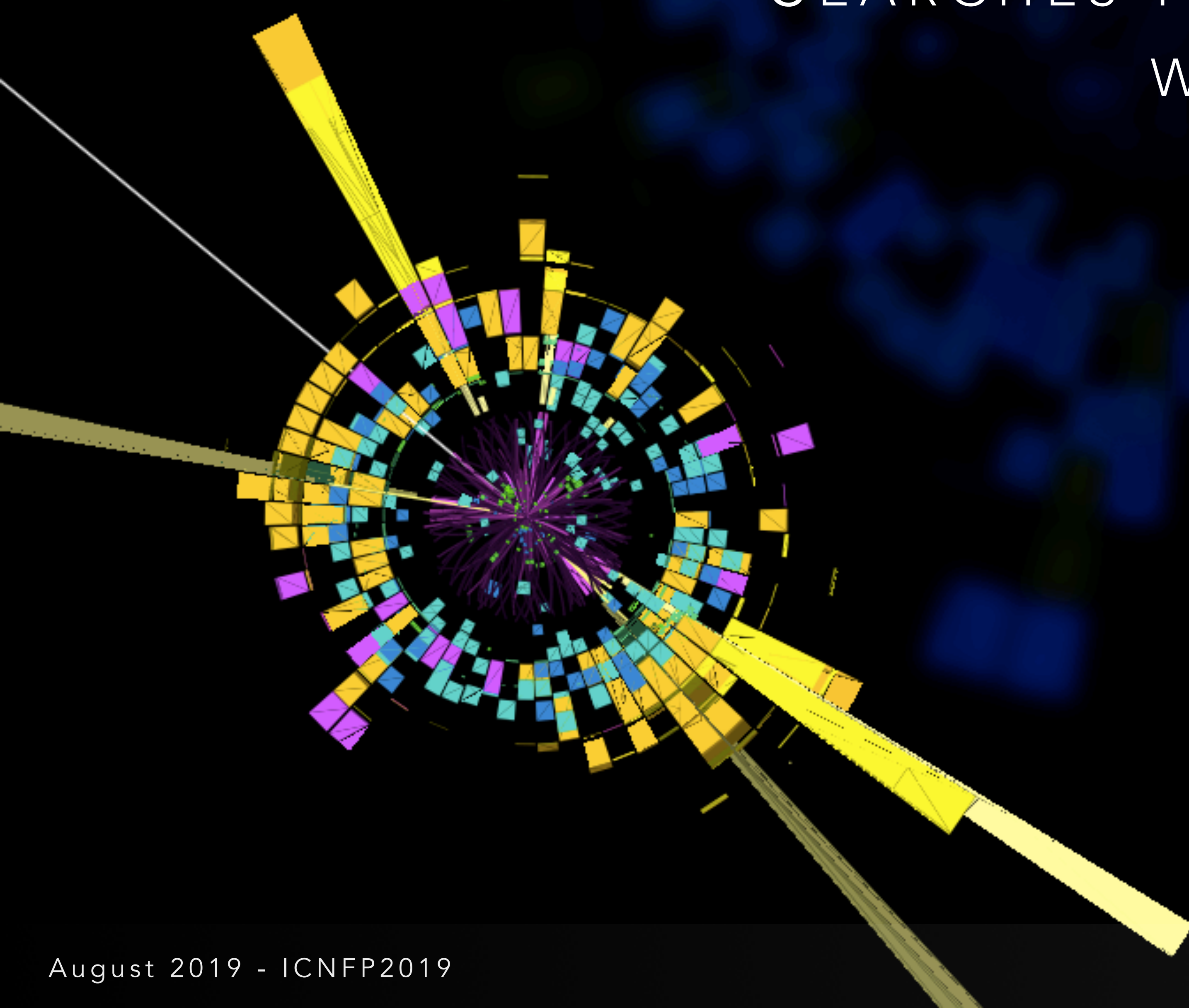
Searches for Long-lived Particles with the ATLAS detector

Lawrence Lee
On behalf of the ATLAS Collaboration



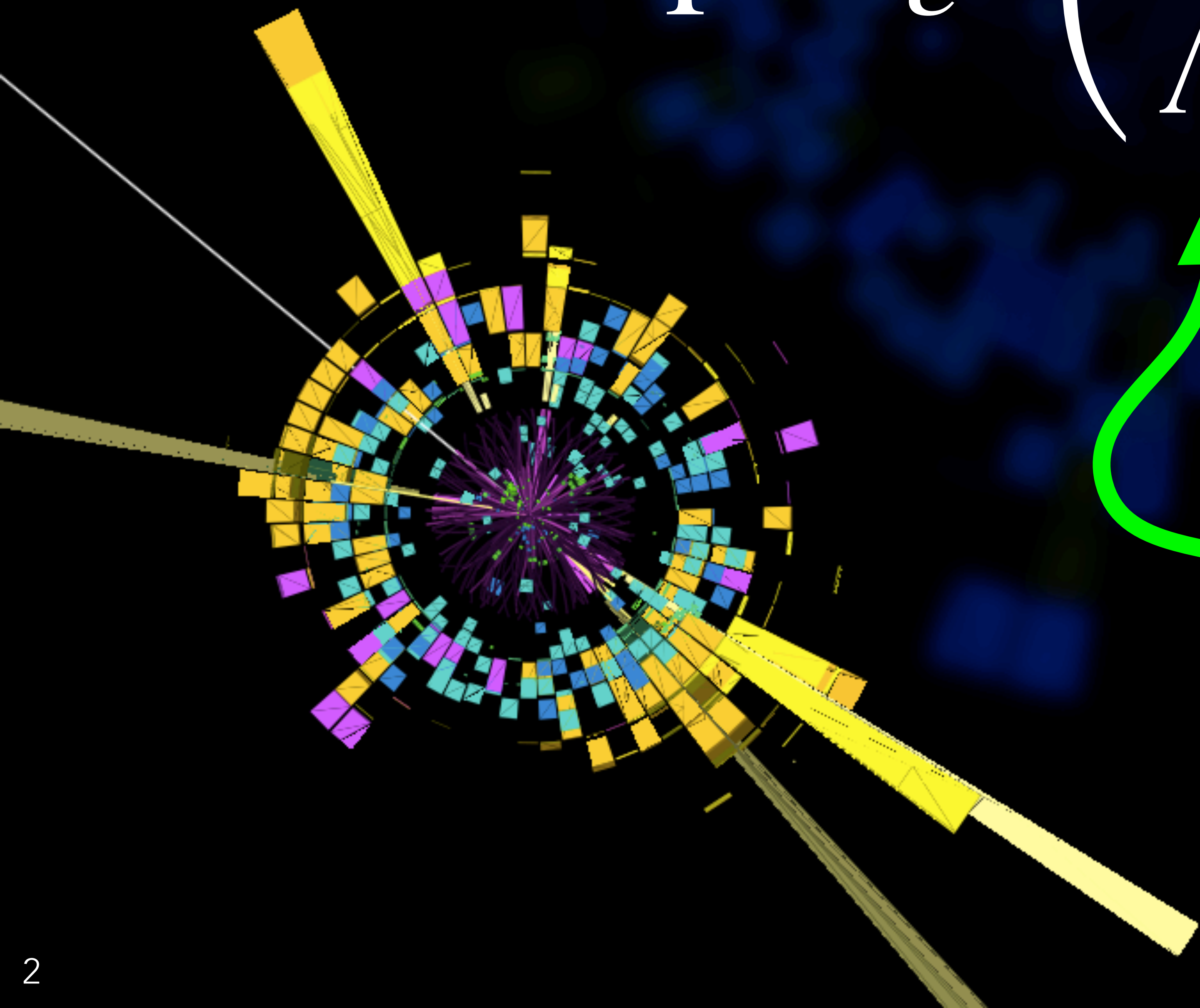
Particles can gain a large lifetime (small **Γ**) a number of ways

Small couplings
(e.g. RPV decays)

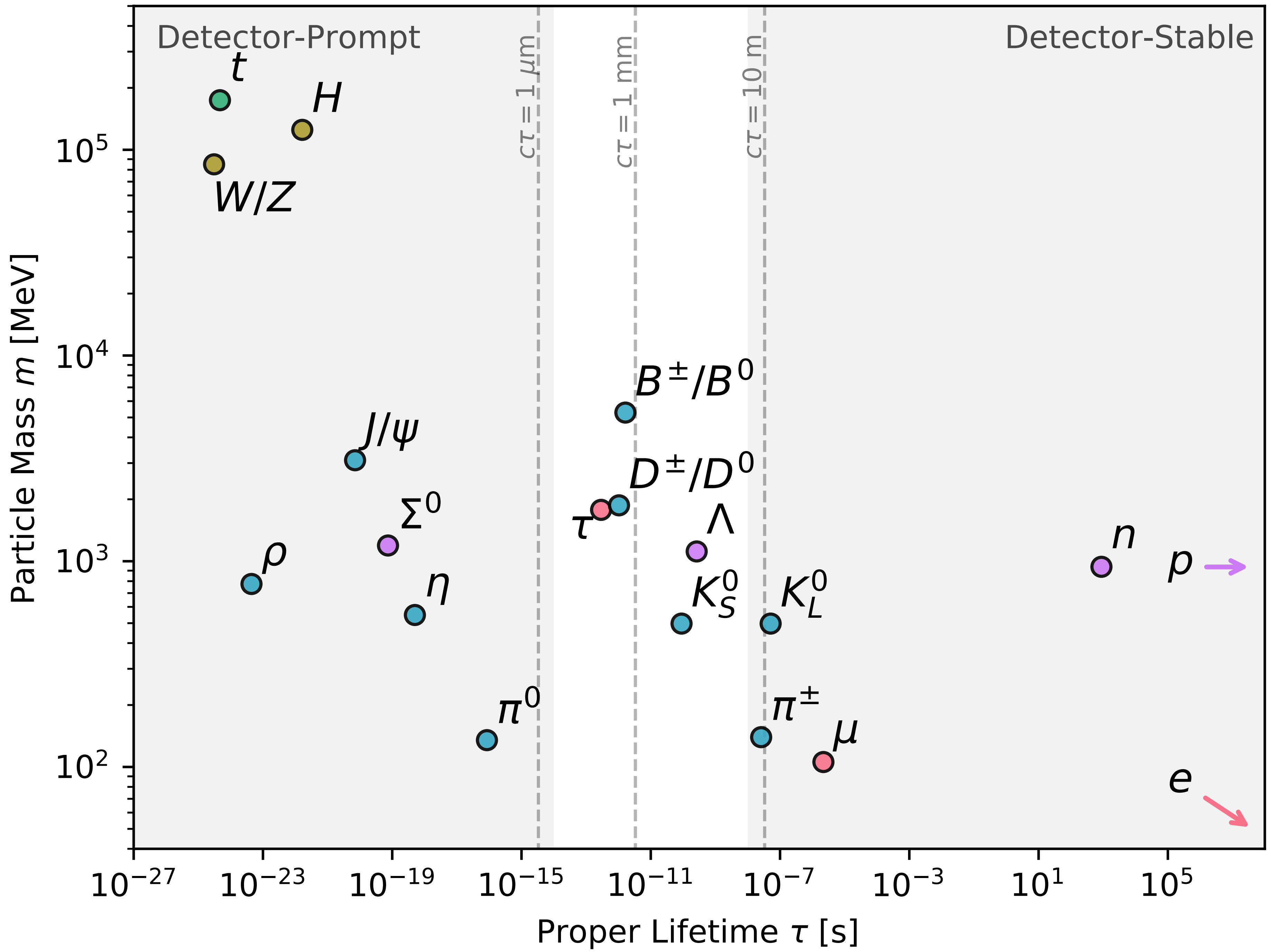
$$\Gamma \sim \varepsilon^2 \left(\frac{m}{\Lambda}\right)^{2n} \Phi$$

Small phase space

Effective Coupling
(+Loop Suppression)



And particles do in the SM!



[1810.12602] LL, C Ohm, A Soffer, T Yu

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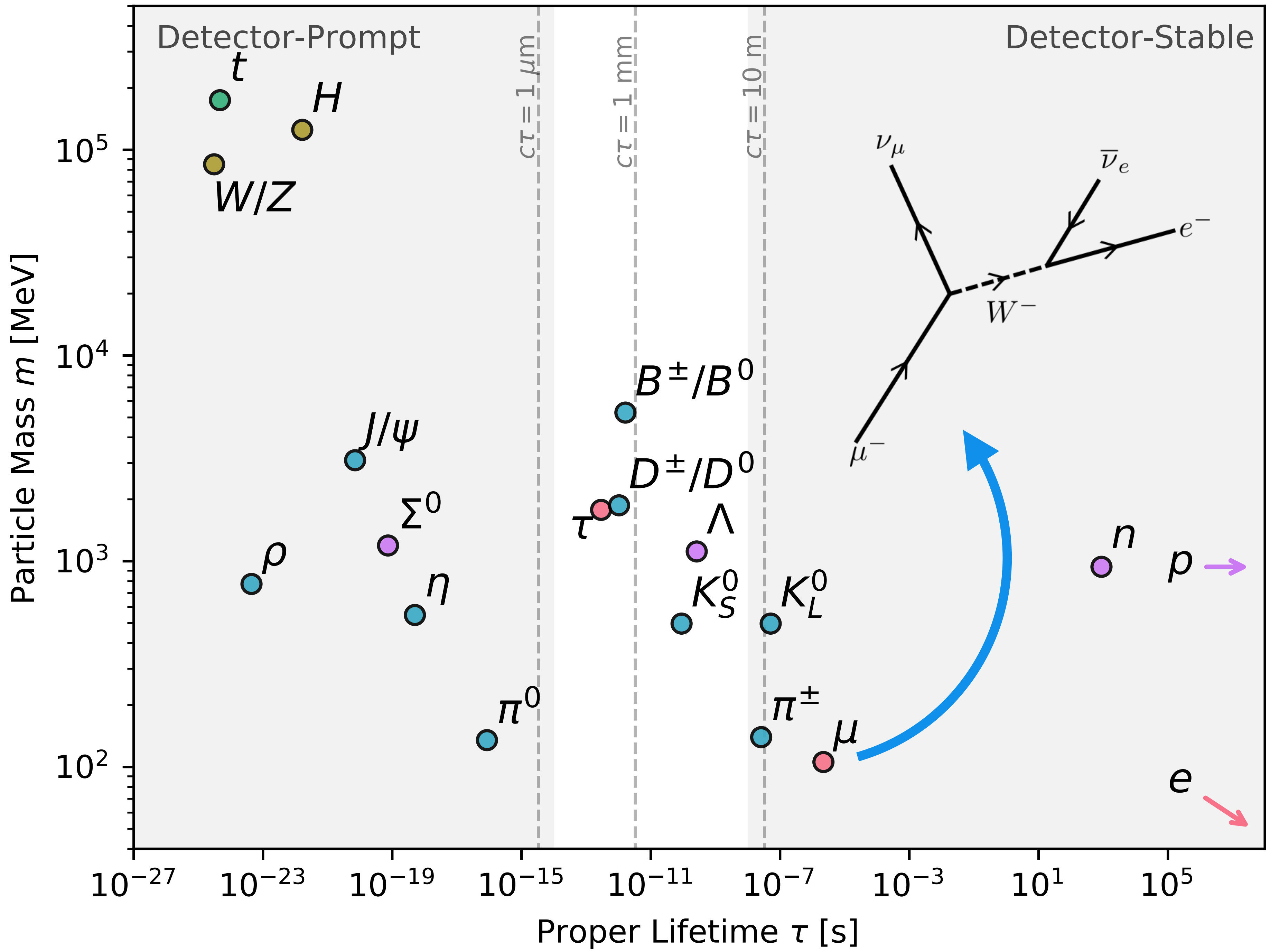

[1810.12602] LL, C Ohm, A Soffer, T Yu

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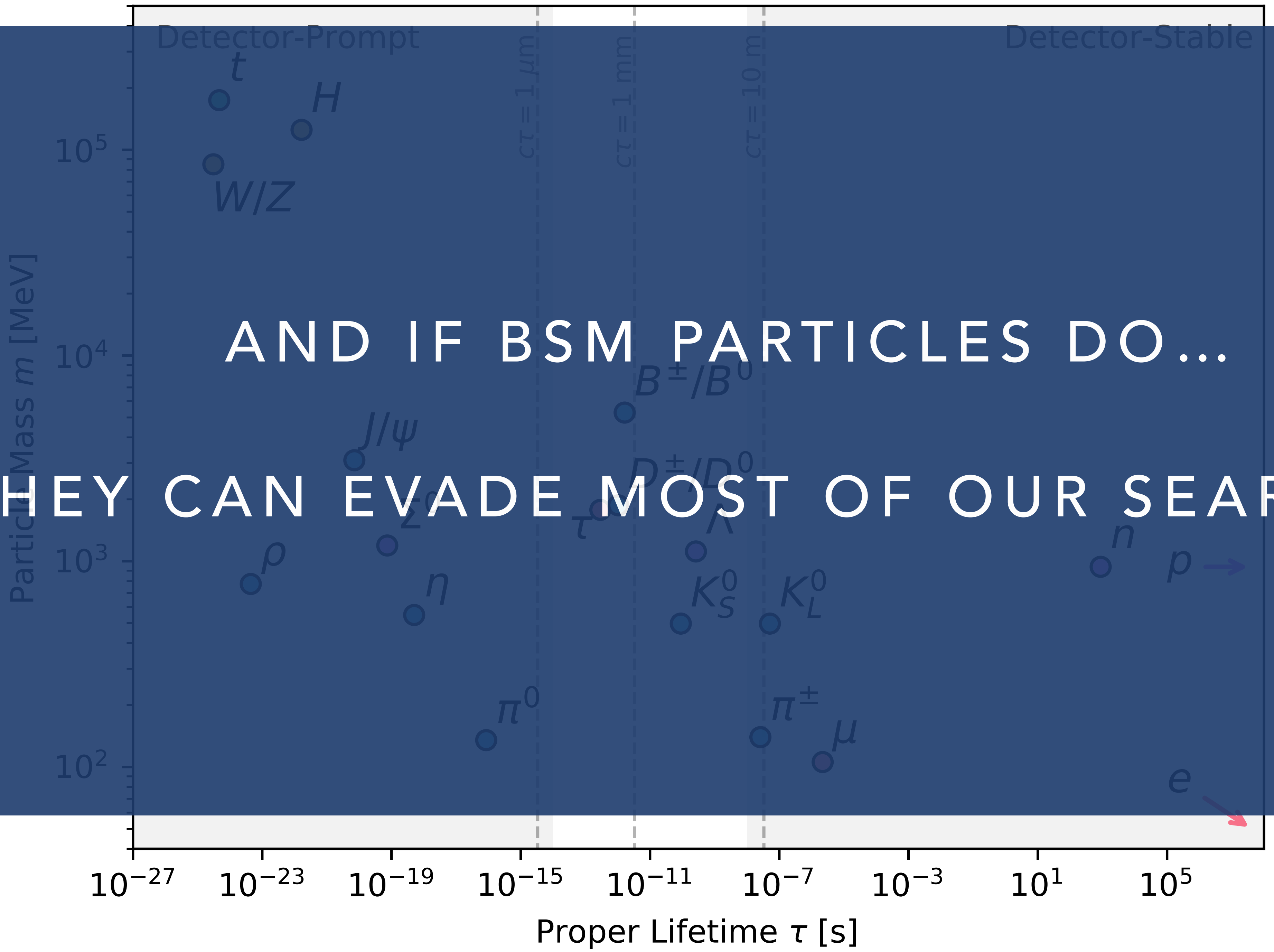


AND IF BSM PARTICLES DO…

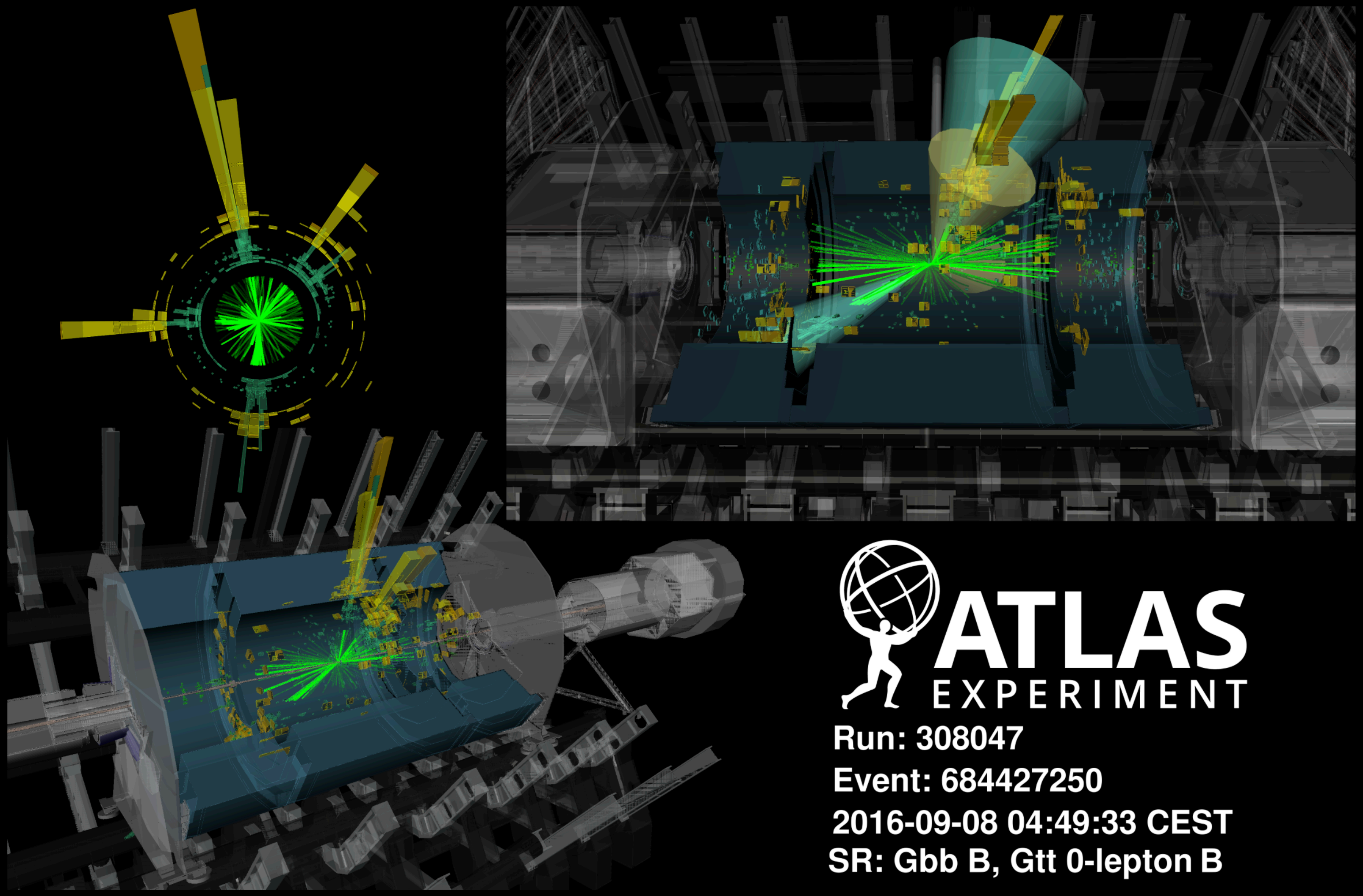
THEY CAN EVADE MOST OF OUR SEARCHES!

[1810.12602] LL, C Ohm, A Soffer, T Yu

Why is this hard?

ATLAS was **not designed** to look for **displaced** new physics

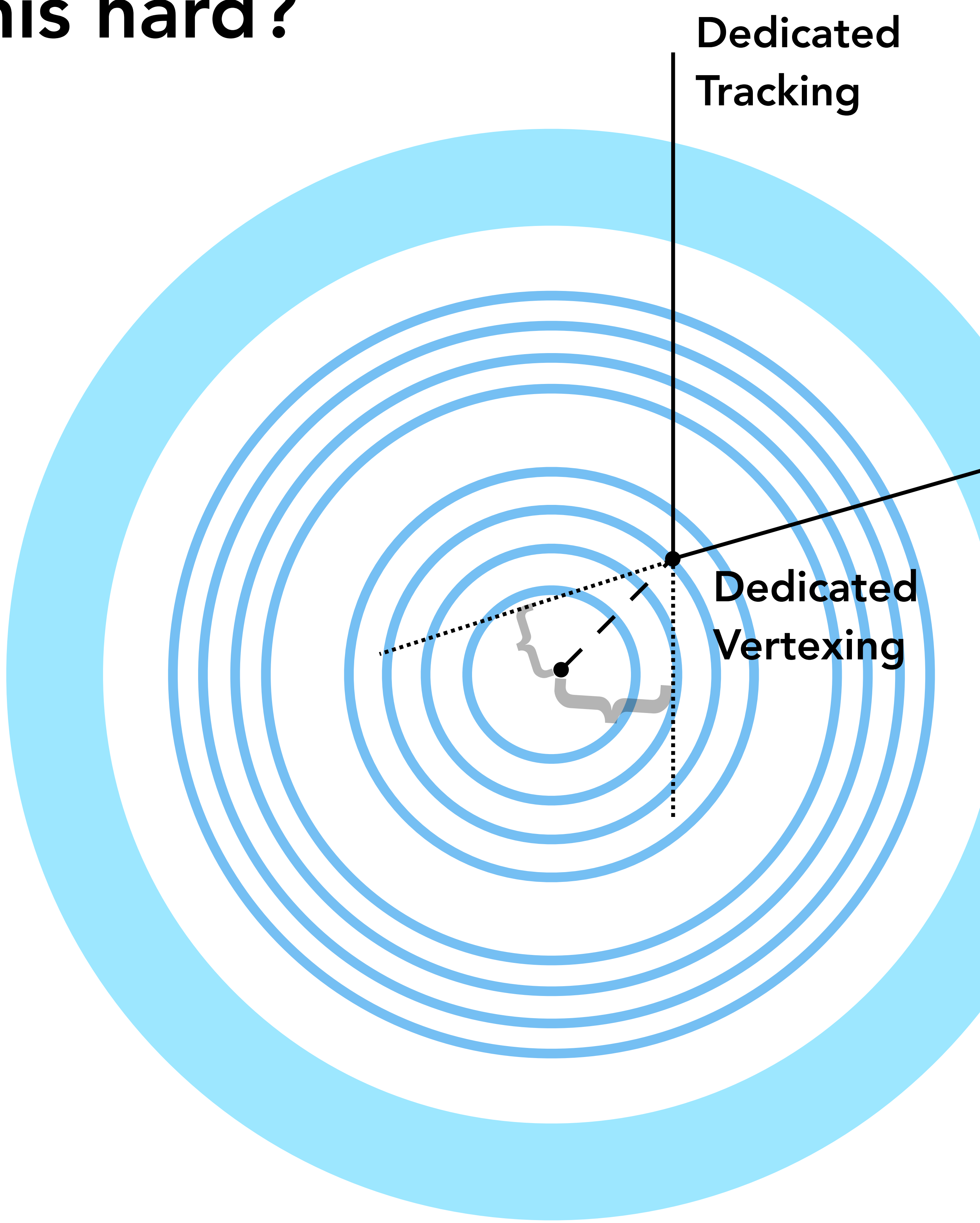
Reconstruction algorithms, detector geometry, trigger, all designed **assuming particles emerge from the collision point**



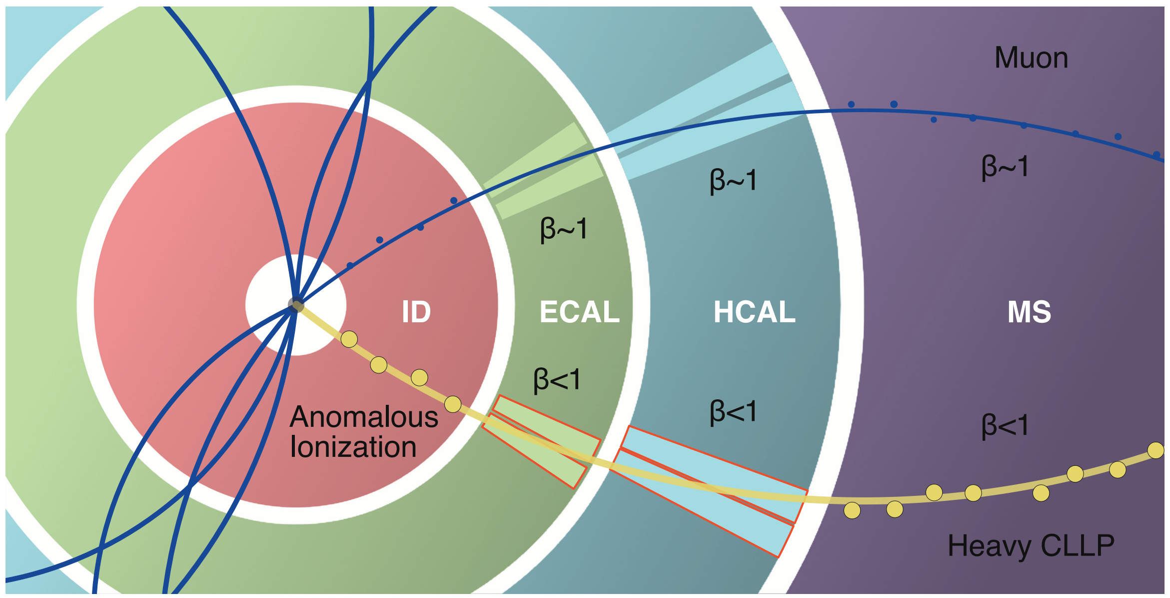
A Long-Lived Particle could break any of these!

Why is this hard?

- Very few dedicated triggers for Long-Lived Particles
- Custom reconstruction
  - Rerun tracking for large displacement
  - Displaced Vertexing
  - “Disappearing Tracks”
  - “Slow muons", etc etc etc
- In order to re-run reco, very special data handling needs
  - Save a subset of the events in a RAW format for special reconstruction

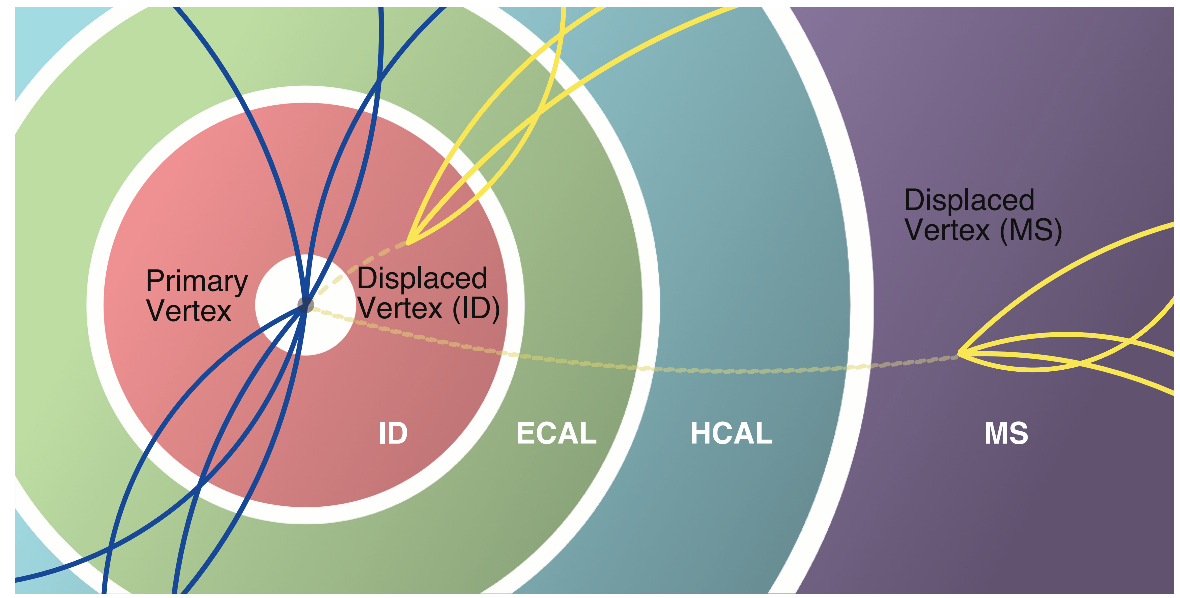


Direct vs Indirect Detection



Direct Detection

Measure interactions of SM-charged LLP with detector

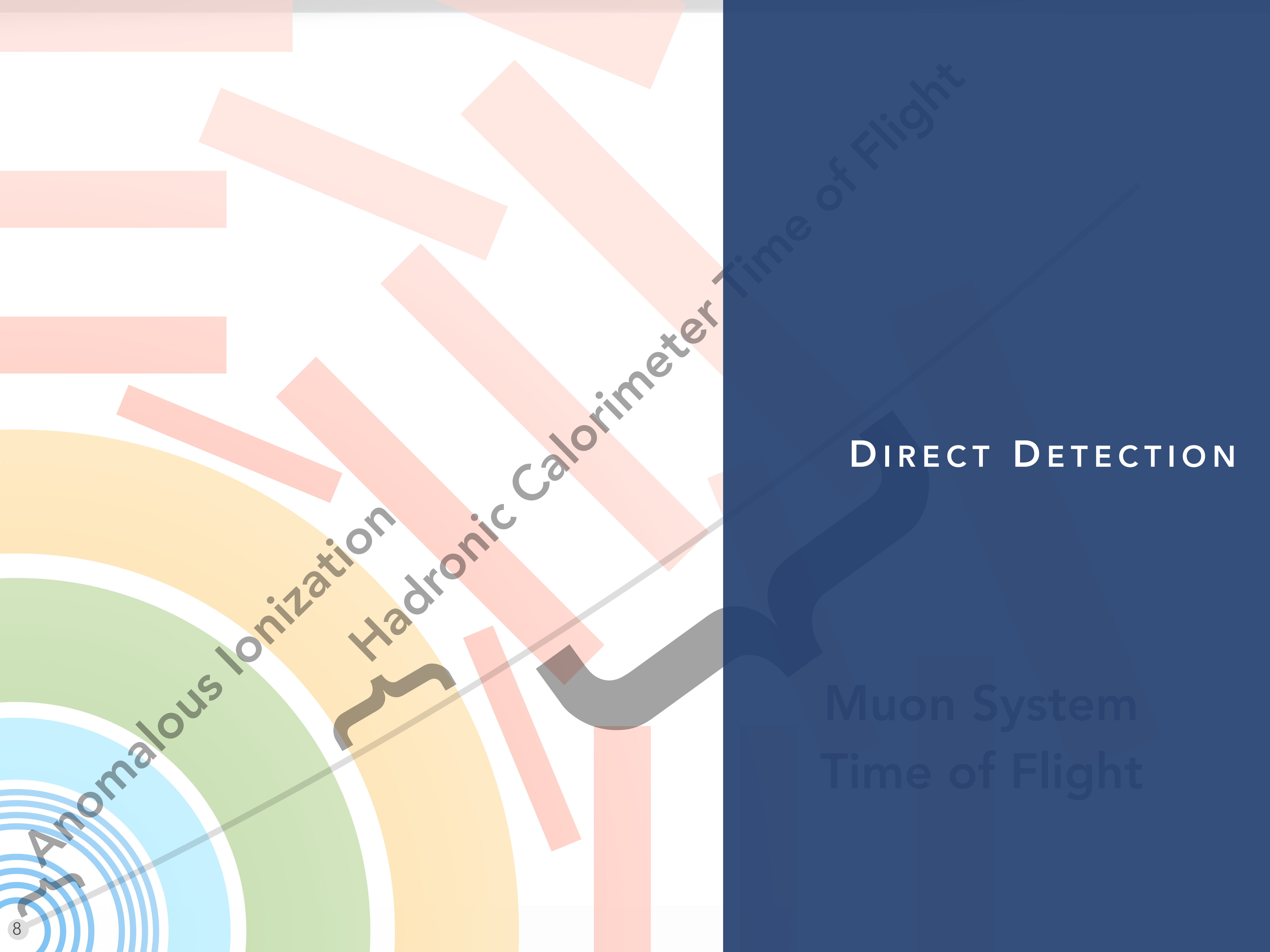


Indirect Detection

Measure displaced decay products

[Same as in Dark Matter case]

[1810.12602]



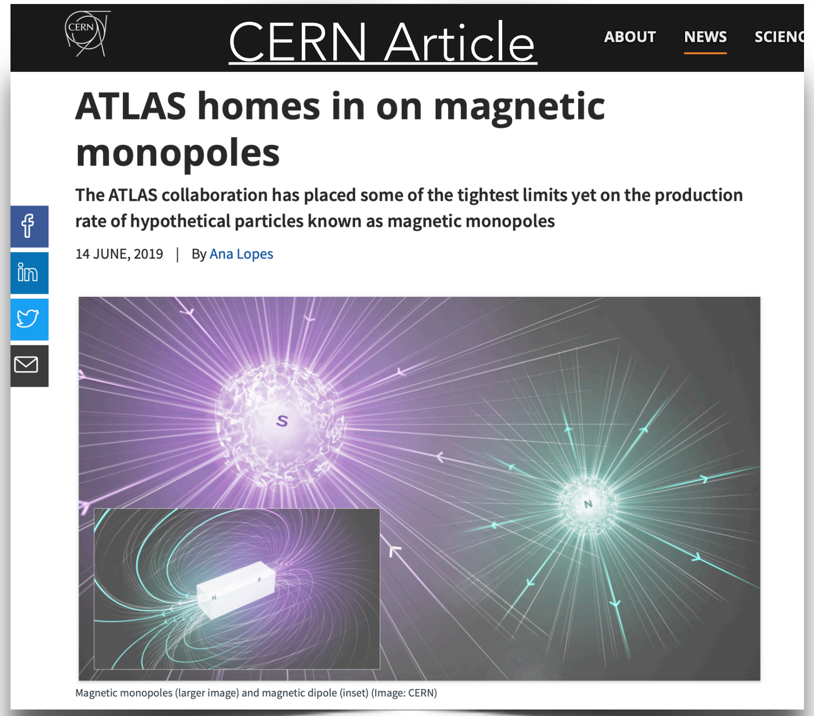
Direct Detection

Direct Detection

- Highly Ionizing Particles / Magnetic Monopoles
- Anomalous Pixel dE/dx
- Slow Muon, dE/dx, Tile Timing
- Disappearing Tracks
- Multiply Charged Particles

NEW!

<6 MO OLD


CERN Article

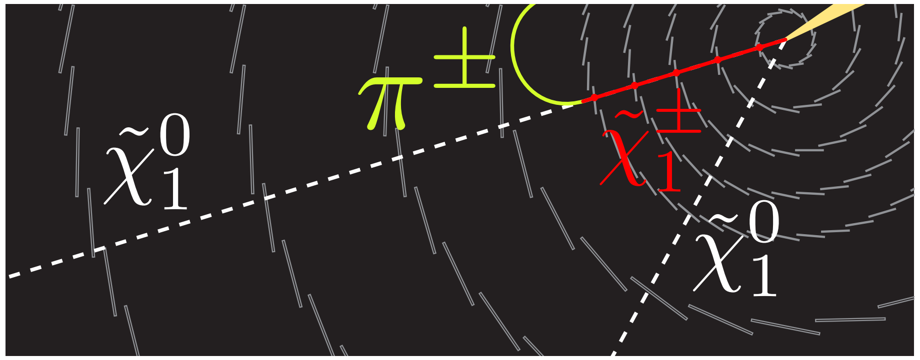
ABOUT NEWS SCIENC

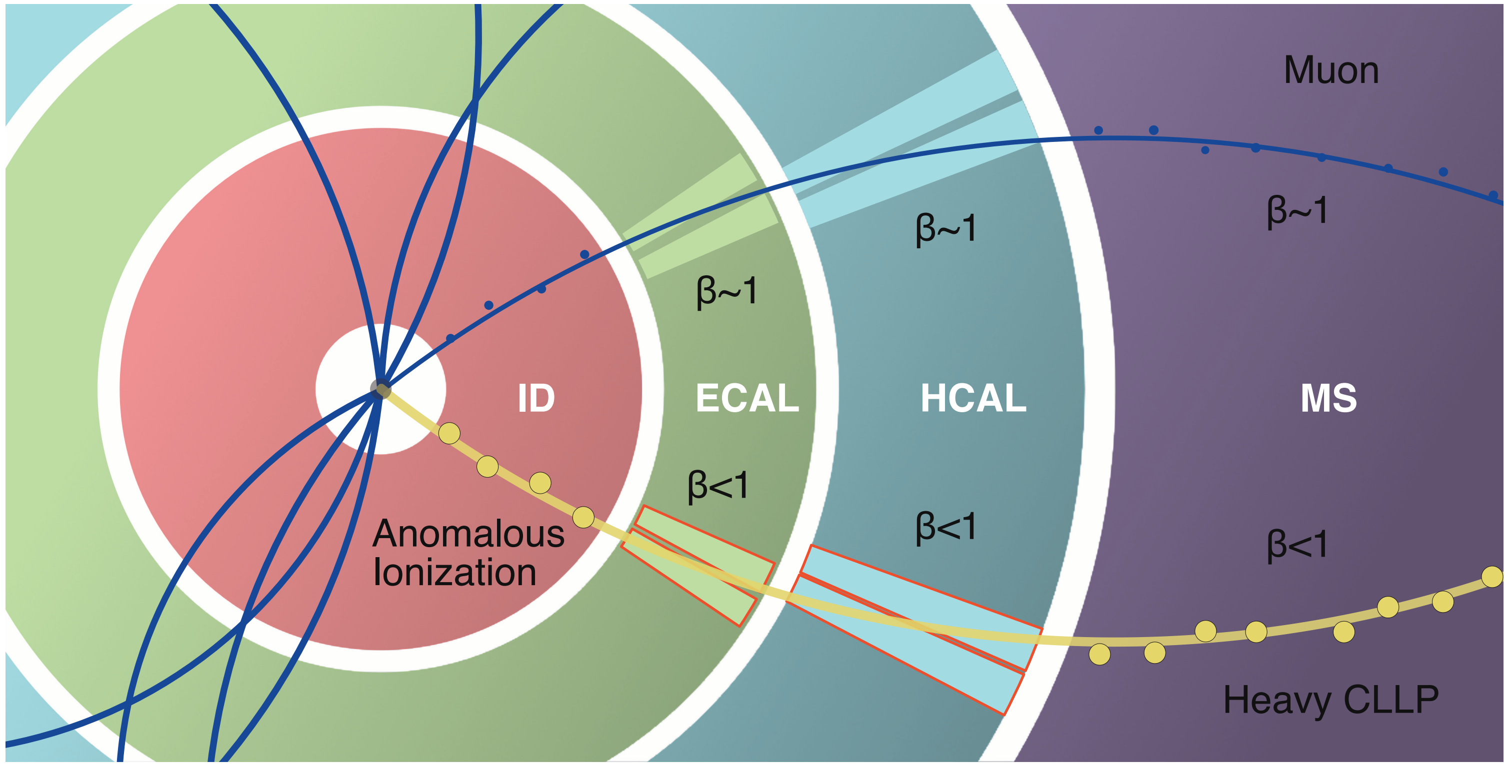
ATLAS homes in on magnetic monopoles

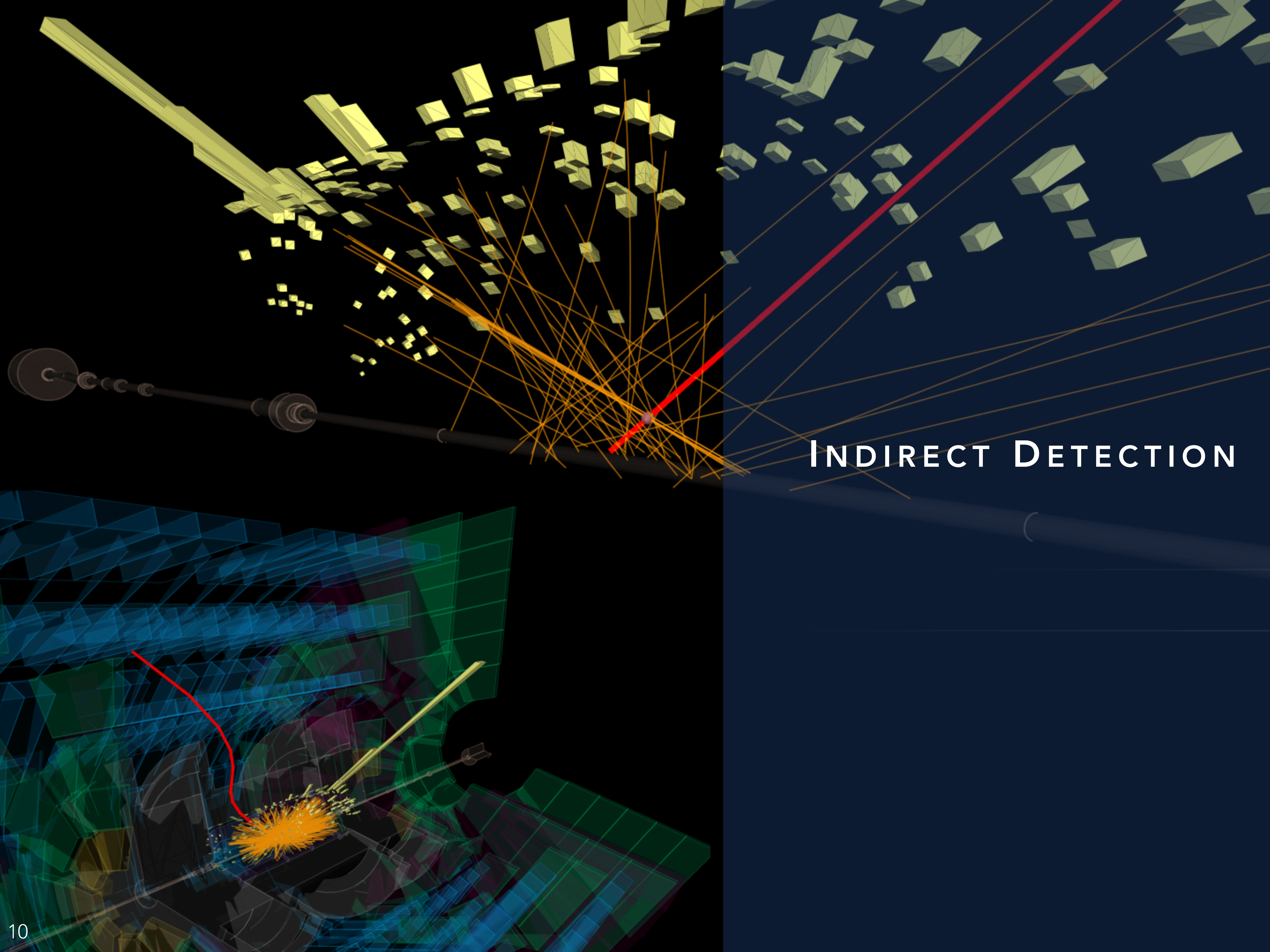
The ATLAS collaboration has placed some of the tightest limits yet on the production rate of hypothetical particles known as magnetic monopoles

14 JUNE, 2019 | By Ana Lopes

Magnetic monopoles (larger image) and magnetic dipole (inset) (Image: CERN)





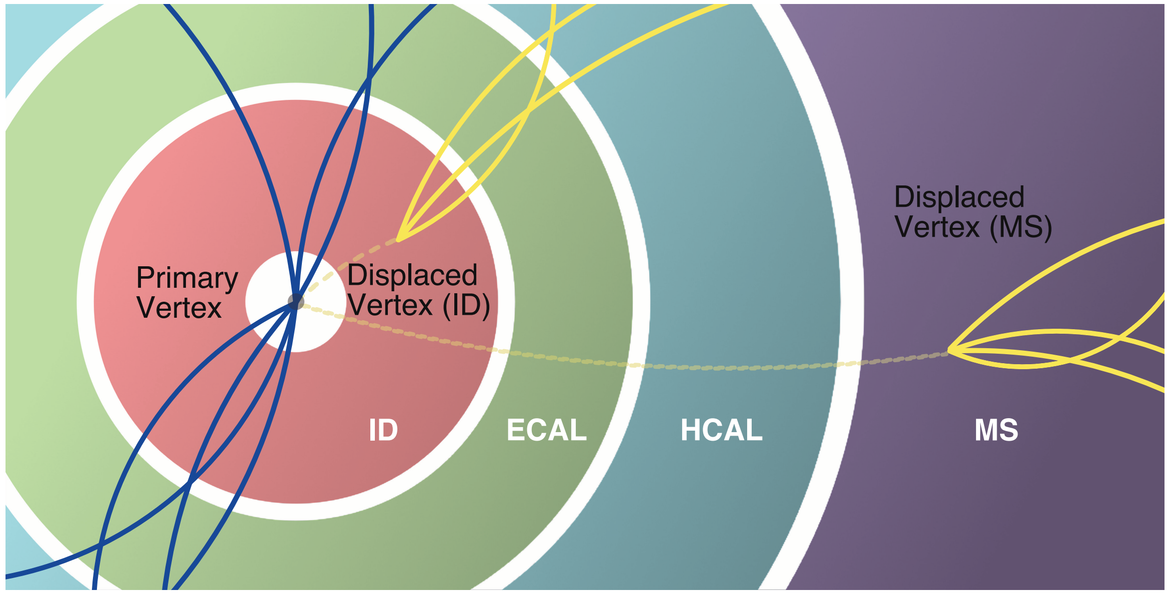


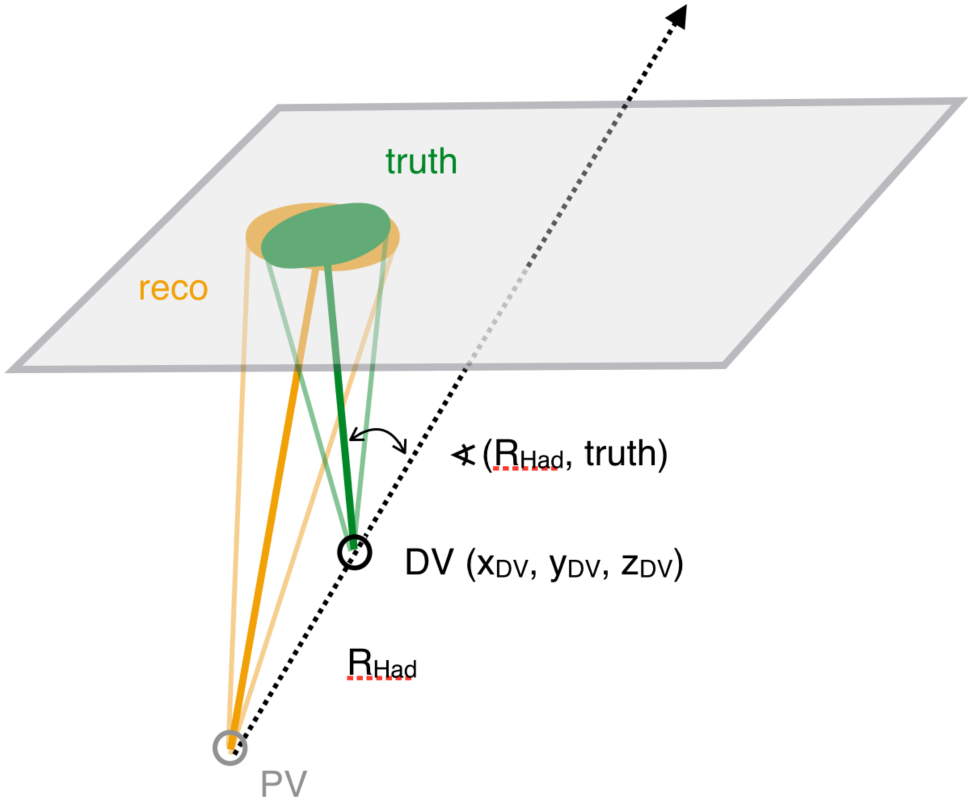
Indirect Detection

Indirect Detection

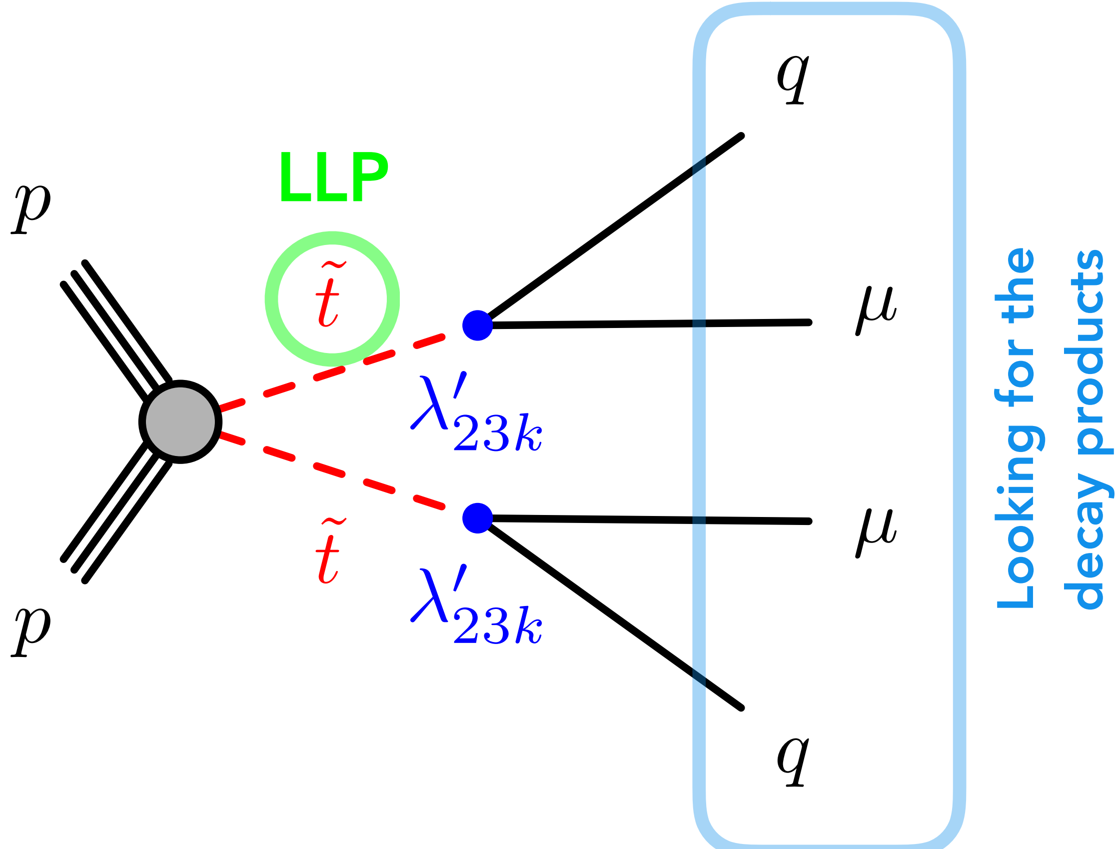
- Looking for the displaced decay products of BSM LLPs
- Displaced vertexing in tracker or muon system
- Mid-calorimeter jets
- Late-arriving decay products
- Non-pointing decay products
    - Studies on non-pointing jets from LLPs [ATL-PHYS-PUB-2019-025]

NEW!



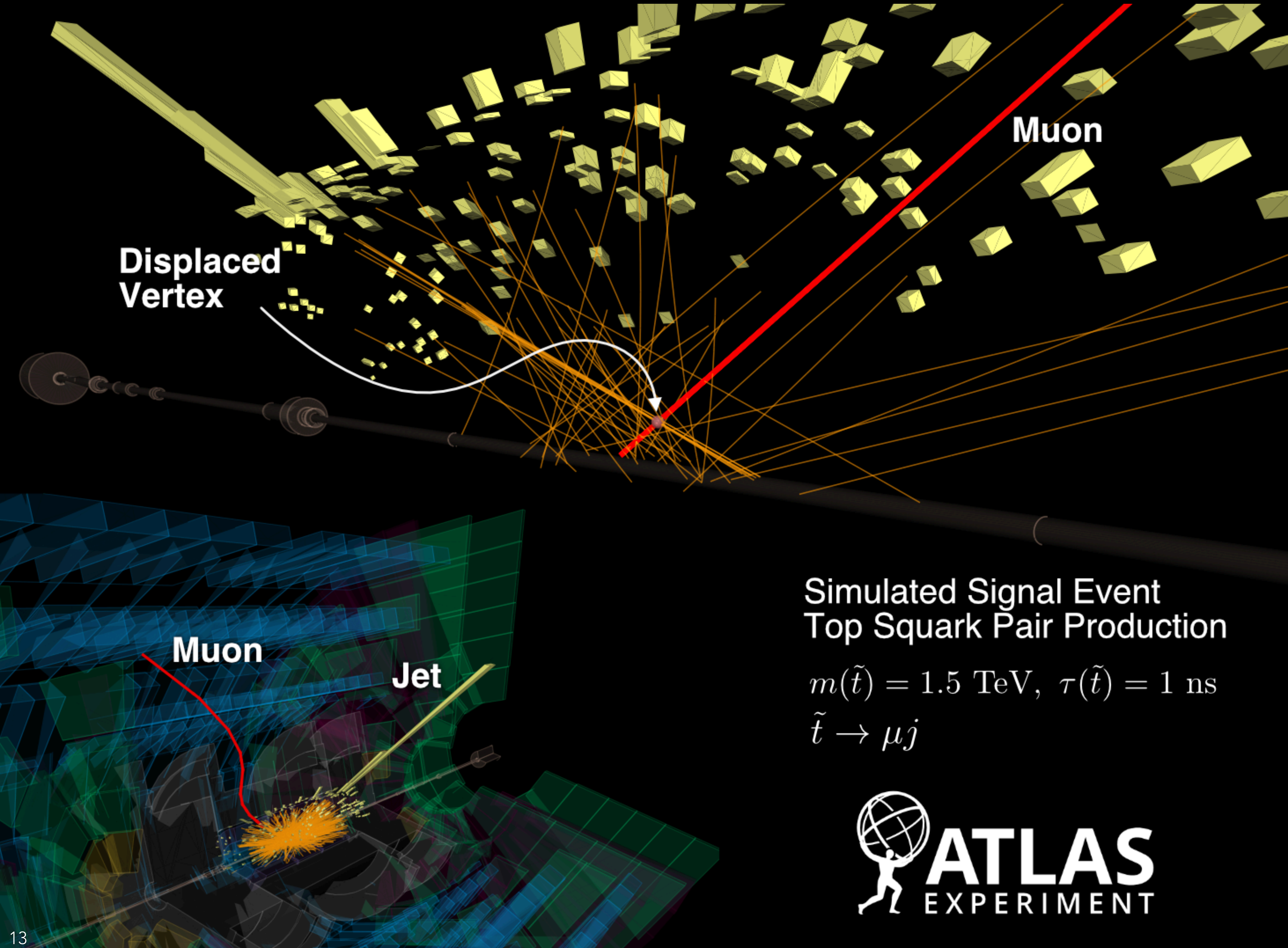


Long-Lived Scalar Top Partners (Stops)



$$\tau(\tilde{t}) = \left(\frac{1\ \text{TeV}}{m(\tilde{t})}\right)\left(\frac{10^{-7}}{\lambda'_{23k}}\right)^2\left(\frac{0.06}{\cos^2\theta_t}\right)\times 10^{-3}\ \text{ns}$$

- In "natural" SUSY models, a light stop is favored to address naturalness problem
  - But in models with "R-Parity Violation" (RPV), stop gains large lifetime from small coupling
  - Squarks will hadronize to a color singlet ("R-Hadron")
    - Complex problems in simulating production, propagation, decay [ATL-PHYS-PUB-2019-019] NEW!



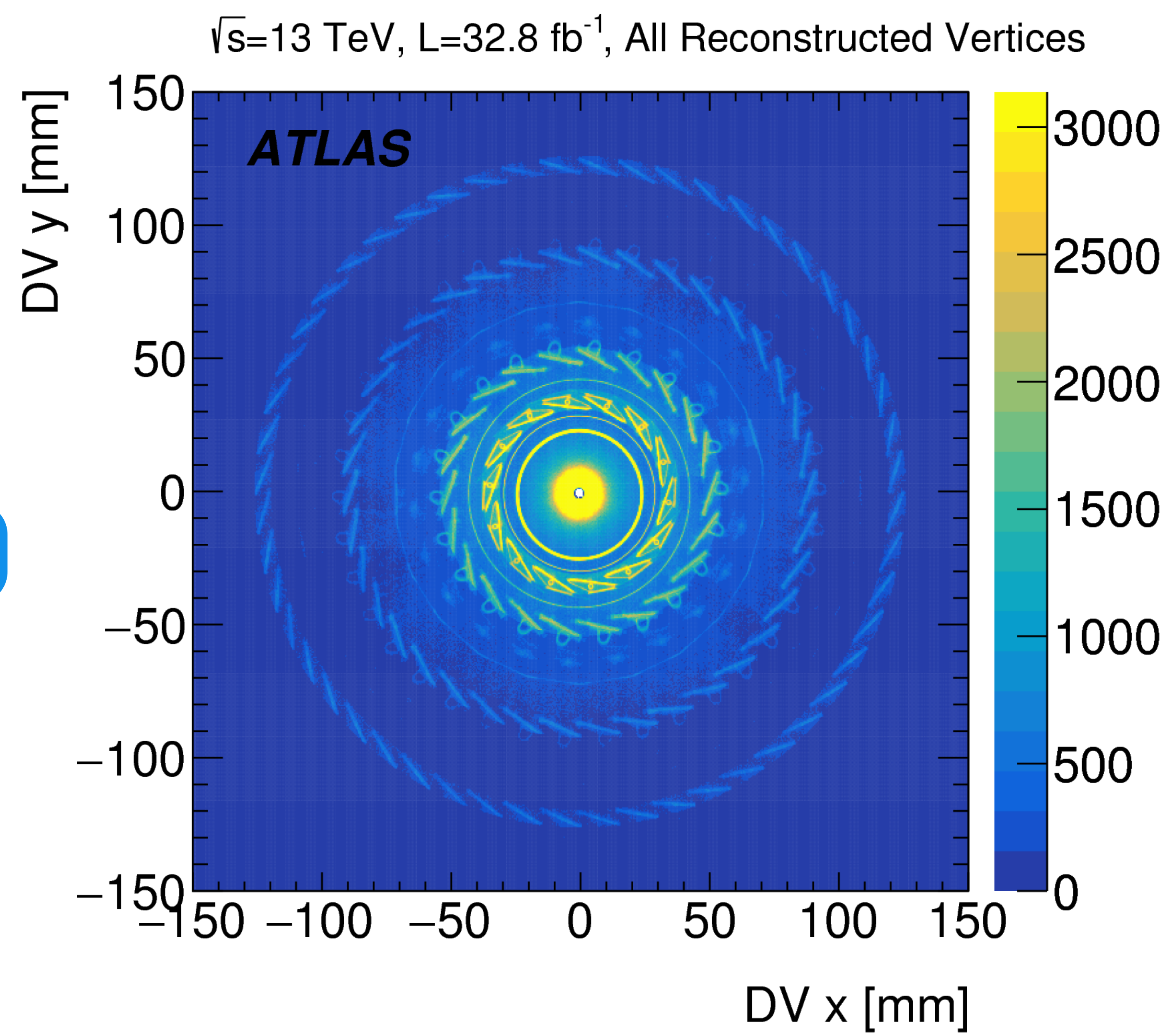
Simulated Signal Event
Top Squark Pair Production

$m(\tilde{t}) = 1.5\ \mathrm{TeV},\ \ \tau(\tilde{t}) = 1\ \mathrm{ns}$

$\tilde{t} \rightarrow \mu j$

Displaced Vertices

- If LLP decays in tracking volume, reconstruct displaced vertex
  - Dedicated displaced tracking [ATL-PHYS-PUB-2017-014]
  - and displaced vertexing [ATL-PHYS-PUB-2019-013] NEW!
- No SM Background! Just instrumental backgrounds
- Requires detailed material map to veto backgrounds



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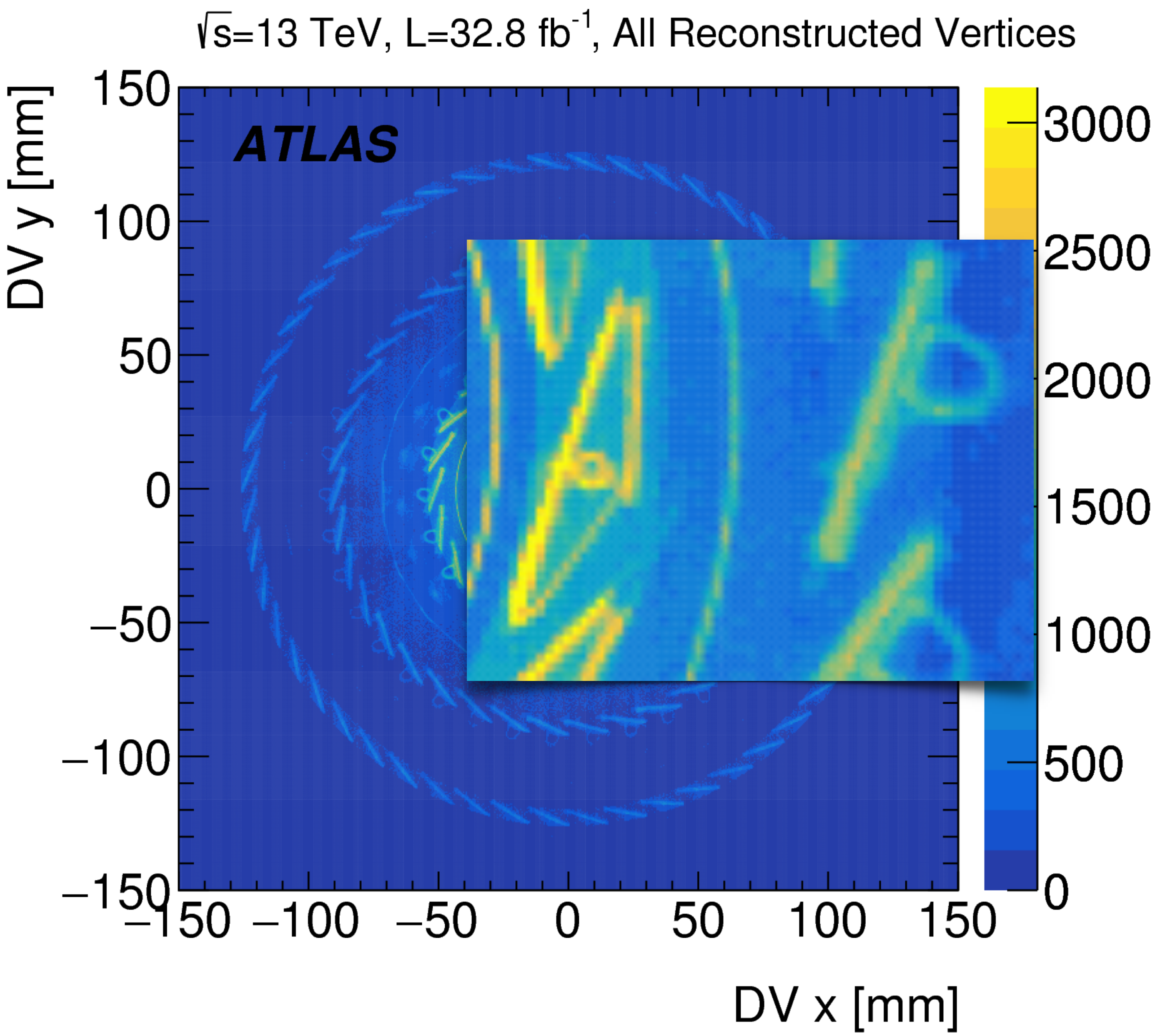
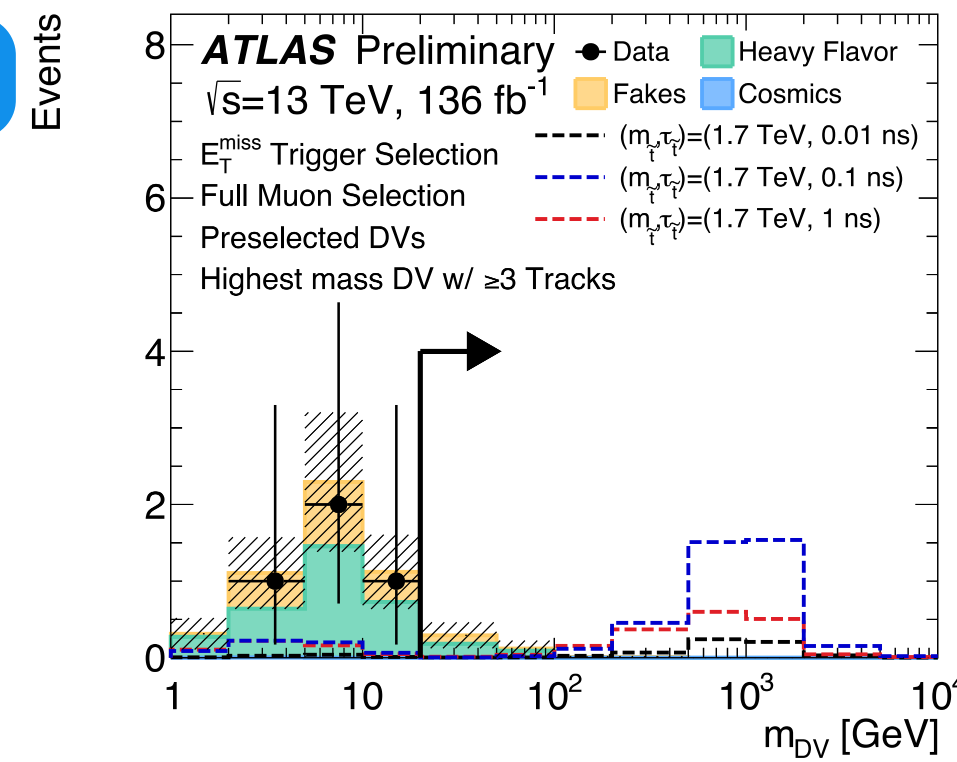
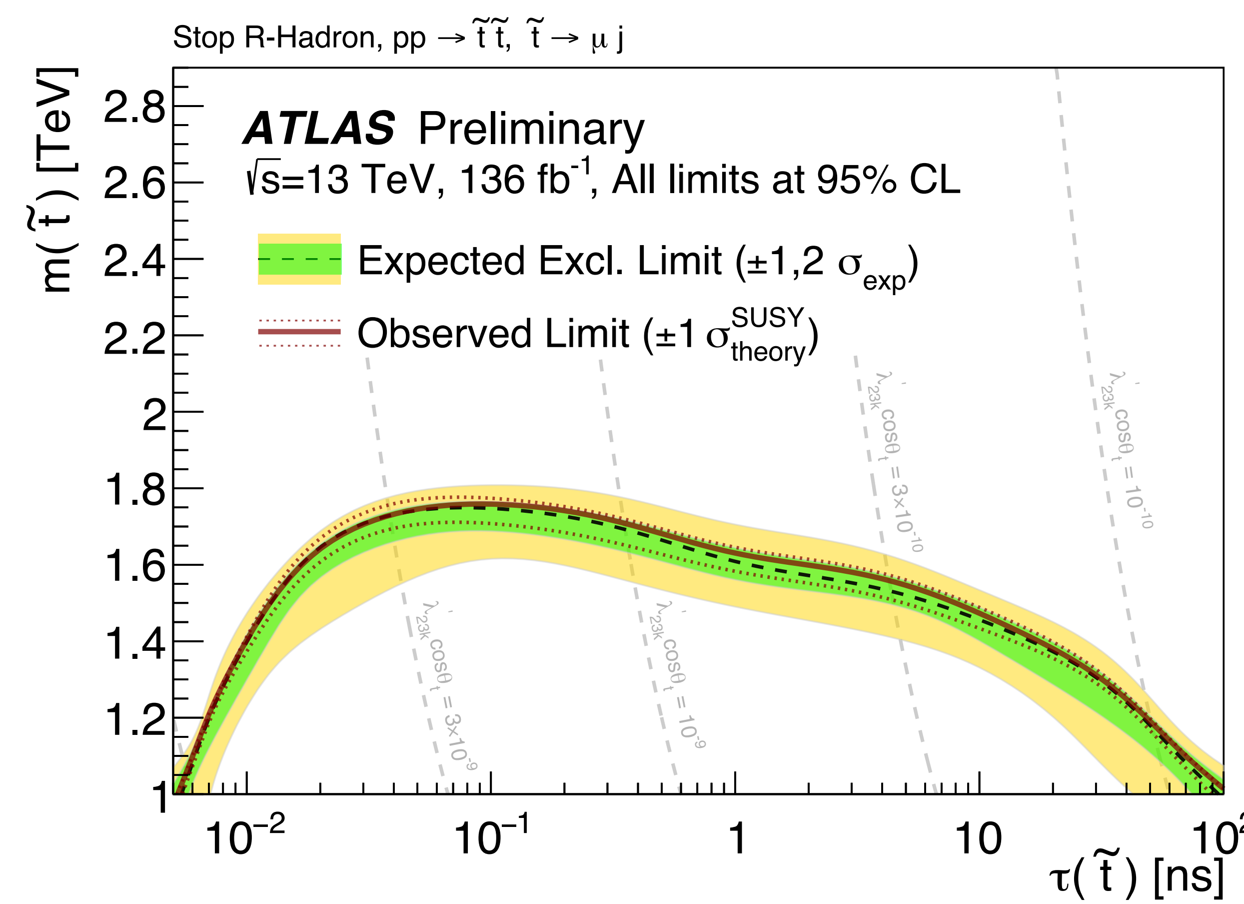


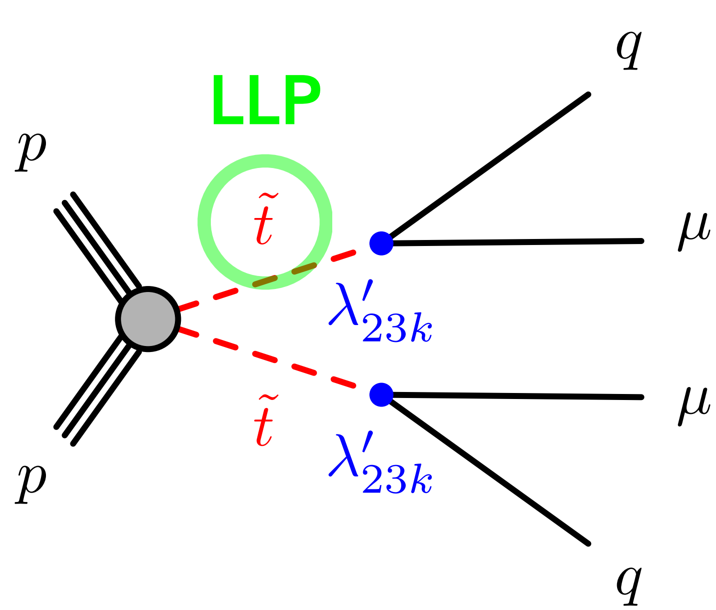
DISPLACED VTX + MUON [ATLAS-CONF-2019-006]

NEW!

- Full Run-2 Analysis! 136 fb^{-1}
- Background estimation uses
  - BG-like DVs (e.g. hadronic interactions)
  - BG-like muons (e.g. cosmic rays)
- Expected BG:
  0.43 ± 0.16 (stat) ± 0.16 (syst) events
- Observe **0 events**







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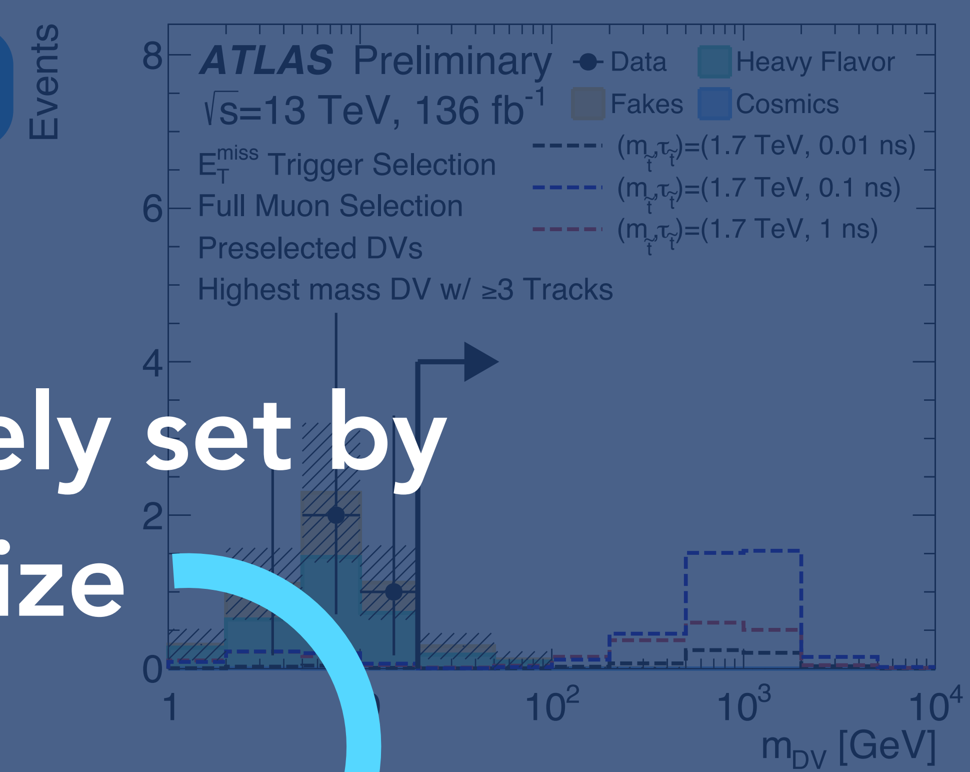
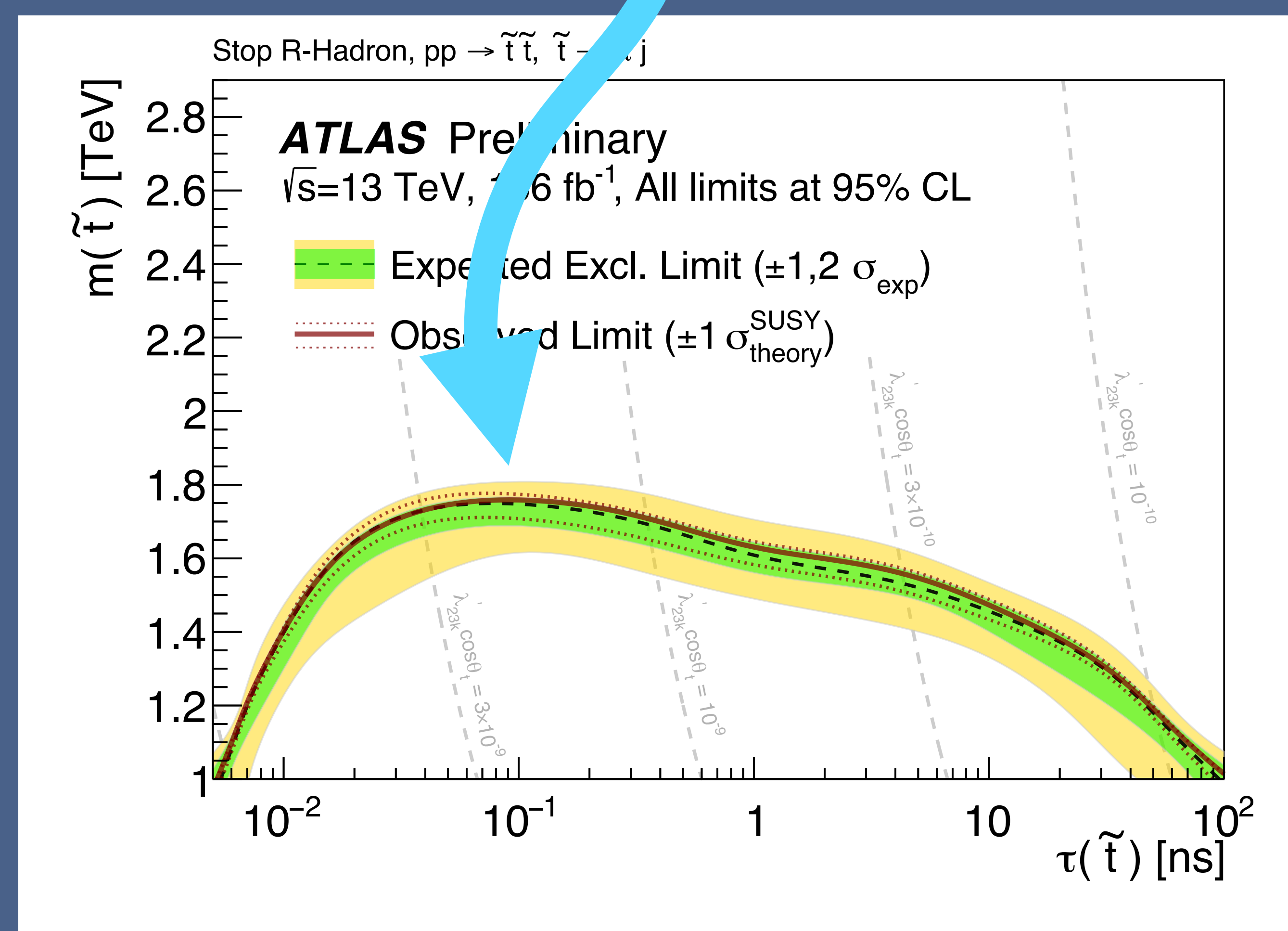
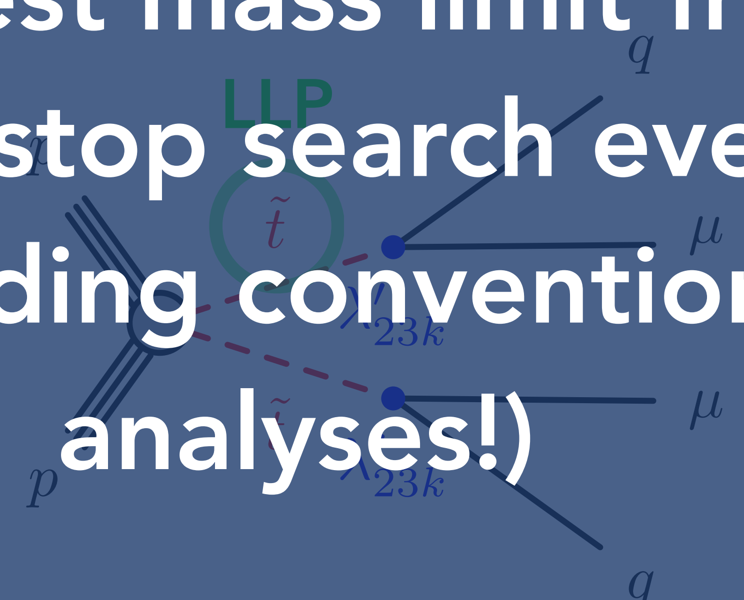


Lifetime sensitivity largely set by physical tracker size

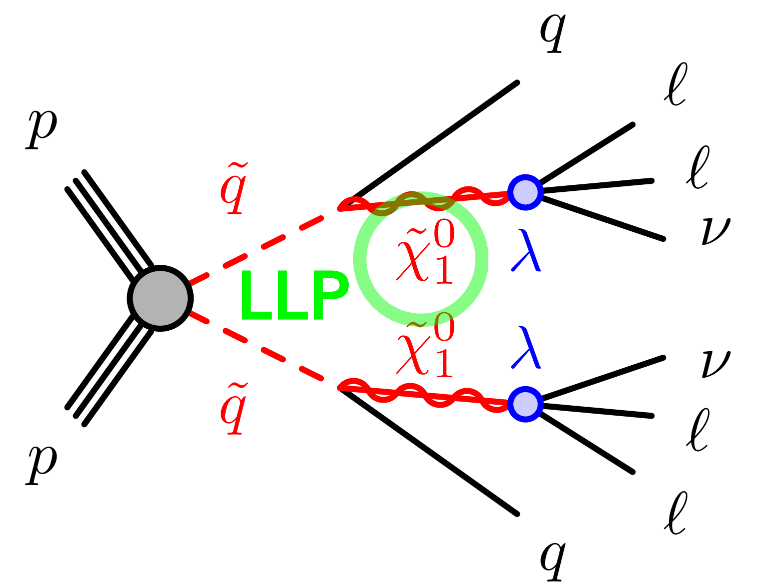


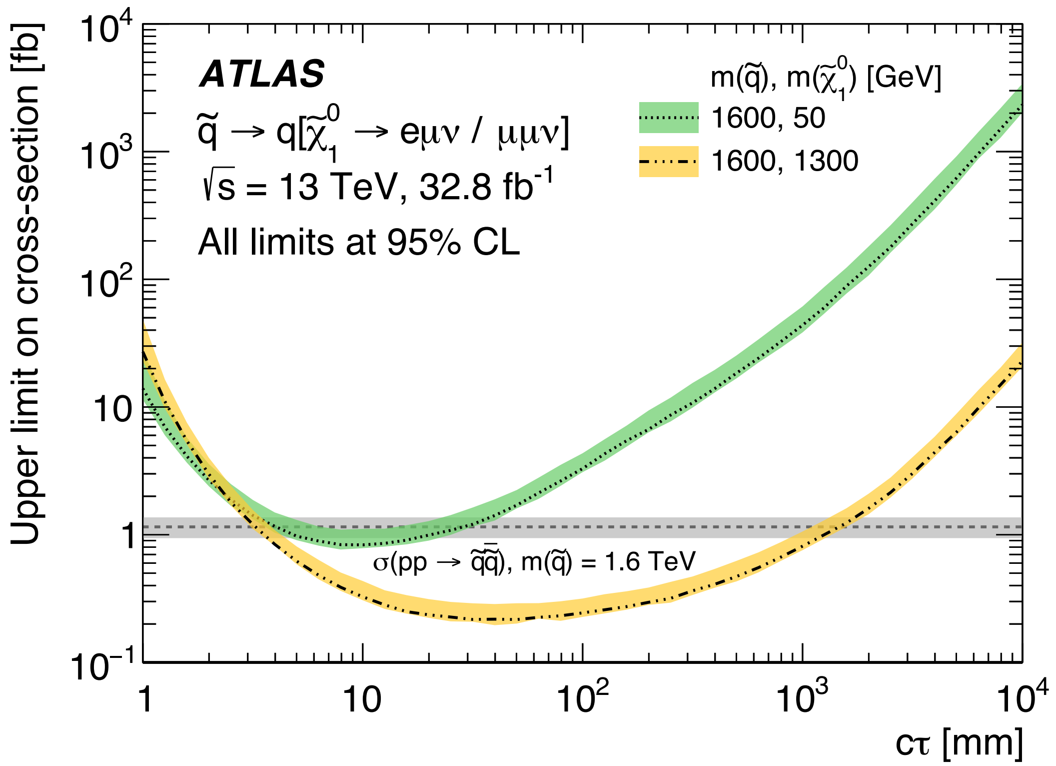


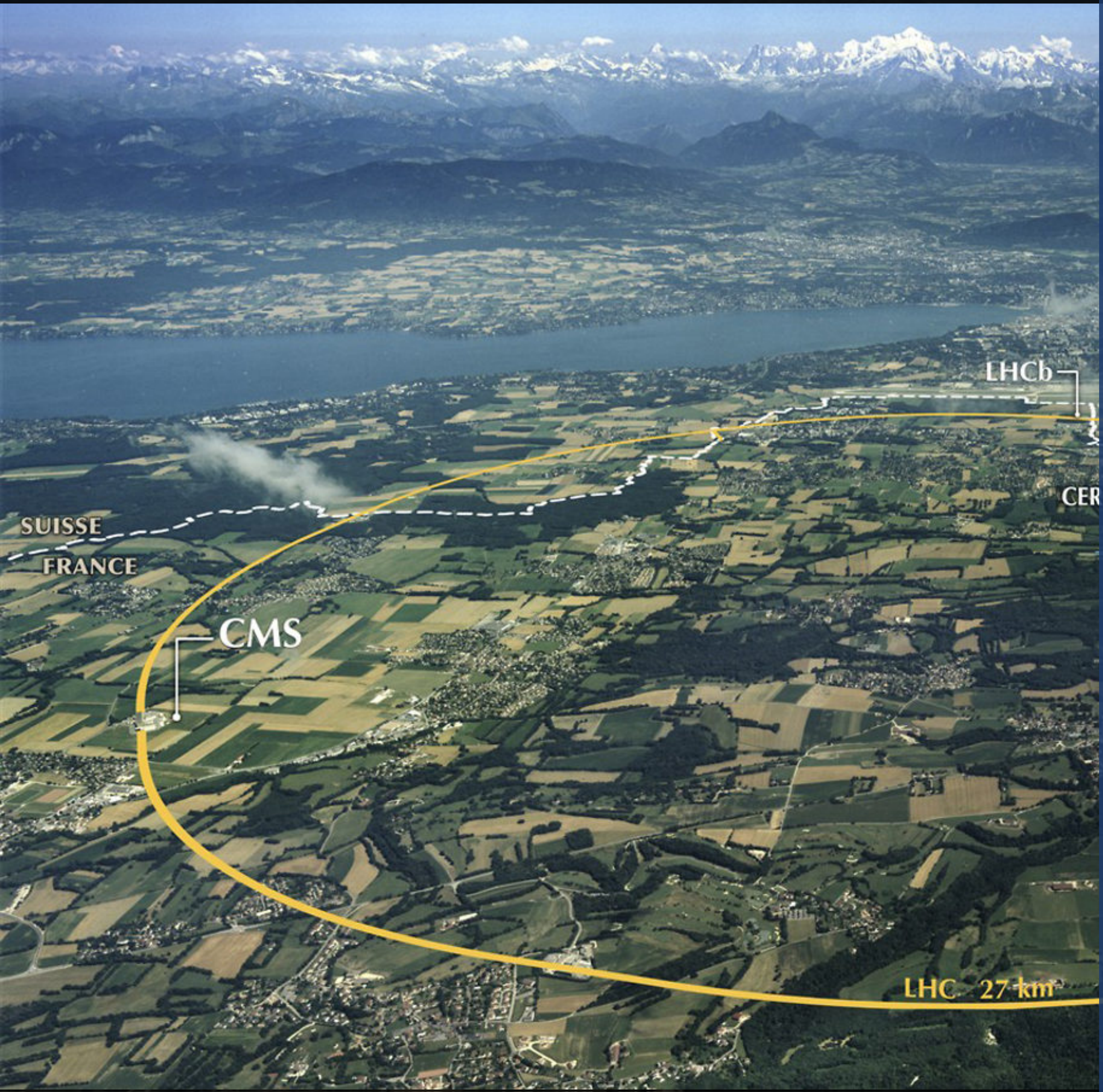
Strictest mass limit from any stop search ever (including conventional analyses!)

Displaced Dilepton Vertex [arXiv: 1907.10037] NEW!

- Or look for displaced dilepton vertices
- Primary background from cosmics
  - Smaller contributions from accidental crossings,
  - Heavy-flavor effects
- Expected BG: **0.27 ± 0.17 events**
- Observe **0 events**
- Limits set on RPV models with squark masses up to 1.6 TeV

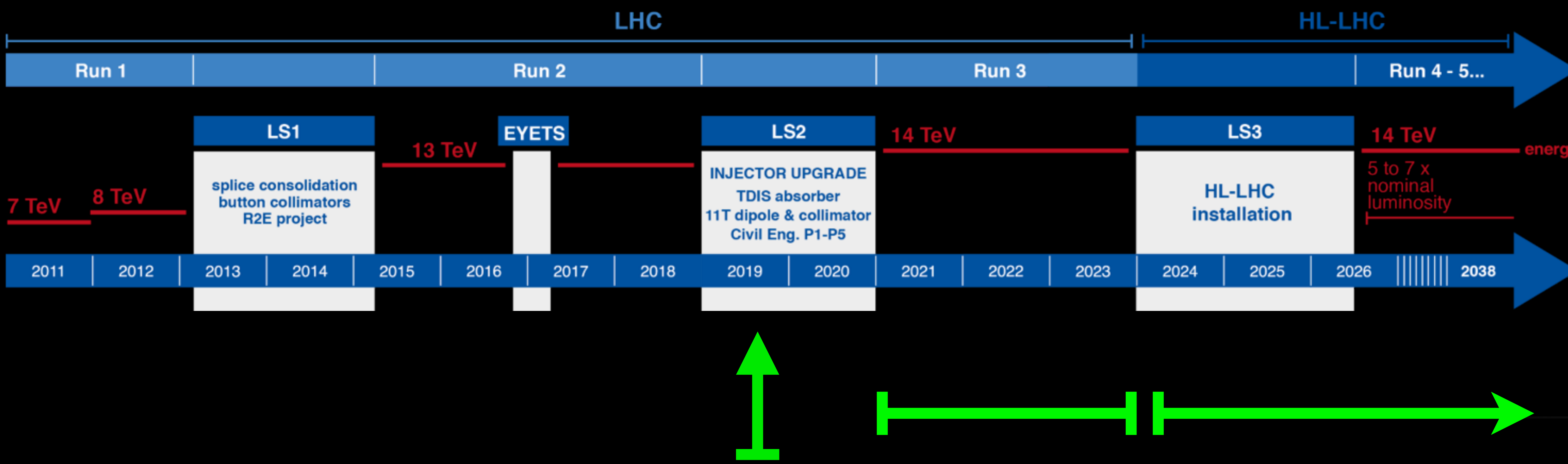






Future Prospects for Long-Lived Particles with ATLAS

For more details on upgrade prospects for ATLAS, see Monday's talk from Francesca Pastore



Today
(~140 fb^{-1})

Run-3
(~170 fb^{-1})

High Luminosity
LHC (3000 fb^{-1})

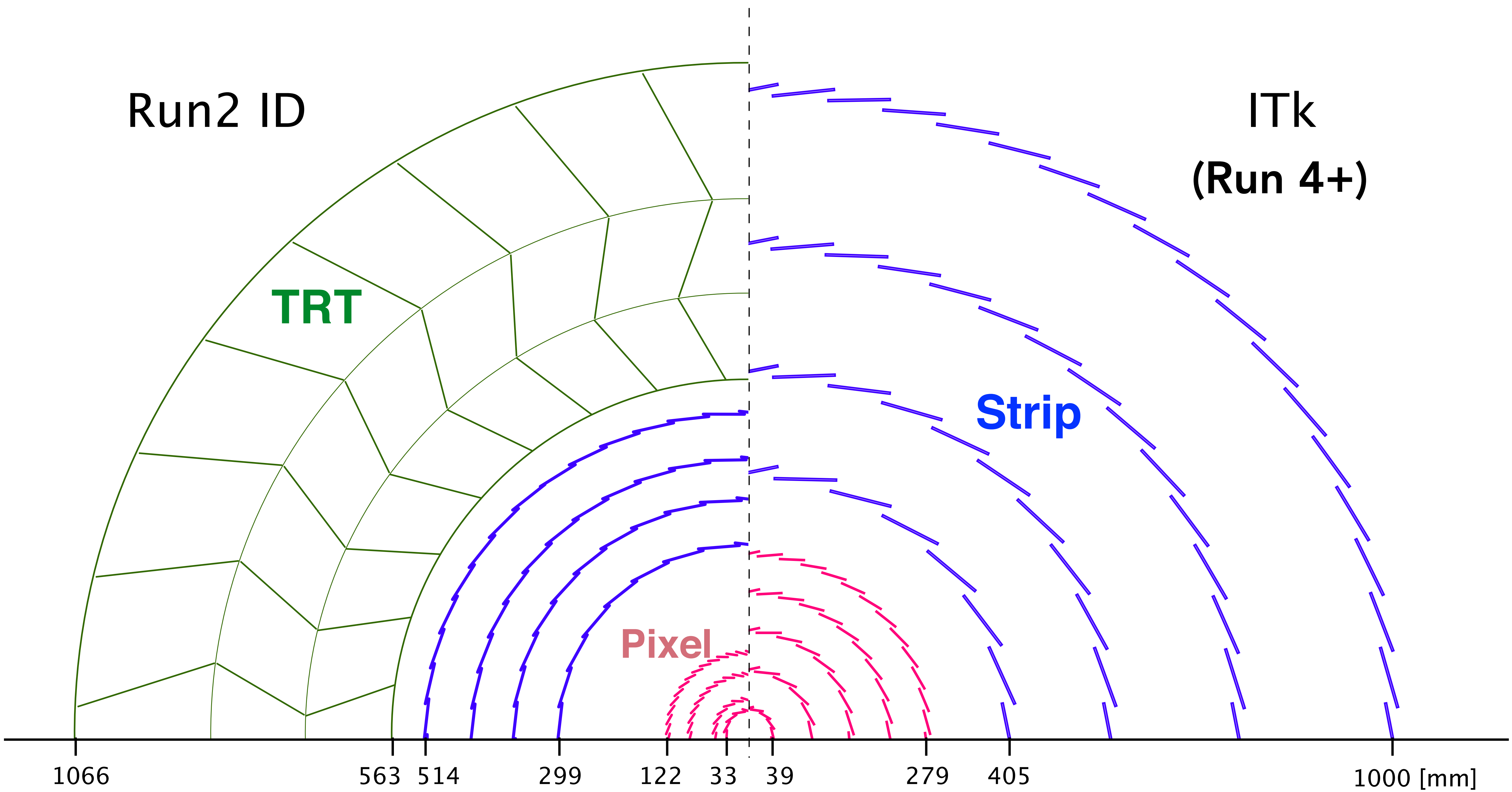
LLP Searches often in ~0 BG regime
Benefit from lumi more than most!

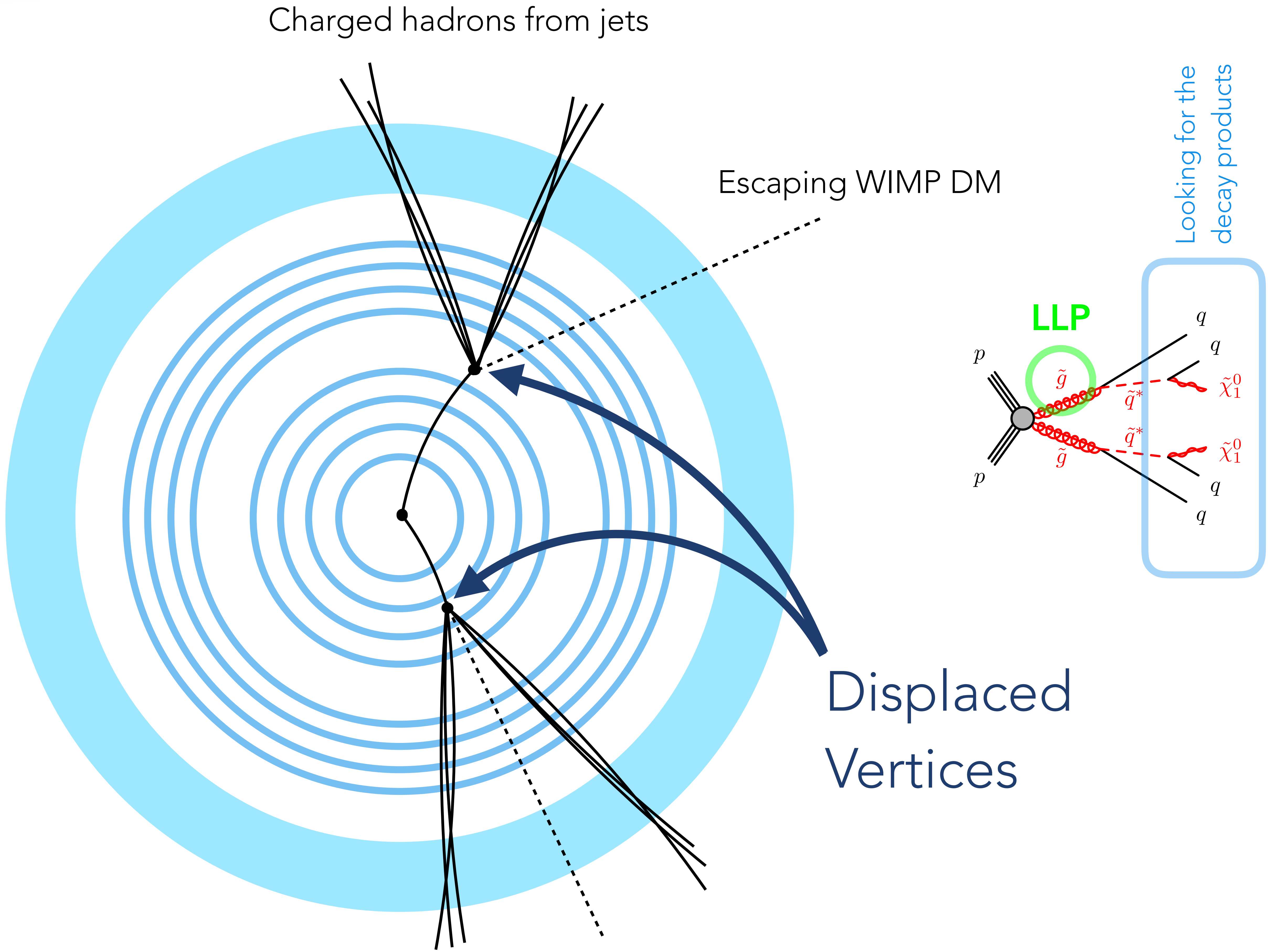
LHC HL-LHC

ATLAS RUN-3 WILL HAVE NEW TRIGGERING CAPABILITIES WHICH MAY HELP LLP SEARCHES

LOTS OF DETECTOR UPGRADES FOR ATLAS@HL-LHC TO HANDLE THIS LUMINOSITY

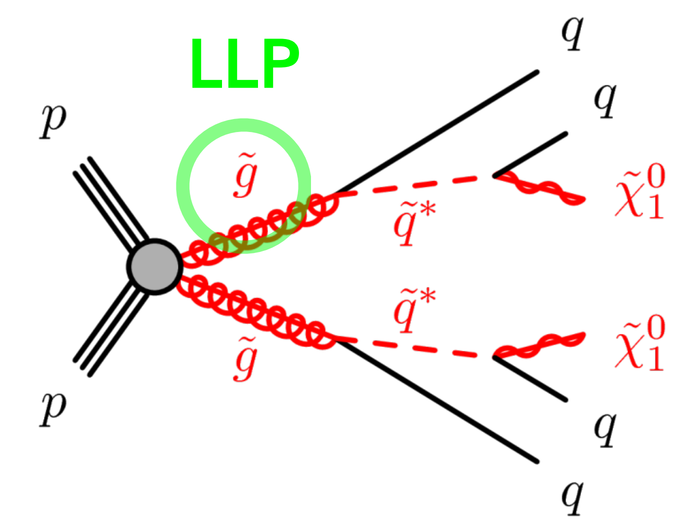
E.G. INNER TRACKER COMPLETELY REPLACED BY “ITK”


Run2 ID
ITk
(Run 4+)
TRT
Strip
Pixel
1066
563
514
299
122
33
39
279
405
1000 [mm]

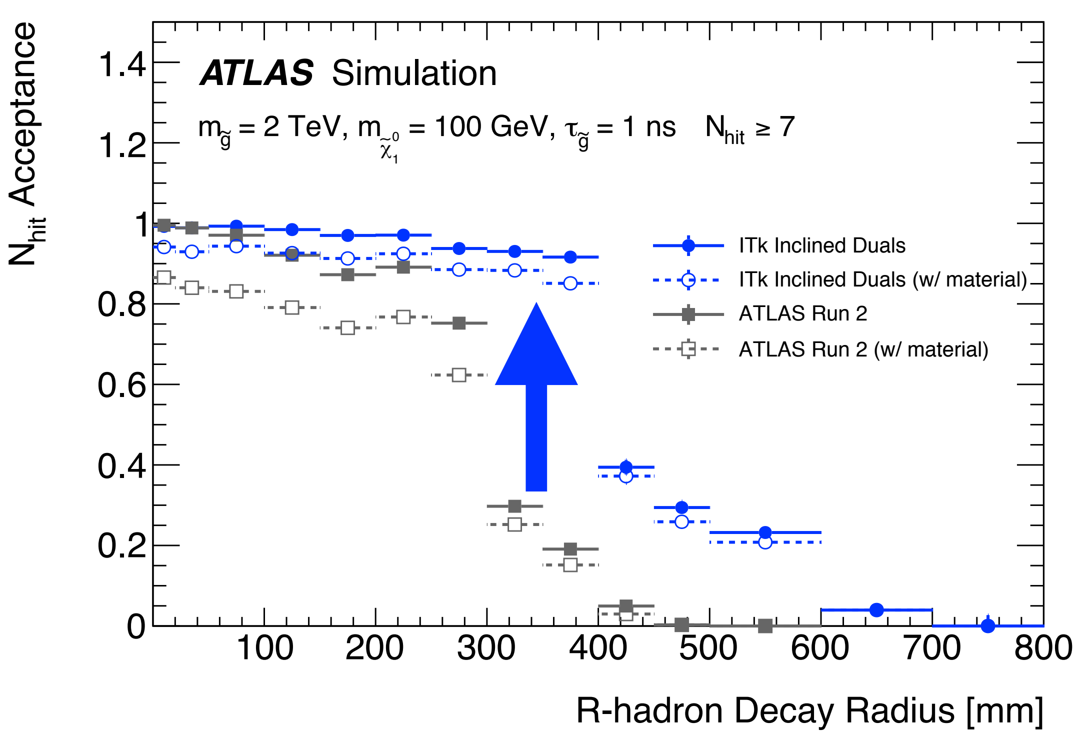


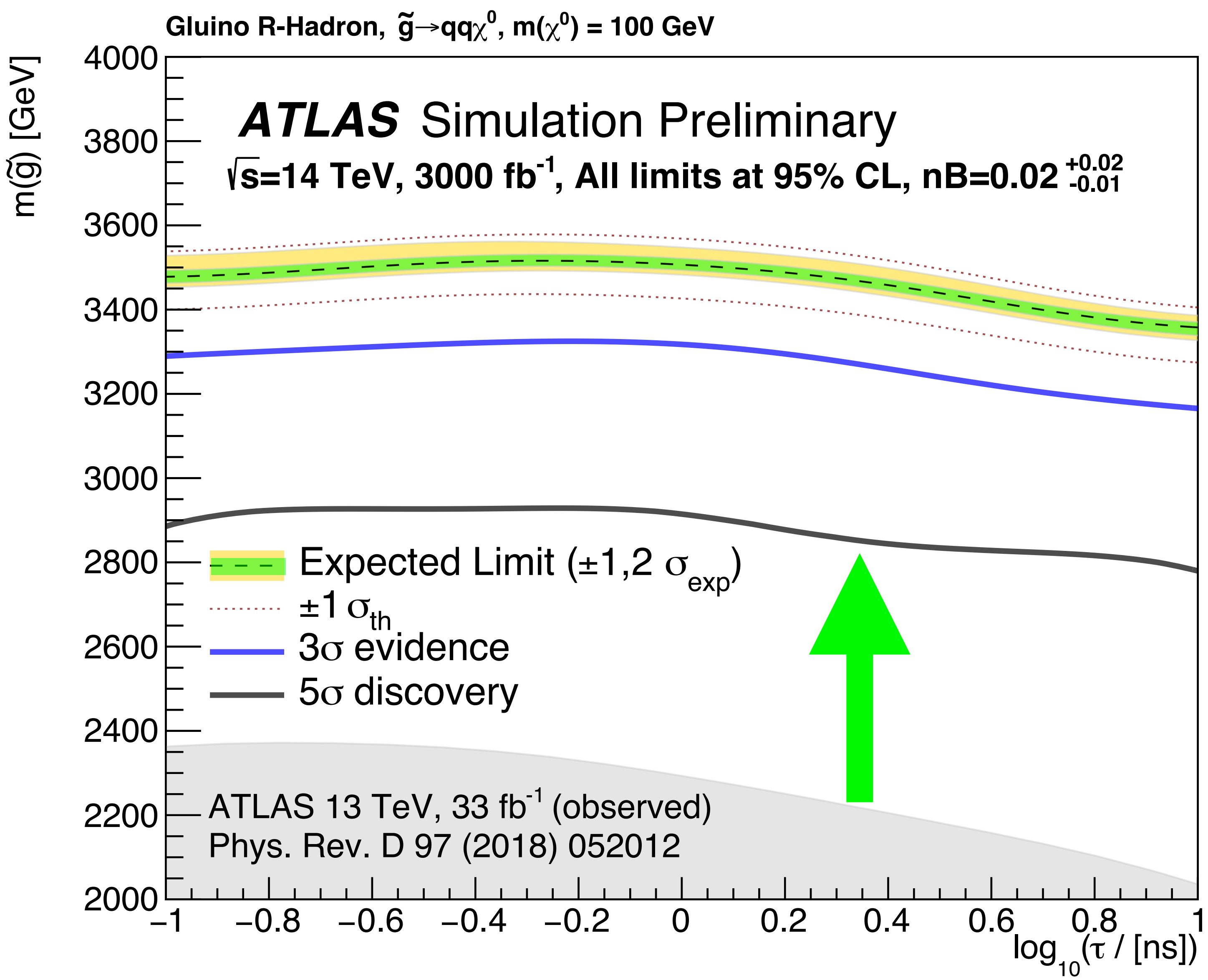
Charged hadrons from jets
Escaping WIMP DM
Displaced Vertices
LLP
Looking for the decay products
p
p
$\tilde{g}$
$\tilde{g}$
$\tilde{q}^*$
$\tilde{q}^*$
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$
q
q
q
q

DISPLACED VTX + MISSING E_T [ATL-PHYS-PUB-2018-033]

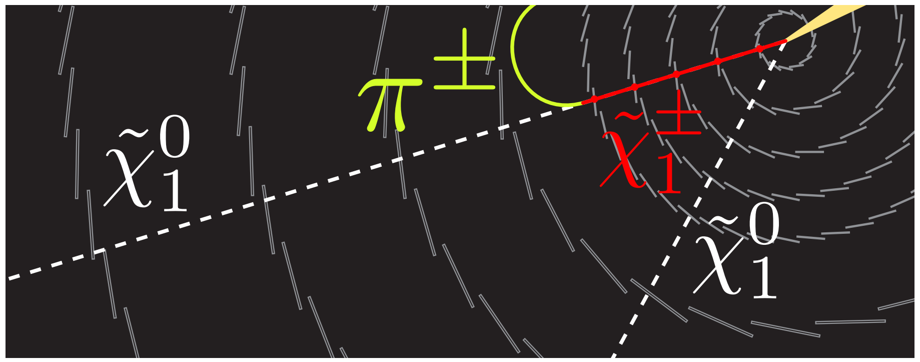


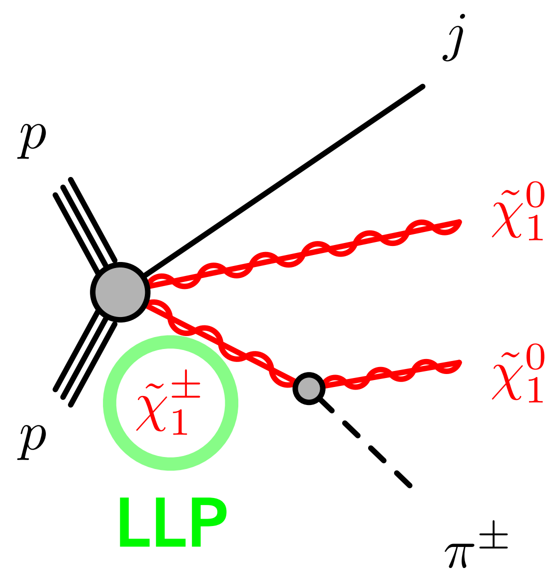
- Long-lived gluinos (e.g. Split-SUSY Models)
    - Signature of displaced vertices + large missing E_T
- Improved tracker gives sensitivity increase for larger lifetimes
- 5-sigma gluino discovery potential to 2.9 TeV!

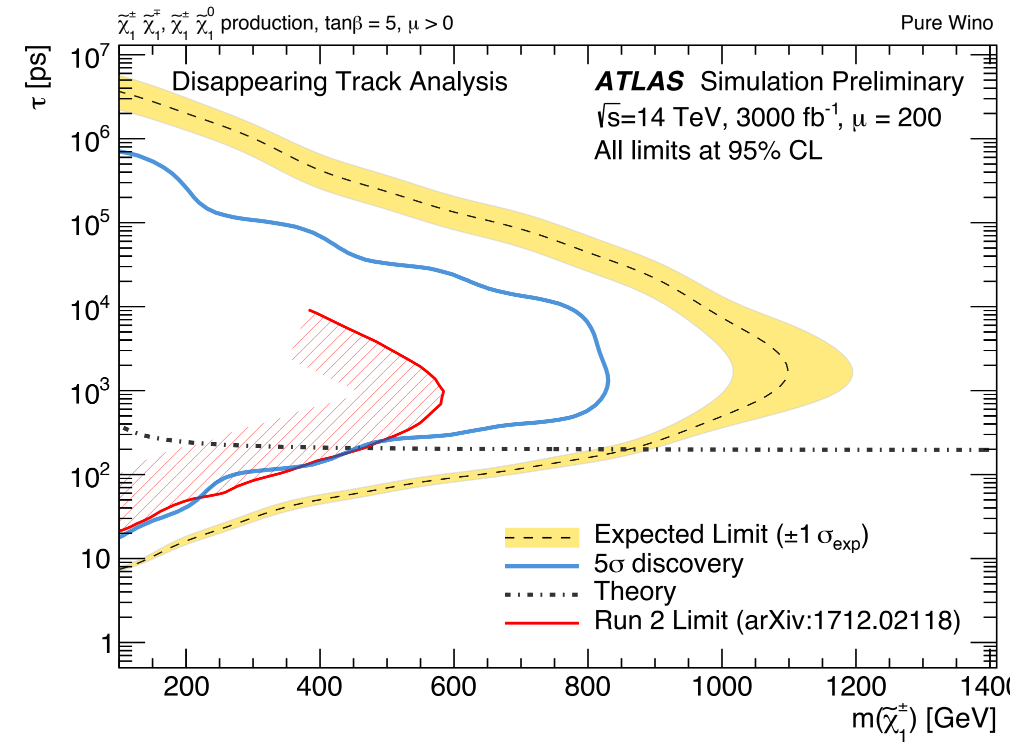


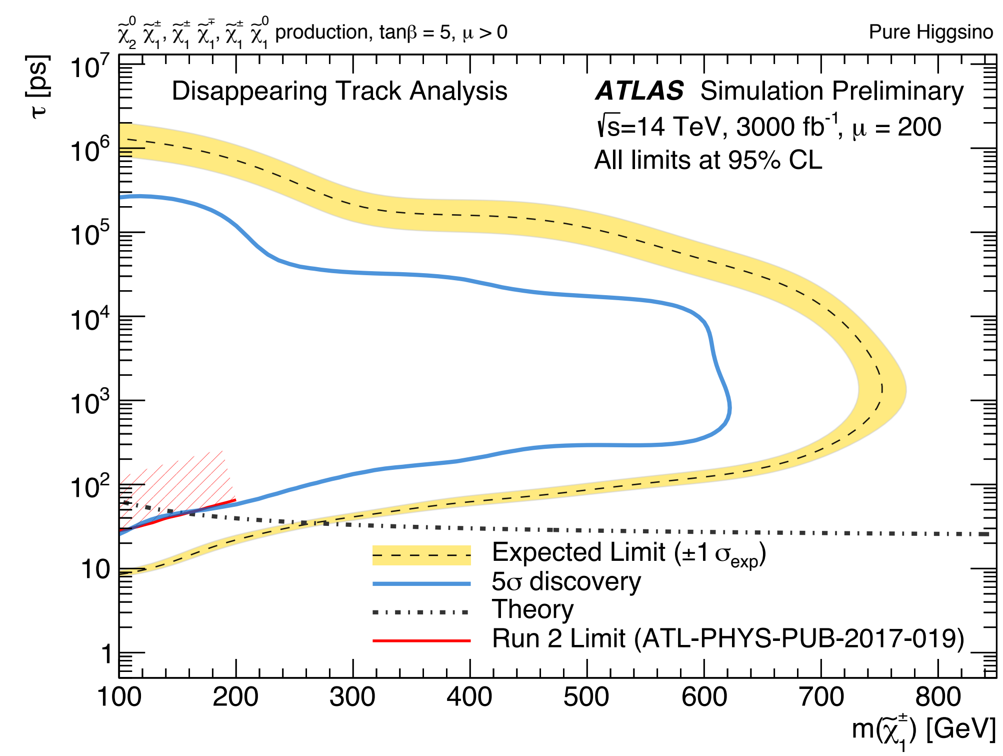


Disappearing Tracks [ATL-PHYS-PUB-2018-031]

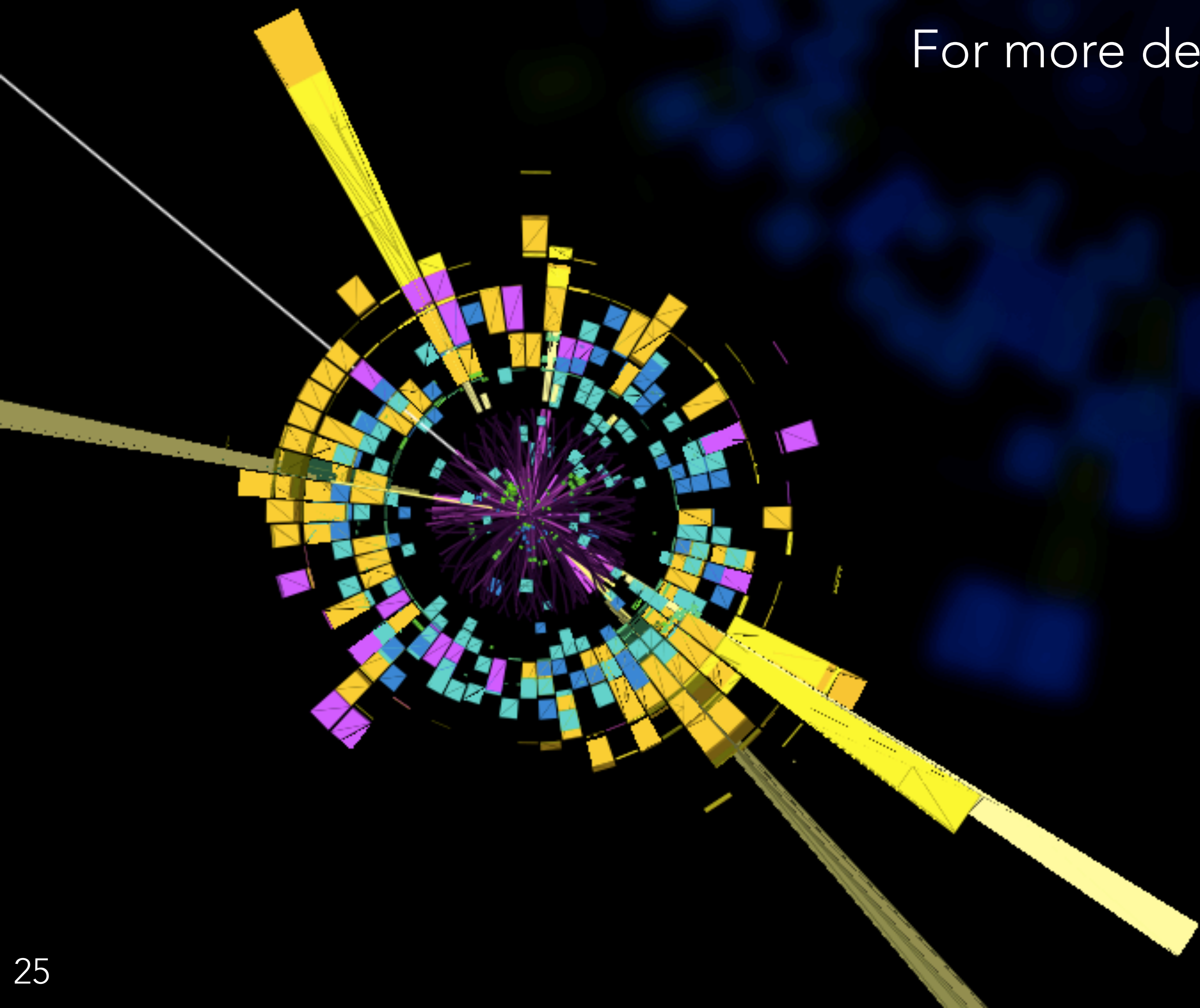






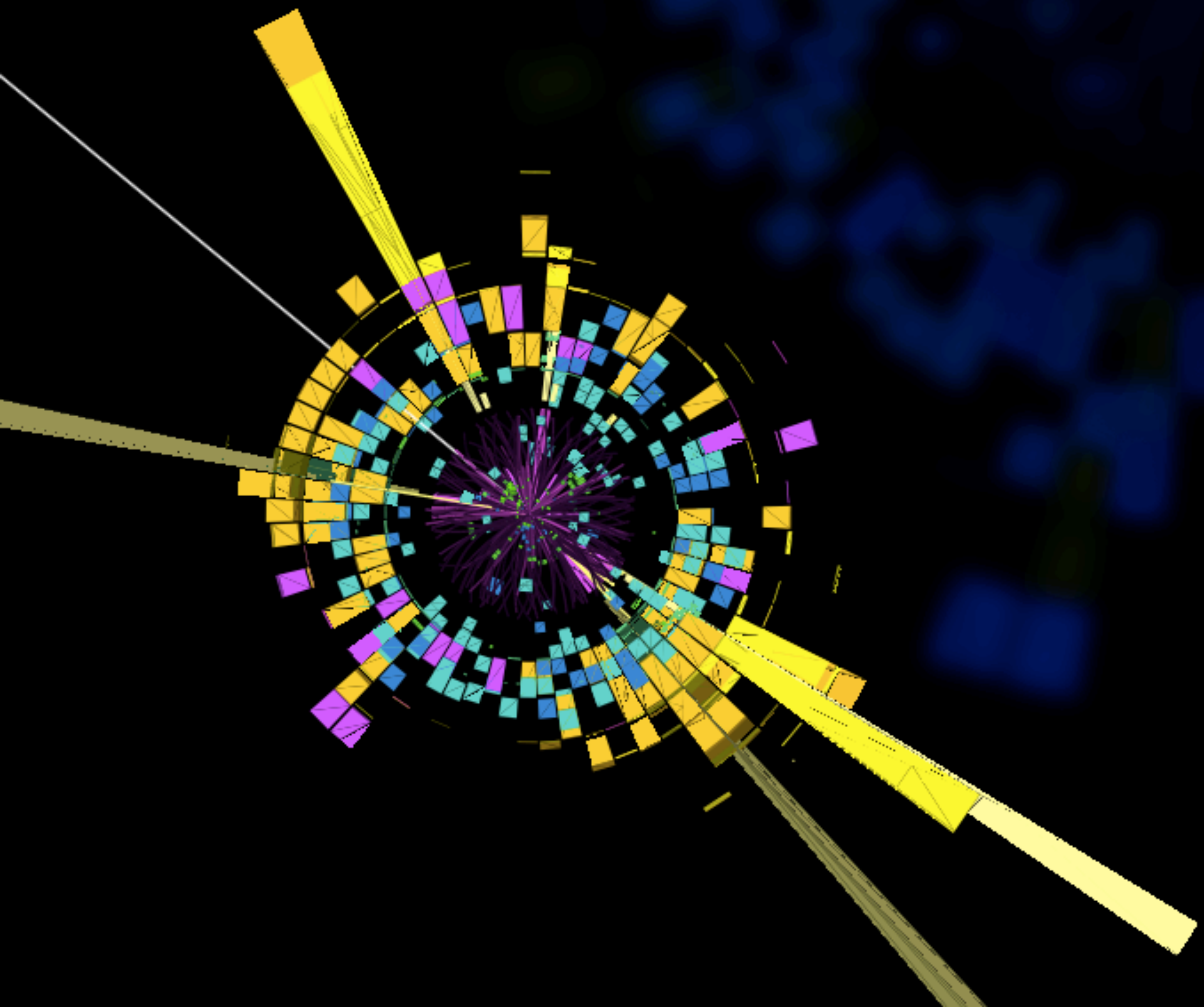


- "AMSB" SUSY models often predict long-lived charged particles
- With 3000 fb^{-1}, edge of current 95% CL exclusion is 5σ discoverable!
- Great prospects, but new techniques could give even more improvements!
  - [ATL-PHYS-PUB-2019-011] NEW!

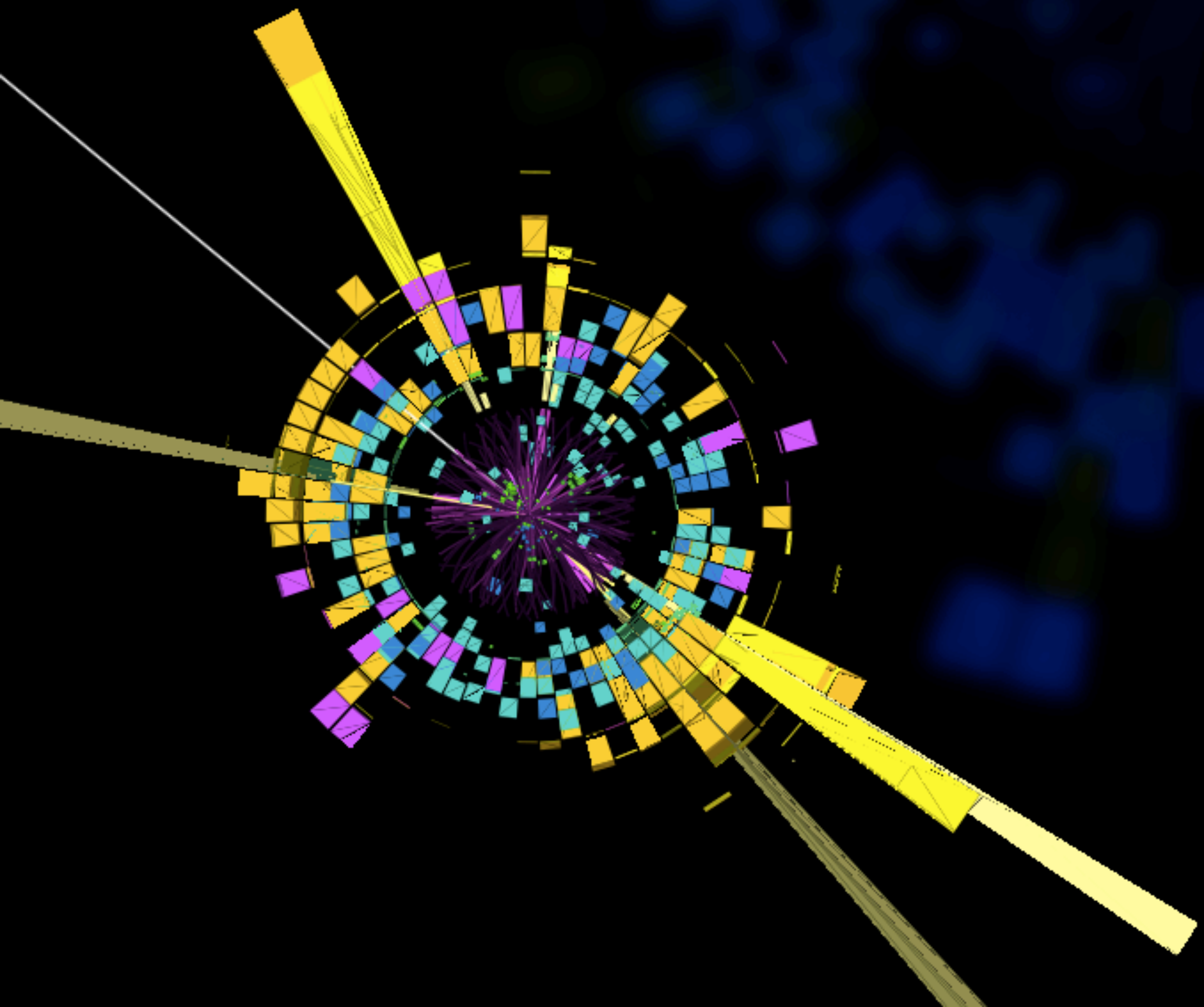


For more details on upgrade prospects for ATLAS, see Monday’s talk from Francesca Pastore

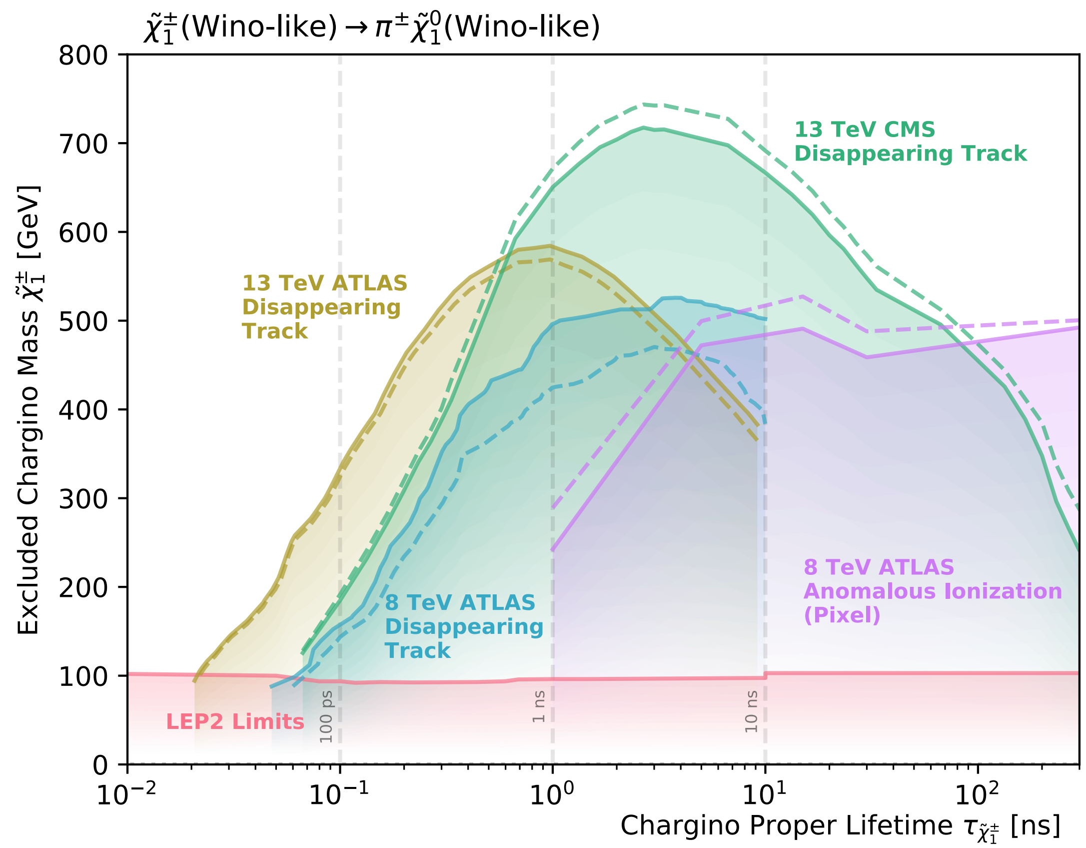
For more details on our entire LLP search program, see our many public results



Thanks for your attention!



Backup



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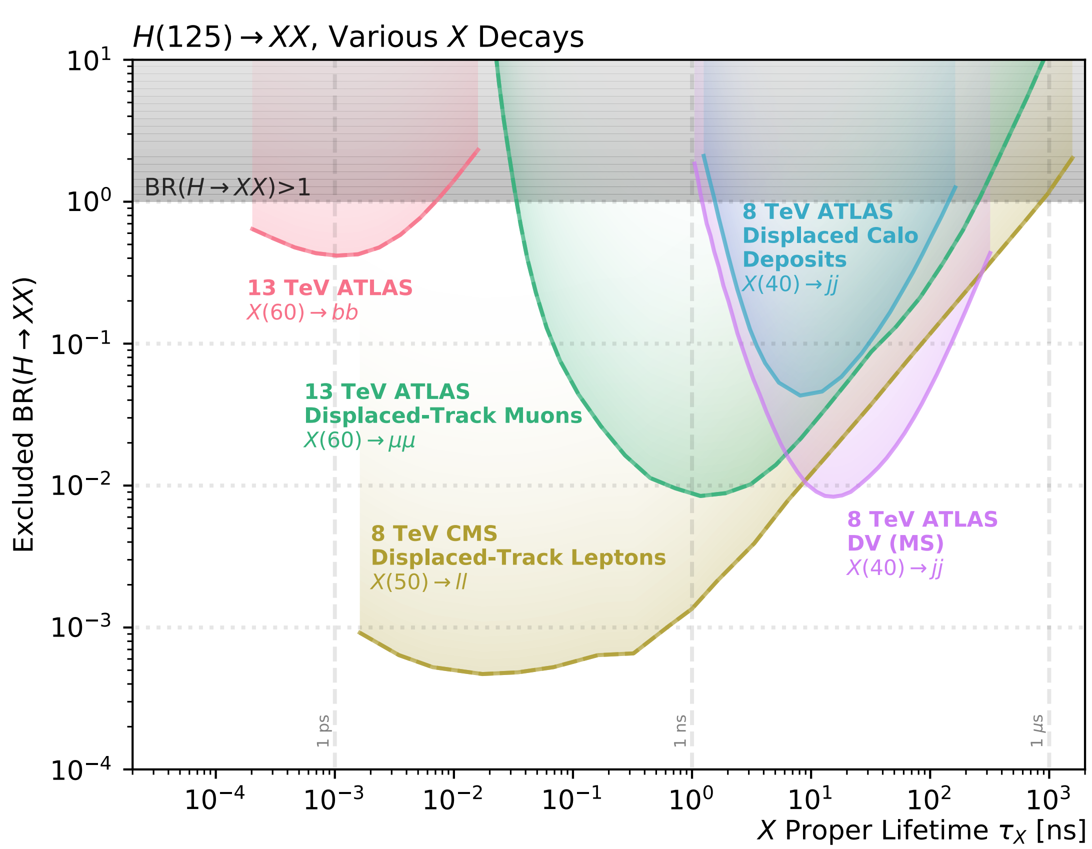

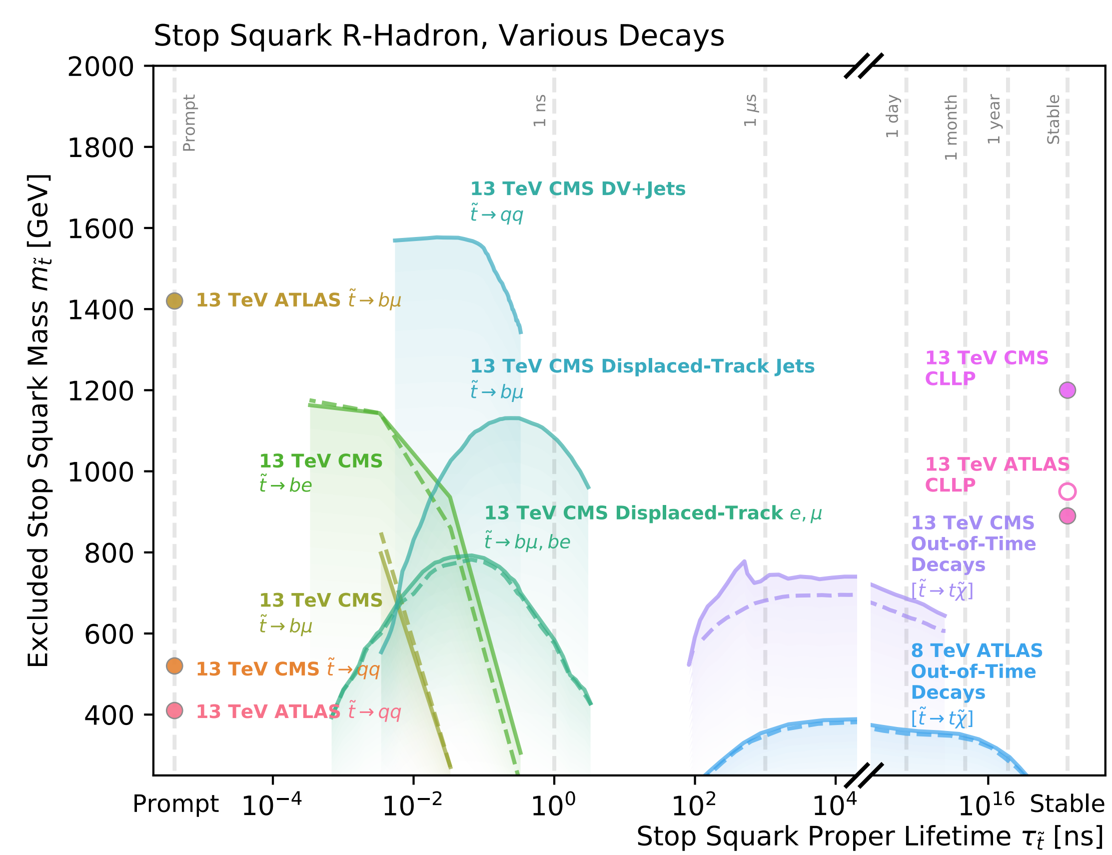

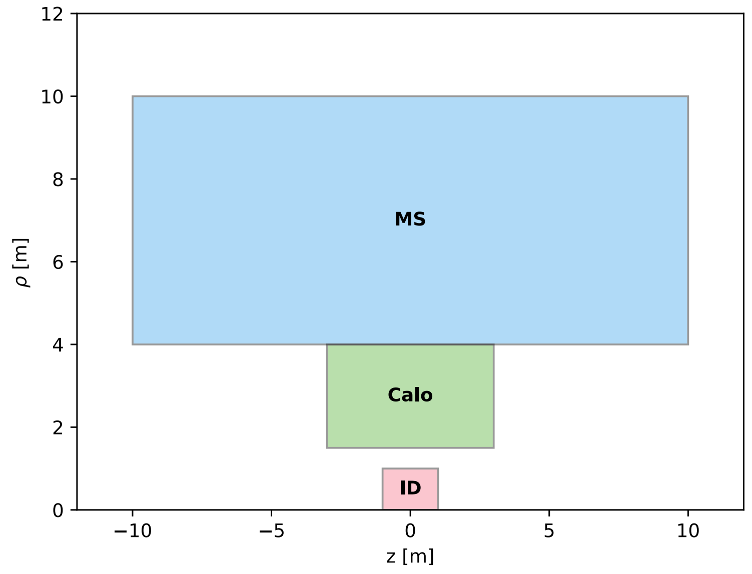

Because the time of decay is exponential (in rest frame), getting the largest, closest detector is important.

Requiring pair-produced LLPs to both decay in far away detectors doesn't make sense…

[1810.12602] - LL, C. Ohm, A. Soffer, T. Yu