Solutions for a hadronic shower trigger in CMS for Run-3

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For the hadronic shower trigger team

HEP Software Foundation Trigger & Reconstruction Working Group and the LLP Community Meeting

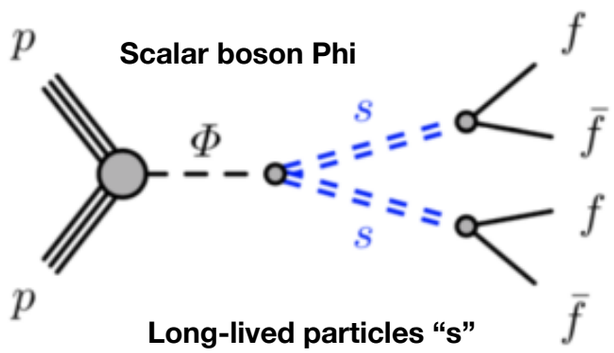
November 18, 2020

Introduction

- Long-lived particles are predicted in many extensions beyond the standard model.
  - ✓ Examples: supersymmetric modules (mini-split SUSY, gauge mediated SUSY, RPV…), Hidden valley models, dark matter models, baryon asymmetry generating models etc.
- Also within the SM searches for massive long-lived particles can offer insight into the nature of the Higgs boson
  - ✓ E.g. H->2X->4f
- LLPs are predicted to have unique signatures in the detector
  - ✓ Displaced particles or jets, missing/stopped tracks, kinked tracks etc.
- Require special triggers and reconstruction methods in CMS
- In this presentation we have a closer look at how we can deploy a new muon trigger for CMS to trigger on displaced jets

LLP to displaced jet

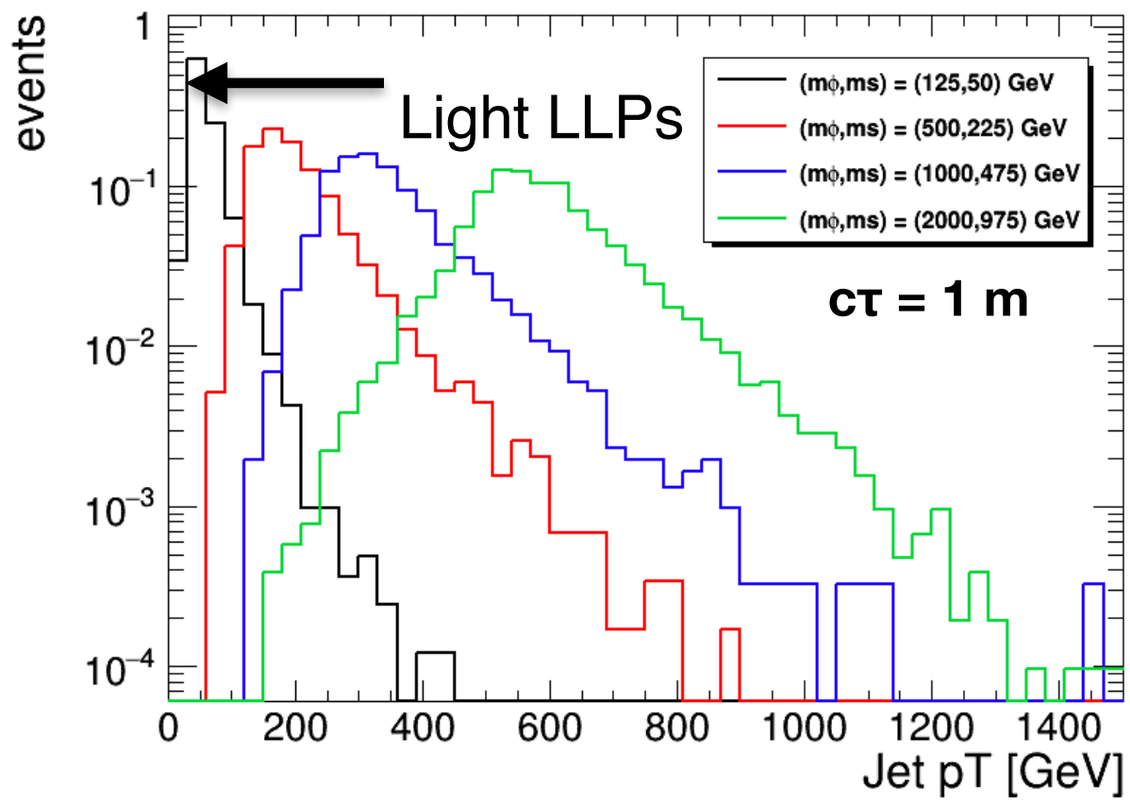
- Heavy (scalar) particle decays to two long-lived particles “s”, each of which decays to 2 quarks (multi-jet final state)

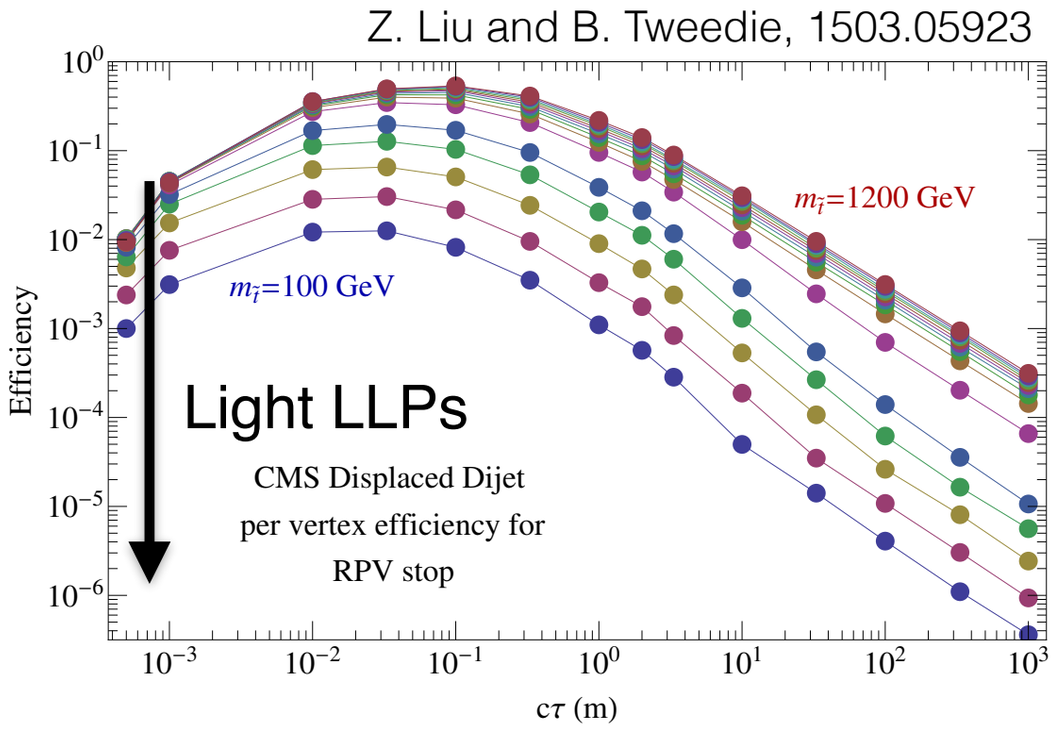


- If “s” is sufficiently short-lived, reconstruct a displaced jet in calorimeter

- Typical displaced jet trigger in calorimeter rely on jet pT and/or HT (sum of all visible energy)
  - ✓ E.g. Jet pT > 170 GeV, HT > 280 GeV
  - ✓ Sensitive to very heavy LLPs (hundreds of GeV)
  - ✓ Very soft (displaced) jets: well **below current thresholds**

- **Critical need** for dedicated triggers in CMS
  - ✓ Low LLP mass
  - ✓ Large LLP displacement

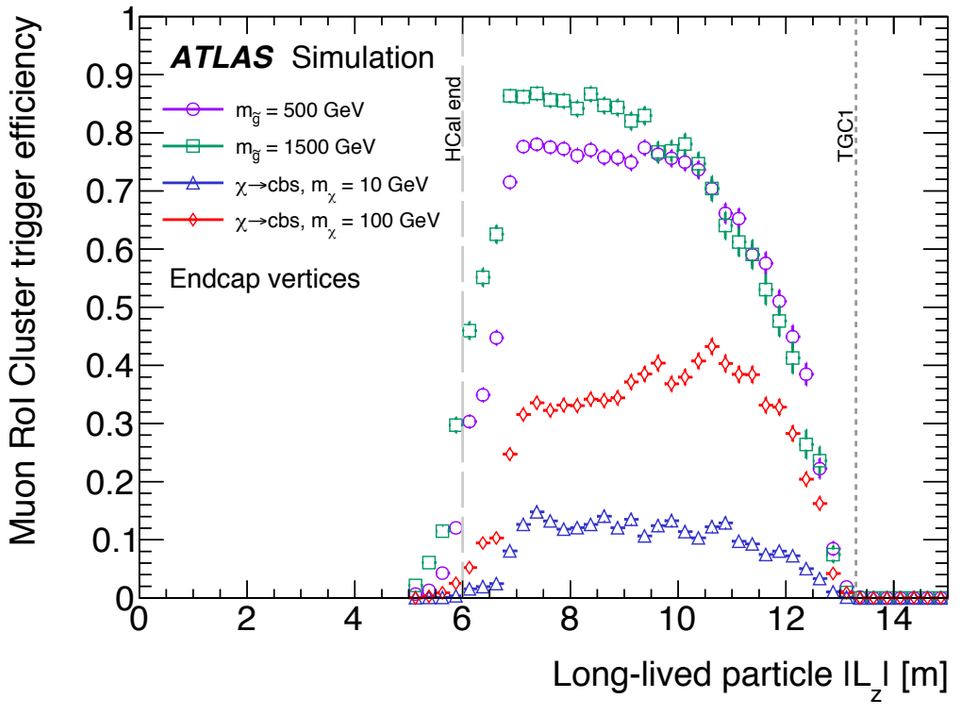


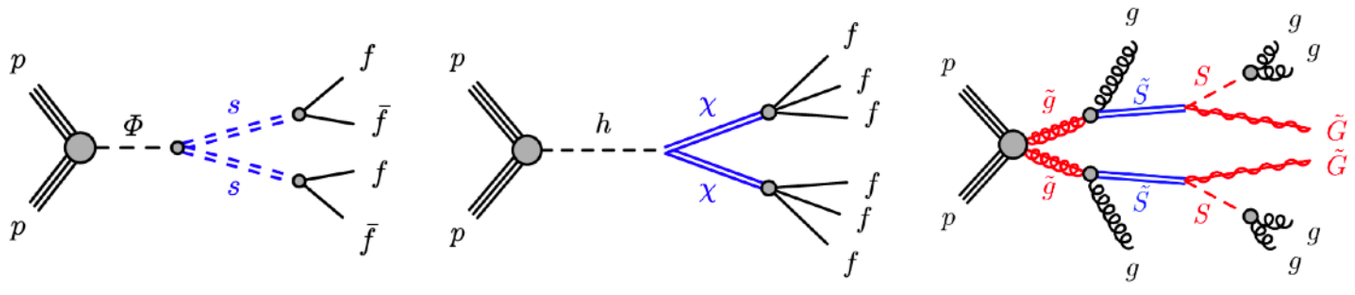


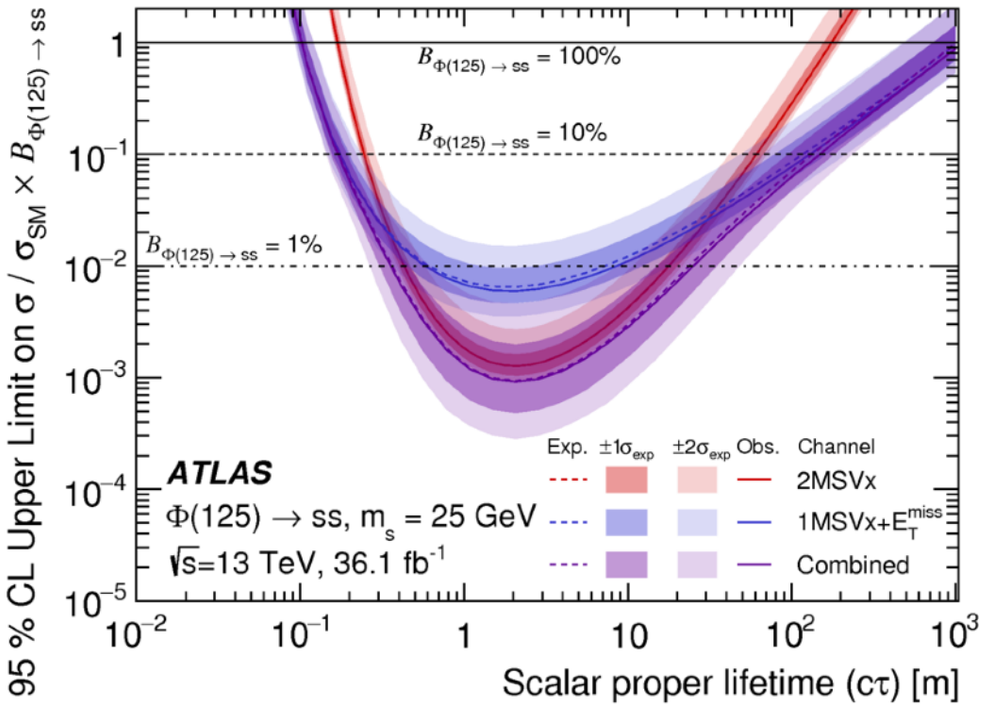
LLP to displaced jet in ATLAS

https://arxiv.org/pdf/1811.07370.pdf

- For LLPs decaying outside calorimeter, ATLAS developed an trigger based on a ROI of clustered hits in the muon system
- Two approaches:
  - ✓ 2 muon vertices
  - ✓ 1 muon vertex + missing energy
- Sensitive to large lifetime and light LLPs (H→ss)
  - ✓ LLP mass between 10 and 500 GeV
  - ✓ Higher mass LLPs easier to detect with ROI trigger
- Interpretation for different models

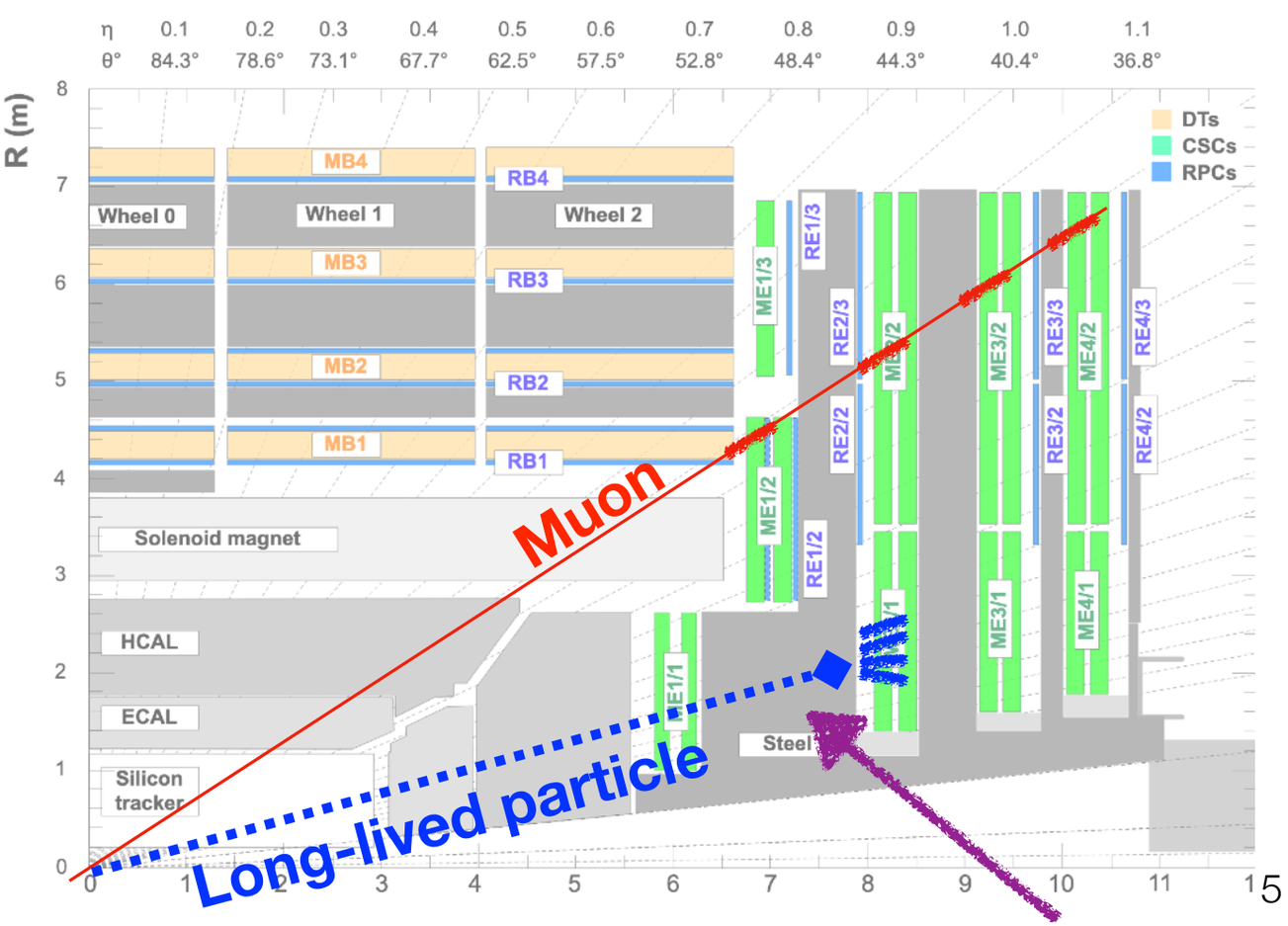


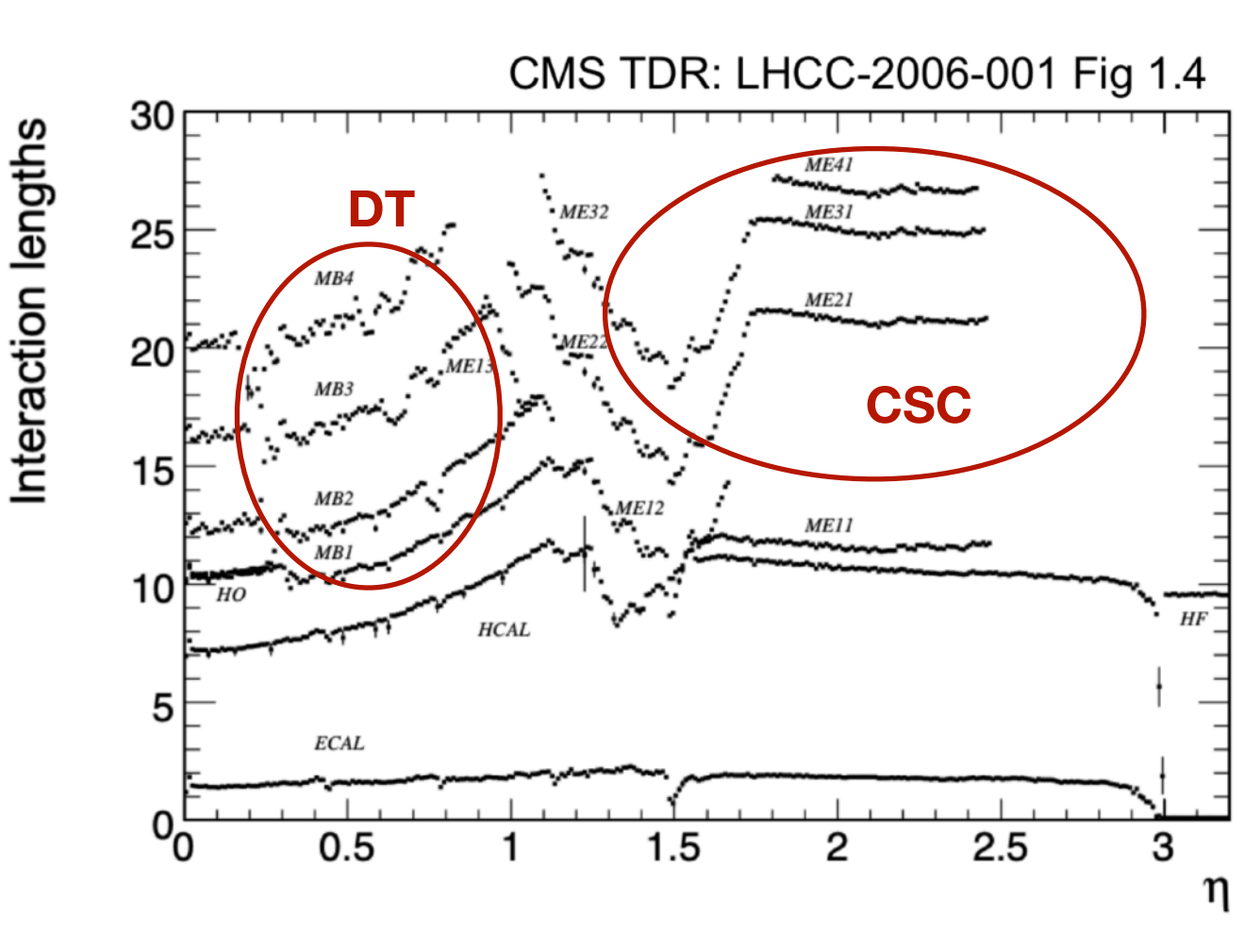




LLP to displaced jet in CMS muon system

- Opportunity to provide better sensitivity for 1-displaced vertex search.
- CMS has **more iron to reject background**
  - ✓ Several meter of iron (12-27 nuclear interaction lengths)
- Furthermore, pion-to-muon mis-ID rate ~0.001
  - ✓ Potential for high purity triggers
- 3 to 4 layers of sensitive elements to detect muon clusters
  - ✓ Sensitivity to large range of displacements (LLP decays 6-10 m from IP)

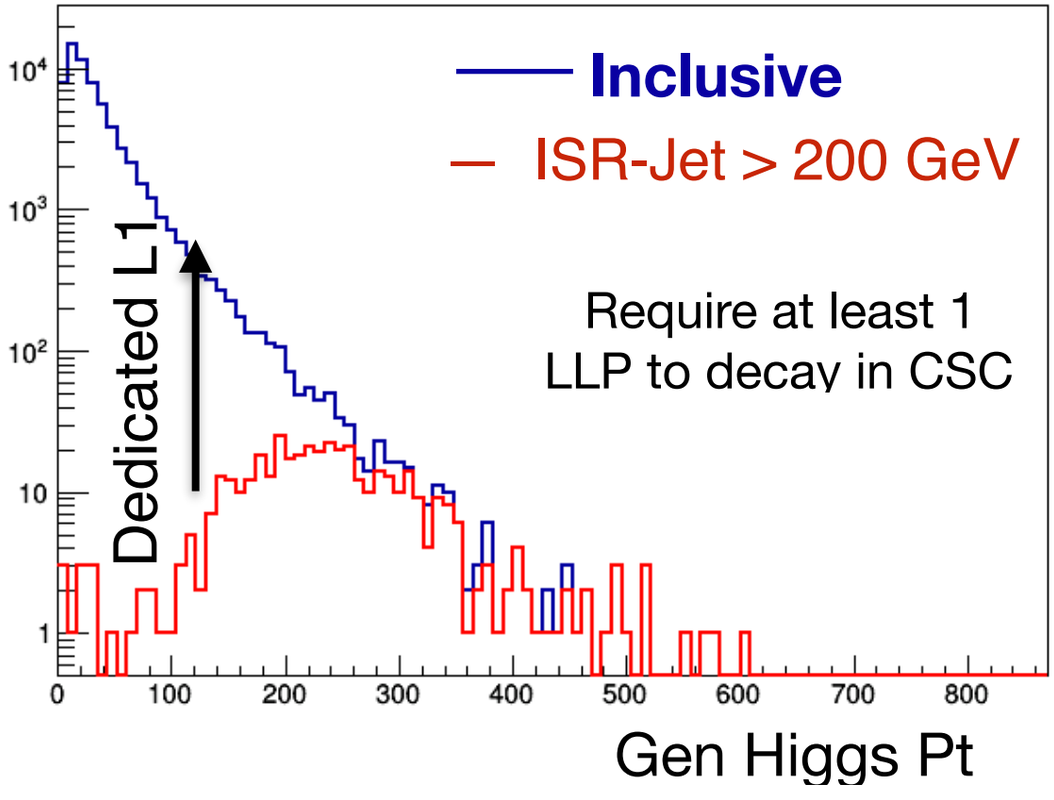


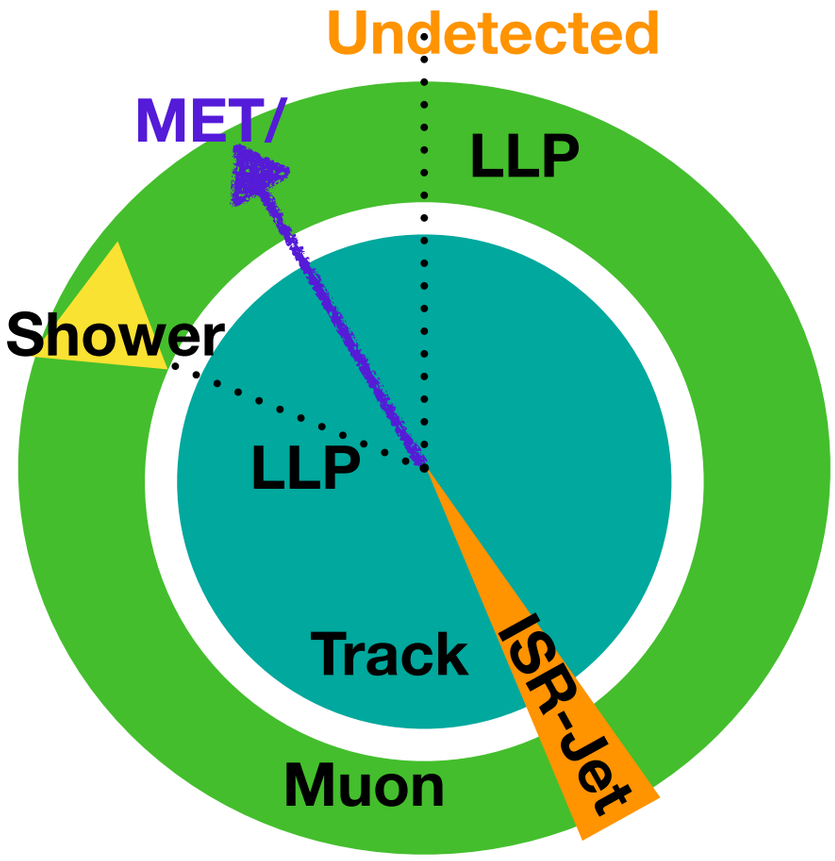


LLP to displaced jet in CMS muon system

- State of current studies in CMS?
  - ✓ Search can be done for ggH->2s->4b on Run-2 data
- No dedicated trigger
  - ✓ Rely on missing energy from recoil of Higgs against initial state radiation jet…
  - ✓ Recently public CMS displaced jets search relied on ISR for H->XX sensitivity (http://cds.cern.ch/record/2717071)

✓ **…with ~1% trigger acceptance**





- **Clearly, a dedicated L1-trigger seed would have a great impact on these studies**

A L1 trigger for hadronic showers

- Need to dig deep into the hardware & firmware design of the current trigger to understand the possibilities and limitations

  ✓ Both CMS DTs and CSCs send max 2 track segments per BX per chamber

- CMS muon barrel (drift tubes):

  ✓ Sorting of track segments in DT mini crates is performed in tree of ASICs.

  ✓ No flexibility to add/modify bits in the data stream

- CMS muon endcap (cathode strip chambers):

  ✓ Construction and sorting of track segments done with FPGAs

  ✓ CSC trigger being upgraded during long shutdown 2 with new hardware and firmware

  ✓ (Some) usable bandwidth to identify high-multiplicity events

Hadronic shower trigger with CSCs

- Initially two main upgrade projects geared towards displaced muons (Phase-2 Muon):

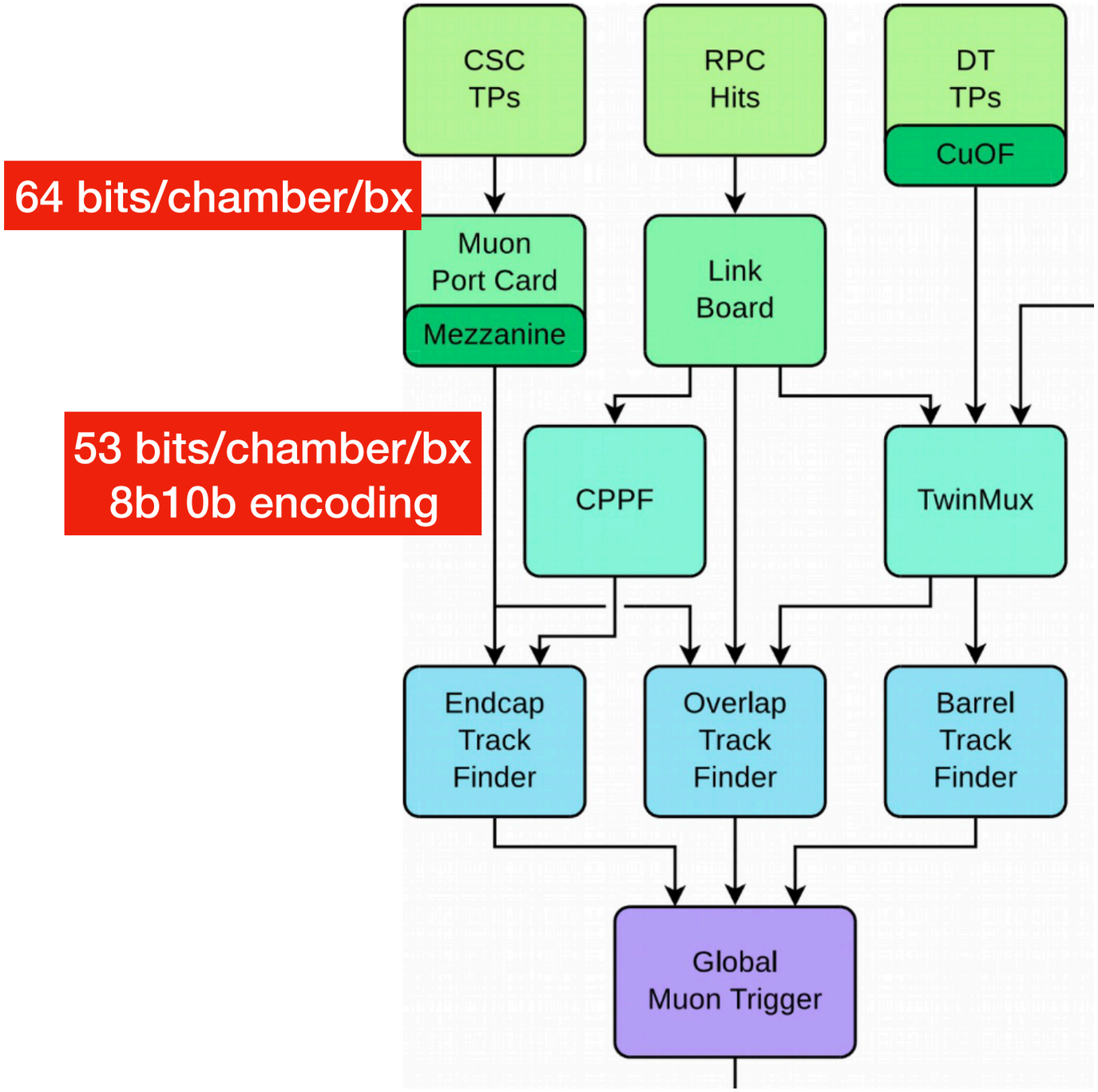
  ✓ Improving the per-chamber position and bending resolution

  ✓ Including GEM hits (GE1/1, GE2/1, ME0) in the muon trigger

- Late 2019 we started looking into hadronic shower trigger options in the endcap

- **Consideration 1**: Muon Port Card multiplexes 64 bits from **9 chambers** onto 8 fiber links (effectively sending 53 bits/chamber/bx) means just 1 bit per chamber per BX available

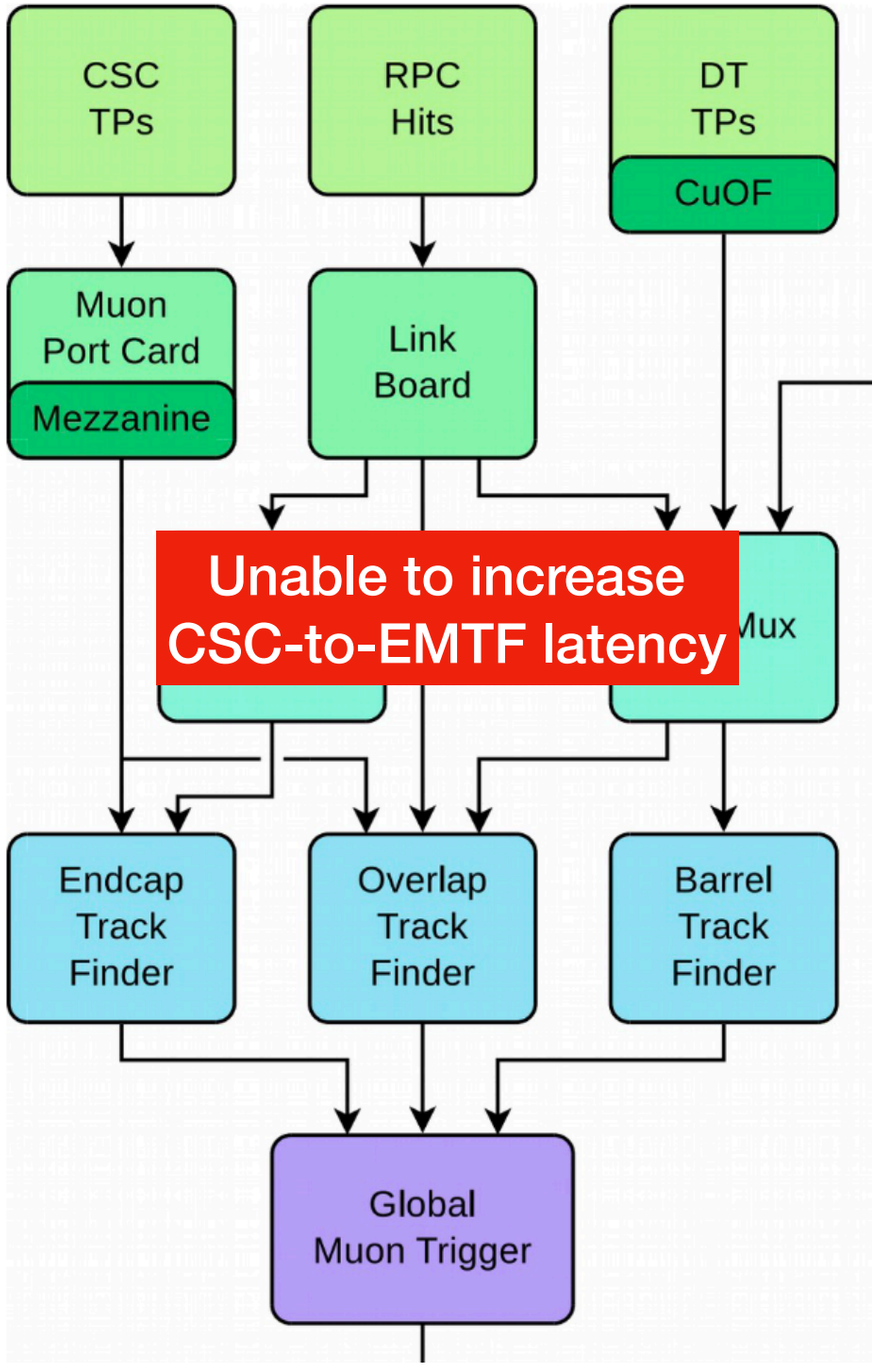
  ✓ This is after considering data needed for displaced muons



Hadronic shower trigger with CSCs

Limited processing capabilities in CSC FGPAs on non-upgraded chambers

- **Consideration 2:** Latency requirement from CSC to EMTF is particularly tight
  - ✓ No room to increase latency of the CSC trigger data to EMTF in Run-3
  - ✓ Shower processing should be
- **Consideration 3:** FPGAs on trigger motherboards for most chambers are ~10 years old
  - ✓ Unable to fit complicated shower logic based on neural networks
    - ◉ >95% full already
  - ✓ Chambers in forward region ME1/1, ME2/1, ME3/1 and ME4/1 will run trigger on Virtex-7 FPGAs
    - ◉ More options here… although ultimately we prefer uniformity in the firmware



Hadronic shower trigger with CSCs

- Considering the limitations we focus on **counting hits in each chamber per BX** and sending the trigger decision via the MPC to EMTF

  ✓ With 8b10b encoding just 1 bit

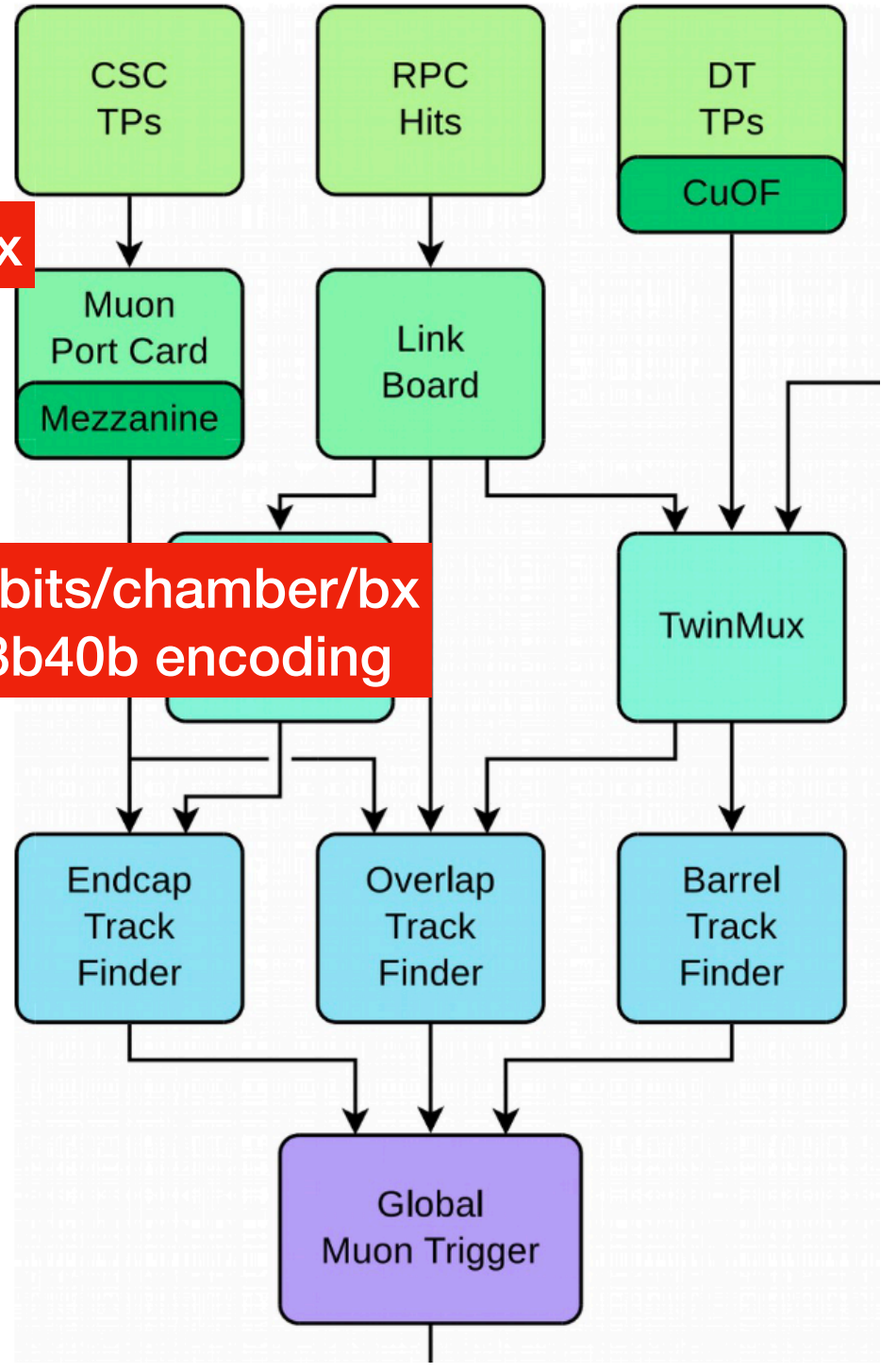
- Breakthrough after the EMTF design engineer started looking into alternative MPC-to-EMTF encoding schemes

- A **38b40b** (similar to 64b66b) encoding scheme was implemented for MPC-to-EMTF

  ✓ Tests during global runs have show that data is correctly transmitted to EMTF

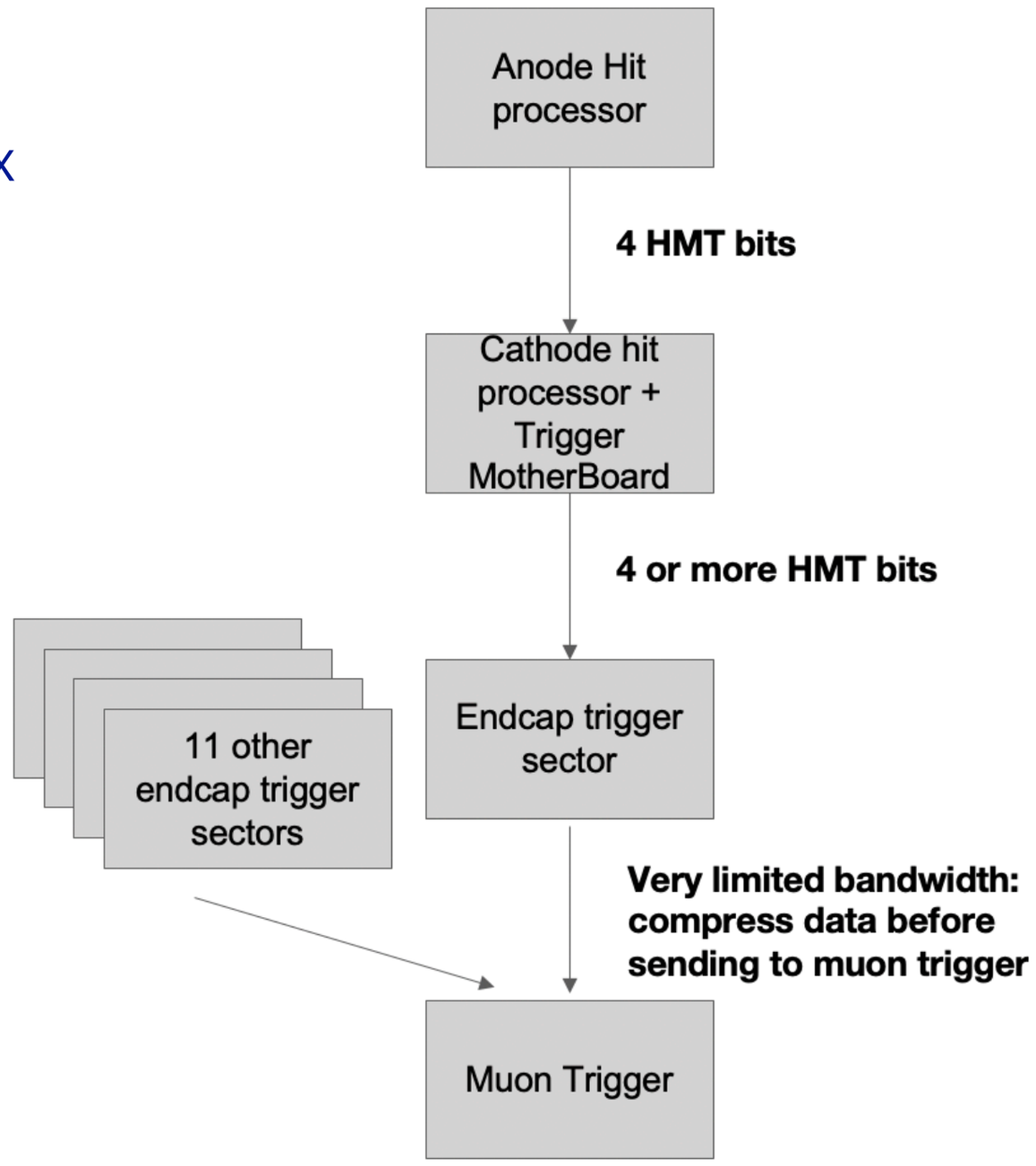
- 11 bits now become available. We reworked all CSC trigger data formats (several iterations over 6 months)

- Ended up reserving **4 bits per chamber per BX** for high-multiplicity events (such as hadronic showers)



Hadronic shower trigger with CSCs

- Simple baseline design of the trigger:
  - ✓ Count hits in each chamber
    - ◉ Thresholds determined per chamber
  - ✓ 4 high-multiplicity trigger (HMT) bits per chamber per BX
    - ◉ Option to send more bits
  - ✓ Indicate size of shower to EMTF using 2 bits:
    - ◉ No shower / loose / nominal / tight
  - ✓ Determination of the depth of the shower is done in the EMTF sector processors
    - ◉ Data format still being designed (first version ready)
    - ◉ More flexibility, than having the logic in the global muon trigger
- Data acquisition is now being reviewed for CSC local trigger, EMTF and global muon trigger
  - ✓ E.g. CSC local trigger: considering a new rule to buffer the DAQ data



Summary and outlook

- We are designing a new trigger for the CMS muon system that targets long-lived particles to hadronic shower decays
- We have adopted an approach based on counting hits in the CSC, considering several limitations in the current CMS muon trigger
- The approach is made possible by a redesign of the CSC MPC-to-EMTF trigger data, allowing for more bits to be sent per chamber per BX
- Current simulations show x10-x20 improvement in sensitivity.
- We are moving forward with implementing the trigger in simulation and firmware