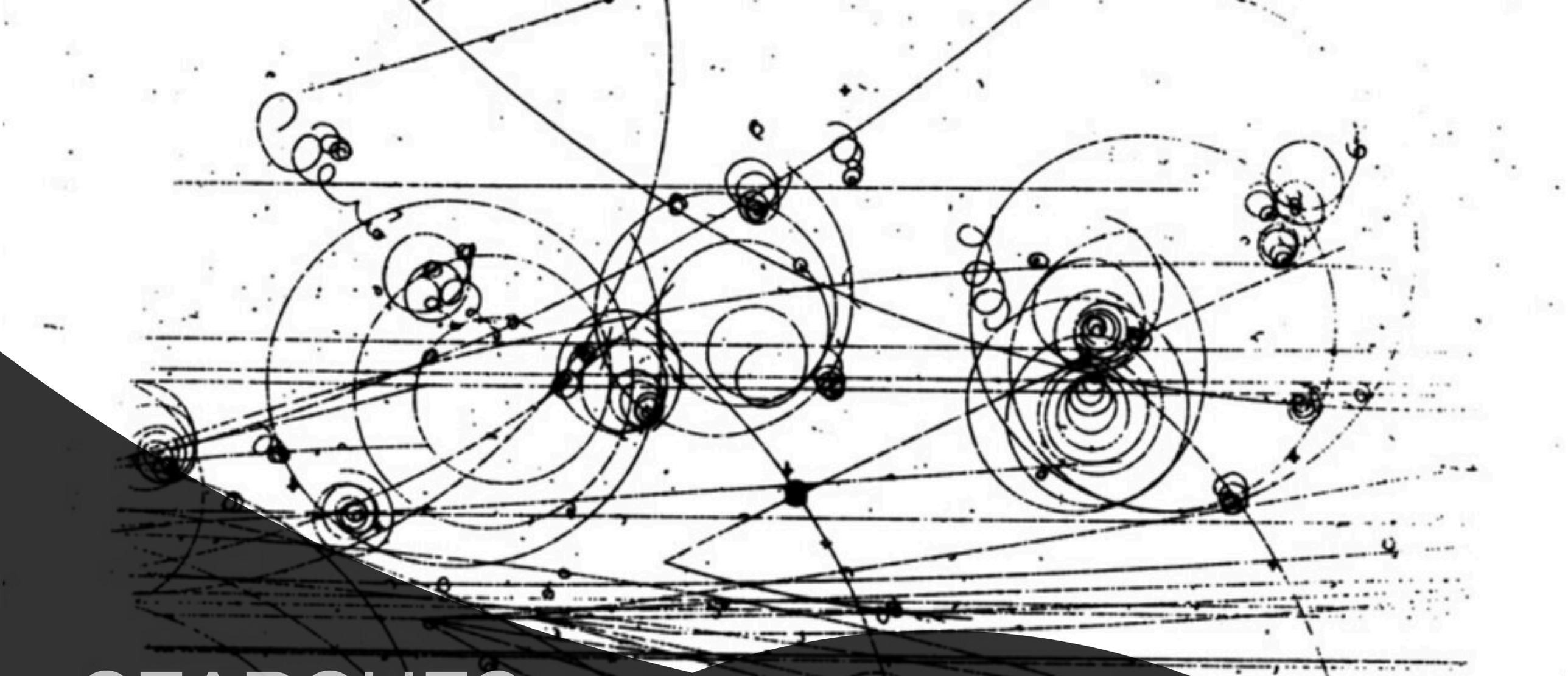


SEARCHES FOR LONG-LIVED PARTICLES IN CMS

Karri Folan DiPetrillo [Fermilab]
on behalf of the CMS collaboration

DPF 2021

Why long-lived particles

Most pressing issue for LHC physicists:

We need to make sure that if we're producing BSM physics at the LHC, we don't miss it

BSM long-lived particles (LLPs)

Well motivated, challenging signatures

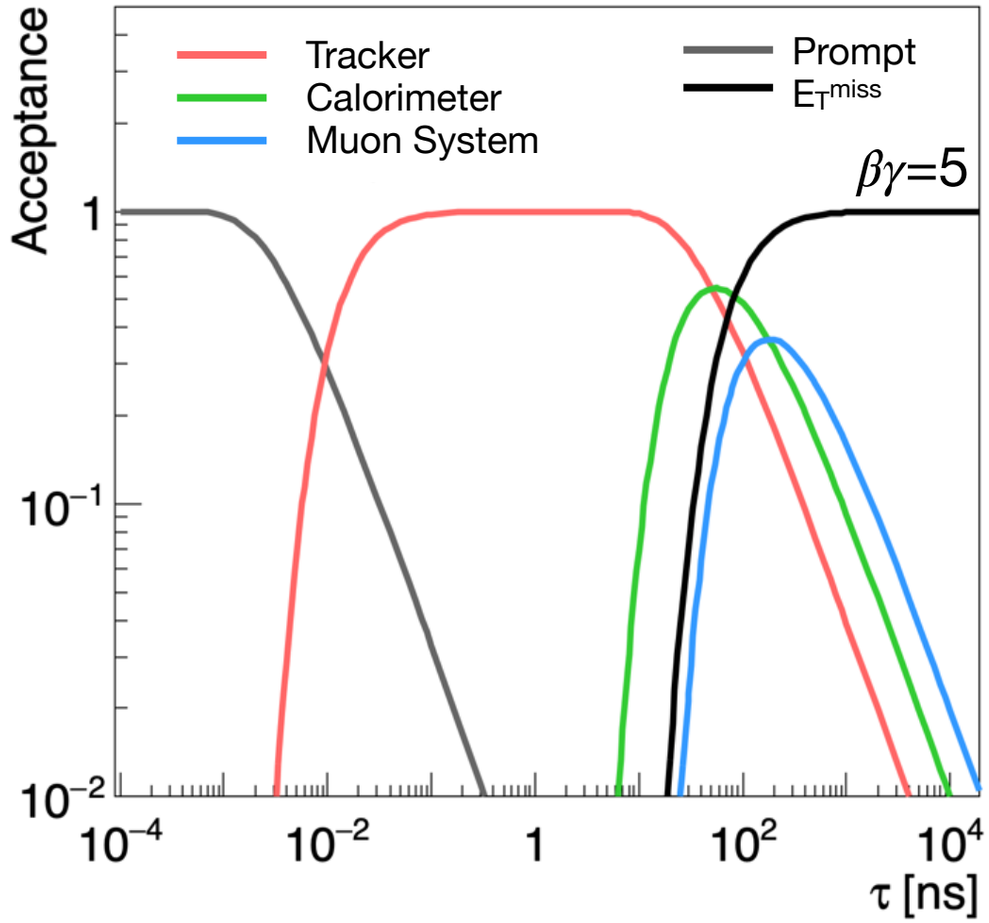
May have evaded prompt/missing E_T searches

Understanding LLP sensitivity

Acceptance

driven by detector volume

LLP decay follows an exponential



require 1 LLP decay in a given volume

approximate CMS geometry

Efficiency

driven by everything else

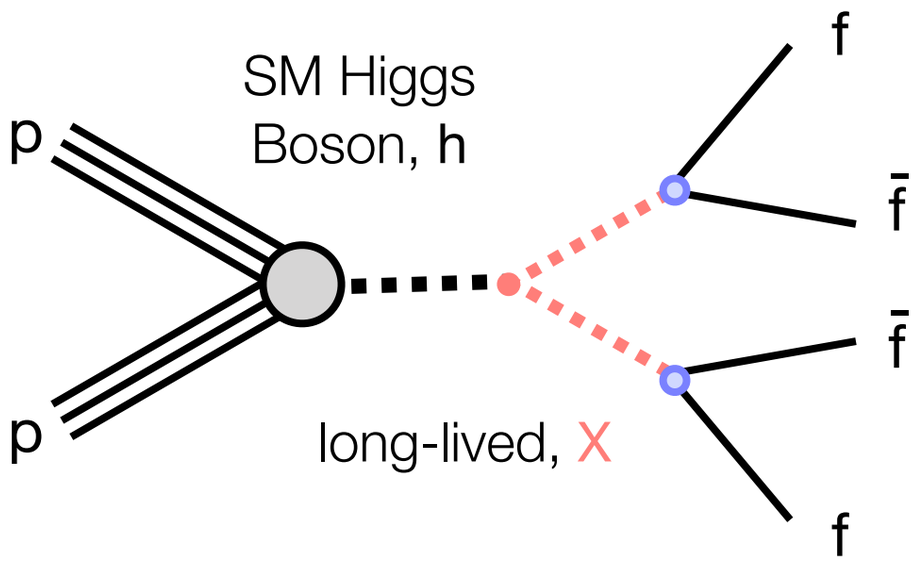
often non standard

1. triggers
2. reconstruction
3. backgrounds

New emphasis: low mass LLPs

Most previous LLP searches targeted O(TeV) BSM particles

Well-motivated example benchmark model



Challenges

decay products p_T~30 GeV

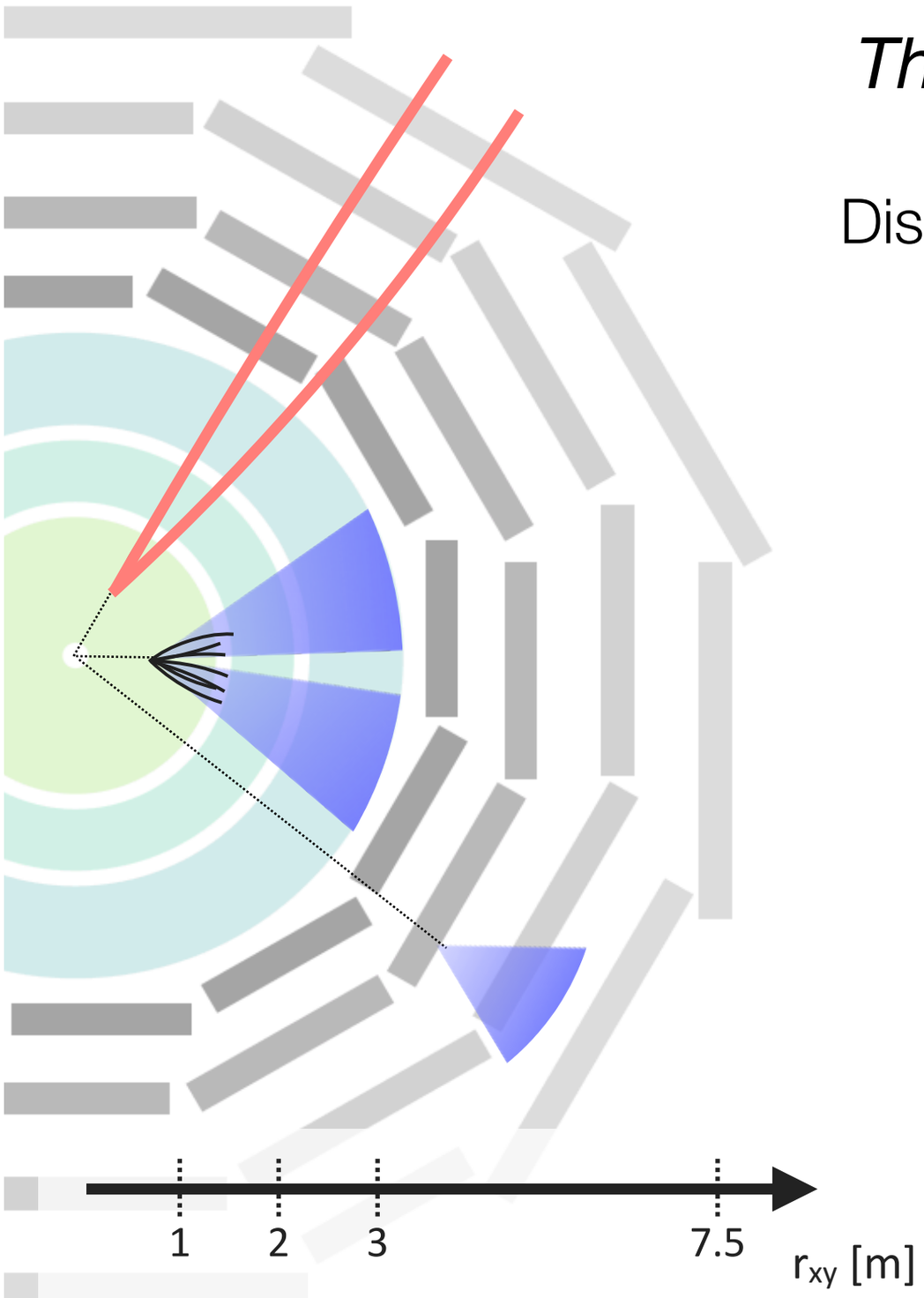
hadronic LLP decays often favored
eg. if X decays via Higgs portal

→difficult to trigger on gluon gluon fusion (ggF) production

backgrounds: standard model LLPs, randomly crossing tracks, material interactions

Efficiency tends to drop with m_X

Targeting h→LLPs in CMS



Three strategies highlighted in this talk

Displaced di-muon with scouting
Decays in Tracker
$L_{XY} < 11$ cm

Displaced jets
Decays in Tracker
$L_{XY} < 60$ cm

Hadronic decays
in the Muon System Endcaps
$2.5 < L_{XY} < 7$ m
$6.5 < Z < 10$ m

full list of Run 2 CMS results in back-up

Di-muon with scouting

New! EXO-20-014

Leptonic decay in Tracker

Start with leptonic decays: look for di-muon displaced vertex

$h \rightarrow ZdZd \rightarrow \mu\mu+XX$ or $b \rightarrow \phi X \rightarrow \mu\mu+X$

Novel use of ***data scouting*** to access O(GeV) LLP decays to two muons

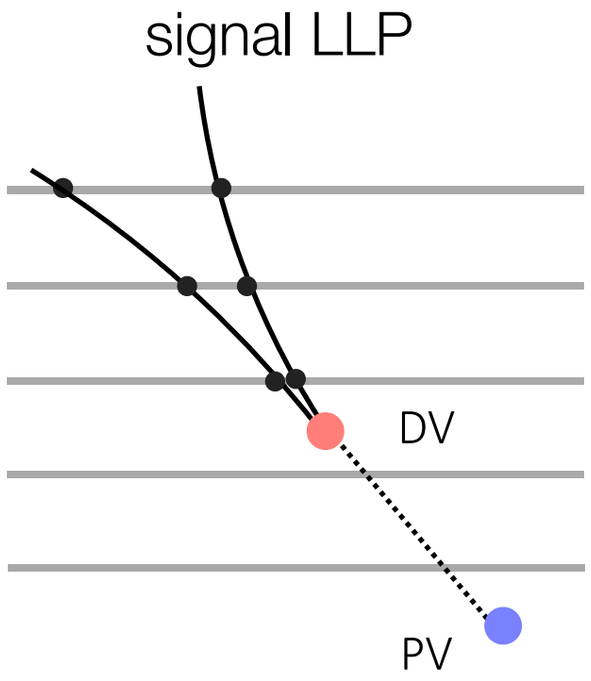
scouting: saves more events but with reduced, trigger level, event content

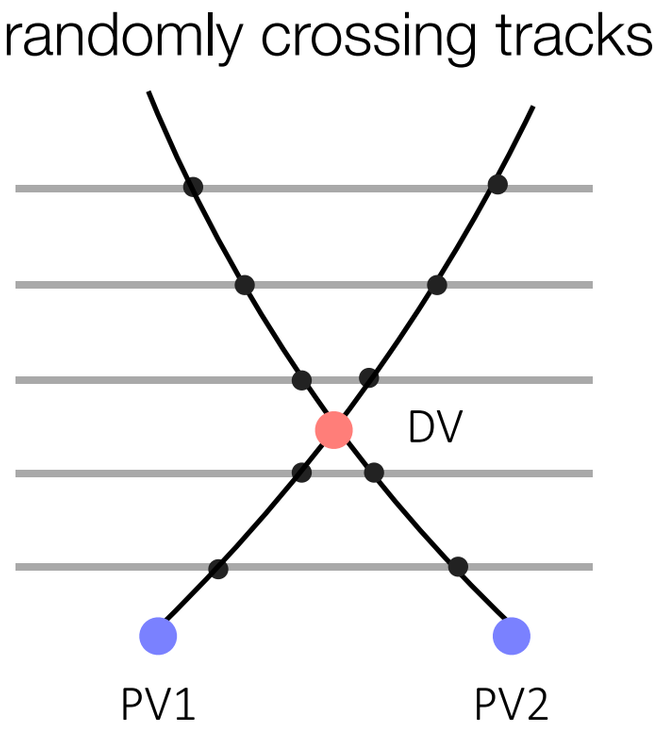
this analysis: events with ≥2 muons, $p_T > 3$ GeV, vertex $L_{XY} < 11$ cm

Creativity needed to reject non-standard backgrounds

excess pixel hits ≤ 0

$\log_{10}(\Delta\eta/\Delta\phi) < 1.25$





Di-muon with scouting

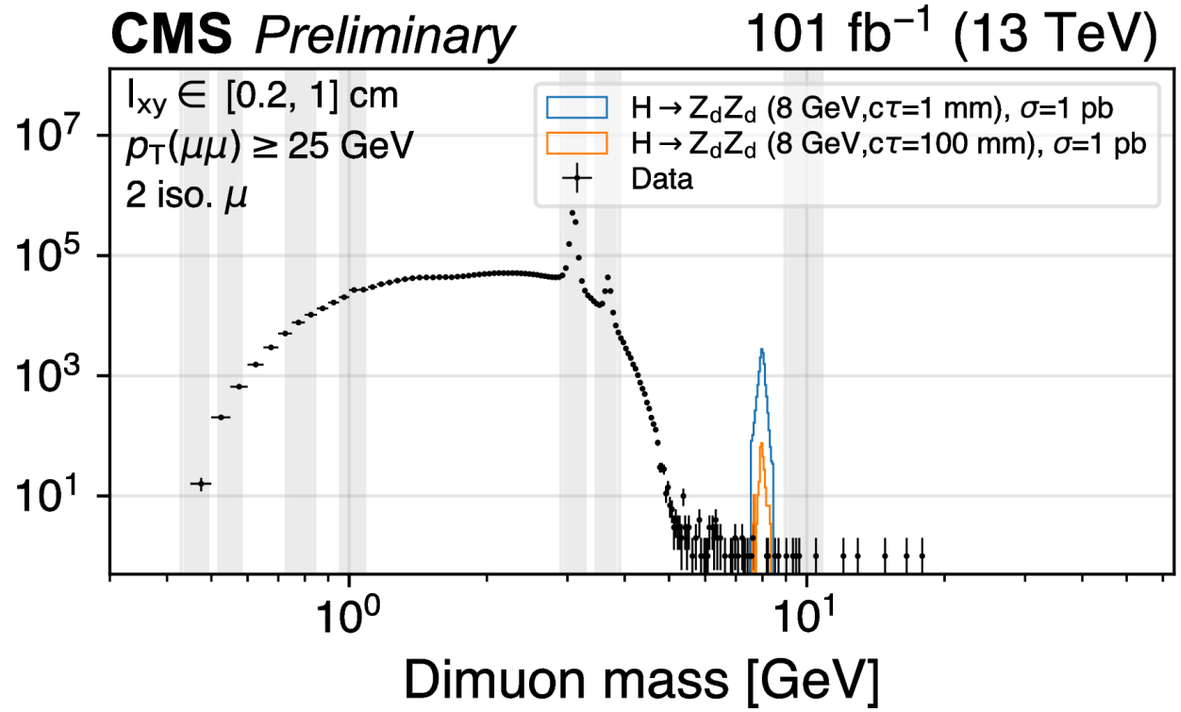
New! EXO-20-014

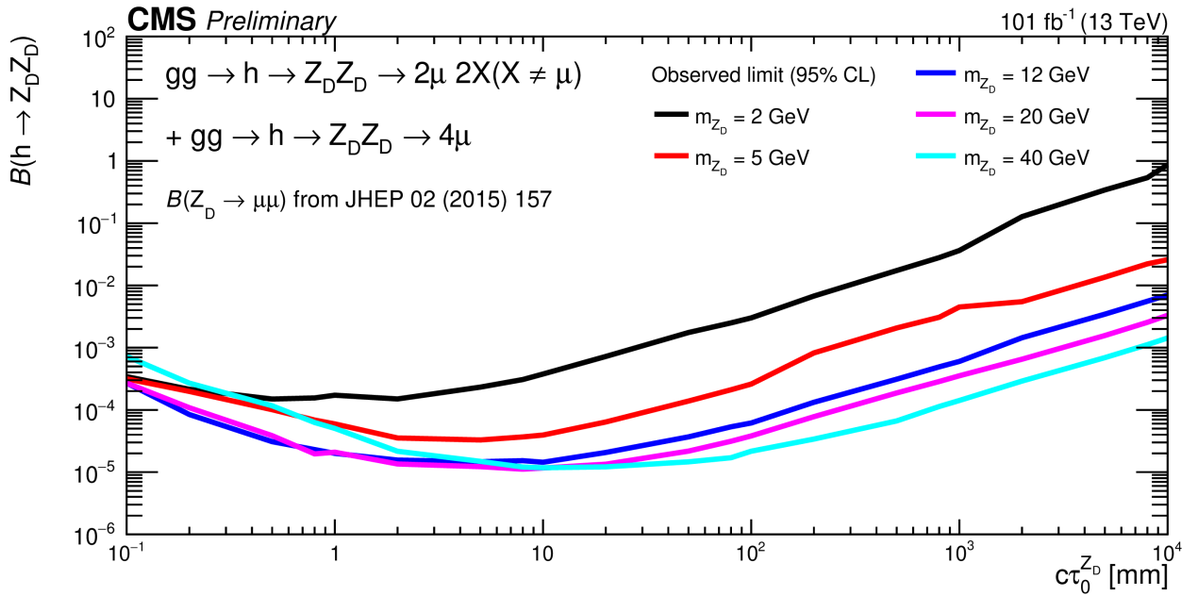
Leptonic decay in Tracker

Remaining Backgrounds:
SM resonances
non-resonant SM b→μμ+X
random track crossings

Strategy: categorize & perform bump-hunts in m(μμ)
$p_T^{\mu\mu}$, muon isolation, vertex L_{XY}

Results:
stringent limits on a range of BSM scenarios





back-up: sensitivity to b→ϕ+X comparable with LHCb!

Inclusive displaced jets

2012.01581

Hadronic decay in Tracker

For hadronic decays: story begins with flagship analysis (from 2020)

Analysis strategy: Select events with ≥1 displaced vertex reconstructed from tracks associated to a pair of jets

Dedicated trigger!

$H_T \geq 430$ GeV

≥ 2 displaced jets

~0.3% efficiency to ggF

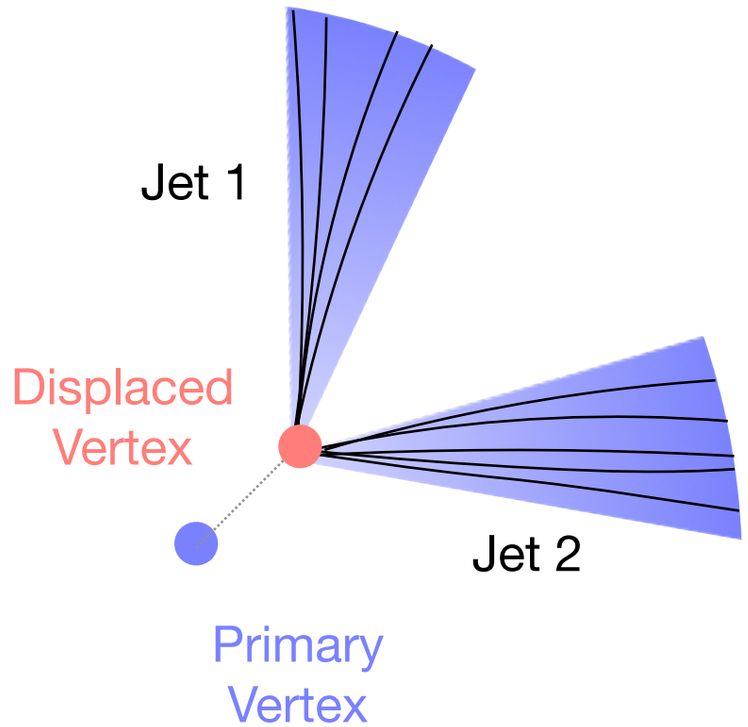
Results

0.75 ± 0.60 expected

1 observed

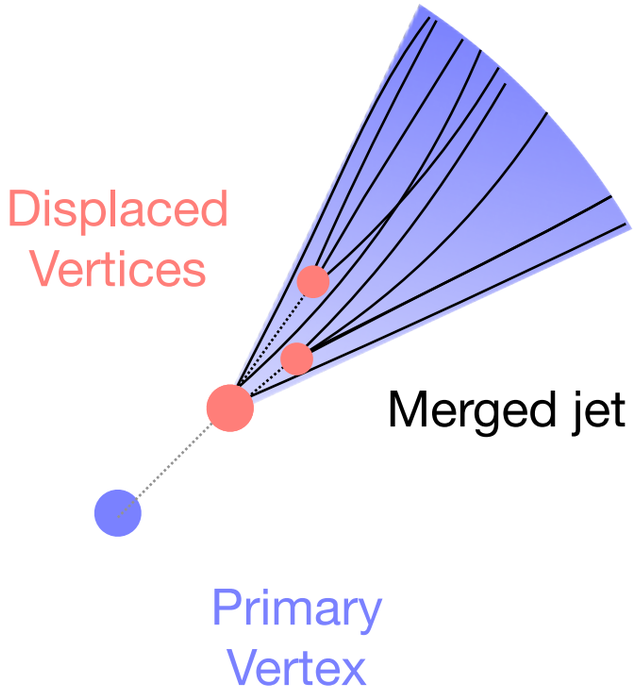
first CMS sensitivity to wide range of hadronic h→LLP decays

Target signature



Gap in coverage

m_X<20 GeV, X→bb



Z+displaced jets

New! EXO-20-003

Hadronic decay in Tracker

Analysis goal: follow up inclusive displaced jets

specifically targeting light LLP decays to b-jets

Trigger on Zh production

less boosted than inclusive analysis

Require ≥ two displaced jets

no displaced vertex required to retain efficiency to tertiary vertices

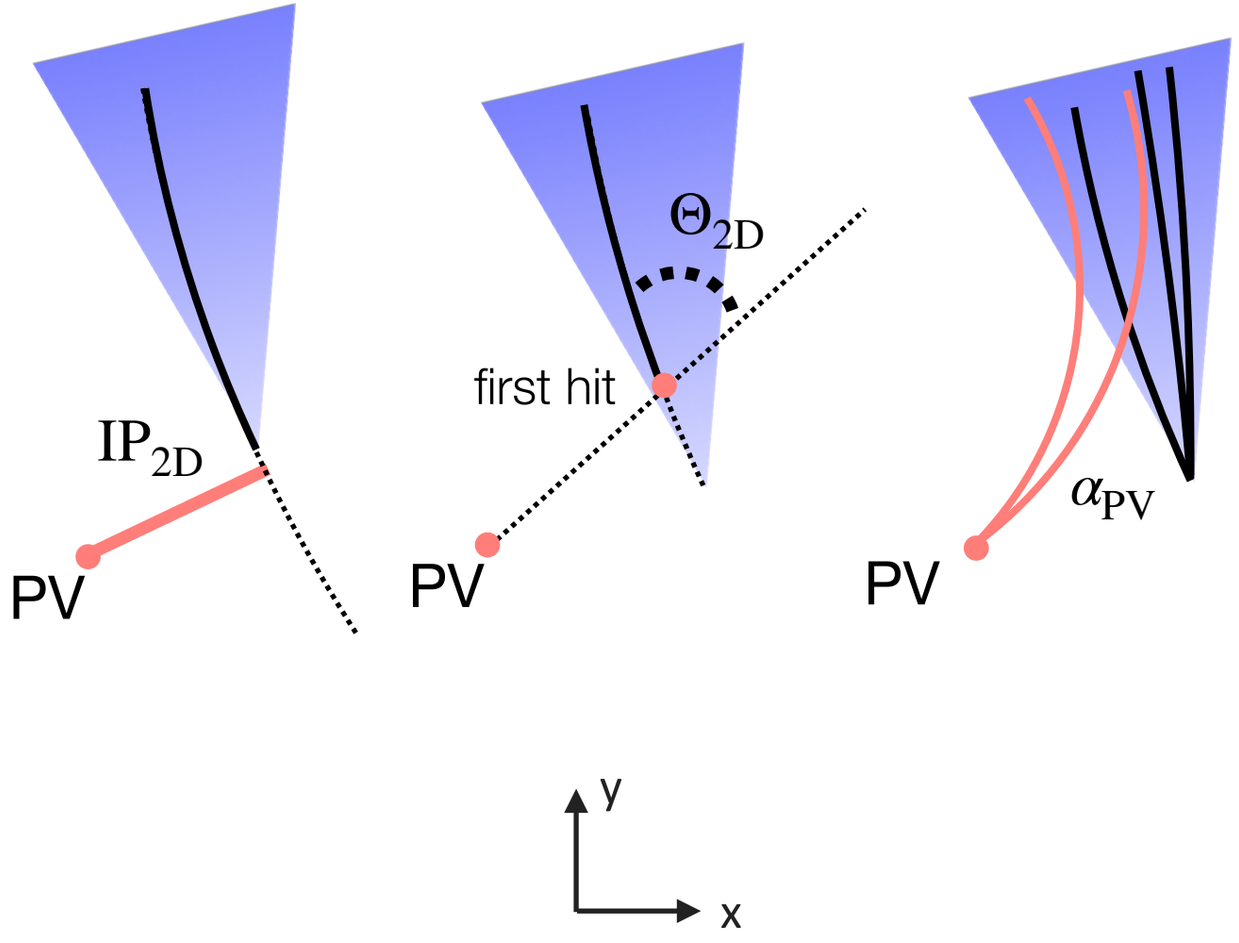
Results

3.5 ± 1.8 events expected

3 observed

Variables used to tag displaced jets

based on EXO-16-003



Decays in Muon Endcaps

New! 2107.04838

Hadronic decay in Muon Spectrometer

Expand reach: look for LLP decays in Muon System

Goal: Extend acceptance to longer lifetimes than Tracker

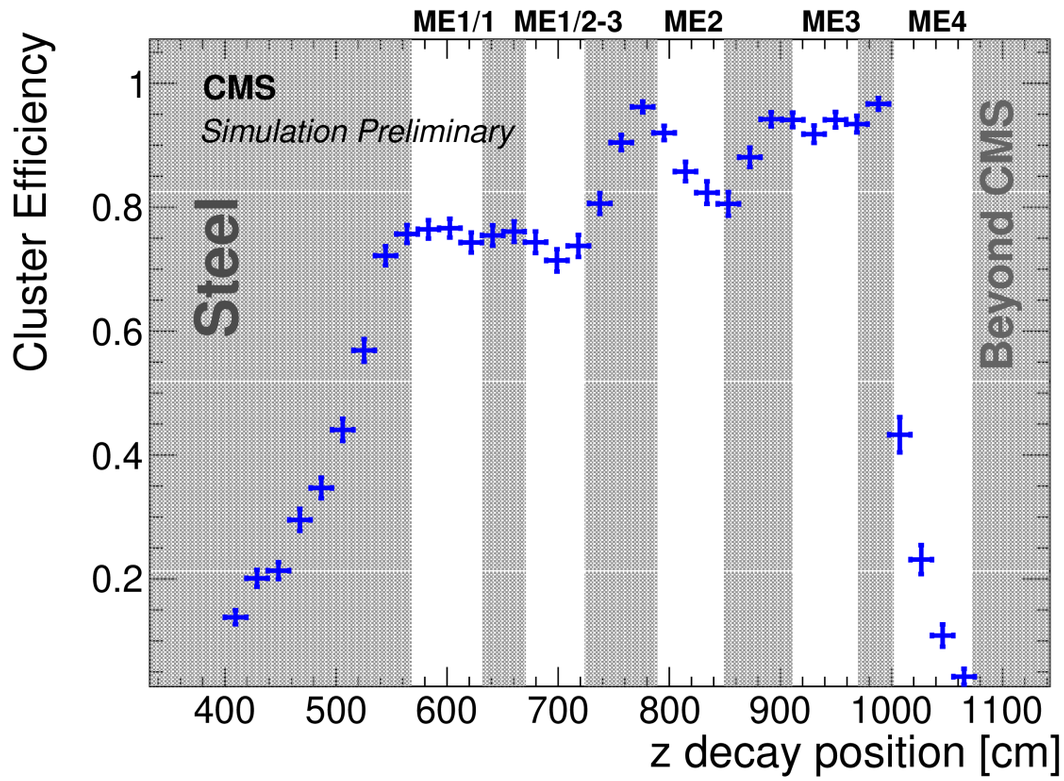
Bonus: much lower backgrounds due to shielding (12<λ<27)

Novel reconstruction technique: use Muon Endcaps as a sampling calorimeter!

hadronic decay products shower in steel of return-yoke

results in a cluster of many hits in Cathode Strip Chambers

efficiency ~ LLP energy, not mass!



Background: punch through, SM decays in flight from pile-up jets, collision/cosmic muon brem

Decays in Muon Endcaps

New! 2107.04838

Hadronic decay in Muon Spectrometer

To trigger: LLP decays after calorimeter produce E_T^{miss}

E_T^{miss} >200 GeV: ~1% efficiency for ggF

Selection

reject clusters near muons/jets

geometric & timing cuts

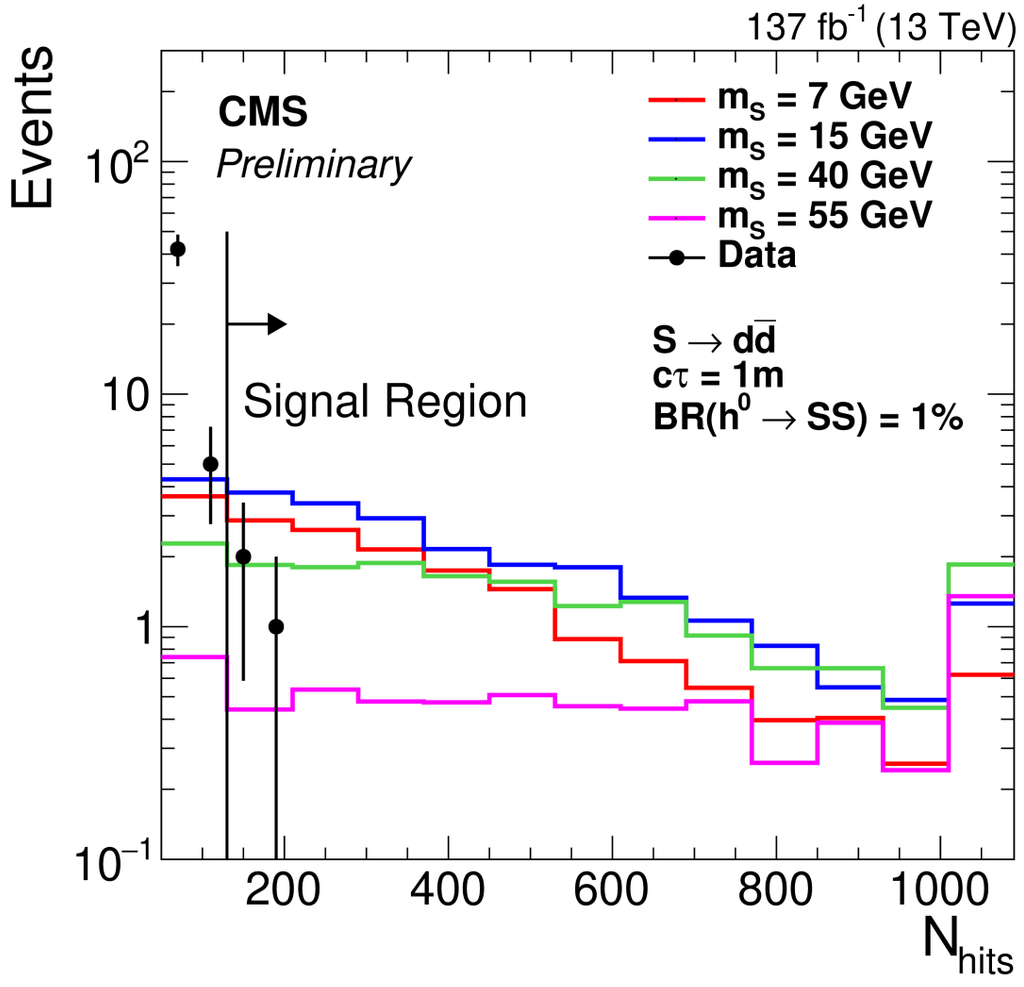
$\Delta\phi(\text{cluster}, p_T^{miss}) < 0.75$

N_{hits} >130

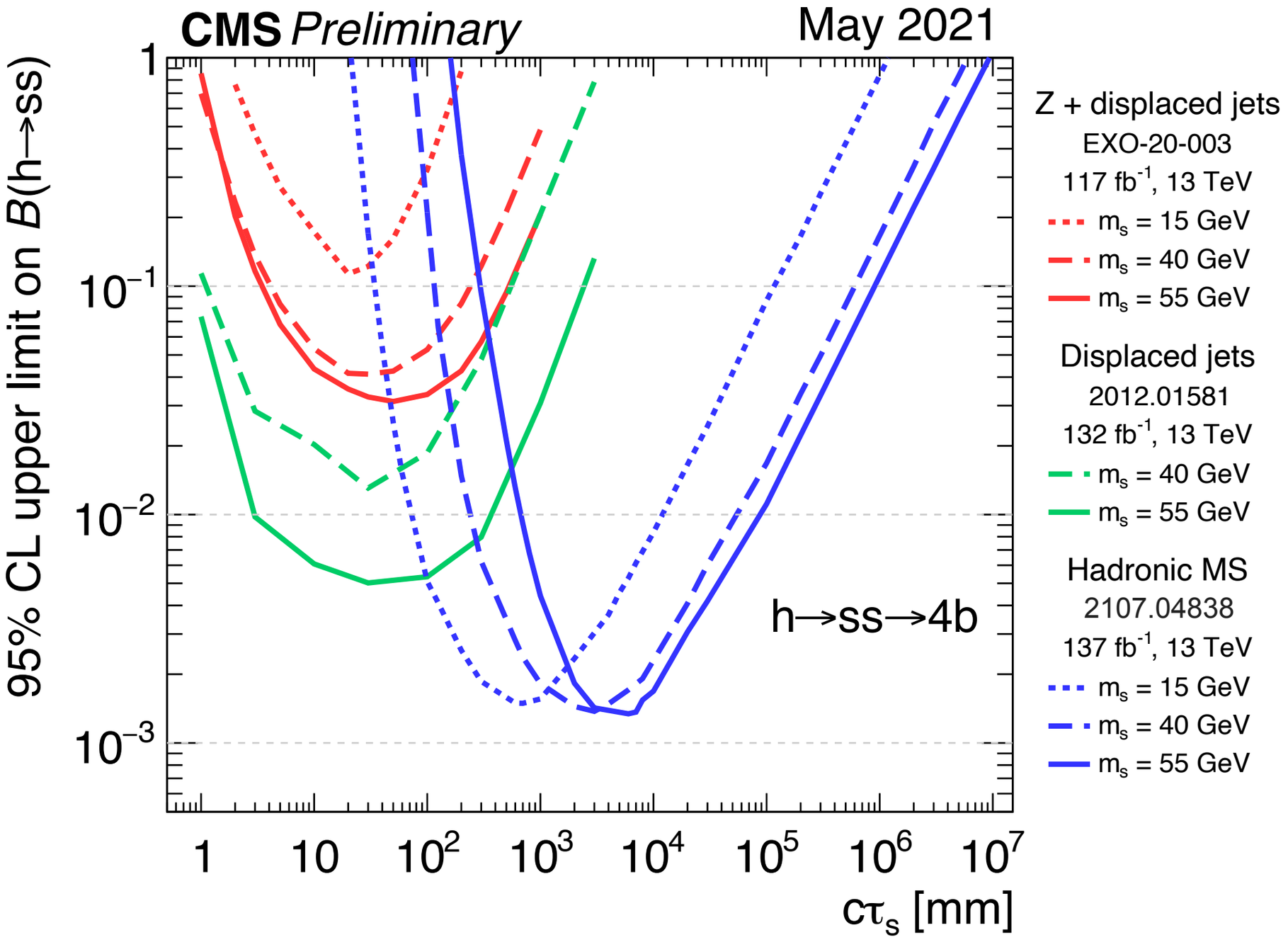
Results

2.0 ± 1.0 events expected

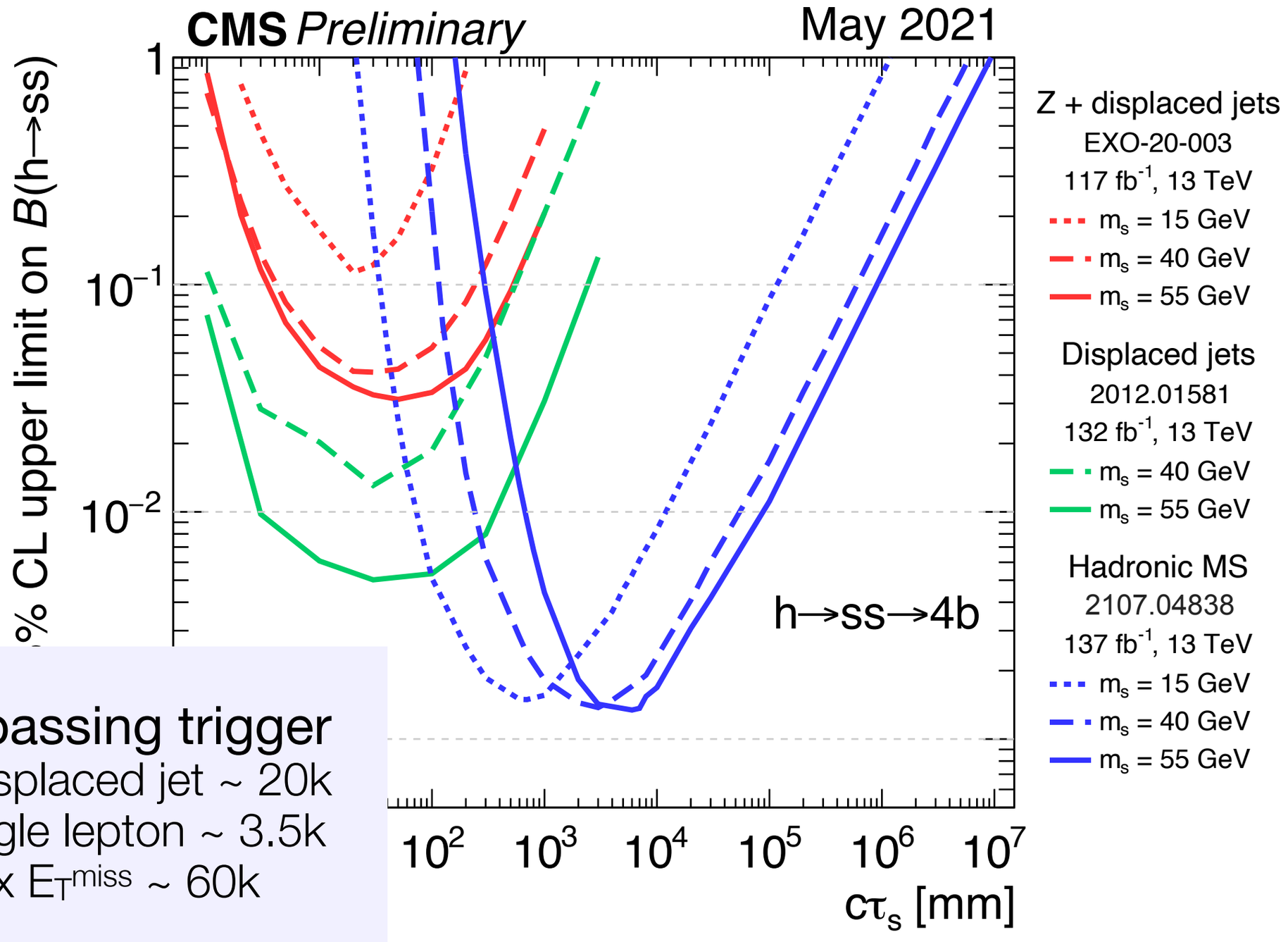
3 observed



All together now



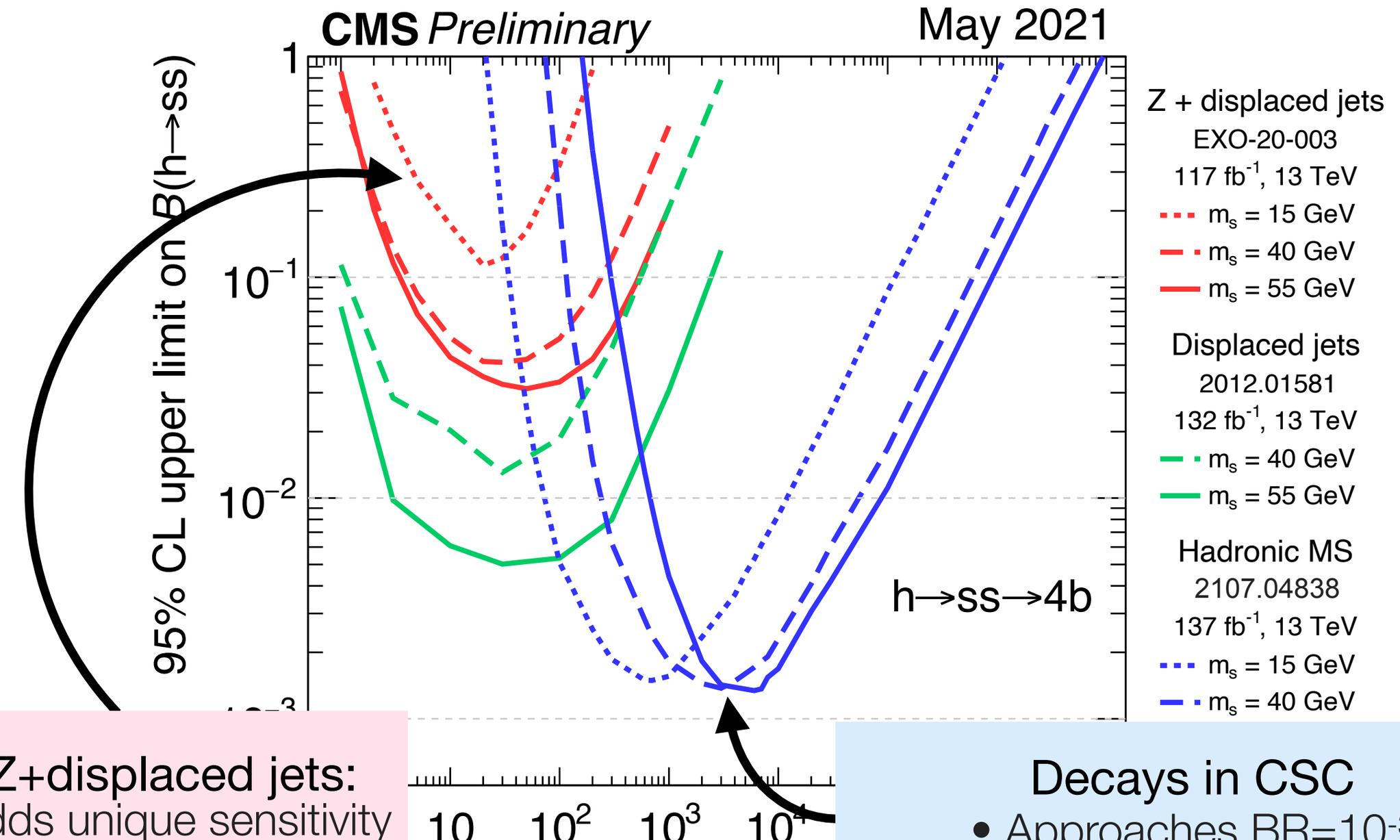
All together now



#Higgs passing trigger

- ggF x displaced jet ~ 20k
- Zh x single lepton ~ 3.5k
  - ggF x E_T^{miss} ~ 60k

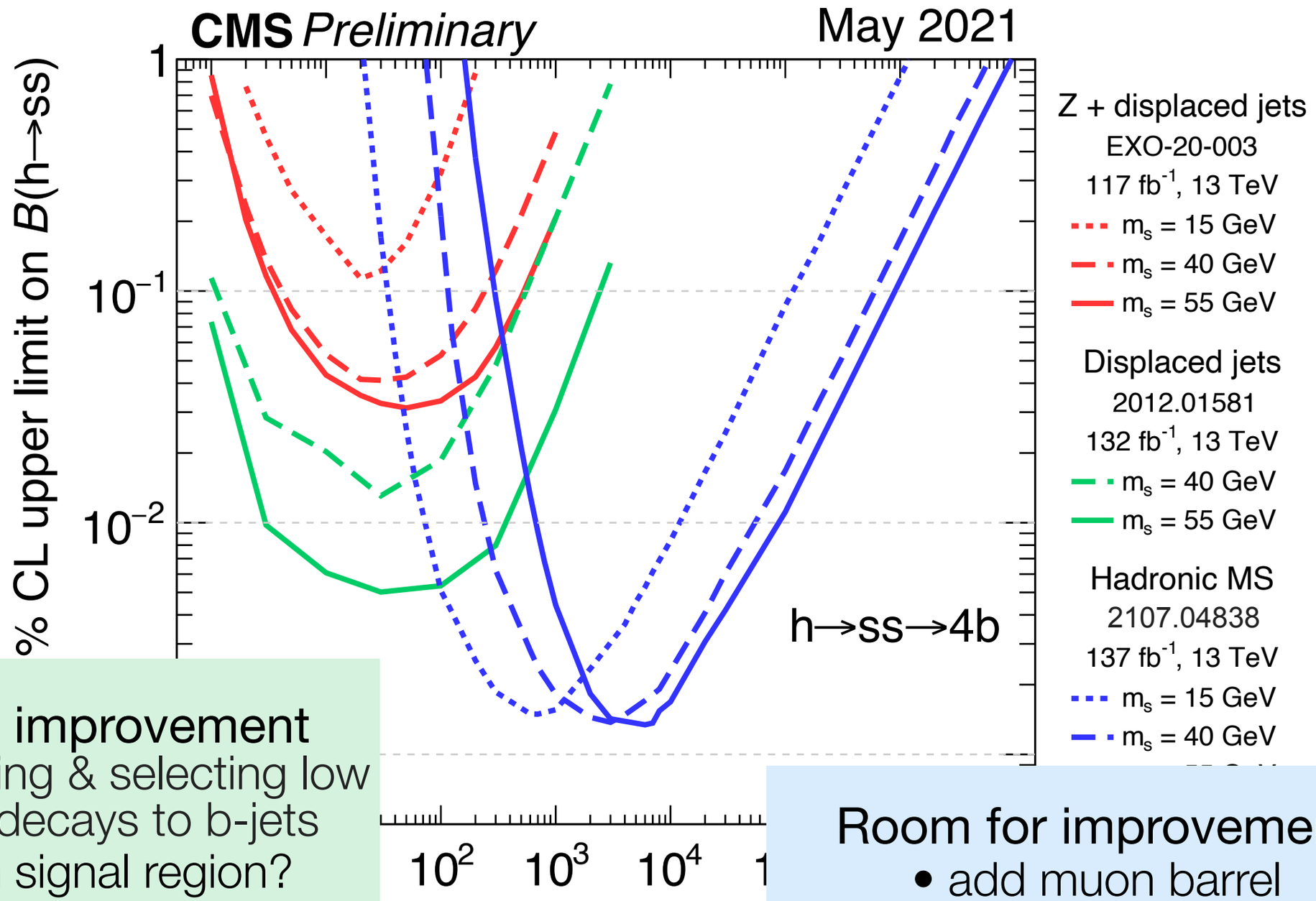
All together now



Z+displaced jets:
Adds unique sensitivity to mX=15 GeV, X→bb for CMS

Decays in CSC
- Approaches BR=10^{-3} regardless of LLP mass
- best lifetime varies with LLP boost
- best LHC sensitivity cτ ≳10 m

All together now



Room for improvement
- reconstructing & selecting low mass LLP decays to b-jets
- add Wh signal region?

Room for improvement
- add muon barrel
- design dedicated trigger
- 1 & 2 cluster signal regions

Conclusions

Three new LLP results from CMS

Displaced di-muon with scouting*

Z + displaced jets

Hadronic Decays in the Muon Endcaps*

Enable new sensitivity to low mass LLPs

including well motivated SM higgs scenarios

Keep an eye out!

Many places where new physics could be hiding @LHC

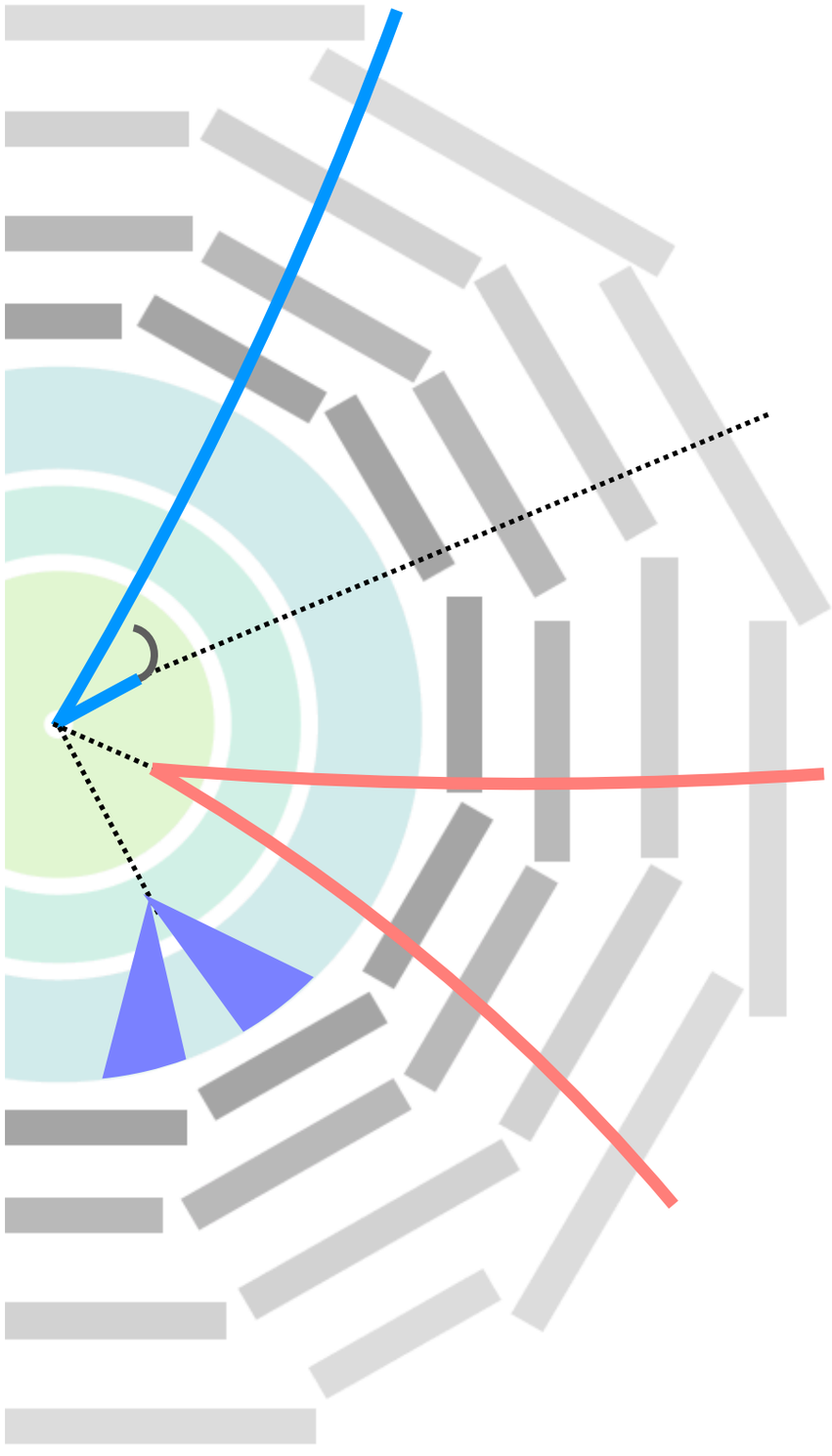
Several Run 2 LLP searches still in the works

Run 3 = exciting opportunity for discovery

* material provided for re-interpretation

BACKUP SLIDES

How to search for LLPs



Direct Detection of Charged LLPs

anomalous ionization

time of flight

infer decay via missing hits

Indirect Detection via decay products

Tracking

impact parameter

secondary vertex

Calorimetry

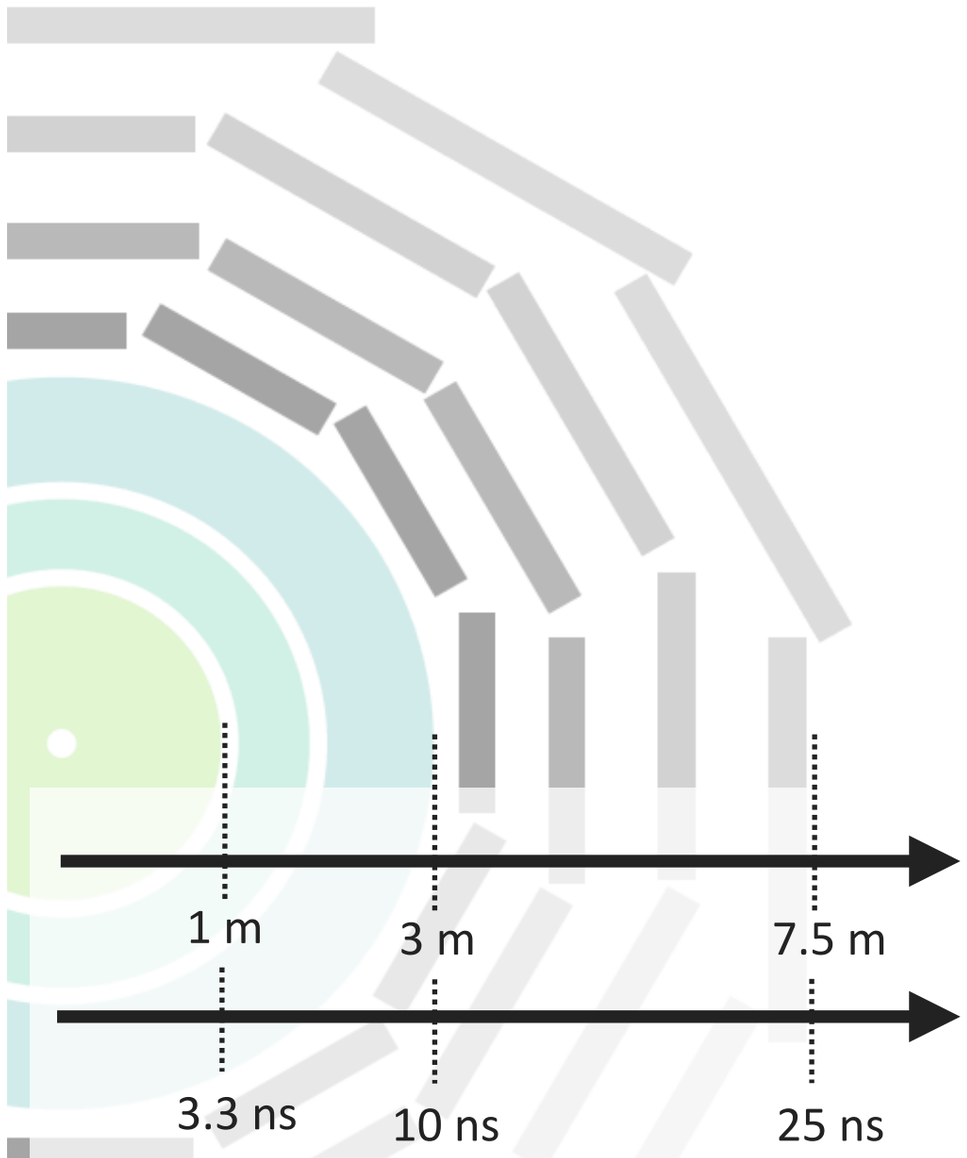
shower shape

delay

Common challenges

trigger, data format, reconstruction, non-standard backgrounds, person power

Connecting detector and lifetime



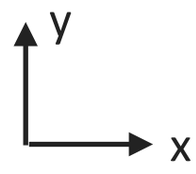
for a long-lived particle
with $\beta\gamma$=1

LLP decay position sampled
from exponential distribution

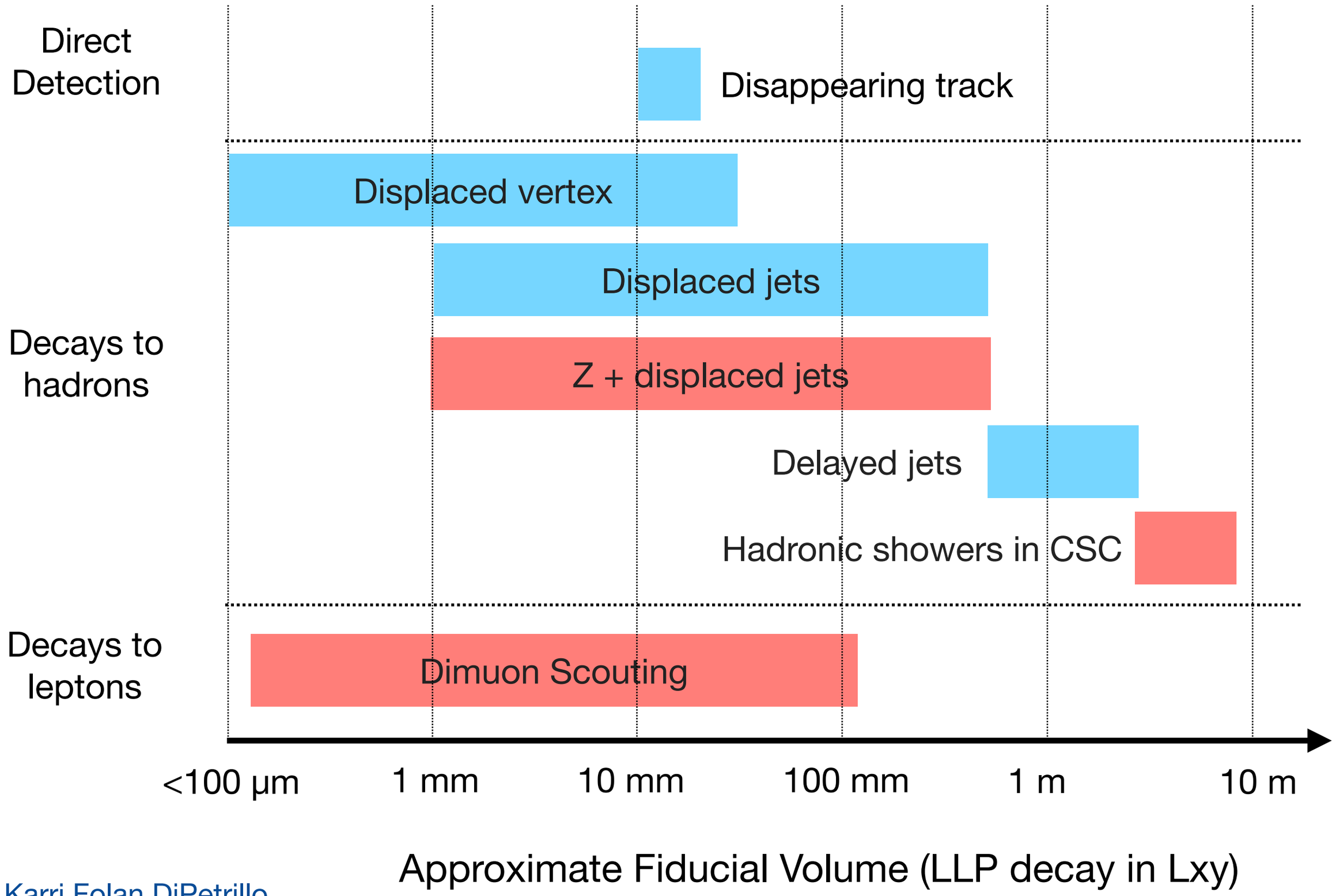
Mean distance travelled = βγcτ

cτ = distance metric
~ 30cm for τ = 1 nanosecond

Lorentz boost βγ = p/M.
Ranges from ~ 0.8 or 0.9 for heavy particles
to ~30 for light ones



CMS Full Run 2 LLP Results



CMS Full Run 2 LLP Results

Disappearing Tracks	EXO-19-010	2004.05153
Delayed jets	EXO-19-001	1906.06441
Inclusive Displaced jets	EXO-19-021	2012.01581
Multi-track Displaced vertices	EXO-19-013	2104.13474
Z+displaced jets	EXO-20-003	-
Hadronic Decays in the CSC	EXO-20-015	2107.04838
Dimuon DV scouting	EXO-20-014	-

CMS tracking

Iterative approach to tracking

Reduce combinatorics for more difficult tracks

With respect to ATLAS

- slightly lower efficiency
- much lower fake rate
- no need for LLP data stream!
- global/displaced tracks @HLT

Useful radii

25 cm - Pixel/strip transition

60 cm - Inner/Outer Barrel transition

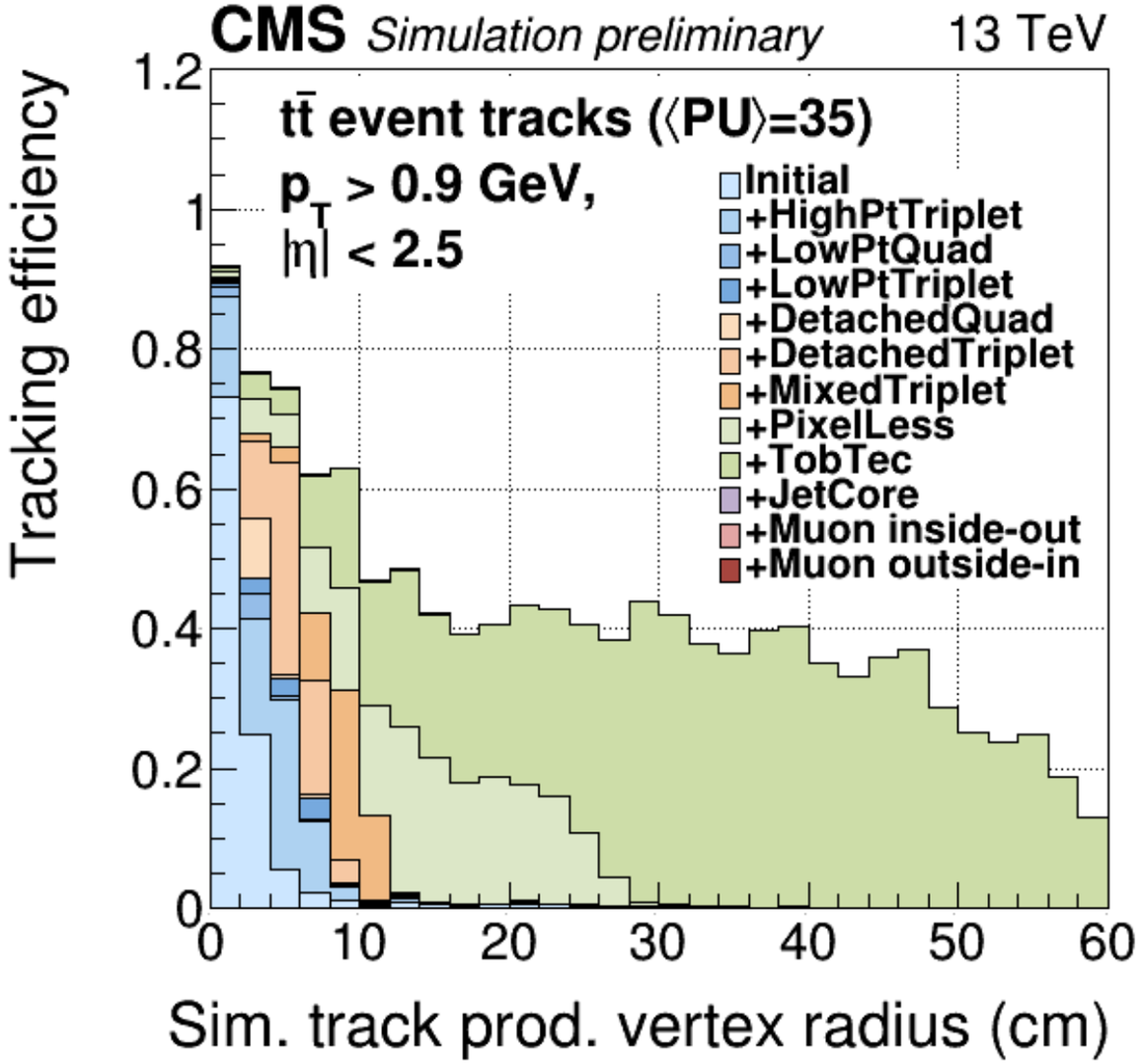
1.1 m - End of tracker

New pixel detector (2017+2018)

Efficiency: 5-10%

Fake rate: halved

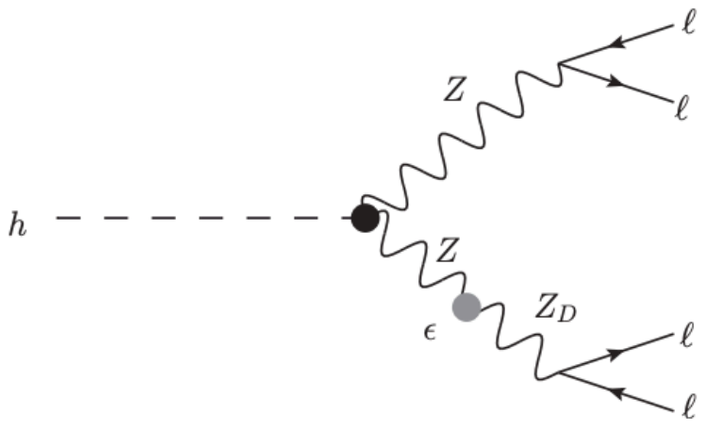
Impact parameter resolution: 25-40%



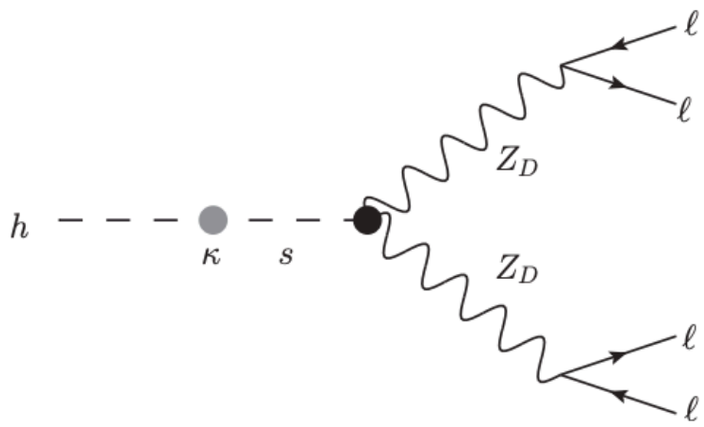
Di-muon with scouting BR

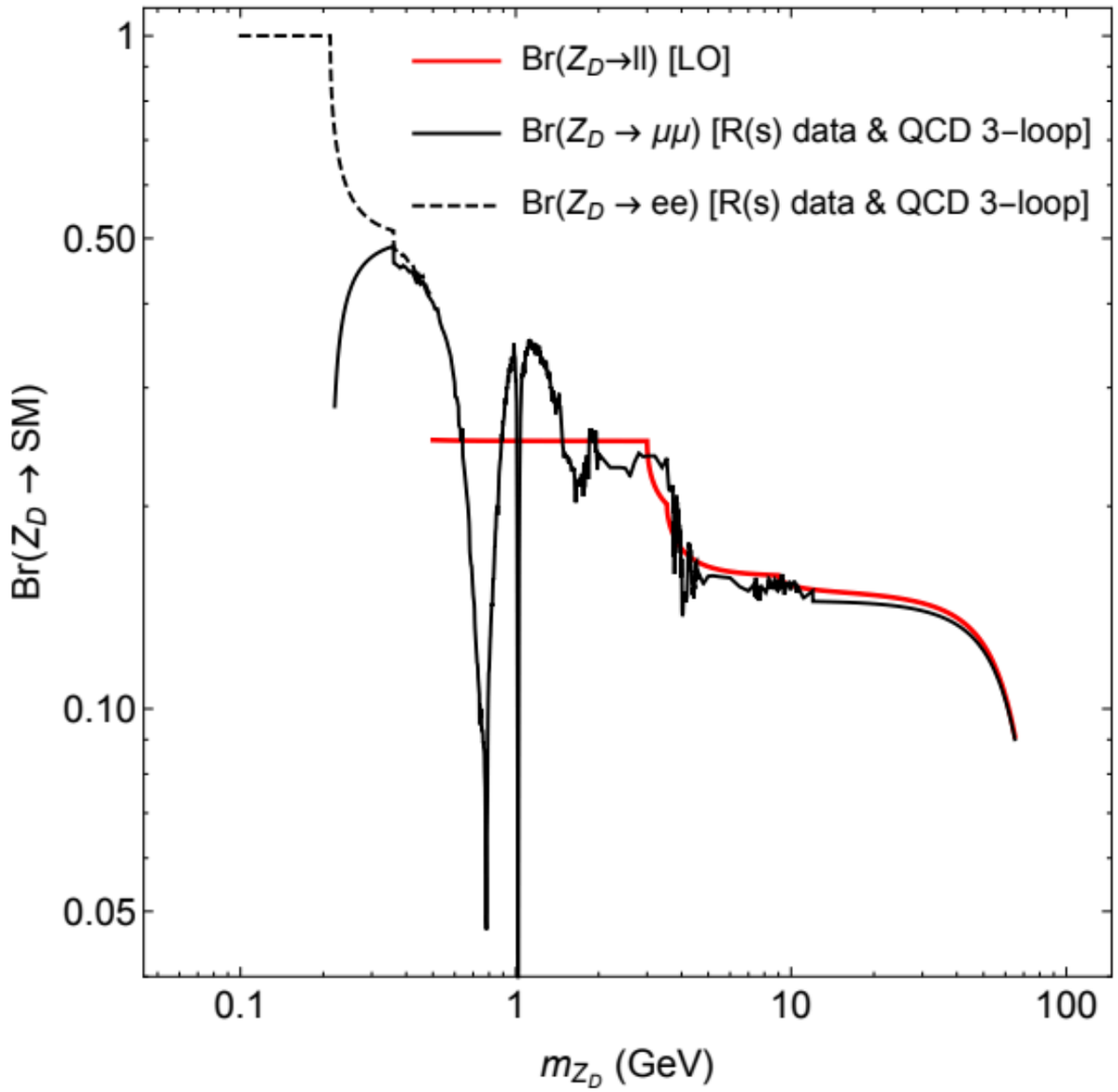
1412.0018

h→ZdZ$^{(*)}$→4l
via hypercharge portal

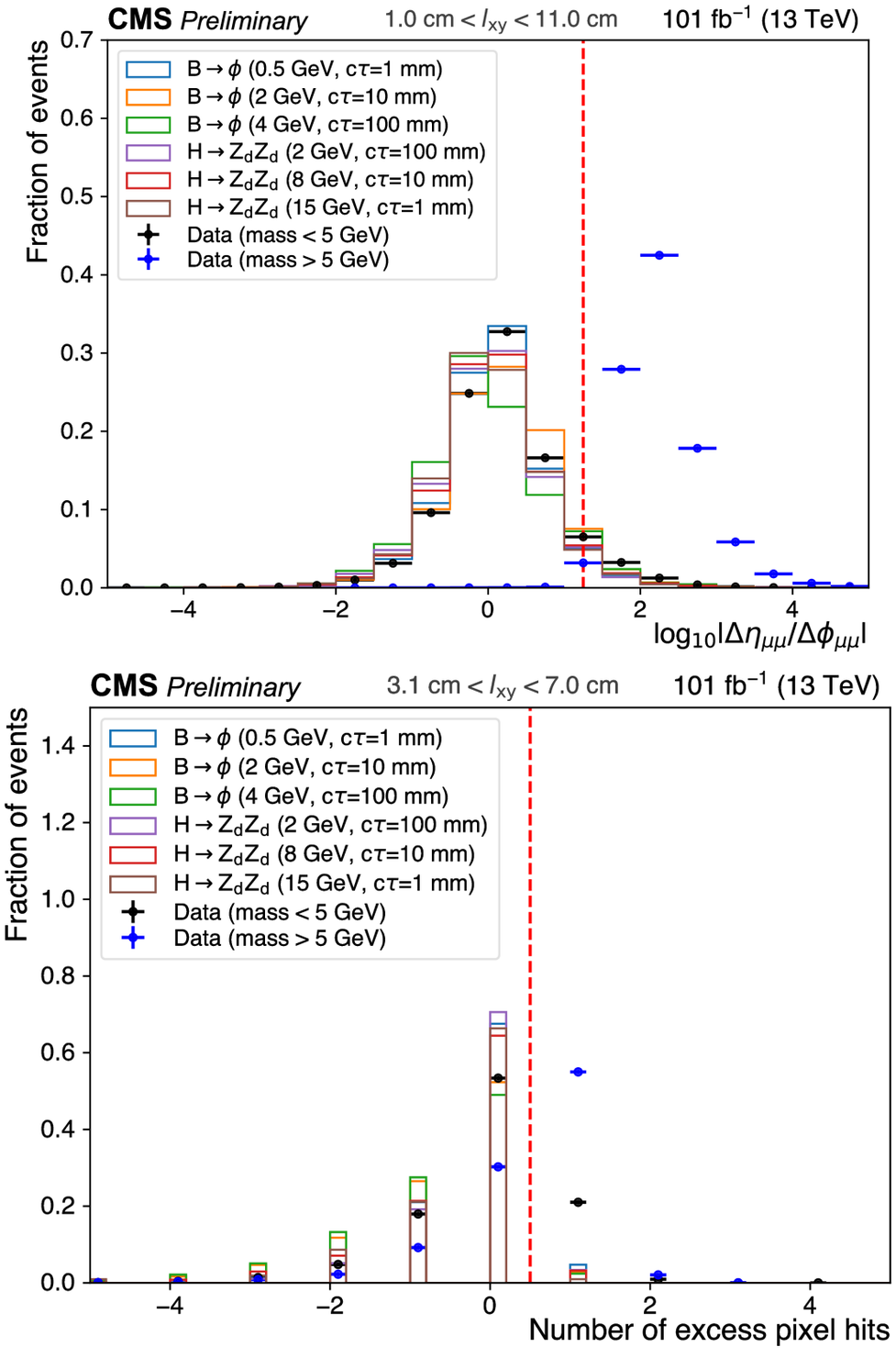


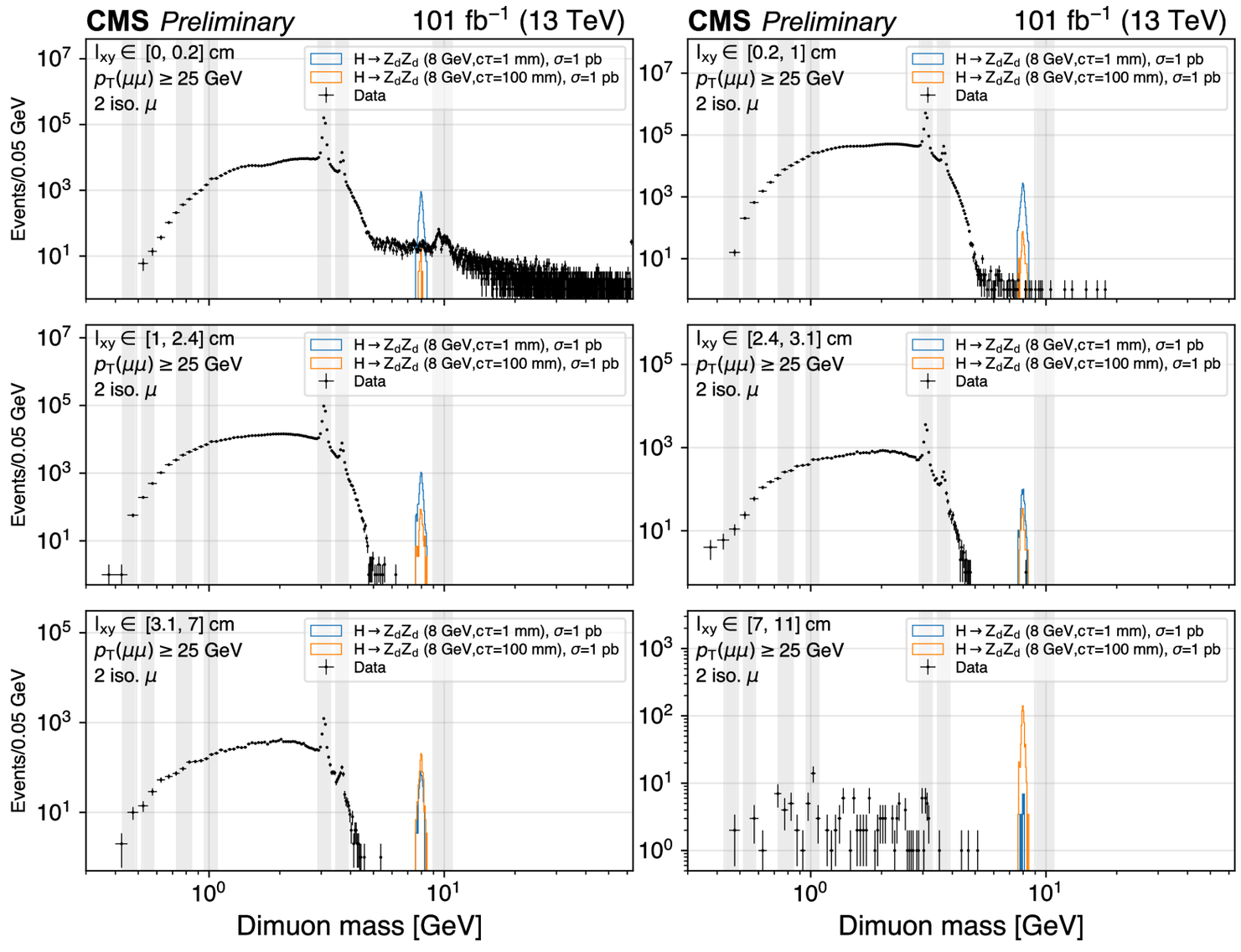
h→ZdZd→4l
via higgs portal





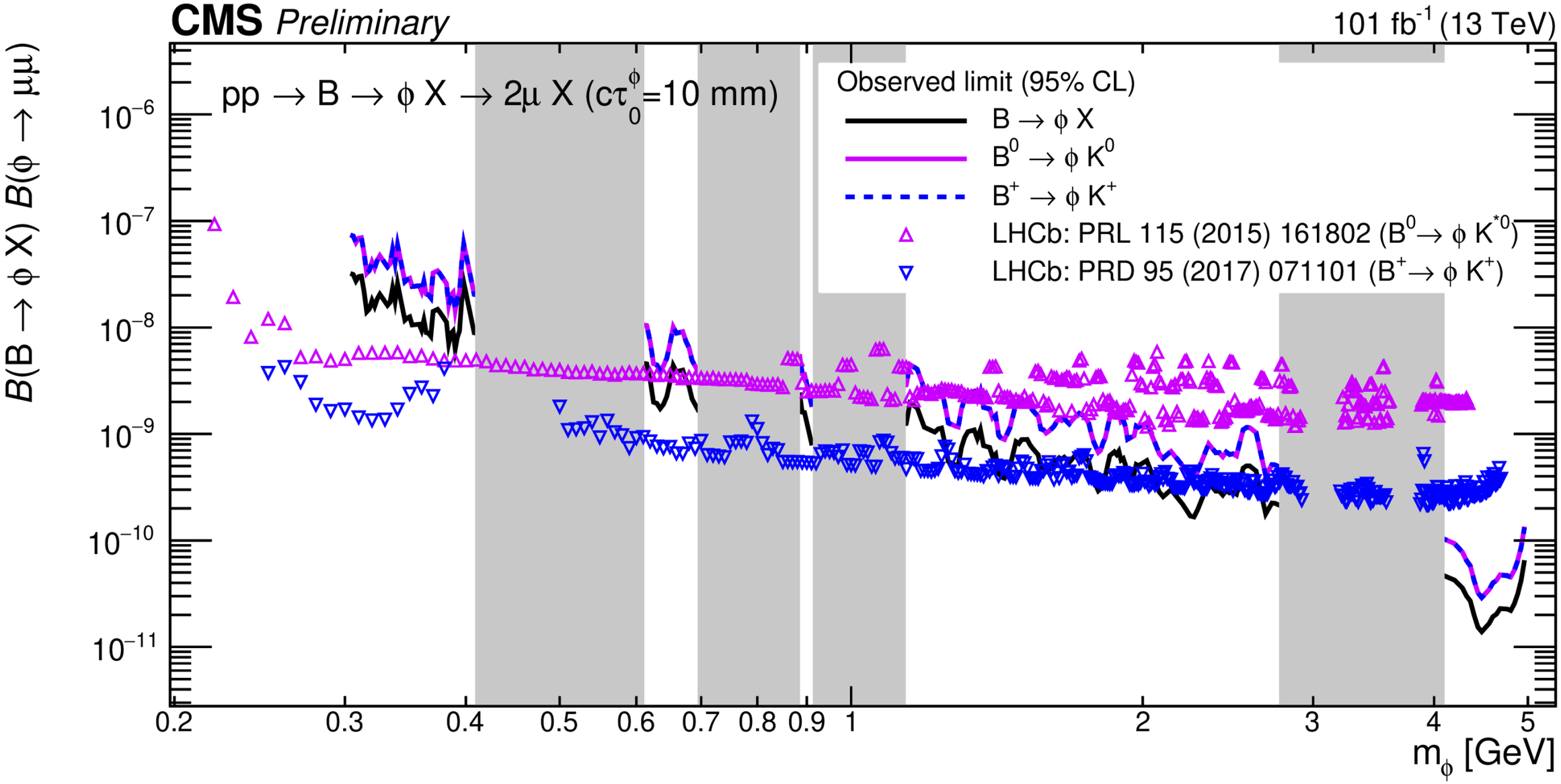
Dimuon with scouting variables





Dimuon with scouting b→ϕX

for cτ = 10 mm



Displaced jet backgrounds

EXO-19-021

Material interactions

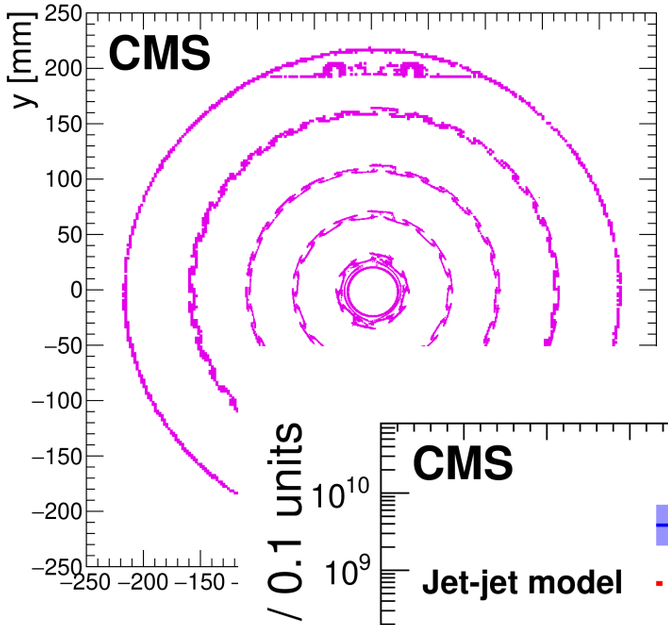
reject with material veto

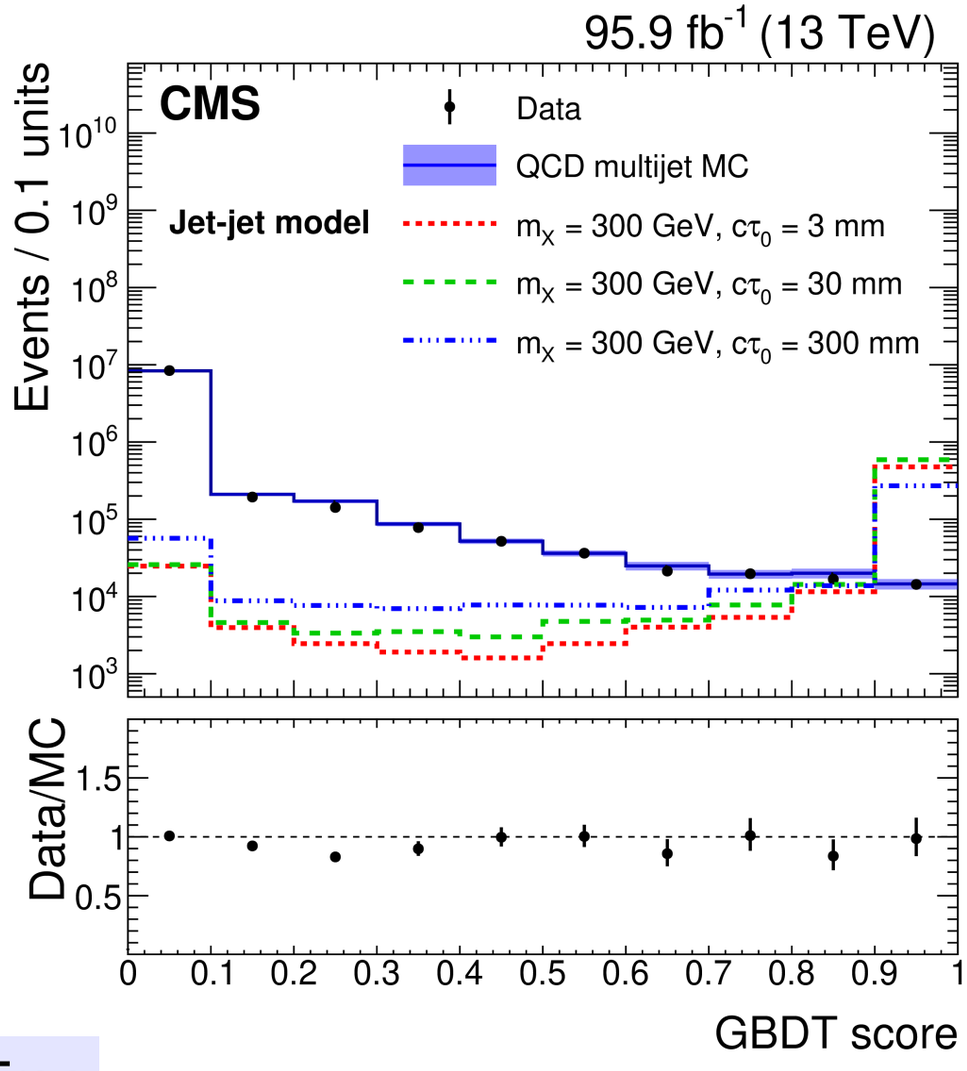
Real SM LLPs

2nd largest track d0-significance
sum track d0-significance*
DV Lxy-significance*
< 3 tracks prompt tracks per jet

Randomly crossing tracks

DV-dijet p_T consistency
DV-dijet position consistency*
vertex track multiplicity*





*input to Boosted Decision Tree

Inclusive displaced jets

EXO-19-021

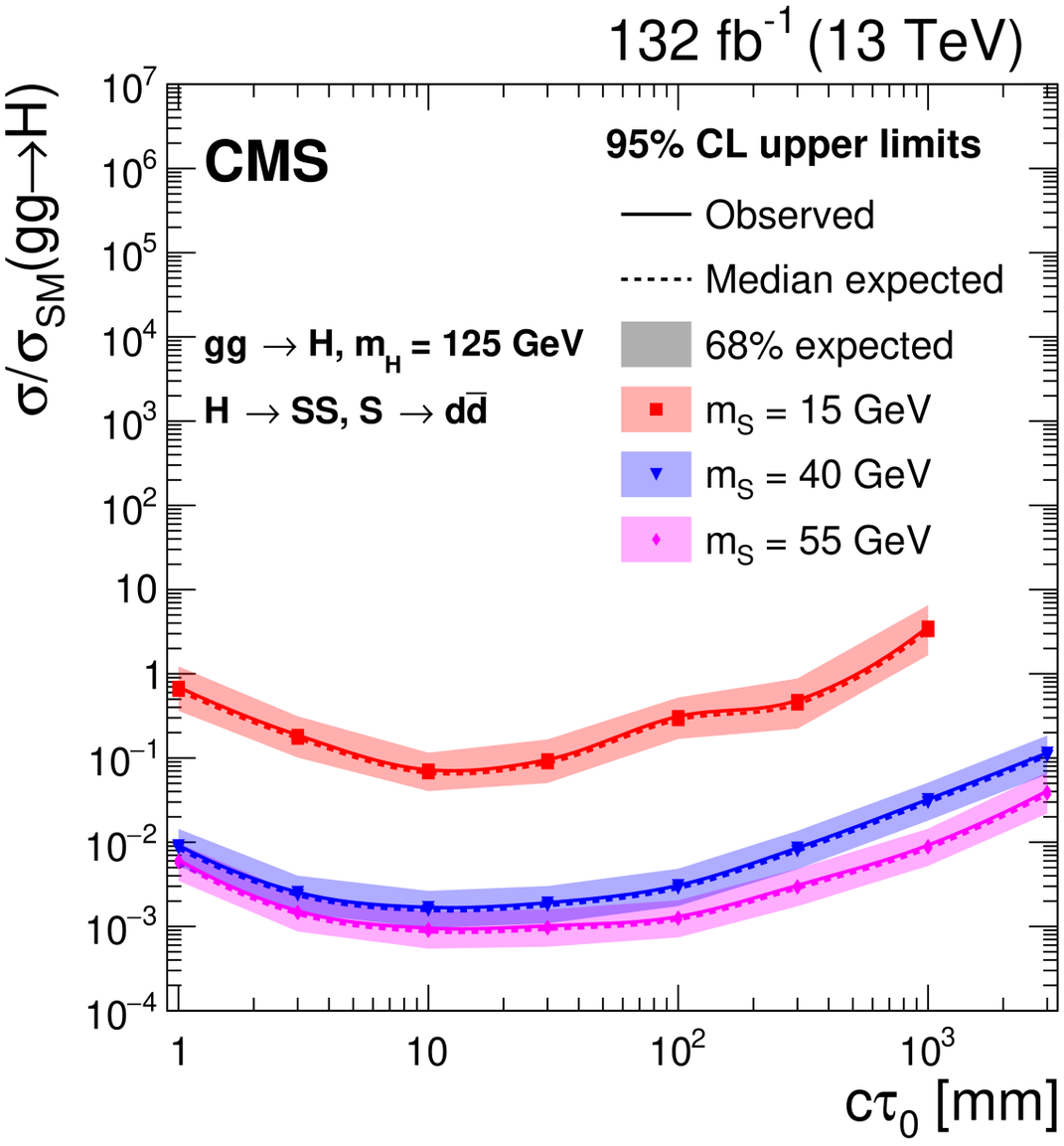
Hadronic decays in Tracker

Results: 0.75 ± 0.60 events expected, 1 observed

Room for improvement

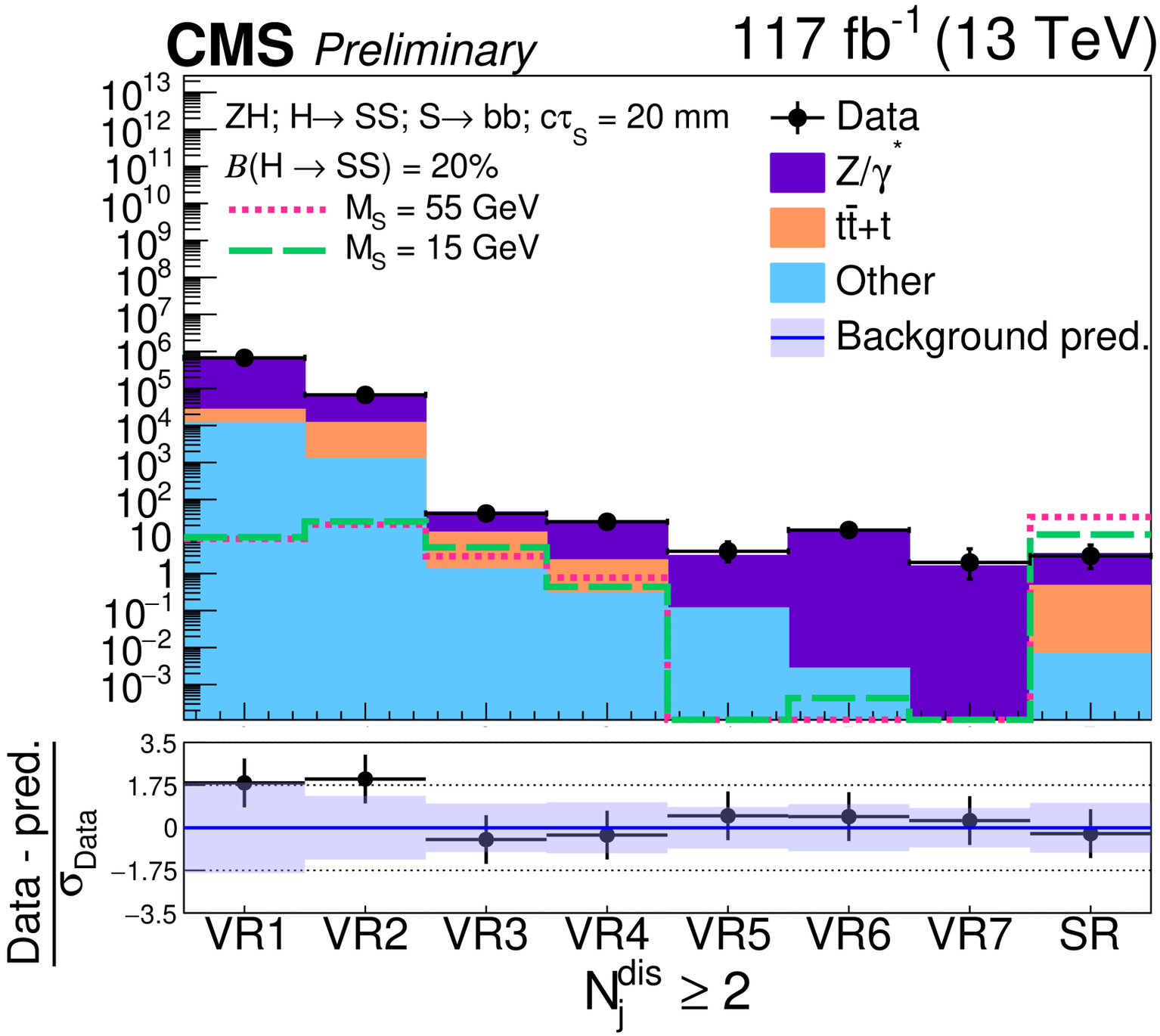
1. very low mass, m_X = 15 GeV
decay products merged into one jet

2. decays to b-jets
~10x worse than light-jets
reduced tracking/vertexing
efficiency due to b-meson lifetime



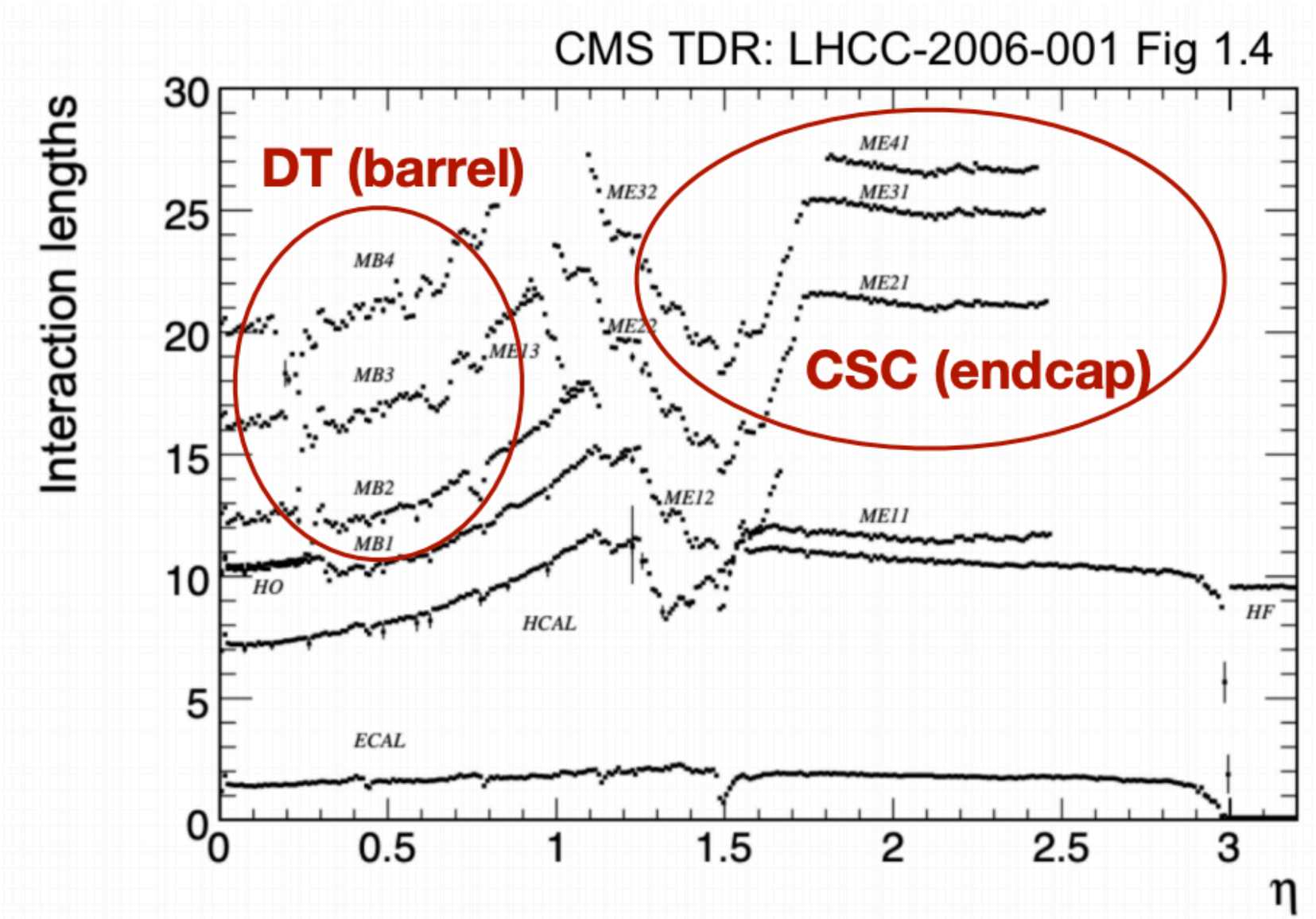
Z+displaced jets

New! EXO-20-003



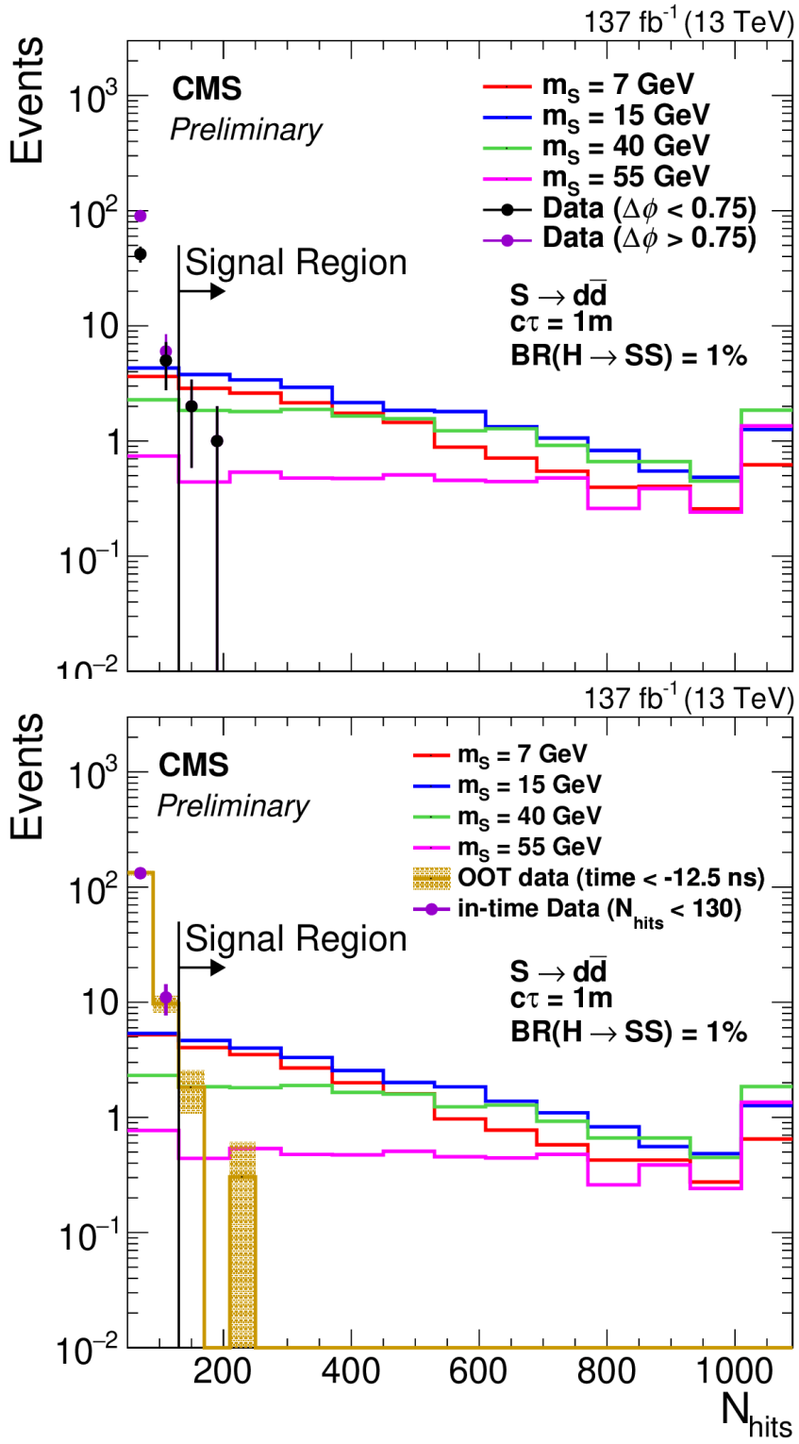
CMS Shielding

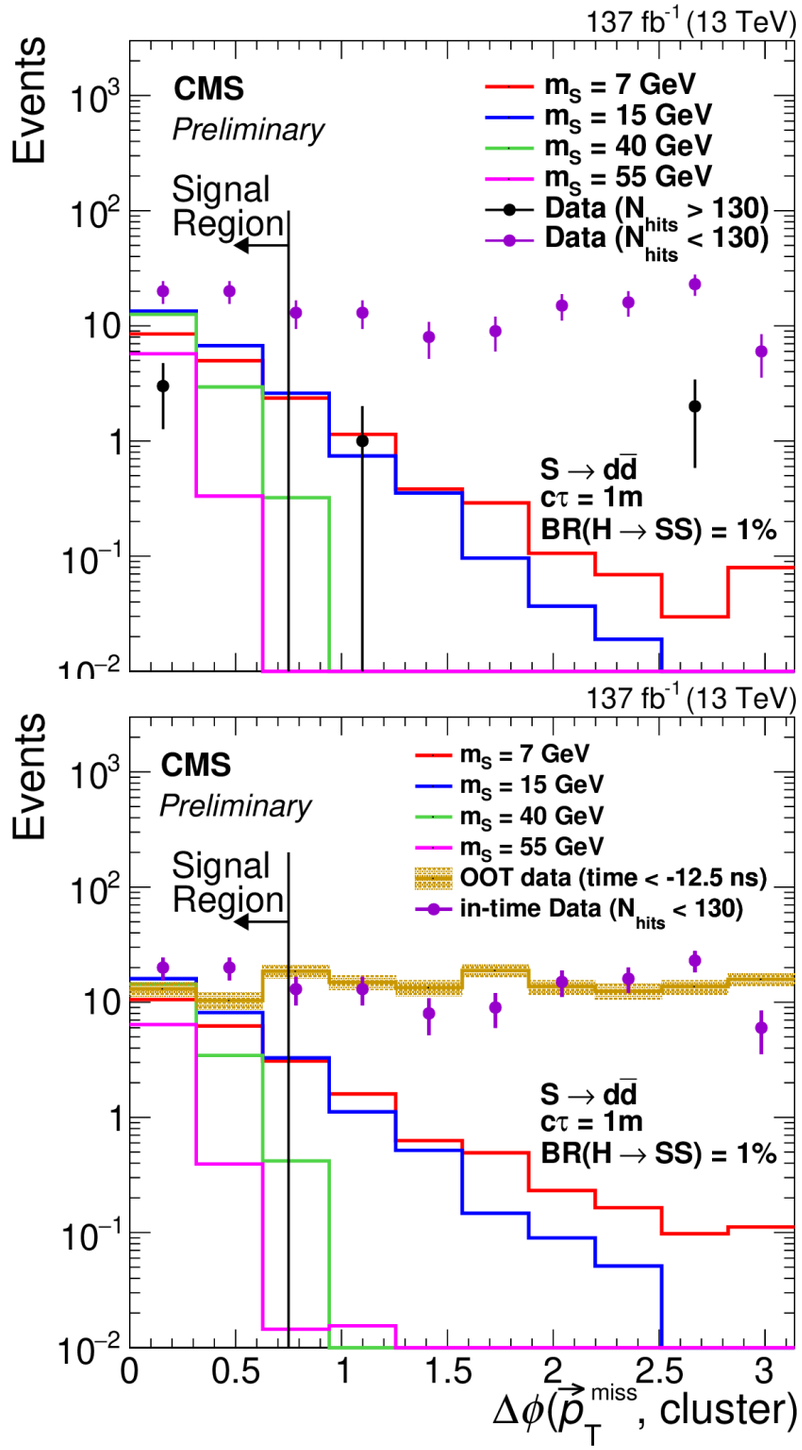
12-27 nuclear interaction lengths



Decays in Muon Endcaps

New! [2107.04838]





Decays in Muon Endcaps

New! [2107.04838]