Dedicated Delphes Module for Neutral Long-lived Particles Decaying in the CMS Endcap Muon Detectors

Christina Wang (Caltech)

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Motivation for Using Delphes Simulation

Generic

CMS full simulation (Private)

- Simulates all particle-detector interactions with GEANT 4

CMS fast simulation (Private)

Delphes (Public)

Parameterize detector response using only particle-level information

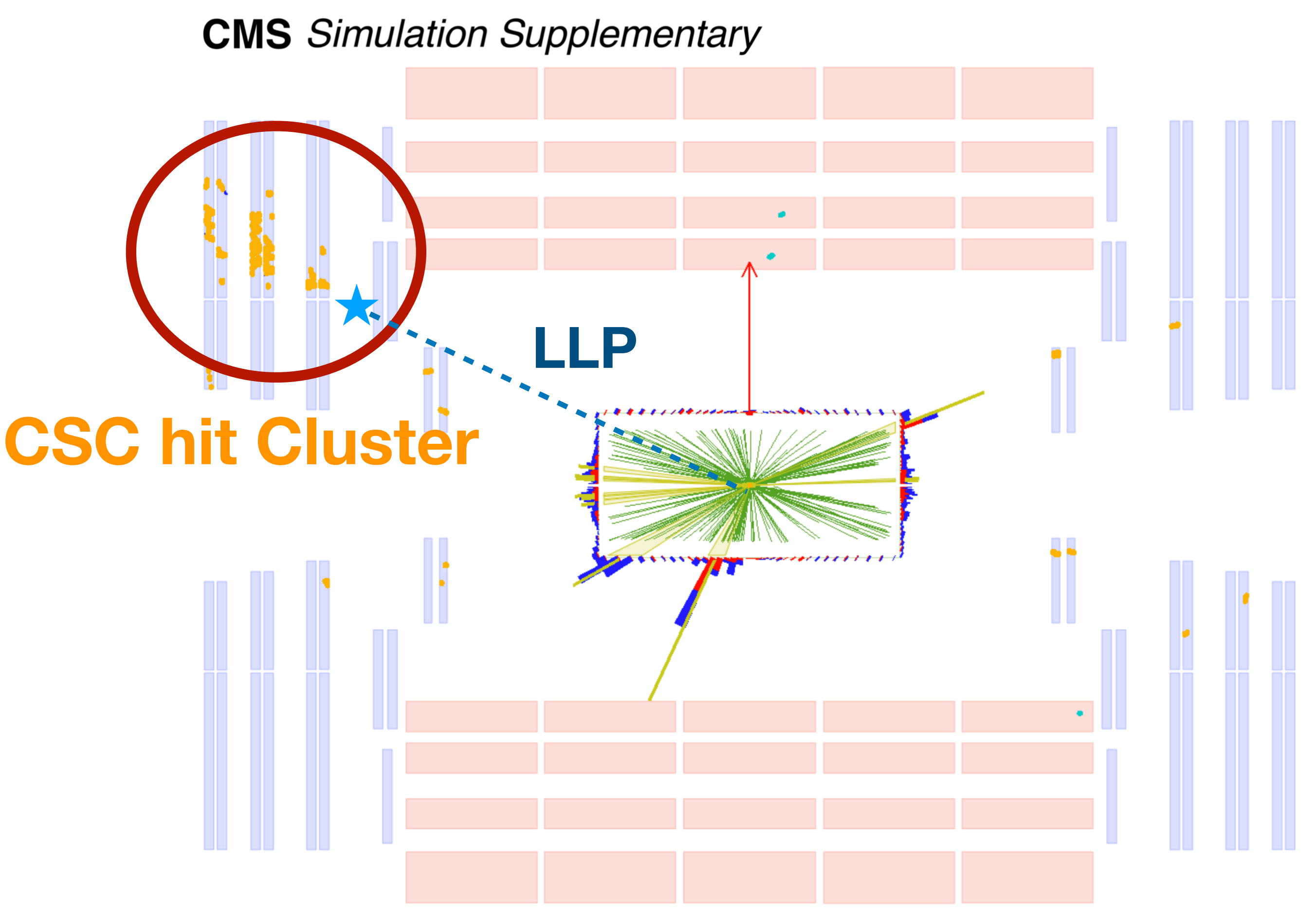
Speed

Overview of Delphes

- Delphes is a very-fast-simulation for generic detectors
- Simulation is split into generic modules, with different functions parameterizing detector response (efficiency, isolation, energy smearing…)
- Detector geometry and sequence of module is entirely described by cards
- Works well with standard PF objects, but are **not designed for LL displaced signatures**
- **In this talk, we present a dedicated module for muon system showers from LLP decays by using the HEPData entry for EXO-20-015**
- The predictions from the Delphes module are compared with the CMS results and are found to be in good agreement.
- Using the dedicated modules and the existing CMS detector description for PF candidates would allow us to recast the analysis on any other models → **See Andrea's talk**

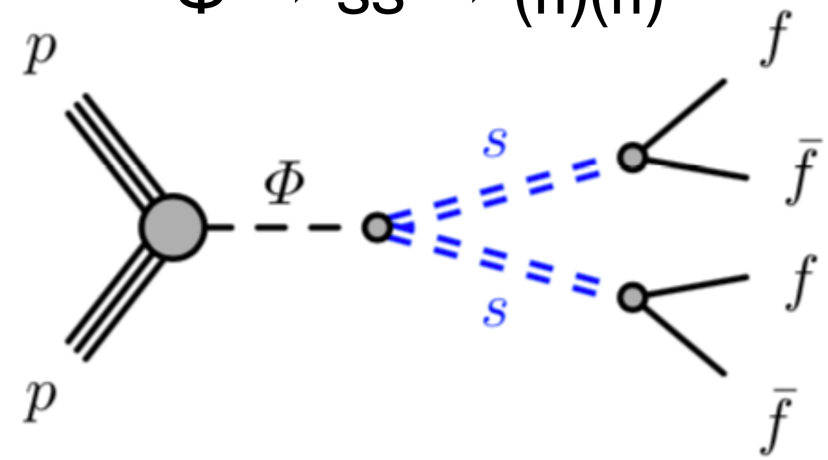
Experimental Signature: Showers in the Muon System

- Neutral long-lived particles decaying in the muon system leave a signature with:
  - No tracks
  - No jets
  - Large **cluster of CSC hits (>100 hits)** in the muon system
- Muon system acts as a **sampling calorimeter:** sensitive to a broad range of decays
- **Unique signature** due to the presence of steel in the CMS muon system



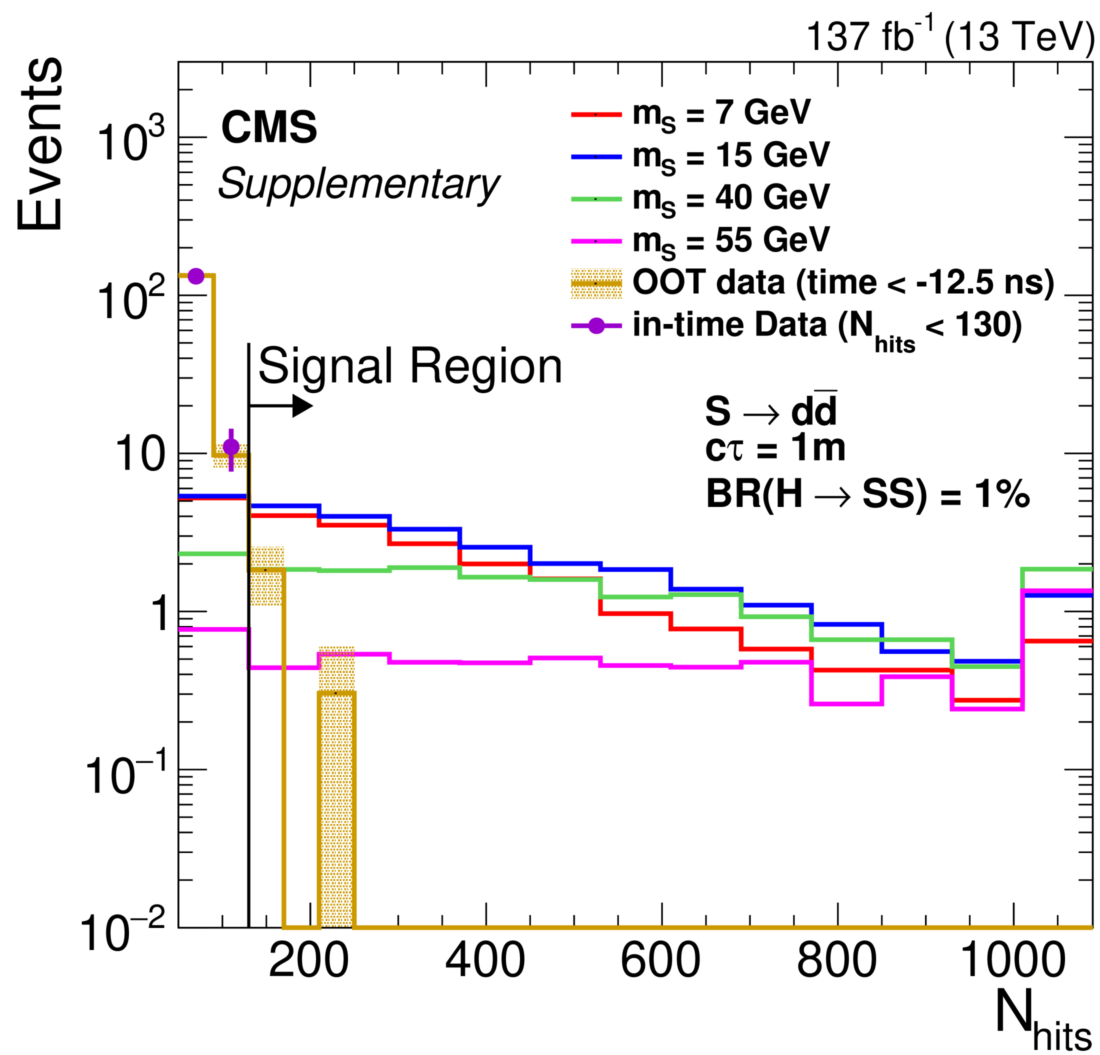
Twin Higgs as benchmark model:

$\Phi \rightarrow ss \rightarrow (ff)(ff)$

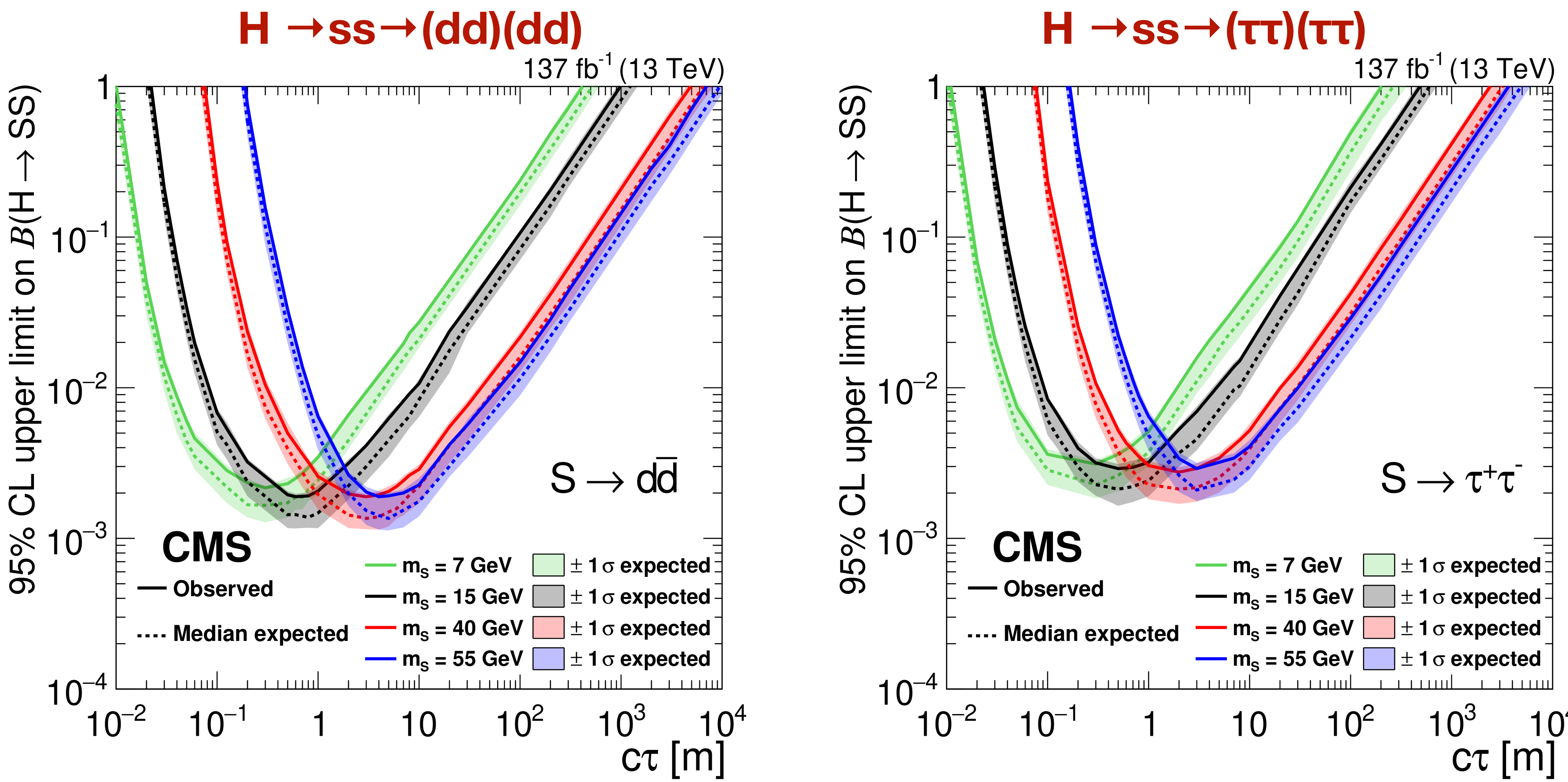


CMS Analysis Strategy

- **Event selection:** select high MET and boosted Higgs phase space
  - Trigger on MET (lack of dedicated trigger, trigger efficiency is ~1%)
- Use **CSC cluster vetos and cut-based ID** to enhance signal purity and reject background from main collision
- **N_{hits}** serves as the main discriminator



CMS Result



Predict 2 ± 1 background events and observed 3 events

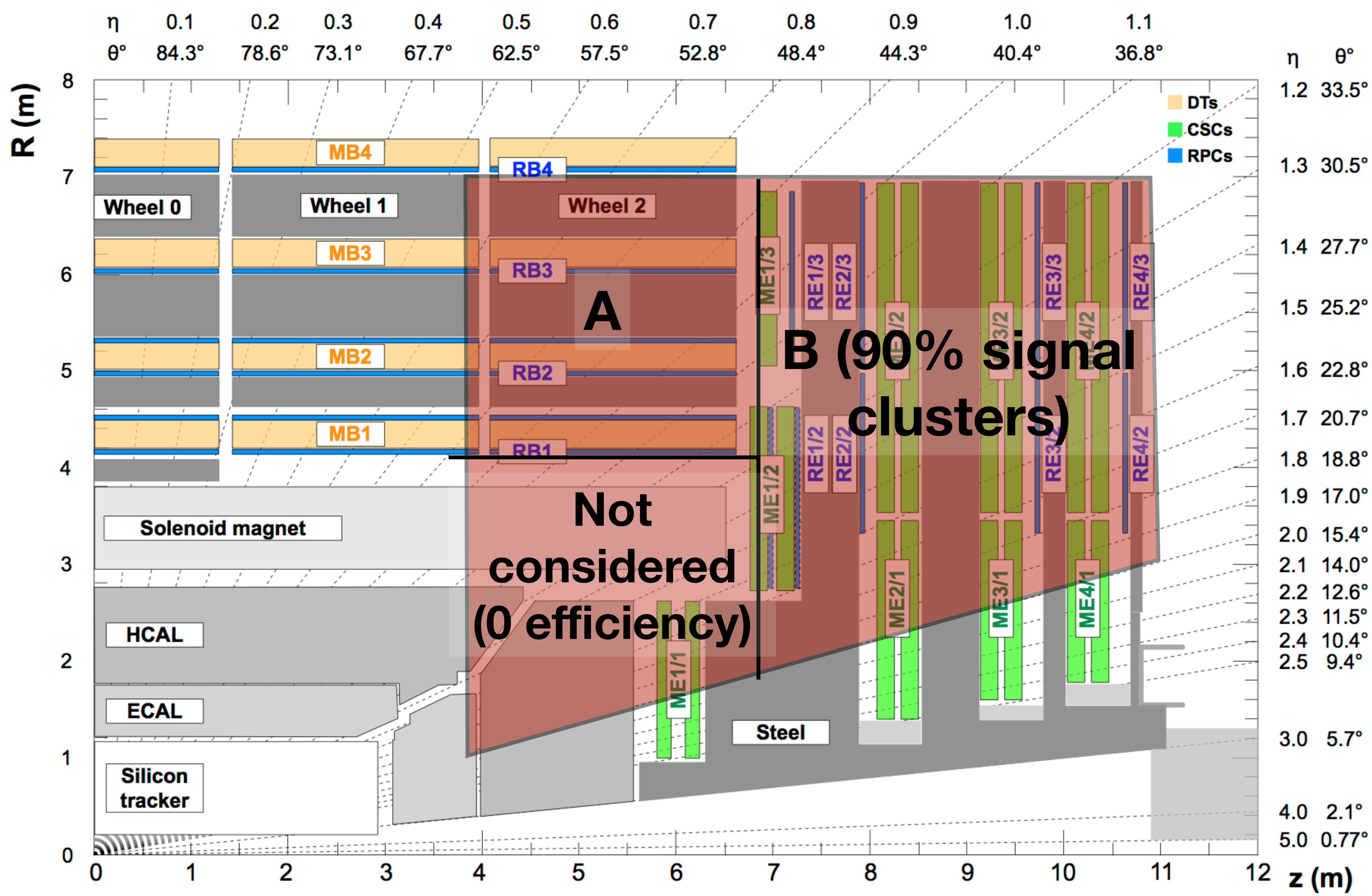
- Limits for S → bb are within 3% to that for S → dd.
- Analysis sensitivity is independent of the **LLP decay modes** and **masses**
- Provides current best LHC limit for LLPs with cτ above 6, 20, and 40 m for mass of 7, 15, and 40 GeV respectively.

Dedicated Delphes Class and Module

- A dedicated class **CscCluster** and 2 dedicated modules **CscClusterEfficiency** and **CscClusterId** for two separate cluster-level selections are introduced
- Signal efficiency parameterization of all cluster-level selections using gen-level LLP hadronic energy, EM energy, and decay positions
- The signal selection efficiencies are split into 3 parts:
  - **Cluster efficiency**: includes cluster reconstruction efficiency, muon veto, active rechit veto, time spread cut, and N_{hit} >= 130 cut efficiency. Efficiency is provided in HEPData entry as a function of LLP EM and hadronic energy.
  - **Cut-based ID efficiency**: Efficiency of a cut-based ID. Use the code that has been provided in HEPData entry.
  - **Others**: including the **time cut**, **jet veto**, and **$\Delta\phi$(cluster, MET)**. These cuts are model dependent, and are not provided in HEPData entry. They are calculated based on gen-level information and are stored as variables in the objects (more details in later slides)

LLP Decay Regions

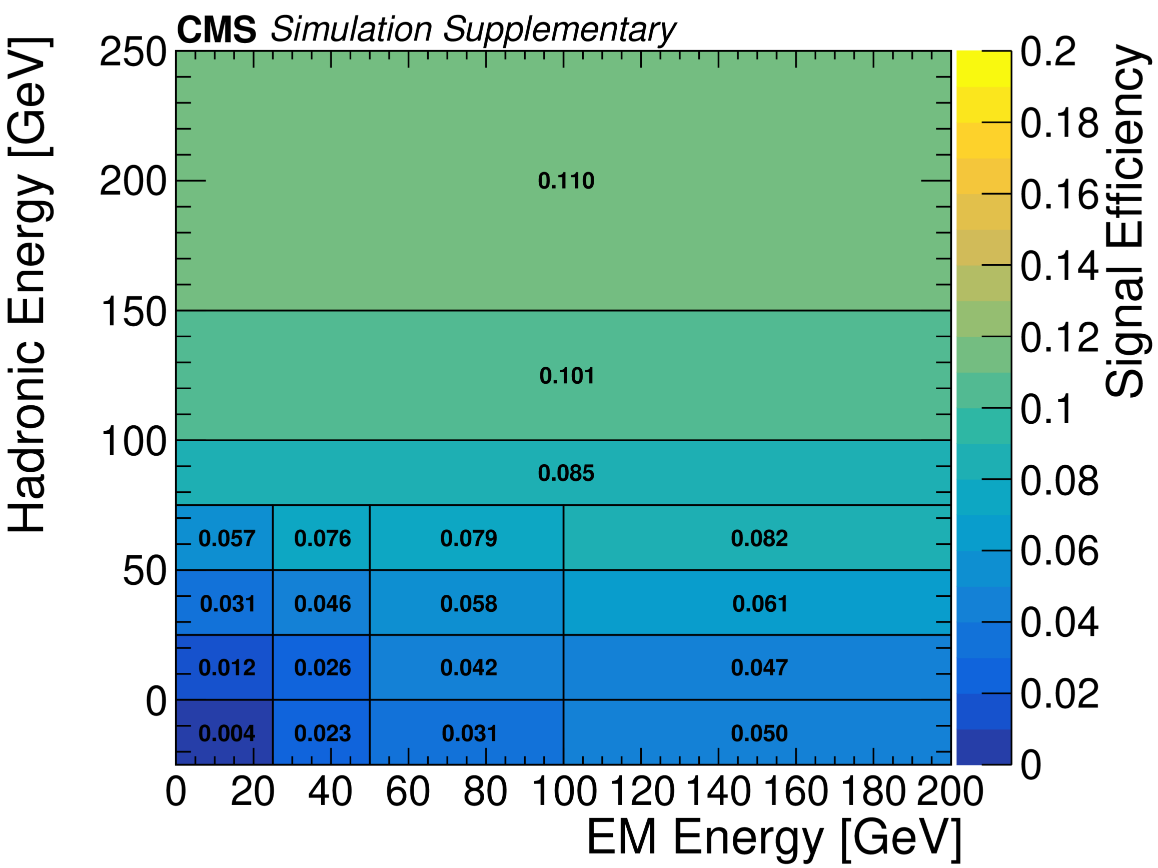
- **LLP decay location is categorized into 2 regions**
- **Efficiency parameterization are provided for each region separately**
- More than 90% of clusters passing all selections are from LLPs that decay in region B
- Used the region definitions in HEPData entry



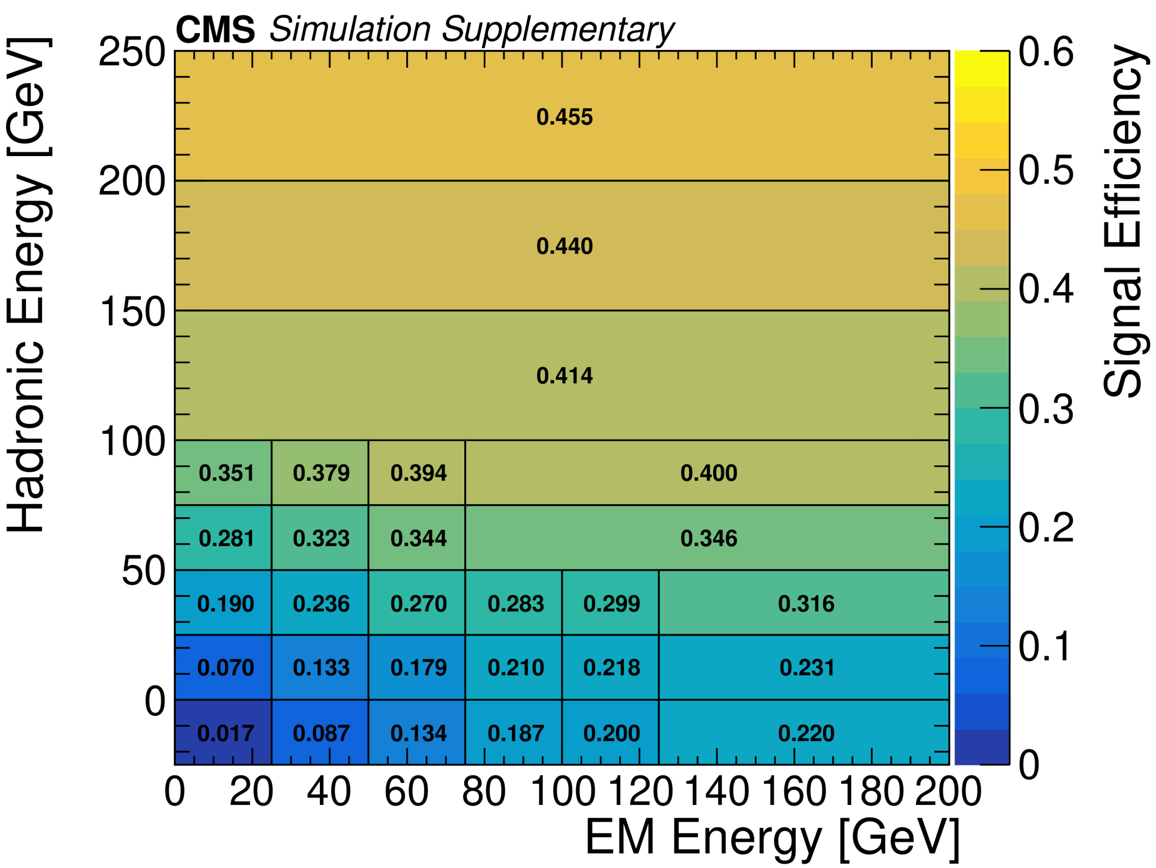
Cluster Efficiency

- Implemented a dedicated **CscClusterEfficiency module** based on the existing Efficiency module used by all other PF candidates
- Cluster efficiency is parameterized in hadronic energy and EM energy (provided in HEPData)
  - Independent of LLP mass (7- 55 GeV), $c\tau$ (0.1 - 100 m), and decay mode (dd and $\tau^+\tau^-$) within each LLP decay region
  - The full simulation signal yield prediction reproduced using this parameterization to within 35% and 20% for region A and B, respectively.

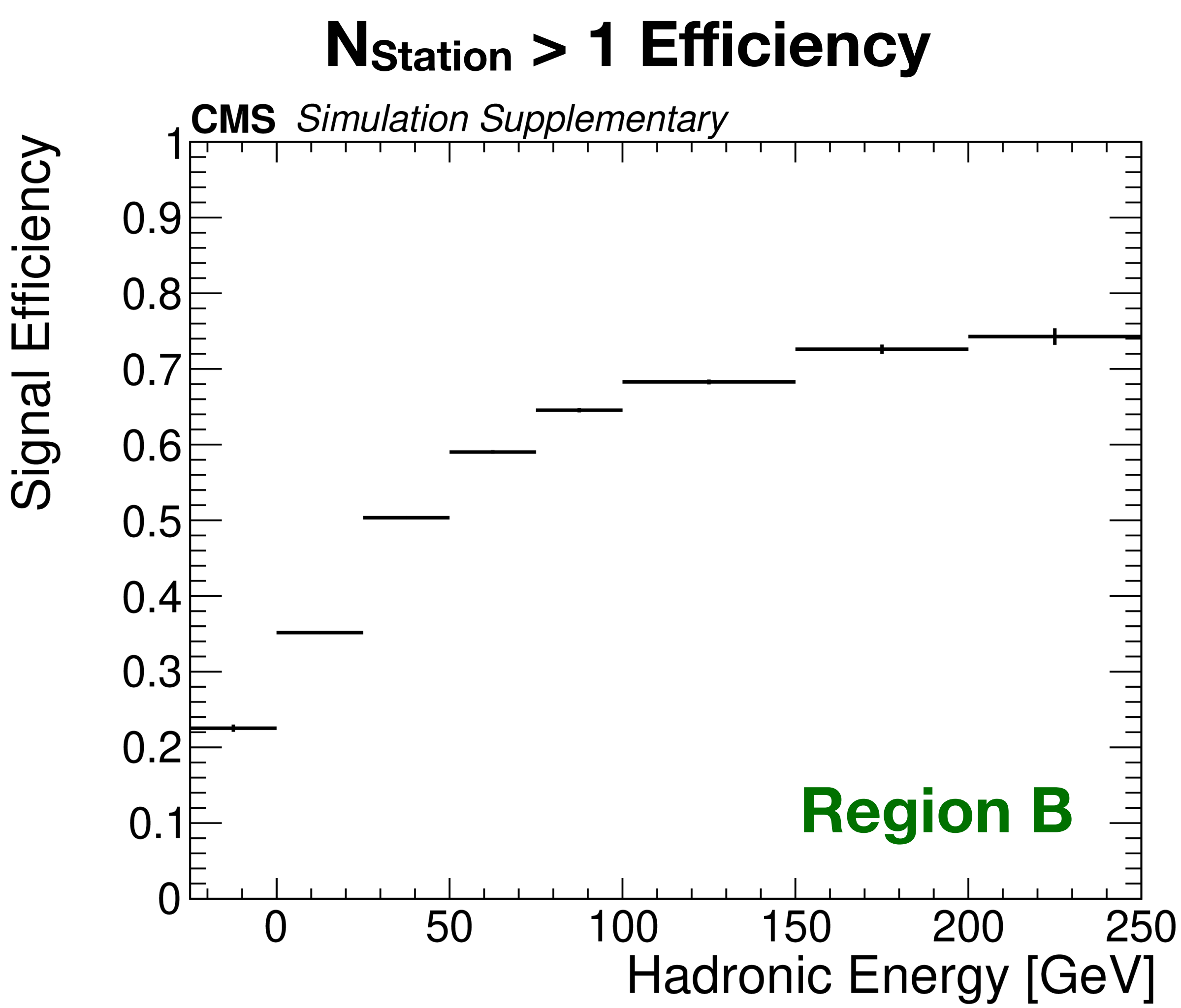
Region A



Region B



Cut-based ID Efficiency



- Implemented a dedicated CscClusterID, which implements the cut-based ID function provided in HEPData entry
- **Only gen-level LLP η , decay position, and hadronic energy are needed as input**
- ID requirement in analysis:
  - If $N_{station} > 1$: | η | < 1.9
  - If $N_{station} = 1$: apply | η | < X, where X = 1.6 or 1.8 depending on the Average Station Number
- ID efficiency is 100% for clusters in region A (| η | < 1.3)
- ID efficiency for region B is calculated using:
  1. Efficiency of $N_{station} > 1$ requirement
  2. Transfer function that takes gen-level LLP decay position to RECO-level cluster Average Station (Only for clusters with $N_{station} = 1$),
  3. LLP η as a proxy for cluster η
- **The full simulation signal yield prediction reproduced using this procedure to within 10%.**

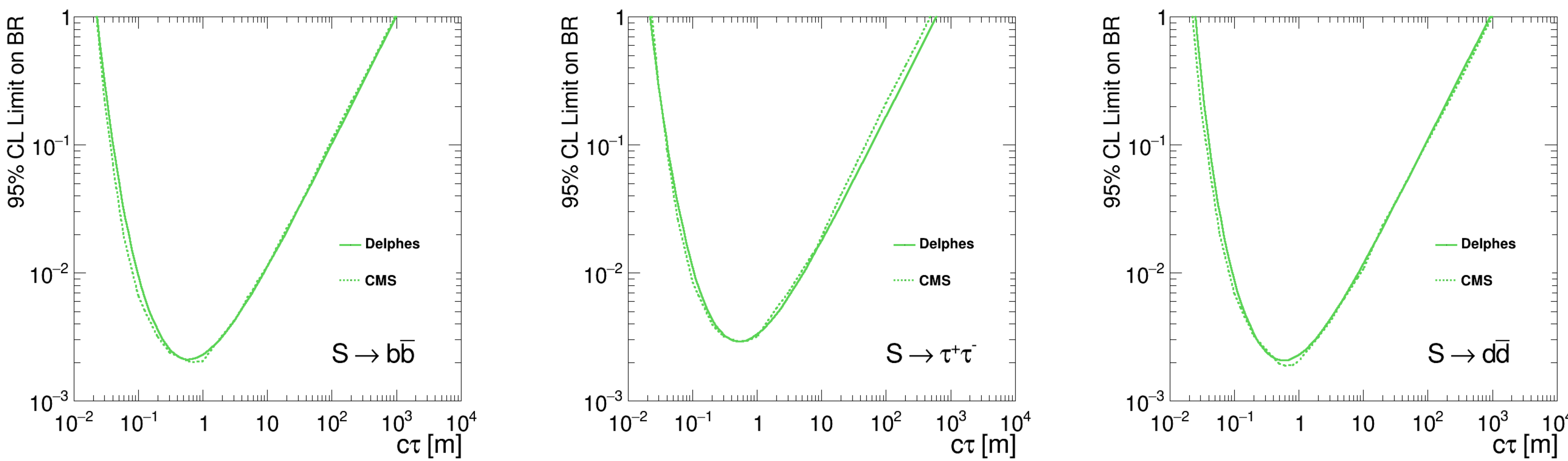
Other Cuts

- **The following cuts applied in the analysis are model dependent, and are not provided in HEPData entry**
- **Time cut**
  - -5 ns < $t_{cluster}$ < 12.5 ns
  - Travel time highly depends on the lifetime and boost of the LLP
  - $t_{cluster}$ calculated using gen-level LLP travel time from IP to decay vertex and is stored as a variable of the CscCluster class
- **Jet Veto**
  - Clusters matched ($\Delta R < 0.4$) to jets (>10 GeV) are vetoed in the analysis
  - This variable is not implemented as a variable of CscCluster, but is calculated in analysis workflow by matching the cluster to the jet collection from Delphes
- **$\Delta\phi$ (cluster, MET)**
  - abs($\Delta\phi$ (cluster, MET)) < 0.75
  - This variable is not implemented as a variable of CscCluster, but is calculated in analysis workflow by matching the cluster to the MET collection from Delphes

Limits & Validation

- Generate the twin Higgs model that are used in the CMS paper for validation
- Use the dedicated Delphes class/module and implement all cuts applied in the CMS paper
- Use the **data** and expected **background** yield in signal region provided in paper
- Calculated limits using 1-bin cut and count experiment using RooStat
    - Signal bin contains more than 90% of the signal events
- Validated that the standalone workflow is able to reproduce the limits from the CMS analysis for all 3 decay modes to within 30%

LLP mass = 15 GeV



Summary

- Presented dedicated Delphes module for displaced showers in muon system from LLP decays
- The Delphes module uses information from the HEPData entry, which parameterizes the signal efficiency using only the LLP energy and decay position
- The predictions from the Delphes module are compared with the CMS results and are found to be in good agreement
- The new module allows for recasting of the analysis on any new models that contain LLPs and exploration of other possibilities with this unique signature