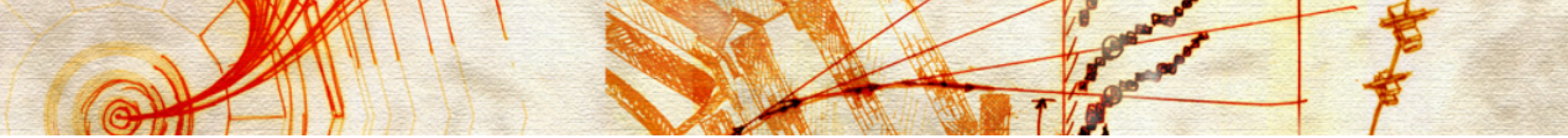


GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

III. Physikalisches
Institut A

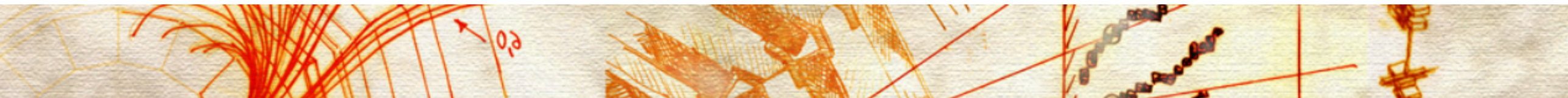
RWTH AACHEN
UNIVERSITY

SEARCHES FOR DARK PHOTONS AT THE LHC

Swagata Mukherjee, *On behalf of the ATLAS, CMS, and LHCb collaborations*

III. Physikalisches Institut A, RWTH Aachen University, Germany

The 10th Annual Large Hadron Collider Physics Conference, May 16-20, 2022

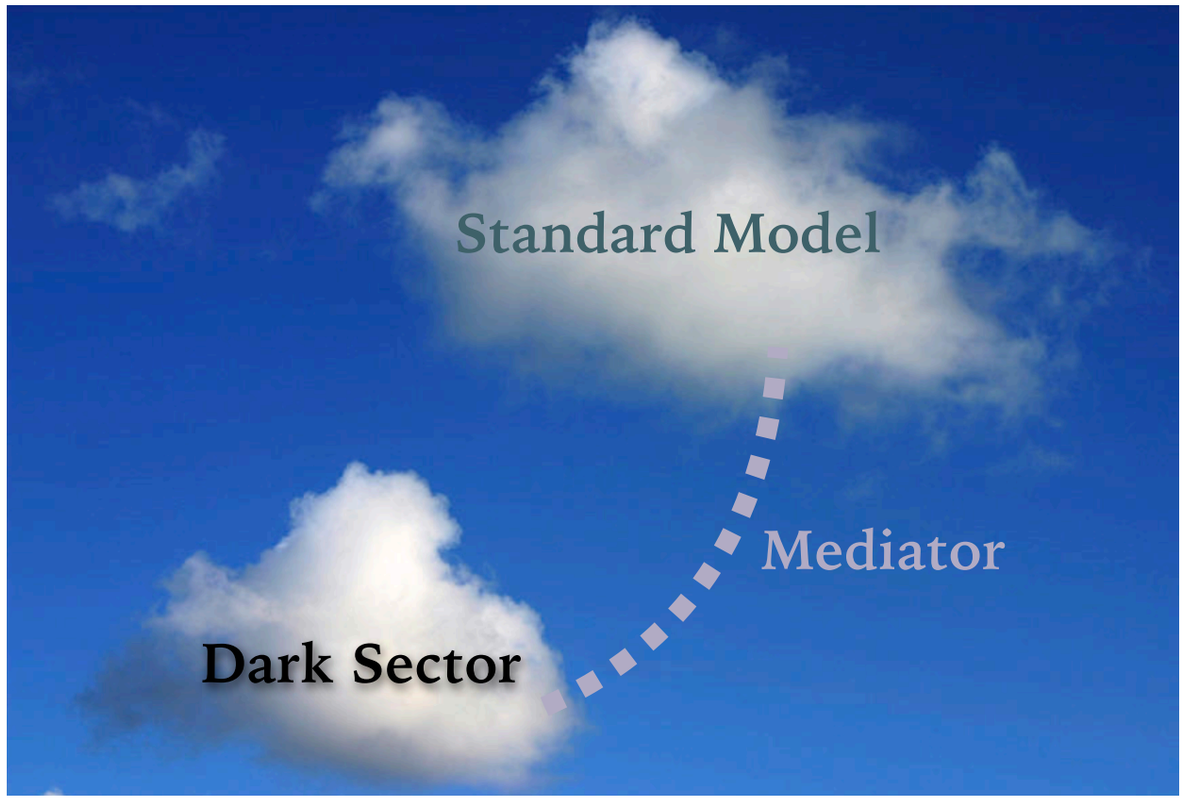


INTRODUCTION

THE ASSUMPTION AND THE HOPE

Let's say we have a Dark Sector, which has its own couplings and particles.

Some field (the mediator) provides at least a weak coupling to Standard Model particles, that can be detected.



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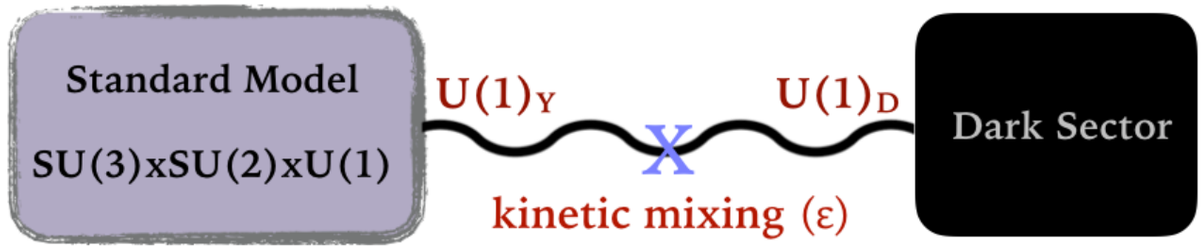

One option is to introduce extra $U(1)_{dark}$

Dark sector can couple to the SM through **kinetic mixing** with the hypercharge gauge boson. $U(1)_{dark}$ leads to a new boson called **dark photon** (A' / Z_D / γ_d)

If the $U(1)_{dark}$ symmetry is broken by the introduction of a **dark Higgs boson**, then there could also be a mixing between the SM Higgs boson (H) and the dark sector Higgs boson (H_d / S). The mixing is often called **κ**.

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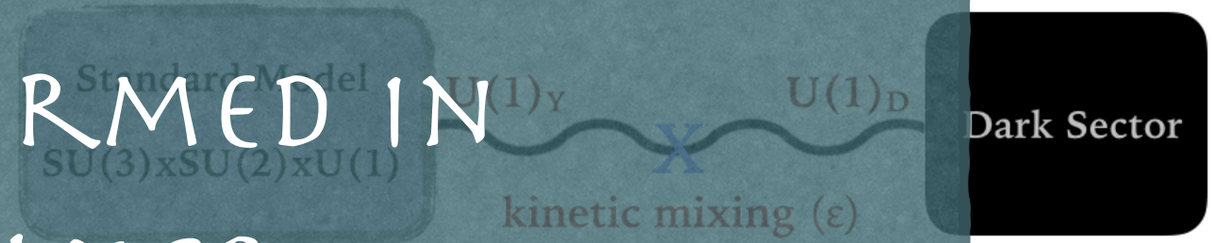

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MANY DARK PHOTON SEARCHES HAVE BEEN PERFORMED IN ATLAS, CMS AND LHCB.

IN 18 MINUTES I WILL BE ABLE TO GIVE ONLY A GLIMPSE OF SELECTED FEW.

DARK PHOTON SEARCH (LHCB)

Search for dark photons decaying into a pair of muons

Real-time reconstruction and calibration (**Turbo stream**)

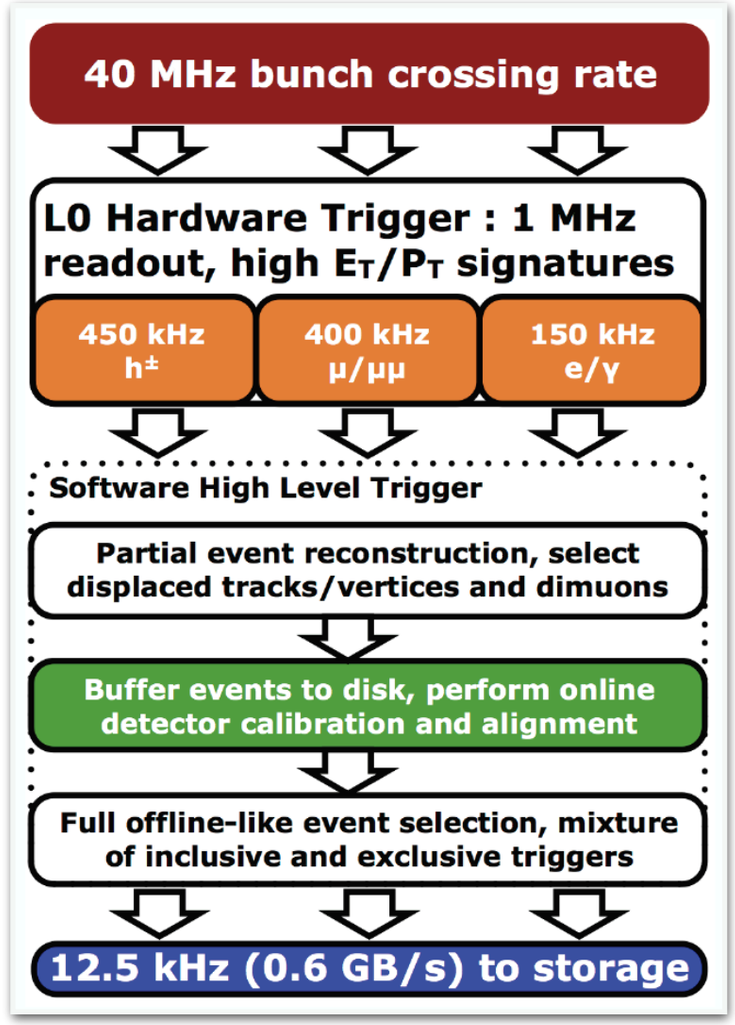
Reduced event content, but fine for bump-hunt

Very low-p_T trigger allows to probe very low masses

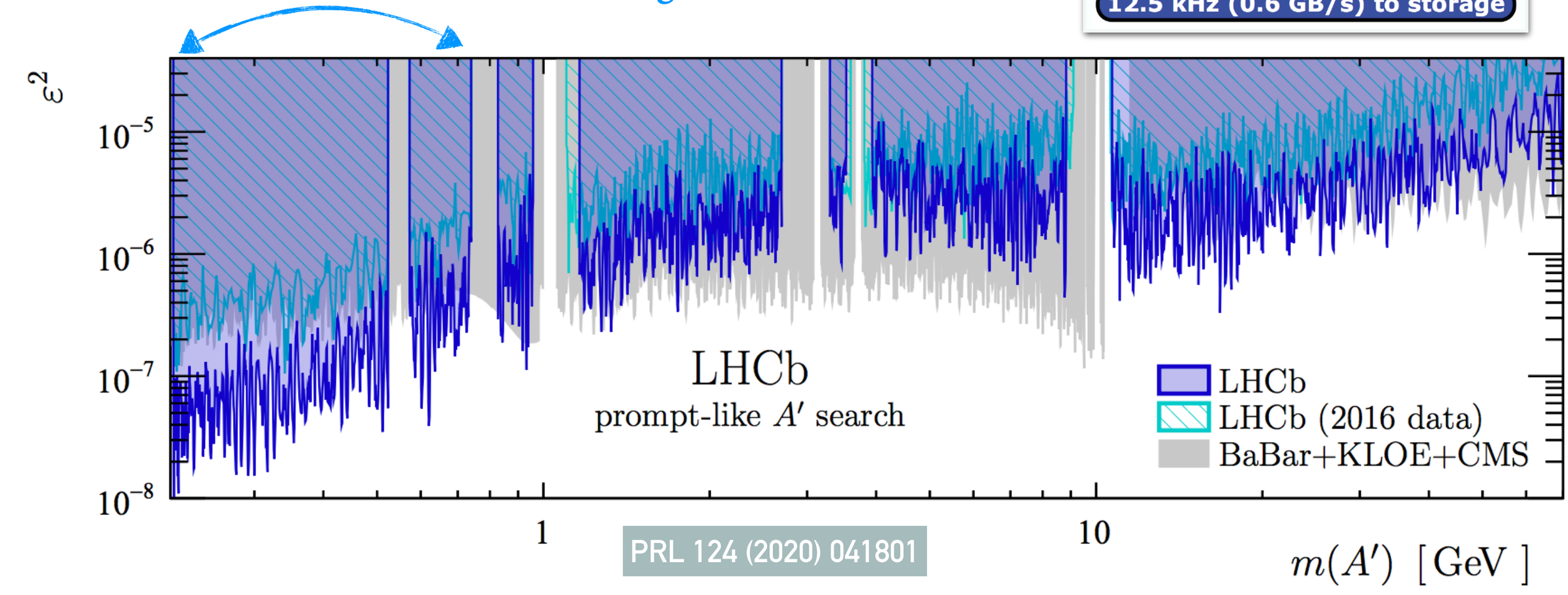
Prompt search up to 70 GeV

Used 5.5 fb^{-1} of Run2 LHCb data (13 TeV)

Fully data-driven analysis



LHCb put the most stringent limit in the 214-740 MeV mass region



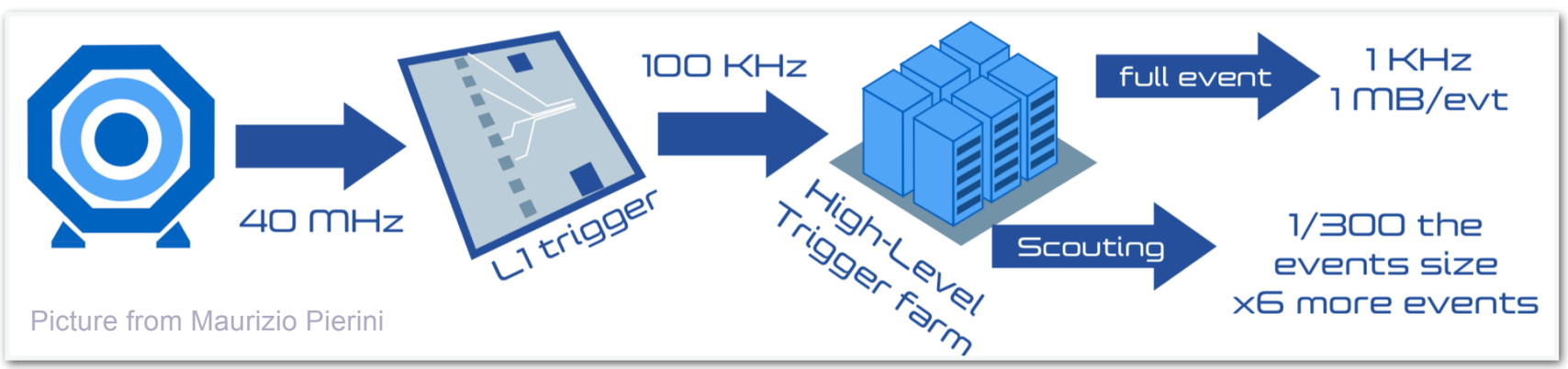
PRL 124 (2020) 041801

PROMPT DARK PHOTON SEARCH (CMS)

Similar analysis in CMS:

Low mass: 11.5-45 GeV, using novel **data-scouting** technique: a new paradigm in CMS software-based trigger.

High mass: 45-200 GeV, using nominal triggers + nominal event content

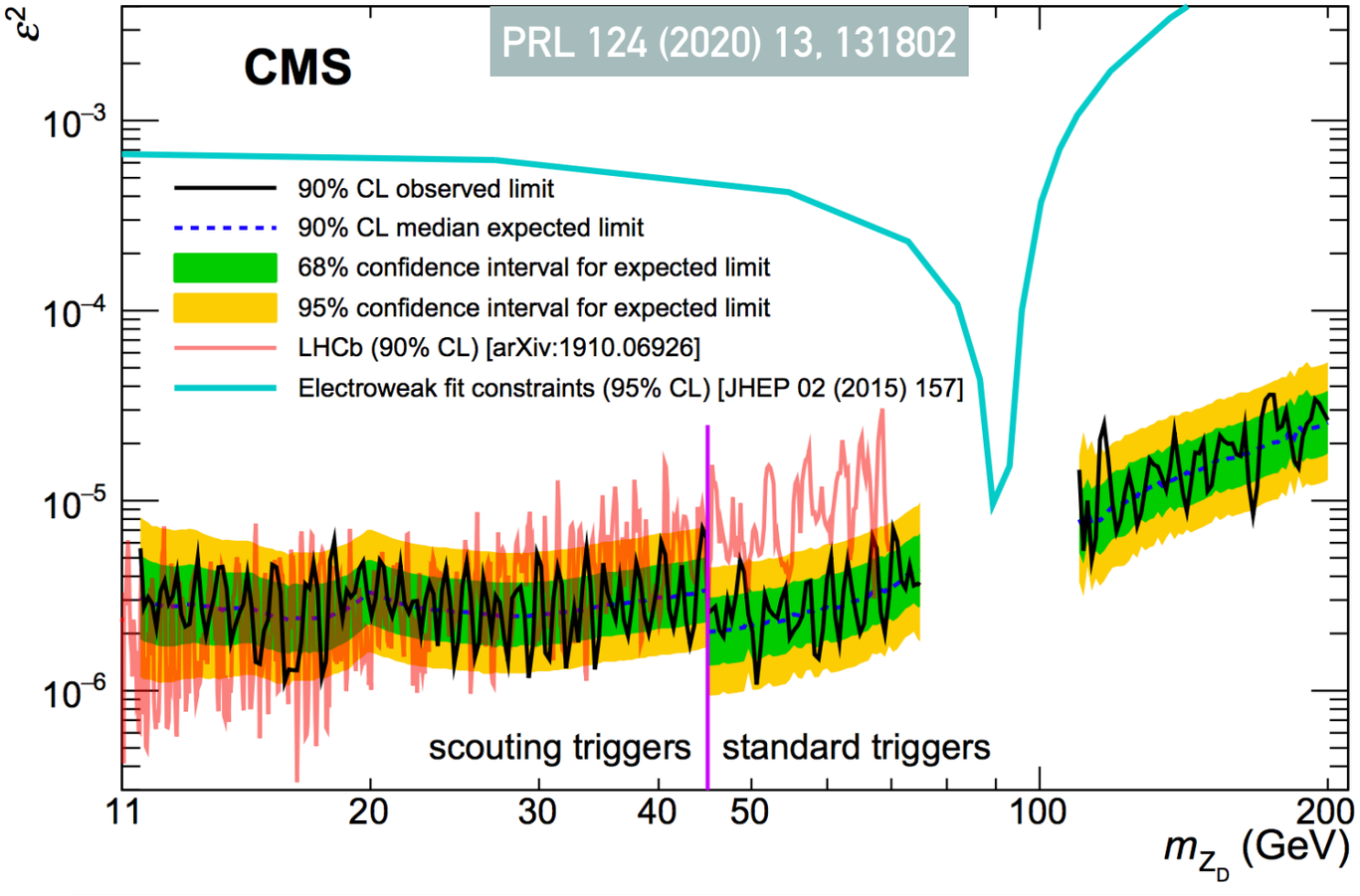


Data Scouting (CMS)

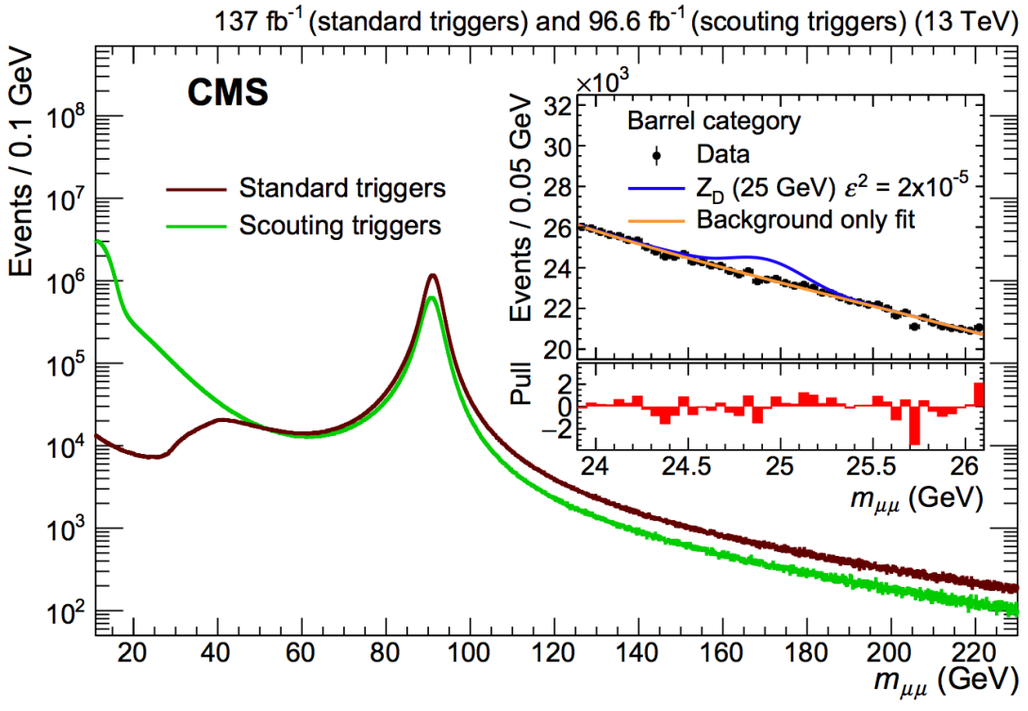
Turbo Stream (LHCb)

DIFFERENT NAMES, SAME GAME 😎

137 fb^{-1} (standard triggers) and 96.6 fb^{-1} (scouting triggers) (13 TeV)



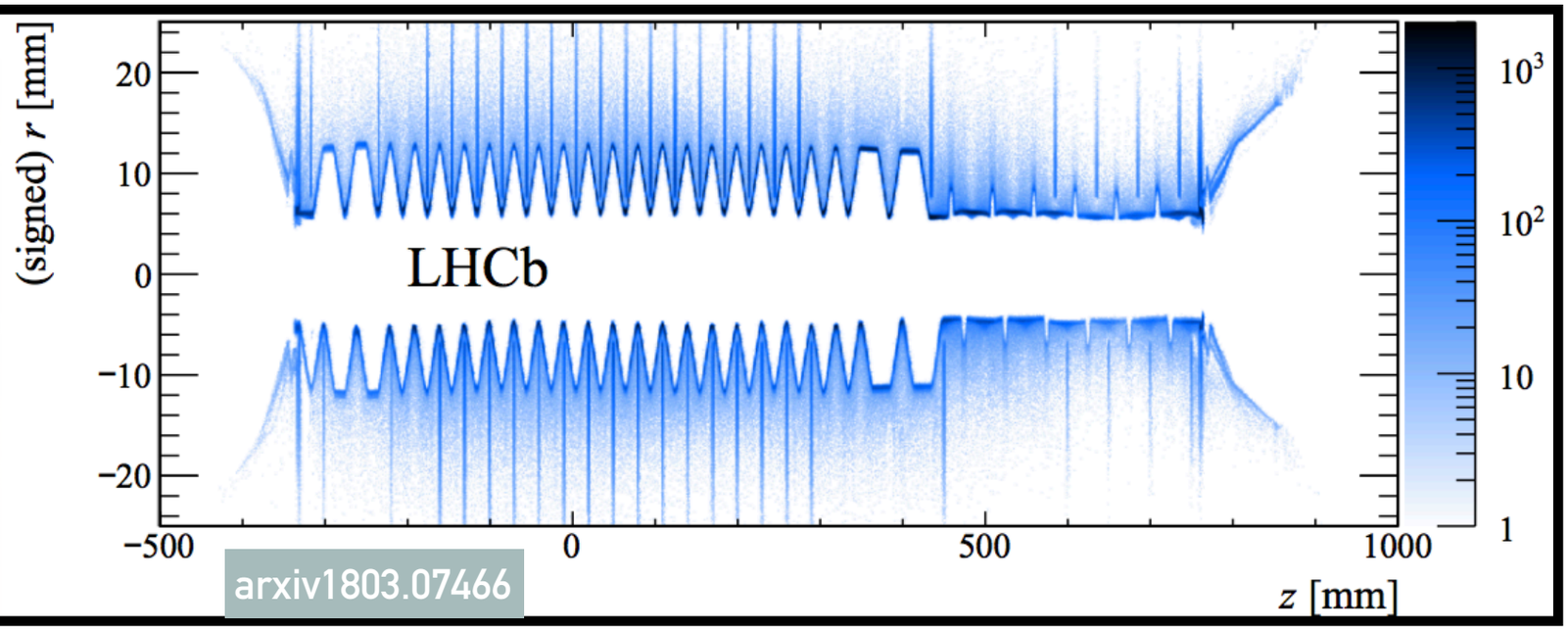
First CMS analysis using muon scouting



Best limits in most of the phase space probed. Even at low masses (11.5-45 GeV), limits competitive to LHCb

LONG-LIVED DARK PHOTON SEARCH (LHCB)

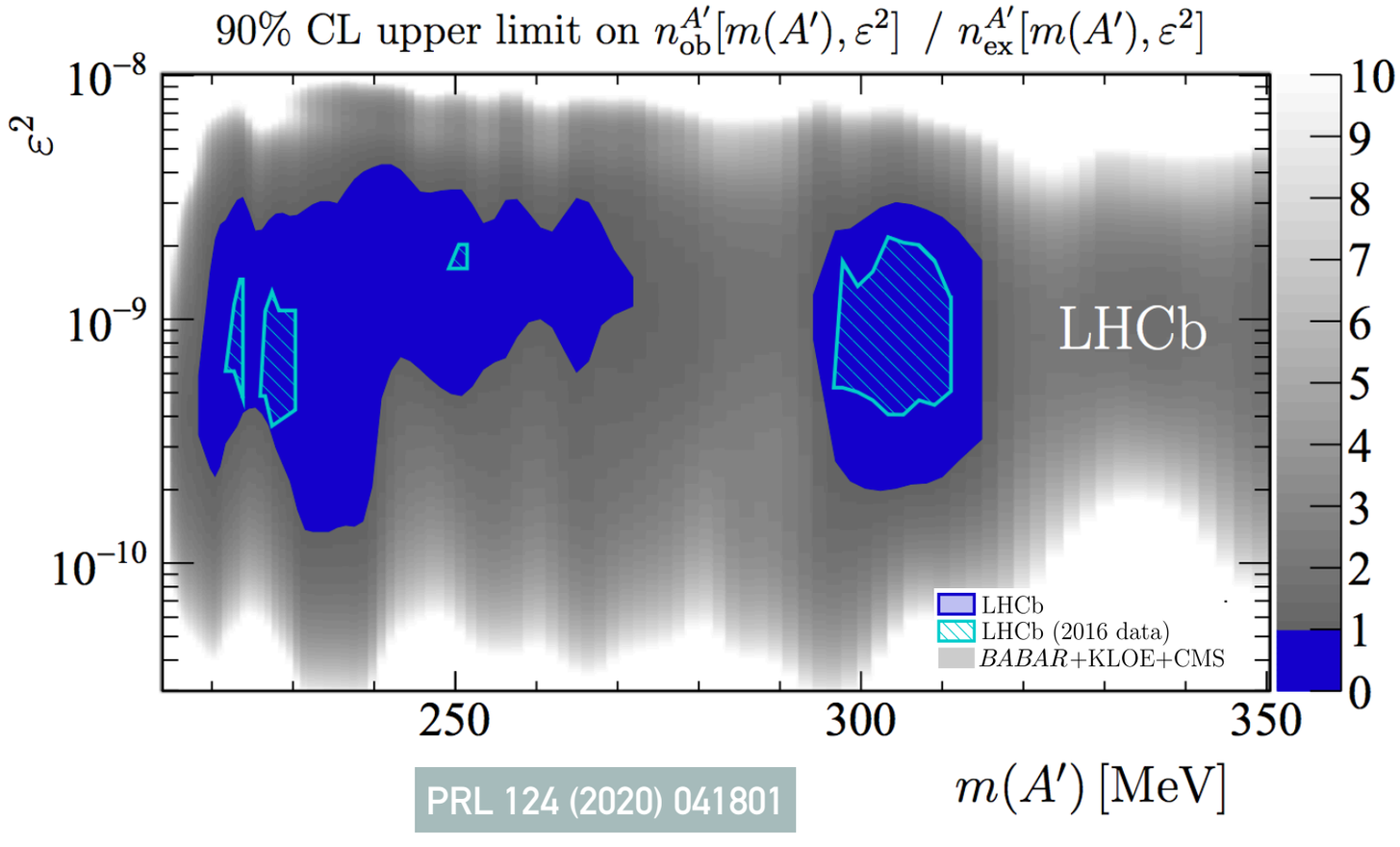
Background dominated by material interactions for displaced dimuon search @LHCb.
Precise knowledge of location of material in LHCb VELO is essential to reduce the background



Material background mainly from photon conversions

Displaced search probes the very low mass region (214-350 MeV)

A region generally accessible only by beam-dump experiments!



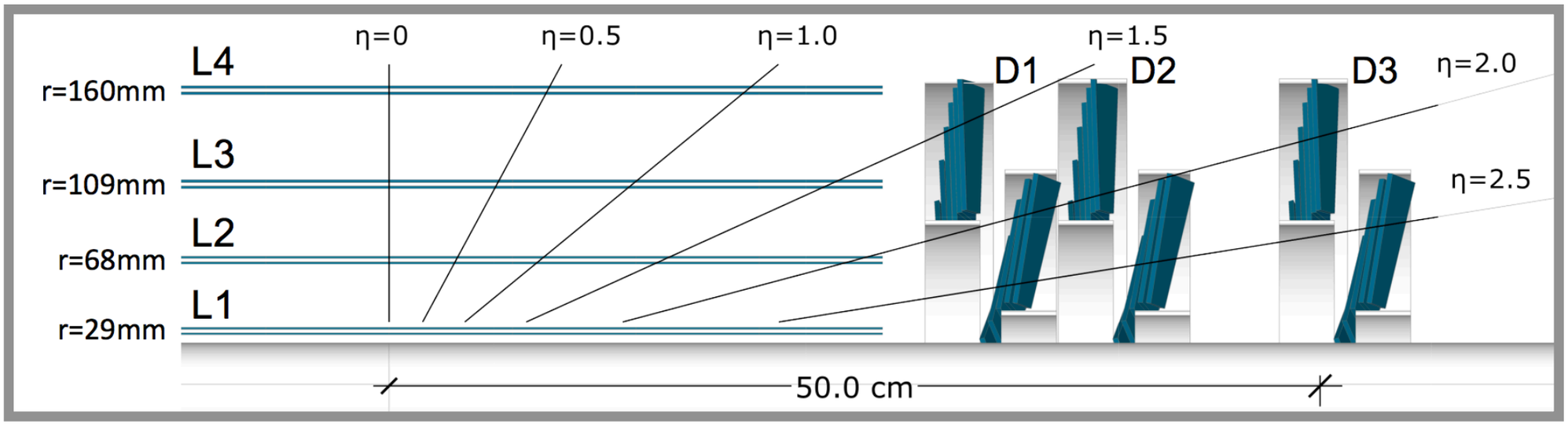
SEARCH FOR DISPLACED DARK PHOTON (CMS)

JHEP 04 (2022) 062

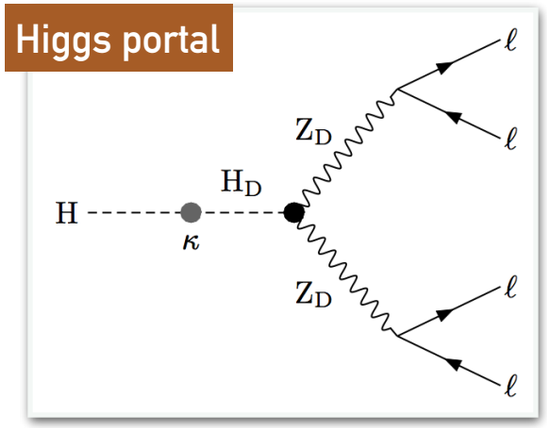
First CMS search for long-lived BSM signatures using scouting data

Presence of ≥2 hits in inner tracker required in scouting dimuon trigger

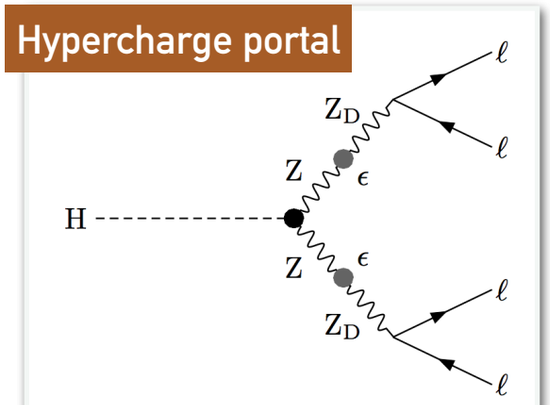
Range of accessible transverse displacement: $0 \leq l_{xy} < 109$ mm

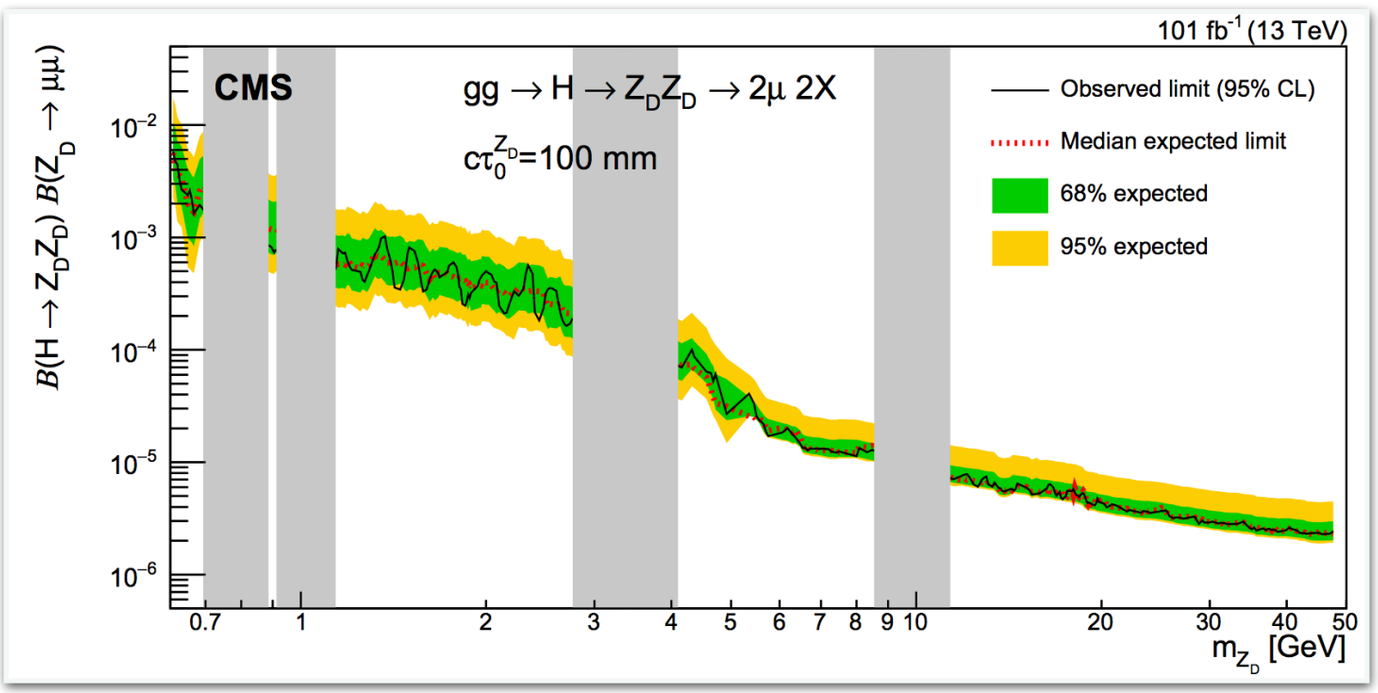


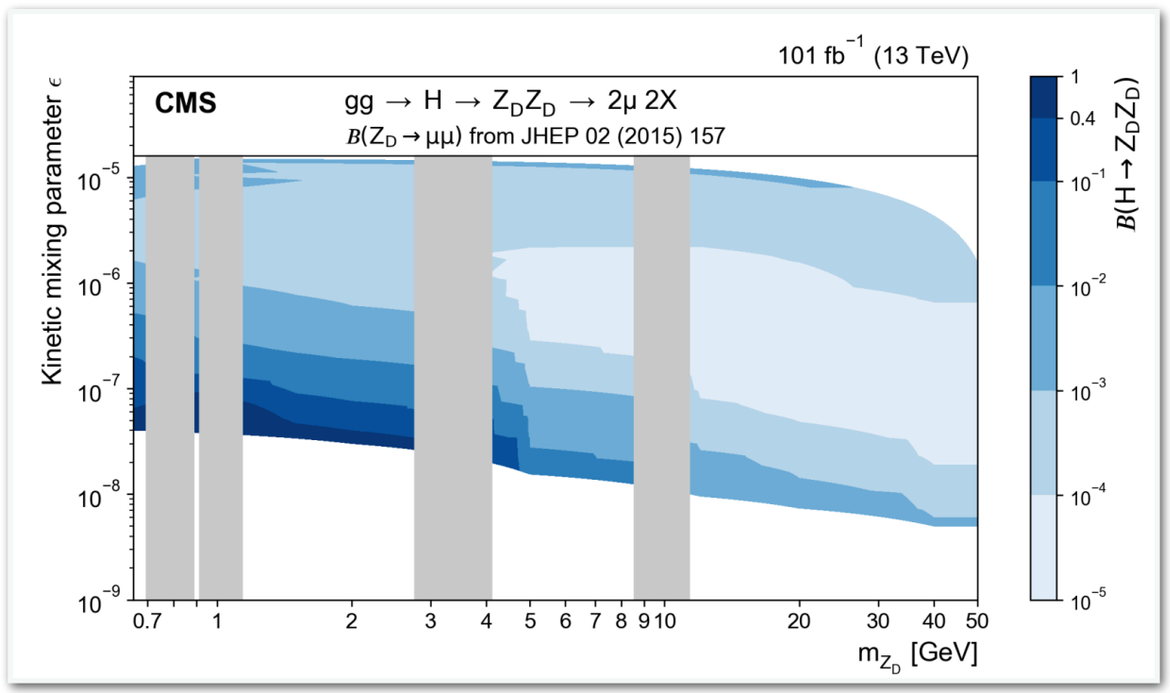
Higgs portal



Hypercharge portal







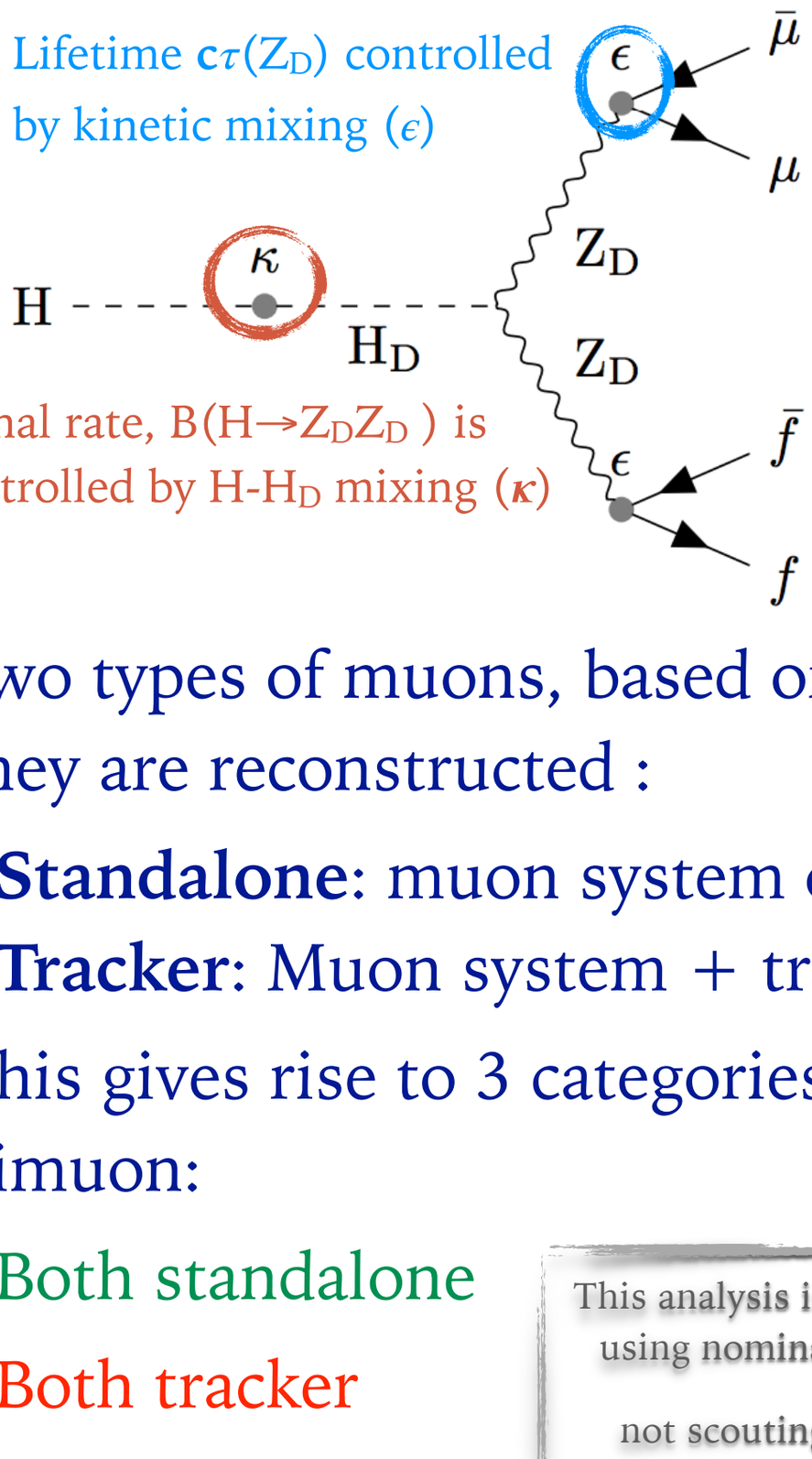
Probed very low masses, thanks to scouting triggers!

Improved previous limits by 2-10 times

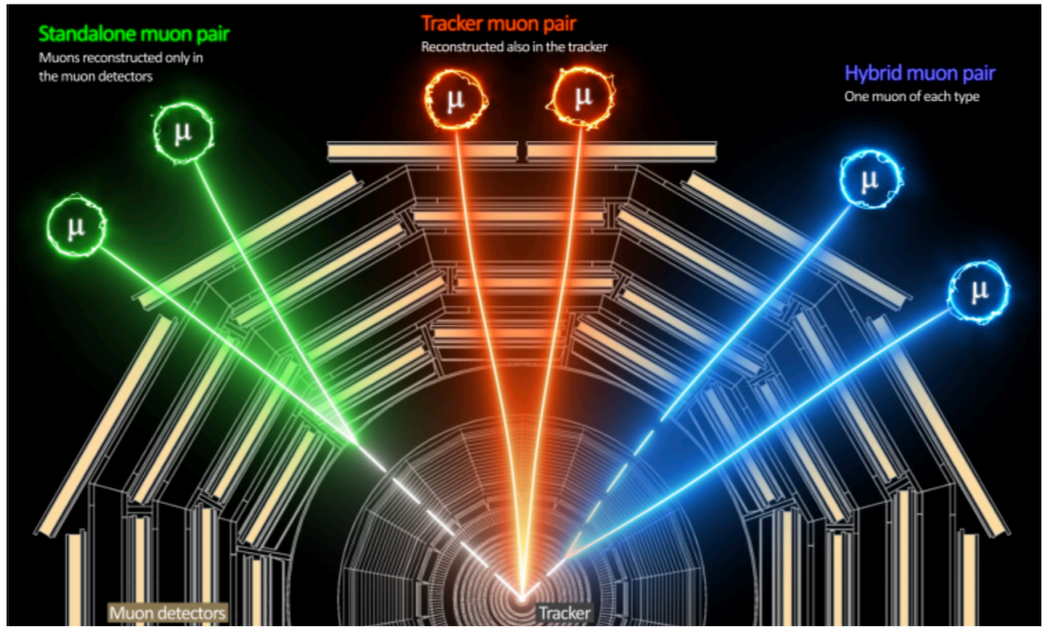
LONG-LIVED DARK PHOTON SEARCH (CMS)

CMS PAS EXO-21-006

Lifetime $c\tau(Z_D)$ controlled by kinetic mixing (ϵ)



Signal rate, $B(H \to Z_D Z_D)$ is controlled by H-H_D mixing (κ)



Two types of muons, based on where they are reconstructed :

Standalone: muon system only

Tracker: Muon system + tracker

This gives rise to 3 categories of dimuon:

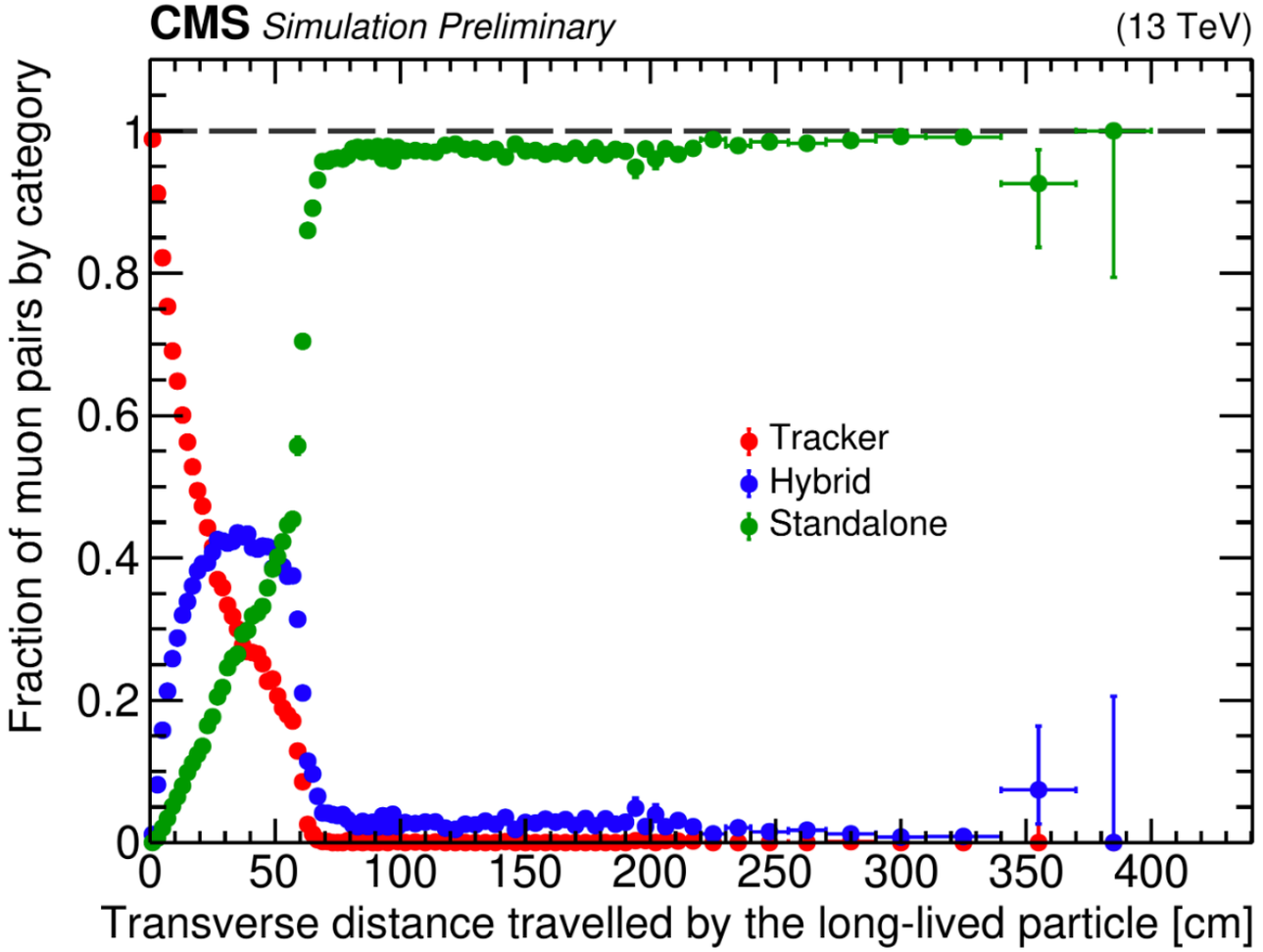
Both standalone

Both tracker

Hybrid

This analysis is performed using nominal triggers,

not scouting triggers



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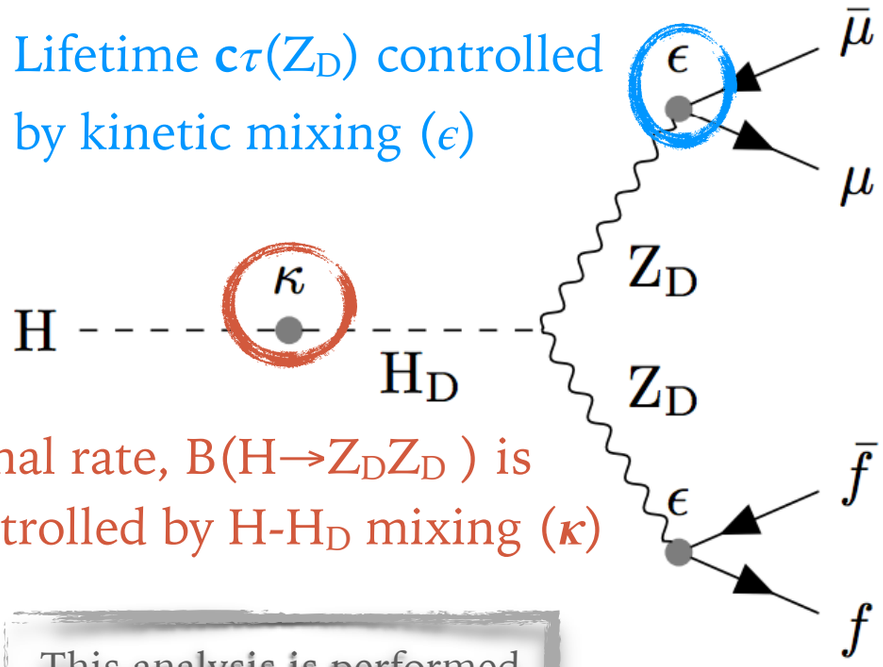


Signal rate, $B(H \to Z_D Z_D)$ is controlled by H-H_D mixing (κ)

This analysis is performed using nominal triggers,

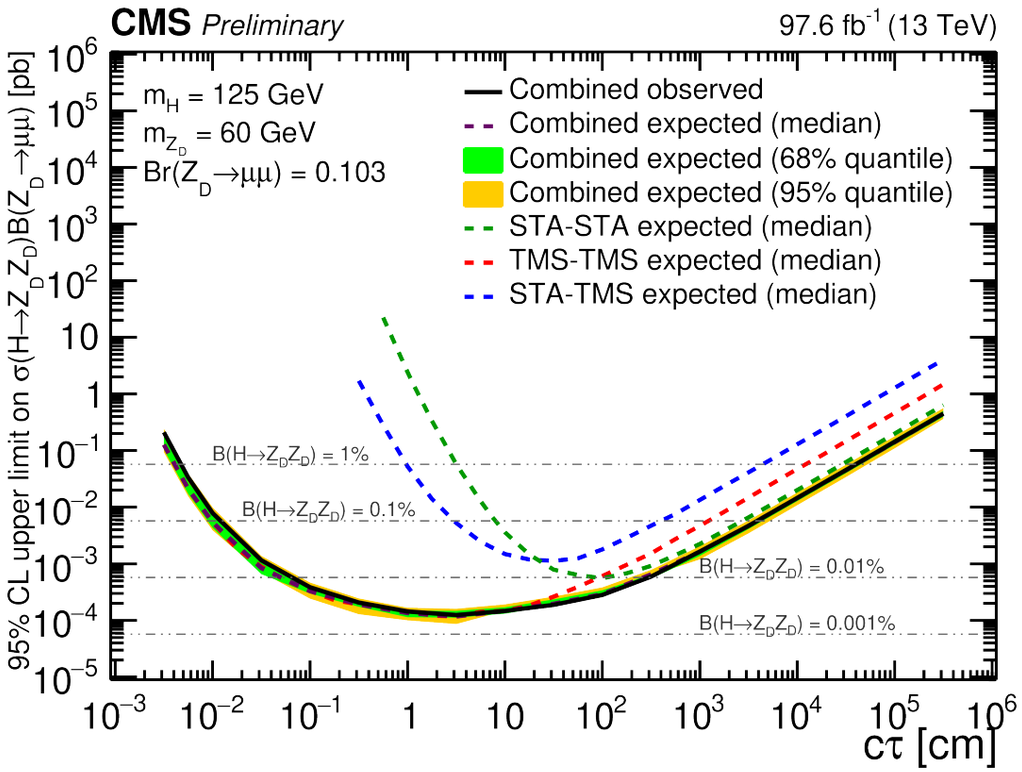
not scouting triggers

Look for **at least one pair of displaced muons**, within and beyond the tracker.

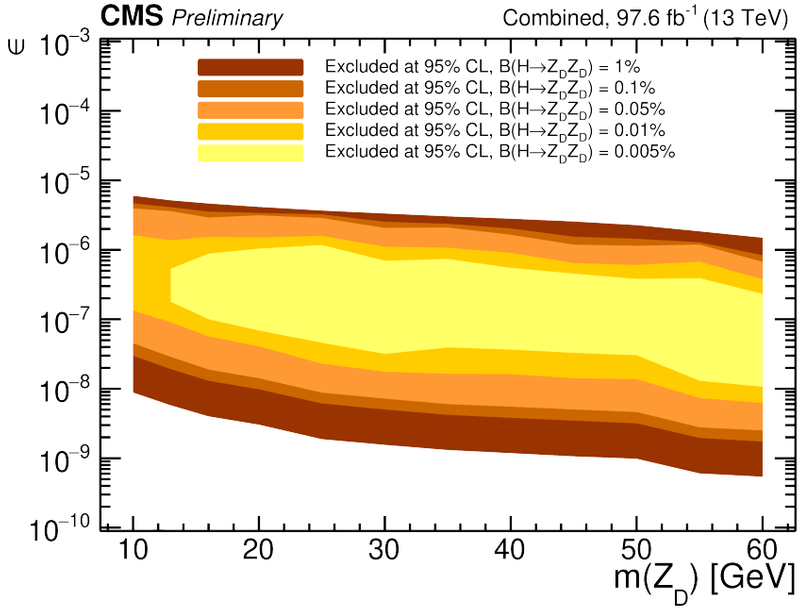
Signal region has very low contribution from SM backgrounds

Potential backgrounds are misidentified muons, or badly reconstructed muons from Drell-Yan, heavy-flavour decay, low mass resonances, cosmic rays

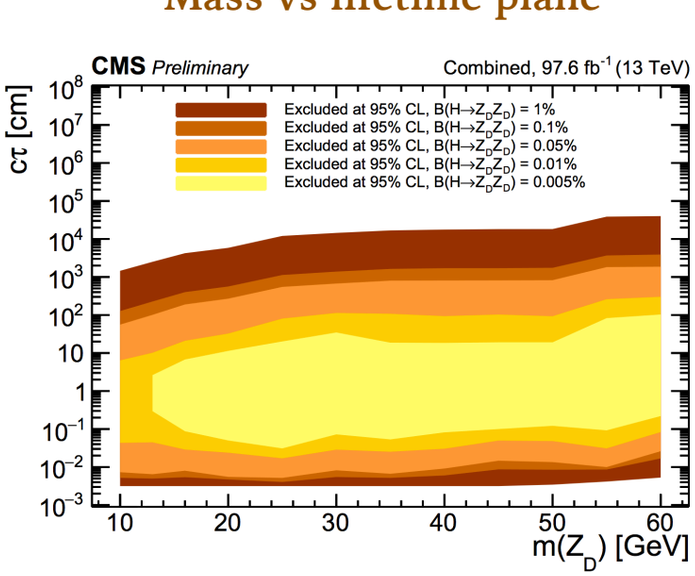
Benchmark model: Hidden Abelian Higgs Model (HAHM)



Mass vs Kinetic mixing plane



Mass vs lifetime plane



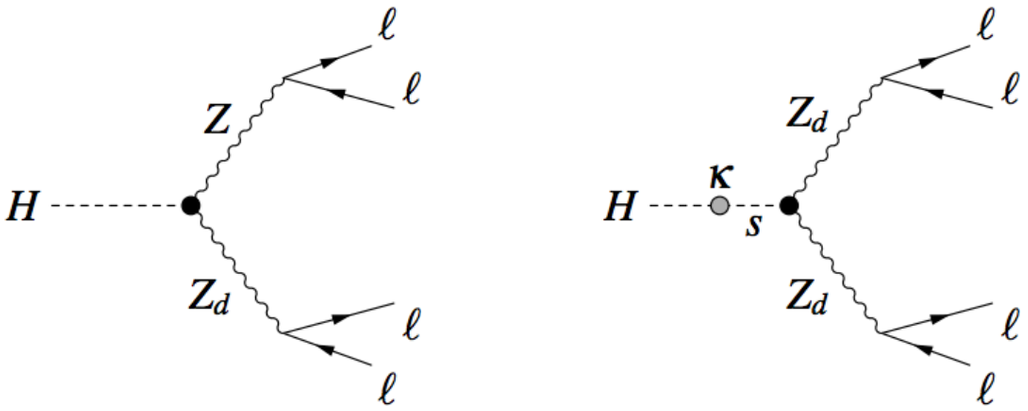
Best limits for most considered masses and lifetimes.

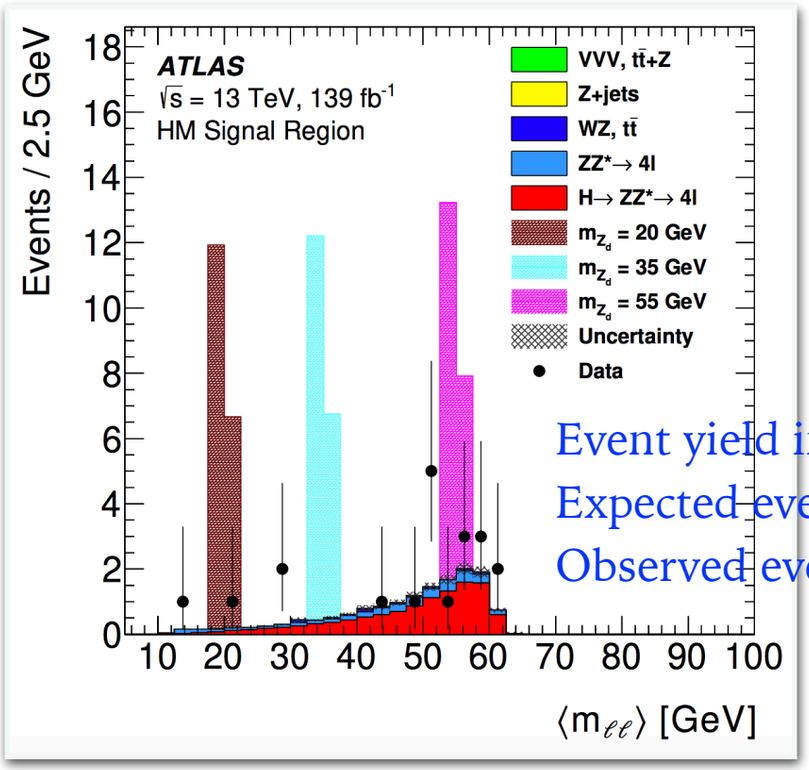
SEARCH FOR HIGGS DECAYING TO DARK PHOTON (ATLAS)

High-mass search: $H \to Z_d Z_d \to 4\ell$ ($15 < m_X < 60$ GeV)

Low-mass search: $H \to Z_d Z_d \to 4\mu$ ($1 < m_X < 15$ GeV)

ZZ_d search: $H \to Z Z_d \to 4\ell$ ($15 < m_X < 55$ GeV)

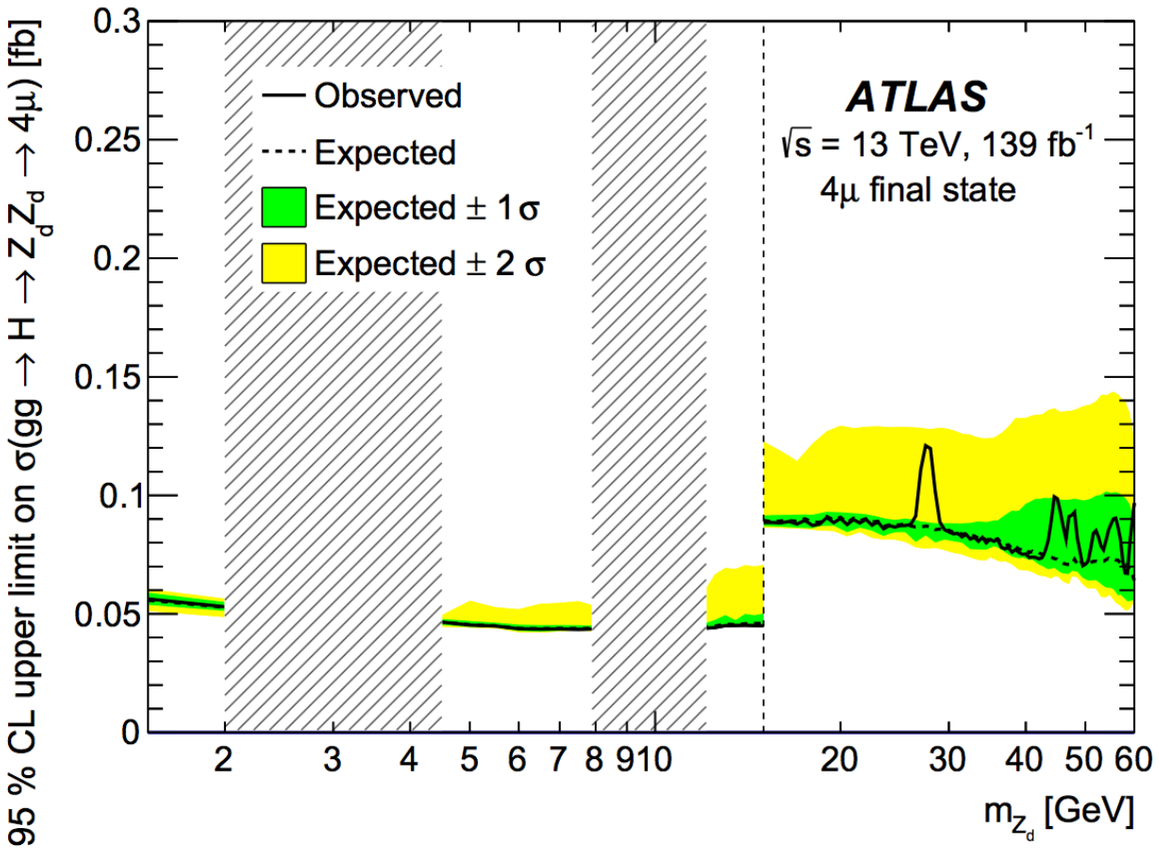


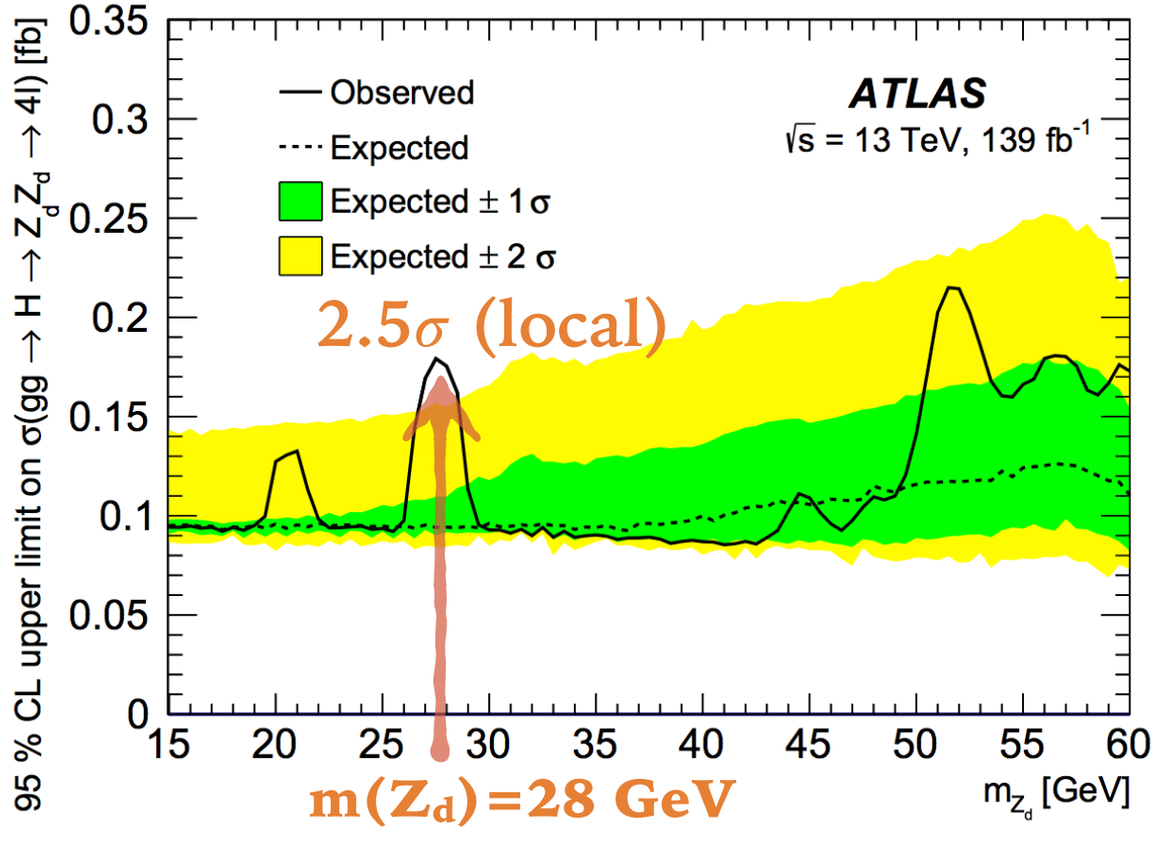


Event yield in high mass search

Expected events: **15.6±0.4±1.2**

Observed events: **20**





arxiv 2110.13673

VBF HIGGS DECAYING TO PHOTON AND DARK-PHOTON (ATLAS)

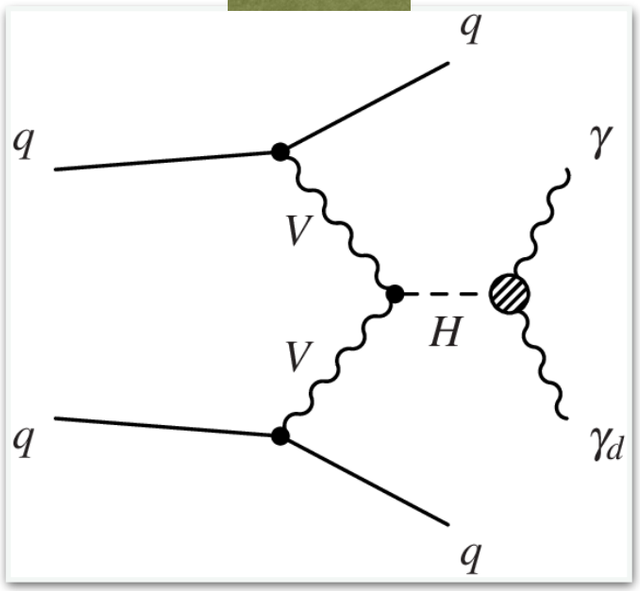
VBF production of Higgs

Higgs decay to photon + dark photon(undetected)

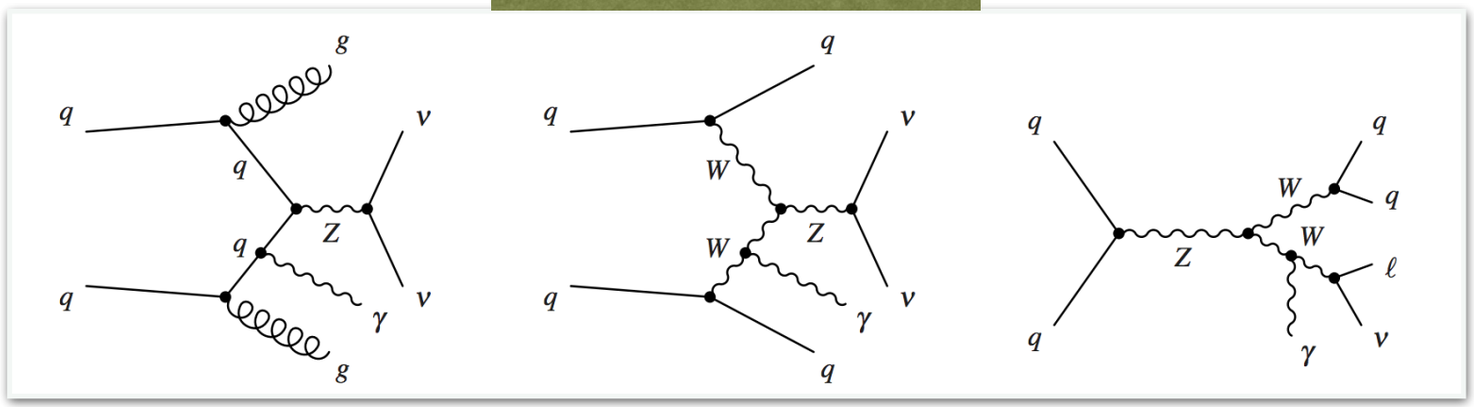
arXiv:2109.00925

Final state: 2 jets + photon + MET

Signal

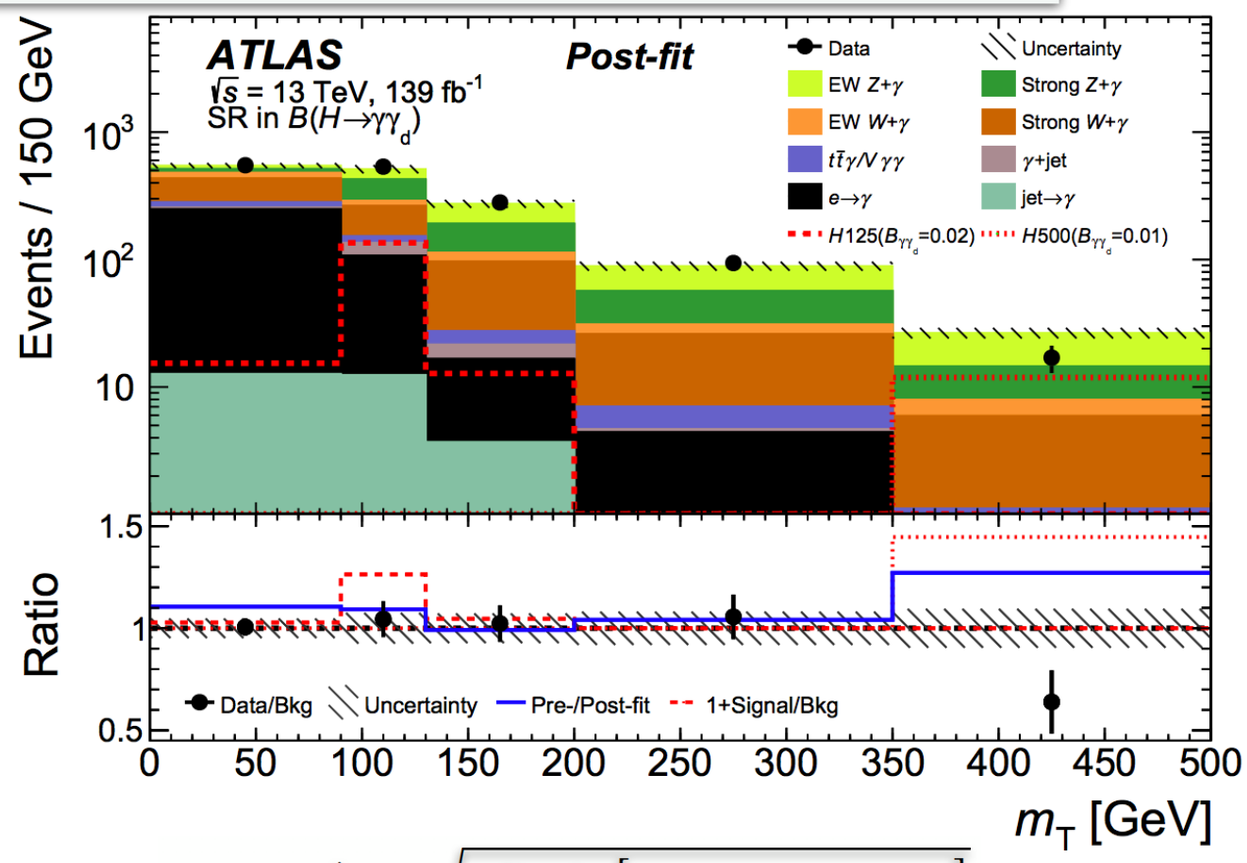


Main backgrounds



Signal-like events selected using highly efficient MET trigger.

Jacobian peak of $H \to \gamma + \gamma_d$ decays characterised by the use of transverse mass.



$$m_{\mathrm{T}}(\gamma, E_{\mathrm{T}}^{\mathrm{miss}}) = \sqrt{2 p_{\mathrm{T}}^{\gamma} E_{\mathrm{T}}^{\mathrm{miss}} \left[1 - \cos(\phi_{\gamma} - \phi_{E_{\mathrm{T}}^{\mathrm{miss}}})\right]}$$

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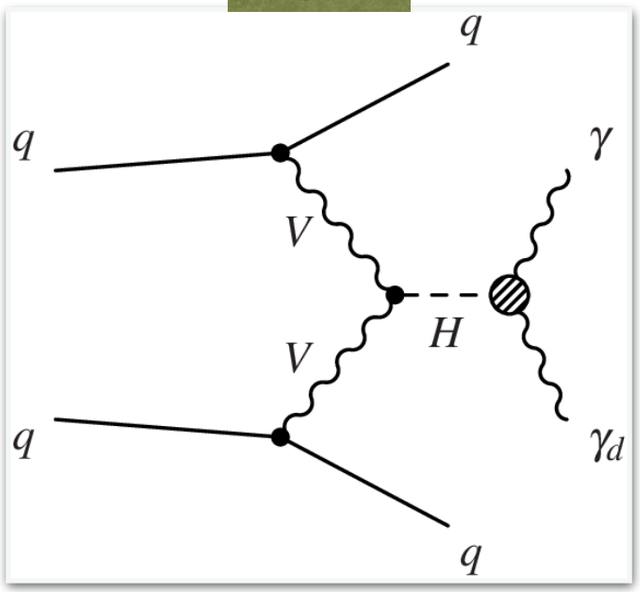

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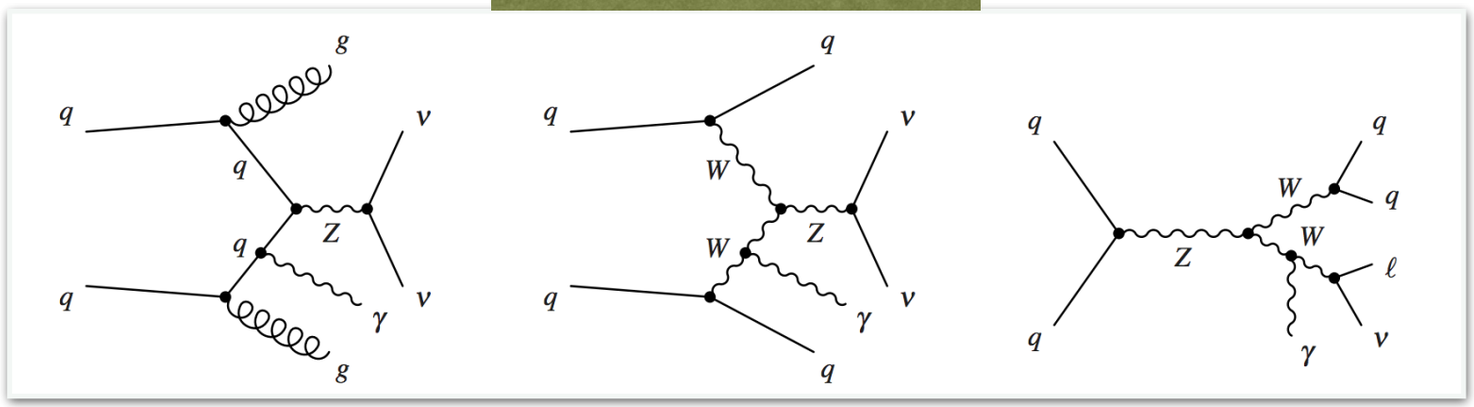
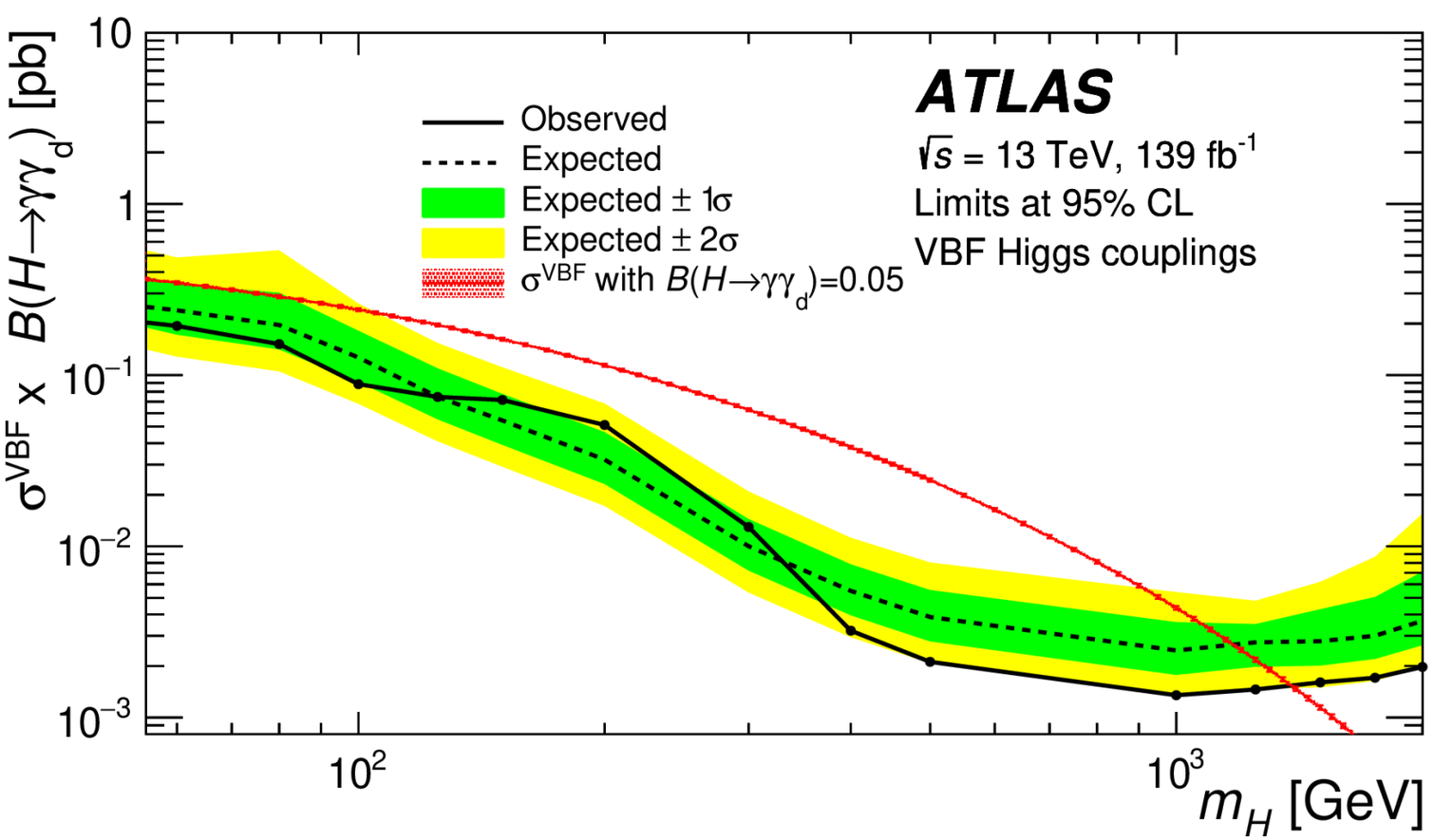


Upper limit on cross-section times branching provided for various Higgs mass hypothesis (60 GeV - 2 TeV)

This search provides very stringent upper limit of 0.018 on branching of H(125)→γ+γ_d



SEARCH FOR DISPLACED LEPTON-JET (ATLAS)

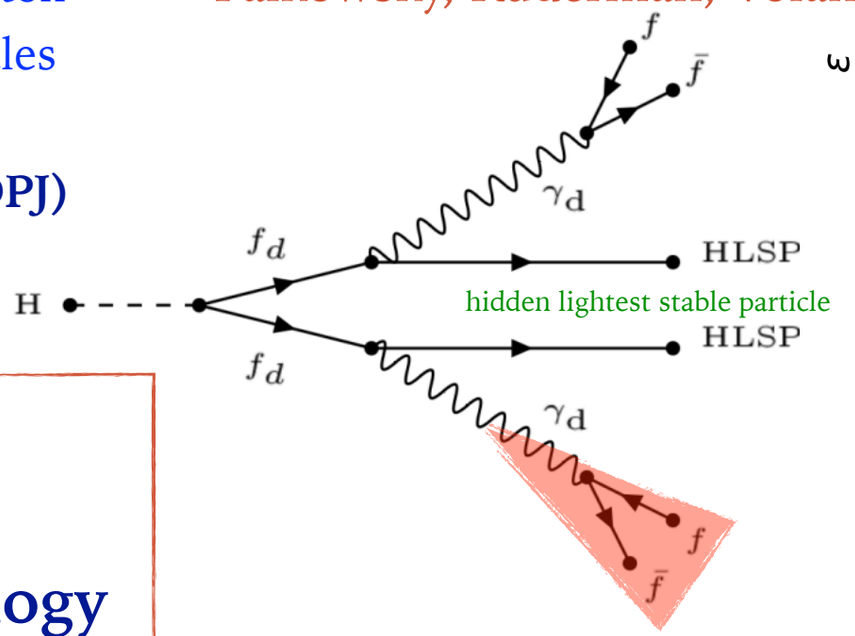
Lepton-jet: boosted, light dark photon decaying to pairs of following particles in a narrow cone:

- **Electrons/light hadrons (caloDPJ)**
- **Muons (μDPJ)**

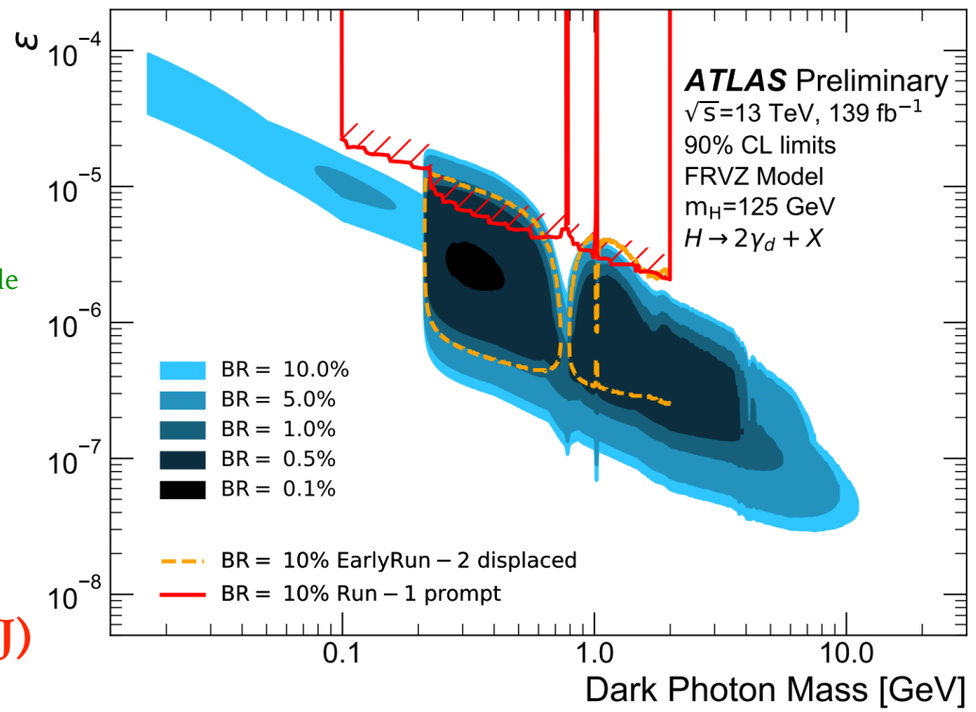
Improved analysis sensitivity due to addition of WH topology (i.e, now we have ggF+WH)

First time exclusion in the fully electron channel

Falkowsky, Ruderman, Volansky, Zupan [FRVZ] model



Dark-photon jet (DPJ)

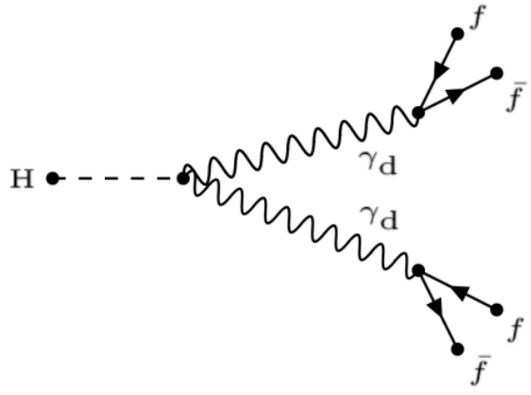


Significant analysis improvements by using sophisticated ML taggers

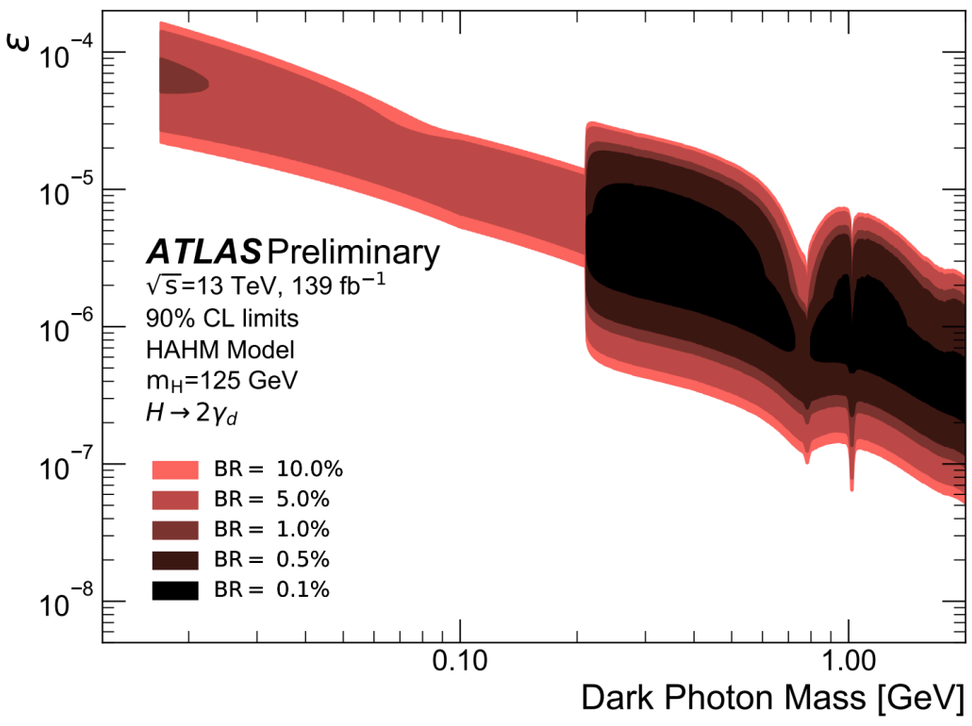
- Cosmic-ray muon tagger (DNN)
- QCD tagger (CNN) for calorimeter-based dark photon signal
- Beam-induced background tagger (CNN)

ATLAS-CONF-2022-001

Hidden Abelian Higgs model [HAHM] model

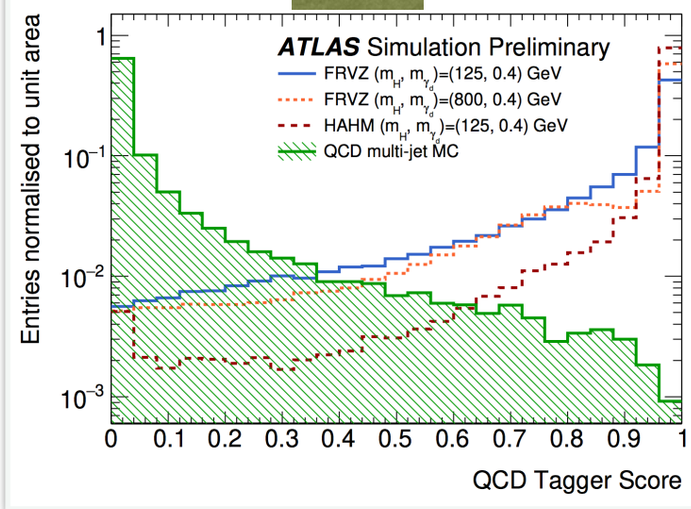


Assumption in this analysis:
Dark gauge coupling (α_d)<0.01
Dark showers are not considered.

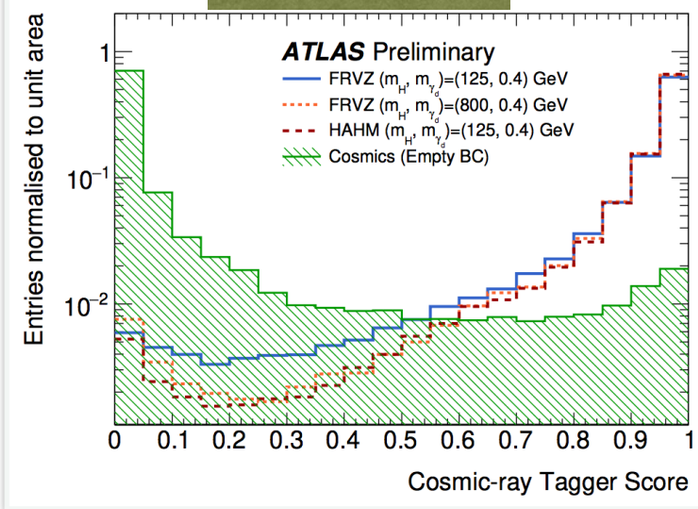


SEARCH FOR DISPLACED LEPTON-JET (ATLAS)

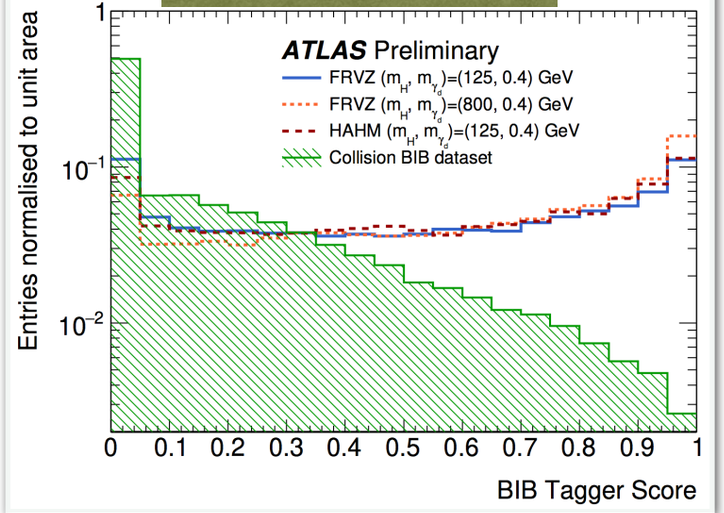
QCD



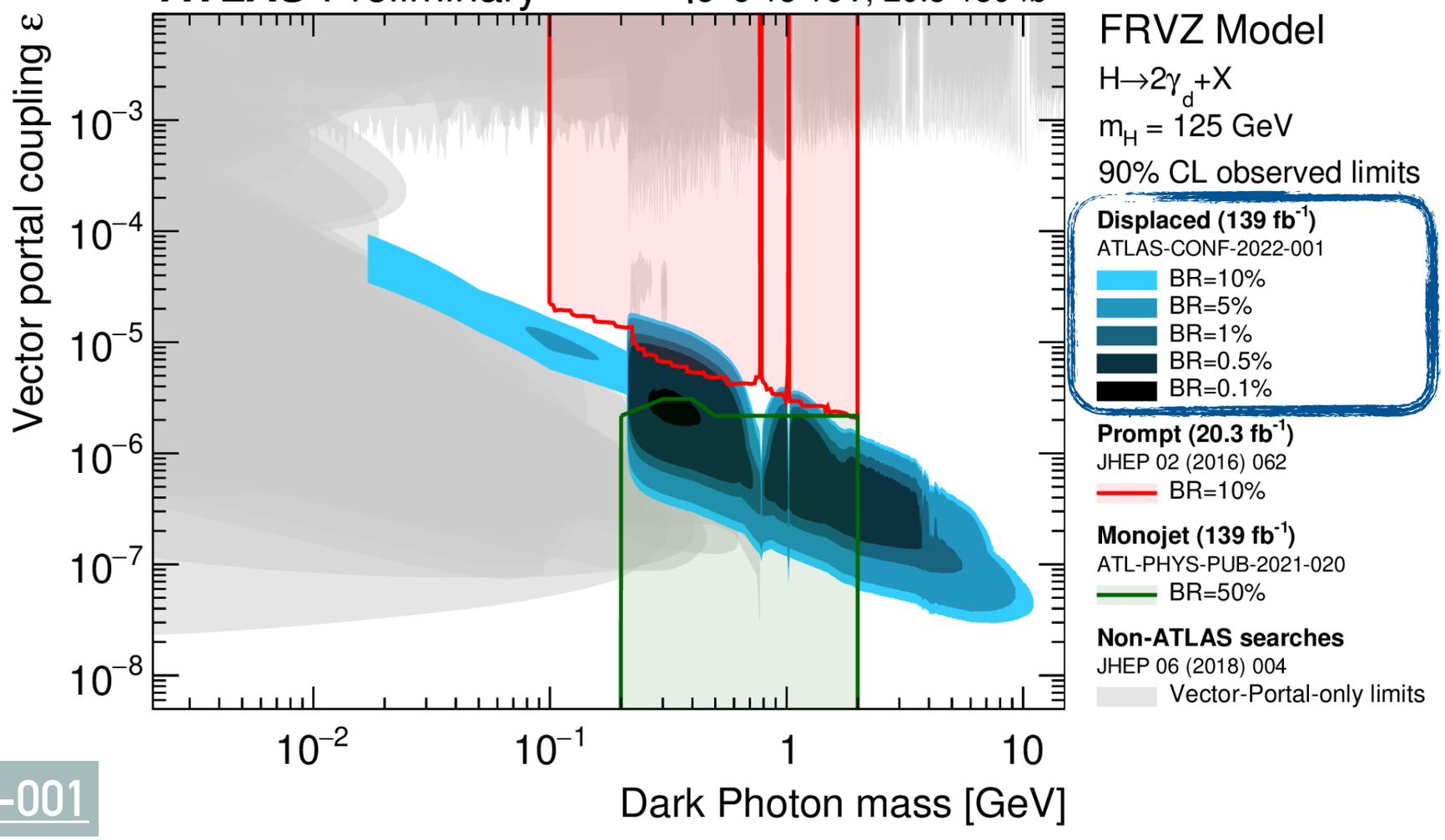
Cosmic ray



Beam-induced



Thanks to the **powerful taggers**, and other improvements in analysis techniques, this search excludes an impressive region of the phase space.

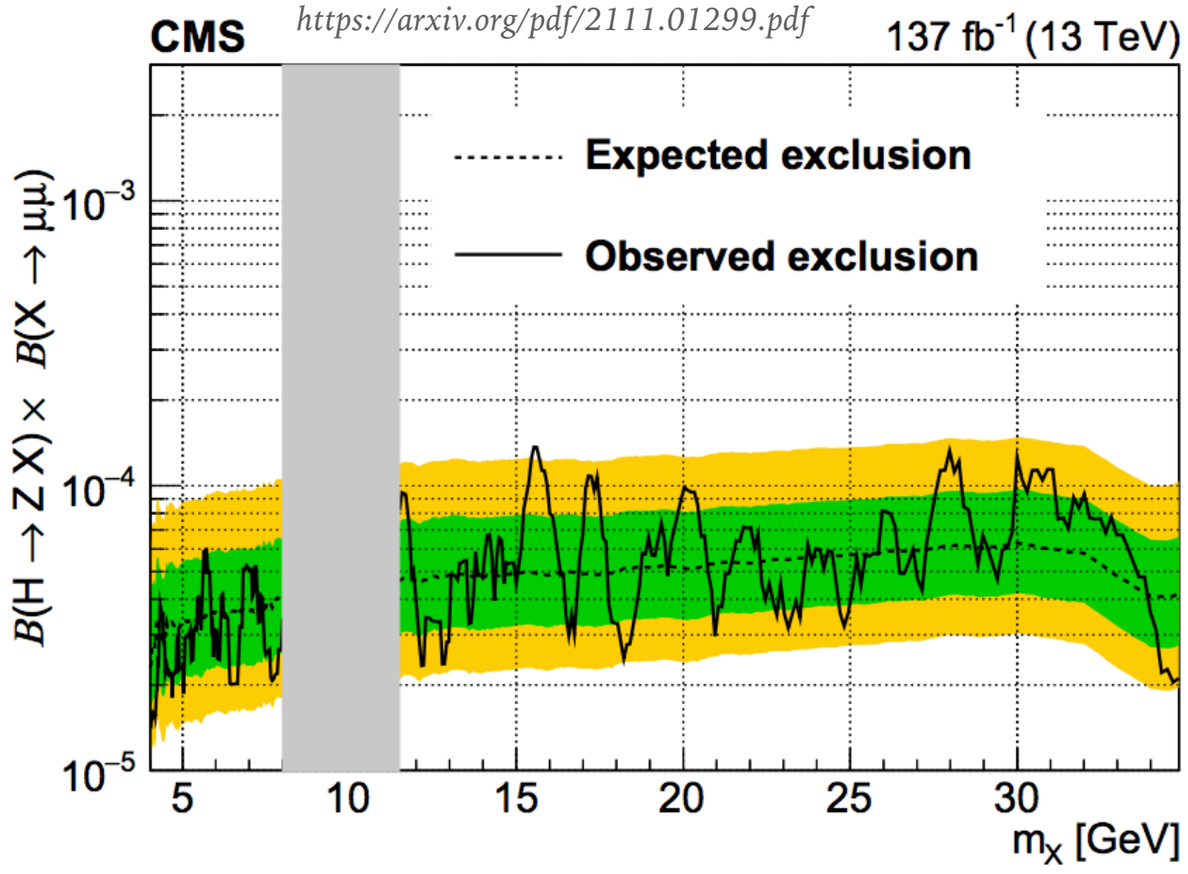


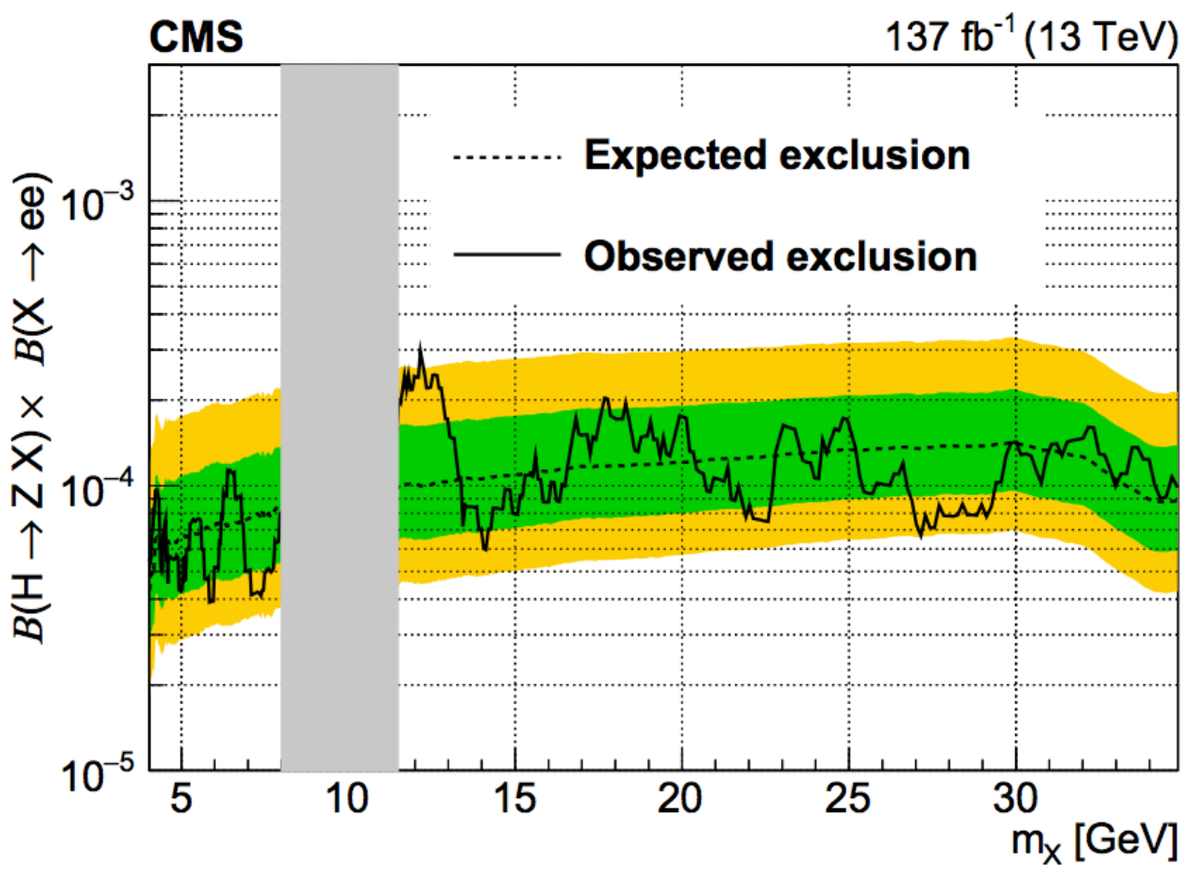
ATLAS-CONF-2022-001

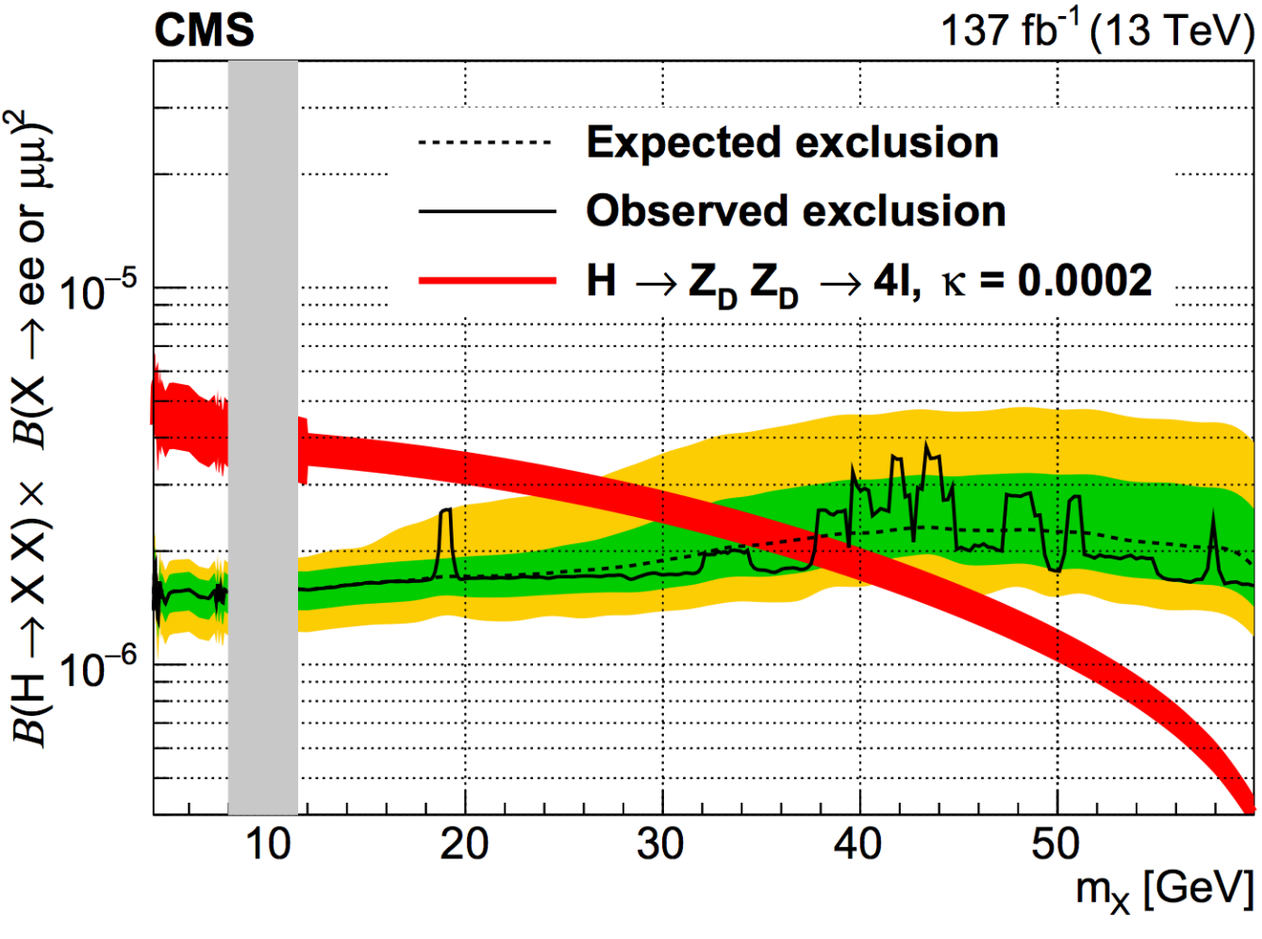
STICK WITH US

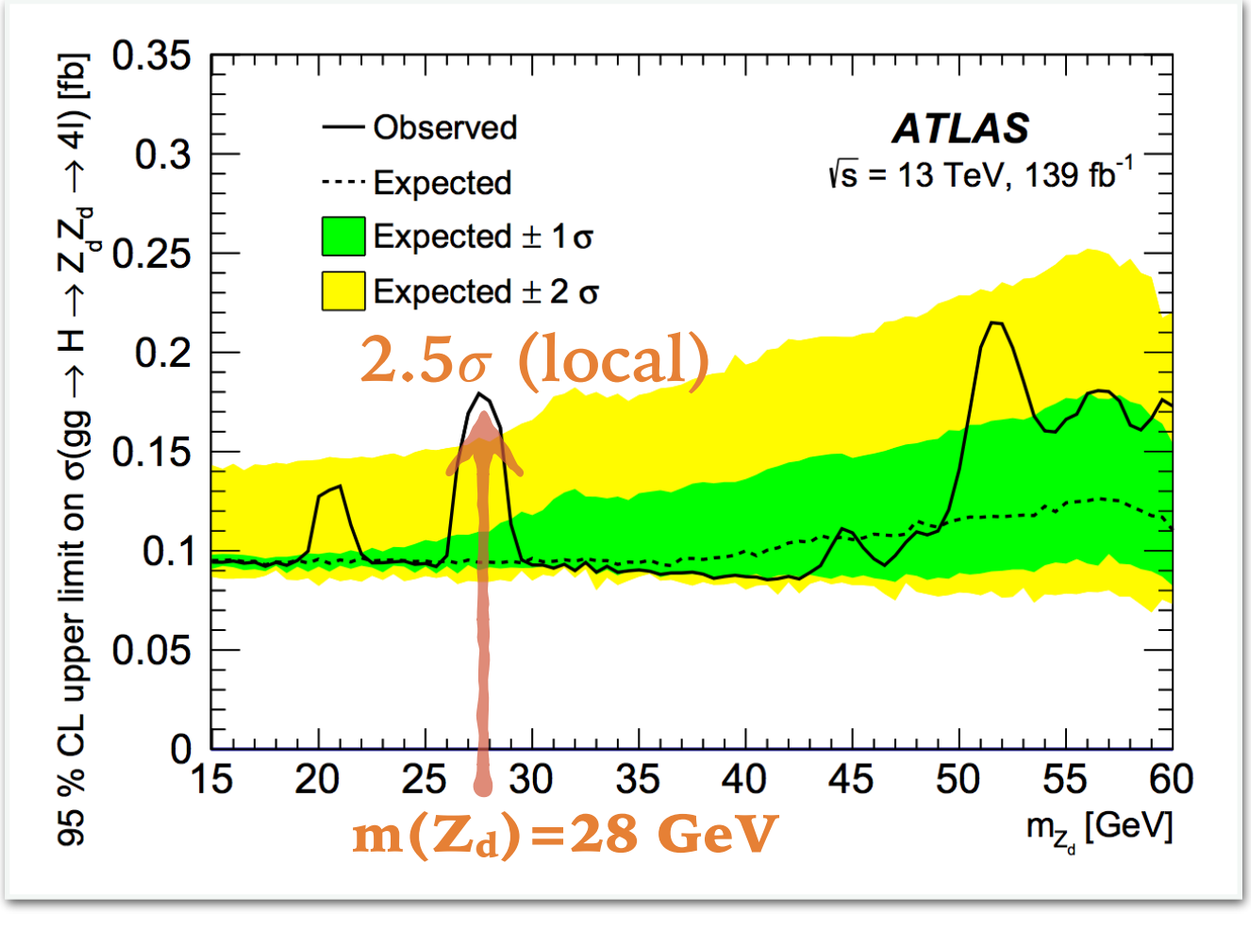
EXTRA SLIDES

https://arxiv.org/pdf/2111.01299.pdf

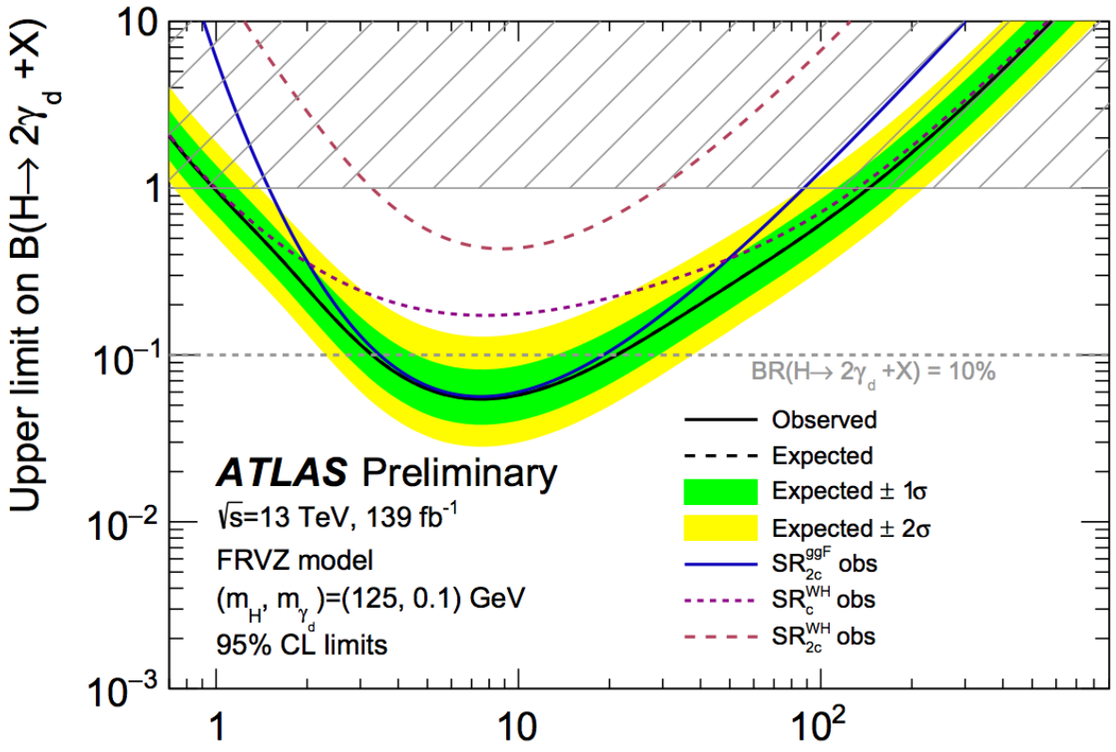


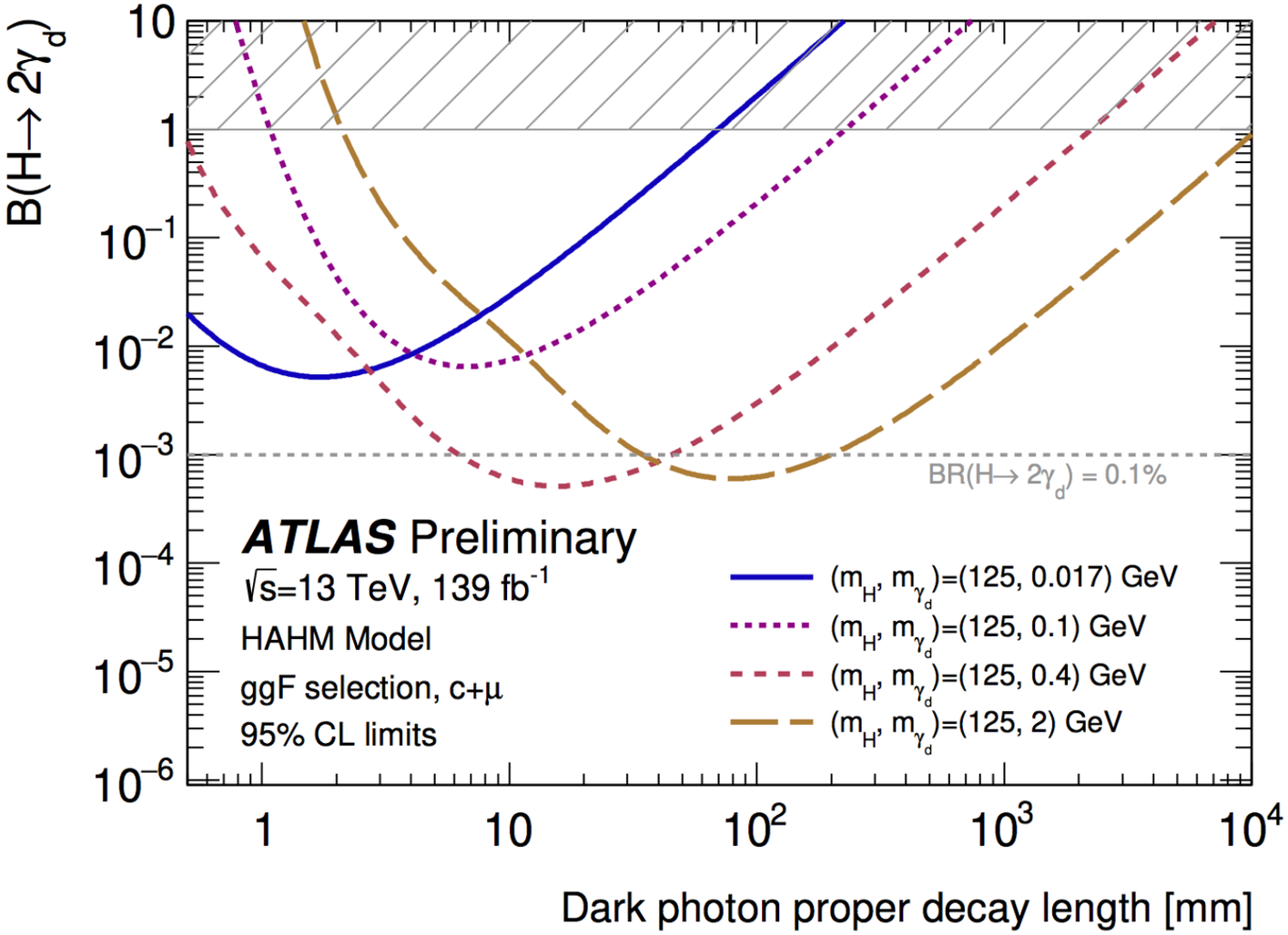




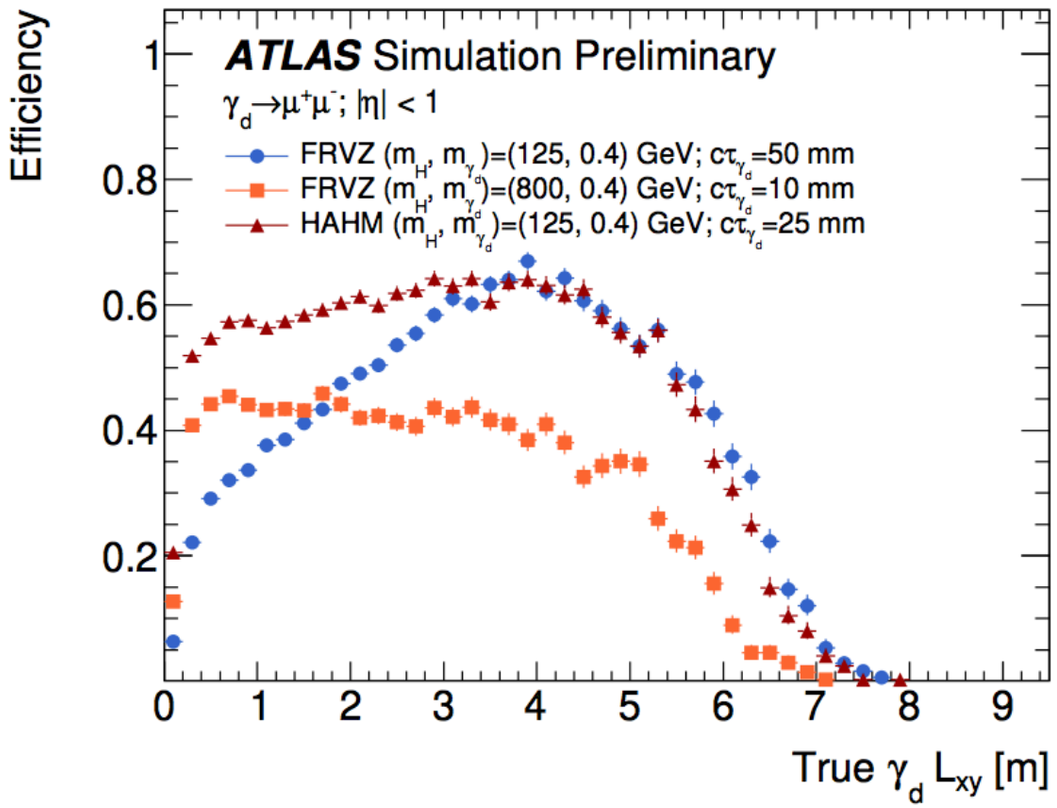


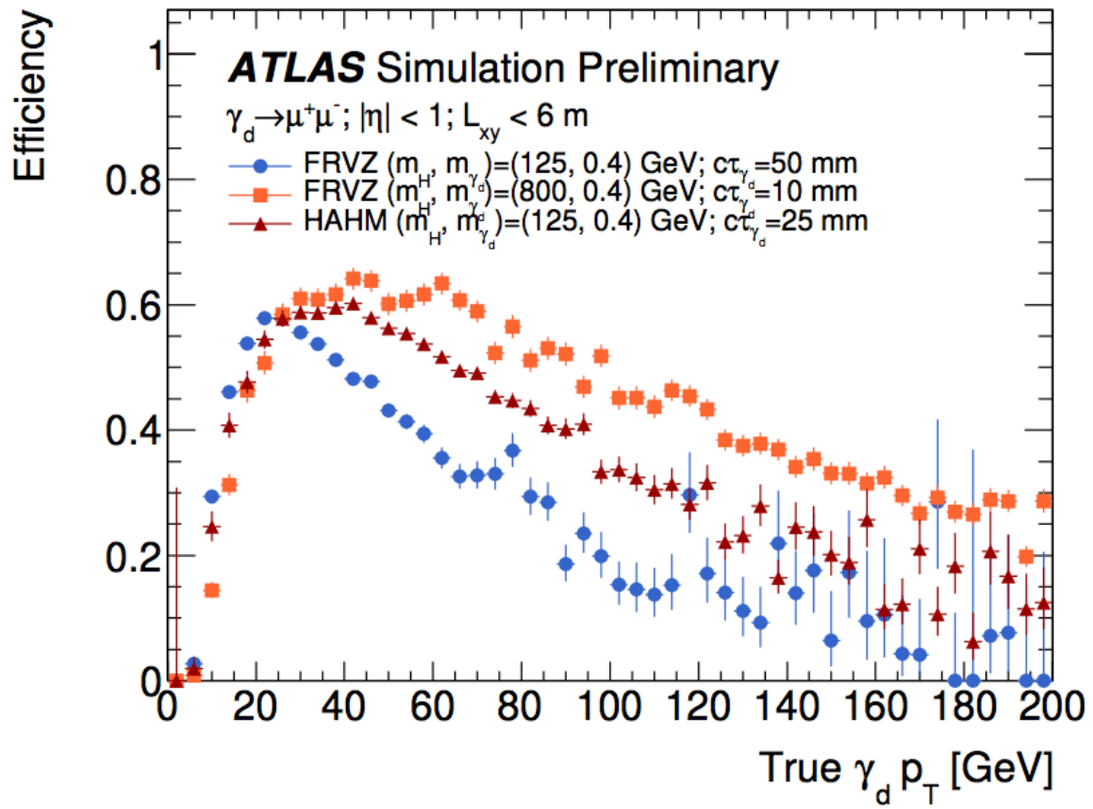
SEARCH FOR DISPLACED LEPTON-JET (ATLAS)

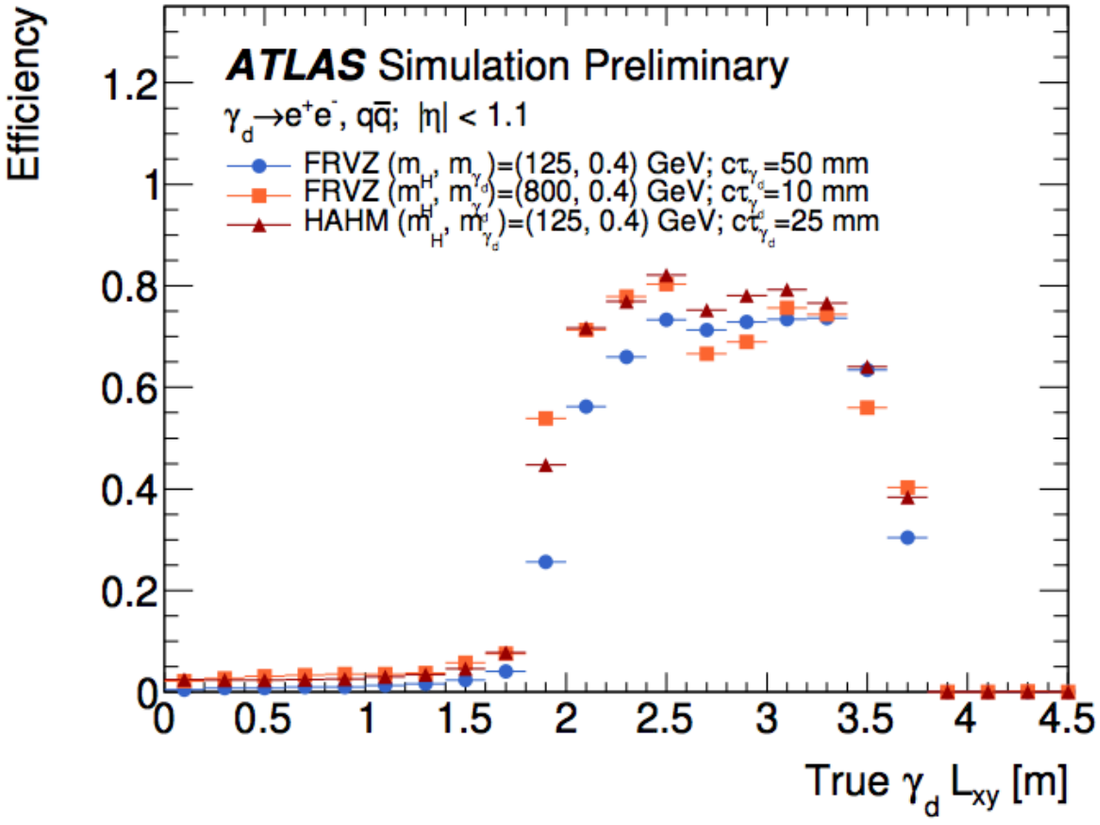


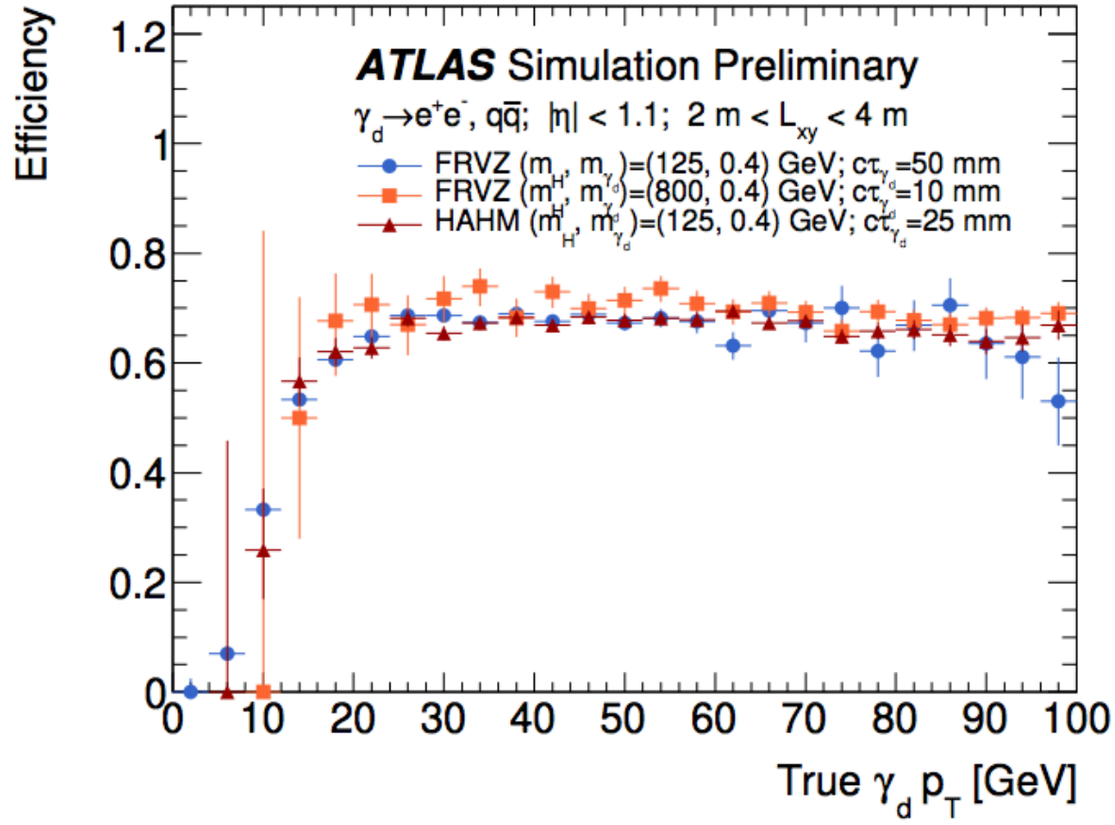


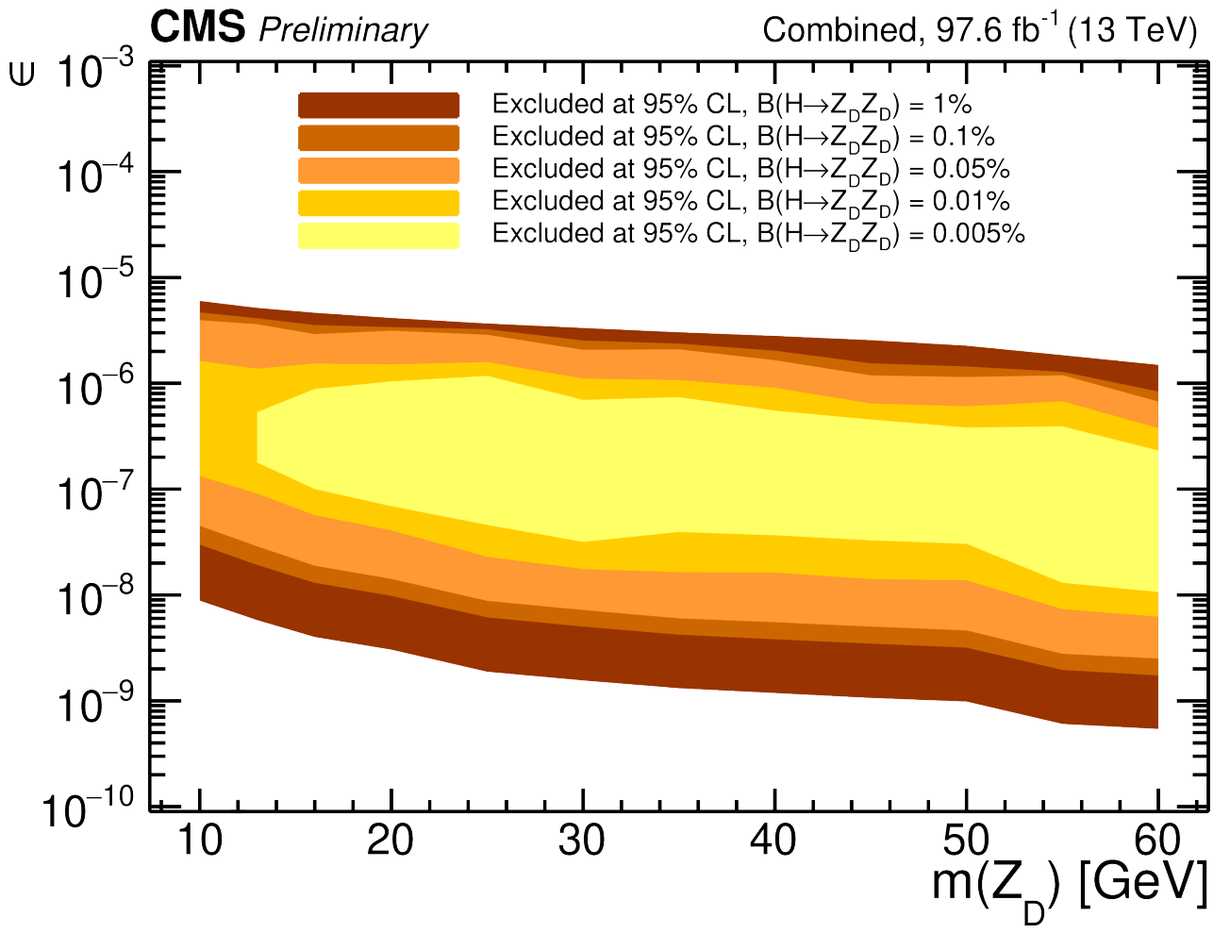
RECO EFF OF MUON DPJ AND CALO DPJ

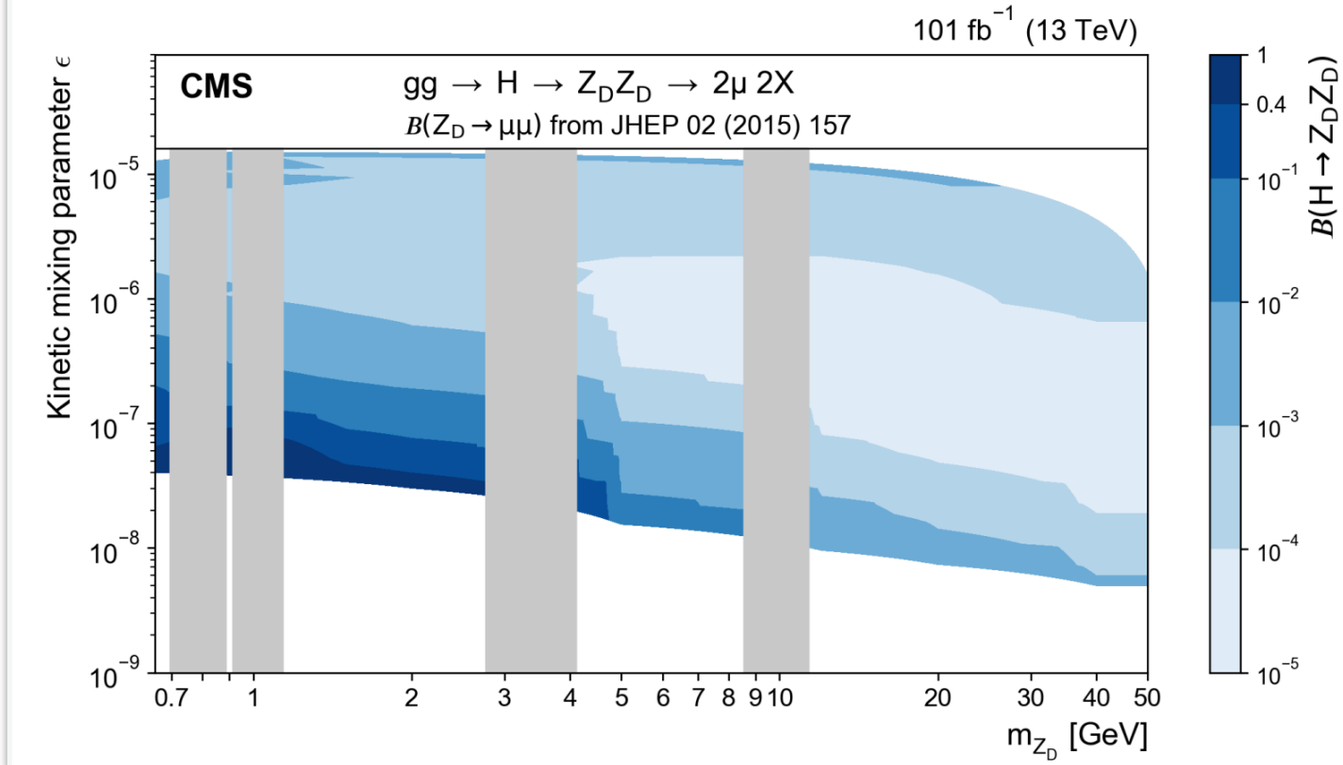


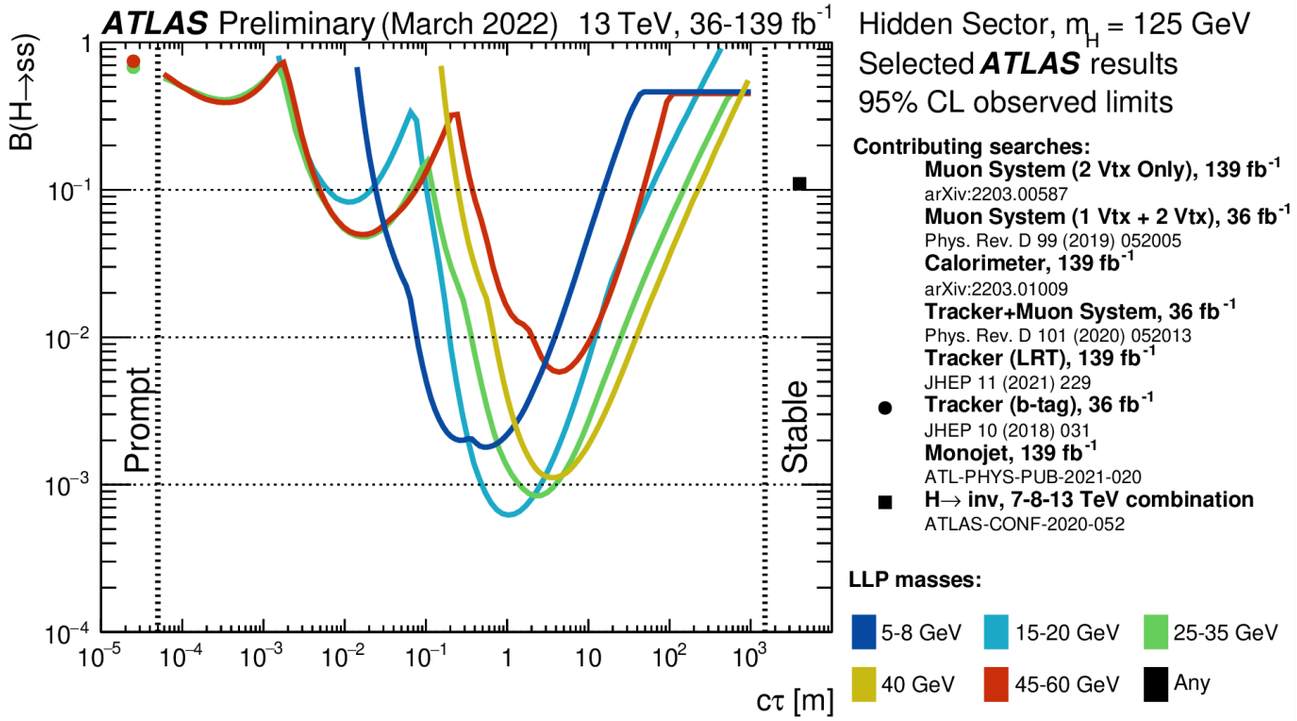


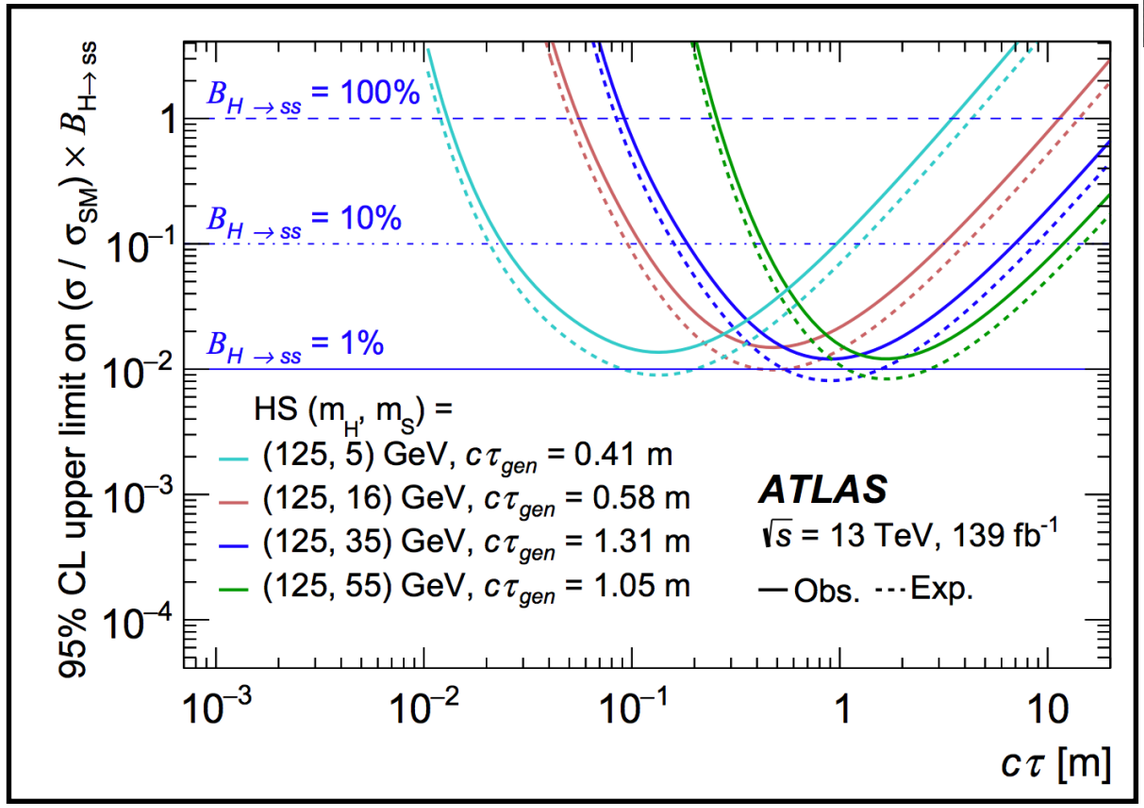


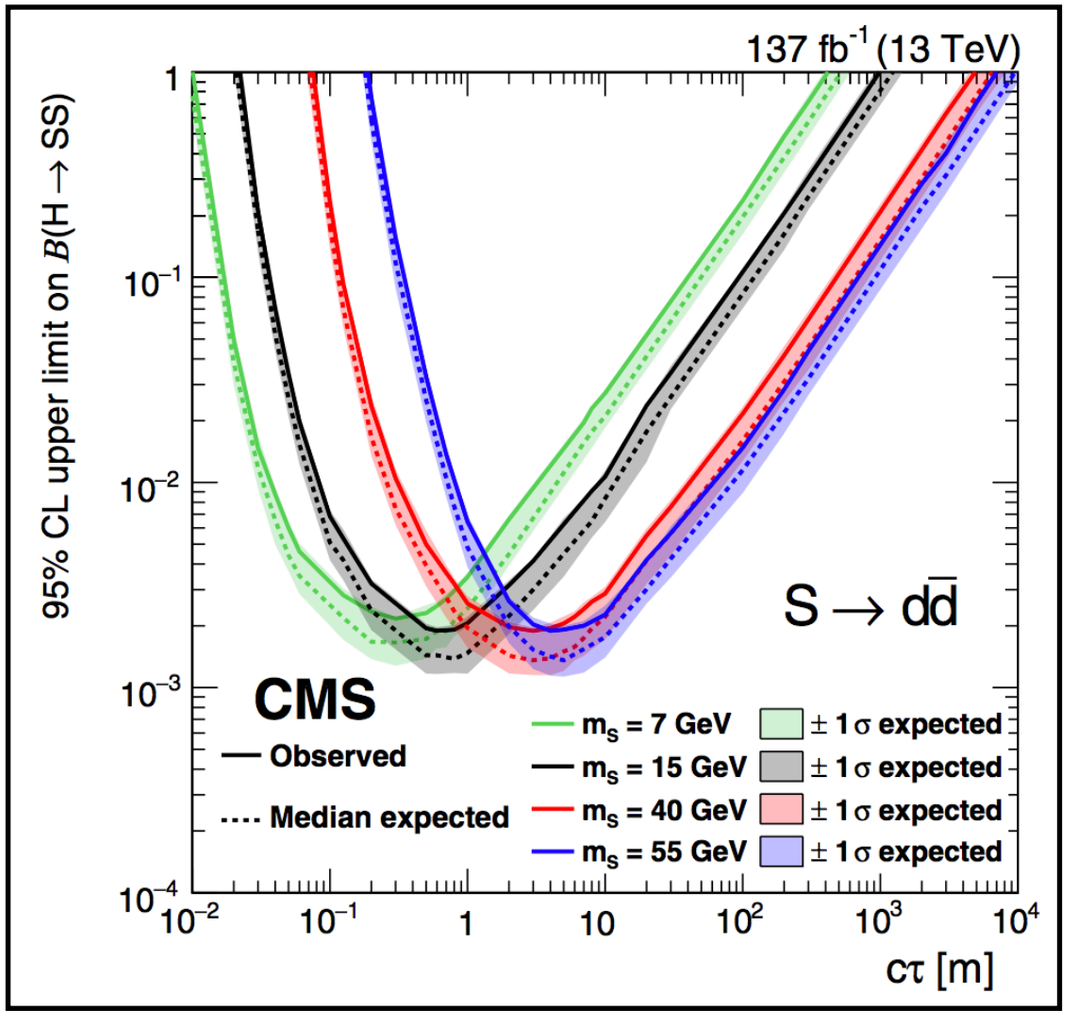


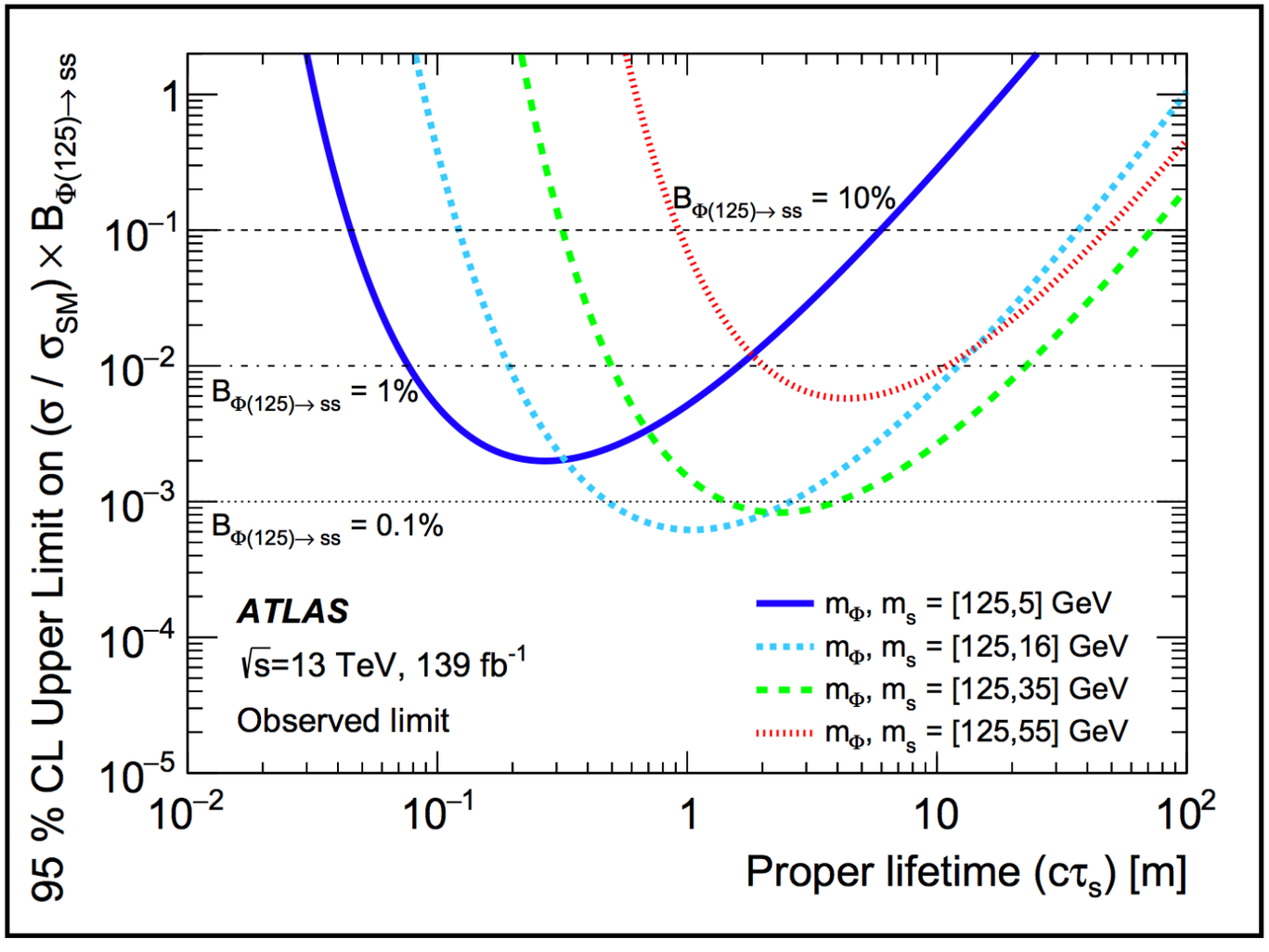

CMS Preliminary
Combined, 97.6 fb^{-1} (13 TeV)
Excluded at 95% CL, B(H→Z$_D$Z$_D$) = 1%
Excluded at 95% CL, B(H→Z$_D$Z$_D$) = 0.1%
Excluded at 95% CL, B(H→Z$_D$Z$_D$) = 0.05%
Excluded at 95% CL, B(H→Z$_D$Z$_D$) = 0.01%
Excluded at 95% CL, B(H→Z$_D$Z$_D$) = 0.005%
Ψ
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10
20
30
40
50
60
m(Z$_D$) [GeV]

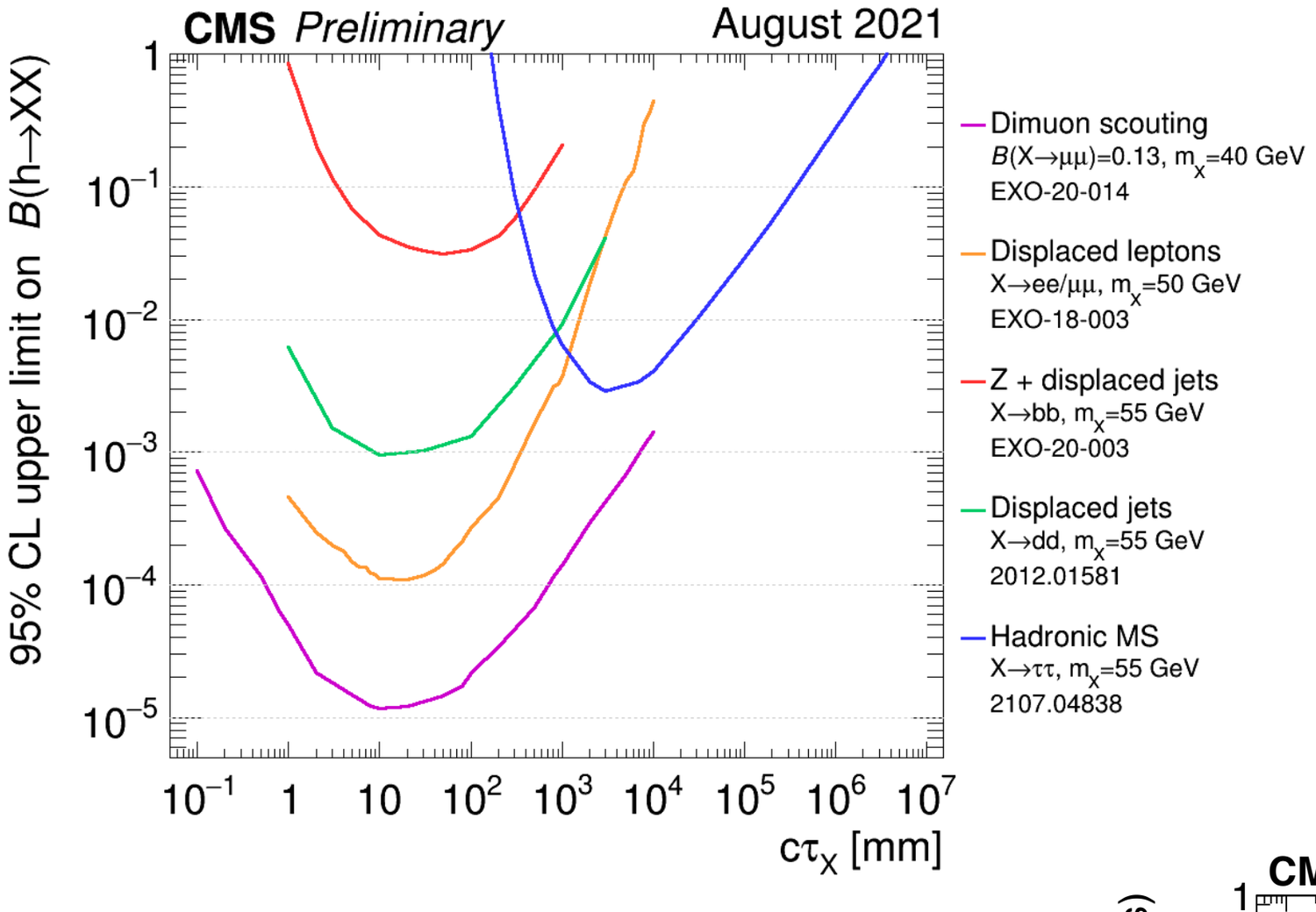

101 fb^{-1} (13 TeV)
CMS
gg → H → Z$_D$Z$_D$ → 2μ 2X
B(Z$_D$ → μμ) from JHEP 02 (2015) 157
Kinetic mixing parameter ϵ
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
0.7
1
2
3
4
5
6
7
8
9
10
20
30
40
50
m$_{Z_D}$ [GeV]
B(H → Z$_D$Z$_D$)
1
0.4
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}

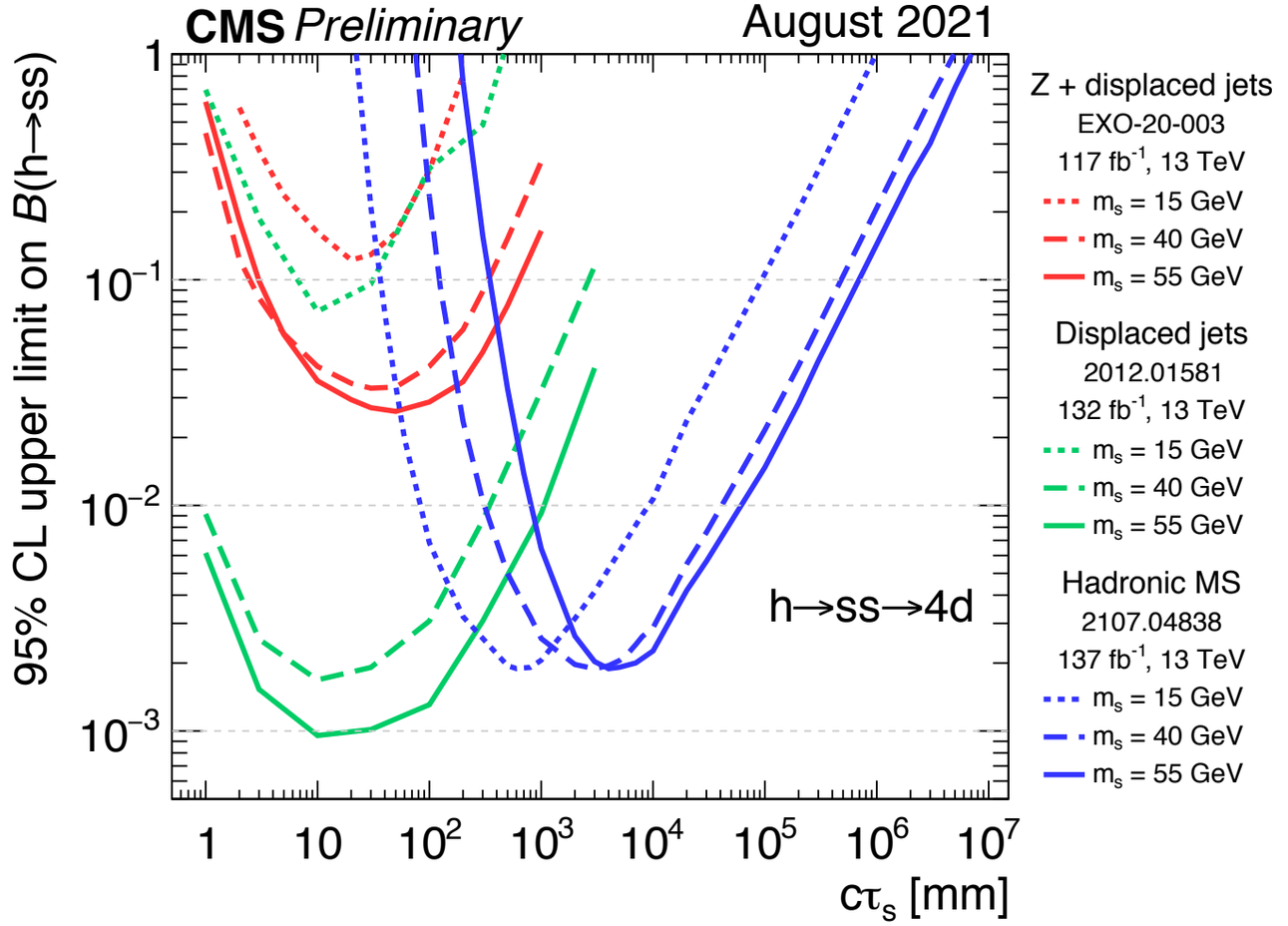

ATLAS Preliminary (March 2022) 13 TeV, 36-139 fb-1
B(H→ss)
Prompt
Stable
cτ [m]
Hidden Sector, mH = 125 GeV
Selected ATLAS results
95% CL observed limits
Contributing searches:
Muon System (2 Vtx Only), 139 fb-1
arXiv:2203.00587
Muon System (1 Vtx + 2 Vtx), 36 fb-1
Phys. Rev. D 99 (2019) 052005
Calorimeter, 139 fb-1
arXiv:2203.01009
Tracker+Muon System, 36 fb-1
Phys. Rev. D 101 (2020) 052013
Tracker (LRT), 139 fb-1
JHEP 11 (2021) 229
Tracker (b-tag), 36 fb-1
JHEP 10 (2018) 031
Monojet, 139 fb-1
ATL-PHYS-PUB-2021-020
H→ inv, 7-8-13 TeV combination
ATLAS-CONF-2020-052
LLP masses:
5-8 GeV
15-20 GeV
25-35 GeV
40 GeV
45-60 GeV
Any


95% CL upper limit on (σ / σSM) × BH→ ss
BH→ss = 100%
BH→ss = 10%
BH→ss = 1%
HS (mH, mS) =
(125, 5) GeV, cτgen = 0.41 m
(125, 16) GeV, cτgen = 0.58 m
(125, 35) GeV, cτgen = 1.31 m
(125, 55) GeV, cτgen = 1.05 m
ATLAS
√s = 13 TeV, 139 fb-1
Obs. Exp.
cτ [m]


137 fb-1 (13 TeV)
95% CL upper limit on B(H → SS)
S → dd̄
CMS
Observed
Median expected
ms = 7 GeV
ms = 15 GeV
ms = 40 GeV
ms = 55 GeV
± 1σ expected
cτ [m]


95 % CL Upper Limit on (σ / σSM) × BΦ(125)→ ss
BΦ(125)→ ss = 10%
BΦ(125)→ ss = 1%
BΦ(125)→ ss = 0.1%
ATLAS
√s=13 TeV, 139 fb-1
Observed limit
mΦ, ms = [125,5] GeV
mΦ, ms = [125,16] GeV
mΦ, ms = [125,35] GeV
mΦ, ms = [125,55] GeV
Proper lifetime (cτs) [m]





https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryPlotsEXO13TeV