Searches for new physics using long-lived particles and other non-conventional signatures with the CMS detector

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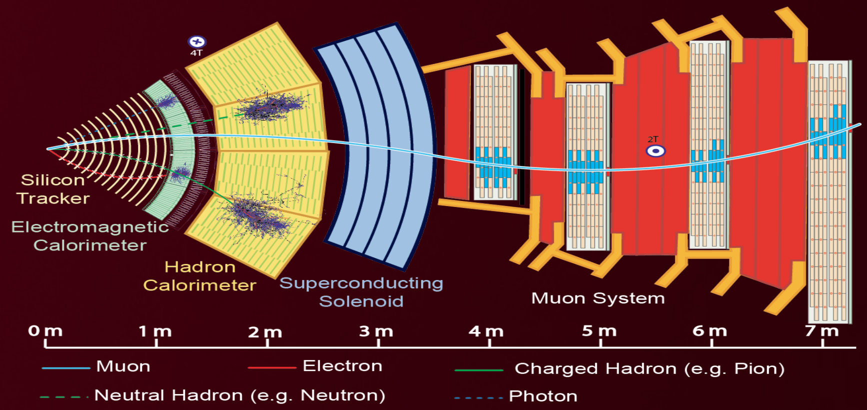
Long-lived and Non-conventional

- CMS has an extensive program to search for new physics
  - >500 papers
  - most assume new particles are very short-lived



- Reasons to think that new particles may be long-lived
  - many models make predictions
    - SUSY – small couplings, small mass splittings
    - hidden valley models
  - standard model (SM) has numerous examples of long-lived particles
    - muon, pion, kaon, neutron, hyperons, etc.
- CMS has developed a diverse program of searches for new, long-lived particles (LLPs)

Challenges

(A) Detectors not optimized for long-lived particles

(B) Algorithms not optimized for long-lived particles

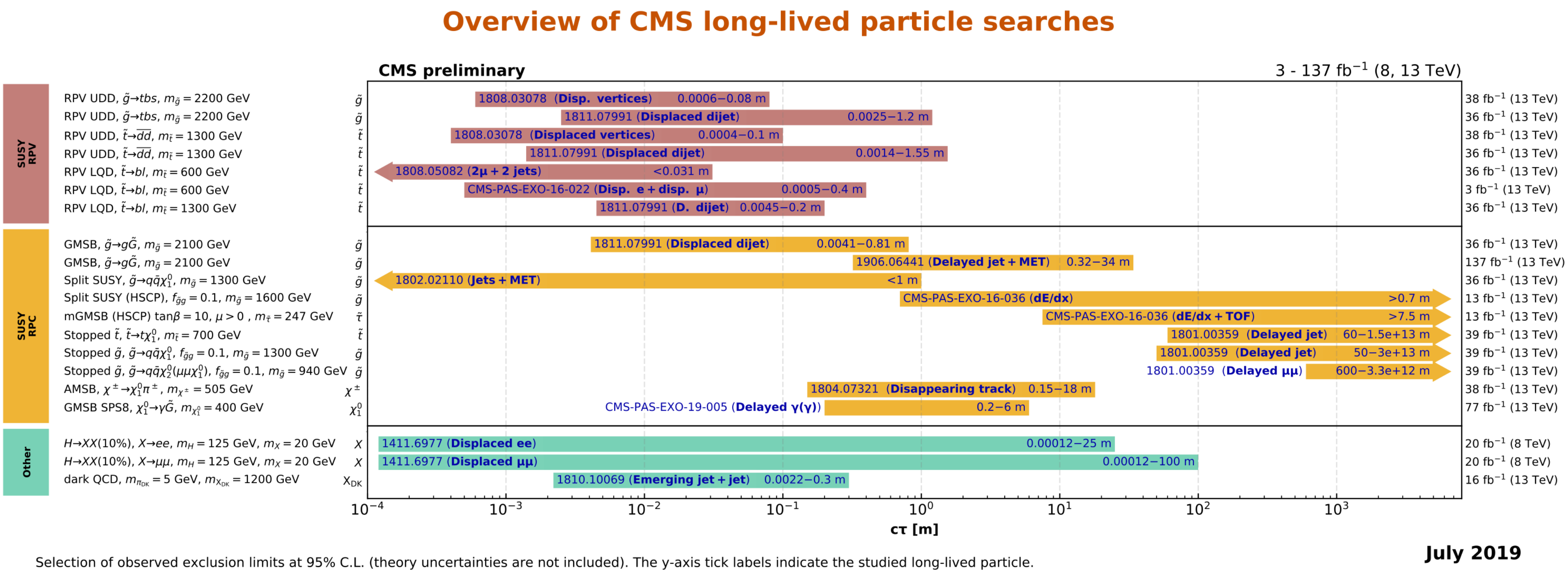
- both obvious and subtle effects
- many steps that reduce backgrounds from multiple interactions per bunch crossing also reduce discovery of LLPs
  - example: require particles to be in time with bunch crossing
- many assumptions that make code faster also reduce discovery
  - example: only fitting combinations of hits in tracker that point to interaction vertex…
  - …or only reconstructing combinations that curve in r-phi plane (problematic for magnetic monopoles or quirks)

(C) Analyses (often) not optimized for long-lived particles

We can overcome (C) and (B) and to some extent (A)

Long-lived searches

- Many searches
- Wide range of lifetimes explored

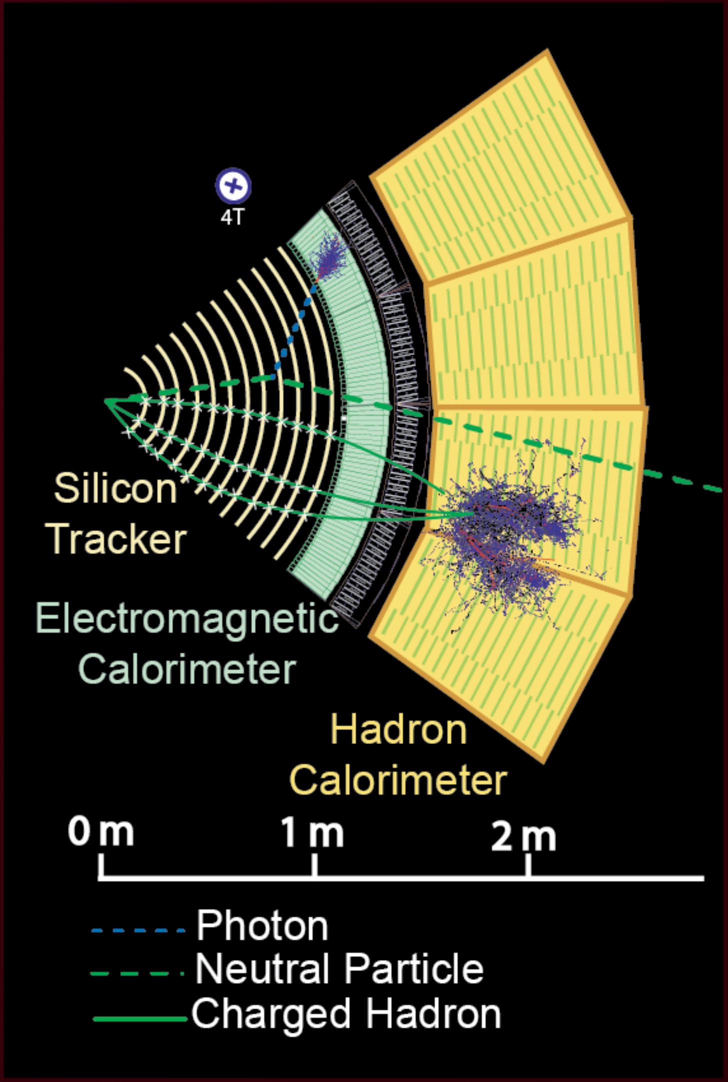


- Two recent results presented today

Delayed Photons
EXO-19-005

- Neutral LLP decaying to photon (and other particles)
- Use timing in ECAL
  - custom out-of-time photon reconstruction
- Also require missing transverse energy (MET)

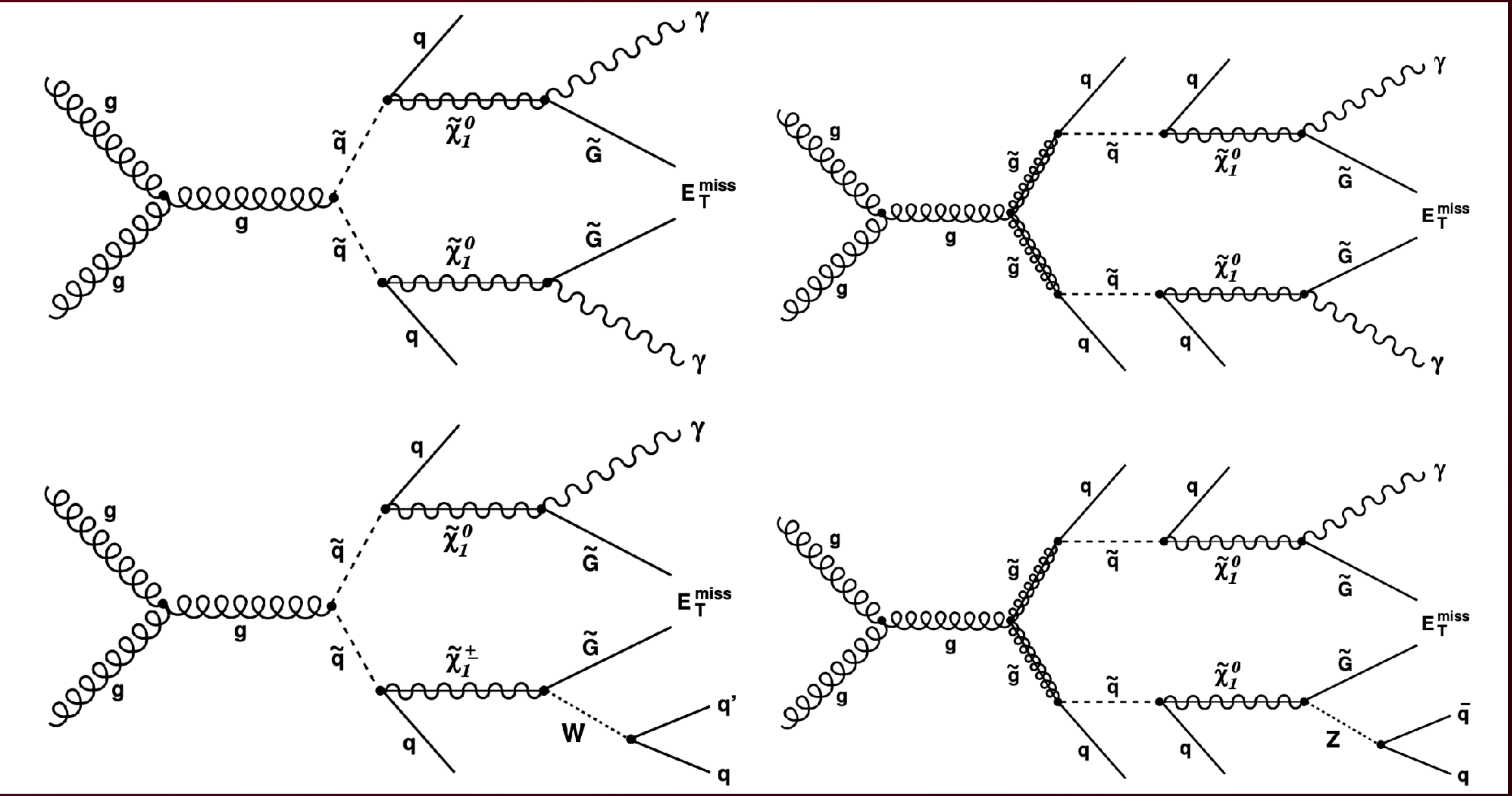
2016	2017
35.9 fb^{-1}	41.5 fb^{-1}
Diphoton trigger (95% effic. after offline selection)	Dedicated displaced photon + H_T trigger (99.9% effic. after offline selection)



Signal model

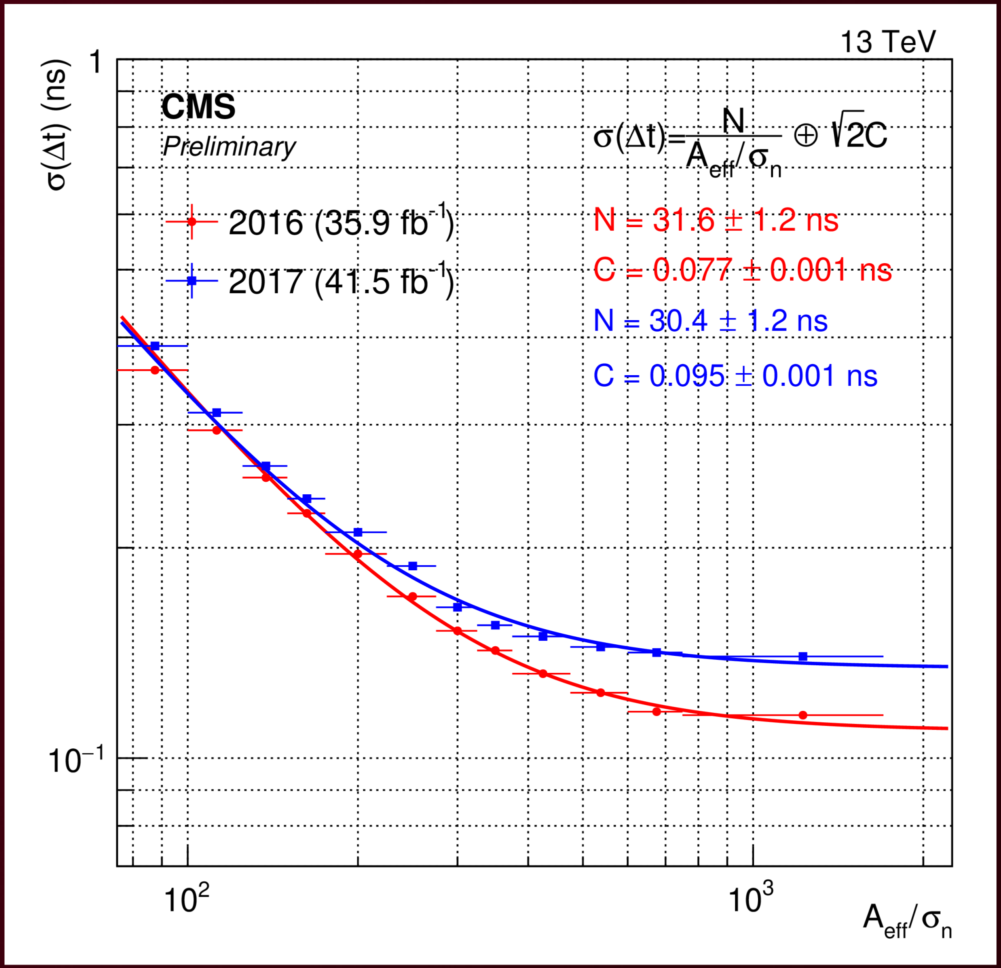
Gauge mediated supersymmetry breaking

- Neutralino is long-lived



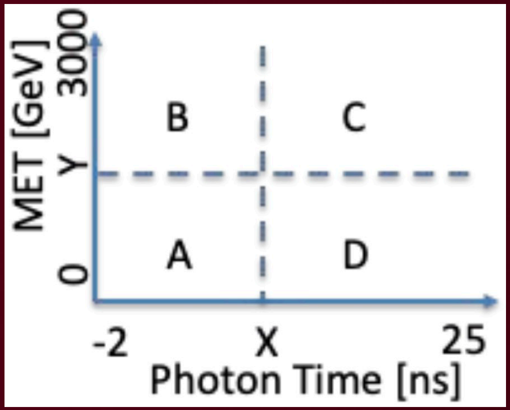
ECAL timing resolution

- ECAL timing resolution important
- Resolution measured by comparing timing from alike channels
- Resolution reaches a plateau at high energy



Data and background

- Use ABCD background estimate
  - use photon time and MET

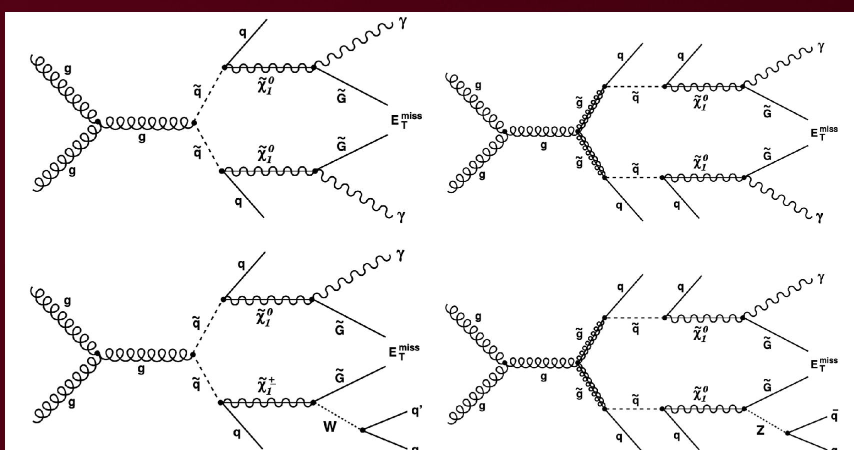


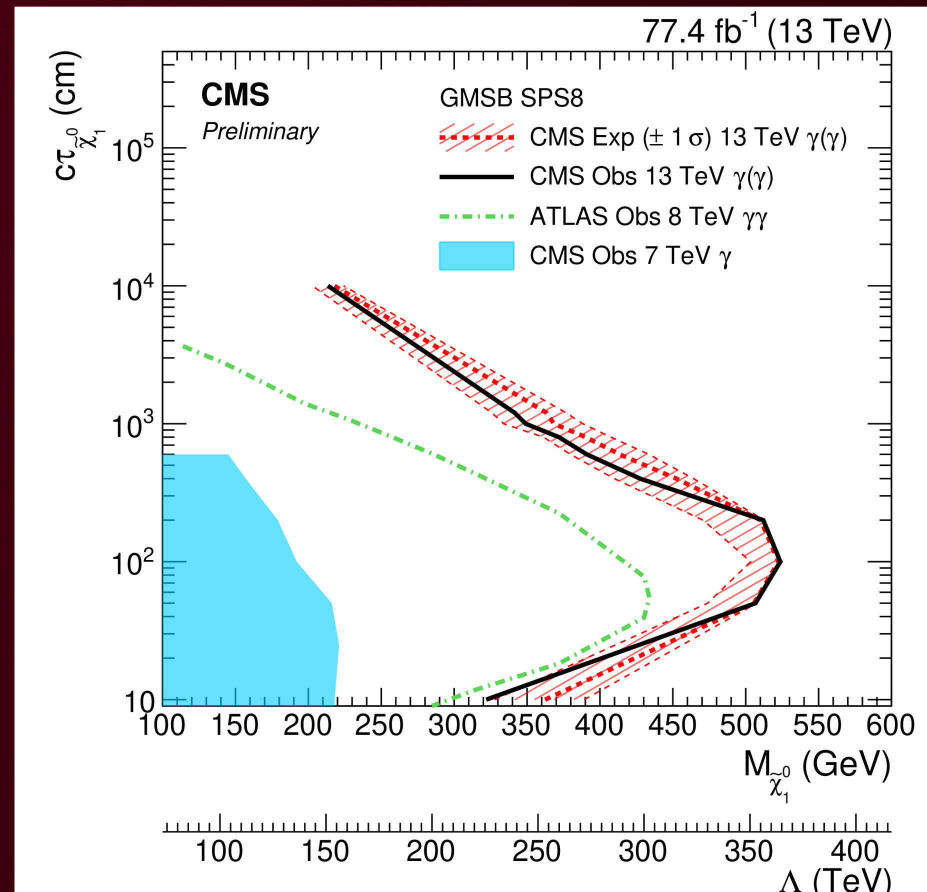
- Optimize selection for each signal point
- Fit for signal+background in each region simultaneously

Year / Category	Bin Split $[t_\gamma$ (ns), p_T^{miss} (GeV)]		A	B	C	D
2016$\gamma\gamma$	(0, 250)	N_{obs}^{data}	16139	41	62	18826
		$N_{bkg}^{post-fit}$	16133 ± 114	47.5 ± 4.8	55.6 ± 5.6	18832 ± 130
		$N_{bkg(mask)}^{post-fit}$	16139 ± 114	41.0 ± 6.5	47.8 ± 7.7	18826 ± 130
	(1.5, 100)	N_{obs}^{data}	33760	1302	1	5
		$N_{bkg}^{post-fit}$	33759 ± 164	1303 ± 37	0.29 ± 0.28	5.7 ± 2.2
		$N_{bkg(mask)}^{post-fit}$	33761 ± 165	1302 ± 37	0.19 ± 0.21	5.0 ± 2.1
	(1.5, 150)	N_{obs}^{data}	34595	467	0	6
		$N_{bkg}^{post-fit}$	34596 ± 166	467 ± 22	0.08 ± 0.08	5.9 ± 2.3
		$N_{bkg(mask)}^{post-fit}$	34596 ± 167	467 ± 22	0.08 ± 0.09	6.0 ± 2.3
2017γ	(0.5, 300)	N_{obs}^{data}	458372	281	41	67655
		$N_{bkg}^{post-fit}$	458368 ± 660	281 ± 15	41.4 ± 2.4	67656 ± 280
		$N_{bkg(mask)}^{post-fit}$	458369 ± 662	281 ± 16	41.5 ± 2.7	67657 ± 281
	(1.5, 200)	N_{obs}^{data}	524652	1364	1	332
		$N_{bkg}^{post-fit}$	524653 ± 706	1364 ± 36	0.9 ± 0.8	332 ± 20
		$N_{bkg(mask)}^{post-fit}$	524653 ± 704	1364 ± 35	0.9 ± 1.0	332 ± 20
	(1.5, 300)	N_{obs}^{data}	525694	322	0	333
		$N_{bkg}^{post-fit}$	525694 ± 707	322 ± 17	0.19 ± 0.21	333 ± 20
		$N_{bkg(mask)}^{post-fit}$	525694 ± 704	322 ± 17	0.20 ± 0.24	333 ± 20
2017$\gamma\gamma$	(0.5, 150)	N_{obs}^{data}	21640	362	56	3201
		$N_{bkg}^{post-fit}$	21638 ± 143	364 ± 17	54.0 ± 3.0	3203 ± 61
		$N_{bkg(mask)}^{post-fit}$	21639 ± 143	362 ± 18	53.6 ± 3.3	3201 ± 61
	(0.5, 200)	N_{obs}^{data}	21863	139	24	3233
		$N_{bkg}^{post-fit}$	21860 ± 144	142 ± 11	21.1 ± 1.7	3236 ± 61
		$N_{bkg(mask)}^{post-fit}$	21863 ± 144	139 ± 11	20.6 ± 1.8	3233 ± 61
	(1.5, 150)	N_{obs}^{data}	24824	418	0	17
		$N_{bkg}^{post-fit}$	24824 ± 154	418 ± 20	0.25 ± 0.28	16.7 ± 4.4
		$N_{bkg(mask)}^{post-fit}$	24824 ± 154	418 ± 20	0.29 ± 0.36	17.0 ± 4.4
	(1.5, 200)	N_{obs}^{data}	25079	163	0	17
		$N_{bkg}^{post-fit}$	25079 ± 154	163 ± 12	0.11 ± 0.12	16.9 ± 4.4
		$N_{bkg(mask)}^{post-fit}$	25079 ± 154	163 ± 12	0.11 ± 0.14	17.0 ± 4.4

Delayed photon results

- No significant excess observed
- Limits set on GMSB SPS8 model
  - mass and lifetime dependent

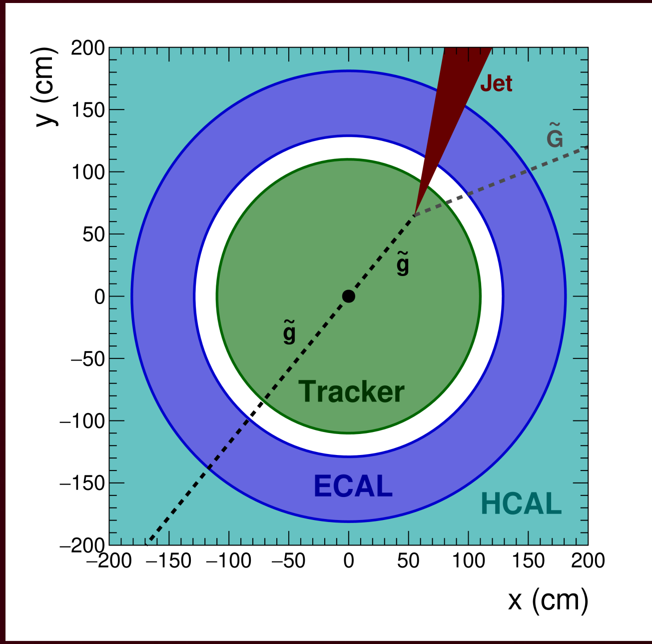


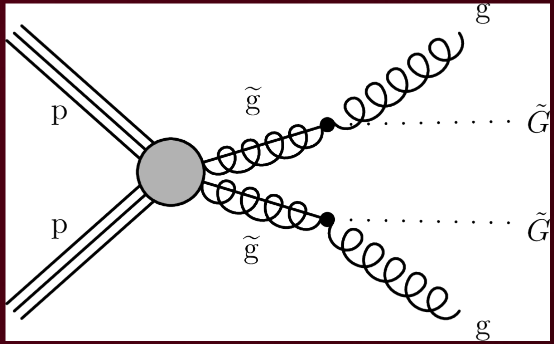


Non-prompt Jets

arXiv:1906.06441 [hep-ex]

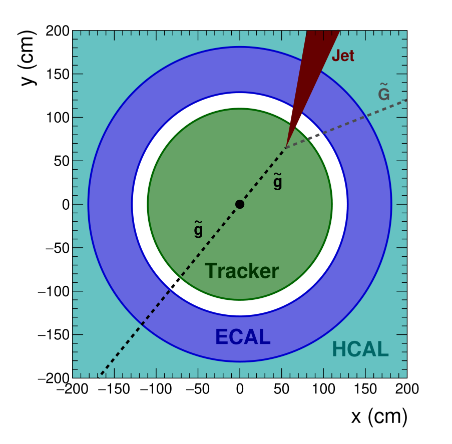
- Search for events with late arriving jets
- Use ECAL timing
- Sensitive to decays beyond acceptance of tracker
- Also, require missing transverse momentum (p_T^{miss})
- 2016-2018 data
- Model based on GMSB with long-lived gluino





Overcoming Challenges

- Jets reconstructed with calorimeter energy
  - not using particle flow (PF) jets which require reconstructed tracks
    - non-prompt jets may not produce reliable information in the tracker
    - out-of-time energy deposits not included in PF jets
- Jet timing
  - all ECAL cells within $\Delta R<0.4$ of jet axis and $E>0.5$ GeV
  - use only cells within -20 ns $< t <$ 20 ns of bunch crossing
  - t_{jet} is median cell time
- p_T^{miss} calculated with calorimeter energy
  - not using PF MET
  - p_T^{miss} is vector sum of calorimeter momenta deposits in event



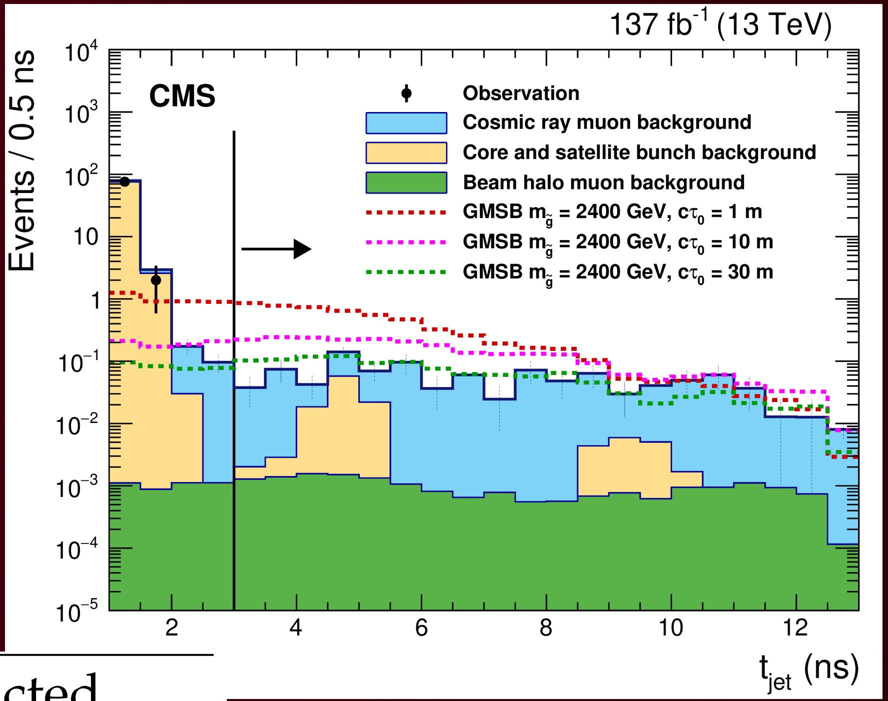
Non-prompt jet backgrounds

- Problematic backgrounds
  - ECAL time resolution tails
  - Electronic noise
  - Direct ionization in the ECAL APDs
  - In-time pileup
  - Out-of-time pileup
  - Satellite bunches
  - Beam halo
  - Cosmic ray muon hits

- Numerous selections used to reduce backgrounds
  - E_{ECAL} > 20 GeV
  - use cells with $-20 < t_{ECAL} < 20$ ns
  - t_{ECAL} > 3 ns
  - $N_{ECAL}^{cell} > 25$
  - $t_{jet}^{RMS} < 2.5\, ns$
  - $t_{jet}^{RMS} < 0.4 t_{jet}$
  - E_{HCAL} > 50 GeV
  - $HEF = \frac{E_{HCAL}}{E_{ECAL}+E_{HCAL}} > 0.2$
  - $PV_{track}^{fraction} < 0.083$
  - $E_{ECAL}^{CSC}/E_{ECAL} < 0.8$
  - $\max(\Delta\phi_{DT}) < \pi/2$
  - $\max(\Delta\phi_{RPC}) < \pi/2$

Delayed jets final sample

- Require
  - at least one jet with t_{jet}>3 ns
  - p_T^{miss} > 300 GeV
- Estimate backgrounds from control regions with inverted selection

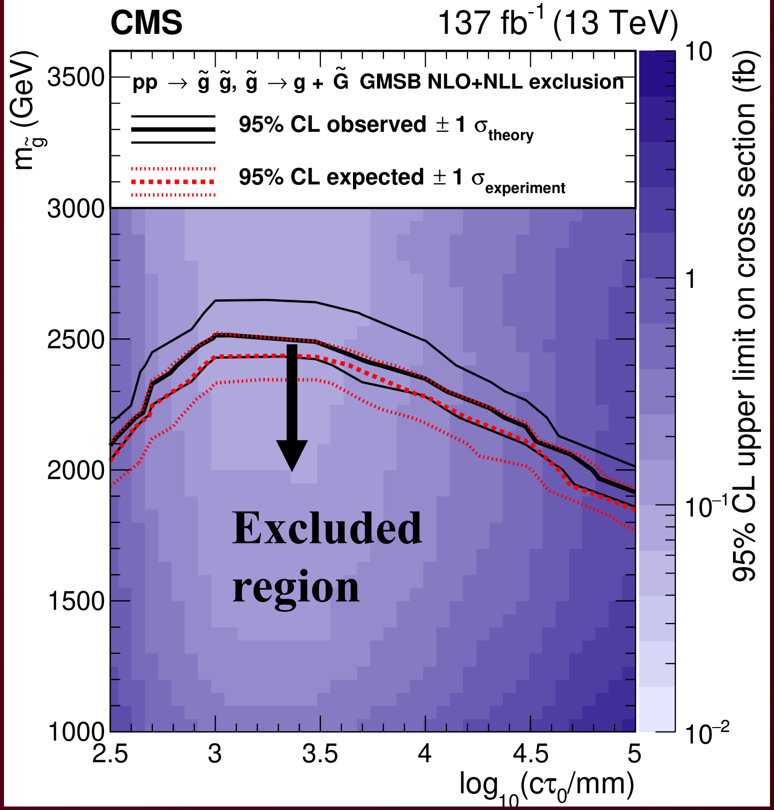


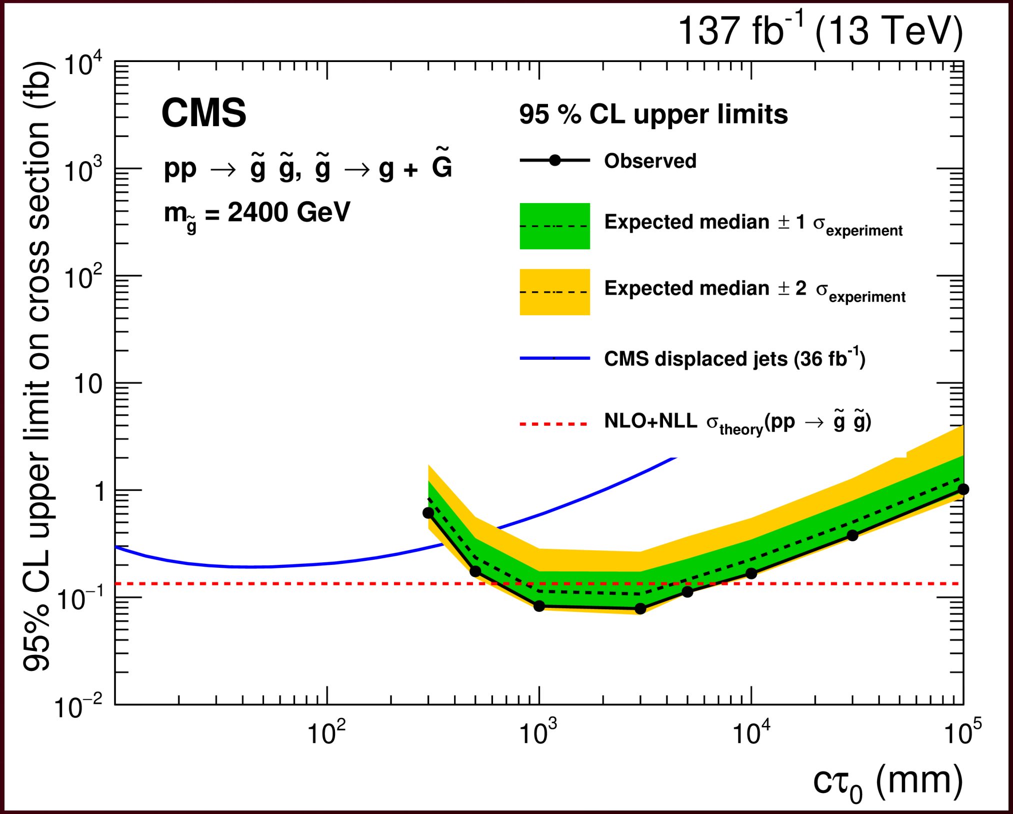
Background source	Events predicted
Beam halo muons	$0.02^{+0.06}_{-0.02}$ (stat)$^{+0.05}_{-0.01}$ (syst)
Core and satellite bunch collisions	$0.11^{+0.09}_{-0.05}$ (stat)$^{+0.02}_{-0.02}$ (syst)
Cosmic ray muons	$1.0^{+1.8}_{-1.0}$ (stat)$^{+1.8}_{-1.0}$ (syst)

Detailed info available:
HEPData link

Limits on non-prompt jets

- No events observed
- Limits on cross section for GMSB gluino production





Searching Far and Wide…

Summary

- CMS has performed a wide range of searches for long-lived and non-conventional signatures
  - displaced leptons, delayed photons, delayed jets, disappearing tracks, heavy long-lived charged particles, stopped particles
- Signature based searches offer significant discovery potential
- Challenging analyses
- New techniques under development
- http://cms.cern/

Backup slides