Searches for New Resonances with CMS

Irene Andreou

QCD@LHC 2026
University of Oxford

Why search for new resonances?

Motivation

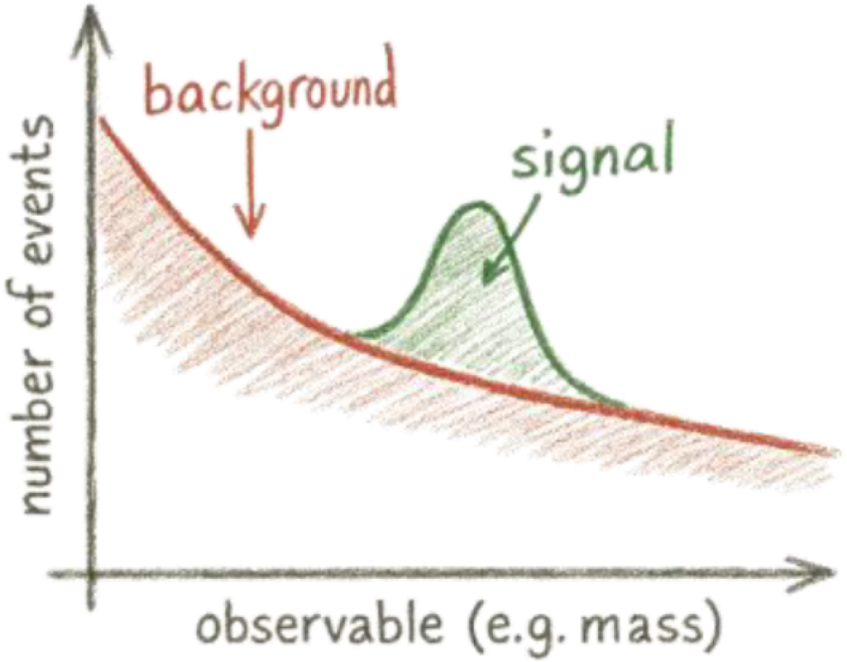
The Standard Model is our most successful theory of particle physics, but it's incomplete:

- Dark matter
- Matter-antimatter asymmetry
- Hierarchy problem
- Neutrino masses

- Unlike Standard Model discoveries, we don't know where to look: **unknown mass scale, couplings, decay modes**

- Many beyond-the-standard-model (BSM) frameworks predict a heavy state, decaying preferentially to W, Z, H bosons, photons, leptons, or jets

- CMS runs a broad search program covering many final states: **"we need to look everywhere"**



https://cms.cern/news/double-higgs-double-mystery-hunt-new-heavy-particle-decaying-pair-higgs-bosons

Where could new resonances hide?

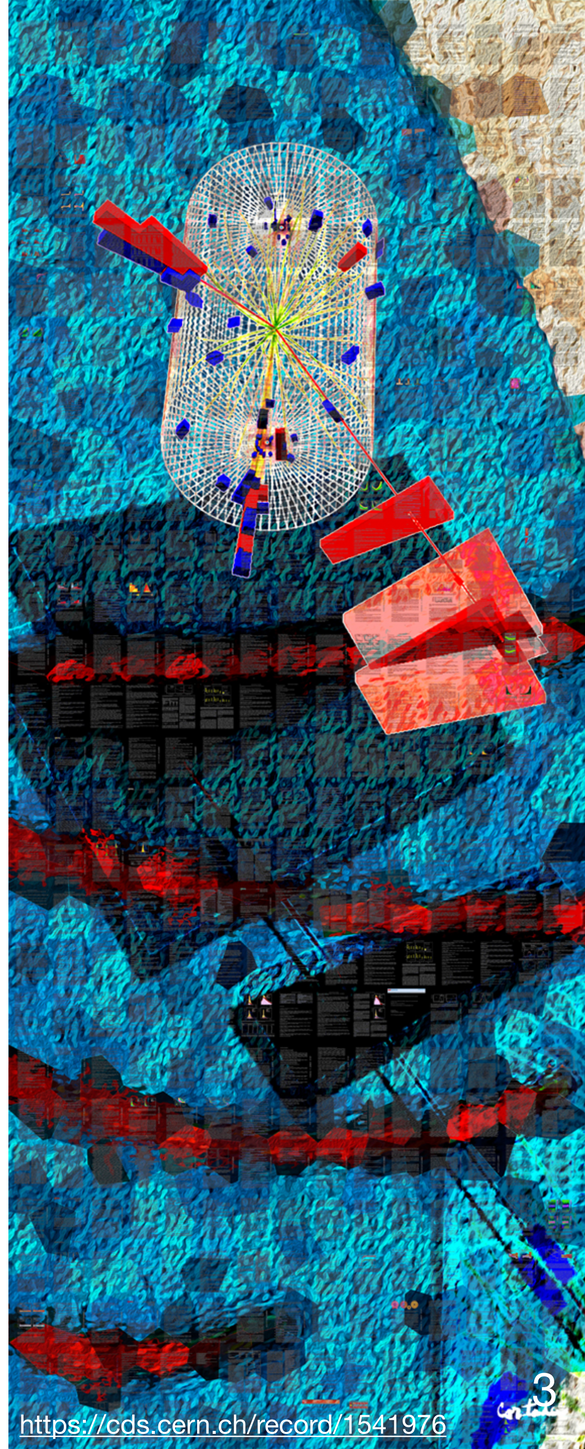
Scope of the talk

New resonances could show up **almost anywhere**. The goal is to map out where CMS has recently looked.

This talk covers:

- Heavy gauge bosons and gravitons in the dilepton channel
- Heavy states decaying to Higgs/Z/top
- Resonances hidden inside Higgs decays
- Low-mass dark photon resonance
- Vector-like quarks and leptoquarks

Not covered here: extended/hidden-valley dark sector signatures where complex, non-resonant final states are produced rather than a clean bump. See J. L. Holgado's talk!



https://cds.cern.ch/record/1541976

Unlocking new phase space

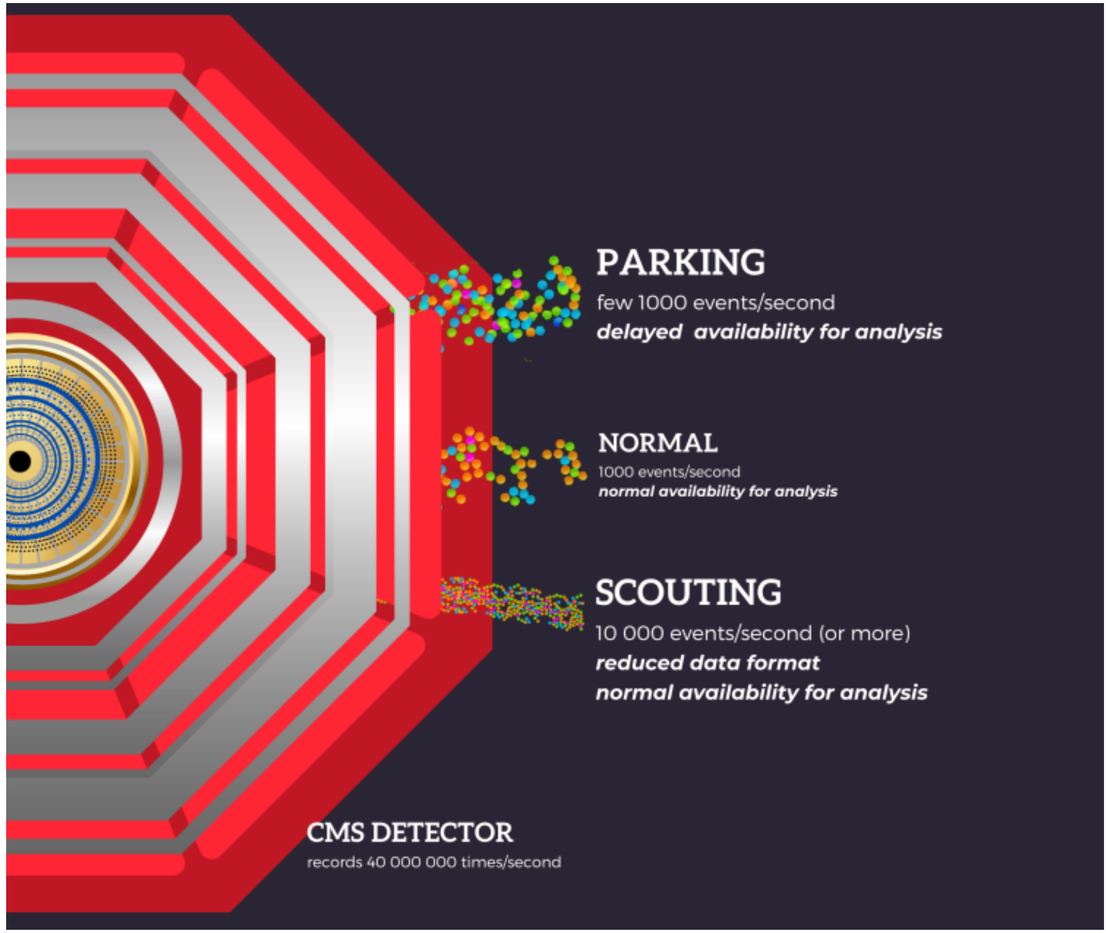
Data scouting and parking

Standard data streams can’t reach low-p_T muons/ electrons since the trigger rate budget forces high thresholds

CMS uses two dedicated streams to get around this:

- **Data scouting:** trigger-level objects only, no offline reconstruction, ~10× the rate of the standard stream
- **Data parking:** full offline reconstruction, but delayed, ~2–3× the rate, with lower p_T thresholds

This is the ***enabling technology*** behind the low-mass $Z_D \to \mu\mu$ search (slide 21) and CMS's push into low-mass and displaced signatures across Run 3.



https://cms.cern/news/same-lhc-same-cms-more-physics

Where could new resonances hide?

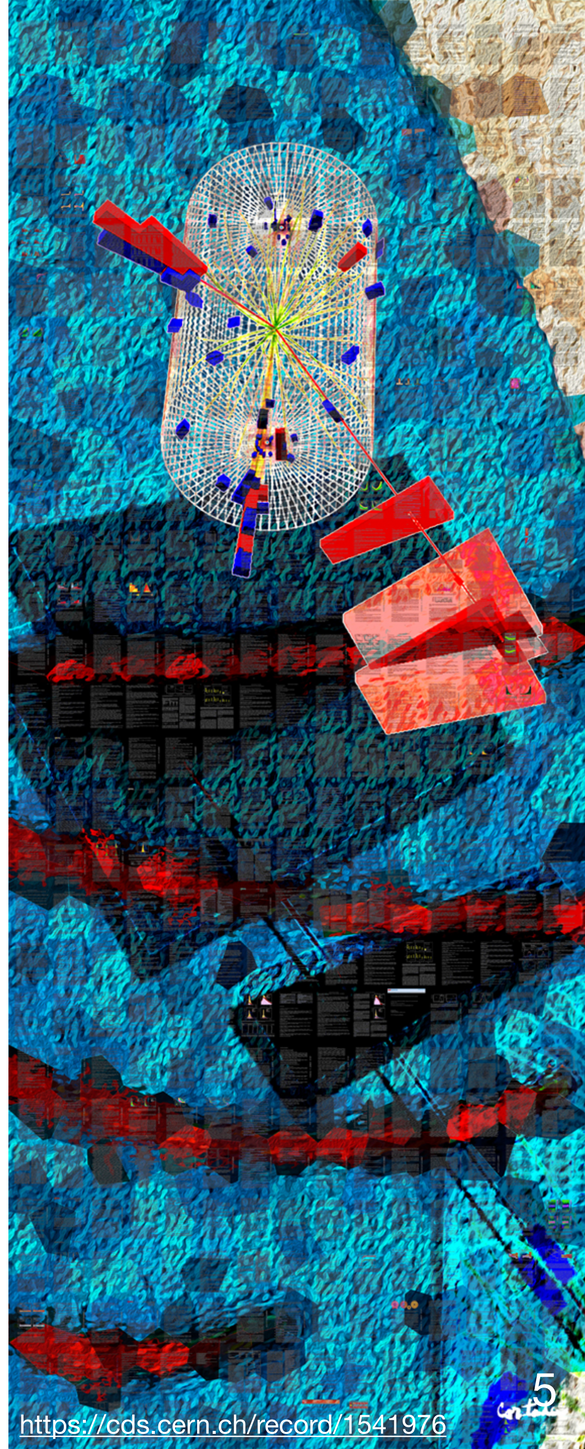
Heavy gauge bosons and gravitons in the dilepton channel

Signature: High-p_T single lepton + missing transverse momentum, or high-mass dilepton pair

BSM motivation: Extended electroweak gauge sector (Left-Right Symmetric, E6-motivated), warped extra dimensions, Heavy Vector Triplet framework

Results:

- Search for $W' \rightarrow ev/\mu\nu$
- Z' and Randall-Sundrum graviton searches
- Heavy Vector Triplet (HVT) combination



https://cds.cern.ch/record/1541976

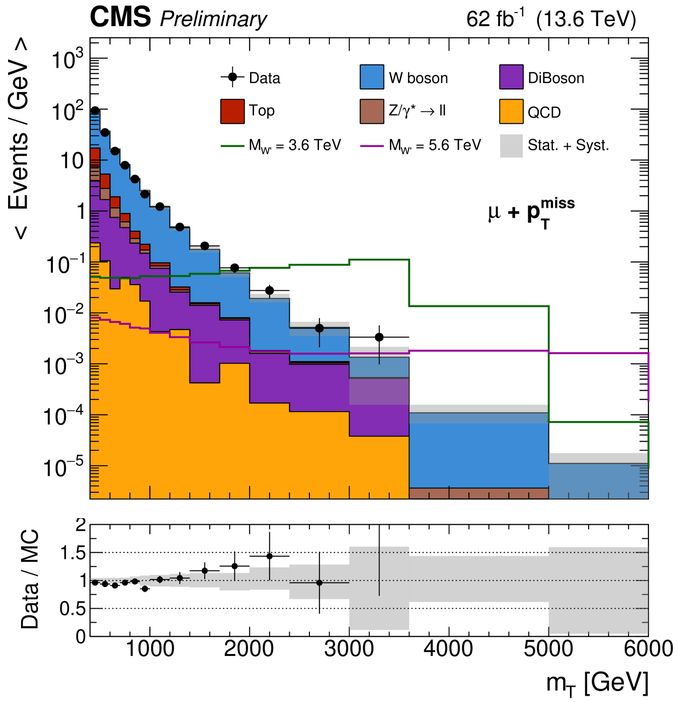
A heavier partner for the W

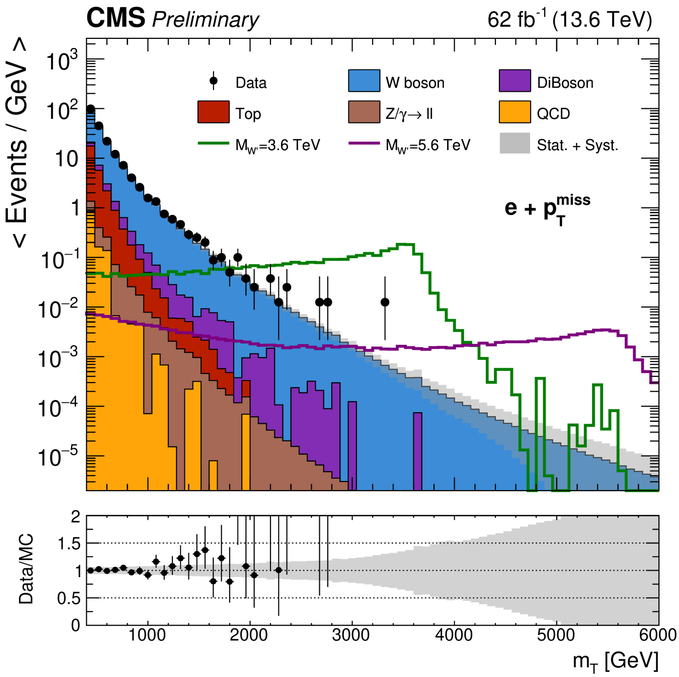
Search for W′→ eν/μν (EXO-24-021)

Run 3 - 62 fb^{-1} - 13.6 TeV

- W′ predicted in extended electroweak gauge sector; benchmark is the Sequential Standard Model (W'_{SSM})
- **Signature:** a single high-p_T lepton and significant MET
- **Discriminant:** transverse mass

$$m_T = \sqrt{2p_T^{\ell} p_T^{miss} \left(1 - \cos \Delta\phi(\vec{p}_T^{\,\ell}, \vec{p}_T^{\,miss})\right)}$$





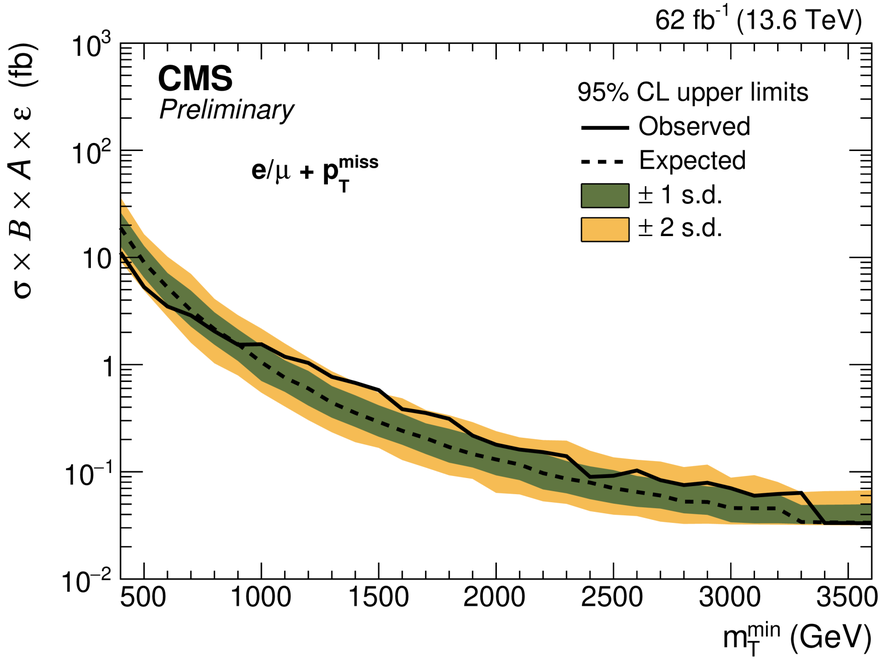
A heavier partner for the W

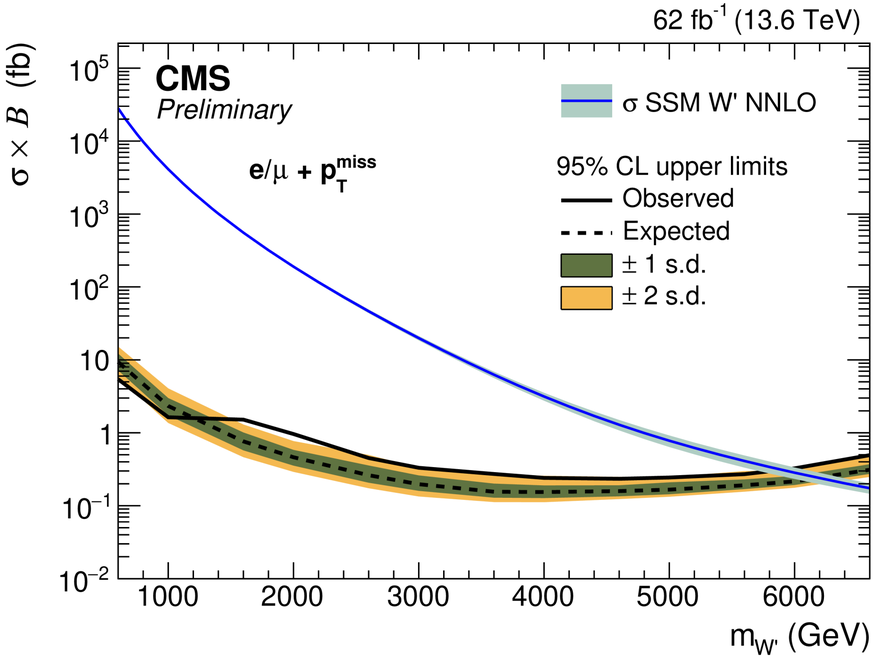
Search for W′→ eν/μν (EXO-24-021) - Results

Run 3 - 62 fb^{-1} - 13.6 TeV

- **No significant deviation from the SM;** largest local excess 2.6σ in the 1.8–2 TeV region

- SSM W′ excluded below 5.9 TeV, improved from Run 2's 5.6 TeV, **driven by a lower electron-channel trigger threshold and the higher Run 3 centre-of-mass energy**



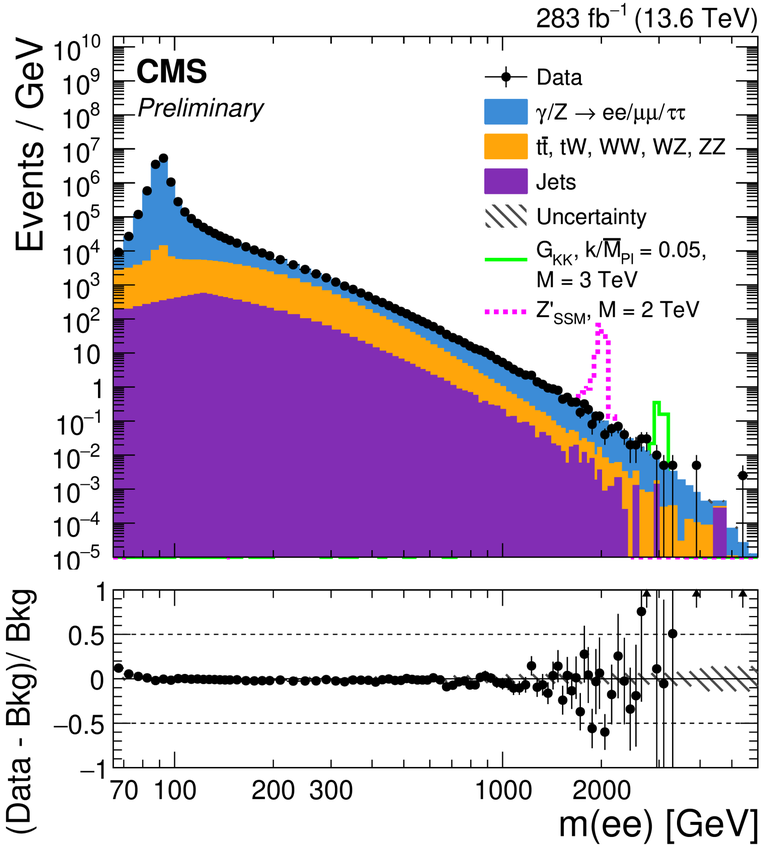


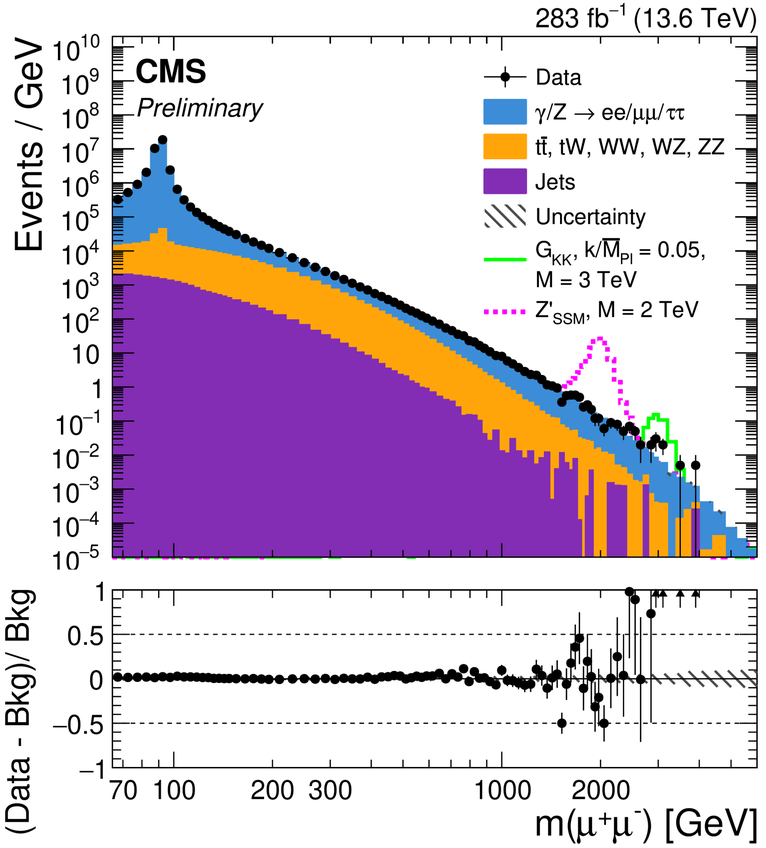
High-mass dilepton resonances

Run 3 - 283 fb^{-1} - 13.6 TeV

Z′ and Randall–Sundrum graviton searches (EXO-25-021)

- Neutral counterpart to the W′ search: Z′ (Left-Right Symmetric, E6-motivated models) and spin-2 RS graviton; Benchmarks: Z′_SSM, Z′_ψ
- Probing 200 GeV–6 TeV in ee and μμ
- **Method**: unbinned likelihood fits in sliding mass windows across the high-mass tail





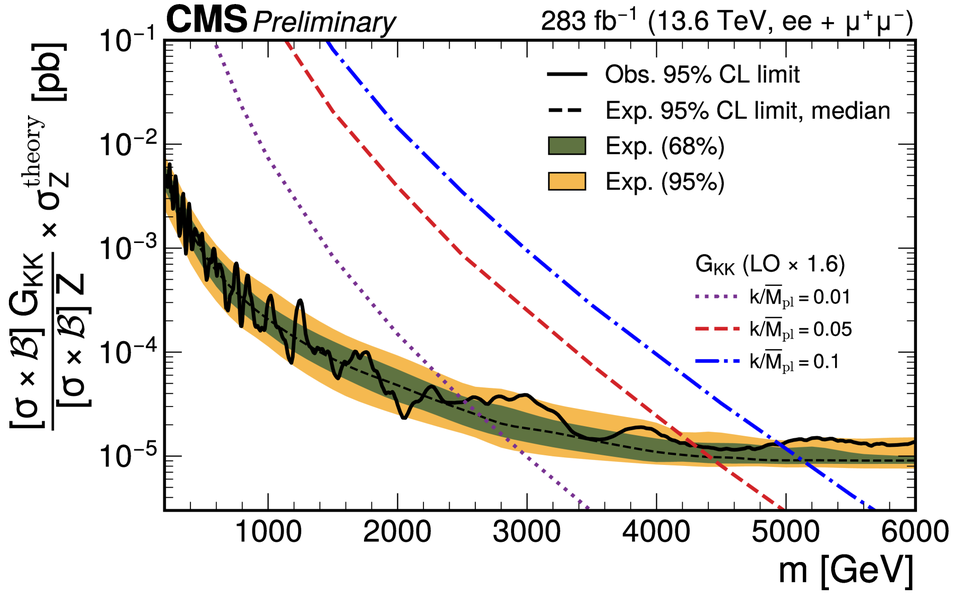
High-mass dilepton resonances

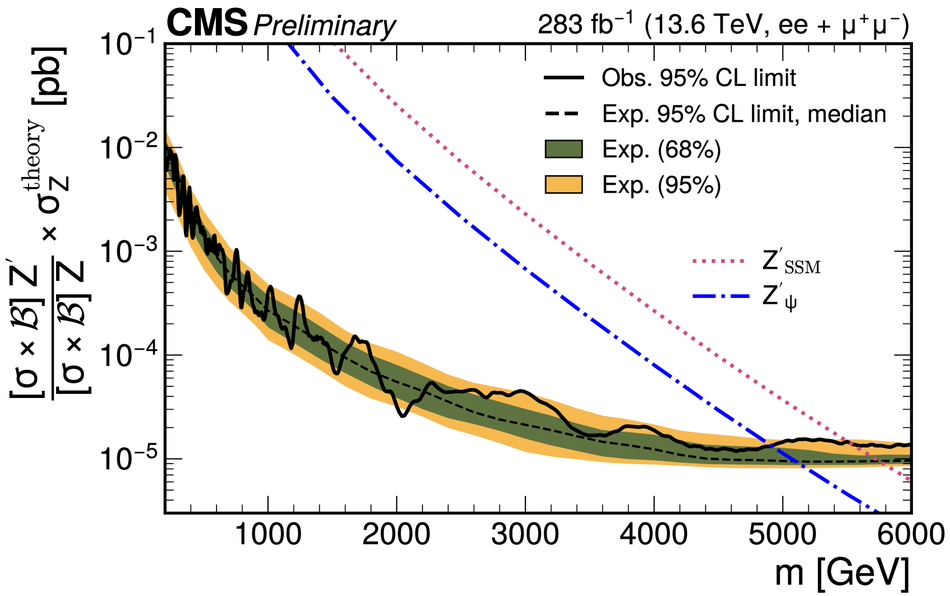
Run 3 - 283 fb^{-1} - 13.6 TeV

Z′ and Randall–Sundrum graviton searches (EXO-25-021) - Results

- **No significant deviation observed**; largest local excess 2.6σ at 5.2 TeV
- Results have been improved over Run 2, with the **improvement driven by larger dataset and higher centre-of-mass energy**

Z'_{SSM} > 5.55 TeV (Run 2: 5.15 TeV)
Z'_{ψ} > 4.95 TeV (Run 2: 4.56 TeV)
RS graviton: > 2.5 / 4.4 / 5.0 TeV (Run 2: 2.47 / 4.16 / 4.78 TeV) for k/M_{Pl} = 0.01 /0.05 / 0.10





Combination → sharper limits

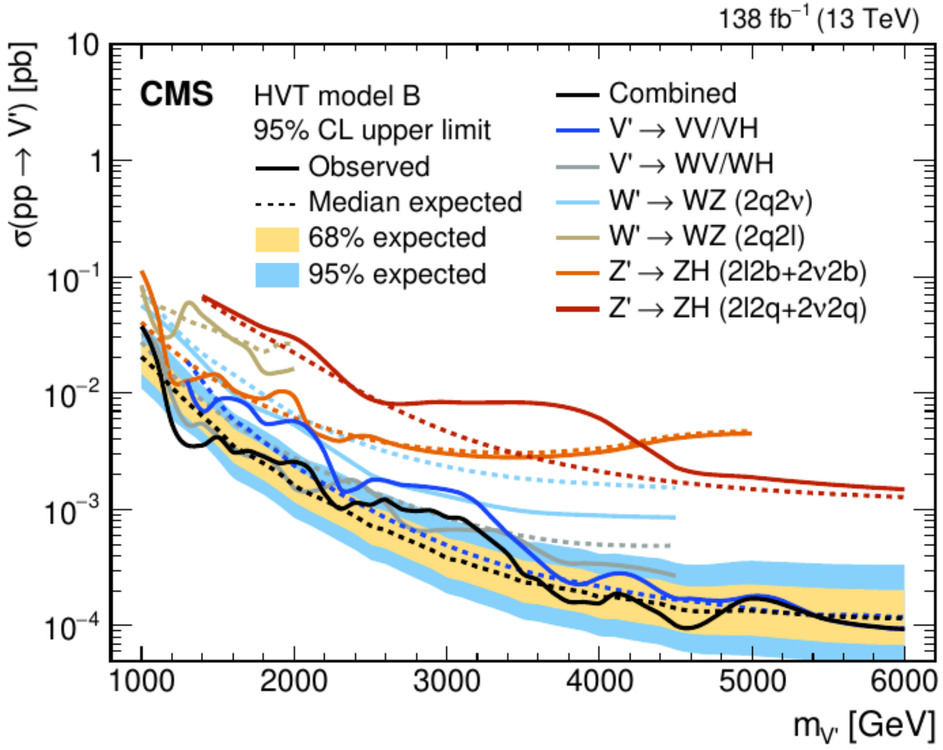
Run 2 - 138 fb^{-1} - 13 TeV

Combining searches for HVT (B2G-25-003)

- A heavy spin-1 resonance V′ (W′/Z′) predicted in the HVT framework, decaying to VV/VH

- **Motivation for combining**: individual channels each show mild local excesses*
  None individually significant, but suggestive enough to motivate a full combination

- This combination: **16 channels from 14 analyses:**
  6 of them diboson (V′→VV/VH (all-hadronic), V′→WV/WH (lepton+merged jet), W′→WZ (2q2ℓ, 2q2ν), Z′→ZH (2ℓ2b, 2ν2b, 2ℓ2q, 2ν2q)), plus 8 fermionic channels (Z′→ττ, Z′→ℓℓ, W′→ℓν, W′→τν, V′→qq̄, W′→tb̄, Z′→tt̄)



*(CMS's V′→VV/VH (all-hadronic) saw 3.6σ at 2.1 and 2.9 TeV, >2σ at 1 TeV in W′→VW(ℓν) and Z′→ZH(bb̄); ATLAS's spin-1 combination saw 2.6σ at 1.5 TeV in VBF.)

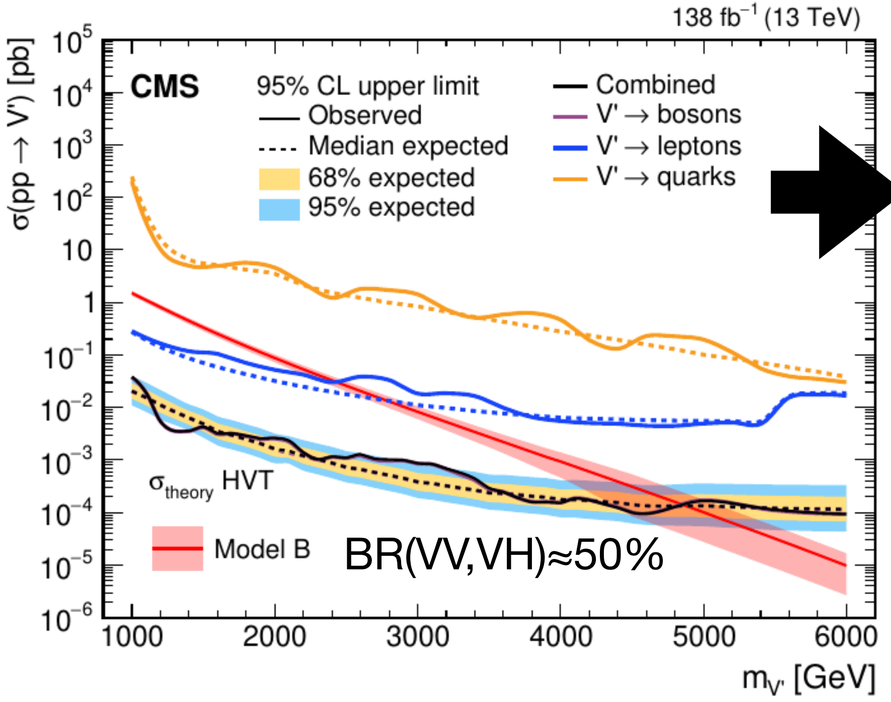
Combination → sharper limits

Run 2 - 138 fb^{-1} - 13 TeV

Combining searches for HVT (B2G-25-003) - Results

- **No significant excess** in the combination; largest local excess in the combination: 2.3σ at 2.9 TeV, 2.4σ at 3.0 TeV

- Sensitivity primarily driven by the fully hadronic final states (3D fit, jet substructure tagging)

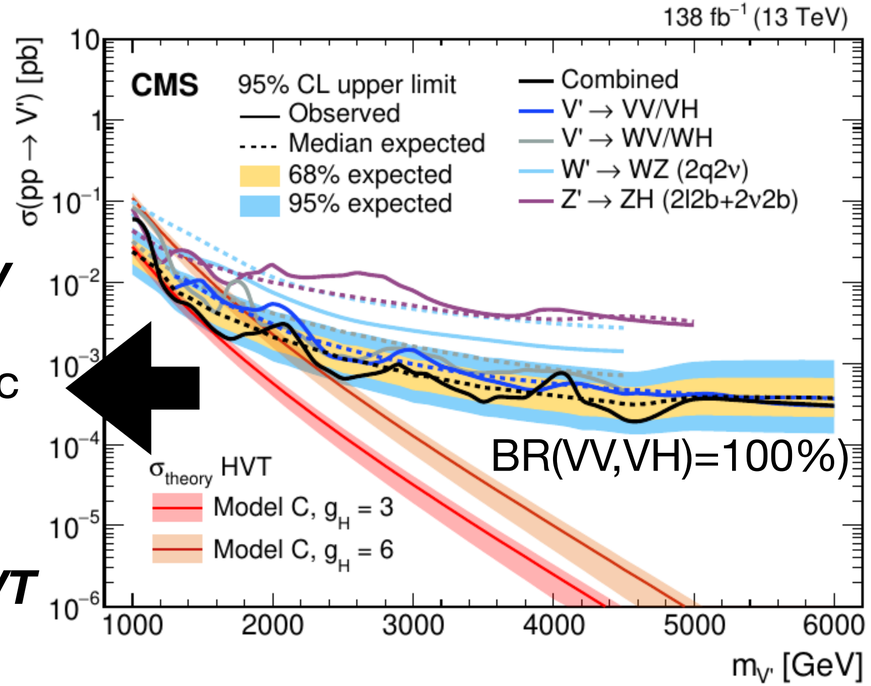


Theory interpretation,
two benchmark HVT models:

Model B (strongly coupled SM extension, fermionic couplings suppressed, ***excludes below 4.8 TeV***

Model C (VBF-exclusive, no fermionic couplings): **1.2–1.4 TeV excluded at g_H=3, extending to <2 TeV at g_H=6**

Most stringent limits to date for HVT Models B and C



Where could new resonances hide?

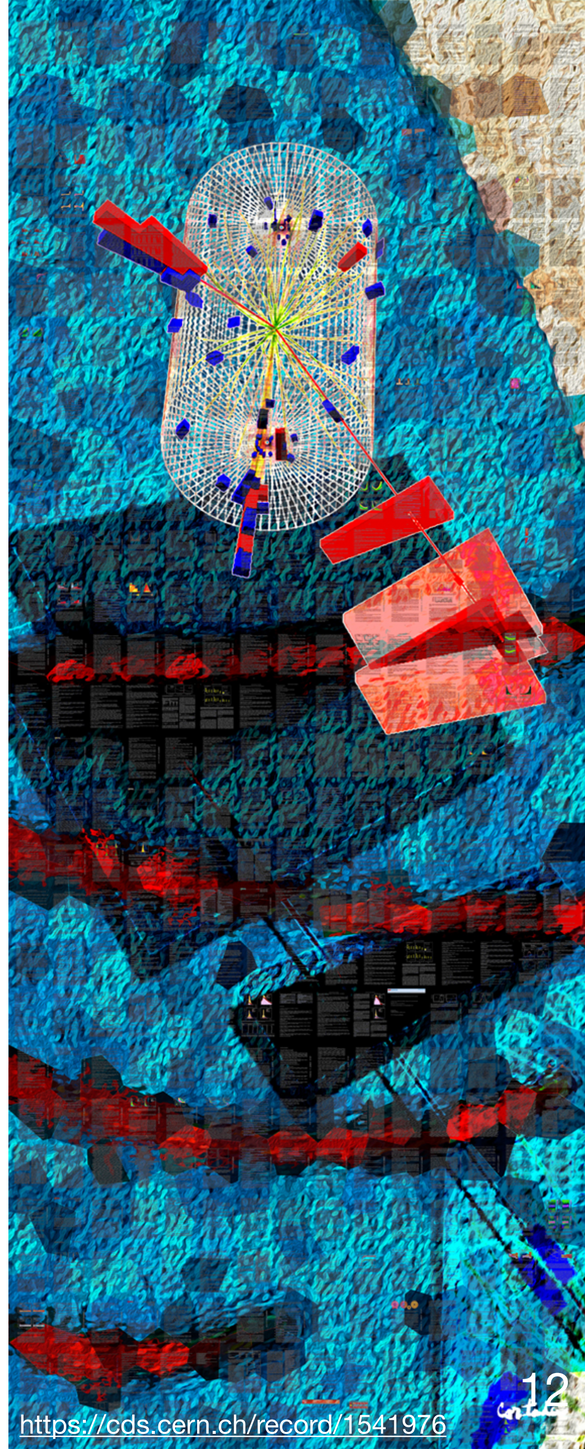
Heavy states decaying to Higgs/Z/top

Signature: Three leptons + b-jets/top

BSM motivation: two-Higgs-doublet model (Type-II), electroweak baryogenesis

Results:

- Search for A → ZH → $\ell\ell\bar{t}t$



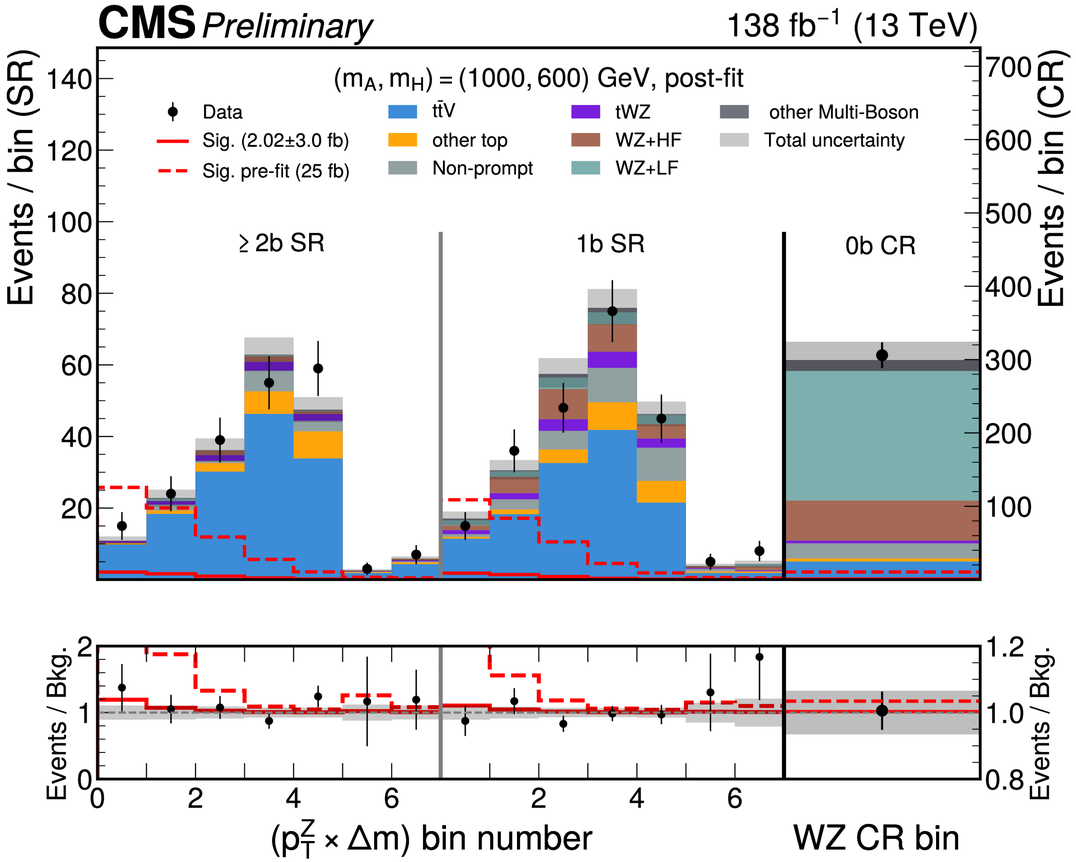
https://cds.cern.ch/record/1541976

New channel, new limit

Run 2 - 138 fb^{-1} - 13 TeV

Search for A → ZH → ℓℓt̄t (B2G-24-002)

- Heavy pseudoscalar A→Z boson + SM Higgs, with H→t̄t in the 2HDM Type-II framework
- Two channels: **three-lepton final state** (Z→ℓℓ, H→t̄t semileptonic) **(the result)** combined with a previously published **all-hadronic search** (Z→ℓℓ, H→t̄t→jets)
- Mass range probed: $m_A \in [430, 2100]$ GeV, $m_H \in [330, 2000]$ GeV
- Fit discriminant: **Δm(A,H)** (robust to interference and jet energy resolution) **combined** with **$p_T(Z)$** (whose kinematic edge is set by Δm(A,H)).



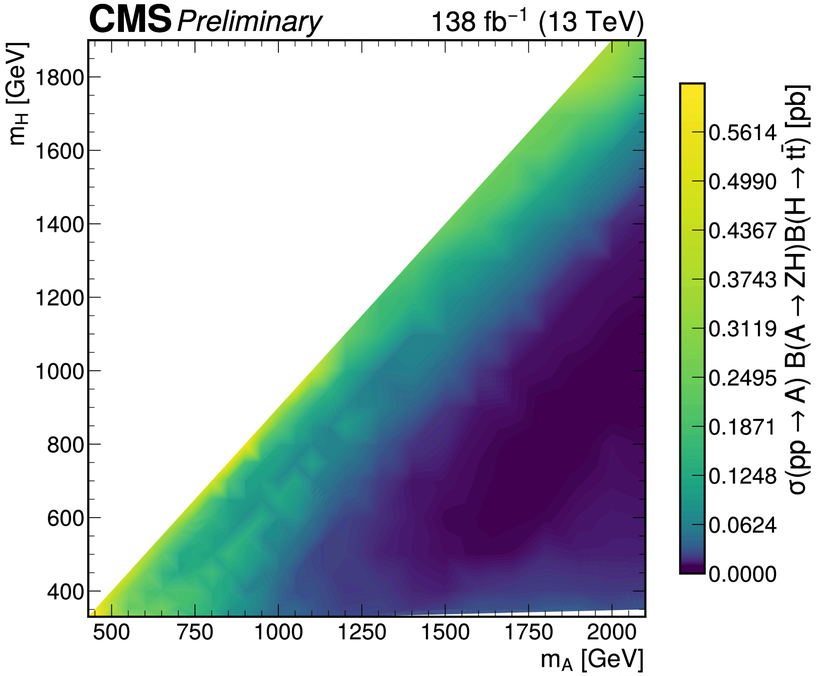
New channel, new limit

Run 2 - 138 fb^{-1} - 13 TeV

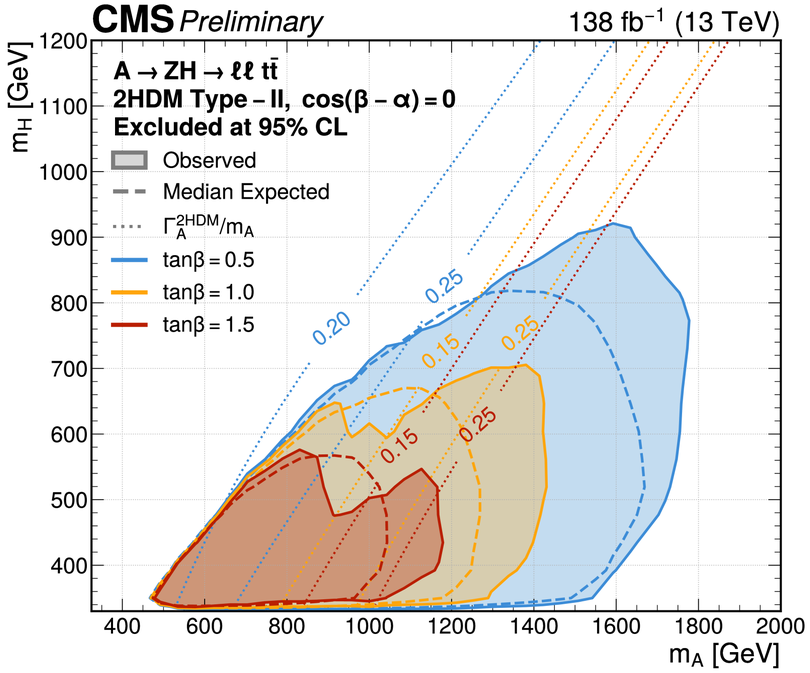
Search for A → ZH → ℓℓt̄t (B2G-24-002) - Results

- **No significant excess observed**; largest fluctuation at (m_A, m_H) = (850, 500) GeV, local significance **1.5σ**

- 2HDM Type-II exclusion contour, cos(β−α)=0: excluded region grows as tanβ decreases (i.e. **the search is most sensitive/restrictive at low tanβ**)



Combination with the previously-published all-hadronic A→ZH(t̄t→jets) channel **further constrains the 2HDM Type-II phase space beyond either channel alone**



Where could new resonances hide?

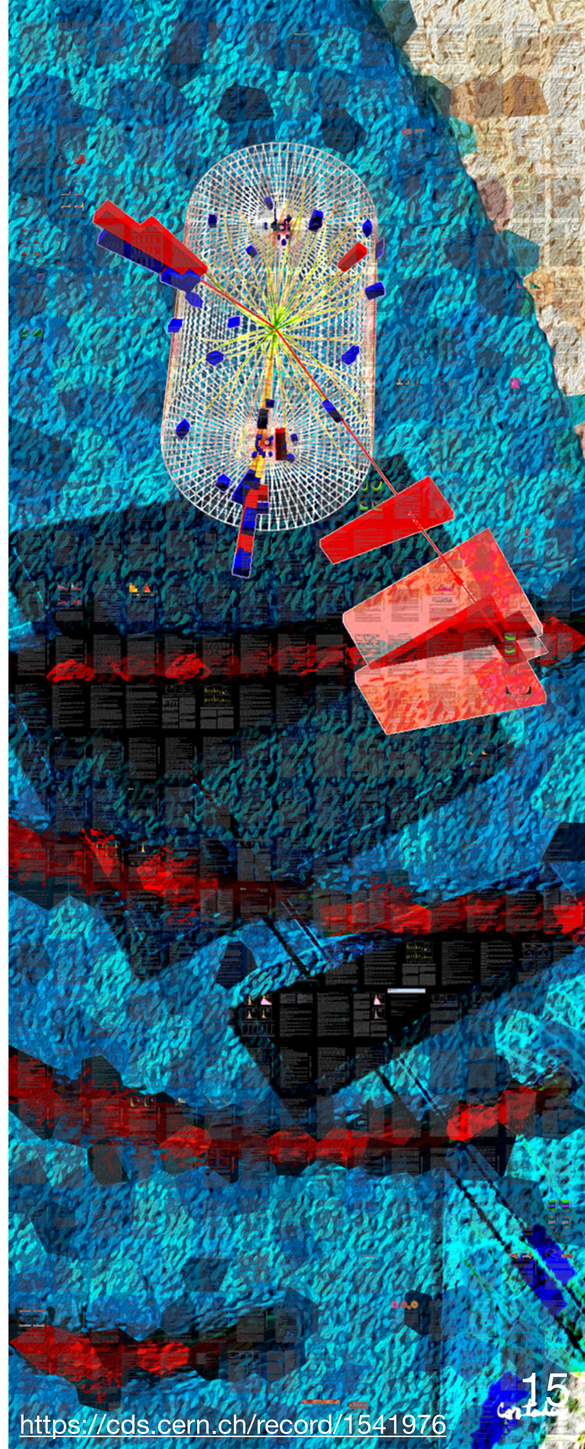
Resonances hidden inside Higgs decays

Signature: A regressed mass inside a single boosted jet, or a geometrically-reconstructed displaced vertex (not a classic bump-hunt)

BSM motivation: Extended Higgs sectors (2HDM+S), hidden sector portals linking the Higgs to dark states

Results:

- Search for $H \rightarrow a_1 a_1 \rightarrow 4b$ (boosted)
- Search for long-lived particles decaying to photons in Higgs decays



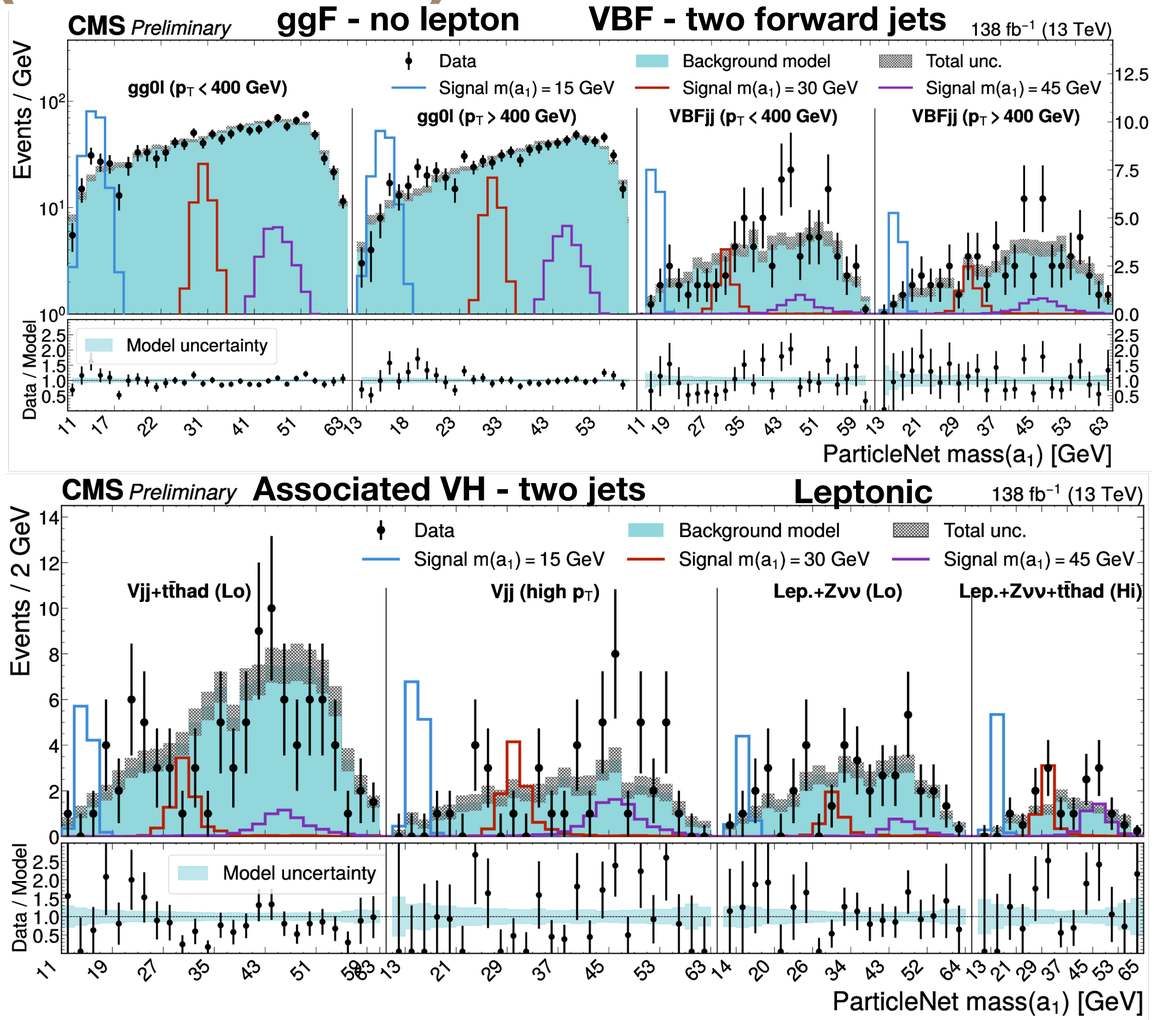
https://cds.cern.ch/record/1541976

Hiding in plain sight

Search for H → a_1a_1 → 4b (boosted) (NPS-25-005)

Run 2 - 138 fb^{-1} - 13 TeV

- Boosted Higgs decays to a pair of new spin-0 particles, each to a b-quark pair
- **ParticleNet four-prong jet tagger (X4b)** isolates the boosted H→a1a1→b$\bar{b}$b$\bar{b}$ topology from QCD/ t$\bar{t}$ background; a dedicated ParticleNet mass regressor reconstructs both m(X) (the full boosted Higgs candidate) and m(a_1) with improved resolution over standard jet mass techniques; background is modeled data-driven via the **2DAlphabet method**, fit simultaneously across four production-mode categories
- **Largest deviation**: local 3.0σ (global 1.7σ) near m(a_1) = 45 GeV

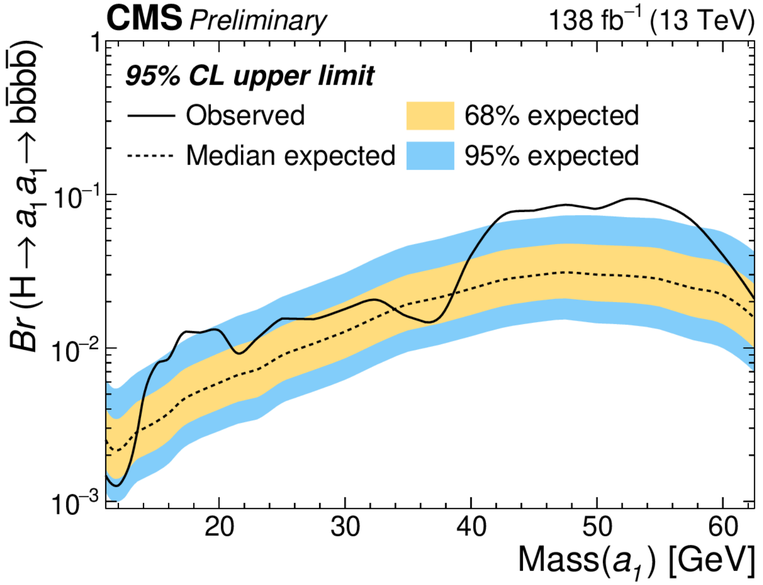


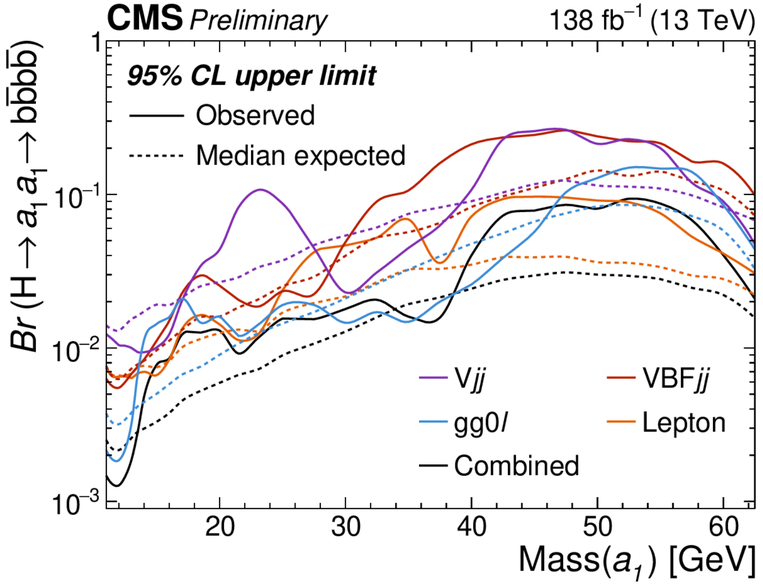
Hiding in plain sight

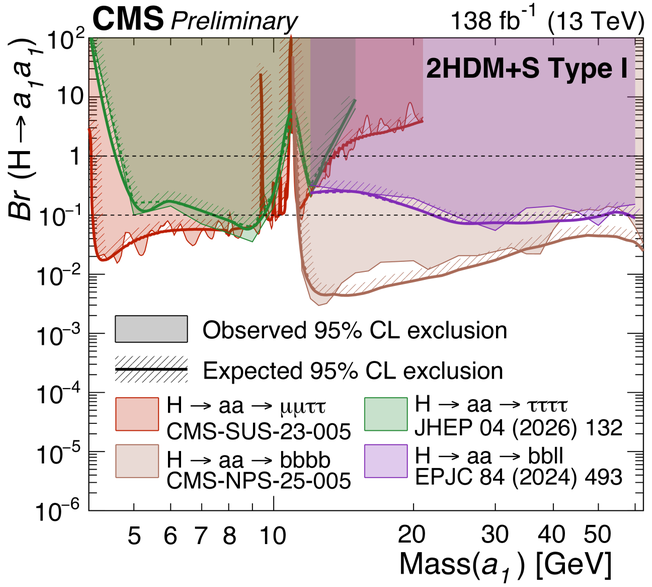
Search for H → a_1a_1 → 4b (boosted) (NPS-25-005) - Results

Run 2 - 138 fb^{-1} - 13 TeV

- 95% CL limits on Br(H → a_1a_1 → 4b): 0.13% to 9.4%, depending on m(a_1)
- **Improves on previous constraints by up to an order of magnitude**
- **Most stringent limits to date on 2HDM+S extended Higgs sector scenarios**







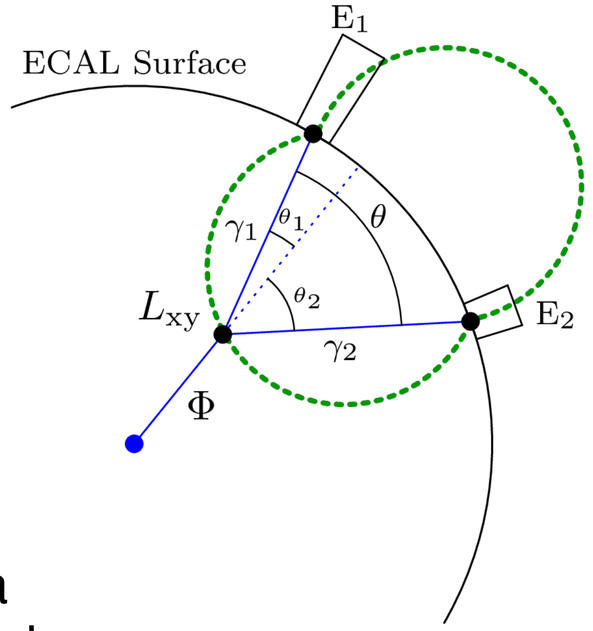
More interpretations in the PAS!

Hiding in plain sight

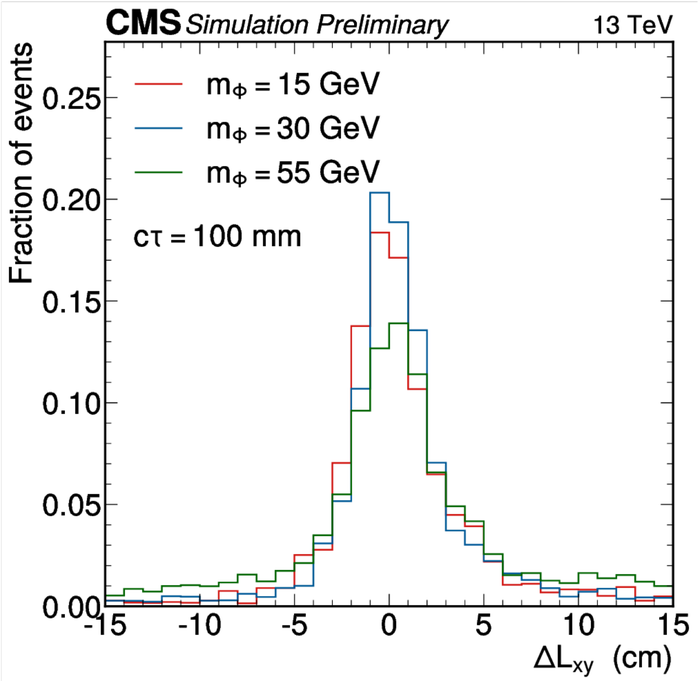
Run 2 - 138 fb^{-1} - 13 TeV

Search for long-lived particles decaying to photons in Higgs decays (EXO-23-012)

- **Benchmark**: rare Higgs decay H → ΦΦ → 4γ, where Φ is a new long-lived neutral scalar decaying to a photon pair
- **Novel technique:** a kinematic fit reconstructs the displaced decay vertex of the diphoton pair using only the ECAL's position and energy resolution, This is notable because the ECAL has no longitudinal segmentation, so this is a geometric reconstruction trick rather than a hardware-based displacement measurement
- Probes m_Φ = 15–55 GeV, proper lifetimes (cτ) up to 1000 mm



The geometric reconstruction diagram itself: γ_1/γ_2 photon trajectories, their ECAL hit positions, the angles θ_1/θ_2 used in the kinematic fit, and the reconstructed displaced vertex L_{xy}.



The resolution plot: fraction of events vs. ΔL_{xy} (reconstructed minus true displacement), shown for three m_Φ hypotheses (15/30/55 GeV) at cτ = 100 mm. Shows the technique actually works (the distributions peak sharply at zero).

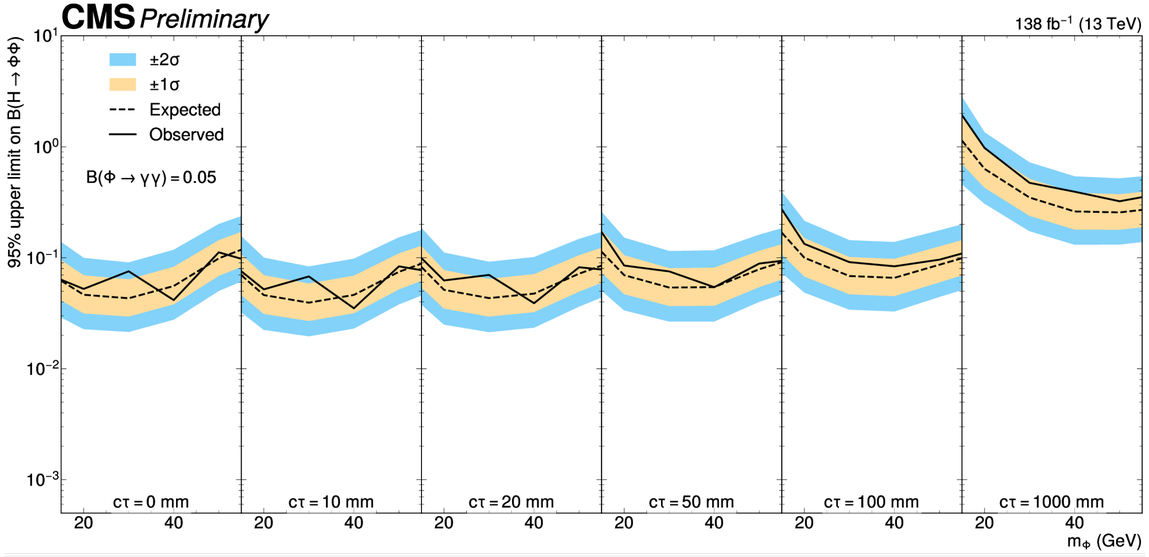
Hiding in plain sight

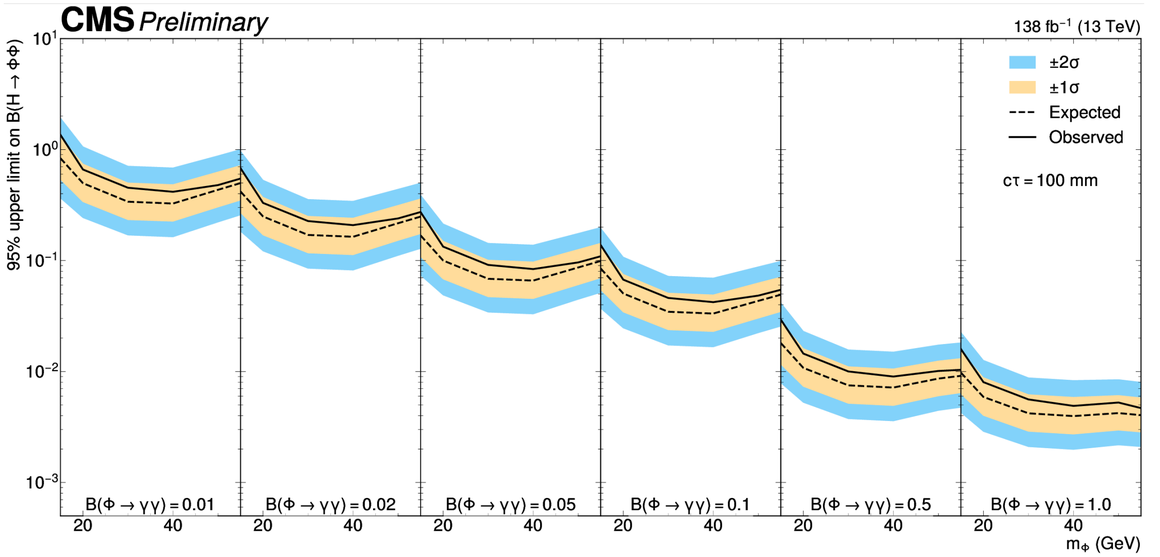
Run 2 - 138 fb^{-1} - 13 TeV

Search for long-lived particles decaying to photons in Higgs decays (EXO-23-012) - Results

- **No significant excess** observed; expected 95% CL limits probe B(H→Φ) below 10% for modest B(Φ→γγ)

- **First CMS search for LLP decays to photons in the 15–55 GeV mass range and lifetimes up to 1000 mm**





Where could new resonances hide?

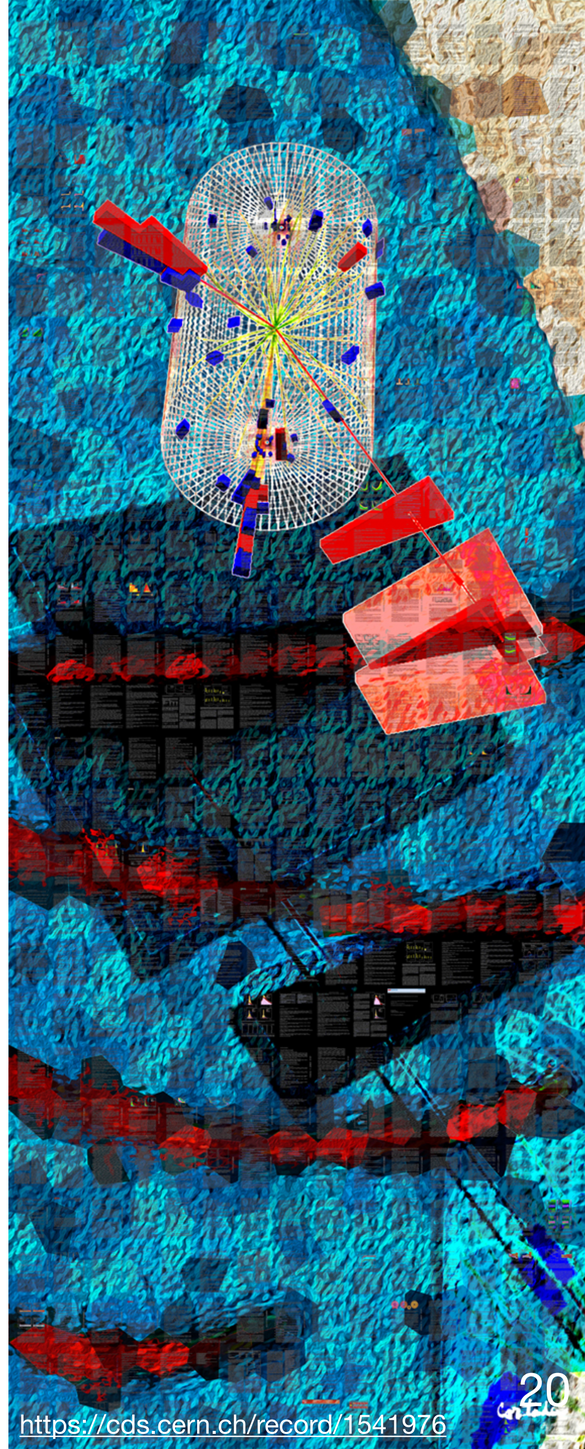
Low-mass dark photon resonance

Signature: Soft / displaced dimuon pair

BSM motivation: Dark photon, simplified dark sector portal model

Results:

- Search for $Z_D \rightarrow \mu\mu$



https://cds.cern.ch/record/1541976

Opening the low-mass frontier

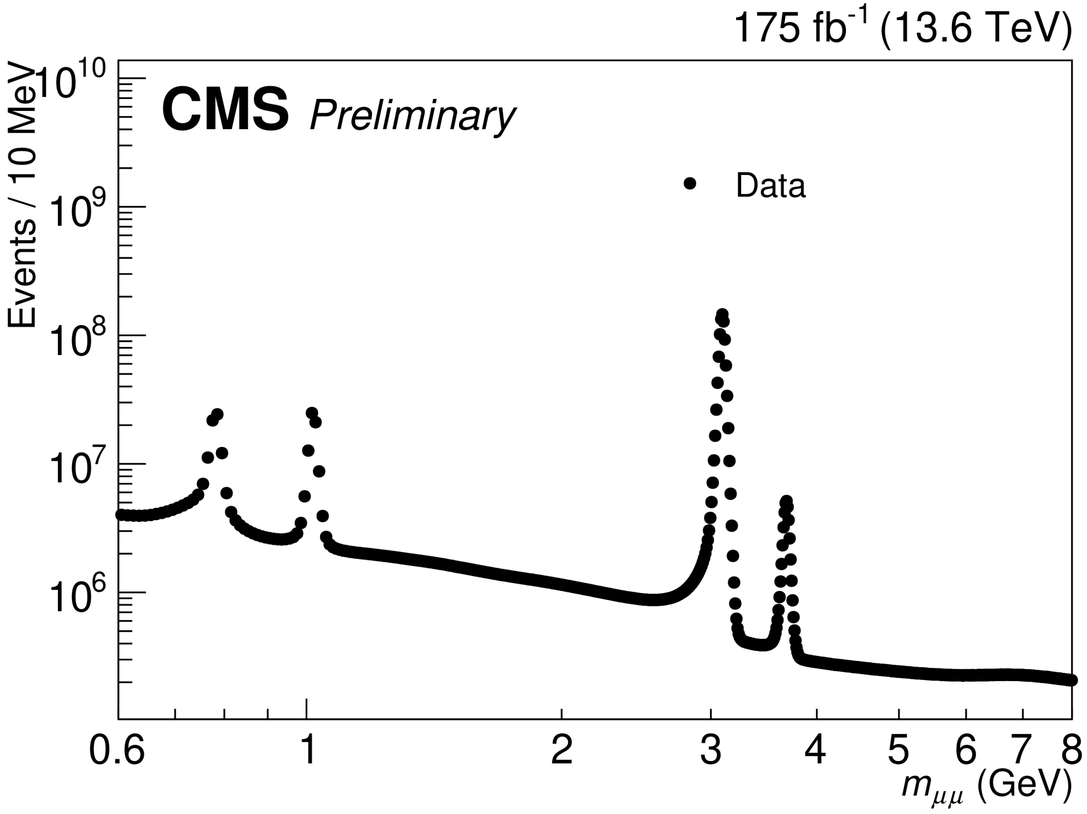
Run 3 - 175 fb^{-1} - 13.6 TeV

Search for $Z_D \rightarrow \mu\mu$ (EXO-25-019)

- Dark photon $Z_D \rightarrow \mu\mu$; distinct from the hidden-valley signatures covered in the next talk

- Enabled by a **new inclusive dimuon parking trigger.** This is the same scouting/ parking technology introduced in slide 4, now applied at low mass: allows muon p_T down to 4 GeV, giving increased sensitivity across the 0.6–8 GeV window

- Probing the 0.6–8 GeV mass range (in three windows, excluding ϕ/J-ψ/ψ(2S) regions)

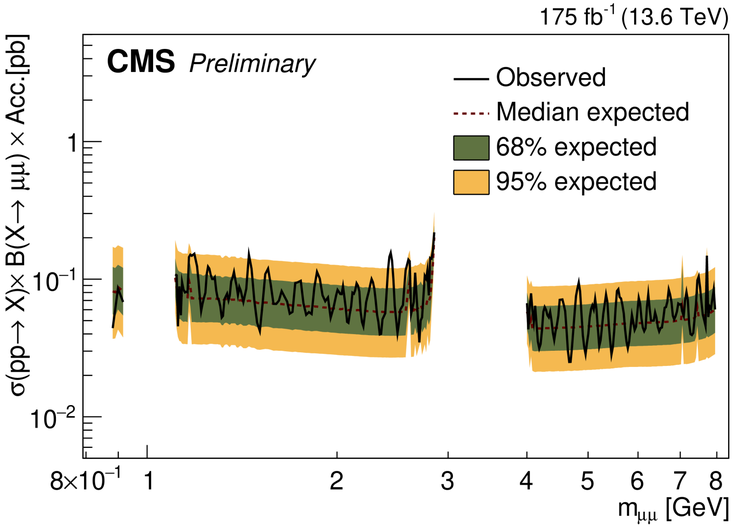


Opening the low-mass frontier

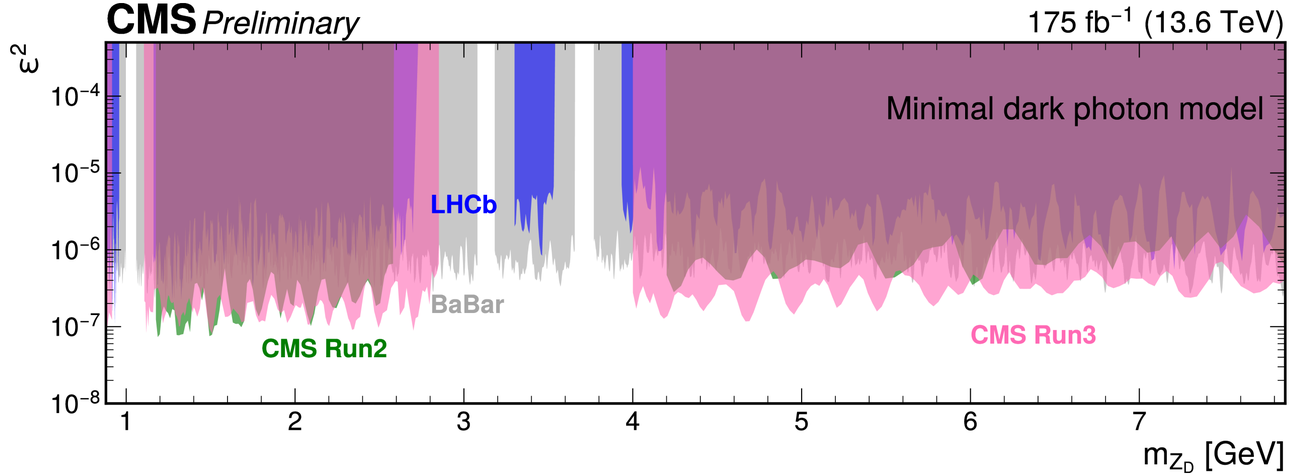
Search for $Z_D \rightarrow \mu\mu$ (EXO-25-019) - Results

Run 3 - 175 fb^{-1} - 13.6 TeV

- No significant excess observed overall
- Sensitivity up to **2× better than Run 2**, and now competitive with dedicated low-energy experiments (BaBar, LHCb)
- One local fluctuation worth a mention: **2.8σ at 2.43 GeV** (global significance <1σ); notably consistent with previous hints seen by LHCb (3.1σ at 2.42 GeV) and CMS Run 2 (2.4σ)



Limits set on the dark photon kinetic mixing coefficient ε^2 across the full mass range



Where could new resonances hide?

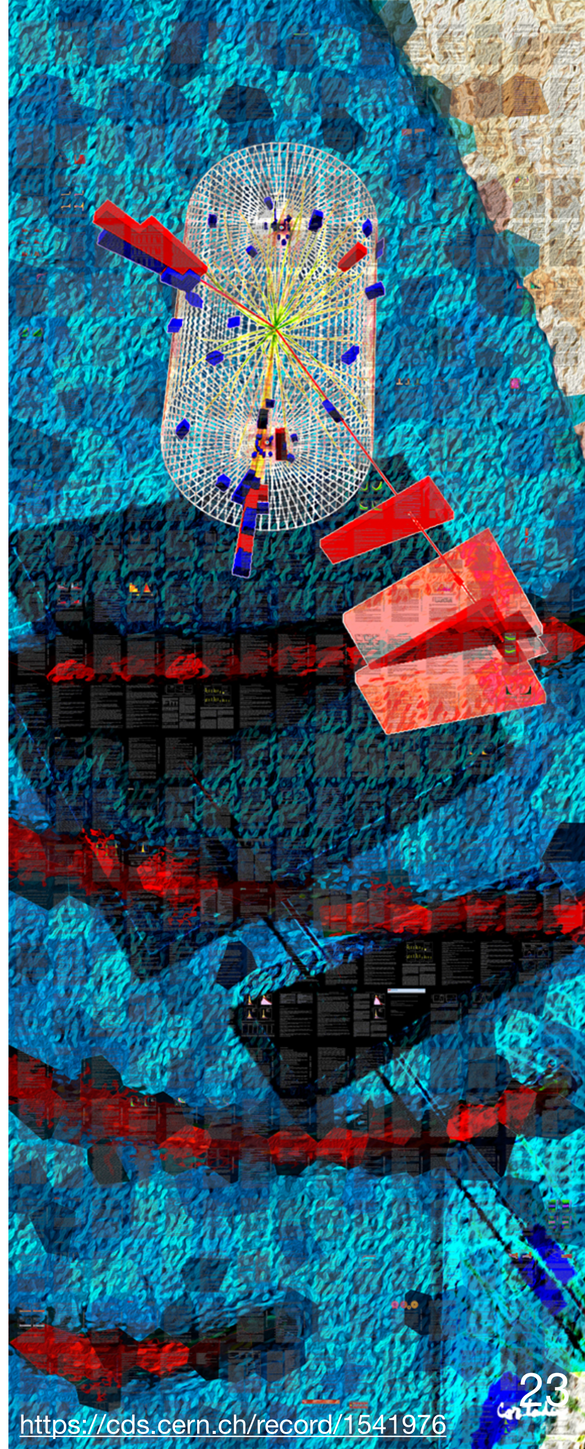
Vector-like quarks

Signature: Boosted top + photon pair, or top + W/Higgs boson

BSM motivation: Composite Higgs, naturalness

Results:

- Vector-like T → tϕ, ϕ → γγ
- Vector-like $X_{5/3}$



https://cds.cern.ch/record/1541976

Completing the quark sector

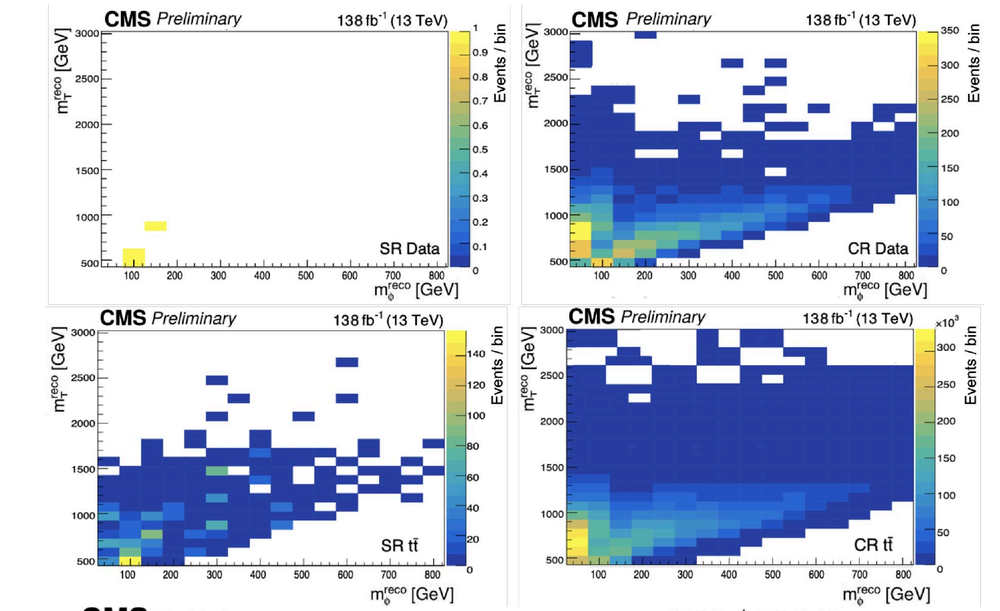
Run 2 - 138 fb^{-1} - 13 TeV

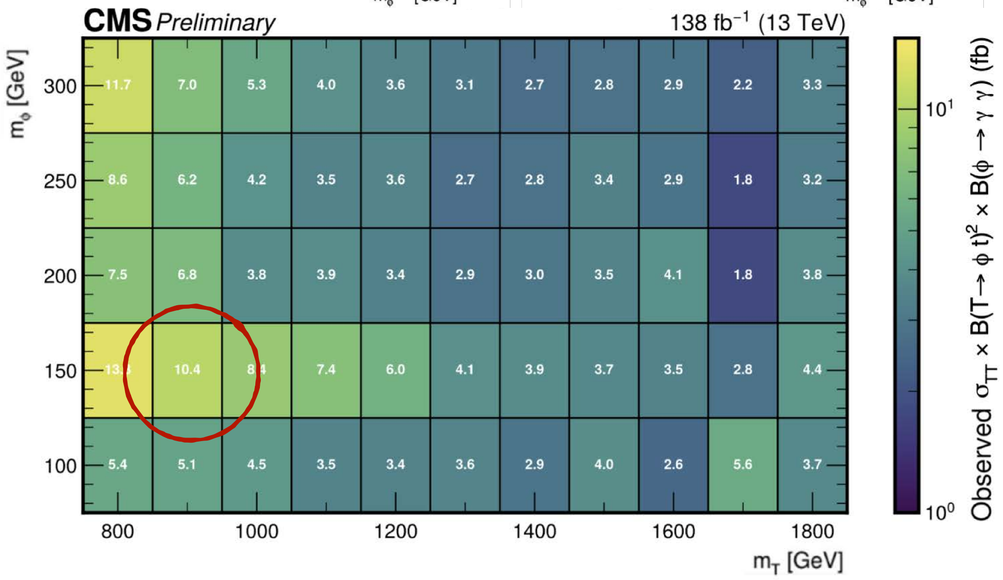
Vector-like T → tϕ, ϕ → γγ (B2G-24-016) - Results

- **First-ever search for this topology**; ϕ→γγ has a small branching ratio (0.4%) but a very clean signature; signature is two boosted large-radius jets (top-tagged + diphoton)

- **Discriminant:** the 2D (m_T^{reco}, m_ϕ^{reco}) plane itself where signal appears as a localised excess at the tested (m_T, m_ϕ) point; background (dominated by $\bar{t}t$) is estimated from a control region and transferred into the signal region via a data-driven transfer function, validated in the projections shown here

- Result: VLQ excluded below **1.39 TeV** (assuming B(ϕ→γγ)=100%); a local **2.6σ excess** in this channel worth watching





Completing the quark sector

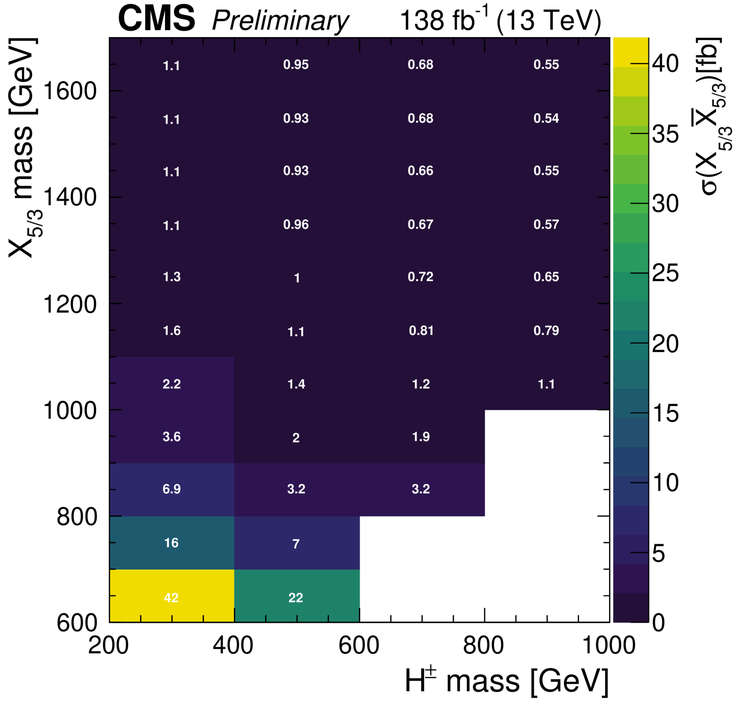
Vector-like $X_{5/3}$ (B2G-24-005) - Results

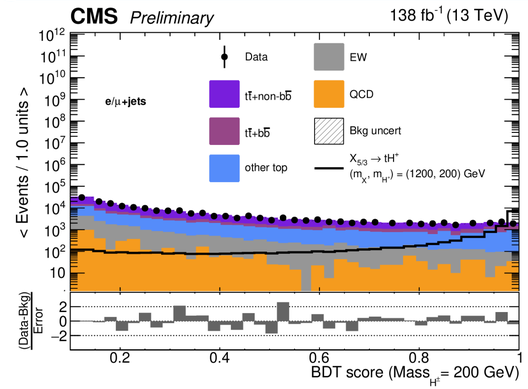
- Pair-produced, single-lepton final state + ≥1 b-jet; two decay modes (SM mode ($X_{5/3}\rightarrow tW$) and BSM mode ($X_{5/3}\rightarrow tH^{\pm}\rightarrow ttb$))

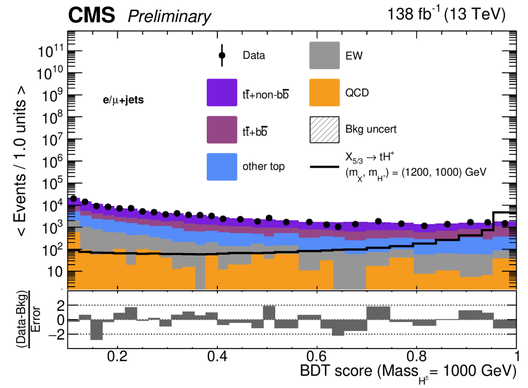
- **Discriminant:** built from an XGBoost classifier trained on kinematic variables, which individually show only modest signal over background separation but the BDT combines them into a single powerful discriminant

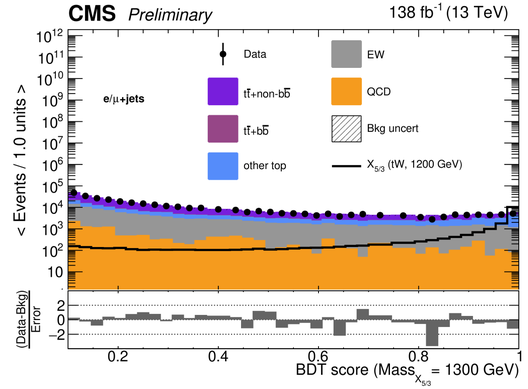
- Result: SM mode excluded up to **1.63 TeV**; BSM mode excluded **1.62–1.74 TeV; first-ever $X_{5/3}\rightarrow tH^{\pm}$ result**

Run 2 - 138 fb^{-1} - 13 TeV









Where could new resonances hide?

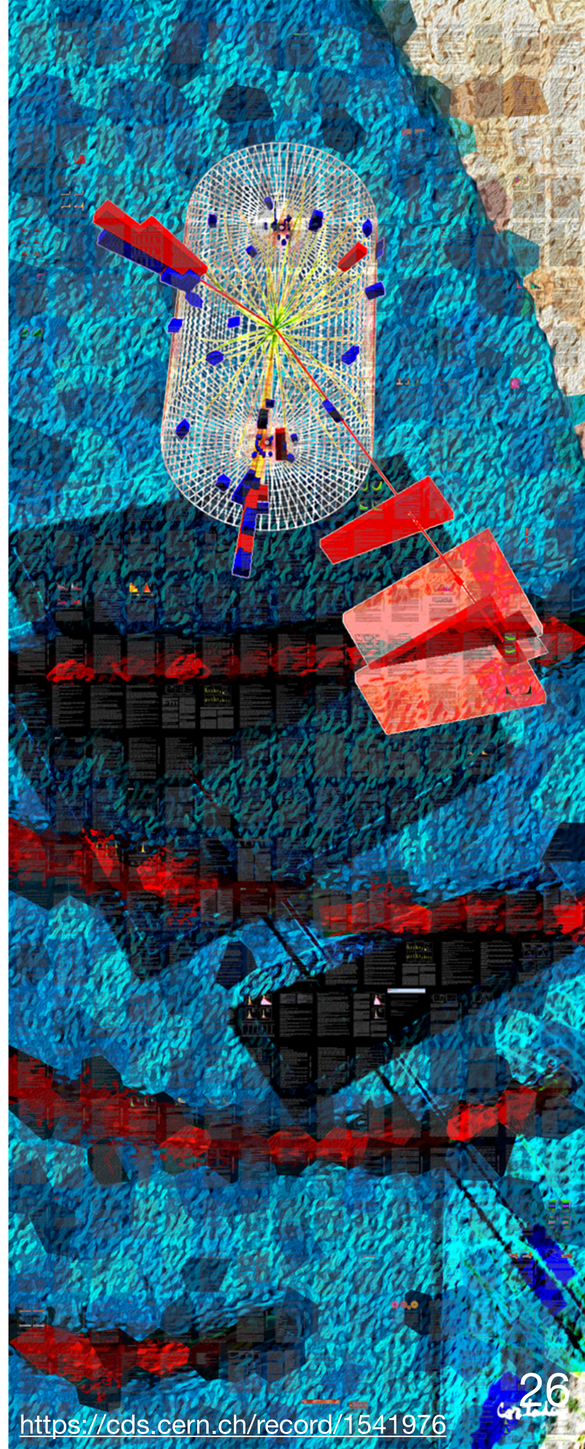
Leptoquarks

Signature: Lepton + jet resonance (single production), or di-lepton + di-jet (pair production)

BSM motivation: Grand unified theories, persistent B-meson flavour anomalies

Results:

- Single production, lepton-induced
- Pair production, eejj
- Cross-generational



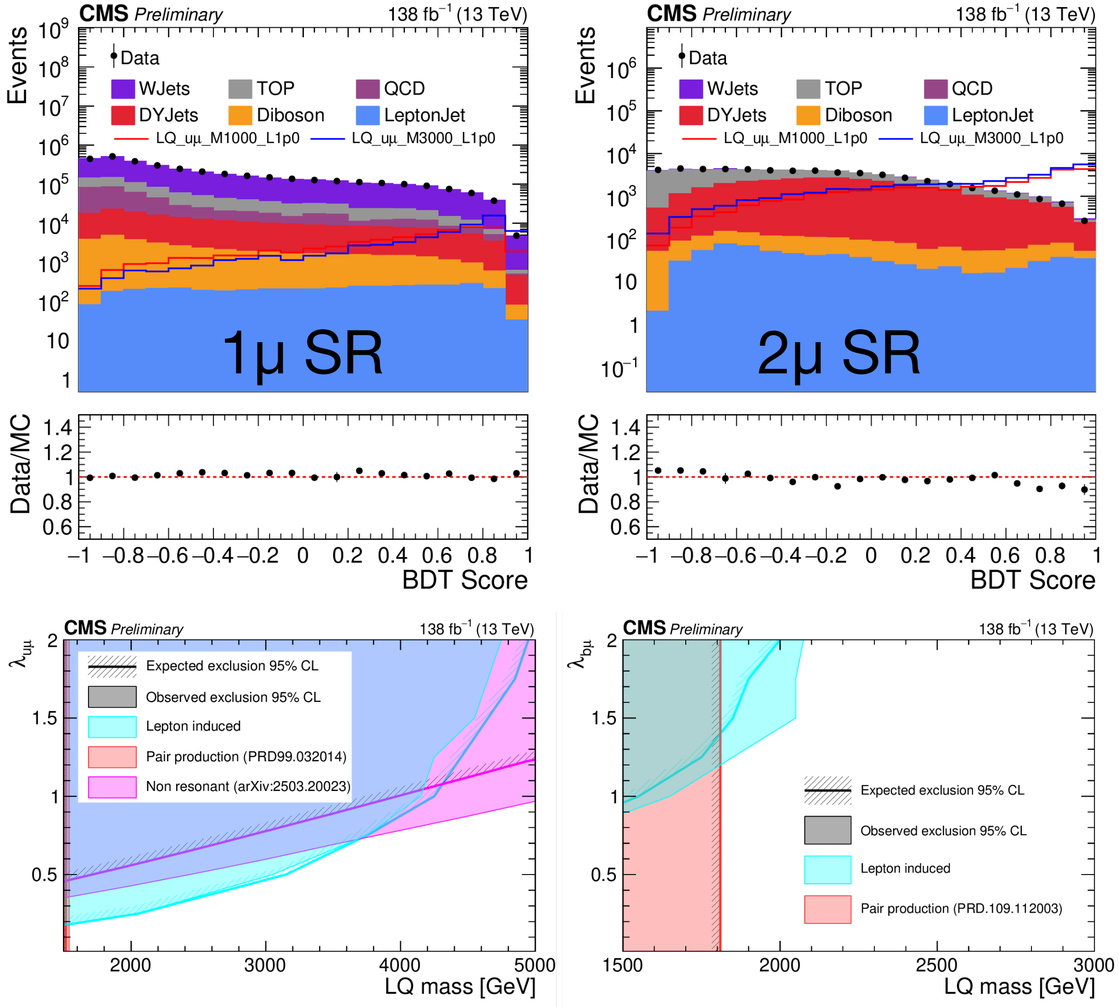
https://cds.cern.ch/record/1541976

Completing the quark sector

Run 2 - 138 fb^{-1} - 13 TeV

Single production, lepton-induced (EXO-24-005) - Results

- Leptoquark produced via muon-quark scattering, using the proton's charged-lepton PDF content
- **First search for this production mechanism at the TeV scale**
- A BDT trained on event kinematics splits events into signal-enriched categories (0/1 b-tag, loose/tight); within each category, the search fits the muon–jet invariant mass $M_{\mu j}$ which peaks at the LQ mass.
- No significant deviation observed. **LQ(uμ) excluded for masses 1.5–3.6 TeV in the coupling range λ=0.2–0.6; LQ(bμ) excluded above 1.8 TeV for λ>1**.



Completing the quark sector

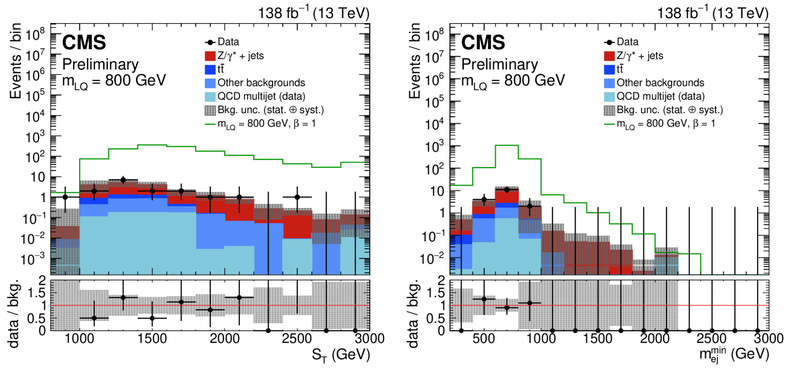
Pair production, eqeq (EXO-24-019) - Results

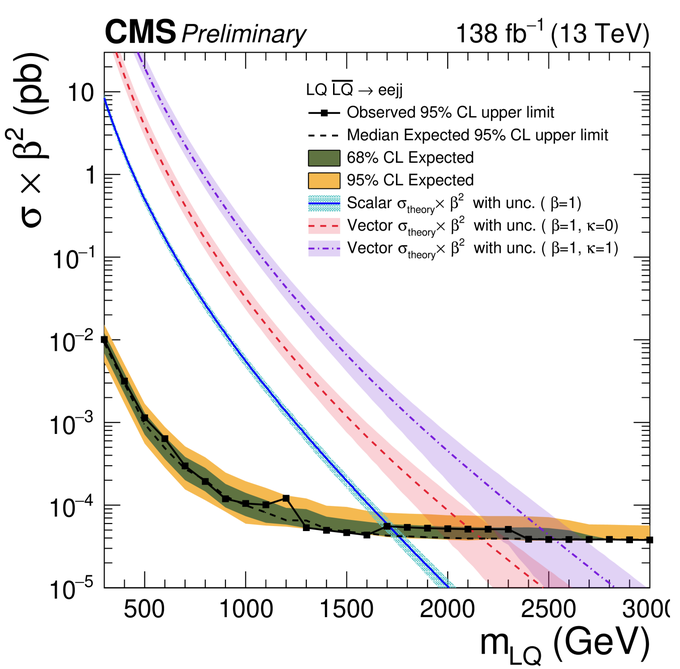
Run 2 - 138 fb^{-1} - 13 TeV

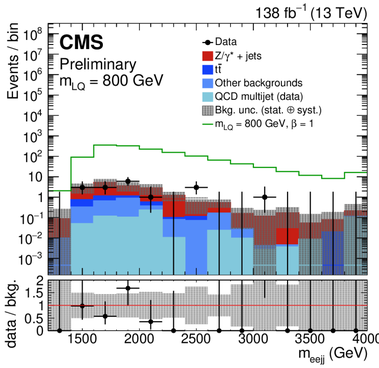
- Di-quark + di-lepton final state (eejj); first-generation couplings only; **coupling-independent** search (not λ-dependent, unlike the single-production channel)

- **Discriminant:** a mass-dependent selection ($m_{eejj} > m_{LQ}$) combined with a per-mass-point BDT defines the search region; Validates the post-selection agreement across S_T, m^{min}_{ej}, and m_{eejj}

- **No significant excess**. Scalar LQ excluded below **1710 GeV**; vector LQ excluded below **2110 GeV** (minimal coupling) / **2525 GeV** (Yang-Mills coupling), all at β = 1





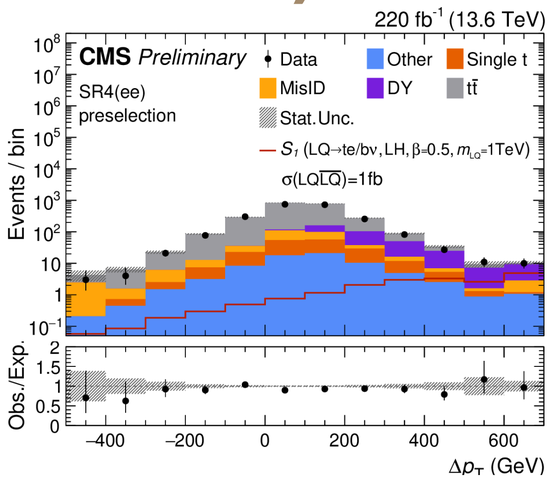


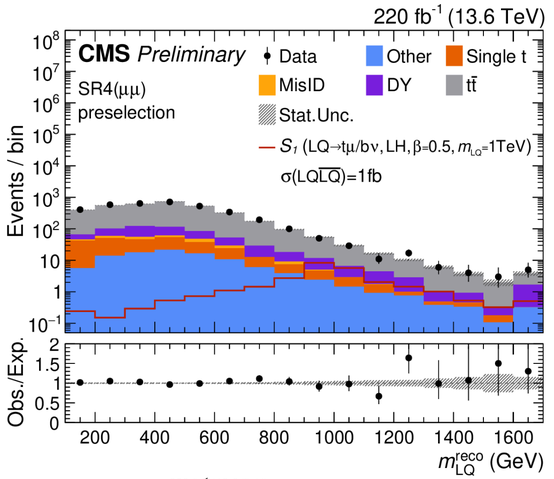
Completing the quark sector

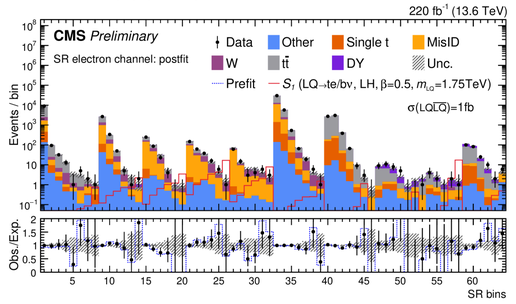
Cross-generational leptoquarks (B2G-25-011)

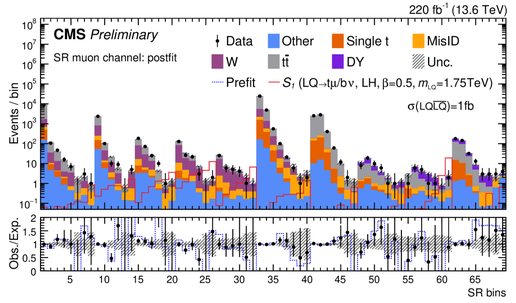
Run 3 - 220 fb^{-1} - 13.6 TeV

- Third-generation quarks + first-/second-generation leptons; scalar LQ decaying to tℓ or bν depending on coupling chirality
- Boosted hadronic top reconstruction (AK12 jets); signal regions split by lepton/b-jet multiplicity and leading-lepton p_T, further binned in m^{reco}_{LQ} and L_T+p_T^{miss}(+H_T^{AK12})
- **Discriminant:** Search built around Δp_T and m^{reco}_{LQ}
- **No significant deviation from background expectation**









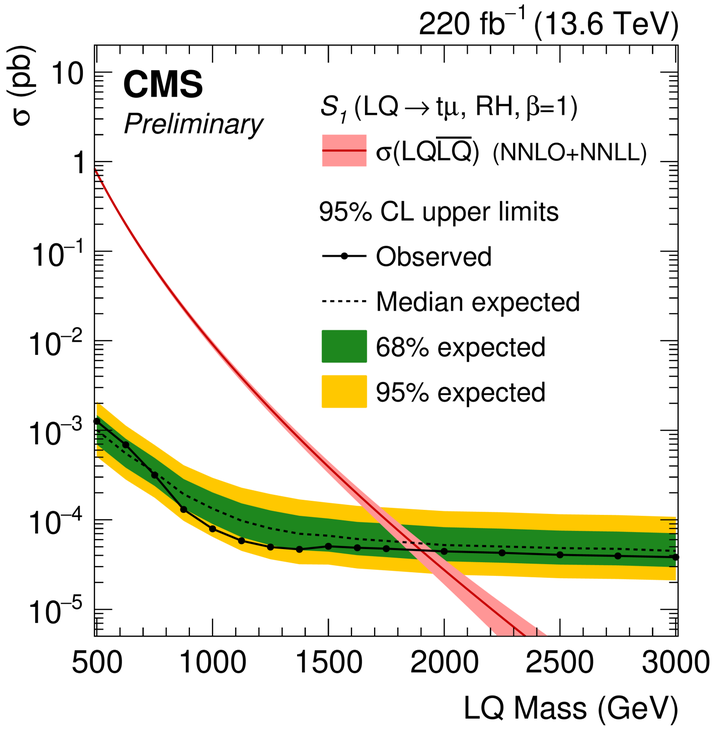
Completing the quark sector

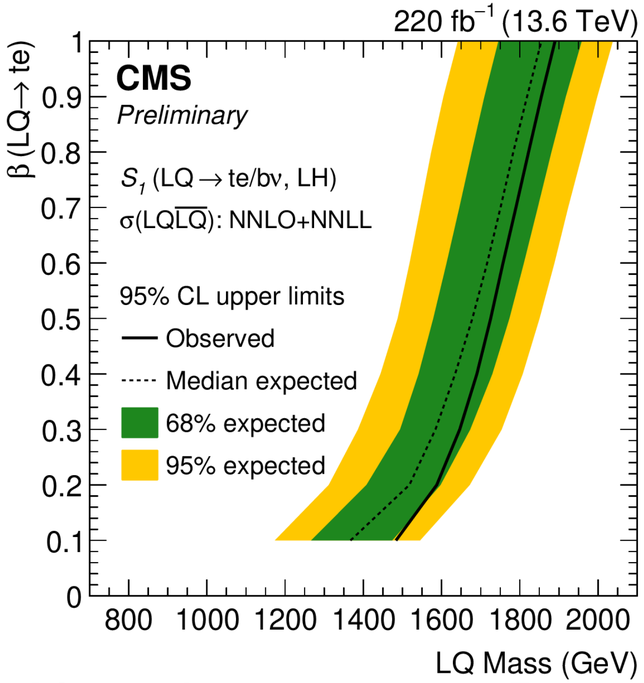
Run 3 - 220 fb^{-1} - 13.6 TeV

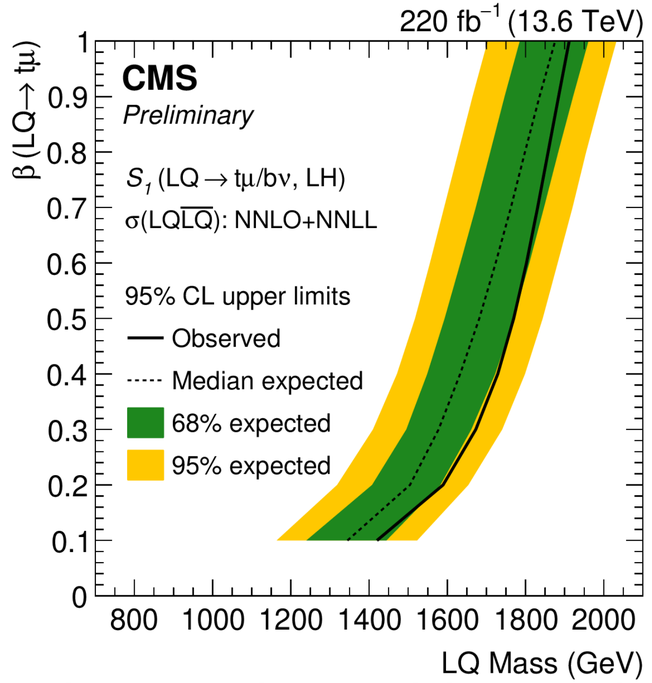
Cross-generational leptoquarks (B2G-25-011) - Results

- **Most stringent cross-generational leptoquark limits to date**

- Excludes 1720 GeV (e, LH) / 1860 GeV (e, RH); 1760 GeV (μ, LH) / 1890 GeV (μ, RH)





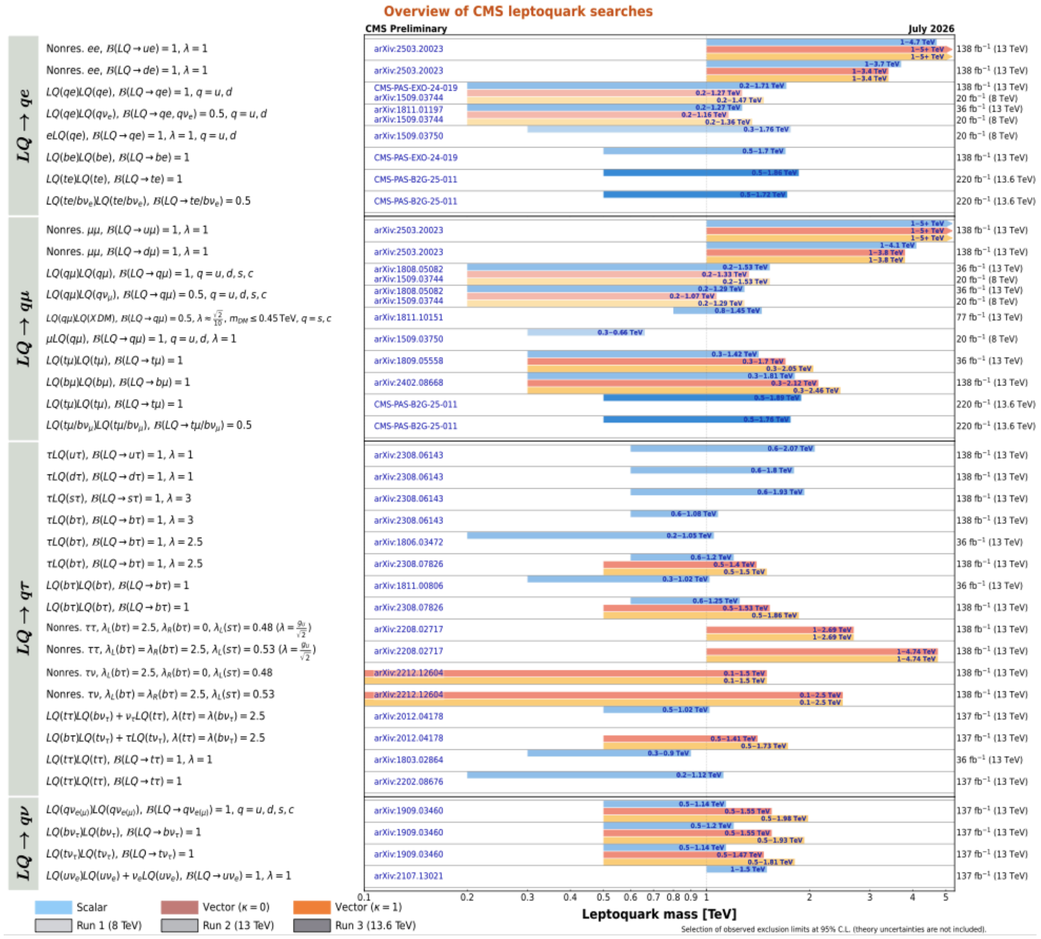


Also shown as a 2D exclusion vs. branching ratio

Completing the quark sector

Leptoquark landscape across searches Summary Results

Several first-ever results and Run-3-driven improvements this cycle across the whole VLQ/LQ program



https://cms-summary-searches.docs.cern.ch/lq_bar/

The search continues

Summary and outlook

- Across every mass scale and final state covered today (heavy dilepton gauge bosons, resonances hidden inside Higgs decays, the low-mass dark photon, and the quark sector) the story is the same: **no significant excess observed anywhere**

- Several local fluctuations that are worth watching

- Several **first-ever** results delivered this cycle: the $A \to ZH \to \ell\ell\bar{t}t$ semileptonic channel, the first CMS search for $LLP \to \gamma\gamma$ in this mass/lifetime window, the first search for $T \to t\phi(\gamma\gamma)$, and the first $X_{5/3} \to tH^{\pm}$ result

- Recurring theme: **novel triggering and analysis techniques** are what's actually driving the sensitivity gains.

https://www.quantamagazine.org/why-feynman-diagrams-are-so-important-20160705/

We don't know where new physics is, but we know a lot more places it *isn't*, and the map keeps getting sharper.

Thank you!

Backup slides

Benchmark models
W′, Z′, graviton

A Run 2+3 Z′ combination is in preparation for publication

Complementary results exist: EXO-25-001 (non-resonant Z′ interpretation), EXO-24-011 (wide-resonance interpretation)

Z′ constraints also come from CMS's dijet summary page (https://cms-summary-searches.docs.cern.ch/dijet_summary/)

- **HVT framework:** heavy spin-1 V′ with three free couplings — g_H (Higgs/boson current, governs V′→VV/VH and VBF production), g_F (fermion current, governs Drell-Yan production and V′→ℓℓ/ℓν), g_V (overall coupling scale). Model A = weakly coupled (g_F dominant), Model B = strongly coupled (mixed), Model C = VBF-exclusive (g_F=0)

- **Left-Right Symmetric Model:** restores parity at high scale via an added $SU(2)_R$ gauge group; predicts W_R/Z_R partners

- **E6-motivated models:** superstring-inspired GUT extension predicting an extra U(1)′ and Z'_ψ

- **Randall-Sundrum warped extra dimensions:** addresses the hierarchy problem via a warped 5th dimension; the RS graviton is the KK excitation of the 4D graviton

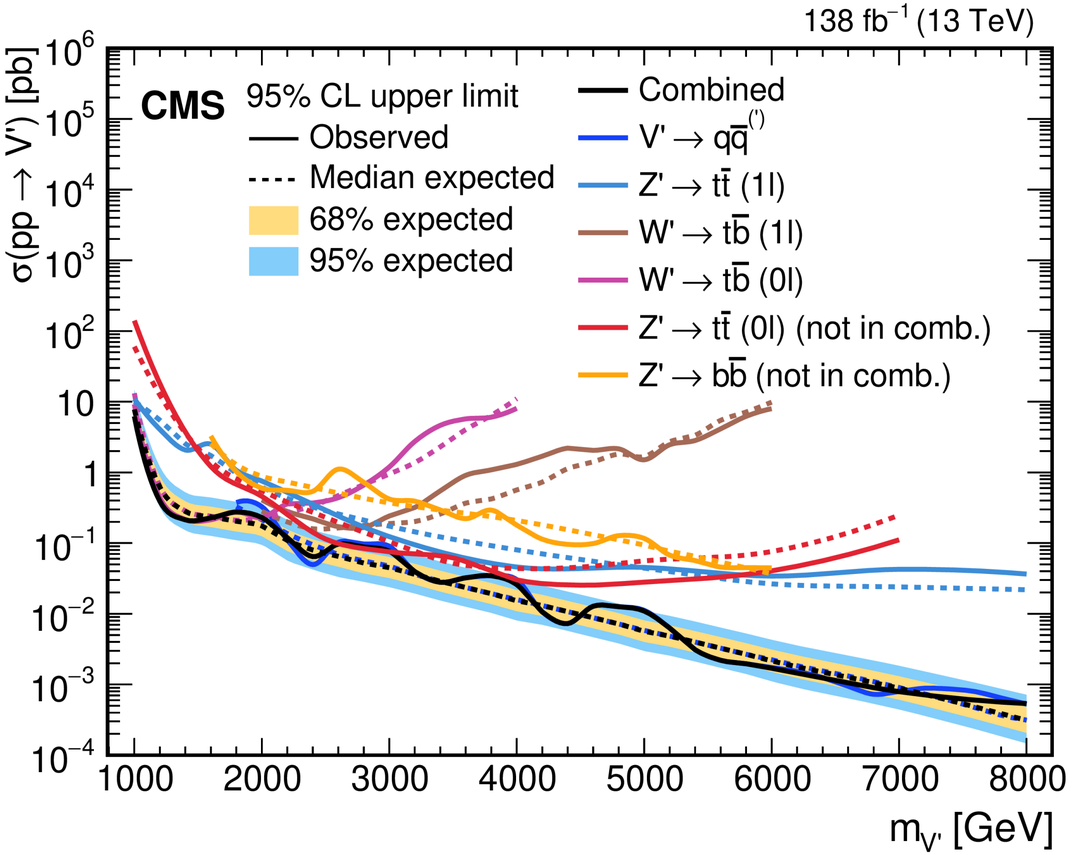
HVT
Analyses

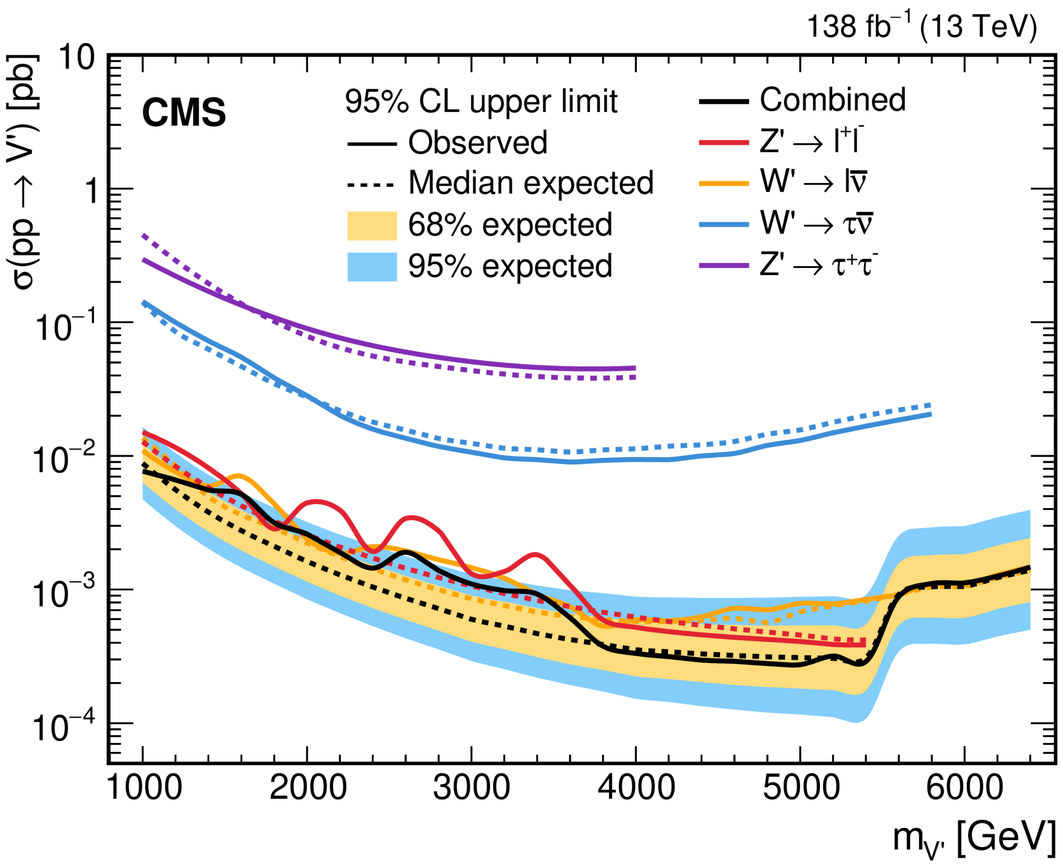
Channel	Prod. modes	$m_{V'}$ range [TeV]	Leptons	Jets	Reference
$Z' \to \tau^+\tau^-$	DY	0.5–4.0	$\ell\tau_h$ or $2\tau_h$	—	[47]
$Z' \to \ell^+\ell^-$	DY	0.8–5.5	2ℓ	—	[48]
$W' \to \ell\bar{\nu}$	DY	0.8–6.0	1ℓ	—	[49]
$W' \to \tau\bar{\nu}$	DY	0.8–6.0	$1\tau_h$	—	[50]
$V' \to q\bar{q}^{(\prime)}$	DY	1.8–8.7	0ℓ	jj	[51]
$W' \to t\bar{b}$ (0ℓ)	DY	1.0–4.0	0ℓ	$j^t j^b$	[52]
$W' \to t\bar{b}$ (1ℓ)	DY	2.0–6.0	1ℓ	$j^b j^b$	[53]
$Z' \to t\bar{t}$ (1ℓ)	DY	0.8–5.0	1ℓ	j^t or jjj^b	[54]
$Z' \to ZH$ $(2\ell 2b)$	DY + VBF	0.8–5.0	2ℓ	j^{bb}	[55]
$Z' \to ZH$ $(2\nu 2b)$	DY + VBF	0.8–5.0	0ℓ	j^{bb}	[55]
$Z' \to ZH$ $(2\ell 2q)$	DY	1.2–6.0	2ℓ	j^H	[56]
$Z' \to ZH$ $(2\nu 2q)$	DY	1.2–6.0	0ℓ	j^H	[56]
$W' \to WZ$ $(2q2\ell)$	DY	0.6–2.0	2ℓ	j^V or jj	[57]
$W' \to WZ$ $(2q2\nu)$	DY + VBF	1.0–4.5	0ℓ	j^V	[58]
$V' \to WV/WH$	DY + VBF	1.0–4.5	1ℓ	j^V	[59]
$V' \to VV/VH$	DY + VBF	1.3–6.0	0ℓ	$j^V j^V$	[20]

Table 1. Summary of the searches for difermion and diboson resonances used as inputs to this combined statistical analysis. The targeted production modes, resonance mass ranges, reconstructed particles, and references are listed. In the "Jets" column, only jets from the heavy resonance decay are indicated. Detailed definitions of reconstructed particles in the "Leptons" and "Jets" columns, such as τ_h and various types of jets, are provided later in the main text.

HVT

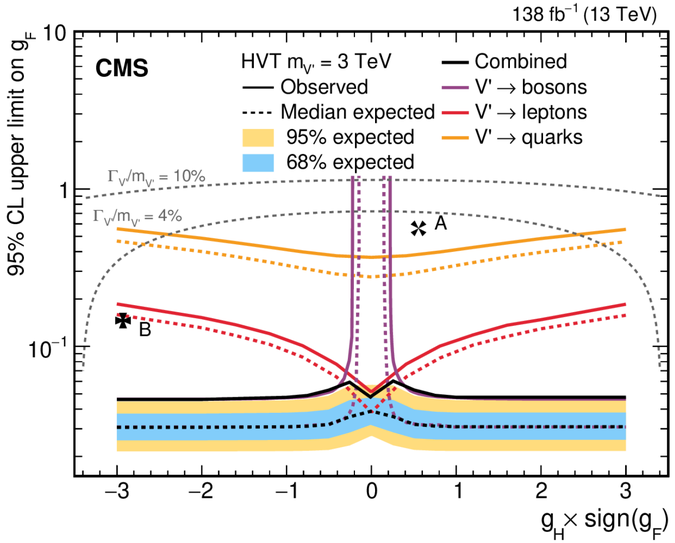
Individual-channel breakdown

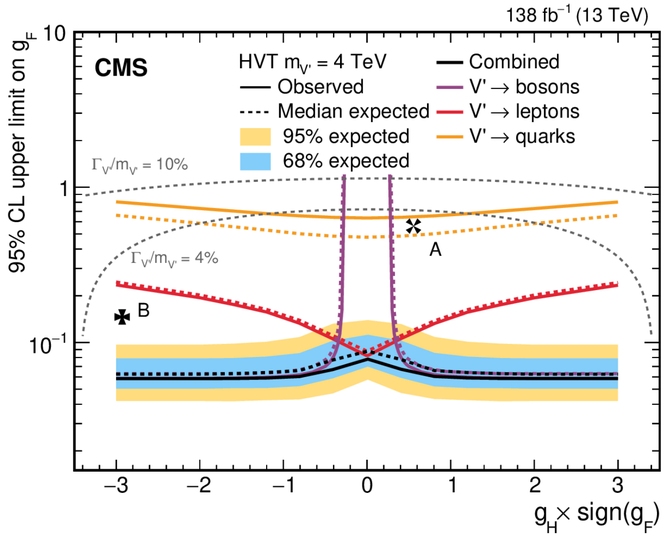


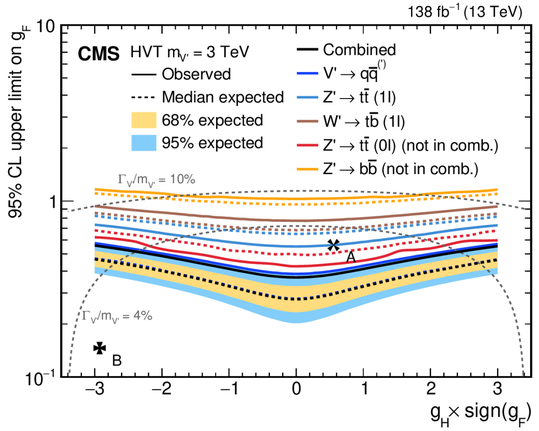


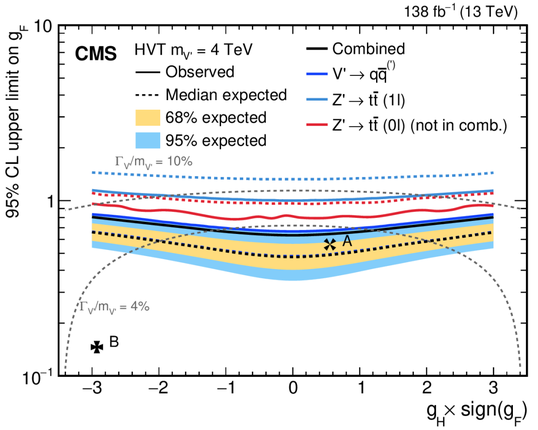
HVT

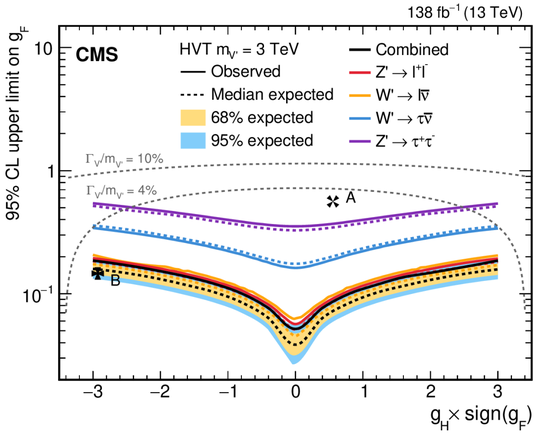
Coupling-plane limits

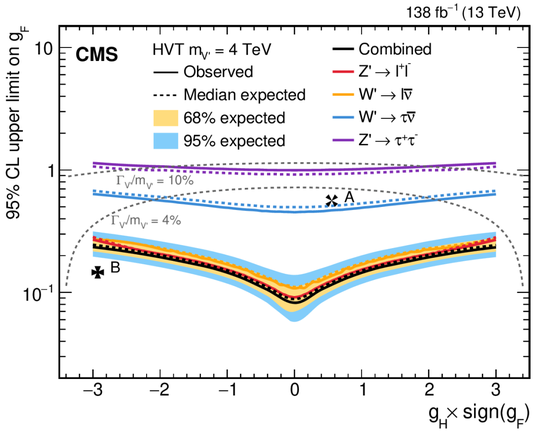


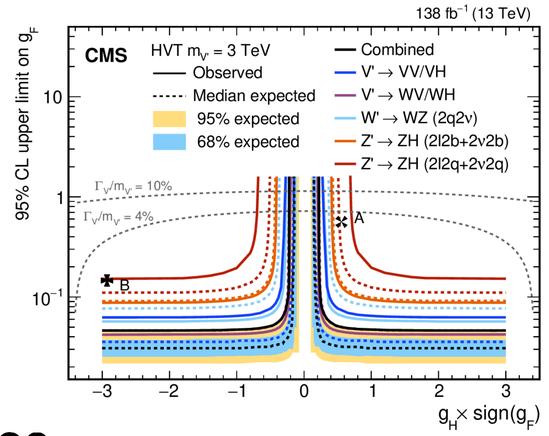


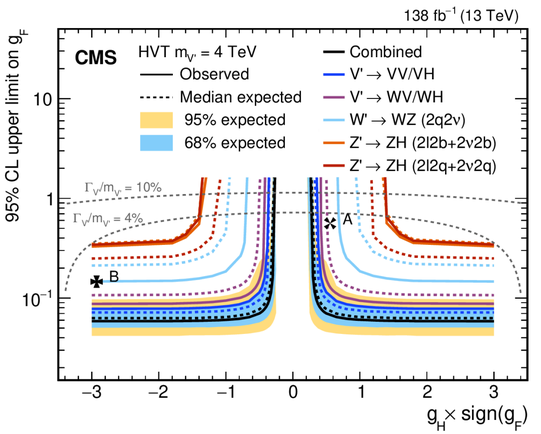








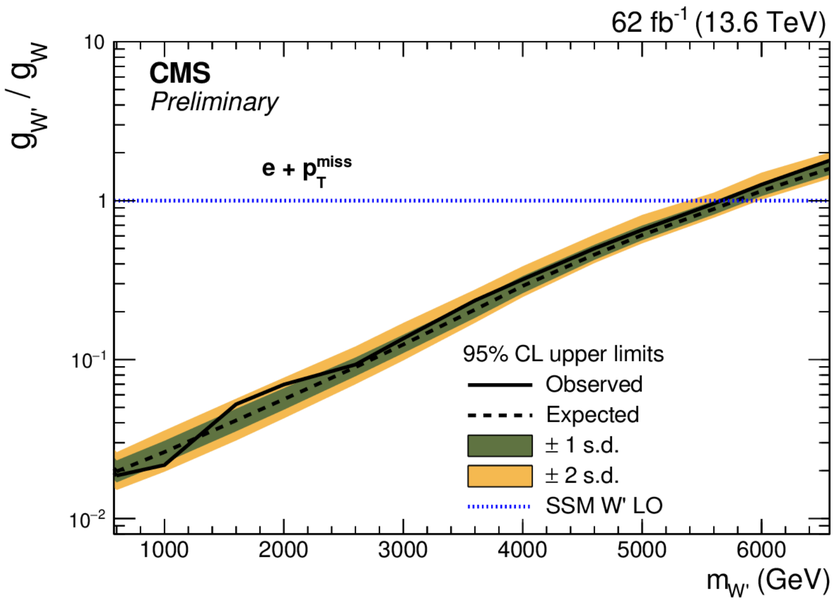


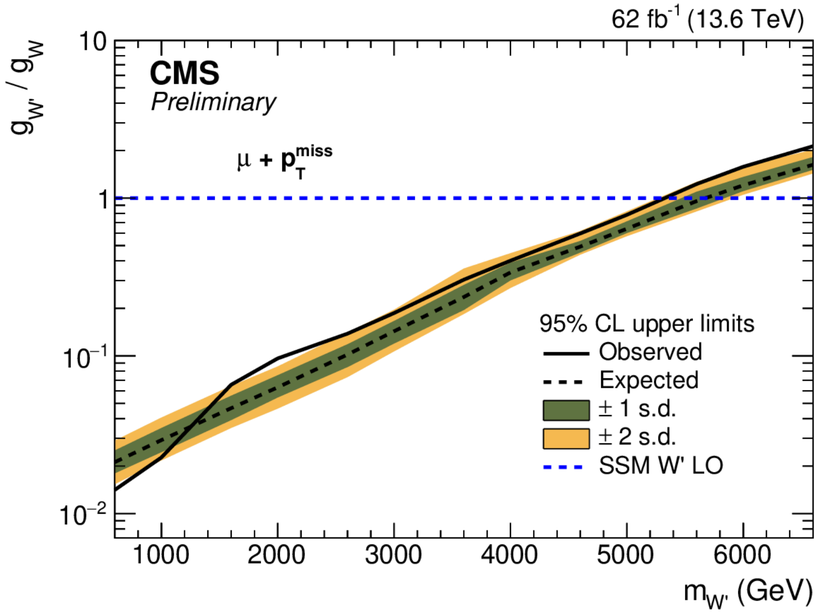


W′

Model-independent coupling limit

- Limit on $g_{W'}/g_W$ vs. W′ mass, independent of the SSM benchmark assumption
- Models with g_W′/g_W ≈ 2×10^{-2} excluded up to 0.5 TeV; constraint weakens at higher mass, approaching $g_{W'}/g_W = 1$ near the SSM exclusion limit



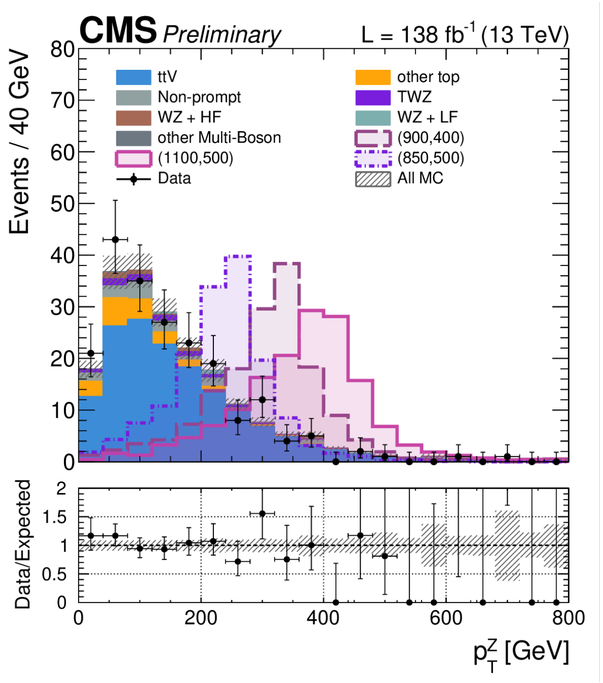


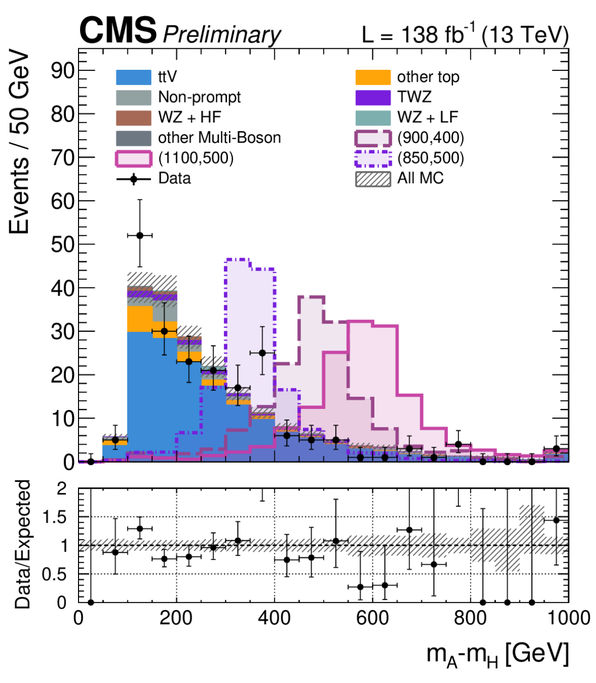
A→ZH

Model & discriminant construction

- **2HDM Type-II:** second Higgs doublet with the same Yukawa structure as the MSSM; this parameter space is tied to models of electroweak baryogenesis

- Before the final $p_T(Z)\times\Delta m$ discriminant, the two individual variables are validated separately: $\Delta m(A,H)$ (robust to interference/JER) and $p_T(Z)$ (kinematic edge set by Δm)



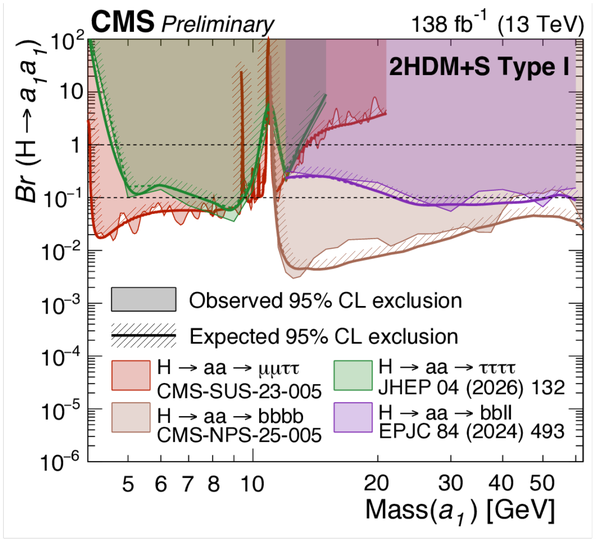


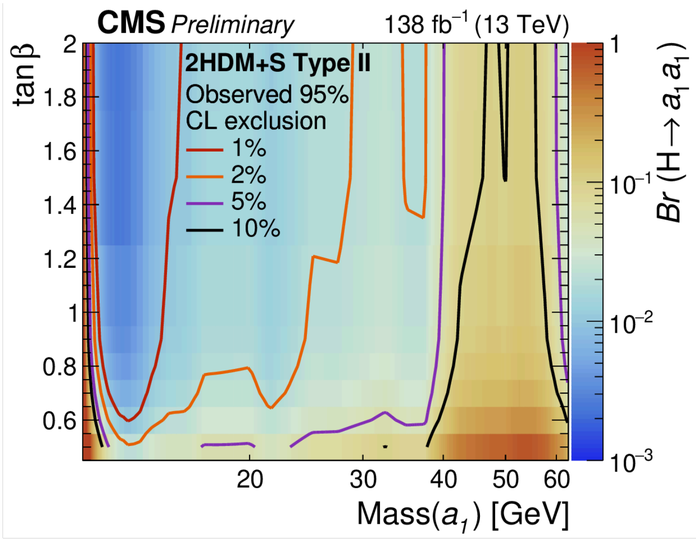
$H \rightarrow a_1 a_1$

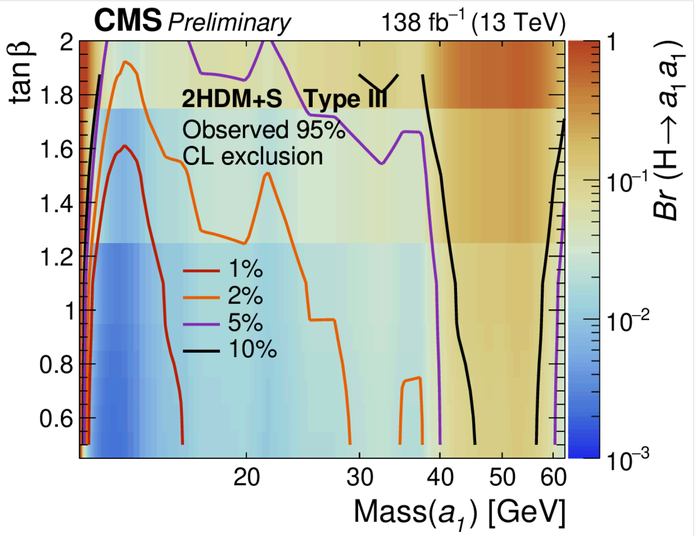
Full 2HDM+S interpretation

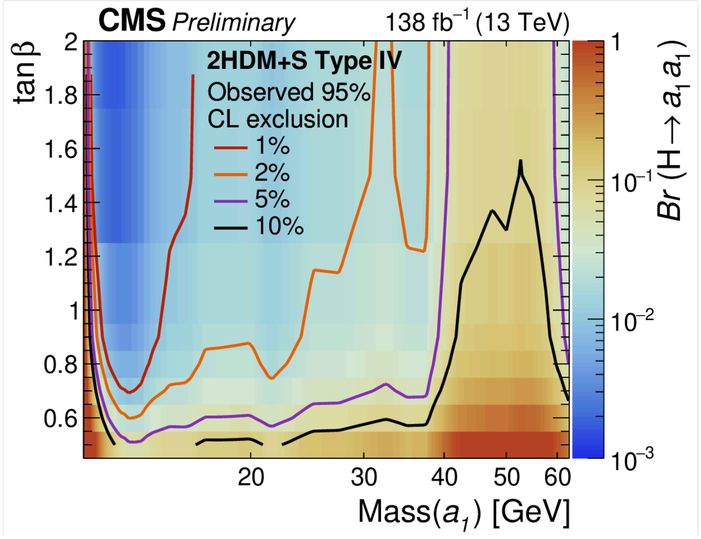
- **2HDM+S:** a singlet scalar added to 2HDM; the lightest CP-odd state a_1 can appear in exotic 125 GeV Higgs decays

- Four Yukawa-structure types (I–IV) give different predictions; Type I shown vs. m(a_1) directly, Types II–IV shown in the tanβ vs. m(a_1) plan







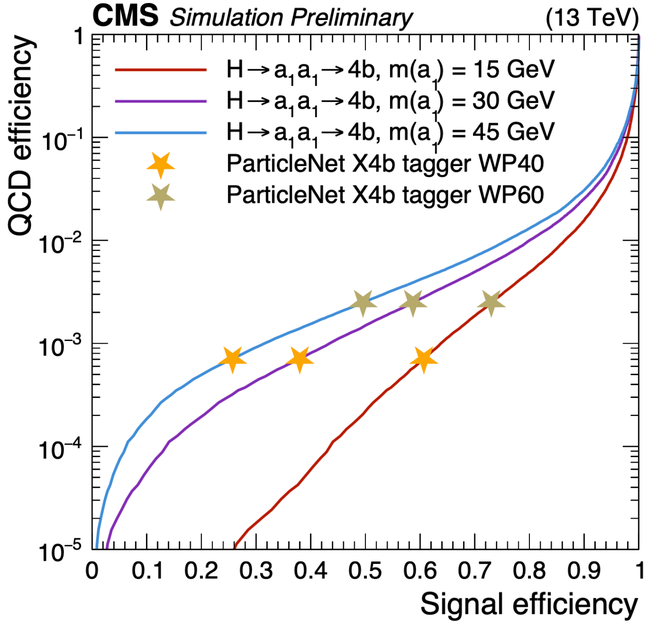


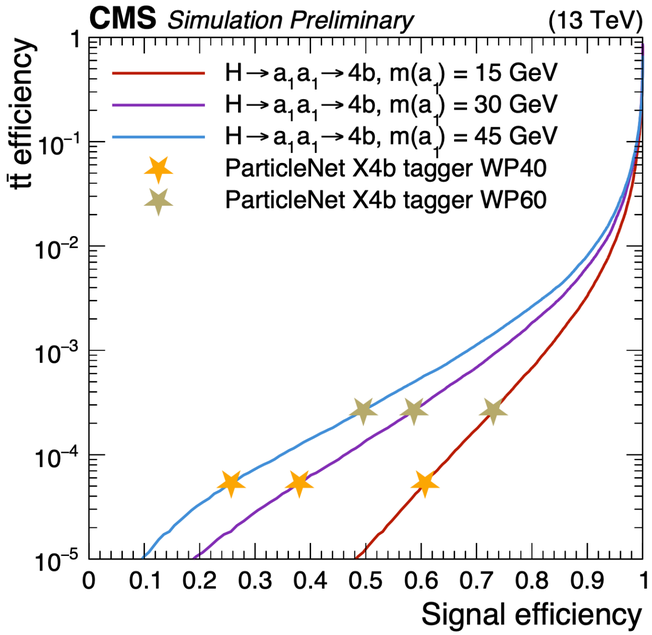
$H \rightarrow a_1 a_1$

Tagger performance & categories

- ParticleNet X4b tagger ROC curves (signal efficiency vs. QCD/$t\bar{t}$ background efficiency) at the two working points used (WP40, WP60)

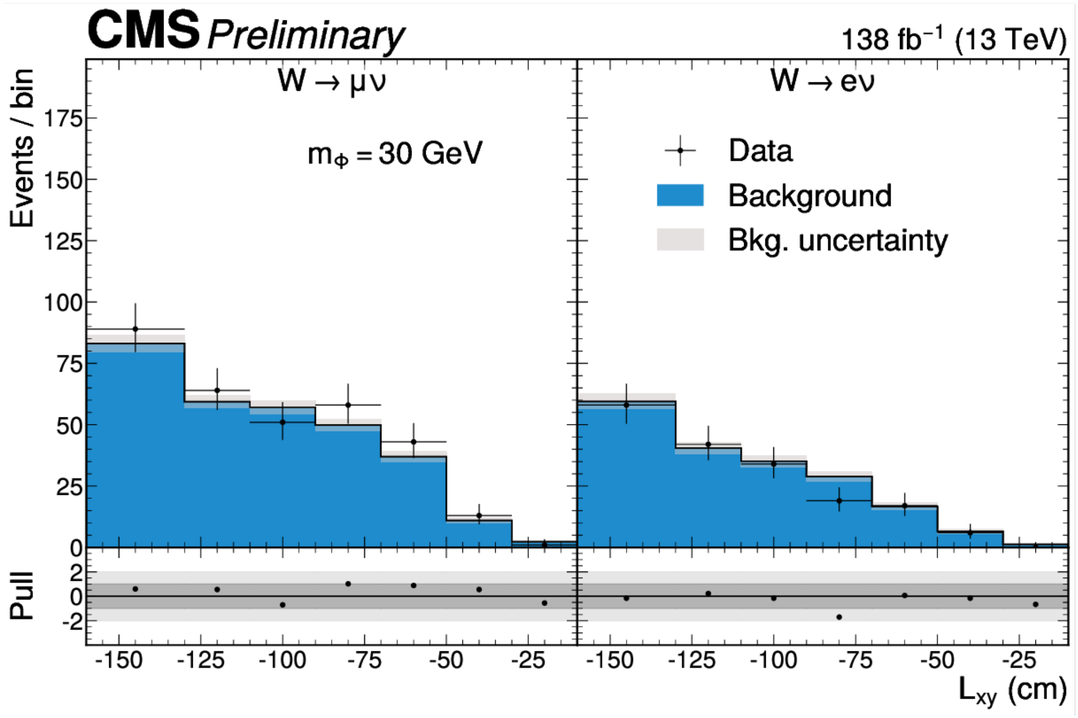
- Category definitions (Table 1) and expected signal/ background yields per category (Table 2), for the breakdown across gg0ℓ/ VBFjj/Vjj/leptonic

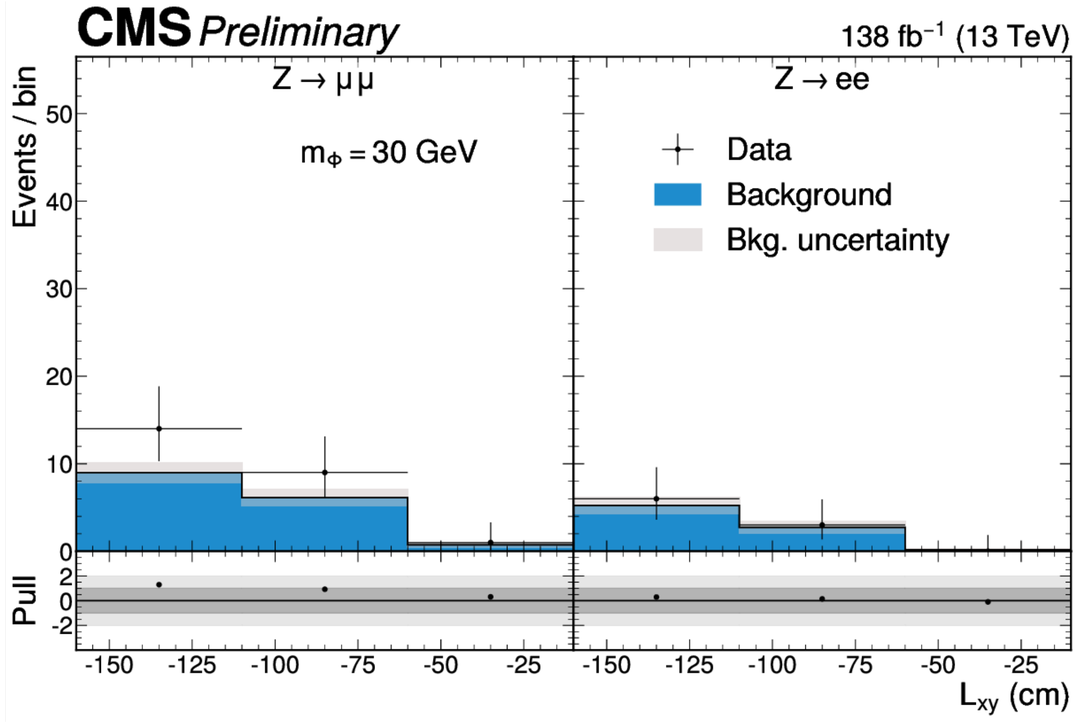




LLP→γγ
Background validation

- Data vs. predicted background for $L_{xy} < -10$ cm sideband, W and Z categories; demonstrates the background model's validity before looking at the signal region





Dark photon portal model & Z_D Run 2/3

- **Dark photon kinetic mixing:** a new $U(1)_D$ gauge boson mixing with the SM photon via a small parameter ε — the simplest "portal" linking a hidden sector to the SM

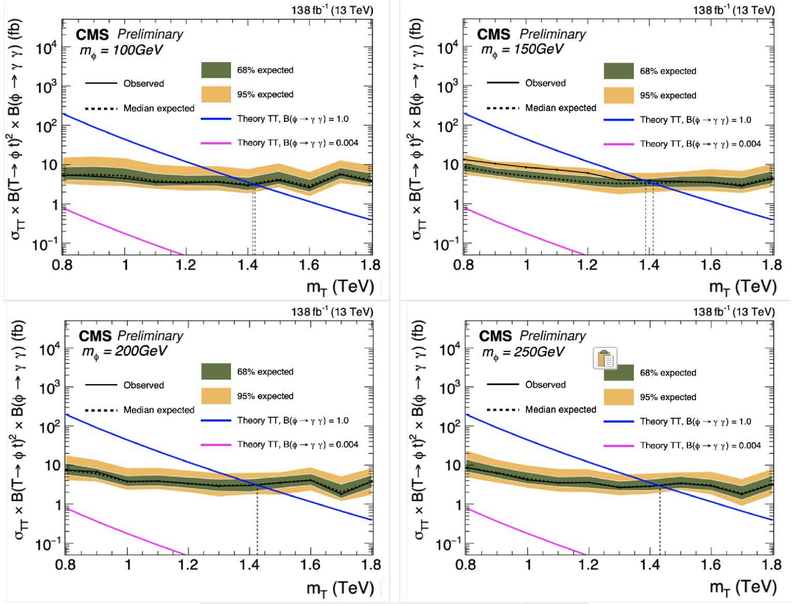
- The Run 2 low-mass ε^2 limit appears *better* than Run 3's at some masses — this is reflects a change in the dark-photon interpretation procedure

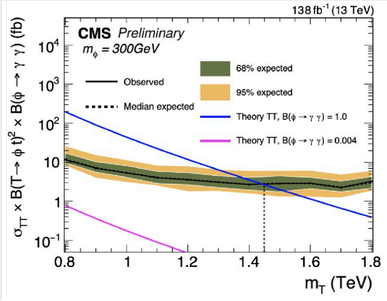
VLQ

Composite Higgs motivation & additional T→tϕ limits

- **Composite Higgs / naturalness:** vector-like top partners cancel the top-loop quadratic divergence to the Higgs mass, addressing naturalness without supersymmetry

- Per-m_ϕ exclusion curves (100–300 GeV), both $B(\phi\rightarrow\gamma\gamma)$=1.0 and 0.004 scenarios





$X_{5/3}$

BDT input variables ranking

Rank	Variable
1	S_{T}
2	Number of W-tagged AK8 jets
3	Invariant mass of all jets and leptonically decaying W bosons
4	Invariant mass of the ℓ and angularly closest b jet pair
5	Number of t-tagged AK8 jets
6	Invariant mass of the ℓ and jet with subleading p_{T}
7	Invariant mass of the ℓ and jet with third-highest p_{T}
8	Invariant mass of the ℓ and leading b jet pair
9	Sphericity
10	Minimum invariant mass of the ℓ and any b jet pair
11	Minimum angular distance between the ℓ and any AK4 jet
12	Transverse mass of the ℓ and $\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}$
13	$p_{\mathrm{T}}^{\mathrm{miss}}$
14	Transverse momentum of the system of the two leading b jets and $\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}$
15	Minimum angular distance between the ℓ and any b jet pair
16	Lepton energy
17	Third-highest DEEPJET discriminant value
18	Second-highest DEEPJET discriminant value
19	ΔR between the ℓ and the b jet yielding the minimum invariant mass
20	ΔR between the ℓ and the jet yielding the minimum invariant mass

Leptoquarks

Theory motivations

- **GUT frameworks:** Pati-Salam and SU(5) naturally predict leptoquarks as states unifying the quark and lepton sectors

- **B-anomalies:** persistent tensions in R(D*), R(K*) measurements favour leptoquarks coupling preferentially to third-generation quarks; directly motivates the cross-generational search (B2G-25-011)

- RH couplings exclude higher masses than LH (1860/1890 vs. 1720/1760 GeV) — LH leptoquarks share their decay between $t\ell$ and bv (SU(2) doublet structure), while RH leptoquarks decay almost purely to $t\ell$, giving more signal in the searched channel

References

1. CMS Collaboration, "Enriching the physics program of the CMS experiment via data scouting and data parking," *Phys. Rept.* **1115** (2025) 678, arXiv:2403.16134

2. CMS Collaboration, "Search for new charged gauge bosons in the e/μ + p_T^{miss} channel using pp collisions at √s = 13.6 TeV," CMS-PAS-EXO-24-021

3. CMS Collaboration, "Search for resonant new phenomena in high-mass dilepton final states at √s = 13.6 TeV," CMS-PAS-EXO-25-021

4. CMS Collaboration, "Combination of searches for heavy vector boson resonances in proton-proton collisions at √s = 13 TeV," CMS-B2G-25-003, JHEP 07 (2026) 005

5. CMS Collaboration, "Search for heavy Higgs bosons in the A→Z(→ℓℓ)H(→$\bar{t}$t semileptonic) channel," CMS-PAS-B2G-24-002

References

6. CMS Collaboration, "Search for Lorentz-boosted Higgs boson decays to a pair of new spin-0 particles in the $\bar{b}b\bar{b}b$ final state at $\sqrt{s}$ = 13 TeV," CMS-PAS-NPS-25-005

7. CMS Collaboration, "Search for long-lived particles decaying to photons in decays of the Higgs boson at $\sqrt{s}$ = 13 TeV," CMS-PAS-EXO-23-012

8. CMS Collaboration, "Search for low-mass resonances decaying to a pair of muons in proton-proton collisions at $\sqrt{s}$ = 13.6 TeV," CMS-PAS-EXO-25-019

9. CMS Collaboration, "Search for pair-produced vector-like top quarks decaying to Lorentz-boosted top quarks and scalar bosons in proton-proton collisions at $\sqrt{s}$ = 13 TeV," CMS-PAS-B2G-24-016

References

10. CMS Collaboration, "Search for heavy top quark partners with charge 5/3 in the single-lepton final state in proton-proton collisions at √s = 13 TeV," CMS-PAS-B2G-24-005

11. CMS Collaboration, "Search for scalar leptoquarks produced via muon-quark scattering in proton-proton collisions at √s = 13 TeV," CMS-EXO-24-005, submitted to JHEP, arXiv:2608.28377

12. CMS Collaboration, "Search for pair production of leptoquarks decaying to electrons and quarks in proton-proton collisions at √s = 13 TeV," CMS-PAS-EXO-24-019

13. CMS Collaboration, "Search for leptoquarks coupling to third-generation quarks and first- or second-generation leptons at √s = 13.6 TeV," CMS-PAS-B2G-25-011