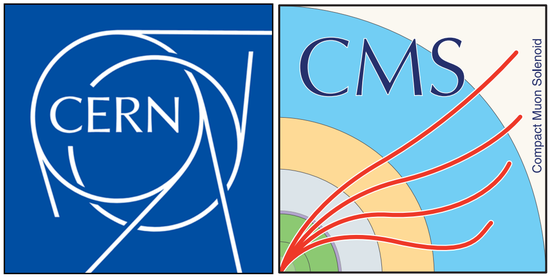

Dark photon searches with CMS

Simranjit S. Chhibra[1*] on behalf of the CMS collaboration

[1]CERN

33rd Rencontres de Blois, 22–27 May 2022

https://indico.cern.ch/event/1133536/

*simranijt.singh.chhibra@cern.ch

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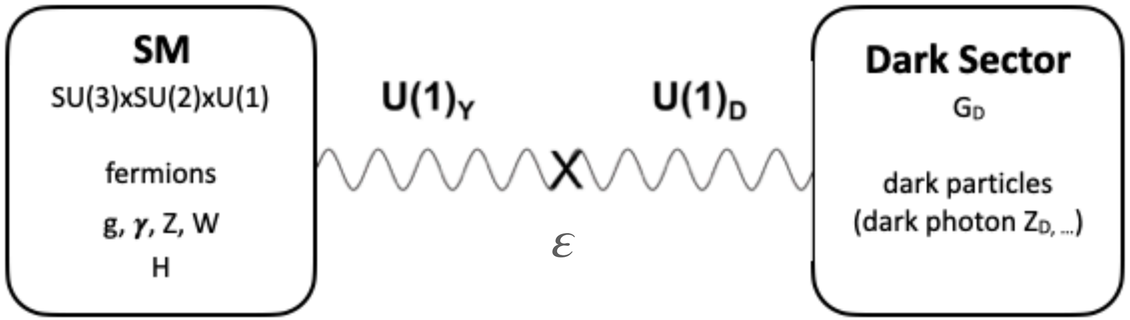
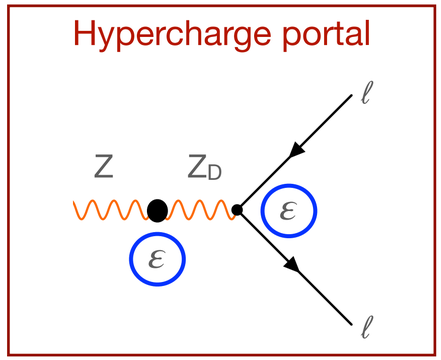
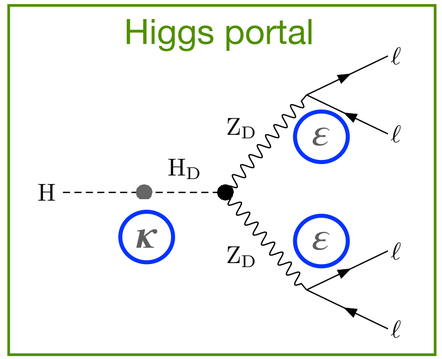
Physics motivation



Kinetic-mixing term

$$\mathcal{L} \subset -\frac{1}{4}\hat{B}_{\mu\nu}\hat{B}^{\mu\nu} - \frac{1}{4}\hat{Z}_{D\mu\nu}\hat{Z}_D^{\mu\nu} + \frac{1}{2}\frac{\epsilon}{\cos\theta}\hat{Z}_{D\mu\nu}\hat{B}^{\mu\nu} + \frac{1}{2}m_{D,0}^2\hat{Z}_D^{\mu}\hat{Z}_{D\mu}$$





- Like a photon of electromagnetism, dark photon (Z_D or A') mediates an interaction, arising from a $U(1)_D$ gauge symmetry, between particles of the dark sector
- The SM coupling to the dark sector is described via the gauge invariant kinetic-mixing term
- The Z_D interaction with SM fermions is similar to that of a photon or a Z boson and its coupling with them is proportional to ε

Z_D decay length

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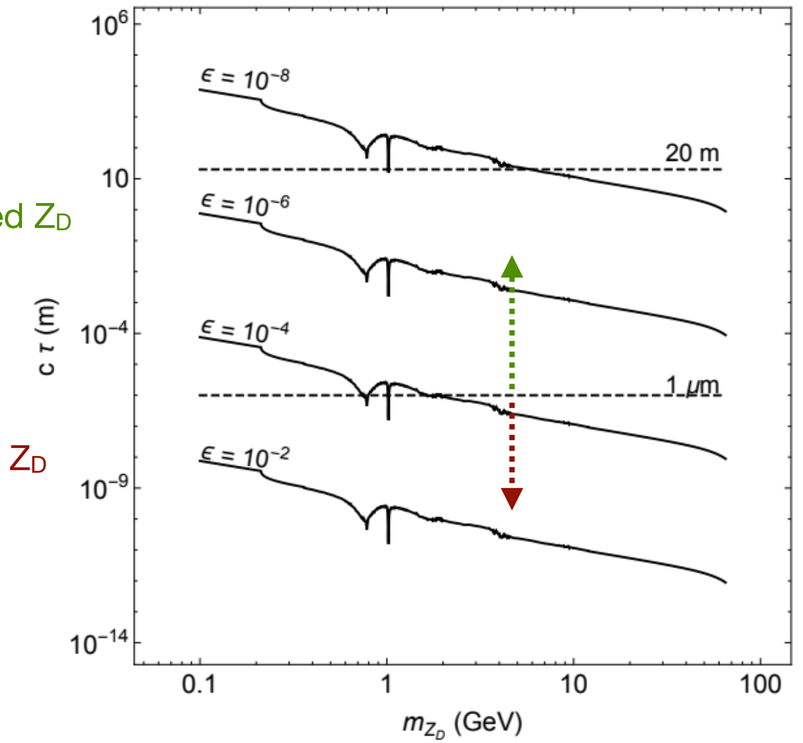
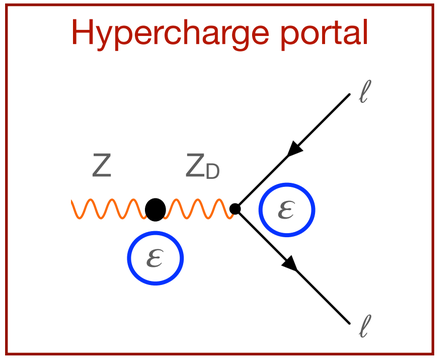
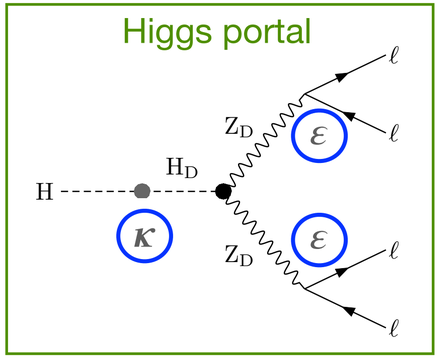
Long-lived Z_D

Prompt Z_D







Experimental search status

- **Exclusion limits in [m_{ZD}, $\varepsilon(\varepsilon^2)$] parameter space**
- **[0.02, 10.2] GeV:** BaBar has put the strongest limits so far, ε ~10^{-3}
- **> 10 GeV:** ε ~3x10^{-2} from the EWPT measurements from LEP
- **[0.2, 70] GeV:** ε^2 ~10^{-7}–10^{-5} from LHCb
- LHCb places world-leading constraints on a low-mass long-lived dark photon

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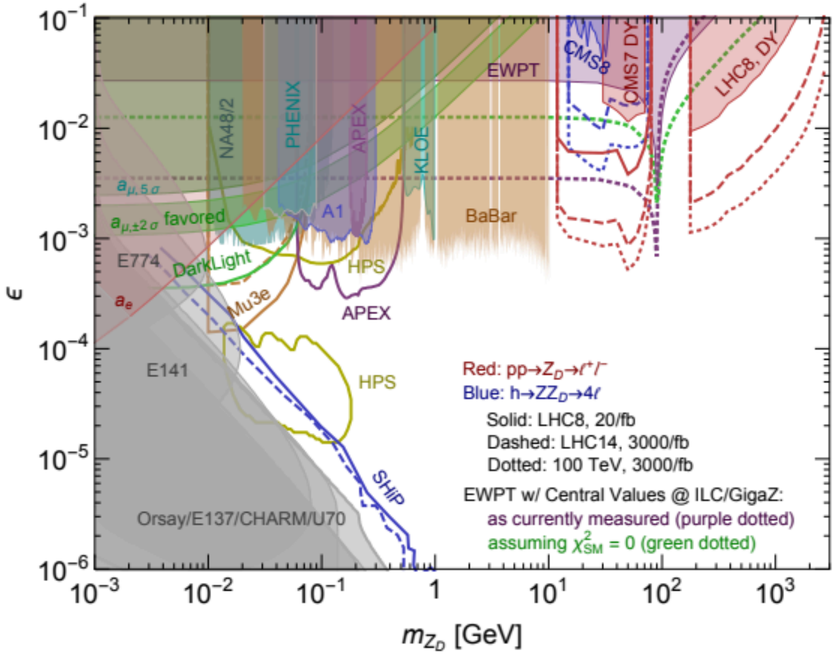
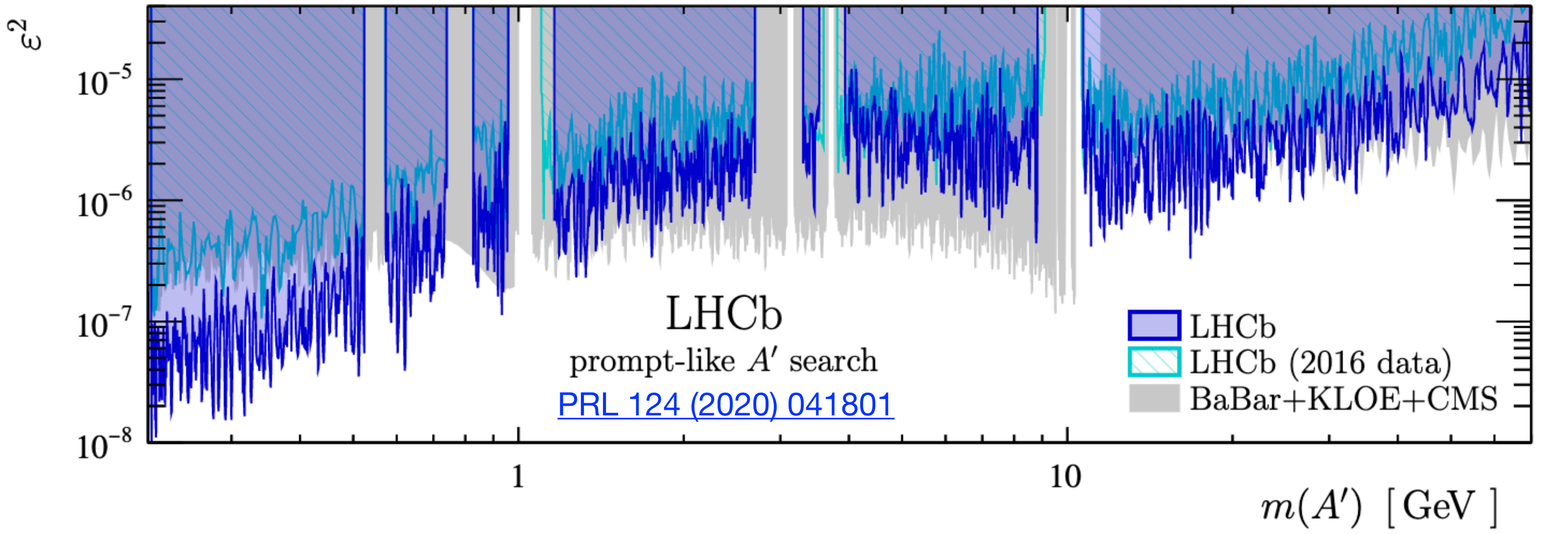
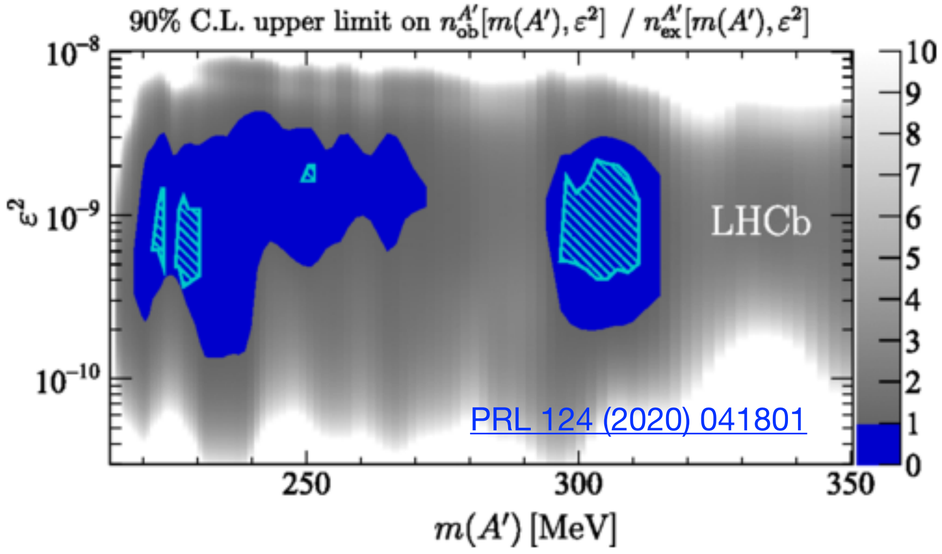
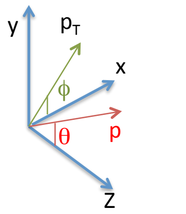




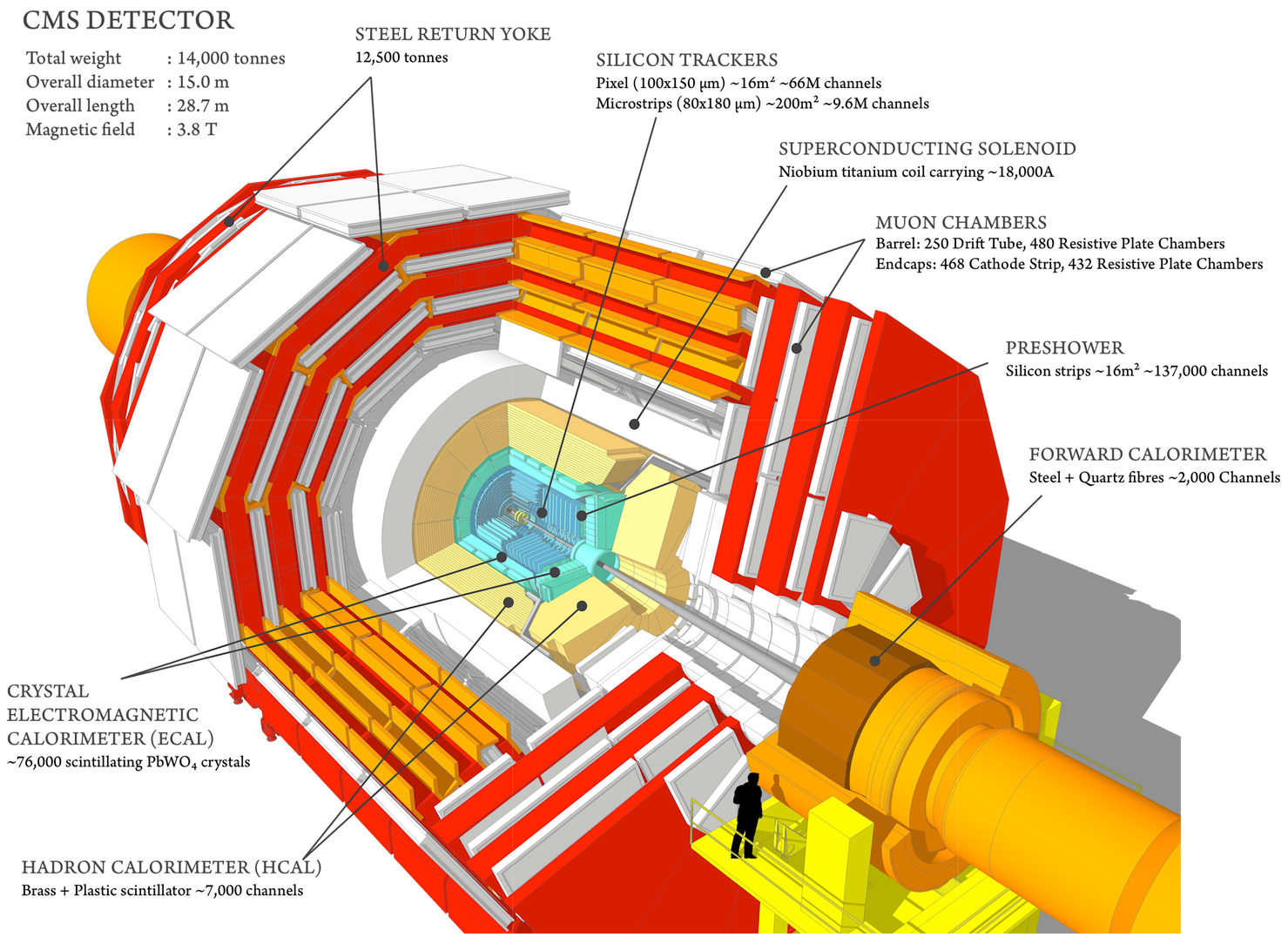


The CMS experiment

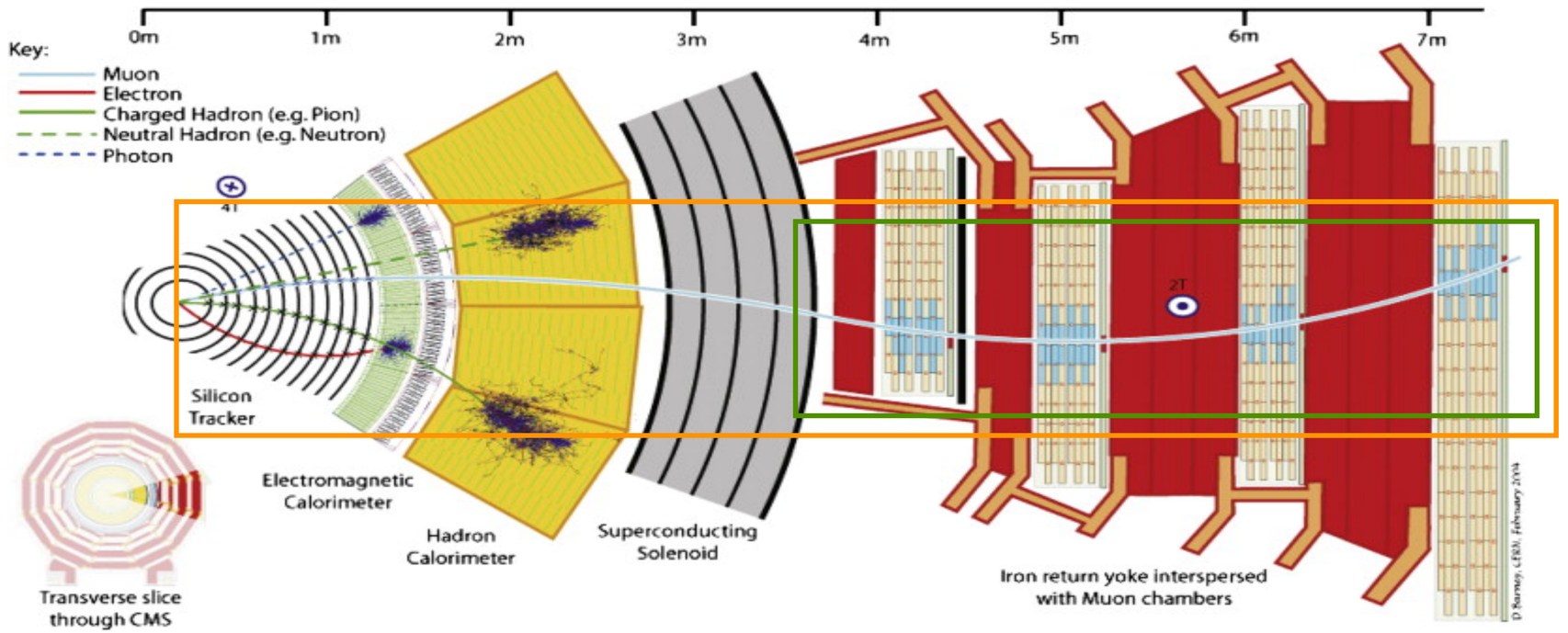
JINST 3 (2008) S08004



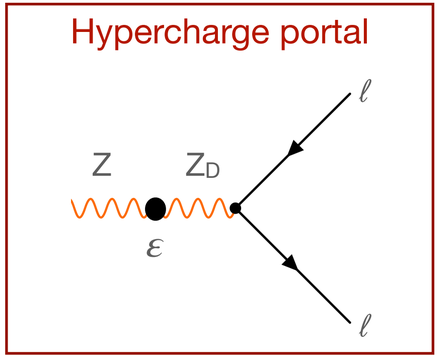
$$\eta = -ln \tan \frac{\theta}{2}$$

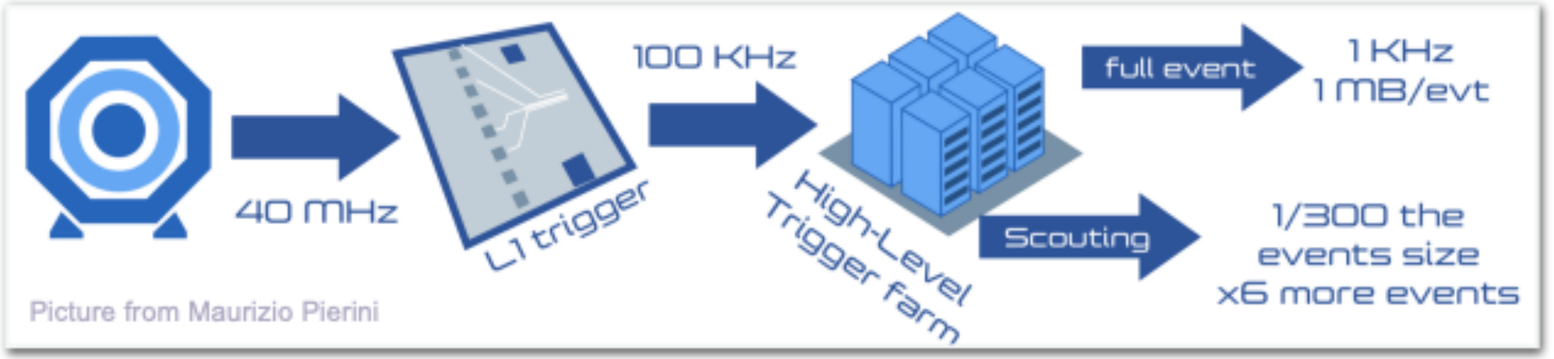


Particles' signature in CMS



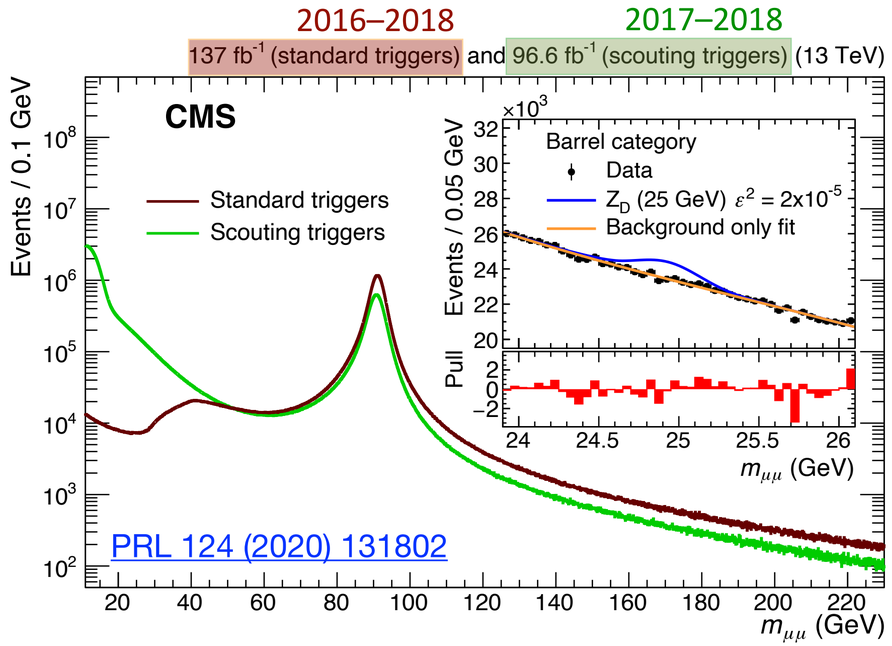
Prompt dark photon search





- *Scouting dimuon triggers*, deployed during LHC run 2 (2017–2018), requiring two muons with $p_T > 3$ GeV in an event, allowed to explore otherwise inaccessible 11.5 GeV < m_{ZD} < 45 GeV

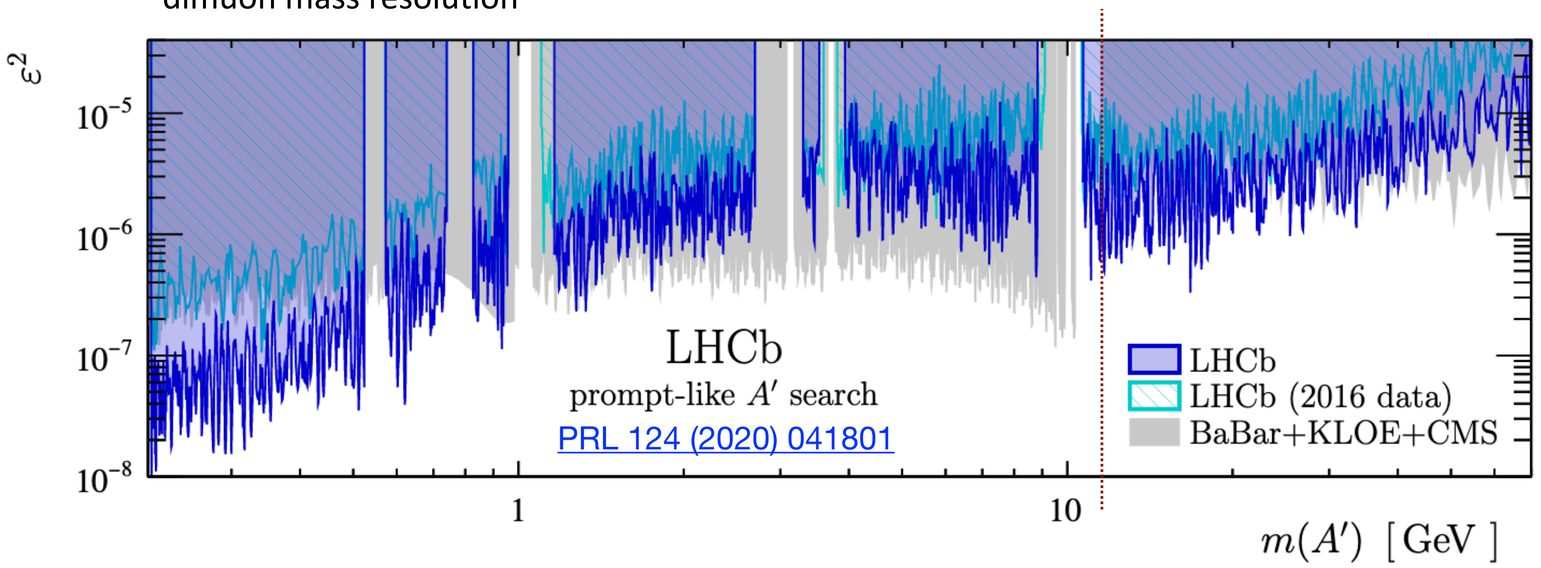
- For 45 GeV < m_{ZD} < 200 GeV, *standard dimuon triggers* (requiring two muons with $p_T > 17, 8$ GeV @ the HLT) data was analysed

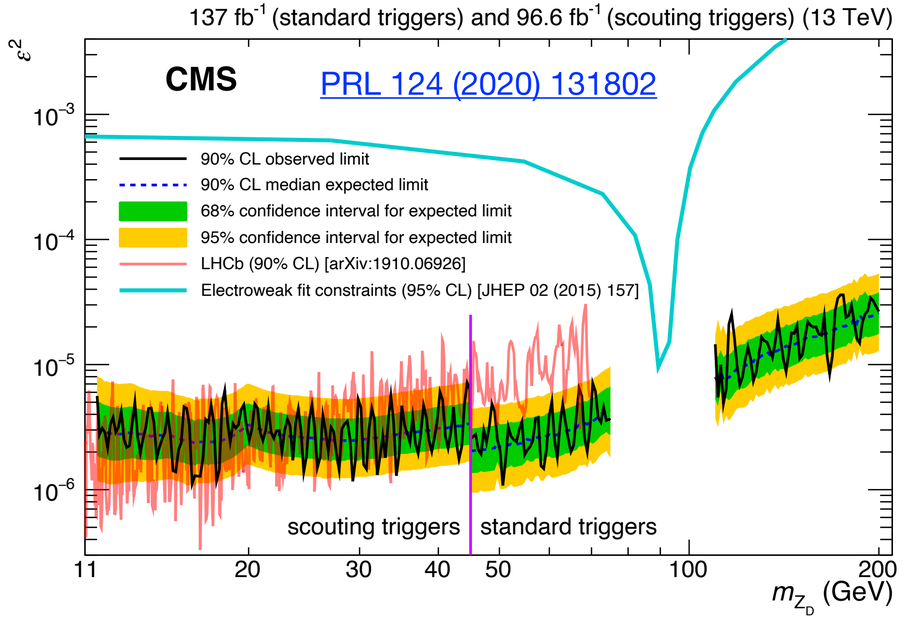


Prompt dark photon search

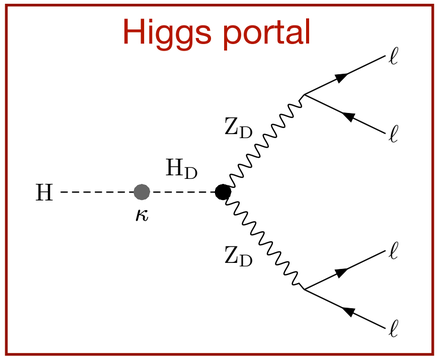
- **Search for a narrow resonance peak in dimuon mass spectrum**
  - Event selection: 2 identified and isolated opposite-charge muons
    - p_T > 4 GeV && $|\eta|$ < 1.9 (11.5 GeV < m_{ZD} < 45 GeV)
    - p_T > 20, 10 GeV && $|\eta|$ < 1.9 (45 GeV < m_{ZD} < 200 GeV)
  - Main backgrounds:
    - < Z peak: Drell-Yan, non-prompt muons and fake muons
    - > Z peak: Drell-Yan and ttbar
  - For a signal mass hypothesis, a simultaneous binned maximum likelihood fit is performed in a mass window of +-5(7)σ for scouting(standard) analysis to extract the signal, where σ is dimuon mass resolution

Most stringent constraints to date in the ~30–75 and 110–200 GeV mass ranges

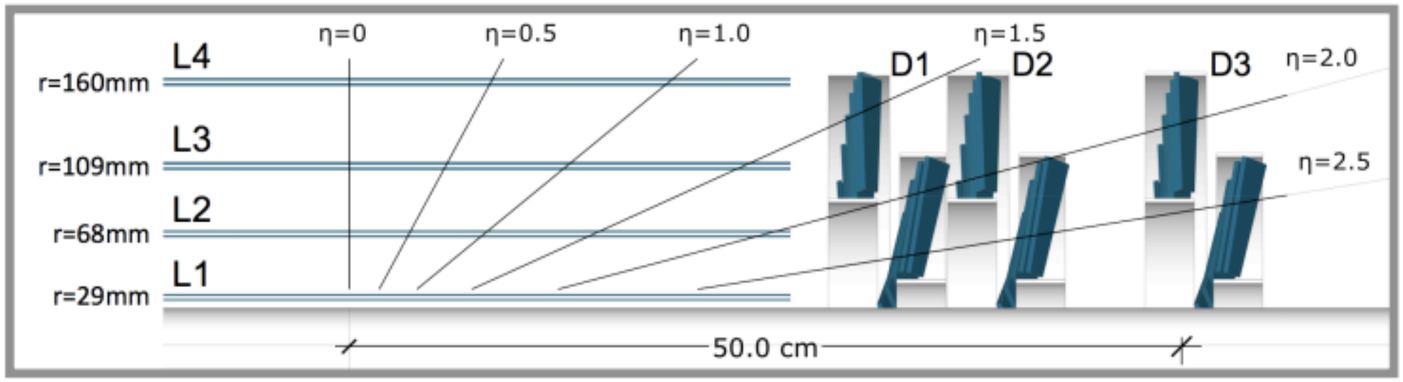




Long-lived dark photon search



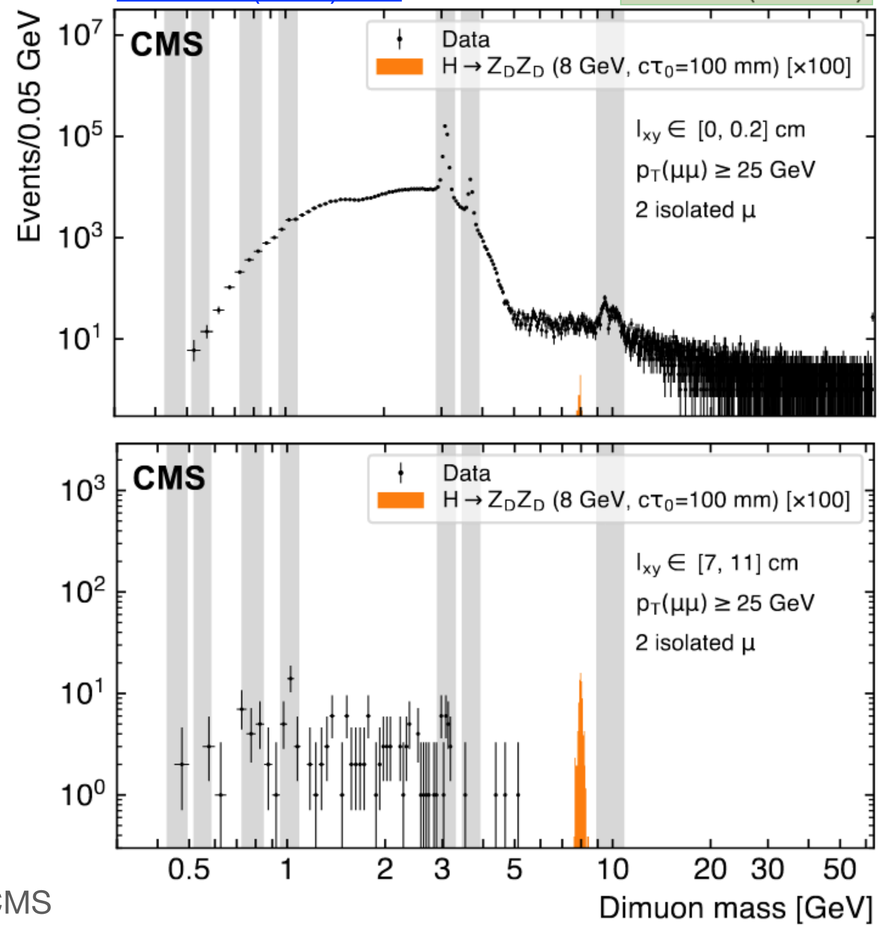
- **~200 MeV < m_{Z_D} < 50 GeV; transverse displacement l_{xy} < 11 cm (imposed by scouting triggers)**
- **Scouting dimuon triggers data only**
- **Search for a narrow resonance peak in dimuon mass spectrum**
  - Event selection: 2 identified and isolated opposite-charge muons
    - At least one pair of displaced muons (p_T > 10 GeV && $|\eta|$ < 2.4 && **>= 2 pixel-tracker hits**) forming a secondary vertex (SV)
  - Event categorisation:
    - l_{xy} bins **(0, 0.2**, 1, 2.4 ,3.1, **7, 11) cm**
    - $p_T^{\mu\mu}$: < 25 GeV or > 25 GeV
    - # isolated muons: 0, 1 or 2
  - For a signal mass hypothesis, a simultaneous binned maximum likelihood fit is performed in a mass window of +-5σ to extract the signal, where σ is dimuon mass resolution



2017–2018

JHEP 04 (2022) 062

101 fb^{-1} (13 TeV)



Long-lived dark photon search

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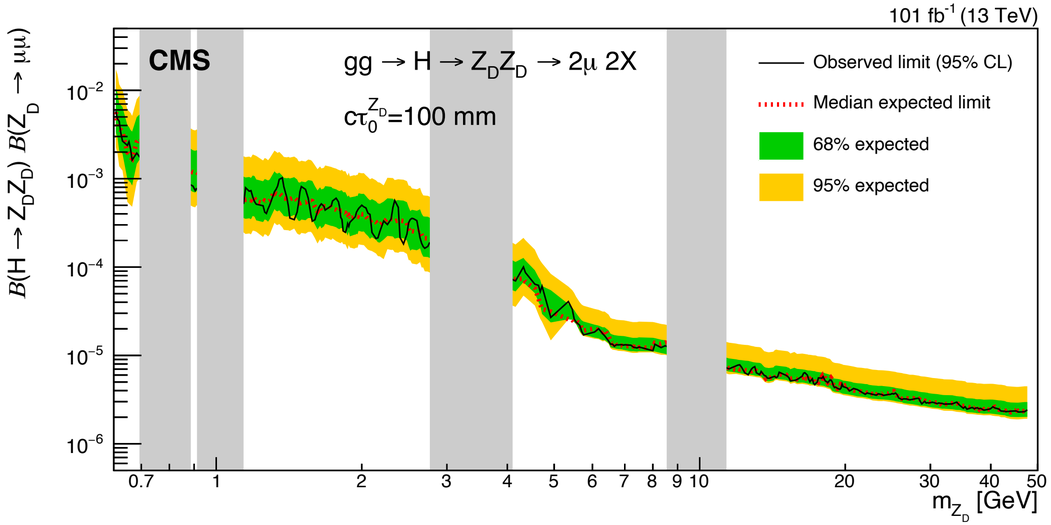
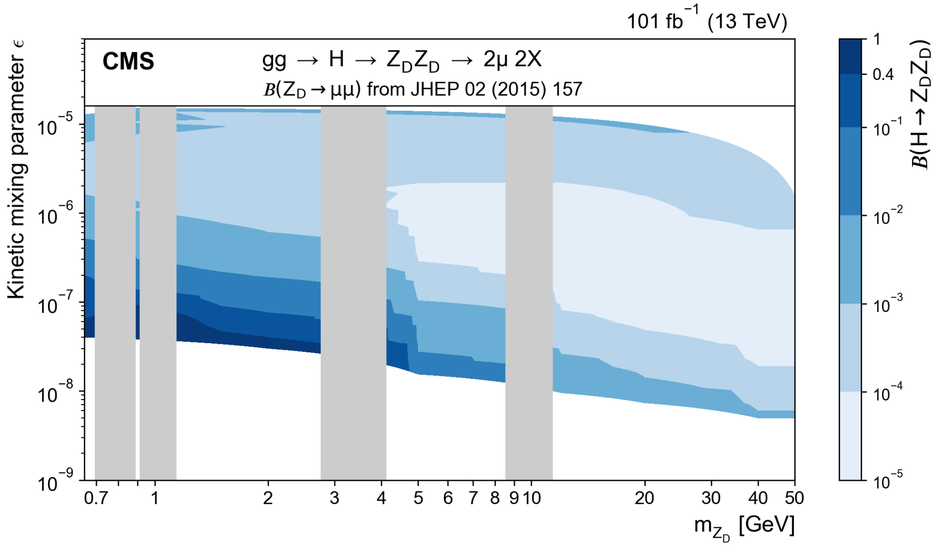
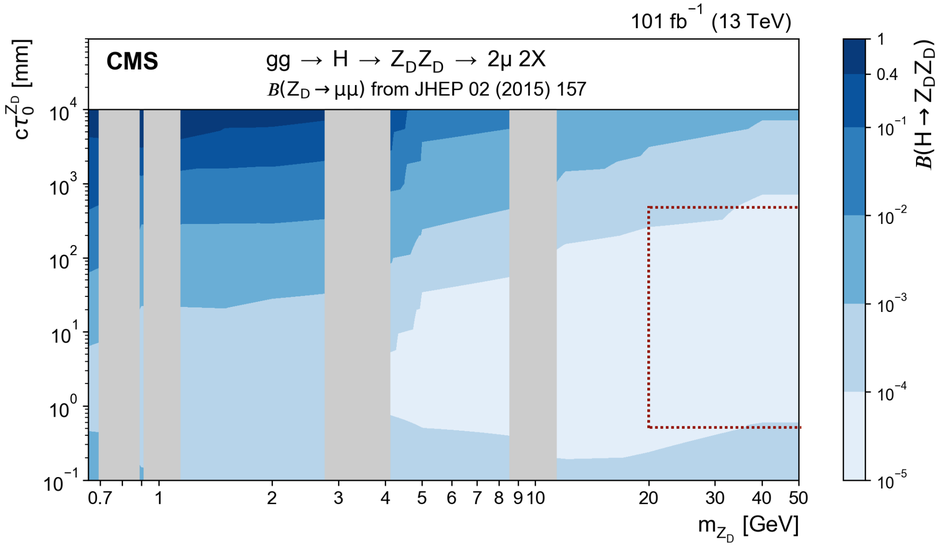
Most stringent constraints to date for substantial regions of the parameter space



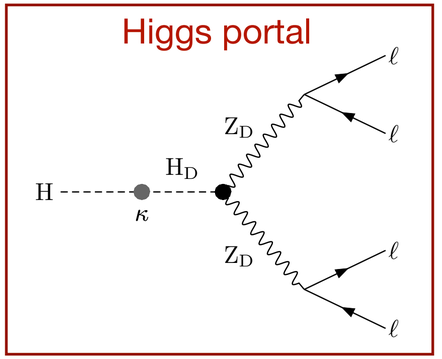


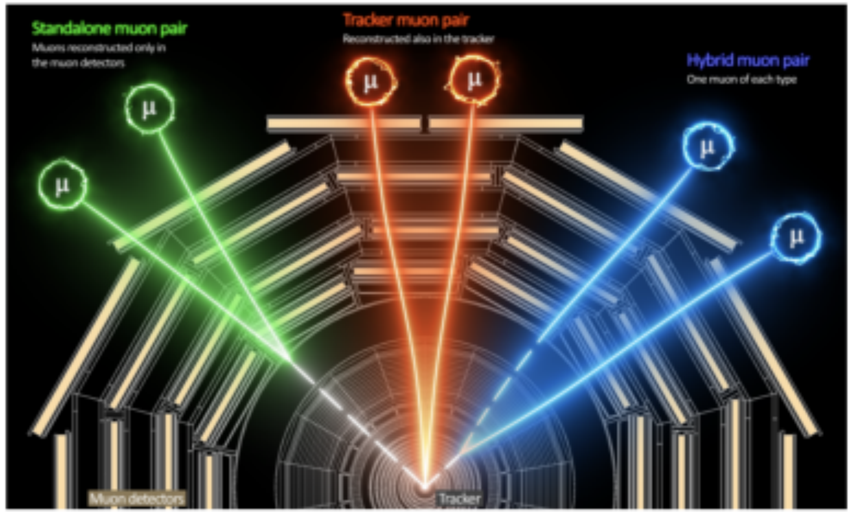


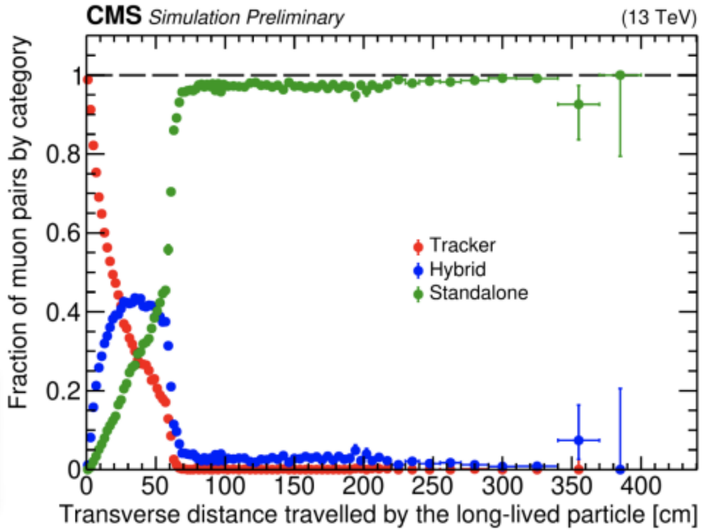
Very long-lived dark photon search

arXiv:2205.08582

- **$10 < m_{Z_D} < 60$ GeV; O(10^2 μm) < l_{xy} < several meters**
- **Standard dimuon trigger ($p_T > 28(23)$ GeV @ the HLT for 2016(2018)) data only (total luminosity = 97.6 fb^{-1})**
- **Search for excess of events in dimuon mass spectrum**
  - Event selection: 2 identified and isolated opposite-charge muons
    - At least one pair of displaced muons forming a SV
  - Event categorisation:
    - TMS-TMS, STA-STA, Hybrid pair
  - Main backgrounds:
    - Drell-Yan and QCD
  - Counting experiment to derive the exclusion upper limits

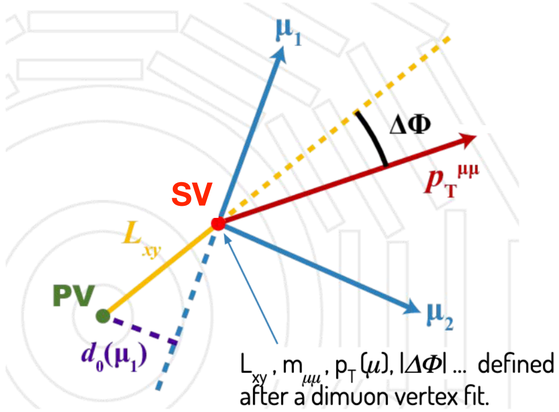


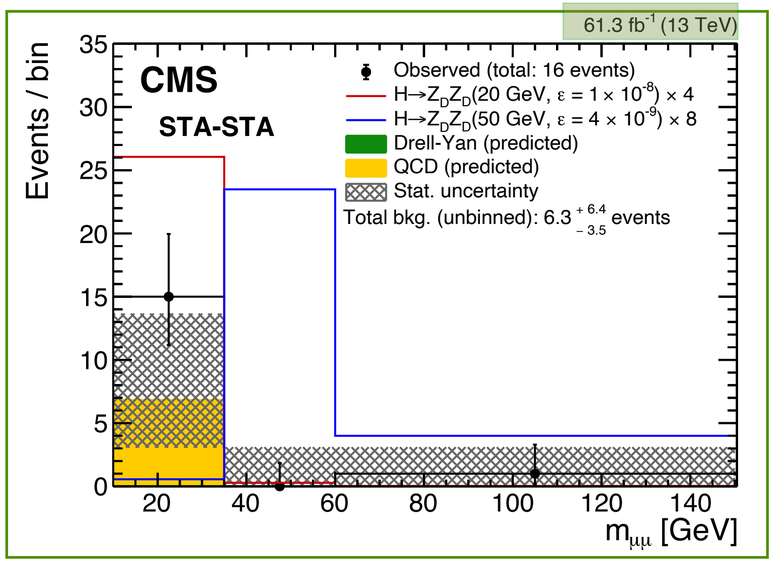


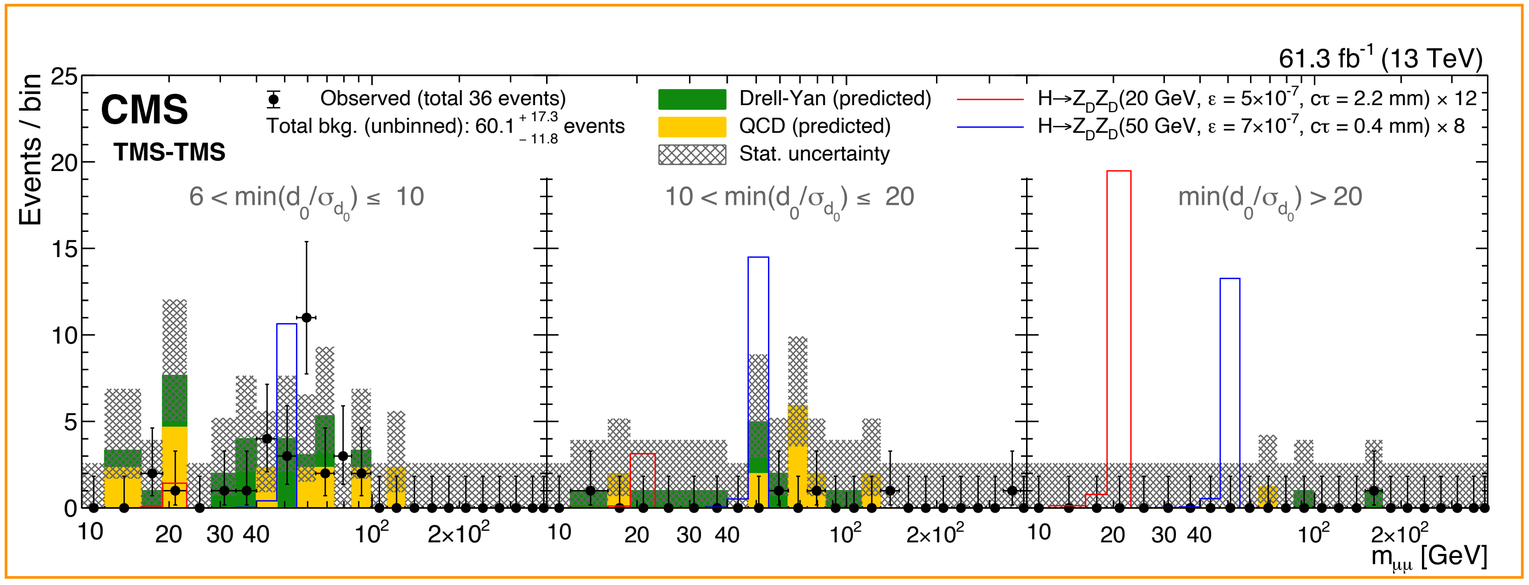


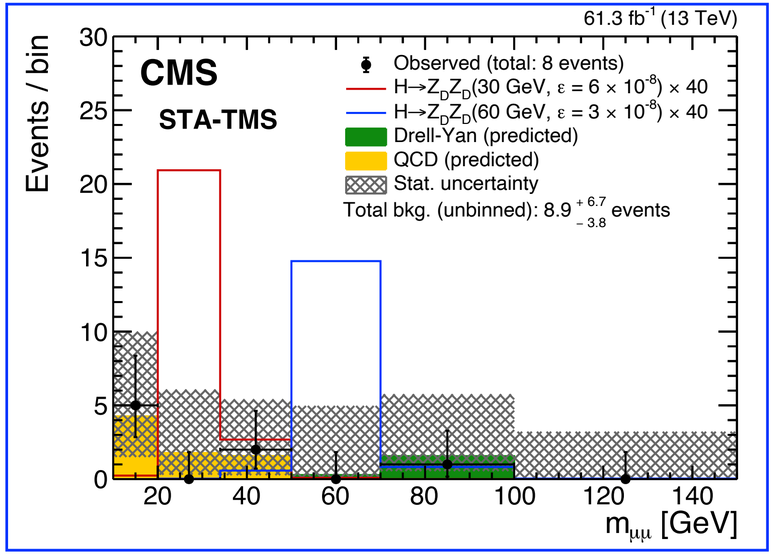
Very long-lived dark photon search

arXiv:2205.08582









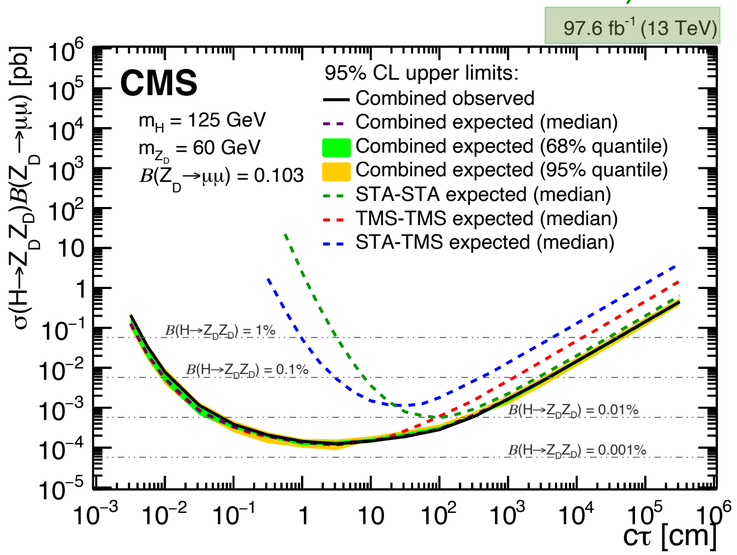
Very long-lived dark photon search

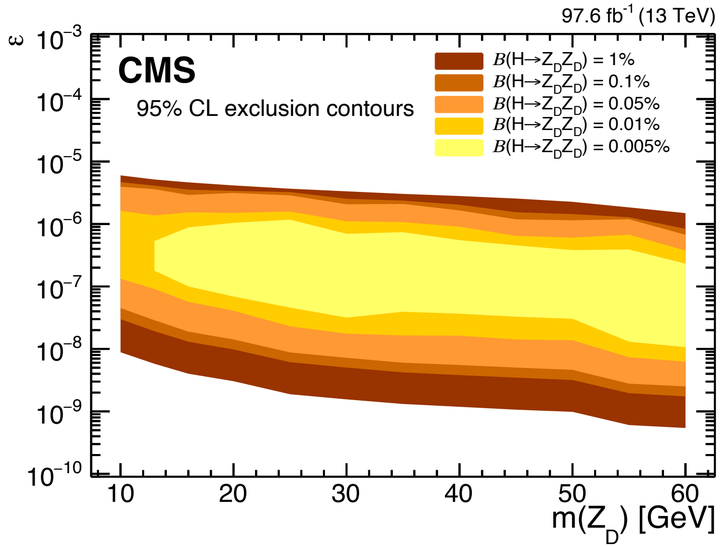
arXiv:2205.08582

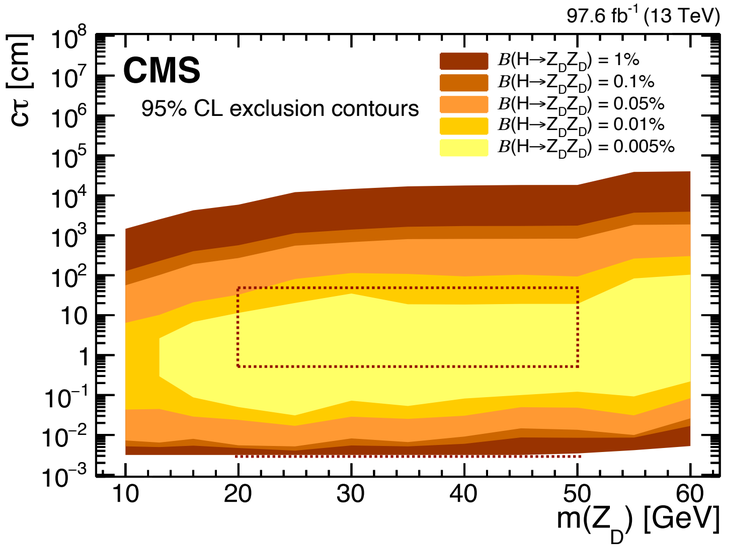
Most stringent constraints to date for

m_{ZD} > 20 GeV and cτ = 0.003–0.05 cm and >50 cm

2016, 2018







Summary

- **Z_D could serve as a mediator between SM and the dark sector [JHEP 02 (2015) 157]**
- Z_D can be performed at the LHC exploiting $Z_D \rightarrow 2\mu$ (hypercharge portal) and $H \rightarrow Z_D Z_D \rightarrow 4\mu$ (Higgs portal) events
- CMS deployed dedicated high-rate dimuon triggers (decreased event size) during LHC run 2 to explore $m_{ZD} <$ 45 GeV
- Several dark photon searches with CMS have been discussed today
  - Prompt search: 11.5 GeV $< m_{ZD} <$ 45 GeV and 45 GeV $< m_{ZD} <$ 200 GeV [PRL 124 (2020) 131802]
  - Long-lived search: $l_{xy} <$ 11 cm; ~200 MeV $< m_{ZD} <$ 50 GeV [JHEP 04 (2022) 062]
  - Very long-lived search: l_{xy} up to several meters; 10 $< m_{ZD} <$ 60 GeV [arXiv:2205.08582]
- No significant excess of events has been observed beyond the standard model expectation
- **These searches place most stringent constraints to date for substantial regions of the [m_{ZD}, ε^2] and [m_{ZD}, $c\tau$] parameter spaces**

Backup slides

Z_D branching ratio

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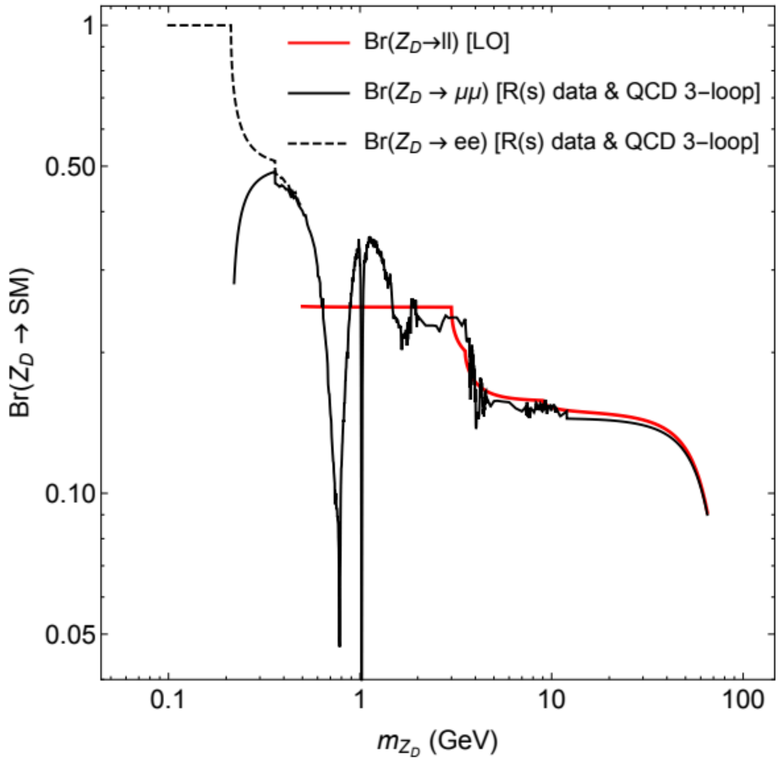

Z_D decay length

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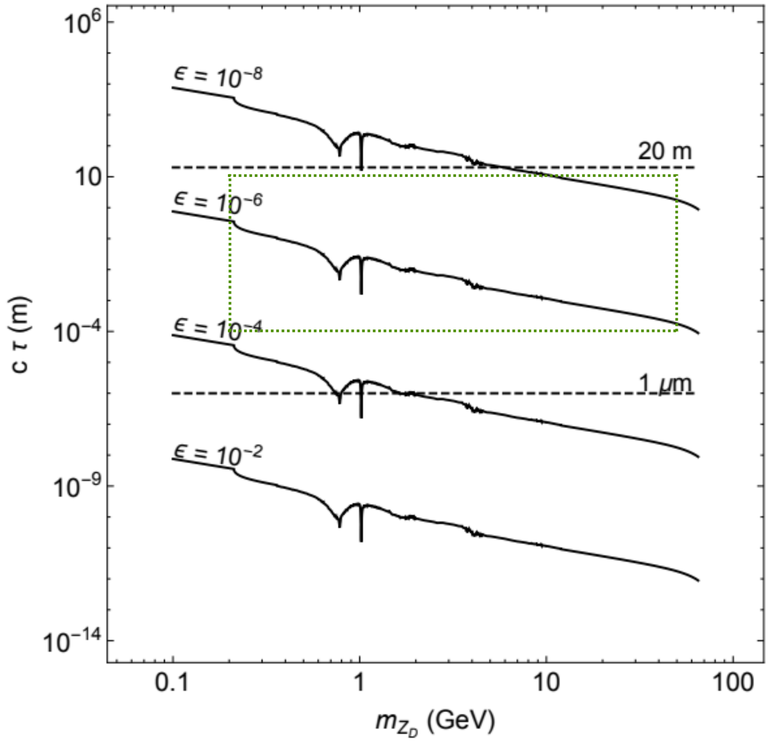
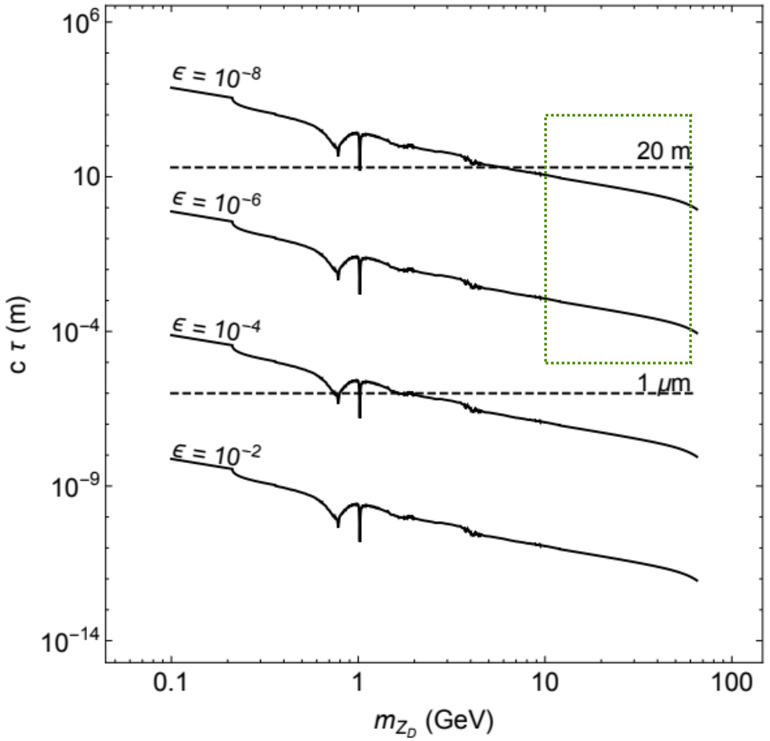
Long-lived Z_D



Very long-lived Z_D



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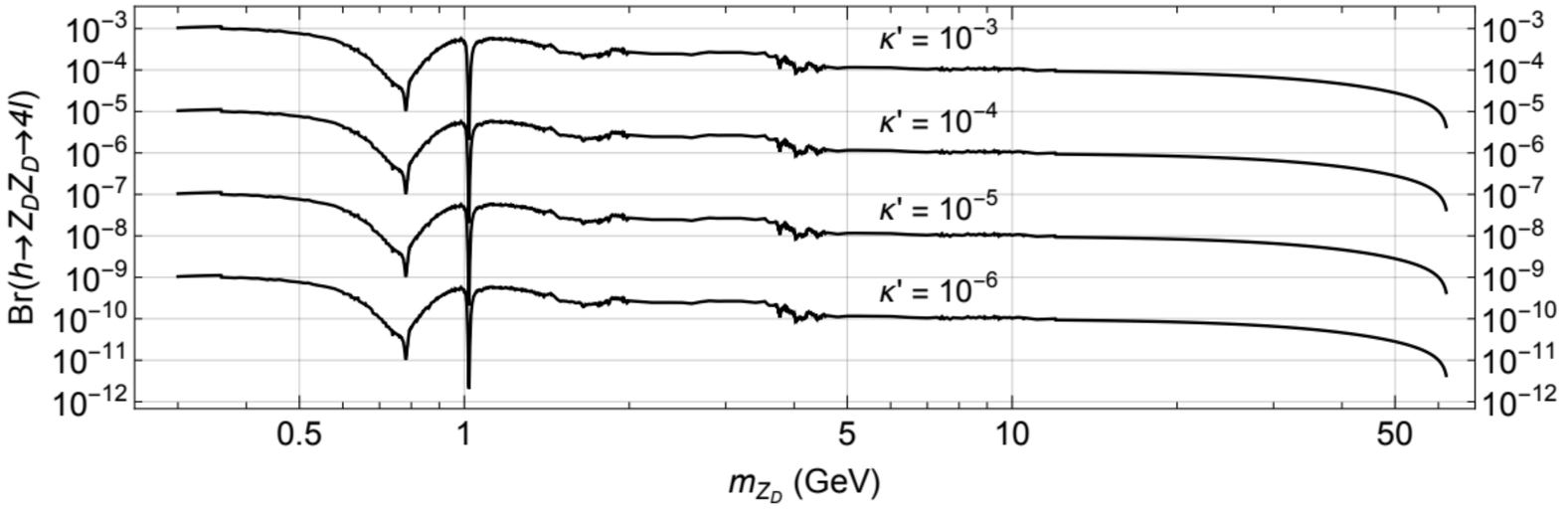
Z_D decay length



Scouting dimuon triggers' data