Considerations for displaced Higgs searches at CMS

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Executive summary

CMS has a broad and ever-expanding program of searches
for long-lived particle signatures

Other than muon-jet search, no real sensitivity to h(125) decays

Accessing long-lived Higgs decays is challenging due to low final-state energy

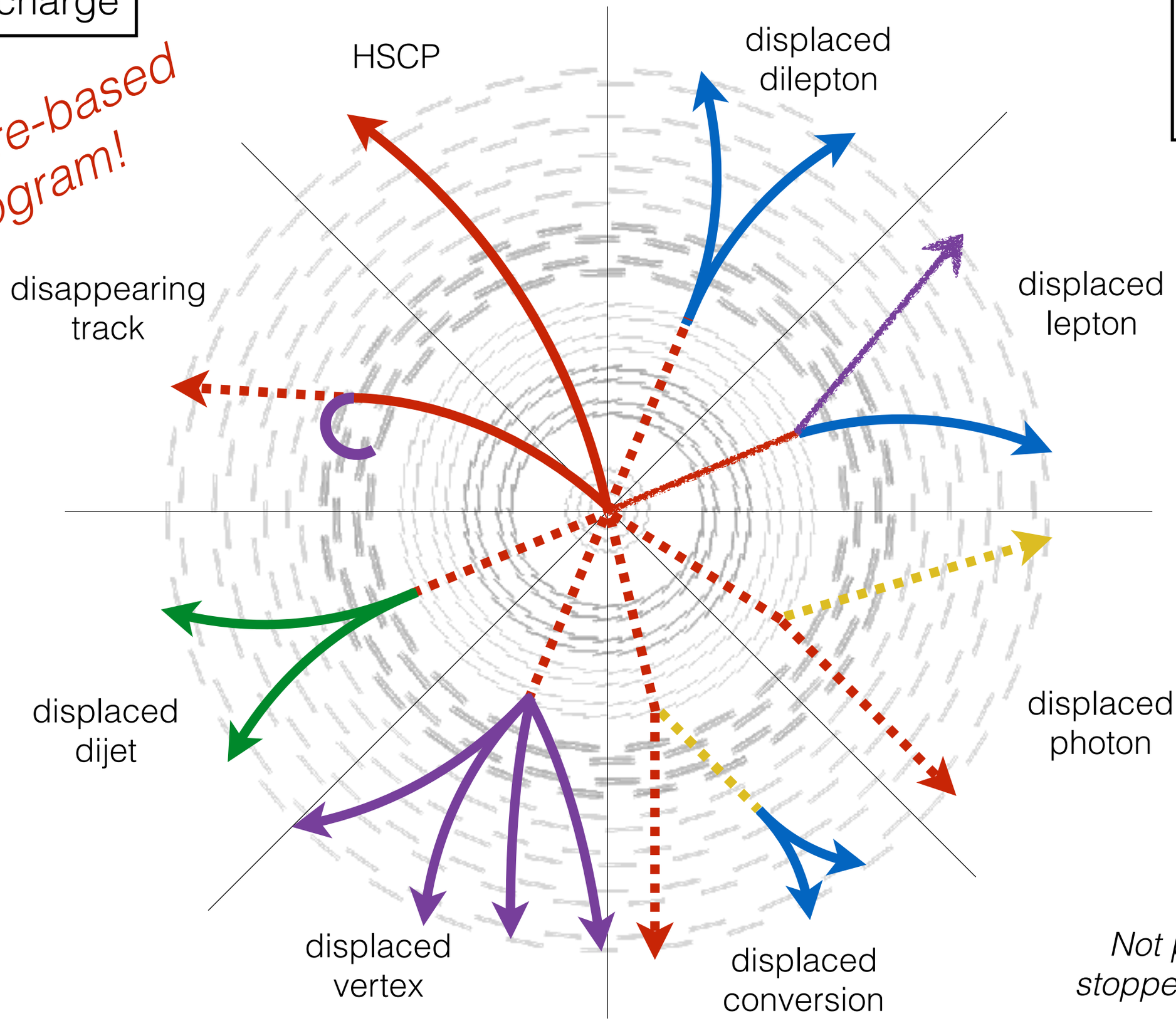
- but we like challenges
- will require dedicated Higgs-focused searches

CMS Public Results

neutral
charged
any charge

BSM
lepton
quark
photon
anything

signature-based program!



Not pictured: stopped particles

Search strategy driven by targeted lifetime

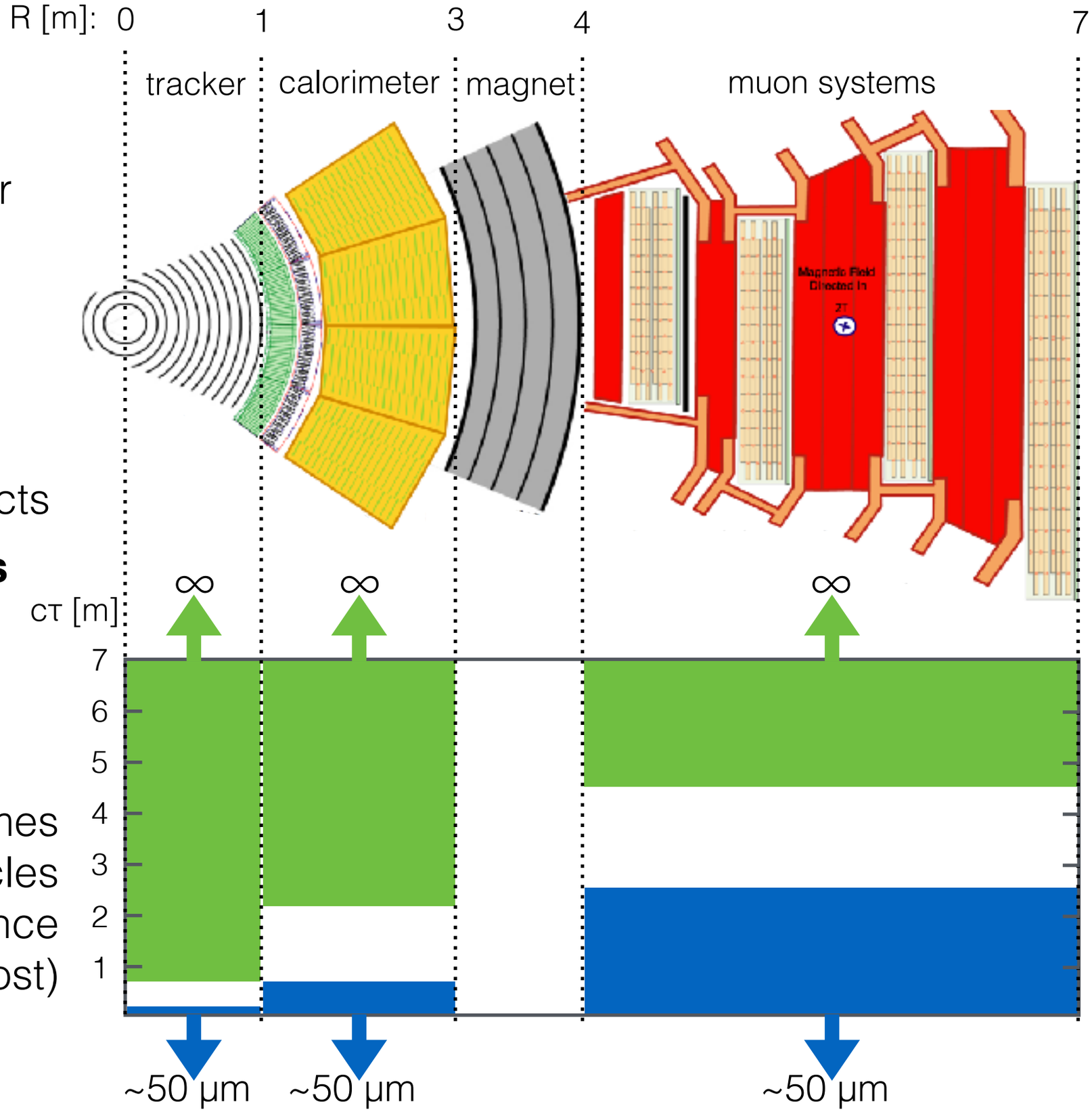
Direct searches

- observe BSM particle passing through detector
- better for **long lifetimes**
- good for **charged LLPs**

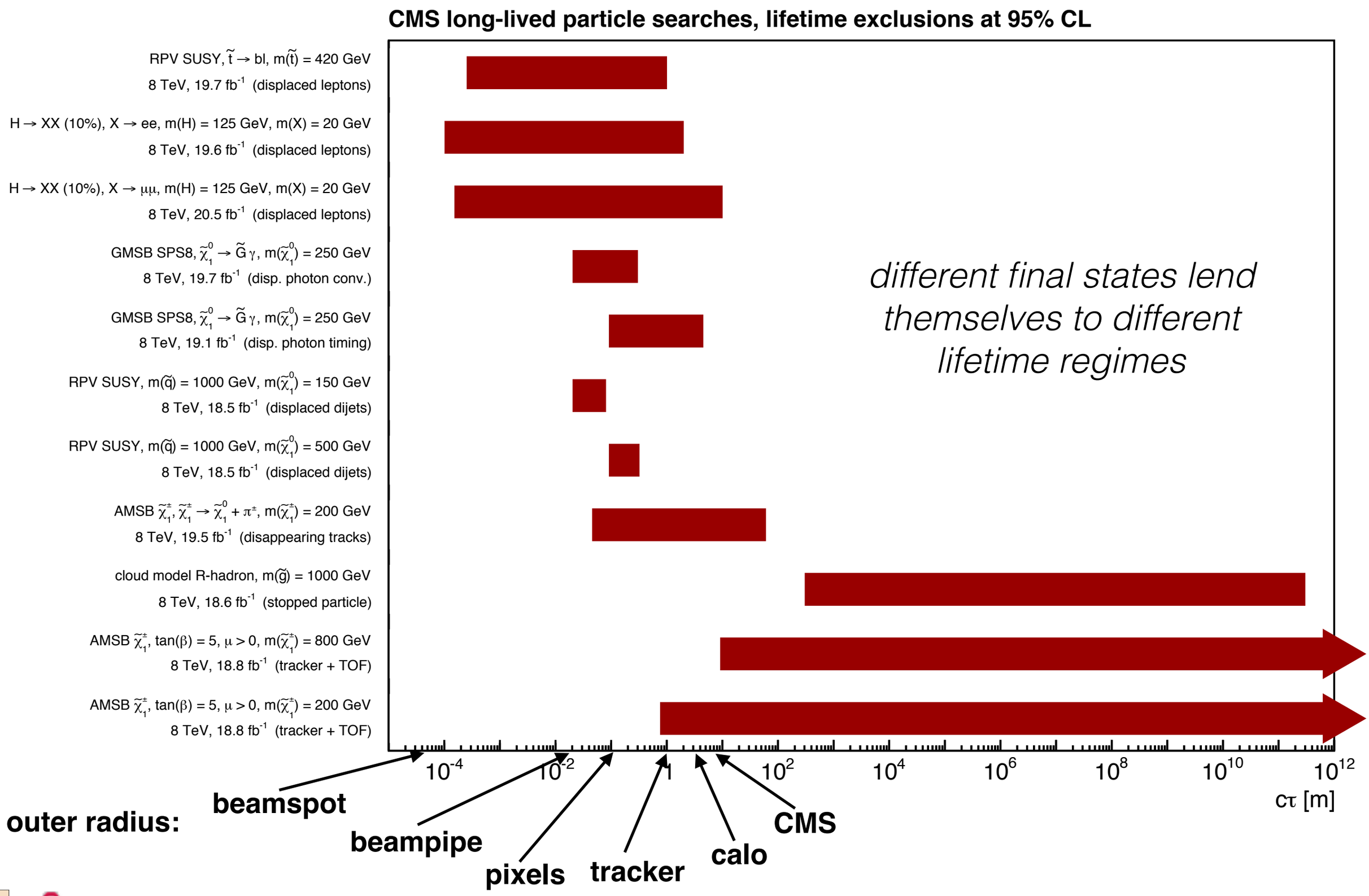
Indirect searches

- detect LLP decay products
- better for **short lifetimes**
- good for **neural LLPs**

Shaded area: range of lifetimes for which half of the particles are within the acceptance (ignoring boost)



Run 1 Legacy in lifetime space



different final states lend themselves to different lifetime regimes

Many public 7/8 TeV searches (and two at 13 TeV)

	Final state targeted	7 TeV	8 TeV	13 TeV
1	displaced e-e/μ-μ pairs	1211.2472	1411.6977	
2	displaced μ-μ pairs in muon system		2005761	
3	displaced e-μ events		1409.4789	2205146
4	displaced μ-μ pairs (dark photons)		1506.00424	
5	displaced photons using ECAL timing	1212.1838	2063495	
6	displaced photons using conversions	1207.0627	2019862	
7	displaced vertices		2160356	
8	displaced dijets		1411.6530	
9	short, highly ionizing disappearing tracks		thesis	
10	disappearing tracks		1411.6006	
11	kinked tracks		thesis	
12	fractionally charged particles	1210.2311	1305.0491	
13	heavy stable charged particles (HSCP)	1205.0272	1305.0491	2114818 (2015) 2205281 (2016)
14	stopped particles	1207.0106	1501.05603	
15	out of time muons		thesis	

Other than HSCP, analyses are relatively "immature"

Still working through "lowest-hanging fruit"

Small analysis groups - teams can evaporate easily

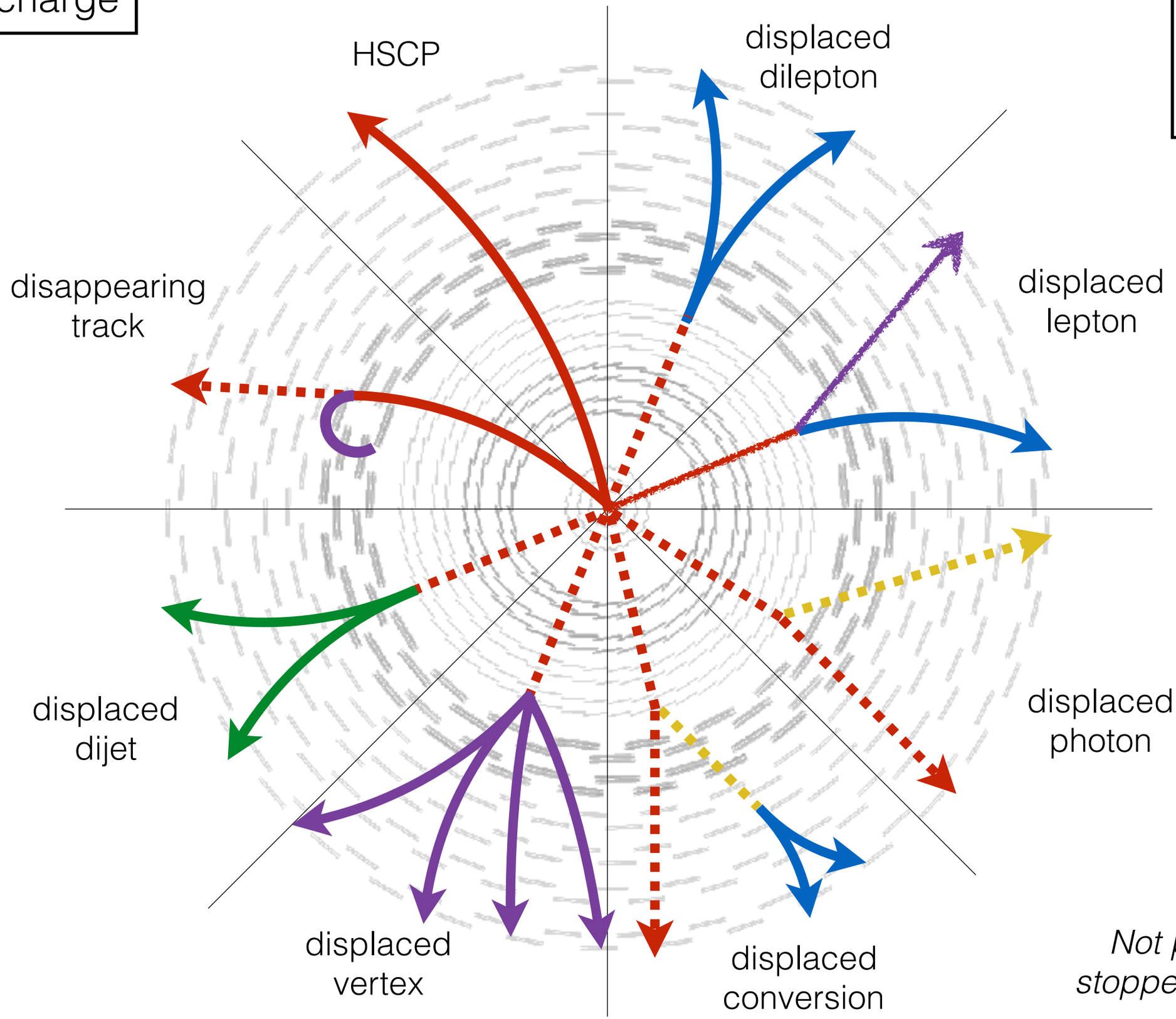
Many 13 results in the pipeline - updates and new searches!

Roughly 3% of CMS papers

Which topologies are higgs-like?

neutral
charged
any charge

BSM
lepton
quark
photon
anything



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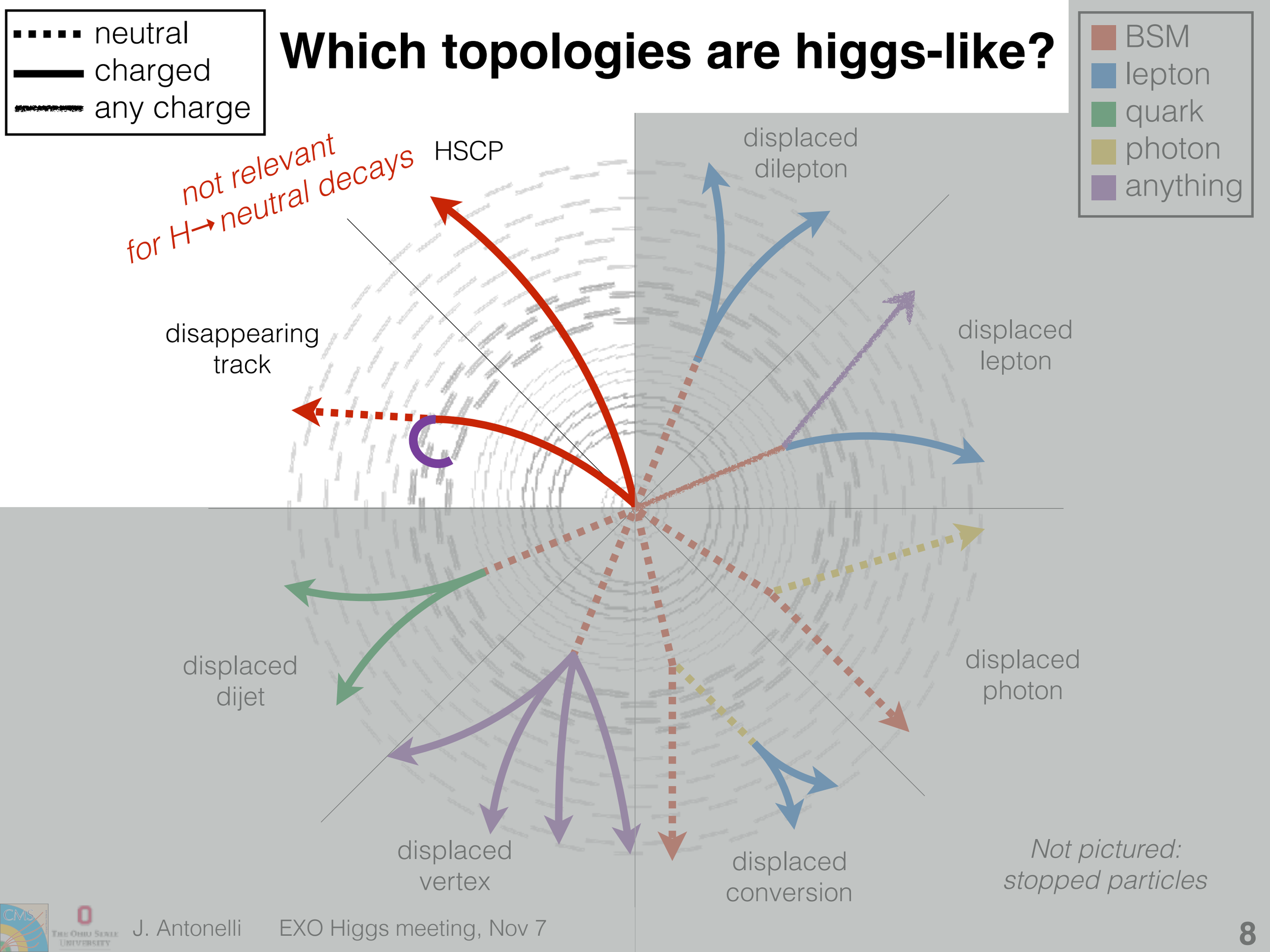

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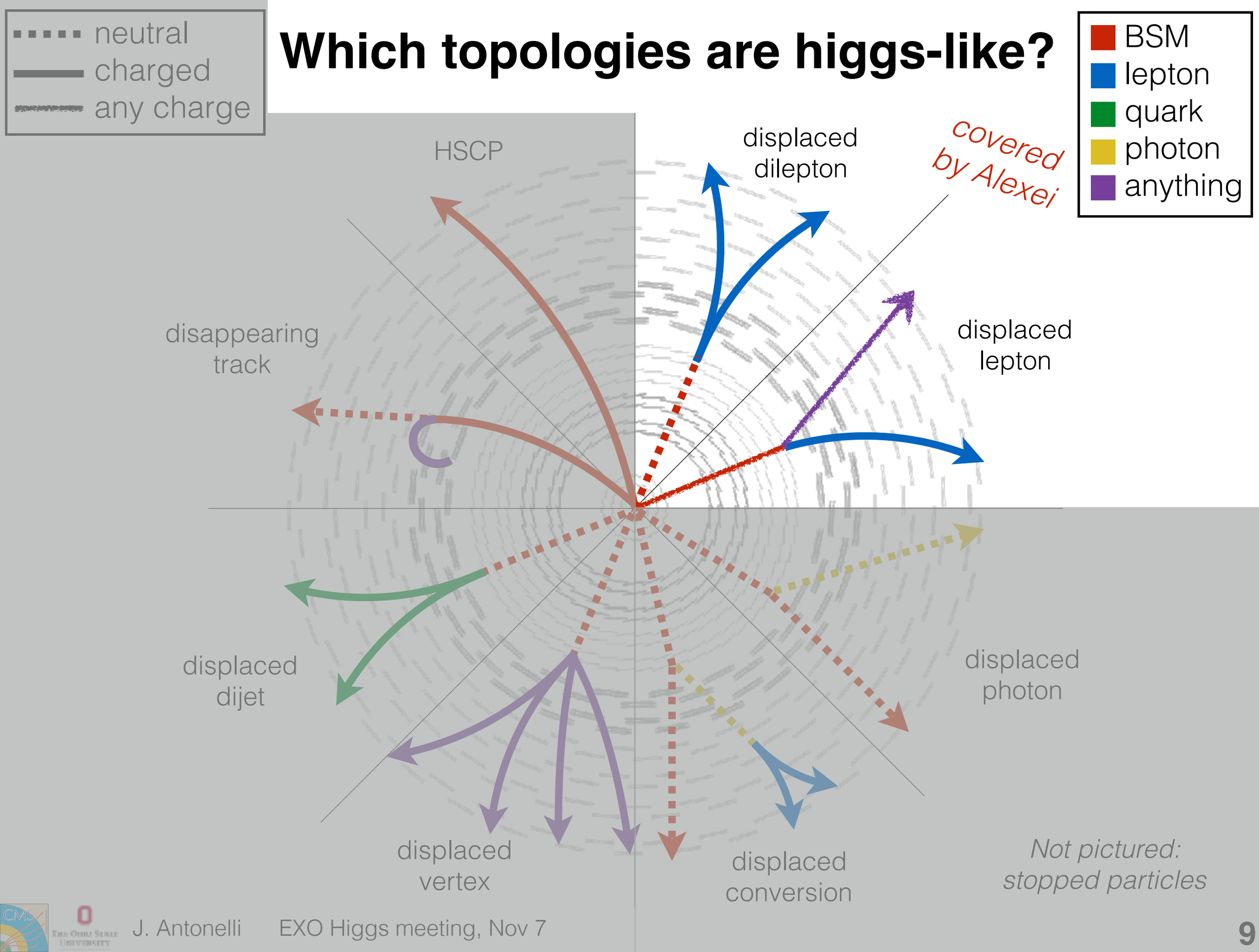


Which topologies are higgs-like?

neutral
charged
any charge

BSM
lepton
quark
photon
anything

HSCP

displaced
dilepton

disappearing
track

displaced
lepton

displaced
dijet

displaced
vertex

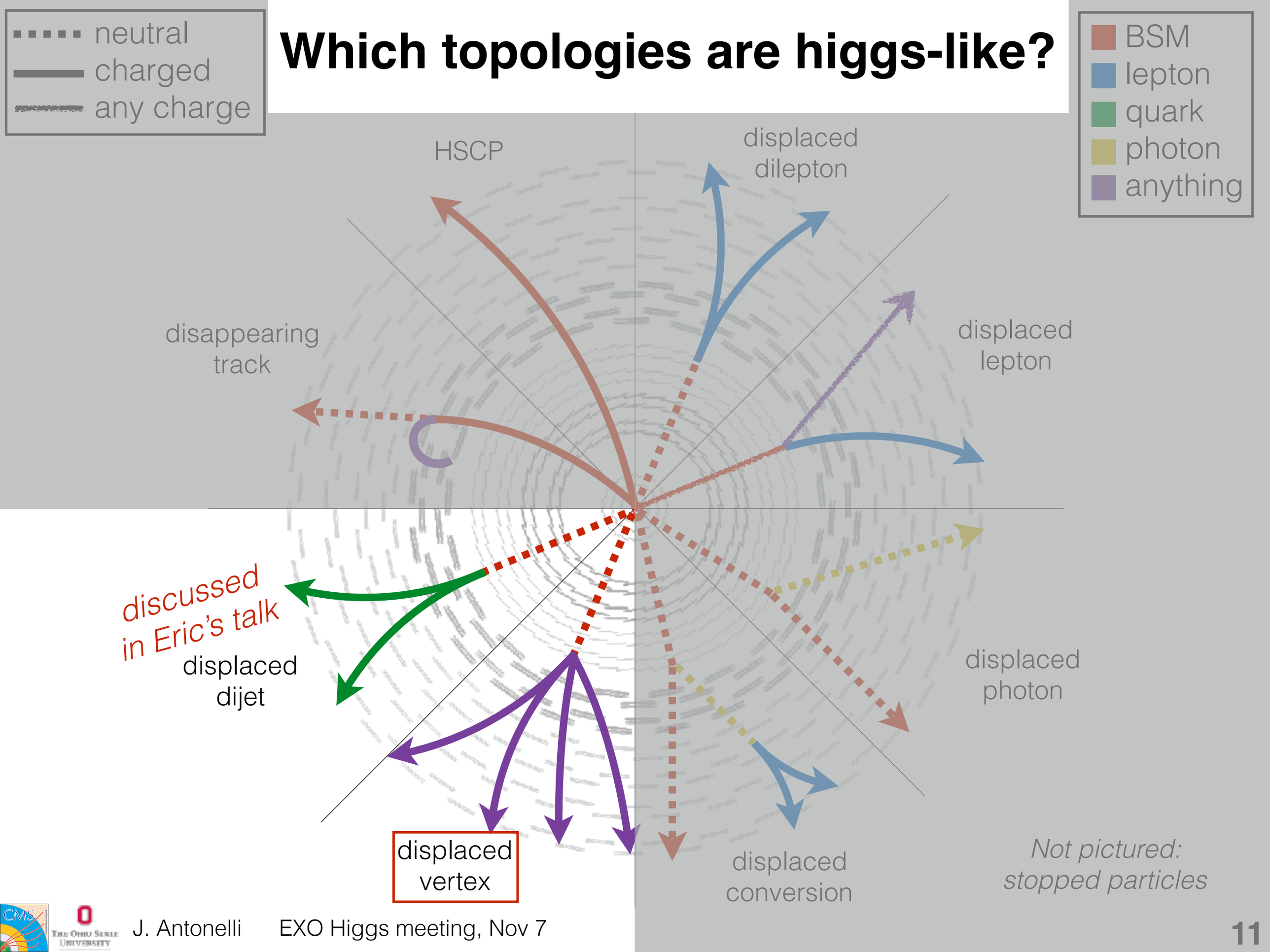
displaced
photon

displaced
conversion

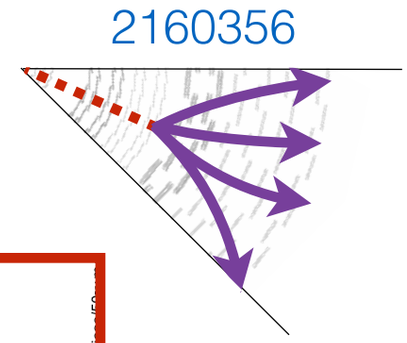
potentially interesting, low BRs

Not pictured: stopped particles

Which topologies are higgs-like?



Displaced vertex search



First of its kind on CMS (8 TeV)

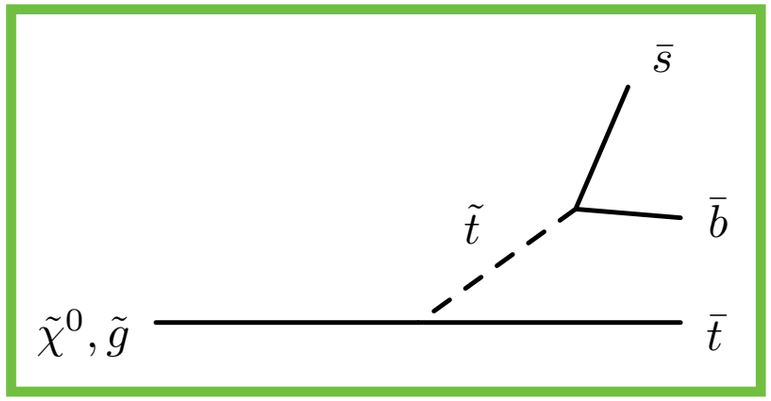
Targets **SUSY RPV → tbs**
- small couplings → long lifetimes

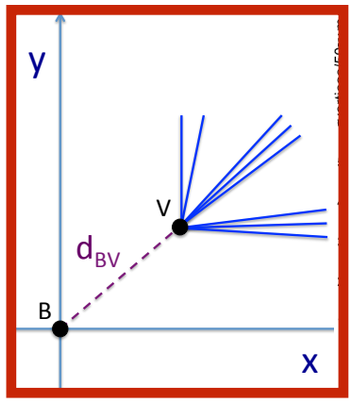
Short-ish lifetimes (inside beampipe)

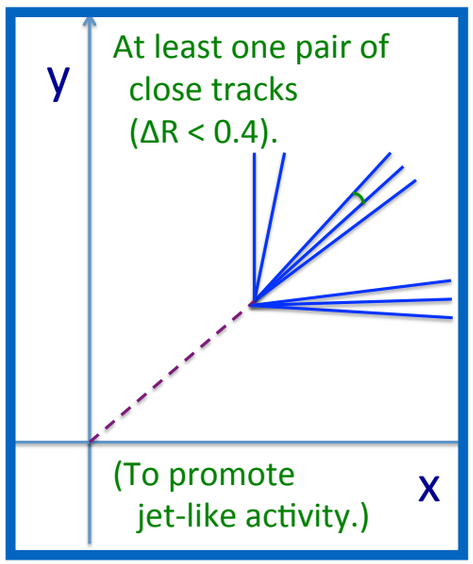
Reconstruct displaced vertices
- using tracks with $d_0 > 100$ μm

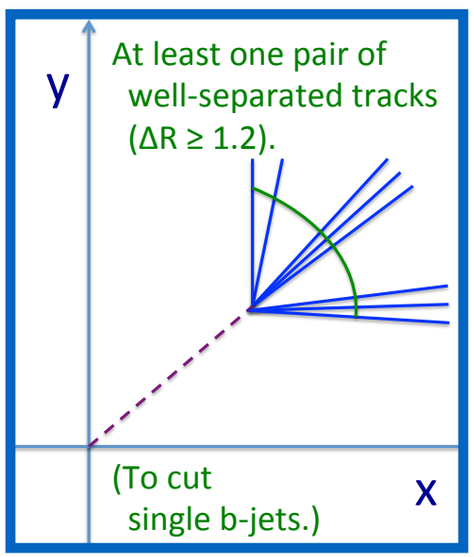
Vertex selection:
- ≥ 5 tracks, ≥ 3 with $p_T > 3$ GeV
- well measured vertex position
- ≥ 1 track matched to jet
- "substructure lite":
  0 track pairs with ΔR > 4
  ≥ 1 track pair with ΔR < 0.4
  ≥ 1 track pair with ΔR > 1.2

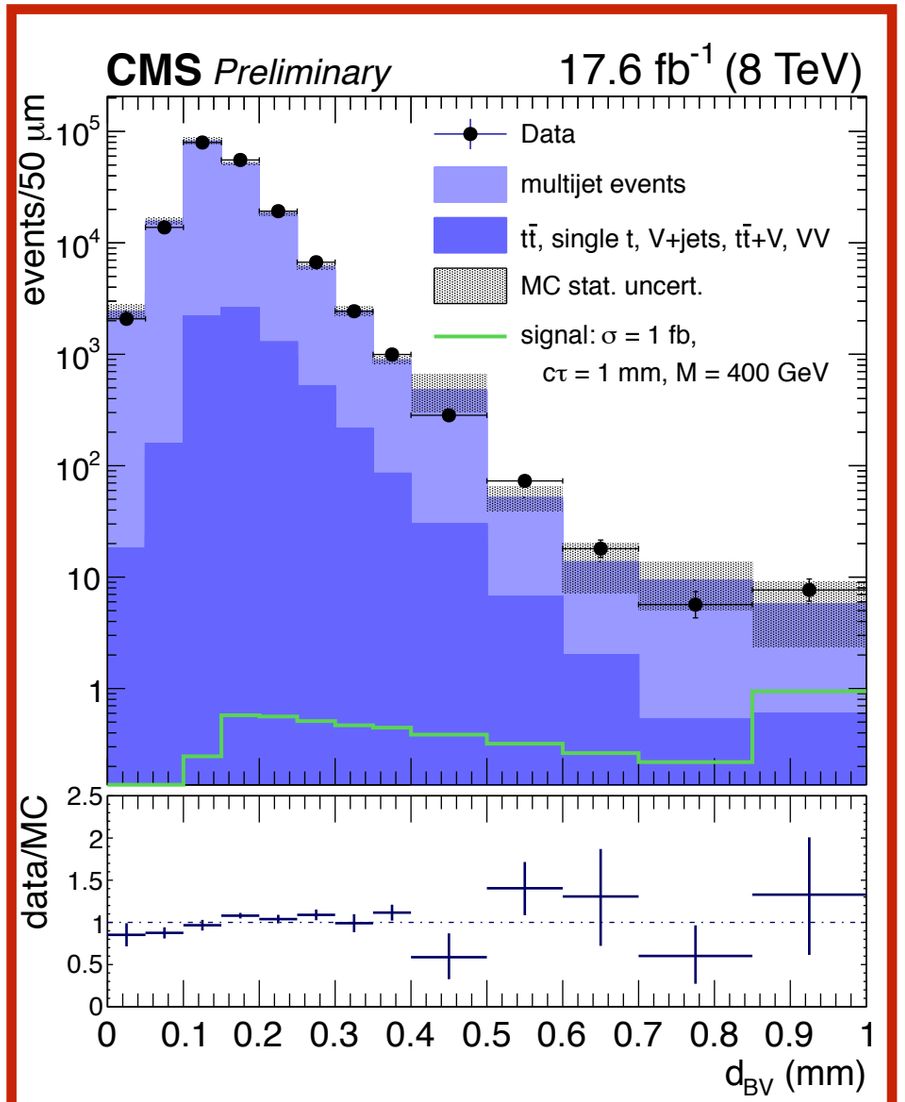
Create sample of **1-vertex events**



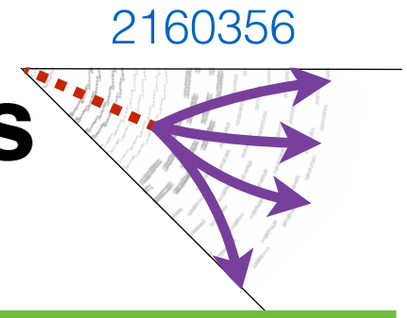








Background taken from 1-vertex data events



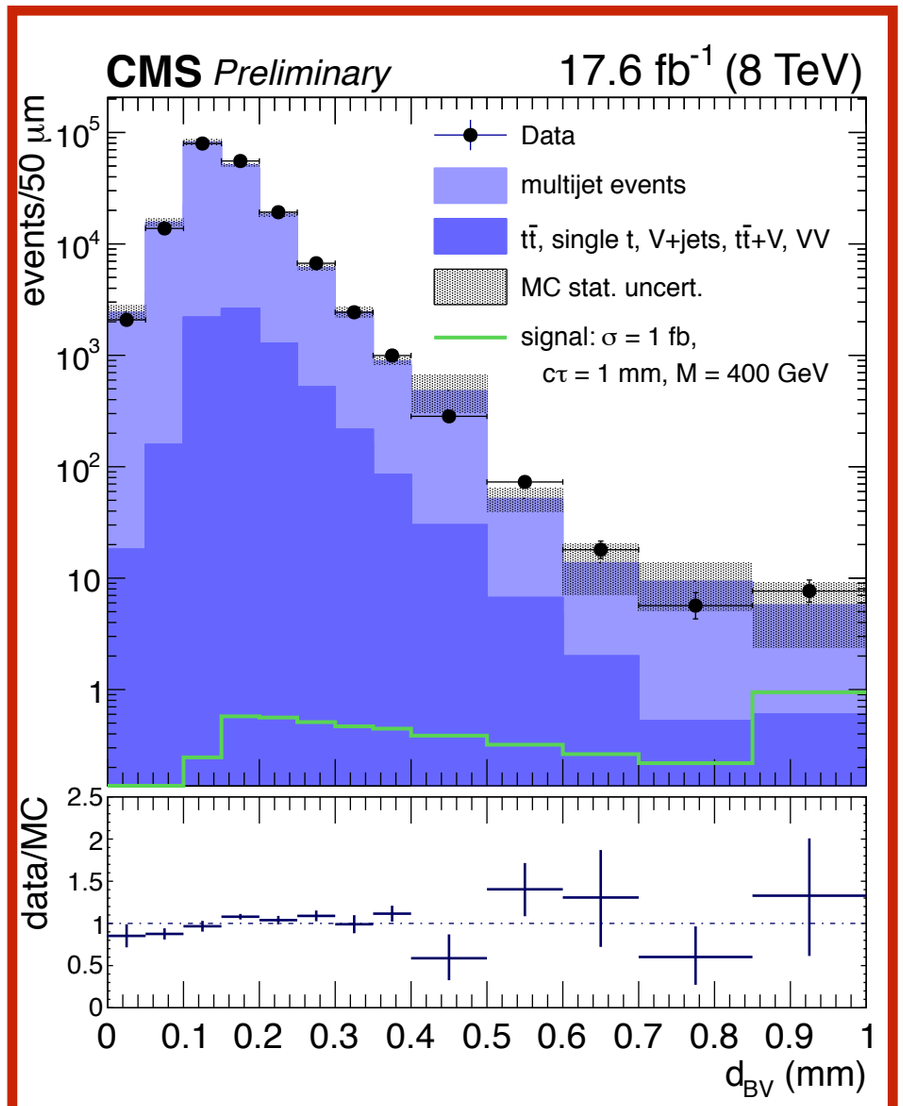
Signal expected in 2-vertex events

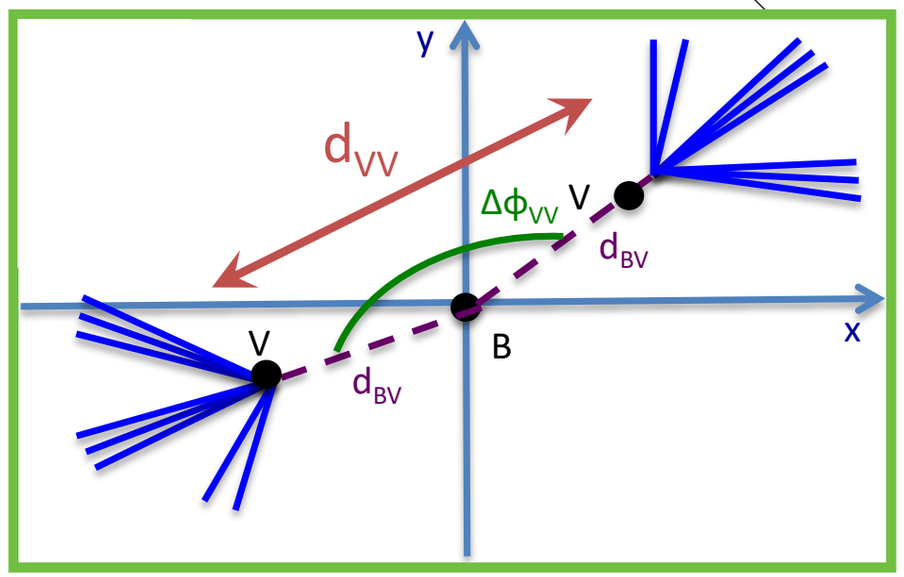
d_{VV}: distance between vertices in transverse plane

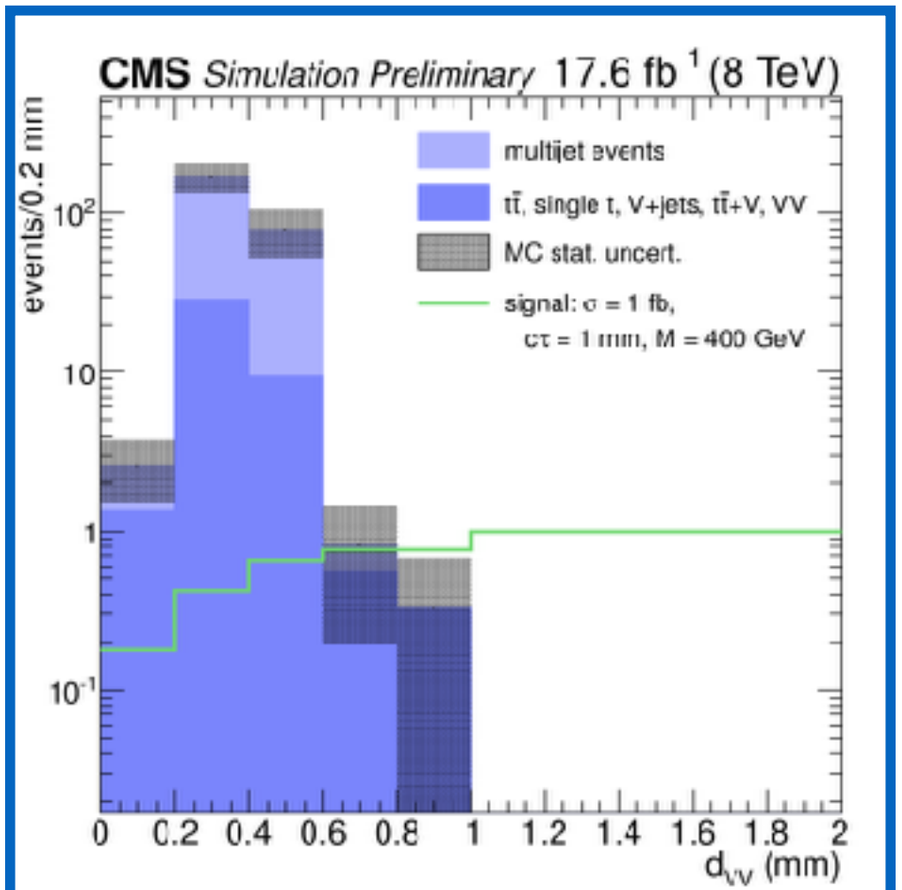
High discrimination power expected from d_{VV}

Taking two events from **1-vertex data**:
d_{BV}: vertex displacement
$\Delta\phi_{VV}$: angular separation

Create expected d_{VV} shape in background







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Exclusions at the fb scale

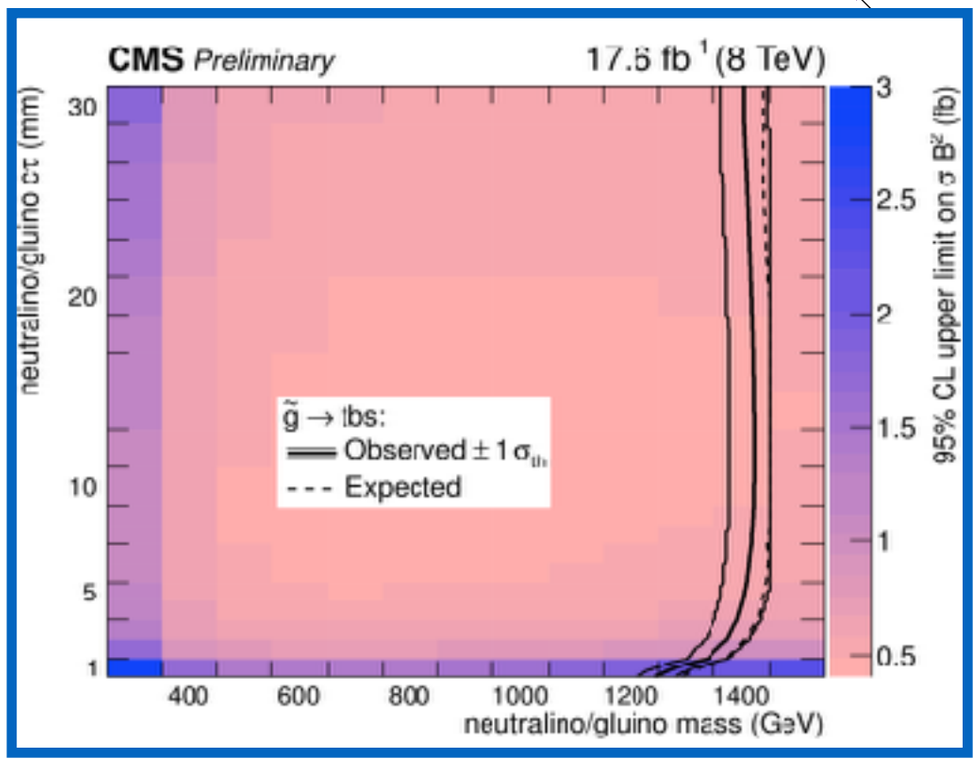
Signal extracted using d_{VV} distribution

Observation agrees well with background expectation

- slight excess for d_{VV} > 0.6 mm

$\chi_0/\tilde{g}$ models excluded beyond 1 TeV

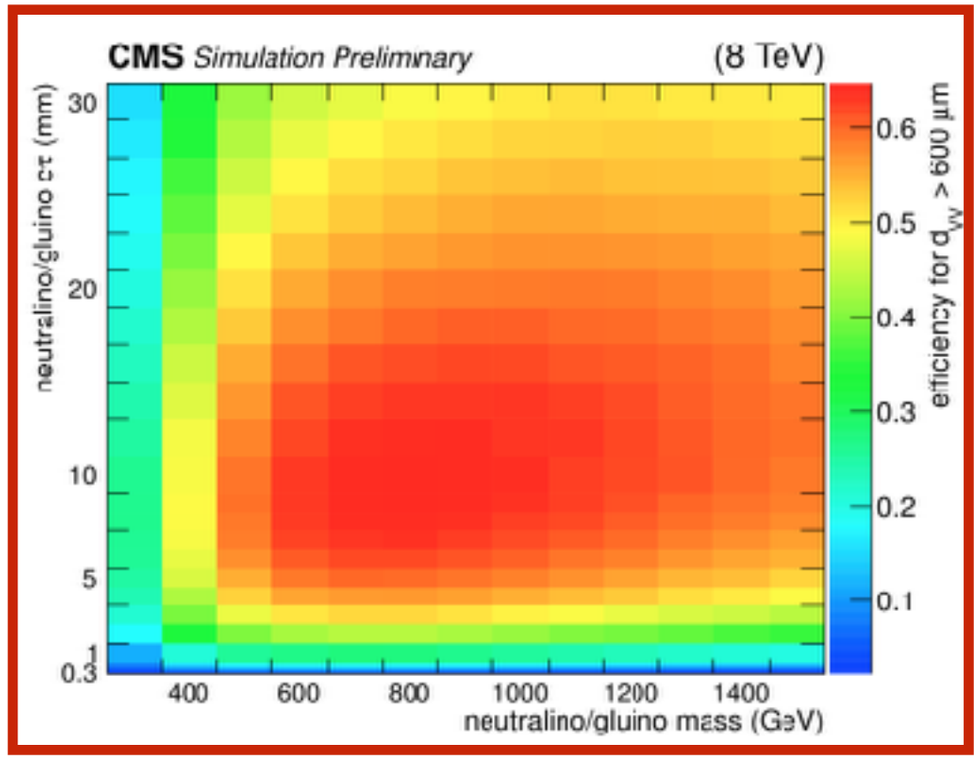
Signal efficiency as high as 60%



Little sensitivity to h(125) decays:

- QuadJet50 trigger
- H_T > 500 GeV

Bin i	d_{VV} range	Observed n_i	Mean expected count
1	0.0–0.2 mm	6	6.2 ± 1.0
2	0.2–0.4 mm	193	192.2 ± 3.9
3	0.4–0.6 mm	45	48.0 ± 3.8
4	0.6–0.8 mm	5	3.5 ± 1.4
5	0.8–1.0 mm	1	0.3 ± 0.1
6	1.0–50 mm	1	0.3 ± 0.1



Designing new searches

Clearly we're going to need more focused searches to attack displaced Higgs decays

Some things are hard:

- Redesigning algorithms
  - E.g. Tracking (kinked tracks, quirks)
  - E.g. B-taggers (finding non-B displaced jets, finding tertiary vertices)
  - Difficult to implement but also difficult to validate and to get approved

Some things are (relatively) easy:

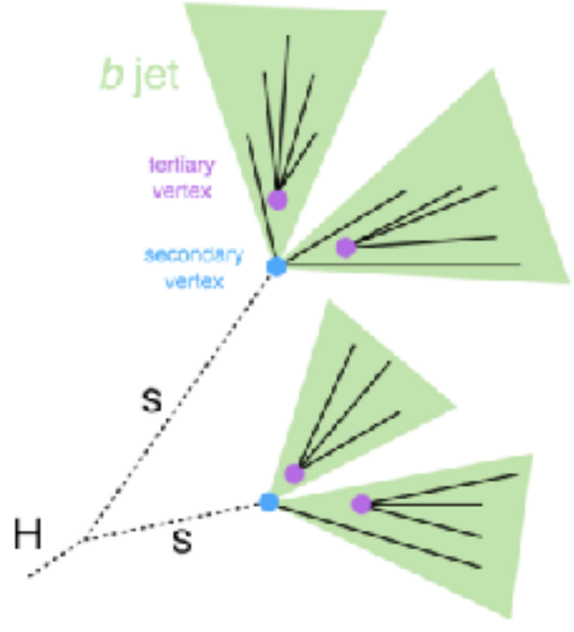
- Refreshing existing searches with iterative improvements
- Combining existing validated objects - e.g. displaced lepton + jet search
- Rerunning existing searches with different trigger strategy

Displaced VH search (ongoing)

Both displaced dijet and displaced vertex search are being updated at 13 TeV

Additionally, efforts are underway on a focused search in the VH channels

- Smaller cross-section than VBF but cleaner signature and smaller backgrounds

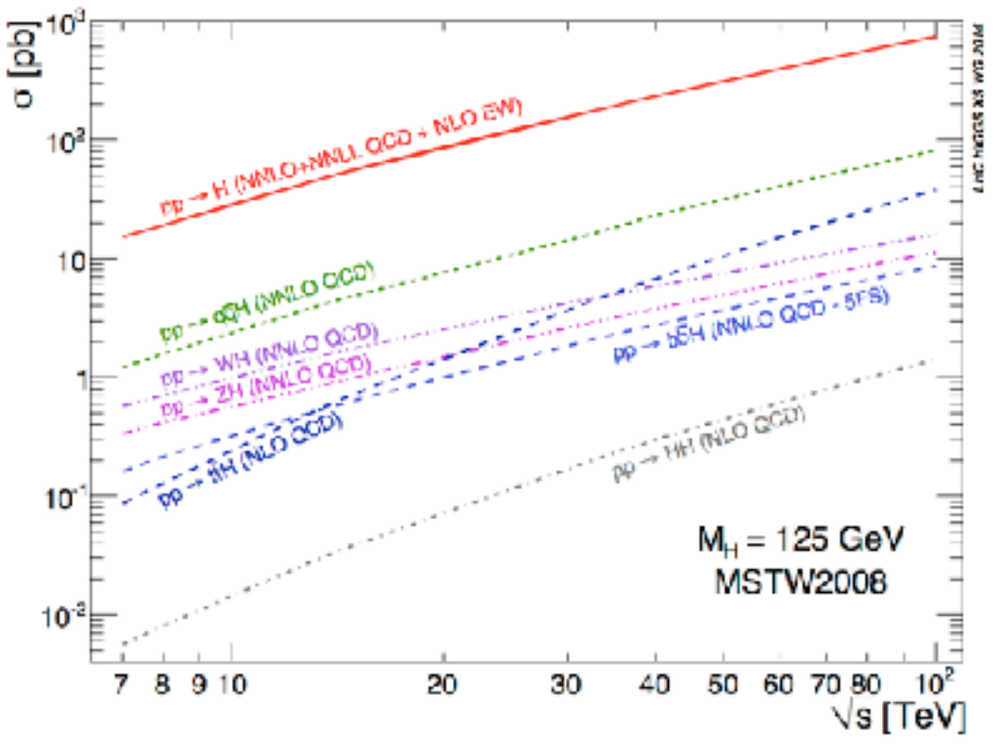


Trying track-based variables instead of explicitly reconstructing DV

Boosted B pairs can become a single jet

Low energy jets are susceptible to large fluctuations - careful consideration is required

Expect to probe BRs at <20% level in w/ 2016 data (strongly dependent on scalar mass, ctau)



WH: 1.362 pb → BR(W→lν) ~20% → 270/fb-1 → 10k events
ZH: 0.8594 pb → BR(Z→ll) ~6% → 50/fb-1 → 2k events

Outlook

	Final state targeted	13 TeV
1	displaced e-e/μ-μ pairs	
2	displaced μ-μ pairs in muon system	
3	displaced e-μ events	2205146
4	displaced μ-μ pairs (dark photons)	
5	displaced photons using ECAL timing	
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9	short, highly ionizing disappearing tracks	
10	disappearing tracks	
11	kinked tracks	
12	fractionally charged particles	
13	heavy stable charged particles (HSCP)	2114818 (2015) 2205281 (2016)
14	stopped particles	
15	out of time muons	
16	***top secret new searches***	

This are tricky analyses:

- Very sensitive to detector performance
- generally wait for final calibration/alignments

Next generation of searches will include more model-specific strategies

Following generation may include searches with more dramatic rethinking of existing algorithms

Fin