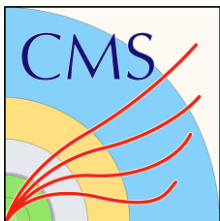


Search for light scalars decaying to muons and hadrons via Higgs portal

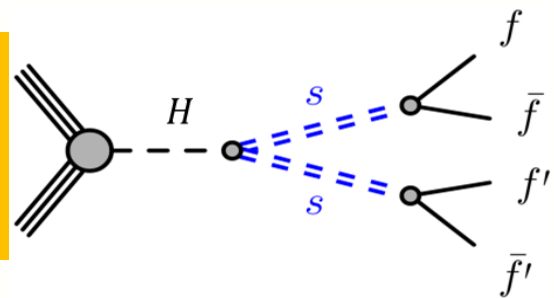
Soumya Dansana (ULB-VUB), on behalf of the CMS Collaboration



Belgian Physical Society General Scientific Meeting, 2024

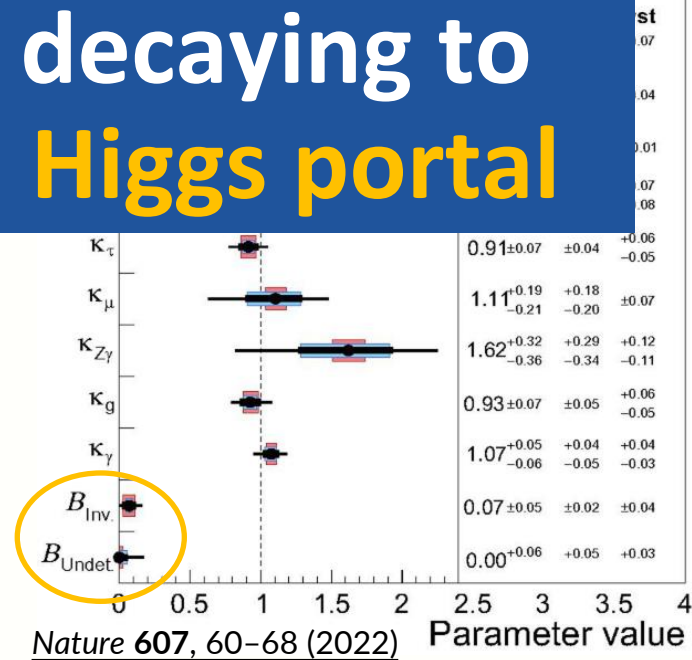
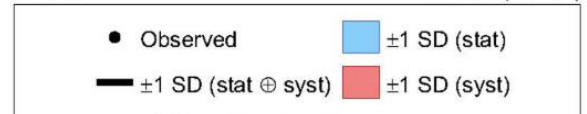
Search for **light scalars** decaying to muons and hadrons via Higgs portal

Higgs boson: Only fundamental scalar found in Standard Model
Physics beyond SM: Extend SM with additional light scalars!
[$m_S \sim \mathcal{O}(\text{GeV})$]



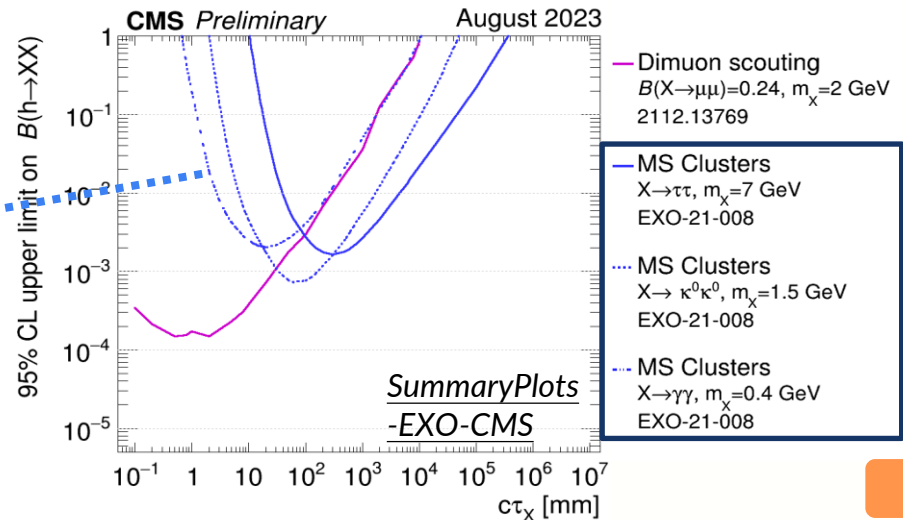
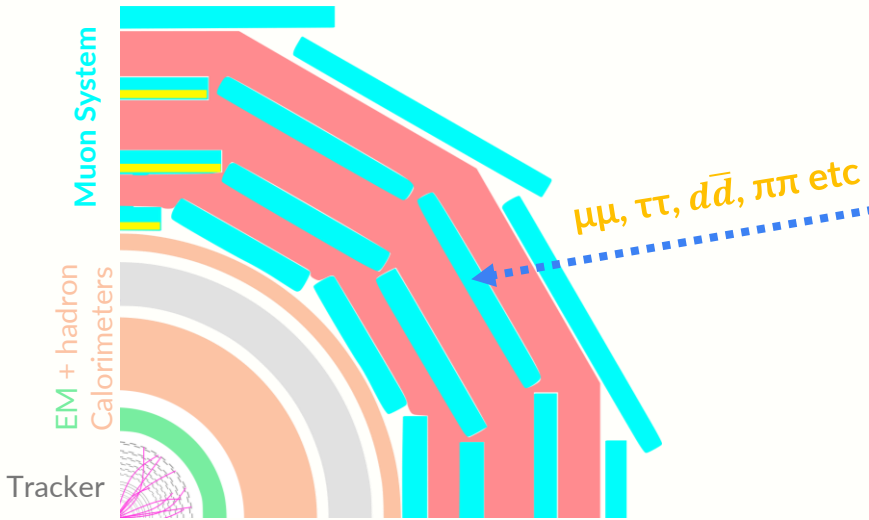
Search for light scalars decaying to muons and hadrons via **Higgs portal**

Higgs portal : Exotic decays of SM Higgs
 $BR(H \rightarrow \text{undetected}) < 0.16$ @ 95% CL \rightarrow
 Lots of phase space for new physics!



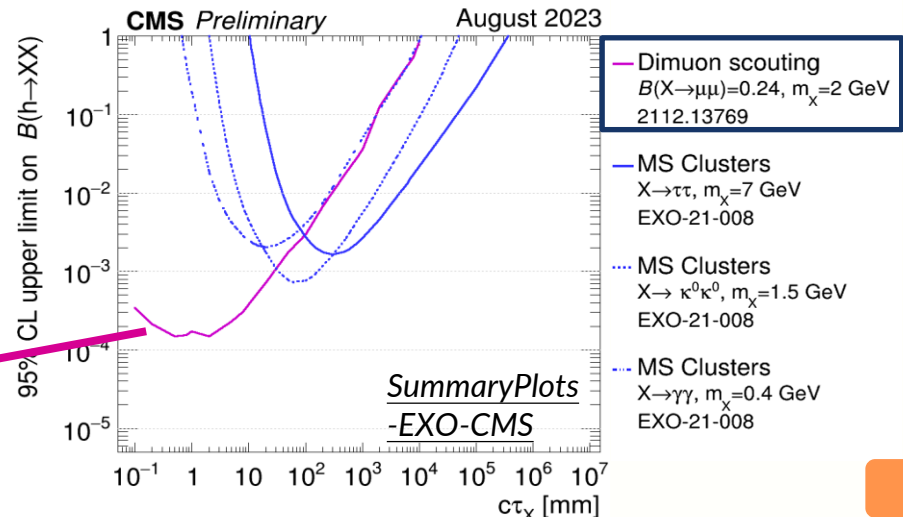
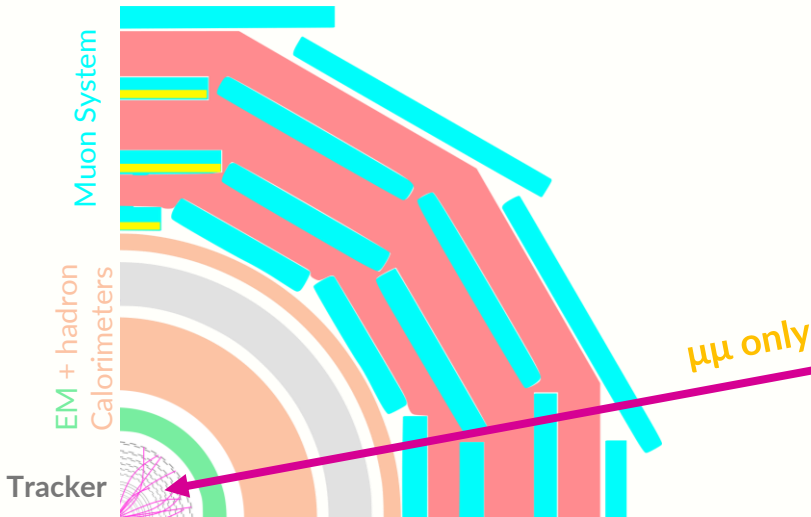
Several decay modes possible, with lifetime as the free parameter

Search for light scalars decaying to muons and hadrons via Higgs portal

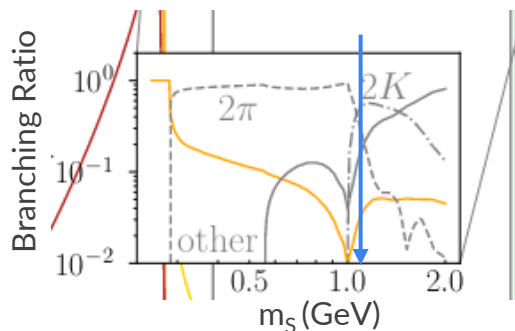
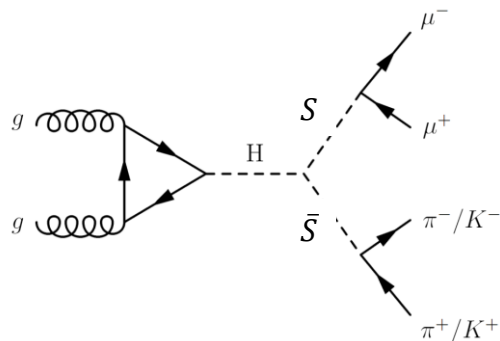


This analysis: $\mu\mu$ + hh final states in the tracker volume!

Search for light scalars decaying to muons and hadrons via Higgs portal

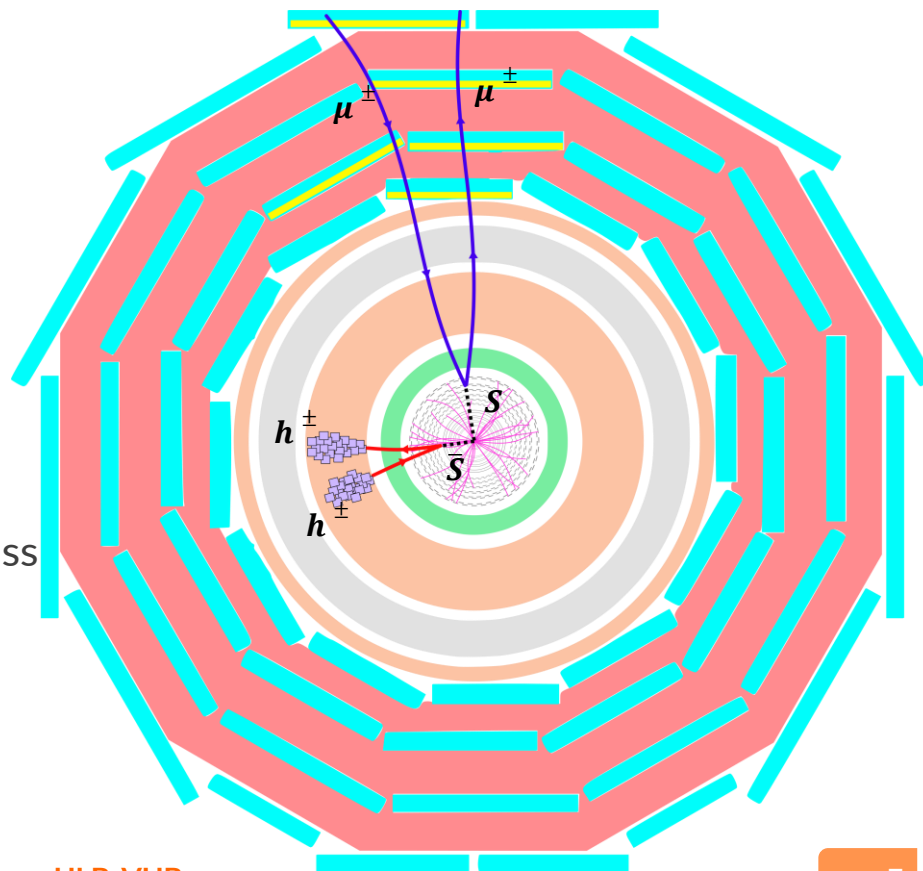


- Search signal: $H \rightarrow S\bar{S} \rightarrow \mu^+\mu^- + \pi^+\pi^-/K^+K^-$
 - $m_S \in [0.4, 2]$ GeV; $c\tau \in [0, 100]$ mm
- Signature: Highly collimated muon pairs & hadron pairs
 - No jets due to limited phase space
- Split the analysis into:
 - $H \rightarrow S\bar{S} \rightarrow \mu^+\mu^- + \pi^+\pi^-$ $m_S \in [0.4, 1.1]$ GeV
 - $H \rightarrow S\bar{S} \rightarrow \mu^+\mu^- + K^+K^-$ $m_S \in [1.1, 2]$ GeV
- Analysis targeting full CMS Run-2 data-taking
 - Current results for 2017 only

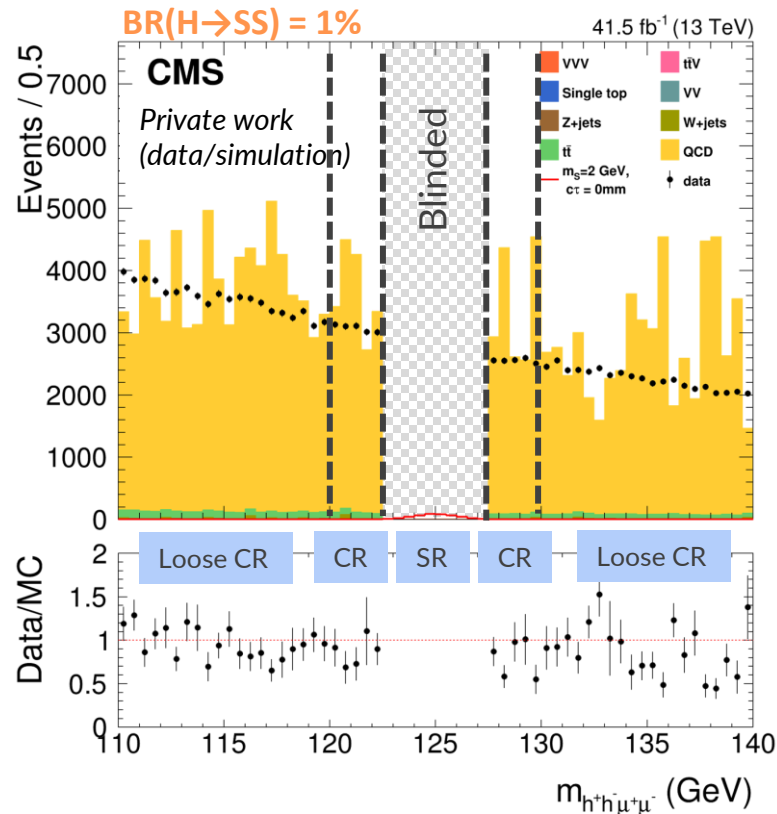


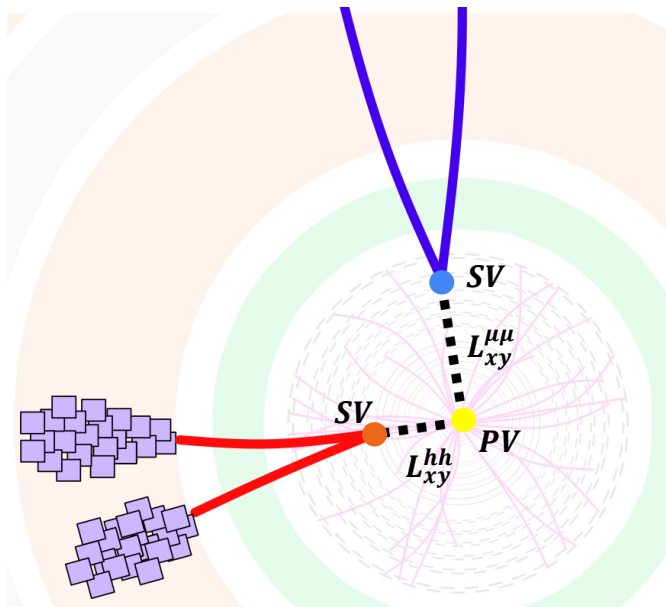
[j.physletb.2021.136758](https://arxiv.org/abs/2103.13675)

- Challenge(s):
 - Large possibility of hadron pair formation
 - Large bkg at low dimuon masses
- Trigger on leading muon
- Selection: Events with boosted dimuon & dihadron vertices with reco. SM Higgs mass

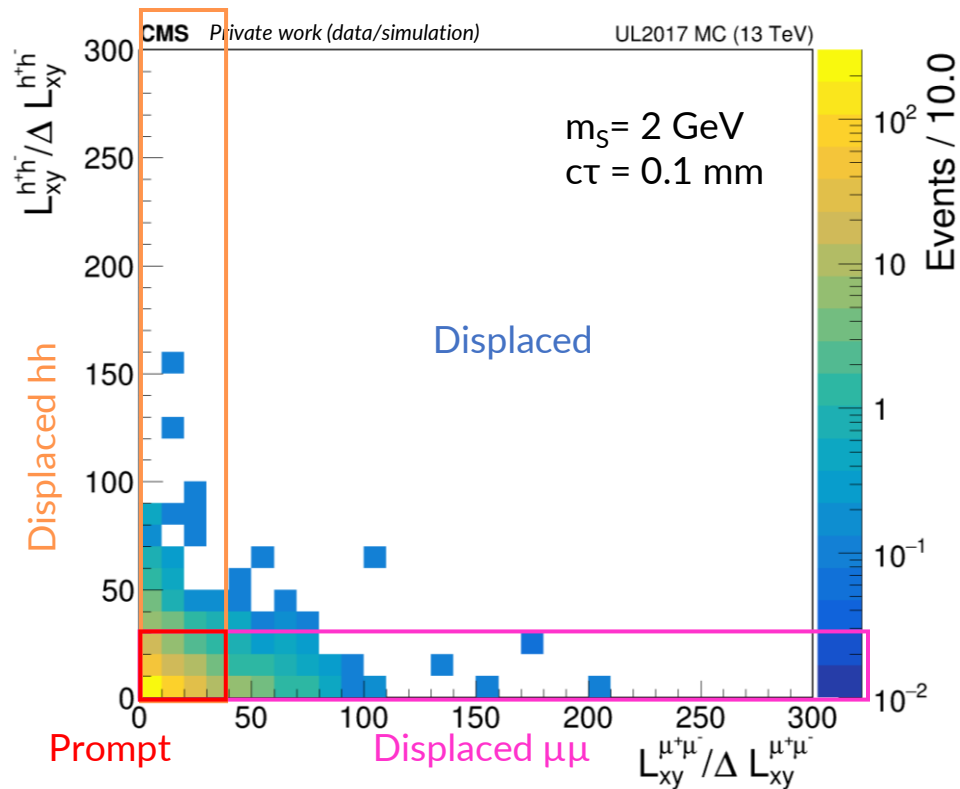


- Reject low energy events coming from SM processes
- Major background contribution : multijet events from QCD processes
- Blinding applied to data in Signal Region (SR)
- Define Control Regions (CR) in sidebands

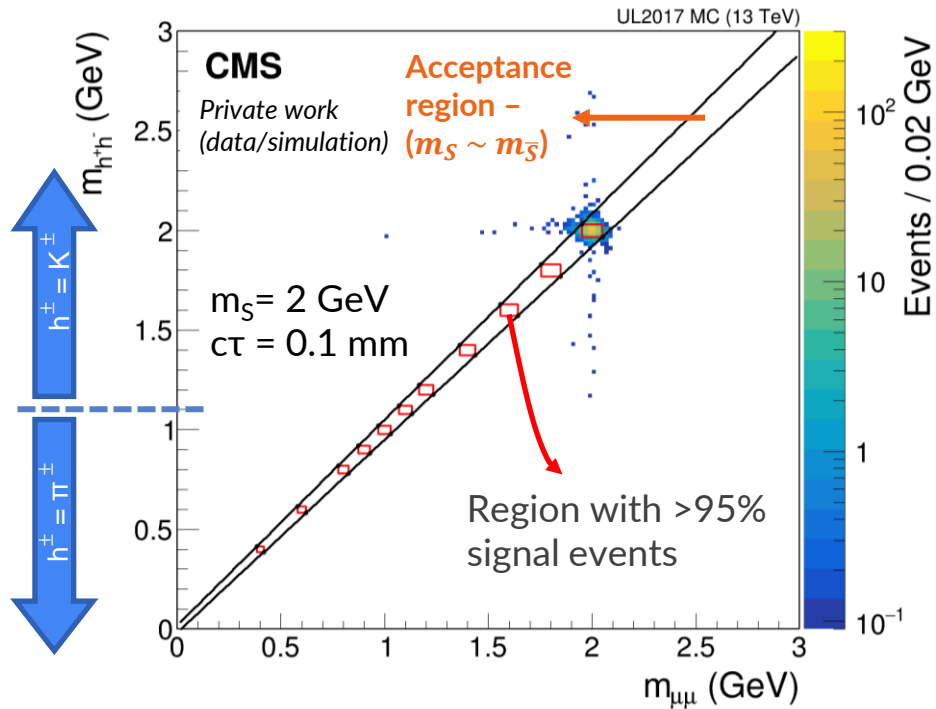




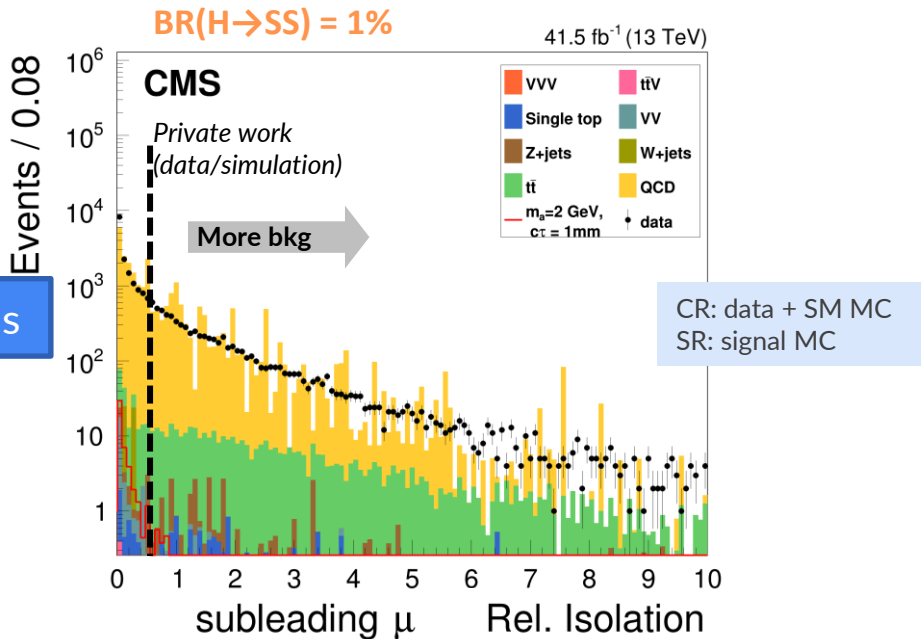
- Transverse displacement from primary vertex (L_{xy}) acts as additional handles
 - Reject bkg: Require a valid secondary vertex
- Tracks “refitted” to secondary vertex lead to better reco. scalar mass resolution



- Based on L_{xy} significance ($=L_{xy}/\Delta L_{xy}$)
 - Accounts for error in SV reconstruction
- Categories:
 - Prompt: ~90% of $c\tau=0.1\text{mm}$ signal
 - Displaced $\mu\mu$
 - Displaced hh
 - Displaced: both reco. scalars are displaced
- Approx. 80% of bkg in prompt

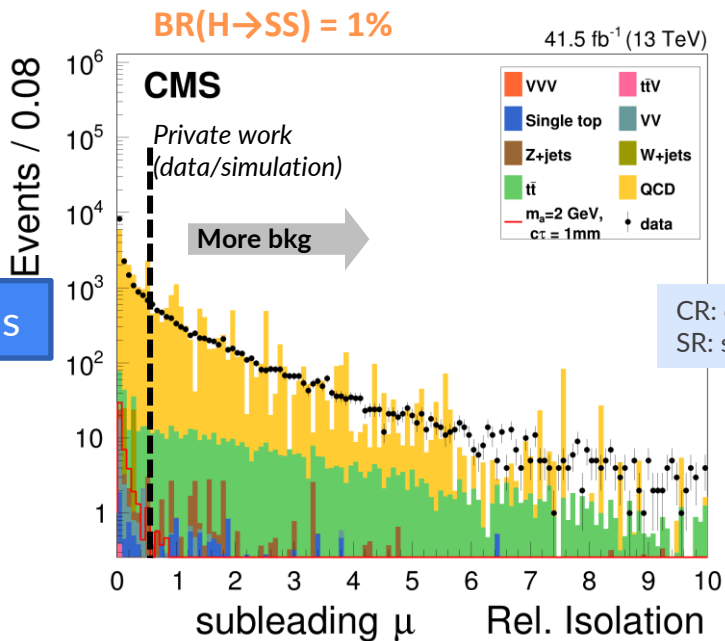


$m_S \in [0.4, 0.6, 0.8, 0.9, 1, 1.1, 1.2, 1.4, 1.6, 1.8, 2] \text{ GeV}$ for each $c\tau = 0.1\text{mm}$

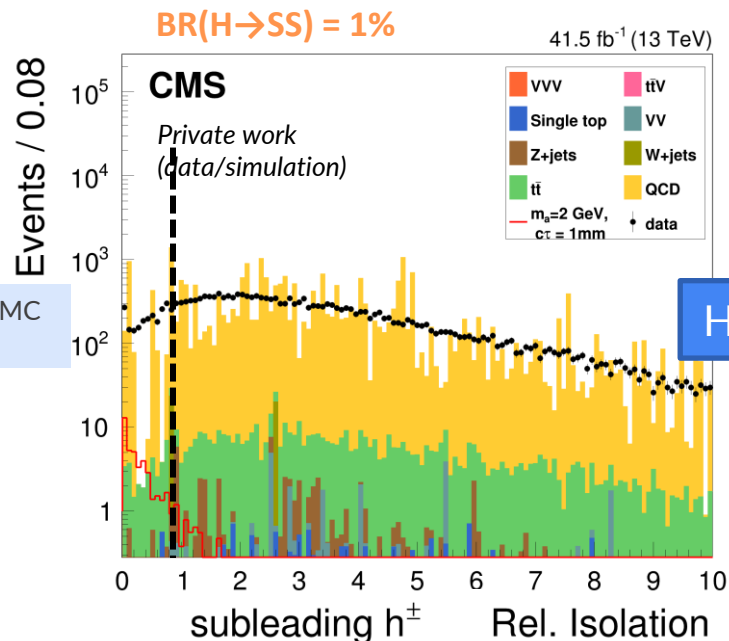


Muons

- Commonly used measure to describe hadronic activity around an object
- Optimise with tight (loose) cuts for “prompt” category (“displaced-” categories)

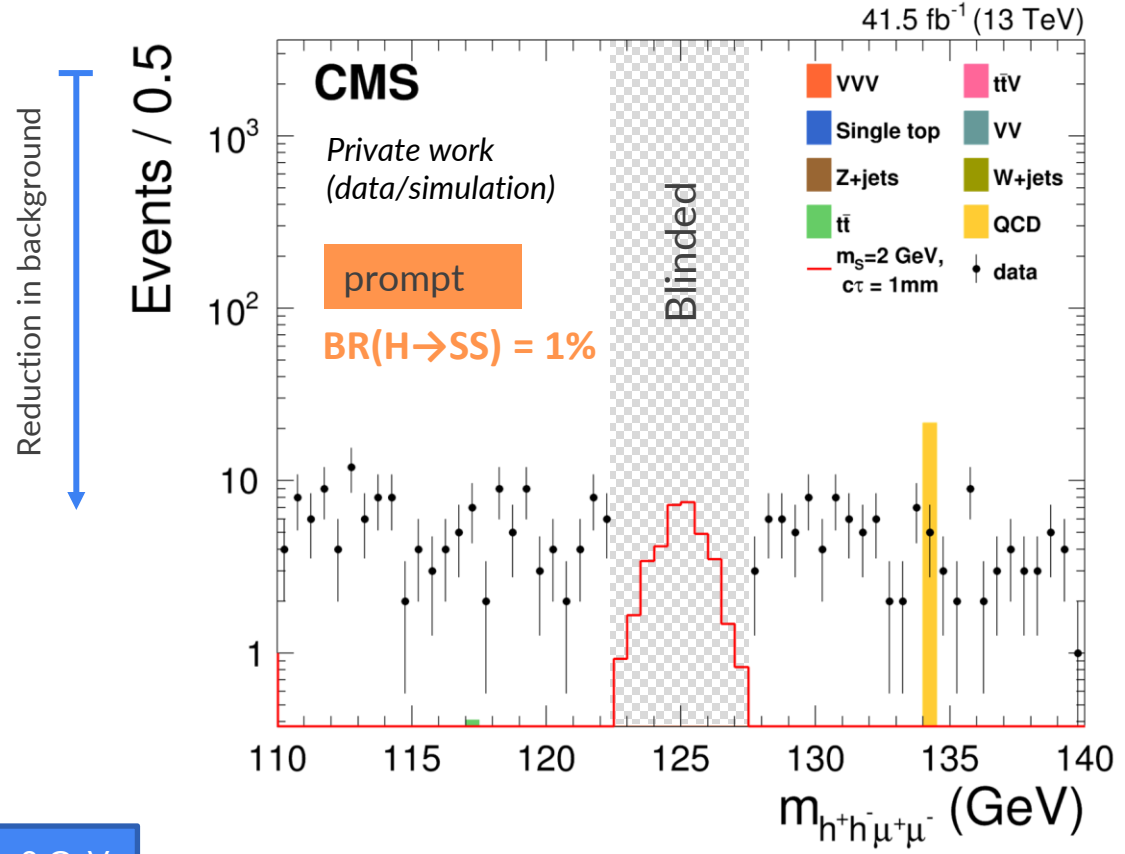


Muons



Hadrons

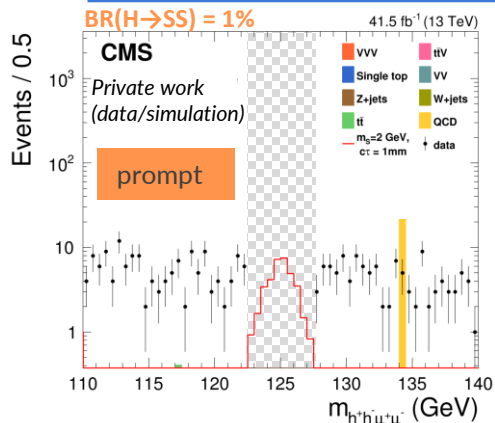
- Commonly used measure to describe hadronic activity around an object
- Optimise with tight (loose) cuts for “prompt” category (“displaced-” categories)



Low statistics in background MC

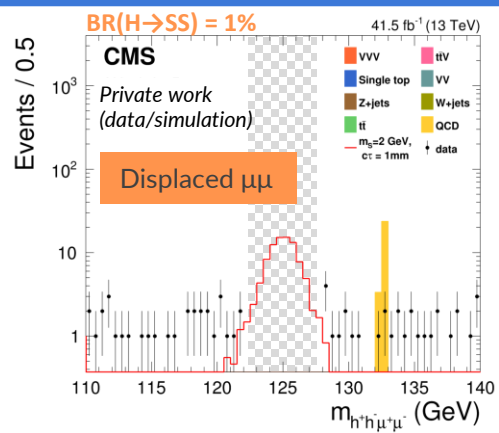
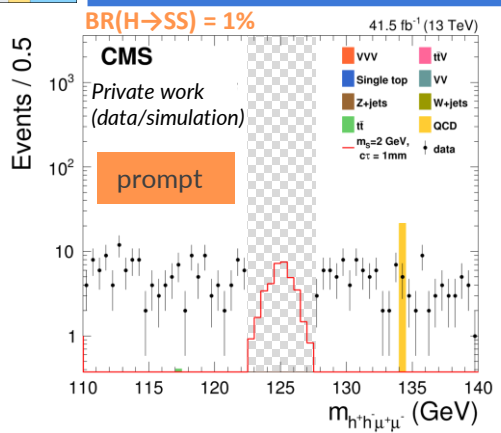
Rely on data for background estimation

m_S=2 GeV,
c τ =1 mm



Displaced category ~ bkg free

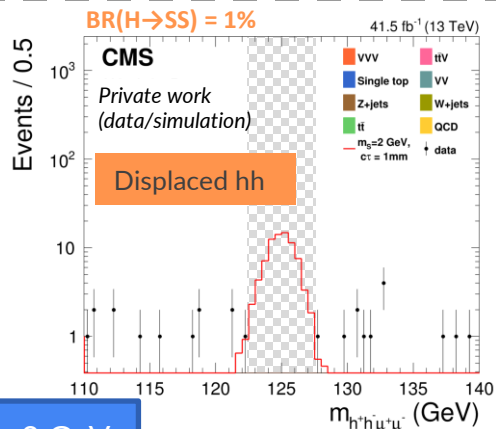
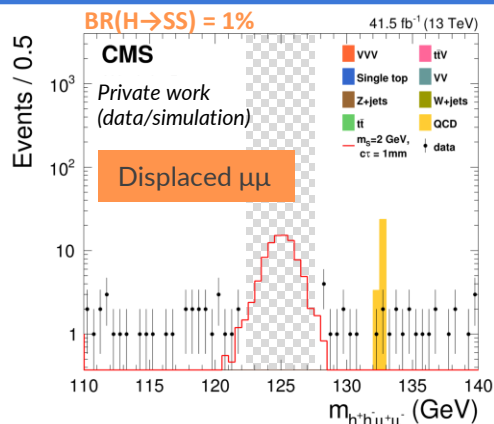
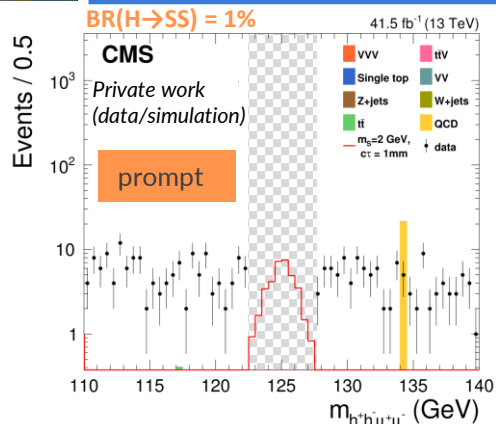
$c\tau=1$ mm has sensitivity across all categories



Displaced category ~ bkg free

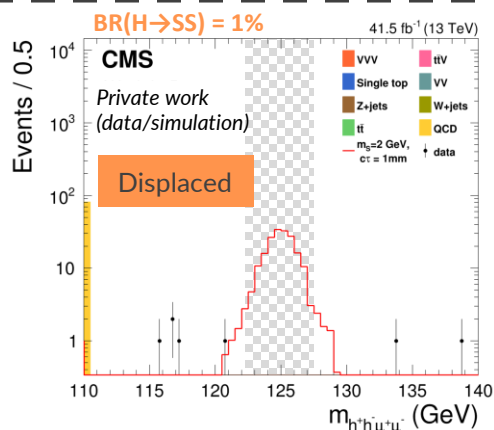
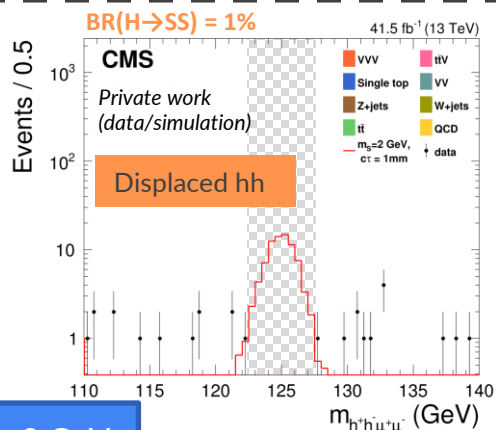
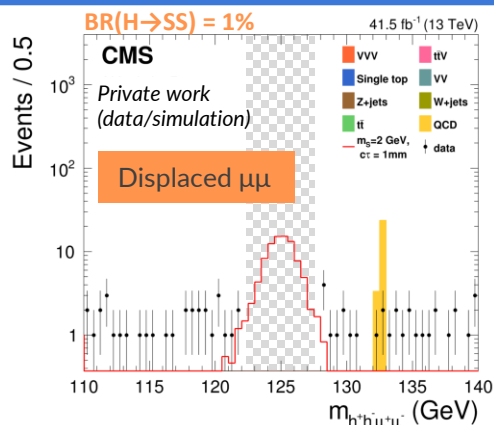
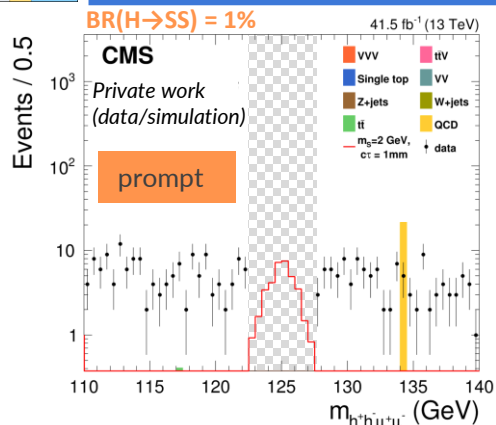
$\tau=1\text{mm}$ has sensitivity across all categories

$m_s=2\text{ GeV}$,
 $\tau=1\text{ mm}$



Displaced category ~ bkg free
 $\tau=1\text{mm}$ has sensitivity across all categories

$m_h=2\text{ GeV}$,
 $\tau=1\text{ mm}$

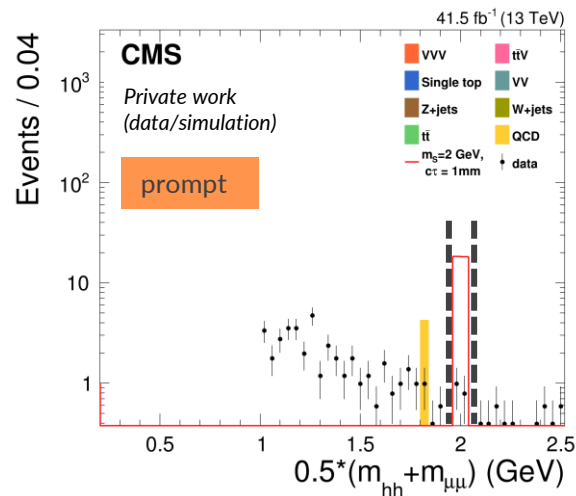


Displaced category ~ bkg free
 $\tau=1\text{mm}$ has sensitivity across all categories

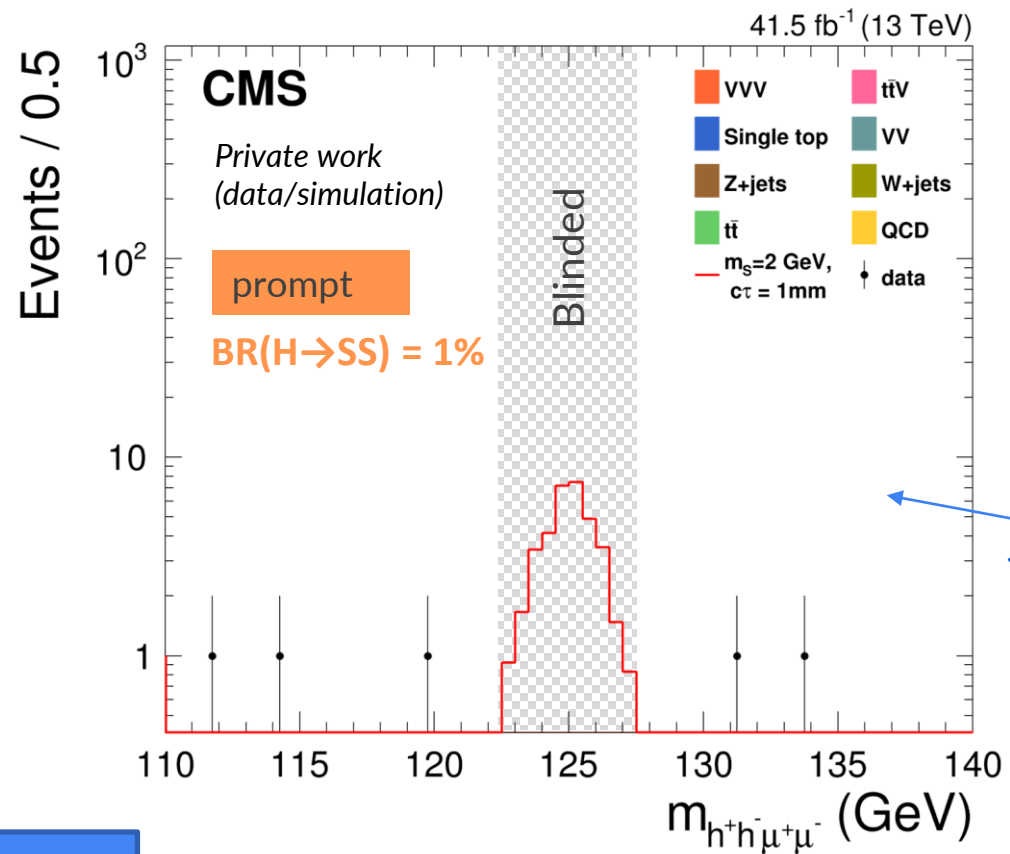
$m_S=2\text{ GeV}$,
 $\tau=1\text{ mm}$

Signal & background yield from higgs mass distribution!

- o Use scalar mass hypothesis



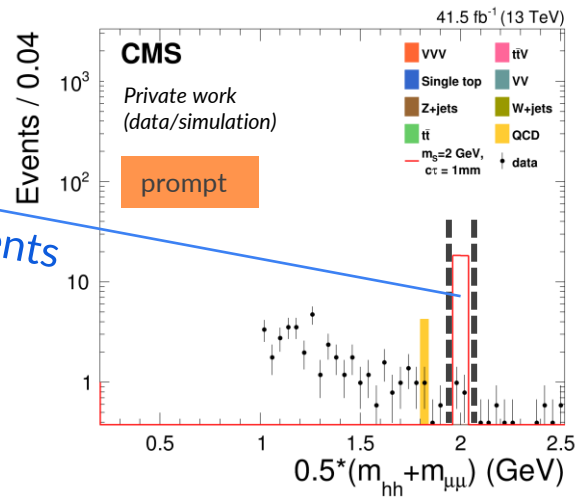
m_s=2 GeV,
cτ=1 mm



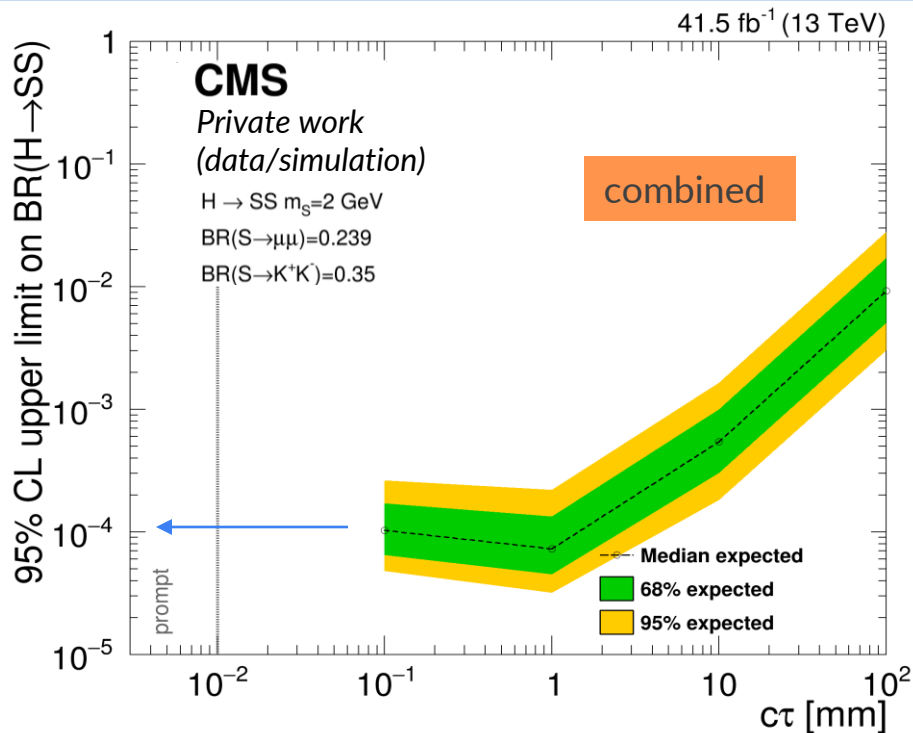
Signal & background yield from higgs mass distribution!

- Use scalar mass hypothesis

Same events



m_s=2 GeV,
cτ=1 mm

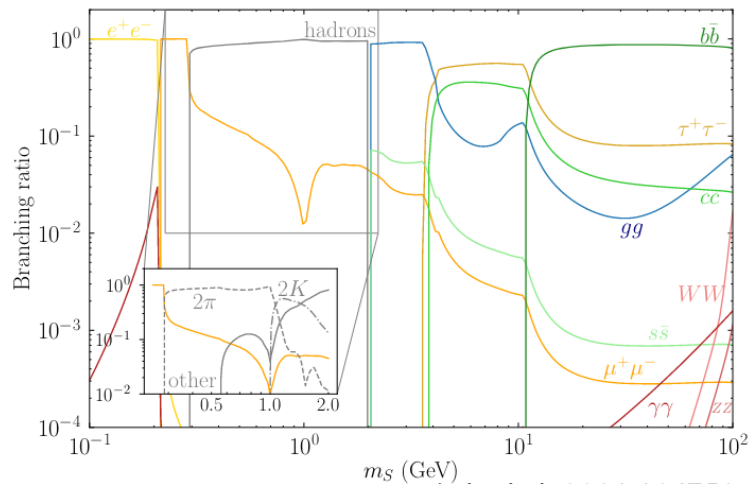


- Expected limits with 2017 data (i.e. blinded data & signal MC only)
- Early results -
 - Syst. uncertainties to be added
 - Statistical unc. expected to dominate
- $\tau = 1$ mm has the best sensitivity
- Use lifetime reweighting to extra/intra-polate to other lifetimes

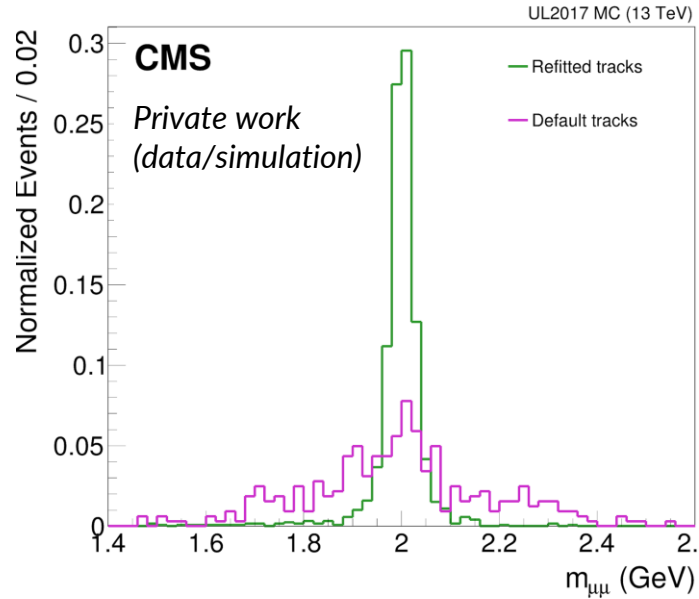
- A search for light BSM scalars with lepton+hadron decays within the tracker volume has been performed
- Looks for a unique signature with light hadron final states, in place of jets
- Preliminary results indicate potential to access a unique phase space largely unexplored so far
- More luminosity (all of Run-2) & unblinding to follow!

Thank you!

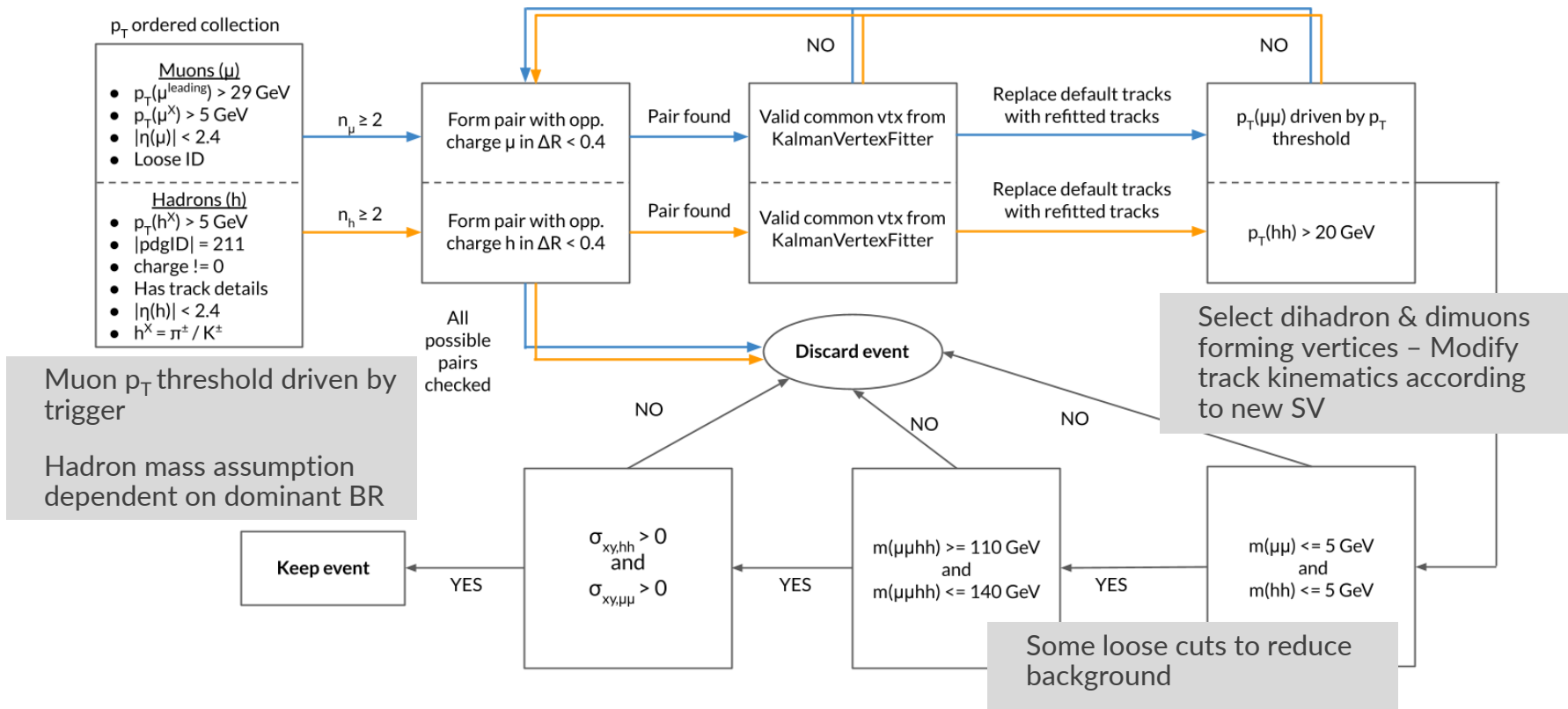
Backup

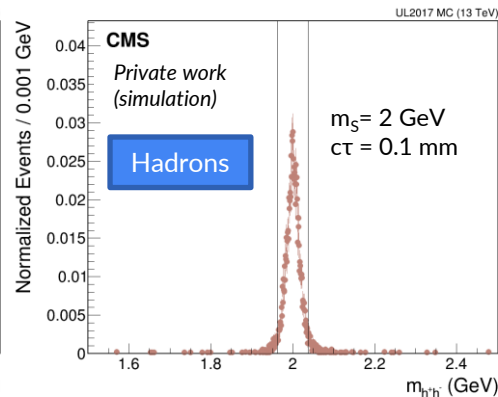
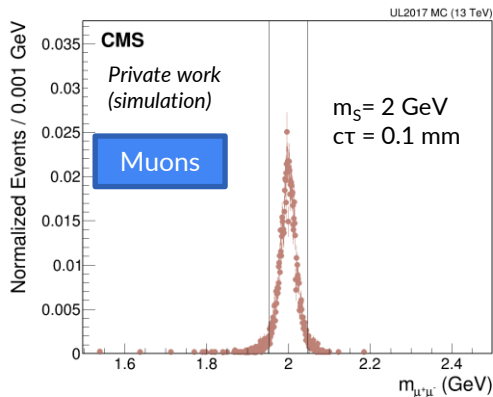
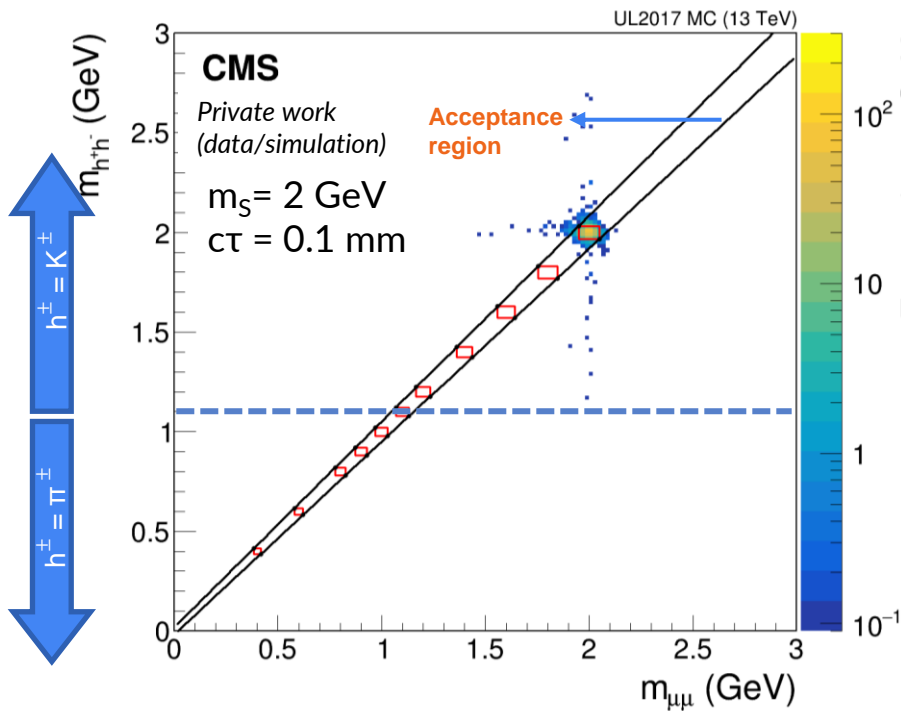


[j.physletb.2021.136758](https://arxiv.org/abs/j.physletb.2021.136758)



Event preselection

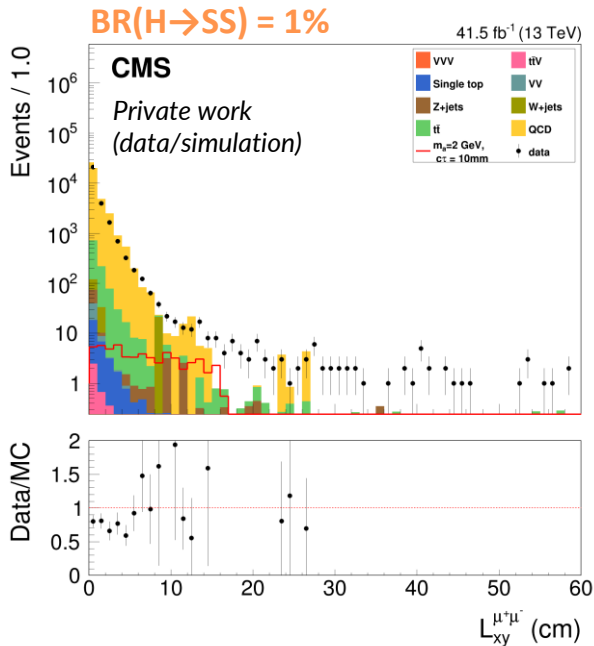




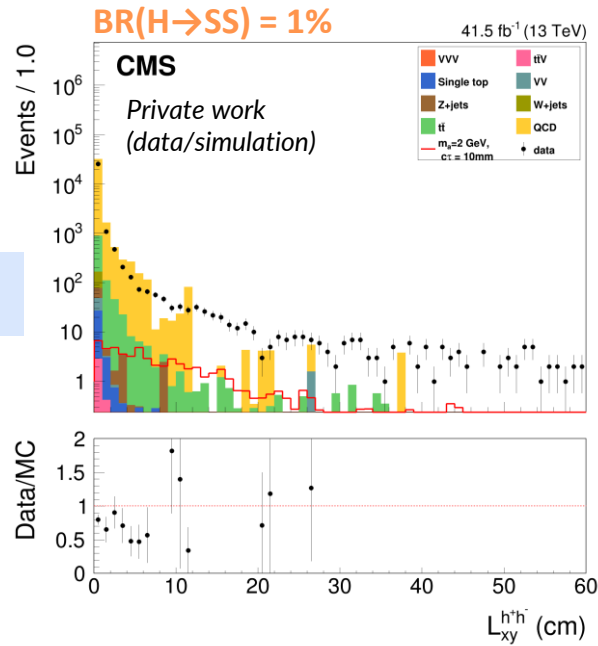
- Gaussian fit on dimuon & dihadron mass to derive bounds to form the bounded box
- Linear fit on edges to form window ($m_S \sim m_{\bar{S}}$)
- Repeat for each $c\tau = 0.1$ mm mass point
- Stable with respect to displacement

$m_S \in [0.4, 0.6, 0.8, 0.9, 1, 1.1, 1.2, 1.4, 1.6, 1.8, 2]$ GeV

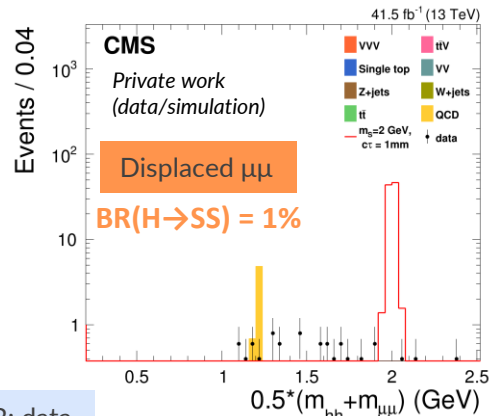
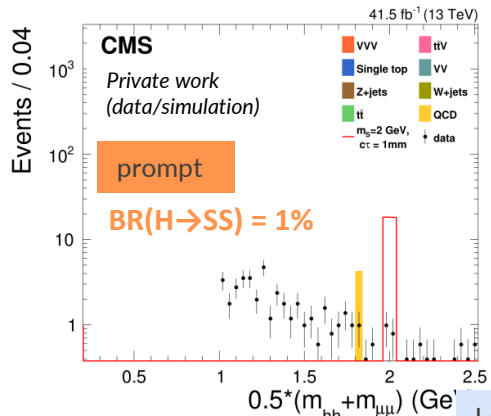
Muons



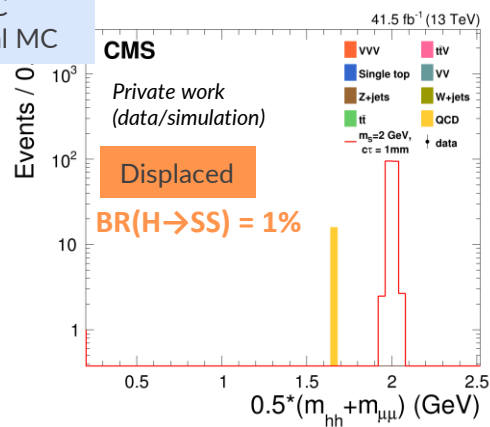
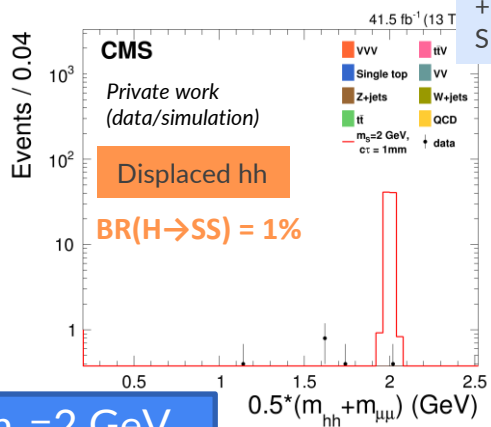
Hadrons



- Replace default with “refitted” tracks to valid secondary vertex
 - Additional handle to reject bkg: Require a secondary vertex
- Transverse displacement (& significance) act as additional handles

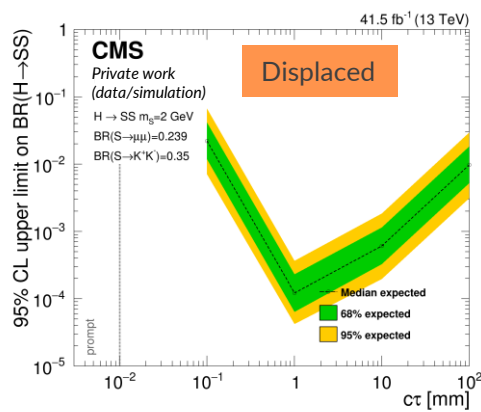
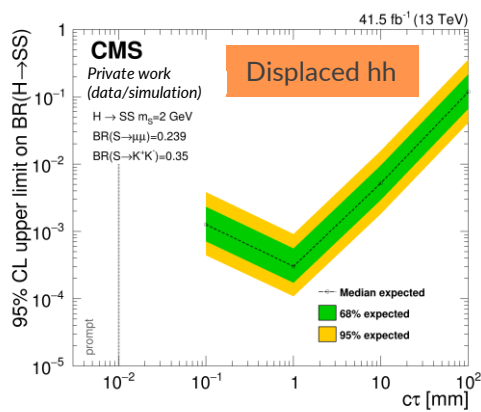
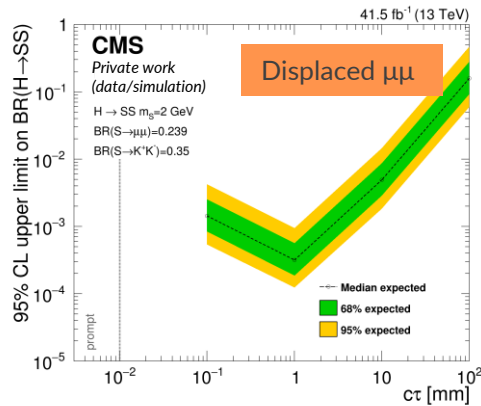
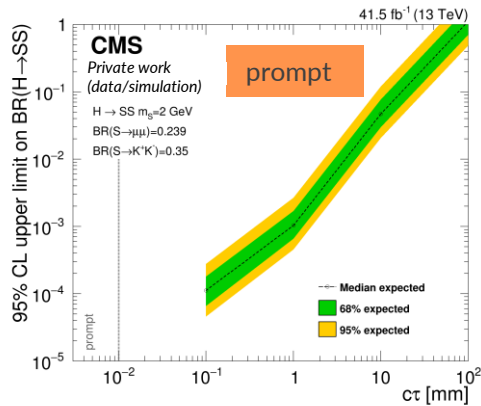


Loose CR: data + SM MC
SR: signal MC



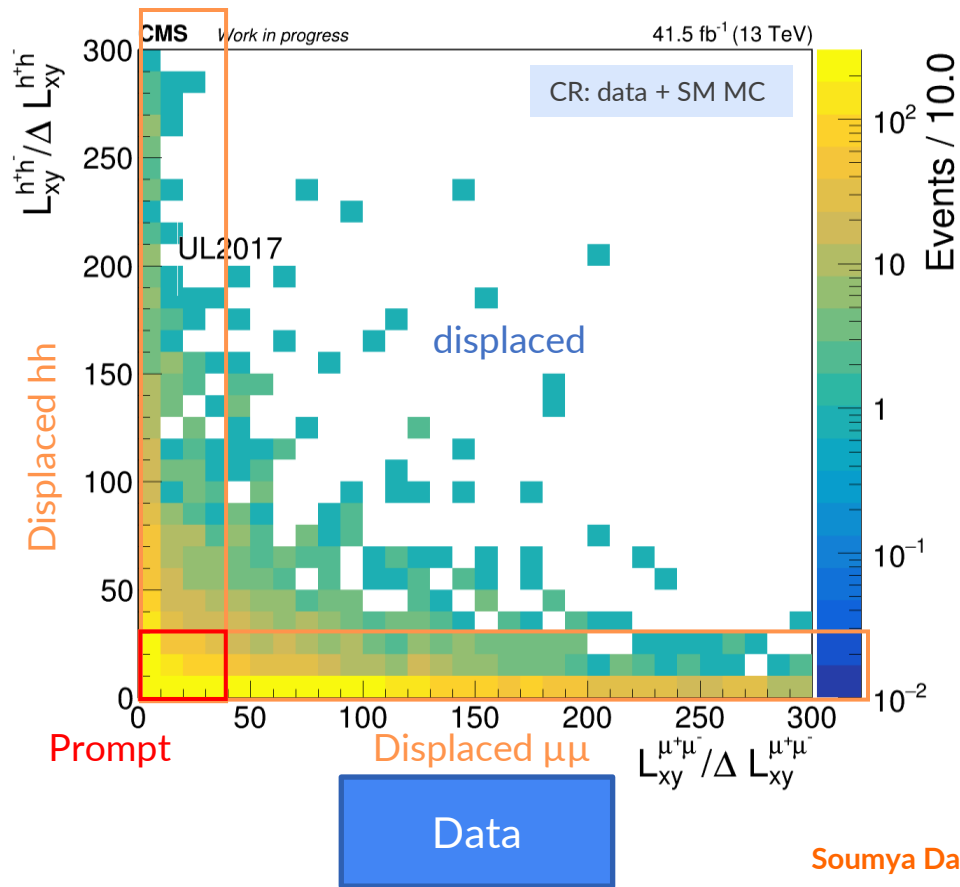
- Low statistics in bkg MC
- Displaced category ~ bkg free
- $\tau=1\text{mm}$ has sensitivity across all categories

$m_s=2\text{ GeV}$,
 $\tau=1\text{ mm}$



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CR: data + SM MC
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