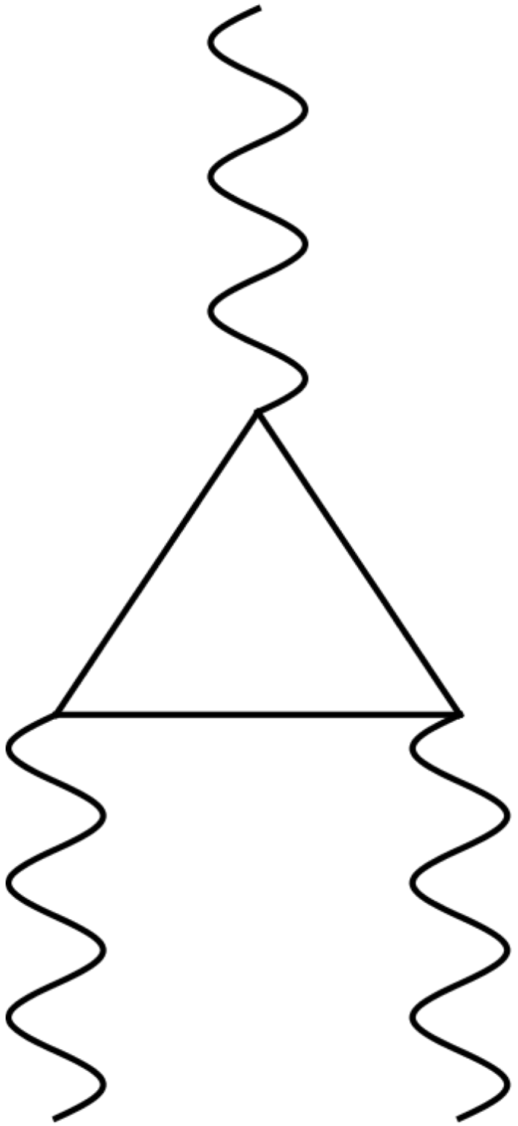
Anomalous Diboson Resonances at HL-LHC



Ahmed Ismail

University of Pittsburgh

HL/HE LHC Meeting, Fermilab

April 5, 2018

based on 1712.01840, with A. Katz

Resonance searches

Scalar

- e.g. extra Higgs going to 3rd generation quarks
- motivated by 2HDM, SUSY, ...

Fermion, e.g. excited quark from compositeness

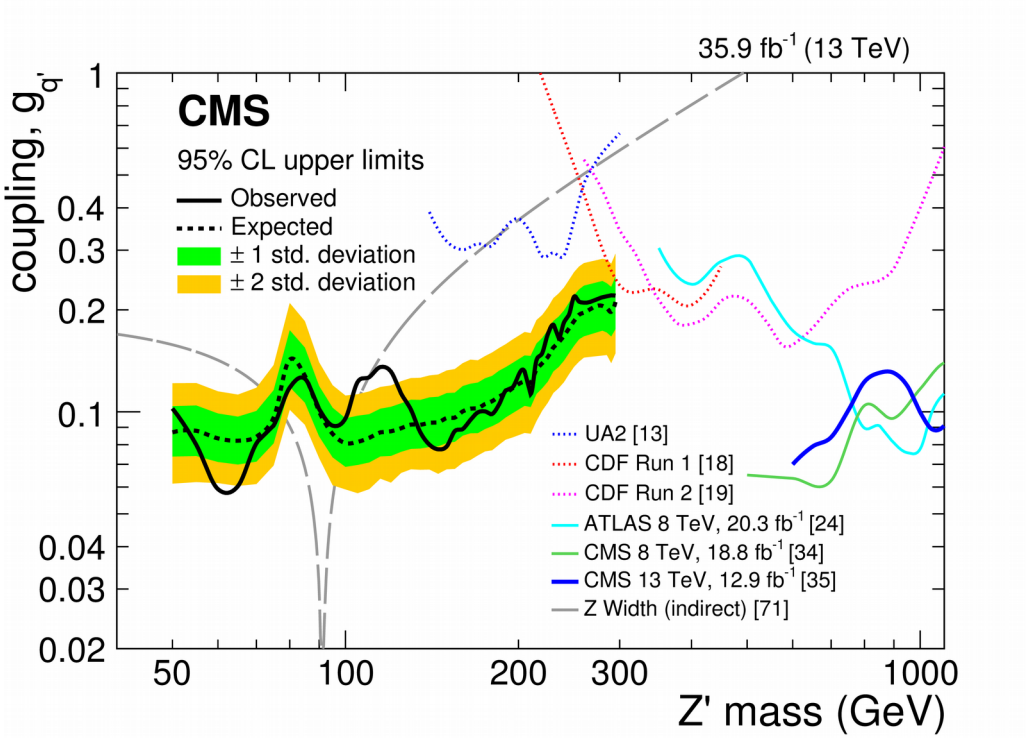
Vector

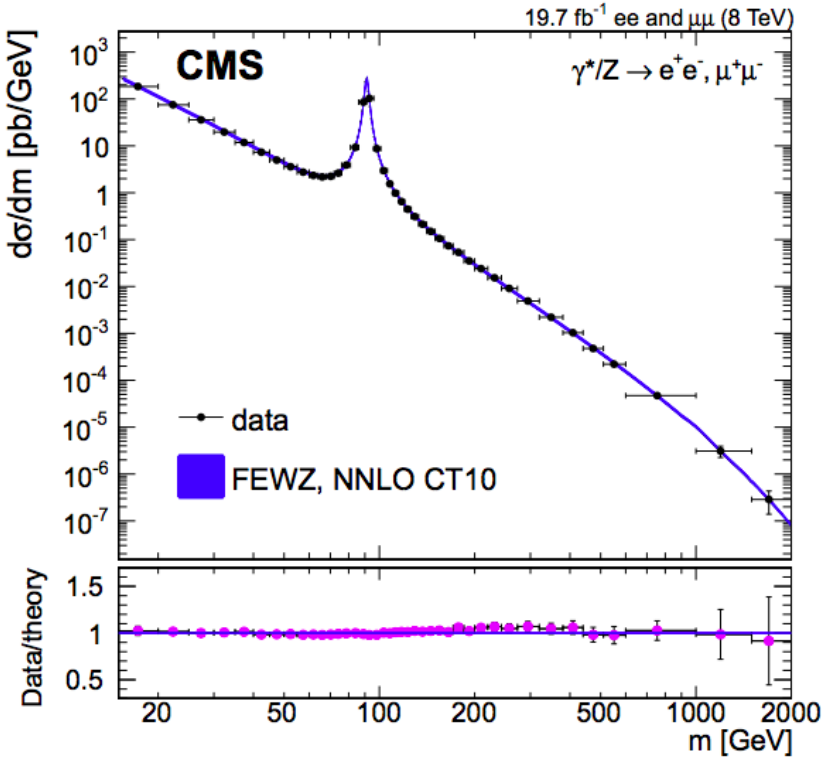
- typical example is new boson of extra gauge group
- e.g. use to explain experimental anomalies

Light Z' searches as a high lumi opportunity

High mass: Eventual HL-LHC reach of several TeV
see earlier talks in this session

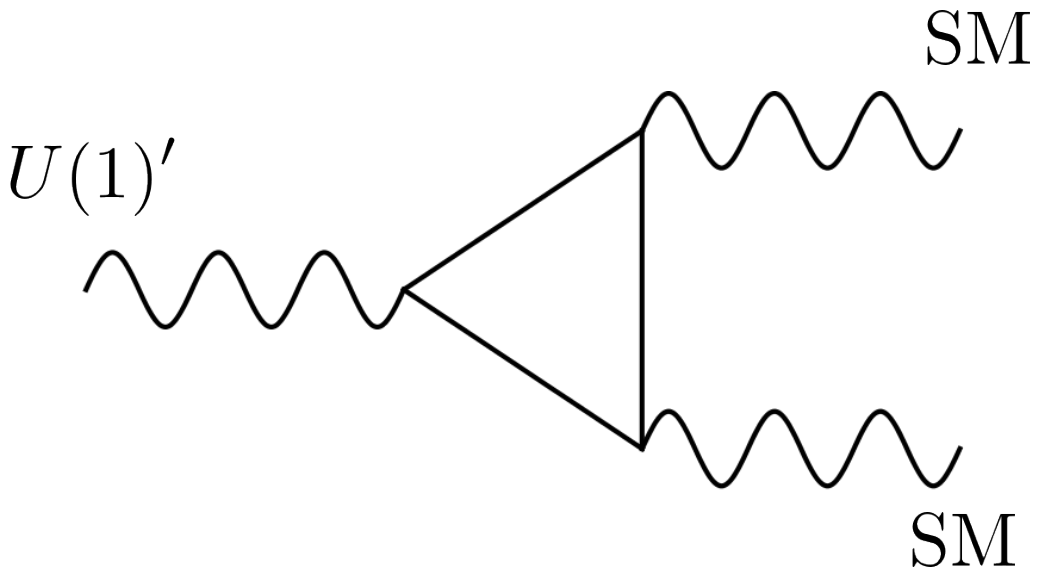
LEP: couplings below ~0.01 for masses up to 200 GeV





More difficult without first-generation couplings

Theoretical considerations



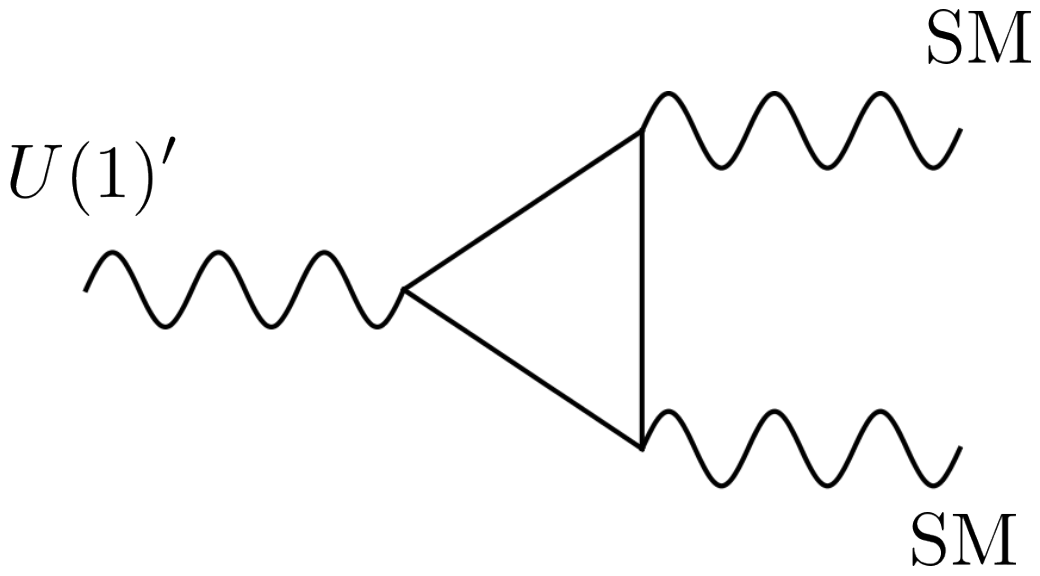
Chiral anomalies can break gauge invariance

Symmetry preserved if divergences from all triangle diagrams cancel

$$\mathcal{A}^{abc} = \mathrm{Tr}\ (T^a T^b + T^b T^a) T^c$$

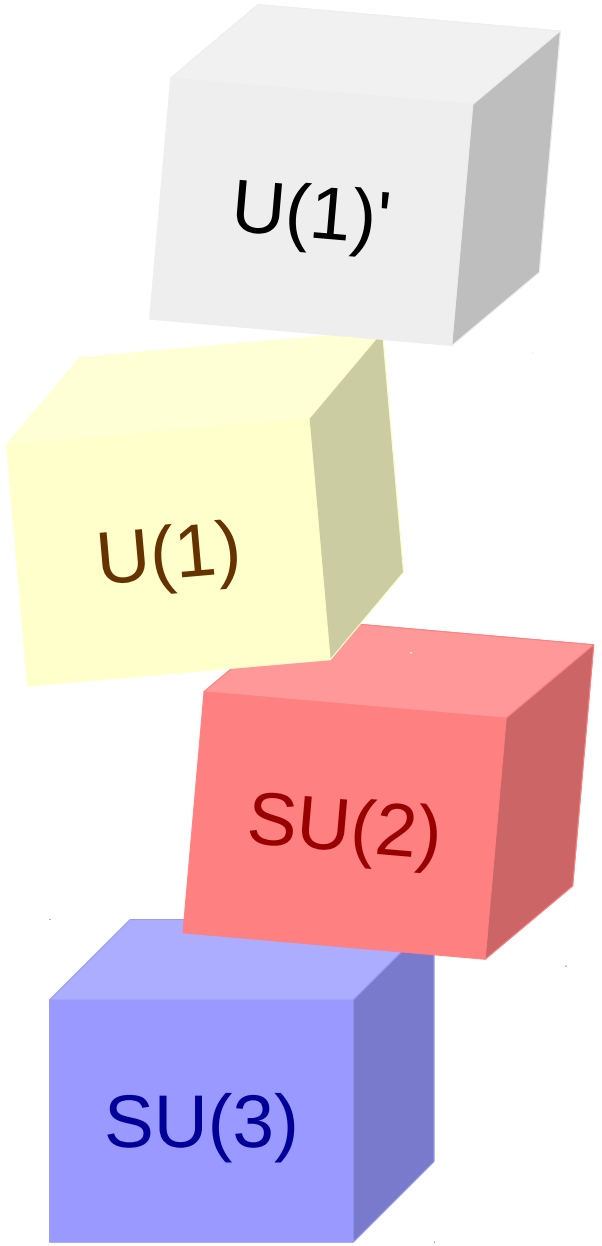
Non-zero anomaly coefficient → at least one of the external gauge bosons does not correspond to a true symmetry of the theory

Anomaly cancellation



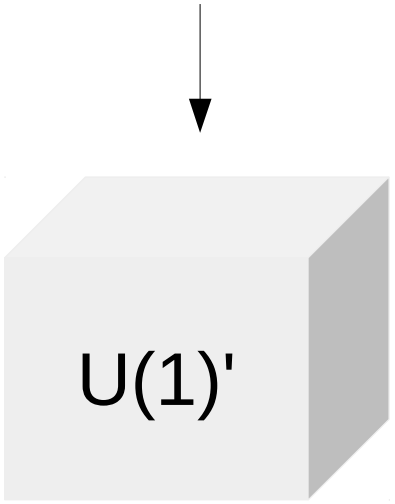
Almost any new non-trivial U(1)' requires additional SM-charged fermions to preserve gauge invariance

exception: inter-generational, B - L



Possibilities for a new gauge group

dark matter
flavor
what's your pleasure?

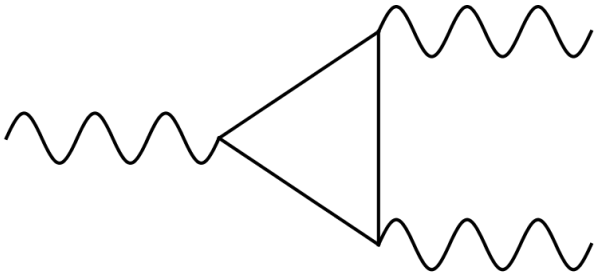


Should be able to see new matter charged under SM: anomalons

Standard defense:

“they're too heavy”

Very massive fermions do not decouple in triangle diagrams

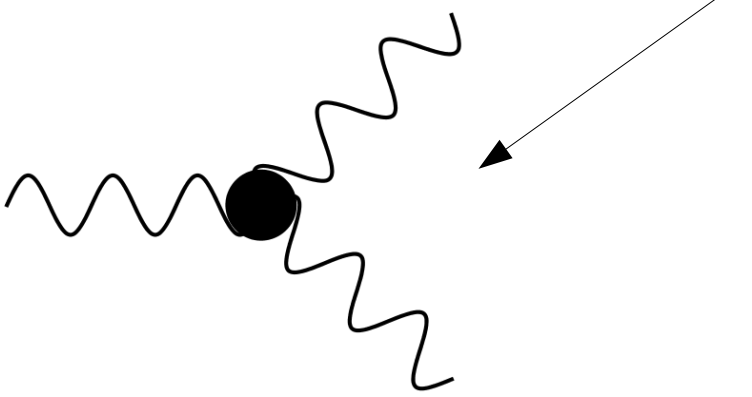


Effectively anomalous gauge theories

Below anomalon scale, U(1)' current not conserved

Integrating out heavy fermions adds Wess-Zumino terms to action which parametrize the symmetry breaking but restore SM gauge invariance

$$\frac{g' g_w^2}{12\pi^2} \mathcal{A}^{Z'WW} \epsilon^{\mu\nu\rho\sigma} Z'_\mu \left(W^a_\nu \partial_\rho W^a_\sigma + \frac{1}{3} \epsilon^{abc} W^a_\nu W^b_\rho W^c_\sigma \right)$$



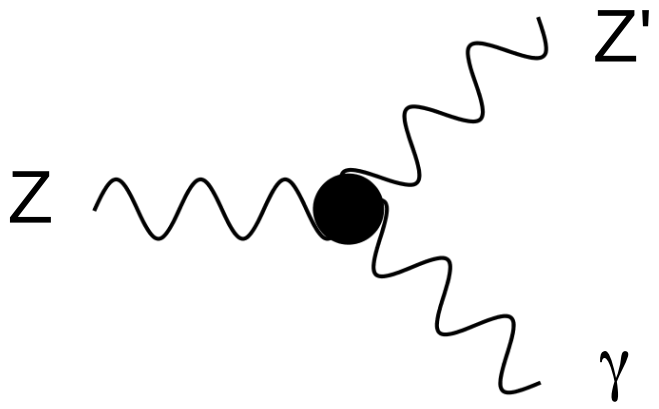
Don't need details of heavy fermions, as long as they're vector-like under SM (strongly constrained otherwise)

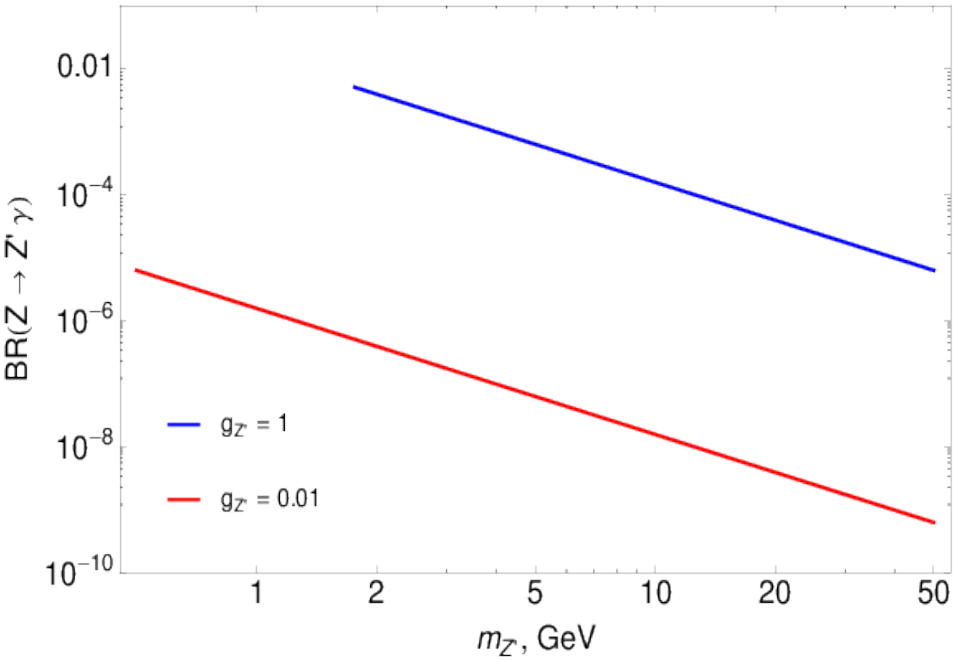
Probing a light Z' through rare Z decays

If kinematically accessible and anomaly exists, can look for Z' in rare Z decays at colliders

$$Z \rightarrow Z' \gamma$$

LHC Z production cross section is ~60 nb





$$\Gamma \sim \mathcal{A}^2 \frac{m_Z^3}{m_{Z'}^2}$$

EFT cutoff: $M \lesssim \dfrac{64\pi^3 m_{Z'}}{g' g_{\rm SM}^2 \mathcal{A}}$

Illustrative final state: Z' coupling to leptons

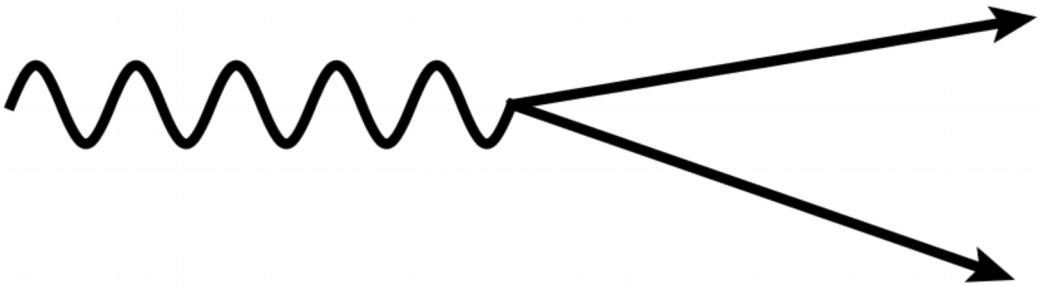
(other signatures possible, like photon + MET)

Look for $Z \rightarrow Z' \gamma$, $Z' \rightarrow$ leptons

Lepton separation in Z decay is characteristic of Z' mass scale

$$\Delta R(\ell,\ell) \sim 2m_{\ell\ell}/p_T \sim 4\frac{m_Z m_{Z'}}{m_Z^2 - m_{Z'}^2}$$

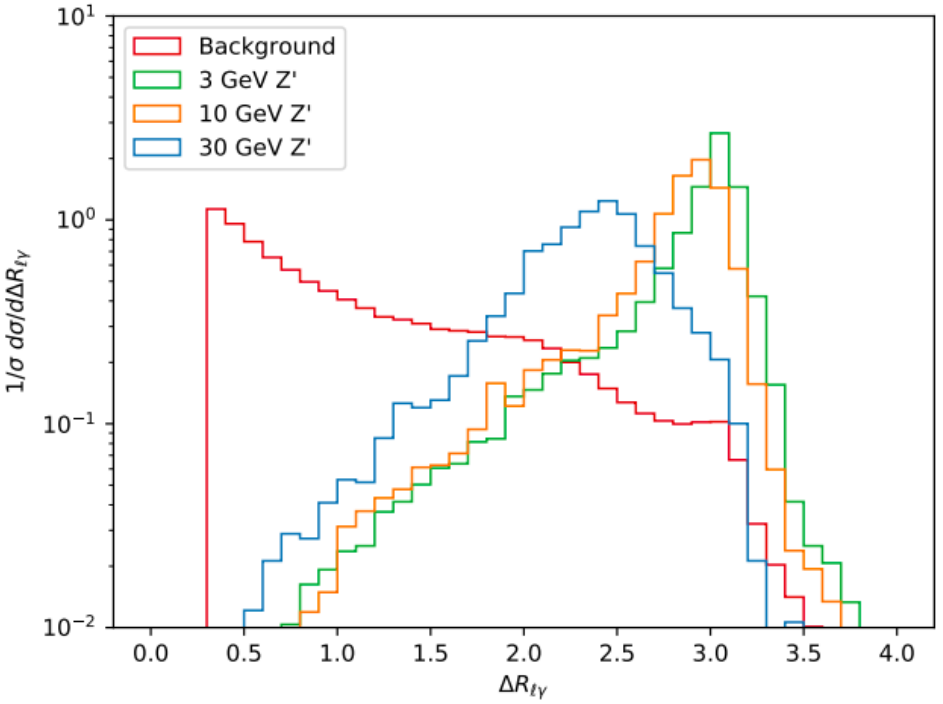
$\rightarrow$ Kinematics significantly different from radiative Z decay background

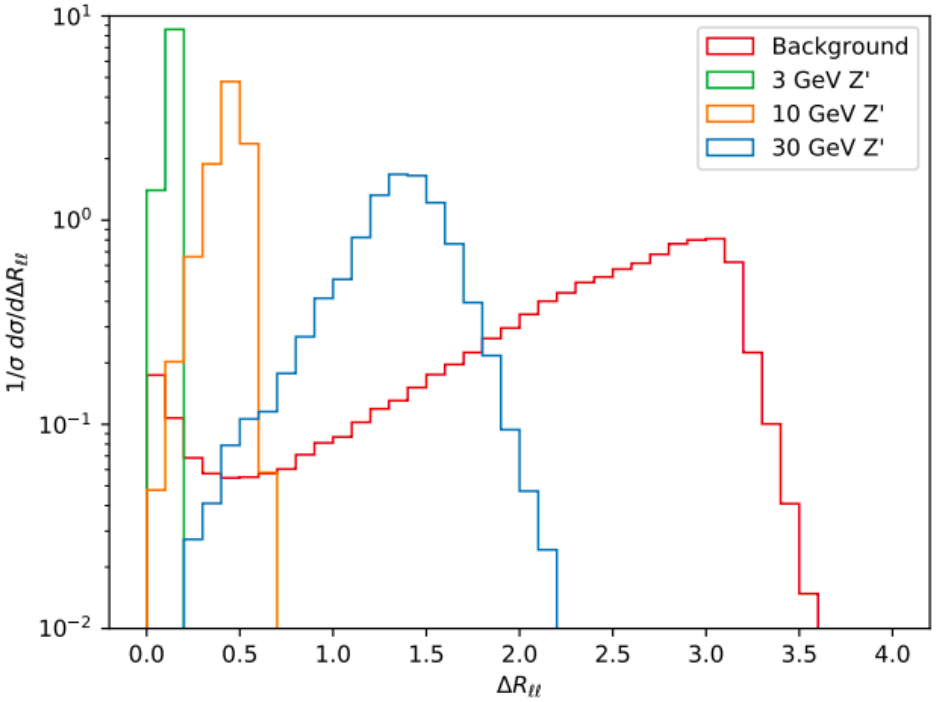


Conventional search

Two leptons and photon that reconstruct Z

Cuts on lepton-lepton and lepton-photon separation





Bump hunt in dilepton mass distribution, assuming 2 GeV resolution

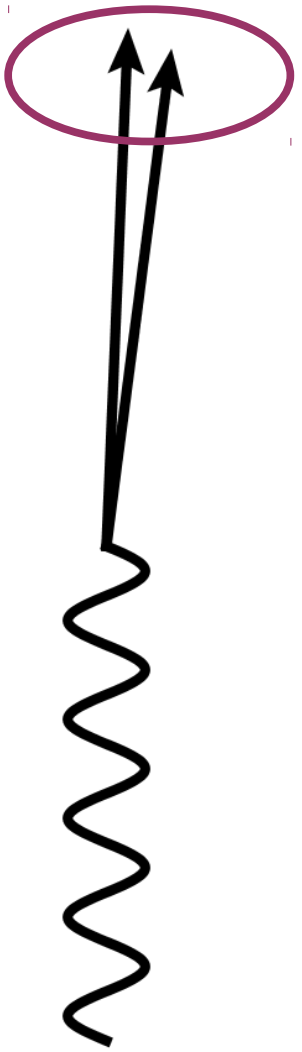
Prompt lepton-jet search

For very light Z', overlapping leptons motivate lepton-jet search

Look for two muons within $\Delta R < 0.5$ of each other

Require nearly opposite photon such that total mass reconstructs Z

20 MeV bins in dilepton mass, look for resonance

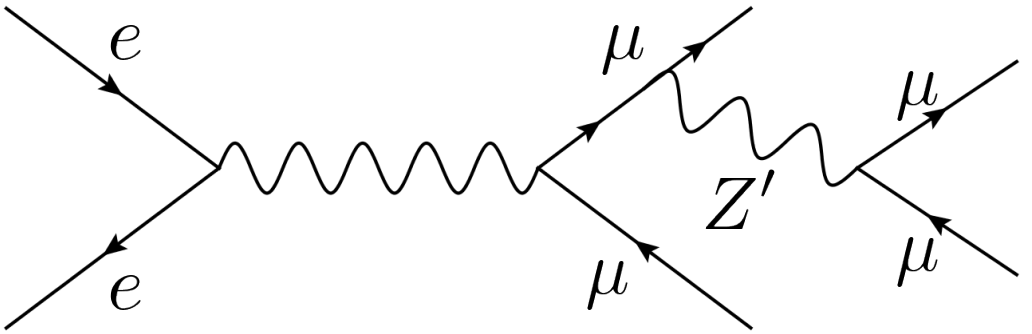


Other searches for a light Z'

Low-energy ee colliders

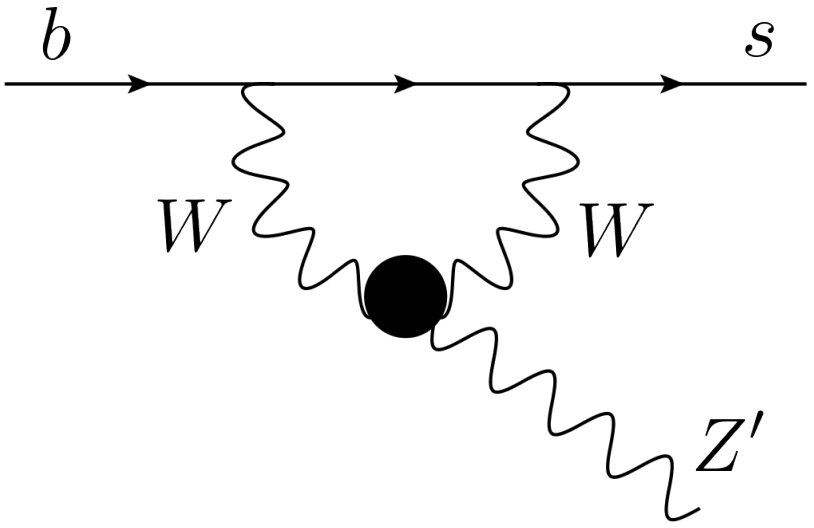
- Z'γ production in presence of coupling to electrons

- 4μ for muon coupling



$Z \rightarrow 4\mu$

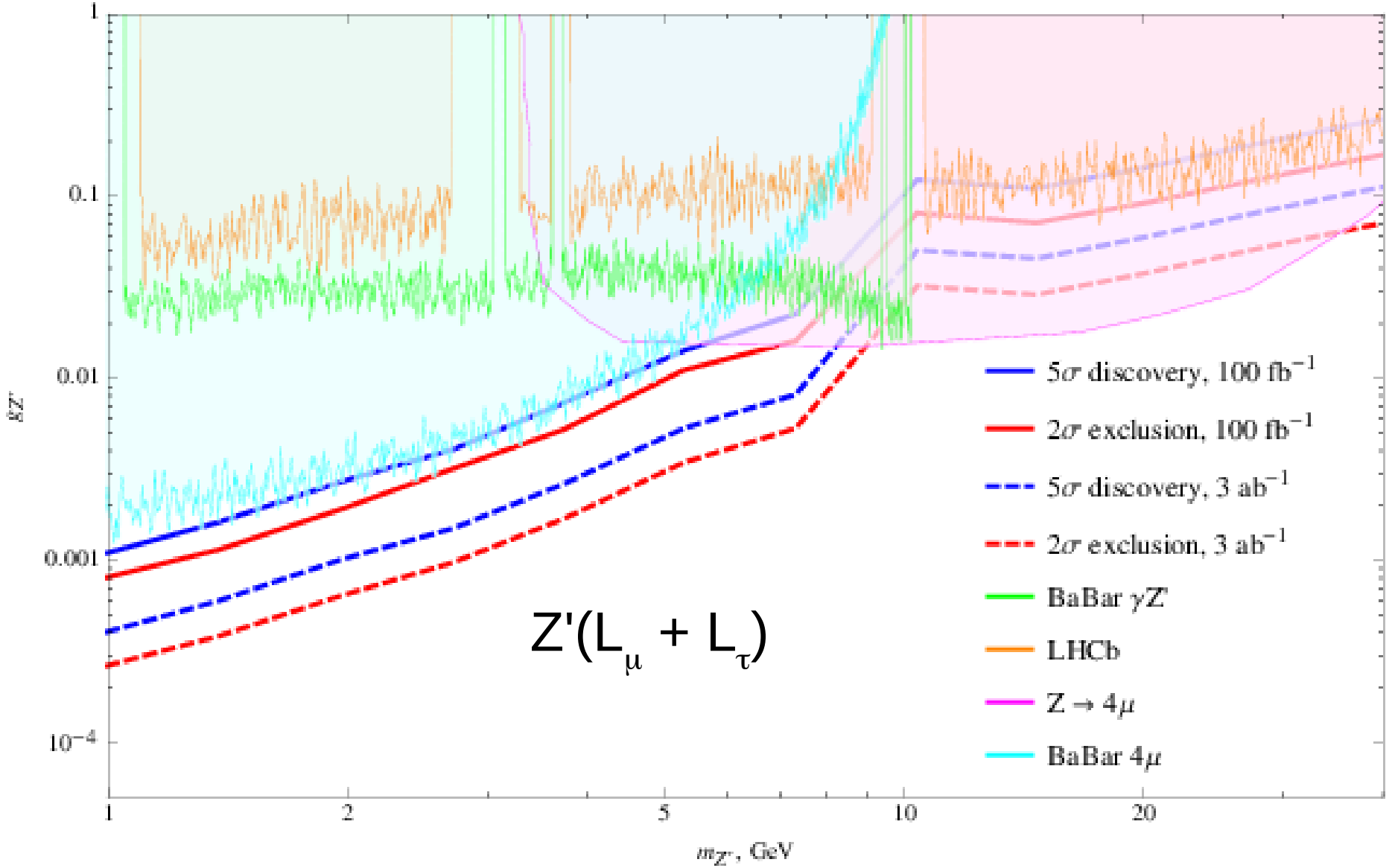
Altmannshofer, Gori, Pospelov, Yavin
1406.2332



Rare meson decays

Dror, Lasenby, Pospelov 1705.06726

HL-LHC gains for light Z'



Summary

Large Z cross section at HL-LHC enables study of rare anomaly-mediated decays

Limits complement other searches for new light gauge bosons, especially without 1st generation couplings

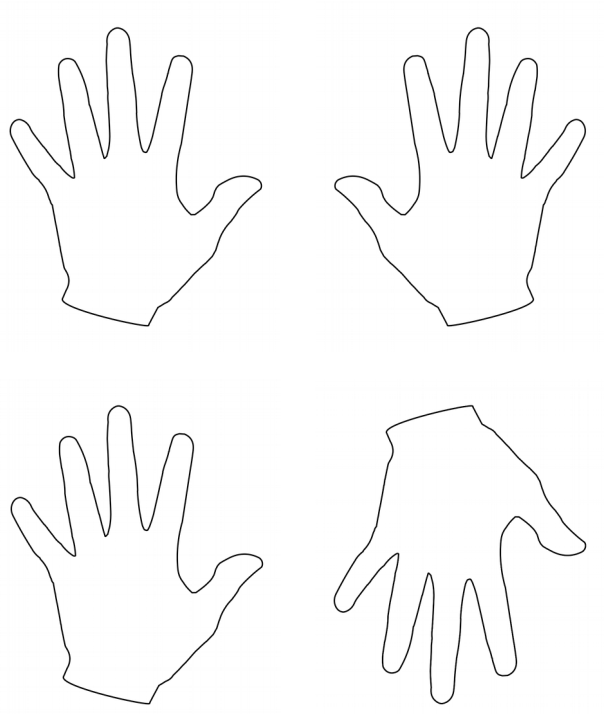
Signature can largely be predicted from SM fermion charges, detailed structure of theory not too important

At low mass, can set significant constraint with search for lepton-jets from collimated Z' decay products

Anomalies

Breaking of a classical symmetry by quantum effects

Chiral anomaly: For massless fermions, left-handed and right-handed components are *independent*



Chiral current classically conserved

$$\psi \to e^{i\alpha\gamma^5}\psi$$

$$J^{5\mu} = \bar{\psi}\gamma^\mu\gamma^5\psi$$

$$\partial_\mu J^{5\mu} = 0$$

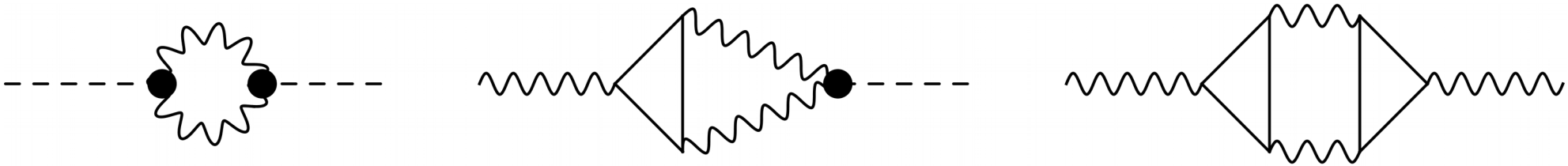
Effectively anomalous gauge theories

Under U(1)' transformation, action gets extra term

$$\Delta\mathcal{L} \propto W^{\mu\nu}\tilde{W}_{\mu\nu}$$

Can remove by introducing shift degree of freedom

$$\theta W^{\mu\nu}\tilde{W}_{\mu\nu}, \theta \to \theta + \epsilon$$



Leads to Stückelberg mass for Z', set by loop cutoff

$$M \lesssim \frac{64\pi^3 m_{Z'}}{g' g_w^2 \mathcal{A}^{Z'WW}}$$

→ correspondence between Z' and anomaly-canceling fermion masses (Preskill, 1991)