First some Introductory Stuff => On The Web

http://hep.physics.utoronto.ca/~orr/wwwroot/phy357/PHY357S.htm

PHY357 = What is the Universe Made Of?



Is the Universe Made of These?



Proton = (u u d) – held together by gluons Neutron = (u d d)

Quantum Forces In Quantum Field Theory, particles interact via: Exchange of virtual particles



Electrons interact by exchanging: Virtual Photons - EM Force Quarks interact by exchanging: Virtual Gluons – Color Force

Higgs Boson

- Electromagnetism on its own can be made to give finite results for all calculations.
- Unified Electroweak theory gives infinite results for process
 like: w* w*



• Become finite if include new particle



Spontaneous Symmetry Breaking Renormalizable Gauge Theory

W

• Higgs makes $W^{\pm} Z^{0}$ massive, and actually generates masses of fundamental particles. It is a quantum field permeating the universe.

How Does Higgs Generate Mass?

 In vacuum, a photon: has velocity c and has zero mass

 In glass, a photon: has velocity < c , same as an effective mass

Refractive Index

- This is due to photon interacting with electromagnetic field in condensed matter
- By analogy can understand masses of particles generated by Higgs Field in vacuum

Grand Unification.

 At a high enough energy electromagnetism weak force strong (colour) force

become aspects of Grand Unified Force



Understand History of Universe?

• What we think (thought?) visible matter is made of.





Measuring $\Omega_0 = \rho_0 / \rho_C$

- Amazingly enough can measure Total matter/energy density in universe Seems equal to critical density for flat space/time
- Measure temperature fluctuations in remnant of fireball from Big Bang.



Density of Standard Model Matter

- Referred to as Baryonic Matter
- Density is Ω_B
- If Universe is made of quarks & leptons

$$\Omega_B = \Omega_0 = 1$$

• Ω_B measured from abundance of elements produced in nucleosynthesis of Big Bang.

Deuterium, Helium, Lithium

 $\Omega_B = 0.044$ $\Omega_B \neq \Omega_0$

 Most of Universe is not Standard Model matter. Some kind of Dark Matter

Density of All Matter Ω_M

• Can measure density of all matter, whatever its nature, Ω_M , by looking at gravitational motion

rotation curves of galaxies

motion of galactic clusters

Fit to global parameters of Universe

$$\Omega_M = 0.26 \pm 0.012$$

• There is indeed Dark Matter

$$\Omega_0=1$$

- So even with this Dark Matter, cannot account for
- Universe must be 75% Something Else



 Ω_{M}

Need for Supersymmetry

- In Grand Unified Theories cannot Unify forces, unless postulate unseen form of matter
 - Higgs mass runs away to Plank Scale
 - Three forces never have same strength
- Unless all particles have supersymmetric

sparticle partners (of higher mass)



SUSY + Dark Matter

• Supersymmetric Particles are unstable

 $Susy \rightarrow Normal + Susy$

- Eventually decay chain ends in Normal matter + lightest SUSY particle
- Lightest SUSY particle cannot interact with normal matter
- Lightest SUSY particle good candidate for

Dark Matter

• Hope to produce

(SUSY - antiSUSY) pairs and Higgs

at Large Hadron Collider

How to Make Matter / AntiMatter?

Colliding high energy beams

Energy of beams transformed into mass of new particles



- LHC is a proton proton collider
- For SUSY observation must contain ALL visible energy, in order to infer invisible SUSY

CERN Seen from the Air



- Tunnels of CERN accelerator complex superimposed on a map of Geneva.
- Accelerator is 50 m underground
- 25 km in circumference

Superconducting Magnet 8 Tesla



- In order to accelerate protons to high energy, must bend them in circular accelerator
- 7 TeV momentum needs intense magnetic field

Underground















ATLAS Cavern – November 2004





LAr and Tile Calorimeters



HEC 2 A-wheel on the insertion stand, Aug. 2004



LAr Forward Calorimeters



• FCAL C assembly into tube - Fall 2003





Fig. 5 Display of a $H{\rightarrow}\gamma\gamma$ event candidate in the 8 TeV data.



Fig. 8 A candidate event for H→WW→evµv shown in transverse (left) and longitudinal (top right) projections through the complete detector.

