Search for Hidden Valleys at CMS

Dark Interactions Workshop

John Paul Chou
Rutgers University

Thursday, June 12th, 2014

RUTGERS

THE STATE UNIVERSITY
OF NEW JERSEY

OUTLINE

- Focus on 8 TeV searches from CMS with Long-lived final states
    - HSCPs (EXO-12-026 & EXO-13-006)
    - Displaced Leptons (EXO-12-037)
    - (Slightly) Displaced Leptons (B2G-12-024)
    - Displaced Jets (EXO-12-038)

HSCPs

- Broad class of models that predict HSCPs (e.g. split-SUSY, GMSB, etc.)

- Five distinct analyses at CMS to capture different phenomena
  - Tracker+Time of Flight
  - Tracker-Only
  - Muon-Only
  - $|Q|<1e$
  - $|Q|>1e$

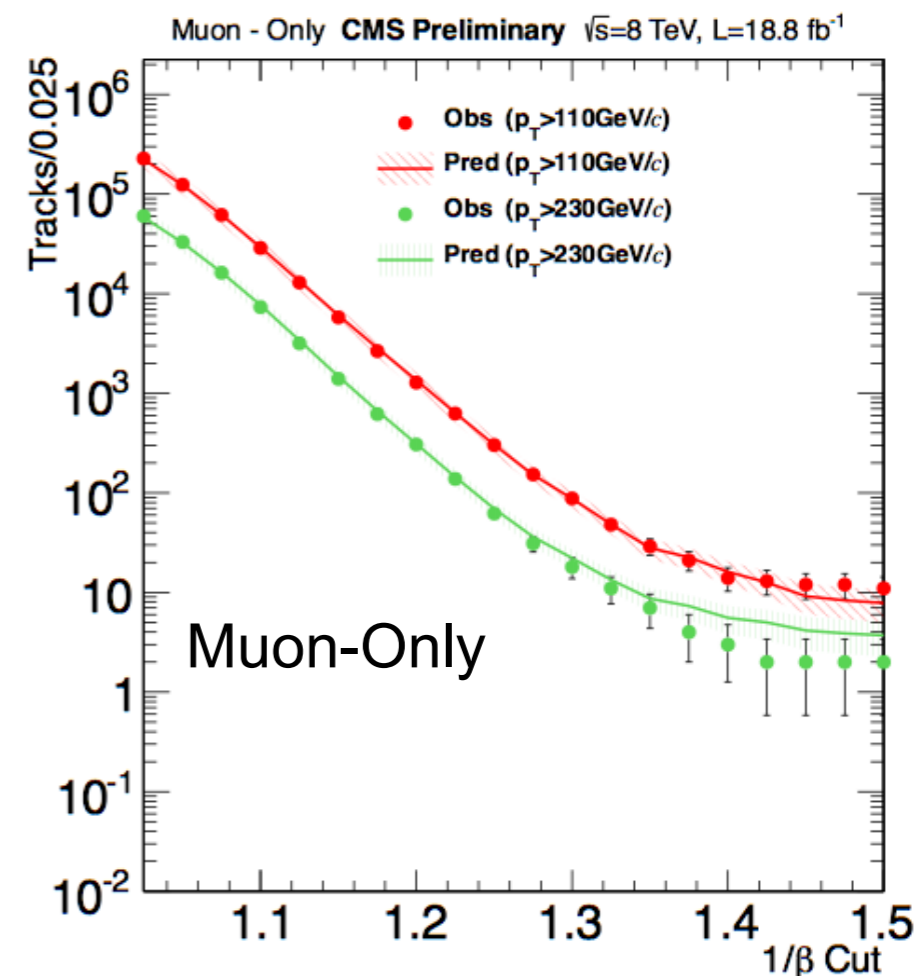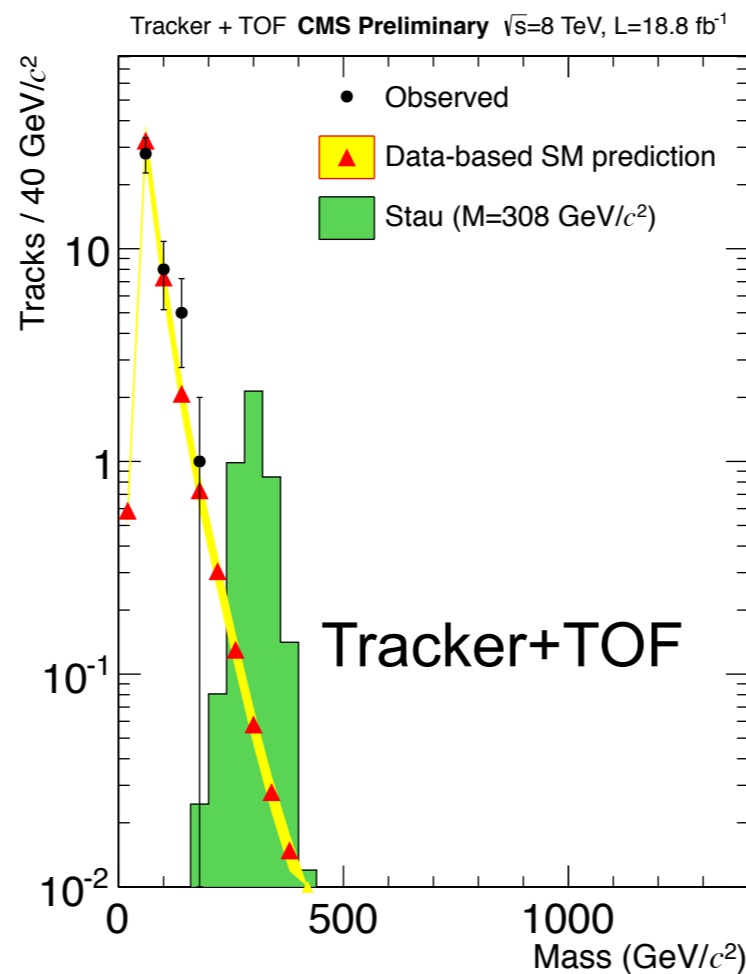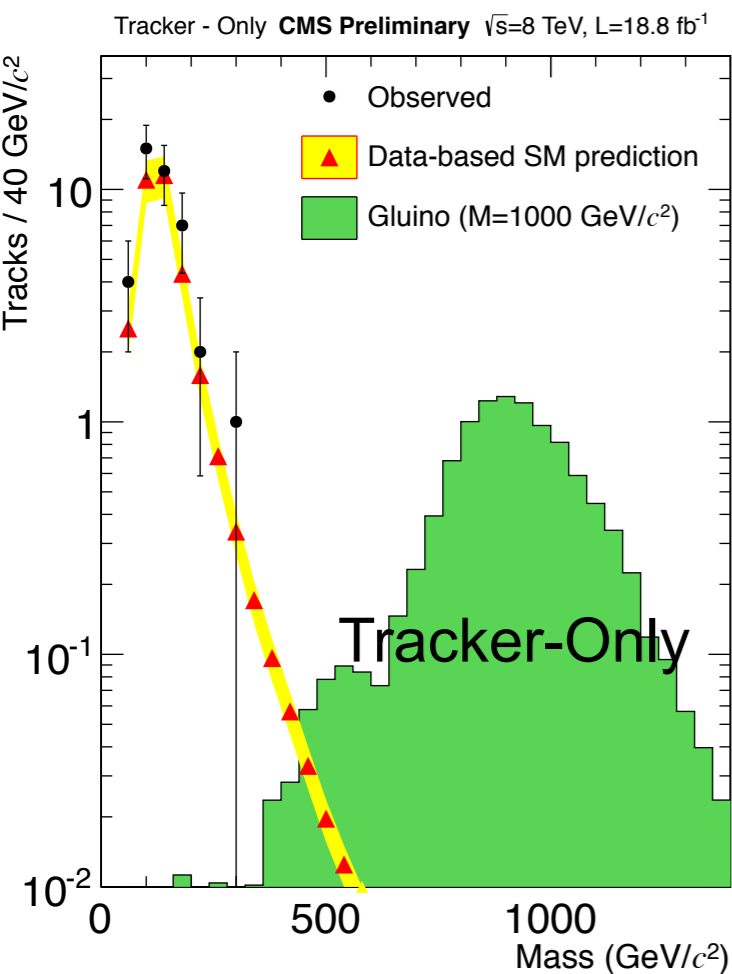- Trigger on logical OR of muon and MET

--- HSCP (becoming neutral)

--- HSCP (neutral in tracker)

--- HSCP
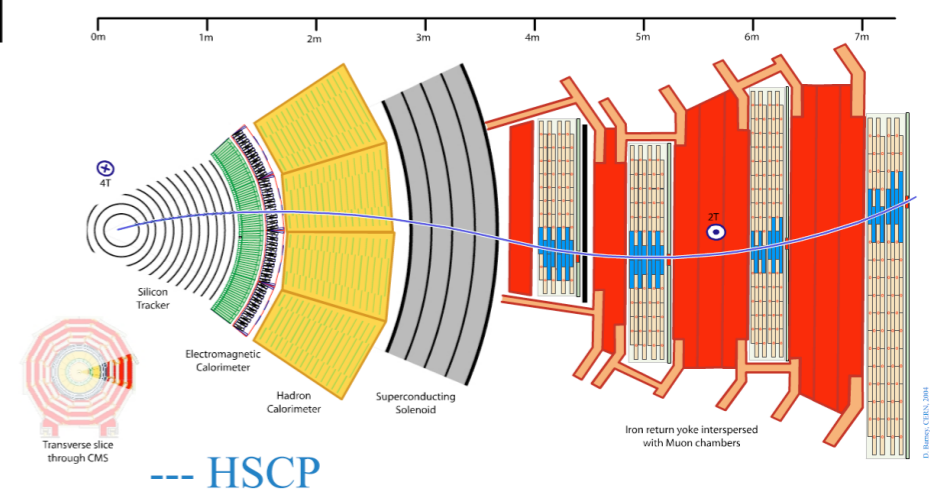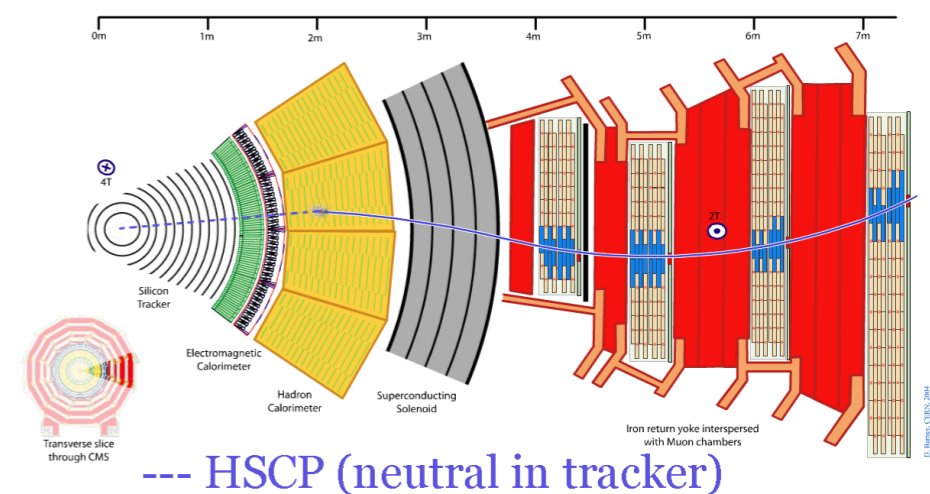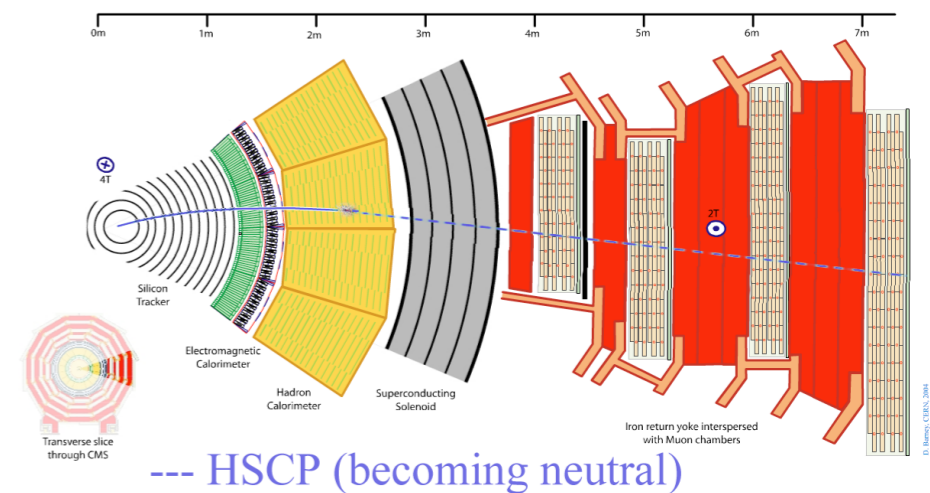
Q=1 MEASUREMENTS

- Tracker-Only and Tracker+TOF
  - use dE/dx and momentum to measure the mass
  - For Muon-Only, only TOF is available
  - Assume dE/dx, β, and p_T are statistically uncorrelated for the background

    [EXO-12-026]
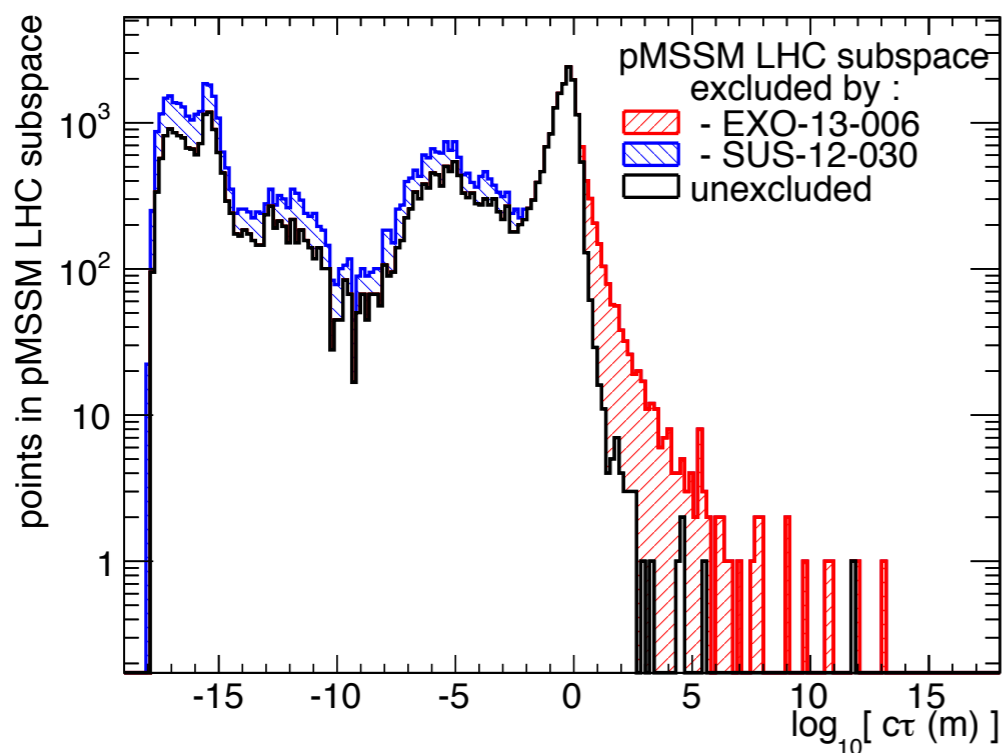
    - Use "ABCD" method to extrapolate into the signal region
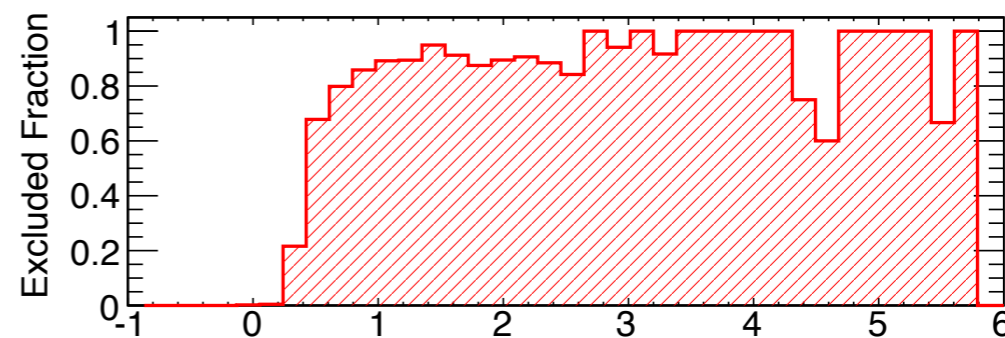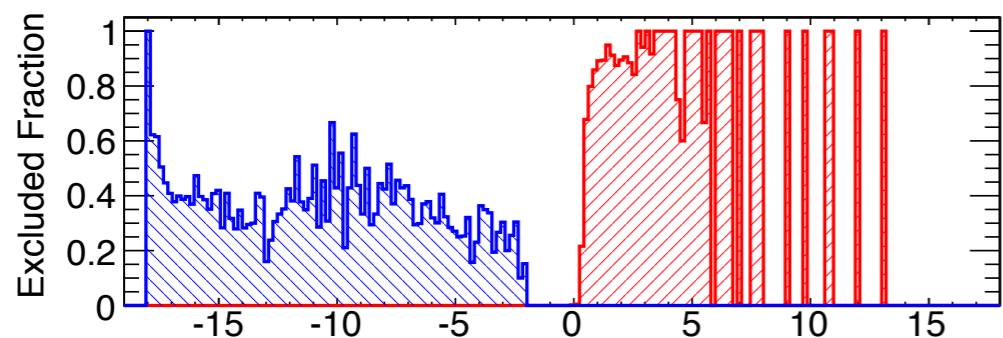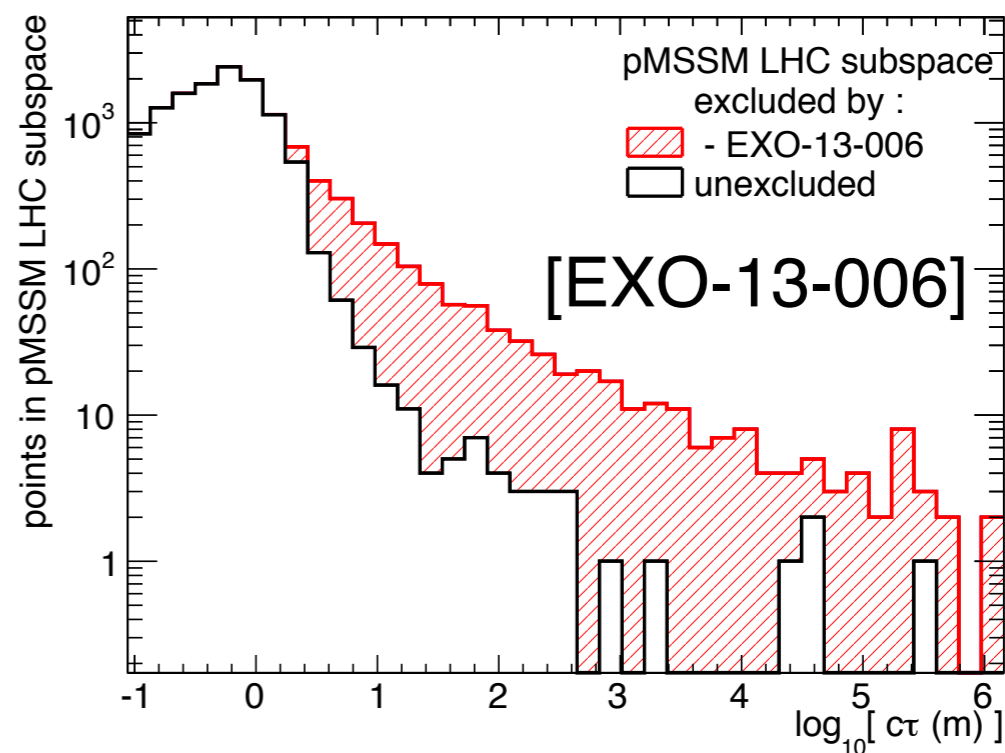
HSCP RE-INTERPRETATION

- Recently added a simplified Acc*Eff maps (in p_T, η, and β)

  - Can use generator-level information to accurately reproduce limits at ~10% level

  - As an example: excludes long-lived charginos in pMSSM

CMS Preliminary - $\sqrt{s}$ = 8 TeV - L = 18.8 fb^{-1}

CMS Preliminary - $\sqrt{s}$ = 8 TeV - L = 18.8 fb^{-1}

DISPLACED LEPTONS

- Search for two displaced **isolated** leptons (e^+e^- or $\mu^+\mu^-$) originating from a **common vertex**

  - trigger on "photons" or "L2 muon tracks" and match tracks to these objects

    - avoids d0 bias of dedicated electron/muon **trigger** reconstruction
    - Primary discriminating variable: **d0 significance of tracks**

Control Regions have $|\Delta\phi|>\pi/2$

[EXO-12-037]
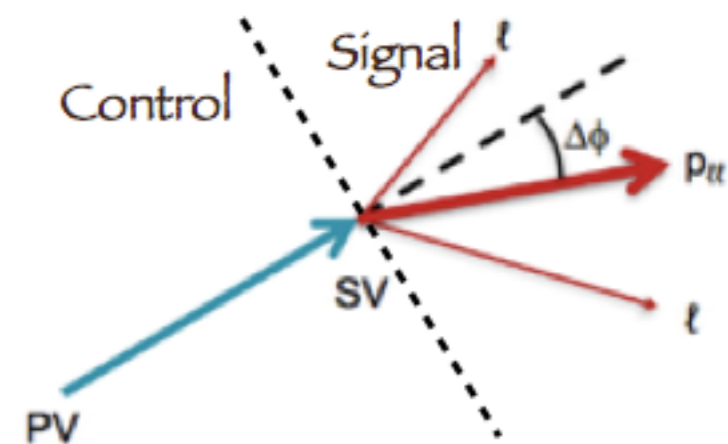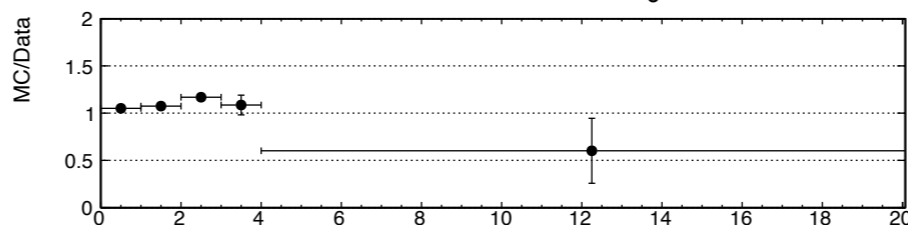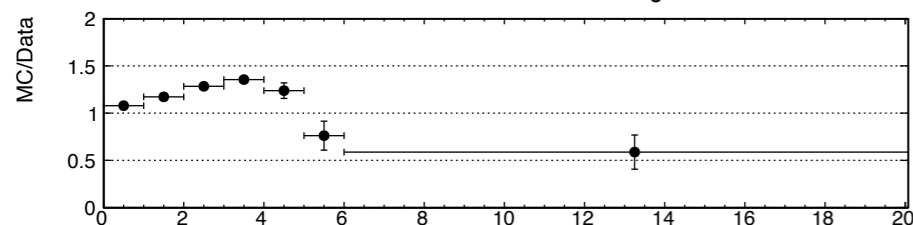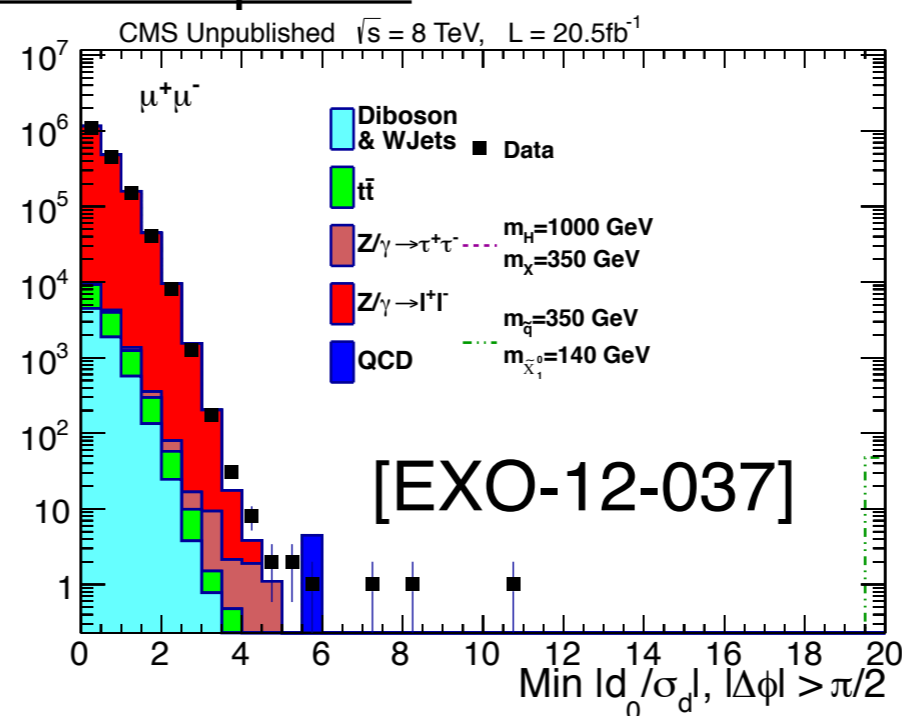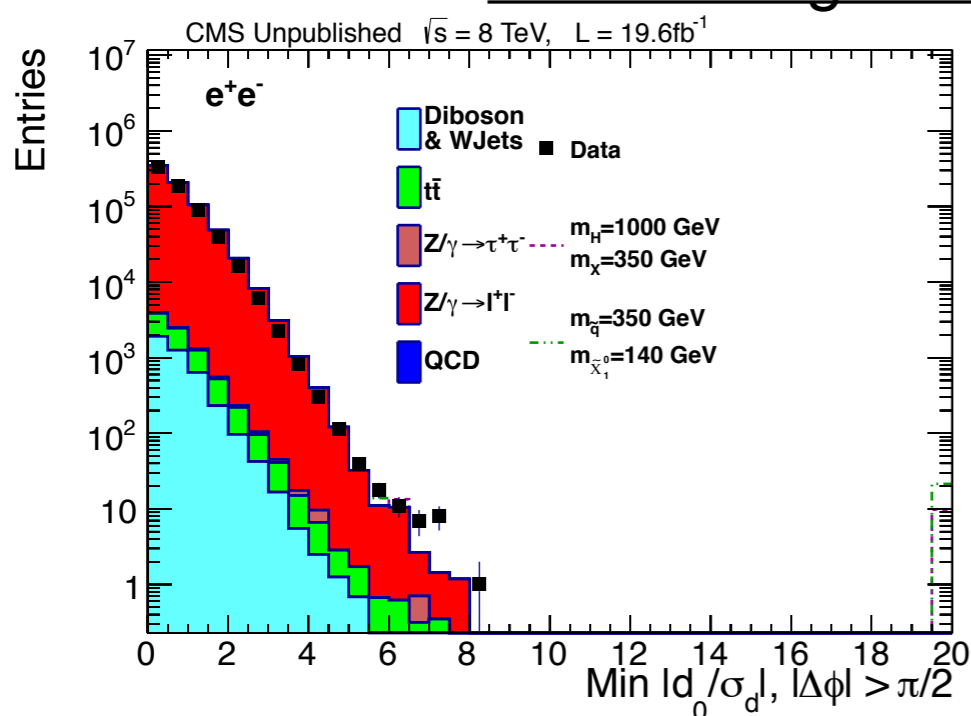
Assume backgrounds are mirror symmetric about $|\Delta\phi|=\pi/2$

TRACK RECONSTRUCTION

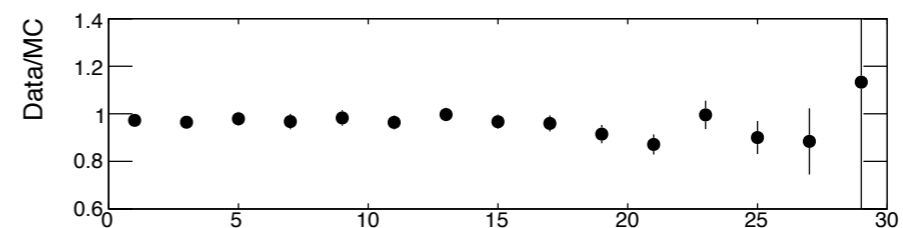- Efficiency driven by track reconstruction efficiency
  - cross check with cosmic muons
  - Require at least one X-candidate per event:
    - A common vertex with χ2/ndf<10(5) for e(μ) channel
    - **M(ee/μμ)>15 GeV**, ΔR(μμ)>0.2, pT(e) from ECAL
    - Isolation: ΣpT /pT<0.1 counting tracks w/ pT>1 GeV in ΔR(trk,e/μ)<0.3 around each lepton (not counting the other lepton in the X-candidate)

- ● hit
- ○ missing hit

≤ 3(4) total missing hits for e's (μ's) between S.V. and innermost hits

Secondary Vertex (S.V.)

≤ 1 total hits between P.V. and S.V.

Primary Vertex (P.V.)
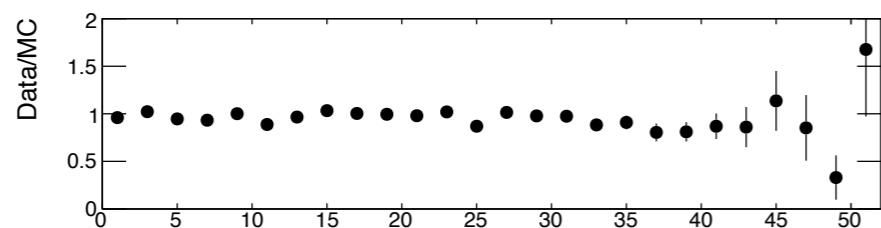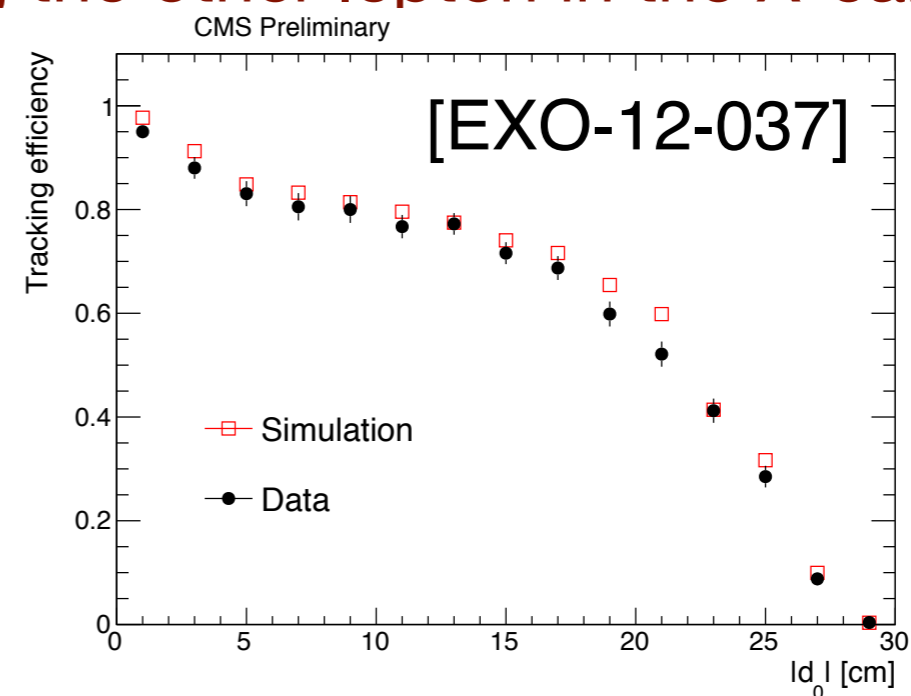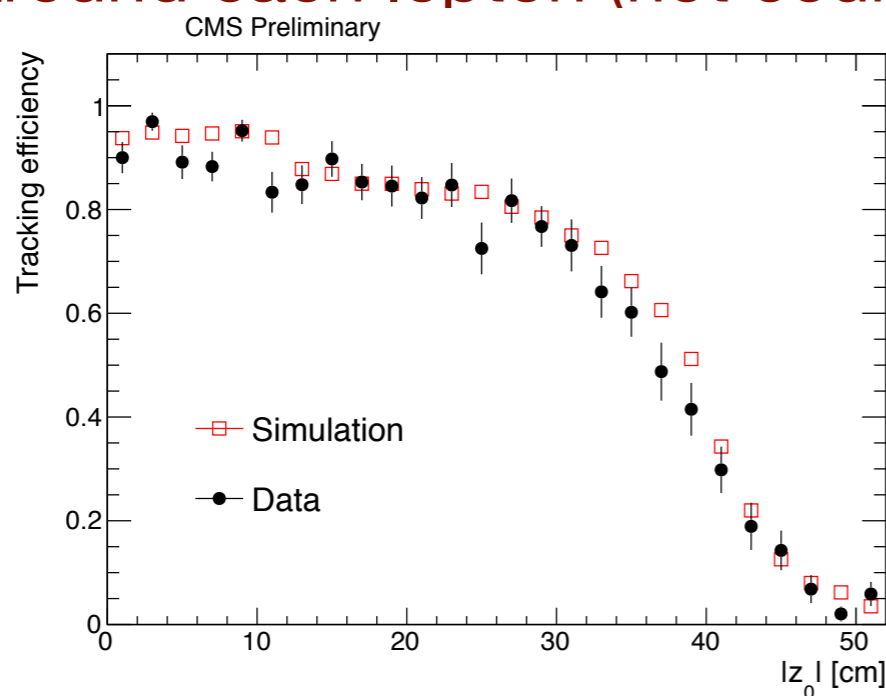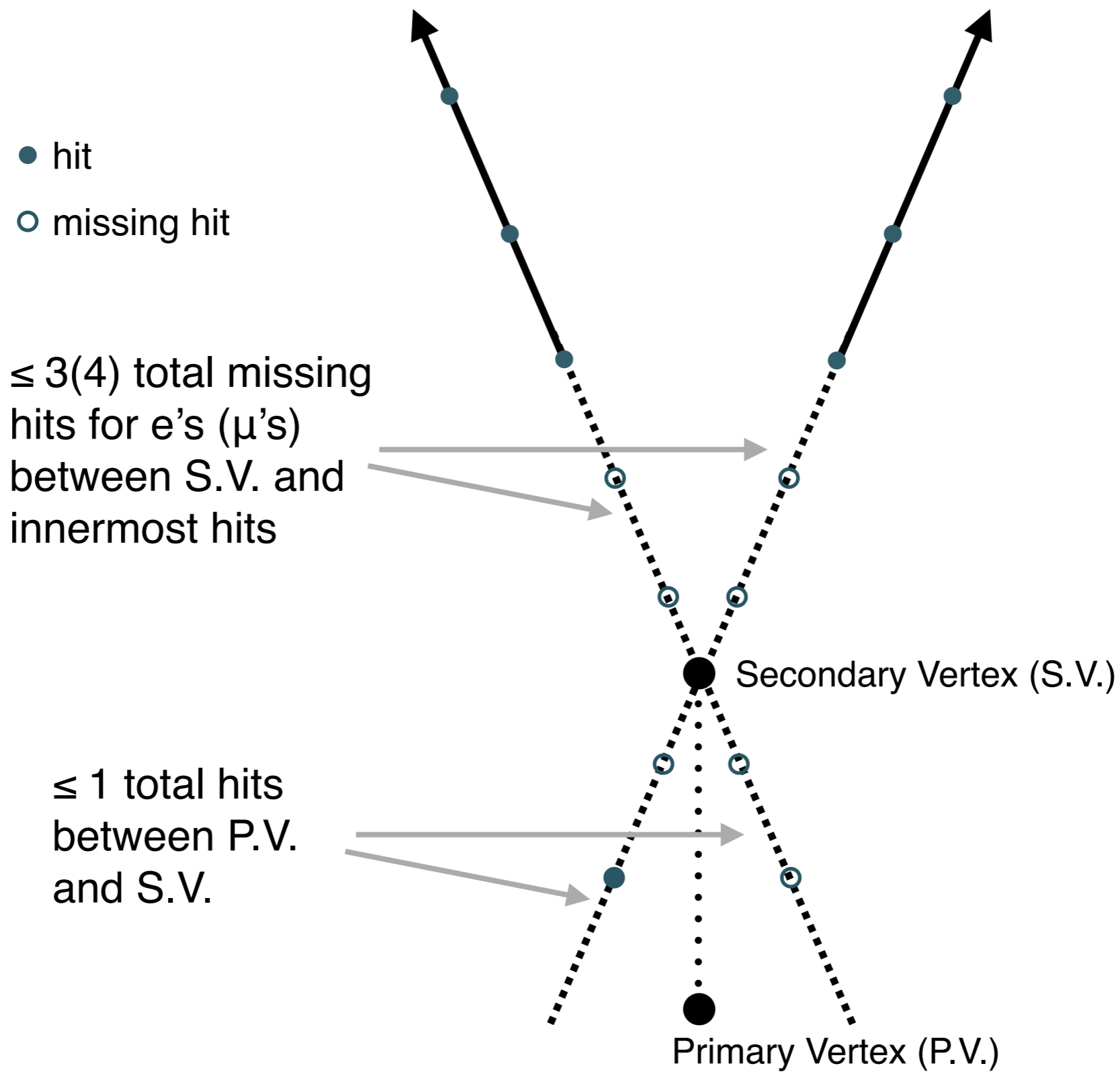
DISPLACED DILEPTON SIGNAL REGION

- Optimize cut on d0 significance to reduce backgrounds <0.5 total events
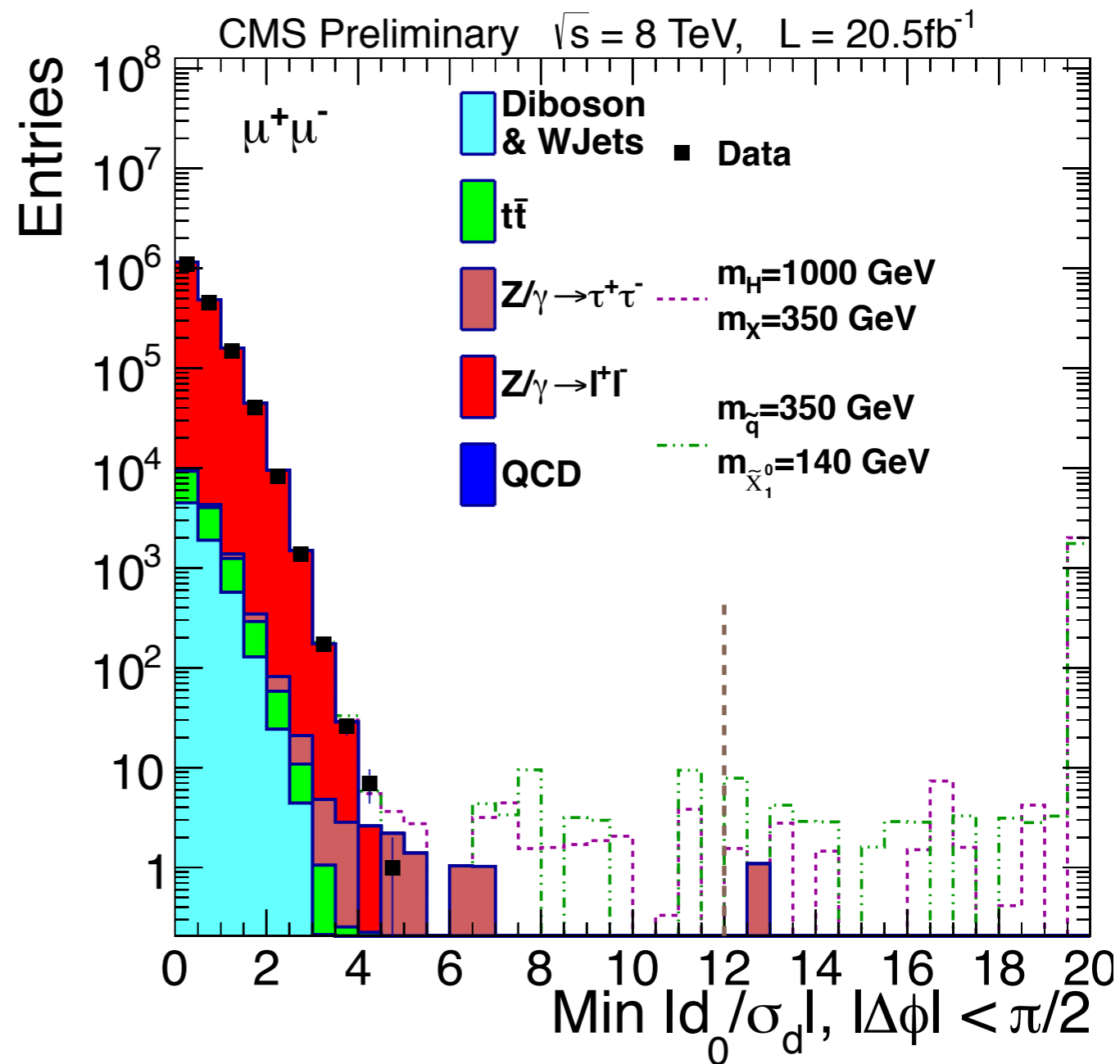
LIMITS ON DISPLACED DILEPTONS

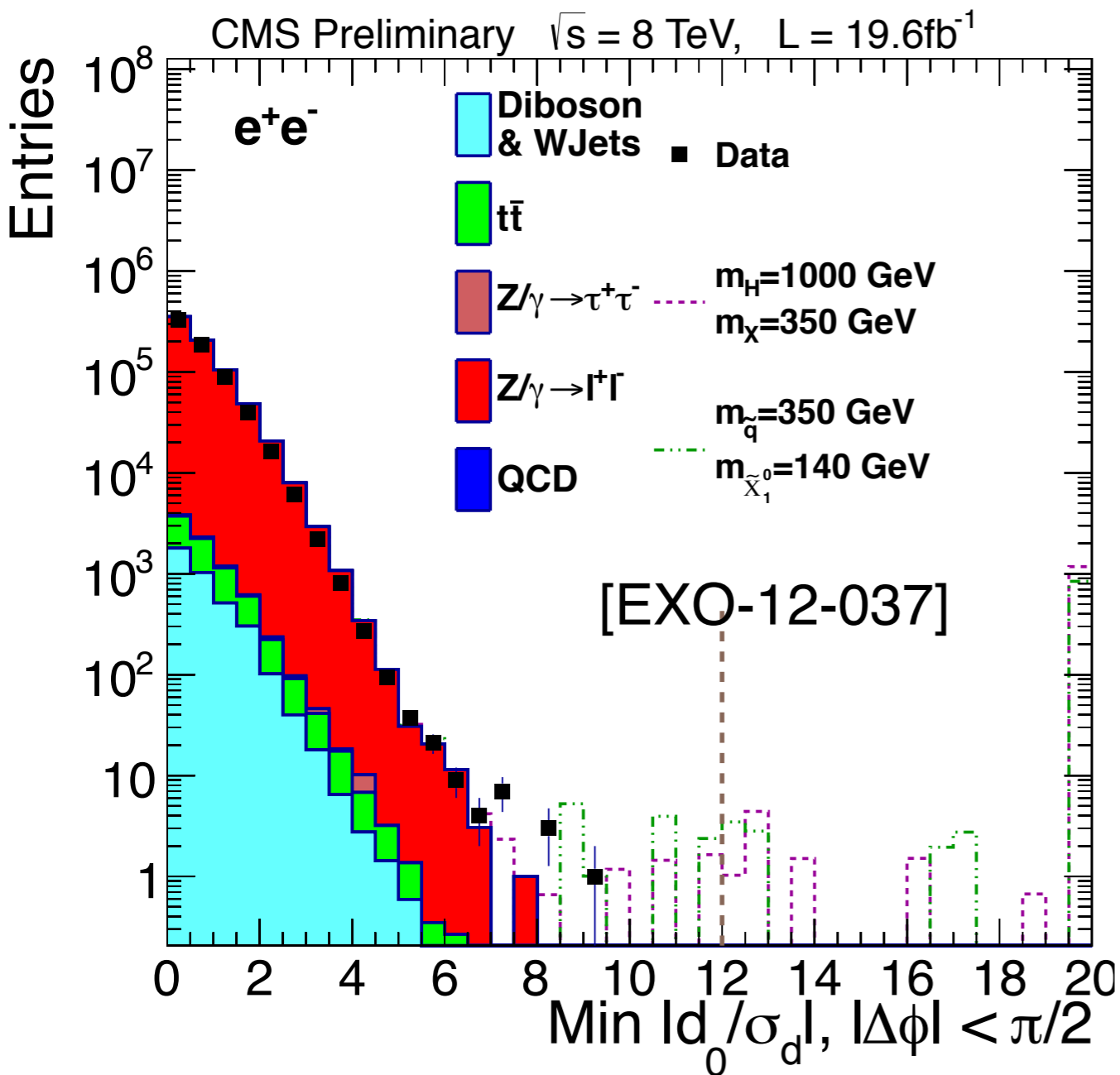- Set limits at O(fb-pb) levels on the process H→XX→$\ell\ell\ell\ell$
  - Limits also set on RPV slepton → $\ell\ell$v
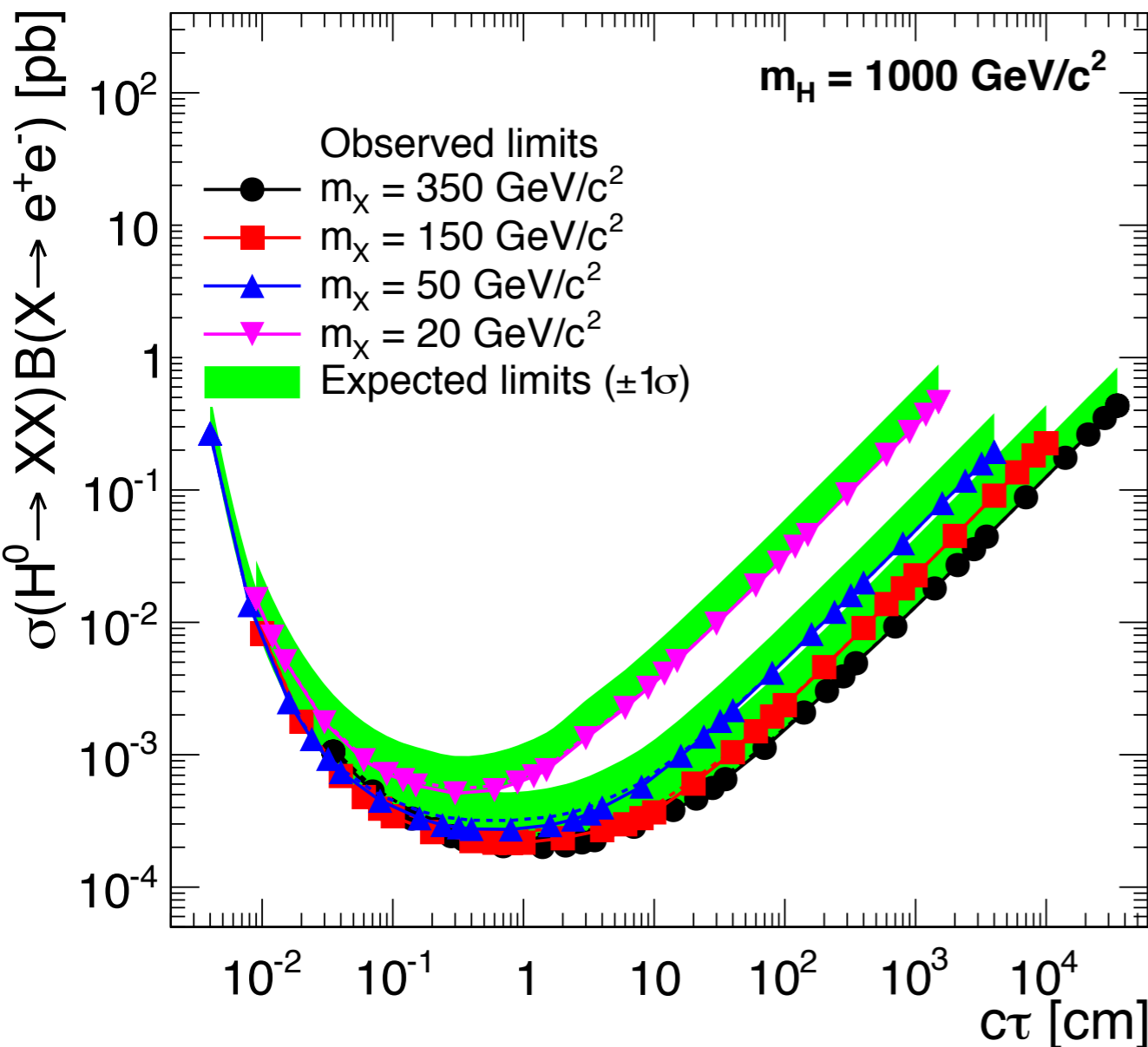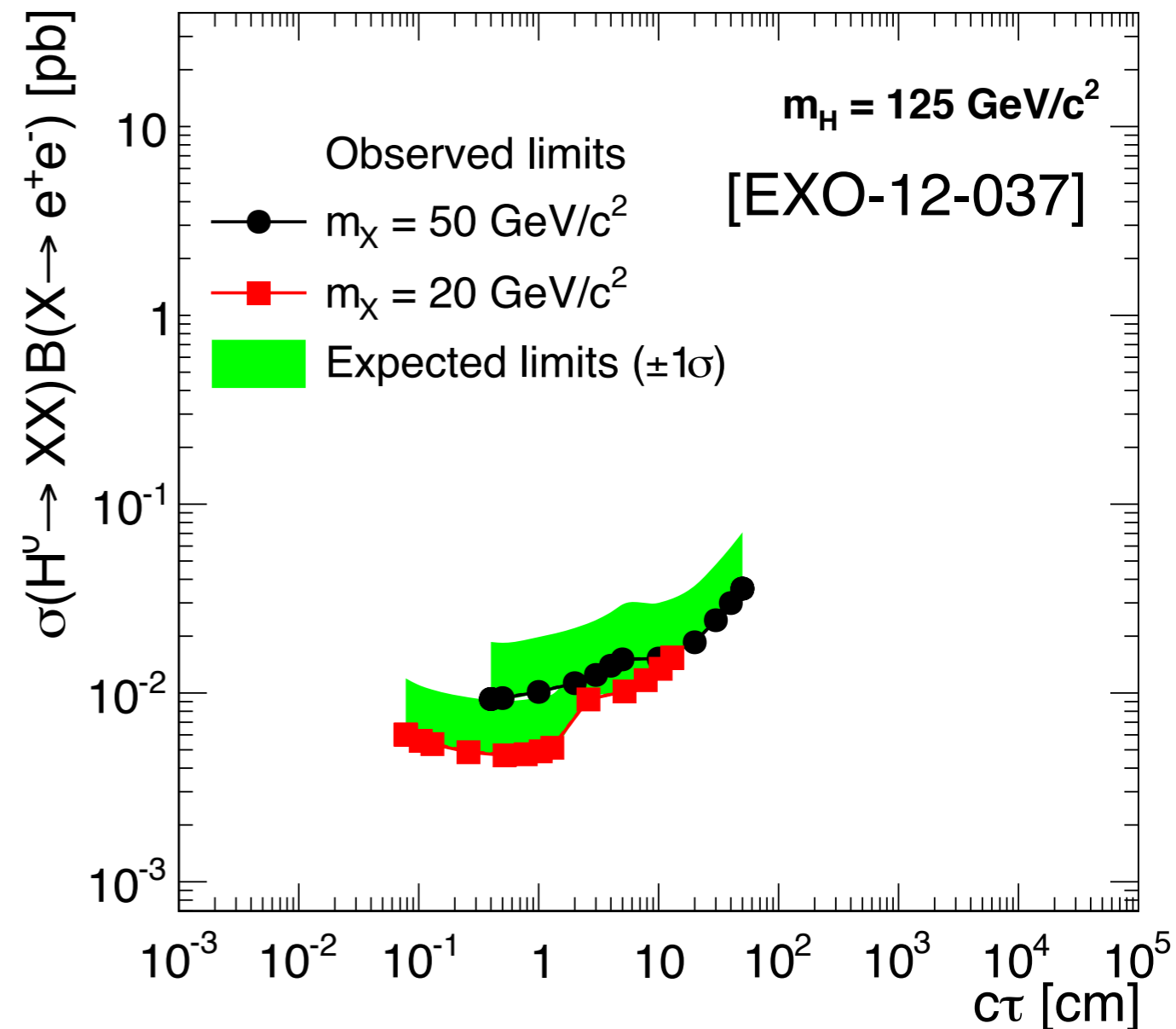
(Slightly) Displaced Leptons

- Look for two isolated, opposite-sign, opposite-flavor leptons
  - require 2D impact parameters **between 0.05 cm and 2.0 cm**
    - Does **not require** that the two leptons originate from a common vertex
  - Dominant backgrounds: Z→ττ and QCD
    - Check (below) that leptons with moderate displacements are still well-reconstructed

non-prompt e and prompt μ

non-prompt μ and prompt e
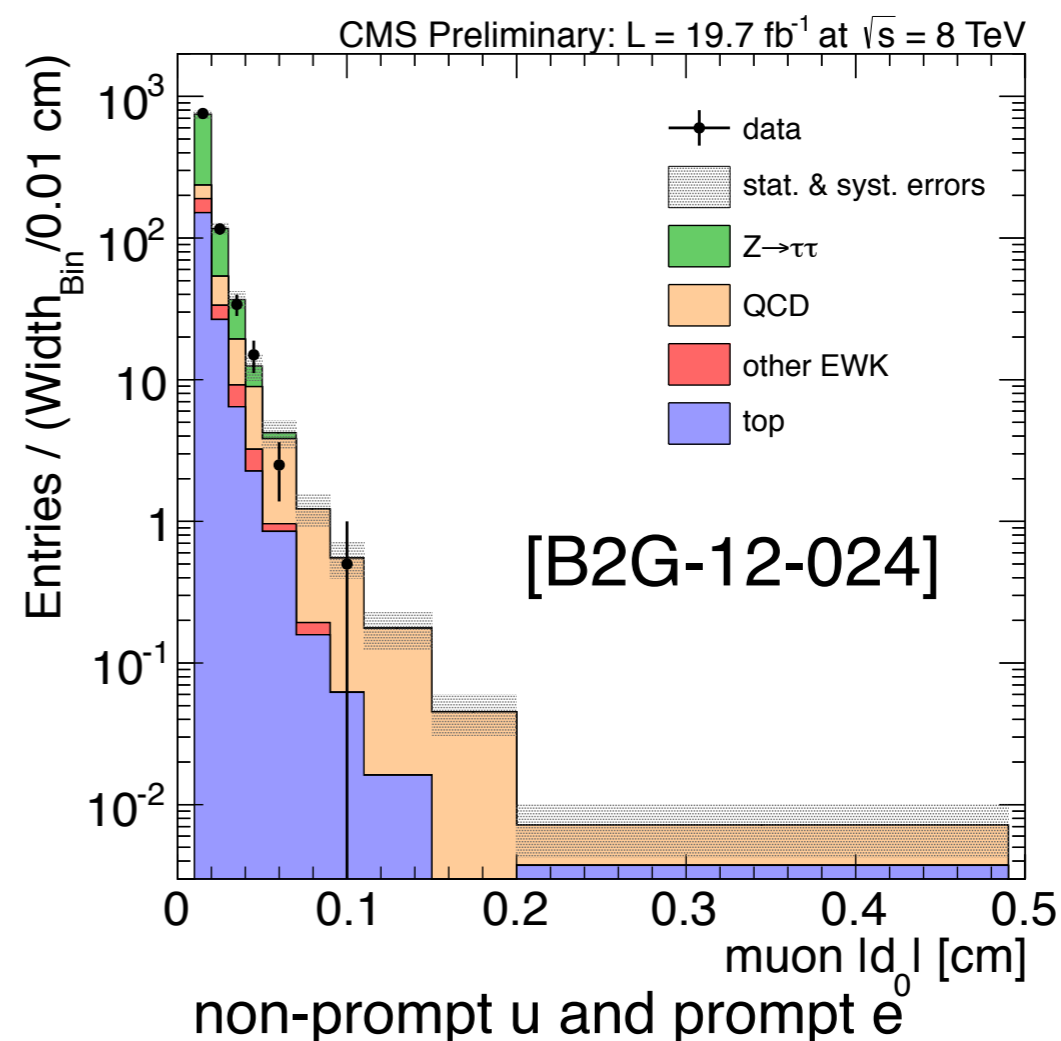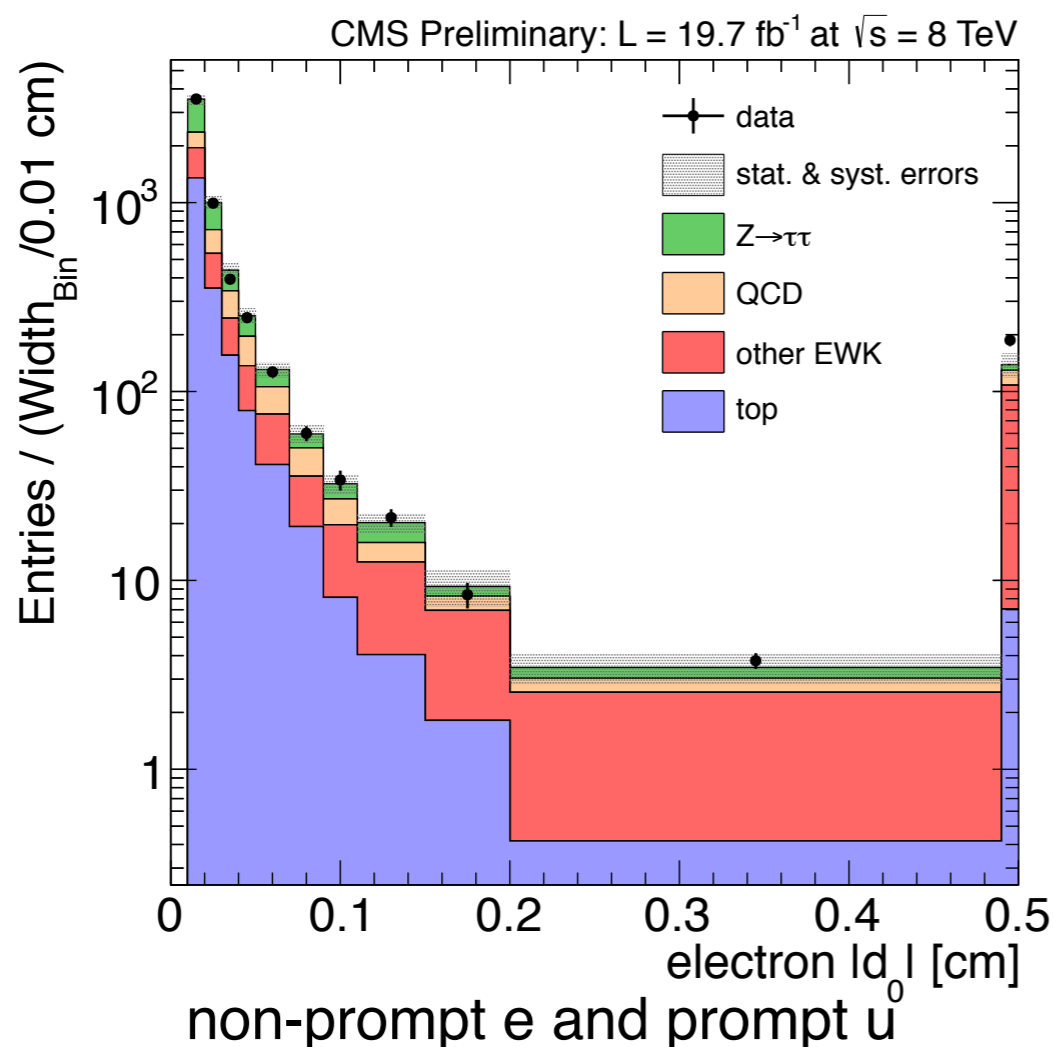
[B2G-12-024]

MC BACKGROUND CONTROL REGION

- Test modeling of Z→ττ in signal-depleted, Z→ττ-enriched region
  - $M_T(\ell\text{'s,MET}) < 50$ GeV, $H_T < 100$ GeV, $\Delta\phi(\ell,\ell) > 2.5$

[B2G-12-024]

RESULTS

- QCD background estimated with "ABCD" method
  - Opposite Sign v. Same Sign and Isolated v. Non-Isolated

- Three non-overlapping signal regions based on the minimum lepton d0
  - interpreted in terms of RPV stops

CMS Preliminary: L = 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV

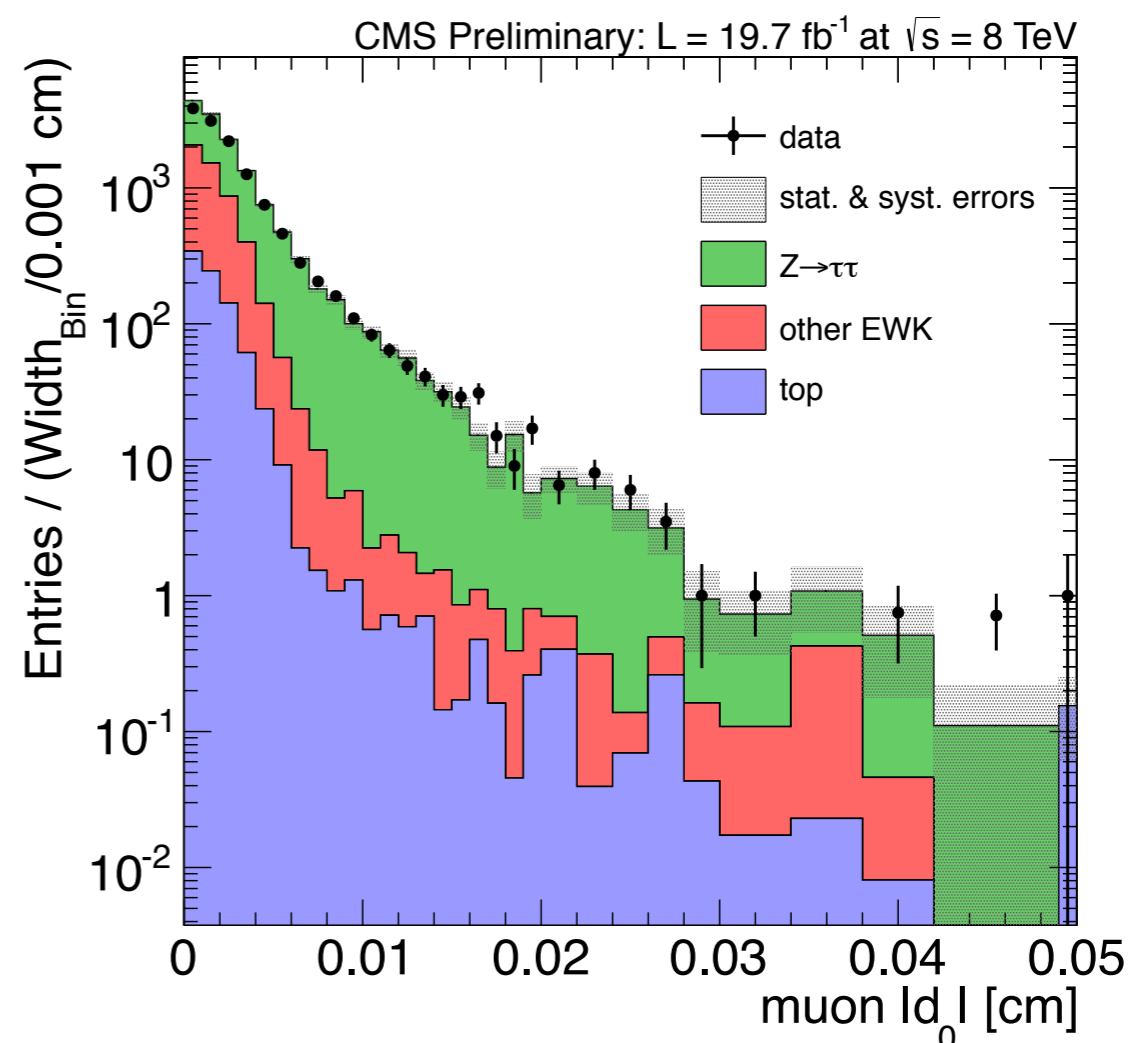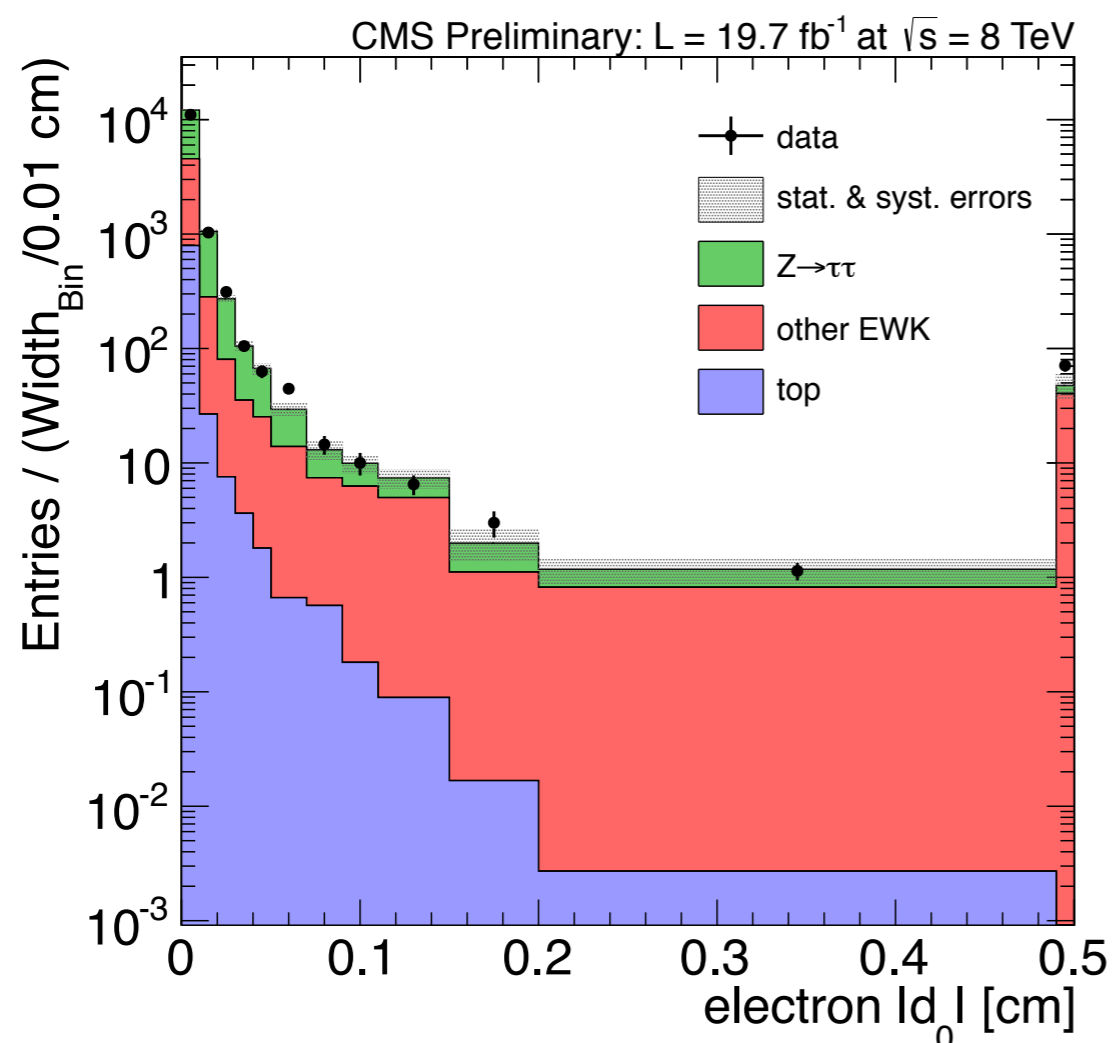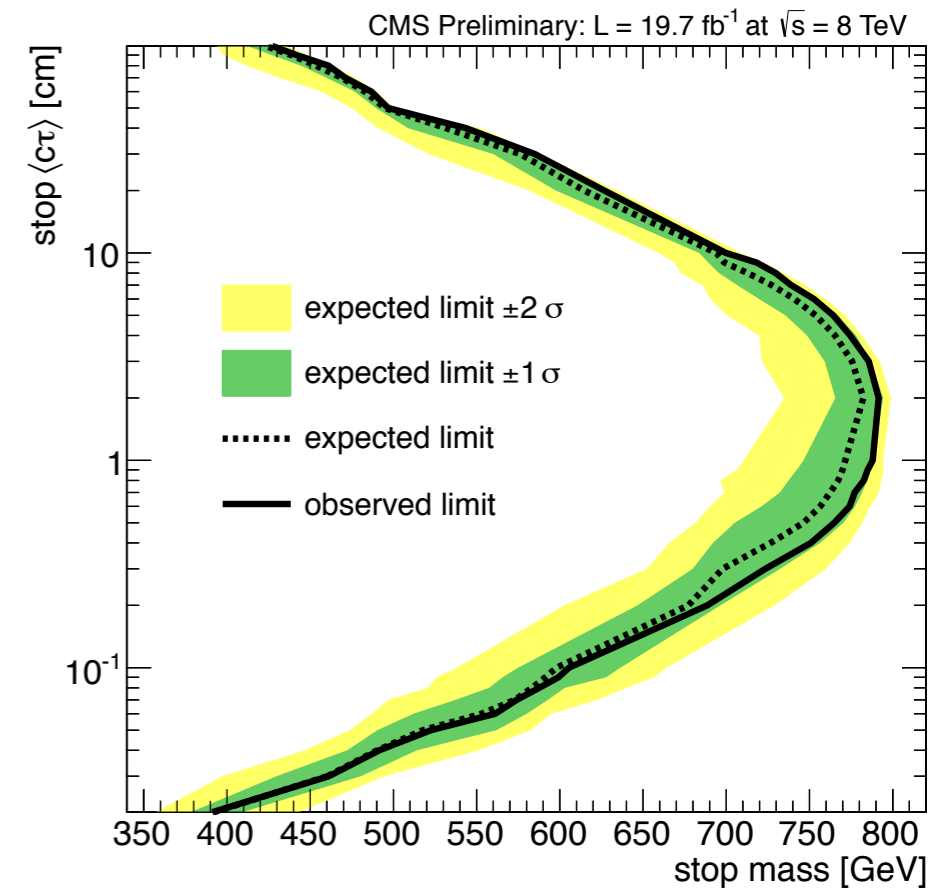| Event Source	0.02 cm $< |d_0| <$ 0.05 cm	0.05 cm $< |d_0| <$ 0.1 cm	$|d_0| >$ 0.1 cm
other EWK	$0.65 \pm 0.13 \pm 0.08$	$(0.89 \pm 0.53 \pm 0.11) \times 10^{-2}$	$< (89 \pm 53 \pm 11) \times 10^{-4}$
top	$0.767 \pm 0.038 \pm 0.061$	$(1.25 \pm 0.26 \pm 0.10) \times 10^{-2}$	$(2.4 \pm 1.3 \pm 0.2) \times 10^{-4}$
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	$4.73 \pm 0.30 \pm 0.17$	$5.57 \pm 0.32 \pm 0.20$	$26.27 \pm 0.70 \pm 0.93$

DISPLACED DIJETS

- Massive long-lived particles can decay to jets
  - Split SUSY, RPV SUSY, Gauge Mediated SUSY, Hidden Valley models, etc.

- Search for events with **dijets from a common, displaced vertex**
  - Trigger on events with $H_T > 300$ GeV and **≥2 jets with small fraction of prompt tracks**
    - Offline: form multivariate discriminant based on vertex track multiplicity, fraction of tracks with positive d0, # of missing hits, and variables from a **dedicated track clustering algorithm**


control sample
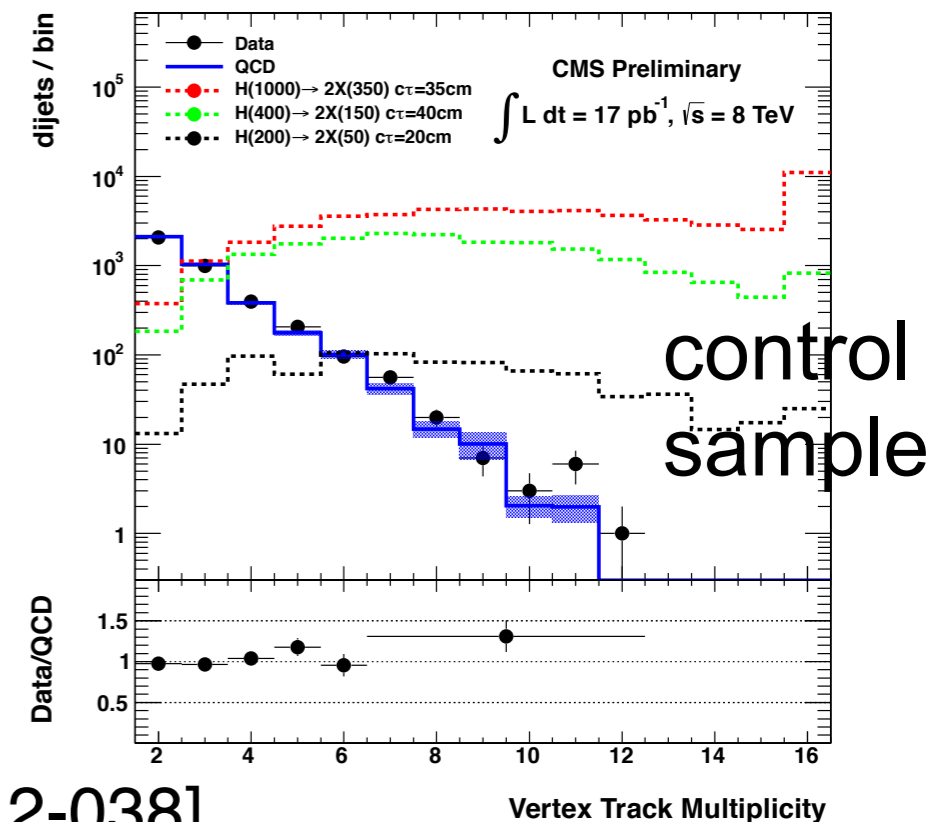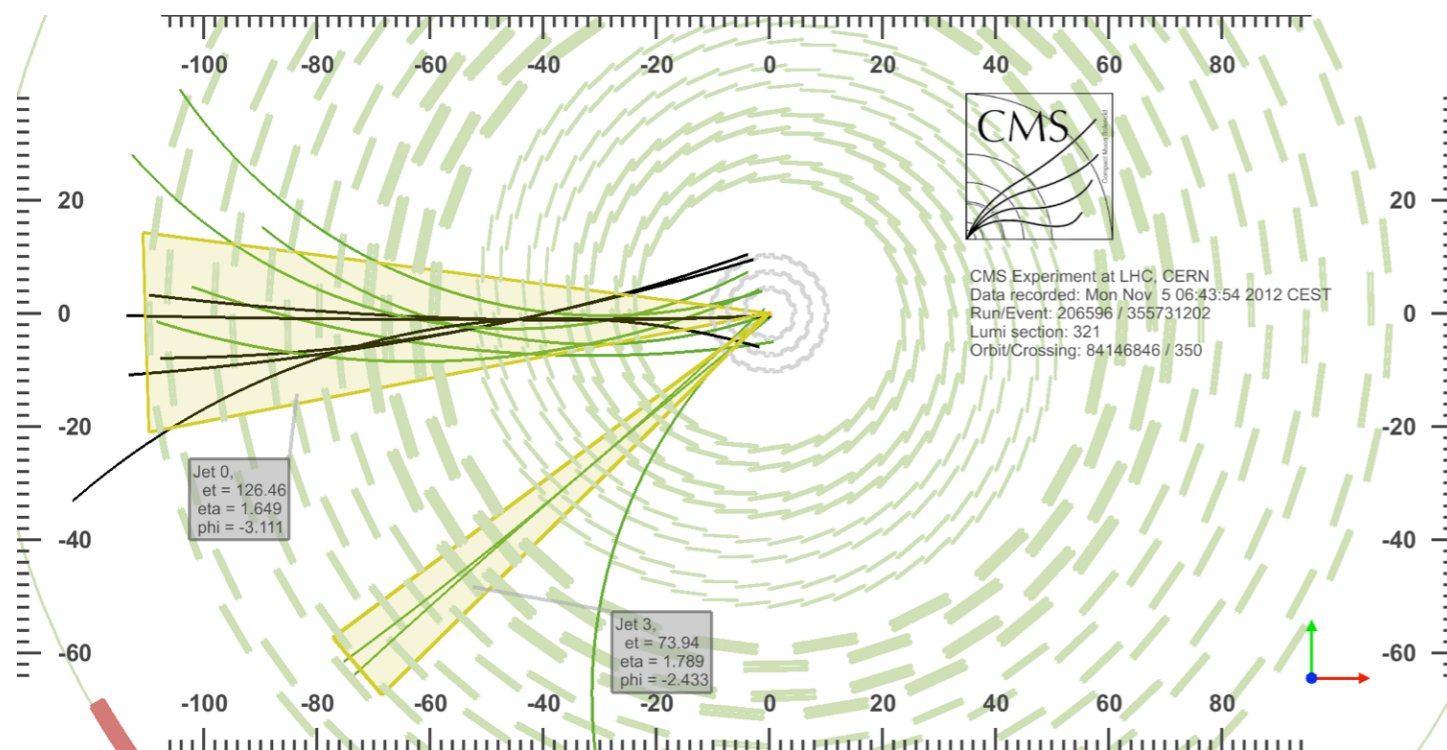
[EXO-12-038]

DISPLACED DIJETS

- **Search strategy: Identify two (overlapping) search regions targeting signals with low and high L_{xy}**

L_{xy}	< 20 cm(low)	> 20 cm(high)
prompt tracks	≤ 1	≤ 1
prompt energy fraction	< 0.15	< 0.09
vertex/cluster disc.	> 0.9	> 0.8
expected background	$1.60 \pm 0.26(stat.) \pm 0.51(syst.)$	$1.14 \pm 0.15(stat.) \pm 0.52(syst.)$
observed	**2**	**1**

Table 1: Predicted background and the number of observed candidates for optimised selections.

- **Use data-driven techniques (generalized ABCD method) to estimate backgrounds**

low L_{xy}

[EXO-12-038]

high L_{xy}
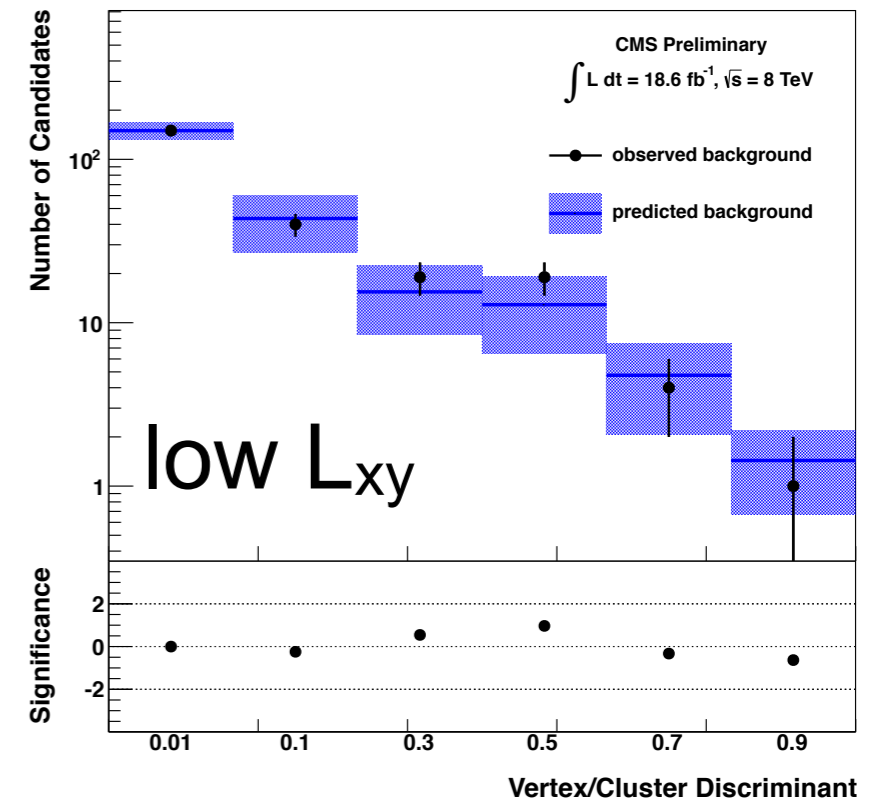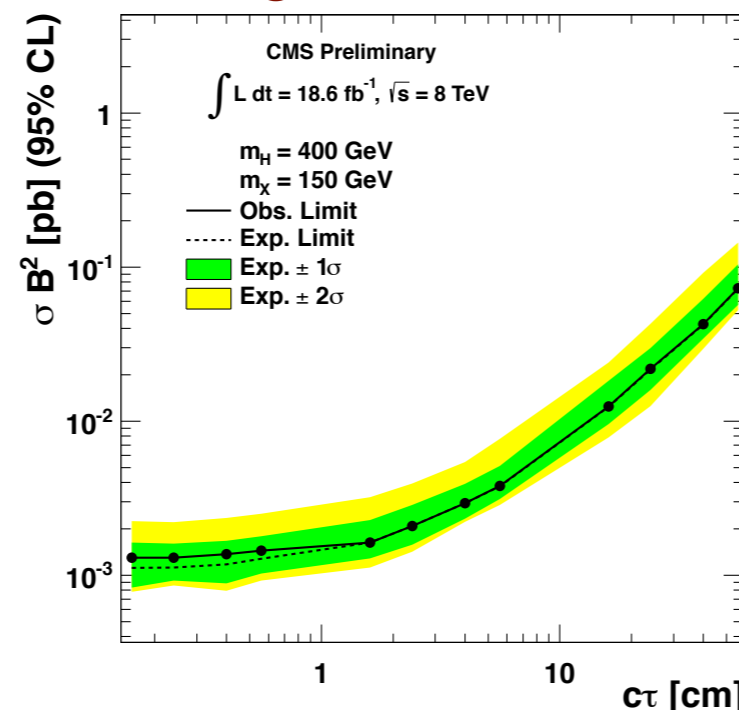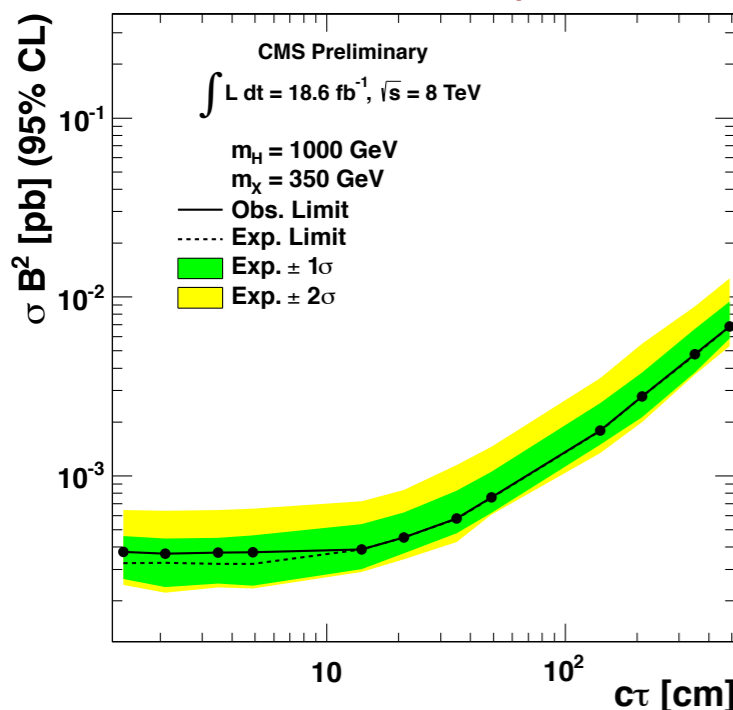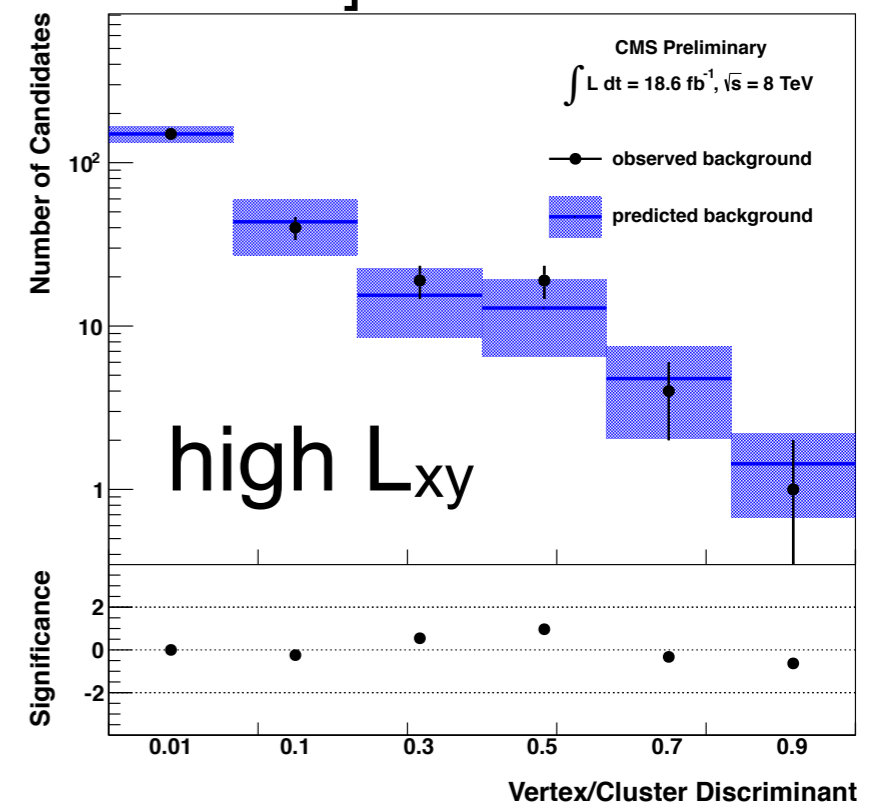
Set limits on H→XX→(jj)(jj)

CONCLUSIONS

- The CMS ~~Hidden Valley~~ long-lived program is active and much more is in the pipeline
  - Still, we're only beginning to scratch the surface
    - Need to cover a greater diversity of final states
    - Need to probe both shorter lifetimes and longer lifetimes
  - More to go with the 8 TeV program, and 13 TeV looks to be promising

  - Stay tuned!