NEW DISPLACED SEARCHES AND STRATEGIES AT THE LHC

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New Physics Interpretations at the LHC, Argonne
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Displaced physics at the LHC

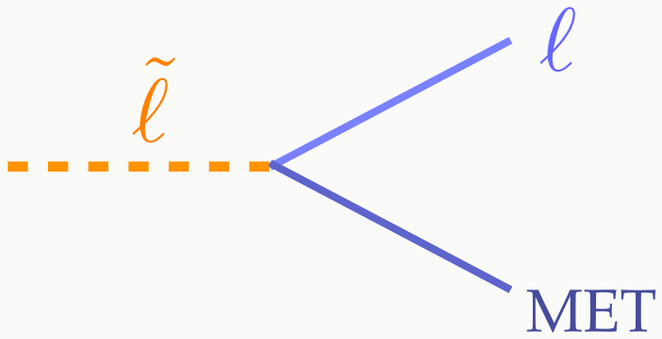
- Particles with macroscopic lifetimes offer huge opportunities as well as major challenges for the LHC
  - SM physics is overwhelmingly prompt! Backgrounds to displaced searches are very small
  - But detectors were not designed for displaced searches: triggering and reconstruction can be enormous challenges
  - (nearly-) background-free search regions powerful but limited. But beyond the background-free regime requires knowledge of difficult-to-compute backgrounds

Displaced physics at the LHC

- Two proposals to extend search coverage of displaced decays at the LHC:
  - solitary leptons with large impact parameters [Evans, JS, 1601.01326]
  - searches with one displaced vertex in the muon spectrometer [Coccaro, Curtin, Lubatti, Russell, JS, 1605.tbd]

Displaced leptons at the LHC

- Solitary displaced leptons:



- detector signature depends on lifetime:
  - short: lepton with high impact parameter
  - medium: disappearing track
  - long: heavy stable charged particle

well-developed, very powerful at long lifetimes

Displaced leptons at the LHC

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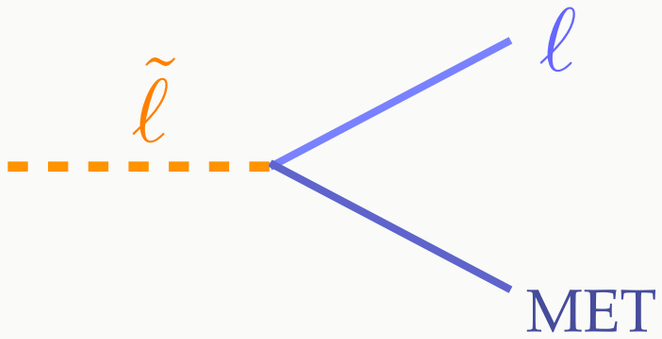

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well-developed but highly specialized to near-degenerate electroweakinos

Displaced leptons at the LHC

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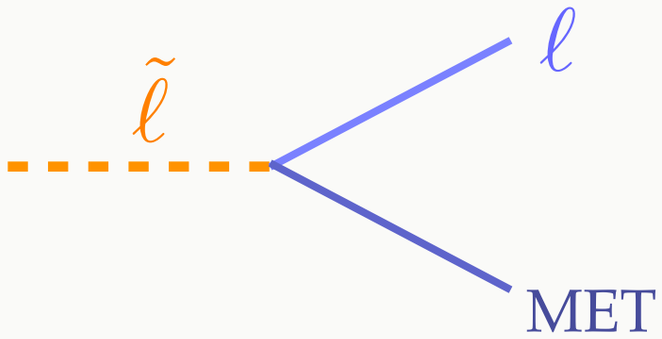

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newest: OS e, μ only, no SF searches

[CMS, 1409.4789]

Why displaced leptons?

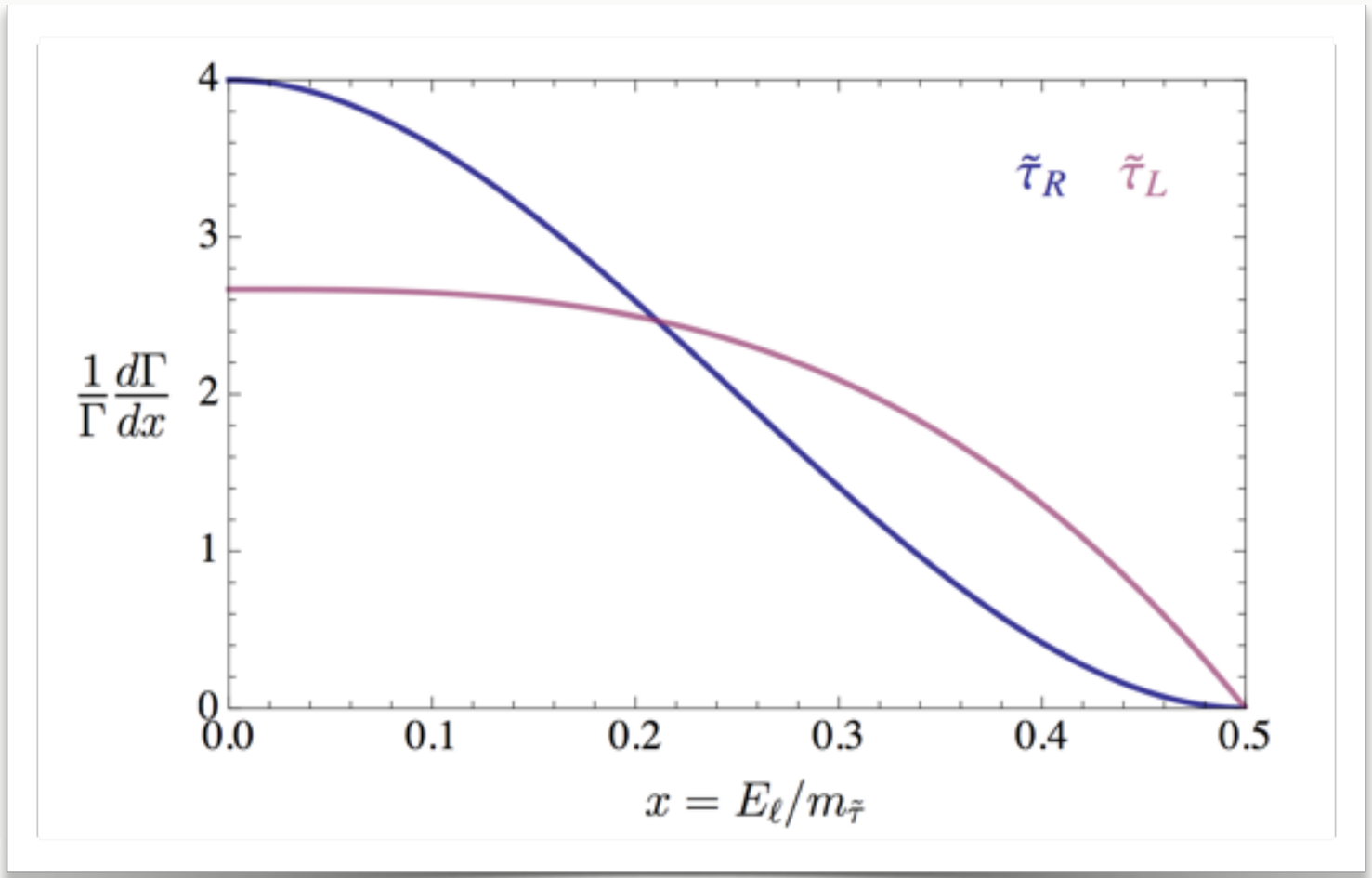
- Very well motivated in models of gauge-mediated SUSY-breaking
  - (RH) stau NLSP quickly becomes displaced for moderate F:

$$c\tau \approx 100\mu m \times \left(\frac{\sqrt{F}}{100\mathrm{TeV}}\right)^4 \left(\frac{100\,\mathrm{GeV}}{m_{\tilde{\tau}}}\right)^5$$

  - taus: (e, μ)-symmetric signal
  - natural target for existing CMS search

Double the flavor, double the fun

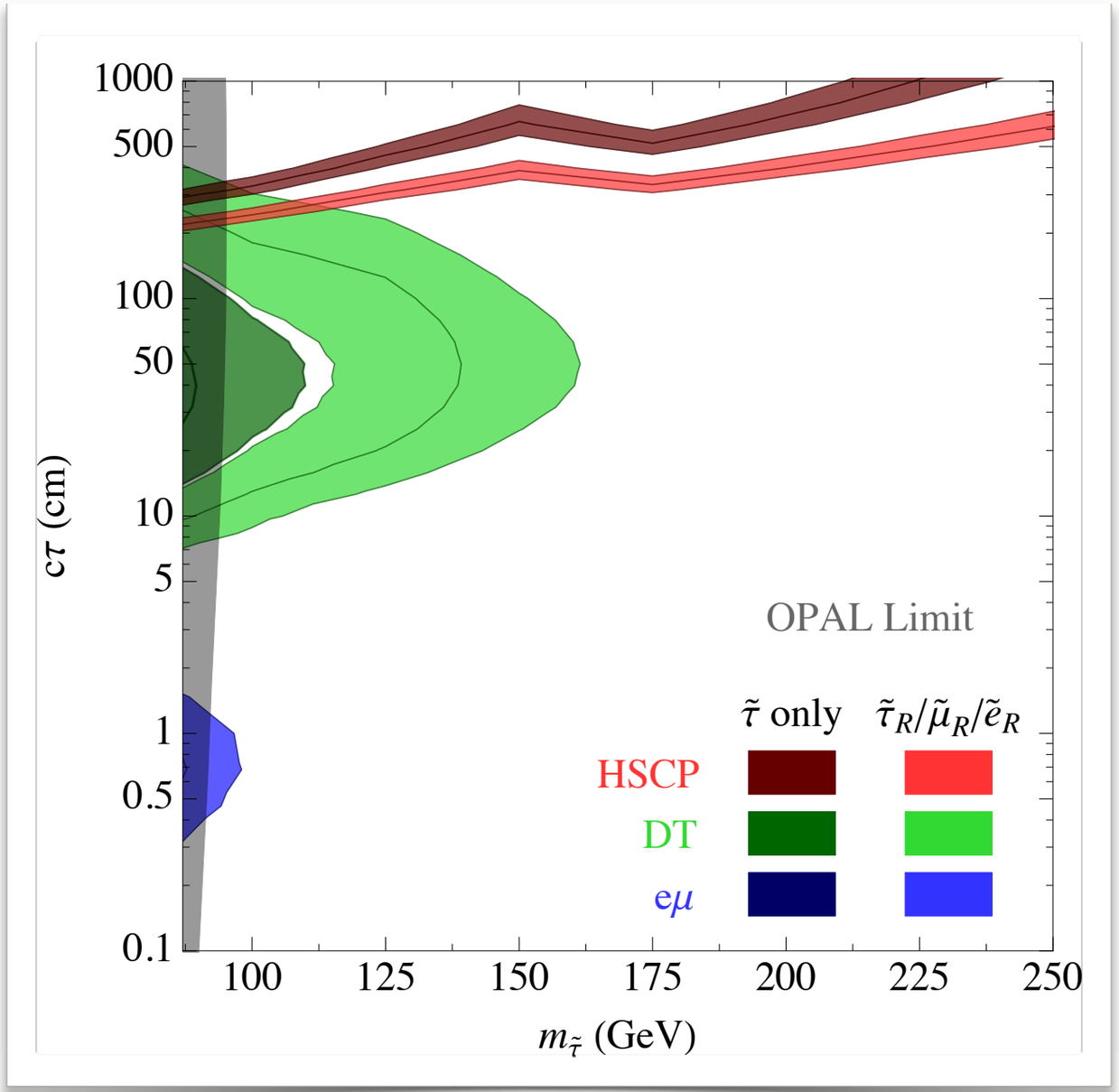
- But...



- soft leptons from RH stau decay severely limit acceptance

Displaced leptons

- Current limits on direct stau production



CMS: 1502.02522

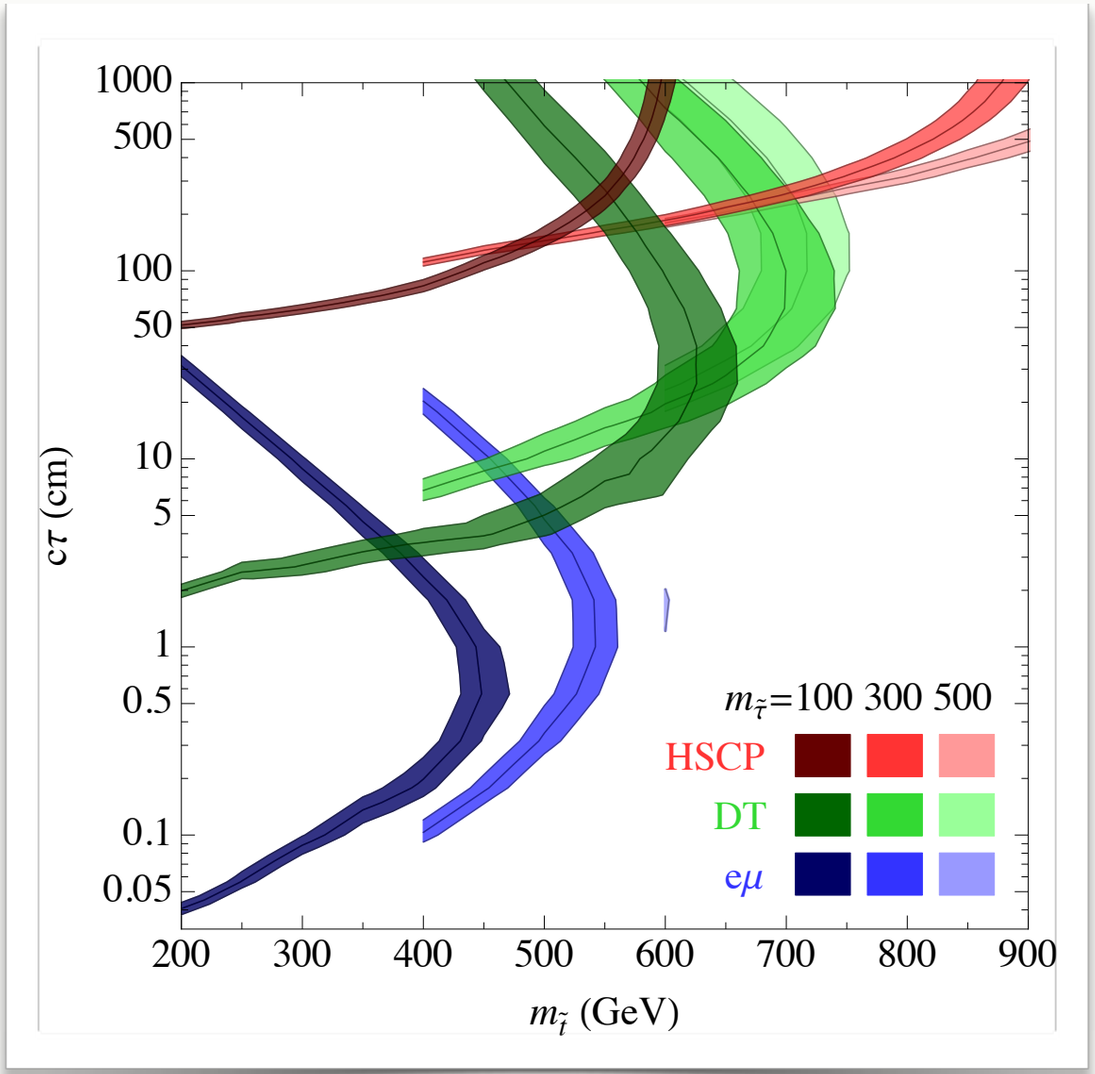
ATLAS: 1310.3675
CMS: 1411.6006

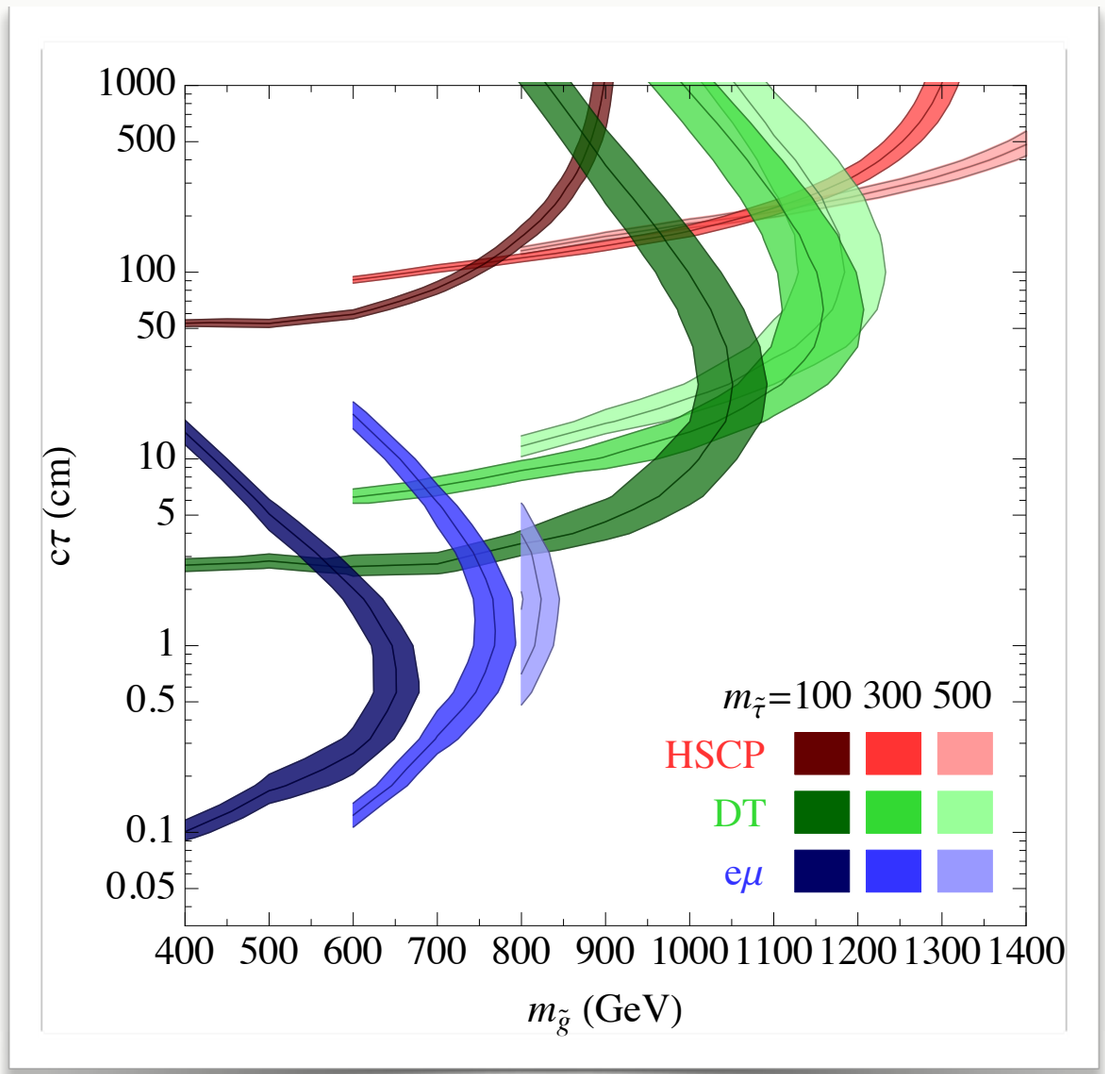
CMS: 1409.4789

[Evans, JS]

Displaced leptons

- Cascade decays: $\tilde{g} \to t\tilde{t},\ \tilde{t} \to \tilde{H}b,\ \tilde{H} \to \tilde{\tau}\nu$





$$m_{\tilde{t}} - m_{\tilde{H}} = 50\,\mathrm{GeV},\ \ m_{\tilde{g}} - m_{\tilde{t}} = 200\,\mathrm{GeV}$$

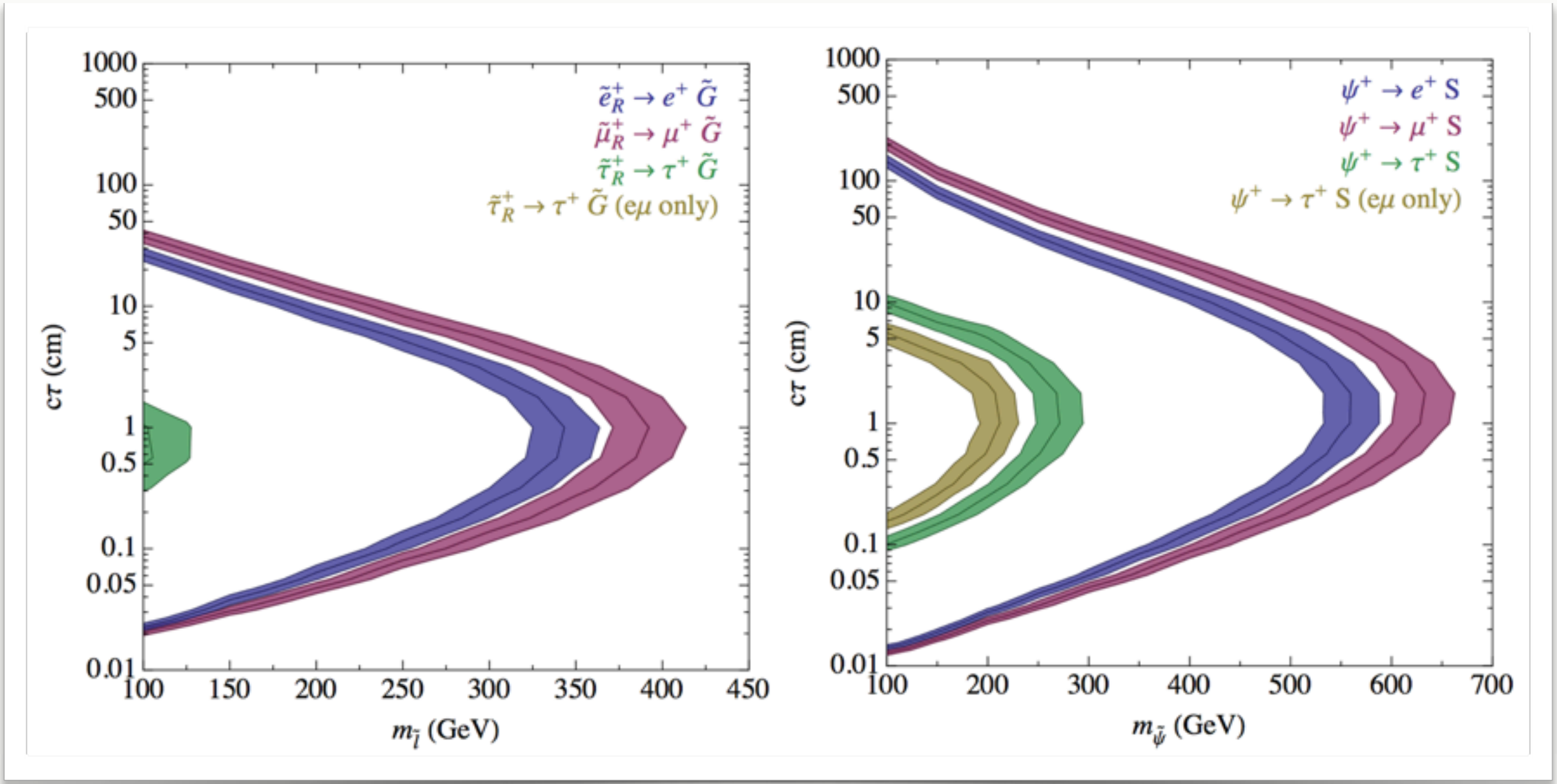
[Evans, JS]

Double the flavor, double the fun

- Maximize acceptance: add same-flavor channels!
- Solitary displaced SF leptons are a gap in coverage:
  - also generic in GMSB to have slepton co-NLSPs
  - flavored messenger sectors (extended GMSB) can give smuon, selectron NLSPs
  - RPV SUSY can do anything
  - displaced signal generators: matter-dominated freeze-in DM can give SF signals

[Co, D'Eramo, Hall, Pappadopulo]

Projected sensitivity to direct stau

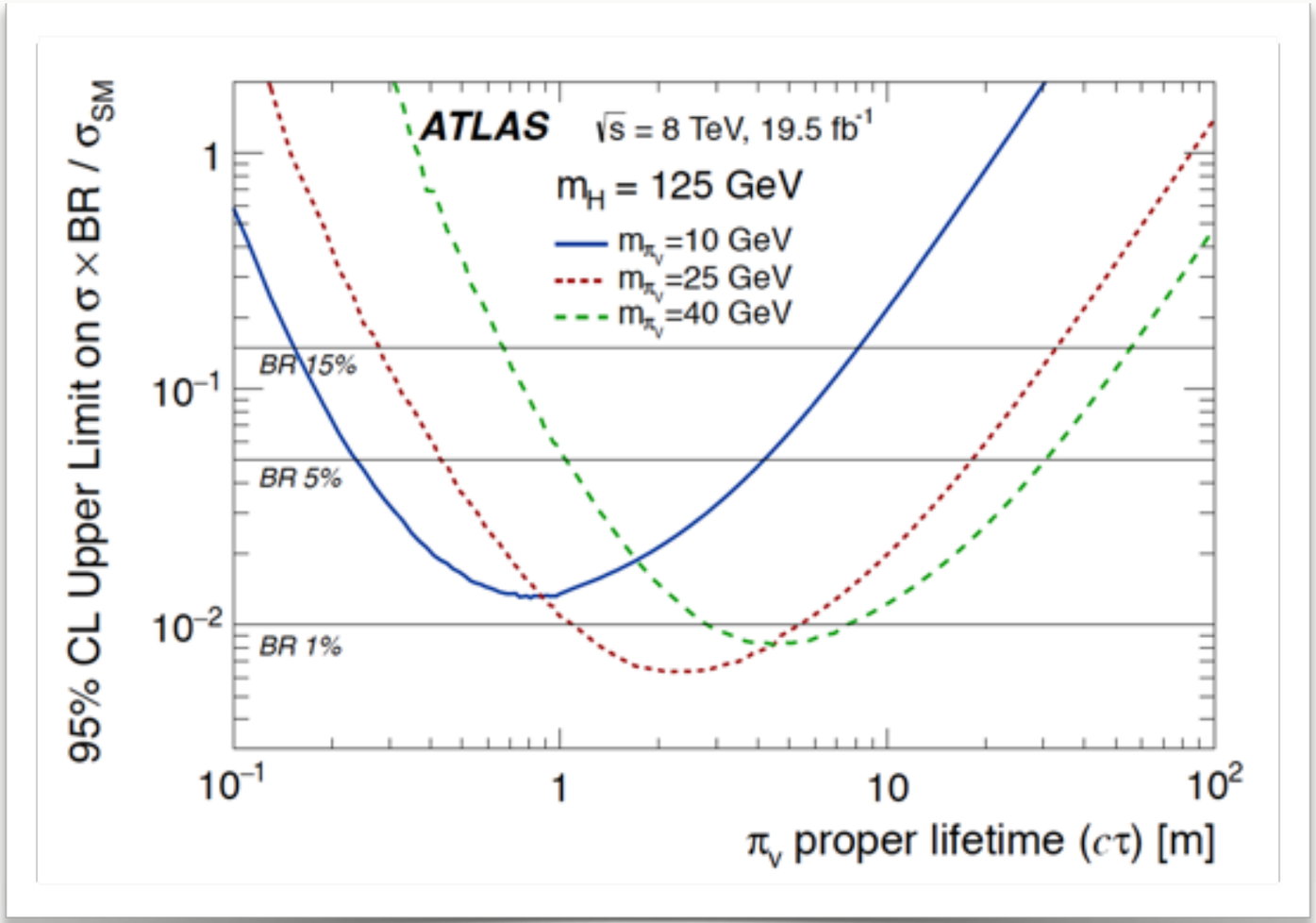


Projected sensitivity from a SF search with 20 ifb at 13 TeV;
cuts and background estimates based on CMS 8 TeV OF search

[Evans, JS]

Displaced vertex searches

- Run I ATLAS search requiring 2 displaced vertices in the muon system and inner tracker:



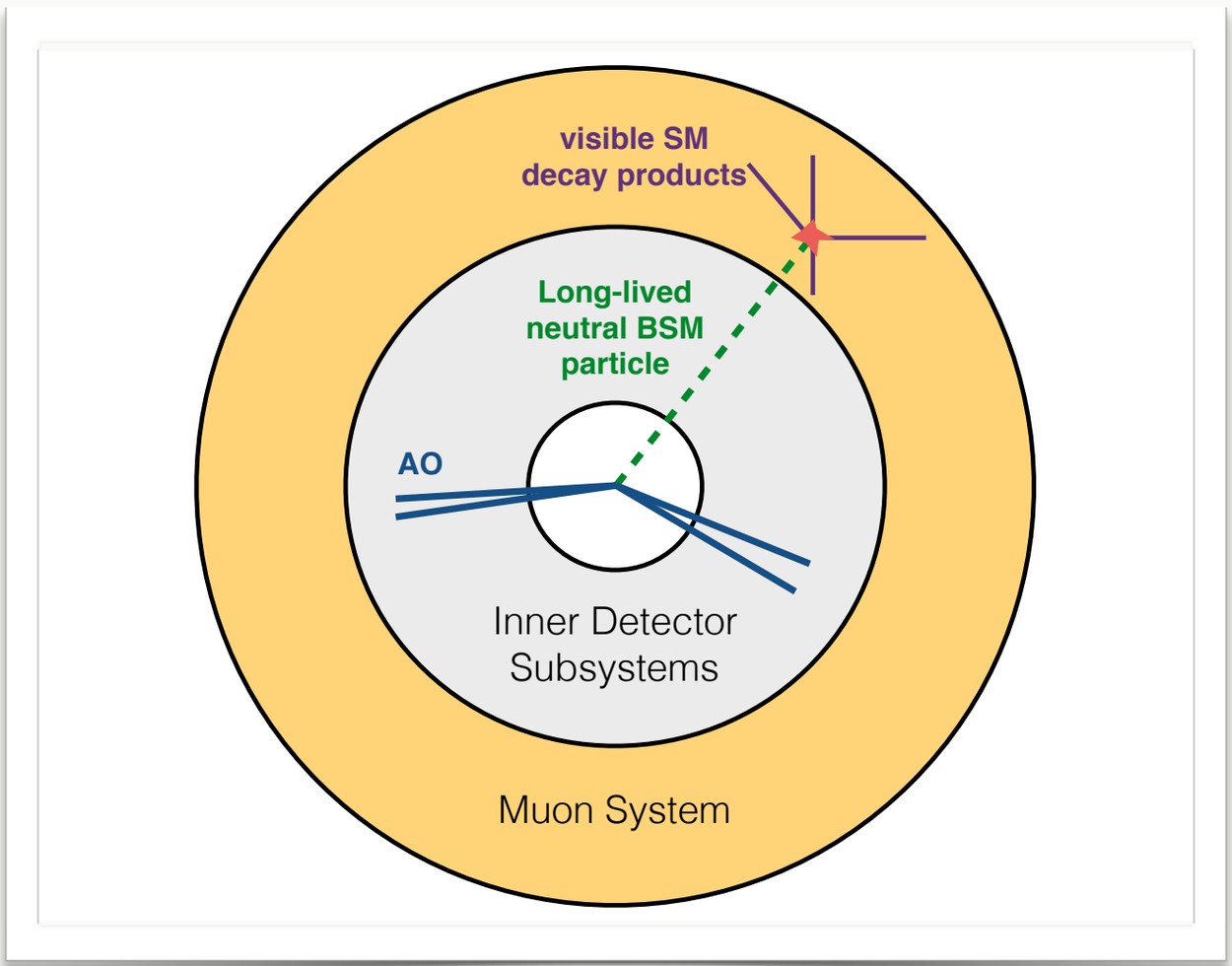
Expected SM background for 2 MS vertices: 0.4 events, dominantly QCD

SM events giving single MS vertex: not given explicitly, but ~3000

[ATLAS, 1504.03634]

Single displaced vertex searches

- To extend the range of sensitivity, e.g. to longer lifetimes, need to understand background



- Dedicated trigger records events with decays that occur in the muon system

Single displaced vertex searches

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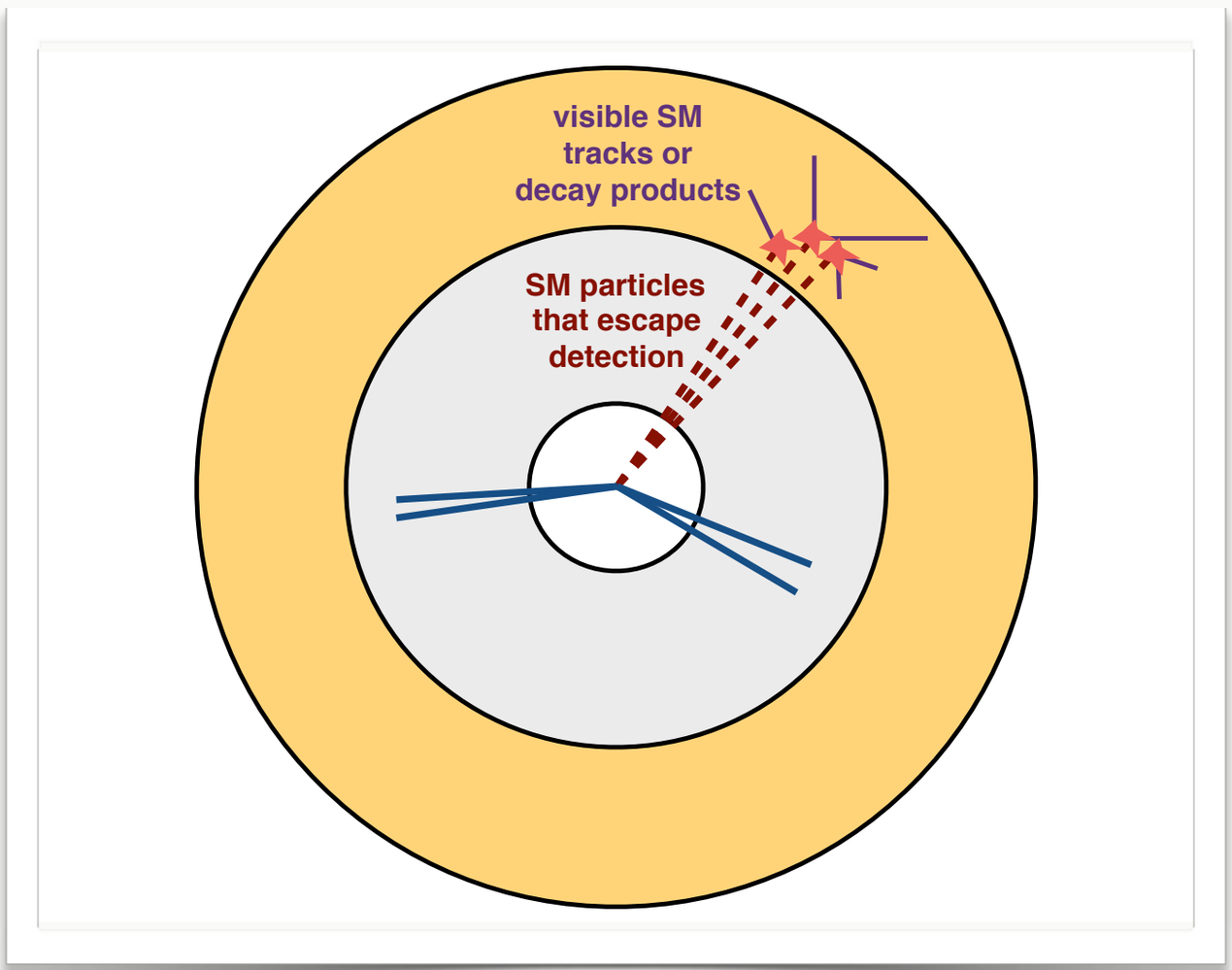
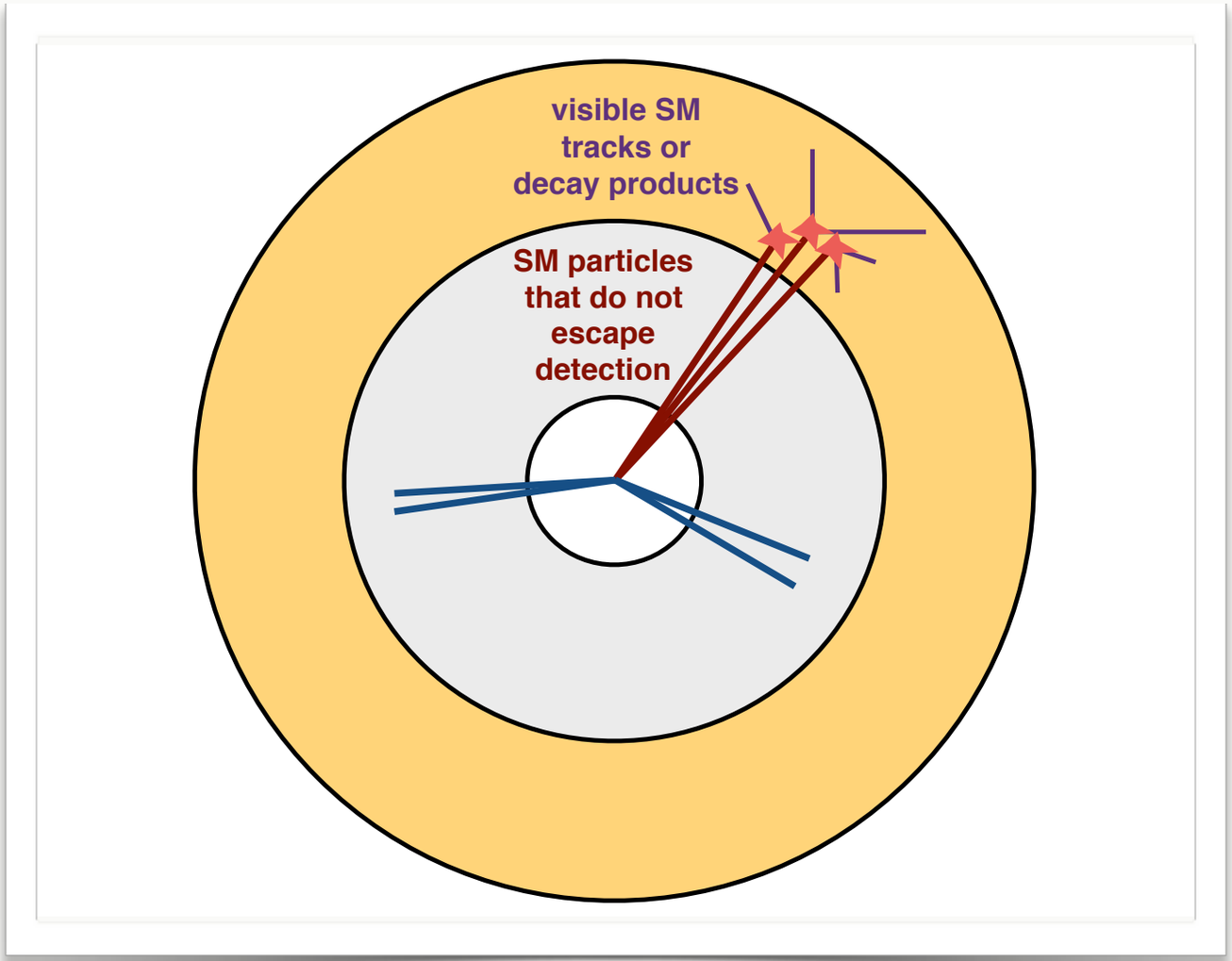


- SM background is dominated by QCD
- Cannot model this background reliably from first principles. Weird 'truth-level' physics and weird detector response

Single displaced vertex searches

- To extend the range of sensitivity, e.g. to longer lifetimes, need to understand background



- So: use suitable control sample to estimate background from data.
- Simply obtaining related control sample is a major step: requires dedicated 'orthogonal' trigger (new in ATLAS Run 2)

[Coccaro, Curtin, Lubatti, Russell, JS, to appear]

Data-driving displaced backgrounds

- Rate of SM 'iso' events closely related to rate of SM 'non-iso' events:

$$\frac{\Delta\sigma^{\rm iso}}{\Delta H_T'} = r(H_T')\frac{\Delta\sigma^{\rm noniso}}{\Delta H_T'}$$

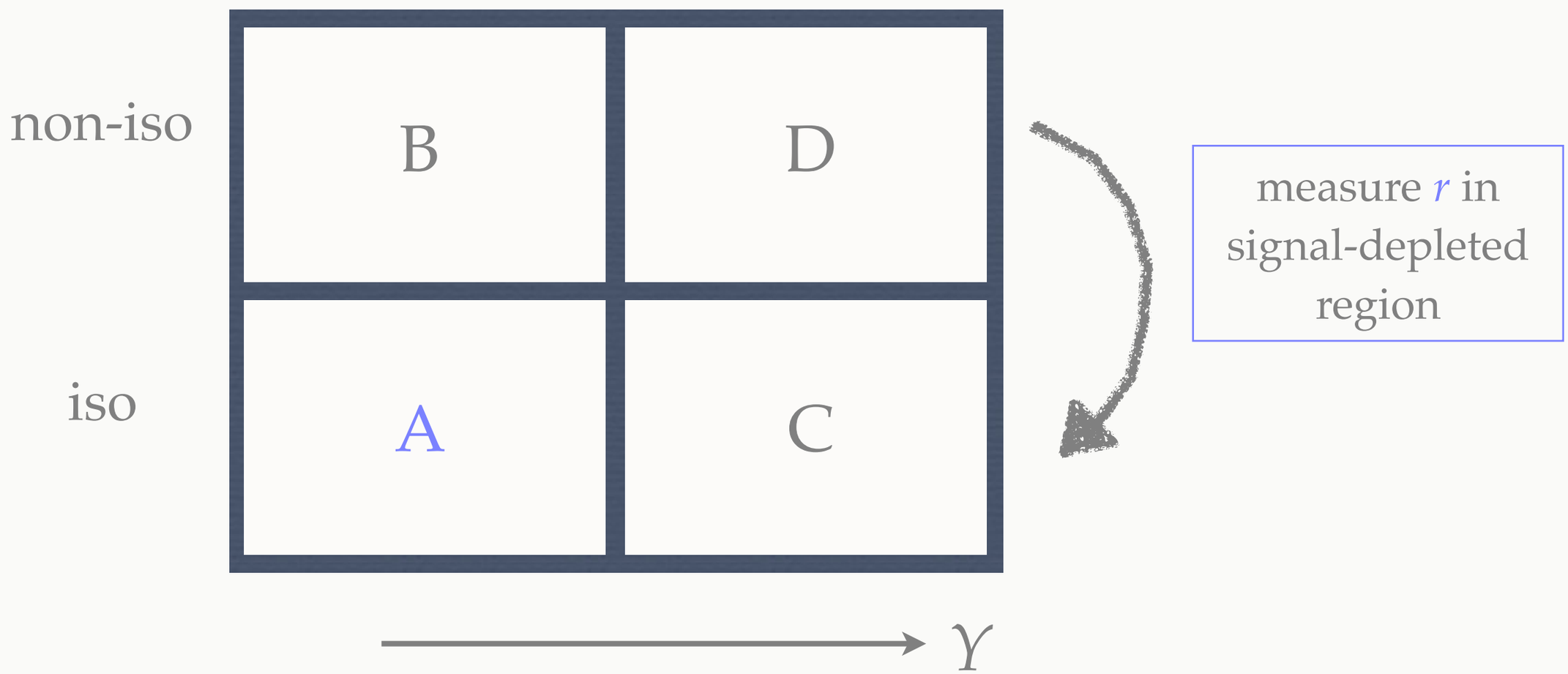
H_T': proxy for (un-measured) p_T of jet yielding DV. p_T spectrum of iso, non-iso jets similar but not identical.

non-isolated events occur at much larger rates: excellent control sample

rescaling function $\sim \epsilon^{\rm iso}/\epsilon^{\rm noniso}$, to be measured in data

Data-driving displaced backgrounds

- To measure r, find a variable Y, depending on the signal model: then, bin-by-bin in H_T',

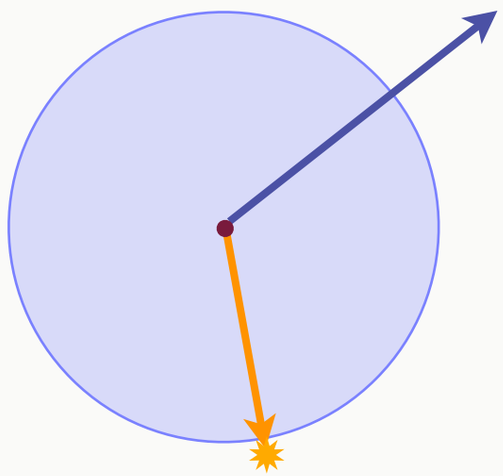


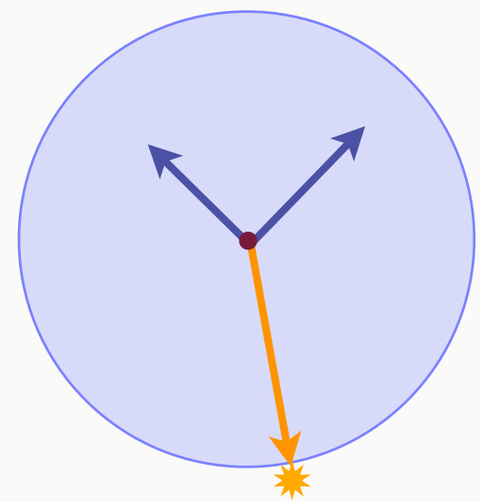
Example: Higgs decay to $X\,X$

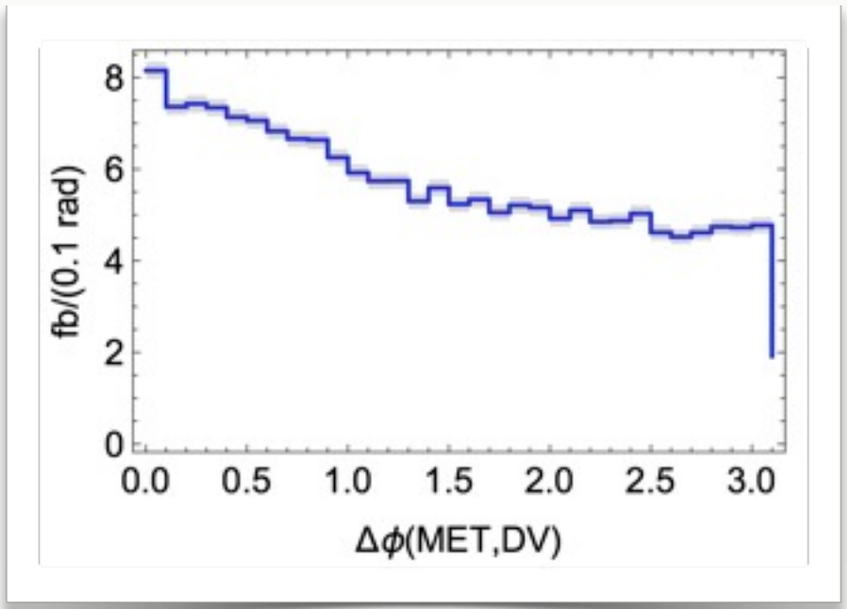
- To see how this works in practice, consider exotic Higgs decays to a pair of long-lived X
  - very well motivated! e.g., can be leading discovery signature for neutral naturalness
- Actually one of the most challenging signal models: dominant production is inclusive
  - choice of Y: use the fact that signal makes two X's per event
    - long lifetime: additional physical source of MET
    - short lifetime: displaced decay elsewhere in detector

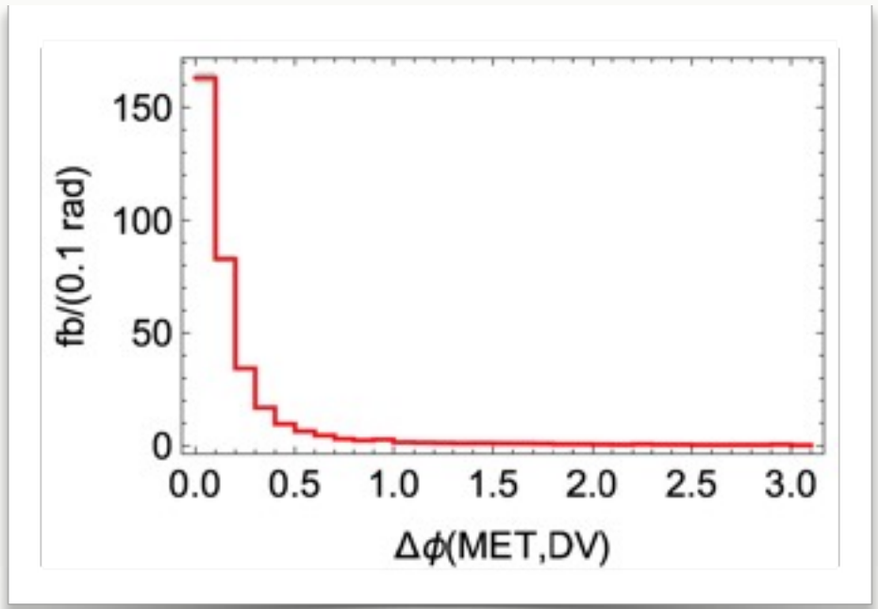
Example: Higgs decay to $X\,X$

- direction of MET distinguishes signal from background:





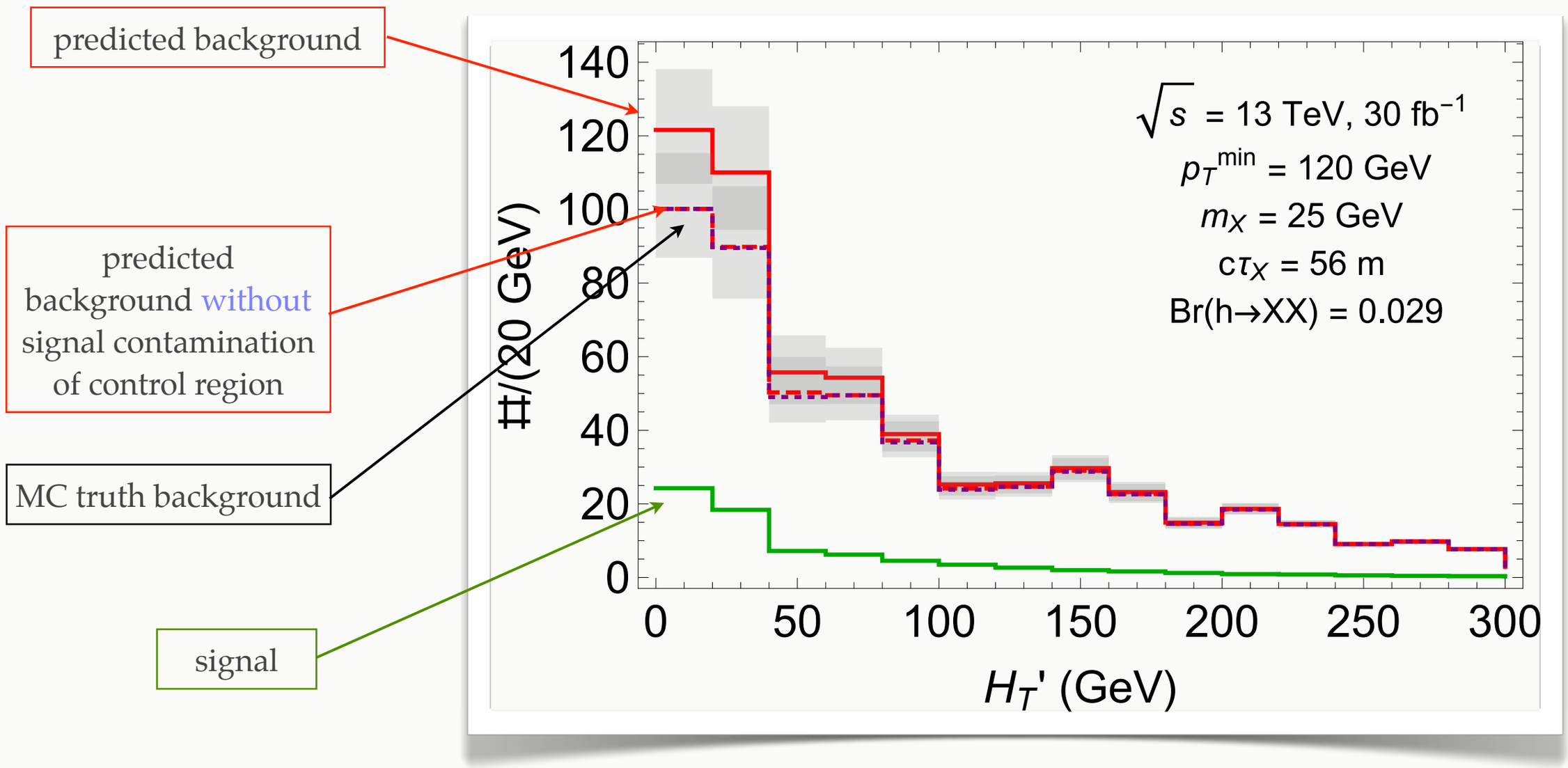




[Coccaro, Curtin, Lubatti, Russell, JS, to appear]

Example: Higgs decay to $X\,X$

- Self-consistent!



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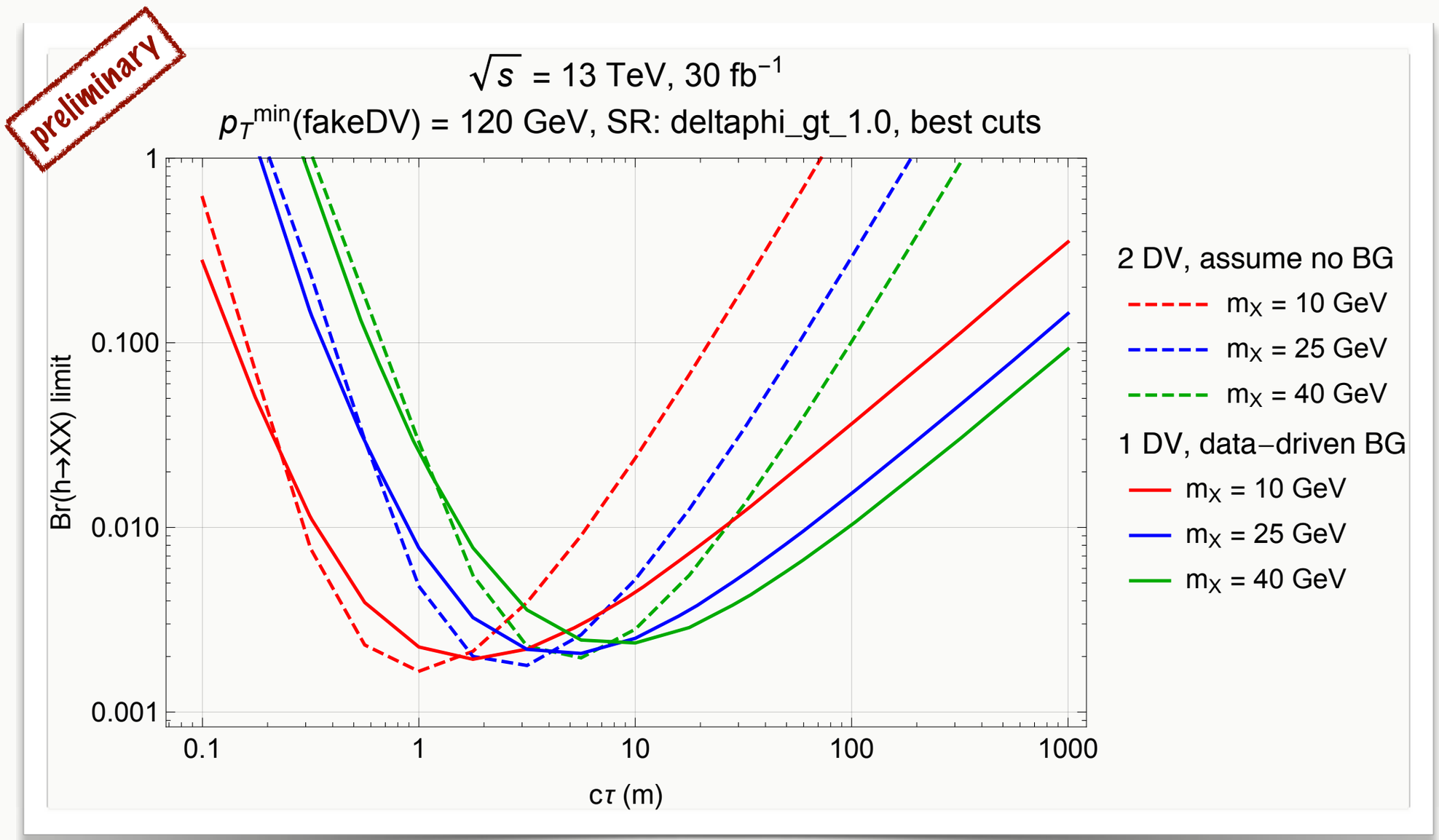
Example: Higgs decay to $X\,X$

- Dramatic enhancements in sensitivity at long lifetime:



[Coccaro, Curtin, Lubatti, Russell, JS, to appear]

Conclusions

- Displaced decays of BSM states are a major discovery opportunity at LHC Run II
  - Technically challenging searches, still areas of unexplored territory
- Solitary displaced leptons
  - possible hiding place for SUSY
  - several suggestions for increasing sensitivity of search program:
    - SF searches, modifications to disappearing track searches

Conclusions

- Single displaced vertex searches in the muon spectrometer
  - Not background-free: develop techniques to data-drive background predictions
  - Proof of concept: $h \rightarrow XX$, major gains for long-lived X
  - Provides jumping-off point for flexible, model-independent search program for displaced decays