Minimal Z' models: present bounds & early LHC reach

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Based on work with
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Fabio Zwirner (Padova)
arXiv:0909.1320 [hep/ph]

Z' models

Motivations

- Theoretical:
  - GUTs with groups of rank > 4, e.g. $SO(10)$ or E_6
  - string compactifications
  - alternative models of EWSB: little Higgs, Higgsless models with extra dimensions, strong EWSB, and others
- Phenomenological: one of the cleanest signals to detect for the LHC experiments

Framework: minimal models

- $G = G_{SM} \times U(1)'$
- SM fermions + 3 RH neutrinos
- anomaly-free $\Longleftrightarrow$ $U(1)'$ lin. comb. of *Y* and *B-L*
- flavor-blind couplings

Not restrictive to write, in **mass eigenstate basis** (kinetic & mass mixing included): $\mathcal{L}_{NC} = eJ_{em}A + g_Z(Z\,J_Z + Z'\,J_{Z'})$

$J_Z, J_{Z'}$ obtained rotating by θ' the currents

$$J_{Z'^0} = \frac{g_Y}{g_Z} J_Y + \frac{g_{BL}}{g_Z} J_{B-L},$$

J_{Z^0} = current coupled to the *Z in the SM*

Z-Z' mixing angle

$$\tan\theta' = -\widetilde{g}_Y \frac{M_{Z^0}^2}{M_{Z'}^2 - M_{Z^0}^2}$$

(M_{Z^0} = *SM expression for the Z mass*)

Framework (continued)

Only 3 independent parameters:

$$M_{Z'}, \quad \widetilde{g}_Y \equiv \frac{g_Y}{g_Z}, \quad \widetilde{g}_{BL} \equiv \frac{g_{BL}}{g_Z}$$

(neglect ν_R and extra Higgs scalar in 'discovery study')

Some well-known examples:

	Z_{B-L}	Z_χ	Z_{3R}
g_Y	0	$\frac{2}{\sqrt{10}} g_{Z'}$	$g_{Z'}$
g_{B-L}	$\sqrt{\frac{3}{8}} g_{Z'}$	$-\frac{5}{2\sqrt{10}} g_{Z'}$	$-\frac{1}{2} g_{Z'}$

($g_{Z'} = \sqrt{\frac{5}{3}} g'$ often used at the weak scale)

Outline:

- GUT-favored region of parameters
- **Present bounds**: EWPT, Tevatron
- **Early LHC reach**: discovery or exclusion

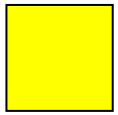
GUT-favored region of parameters

approximate unification at

$$M_U \approx 10^{16}\ \mathrm{GeV}$$

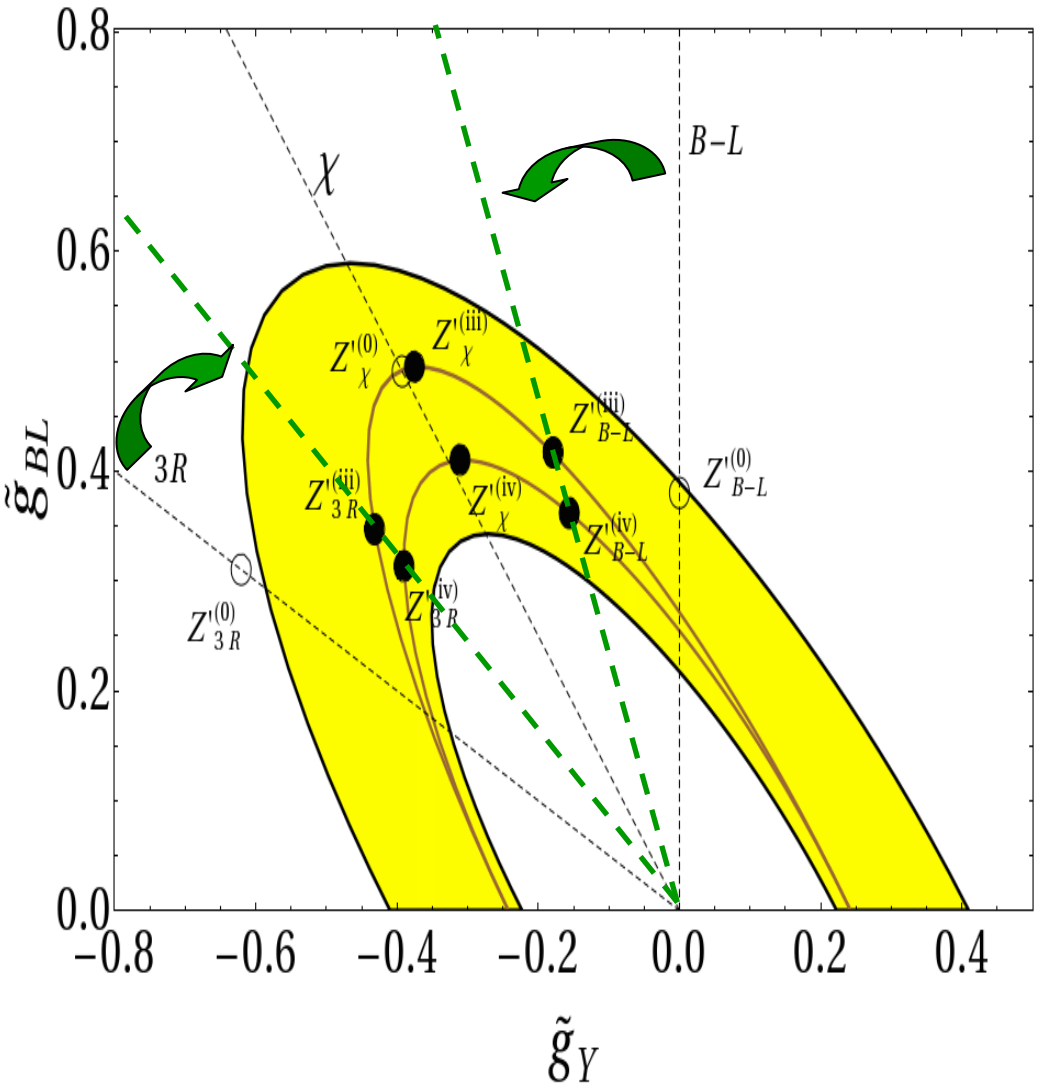
RGE running

$$M_U \to M_Z$$

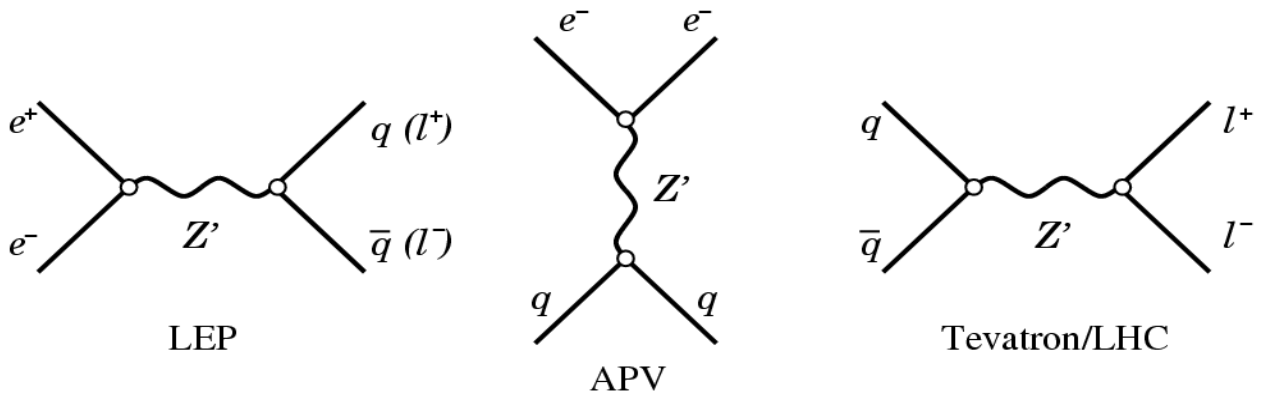


= preferred region of eff.couplings $(\widetilde{g}_Y, \widetilde{g}_{BL})$

- **points & lines** = specific models
- **kinetic mixing effects sizable !**



Direct vs indirect bounds



…the parameters involved are the same!

➡ bounds from EWPT should **not** be neglected when assessing the discovery potential of direct searches

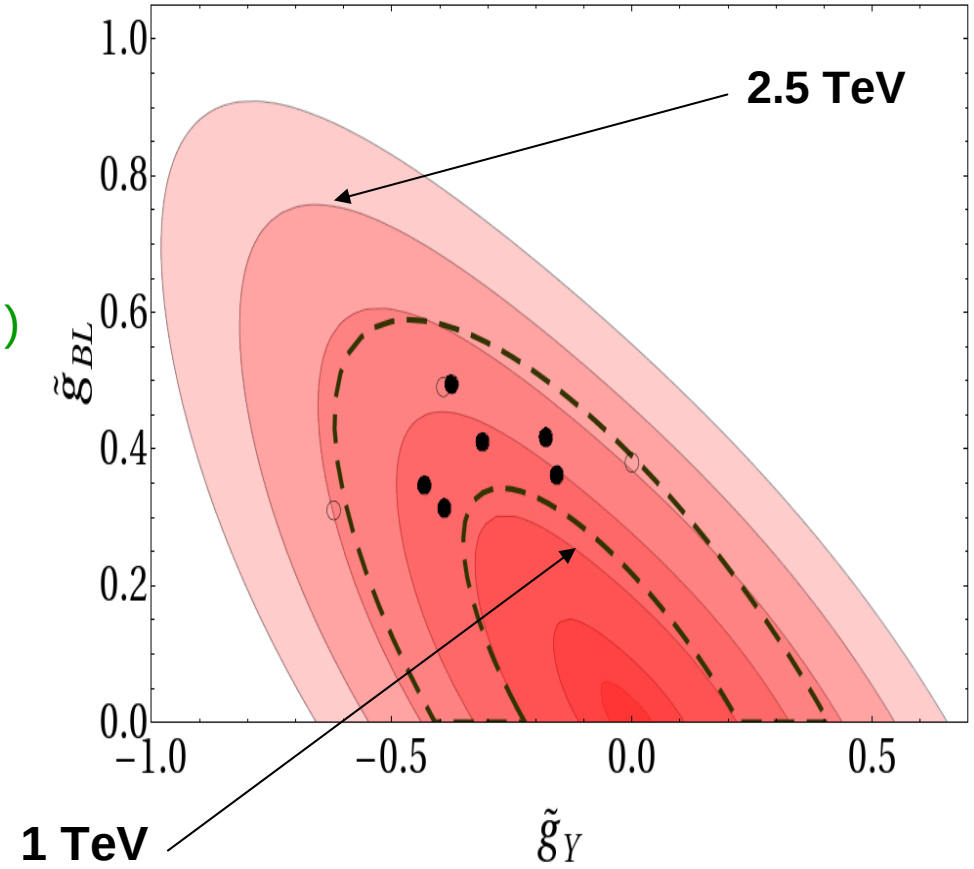
Bounds from EWPT

- LEP1 constrains *Z*-*Z'* mixing ⇒ $|\theta'| < O(10^{-3})$
- LEP2 & APV constrain 4-fermion effective operators

Applying Cacciapaglia-Csaki-Marandella-Strumia, hep-ph/0604111

- **least constrained** for $\tilde{g}_Y \approx -\tilde{g}_{BL}$ (*Z'* less coupled to matter fields)
- linear bound (constrain $g_{Z'}/M_{Z'}$)
- $M_{Z'} > 1$ TeV for all GUT models

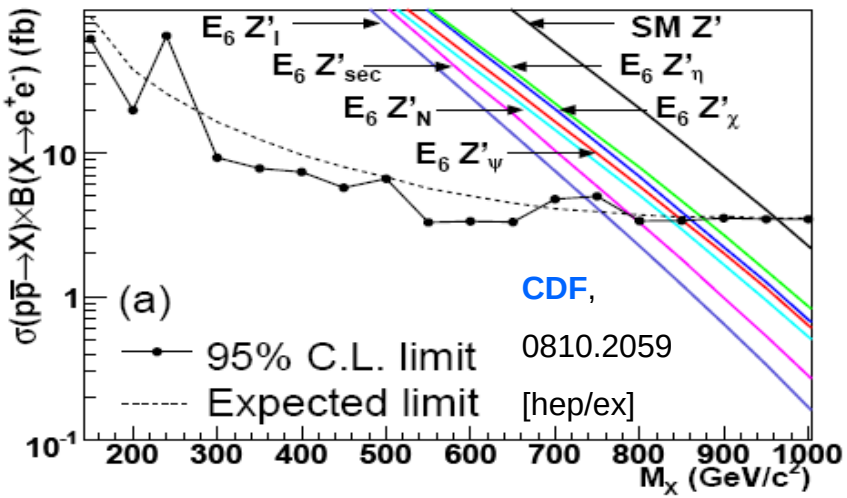
= 95 % CL allowed region for each $M_{Z'}$

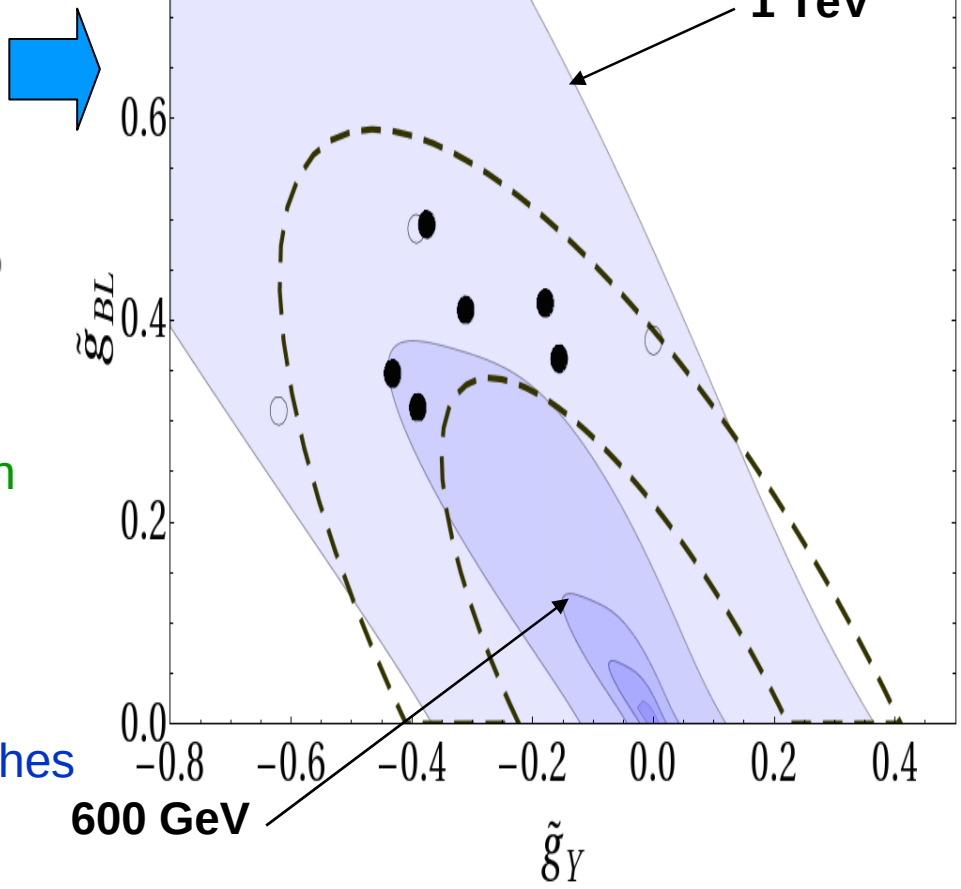


Bounds from the Tevatron

CDF/D0 dielectrons & dimuons: bounds on $\sigma(\bar{p}p \to Z')Br(Z' \to l^+l^-)$

$(l = e,\ \mu)$



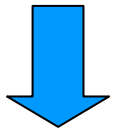


- shape similar to EWPT
- allowed regions grow **faster** than linearly with $M_{Z'}$, due to suppression of PDFs at large *x*

= allowed by direct searches for each $M_{Z'}$

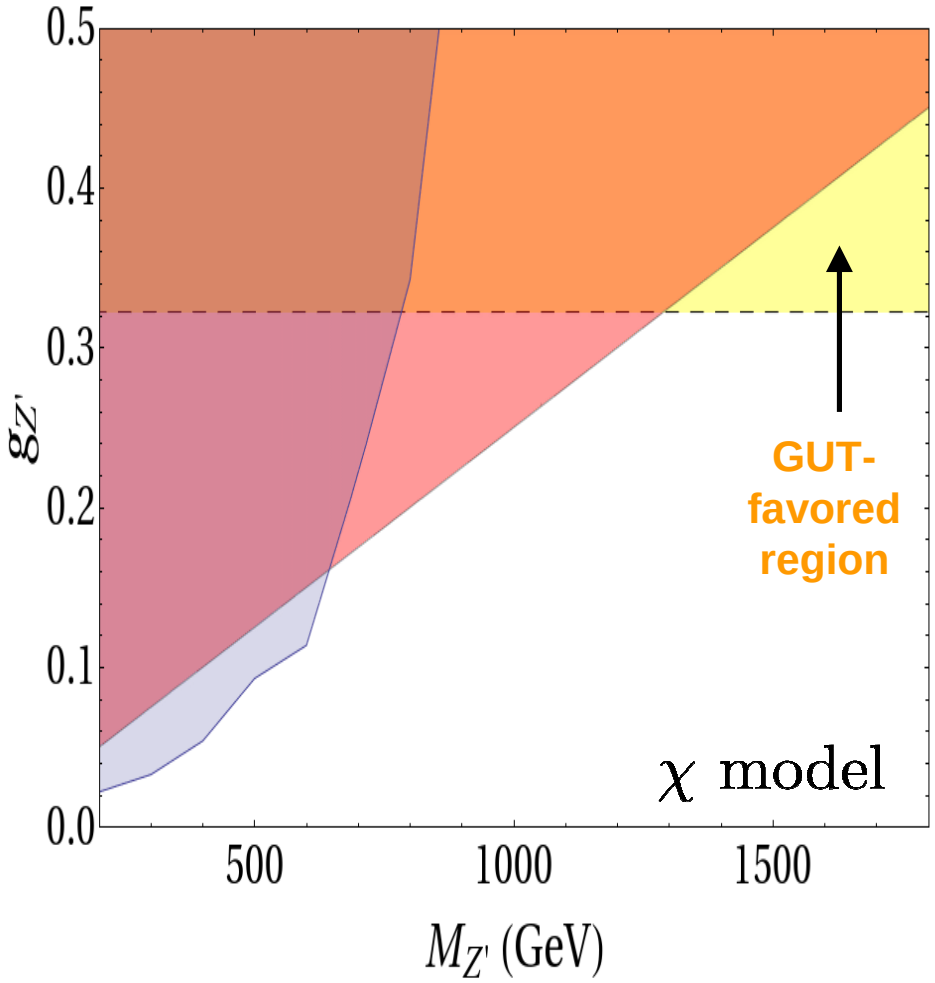
Summary of present bounds

- bounds on $g_{Z'}$ vs $M_{Z'}$ only weakly dependent on the specific model
- Tevatron leading for "low" mass, $M_{Z'} < 700$ GeV with increasing mass, PDF dumping quickly takes over



- EWPT stronger in the high-mass range, in particular for GUT-*Z'*

(see also Contino, arXiv:0804.3195)

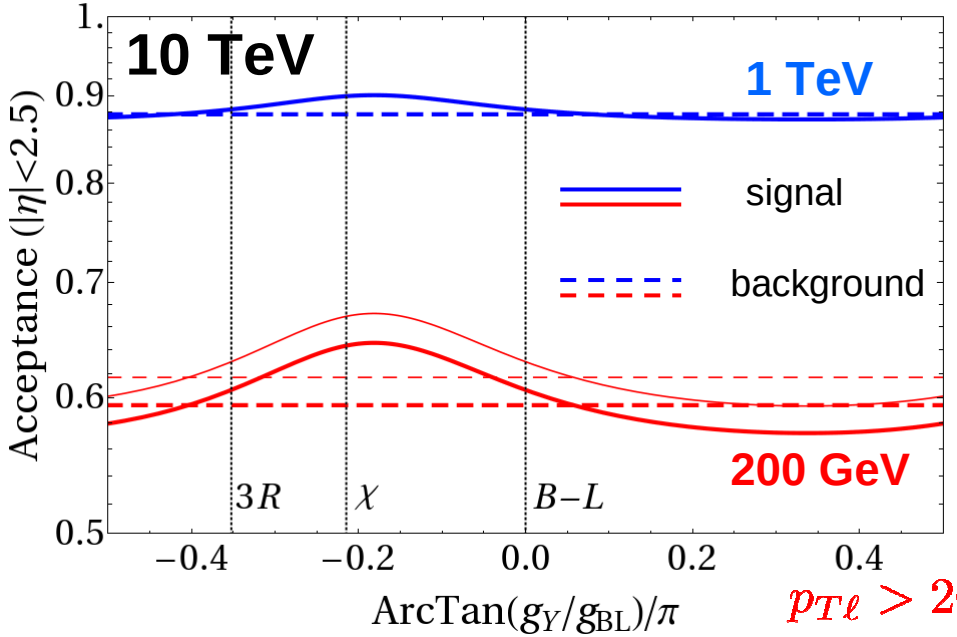


= **excluded** at 95 % CL by EWPT

= **excluded** at 95 % CL by Tevatron

Early LHC reach

- LHC in 2010: CoM energy 7 – 10 TeV, luminosity $50 \div 300\,\mathrm{pb}^{-1}$
- main background : SM Drell-Yan



- **NLO calculation** (MSTW08 PDFs)
- acceptance similar for signal and background
- model-dependence < 10 %

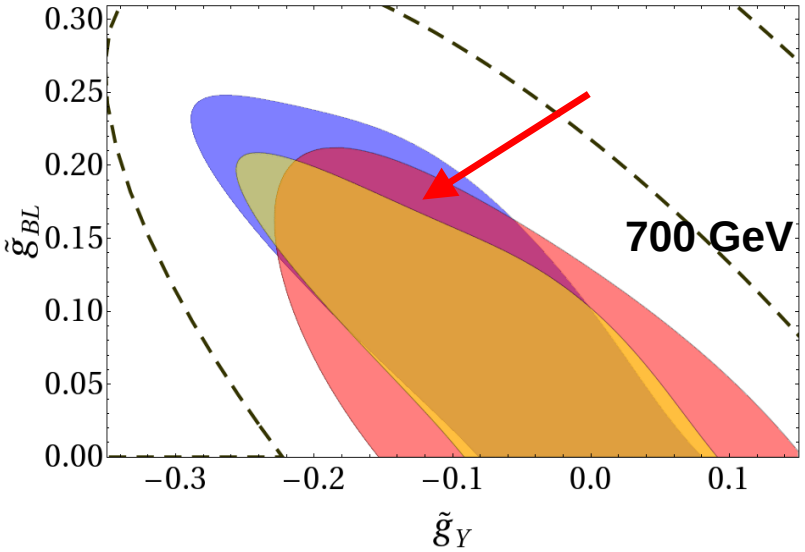
➡ assumed acceptance depending **only on invariant mass** of dilepton pair

$p_{T\ell} > 20\ (\mathbf{80})$ GeV

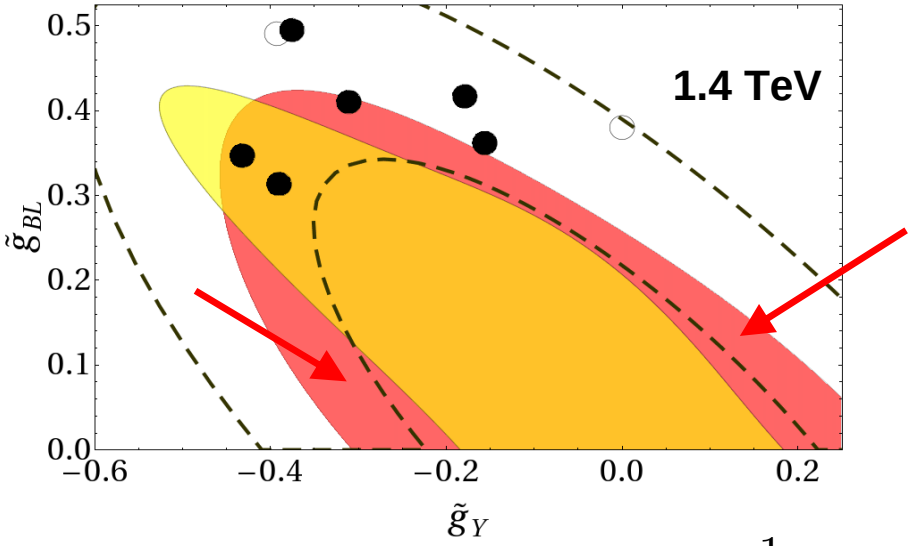
- $\Gamma_{Z'}/M_{Z'} \leq 2\%$, not far from initial experimental resolution

Compare signal & background in $\pm 3\%$ interval (simplifying assumption) around lepton inv. mass ➡ '5σ' discovery limits

Early LHC reach



7 TeV, $100\,\mathrm{pb}^{-1}$



10 TeV, $200\,\mathrm{pb}^{-1}$

= region allowed (95%) by EWPTs

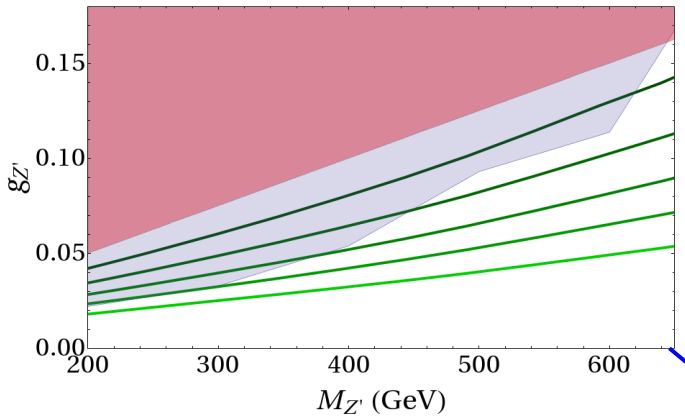
= region allowed (95%) by Tevatron searches

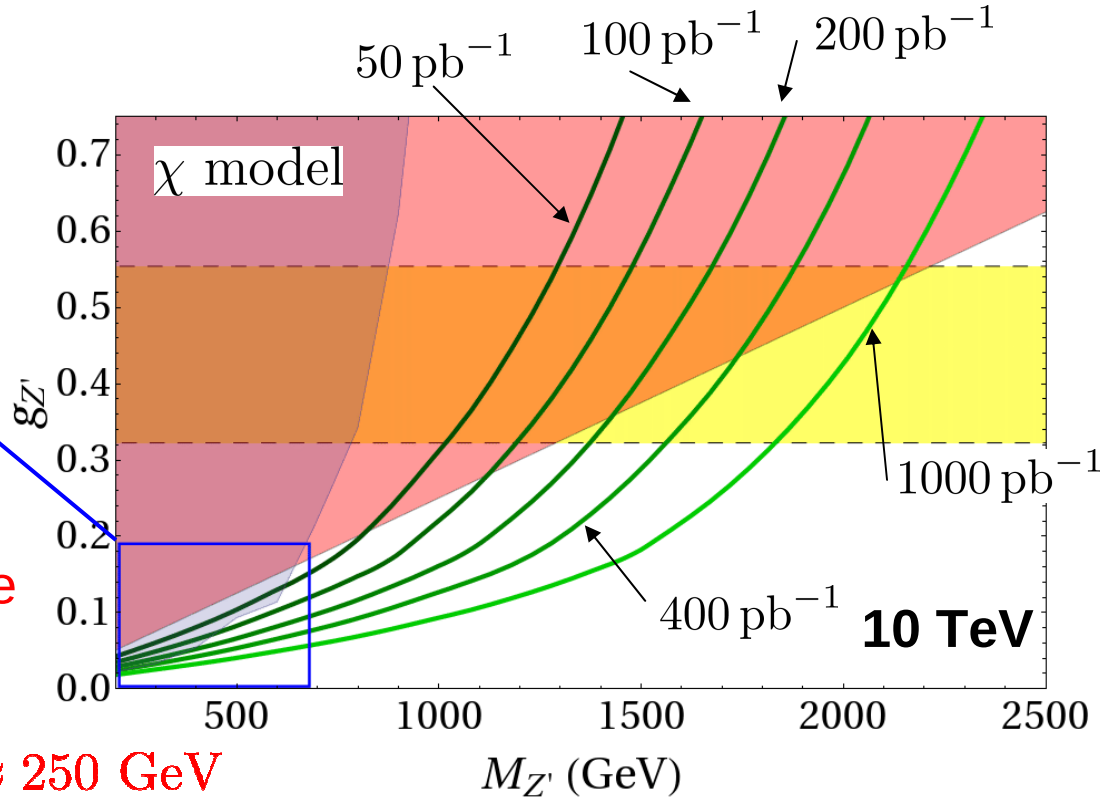
= region NOT accessible to the LHC (5σ discovery)

POSSIBLE DISCOVERY

Early LHC reach: discovery prospects

- At **7 TeV** and $100\,\mathrm{pb}^{-1}$, discovery possible only in a very narrow region at $M_{Z'} = 600 \div 800\ \mathrm{GeV}$
- At **10 TeV** and $200\,\mathrm{pb}^{-1}$, range $M_{Z'} = 400 \div 1500\ \mathrm{GeV}$ opens up, but still for small regions of the $(\tilde{g}_Y, \tilde{g}_{BL})$ plane

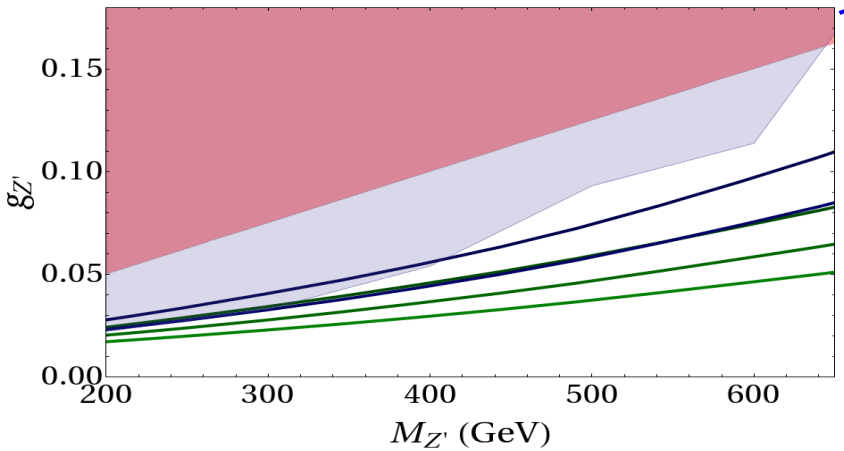


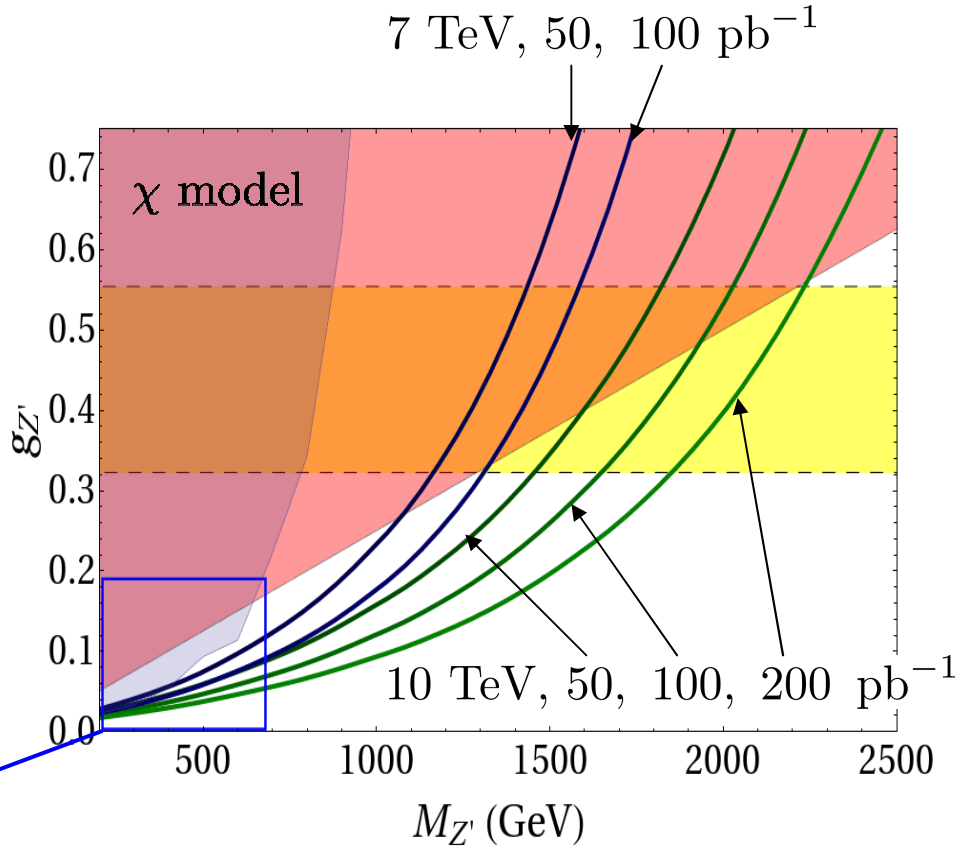


- $O(1)\ \mathrm{fb}^{-1}$ at 10 TeV needed to explore a wide region of parameters for GUT *Z'* and to beat the Tevatron at mass $M_{Z'} \approx 250\ \mathrm{GeV}$

If the Z' does **not** show up…

- already at 7 TeV, $100\,\mathrm{pb}^{-1}$ the LHC will do better than EWPT & Tevatron up to 1.3 TeV
- $200\,\mathrm{pb}^{-1}$ at 10 TeV are enough to push the lower limit on the mass of a GUT *Z'* close to 2 TeV





95 % CL **exclusion**

(region above each curve can be excluded)

Conclusions

- Mixing effects in RGE are important: the running generates sizable corrections to the effective weak-scale couplings.

- Even for minimal *Z'* models, the present experimental bounds (including EWPT!) cannot be neglected in assessing the discovery potential of the LHC in its early phase.

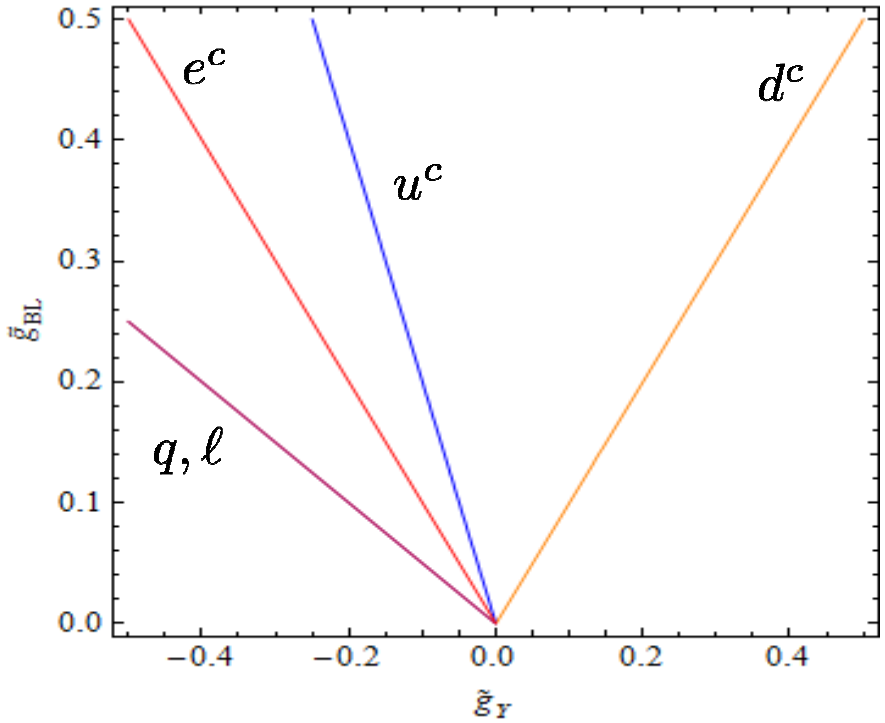
- Not only it is important to increase energy and luminosity as soon as it can be safely done, but also to combine data from different channels and experiments already in the early analyses.

- Different regions of parameter space will open up for discovery at different energies and luminosities.
  This recommends the use of general parameterizations such as the one presented here, as the specific parameterizations commonly employed may focus on regions already ruled out.

Backup slides

Z' charges

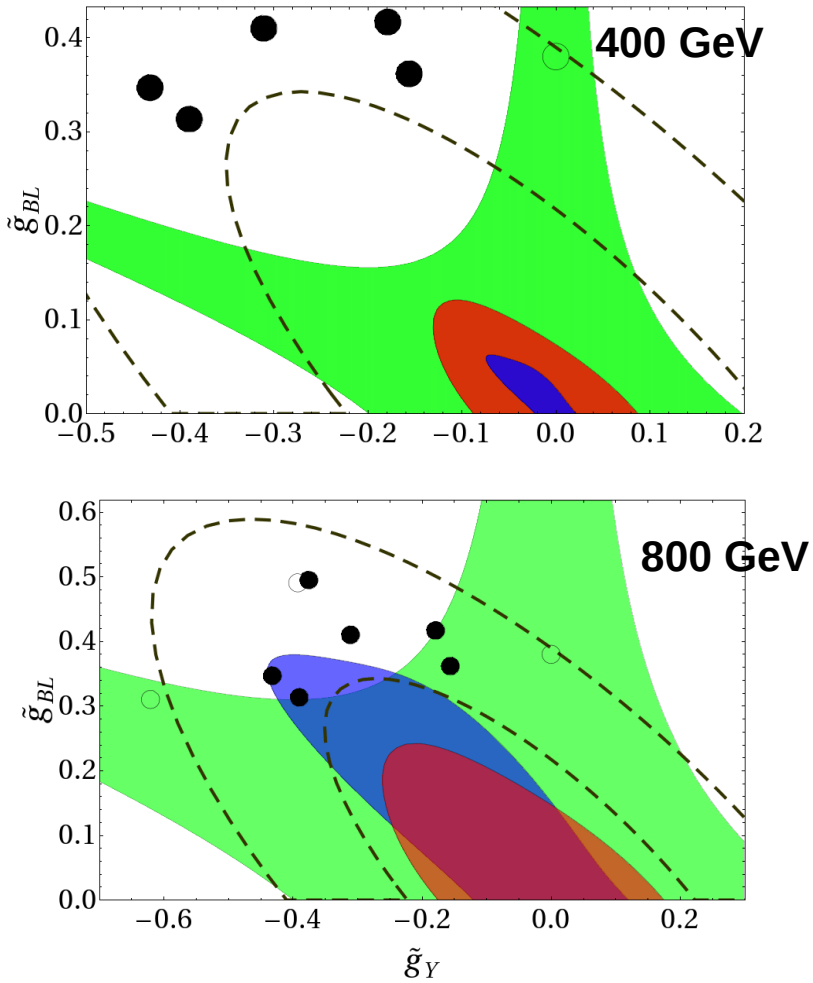
	$q=(u,d)$	u^c	d^c	$\ell=(\nu,e)$	ν^c	e^c
T_{3L}	$(+\frac{1}{2},-\frac{1}{2})$	0	0	$(+\frac{1}{2},-\frac{1}{2})$	0	0
Y	$+\frac{1}{6}$	$-\frac{2}{3}$	$+\frac{1}{3}$	$-\frac{1}{2}$	0	$+1$
$B-L$	$+\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	-1	$+1$	$+1$
$Q_{Z'}$	$\frac{1}{6}\widetilde{g}_Y+\frac{1}{3}\widetilde{g}_{BL}$	$-\frac{2}{3}\widetilde{g}_Y-\frac{1}{3}\widetilde{g}_{BL}$	$\frac{1}{3}\widetilde{g}_Y-\frac{1}{3}\widetilde{g}_{BL}$	$-\frac{1}{2}\widetilde{g}_Y-\widetilde{g}_{BL}$	$\widetilde{g}_{BL}$	$\widetilde{g}_Y+\widetilde{g}_{BL}$



Matter fields least coupled to the *Z'* for

$$\widetilde{g}_Y \approx -\widetilde{g}_{BL}$$

APV: recent re-analysis



- APV was included in fit to electroweak data
- re-analysis in (Porsev-Beloy-Derevianko, 0902.0335)

↓

- new bounds from APV can be stronger than those from the Tevatron, but are always weaker than previous EWPT

green = bound from APV