Timing for LLP Searches

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Caltech

Introduction

- HL-LHC Phase 2 detector upgrade includes scope for precision timing capabilities in multiple detector sub-systems
  - CMS : Barrel ECAL, Endcap Calorimeter, dedicated MIP Timing Detector (MTD)
  - ATLAS : High-Granularity Timing Detector (HGTD)

- Additional time dimension yields new opportunities to make big gains in sensitivity for LLP searches
- Many challenges as well : trigger, tracking, vertexing, …

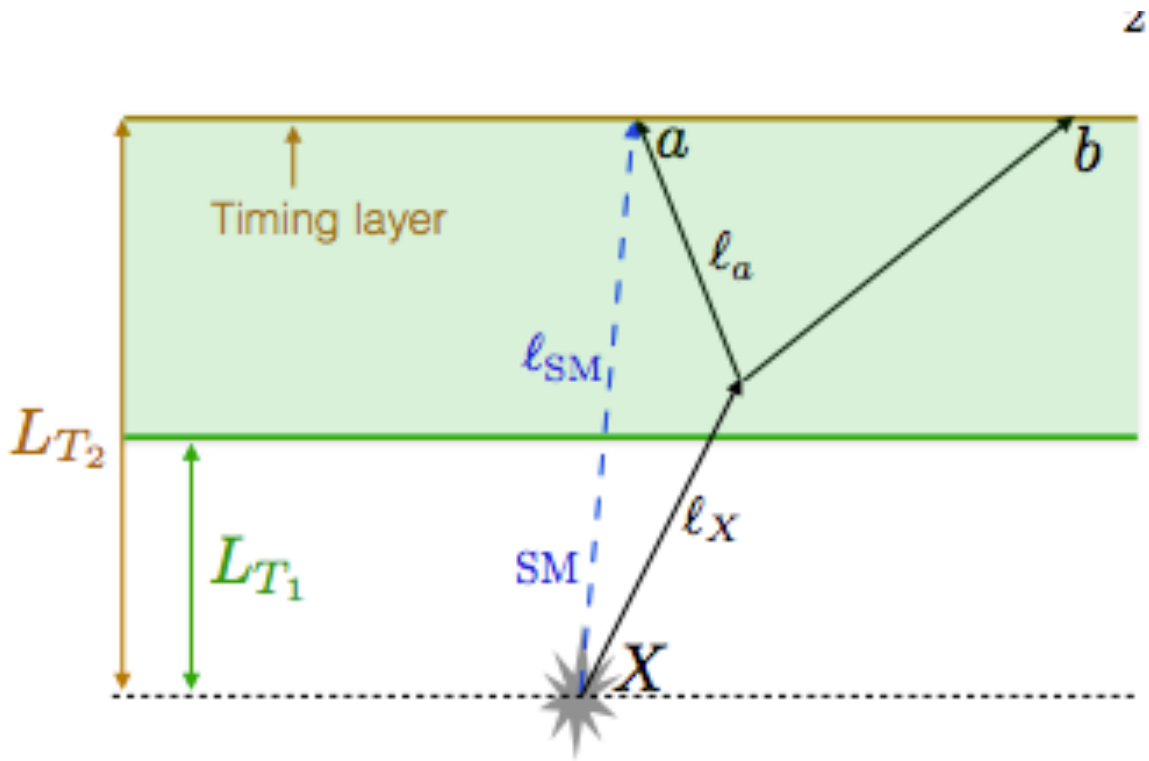
Timing for LLPs

- LLPs will generically give delayed signals
- Delay comes from two effects:
  1. Path length difference (LLP travels in some direction, then decays possibly towards a different direction)
  2. LLP can be significantly slower than speed of light

(1)

$$\Delta t = \frac{\ell_X}{\beta_X} + \frac{\ell_a}{\beta_a} - \frac{\ell_{\rm SM}}{\beta_{\rm SM}}$$

(2)



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Proposed Goals for the Workshop

1. Initiate further interest in using timing for LLP searches & discover new enthusiastic collaborators

2. Produce a more expansive list of LLP models / scenarios that would benefit significantly from time-stamp information
   - **To demonstrate to the LHC experiments that timing (if done right) can have BIG impact on the LLP physics program**
   - **Could include inventing entirely new ways of using timing that have yet been proposed**

B physics / heavy flavors?

3. Make progress on important technical challenges
   - Triggering schemes
   - New reconstruction techniques that use timing

Very Brief Summary of Timing Capabilities

- Dedicated MIP Timing Detector (CMS & ATLAS)
  - Time-stamp charged particle hit (p_T>~1 GeV) in a thin layer located between last tracker layer and the ECAL
  - Target resolution : 30-50 ps (depending on irradiation level)

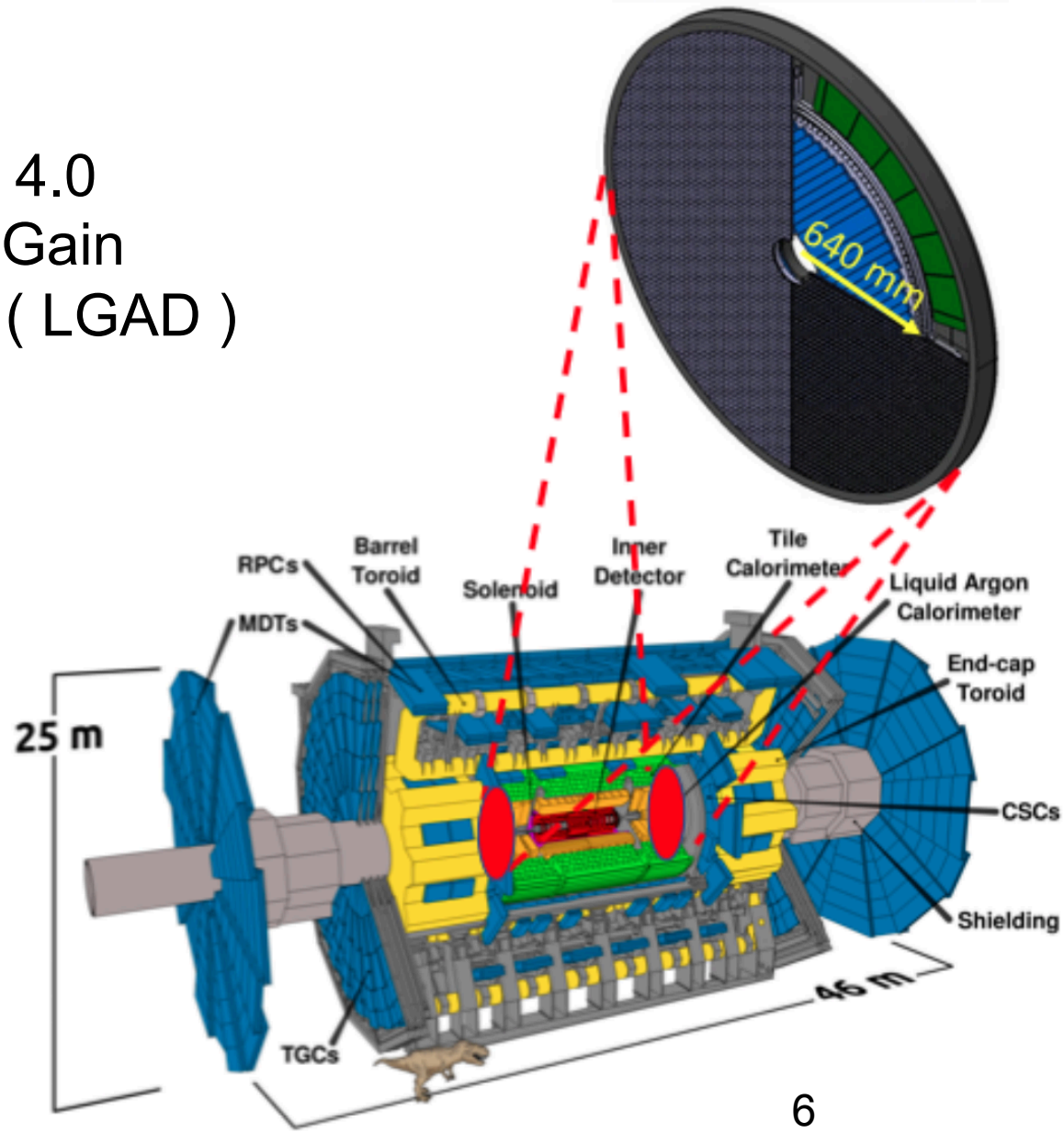
- ECAL
  - CMS: Time-stamp ECAL energy clusters with 30 ps resolution for clusters with energy above 20 GeV

- Endcap Calorimeter
  - CMS: Time-stamp clusters with 30 ps resolution

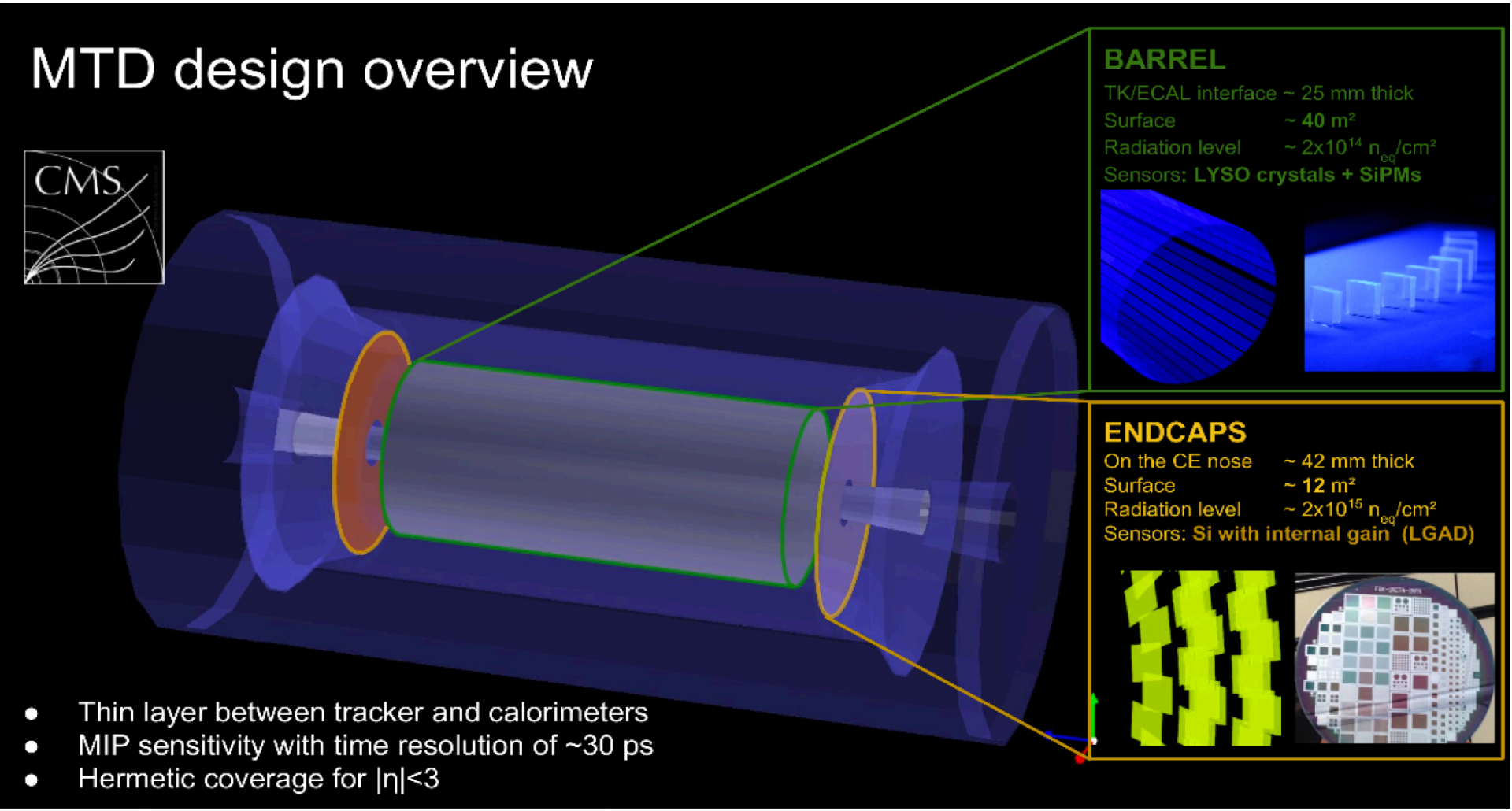
- Muon systems
  - CMS: Time resolution : 1.5-2 ns

ATLAS High-Granularity Timing Detector

- Covers 2.4 < |η| < 4.0
- 2-3 Layers of Low Gain Avalanche Diodes (LGAD)

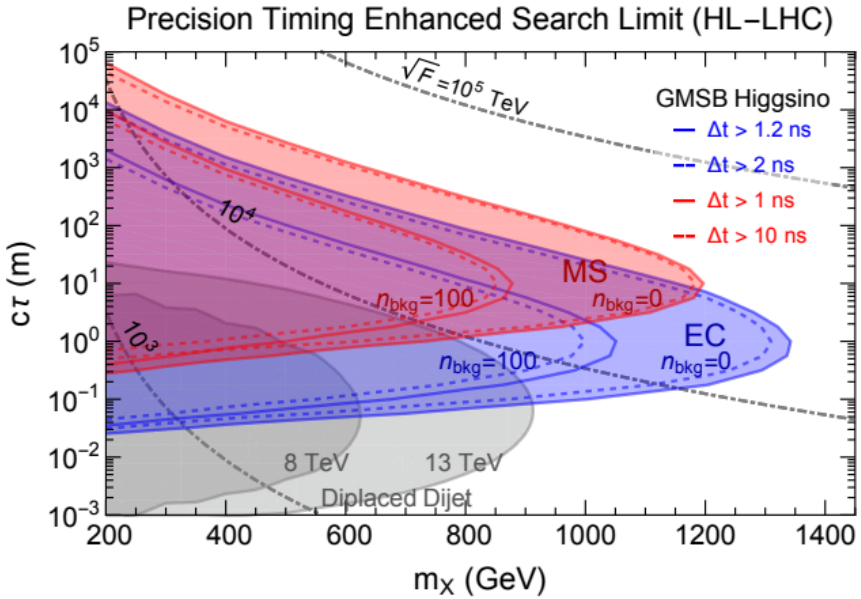


CMS MIP Timing Detector (MTD)



Existing Studies

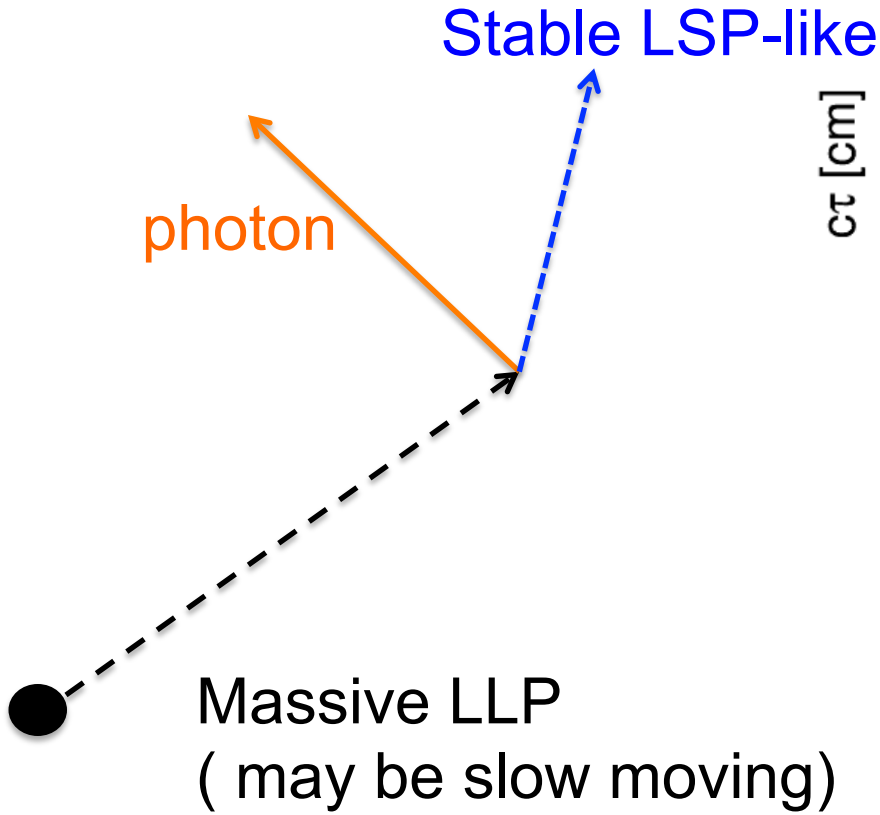
- Comprehensive study by Jia Liu, Zhen Liu, Lian-Tao Wang
  - https://arxiv.org/abs/1805.05957



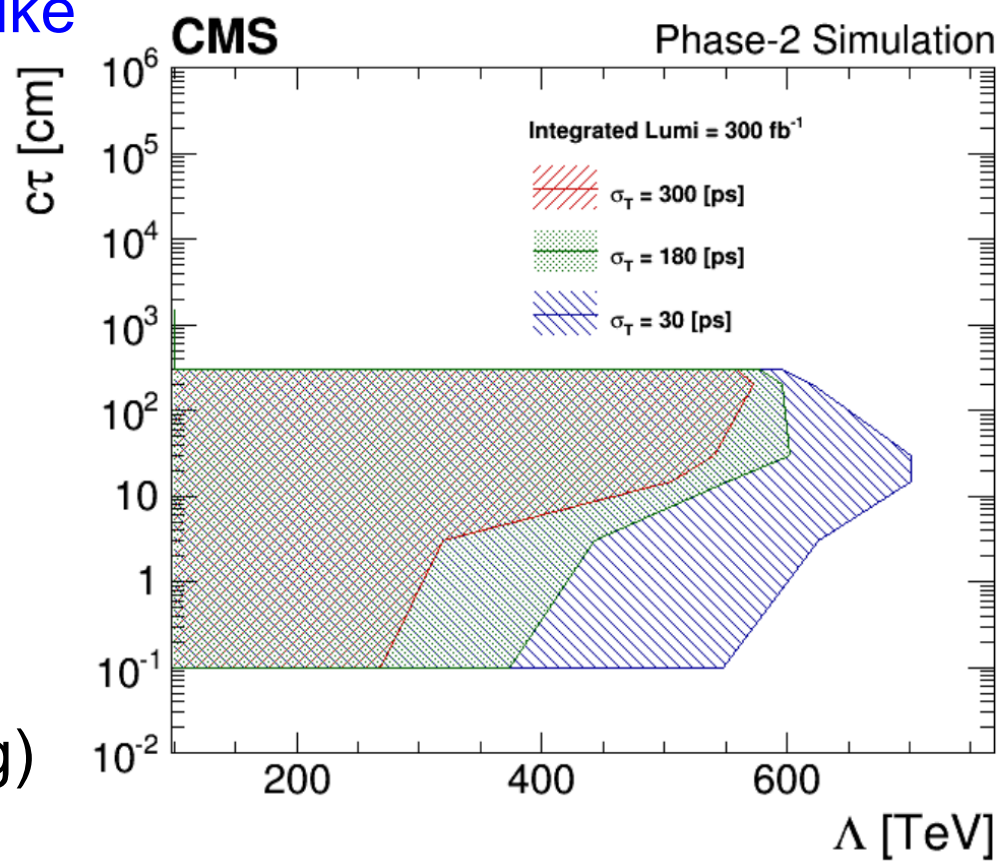
- Gains of 5×10^2 – 10^3 in $c\tau$, and 400 GeV in mass
  - Need only one delayed leg – so we gain acceptance vs double displaced vertex requirement
  - Gain big acceptance factor…**assuming we can trigger on delayed signal**

Delayed Photons

- In GMSB, can get photon final state that is **delayed**
- With timing capability, the delay enhances search sensitivity



CMS MTD Technical Proposal – LHCC-P-009
https://cds.cern.ch/record/2296612/



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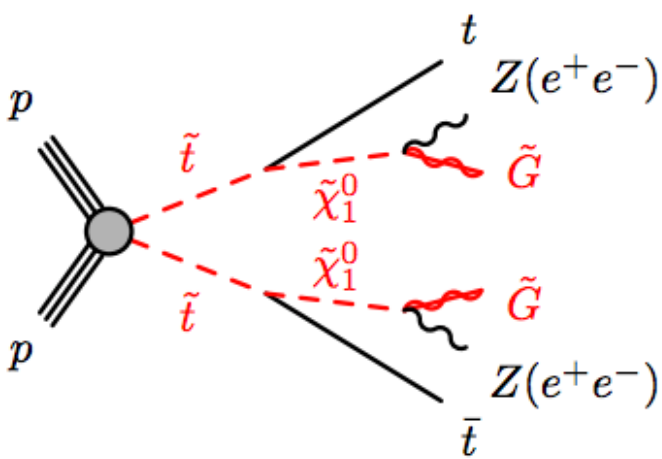
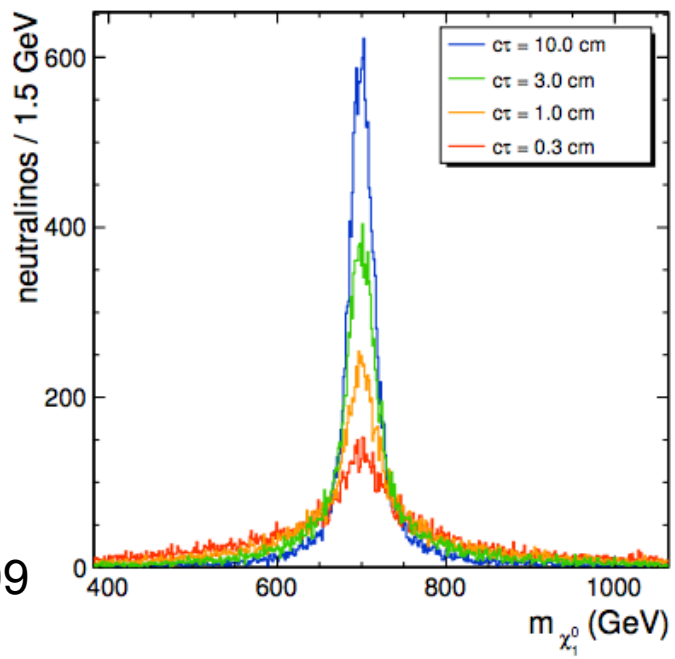
Resonances from Secondary Vertices

- If an LLP decays with a visible secondary vertex, can use time-of-flight between primary vertex and secondary vertex to reconstruct the LLP velocity β, and then its mass resonance





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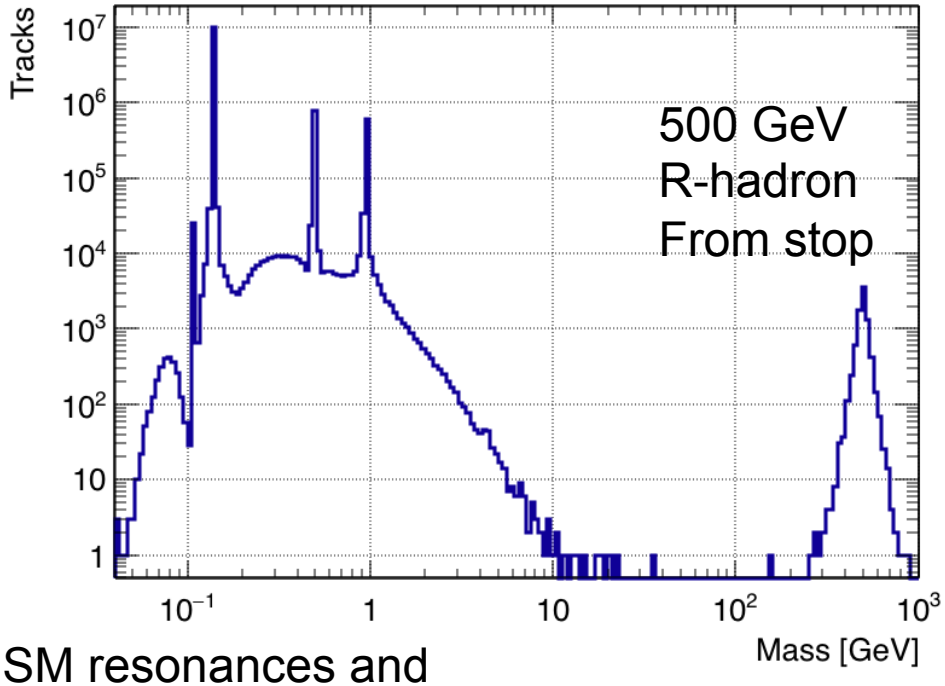
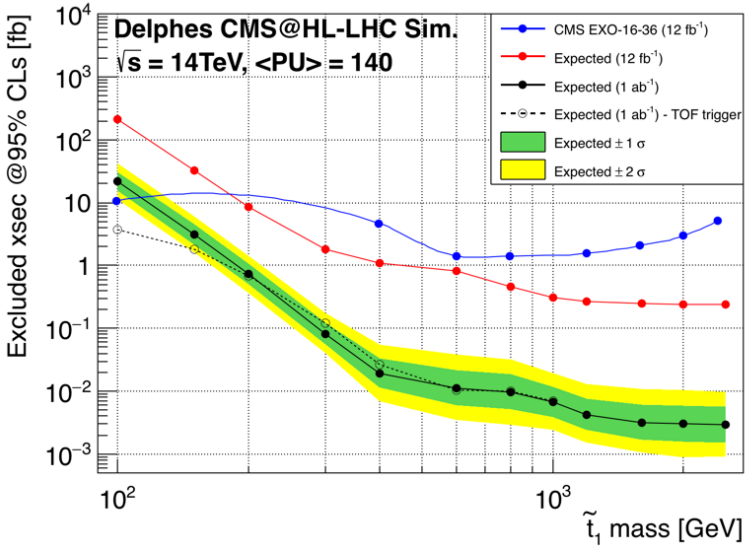
- I believe this works also when the LLP decays into jets (not explicitly worked out though) → applicability to broad model space and scenarios

TOF Particle ID

- Long-lived stop hadronizes into long-lived R-hadrons
- Use time-of-flight between primary vertex and timing layer to compute velocity β, then use track trajectory to reconstruct mass resonance
- Get 5-10 times better sensitivity than CMS HSCP search



SM resonances and backgrounds



Submitted to JHEP
Olmo Cerri, C. Pena, M. Spiropulu, SX

Timing Trigger

- LLP signatures currently rely on generic L1 triggers (eg. HT)
  → a major loss of efficiency for low mass LLPs: ~ $O(10^{-2})$
- If one can trigger on a delayed signature, the efficiency could be improved by **more than an order of magnitude**
- However, timing trigger implies serious hardware challenges as community has not spent enough time working it out
- Some ideas exist:
  - "ROI" - Region of interest
  - Synchronous readout for sufficiently delayed signals
  - ECAL delayed hit trigger
  - Hoping for additional ideas…

- **In this workshop, we hope to quantify more precisely the benefits**
- Can discuss in more details on this topic in the following days

New Ideas?

- We hope you are convinced timing is a very useful new direction in LLP searches
- We hope to generate more new ideas this week!

Backup

HL-LHC Beamspot

- Beamspot has a width in time of ~180ps