HIGGS, NATURALNESS AND NEW PHYSICS

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SUMMARY

1. SM: SHORT HISTORY

GAUGE THEORIES → EINSTEIN:

"SYMMETRY DICTATES DYNAMICS"

QED →

YANG-MILLS GENERALIZATION →

EW THEORY - QCD

RENORMALIZABLE THEORIES

BUT MASSLESS: HOW TO INTRODUCE

MASS? FERMI EFF. LAGR.?

HIGGS – ENGLERT SOLUTION (1964):

P. Higgs: PRL **13** (1964) 508;

F. Englert & R. Brout: PRL **13** (1964) 321

SPONTANEOUS SYMMETRY BREAKING

THROUGH SELF-INTERACTING

SCALAR BOSON WITH "MEXICAN

HAT" POTENTIAL, WHICH GIVES

MASS TO PARTICLES

EW SCALE BREAKING: 246 GeV

RENORMALIZABILITY OF THE

THEORY GUARANTEED

(IN PARTICULAR W-W INTERACTIONS)

M. Veltman: Acta Phys. Pol. **B12** (1981) 437;

Sci. Am. **255** (1986) 88

1. STRANGE BEHAVIOR OF HIGGS: COUPLING CHANGES FROM PARTICLE TO PARTICLE

2. DIFFICULTY WITH GRAVITON: WHY SO SMALL COSMOLOGICAL C.?

3. HARDLY COMPATIBLE WITH AXION AND SU_5 GUT

2. NATURALNESS

V. WISHED FOR SOLVING IN A MORE NATURAL WAY THE PROBLEMS OF MASS AND RENORMALIZABILITY: SM AS EFFECTIVE THEORY OF A MORE FUNDAMENTAL ONE:

350 EW (GeV) 10^{19} QG

WHAT IN BETWEEN ?

GUTS ?

350 (GeV) 10^{17}
EW QCD+EW

VELTMAN: COMPOSITE MODELS,

LEPTONS & QUARKS BOUND STATES

OKUN: DIFFICULTY WITH

UNCERTAINTY PRINCIPLE →

ABSENCE OF LARGE MASS

DIFFERENCES

IN ANY CASE, MINIMAL

REQUIREMENTS OF NATURALNESS:

G.U.T. FOR QED, W, QCD

A UNIQUE COUP. CONST.

A RENORMALIZABLE THEORY

TWO SSB

AT INTERMEDATE ENERGIES

SSB: LOW ENERGY APPROX.,

LIKE SUPERCONDUCTIVITY

AND FERROMAGNETISM

3. TOP & HIGGS MASS CALCULATIONS

A) TOP MASS

SM: MASS FROM COUPL. TO HIGGS

RGE FOR COUPL. CONST. H-quark:

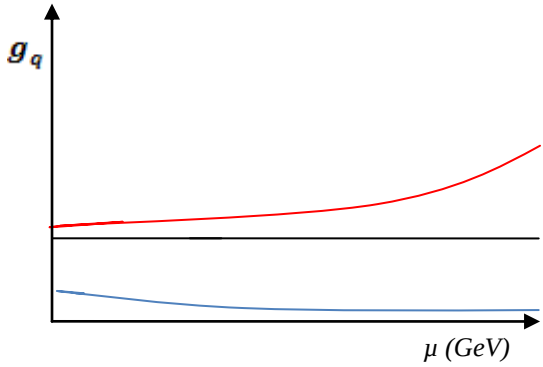
$$\mu \frac{\partial}{\partial \mu} g_q = \frac{1}{16\pi^2} g_q \times$$

$$\times \left(\frac{9}{2} g_q^2 - 8 g_3^2 - \frac{9}{4} g_2^2 - \frac{17}{20} g_1^2 \right)$$

$$g_q = (Hq) \; CC$$

$$g_3 = QCD \; CC$$

TWO POSSIBLE SOLUTIONS:



BLUE: SMALL g_q FOR μ O (10^{17} GeV):

INCREASES AT LOW μ: q = u, d, s, c, b

RED: LARGE g_q FOR μ O (10^{17} GeV):

QUASI-IR FIXED POINT: q = t

* SM → $M_t = 250$ GeV

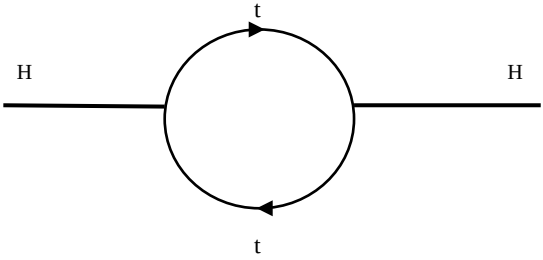
* 2DHM EXTENSION → LOWER M_t

CONCLUSION: MODELS BSM

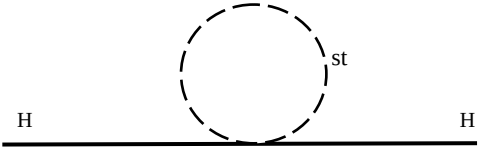
PREFERRED

B) HIGGS MASS →

QUADRATIC DIVERGENCE IN SM:



QUENCHED BY APPROXIM. SUSY:



4. UNNATURAL ASPECTS OF SM

* "BIG DESERT": NOTHING BETWEEN EW & PLANCK SC.
* EM, W & QCD C. C.: DO NOT CONVERGE TO A UNIQUE VALUE AT HIGH EN. AS WOULD BE EXPECTED
* QUADRATIC DIVERG. M_H
* K. G. Wilson: P. R. D **3** (1971) 1818 SCALAR BOSONS UNNATURAL AS ELEMENTARY PARTICLES

5. HIGGS DISCOVERY & NATURALNESS

JULY 4, 2012: ATLAS & CMS

ANNOUNCE DISCOVERY OF BOSON:

$M_H = 125.3 \pm 0.6$ GeV

SPIN = 0

CMS Coll.: Nuovo Cim. **C036** (2013) 356

ATLAS Coll.: ATLAS-CONF-2013-012

IMPLICATIONS OF NATURALNESS:

G.Altarelli: Phys.Scripta **T158** (2013) 014011

SM AS AN EFFECTIVE THEORY OF A RENORMALIZABLE ONE:

$$\mathcal{L} = \mathcal{L}_R + \mathcal{L}_{NR}$$

$\mathcal{L}_R = o(\Lambda^4) + \mathcal{L}_2\, o(\Lambda^2) + \mathcal{L}_3\, o(\Lambda) + \mathcal{L}_4\, o(1)$

$\mathcal{L}_{NR} = \mathcal{L}_5\, o(\Lambda^{-1}) + \mathcal{L}_6\, o(\Lambda^{-2})$

Λ: CUTOFF, $\mathcal{L}_2 = \Phi^+ \Phi$, $\mathcal{L}_3 = \bar{\psi}\, \psi$,

$\mathcal{L}_4$ = GAUGE & HIGGS INTERACTIONS,

$\mathcal{L}_5$ = WEINBERG OPERATOR ν MASS,

$\mathcal{L}_6 \supset$ 4-FERMION OPERATOR

$\mathcal{L}_2 \supset \delta M_H^2$ (t-LOOP) = $-\frac{3G_F}{2\sqrt{2}\pi^2} M_t^2 \Lambda^2$

$-\delta M_H^2$ (t-LOOP) $\approx$ $(0.2\ \Lambda)^2$

BUT

$M_H^2 = M_{bare}^2 + \delta M_H^2$ (tLOOP) + ...

NATURALNESS →

$-\delta M_H^2$ (t-LOOP) < $(125\ \text{GeV})^2$

→ Λ = O (1 TeV) :

SCALE FOR WHICH NEW PHYSICS

IS EXPECTED BY NATURALNESS

6. SEARCH FOR NEW PHYSICS

* NO NEW PARTICLES & NO NEW INTERACTIONS FOUND:

NEITHER VIRTUAL PARTICLES,

LIKE TOP IN $B_0 \leftrightarrow \bar{B}_0$ OSCILL.

* STRONG SUPPRESSION OF:

➔ FCNC;

➔ CP VIOLATIONS OUTSIDE CKM;

➔ HIGHER-DIMENSIONAL OPS.

* ANY COUPLING HIGGS - PARTICLE $\propto M_{PARTICLE}$, ACCORDING TO SM

* MORE GENERALLY: FOUND

NO SIGNIFICANT DEVIATION

FROM SM PREDICTIONS

PHYSICS BSM MUST RESPECT

LIMITS SET BY PRESENT

EXPERIMENTAL DATA

MFV MODELS ELABORATED

SUSY PARTICLES CONFINED TO

STILL UNEXPLORED PHYSICS

(Λ^2 DIVERGENCE QUENCHED)

TECHNICOLOR UNLIKELY, TOO

LARGE BINDING ENERGY REQUIRED

(Λ^2 DIVERGENCE ELIMINATED)

WARPED DIMENSIONS: 5 DIM.,

GRAVITY INCLUDED

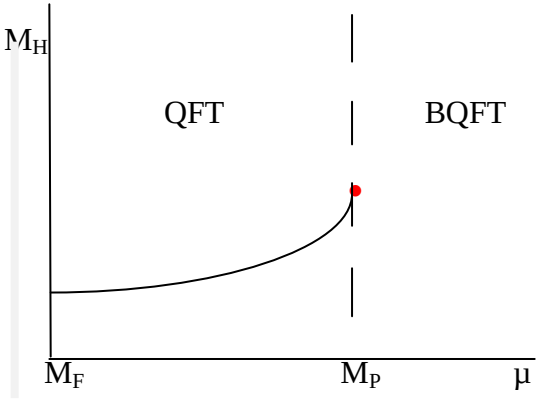
NO CONTRADICTION WITH

EXPERIMENT, NO INDICATION

7. IS THE STANDARD MODEL SO BAD?

HIGGS MASS CALCULATION BY

ASSUMING SM + "BIG DESERT":



BOUNDARY CONDITIONS FOR λ,

QUARTIC COUPLING AT $\mathbf{M_P} \approx 10^{19}$ GeV

M. Holthausen et al., JHEP **1202** (2012) 037:

$\lambda (M_P) = 0 \rightarrow$ EVOLUTION TO M_F

AS A FUNCTION OF Λ^2 & $M_H(\Lambda^2)$

$\rightarrow$ $M_H = (127 - 142)$ GeV

SIMILAR PROCEDURES:

LEP EWG: SM + EW MEASUREMENTS:

$M_H = 150 \pm 36$ GeV

Cabibbo et al.: Nucl. Phys. B **158** (1979) 295

$M_H = 143 \pm 37$ GeV

NON-SUSY MODELS → MINIMAL

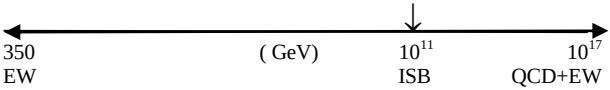
EXTENSIONS OF THE SM: E. G.,

G.Altarelli&D.Meloni: JHEP **1308** (2013) 021

COUPLING UNIFICATION →

SO(10) GUT WITH INTERM. BREAKING

SCALE $M_I \approx 10^{11}$ GeV



COMPATIBLE WITH EXISTING

BOUNDS OF PROTON LIFETIME

BARYOGENESIS →

YUKAWA SECTOR WITH MASSIVE ν'S

+ LEPTOGENESIS (LEP.-ANTILEP. AS.)

DARK MATTER →

AXION ARISING FROM HIGGS SECTOR:

SOLUTION TO STRONG CP PROBLEM

8. PERSPECTIVES & CONCLUSIONS

WHAT TO DO ?

* EXPERIMENTS TO VERIFY OR FALSIFY PREDICTIONS OF PRESENT THEORIES (SUSY, GUTS,...)

  E. G. BOUNDS ON PROTON LIFETIME

* STUDY OF QUANTUM GRAVITY BY MEANS OF BICEP2 DETECTION:

  L.M.Krauss & F.Wilczek, arXiv:1404.0634

1981-86 M. Veltman: SERIOUS DOUBTS ON THE EXISTENCE OF THE HIGGS BOSON

2013 G. Altarelli: "THE HIGGS: SO SIMPLE YET SO UNNATURAL"