Hunting for Minimal Walking Technicolor using Z' searches at the LHC

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Outline

Motivation for Technicolor

- Standard Model has many issues, e.g hierarchy problem, no dark matter candidate
- **Technicolor** originally proposed as an alternative to Spontaneous EWSB
- Higgs discovery = Technicolor is dead...?
- TC with **walking** regime means Dynamical EWSB still a strong BSM candidate!
- WTC addresses hierarchy problem whilst containing a consistent Higgs boson-like particle

Walking vs. Running TC

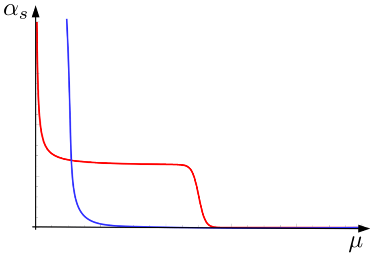

Figure: Behaviour of the strong coupling constant with energy scale

Setup of NMWT

NMWT is encoded into the chiral Lagrangian (low energy description)

$$
\begin{aligned}
\mathcal{L}_{boson} = &-\frac{1}{2}\mathrm{Tr}\left[\tilde{W}_{\mu\nu}\tilde{W}^{\mu\nu}\right] - \frac{1}{4}\tilde{B}_{\mu\nu}\tilde{B}^{\mu\nu} - \frac{1}{2}\mathrm{Tr}[F_{L\mu\nu}F_L^{\mu\nu} + F_{R\mu\nu}F_R^{\mu\nu}] \\
&+ m^2\mathrm{Tr}[C_{L\mu}^2 + C_{R\mu}^2] + \frac{1}{2}\mathrm{Tr}[D_\mu M D^\mu M^\dagger] - \tilde{g}^2 r_2 \mathrm{Tr}[C_{L\mu} M C_R^\mu M^\dagger] \\
&- \frac{i\tilde{g}r_3}{4}\mathrm{Tr}[C_{L\mu}(M D^\mu M^\dagger - D^\mu M M^\dagger) + C_{R\mu}(M^\dagger D^\mu M - D^\mu M^\dagger M)] \\
&+ \frac{\tilde{g}^2 s}{4}\mathrm{Tr}[C_{L\mu}^2 + C_{R\mu}^2]\mathrm{Tr}[M M^\dagger] + \frac{\mu^2}{2}\mathrm{Tr}[M M^\dagger] - \frac{\lambda}{4}\mathrm{Tr}[M M^\dagger]^2
\end{aligned}
\tag{1}
$$

Belyaev *et al* 0809.0793v1

Key constructs in equation 1:

$$C_{L\mu} \equiv A_{L\mu} - \frac{g}{\tilde{g}}\tilde{W}_{\mu}, \qquad C_{R\mu} \equiv A_{R\mu} - \frac{g'}{\tilde{g}}\tilde{B}_{\mu}, \tag{2}$$

encodes all of the EW/TC gauge fields.

Parameter space from Lagrangian M_V, M_A, $\tilde{g}$, r_2 and r_3.

We can use Weinberg Sum Rules to reduce and rephrase these parameters to the parameter space:

$$\boxed{M_A, \qquad \tilde{g}, \qquad S.} \tag{3}$$

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Particle Spectrum

NMWT adds chiral $SU(2)$ groups to SM, overall

$$SU(3)_C \times SU(2)_L \times U(1)_Y \times SU(2)_L \times SU(2)_R \times U(1)_V \quad (4)$$

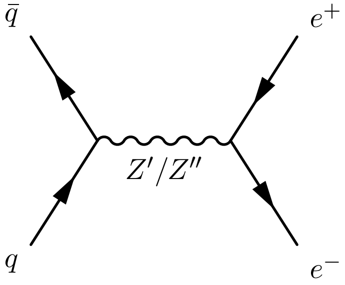
In dynamical symmetry breaking:

$$2_L \otimes 2_R \to 3_V + 1_V , \quad (5)$$

so have *two gauge triplets* in TC sector. Physical particles are $Z', W'^{\pm}$ and $Z'', W''^{\pm}$

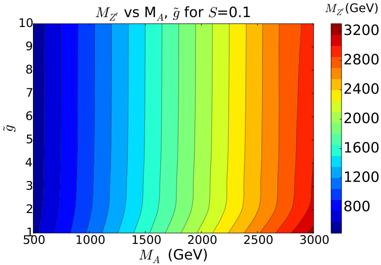
We can use processes with **new neutral resonances** to explore the parameter space of NMWT.

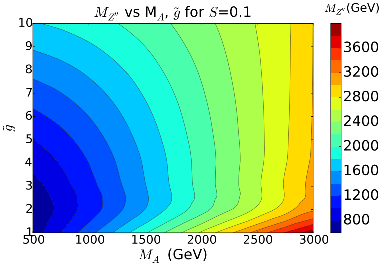
Specific process explored is Drell-Yan channel:



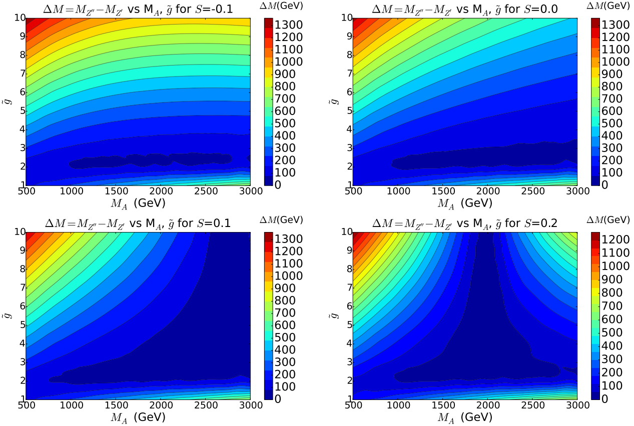
Properties of Z'/Z''

We use **CalcHEP Matrix Element Generator** to scan the 3-D parameter space.



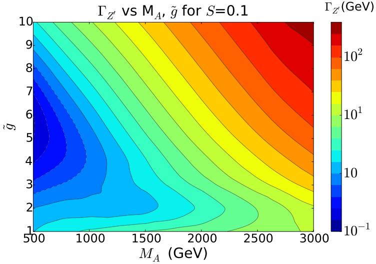


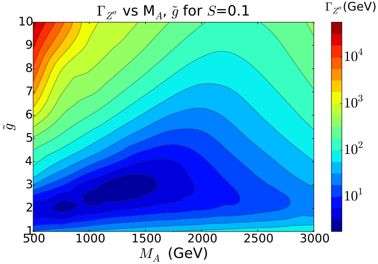
Dependence on S



Increasing S provides a large central region where the resonances are very close in mass.

Widths of Z' and Z'' resonances

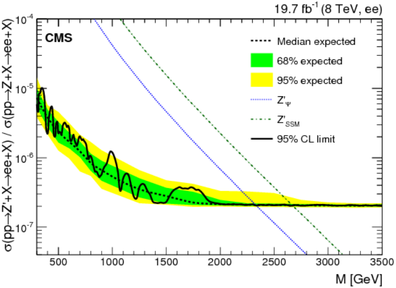


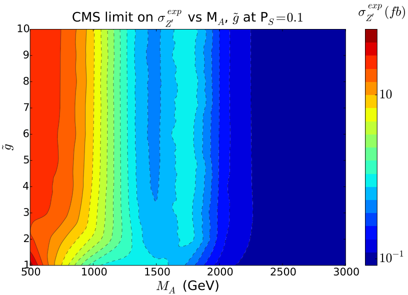


Effective Lagrangian describes majority of parameter space, but non-perturbative effects take over in low M_A, high $\tilde{g}$ for Z''.

Experimental limit

CMS limits on the cross section $\sigma(pp \to Z' \to e^+e^-)$ at $\sqrt{s} = 8$TeV to 95% CL projected into the NMWTC parameter space.





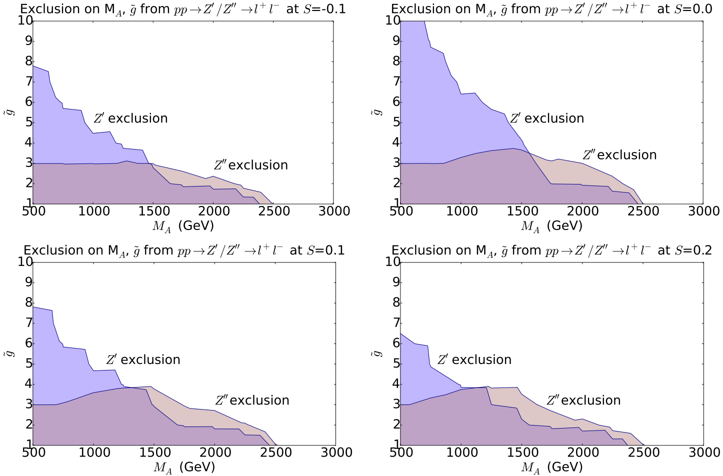
CMS Collaboration 1412.6302v2

Combined Z', Z'' Exclusions

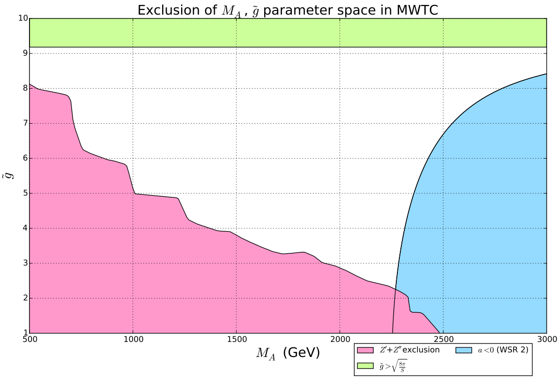
- Limits from single Z' searches are common, not so for multi-Z'
- We exploit the presence of distinct resonances to create the **first combined limits**
- Used **HEPMDB** to calculate $\sigma_{Z'}^{theory}$ and $\sigma_{Z''}^{theory}$ at $\sqrt{s} = 8$TeV
- Compared to CMS limit in $M_A - \tilde{g}$ space to find zero level contour of $\sigma^{theory} - \sigma^{exp}$
- Upper limit at 95% CL on $M_A - \tilde{g}$ parameter space produced for the range of discrete S

NMWTC Exclusion Limits

Z' and Z'' exclude complimentary regions. Combined, they produce stronger exclusion limits.



NMWTC Exclusion Limits



These are the strongest current limits on the NMWTC parameter space in the dilepton channel, alongside theoretical constraints on $M_A, \tilde{g}$ from walking α_S and electroweak precision test data.

Summary

- Walking Technicolor is a well motivated and phenomenologically interesting BSM theory
- We have produced the first combined Z'/Z'' limits on the WTC parameter space
- Combined limit from Drell-Yan processes exclude much of the low $M_A, \tilde{g}$ space
- We will extend our work to include exclusions at $\sqrt{s} = 13$TeV
- Also finding limits from all other possible decay channels with aim of "no-lose" theorem exclusions

Thank you!

Weinberg Sum Rules

- Zeroth WSR

$$S = 4\pi \left[\frac{F_V^2}{M_V^2} - \frac{F_A^2}{M_A^2} \right] \tag{6}$$

- First WSR

$$F_V^2 - F_A^2 = F_\pi^2 \tag{7}$$

- Second WSR

$$F_V^2 M_V^2 - F_A^2 M_A^2 = a \frac{8\pi^2}{d(R)} F_\pi^4 \tag{8}$$

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Masses and Decay Constants

Vector-vector field:

$$M_V^2 = m^2 + \frac{\tilde{g}^2(s - r_2)v^2}{4} \qquad F_V = \frac{\sqrt{2}M_V}{\tilde{g}} \tag{9}$$

Axial-vector field:

$$M_A^2 = m^2 + \frac{\tilde{g}^2(s + r_2)v^2}{4} \qquad F_A = \frac{\sqrt{2}M_A}{\tilde{g}}\chi \tag{10}$$

where

$$\chi \equiv 1 - \frac{v^2\tilde{g}^2 r_3}{4M_A^2} \tag{11}$$

Pion Decay Constant:

$$F_\pi = v = 246GeV \tag{12}$$