The Higgs and beyond

Theoretical particle physics
at Carleton University

Heather Logan

Particle physics studies the structure of matter on the smallest scales that we can probe experimentally.

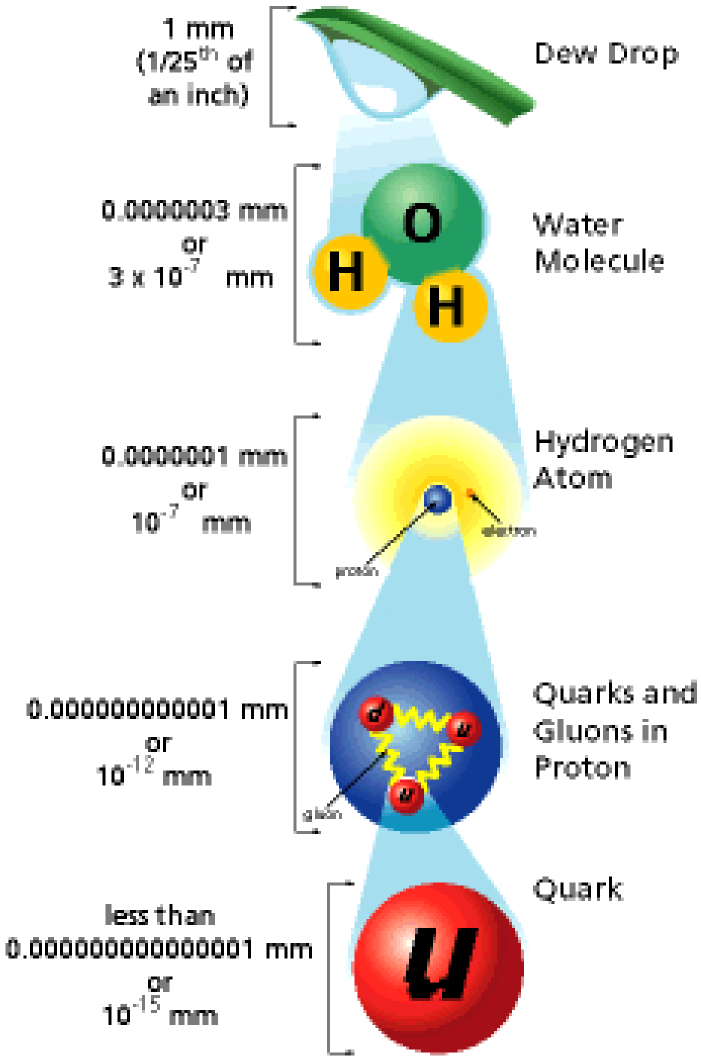


Image: Fermilab

Size of atom = 1/100-million cm
Size of nucleus = 1/100,000 of atom

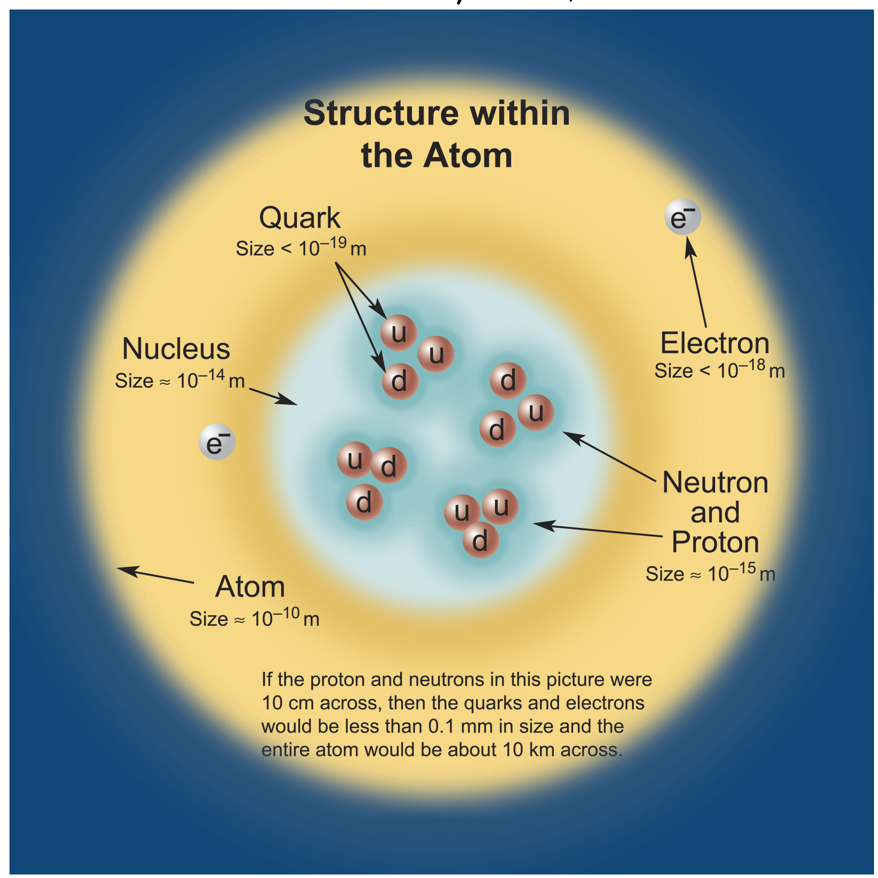


Image: Contemporary Physics Education Project

Theoretical particle physics interprets the experimental results in a coherent mathematical framework.

- Make detailed predictions based on current understanding

o "Standard Model" of particle physics: works very well so far!

o Detailed understanding of "backgrounds": allows experiments to know when they've found something new.

- Develop new ideas (theories) to address observational or theoretical problems

o There are holes in our understanding: we know the Standard Model can't be the whole story.

- Figure out predictions of the new theories so they can be tested by experiments

o This is the only way to tell whether a new theory is right or wrong!

o Theory input helps community figure out what experiments to build.

Theoretical particle physics at Carleton has a long history

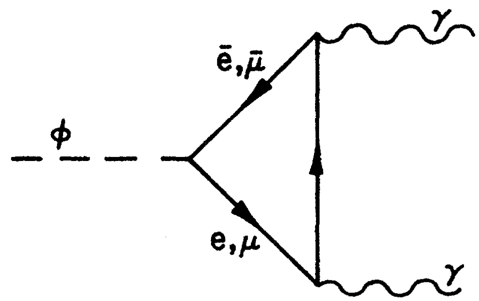
Working on the Higgs since the beginning!

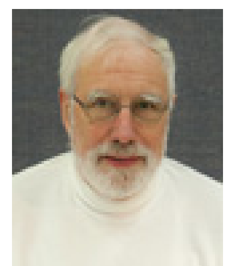
PHYSICAL REVIEW D VOLUME 8, NUMBER 1 1 JULY 1973

Is There a Light Scalar Boson?

L. Resnick, M. K. Sundaresan, and P. J. S. Watson
Department of Physics, Carleton University, Ottawa, Canada
(Received 28 July 1972; revised manuscript received 2 January 1973)

In view of recent theoretical interest in the possibility of a light scalar boson ϕ we discuss some of its properties and possible methods for detecting it. Cross sections for its production are typically 10^{-8} of competing processes, with the possible exception of $0^+ - 0^+$ transitions in nuclei. We also give a





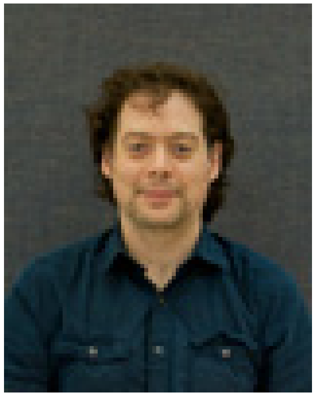
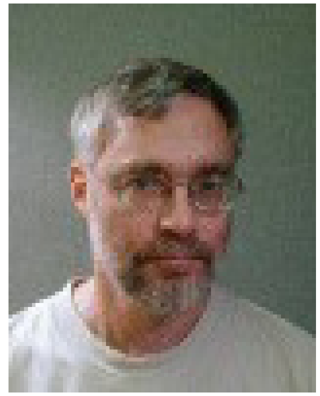
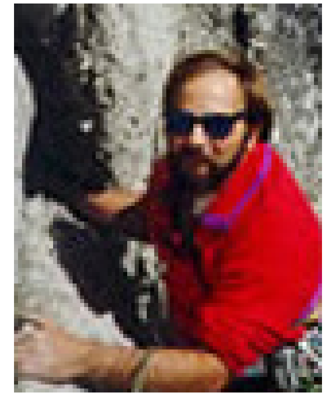
Prof. Emeritus Peter Watson

Higgs mechanism theorized 1964, incorporated into Standard Model 1967;

Standard Model became respectable 1971 with development of renormalization;

Strong evidence for Standard Model 1973 with discovery of weak neutral currents.

Carleton Physics theory group faculty

+ 2 postdoctoral Research Associates

+ 3 Ph.D. students

This academic year:
+ 2 fourth-year honours project students

Summer 2013:
+ 1 NSERC USRA student
+ 1 summer student

Training the next generation of students

Peer-reviewed journal articles with Carleton students (since 2011)

S. Godfrey, T. Gregoire, P. Kalyniak, T. A. W. Martin, and K. Moats, "Exploring the heavy quark sector of the Bestest Little Higgs model at the LHC," JHEP **1204**, 032 (2012).

C. Frugiuele and T. Gregoire, "Making the Sneutrino a Higgs with a $U(1)_R$ Lepton Number," Phys. Rev. D **85**, 015016 (2012).

K. Hally, H. E. Logan, and T. Pilkington, "Constraints on large scalar multiplets from perturbative unitarity," Phys. Rev. D **85**, 095017 (2012).

R. Diener, S. Godfrey, and I. Turan, "Constraining Extra Neutral Gauge Bosons with Atomic Parity Violation Measurements," Phys. Rev. D **86**, 115017 (2012).

T. Brown, C. Frugiuele, and T. Gregoire, "UV friendly T-parity in the SU(6)/Sp(6) little Higgs model," JHEP **1106**, 108 (2011).

H. E. Logan and J. Z. Salvail, "Model-independent Higgs coupling measurements at the LHC using the $H \to ZZ \to 4l$ lineshape," Phys. Rev. D **84**, 073001 (2011).

G. Cree and H. E. Logan, "Yukawa alignment from natural flavor conservation," Phys. Rev. D **84**, 055021 (2011).

R. Diener, S. Godfrey, and T. A. W. Martin, "Unravelling an Extra Neutral Gauge Boson at the LHC using Third Generation Fermions," Phys. Rev. D **83**, 115008 (2011).

The Big Questions

Is the Higgs boson really responsible for other particles' masses?

What keeps the Higgs boson from getting a huge mass from quantum effects?

What is the dark matter?

What happened to all the antimatter?

Why are neutrinos so much lighter than all the other particles?

Why are there so many quarks and leptons, with such different masses?

 $\rightarrow$ 

The Big Questions Carleton people are working on

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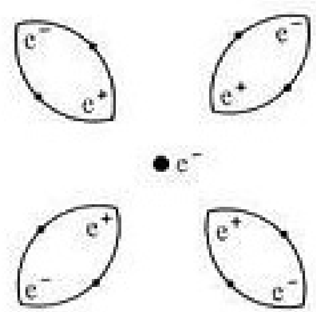
What keeps the Higgs boson from getting a huge mass from quantum effects?

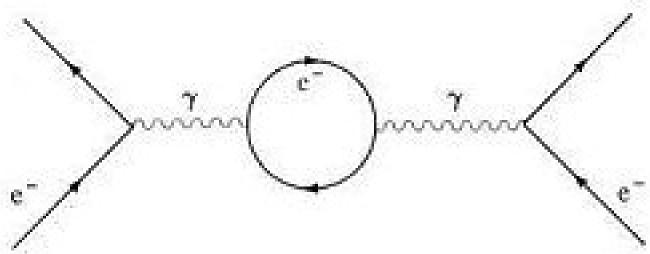
Properties of particles get "screened" at very short distances by virtual particles (a quantum-mechanics effect; they kind of tunnel into existence).



Charge of electron is a little stronger if you measure it really close up.

(within less than 1/100 of size of atom)

Calculation of this effect uses language of loop diagrams.



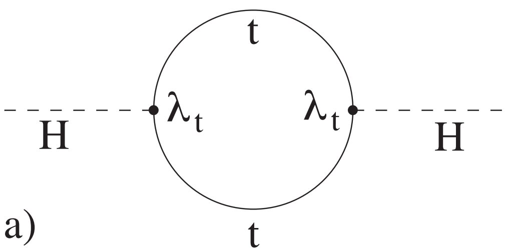
Masses of particles also get a quantum correction: mass that we measure is not the "original input" to the theory.

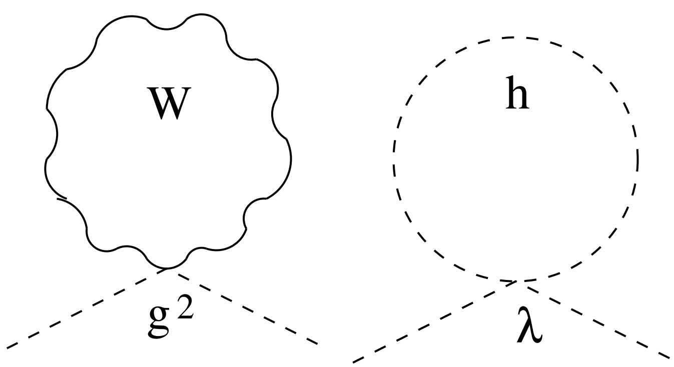
What keeps the Higgs boson from getting a huge mass from quantum effects?

For most particles, these quantum corrections to charges and masses are pretty small, no big deal.

For the Higgs boson, these quantum corrections are enormous.

The Higgs is special: the only fundamental spin-zero particle we know of.





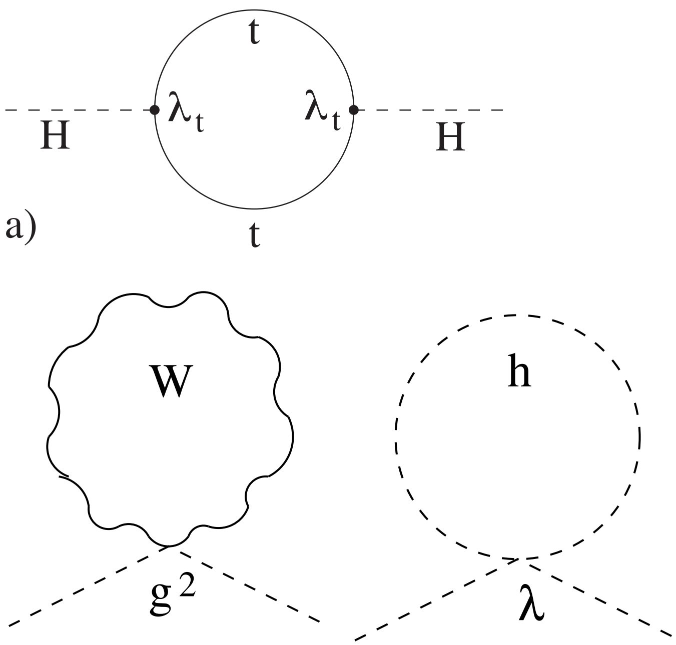
Physical mass =
"original input" + quantum correction

Quantum correction is ~ 30 orders of magnitude bigger than the physical mass! Second-worst prediction in all particle physics.

Has to be cancelled by "original input": a very implausible coincidence.

What keeps the Higgs boson from getting a huge mass from quantum effects?

To solve this problem we need a new theory with a physical mechanism to get rid of the enormous quantum correction.



Physical mass =
"original input" + quantum correction
+ new quantum correction

A good new theory will give us

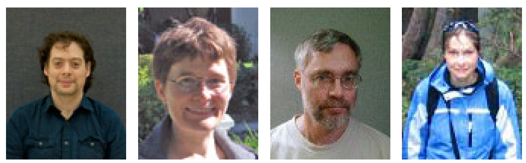
Physical mass ≈ "original input"
≈ quantum correction + new quantum correction

The new quantum correction comes from new particles.
Not just random new particles: their properties need to be just right to fix the Higgs mass problem. New physical principles → very specific expt. predictions.

What keeps the Higgs boson from getting a huge mass from quantum effects?

Some candidates for the new theory:

*Supersymmetry 

*Little Higgs 

Composite Higgs 

* Bonus:
could explain
dark matter! 

All these predict new particles with very specific properties.
- How to search for them at the LHC and other colliders?
- How to measure their properties and test whether they solve the Higgs mass problem?

backup slides

Active group with student and physics-community involvement

LHC Physics Theory workshop at TRIUMF (Vancouver) April 2009
Co-organized by theorists from TRIUMF and Carleton