Wilson, Naturalness, and the Higgs

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Tohoku Forum on Creativity

The Higgs

$M \simeq 125$ GeV

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$M \simeq 125$ GeV

A surprise to many

A shock to some

EW Superconductivity

Ideas colored by

naturalness

for decades.

EW Superconductivity

Ideas colored by
naturalness
for decades;

But the LHC has
changed things

BNW

We should re-examine and refine our arguments

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We should re-examine and refine our arguments

to better speculate about their inadequacy

WILSON

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Theory specified by

Lagrangian $\mathcal{L}$

Scale Λ

WILSON

Theory specified by

Lagrangian $\mathcal{L}$

scale Λ

For all observables $p<\Lambda$

$$\mathcal{L} = \sum_j c_j(\Lambda)\Lambda^{\delta_j} \mathcal{O}_j$$

LONG DISTANCE

For physics at p

choose $\Lambda = p$

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For physics at p

choose $\Lambda = p$

so that

$$\text{Observables} = p^k F[g(p)]$$

EXAMPLES

Gauge Theory

$$\mathcal{L} = -\frac{1}{2}\frac{c}{G^2}\,\mathrm{Tr}\,G^2$$

EXAMPLES

Gauge Theory

$$\mathcal{L} = -\frac{1}{2} c_{G^2} \, \mathrm{Tr}\, G^2 + \ldots$$

$$\Lambda \frac{\partial}{\partial \Lambda} c_{G^2} = \frac{b}{16\pi^2}$$

EXAMPLES

Gauge Theory

$$C_{G^2} = \frac{b}{16\pi^2} \ln \frac{\Lambda}{f} + c(f)$$

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Gauge Theory

$$C_{G^2} = \frac{b}{16\pi^2}\ln\frac{\Lambda}{f} + c(f)$$

$$\simeq c(f)\left\{1 + \frac{b}{16\pi^2 c(f)}\ln\right\}$$

$$\simeq c(f)\left(\frac{\Lambda}{f}\right)^{\gamma}$$

EXAMPLE

Yukawa

$$\mathcal{L} = \cdots + c_y \phi \bar{\psi} \psi + \cdots$$

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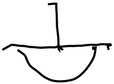
Yukawa

$$\mathcal{L} = \cdots + c_y \phi \bar{\psi} \psi + \cdots$$

$$\Lambda \frac{\partial}{\partial \Lambda} c_y = \frac{b}{16\pi^2} c_y^3$$



EXAMPLE

Yukawa

$$\frac{1}{c_y^2} = \frac{1}{c(f)^2} - \frac{b}{16\pi^2} \ln \frac{\Lambda}{f}$$

$$c_y^2 = c(f)^2 \left(\frac{\Lambda}{f}\right)^{\gamma}$$

EXAMPLE

Scalar mass

$$\mathcal{L} = \cdots c\Lambda^2\phi^\dagger\phi + \text{Yukawa}$$

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Scalar mass

$$\mathcal{L} = \cdots c\Lambda^2 \phi^\dagger \phi + \text{Yukawa}$$

$$\left(\Lambda \frac{\partial}{\partial \Lambda} + 2\right) c = \frac{b c_y^2}{8\pi^2}$$

EXAMPLE

Scalar mass

$$c = \left(\frac{a}{\Lambda}\right)^2 + \frac{b}{16\pi^2} c_y^2$$

$$\equiv \left(\frac{a}{\Lambda}\right)^2 + R$$

SCALAR MASS

$$c(\mu) = -1$$

SCALAR MASS

$$c(\mu) = -1$$

or

$$c(\Lambda) = -\left(\frac{\mu}{\Lambda}\right)^2 [1 + R]$$

$$+ R$$

SCALAR MASS

$c(\Lambda)$ must be finely tuned to cancel the running

$$\frac{\delta c}{c} \sim \left(\frac{\mu}{\Lambda}\right)^2 \frac{1}{R}$$

FINE TUNING

The higher the scale Λ at which we trust the theory, the more closely the UV BC must match the running.

COMMENTS

The running is physical

can't be avoided by particular regularization or renormalization scheme

WHAT TO DO

Two classes of solutions

i) Eliminate the operator

$$\phi^\dagger \phi$$

ii) Eliminate the bad scaling

NO HIGGS

Theories which have no light scalar have no dangerous operator

TECHNICOLOR

NO BAD SCALING

Need a symmetry that can forbid running of a scalar mass

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i) SUPERSYMMETRY

NO BAD SCALING

Need a symmetry that can forbid running of a scalar mass

i) SUPERSYMMETRY

ii) Nambu-Goldstone Boson

OTHER IDEAS

iii) Composite Higgs

iv) Conformal Symmetry

THE HIGGS

$M \simeq 126$ GeV

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Large Couplings to W, Z

THE HIGGS

$M \simeq 126$ GeV

Large Couplings to

W, Z

Small Couplings to

$gg, \gamma\gamma$

HIGGS PROPS

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W, Z consistent with mass coupling

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It's a Higgs!

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It's a Higgs!

$gg, \gamma\gamma$ consistent with Yukawa of top

HIGGS PROPS

W, Z consistent with mass coupling

It's a Higgs!

gg, $\gamma\gamma$ consistent with Yukawa of top

top couples to EW breaking!

HIGGS ANTIPROPS

No other new physics!

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No other new physics!

$\Lambda \gtrsim$ many TeV

DATA TELLS US

Its a light Higgs

DATA TELLS US

It's a light Higgs

Not technicolor

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Its a light Higgs

Not technicolor

Yukawa couples to top

DATA TELLS US

Its a light Higgs

Not technicolor

Yukawa couples to top

The running is what we calculated

DATA TELLS US

It's a light Higgs

Not technicolor

Yukawa couples to top

The running is what we calculated

No new physics

NATURALNESS

We have fine-tuning at the level of 2

%

SUPERSYMMTRY

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Absence of stops

SUPERSYMMTRY

Absence of stops generically

$$m_{\tilde{t}} \gtrsim 600 \text{ GeV}$$

SUPERSYMMTRY

Absence of stops generically

$m_{\tilde{t}} \gtrsim 600$ GeV

light squarks

$m_{\hat{q}} \gtrsim$ TeV

LOOPHOLE

LOOPHOLE

Light stops and all other superpartners heavy

LOOPHOLE

Light stops and all other superpartners heavy

Natural SUSY

南部 - GOLDSTONE

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i) Composite Higgs

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i) Composite Higgs

strongly coupled

$\Lambda \sim \text{TeV}$

南部 - GOLDSTONE

i) Composite Higgs

strongly coupled

$\Lambda \sim$ TeV

Only works by

ACCIDENT

南部 - GOLDSTONE

南部 - GOLDSTONE

ii) Little Higgs

南部 - GOLDSTONE

ii) Little Higgs

weakly coupled

$\Lambda \lesssim 10$ TeV

南部 - GOLDSTONE

ii) Little Higgs

weakly coupled

$p \lesssim 10$ TeV

top-prime to cancel running

南部 - GOLDSTONE

ii) Little Higgs

Generic Limits on

t'

$m_{t'} \gtrsim \text{TeV}$

LOOPHOLE

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lighter t' possible for special cases

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lighter t' possible for special cases

About the same as SUSY

LITMUS TEST

Absence of top partner indicates fine tuning

IMPLICATIONS

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Naturalness has been the guiding principle behind our attempts to understand the physics of the TeV scale and beyond

IMPLICATIONS

We can establish the status of naturalness by experiment

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We can establish the status of naturalness by experiment

i) search for top partners

ii) establish running

WHAT IF

fine tuning established at the 1% level ?

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i) Its an accident

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i) Its an accident

might want to test at 10^{-3} or 10^{-4} level

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100 TeV collider

WHAT IF

fine tuning established at the 1% level?

ii) Naturalness is wrong

IMPLICATIONS ARE HUGE !

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Without naturalness as a guide we are at sea

no expectation for BSM physics

IMPLICATIONS ARE HUGE !

Wilsonian Ideas are called into question

IMPLICATIONS ARE HUGE!

Wilsonian Ideas are called into question

No clear separation between UV and IR

EXCITING

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Experiments are calling into question one of our most used guides to TeV scale physics.

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Experiments are calling into question one of our most-used guides to TeV scale physics

Ignorance is an Opportunity!