Electroweak Superconductivity

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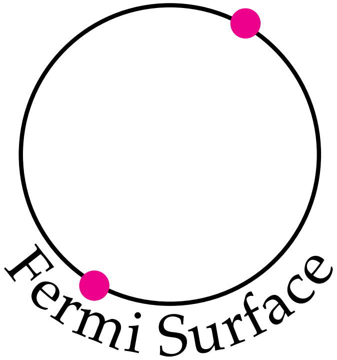
Introduction

EW Superconductivity

The Weak Interactions are realized in nature in the **Higgs** (or **superconducting**) phase. The origin of this superconductivity remains mysterious.

We need the analogue of BCS!



BCS

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

Physics responsible for EW Superconductivity might be:

- Fundamental field (Higgs doublet).
- Supersymmetry.
- Technicolor.
- Higgsless or other composites.
- Little Higgs.

BCS

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- Something Unexpected

Effective Theories and NDA

Model Builder's Goal:
Construct a theory that adequately describes the degrees of freedom up to some scale Λ.

All operators should have a size consistent with that determined by NDA.

$$S = \sum \frac{1}{16\pi^2}\left(\frac{g^2}{16\pi^2}\right)^{L-1}\int \Lambda^4 F_L(\Phi/\Lambda, \partial/\Lambda)$$

Strong coupling corresponds to $g \rightarrow 4\pi$

Hierarchy

Relevant couplings unprotected by symmetry have a natural size as large as the highest momentum scale in the theory (possibly times weak couplings).

Hierarchy

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

Relevant couplings unprotected by symmetry have a natural size as large as the highest momentum scale in the theory (possibly times weak couplings).

Two such operators in the Standard Model:

$\mathbb{1} \quad \Longrightarrow$ Cosmological Constant

$H^\dagger H \quad \Longrightarrow$ quadratic Higgs potential

☞ Higgs doublet

Unnatural

From experiment:

$$\mathrm{C.C.} \sim (3 \cdot 10^{-3}\ \mathrm{eV})^4$$

$$\mu^2 \sim (200\ \mathrm{GeV})^2$$

From one-loop in the Standard Model (momentum space cutoff):

$$\delta\mu^2 \sim \Lambda^2 \frac{3}{4} \frac{G_F}{\sqrt{2}\pi^2} \left(2M_W^2 + M_Z^2 + M_H^2 - 4m_t^2\right) \sim -\left(\frac{\Lambda}{3}\right)^2$$

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This requires $\Lambda < 1$ TeV .

Unnatural2

We have already explored physics in this region—effects of quantum modes with momenta greater than 1 TeV have been probed. Somehow the effects of these modes are not reflected in the weak scale of $v \sim 250$ GeV. Fine tuning to achieve this is inconsistent with NDA.

How can fine-tuning show up?

Example Fine Tuning

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

The Veltman Condition:

$$2M_W^2 + M_Z^2 + M_H^2 - 4m_t^2 = 0$$

No symmetry! This is fine tuning:

A relation not enforcable by symmetry.

☞ High energy physics won't respect such conditions.

It's cutoff-scheme dependent.

Solution?

Two ways out:

Solution?

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

Two ways out:

- Cancel the SM contributions (new physics related to existing modes by symmetry).

Solution?

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

Two ways out:

- Cancel the SM contributions (new physics related to existing modes by symmetry).
- Eliminate the operator.

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A third option:

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A third option:

- Live with it (Anthropics).

Scales

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

Highest momentum scale that we have probed?
We have seen physics well in excess of a TeV!
LEP1, LEP2, SLD, TEVATRON, Low energy Expt’s

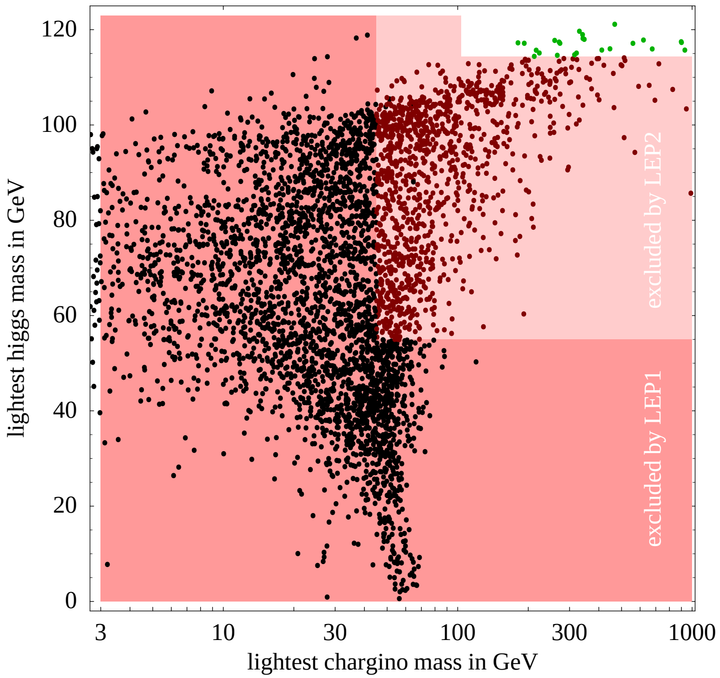

Figure 1: Barbieri and Strumia

New physics incorporated into effective theory with dimension 6 operators.

ElectroWeakPrecisionTests

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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ElectroWeakPrecisionTests

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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Prior to LEP2 there were two most relevant parameters:

$$T \text{ and } S$$

Strongest Constraints

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

(Old-fashioned): Ratio of charged-current to neutral current weak interactions (the ρ parameter).
Equivalently, the Z mass relative to W mass and $\sin^2\theta$.
(These definitions differ.)

(Modern): The T parameter.

The ρ parameter is nearly one. The Standard Model has an (approximate) symmetry which ensures this.

Custodial SU(2)

Standard Model:

$$U \equiv \begin{pmatrix} \widetilde{H} & H \end{pmatrix} \text{ where } \widetilde{H}_j \equiv \epsilon_{ji} H_i^*$$

Consider $SU(2)_L \times SU(2)_C$ transformations:

$$U \to L U R^\dagger$$

Gauge Interactions:

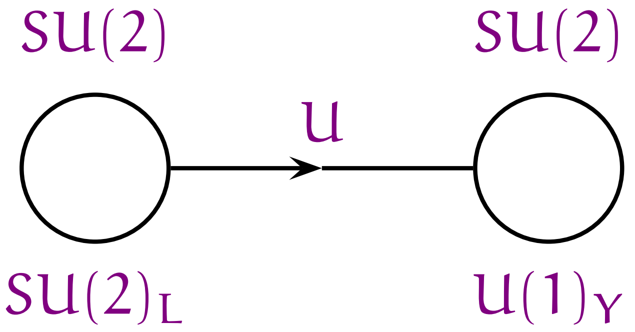
$$DU = \partial U + i\vec{W} \cdot \frac{\vec{\sigma}}{2} U + iBU \frac{\sigma^3}{2}$$

Custodial symmetry broken by $U(1)$ gauge interactions (and up–down Yukawa differences).

Notation

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

A nice notation:



Global:

Gauge:

The T parameter

This corresponds to the dimension six operator

$$\frac{1}{\Lambda^2}\left(H^\dagger D H\right)^2 \sim \frac{1}{\Lambda^2}\left(\mathrm{Tr}\,\sigma^3 U^\dagger D U\right)^2$$

(where the second form makes it is easy to see the symmetry violation). A vev for an electroweak triplet would have a dimension 4 operator contribution.

The current EWPT bound is

$$\Lambda \sim 8\ \mathrm{TeV}$$

The S parameter

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

The other well-constrained parameter: the strength of weak interactions relative to the masses of the W and Z. This is the so-called S parameter. The operator corresponding to S is

$$\frac{1}{\Lambda^2} H^\dagger W_{\mu\nu} H B^{\mu\nu} \sim \frac{1}{\Lambda^2} B^{\mu\nu}\, \mathrm{Tr}\, U \sigma^3 U^\dagger W_{\mu\nu}$$

The current EWPT bound is

$$\Lambda \sim 10\ \mathrm{TeV}$$

Other operators

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

Scales of some typical dimension 6 operators:

$\left(H^\dagger D H\right)^2$	$\Lambda \sim 8$ TeV
$H^\dagger W_{\mu\nu} H B^{\mu\nu}$	$\Lambda \sim 10$ TeV
$\bar{e}\gamma_\mu e \bar{l}\gamma^\mu l$	$\Lambda \sim 6$ TeV
$\bar{d}^c \sigma_{\mu\nu} H^\dagger q F^{\mu\nu}$	$\Lambda \sim 9$ TeV

Since LEP2, there are about 10 operators that provide important contraints. (For example, $(DW)^2$, $(\partial B)^2$).

Generally EWPTs require (dimensionless) measures of new physics $\sim v^2/\Lambda^2$ to be less than the parts per mille level!

General Constraints

We have strong evidence for a condensate with a scale of 250 GeV.

- Symmetry breaking is predominantly isodoublet (Custodial SU(2) symmetry)
- Symmetry breaking is weakly coupled.
- Must describe new physics to a (relatively) high scale near 10 TeV . This new physics must not couple significantly to avoid producing large dimension six (4-fermion) operators.

Requirements

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Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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- Natural (aside from C.C.) and Unitary.
- Preserve custodial $SU(2)$ (or something similar).
- Weakly coupled (or otherwise satisfy EWPTs).

SUSY

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Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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Home Movies

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- Preserves custodial $SU(2)$.
- R-parity eliminates tree-level corrections and weak coupling keeps loops small.

Unique?

None of these is unique to supersymmetry!

For a model builder, just need to incorporate these features.
Other considerations are secondary.

Example I

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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Example I

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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Example I

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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- (Can) preserve custodial $SU(2)$.
- Difficulty with EWPT: FCNCs (cured by walking?) and other dim-6 operators with large coefficients.

Example II

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

And another: the Little Higgs.

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Example II

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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Example II

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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BCS

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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BCS

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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- Something Unexpected

Next Time

A look at the techniques of model building (deconstruction). Then application to several examples to understand how these tools relate to the goals outlined above. Lessons can then be drawn.

Home Movies

Home Movies

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Home Movies

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Home Movies

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Home Movies

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Home Movies

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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- Neither is anything else.

Introduction
EW
BCS
NDA
Hierarchy
Unnatural
Unnatural2
Example Fine Tuning
Solution?
Scales
EWPT
Constraints
Custodial SU(2)
Notation
T parameter
S parameter
Other operators
General Constraints
Requirements
SUSY
Unique?
Example I
Example II
BCS
Next Time
Home Movies

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Tomorrow I might be something different.