



Today

- Announcements:
 - HW#10 is due April 9 at 8:00 am.
 - The Spring Break Story Winner is ..
- What is matter? What is mass?



Standard Model

- The fundamental theory of nature's constituents and their interaction is called the Standard Model
- The theory includes:
 - Strong interactions due to the color charges of quarks and gluons.
 - A combined theory of weak (weak charge) and electromagnetic interaction (charge), known as electroweak theory.
- The theory does not include the effects of gravity. Gravity is tiny compared to the other forces and can be neglected in describing atoms.



What is matter

- Matter is the collection of objects made of baryons and leptons.
- Objects have quantum numbers that describe their nature

Electron:
Charge, lepton number, baryon number, etc.

Electrons also have mass. What is mass?



Four Fundamental Forces

<u>Force</u>	<u>Particles</u>	<u>Strength</u>	<u>Range</u>	<u>Mediator</u>
Gravity	All	6E-39	Infinite	Graviton
Weak	All	1E-5	1E-17 m	W [±] , Z ⁰
Electro-magnetic	Charged Particles	1/137	Infinite	Photon
Strong	Hadrons (protons and neutrons)	1	1E-15 m	Gluon

Standard Model Particles

Charge	matter particles			gauge particles		
	1st gen.	2nd gen.	3rd gen.			
+2/3 →	u <i>up</i>	c <i>charm</i>	t <i>top</i>	g <i>Gluon</i>		
-1/3 →	d <i>down</i>	s <i>strange</i>	b <i>bottom</i>	γ <i>photon</i>		
Anti-particles have the opposite charge.	ν_e <i>e neutrino</i>	ν_μ <i>μ neutrino</i>	ν_τ <i>τ neutrino</i>	W⁺ W⁻ Z <i>W bosons Z boson</i>		
	e <i>electron</i>	μ <i>muon</i>	τ <i>tau</i>			
	scalar particle(s)			H ? ? . . . <i>Higgs</i>		

Quantum Numbers (1)

The row gives the principle quantum number.

n = 1	1 1.01 H Hydrogen																	2 4.00 He Helium
n = 2	3 6.92 Li Lithium	4 9.01 Be Beryllium											6 10.81 B Boron	7 12.01 C Carbon	8 12.81 N Nitrogen	9 13.80 O Oxygen	10 15.85 F Fluorine	18 19.82 Ne Neon
n = 3	11 22.99 Na Sodium	12 24.31 Mg Magnesium											13 26.98 Al Aluminum	14 28.09 Si Silicon	15 30.97 P Phosphorus	16 32.06 S Sulfur	17 35.45 Cl Chlorine	18 39.90 Ar Argon
n = 4	19 39.10 K Potassium	20 40.08 Ca Calcium	21 44.96 Sc Scandium	22 47.88 Ti Titanium	23 50.94 V Vanadium	24 52.00 Cr Chromium	25 54.94 Mn Manganese	26 55.85 Fe Iron	27 58.93 Co Cobalt	28 58.93 Ni Nickel	29 63.55 Cu Copper	30 65.39 Zn Zinc	31 69.72 Ga Gallium	32 72.64 Ge Germanium	33 74.92 As Arsenic	34 78.94 Se Selenium	35 79.90 Br Bromine	36 85.36 Kr Krypton
n = 5	37 85.47 Rb Rubidium	38 87.62 Sr Strontium	39 88.91 Y Yttrium	40 91.22 Zr Zirconium	41 92.91 Nb Niobium	42 95.94 Mo Molybdenum	43 97.90 Tc Technetium	44 101.07 Ru Ruthenium	45 102.91 Rh Rhodium	46 106.42 Pd Palladium	47 107.87 Ag Silver	48 112.41 Cd Cadmium	49 114.82 In Indium	50 118.71 Sn Tin	51 121.76 Sb Antimony	52 127.60 Te Tellurium	53 127.60 I Iodine	54 131.29 Xe Xenon
n = 6	55 132.91 Cs Cesium	56 137.33 Ba Barium	57 138.91 La Lanthanum	58 175.07 Hf Hafnium	59 178.49 Ta Tantalum	60 180.95 W Tungsten	61 183.85 Re Rhenium	62 186.21 Os Osmium	63 187.54 Ir Iridium	64 190.23 Pt Platinum	65 193.06 Au Gold	66 197.04 Hg Mercury	67 197.04 Tl Thallium	68 200.59 Pb Lead	69 200.59 Bi Bismuth	70 208.98 Po Polonium	71 208.98 At Astatine	72 208.98 Rn Radon
n = 7	87 223.02 Fr Francium	88 226.03 Ra Radium	89 227.03 Ac Actinium	90 223.02 Th Thorium	91 223.02 Pa Protactinium	92 223.02 U Uranium	93 223.02 Np Neptunium	94 223.02 Pu Plutonium	95 223.02 Am Americium	96 223.02 Cm Curium	97 223.02 Bk Berkelium	98 223.02 Cf Californium	99 223.02 Es Einsteinium	100 223.02 Fm Fermium	101 223.02 Md Mendelevium	102 223.02 No Nobelium	103 223.02 Lr Lawrencium	118

- The structure of the periodic table arises from the underlying quantum numbers.

Quantum Numbers (2)

- Names like top, charm, strange, color, etc. do not mean the same things they do in everyday life. They are just identifiers.
- These names represent a set of quantum numbers that explain the number and types of particles that we observe.
- Chemistry, nuclear science, and particle physics all use different sets of quantum numbers, although they are all based on related ideas.

Rules for particle interactions

Example: $e^- + \bar{e}^+ \rightarrow u + \bar{u}$ ALLOWED

$n \rightarrow p^+ + e^-$ NOTALLOWED (lepton number)

$n \rightarrow p^+ + e^- + \bar{\nu}$ ALLOWED

Conserved: Electric charge, lepton number ($e = +1$, $\bar{e} = -1$), color charge, baryon number (could also count quarks: quarks +1/3, antiquarks -1/3), energy, momentum, and angular momentum.

$$n + p^+ \rightarrow \pi^+ + \pi^+ + \pi^- \qquad \pi^- \rightarrow e^- + \bar{\nu}$$

The standard model explains how particles interact and transform.

What is mass

- Most mass in matter comes from energy:
 $E=mc^2$
- The mass of the quarks that make up a proton is only a few percent of the mass. Most of the mass is in gluons (the carriers of the force).

What is mass? The interaction with a field

Space is filled with a (scalar) particle called the Higgs boson. The more a particle interacts with the Higgs field, the greater its mass is.

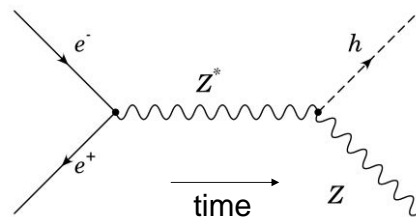


CERN

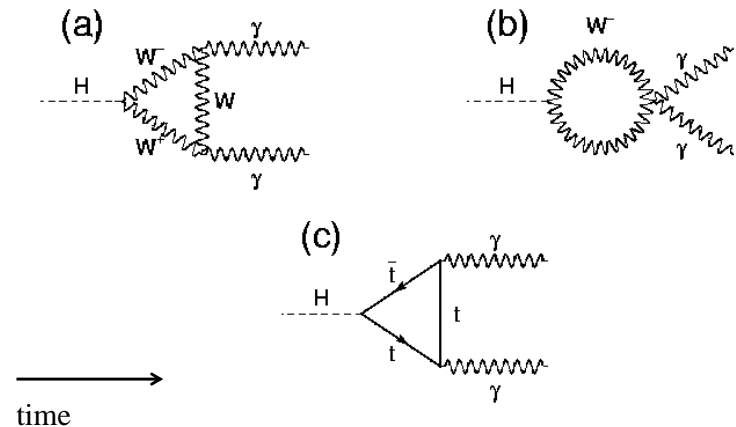
Higgs Particle

- The Higgs is the most famous undiscovered particle. A new collider called the Large Hadron Collider may find it.
- The world community is spending 10 billion \$ to find this.

Here is how to produce one:



How the Higgs will decay and be detected





Problems with the Standard Model

- Why so many particles?
- Are there more particles we don't know about yet?
- What is charge? Why does it come in fixed units? Same for lepton number and baryon number...
- Why is the standard model so complicated?
- Why 4 forces?
- How is gravity related to the other forces?
- In general the standard model does not answer the WHY question. Everyone agrees it is not a complete theory.



What comes next?

- There are attempts to extend the standard model to include gravity; these are called supersymmetric theories.
- These say that all fermions (which make up matter) and bosons (that transmit forces) have a corresponding partner boson (to go with our standard fermions) and fermion (to go with our standard bosons).
- Supersymmetric theories predict a whole set of new particles called s-particles, e.g. selectron, sneutrino, photino, Wino, and so on
- A new accelerator (Large Hadron Collider at CERN [Europe]) may be able to produce some of these particles in the next two years.

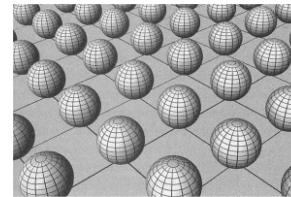


Superstring Theory

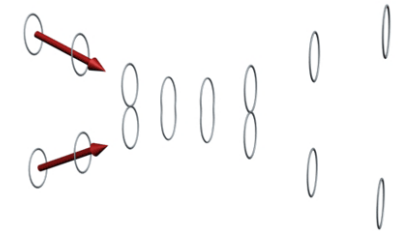
- One of the promising new theories is string theory. It says that the fundamental building blocks of nature are tiny (10^{-35} m) strings.
- The particles we observe in nature are different ways for strings to vibrate.
- String theory is not accepted because so far it has not devised an experiment that could test it.
- String theories require at least 10 dimensions.
- Gravity is weak because the graviton exists mostly in another dimension, but there is a slight overlap with us



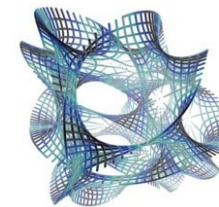
String Theory Pictures



Extra Dimensions



What one of the dimensions might look like (Calabi-Yau space)



Interaction of Strings:
The finite size (10^{-35} m) overcomes many of the problems with the interaction of point particles.



More energy – smaller wavelength

- It is a quirk of nature that, the smaller a particle is, the greater is the energy need to see it.
- To study a particle you have to have sufficient concentrated energy to create it.
- This has fueled the construction of particle accelerators, then colliders, which have continuously increased in size.

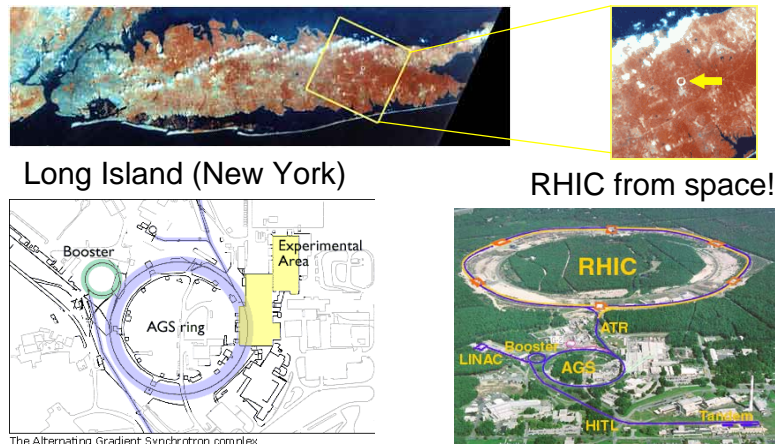


Scale of Energy (per Particle)

- Chemistry Experiment ~0.1-5 eV
- First Cyclotron (USA) 8E4 eV
- National Superconducting Cyclotron Laboratory (USA) 1.4E8 eV
- Super Proton Synchrotron (Europe) 4E11 eV
- Relativistic Heavy Ion Collider (USA) 1E11 eV
- Tevatron (USA) 1E12 eV
- Large Hadron Collider (Europe) 7E12 eV
- [Superconducting Super Collider (USA)] 2E13 eV



Relativistic Heavy-Ion Collider



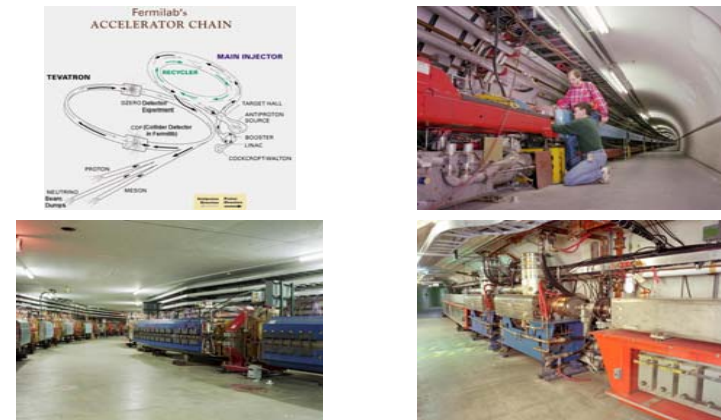
Long Island (New York)

RHIC from space!

Goal: Create a plasma of quarks and gluons



Tevatron – Fermilab (Illinois)



Goal: Produce the top quark

Tevatron - Fermi National Laboratory (Illinois)

Goal: Produce the top quark

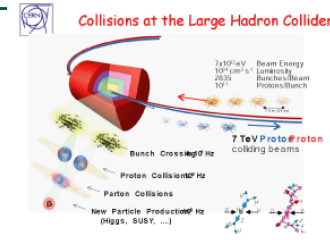


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Large Hadron Collider – CERN (Europe)

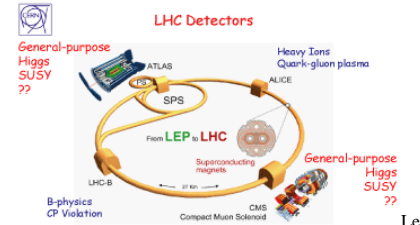


Introduction to CERN David Barney, CERN

CERN in numbers

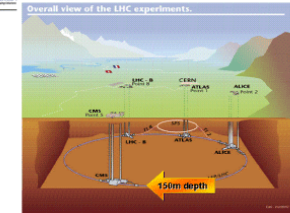
- Financed by 20 European countries
- Special contributions also from other countries: USA, Canada, China, Japan, Russia, etc.
- 1000 CHF (650 M€) budget to cover operation + new accelerators
- 2,200 staff (and diminishing)
- 6,000 users (researchers) from all over the world
- broad visitor and fellowship program

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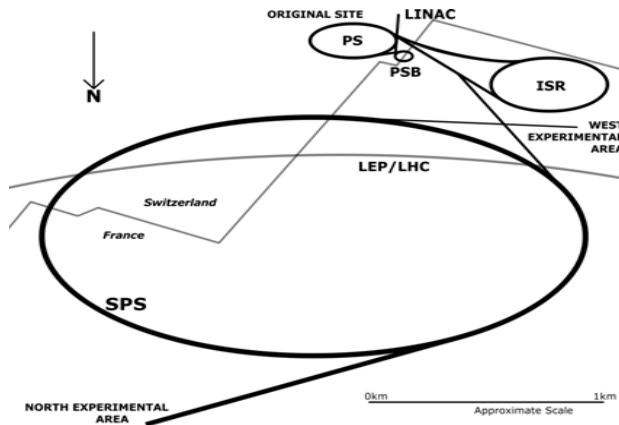
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Accelerators and detectors in underground tunnels and caverns



Lec

CERN Beam Gymnastics (2)



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Cost

- It is worth noting that these experiments are very expensive. The cost of a single particle:
 - Burning one carbon atom tiny, almost free
 - Gold small, almost free
 - Radioactive isotope (^{64}Fe) ~\$0.001
 - Superheavy nucleus (^{272}Rg) ~\$200,000
 - Higgs particle \$0.1-1 billion
- How much are you/we willing to pay for a greater understanding of the universe?

ISP209s8 Lecture 21