Beyond the beamspot

Disappearing tracks, out-of-time jets, and other signatures of exotic long-lived particles

Wells Wulsin
The Ohio State University

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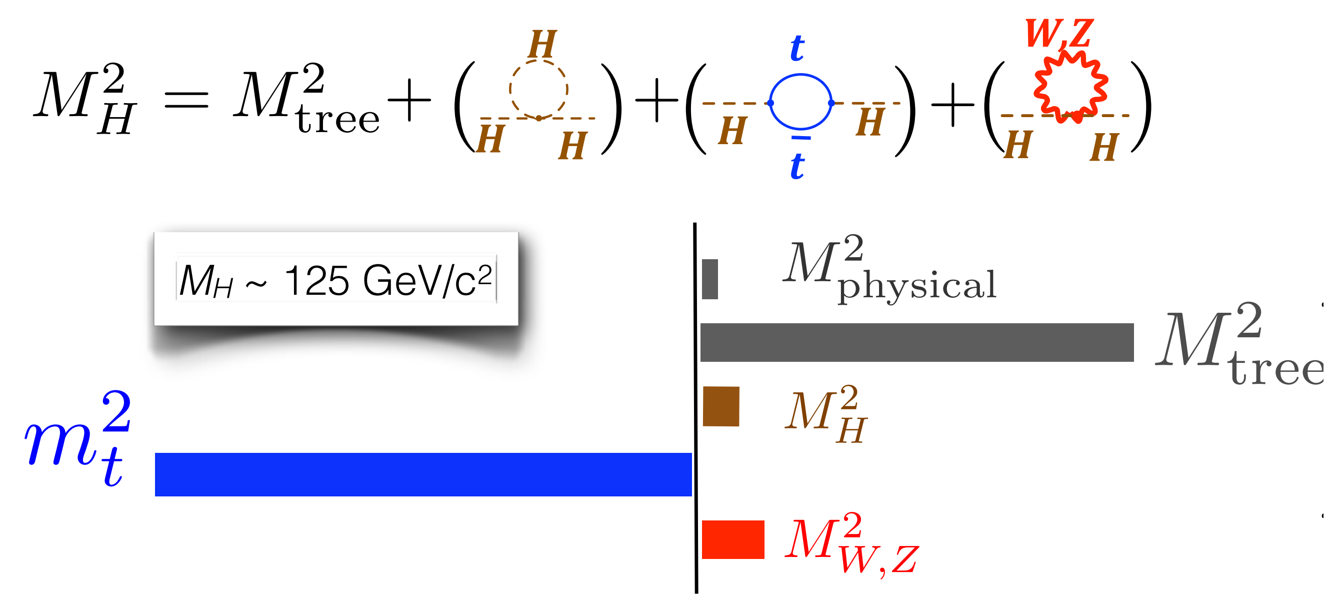
UC Irvine
High Energy Physics Seminar

There are many reasons to expect physics beyond the Standard Model

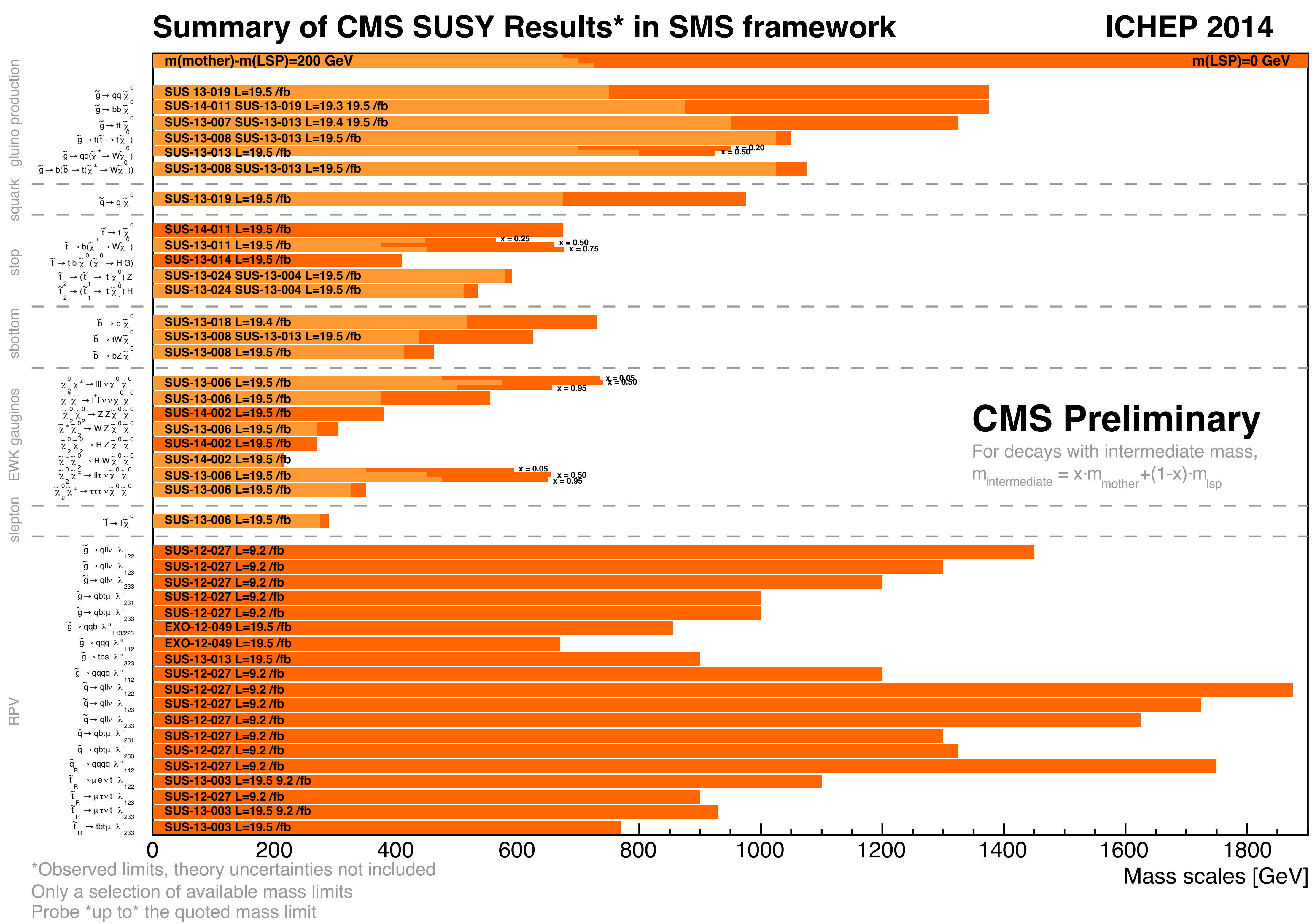
dark matter

stabilizing the Higgs mass



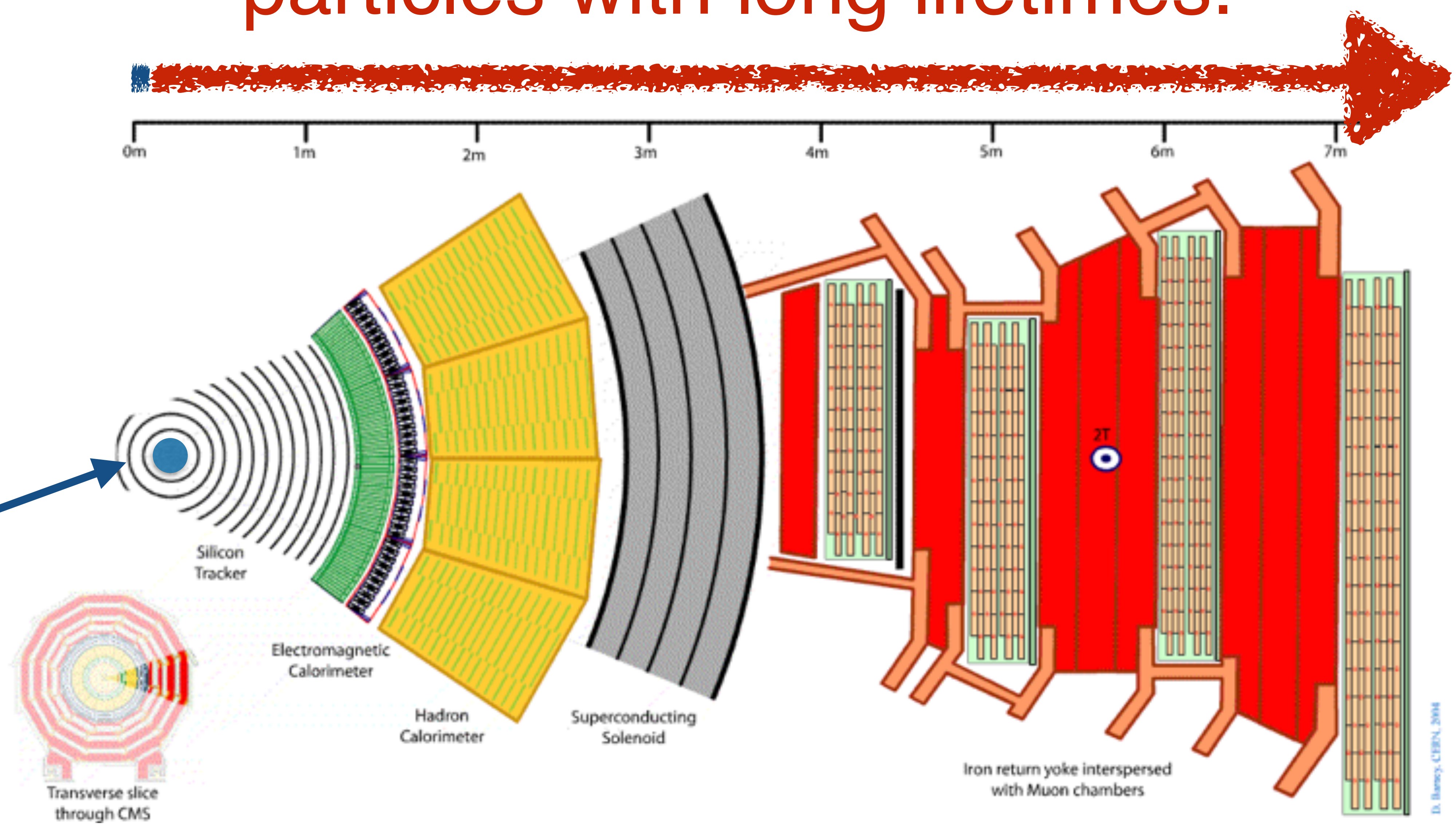
Source of neutrino masses, baryon asymmetry of the universe, quantum theory of gravity, dark energy, and others…

Despite a broad search program, no clear signs of physics Beyond the Standard Model



Where is BSM physics hiding?

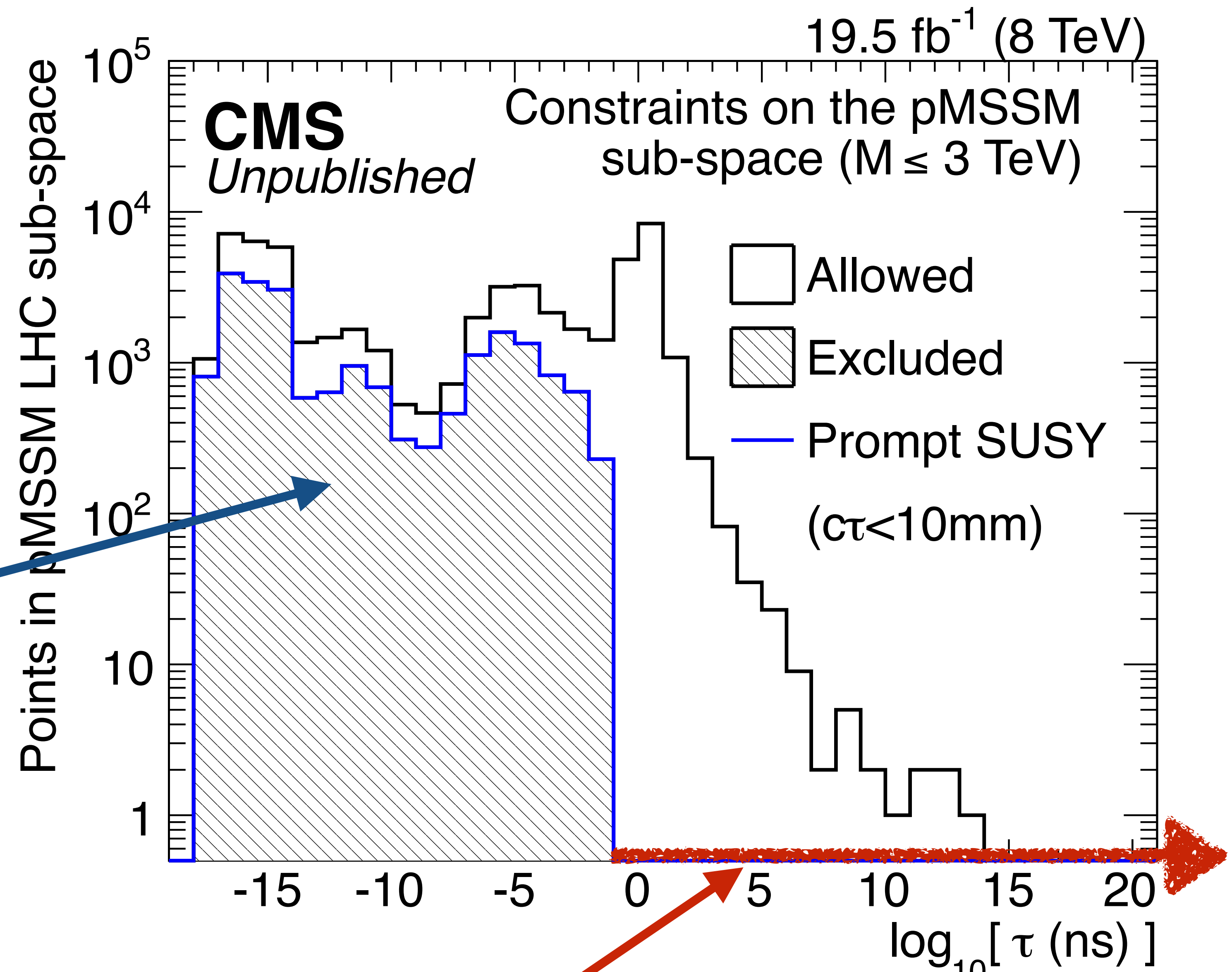
Relatively sparse limits on particles with long lifetimes.



Most SUSY searches target prompt decays, d_0 ~< mm.

Large parameter space available for particles with long lifetimes.

Each entry is a point in
19-D pMSSM parameter space.



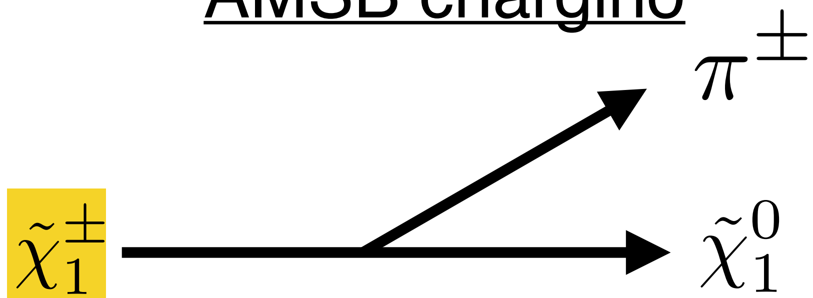
Most SUSY searches target prompt decays, d_0 ~< mm.

27% of pMSSM points have NLSP (chargino) with cτ > 1 cm.

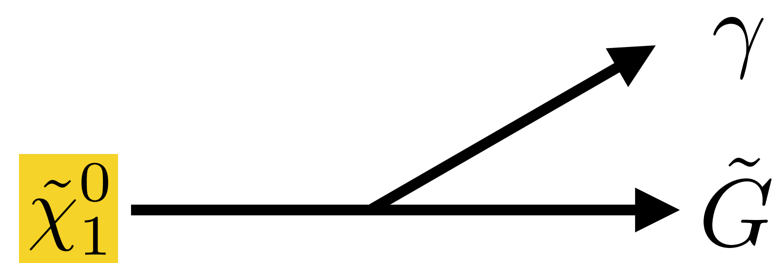
Various mechanisms could lead to long lifetimes.

Long-lived particle highlighted

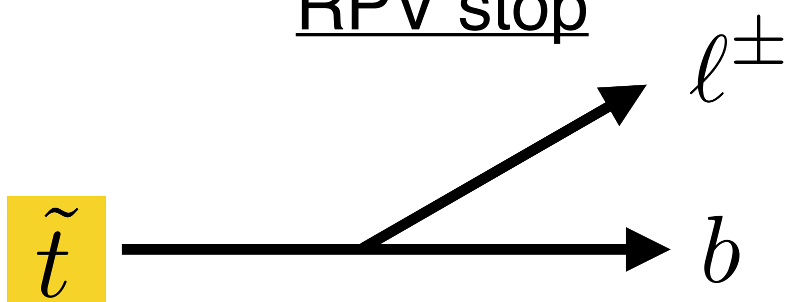
AMSB chargino



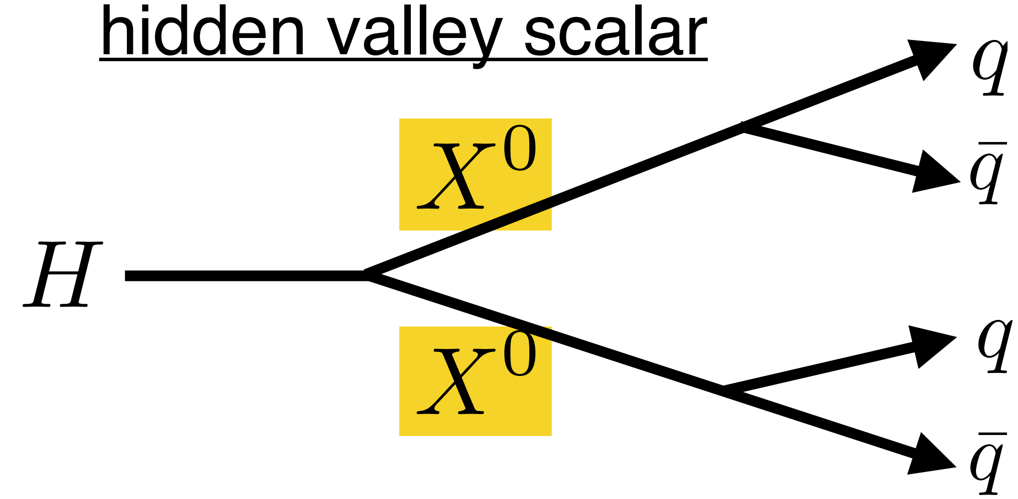
GMSB neutralino



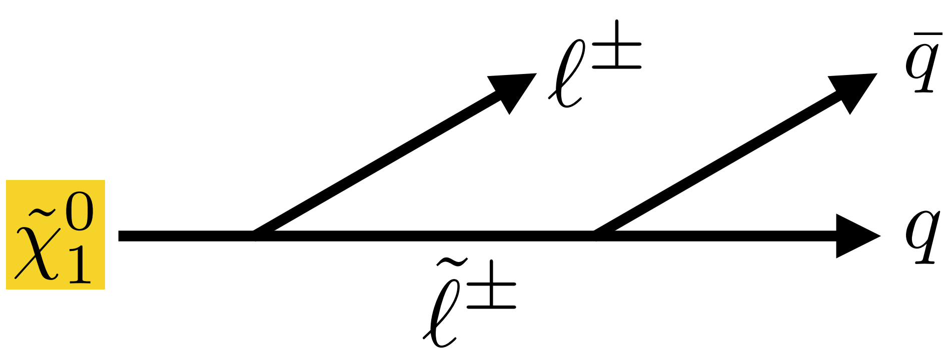
RPV stop



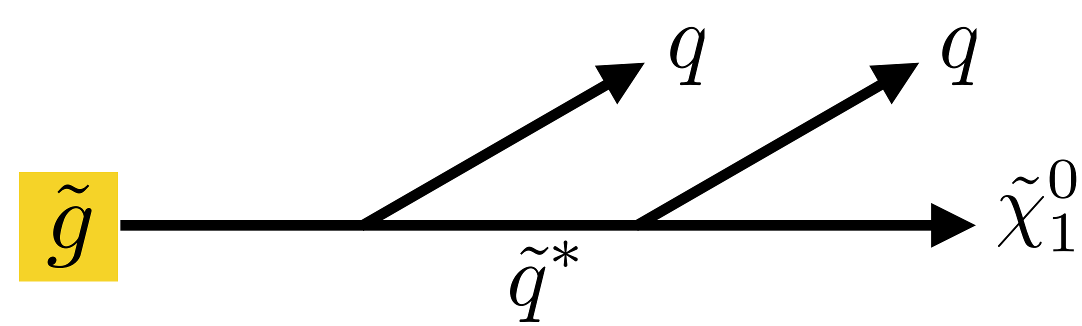
hidden valley scalar



RPV neutralino

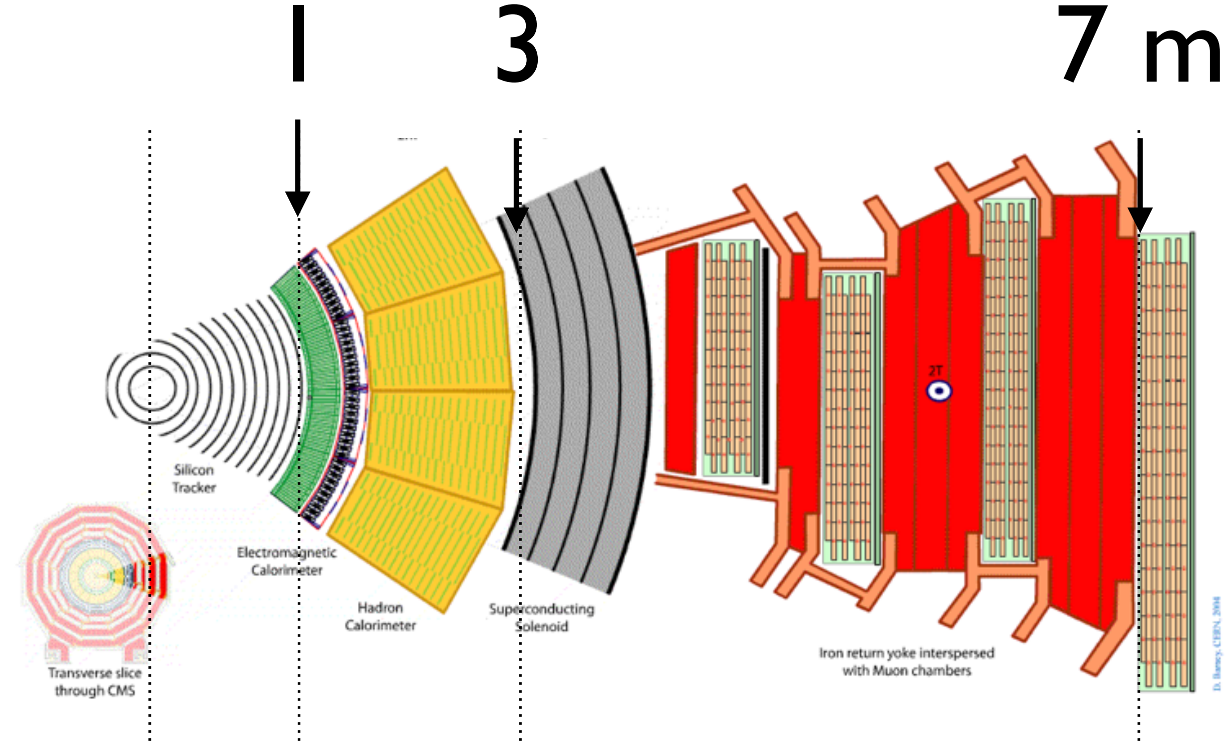


mini-split gluino



Long-lived searches are signature-driven.

LL particle may be neutral or charged (or both)



Region of BSM particle decay

displaced jets

lepton jets

displaced leptons

displaced vertices

displaced / delayed photons

stopped particles

heavy stable charged particles

disappearing tracks

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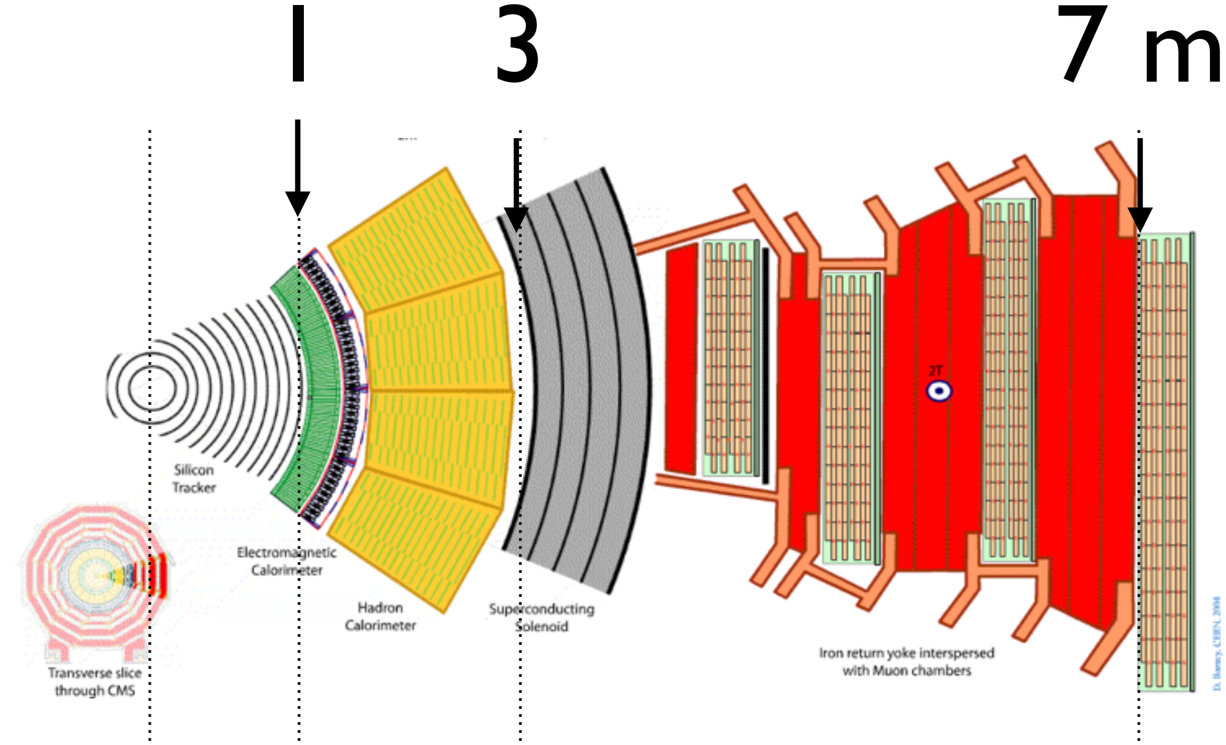

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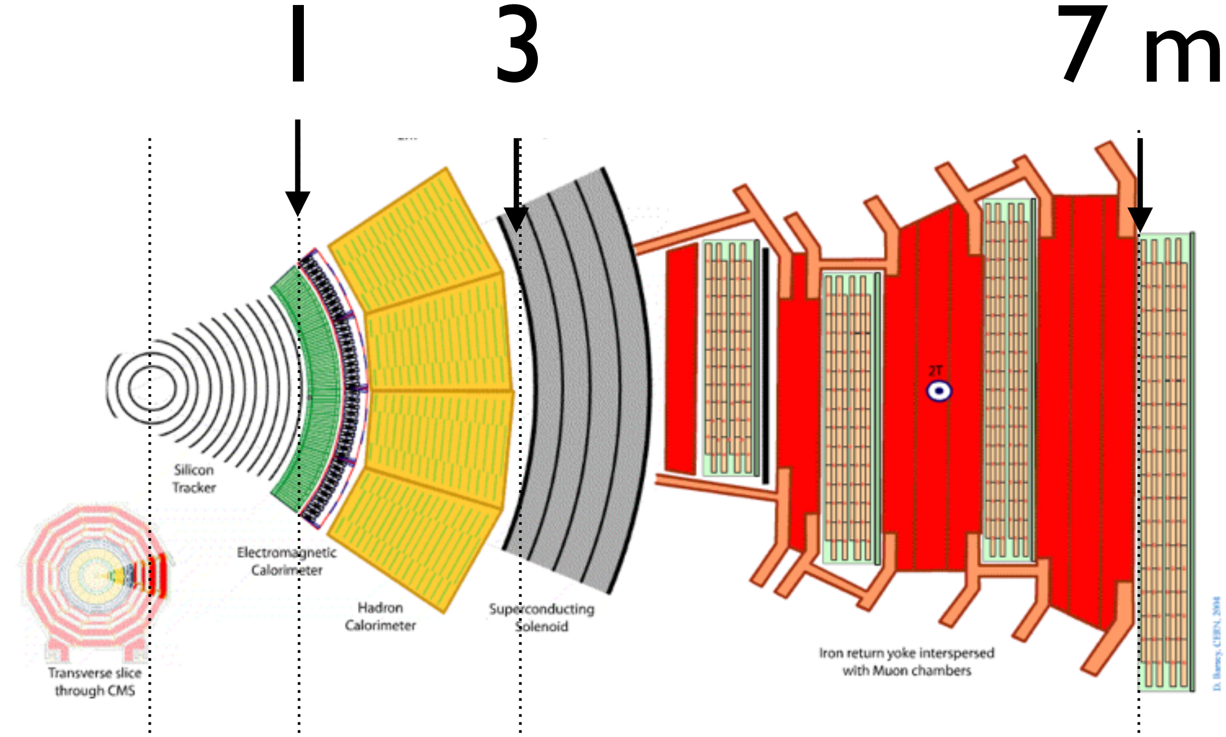
Backgrounds outside the beamspot

- Few from Standard Model → discovery potential
- Unusual, e.g., detector noise, cosmic rays, reconstruction failure
- MC often inadequate
- Estimates based on data

CMS and ATLAS have many recent results



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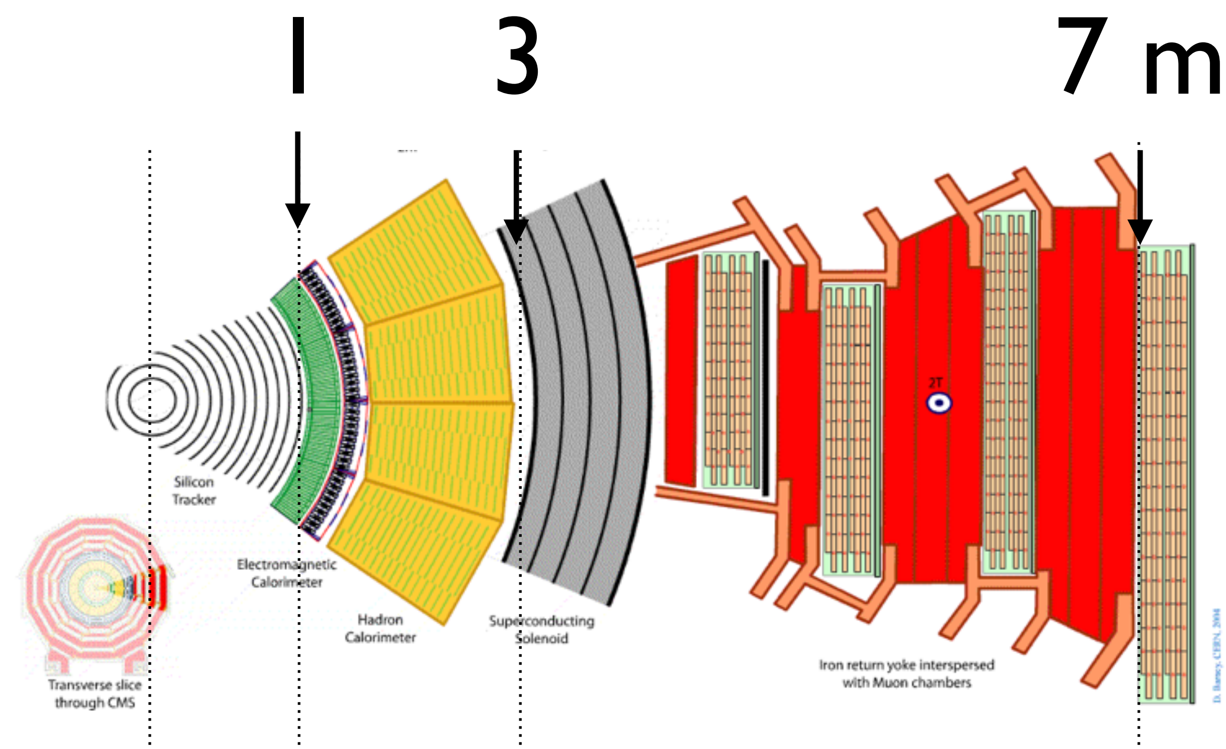
Region of BSM particle decay

displaced jets	Phys. Lett. B 743, 15 (2015) ATLAS Preliminary
lepton jets	JHEP 11, 088 (2014)
displaced leptons	arXiv:1411.6977 & CMS-PAS-EXO-14-012 Phys. Rev. Lett. 114, 061801 (2015)
displaced vertices	ATLAS Preliminary (paper in preparation)
displaced / delayed photons	Phys. Rev. D 90, 112005 (2014)
stopped particles	Phys. Rev. D 88, 112003 (2013) arXiv:1501.05603
heavy stable charged particles	JHEP 07 (2013) 122 JHEP 01, 068 (2015) ATLAS-CONF-2015-013 & ATLAS Preliminary
disappearing tracks	Phys. Rev. D 88, 112006 (2013) JHEP 01 (2015) 096
reinterpretations	ATLAS-CONF-2014-037 arXiv:1502.02522

Selected CMS results



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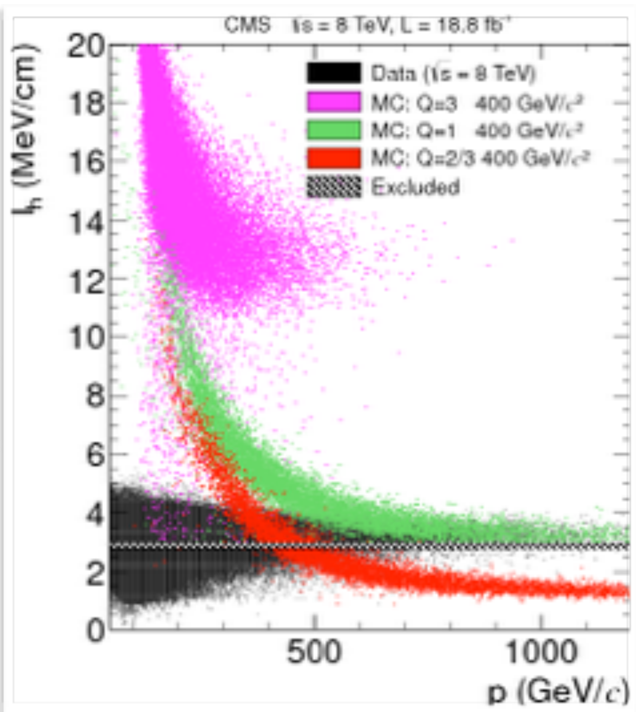
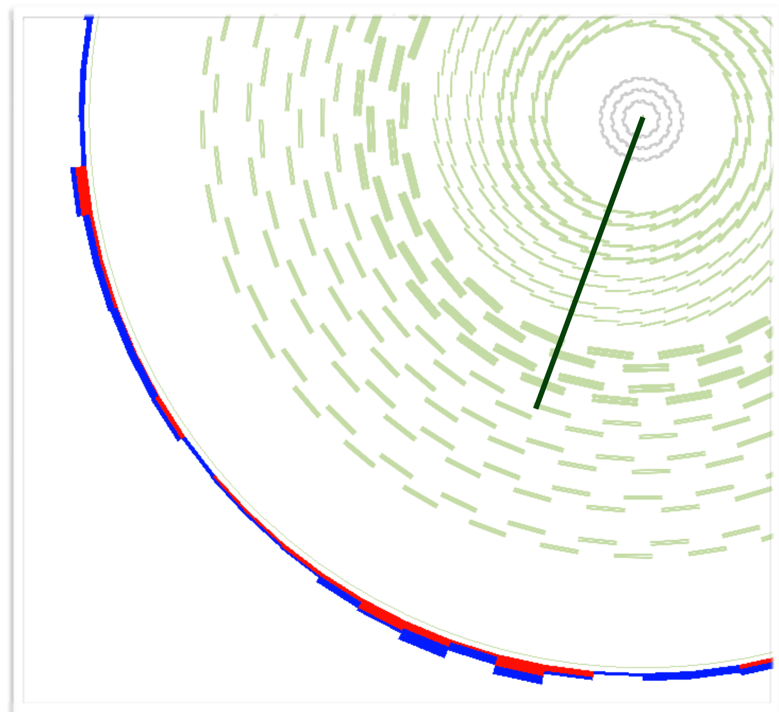
Selected CMS searches for exotic long-lived particles

Fractionally charged particles



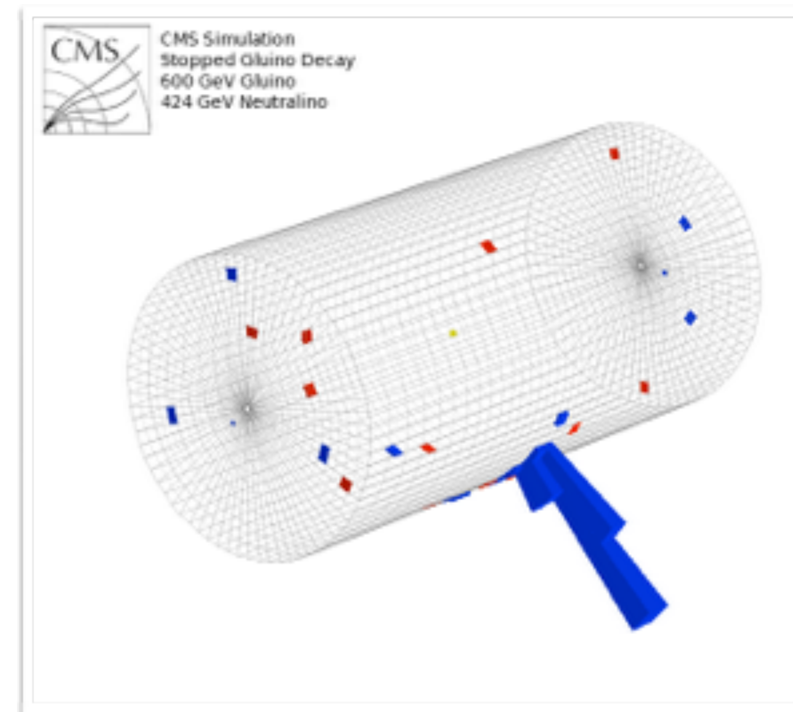
Phys. Rev. D 87 (2013) 092008
arXiv:1210.2311

Disappearing tracks



JHEP 01 (2015) 096
arXiv:1411.6006

Stopped particles



Eur. Phys. J. C 75 (2015) 151
arXiv:1501.05603

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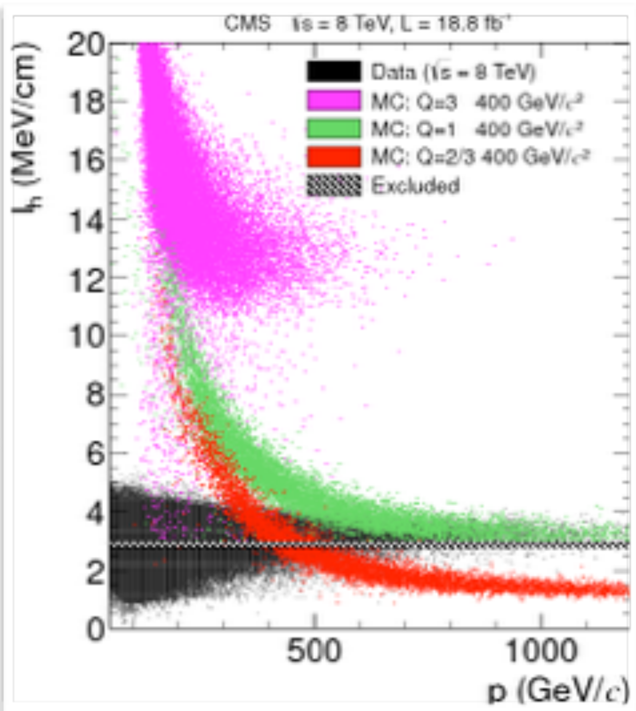

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Disappearing tracks

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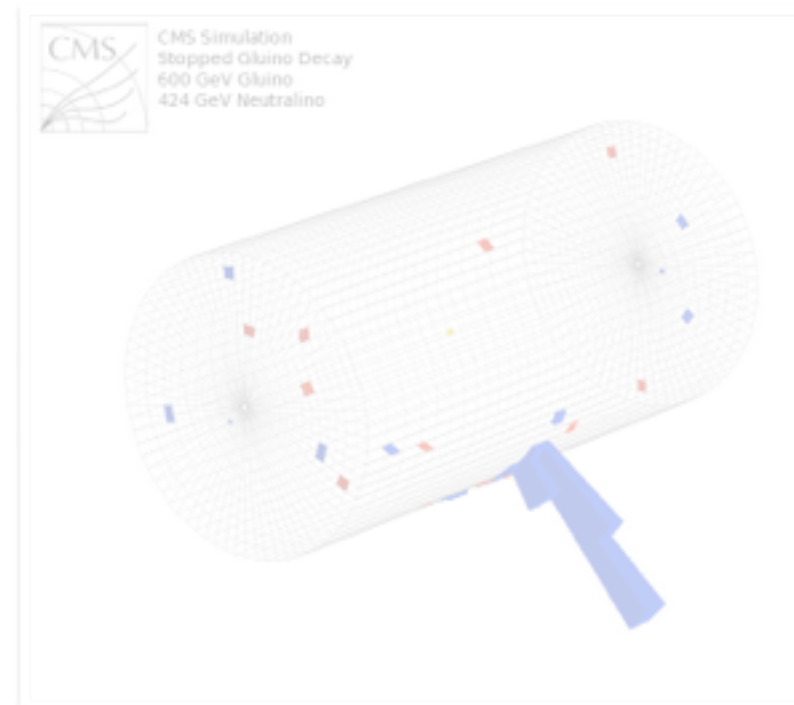

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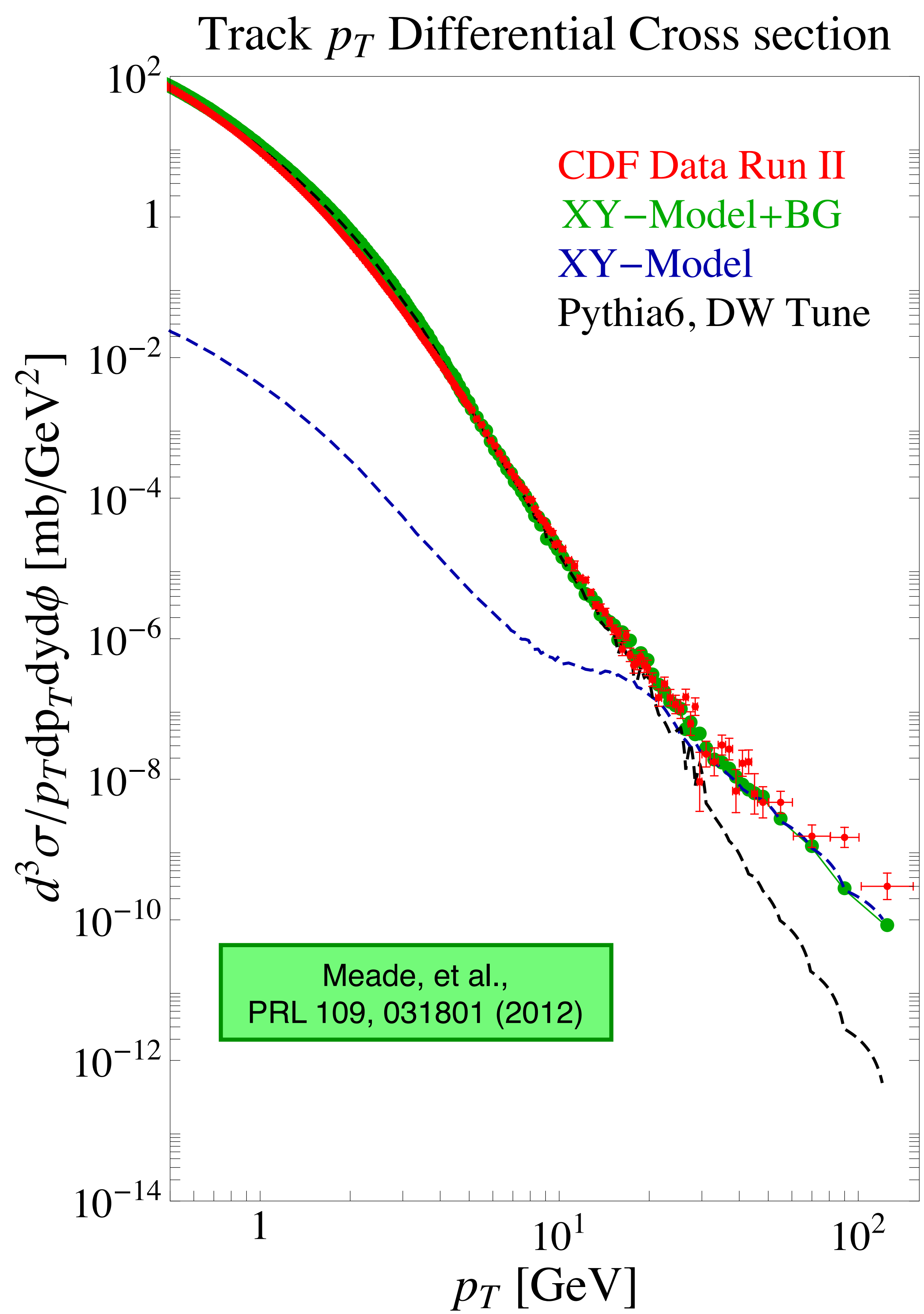
A theory paper sparked our interest

Meade, et al. proposed “new odd tracks” (NOTs) to explain CDF data excess above QCD prediction at large p_T

NOTs could come in several forms:

- kinked tracks
- displaced vertices
- **anomalous dE/dx**
- anomalous timing
- intermittent hits
- anomalous curvature
- disappearing tracks

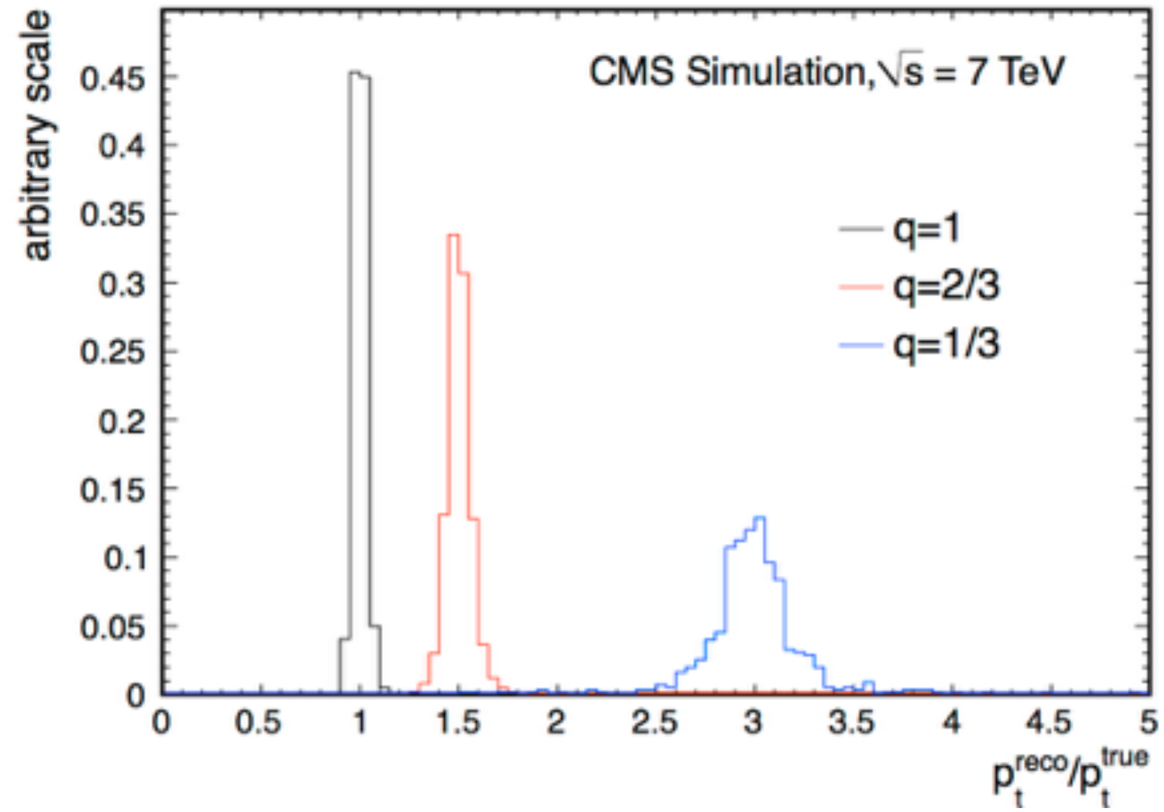
If the p_T of the NOTs is mismeasured (e.g., from fractional charge), they could populate the region of the CDF excess.



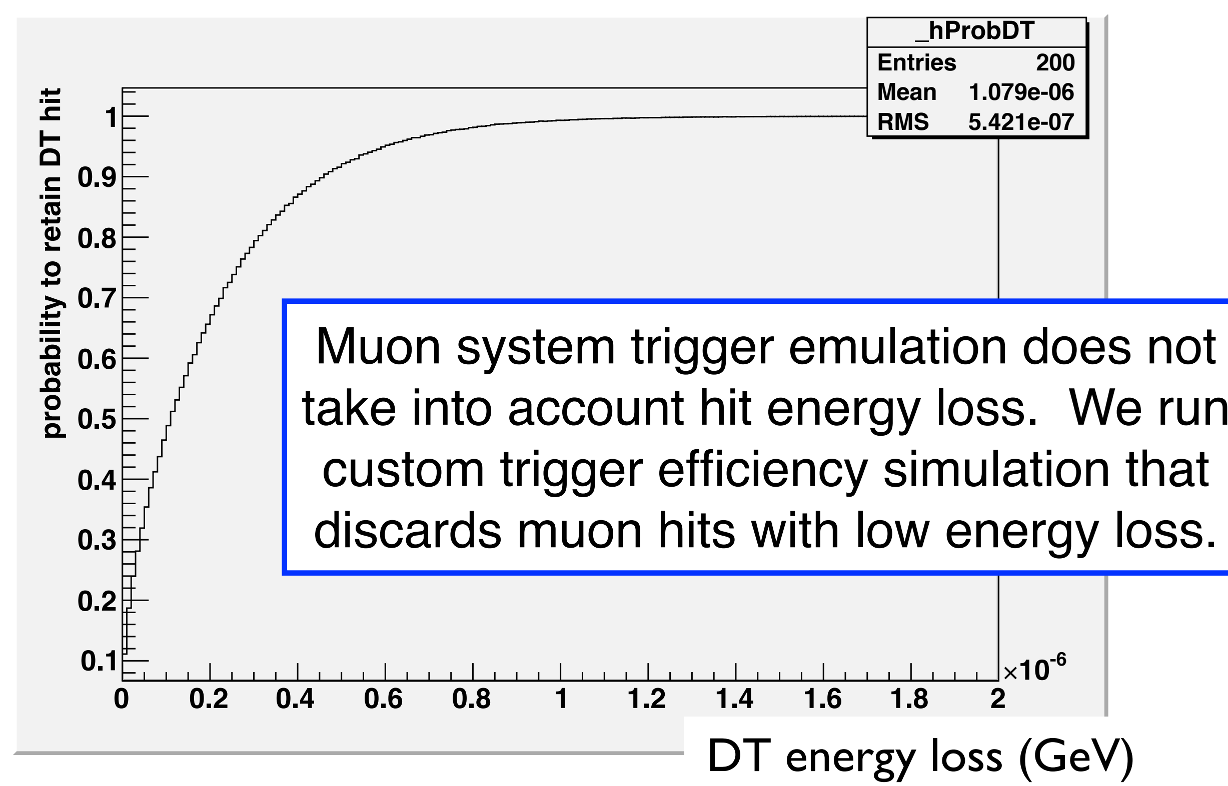
Meade, et al.,
PRL 109, 031801 (2012)

Standard reconstruction/ simulation requires modification for fractionally charged particles

Fractionally charged particles have p_T **mismeasured** by factor of 1/lql.



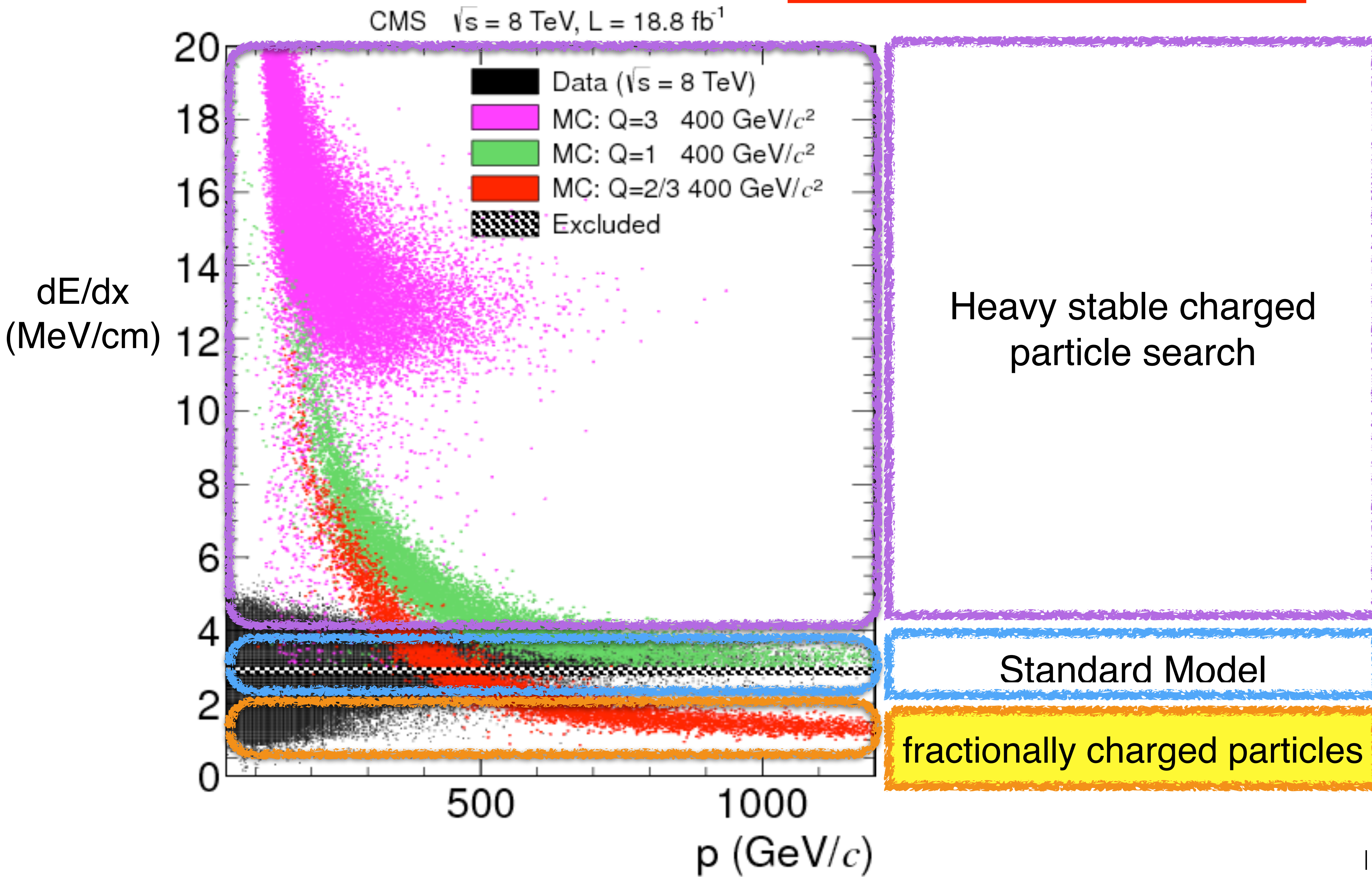
Stable fractionally charged particles **deposit less energy** in tracker, muon detectors. Reduced efficiency to trigger & reconstruct track offline. Important systematic uncertainty on signal efficiency.



Fractionally charged particles populate unchartered territory

$$-\left\langle \frac{dE}{dx} \right\rangle = Kq^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

Bethe eqn: ionization energy loss is proportional to q^2



Number of low-ionizing hits follows a binomial distribution

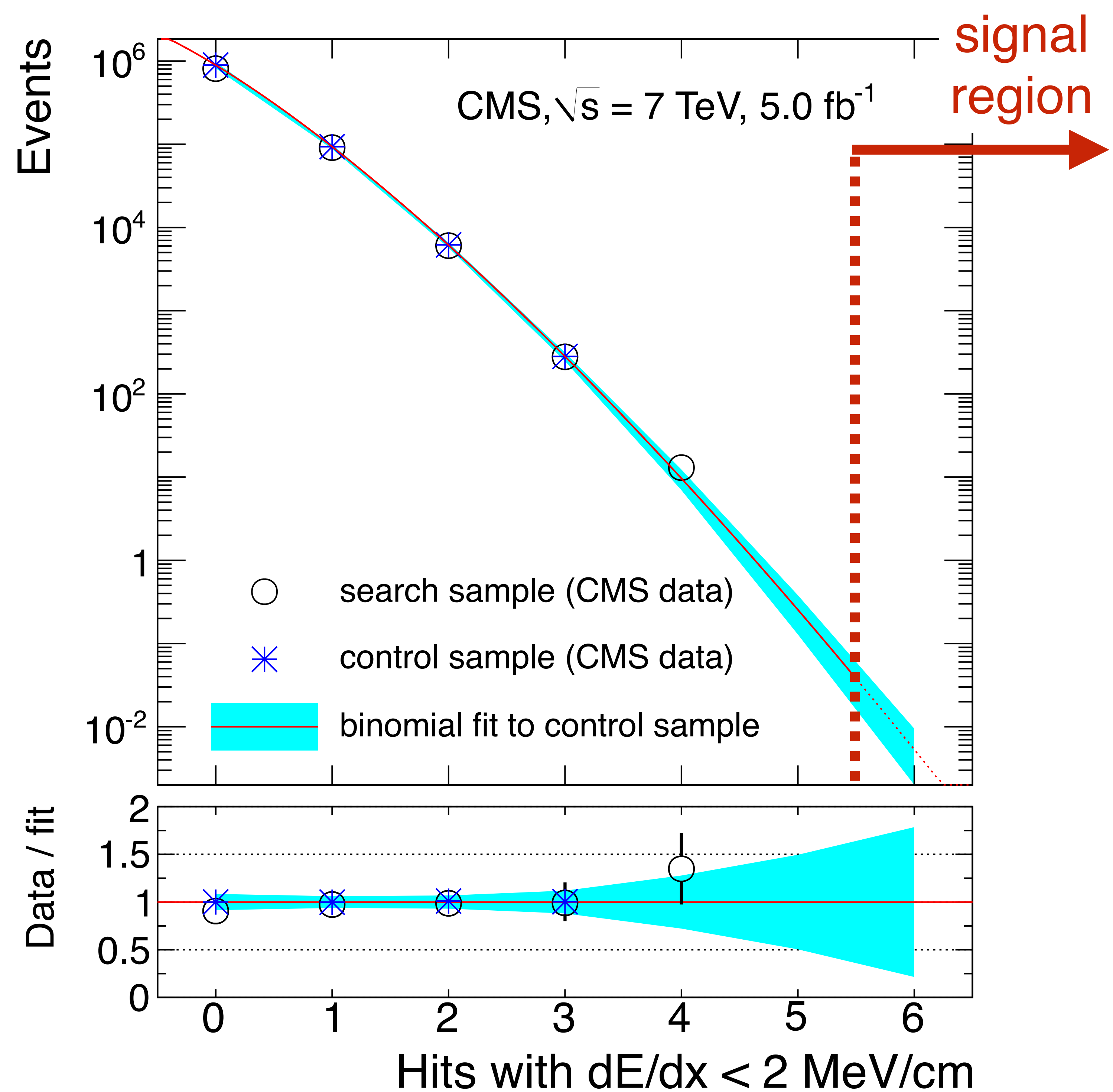
$$N_{\mathrm{evts}} = \boxed{N_0}\binom{\boxed{\mu}}{n} p^n (1-\boxed{p})^{\mu-n},$$

$$\binom{\mu}{n} = \frac{\Gamma(\mu+1)}{\Gamma(n+1)\Gamma(\mu-n+1)},$$

3 free parameters

Each hit is an independent ionization energy loss measurement.

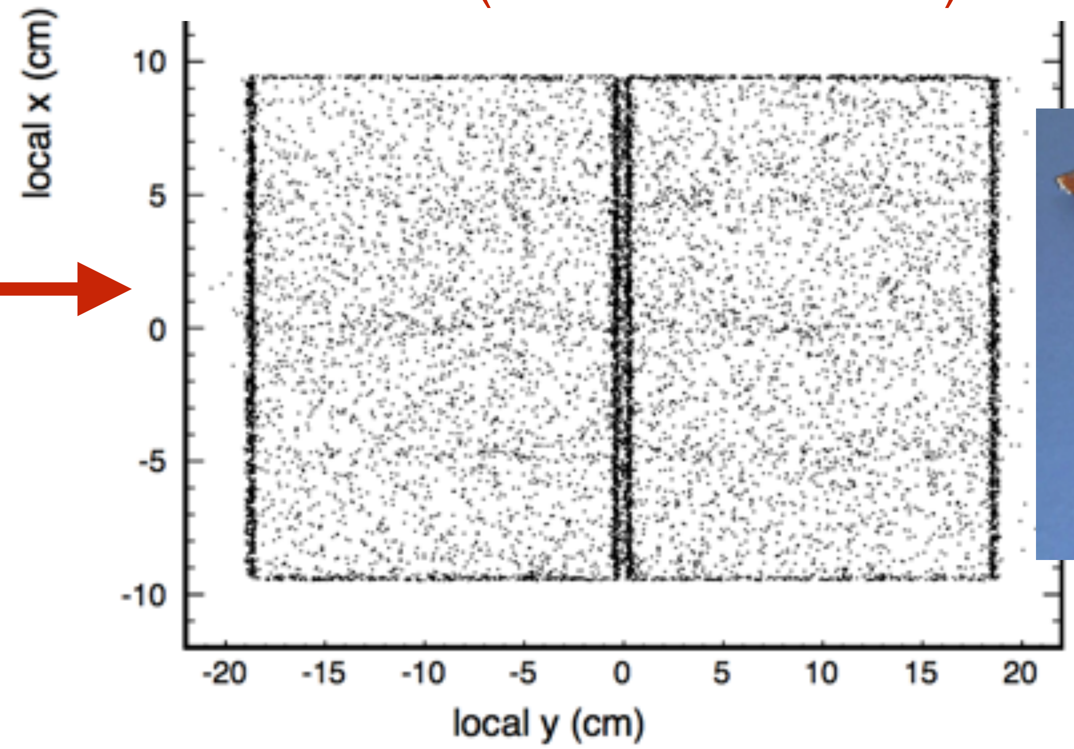
Background distribution from first principles allows for a precise bkgd estimate.

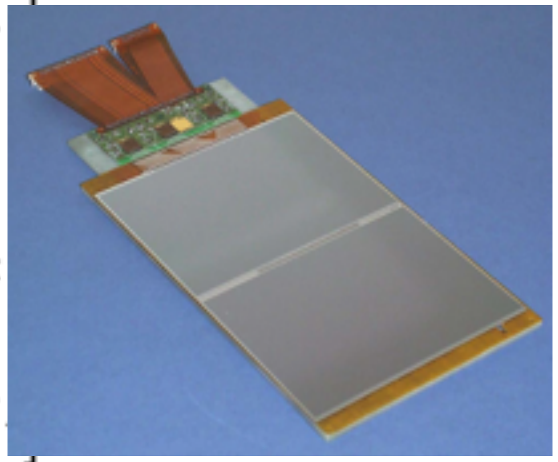


Binomial distribution results from uncorrelated measurements

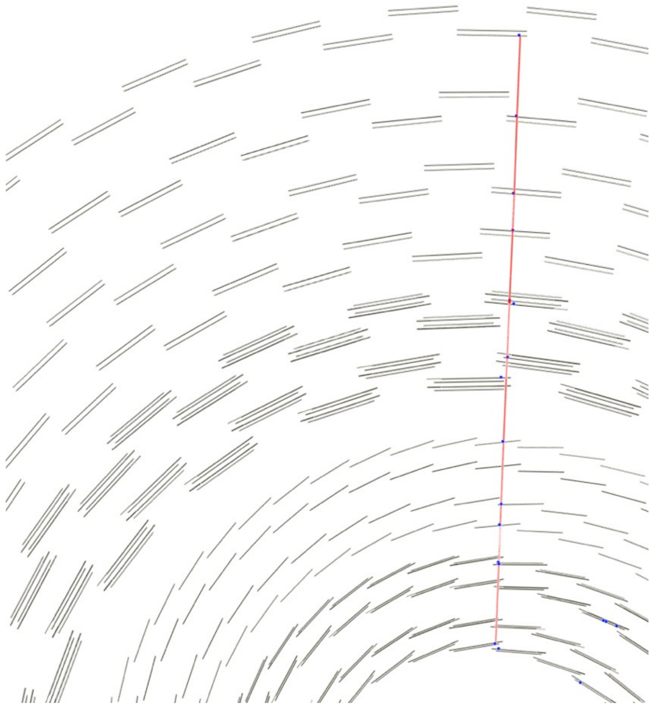
Particles that intersect the edge or center (glue joint) of a tracker module are more likely to produce a low-dE/dx hit.

local position of hits with dE/dx < 1.7 MeV/cm
(tracker outer barrel)





Some high-p_T trajectories may violate uncorrelated assumption



Solution: exclude hits close to edge/center of modules.

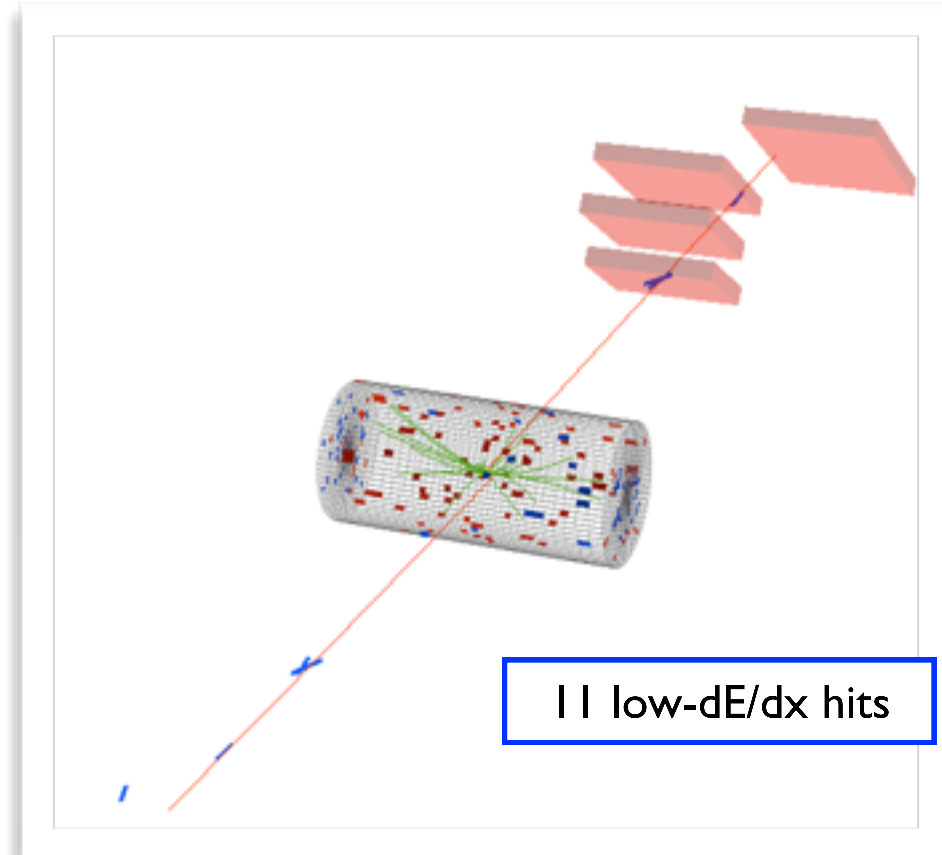
First look at data: a signal?

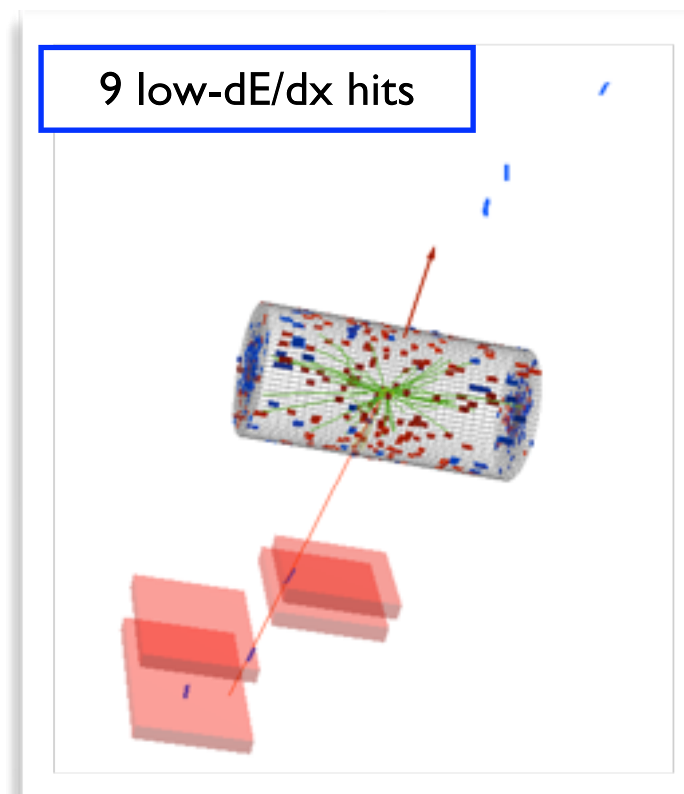
Looked at sample of data after a preliminary version of the selection.

Several events had tracks with many low-dE/dx hits → expected signature of signal!

But, upon examination of event displays these events had signature of cosmic ray muons → muon hits 180 degrees opposite the candidate track.

Suppressed the cosmic ray bkgd by adding cuts on several variables (quality of primary vertex, # pixel hits, d_{xy}, d_z, IP time, 3D angle between candidate track and any other high-pT track).



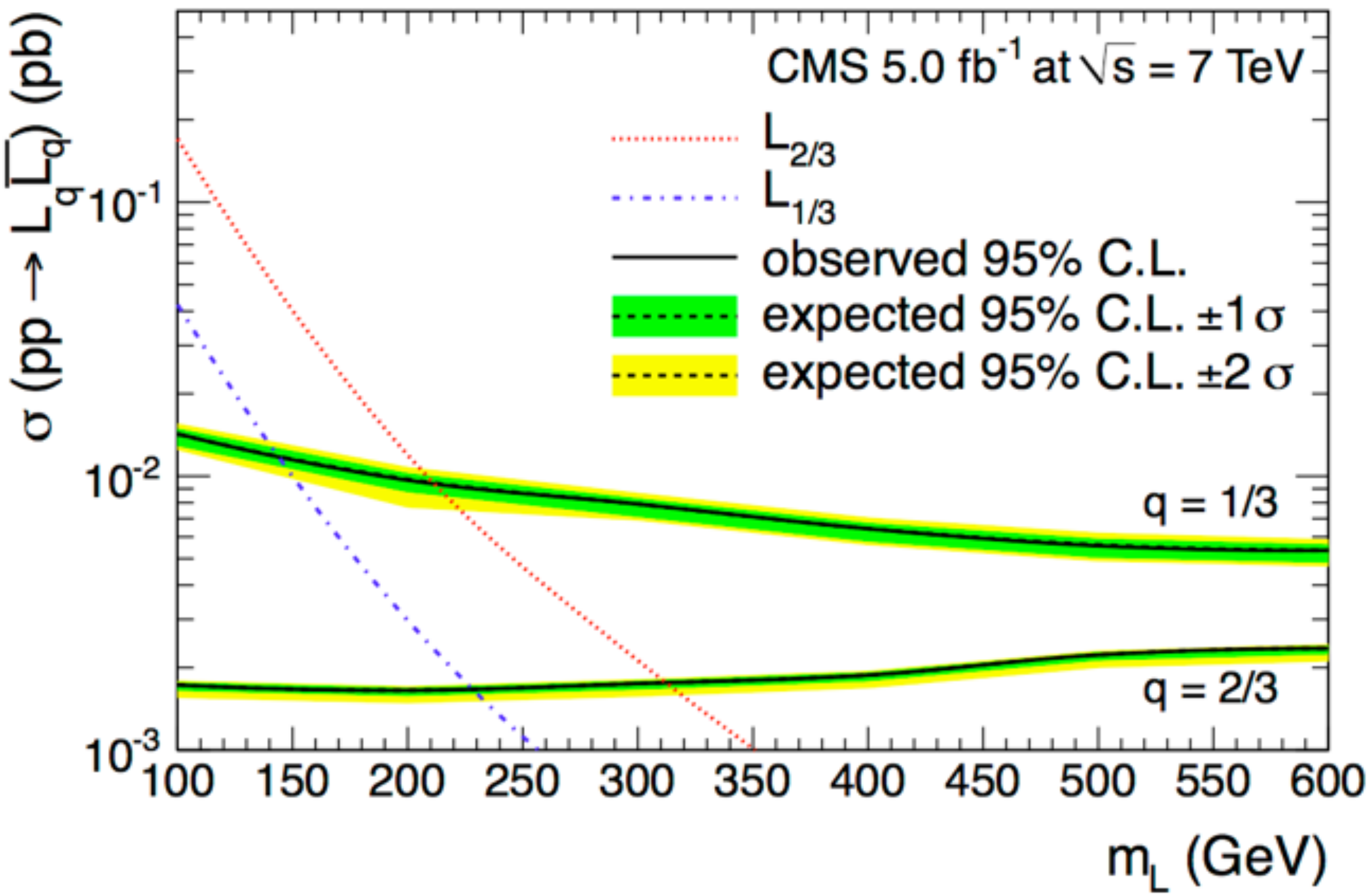


First limits on 0<|q|<1 stable particles at LHC

	# events
Cosmic rays	0.007 ± 0.006
pp collisions	0.005 ± 0.004
Total bkgd	0.012 ± 0.007
Observation	0

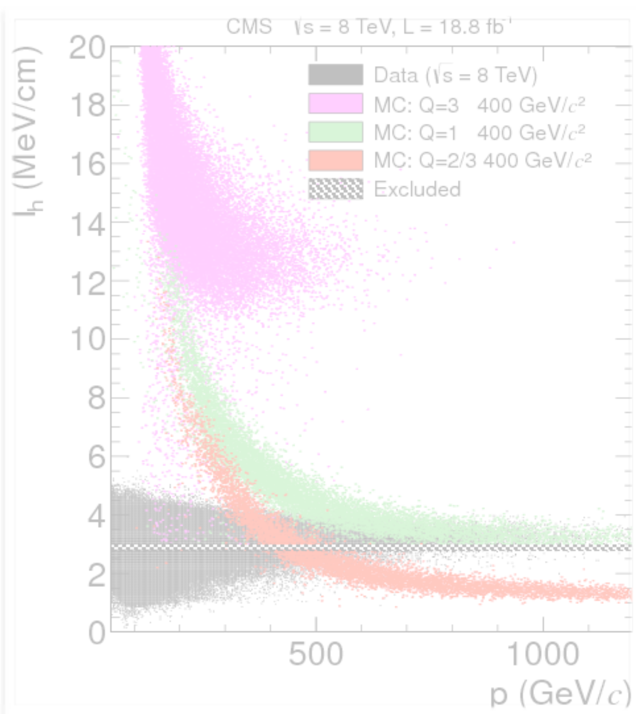
Careful understanding of backgrounds → small contribution & precise estimate

Set lower mass limits on DY production of particles with
lql = 2e/3: 310 GeV
lql = e/3: 140 GeV



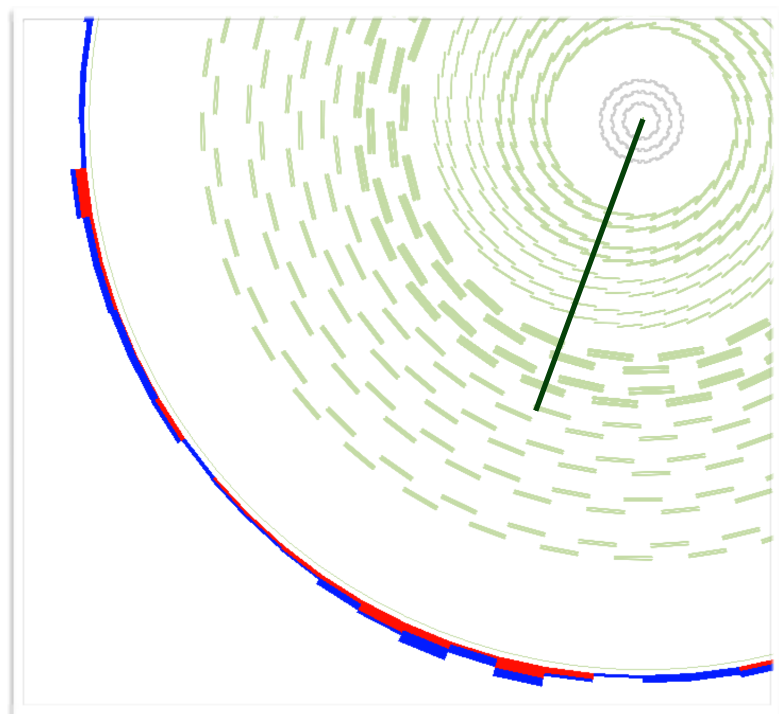
Selected CMS searches for exotic long-lived particles

Fractionally charged particles



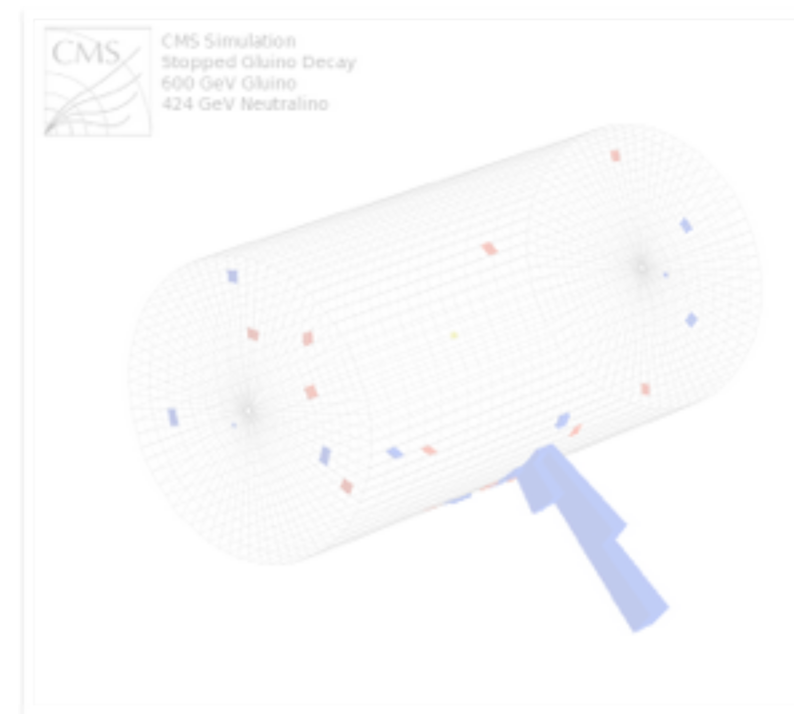
Phys. Rev. D 87 (2013) 092008
arXiv:

Disappearing tracks



JHEP 01 (2015) 096
arXiv:1411.6006

Stopped particles



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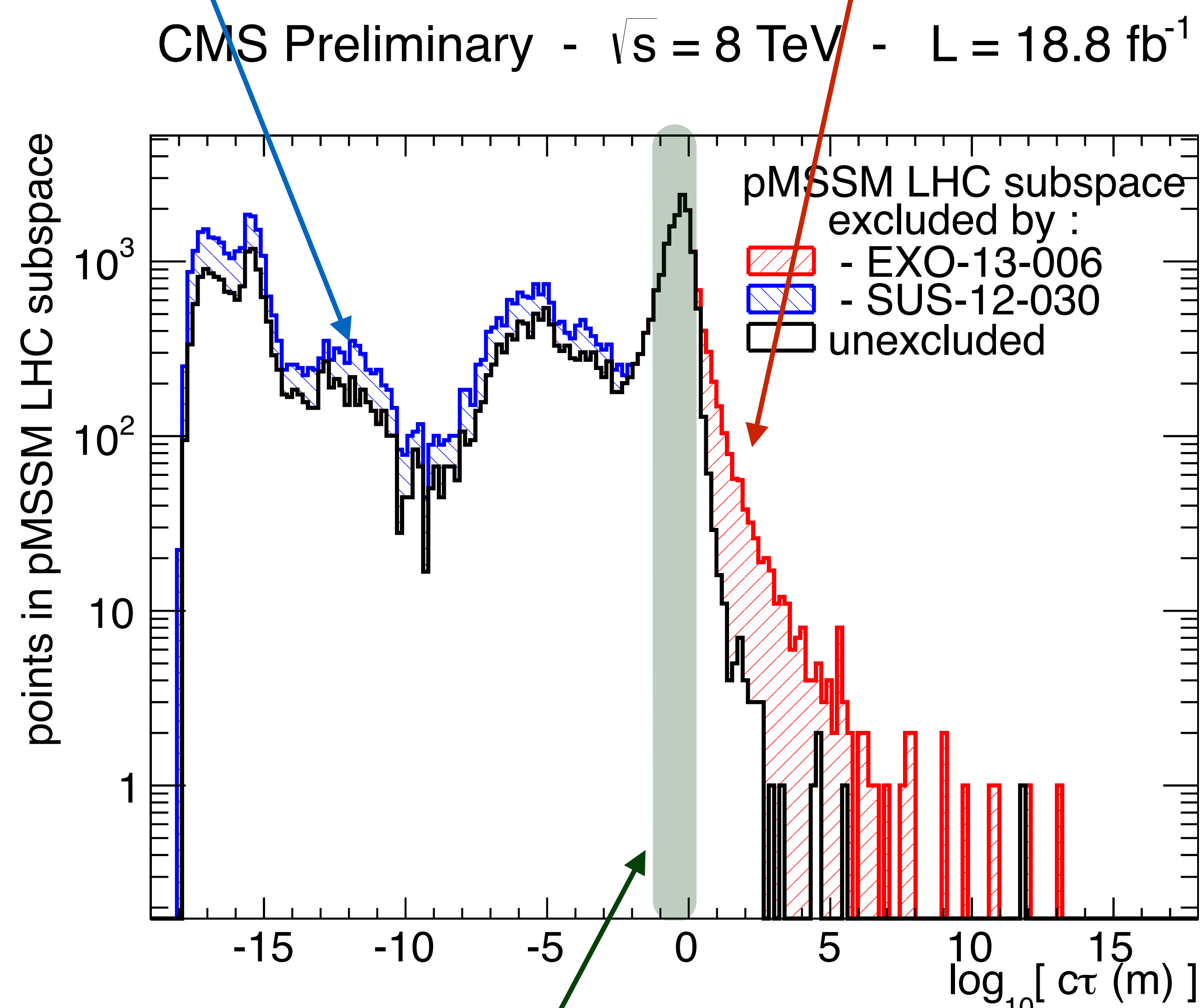
Motivation: fill important gap in parameter space

Explore 0.1 < cτ < 1 m, a region well-motivated for a variety of reasons.

- Important lifetime region (**peak** in pMSSM plot at right)
- Distinct experimental signature.
- Few Standard Model backgrounds.

classic SUSY: ~< 1 mm

HSCP: >~ 1 m



(chargino lifetime)

this search: 0.1 - 1 m

Disappearing track signature

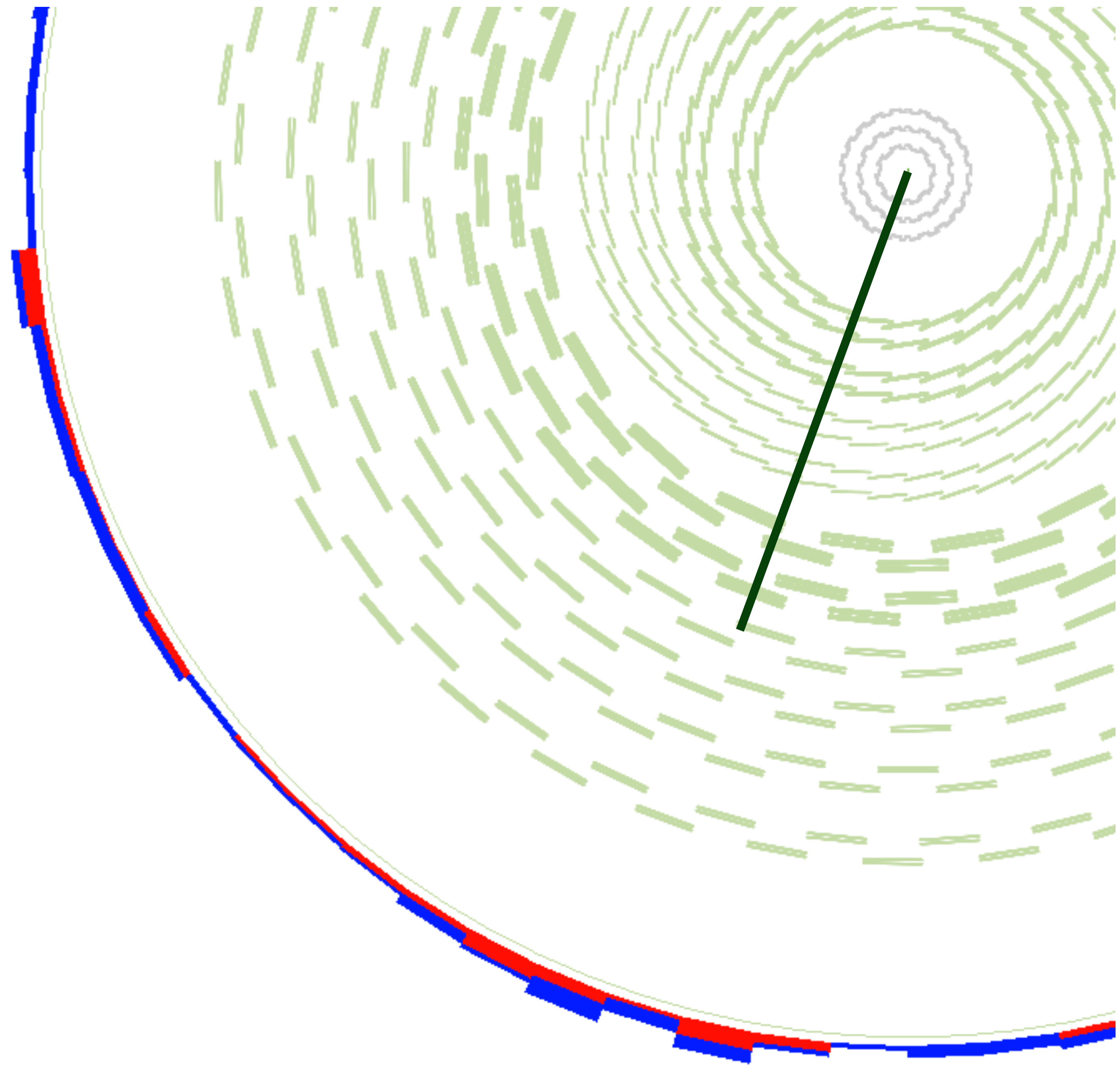
- Disappearing track: stops partway through the tracker

- Produced by charged BSM particle if decay products are undetected because they are low-momentum or neutral/weakly-interacting.

- Striking signature of new physics

- Would provide multiple handles to study a BSM particle, e.g., lifetime, mass, recovery of some decay products.

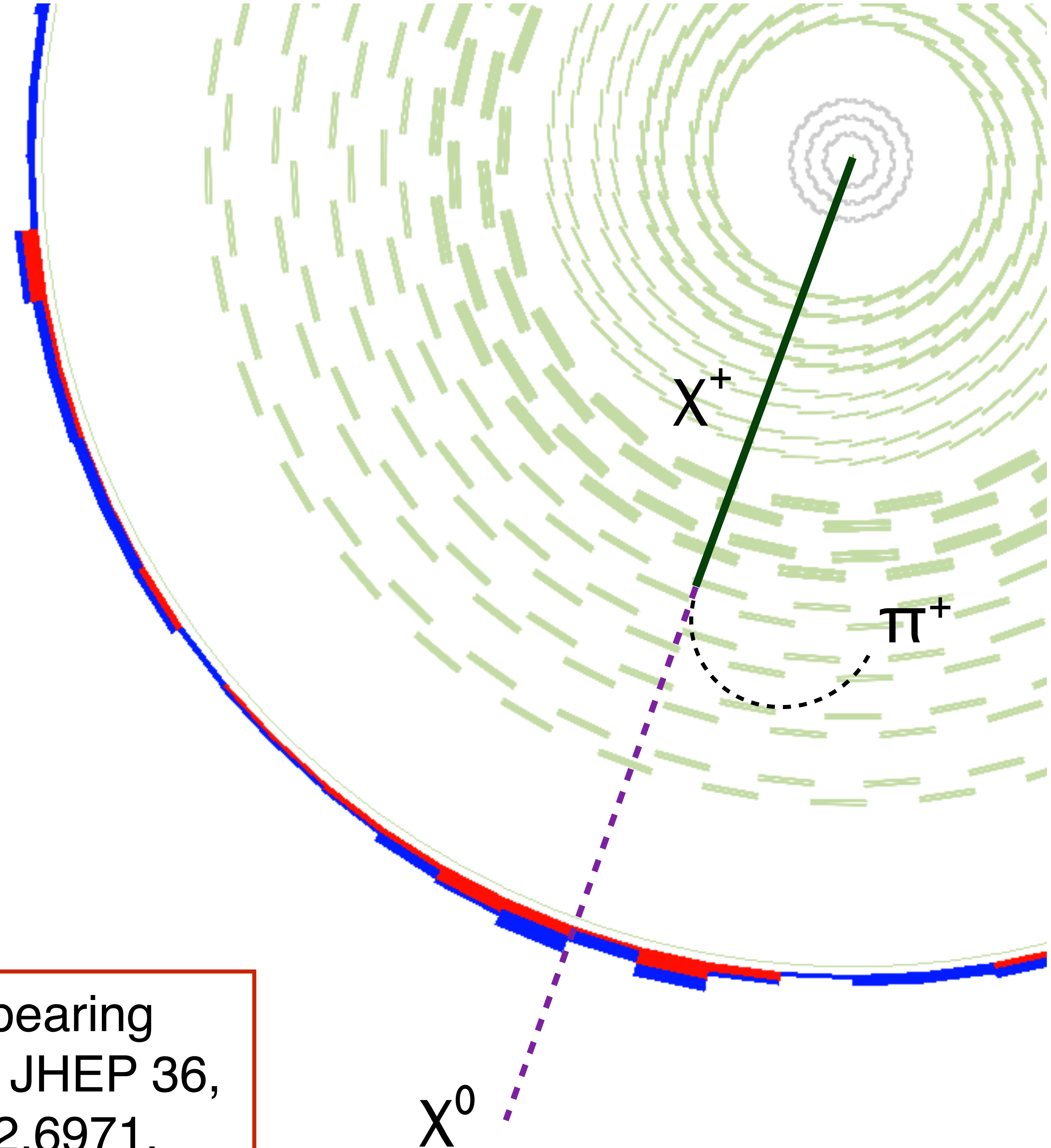
- Signature-driven search, not designed for particular model.



Benchmark signal model

Anomaly-Mediated SUSY Breaking (Nucl. Phys. B 557, 79 (1999))

- small mass splitting between the lightest chargino ($\chi^{\pm}$) and neutralino (χ^0)
- $\chi^{\pm}$ decays to $\chi^{\pm} \rightarrow \chi^0 \pi^{\pm}$ with lifetime ~ 1 ns
- χ^0 interacts only weakly and $\pi^{\pm}$ has too little momentum to be reconstructed
- direct electroweak production: $pp \rightarrow \chi^{\pm}\chi^{\mp}$ & $pp \rightarrow \chi^{\pm}\chi^0$



Many other models could produce disappearing tracks: Phys. Rev. D 85, 095011 (2012), JHEP 36, 1 (2013), JHEP 2, 126 (2013), arXiv:1212.6971.

Candidate Track Selection

Data sample: 19.5 fb^{-1} of pp collisions at $\sqrt{s}$ = 8 TeV

Trigger on MET (produced by recoil of $\chi\chi$ from ISR jet) — Triggers, Missing Energy

Jet Criteria — Leading jet criteria, Additional jet criteria

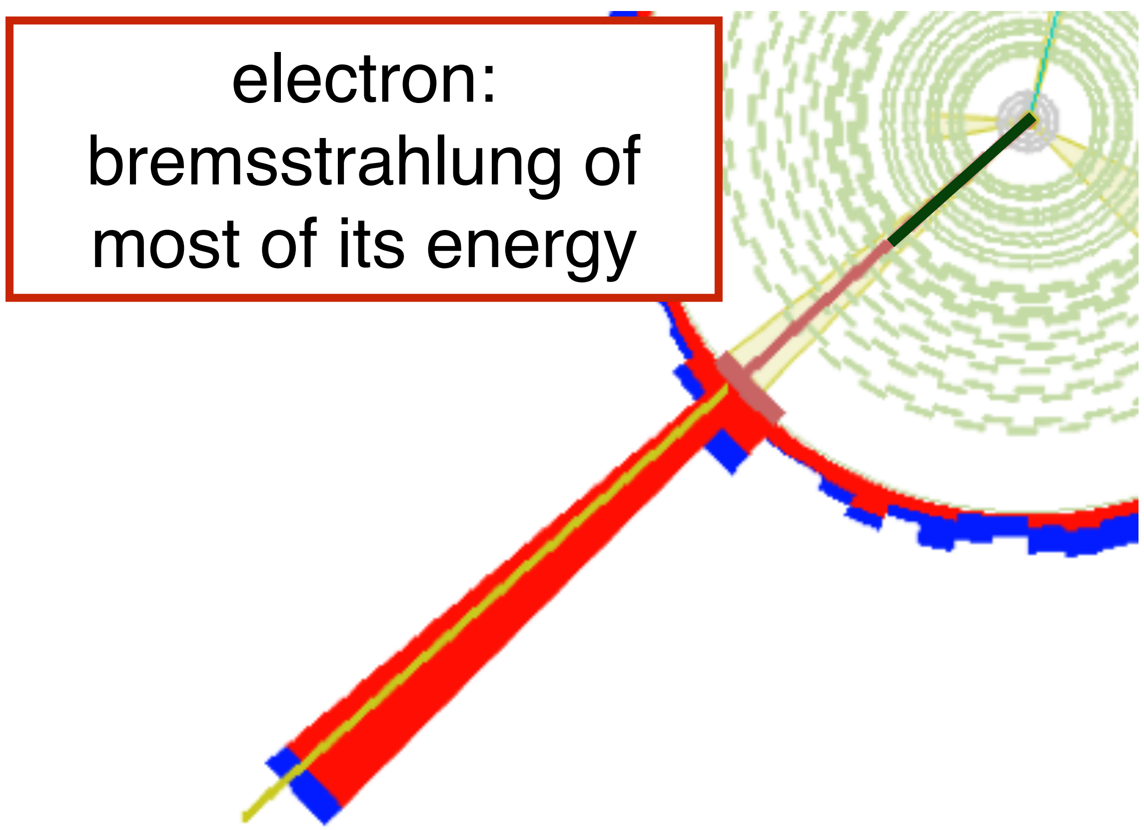
Candidate Track Criteria — Track quality, Track isolation, Lepton vetoes

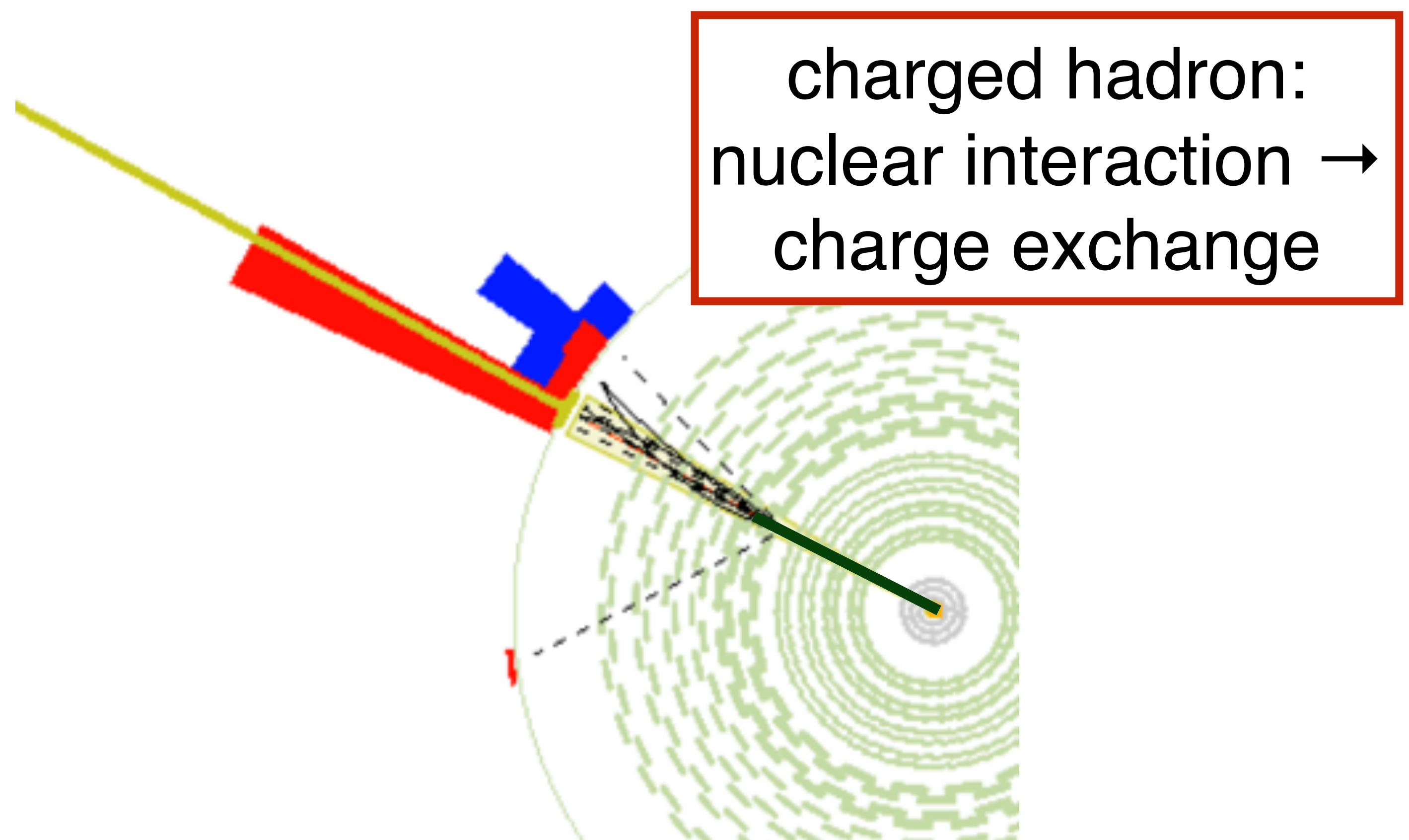
Triggers	HLT_MonoCentralPFJet80_PFMETnoMu95_NHEF0p95 HLT_MonoCentralPFJet80_PFMETnoMu105_NHEF0p95 HLT_MET120_HBHENoiseCleaned
Missing Energy	$\not{E}_T > 100\,\text{GeV}$
Leading jet criteria	$p_T > 110\,\text{GeV}$ $\lvert\eta\rvert < 2.4$ charged hadron energy fraction > 0.2 neutral hadron energy fraction < 0.7 charged EM energy fraction < 0.5 neutral EM energy fraction < 0.7
Additional jet criteria	no jet pairs with $\Delta\phi > 2.5$ $\Delta\phi > 0.5$ - $\not{E}_T$ && 2 highest-p_T jets
Track quality	$p_T > 50\,\text{GeV}$ $\lvert\eta\rvert < 2.1$ $d_0 < 0.02\,\text{cm}$ $d_z < 0.5\,\text{cm}$ ≥ 7 valid hits 0 missing middle hits 0 missing inner hits
Track isolation	$(\Sigma p_T^{\Delta R<0.3} - p_T)/p_T < 0.05$ $\Delta R > 0.5$ between track and any jet
Lepton vetoes	!in ECAL barrel-endcap crack, $1.42 < \lvert\eta\rvert < 1.65$!in DT Wheel 0 gap, $0.15 < \lvert\eta\rvert < 0.35$!in region of larger μ reco. inefficiency $1.55 < \lvert\eta\rvert < 1.85$!within $\Delta R < 0.05$ of dead or noisy ECAL cluster !within $\Delta R < 0.25$ of errant CSC !within $\Delta R < 0.15$ of e, $p_T > 10\,\text{GeV}$ && `mvaNonTrigV0` > 0 !within $\Delta R < 0.15$ of μ, $p_T > 10\,\text{GeV}$!within $\Delta R < 0.15$ of τ, $p_T > 30\,\text{GeV}$, $\lvert\eta\rvert < 2.3$, loose tau ID

Disappearing Track Criteria

We promote a candidate track to a "disappearing track" if it … disappears

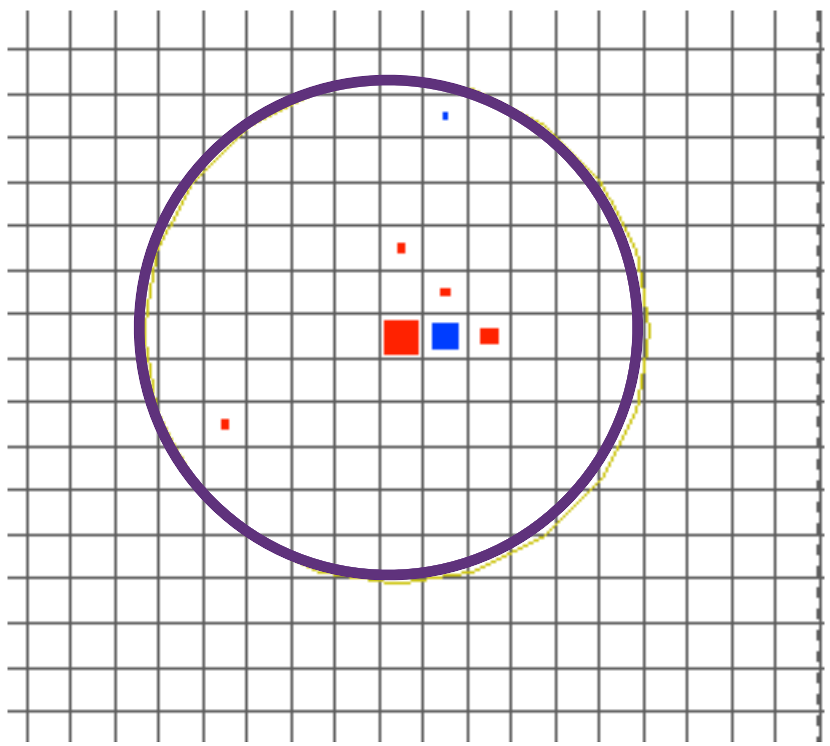
- Missing outer hits are the characteristic sign of a disappearing track
- $N_{miss}^{outer} \geq 3$ rejects most SM tracks, which pass through all layers of the tracker
- But electrons and charged hadrons can produce missing outer hits

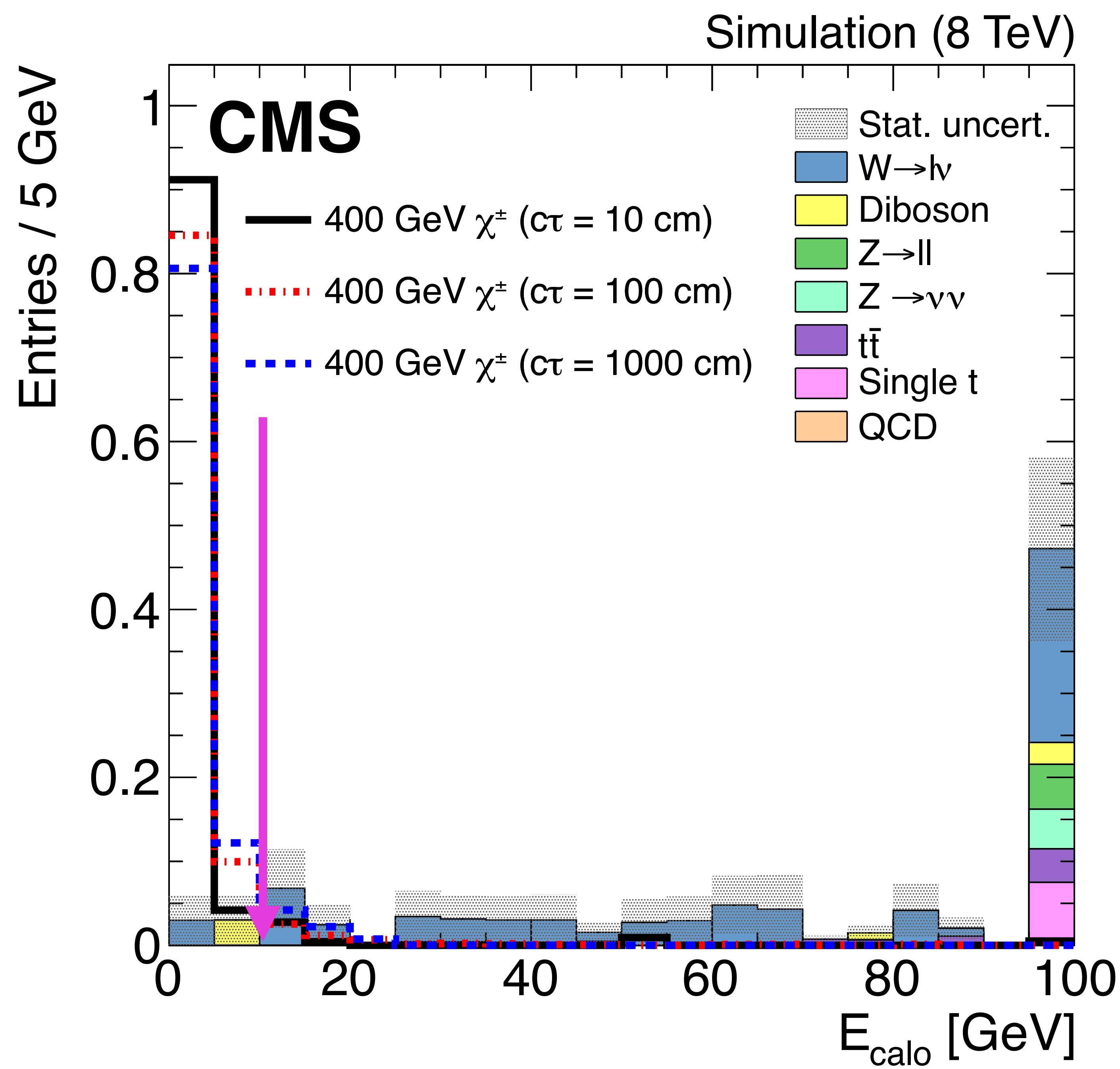




To avoid these SM sources of tracks with missing outer hits, we additionally require….

Disappearing Track Criteria





- We require there be not much energy in the calorimeter in the region geometrically associated to the our candidate track
  - **E_{calo} < 10 GeV**
- Ensures that missing outer hits are not from brem or nuclear interaction.

Candidate tracks with missing outer hits and little associated calorimeter energy form the search sample

Missing outer hits: algorithmic sources

We were surprised to discover that **muons** sometimes produce missing outer hits.

For a single pixel seed, the trajectory with the largest quality score Q is retained:

Q = 5*(# found hits) - 20*(# lost hits) - X^2

Sometimes the wrong set of hits is chosen: trajectory with missing outer hits has larger Q than one without missing outer hits.

In muon particle gun events, 11% of tracks produce ≥1 missing outer hit.

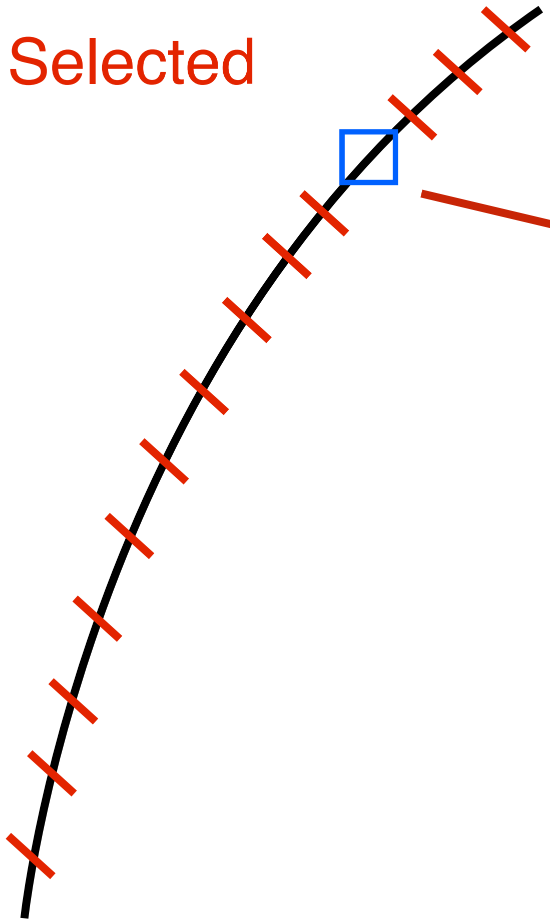
- 7.3%: track passes through a glue joint (near local y=0) (now fixed in software)
- 2.7%: trajectory without missing outer hits has larger X^2
- 0.7%: the last hit is mistakenly removed (now fixed in software)

All tracks are impacted by these algorithmic sources of “fake” missing outer hits.

Missing outer hits: pass through glue joint

Trajectory1

Not Selected



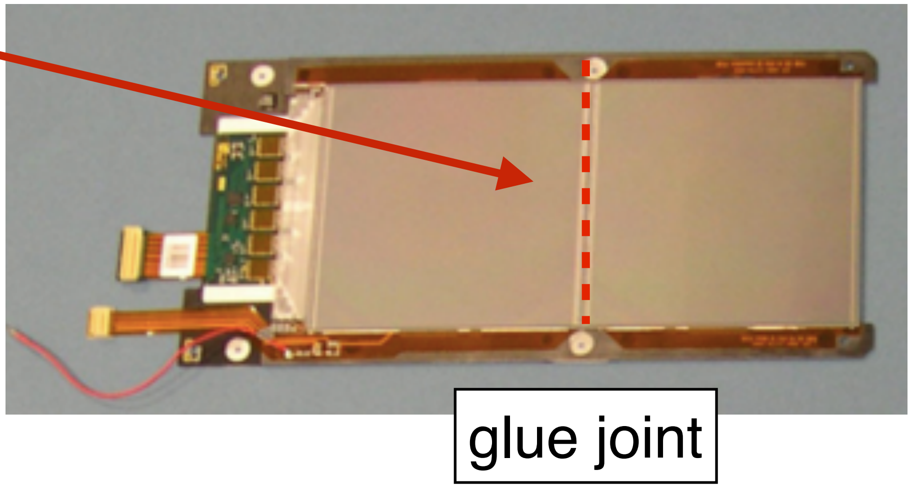
- 0 missing outer hits
- 13 valid measurements
- 1 lost measurement
- X^2=14.5

Score = 30.5

missing outer hit

lost hit

valid hit



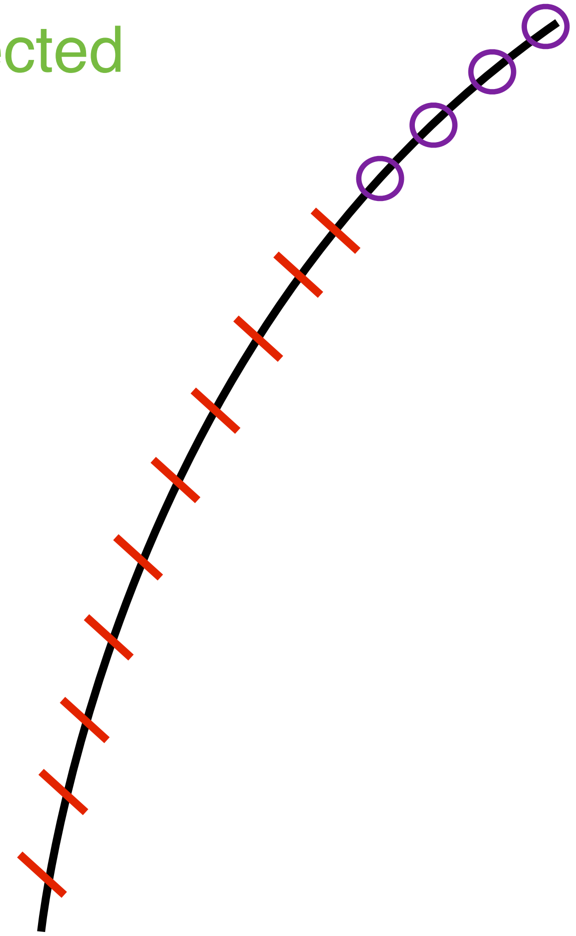
Score =5*(# hits) -20*(# lost hits) - X^2

Trajectory 2 has the higher score so it is chosen even though it has a larger number of missing outer hits than Trajectory 1

<u>Note:</u> Missing outer hits do not count as lost hits in the calculation of the score.

Trajectory 2

Selected



- 4 missing outer hits
- 10 valid measurements
- 0 lost measurements
- X^2=10.3

Score = 39.7

Backgrounds arise from reconstruction failure modes

1. **Electrons:** Can survive electron veto if directed toward a dead or noisy ECAL crystal.

2. **Muons:** Can survive muon veto from decay in flight, secondary electromagnetic shower, or no recorded hit in muon system.

3. **Taus:** Can survive tau veto if pion track from $\tau \to \pi\nu$ has mismeasured p_T.

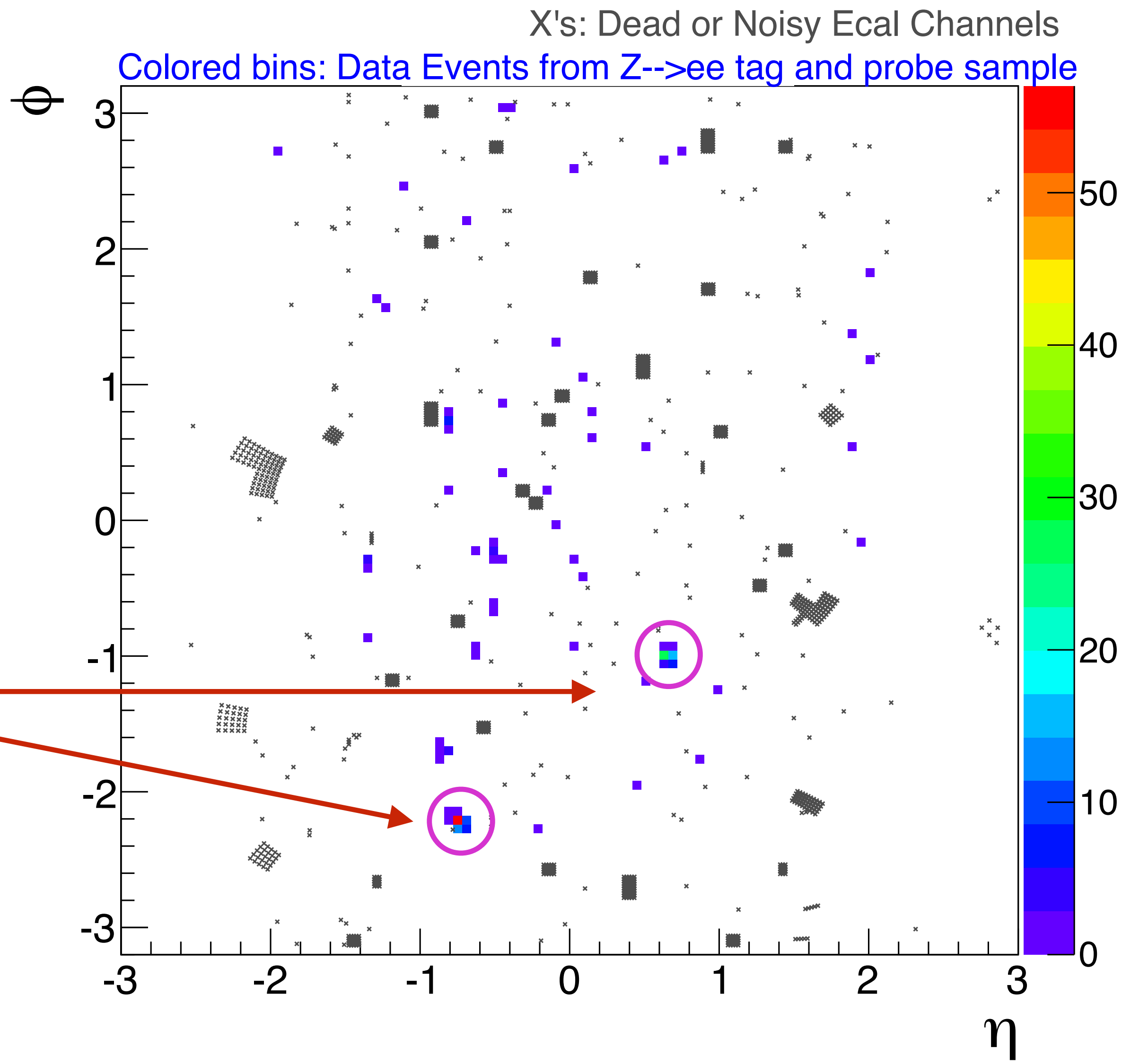
4. **Fake tracks:** False trajectories from pattern recognition failure → mimic signal.

Background Sources: Electrons

An electron track can survive the electron veto if its energy is not fully measured by the ECAL. Therefore we avoid regions where this is likely to happen.

- Veto tracks in the ECAL barrel-endcap gap.
- Veto tracks within ΔR<0.05 of an ECAL channel known to be dead/noisy.
- Veto any tracks pointing toward additional problematic ECAL channels, identified with a Z→ee tag/probe study.

Unreconstructed electrons from tag/probe sample

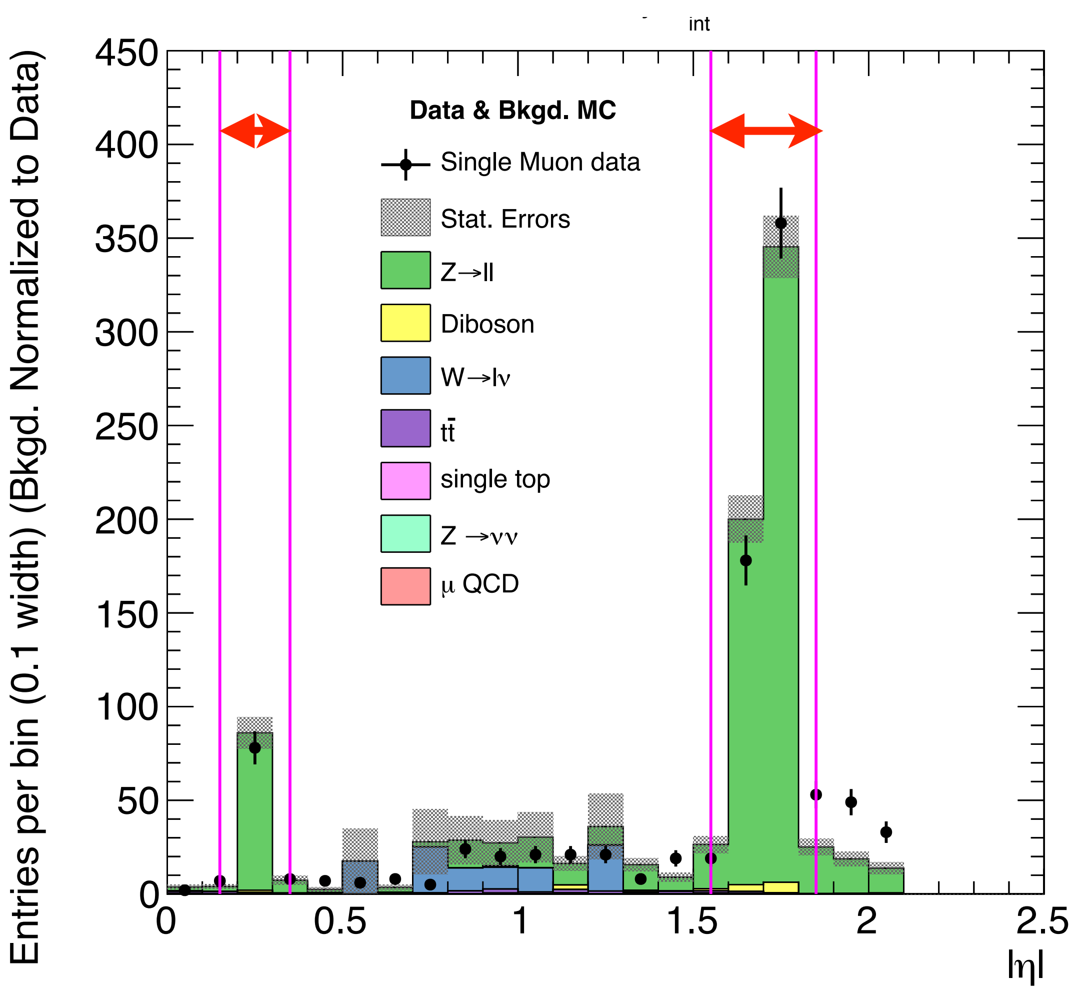


Background Sources: Muons

Veto tracks from global/standalone/tracker muon.

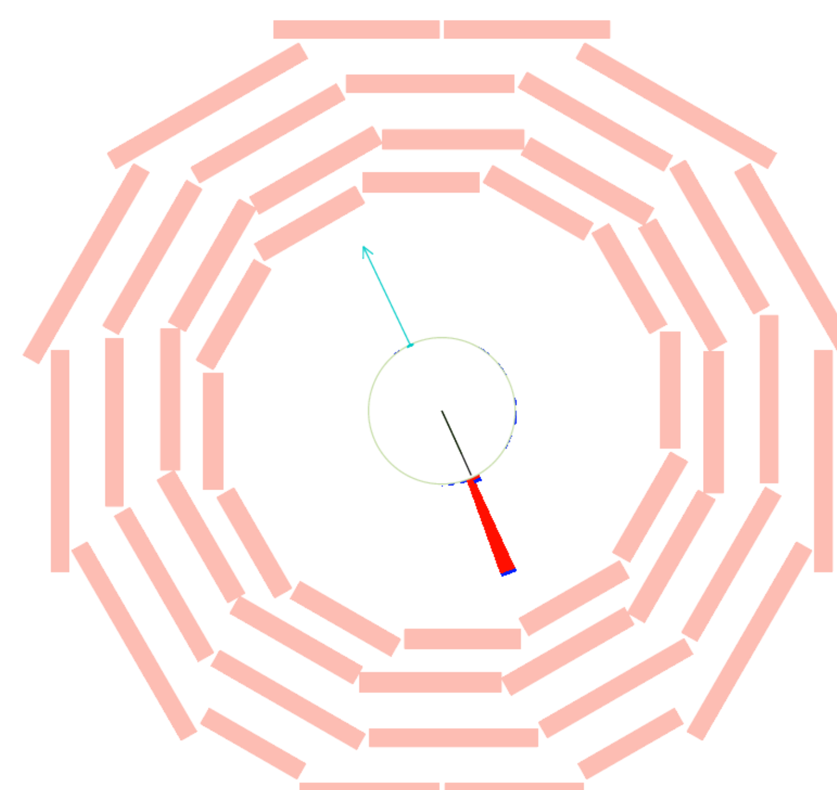
We avoid regions where muon reconstruction can fail:

- Veto η regions of large inefficiency
- Veto tracks within $\Delta R < 0.25$ of bad CSC



Unreconstructed muons from tag/probe sample

- Even after fiducial cuts, muon may be unreconstructed when it decays in flight or produces a secondary electromagnetic shower.
- From muon particle gun sample, muon reconstruction inefficiency is 6.8×10^{-5}. Very rare!

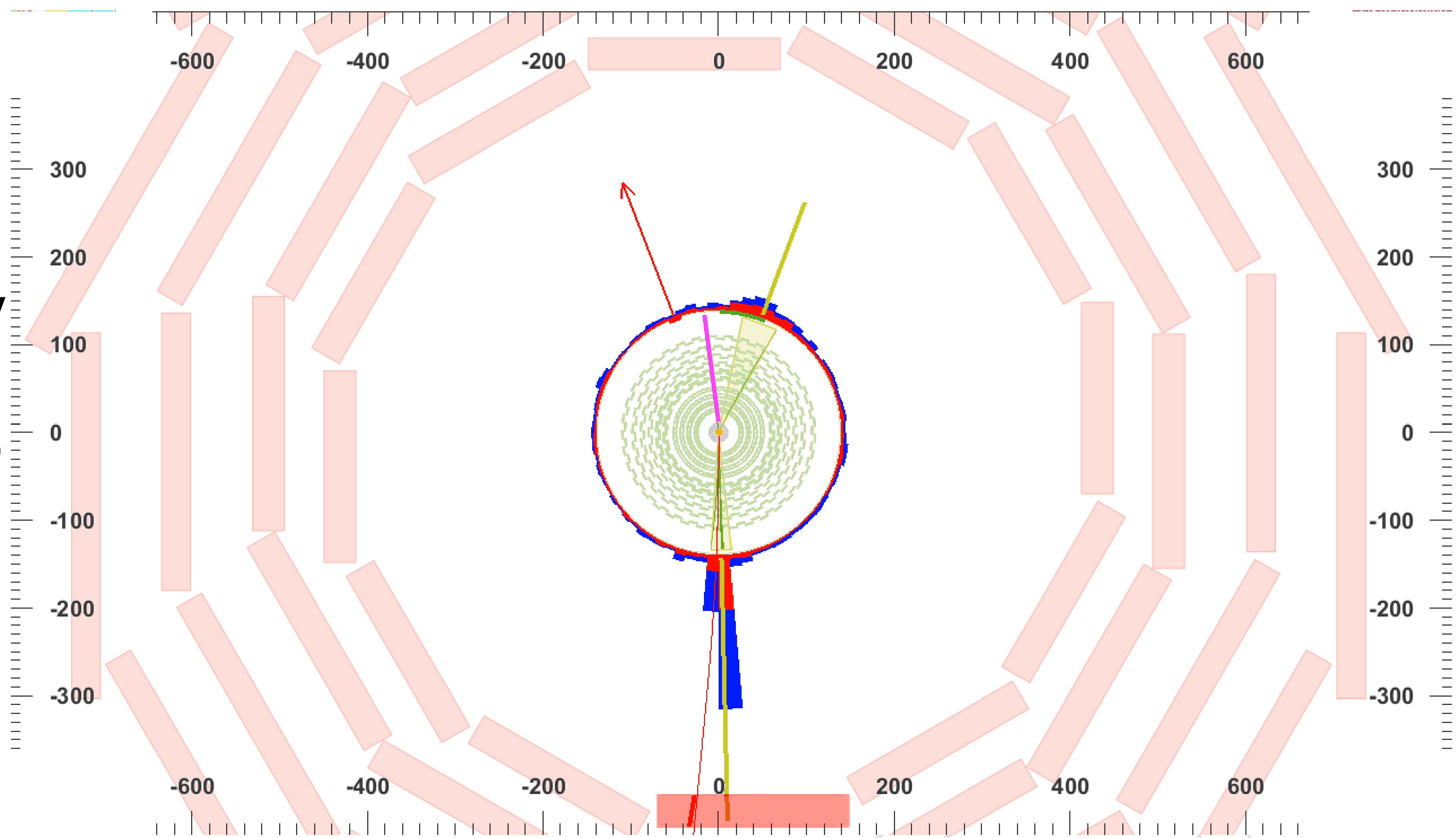


Background Sources: Taus

A charged hadron track from a tau decay can survive if its p_T is mismeasured (which is easier to do for a disappearing track)

$W \rightarrow \tau\nu$ event

- Candidate track in magenta π from $\tau \rightarrow \pi\nu$
- Generated p_T = 15.2 GeV
- Reco'd p_T = 74.5 GeV: **passes p_T > 50 GeV cut.**
- E_{calo} = 8.1 GeV: **passes E_{calo} < 10 GeV cut.**
- **Not reconstructed as tau,** since track p_T and E_{calo} are very different.

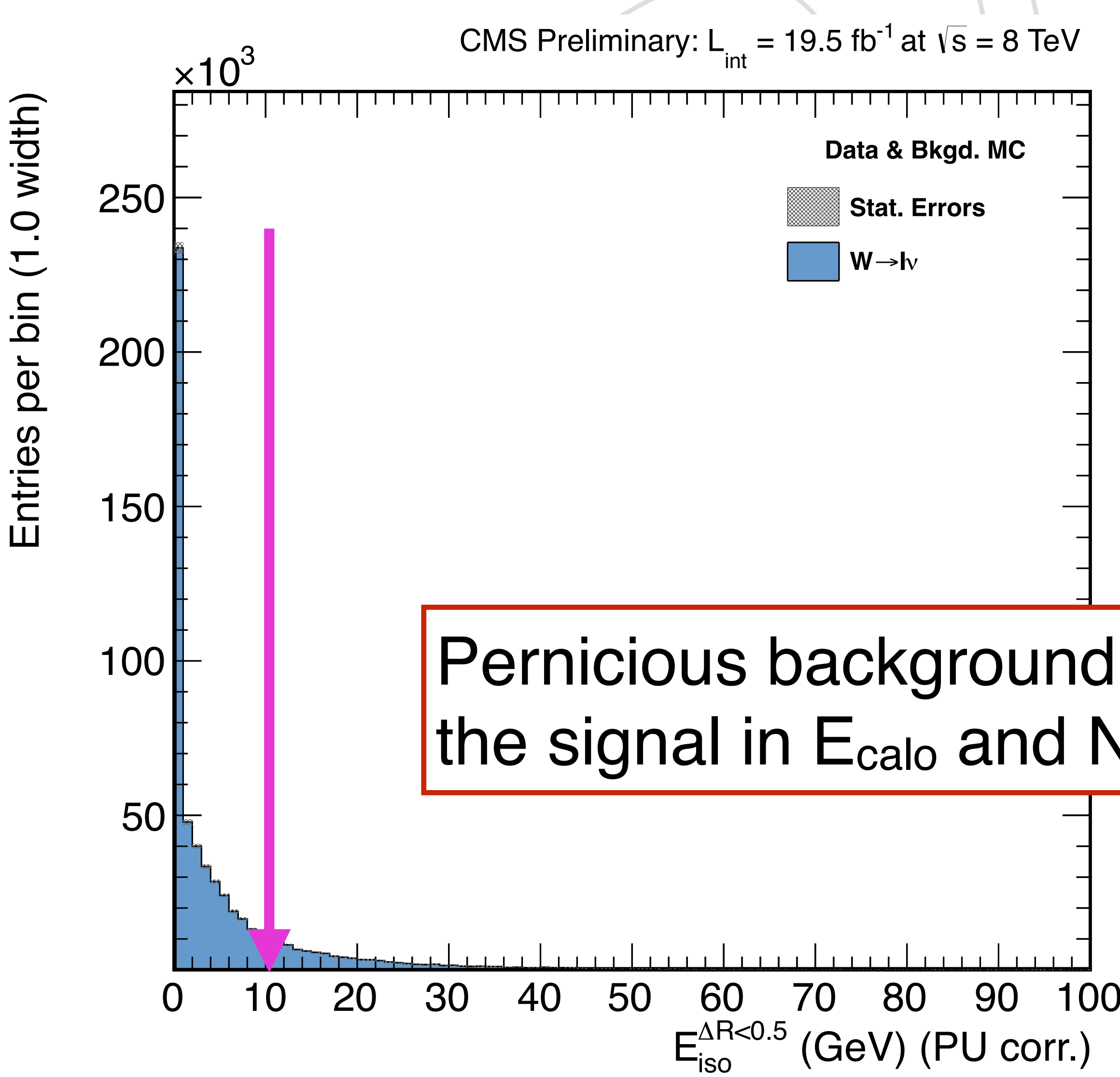


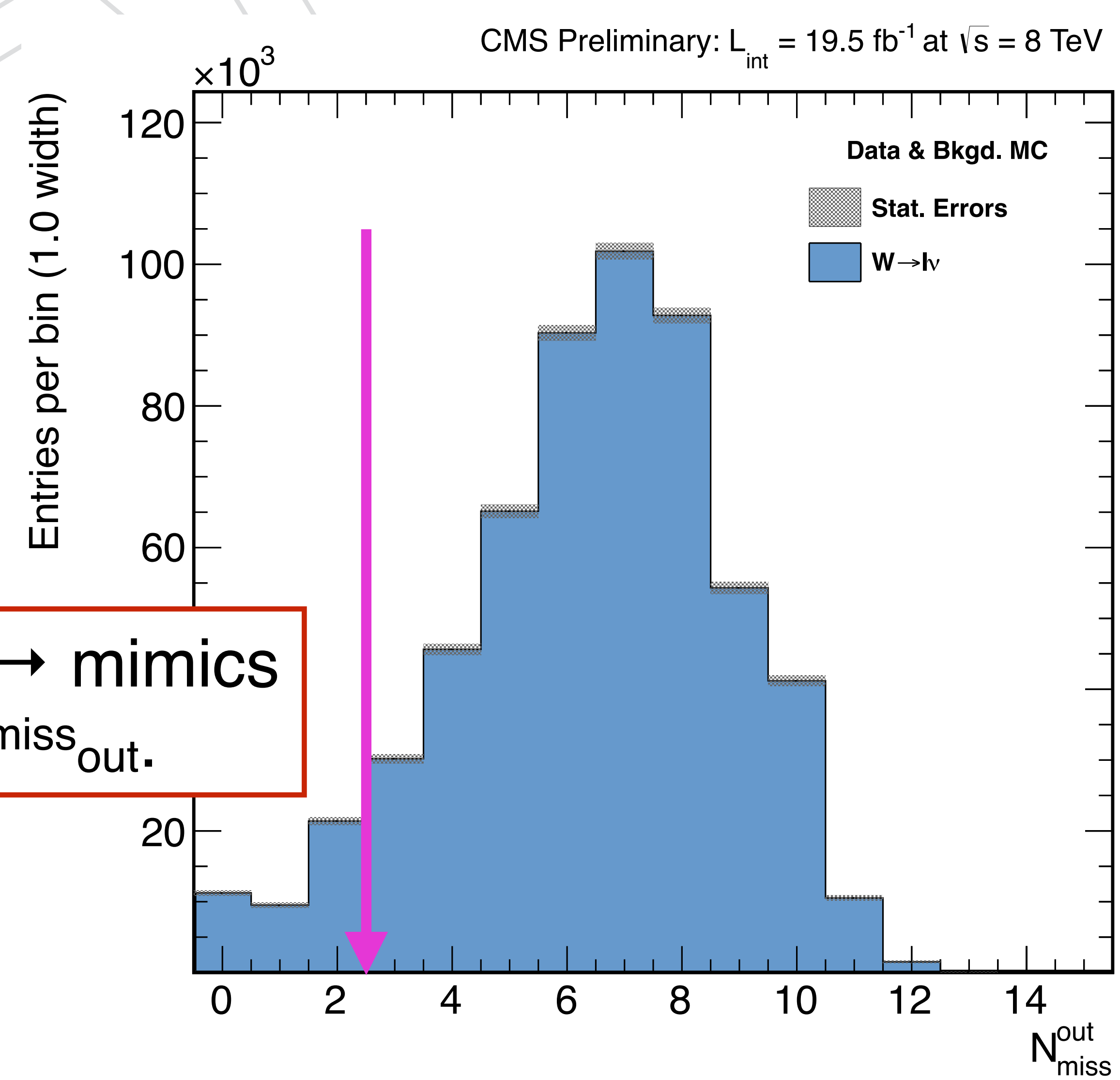
We require ≥7 hits to reduce the fraction of tracks with mismeasured p_T.

Background Sources: Fake Tracks

Fake tracks are false trajectories that result from fake pattern recognition of a combination of random hits in the event.

- Mostly rejected by track isolation and track quality requirements.
- With each additional hit, probability to find a fake track decreases: **large N^{miss}_{out}.**
- Hits not produced by a single particle: **little E_{calo}.**





Pernicious background → mimics the signal in E_{calo} and N^{miss}_{out}.

Lepton Background Estimates

- Developed a factorized data/MC estimate.
- Use MC only to model lepton inefficiency.
- Don't rely on MC to model missing outer hits or other selection criteria.
- Test the simulation of P^{lep} with tag and probe samples.

$$\boxed{N^i = N^i_{ctrl} P^i}$$

N^i_{ctrl} (data): # events passing search region criteria, without the lepton veto

P^i (MC): probability of track from lepton to survive the lepton veto

	Electrons	Muons	Taus
Criteria removed to select control sample	e veto $E_{\mathrm{calo}} < 10\,\mathrm{GeV}$	μ veto	τ_{h} veto $E_{\mathrm{calo}} < 10\,\mathrm{GeV}$
N^i_{ctrl} from data	7785	4138	29
P^i from simulation	$< 6.3 \times 10^{-5}$	$1.6^{+3.6}_{-1.3} \times 10^{-4}$	<0.019
$N^i = N^i_{\mathrm{ctrl}} P^i$	<0.49 (stat)	$0.64^{+1.47}_{-0.53}$ (stat)	<0.55 (stat)
P^i systematic uncertainty	31%	50%	36%
N^i	<0.50 (stat+syst)	$0.64^{+1.47}_{-0.53}$ (stat) $\pm$ 0.32 (syst)	< 0.57 (stat+syst)

Fake Track Background Estimate

- The fake track rate is independent of the underlying physics process.
- Developed entirely data-driven bkgd estimate.

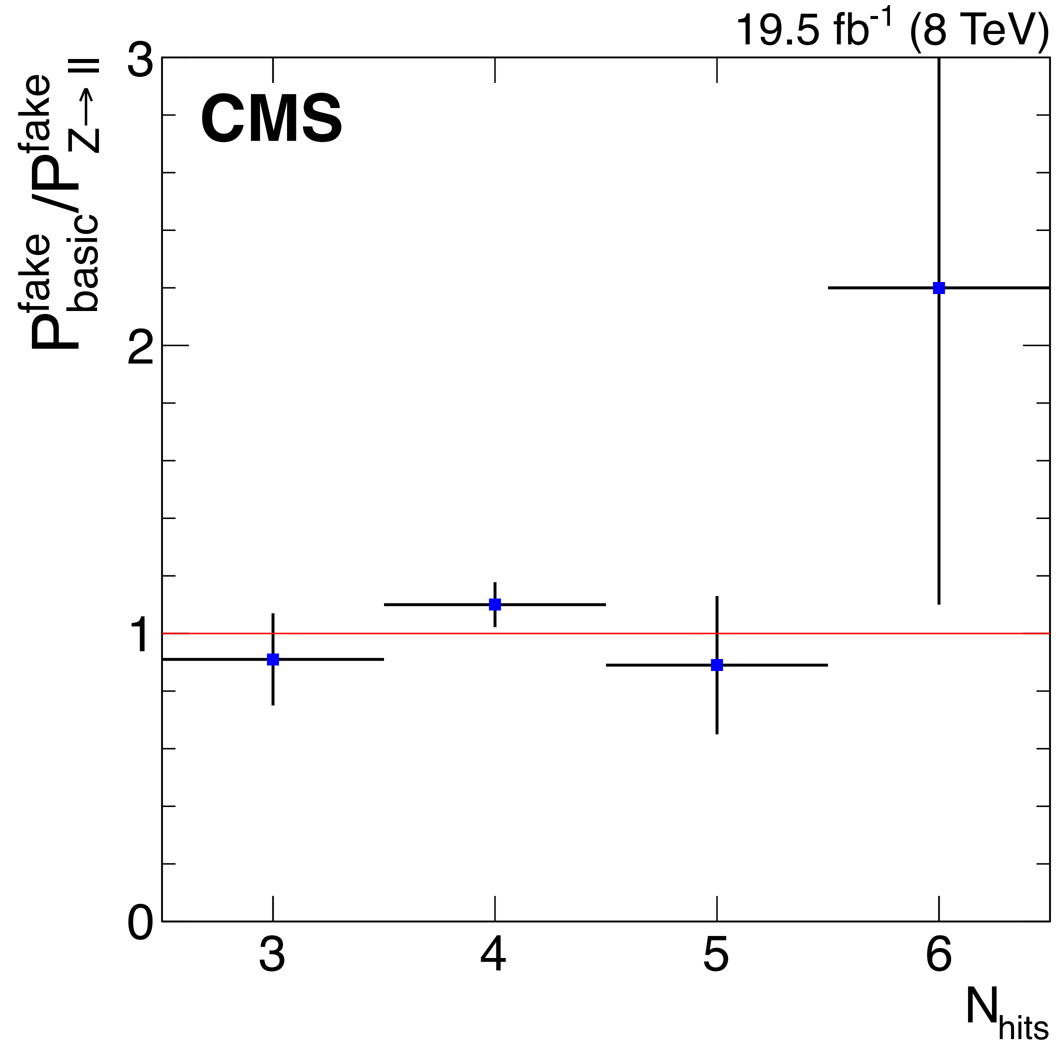
$$\boxed{N^{fake} = N^{fake}_{ctrl} \, P^{fake}}$$

N^{kin}: number of events in search sample, before track selection criteria

P^{fake}: fake track rate from $Z \to \mu\mu$ control sample

N^{fake}_{ctrl} (data)	1.77×10^6
P^{fake} (data)	$(2.0^{+2.7}_{-1.3}) \times 10^{-7}$
N^{fake}	$0.36^{+0.47}_{-0.23}$

Ratio of P^{fake} in the search sample and $Z \to \mu\mu$ control sample



Systematic uncertainty from P^{fake} for 4 hits: **35%.**

Background validation & summary

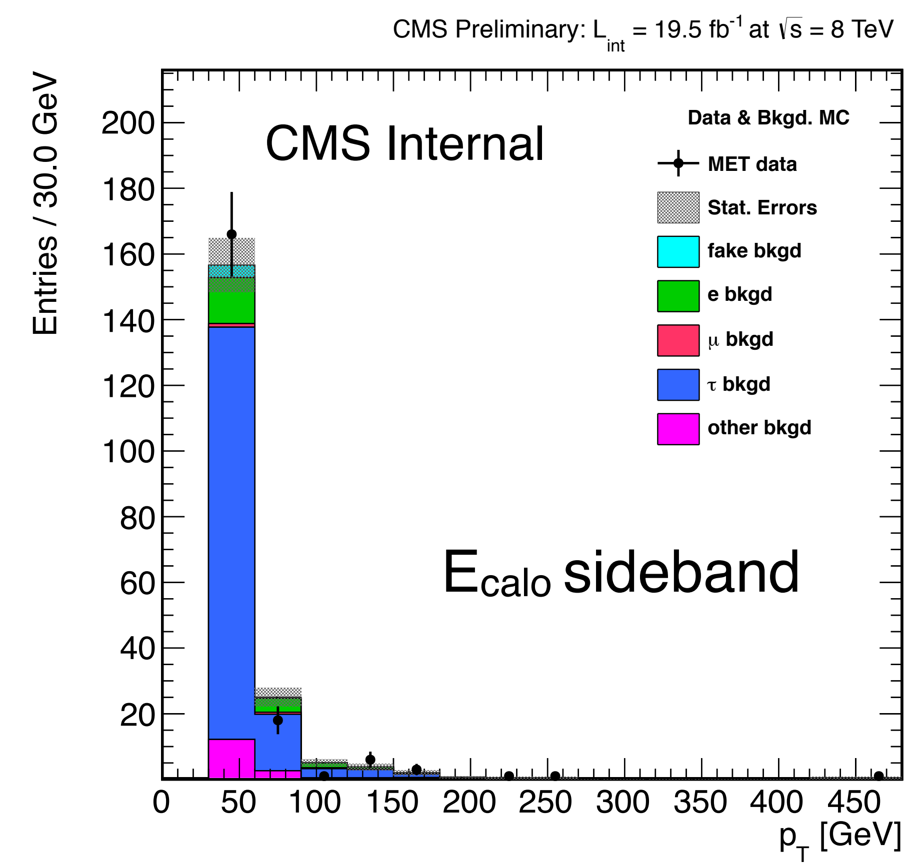
Validate the background estimates in two looser p_T ($p_T > 30$ GeV), sideband regions:

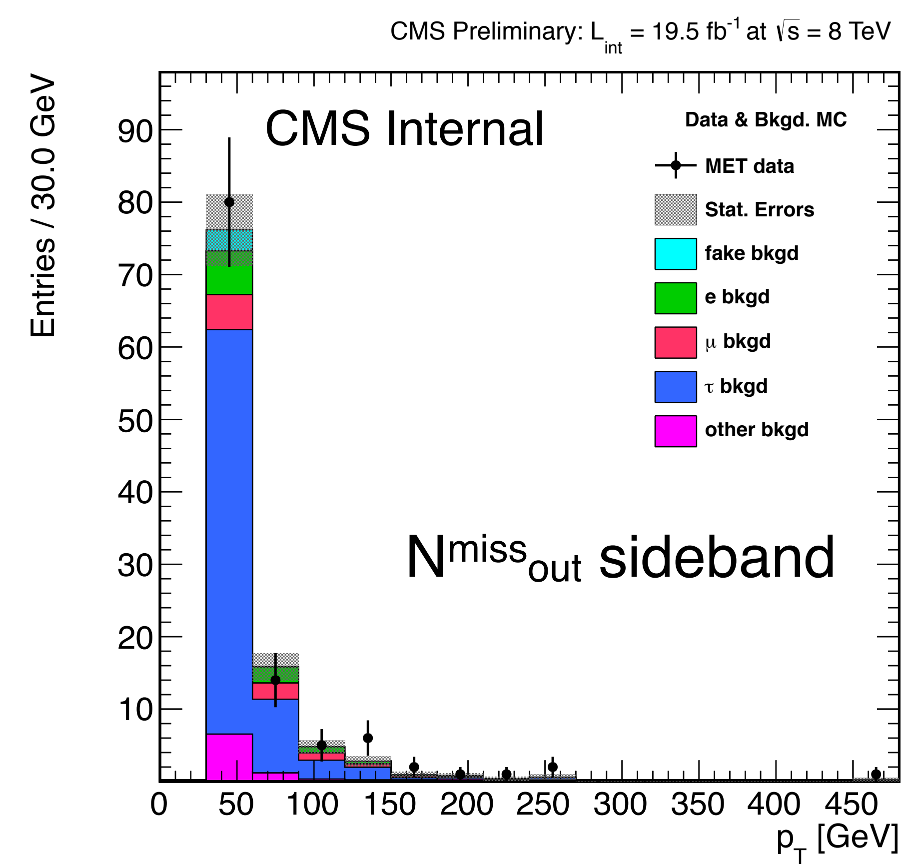
- Replace $N^{outer}_{miss} \geq 3$ with $N^{outer}_{miss} \leq 2$
- Replace $E_{calo} < 10$ GeV with $E_{calo} > 10$ GeV

E_{calo} sideband	197	195 ± 13	1.01 ± 0.10
N_{outer} sideband	112	103 ± 9	1.09 ± 0.14

The background estimates are consistent with the yield from data in these control regions.

After the full selection, the expected background is **1.4 ± 1.2 events.**

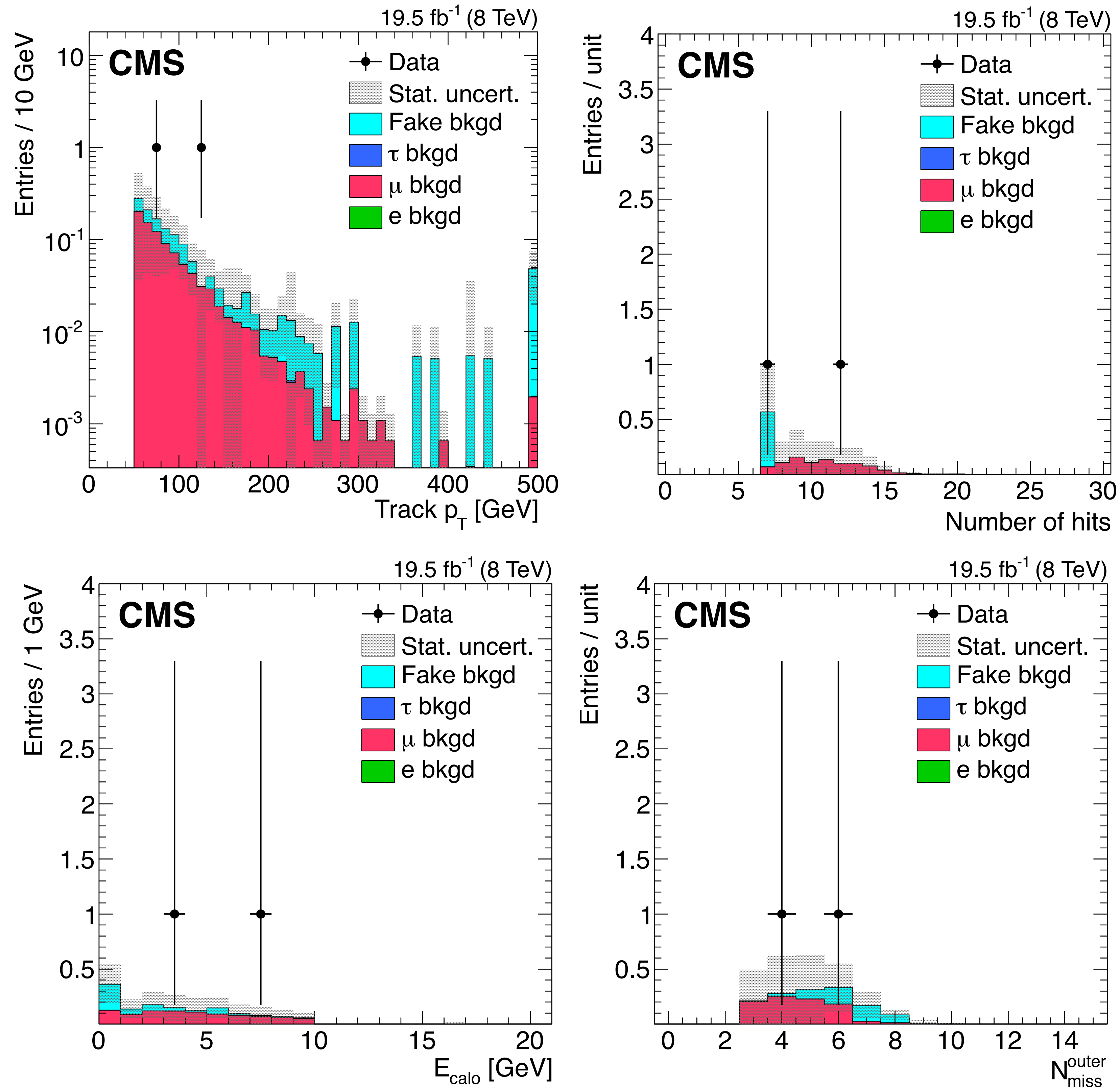




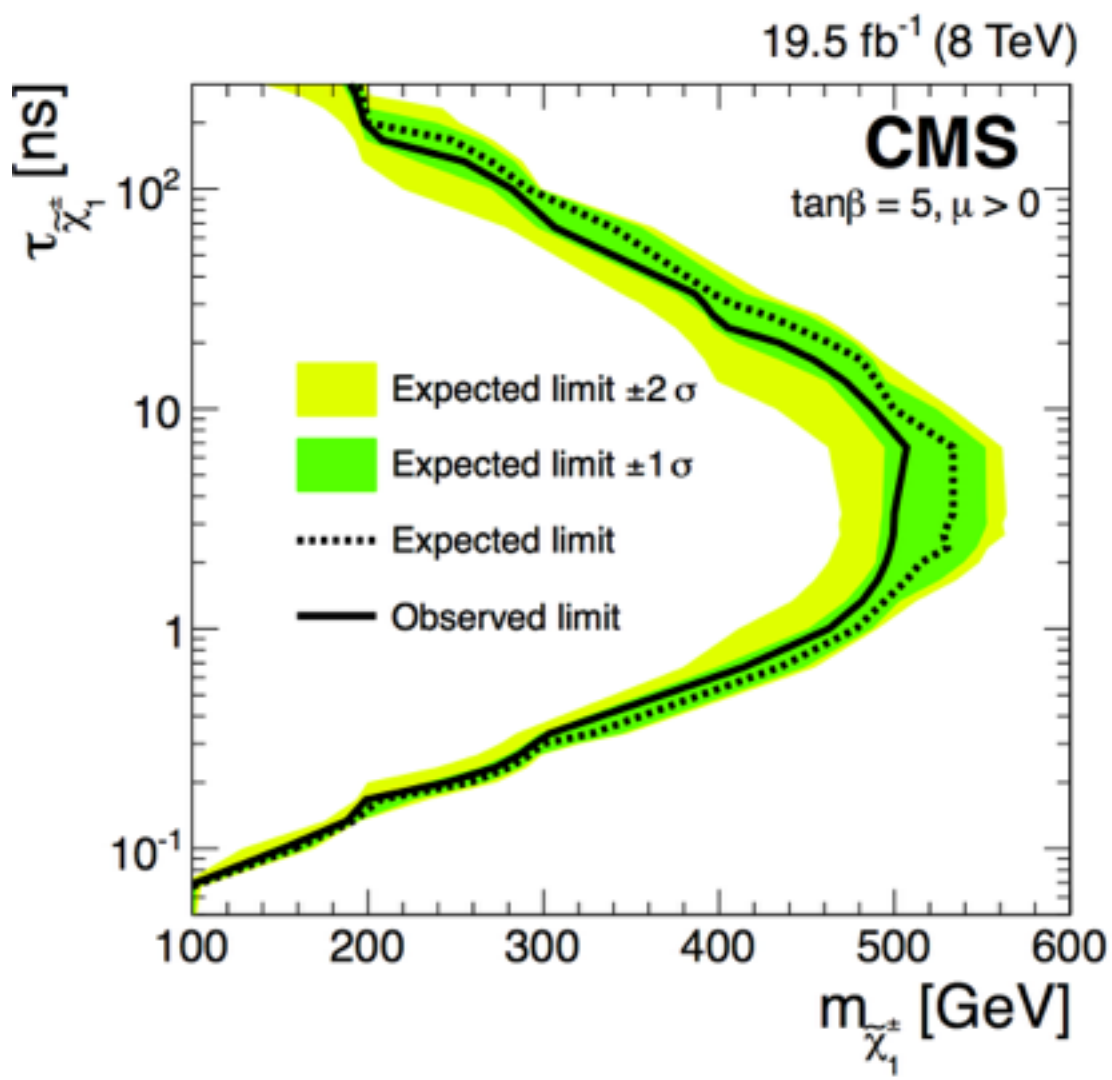
Results

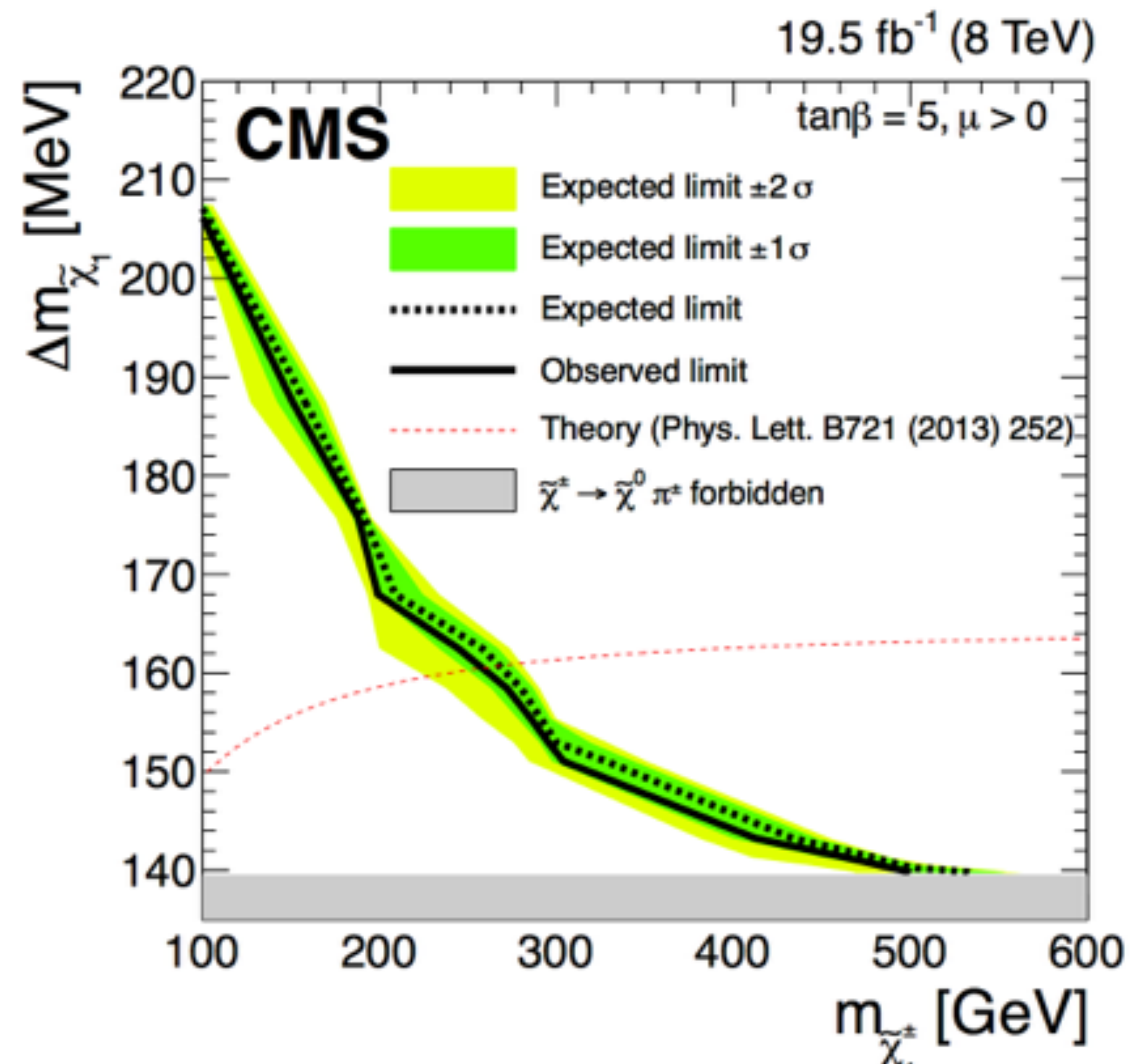
Observed 2 data events, consistent with the expected background of 1.4±1.2.

Distributions of key variables consistent with background-only hypothesis.



Limits





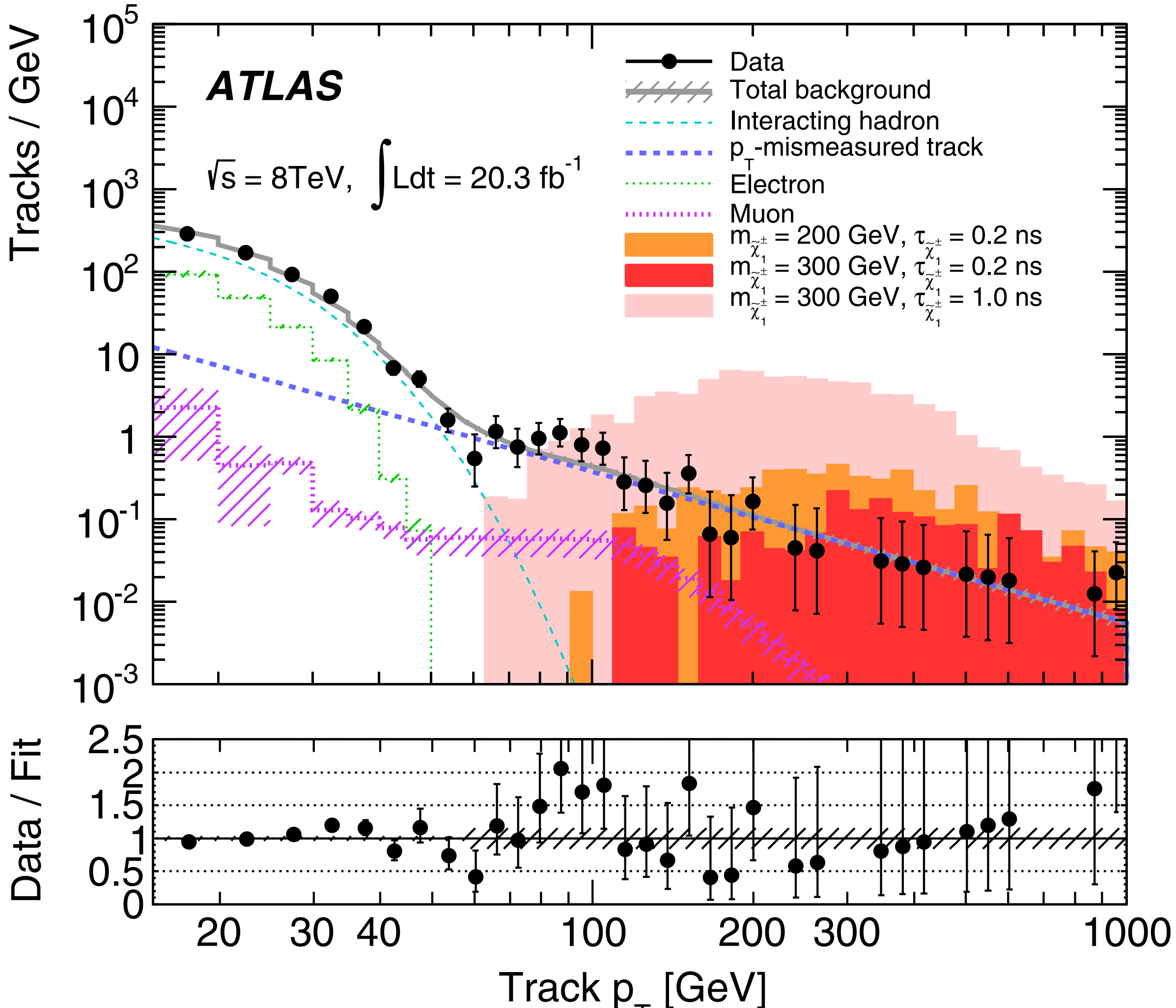
- Generic chargino limits
- Region to the left of the solid curve is excluded at 95% C.L.
- Maximum sensitivity for lifetimes of 7 ns, exclude charginos with mass less than 505 GeV

- Constraint on mass of chargino and mass difference between the chargino and neutralino in AMSB
- Exclude charginos with mass of 260 GeV i.e. lifetime of ~0.2 ns and mass difference of 160 MeV

Different search strategies

Inclusive approach: Exploit difference in shape of a discriminating variable between signal vs. backgrounds (e.g., track p_T).

Exclusive approach: Identify, understand, mitigate, and estimate each source of background.

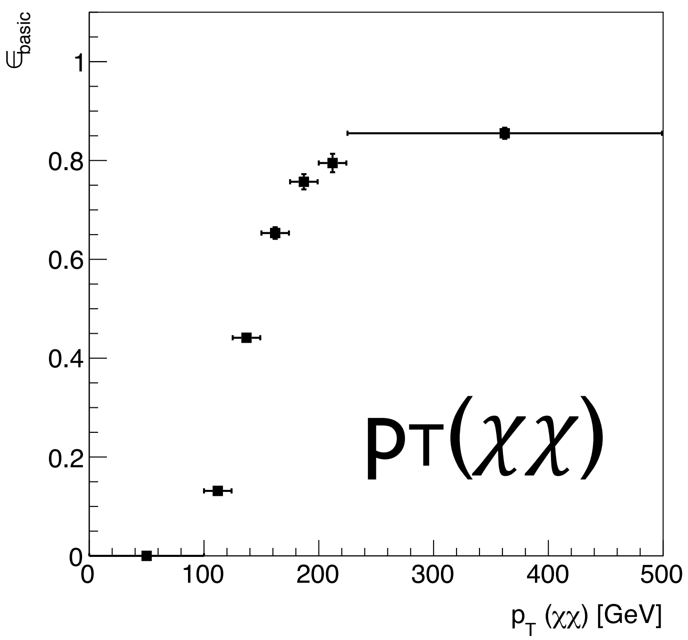


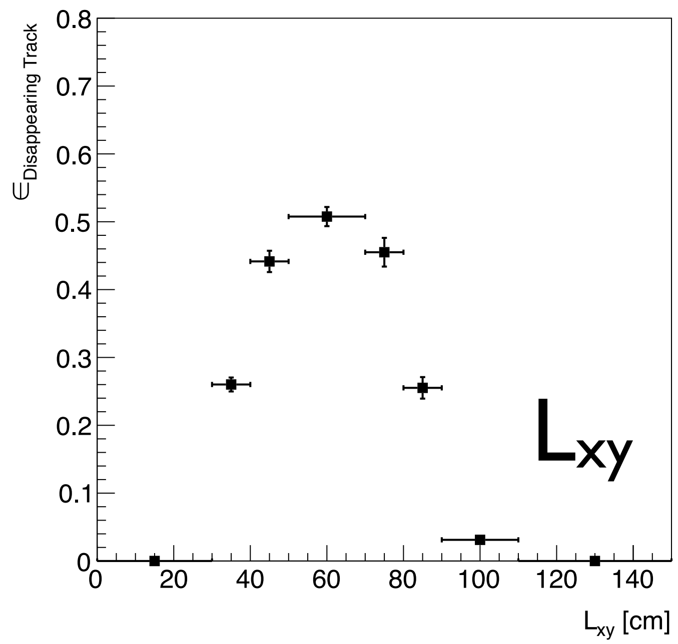
Phys Rev D 88, 112006 (2013), arXiv:1310.3675

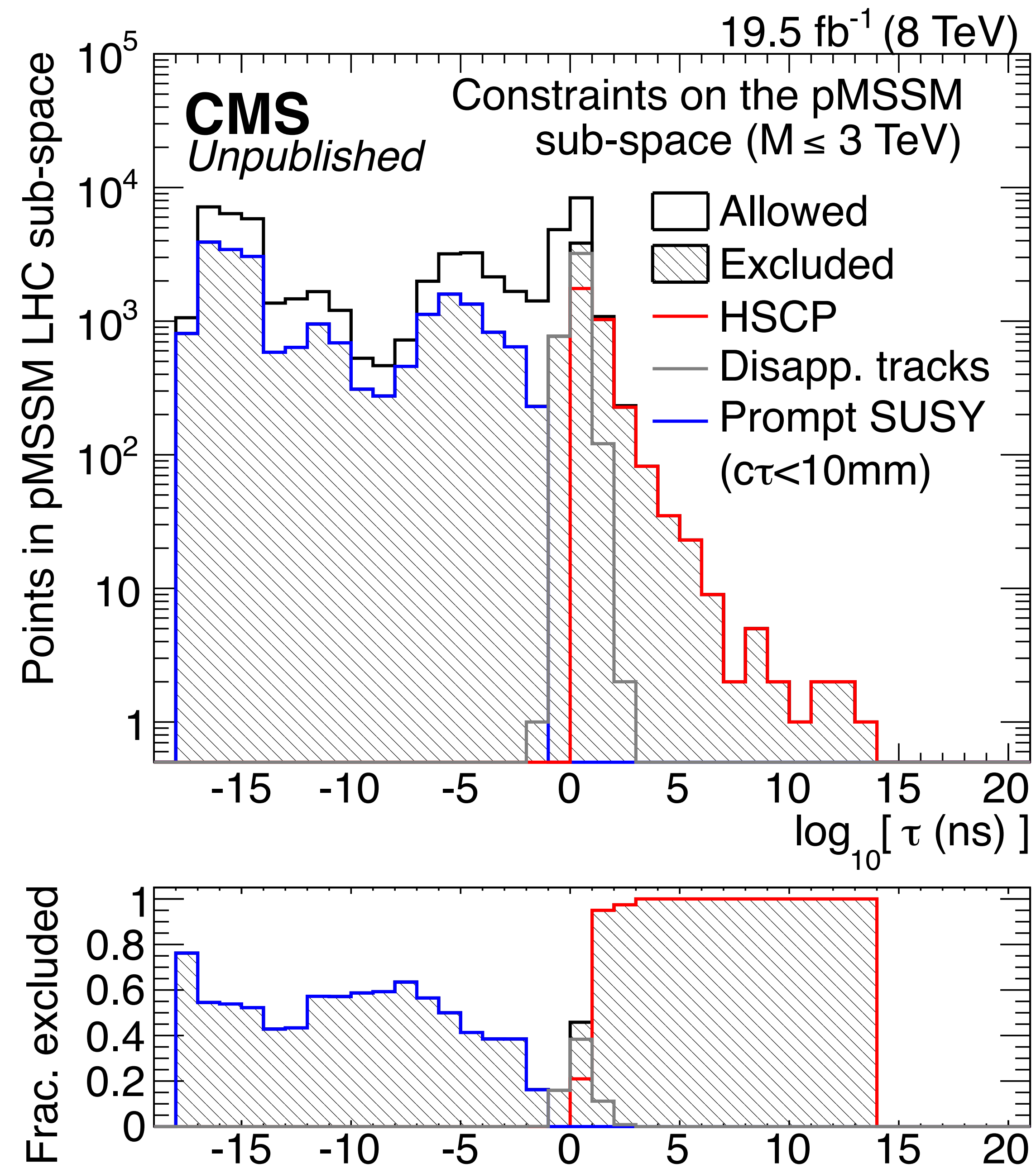
Event source	Yield	
Electrons	<0.49 (stat.)	<0.50 (stat+syst)
Muons	$0.64^{+1.47}_{-0.53}$ (stat.) ± 0.32 (syst.)	
Taus	<0.55 (stat.)	<0.57 (stat+syst)
Fake tracks	$0.36^{+0.47}_{-0.23}$ (stat.) ± 0.13 (syst.)	

Disappearing tracks reinterpretation

Parameterize signal efficiency in terms of 2 generator-level quantities







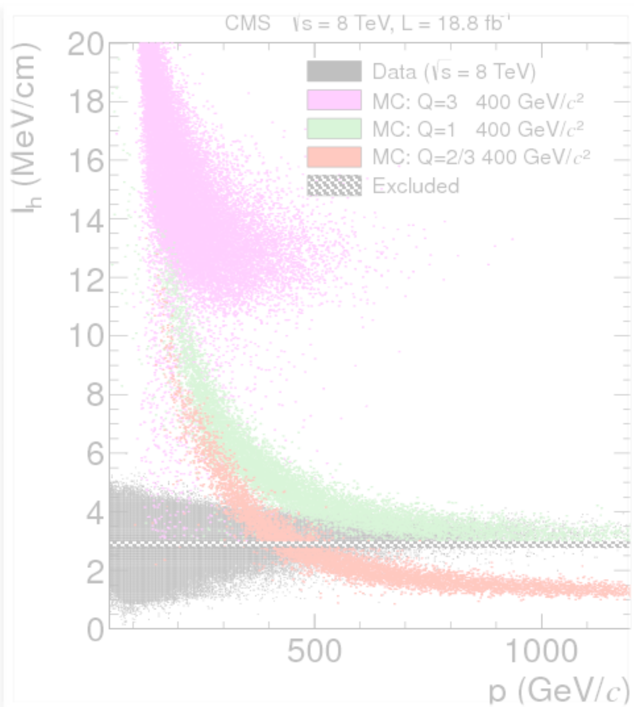
Parameterized efficiency allows setting limits on an arbitrary model.

Used to find coverage of disappearing tracks search in pMSSM model space.

Sensitive to previously-uncovered gap in parameter space.

Selected CMS searches for exotic long-lived particles

Fractionally charged particles

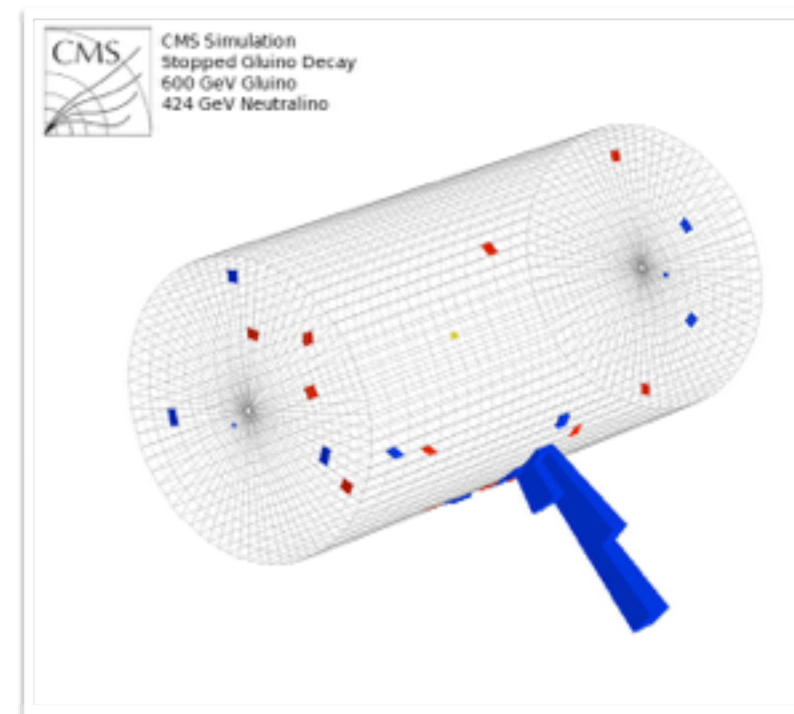


Phys. Rev. D 87 (2013) 092008
arXiv:

Disappearing tracks

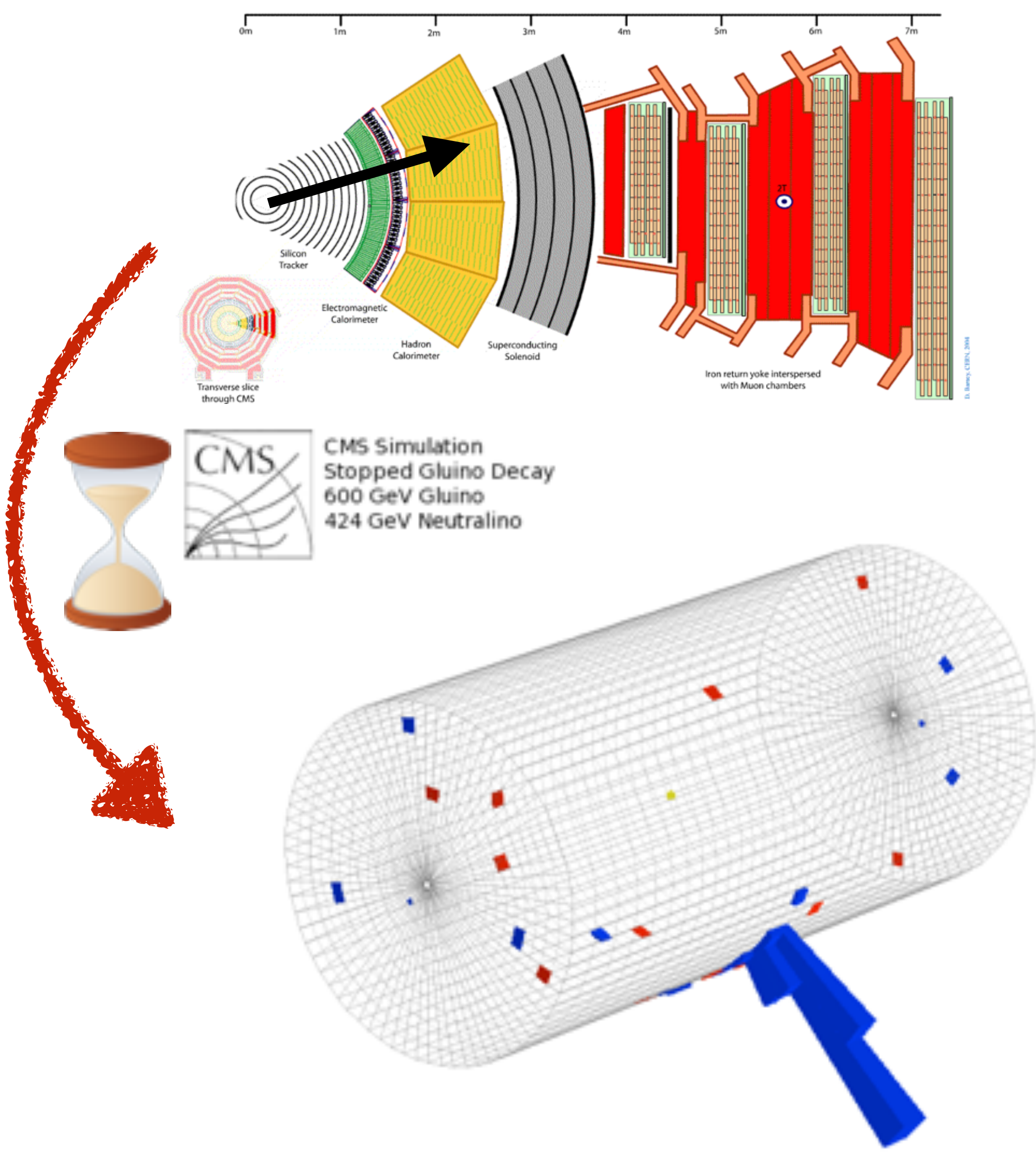
JHEP 01 (2015) 096
arXiv:1411.6006

Stopped particles

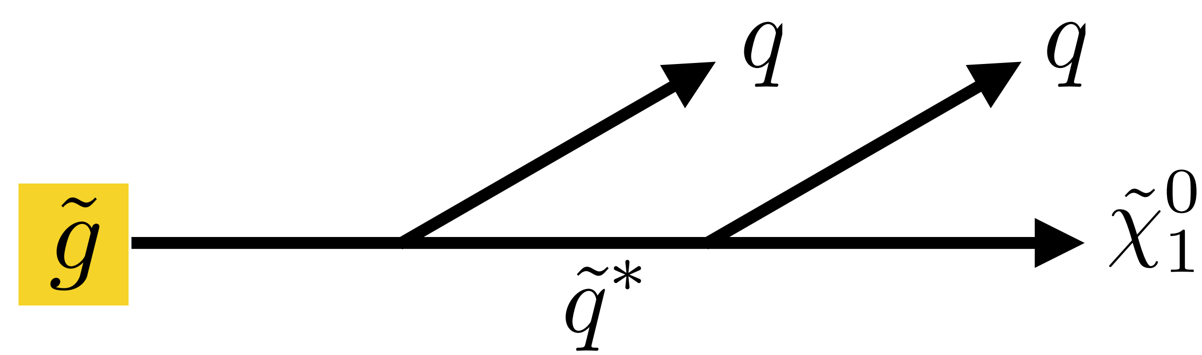


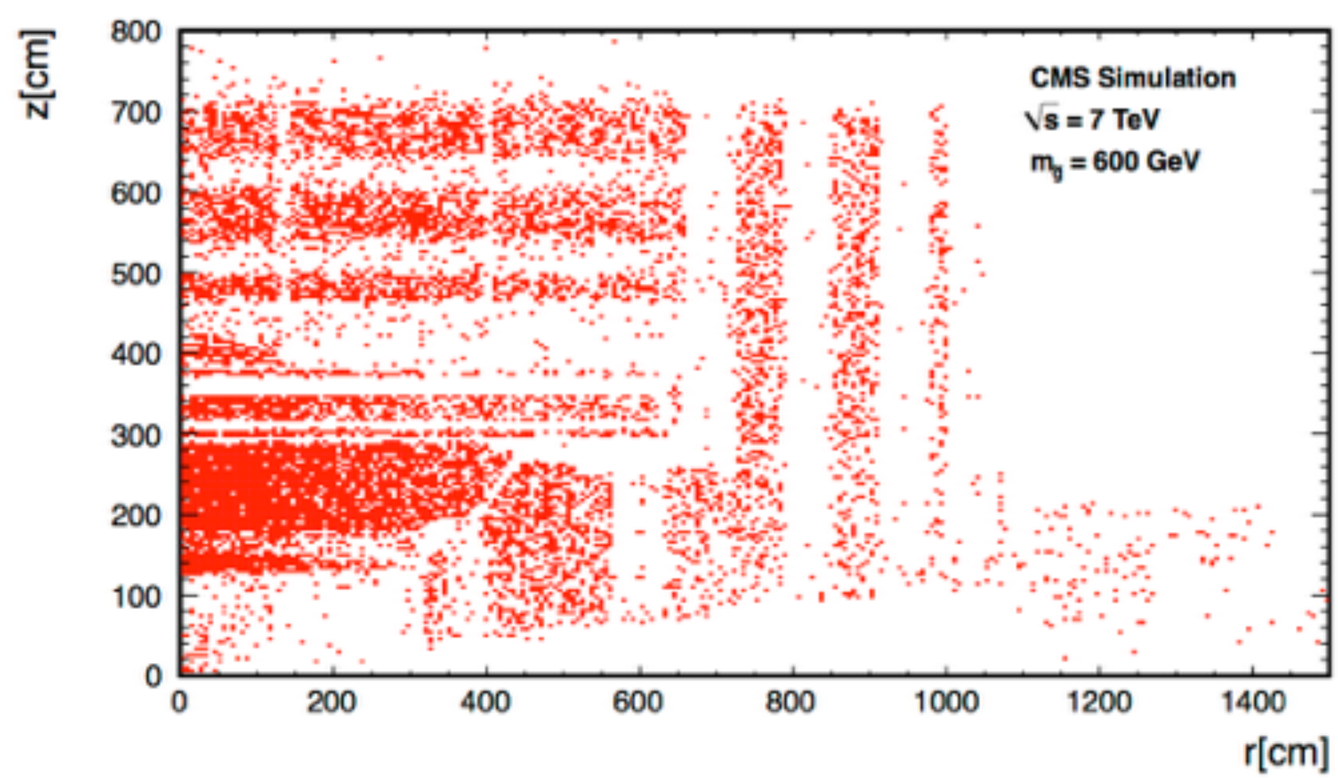
Eur. Phys. J. C 75 (2015) 151
arXiv:1501.05603

Stopped particles overview



mini-split gluino





Look for calorimeter cluster **asynchronous** with p-p collisions. 281 hours of trigger livetime.

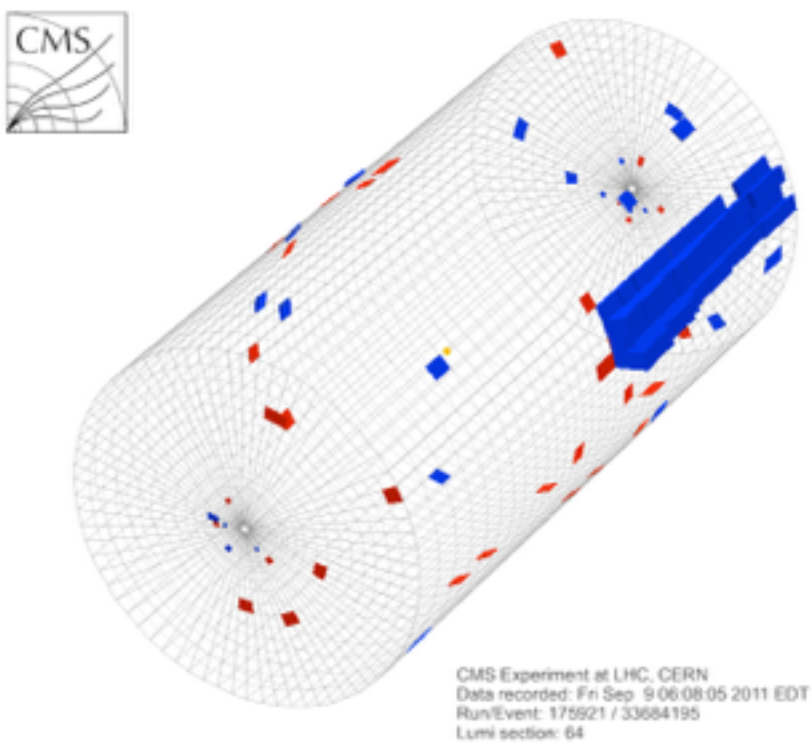
R-hadrons typically stop in calorimeters or muon yoke flux return.

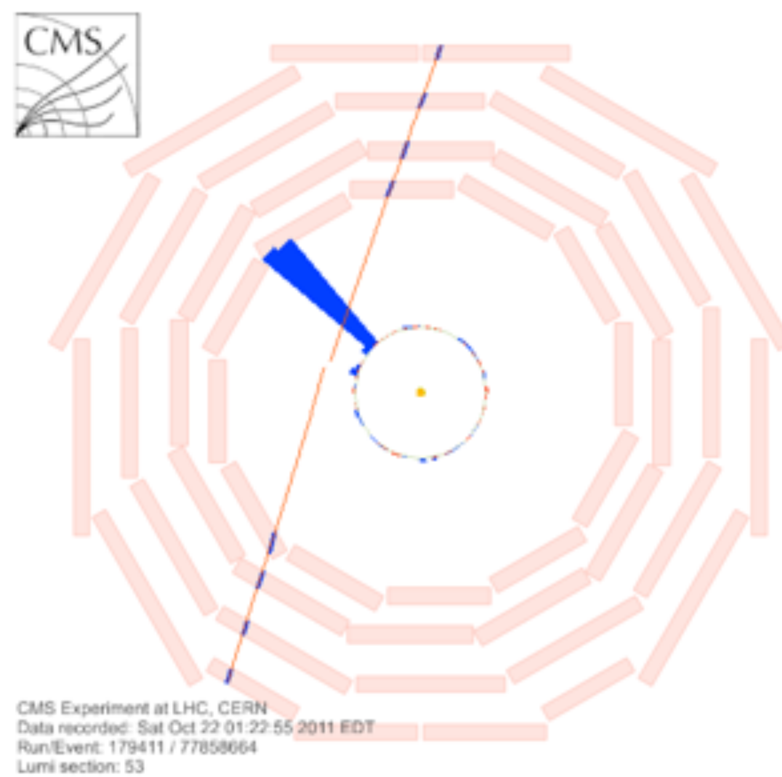
Stopped particles backgrounds

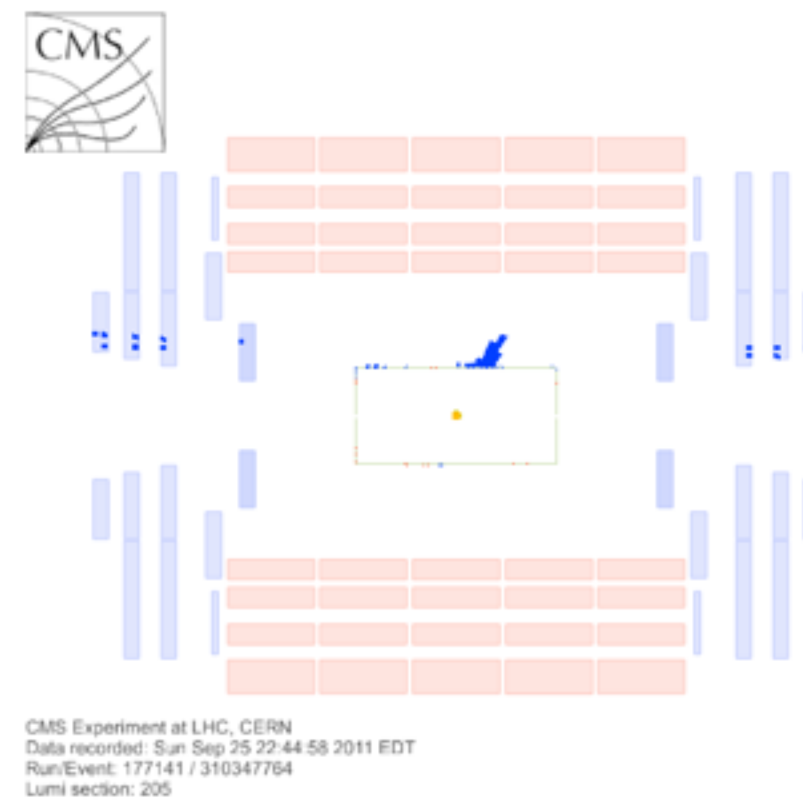
Instrumental noise (HCAL)
Combat with cuts on jet topology and timing.

Cosmic ray muons
Cosmic veto was found to introduce energy dependence in the signal efficiency, so the offline cuts were modified.

Beam halo muons
Caused by stray protons striking beam pipe & collimators







Period	Trigger livetime (h)	$N^{\text{bkg}}_{\text{noise}}$	$N^{\text{bkg}}_{\text{cosmic}}$	$N^{\text{bkg}}_{\text{halo}}$	$N^{\text{bkg}}_{\text{total}}$	N^{obs}
2010	253	$0.0^{+2.3}_{-0.0}$	4.8 ± 3.6	–	$4.8^{+4.3}_{-3.6}$	2
2012	281	$0.0^{+2.6}_{-0.0}$	5.2 ± 2.5	8.0 ± 0.4	$13.2^{+3.6}_{-2.5}$	10

Stopped particles: challenges

- Use **dedicated trigger**, with unusual requirement of no beam present within ±1 bunch crossing.

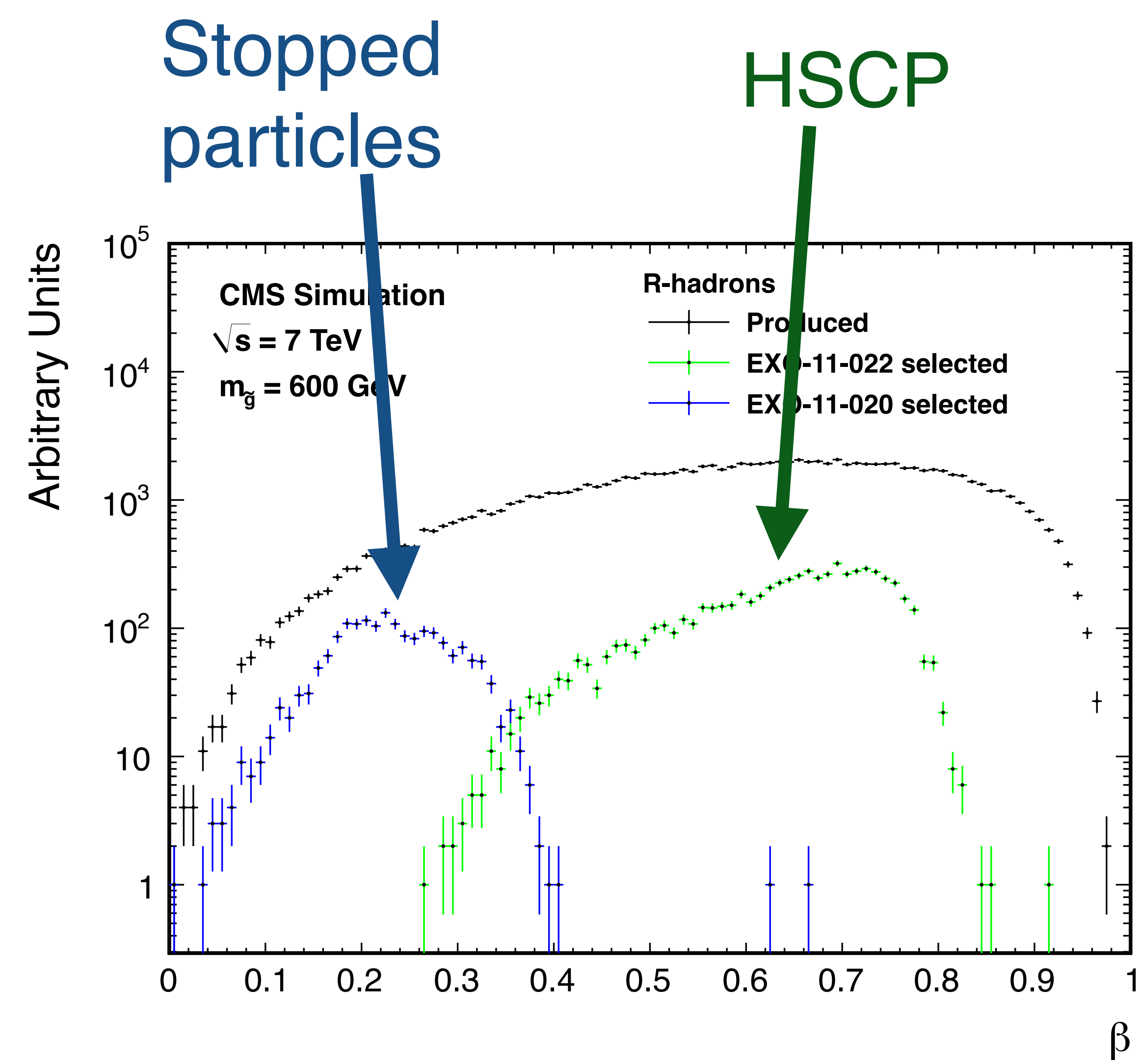
- **Unusual backgrounds** are not well-studied. For example, one peculiar type of HCAL noise was from a few towers that sometimes unlatched from LHC clock and fired 1-2 bunch crossings early, causing a dijet event to be split between 2 events.

- **Signal simulation** is performed in two steps. First, find stopping position by simulating pair production of gluinos or stops (Pythia8), R-hadronization (PYRHAD), and detector interactions via cloud model (GEANT). Second, simulate R-hadron decay at position from first step.

Stopped particles: lifetime sensitivity

Effective luminosity degrades for short lifetimes because particles may decay within ±1 bunch crossing of a pp collision.

Lifetime hypothesis	L_{eff} (fb^{-1})	Trigger livetime (s)	Expected bkg.	Observed
50 ns	0.121	5.0×10^4	$0.66^{+0.18}_{-0.07}$	0
75 ns	0.271	1.0×10^5	$1.3^{+0.4}_{-0.2}$	3
100 ns	0.512	2.0×10^5	$2.6^{+0.7}_{-0.5}$	3
1 μs	2.864	8.4×10^5	$11.0^{+3.0}_{-2.1}$	6
10 μs	3.885	1.0×10^6	$13.1^{+3.6}_{-2.4}$	10
100 μs	3.972	1.0×10^6	$13.2^{+3.6}_{-2.5}$	10
10^3 s	3.868	1.0×10^6	$13.2^{+3.6}_{-2.5}$	10
10^4 s	3.004	1.0×10^6	$13.2^{+3.6}_{-2.5}$	10
10^5 s	1.727	1.0×10^6	$13.2^{+3.6}_{-2.5}$	10
10^6 s	1.181	1.0×10^6	$13.2^{+3.6}_{-2.5}$	10

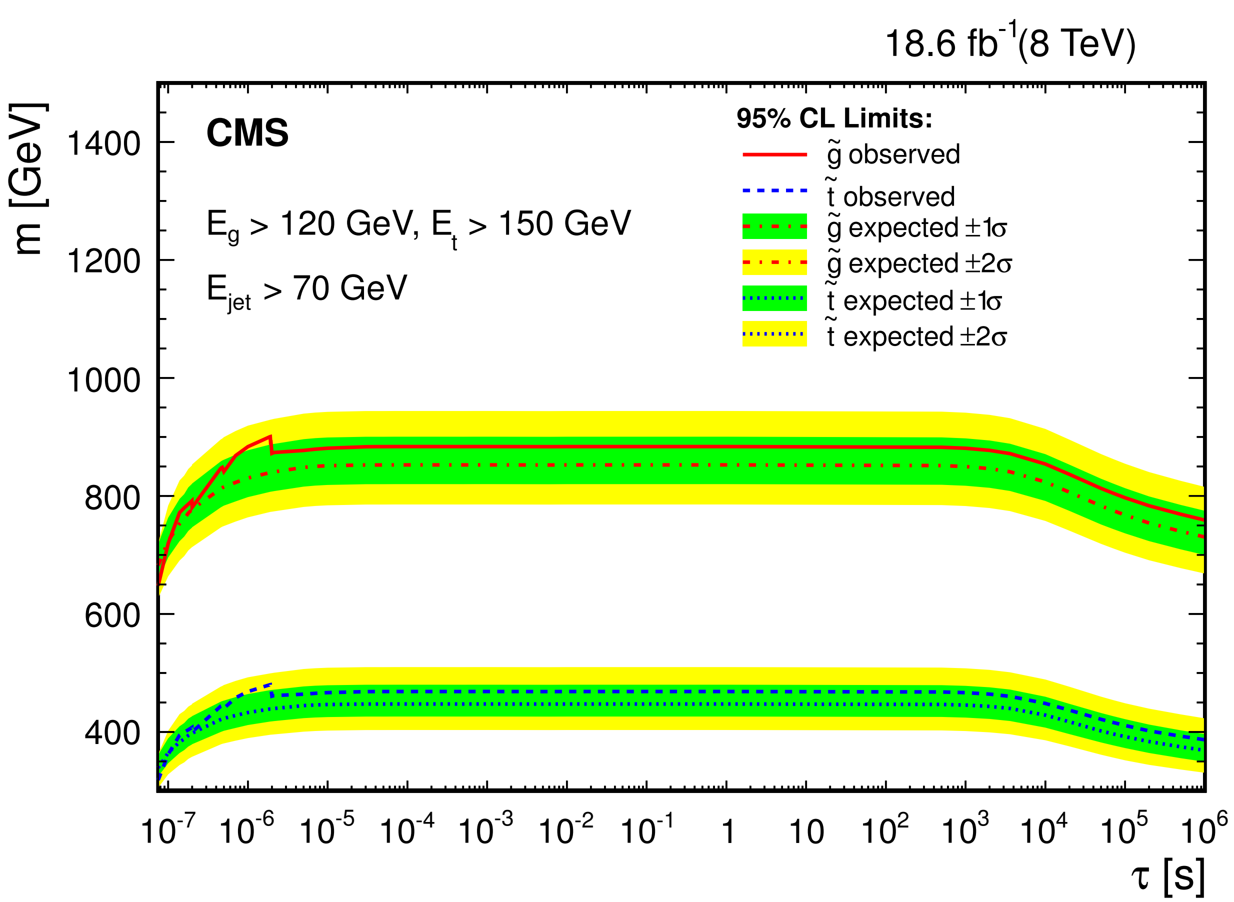


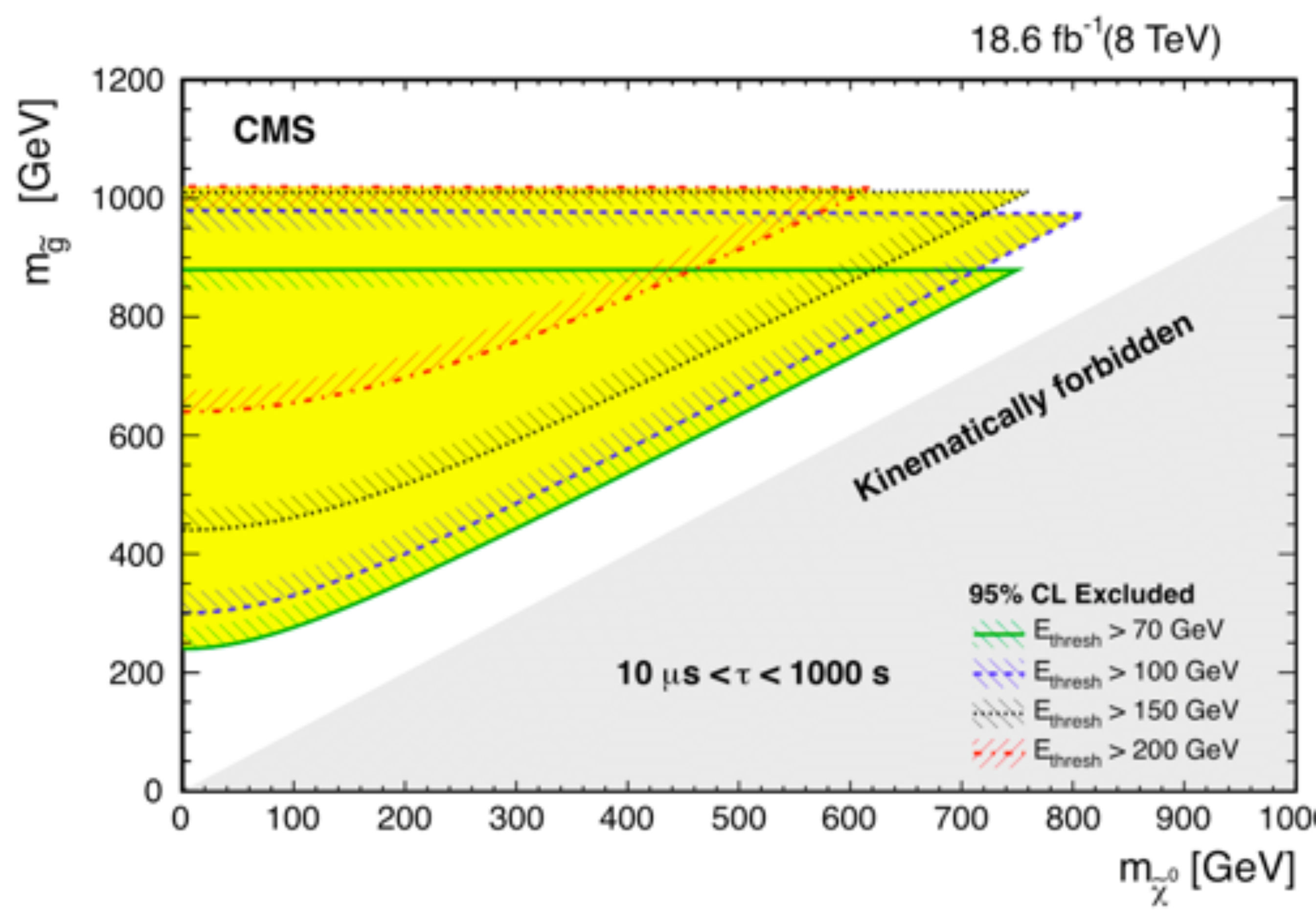
Effective luminosity degrades for very long lifetimes because particles may decay after data collection has stopped.

Complementary with HSCP analysis in terms of particle velocity.

Stopped particles results

Limits on gluino, stop mass for
over 13 orders of magnitude!



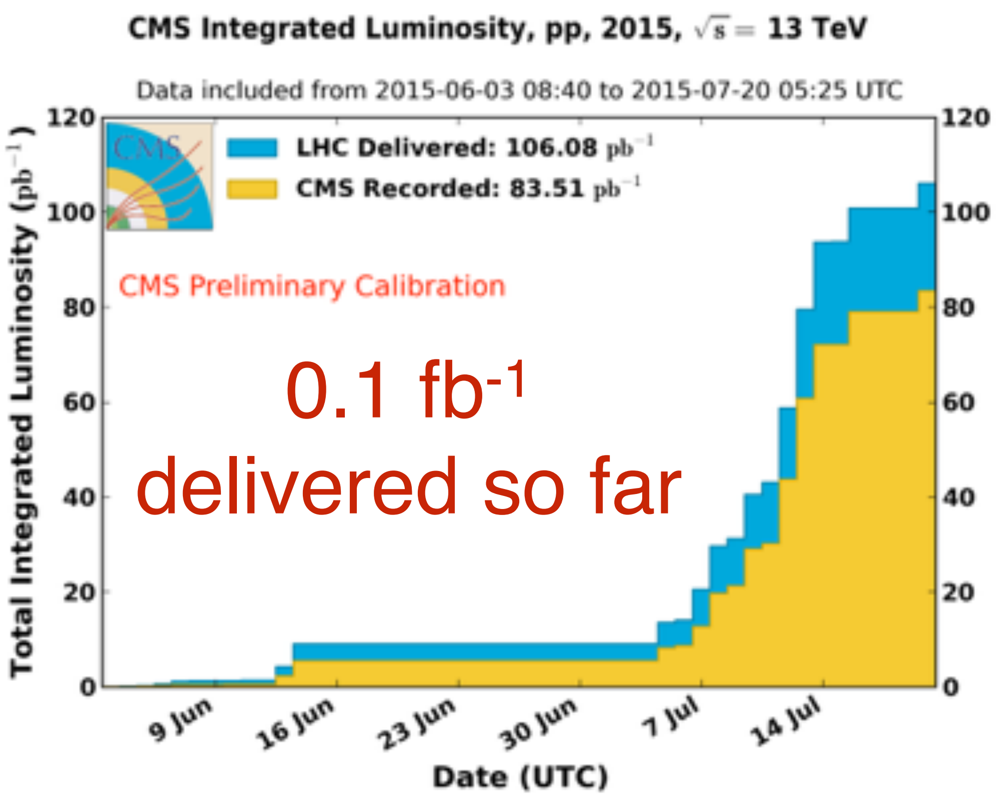


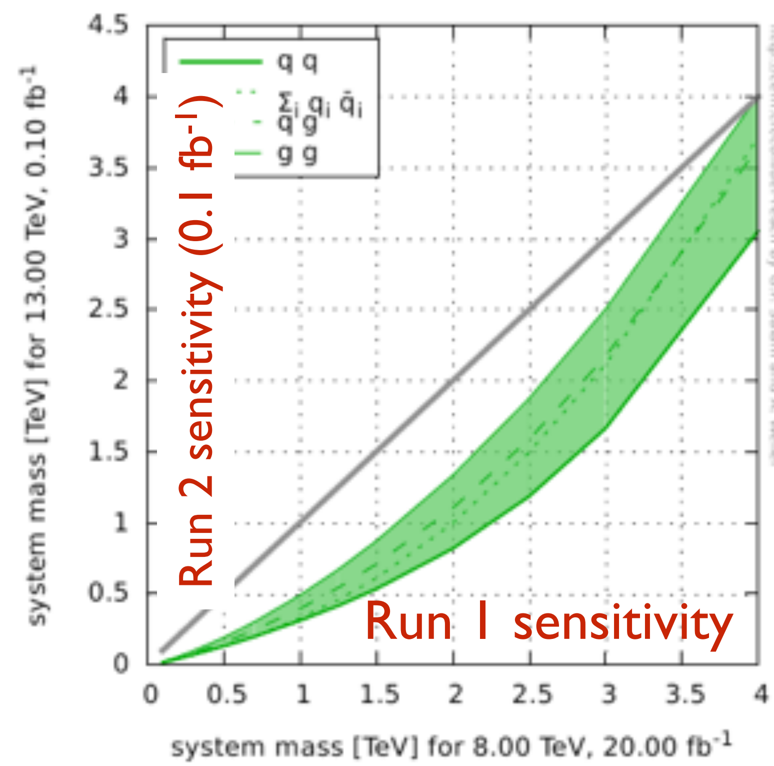
Outlook: Run 2 has (barely) begun

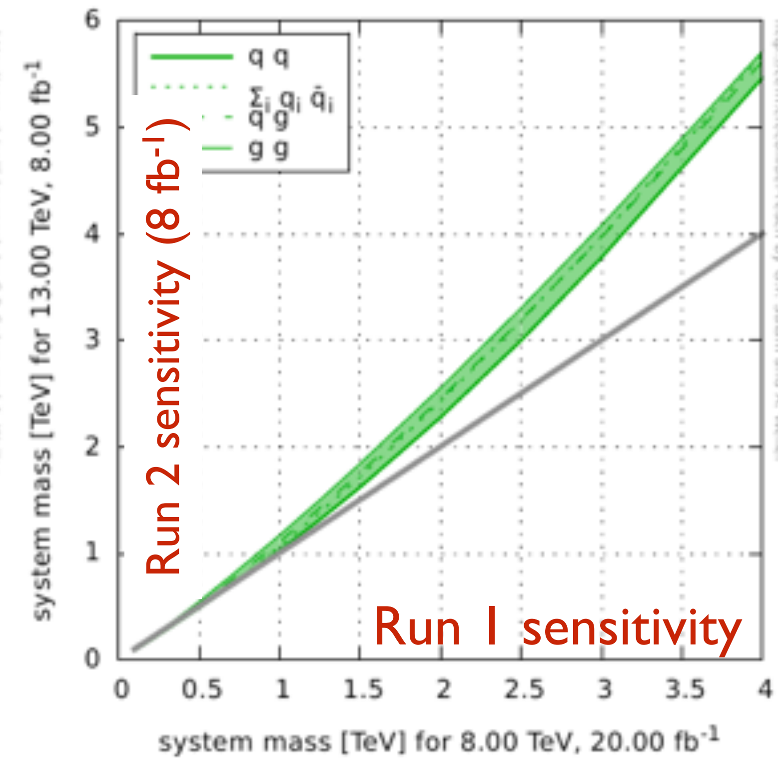
We are here

We'll soon be here

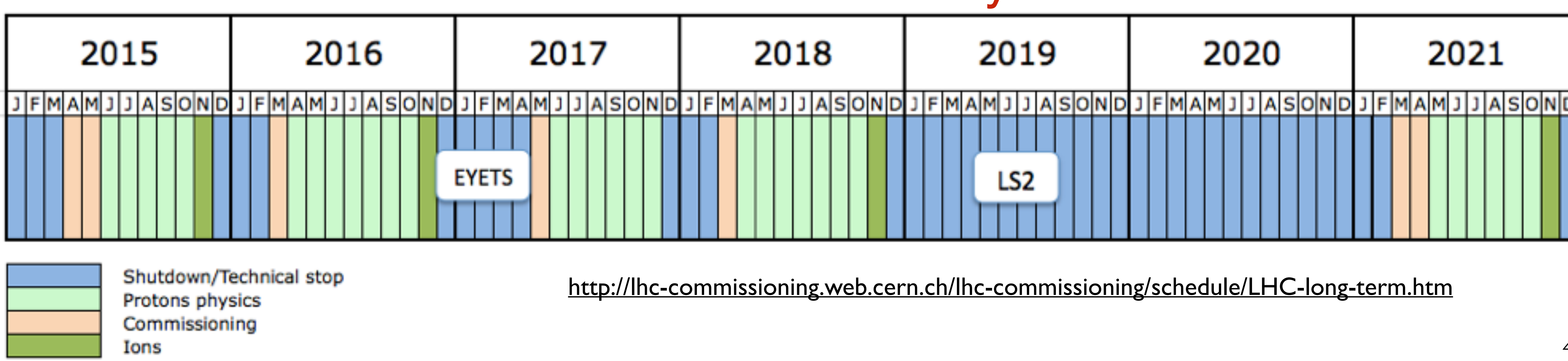
With 8 fb^{-1} of 13 TeV data, the mass reach for systems of >1 TeV will exceed that of 20 fb^{-1} of 8 TeV data







8 + 34 + 47 = 89 fb^{-1} by end of 2017



http://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/LHC-long-term.htm

Outlook: Efforts underway to repeat & improve these searches at $\sqrt{s}=13$ TeV

Fractionally charged particles: search techniques incorporated into 8 TeV search for Heavy Stable Charged Particles, for $|q|<1$, $|q|=1$, $|q|>1$ (JHEP 07, 122 (2013), arXiv:1305.0491).

Disappearing tracks: Implemented a new dedicated trigger path for Run 2 that selects events with MET>75 GeV and an isolated track with p_T>50 GeV.

Stopped particles: Plan to exploit shape of jet energy distribution to improve sensitivity.

Beyond the beamspot

is an important place to look for new physics.

- Many models predict new particles with long lifetimes.
- Backgrounds typically small but unusual.
- Standard reconstruction algorithms often inadequate.
- Novel analysis techniques are needed.

Despite a lot of searching, no signs of BSM physics yet…

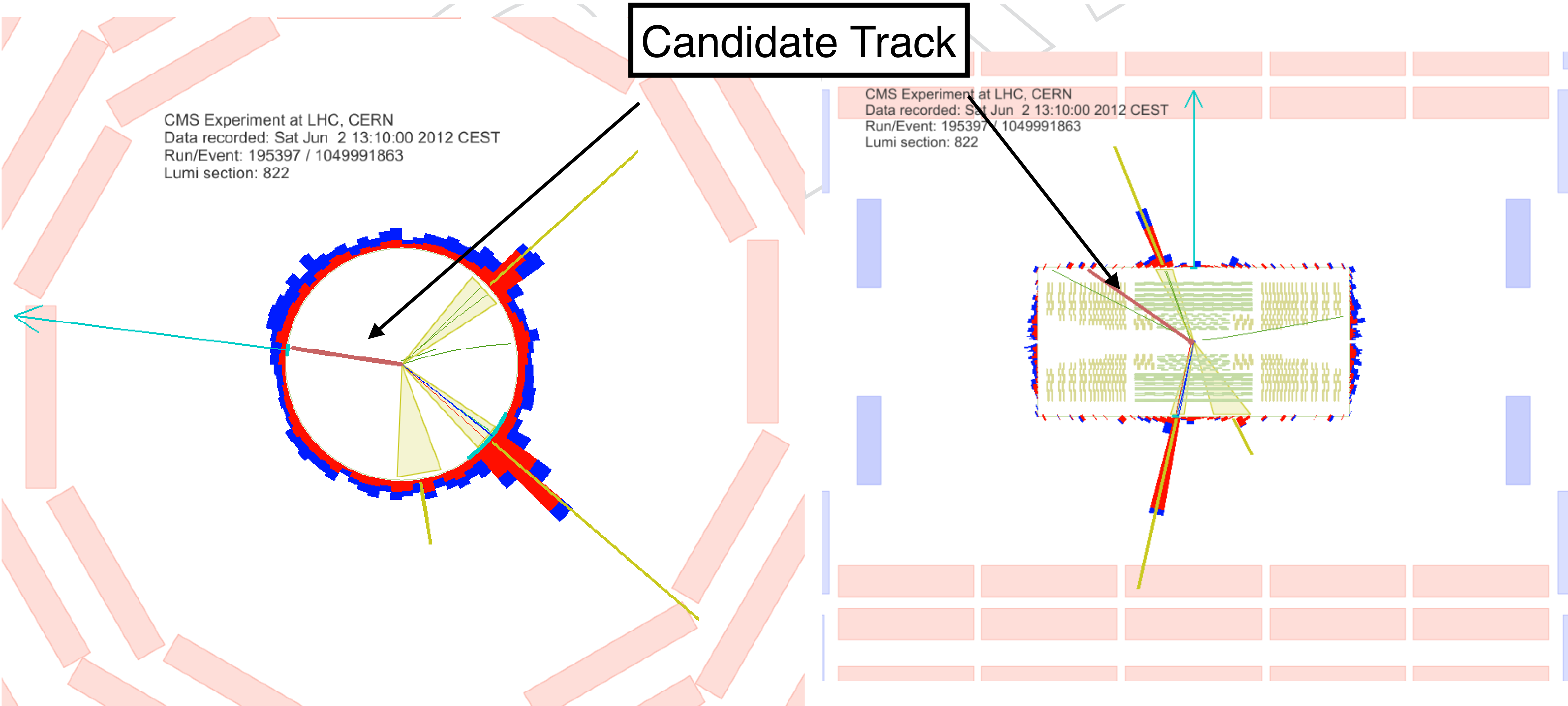
… and we can’t be sure where new physics will show up…

… so a comprehensive BSM search program should pursue a wide range of signatures and lifetimes.


Thank you

Additional material

Observed Event 1

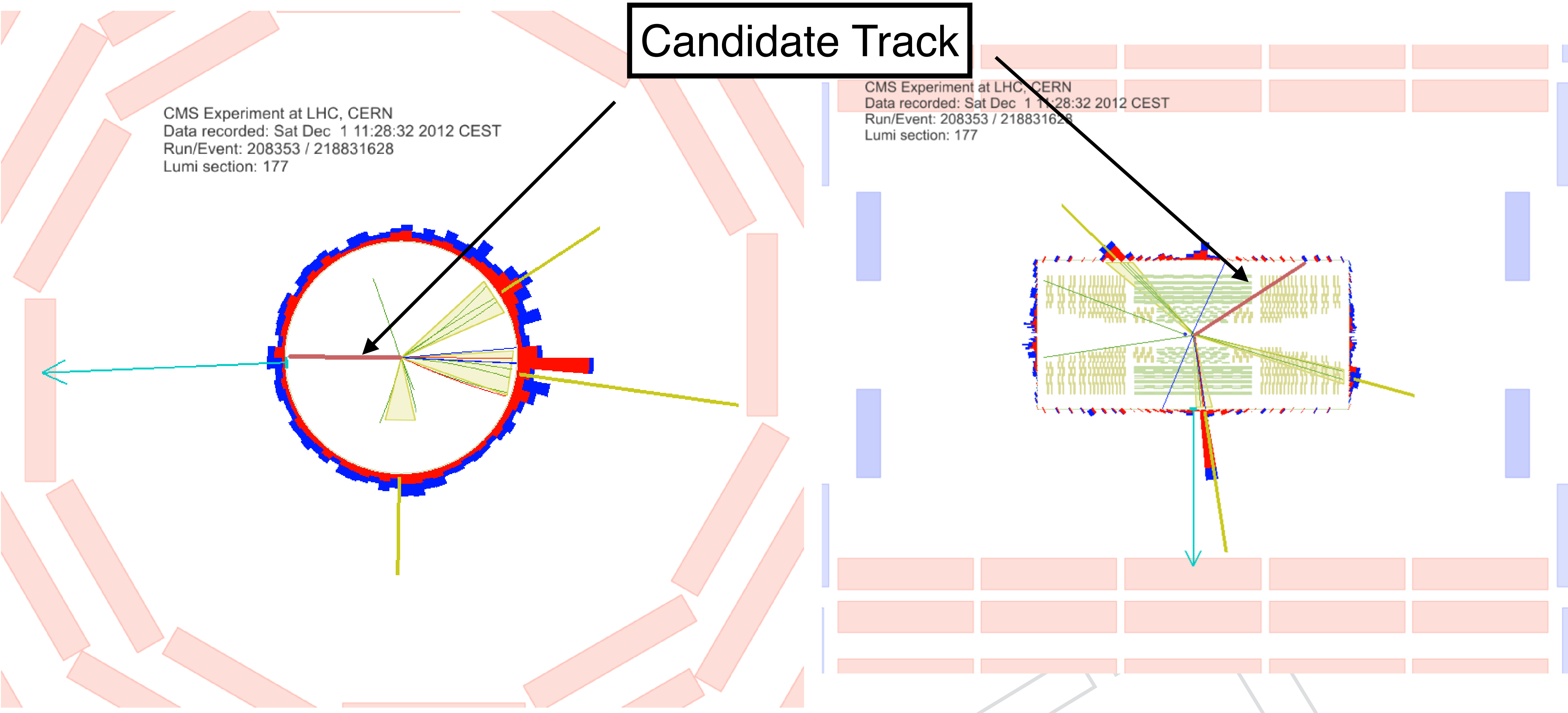


195397:822:1049991863 (2012B)

- p_T = 70.8 GeV
- η = -1.16, ϕ = 3.00
- number of valid hits = 7

- E_{calo} = 7.7 GeV
- N^{outer}_{miss} = 6
- MET = 151.7 GeV
- Leading jet p_T = 132.5 GeV

Observed Event 2



208353:177:218831628 (2012D)

- p_T = 129.2 GeV
- η = 1.21, ϕ = 3.13
- number of valid hits = 12

- E_{calo} = 3.3 GeV
- N^{outer}_{miss} = 4
- MET = 132.4 GeV
- Leading jet p_T = 111.5 GeV