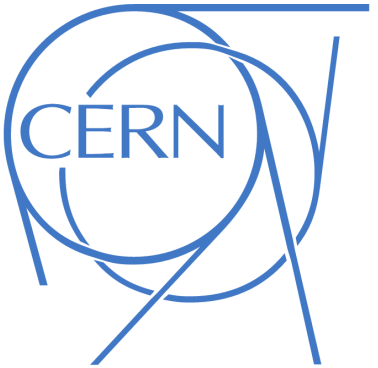
*Rencontres de Moriond 2010 EW – Mar. 6-13, 2010*

# Z′ review

**Giovanni Villadoro**




**Refs.**

**0909.1320: Salvioni, GV, Zwirner**

**0911.1450: Salvioni, Strumia, GV, Zwirner**

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- *Grand Unified Theories ( SO(10), $E_6$ … ) ,*
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## *Z': a smoking gun for new physics*

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*Both indirect (LEP2, EWPT, APV, $(g\text{-}2)_\mu$ …) and direct (Tevatron) searches see no significant deviation from SM (except for some 'few-$\sigma$' fluctuations)*

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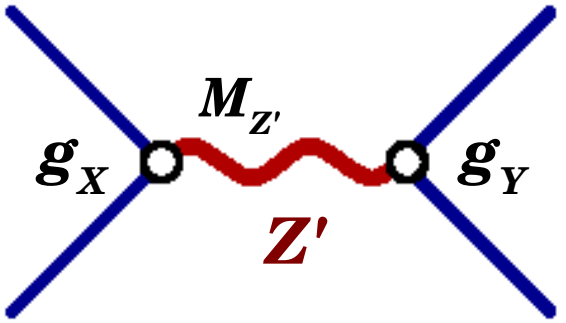
⇒ *Bounds on Z′ parameters*



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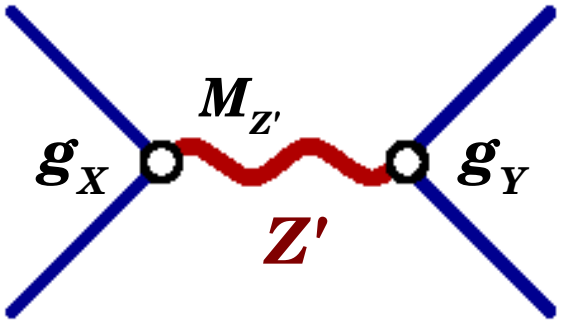


***The most general Z' couplings:***

$$Z'_\mu \left( g_e J_e + \ldots + g_\tau J_\tau + g_u J_u + \ldots g_t J_t + \right)^\mu$$

$$+ Z'_\mu \left( g_{WW}\, W^{+\nu}\, \partial_\nu W^{-\mu} + g_{Zhh}\, Z^\mu\, h\, h + \ldots \right) + \ldots$$

<u>*very model dependent…*</u>

$Z_\chi$, $Z_\psi$, $Z_{LR}$, $Z_{B\text{-}L}$, $Z_\eta$, $Z_{leptophobic}$, $Z_{KK}$, $Z_{composite}$, $Z_{string}$, ……..

***see e.g. Langacker 2008***

## *Working example – the **minimal Z'***

*SM + Z′ and only renormalizable couplings*

***Appelquist, Dobrescu and Hopper 2002***

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| $g_Y$ | $0$ | $-\frac{2}{\sqrt{10}} g_{Z'}$ | $-g_{Z'}$ |
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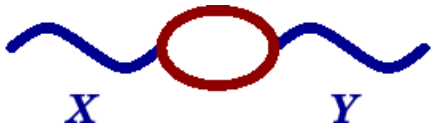


***Holdom 1986***

$$-\frac{1}{4} h_{AB} F^A_{\mu\nu} F^{B\,\mu\nu}$$

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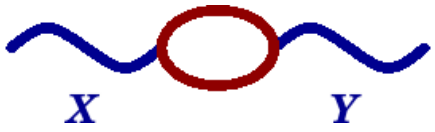


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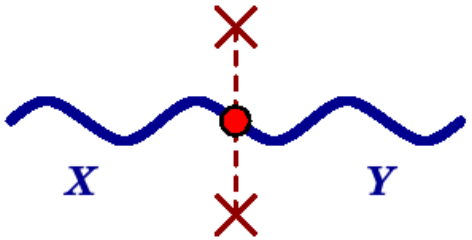


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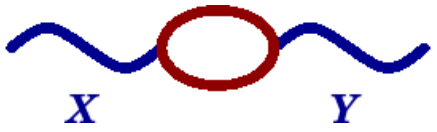


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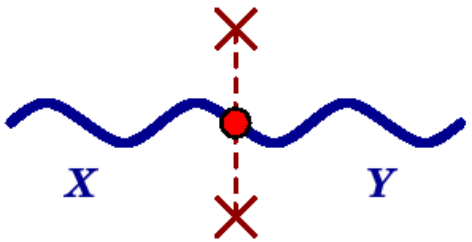


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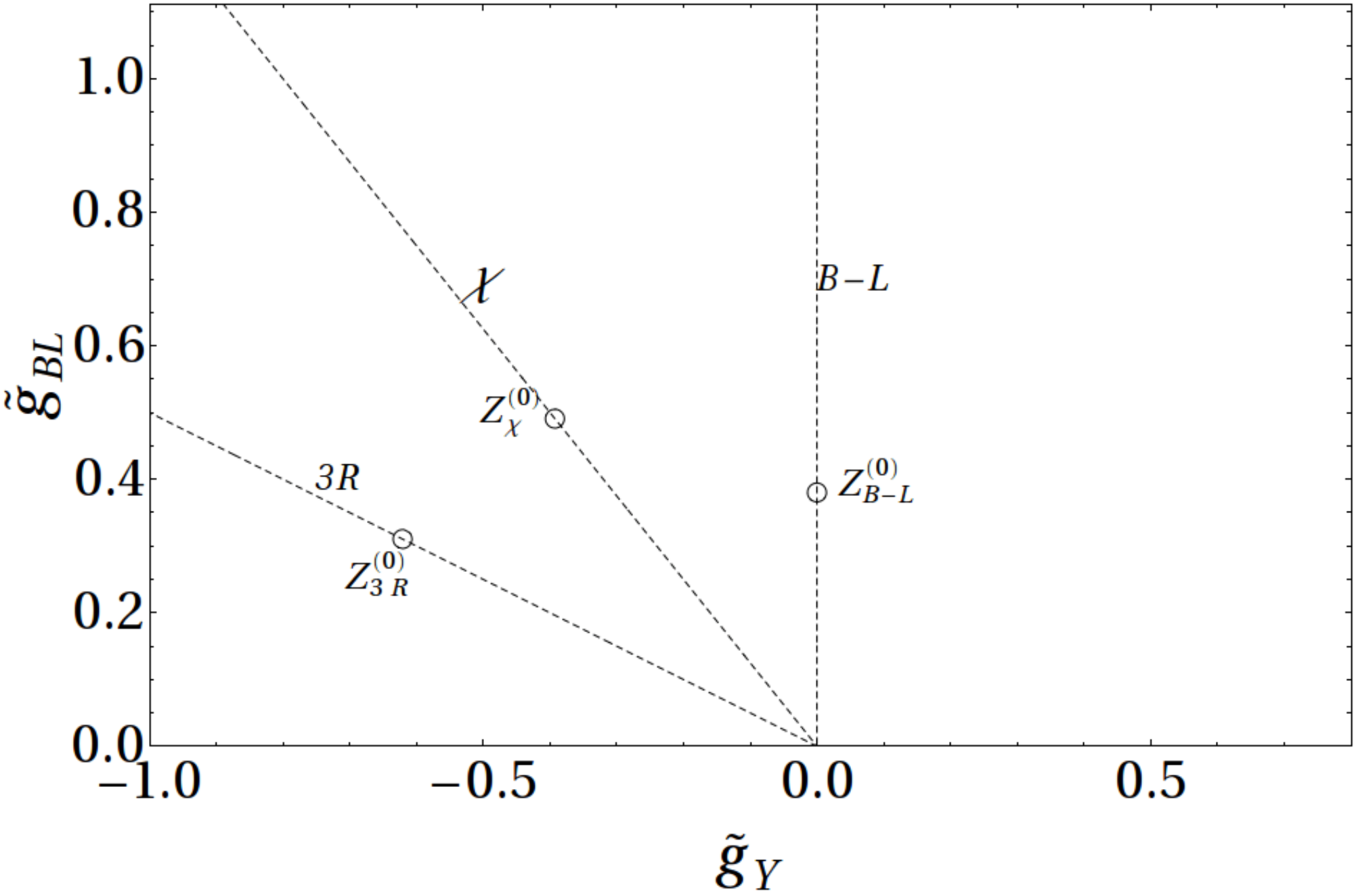
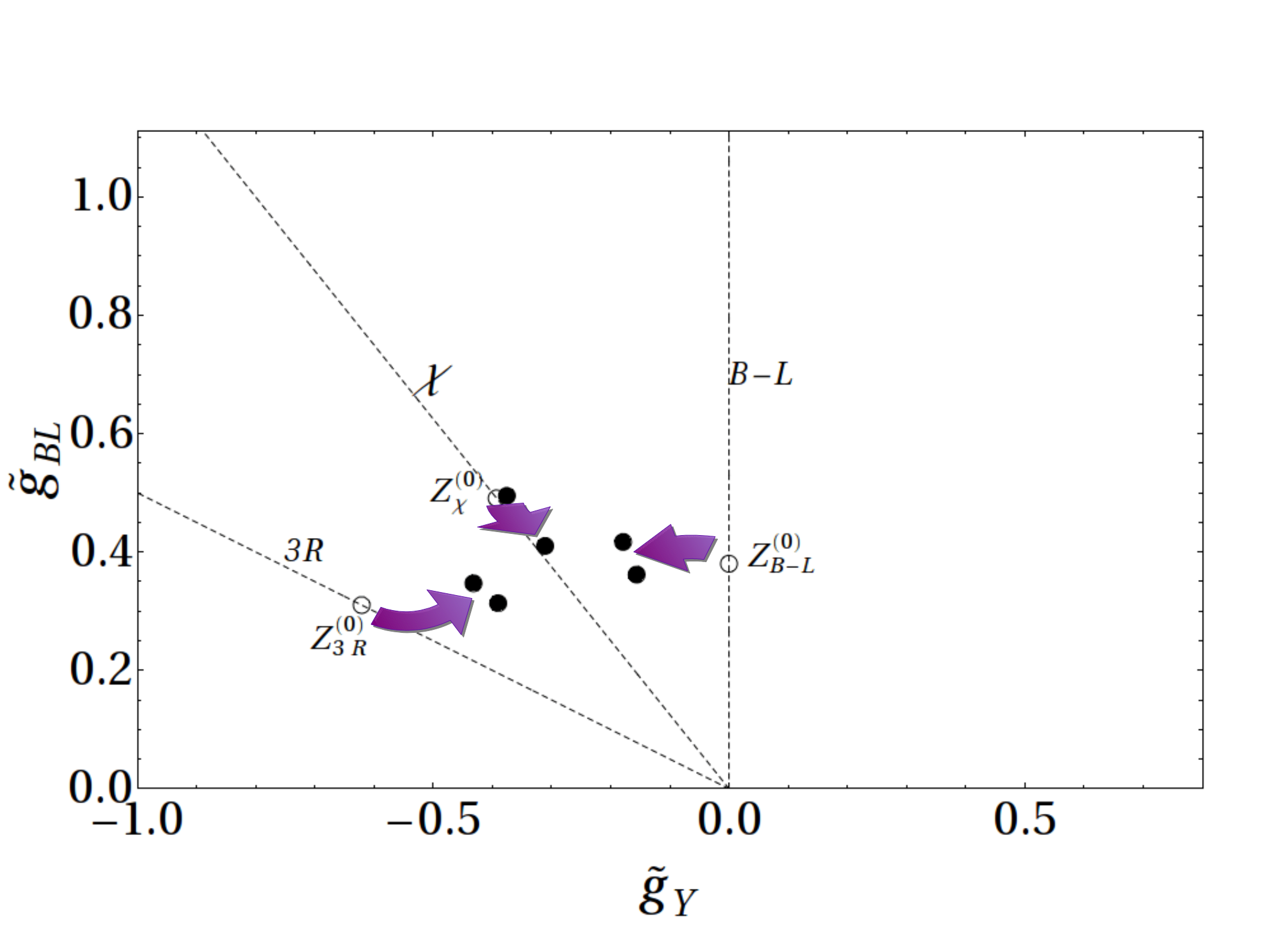
***Z – Z' mixing angle:***

$$\tan\theta' = -\tilde{g}_Y \frac{M^2_{Z^0}}{M^2_{Z'} - M^2_{Z^0}}$$


1.0
0.8
0.6
0.4
0.2
0.0
−1.0
−0.5
0.0
0.5
$\tilde{g}_{BL}$
$\tilde{g}_Y$
$\chi$
$B-L$
$3R$
$Z_\chi^{(0)}$
$Z_{B-L}^{(0)}$
$Z_{3\,R}^{(0)}$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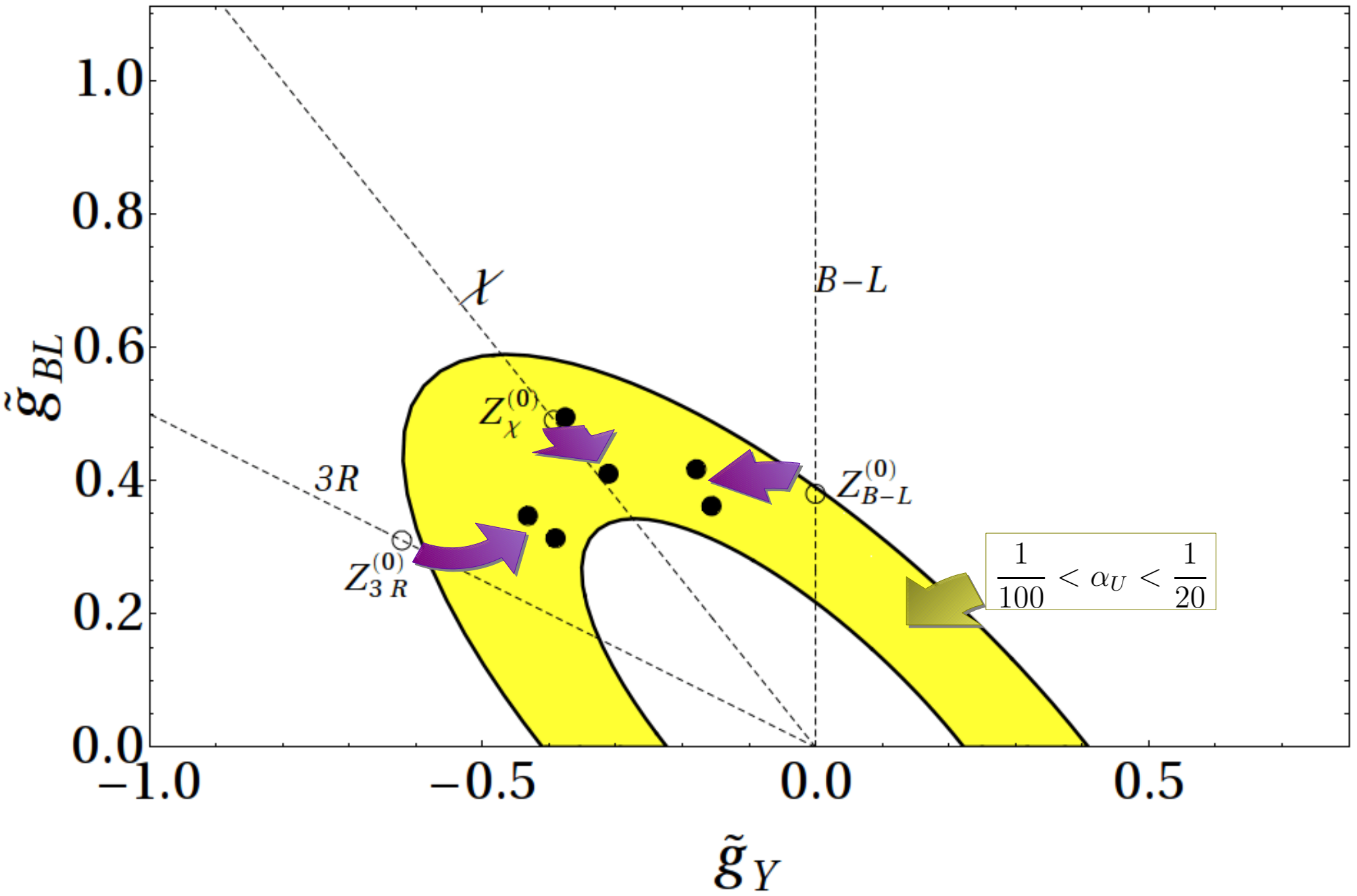
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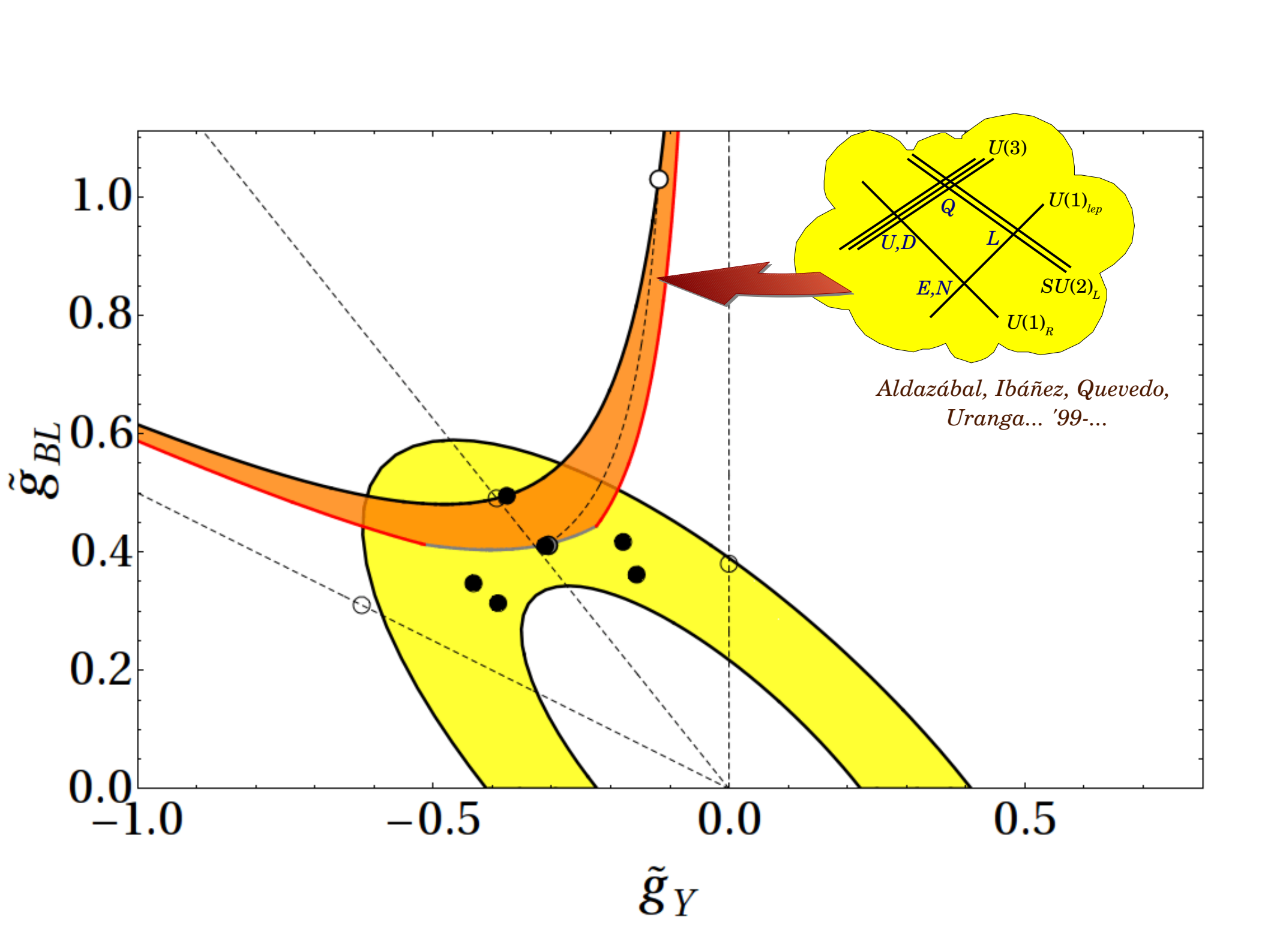
$\frac{1}{100} < \alpha_U < \frac{1}{20}$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0.0
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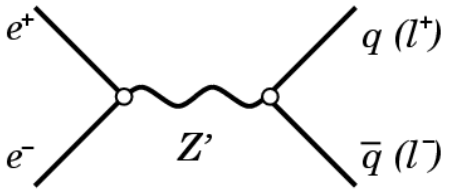
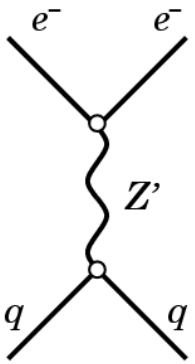
$\tilde{g}_{BL}$
$\tilde{g}_Y$
U(3)
Q
U(1)lep
U,D
L
E,N
SU(2)L
U(1)R
Aldazábal, Ibáñez, Quevedo,
Uranga... '99-...

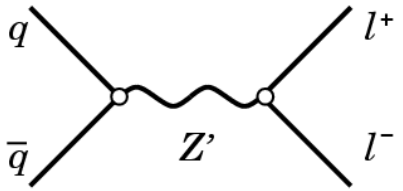
# *EWPT vs Tevatron vs LHC*




LEP




APV




Tevatron/LHC

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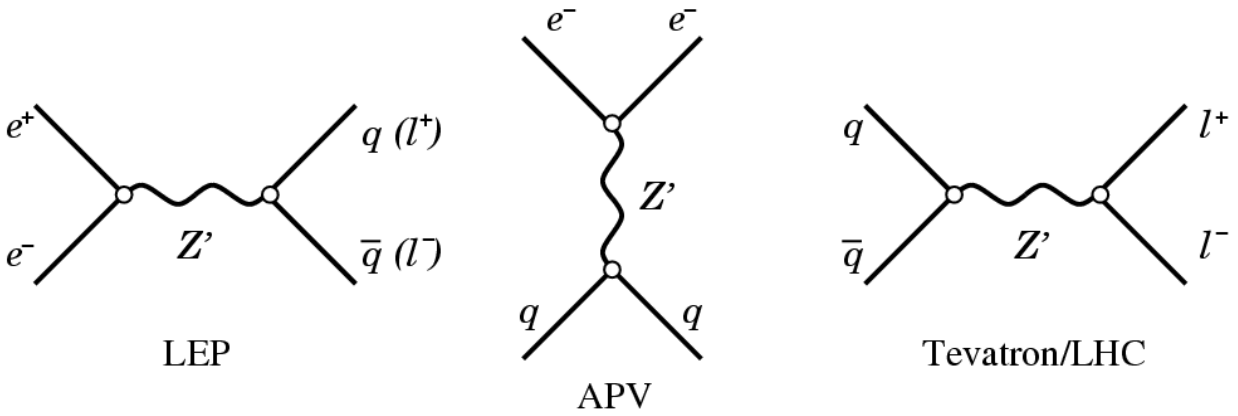
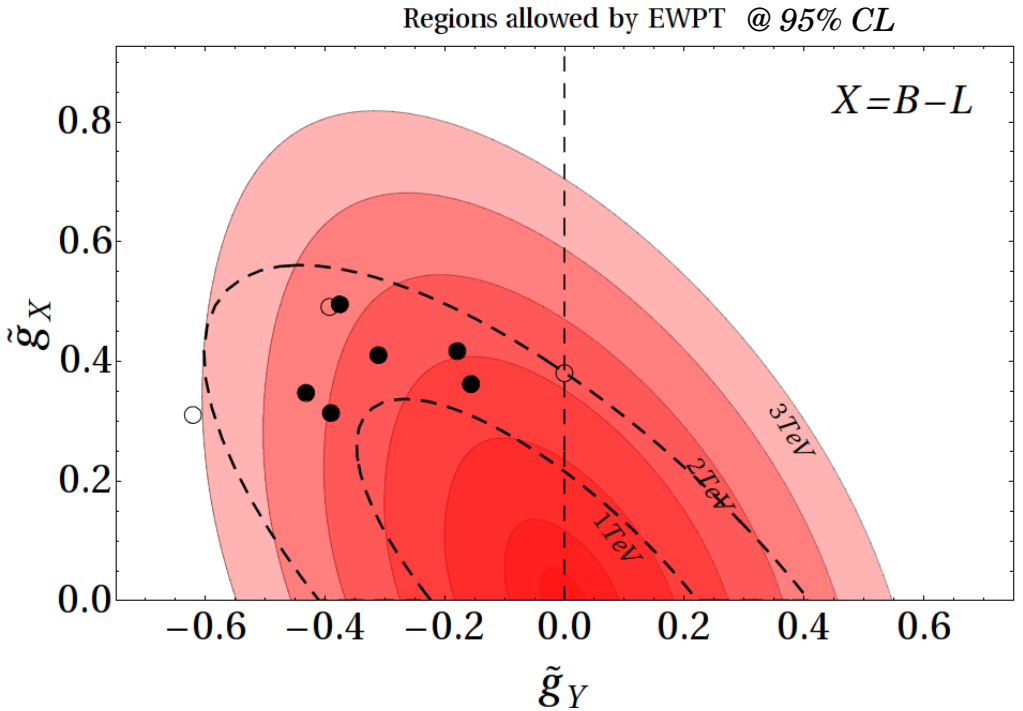



**LEP1, Tevatron, SLD:** $M_Z$, $M_W$, $m_{top}$, $G_F$, $\alpha_s(M_Z)$, $\alpha_{em}(M_Z)$, $\Gamma_Z$, $\sigma(e^+e^- \to hadrons)$, $A_{FB}^{e,\mu,\tau,b,c}$, *τ-pol asym*, $BR(Z \to hadrons, cc, bb)$, $A_{LR}^{e,\mu,\tau,b,c}$. **LEP2 (183÷207 GeV):** $\sigma(e^+e^- \to qq, bb, \mu^+\mu^-, \tau^+\tau^-)$, $A_{FB}^{\mu,\tau,b}$, $d(e^+e^- \to e^+e^-)/d\cos\theta$ **Low-energy measurements:** *Möller scattering at* $Q^2 = 0.026\ GeV^2$, *APV in Cs*, *ν-N* (NuTeV), $(g-2)_\mu$



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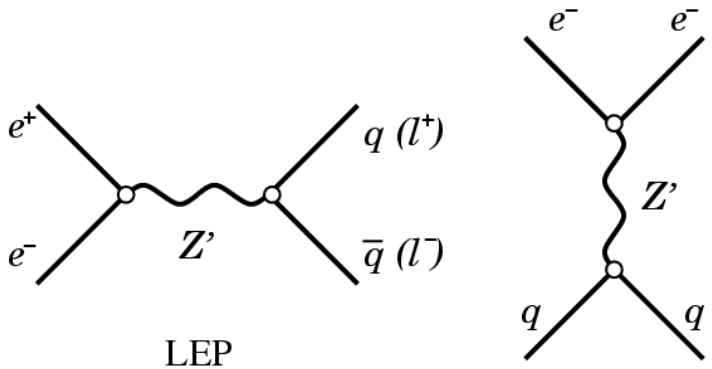
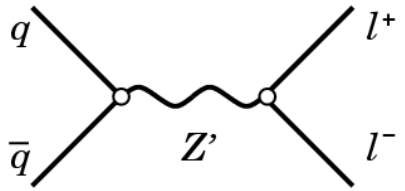



LEP




APV

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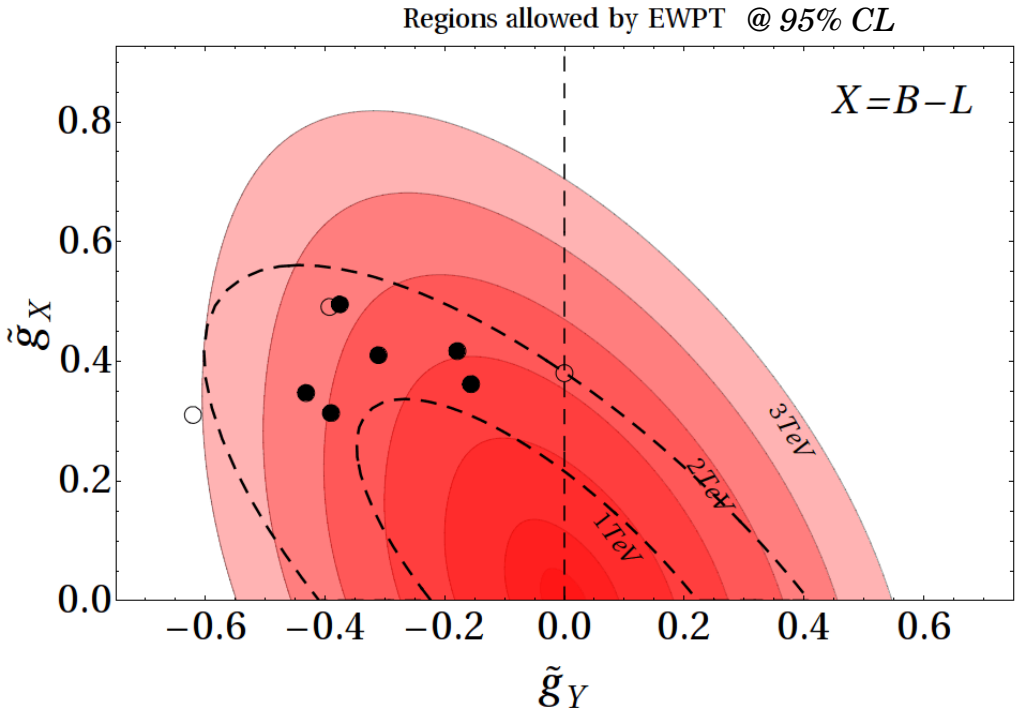
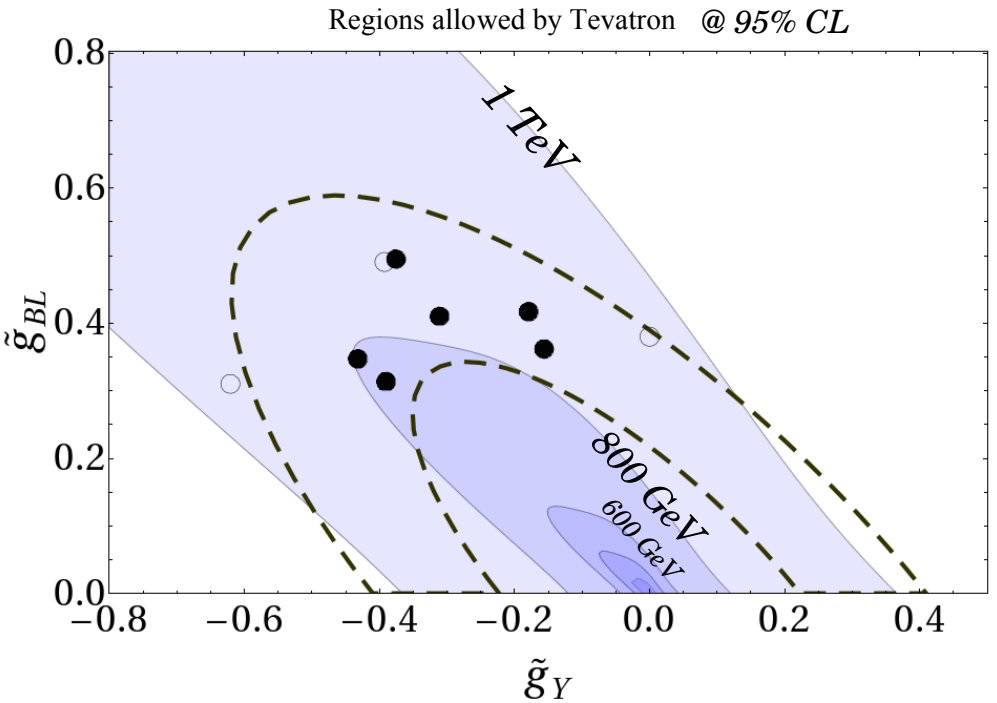
***Tevatron:*** $\sigma(p\bar{p} \to Z'X) \times BR(Z' \to l^+l^-)$

CDF ('08): $e^+e^-$ (2.5 fb$^{-1}$, 27÷38%)

D0 ('09): $e^+e^-$ (3.6 fb$^{-1}$, 17÷22%)

CDF ('08): $\mu^+\mu^-$ (2.3 fb$^{-1}$, 13÷40%)



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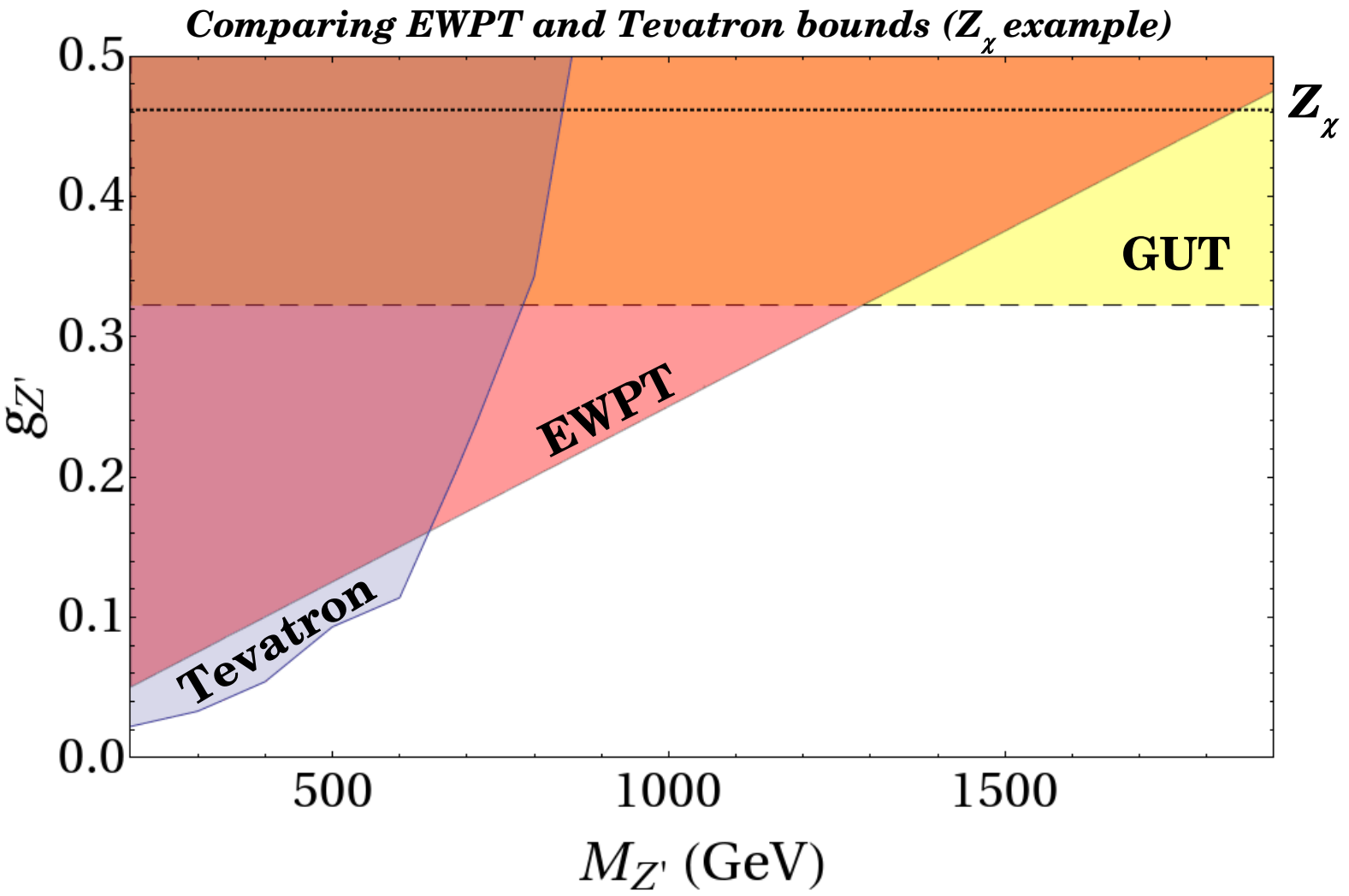

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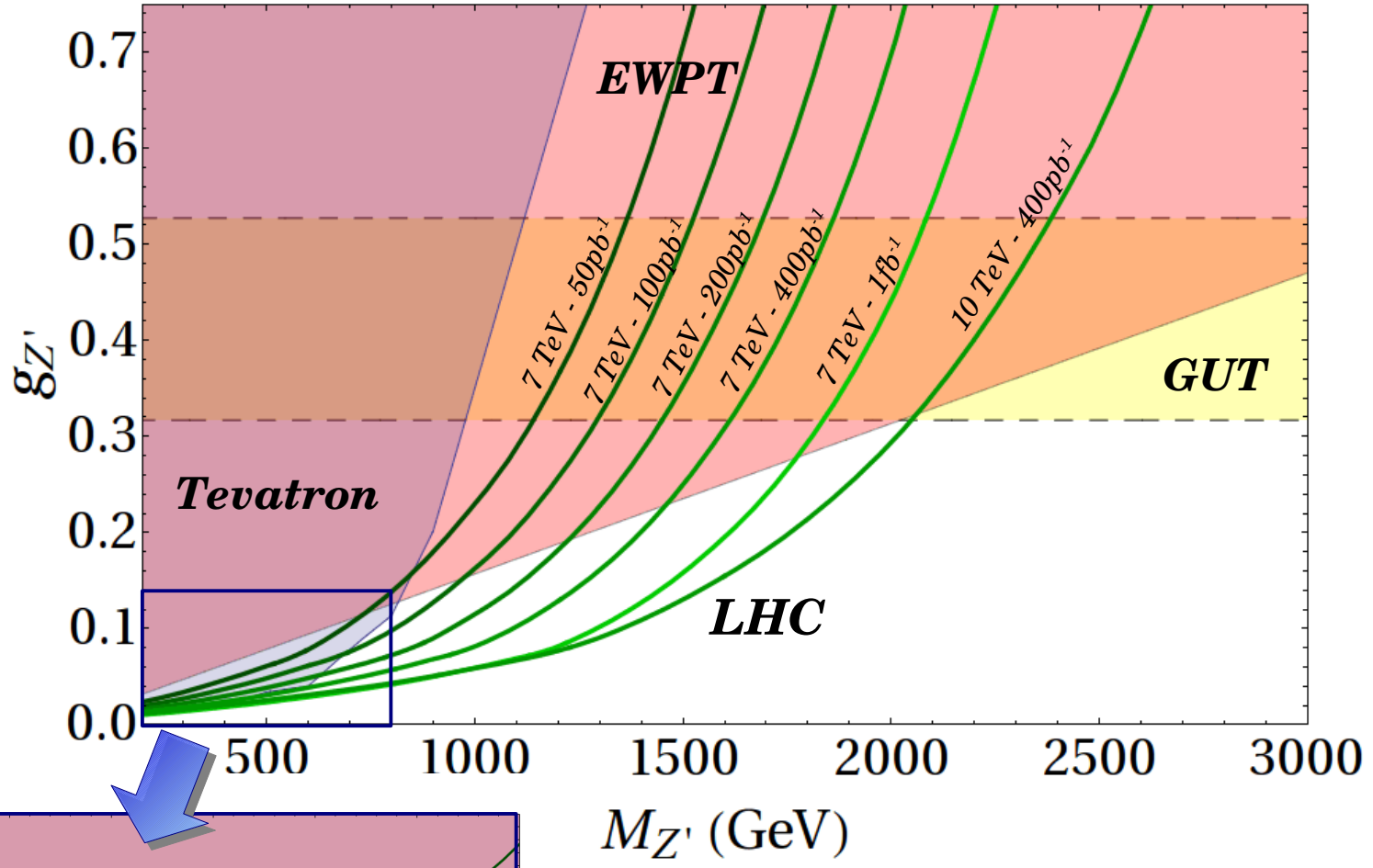


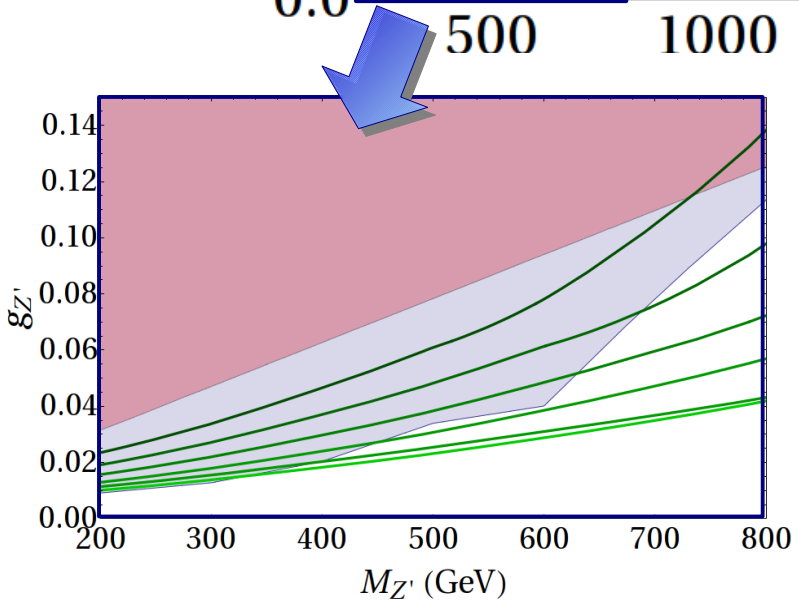


## LHC: 5σ discovery reach

***assuming:***

***only SM DY-background***

***50-85% acceptance (from $p_T$, rapidity cuts, etc.)***

***3% energy resolution (Z' width)***

***(PDFs at NLO)***

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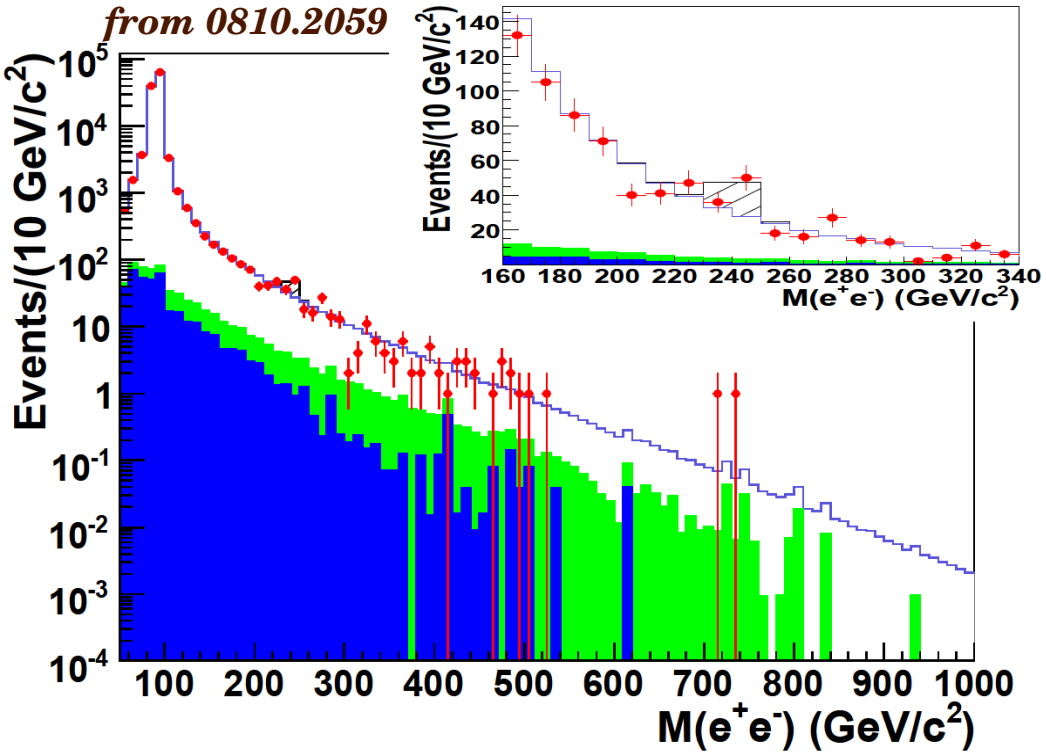
**2 examples:** $Z'_{\mu}\left(g_Y J_Y + g_X J_X\right)^{\mu}$

1) $X = B - 3\,L_e$

2) $X = B - 3\,L_{\mu}$

# *1) The CDF dielectron excess: a playground for the* $X = B - 3L_e$ *model*



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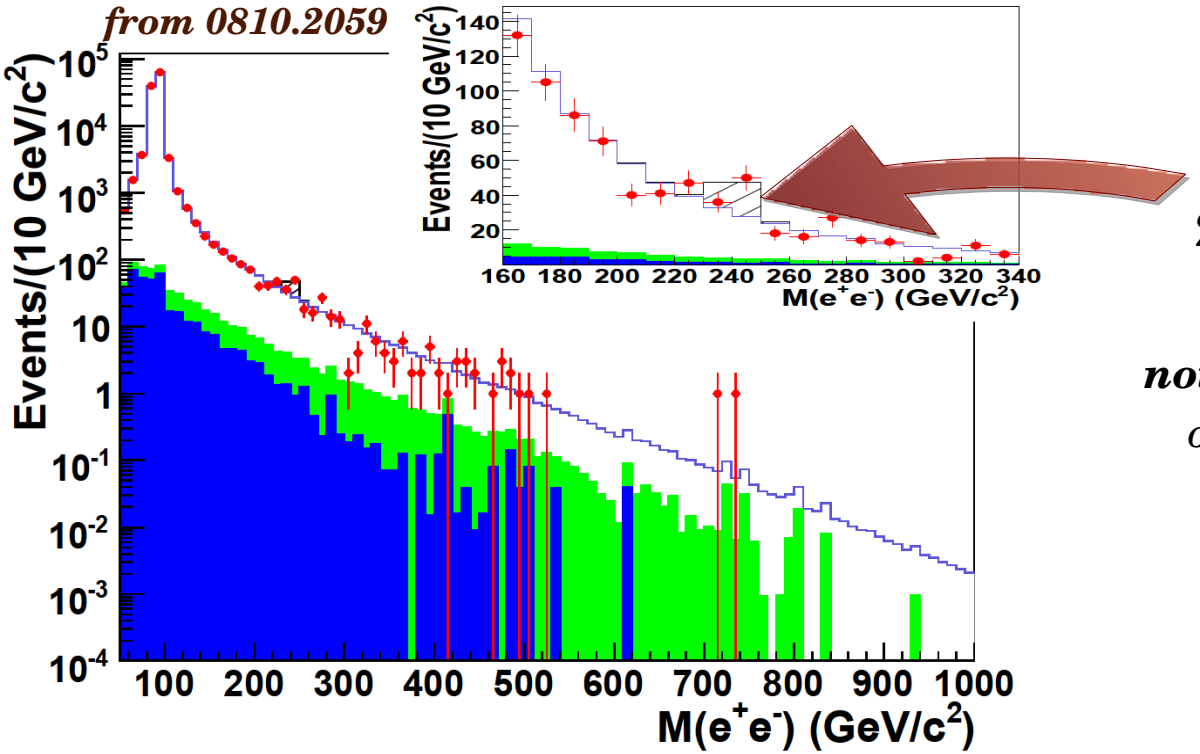


*Luminosity: 2.5 fb⁻¹*

**2.5σ *excess* @ ~ 240 GeV**

***not seen in CDF dimuon channel !***

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*(but less significant)*

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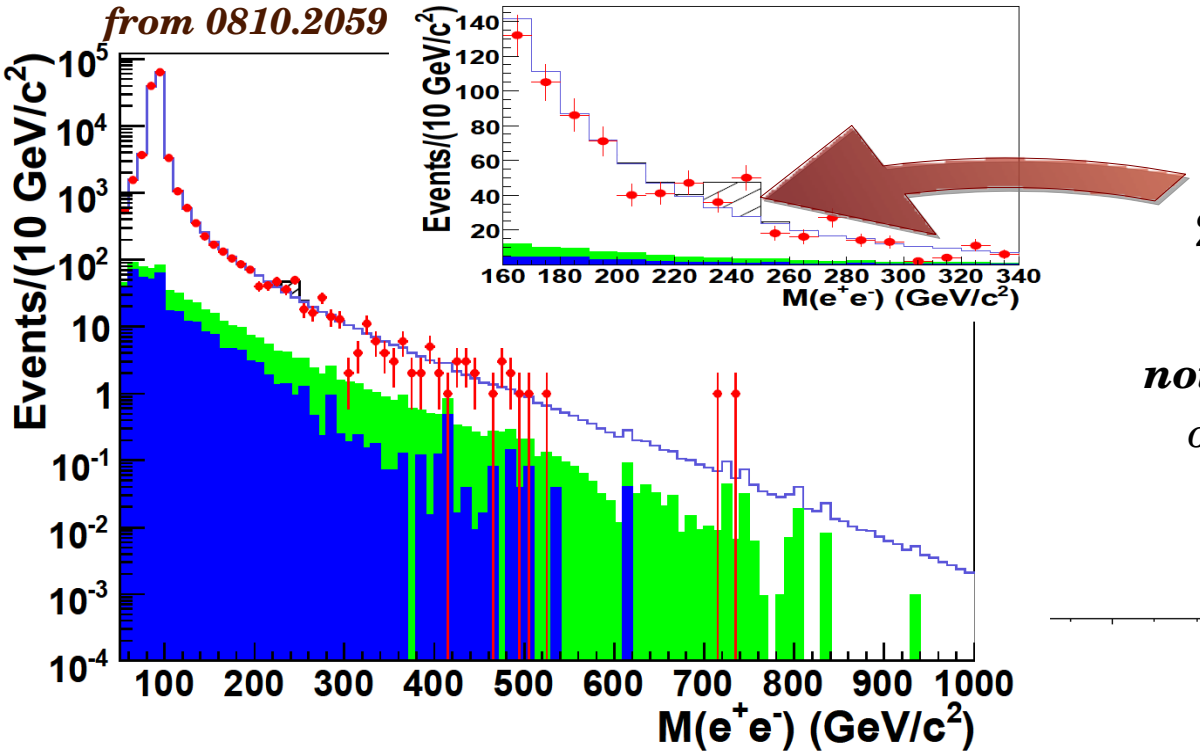


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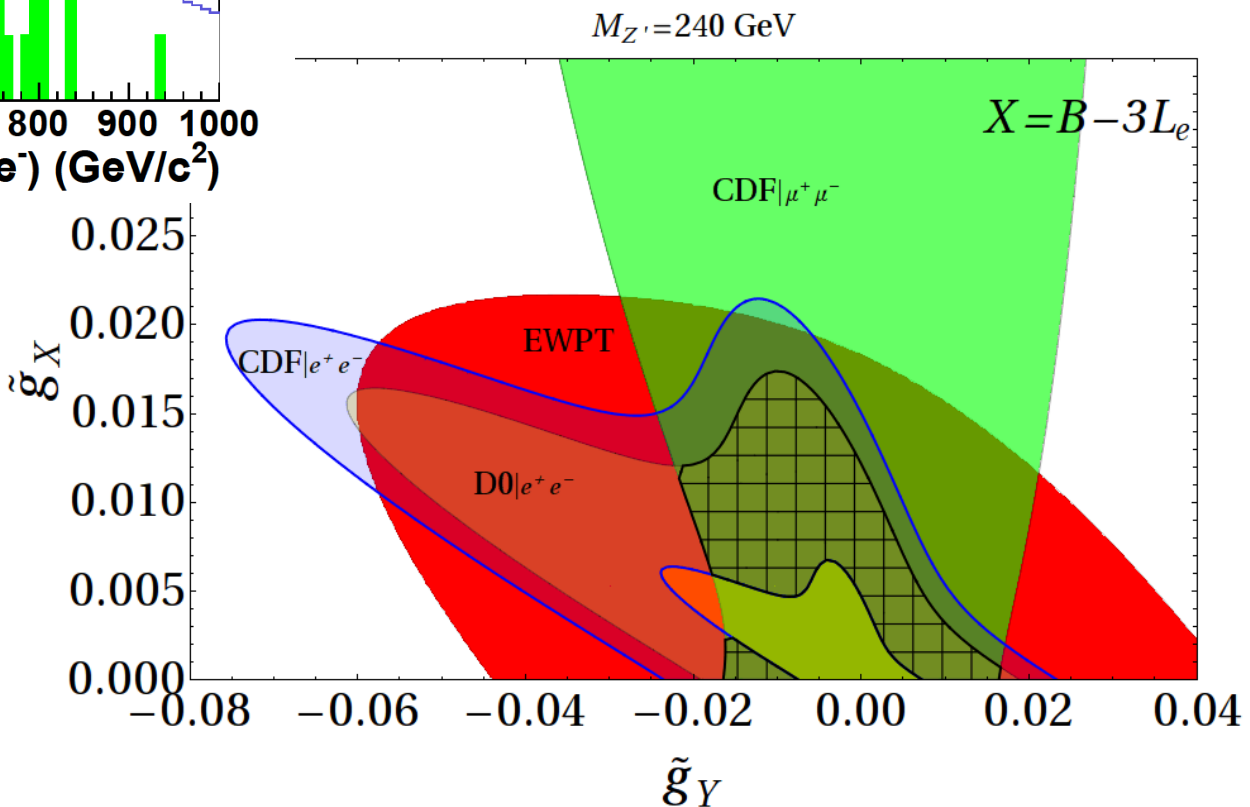

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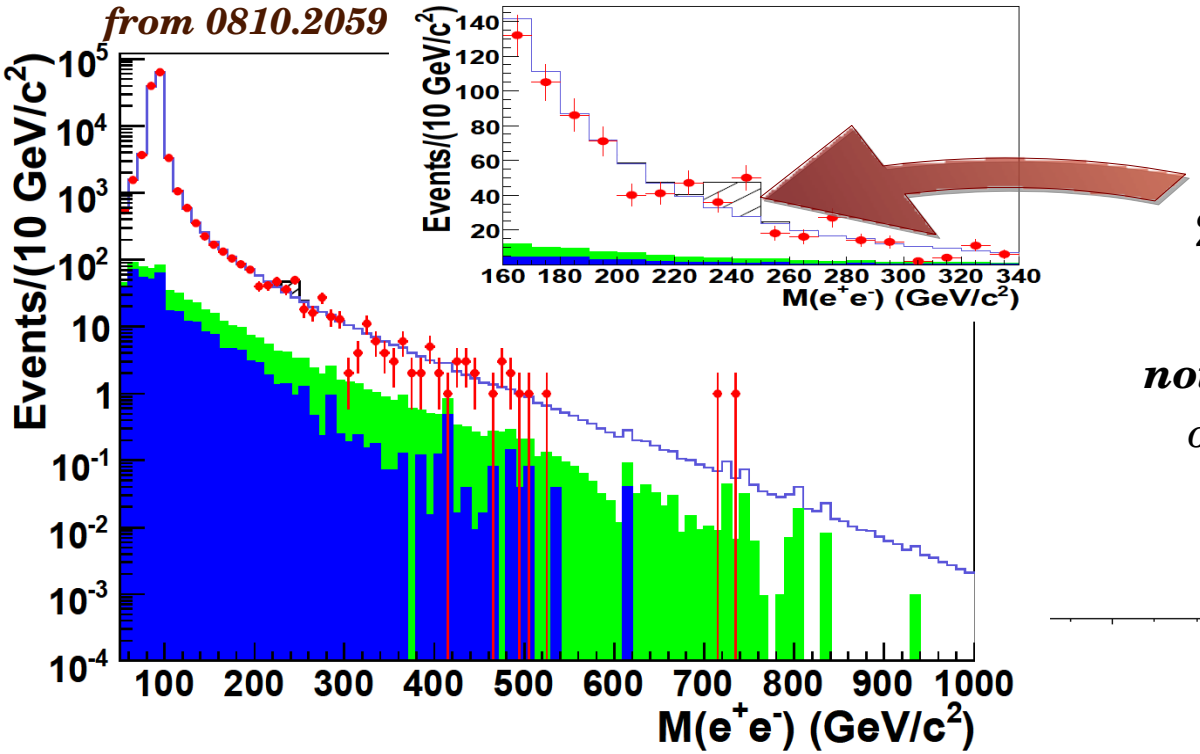


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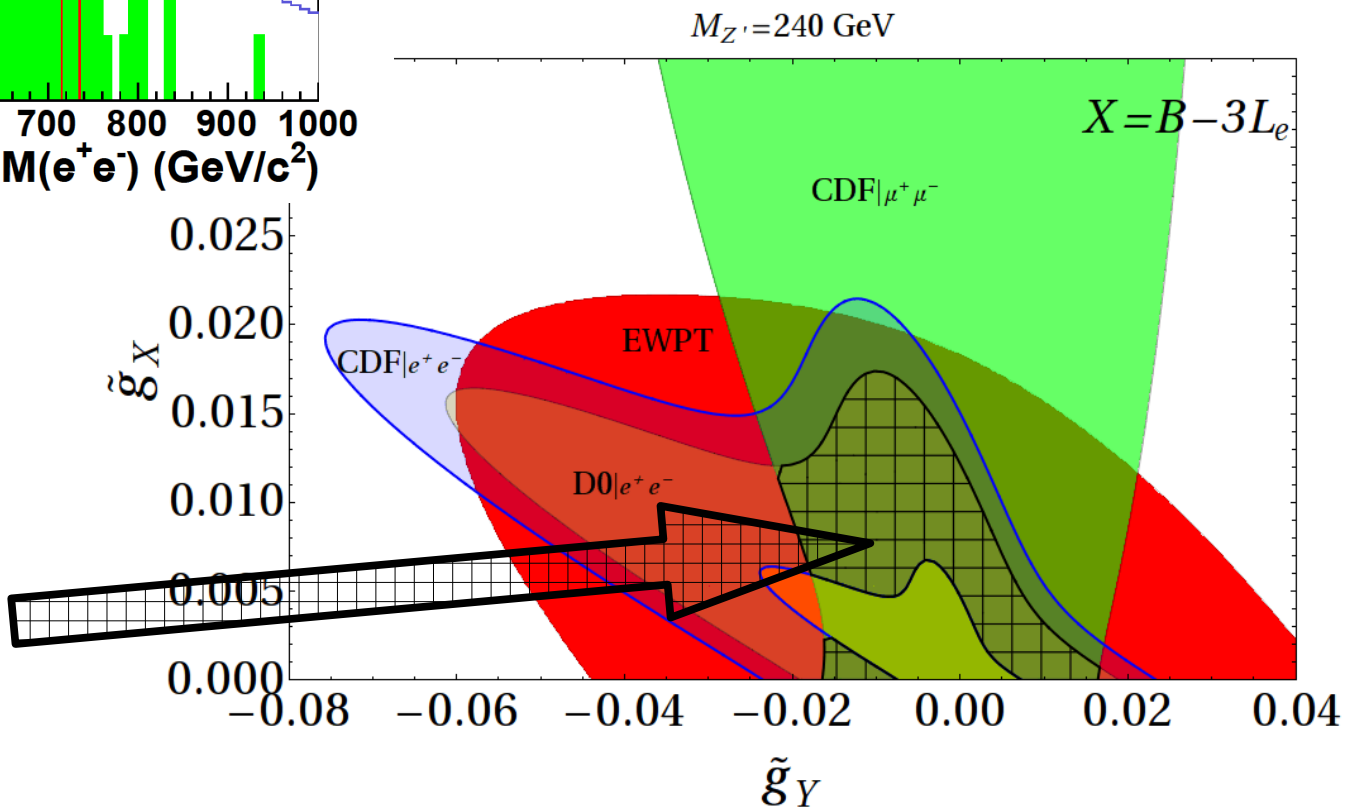


***Region allowed by all experiments***

# *The* $X = B - 3L_\mu$ *as a* ***supermodel***

1) ***no coupling to electrons ⇒ weak bounds from EWPT***

2) ***Tevatron limited to ~ 1 TeV***

***easily accessible at very early LHC***

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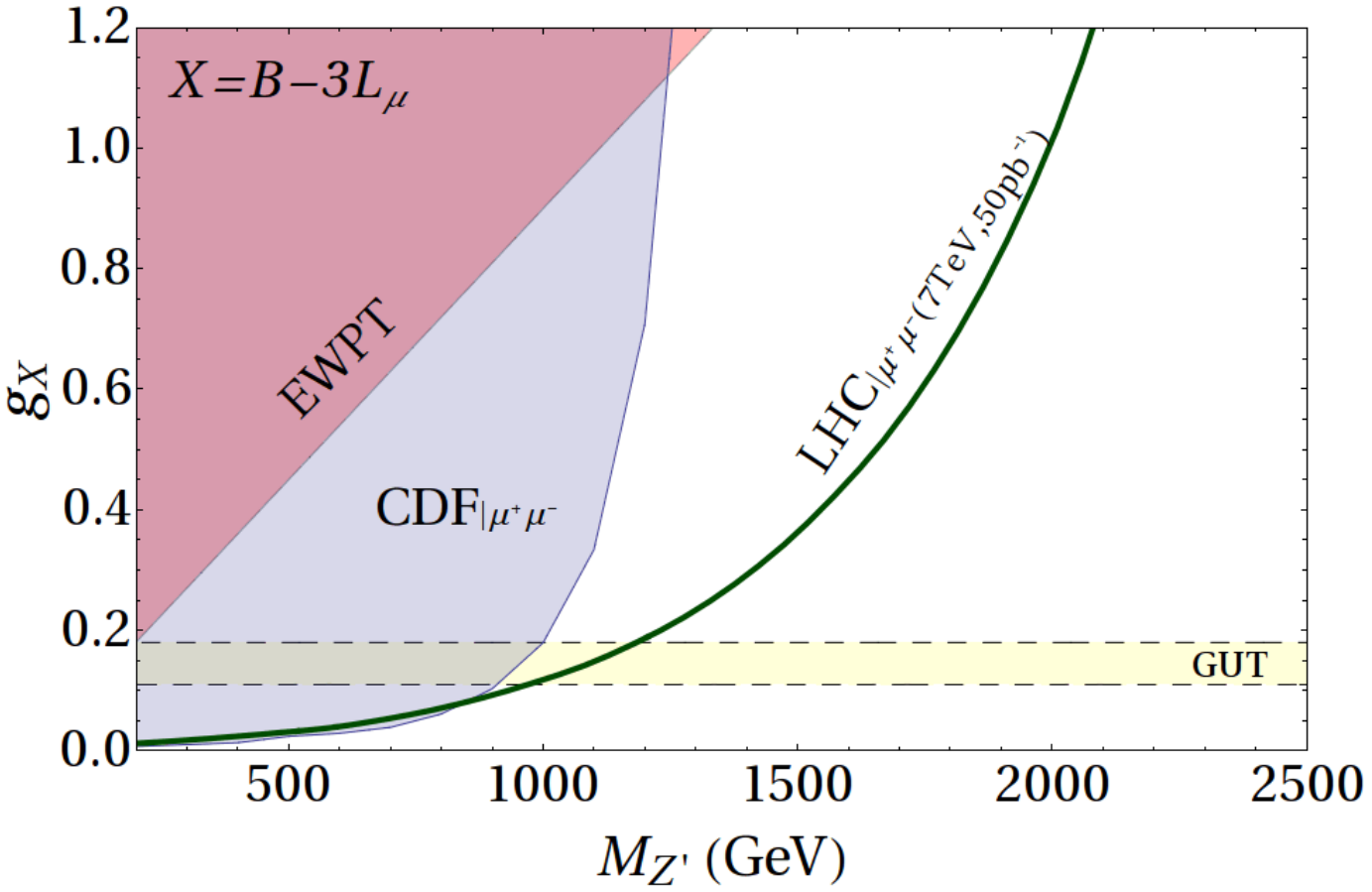
1) ***no coupling to electrons ⇒ <u>weak bounds from EWPT</u>***

2) ***<u>Tevatron limited to ~ 1 TeV</u>***

***easily accessible at very early LHC***

***e.g.* 7 TeV & 50 pb$^{-1}$**



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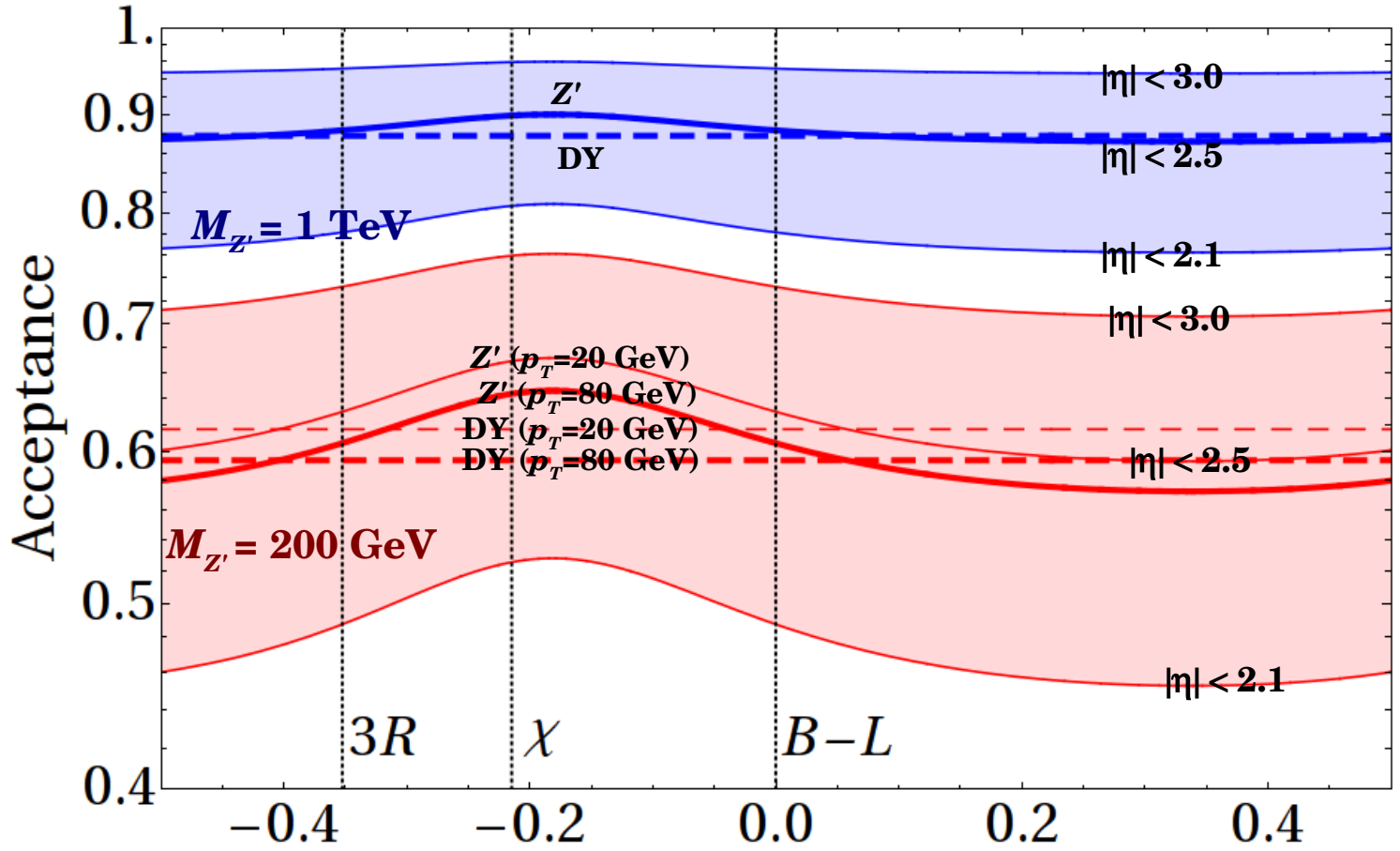
***Lesson:***

*Important to consider all existing constraints*

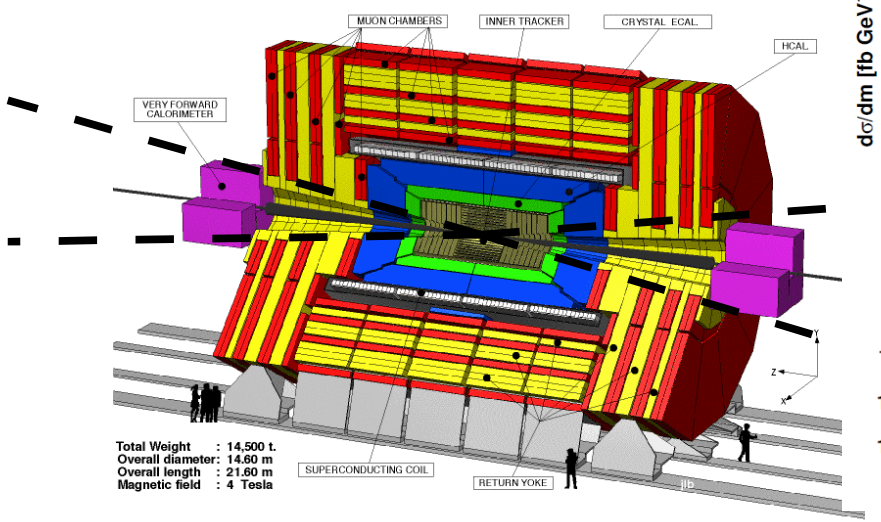
*at least for the early phase of the LHC*

# *Back-up*

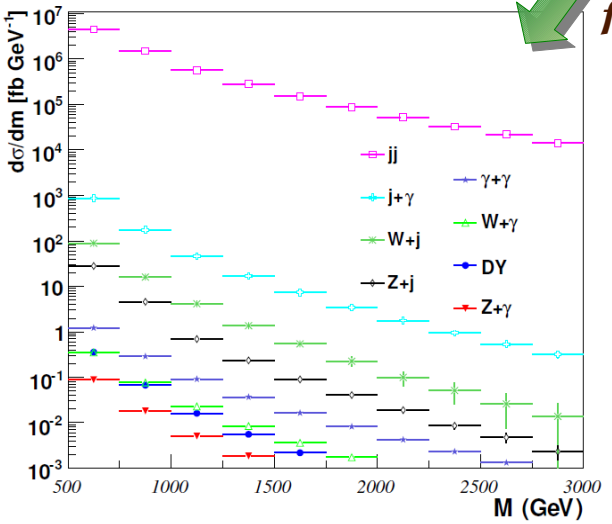



## *Acceptance*

**(η and $p_T$ cuts)**

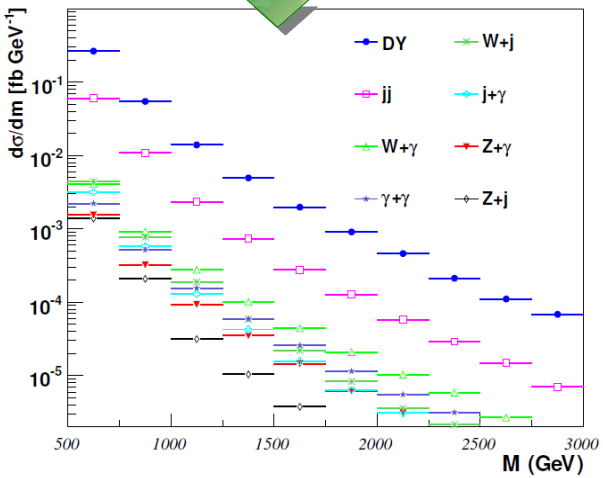


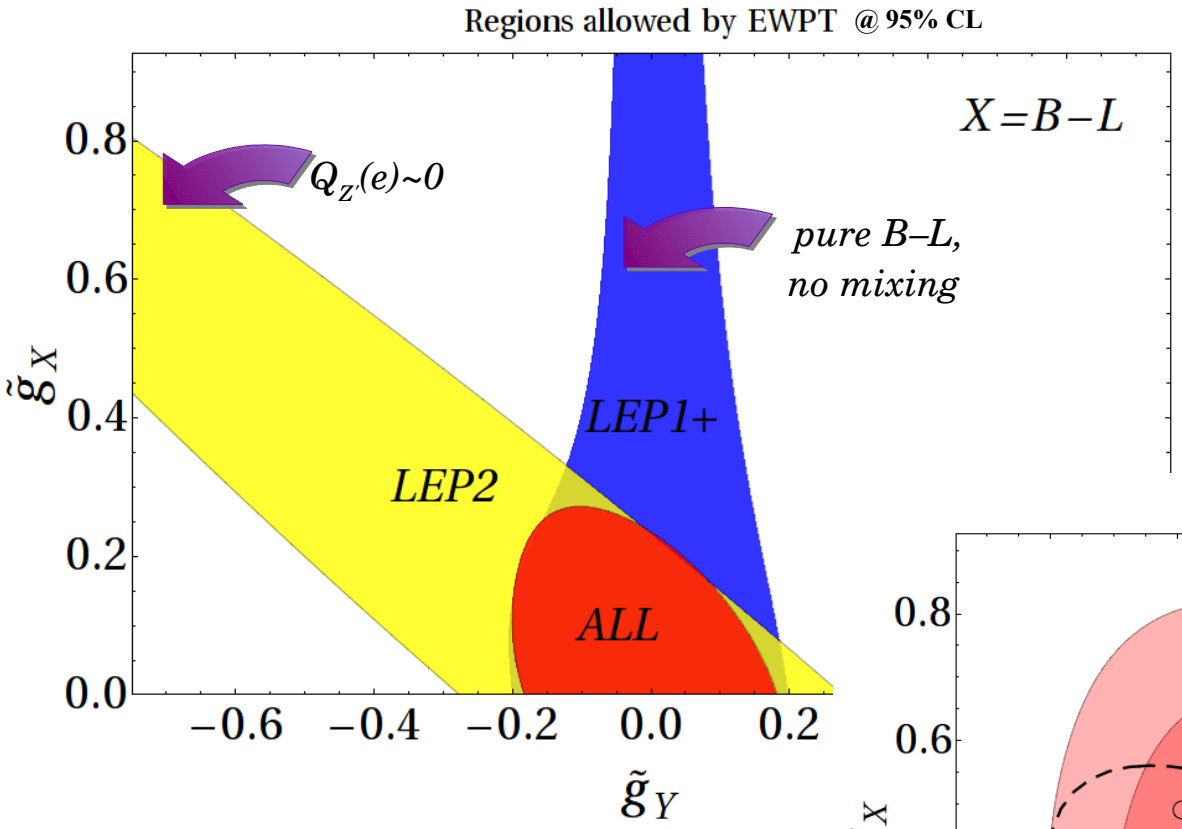

***before***

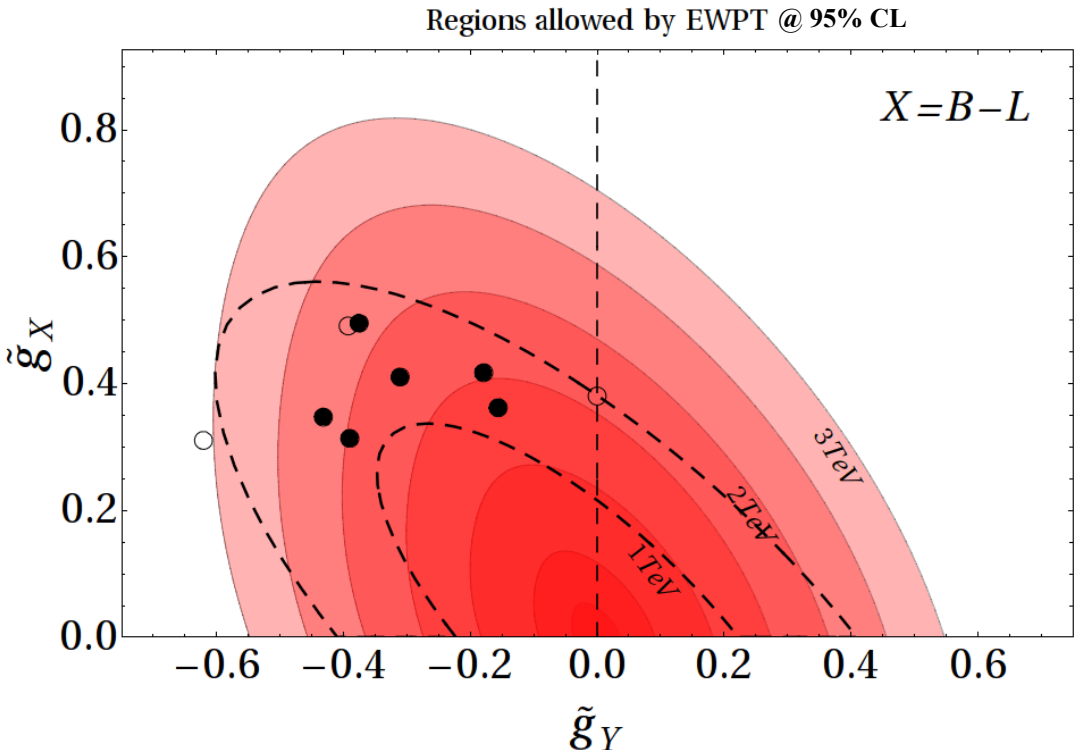



***after cuts***

***from 0901.0512***





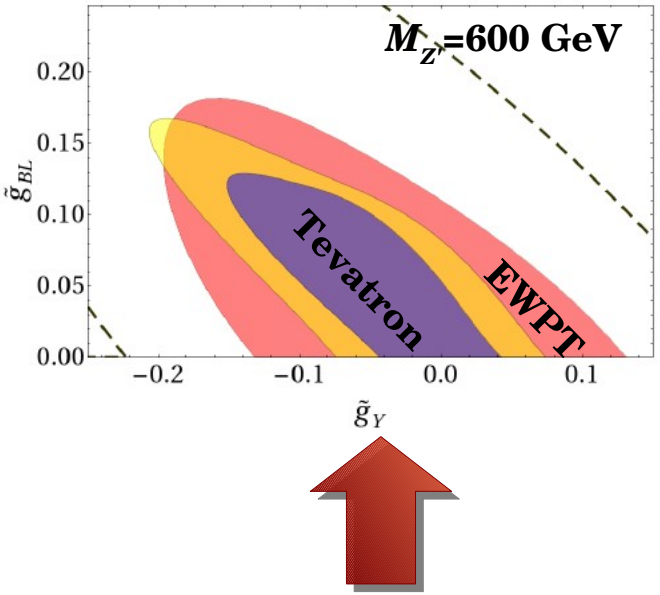

| | $Z'^{(0)}_{B-L}$ | $Z'^{(\mathrm{iii})}_{B-L}$ | $Z'^{(\mathrm{iv})}_{B-L}$ | $Z'^{(0)}_{\chi}$ | $Z'^{(\mathrm{iii})}_{\chi}$ | $Z'^{(\mathrm{iv})}_{\chi}$ | $Z'^{(0)}_{3R}$ | $Z'^{(\mathrm{iii})}_{3R}$ | $Z'^{(\mathrm{iv})}_{3R}$ |
|---|---|---|---|---|---|---|---|---|---|
| $M_{Z'}$ (TeV) | 1.80 | 1.77 | 1.53 | 2.61 | 2.54 | 2.11 | 3.64 | 2.61 | 2.36 |

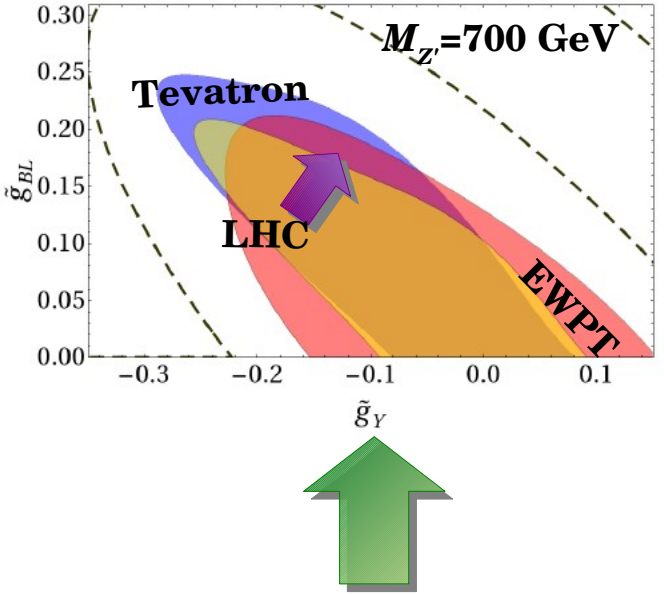
# $5\sigma$ *discovery reach @LHC*

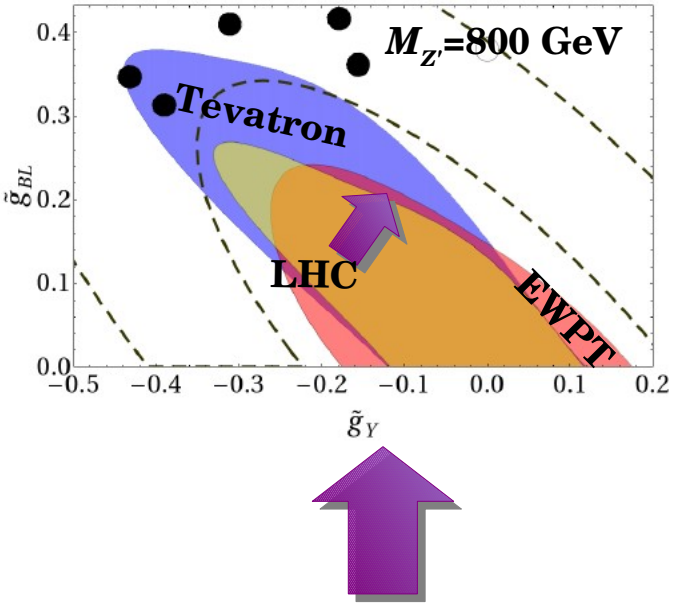
# *vs*

# 95% CL *bounds from Tevatron and EWPT*

## *Example: LHC @ 7 TeV & 100 pb$^{-1}$*




***Low Energy:***
***luminosity more important***
***Tevatron wins***

***Intermediate Energies:***
***first available window for LHC***

***Higher Energy:***
***hadron colliders weaker***
***EWPT wins***