Search for Displaced Supersymmetry using the Compact Muon Solenoid Detector

Q. Python
on the behalf of the CMS collaboration

reference: CMS-PAS-B2G-12-024

Vrije Universiteit Brussel

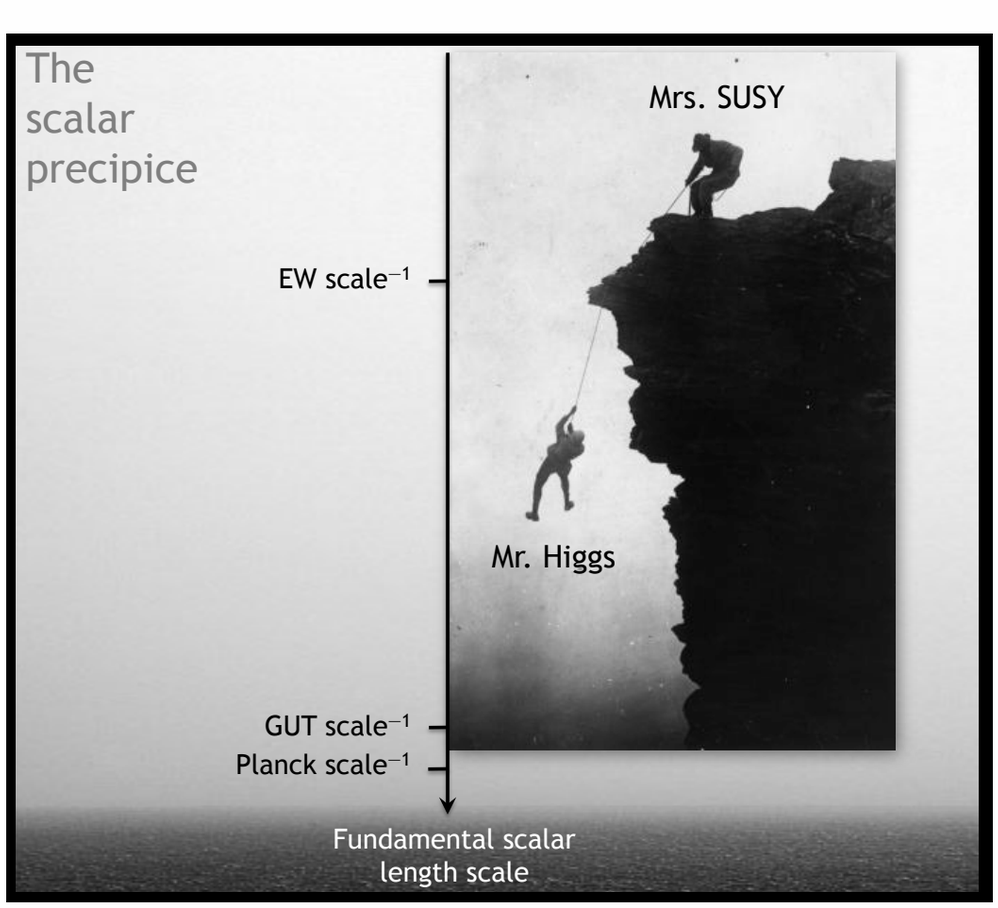
Outline

- Context and Motivation
- Experimental Setup
  - LHC
  - Compact Muon Solenoid (CMS) Detector
- Displaced Supersymmetry Search
  - Signal Model
  - Background Estimation
  - Results
- Summary

Context and Motivation

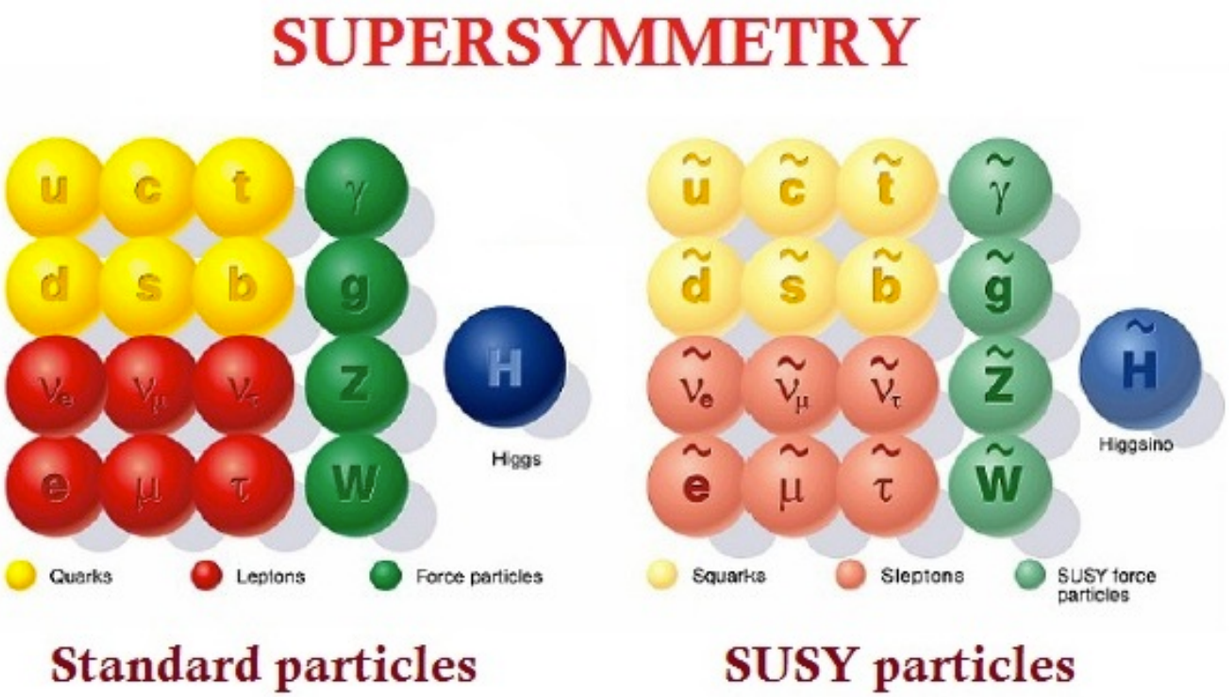
Motivation for physics Beyond the Standard Model (BSM)

- Various motivations for SUper SYmmetry (SUSY)
  - SUSY could explain why the Higgs boson has such a small mass (hierarchy problem)



A bit more on SUSY

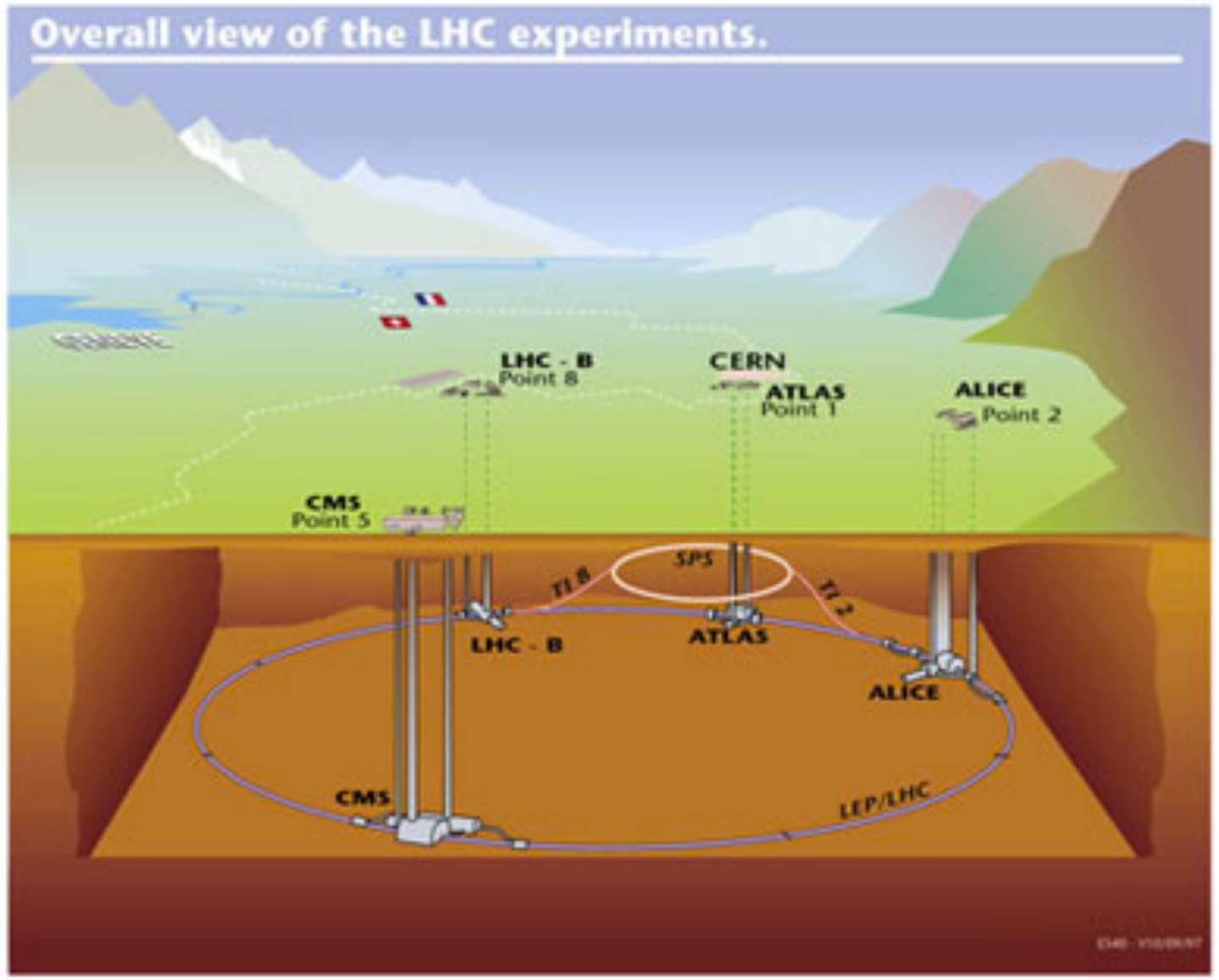
- SUSY is a theory that adds an additional symmetry that gives a partner to all SM particles
- SUSY is getting more and more constrained by direct searches by ATLAS and CMS
- Most of these searches use prompt leptons, jets and/or missing energy
- There are SUSY models that might have been overlooked. No stone should be left unturned!
- In some models, SUSY particles have long lifetime



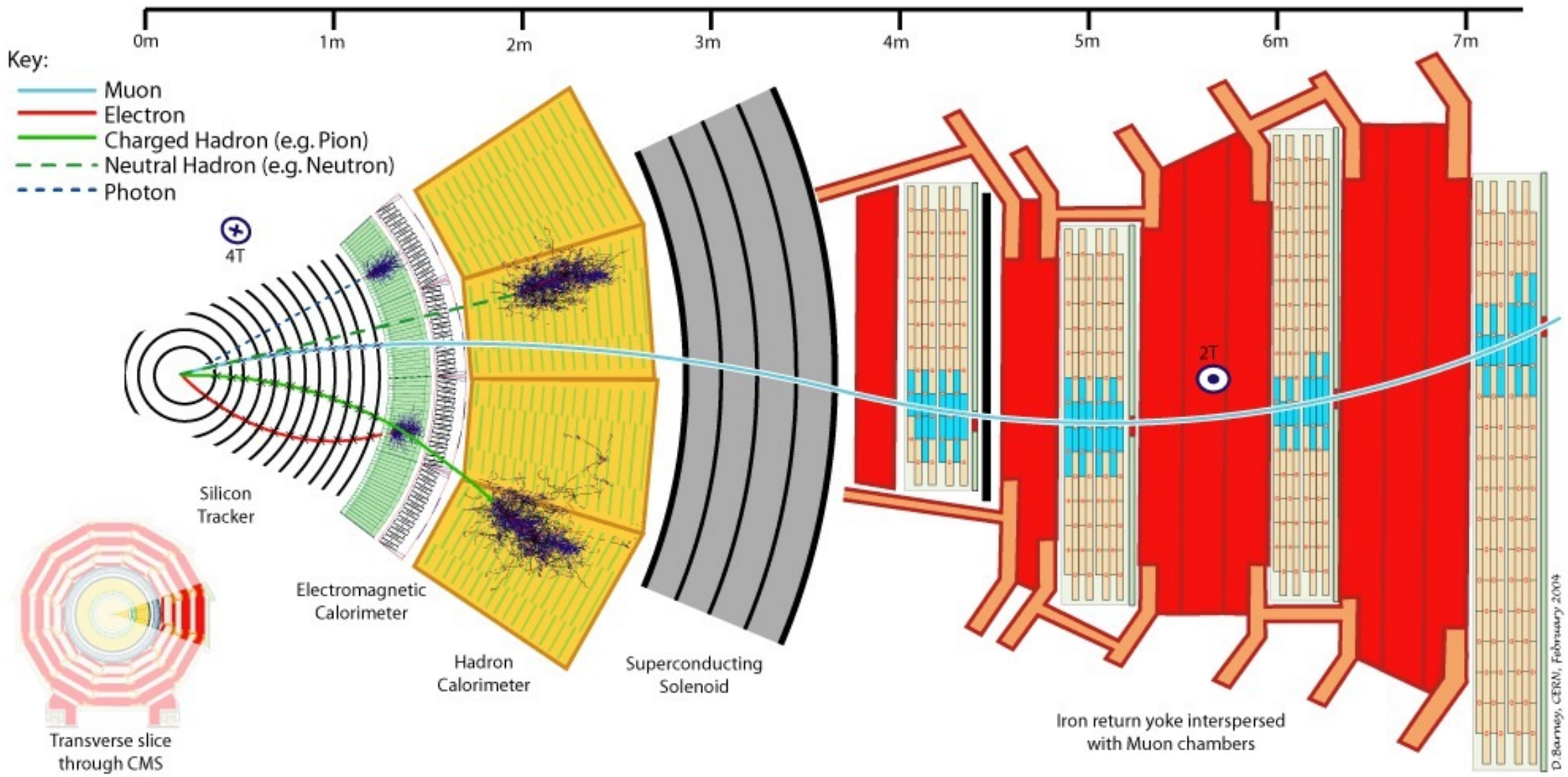
Experimental Setup

The Large Hadron Collider (LHC)

- Located close to the Swiss-French border
- 27 km circumference ring ~100 m underground
- Multiple experiments designed to conduct different physics programs
- Used 2012 data sample of proton-proton collisions with an energy of 8 TeV



The CMS detector



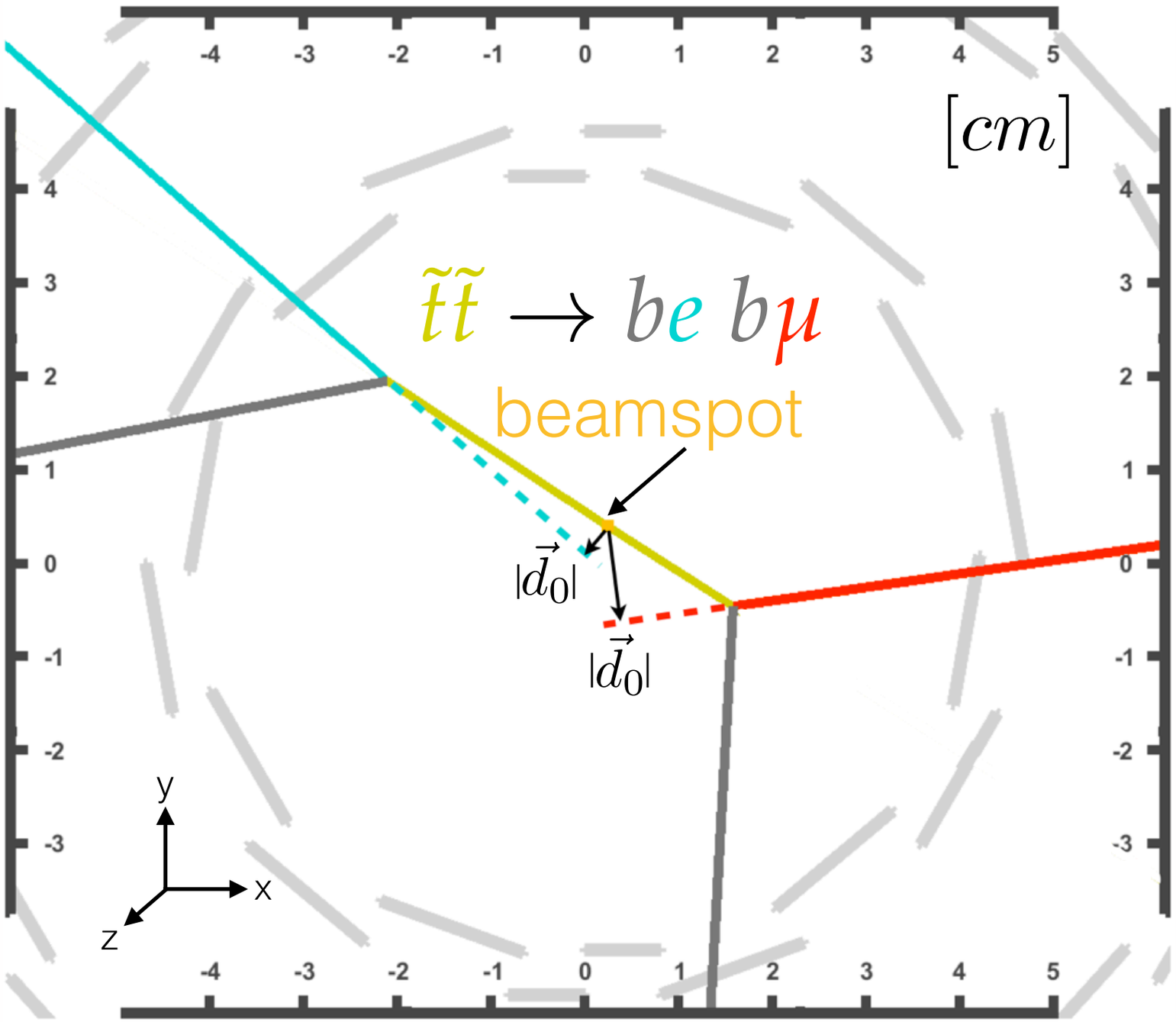
Displaced

Supersymmetry Search

Signal model

Displaced Supersymmetry
arXiv:1204.6038v1

Final state with one displaced electron and one displaced muon

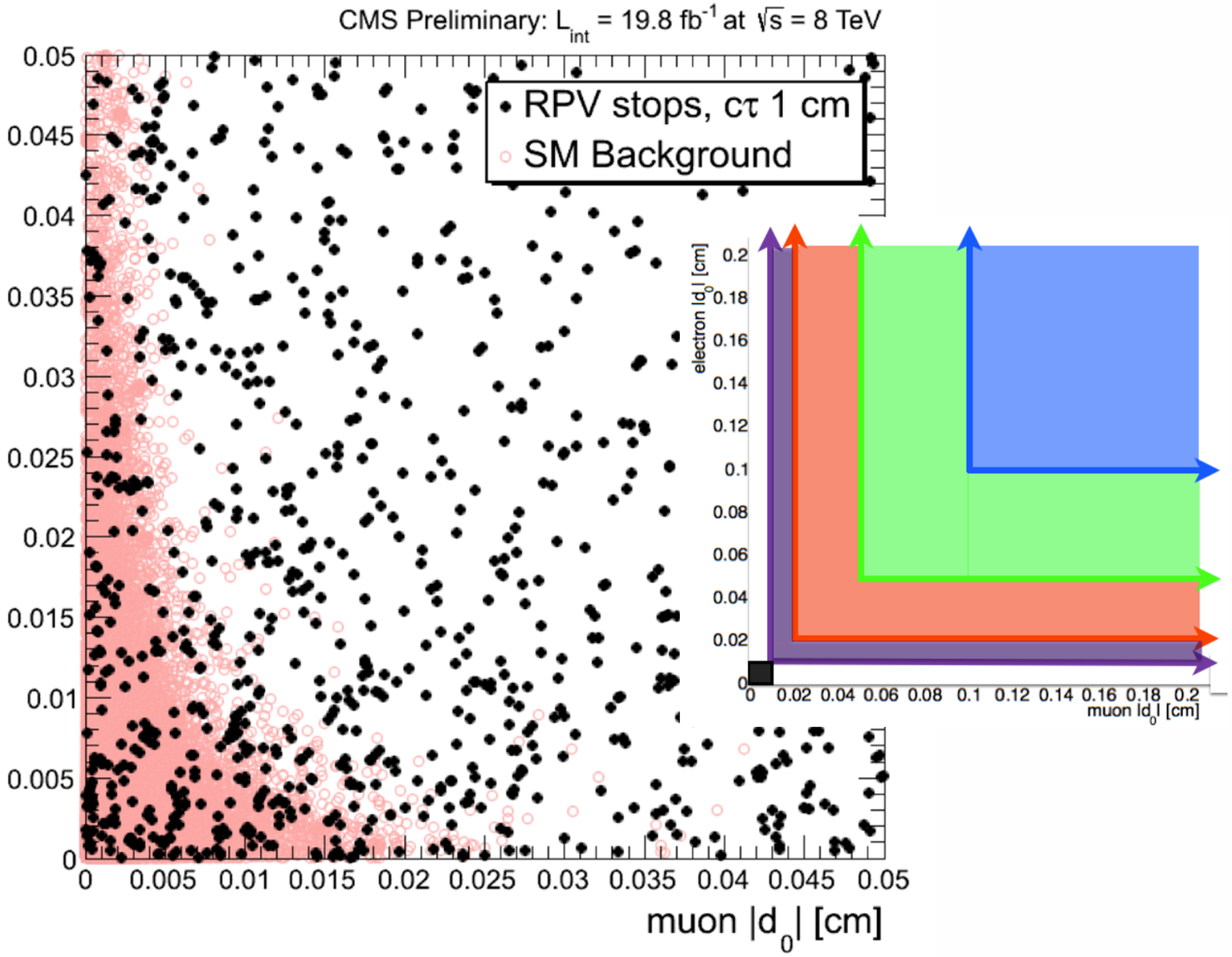


Background sources

1. Leptons from heavy flavor QCD decays (referred to as “QCD”)
   - Real displacement due to B,D meson lifetime
   - Typically some hadronic activity expected near lepton
   - Data-driven prediction from sidebands

2. $Z \rightarrow \tau\tau \rightarrow e\mu$
   - Real displaced leptons due to τ lifetime
   - Taken from MC prediction after validating in control regions
3. Prompt SM backgrounds
   - $W \rightarrow l\nu$+jets, $Z \rightarrow ee/\mu\mu$, ttbar, single top, diboson
   - <10% of background, taken from (validated) MC prediction

Region definitions



Prompt control region

$|d_0| < 100$ μm

Displaced control region

$|d_0| > 100$ μm

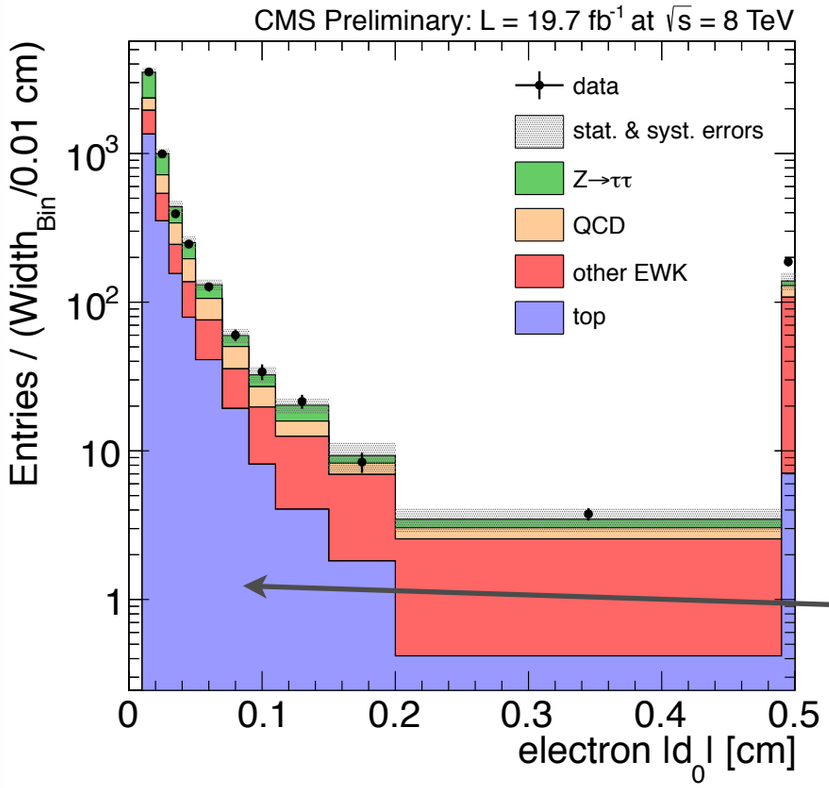
Signal regions

200 μm < $|d_0|$ < 500 μm

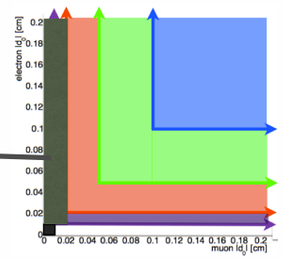
500 μm < $|d_0|$ < 1 mm

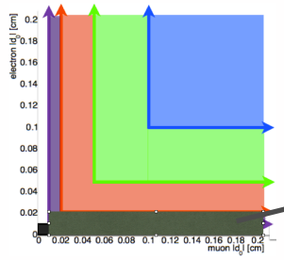
1 mm < $|d_0|$ < 2 cm

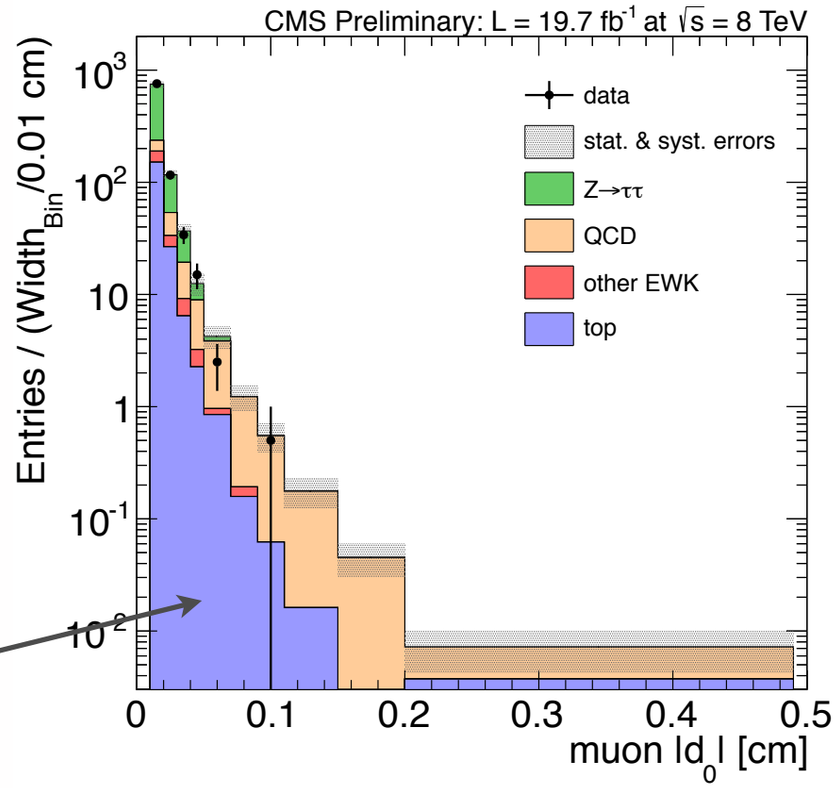
Background-data comparison

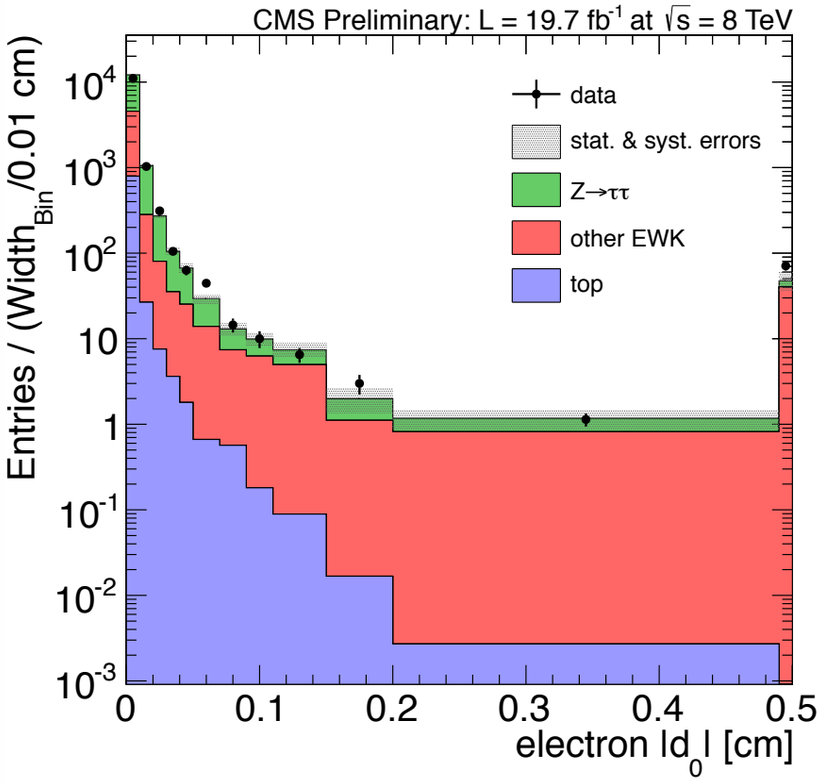


$|d_0|$ distribution of a lepton when the other lepton has $|d_0| < 0.02$ cm

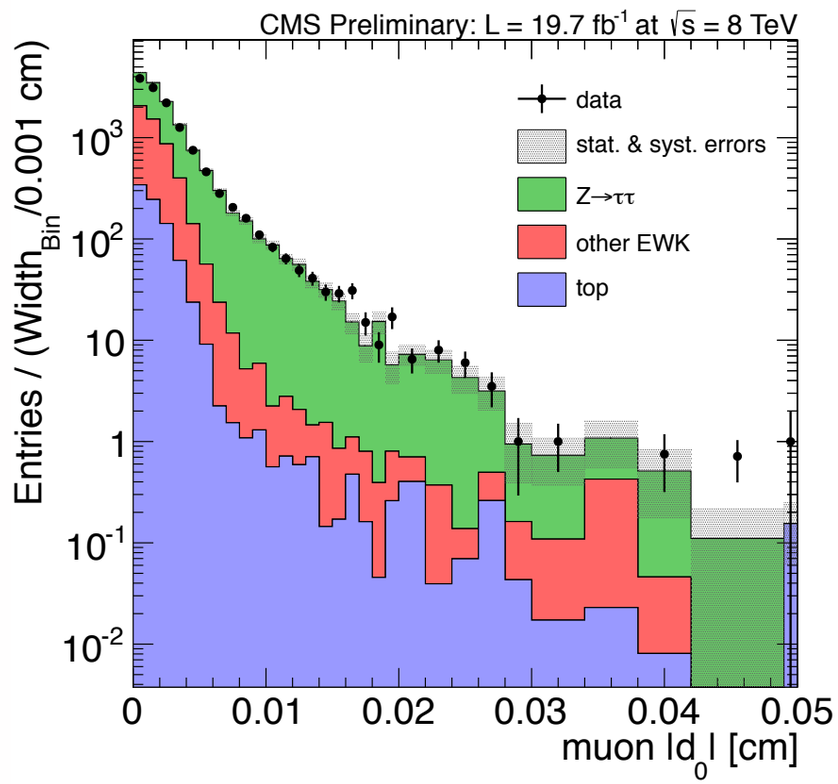




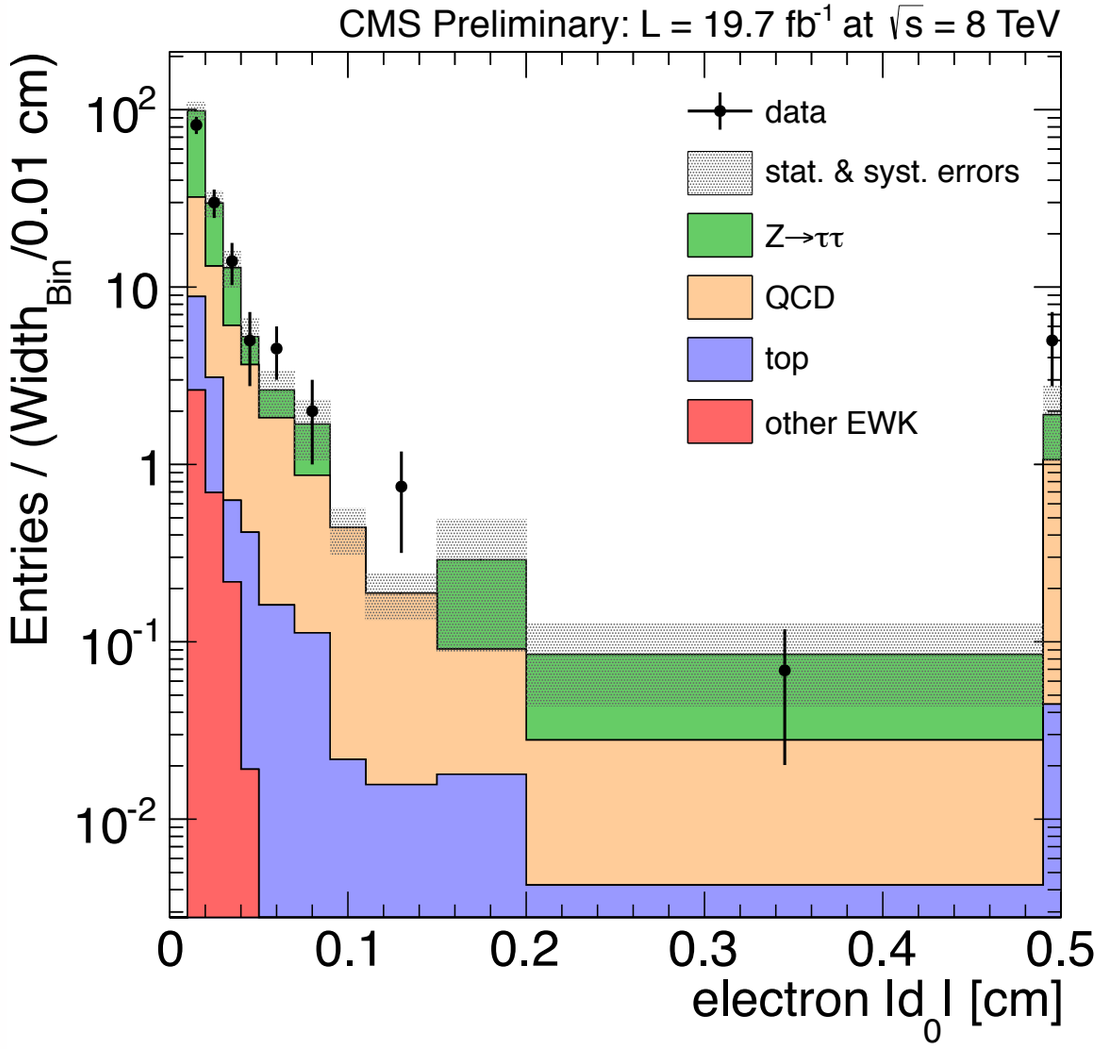


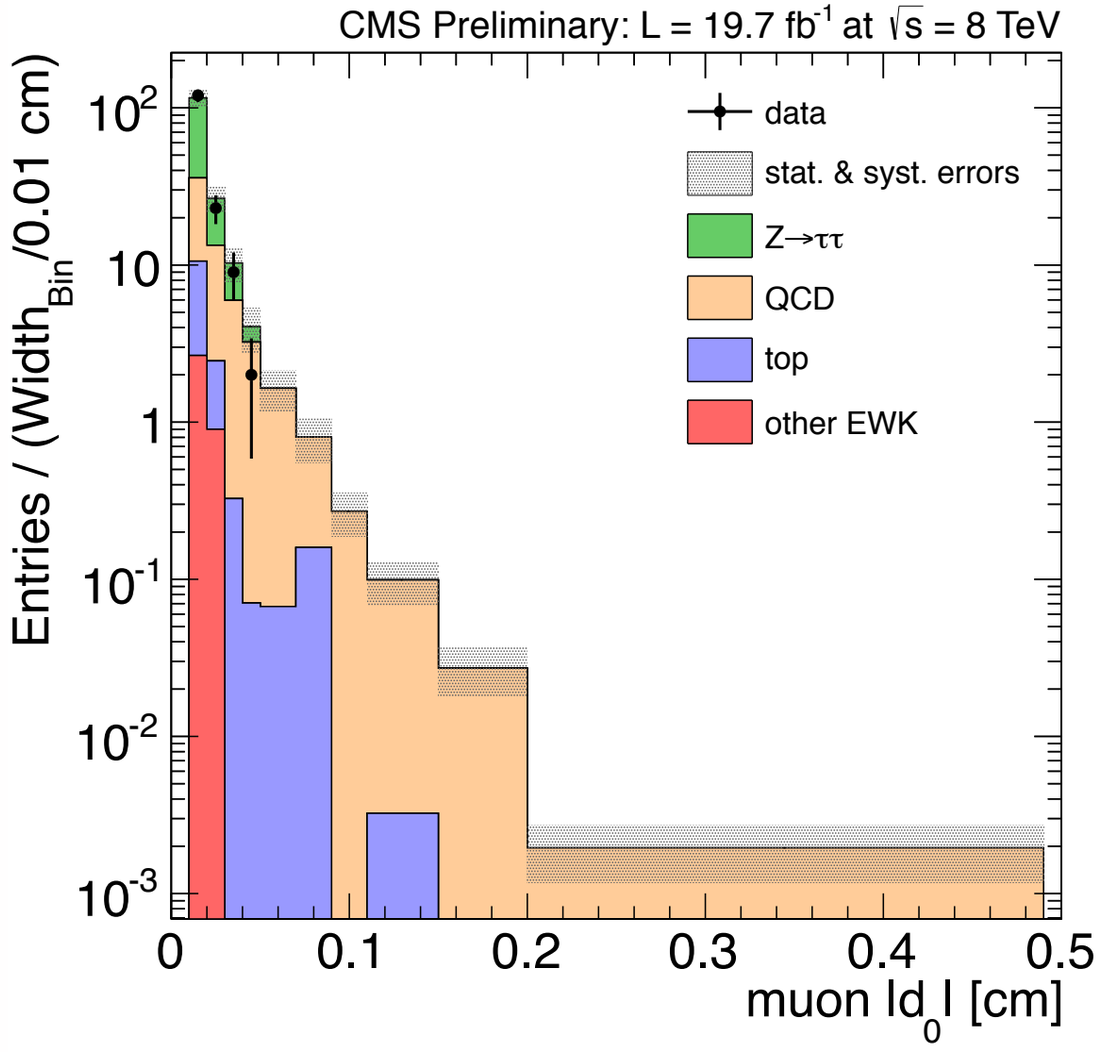


$|d_0|$ distribution in a control region enriched in $Z \rightarrow \tau\tau$



Background-data comparison in signal region projected to electron or muon $|d_0|$





Note that in the analysis the cut on $|d_0|$ is applied on the electron and the muon simultaneously

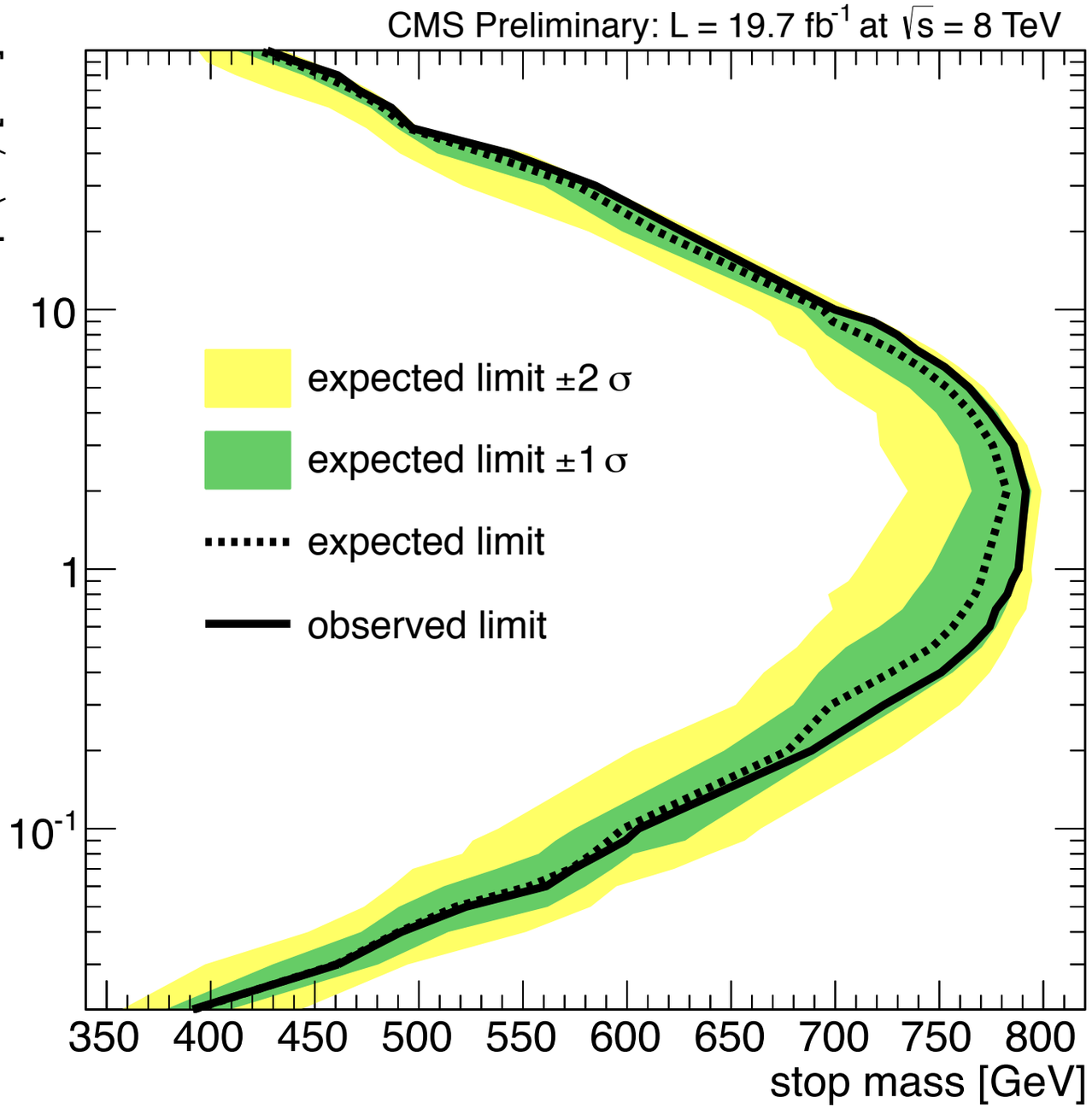
Results

Yields in search regions

Event Source	$0.02\text{ cm} < \lvert d_0\rvert < 0.05\text{ cm}$	$0.05\text{ cm} < \lvert d_0\rvert < 0.1\text{ cm}$	$\lvert d_0\rvert > 0.1\text{ cm}$
other EWK	$0.65 \pm 0.13 \pm 0.08$	$(0.89 \pm 0.53 \pm 0.11) \times 10^{-2}$	$<(89 \pm 53 \pm 11) \times 10^{-4}$
top	$0.767 \pm 0.038 \pm 0.061$	$(1.25 \pm 0.26 \pm 0.10) \times 10^{-2}$	$(2.4 \pm 1.3 \pm 0.2) \times 10^{-4}$
$Z \to \tau\tau$	$3.93 \pm 0.42 \pm 0.32$	$(0.73 \pm 0.73 \pm 0.06) \times 10^{-2}$	$<(73 \pm 73 \pm 6) \times 10^{-4}$
QCD	$12.7 \pm 0.2 \pm 3.8$	$(98 \pm 6 \pm 30) \times 10^{-2}$	$(340 \pm 110 \pm 100) \times 10^{-4}$
Total expected background	$18.0 \pm 0.5 \pm 3.8$	$1.01 \pm 0.06 \pm 0.30$	$0.051 \pm 0.015 \pm 0.010$
Observation	19	0	0
$pp \to \tilde{t}_1 \tilde{t}_1^*$			
$M = 500$ GeV, $\langle c\tau \rangle = 1$ mm	$30.1 \pm 0.7 \pm 1.1$	$6.54 \pm 0.34 \pm 0.24$	$1.34 \pm 0.15 \pm 0.05$
$M = 500$ GeV, $\langle c\tau \rangle = 1$ cm	$35.3 \pm 0.8 \pm 1.3$	$30.3 \pm 0.7 \pm 1.1$	$51.3 \pm 1.0 \pm 1.9$
$M = 500$ GeV, $\langle c\tau \rangle = 10$ cm	$4.73 \pm 0.30 \pm 0.17$	$5.57 \pm 0.32 \pm 0.20$	$26.27 \pm 0.70 \pm 0.93$

No excess is observed.
We set limits on this model.

Exclusion curve



sensitivity limited by:

short lifetime:
prompt backgrounds

long lifetime:
signal acceptance

Total expected background	$18.0 \pm 0.5 \pm 3.8$	$1.01 \pm 0.06 \pm 0.30$	$0.051 \pm 0.015 \pm 0.010$
Observation	19	0	0

Summary

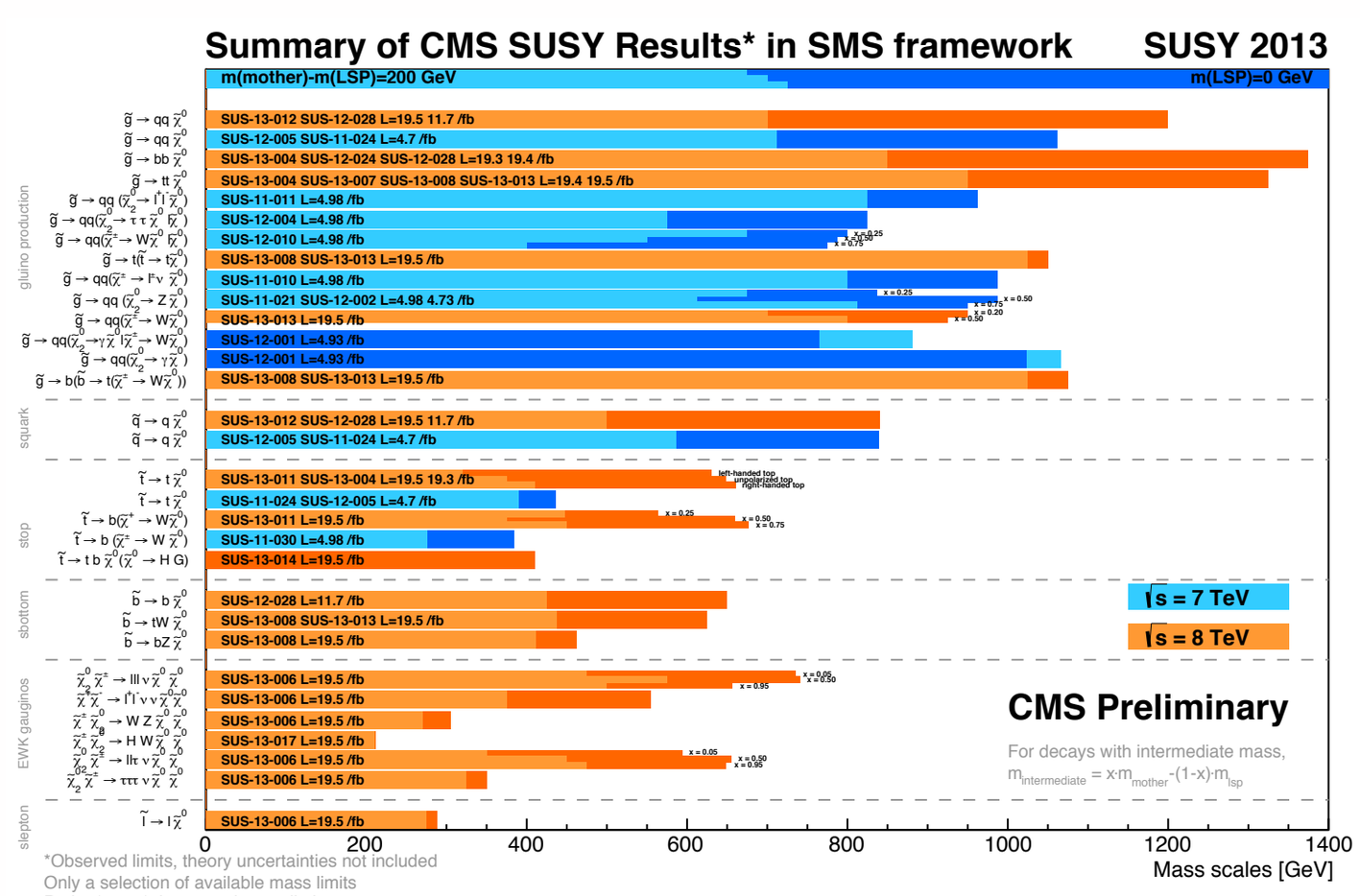
- We have conducted a search for long-lived BSM particles decaying to e-mu final states
- This search covers a region of parameter space that no previous searches are optimized for
- In the absence of any excess, we have set limits on the *Displaced Supersymmetry* model arXiv:1204.6038v1
- For a lifetime hypothesis of 2 cm/c, we exclude stops with a mass up to 790 GeV/c^2 at 95% C.L.
- For more details see CMS-PAS-B2G-12-024

Backup Slides

Motivation for Long-lived Searches

- Lots of exciting results in Run 1, but…
  - No physics beyond the standard model observed
- CMS has generally been looking for prompt signatures
- There are many well-motivated scenarios with long-lived particles

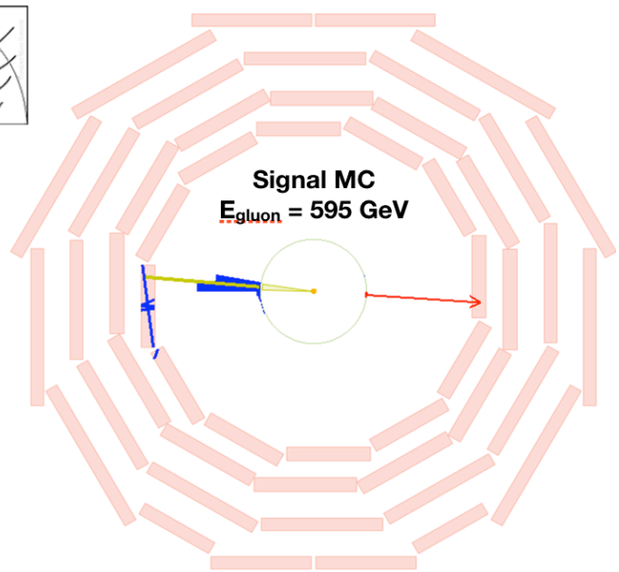
vast majority of previous limits apply to prompt decays



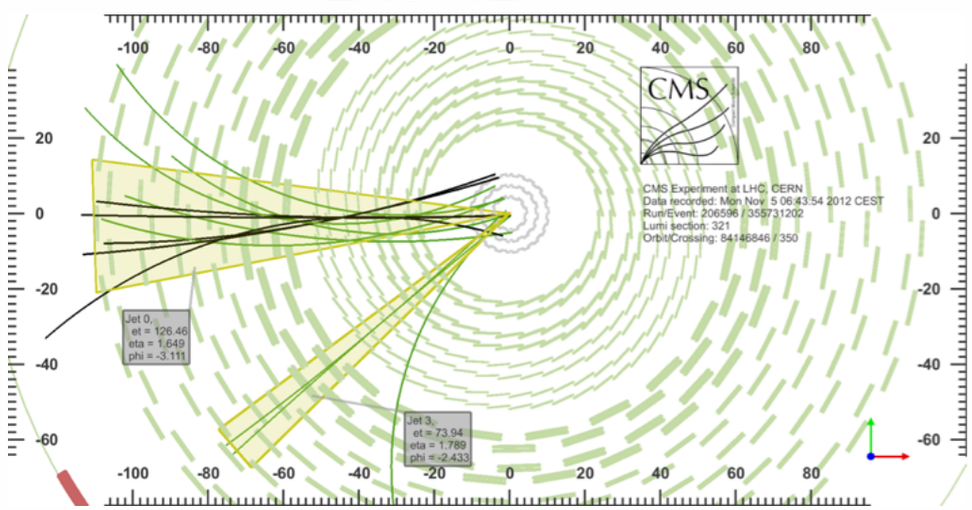
Motivation for *this* Search

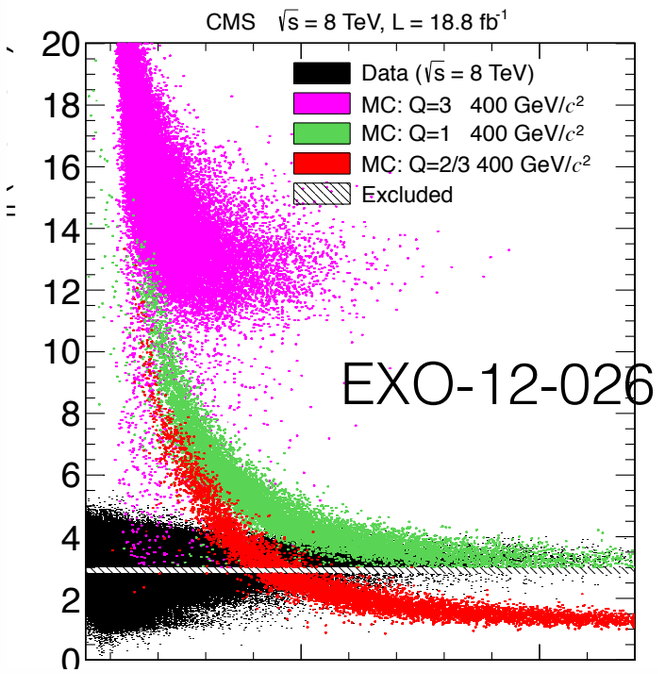
CMS has searches for non-prompt signatures, but they focus on longer lifetimes

EXO-12-036



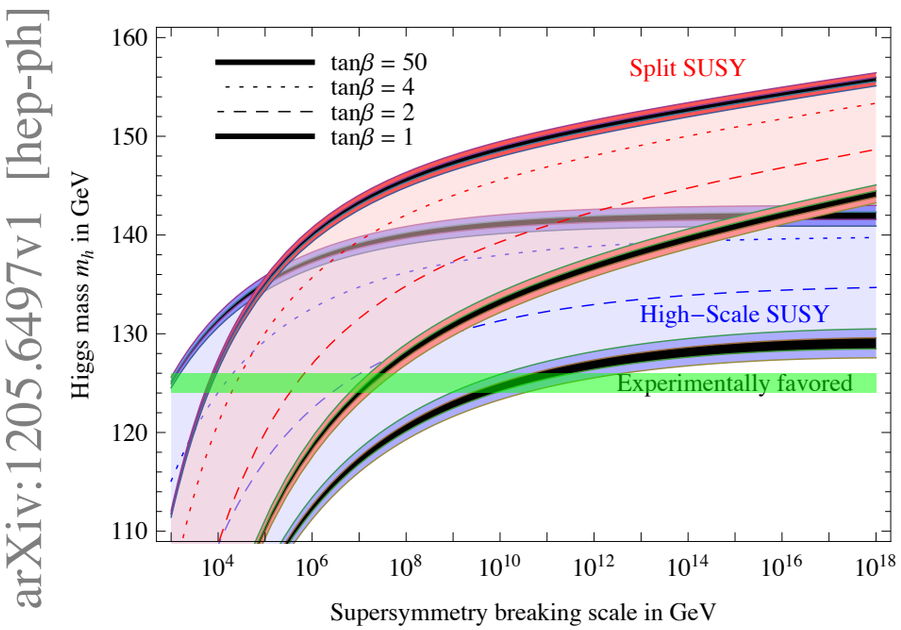
EXO-12-038





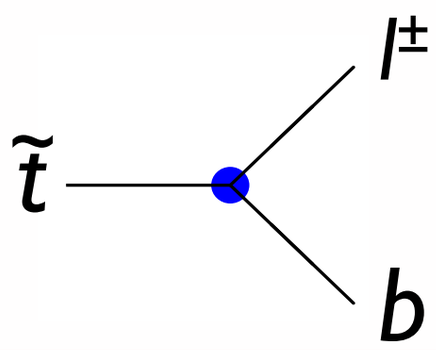
- A Higgs at 126 GeV favors shorter lifetimes for BSM ($\langle c\tau \rangle$ ~100 μm - 1 cm)
- This search targets this range. It is designed to explore the gap between prompt and very long-lived signatures

Predicted range for the Higgs mass



Benchmark Model

- The "*Displaced Supersymmetry*" model
  - arXiv:1204.6038v1 (P. Graham, D. Kaplan, S. Rajendran, P. Saraswat)
  - Small RPV couplings generate long-lived LSP
  - One of many such models
- As benchmark, we consider a stop LSP, decaying as $\tilde{t} \rightarrow b l^{\pm}$



$\tilde{t}\tilde{t}^{*} \rightarrow bbl^{+}l^{-}$ $\quad BR(e,\mu,\tau) = 1/3$

- Look for final states containing an electron and a muon

ABCD Methodology

Our goal is to predict the number and d_0 shapes of QCD events in Region B

$$\frac{A}{C}=\frac{B}{D} \Longrightarrow B=\frac{A}{C}\times D$$

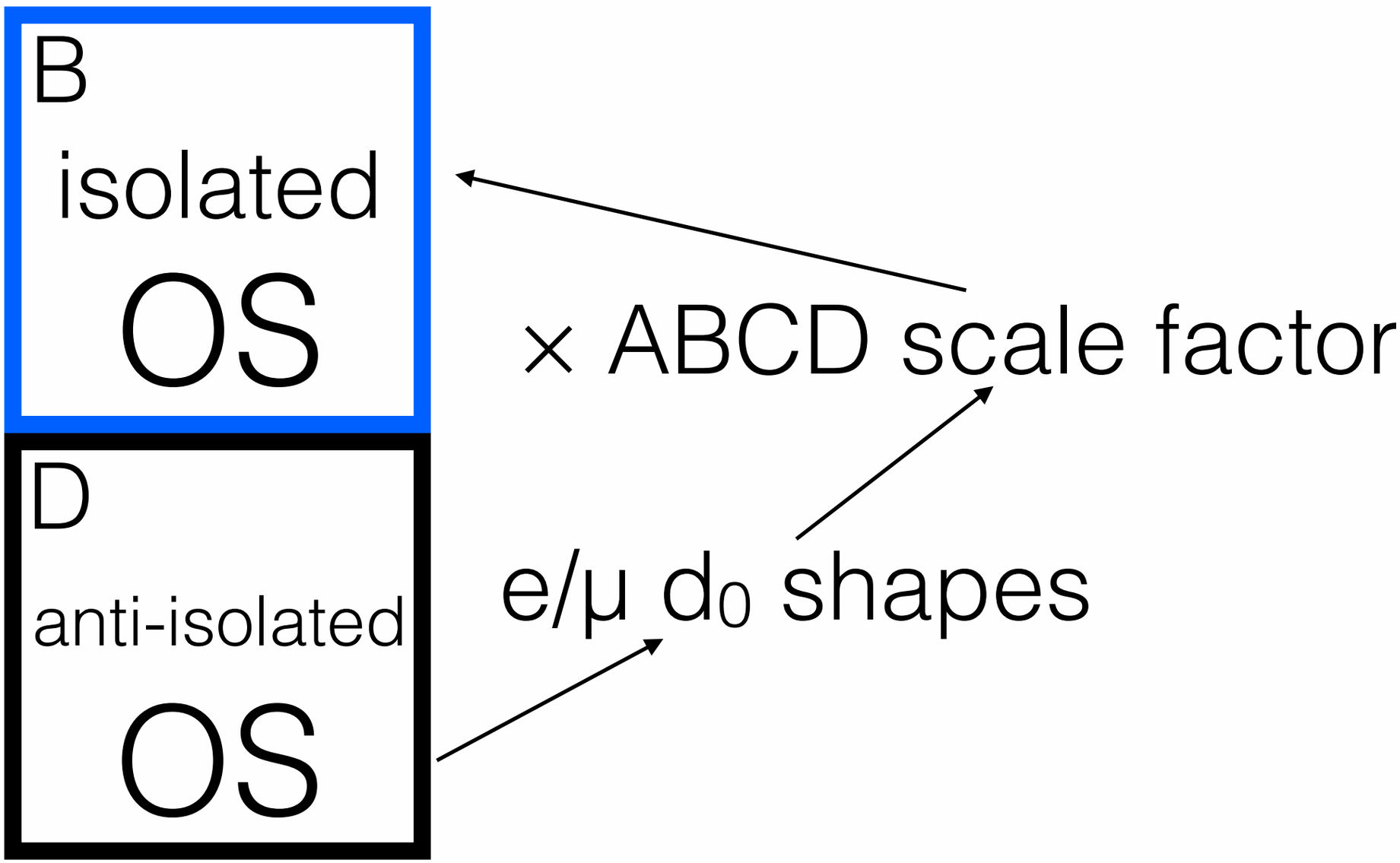
A isolated SS	B isolated OS
C anti-isolated SS	D anti-isolated OS

1. By measuring the QCD events in A,C, and D, we can predict the number of QCD events in B

2. Then we can scale the events in region D to this number to obtain the d_0 shapes

QCD Impact Parameter Shapes

Take lepton d_0 shapes from data in region D, normalize using yield from ABCD method

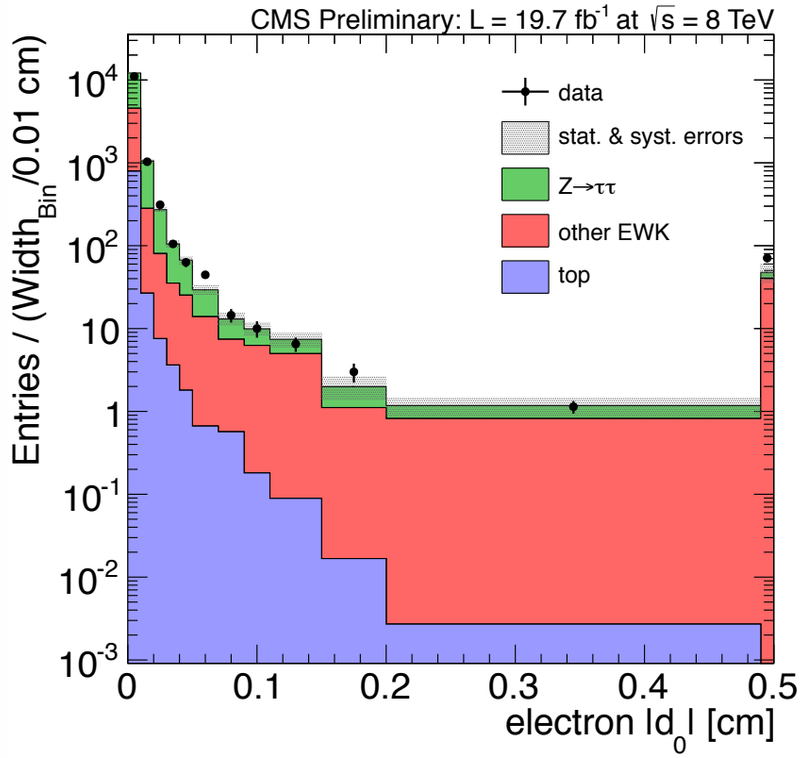


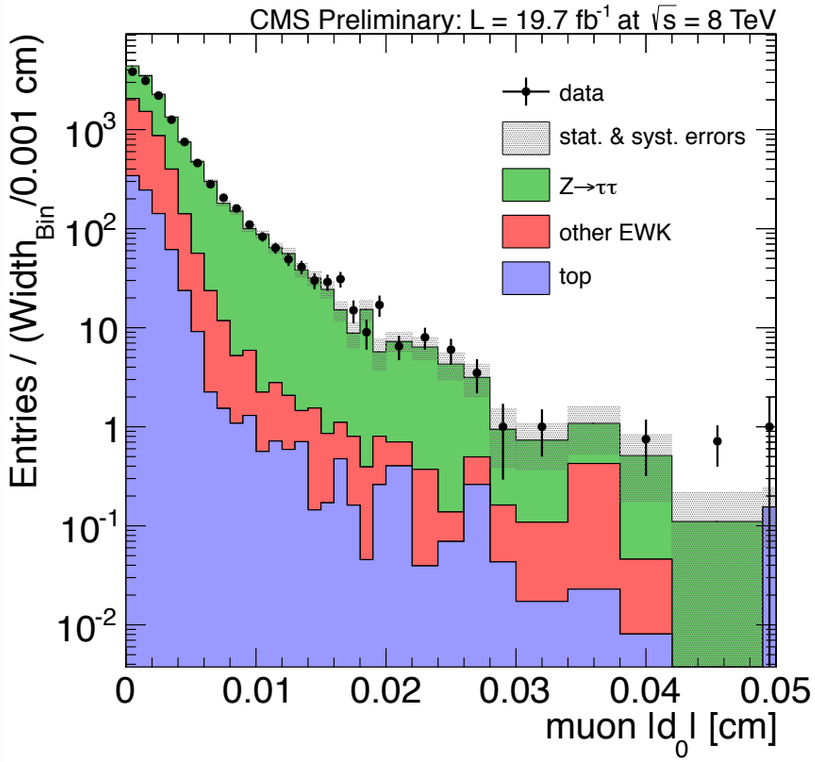
MC Validation: Region I

$Z \rightarrow \tau\tau$ *control region:*

analysis preselection
+
exactly one electron with $M_T < 50\,\text{GeV}$
exactly one muon with $M_T < 50\,\text{GeV}$
exactly one electron-muon pair with $\Delta\phi > 2.5$
$\sum p_{\text{T}\,jet} < 100\,\text{GeV}$

- Negligible QCD contribution
- Limited statistics restrict $|d_0|$ range
- Shows good data/MC agreement at high d_0





Summary of Systematic Uncertainties on background and signal yield

Dataset	Cross-section	Pileup	e ID/ISO	μ ID/ISO	PDF	Total
W$\to$lν	$\pm$3.5%	$\pm$0.07%	$\pm$0.42%	$\pm$0.61%	$\pm$0.66%	$\pm$11.0%
diboson	$\pm$6.2%	$\pm$0.28%	$\pm$0.35%	$\pm$0.63%	$\pm$0.59%	$\pm$9.0%
single top	$\pm$6.9%	$\pm$0.17%	$\pm$0.29%	$\pm$0.64%	$\pm$2.15%	$\pm$9.4%
$t\bar{t}$	$\pm$4.3%	$\pm$0.19%	$\pm$0.49%	$\pm$0.56%	$\pm$0.11%	$\pm$8.0%
Z$\to$ll	$\pm$4.6%	$\pm$0.21%	$\pm$0.29%	$\pm$0.64%	$\pm$1.66%	$\pm$8.1%
QCD	—	—	—	—	—	$\pm$30%
signal	$\pm$15-28%	$\pm$0.1-5.4%	$\pm$0.13-0.29%	$\pm$0.9-3.8%	$\pm$0.06-4.6%	$\pm$15-28%

Additional systematics on MC included in the “Total” column:

Luminosity: 2.6%
Trigger Efficiency: 2.0%
Displaced Track Reconstruction Efficiency: 5.7%
Matching and Scale Uncertainty (ttbar and W)