# Search for Displaced Supersymmetry using the Compact Muon Solenoid Detector

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# Outline

Motivation

The LHC and the CMS Detector

Displaced Supersymmetry Search

Results and Summary

# Motivation

# Motivation for Non-prompt Search

1. **The mass of the Higgs boson is found to be 126 GeV, giving rise to the hierarchy problem.**

   Many extensions to the standard model are trying to provide solutions to the hierarchy problem. Many searches for one of the most popular theories known as Super Symmetry(SUSY) have been conducted at various experiments.

2. **SUSY becomes more and more constrained by searches done by CMS and ATLAS.**

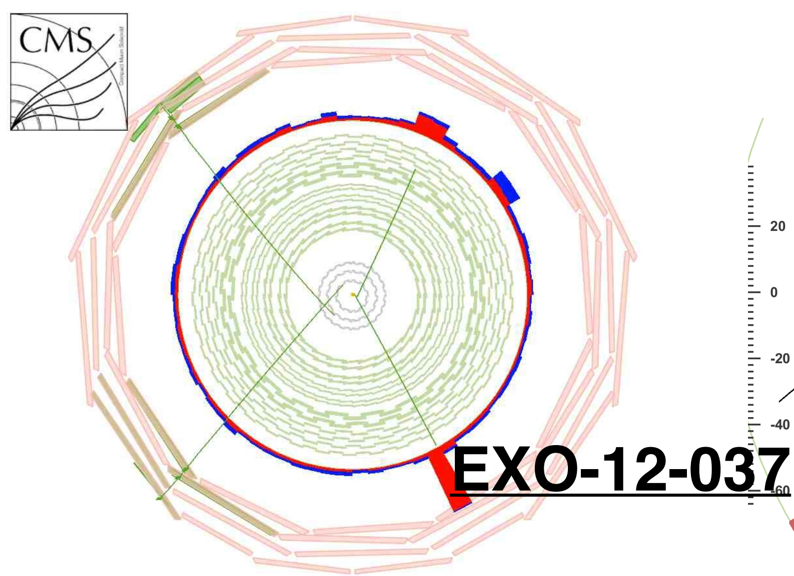
3. **However, the previous searches may have overlooked some SUSY models since:**

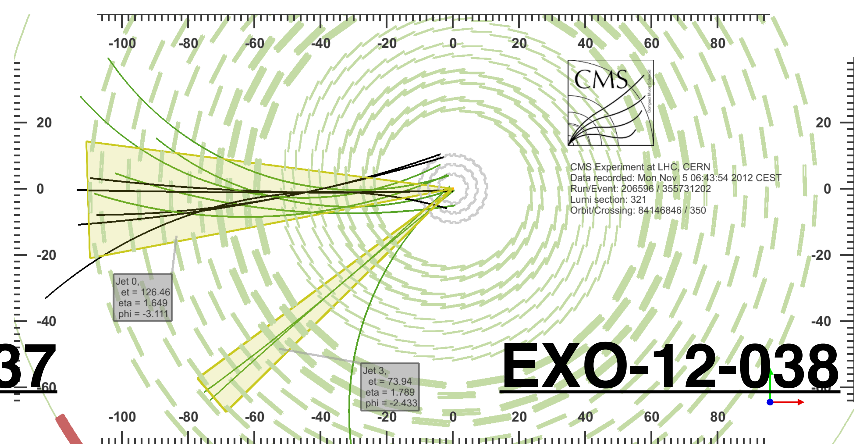
   1. Most of the previous searches were concentrated on prompt products(jets, leptons,etc).
   2. Most of the previous searches were assuming the lightest SUSY particles(LSP) cannot decay, leading to large missing energy in the detector. Consequently, large missing energy was used as the discriminating variable.

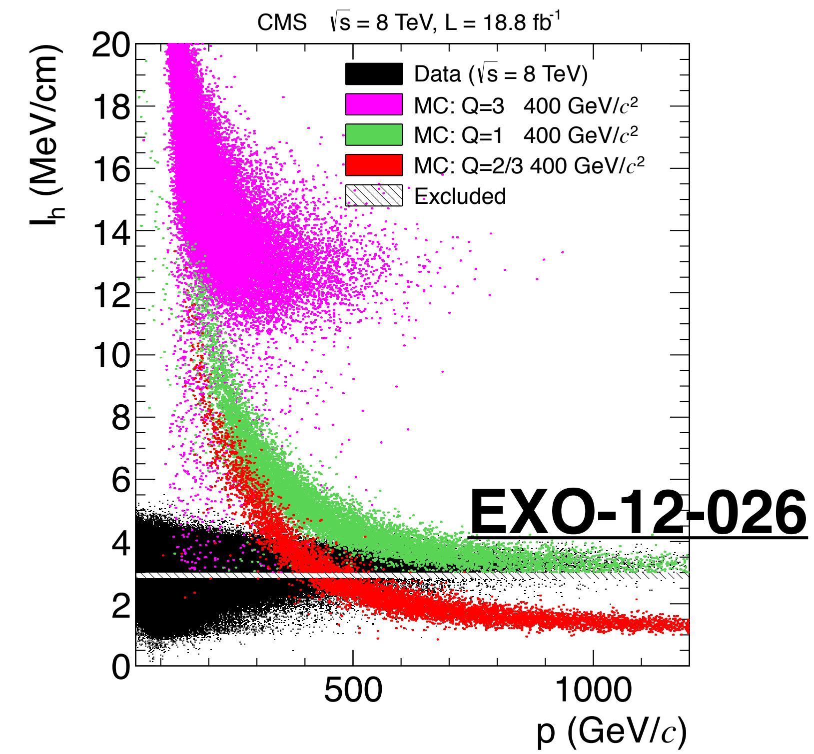
***Searches for non-prompt products with no requirements on missing energy are motivated!***

# Motivation for this Search

**Some searches in CMS have looked into non-prompt signatures, but they focus on longer lifetimes.**



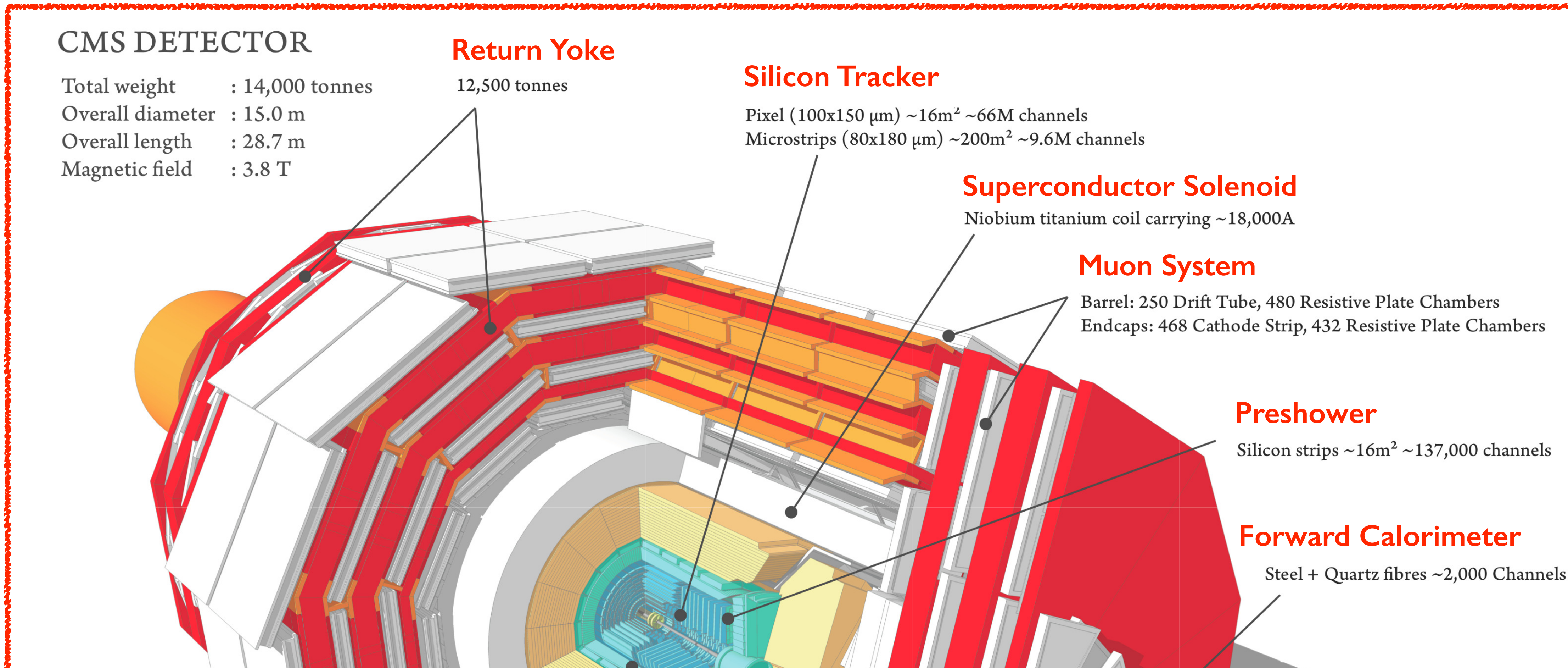



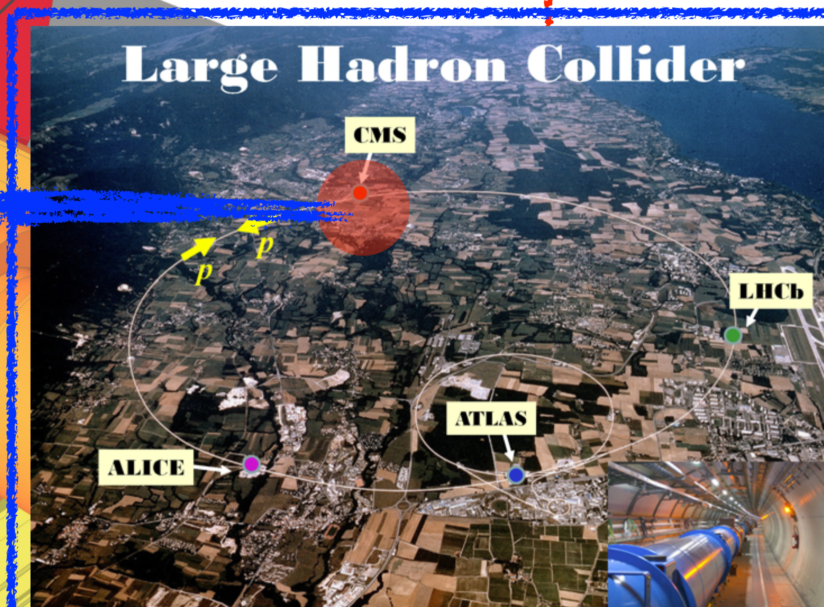

**This search will focus on the gap between prompt and very long-lived signatures. In addition, it is designed to be largely model-independent.**

# The LHC and the CMS Detector

# The LHC and the CMS Detector

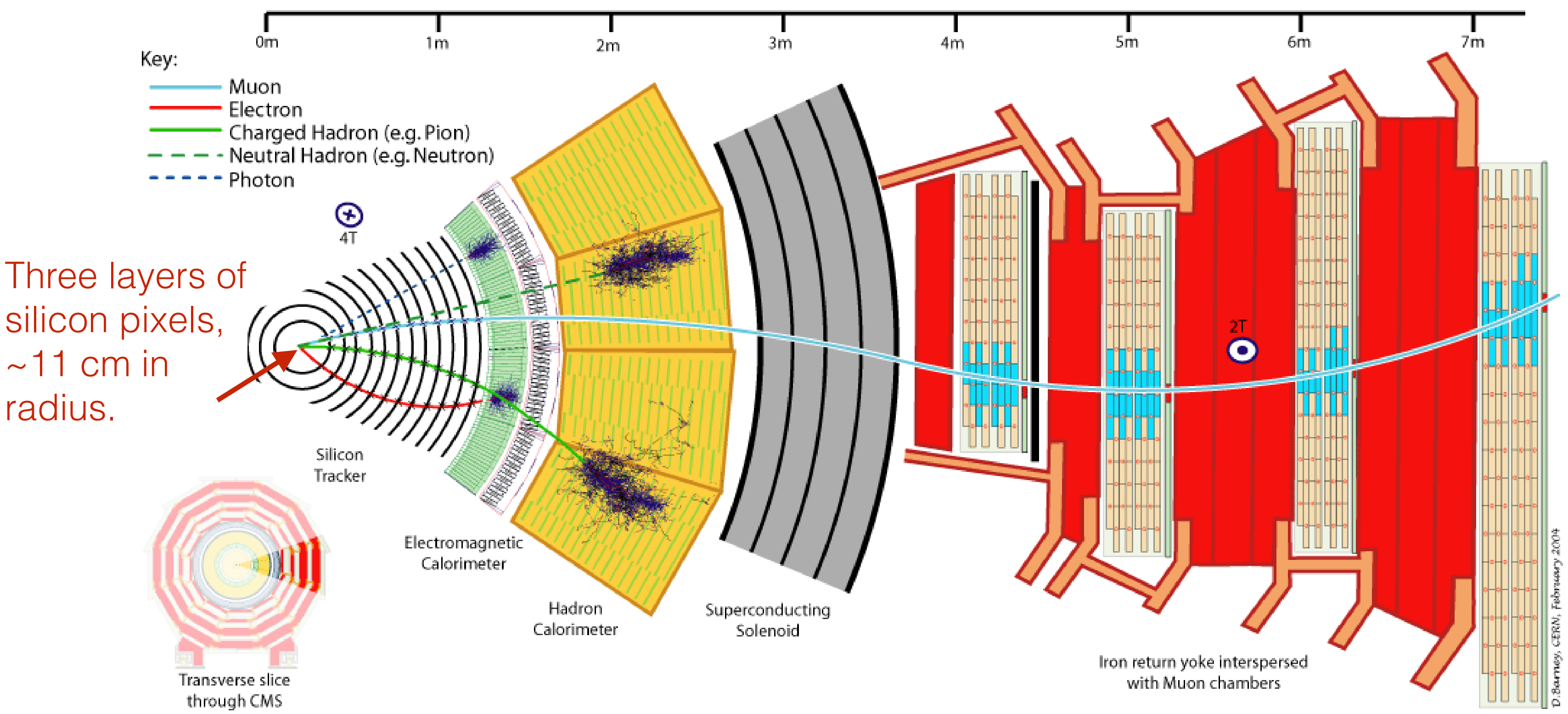



Sectional View of the CMS detector




Overview of the Large Hadron Collider

# Passages of Particles in CMS




Passages of particles in the CMS detector.

Once charged particles go trough the tracker, electron-hole pairs are created and move in opposite directions due to the bias voltage.

Photons and electrons will have electromagnetic showers in the ECAL: electrons radiate photons(Bremsstrahlung) and photons can produce electron-positron pairs...continue until go below threshold.

Hadronic showers are more complex: pion production, nuclear interaction, invisible energy, electromagnetic showers

| | Tracker | ECAL | HCAL | Muon System | Reasons |
|---|---|---|---|---|---|
| Electron | ● | ● | | | Charged, light lepton. |
| Photon | | ● | | | Neutral, interact electromagnetically |
| Charged Hadron | ● | ● | ● | | Charged, interact hadronically |
| Neutral Hadron | | | ● | | Neutral, interact hadronically |
| Muon | ● | | | ● | Charged, heavy lepton |

# Displaced Supersymmetry Search

# Displaced Supersymmetry Signature

**Model used:**

Displaced Supersymmetry
[arXiv:1204.6038v1](arXiv:1204.6038v1)

**Key features of the model:**

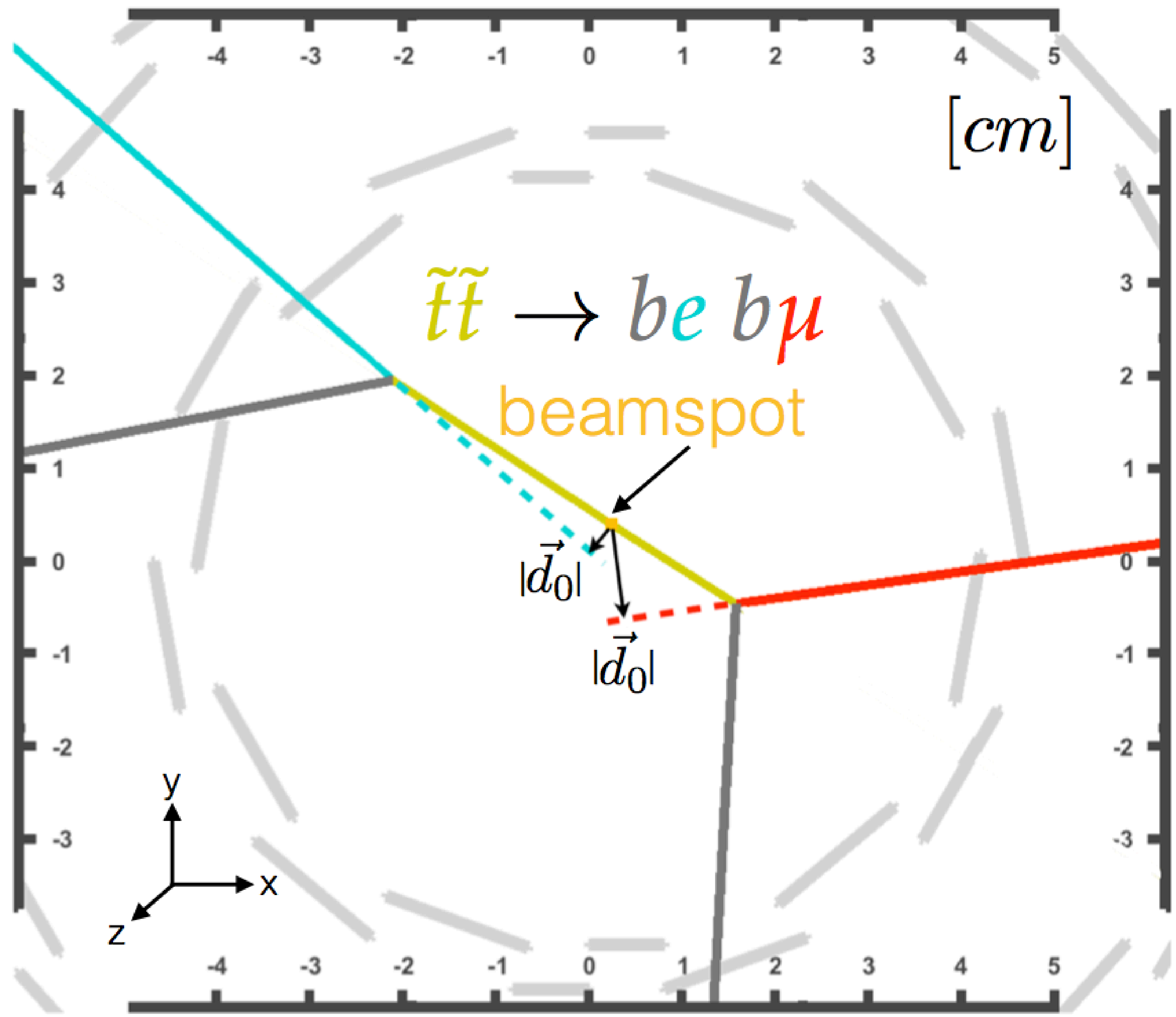
LSP can decay.
LSP has long lifetime.

**Benchmark:**

We consider the **top squark** as the LSP, decaying to **a bottom quark** and a lepton.

**Final states:**

An **electron** and a **muon**.




**Leptons from top squark will have large impact parameters($|d_0|$) due to top squarks' long lifetime.**

# Major SM Background

## 1. Contribution from relatively long-lived SM particles:

Some Standard Model particles have relatively longer lifetime, which could produce leptons with relatively large impact parameters, contributing to the background of this search. Such as:

1. τ from Drell-Yan process($Z \rightarrow \tau\tau$), where τ decays to an electron or a muon.

   We estimate the contribution from $Z \rightarrow \tau\tau$ using MC simulation.

2. B,D mesons from $b\bar{b}$ production, where B,D mesons decay weakly(Heavy flavor QCD).

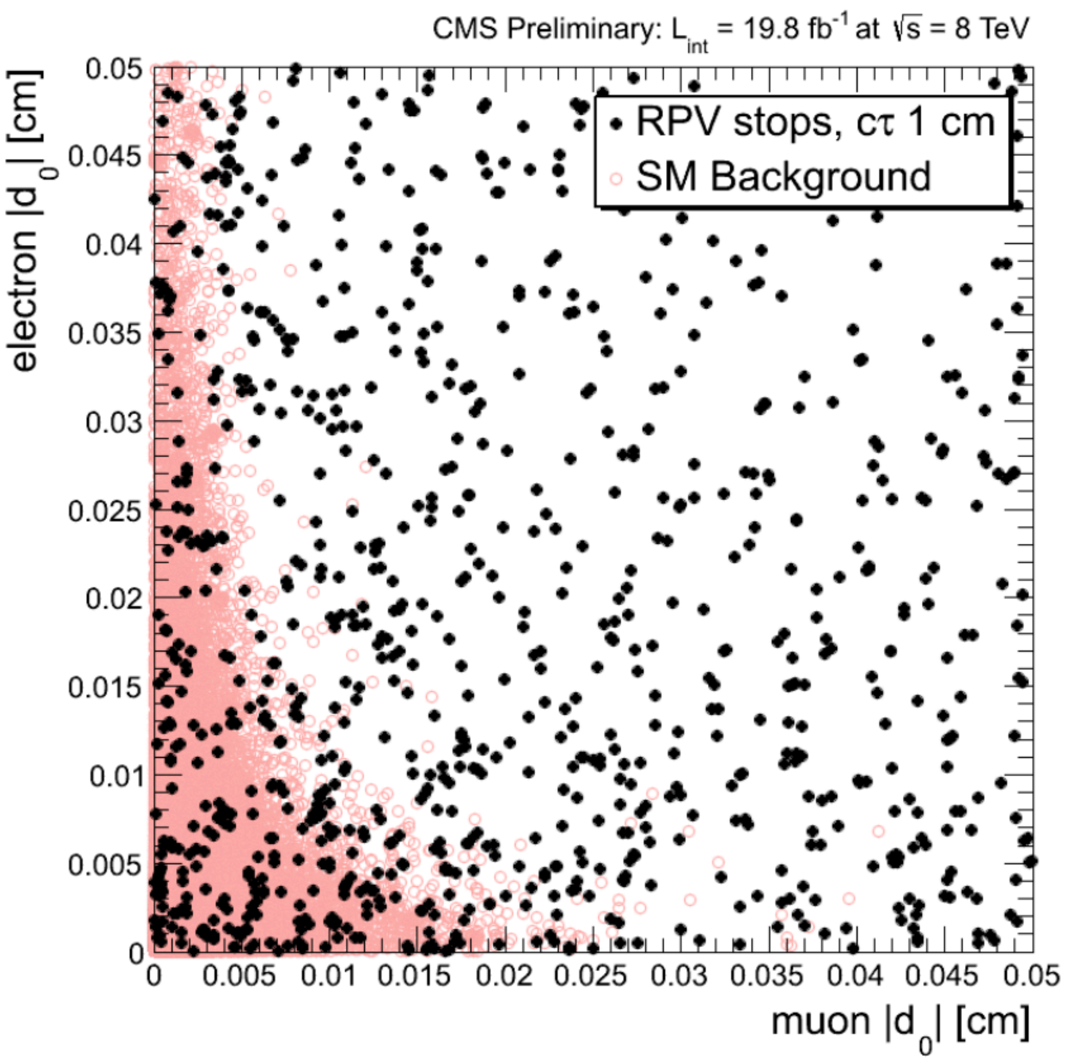
   We apply a data-driven method to estimate its contribution.

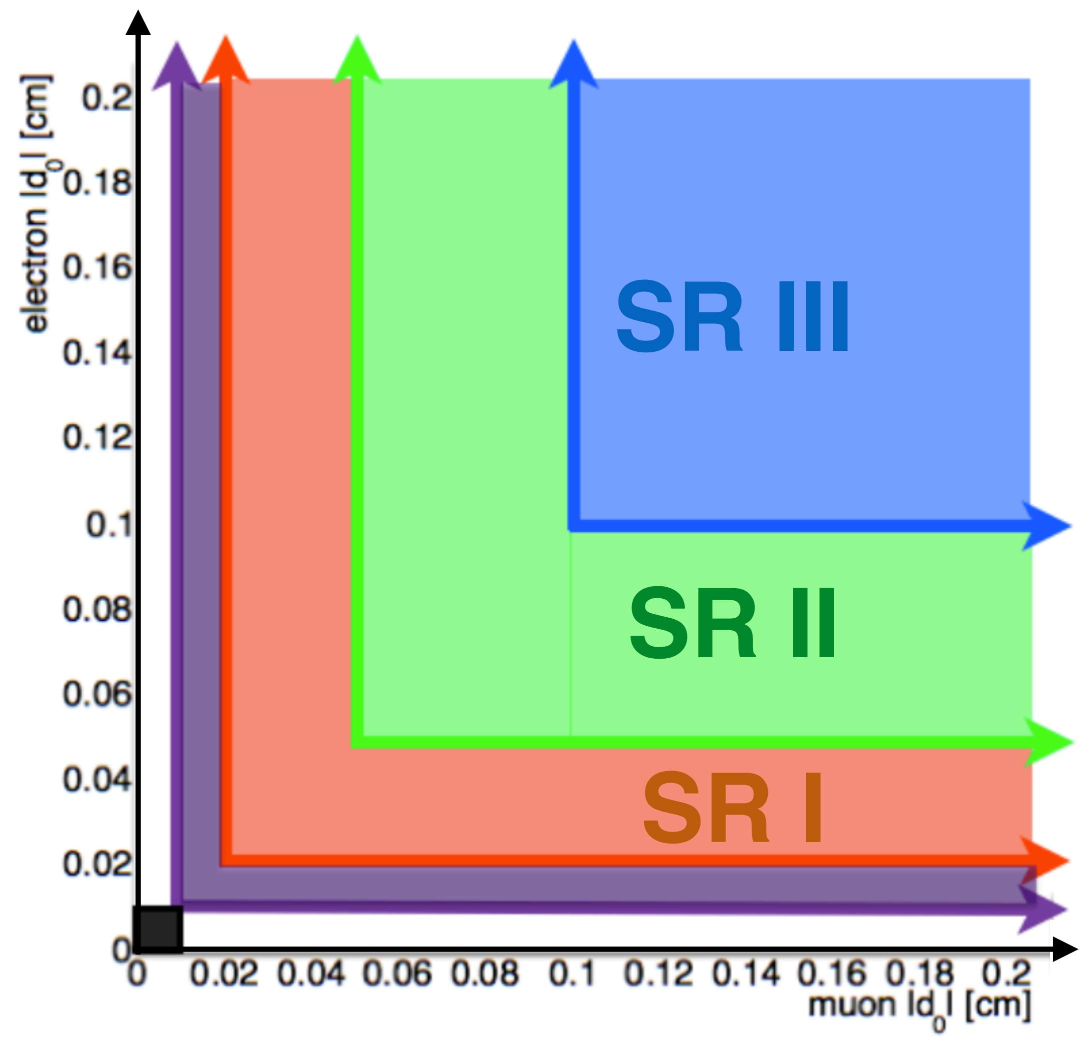
## 2. Contribution from prompt SM background:

Other SM processes such as: $W \rightarrow l\nu$+jets, $t\bar{t}$, $Z \rightarrow ee/\mu\mu$, single top, diboson(WW,WZ,ZZ,Zγ,Wγ)

Contributions from the above processes are very small, taken from MC simulation.

# Search Regions




Distributions of **SM background** and **signal events** in muon $|d_0|$-electron $|d_0|$ 2-D plane.

**Impact parameter is a powerful discriminating variable!**

**Prompt control region($|d_0|$ < 100 um):**
Check the analysis setup is OK
**Displaced control region($|d_0|$ > 100 um):**
Used to Estimate the QCD background
**Three non-overlapping signal regions(SR X)**
**SR III: Both $|d_0|$ > 0.1 mm**
**SR II: Both $|d_0|$ > 0.05 mm but not in SR III**
**SR I: Both $|d_0|$ > 0.02 mm but not in SR II or III**

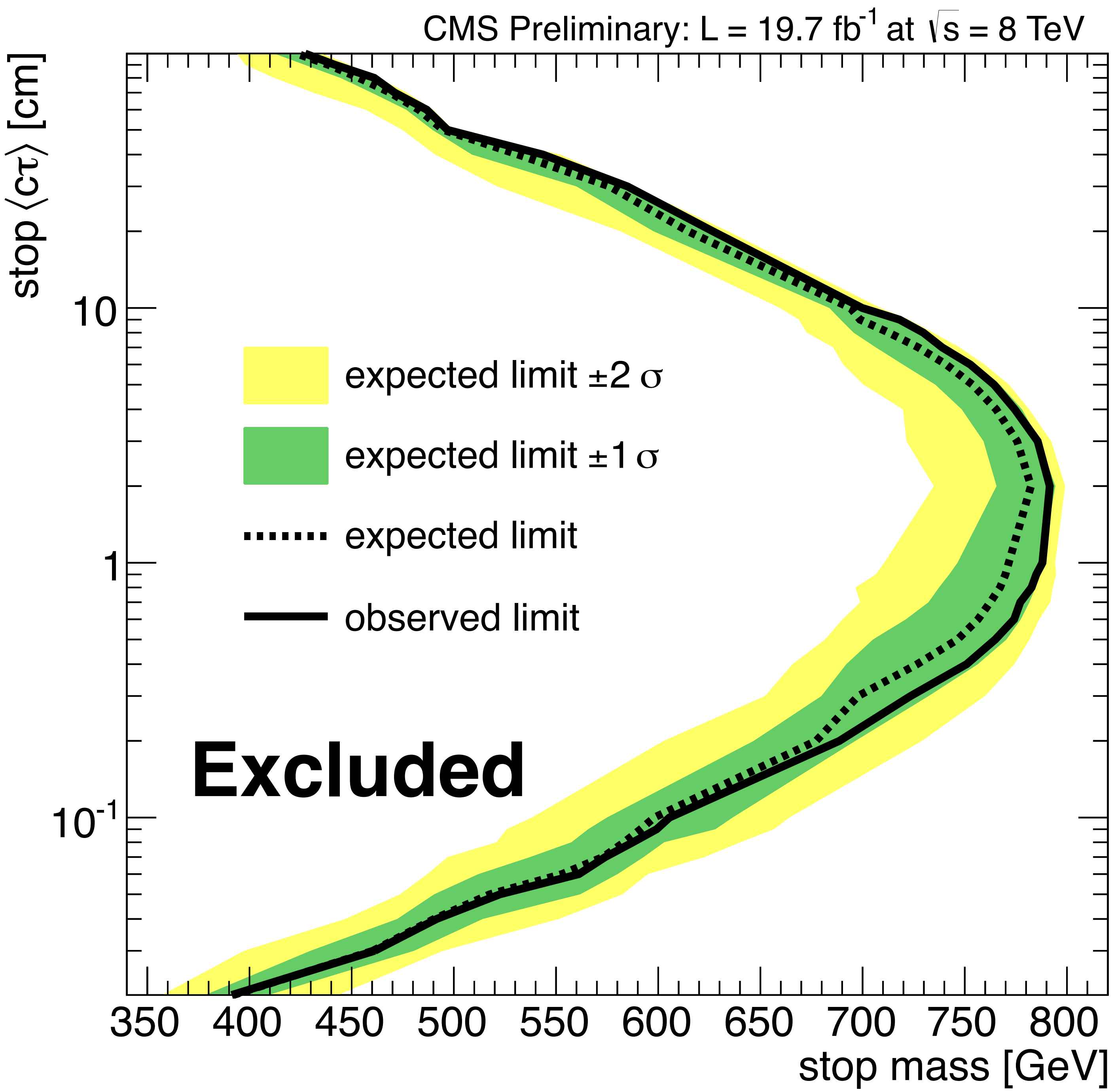
# Results and Summary

# Yields in Signal Regions

| 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 | $0.77 \pm 0.04 \pm 0.08$ | $(1.25 \pm 0.26 \pm 0.12) \times 10^{-2}$ | $(2.4 \pm 1.3 \pm 0.2) \times 10^{-4}$ |
| $Z \to \tau\tau$ | $3.93 \pm 0.42 \pm 0.39$ | $(0.73 \pm 0.73 \pm 0.07) \times 10^{-2}$ | $<(73 \pm 73 \pm 7) \times 10^{-4}$ |
| 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 bkgd. | $18.0 \pm 0.5 \pm 3.8$ | $1.01 \pm 0.06 \pm 0.30$ | $0.051 \pm 0.015 \pm 0.010$ |
| Observed | 19 | 0 | 0 |
| $pp \to \tilde{t}\tilde{t}^*$ ($M_{\tilde{t}} = 500\,\text{GeV}$) | | | |
| $c\tau = 0.1\,\text{cm}$ | $30.1 \pm 0.7 \pm 5.3$ | $6.54 \pm 0.34 \pm 1.16$ | $1.34 \pm 0.15 \pm 0.24$ |
| $c\tau = 1\,\text{cm}$ | $35.3 \pm 0.8 \pm 6.2$ | $30.3 \pm 0.7 \pm 5.3$ | $51.3 \pm 1.0 \pm 9.0$ |
| $c\tau = 10\,\text{cm}$ | $4.73 \pm 0.30 \pm 0.83$ | $5.57 \pm 0.32 \pm 0.98$ | $26.3 \pm 0.7 \pm 4.6$ |

**No obvious excess was observed.**
**Limits are set on this model.**

# Exclusion Curve




For a lifetime hypothesis of cτ = 2 cm, top squark masses up to 790GeV are excluded.

The limits curve has such feature on the left is because:

1. For short lifetime, the signal are more like StandardModel.
2. For really long lifetime, there are constraints on the acceptance to the signal(from both hardware and software)

# Summary && Outlook

1. We performed a search for long-lived BSM particles decaying into e-μ final state.
2. This search is more sensitive to a region in the parameter space where no previous LHC analyses were optimized for.
3. Limits are set on the Displaced Supersymmetry model.
4. Planning to look into more final states in Run 2 and already started early stage studies.

For more information or technical details on this analysis, please check the CMS public results page:

CMS-PAS-B2G-12-024

Paper available on arXiv:1409.4789

# *Gracias!*