Searches for Long-Lived Particles with the ATLAS Detector

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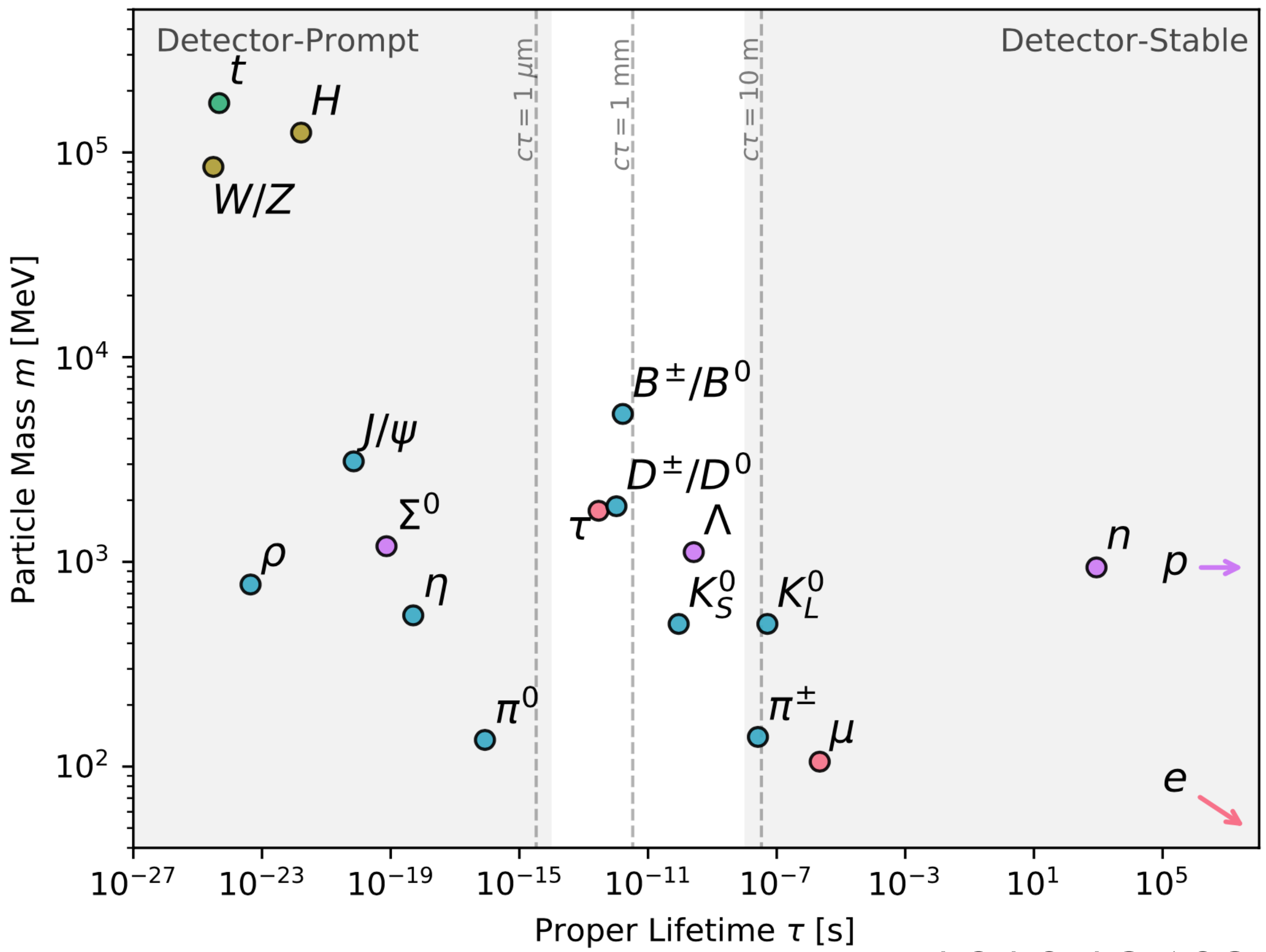
on behalf of the ATLAS Collaboration

Overview

- What are long lived particles? How do we search for them?
- Many LLP searches in ATLAS — I will focus on results that use the full Run 2 dataset (139 fb^{-1} of pp data at $\sqrt{s}$ = 13 TeV)
    - Search for R-Parity Violating (RPV) SUSY → displaced vertices and muon signatures
    - Search for Gauge Mediated Supersymmetry Breaking (GMSB) SUSY → displaced leptons — **new today!**
    - Brief sampling of some previous results

Long Lived Particles

- Standard Model is full of long lived particles!
  - Result from small couplings, near degenerate masses, heavy mediators



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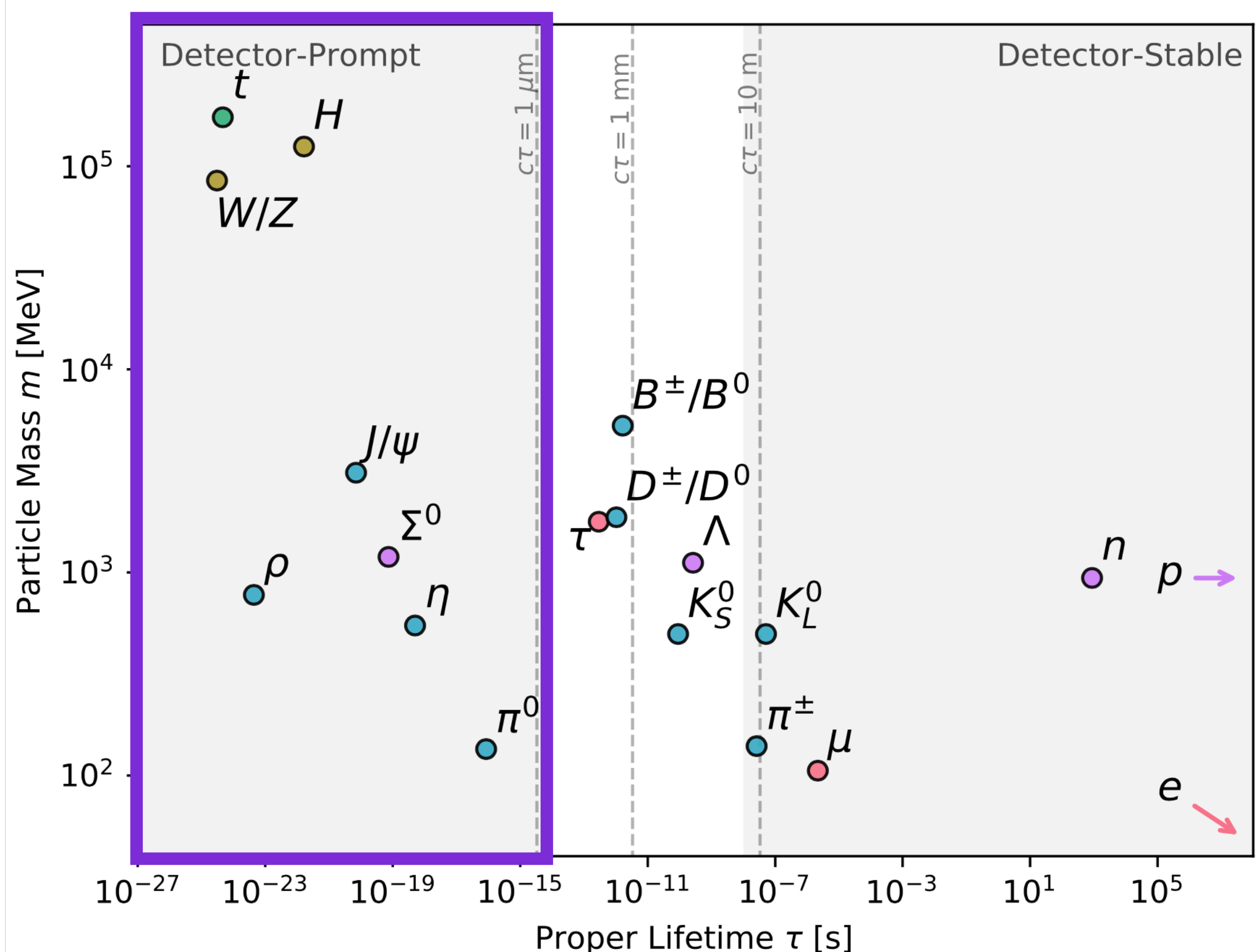

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look for decay products
most BSM searches
"prompt"

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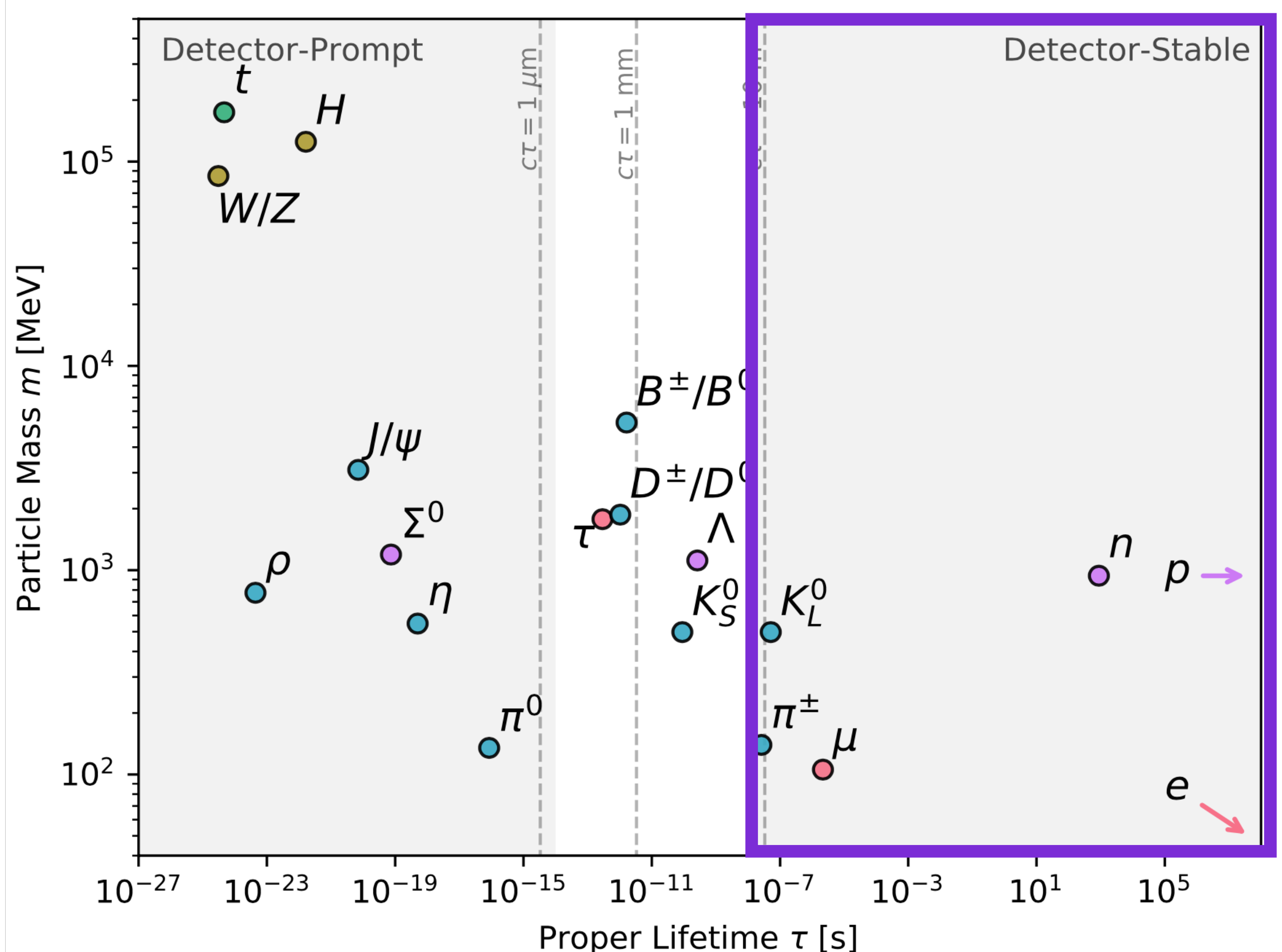

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measure directly "detector-stable"

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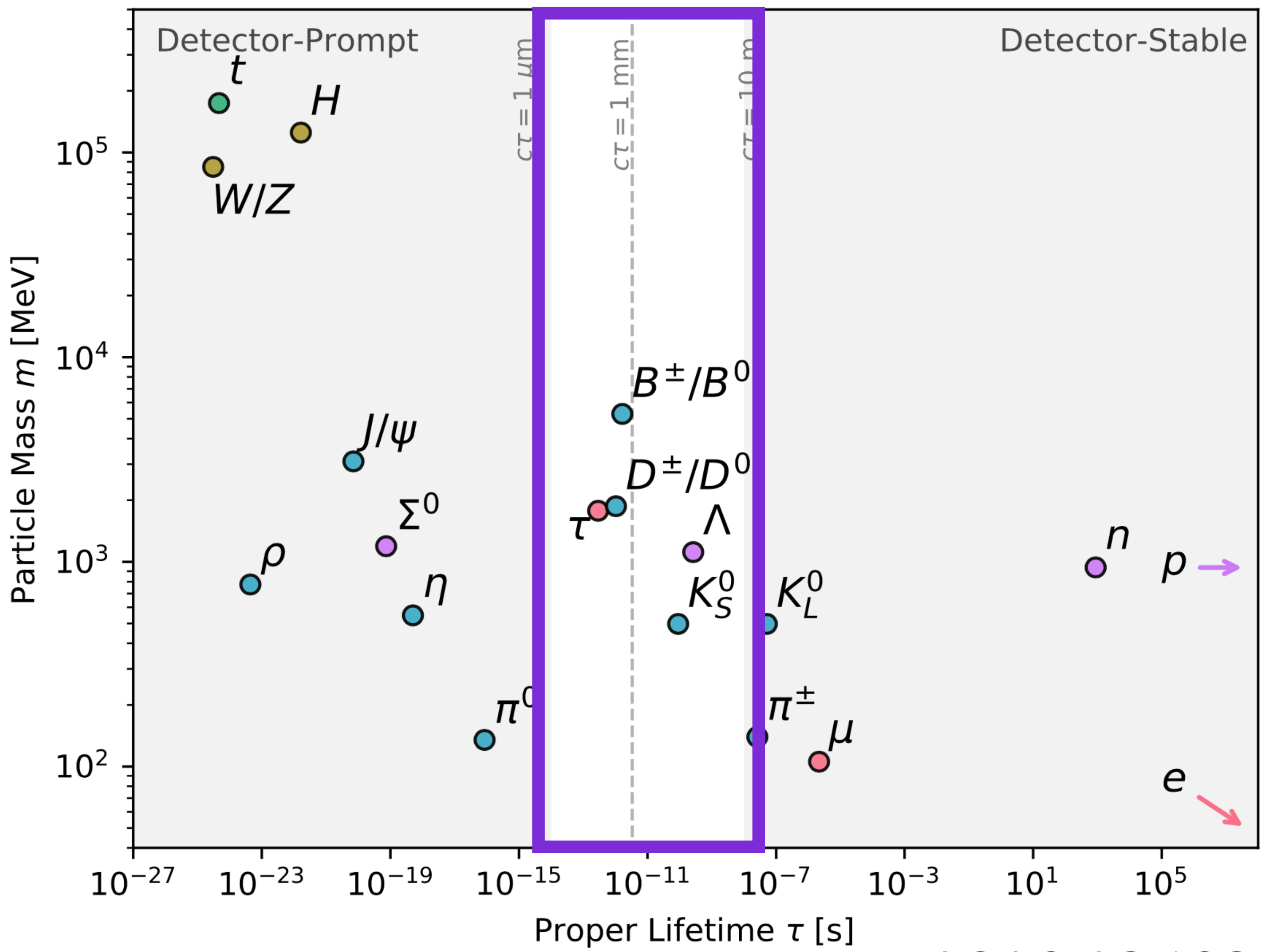

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reconstruct distinct signatures
"metastable"

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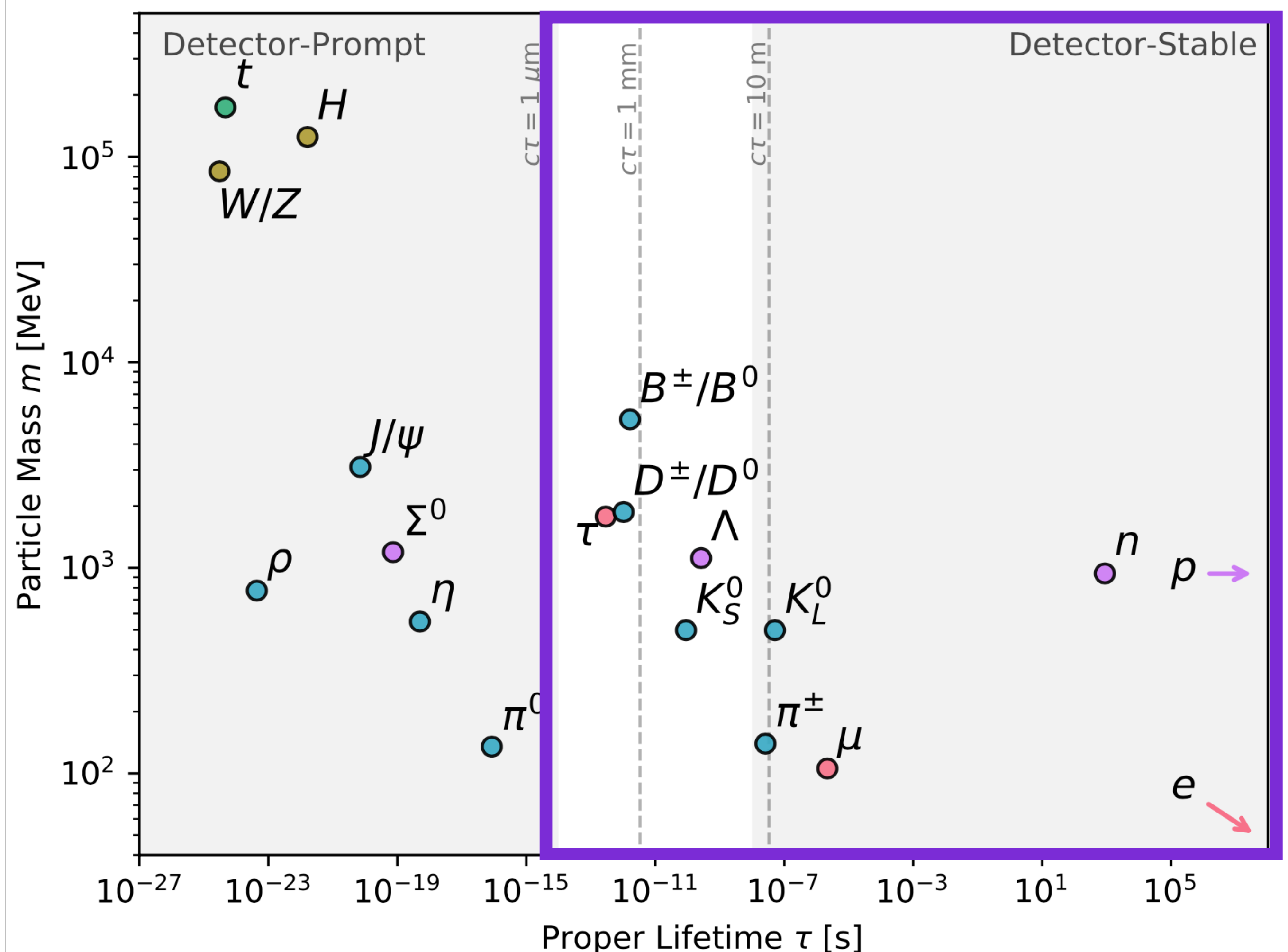

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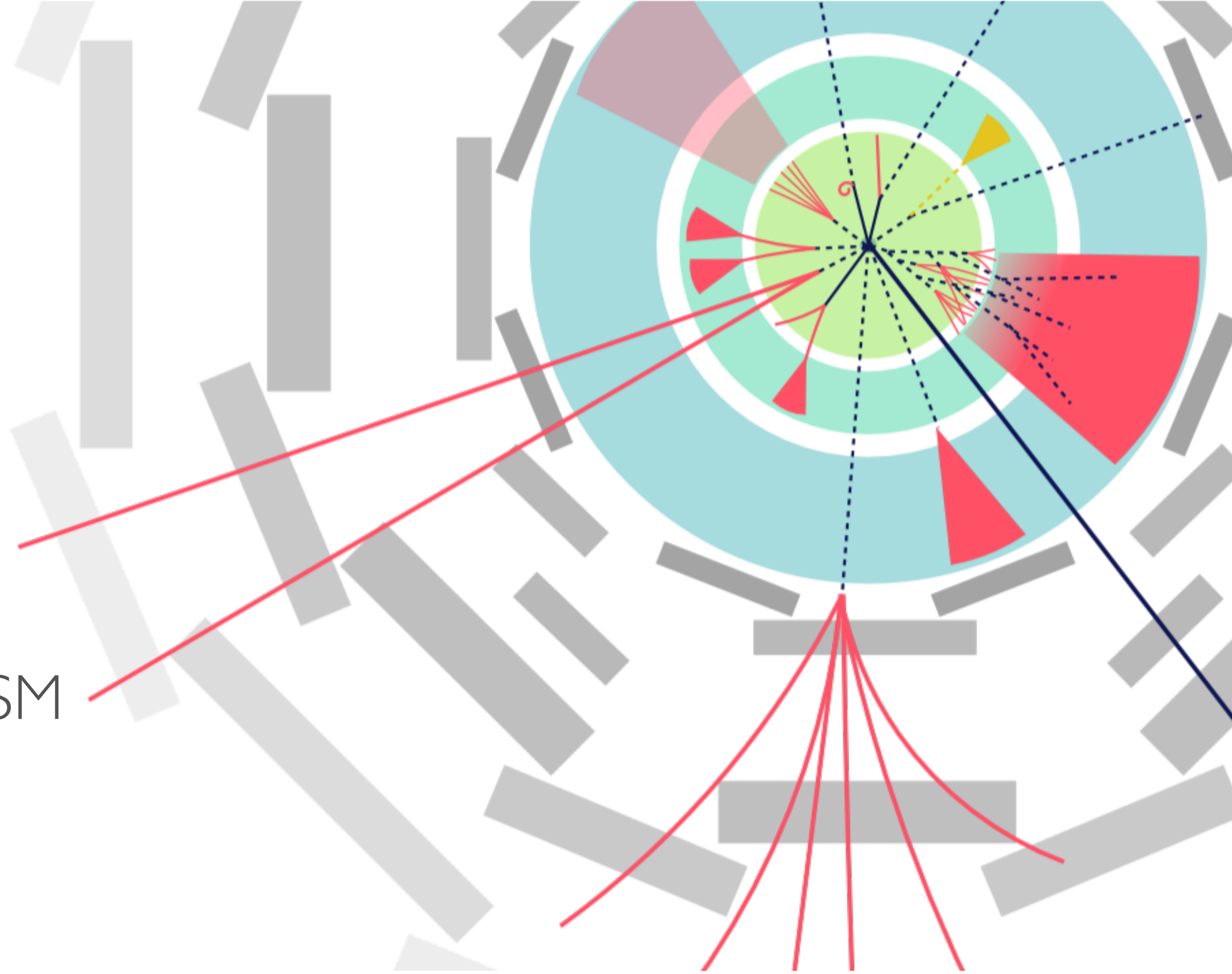
Long lived particles

Signatures

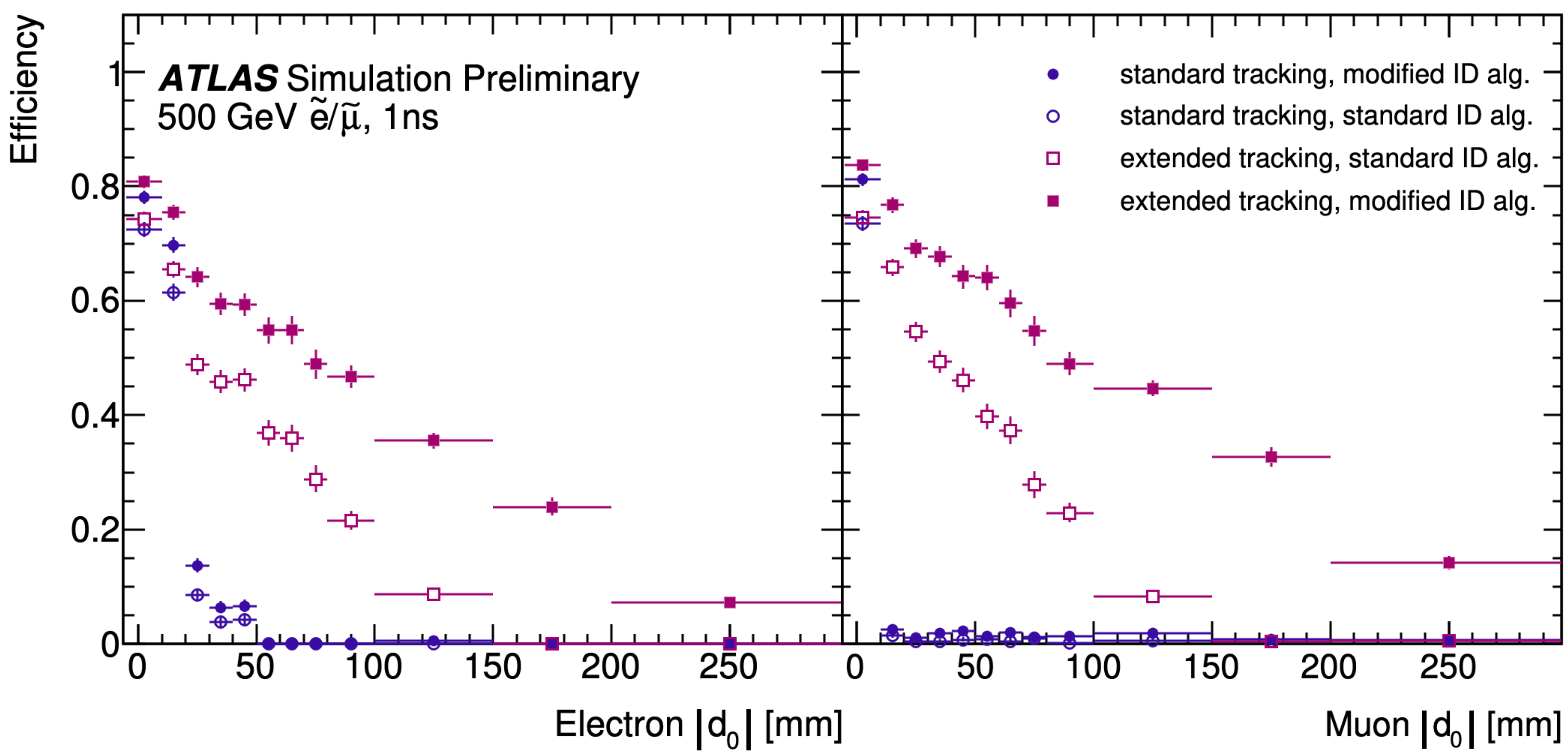


- Huge phase space of possible BSM signatures!
  - Requires dedicated effort
- Technically, very challenging
  - Identification of metastable SM particles require huge effort (e.g. b-jets, τ leptons)
- But, has several advantages:
  - Probe underexplored models that allow TeV-scale BSM physics!
  - Unconventional signatures have no irreducible SM background
    - Probe small cross sections
    - Signature focused searches can be applied to many BSM models

Technical Challenges

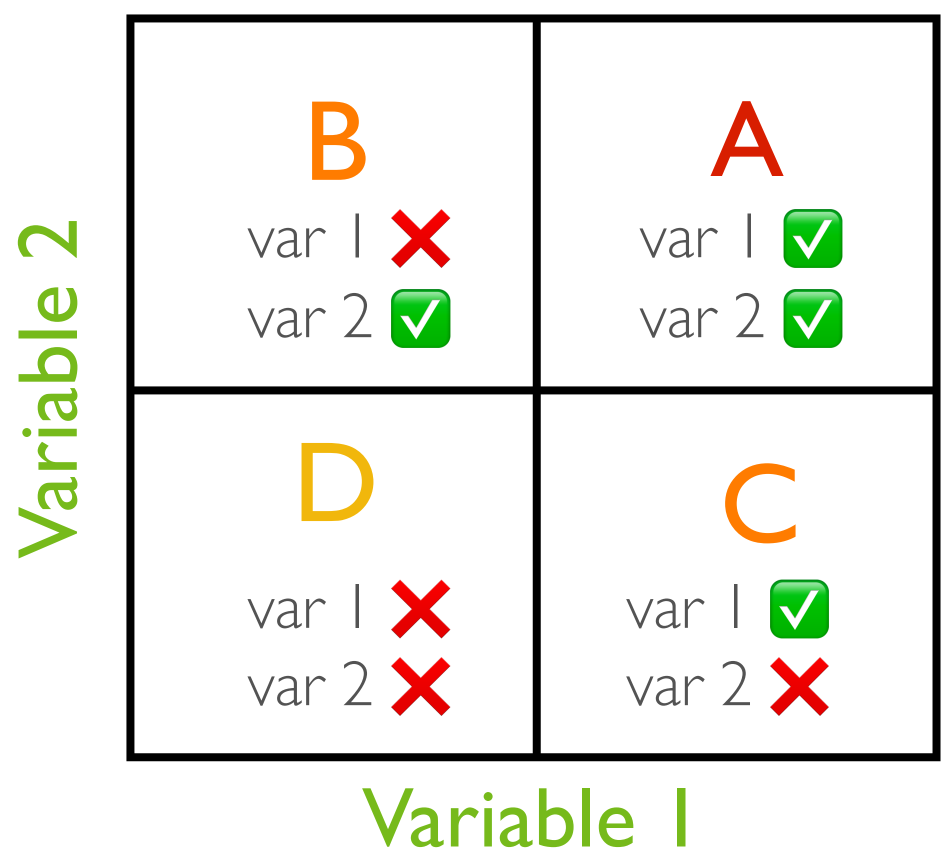
d_0 is the distance of closest approach to the interaction point of a track in the x-y plane

- Suite of techniques and algorithms must be developed to probe non-standard signatures — requires collaboration across community
  - Custom tracking for impact parameters (d_0) up to 300 mm
  - Modified identification algorithms for displaced objects
  - Displacement-independent quality requirements need to be defined



Background Challenges

- Lack of SM background means that backgrounds are not well modeled in MC
  - Common backgrounds from interactions with detector material, high-d_0 tails of heavy flavor decays, cosmic-ray muons
  - Must be estimated in data → typically statistically limited, need clever regions to maintain blinding
- Often use ABCD method — use 2 uncorrelated variables in the signal selection to make an estimate

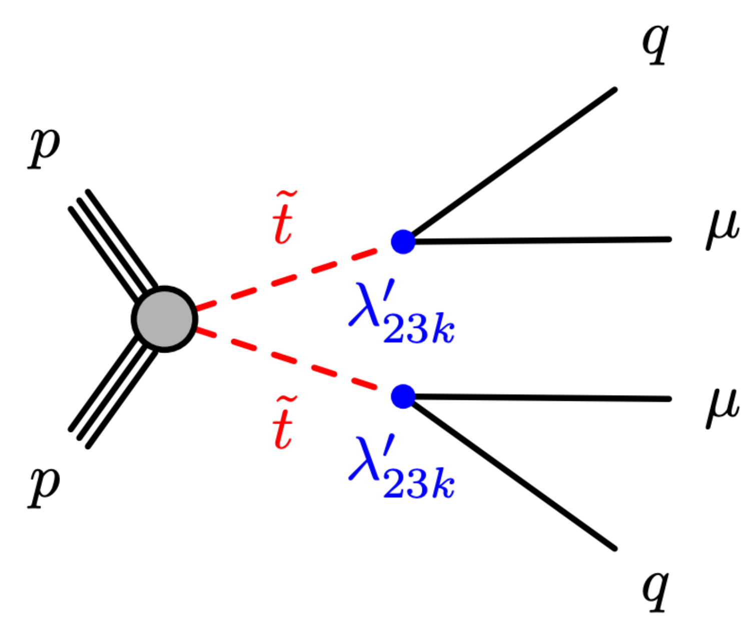


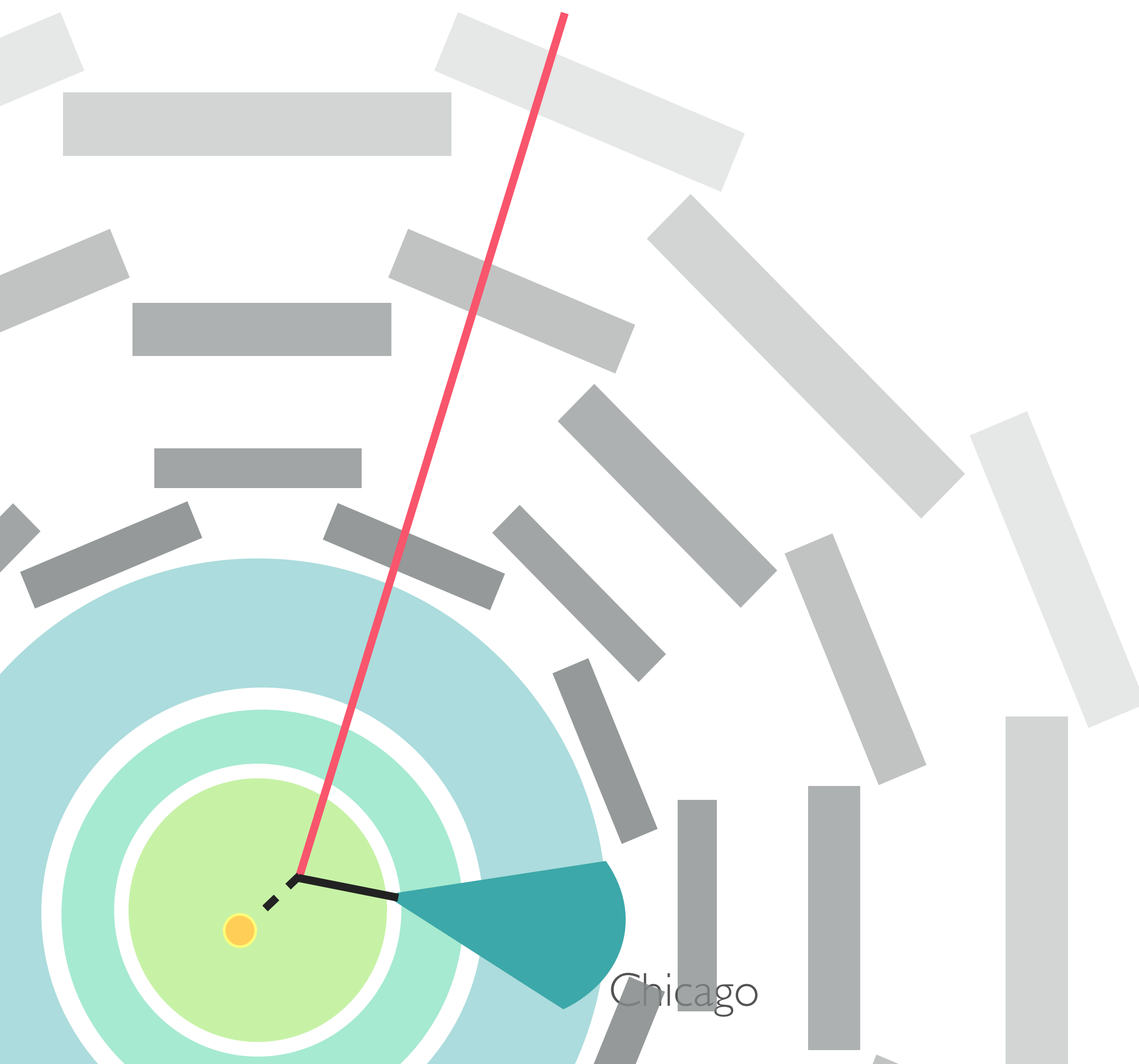
$$N_A = N_C \times \frac{N_B}{N_D}$$

Displaced Vertex + Muon

2003.11956

- High mass displaced vertex (DV) + muon with large d_0
  - Sensitivity to R-parity violating (RPV) SUSY
  - Small RPV coupling leads to long-lived stop lightest Supersymmetric Particle (LSP)





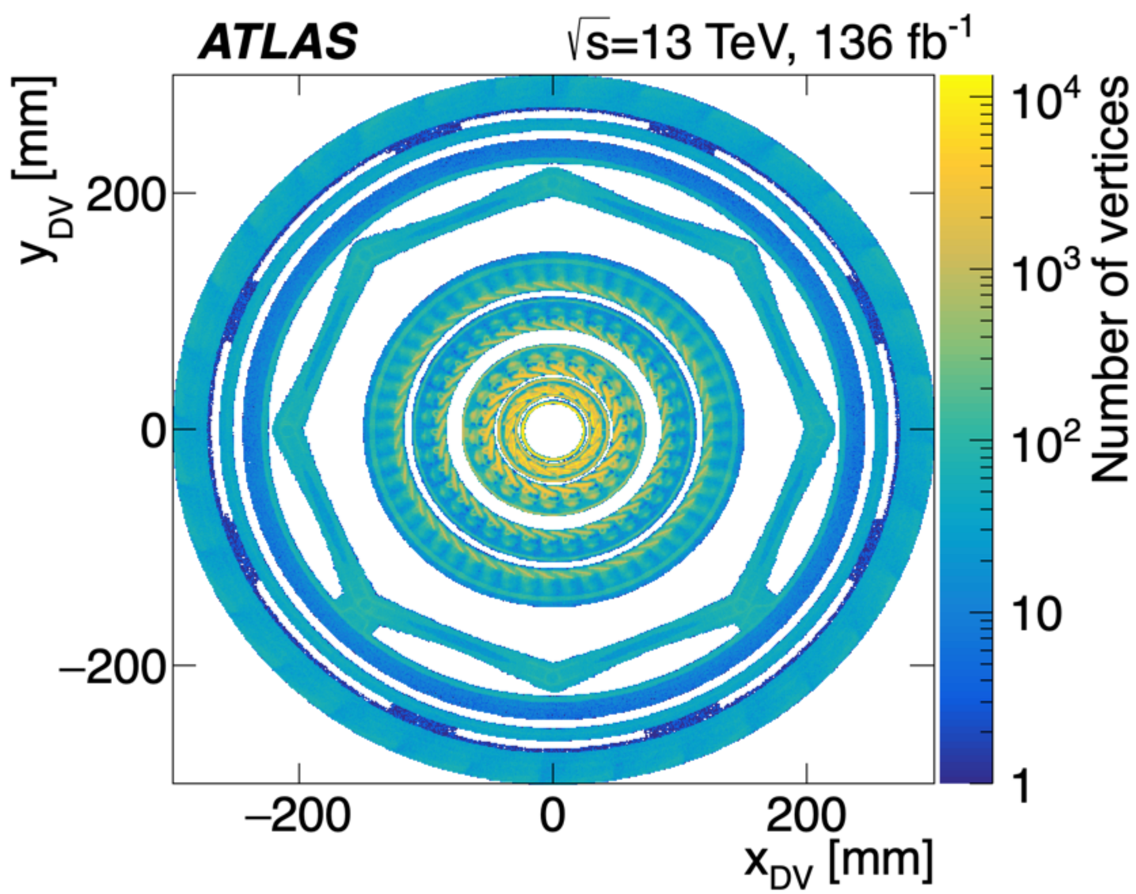
- Significant improvements over Run 1 analysis
  - Improved vertexing increases selection efficiency by 20%
  - MET trigger used along with MS-only trigger to select events with displaced muons
    - Muons not included in trigger MET calculation

Displaced Vertex + Muon

2003.11956

- Signature mimicked by interactions with material, cosmic muons

Veto vertices originating in detector material
common to all analyses with DVs!



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Veto cosmic-ray muons —
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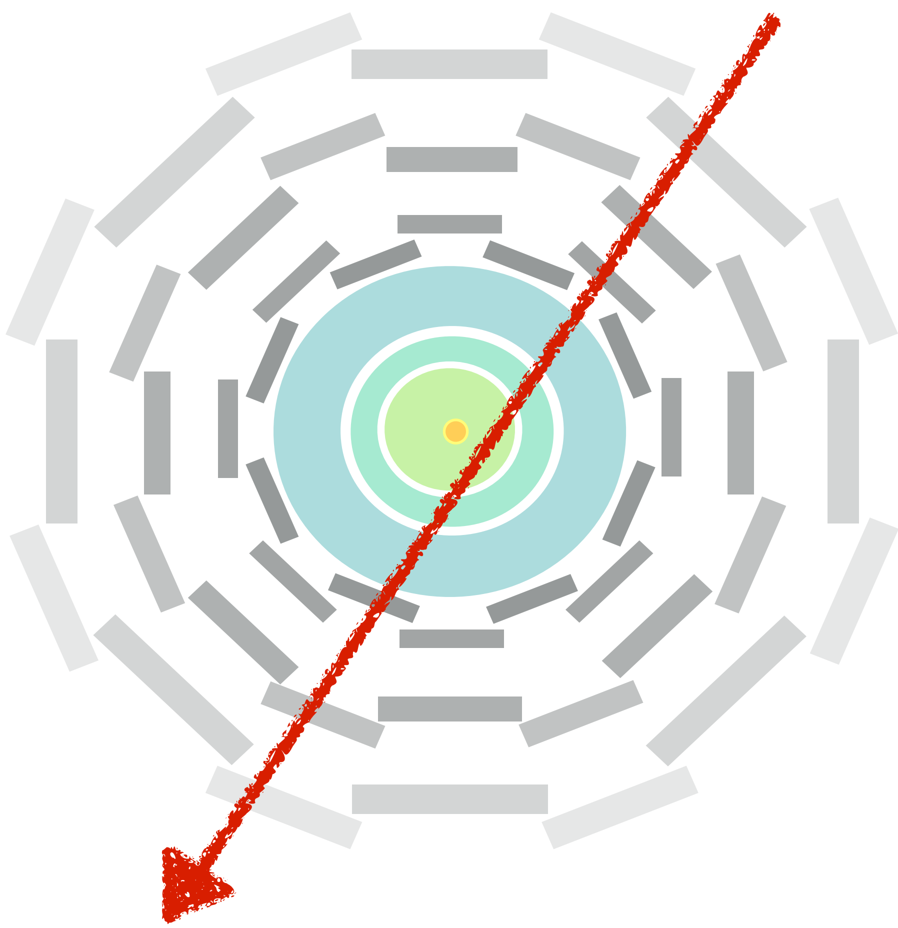

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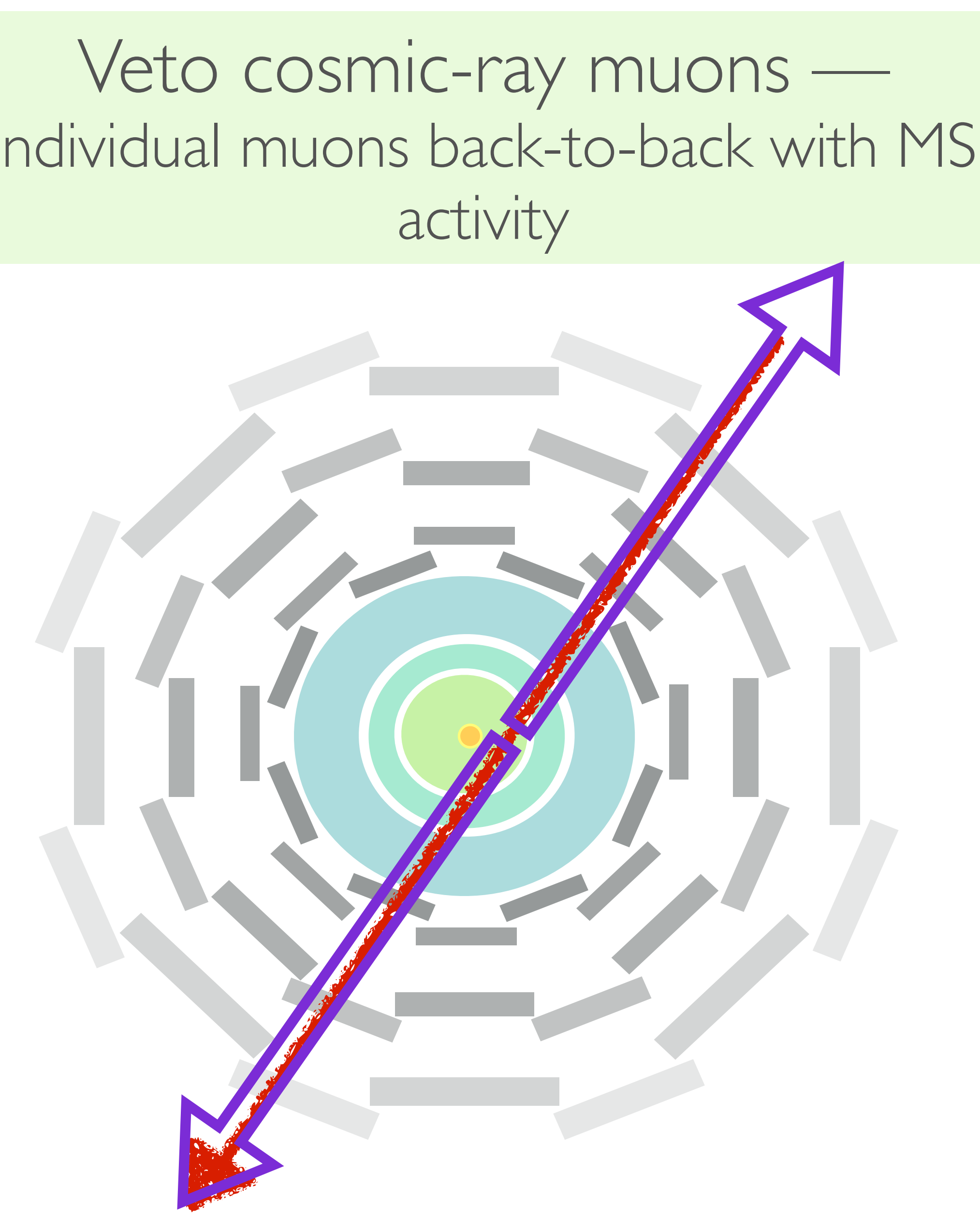

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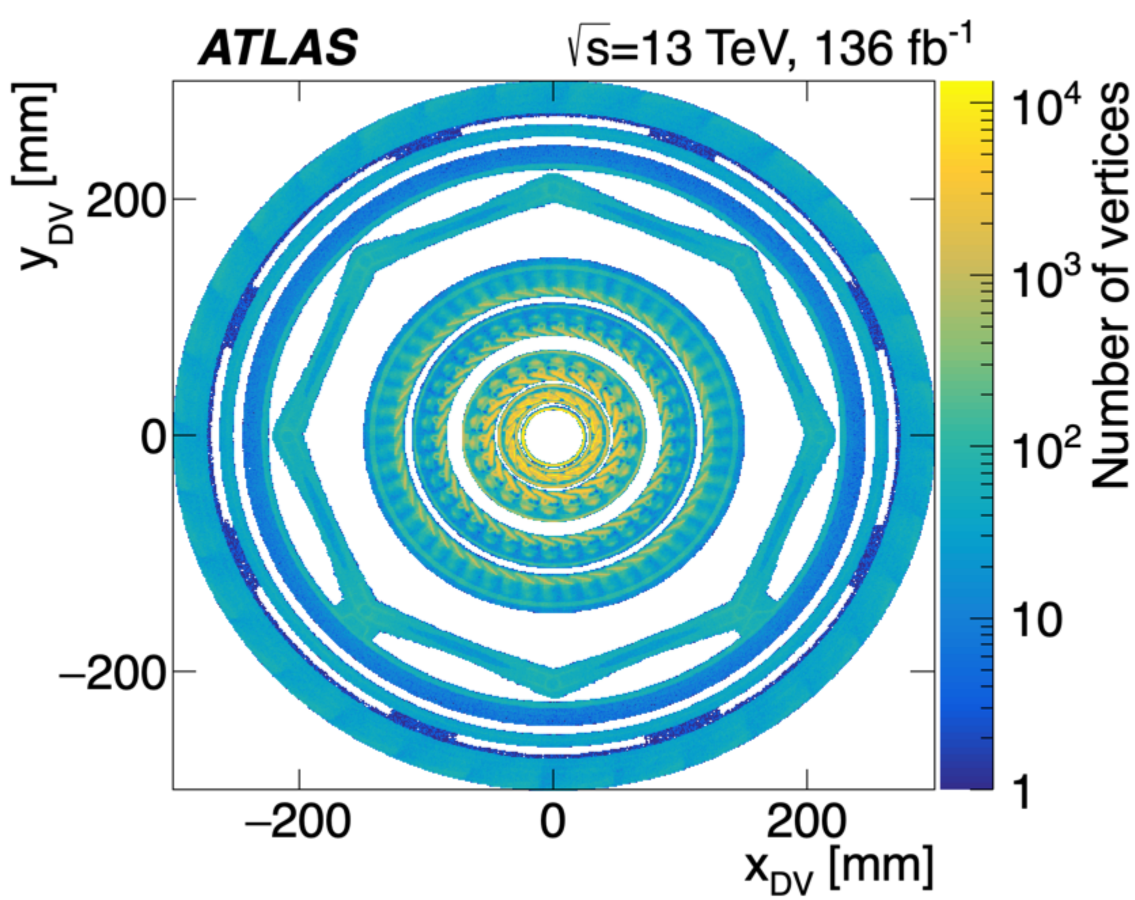

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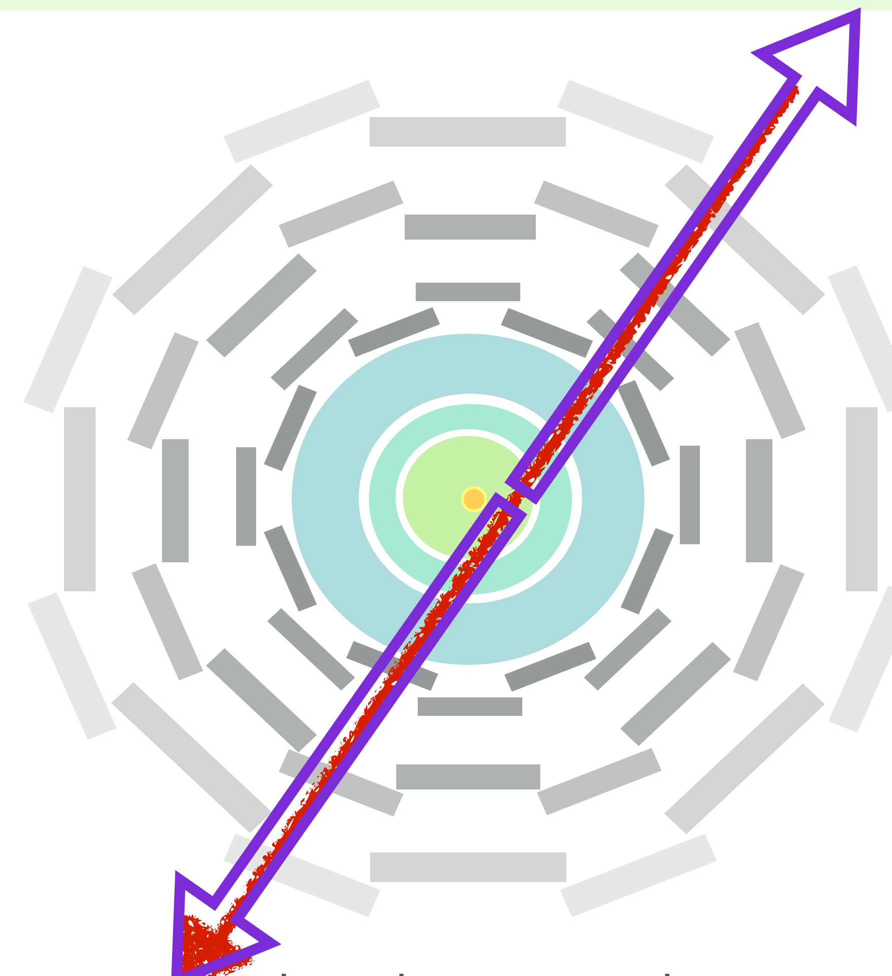
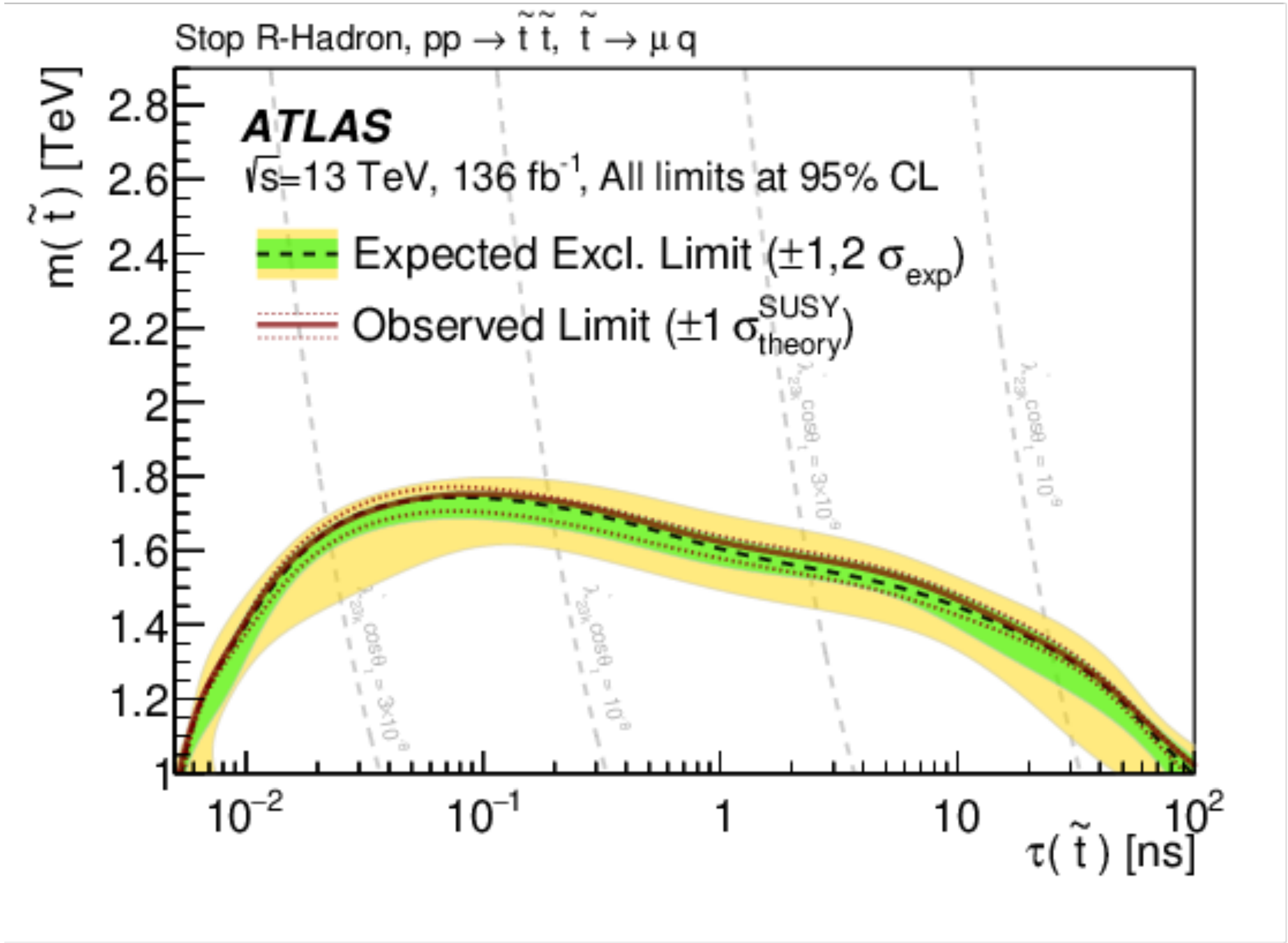


- Use lack of correlation between DV and muon in background to estimate number of events via ABCD

Displaced Vertex + Muon

2003.11956

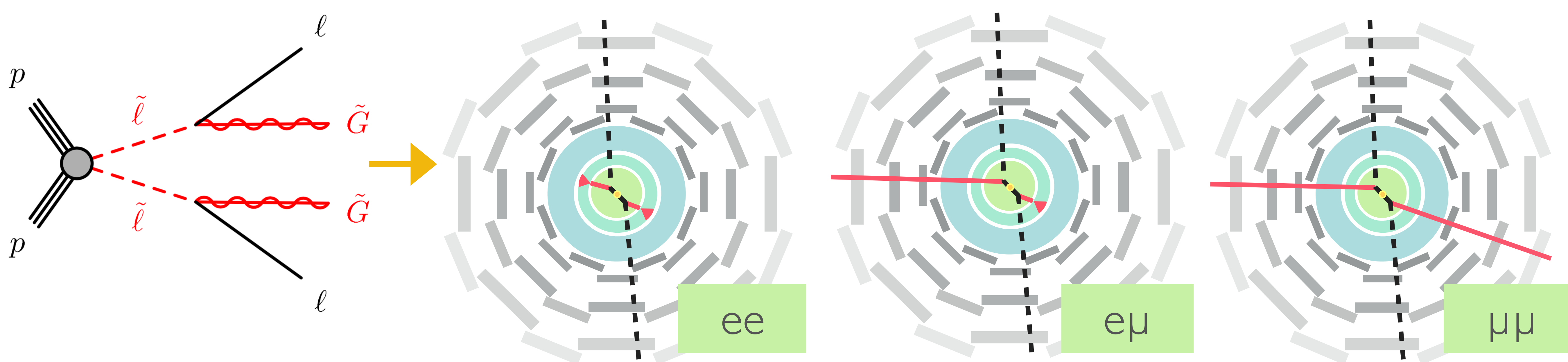
- Yields consistent with background — no SUSY here
- Exclude stop mass up to 1.75 TeV around ~0.1 ns lifetime.



Displaced Leptons

NEW

- Search for two leptons with high p_T and high d_0
  - Unique sensitivity to slepton in GMSB SUSY at the LHC
    - LSP gravitino, suppressed decay with no secondary vertex
    - Last limits at ~90 GeV from LEP (0507048, ALDO)
    - First LHC analysis to target this model with this signature



Displaced Leptons

- Nonstandard backgrounds estimated from data
  - New in LHC environment → need to determine *what* they are!

Algorithmic Fakes

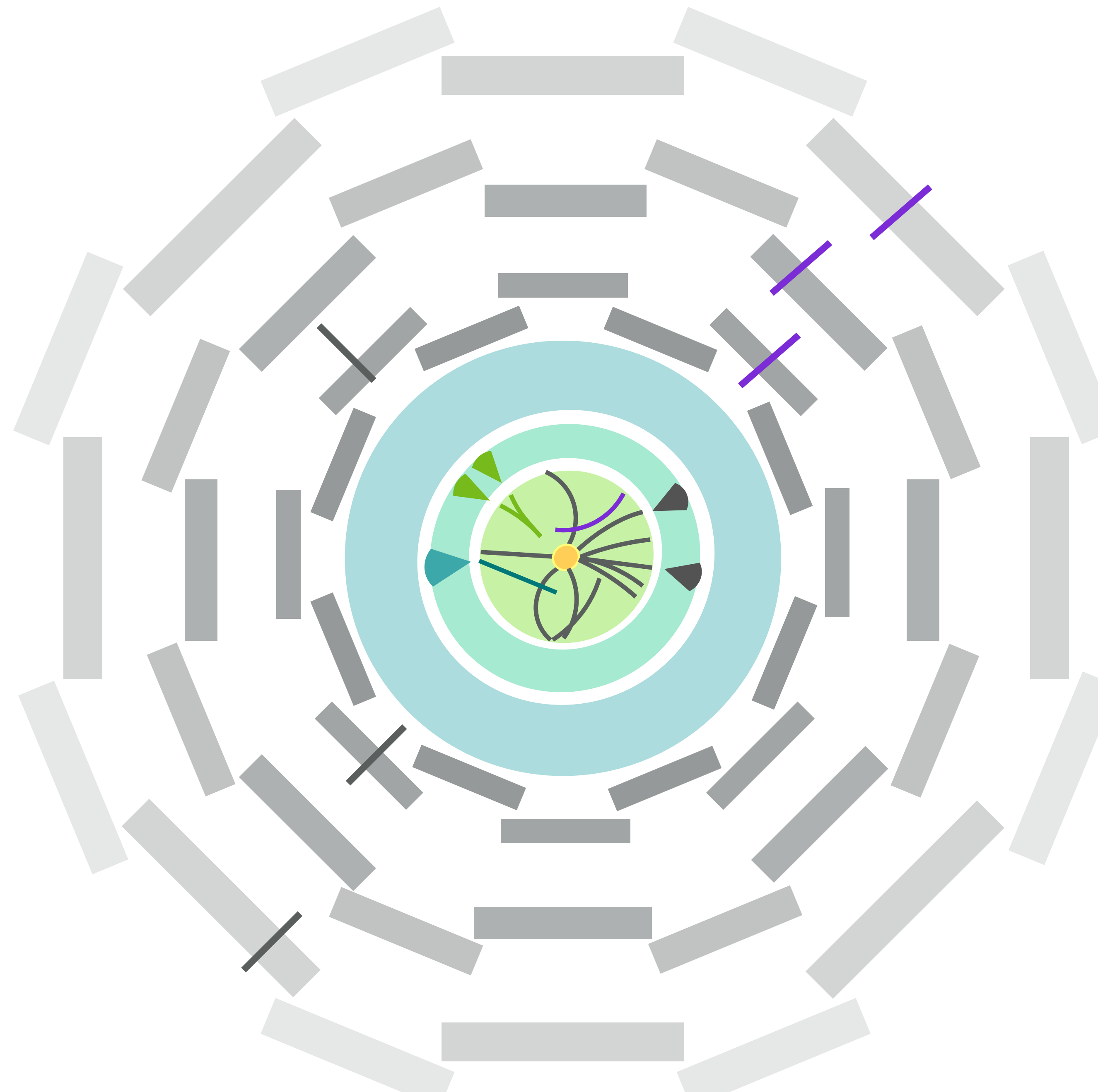
Extended tracking introduces more fake tracks

displacement-independent quality cuts defined to reduce contribution

Fake electrons more common than fake muons

2 in an event are uncorrelated → ABCD

ee and eμ channels



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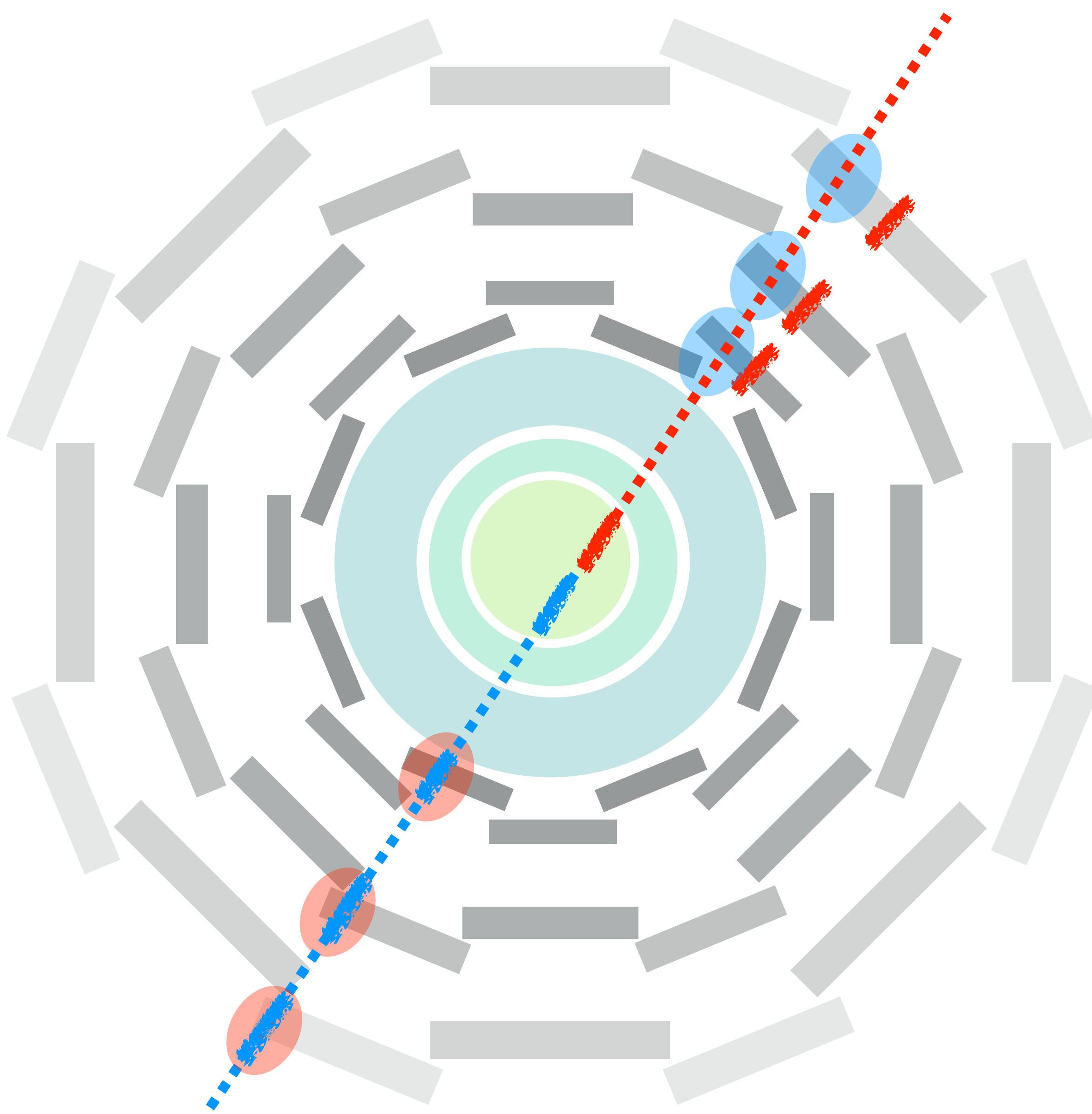


Cosmic Muons

Could reconstruct 2 high-d_0 correlated muons from 1 cosmic ray muon — challenging estimate for μμ channel!

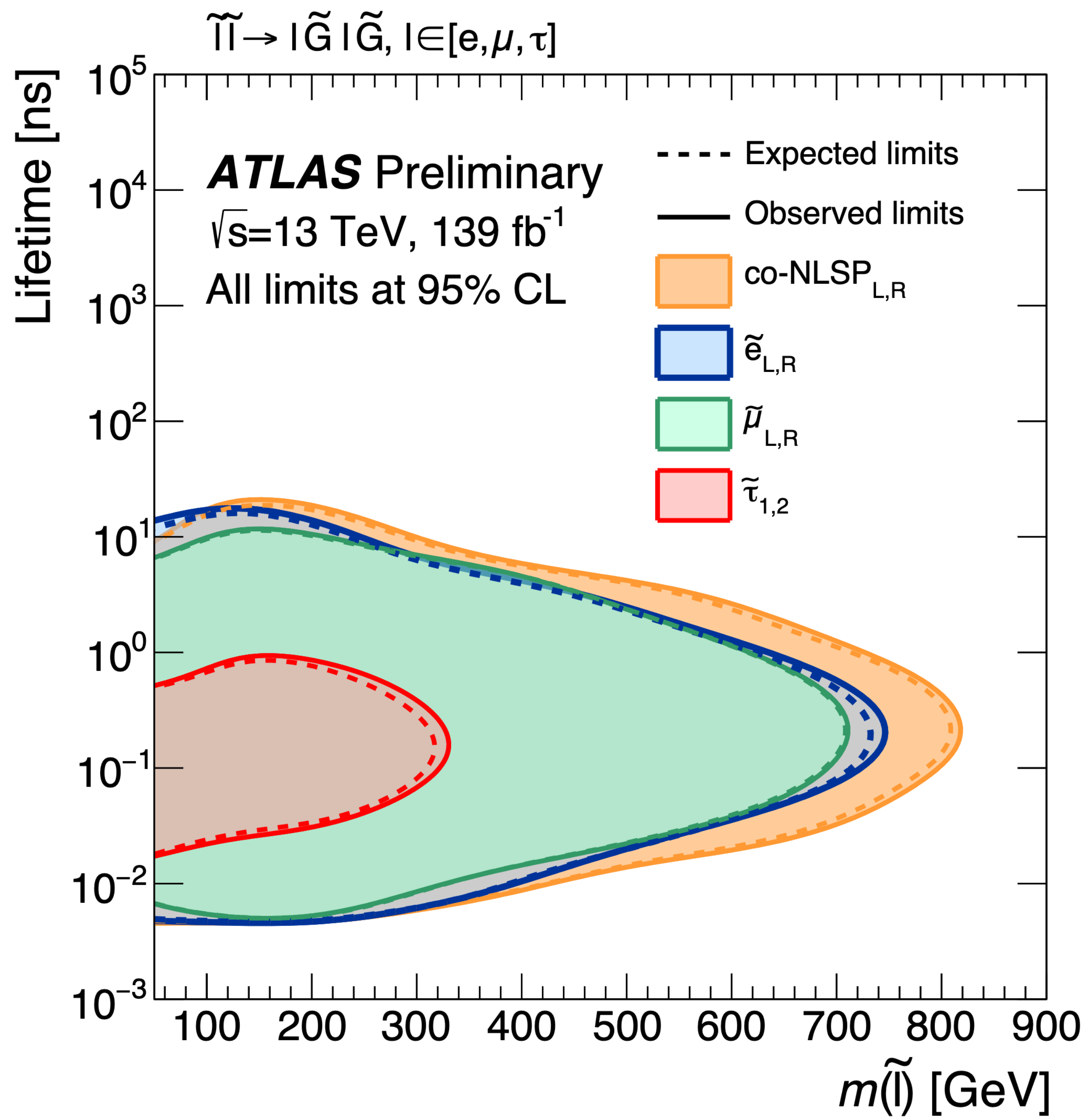
Time to traverse the detector ≈ bunch crossing

Muons missing detector info
→ other muon can't be ID'd as a cosmic
→ MS timing cut reduces contribution

Use de-correlation between muon quality and cosmic tag to do ABCD-like estimate

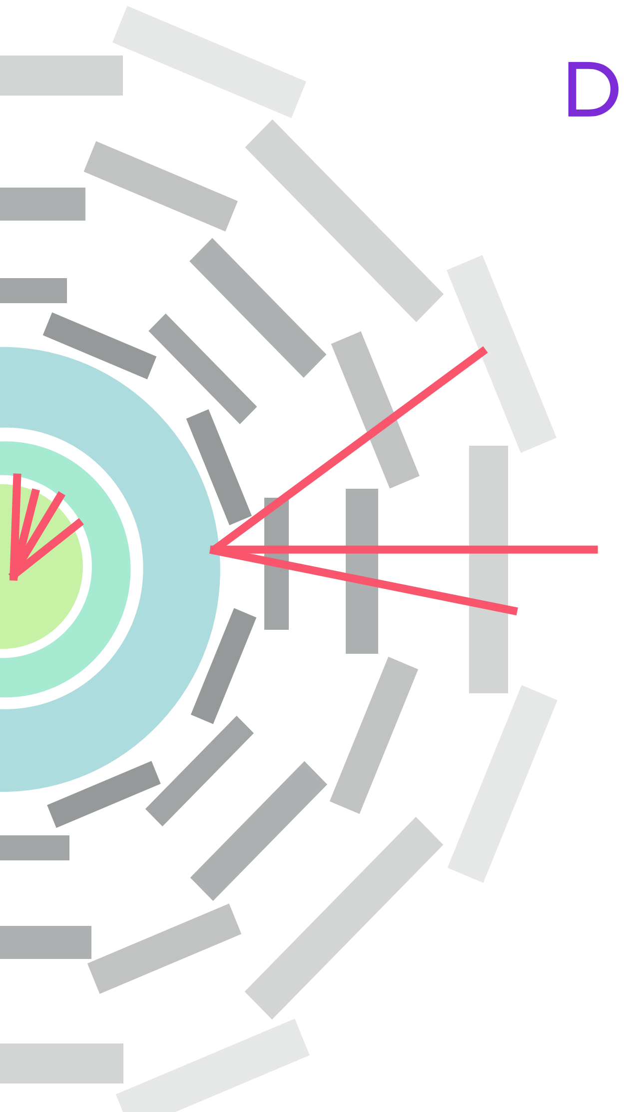
Displaced Leptons

- Expect < 1 event per region, observe 0 — no SUSY here either
- Exclude huge range of phase space previously under-explored!
  - Slepton co-NSLP scenarios up to 800 GeV for 0.1ns!



Lots of LLP searches in ATLAS!

- Many explorations of SUSY and exotic models with partial Run 2 dataset (34 fb^{-1}) with a variety of signatures

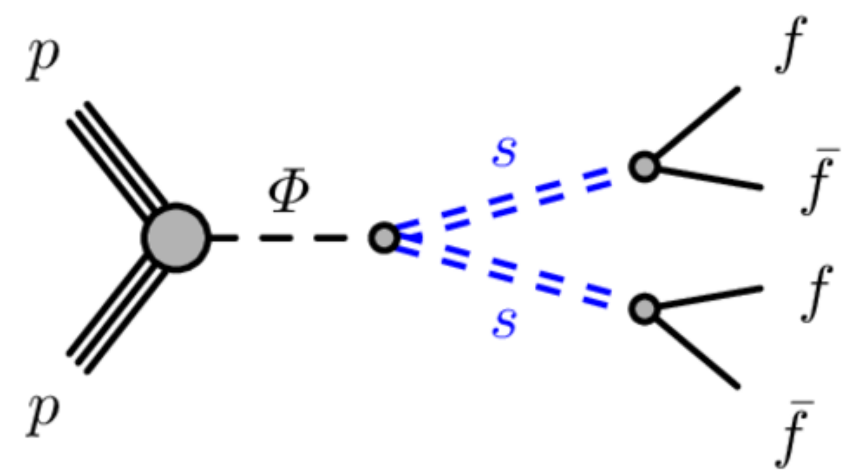


Displaced Vertices in the MS and ID (1911.12575)

Target hadronic signature of Hidden Sector model mediator **φ** decaying into long-lived scalars **s**

Vertexing in ID and MS
ID backgrounds from material interactions, MS from jets not fully absorbed by calorimeter

Exclude **ϕ** with mass 125 GeV to 1000 GeV
Exclude **s** with masses from 8 GeV to 400 GeV and lifetimes 0.1ns - 3ns



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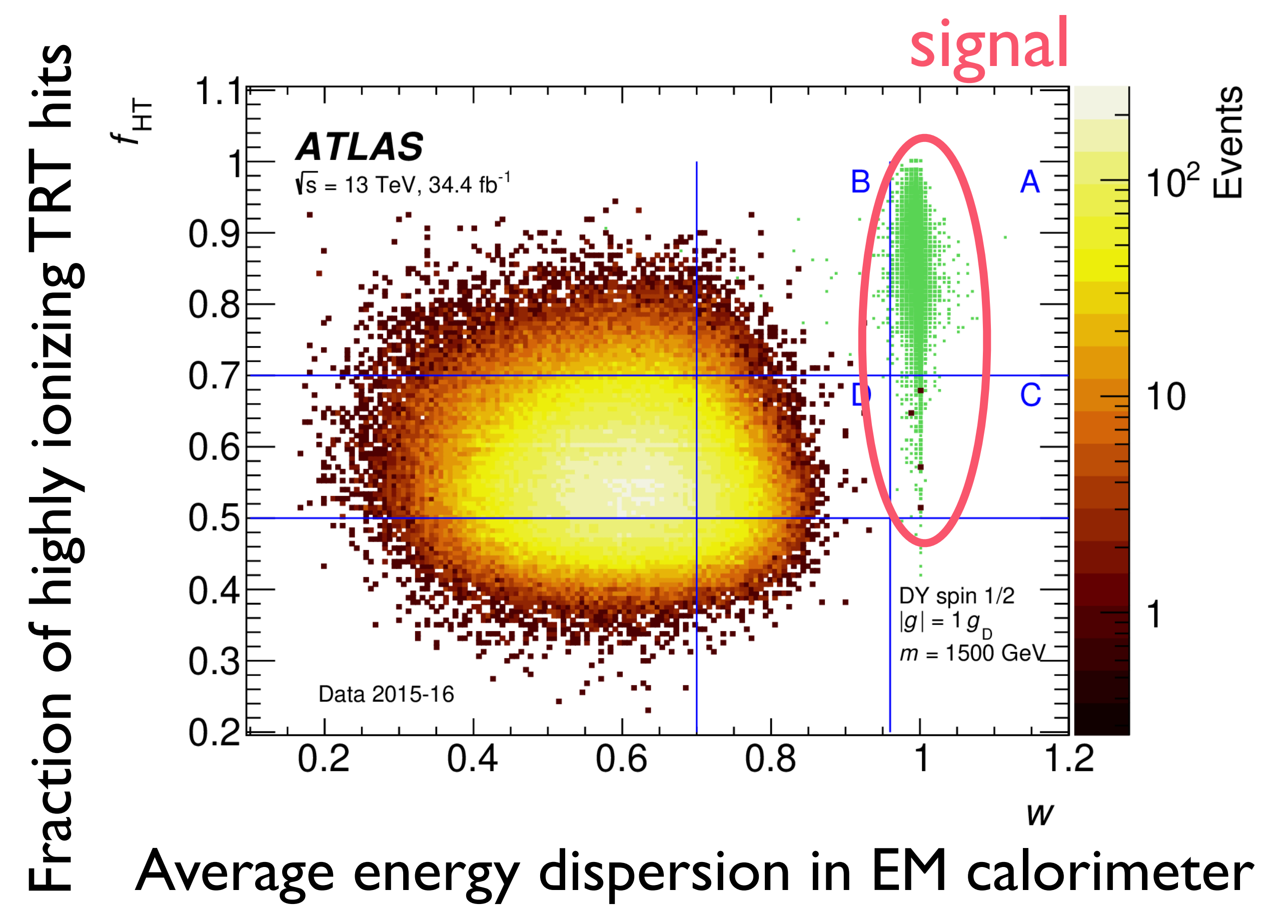
Magnetic Monopoles and High-Electric-Charge Objects (1905.10130)

5000x ionization vs MIP!

Leaves high ionization in Transition Radiation Tracker, very narrow signature in calorimeter

Exclude scalar monopole m < 1.85 TeV

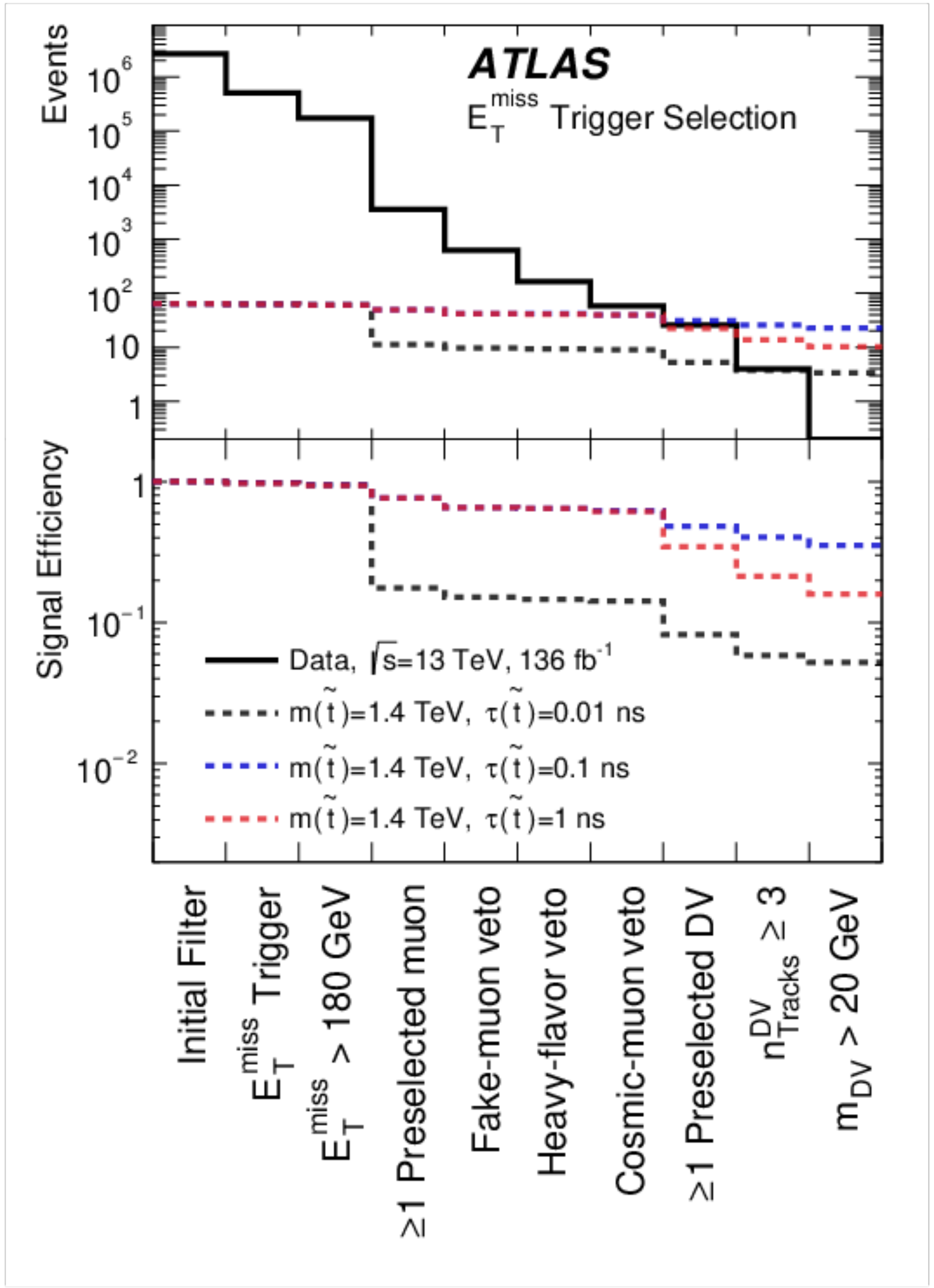


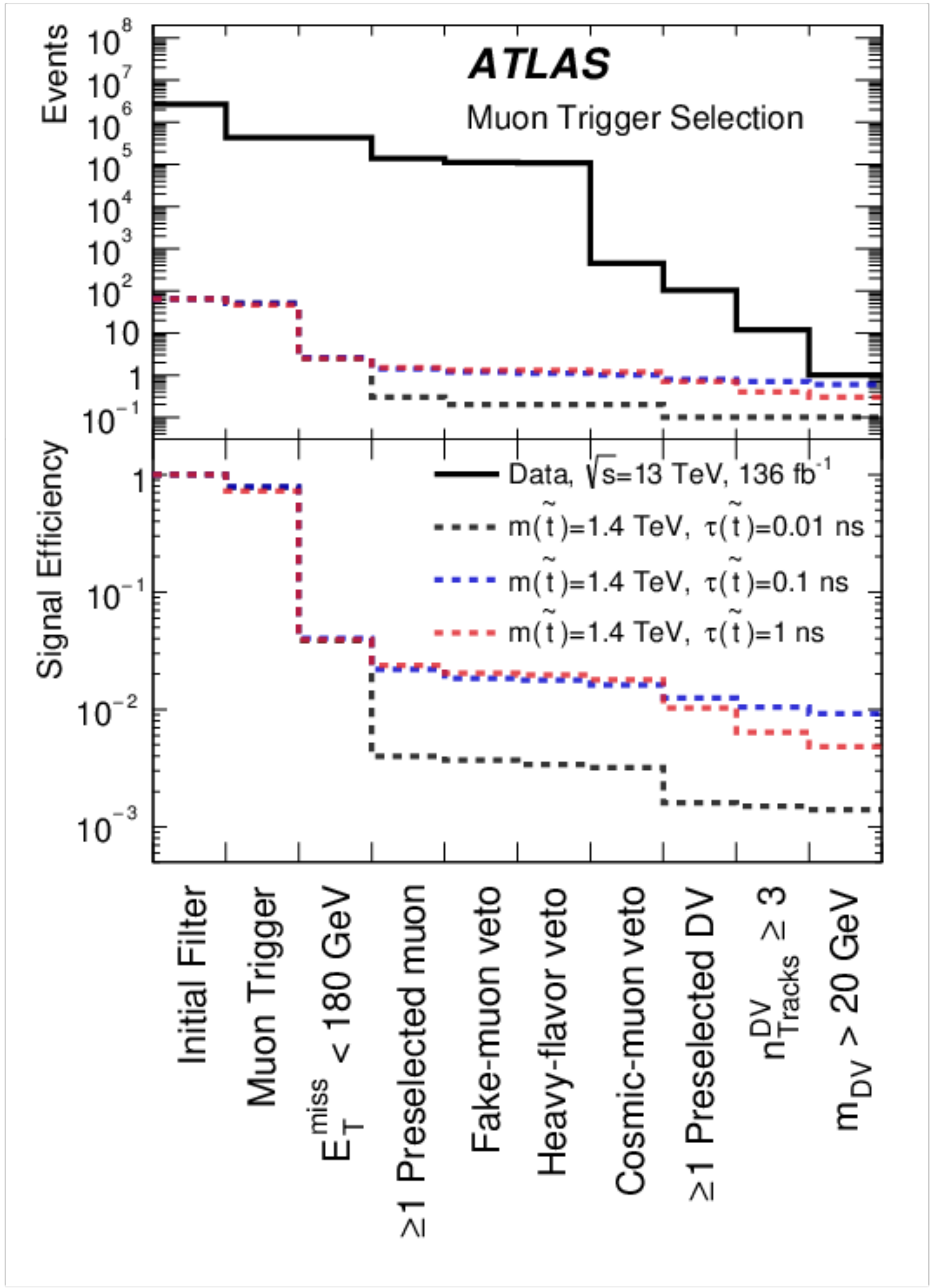
Conclusions

- Searches for LLPs are technically challenging, but allow us to explore lots of undercovered phase space and small cross sections
- Collaboration is crucial to develop non-standard algorithms
- Many more searches that I couldn't cover today
- Lots of LLP searches with Run 2 dataset in the works — stay tuned!

Backup

Displaced Vertex + Muon





Displaced Leptons

- Event selection:
  - 2 signal leptons with p_T > 65 GeV, d_0 > 3 mm
  - dR_{ll} > 0.2
  - No cosmic-tagged muons
  - ID tracks associated to leptons
    - χ^2 < 2, # missing hits after the first hit < 2
  - Signal Muons
    - Combined track χ^2 < 3, hits in 3 precision tracking layers in MS, direct φ measurement, isolated in calorimeter and tracker
  - Signal Electrons
    - (track p_T - electron p_T)/electron p_T > 0.5, isolated in calorimeter and tracker

Displaced Leptons

- Fakes and heavy flavor impossible to disentangle in electrons, separate estimate for muons found to be negligible

Region	SR-ee	SR-$\mu\mu$	SR-$e\mu$
Fake + Heavy-Flavor	0.46 ± 0.10	–	$0.007^{+0.019}_{-0.007}$
Cosmics	–	$0.11^{+0.20}_{-0.11}$	–
Expected Background	0.46 ± 0.10	$0.11^{+0.20}_{-0.11}$	$0.007^{+0.019}_{-0.007}$
Observed events	0	0	0

Displaced Vertices in ID and MS

	Background events	Muon RoI Cluster trigger events with a good MSVx
Has IDVx passing full signal selection	*Bkg+IDVx*	*Sig*
Agnostic to IDVx	*Bkg*	*Sig–IDVx*

	n_{obs}	
Region *Bkg*	6,099,660	
Region *Bkg+IDVx*	45	
Region *Sig–IDVx*	156,805	
	n_{pred}	n_{obs}
Region *Val*, 2-*trk*	$11,269 \pm 46$ (stat.)	11,470
Region *Trig*, 3-*trk*	1750 ± 64 (stat.)	2132
Region *Sig*	1.16 ± 0.18 (stat.) ± 0.29 (syst.)	1

Magnetic Monopoles

Lower limits on the mass of Drell–Yan magnetic monopoles and HECOs [GeV]

	$\|g\| = 1g_D$	$\|g\| = 2g_D$	$\|z\| = 20$	$\|z\| = 40$	$\|z\| = 60$	$\|z\| = 80$	$\|z\| = 100$
Spin-0	1850	1725	1355	1615	1625	1495	1390
Spin-1/2	2370	2125	1830	2050	2000	1860	1650

g is the fundamental magnetic charge
z is the electric charge of a HECO