Minimal (anomalous) U(1) theories & collider phenomenology

Johan Löfgren

Nov. 7, 2017

UPPSALA
UNIVERSITET

Minimal U(1) theories

Ingredients:

1. The SM
2. One additional U(1) gauge group; a Z' with $M_{Z'} \sim \mathcal{O}(\text{TeV})$
3. A complex scalar φ; $m_\varphi = 500$ GeV
4. Three right handed neutrinos ν_R; $m_{\nu_R} = 500$ GeV

Our paper:
ArXiv:1605.04855
(Andreas Ekstedt, Rikard Enberg, Gunnar Ingelman, Tanumoy Mandal, Johan Löfgren)

Model features

Field	q_L	u_R	d_R	l_L	e_R	ν_R	H	φ
Charge	z_q	z_u	z_d	z_l	z_e	z_k	z_H	$+1$

- $\mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)_\mathrm{Y} \times \mathrm{U}(1)_\mathrm{z} \xrightarrow{\langle\varphi\rangle} \mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)_\mathrm{Y} \xrightarrow{\langle H\rangle} \mathrm{U}(1)_\mathrm{Q}$

Field	q_L	u_R	d_R	l_L	e_R	ν_R	H	φ
Charge	z_q	z_u	z_d	z_l	z_e	z_k	z_H	$+1$

- $\mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)_\mathrm{Y} \times \mathrm{U}(1)_z \xrightarrow{\langle\varphi\rangle} \mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)_\mathrm{Y} \xrightarrow{\langle H\rangle} \mathrm{U}(1)_\mathrm{Q}$
  $\Longrightarrow$ mixing between Z and Z' if $z_H \neq 0$.

Field	q_L	u_R	d_R	l_L	e_R	ν_R	H	φ
Charge	z_q	z_u	z_d	z_l	z_e	z_k	z_H	$+1$

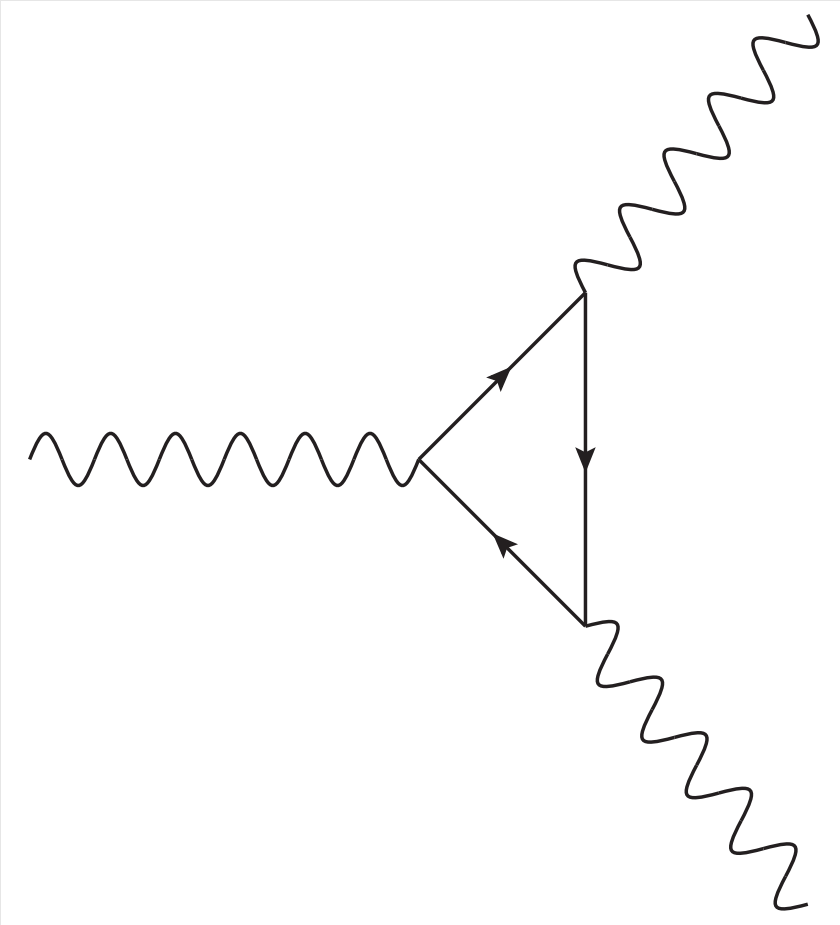
- $\mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)_\mathrm{Y} \times \mathrm{U}(1)_\mathrm{z} \xrightarrow{\langle\varphi\rangle} \mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)_\mathrm{Y} \xrightarrow{\langle H\rangle} \mathrm{U}(1)_\mathrm{Q}$
  $\Longrightarrow$ mixing between Z and Z' if $z_H \neq 0$.
- SM Yukawa couplings $\Longrightarrow$ $z_H = z_l - z_e$.

Model features

Field	q_L	u_R	d_R	l_L	e_R	ν_R	H	φ
Charge	z_q	z_u	z_d	z_l	z_e	z_k	z_H	$+1$

- $\mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)_\mathrm{Y} \times \mathrm{U}(1)_\mathrm{z} \xrightarrow{\langle\varphi\rangle} \mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)_\mathrm{Y} \xrightarrow{\langle H\rangle} \mathrm{U}(1)_\mathrm{Q}$
  $\implies$ mixing between Z and Z' if $z_H \neq 0$.
- SM Yukawa couplings $\implies$ $z_H = z_l - z_e$.
- Neutrino seesaw only if $z_k = \pm\frac{1}{2}$.

Gauge anomalies



Anomaly	Factor
$[SU(2)_L]^2\,[U(1)_z]$	$\mathrm{Tr}\left[\left\{T^i, T^j\right\} z\right]$
$[SU(3)_c]^2\,[U(1)_z]$	$\mathrm{Tr}\left[\left\{\mathcal{T}^a, \mathcal{T}^b\right\} z\right]$
$[U(1)_Y]^2\,[U(1)_z]$	$\mathrm{Tr}\left[Y^2 z\right]$
$[U(1)_Y]\,[U(1)_z]^2$	$\mathrm{Tr}\left[Y z^2\right]$
$[U(1)_z]^3$	$\mathrm{Tr}\left[z^3\right]$
$[U(1)_z]\,[\mathrm{Grav.}]^2$	$\mathrm{Tr}\left[z\right]$

$$Q_z = \left(4z_q - z_u\right)(B - L) + z_H Y$$

Interesting models

$$Q_z = \left(4z_q - z_u\right)(B - L) + z_H Y$$

Model	$\kappa = z_q/z_u$
$B - L$	1
Y-sequential	1/4
SO(10)-GUT	-1
Right-handed	0

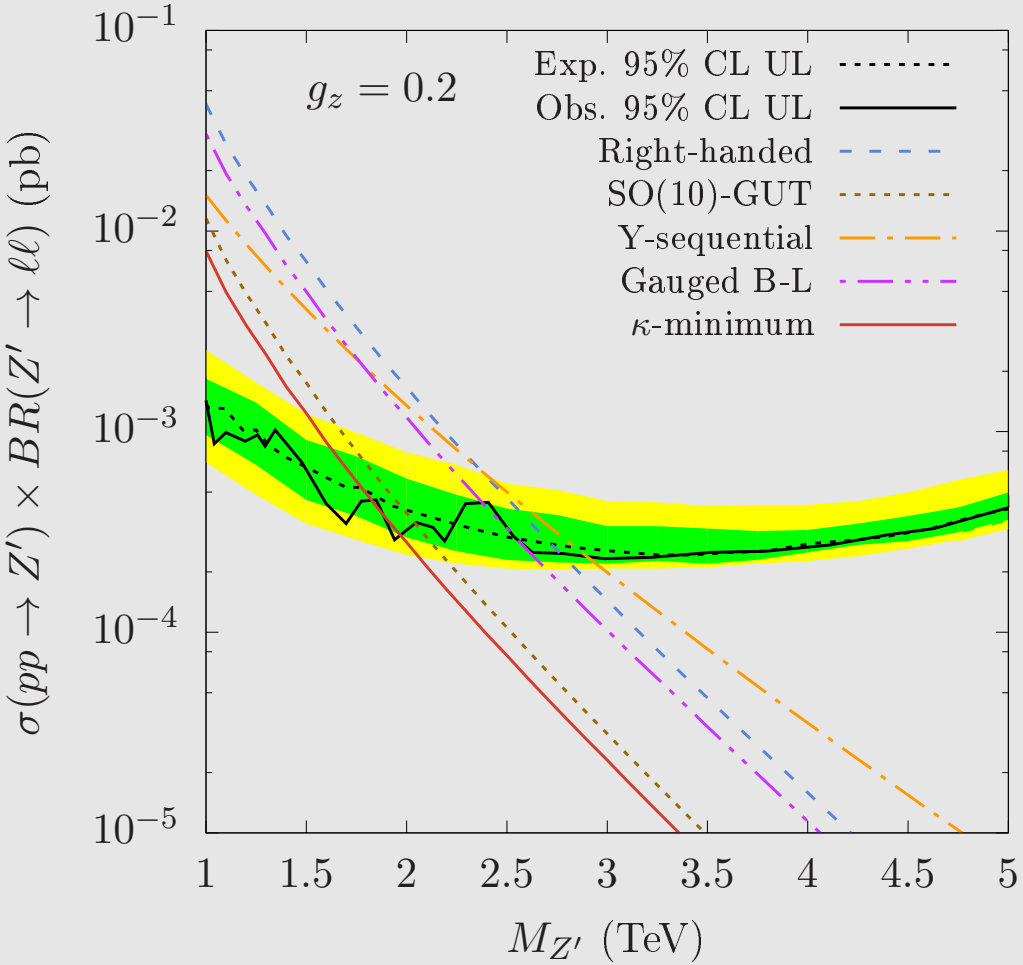


Figure 1: Comparison of the observed and expected 95% CL UL on $\sigma \times$BR from 13 TeV ATLAS dilepton resonance search data (2016) with the theoretical predictions of various models.

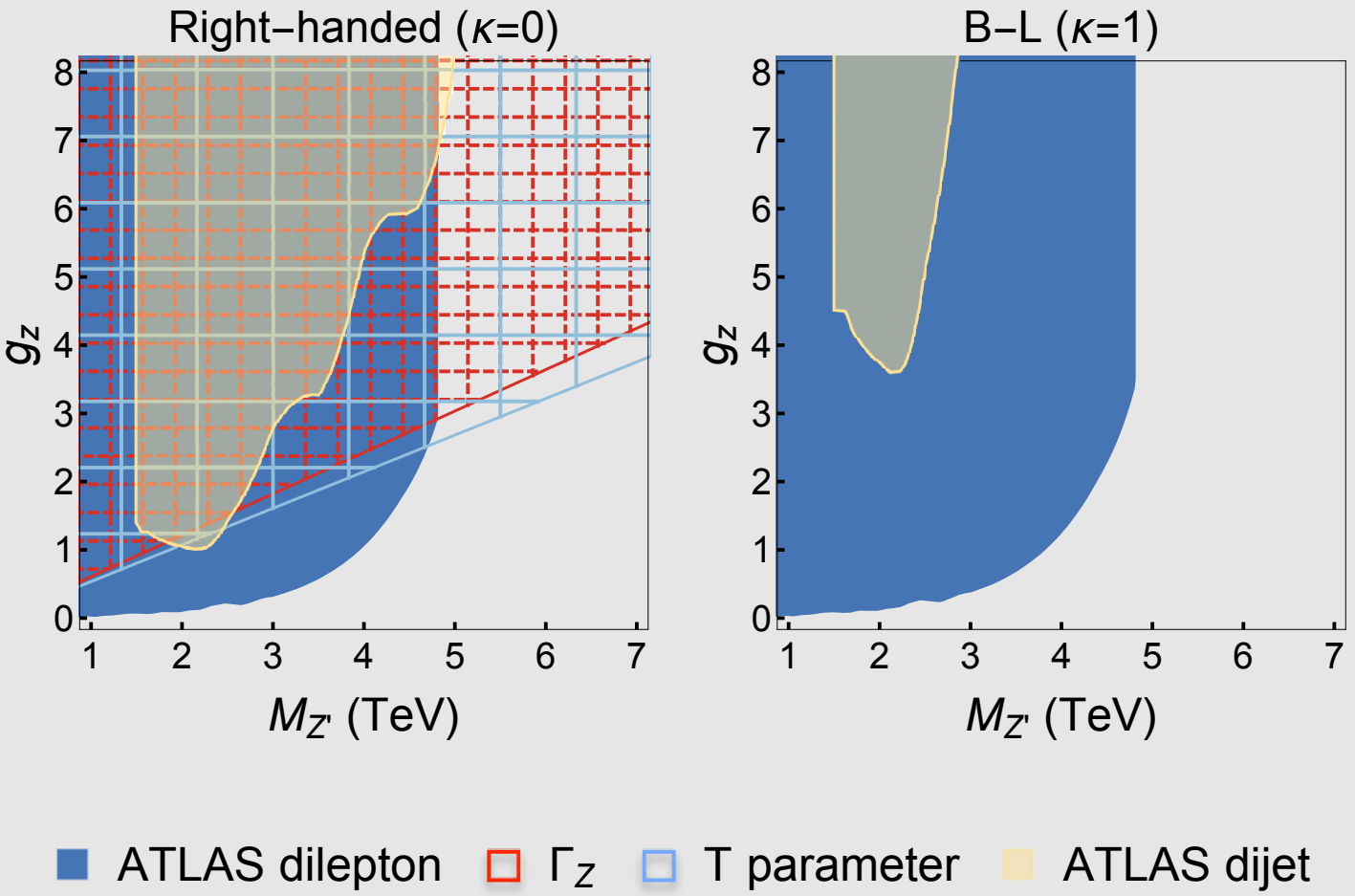


Figure 2: Exclusion in the g_z-$M_{Z'}$ plane, using 13 TeV ATLAS dilepton and dijet data (2016) and electroweak precision data.

Minimal (anomalous) $\mathrm{U}(1)$ theories

Relaxing the constraints

$M_{Z'}$ g_z z_H z_q ~~z_u~~ ~~z_d~~ z_l ~~z_e~~

The Green-Schwarz mechanism:

- Integrate out heavy physics which cancels the anomalies
- $\mathcal{L} \supset \frac{\hbar}{M} G_{Z'} \mathrm{Tr}\left[F^2\right] + \hbar AAF$
- Cancels the triangle diagrams with a gauge variant term in $\mathcal{L}$
- The effective action (path integral) **is** gauge invariant, and hence observables are too

Differences to explicit cancellation

$M_{Z'}$ g_z z_H z_q ~~z_u~~ ~~z_d~~ z_l ~~z_e~~

- $Q_z = 3z_q B + z_l L + z_H \left[Y - (B - L)\right]$
- No additional scalar
- No righthanded neutrinos
- Modification of exotic signatures:
  $Z' \to Z\gamma, Z' \to ZZ$

Interesting models

$$Q_z = 3z_q B + z_l L + z_H \left[Y - (B - L)\right]$$

Model	z_H	z_q	z_l
B	0	1/3	0
L	0	0	1
$B + L$	0	1/3	1
Q_R	1/2	0	−1/2
L_R	1	1/3	0
⋮			

Results: Exclusion plots

Preliminary results, ArXiv:1711.XXXXX.

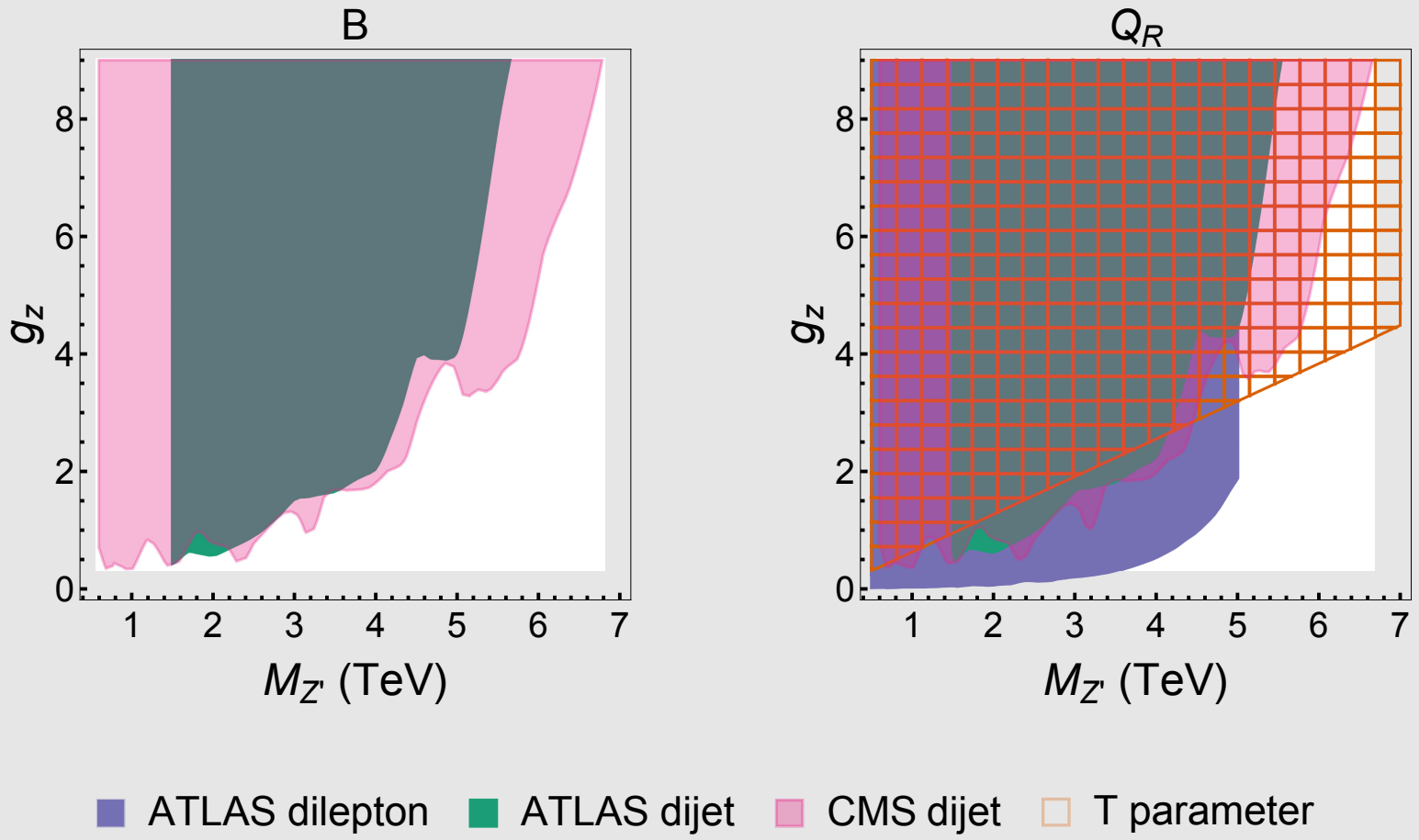


Figure 3: Exclusion in the g_z-$M_{Z'}$ plane, using ~ 36 fb^{-1} ATLAS and CMS 13 TeV data (2017), and electroweak precision tests.

Results: Exotic signatures

Preliminary results, ArXiv:1711.XXXXX.

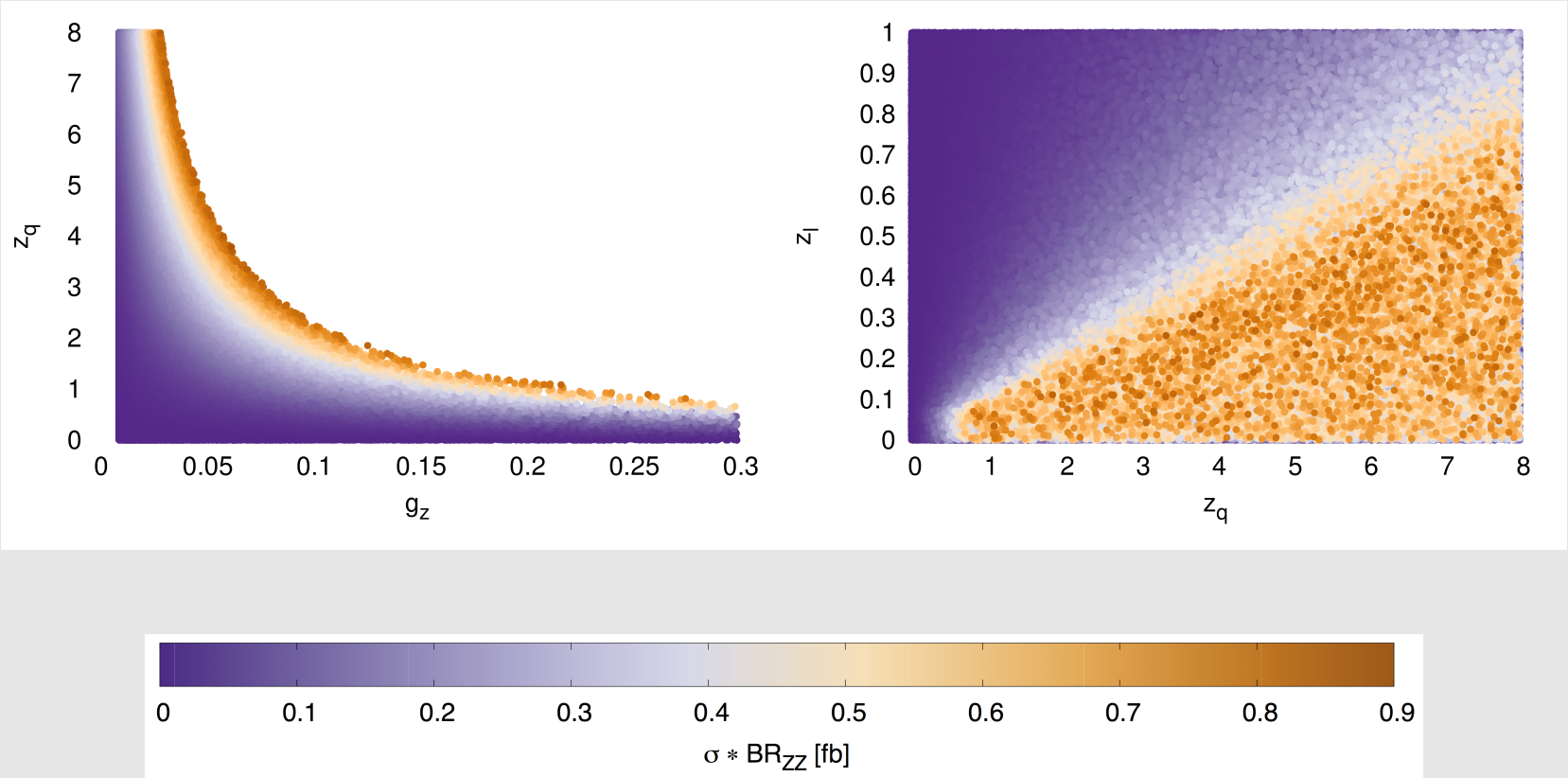


Figure 4: 2D heat maps of $\sigma(pp \to Z') \times BR(Z' \to ZZ)$ in fb, for $M_{Z'} \sim 0.5$TeV

Summary

- Substantial differences between the phenomenology of (anomalous) and non-anomalous U(1) theories
- LHC data heavily constrains the parameter space
- Plausible to detect Green-Schwarz nature of an anomalous Z' at high luminosity LHC

Questions?