Search for long-lived particles at CMS

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for the CMS Collaboration

Outline

- Brief introduction to long-lived particle
- Neutral long-lived particles
  - Search for displaced lepton pair **CMS-PAS-EXO-11-004**
  - Search for displaced photon **CMS-PAS-EXO-11-067**
- Heavy stable charged particles
  - Stopped gluino/stop search **CMS-PAS-EXO-11-020**
  - Slowly moving gluino/stop/stau/hyperk searches **CMS-PAS-EXO-11-022**
- Conclusions

Introduction

Long-lived massive particle

- Neutral
  - ~cm < $\beta\gamma c\tau$ < detector scale: non-prompt decay to
    - displaced leptons
    - displaced photon+X
    - displaced jets, top, W, Z…..
  - $\beta\gamma c\tau$ > detector scale: decay outside detector
    - MET, covered by SUSY/DM searches.
- Charged
  - ~cm < $\beta\gamma c\tau$ < detector scale: kink/fork track
  - $\beta\gamma c\tau$ >detector scale: decay outside detector or readout time window → Heavy Stable Charged Particle (HSCP)

Theoretical Motivation:
SUSY, Extra Dimension, Hidden Valley and other BSMs.

Neutral long-lived particles searches at CMS

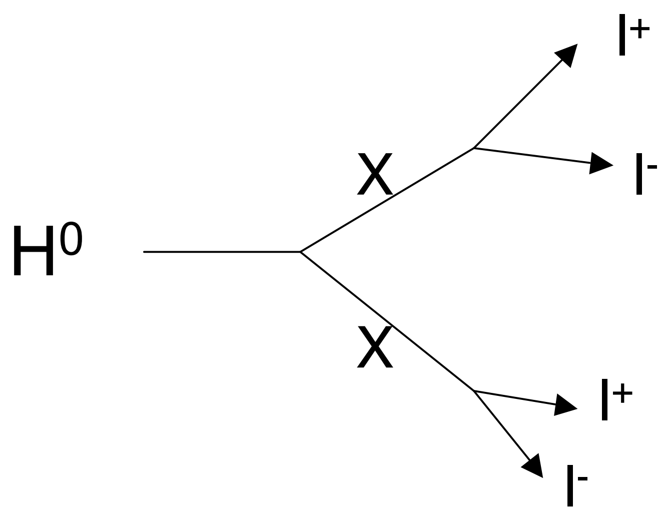
- displaced leptons **CMS-PAS-EXO-11-004**
- displaced photon **CMS-PAS-EXO-11-067**

Displaced Lepton Pair

Model considered:

$gg \rightarrow H^0 \rightarrow 2X$, $X \rightarrow l^+l^-$ X being long-lived spin 0 particle.

- Different Higgs (200-1000 GeV) and X boson (20-500 GeV) masses, with X boson lifetimes $c\tau$=1.5-40 cm
- Br($X \rightarrow ee/\mu\mu$) is set to 50% each

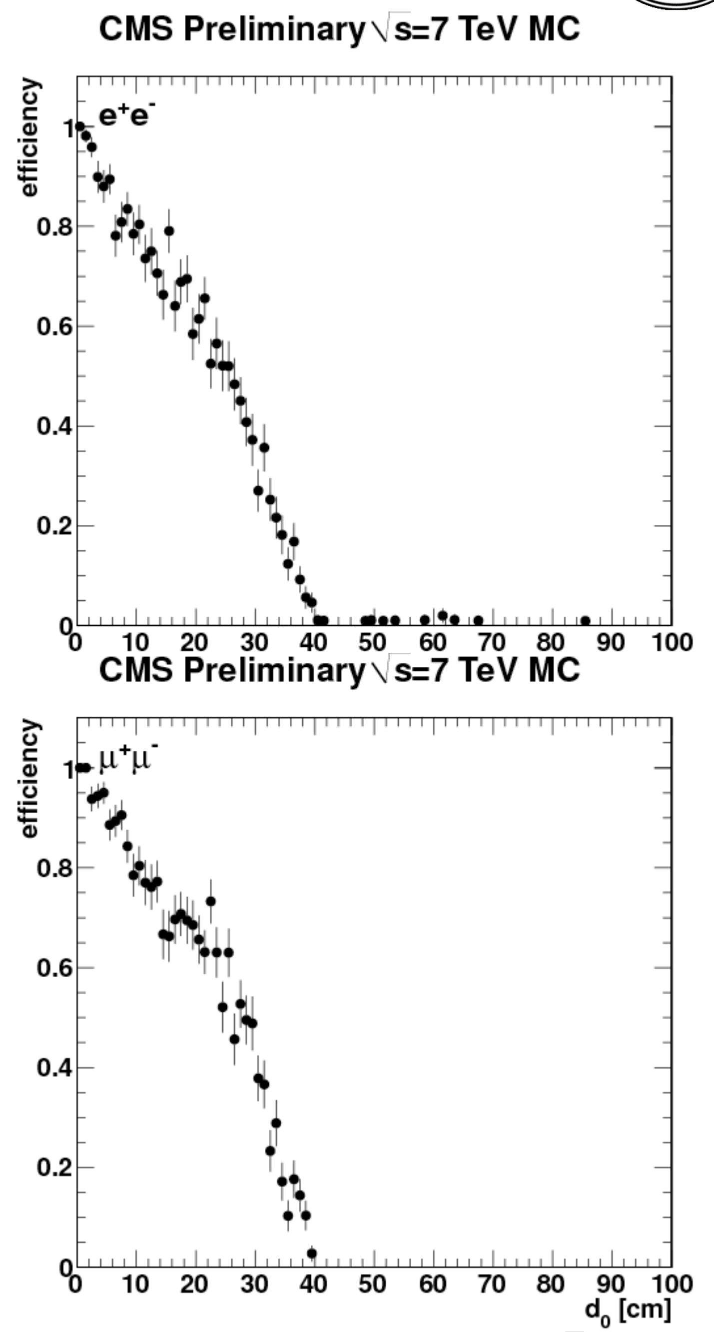


Displaced Lepton Pair

- Dataset: 1.1~1.2 fb^{-1} from 2011 run
- Trigger: di-μ(e) each with p_T>33(23) GeV

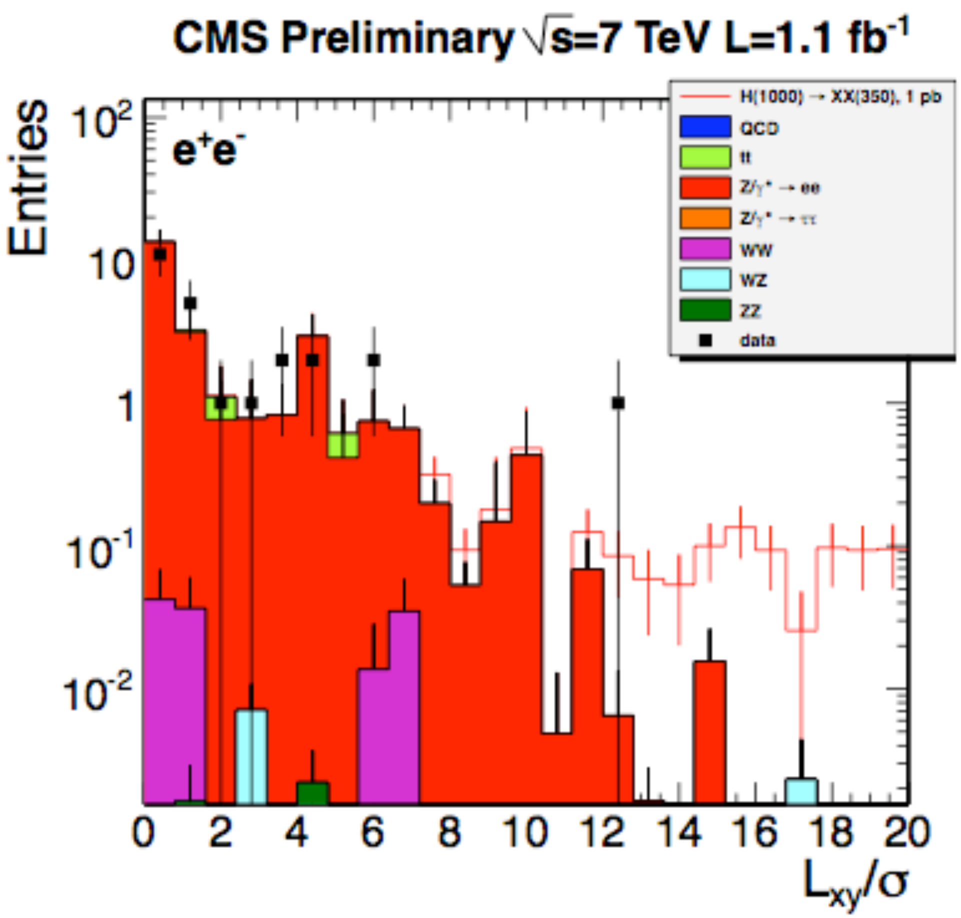
- Displaced track reco: seeding from SST stereo layers, can reconstruct tracks missing the primary vertex by nearly half a meter

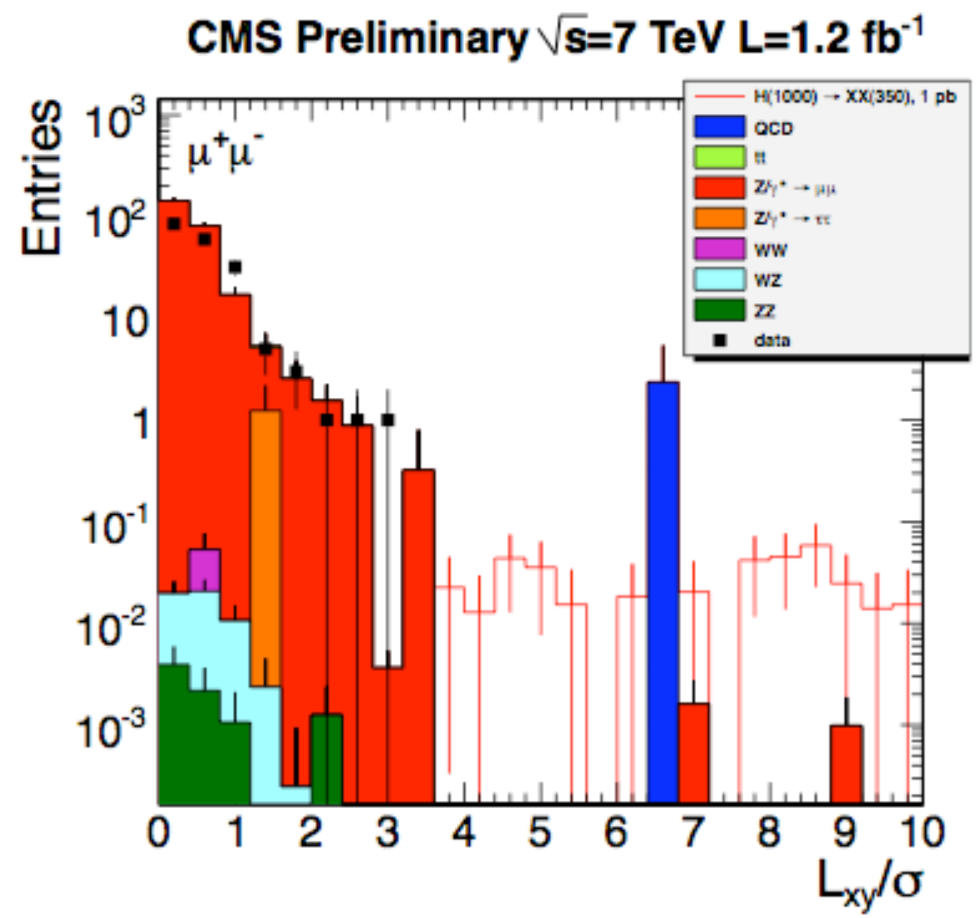
- Selection:
  - primary vertex; isolated, high purity track
  - opposite charged pair with well fitted common secondary vertex
  - collinearity angle< 0.2(0.8) between di-lepton total momentum and vector from primary to secondary vertex
  - lepton-id: only trigger matching required



Displaced Lepton Pair

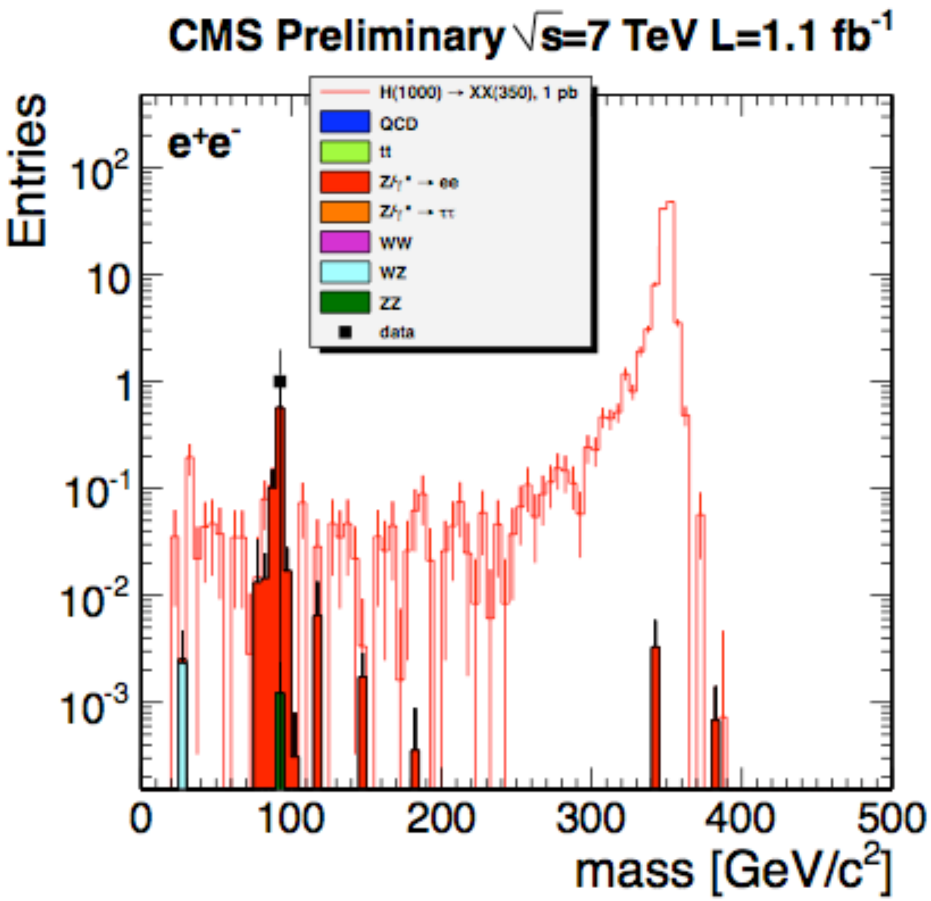
- Signal MC: $H^0 \rightarrow 2X$, $X \rightarrow l^+l^-$
- Look for one or two displaced vertices from oppositely charged leptons, the vertex significance (L_{xy}/σ) > 8(5) (e/μ)

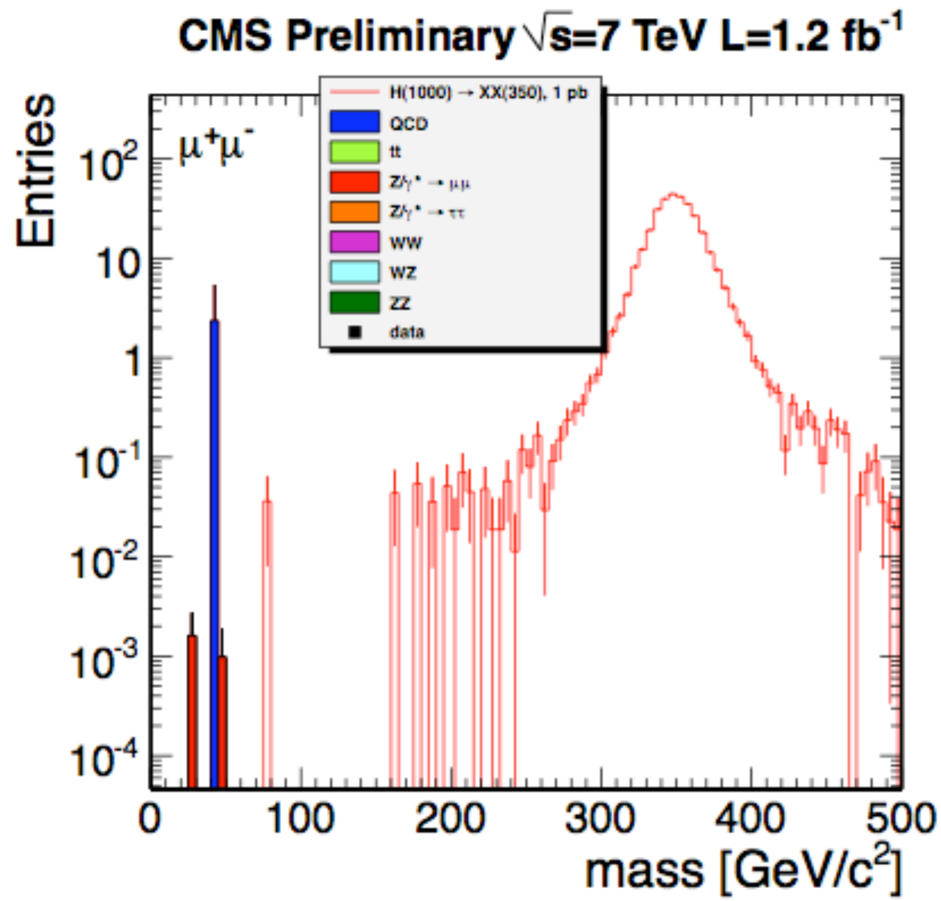




Displaced Lepton Pair

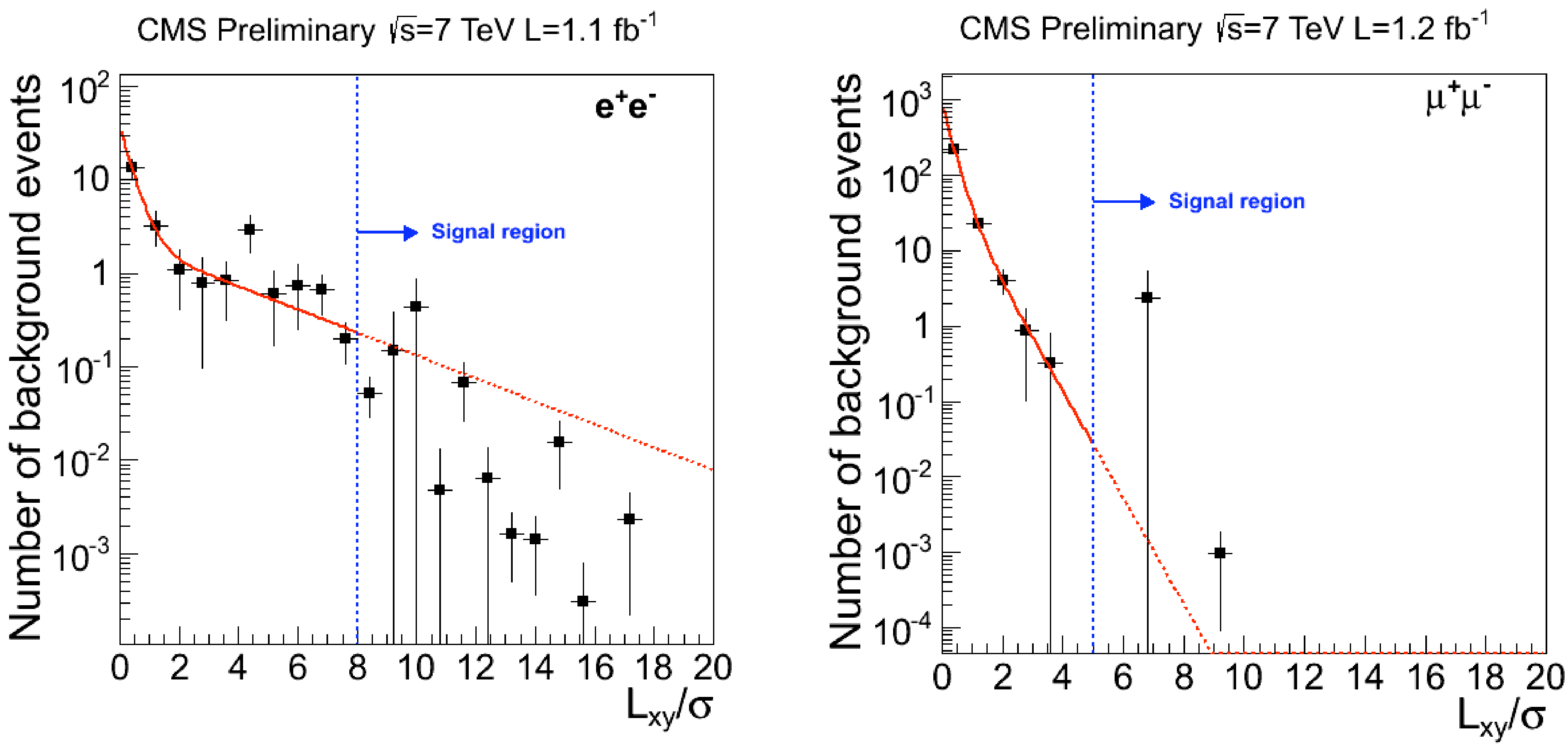
- Reconstructed di-lepton mass





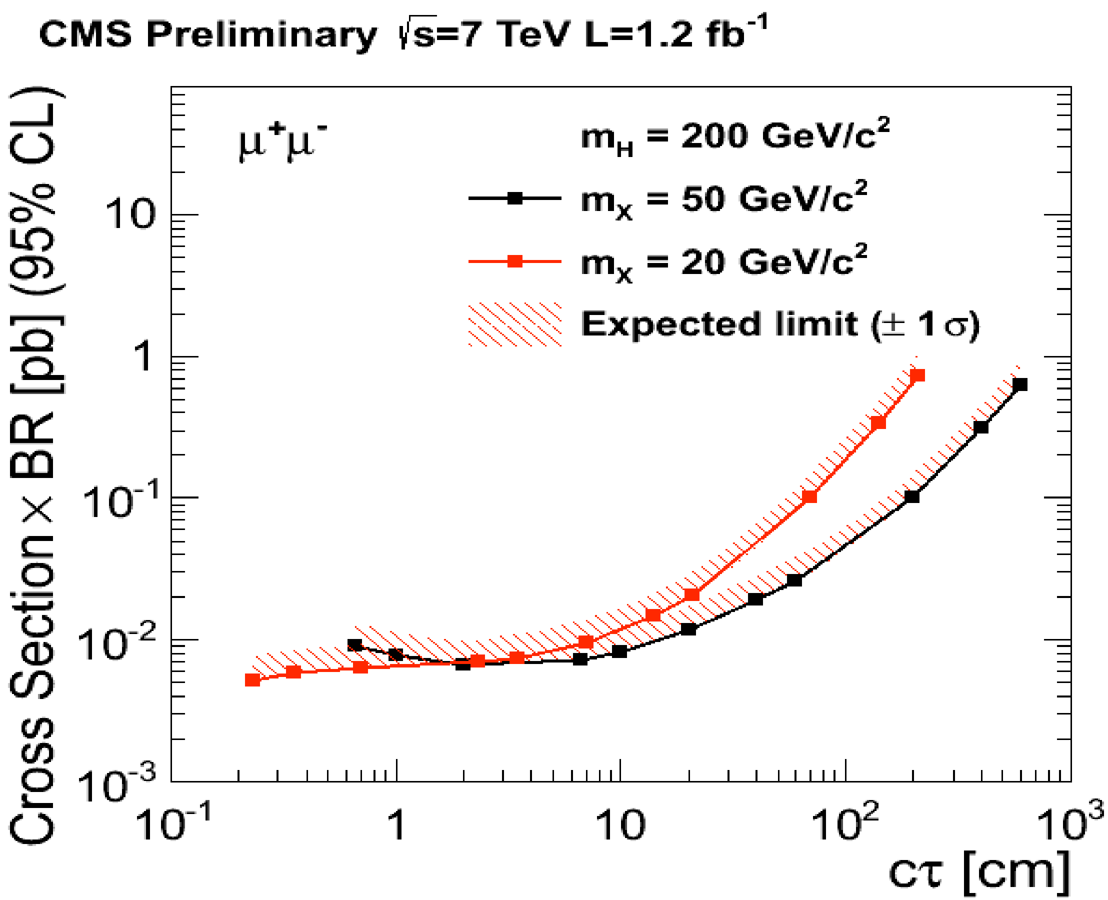
Displaced Lepton Pair

- Background is estimated with fit in control region of MC, extrapolating to signal region
- Difference to direct MC prediction as systematic

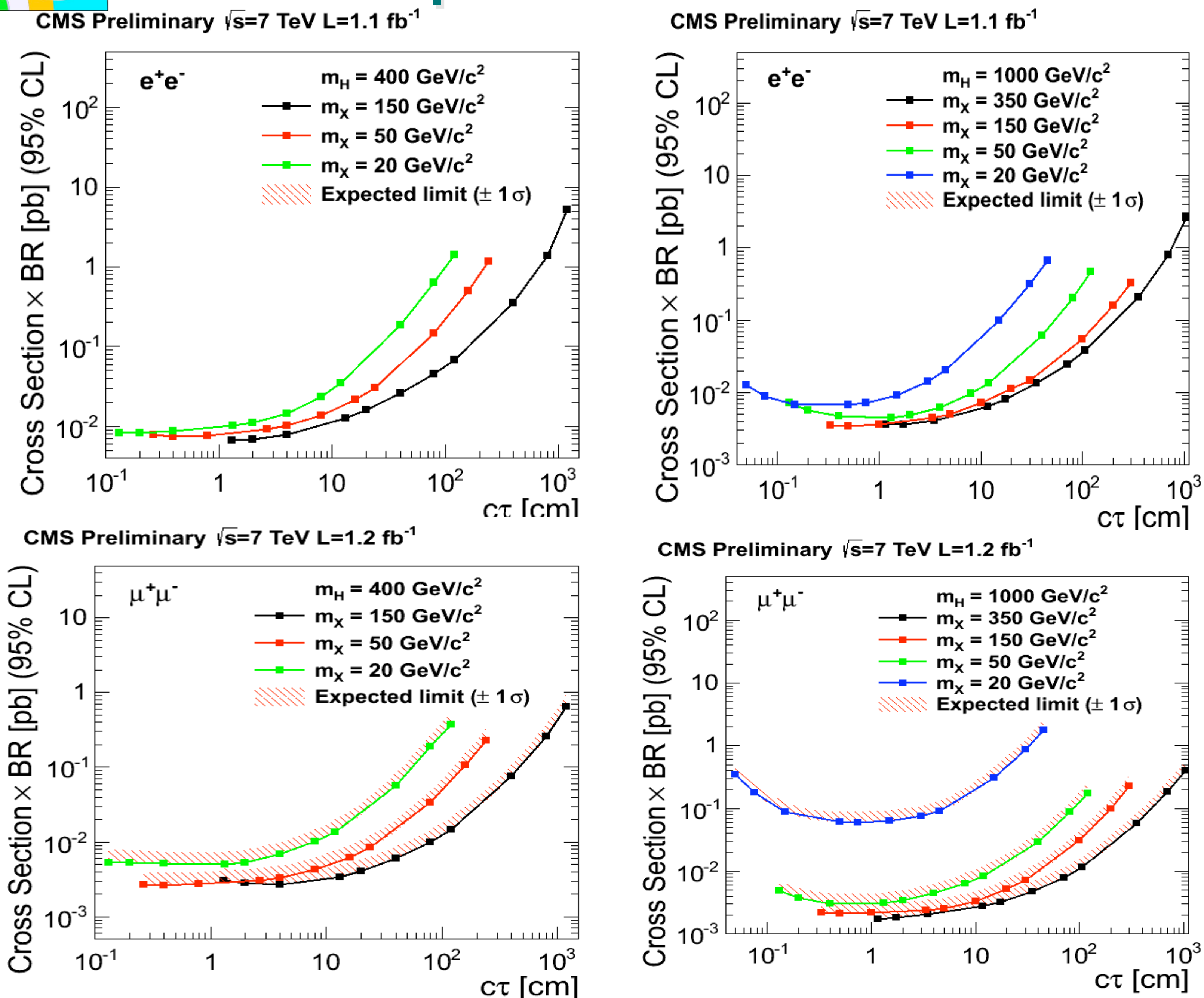


Displaced Lepton Pair

- For $H^0 \rightarrow 2X$, $X \rightarrow l^+l^-$, selection efficiency
  - 20-30%(mu channel)
  - 10-20%(electron channel)
- Interpret 95% CL limits in mass of X boson for fixed H^0 mass



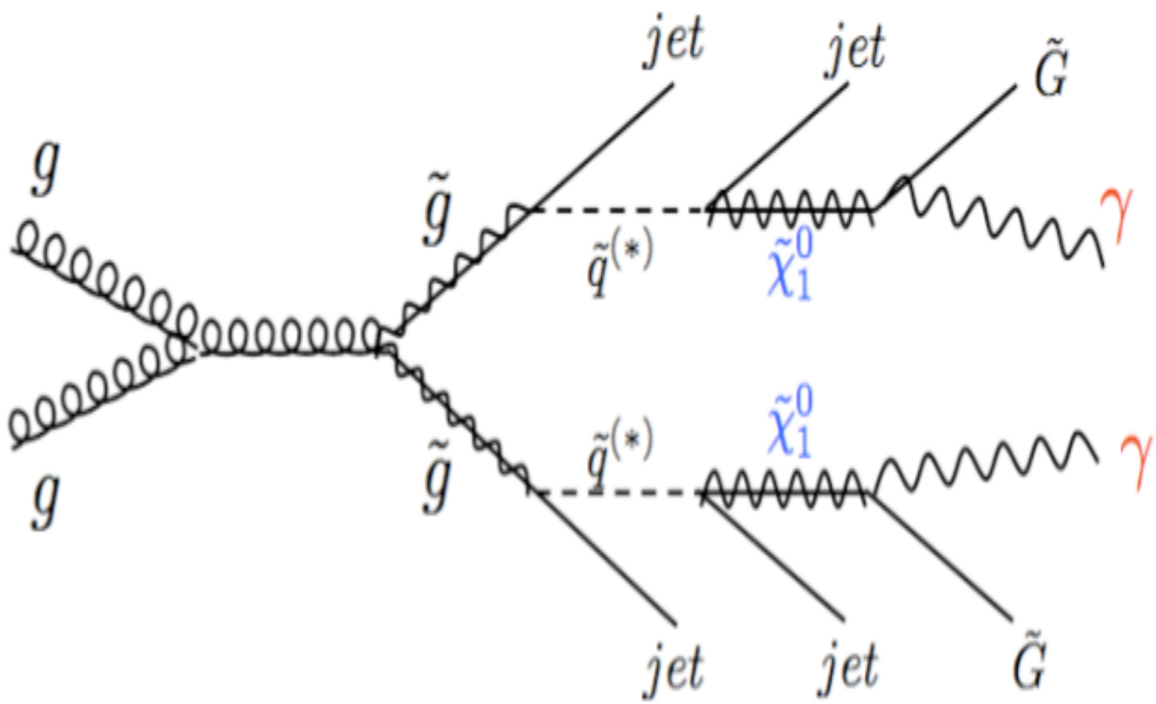
Displaced Lepton Pair



Limits for other H^0 masses

Displaced Photon

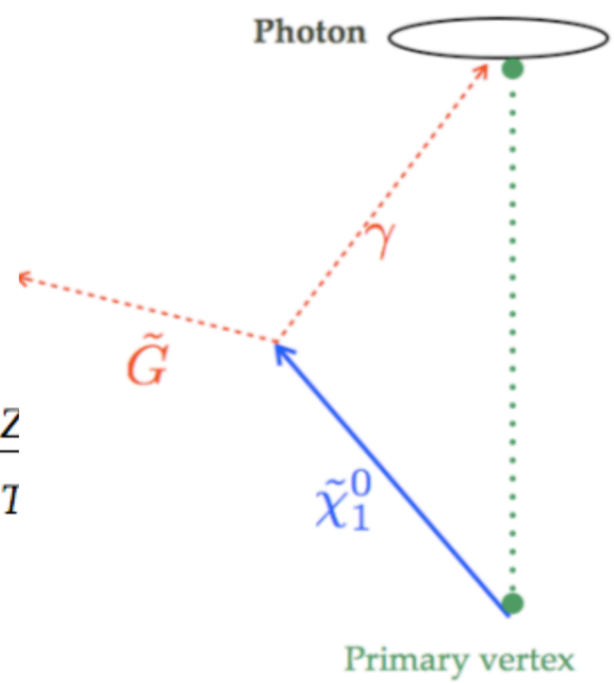
- GMSB motivation
- Long-lived 140 GeV neutralino with 2cm <cτ< 25cm

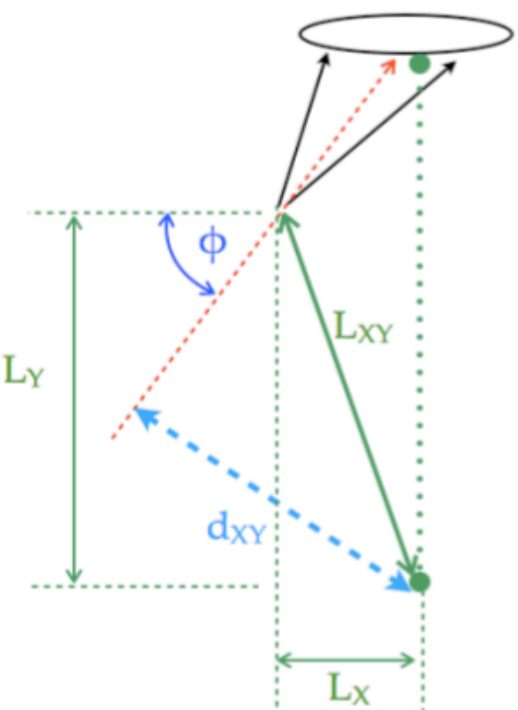


Displaced Photon

- Dataset: 2.1 fb^{-1} from 2011 run.
- Trigger: di-photon Et>32(22) to 40(28) Gev for leading (sub-leading) photon.
- Offline Selection:
  - isolated photon E_T>45 GeV; jets: p_{T1}>80, p_{T2}>50 GeV in $|\eta|$<2.6; MET > 30 GeV
- Converted photon selection:
  - Transverse impact parameter d_{XY} > 0.6 cm.
- Background:
  - data driven estimation

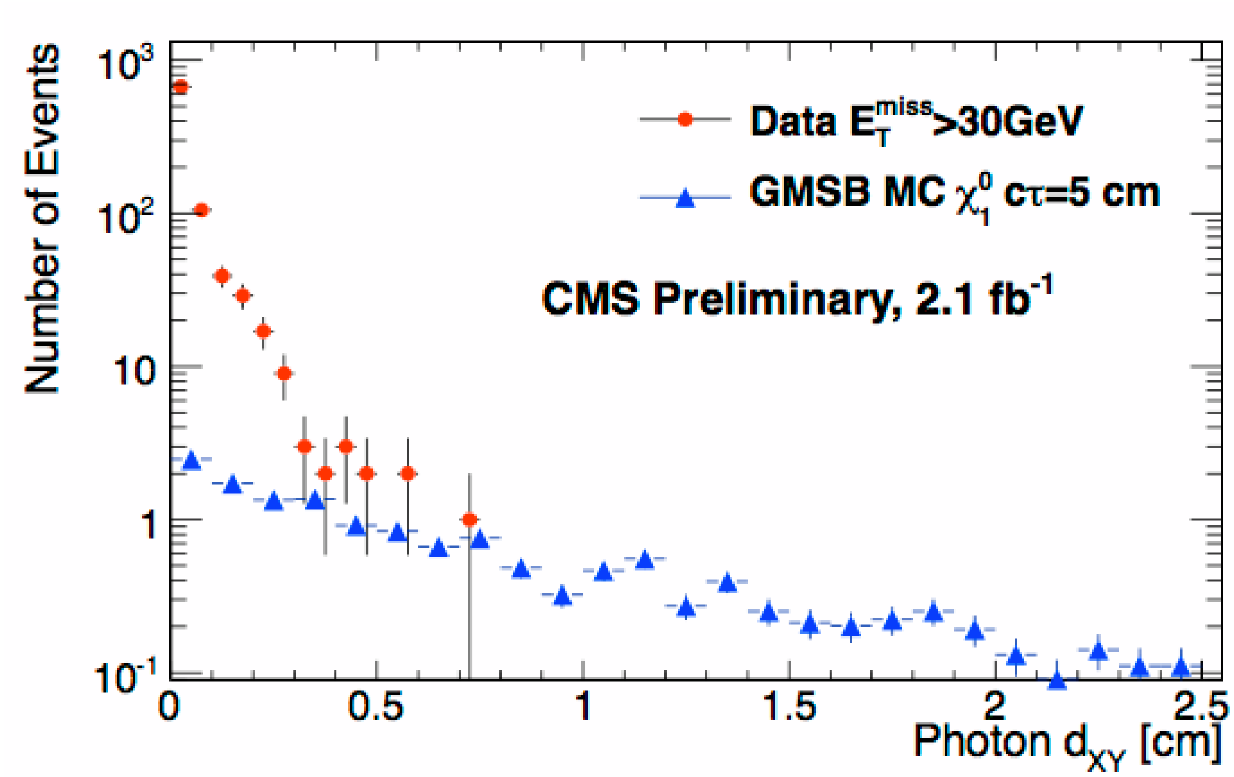
$$d_{XY} = -L_X \cdot \sin\phi + L_Y \cdot \cos\phi$$
$$d_Z = L_Z - \frac{L_X \cdot p_X + L_Y \cdot p_Y}{p_T} \cdot \frac{p_Z}{p_T}$$





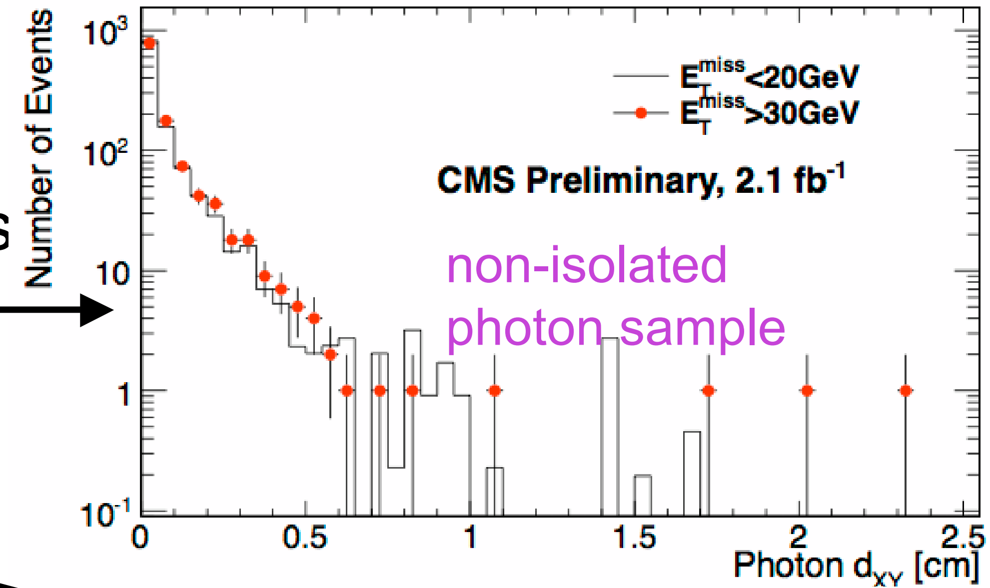
Displaced Photon

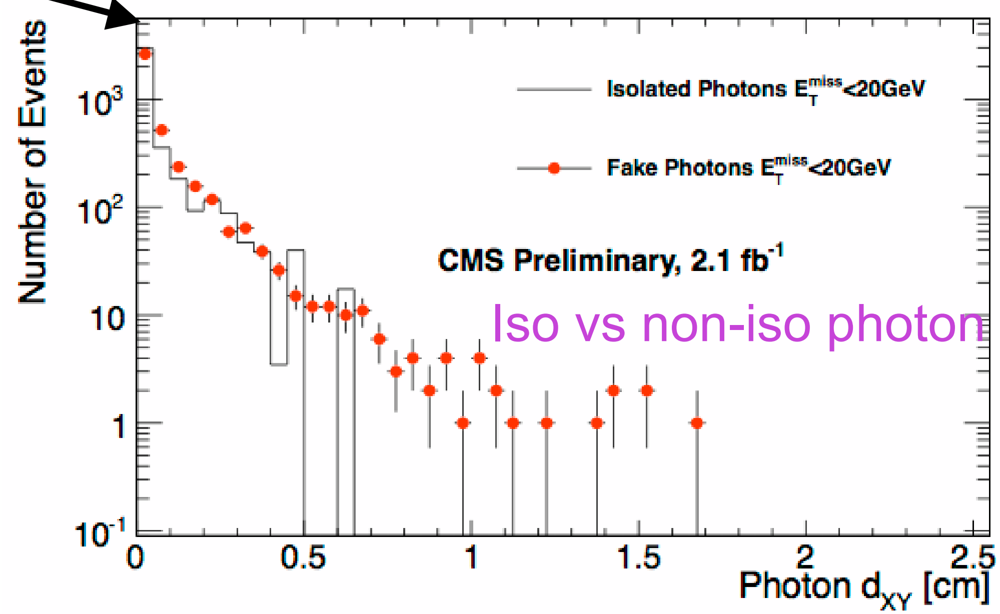
d_{XY} distribution for data with MET>30 GeV vs. signal simulation for $c\tau$ = 5 cm, normalized to luminosity



Displaced Photon

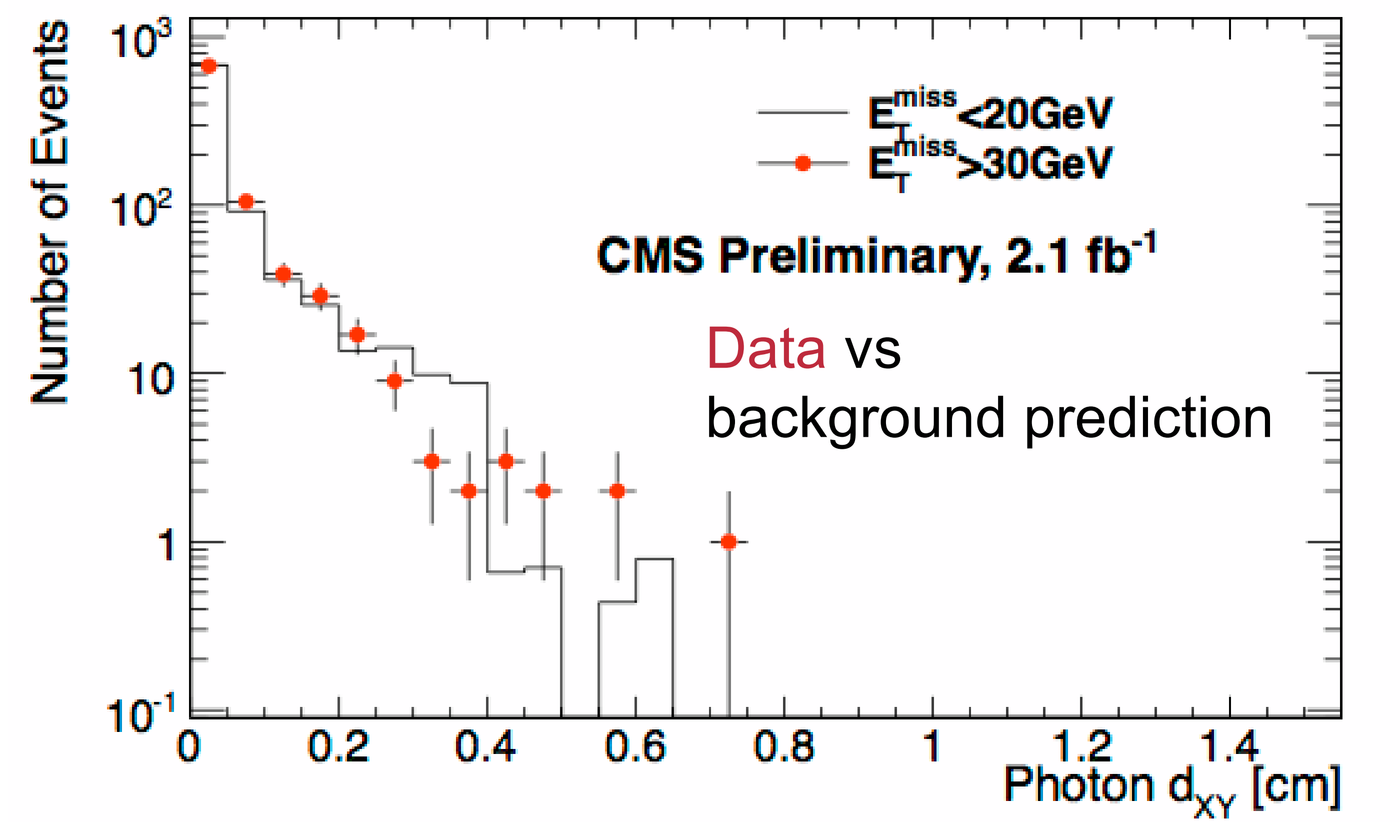
- Photon d_{XY} comparison for
  - non-isolated(fake) photons in low/high MET region.
  - isolated photons, fake photons in same low MET region.
- d_{XY} independent of MET
- Background can be predicted using MET<20 control sample.





Displaced Photon

- Isolated photon d_{XY} for MET<20 GeV (background region) and MET>30 GeV (signal region)

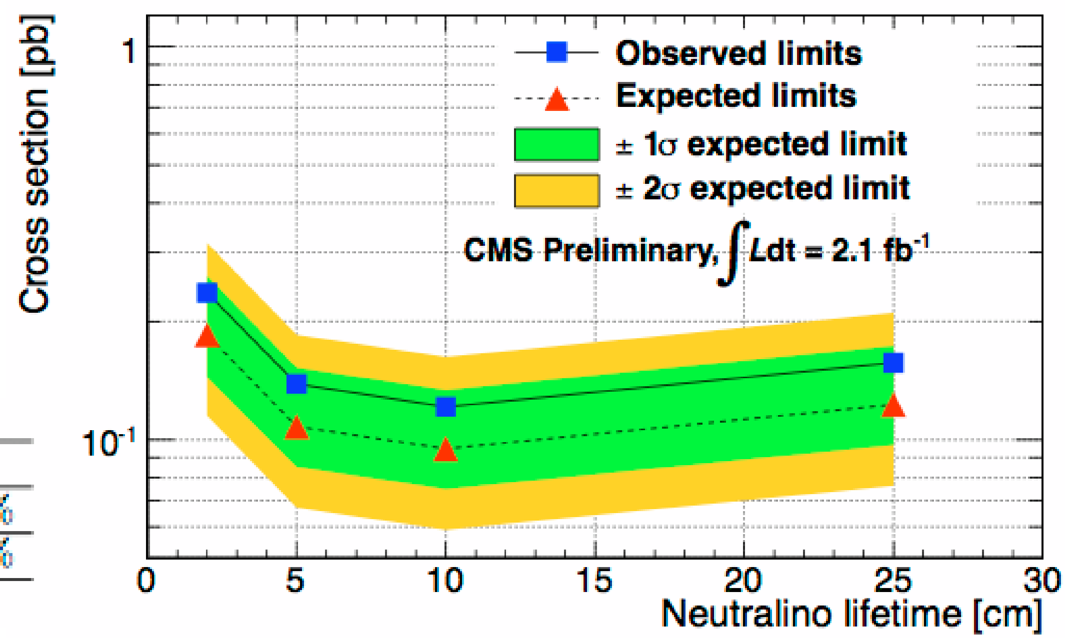


Displaced Photon

- conversion reco systematic 20% from $Z \rightarrow \mu\mu\gamma$ data-MC comparison

Systematics	Uncertainty (%)
Integrated luminosity	4.5
Jet p_T/E_T^{miss} energy scale	<0.5
Pile-up	2.5
Photon identification Data/MC scale	2.6
Photon-electron difference	0.5
Conversion reconstruction efficiency	20.6
Photon d_{XY} resolution	<0.5
Total	25

- 95% C.L. upper limits on neutralino productions cross section as a function of neutralino lifetime.



- Event selection efficiency vs neutralino lifetime.

$c\tau$ [cm]	2	5	10	25
Efficiency	0.921%	1.578%	1.797%	1.388%
Statistical errors	0.046%	0.059%	0.064%	0.055%

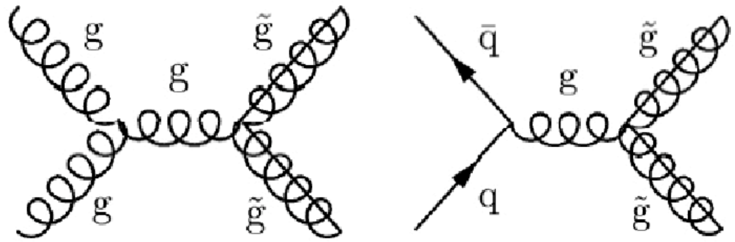
Heavy Stable Charged Particles

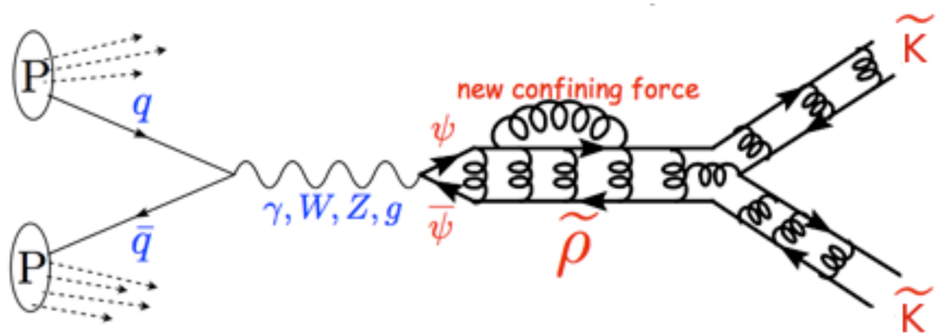
- stopped HSCP search **CMS-PAS-EXO-11-020**
- slow moving HSCP search **CMS-PAS-EXO-11-022**

HSCP

Model Considered:

- pair produced gluino/stop (R-hadrons)
- pair produced stau (lepton-like)
- stau from GMSB SPS7 cascade decay
- pair produced hyper-k (through DY + hyper-rho resonance)





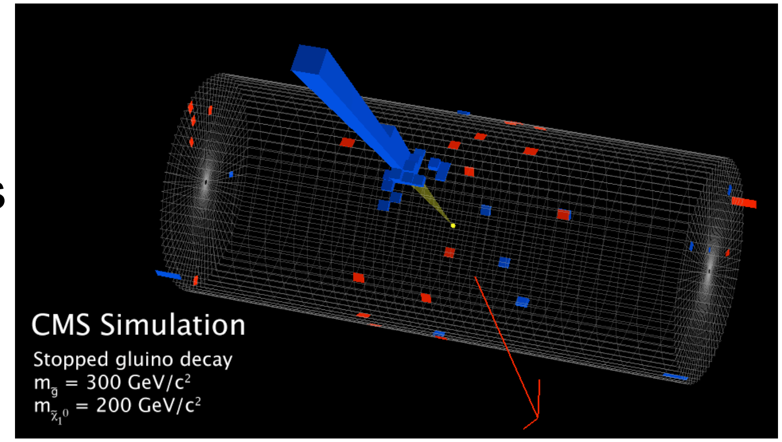
Lepton-like HSCPs behave like (heavy) muons with large ionization energy loss

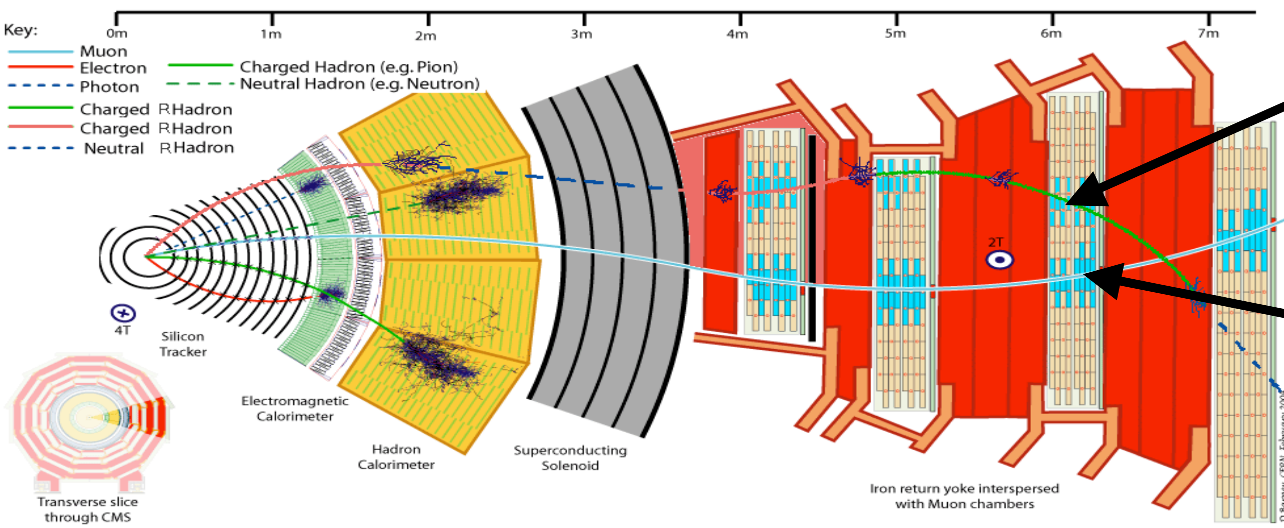
R-Hadron, also has hadronic interactions

- Cloud model: most R-hadrons end up charged after several interactions. Eur. Phys. J. C50 (2007) 353
- Charge suppression interaction scenario: all R-baryons become neutral after a hadronic interaction

HSCP detection

- HSCPs can possibly stop inside (β<0.4) or slowly escape (0.4<β<0.9) detector
- Stopped HSCP: look for energetic hadronic jet from HSCPs decaying when beam off or during beams collisions intervals
- Slowly moving HSCP: measure β from delayed time of flight (T.O.F) and tracker dE/dx (ionization energy loss per path length)
  - Can measure mass from p/(βγc)
- Two searches are complimentary





R-hadron

μ/Lepton-like HSCP

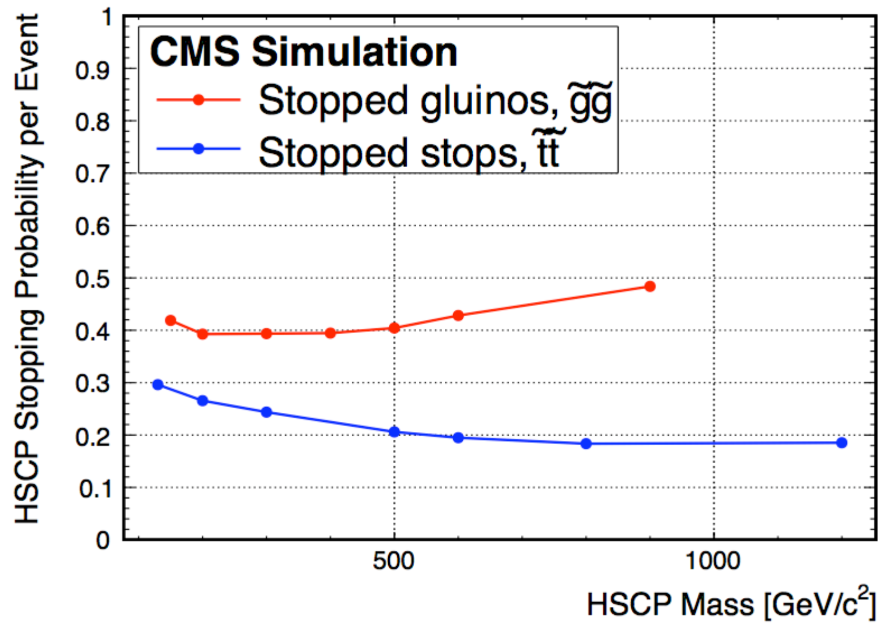
Stopped HSCP

Data Samples:

- 168 hours of trigger live-time LHC fills, peak luminosity up to 10^{33} cm^{-2} s^{-1}
- 2010 data with peak luminosity of 10^{28}~10^{32} cm^{-2} s^{-1}, as background control sample

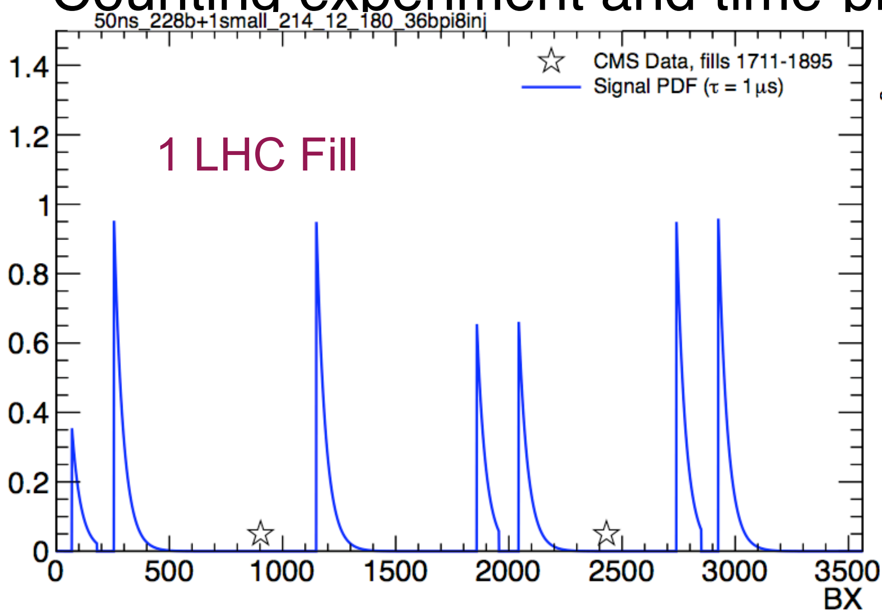
Selection:

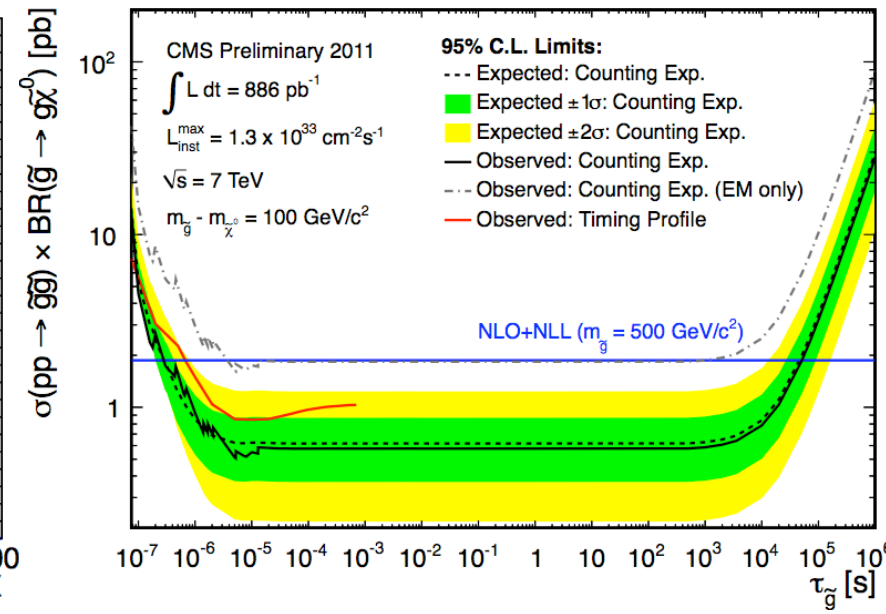
- dedicated 50 GeV jet trigger: no signals from beam position and timing (BPTX) monitors in a window of ±1 Bunch Crossing (BX)
- 70 GeV jet energy requirement
- beam-related, cosmic and instrumental background rejection



Stopped HSCP

Counting experiment and time-profile analysis are performed



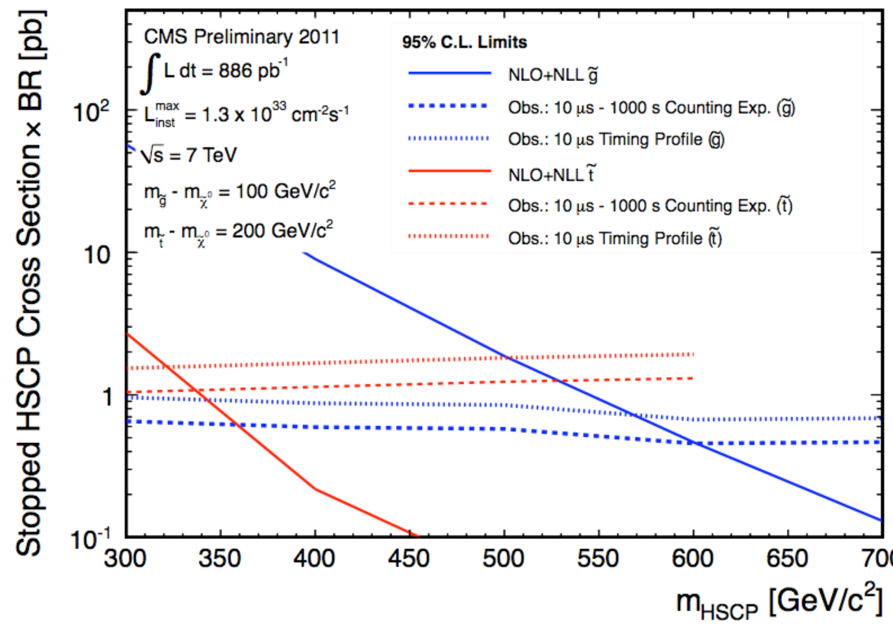


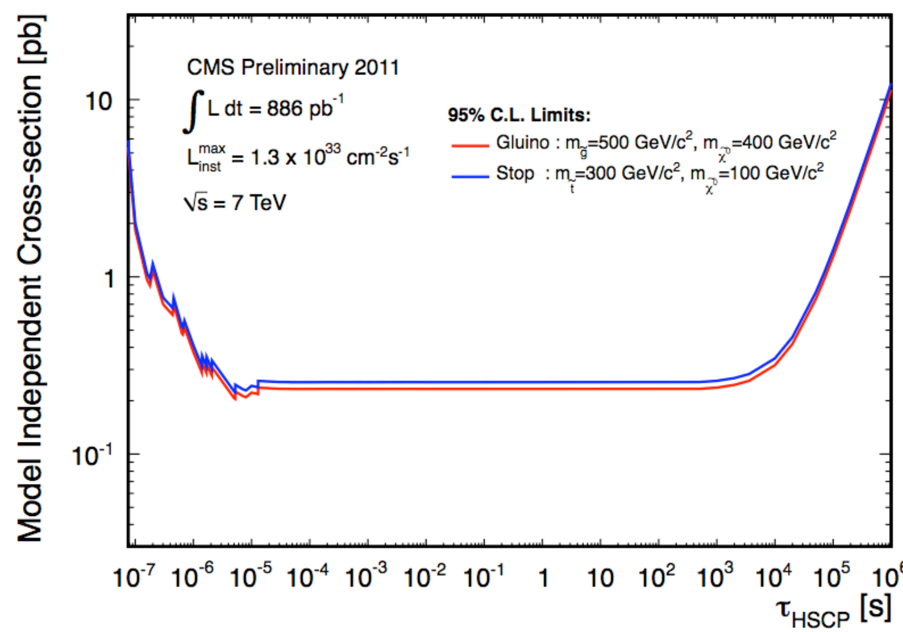
Lifetime	$L_{eff}(pb^{-1})$	Expected Bg	Observed
75 ns	4.3	0.11 ± 0.05	0
100 ns	12.5	0.35 ± 0.14	0
1 μs	139	3.3 ± 1.3	4
10 μs	352	10.1 ± 4.1	9
30 μs - 10^3 s	360	10.4 ± 4.2	10
10^4 s	268	10.4 ± 4.2	10
10^5 s	65	10.4 ± 4.2	10
10^6 s	7.5	10.4 ± 4.2	10

Counting Exp.

Stopped HSCP

- Gluino
  - M_{gluino} - $M_{neutralino}$ > 100 GeV, Br(gluino → g + neutralino) =100%, m_{gluino} < 601 GeV are excluded @95% C.L. for lifetimes from 10 μs to 1000 s
- Stop
  - For M_{stop} - $M_{neutralino}$ > 200 GeV, Br(stop → top + neutralino) =100%, m_{stop} < 337 GeV are excluded @95% C.L. for lifetimes from 10 μs to 1000 s
- 95% C.L. limits are also set for cross-section X BR X stopping efficiency to be interaction model independent

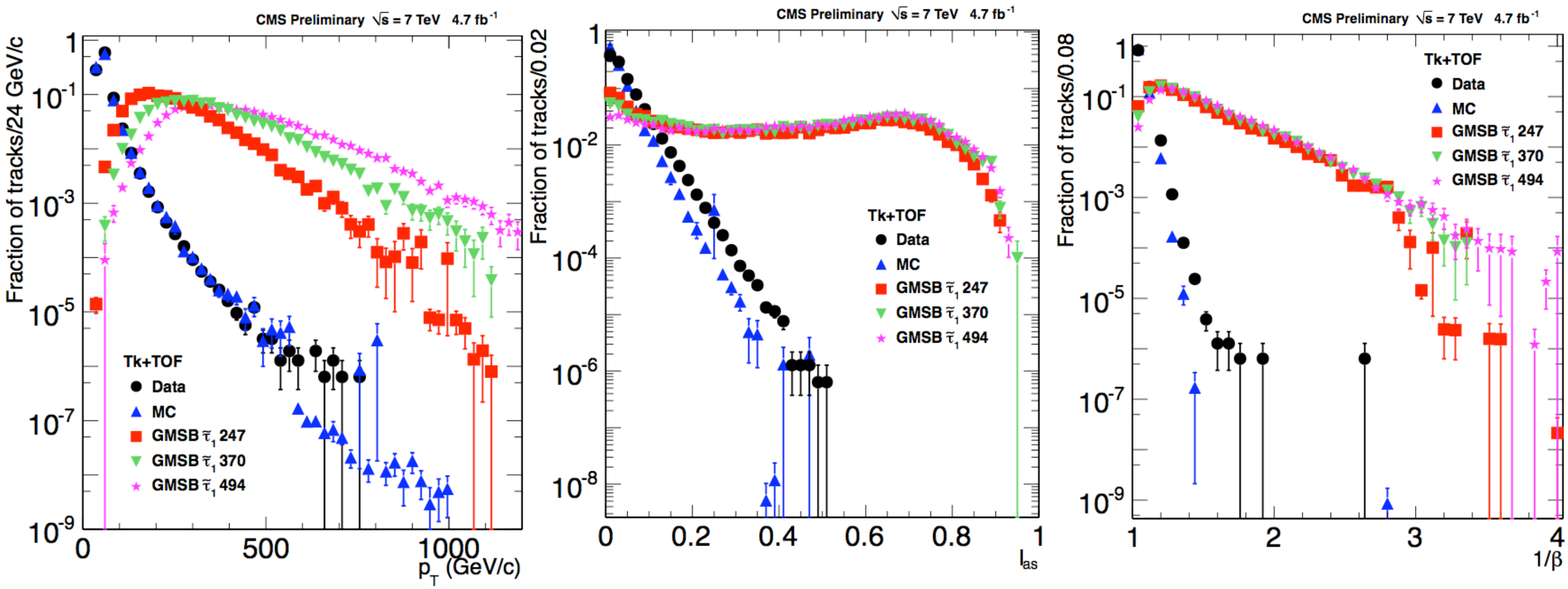




Slowly Moving HSCP

4.7 fb^{-1} data used with Muon40 and MET150 trigger

- Two analysis methods
  - ✓ Tracker-only (discriminator I_{as} from tracker dE/dx measument)
  - ✓ Tracker+TOF (β^{-1} measurement from muon system in addition)
- Look for enhancement in high I_{as}, high β^{-1} and high p_T region.



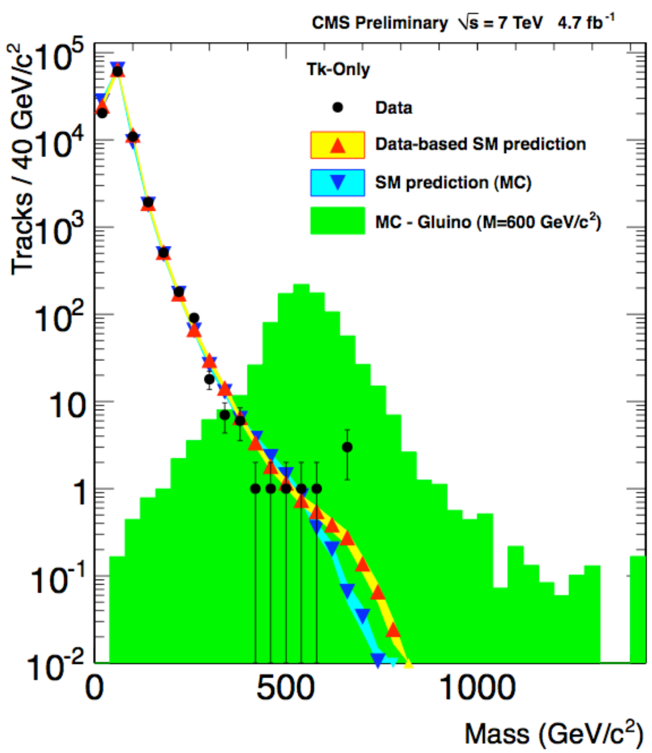
Slowly Moving HSCP

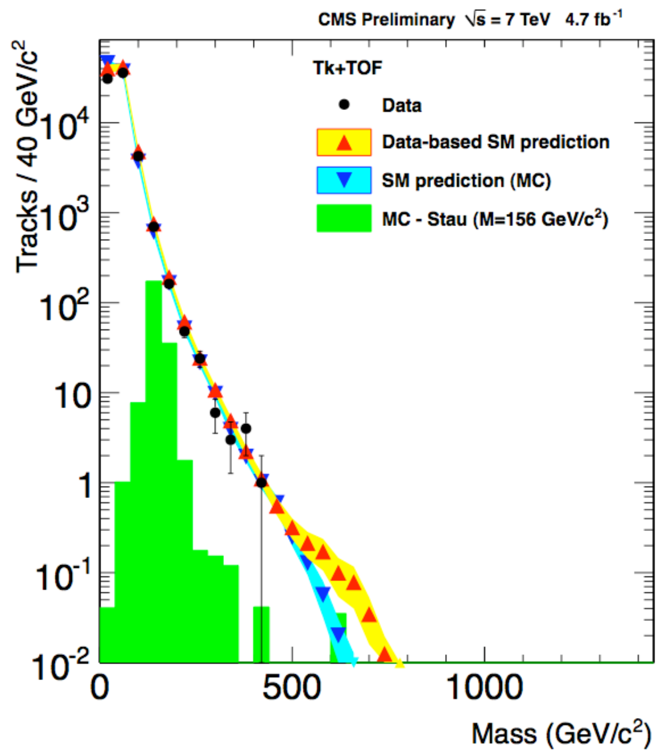
Background estimation :

- utilizing the non-correlation between I_{as}, β^{-1} and $p_{T,}$
- mass prediction from pseudo-exp, using p, I_h, and β^{-1} PDF from non-signal region

Counting experiment:

- in mass window $[M_{reco} - 2\sigma_{Mreco}$, 2 TeV]
- optimized I_{as}, β^{-1} and p_T selection for best reach



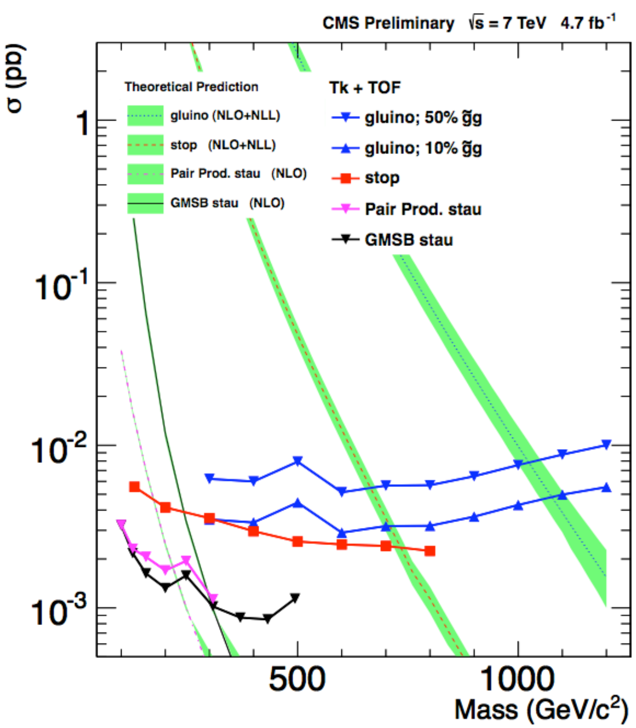


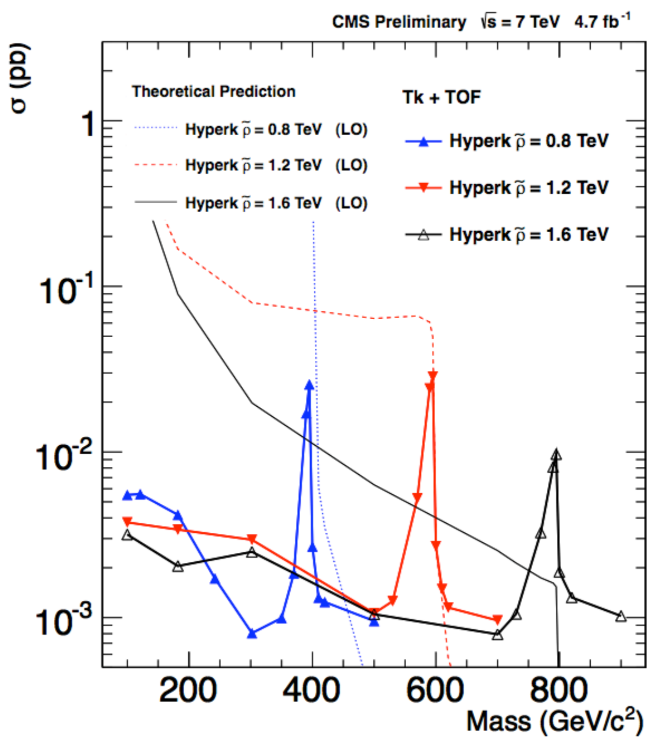
Slowly Moving HSCP

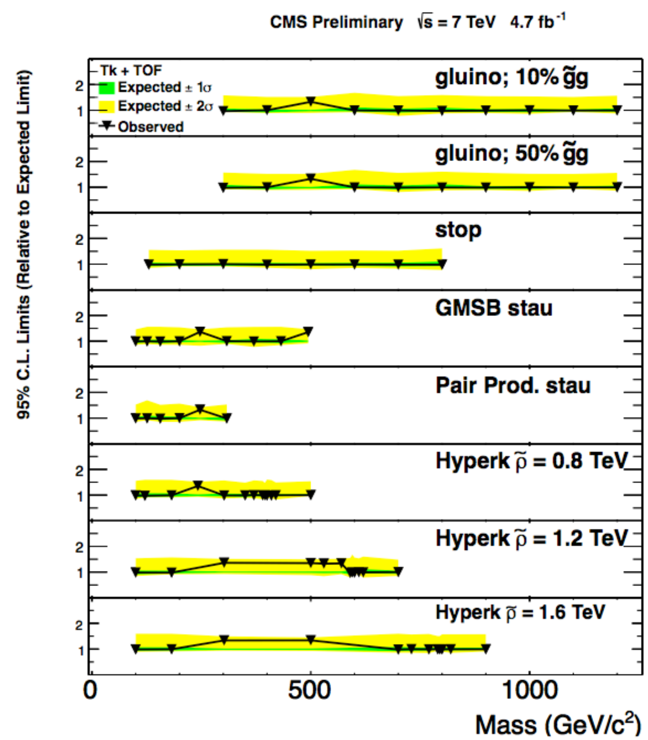
95% C.L. mass limits are set for

- Cloud model interaction scenario
  - Gluino (10% ~gg): 1091GeV, Stop: 735 GeV
- Charge suppression interaction scenario
  - Gluino(10% ~gg): 923 GeV, Stop: 623 GeV

- Direct pair produced stau: 232 GeV
- hyper-kaon: 482, 599, and 747 GeV for hyper-ρ masses of 800, 1200, and 1600 GeV







Summary

- With 1-4.7 fb^{-1} integrated luminosity, CMS searched various long-lived particle signatures.
  - displaced di-lepton
  - displaced di-photon
  - stopped and slow moving HSCPs
  - No significant excess observed
- 95% C.L. cross section limits are set on
  - Various BSM models
  - Significant improvement over our 2010 data limits
  - New displaced lepton/photon results
  - new models studied for HSCP analysis
- Results shown are available https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Stay tuned for more exciting long-lived particle searches

Back Up

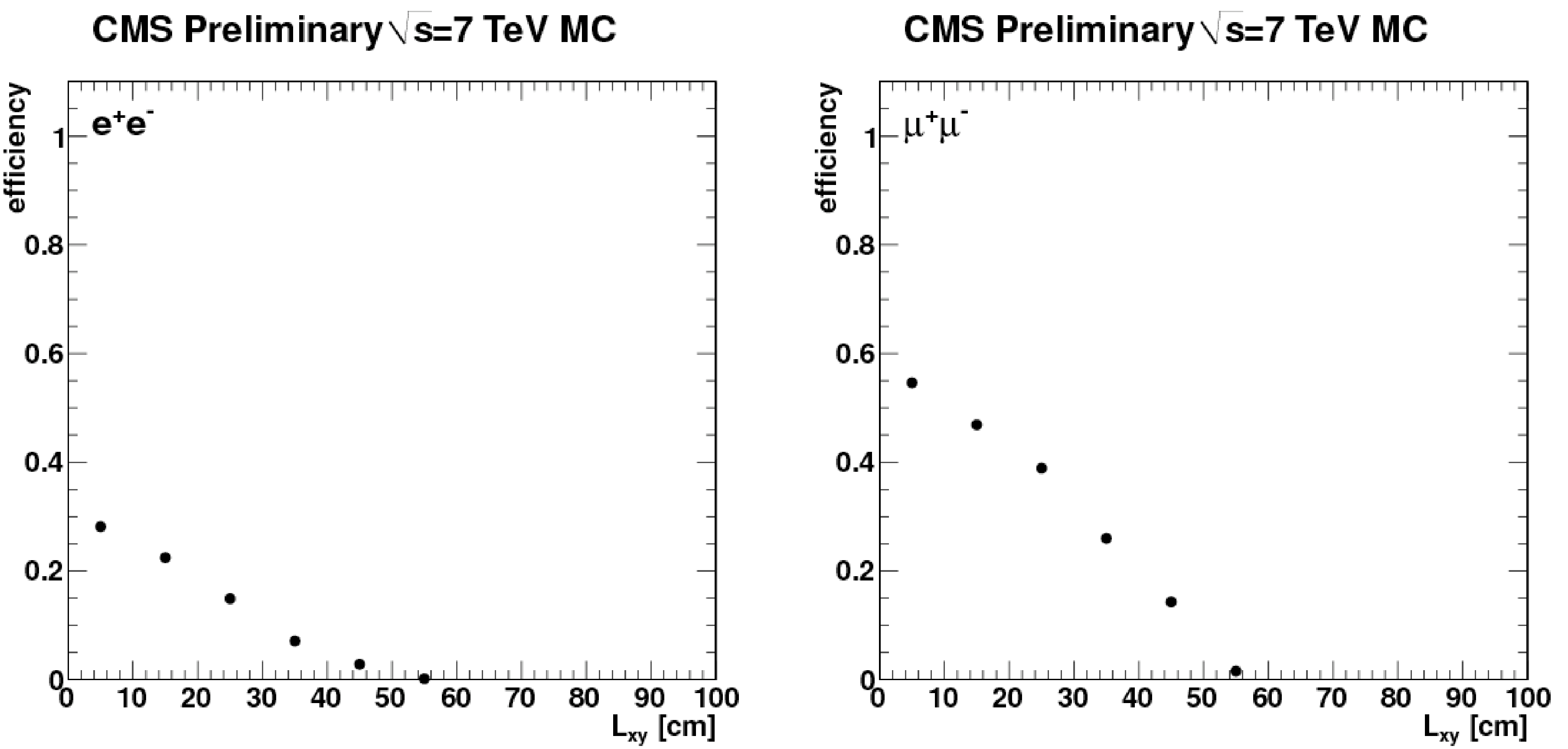
Displaced Lepton

- Limits for Z'.

$M_{Z'}$ or M_{H^0} (GeV/c^2)	M_X (GeV/c^2)	Dielectron channel		Dimuon channel	
		H^0	Z'	H^0	Z'
1000	350	0.86	0.84	0.87	0.85
1000	150	0.74	0.73	0.80	0.79
1000	50	0.73	0.72	0.80	0.78
1000	20	0.74	0.72	0.80	0.79
400	150	0.60	0.54	0.75	0.68
400	50	0.45	0.41	0.58	0.54
400	20	0.45	0.41	0.59	0.55
200	50	0.117	0.077	0.31	0.25
200	20	0.134	0.010	0.32	0.27

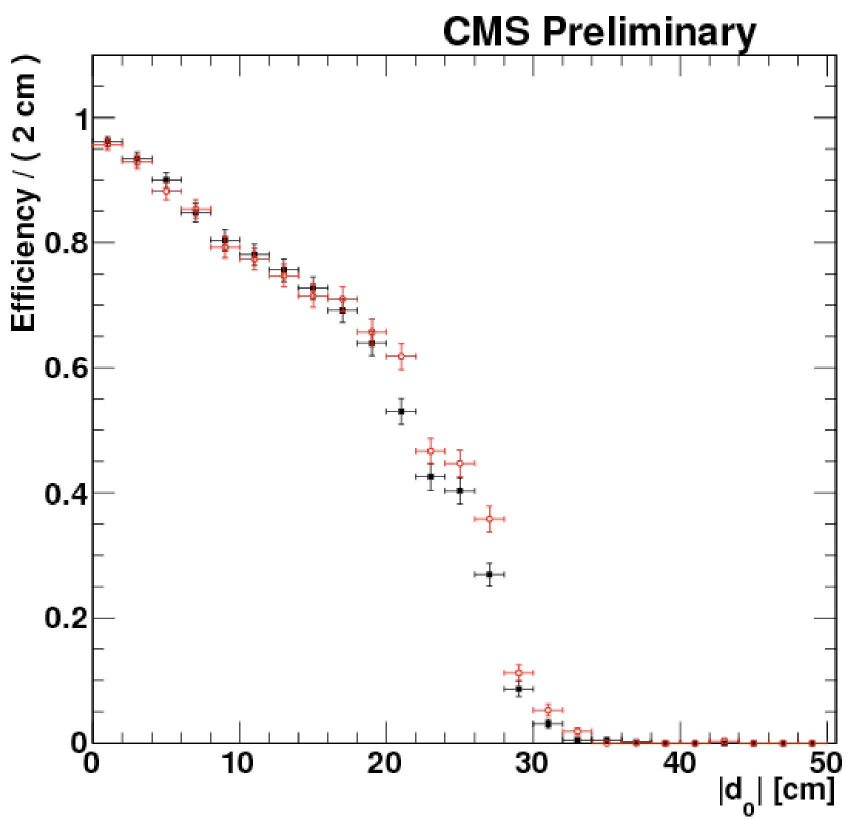
Displaced Lepton

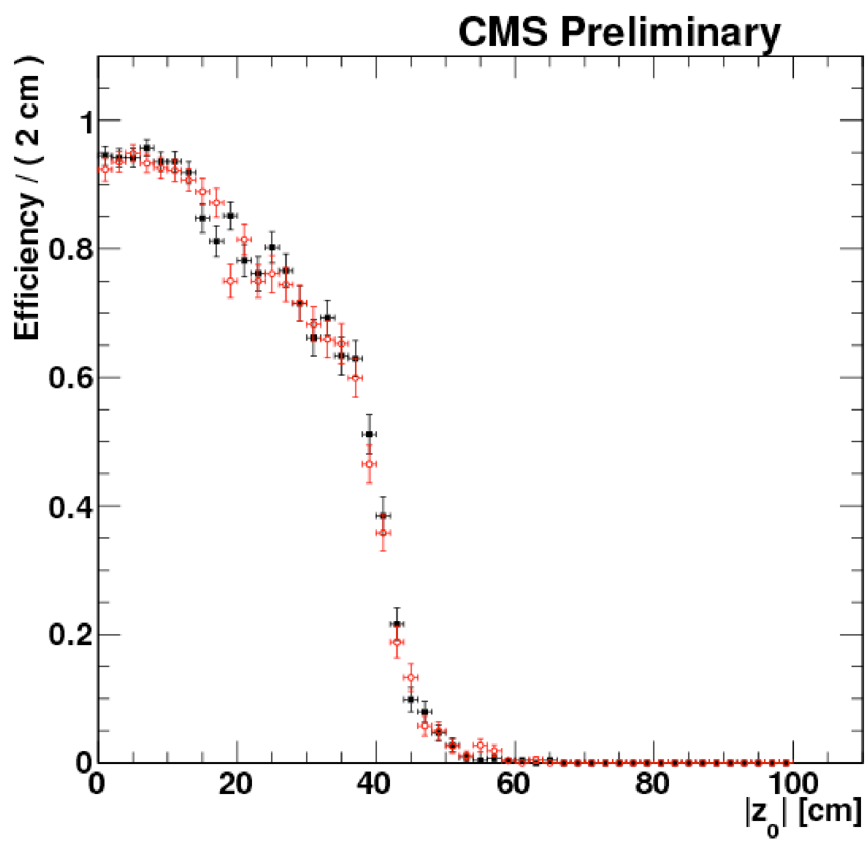
- The efficiency to select X -> l^+l^- decay as a function of transverse decay length for dielectron (left) and dimuon candidates (right), shown for the case M_H = 1000 GeV, M_X = 150 GeV/c2.



Displaced Lepton

- Efficiency of finding a tracker track, given a cosmic muon reconstructed in the muon chambers. Data vs. Simulation
- Good understanding of displaced track reconstruction.





Displaced Lepton

M_{H^0} (GeV/c^2)	M_X (GeV/c^2)	$c\tau$ (cm)	Dielectron channel		Dimuon channel	
			ϵ_1	ϵ_2	ϵ_1	ϵ_2
1000	350	11.7	0.22	0.22	0.51	0.53
		35.0	0.11	0.11	0.29	0.31
		105.0	0.038	0.045	0.12	0.12
1000	150	3.3	0.32	0.34	0.58	0.61
		10.0	0.20	0.20	0.41	0.44
		30.0	0.099	0.085	0.19	0.20
1000	50	1.3	0.32	0.31	0.44	0.56
		4.0	0.23	0.23	0.31	0.40
		12.0	0.11	0.11	0.17	0.20
1000	20	0.5	0.22	0.24	0.023	0.037
		1.5	0.16	0.17	0.022	0.033
		4.5	0.070	0.076	0.017	0.022
400	150	13.3	0.11	0.11	0.40	0.46
		40.0	0.054	0.053	0.23	0.25
		120.0	0.021	0.026	0.094	0.10
400	50	2.7	0.16	0.16	0.45	0.48
		8.0	0.10	0.11	0.33	0.35
		24.0	0.047	0.052	0.17	0.16
400	20	1.3	0.14	0.16	0.28	0.37
		4.0	0.098	0.10	0.20	0.26
		12.0	0.041	0.044	0.10	0.13
200	50	6.7	0.018	0.022	0.19	0.21
		20.0	0.010	0.11	0.12	0.13
		60.0	0.023	0.003	0.054	0.050
200	20	2.3	0.033	0.029	0.12	0.23
		7.0	0.019	0.019	0.14	0.16
		21.0	0.007	0.010	0.066	0.074

- Final selection efficiency of Higgs -> XX, both for events in which only one long-lived exotic decays to the chosen lepton species ε_1 and for the case where both decay to the chosen lepton species ε_2.

- The uncertainties on efficiencies are dominated by the 20% relative uncertainty related to the tracking performance.

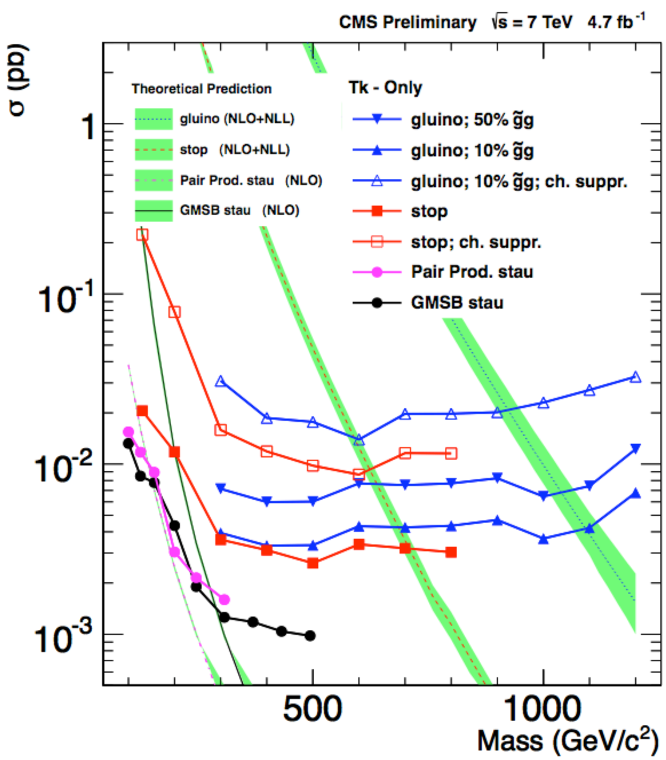
Displaced Photon

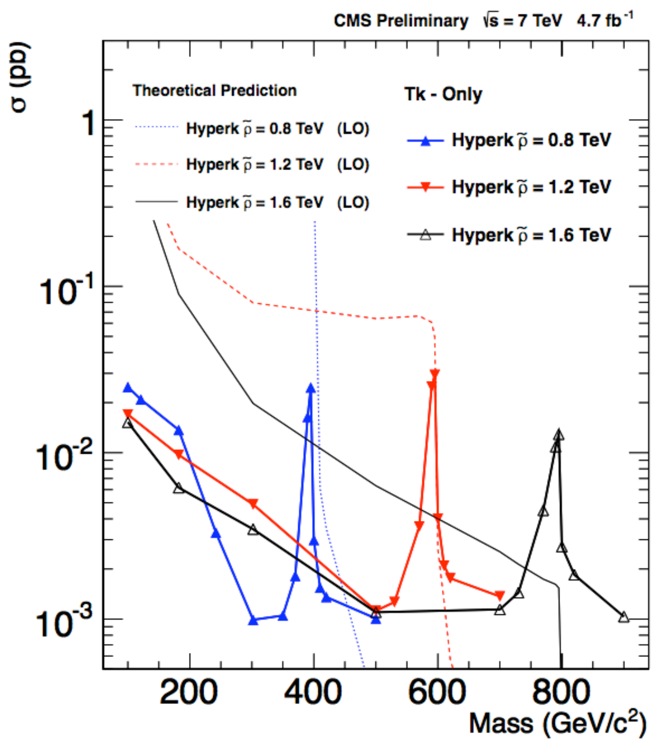
- Signal selection flow for $c\tau$= 5 cm.

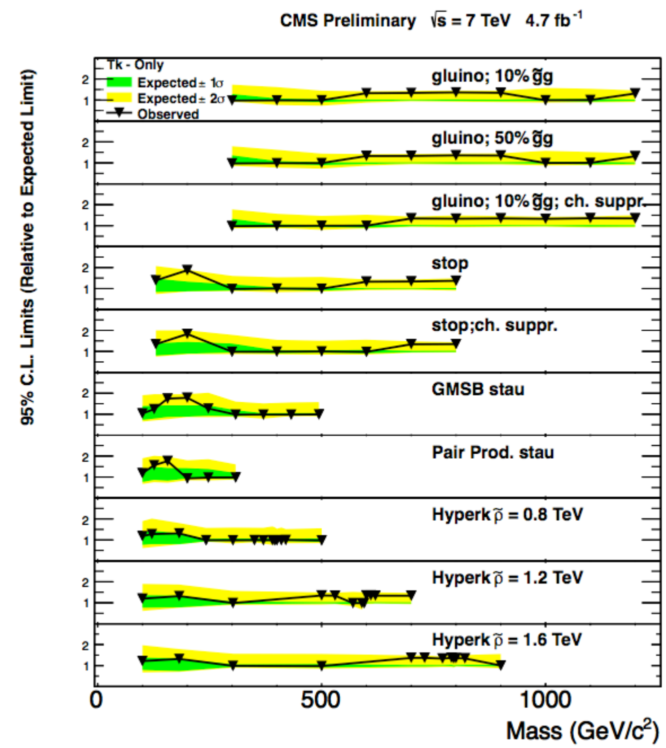
Selection	Events in Monte Carlo
Total	45057
DiPhoton trigger	39988
Photon E_T > 45 GeV and E_T > 30 GeV	37398
Any ECAL barrel photon E_T > 45 GeV and Photon identification	27766
Jets p_T > 80 GeV and p_T > 50 GeV	26229
Conversion selection	1602
E_T^{miss} > 30 GeV	1542
d_{XY} > 0.6 cm	711

Slow moving HSCP

- Tk+only Analysis

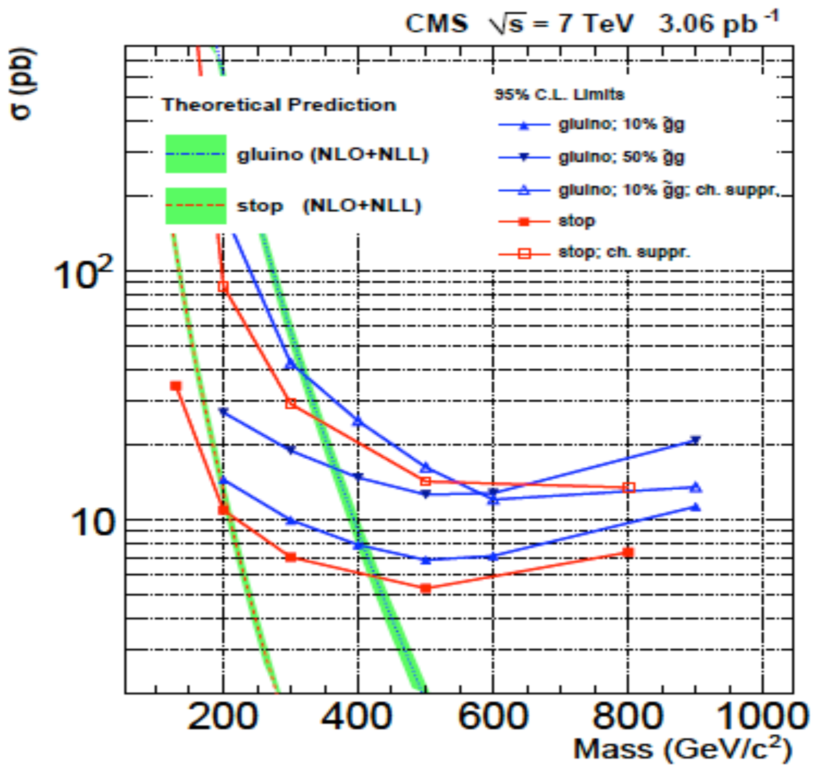




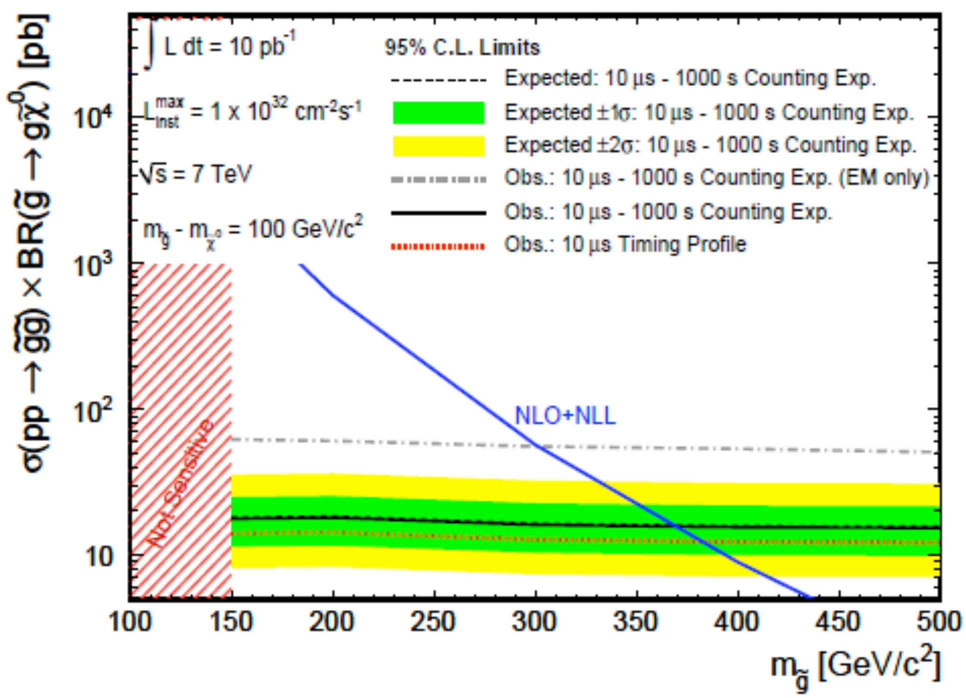


Previous CMS Limits

- CMS HSCP published results from 2010 dataset **Gluino exclusion: m < 398, 370 GeV/c²**



arXiv:1101.1645 JHEP 03 (2011) 024



arXiv:1011.5861 Phys.Rev.Lett.106:011801,2011