}$	1	1/3	$\bar{q}_L^c \ell_L$ or $\bar{u}_R^c e_R$
0	-2	$\bar{3}$	1	4/3	$\bar{d}_R^c e_R$
0	-2	$\bar{3}$	3	1/3	$\bar{q}_L^c \ell_L$
1	-2	$\bar{3}$	2	5/6	$\bar{q}_L^c \gamma^\mu e_R$ or $\bar{d}_R^c \gamma^\mu \ell_L$
1	-2	$\bar{3}$	2	-1/6	$\bar{u}_R^c \gamma^\mu \ell_L$
0	0	3	2	7/6	$\bar{q}_L e_R$ or $\bar{u}_R \ell_L$
0	0	3	2	1/6	$\bar{d}_R \ell_L$
1	0	3	1	2/3	$\bar{q}_L \gamma^\mu \ell_L$ or $\bar{d}_R \gamma^\mu e_R$
1	0	3	1	5/3	$\bar{u}_R \gamma^\mu e_R$
1	0	3	3	2/3	$\bar{q}_L \gamma^\mu \ell_L$

- Several searches for 1st, 2nd and 3rd and cross-generations final states
- Investigating both Scalar and Vector LQ, both single and pair production

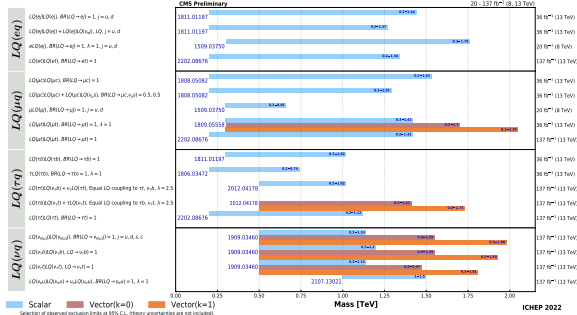
Single LQ prod



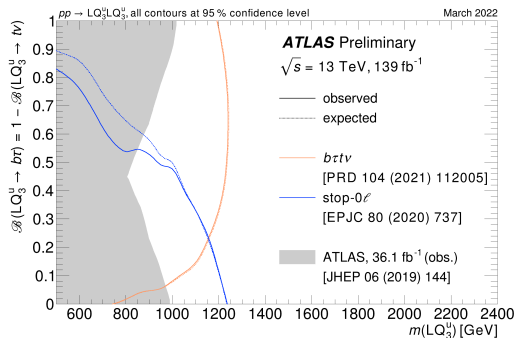
Pair LQ prod



Overview of CMS leptoquark searches

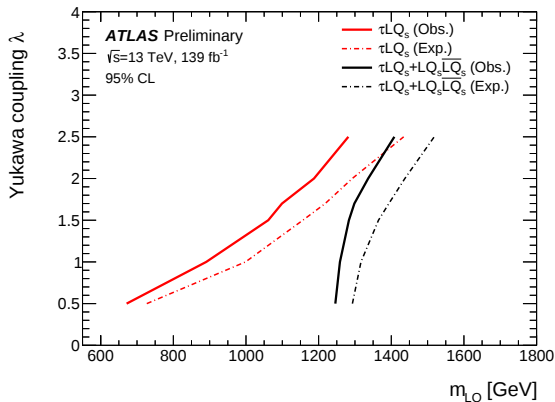
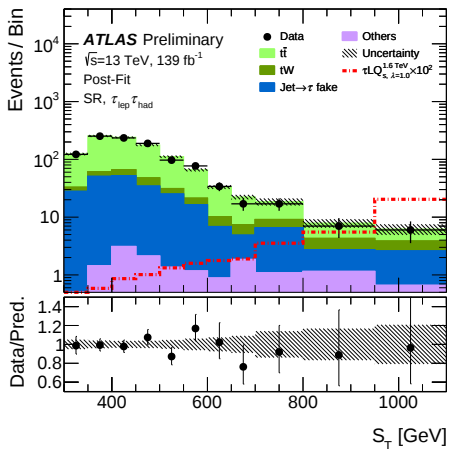


CMS Summary plots



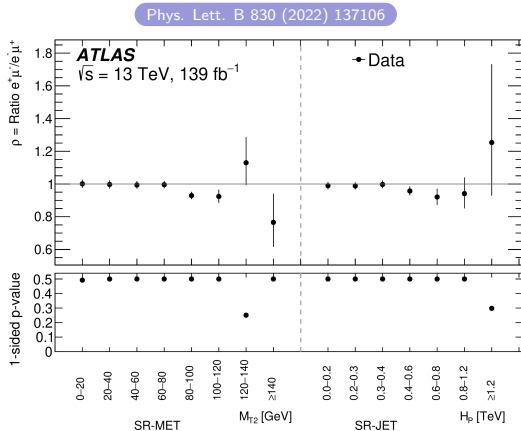
ATL-PHYS-PUB-2022-012

- Main focus on singly produced scalar LQ:
 - considering $\tilde{S}_1$ model with LQ having $4/3e$ and $3B + L = -2$
 - LQ production mostly through quark-gluon fusion and scattering
- Include also pair production of scalar LQs since similar final state
- Assuming LQ exclusive decay in $b\tau$



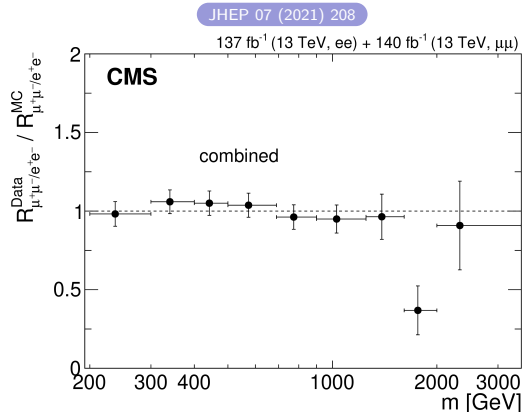
- First ATLAS result for the search of singly-produced LQ in $b\tau$ final state
- For singly+pair LQ production, masses below 1.25 TeV excluded for λ values > 0.5

- Test possible SM extension looking at $\mu\mu/ee/e\mu$ production



$$\rho = \frac{\sigma(pp \rightarrow e^+\mu^- + X)}{\sigma(pp \rightarrow e^-\mu^+ + X)}$$

Expect $\rho < 1$ at LHC; $\rho > 1$ can be introduced by BSM physics



$$R_{\mu^+\mu^-/e^+e^-} = \frac{d\sigma(qq \rightarrow \mu^+\mu^-)/dm_{\ell\ell}}{d\sigma(qq \rightarrow e^+e^-)/dm_{\ell\ell}}$$

BSM can cause R to deviate from unity

- Still no sign of BSM physic observed

- The Standard Model *fails* to explain/leave several opened questions
 - many possibilities to search for physics Beyond the Standard Model
- At LHC, several data analyses using Run1/Run2 datasets are trying to search for BSM
 - possible to develop new object reconstruction and machine learning algorithms
- A selected collection of results from ATLAS and CMS has been shown but still no robust sign of BSM has been found across several search types/final states
 - other results include also Long Lived Particles, searches in final states with jets, search for dark matter candidates and many others
- Looking forward to continue the BSM search using LHC Run3 data

Thanks For Your Attention