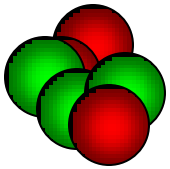
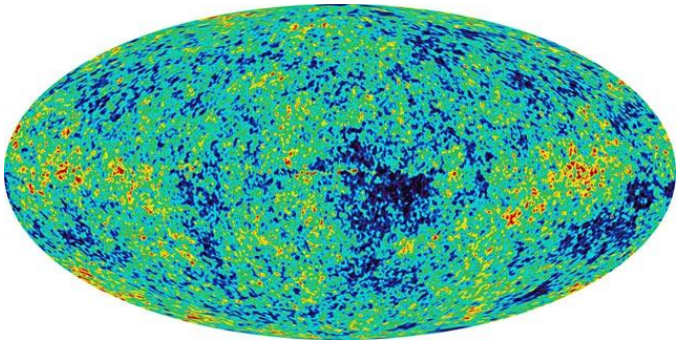
Finish up our overview of small and large





Lecture 5

Limits of our knowledge

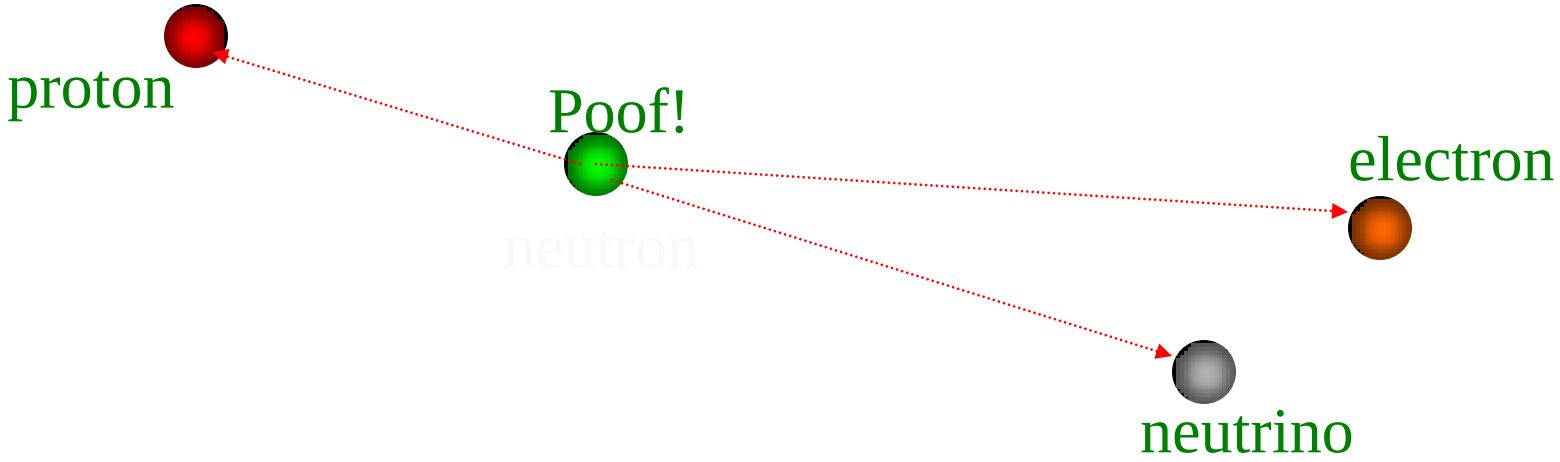
Clicker practice quiz

Some terminology...

- "Elementary particles" = objects that make up atoms (n,p,e) or are produced when atoms are smashed (over 200 identified)
  - "elementary" because thought to be fundamental in 1950s
- "Fundamental" particles or constituents of matter
  - Truly no substructure (as of today!)
- *Hadrons* = elementary particles subject to *strong nuclear force* (Greek: *hadros* = strong)
  - protons, neutrons; plus *pions, kaons, lambda* particles...etc
  - now known to be made of fundamental particles: *quarks*
- *Leptons* = elementary particles subject to *weak nuclear force* (Greek: *leptos* = weak)
  - responsible for radioactive decays
  - electrons, plus *muons, taus* and associated *neutrinos*

The Elementary Particles are *related*

- *Symmetries and connections* allow us to deduce structure of elementary particles, and properties of fundamental particles
  - Electric charge of electron and proton are equal and opposite, to the greatest accuracy possible today (about 13 decimals)
  - Neutron left alone for about 15 minutes on average will "Beta-decay" (old term for radioactive decay process) into e, p, and *neutrino* (very light, chargeless lepton)



But that's not all...

- Antimatter : Each elementary particle has an "antimatter" counterpart

  Electron $\leftrightarrow$ Antielectron (Positron)

  Proton $\leftrightarrow$ Antiproton

  Neutron $\leftrightarrow$ Antineutron

  etc. $\leftrightarrow$ *anti-etc.*

  Antiparticles have *opposite* electric charge (and other properties) but are otherwise identical

- $E=mc^2$ says matter and energy are interchangeable
  - just as easy to make antimatter as matter
  - happens all the time in nature - and we can do it in labs
- If particle and antiparticle meet – annihilation!
  - How come we live in a universe where there is almost no antimatter nearby?

The "Standard Model" of Particle Physics

Basic ingredients of *matter* are the fundamental particles: quarks and leptons

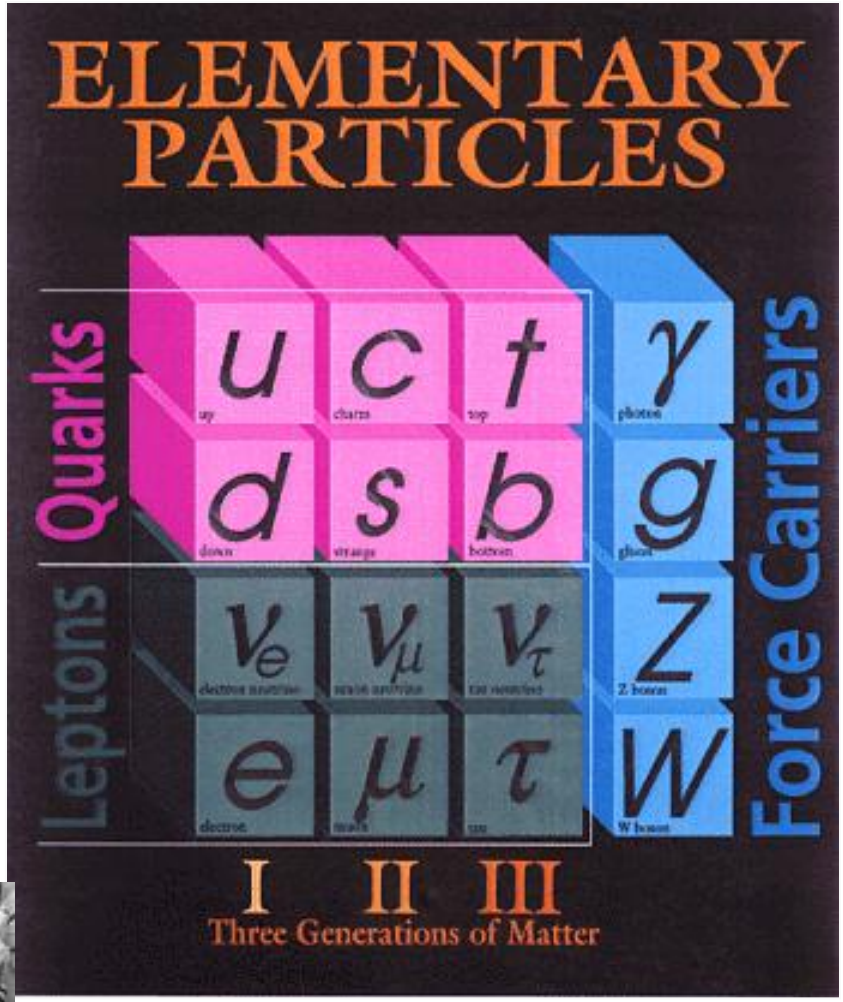
- 6 quarks
- 6 leptons

+ their antiparticles

(Symmetry!)

These types of particles are called 'fermions'

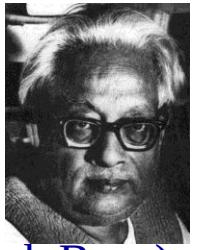
(after Enrico Fermi)



(from http://www.fnal.gov)

Fundamental *forces* are mediated by photons, gluons, Z's and W's

These types of particles are called 'bosons'



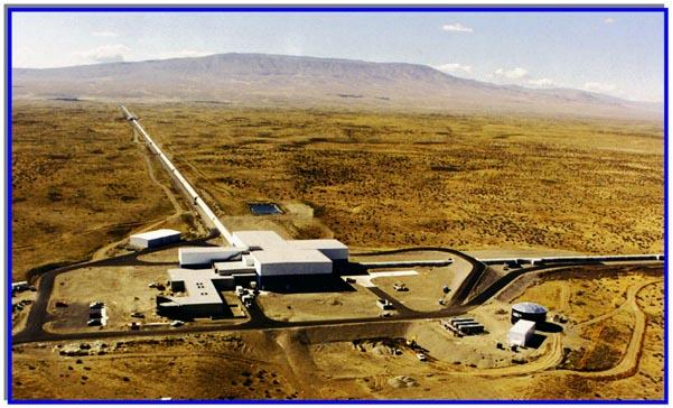
(after Satrendyanath Bose)

All Forces are *Mediated* by Exchanged Particles

Forces = interactions: exchange of particles - for illustration see http://particleadventure.org/frameless/unseen.html

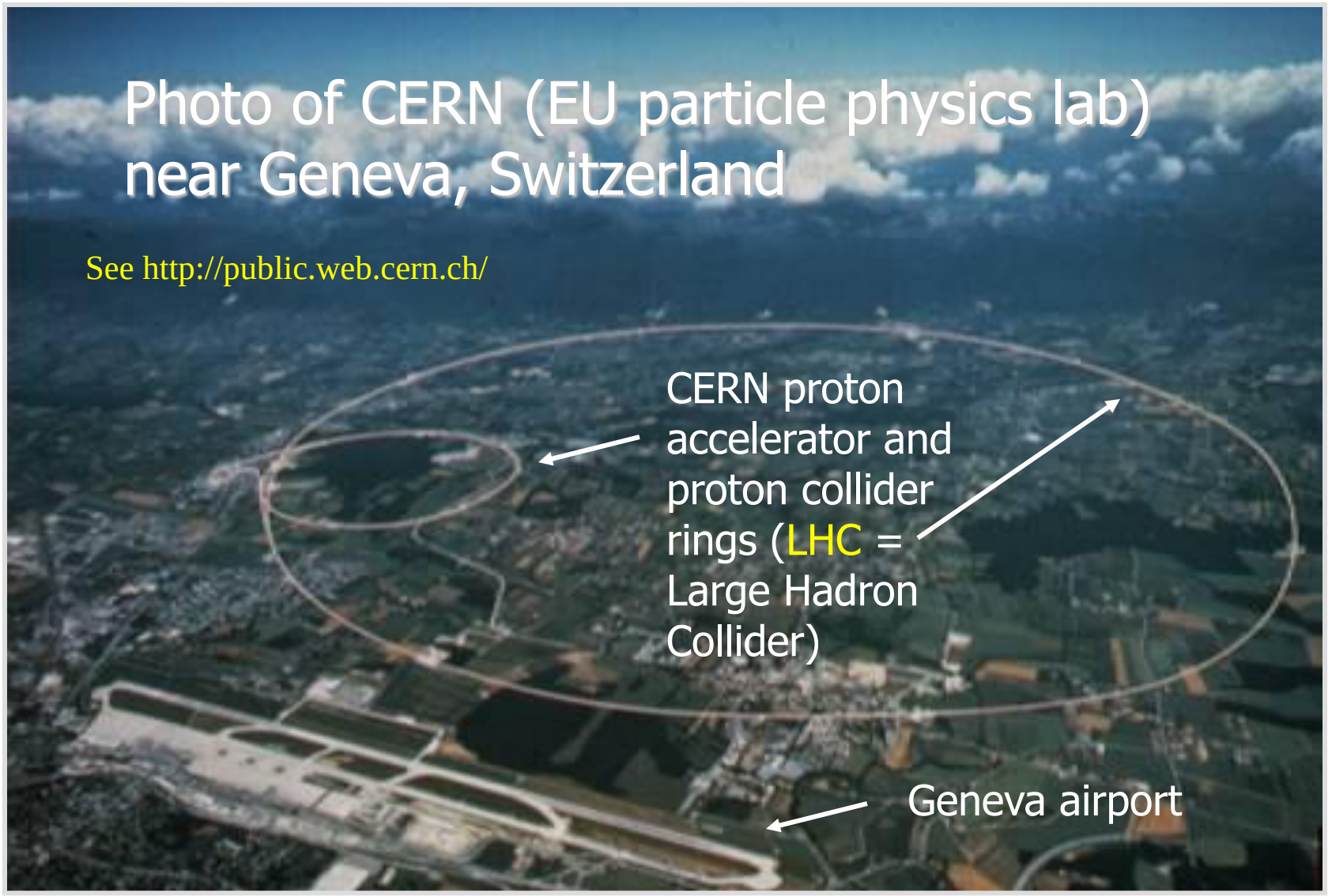
- Electrical and Magnetic forces – photon (massless)
- Strong nuclear force – "gluons" (massive)
- Weak nuclear force – W and Z bosons (massive)
- Gravity – graviton (massless, although no one has yet seen one)
  - LIGO experiment in Hanford, WA will try!
    - search for *gravity waves*
    - Laser beams in 4km-long tunnels
    - Look for changes in length of 10^{-15} m!

LIGO Hanford Observatory
http://www.ligo-wa.caltech.edu/



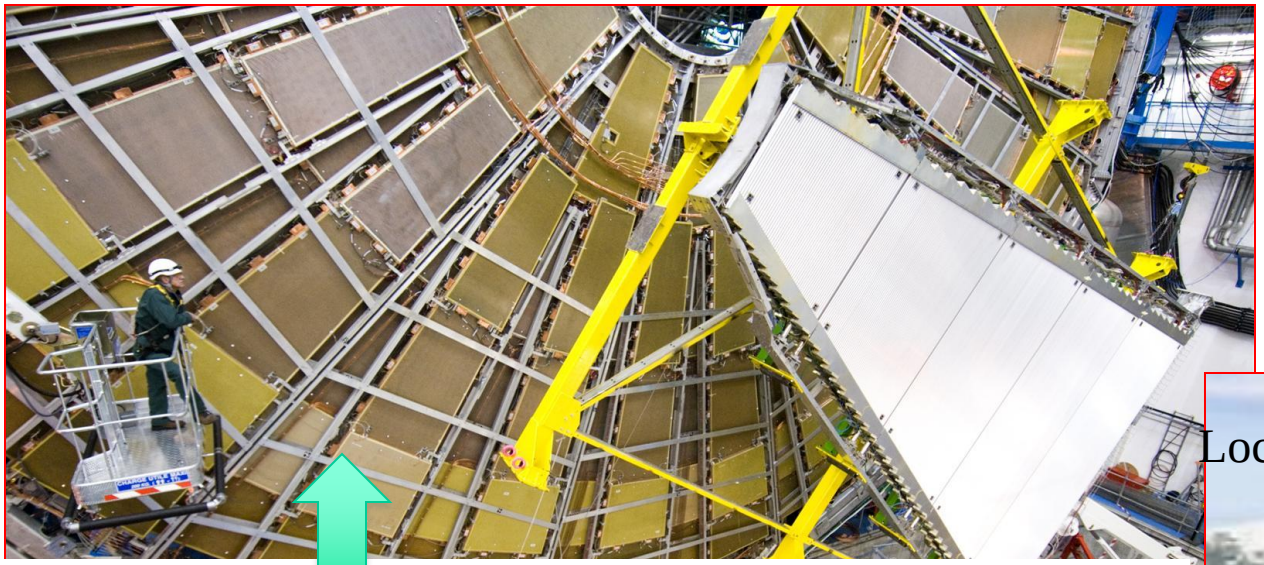
- The range (reach) of each force depends on the mass of the exchanged particle
  - Gravity and electromagnetic forces extend infinitely far (though weaken with increased distance)
  - Strong and weak nuclear forces are remote from everyday experience: only work at short range - distances like nuclear size

Need heavy-duty equipment to make high energy particle beams!

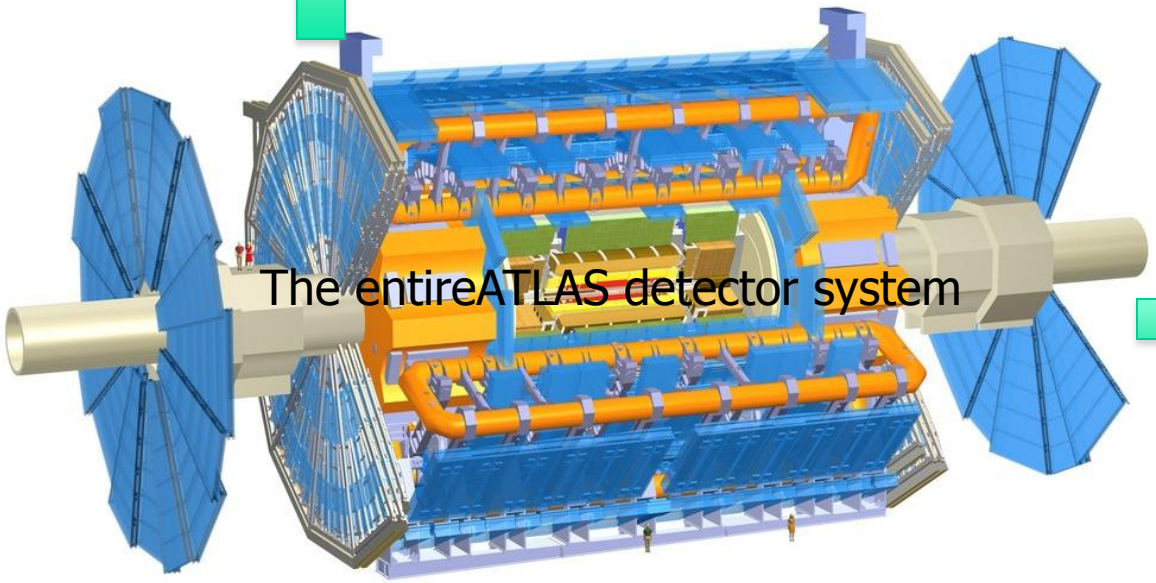


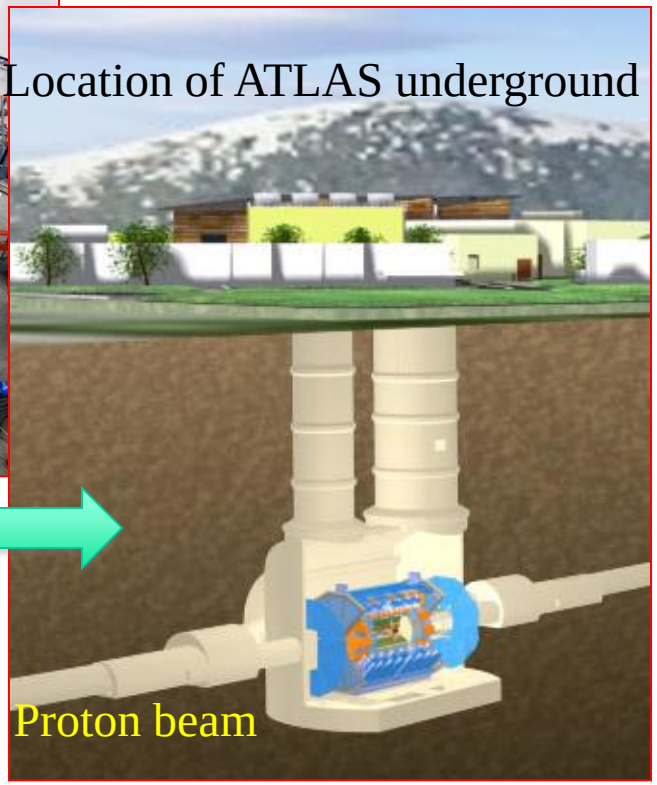
CERN, Switzerland

UW physicists are doing LHC research

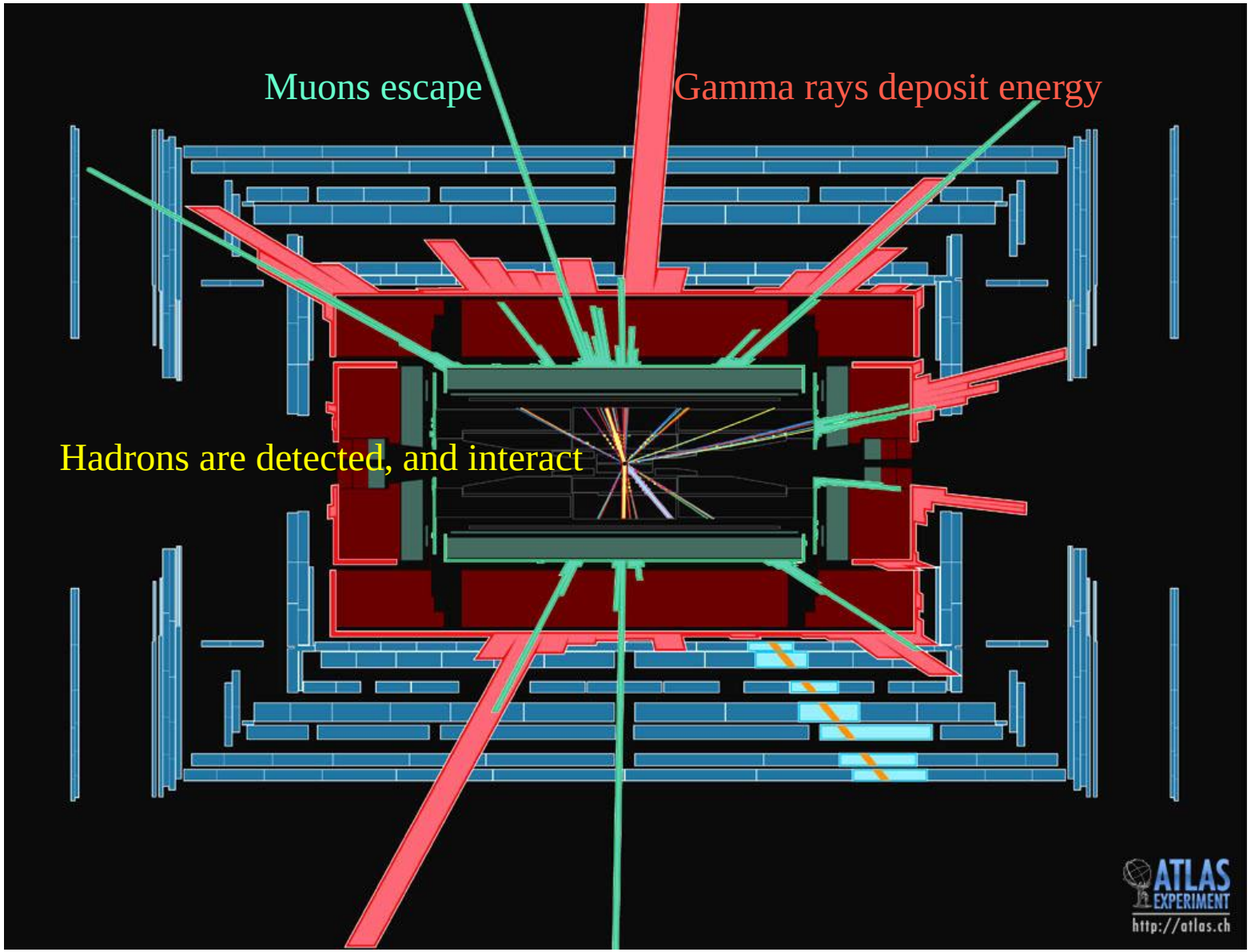


Prof. Henry Lubatti and his students built these muon detector layers here at UW





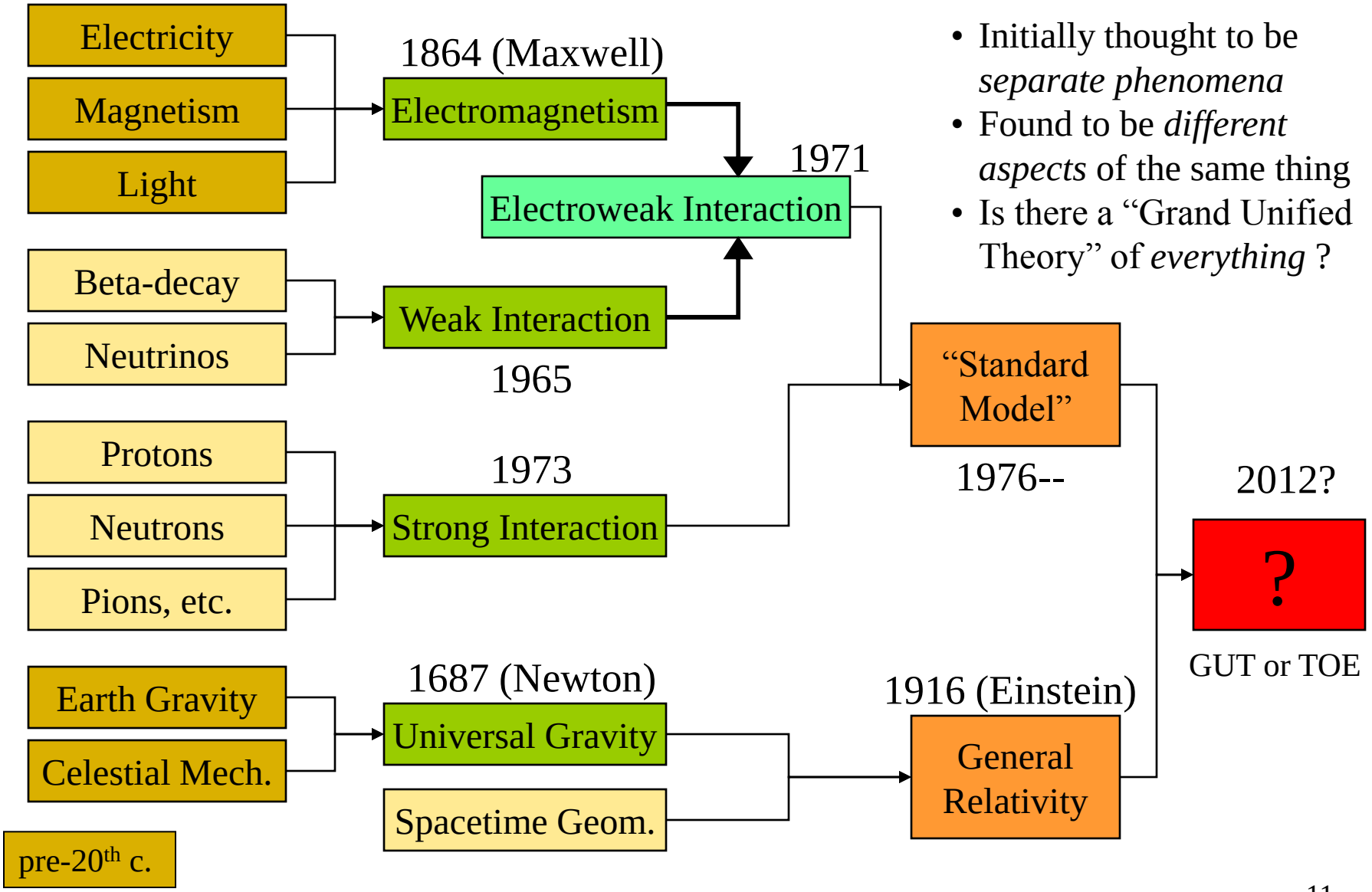
Here's how ATLAS detects and displays particles



Is there even further substructure?

- Much current debate on this topic!
  - Are quarks fundamental, or are there smaller things inside them?
  - No evidence for quarks having structure to date, but…
- Could all the particles be different "states" of a more basic entity? "String theory" suggests so.
  - Universe is actually 11-dimensional (!?)
    - All but 3 space dimensions are folded up inside "strings"…
      - Particles we detect correspond to different vibration modes, like notes from violin strings
  - *The Elegant Universe*, by Brian Greene, describes this view
- One difficulty: inaccessible for experimental tests!
  - "Planck Scale", 10^{-35} meters, needs *solar-system* sized accelerator!
    - we need new ideas...

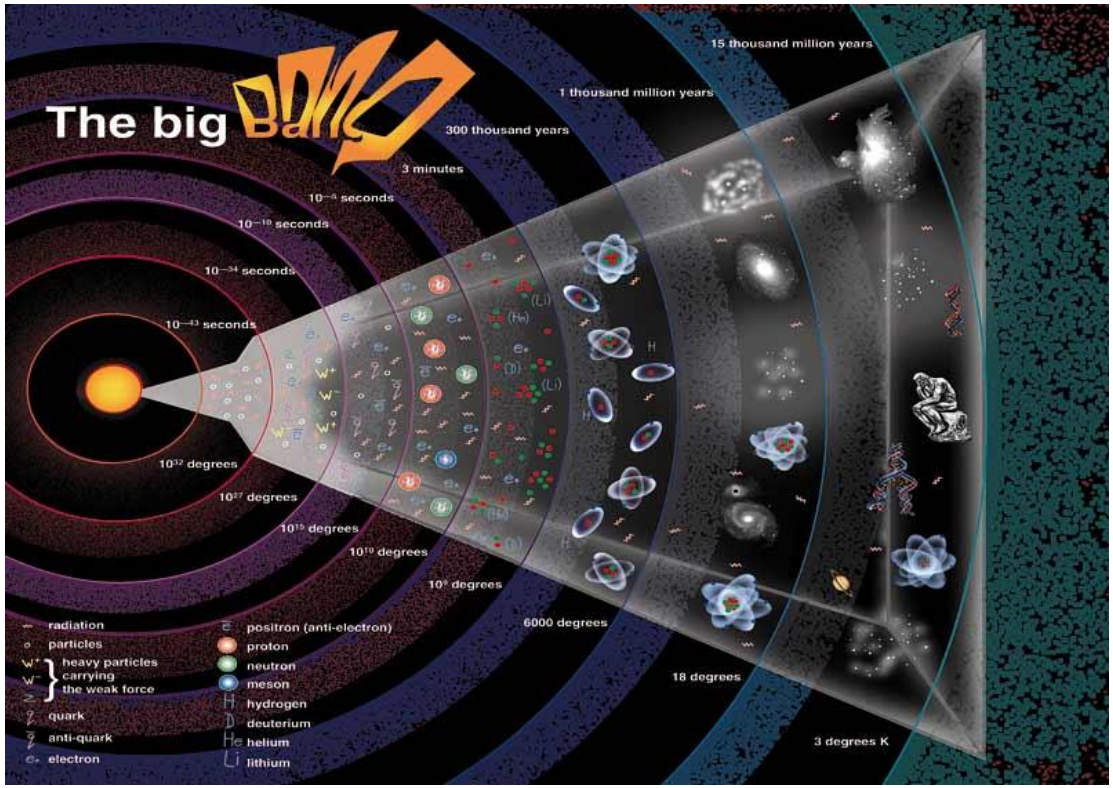
Unification of Fundamental Forces



- Initially thought to be *separate phenomena*
- Found to be *different aspects* of the same thing
- Is there a "Grand Unified Theory" of *everything* ?

The birth of the Universe

- "Big Bang" started the Universe out of a singularity.
- Period of faster-than-light "inflation" followed that created causally-disconnected regions of the universe. Inflation was mere creation of more space, not faster-than-light motion.



Practice Quiz – doesn't count!

- The LHC is
  A. A telescope used for seeing the most distant galaxies

  B. A high speed train connecting Seattle and Vancouver

  C. A new particle accelerator in Switzerland, which will allow us to study the interactions of fundamental particles

  D. The term used for the Little Hot Cooker, a device used for advanced scientific heating experiments