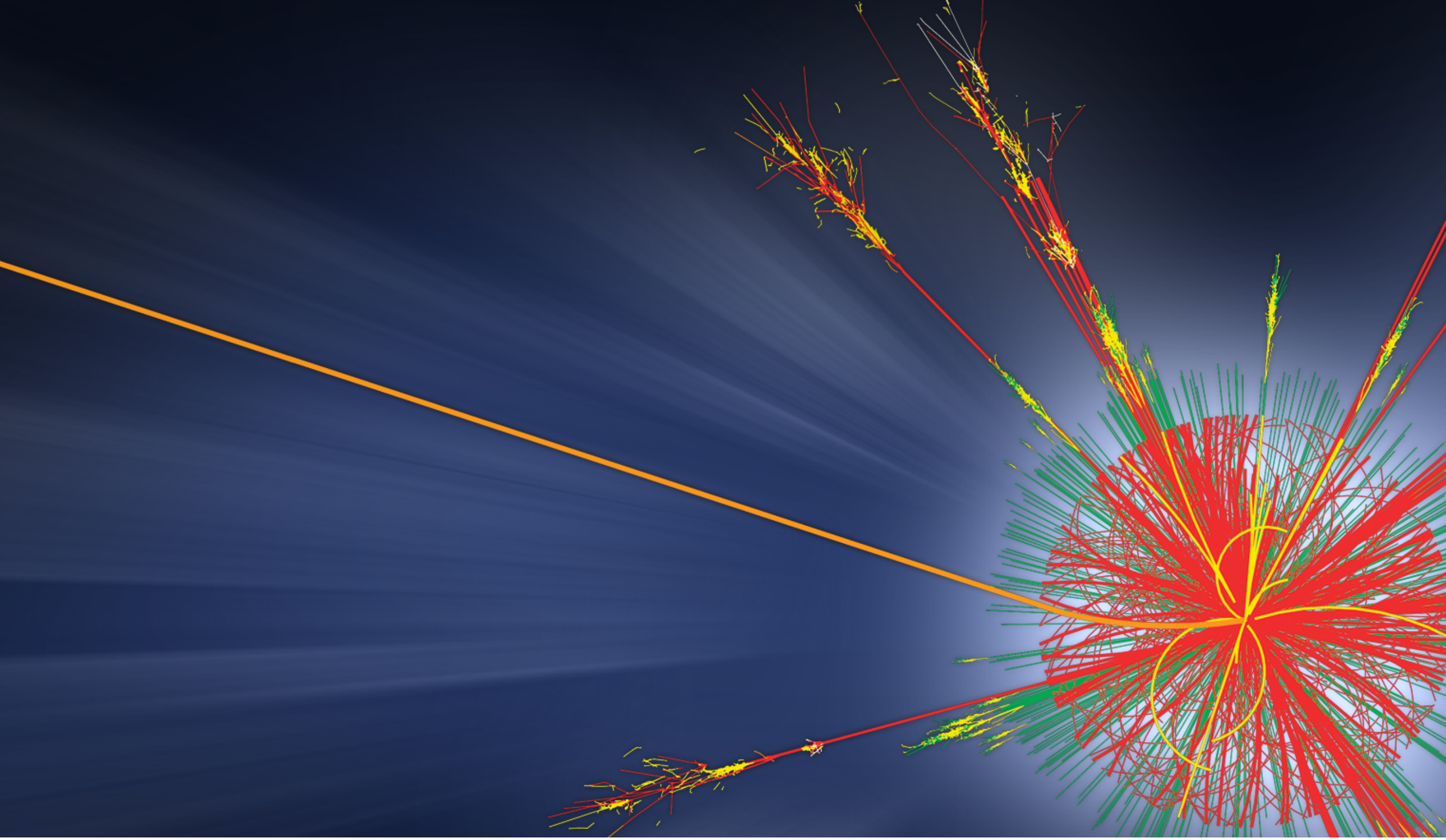
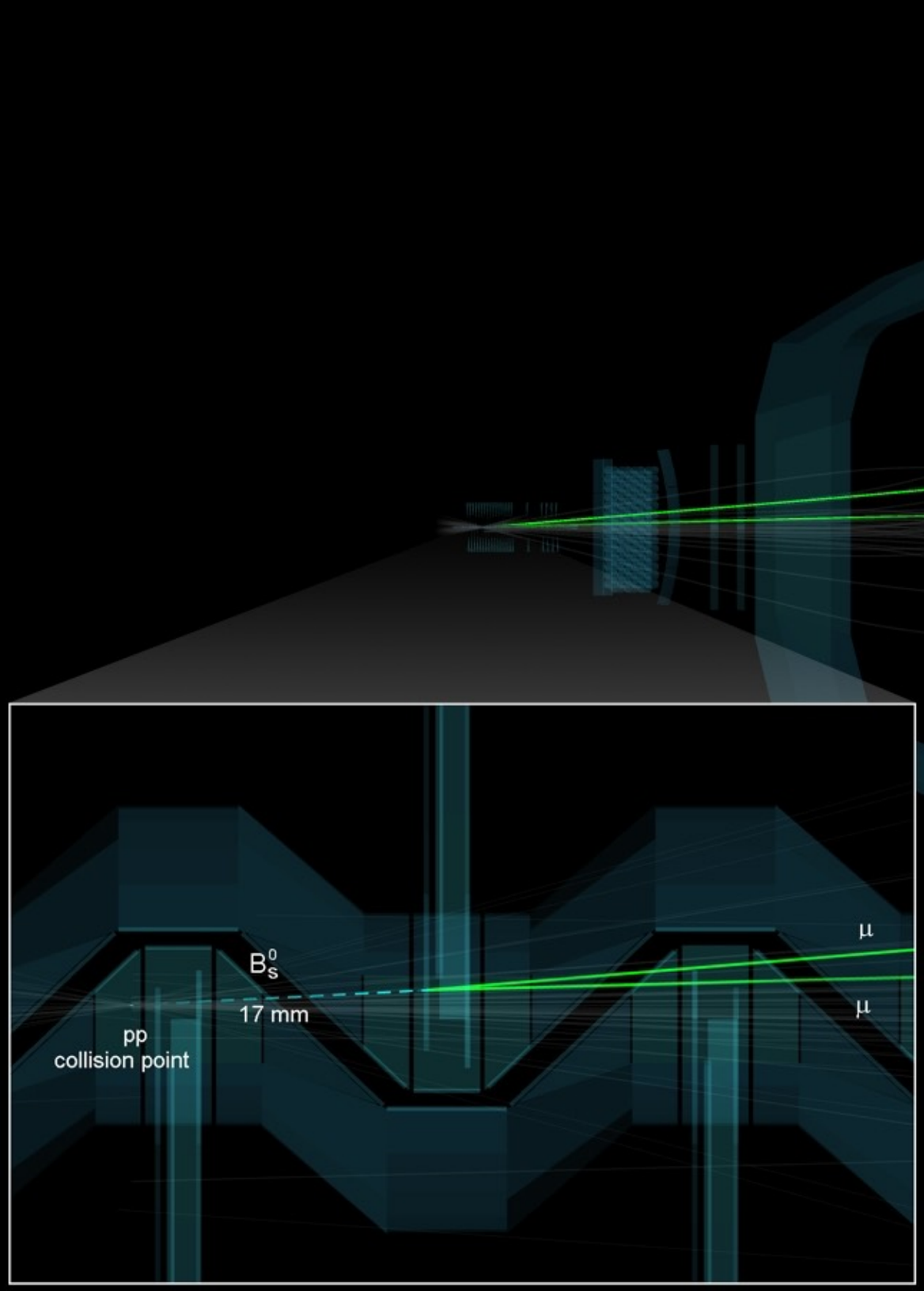
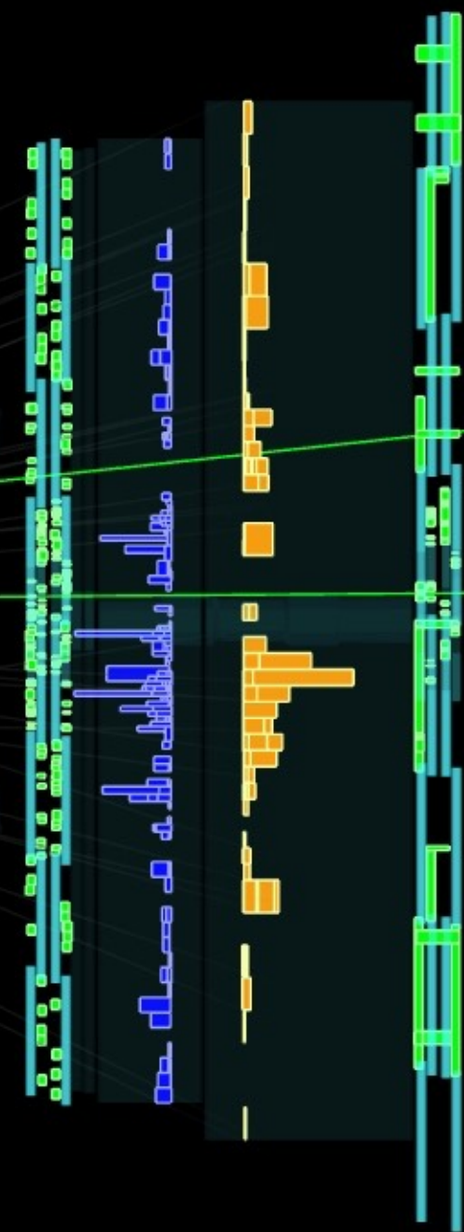


Searches for dark sectors and long-lived particles at ATLAS+CMS

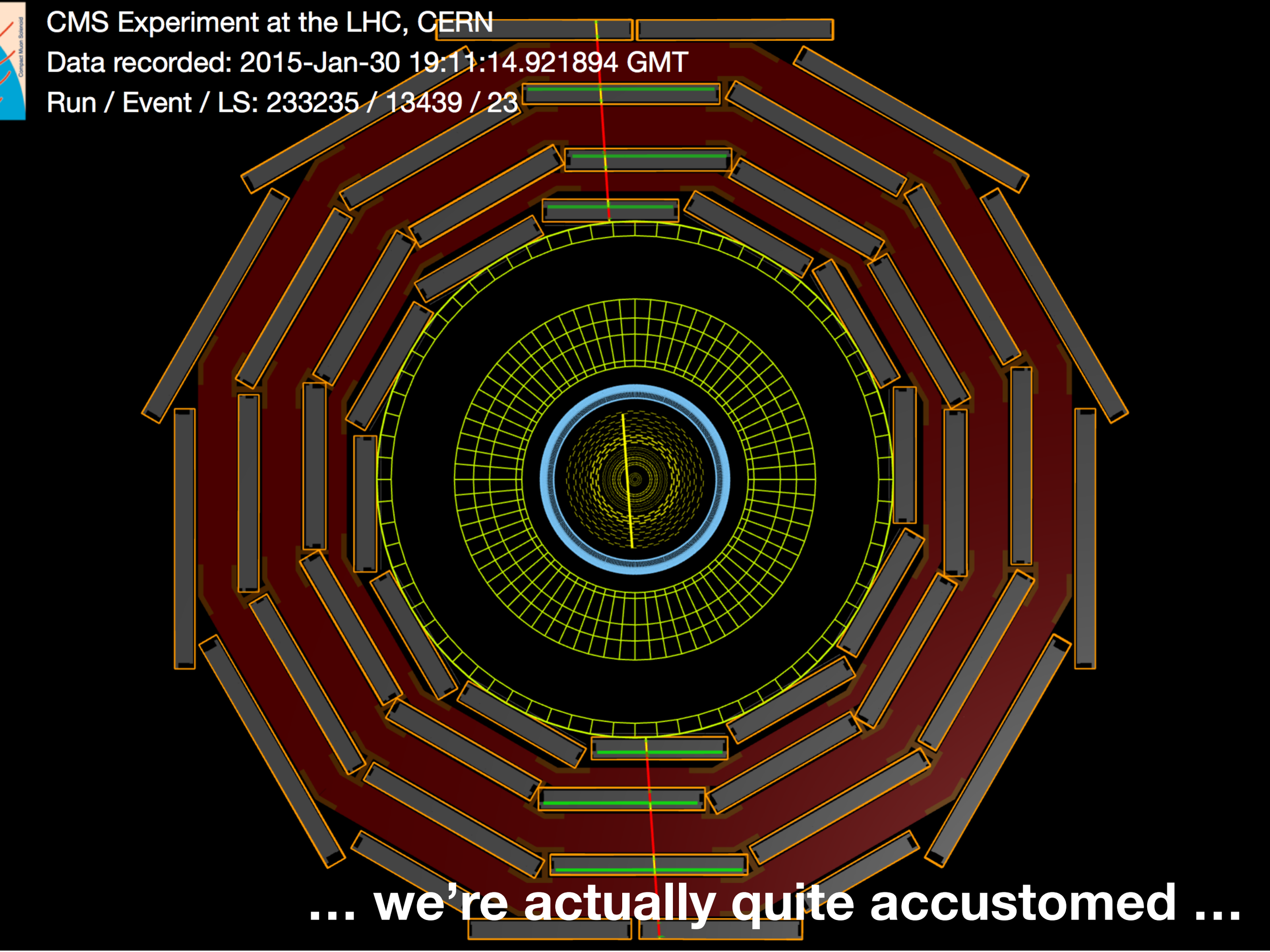
Kate Pachal
on behalf of the ATLAS + CMS collaborations

When it comes to SM processes….





LHCb



… we're actually quite accustomed …

… to seeing long-lived particles.

CERN 2m bubble chamber

So what about for our new physics signatures?

- Long lived particles and dark sector interactions can give non-prompt signatures we should be looking for

- Well motivated! Plenty of models suggest long-lived particles, but this search program picking up steam now essentially due to difficulty of doing the searches.

- Challenging!

  - Analyses often require complex trigger strategies

  - Final states many need dedicated reconstruction processes (e.g. large-radius tracking) or otherwise use the detector in unconventional ways

- Early Run 2 was a great time for standard searches, but we need to start looking in new corners!

What makes particles long-lived?

Decays via heavy particle

e.g. μ to e via off-shell W

Limited phase space

e.g. K_{short} vs K_{long}

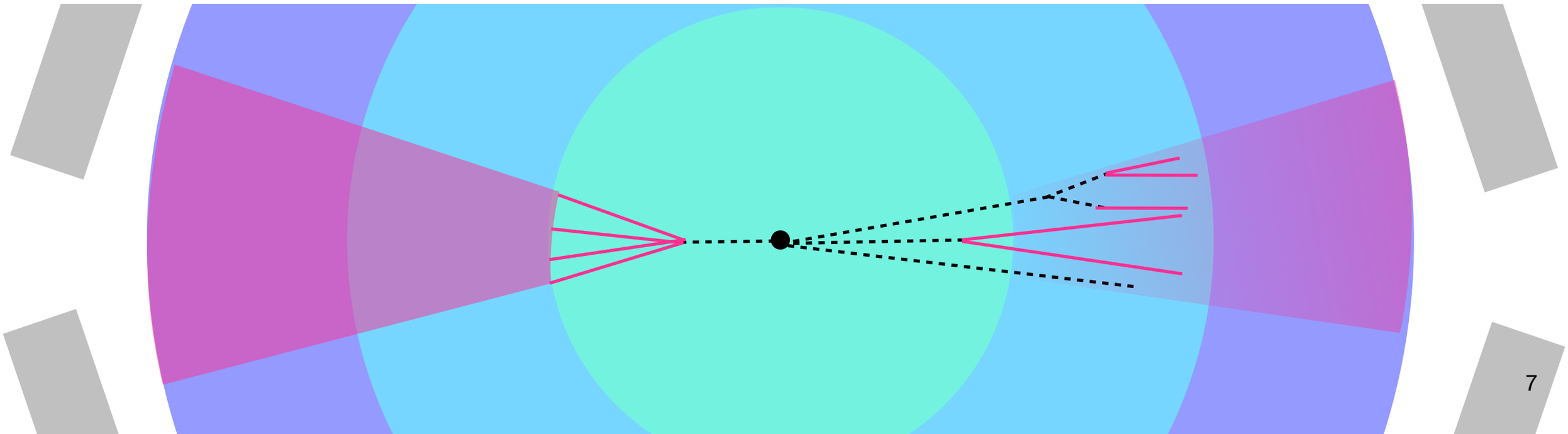
$m_{kaon} \sim m_{3\pi}$

Small couplings

e.g. B meson decays via electroweak processes

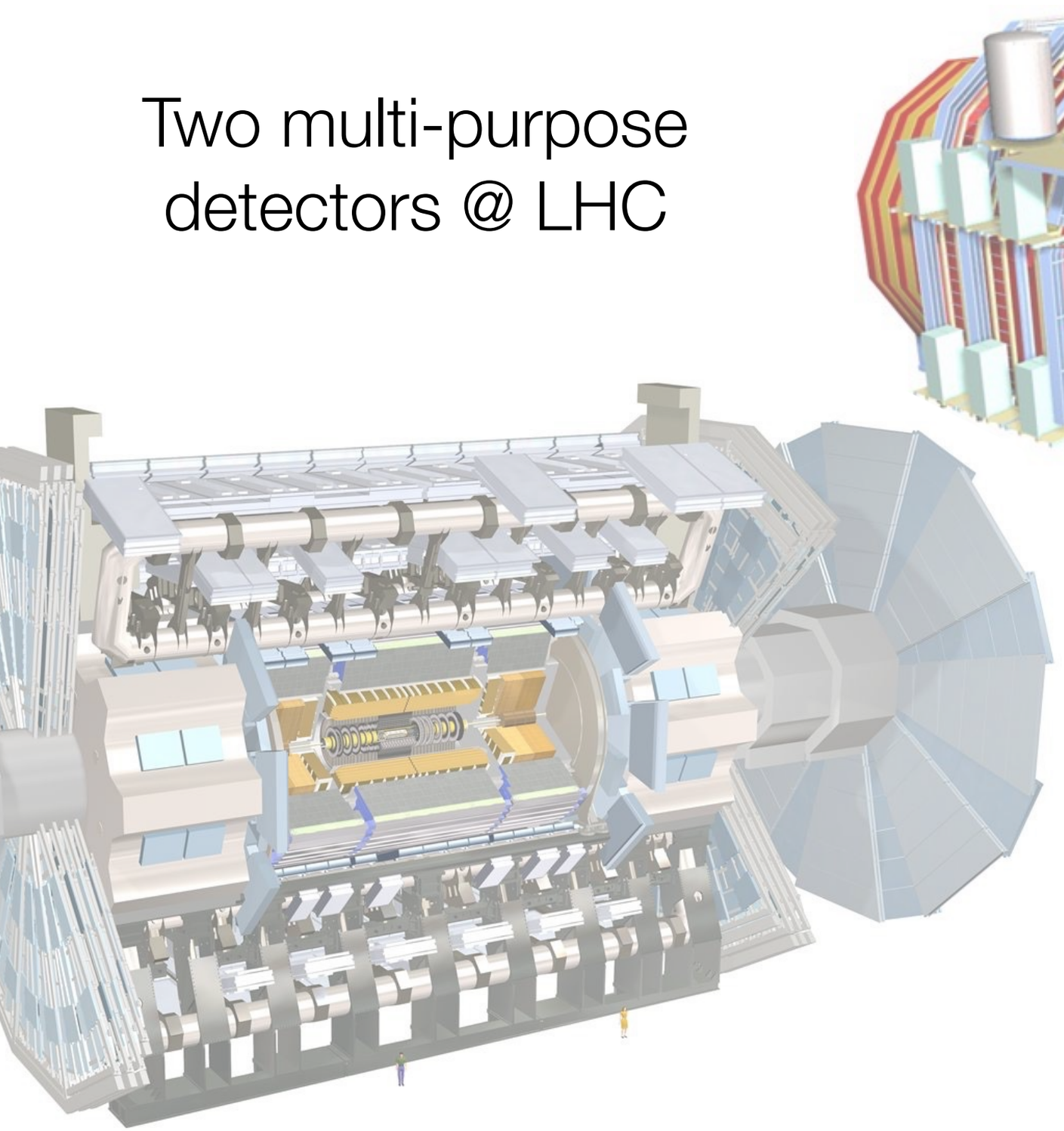
Dark sector searches: similar experimental challenges!

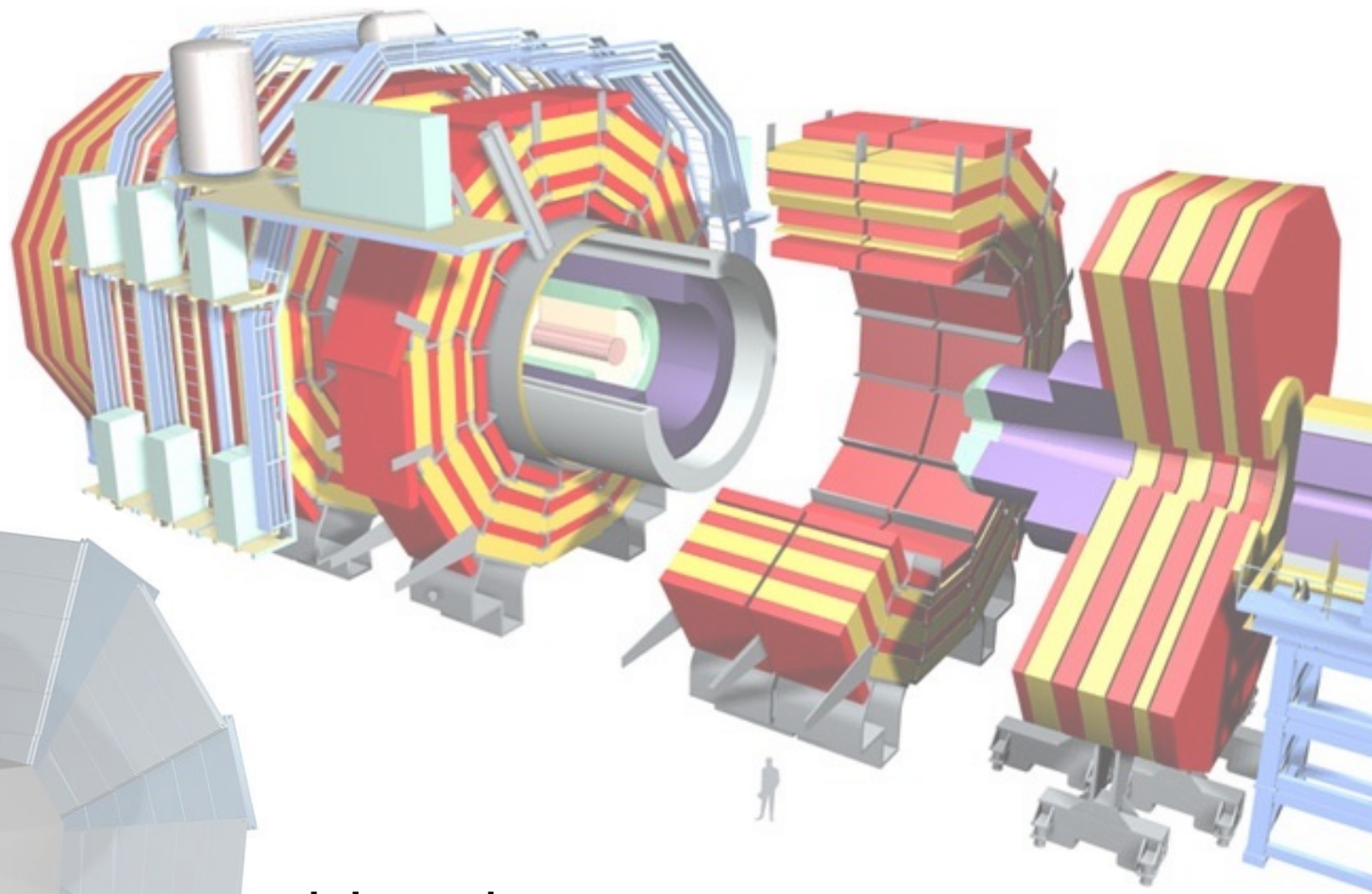
- Presence of a “dark sector” means decay chain includes particles which don’t interact with the detector in standard-model-like ways
- Can provide similar experimental challenges to long lived particles
- Example: displaced jets (from long-lived particle) versus emerging jets (dark QCD) both have displaced vertices and tracks which don’t point to the PV



The detectors

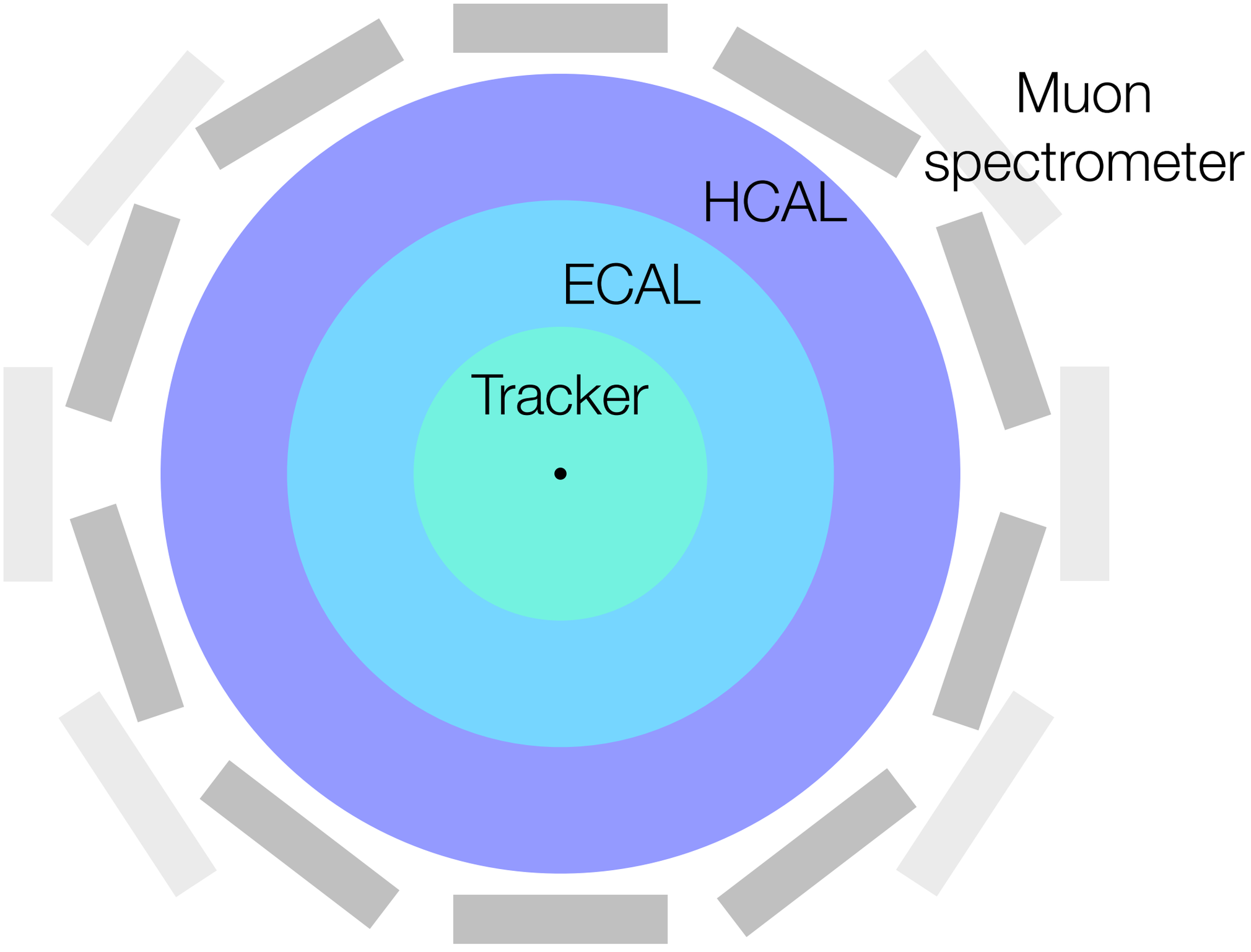
Two multi-purpose detectors @ LHC



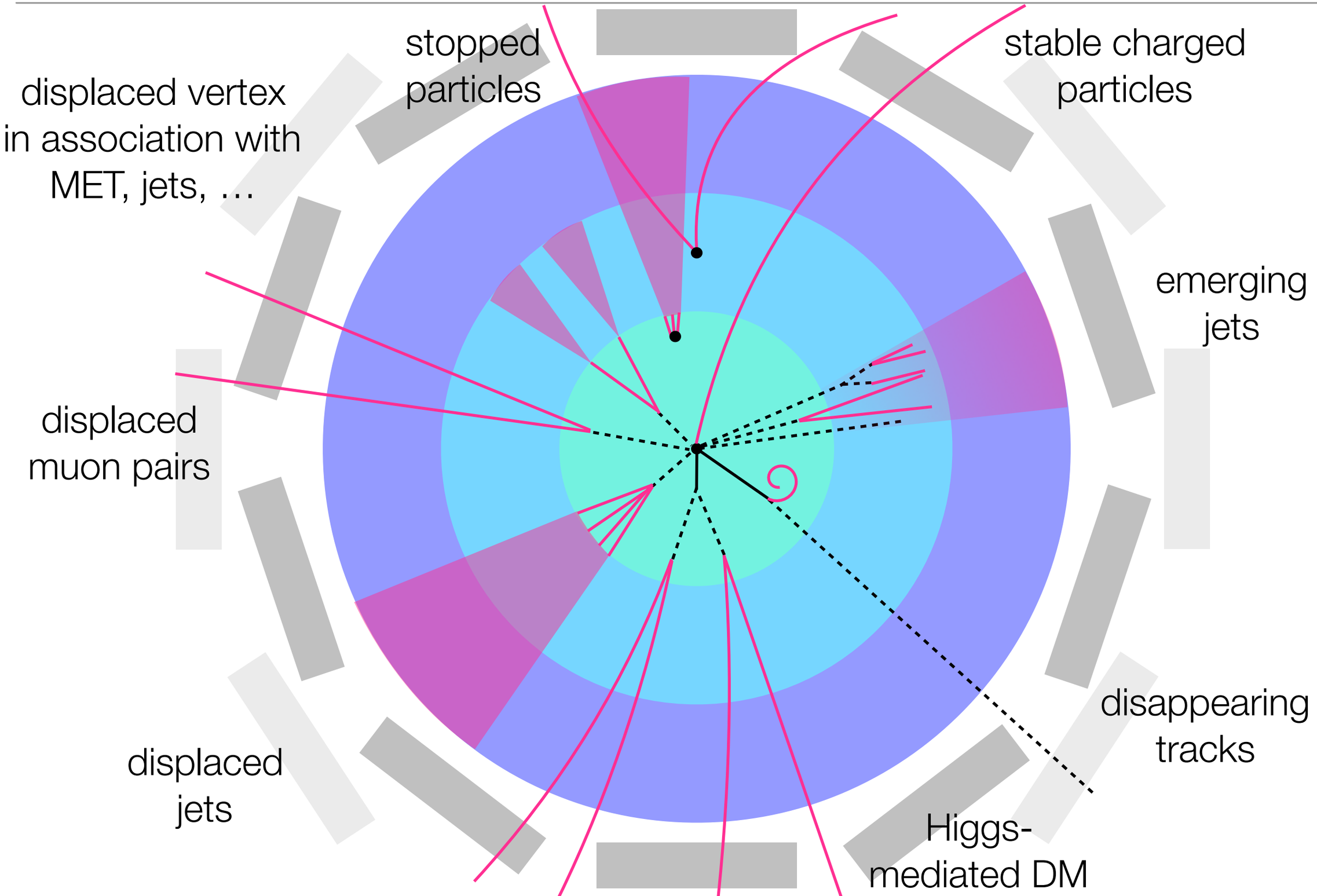


Used to reconstruct “physics objects” for analysis: jets, photon, electrons, muons, missing energy, …

Long lived & dark sector signatures

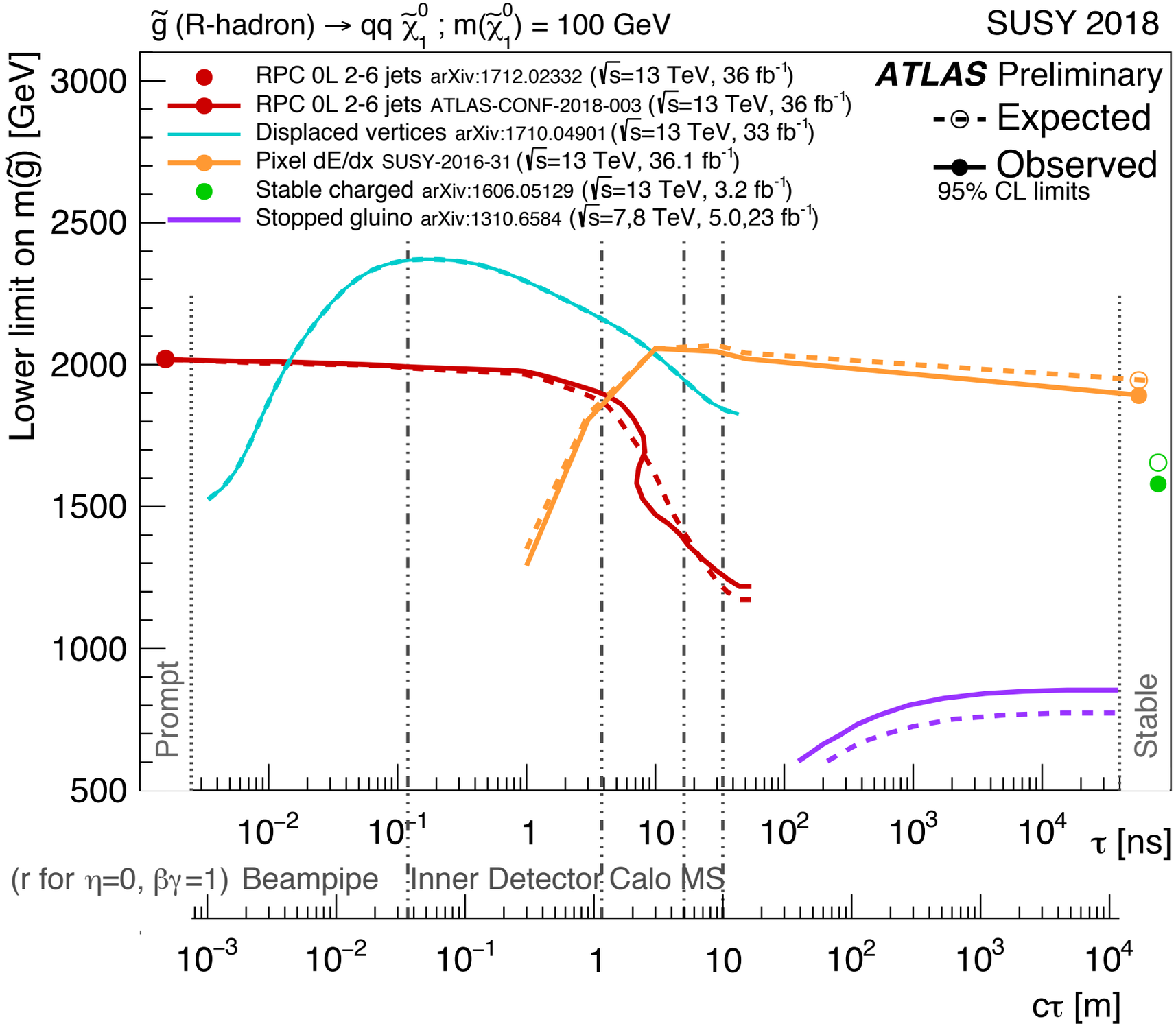


Long lived & dark sector signatures



Can’t prompt searches cover this?

Kind of!



But dedicated searches dominate pretty quickly

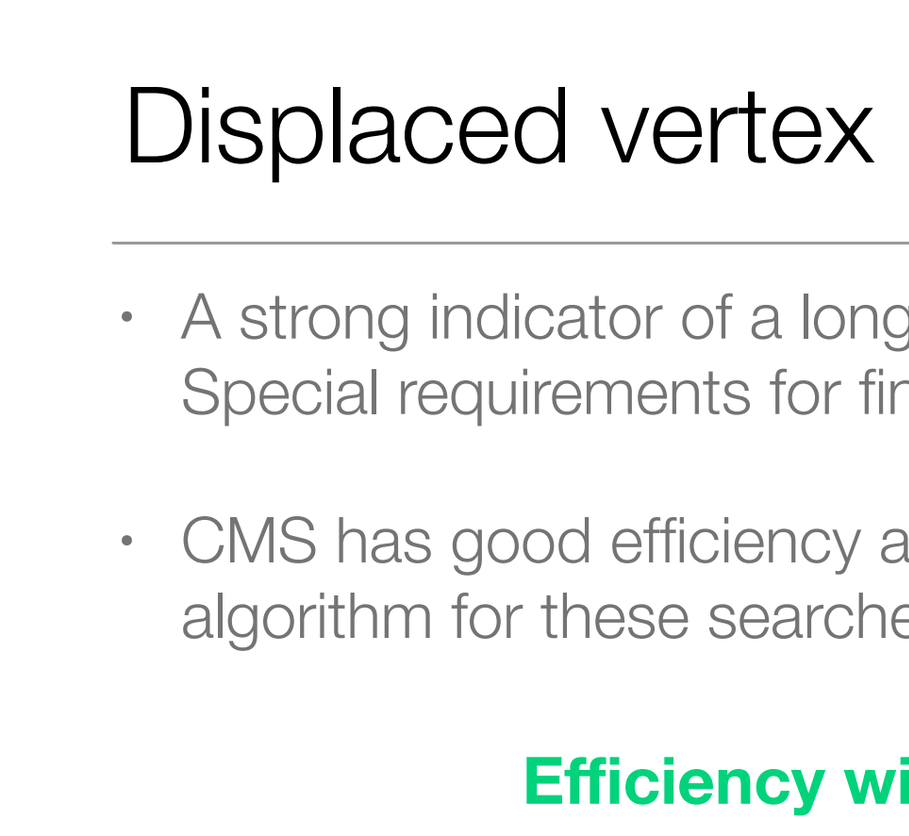
Displaced vertex + [X]

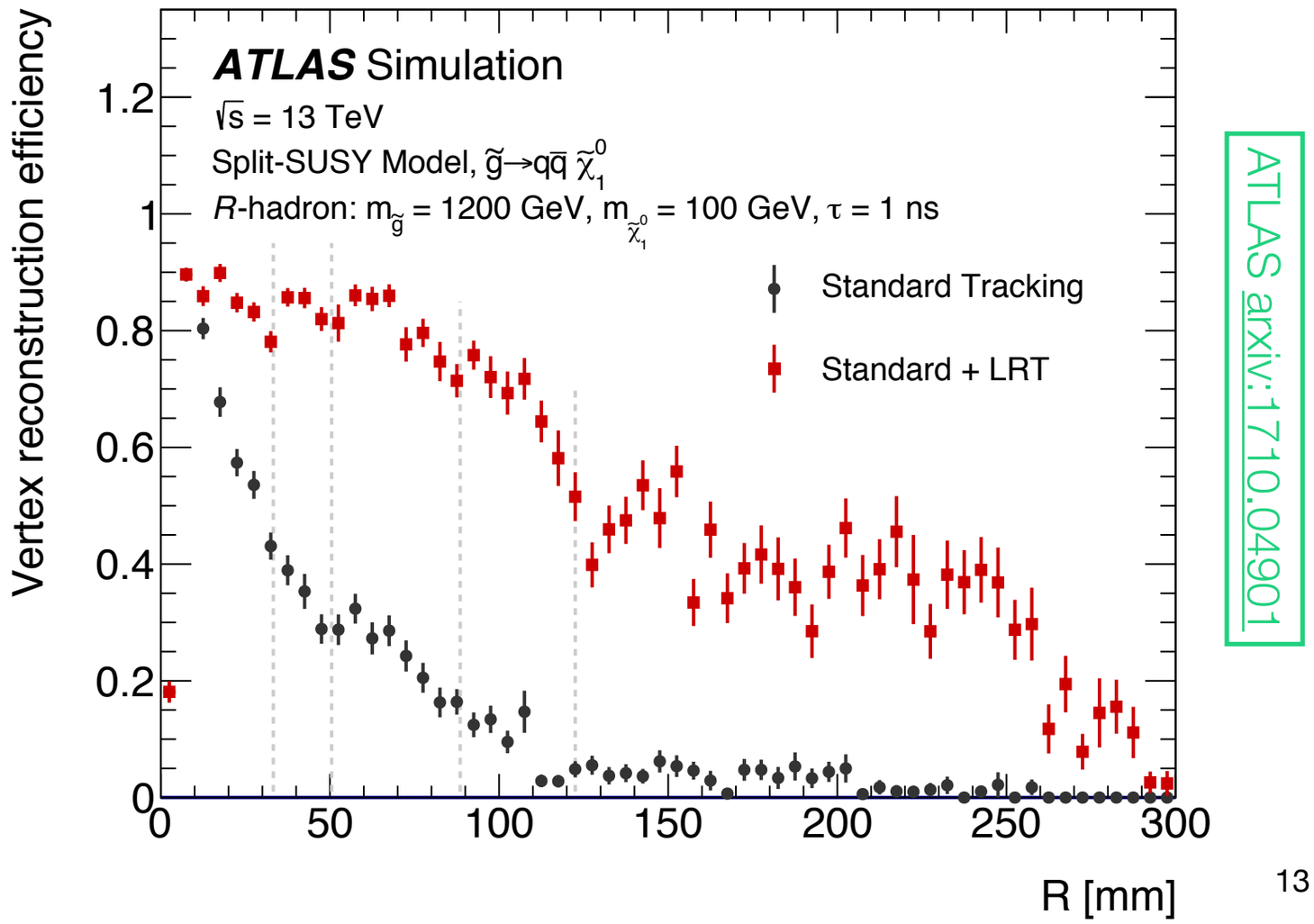
Displaced vertex + [X]

- A strong indicator of a long-lived particle is secondary vertex at large displacement. Special requirements for finding displaced vertices: large-radius tracking!

- CMS has good efficiency already from standard tracking. ATLAS needs custom algorithm for these searches:

Efficiency with standard and LR tracking for example signal

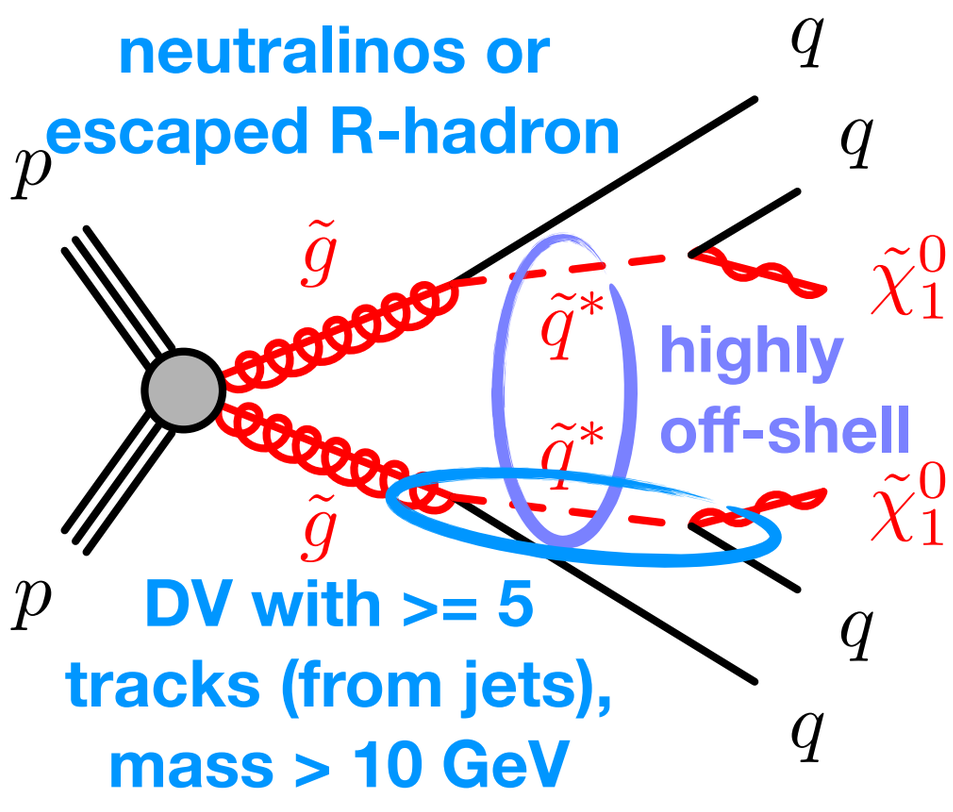


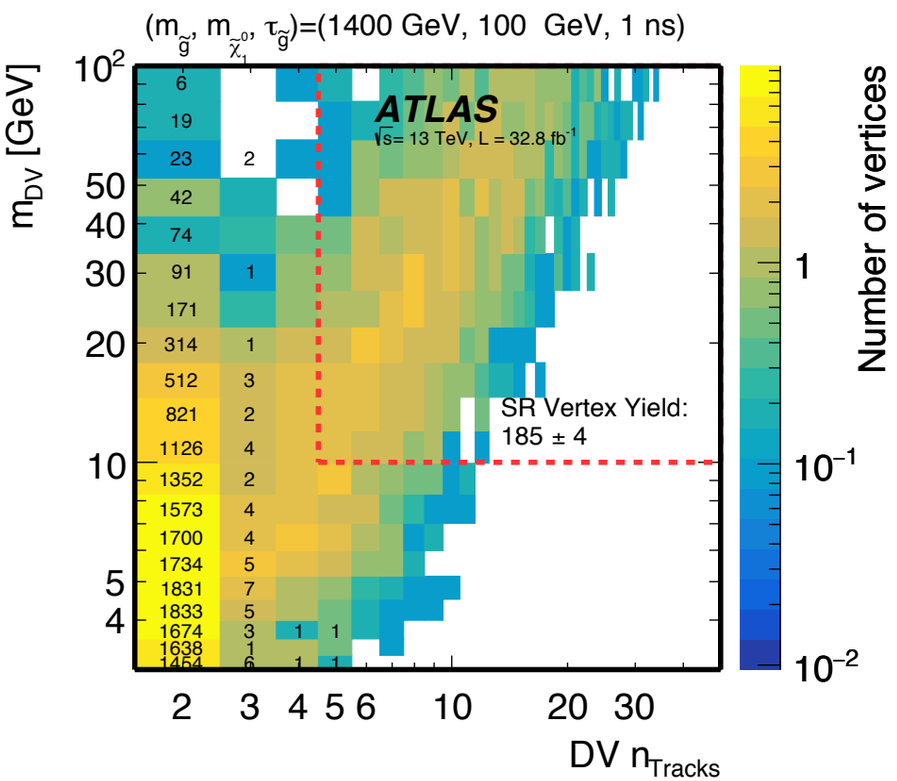


ATLAS arxiv:1710.04901

Displaced vertex + missing energy

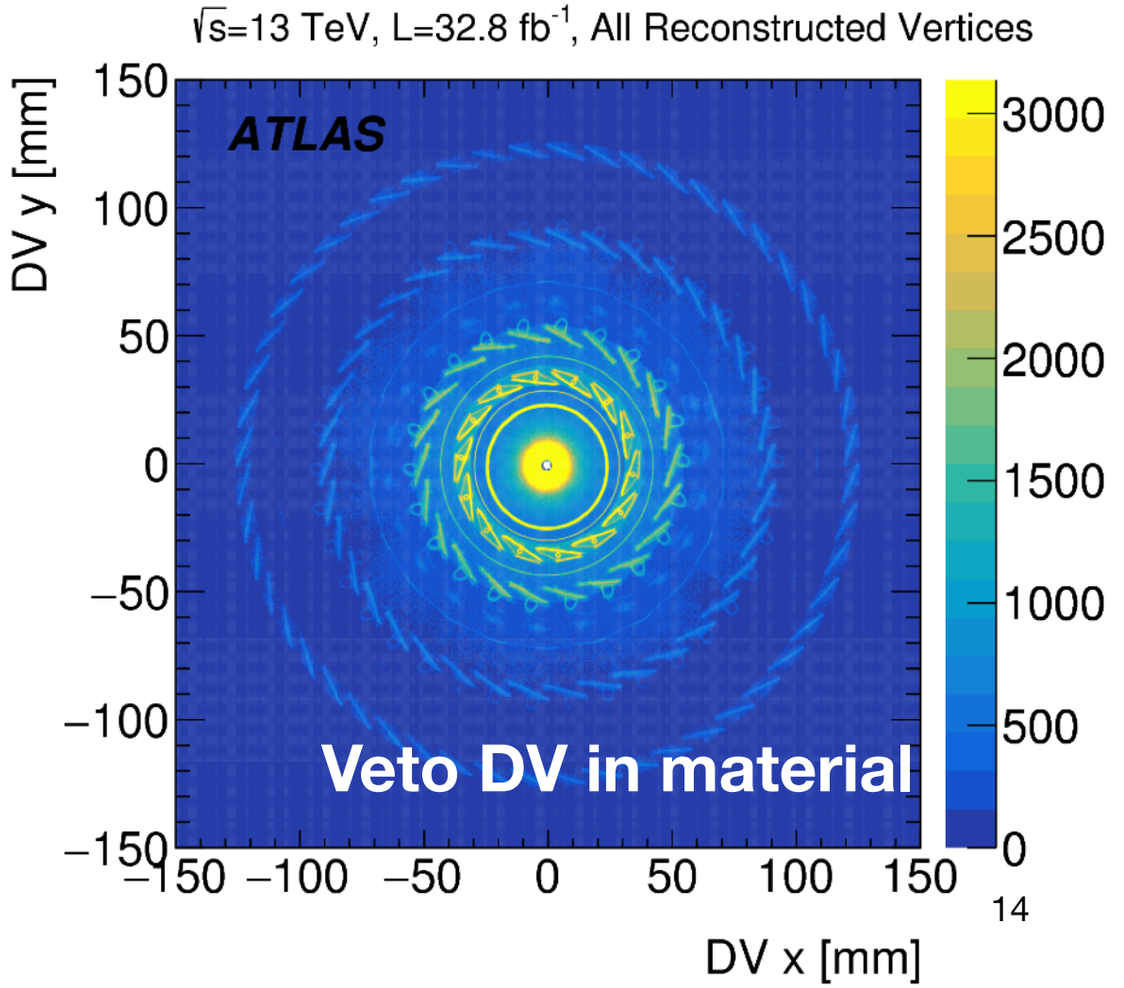
- Sensitive to: pair-produced particles decaying to jets; lifetimes 0.02-10ns
- Benchmark: split SUSY. High squark mass means gluinos live long enough to produce R-hadrons
- Backgrounds: hadronic interactions, merged vertices, accidental track crossings





ATLAS arxiv:1710.04901

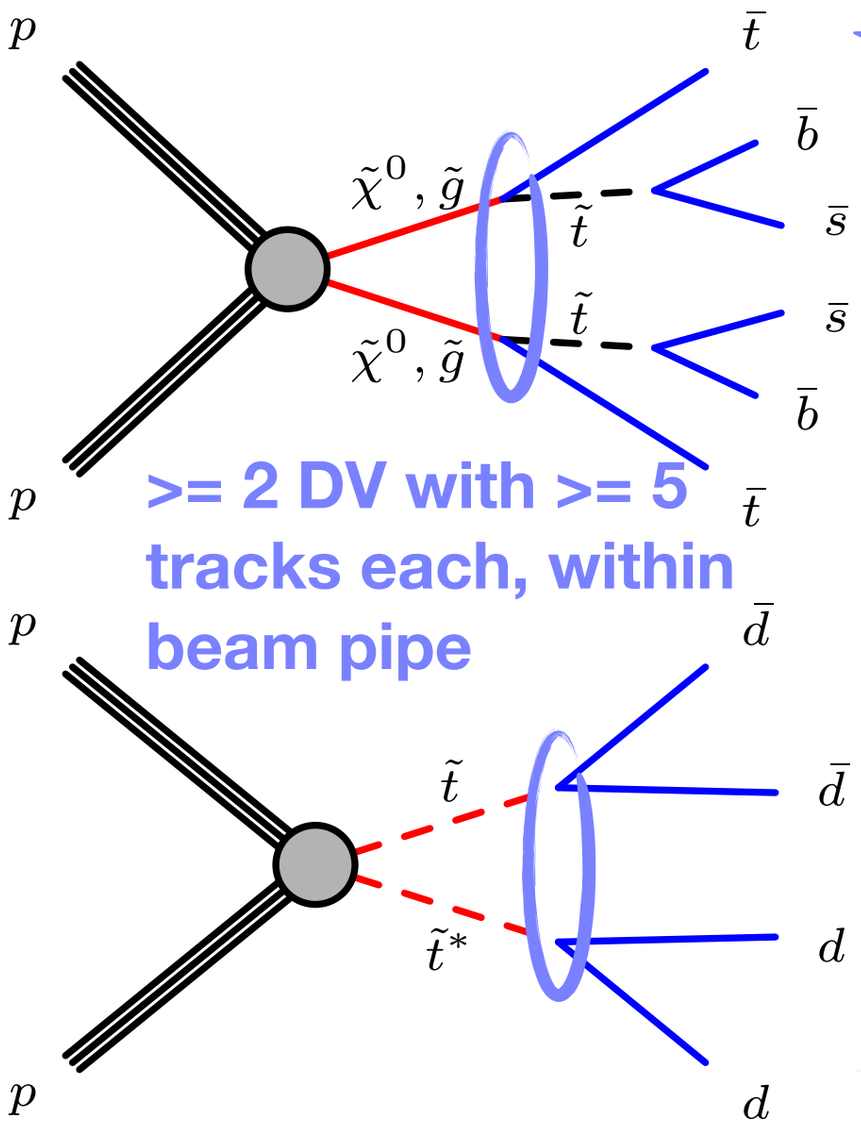
obs: 0 events
exp: 0.02 events



CMS PAS EXO-17-018

Displaced vertex + jets

What if no neutralinos or escaped long-lived particles? Select for two DVs and presence of jets.

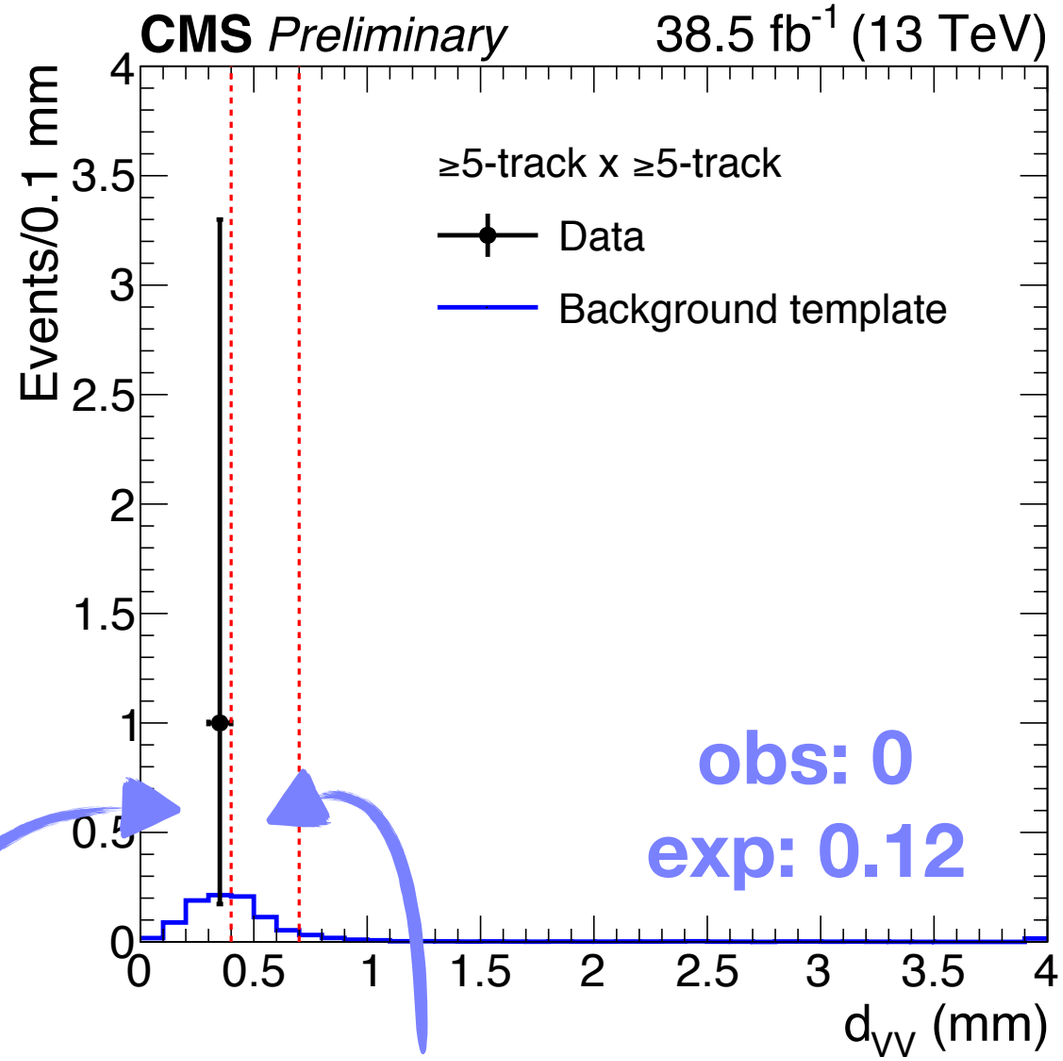


>= 2 DV with >= 5 tracks each, within beam pipe

Use H_T trigger

>= 4 jets

Variable of interest: distance between two displaced vertices



obs: 0
exp: 0.12

obs: 1
exp: 0.51

obs: 0
exp: 0.37

CMS PAS EXO-17-018

Displaced vertex + jets

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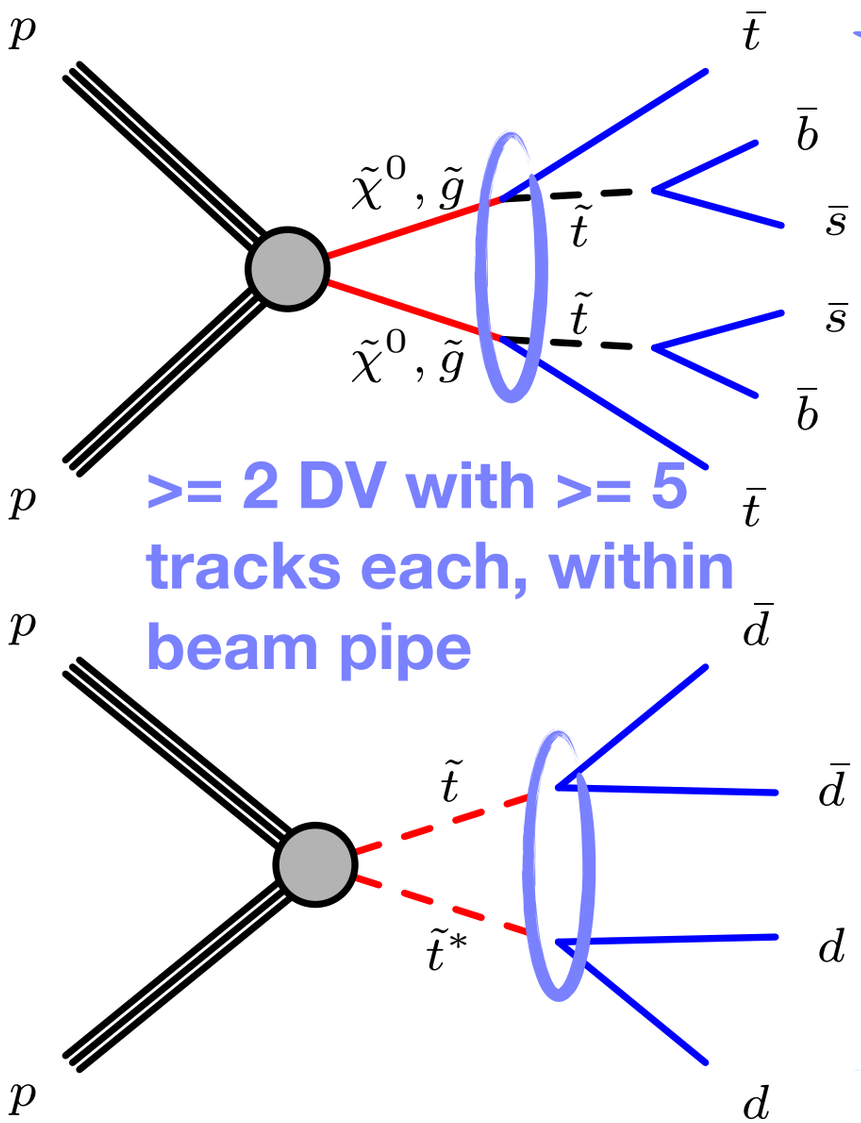

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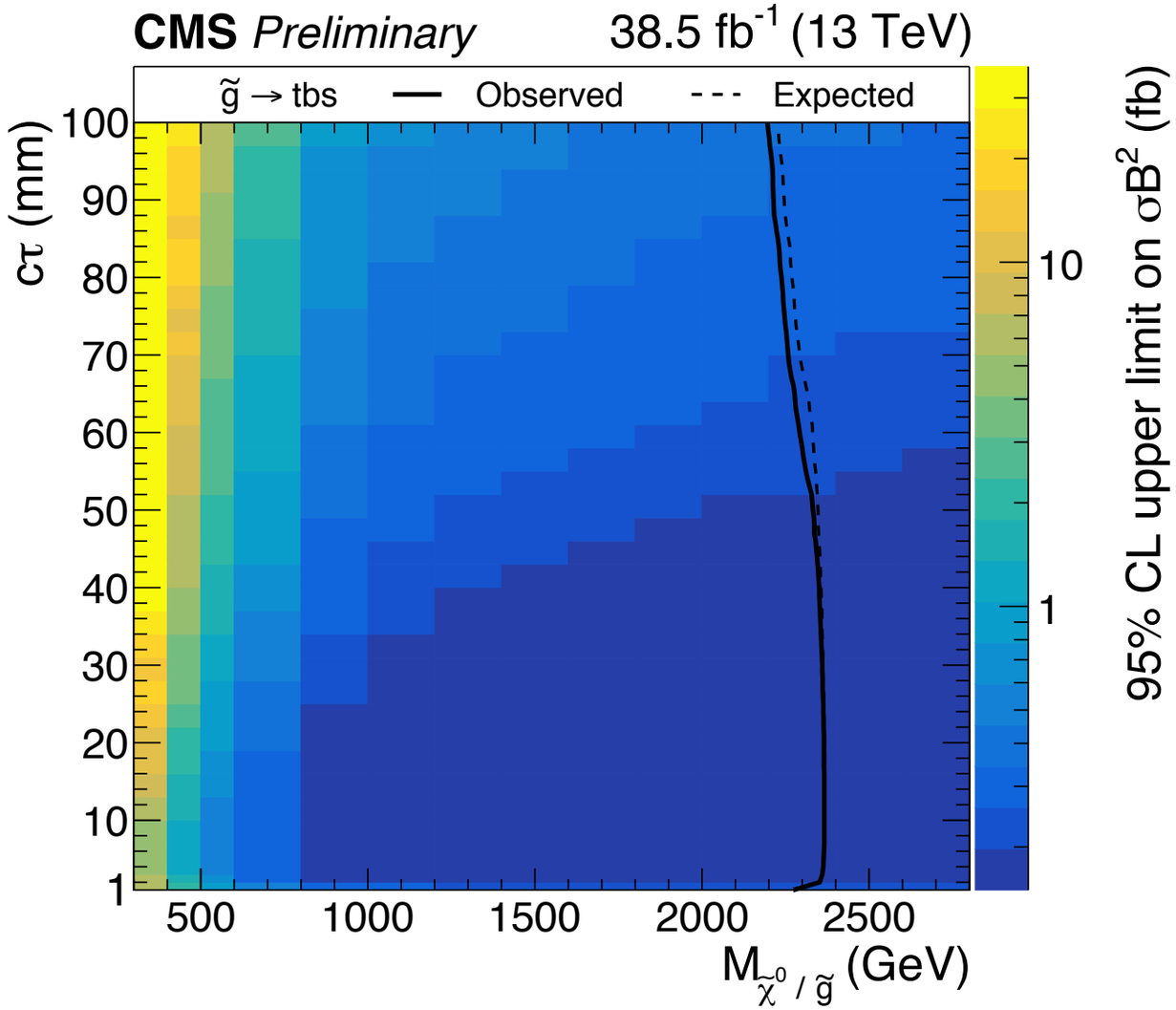
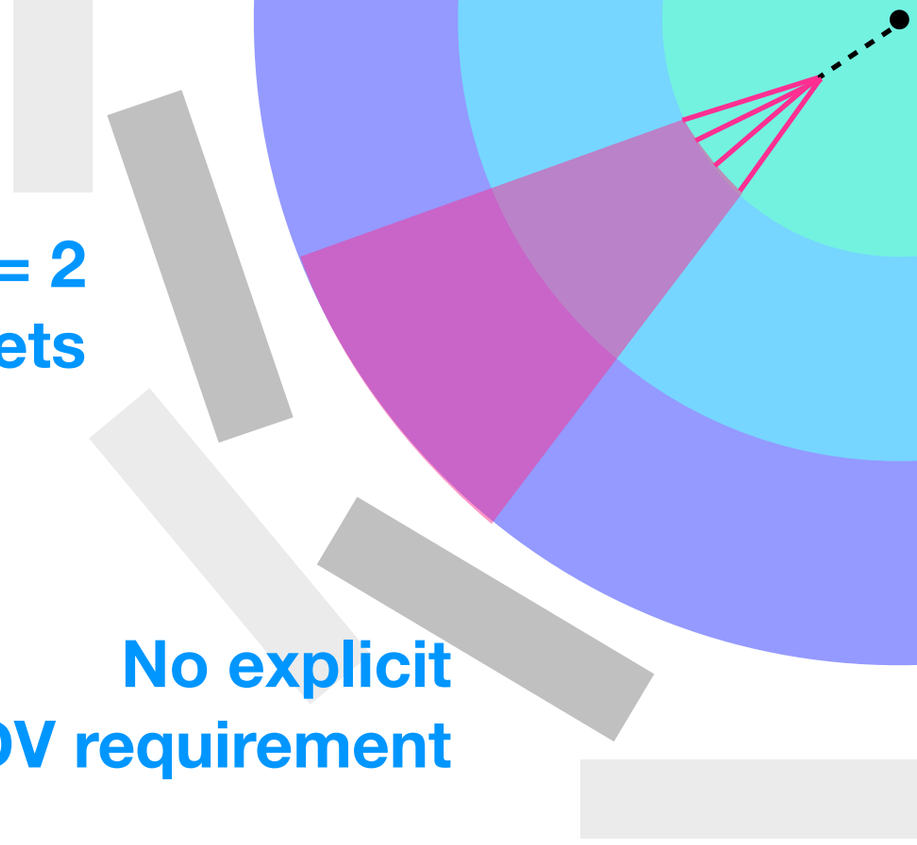


Set limits versus mass and lifetime for each benchmark process

Along those lines — displaced objects

Displaced jets

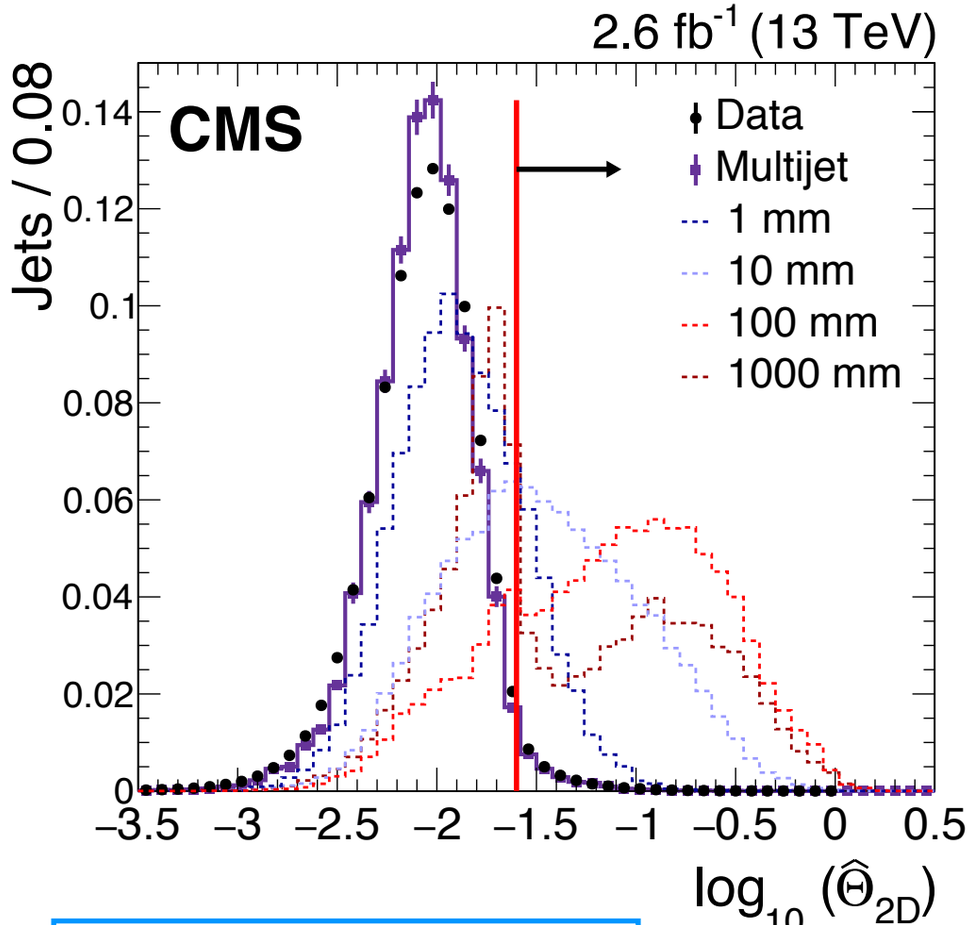


Require >= 2 displaced jets

No explicit DV requirement

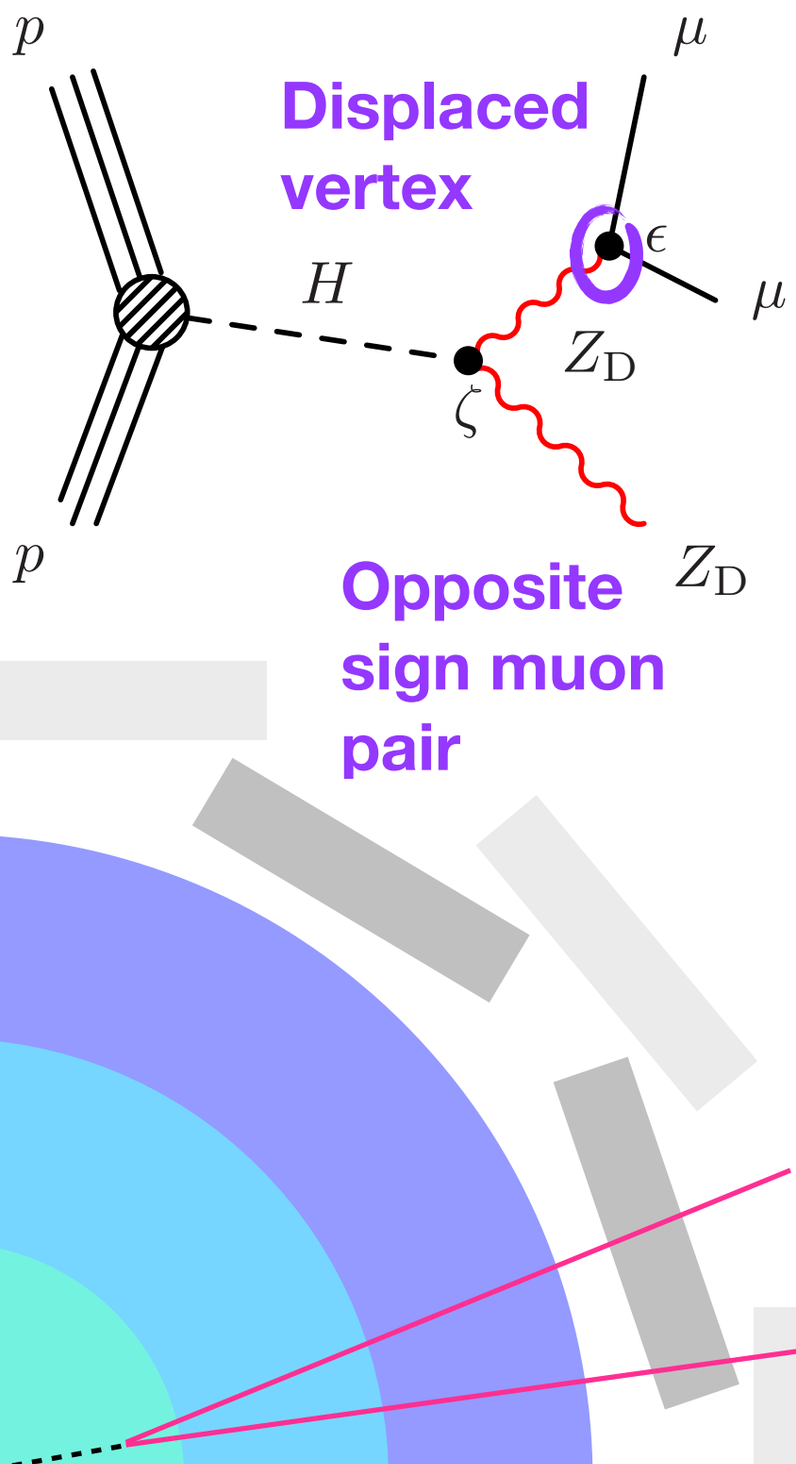
- Reminder: CMS default reconstruction already good at finding large-radius tracks!
- Associate tracks to jet and select on displacement: impact parameter, jet angle, # of tracks associated to PV
- Two custom HLTs: High H_T, >=2 jets, <=2 prompt tracks, >=1 high IP track (2nd trigger)
- Backgrounds: mis-measured jets; b-, c-, and s-jets. Model in N_j^{disp} == 1 control region

N_{tags}	Expected	Observed
2	1.09 ± 0.16	1
≥ 3	$(4.9 \pm 1.0) \times 10^{-4}$	0

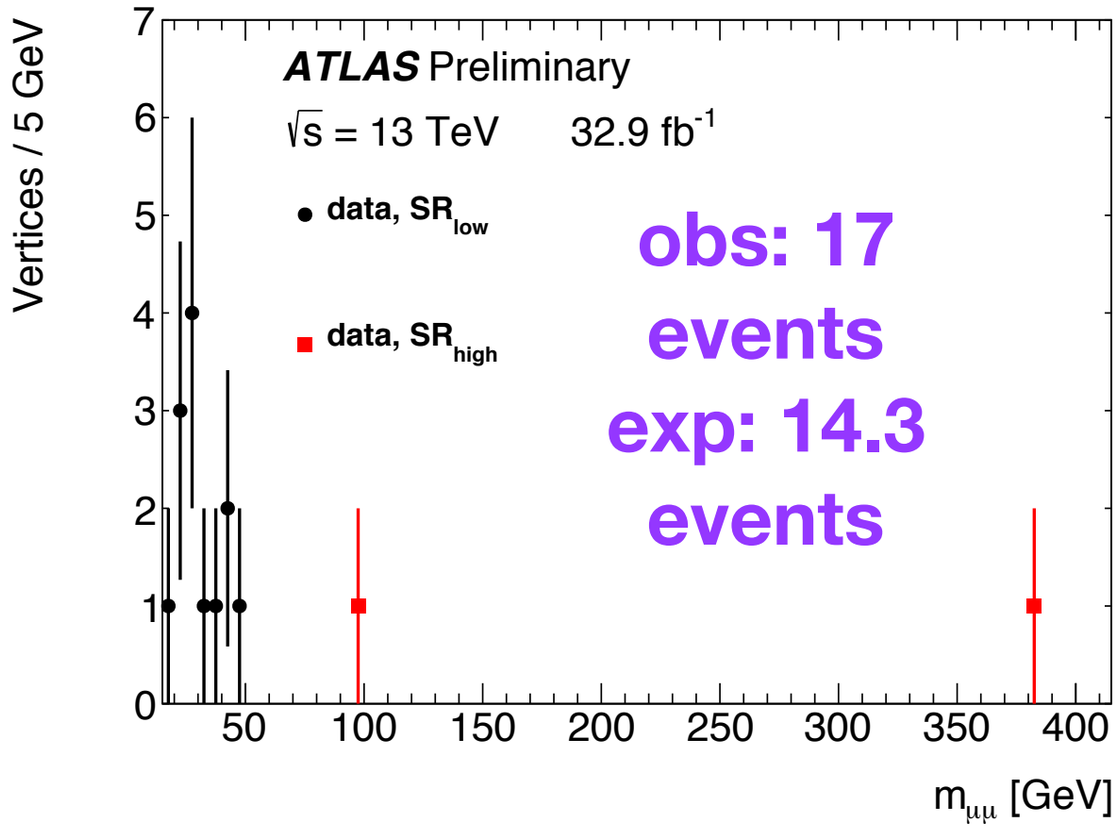


CMS arXiv:1711.09120v2

Dark photons to displaced muon pairs

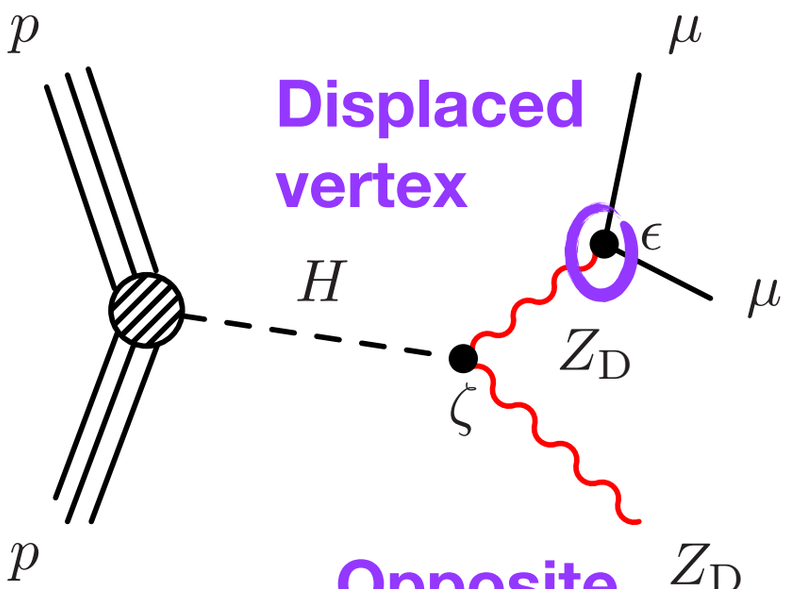


- Benchmarks: Higgs to $Z_D Z_D$, gauge-mediated SUSY breaking
- MET or (multi-)muon trigger. Extrapolate tracks from MS to determine if consistent with a common vertex. Require large boost (p_T/mass > 2) to suppress DY/Z+jets
- Other backgrounds: cosmic μs, beam-induced background, π/K decays

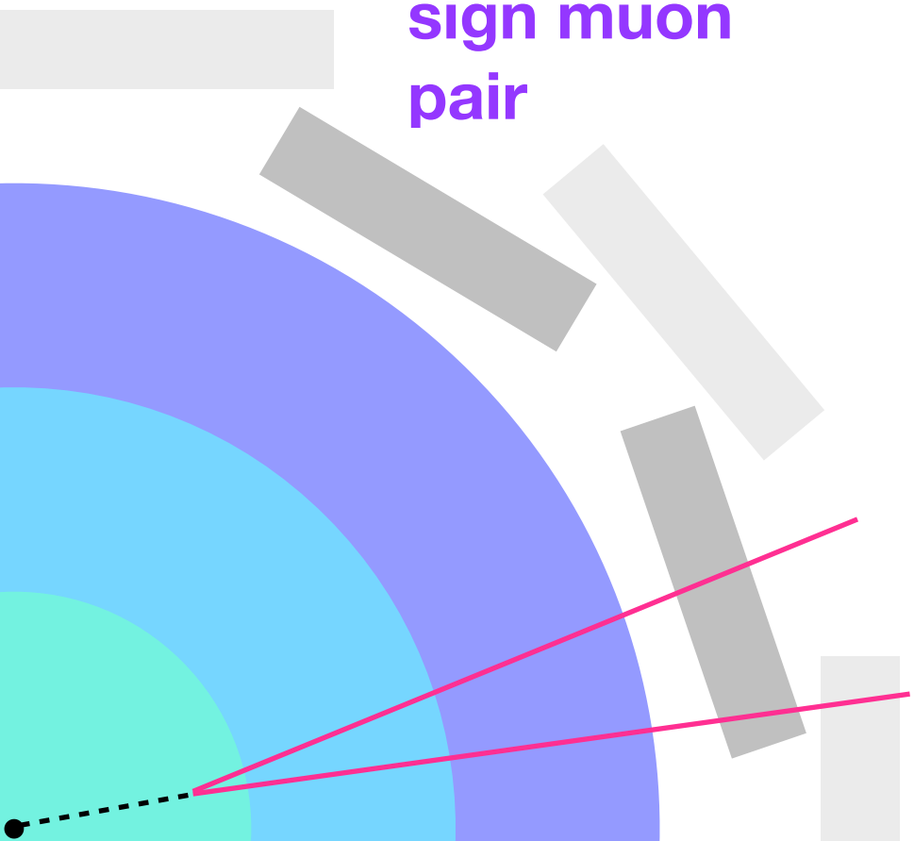


ATLAS EXOT-2017-03

Dark photons to displaced muon pairs



Opposite sign muon pair



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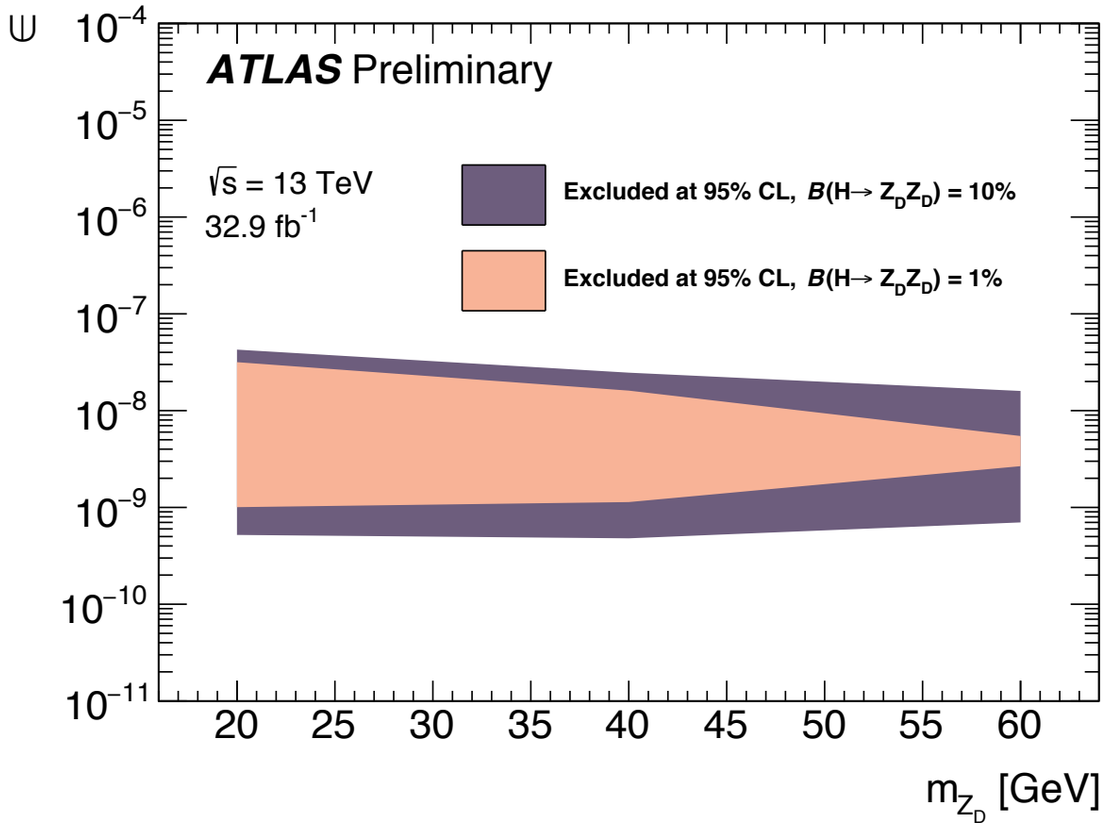
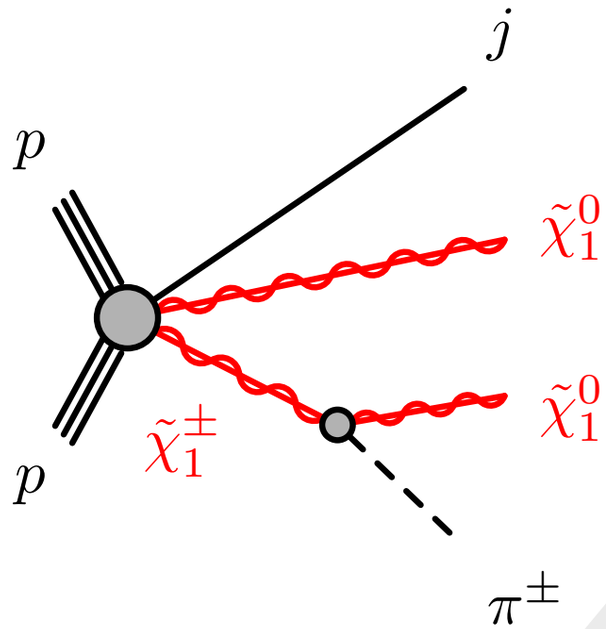


ATLAS EXOT-2017-03

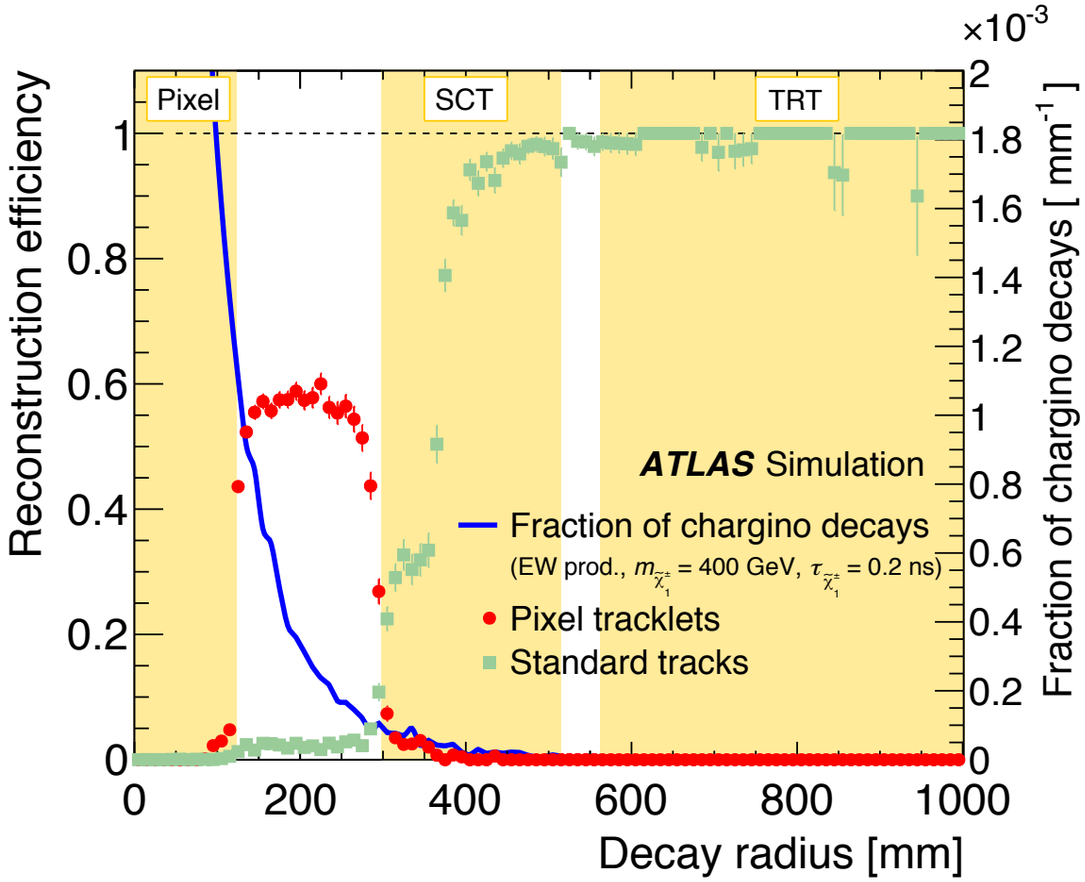
Searching from tracks

Disappearing tracks

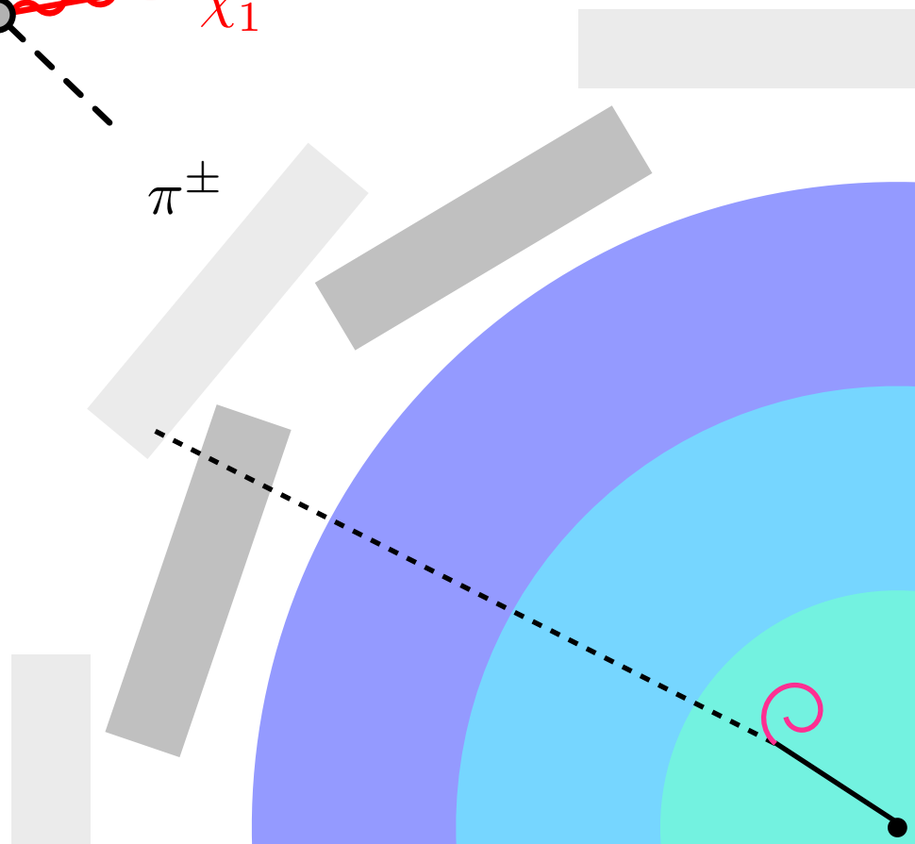
- Charged particle decaying to invisible particle of nearly degenerate mass gains long lifetime from small Δm. SM particle (π) too soft to reconstruct
- Signature: MET, track vanishing after *n* ID layers, high-p_T ISR jet for boost



Example: AMSB SUSY



Benefit from shortest possible tracks



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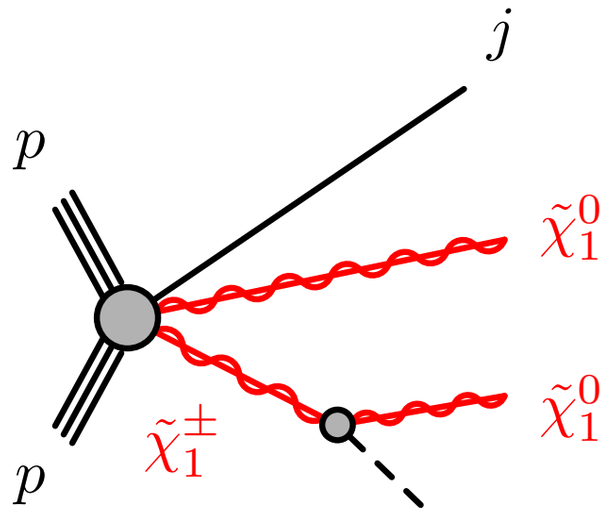

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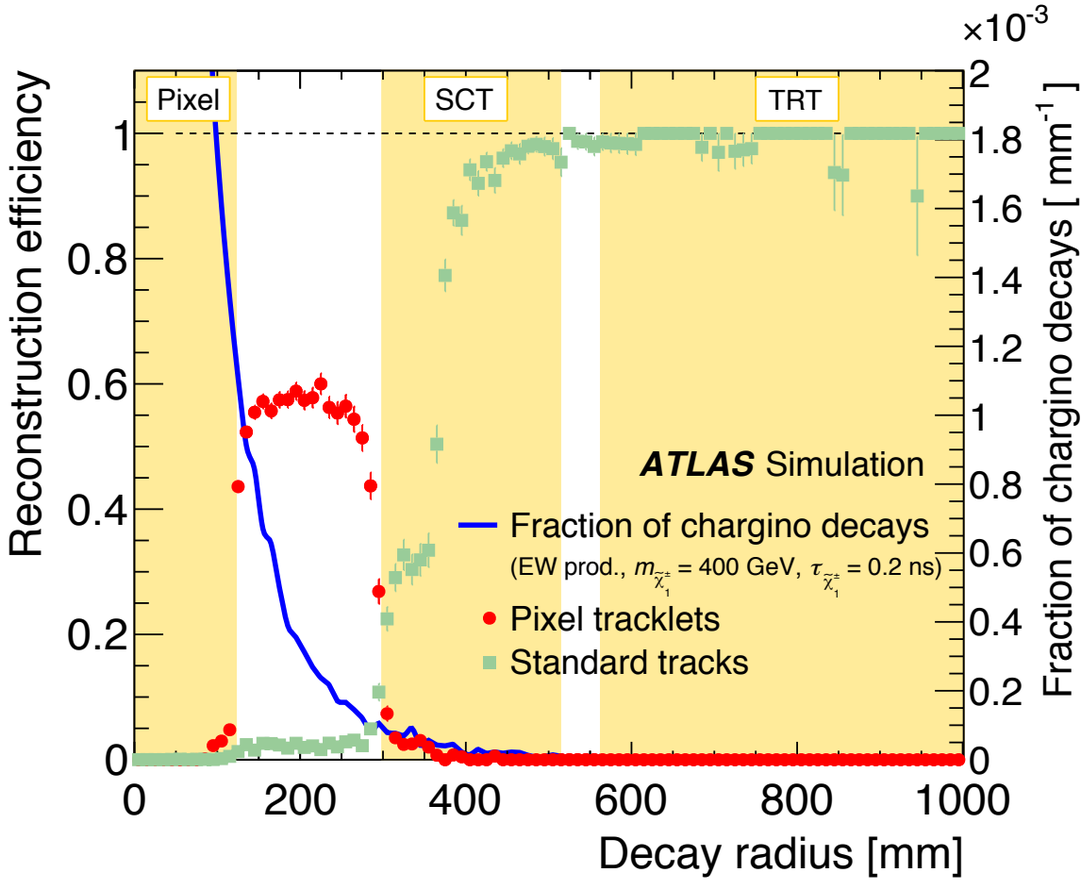

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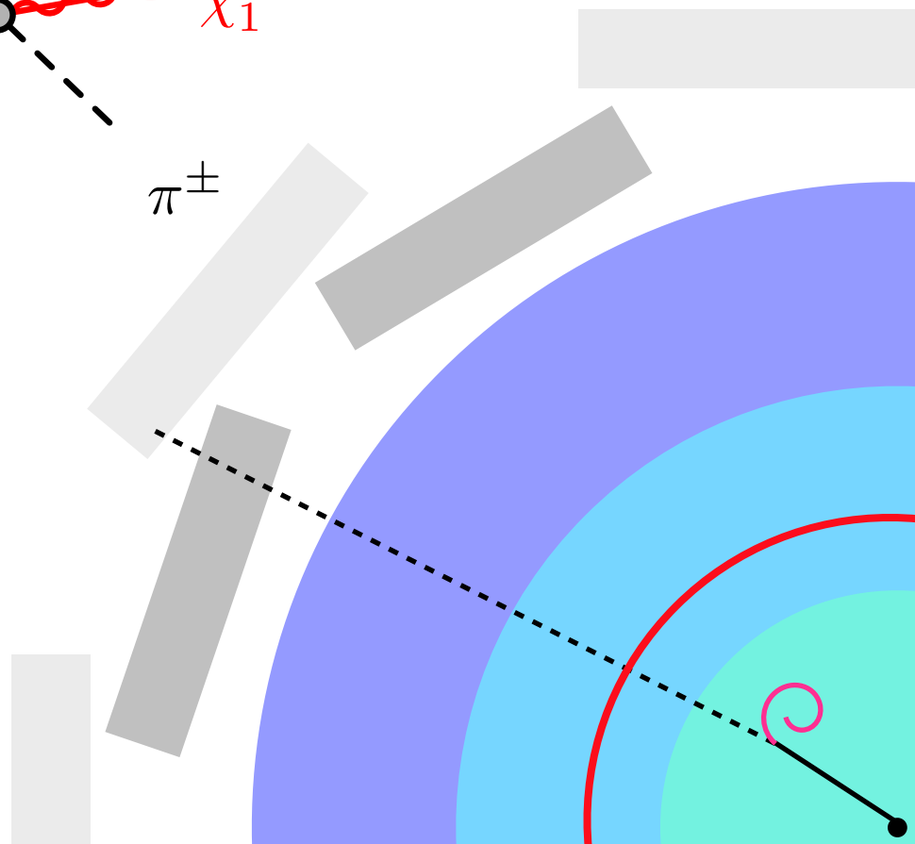

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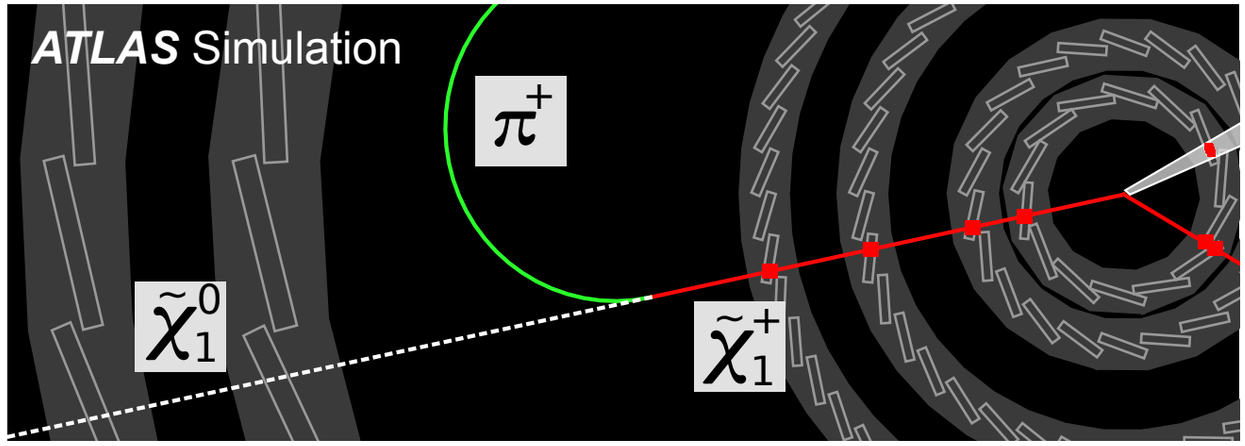

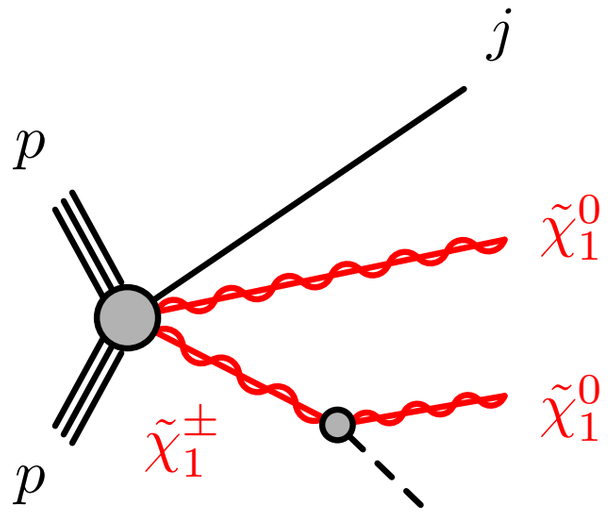

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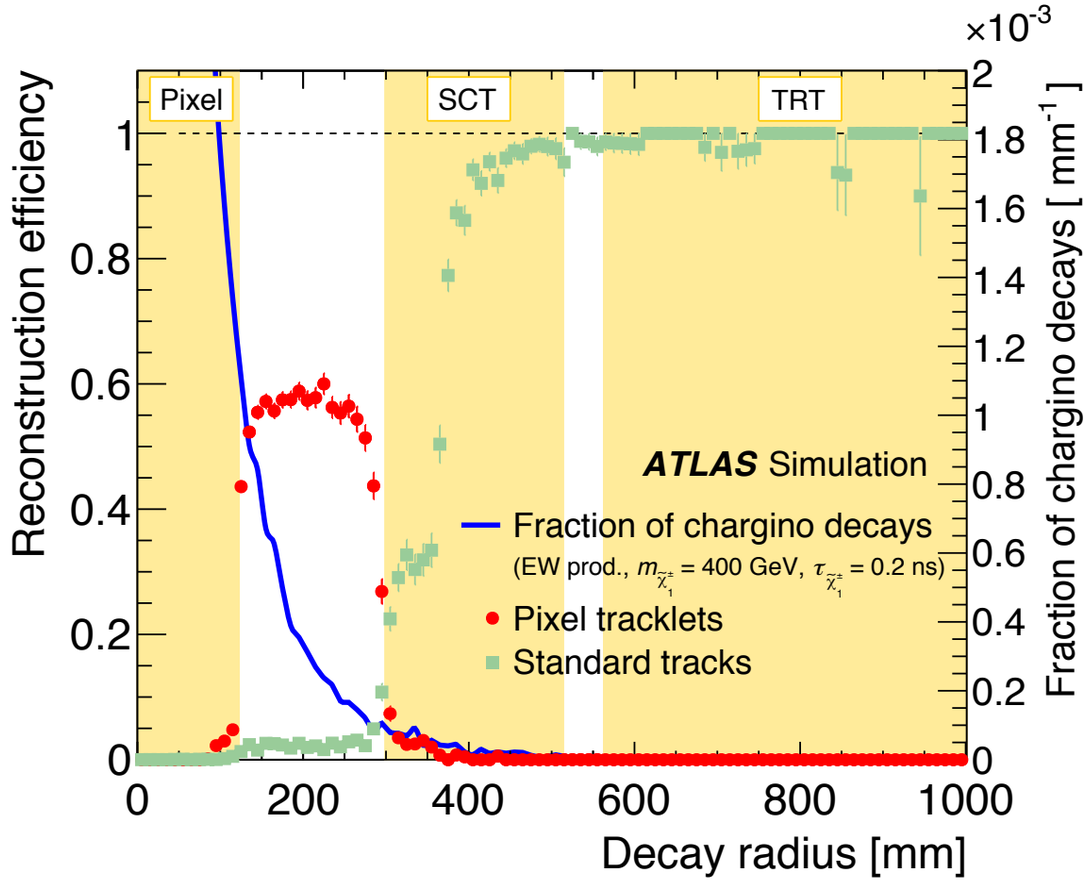

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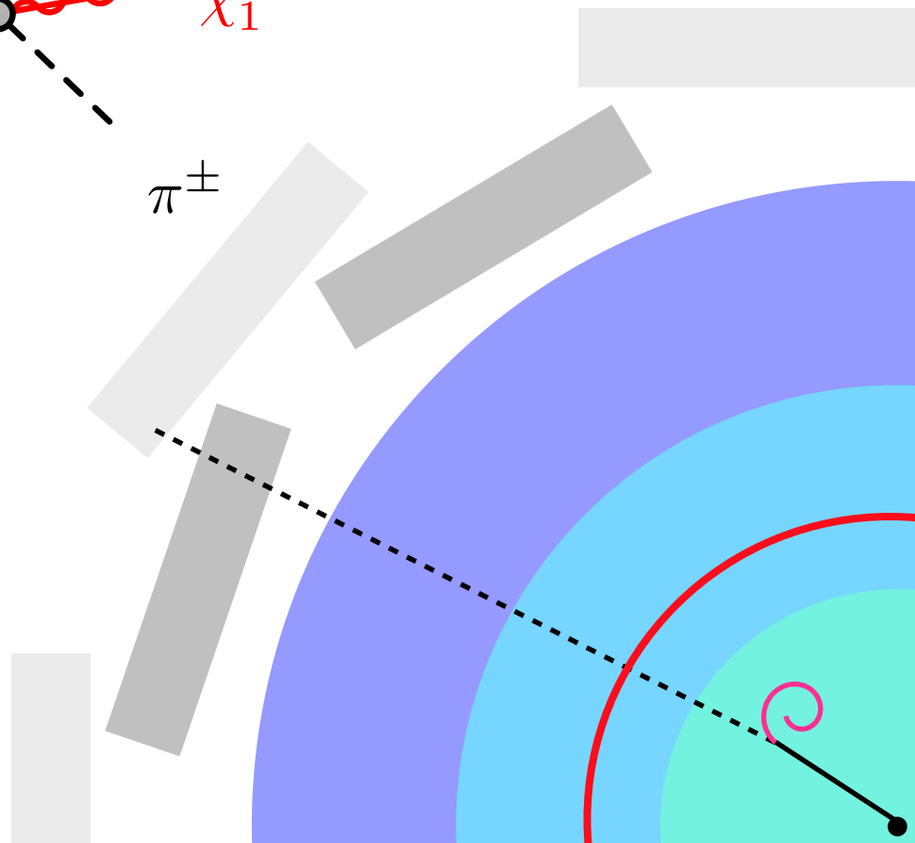
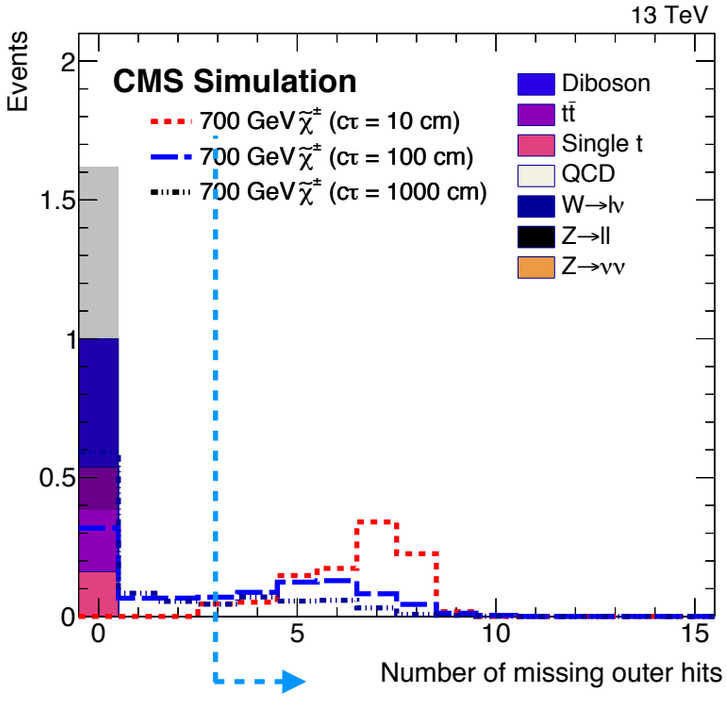


Disappearing tracks: CMS highlight

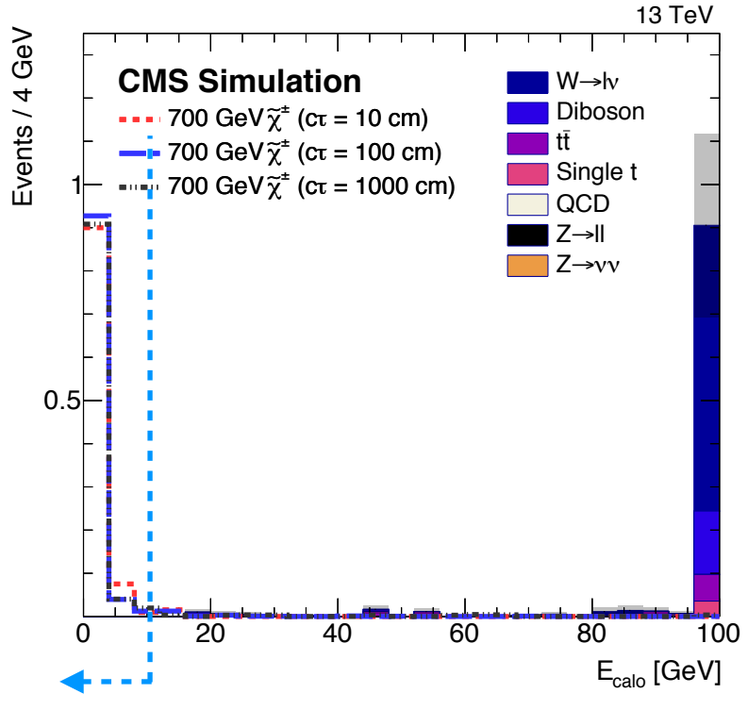
CMS arXiv:1804.07321v1
ATLAS arXiv:1712.02118v2

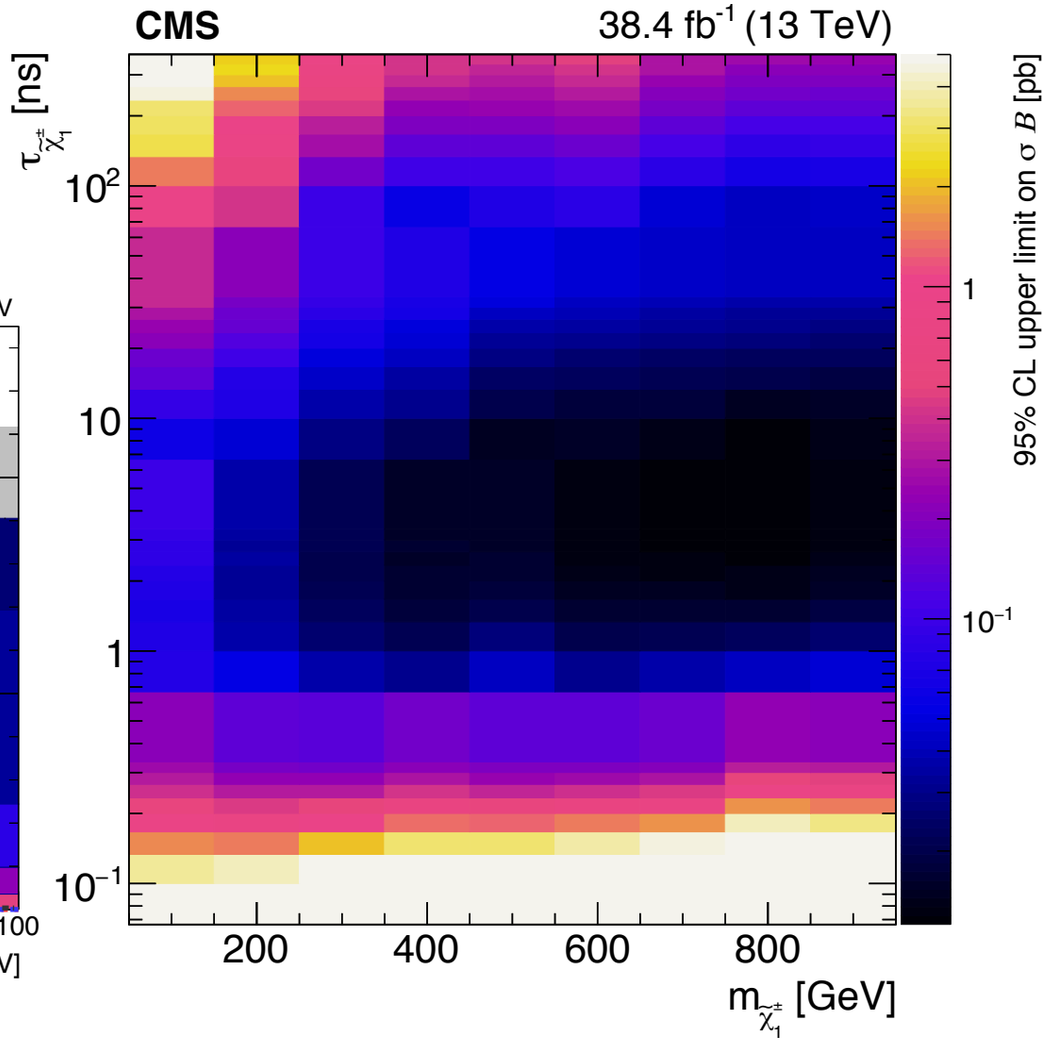
- Selection: p_T^{miss} + isolated track trigger and >= 1 (distant) jet of 100 GeV.
  Track selection: isolated, no associated calo or MS hits, only outer hits missing
- Backgrounds: mis-reconstructed leptons, spurious tracks
- Results: expected 6.5 events, observed 7

At least 3 missing outer hits

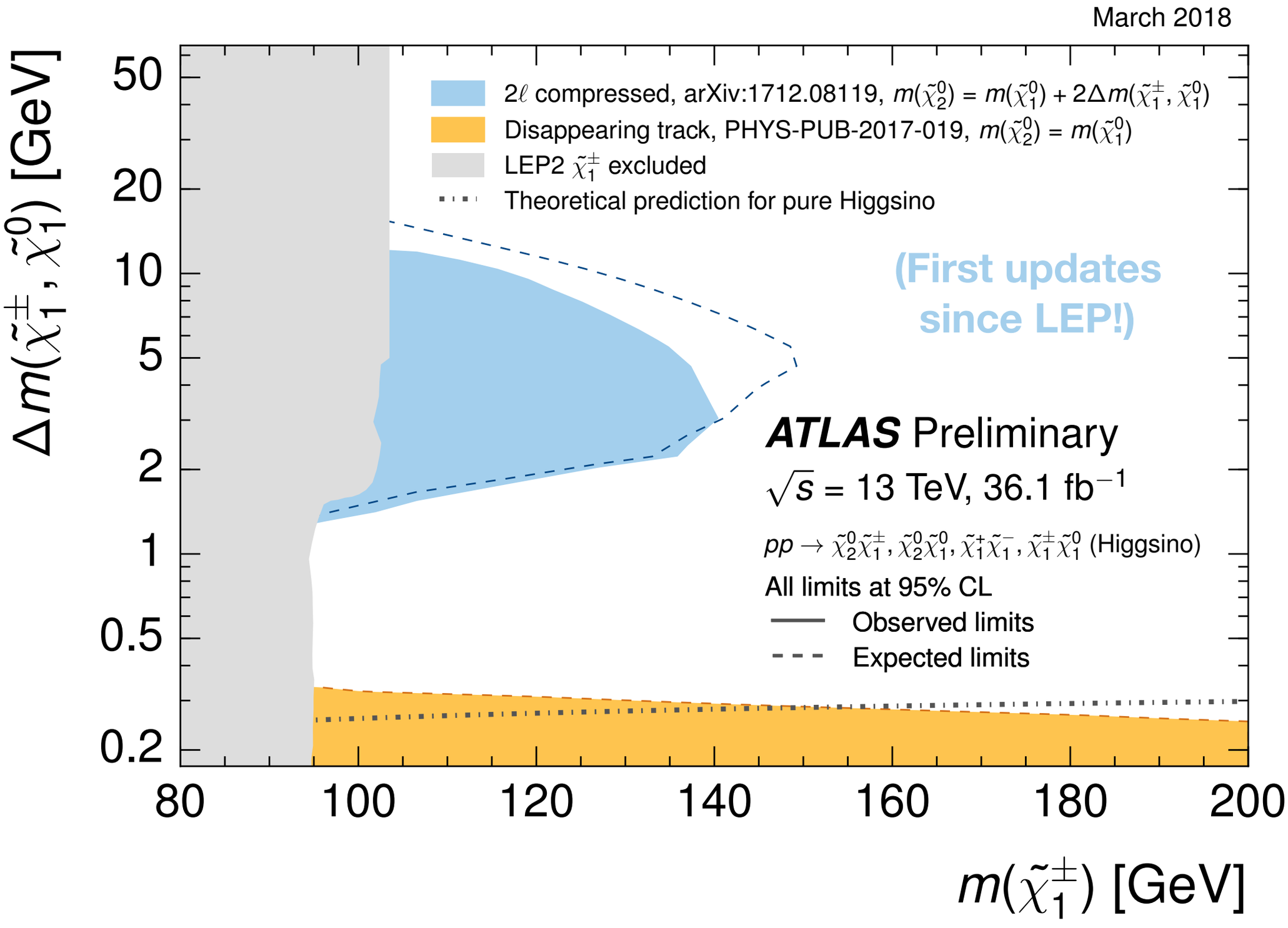


< 10 GeV of nearby energy in the ECAL





Constraining Higgsinos with disappearing tracks

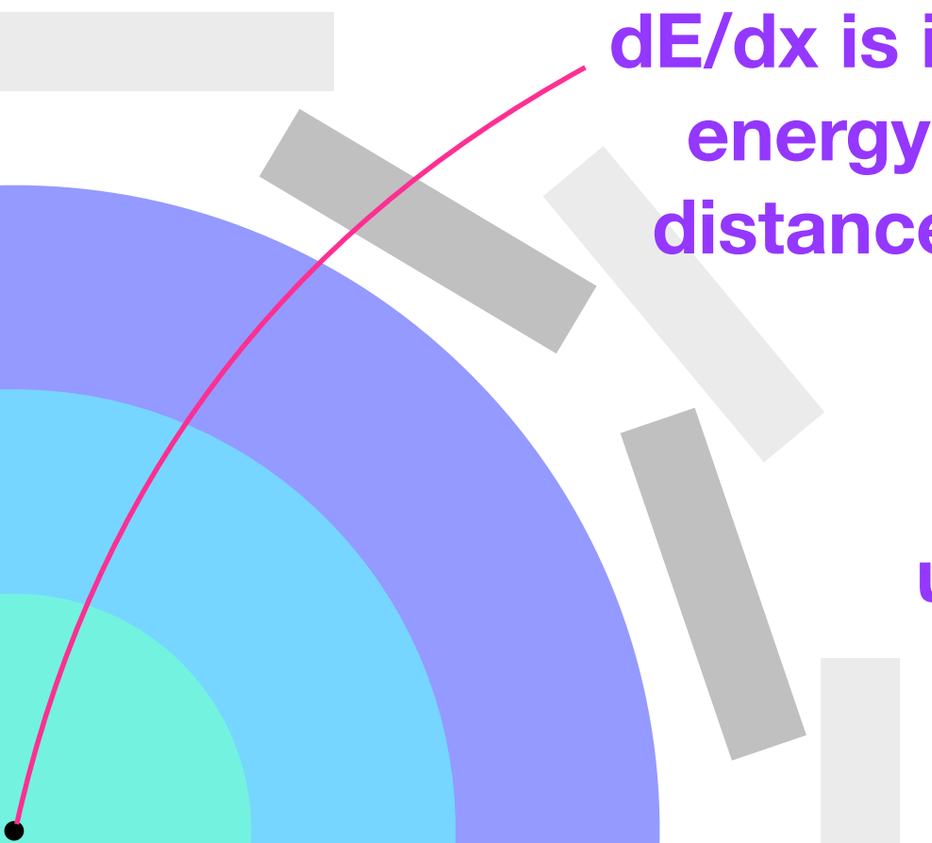


Stable charged particles

CMS PAS EXO-16-036
ATLAS SUSY-2016-31

- Search for heavy, long-lived charged particles using track dE/dx
  - SM particles travel ~c and have consistent dE/dx while values larger for heavy stable particles.

- Time of flight can also be longer!



Benchmarks

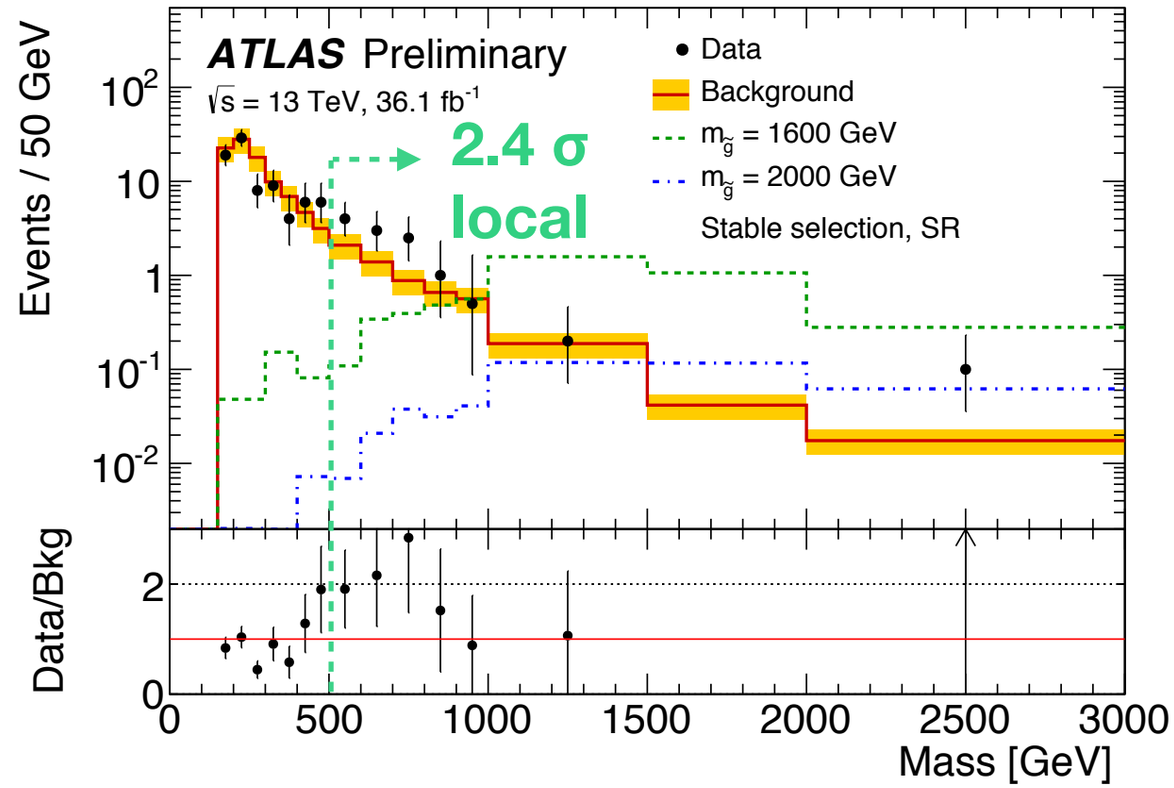
- R-hadrons
- Stops
- Staus
- Lepton-like fermions

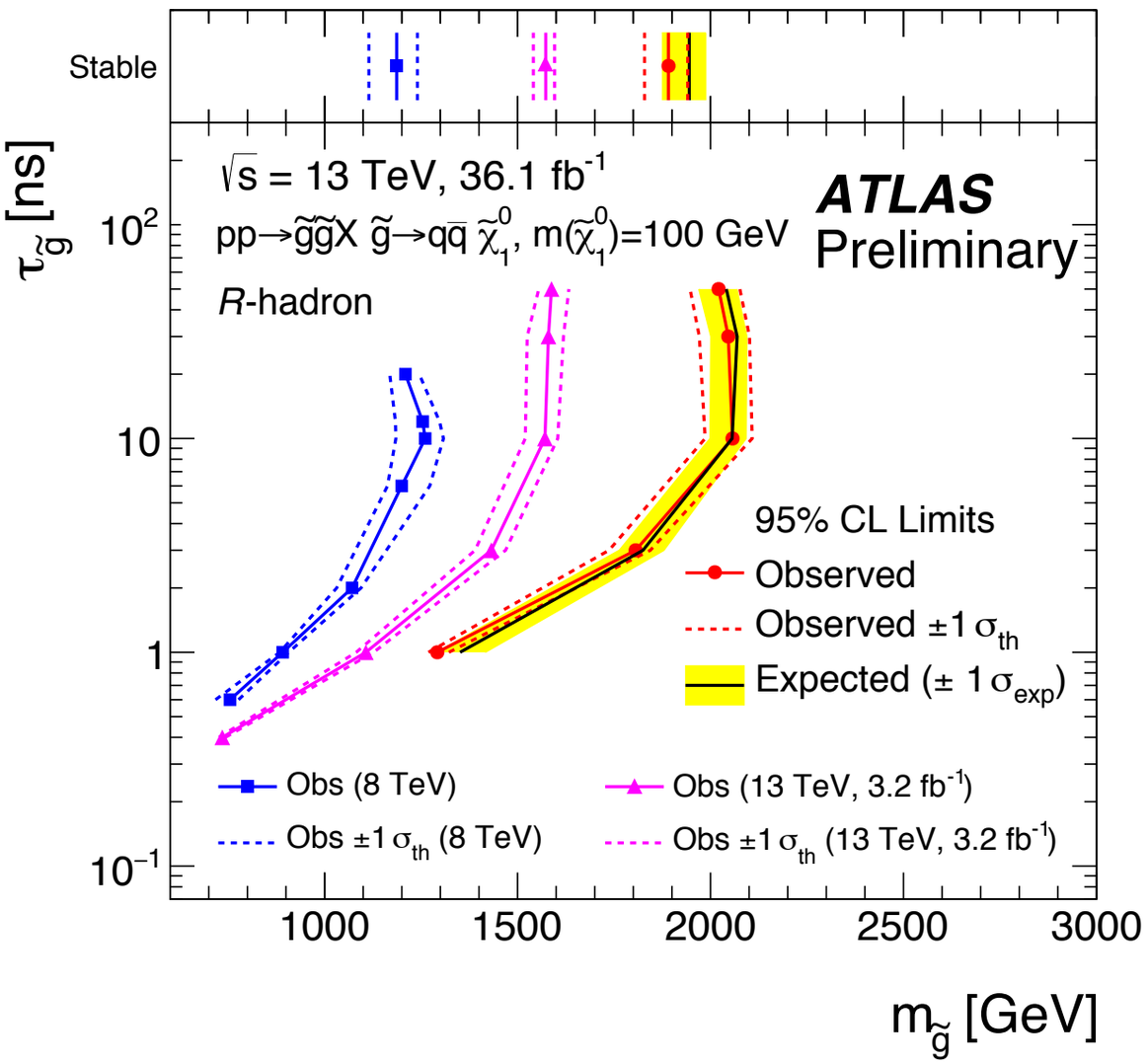
Stable charged particles: ATLAS highlight

- MET trigger; high-mass and momentum isolated track with high dE/dx
- Stable & metastable signal regions optimised for different lifetimes:

metastable	**stable**
τ ~ 1-50 ns	τ long w.r.t. detector
isolation looser	isolation tighter
muon veto	

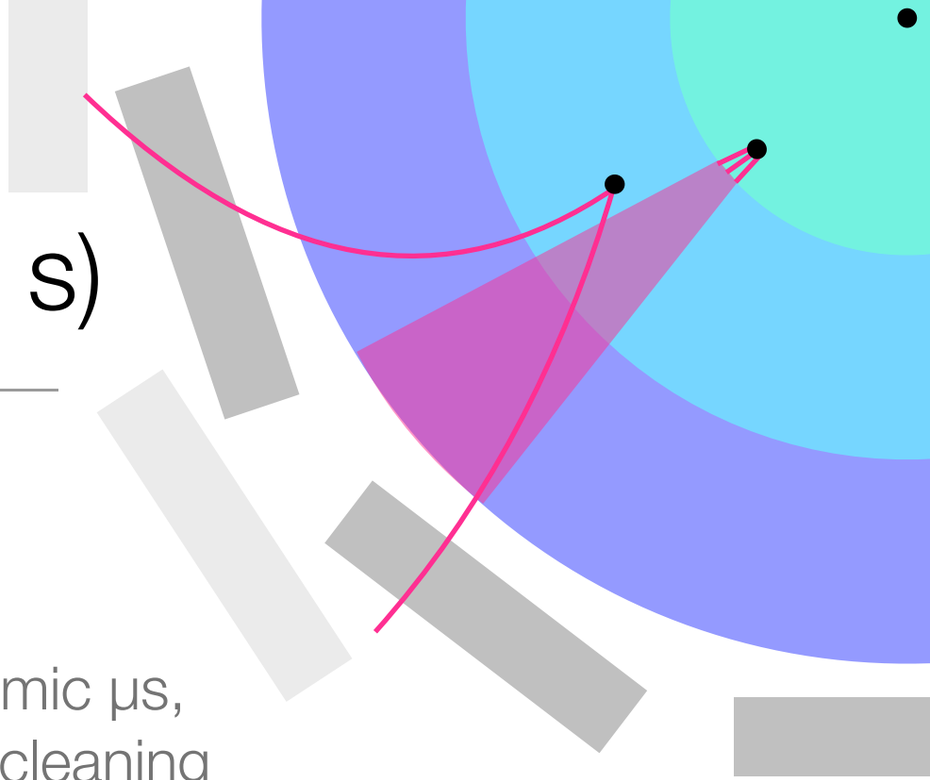
- Background is unlucky tails of charge distribution or mismeasured tracks: overlapping particles, spurious hits, …
  - Estimate from regions with low MET, low dE/dx





Even longer lifetimes …

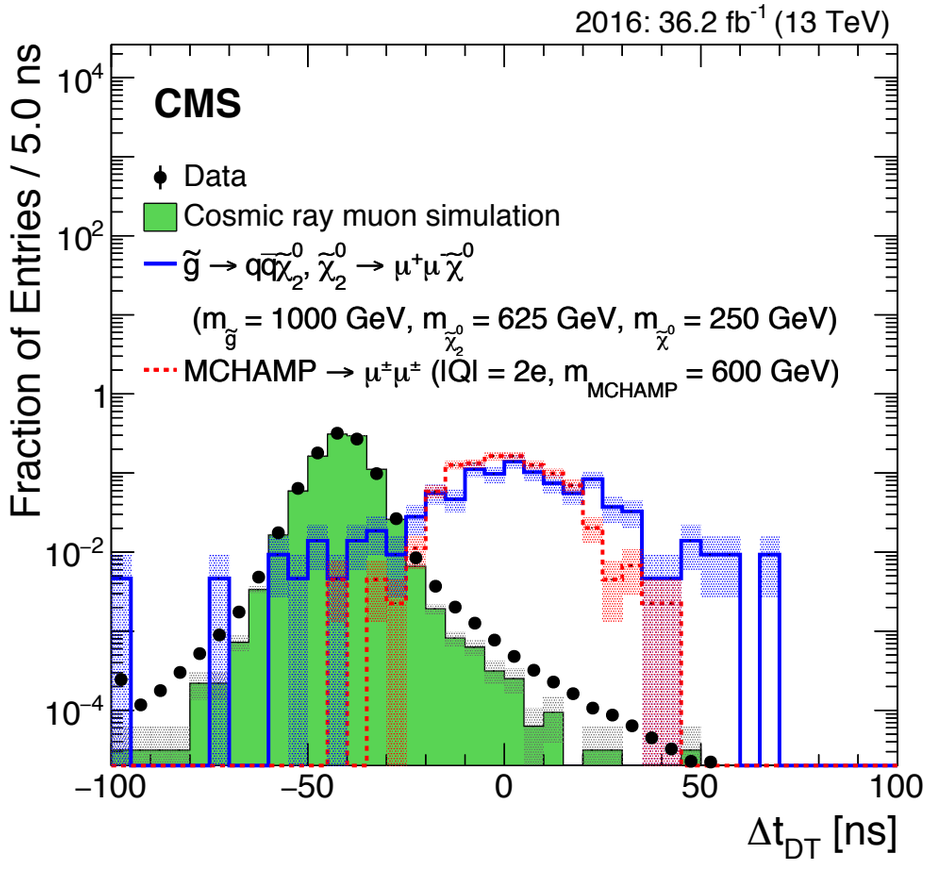
Stopped particles (τ 10 μs - 1000 s)

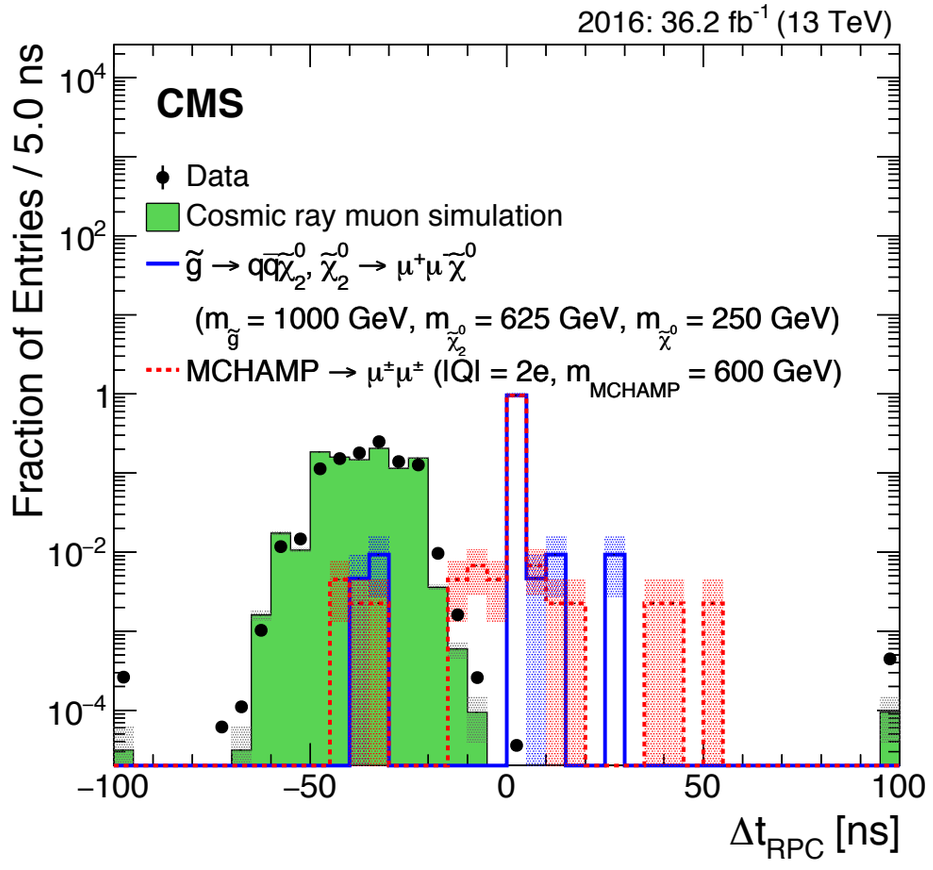


- Search bunch crossings with no pp collisions (no PVs) for stopped particles decaying to jet or muon pair
- Calorimeter search: >= 1 central high p_T jet. Bkgs from cosmic μs, beam halo, HCAL noise. Suppress with MS based vetoes, cleaning
- Muon search: two high-p_T custom MS-only tracks (allow DVs) with outgoing times of flight. Bkg: cosmic muons, suppressed by timing

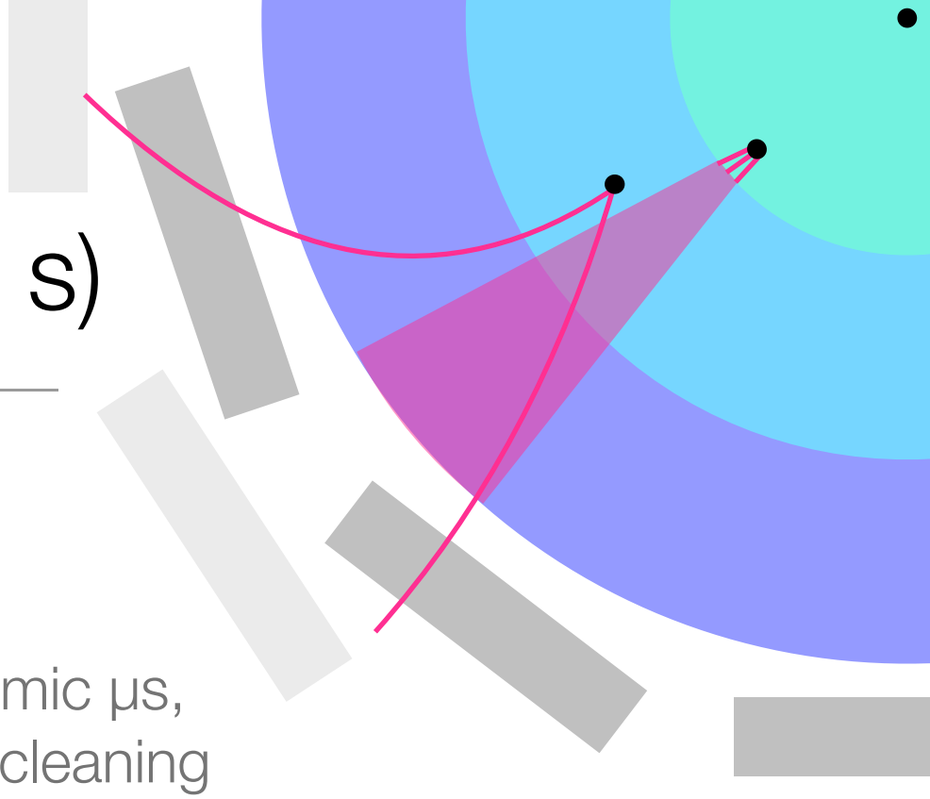
CMS arXiv:1801.00359v2

timing upper μ - timing lower μ using RPCs and drift tubes



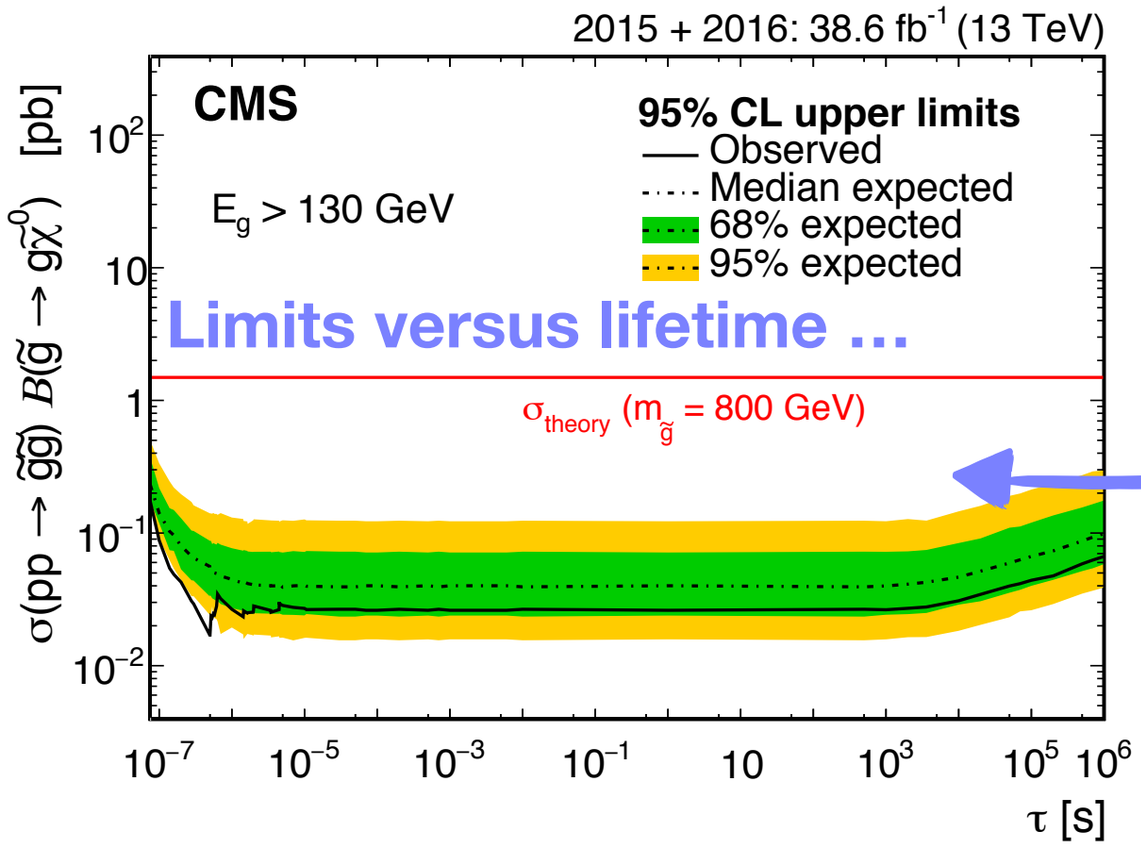


Stopped particles (τ 10 μs - 1000 s)



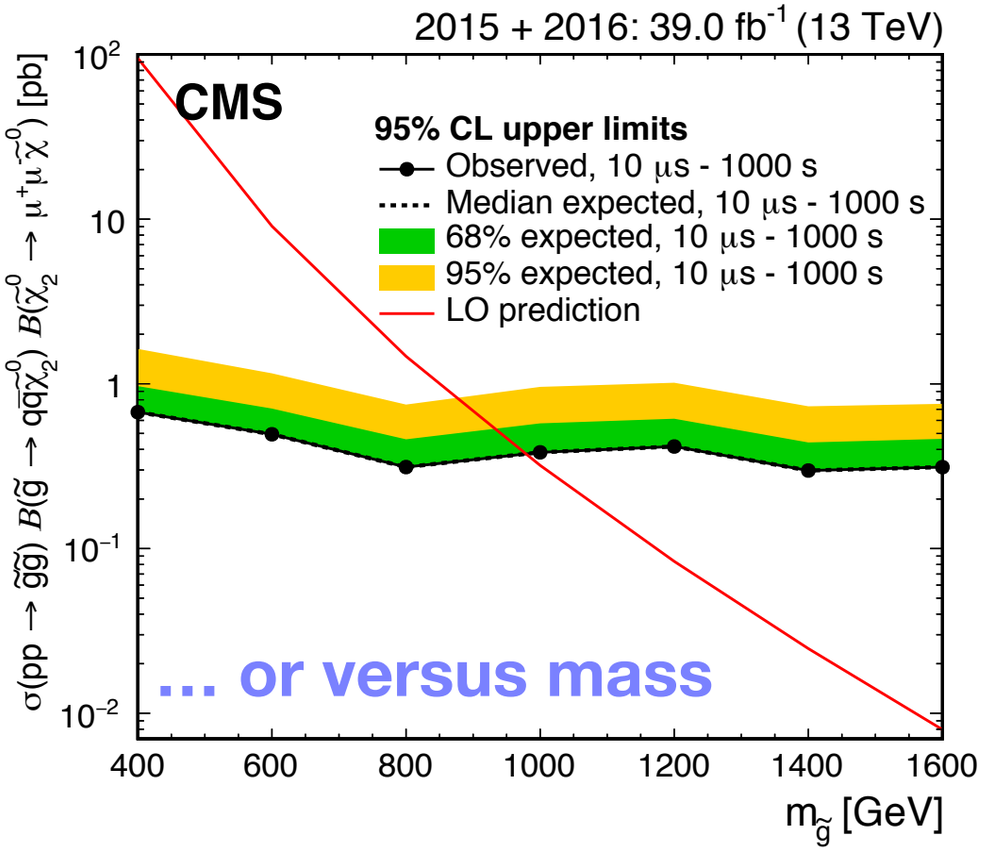
- Search bunch crossings with no pp collisions (no PVs) for stopped particles decaying to jet or muon pair
- Calorimeter search: >= 1 central high p_T jet. Bkgs from cosmic μs, beam halo, HCAL noise. Suppress with MS based vetoes, cleaning
- Muon search: two high-p_T custom MS-only tracks (allow DVs) with outgoing times of flight. Bkg: cosmic muons, suppressed by timing

CMS arXiv:1801.00359v2



Gluino 2-body decay. Calorimeter search,

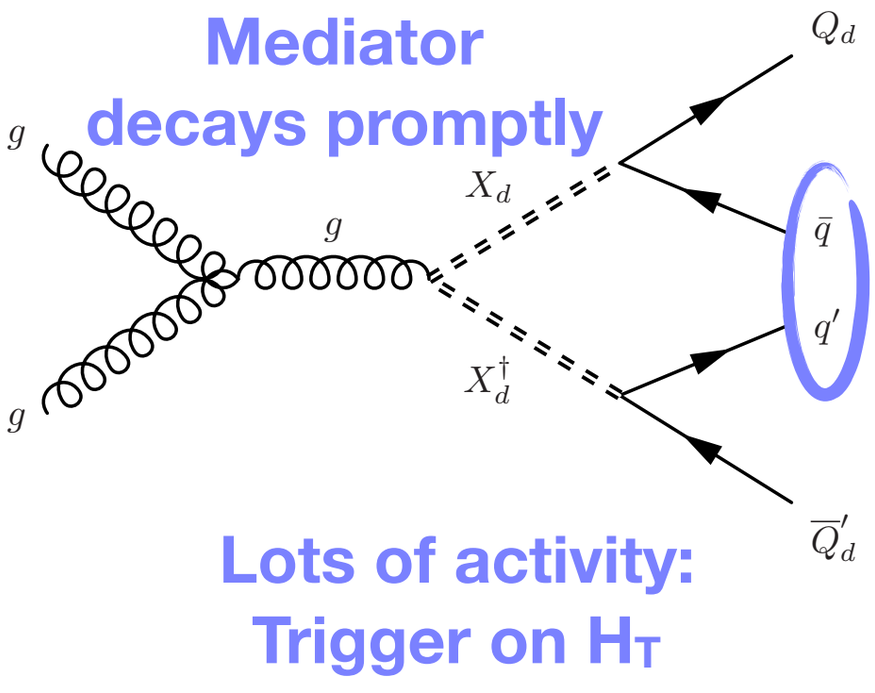
muon search



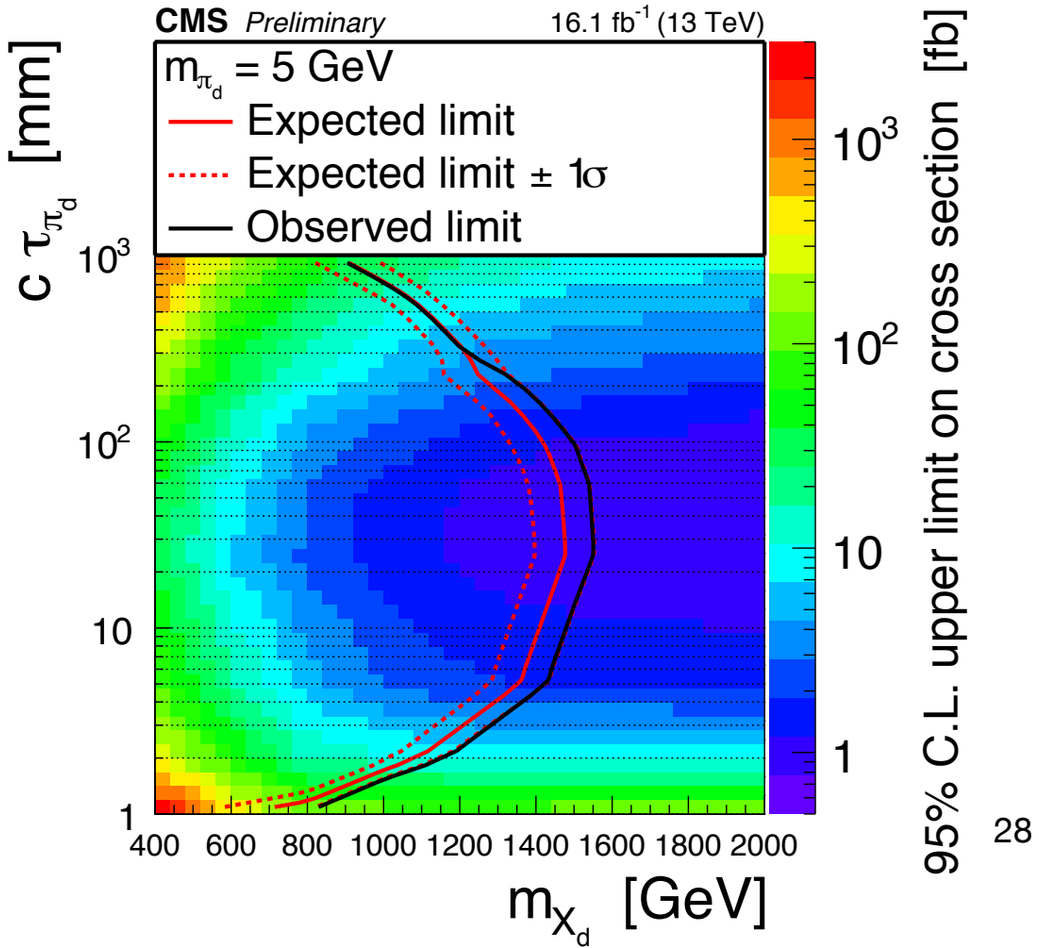
Dark sector

CMS PAS EXO-18-001

Emerging jets



- Benchmark: Dark QCD
- 4 jets; either 2 emerging jets (EJs) or 1 EJ and large MET
- Use displacement of associated tracks and vertices to tag EJs
- Multijets with b-jets main background; use data-driven estimate studied versus n_{track}

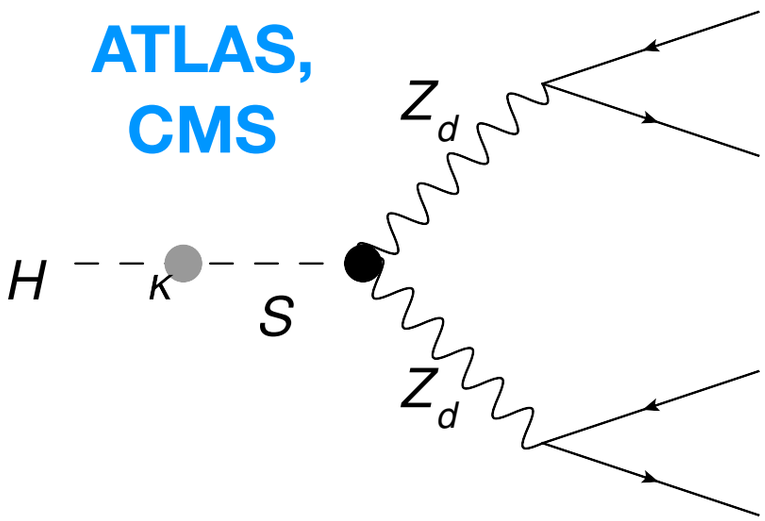


Higgs-portal dark sector

- Assume Higgs is the connection between dark sector & Standard Model. Various benchmark models with 2HDM gaining in popularity lately.
- Strongly motivates Higgs -> invisible searches (see Ruth's talk!)
- Various other interesting signatures too; growing collection of LHC searches!

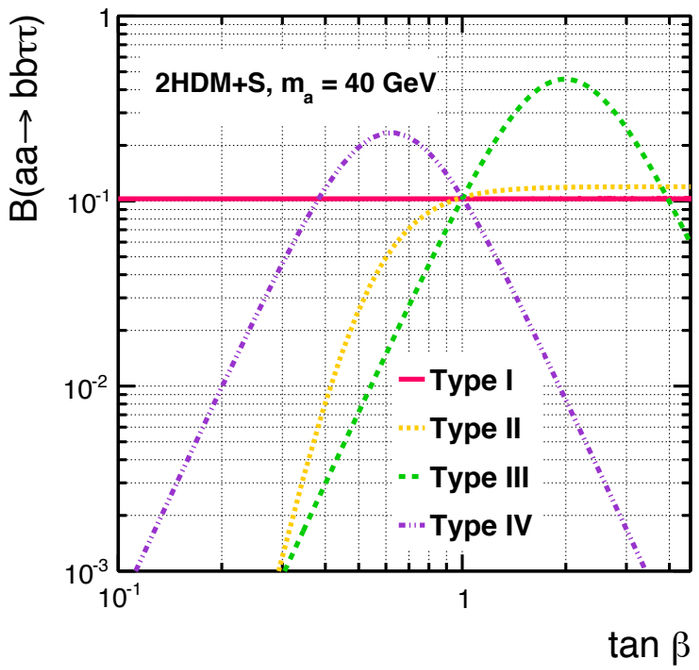
Today covering only a small selection:

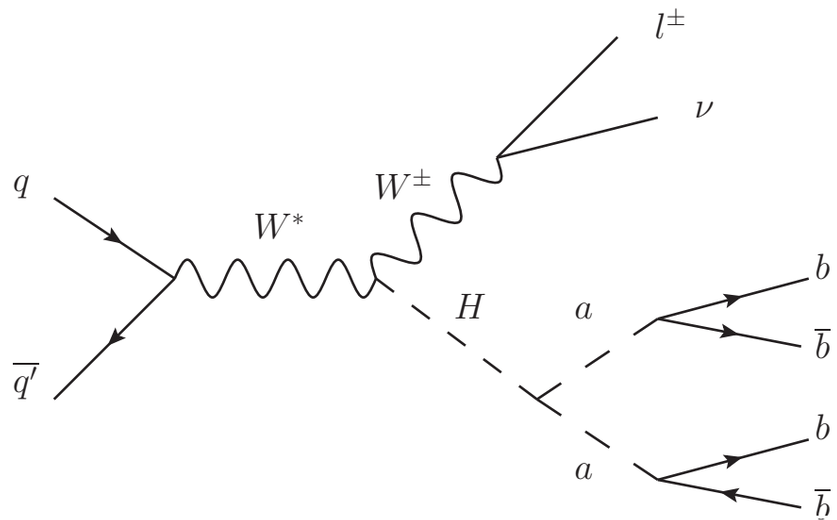
ATLAS, CMS



Higgs to a pair of dark photons to 4μ

CMS
h→aa→bbττ



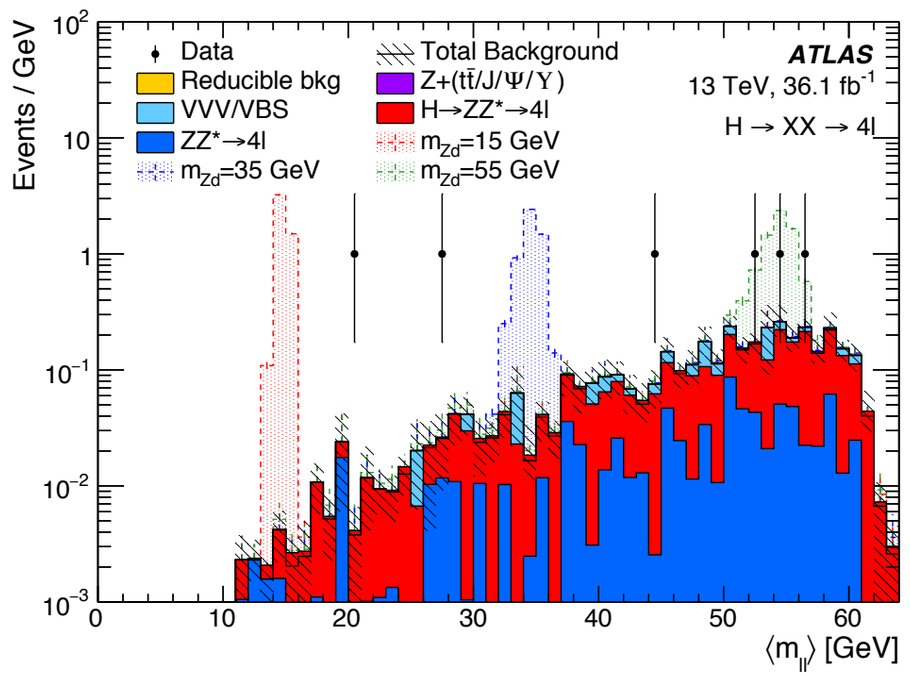


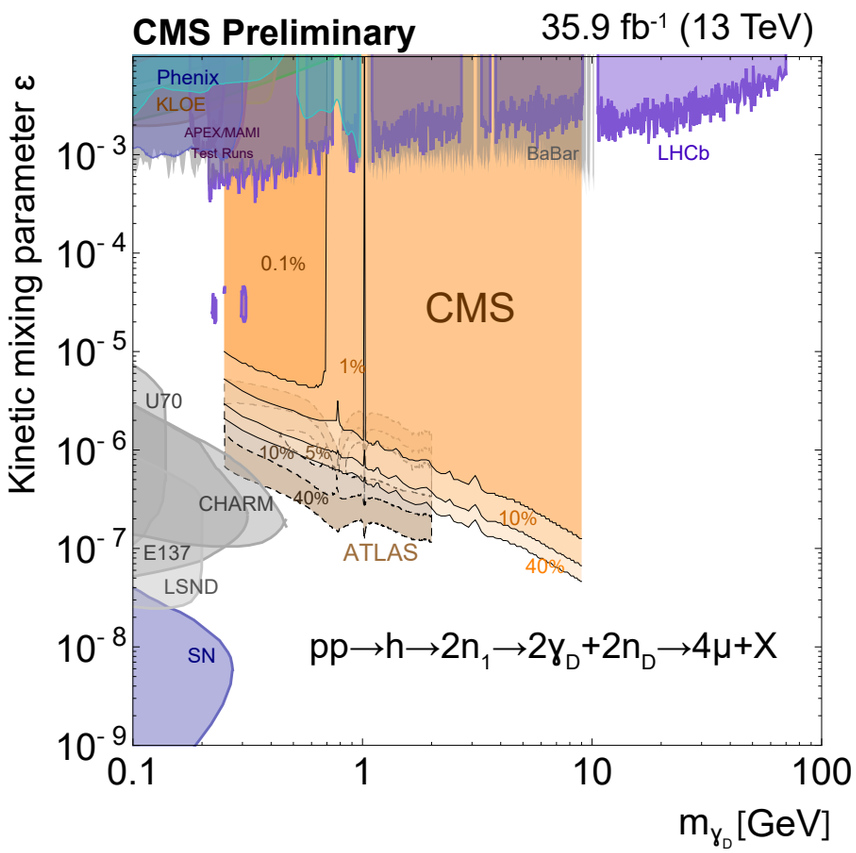
ATLAS
h→aa→bbbb

Higgs to dark photons to 4 muons

CMS PAS HIG-18-003
ATLAS arXiv:1802.03388v2

- Extremely low background from SM at these low masses. Contributions: bb, J/ψ pair production, Z+ J/ψ, electroweak 4μ via off-shell Zs
- No observed excesses; constrain γ_D masses 0.25-8.5 GeV (CMS), 15-55 GeV (ATLAS)



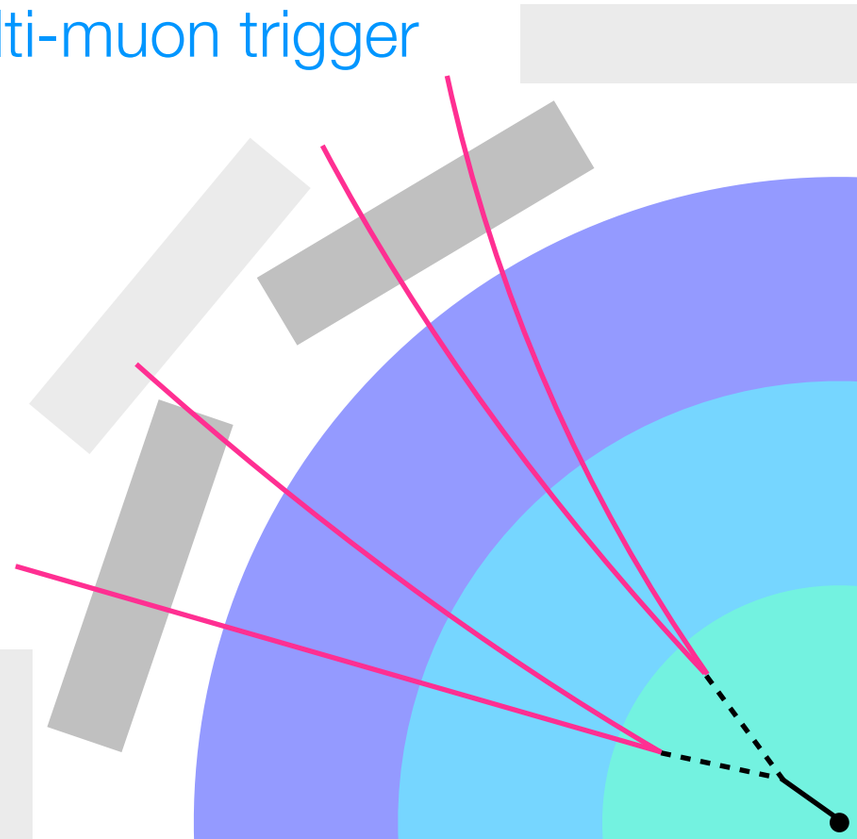


Selection: Multi-muon trigger

Two opposite-sign muon pairs

Common PV even if DV between muon pairs (CMS)

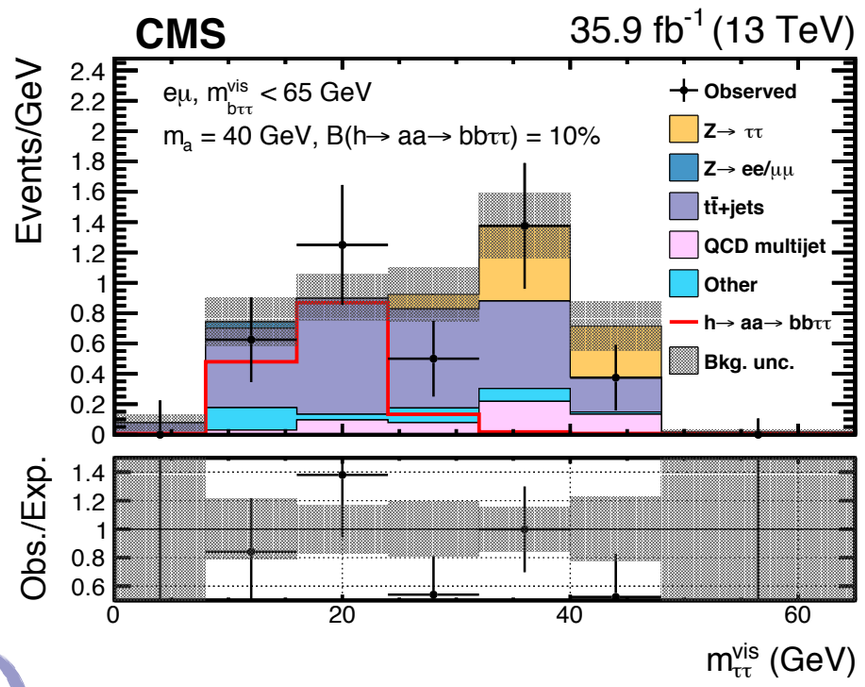
Invariant mass of muon pairs very similar

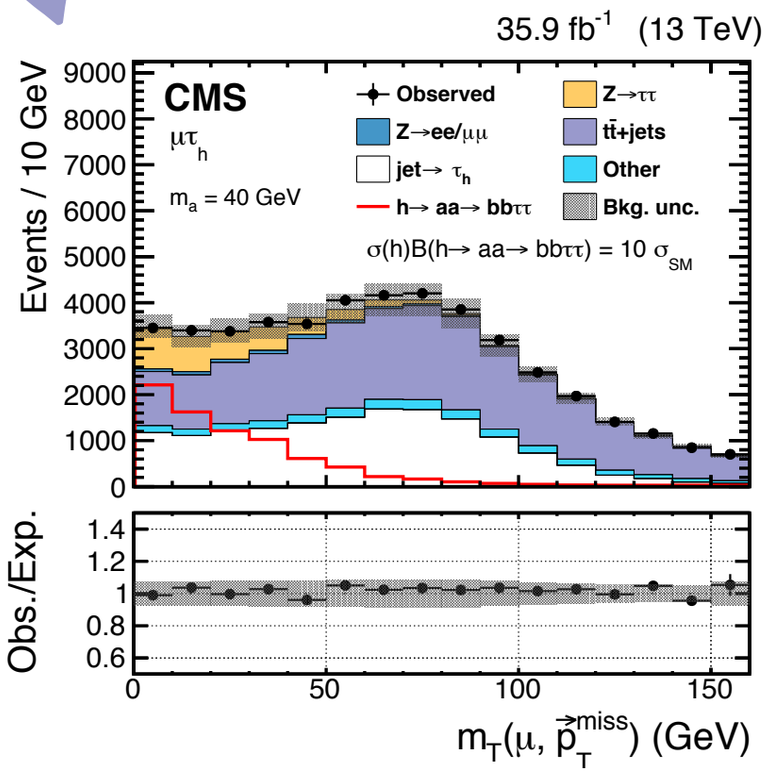


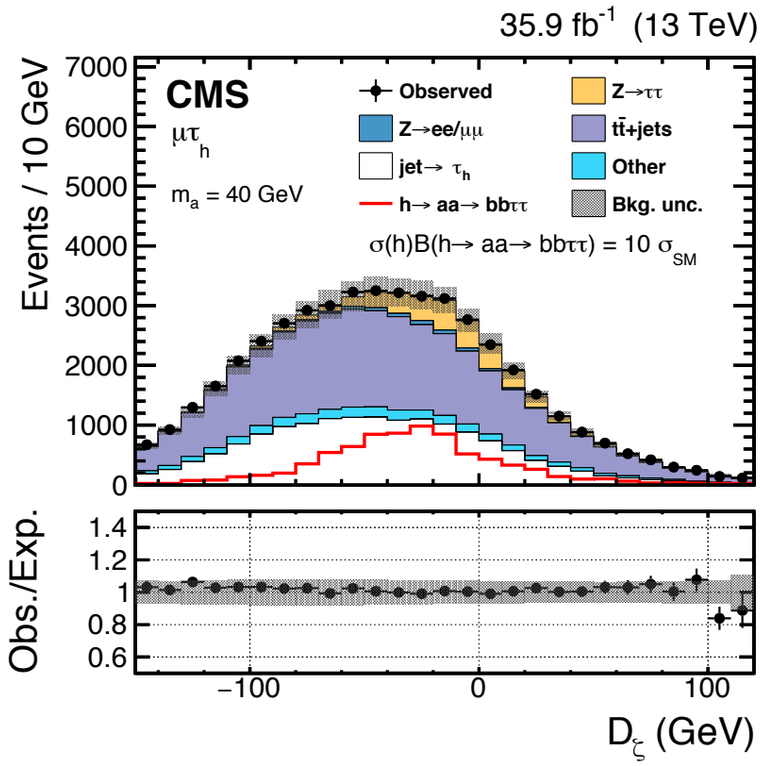
Light pseudoscalars to bbττ

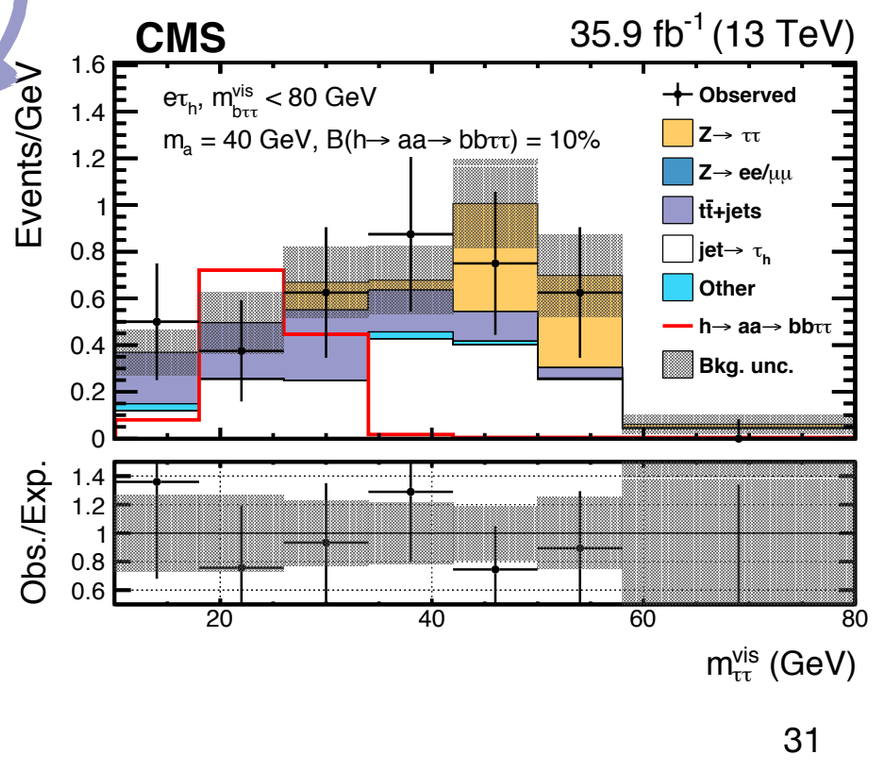
CMS arXiv:1805.10191v1

- Process: h(125)→aa→2τ2b, m_a 15 GeV - 60 GeV. Benchmark 2HDM+S.
- ττ final states: eμ, e+had, or μ+had. Search in $m_{\tau\tau}$.
- Trigger on μ, e, μτ; require >= 1 b-jet plus desired leptons. Low lepton transverse mass suppresses W, ttbar; cut on correlation of MET to ττ system removes Z→ττ and ttbar









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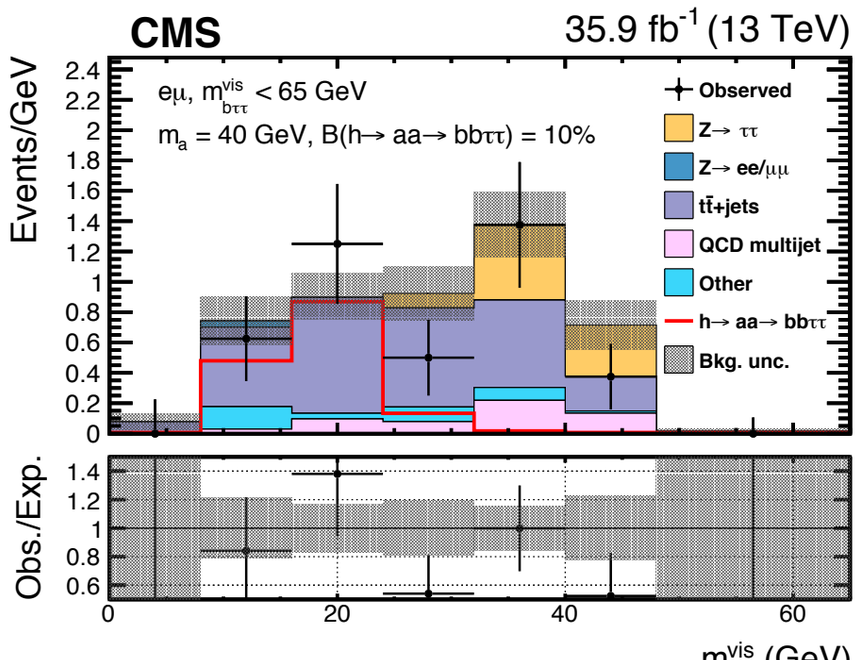
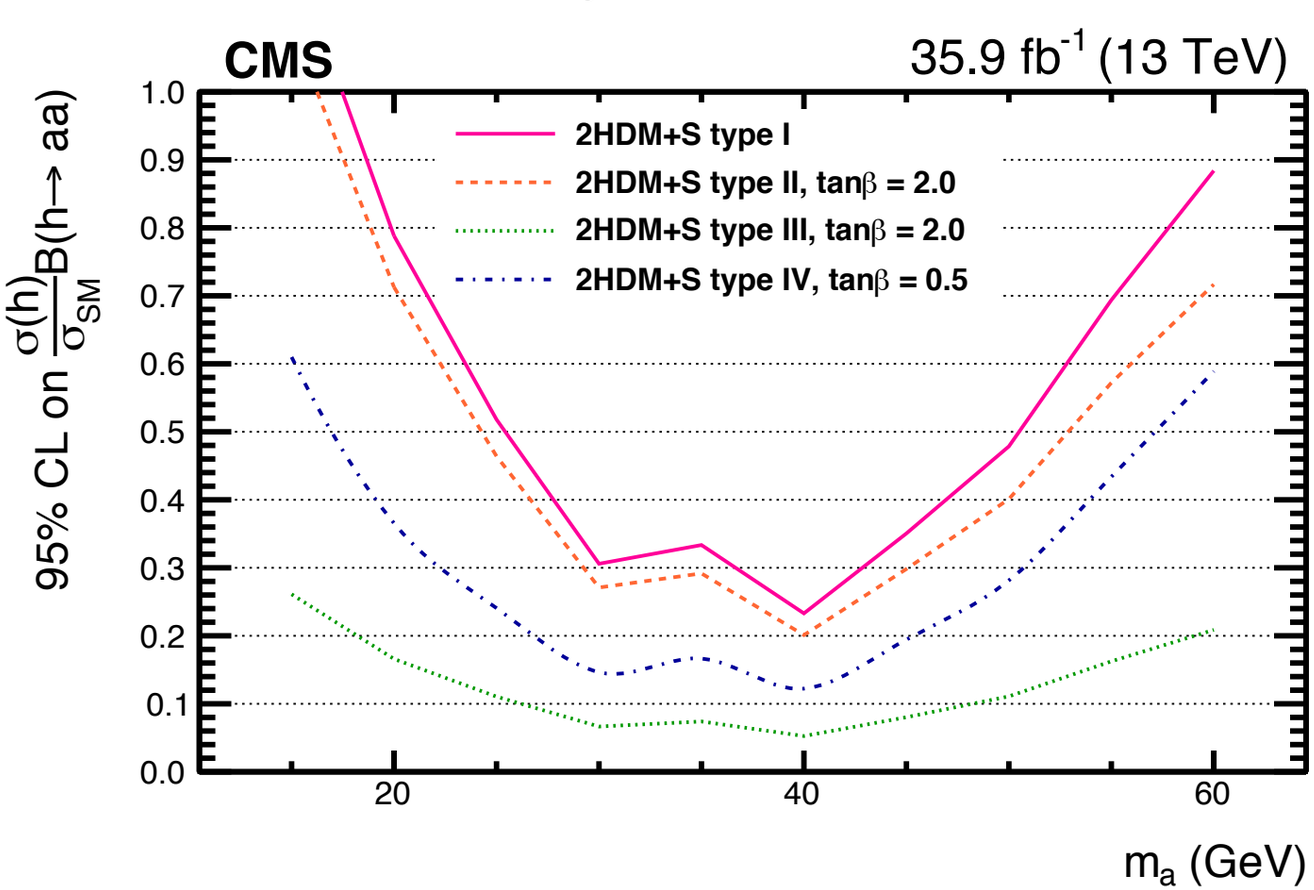
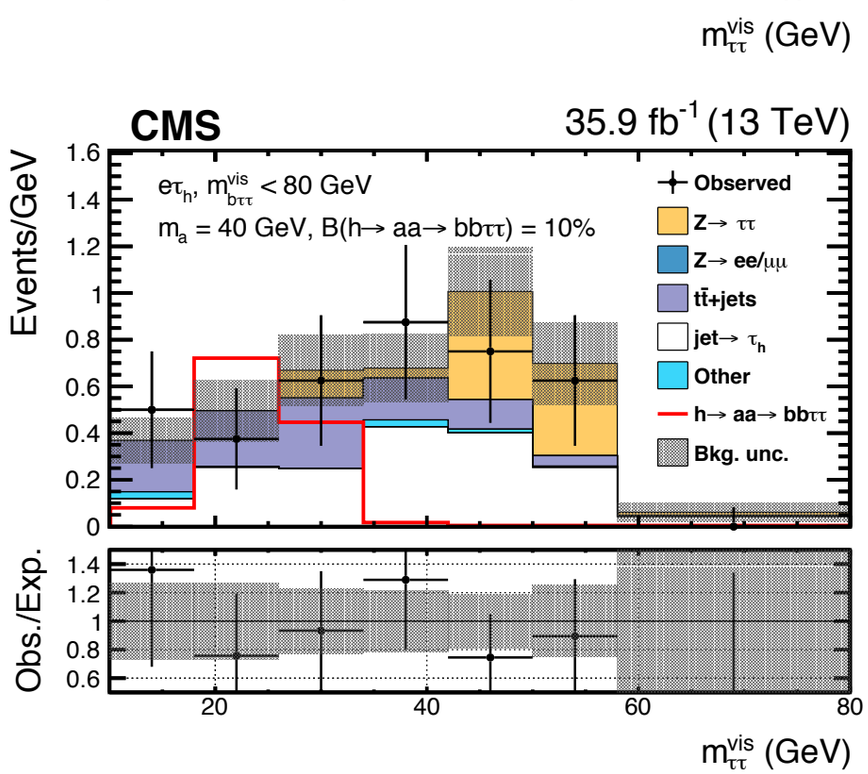






Light pseudoscalars to 4b

ATLAS arXiv:1806.07355v1

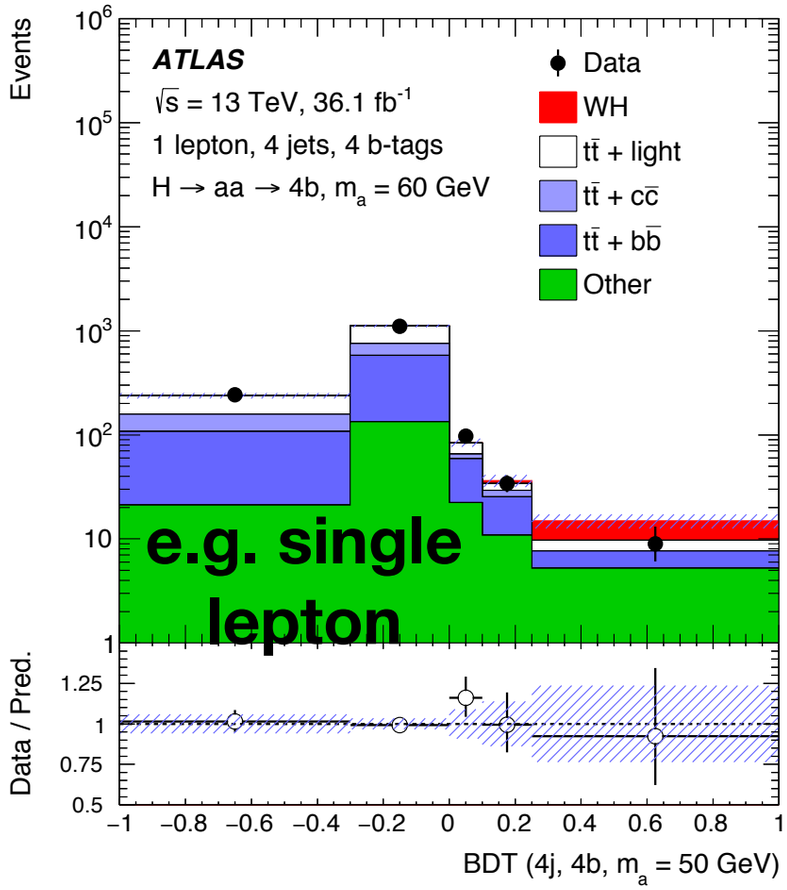
- Process: h(125)→aa→4b with a leptonic W or Z. Trigger on e or μ.
- 2l or 1l+MET with mass near W, Z; >=3 jets; >=2 b-tagged. Dominant bkg ttbar, Z+jets
- Use BDT for discrimination in six signal regions

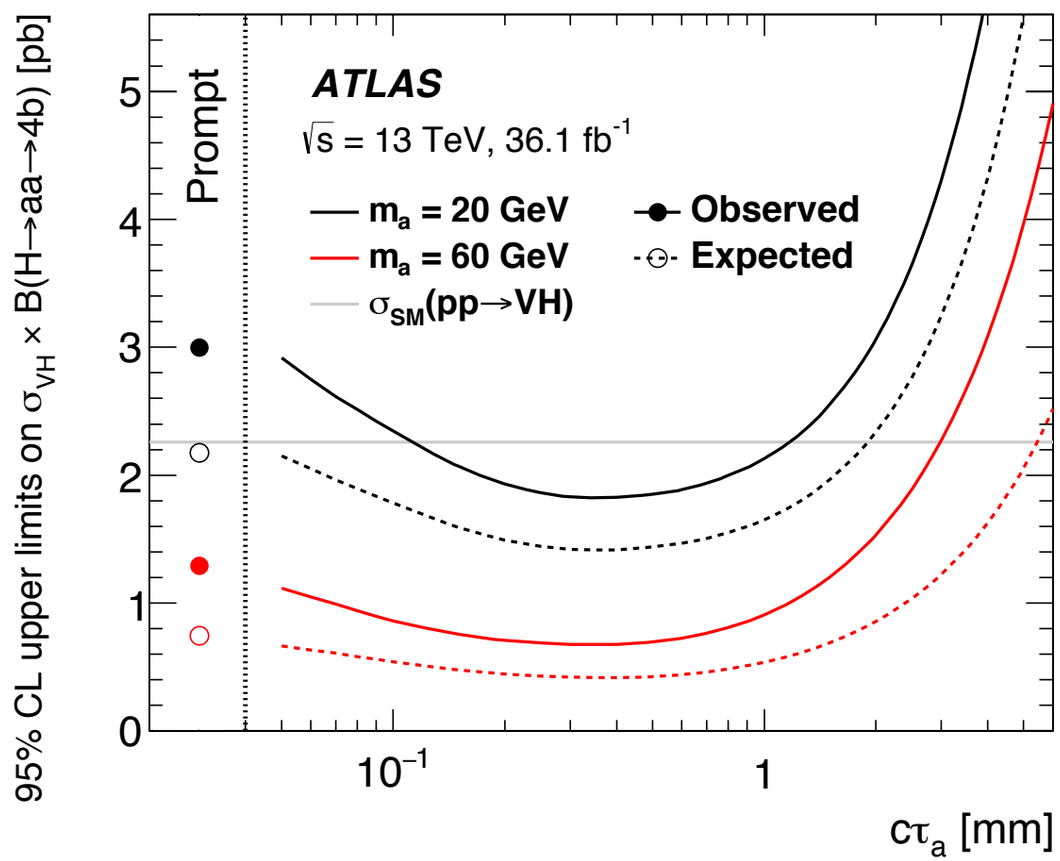
Variable	(1ℓ, 3j, 3b)	(1ℓ, 4j, 3b)	(1ℓ, 4j, 4b)	(2ℓ, 3j, 3b)	(2ℓ, ≥4j, 3b)	(2ℓ, ≥4j, ≥4b)
m_{bbb}	✓	✓		✓	✓	
m_{bbbb}			✓			✓
m_{bb1}			✓			✓
m_{bb2}			✓			✓
Average $\Delta R(b,b)$	✓	✓	✓	✓	✓	✓
H_{T}	✓	✓	✓			
p_{T}^{W}	✓					
m_{bbj}		✓				
m_{T2}	✓	✓	✓			
$\Delta R(\ell,\ell)$				✓	✓	✓
$\Delta R(Z,H)$				✓	✓	
$\cos\theta^{*}$						✓
$E_{\mathrm{T}}^{\mathrm{miss}}$				✓	✓	✓

Light pseudoscalars to 4b

ATLAS arXiv:1806.07355v1

- Process: h(125)→aa→4b with a leptonic W or Z. Trigger on e or μ.
- 2l or 1l+MET with mass near W, Z; >=3 jets; >=2 b-tagged. Dominant bkg ttbar, Z+jets
- Use BDT for discrimination in six signal regions





Conclusion

ATLAS Long-lived Particle Searches* - 95% CL Exclusion

Status: July 2018

ATLAS Preliminary

$\int \mathcal{L}\, dt$ = (3.2 – 36.1) fb^{-1} $\sqrt{s}$ = 8, 13 TeV

	Model	Signature	$\int \mathcal{L}\, dt$ [fb^{-1}]	Lifetime limit		Reference
SUSY	RPV $\chi_1^0 \to ee\nu/e\mu\nu/\mu\mu\nu$	displaced lepton pair	20.3	χ_1^0 lifetime	7-740 mm	$m(\tilde{g})$= 1.3 TeV, $m(\chi_1^0)$= 1.0 TeV	1504.05162
	GGM $\chi_1^0 \to Z\tilde{G}$	displaced vtx + jets	20.3	χ_1^0 lifetime	6-480 mm	$m(\tilde{g})$= 1.1 TeV, $m(\chi_1^0)$= 1.0 TeV	1504.05162
	GGM $\chi_1^0 \to Z\tilde{G}$	displaced dimuon	32.9	χ_1^0 lifetime	0.029-18.0 m	$m(\tilde{g})$= 1.1 TeV, $m(\chi_1^0)$= 1.0 TeV	CERN-EP-2018-173
	GMSB	non-pointing or delayed γ	20.3	χ_1^0 lifetime	0.08-5.4 m	SPS8 with Λ= 200 TeV	1409.5542
	AMSB $pp \to \chi_1^\pm\chi_1^0, \chi_1^+\chi_1^-$	disappearing track	20.3	$\chi_1^\pm$ lifetime	0.22-3.0 m	$m(\chi_1^\pm)$= 450 GeV	1310.3675
	AMSB $pp \to \chi_1^\pm\chi_1^0, \chi_1^+\chi_1^-$	disappearing track	36.1	$\chi_1^\pm$ lifetime	0.057-1.53 m	$m(\chi_1^\pm)$= 450 GeV	1712.02118
	AMSB $pp \to \chi_1^\pm\chi_1^0, \chi_1^+\chi_1^-$	large pixel dE/dx	18.4	$\chi_1^\pm$ lifetime	1.31-9.0 m	$m(\chi_1^\pm)$= 450 GeV	1506.05332
	Stealth SUSY	2 ID/MS vertices	19.5	$\tilde{S}$ lifetime	0.12-90.6 m	$m(\tilde{g})$= 500 GeV	1504.03634
	Split SUSY	large pixel dE/dx	36.1	$\tilde{g}$ lifetime	> 0.9 m	$m(\tilde{g})$= 1.8 TeV, $m(\chi_1^0)$= 100 GeV	CERN-EP-2018-198
	Split SUSY	displaced vtx + E_T^{miss}	32.8	$\tilde{g}$ lifetime	0.03-13.2 m	$m(\tilde{g})$= 1.8 TeV, $m(\chi_1^0)$= 100 GeV	1710.04901
	Split SUSY	0 ℓ, 2 – 6 jets + E_T^{miss}	36.1	$\tilde{g}$ lifetime	0.0-2.1 m	$m(\tilde{g})$= 1.8 TeV, $m(\chi_1^0)$= 100 GeV	ATLAS-CONF-2018-003
Higgs BR = 10%	$H \to s\,s$	2 low-EMF trackless jets	20.3	s lifetime	0.41-7.57 m	$m(s)$= 25 GeV	1501.04020
	$H \to s\,s$	2 ID/MS vertices	19.5	s lifetime	0.31-25.4 m	$m(s)$= 25 GeV	1504.03634
	FRVZ $H \to 2\gamma_d + X$	2 $e-, \mu-$jets	20.3	γ_d lifetime	0-3 mm	$m(\gamma_d)$= 400 MeV	1511.05542
	FRVZ $H \to 2\gamma_d + X$	2 $e-, \mu-, \pi-$jets	3.4	γ_d lifetime	0.022-1.113 m	$m(\gamma_d)$= 400 MeV	ATLAS-CONF-2016-042
	FRVZ $H \to 4\gamma_d + X$	2 $e-, \mu-, \pi-$jets	3.4	γ_d lifetime	0.038-1.63 m	$m(\gamma_d)$= 400 MeV	ATLAS-CONF-2016-042
	$H \to Z_d Z_d$	displaced dimuon	32.9	Z_d lifetime	0.009-24.0 m	$m(Z_d)$= 40 GeV	CERN-EP-2018-173
Scalar	VH with $H \to ss \to bbbb$	1 – 2ℓ + multi-b-jets	36.1	s lifetime	0-3 mm	$\mathcal{B}(H \to ss)$= 1, $m(s)$= 60 GeV	1806.07355
	Φ(300 GeV) $\to s\,s$	2 low-EMF trackless jets	20.3	s lifetime	0.29-7.9 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1501.04020
	Φ(300 GeV) $\to s\,s$	2 ID/MS vertices	19.5	s lifetime	0.19-31.9 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1504.03634
	Φ(600 GeV) $\to s\,s$	2 low-EMF trackless jets	3.2	s lifetime	0.09-2.7 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	ATLAS-CONF-2016-103
	Φ(900 GeV) $\to s\,s$	2 low-EMF trackless jets	20.3	s lifetime	0.15-4.1 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1501.04020
	Φ(900 GeV) $\to s\,s$	2 ID/MS vertices	19.5	s lifetime	0.11-18.3 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1504.03634
	Φ(1 TeV) $\to s\,s$	2 low-EMF trackless jets	3.2	s lifetime	0.78-16.0 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 400 GeV	ATLAS-CONF-2016-103
Other	HV Z'(1 TeV) $\to q_v q_v$	2 ID/MS vertices	20.3	s lifetime	0.1-4.9 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1504.03634
	HV Z'(2 TeV) $\to q_v q_v$	2 ID/MS vertices	20.3	s lifetime	0.1-10.1 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1504.03634

0.01 0.1 1 10 100

$c\tau$ [m]

$\sqrt{s}$ = 8 TeV $\sqrt{s}$ = 13 TeV

**Only a selection of the available lifetime limits on new states is shown.*

($\gamma\beta = 1$)

ATLAS Long-lived Particle Searches* - 95% CL Exclusion

Status: July 2018

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	GMSB	non-pointing or delayed γ	20.3	χ_1^0 lifetime	SPS8 with Λ= 200 TeV	1409.5542
	AMSB $pp \to \chi_1^\pm\chi_1^0, \chi_1^+\chi_1^-$	disappearing track	20.3	$\chi_1^\pm$ lifetime	$m(\chi_1^\pm)$= 450 GeV	1310.3675
	AMSB $pp \to \chi_1^\pm\chi_1^0, \chi_1^+\chi_1^-$	disappearing track	36.1	$\chi_1^\pm$ lifetime	$m(\chi_1^\pm)$= 450 GeV	1712.02118
	AMSB $pp \to \chi_1^\pm\chi_1^0, \chi_1^+\chi_1^-$	large pixel dE/dx	18.4	$\chi_1^\pm$ lifetime	$m(\chi_1^\pm)$= 450 GeV	1506.05332
	Stealth SUSY	2 ID/MS vertices	9.5	S lifetime	$m(\tilde{g})$= 500 GeV	1504.03634
	Split SUSY	large pixel dE/dx	36.1	g lifetime	$m(\tilde{g})$= 1.8 TeV, $m(\chi_1^0)$= 100 GeV	CERN-EP-2018-198
	Split SUSY	displaced vtx + E_T^{miss}	32.8	$\tilde{g}$ lifetime	$m(\tilde{g})$= 1.8 TeV, $m(\chi_1^0)$= 100 GeV	1710.04901
	Split SUSY	0 ℓ, 2 – 6 jets + E_T^{miss}	36.1	$\tilde{g}$ lifetime	$m(\tilde{g})$= 1.8 TeV, $m(\chi_1^0)$= 100 GeV	ATLAS-CONF-2018-003
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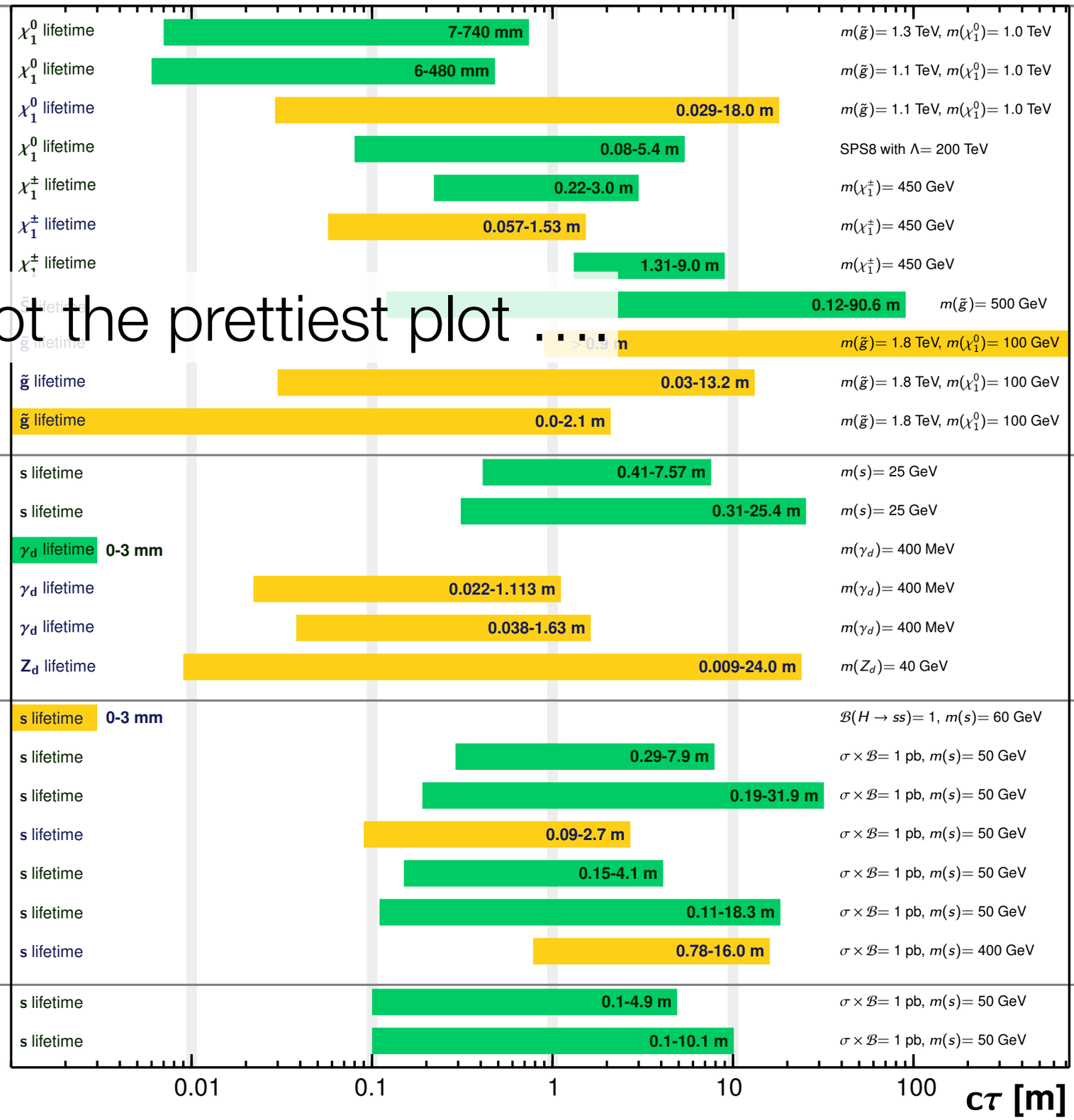
	HV Z'(2 TeV) $\to q_v q_v$	2 ID/MS vertices	20.3	s lifetime	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1504.03634



Not the prettiest plot ....

$\sqrt{s}$ = 8 TeV $\sqrt{s}$ = 13 TeV

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	AMSB $pp \to \chi_1^\pm\chi_1^0, \chi_1^+\chi_1^-$	disappearing track	20.3	$\chi_1^\pm$ lifetime	0.22-3.0 m	$m(\chi_1^\pm)$= 450 GeV	1310.3675
	AMSB $pp \to \chi_1^\pm\chi_1^0, \chi_1^+\chi_1^-$	disappearing track	36.1	$\chi_1^\pm$ lifetime	0.057-1.53 m	$m(\chi_1^\pm)$= 450 GeV	1712.02118
	AMSB $pp \to \chi_1^\pm\chi_1^0, \chi_1^+\chi_1^-$	large pixel dE/dx	18.4	$\chi_1^\pm$ lifetime	1.31-9.0 m	$m(\chi_1^\pm)$= 450 GeV	1506.05332
	Stealth SUSY	2 ID/MS vertices	32.8	$\tilde{g}$ lifetime	0.12-90.6 m	$m(\tilde{g})$= 500 GeV	1504.03634
	Split SUSY	large pixel dE/dx	36.1	$\tilde{g}$ lifetime	> 0.3 m	$m(\tilde{g})$= 1.8 TeV, $m(\chi_1^0)$= 100 GeV	CERN-EP-2018-198
	Split SUSY	displaced vtx + E_T^{miss}	32.8	$\tilde{g}$ lifetime	0.03-13.2 m	$m(\tilde{g})$= 1.8 TeV, $m(\chi_1^0)$= 100 GeV	1710.04901
	Split SUSY	0 ℓ, 2 – 6 jets + E_T^{miss}	36.1	$\tilde{g}$ lifetime	0.0-2.1 m	$m(\tilde{g})$= 1.8 TeV, $m(\chi_1^0)$= 100 GeV	ATLAS-CONF-2018-003
Higgs BR = 10%	$H \to ss$	2 low-EMF trackless jets	20.3	s lifetime	0.41-7.57 m	$m(s)$= 25 GeV	1501.04020
	$H \to ss$	2 ID/MS vertices	19.5	s lifetime	0.31-25.4 m	$m(s)$= 25 GeV	1504.03634
	FRVZ $H \to 2\gamma_d + X$	2 $e-, \mu-$jets	20.3	γ_d lifetime	0-3 mm	$m(\gamma_d)$= 400 MeV	1511.05542
	FRVZ $H \to 2\gamma_d + X$	2 $e-, \mu-, \pi-$jets	3.4	γ_d lifetime	0.022-1.113 m	$m(\gamma_d)$= 400 MeV	ATLAS-CONF-2016-042
	FRVZ $H \to 4\gamma_d + X$	2 $e-, \mu-, \pi-$jets	3.4	γ_d lifetime	0.038-1.63 m	$m(\gamma_d)$= 400 MeV	ATLAS-CONF-2016-042
	$H \to Z_d Z_d$	displaced dimuon	32.9	Z_d lifetime	0.009-24.0 m	$m(Z_d)$= 40 GeV	CERN-EP-2018-173
Scalar	VH with $H \to ss \to bbbb$	1 – 2ℓ + multi-b-jets	36.1	s lifetime	0-3 mm	$\mathcal{B}(H \to ss)$= 1, $m(s)$= 60 GeV	1806.07355
	Φ(300 GeV) $\to ss$	2 low-EMF trackless jets	20.3	s lifetime	0.07-7.3 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1501.04020
	Φ(300 GeV) $\to ss$	2 ID/MS vertices	19.5	s lifetime	0.15-19.5 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1504.03634
	Φ(600 GeV) $\to ss$	2 low-EMF trackless jets	3.2	s lifetime	0.09-2.7 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	ATLAS-CONF-2016-103
	Φ(900 GeV) $\to ss$	2 low-EMF trackless jets	20.3	s lifetime	0.15-1.9 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1501.04020
	Φ(900 GeV) $\to ss$	2 ID/MS vertices	19.5	s lifetime	0.11-18.3 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1504.03634
	Φ(1 TeV) $\to ss$	2 low-EMF trackless jets	3.2	s lifetime	0.78-16.0 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 400 GeV	ATLAS-CONF-2016-103
Other	HV Z'(1 TeV) $\to q_v q_v$	2 ID/MS vertices	20.3	s lifetime	0.1-4.9 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1504.03634
	HV Z'(2 TeV) $\to q_v q_v$	2 ID/MS vertices	20.3	s lifetime	0.1-10.1 m	$\sigma \times \mathcal{B}$= 1 pb, $m(s)$= 50 GeV	1504.03634

Not the prettiest plot ....

But shows the scope of the existing search program!

0.01 0.1 1 10 100

$c\tau$ [m]

$\sqrt{s}$ = 8 TeV $\sqrt{s}$ = 13 TeV

**Only a selection of the available lifetime limits on new states is shown.*

($\gamma\beta = 1$)

Conclusion

- Lots of exciting, hot-off-the-press searches from ATLAS & CMS
  - Highlighted several very recent results today, including dark photons to 4μ, ATLAS stable charged particles, CMS emerging jets
- Long-lived particle searches gaining popularity and continuing to attract new efforts and attention
  - As more traditional searches become stats limited and begin to slow down, lots left to do in this comparatively unexplored frontier
  - Fun experimental challenges for everyone!

Backup