$Z_D \rightarrow$ prompt dimuon search with CMS Run-2 data (13 TeV; 2016-2018)
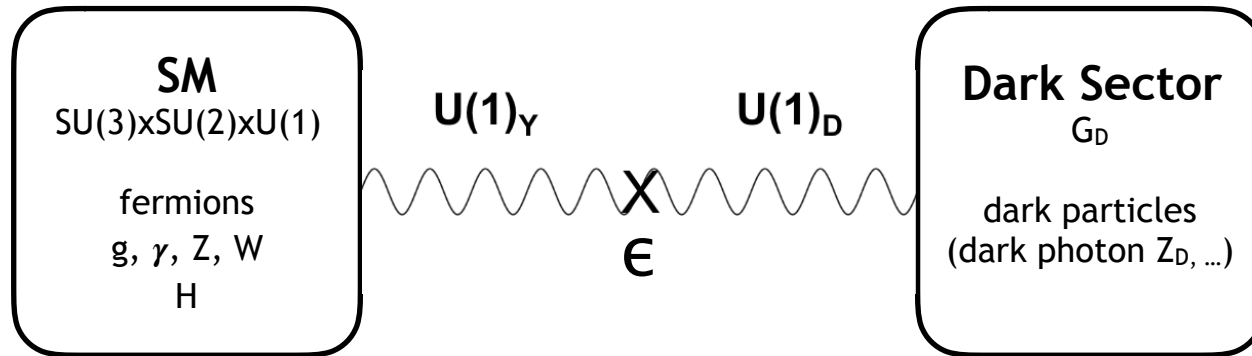
Simranjit Singh Chhibra (VUB)
On behalf of the CMS collaboration

Theoretical motivation

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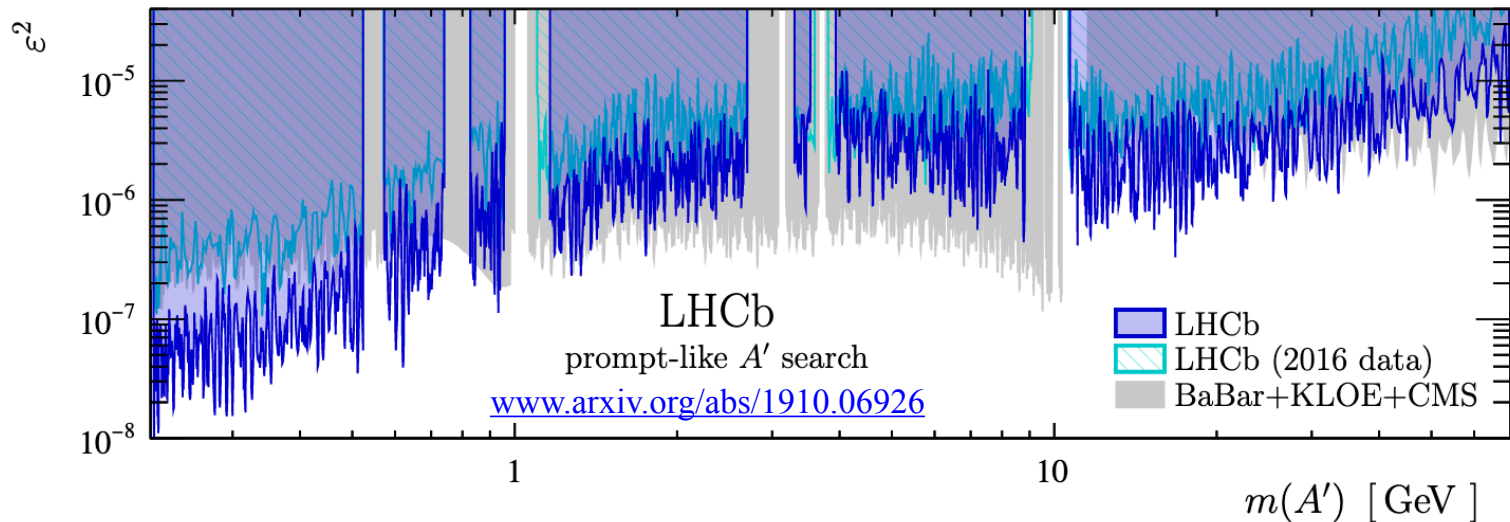
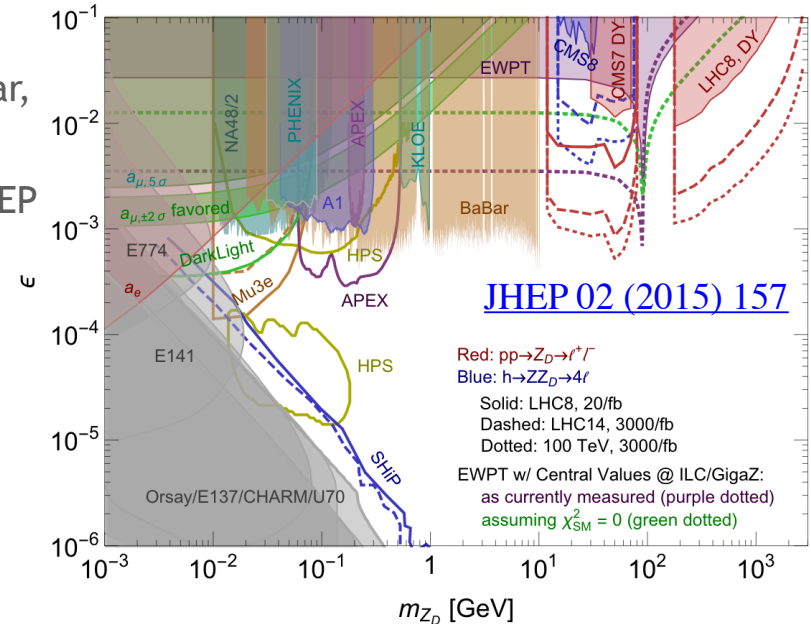**Kinetic-mixing term**

- Like the photon of electromagnetism, dark photon (Z_D) mediates an interaction, arising from a U(1)$_D$ gauge symmetry, between particles of 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, ∝ kinetic-mixing coefficient (ε)
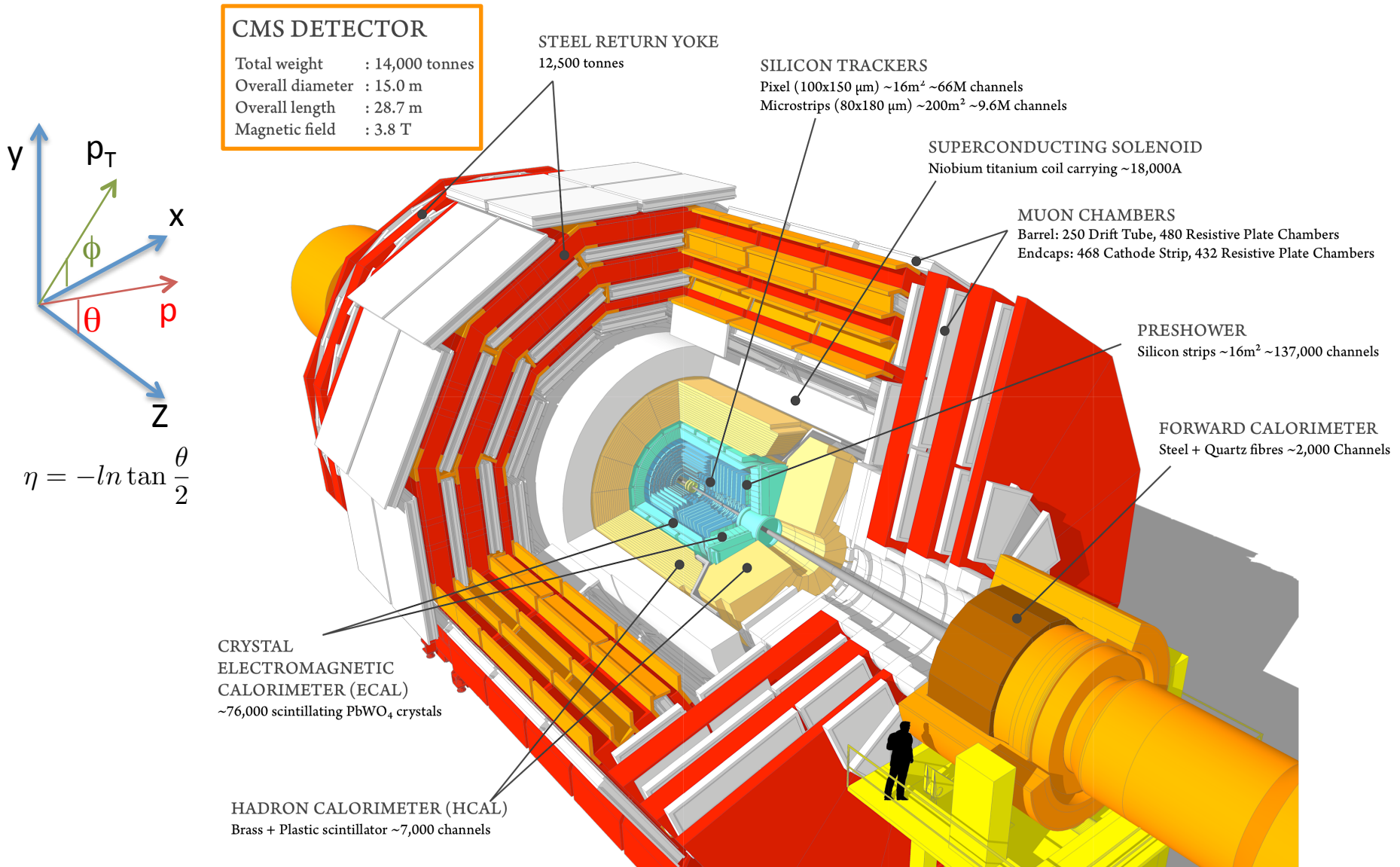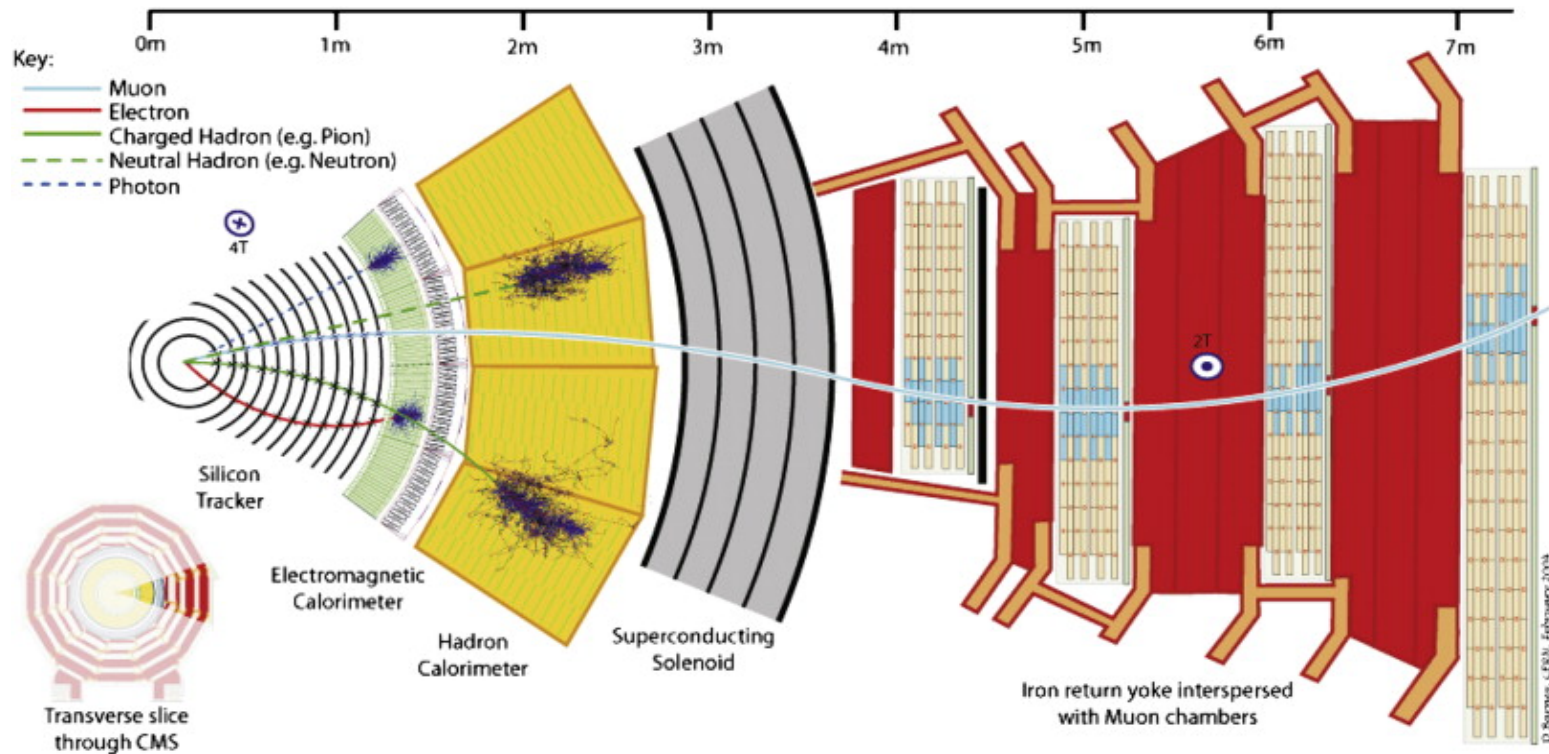
Experimental status

- **Exclusion limits in [m_{ZD}, $\varepsilon(\varepsilon^2)$] parameter space**

- **[0.02, 10.2] GeV:** BaBar has put the strongest limits so far, $\varepsilon \sim 10^{-3}$

- **> 10 GeV:** $\varepsilon \sim 3\times10^{-2}$ from the EWPT measurements from LEP

- **[0.2, 70] GeV:** $\varepsilon^2 \sim 10^{-6}$—$10^{-5}$ from LHCb

- CMS high-mass resonance (Z′) search in dilepton decay channel covers masses > 200 GeV (CMS-PAS-EXO-19-019)

- **CMS has performed the dark photon search in prompt Dimuon channel, in mass range of [11.5, 200] GeV (omitting the Z boson resonance in [75, 110] GeV)**

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Red: $pp \to Z_D \to \ell^+\ell^-$
Blue: $h \to ZZ_D \to 4\ell$
  Solid: LHC8, 20/fb
  Dashed: LHC14, 3000/fb
  Dotted: 100 TeV, 3000/fb
EWPT w/ Central Values @ ILC/GigaZ:
  as currently measured (purple dotted)
  assuming $\chi^2_{SM} = 0$ (green dotted)

LHCb
prompt-like A' search
www.arxiv.org/abs/1910.06926

LHCb
LHCb (2016 data)
BaBar+KLOE+CMS

The CMS experiment

CMS DETECTOR

Total weight	: 14,000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating PbWO$_4$ crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

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

Particles' signature in CMS

Key:
- Muon
- Electron
- Charged Hadron (e.g. Pion)
- Neutral Hadron (e.g. Neutron)
- Photon

4T

Silicon Tracker

Electromagnetic Calorimeter

Hadron Calorimeter

Superconducting Solenoid

2T

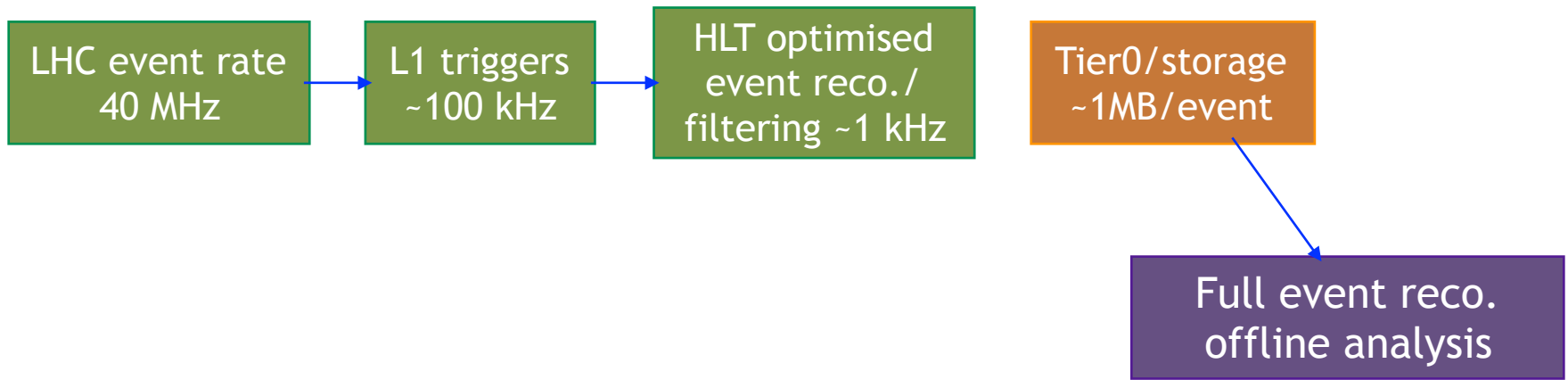Iron return yoke interspersed with Muon chambers
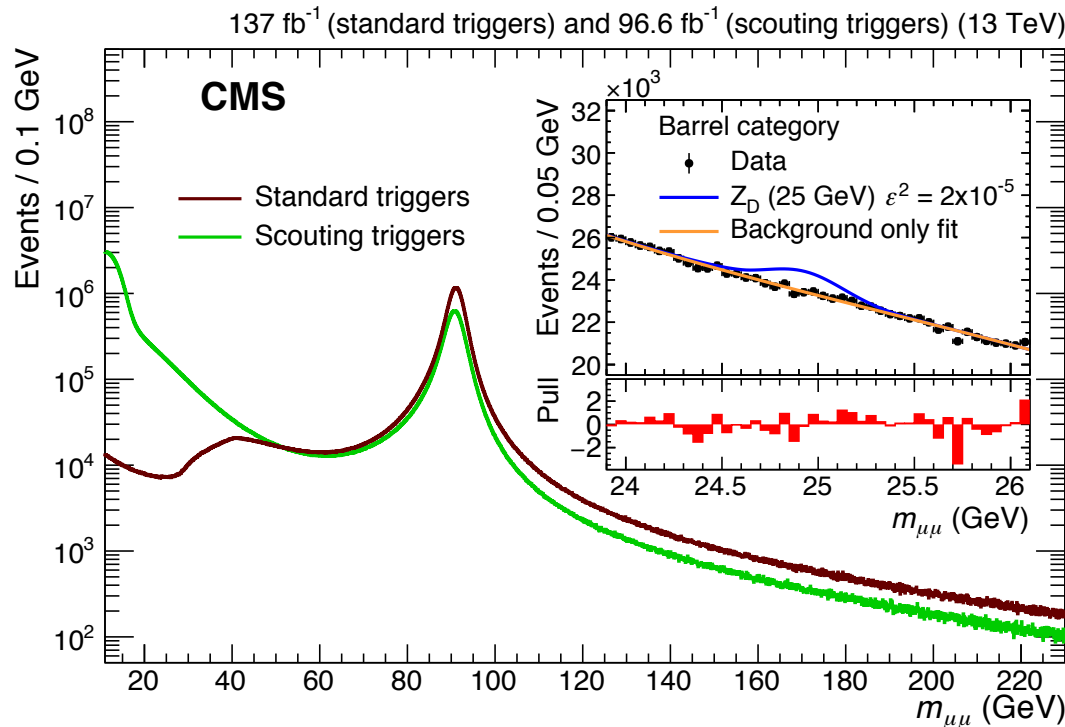
Transverse slice through CMS

The CMS trigger system

- Two-step process to select events of physics interest (event size ~1 MB)
    - Hardware-based Level-1 triggers (L1)
        - Uses information from calorimeters and muon system → 40 MHz to 100 kHz
    - Software-based high-level triggers (HLT)
        - Run an optimised version of full event reconstruction → 100 kHz to ~1 kHz
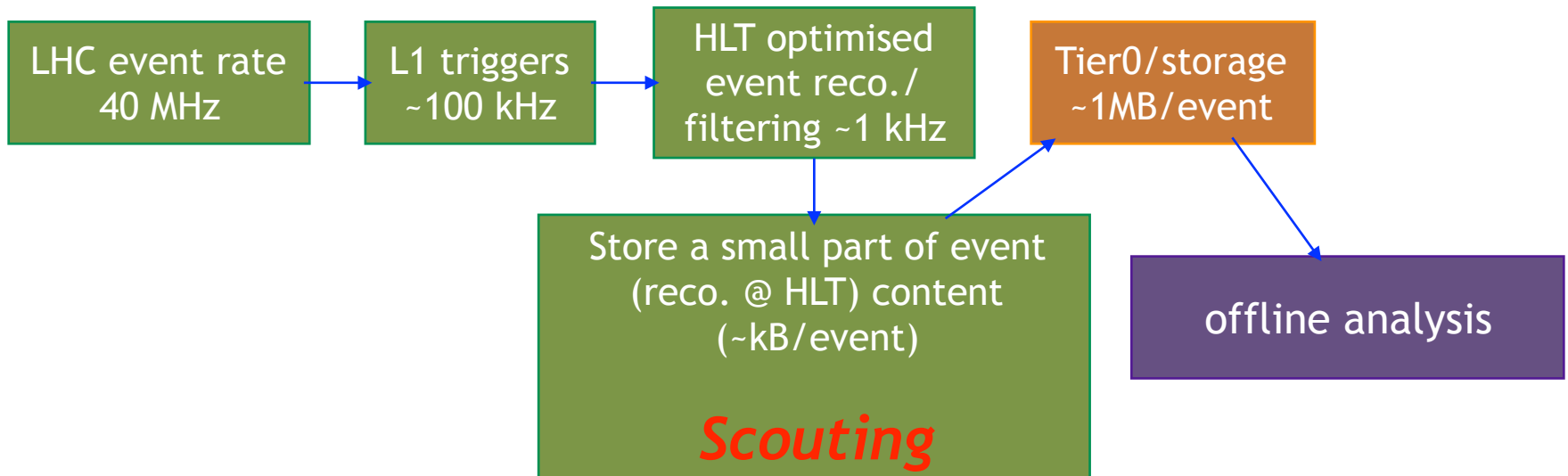
| LHC event rate 40 MHz | → | L1 triggers ~100 kHz | → | HLT optimised event reco./ filtering ~1 kHz | | Tier0/storage ~1MB/event |

Full event reco. offline analysis

The CMS trigger system

- Two-step process to select events of physics interest (event size ~1 MB)
  - Hardware-based Level-1 triggers (L1)
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  - Software-based high-level triggers (HLT)
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- Dimuon HLTs require to have two muons in an event with pt > 17 and 8 GeV
  - Rate ~30 Hz @ peak luminosity of 2×10^{34} $cm^{-2}s^{-1}$
 - Loss of events for masses below ~40 GeV

Scouting dimuon triggers during Run 2

- Two-step process to select events of physics interest (event size ~1 MB)
  - Hardware-based Level-1 triggers (L1)
    - Uses information from calorimeters and muon system → 40 MHz to 100 kHz
  - Software-based high-level triggers (HLT)
    - Run an optimised version of full event reconstruction → 100 kHz to ~1 kHz
- Dimuon HLTs require to have two muons in an event with pt > 17 and 8 GeV
  - Rate ~30 Hz @ peak luminosity of 2×10^{34} cm^{-2}s^{-1}
  - Loss of events for masses below ~40 GeV
- A dedicated set of *scouting* dimuon triggers were implemented during Run 2 with pt > 3 GeV for the two muons
  - Store limited muon information only reconstructed at HLT → ~4-8 kB/event
  - Rate ~2000 Hz @ peak luminosity of 2×10^{34} cm^{-2}s^{-1}


```
LHC event rate        L1 triggers        HLT optimised            Tier0/storage
40 MHz            →    ~100 kHz      →    event reco./        →    ~1MB/event
                                          filtering ~1 kHz
                                                ↓                        ↑           ↘
                                          Store a small part of event          offline analysis
                                          (reco. @ HLT) content
                                          (~kB/event)

                                                Scouting
```

Dimuon invariant mass spectrum
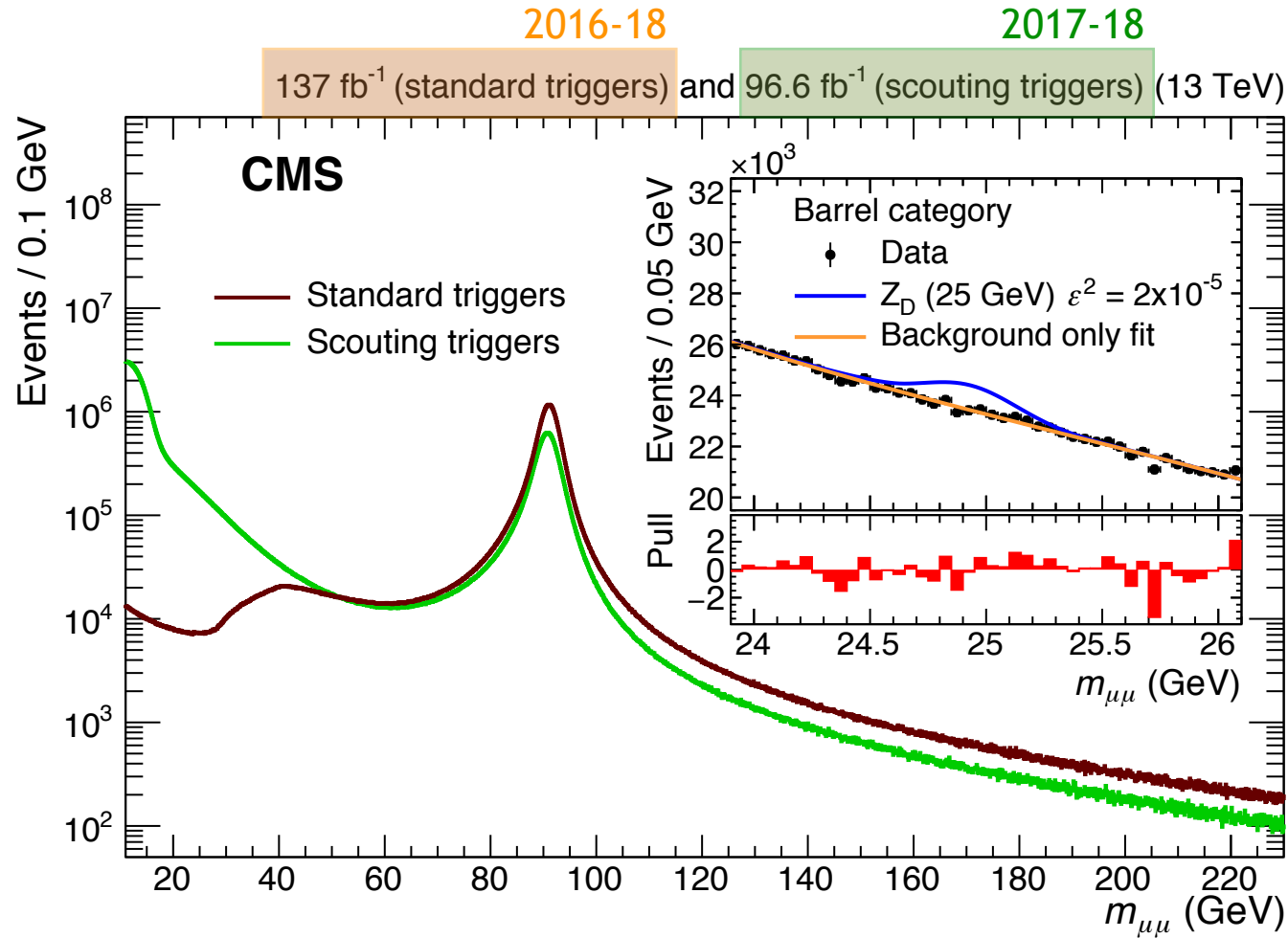
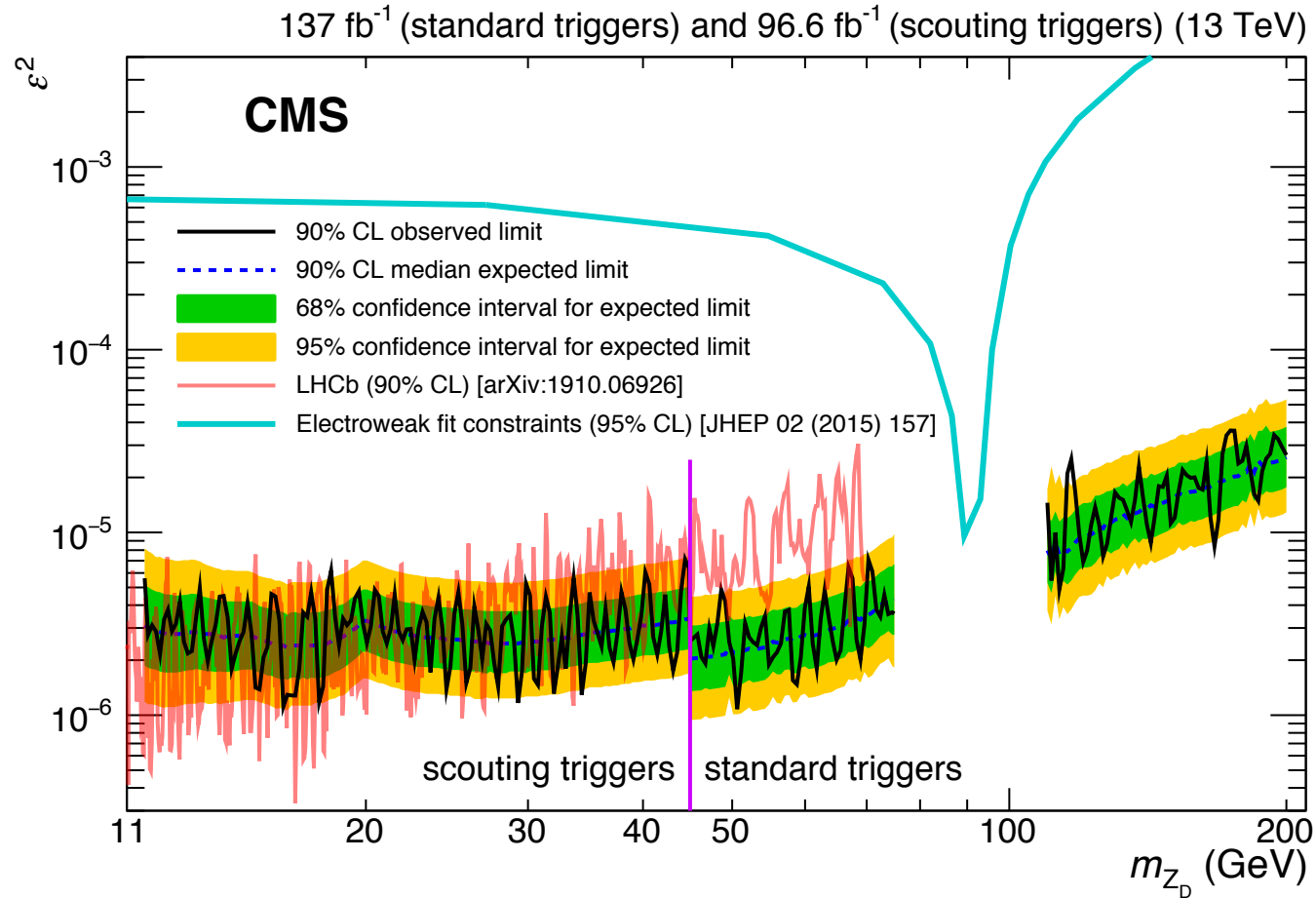# Search strategy

- It's a classic bump-hunt in the dimuon mass spectrum
  - Low mass (< Z peak): DY, non-prompt muons and fakes
  - High mass (> Z peak): DY and ttbar

- Standard event analysis: 2 muon with pt > 20 and 10 GeV, $|\eta|$ < 1.9
- Scouting event selection: 2 muon with pt > 4 GeV, $|\eta|$ < 1.9

- Signal and background event yields and shapes are obtained from simulation and data, respectively
  - Signal shape: double-sided Crystal Ball function
  - Background shapes:
    - Standard: 4th order Bernstein polynomial
    - Scouting: modified Breit–Wigner function x 2nd order Bernstein polynomial

- For a given mass hypothesis, in order to extract the signal from data, a signal plus background fit is performed to the dimuon mass distribution (in +-5(7)σ mass window for scouting(standard) analysis)
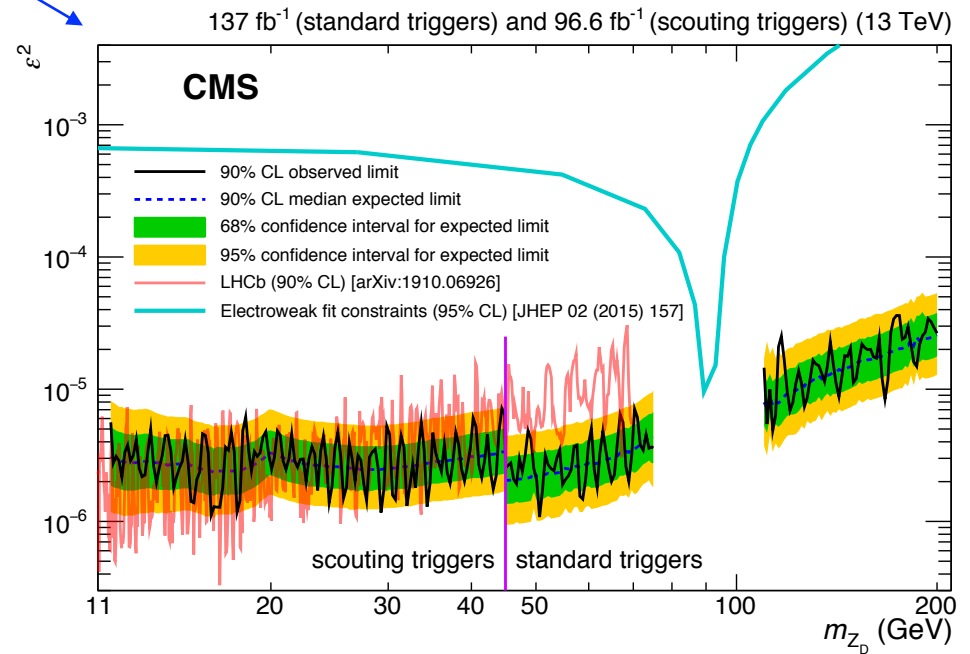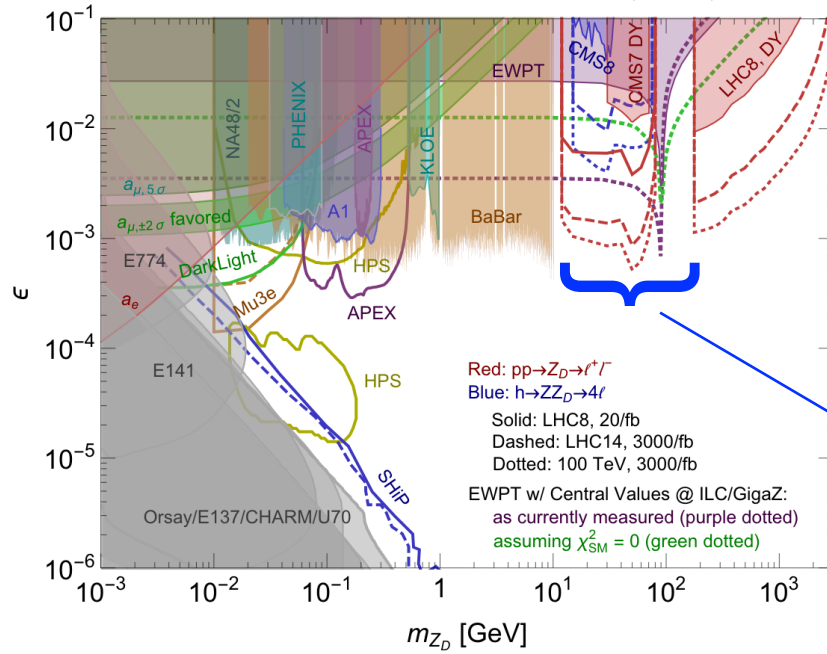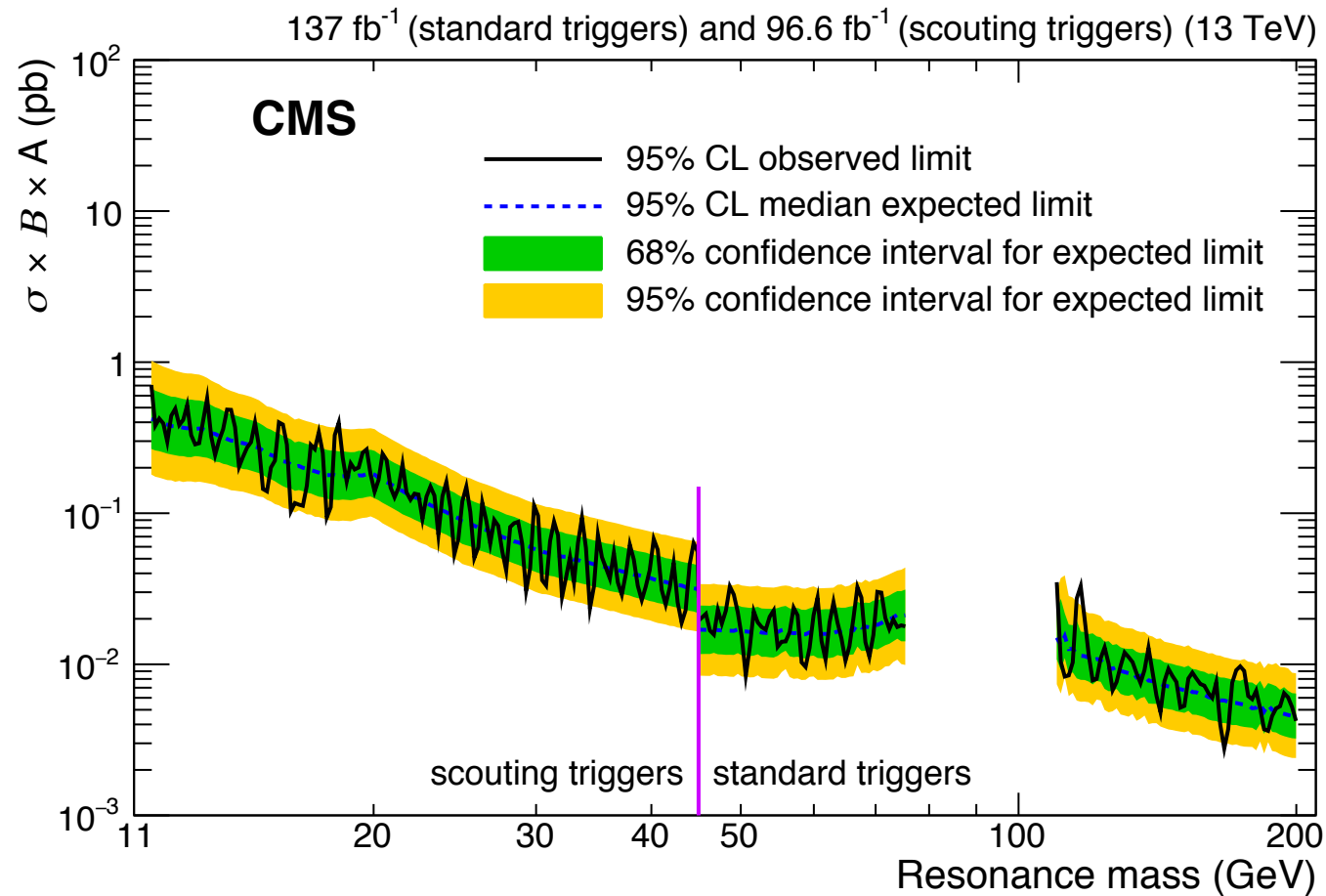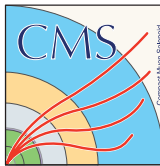
Exclusion upper limits

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

CMS

- 90% CL observed limit
- 90% CL median expected limit
- 68% confidence interval for expected limit
- 95% confidence interval for expected limit
- LHCb (90% CL) [arXiv:1910.06926]
- Electroweak fit constraints (95% CL) [JHEP 02 (2015) 157]

scouting triggers | standard triggers

ε^2

m_{Z_D} (GeV)

Exclusion upper limits

Model-independent exclusion upper limits

137 fb⁻¹ (standard triggers) and 96.6 fb⁻¹ (scouting triggers) (13 TeV)

CMS

- 95% CL observed limit
- 95% CL median expected limit
- 68% confidence interval for expected limit
- 95% confidence interval for expected limit

scouting triggers | standard triggers

$\sigma \times B \times A$ (pb)

Resonance mass (GeV)

Summary

- A search for Z_D in prompt dimuon decay channel has been performed with CMS Run-2 data
  - 137(96.6) fb-1 data collected with standard(scouting) dimuon triggers
  - [11.5, 200] GeV mass range (omitting Z peak)

- First search of its kind in CMS (also in ATLAS)

- No significant resonant peaks are observed in the probed mass ranges

- Exclusion upper limits are derived in [m_{ZD}, ε^2] parameter space, and compared with other searches
  - For masses < 30 GeV, the limits are **among the most strongest limits till date**
  - For masses > 30 GeV, the **word's strongest limits till date**

- *Submitted to PRL: https://arxiv.org/abs/1912.04776*

Backup

Dark photon BR and lifetime
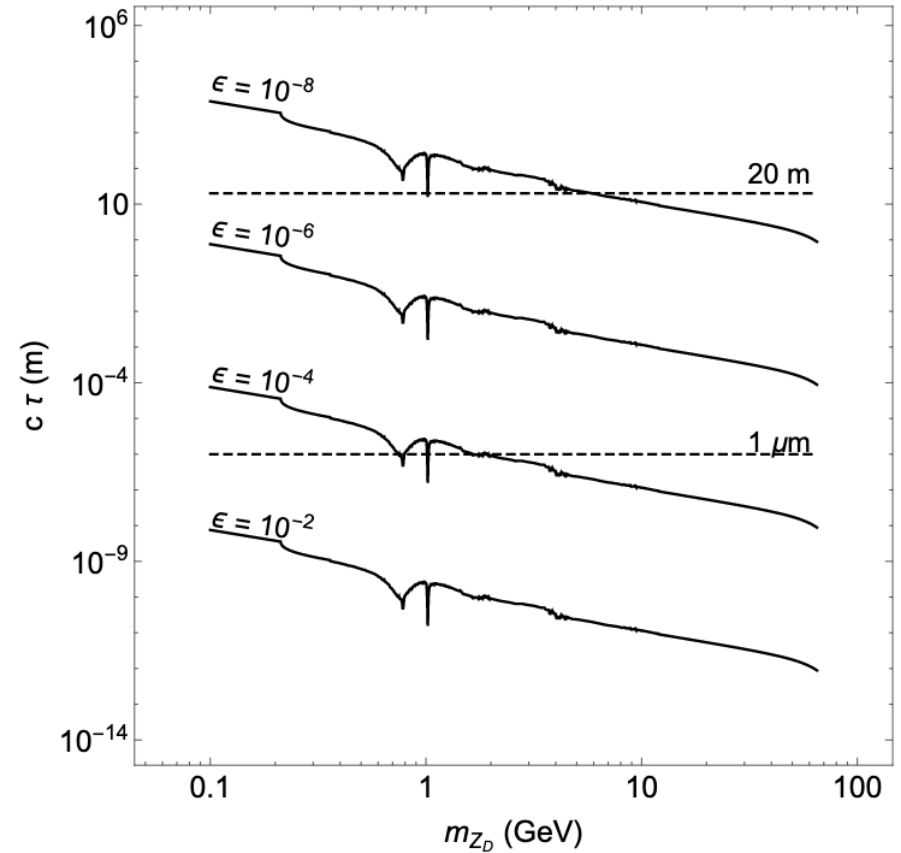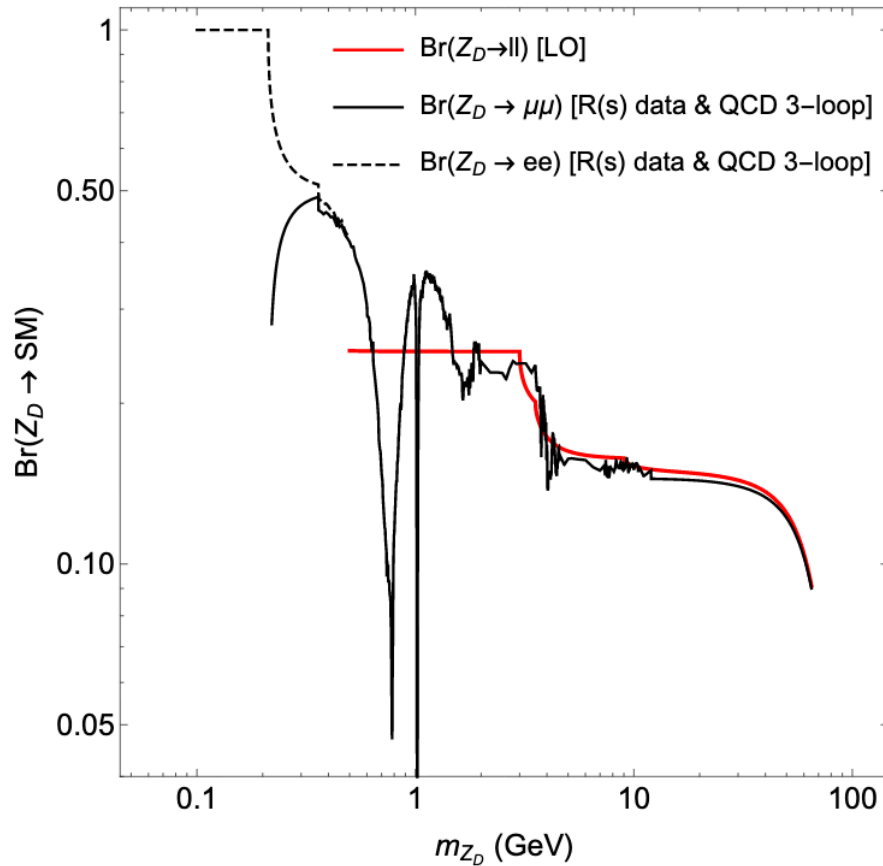
Scouting dimuon data collected in 2017