Exotic searches in CMS

07 Nov 2023 - Beyond Standard Model: From Theory to Experiment (BSM- 2023)

Francesco Romeo for the CMS collaboration

Why exotic searches are important

- Standard Model of particle physics is successful in its predictions, though it is incomplete and misses
  - Neutrino masses
  - Matter-antimatter asymmetry
  - Dark matter
  - Gravity
  - Unanimously satisfactory theoretical explanations to several aspects (naturalness, fermion masses, …)

- Several extensions of the Standard Model can address some of the above points
  - They foresee new particles, forces, dimensions, or symmetries
  - They provide quantitative predictions
  - Such predictions can be tested at LHC ($\sqrt{s}$ = 13(.6) TeV)

- Probe new physics from O(1) GeV to TeV scale

Where are we and where are we looking

- As Run 2 data taking (13 TeV and 138 /fb) has been completed
  - we have not found new physics in the most straightforward searches for heavy particles with current luminosity
    - there are some mild excesses
      I will discuss some of them
  - Current searches help us to constrain models and parameters and to point out unprobed regimes and hypotheses

- Yet a large untested territory where physics beyond the Standard Model may appear and
  CMS has a comprehensive program to investigate it. I will discuss some among the most recent searches
  - Dedicated experimental techniques to access lower mass / couplings
    → Trigger
    → ISR jet/photon
    → Long lived
  - Searches at higher mass / coupling related to anomalies in high-energy physics (g-2, RD/D*, …)
    → Leptoquark (LQ)
    → Vector-Like Leptons (VLL)
  - Unprecedented analyses
    → Heavy neutrinos
    → Inelastic dark matter

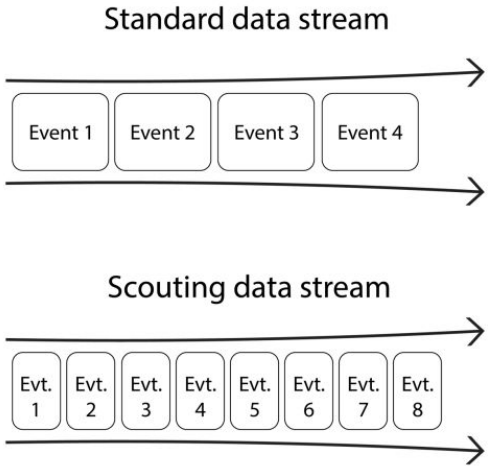
- I will not be able to cover all analyses.
  SUSY searches covered in talk from Emery Nibigira
  Please see CMS scientific results page for more results and summary plots.

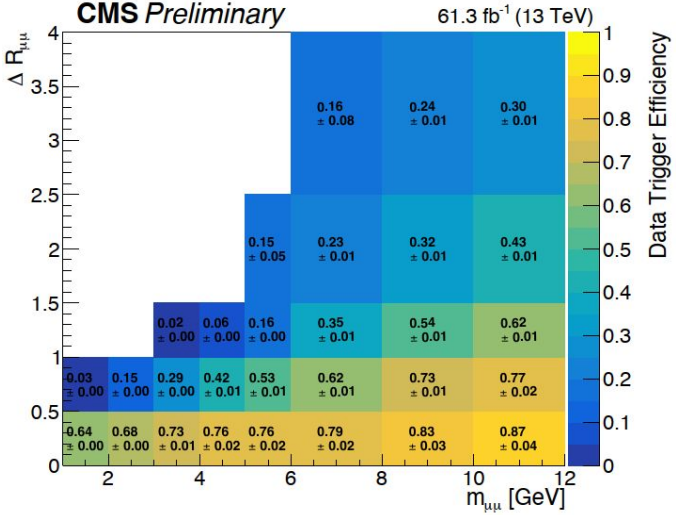
Optimal use of trigger selection for low mass searches (link)

- With pp collisions at 13(.6) TeV, natural to search for O (1) TeV resonances

- However, possible to access very low mass region revising trigger selection:
  Swap event size with number of events, for the same band width (scouting)

- As a physics case, collect only muon information and reduce the momentum threshold in dimuon triggers (from 17 to 3 GeV)
  (4-8 kB/event instead of 1MB) at higher rate (2kHz instead of 0.45kHz)

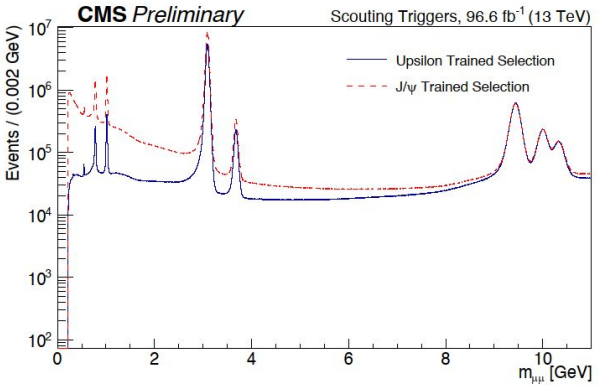




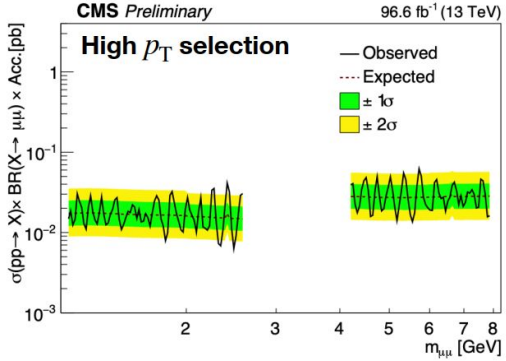
- High trigger efficiency for dimuons mass < 12 GeV

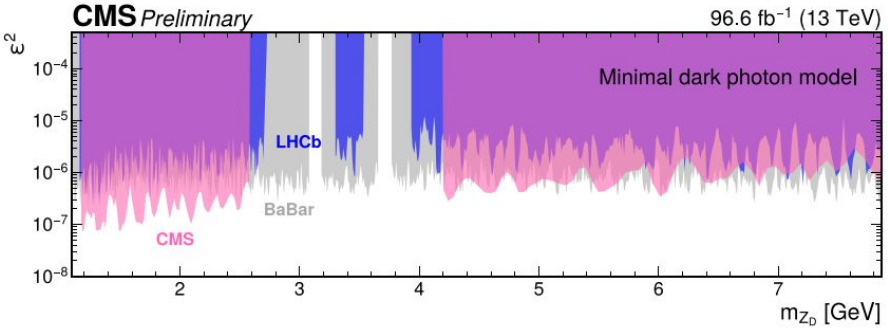
Searches for mass resonances at O(1-10) GeV (link)

- Select two muons with pT>4 GeV and |eta|<1.9



Identification optimized using known resonances
Upsilon (J/ψ) above (below) 4 GeV



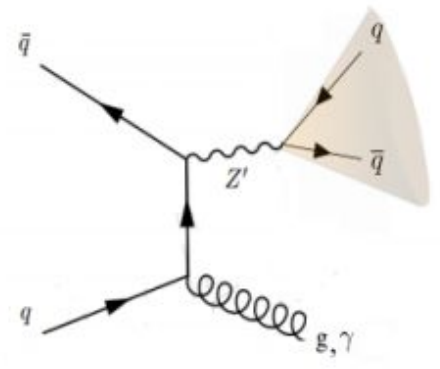


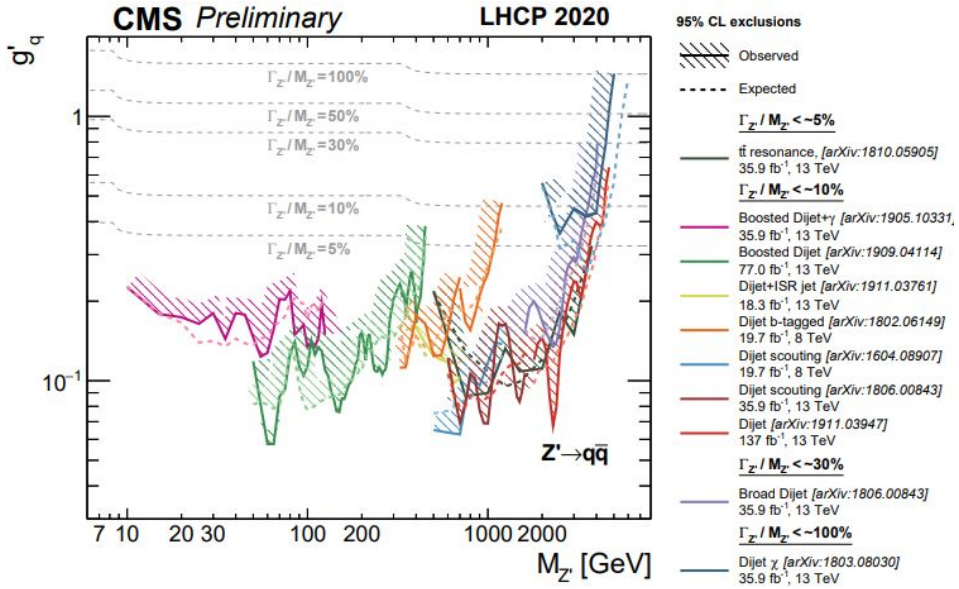
- Competitive with LHCb
- Largest excess at 2.41 GeV (1.27 σ global).
  LHCb reports 3.1 σ at 2.42 GeV (link)

Searches for mass resonances at O(10-100) GeV and above

- To comply with jet trigger requirements, whose threshold is several hundreds GeV we exploit unique topology of lorentz-boosted resonances produced in association with a photon or a jet

- X→ab, DR(ab) >~ 2 m(X)/pT(X)
  DR(ab) within 0.8 (0.4) when pT(X) ~ pT(g/γ) > 2.5 (5) m(X)
  single jet with multi-prong structure → low background



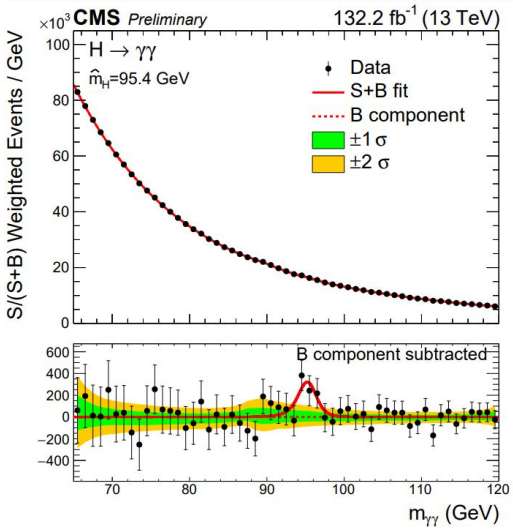


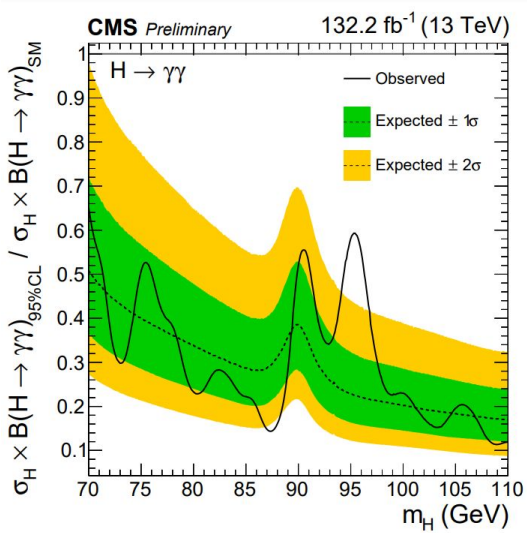
- Sensitive to O(10-100) GeV for photon emission

- Can combine with scouting (Dijet+ISR jet)

Low mass H→diphoton (70-110 GeV) search (link)

- Photon pT>30,18 GeV (clean signature and good mass resolution)
- Event selection optimized for ggH, VBF, VH, ttH modes
- Extraction of signal through fit of di-photon invariant mass spectrum for each event class



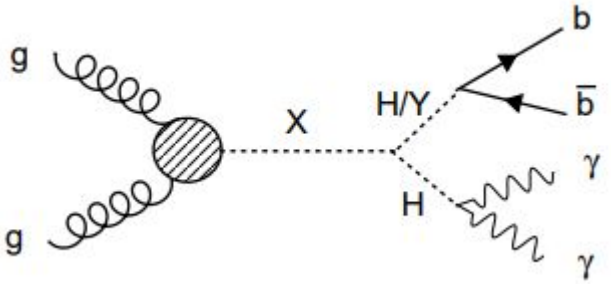


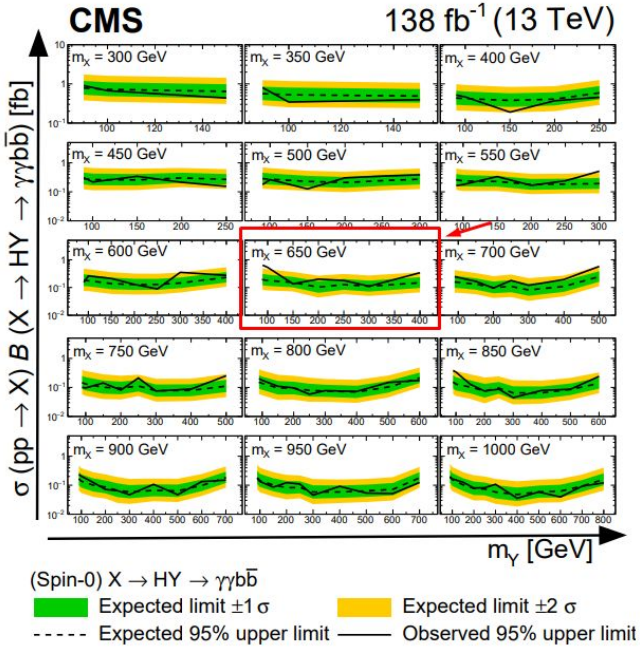
- Excess with approximately 2.9σ local (1.3σ global) significance is observed for a mass hypothesis of 95.4 GeV

X→H (→) diphoton plus H/Y (→) dibottom search (link)

- 100 < M(γγ) < 180 GeV
- pT (jets) > 25 GeV, |η(jets)| < 2.5
  70 < M(jj) < 190-1200 GeV

- ttH (resonant) and γ(γ)+Jets (non-resonant) backgrounds rejected with dedicated neural network event tagger



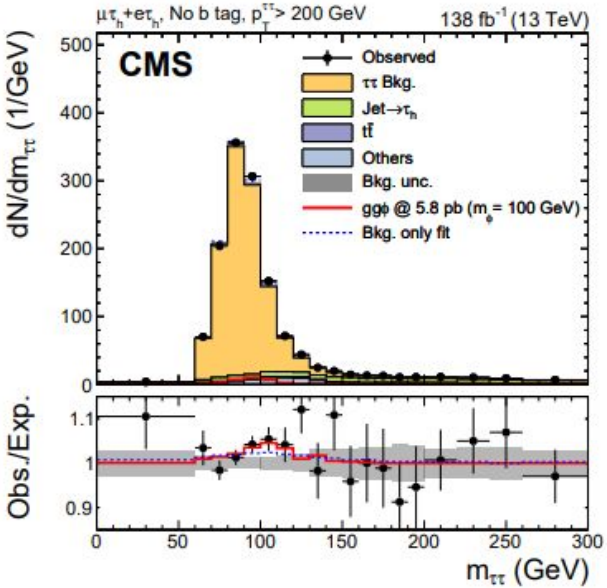


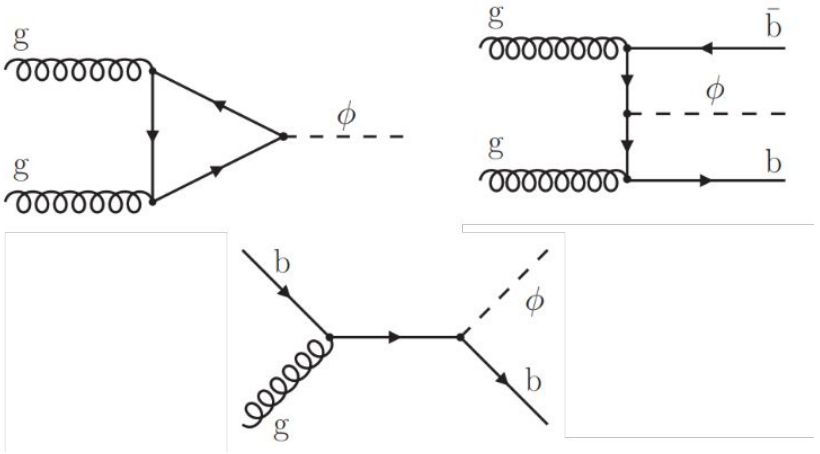
- The largest deviation from the background-only hypothesis with a local (global) significance of 3.8 (2.8) σ is observed for X and Y masses of 650 and 90 GeV, respectively.

X→tau tau (> 60 GeV) search (link)

- τh τh , e τh , μ τh , e μ channels
  b tag categories

- Ditau background modelled relying on lepton universality
  Replaced μ with τh in data events (embedding method)
- j→τh contamination estimated parametrizing the fake-rate



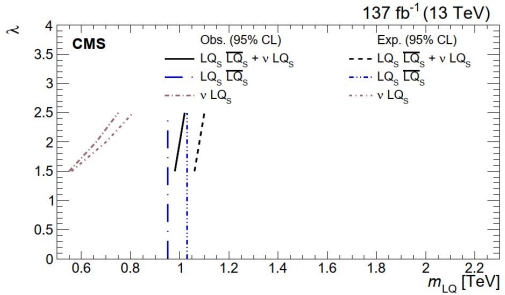


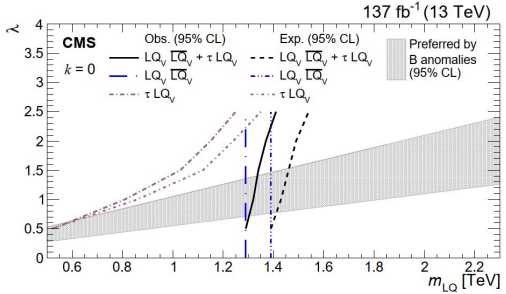
- For the low-mass search, the largest deviation from the expectation is observed for ggϕ production at mϕ = 100 GeV with a local (global) p-value equivalent to 3.1 (2.7) σ.

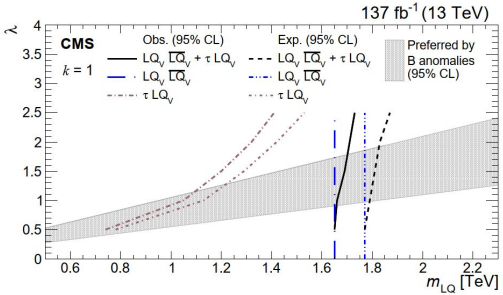
Search for LQs (LQv) → t tau (t v), b nu (b tau) ([link])

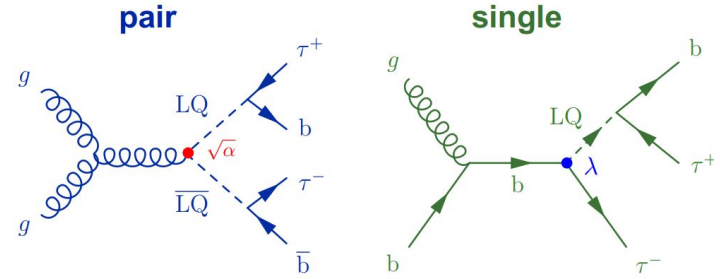
- Full hadronic analysis
  1 tauh
  >= 1 top candidate (resolved or boosted)
  Event categories w.r.t b and top quarks

- j→τh contamination estimated parametrizing the fake-rate









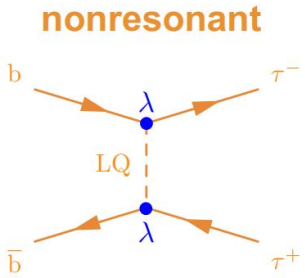
- large,
- model independent

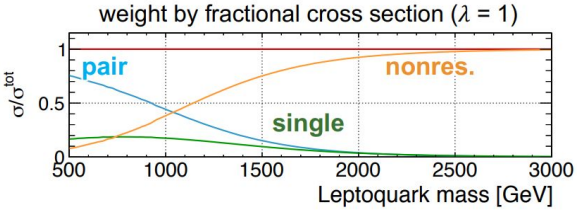
- $\sigma \propto \lambda^2$
- b-PDF suppression
  width $\propto \lambda^2$

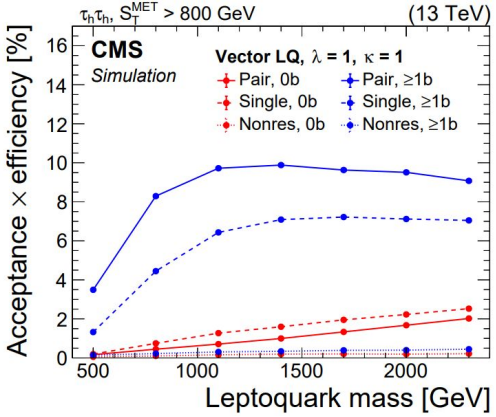
- Constrain region of phase-space relevant for flavor anomalies

Search for LQ coupling to tau b (link)

- Combine pair, single, t-channel nonresonant
- τh τh , e τh , μ τh , e μ channels
  b tag categories



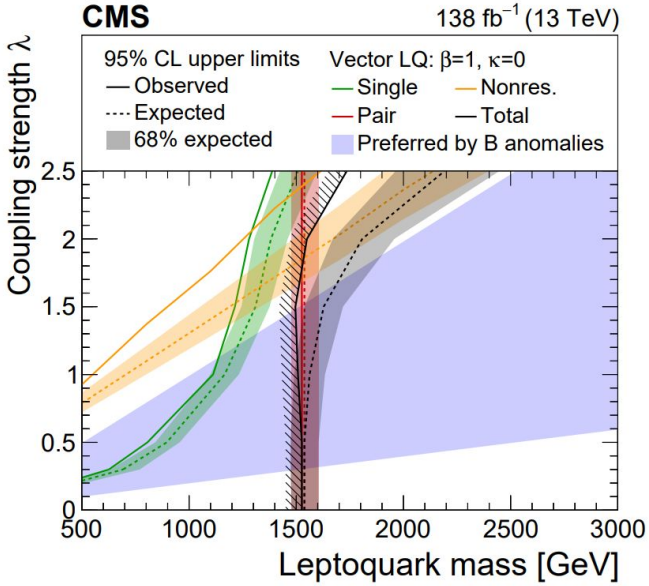




- 🥵 $\sigma \propto \lambda^4$
- 😱 PDF suppression ^ 2
- 😰 wide resonance

  but kinematics largely independent of λ and mass

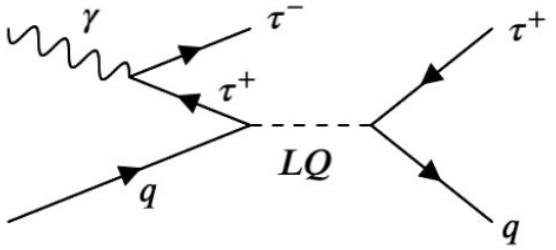
  dominant at high mass

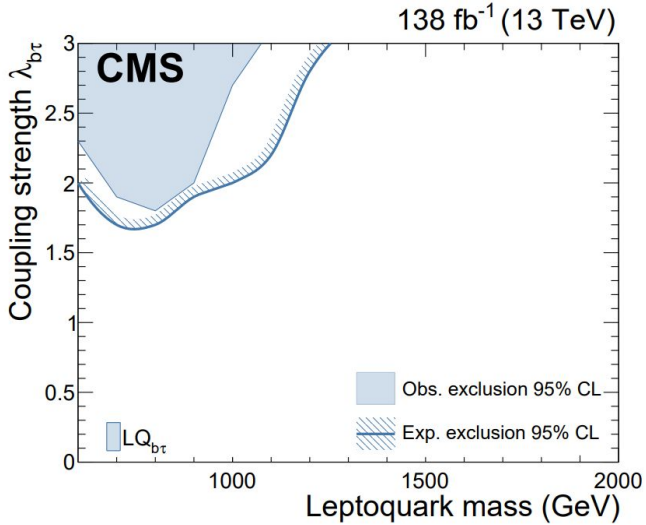


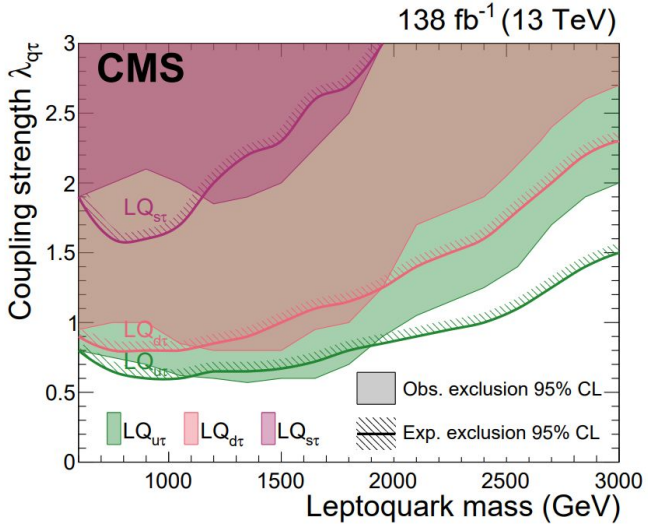
- Constrain relevant region of phase-space relevant for flavor anomalies
- For LQ mass of 2 TeV and an LQ-b-τ coupling strength of 2.5, the excess reaches a local significance of up to 2.8 σ.

Search for LQ coupling from lepton-quark collisions (link)

- LQs may be produced from a lepton-quark collision (J. Ohnemus et al., 1994)
  Recently feasible due to an improved estimate of the lepton density function (LDF) (L. Buonacore et al., 2020)
- First search at CMS this year
  τh q , e q, μ q plus b and non b categories

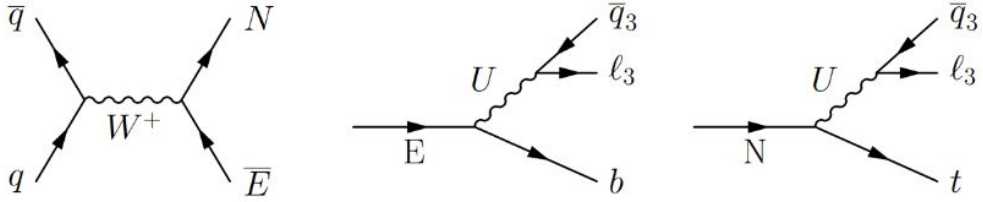






- No excess
- Exclusion in cross-generation lepton-quark couplings

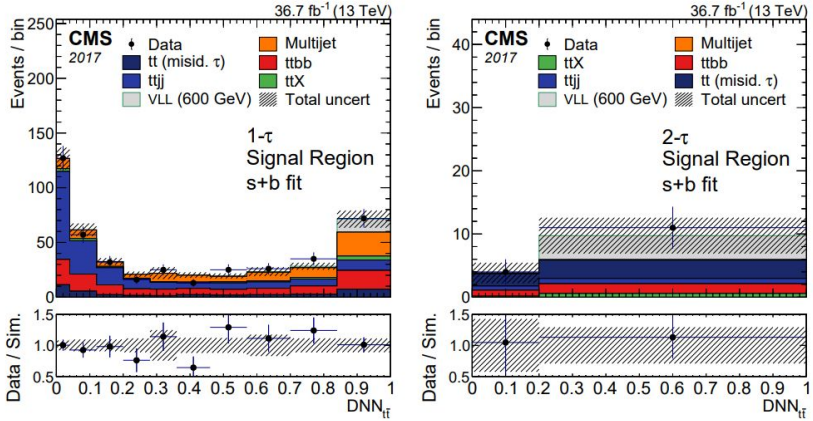
Vector like lepton searches with tau (link)

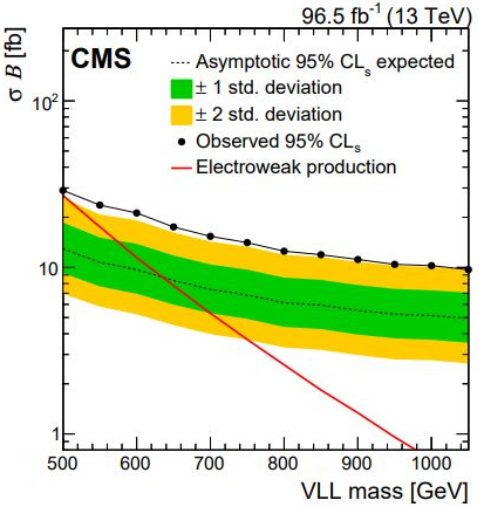


Decay via LQ

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

- Jet multiplicity and graph neural network (kin and geometrical variables) to select events against dominant multijet and ttbar events

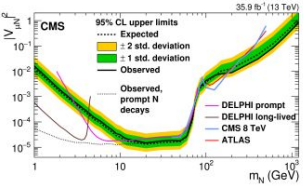


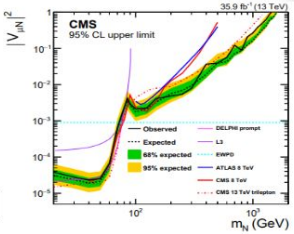


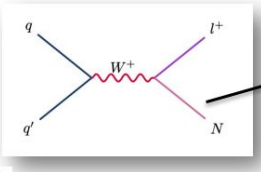
- Data shows an excess of 2.8 σ for both the 1-τh and 2-τh channels at the representative VLL mass point of 600 GeV.

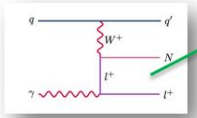
Search for Heavy Neutrinos at very high mass-couplings (link)

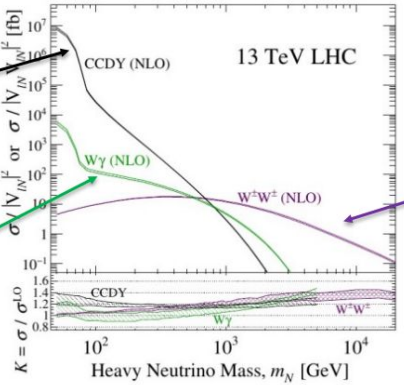
Phys. Rev. D 103, 055005



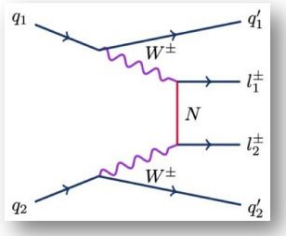




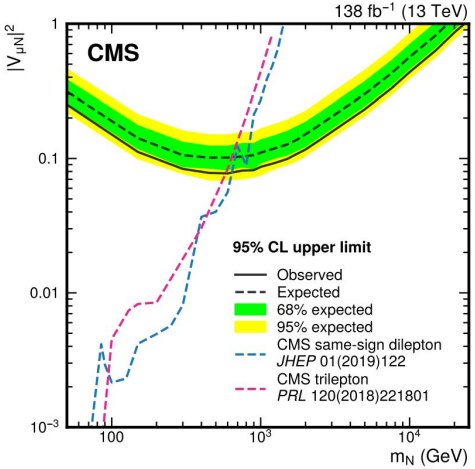




The t-channel production have more sensitivity at higher mass phase space

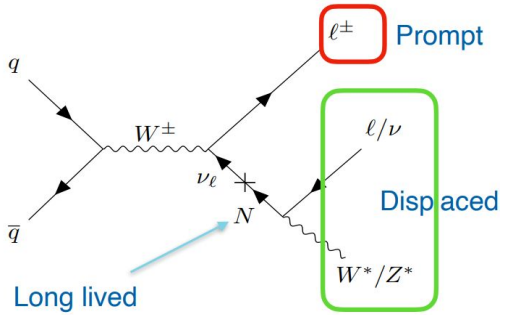


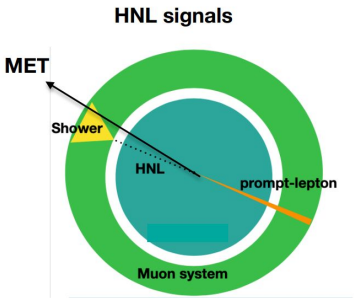
- 2 same-sign muons
- b quark veto
- VBF topology
  - |delta_eta_jj|>2.5
  - m_jj>750 GeV



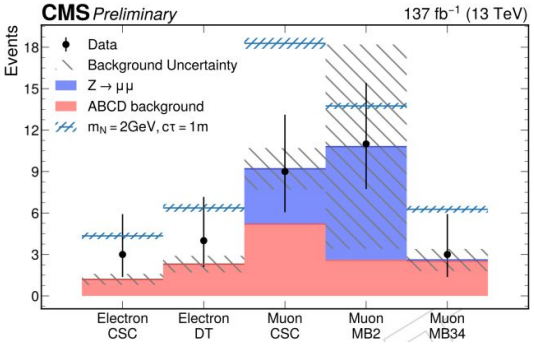
- Results are consistent with the predictions from the Standard Model
- Upper limits on the mixing element |VμN| 2 are set for the mass range 50 GeV < mN < 25 TeV and the best sensitivity is reached for mN ≳ 650 GeV

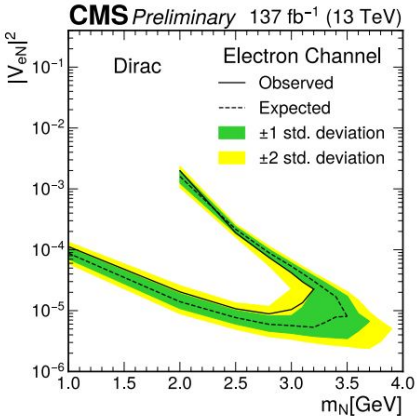
Search for Heavy Neutrinos at very low mass-couplings (link)

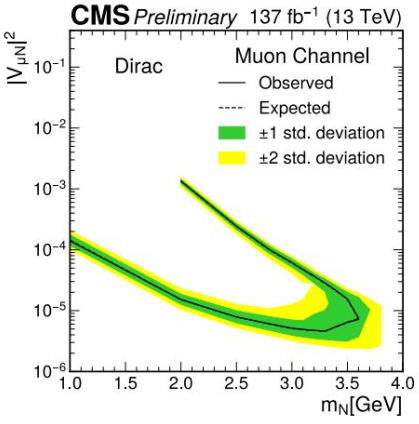


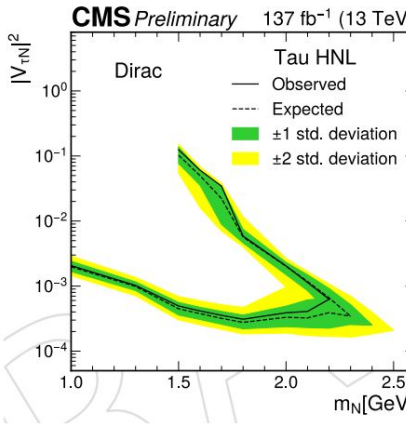


- Trigger on prompt lepton
- Displaced N in muon system
- Cluster size (Nhit) as discrimination
- ABCD method, deltaPhi(lep,cluster) and cluster size





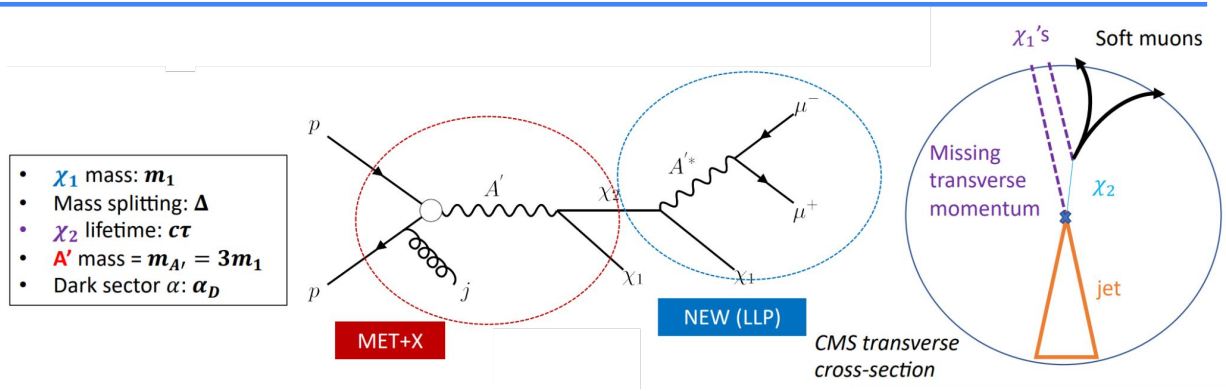


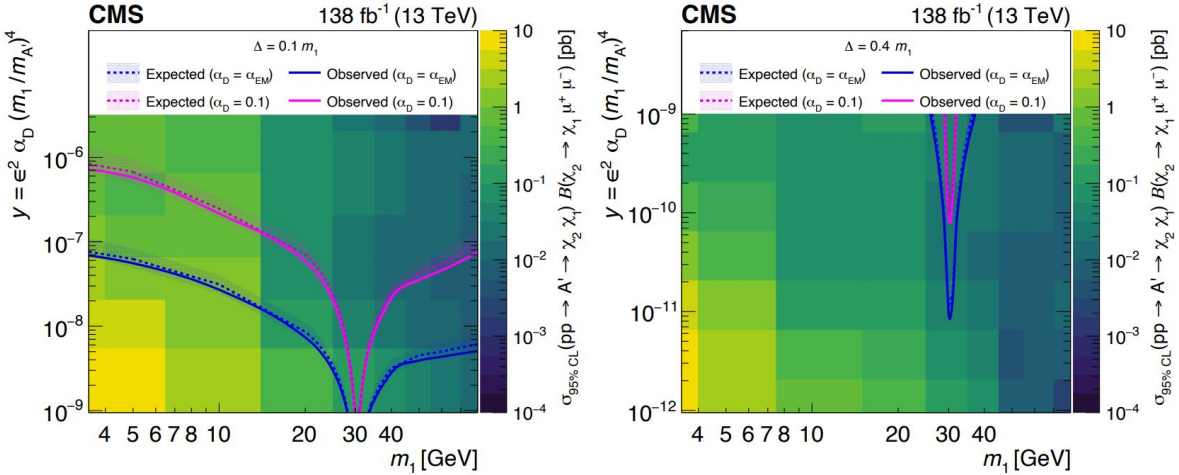


- No excess over SM
- Extends current sensitivity by ~1.3x to ~2.3x at 2 GeV
- Sensitive to all three lepton flavors

Search for inelastic dark matter (link)

- Dark matter model involving dark sector
- Inelastic (off-diagonal) coupling between χ_1 and χ_2
- Mass degenerate (small Δ) —> increased lifetime of heavier state and soft muon
- Trigger on missing transverse energy





- No excess
- Sensitivity to m_1 above the GeV scale
- First dedicated collider search for inelastic dark matter

Conclusion and remarks

- With about 5% of the total expected luminosity by the end of LHC already analyzed we have
  - verified that new physics is not showing up in the most straightforward searches for heavy particles, with current luminosity
  - constraining beyond SM models parameters

- However, there is still a lot to investigate in the full energy regime of LHC. This may require to rely on sophisticated experimental techniques at different levels
  - Trigger
  - Reconstruction
  - Analysis (machine learning more and more important, unsupervised / weakly supervised searches to come)

  novel phenomenology ideas
  - Unprobed phase-space
  - New mechanisms and signatures

- CMS has a broad and exciting program to continue the hunt for new physics
  - Some analyses in Run 2 reported mild excesses and will require ongoing Run 3 data taking (13.6 TeV and 67 /fb so far) and High-Luminosity data analysis to be clarified.