

# Snowmass 2021: HL-LHC Searches for Long- Lived Particles with CMS

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Performance Studies group



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# Outline

- CMS projections in development for Long-Lived Particle searches with HL-LHC:
  - Search for heavy, neutral long-lived particles in decays to delayed jets
  - Searches with disappearing tracks
  - Exploring exotic final states with unconventional track signatures

# HL-LHC (Phase 2) CMS Detector Upgrade

Technical proposal CERN-LHCC-2015-010 <https://cds.cern.ch/record/2020886>

Scope Document CERN-LHCC-2015-019 <https://cds.cern.ch/record/2055167>

## L1-Trigger/HLT/DAQ

<https://cds.cern.ch/record/2283192>

<https://cds.cern.ch/record/2283193>

- Tracks in L1-Trigger at 40 MHz
- PFlow-like selection 750 kHz output
- HLT output 7.5 kHz

## Calorimeter Endcap

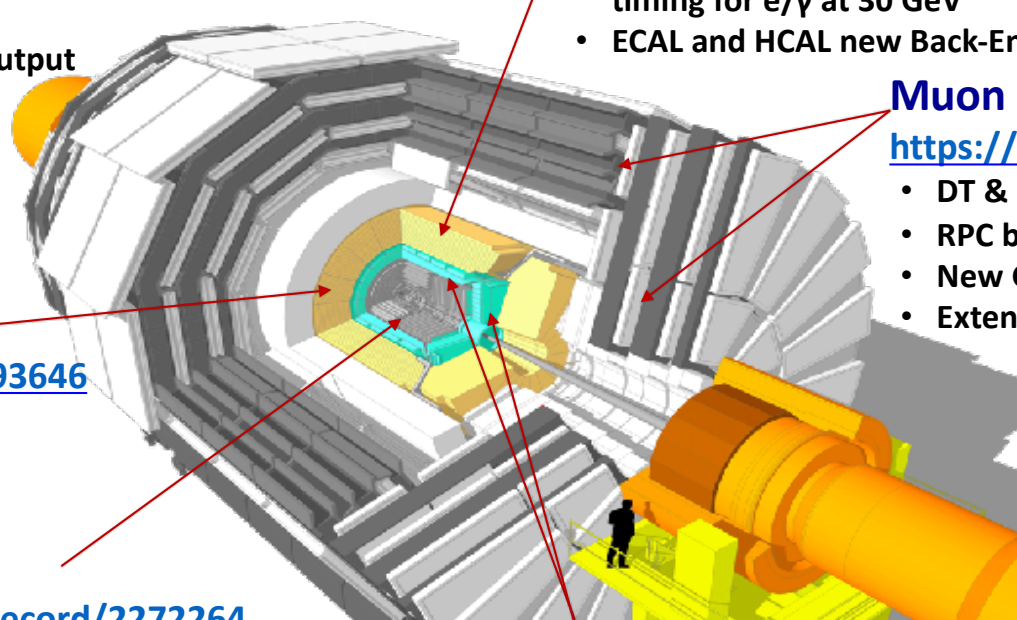
<https://cds.cern.ch/record/2293646>

- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

## Tracker <https://cds.cern.ch/record/2272264>

- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to  $\eta \approx 3.8$

**New paradigms (design/technology) for an HEP experiment to fully exploit HL-LHC luminosity**



## Barrel Calorimeters

<https://cds.cern.ch/record/2283187>

- ECAL crystal granularity readout at 40 MHz with precise timing for e/ $\gamma$  at 30 GeV
- ECAL and HCAL new Back-End boards

## Muon systems

<https://cds.cern.ch/record/2283189>

- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC  $1.6 < \eta < 2.4$
- Extended coverage to  $\eta \approx 3$

## Beam Radiation Instr. and Luminosity, and Common Systems and Infrastructure

<https://cds.cern.ch/record/002706512>

## MIP Timing Detector

<https://cds.cern.ch/record/2296612>

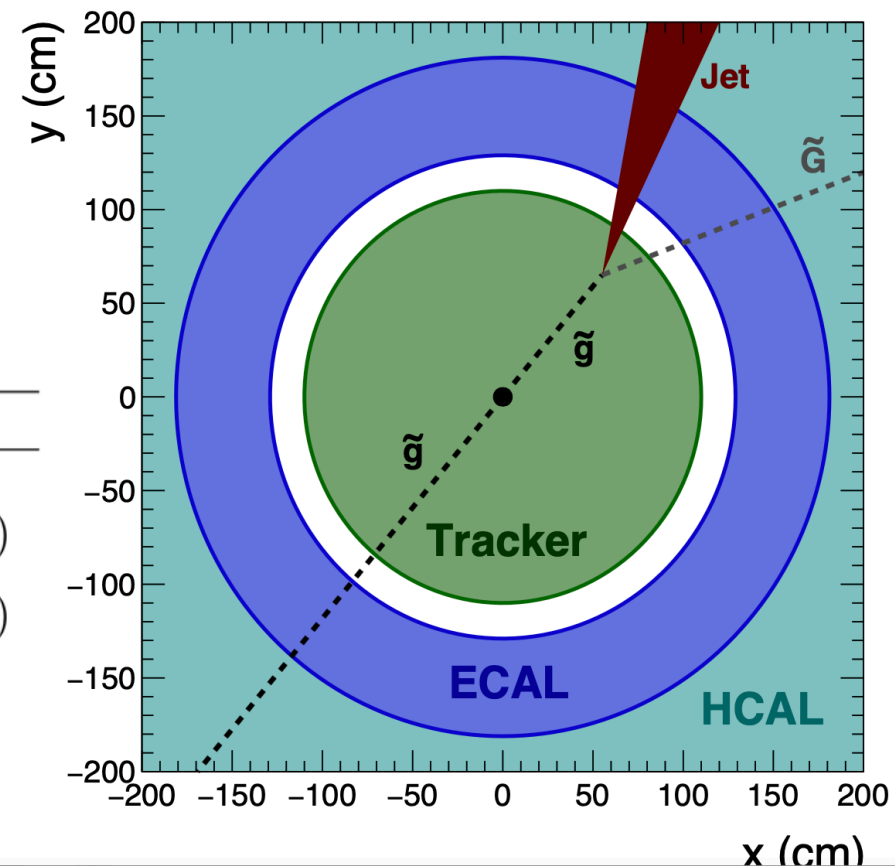
Precision timing with:

- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

# Delayed Jets

- Use timing to search for jets from decay of heavy neutral Long-Lived Particles; extends coverage for lifetimes beyond tracker
- Extension of Run 2 search (CMS-EXO-19-001), where bkg were:

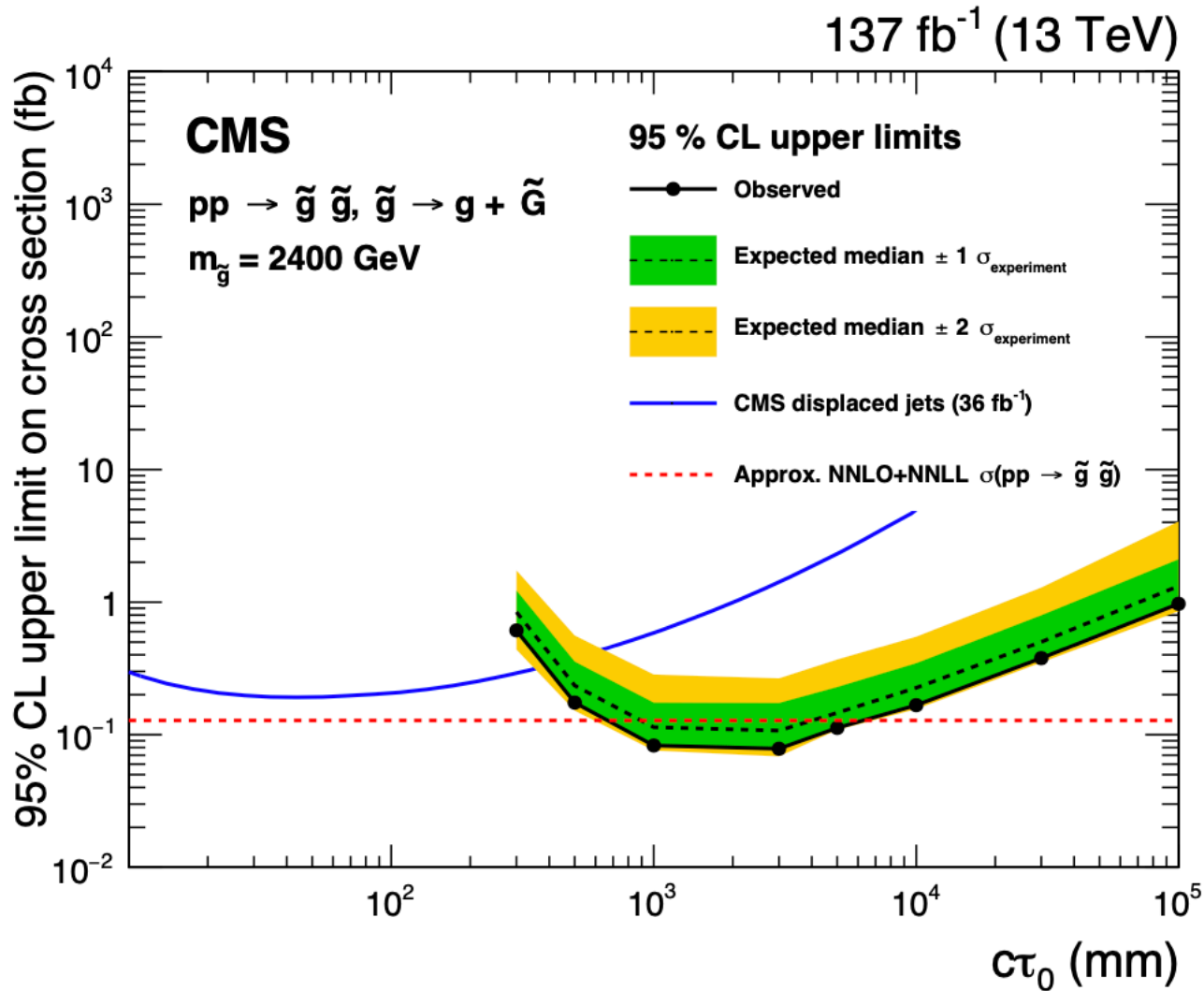
Background	Prediction
Beam halo	$0.02^{+0.06}_{-0.02}$ (stat) $^{+0.05}_{-0.01}$ (syst)
Core and satellite bunches	$0.11^{+0.09}_{-0.05}$ (stat) $^{+0.02}_{-0.02}$ (syst)
Cosmics	$1.0^{+1.8}_{-1.0}$ (stat) $^{+1.8}_{-1.0}$ (syst)



# Delayed Jets with CMS Phase 2 Detector

- CMS Phase 2 detector offers tremendous potential for timing-based long-lived particle searches:
  - MIP Timing Detector with 30-40ps resolution
  - Endcap Calorimeter timing and improved ECAL timing
  - ECAL timing in L1 trigger
  - Muon chamber (DT/RPC) timing (lower resolution, but far from interaction point)
- Analyses with dominant non-collision bkg's stand to gain even more than  $\sqrt{L}$  from HL-LHC
- (Internal: Important that Phase 2 energy reco algorithms not be biased against long-lived particle signatures)

# CMS Delayed Jets Run 2 Result

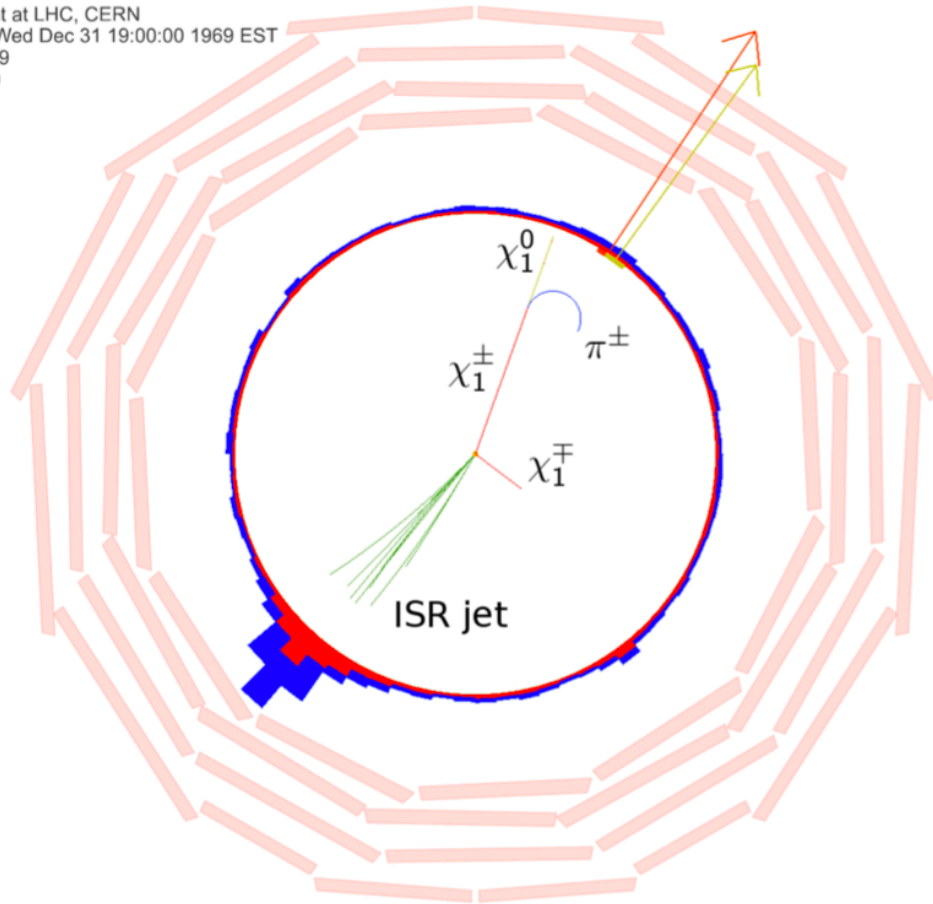


Gluino pair  
production  
with  
 $m=2400$   
GeV

CMS EXO-19-001, Phys. Lett. B 797 (2019) 134876

# Disappearing Tracks in CMS

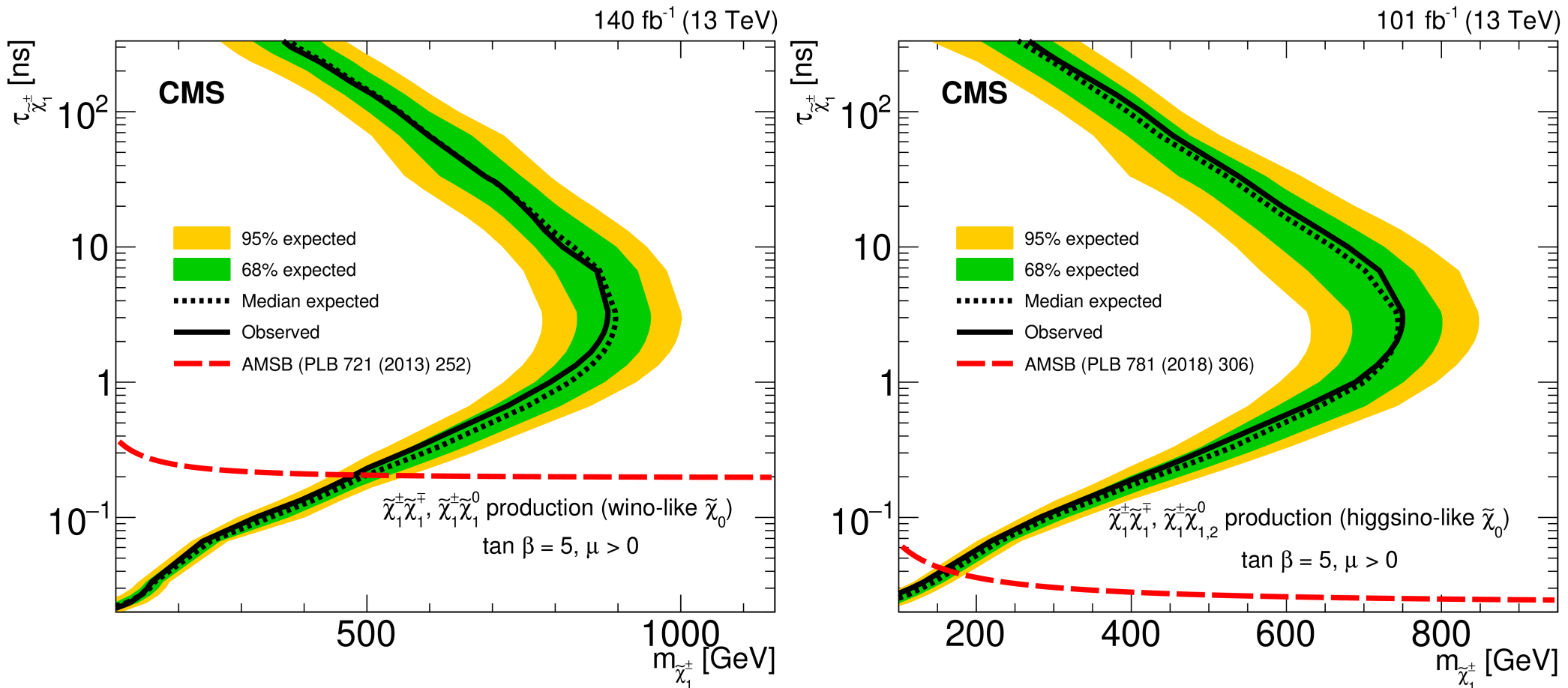
presented at LHC, CERN  
Date: Wed Dec 31 19:00:00 1969 EST  
/ 39  
20



Isolated track  
Missing outer tracker hits  
Low associated calorimeter energy  
No muon hits

- Extension of Run 2 search (CMS-EXO-19-010)
- Run 2 analysis triggers on MET; could gain in signal efficiency if tracking available at L1 trigger
- Will be available with CMS Phase 2 trigger

# CMS Disappearing Tracks Run 2 Result

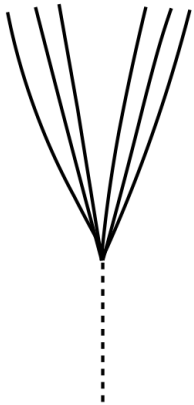


- Limits on chargino lifetime vs mass for wino-like (Left) and higgsino-like (Right) LSP in AMSB
- CMS-EXO-19-010: Phys. Lett. B 806 (2020) 135502



# Exploring Unconventional Track Signatures

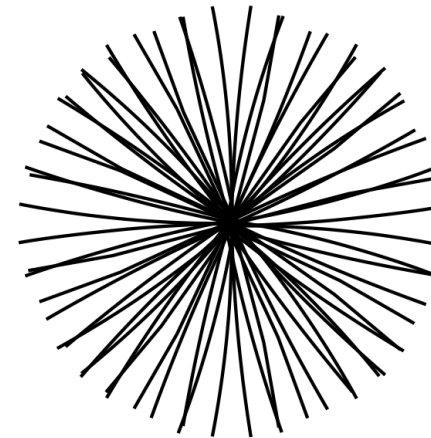
long-lived particles  
→ displaced tracks



heavy stable  
charged particles  
→ anomalous tracks



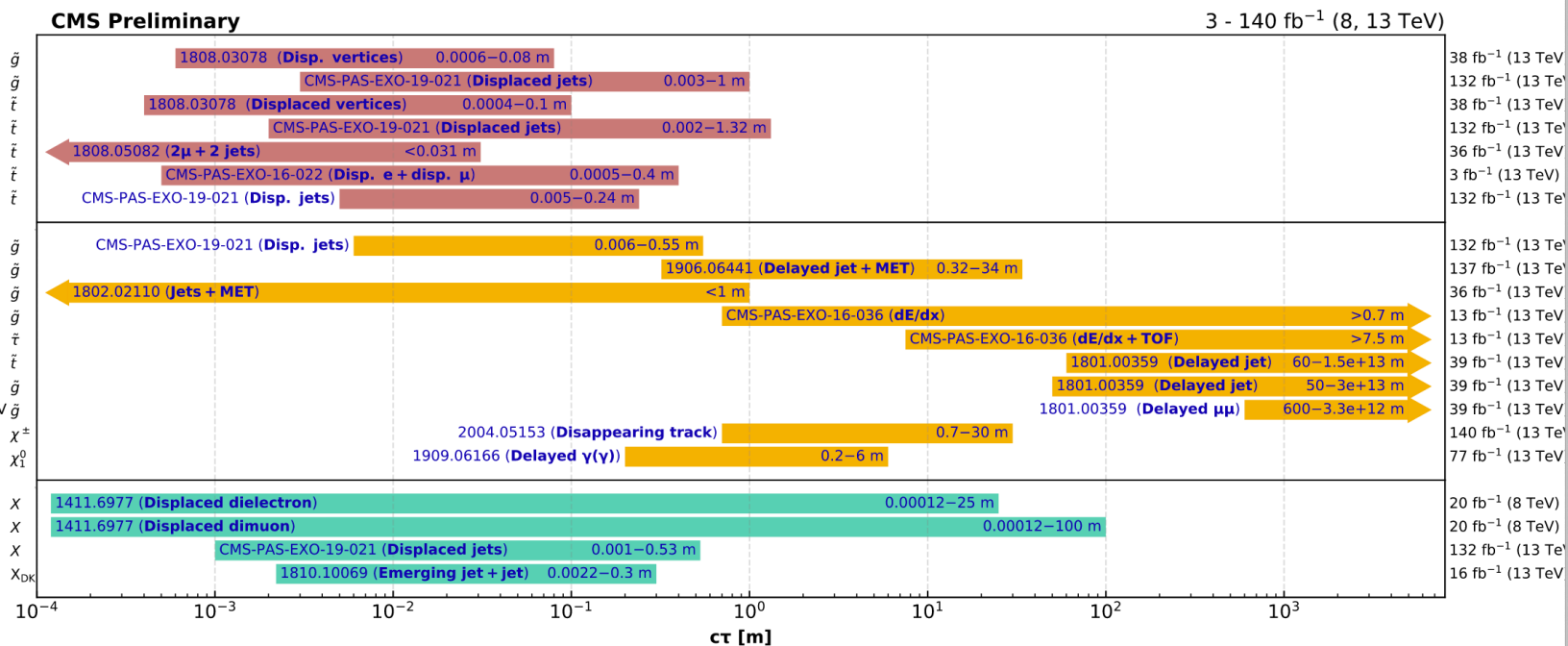
SUEPs (Soft Unclustered  
Energy Patterns)  
→ large multiplicity  
of soft tracks



- Different needs for different models
  - LLPs: prioritize large impact parameters
  - SUEPs: prioritize low  $p_T$  threshold
  - Stable charged particles: benefit from  $dE/dx$  or timing information
- Goal: Extend tracking + trigger reach with HL-LHC detectors

# Overview of CMS Long-Lived Particle Searches

## Overview of CMS long-lived particle searches



Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.

LHCP 2020

- CMS LLP Results: <http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/LLP.html>

# CMS Public HL-LHC Physics Projections

- Full list of CMS public HL-LHC physics projections:
- <http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/FTR/index.html>

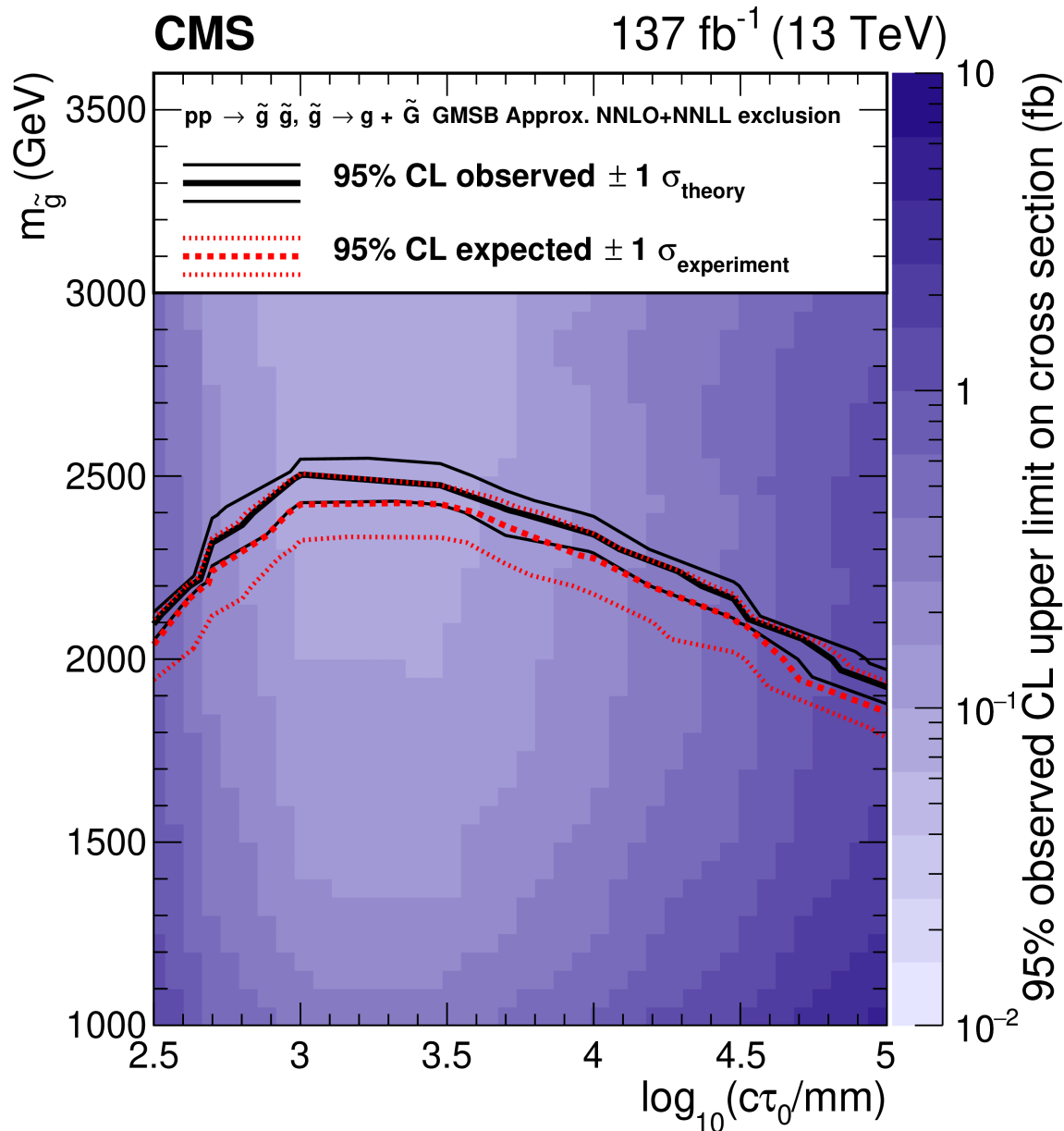
Projected Physics Results			
<a href="#">CMS-PAS-FTR-18-040</a>	Search for a new scalar resonance decaying to a pair of Z bosons at the High-Luminosity LHC		February 2019
<a href="#">CMS-PAS-FTR-18-037</a>	HL-LHC searches for new physics in hadronic final states with boosted W bosons or top quarks using razor variables		February 2019
<a href="#">CMS-PAS-FTR-18-035</a>	Projection of searches for exotic Higgs boson decays to light pseudoscalars for the High-Luminosity LHC		February 2019
<a href="#">CMS-PAS-FTR-18-030</a>	Sensitivity study for a heavy gauge boson $W'$ in the decay channel with a tau lepton and a neutrino at the High-Luminosity LHC		February 2019
<a href="#">CMS-PAS-FTR-18-019</a>	Prospects for HH measurements at the HL-LHC		December 2018
<a href="#">CMS-PAS-FTR-18-028</a>	Prospects for exclusion or discovery of a third generation leptoquark decaying into a $\tau$ lepton and a b quark with the upgraded CMS detector at the HL-LHC		December 2018
<a href="#">CMS-PAS-FTR-18-027</a>	Constraining nuclear parton distributions with heavy ion collisions at the HL-LHC with the CMS experiment		December 2018
<a href="#">CMS-PAS-FTR-18-036</a>	Anomalous couplings in the $t\bar{t}Z$ final state at the HL-LHC		December 2018
<a href="#">CMS-PAS-FTR-18-029</a>	Search for excited leptons in $l\bar{l}\gamma$ final states in proton-proton collisions at the HL-LHC		December 2018
<a href="#">CMS-PAS-FTR-18-025</a>	Performance of jet quenching measurements in pp and PbPb collisions with CMS at the HL-LHC		December 2018

# Summary

- HL-LHC and Phase 2 upgrade of CMS detector will open up new opportunities for long-lived particle searches
- CMS sensitivity studies for LLP being developed for Snowmass:
  - Search for heavy, neutral long-lived particles in decays to delayed jets
  - Searches with disappearing tracks
  - Exploring exotic final states with unconventional track signatures

# Backup

# CMS Delayed Jets Run 2 Result



- Limits on gluino mass vs lifetime in GMSB scenario

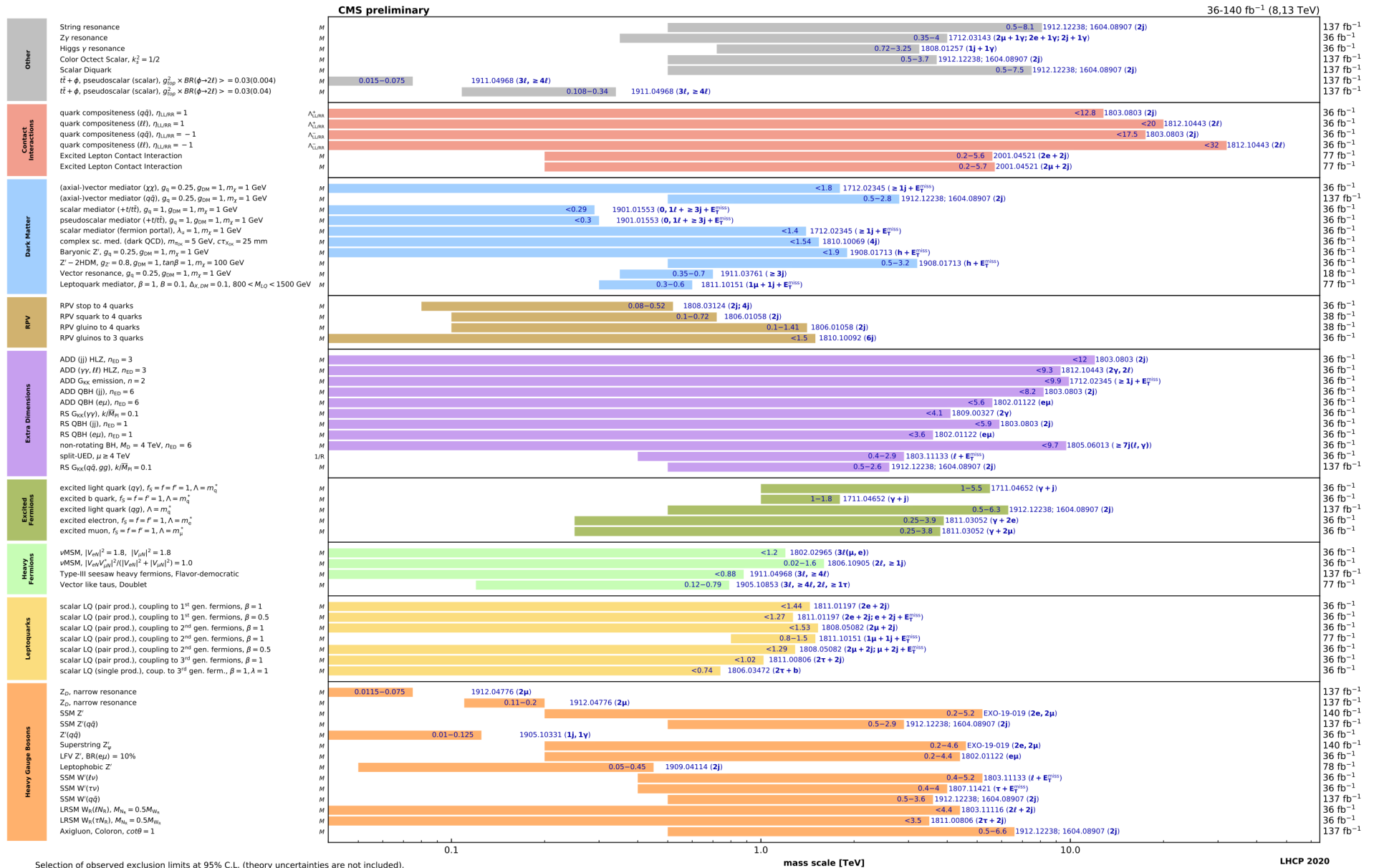
# Disappearing Tracks (CMS-EXO-19-010)

Data-taking period	$n_{\text{lay}}$	Expected backgrounds			Observation
		Leptons	Spurious tracks	Total	
2017	4	$1.4 \pm 0.9 \pm 0.2$	$10.9 \pm 0.7 \pm 4.7$	$12.2 \pm 1.1 \pm 4.7$	17
	5	$1.1 \pm 0.4 \pm 0.1$	$1.0 \pm 0.2 \pm 0.6$	$2.1 \pm 0.4 \pm 0.6$	4
	$\geq 6$	$6.7 \pm 1.1 \pm 0.7$	$0.04 \pm 0.04^{+0.08}_{-0.04}$	$6.7 \pm 1.1 \pm 0.7$	6
2018 A	4	$1.1^{+1.0}_{-0.6} \pm 0.1$	$6.2 \pm 0.5 \pm 3.5$	$7.3^{+1.1}_{-0.8} \pm 3.5$	5
	5	$0.2^{+0.6}_{-0.2} \pm 0.0$	$0.5 \pm 0.1 \pm 0.3$	$0.6^{+0.6}_{-0.2} \pm 0.3$	0
	$\geq 6$	$1.8^{+0.6}_{-0.5} \pm 0.2$	$0.04 \pm 0.04^{+0.06}_{-0.04}$	$1.8^{+0.6}_{-0.5} \pm 0.2$	2
2018 B	4	$0.0^{+0.8}_{-0.0} \pm 0.0$	$10.3 \pm 0.6 \pm 5.4$	$10.3^{+1.0}_{-0.6} \pm 5.4$	11
	5	$0.4^{+0.7}_{-0.3} \pm 0.1$	$0.6 \pm 0.2 \pm 0.3$	$1.0^{+0.7}_{-0.3} \pm 0.3$	2
	$\geq 6$	$5.7^{+1.2}_{-1.1} \pm 0.6$	$0.00^{+0.04}_{-0.00} \pm 0.00$	$5.7^{+1.2}_{-1.1} \pm 0.6$	1

- Phys. Lett. B 806 (2020) 135502

# CMS EXO Results

## Overview of CMS EXO results





# CMS EXO Results

- <http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html>