Z' and beyond

A model-independent analysis of new vector bosons

Manuel Pérez-Victoria

Universidad de Granada

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with
Francisco del Aguila
and Jorge de Blas

The LHC roulette

Place your bet on New Physics!

- Too many models in the market $\longrightarrow$ Risky to bet on a single number
- ... and maybe none is real $\Rightarrow$ The bank wins :-(
- Better chances if model independent

Ideal model-independent strategy

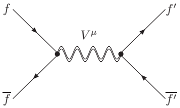
- Classify extra particles: spin and quantum numbers
- Write "most general" interactions with SM particles
- Impose constraints on masses and couplings (EWPT, flavour, Tevatron, ...
- Check parameter space available for LHC searches
- If discovered, try to measure spin & couplings $\longrightarrow$ determine quantum numbers
- Once identified, look for models that predict them

Here: Spin 1

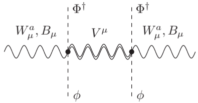
Candidates for early discovery at LHC
GUT, Technicolor, Xdims, little Higgs, Unknown models

SM extensions with New Vector Bosons

1. Gauge invariant under $SU(3)_C \times SU(2)_L \times U(1)_Y$
2. Renormalizable
3. Interactions linear in the new fields
    - Can be singly produced
    - Contribute to electroweak precision data:



(a)



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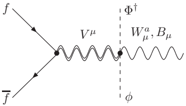


(c)

Types of Extra Vector Bosons

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	$(3,1)_{\frac{2}{3}}$	$(3,1)_{\frac{5}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,\mathrm{Adj})_{\frac{2}{3}}$	$(\bar{6},2)_{\frac{1}{6}}$	$(\bar{6},2)_{-\frac{5}{6}}$

Quantum numbers determine possible couplings. For instance,

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

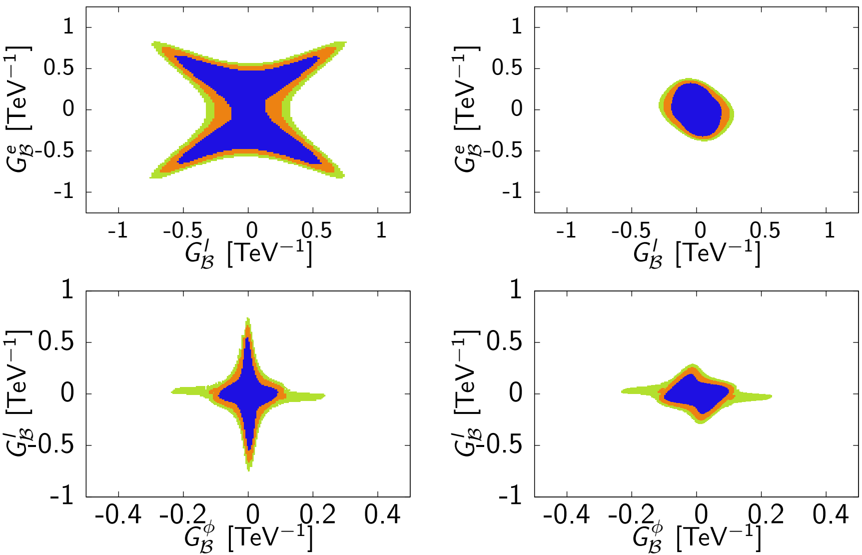
Impact on Electroweak Precision Data

Vector	LEP & SLD	M_W	νN	νe	APV	ee	LEP II
$\mathcal{B}_\mu$	✓	✓	✓	✓	✓	✓	✓
$\mathcal{W}_\mu$	✓	✓	✓	✓	✓	✓	✓
$\mathcal{G}_\mu$							
$\mathcal{H}_\mu$							
$\mathcal{B}^1_\mu$	×	✓	✓	×	×	×	×
$\mathcal{W}^1_\mu$	×	✓	×	×	×	×	×
$\mathcal{G}^1_\mu$							
$\mathcal{L}_\mu$				✓		✓	✓
$\mathcal{U}^2_\mu$					✓		✓
$\mathcal{U}^5_\mu$					✓		✓
$\mathcal{Q}^1_\mu$					✓		✓
$\mathcal{Q}^5_\mu$					✓		✓
$\mathcal{X}_\mu$			✓		✓		✓
$\mathcal{Y}^1_\mu$							
$\mathcal{Y}^5_\mu$							

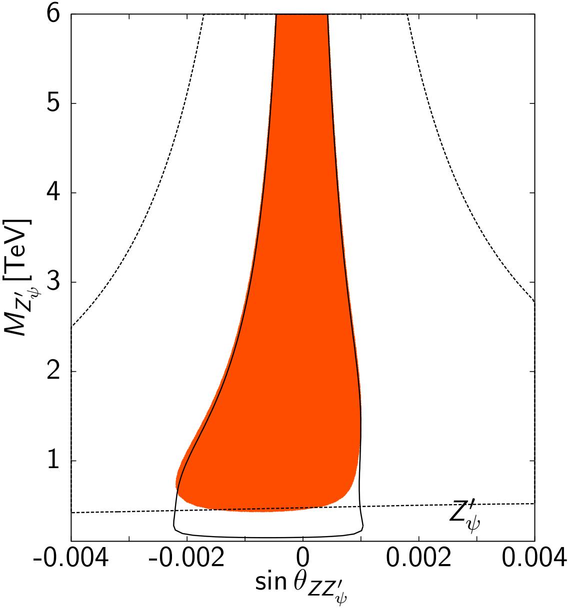
Limits from Precision Tests

Vector V_μ	$-\Delta\chi^2_{\mathrm{min}}$ $(\chi^2_{\mathrm{min}}/\mathrm{d.o.f})$	Parameter $G_V^k \equiv g_V^k/M_V$	Best Fit [TeV^{-1}]	Bounds [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 σ
	(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)	$G_{\mathcal{B}^1}^{du}$	-	-	-
$\mathcal{W}_\mu^1$	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%
$\mathcal{U}_\mu^2$	0 (0.79)	$\lvert G_{\mathcal{U}^2}^{ed} \rvert$	0	$< \begin{pmatrix} 0.21 & 0.49 & 0.49 \\ - & - & - \\ - & - & - \end{pmatrix}$	95%
		$\lvert G_{\mathcal{U}^2}^{lq} \rvert$	0	$< \begin{pmatrix} 0.12 & 0.29 & 0.29 \\ 0.56 & 0.65 & - \\ - & - & - \end{pmatrix}$	95%
			...		

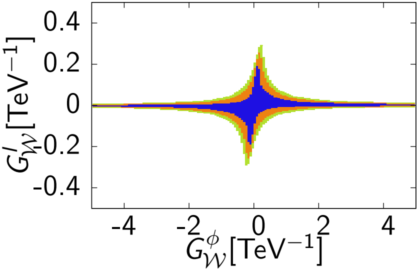
Neutral Singlet (lepton and Higgs couplings)



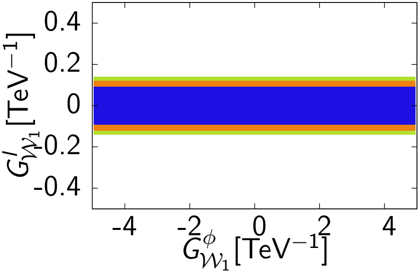
Constrains specific models, for instance Z'_ψ



Triplet (lepton and Higgs couplings)

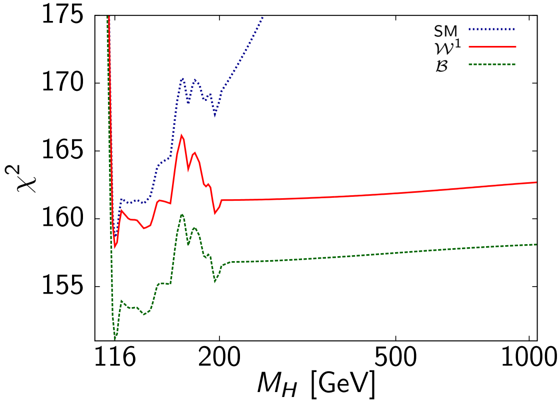


One $\mathcal{W}$



Two mirror $\mathcal{W}$s

Implications on the Higgs mass



Solving the A^b_{FB} anomaly

(should it be a problem)

SM with $M_H = 115$ GeV $\rightarrow$ Pull$[A^b_{\mathrm{FB}}] = -2.6$

SM with extra neutral (and charged) singlet vector bosons coupling to 3rd family:

	$\mathcal{B}$				$\mathcal{B}+\mathcal{B}^1$	
	Free	$G^b_{\mathcal{B}} \equiv 1$	$M_H = 200\,\mathrm{GeV}$	$M_H = 500\,\mathrm{GeV}$	Free	$G^b_{\mathcal{B}} \equiv 1$
$-\Delta\chi^2_{\mathrm{min}}$	8.2	2.7	14.1	47.7	8.2	8.2
Pull$[A^b_{FB}]$	-0.5	-2.5	-0.4	-0.4	-0.5	-0.5
$G^b_{\mathcal{B}}$ [TeV^{-1}]	6.4	1	3.8	2.4	3.2	1
$G^\phi_{\mathcal{B}}$ [TeV^{-1}]	0.082	0.078	0.13	0.19	0.16	0.53
$G^\phi_{\mathcal{B}^1}$ [TeV^{-1}]	-	-	-	-	0.20	0.73

General rough results from EWPT

- EWPT place limits on *couplings/masses* of new vectors
  Different dependence at hadron colliders!
- Cancellations can open new regions in parameter space
- But LEP 2 $\rightarrow$ Couplings to leptons always small or masses big
  $M \gtrsim 1\text{TeV}$ for $g_l \simeq .2$
- Couplings to Higgs (mixings) small if Higgs is light
- Couplings to quarks can be large
- No EWPT constraints on leptophobic vector bosons
- All this relevant for specific models as well

LHC searches

Drell-Yan dilepton resonance $V \to l\,l$ (neutral vectors)

- Only possible for $\mathcal{B}$ and $\mathcal{W}$
- Requires large enough lepton couplings
- EWPT + Tevatron → Little space for discovery at 7 TeV, 100 pb^{-1}
- Better at 14 TeV, 100 fb^{-1}

$V \to l\nu$ (charged vectors)

- Only for $\mathcal{W}$ (or $\mathcal{B}^1$ if light RH neutrinos)
- Similar considerations

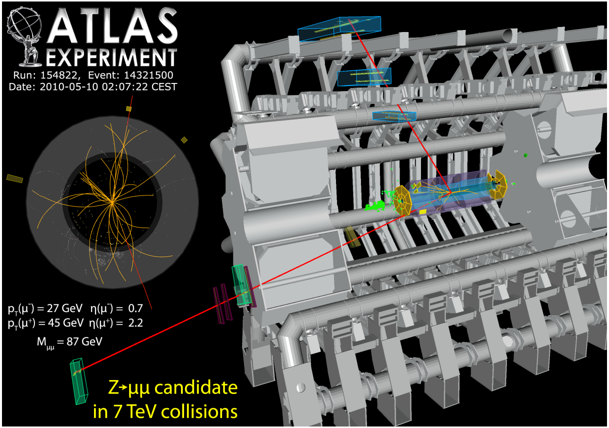
$V \to jj$, $V \to \bar{t}t$, $V \to tb$, ...

- Required for leptophobic vector bosons
- Plenty of room for discovery

Pair production through gluon couplings

- Leptoquarks (decay via trilinear couplings)
- Exotic vectors without linear interactions

Vector Boson event at LHC



BACKSLIDES

Vector	Model
$\mathcal{B}_\mu$	$U(1)'$, Extra Dimensions
$\mathcal{B}_\mu^1$	$SU(2)_R \otimes U(1)_X \to U(1)_Y$
$\mathcal{W}_\mu$	$SU(2)_1 \otimes SU(2)_2 \to SU(2)_D \equiv SU(2)_L$, Extra Dimensions
$\mathcal{W}_\mu^1$	$SU(4) \to U(1) \otimes (SU(3) \to SU(2))$
$\mathcal{G}_\mu$	$SU(3)_1 \otimes SU(3)_2 \to SU(3)_D \equiv SU(3)_c$, Extra Dimensions
$\mathcal{G}_\mu^1$	$SO(12) \to (SO(8) \to SU(3)) \otimes (SU(2) \otimes SU(2) \to SU(2)_D \to U(1)_Y)$
$\mathcal{H}_\mu$	$SU(6) \to SU(3) \otimes SU(2)$
$\mathcal{L}_\mu$	$G_2 \to SU(2) \otimes (SU(2) \to U(1)_Y)$
$\mathcal{U}_\mu^2,\ \mathcal{U}_\mu^5$	$SU(4) \to SU(3) \otimes U(1)$
$\mathcal{Q}_\mu^1,\ \mathcal{Q}_\mu^5$	$SU(5) \to SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$
$\mathcal{X}_\mu$	$SU(6) \to U(1) \otimes SU(3) \otimes (SU(3) \to SU(2))$
$\mathcal{Y}_\mu^1,\ \mathcal{Y}_\mu^5$	$F_4 \to SU(3) \otimes (SU(3) \to SU(2) \otimes U(1))$