

WG3 UPDATE: EXOTIC HIGGS DECAYS

Georgia Karapostoli (CMS), Matthias König (theory),
Verena Martinez Outschoorn (ATLAS), Lorenzo Sestini
(LHCb), Brian Shuve (theory)

*18th Workshop of the CERN LHC Higgs Working Group
2 December 2021*

SUBGROUP INTRODUCTION

- Subgroup twiki page: <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHSWGExoticDecay>
- Our task is to inform, aggregate, and make recommendations for studies of decays of H(125) to BSM states
- **This talk:**
 - Overview of new, recent experimental and theoretical results
 - Focus on results since the last WG meeting
 - Discuss activities and plans for the subgroup in 2022

OVERVIEWS

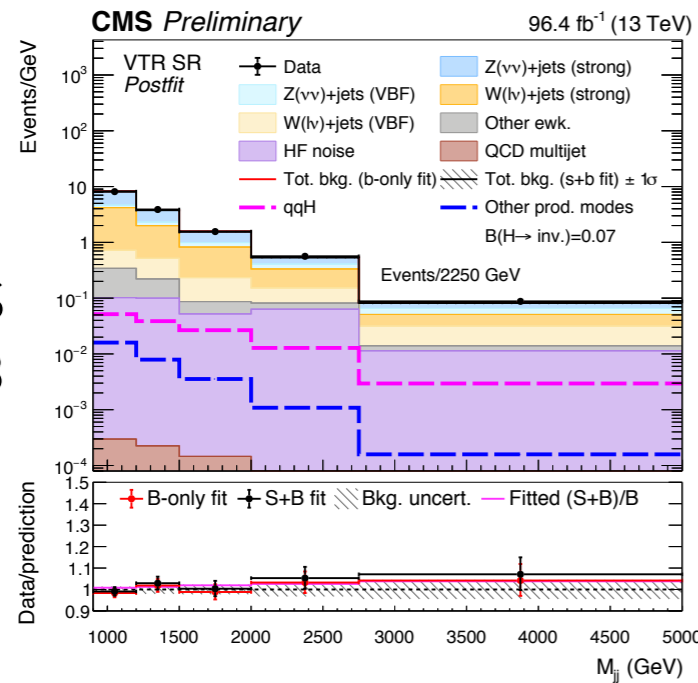
- Several new extensive documents on theories and signatures relevant for exotic Higgs decays!
 - Comprehensive review of models, current constraints, and gaps in coverage for exotic Higgs decays
M. Cepeda, S. Gori, V. Martinez Outschoorn, J. Shelton, 2111.12751
 - Maximizing discovery prospects for stealth new physics at LHCb
M. Borsato *et al.*, 2105.12668
 - Opportunities for triggers in searches for long-lived particles in Run 3
J. Alimena *et al.*, 2110.14675

INVISIBLE HIGGS DECAYS

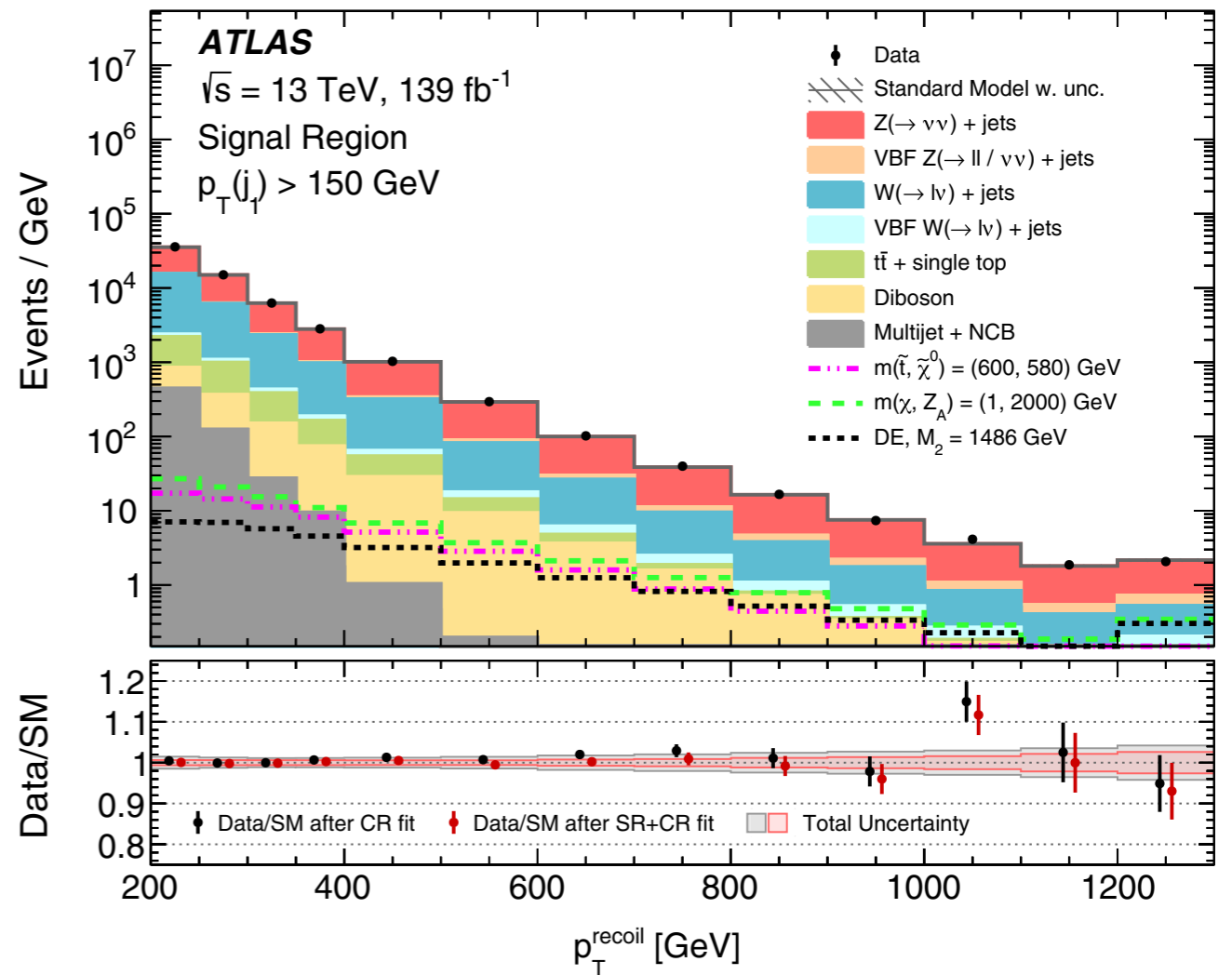
NEW RESULTS

VBF

monojet

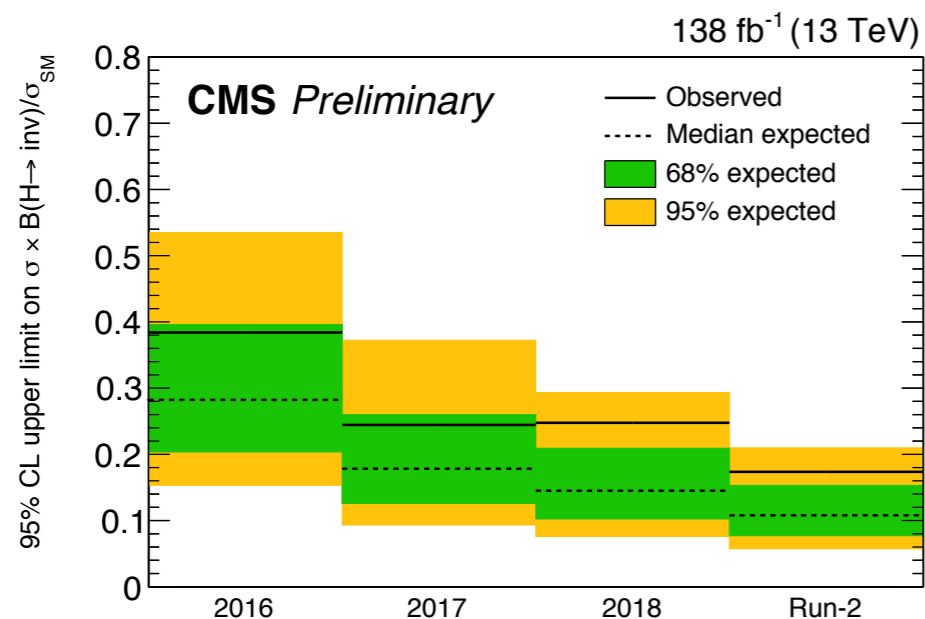


ATLAS 2102.10874 [PRD]



95% CL inv BF: 34%

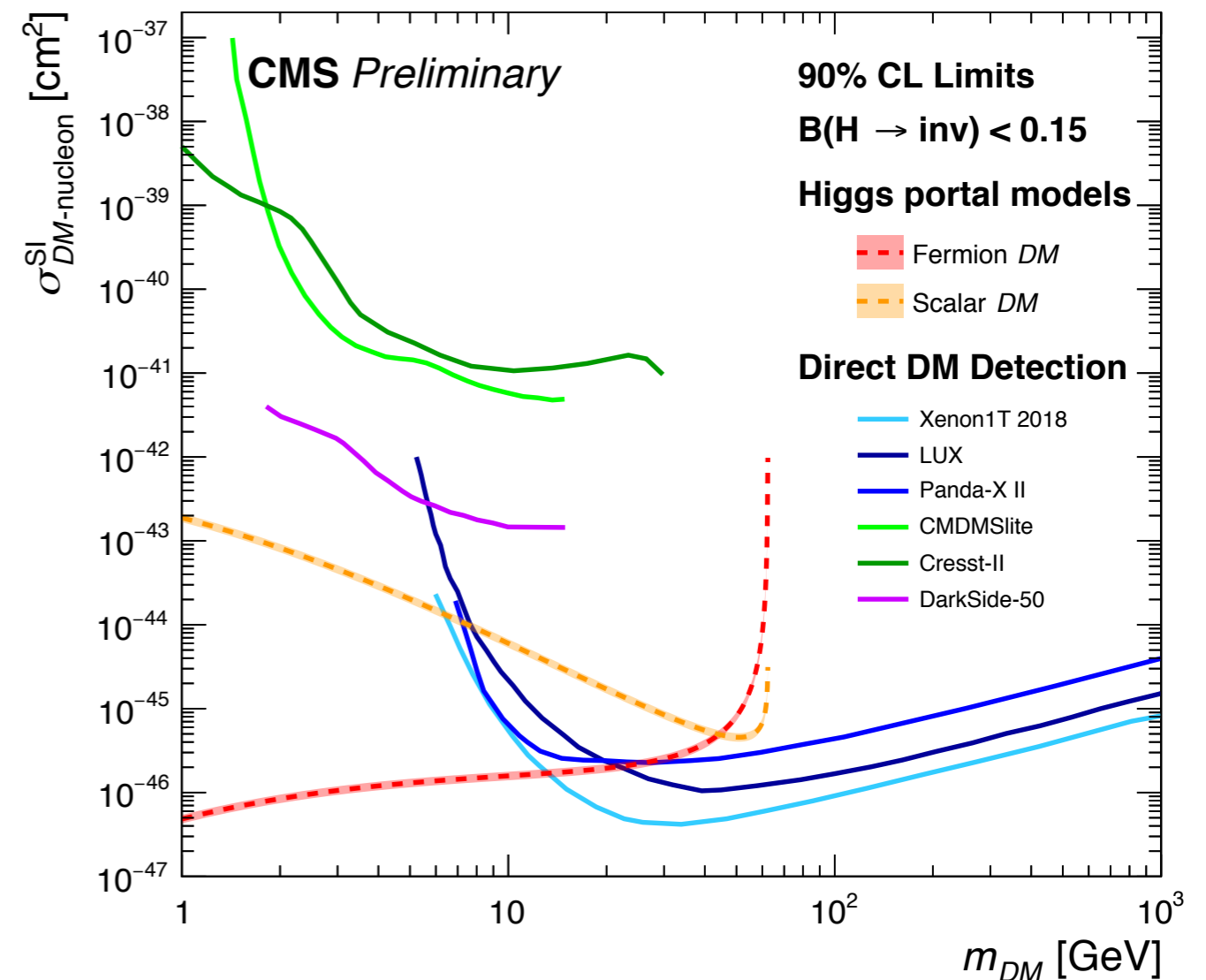
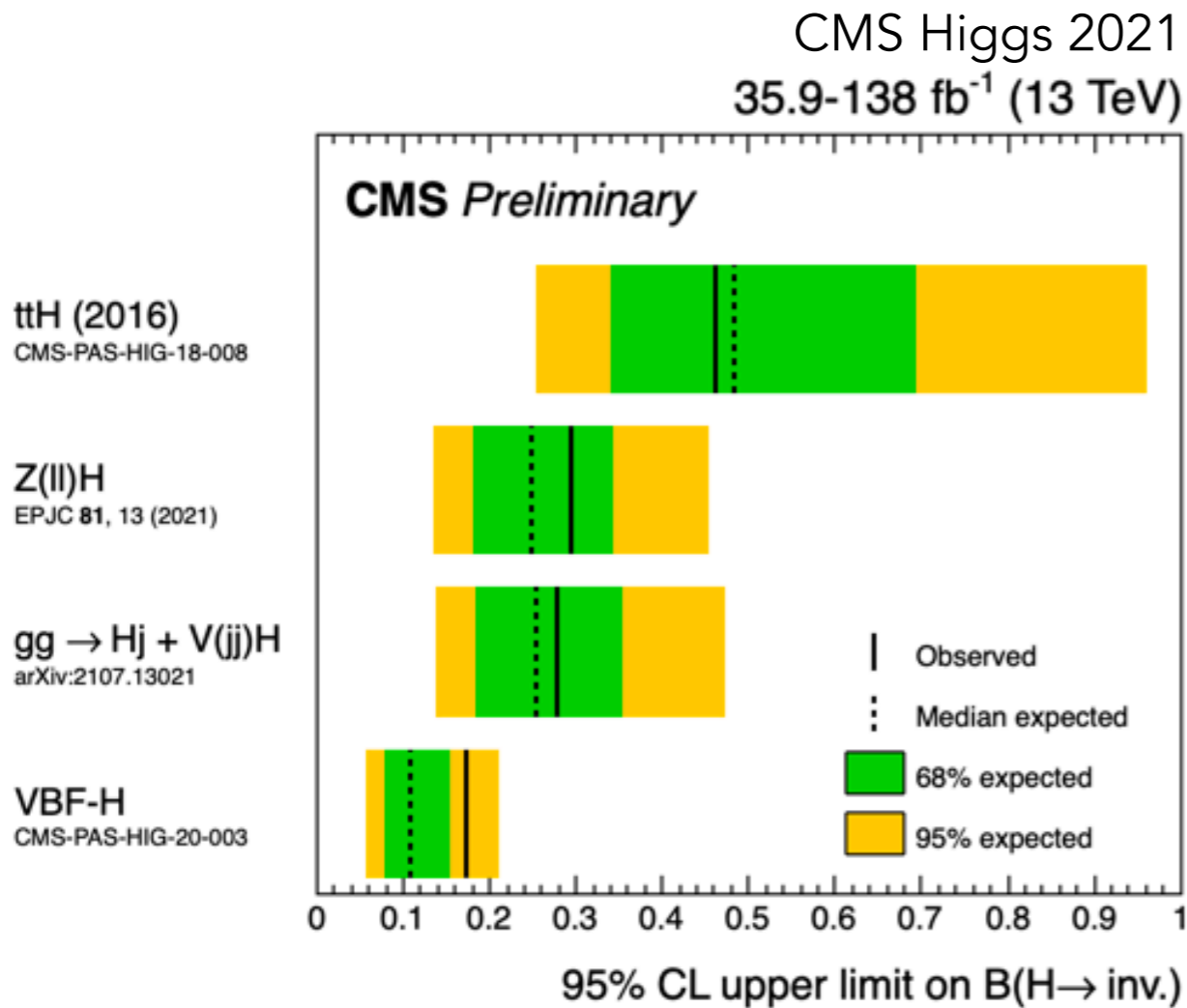
CMS PAS
HIG-20-003



see also ATLAS 2109.00925

COMBINATIONS

CMS PAS HIG-20-003
138 fb⁻¹ (13 TeV)

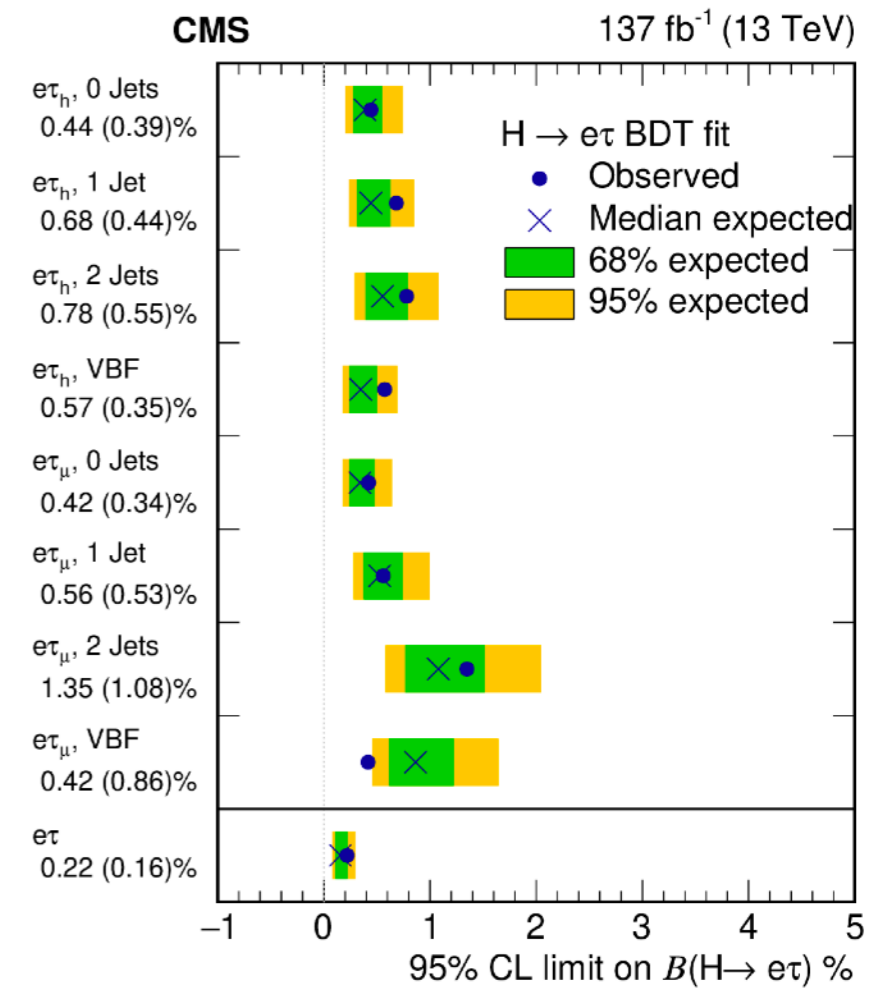
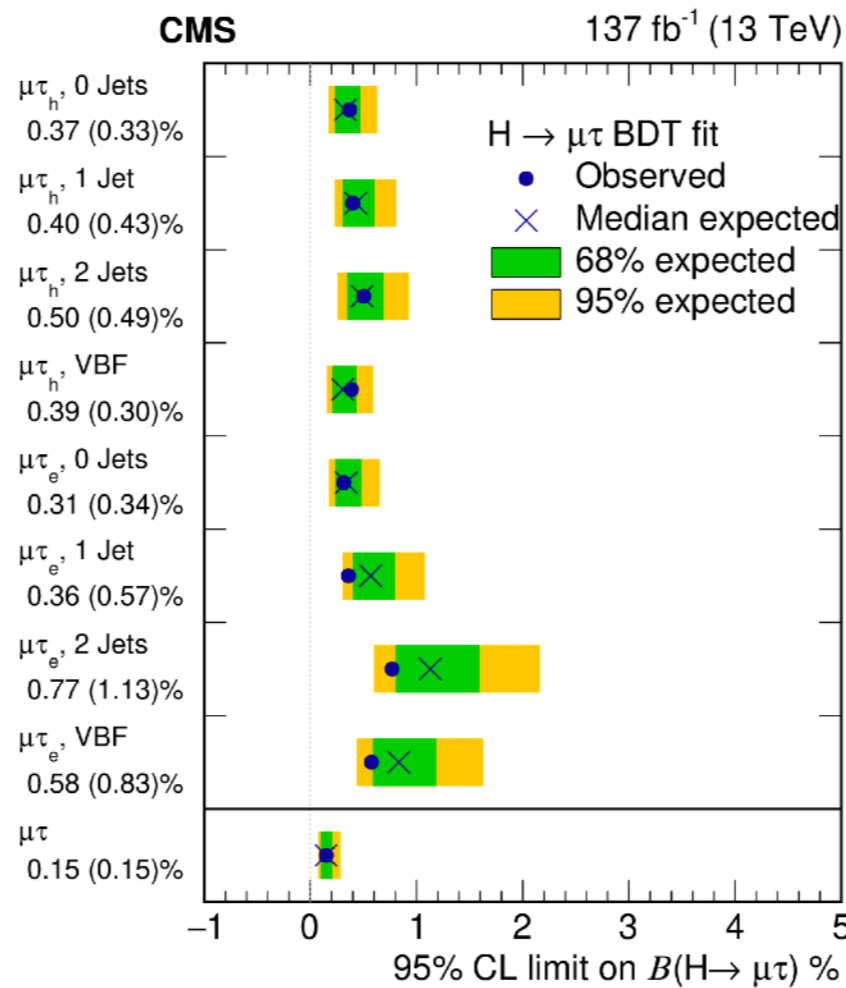
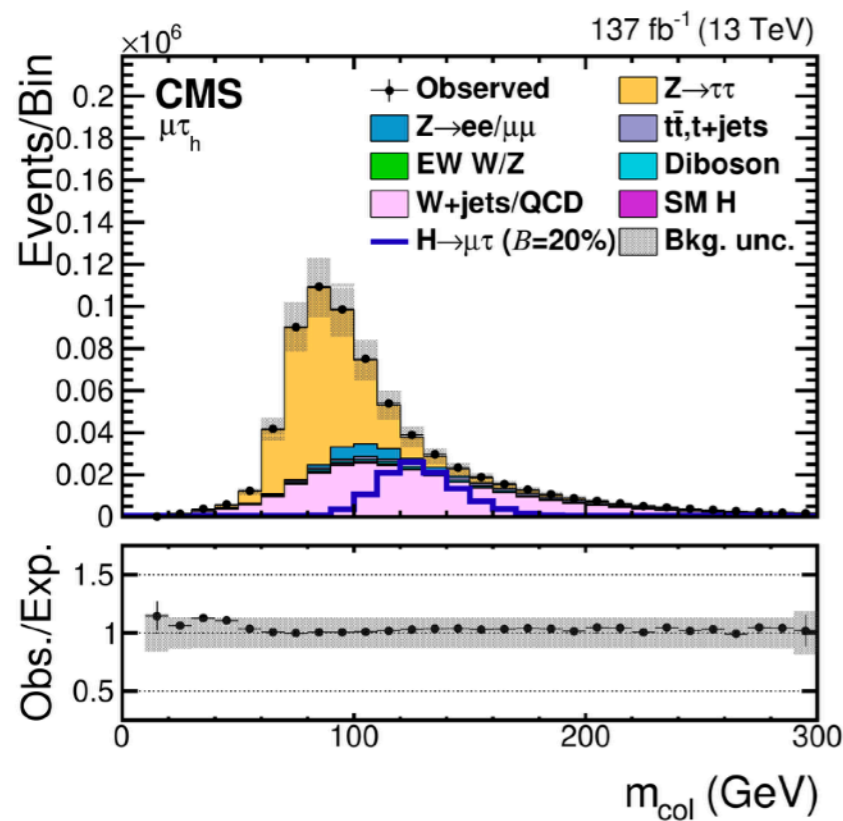


- New theory review: "Collider Searches for DM Through the Higgs Lens", S. Arygropoulos, O. Brandt, U. Haisch, 2109.13597

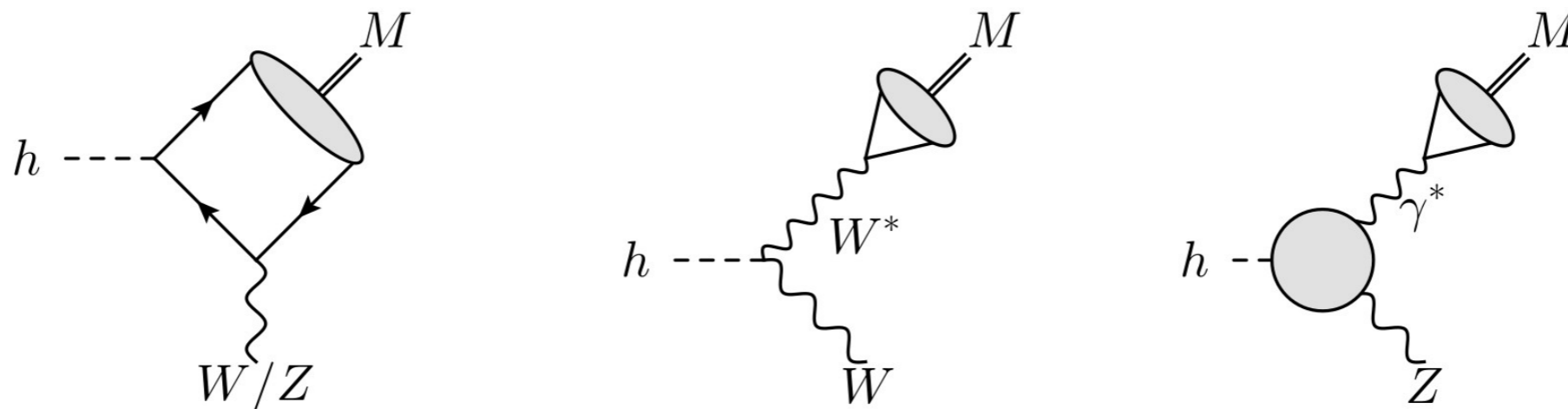
LEPTON FLAVOUR VIOLATION & RARE DECAYS

LFV HIGGS DECAYS

- Use collinear mass (assuming neutrinos aligned with track in tau decays) & BDT to discriminate signal & background



V+MESON (THEORY)

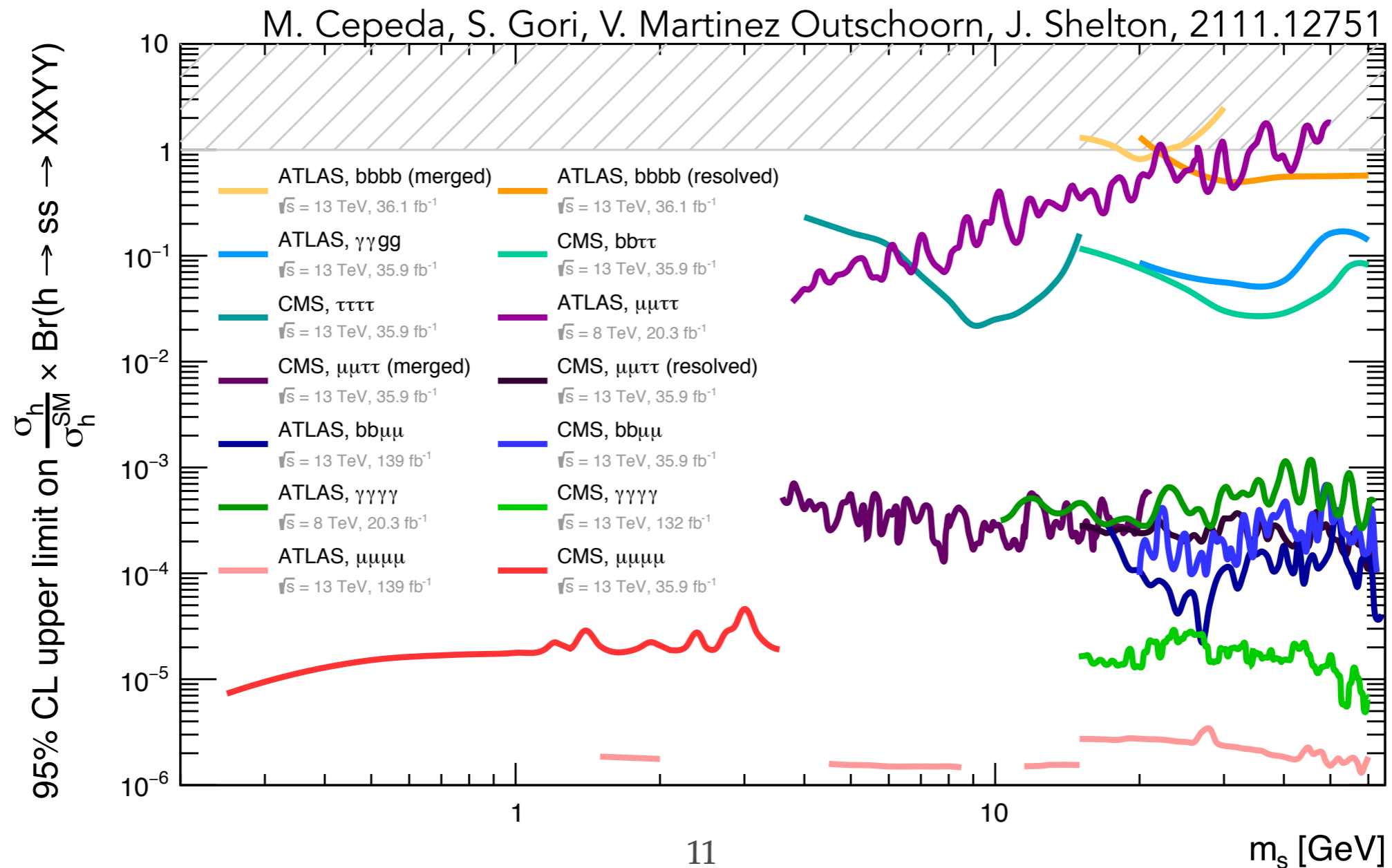
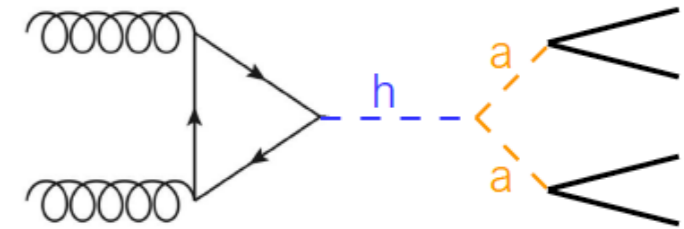


- Use meson as “flavour proxy” to test SM fermion Yukawas
- QCD corrections known and are sizable in some cases
- **Current work:** supplement QCD corrections for all channels and gather in one place, including possible deviations from SM Yukawas
- **Status:** mostly done, intend to publish in a short internal note

PROMPT EXOTIC DECAYS

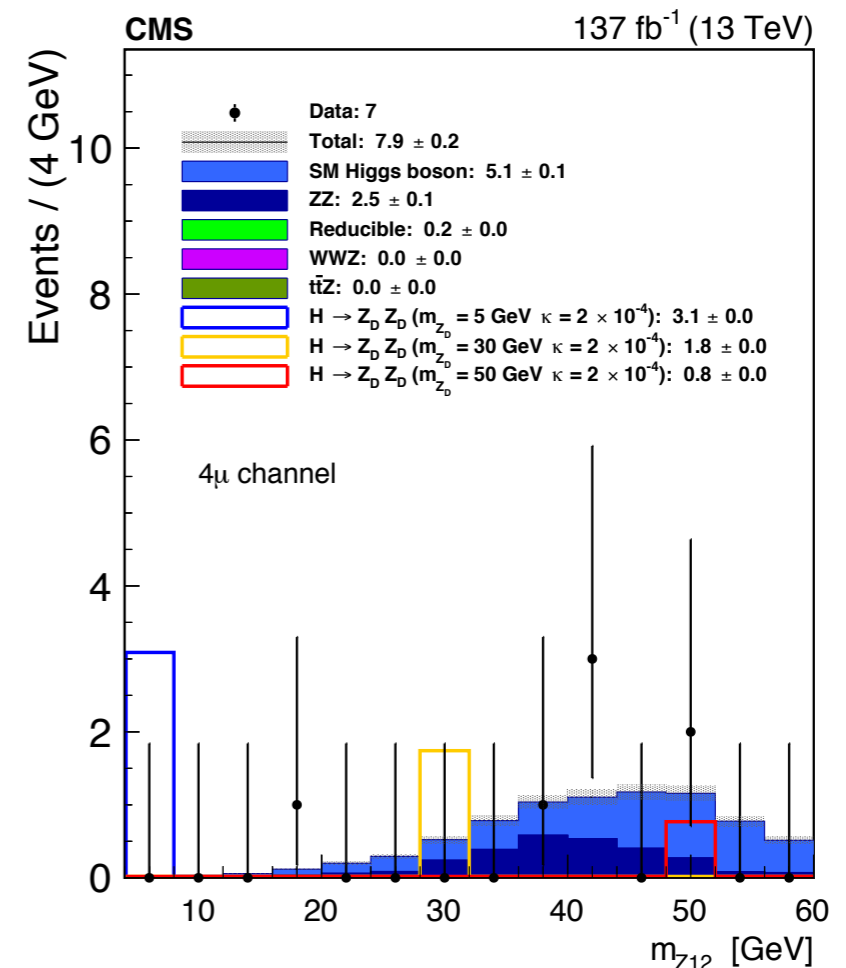
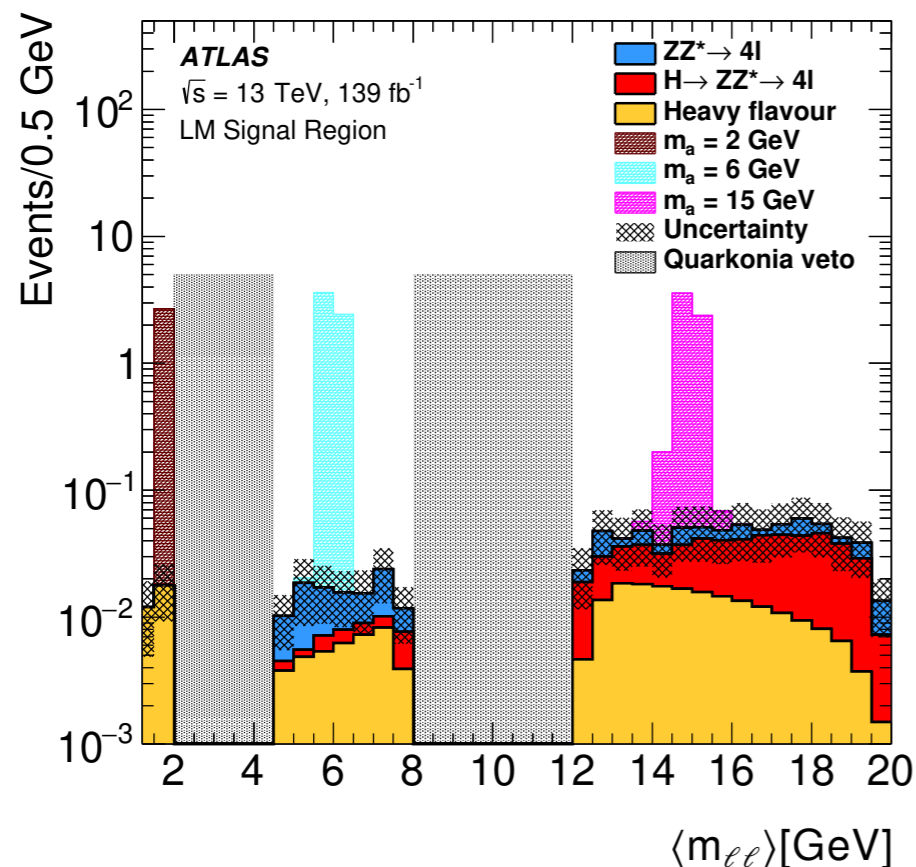
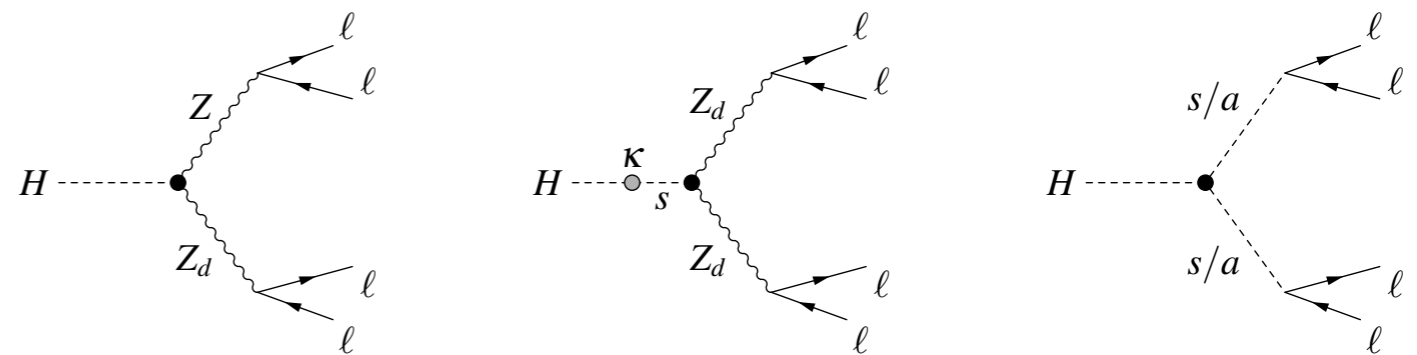
DECAYS TO RESONANCE PAIR

- Signal models include decays to pair of (pseudo)scalars, dark photons, Z + dark photon



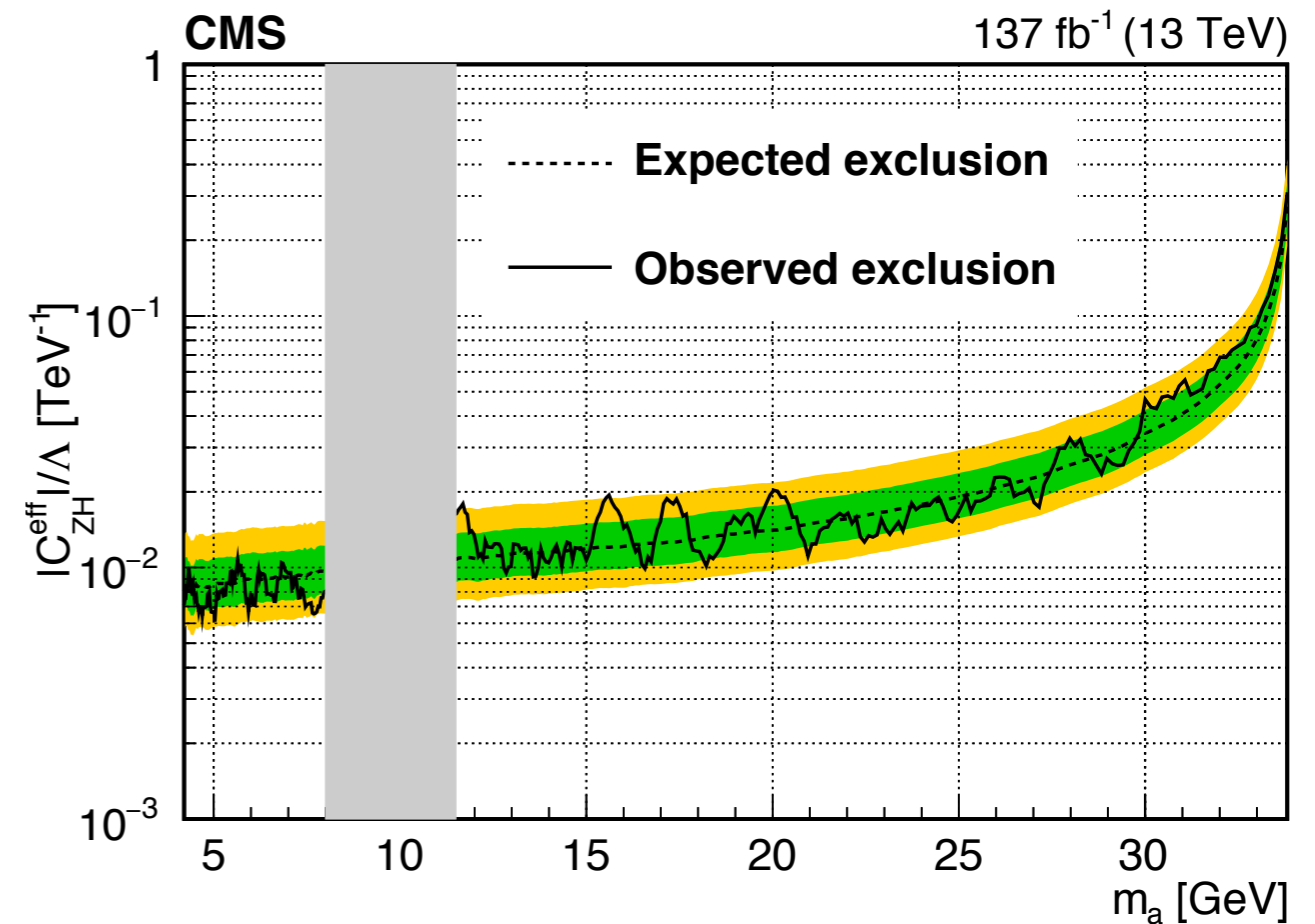
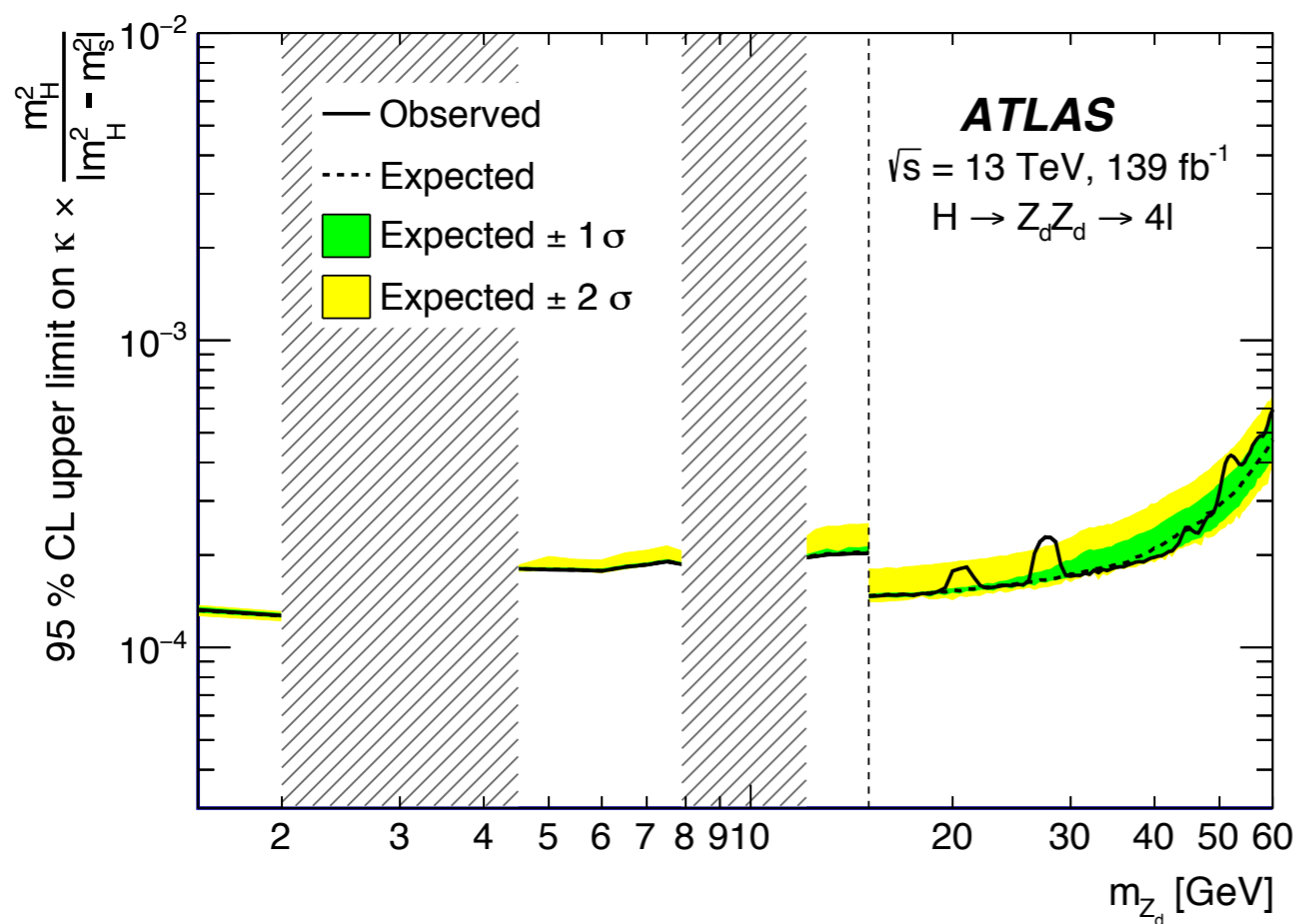
DECAYS TO 2 LEPTON PAIRS

- Full Run 2 analyses from ATLAS & CMS
- ATLAS has dedicated "low mass" search with tighter cut on 4-lepton mass, allows for collinear lepton pairs



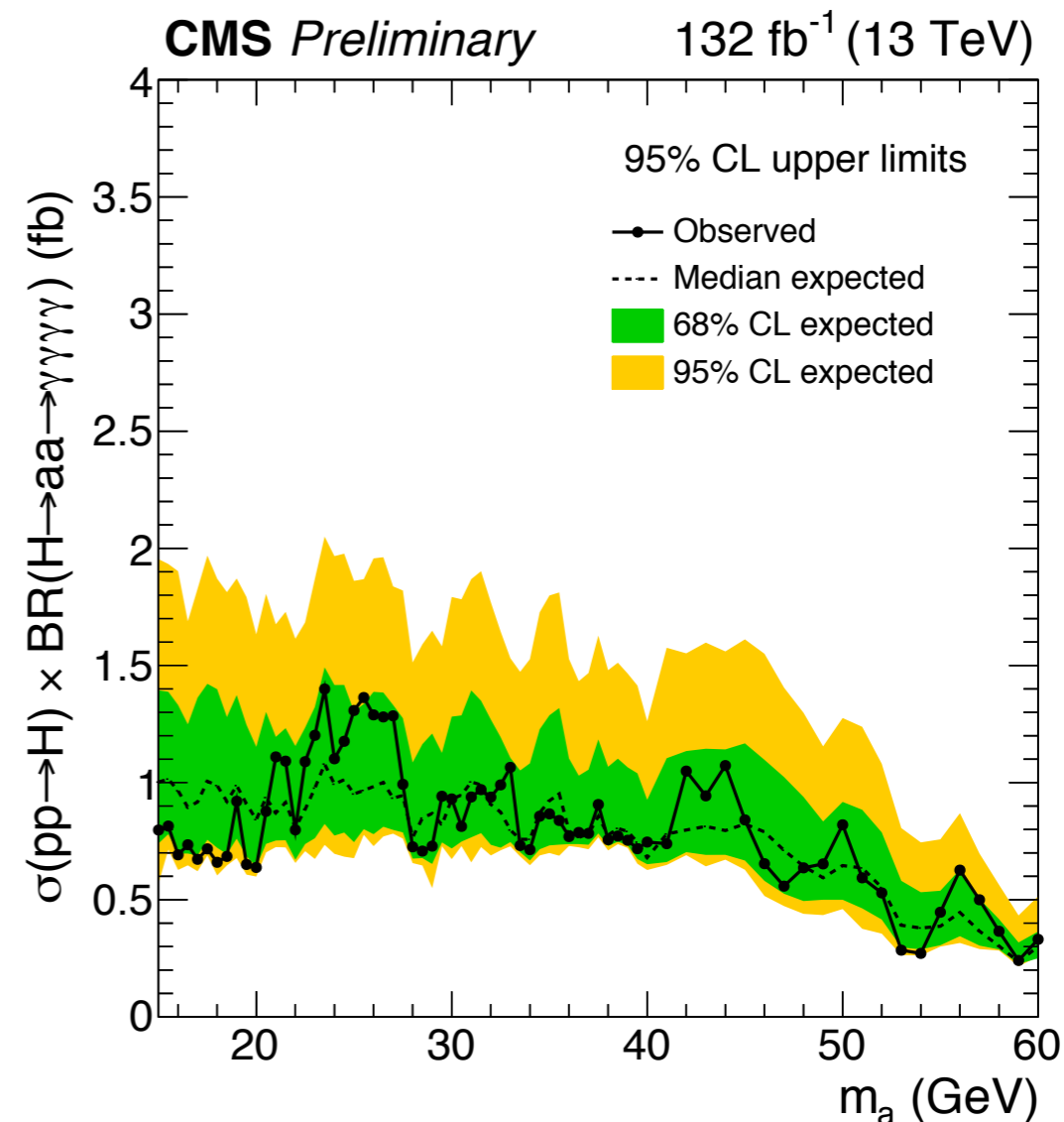
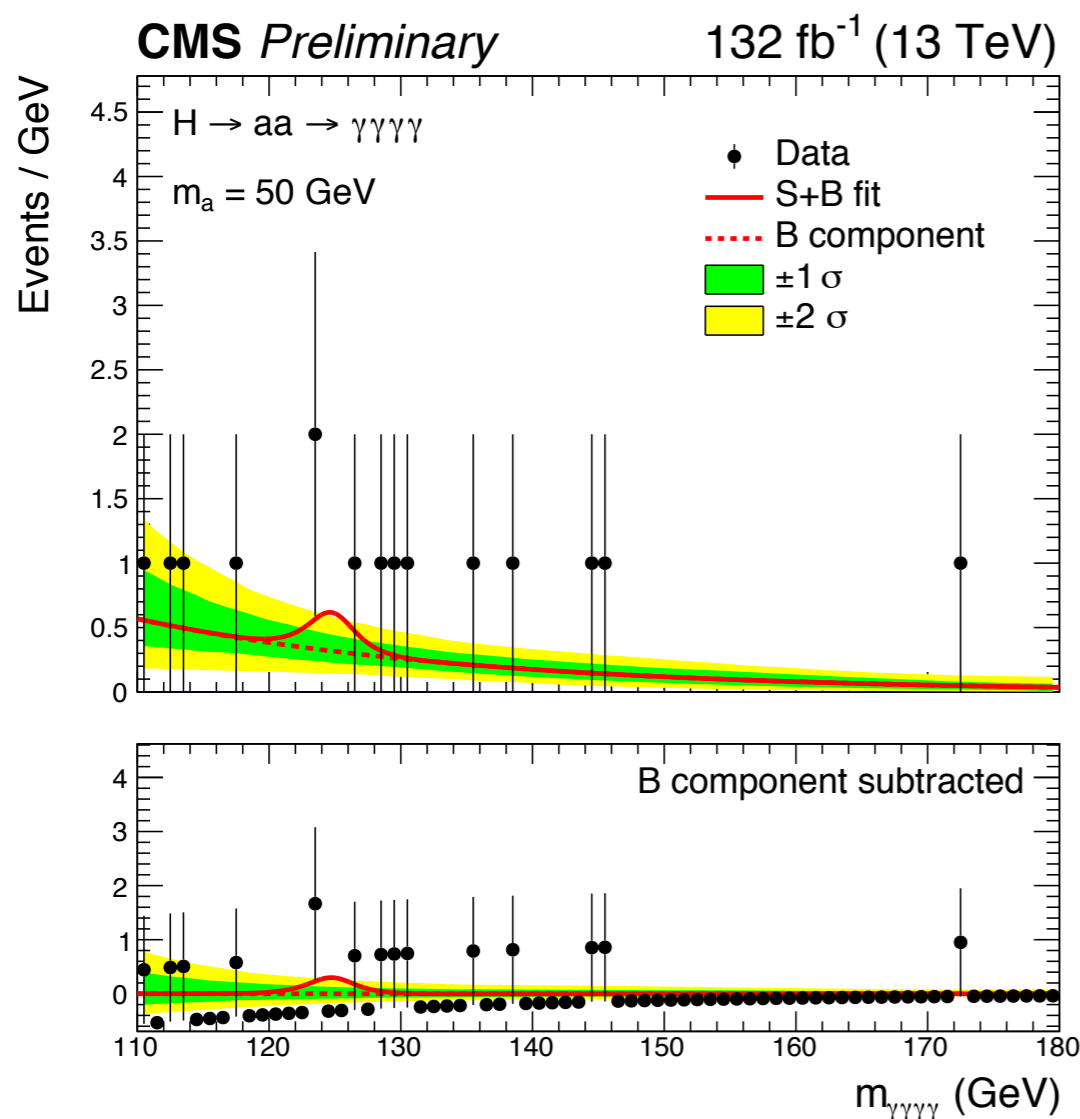
DECAYS TO 2 LEPTON PAIRS

- Results interpreted in terms of ALPs, 2HDMs, dark photon, and dark photon + dark Higgs models



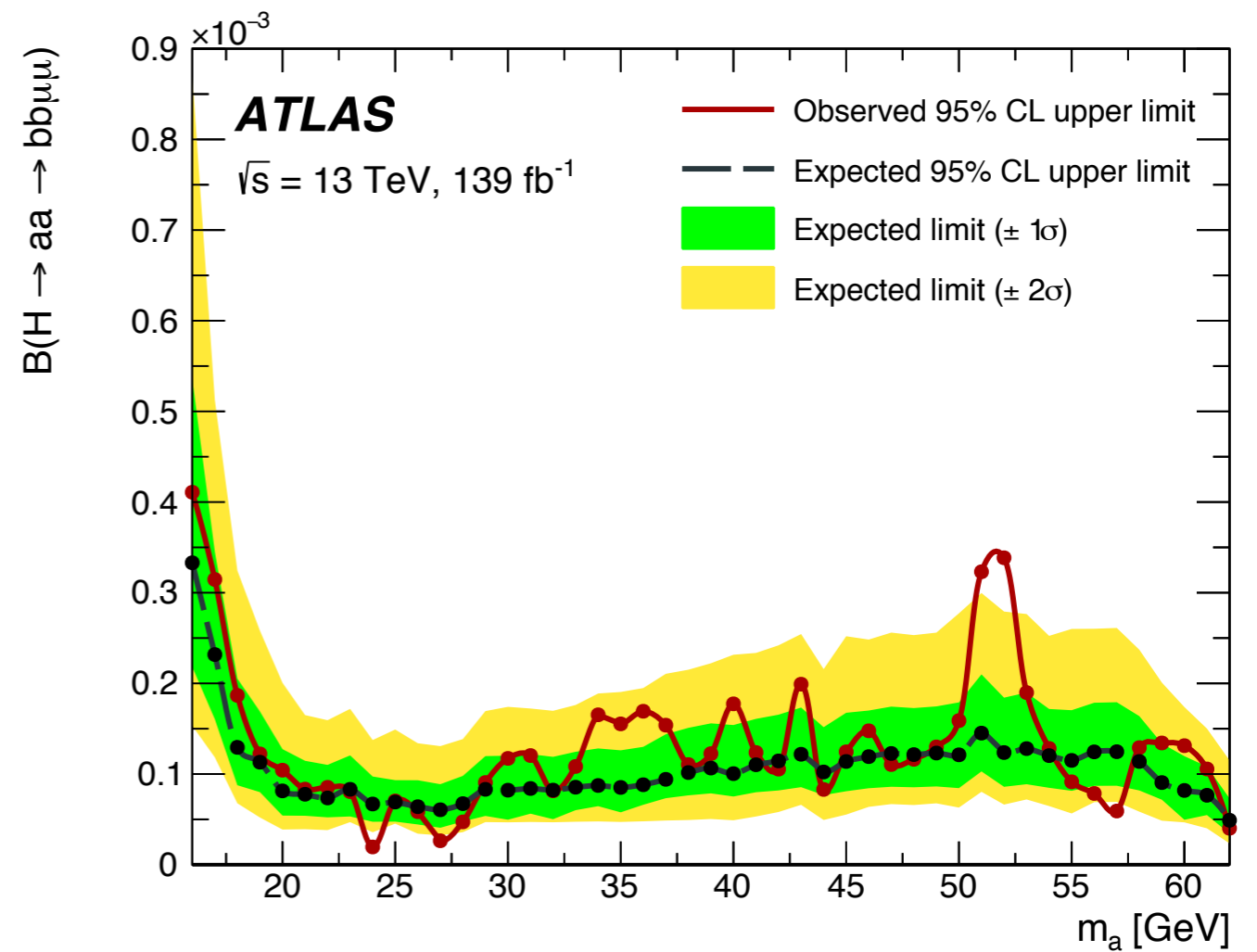
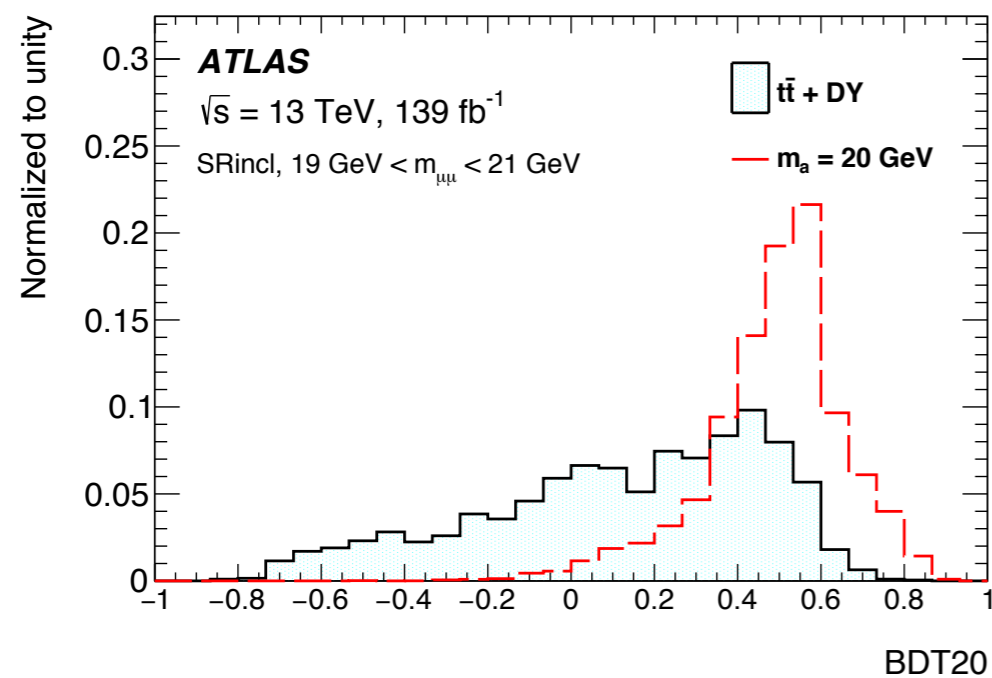
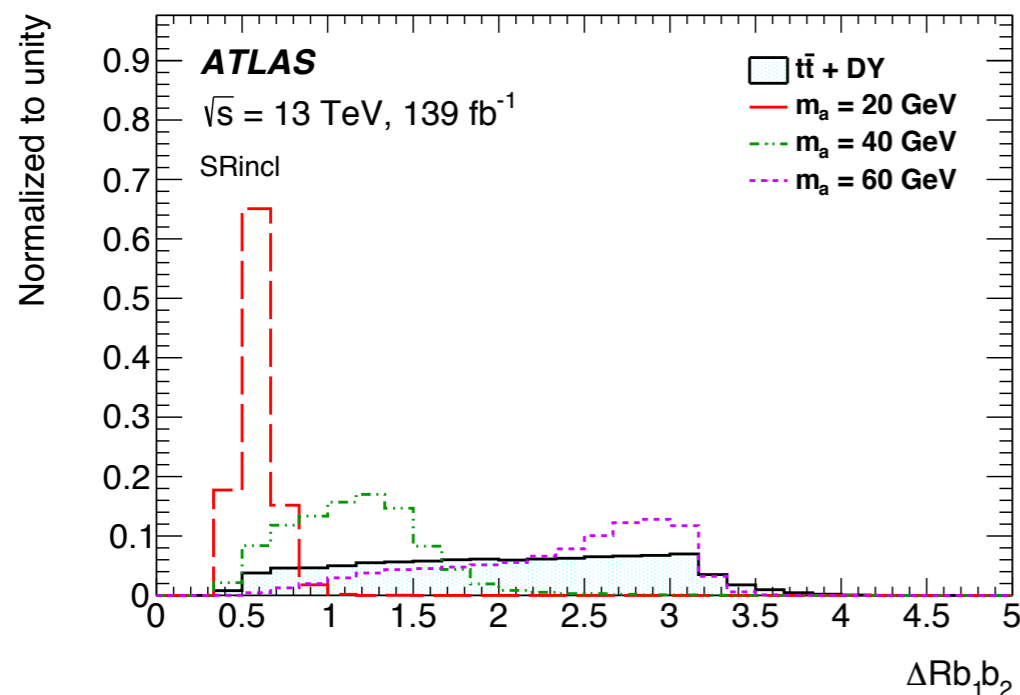
DECAYS TO 2 PHOTON PAIRS

- Use diphoton trigger; pT requirements on 4 photons are 30, 18, 15 and, 15 GeV, with one pair having invariant mass > 55 GeV
- MVA is used to further separate signal from background



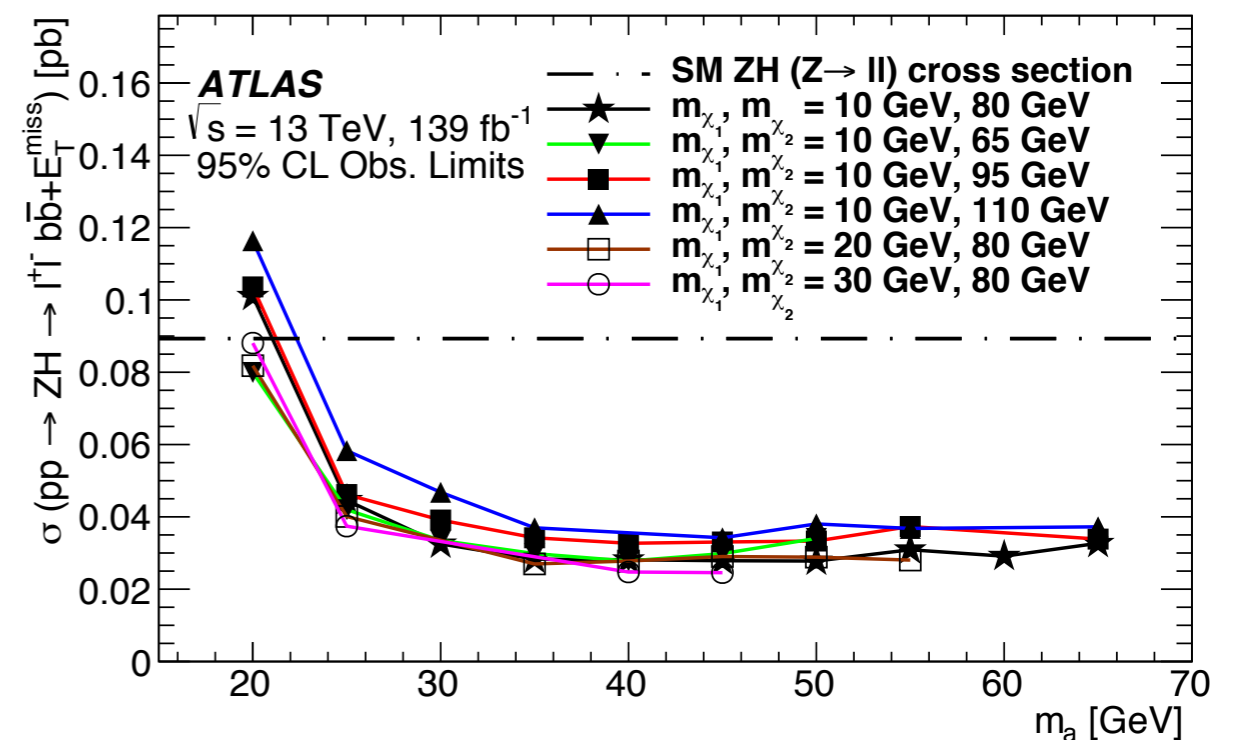
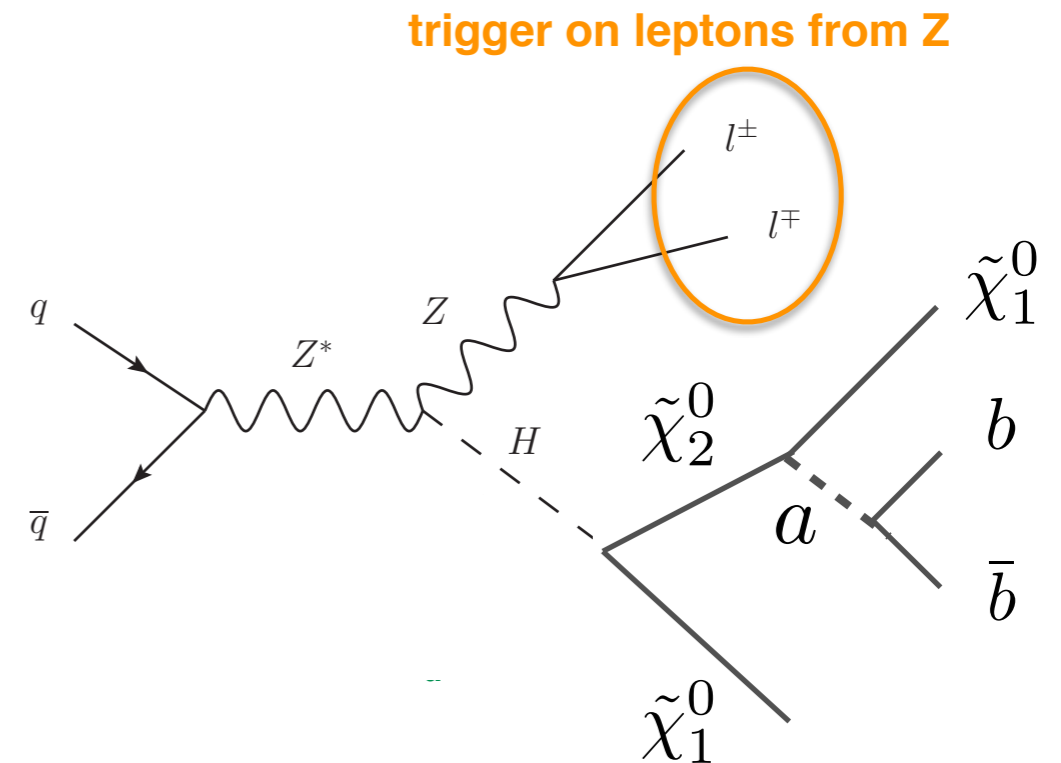
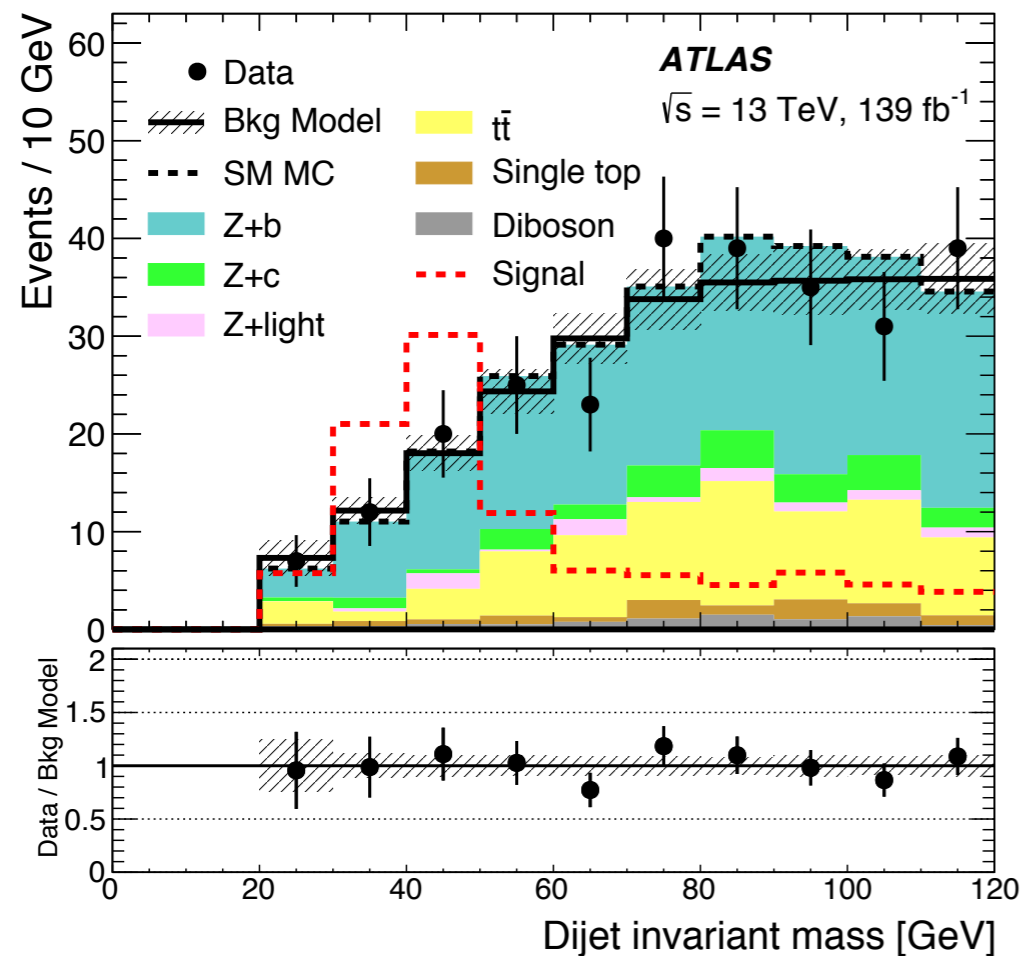
DECAYS TO $bb\mu\mu$

- Trigger on di-muon pair, b-jets are boosted



DECAYS TO $bb + \text{MET}$

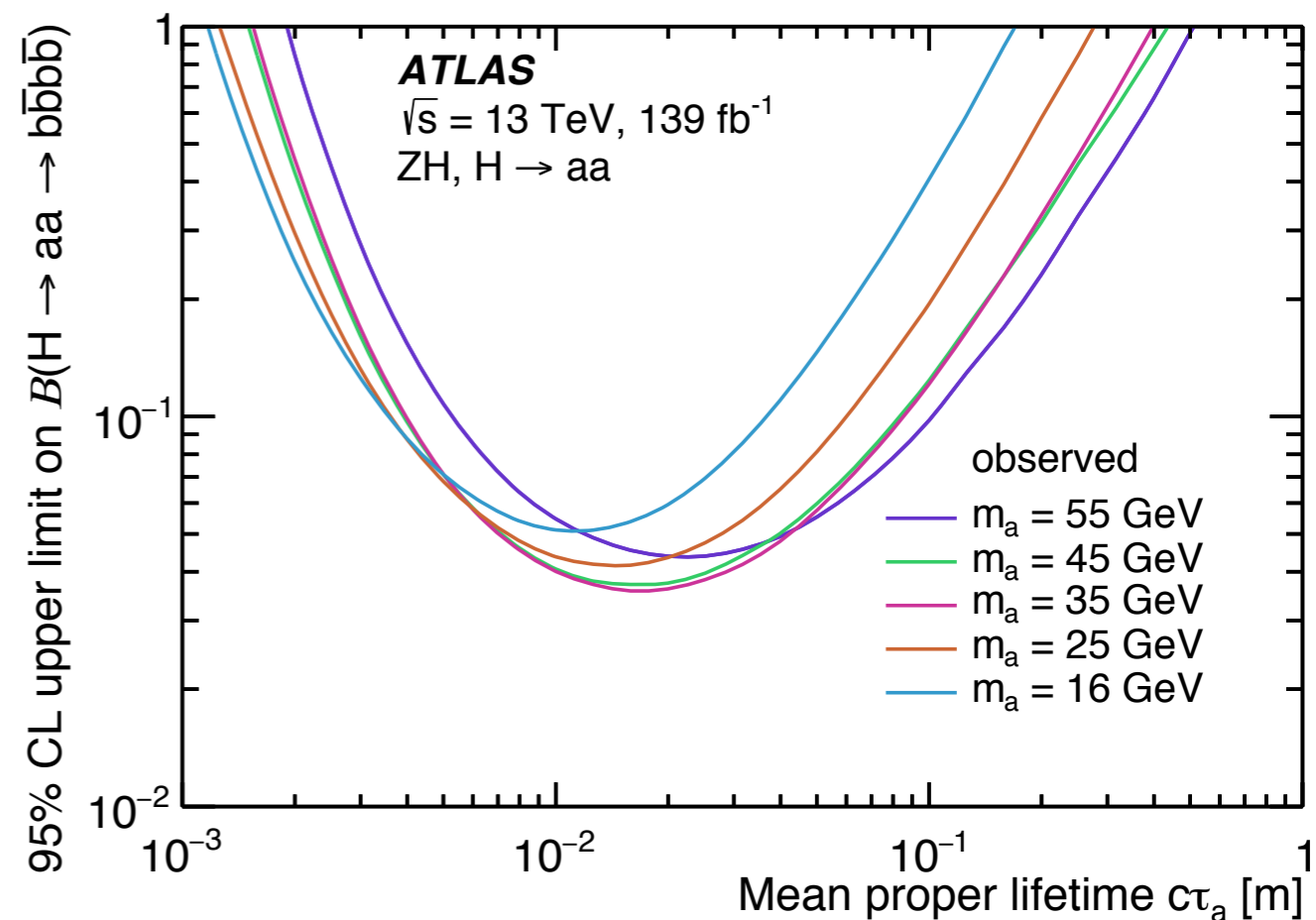
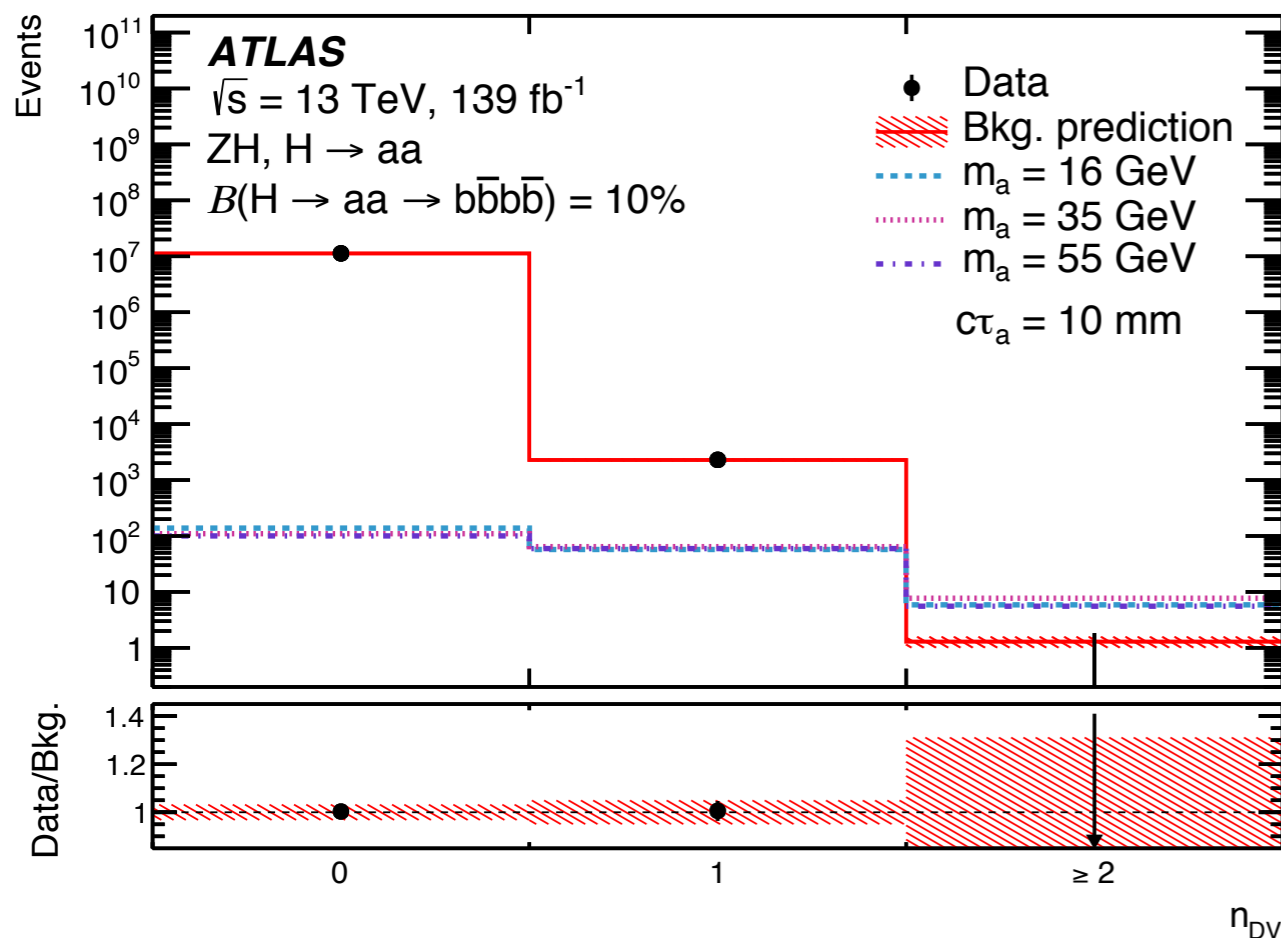
- Look for leptonic Z decay in Higgs-strahlung process
- Require one b -tag, sensitive to masses 25-65 GeV



LONG-LIVED EXOTIC DECAYS

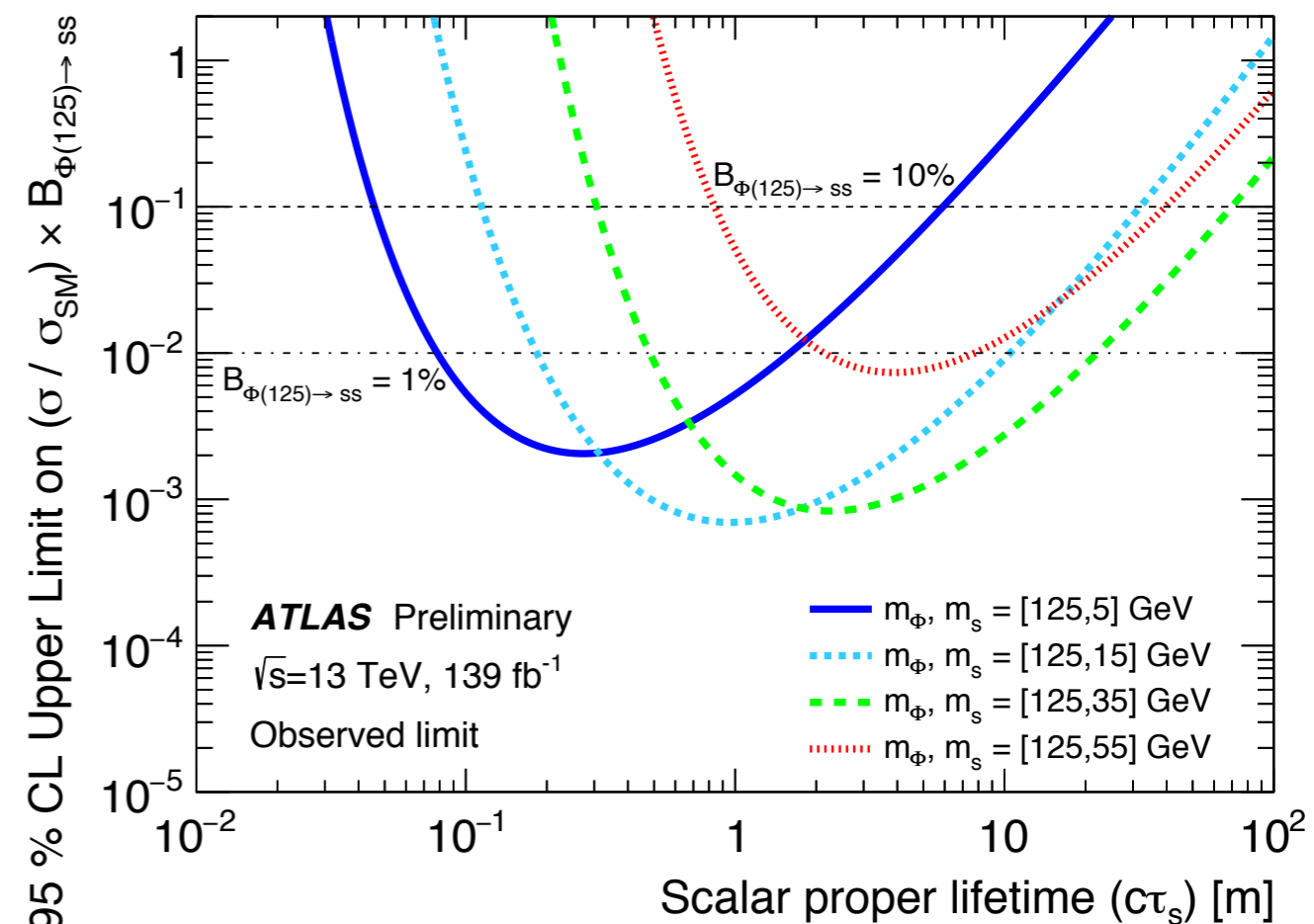
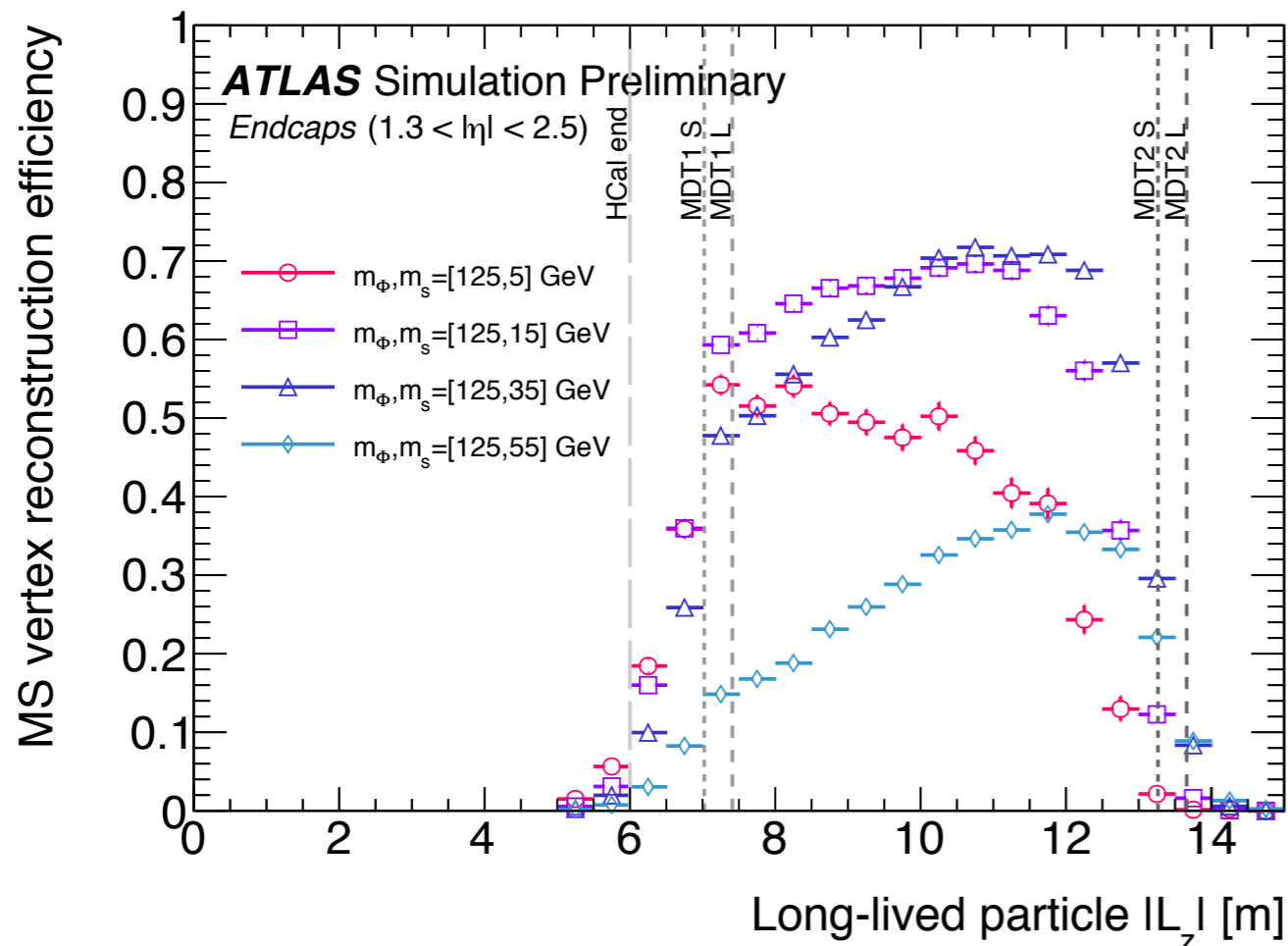
HADRONIC DECAYS

- $h \rightarrow SS$ difficult to probe when scalars decay hadronically
- One approach: trigger on leptonic associated Z decay!
- Require more than 2 tracks per vertex, reduced mass > 3 GeV



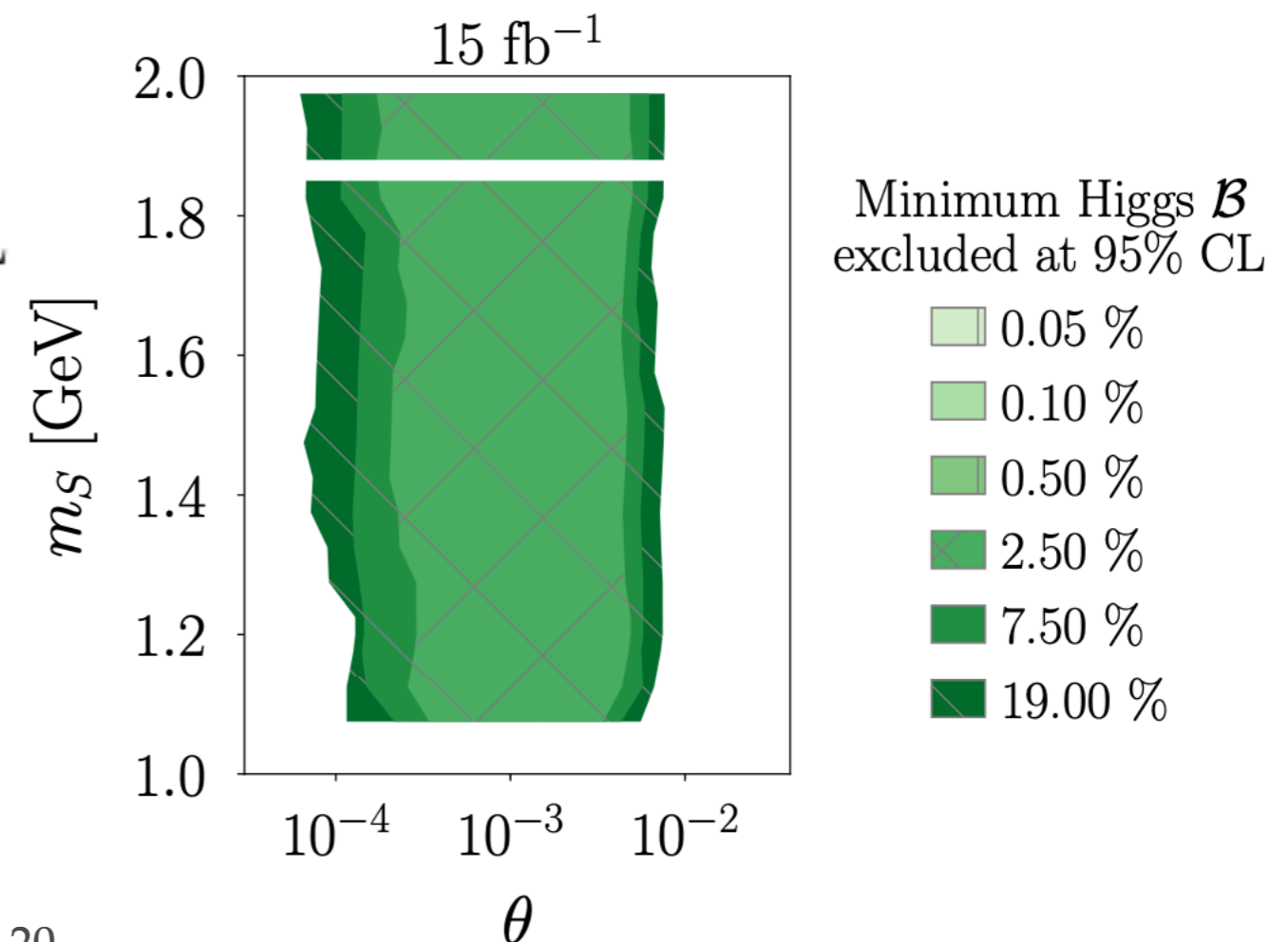
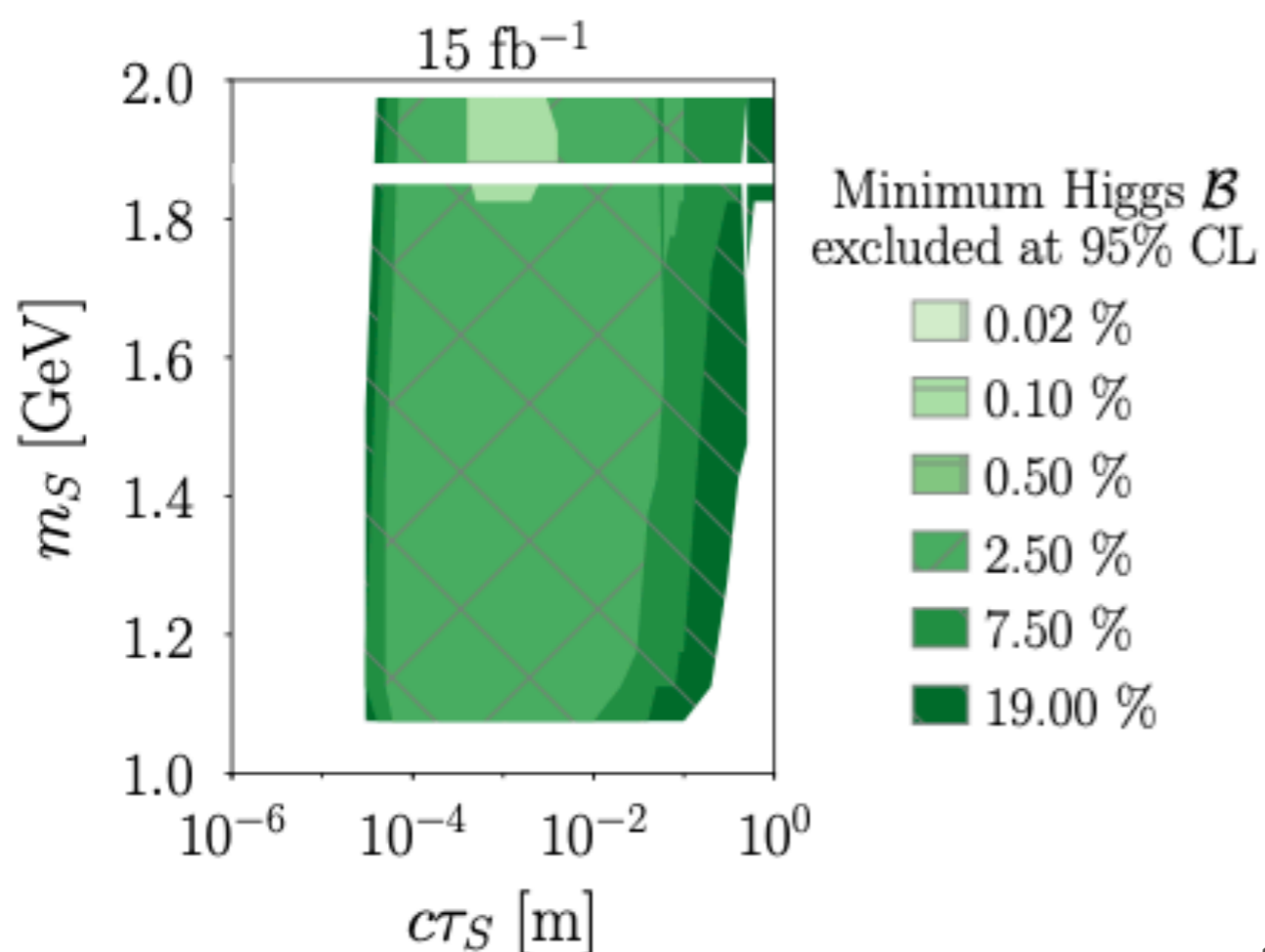
HADRONIC DECAYS

- $h \rightarrow SS$ difficult to probe when scalars decay hadronically
- Another approach: trigger on decays in muon spectrometer!
- Zero background search with full Run 2 data



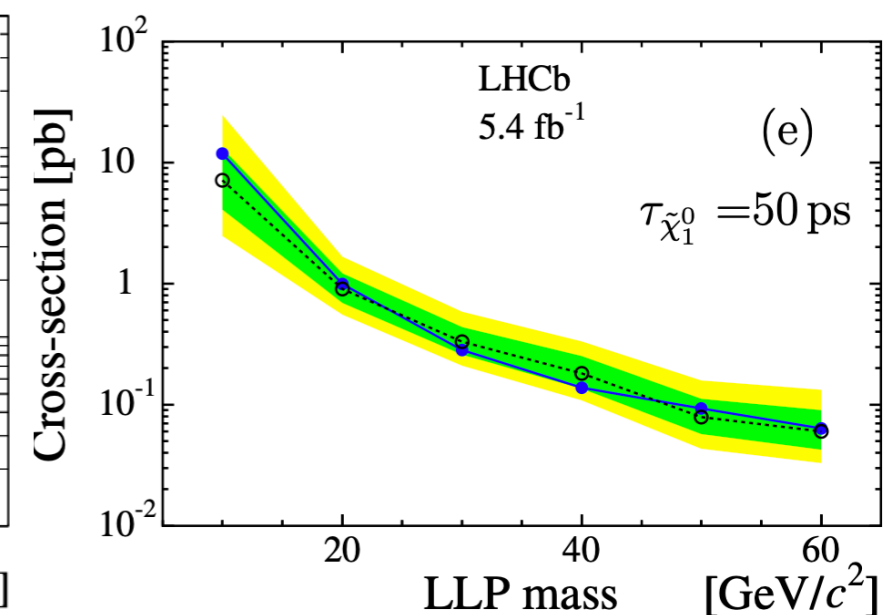
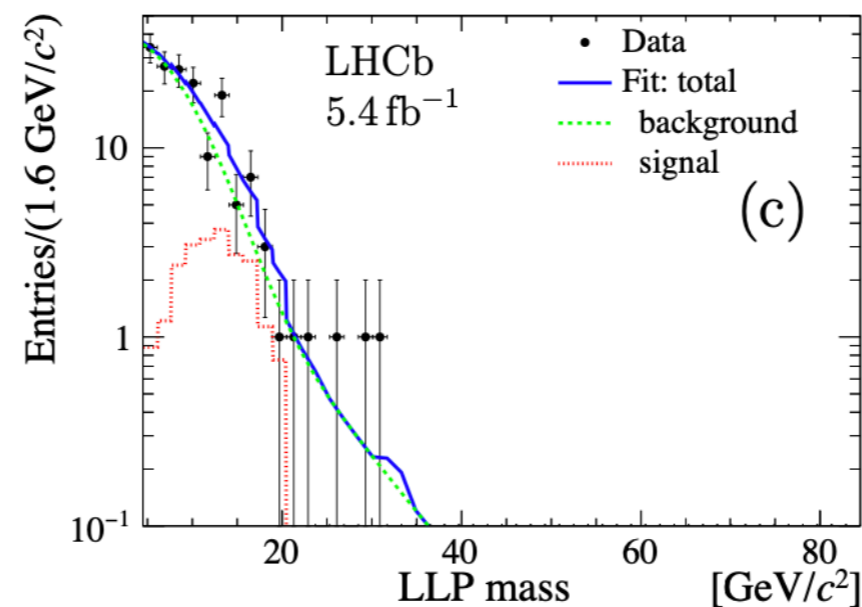
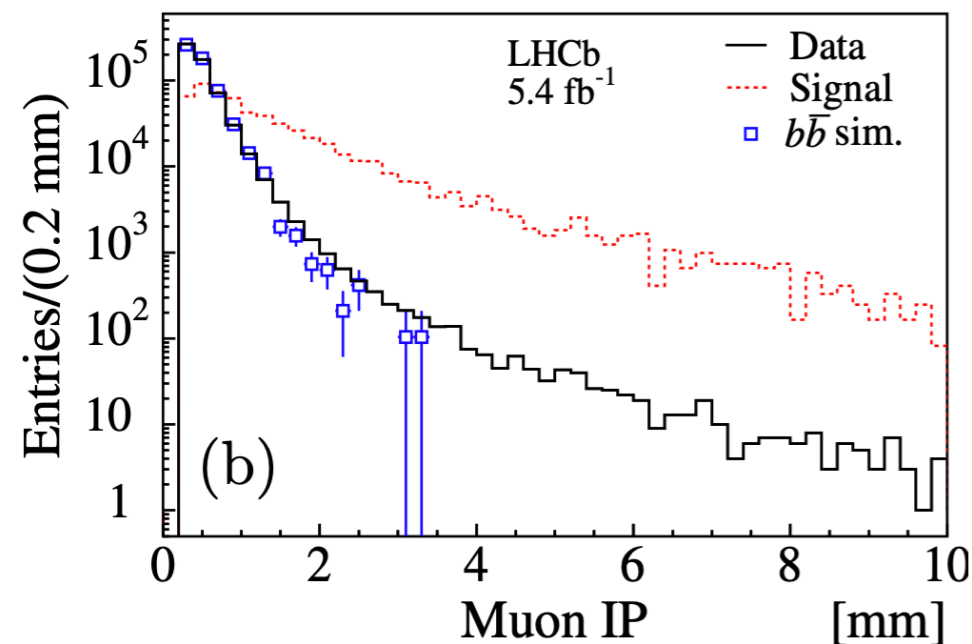
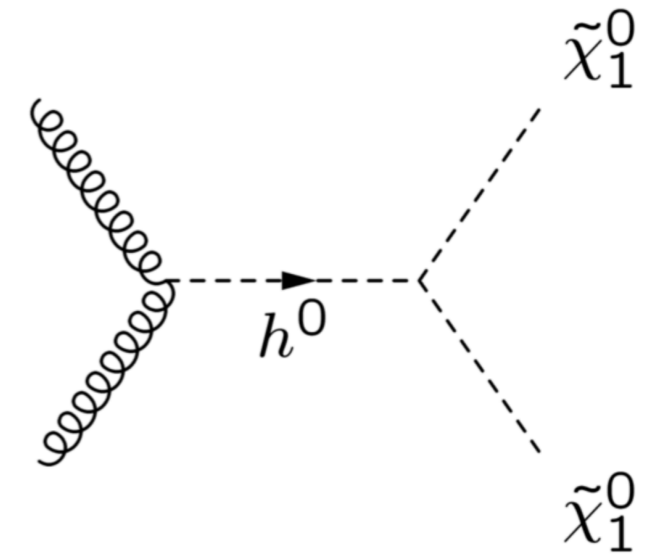
HADRONIC DECAYS

- LHCb ideal environment for reconstructing exclusive hadronic decays of long-lived particles using precise vertexing, PID
- Studied prospects for the decay $h \rightarrow SS \rightarrow K^+ K^- K^+ K^-$
- Analysis planned for Run 3!



SEMILEPTONIC DECAYS

- LLP decays to muon + 2 quarks
- Muon isolation & impact parameter are used to separate signal and background
- Vertices have 3 or more tracks, >4.5 GeV mass

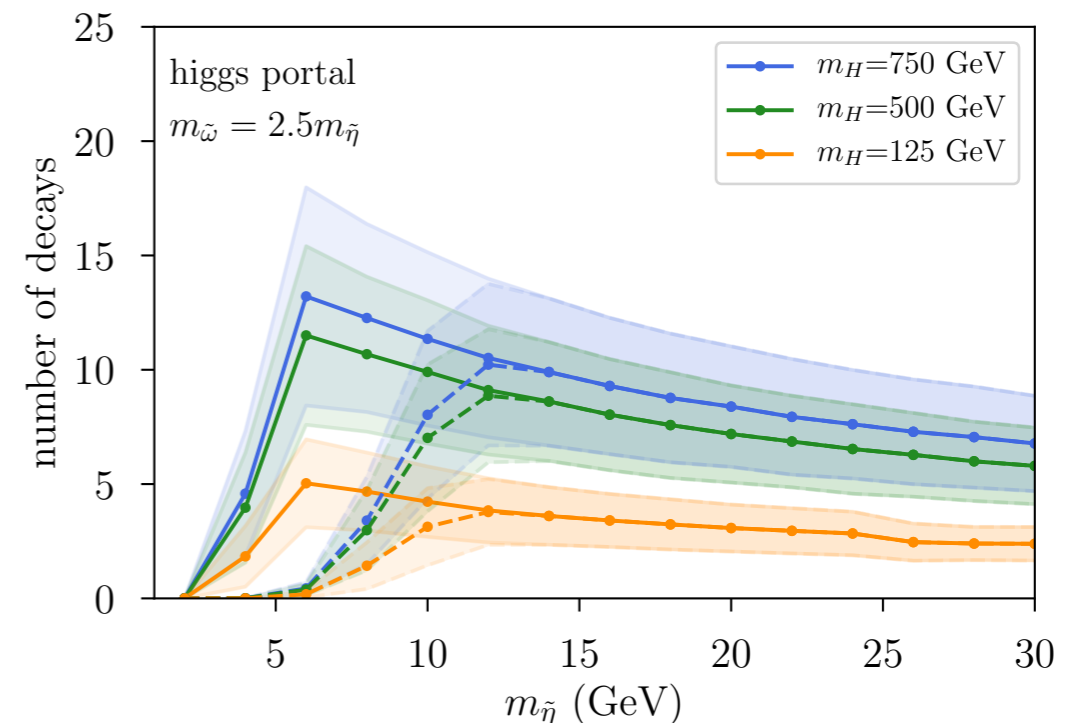
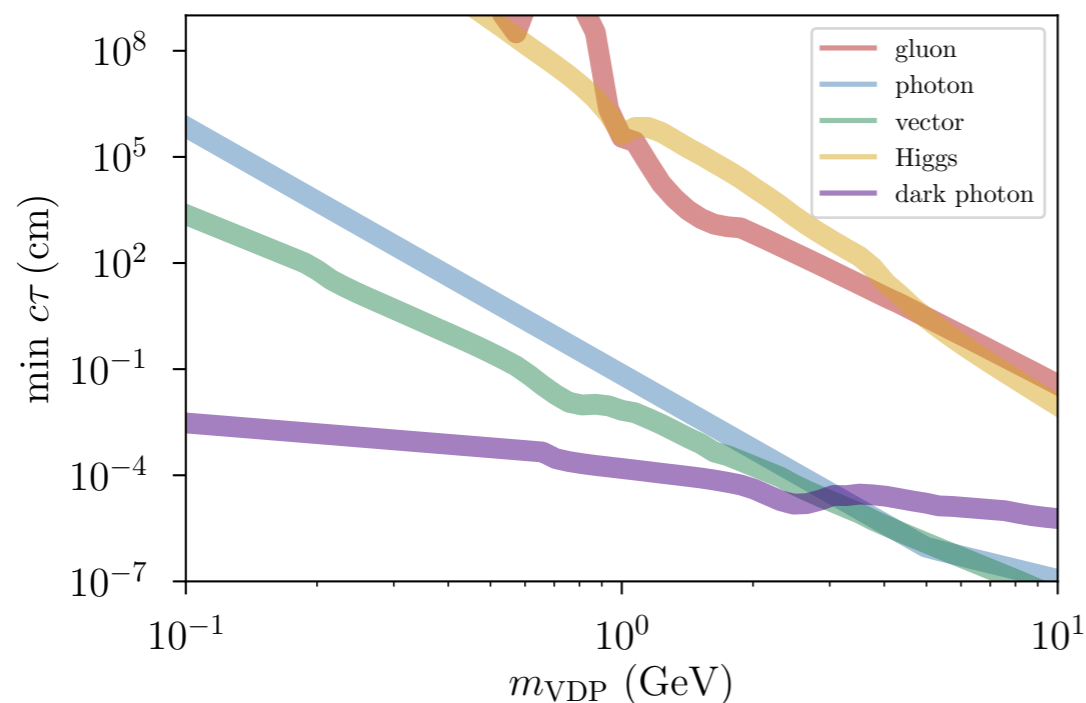


NEW FRONTIERS: GAPS, IDEAS, AND FUTURE WORK

DARK SHOWERS

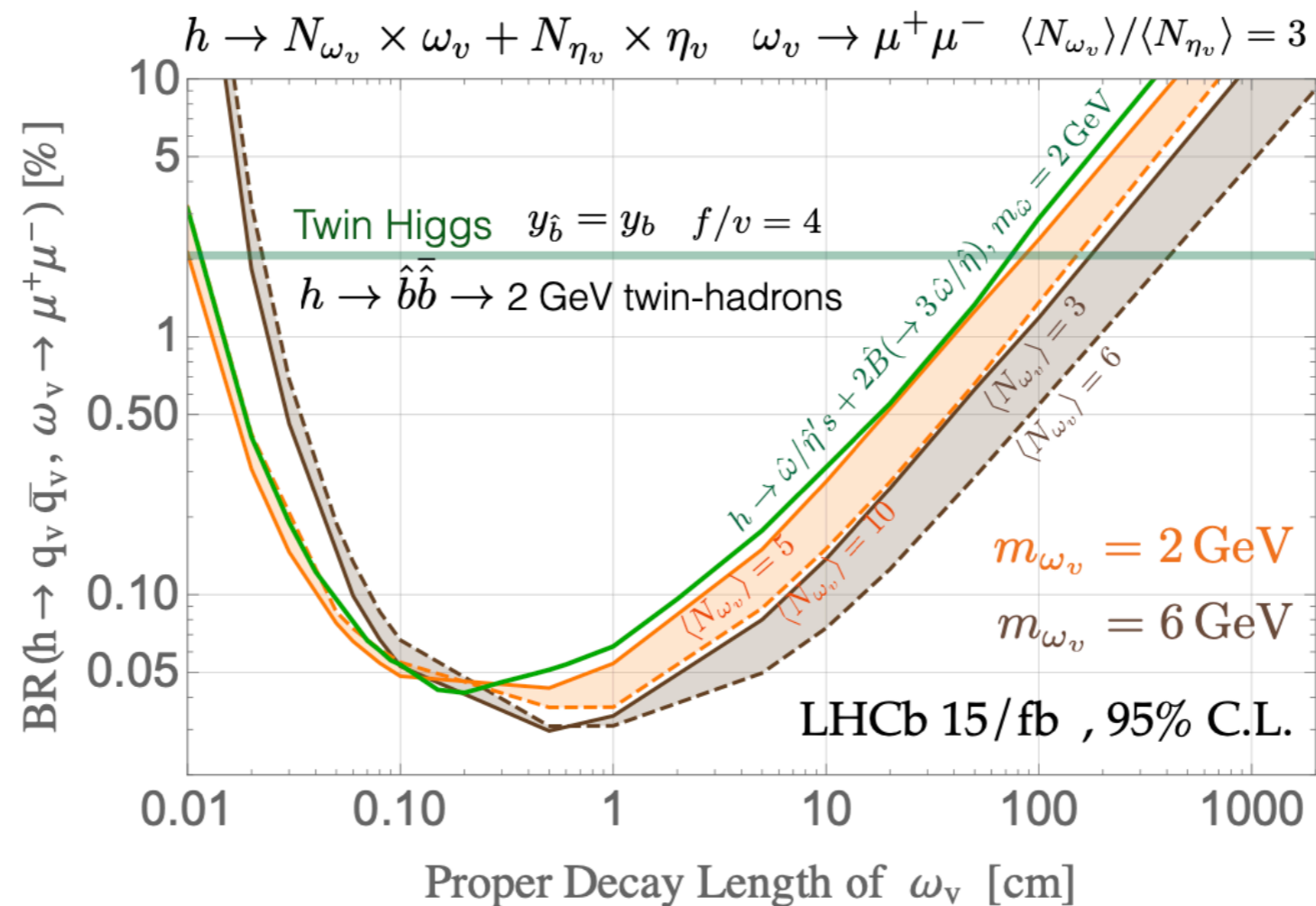
- Recent progress in developing **benchmark models** for “visibly decaying particle” produced in dark showers

Decay portal	decay operator	VDP	other dark hadron	features	section
A. gluon portal	$\tilde{\eta} G^{\mu\nu} \tilde{G}_{\mu\nu}$	$\tilde{\eta}$	$\tilde{\omega}$ stable or $\tilde{\omega} \rightarrow \tilde{\eta}\tilde{\eta}$	hadron-rich shower	III A
B. photon portal	$\tilde{\eta} F^{\mu\nu} \tilde{F}_{\mu\nu}$	$\tilde{\eta}$	$\tilde{\omega}$ stable or $\tilde{\omega} \rightarrow \tilde{\eta}\tilde{\eta}$	photon shower	III B
C. vector portal	$\tilde{\omega}^{\mu\nu} F_{\mu\nu}$	$\tilde{\omega}$	$\tilde{\eta}$ stable	semi-visible jet	III C
D. Higgs portal	$\tilde{\eta} H^\dagger H$	$\tilde{\eta}$	$\tilde{\omega}$ stable or $\tilde{\omega} \rightarrow \tilde{\eta}\tilde{\eta}$	heavy flavor-rich shower	III D
E. dark photon portal	$\tilde{\eta} F'^{\mu\nu} \tilde{F}'_{\mu\nu} + \epsilon F'^{\mu\nu} F_{\mu\nu}$	A'	$\tilde{\omega}$ stable or $\tilde{\omega} \rightarrow \tilde{\eta}\tilde{\eta}$	lepton-rich shower	III E



DARK SHOWERS

- New proposals for LHCb searches for softer dimuon displaced vertices - dark shower provides larger acceptance for search
- Based on twin Higgs benchmark model



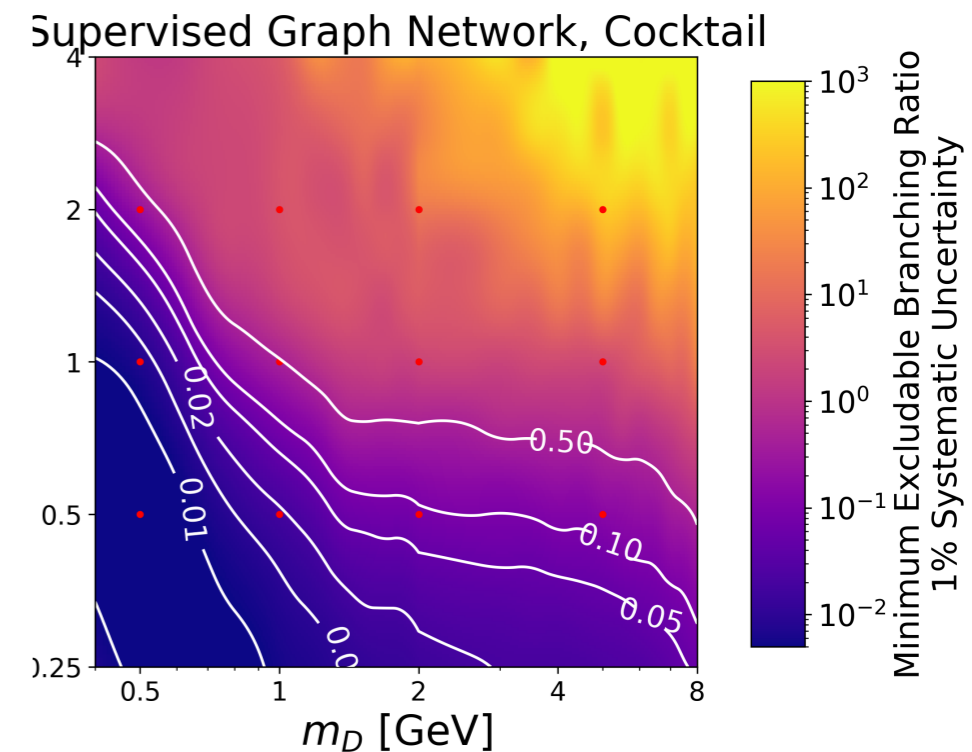
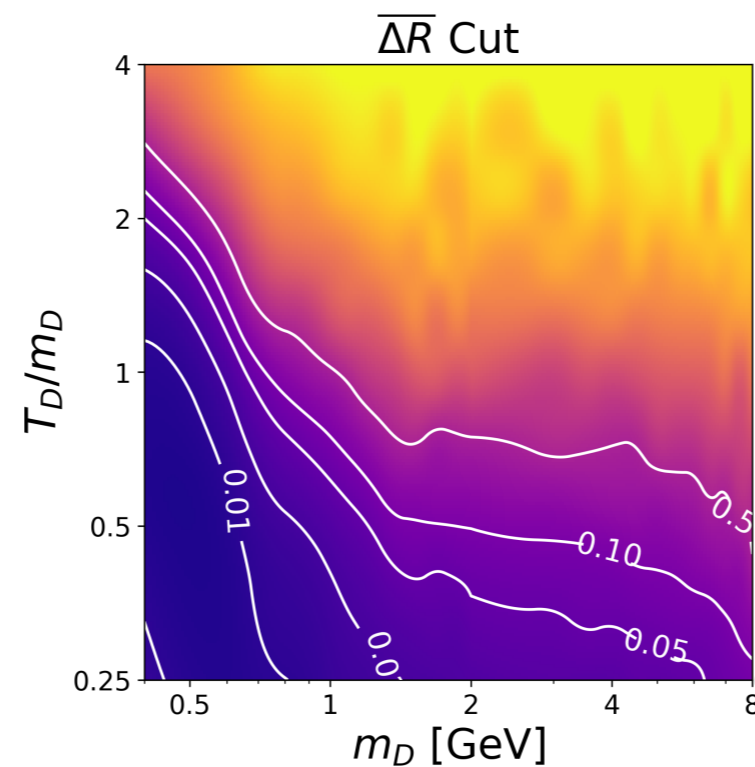
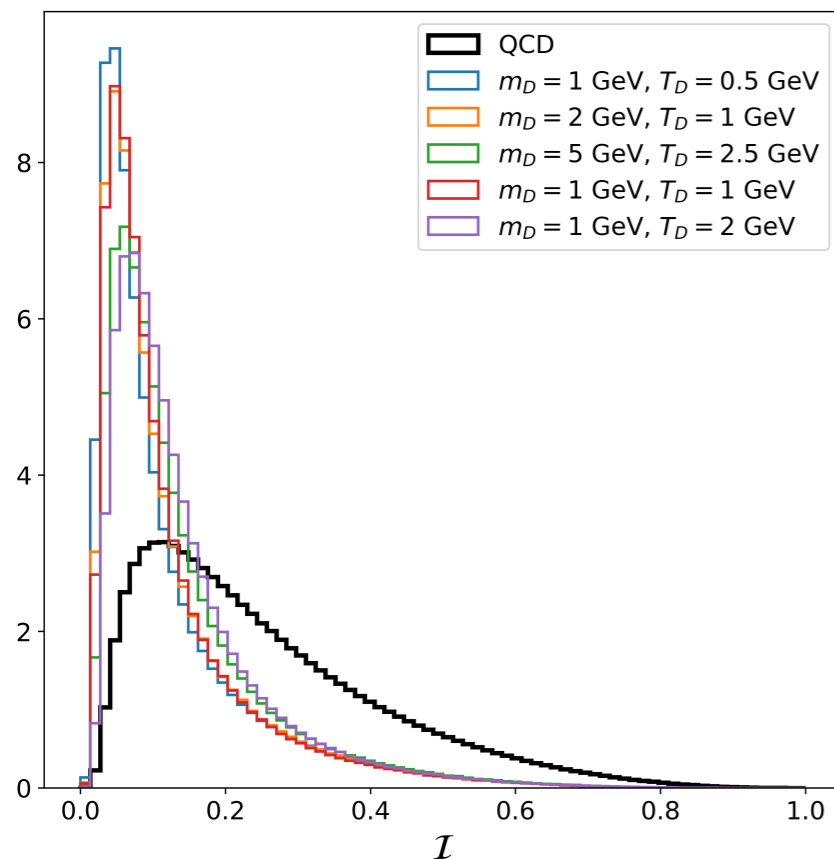
HIGGS SUEP

- Confining hidden sectors can also lead to highly isotropic distributions (SUEP = "soft unclustered energy patterns")

S. Knapen *et al.*, 1612.00850 [JHEP]

- Recent study of SUEP produced in exotic Higgs decays

J. Barron *et al.*, 2107.12379



GAPS & OPPORTUNITIES

- Prompt:
 - Fully hadronic decays ($h \rightarrow gggg, ggbb, \dots$). Machine learning can help! S. Jung et al., 2109.03294
 - Semi-visible decays, especially non-resonant (hadrons, leptons, photons)
 - J/ψ and Υ regions
- Displaced:
 - Final states with photons and taus
 - Low-pT final states
 - Opportunities for seeding HLT displaced triggers from L1 lepton or photon triggers
- Both:
 - Large number of BSM states (cascade decays, dark showers)

SUBGROUP TASKS

- Work on benchmarks:
 - ALPs for photon/gluon decays
 - Semi-visible decays (ff+MET); goal: summer 2022
- LLP searches and opportunities:
 - Note in early stages; goal: first quarter 2022
- Improved calculation of meson + vector boson decays of SM Higgs
 - Calculation in advanced stages; goal: soon
- Reinterpret prompt decay results for LLP searches. Should be do-able now that many full Run 2 results are out
- Reinterpretation of long-lived exotic Higgs decay searches
- After 2 difficult years, there is energy for organizing more regular meetings, mini-workshops, and making progress on these items!

DISCUSSION QUESTIONS

- What are the most pressing first searches for Run 3?
- Any gaps in long-lived particle searches not discussed here? New ideas for LLPs?
- What are well-motivated and best benchmarks for high multiplicity exotic Higgs decays?
- Is it straightforward to compare results from ATLAS, CMS, LHCb? Are there reinterpretation materials you wish you had?
- New ideas for exotic Higgs decay-related triggers?
- What are good ALP benchmarks for gauge boson rich signatures?