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Searches for Higgs boson decaying to long-lived particles at LHC

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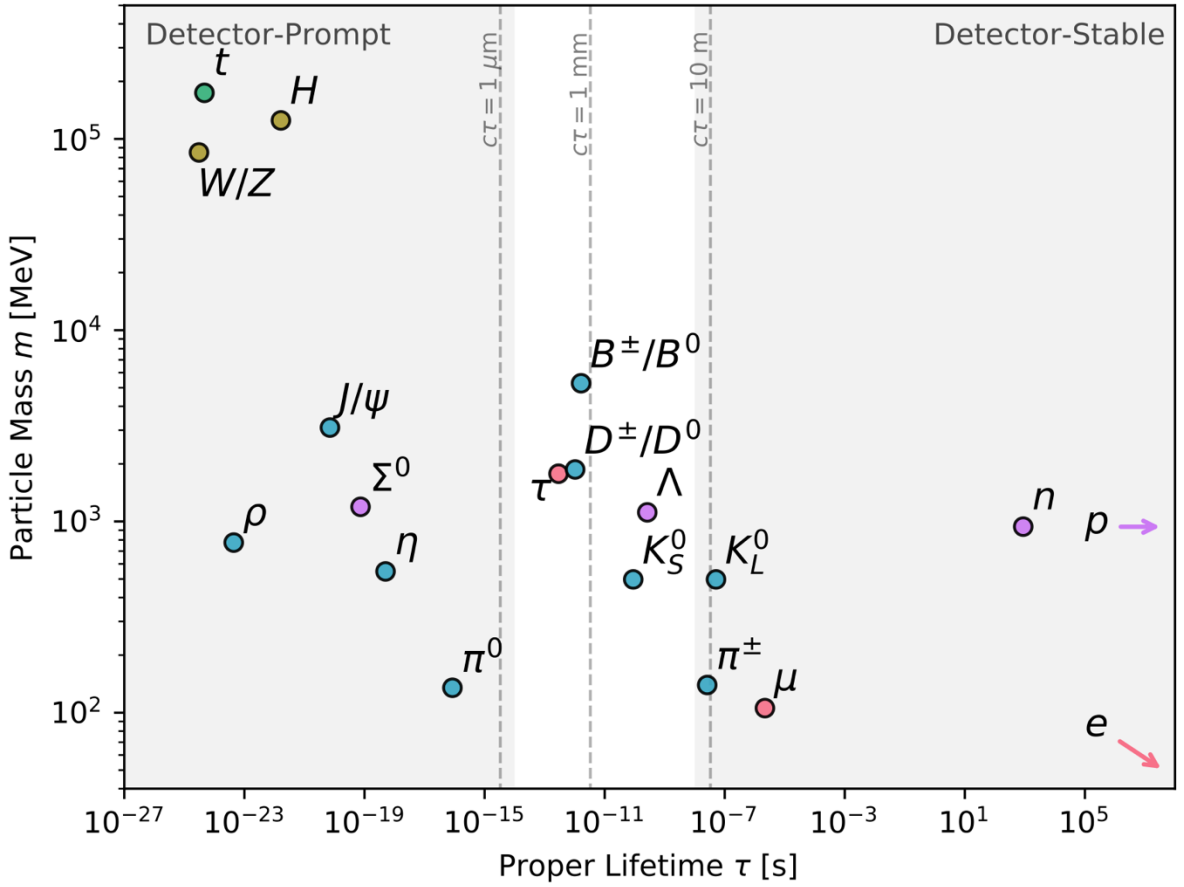
Higgs Potential 2024
Hefei

Why search for long-lived particles

Long-Lived Particles in the SM



[JPPNP 3695 (2019)] - LL, C. Ohm, A. Soffer, T. Yu

The proper lifetime of a particle

$$\tau^{-1} = \Gamma = \frac{1}{2m_X}\int d\Pi_f |\mathcal{M}(m_X \to \{p_f\})|^2$$

But if the decay of a particle is suppressed by some reasons…

- Small couplings
- Nearly Mass-Degenerate Spectra
- highly virtual intermediate states

Giving rise to potentially macroscopic proper decay lengths ($c\tau \gtrsim 100\ \mu$m).

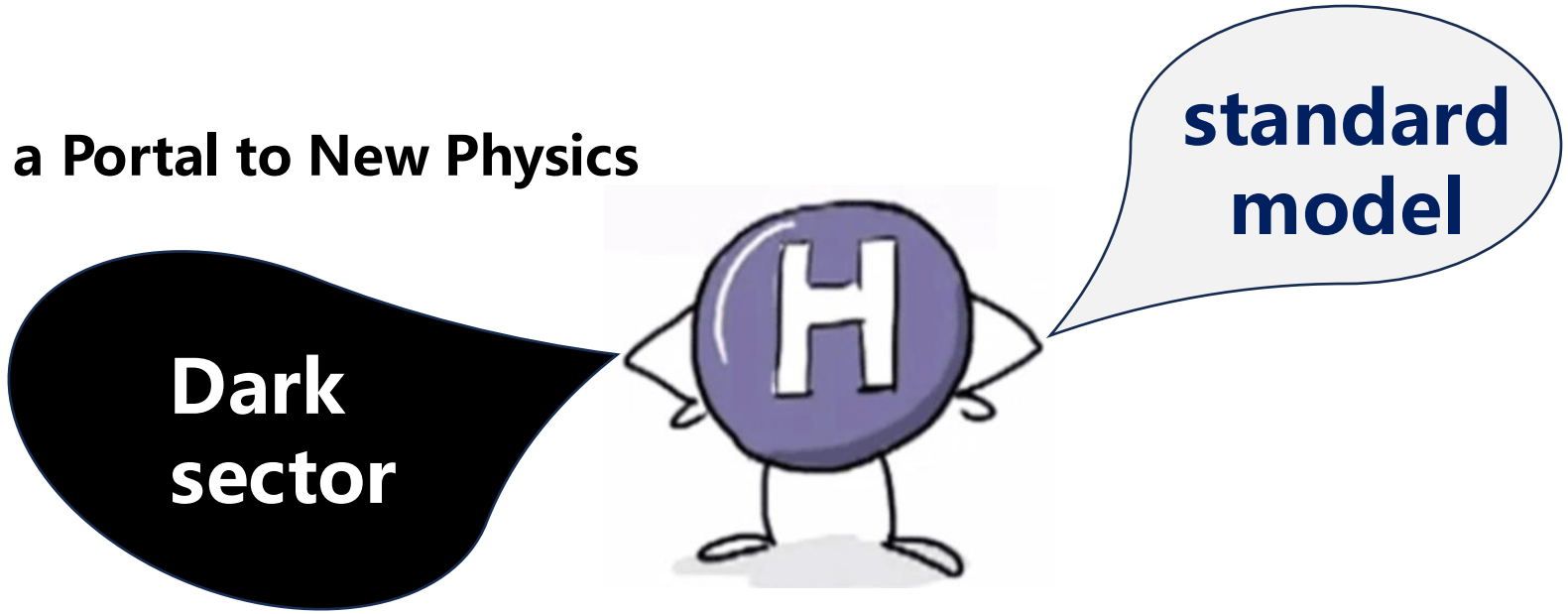
Those are defined as **long-lived particles (LLPs)**

Why search for long-lived particles

Many BSM predict the existence of long-lived particles

- Supersymmetry (SUSY)
- Neutral Naturalness
- Mechanisms of producing dark matter (DM)
- Portal interactions hidden sector ↔ SM
- Twin Higgs models

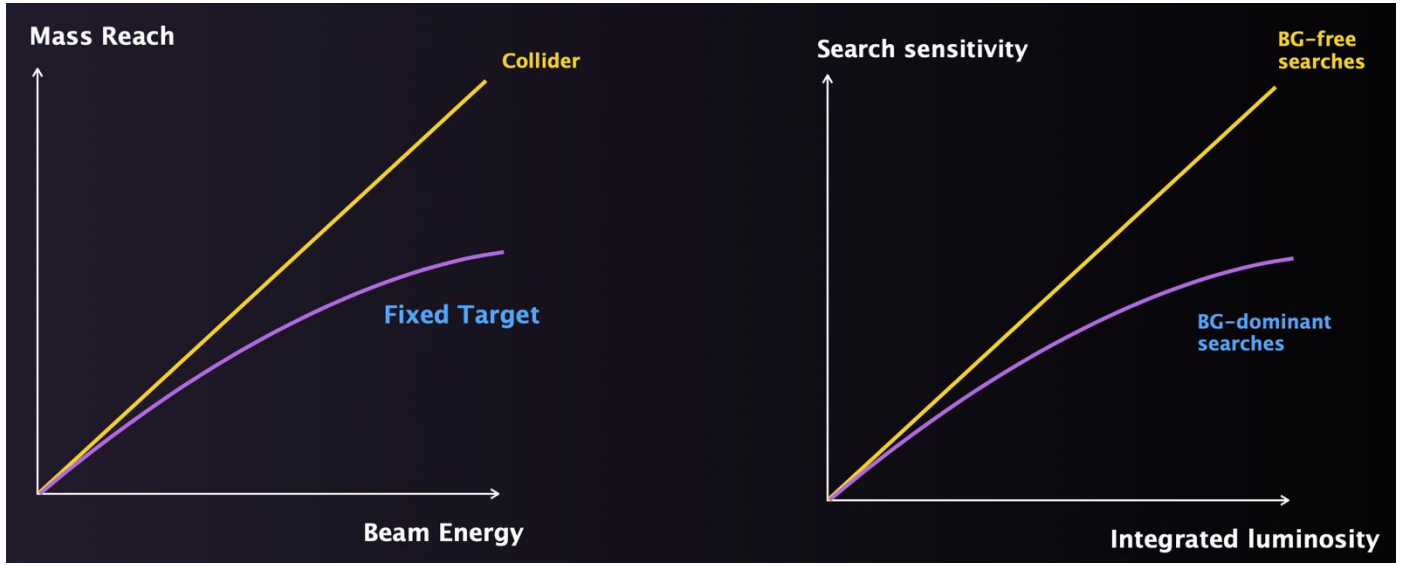
Higgs boson can be a Portal to New Physics



Why search for long-lived particles

LLPs can be produced at LHC

- Distinctive signature → Zero or Low SM Bkg
- Sensitivity gain promised with accumulating luminosity
- Unconventional / Dedicated reconstruction + trigger
- Instrumental backgrounds: Beam-induced backgrounds, Cosmic rays, Fake Vertices, etc.



ATLAS Long-lived Particles searches

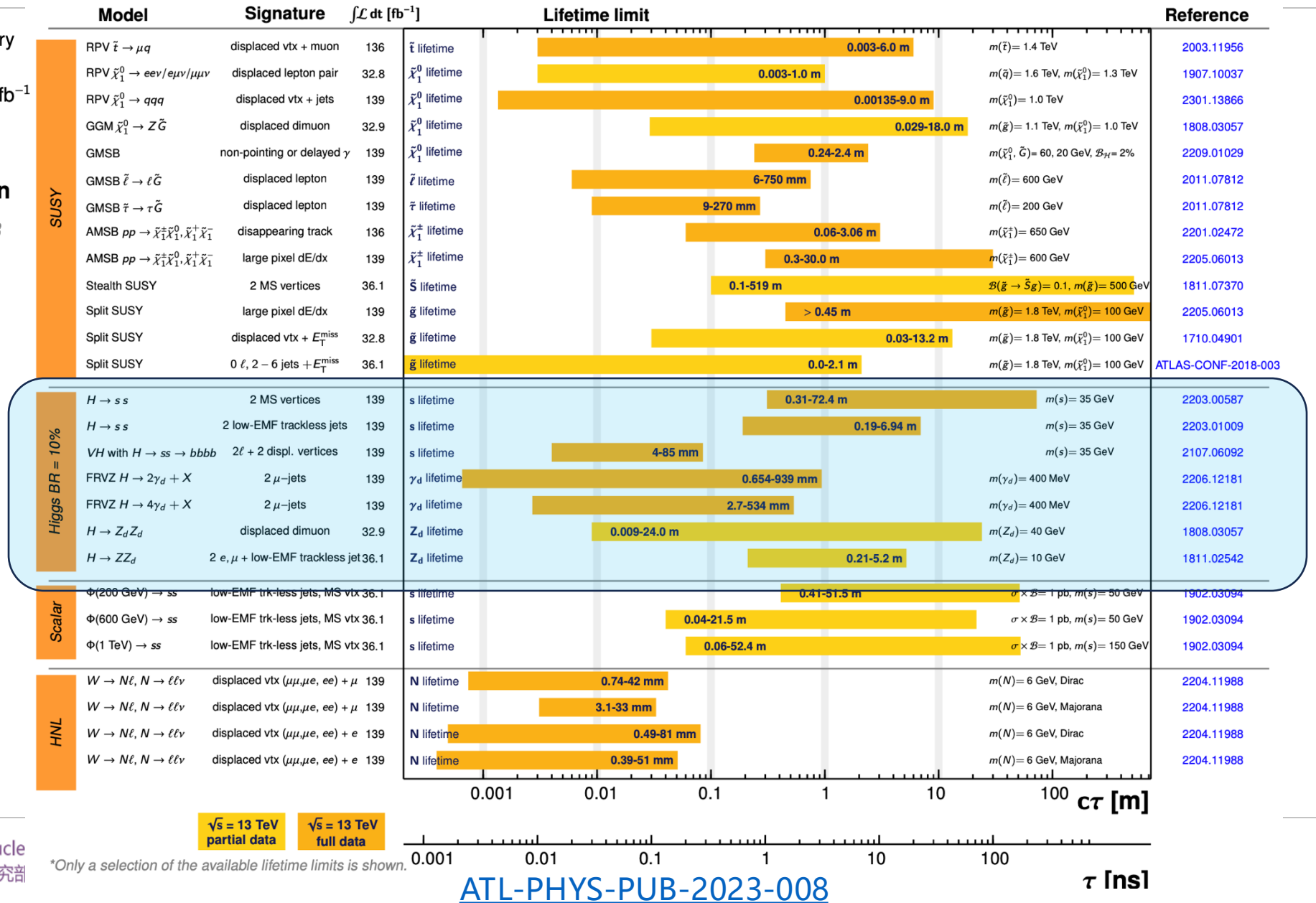
ATLAS Preliminary

$\int \mathcal{L}\, dt$ = (32.8 – 139) fb^{-1}

$\sqrt{s}$ = 13 TeV

95% CL Exclusion

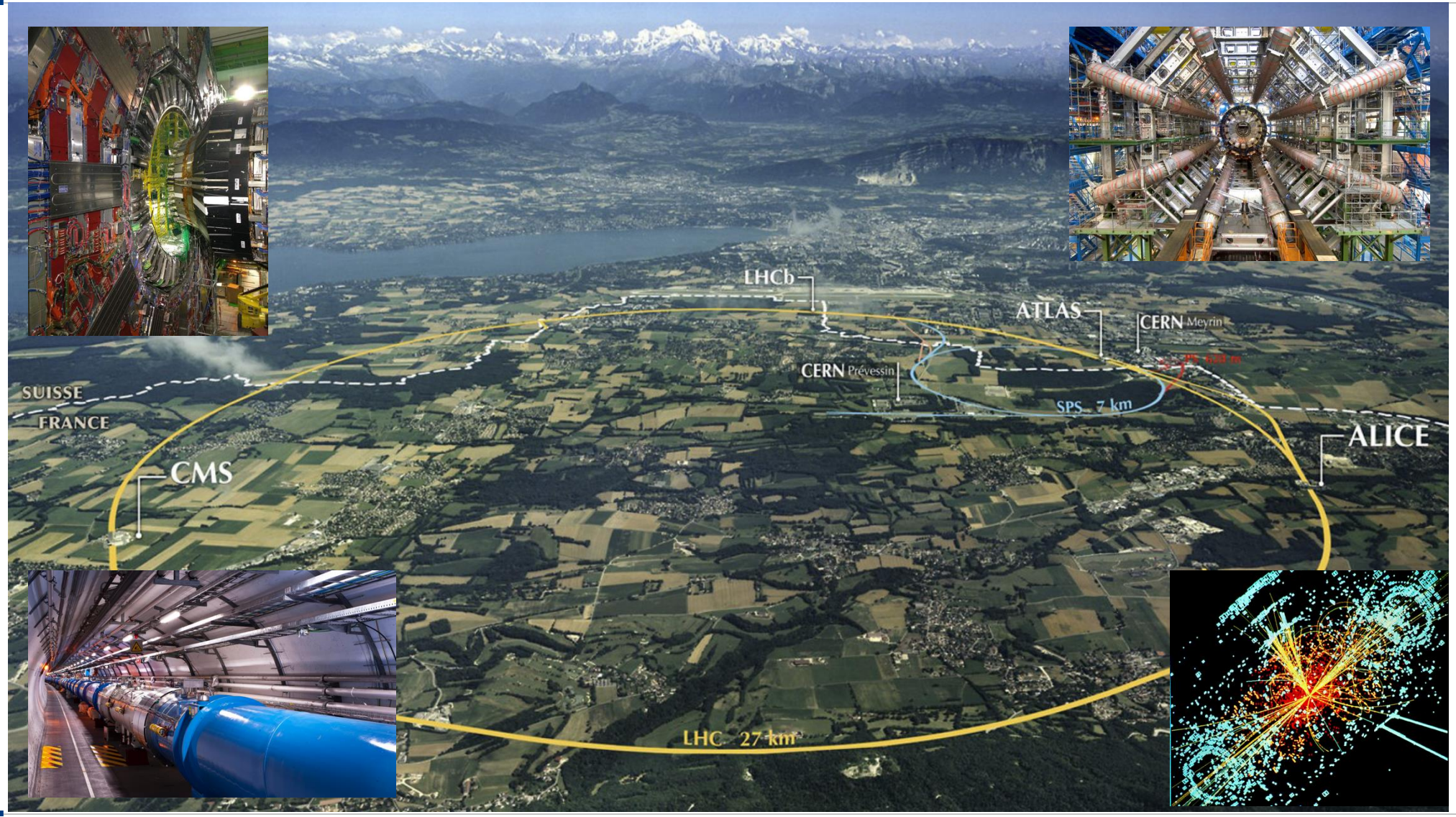
Status: March 2023



*Only a selection of the available lifetime limits is shown.

ATL-PHYS-PUB-2023-008

The Large Hadron Collider (LHC)



Signatures of long-lived particles at LHC

In the inner tracking detector

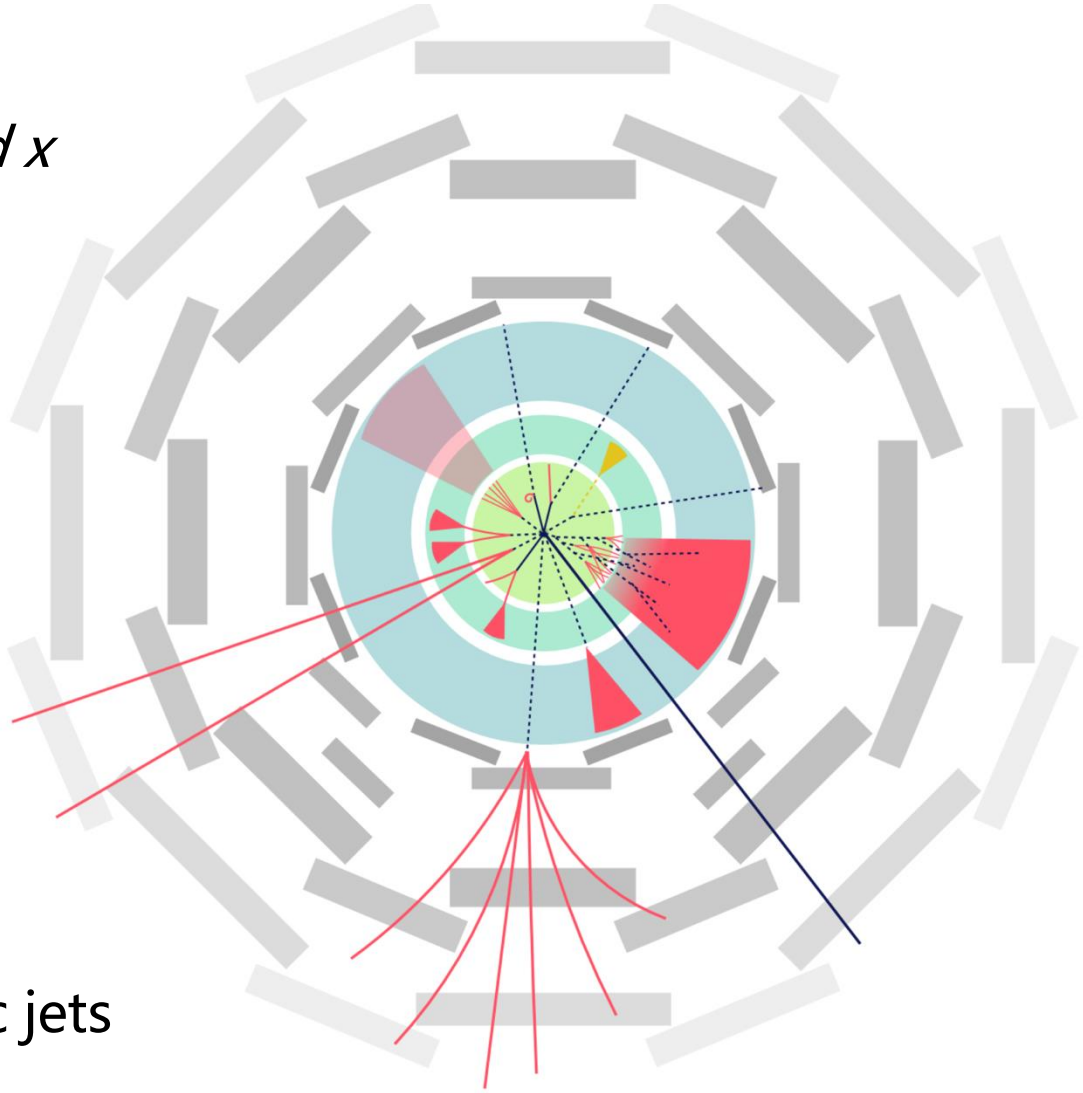
- Displaced Vertex (DV): *neutral LLPs ->charged x*
- disappearing track: *charged LLPs -> neutral x*
- low velocity: *Larger energy loss (dE/dx)*
- kinked track

In the calorimeters

- displaced jets: *LLPs -> Quarks/gluons*
- emerging jets: *Dark QCD*
- delayed jet, non-pointing photons

In the muon spectrometer

- Displaced Vertex (DV), Very displaced hadronic jets

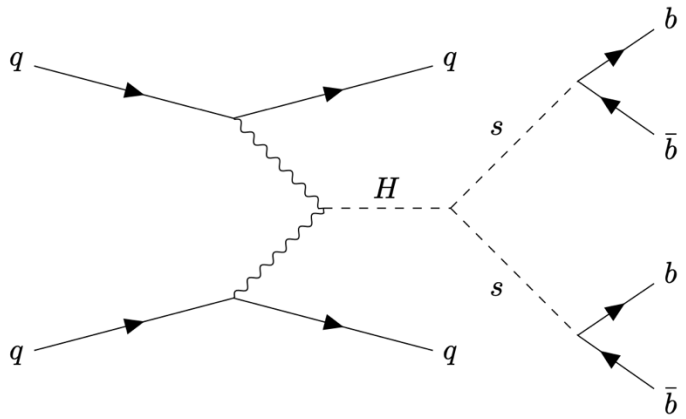


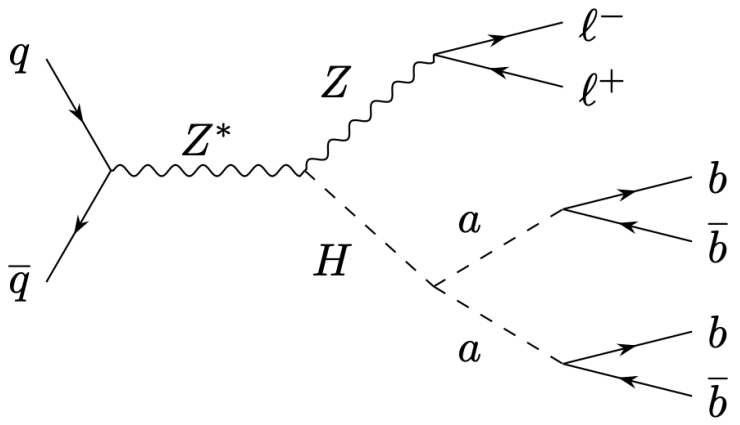
Search for long-lived particles at the ATLAS

Explore the **Higgs portal model** at the ATLAS, in which the Higgs boson exotic decays to a pair of long-lived s particles.

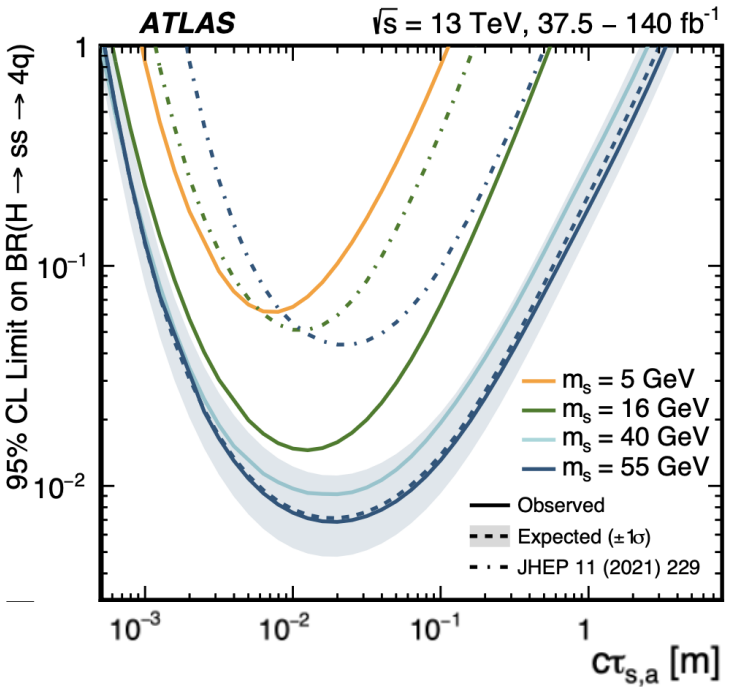
A new "Large-Radius Tracking" algorithm (LRT) was implemented in Phys. Rev. Lett. **133** (2024) 161803 to boost sensitivity.

- An additional track finding only using the left-over hits.
- Extending up to $|d_0|$ < 300 mm (near the 1st strip layer).

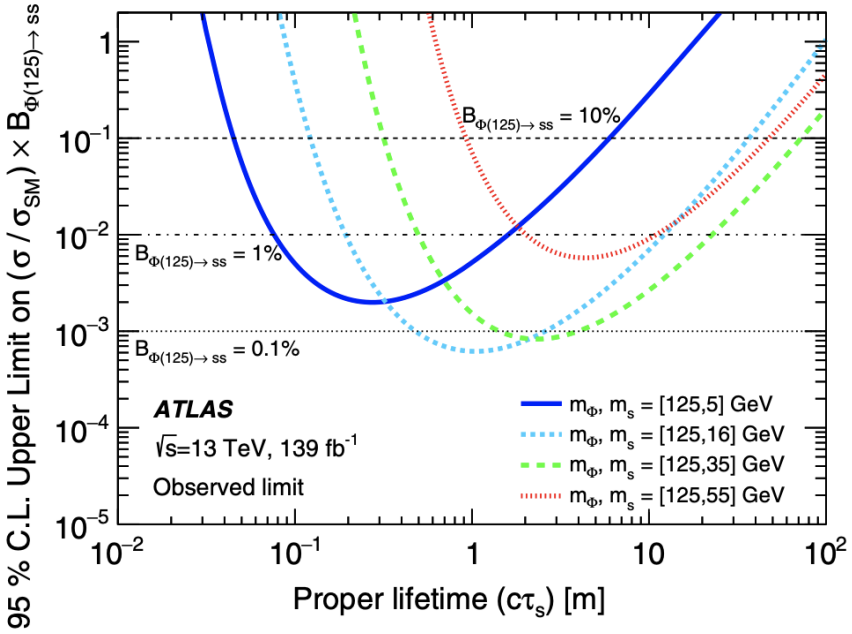




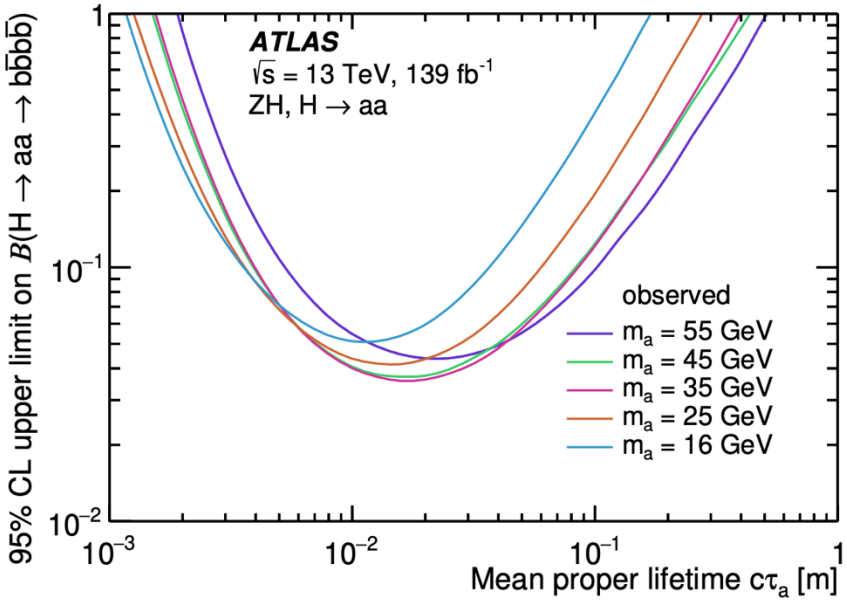
Search for long-lived particles at the ATLAS



Phys. Rev. Lett. **133** (2024) 161803



Phys. Rev. D **106** (2022) 032005

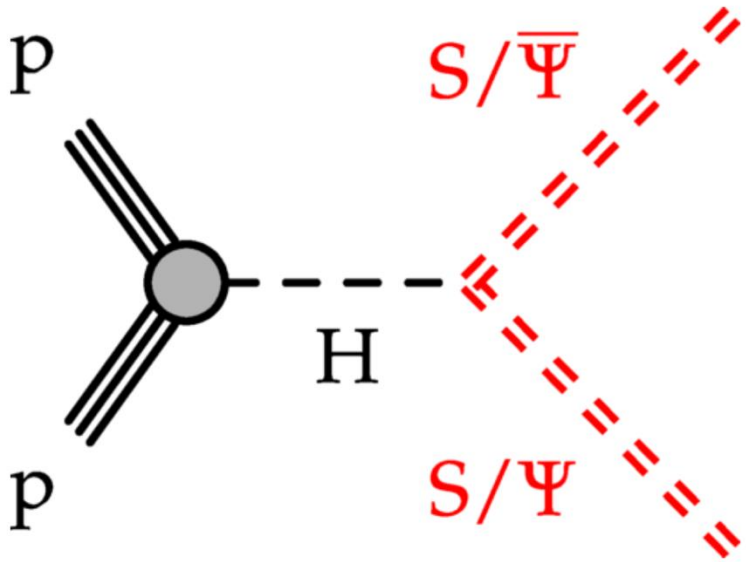


JHEP 11 (2021) 229

95% CL exclusion limits on BR($H \rightarrow ss$) as a function of the mean proper decay length cτ provided by ATLAS experiment at 2024, 2022, 2021.

Search for long-lived particles at the CMS

Search for Higgs decays to LLPs at the CMS using 138 fb^{-1} of pp collision data with $\sqrt{s}$ = 13 TeV. In which LLPs (S) described by the **Twin Higgs model** or **dark shower model**.



Twin Higgs model

- Higgs boson decays to a pair of neutral long-lived scalars (S), each of which decays in turn to a pair of fermions or a pair of photons.

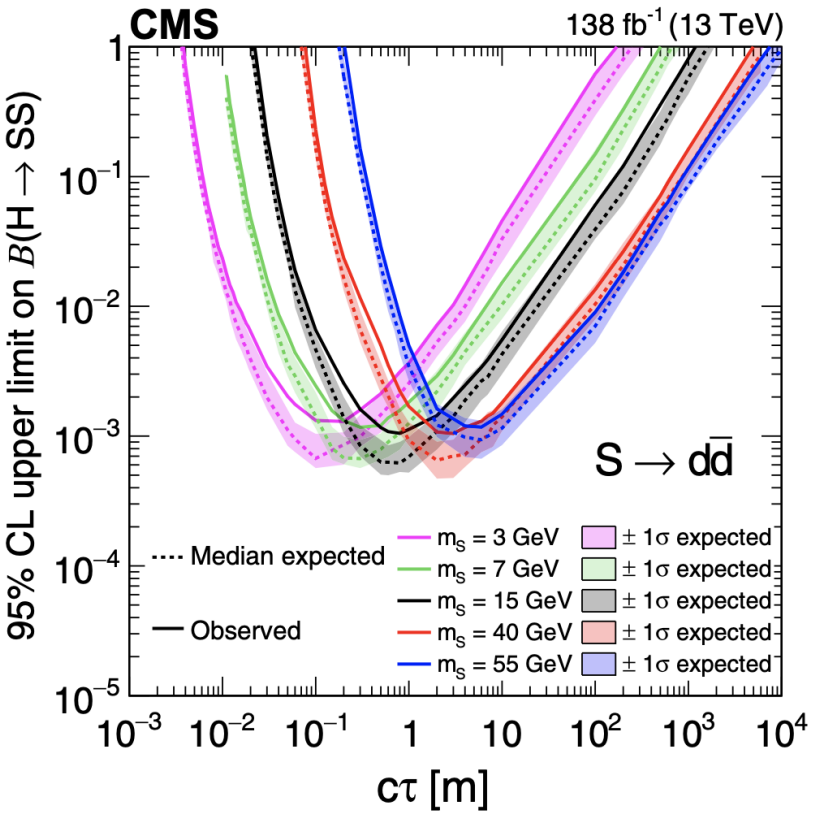
Dark shower model

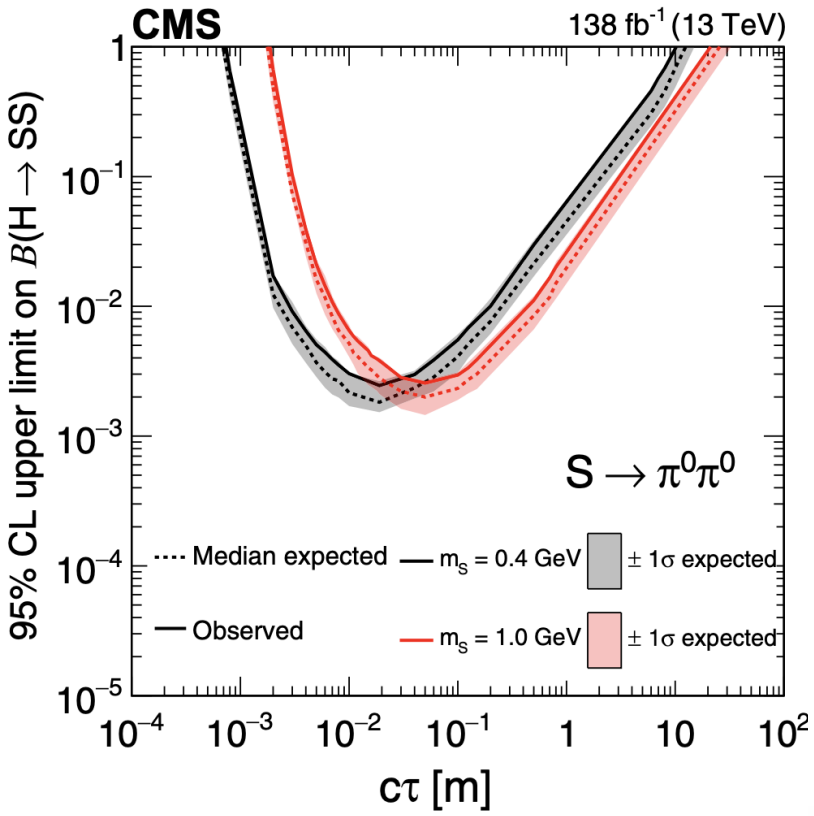
- Higgs boson decays to a pair of dark-sector quarks (Ψ).

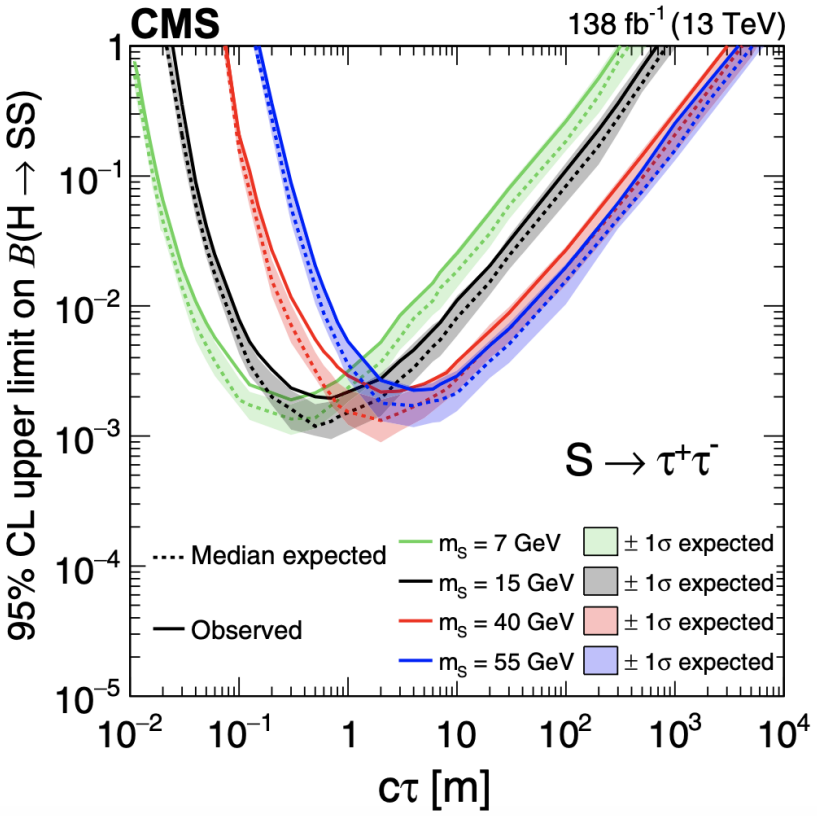
Phys. Rev. D 110 (2024) 032007

Search for long-lived particles at CMS detector

$H \to SS$, S: neutral long-lived scalars



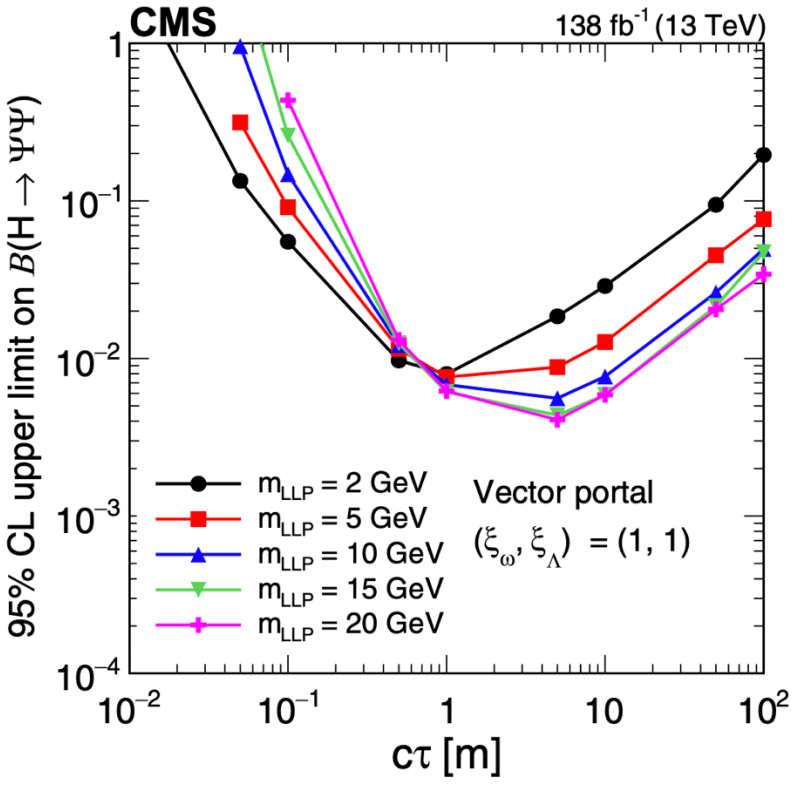


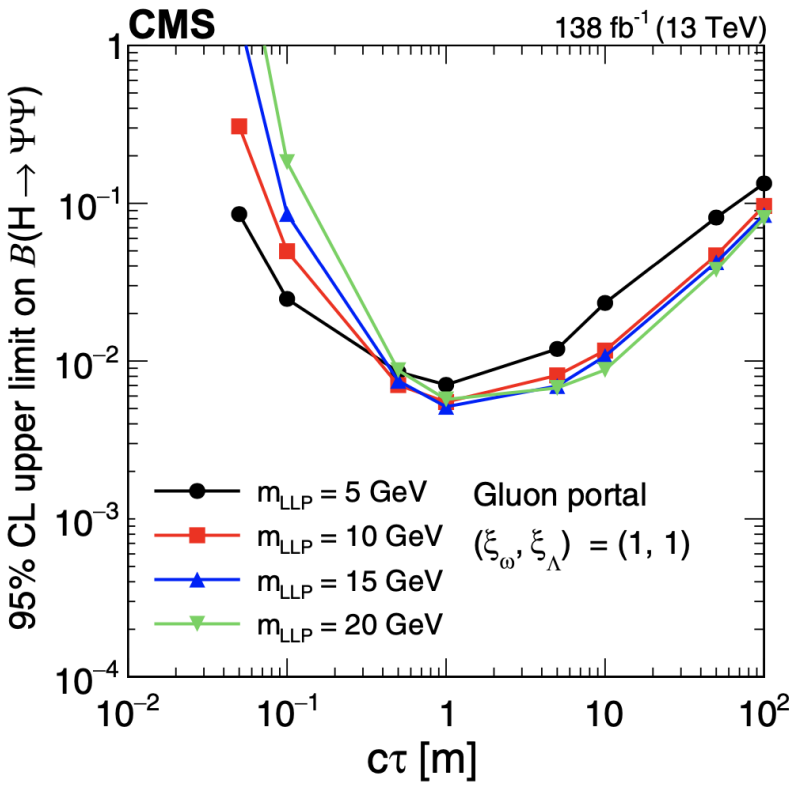


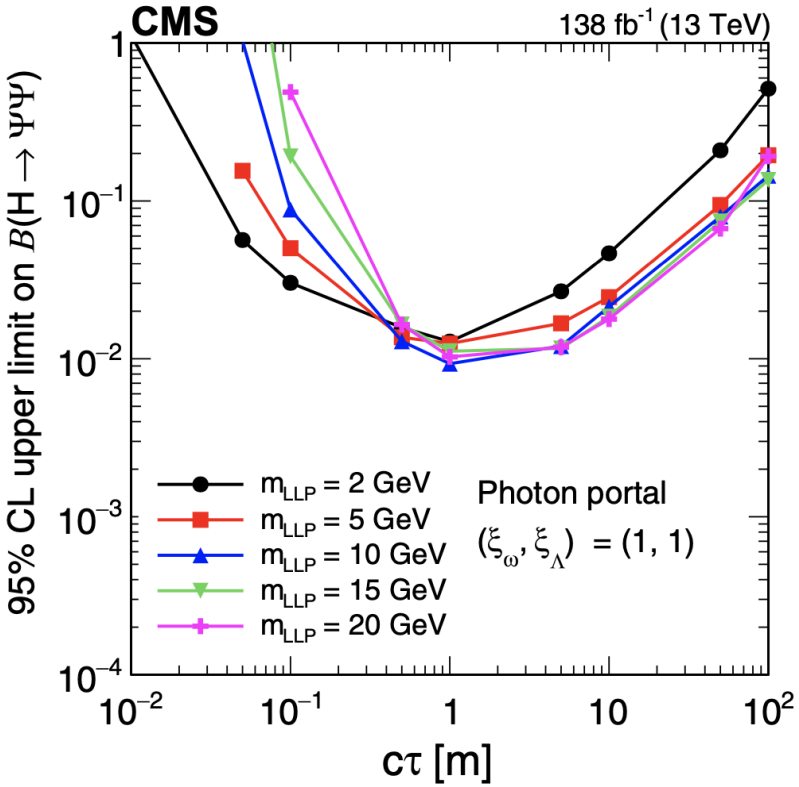
Phys. Rev. D 110 (2024) 032007

Search for long-lived particles at CMS detector

$H \to \Psi\bar{\Psi}$, Ψ: dark-sector quarks







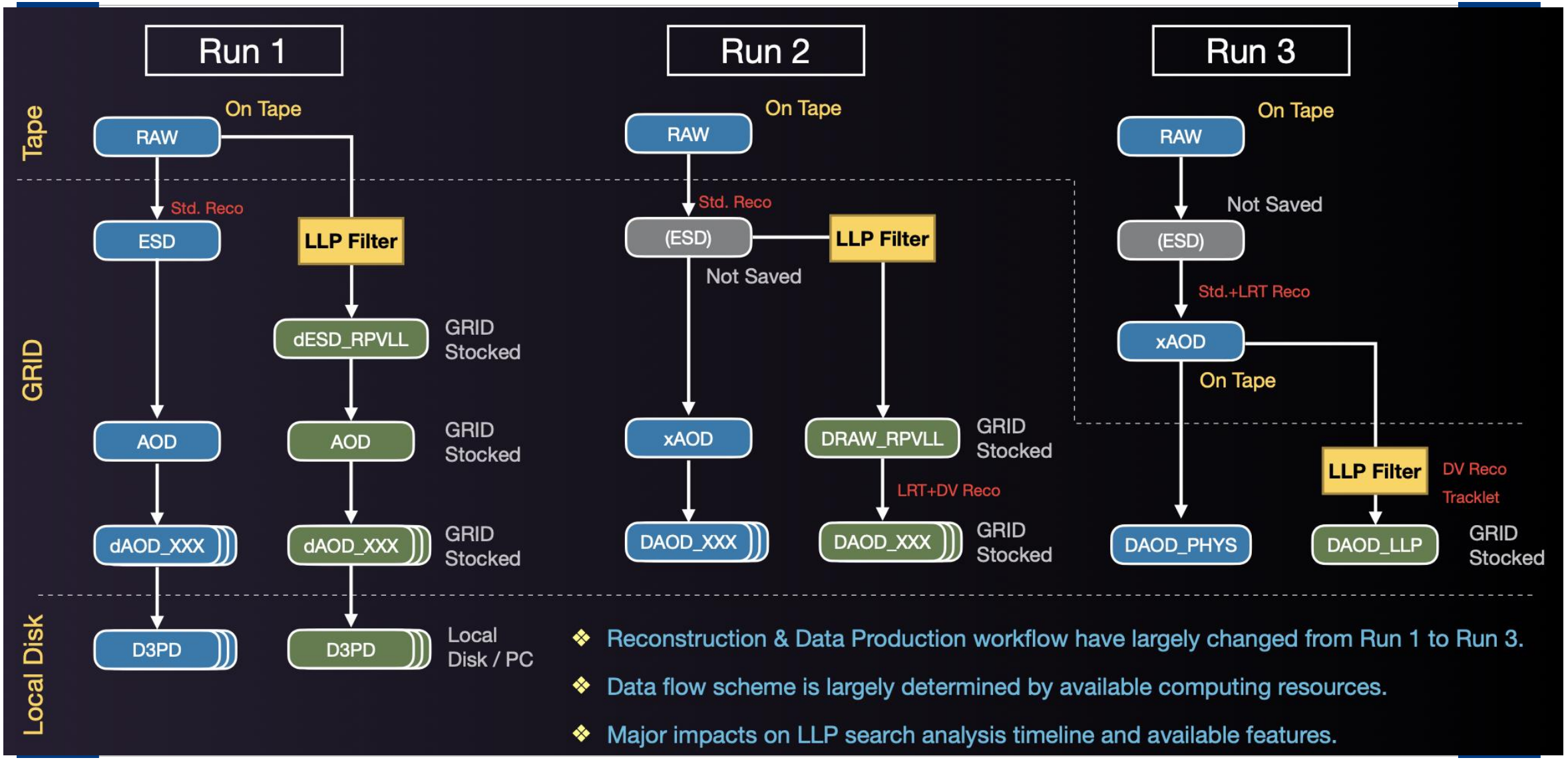
Phys. Rev. D 110 (2024) 032007

Summary

- Long-lived particles (LLPs) are natural predictions of many BSM
- Higgs boson can be a portal to New Physics
- The ATLAS provided the most stringent constraints to date on BR($H \to SS$) for m_s < 40 GeV and 1 < $c\tau_s$ <100 mm
- The CMS provided the first limits at the LHC on a dark quantum chromodynamic sector, branching fractions of $H \to \Psi\bar{\Psi}$ as low as 2×10^{-3} at 95% CL
- Improved analysis techniques and higher luminosity at the HL-LHC will enhance the sensitivity of LLP searches.

Backup

Schematic Data Flow Evolution



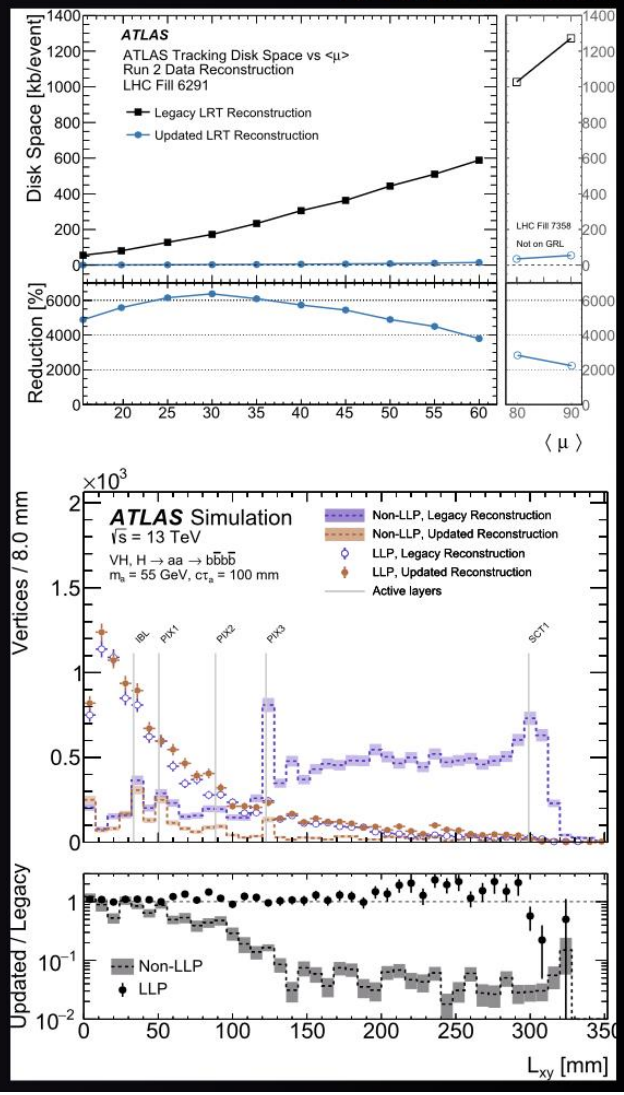
from Hideyuki Oide`s slides

Technical Advancement: Track Reconstruction

- LLP-dedicated extended tracking (large-d_0 tracking)
  $\Longrightarrow$ ATLAS Jargon: Large-Radius Rracking (LRT)
  - An additional track finding only using the left-over hits.
  - Extending up to $|d_0| < 300$ mm (near the 1st strip layer).
- LRT in Run 2: specially processed for exclusive RAW data samples reserved for LLP searches.
  - While efficiency for real particles is high, both the CPU cost and the amount of fake track rate were high.
  - Acceptable in Run 2, as this "distilled" data sample size is small.
  - Somewhat vulnerable against pileup: CPU cost and fake rate.
- Run3: re-optimization of the LRT algorithm.
  - Strategy-#1: Find & quit seeking the fake tracks as early as possible.
  - Strategy-#2: Significantly reduce fake tracks by optimizing selections.
- Significantly robust against pileup.
  - "Standardizing" LRT as a part of the nominal reconstruction.
  - Opening up wide opportunities for LLP searches (also for Run 2 data!)

Hideyuki Oide 2024-07-01

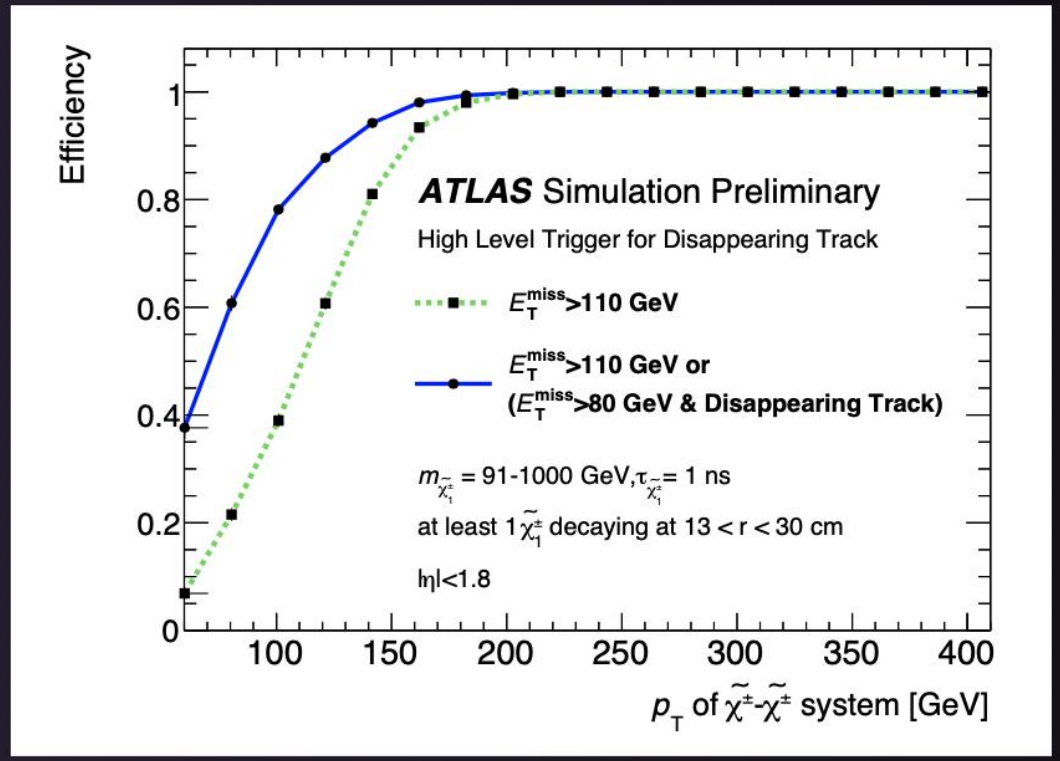
EPJC (2023) 83:1081

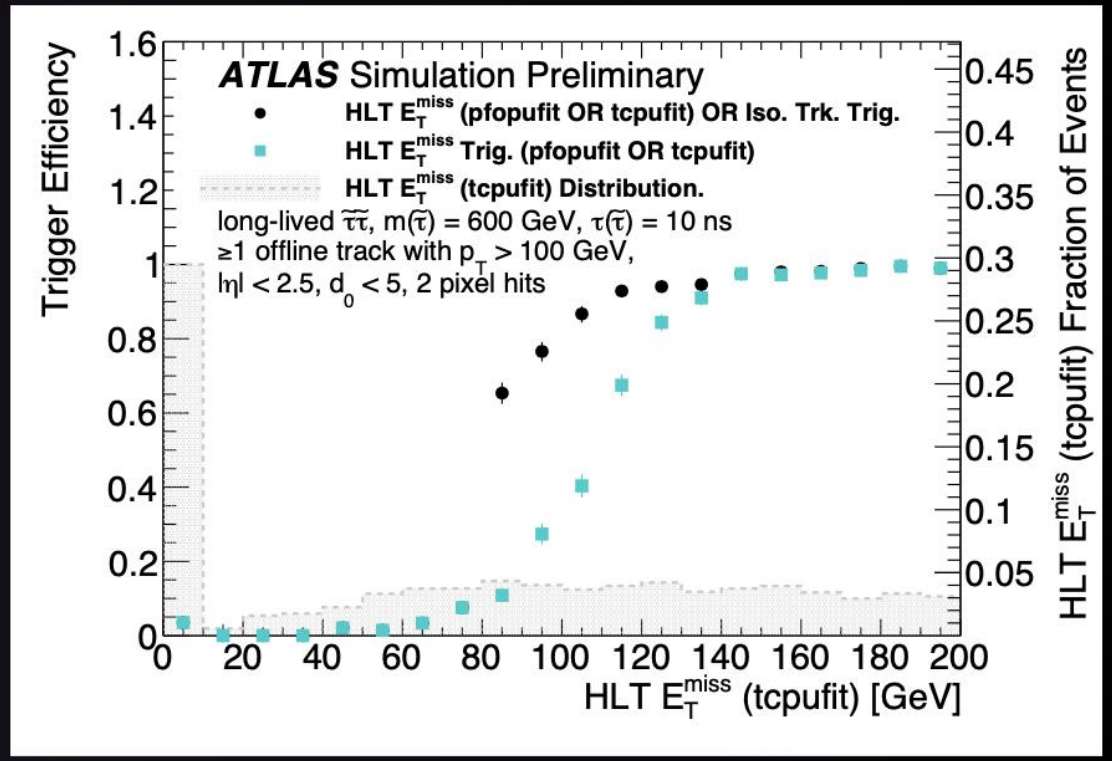


from Hideyuki Oide`s slides

Technical Advancement: Trigger Development

- A number of strong initiatives towards Run 3 for devising LLP-dedicated triggers in High-Level Triggers.
  - Combined with L1, these help to lower thresholds for conventional trigger signatures.
- Much flexibility in implementation of filters for LLP derivation in Run3.





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