Exotics (non-SUSY) searches at the LHC

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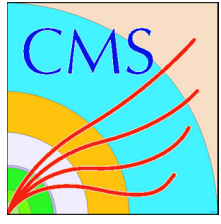
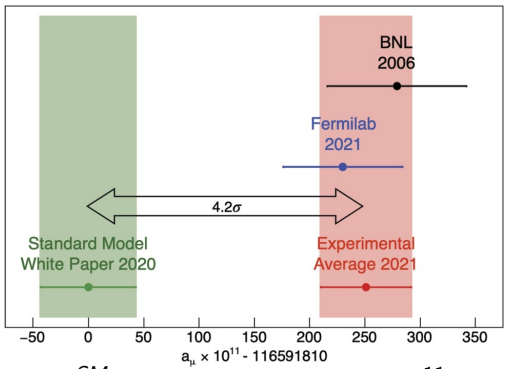
CLHCP 2022



Standard Model limitations

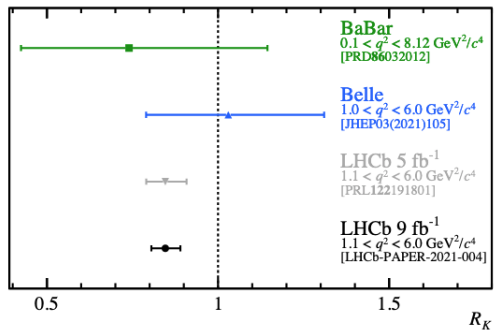
- The Standard Model *fails* to explain/leave several opened questions :
  - Lepton Flavour Violation (LFV), like in neutrino oscillation
  - Muon anomalous magnetic moment (*g-2*)
  - Anomalies in B-physics: $R_D^{(*)}$ and $R_K^{(*)}$
  - Dark matter in the universe
  - Many Others ...
- All these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

arxiv-2104.03281



$$a_\mu^{SM} = 116591810(43) \times 10^{-11}$$
$$a_\mu^{exp} = 116592061(41) \times 10^{-11}$$

arxiv-2103.11769

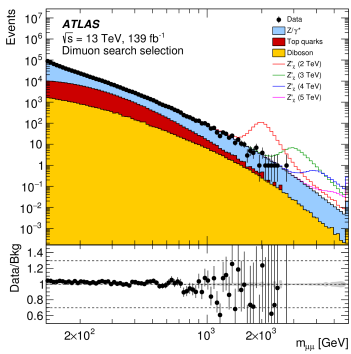


3.1 σ discrepancy with respect SM

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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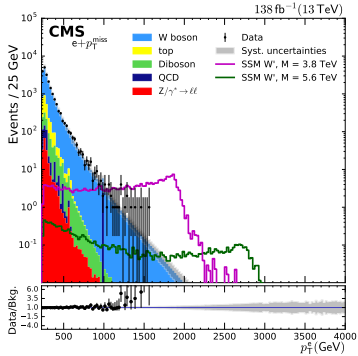
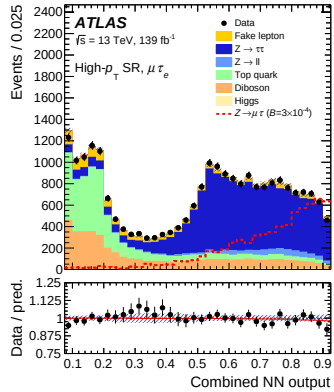
Excess at high p_T regime



JHEP 07 (2022) 067

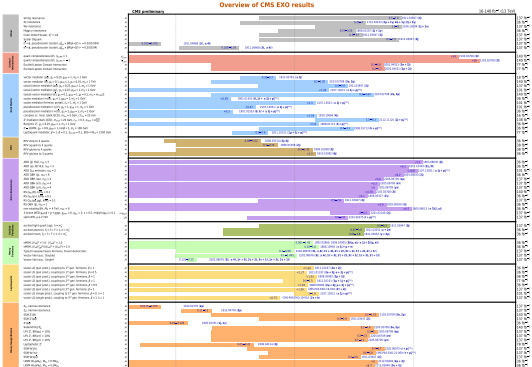
MVA



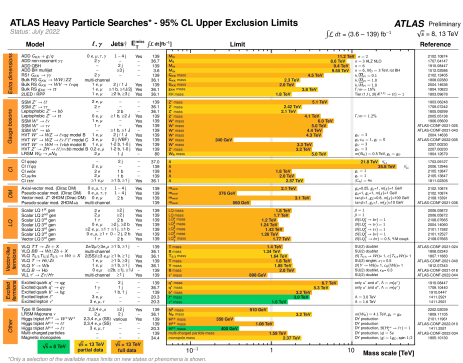
Phys. Rev. Lett. 127 (2021) 271801

ATLAS/CMS summary results

- 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



CMS Summary plots



ATLAS Summary plots

Z' boson search

- 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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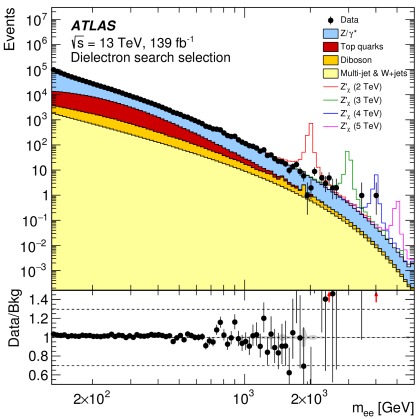
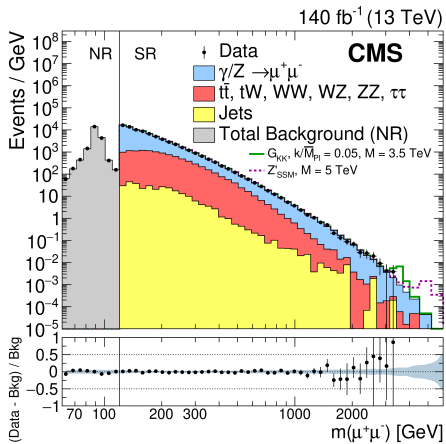


Model	Lower limits on $m_{Z'}$ [TeV]					
	ee		$\mu\mu$		$\ell\ell$	
	obs	exp	obs	exp	obs	exp
Z'_ψ	4.1	4.3	4.0	4.0	4.5	4.5
Z'_χ	4.6	4.6	4.2	4.2	4.8	4.8
Z'_{SSM}	4.9	4.9	4.5	4.5	5.1	5.1

arxiv-arXiv:2103.02708



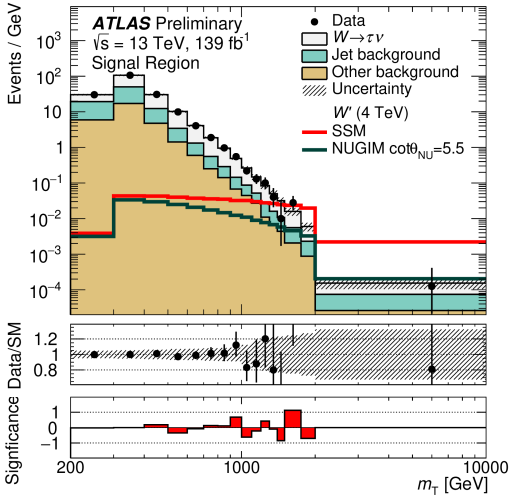
Channel	Z'_{SSM}		Z'_ψ	
	Obs. [TeV]	Exp. [TeV]	Obs. [TeV]	Exp. [TeV]
ee	4.72	4.72	4.11	4.13
$\mu\mu$	4.89	4.90	4.29	4.30
ee + $\mu\mu$	5.15	5.14	4.56	4.55

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

W' boson search

- 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

ATLAS-CONF-2021-025



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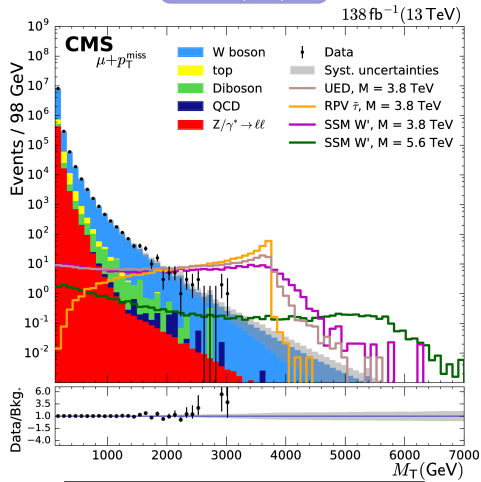


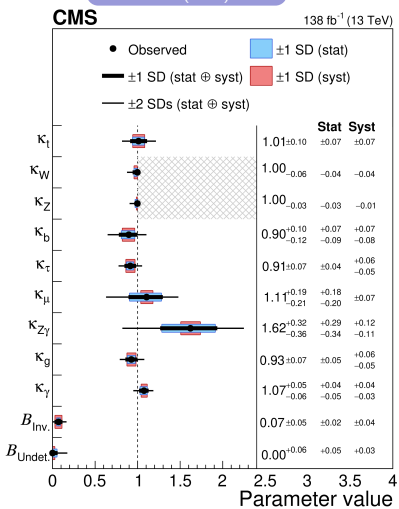
Channel	$M_{W'}$ lower limit (TeV)	
	Observed	Expected
Electron	5.4	5.3
Muon	5.6	5.5
Combination	5.7	5.6

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

Higgs combination measurement

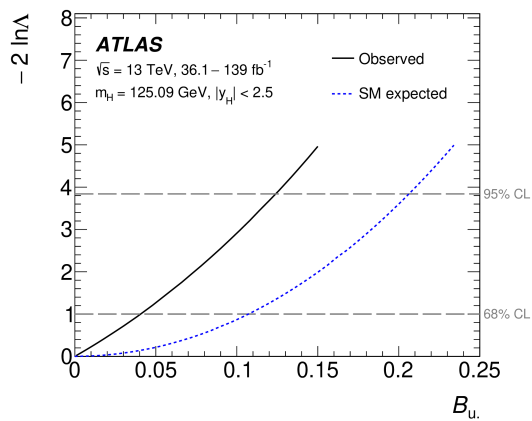
- This year it's the 10th year after the Higgs boson discovery in 2012
- Both ATLAS and CMS published Higgs combination measurements setting limits to invisible/undetected Higgs boson decays
- However, we can consider exotic and invisible Higgs decays to probe new physics

Nature 607 (2022) 60-68



$\mathcal{B}_{inv.} < 0.16$, $\mathcal{B}_{un.} < 0.16$ at 95% CL

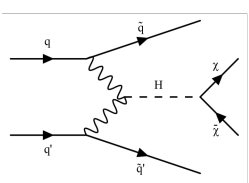
Nature 607, pages 52-59 (2022)

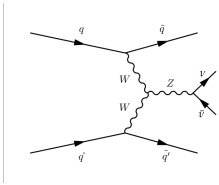


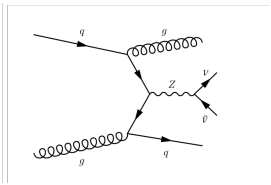
$\mathcal{B}_{inv.} < 0.13$ (0.08 exp), $\mathcal{B}_{un.} < 0.12$ (0.21 exp.) at 95% CL

H→ invisible in VBF final state

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

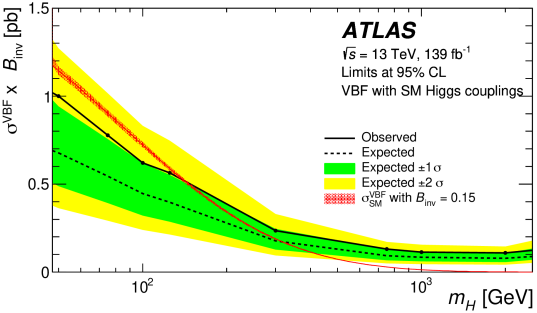


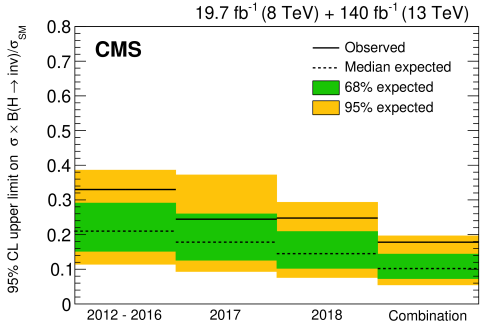




JHEP 08 (2022) 104

Phys. Rev. D 105 (2022) 092007



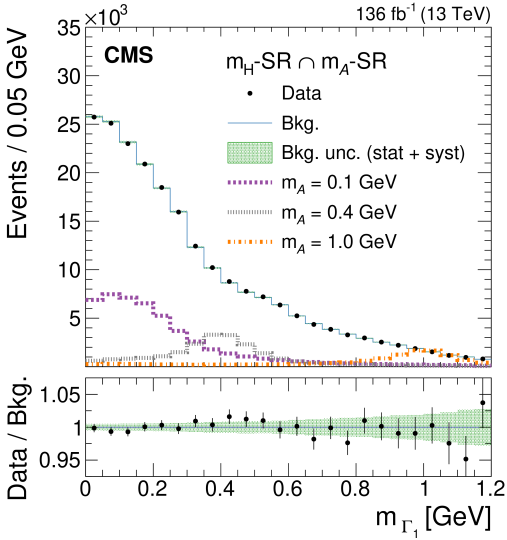


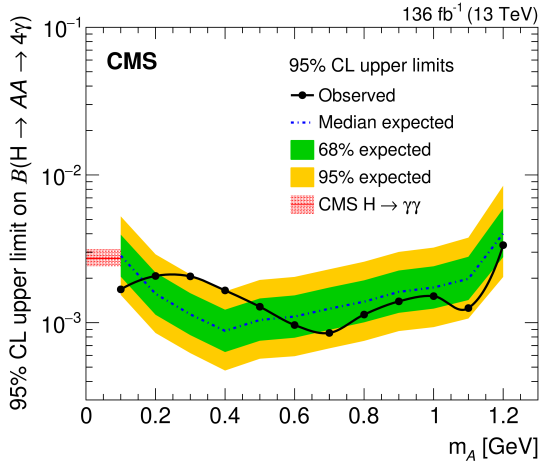
$\mathcal{B}_{inv.} < 0.15$ (0.10 exp.) at 95% CL

$\mathcal{B}_{inv.} < 0.18$ (0.10 exp.) at 95% CL

Search for $H \to \mathcal{A}\mathcal{A} \to 4\gamma$ arXiv:2209.06197

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

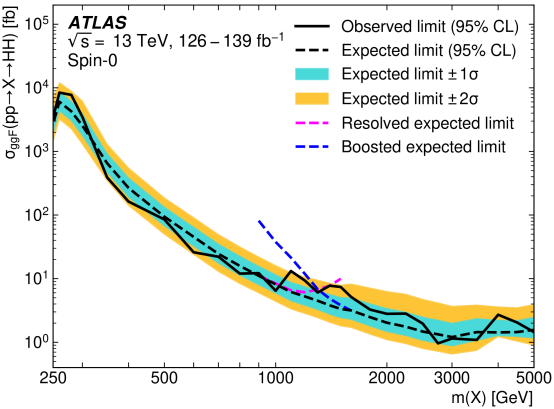


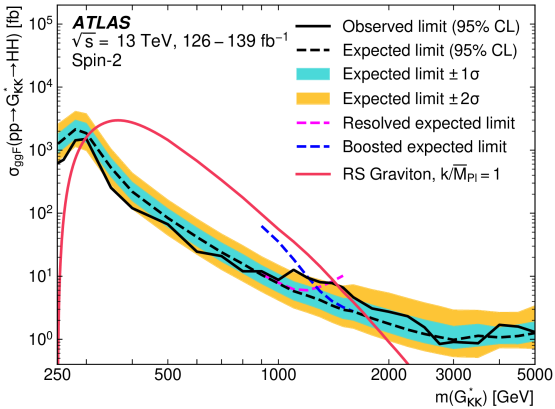


- No excess observed in μS+B fit of Γ distributions → set limits on exotics Higgs decay $\mathcal{B}(H \to \mathcal{A}\mathcal{A} \to 4\gamma)\epsilon[0.9, 3.3] \times 10^{-3}$ at 95% CL

Search for $X \to HH \to 4b$ Phys.Rev.D105(2022)092002

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



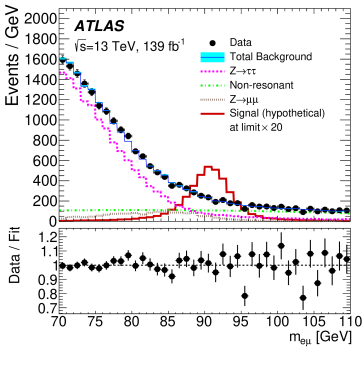


- Bulk Randall-Sundrum model excluded for graviton masses 298 GeV $<$ M $<$ 1460 GeV

LFV search in Z decay

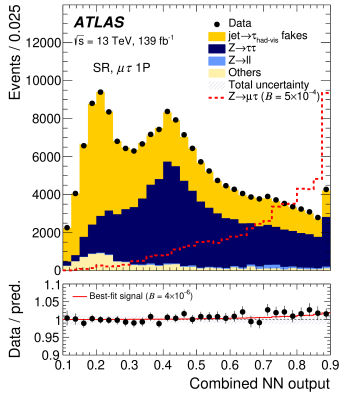
- Lepton Flavour conservation often violated in BSM theories
- Search for LFV in Z decay:
  - peak around the Z mass in the $Z \to e\mu$ final state
  - fit MVA score in the final states involving τ leptons

$Z \to e\mu$



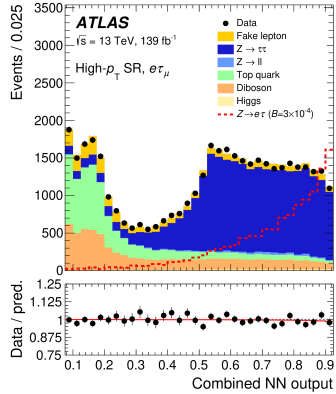
arXiv:2204.10783

$Z \to l\tau_{had}$



Nature Phys. 17 (2021) 819

$Z \to l\tau_{lep}$



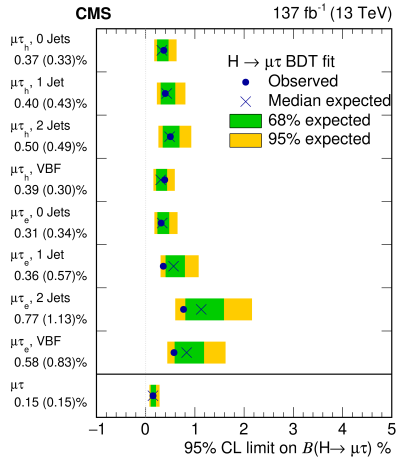
Phys. Rev. Lett. 127 (2021) 271801

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

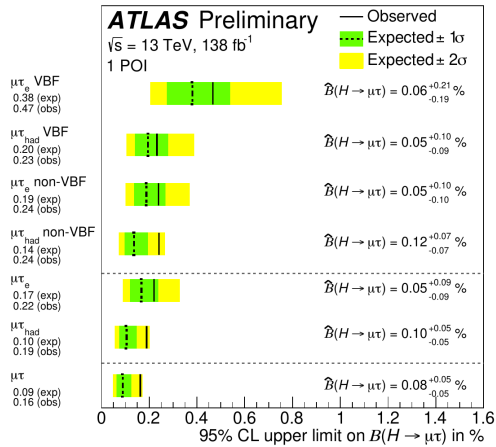
LFV search in H→ lτ final state

- 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) $\mathcal{B}(H \to e\tau) < 0.22(0.16)\%$
Obs. (Exp) $\mathcal{B}(H \to \mu\tau) < 0.15(0.15)\%$

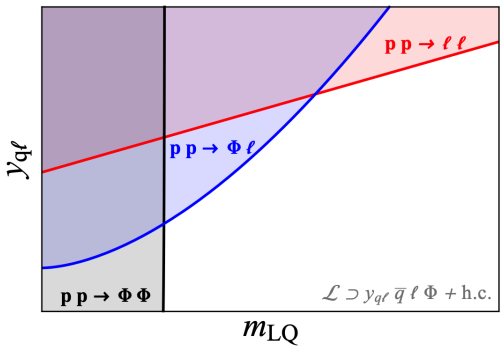
Obs. (Exp) $\mathcal{B}(H \to e\tau) < 0.19(0.11)\%$
Obs. (Exp) $\mathcal{B}(H \to e\tau) < 0.18(0.09)\%$

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

Introduction to Leptoquark (LQ)

- 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)



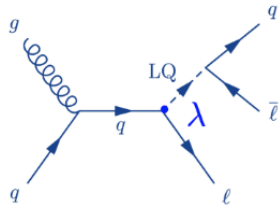
Arxiv-1801.07641

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	$\bar{q}_L \gamma^\mu \ell_L$

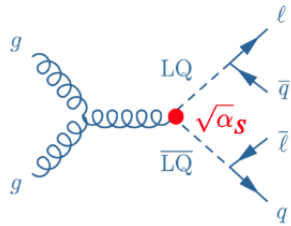
ATLAS/CMS Summary LQ search

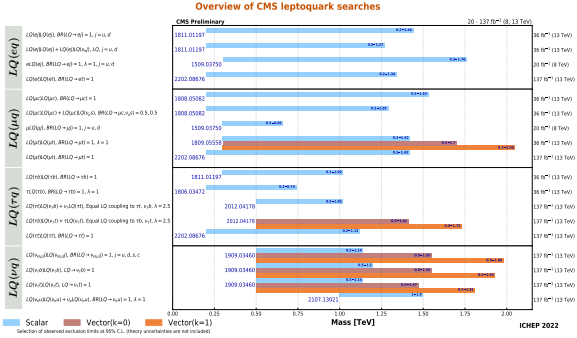
- Several searches for 1st,2nd and 3th and cross-generations final states
- Investigating both Scalar and Vector LQ, both single and pair production

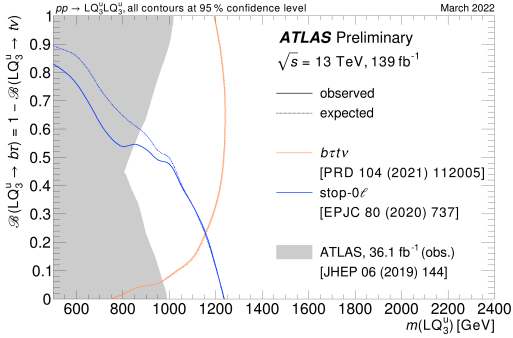
Single LQ prod



Pair LQ prod







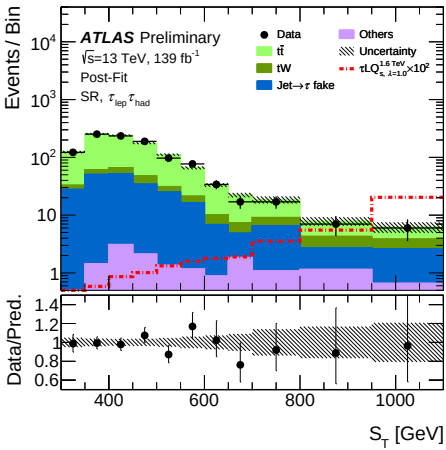
CMS Summary plots

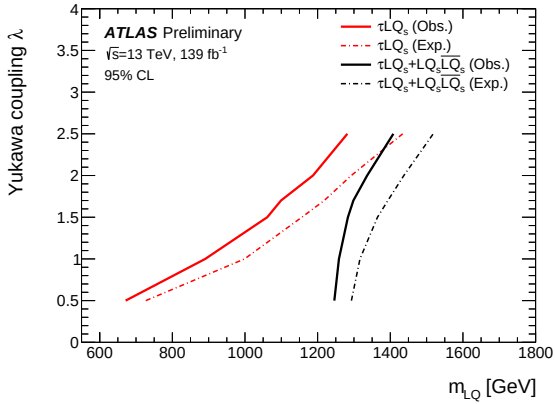
ATL-PHYS-PUB-2022-012

LQ search in bτ final state

ATLAS-CONF-2022-037

- 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 $b\tau$



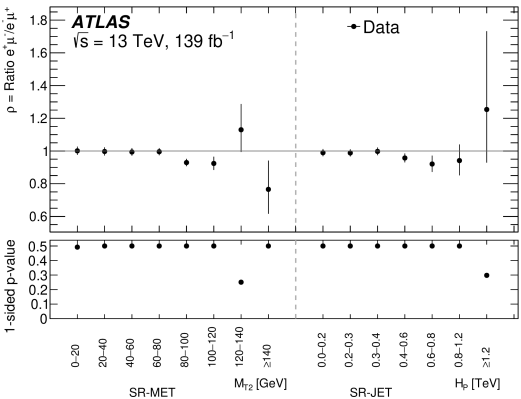


- First ATLAS result for the search of singly-produced LQ in bτ final state
- For singly+pair LQ production, masses below 1.25 TeV excluded for λ values > 0.5

Dilepton-ratio measurements

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

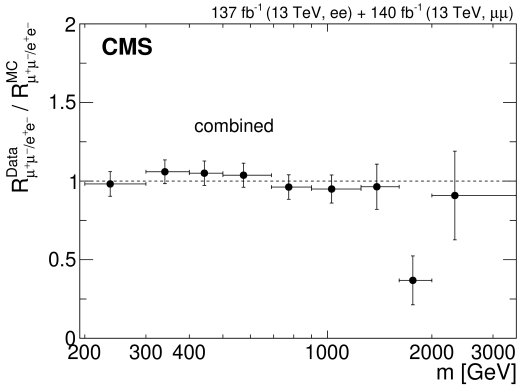
Phys. Lett. B 830 (2022) 137106



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

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

JHEP 07 (2021) 208



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

BSM can cause R to deviate from unity

- Still no sign of BSM physic observed

Summary

- 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 Liver 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