Search for Displaced Supersymmetry in events with an electron and a muon with large impact parameters

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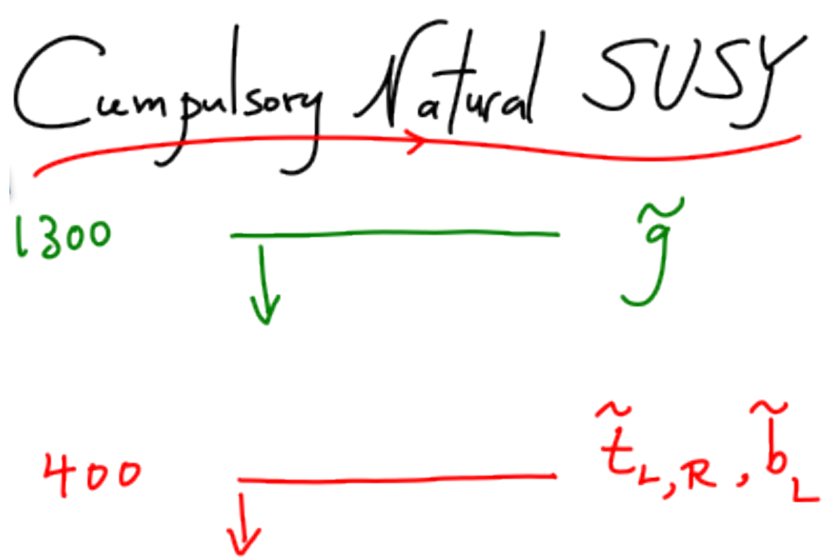
Motivation for long-lived searches

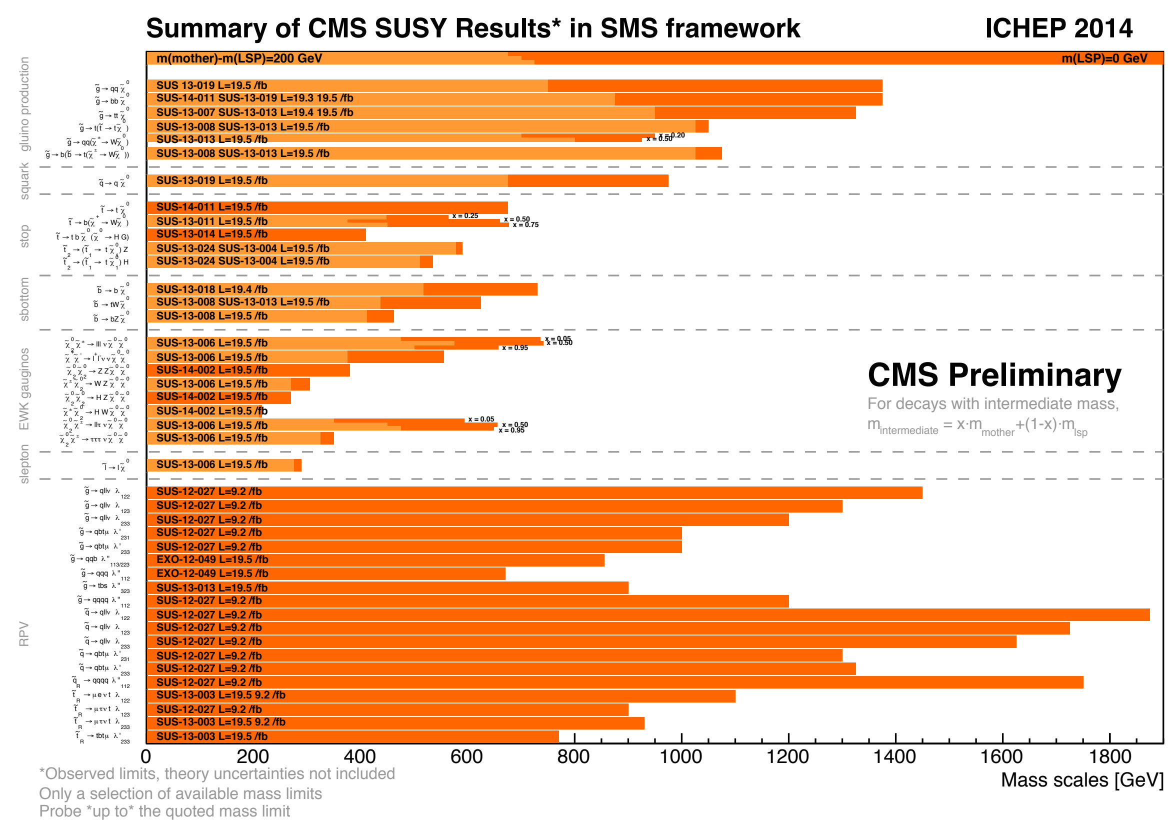
Now that the Higgs mechanism is real, so is the hierarchy problem

There are many well-motivated scenarios with long-lived particles with various mechanisms:

off-shell propagators (Split SUSY), small mass splitting (AMSB), weak couplings (RPV SUSY)



"natural" BSM models are in tension with Run 1 LHC results

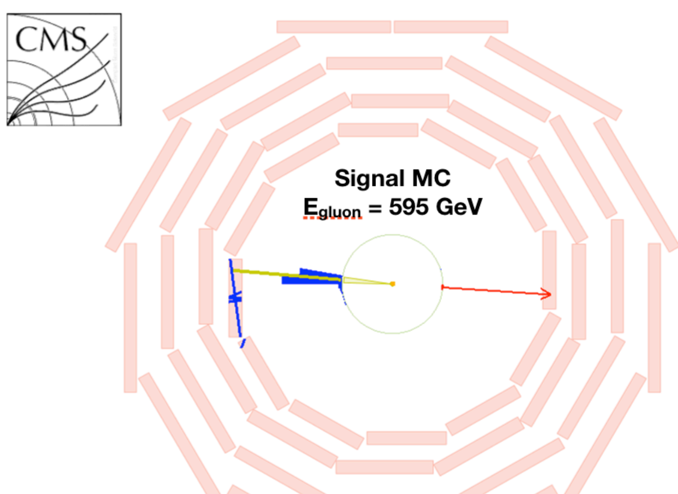


Long-lived BSM, hidden from standard BSM searches, could restore a "veiled" naturalness

Motivation for *this* search

CMS has other searches for non-prompt decays,

but they focus on very long lifetimes and spectacular signatures



CMS-EXO-12-036

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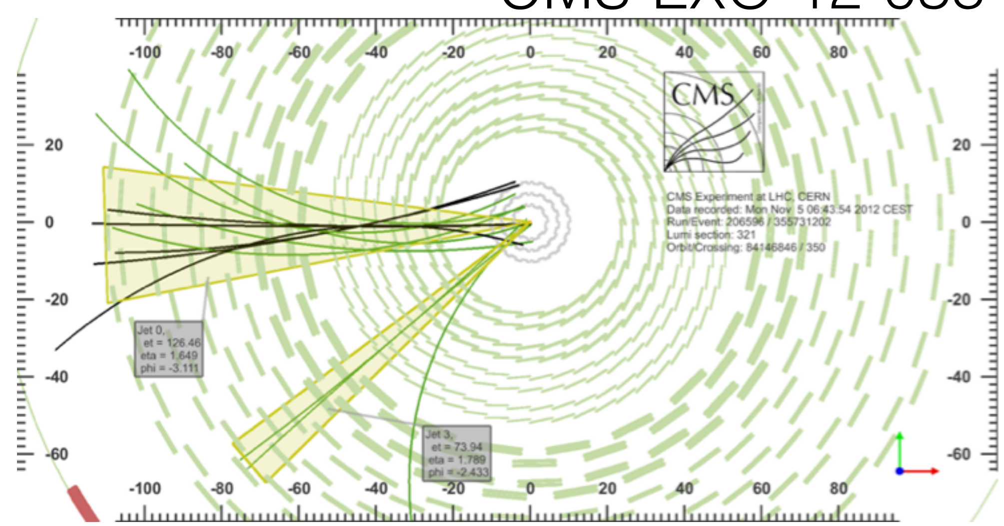

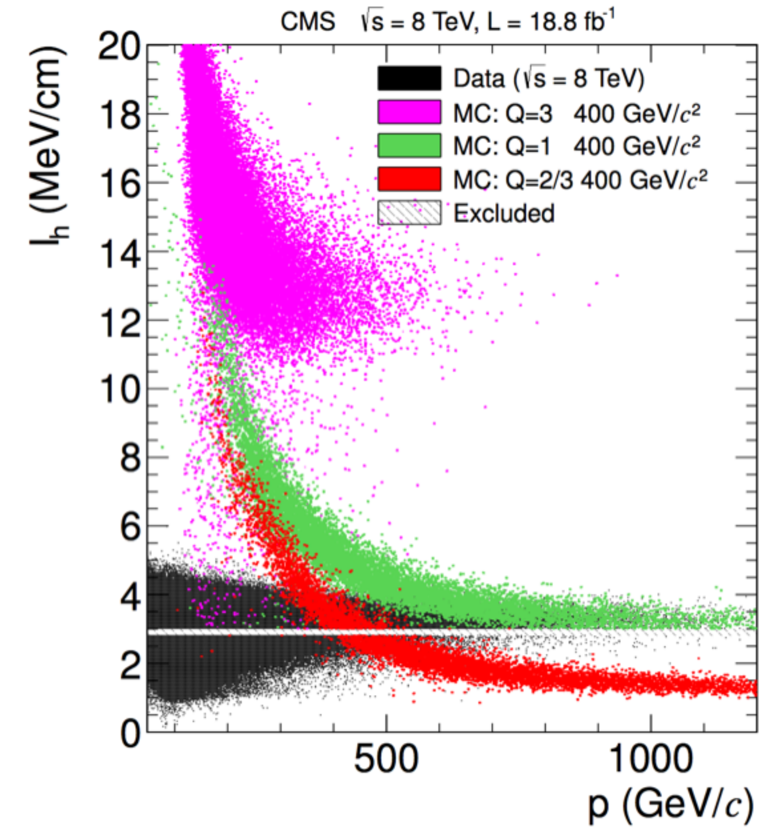

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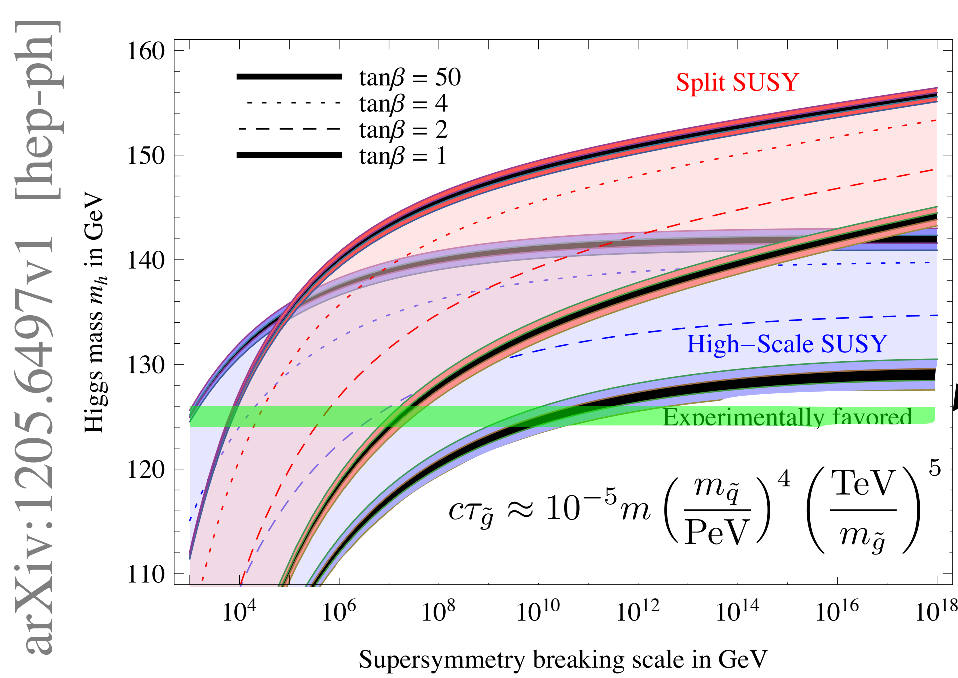
Predicted range for the Higgs mass



A 126 GeV Higgs favors shorter lifetimes for BSM particles (⟨cτ⟩ ~100 μm - 1 cm)

This search targets this range.

It is designed to explore the gap between prompt and very long-lived signatures

Displaced SUSY used as benchmark model

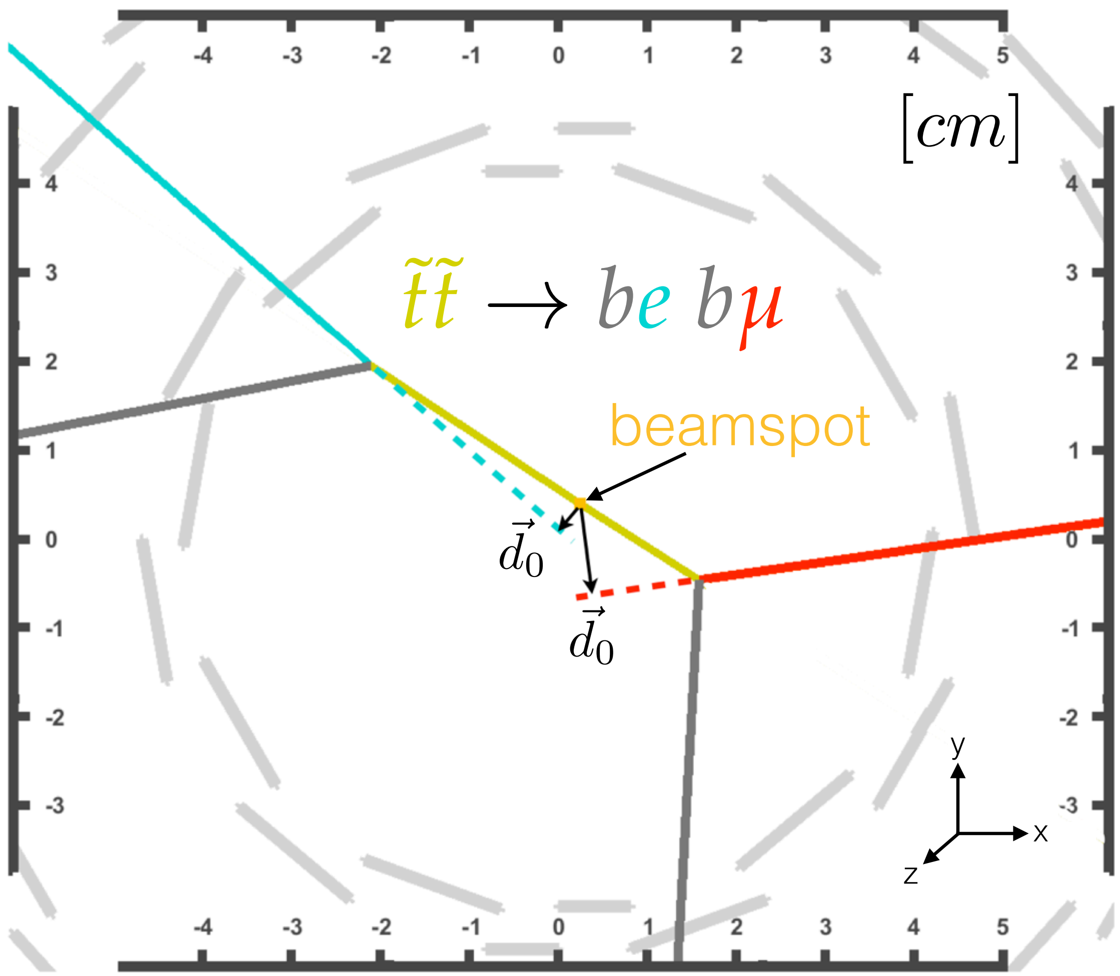
arXiv:1204.6038v1

small RPV couplings generate long-lived LSP

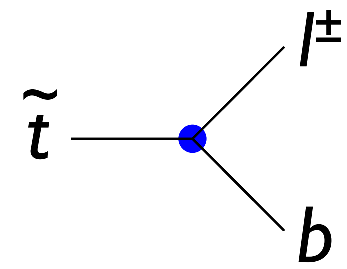
we consider a stop LSP, decaying as $\tilde{t} \to b l^{\pm}$

we perform a search in the eμ final state

CMS Simulation



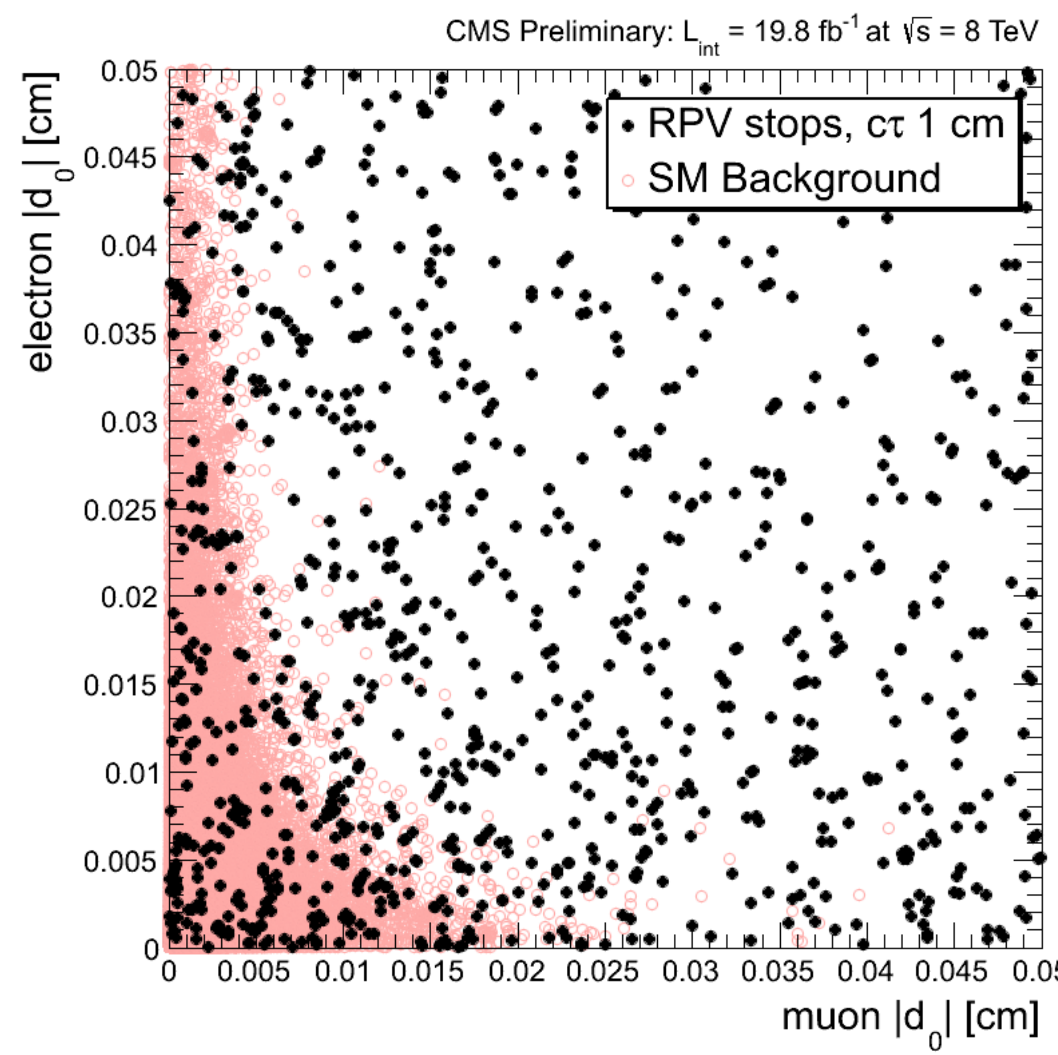
transverse impact parameter (d_0): distance of closest approach of lepton track to beamspot



$\tilde{t}\,\tilde{t}^* \to b\,b\,l^+ l^-$

$BR(e,\mu,\tau) = 1/3$

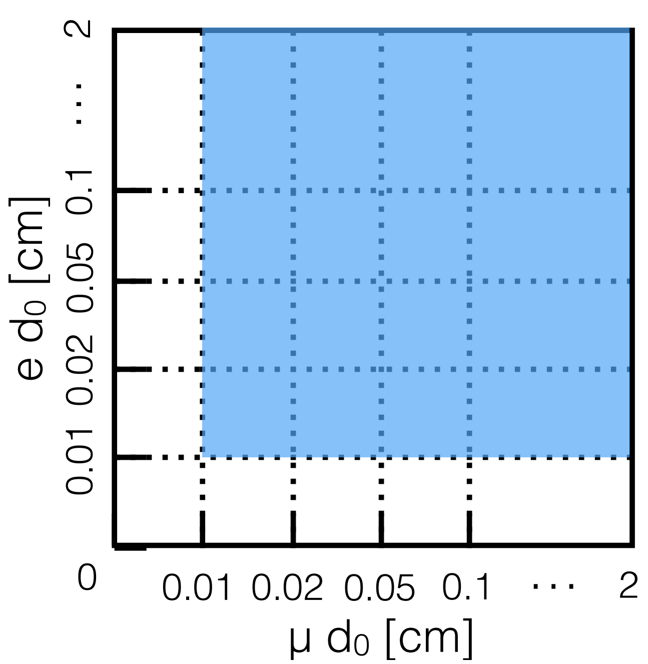
good S/B separation easily achievable in d_0



Simple event selection employed

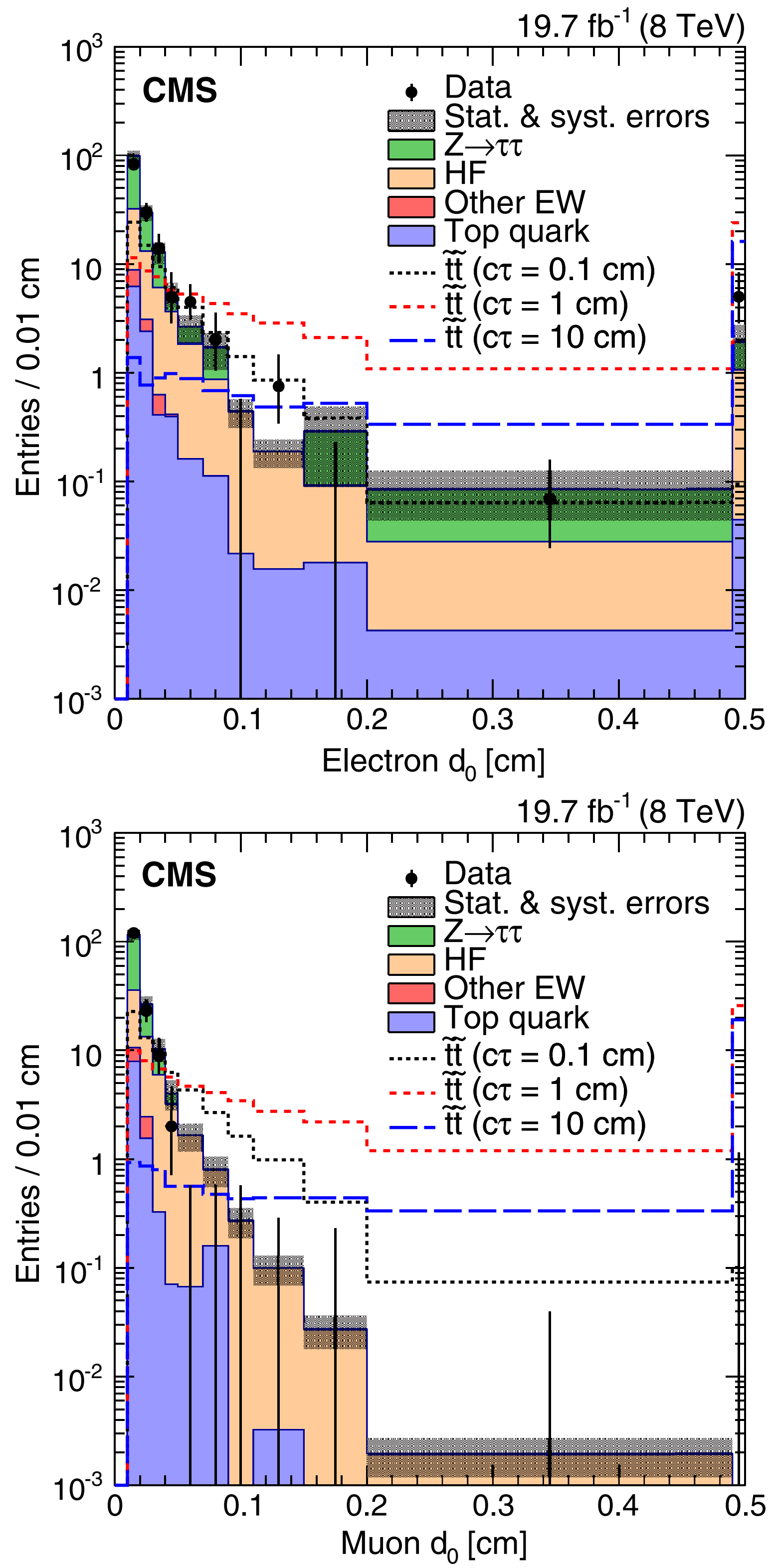
1: Preselection

e-μ pair passing:
$|\eta| < 2.5$
$p_T > 25$ GeV
lepton ID/isolation*
$\Delta R(l, jet) > 0.5$
$100\ \mu m < d_0 < 2$ cm
$\Delta R(e,\mu) > 0.5$
$q_e * q_\mu = -1$



*modified to be efficient for displaced leptons

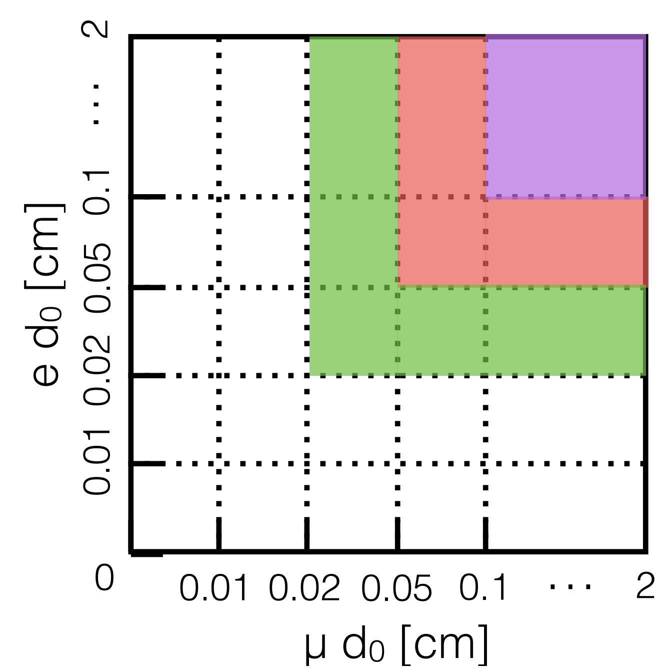
d_0 spectra after preselection



2: Signal Regions (SR)

preselection + d_0 cuts:

SR1: $200\ \mu m < d_0 < 500\ \mu m$
SR2: $500\ \mu m < d_0 < 1000\ \mu m$
SR3: $1000\ \mu m < d_0 < 2$ cm



having multiple signal regions ensures acceptance across different signal lifetimes

Three background sources estimated

1. Heavy Flavor QCD decays (referred to as "QCD")
    - Real displacement due to B,D meson lifetime
    - data-driven technique
2. $Z \to \tau\tau \to e\mu(\nu\nu\nu\nu)$
    - Real displacement due to τ lifetime
    - taken from MC prediction after validating in control regions
3. Prompt SM backgrounds
    - $W \to l\nu$+jets, $Z \to ee/\mu\mu$, ttbar, single top, diboson
    - <10% of background, taken from (validated) MC prediction

We estimate the largest background (QCD) directly from the data

QCD cross sections are so large, simulating ~20/fb worth of events is impractical

Invert the isolation and/or opposite charge requirements to create QCD-dominated control regions (**A**,**C**,**D**)

Measuring the events in data in regions **A**,**C**,**D** lets us calculate the expected QCD yield in our target region (**B**)

We scale the data in region **D** to the expected yield in region **B** to obtain d_0 templates

Orthogonal B-enriched control regions (collected with jet triggers) are use to verify that d_0 is uncorrelated with isolation

Uncertainty on this method (30%) is dominated by the number of events in region **A**

A isolated SS	**B** isolated OS
C anti-isolated SS	**D** anti-isolated OS

$$\frac{\mathbf{A}}{\mathbf{C}} = \frac{\mathbf{B}}{\mathbf{D}} \Rightarrow \mathbf{B} = \frac{\mathbf{A}}{\mathbf{C}} \times \mathbf{D}$$

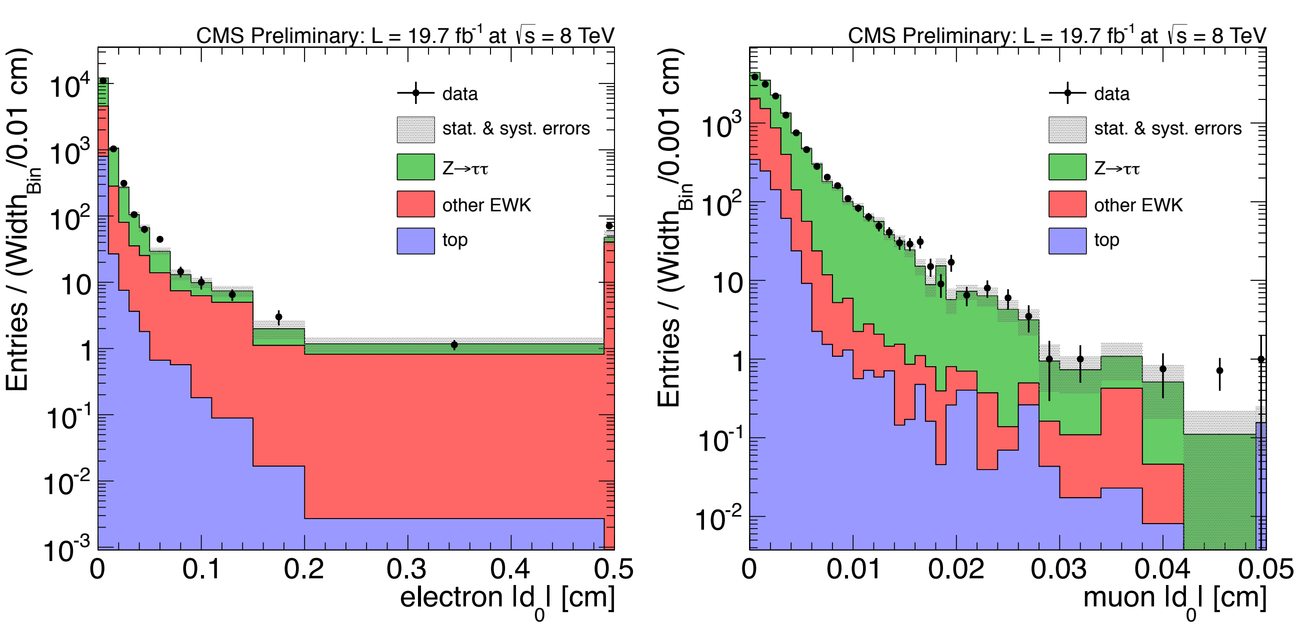
We validate the background predictions in multiple control regions

Z→ττ control region:

meant to verify accuracy of simulation for displaced leptons

defined as preselection + additional cuts:

- $M_T(l, ME_T) < 50$ GeV (rejects W)
- $H_T < 100$ GeV (rejects QCD, di-top)
- $\Delta\phi(e,\mu) > 2.5$ (enriches $Z\rightarrow\tau\tau$)

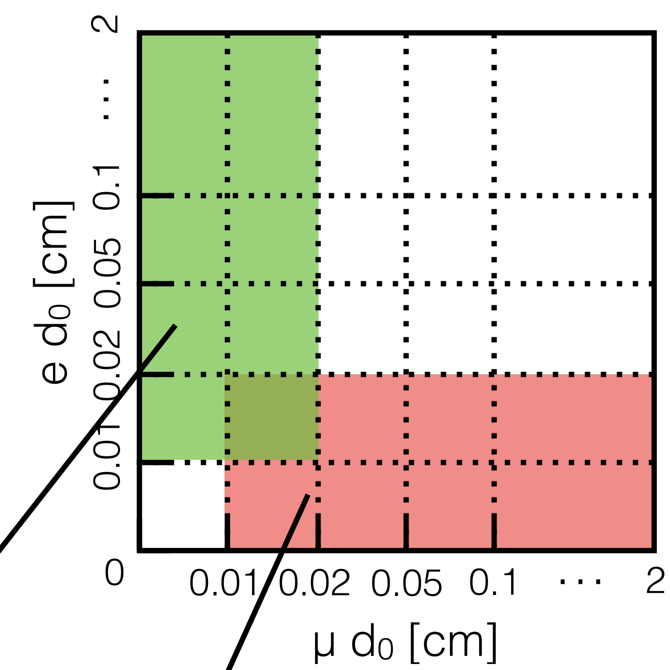


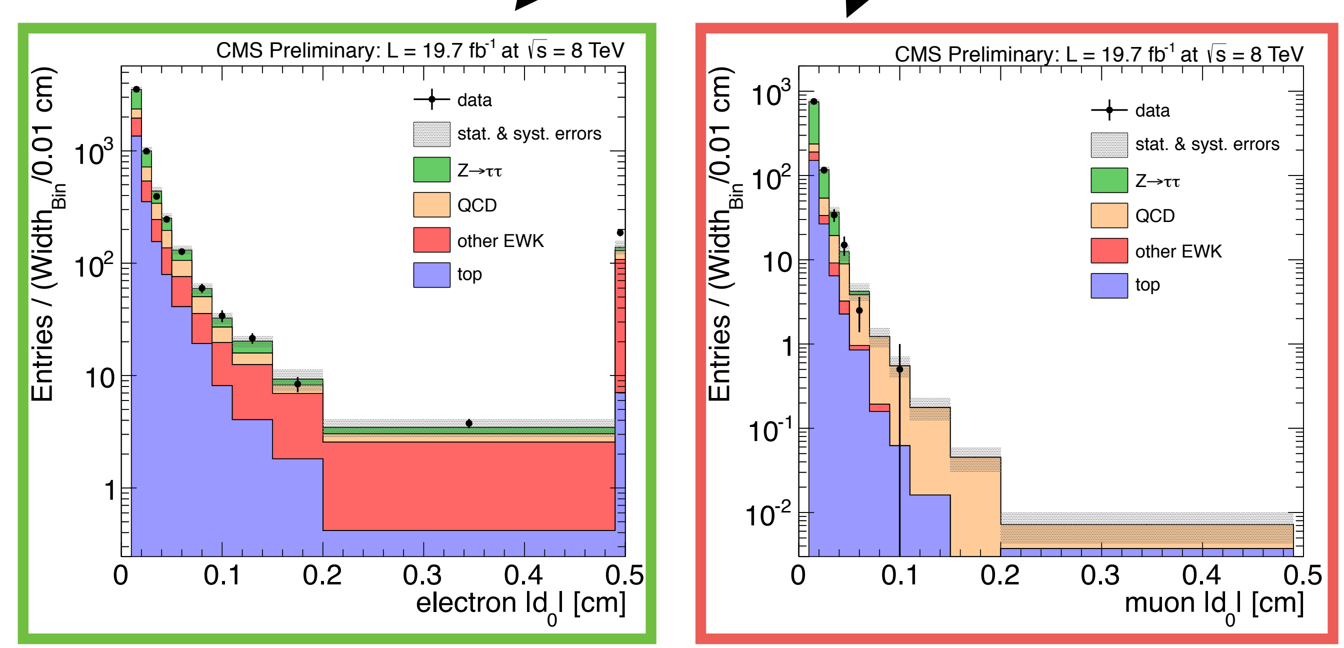
prompt lepton control region:

preselection + inverted d_0 cut on 1 lepton

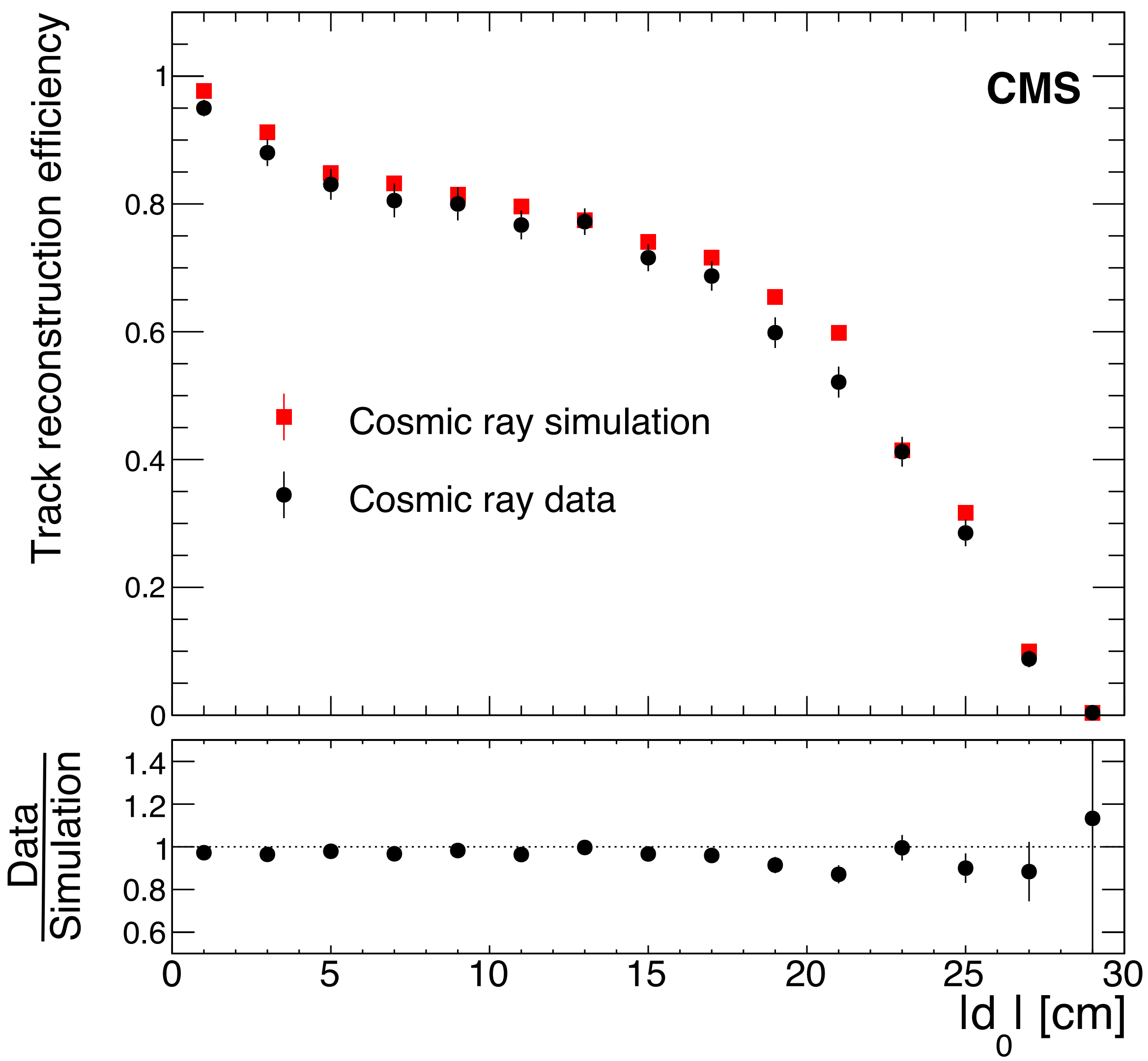
small d_0 ensures no signal contribution

simultaneously verifies simulation and QCD estimate at large d_0





Tracking efficiency measured with cosmic muons



no large source of highly displaced leptons from pp collisions

use non-collision data to collect cosmic muons

apply a tag-and-probe selection using the 2 legs of the muon tracks

compare track reconstruction in data and simulation

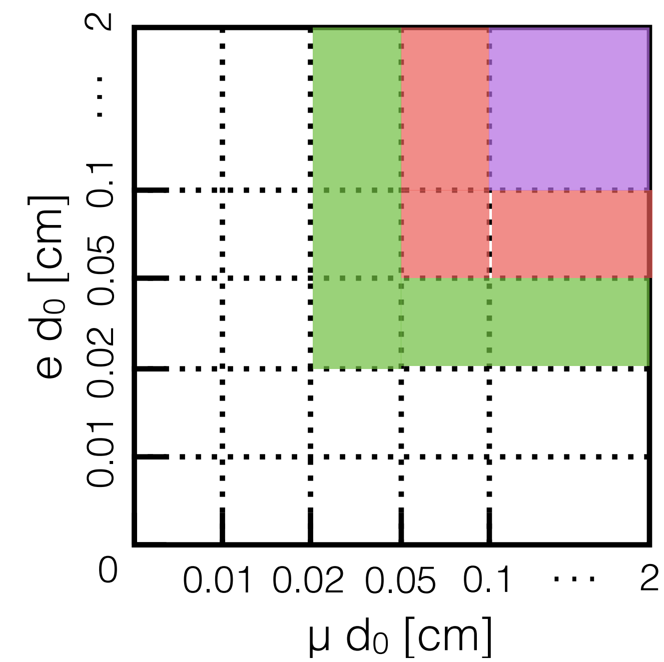
we only use tracks with $d_0 < 2$ cm (roughly the first bin)

We apply a 4% efficiency correction to simulated backgrounds

- We assign a systematic uncertainty of 8% per event (2 leptons/event)

Limits set over four decades of lifetime

Event source	SR1	SR2	SR3
Other EW	$0.65 \pm 0.13 \pm 0.09$	$(0.89 \pm 0.53 \pm 0.12) \times 10^{-2}$	$< (89 \pm 53 \pm 12) \times 10^{-4}$
Top quark	$0.77 \pm 0.04 \pm 0.08$	$(1.25 \pm 0.26 \pm 0.12) \times 10^{-2}$	$(2.4 \pm 1.3 \pm 0.2) \times 10^{-4}$
$Z \rightarrow \tau\tau$	$3.93 \pm 0.42 \pm 0.39$	$(0.73 \pm 0.73 \pm 0.07) \times 10^{-2}$	$< (73 \pm 73 \pm 7) \times 10^{-4}$
HF	$12.7 \pm 0.2 \pm 3.8$	$(98 \pm 6 \pm 30) \times 10^{-2}$	$(340 \pm 110 \pm 100) \times 10^{-4}$
Total expected background	$18.0 \pm 0.5 \pm 3.8$	$1.01 \pm 0.06 \pm 0.30$	$0.051 \pm 0.015 \pm 0.010$
Observed	19	0	0
$pp \rightarrow \tilde{t}\tilde{t}^{*}$ ($M_{\tilde{t}} = 500$ GeV)			
$c\tau = 0.1$ cm	$30.1 \pm 0.7 \pm 5.3$	$6.54 \pm 0.34 \pm 1.16$	$1.34 \pm 0.15 \pm 0.24$
$c\tau = 1$ cm	$35.3 \pm 0.8 \pm 6.2$	$30.3 \pm 0.7 \pm 5.3$	$51.3 \pm 1.0 \pm 9.0$
$c\tau = 10$ cm	$4.73 \pm 0.30 \pm 0.83$	$5.57 \pm 0.32 \pm 0.98$	$26.3 \pm 0.7 \pm 4.6$

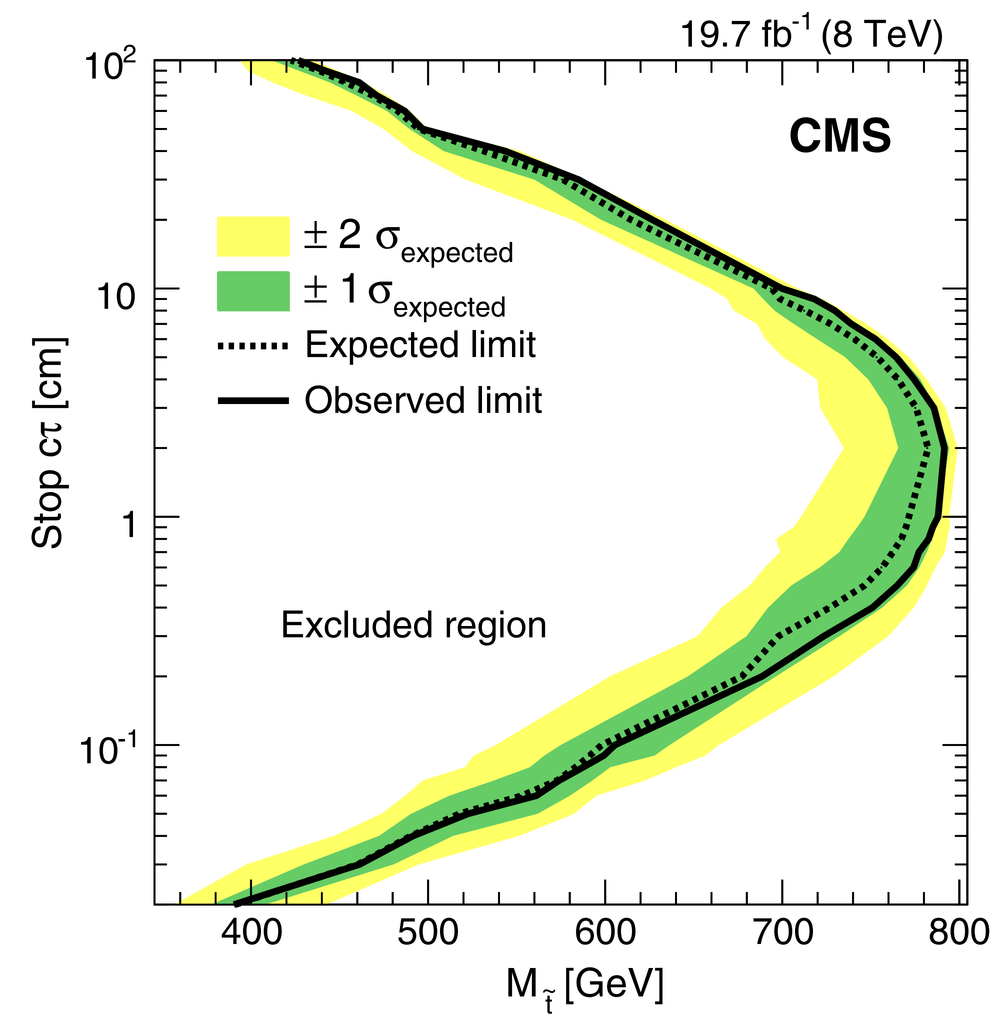


observation consistent with background in all three signal regions

three bin counting experiment performed using the orthogonal signal regions

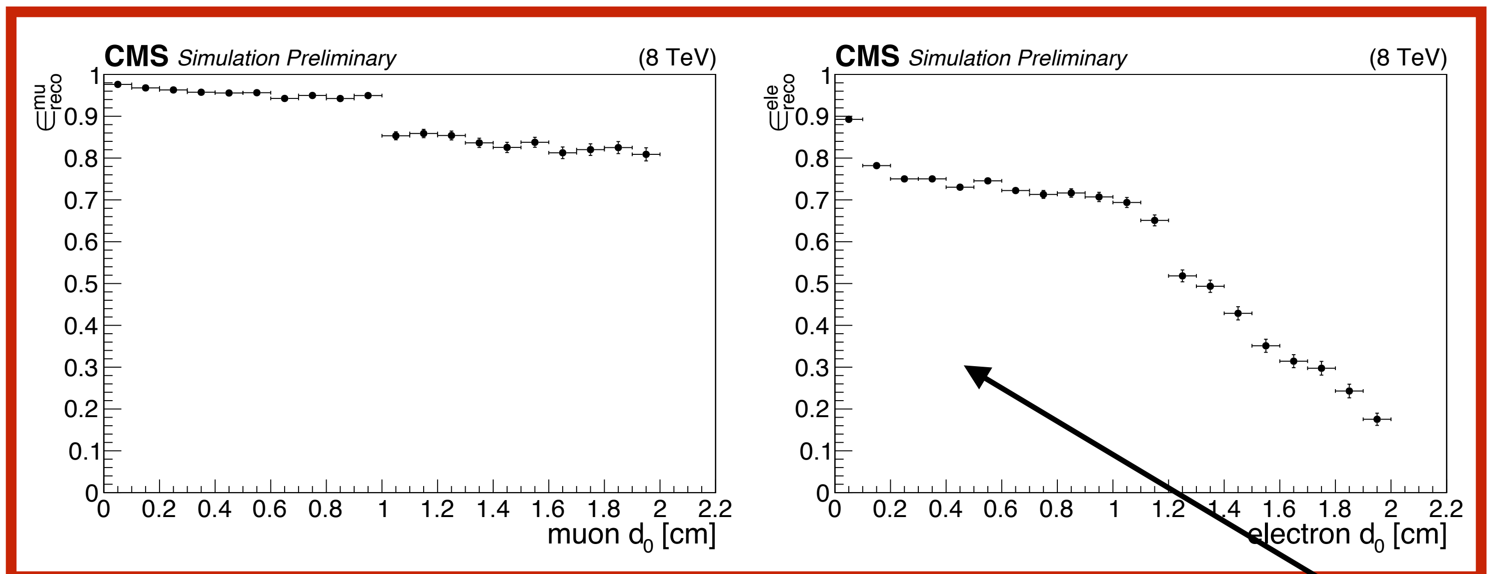
best limit: M > 790 GeV for a stop lifetime of 2 cm

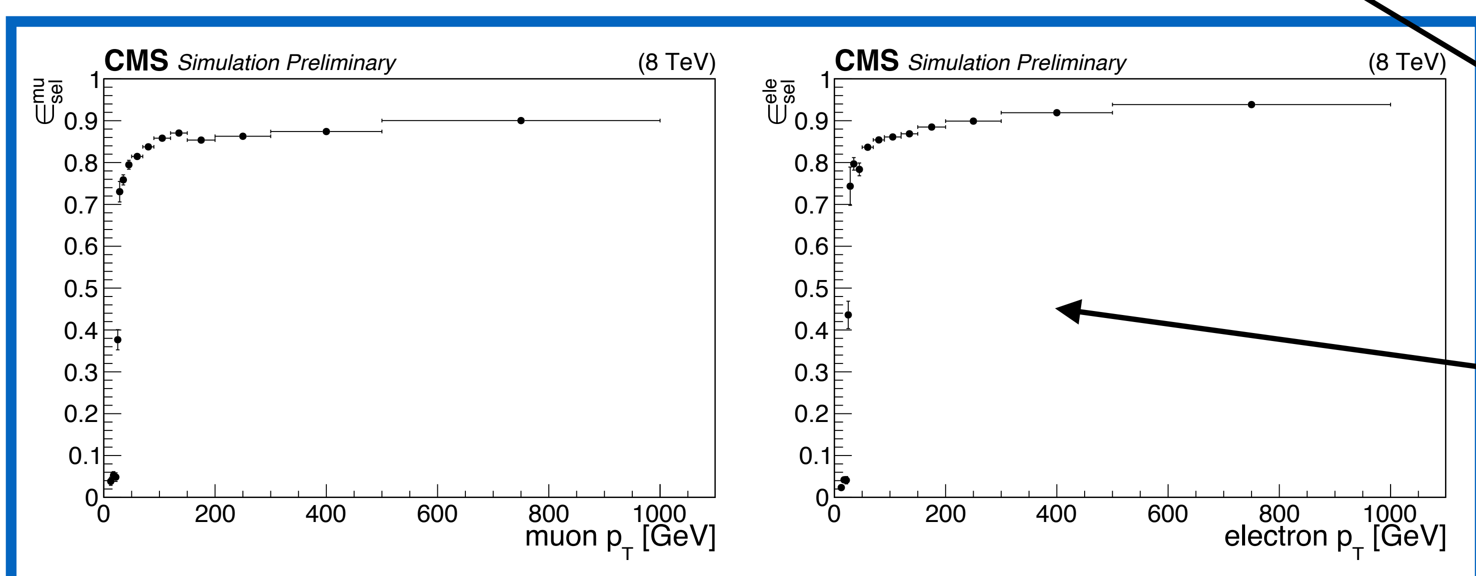
sensitivity bounded at short lifetime by large QCD background and at high lifetime by efficiencies of lepton triggering and reconstruction algorithms



Object selection efficiencies parametrized for easy recasting

our simple event selection makes it easy to describe the selection efficiencies in terms of generator-level quantities





full offline selection efficiency can be attained by a combination of:

1. applying fiducial cuts on simulated particles

2. reweighting simulated particles using the provided efficiency curves

lepton reconstruction efficiencies as a function of d_0

lepton selection efficiencies as a function of p_T
(includes p_T, ID, isolation cuts)

https://twiki.cern.ch/twiki/bin/view/CMSPublic/DisplacedSusyParametrisationStudyForUser

We’ve just scratched the surface of this landscape

We have performed a search for displaced decays containing leptons in an OS e-μ final state, [PRL result linked here]

Our very simple event selection (no common vertex, ME_T, H_T cuts) makes the results applicable to a wide range of models (recasting made easy by providing selection efficiency curves)

There are many straightforward extensions to be done at 13 TeV, e.g.:

- Same flavor leptons
- Same-sign leptons

We’ve increased our lepton acceptance in preparation for Run 2, e.g. displaced muon algorithm