Imperial College London

Discovering new particles with the Large Hadron Collider (LHC)

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First-year seminars

Autumn 2007

A. Parker, “Expedition to Inner Space”,

Writing!

- Avoid the *comma splice*:
  - "Physics is interesting, you ought to study it."
- Instead:
  - "Physics is interesting, so you ought to study it."
  - "Physics is interesting. You ought to study it."
  - "Physics is interesting; you ought to study it."
  - "You ought to study physics since it is interesting."
- (nb. adverbs like "however", "hence", "therefore" are *not* conjunctions like "and", "or", "so"):
  - "Physics is interesting. Hence, you ought to study it."

- Remember to write for your *audience*
- *Define* terms when you first use them.
- *Structure* is as important as *content* (e.g., introduction and conclusion):
  - signposting: give the reader an idea of what's ahead
- Don't be afraid to ask for advice (e.g., College Writing tutor)
- Read a lot!

The LHC: outline

- The standard model — almost complete
  - The Higgs boson
- Beyond the standard model
  - The hierarchy problem
  - large extra dimensions?
  - Supersymmetry?
- Detectors: ATLAS and CMS

The Standard Model: Almost complete

Fermions	quarks	u,d	c,s	t,b
	leptons	e, ν_e	μ, ν_μ	τ, ν_τ
Bosons	Force-carriers	γ, W, Z, g		
	Scalar(s)	Higgs (H)		

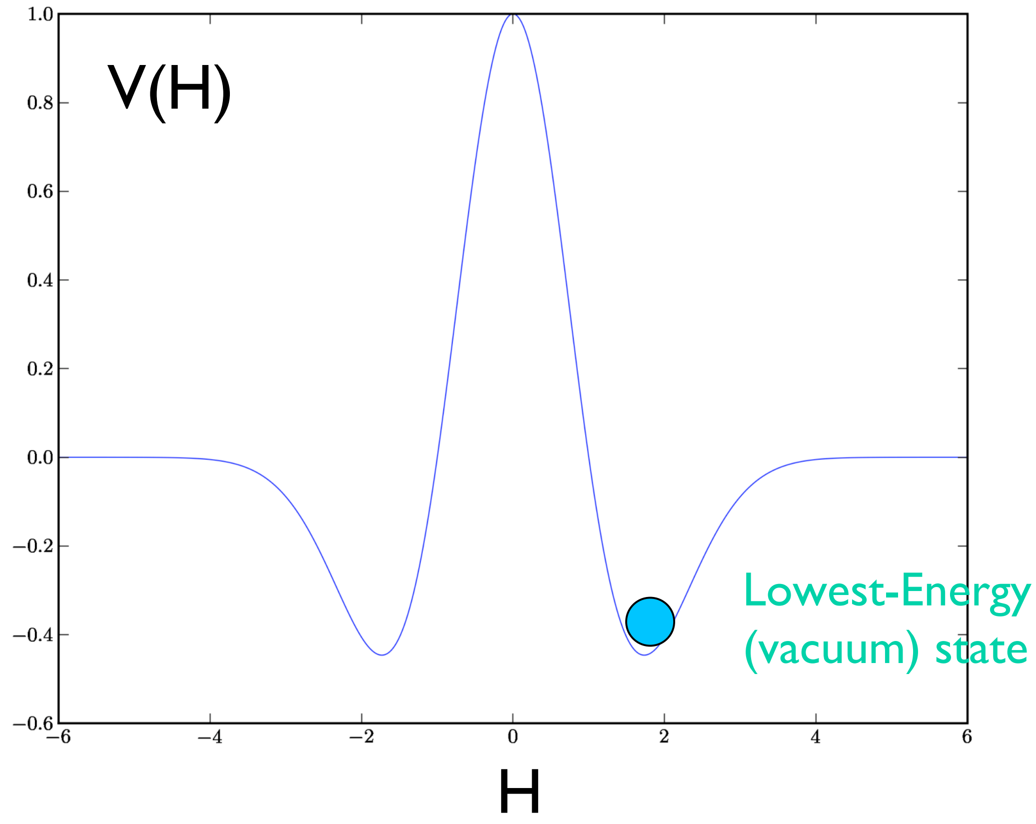
- The Higgs mechanism works because
  $\langle H \rangle \neq 0$
- Particles *constantly* interact with all-pervading "Higgs Field"
- Not yet seen! But they must interact with almost everything…

The Higgs Boson

- Higgs is a "scalar field" — spin 0
- Higgs mechanism — symmetry breaking
  - asymmetric potential $V(H) \Rightarrow \langle H \rangle \neq 0$
- Higgs particle mass related to heaviest 'standard model' particle — top quark (m_t~180 GeV/c^2):
  - m_H~100 GeV/c^2 (D0, Fermilab, *Nature* 2004)
  - upper limit on Higgs mass from 'Electroweak' theory:
  - m_H<1 TeV/c^2
  - need to be able slam particles together with energy >> 100 GeV (and examine the detritus!)

The Higgs Mechanism

- Quantum fields are described by a *potential, V(H)*
- Symmetry-breaking (Nambu 1961; Goldstone 1961; Higgs 1964; Kibble 1967)
- Incorporated into (now) Standard Model (Weinberg 1967; Salam 1968)



Beyond the Standard Model

- The standard model is rather complex:
  - SU(3)xSU(2)xU(1)
  - strong + electroweak forces
  - lots of fundamental particles, each with its own mass
  - no unifying principle or mathematical structure ("gauge group")
  - (we already are pretty sure it's not even right: massive neutrinos)
- Can we simplify, extend, complete, correct?

The Hierarchy Problem

- Most physics formulae contain numbers like 2, π, e, √3, etc, along with 'fundamental constants'.

  (We'll discuss this idea much more next term)
- Expect particle masses to be around

  $M_{Planck}=\sqrt{(\hbar c/G)}\sim 10^{19}$ GeV
- much greater than all other masses!
- need to get very small numbers (cancellations) into these equations…

“Large extra dimensions”

- Another ‘way out’ is to change the value of the Planck Mass!
- Mostly due to N Arkani-Hamed 1998.
  - make gravity “really” as strong as the other forces
- More than 3-D — Gravity propagates differently — weaker (spreads out into more volume)
- Gravity not well-measured on scales less than a few mm!
- (could co-exist with supersymmetry)

Supersymmetry

- SUSY: Every interaction with a standard-model particle is cancelled by an interaction with a "superpartner"
- fermions: electrons → selectrons, quarks → squarks
- bosons: photon → photino, W→wino [(!) or sometimes 'gaugino'], even graviton→gravitino
- expect $M_{partner} \sim M_H$, so if we can find the Higgs, we can find SUSY!
- Cosmology bonus: lightest superpartner could be "dark matter"!
- String theory: expected to look like SUSY + Gravity at low energies

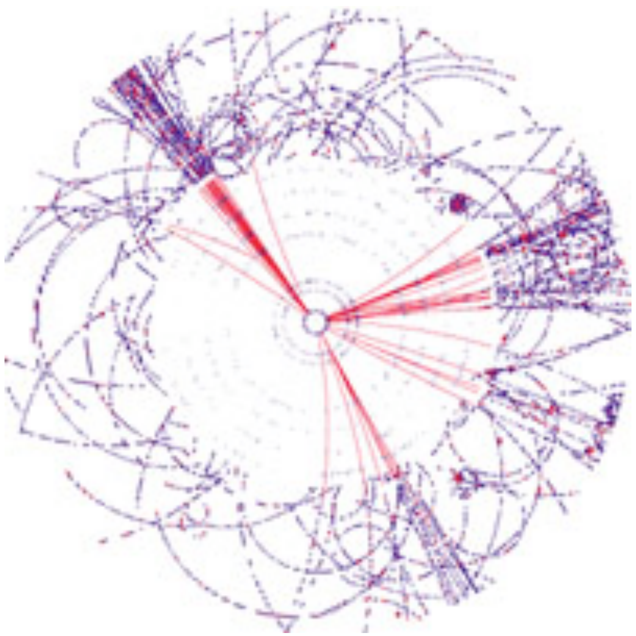
The Large Hadron Collider (LHC) at CERN

- accelerate 10^{11} protons to p~7 TeV/c
- will smash hadrons (protons) into one another with a total energy of $E \sim p/c \sim 14$ TeV/c^2
  - much higher than ~1 TeV maximum for Higgs, SUSY.
- examine the resulting detritus
  - 1000s of particles in ~50 ns!

- "No lose": should find Higgs (or disprove it)

Detectors at the LHC: ATLAS and CMS

- Hard to directly observe Higgs or sparticles…
- p+p→H+stuff→(very specific stuff)+(garbage)
- use magnets to guide the particles, observe their trails through the detector
  - charge
  - energy ("calorimetry")
- must model many possible scenarii
- petabytes of data/year!



Conclusions: Topic Summary

- Interesting directions
  - Theory
    - Beyond the standard model
    - Supersymmetry
  - The LHC
    - how does it work?
    - detector technologies
    - what else will it do?