

# Searches for **long-lived particles** at the CMS detector

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# The case for long-lived particles

- A decade of searches for new physics at the LHC experiments has yielded negative results
- However new physics events might have occurred at the LHC although in unusual topologies
- If true, we have missed them because our reconstruction methods are not optimal for those
- Long-lived particles are theoretically well motivated examples that lie on this category
- Small decay widths give rise to particles with a large life time that decay far from the center

$$\Gamma \sim \frac{g^2}{8\pi} \left( \frac{m}{M} \right)^{2n} m$$

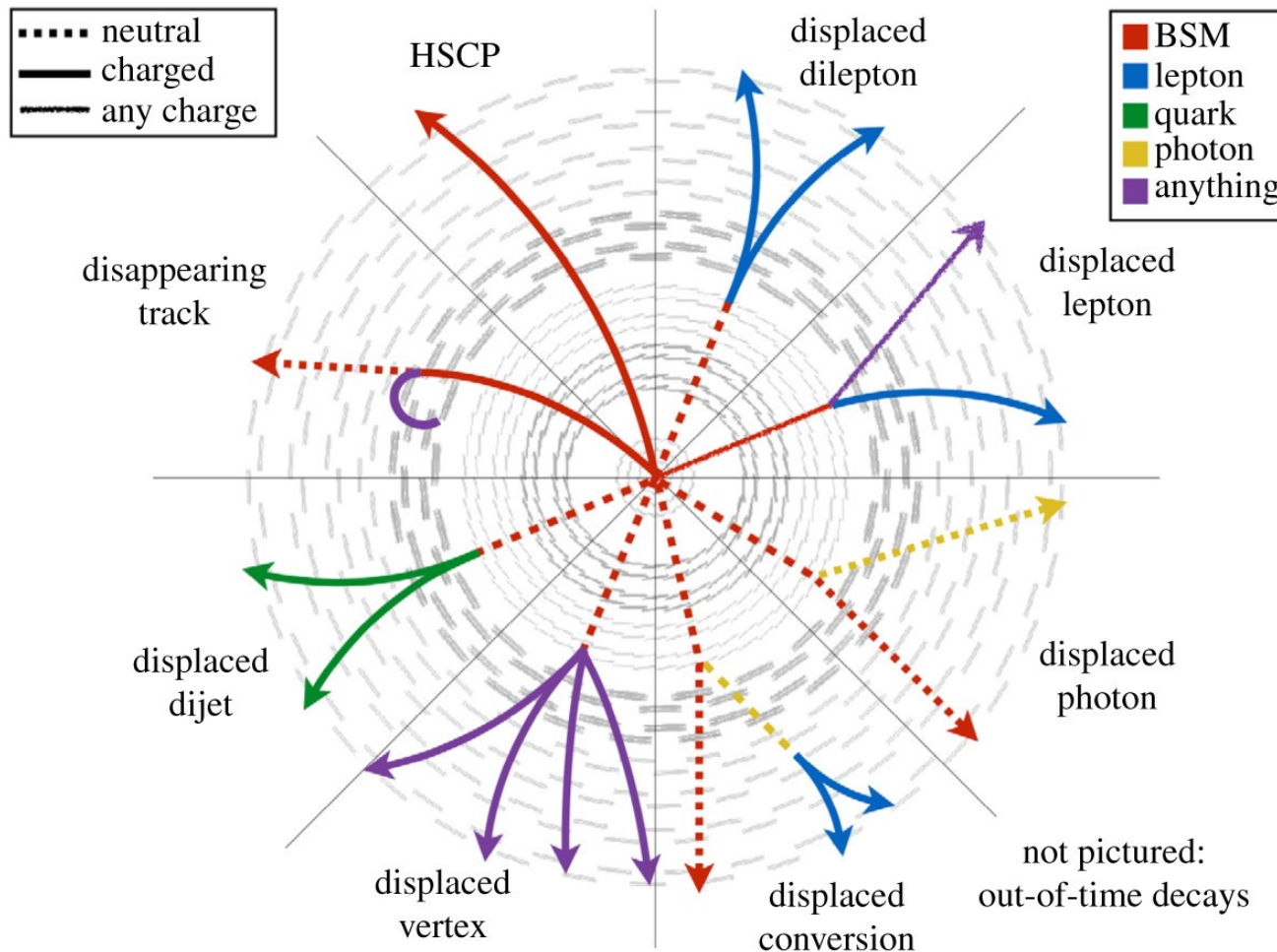
1. Small coupling to SM  
Example: Higgs portal to hidden sectors

2. Scale suppression  
Example: Gauge mediated SUSY  
(SUSY-breaking scale suppression)

3. Phase space suppression  
Example: Small mass splitting between  
NLSP and LSP

# A zoo of unusual topologies

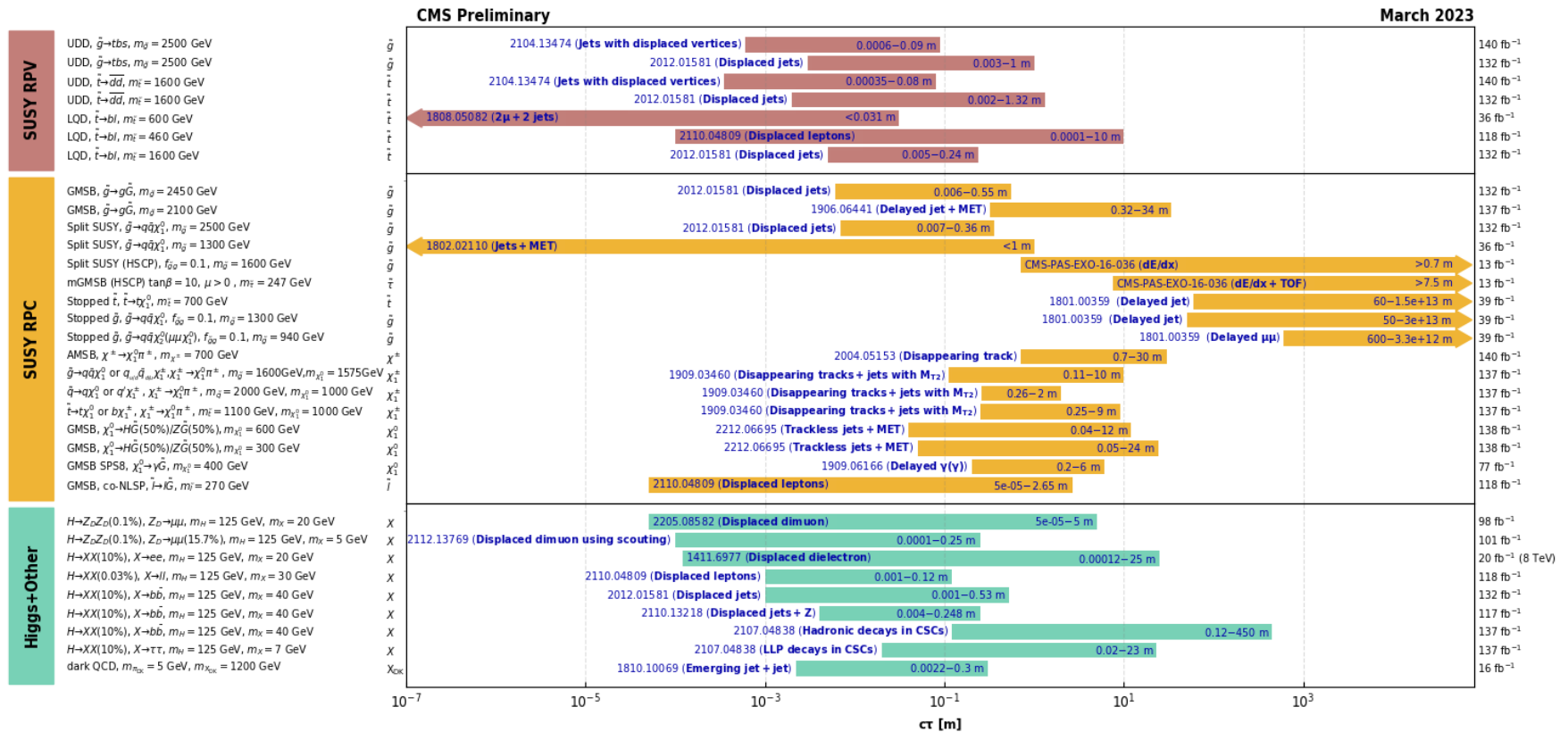
- Reconstruction algorithms are optimized to reconstruct particles coming from the center
- Long Lived Particles can produce many different “displaced” topologies



# Searches during Run 2 / Run 3 ongoing

- A large program of LLP searches has been deployed by CMS during Run 2
  - Some new analysis still coming (Displaced Dilepton Vertices at IFCA)

## Overview of CMS long-lived particle searches

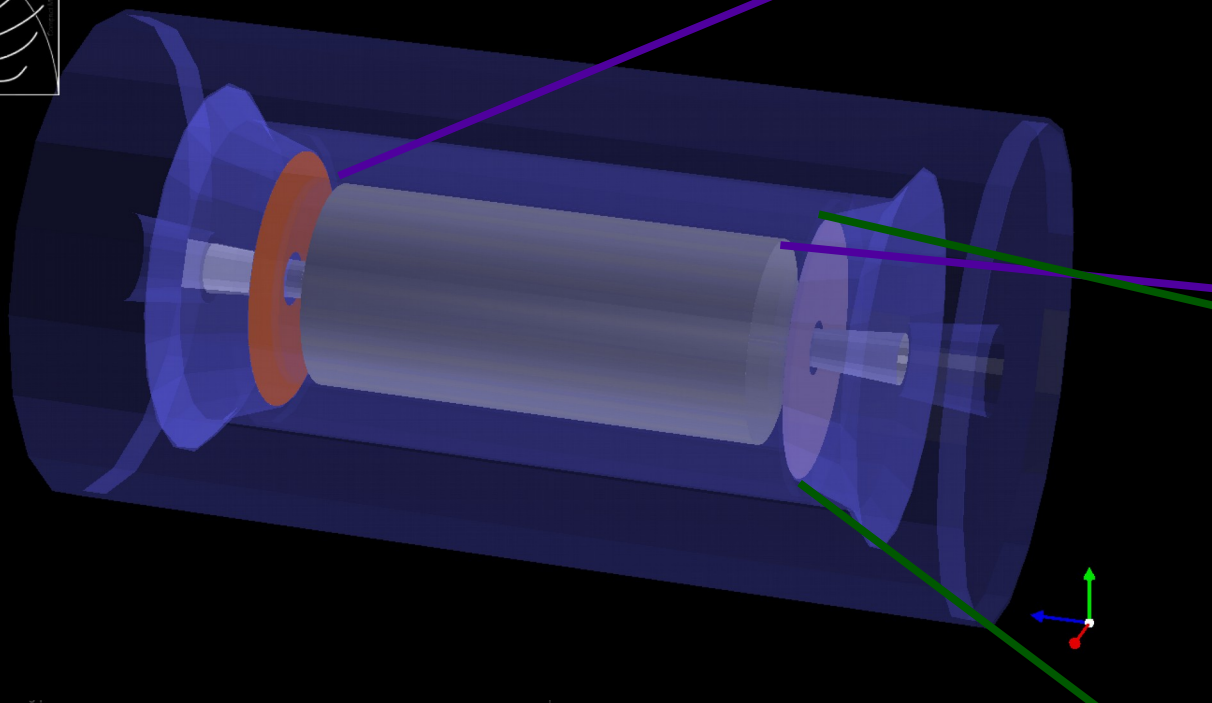


Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.

- New analyses also being done with Run 3 data (Displaced Muons IFCA + Uniovi)

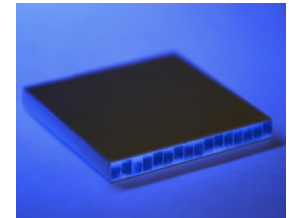
# The MTD: LLPs at the HL-LHC

- Time measurement of charged particles with 30-40 ps at the HL-LHC start and  $< 60$  ps at  $3 \text{ ab}^{-1}$
- Barrel Timing Layer: arrays of LYSO crystal bars + SiPMs at both ends
- Endcap Timing Layer: LGAD sensors



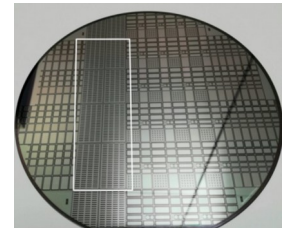
## BTL: LYSO bars + SiPM read-out

- TK/ECAL interface  $\sim 45$  mm thick
- $|\eta| < 1.45$  and  $p_T > 0.7$  GeV
- Active area  $\sim 38 \text{ m}^2$ ; 332k channels
- Fluence at  $3 \text{ ab}^{-1}$ :  $2 \times 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$



## ETL: Si with internal gain (LGAD)

- On the HGC nose  $\sim 65$  mm thick
- $1.6 < |\eta| < 3.0$
- Active area  $\sim 14 \text{ m}^2$ ; 8.5M channels
- Fluence at  $3 \text{ ab}^{-1}$ : up to  $2 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$

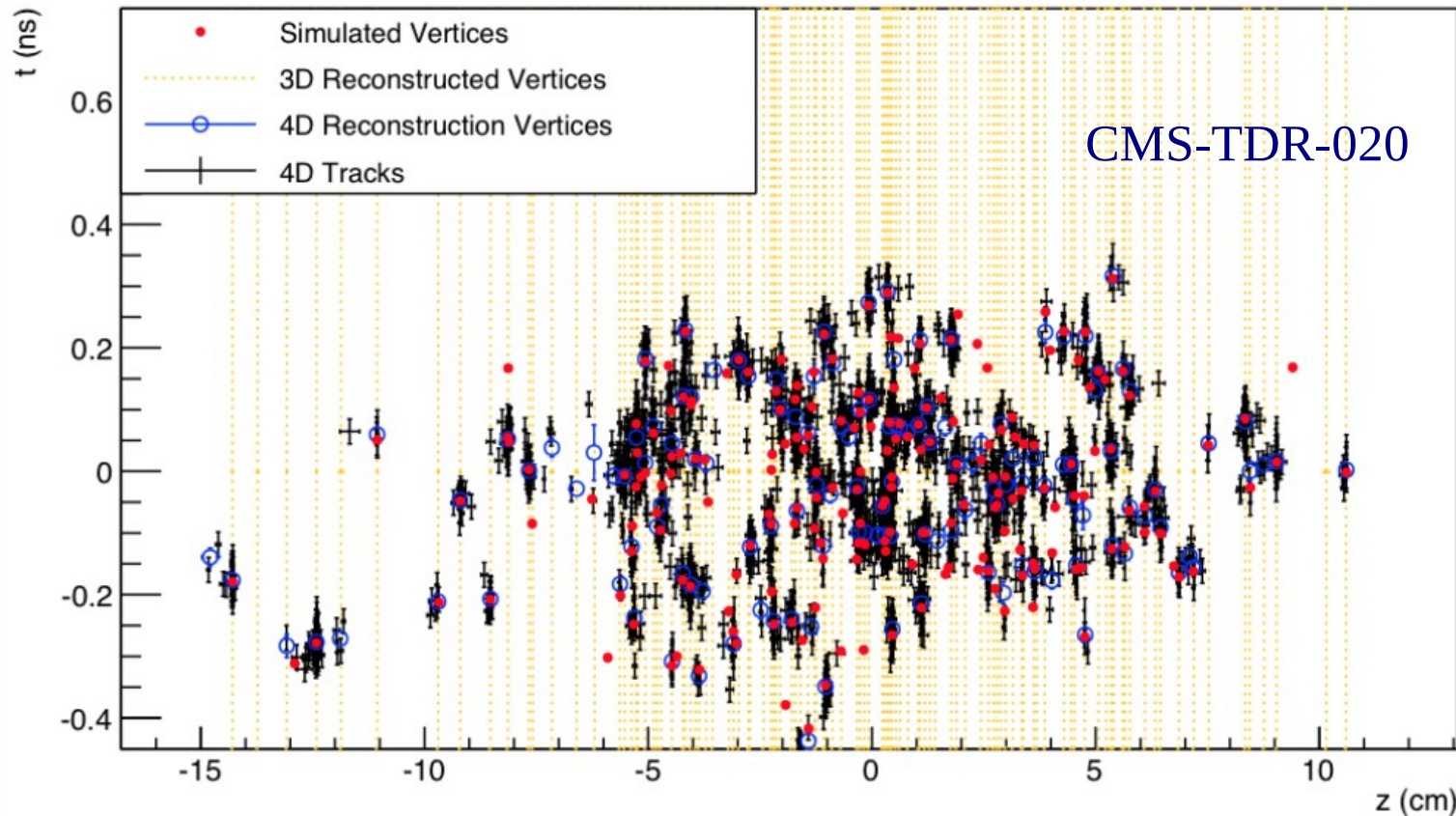


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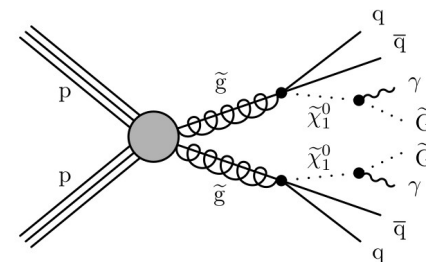
# The MTD: LLPs at the HL-LHC

- The MTD will add a new time dimension on the tracks and therefore also to the vertices
- This will be extremely useful to clean-up the high pile-up at the LHC (PU  $\sim 200$ )
- But it will also bring unique possibilities for LLP physics because we can measure delays!

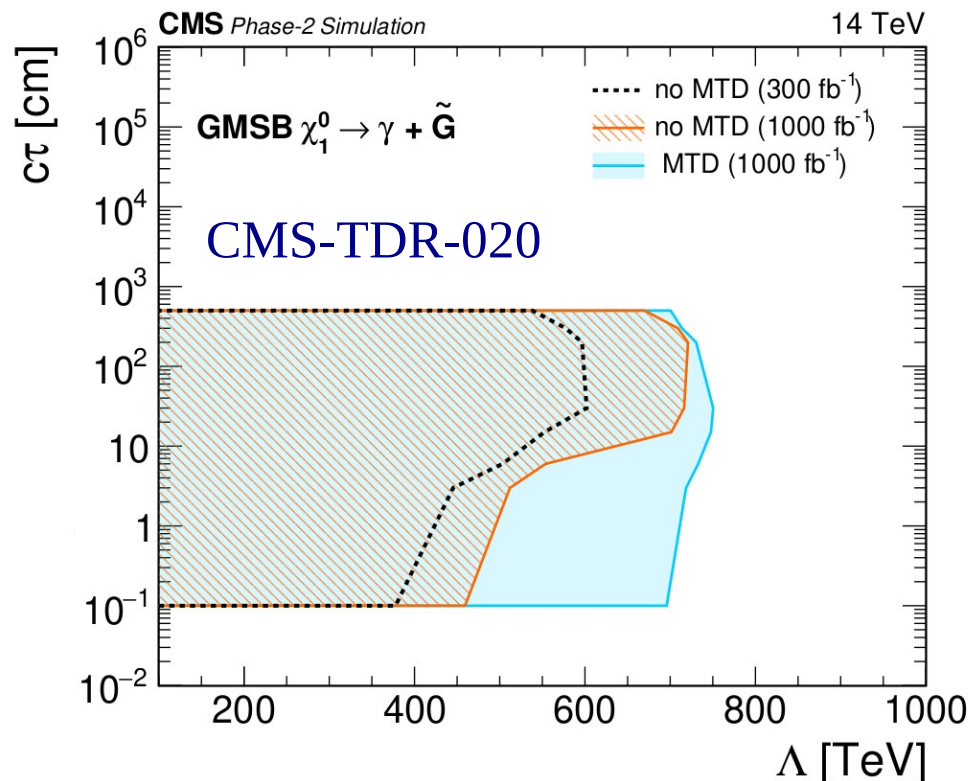
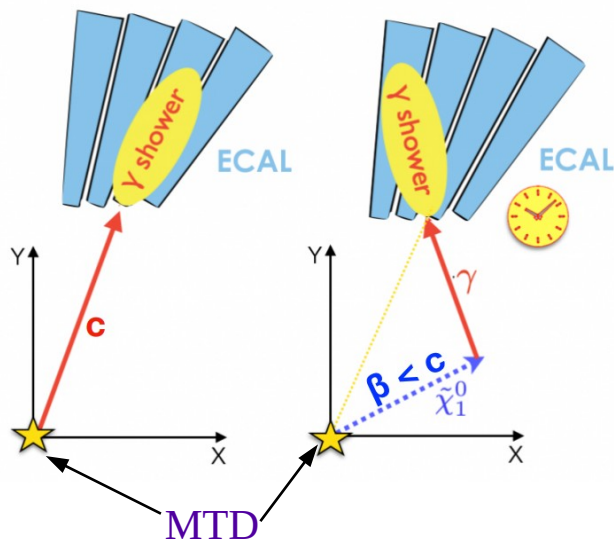


# Delayed photons with the MTD

- SUSY model with gluino production decaying into quarks and a long-lived neutralino
  - Neutralino then decaying into **photon-Gravitino**
- The delay between the photon and the PV is used to discriminate signal
  - Photon time is measured by the ECAL timing
  - The Primary Vertex time is calculated with the MTD

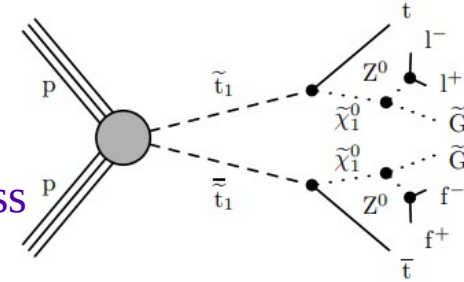


$$\Delta t_{\text{delay}} = \frac{l_X}{\beta_X} + \frac{l_a}{\beta_a} - \frac{l_{\text{SM}}}{\beta_{\text{SM}}}$$

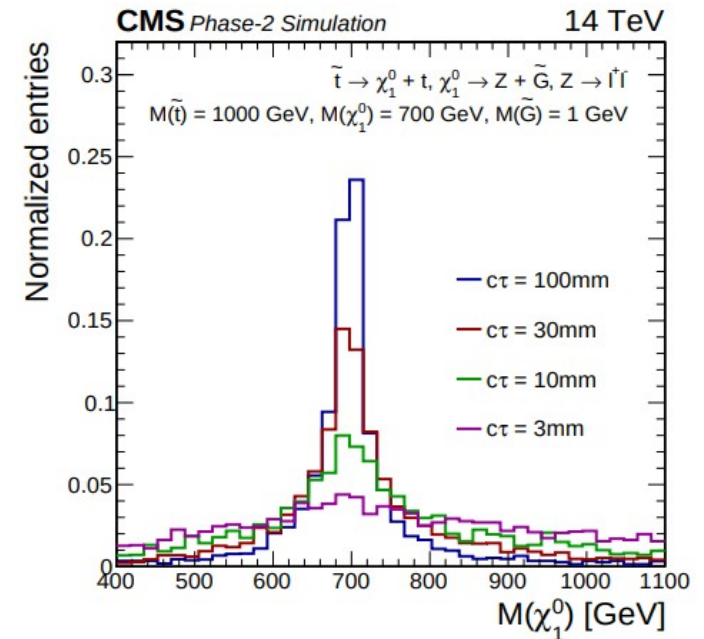
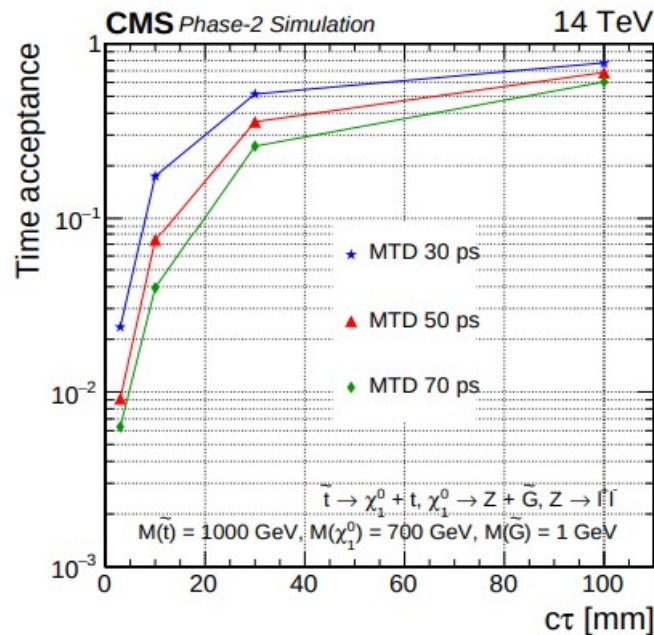
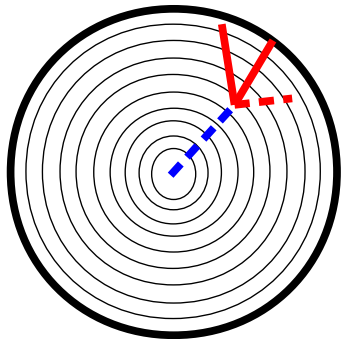


# Delayed leptons: mass reconstruction

- Consider stop pair production in a SUSY model with Gauge Mediated Symmetry Breaking
- Search for long-lived neutralinos decaying into Z (leptons) + Gravitino with  $m(\tilde{G}) \sim 0$
- This signature leads to a pair of displaced leptons
- Time difference between PV and lepton vertex used to discriminate
- The lepton vertex position and the  $\Delta t$  allow to estimate neutralino mass



$$\beta = \frac{\Delta L}{\Delta t}$$

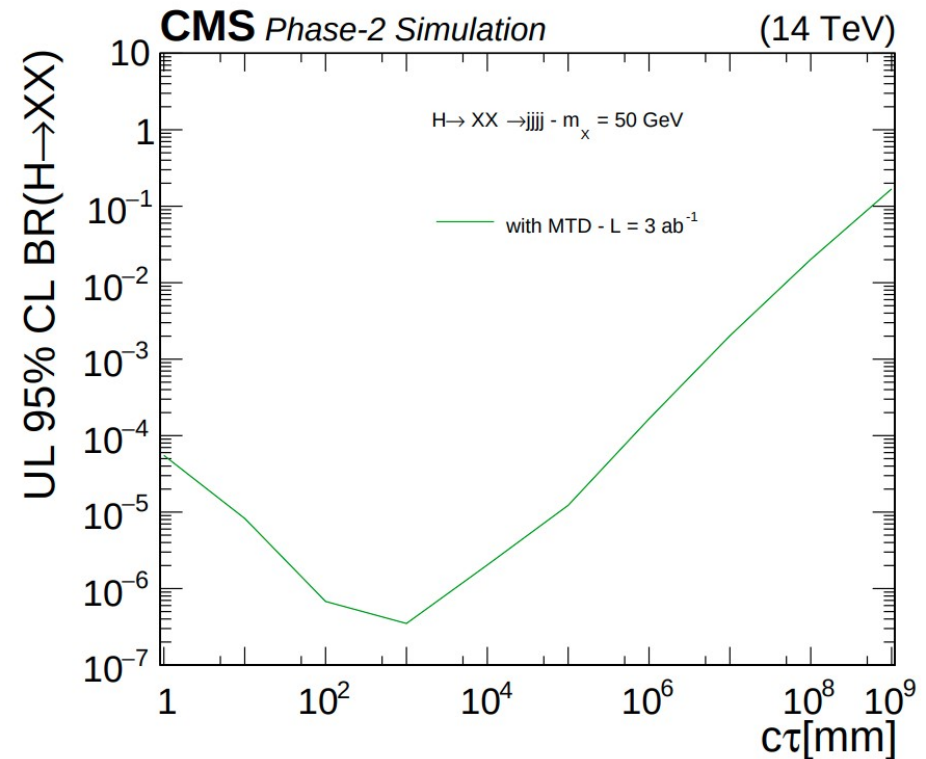
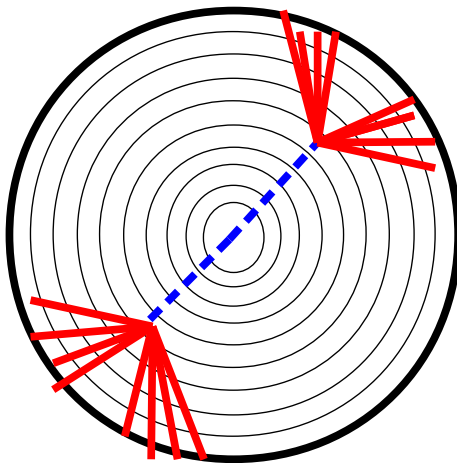
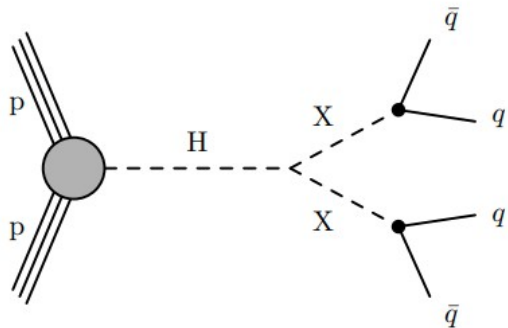


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# Higgs mediator with displaced jets

- Higgs portal model with a Higgs boson decaying into 2 long-lived scalars decaying into jets
- Jet time estimated as a weighted average of charged tracks measured in the MTD
- The time difference between the jet and the PV is used to discriminate signal from background



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- New Physics could show up in the experiments in the form of unusual topologies
- The case of Long-Lived Particles is one of the best theoretically motivated examples
- CMS has an extensive program of LLP searches both in Run2 and incoming for Run3
- In the HL-LHC CMS will bring unique opportunities for LLP searches by using the MTD
- This will open a new dimension for the searches: the delay of the particles
- A few examples have been given showing how the delay can boost the search sensitivity
- More information at the [MTD TDR](#)