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Searches for BSM physics using challenging and Long-Lived signatures with that ATLAS detector

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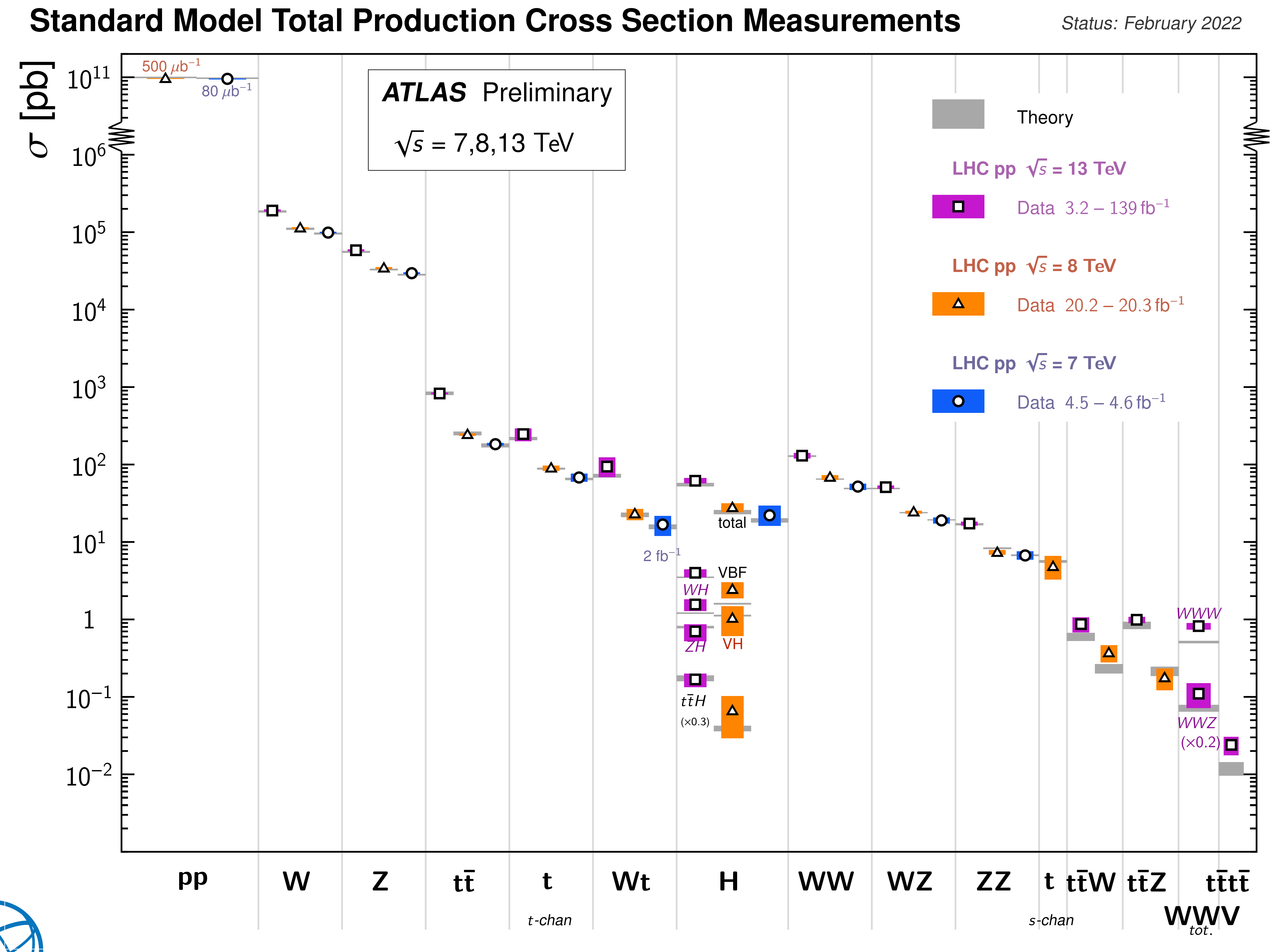
Gen—T

ATLAS EXPERIMENT

Introduction

- Standard Model (SM): very successful theory
- Precise predictions, verified by experiment with impressive agreement with theory across orders of magnitude



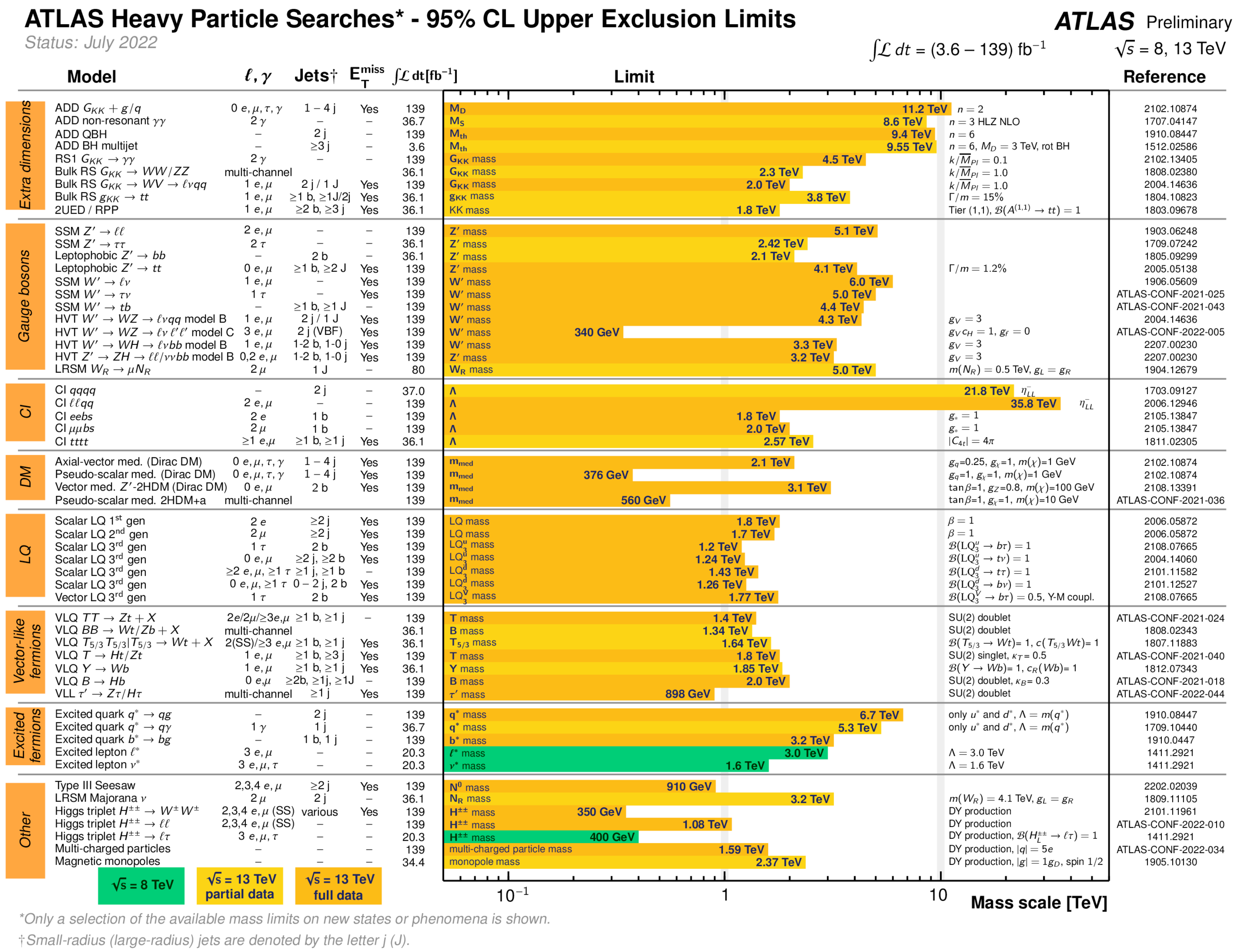
- Cannot be the ultimate theory
- Several open questions in HEP

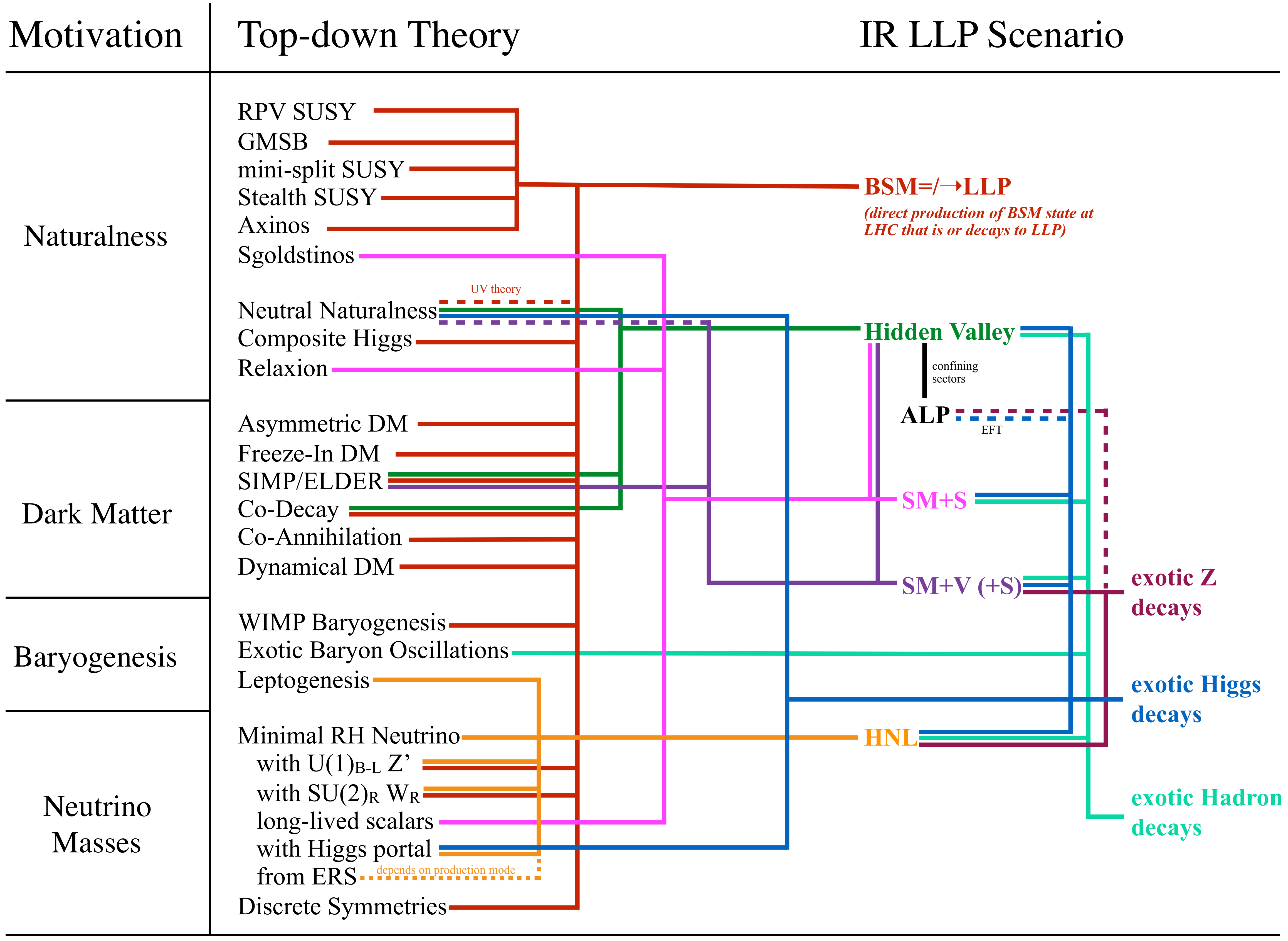
- What is Dark Matter?
- Neutrinos have a mass ≠ 0
- Matter and antimatter are not symmetric
- …

Introduction

To date, **O(100) ATLAS, CMS, LHCb papers** on BSM searches with full Run 2 dataset!

Still, no evidence of new physics…





Curtin et al, 1806.07396

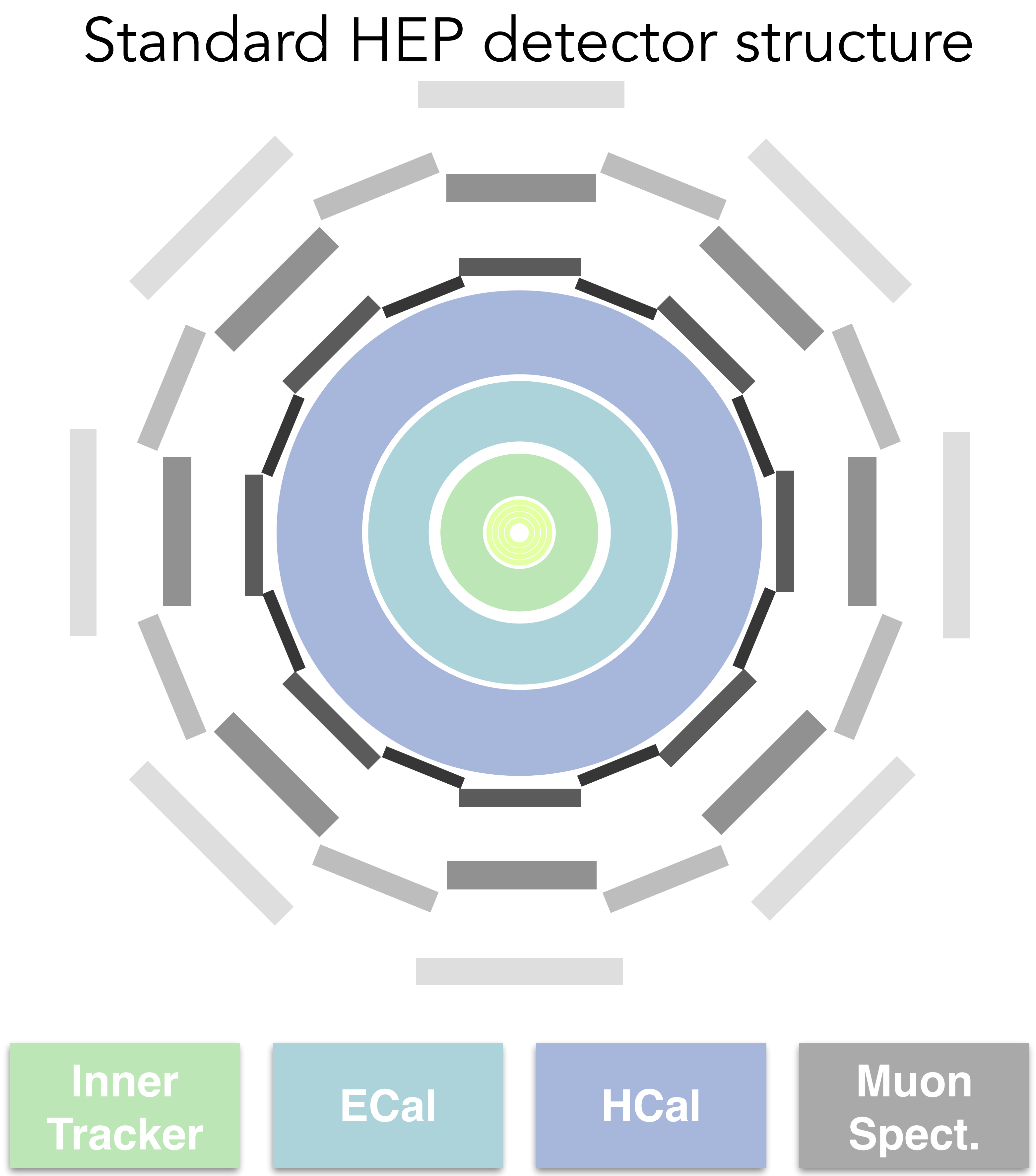
New physics could have long lifetimes

Signatures in ATLAS and CMS not visible in standard searches!!

How can we look for LLPs in collider experiments?

That depends on:

LLP lifetime



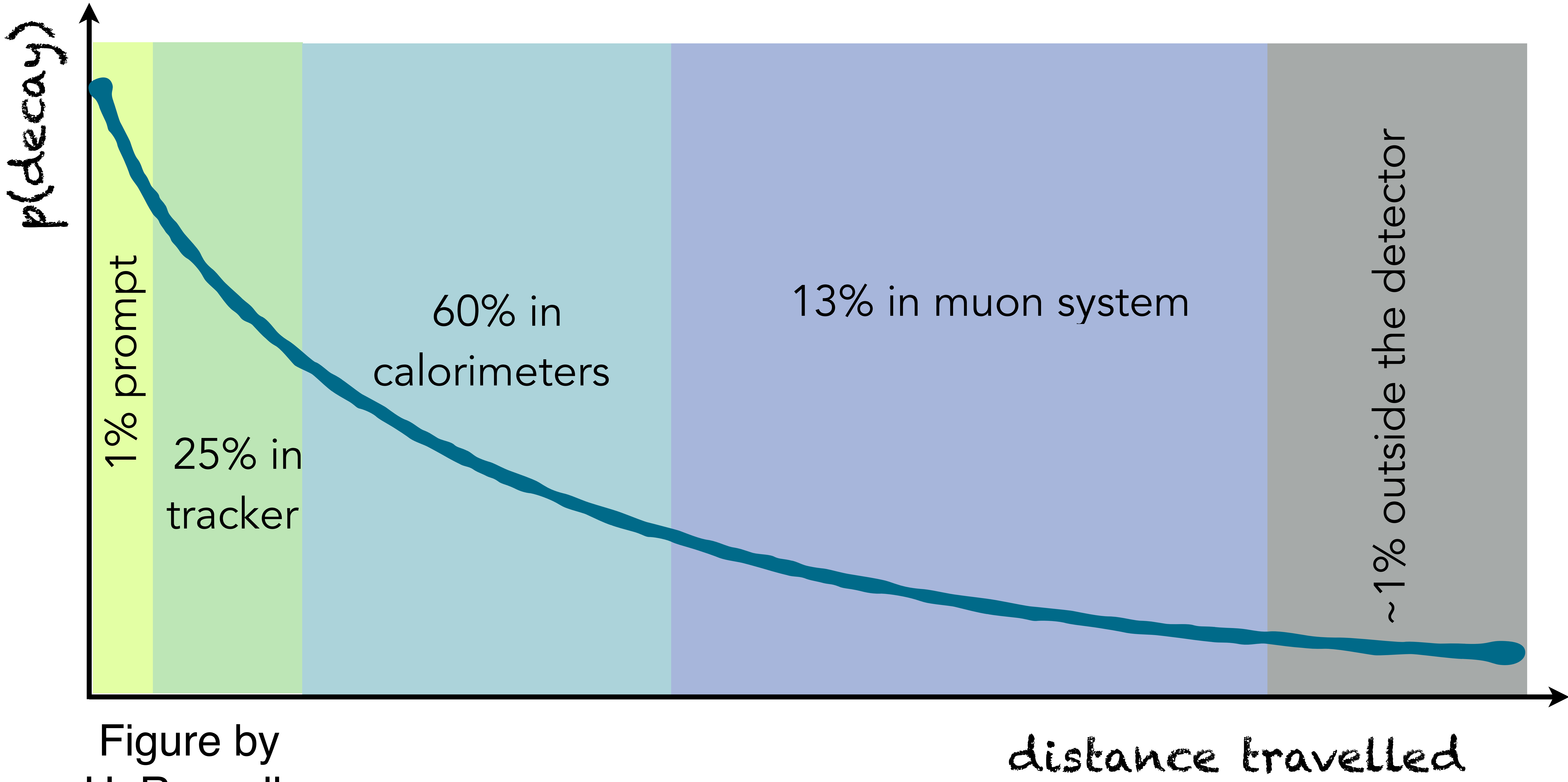


Figure by H. Russell

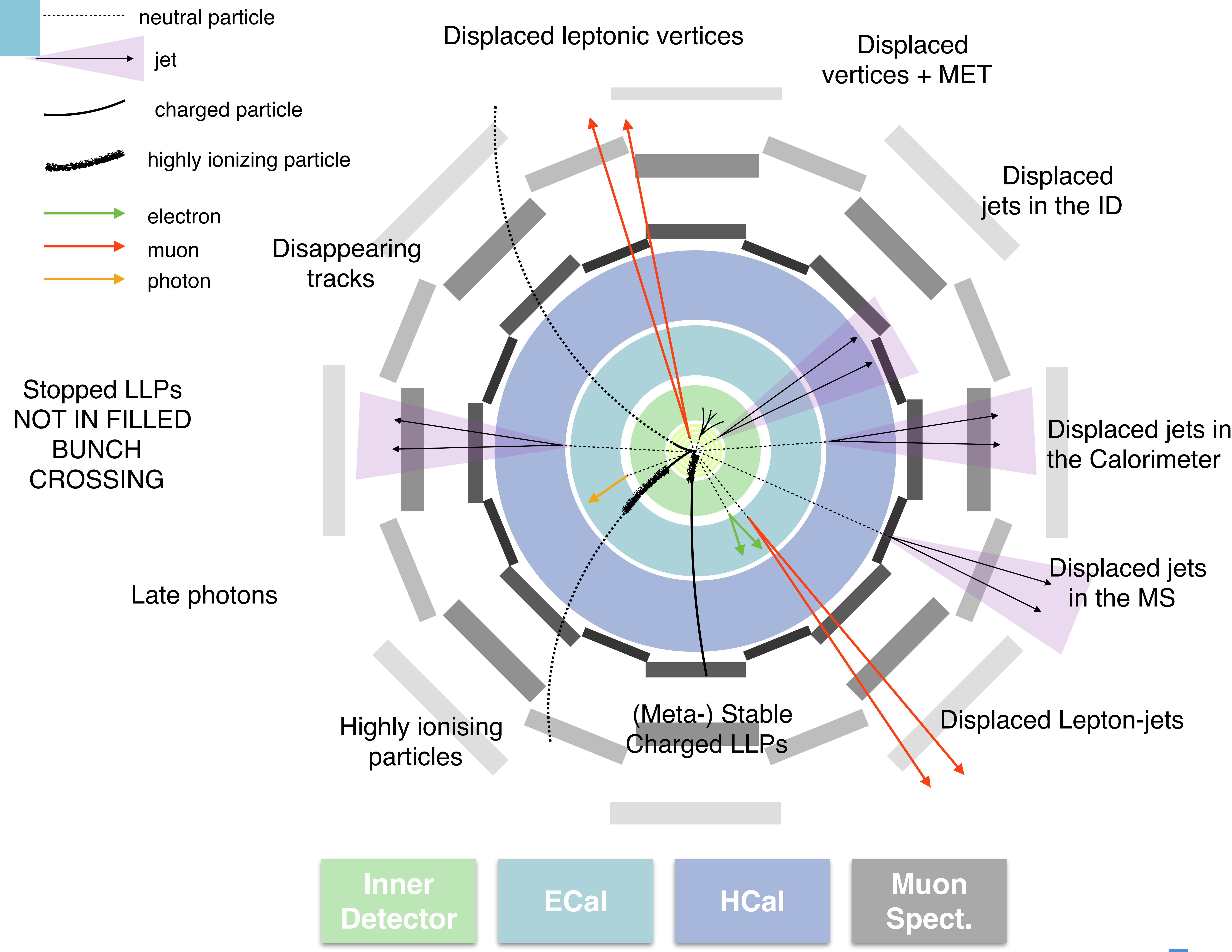
How can we look for LLPs in collider experiments?

That depends on:

LLP lifetime | **LLP nature** | **object identification**

- Is it charged?
  - Does it leave a standard track?
  - Is it highly ionising?
- Is it neutral?
  - which decay mode (hadronic, leptonic, photons, invisible)?

- None of these signatures would be "seen" by a standard HEP search!

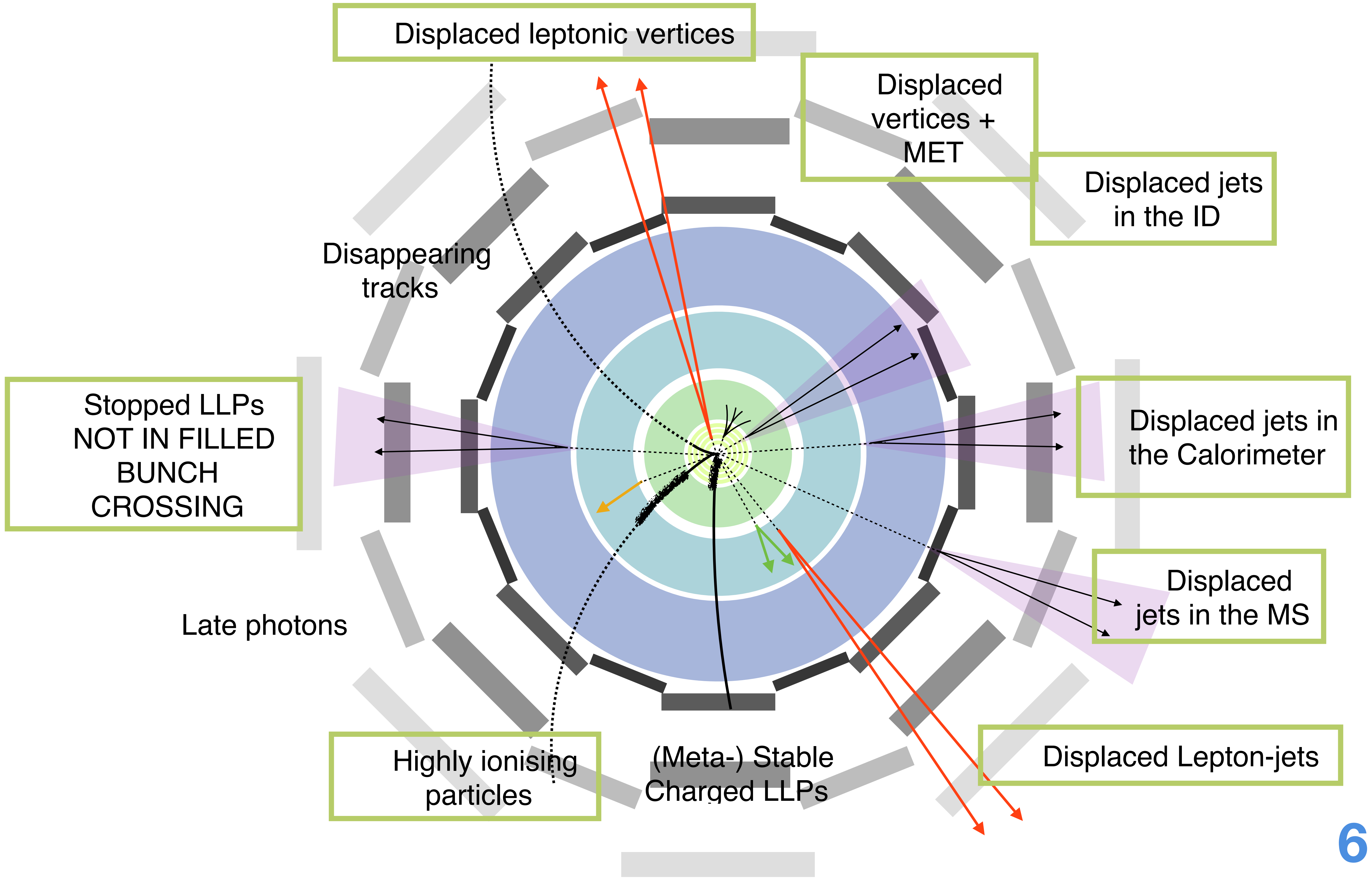


How can we look for LLPs in collider experiments?

That depends on:

LLP lifetime	LLP nature	object identification	trigger

- Trigger: combination of hardware + software that must decide very quickly whether to save an event or lose it forever
- Standard triggers have no sensitivity to LLPs
- Develop dedicated triggers



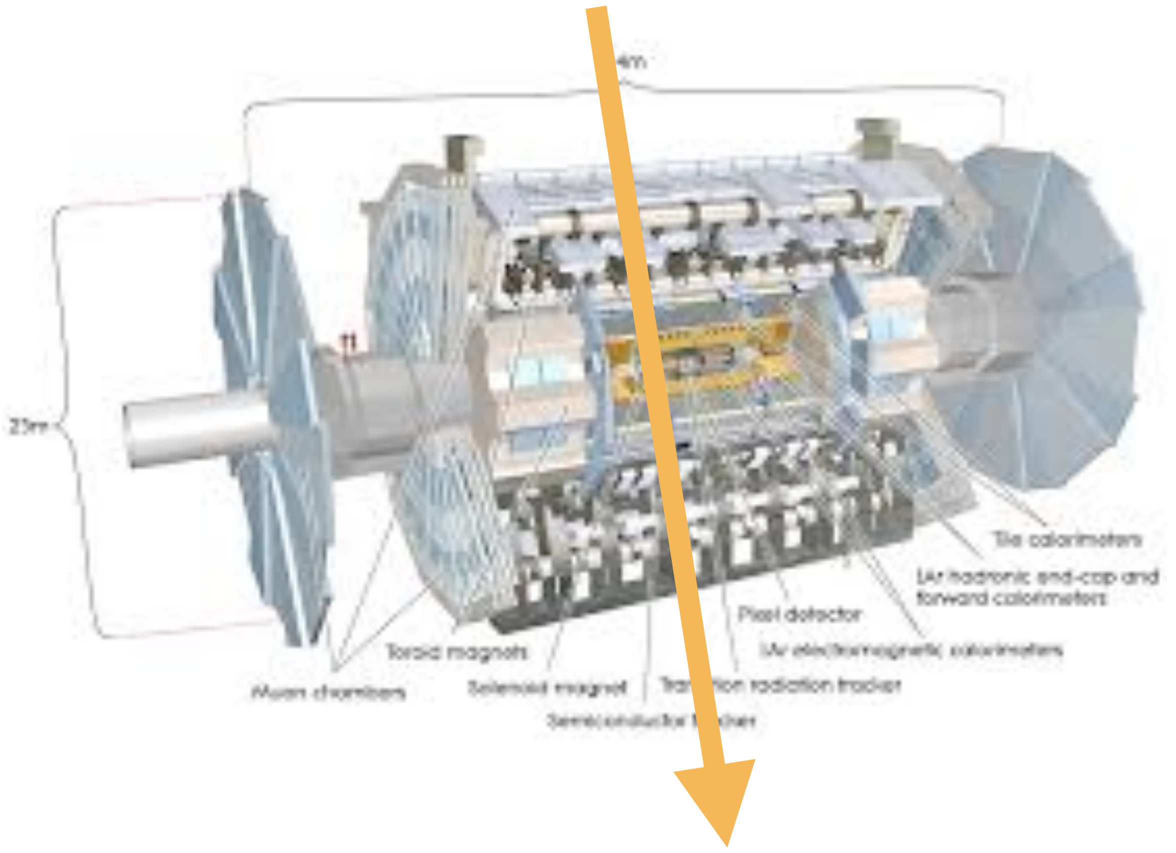
How can we look for LLPs in collider experiments?

That depends on:

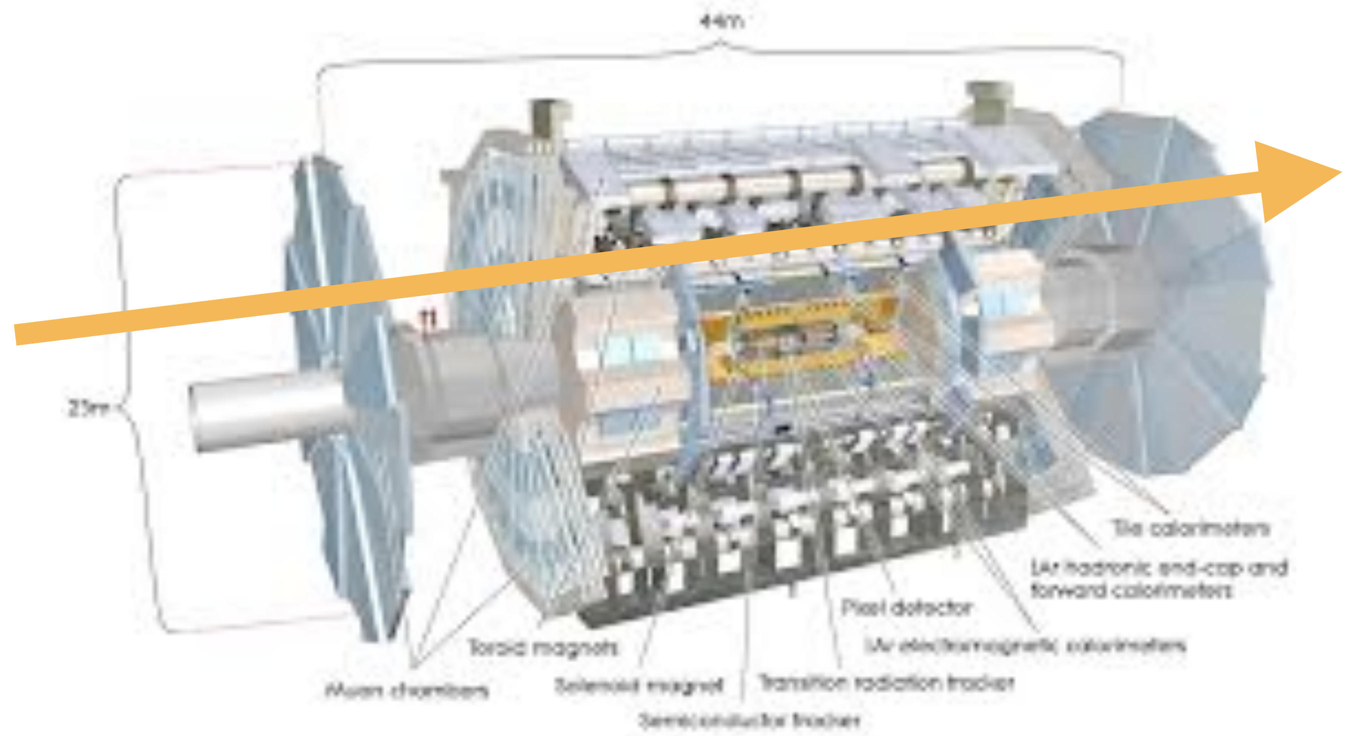
LLP lifetime | LLP nature | object identification | trigger | background rejection

- Small or unusual backgrounds play a key role:

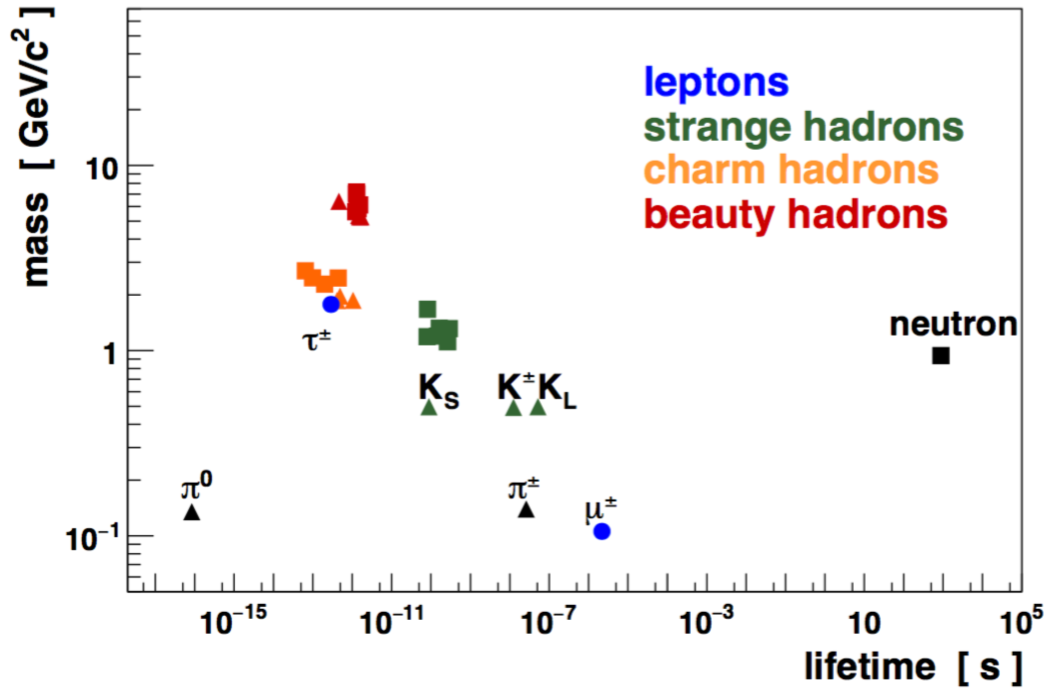
cosmic muons



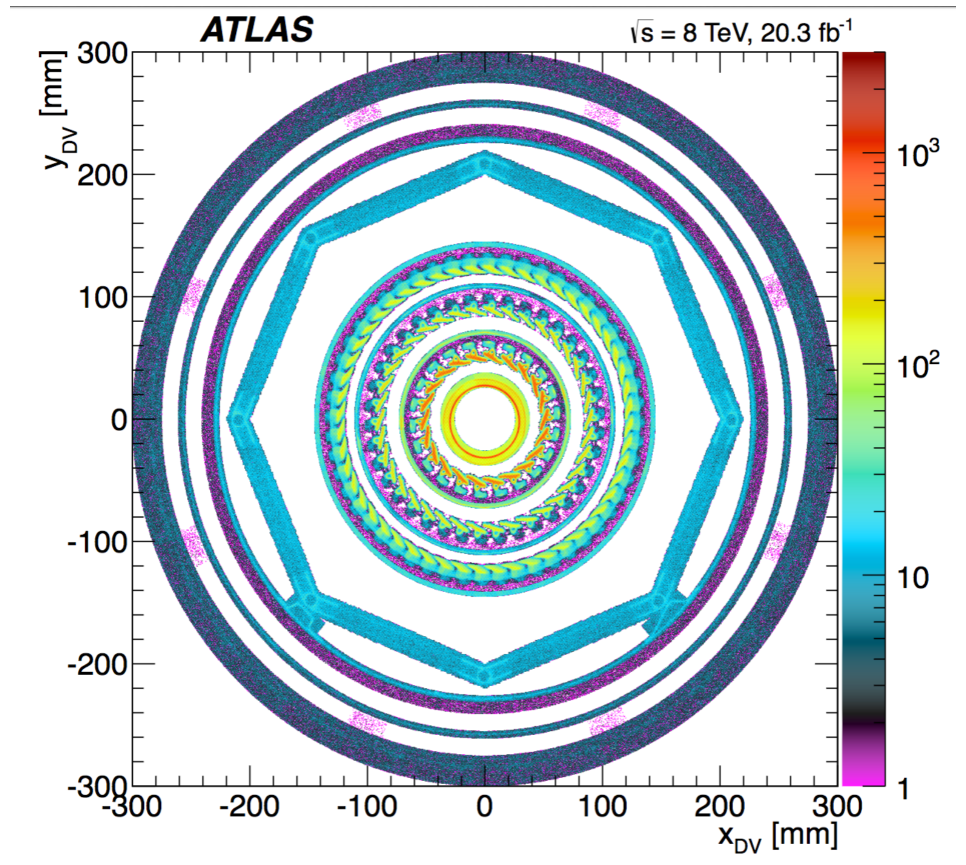
beam halo muons



SM particles with relatively long lifetime



material interactions



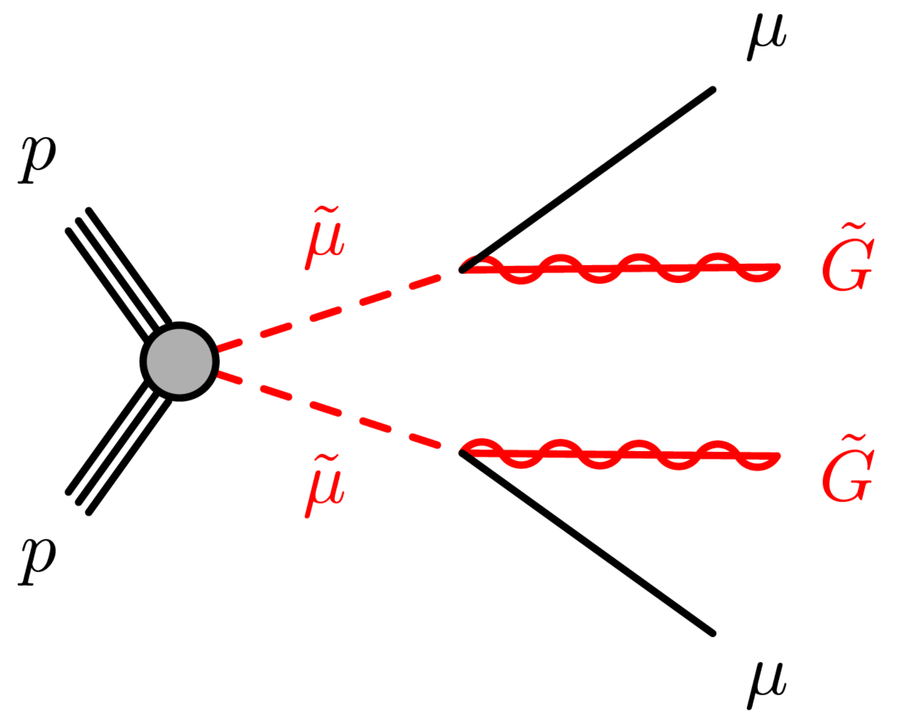
- For most of them, no good simulations
  - All searches rely on data-driven methods

LLP lifetime | LLP nature | object identification | trigger | background rejection

Latest results on Searches for LLPs in ATLAS

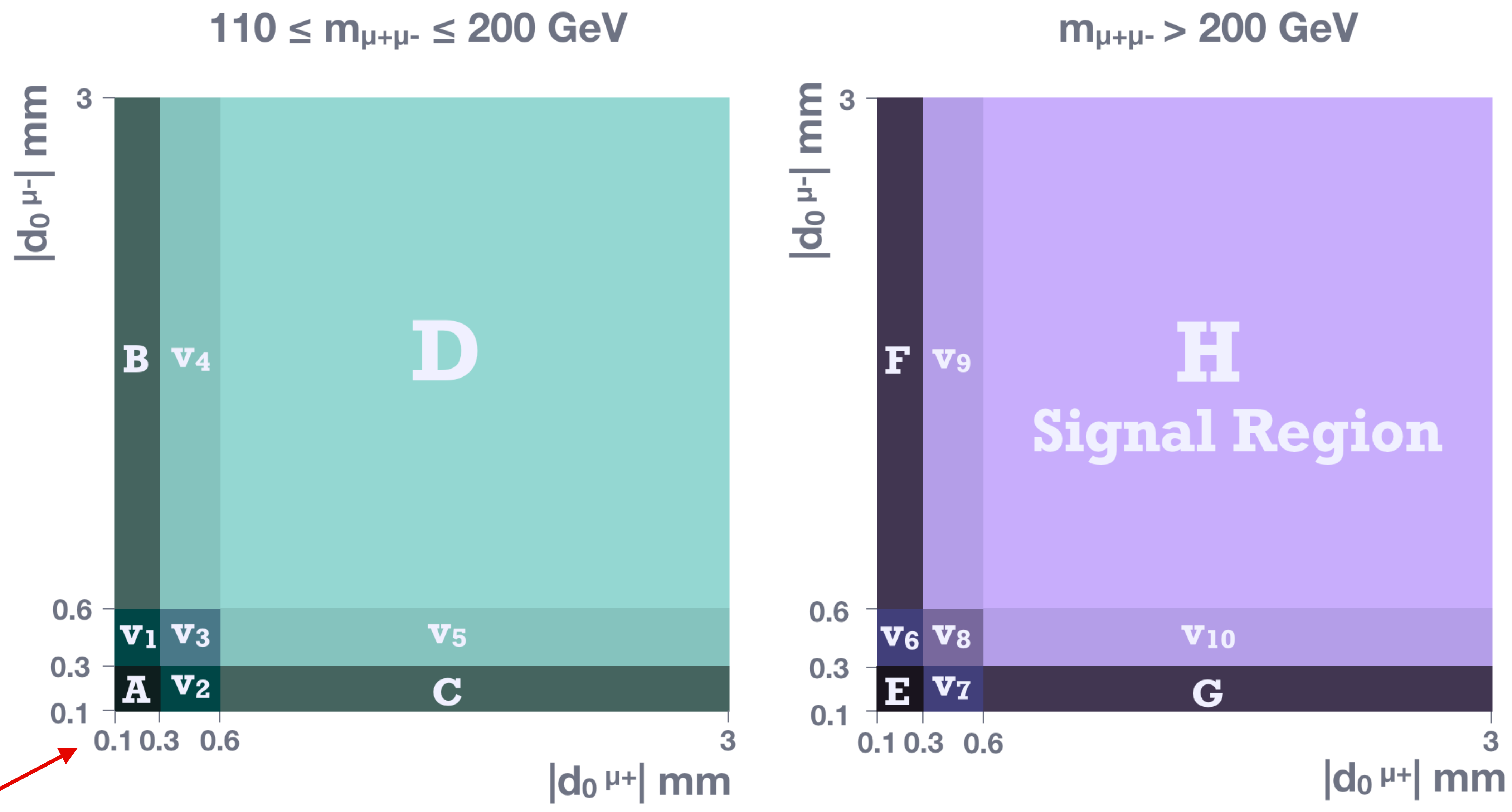
Micro-displaced muons

ANA-SUSY-2020-09



- Search for pairs of opposite charge muons with O(mm) impact parameter
- GMSB SUSY with nearly massless gravitino LSP and long-lived slepton ($\tilde{\tau}$, $\tilde{e}$, $\tilde{\mu}$ NLSP) due to small coupling to the LSP
- Di-muon trigger
- Very simple Signal Region selection: two muons with large transverse impact parameter $|d_0| > 0.6$ mm

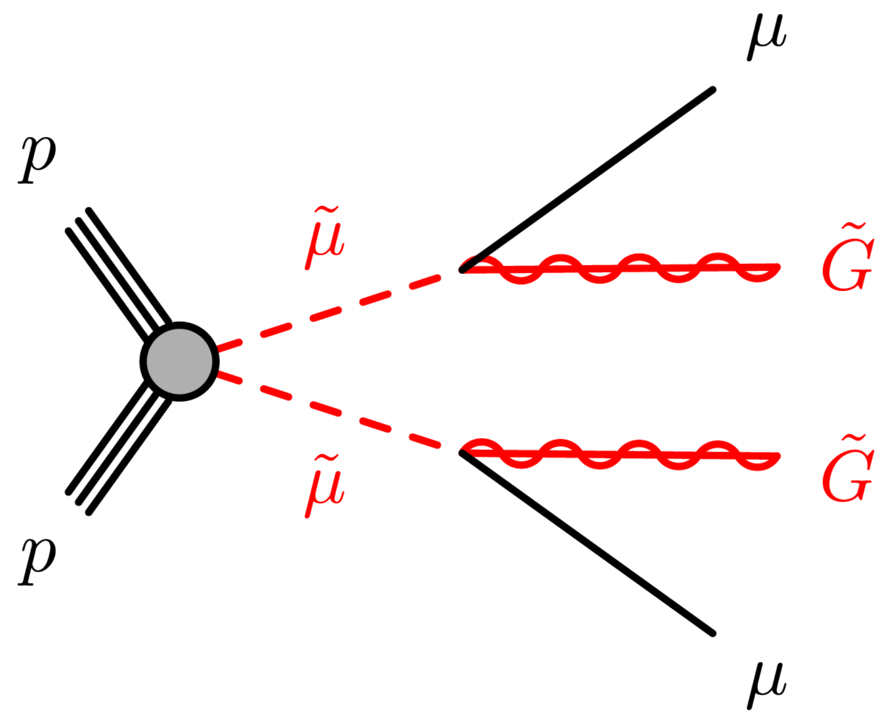
- Dominant SM background: semileptonic B-hadron decays, $bb \to \mu\ \mu$
  - Data driven background ABCD method
- Other SM processes with prompt leptons are negligible (Z/W+jets, tt, single top, di-boson)



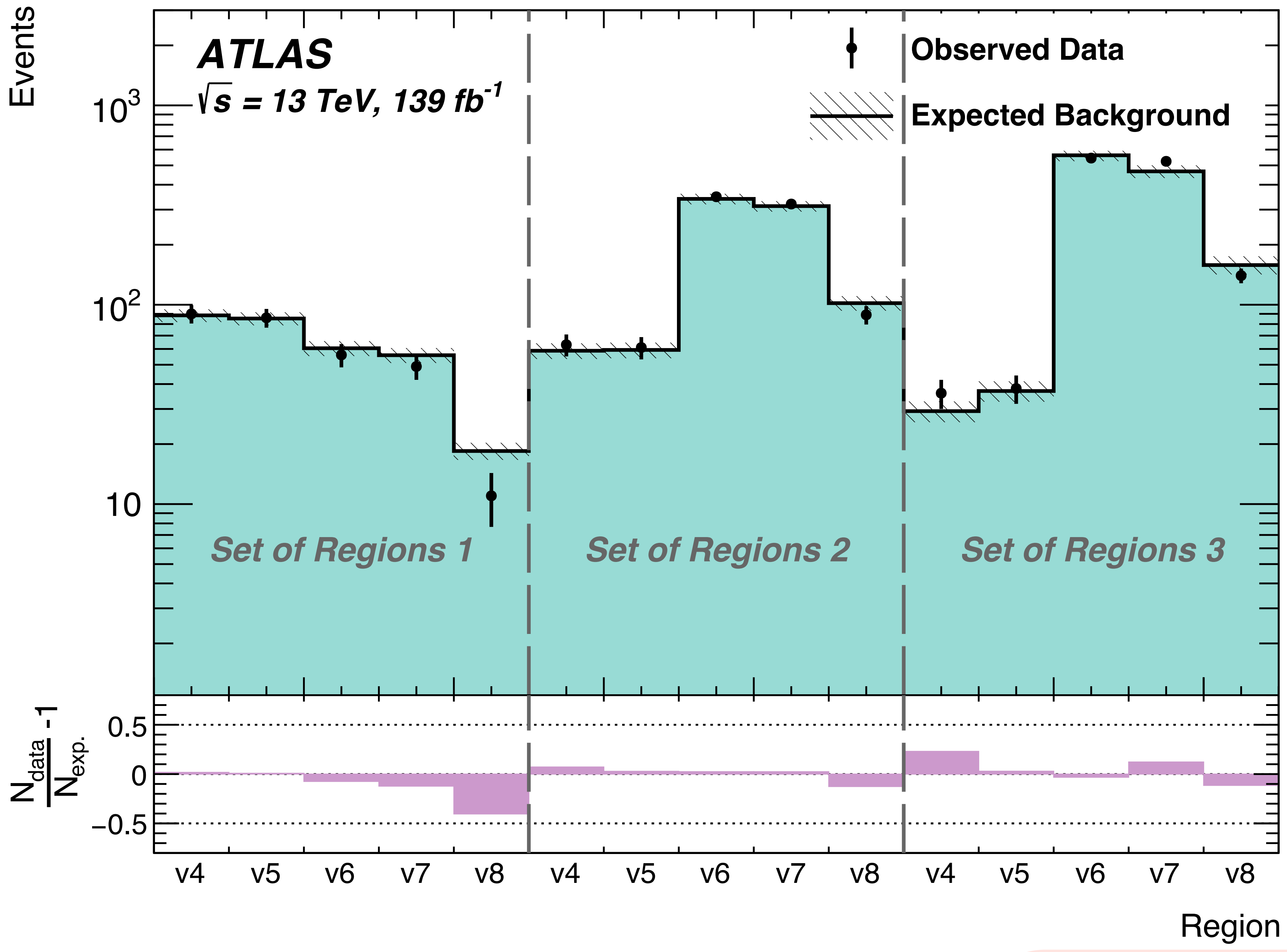
$|d_0| > 0.1$ mm to reduce SM processes

Micro-displaced muons

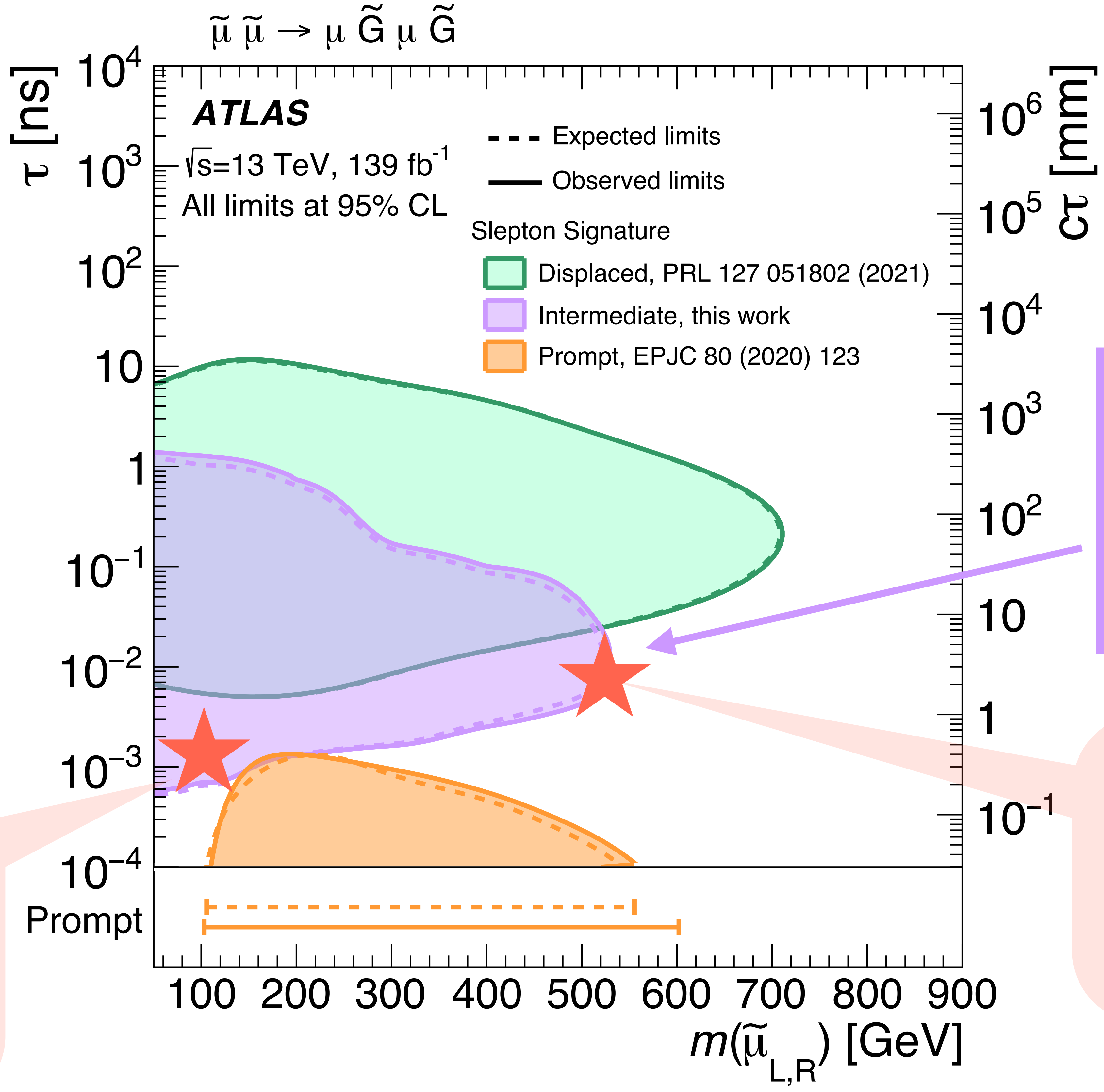
ANA-SUSY-2020-09



- 15 Validation regions to test the ABCD method
  - General good agreement
  - One region has a 2σ non-closure
    - Systematic uncertainty assigned in the signal region.



- No excess observed



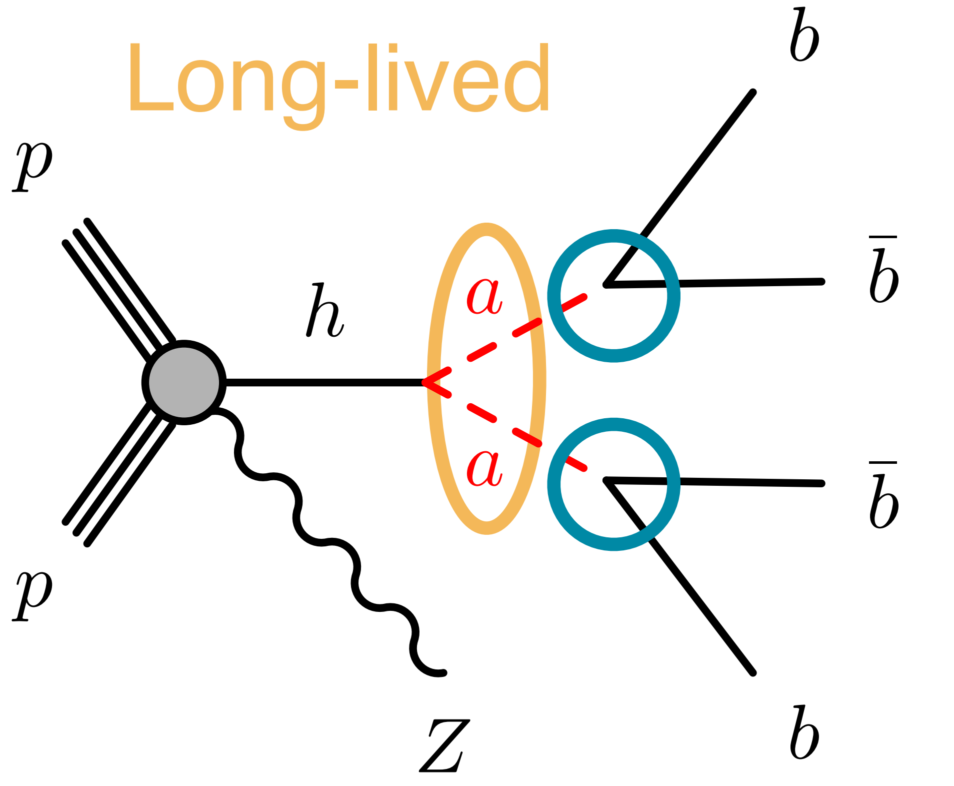
Closing the gap between prompt (reinterpretation) and large displacement searches

Excluded lifetimes down to 1 ps for m(~μ) ~ 100 GeV

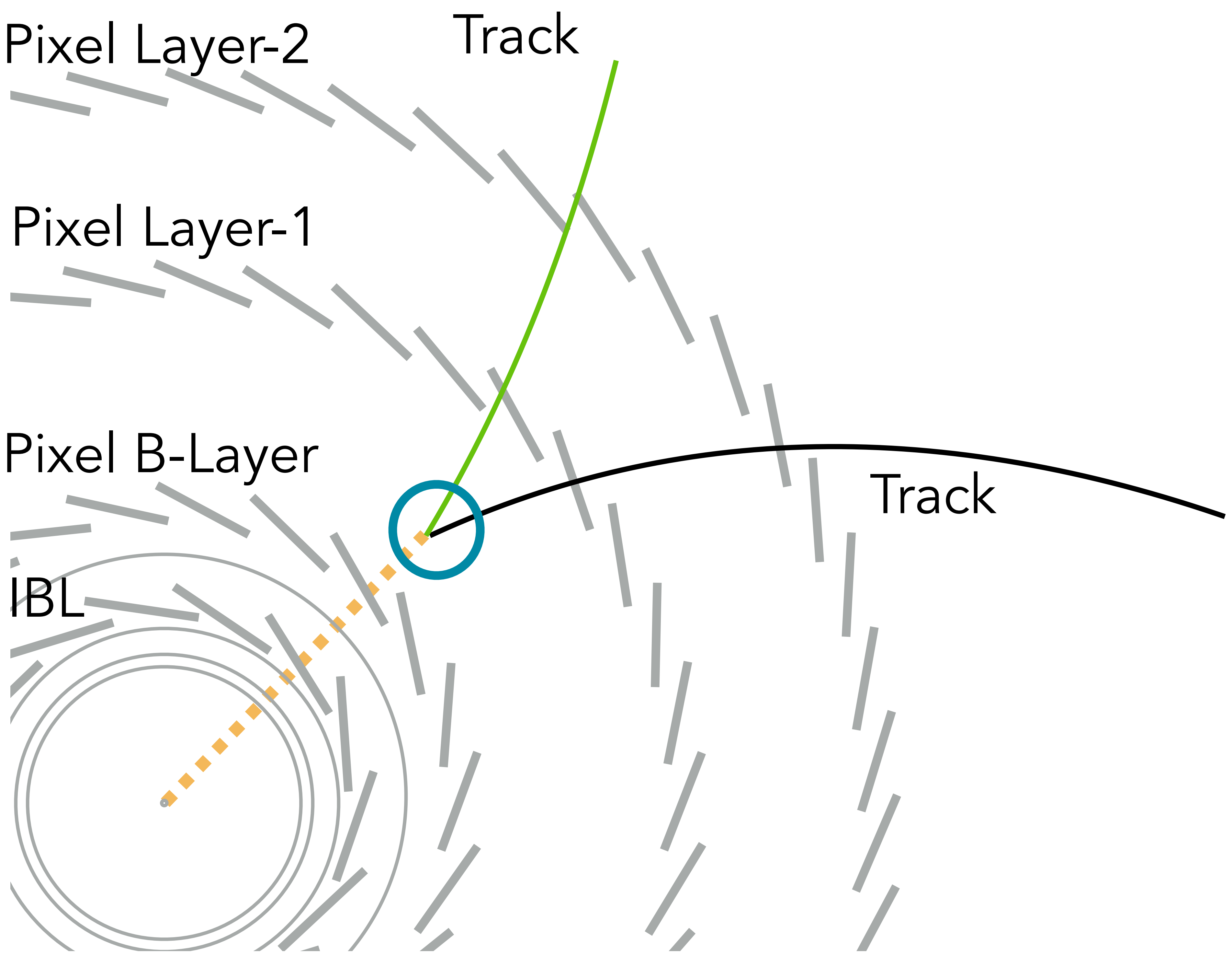
Excluded lifetimes down to 10 ps for m(~μ) ~ 520 GeV

Large-Radius Tracking

IDTR-2021-03



- Standard tracking in ATLAS optimized for particles pointing back to IP
  - tight requirements in number of silicon hits and impact parameter
  - would reject tracks from displaced decays



Large-Radius Tracking

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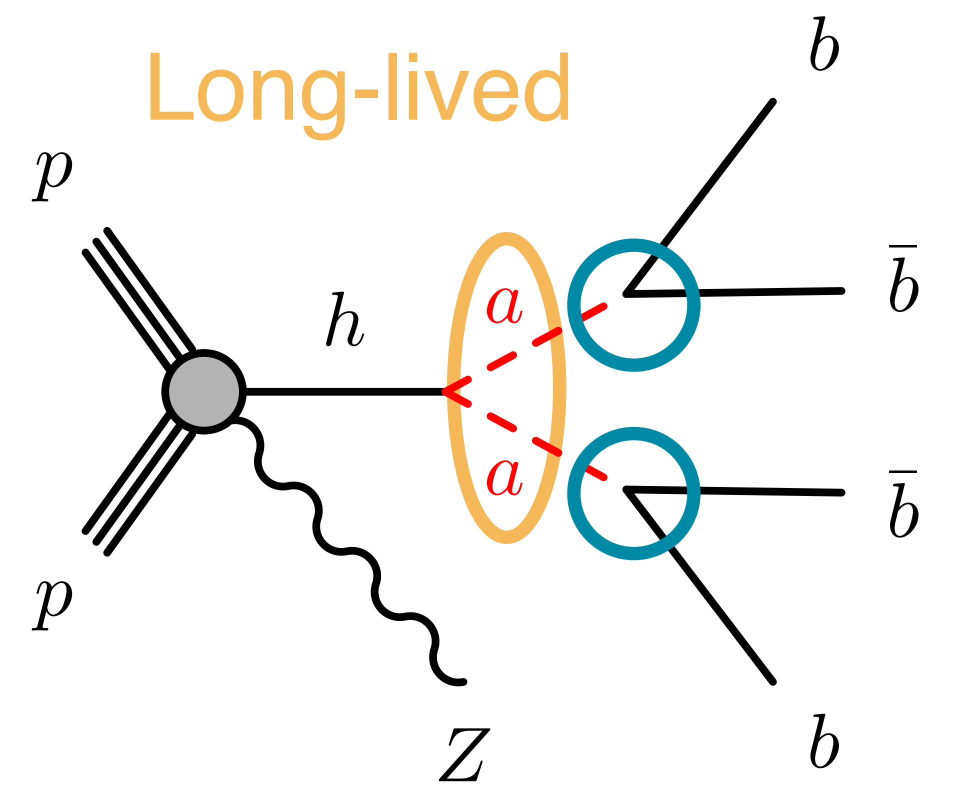

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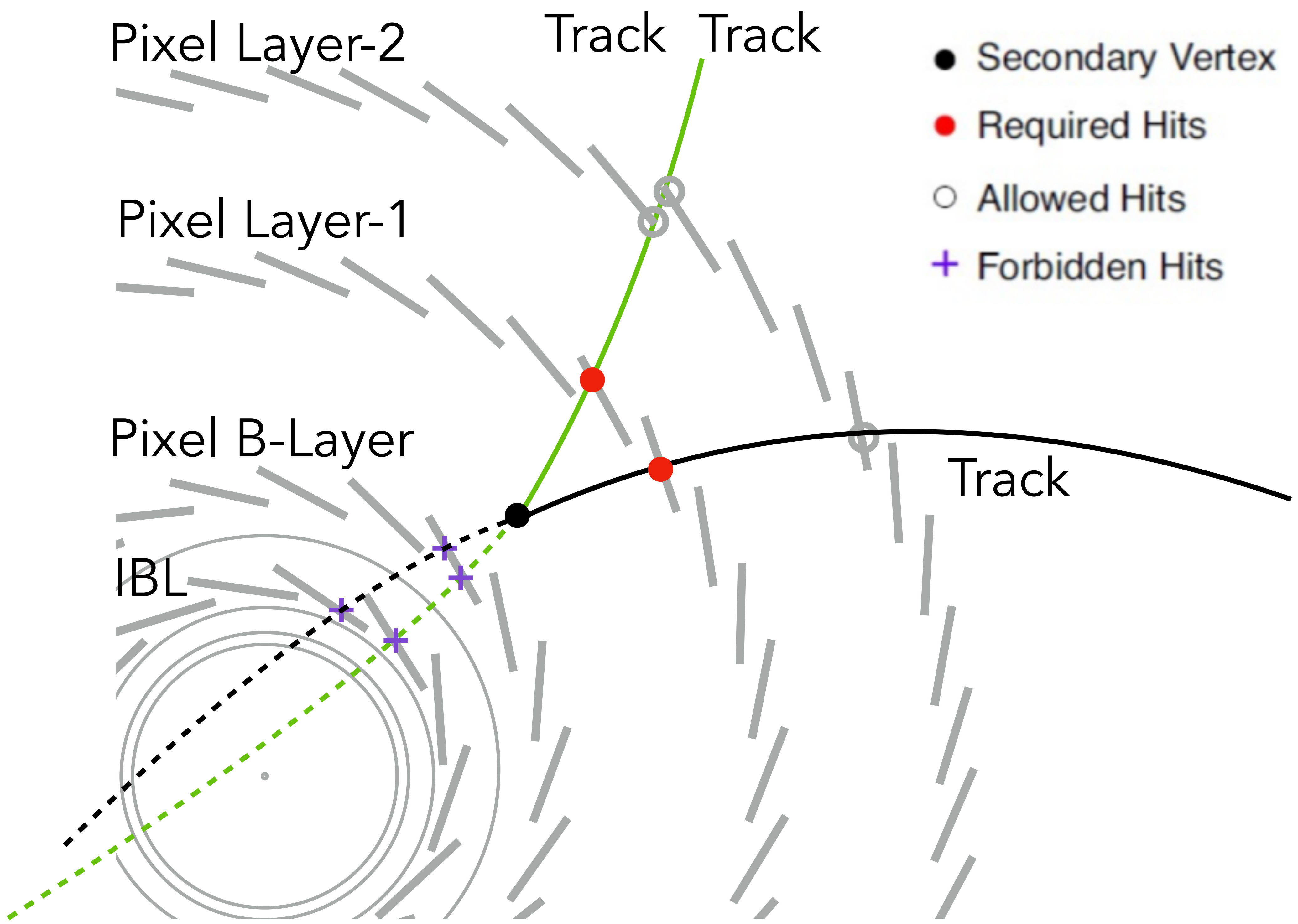
- Large radius tracking (LRT)
  - Relax requirements in number of hits and impact parameter
  - Re-run with hits not associated with standard tracks



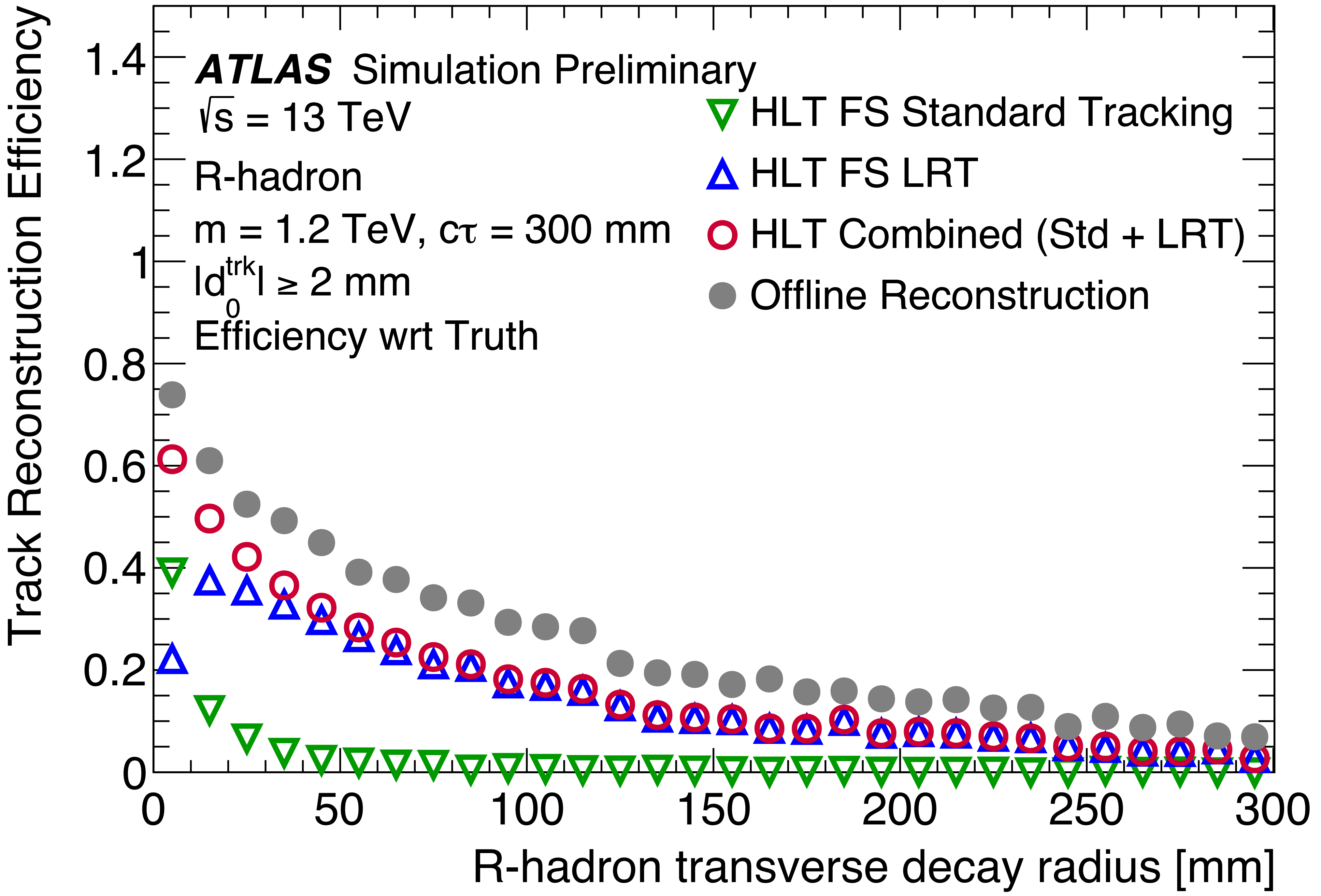
Large-Radius Tracking

ATL-COM-DAQ-2022-023

- Standard tracking in ATLAS optimized for particles pointing back to IP
  - tight requirements in number of silicon hits and impact parameter
  - would reject tracks from displaced decays

- Large radius tracking (LRT)
  - Relax requirements in number of hits and impact parameter
  - Re-run with hits not associated with standard tracks
  - Improves reconstruction for displacements up to 300 mm

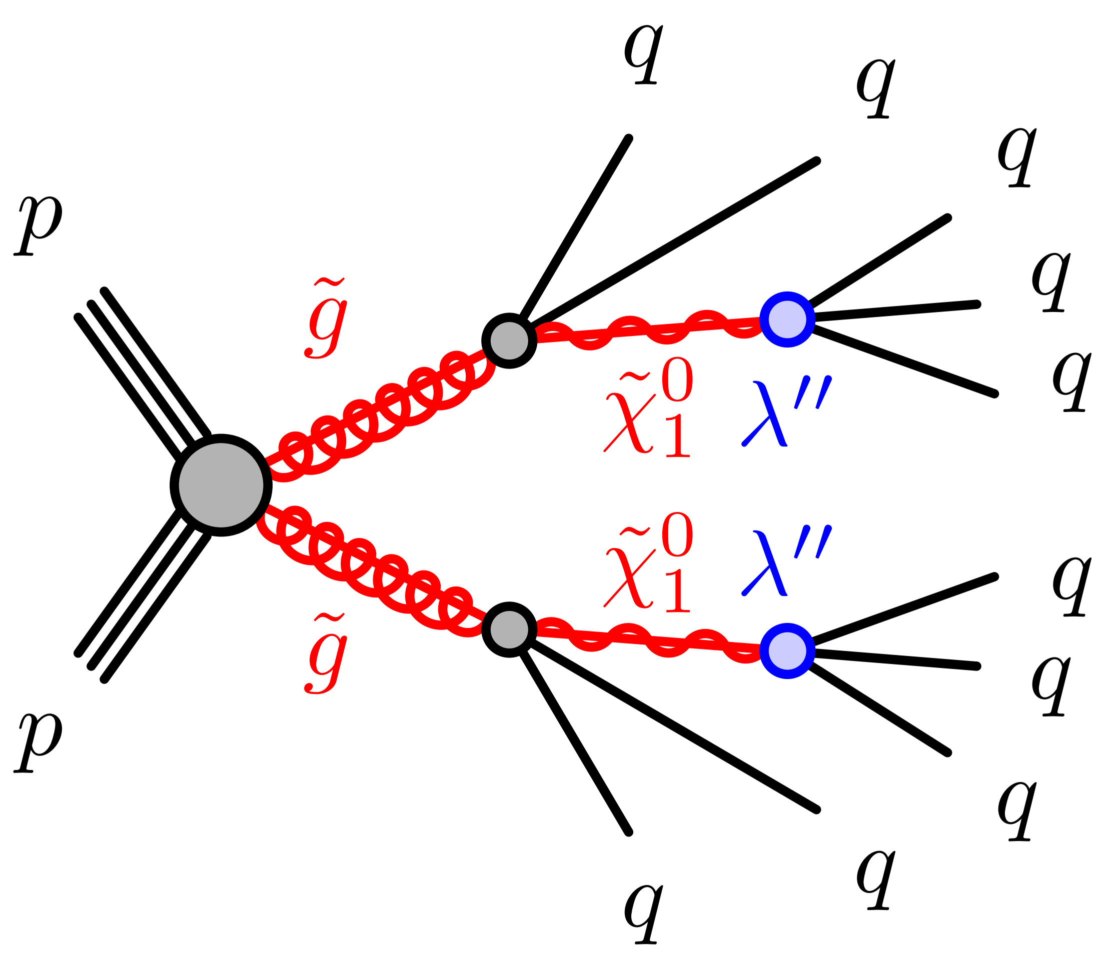
- LRT running at HLT trigger level in Run 3!!



Efficiency to reconstruct displaced electrons, muons and disappearing tracks in backup

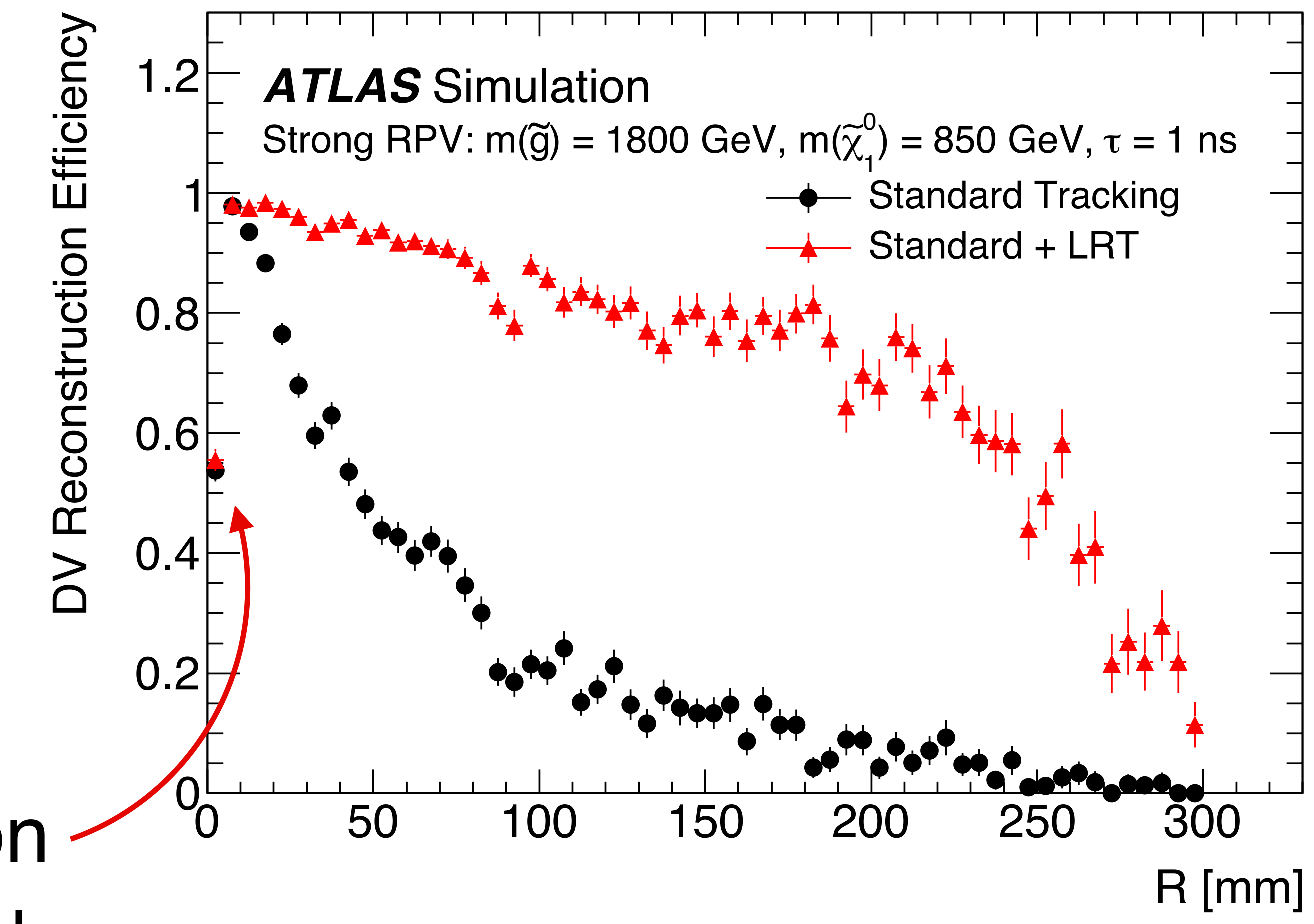
Displaced vertices + jets

SUSY-2018-13

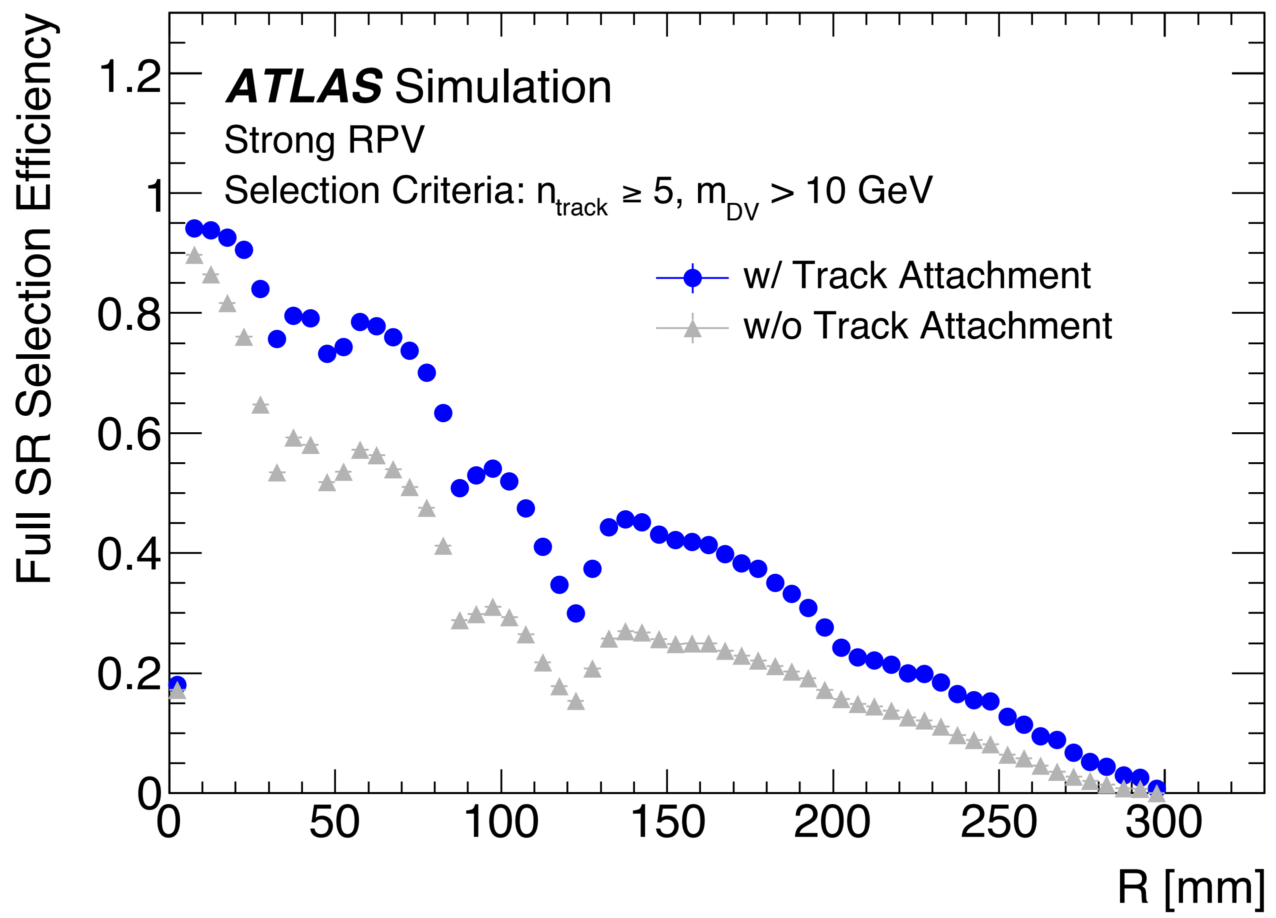


- Long-lived particles decaying into hadrons in the ATLAS inner detector
- SM (MSSM) R-parity-violating (RPV)
  - mean proper lifetimes τ up to $O(10)$ ns

- Using LRT in events with multiple energetic jets and a displaced vertex
- Vertexing:
  - 1. two-track seed vertices, where at least one track with $|d_0| > 2$ mm
    - iteratively merged to form n-track vertices
  - 2. additional tracks with looser selection criteria are attached to the reconstructed vertices

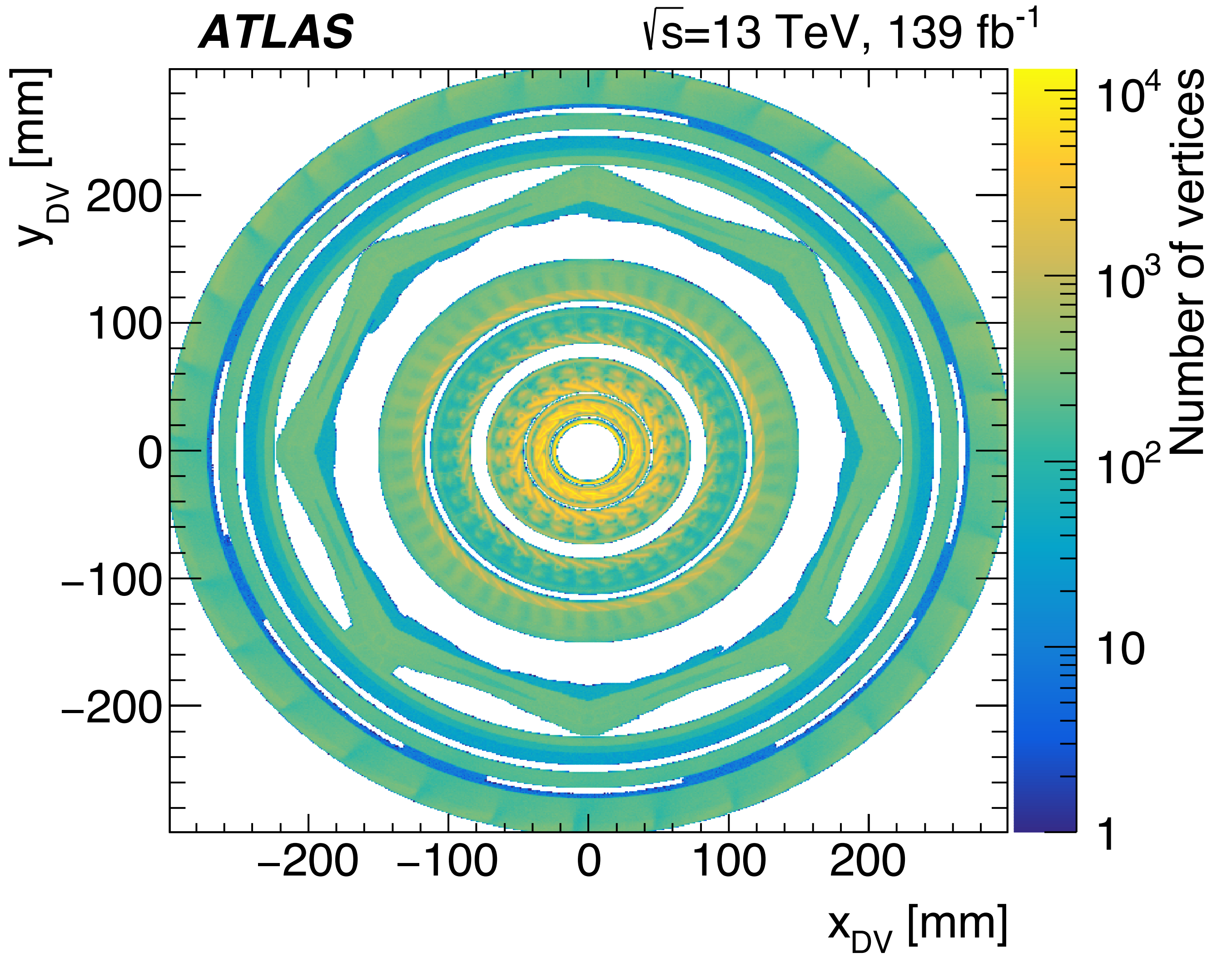


requirement on two-track seed vertices must have $|d_0| > 2$mm

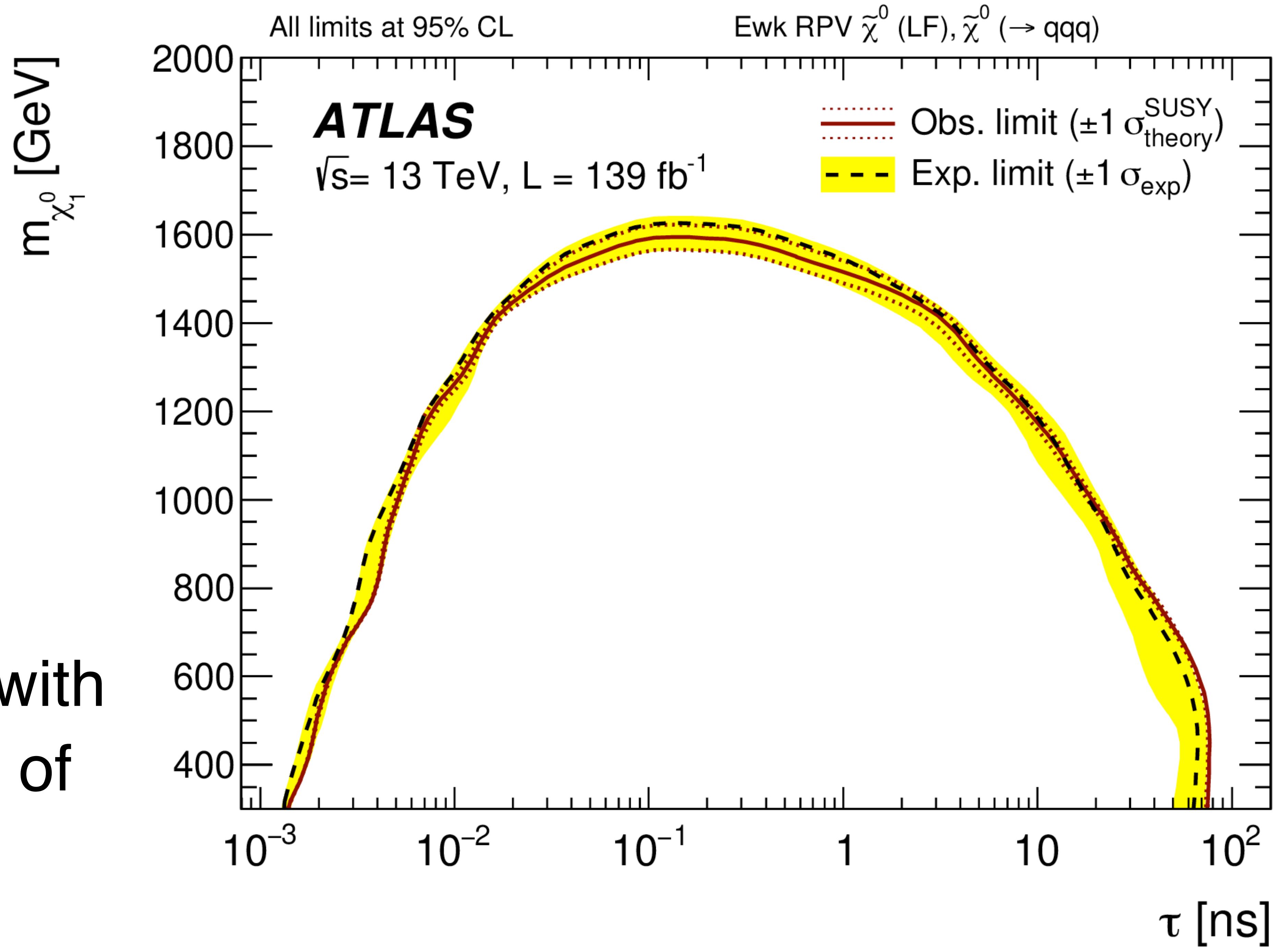


Displaced vertices + jets

SUSY-2018-13

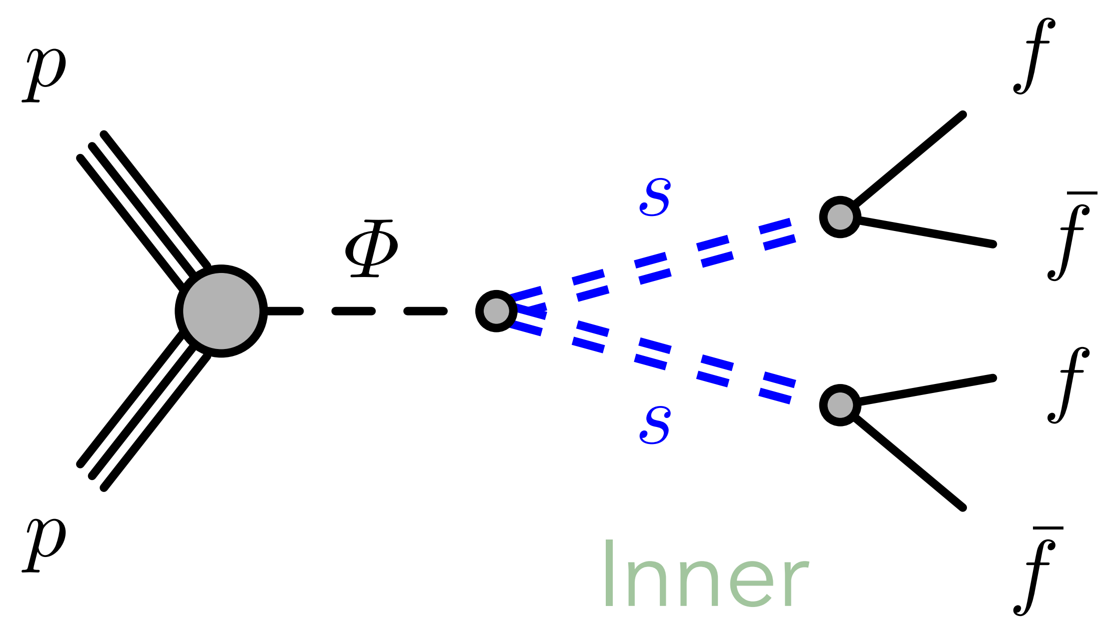


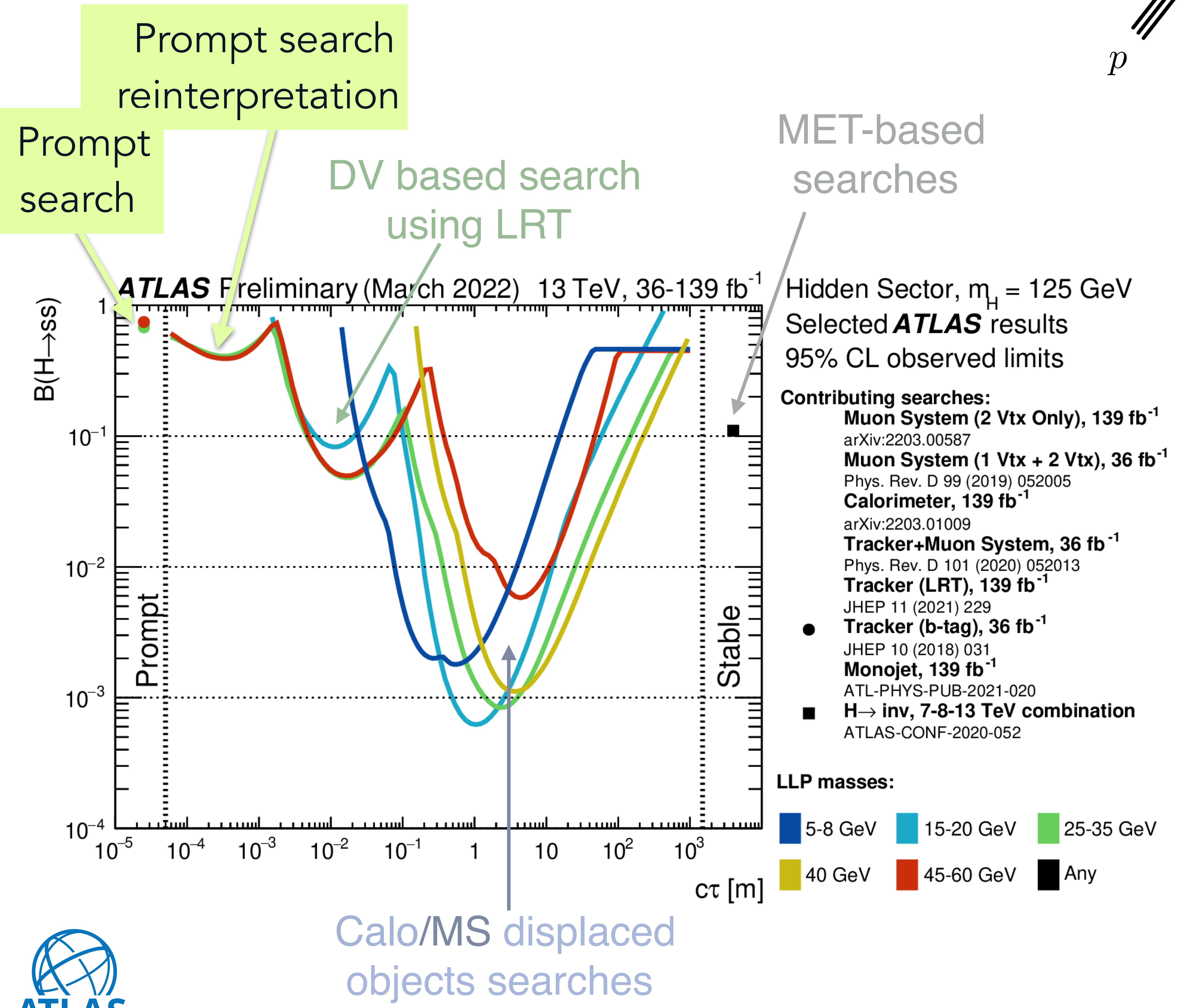
- Three main sources of background:
  - hadronic interactions: detector material
  - accidental crossings: low-mass displaced vertices crossed by an unrelated track
  - merged vertices: close-by low-mass displaced vertices
- Reject them with DV selection:
  - DV at least 4 mm away from any collision vertex
  - DVs must satisfy a material map veto
  - DVs must have at least five tracks
  - $m_{DV} > 10$ GeV
- Data-driven technique that predicts the rate of DVs from all three sources above
- Reach ~zero background analysis
- Neutralinos with m=1.5TeV excluded with lifetimes in the range of 0.02 ns to 4 ns

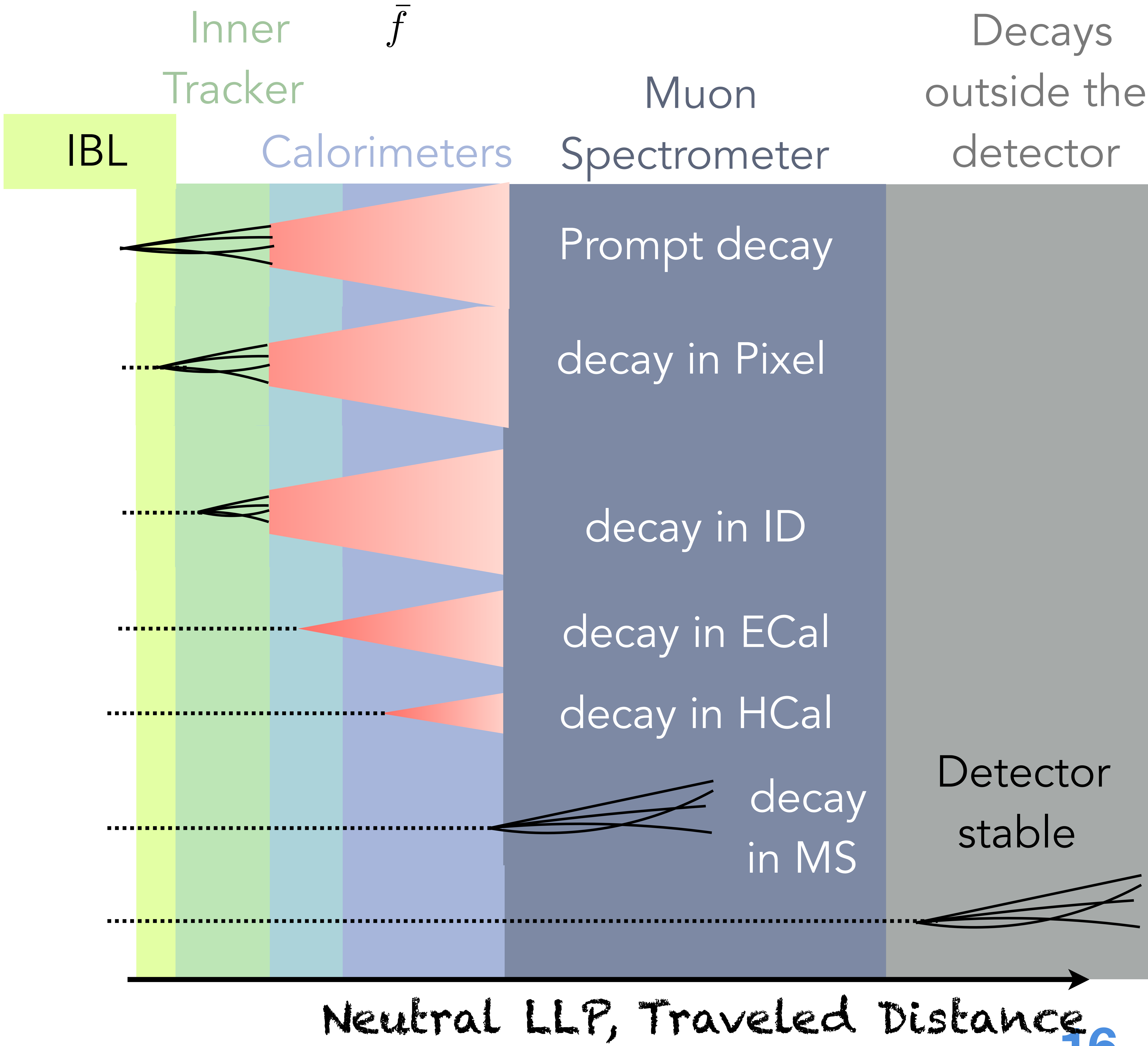


Displaced jets

ATL-PHYS-PUB-2022-007



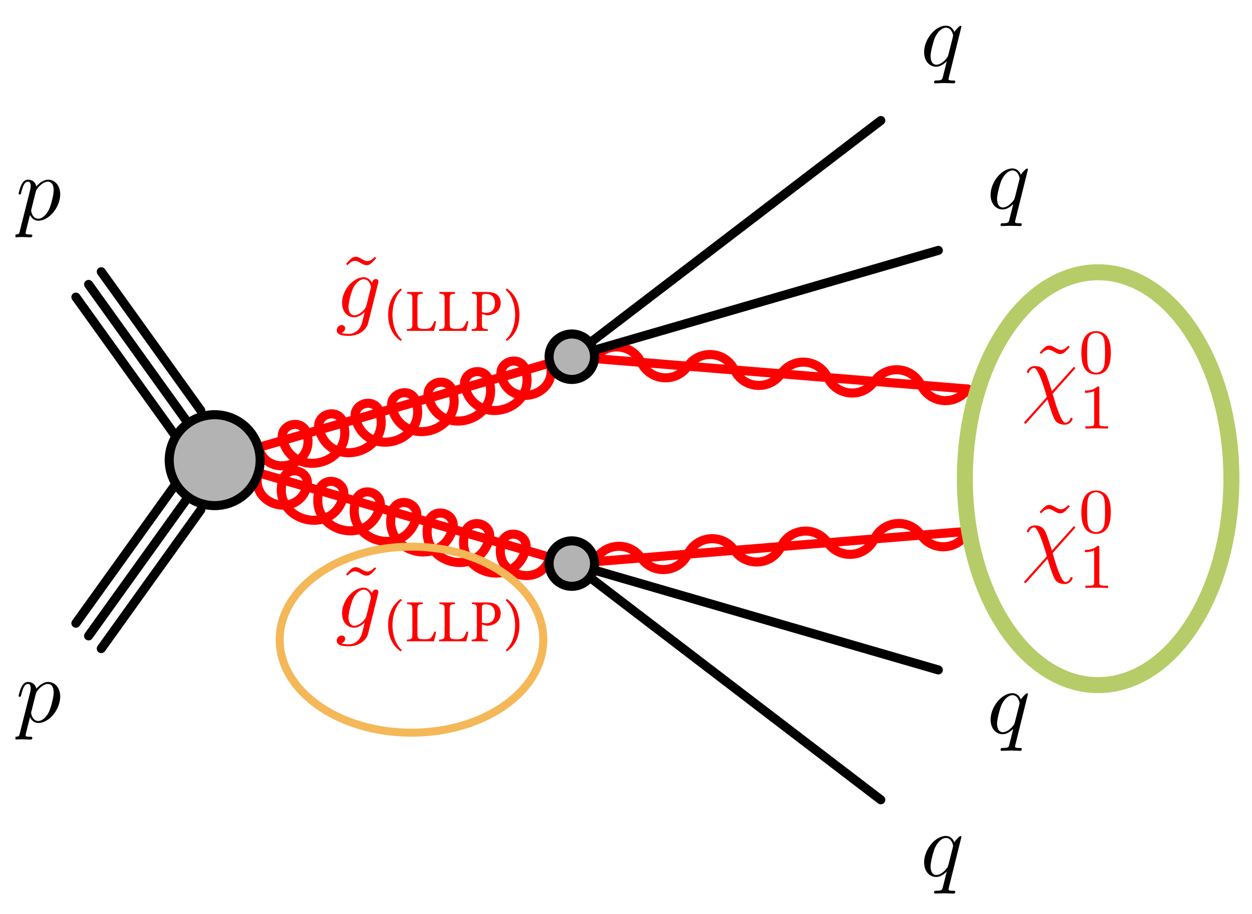




Charged LLPs Large dE/dx

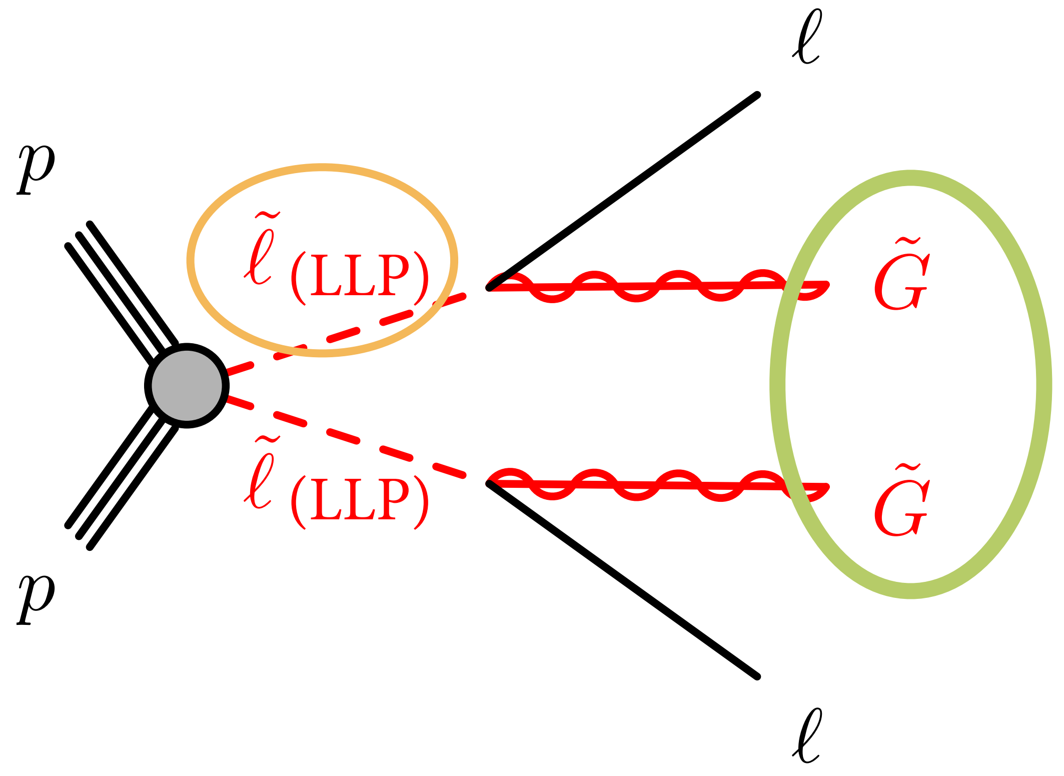
JHEP06(2023)158

- Pair production of different long-lived sparticles of charge $|q|$ = 1
  - isolated tracks with high transverse momenta (pT) and anomalously large specific ionisation losses (dE/dx)
  - particles are expected to move significantly slower than the speed of light
  - Use MET triggers
  - Fully data-driven background estimation!



High pT track with large dE/dx

LSP = MET



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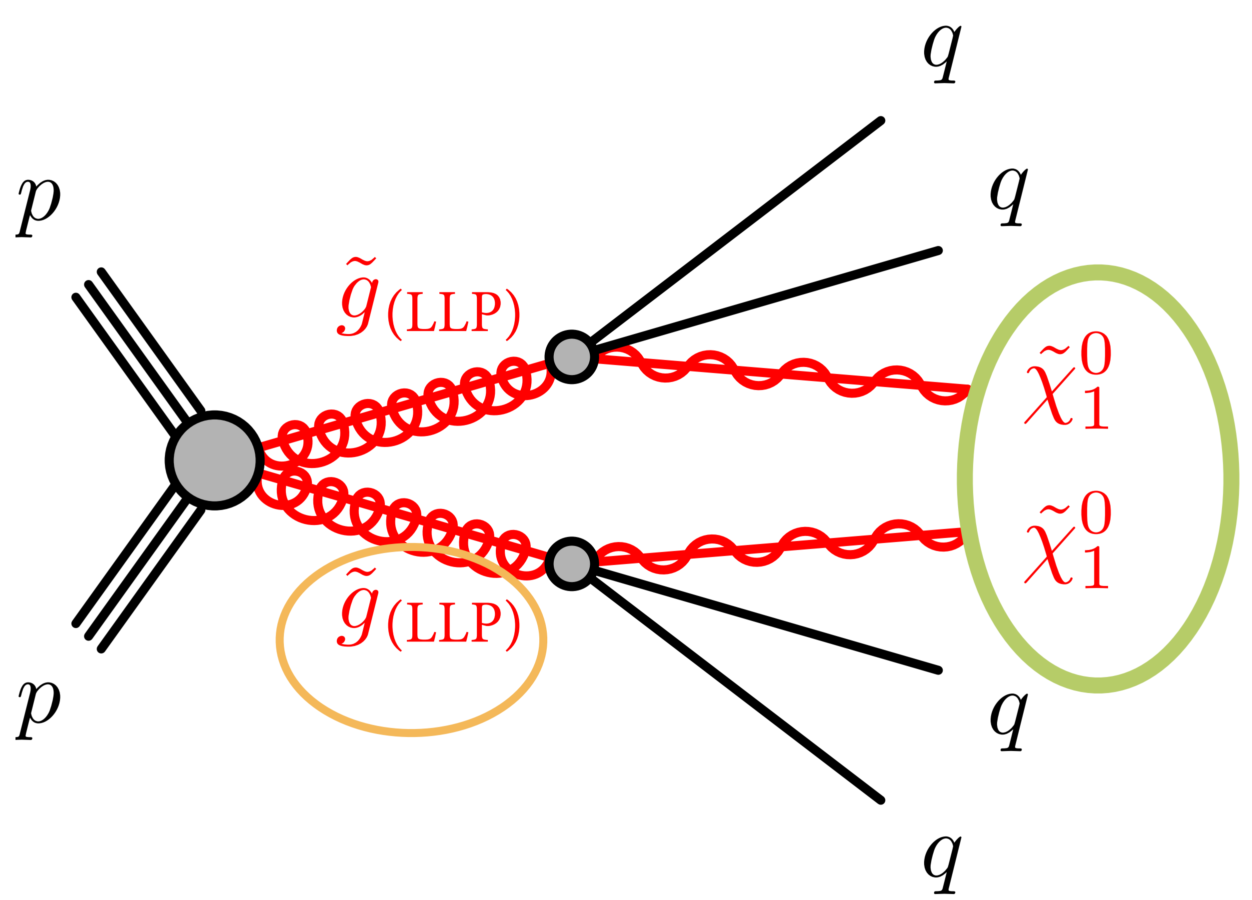
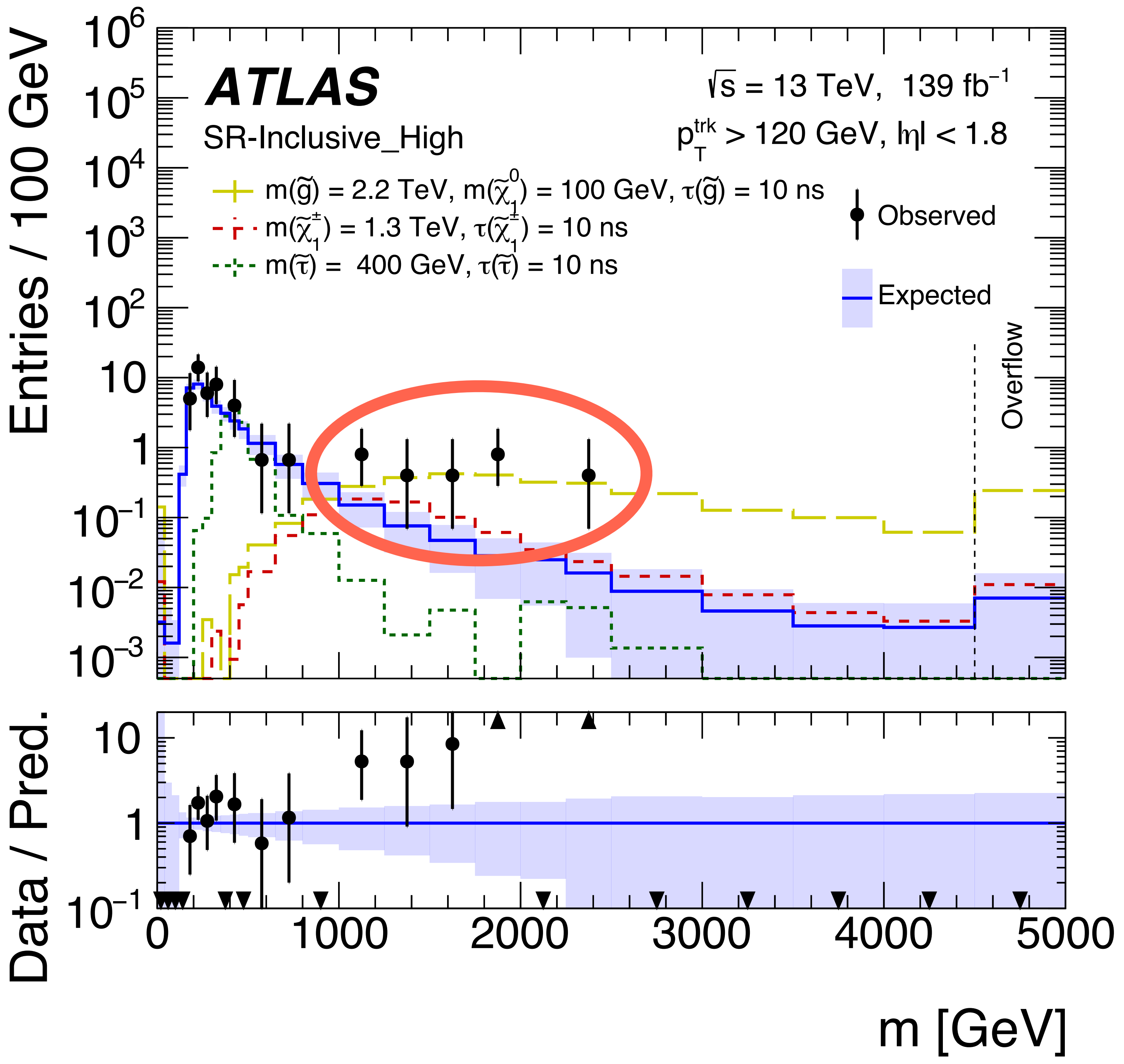
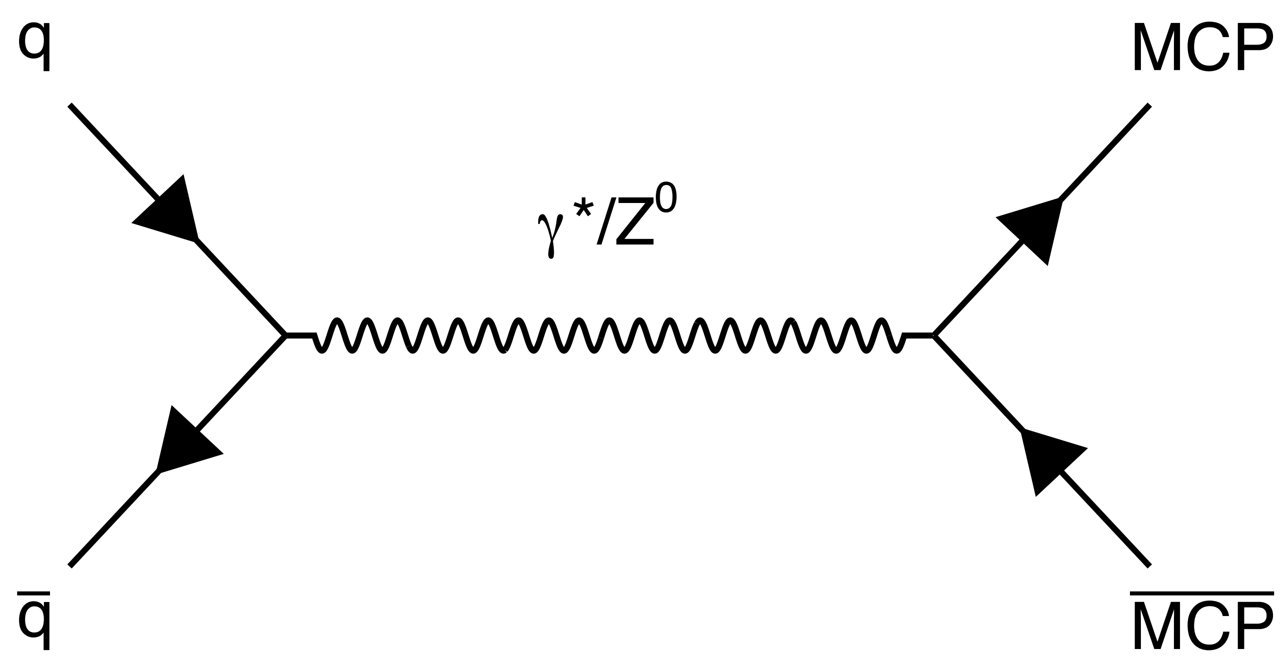


- **3.3 σ** global excess!!
- Is this New Physics???
- Maybe, though… from TOF measurements: none of the candidate tracks are from charged particles moving significantly slower than the speed of light ☹
- Analysis ongoing in Run 3!



Multicharged particles

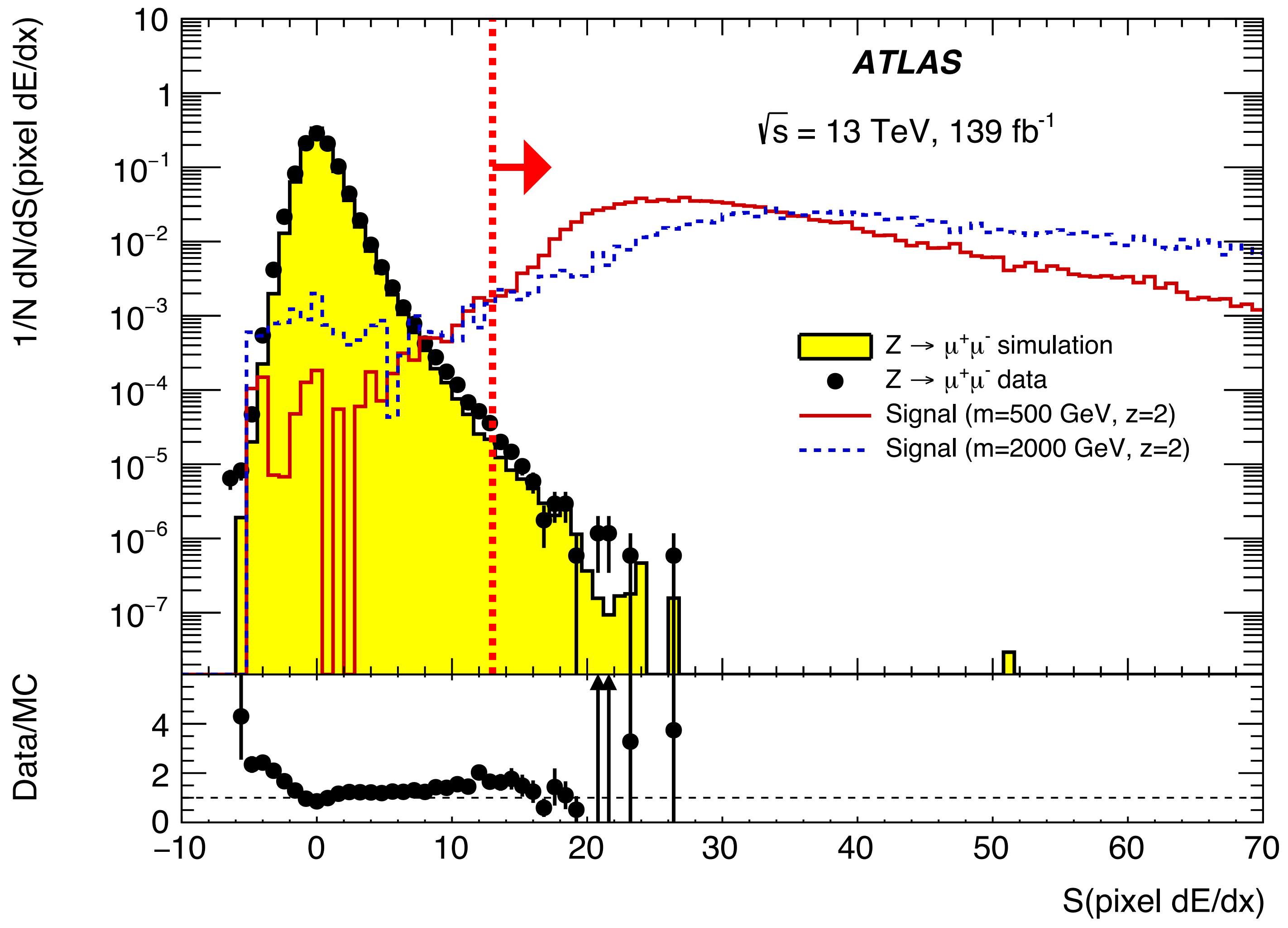
EXOT-2018-54



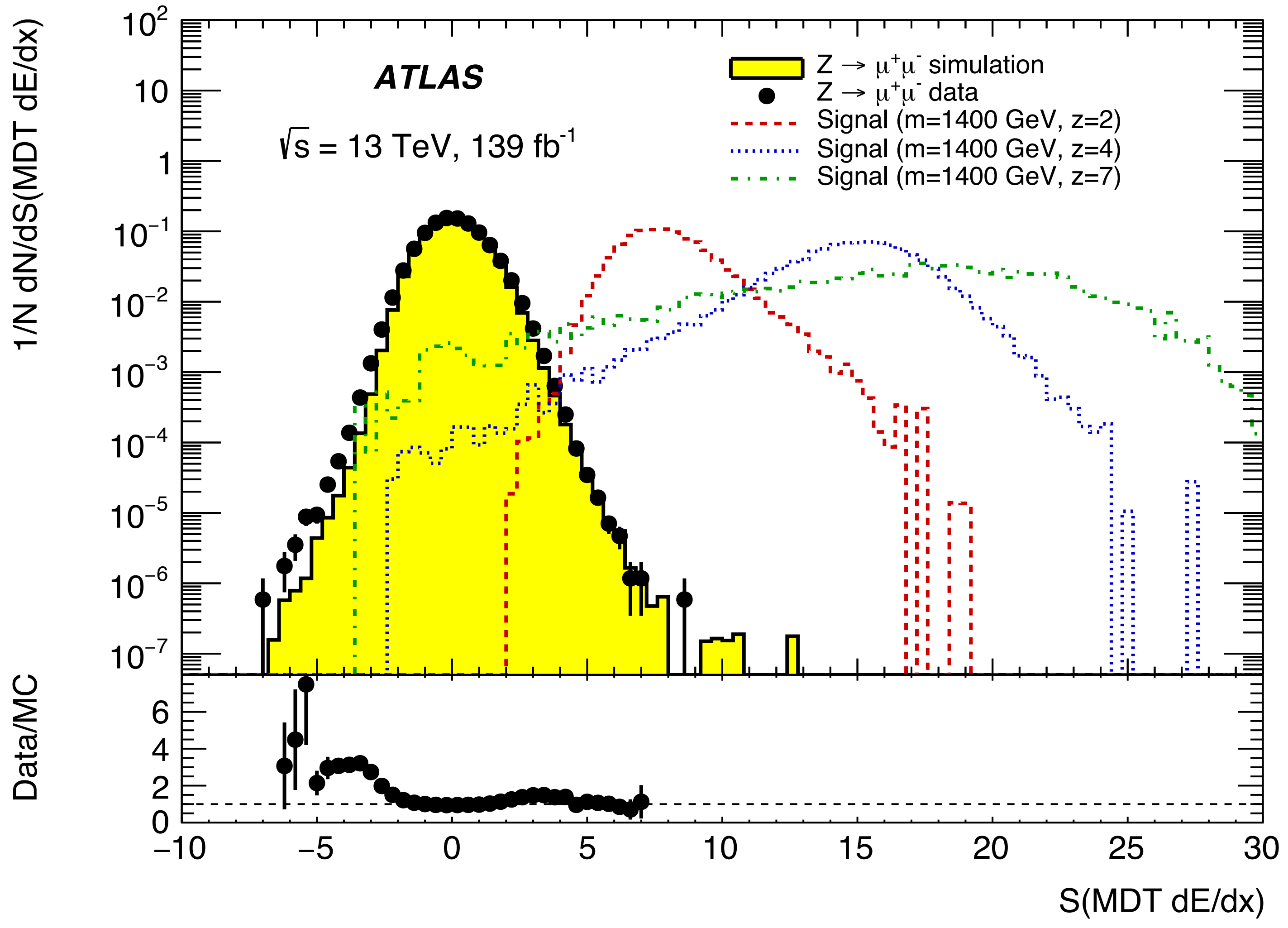
- Search for heavy long-lived multi-charged particles (MCP) with high ionization (higher electric charges and lower velocities)
  - range of electric charges from $|q| = 2e$ to $|q| = 7e$
  - live long enough to traverse the entire ATLAS detector

- Triggers: Muon, MET, late-muon trigger
- Select high-pT muon-like tracks with high dE/dx values in several subdetector systems: pixel ID, TRT, MDT

z=2



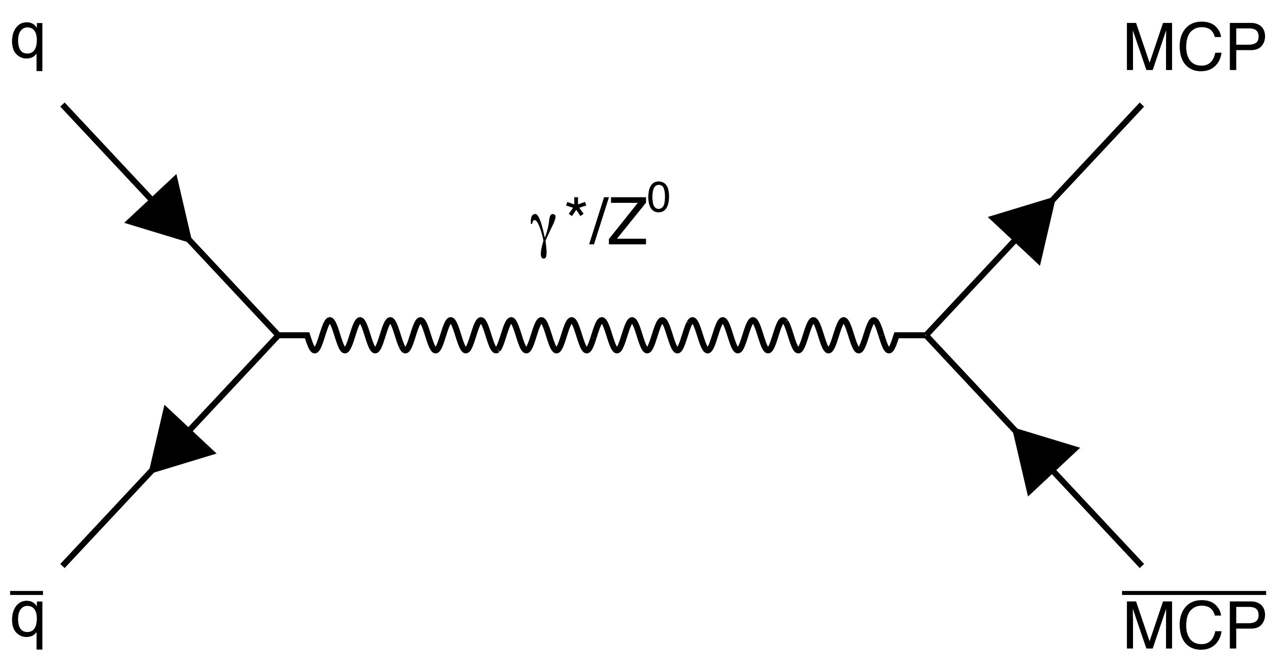
z>2



Multicharged particles

EXOT-2018-54

- Background mainly consists of:
  - high-pT muon reconstructed from several muons losing their energy in the same detector elements
  - sporadic-noise
- All background estimated by using a data-driven technique.



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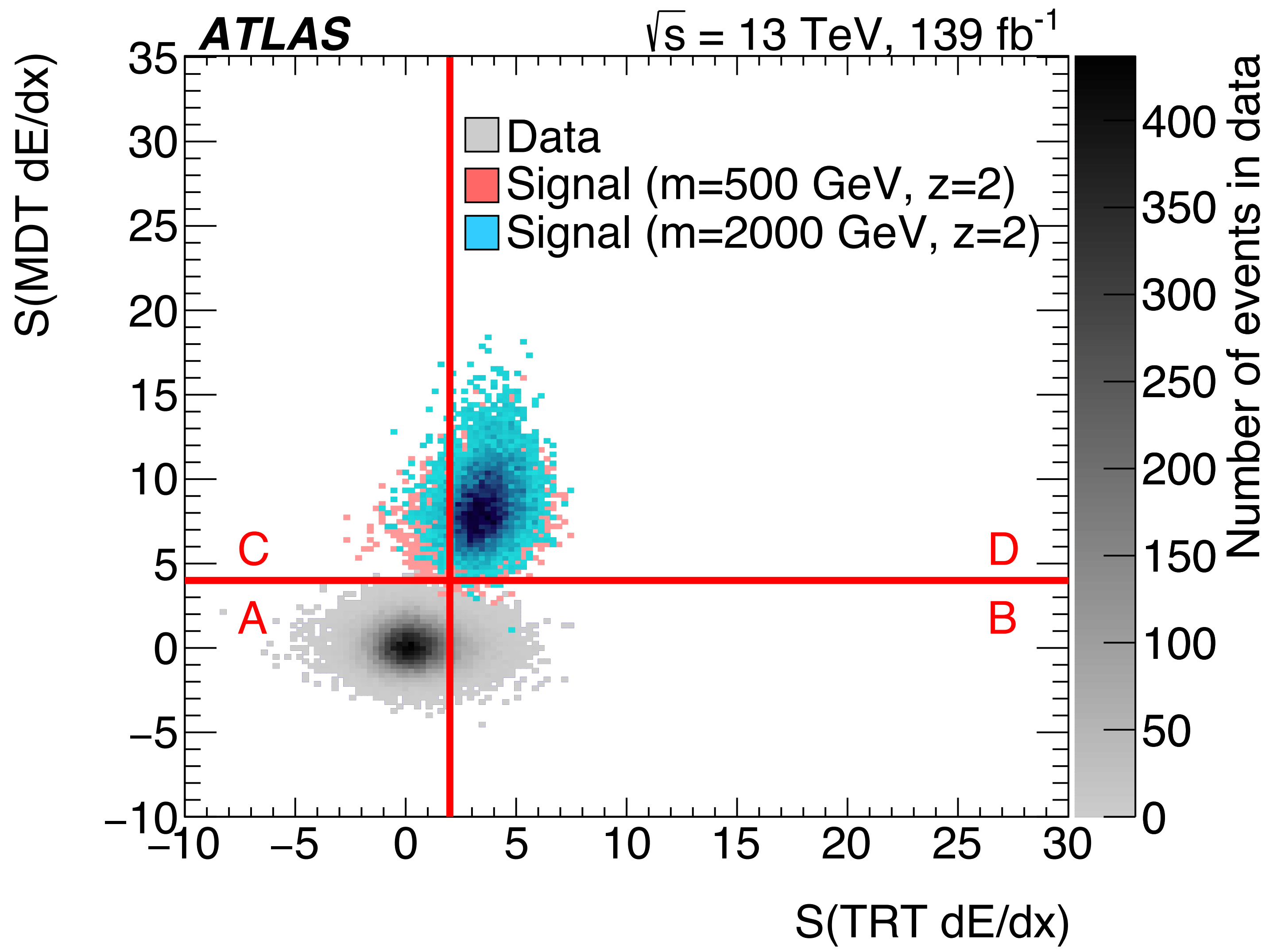

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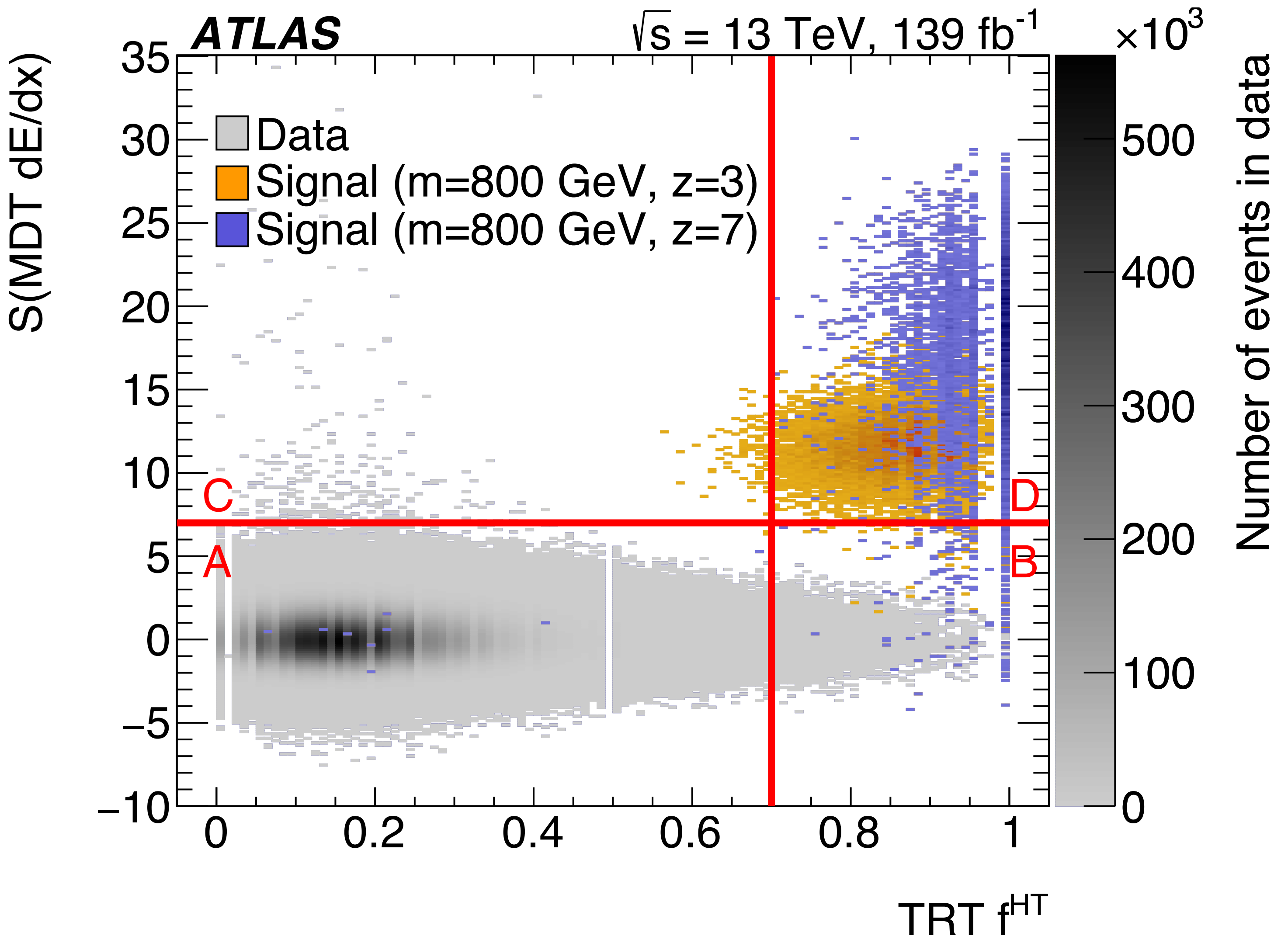
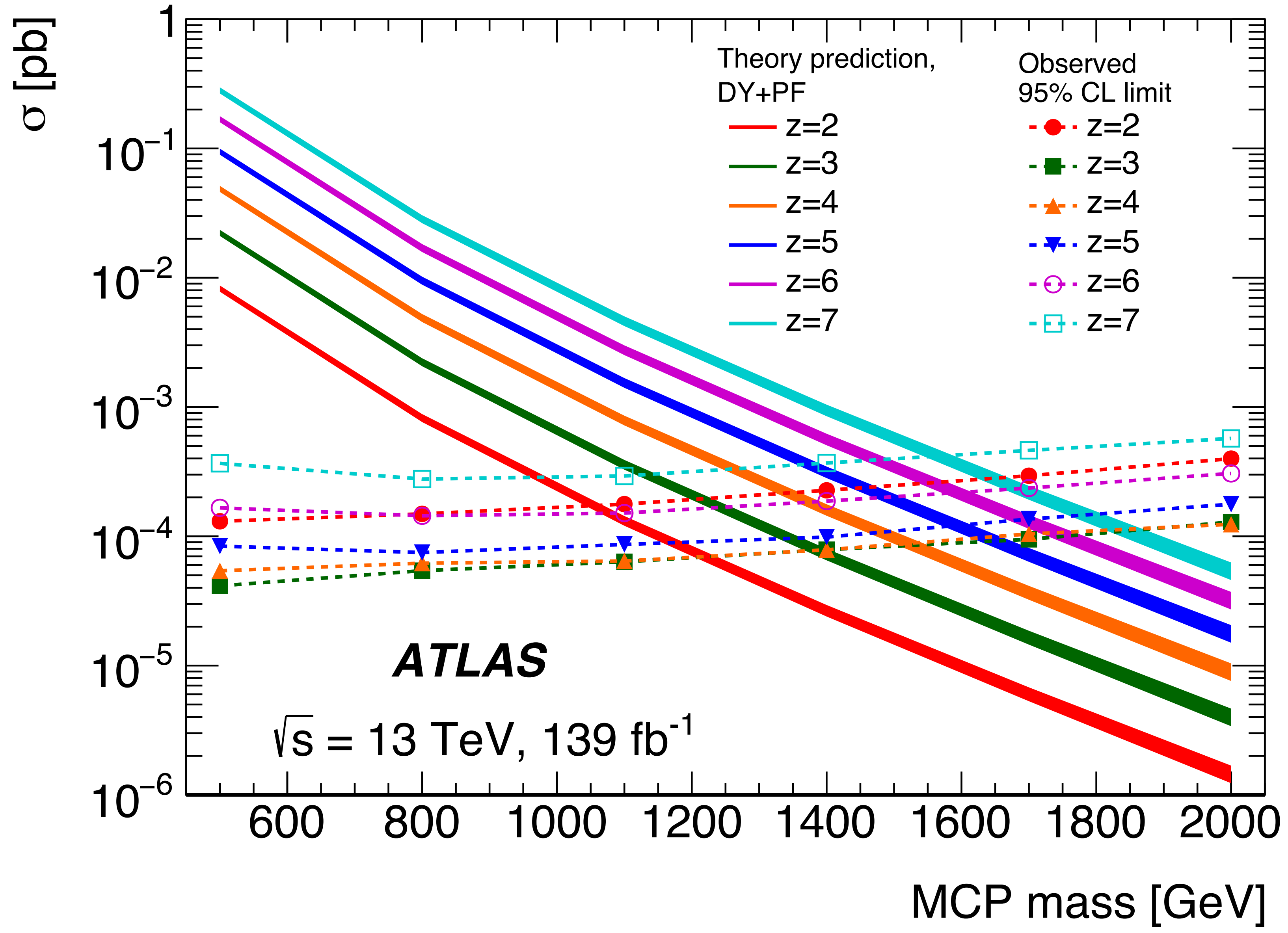
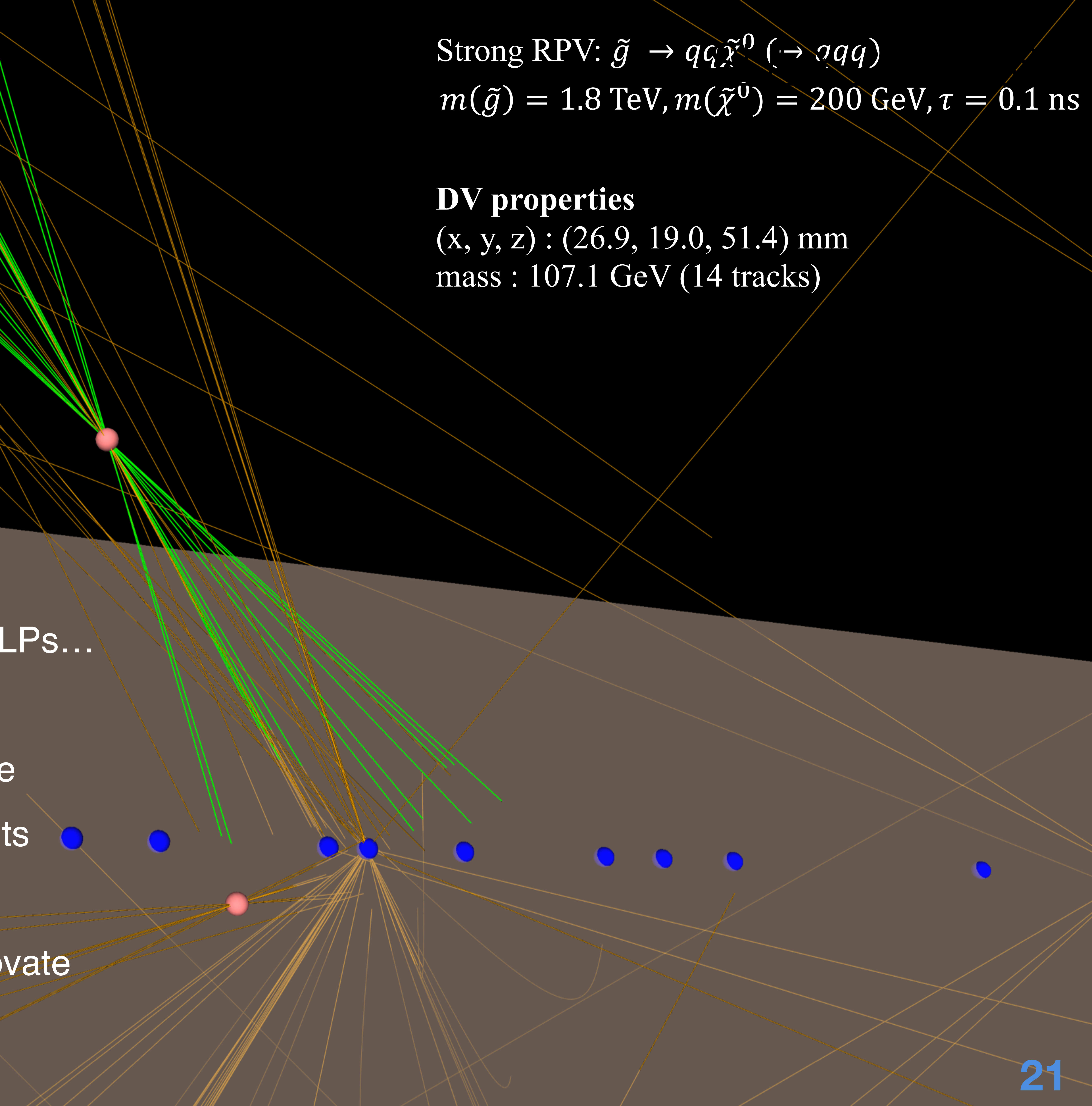




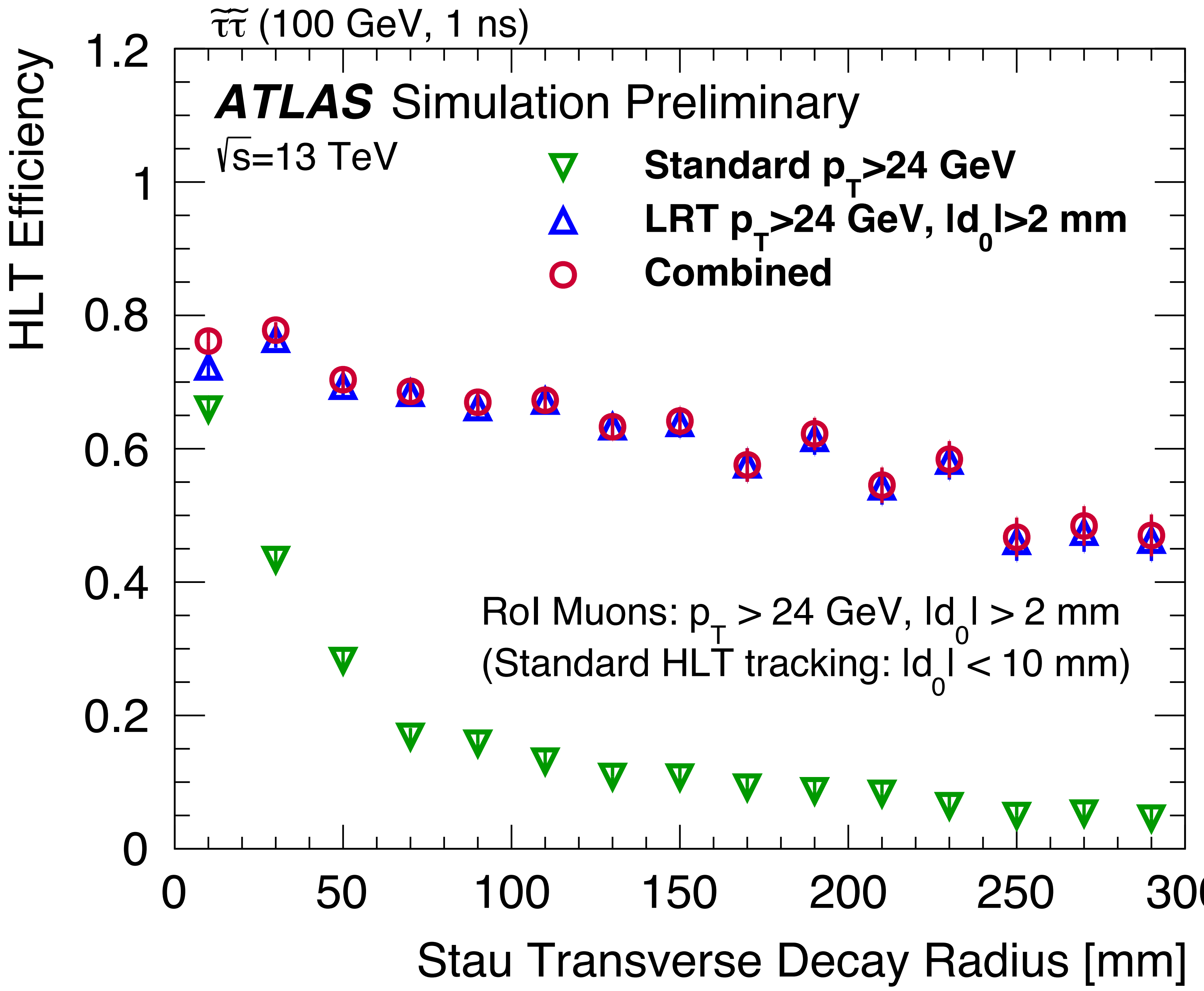
- |q| = 2*e* particles excluded for m < 1060GeV
- |q| = 6*e* particles excluded for m < 1600GeV

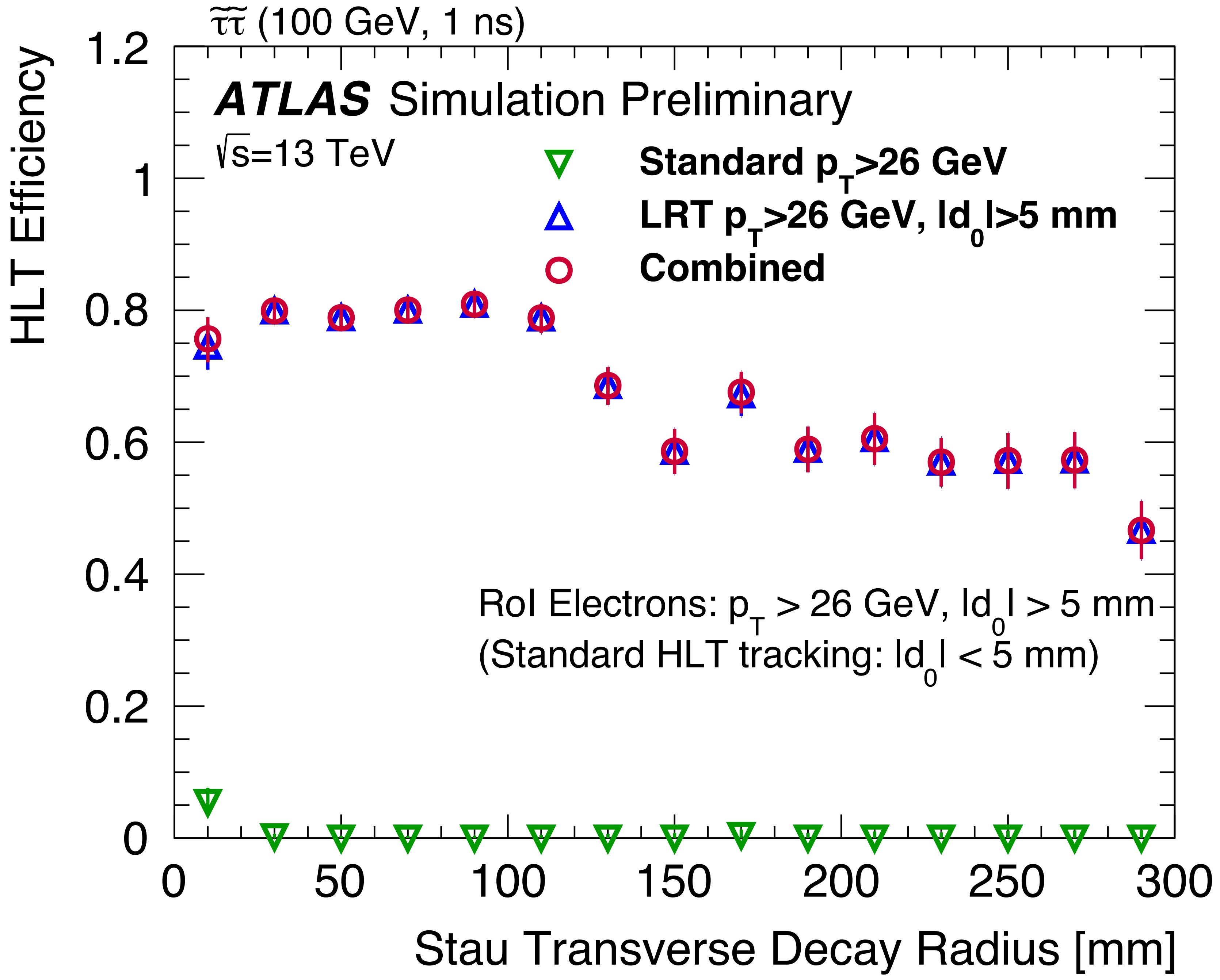
CONCLUSIONS

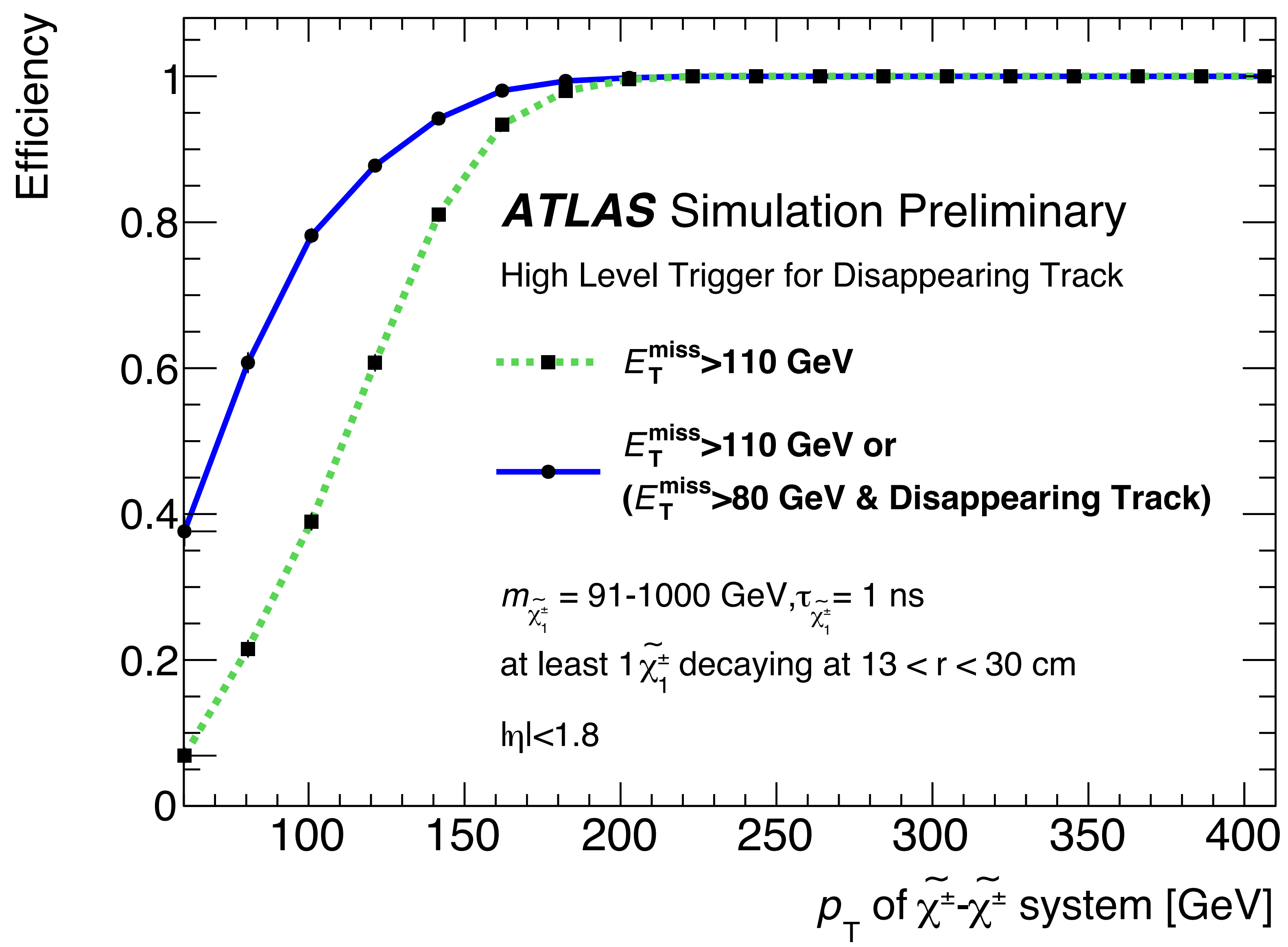
- LLPs might be the key for finding BSM physics
- LLPs are gaining interest!
- Great effort at the LHC experiments to search for LLPs…
  BUT! still some signatures to be exploited
- Development of new tools and strategies to improve identification of LLPs, pushing the detector beyond its original design capabilities
- Run 3 and HL-LHC offer a great opportunity to innovate and plan for new unconventional searches



LRT at HLT trigger level







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