Z′ Bosons and Friends

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with

Francisco del Aguila, Jorge de Blas and Paul Langacker

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and with

Juan Antonio Aguilar Saavedra

hep-ph/today

Outline

- General extra vector bosons:
  a model-independent description
- Electroweak limits
- Consequences: Higgs and $t\bar{t}$ FB asymmetry
- Direct searches

General Extra Vector Bosons

- New spin 1 particles (often gauge bosons, but no necessarily)
- GUT, Xdims, Technicolor, Little Higgs, ...
- Candidates for early discovery at LHC
- Constrained by electroweak precision tests, direct searches and flavour

General Extra Vector Bosons

Model independent description

F. del Aguila, J. de Blas, MPV, 2010

Use full SU(3)xSU(2)xU(1) gauge symmetry → Simple, general and convenient parameterization

My (mild) **Assumption** in this talk:
Single production is possible (No R/T/KK parity)

All Types of Extra Vectors

Vector	$\mathcal{B}_\mu$	$\mathcal{B}^1_\mu$	$\mathcal{W}_\mu$	$\mathcal{W}^1_\mu$	$\mathcal{G}_\mu$	$\mathcal{G}^1_\mu$	$\mathcal{H}_\mu$	$\mathcal{L}_\mu$
Irrep	$(1,1)_0$	$(1,1)_1$	$(1,\mathrm{Adj})_0$	$(1,\mathrm{Adj})_1$	$(\mathrm{Adj},1)_0$	$(\mathrm{Adj},1)_1$	$(\mathrm{Adj},\mathrm{Adj})_0$	$(1,2)_{-\frac{3}{2}}$

Vector	$\mathcal{U}^2_\mu$	$\mathcal{U}^5_\mu$	$\mathcal{Q}^1_\mu$	$\mathcal{Q}^5_\mu$	$\mathcal{X}_\mu$	$\mathcal{Y}^1_\mu$	$\mathcal{Y}^5_\mu$
Irrep	$(3,1)_{\frac{2}{3}}$	$(3,1)_{\frac{5}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,\mathrm{Adj})_{\frac{2}{3}}$	$(\bar{6},2)_{\frac{1}{6}}$	$(\bar{6},2)_{-\frac{5}{6}}$

Electroweak breaking:

$\mathcal{B}^1 \Rightarrow$ Pair of Charged vectors

$\mathcal{W} \Rightarrow \left\{ \begin{array}{l} \text{One neutral vector +} \\ \text{Pair of Charged vectors} \end{array} \right.$

...

All Types of Extra Vectors

Z′ W′

Vector	$\mathcal{B}_\mu$	$\mathcal{B}^1_\mu$	$\mathcal{W}_\mu$	$\mathcal{W}^1_\mu$	$\mathcal{G}_\mu$	$\mathcal{G}^1_\mu$	$\mathcal{H}_\mu$	$\mathcal{L}_\mu$
Irrep	$(1,1)_0$	$(1,1)_1$	$(1,\mathrm{Adj})_0$	$(1,\mathrm{Adj})_1$	$(\mathrm{Adj},1)_0$	$(\mathrm{Adj},1)_1$	$(\mathrm{Adj},\mathrm{Adj})_0$	$(1,2)_{-\frac{3}{2}}$

Vector	$\mathcal{U}^2_\mu$	$\mathcal{U}^5_\mu$	$\mathcal{Q}^1_\mu$	$\mathcal{Q}^5_\mu$	$\mathcal{X}_\mu$	$\mathcal{Y}^1_\mu$	$\mathcal{Y}^5_\mu$
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All Types of Extra Vectors

Leptophilic

Hadrophilic color octets

Higgsphilic

Vector	$\mathcal{B}_\mu$	$\mathcal{B}^1_\mu$	$\mathcal{W}_\mu$	$\mathcal{W}^1_\mu$	$\mathcal{G}_\mu$	$\mathcal{G}^1_\mu$	$\mathcal{H}_\mu$	$\mathcal{L}_\mu$
Irrep	$(1,1)_0$	$(1,1)_1$	$(1,\mathrm{Adj})_0$	$(1,\mathrm{Adj})_1$	$(\mathrm{Adj},1)_0$	$(\mathrm{Adj},1)_1$	$(\mathrm{Adj},\mathrm{Adj})_0$	$(1,2)_{-\frac{3}{2}}$

Vector	$\mathcal{U}^2_\mu$	$\mathcal{U}^5_\mu$	$\mathcal{Q}^1_\mu$	$\mathcal{Q}^5_\mu$	$\mathcal{X}_\mu$	$\mathcal{Y}^1_\mu$	$\mathcal{Y}^5_\mu$
Irrep	$(3,1)_{\frac{2}{3}}$	$(3,1)_{\frac{5}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,\mathrm{Adj})_{\frac{2}{3}}$	$(\bar{6},2)_{\frac{1}{6}}$	$(\bar{6},2)_{-\frac{5}{6}}$

All Types of Extra Vectors

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Irrep	$(1,1)_0$	$(1,1)_1$	$(1,\mathrm{Adj})_0$	$(1,\mathrm{Adj})_1$	$(\mathrm{Adj},1)_0$	$(\mathrm{Adj},1)_1$	$(\mathrm{Adj},\mathrm{Adj})_0$	$(1,2)_{-\frac{3}{2}}$

Vector	$\mathcal{U}^2_\mu$	$\mathcal{U}^5_\mu$	$\mathcal{Q}^1_\mu$	$\mathcal{Q}^5_\mu$	$\mathcal{X}_\mu$	$\mathcal{Y}^1_\mu$	$\mathcal{Y}^5_\mu$
Irrep	$(3,1)_{\frac{2}{3}}$	$(3,1)_{\frac{5}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,\mathrm{Adj})_{\frac{2}{3}}$	$(\bar{6},2)_{\frac{1}{6}}$	$(\bar{6},2)_{-\frac{5}{6}}$

Leptoquarks

Hadrophilic color sextets

W. Buchuller , R. Ruckl, D. Wyler, 1987

All Types of Extra Vectors

Vector	$\mathcal{B}_\mu$	$\mathcal{B}^1_\mu$	$\mathcal{W}_\mu$	$\mathcal{W}^1_\mu$	$\mathcal{G}_\mu$	$\mathcal{G}^1_\mu$	$\mathcal{H}_\mu$	$\mathcal{L}_\mu$
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Irrep	$(3,1)_{\frac{2}{3}}$	$(3,1)_{\frac{5}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,\mathrm{Adj})_{\frac{2}{3}}$	$(\bar{6},2)_{\frac{1}{6}}$	$(\bar{6},2)_{-\frac{5}{6}}$

Quantum numbers determine possible couplings. For instance,

$$\mathcal{L} \supset \mathcal{B}^1_\mu \left[\left(g^{du}_{\mathcal{B}^1} \right)_{ij} \overline{d^i_R} \gamma^\mu u^j_R + g^{\phi}_{\mathcal{B}^1} iD^\mu \phi^T i\sigma_2 \phi \right]$$

Example: Sequential Z'

Many collider searches use as a reference model the sequential Z', with the same couplings as the Z boson.

But it cannot be any of the irreps above!
(it breaks $SU(2)_L$ gauge invariance)

Does it make any sense?

Example: Sequential Z'

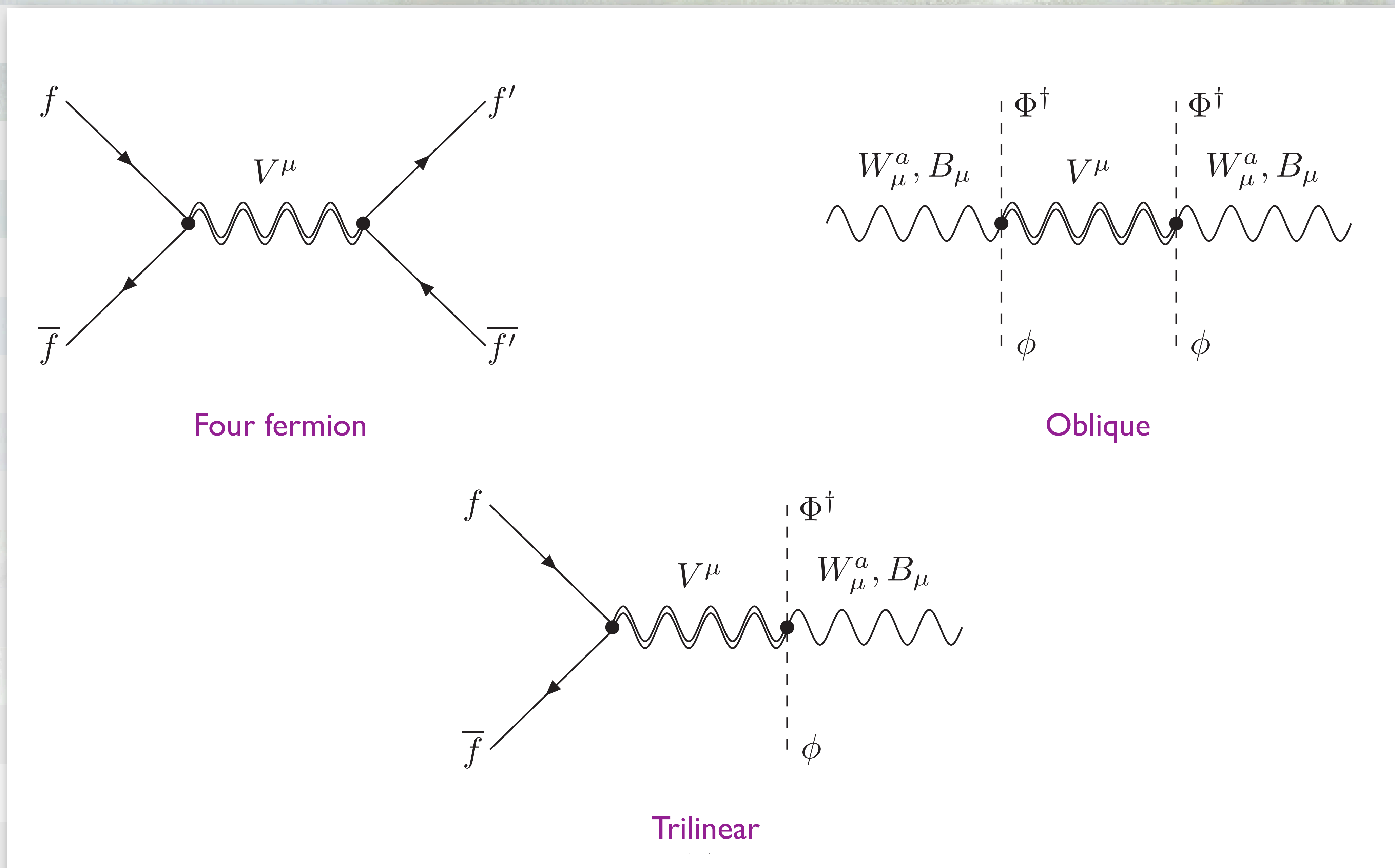
Many collider searches use as a reference model the sequential Z', with the same couplings as the Z boson.

It can only arise as a mixture of an isosinglet $\mathcal{B}$ and and isotriplet $\mathcal{W}$ (after electroweak symmetry breaking)

Sequential Z' comes together with a γ' and a W'

Impact on EW precision tests

Vector	Z pole $e^+e^- \to \bar{f}f$	M_W	CKM	ν-N DIS	NC $\nu e \to \nu e$	APV	PV in $e^-e^- \to e^-e^-$	LEP 2 $e^+e^- \to \bar{f}f$
$\mathcal{B}_\mu$								
$\mathcal{W}_\mu$								
$\mathcal{G}_\mu$								
$\mathcal{H}_\mu$								
$\mathcal{B}^1_\mu$								
$\mathcal{W}^1_\mu$								
$\mathcal{G}^1_\mu$								
$\mathcal{L}_\mu$								
$\mathcal{U}^2_\mu$								
$\mathcal{U}^5_\mu$								
$\mathcal{Q}^1_\mu$								
$\mathcal{Q}^5_\mu$								
$\mathcal{X}_\mu$								
$\mathcal{Y}^1_\mu$								
$\mathcal{Y}^5_\mu$								



Four fermion

Oblique

Trilinear

Limits on General Extra Vectors

$$G \sim \frac{g}{M}$$

Vector V_μ	$-\Delta\chi^2_{\rm min}$ $(\chi^2_{\rm min}/\text{d.o.f.})$	Parameter $G_V^k \equiv g_V^k/M_V$	Best Fit $[\mathrm{TeV}^{-1}]$	Bounds $[\mathrm{TeV}^{-1}]$	C.L.
$\mathcal{B}_\mu$	7.35	$G_{\mathcal{B}}^{\phi}$	-0.045	$[-0.098,\ \ 0.098]$	95%
	(0.77)	$G_{\mathcal{B}}^{l}$	0.021	$[-0.210,\ \ 0.210]$	95%
		$G_{\mathcal{B}}^{q}$	-0.89	-	-
		$G_{\mathcal{B}}^{e}$	0.048	$[-0.300,\ \ 0.300]$	95%
		$G_{\mathcal{B}}^{u}$	-2.6	-	-
		$G_{\mathcal{B}}^{d}$	-6.0	-	-
$\mathcal{W}_\mu$	1.51	$G_{\mathcal{W}}^{\phi}$	0.002	$[-0.12,\ \ 0.12]$	$1\ \sigma$
	(0.79)	$G_{\mathcal{W}}^{l}$	0.004	$[-0.26,\ \ 0.26]$	95%
		$G_{\mathcal{W}}^{q}$	-9.6	-	-
$\mathcal{B}_\mu^1$	0.16	$G_{\mathcal{B}^1}^{\phi}$	$6\cdot 10^{-4}$	$[-0.11,\ \ 0.11]$	95%
	(0.79)	$G_{\mathcal{B}^1}^{du}$	6.6	-	-
$\mathcal{W}_\mu^1$	0.65 (0.78)	$\lvert G_{\mathcal{W}^1}^{\phi}\rvert$	0.18	< 0.50	95%
$\mathcal{L}_\mu$	0 (0.79)	$\lvert G_{\mathcal{L}}^{el}\rvert$	0	$< \begin{pmatrix} 0.29 & 0.33 & 0.39 \\ 0.34 & - & - \\ 0.39 & - & - \end{pmatrix}$	95%

Limits on General Extra Vectors $G \sim \frac{g}{M}$

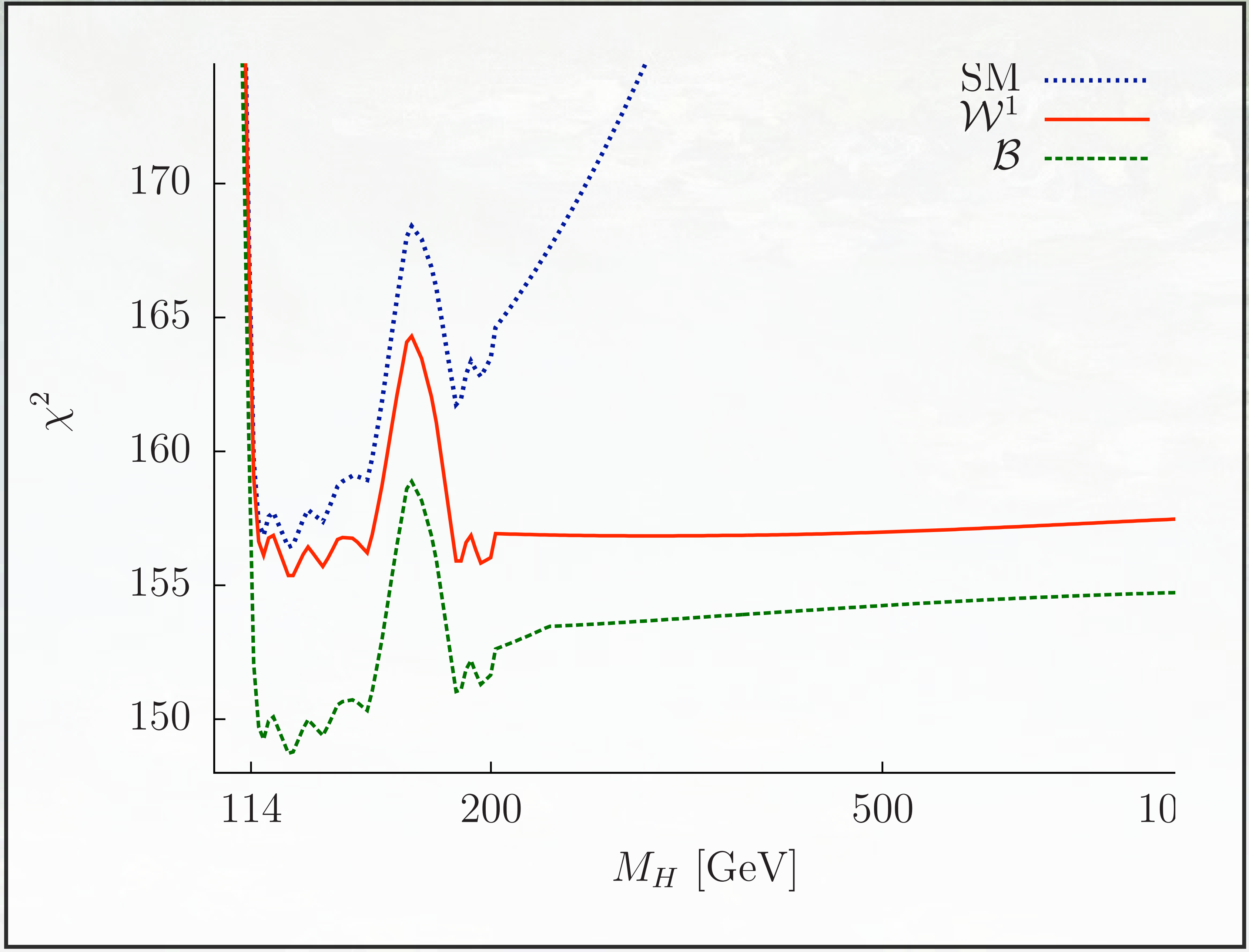
$\mathcal{U}^2_\mu$	0 (0.79)	$\lvert G^{ed}_{\mathcal{U}^2}\rvert$	0	$<$	$\begin{pmatrix} 0.21 & 0.49 & 0.49 \\ - & - & - \\ - & - & - \end{pmatrix}$	95%
		$\lvert G^{lq}_{\mathcal{U}^2}\rvert$	0	$<$	$\begin{pmatrix} 0.12 & 0.29 & 0.29 \\ 0.56 & 0.65 & - \\ - & - & - \end{pmatrix}$	95%
$\mathcal{U}^5_\mu$	≤ 2.77 (0.77)	$\lvert G^{eu}_{\mathcal{U}^5}\rvert$	0.43 $[1,2]$	$<$	$\begin{pmatrix} 0.25 & 0.62 & - \\ - & - & - \\ - & - & - \end{pmatrix}$	95%
$\mathcal{Q}^1_\mu$	≤ 0.45 (0.79)	$\lvert G^{ul}_{\mathcal{Q}^1}\rvert$	0.27 $[1,2]$	$<$	$\begin{pmatrix} 0.22 & 0.54 & - \\ 0.57 & - & - \\ - & - & - \end{pmatrix}$	95%
$\mathcal{Q}^5_\mu$	≤ 3.36 (0.78)	$\lvert G^{dl}_{\mathcal{Q}^5}\rvert$	0.87 $[1,1]$	$<$	$\begin{pmatrix} 1.06 & 0.58 & - \\ 1.07 & - & - \\ 1.07 & - & - \end{pmatrix}$	95%
		$\lvert G^{eq}_{\mathcal{Q}^5}\rvert$	0.64 $[1,1]$	$<$	$\begin{pmatrix} 0.78 & 1.0 & 1.2 \\ - & - & - \\ - & - & - \end{pmatrix}$	95%
$\mathcal{X}_\mu$	≤ 2.86 (0.77)	$\lvert G^{lq}_{\mathcal{X}}\rvert$	0.65 $[1,2]$	$<$	$\begin{pmatrix} 0.27 & 0.93 & 0.57 \\ 1.04 & 1.40 & - \\ - & - & - \end{pmatrix}$	95%

Popular Z' Models

	95% C.L. Electroweak Limits on					
	$\sin\theta_{ZZ'}$ $[\times 10^{-4}]$			$M_{Z'}$ [TeV]		
Model	EWPD (no LEP 2)	LEP 2	All Data	EWPD (no LEP 2)	LEP 2	All Data
Z'_χ	$[-10, \ 7]$	$[-\ 80, 118]$	$[-11, \ 7]$	1.123	0.772	1.022
Z'_ψ	$[-19, \ 7]$	$[-196, 262]$	$[-19, \ 7]$	0.151	0.455	0.476
Z'_η	$[-22, 25]$	$[-150, 164]$	$[-23, 27]$	0.422	0.460	0.488
Z'_I	$[-\ 5, \ 9]$	$[-144, \ 96]$	$[-\ 5, 10]$	1.207	0.652	1.105
Z'_N	$[-14, \ 6]$	$[-165, 223]$	$[-14, \ 6]$	0.635	0.421	0.699
Z'_S	$[-\ 9, \ 5]$	$[-\ 85, 129]$	$[-10, \ 5]$	1.249	0.728	1.130
Z'_R	$[-17, \ 7]$	$[-166, 177]$	$[-15, \ 5]$	0.439	0.724	1.130
Z'_{LR}	$[-13, \ 5]$	$[-147, 189]$	$[-12, \ 4]$	0.999	0.667	1.162

Consequences for/from Higgs Mass

Vector singlet
and
fermiophobic
vector triplet



Mixing with Z (and W)

Shift of masses

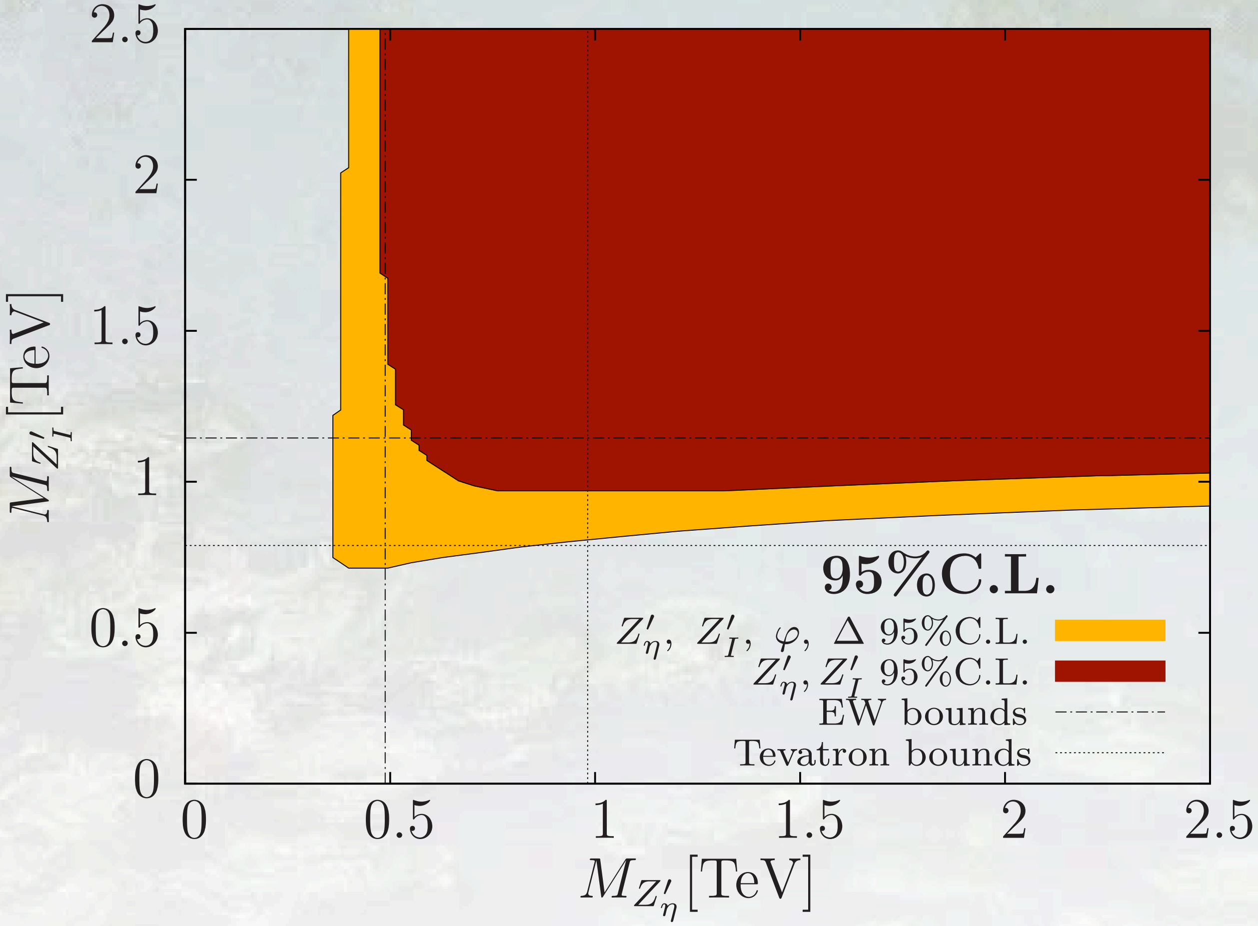
Positive T parameter

How robust are EW limits?

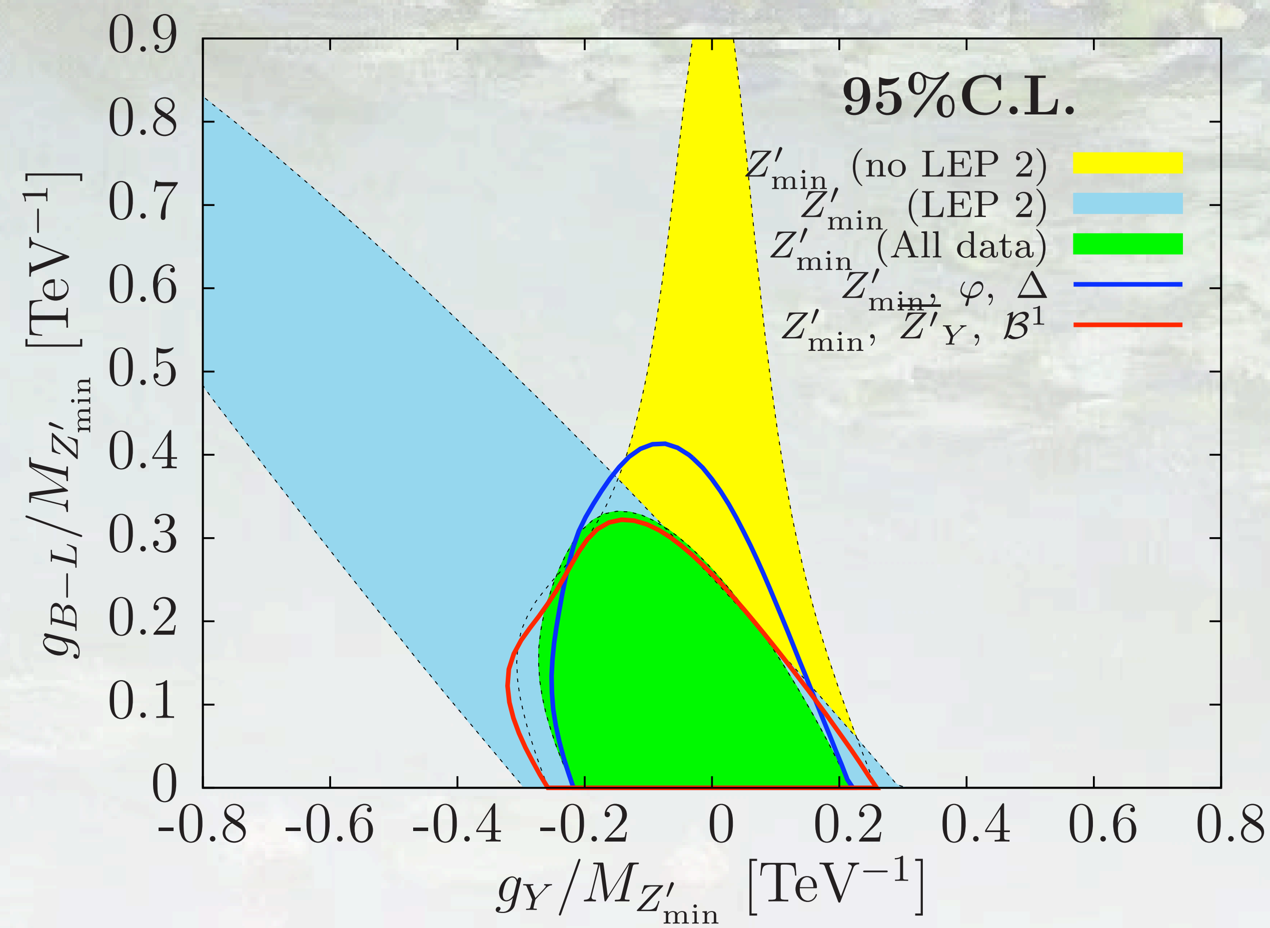
F. del Aguila, J. de Blas, P. Langacker, MPV, 2011 (to appear)

Assume there are *special* additional vectors and/or scalars

Two Examples:



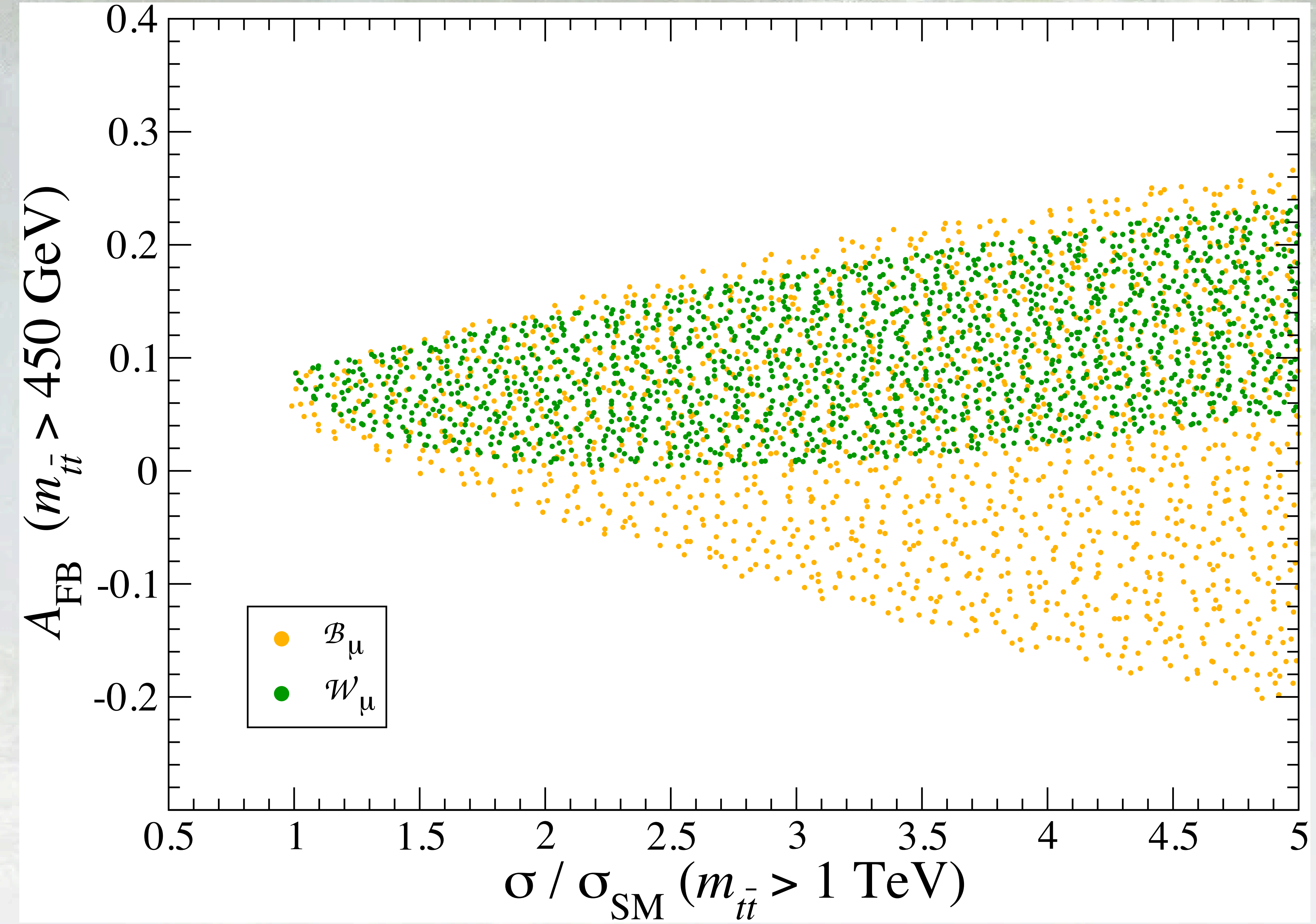
Combination of two E_6 popular models



Minimal models (see Salvioni,Villadoro,Strumia,Zwirner, 2009)

$t\bar{t}$ asymmetry vs tail cross section

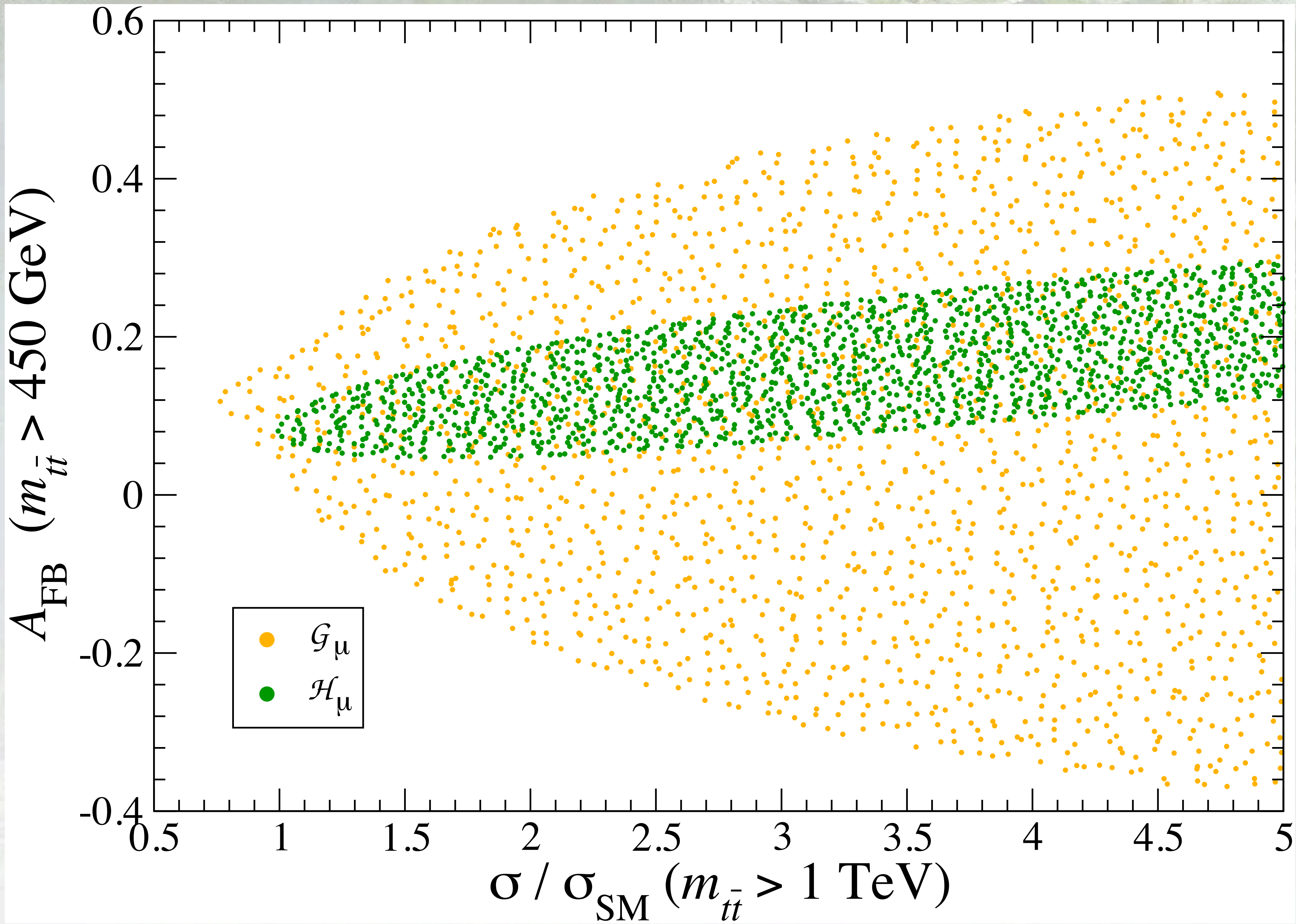
J.A. Aguilar-Saavedra, MPV, 2011 (today)



Can be already seen/excluded by 2010 LHC data!

$t\bar{t}$ asymmetry vs tail cross section

J.A. Aguilar-Saavedra, MPV, 2011 (today)



Axigluon more difficult to exclude

Collider searches/limits

✦ EW limits depend on the ratio g/M
✦ Direct collider limits have different dependence on g and M

Assuming couplings of electroweak strength,

Z' hadron collider limits:

- Tevatron: $M_{Z'} \gtrsim 1.0\,\mathrm{TeV}$
  $\mathrm{D0}, \;\; 5.4\mathrm{fb}^{-1}, \;\; 1.96\,\mathrm{TeV}$
- LHC: $M_{Z'} \gtrsim 1.14\,\mathrm{TeV}$
  $\mathrm{CMS}, \;\; 40\mathrm{pb}^{-1}, \;\; 7\,\mathrm{TeV}$

Z' EWPT limits (without cancellations)

$$M_{Z'} \gtrsim 600 - 1600\,\mathrm{GeV}$$

LHC searches/limits

- ✦ EW limits depend on the ratio g/M
- ✦ Direct collider limits have different dependence on g and M

Assuming couplings of electroweak strength,

W' hadron collider limits:

- Tevatron: $M_{W'} \gtrsim 1.1\,\mathrm{TeV}$
  $\mathrm{CDF},\quad 5.3\,\mathrm{fb}^{-1},\quad 1.96\,\mathrm{TeV}$
- LHC: $M_{W'} \gtrsim 1.58\,\mathrm{TeV}$
  $\mathrm{CMS},\quad 36\,\mathrm{pb}^{-1},\quad 7\,\mathrm{TeV}$

$\mathcal{W}$' EWPT limits (without cancellations)

$$M_{\mathcal{W}} \gtrsim 2.5\,\mathrm{TeV}$$

Conclusions

New particles can be classified into irreps of SM *full* gauge symmetry

With mild assumptions, explicit model independent Lagrangians can be written.

✓ Simple parametrization
✓ Direct contact with *models* and *collider* physics

Similar analysis with general extra leptons in

F. del Aguila, J. de Blas, MPV, 2008