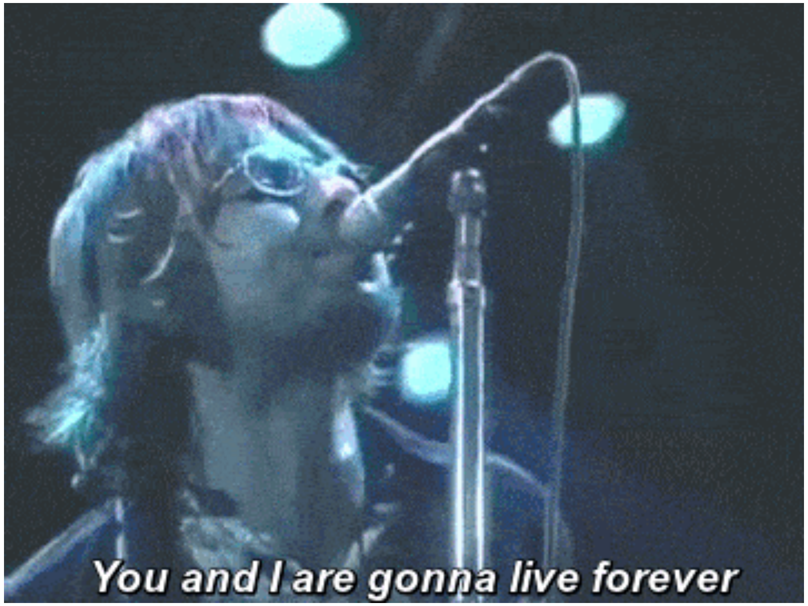


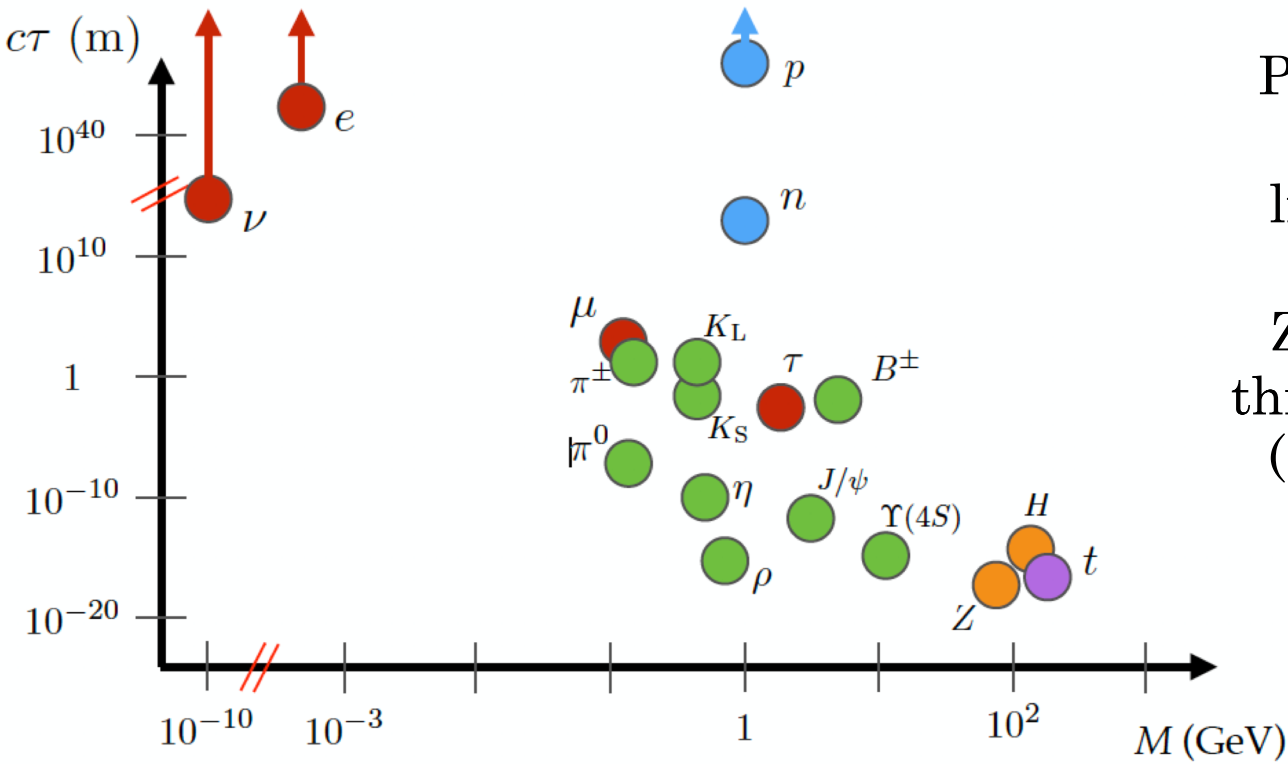
To catch a long-lived particle

Rebeca Gonzalez Suarez

Uppsala University

Spaatind 2020 - Nordic conference on Particle Physics

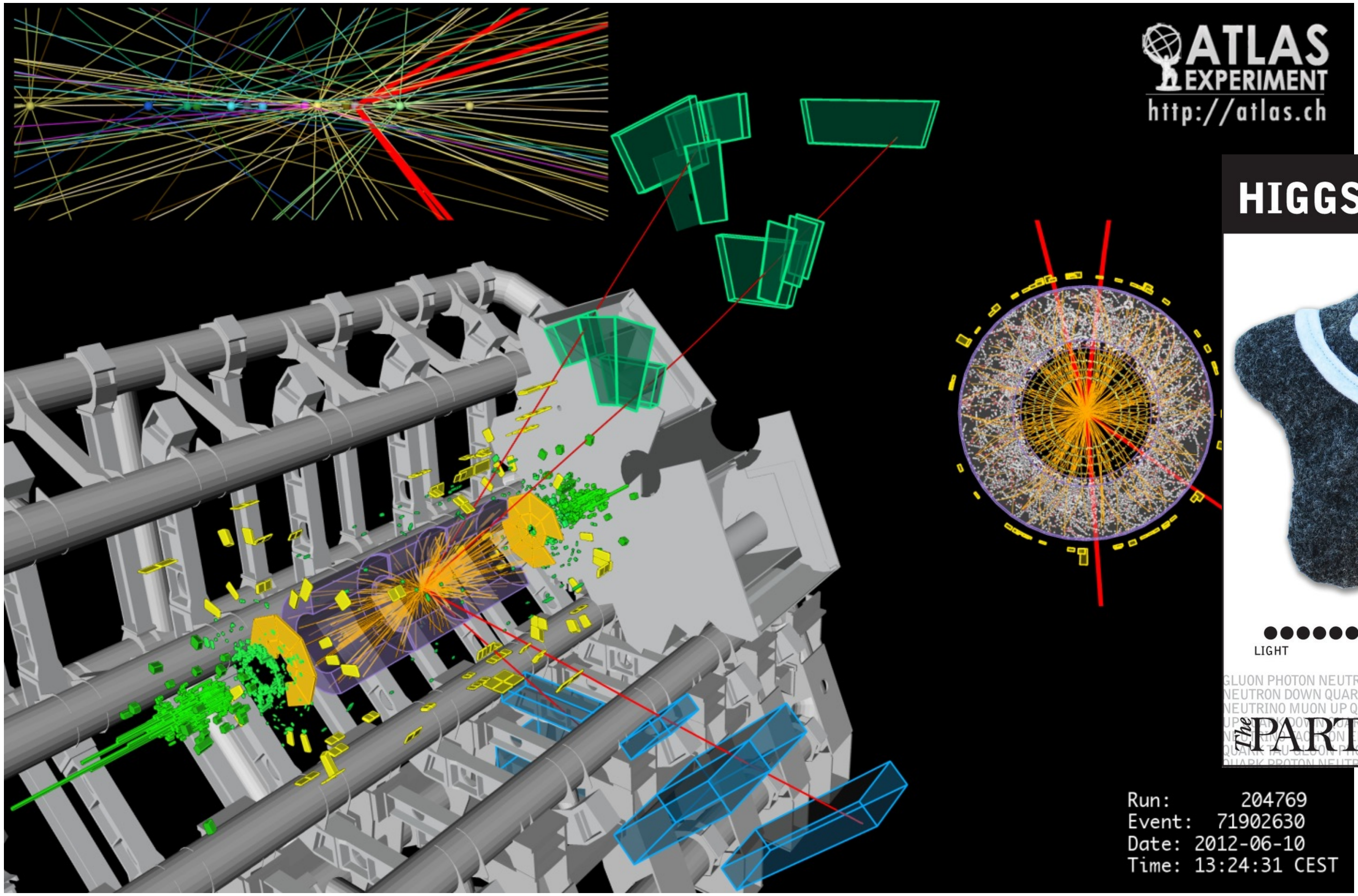
The life of a particle



Particles in the SM have varying lifetimes, from the very short-lived Z boson (2×10^{-25}s) through to the proton (10^{34} years) or the electron (stable)

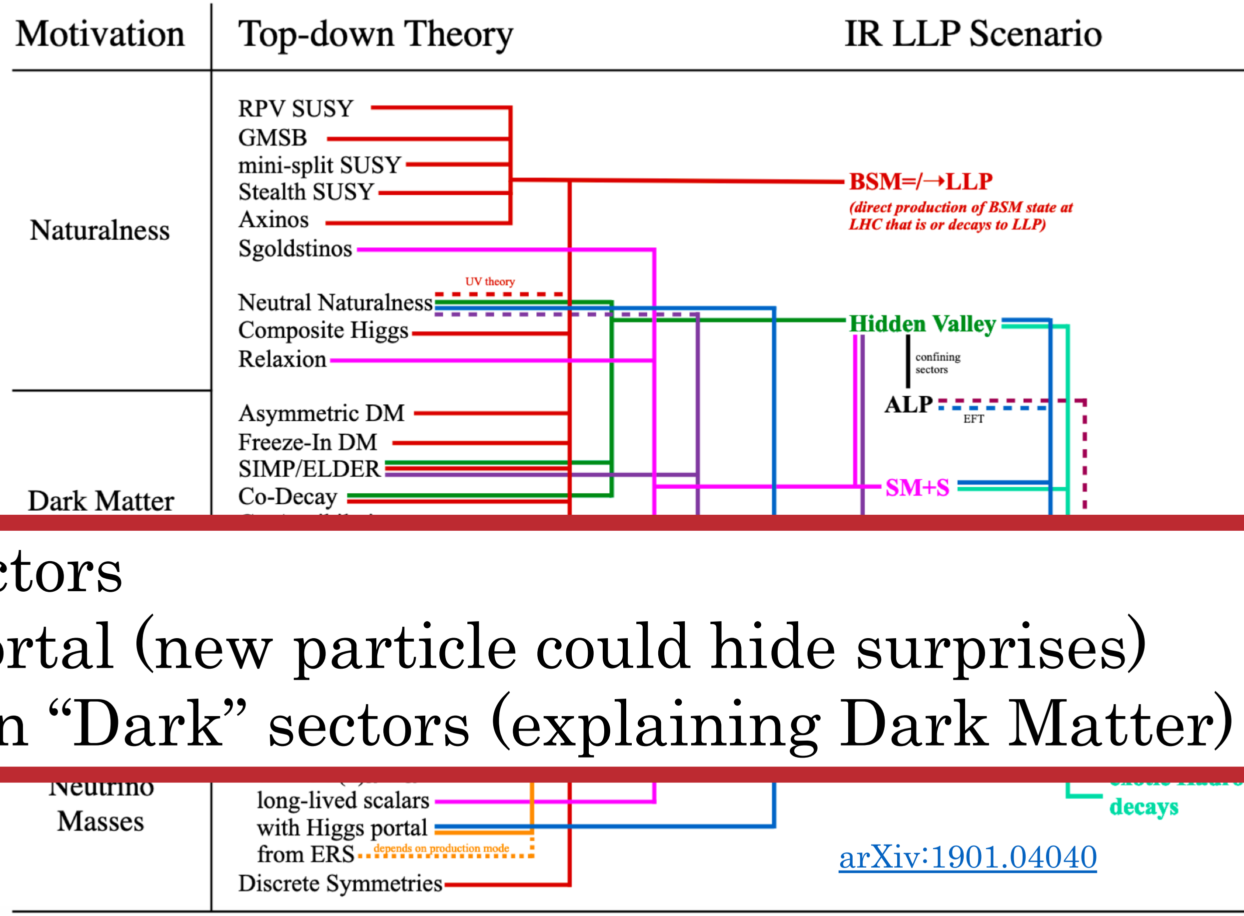
Then why

- Do we assume that new particles have to die young?



Long-lived particles

- There could be new particles with lifetimes long enough to travel some distance inside the detector before decaying
  - Long enough to have **distinct experimental signatures**
  - There are many reasons why they would live long:
    - *Small couplings, large mediator masses, or approximated symmetries*
- Long-lived particles are not a prediction of a new theory
  - A feature of virtually all proposed frameworks for BSM physics
  - Their presence is strongly motivated



🌶️🌶️ Hidden sectors

🌶️🌶️🌶️ Higgs portal (new particle could hide surprises)

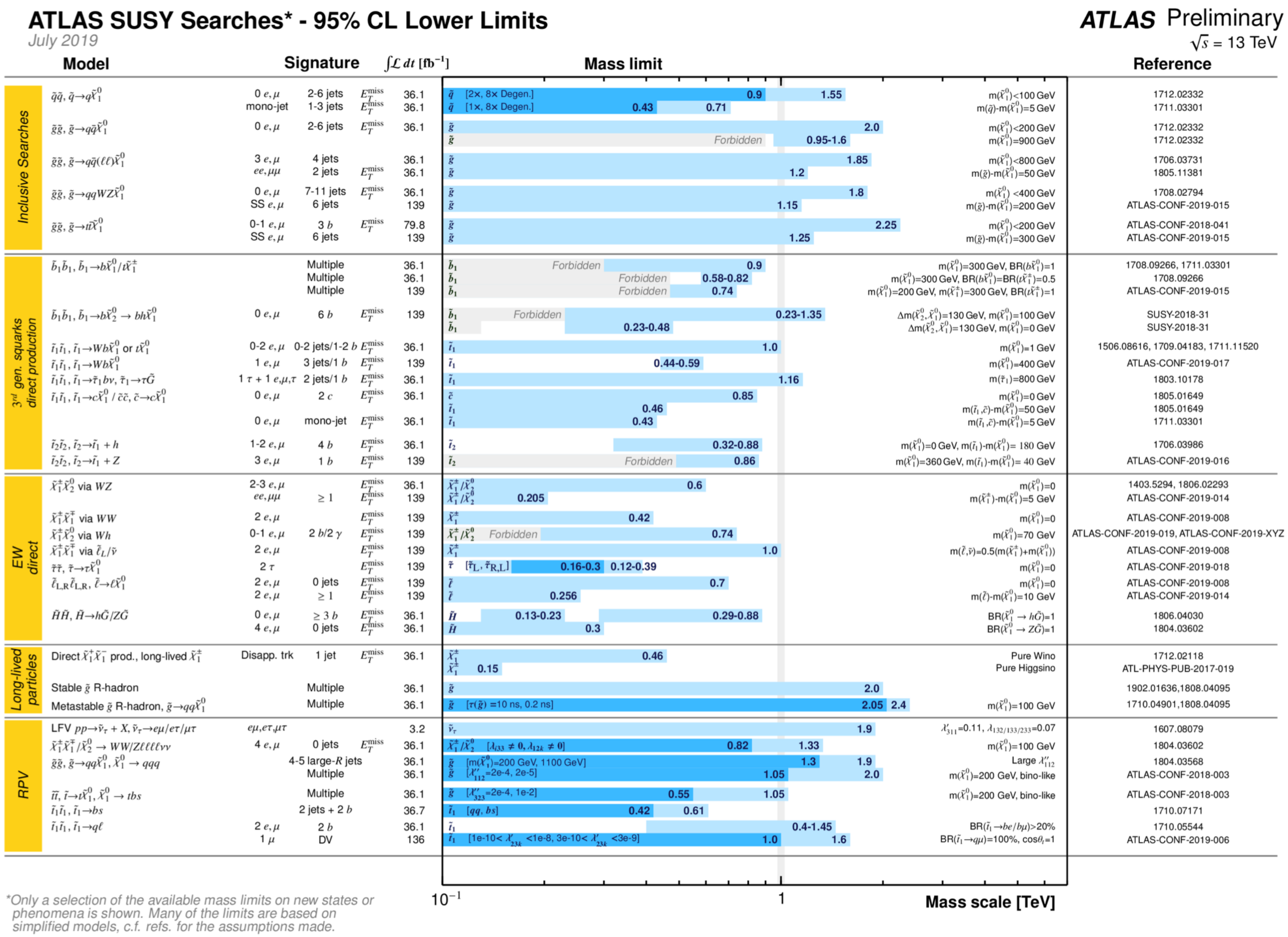
🌶️🌶️🌶️🌶️ Hidden "Dark" sectors (explaining Dark Matter)

LLP are a Hallmark of Hidden sectors, with non-SM matter and forces, that can be connected to the SM via very small effective couplings called [portals]

Hidden sectors could explain big questions of the SM in a way that is compatible with the current lack of new particles

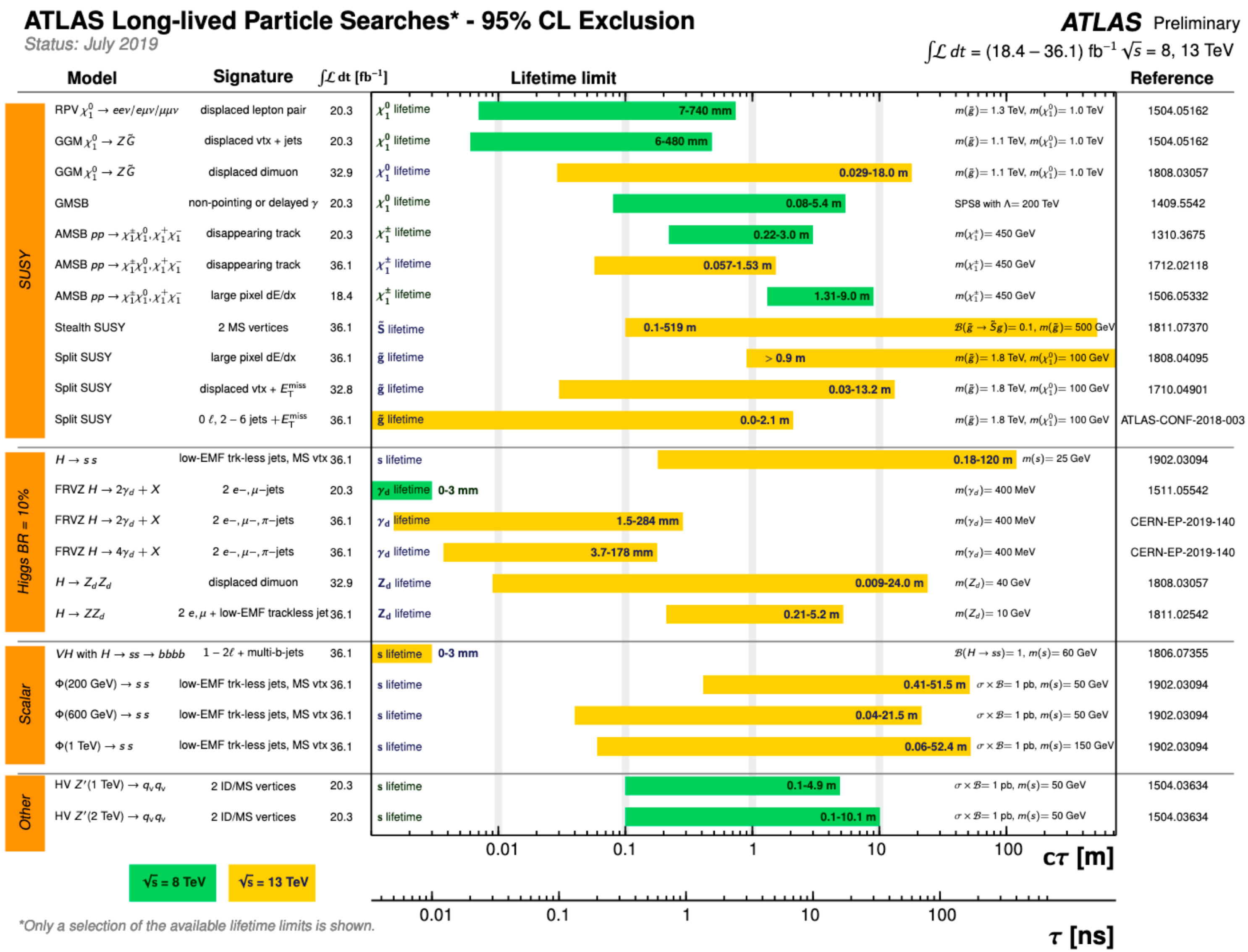
In a panorama

- In which searches for new physics in ATLAS and CMS are systematically coming back empty



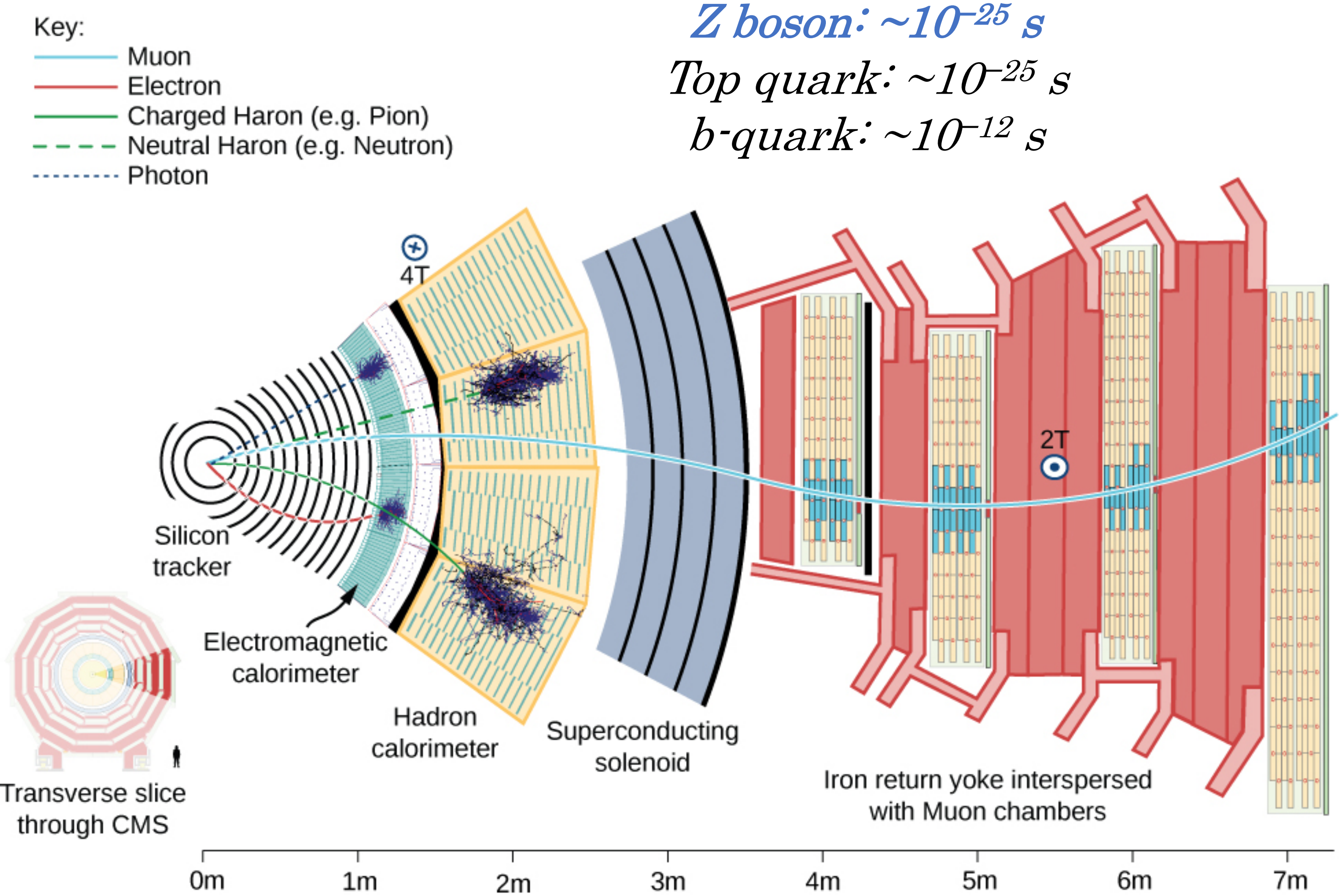
LLP are looking like a very attractive alternative

They are nothing new



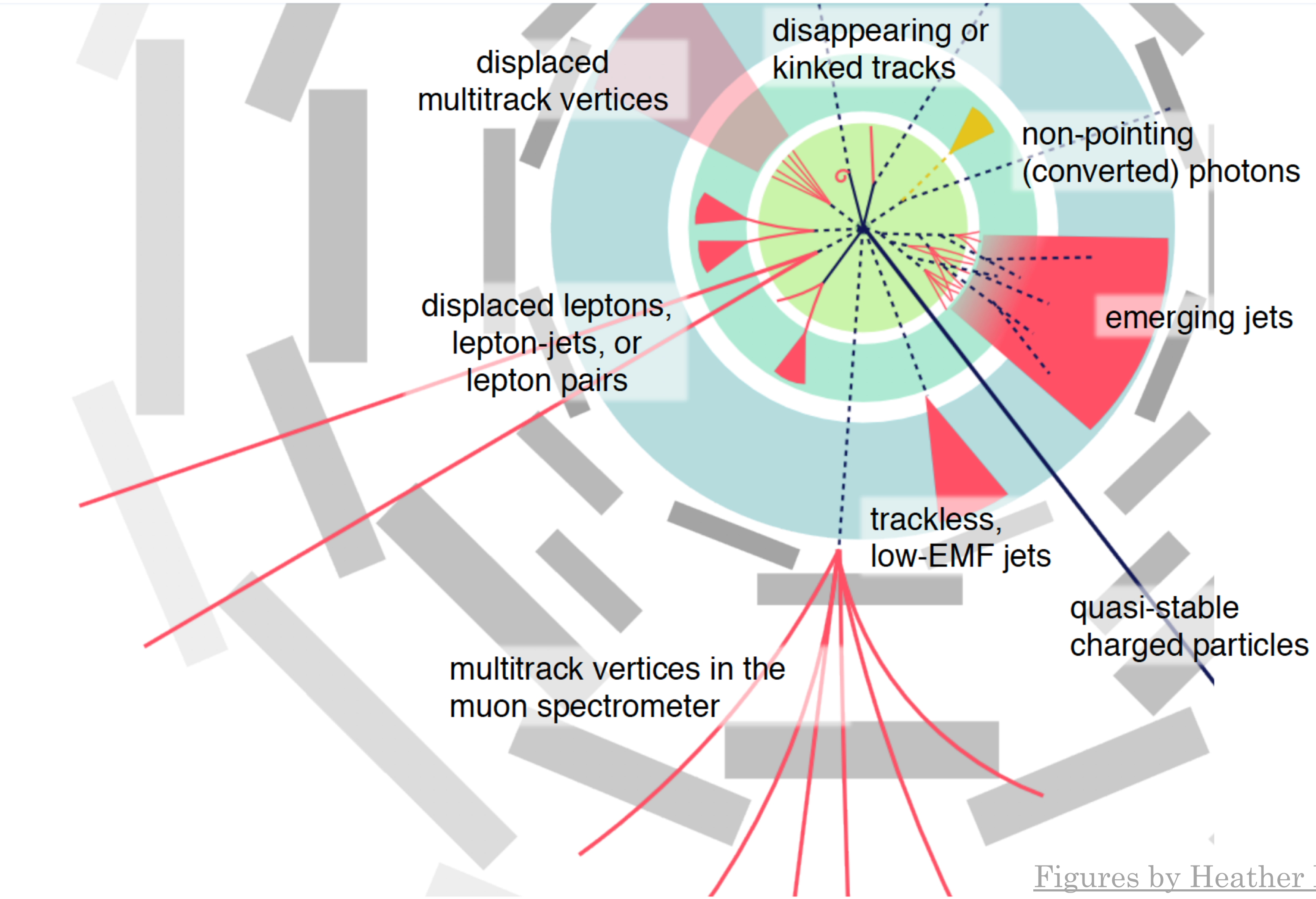
But our detectors

Higgs boson: ~10^{-22} s
Z boson: ~10^{-25} s
Top quark: ~10^{-25} s
b-quark: ~10^{-12} s



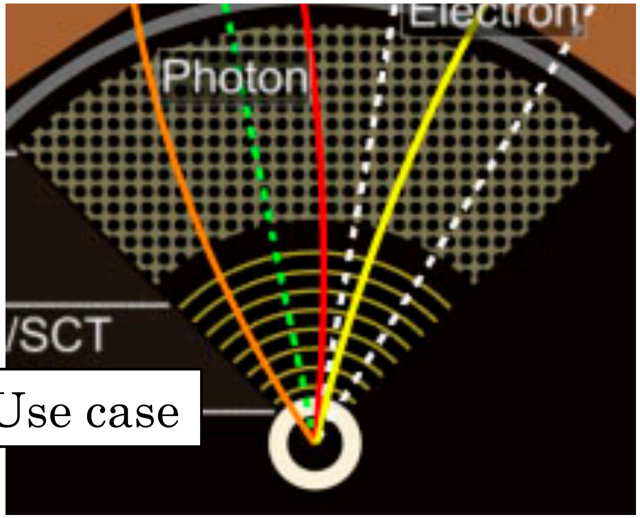
- Are designed and optimized for **very short-lived** particles that pop in and out of existence VERY quickly
- And decay to ~stable products very fast

Long-lived particles are not like that



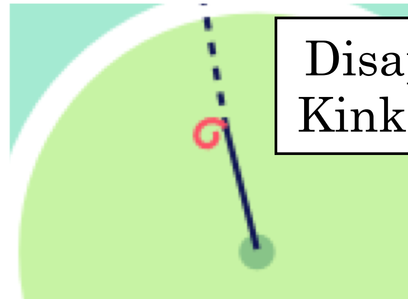
Figures by Heather Russell

Paradigm shift

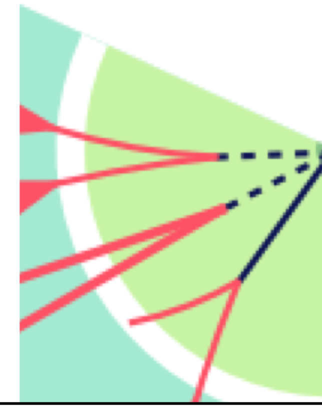


Use case

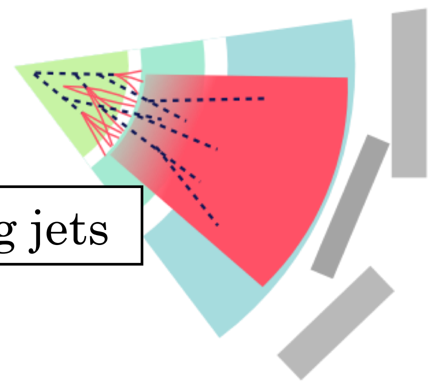
Tracker



Disappearing
Kinked tracks



Displaced
vertices/tracks



Emerging jets

- Looking for LLPs STILL represents a paradigm shift from the usual approach to hunting for new physics
- **Implies exploiting the detectors in ways they were not designed for**

Roadblocks

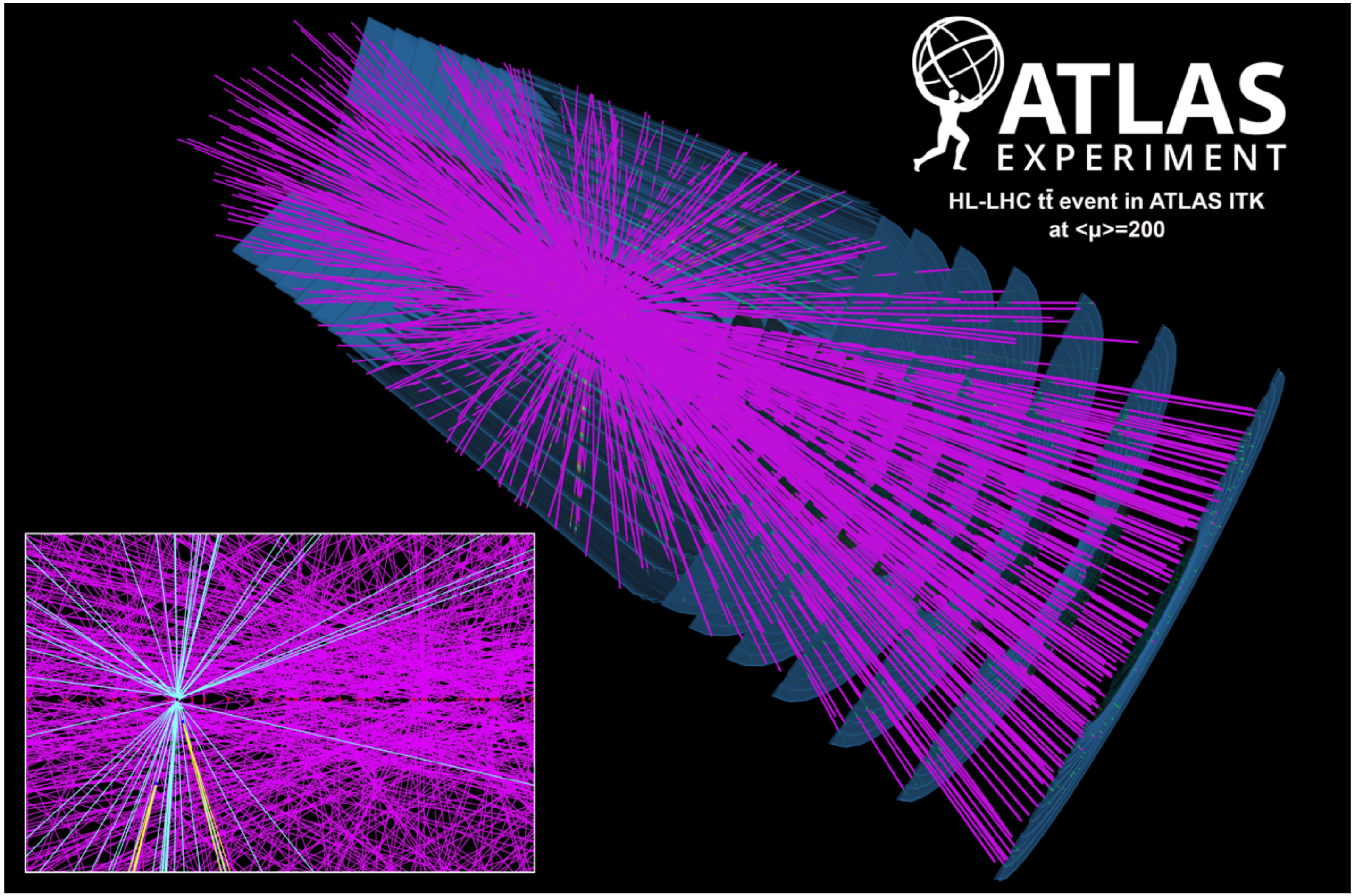
- Need for specialized algorithms
  - Dedicated Track and Vertex reconstruction
- Though they have very low background
  - instrumental effects, still not well-modelled in the simulation

- The clearest challenge:

  TRIGGER

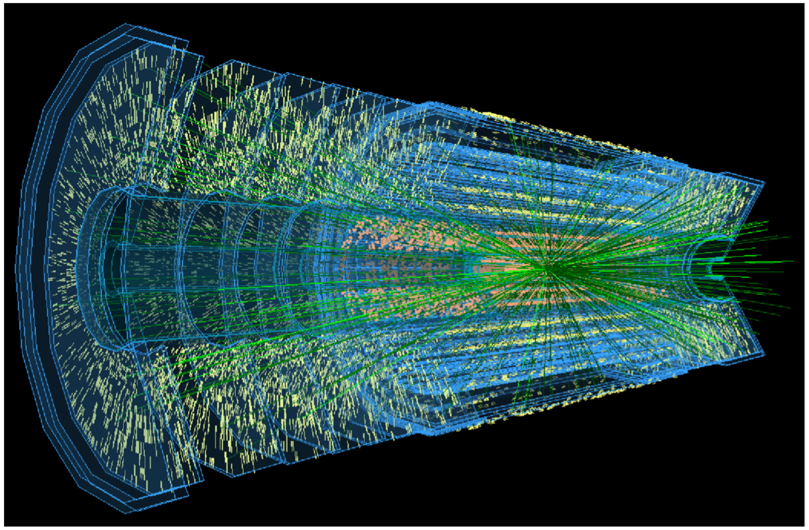
In the HL-LHC

- Neither track reconstruction or trigger are going to get any easier



Hardware Tracking for Trigger

- Charged particle reconstruction in high-pileup conditions → challenge to tackle
- To use of information from the tracking as early as possible in the trigger selection
  - Central to the future ATLAS TDAQ
  - Also present in the CMS Phase-II upgrade



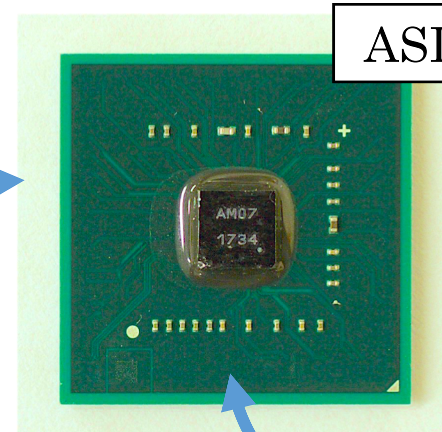
The plan for ATLAS is a **hardware-based system (HTT)** based on custom AM ASICs for pattern recognition and FPGAs for track reconstruction/fitting ⟶ **on-demand, fast tracking done in hardware**

LLP at the HTT

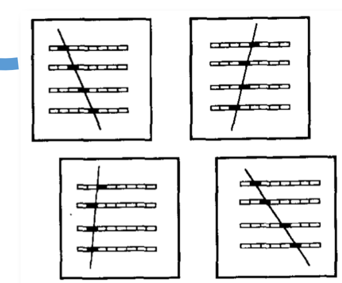
- Our goal is to make sure that LLP with characteristic tracker signatures are taken into account for trigger purposes in ATLAS at the HL-LHC
  - For this **we need to make the HTT aware of them**

Pattern Recognition mezzanine

ASICs



The HTT



Pattern bank

Alessandra will tell you all about it!
check out her [talk]

Work performed mainly by two Uppsala PhD students (now graduated):

Mikael Mårtensson and Max Isacson

JINST

Published by IOP Publishing for Sissa Medialab

Received: *July 25, 2019*
Revised: *September 2, 2019*
Accepted: *October 24, 2019*
Published: *November 6, 2019*

To catch a long-lived particle: hit selection towards a regional hardware track trigger implementation

M. Mårtensson, M. Isacson, H. Hahne, R. Gonzalez Suarez[1] and R. Brenner

Uppsala universitet,
Lägerhyddsvägen 1, 752 37 Uppsala, Sweden

E-mail: rebeca.gonzalez.suarez@physics.uu.se

Abstract: Conventional searches for new phenomena at collider experiments tend to focus on prompt particles, produced at the interaction point and decaying rapidly. New physics models including long-lived particles that travel a substantial distance in the detectors before decaying provide an interesting alternative, especially in light of the lack of new phenomena at the current LHC experiments, and could solve unanswered questions of the Standard Model. Long-lived particles have characteristic experimental signatures that, while making them clearly distinct from other processes, also could make them potentially invisible to current data-acquisition methods. Specific trigger strategies need to be in place to target long-lived particles. In this paper, we investigate the use of tracker information at trigger level to identify displaced signatures. We propose two methods that can be implemented at hardware-level: one based on the Hough transform, and another based on pattern matching with patterns trained on displaced tracks.

Keywords: Pattern recognition, cluster finding, calibration and fitting methods; Data reduction methods; Particle identification methods; Trigger algorithms

ArXiv ePrint: 1907.09846

[1]Corresponding author.

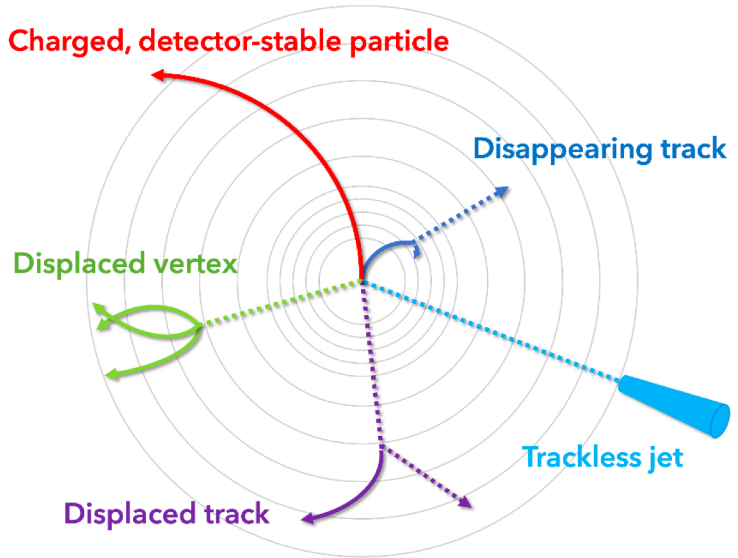
© 2019 The Author(s). Published by IOP Publishing Ltd on behalf of Sissa Medialab. Original content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

https://doi.org/10.1088/1748-0221/14/11/P11009

2019 JINST 14 P11009

Displaced tracks

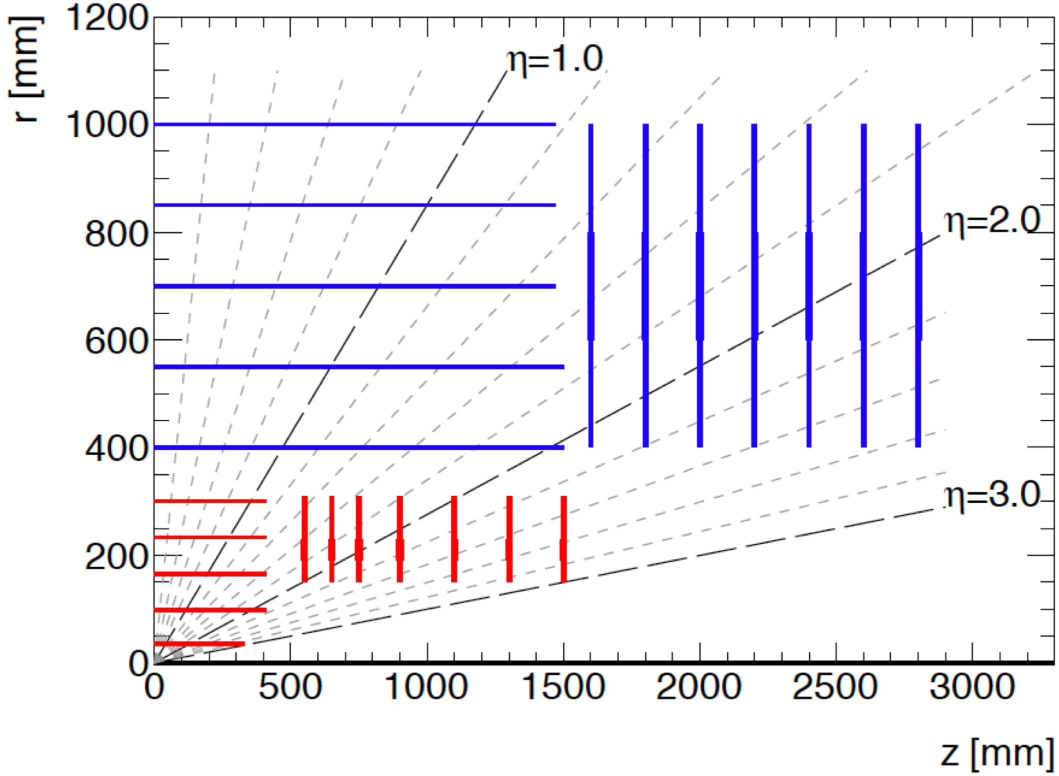
- Many interesting tracker signatures that we would like to identify at trigger level
- In this paper we start with the simplest
    - **Displaced muons**



Displaced μ tracks generated with a particle gun in Pythia
Transverse coordinates of the position of the track vertex: 0–350mm

Custom simulation

- Generic tracker similar to that used in ATLAS and CMS is modelled with Geant4
  - Same geometry as in arXiv:1709.01034



5 pixel layers, in red, and 5 strip double layers, in blue, in the barrel (7/7 in the endcaps)

Study restricted to a single region, using only its outermost layers

Hit selection

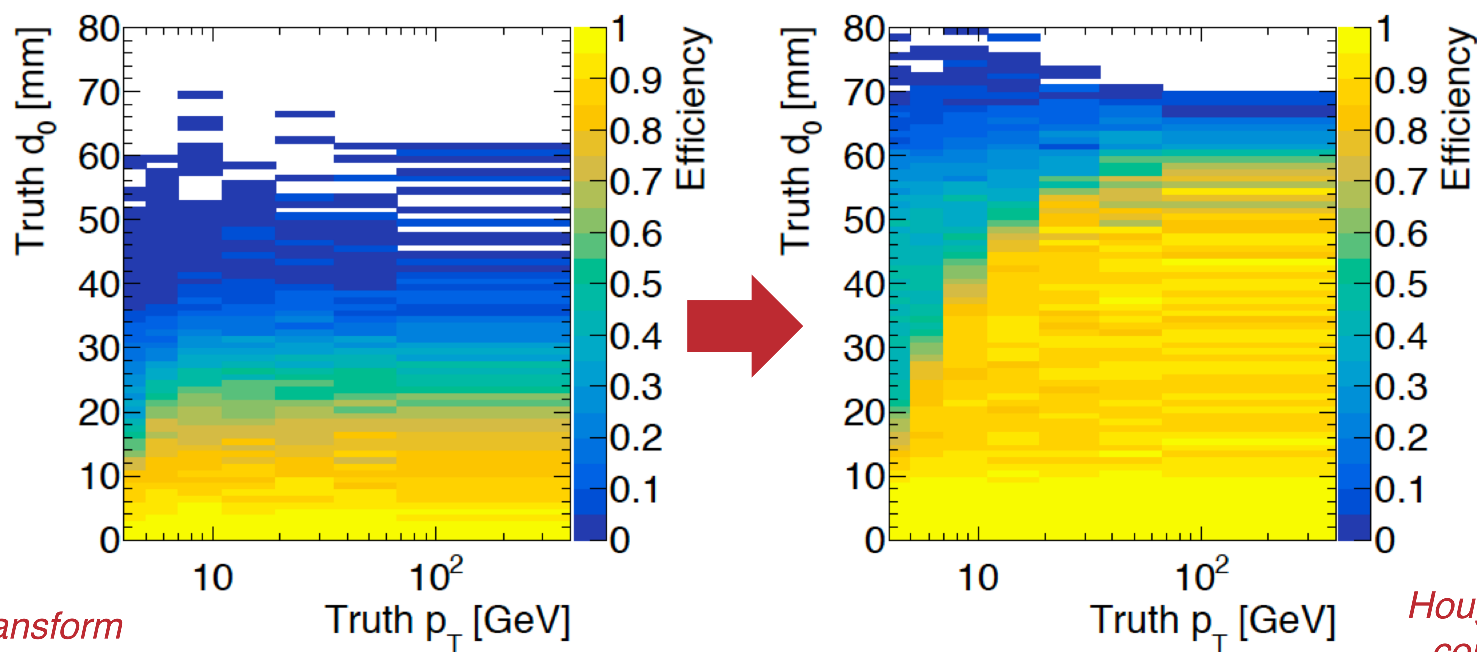
- Two hardware-based hit collection methods:

  - One based on the Hough transform
    - Can be implemented un GPU/FPGAs
    - Used in computer vision applications
    - Can be constructed for any curve that can be described with a few parameters

  - One based on **pattern matching**
    - **Baseline HTT**, done in ASICs
    - Reserving 10% and 20% patterns trained with displaced muons from a prompt muon pattern bank

Hough transform

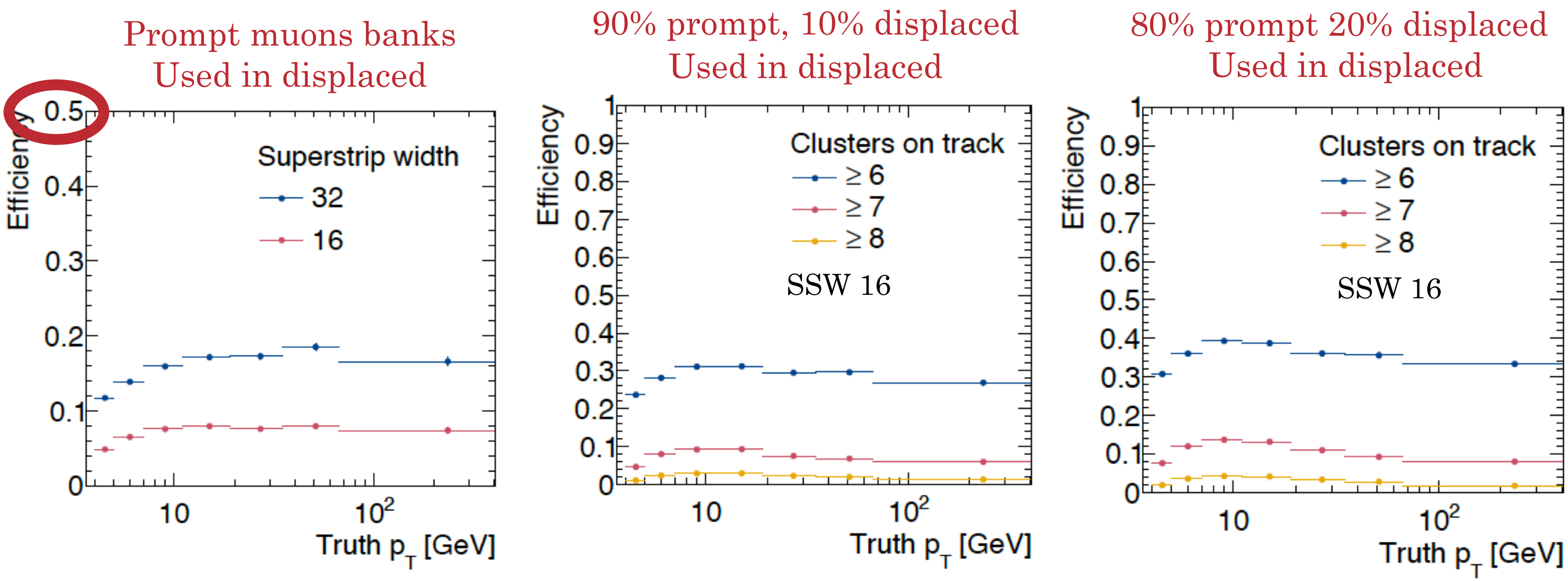
Efficiency of finding hits for the displaced-vertex sample
The efficiency increases overall with respect to the default when tuned for displaced, though it is still hard to finding tracks with low p_T and high d_0



Hough transform configured for prompt (default) Applied to displaced

Hough transform configured for displaced Applied to displaced

Pattern matching

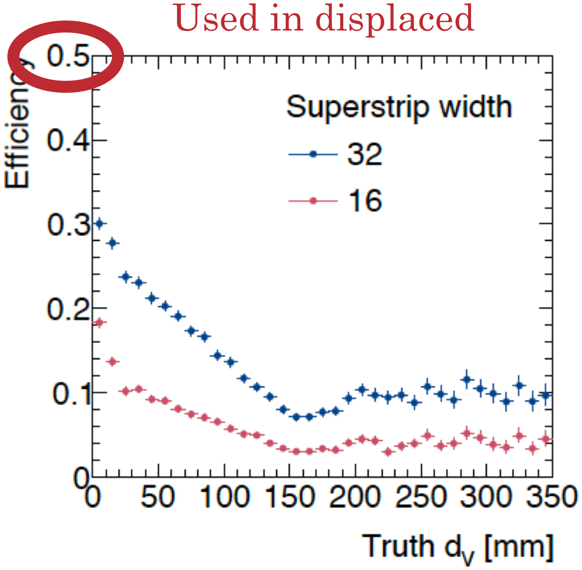


The efficiency rises to ~30% with 10% and close to 40% with 20%

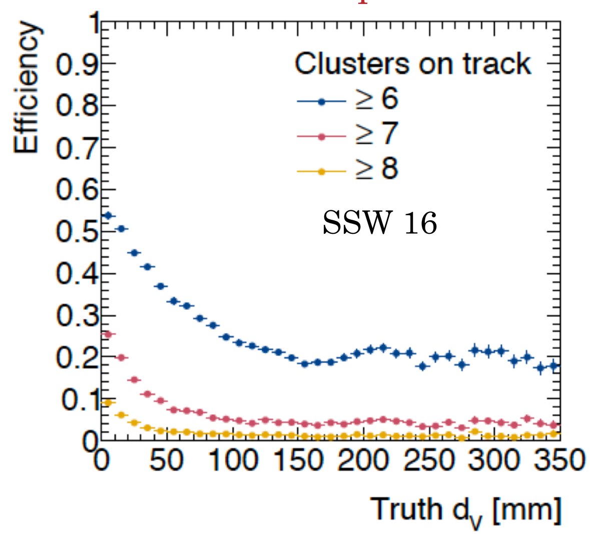
(SSW: superstrip width, proxy of the "resolution" of a pattern in a bank
We use 16 for this exercise)

Pattern matching

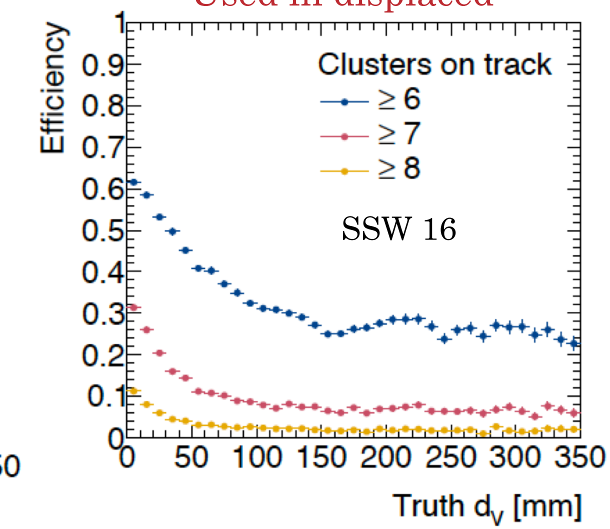
Prompt muons banks
Used in displaced



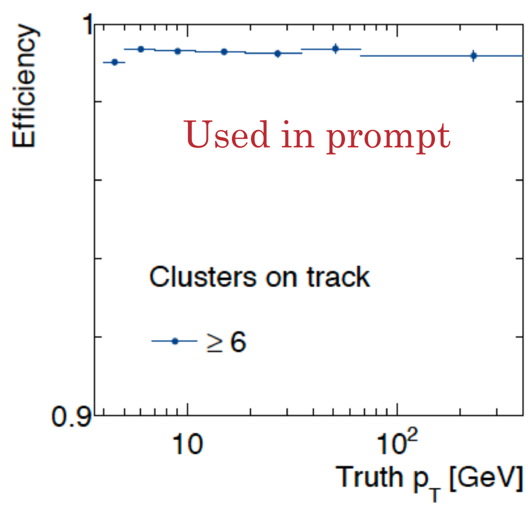
90% prompt, 10% displaced
Used in displaced

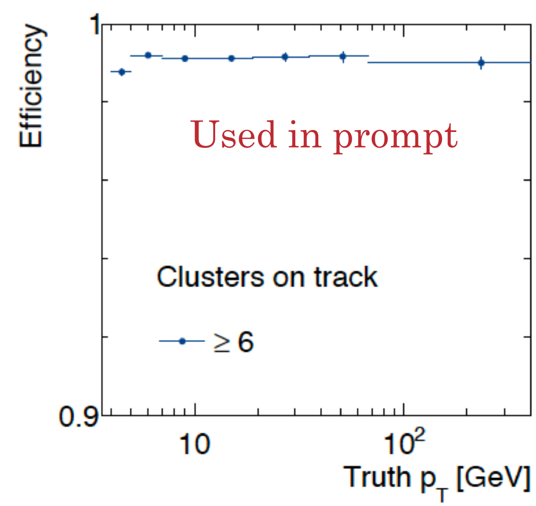


80% prompt 20% displaced
Used in displaced



The efficiency stays well above 20% for all values of d_V while maintaining above 99% efficiency for prompt tracks





Summary

- LLP are cool but we could be missing them, especially at trigger level

- Preliminary study: promising performance of dedicated trigger strategies for long-lived particles at the HL-LHC
  - With small additional resources, the sensitivity to these signals can be improved

- Both methods will increase the load on the data acquisition system because of additional hits from minimum bias
  - This effect can be kept small if only events of interest are kept, how this can be done is left for a future study

- We propose that resources are reserved in the design of the future tracker triggers for the HL-LHC