Hunting for Technicolor at the LHC

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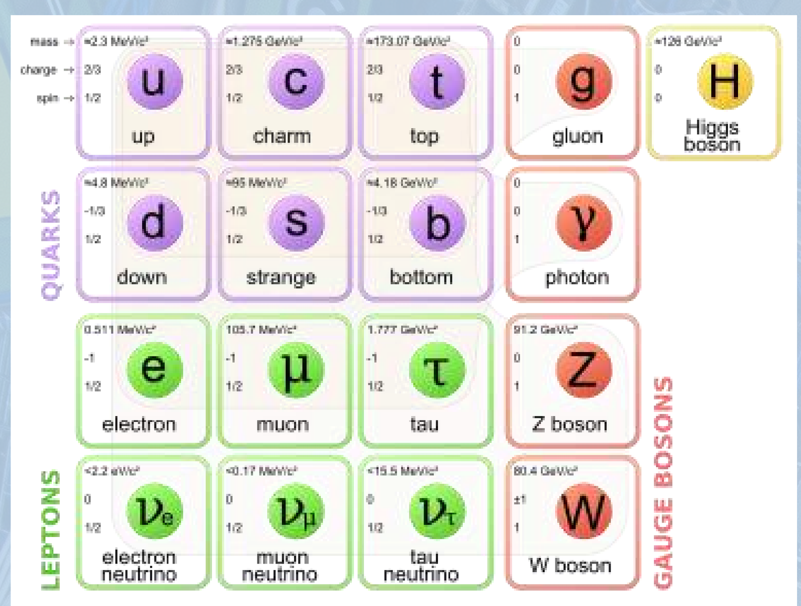
1. Standard Model and Beyond

The **Standard Model** (SM) of particle physics (*Figure 1a)* successfully describes the fundamental particles, and their interactions under the strong, weak and electromagnetic forces. However, there are many puzzling questions that this theory cannot answer, and so physicists must look for answers **beyond** the SM.

One important puzzle to solve is why the mass of the Higgs boson is so much smaller than the highest energy scale we know; the Planck scale (*Figure 1b)*. This is the ***hierarchy problem***, which causes us to calculate a Higgs mass that is 16 orders of magnitude higher than seen at the LHC. The SM cannot explain this without huge corrections, this is the ***fine tuning problem***.

A well-motivated solution to this problem is **Technicolor** theory, where an energy scale at ~1TeV is naturally generated. This solves the fine-tuning problem as the scale is consistent with the Higgs mass.



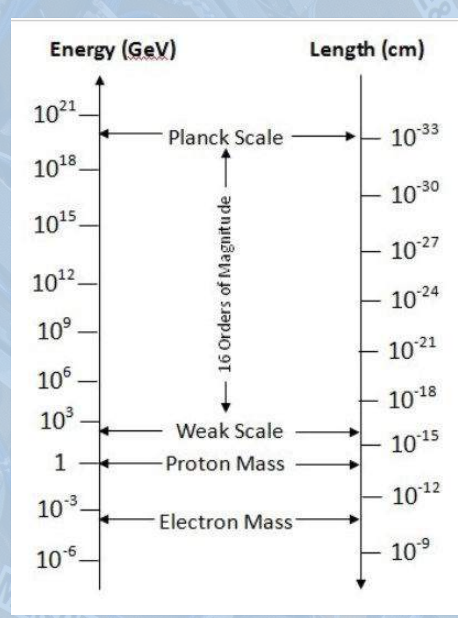


Figure 1: a) These are all the particles of the Standard Model. The bosons carry the forces between interacting particles.

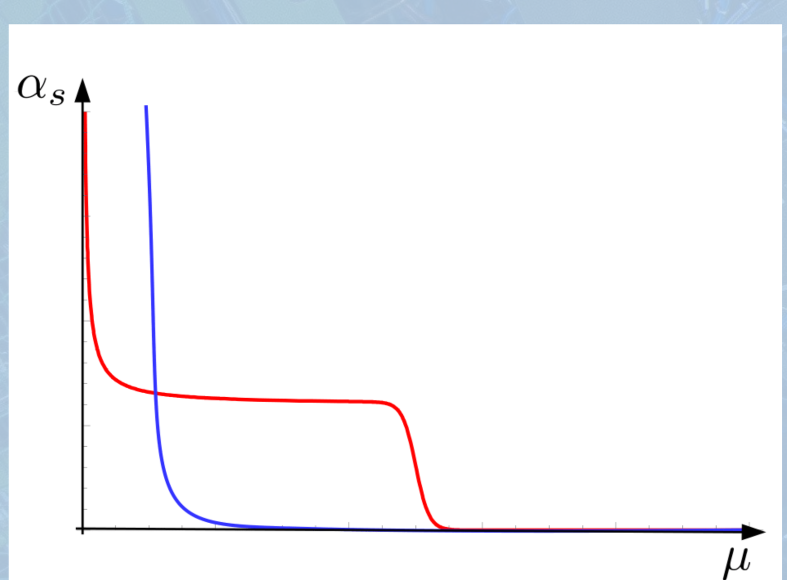
b) Energy scale; the 16 orders of magnitude between the Higgs mass (at the weak scale) and the Planck scale causes the hierarchy problem.

2. What is Technicolor?

As in the SM, in which protons and neutrons are made up of quarks, Technicolor (**TC**) introduces a set of **techni-quarks** which interact via a **new strong force**, which binds them together into new heavy particles.

A viable version of TC is **Minimal Walking Technicolor** (MWTC)[1], named after the characteristic behaviour of the strong coupling constant (*Figure 2a)*, where the coupling changes very slowly (**walks**) with energy scale. Among the new particles of **MWTC** are two new higher mass versions of the Z and W± bosons of the SM, called Z', W±' and Z", W±" respectively.

The properties of the MWTC particles can be described in terms of two parameters, M_A and $\tilde{g}$, where M_A is the energy scale of MWTC, and $\tilde{g}$ defines how the TC particles interact with SM particles[2].



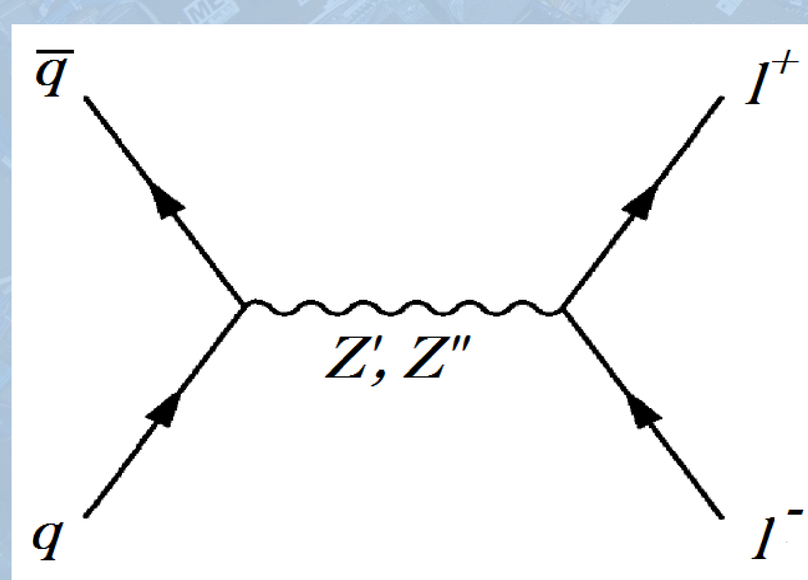


Figure 2: a) Comparison of Running coupling (blue) and Walking coupling (red)

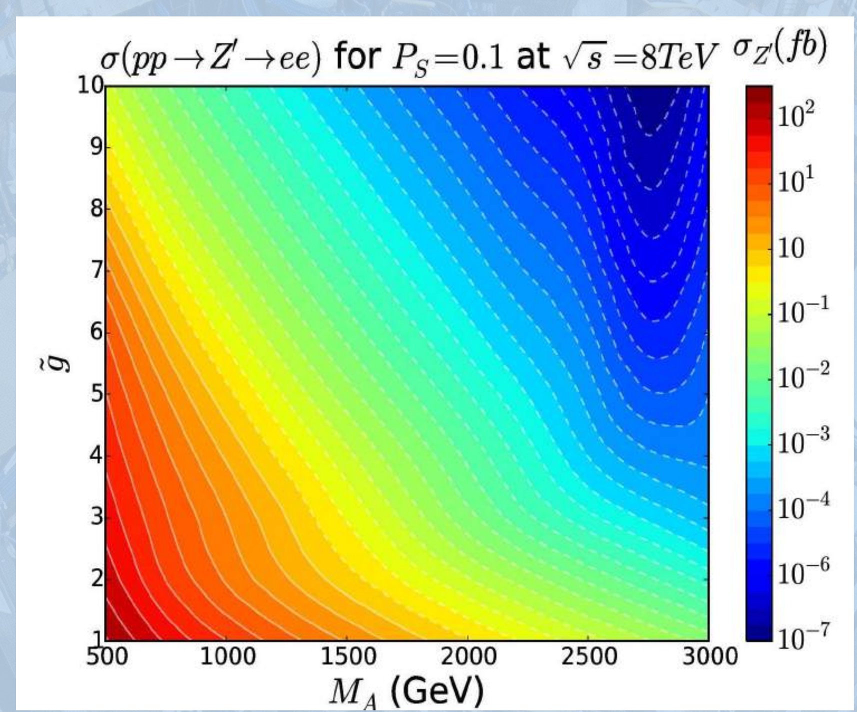
b) A WTC interaction Feynman diagram; production and decay Z' or Z" into a lepton-antilepton pair, e.g into an electron and positron. The Z' (or Z"), carrying the weak force, turns the quark-antiquark pair into a lepton-antilepton pair.

3. Limiting the Parameter Space

I conducted a comprehensive theoretical study of Z' and Z" production and decay (*Figure 2b)* using the ***CalcHEP Feynman Diagram Calculator***, conducting a full investigation of how properties such as the Z'/Z" masses vary with M_A and $\tilde{g}$.

I explored the probability (or cross section, σ) of producing these particles at the LHC for all values of M_A and $\tilde{g}$ (*Figure 3a)* using the ***High Energy Physics Model Database*** (HEPMDB), which runs on the IRIDIS supercomputer.

I then compared this predicted cross section σ^{theory} with experimentally limited cross sections σ^{exp} from the CMS particle detector at the LHC[3], and areas where $\sigma^{theory} > \sigma^{exp}$ are not allowed. We have excluded the MWTC parameter space for the first time using Z' and Z" exclusion limits.



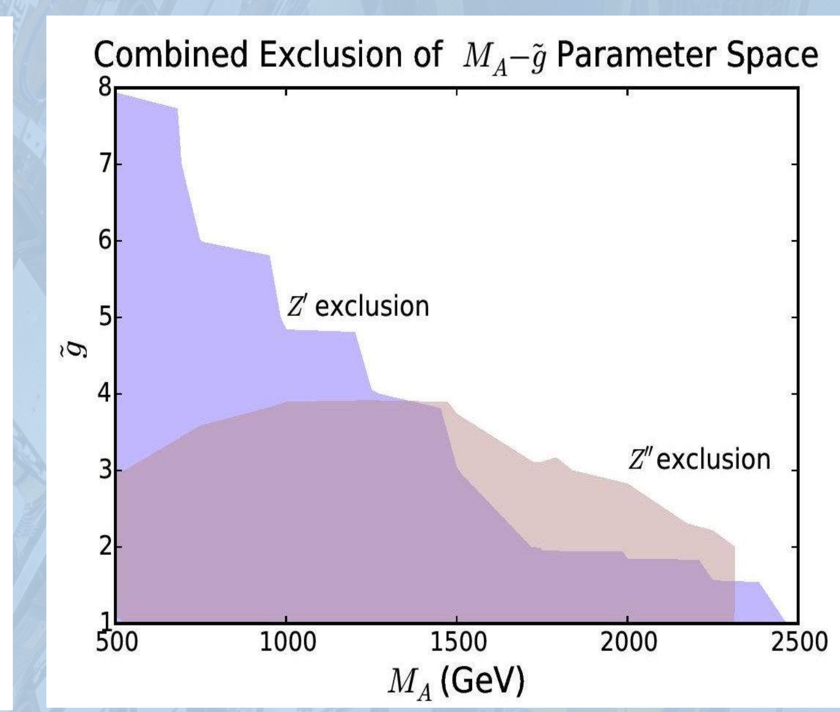


Figure 3: a) Theoretical cross-section for the Z' boson production and decay in the WTC parameter space

b) Final exclusion in the WTC parameter space, with the contributions from the Z' and Z" boson limits. All shaded areas are excluded.

4. Technicolor: Dead or Alive?

Colleagues in the STAG group have been using a mathematical framework called **Holography**, which allows them to perform calculations in strongly interacting theories such as MWTC. Using Holographic calculations, they can predict parameter space values for MWTC theories.

By comparing our exclusions of the MWTC parameter space to their predictions of all of the different versions of MWTC, we can make definitive statements about which of these theories can be ruled out (*Figure 4)*. Using this unique collaboration, we aim to either **discover** or **disprove** MWTC in the near future with LHC data.

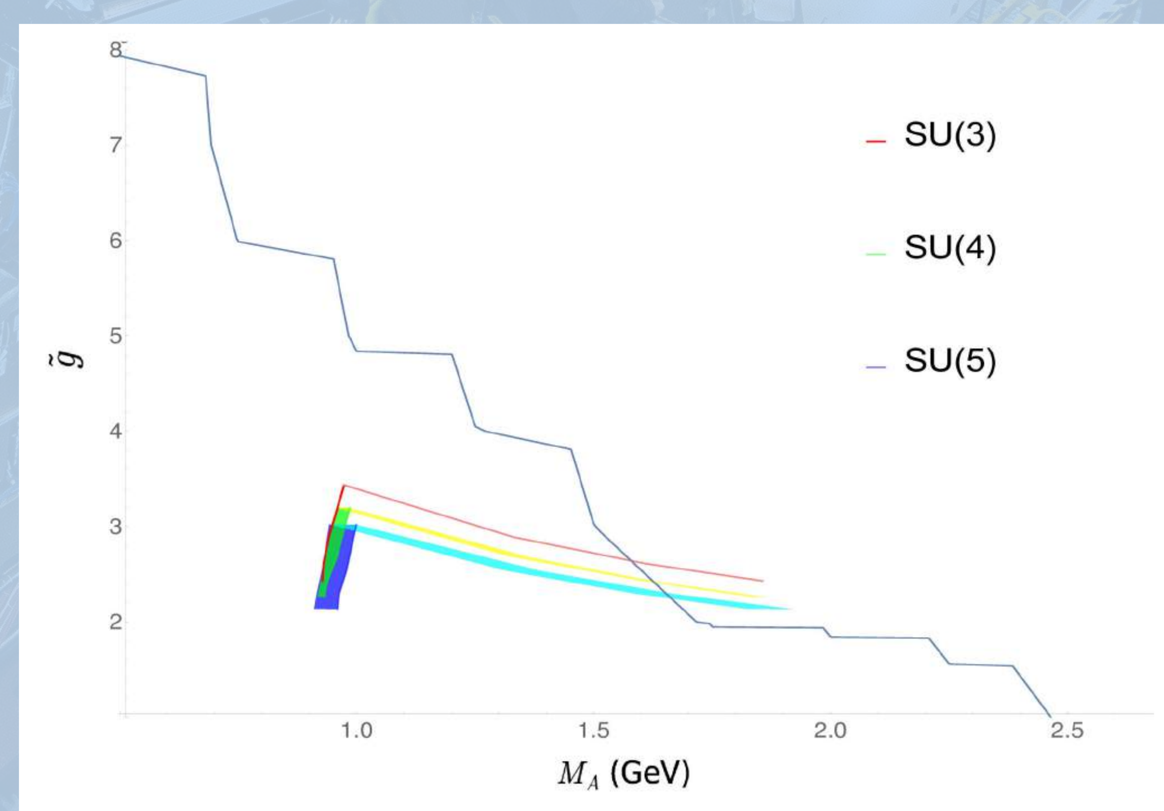


Figure 4: Predictions of a variety of WTC models from Holography, overlaid with the theoretical exclusions from the Z' production and decay cross section. The predictions below the line are excluded WTC theories.

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References:
[1] Belyaev, Foadi, Frandsen, Jarvinen, Sannino, Pukhov; **PRD79**(2009)
[2] Foadi, Frandsen, Ryttov, Sannino; **PRD76, 055005**(2007)
[3] CMS Collaboration; **JHEP04**(2015) 025