CMS delayed jet trigger performance in Run 3

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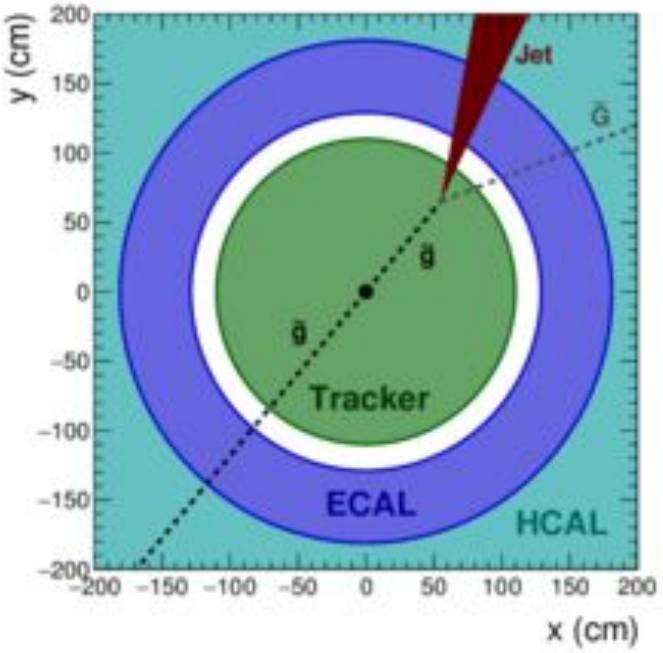
Introduction

- CMS ECAL measures the arrival timing of the objects with a precision of ~200 ps for energy deposits above 50 GeV
- ECAL timing is an extremely powerful handle to search for long lived particles (LLPs)

CMS-PAS-EXO-19-001



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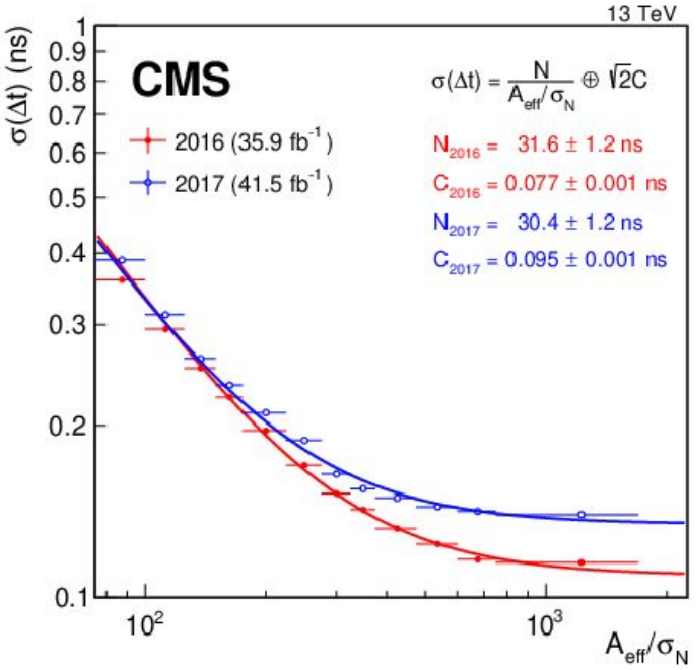

Effective amplitudes of two signals from neighboring crystals

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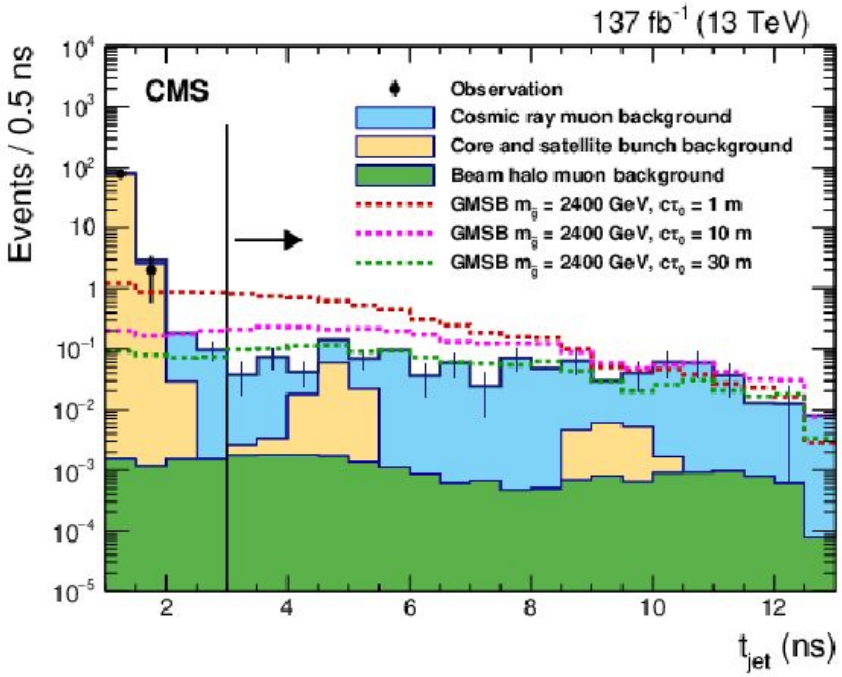
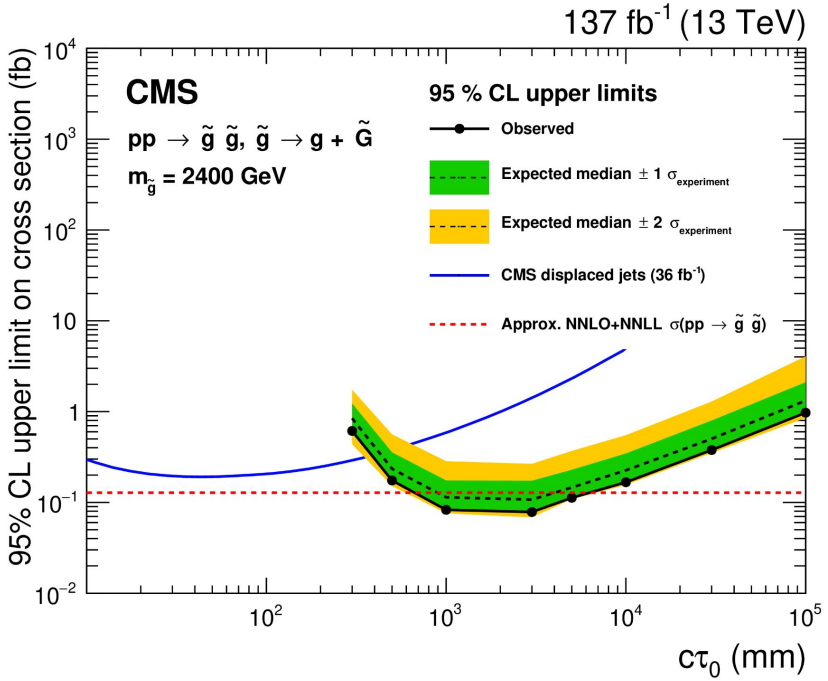
CMS Run 2 delayed jet analysis

- Run 2 delayed jet analysis utilized the arrival time of the jets in ECAL and explored a complementary phase space in LLP searches compared to the displaced-jets analysis
- Delayed-jet searches in Run 2 relied on triggers requiring MET (missing transverse energy of all particles in an event), which limited their sensitivity





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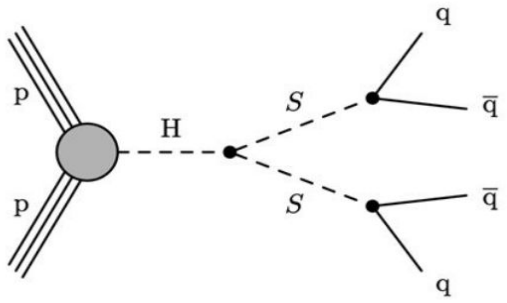
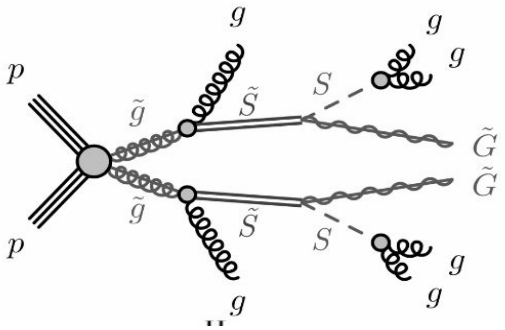
What's new in Run 3?

- Dedicated triggers targeting delayed jet signatures are added for the first time at the High Level Trigger (HLT) level in Run 3
- Delayed jet triggers utilize the ECAL timing information to identify jets produced by the decay of LLPs
- This addition improves sensitivity for a wide range of LLP signal models, in particular for signatures with lower values of H_T (scalar transverse energy sum of all the jets in an event)

Twin higgs signal model



Stealth SUSY signal model



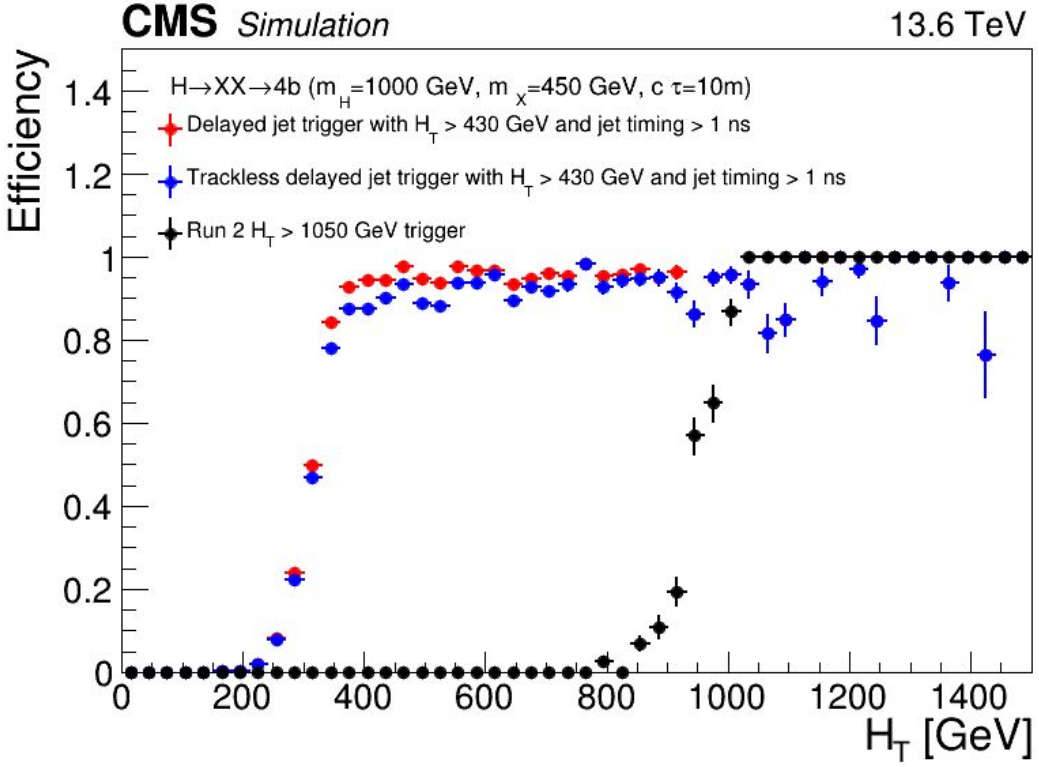
Dedicated delayed jet triggers ⇒ Model-independent and sensitive LLP searches!!

New triggers and rates

- A comprehensive strategy was implemented using high-level triggers based on different requirements
  - At the Level-1 trigger, a lower cut on H_T is placed at 360 GeV, or a L1T tau is required with p_T above 120 GeV.
  - At HLT, requirements are placed on inclusive jets (nominal jets with a track matched to the jet), or on trackless jets (jets which do not have a matched prompt track)
  - At HLT, additional requirements are placed on jet timing
- This flexibility allows for successful operation of the triggers during data taking as the rates can fluctuate with the changes in ECAL crystal transparency
- The delayed jets rate is ~20 Hz at instantaneous luminosity of 2×10^{34} cm^{-2} s^{-1}
- To further increase sensitivity, triggers with lower timing thresholds are added to the parking stream (higher acceptance at the cost of delayed offline reconstruction)

Delayed jet triggers increases signal efficiency

- Trigger efficiency for a signal model H→XX→4b shows significant improvement between 430 < H_T < 1050 GeV compared to Run 2
- Note that the offline H_T calculation includes a correction due to the out of time energy deposits which is not done at the HLT level



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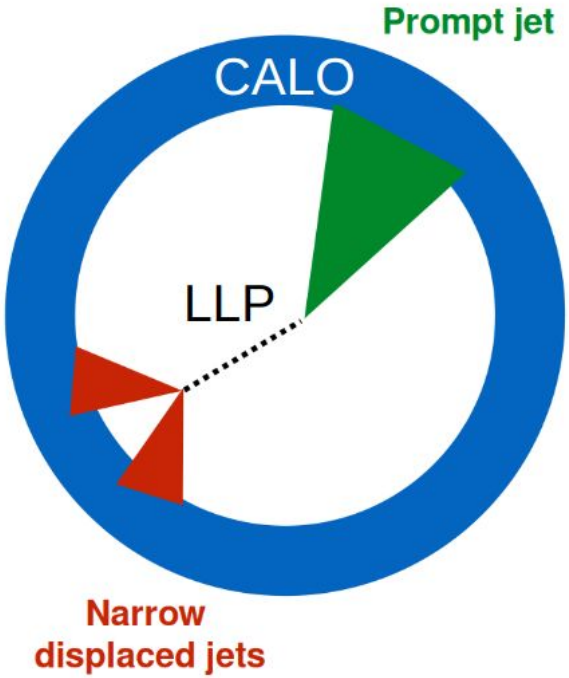
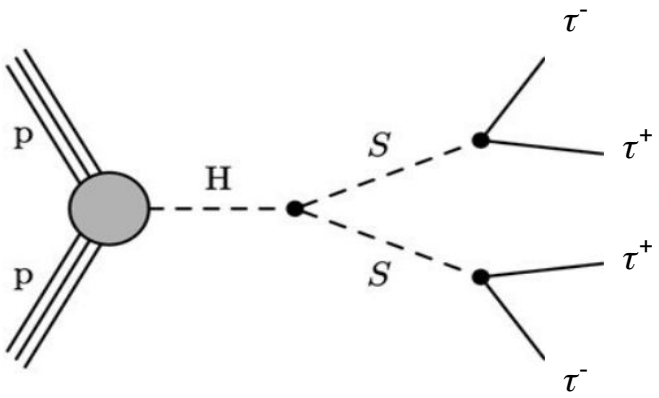
Tau seeded triggers:complementary coverage

- As LLPs become more massive and displaced, the resulting jets become collinear and can look like τ leptons
- Delayed jet triggers requiring a tau at the Level 1 Trigger (L1T) stage and a delayed jet at the HLT level is added to target such signatures
- This strategy allows for higher sensitivity reach in H_T<430 region
- Note that this also allows to search for LLPs decaying into τ leptons



Twin higgs signal model



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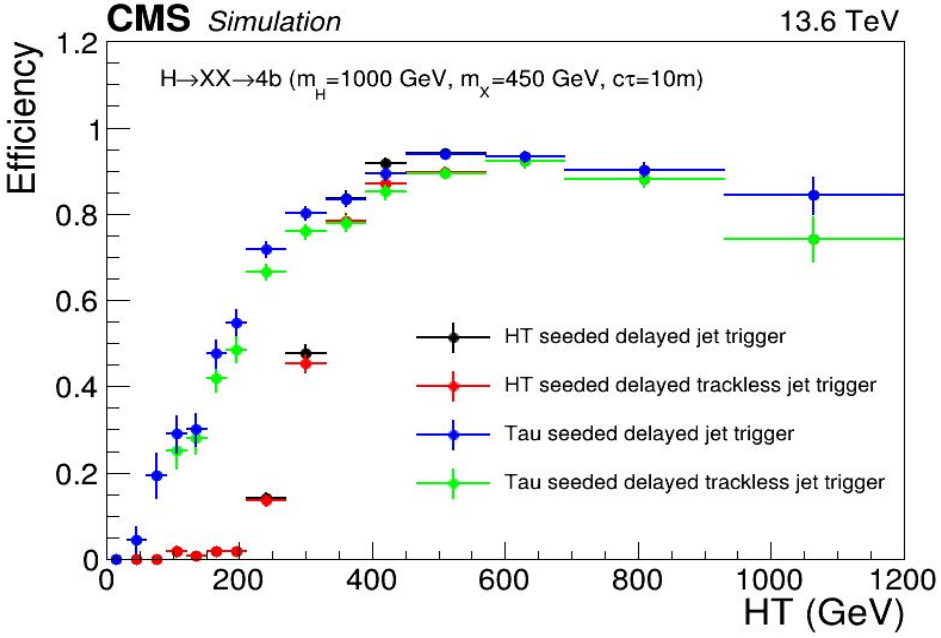
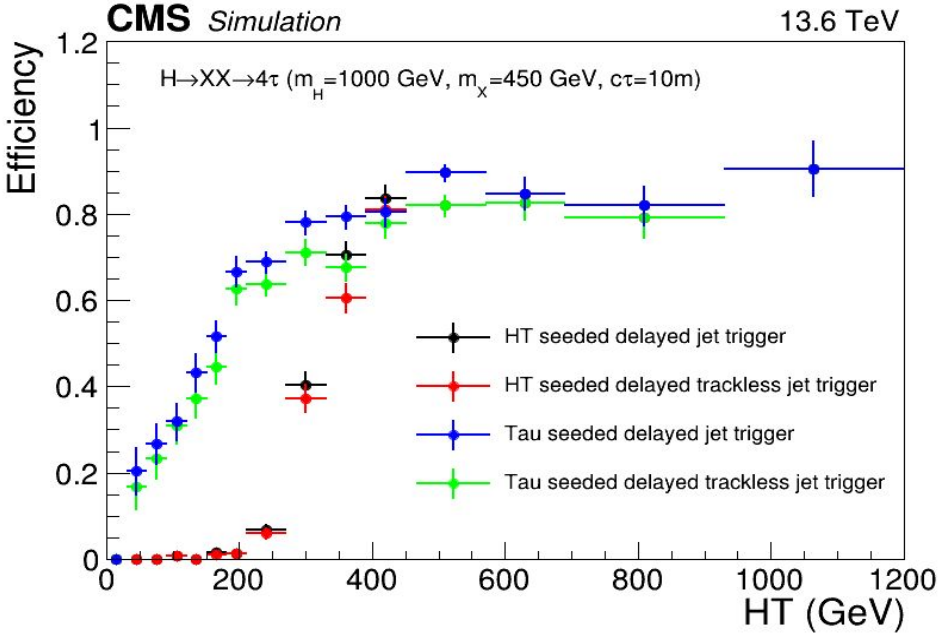
Improved signal efficiency due to tau seeded triggers

- Trigger efficiency for signal models where H→XX→4b on the left and H→XX→4τ on the right with m_H=1000 GeV, m_X=450 GeV and cτ=10m.
- The improvement due to the tau triggers (blue and green curves) can be seen in H_T < 430 GeV region compared to the H_T seeded triggers (black and red curves)
- These plots include events with jets with pT > 40 GeV, number of ECAL cells > 5, barrel region with |η|<1.48 and jet timing > 2 ns





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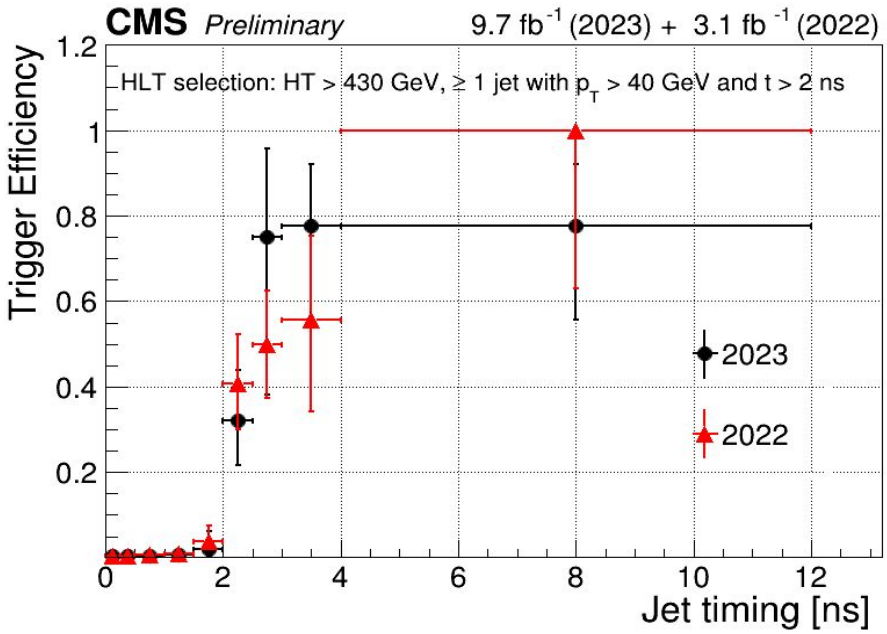
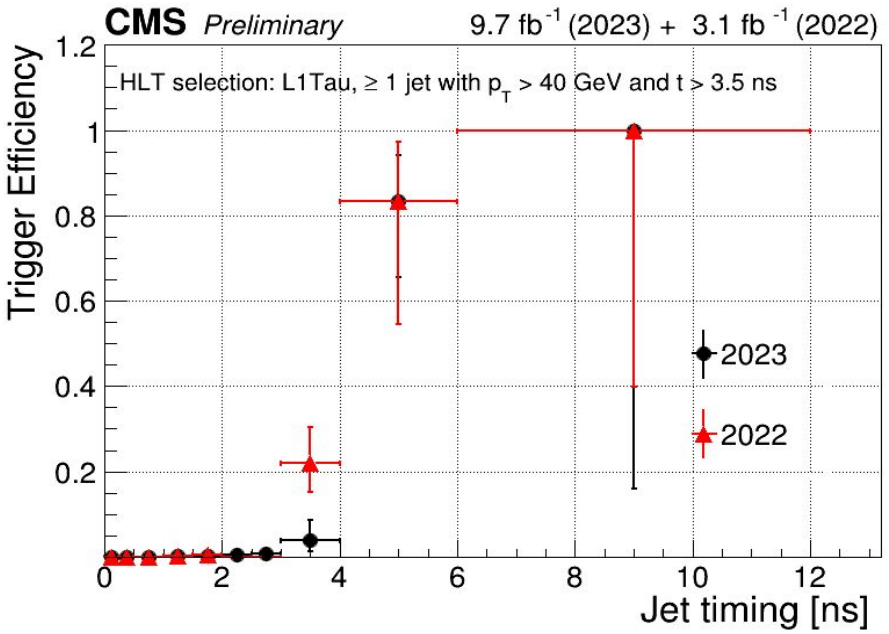
Efficiency of delayed jet triggers in data

- Trigger efficiency as a function of jet timing for 2022 and 2023 data taking periods show a clear turn-on feature around the threshold values. These plots include events which pass MET>200 GeV trigger and have at least one barrel jet with pT> 50 GeV, number of ECAL cells > 8 and ECAL energy > 25 GeV
- Note that H_T is calculated using scalar sum of jets with offline pT>40 GeV and this is different from the H_T calculation used at the HLT level which can cause trigger inefficiencies





Summary and outlook

- Delayed-jet triggers utilising ECAL timing are introduced at HLT in Run 3
- These triggers provide large gains in sensitivity for LLP searches and they are found to perform well in data collected by CMS in 2022 and 2023
- Trigger efficiencies as a function of timing show the efficiency reaching ~100% for delayed jet timing beyond 4 ns
- Further improvements are expected in future with increased statistics and better understanding of offline performance of the ECAL timing
- The tau seeded delayed jet triggers not only provide complementary sensitivity to delayed jet signals in the low H_T regions but also can be used to search for long lived particles decaying into taus
- The delayed jet triggers enable higher sensitivity reach for long lived particles decaying into delayed jets compared to Run 2

Exciting searches ongoing!!