Muon shower L1 trigger: Expanding CMS's long-lived particle lifetime coverage

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Searching for long-lived particles at the LHC:
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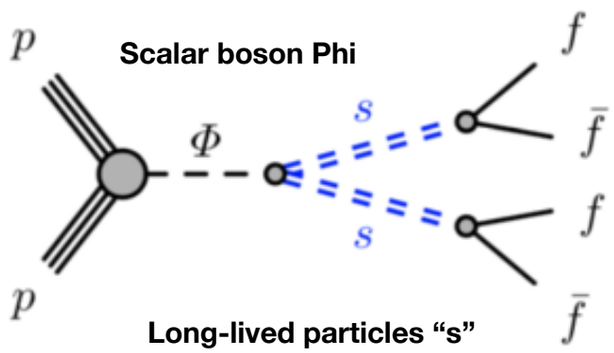
Introduction

- 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

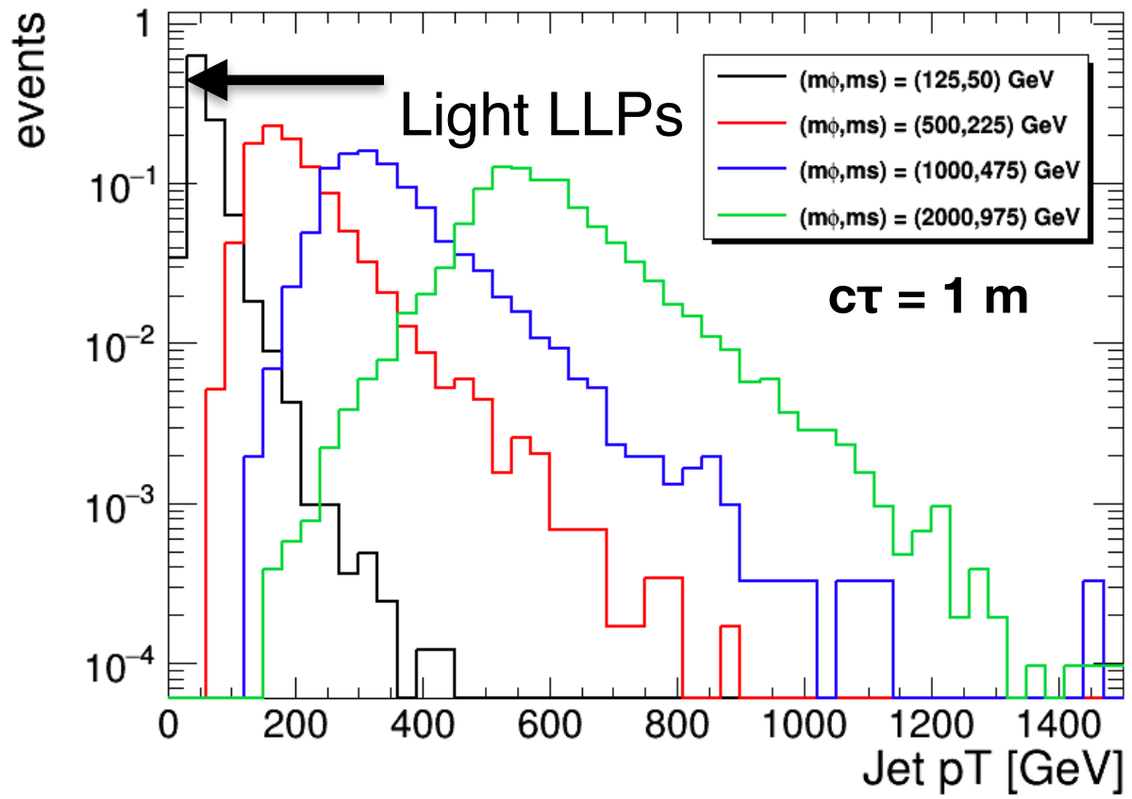
- Heavy (scalar) particle decays to two long-lived particles “s”, each of which decays to 2 quarks (multi-jet final state)

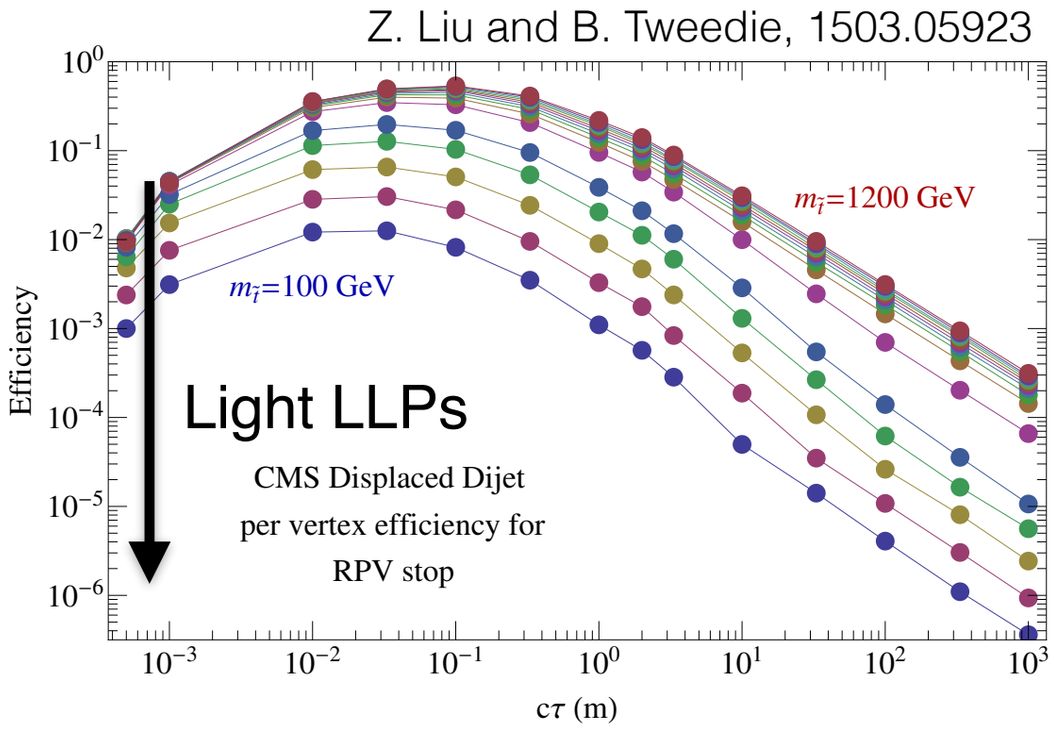


- If “s” is sufficiently short-lived, reconstruct a displaced jet in calorimeter

- 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

- For LLPs decaying outside calorimeter, ATLAS developed an trigger based on a ROI of clustered hits in the muon system

- Two approaches:

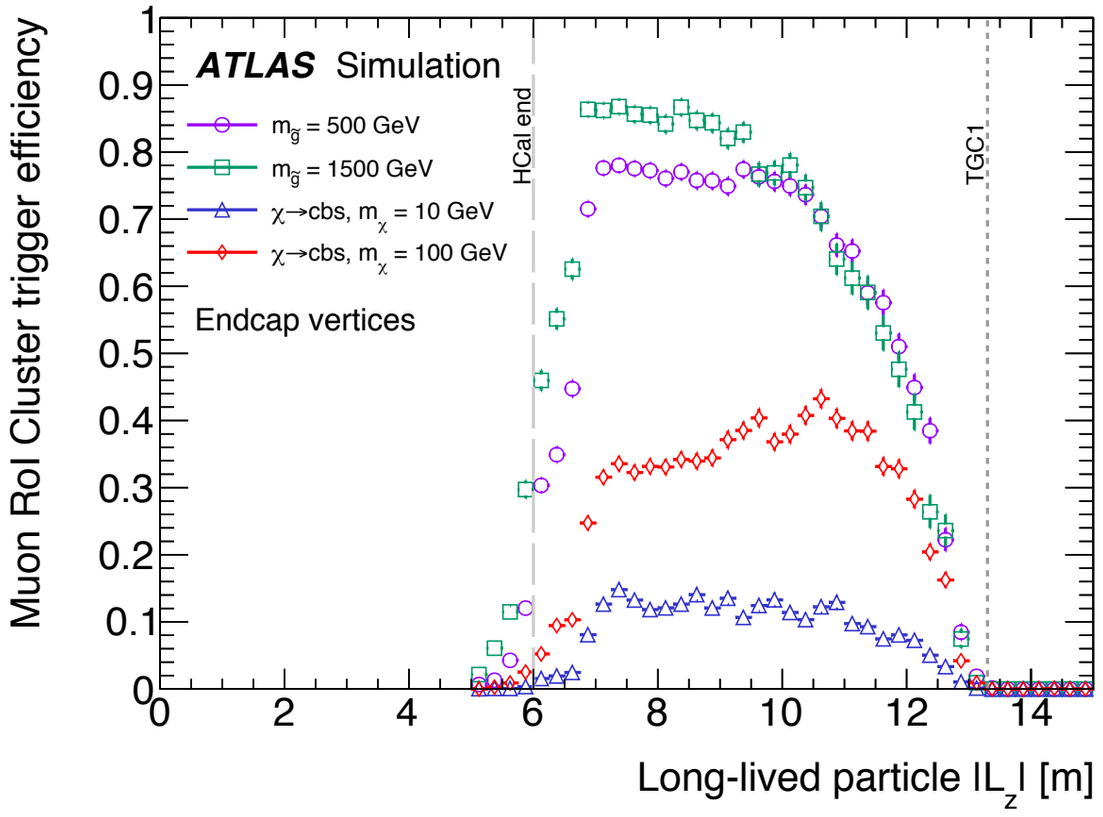
  ✓ 2 muon vertices

  ✓ 1 muon vertex + missing energy

- Sensitive to large lifetime and light LLPs (H→ss)

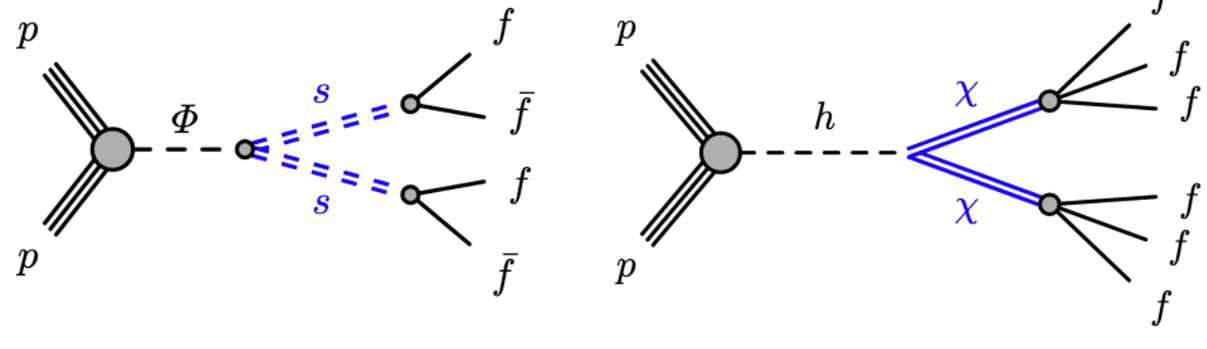
  ✓ LLP mass between 10 and 500 GeV

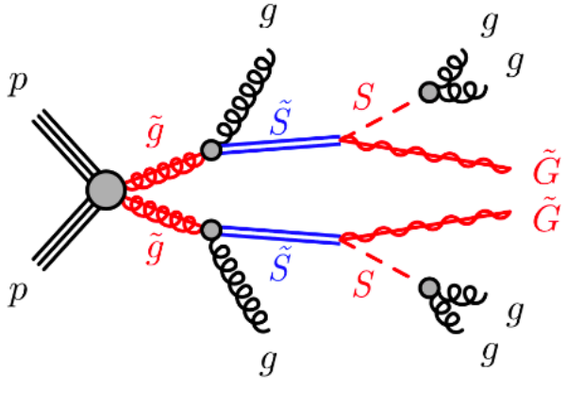
  ✓ Higher mass LLPs easier to detect with ROI trigger



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

- Interpretation for different models





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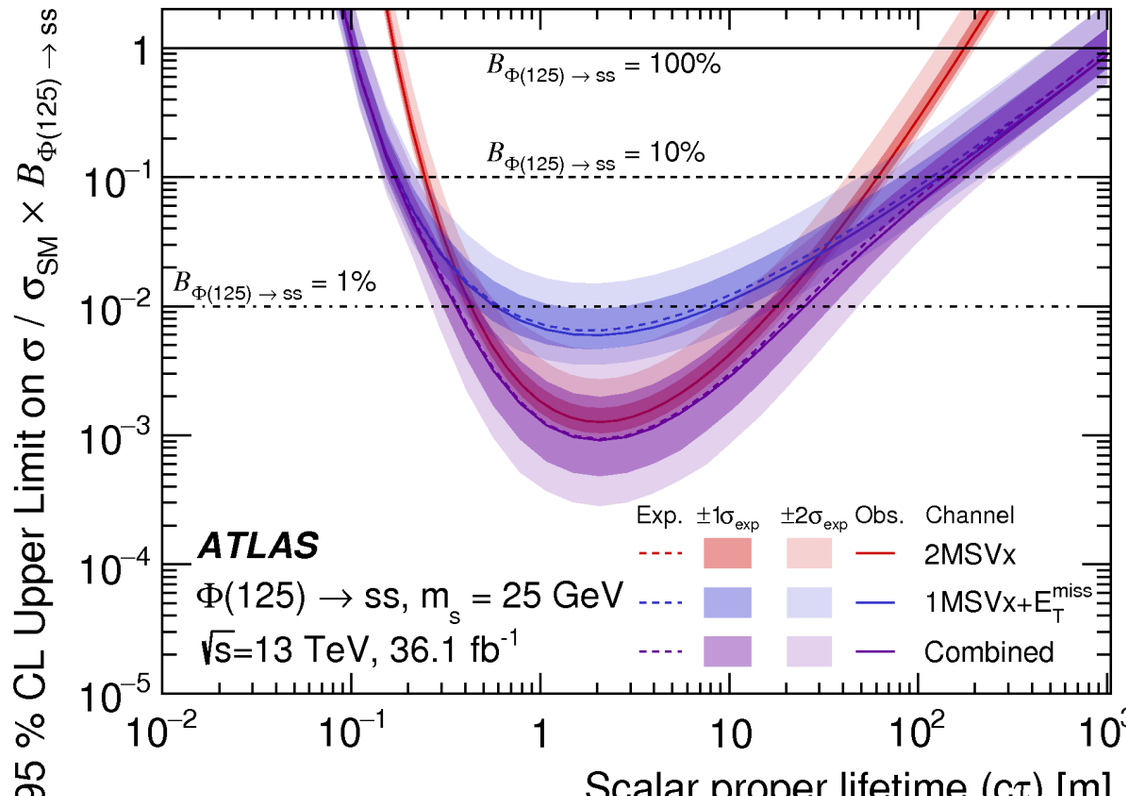

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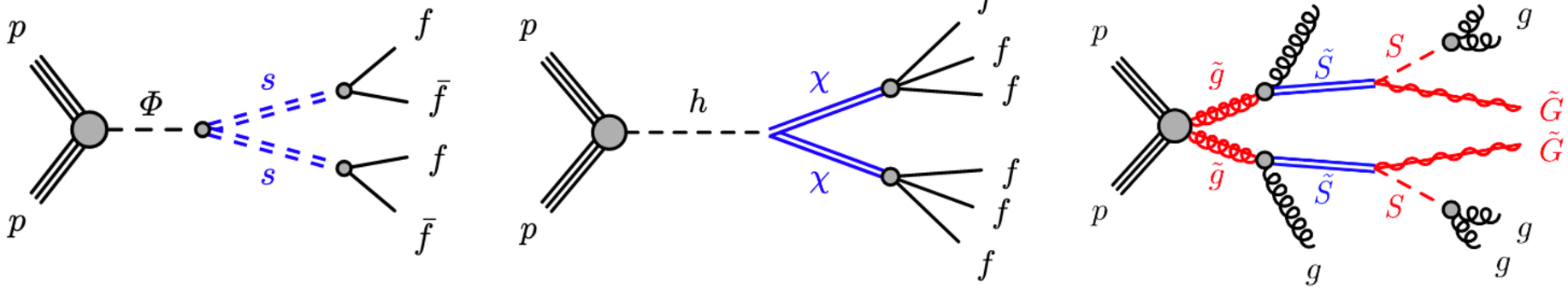
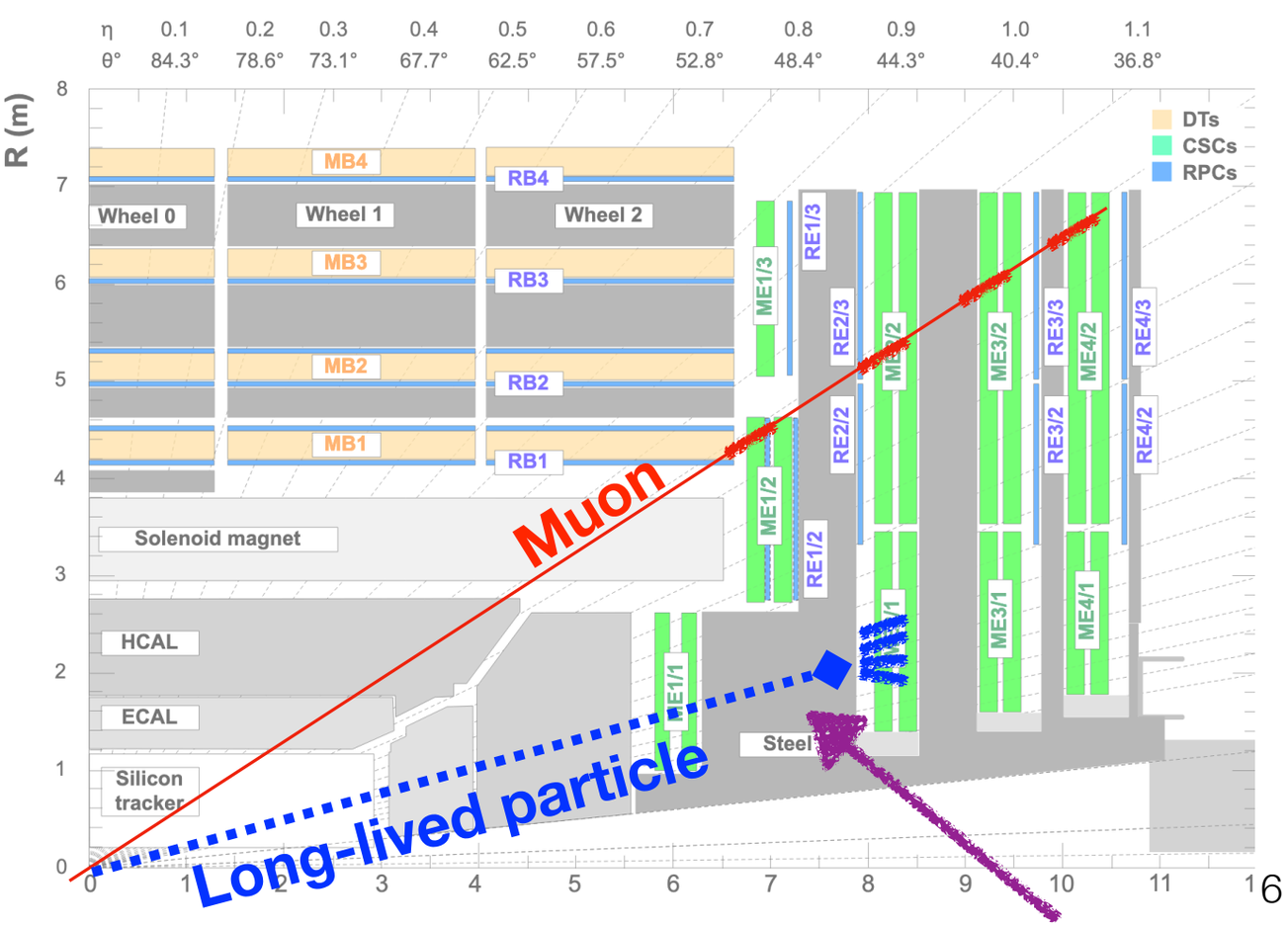
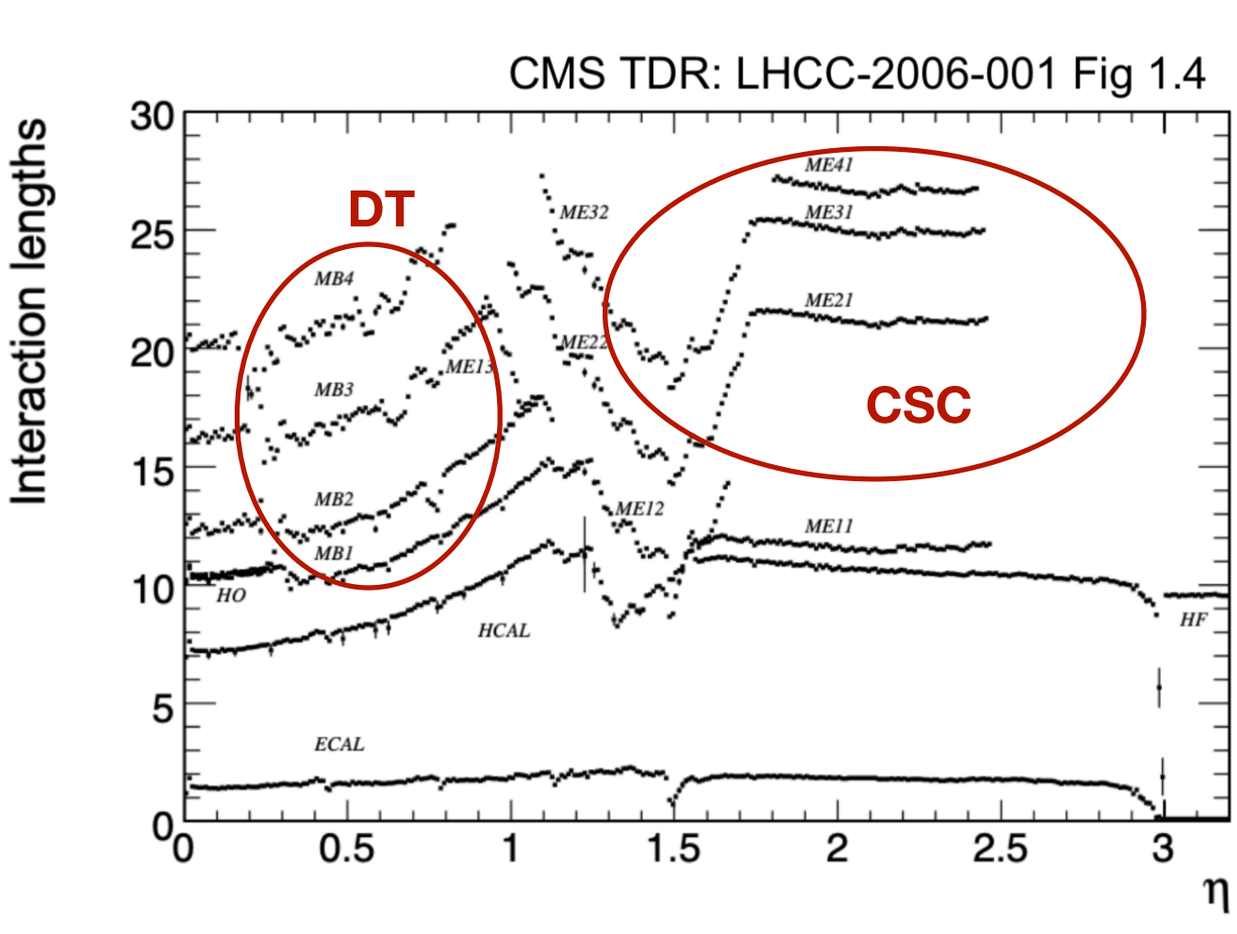


LLP to displaced jet in CMS muon system

- 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)

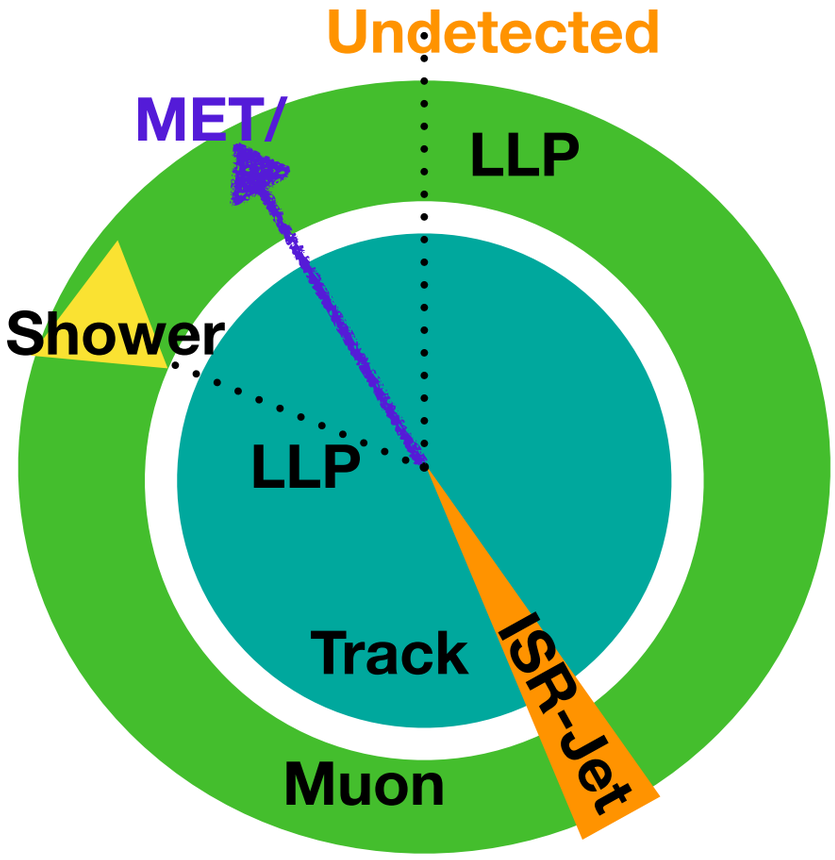


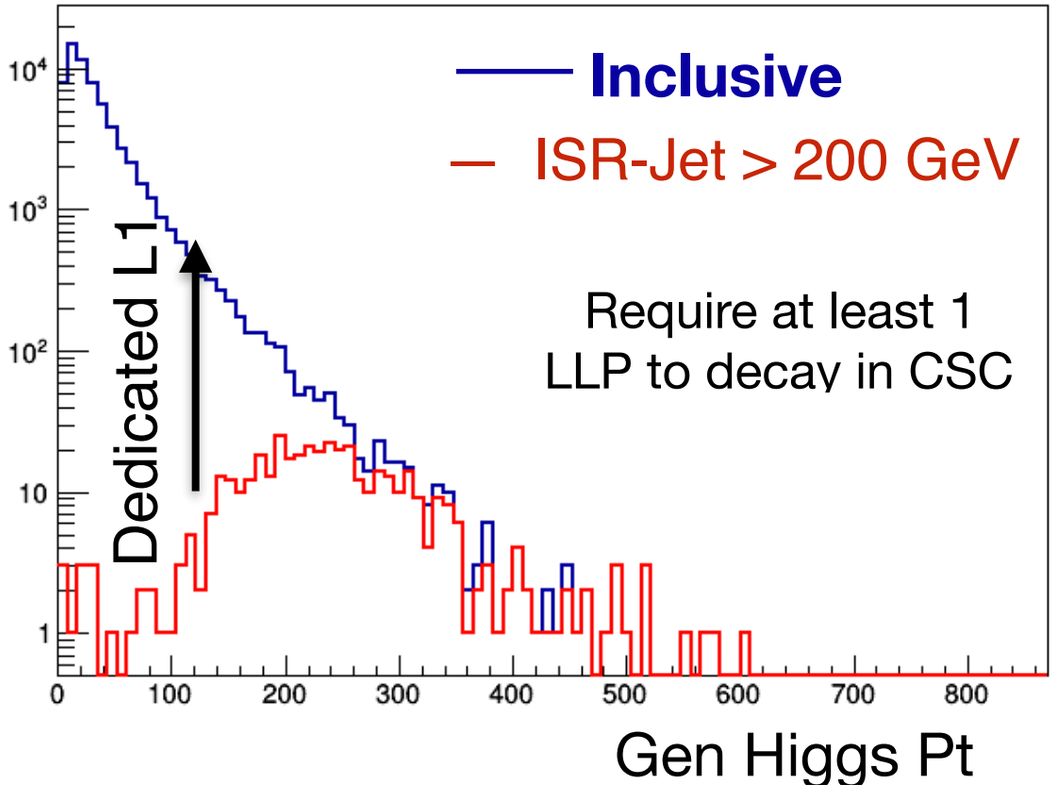


LLP to displaced jet in CMS muon system

- 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 dedicated L1 trigger for muon showers

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

  ✓ Important: both 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

  ✓ Additional usable bandwidth to identify high-multiplicity events

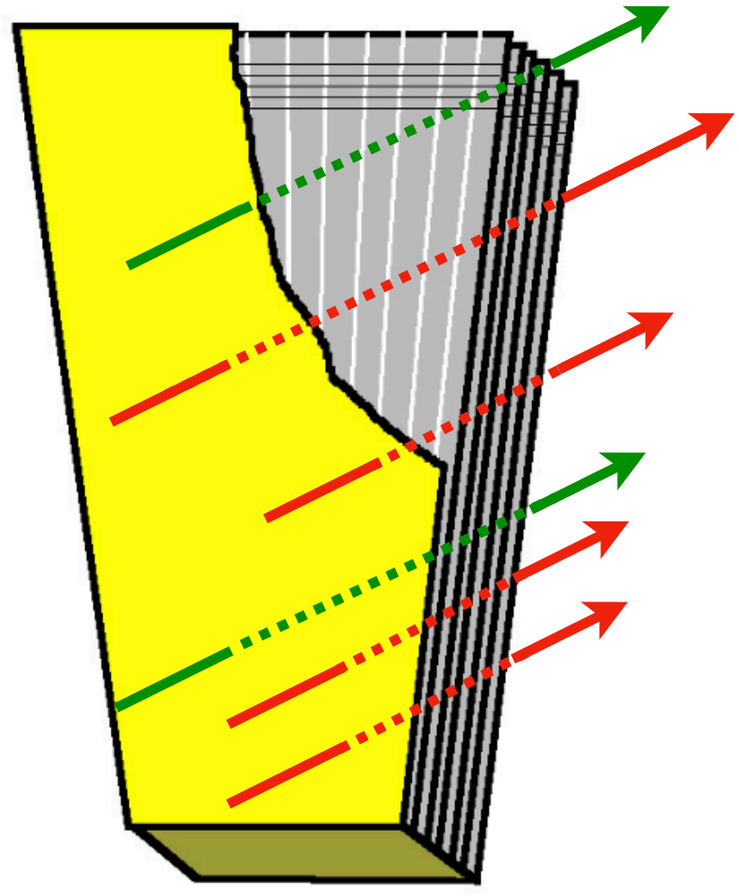
    ◉ LS2 ideal moment to implement new algorithms for Run-3!

- Our current studies focus on counting track segments and raw hits in cathode strip chambers

A dedicated L1 trigger for muon showers

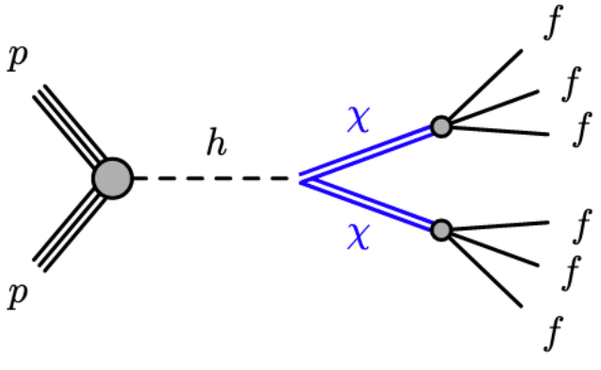
- Maximum 2 track segments are sent from each chamber to the track-finder
- However, CSC trigger data formats have recently been updated
- 2-3 bits per chamber per BX available to count extra track segments and/or count number of raw hits
- Potential to enhance searches for new physics
  - ✓ LLP to displaced jets
  - ✓ Muon-jets predicated in hidden valley models
  - ✓ LFV boosted tau -> 3 muon decay

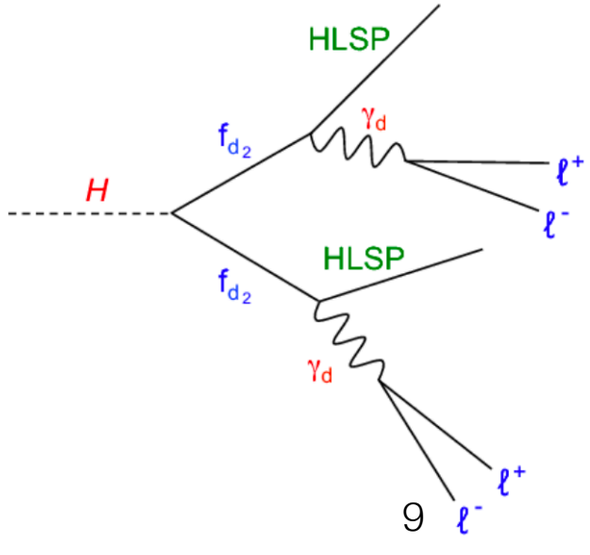
Max 2 segments sent to track-finder

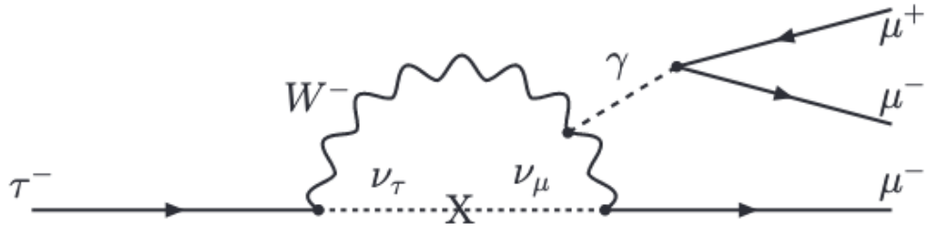


Other track segments not sent in Run-2

Can be counted in Run-3!

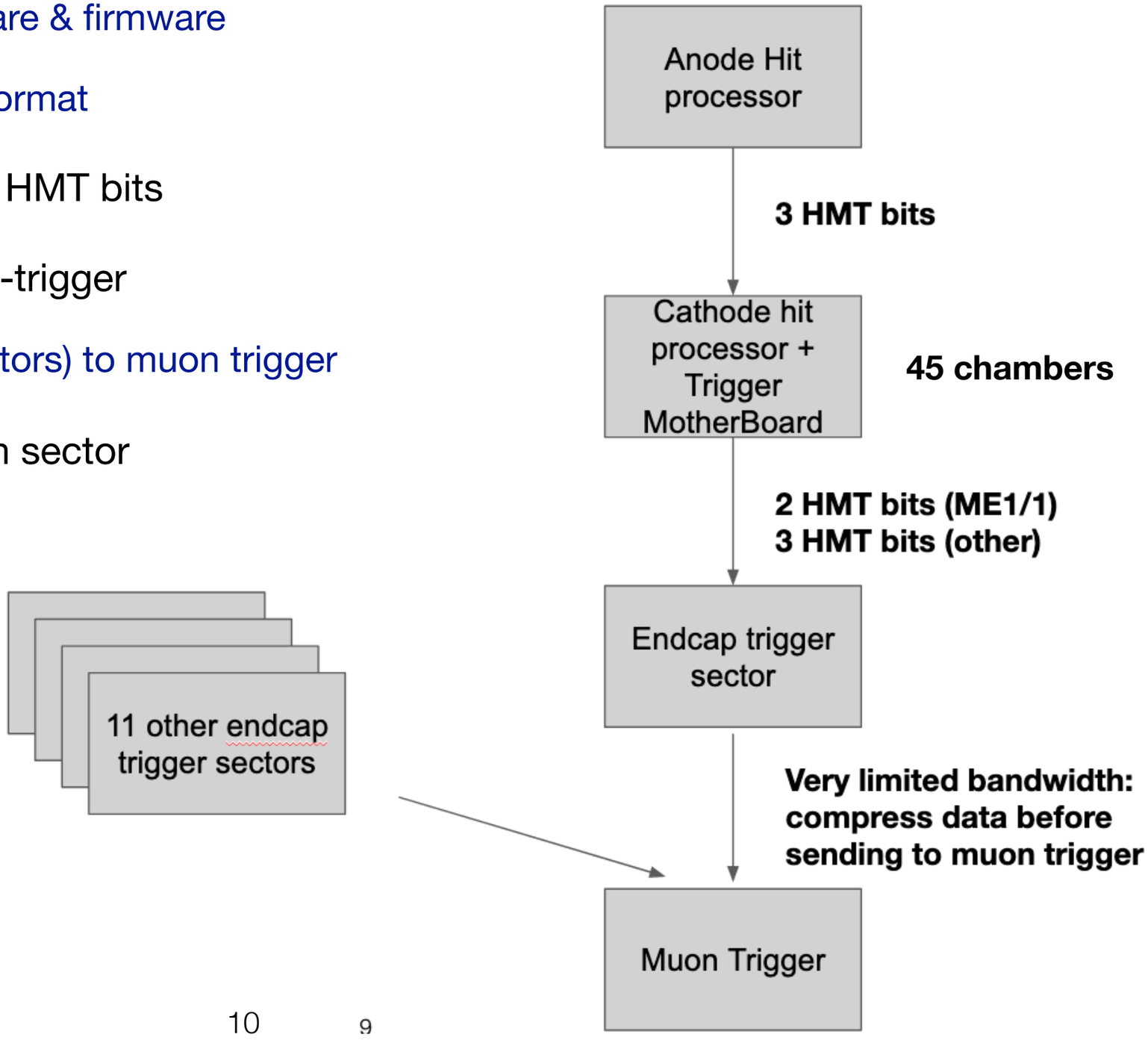






An Extra 2 or 3 Bits: practical

- 2-3 high-multiplicity trigger (HMT) bits per chamber per BX
  - ✓ Upgrade of CSC trigger hardware & firmware
  - ✓ Redesign of CSC trigger data format
- Each endcap sector receives 126 HMT bits
- Tight bandwidth constraints at L1-trigger
  - ✓ Cannot 1512 bits (126 x 12 sectors) to muon trigger
- Plan to compress the data in each sector
- Details have yet to be figured out



Focus of current studies

- In our current studies we look at h->2s->4b decays
  - ✓ Mass “h” between 125 GeV and 1 TeV, mass LLP “s” between 12 and 450 GeV
  - ✓ Lifetimes up to 10m
- Exploring simple raw hit counters and combination with track segment counters
  - ✓ Raw hit thresholds: >= 30, 45, 50, 60, 70, 80, 90
- Preliminary results based on realistic simulation indicate
  - ✓ Able to get down to trigger rates **< 1 kHz** in muon system
  - ✓ Trigger efficiency on low-mass “s” bosons **between 10-20%, as high as 50%** on models with more massive “s” bosons
    - ◉ Reminder: MET-based trigger in CMS analysis achieves ~1% trigger efficiency. Factor x10, x20
- Currently trying to understand background modeling in simulation instrumental to muon cluster trigger
  - ✓ E.g. Beam halo background not taken into account

Summary and outlook

- Big potential for searches for LLPs decaying to hadronic jets in CMS
- Requires modification of endcap muon trigger to tag chambers with muon showers and/or extra track segments
- With 2 or 3 bits per chamber, we can set thresholds and create simple algorithms to maximize acceptance for as many relevant/interesting models as possible.
- So far, we have studied rates and efficiencies in simulation. Factors x10 to x20 possible for efficiency with rates around 1 kHz or less.
- Next steps include determining optimal thresholds with realistic background modeling and designing simple algorithms for the track-finder