Search for dark photon in four-lepton events via rare Z decay with the ATLAS detector

CLHCP-2021 Poster

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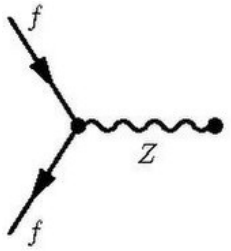
Dark photon: introduction

Motivation

- Important candidate for the dark sector
- Hidden sector couplings and mass generation mechanisms

Gauge boson from $U(1)_D$ couples to Z by kinetic mixing ε
Whose mass generated from Dark Higgs h_D

$$\mathcal{L}_{int} \subset -\frac{1}{4}\widehat{B}_{\mu\nu}\widehat{B}^{\mu\nu} - \frac{1}{4}\widehat{Z}_{D\mu\nu}\widehat{Z}_D^{\mu\nu} + \frac{1}{2}\frac{\varepsilon}{cos\theta_W}\widehat{Z}_{D\mu\nu}\widehat{B}^{\mu\nu} + \frac{1}{2}m_{D,0}^2\widehat{Z}_D^{\mu}\widehat{Z}_{D\mu}$$



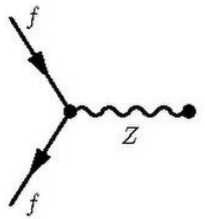
SM EW couplings

$$Z_\mu \to Z_\mu - (\theta_Z + \varepsilon tan\theta_W)A'_\mu$$

$$A'_\mu \to A'_\mu + \theta_Z Z_\mu$$

$$A_\mu \to A_\mu + \varepsilon A'_\mu$$

$$\theta_Z = -\frac{\varepsilon tan\theta_W m_Z^2}{m_Z^2 - m_{A'}^2}$$



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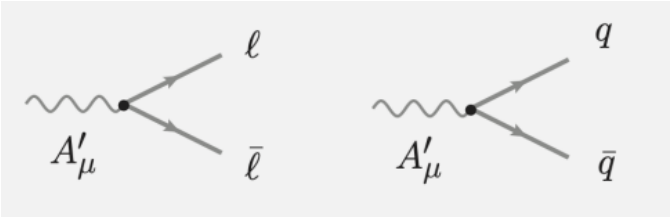


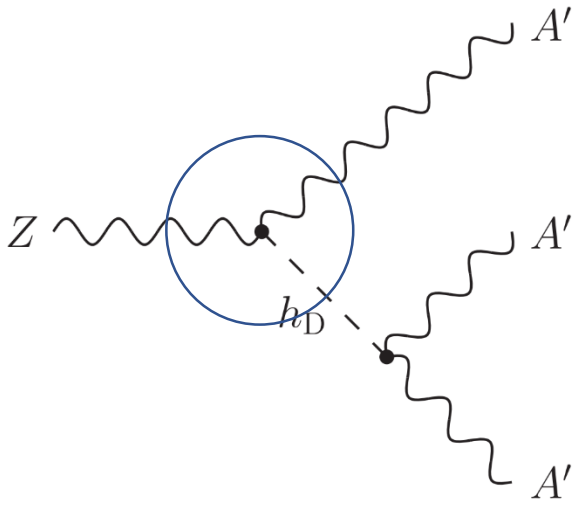
Enable interactions between A' and SM

Introduction: Benchmark model

A new kind of rare Z decay mode: $Z \rightarrow A' h_D$ (h_D is the dark Higgs)

Assumptions:
(Minimal kinetically mixed)

- Br ($h_D \rightarrow A'\ A'$) = 100%
- A' is the lightest BSM particle
- Br ($A' \rightarrow SM\ f\ \bar{f}$) = 100%



$$|\partial_\mu h_D - ie_D A'_\mu h_D|^2$$

$$\mathcal{L}_{int} = g_{h_D A' Z} h_D A'_\mu Z^\mu$$

$$g_{h_D A' Z} \sim 2 e_D \theta_Z cos\theta_h m_{A'}$$

Parameters			
ε	α_D	$M_{A'}$	M_{hD}

Decay rate for $Z \rightarrow A' + h_D \propto \alpha_D \varepsilon^2$

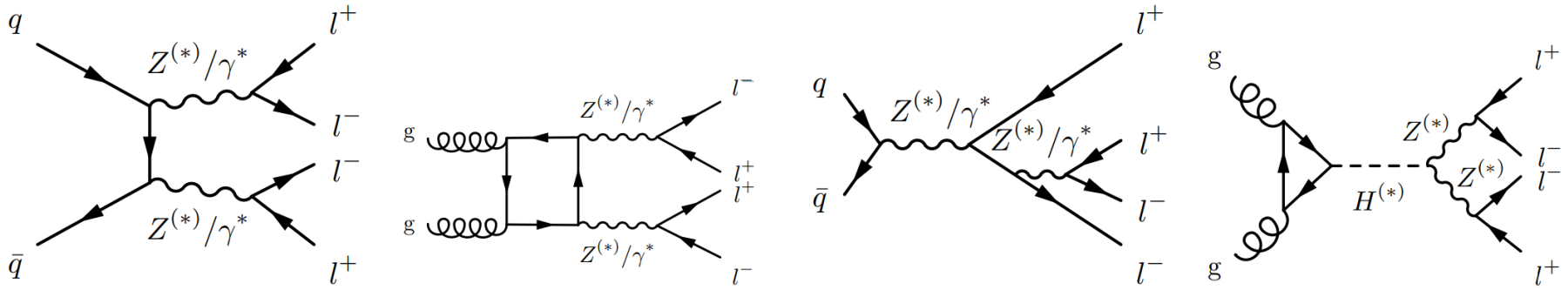
Focusing on the on-shell cases:
$M_{A'}$ (10 ~ 40 GeV) < M_{hD} (20 ~ 70 GeV)

Signal: 4l (e/μ, decayed from **on shell** A's) + X

SM Backgrounds

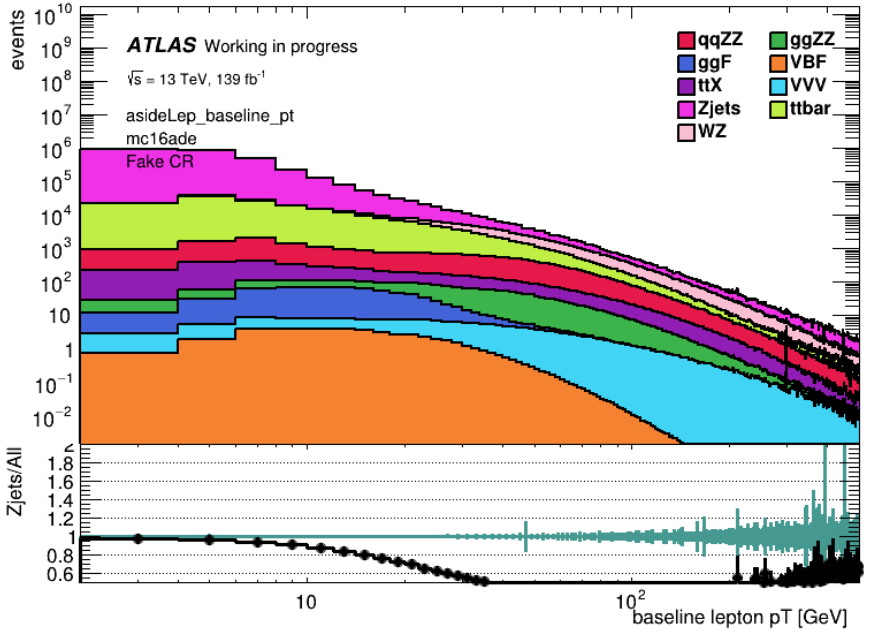
Prompt backgrounds:

- Inclusive Z/ZZ→4l, Higgs, tri-boson, ttX



Non-prompt (fake) backgrounds:

- Fake leptons from Z+jets / tt / WZ, poor modeling
- Data driven fake factor method
  - ➢ Fake enriched (Z+jets) region defined to calculate fake factor
  - ➢ Apply fake factors to events with loose leptons



Validation region defined to check BKG modeling

Signal Region

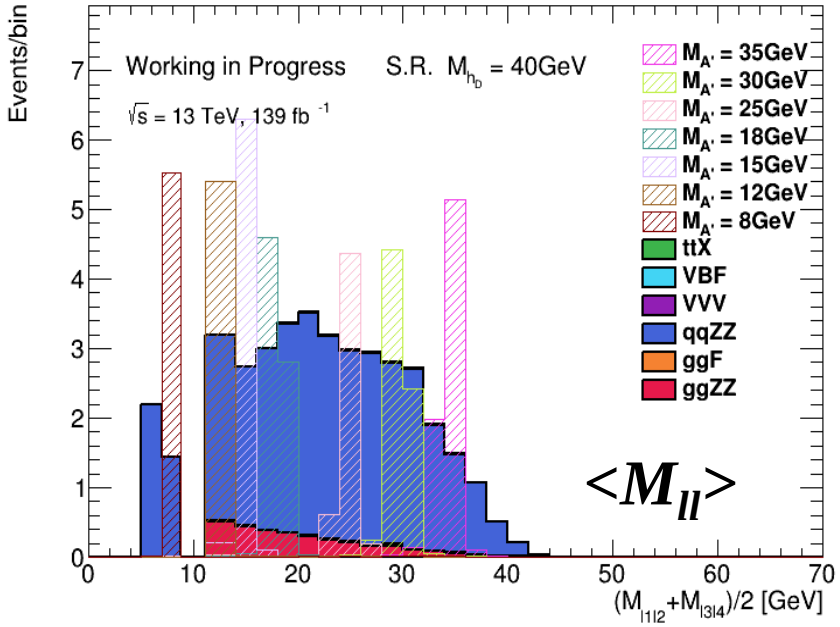
Soft leptons!
Very low Pt requirement:
Muon: Pt > 3 GeV
Electron: Pt > 6 GeV

Selections	Description
Trigger	Fire at least one of the unprescaled lepton trigger
$N_{lepton} \geq 4$	At least 4 leptons (e, μ)
From Z	For all OSSF Quadruplets, $m_{4l} < m_Z - 5GeV$
$N_{quad} \geq 1$	Has at least one OSSF Quadruplet If has more than one Quadruplet, choose the one with min $\lvert m_{l1l2} - m_{l3l4}\rvert$ Label the pair with larger mass as m_{l1l2}, the other one as m_{l3l4}
ΔR_{ll}	In the selected quadruplet, $\Delta R > 0.1(0.2)$ between SF (OF) leptons
On Shell	$m_{l3l4}/m_{l1l2} > 0.85$
J/ψ veto	In the selected quadruplet, the mass of OSSF pairs must be larger than 5GeV
$\Upsilon(bb)$ veto	The mass of OSSF pairs must be out of the Υ mass range $[m_{\Upsilon(1s)} - 0.7, m_{\Upsilon(3s)} + 0.75]$ GeV

Yields (139fb^{-1}):

- qqZ/ZZ ~ 36
- ggZZ ~ 3
- Other BKGs << 1
- Signals ~ 7

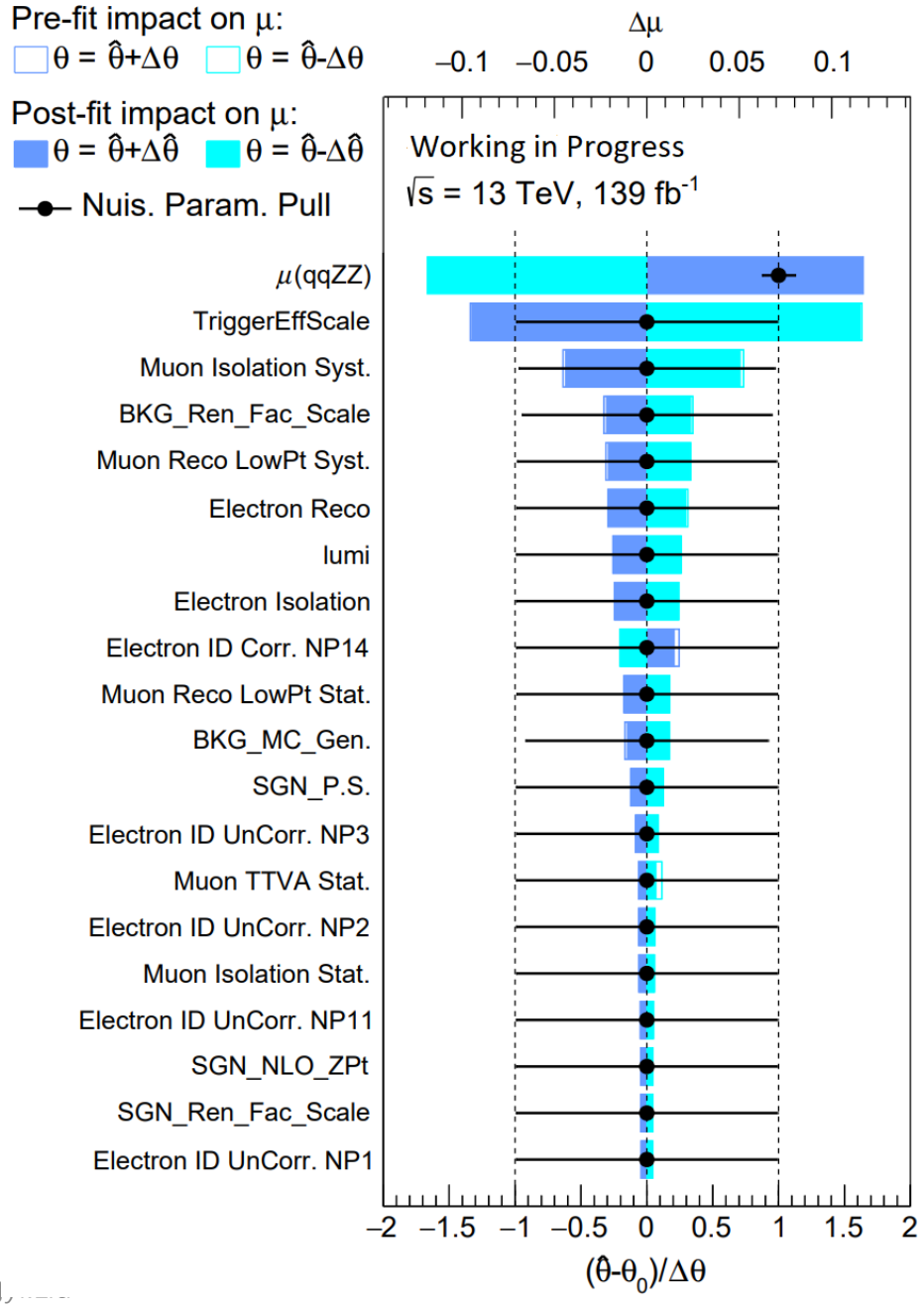
Promising sensitivity!



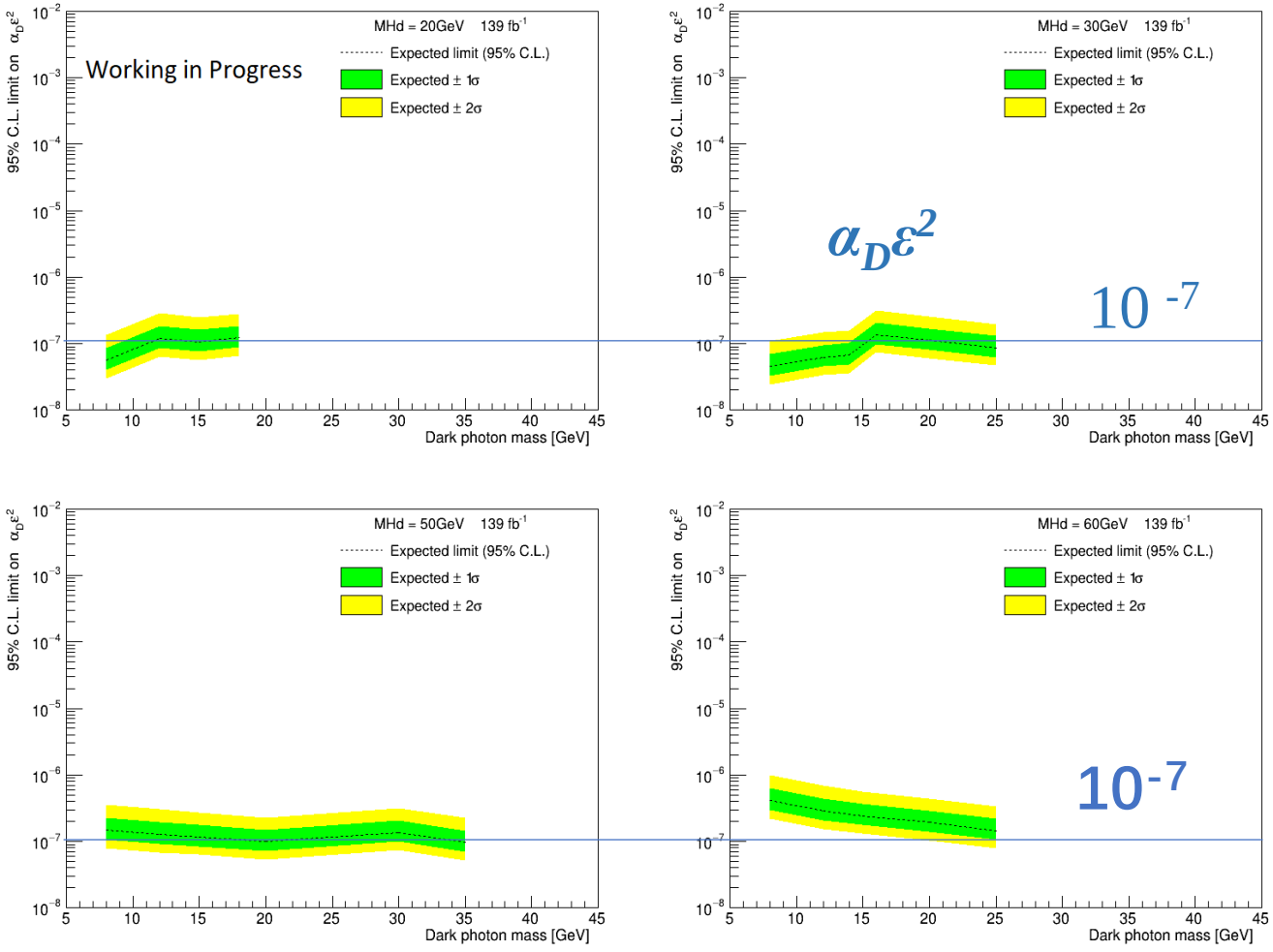
Signals (M_{hD} = 40 GeV) are under
α_D = 0.1; ε = 10^{-3}

Uncertainties

- Statistical uncertainties
- Experimental systematics
  ID, Isolation, Pt resolution
  Pile up / Luminosity
  Global trigger efficiency
  …
- Theoretical systematics
  QCD scale
  PDF + α_S
  Generator tune
  Parton showering
  High order Z Pt correction
  …



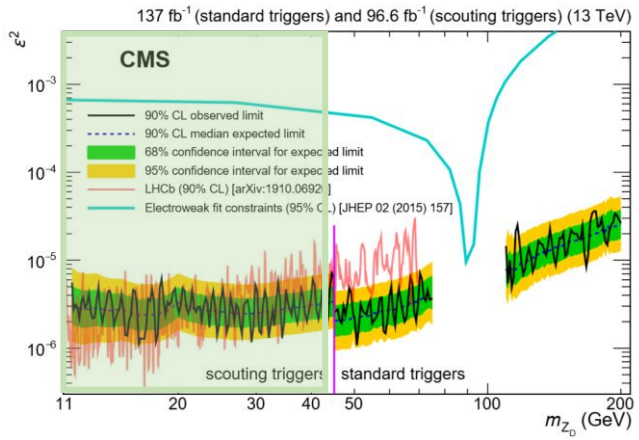
Preliminary limit setting



$\alpha_D\varepsilon^2$

10^{-7}

10^{-7}



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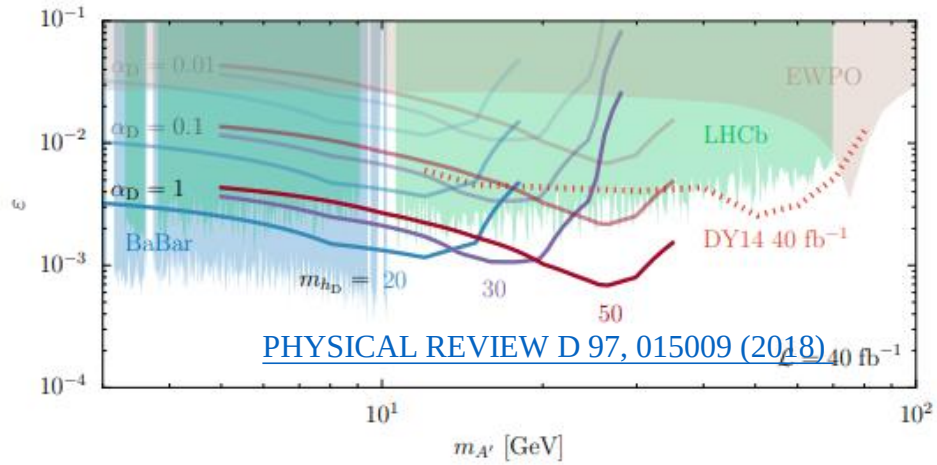

PHYSICAL REVIEW D 97, 015009 (2018)

- ✓ Asimov data fitting
- ✓ Upper limits

  $\alpha_D\varepsilon^2 \sim 10^{-7}$

  Better than theory prediction

  Comparable with limits set by CMS/LHCb