Search for long-lived particles in events with leptons with large impact parameters at CMS

Q. Python
on behalf of the CMS collaboration

references: [Phys. Rev. Lett. 114 (2015) 061801]
[Phys. Rev. D 91 (2014) 052012]

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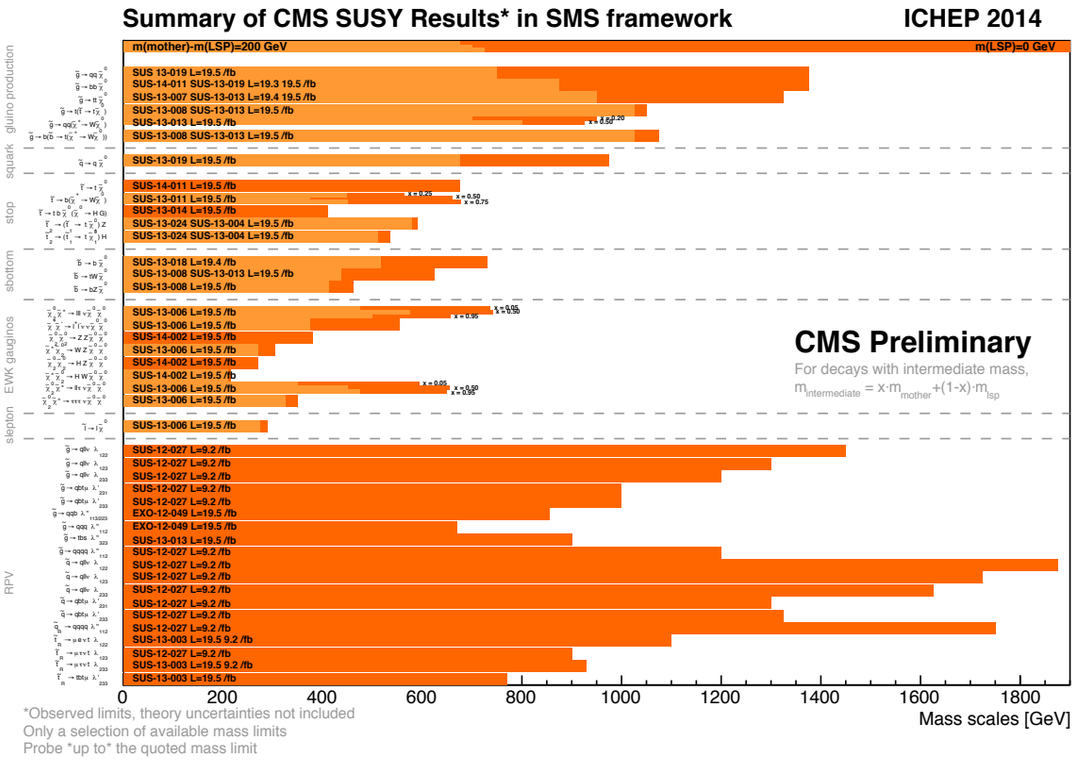
Outline

- Context and Motivation
- E-mu Search (no vertex constraint)
- Dilepton same vertex Search (same flavour)
- Recasting
- Run2 analysis
- Summary

Context and Motivation

Beyond the Standard Model (BSM) searches at the LHC

- There is various motivations for SUper SYmmetry (SUSY). 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. Other BSM models predict long-lived particles.

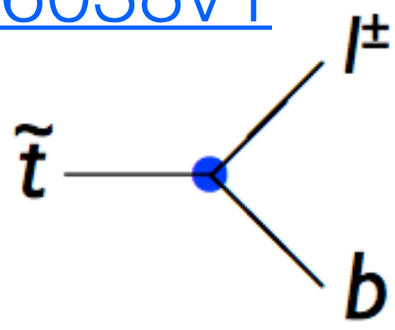


E-mu Search

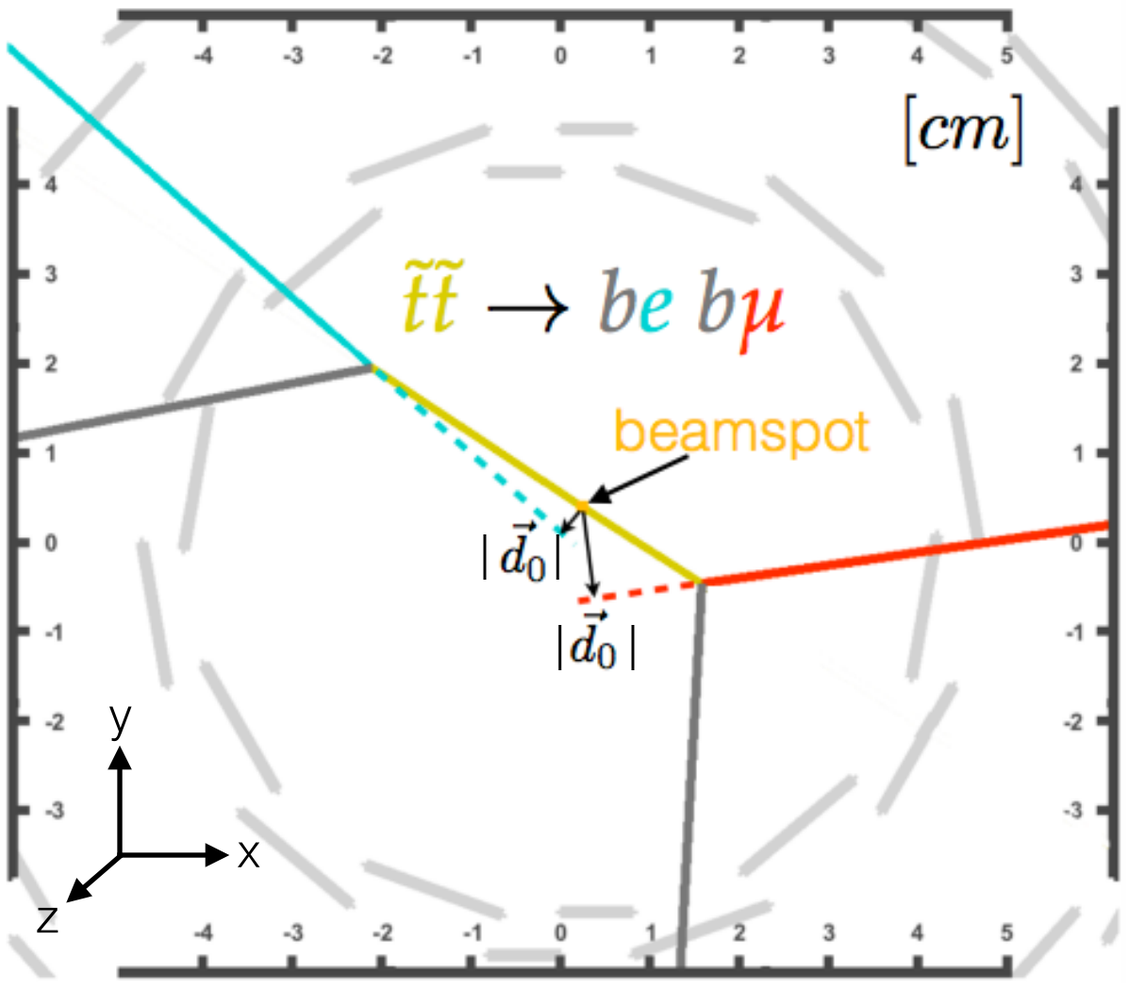
Signal model

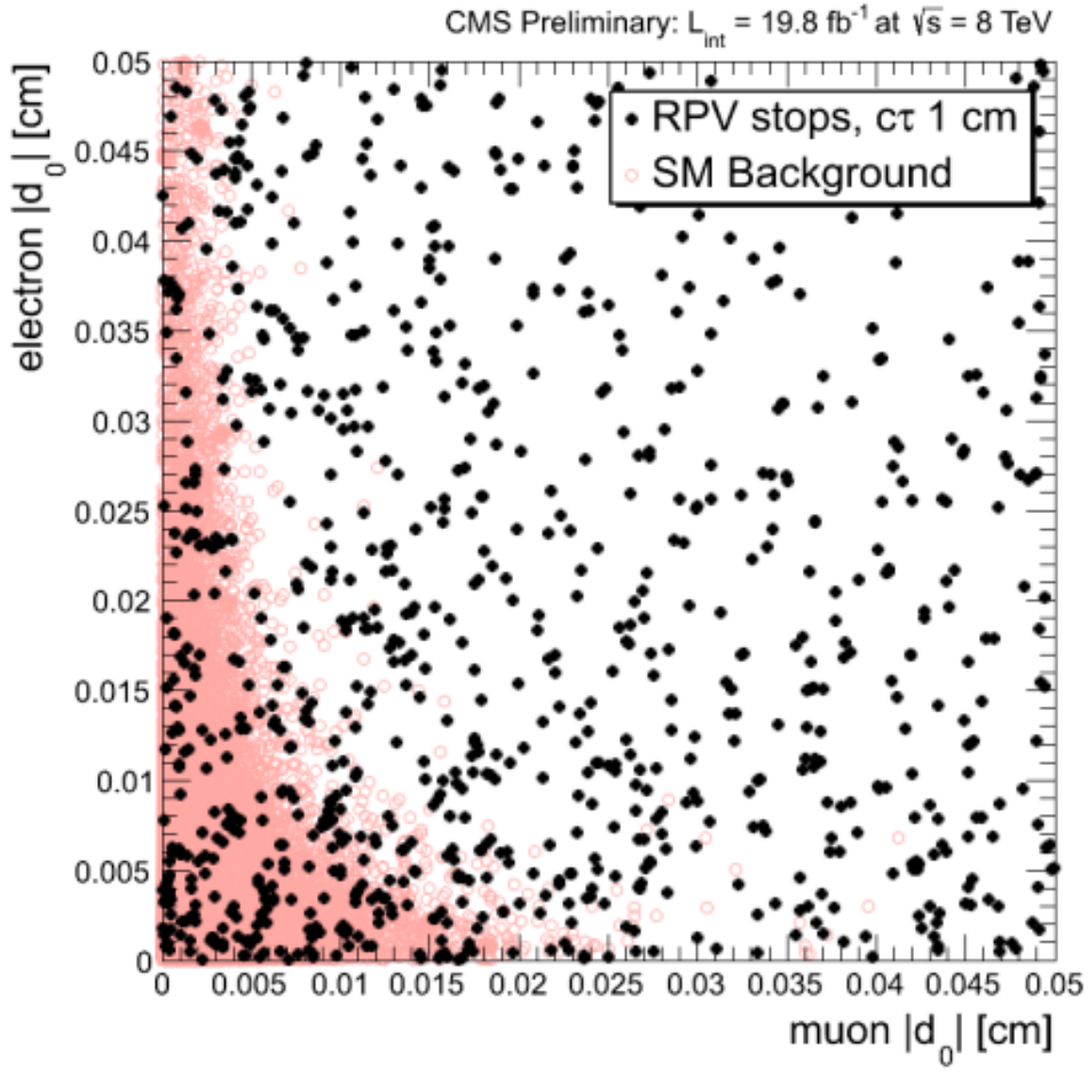
Displaced Supersymmetry as a bench mark model

arXiv:1204.6038v1



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





Event selection

1: Preselection

e-μ pair passing:

$|\eta| < 2.5$

$p_T > 25$ GeV

lepton ID*/ isolation

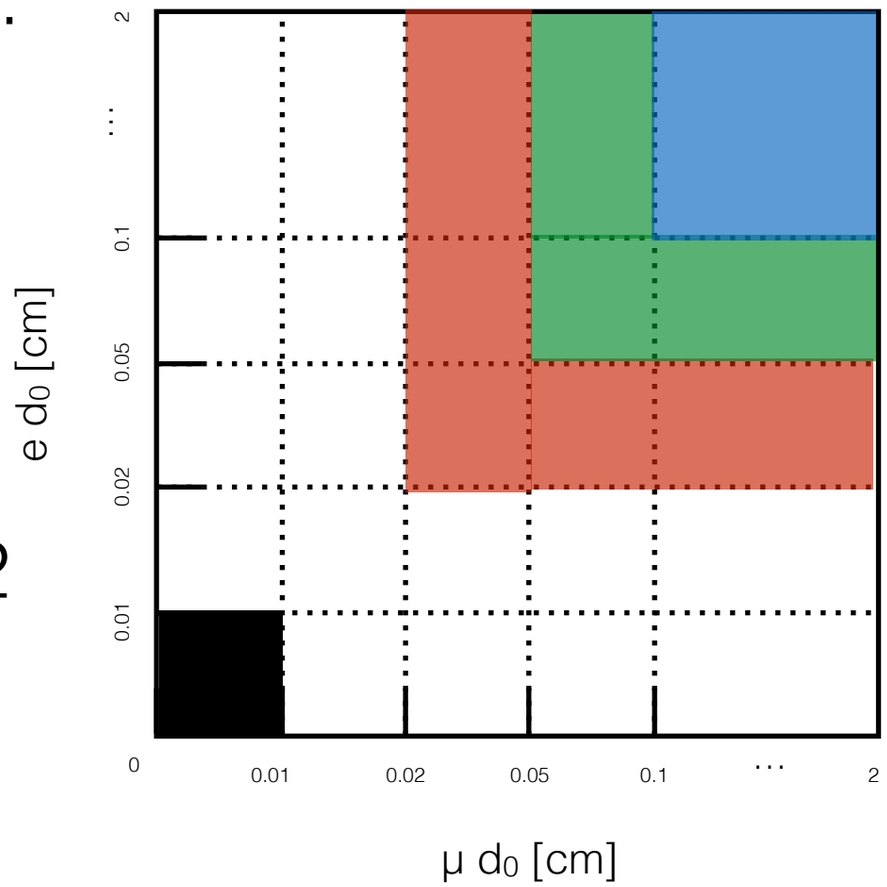
$\Delta R(l,jet) > 0.5$

100 μm < d_0 < 2 cm

$\Delta R(e,\mu) > 0.5$

$q_e * q_\mu = -1$

*modified to be efficient for displaced leptons



2: Region Definition

Prompt control region

$|d_0| < 100$ μm

Signal regions

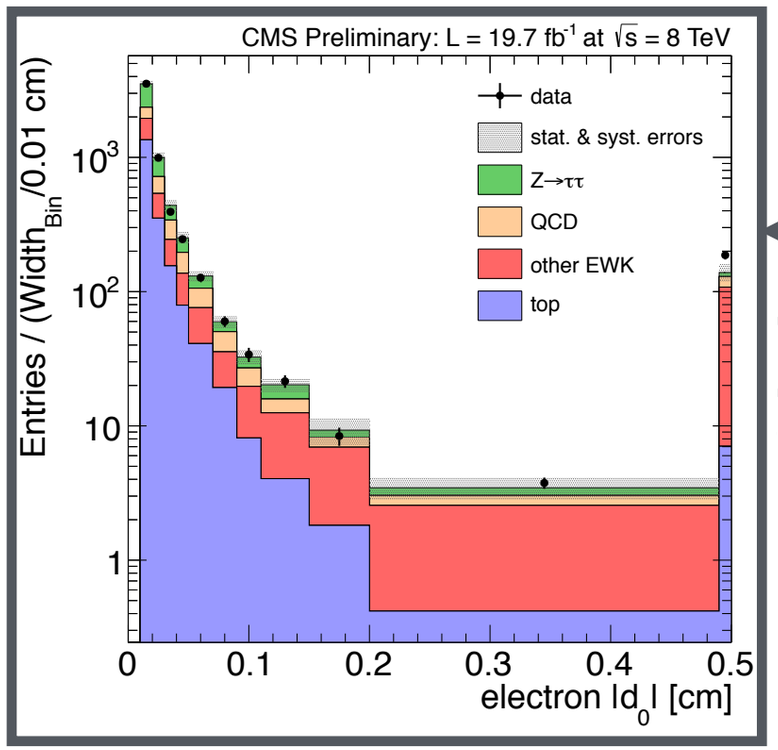
200 μm < $|d_0|$ < 500 μm

500 μm < $|d_0|$ < 1 mm

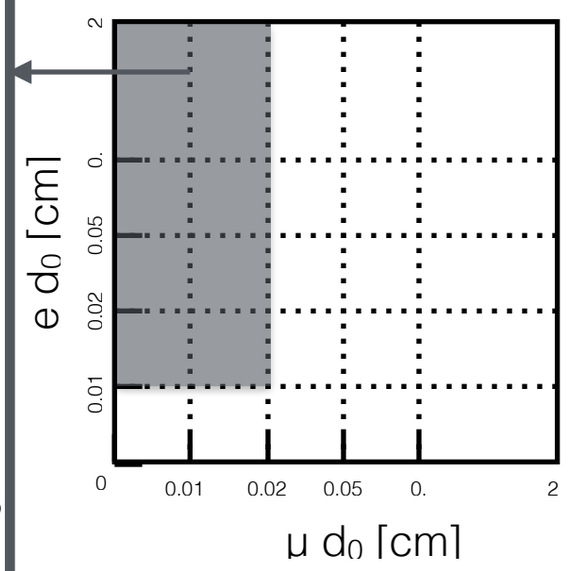
1 mm < $|d_0|$ < 2 cm

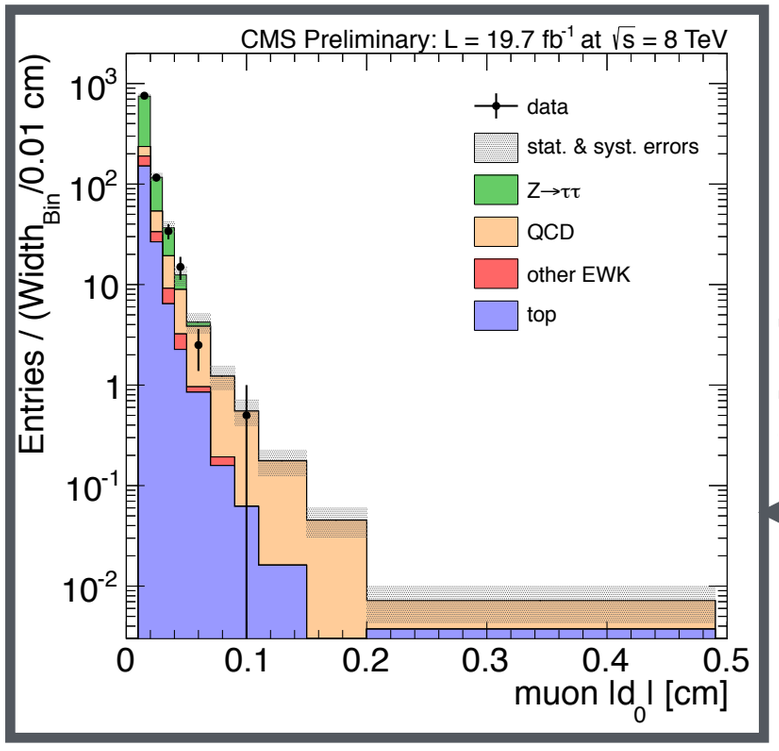
Background sources

1. Leptons from heavy flavour QCD decays (referred to as "QCD")
   - Real displacement due to B,D meson lifetime
   - Data-driven prediction from sidebands
2. Z→ττ→eμ
   - Real displaced leptons due to τ lifetime
   - Taken from MC prediction after validating in control regions
3. Prompt SM backgrounds
   - W→lν+jets, Z→ee/μμ, ttbar, single top, diboson
   - <10% of background, taken from (validated) MC prediction

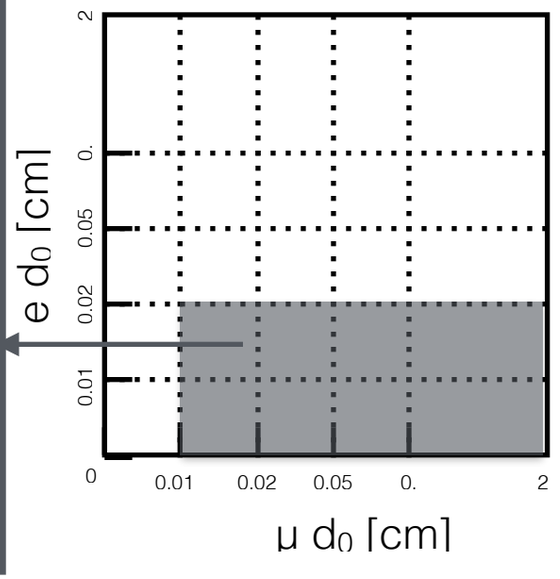


μ d_0 < 0.02 cm



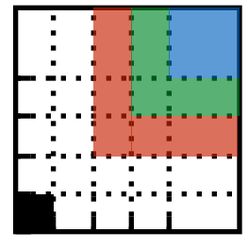


e d_0 < 0.02 cm



Exclusion curve

Event source	SR1	SR2	SR3
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



Number of observed events is consistent with the expected background

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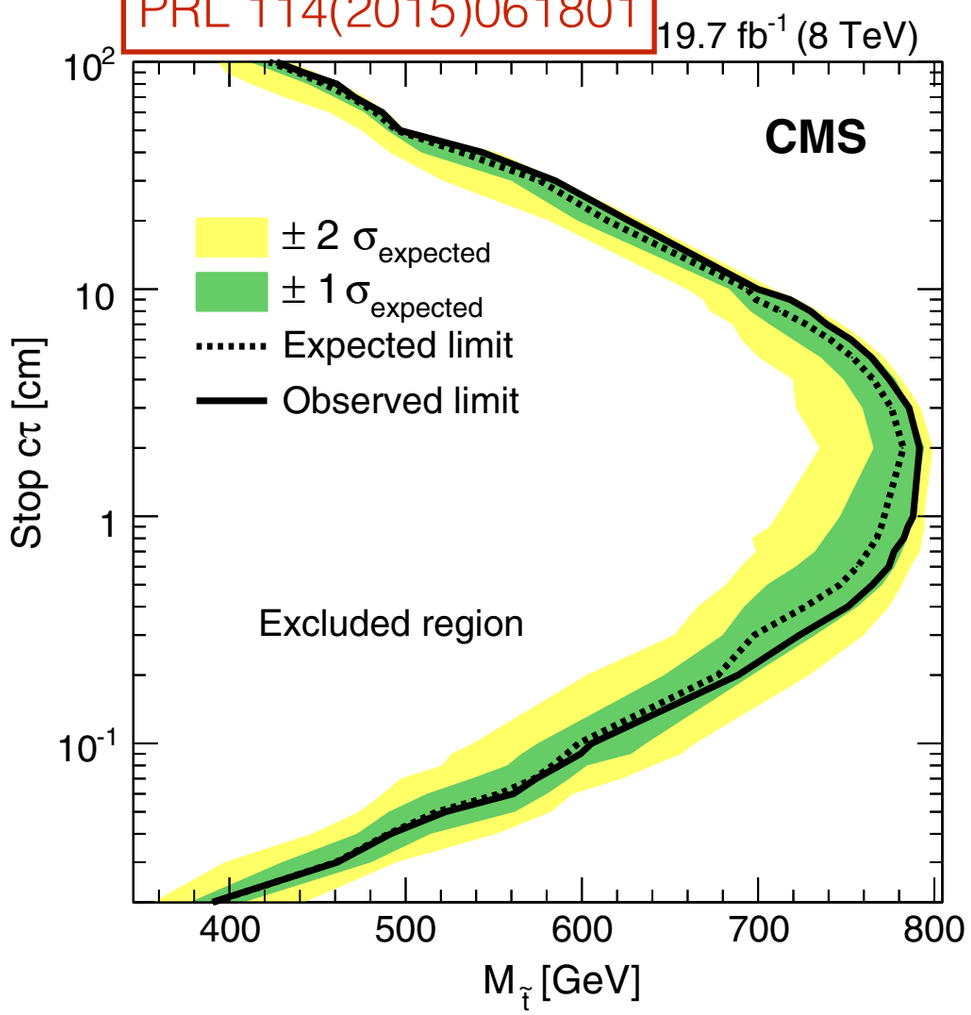


sensitivity limited by:

short lifetime:
prompt backgrounds

long lifetime:
signal acceptance

Dilepton same vertex

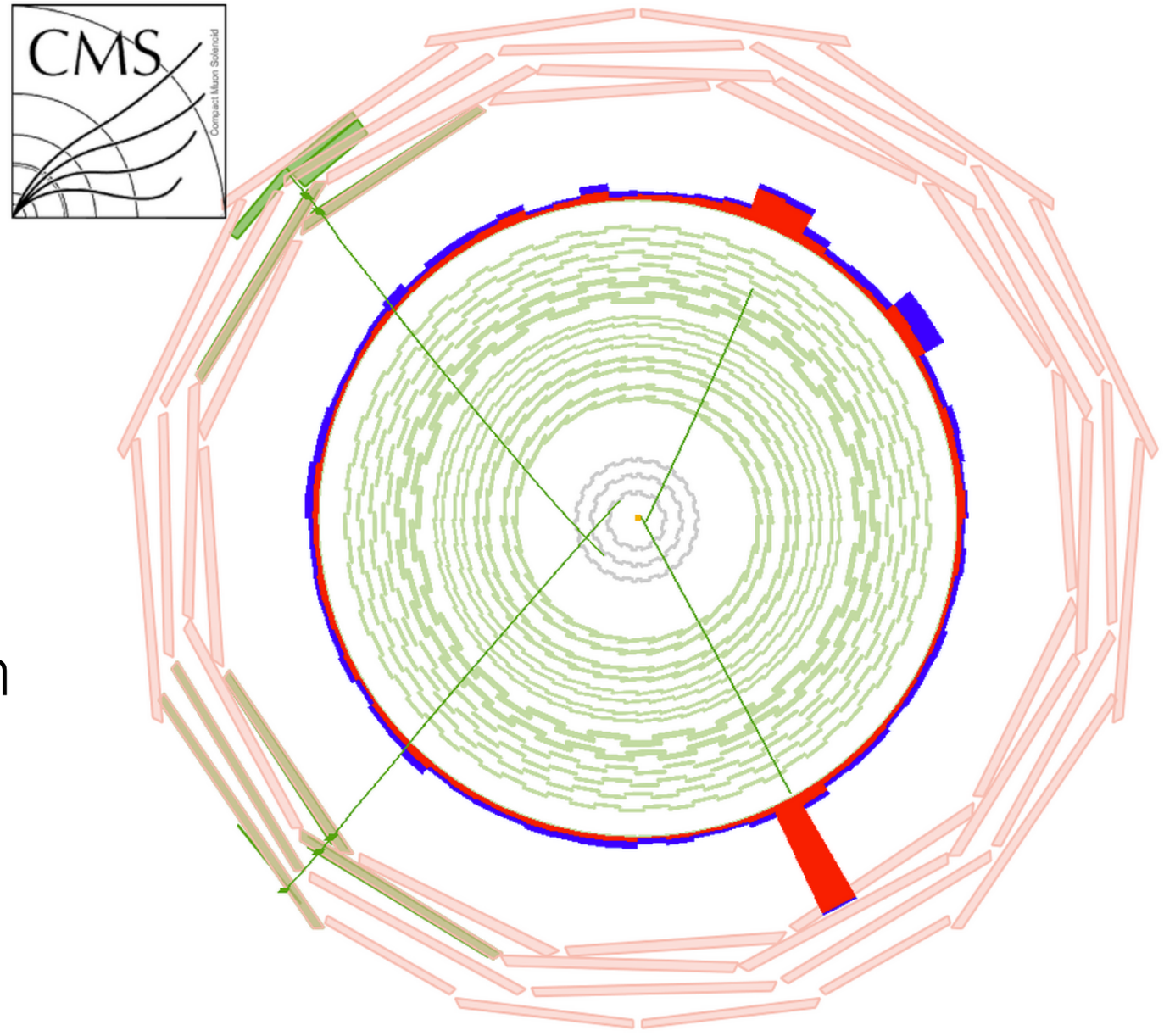
Search

Signal model

R-parity violating supersymmetry

arXiv:hep-ph/0406039

$\tilde{q} \rightarrow q\tilde{\chi}^0, \quad \tilde{\chi}^0 \rightarrow l^+l^- \nu$



Discovering the Higgs through highly-displaced vertices

arXiv:hep-ph/0605193

$H \rightarrow XX, X \rightarrow l^+l^-$

Event selection

1: muons

$|\eta| < 2$

$p_T > 26$ GeV

isolation

$q_{\mu 1} * q_{\mu 2} = -1$

same vertex

$m_{ll} > 15$ GeV

$\alpha < 2.48$

1: electrons:

$|\eta| < 2$

$p_T > 36(21)$ GeV

$E_T > 40(25)$ GeV

isolation

no requirement on q_e

same vertex

$m_{ll} > 15$ GeV

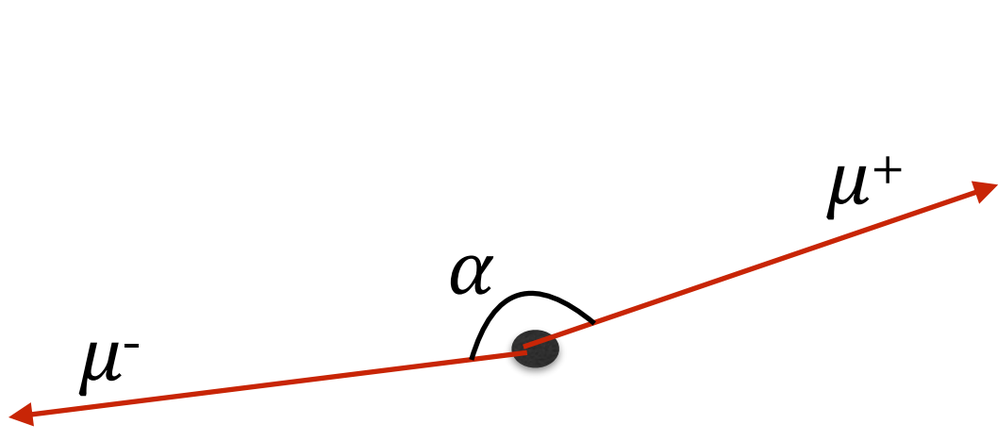
2: Control region

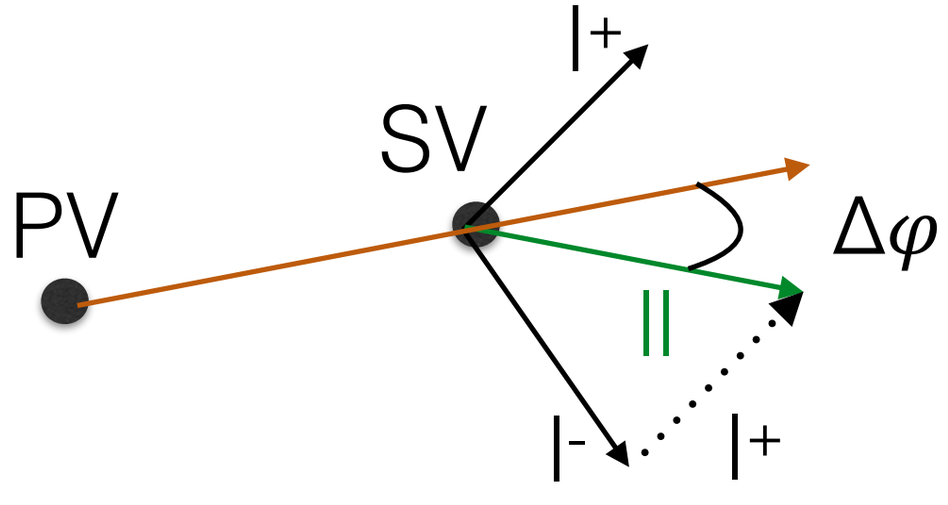
$\Delta\varphi > \pi/2$

3: Signal region

$d_0/\sigma_d > 12$

$\Delta\varphi < \pi/2$

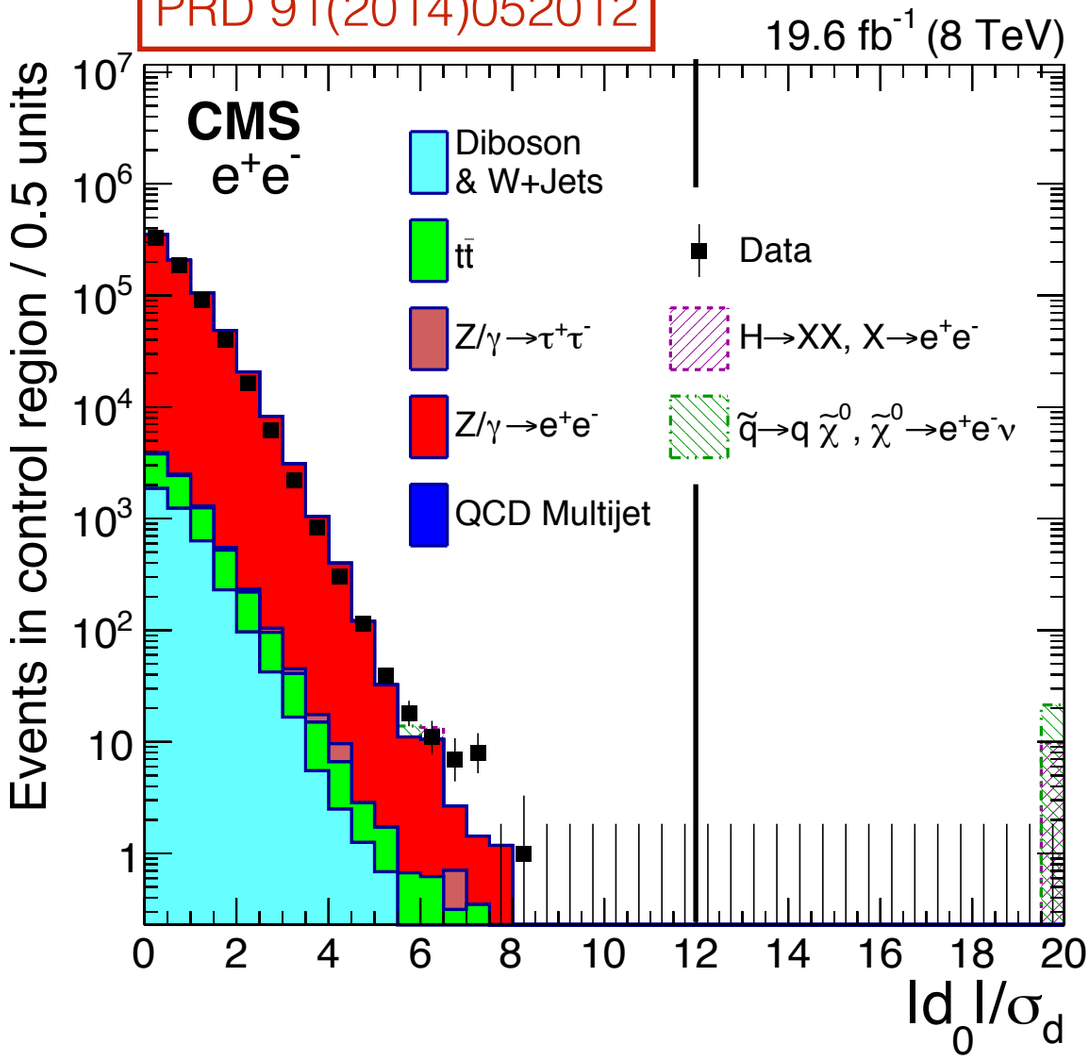




Background distribution

$\Delta\varphi > \pi/2$

PRD 91(2014)052012



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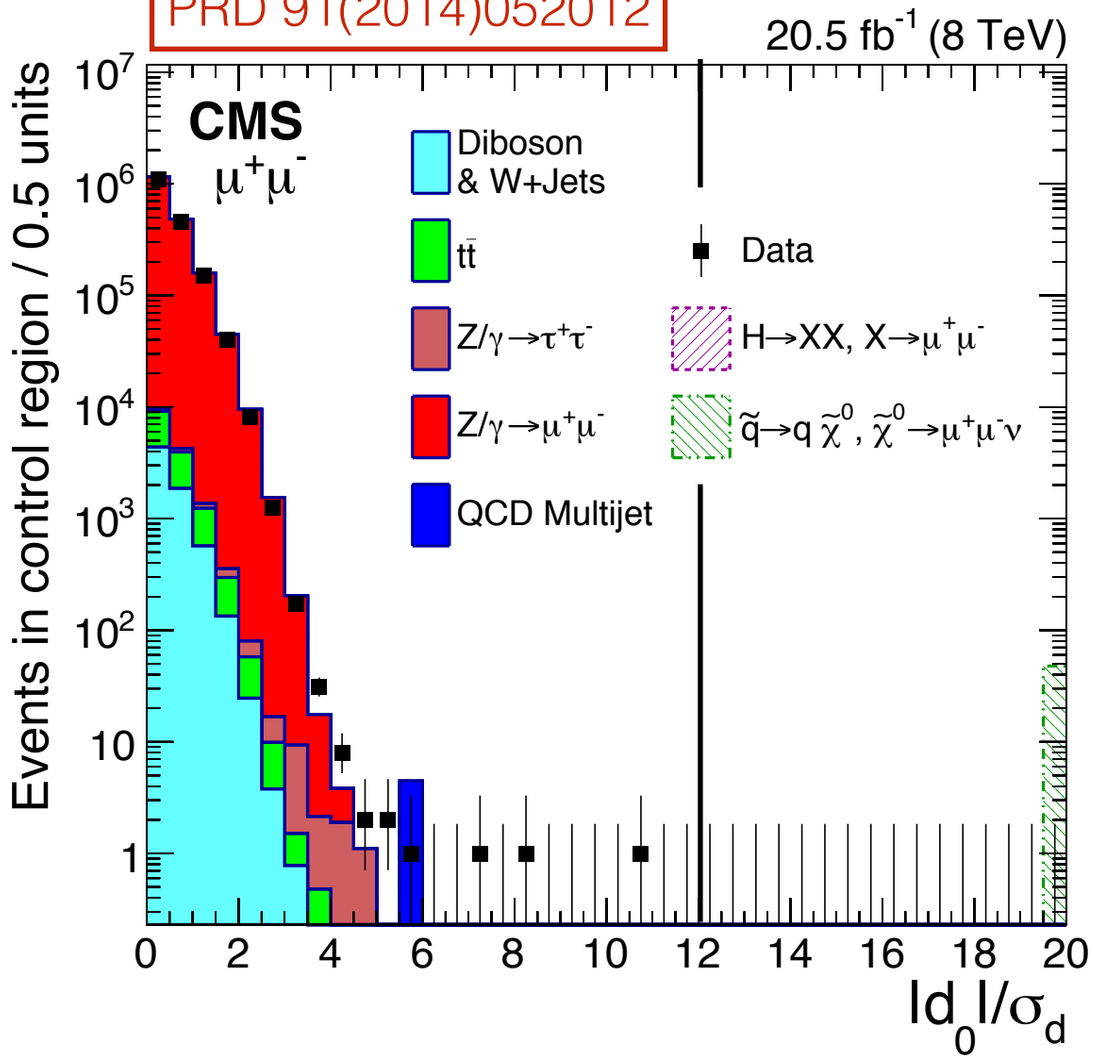
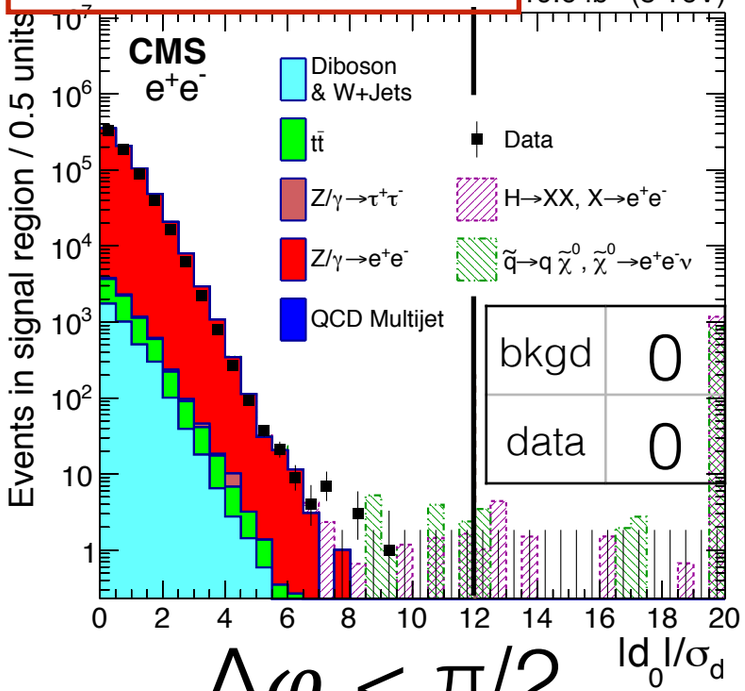


Background largely dominated by Drell Yann

Exclusion curves

PRD 91(2014)052012



$\Delta\varphi < \pi/2$

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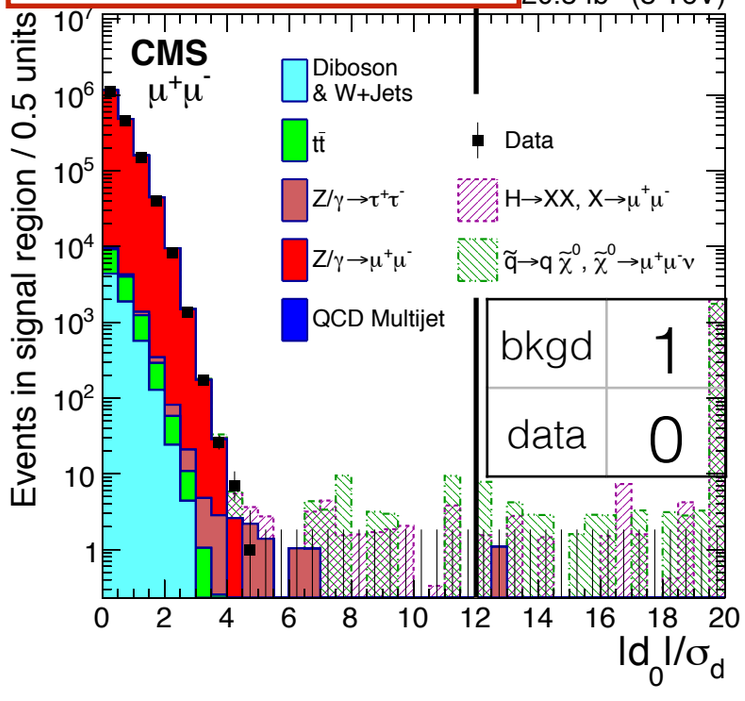

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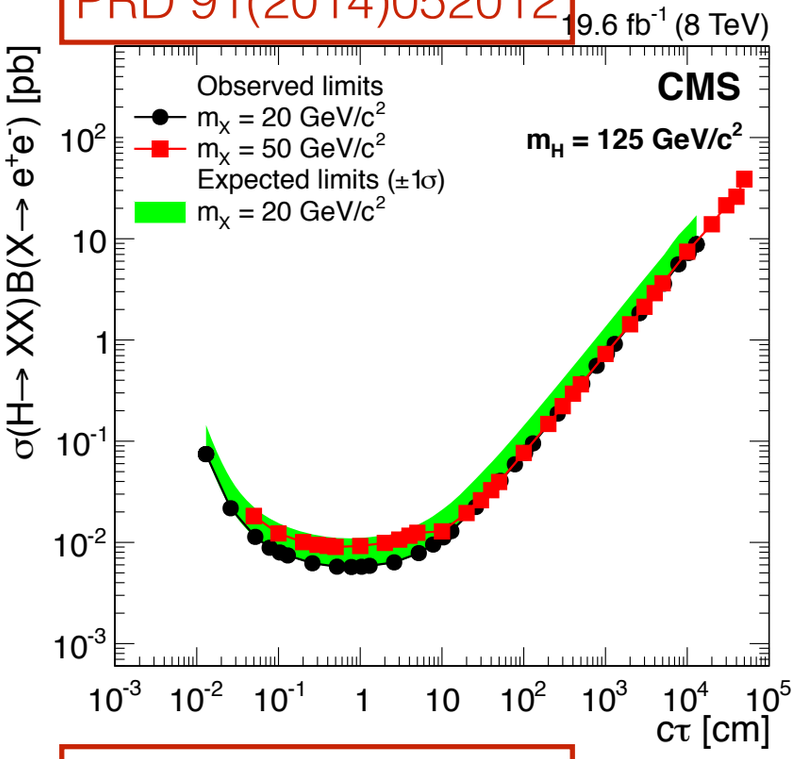

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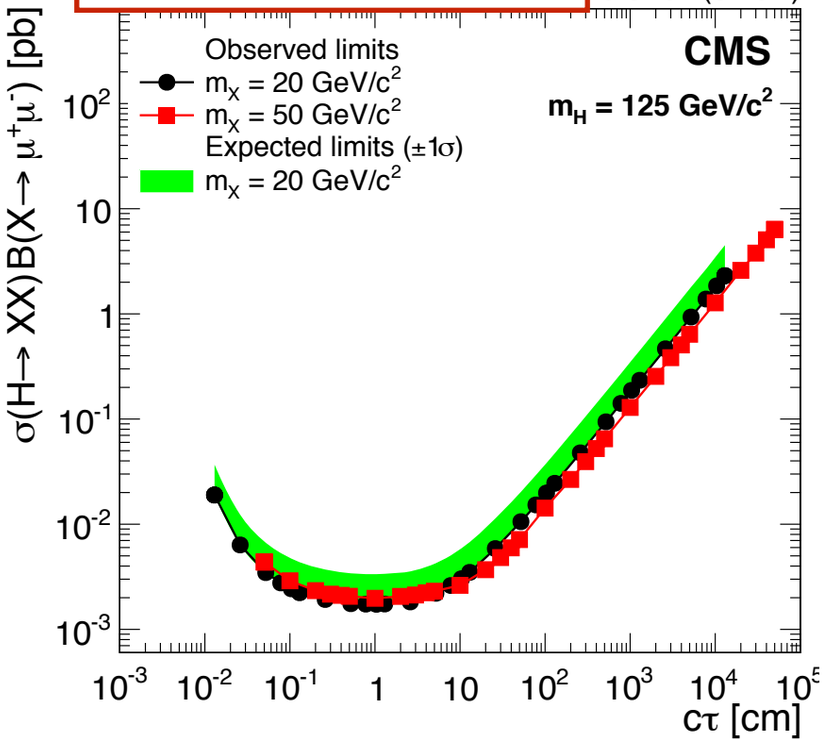

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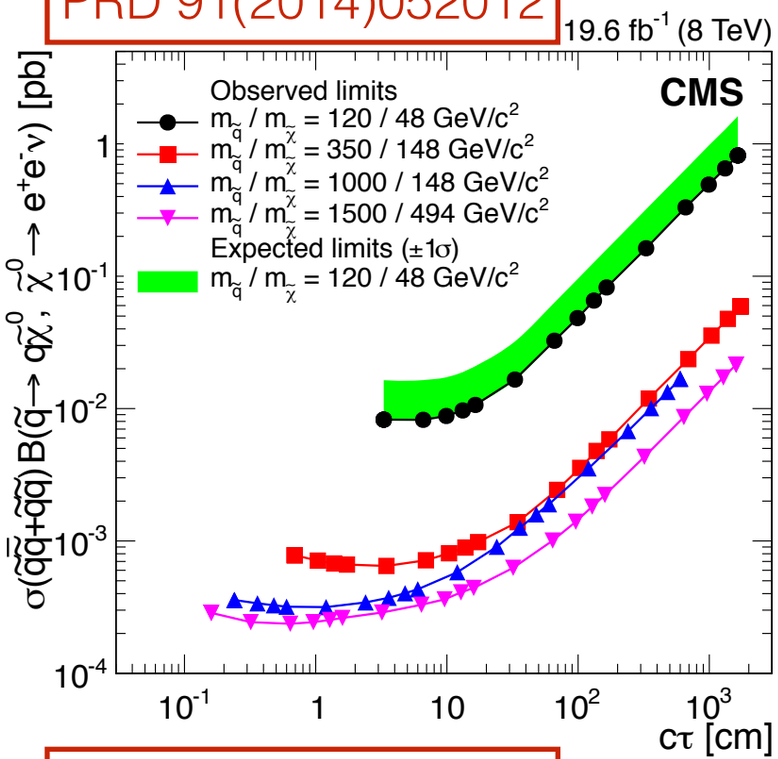

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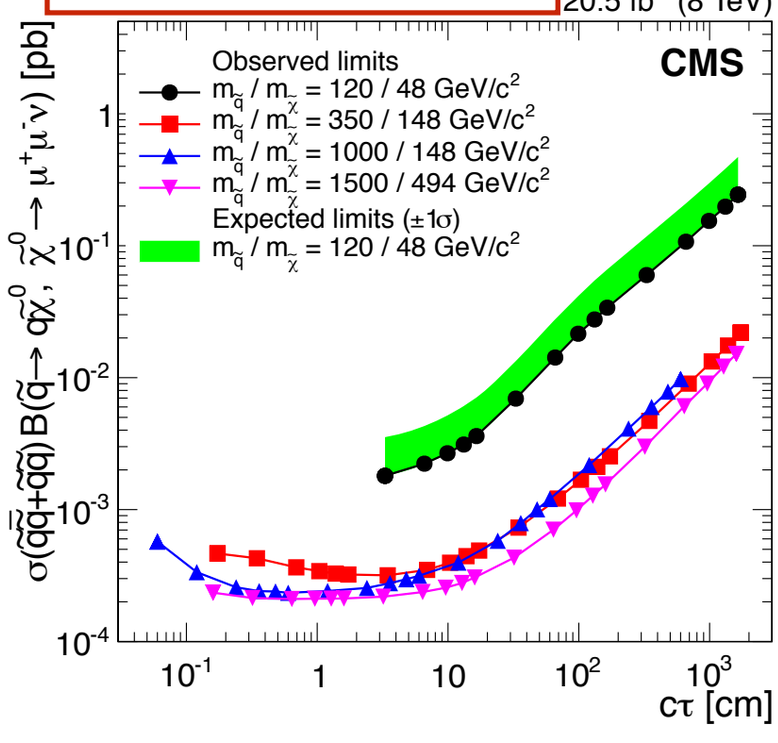


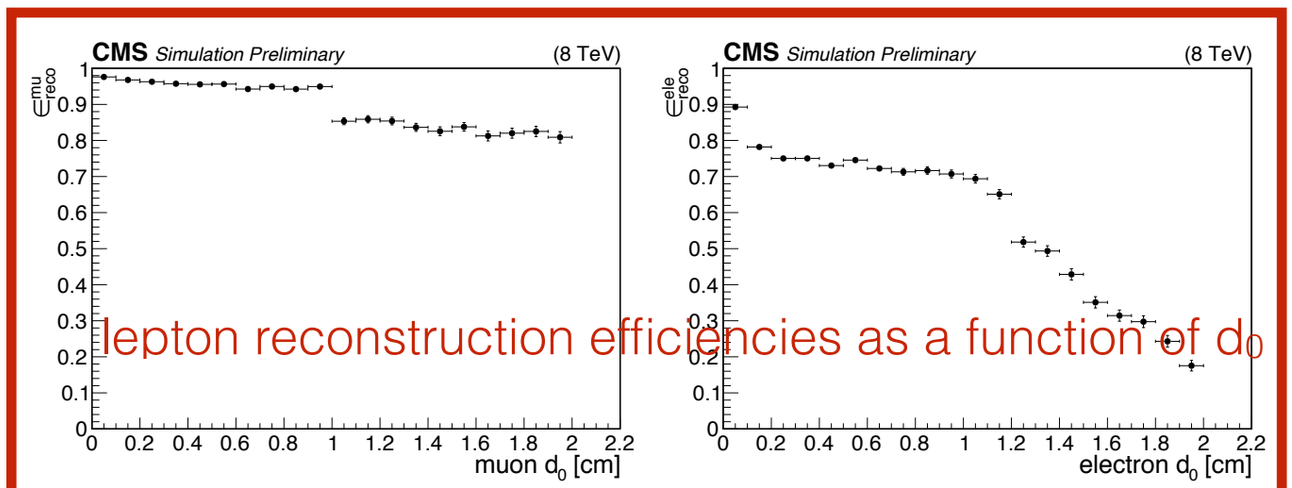
Recasting

Both analyses give useful information to recast their results

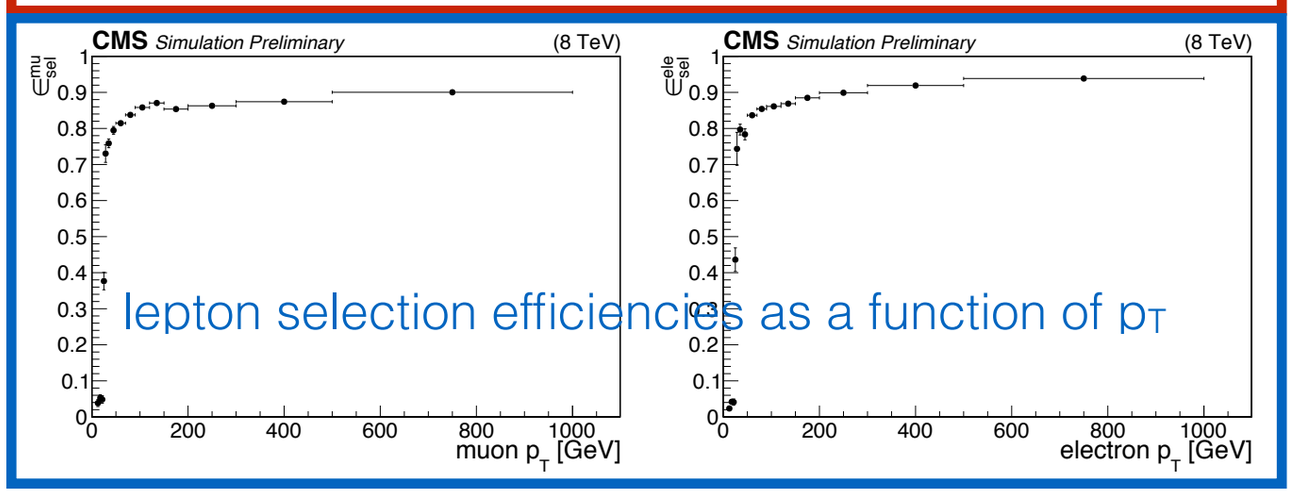
E-mu Search

Single limit plot but provide efficiency curves

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



lepton reconstruction efficiencies as a function of d_0

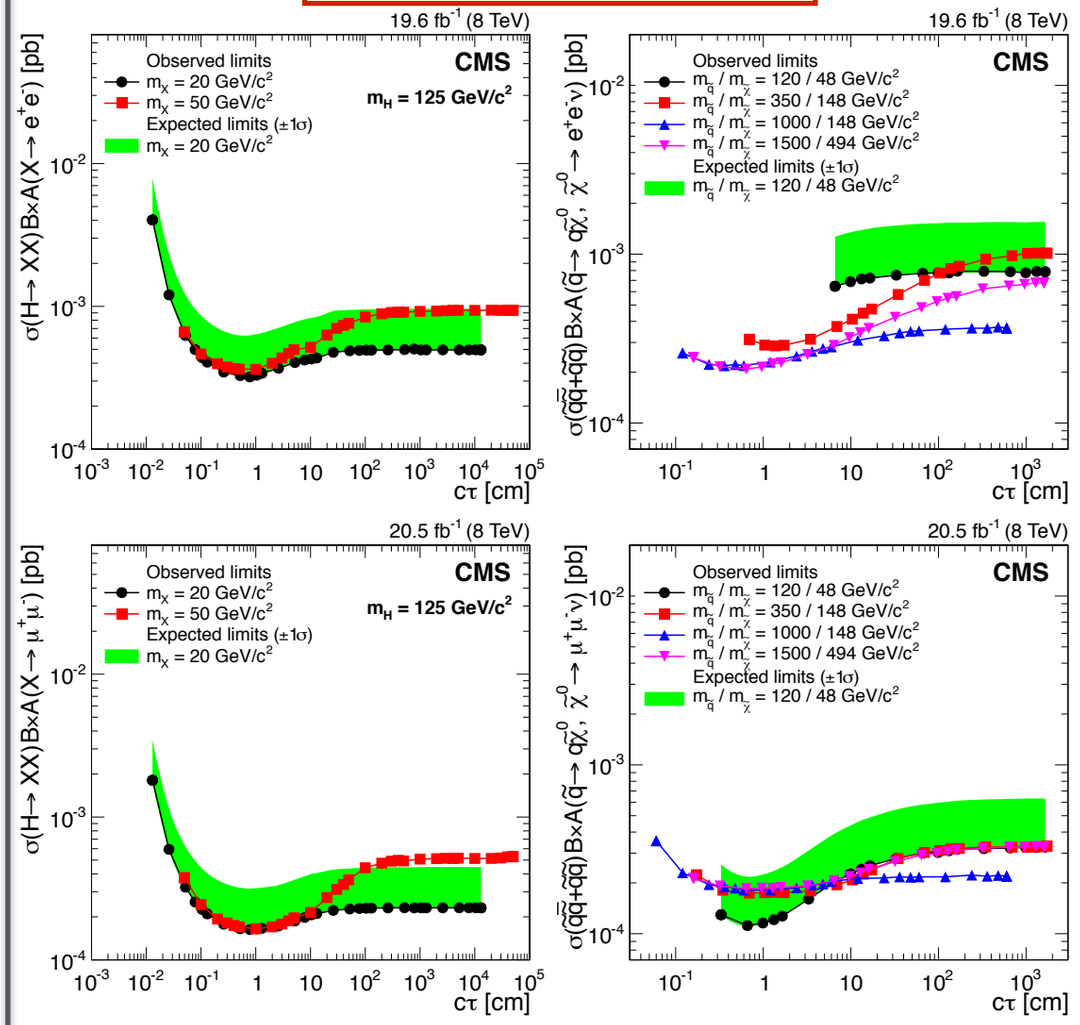


lepton selection efficiencies as a function of p_T

Dilepton same vertex Search

Provide limit plots in which the acceptance is factorised

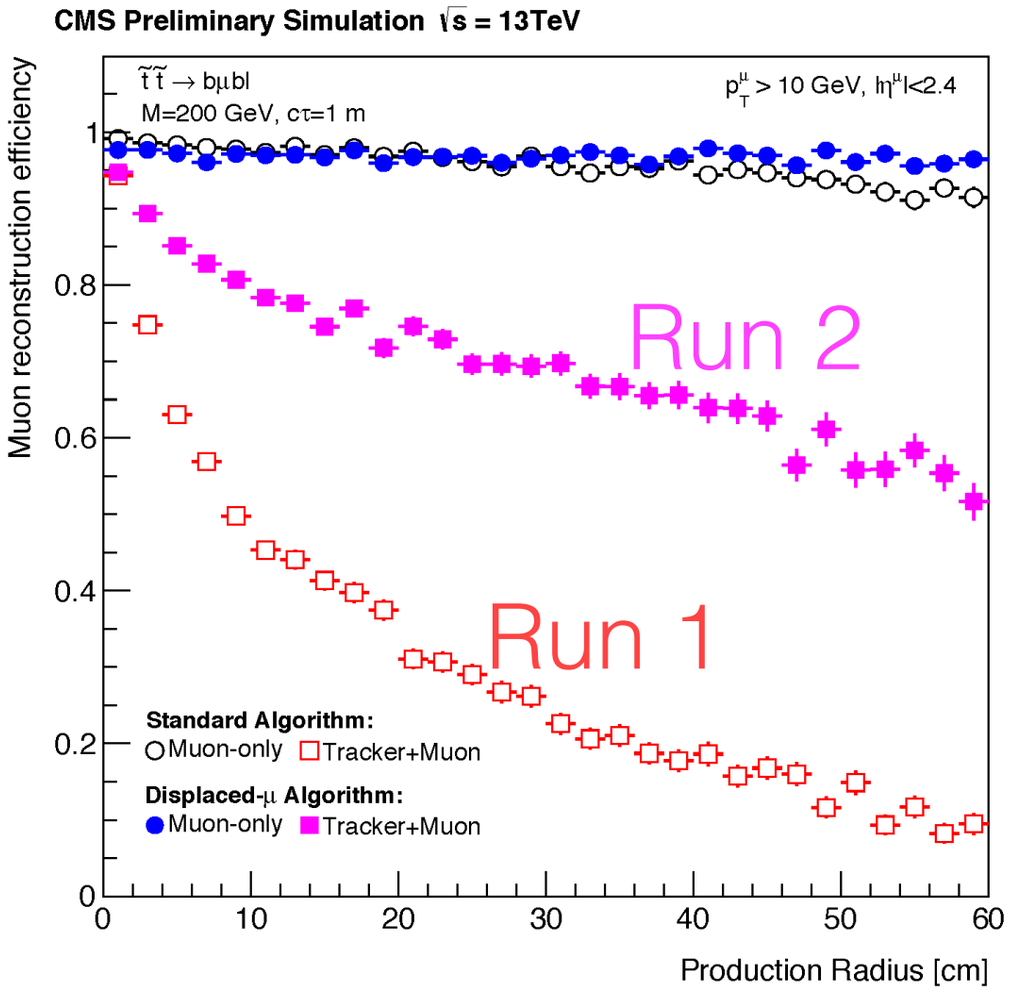
PRD 91(2014)052012



Run2 analysis

- The final states of the two analyses will be covered in single paper
- Many extensions can be done at 13 TeV
  - Same sign leptons

Significant improvement in the muon acceptance has been achieved for Run2



Summary

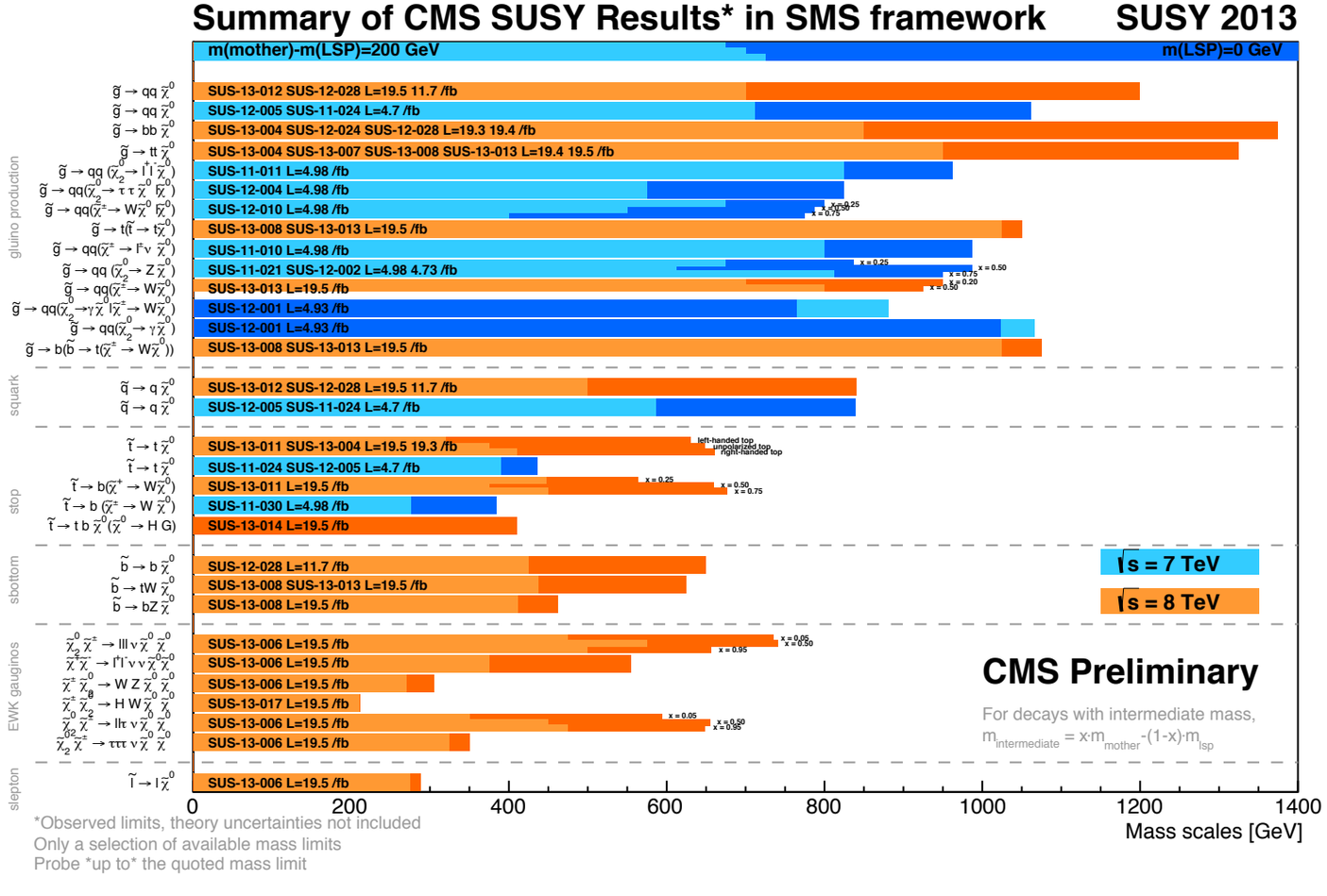
- We have presented two searches for long-lived BSM particles with different final states
- Both searches cover a region of parameter space that no previous searches are optimised for
- In the absence of any excess, we have set limits on various models
- Both analyses provide information to recast easily their results to exclude other models

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

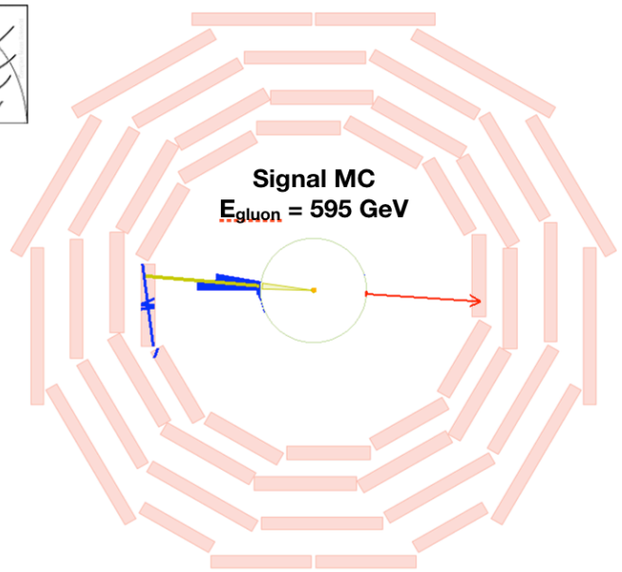
vast majority of previous limits apply to prompt decays



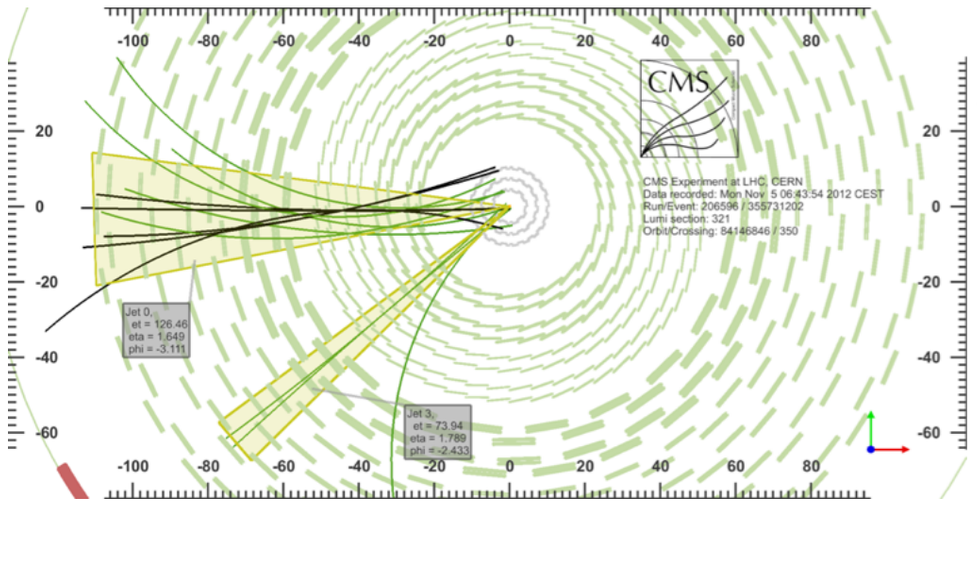
Motivation for *this* Search

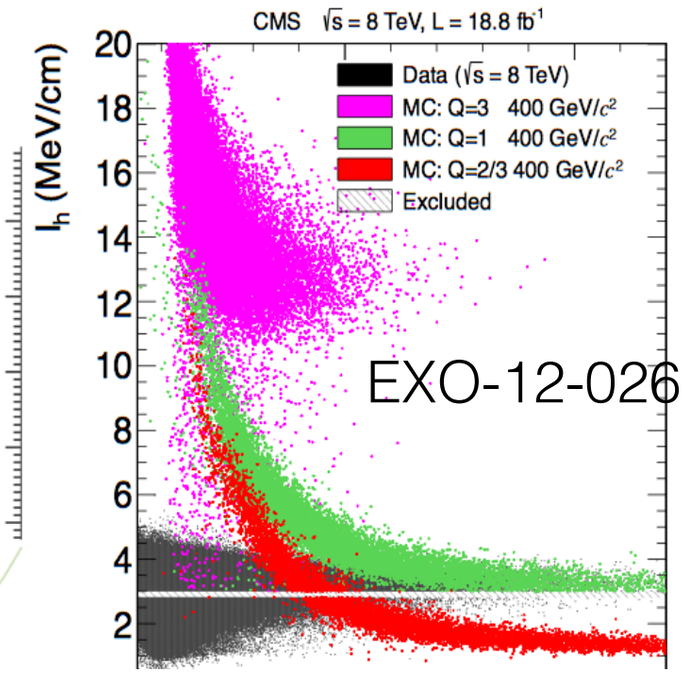
CMS has searches for non-prompt signatures, but they focus on longer lifetimes

EXO-12-036



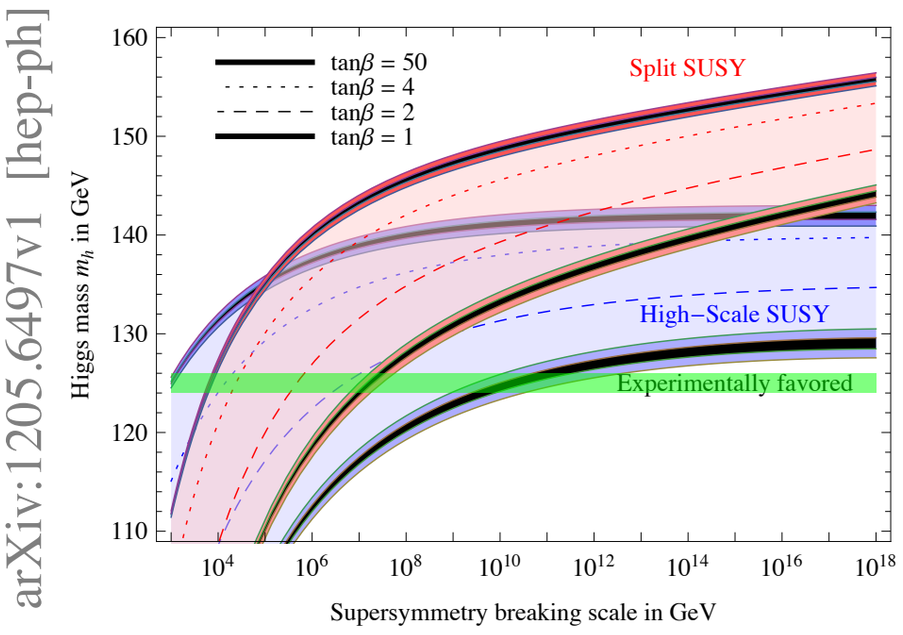
EXO-12-038





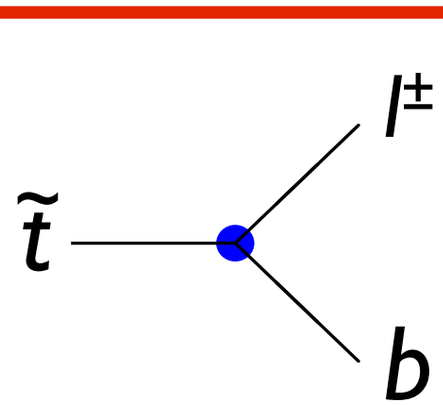
- A Higgs at 126 GeV favors shorter lifetimes for BSM (⟨cτ⟩ ~100 μm - 1 cm)
- This search targets this range. It is designed to explore the gap between prompt and very long-lived signatures

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

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

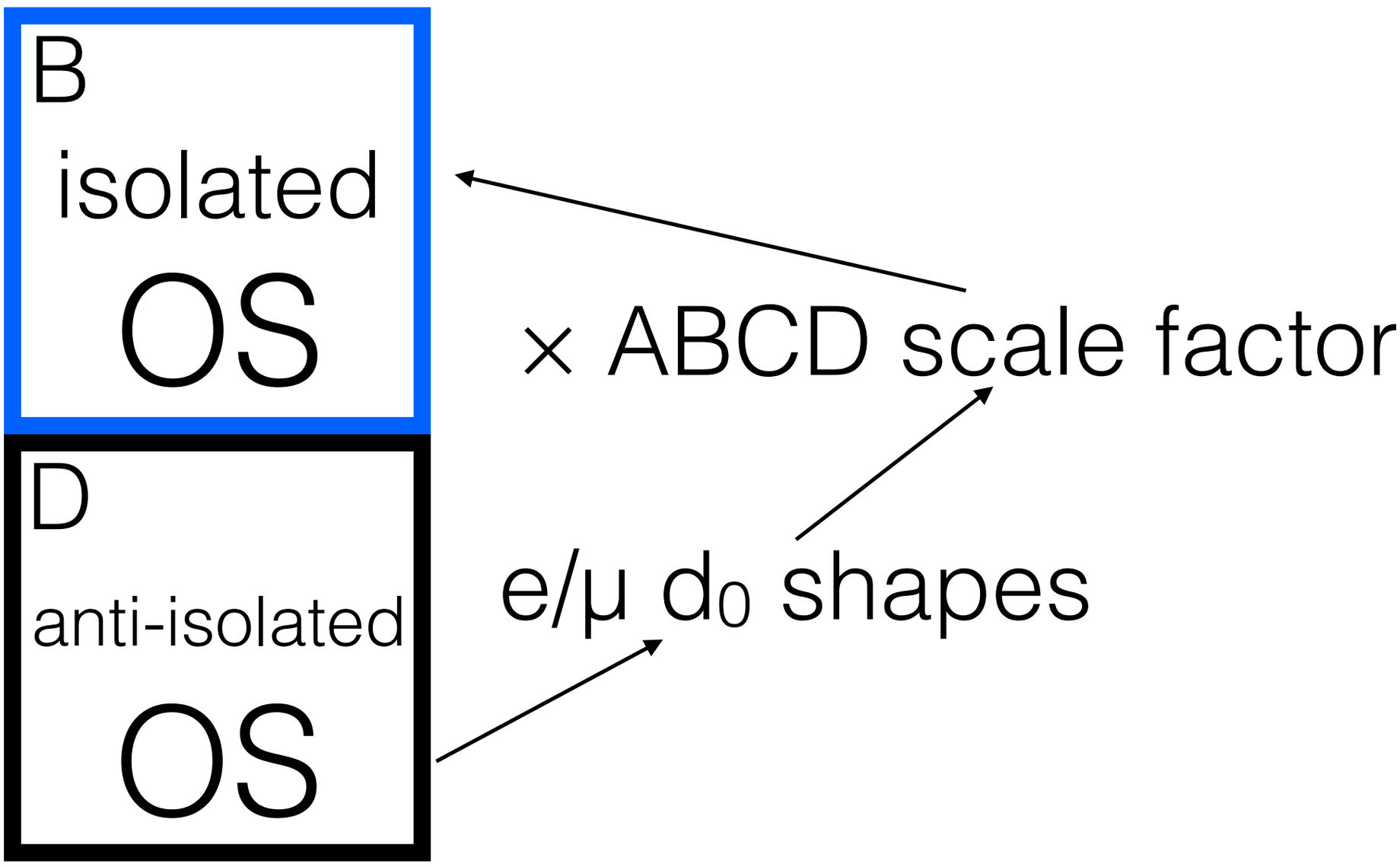
A isolated SS	B isolated OS
C anti-isolated SS	D anti-isolated OS

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



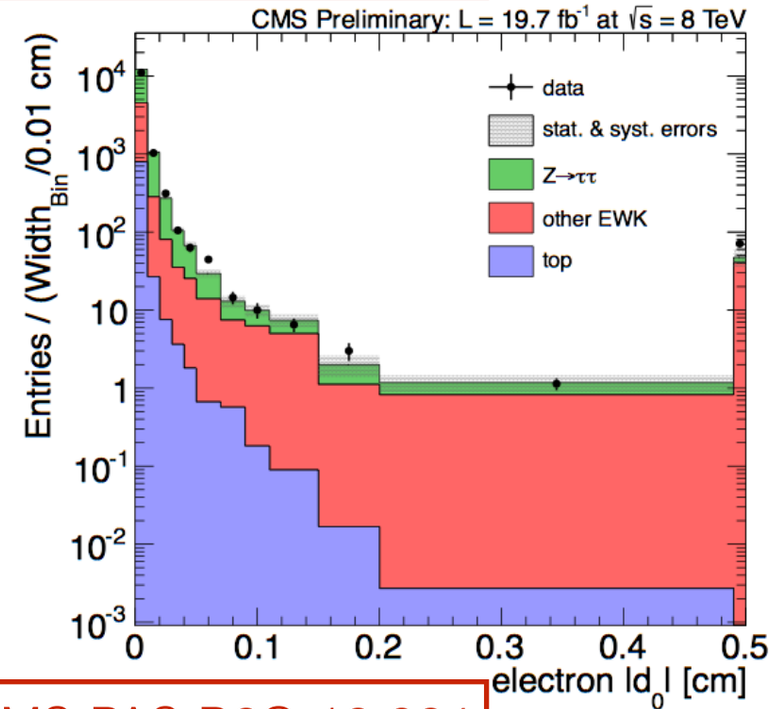
MC Validation: Region I

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

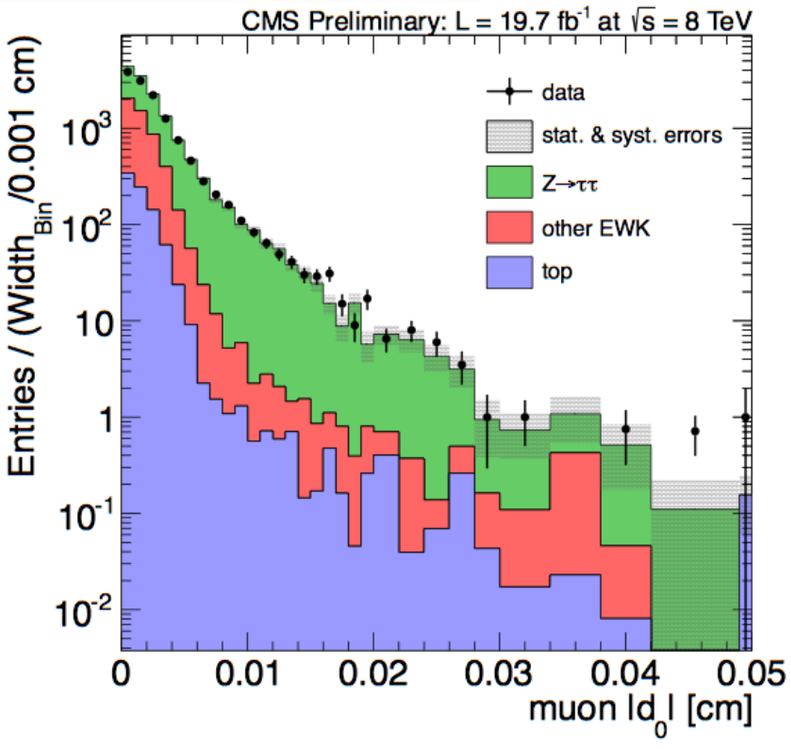
analysis preselection
+
exactly one electron with $M_T < 50\,\text{GeV}$
exactly one muon with $M_T < 50\,\text{GeV}$
exactly one electron-muon pair with $\Delta\phi > 2.5$
$\sum p_{\text{T}\,jet} < 100\,\text{GeV}$

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

CMS-PAS-B2G-12-024



CMS-PAS-B2G-12-024



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)