Invisible Higgs Decay at CMS

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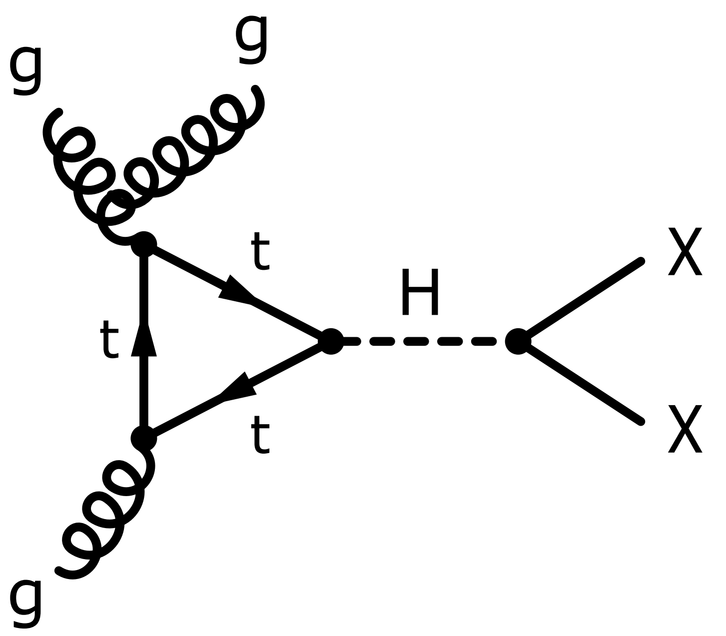
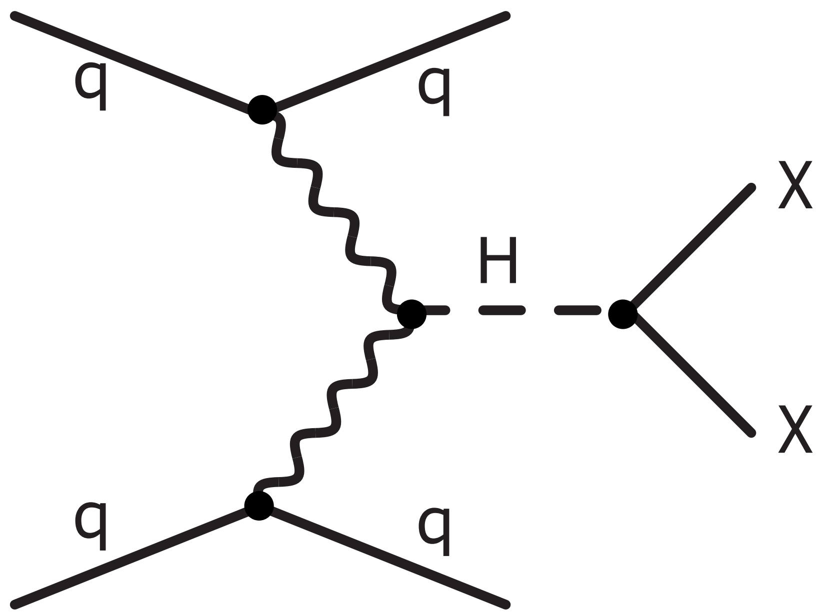
Higgs → BSM

- In the SM, H → inv is only possible via H → ZZ^* → 4v, with BR(H → 4v) ~ 0.1 %
- The Higgs could provide the link to a hidden sector → invisible final states that are stable or meta-stable

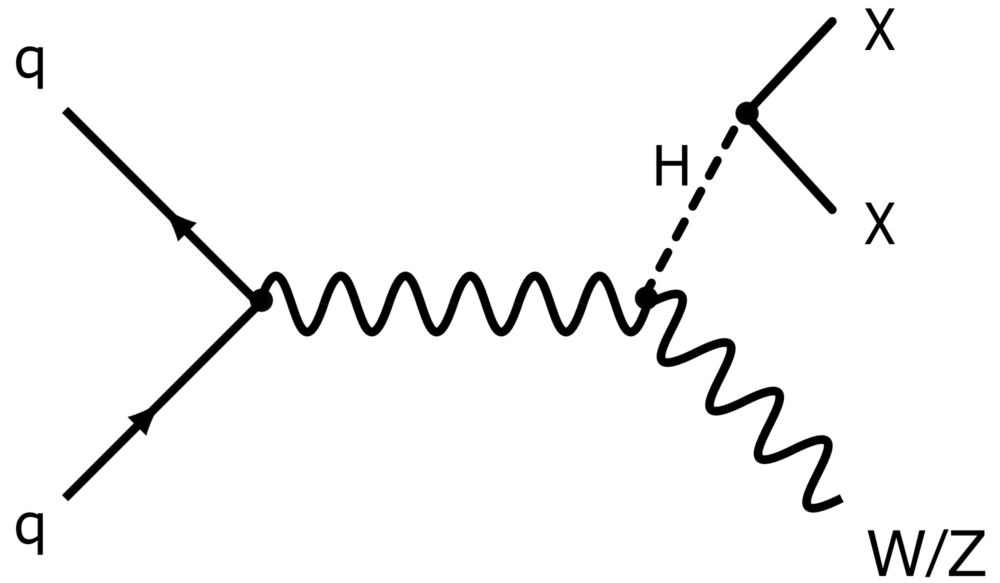
Stable invisible final state → MET



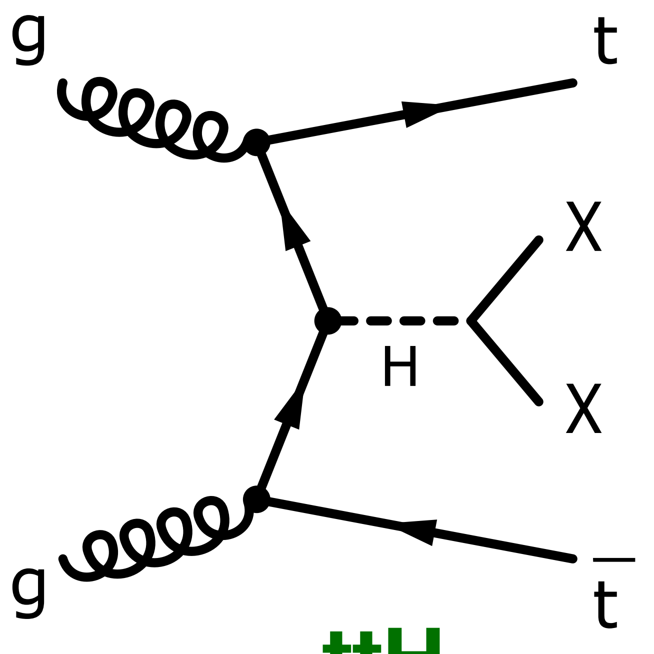
ggH



VBF (most sensitive)



VH

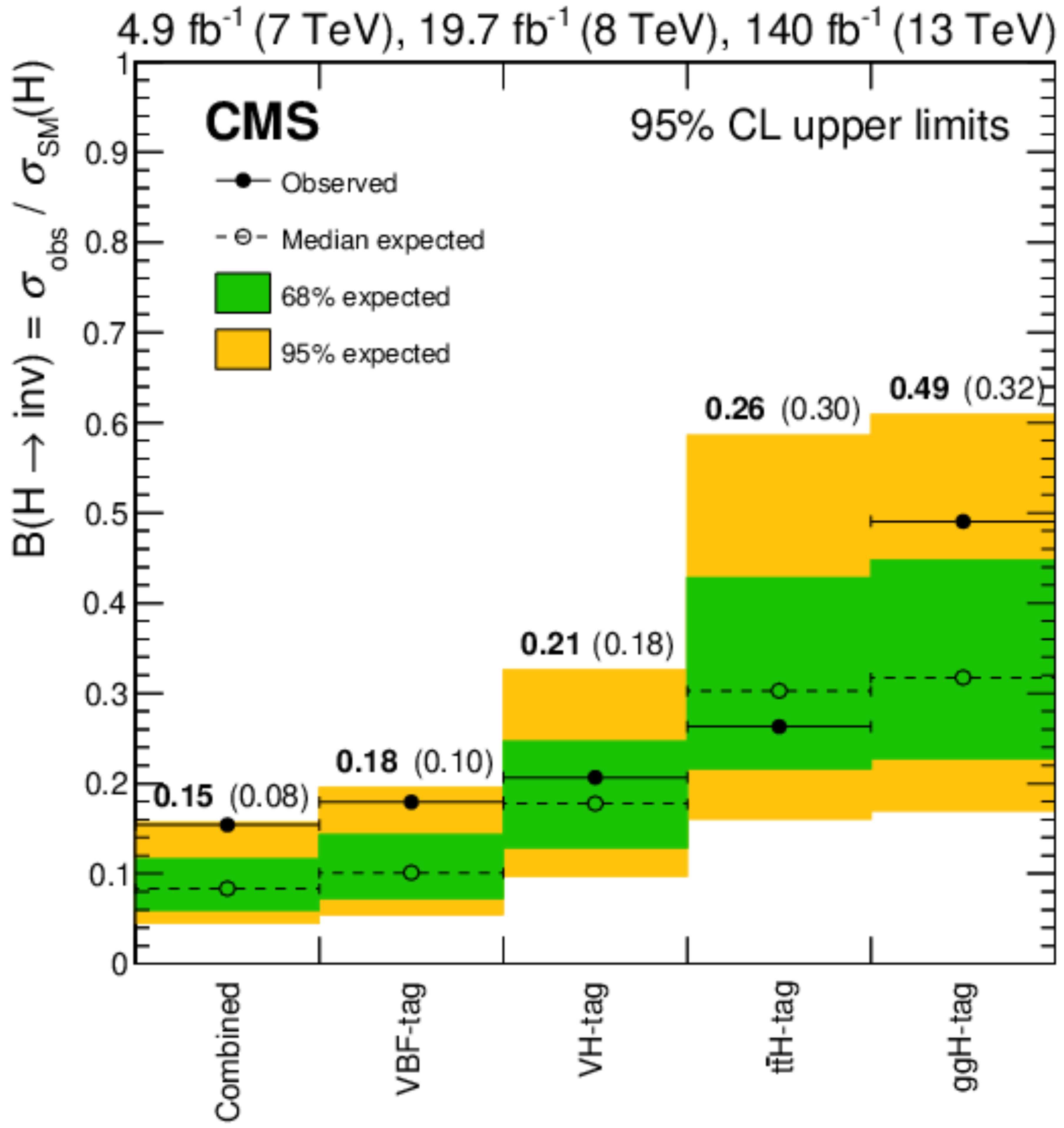


ttH

- **Search for associated visible particles + MET**
- Results with full Run 2 dataset covering all Higgs production modes:
  - gg H(invisible)
  - VBF H(invisible)
  - V H(invisible)
    - Z(ll)
    - V(jj) **NEW!**
  - tt H (invisible)
    - Hadronic **NEW!**
    - Leptonic

Higgs → Invisible (New Combination Result)

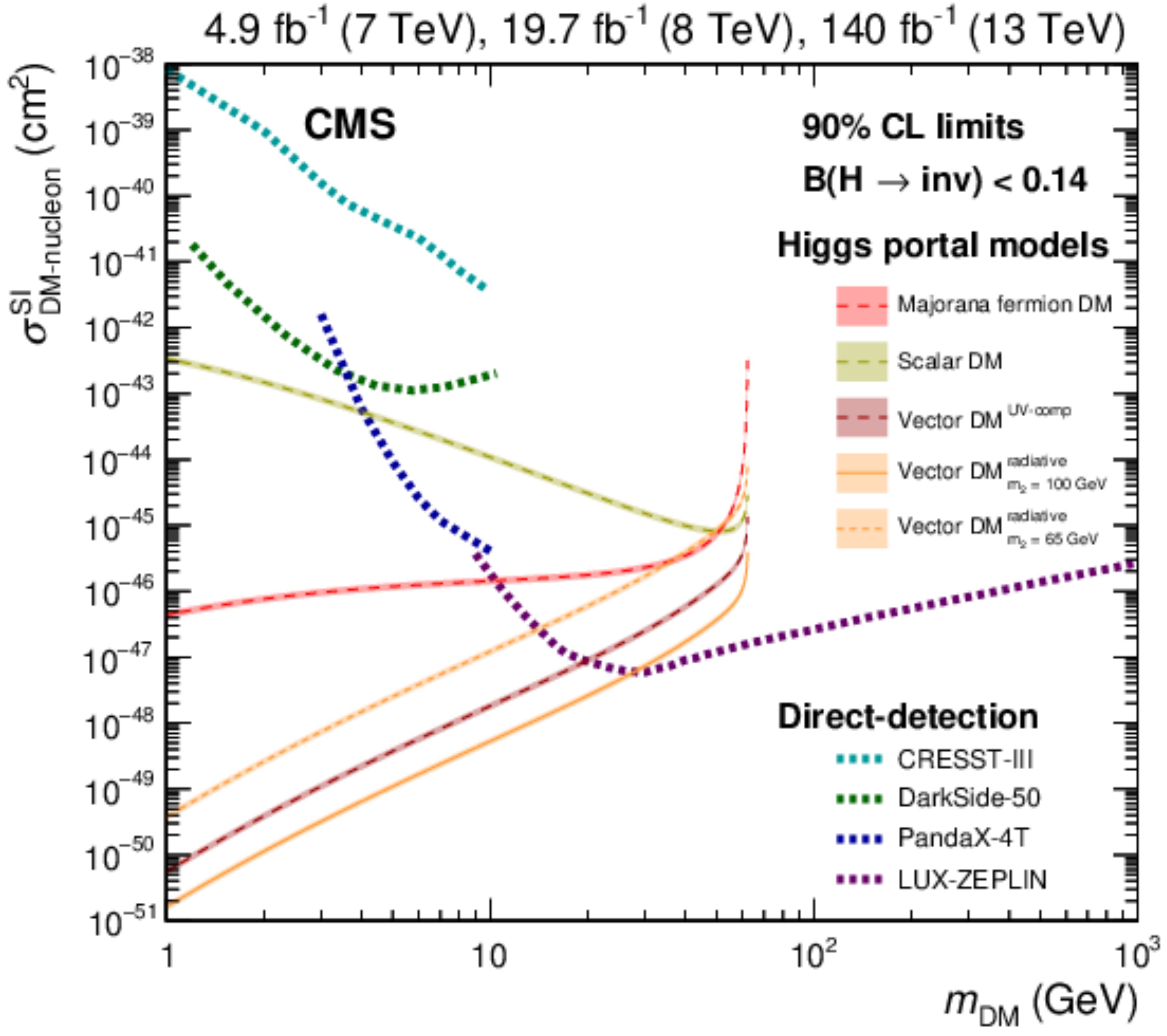
- **New: tt (hadronic) H and V(jj)H, combine with previous Run1 and Run2 result**
  - Main background: Z→ inv, EWK → lost leptons
  - ttH analysis split in events with boosted or resolved Ws or tops
  - VH category requires 2 jets with di-jet mass to be consistent with W/Z mass
  - MET is discriminating variable
- The final combination improves the overall sensitivity by 20% relative to the most sensitive single channel (VBF)



Interpretation in Higgs Portal Models

- Interpretation in spin-independent DM-nucleon scattering cross-section vs DM mass
  - Most stringent limit a low DM masses of a few GeV
- **Complementary to direct DM detection experiments**

H→DM DM



Higgs → BSM

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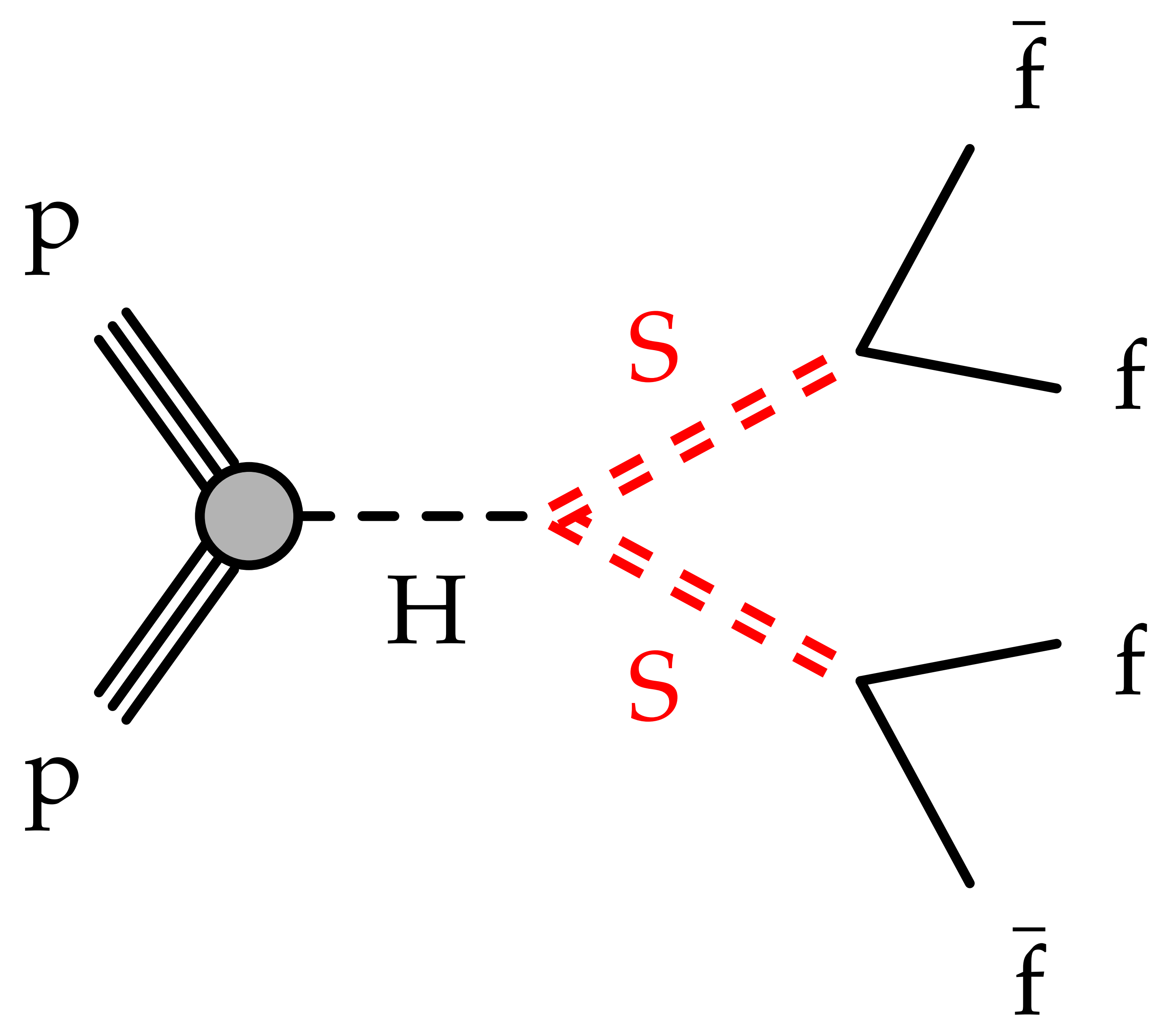
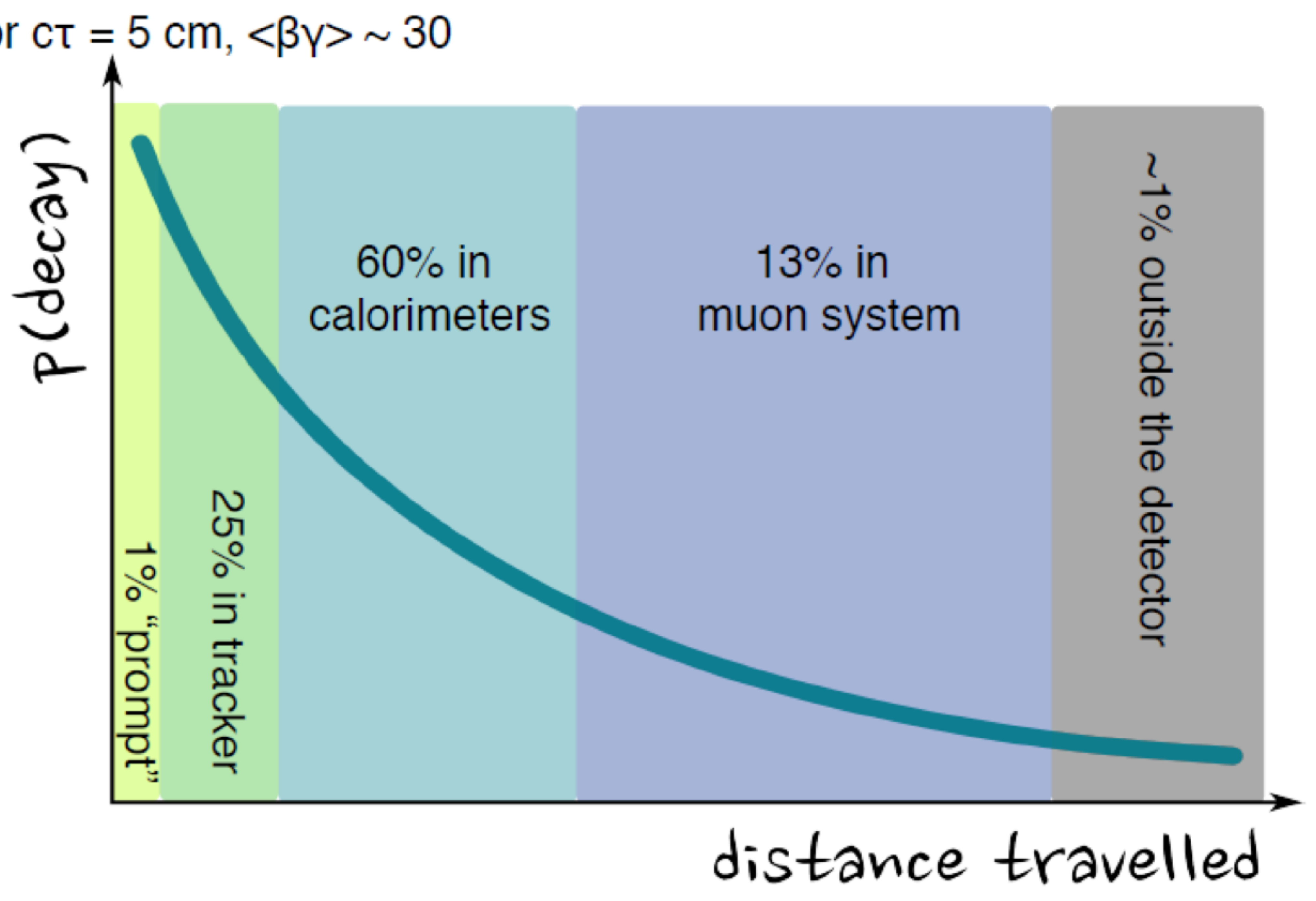
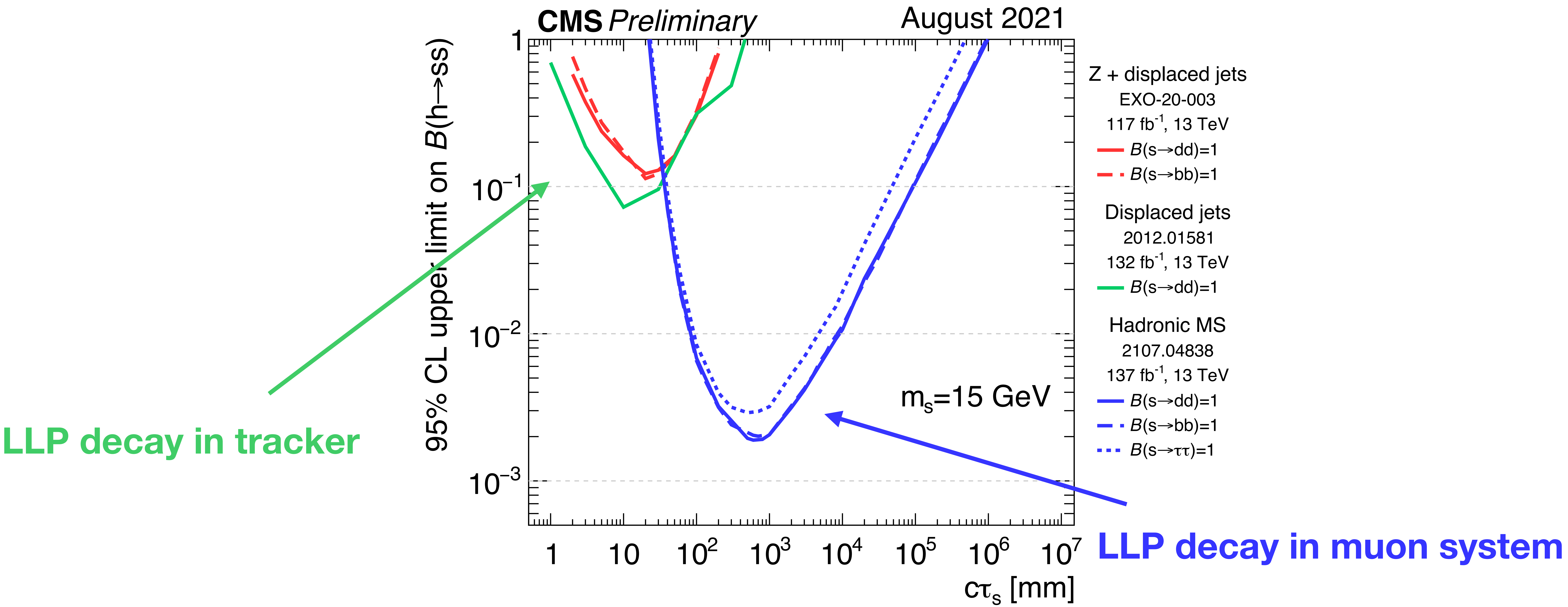
Meta-stable invisible final state → displaced signature



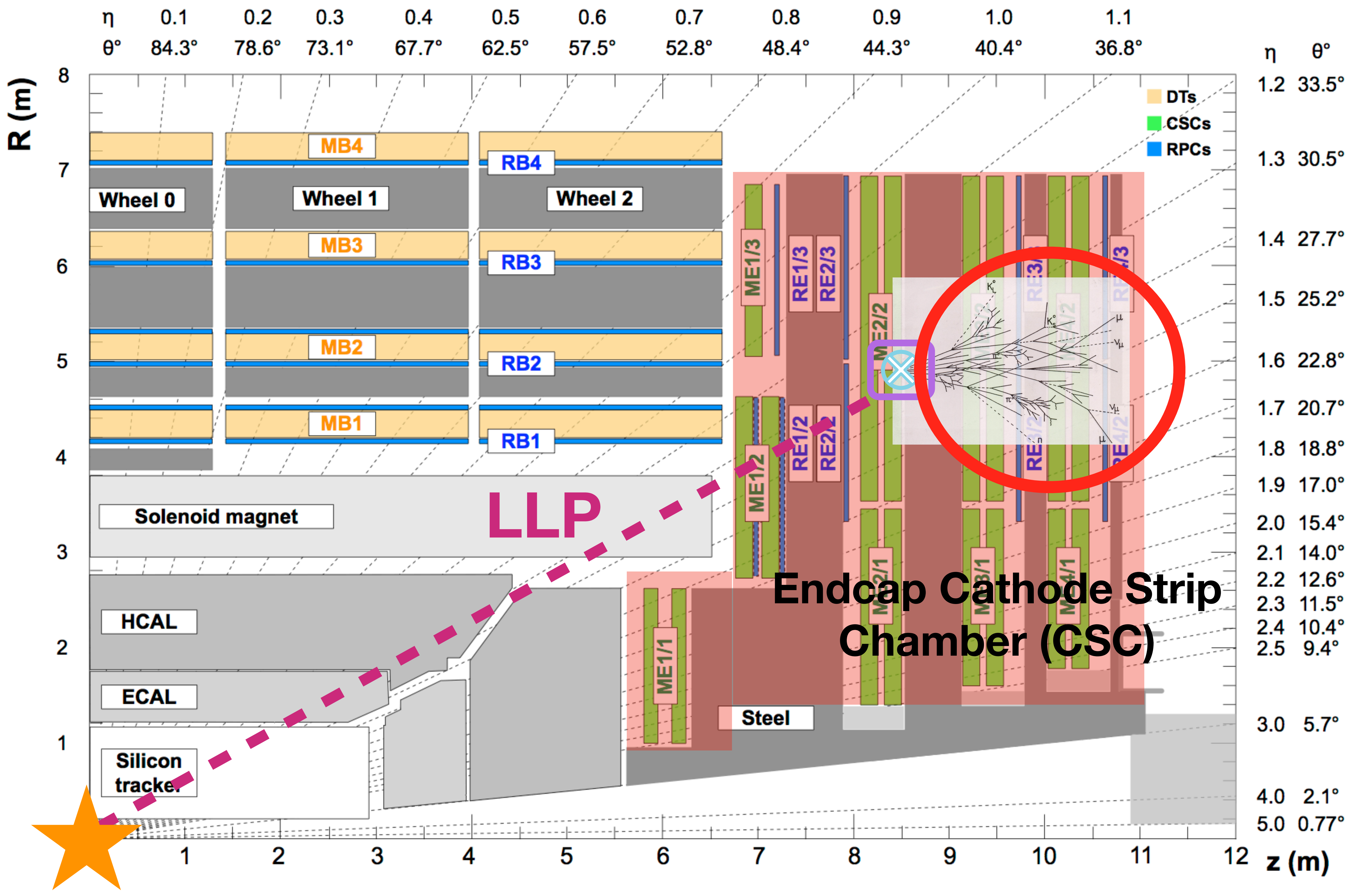


H→LLPs



- **Many LLP searches in CMS using different sub-detectors targeting different final states**
    - Focus on LLP decay in the muon system for this talk

H→LLPs with Muon System

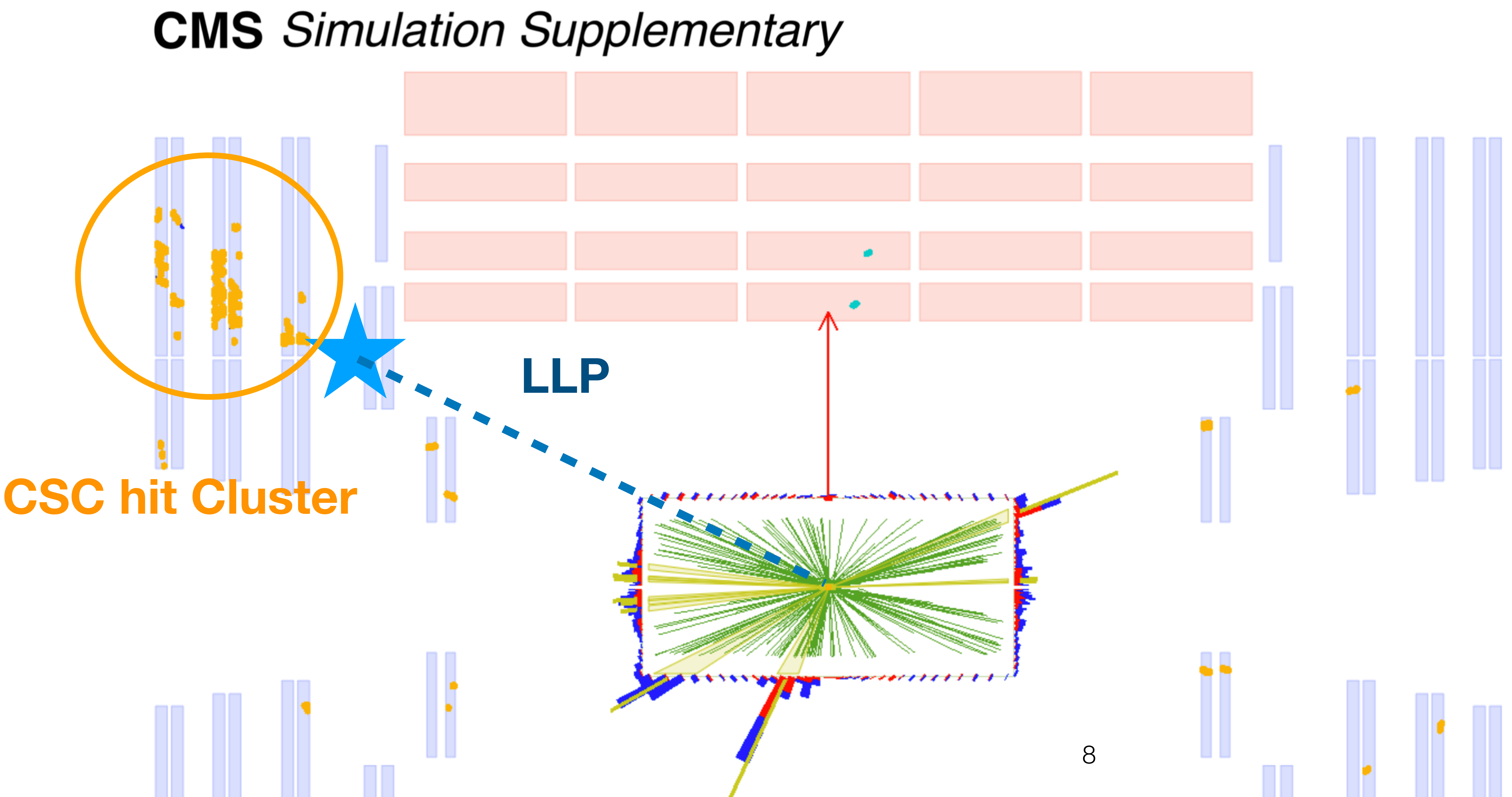


LLP decay and resulting particle shower is detected with a **large hit multiplicity**

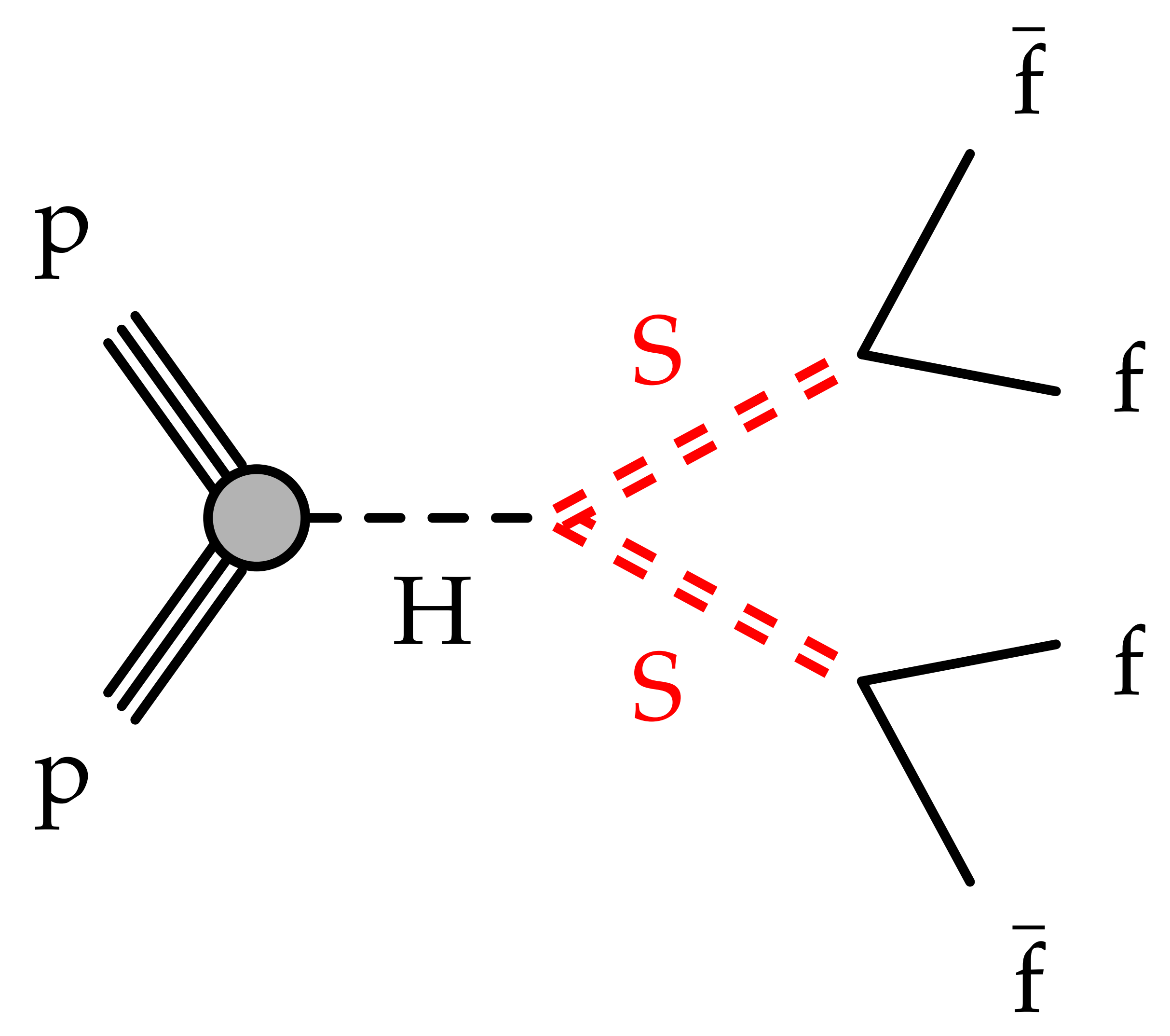
- Muon system covers decays far away from IP (sensitive to large cτ)
- Excellent **background suppression** from shielding material
- Steel interleaved with active chambers → **sampling calorimeter**

Displaced Showers in the CMS Muon System

- Muon system acts as a **sampling calorimeter:** sensitive to a broad range of decays: quarks, taus, pions, kaons, electrons, photons…
- Search for **displaced shower with high multiplicity** isolated from jets and muons
- Due to the shielding and the exotic signature, this analysis can be sensitive to **very light LLPs** (m_{LLP} ~ GeV)



Twin Higgs as benchmark model



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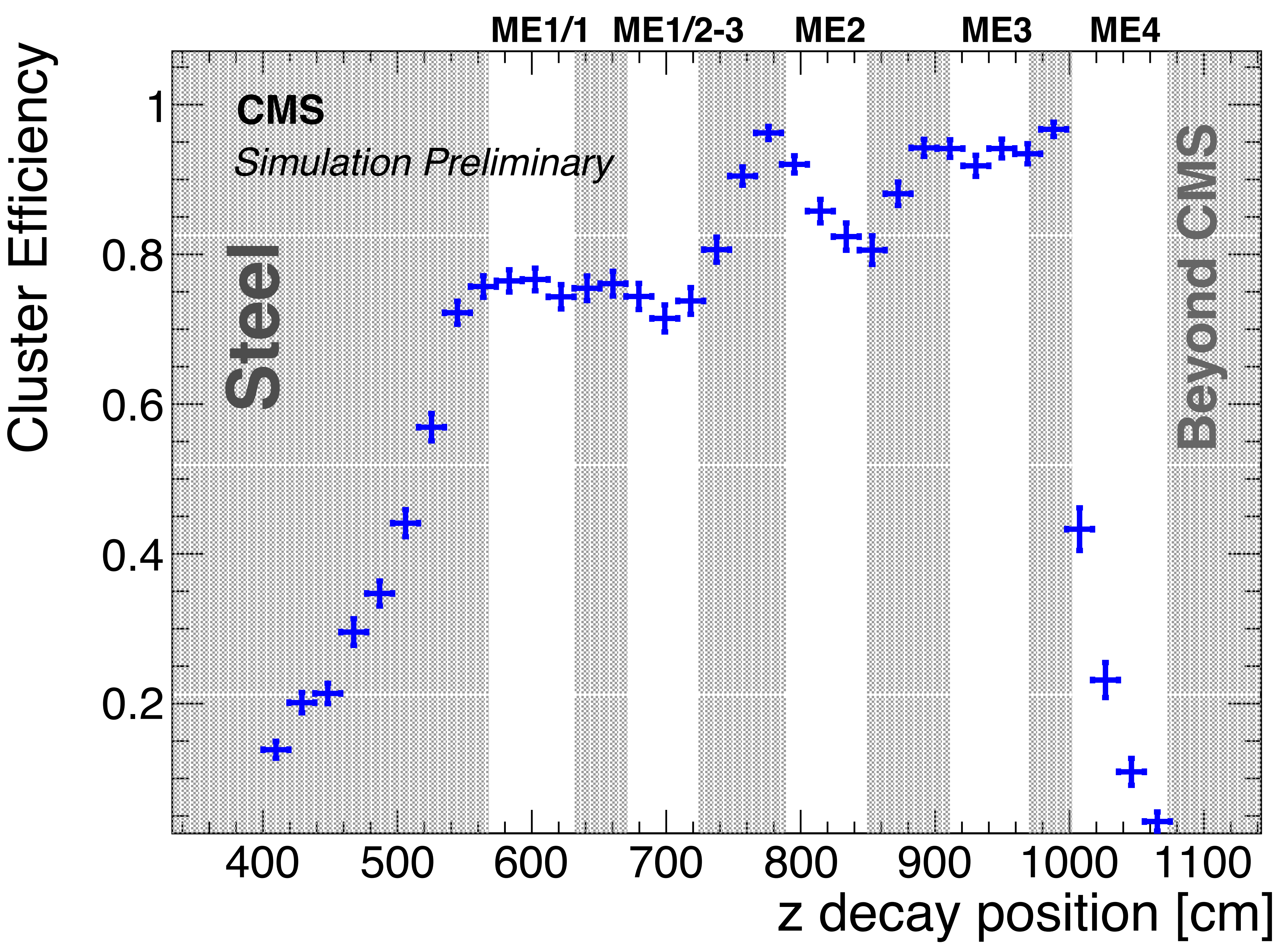
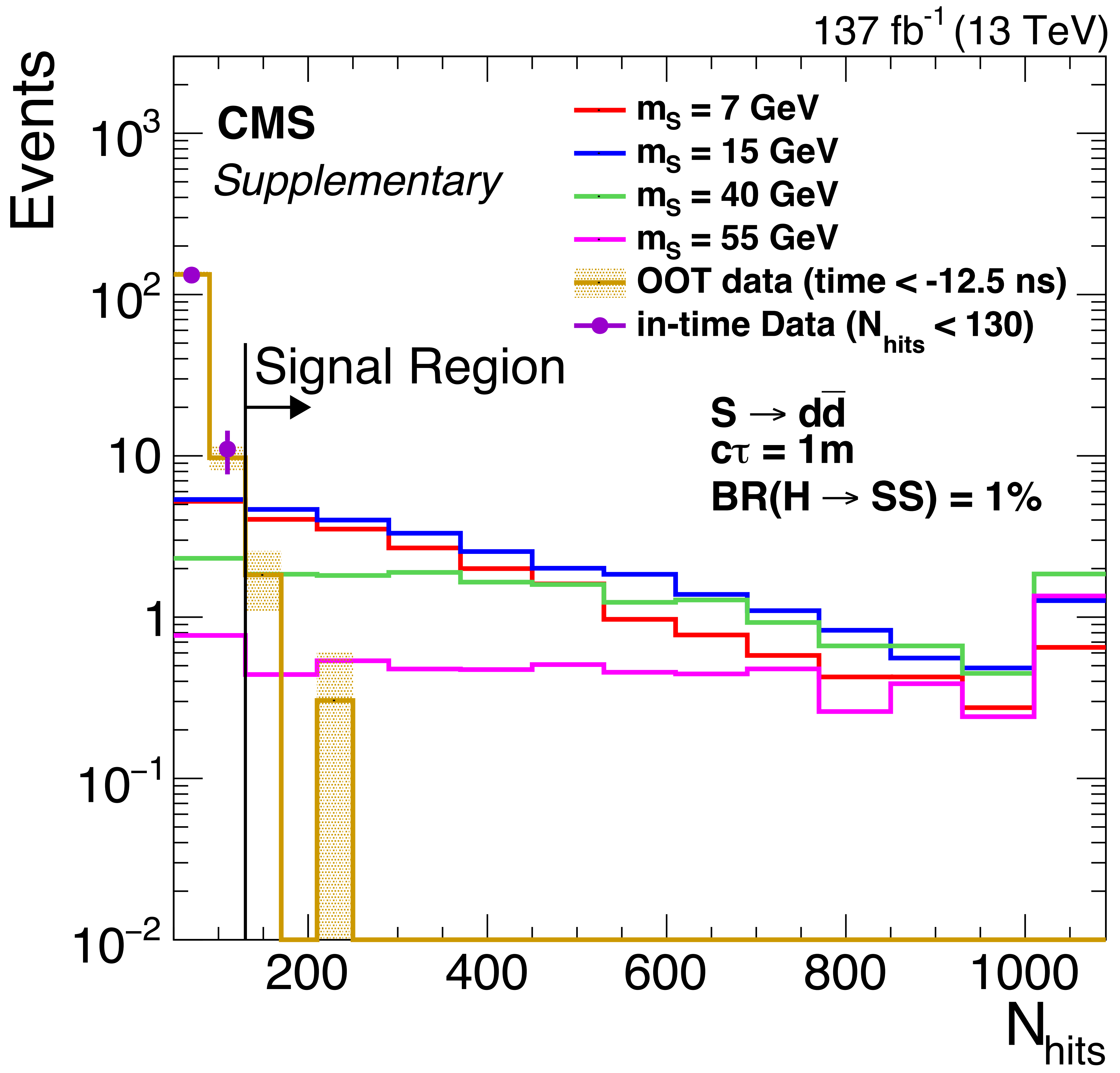
Muon System Analysis Strategy

- **Event selection:** select high MET (MET > 200 GeV) and boosted Higgs phase space
  - Trigger on MET (lack of dedicated trigger, trigger efficiency is ~1%)
- Use **cluster ID** selections to enhance signal purity and reject background from main collision (overall background rejection ~10^6)
- N_{hits} serves as the main discriminator

High cluster reconstruction efficiency

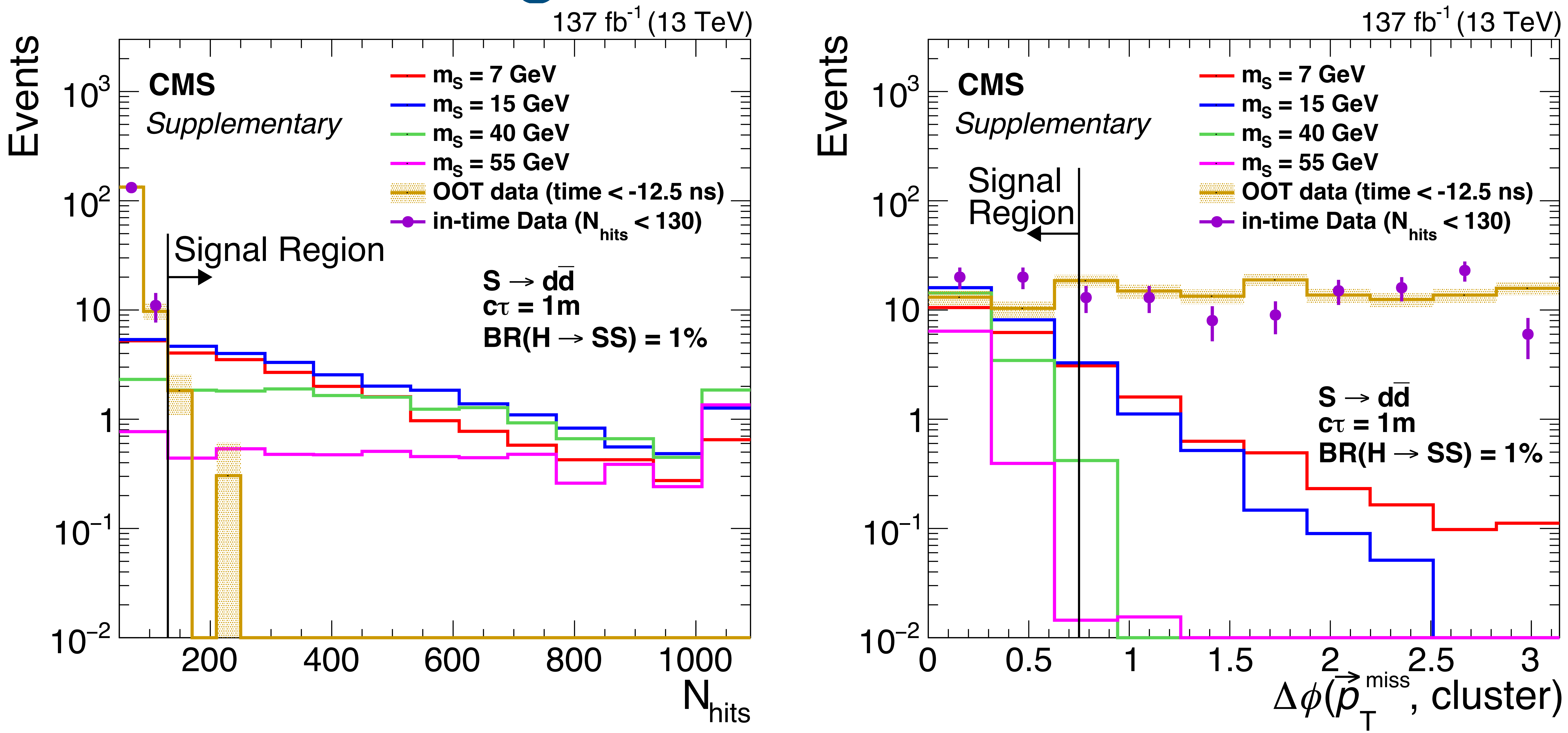


N_{hits} as main discriminator



Only endcap used in this analysis

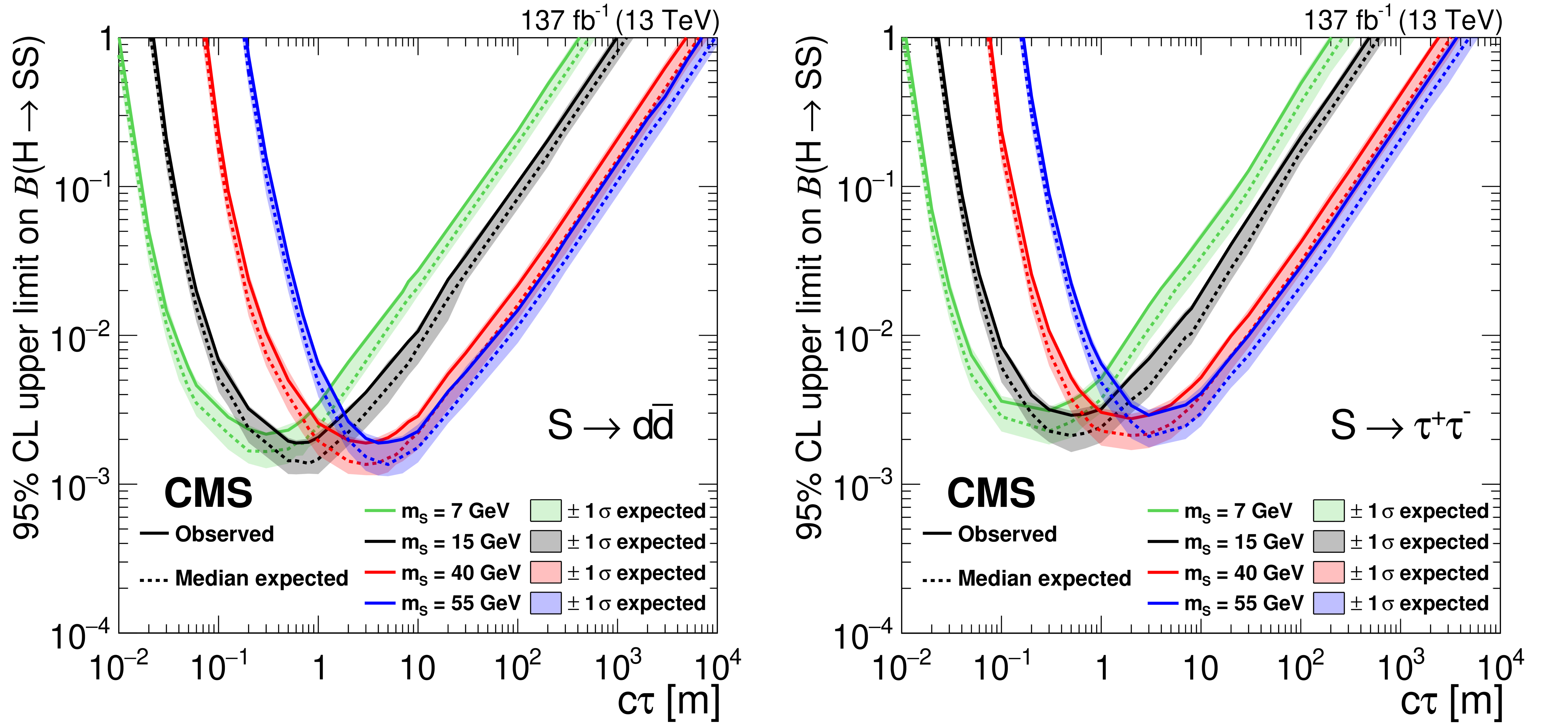
Data-driven Background Estimation



- Use fully data-driven background estimation method (ABCD method) to extract signal using two independent variables for background
- Cluster and MET directions are aligned for signal

Observed and Expected Limits

Predict 2 ± 1 background events and observed 3 events

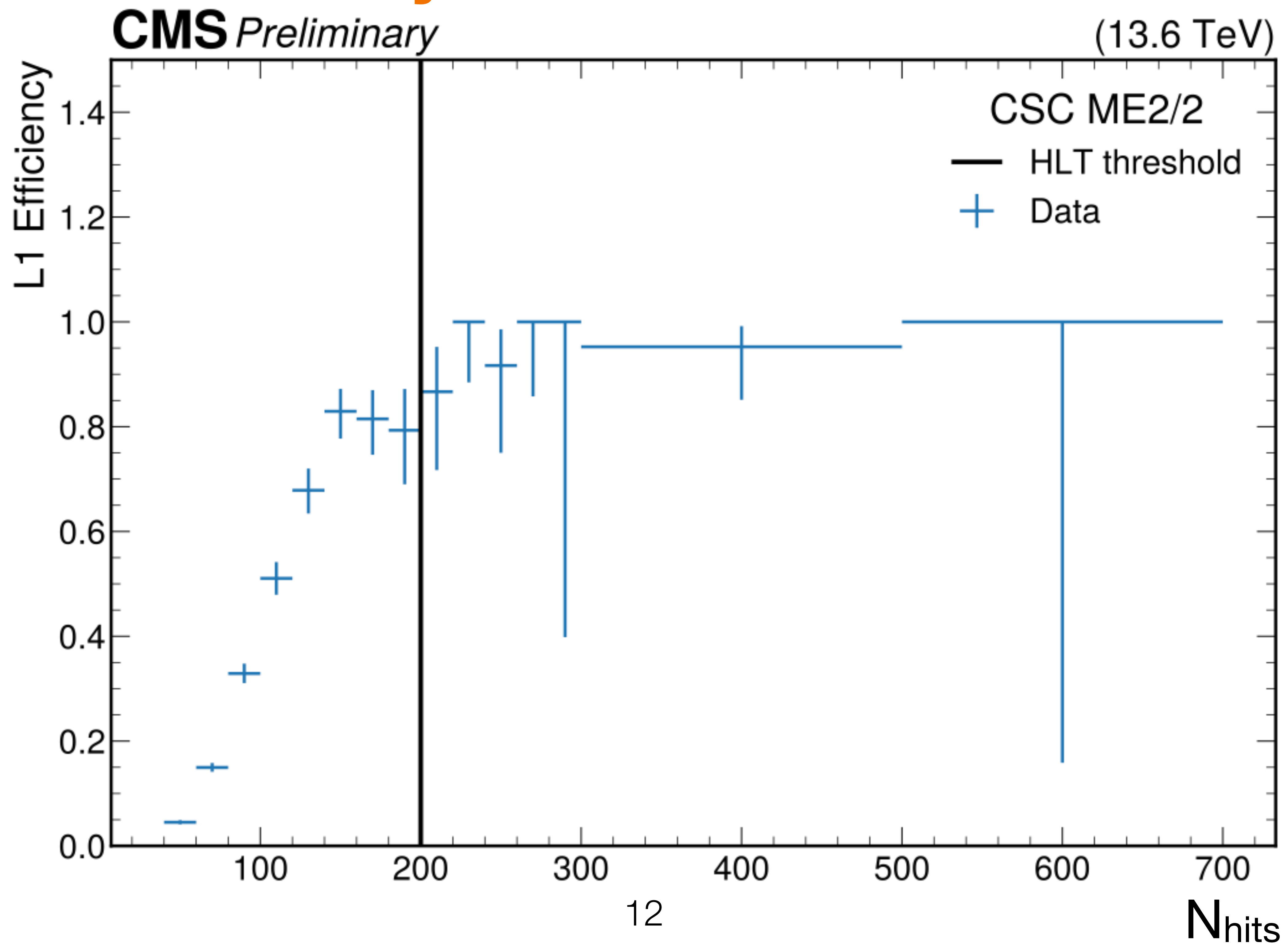


- No excess above SM background observed
- Analysis sensitivity is independent of the **LLP masses**
- Provides current best LHC limit for LLPs with cτ above 6, 20, and 40 m for mass of 7, 15, and 40 GeV respectively.
- Achieve first sensitivity to **τ decay modes** at BR(H →ss) = 10^{-3} level

Outlook to Run 3

- For Run 2, triggering on MET (only 1% efficiency for higgs portal)
- **New L1 CSC shower seed** selecting for a large number of cathode and anode-wire hits in CSC chambers
- **New HLT paths** targeting single and double muon detector showers
- **Actively analyzing the 23/fb of data taken in 2022**

High L1 efficiency measured w.r.t. offline object



Summary

- Presented searches for Higgs decaying to invisible final states that are stable (DM) or meta-stable (LLPs)
  - H→Inv search set upper limit on BR (h → inv) to be 15%
  - H→LLPs decaying in the muon detectors can probe BR(H → ss) ~ 0.1% for light LLPs
- Looking forward: New LLP triggers for Run3, with ~10x trigger efficiency expect to significantly improve the discovery reach for new physics

Backup Slides

Cluster Selections

- Reject clusters from **punch-through jets** and **muon bremsstrahlung shower**:
  - Veto clusters matched to jets and muons ($\Delta R < 0.4$)
  - Active vetos in first station (ME11/12 or MB1)
- ~50% signal efficiency when LLP decays between ME1 and ME4
- Background rejection is ~10^6

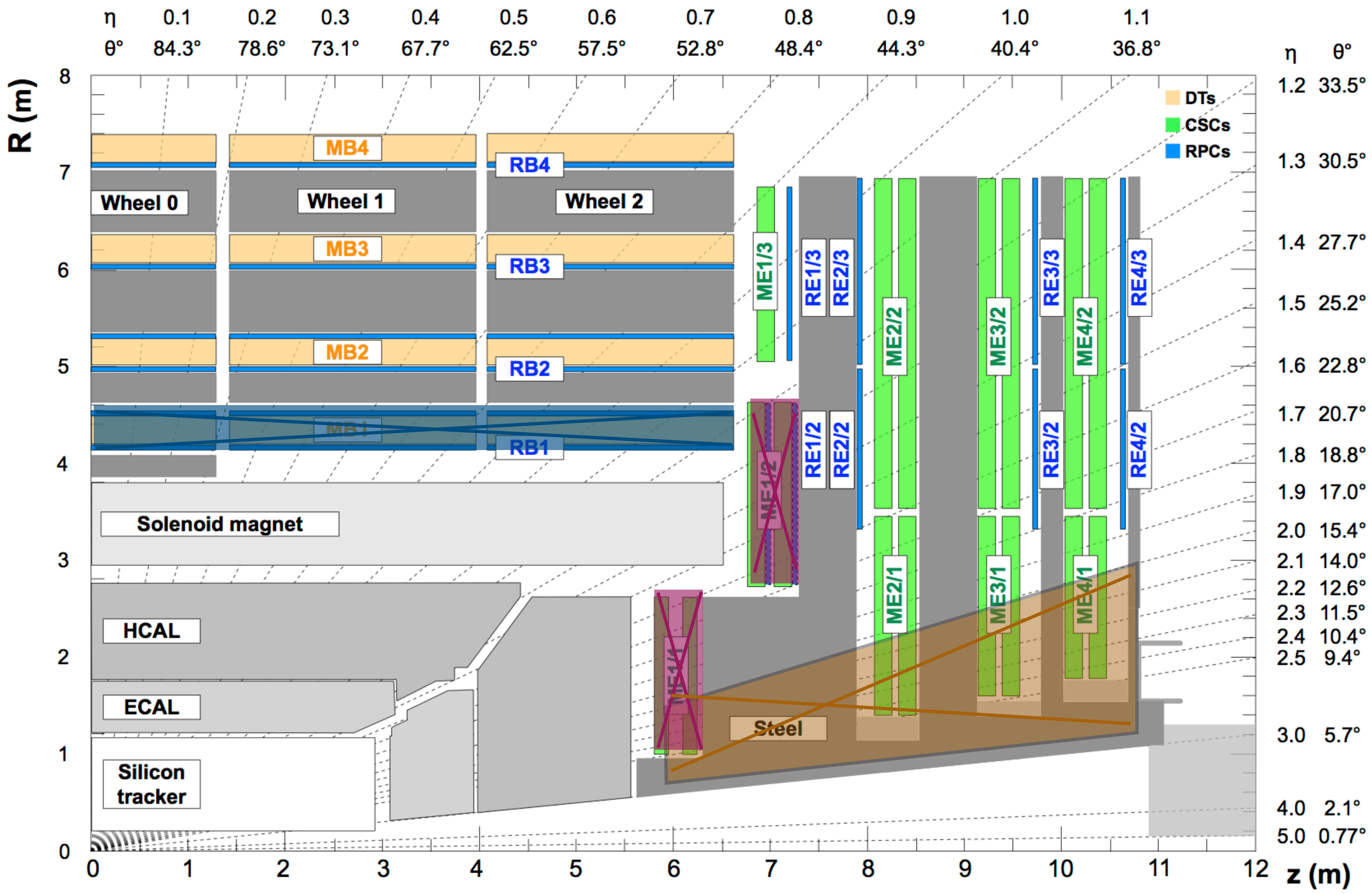
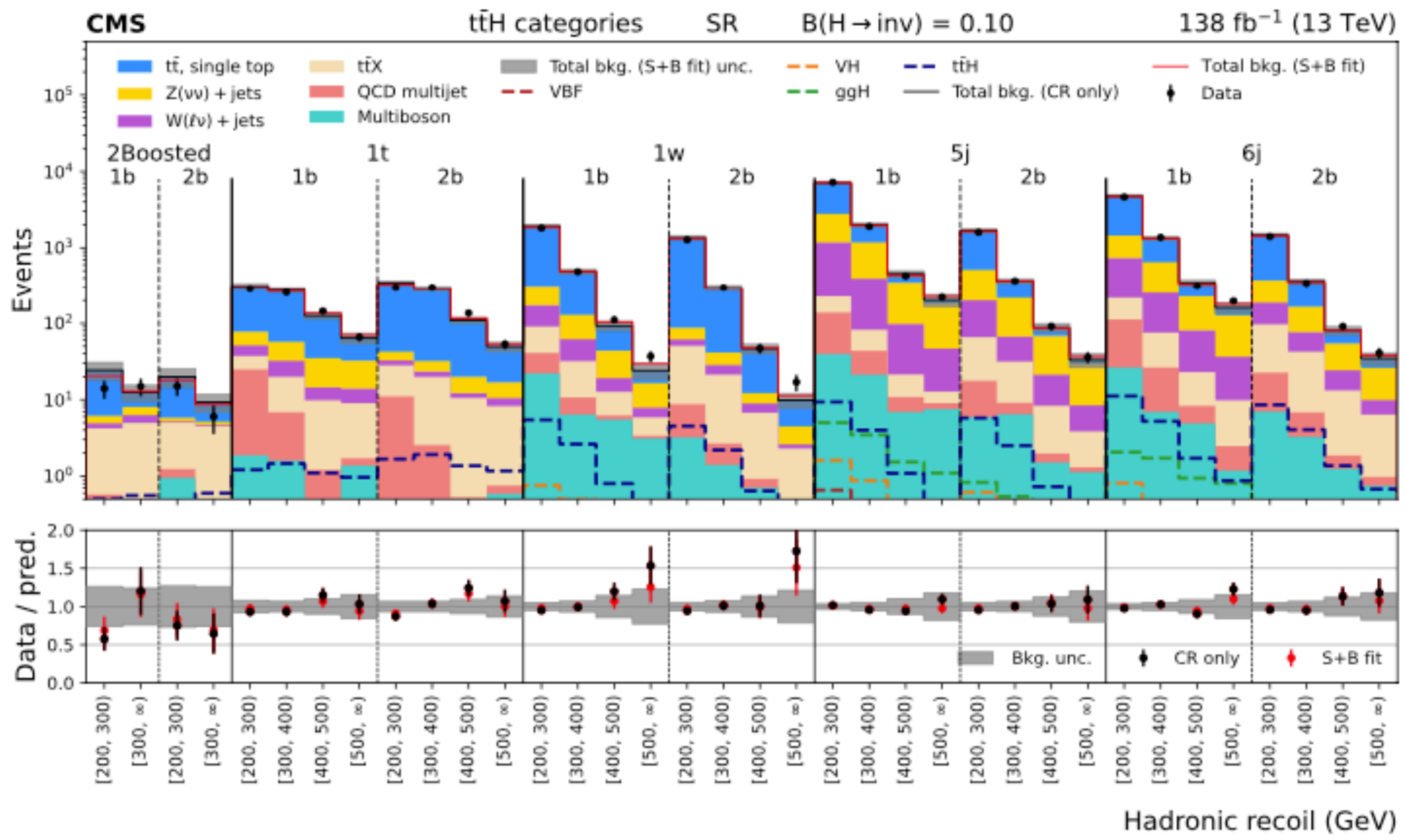
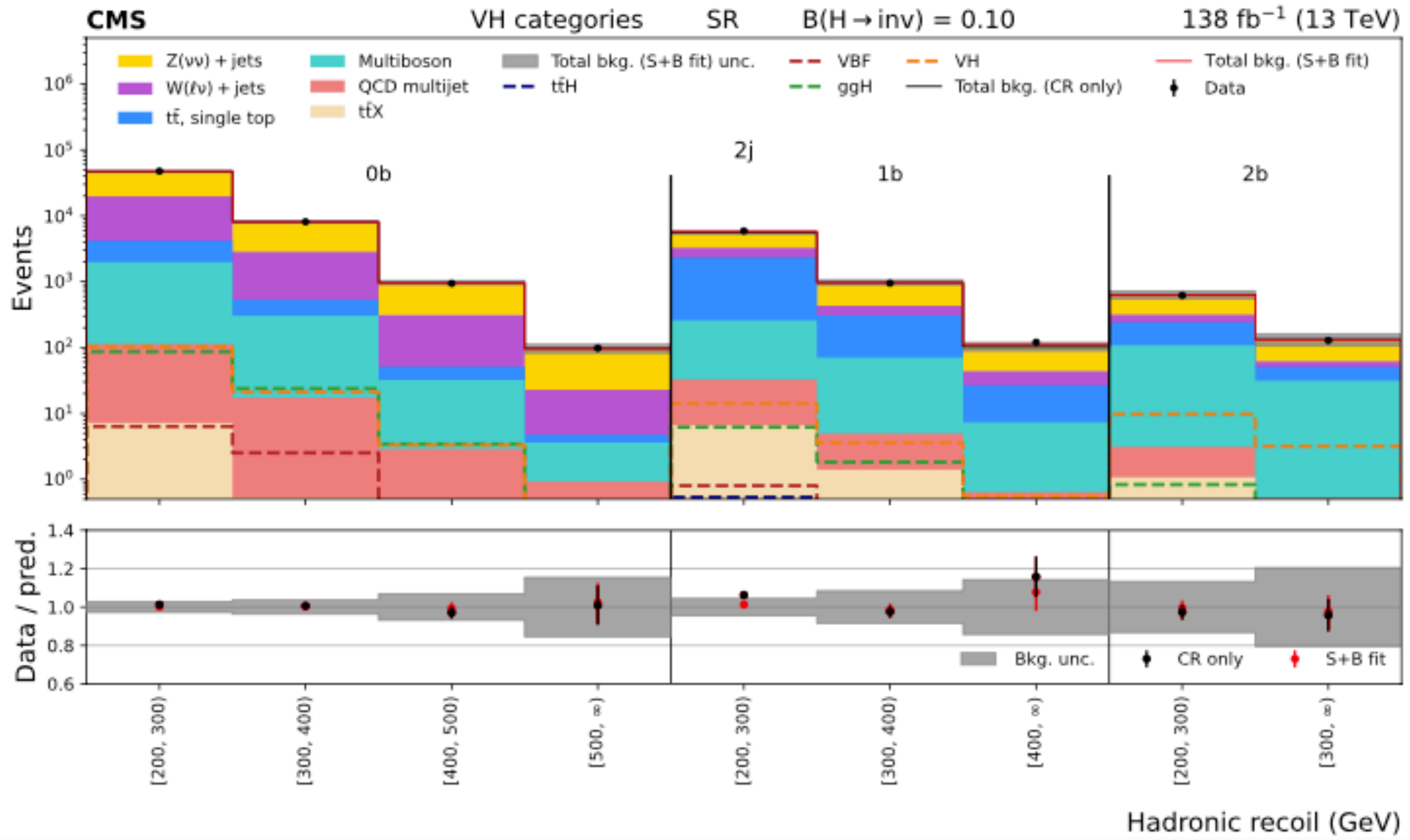


Table 8: Data sets and their respective integrated luminosities used for each production mode across Run 1 and Run 2. For some data-taking periods, no H $\to$ inv search have been performed for the given production mode, and are not included in the combination.

Analysis tag	Production mode	Integrated luminosity (fb^{-1})		
		7 TeV	8 TeV	13 TeV (Run 2)
VBF-tagged	VBF	—	19.2 [90]	140 [89][34]
VH-tagged	$Z(\ell\ell)H$	4.9 [90]	19.7 [90]	140 [89][32]
	$Z(b\bar{b})H$	—	18.9 [90]	—
	V(jj)H	—	19.7 [91]	140 [89][this paper]
	Boosted VH	—	—	138 [33]
$t\bar{t}H$-tagged	$t\bar{t}H$ (hadronic)	—	—	138 [this paper]
	$t\bar{t}H$ (leptonic)	—	—	138 [29, 30]
ggH-tagged	ggH	—	19.7 [91]	140 [89][33]


CMS
tt̄H categories SR B(H→inv) = 0.10
138 fb^{-1} (13 TeV)
tt̄, single top
Z(νν) + jets
W(ℓν) + jets
tt̄X
QCD multijet
Multiboson
Total bkg. (S+B fit) unc.
VBF
VH
ggH
tt̄H
Total bkg. (CR only)
Total bkg. (S+B fit)
Data
2Boosted
1t
1w
5j
6j
1b
2b
Events
Data / pred.
Bkg. unc.
CR only
S+B fit
Hadronic recoil (GeV)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VBF
ggH
VH
Total bkg. (CR only)
Total bkg. (S+B fit)
Data
0b
2j
1b
2b
Events
Data / pred.
Bkg. unc.
CR only
S+B fit
Hadronic recoil (GeV)

$$
\begin{aligned}
\sigma_{SN}^{\mathrm{SI}} &= \frac{\lambda_{HSS}^2}{16\pi m_H^4} \frac{m_N^4 f_N^2}{(m_S + m_N)^2}, \\
\sigma_{VN}^{\mathrm{SI}} &= \frac{\lambda_{HVV}^2}{16\pi m_H^4} \frac{m_N^4 f_N^2}{(m_V + m_N)^2}, \\
\sigma_{fN}^{\mathrm{SI}} &= \frac{\lambda_{Hff}^2}{4\pi \Lambda^2 m_H^4} \frac{m_N^4 m_f^2 f_N^2}{(m_f + m_N)^2},
\end{aligned}
$$