



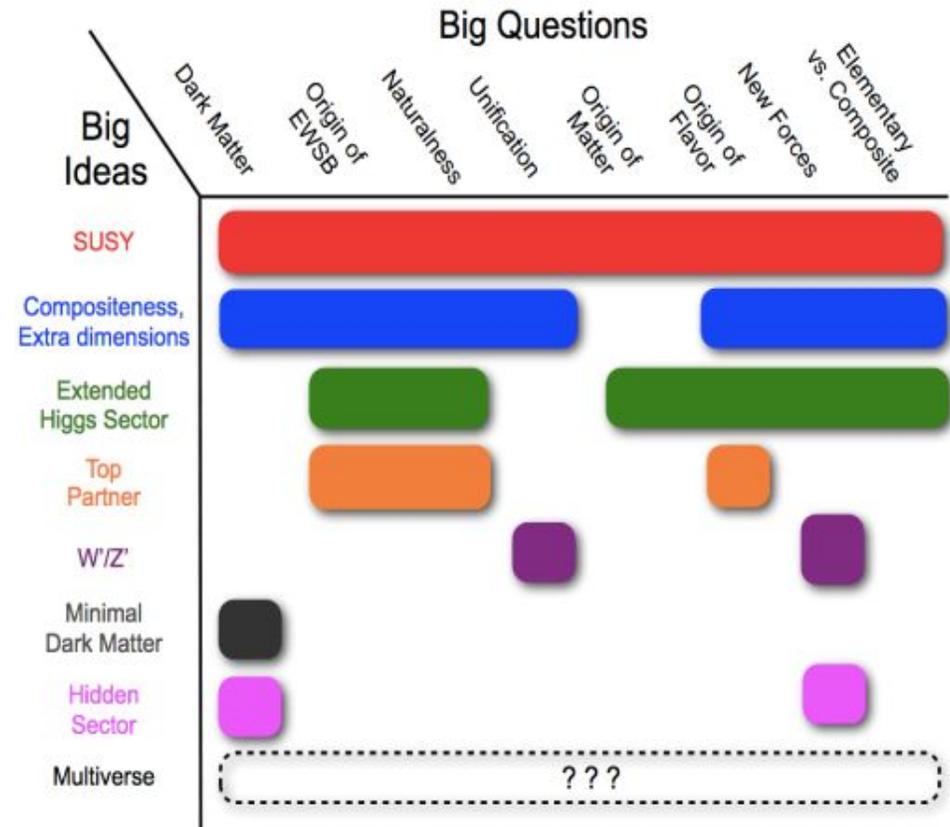
Searches in CMS for new physics in final states with leptons

***Anureet Kaur (Panjab University, Chandigarh, India)
On behalf of the CMS Collaboration***

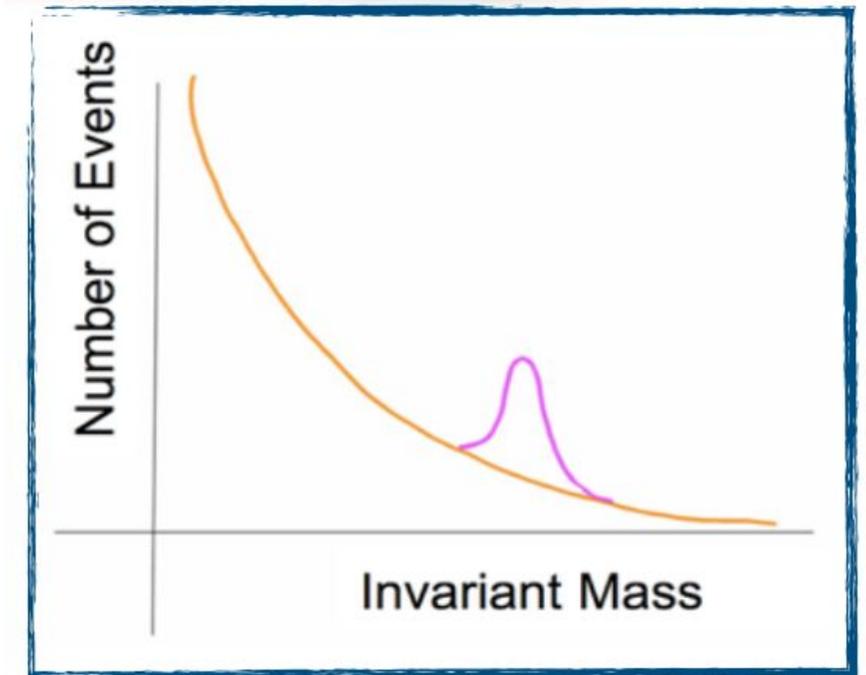
LEPTON PHOTON 2025: August 28, Madison

We are all aware of how successful the SM is

- ❖ But we also know there has to be something more.
- ❖ The SM alone can't explain many things
 - Hierarchy/naturalness/fine-tuning?
 - Matter-antimatter Asymmetry?
 - What are "dark matter" and "dark energy"?
 - Do quarks and leptons have substructure?



- ❖ **Direct searches for BSM physics remains a key part of the CMS physics program.**
- ❖ How we perform BSM searches in CMS:
 - Reconstruct sensitive variables like invariant Mass.
 - Target events with exotic signatures such as higher MET, displaced vertices etc.
 - Look for a “bump” on a smooth falling background.
- ❖ Many BSM models predict **new mediators** (heavy and light resonances).
 - Examples: **SUSY, ALPs, 2HDM, GUTs, leptoquarks, vector-like leptons.**
- ❖ **Leptons (e, μ, τ):** clean, precisely measured in CMS.
- ❖ This talk will cover the latest searches with leptons in the **final state exploring prompt and displaced leptonic signatures.**

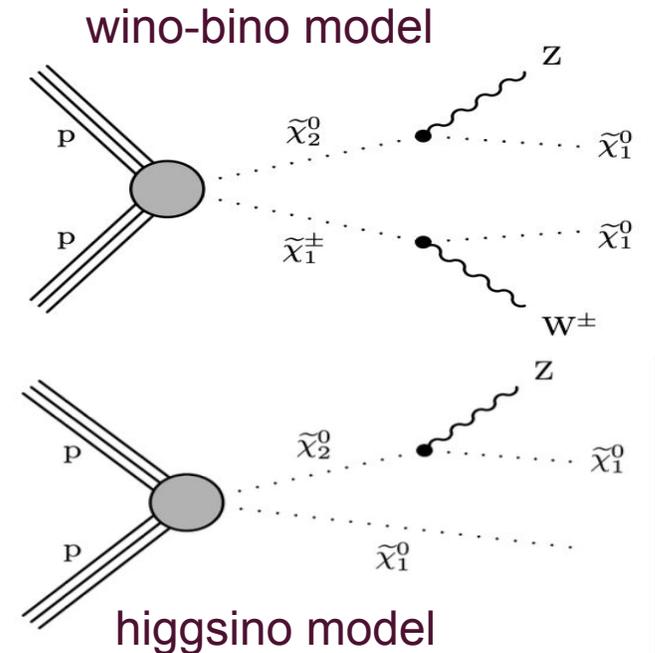
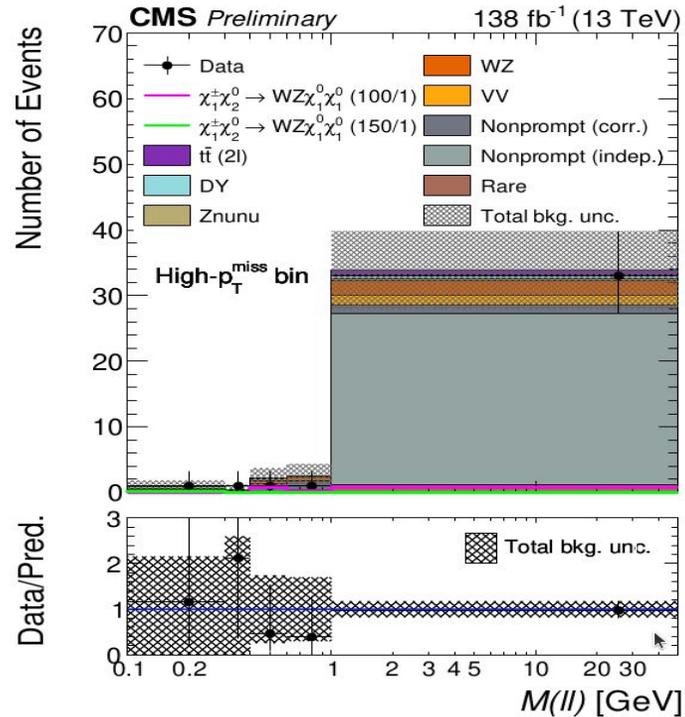
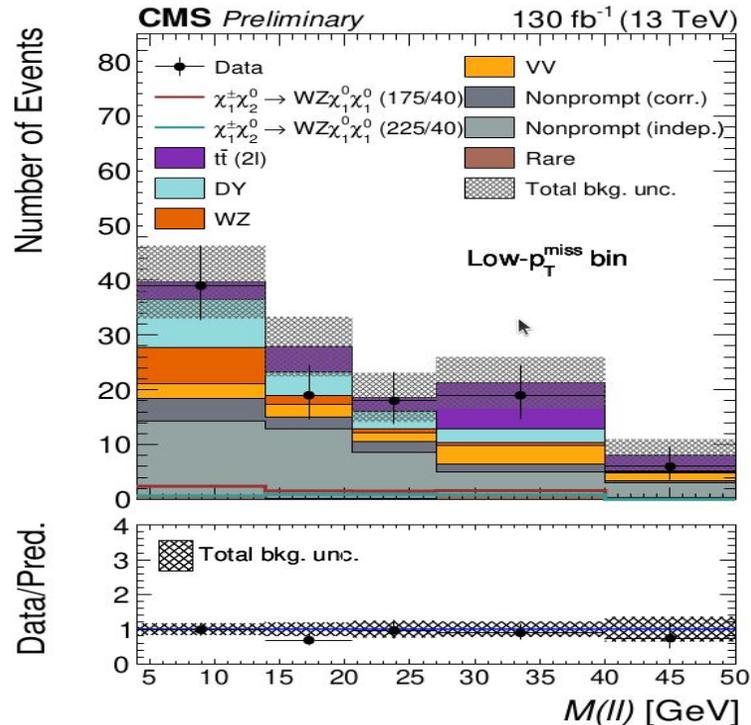


EXO-23-017-PAS

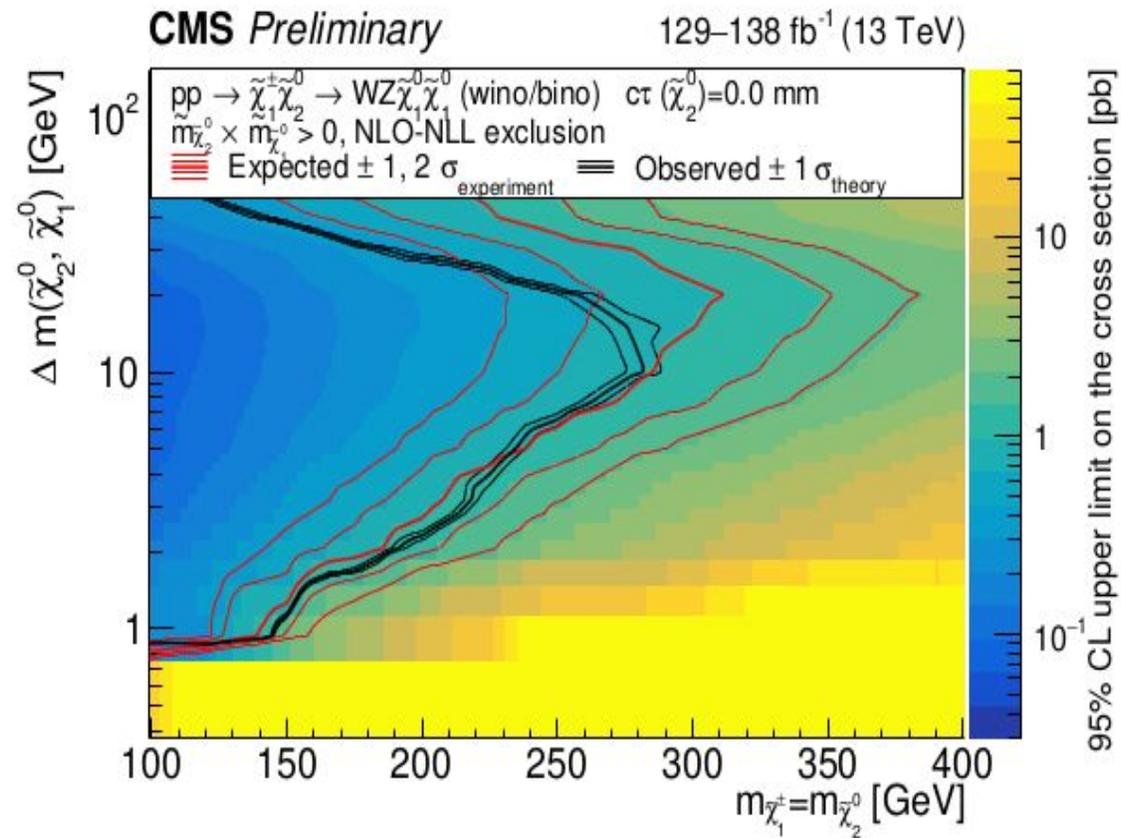
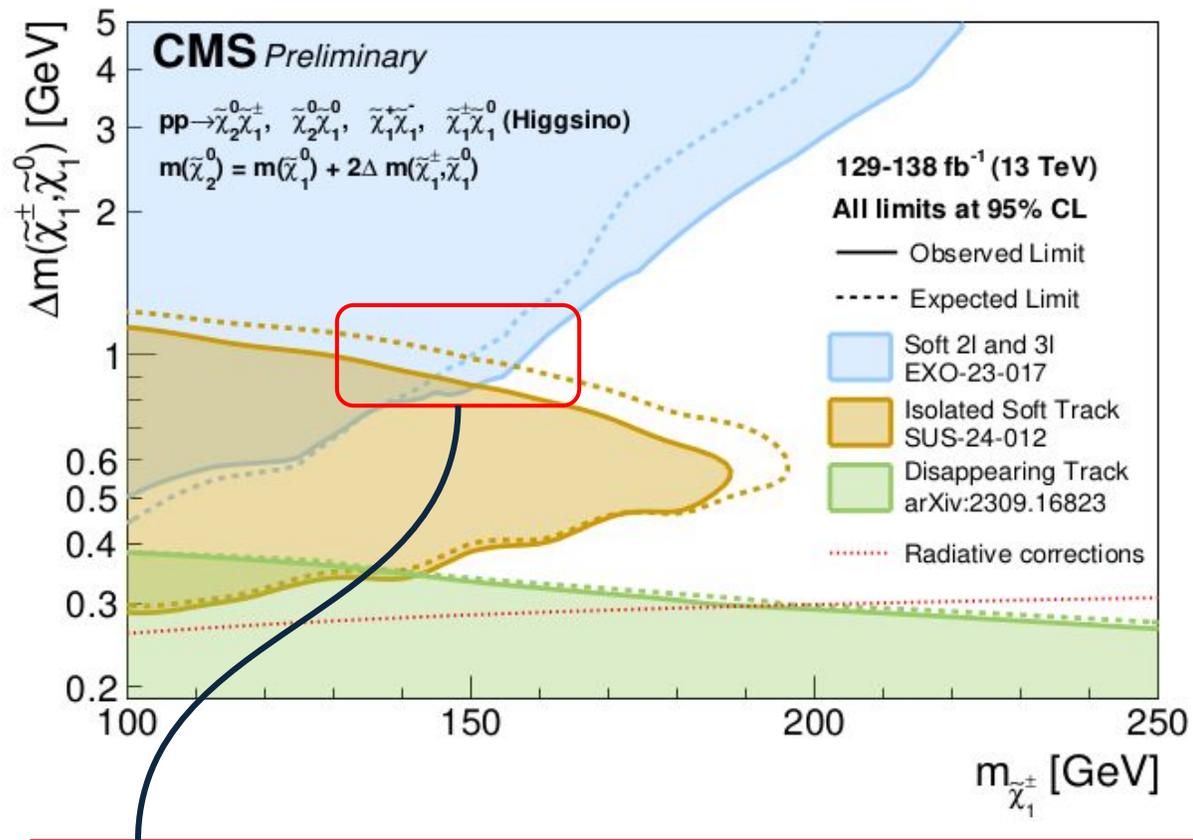
Search for new physics with compressed mass spectra in final states with soft leptons and missing transverse energy in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration

- ❖ **First LHC search with ultra low- p_T electrons down to 1 GeV.**
- ❖ Dedicated low- p_T electron algorithm + optimized isolation \rightarrow extended acceptance down to 1 GeV electrons and 3.5 GeV muons.
- ❖ Covers extremely compressed SUSY spectra: $\Delta m(\chi_2^0, \chi_1^0) \approx 600$ MeV to 50 GeV.
- ❖ Sensitive to both prompt + displaced leptons (up to 10 cm lifetime).
- ❖ Data-driven background estimation (DY, $t\bar{t}$, non-prompt) ensures robust limits.



- Overall, no significant excess of events beyond the prediction is observed: limits at 95% CL are derived on the allowed set of parameters for the TCHIWZ and HIGGSINO signal models.



❖ Closes gaps in Higgsino parameter space — now excluded up to ~140 GeV, beyond LEP reach.

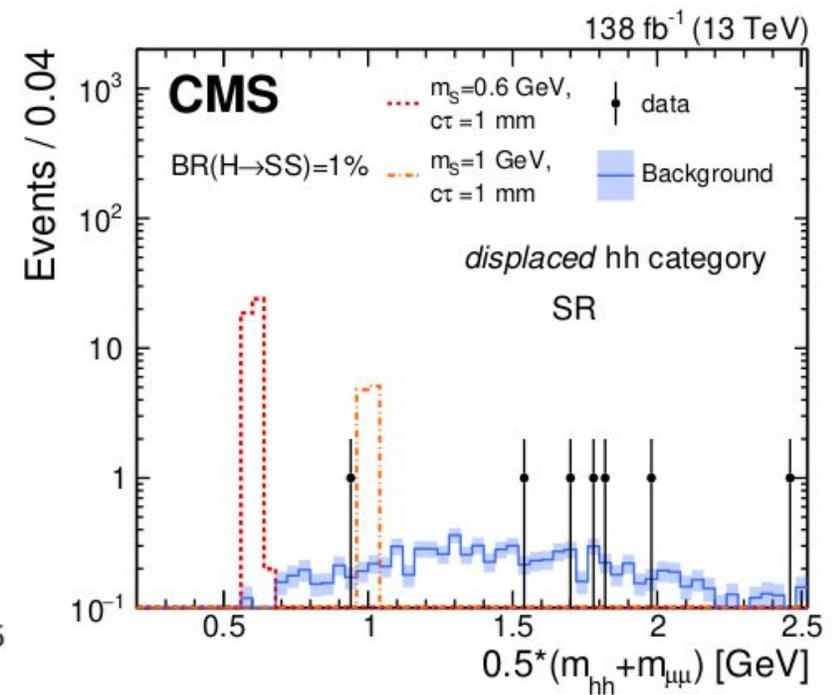
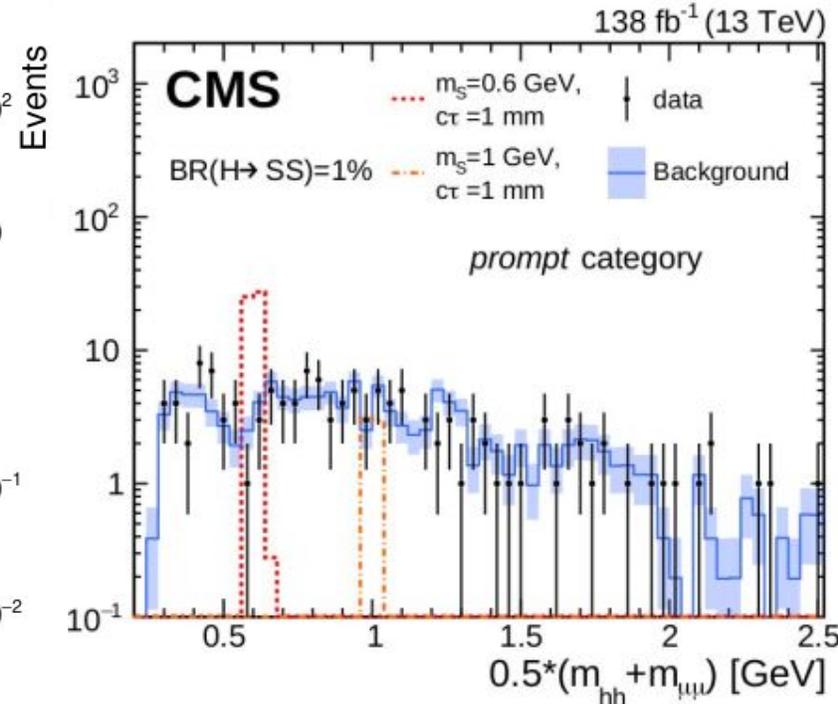
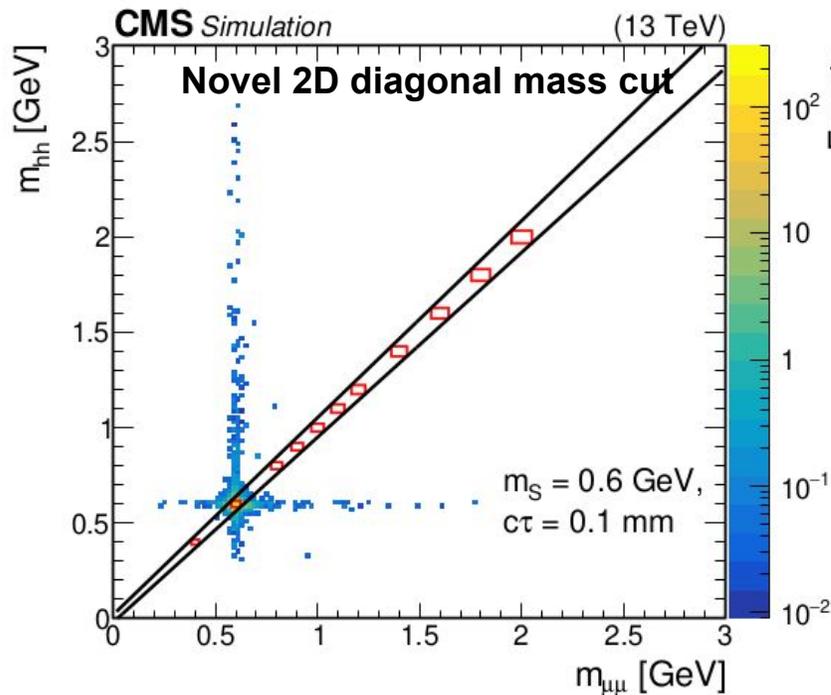
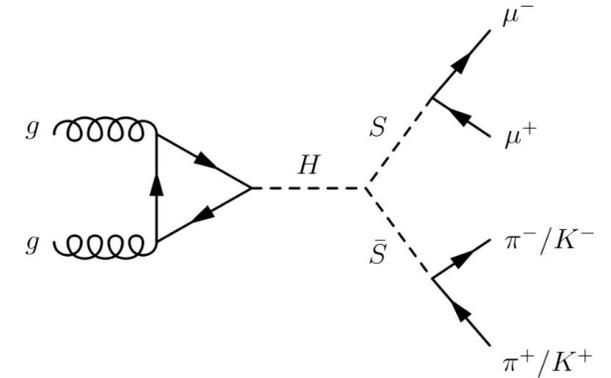
EXO-24-034-PAS

Search for light scalar particles from Higgs boson decays in
exclusive final states with two muons and two hadrons

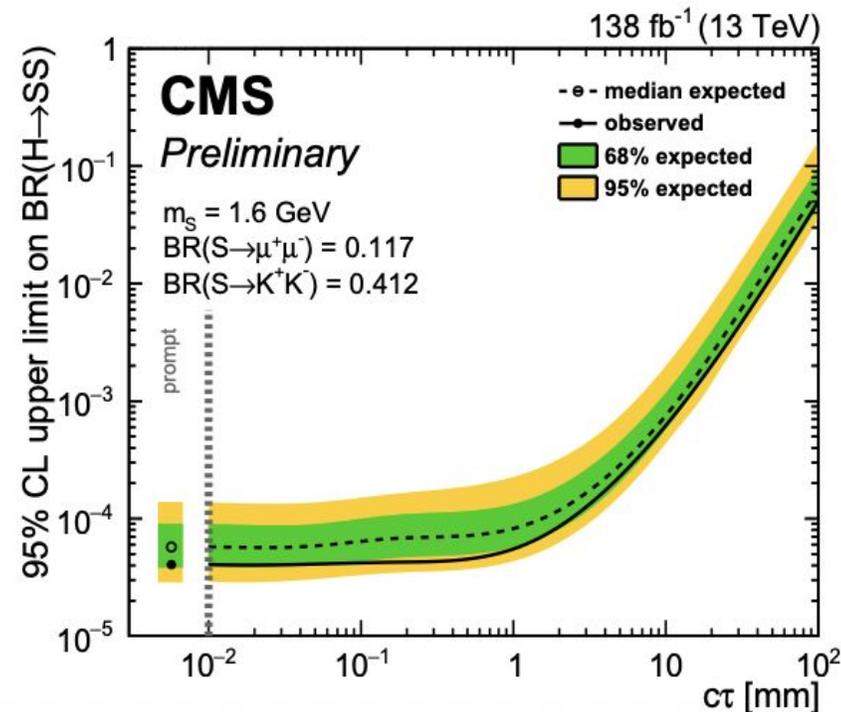
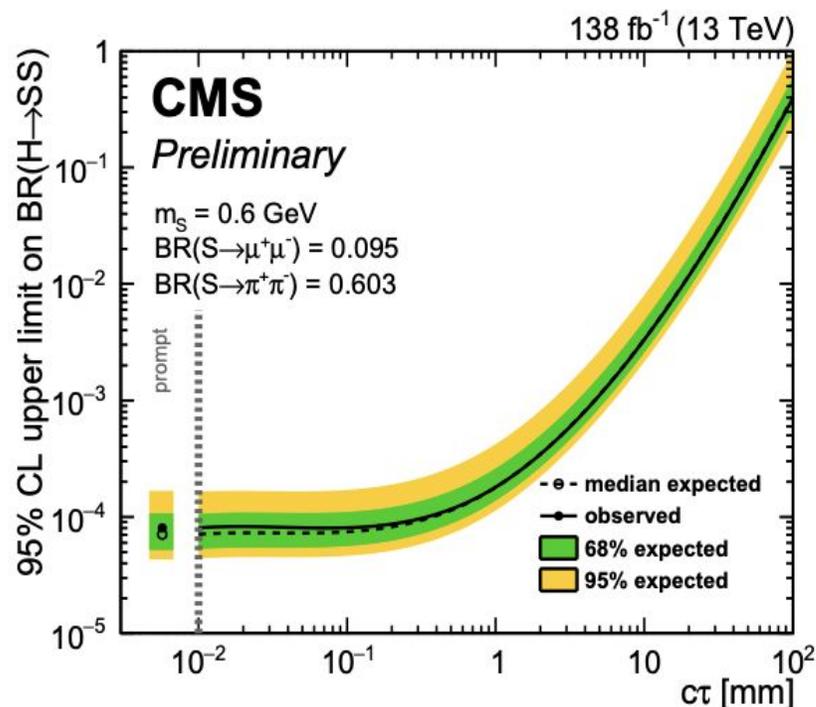
The CMS Collaboration

Analysis Overview

- ◆ **First CMS limits on light scalars between 0.4 to 2 GeV in $\mu\mu$ +hadron final states.**
- ◆ Novel 2D mass window ($m_{\mu\mu} \approx m_{hh}$) \rightarrow suppresses QCD by $\sim 96\%$.
- ◆ Covers prompt & displaced regimes ($c\tau \approx 0.1\text{--}100$ mm).
- ◆ Four-object invariant mass: Split into signal region (peak) & control region (sidebands)
- ◆ Explores Higgs-portal phase space previously inaccessible to dimuon-only searches.



❖ Overall, no significant excess of events beyond the prediction is observed: upper limits at 95% CL on branching fraction of $B(H \rightarrow SS)$ are derived.



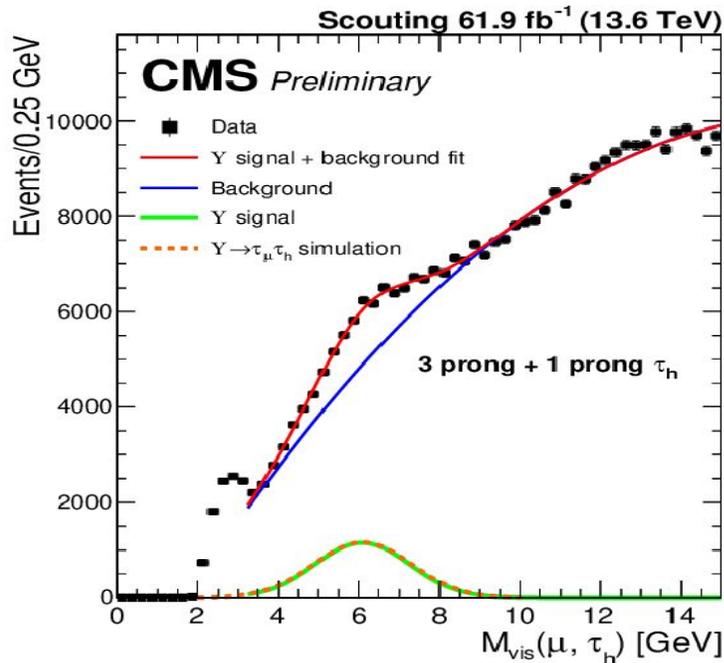
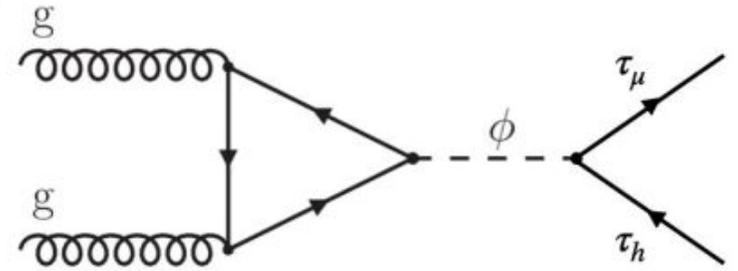
- ❖ Exclusion limits on $BR(H \rightarrow SS)$ of up to 10^{-4} to 10^{-5} for $c\tau = 1$ mm
- ❖ **First limits on some masses below 1 GeV in prompt to displaced decays (within tracker)**

EXO-24-012-PAS

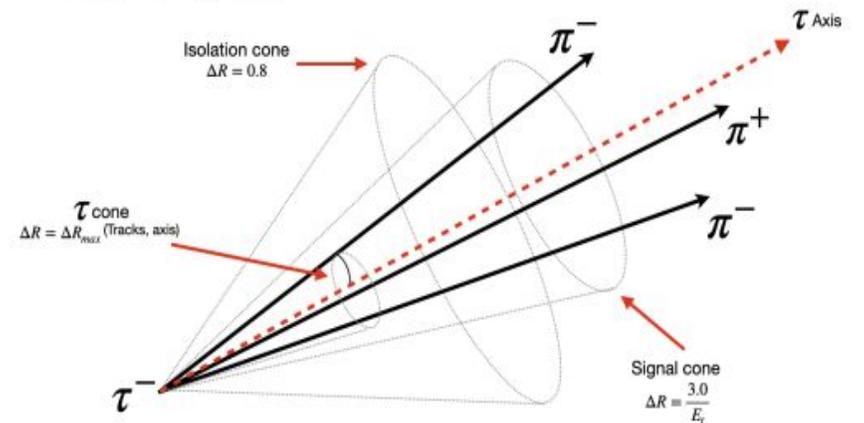
Search for a low mass resonance decaying to $\tau\tau$ using data collected with a dedicated high-rate data stream

The CMS Collaboration

- ❖ **First inclusive LHC limits in τ for 20–60 GeV using scouting — opens previously inaccessible phase space.**
- ❖ CMS Scouting dataset (2022–23, 61.9 fb^{-1}) → extends reach to soft τ 's.
- ❖ **Novel reconstruction:** HPS τ_h down to 5 GeV + π^0 recovery.
- ❖ **TauNet deep-learning** → suppresses QCD fakes
- ❖ Target: $\tau_\mu + \tau_h$ (opposite charge) final state.
- ❖ Data-driven CRs (Z, Y) anchor background + validate low-mass τ reco.



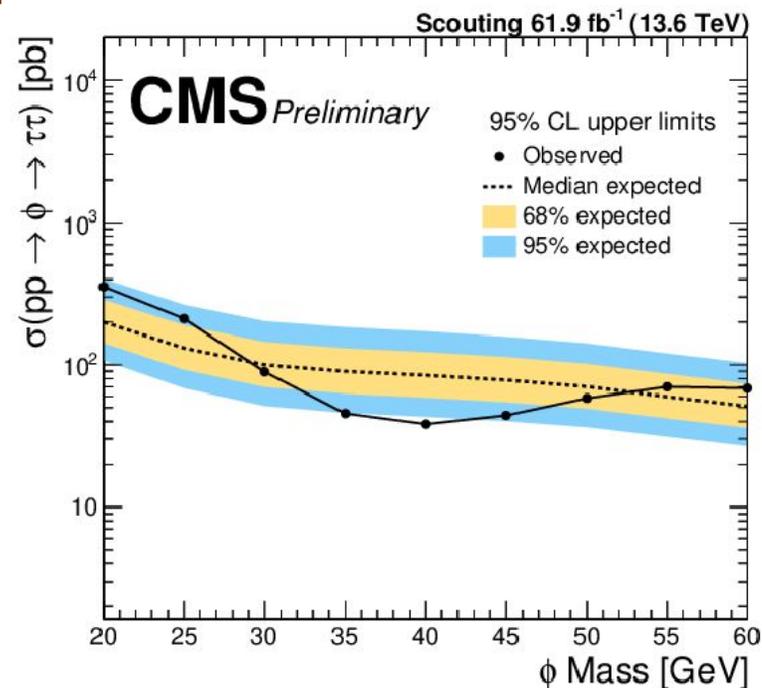
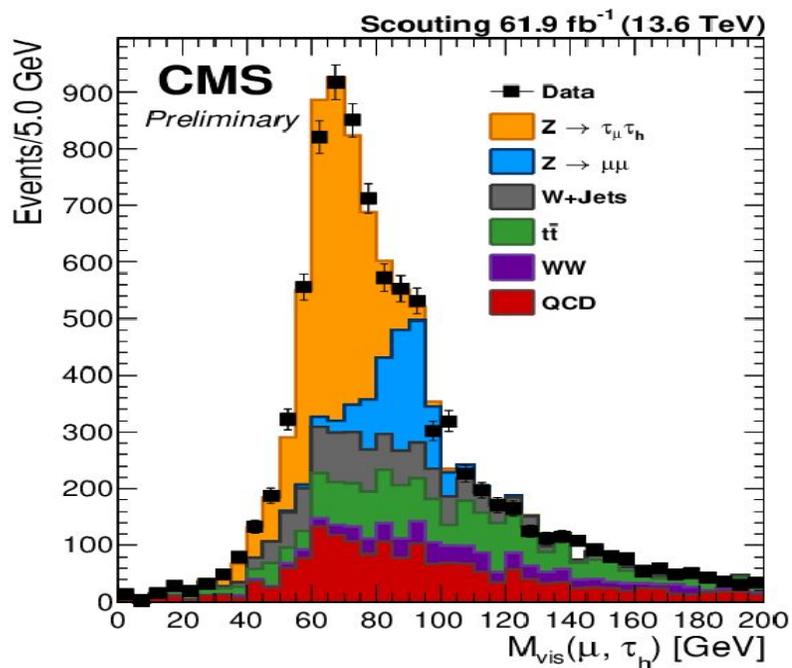
Three prong tau



- ❖ No significant excess observed above SM backgrounds.
- ❖ **First inclusive LHC limits in $\tau\tau$ for 20–60 GeV mass ranges.**
- ❖ 95% CL limits: $\sigma(pp \rightarrow \phi \rightarrow \tau\tau)$ down to **O(10 pb)**.

✦ Impact

- ❖ Demonstrates feasibility of τ scouting reconstruction at low p_T .
- ❖ **Opens previously inaccessible low-mass phase space at the LHC.**



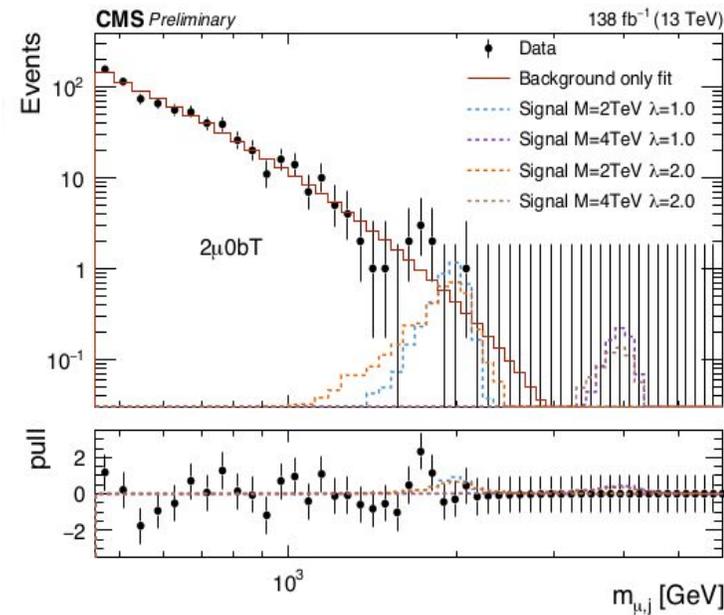
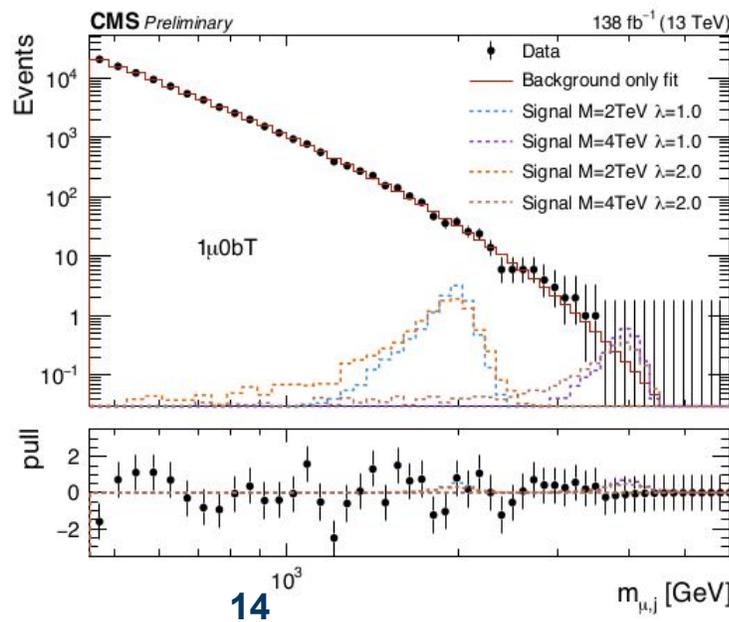
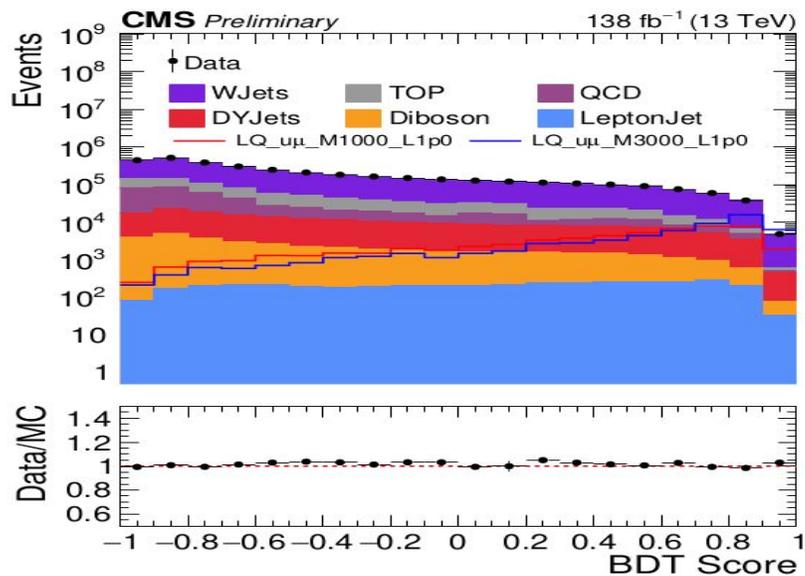
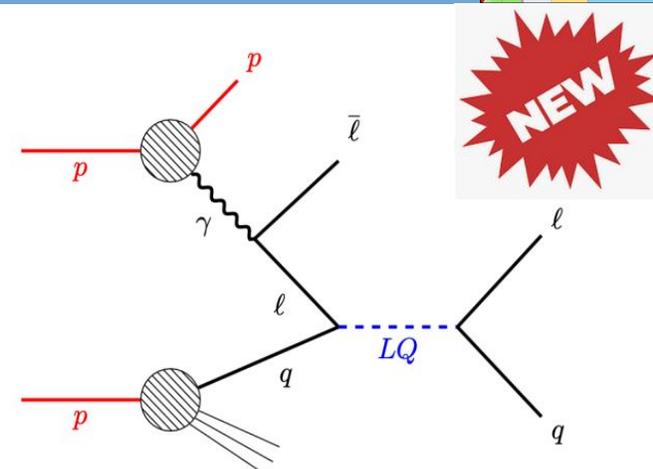
EXO-24-005

Search for scalar leptoquarks produced via muon-quark scattering in pp collisions at $\sqrt{s} = 13$ TeV

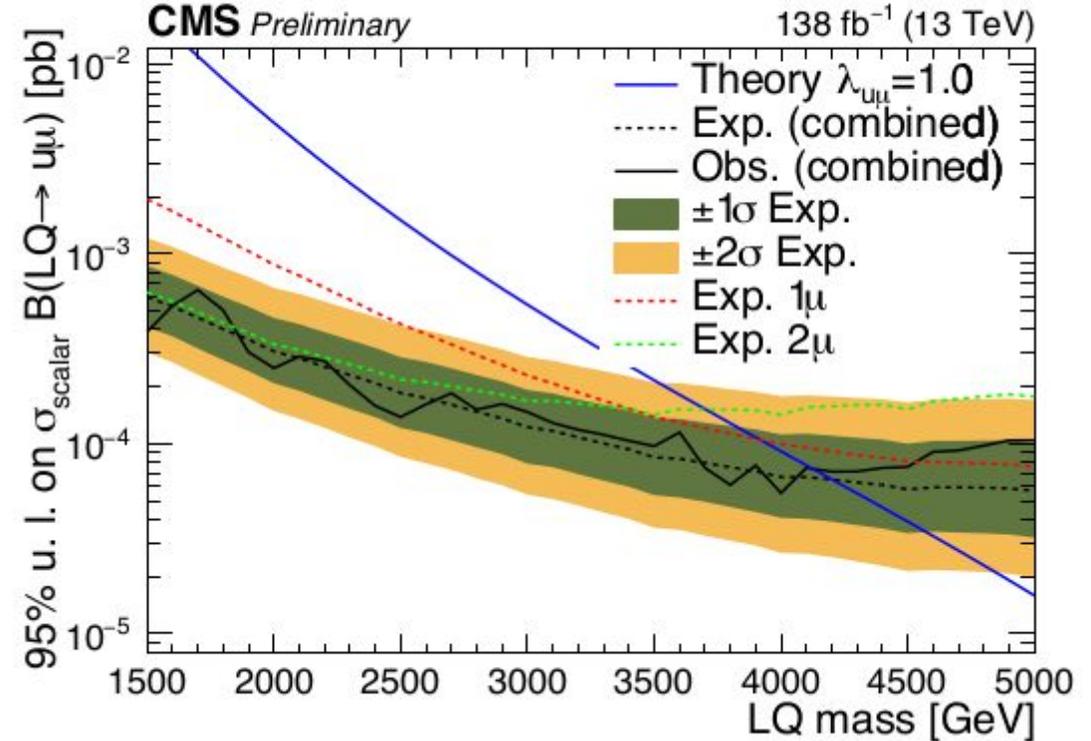
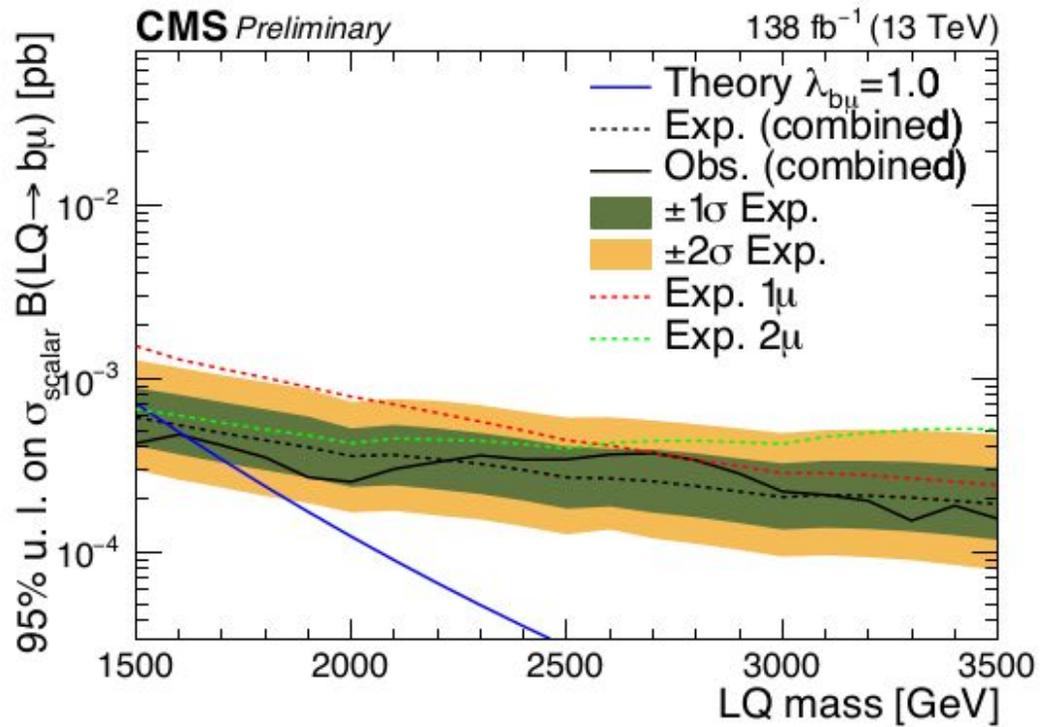
The CMS Collaboration



- ❖ **CMS search for scalar LQs produced via muon-quark collisions for Run-2.**
- ❖ **Signal final state:** one high- p_T muon + jet, with a second soft muon from photon splitting
- ❖ LQ candidate reconstructed using the leading muon-jet pair invariant mass.
- ❖ 8 final BDT-based categories: $1/2\mu$, b-tag / no b-tag, loose / tight (BDT output).
- ❖ **Main backgrounds: W+jets** (dominant in 1μ region) and **Drell-Yan + top quark** production (dominant in 2μ region).
- ❖ Data driven background estimation.



- ❖ No significant excess observed; 95% CL upper limits set on $\sigma \times \text{BR}$ and coupling parameter λ for scalar LQs produced via muon-quark scattering.
- ❖ LQ masses excluded up to ~ 5 TeV for large λ in m - l plane for $u\mu$ and $b\mu$ couplings



EXO-24-031-PAS

Search for light pseudoscalar a bosons in $H \rightarrow aa \rightarrow 4e$
decays in pp collisions at $\sqrt{s} = 13$ TeV

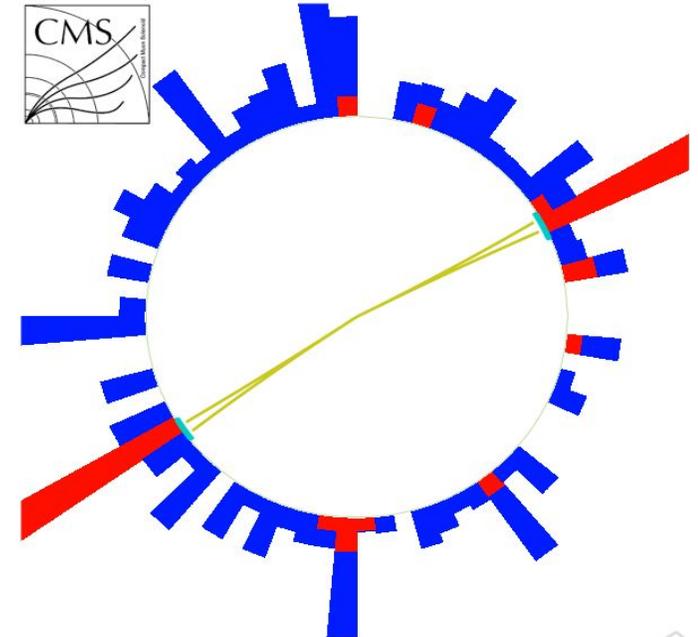
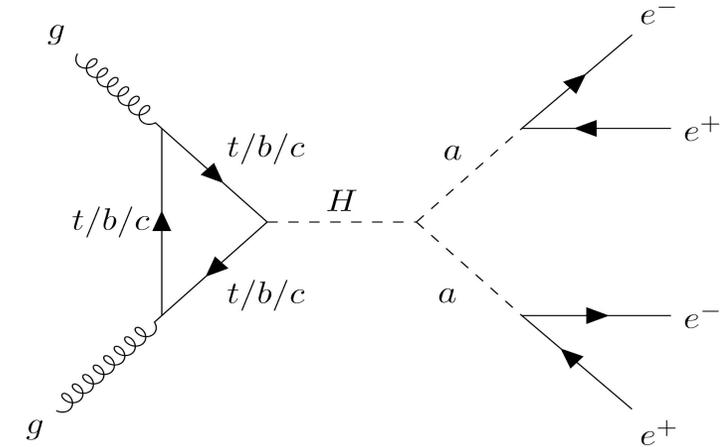
The CMS Collaboration



Analysis Overview

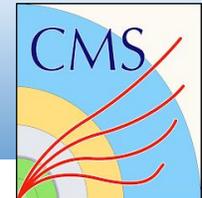


- ❖ **Novelty/Impact:** First CMS search targeting ultra-light ALPs (10–100 MeV) in a fully reconstructible 4e final state.
- ❖ **Benchmark model:** Axion-like pseudoscalars (ALPs), predicted in many BSM extensions.
- ❖ **Final state:** Exotic Higgs decay $H \rightarrow aa \rightarrow (ee)(ee) \rightarrow 4$ prompt, collinear pair of electrons.
- ❖ **Challenge:** Overlapping electron showers \rightarrow need **dedicated reconstruction** and optimized electron ID.
- ❖ **Backgrounds:** Dominated by $ZZ \rightarrow 4e$, with smaller $DY + \gamma$ conversions and electron mis-ID.
- ❖ **Discriminant:** 4 electron invariant mass (m_{4e}) used to extract signal.

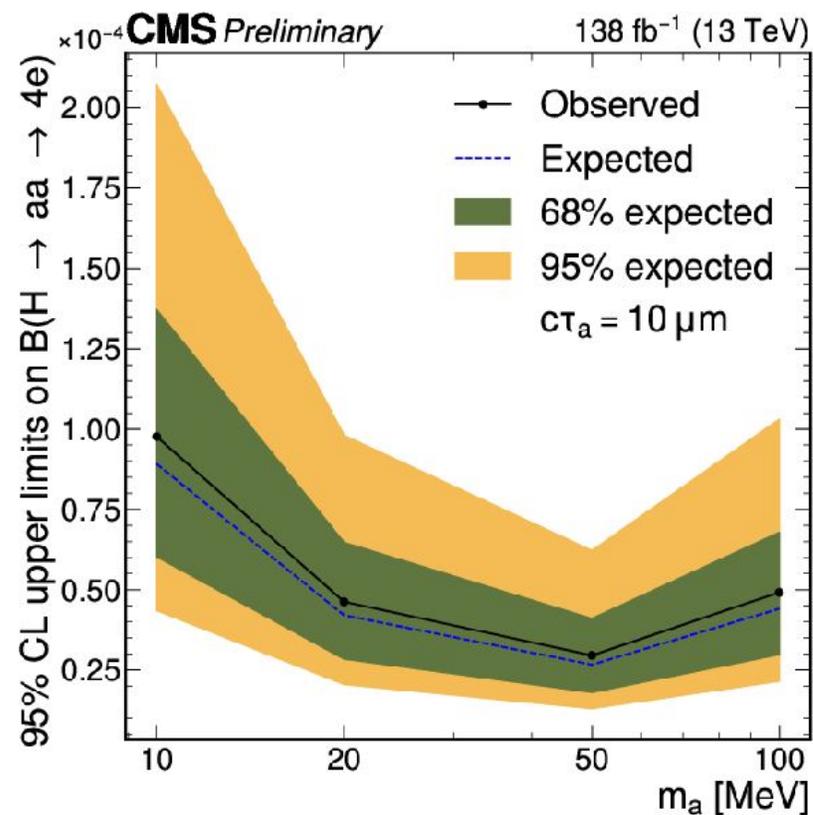
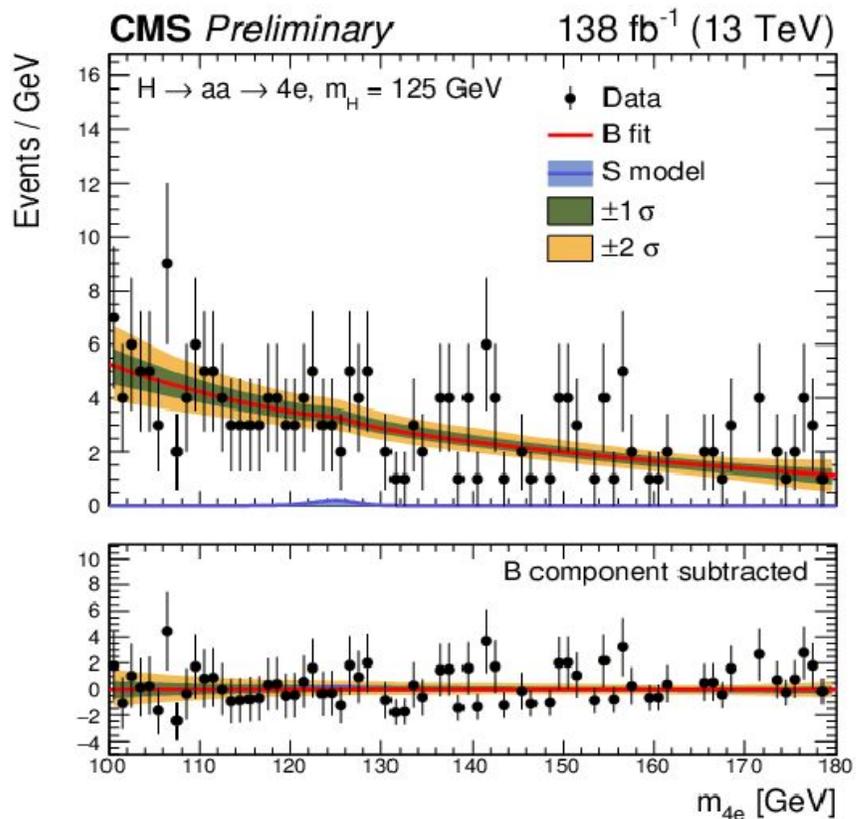




Results



- ❖ No significant excess observed over background prediction
- ❖ 95% CL limits set on $BR(H \rightarrow aa \rightarrow 4e)$ for $m_a = 10\text{--}100$ MeV
- ❖ Sensitivity across **lifetimes** $c\tau = 1\text{--}100$ μm
- ❖ **First CMS search in fully reconstructible 4e final state**, probing ultra-light ALPs inaccessible in direct production.





Summary



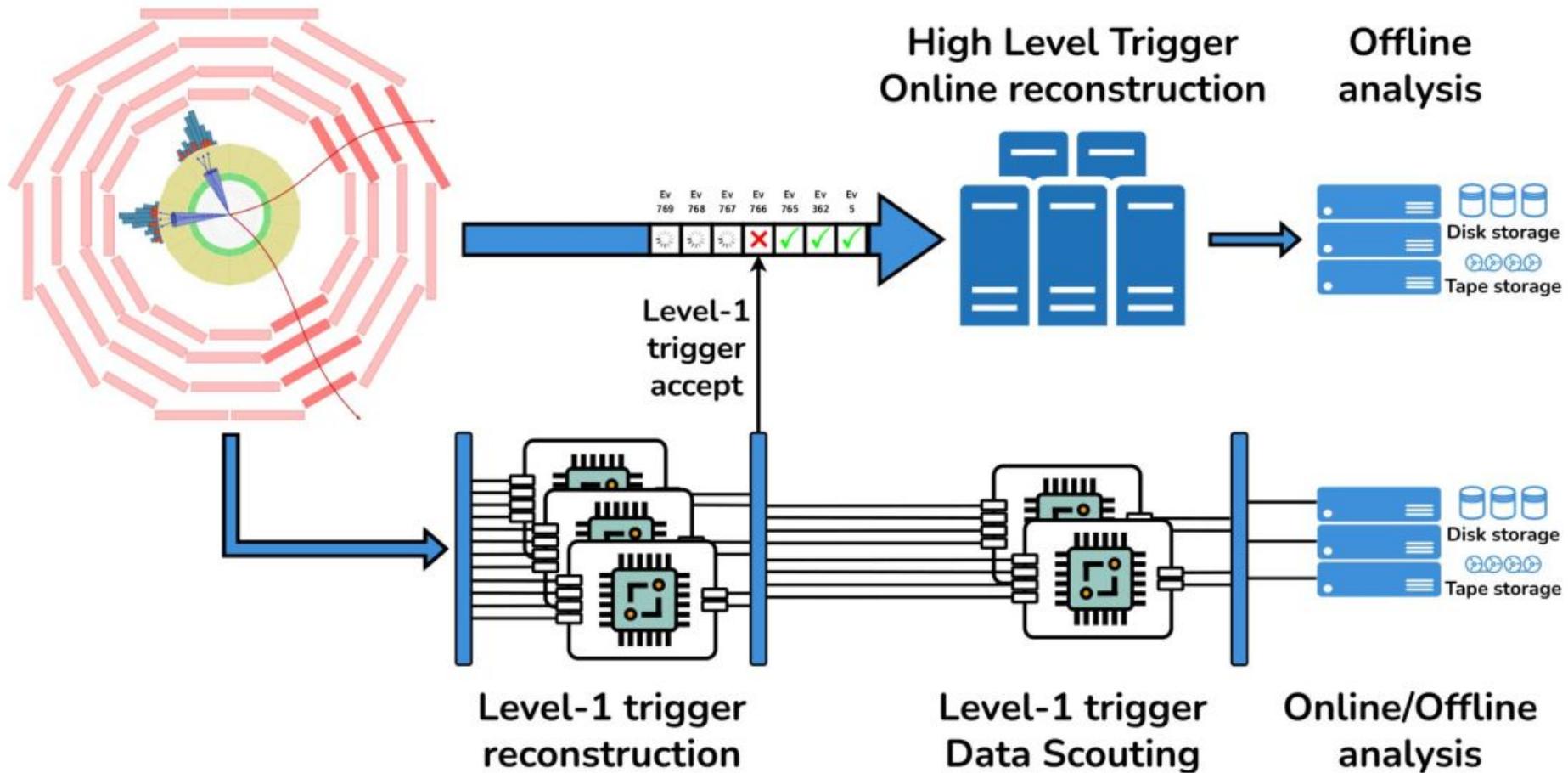
- ❖ **Soft leptons + MET (EXO-23-017):**
 - First LHC search with ultra-low-pT electrons (1 GeV) → probes compressed SUSY spectra down to $\Delta m \approx 0.6$ GeV.
- ❖ **$\mu\mu$ + hadrons (EXO-24-034):**
 - First CMS limits on light scalars from Higgs decays below 1 GeV, sensitive to prompt + displaced lifetimes ($c\tau \approx 0.1$ –100 mm).
- ❖ **$\tau\tau$ with scouting (EXO-24-012):**
 - First inclusive $\tau\tau$ limits in the 20–60 GeV range, enabled by scouting + TauNet → opens new low-mass phase space.
- ❖ **LQs via μ -quark scattering (EXO-24-005):**
 - First CMS search for scalar LQs via μ -quark scattering; excludes masses up to ~ 5 TeV using 138 fb^{-1} Run-2 data.
- ❖ **$H \rightarrow aa \rightarrow 4e$ (EXO-24-031):**
 - First CMS search for ultra-light ALPs (10–100 MeV) in a fully reconstructible $4e$ final state.

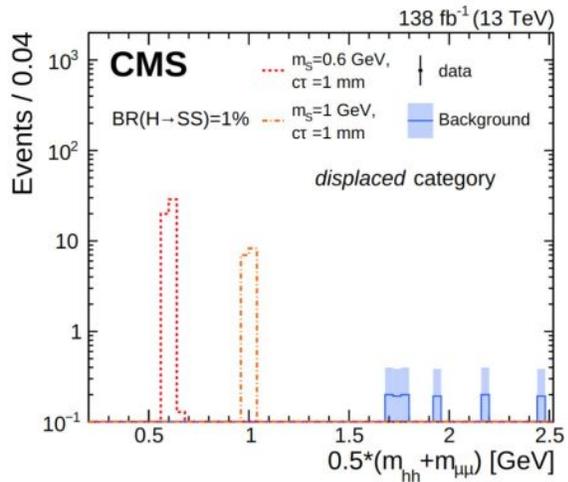
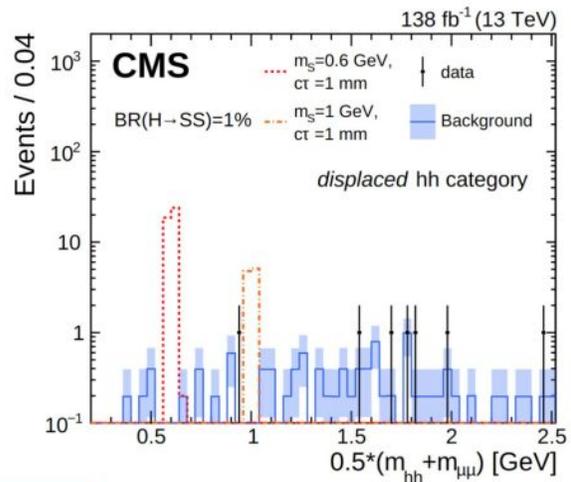
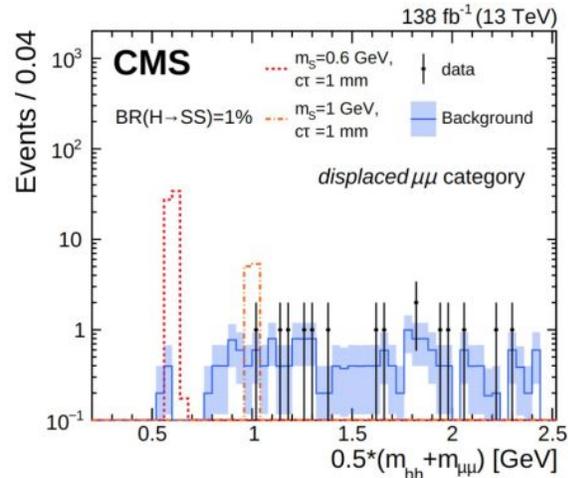
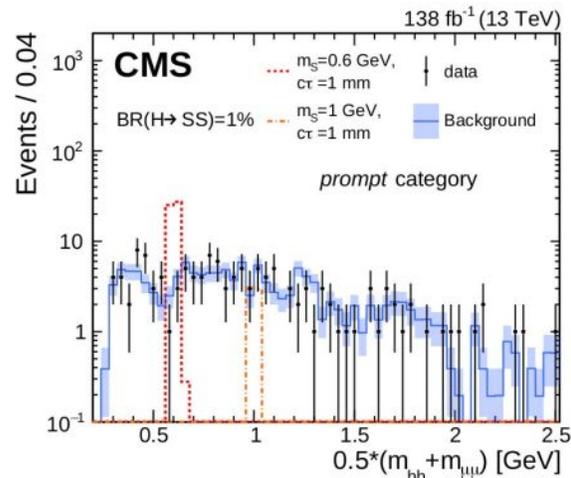
★ **These analyses extend CMS reach for exotic particles from MeV to TeV, opening new phase space for discoveries at the HL-LHC.**



Backup...

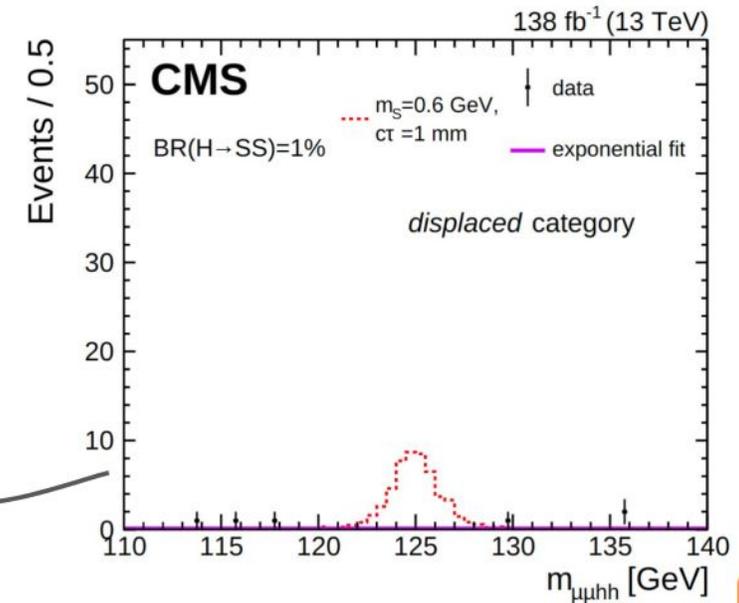
NEW DATA STREAMS: L1T SCOUTING





Cuts: Preselection + m_{μμhh} + isolation

Challenge:
 Very low statistics for non-prompt categories after full selection!



$h^\pm = \pi^\pm$

Soumya Dansana, ULB-VUB