Early W primes at the LHC

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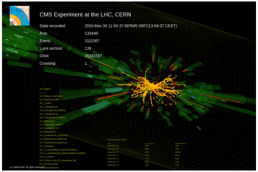
Outline

Why care about W primes?

LHC collisions at 7 Tev $\Rightarrow$ Potential to discover new physics:

- GUTs
- UED
- Little Higgs
- ...



A large subset of BSM theories introduces new, massive gauge bosons $\rightarrow$ observable at LHC? W's are promising candidates:

- Single particle resonance $\rightarrow$ Large cross section
- Low background in leptonic channels $\rightarrow$ Easy discovery
- Complete mass reconstruction in hadronic channnels ($t\bar{b}$)

Limits on early LHC physics: Z primes and W primes

Generically: Models with charged gauge bosons also contain neutral gauge bosons (Z's), constrained by

- PEW
- Lep II
- Tevatron

$\Rightarrow$

$m(Z') > 2 - 3$ TeV
(for EW strength coupling)
Z' out of reach of early LHC

Z' bounds are strong, W' always (?) comes with Z', therefore Z' bounds indirectly also rule out W'

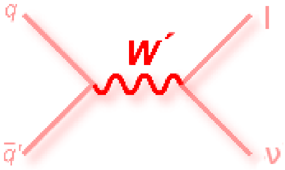
Question we want to answer:

Is this argument unavoidable?

Definition of a (relevant) W' Boson

To restict possible models,
define "interesting" W's:

1. Electric charge $\neq 0$
2. Massive (Tevatron: TeV scale)
3. Spin 1 $\Rightarrow$ gauge boson
4. Color-neutral
5. Coupled to LHC initial state



Further inputs from:

- Group theory (representations of $SU(2)_L \times U(1)_Y$)
- Experimental constraints from Z's (EWP, LEP II)

Restrictions from LHC Initial State

Quantum numbers of quark fields in SM:

field	color	$SU(2)_L$	Y
Q	3	2	1/6
u^c	$\bar{3}$	1	-2/3
d^c	$\bar{3}$	1	1/3

Color-neutral W' with electric charge:
Only couples to quark-antiquark (not qq, qg or gg)

Possible operators:

- $Q^\dagger Q$: triplet contains $Q = 0, \pm 1$
- $(u^c)^\dagger d^c$: singlet with charge +1

$\Rightarrow$ W' charges: ± 1

W's from $SU(2)_L$ Triplets and Singlets

From $q\bar{q}$ initial state, only two possibilities survive:

1. W' from an $SU(2)_L$ triplet with $Y = 0$:
   - Z' with same coupling strength and mass ($\pm$ Higgs VEV)
   - Limits on Z' apply to W' $\Rightarrow$ Not early LHC physics
2. W' from $SU(2)_L$ singlet with $Y = 1$:
   - W' generator doesn't commute with hypercharge
   - W' and B part of a broken non-Abelian gauge group
   - $SU(2)_R \to U(1)_Y$ gives W' with $Q = \pm 1$ and no Z', BUT: predicts incorrect fermion hypercharges

$\Rightarrow$ Minimal model for early LHC W': $SU(2)_L \times SU(2)_R \times U(1)_X$

Scalars in $SU(2)_L \times SU(2)_R \times U(1)_X$ Model

At least two scalar fields have to be included:

1. First, we need to break $SU(2)_R \times U(1)_X$:
   $\Rightarrow SU(2)_R$ doublet with VEV $\langle \Phi \rangle = (0, f/\sqrt{2})$
2. Then, to generate fermion masses:

   A complex bidoublet Higgs with charges $(2,2)_0$ and VEV
   $$\langle H \rangle = v/\sqrt{2} \begin{pmatrix} \cos\beta & 0 \\ 0 & \sin\beta \end{pmatrix}$$
   $\Rightarrow$ 2 Higgs doublets at EWSB scale

Other choices like a single H doublet are possible, but require non-renormalizable Yukawa couplings.

Constraints on Weak Scale Effective Lagrangian

Effective theory approach to EWP and LEP II constraints:

- Find couplings of SM quarks, charged leptons, and Higgs boson to Z' boson
- Integrate out neutral currents
- Obtain coefficients of induced dimension 6 operators

Advantages:

- Numerical constraints on operators from EW precision measurements and LEP II available
- Easy to scan parameter space, modify models

EWP and LEP II Constraints - List of Experiments

Previous work by W. Skiba and Z. Han[1]:
EWP and LEP II constraints on 21 dimension 6 operators

- Atomic parity violation (Weak charge of Cs and Tl)
- DIS (ν nucleon from NuTeV, CDHS, CHARM, CCFR, ν e from CHARM II)
- Z-pole (Z width, hadronic cross section, ratios of decay rates, FB asymmetries, hadronic charge asymmetries, polarized asymmetries)
- Fermion pair production at LEP II (total cross-sections and FB asymmetries in $e^+e^- \to f\bar{f}$, differential cross section for $e^+e^- \to e^+e^-$
- W mass, differential cross section for $e^+e^- \to W^+W^-$

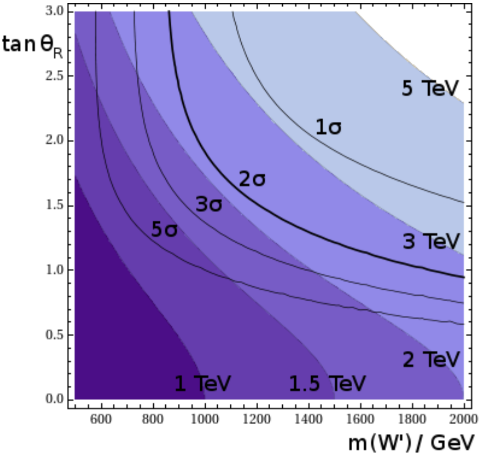
[1] Phys.Rev. D71 (2005) 075009

Exclusion Plot for LR Model with Higgs Bifundamental

1. Higgs couples only to $SU(2)_R$
2. EW precision favors large $U(1)$ coupling constant
3. Large mass splitting between Z' and W'

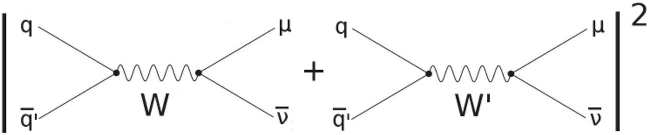
Model point with minimal W' mass at SM+2σ:

$M(W') \approx 1$ TeV
$M(Z') \approx 2\text{-}3$ TeV



Cross section @ 7 TeV: $\sigma(pp \to W' \to \mu\nu_\mu) \approx 400$ fb

How to tell left- and righthanded W primes apart?



- Lefthanded W': Same initial and final state, interference.
- Righthanded W': No interference with W boson.

For intermediate momentum, propagators have different signs:

$$P(W', W) \sim \frac{1}{p^2 - m^2}$$

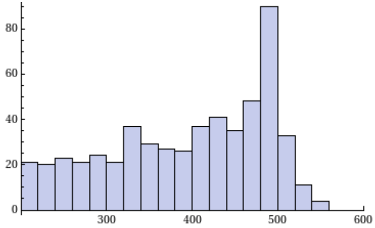
$\Rightarrow$ Destructive interference, LH W' peak more pronounced

MadGraph Simulation: W'_L vs. W'_R

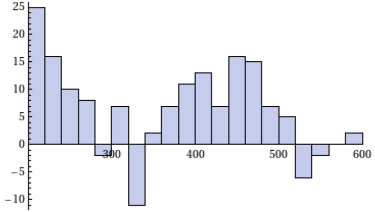
Can we see this effect? Simulate with MadGraph:
Toy model: 1 TeV W' with EW coupling strength

Cross sections: $\sigma(pp \to W'_R\,(W'_L) \to \mu\nu)$ = 680 (550) fb,
Muon p_T distributions for 1/fb of events:

Lefthanded W':



RH W' minus LH W':



Odds and Ends

1. Another possibility to obtain large mass splitting between Z' and W':

   Larger righthanded Higgs representations (with VEV in lowest component).

   E.g. complex scalar in RH isospin s multiplet:
   $\Rightarrow \rho_R = 1/\sqrt{2s}$.

2. The impact of a Z' on EWP and LEP II can (somewhat surprisingly) be lowered by adding extra $U(1)$ factors

   BUT:

   Cancellation requires fine-tuning of fermion and Higgs charges.

Summary

1. For the early LHC, only righthanded W primes are relevant
2. The minimal model with an early W prime at the LHC is $SU(2)_L \times SU(2)_R \times U(1)_X$
3. With bidoublet scalar, expect large Z'/W' mass splitting and $m(W') > 1$ TeV
4. Interference effects with the W can possibly be used to distinguish W's from $SU(2)_L$ and $SU(2)_R$, and test our prediction