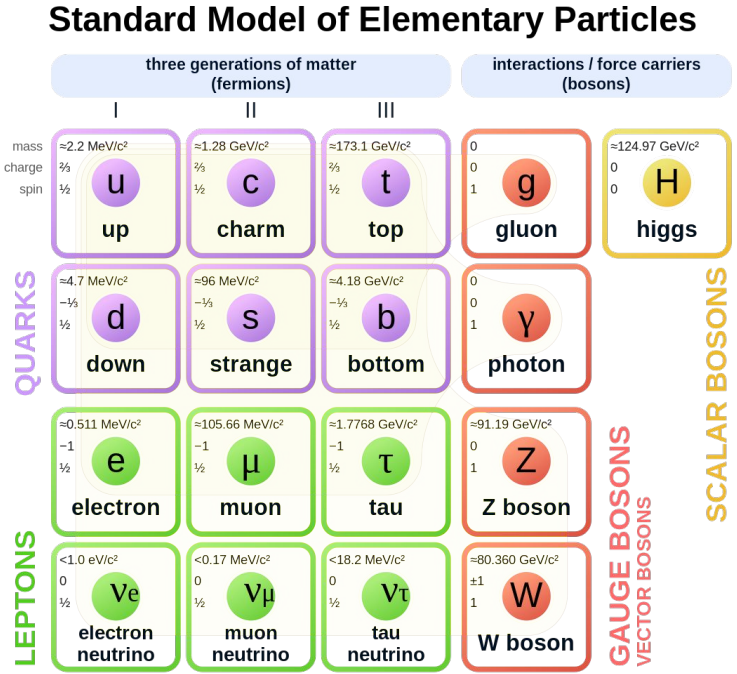
Searches for new physics in CMS in events with jets, leptons and photons in the final state

Andrew Hart (Rutgers University)
on behalf of the CMS Collaboration

Standard model: success and shortcomings

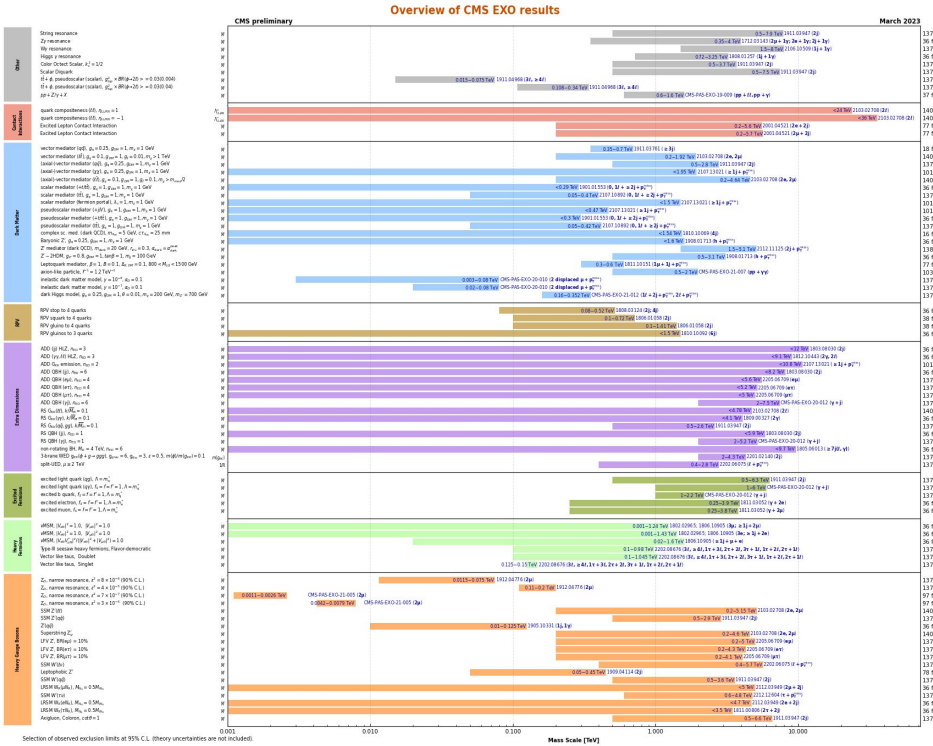
- The standard model (SM) of particle physics has been extremely successful over its ~five decades:
  - With the discovery of the Higgs boson in 2012 by CMS and ATLAS, all predicted particles have been observed!
- Not a complete theory though!
  - No gravity, dark matter, or dark energy
  - Somewhat inelegant
    - Electroweak hierarchy problem
    - Strong CP problem
    - 19 *ad hoc* constants that have to be measured experimentally
  - Some tensions with experiments
    - Anomalous magnetic dipole moment of the muon
    - W boson mass
    - ...



Beyond the SM

- Huge variety of models for beyond the SM (BSM) physics proposed to address shortcomings:
  - Huge variety already explored at the LHC!
- In this talk, we will see some of the most recent searches from CMS in events with jets, leptons, and photons in the final state:
  - All results from Run 2 data:
    - 138 fb^{-1} @ $\sqrt{s}$ = 13 TeV
- Overlaps with other talks at LP:
  - See talk by M. Chen for more direct searches for BSM resonances
  - See talk by V. Sharma for searches for dark matter in CMS
  - See talk by D. Diaz for searches for long-lived particles in CMS
  - See talk by B. Kilminster for searches for leptoquarks in CMS

Click here to zoom in

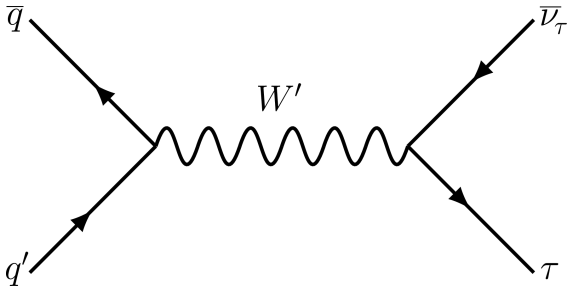


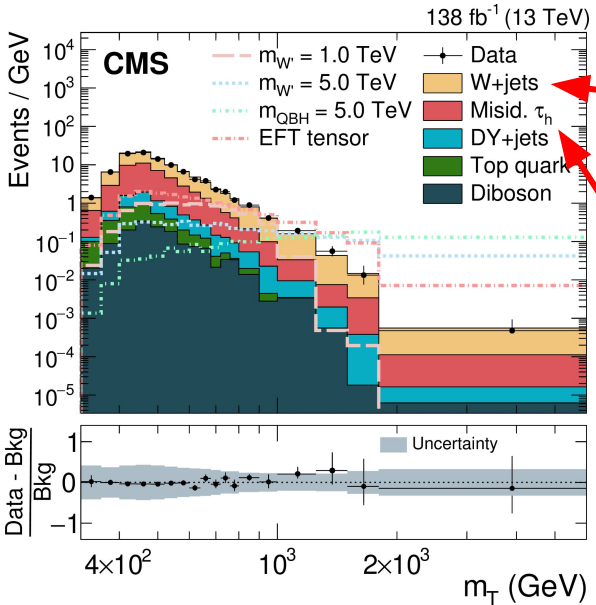
Nonresonant searches

CMS-EXO-21-009
arXiv:2212.12604

τ lepton + missing momentum

- Search for events with a hadronically decaying τ lepton (τ_h) and high missing transverse momentum (p_T^{miss})
- Benchmark model:
  - Heavy charged vector boson W' → τν





Main irreducible background

Jets misidentified as τ_h also significant background

Misidentification rate estimated from signal-free control region in data

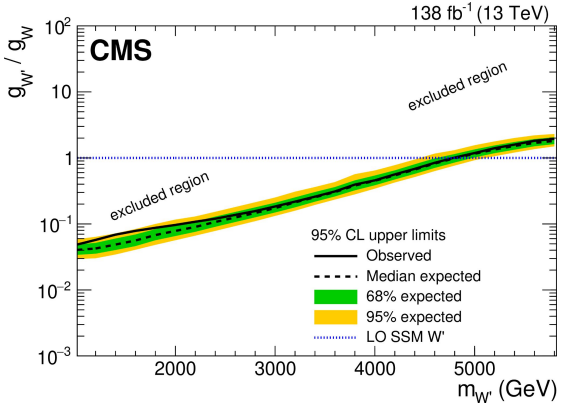
All other backgrounds taken from simulation

- Strategy:
  - Trigger requires at least one τ_h or high p_T^{miss}
  - Offline, hadronically decaying τ identified with DeepTau ID
    - p_T > 190 GeV (130 GeV in 2016)
  - p_T^{miss} > 200 GeV
  - Transverse mass (m_T) used as discriminating variable

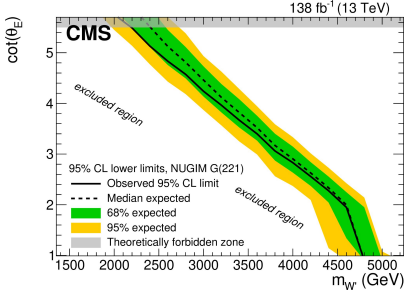
CMS-EXO-21-009
arXiv:2212.12604

τ lepton + missing momentum

- Data agree well with estimated backgrounds
- Limits placed on coupling ratio of W' and W ($g_{W'} / g_W$) versus $m_{W'}$:
  - W' up to 4.8 TeV excluded in sequential SM (SSM) ($g_{W'} = g_W$)

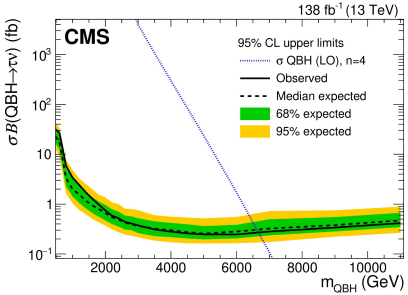


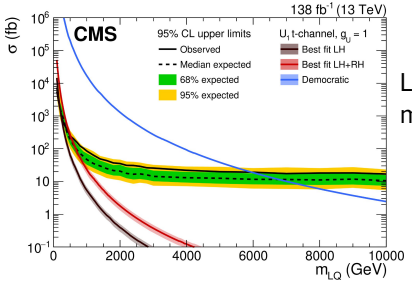
- Results also interpreted within several other models!



Nonuniversal gauge interaction model G(221)
$m_{W'} < 2.2$ TeV for all values of θ_E

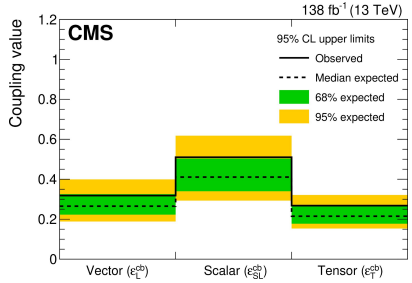
Quantum black holes
$m_{QBH} < 6.6$ TeV





Leptoquarks
$m_{LQ} < 5.9$ TeV (democratic)
< 205 GeV (best-fit LH)
< 515 GeV (best-fit LH+RH)

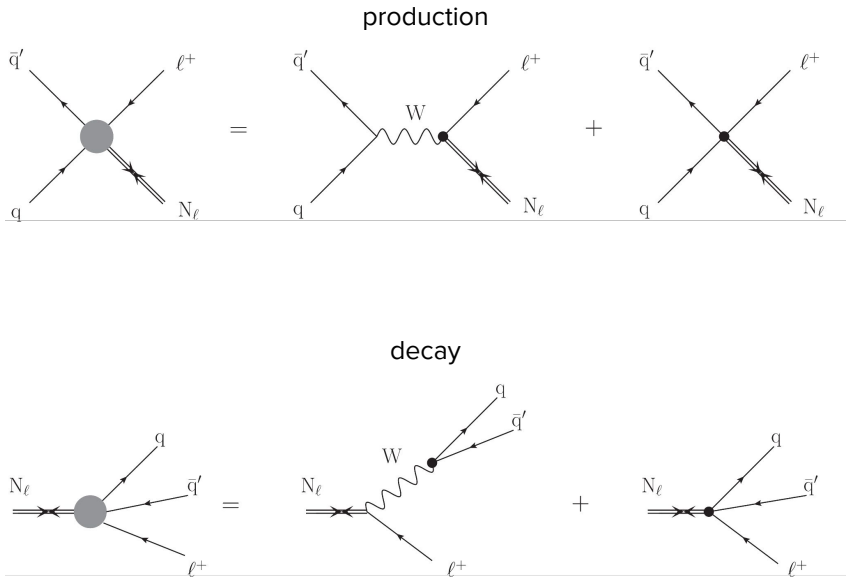
Effective field theory



CMS-EXO-20-011
arXiv:2210.03082

Composite Majorana neutrino

- Composite fermions are one possibility for BSM physics
- N_l = excited neutrino state:
  - Both contact and gauge interactions with ground states
  - Search for events with two same-flavor leptons and a large-radius jet
- Strategy:
  - Events pass single-e or single-μ triggers
  - Two high-p_T leptons of same flavor required offline
    - Leading (subleading) p_T > 150 (100) GeV
    - Invariant mass > 300 GeV
  - Large-radius jet (J) with p_T > 190 GeV
  - m(llJ) used as discriminating variable
    - Peaks at m(llJ) ≥ m(N_l)



CMS-EXO-20-011
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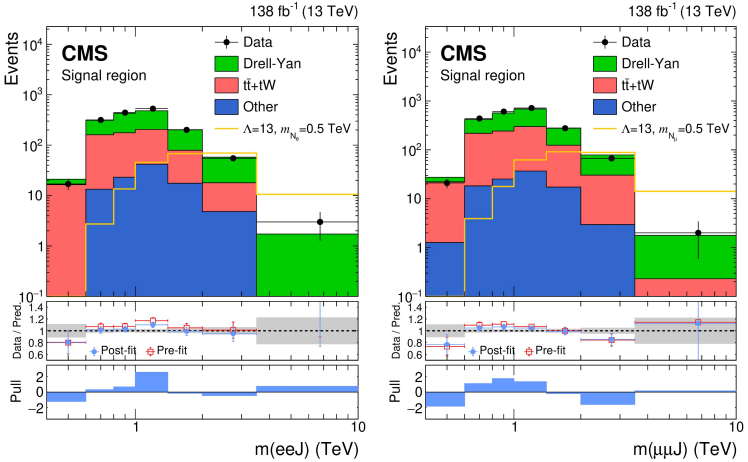
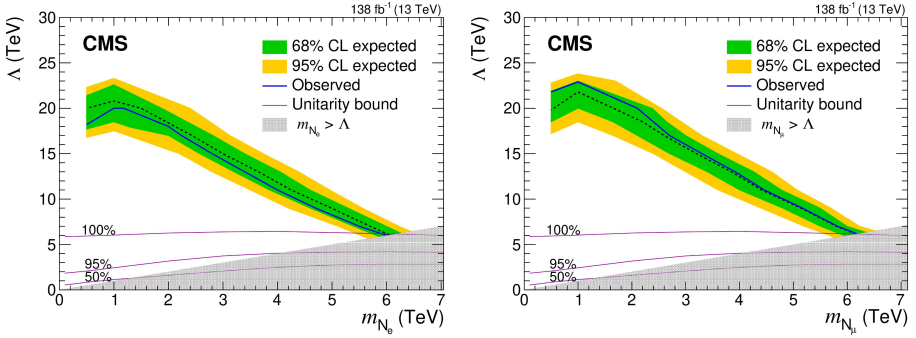
Composite Majorana neutrino

- Background estimates taken from simulation:
  - Shape for Drell-Yan corrected using data-driven scale factors
  - Drell-Yan and top quark control regions included in fit to data to constrain these backgrounds



- No significant excess observed in data



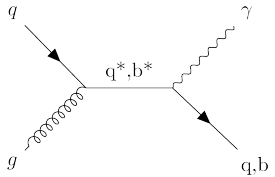
- For masses equal to compositeness scale (Λ), N_e (N_μ) excluded up to 6.0 (6.1) TeV
  - Improves limit on this class of resonances by more than 1 TeV!

Resonant searches (“bump hunts”)

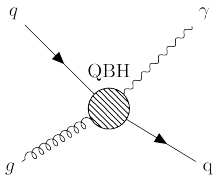
CMS-EXO-20-012
arXiv:2305.07998

γ-jet resonance

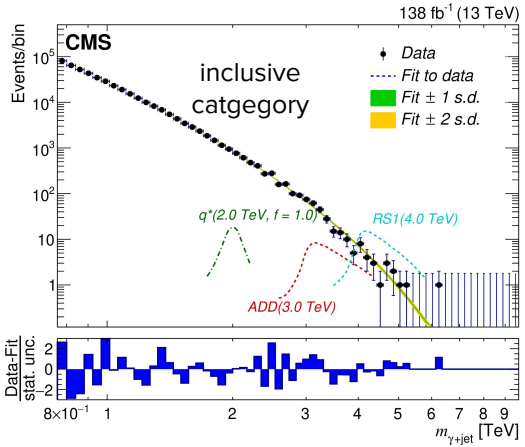
- Search for resonances in γ-jet final state
- Two models explored:
  - Excited states of light quarks (q*) or heavy flavor quarks (b*)

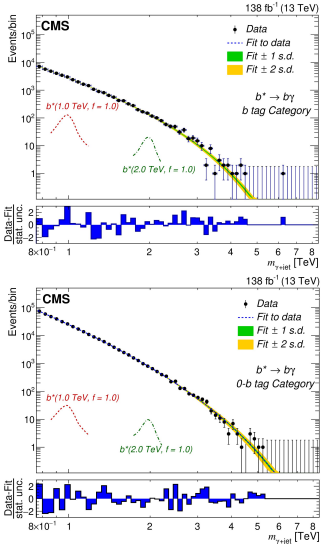


  - Quantum black holes (QBH)



- Strategy:
  - Events collected with single-photon triggers
  - Offline, γ with p_T > 240 GeV required
  - Wide jet with p_T > 170 GeV required
    - Narrow jets within ΔR < 1.1 clustered together
  - Invariant mass of highest-p_T γ and highest-p_T jet ($m_{\gamma+jet}$) used as discriminating variable



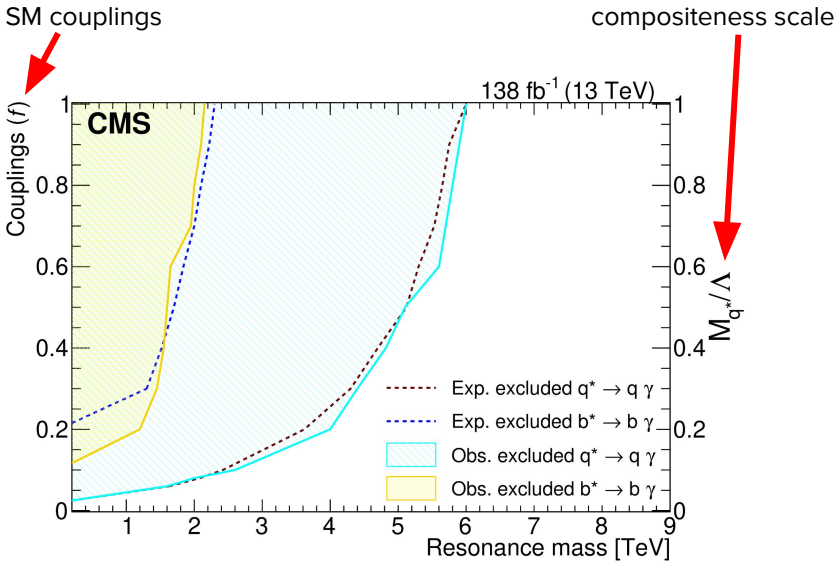


b-tagged categories for b* search

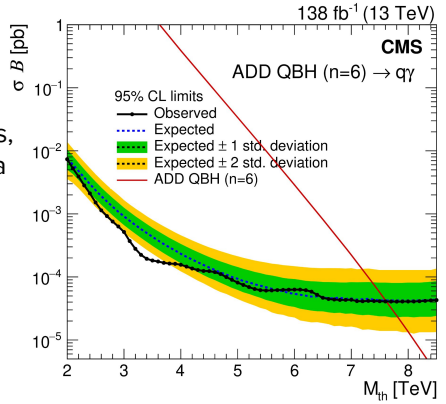
CMS-EXO-20-012
arXiv:2305.07998

γ-jet resonance

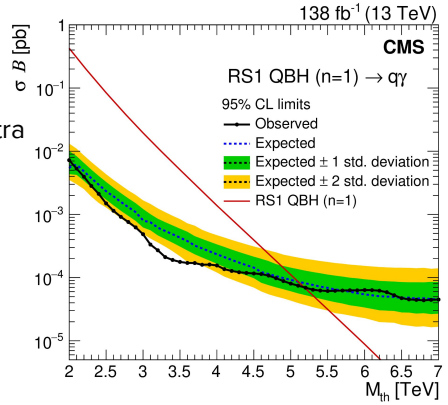
- Results consistent with expected background
- Limits placed on excited quark models and two varieties of QBM models



Arkani-Hamed, Dimopoulos, and Dvali (ADD) with 6 extra dimensions



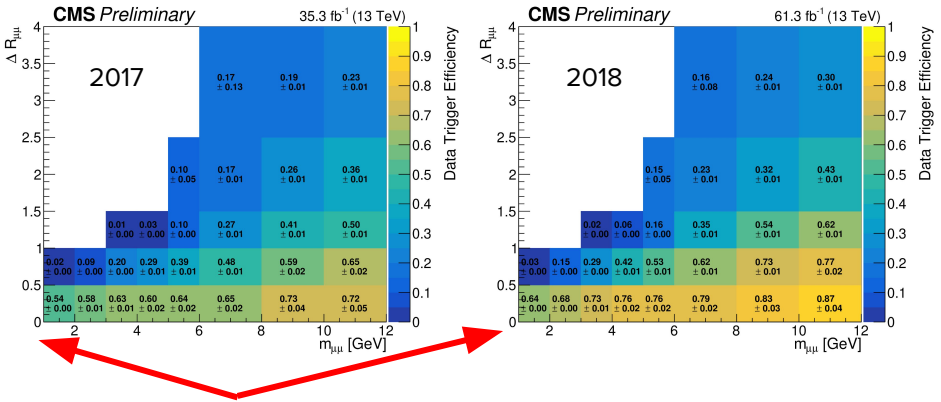
Randall–Sundrum with 1 extra dimension (RS1)



GeV-scale dimuon resonance

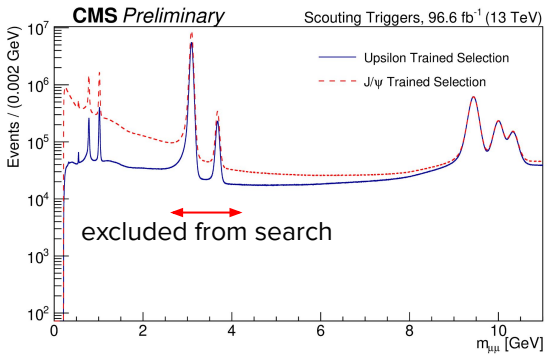
- Search for low mass resonances decaying to two oppositely charged muons:
  - Could act as a portal between SM fields and an unknown dark sector
- Strategy:
  - Unique trigger strategy!
    - High-rate "*scouting*" triggers
    - Trigger requires two muons with $p_T > 3$ GeV
      - Much lower p_T than more conventional triggers
  - Two prompt, oppositely charged muons required offline
    - MVA used to select well-reconstructed muons
  - Dimuon invariant mass used as discriminating variable

data efficiency for high-rate "*scouting*" triggers



Some trigger seeds require small separation between muons

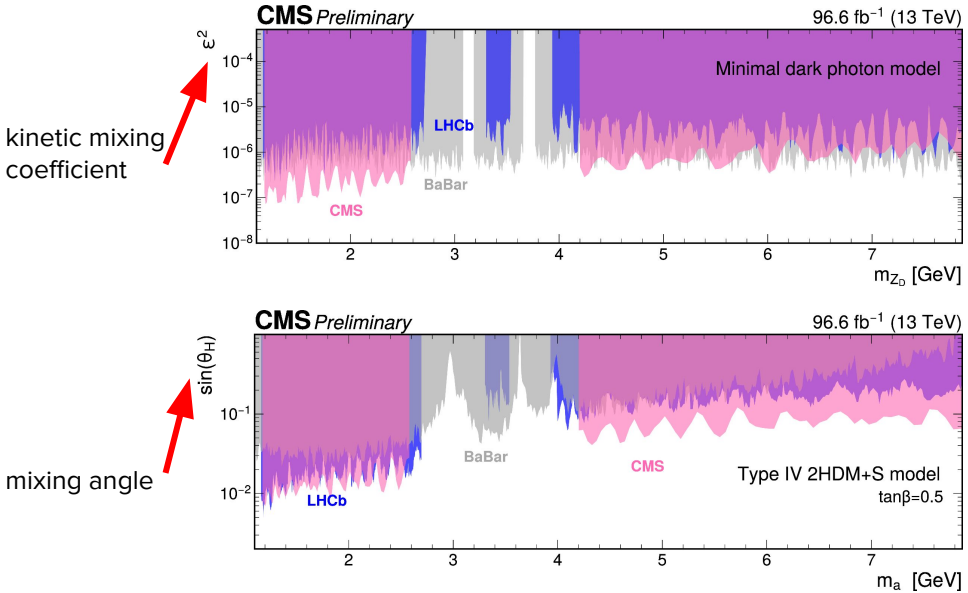
MVA trained on J/ψ (Υ(1S)) for lower (higher) masses



CMS-PAS-EXO-21-005

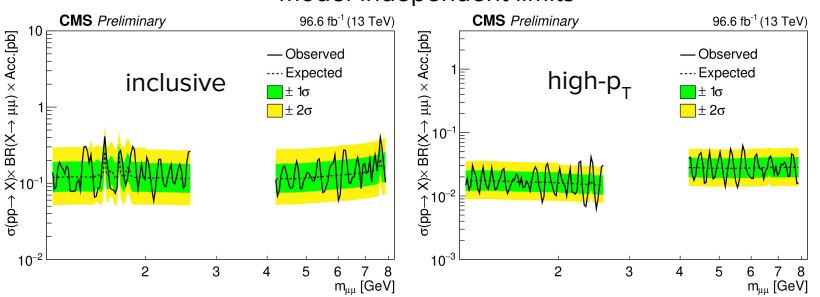
GeV-scale dimuon resonance

model-dependent limits



- High-p_T selection targets pseudoscalars produced via gluon fusion:
  - $p_{T\mu\mu}$ > 35 (20) GeV in lower (higher) mass regions
- Excess observed in high-p_T selection at 2.41 GeV:
  - Local (global) significance of 3.2 (1.3) σ
  - Coincides with 3.1-σ excess observed by LHCb in comparable analysis

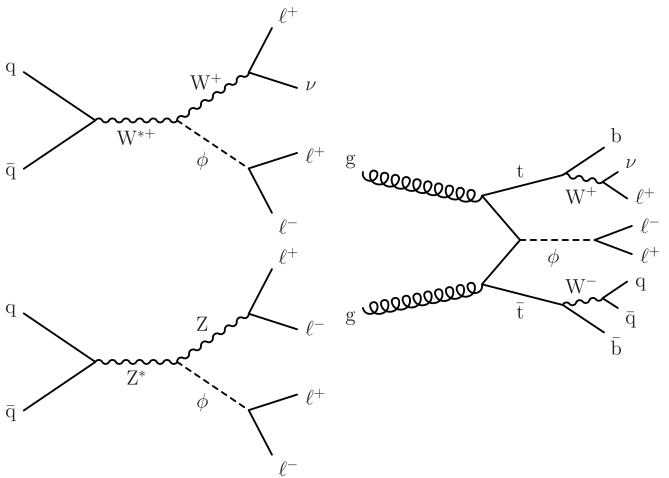
model-independent limits



CMS-PAS-21-018

Associated production of dilepton resonance

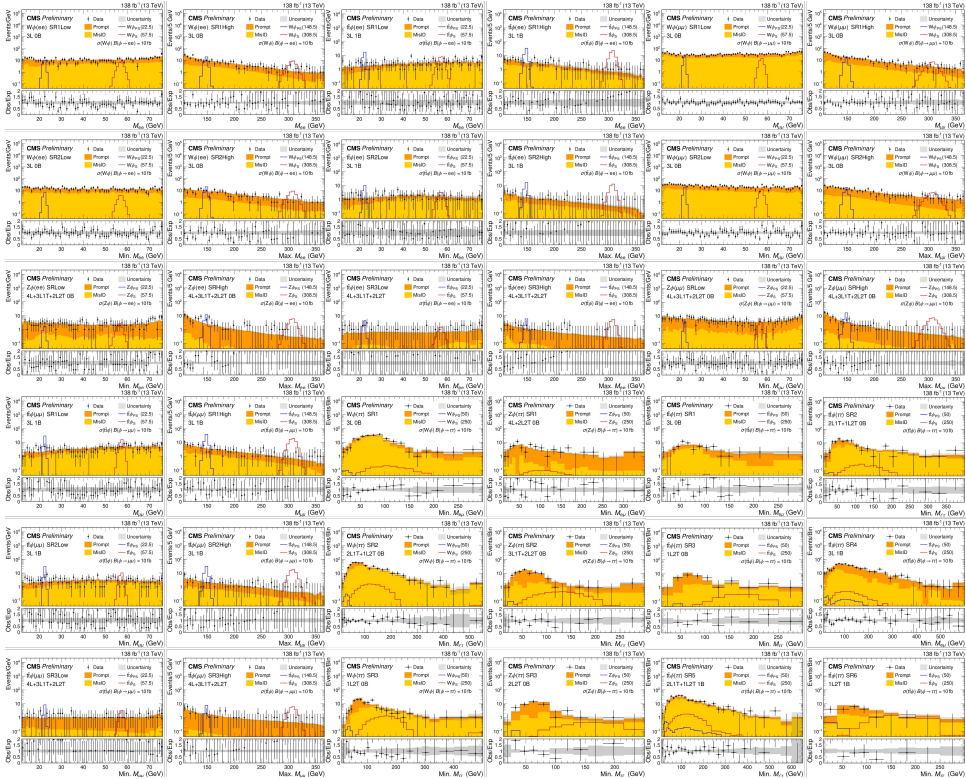
- Search for dilepton (pseudo)scalar resonance (φ) produced with a W, Z, or top quark pair:
  - W/Z decays to charged leptons
  - At least one top quark decays leptonically



- Strategy:
  - Events collected with single-electron or single-muon triggers
  - Seven channels:
    - 4 leptons: 1–4 light leptons, 0–3 τ_h
    - 3 leptons: 1–3 light leptons, 0–2 τ_h
  - Same-flavor dilepton mass used as discriminating variable
- Two types of background:
  - Prompt leptons and leptons from conversions:
    - Mostly from WZ, ZZ, Zγ, ttZ
    - Estimated from simulation
    - Normalized and corrected in dedicated control regions
  - Fake leptons:
    - Fake rate estimated from lepton isolation sidebands in data

Associated production of dilepton resonance

- Separate signal regions above and below Z mass
  - 36 signal regions defined depending on production and decay modes
- No statistically significant deviation from background observed
- Largest excess in high-mass Zφ(ee) region at 156 GeV:
  - Local (global) significance of 2.9 (1.4) σ
- Limits set on scalar, pseudoscalar, and Higgs-like signal models



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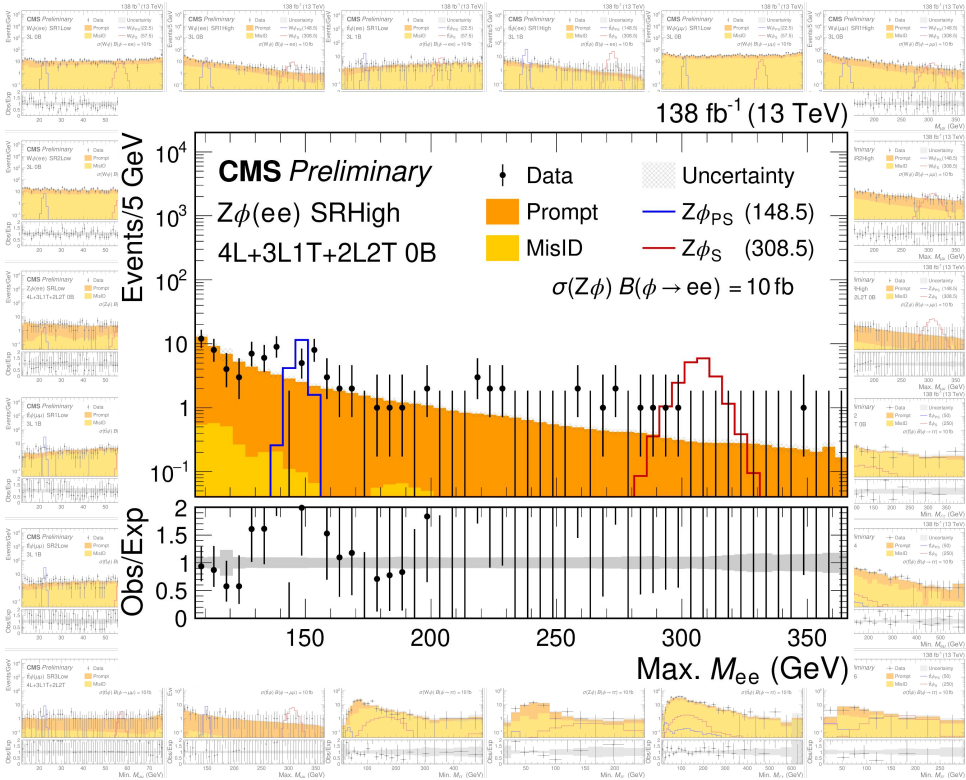

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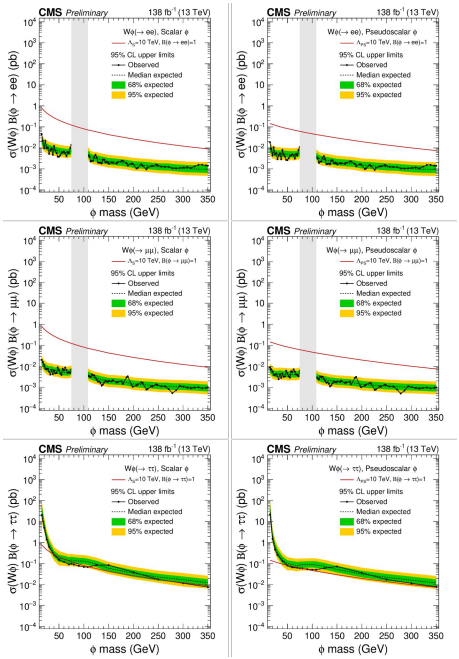
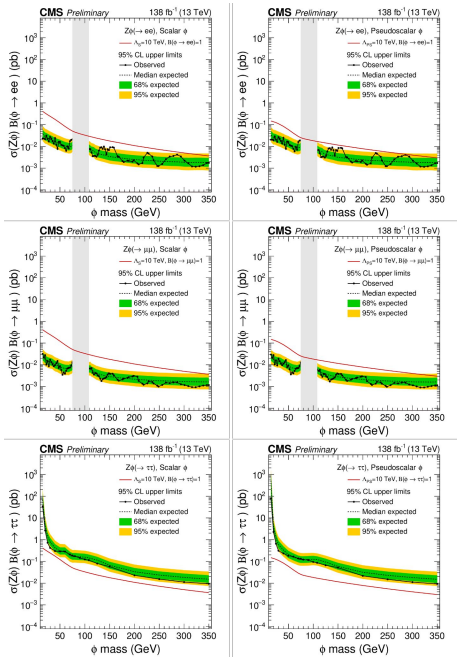
Wφ(scalar/pseudoscalar)



Zφ(scalar/pseudoscalar)



CMS-PAS-21-018

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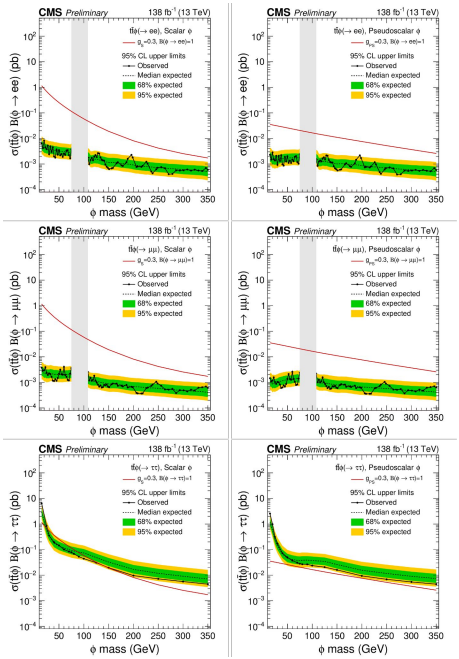
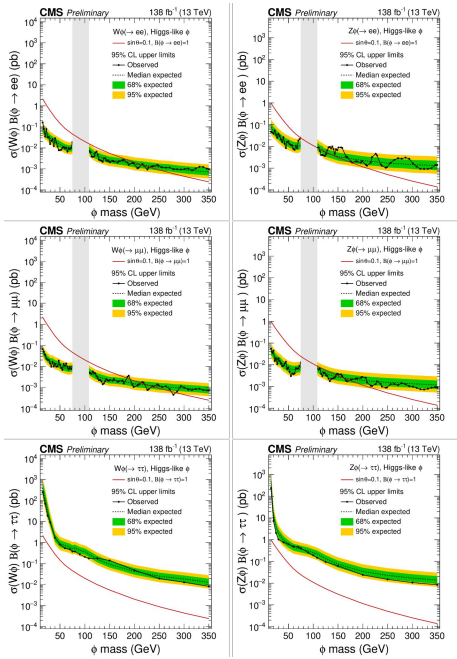
ttφ(scalar/pseudoscalar)



Higgs-like φ



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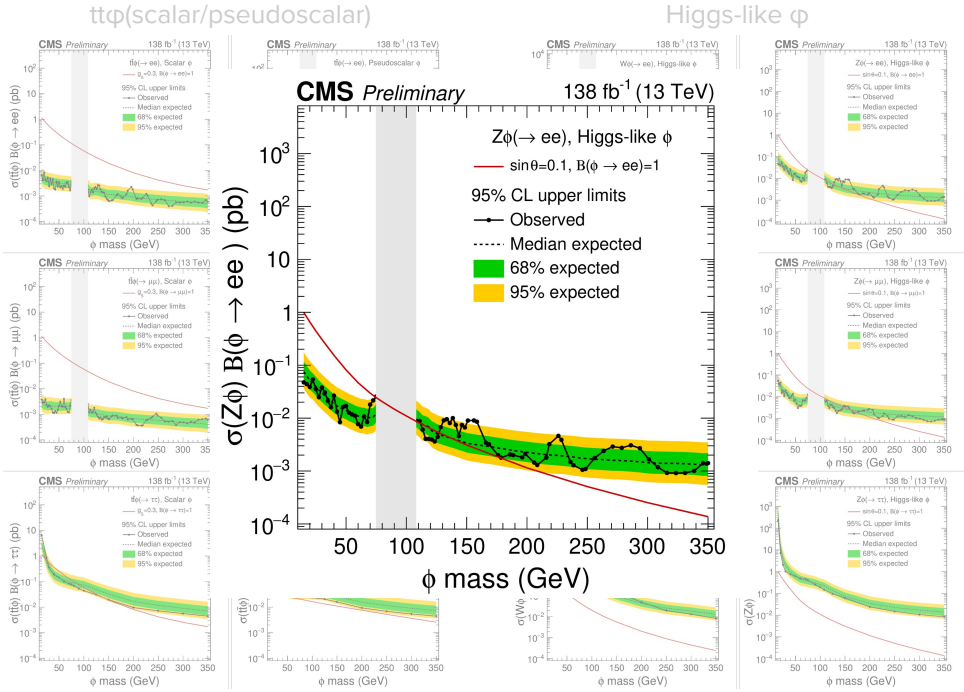

CMS Exotica publications
Recent preliminary results

Conclusion

- CMS has a broad program searching for BSM physics in whatever form it may take
- Here we have seen a selection of recent results from searches in events with jets, leptons, and photons in the final state:
  - No statistically significant excesses seen… yet!
  - Most searches here are statistically limited, especially at higher masses
    - Sensitivity will improve quickly with more data
- Currently in Run 3:
  - ~65 fb^{-1} so far @ $\sqrt{s}$ = 13.6 TeV
  - Even more data are being recorded and analyzed now
  - Stay tuned for new and updated results… and hopefully discoveries!