Studying Dark Z at Future e^+e^- Colliders

[Work in Progress]

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The ‘Simplest’ Extension of the SM

- Additional $\mathrm{U}(1)$ gauge group, kinetically mixed with $\mathrm{U}(1)_Y$
- ‘Dark Photon’ ← Typically sub-GeV
- Consider additional, explicit mass mixing from Higgs sector
  - A 2HDM with an extra singlet Higgs

$$H_{\mathrm{EW}} = \square_{\frac{1}{2},0} \qquad H_{\mathrm{mix}} = \square_{\frac{1}{2},q_{\mathrm{d}}} \qquad H_{\mathrm{d}} = \mathbb{1}_{0,1}$$

- ‘Dark Z’: A' ← Around weak scale

Davoudiasl et al.
(arxiv: 1203.2947)

A Three-Parameter Model

- Mass of dark *Z*: $m_{A'}$
- Kinetic mixing: ϵ

$$\mathcal{L} \supset \epsilon B_{\mu\nu} A'^{\mu\nu}$$

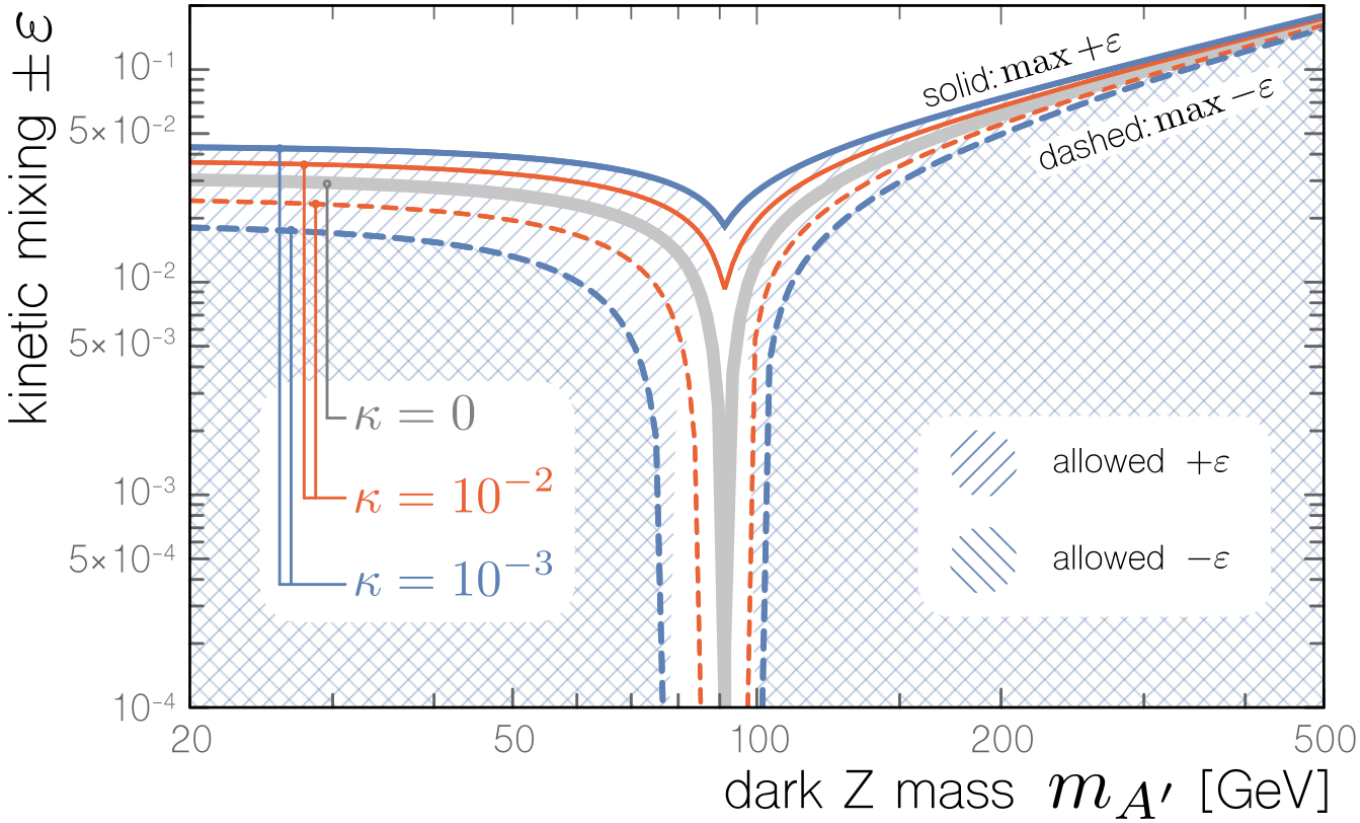
- Mass mixing: κ

$$\kappa = 2q_d \frac{g_d}{\sqrt{g^2 + g'^2}} \frac{v_{\text{mix}}^2}{v^2}$$

Main Questions

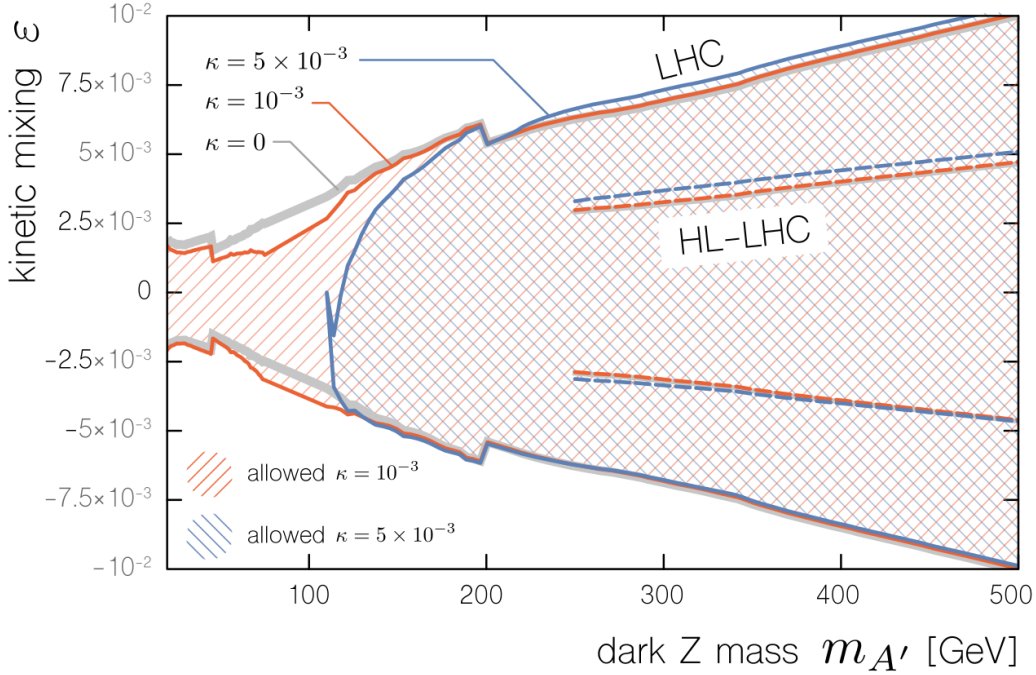
- Current bounds?
  - Electroweak precision observables (EWPO)
  - Resonance searches at CMS/ATLAS
- How to look for dark Z at future e^+e^- colliders (e.g. ILC)?
  - Bump hunting in dilepton invariant mass (?)
- If such a particle is discovered, how well can ILC study it?
  - Precision studies *à la* LEP, SLC

EWPO


kinetic mixing $\pm\varepsilon$
10^{-1}
5×10^{-2}
10^{-2}
5×10^{-3}
10^{-3}
5×10^{-4}
10^{-4}
20
50
100
200
500
dark Z mass $m_{A'}$ [GeV]
solid: max $+\varepsilon$
dashed: max $-\varepsilon$
$\kappa = 0$
$\kappa = 10^{-2}$
$\kappa = 10^{-3}$
allowed $+\varepsilon$
allowed $-\varepsilon$

Current bounds from ATLAS/CMS

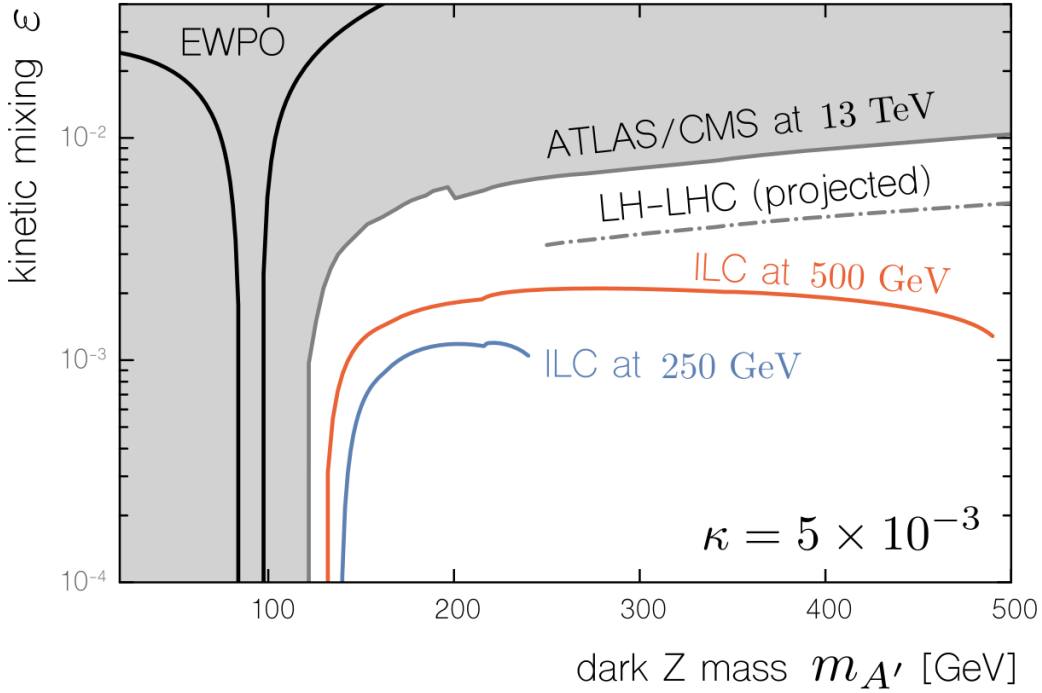
- Drell-Yan process $pp \to A' \to \ell^+\ell^-$



arxiv:
1903.06248
1912.04776
2103.02708

Looking for Dark Z

- At the benchmark value of $\kappa = 0.005$



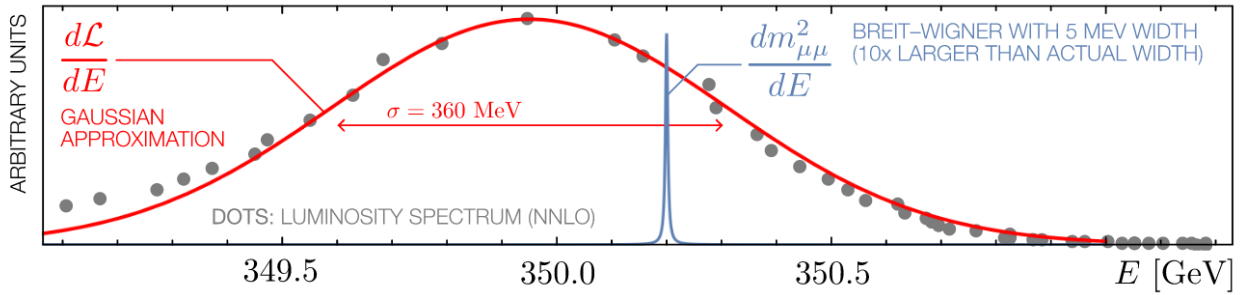
Better sensitivity than HL-LHC (3 ab^{-1})!

Dark Z Precision Studies at ILC

- Benchmark: $m_{A'} = 400\ \mathrm{GeV},\ \epsilon = \kappa = 0.005$
- Proposal: run ILC at resonance for a short period of time
- Unpolarized observables:
  - $N\left(e^+e^- \to A'\right)$
  - A_{FB}
- Polarized observable
  - A_{LR}

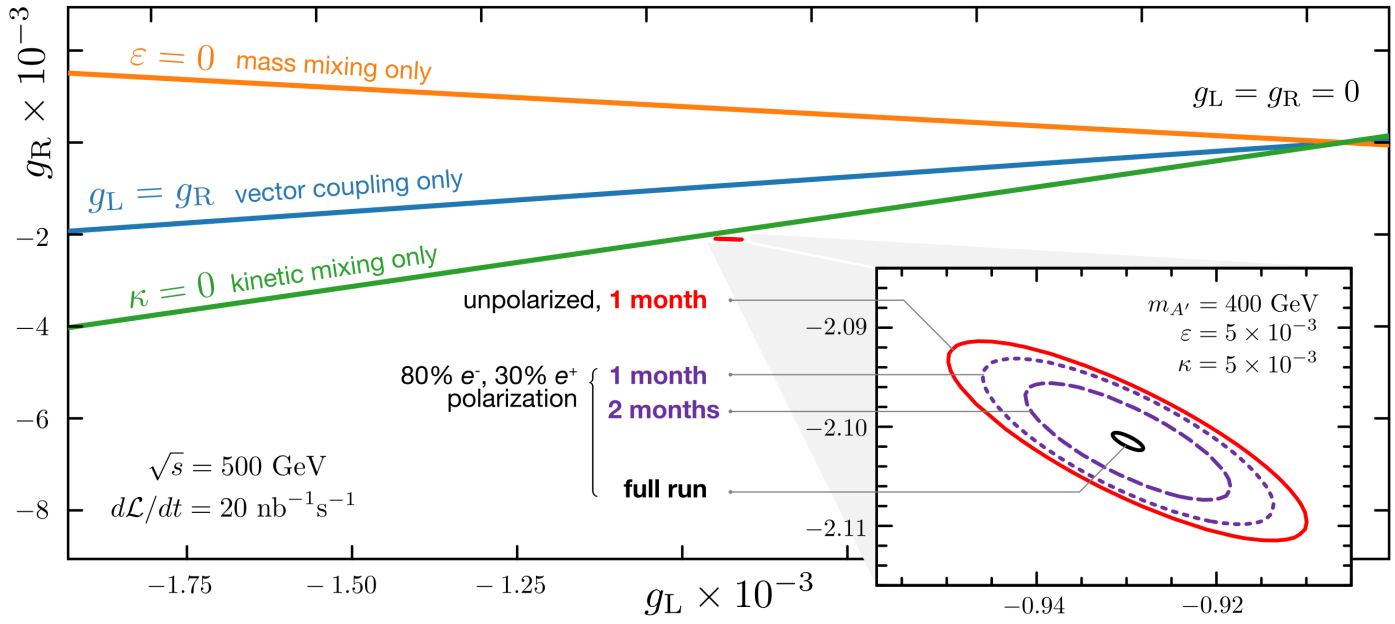
An aside: Measurement of $m_{A'}$

- Dark Z typically has very small decay width
  - when compared to its mass
  - when compared to width in luminosity spectrum at ILC (!)
- Need precise value of $m_{A'}$
  - “Lineshape scan”



Precision Studies at ILC

- χ^2 test at 95% C.L.:



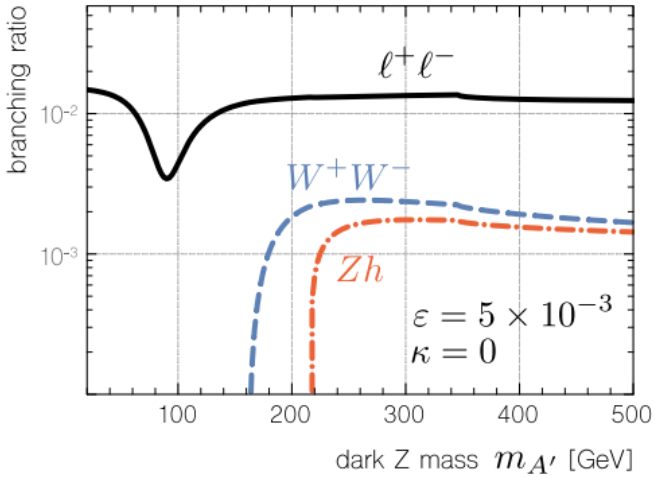
Systematic uncertainty of similar size

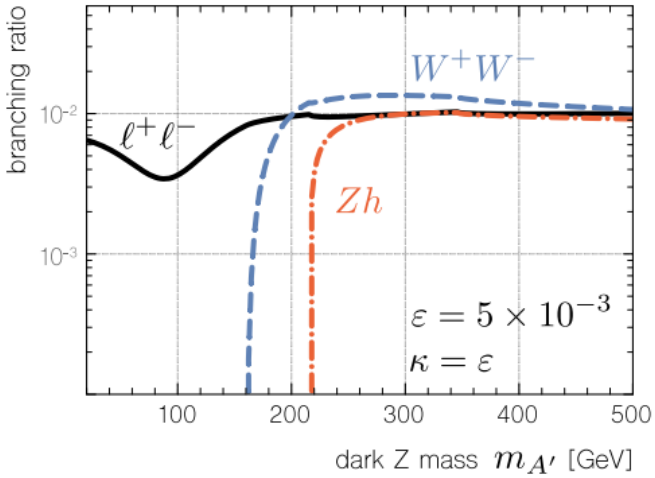
Conclusion

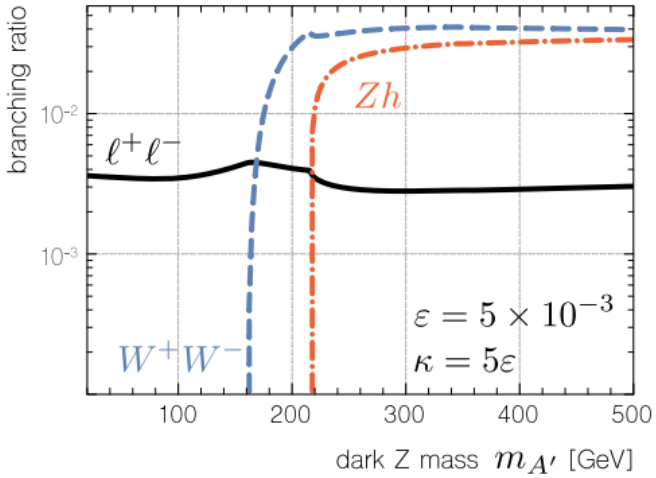
- Future e^+e^- colliders are excellent grounds to study dark Z model
  - Better reach than HL-LHC 
  - Clean environment to perform precision studies 

Thank you!

Back up slides







In this work: $e^+e^- \to (\gamma)\mu^+\mu^-$

Back up slides

- Bump hunting in dimuon invariant mass: