Course evaluation(last 15 minutes), Review Friday

Final Exam

- Thursday, Dec. 21: 2:45 - 4:45 pm
  113 Psychology Building
- Note sheet: **one** double-sided page
- Cumulative exam-covers all material, 40 questions
  - 11 questions from exam 1 material
  - 11 questions from exam 2 material
  - 11 questions from exam 3 material
  - 7 questions from post-exam 3 material

Study Hint: download blank hour exams from web site and take them closed-book, with note sheet only. Solution for Exams will all be posted this week.

From the last time…

- Unification
  - Would like to unify particles and forces show that they have a common origin or at least a regular pattern
- Electroweak unification
  - Electromagnetic and weak force have the same interactions and strength at high energy
  - Had to introduce the Higgs boson to explain the mass of the weak force carriers and all other masses
- Other unifications
  - SUSY unified some particles and forces except gravity, Kaluza-Klein theory unified gravity/electromagnetic

String theory

- A string is a fundamental quantum mechanical object that has a small but nonzero spatial extent.
- Just like a particle has a mass, a string has a 'tension' that characterizes its behavior.
- Quantum mechanical vibrations of the string correspond to the particles we observe

What are these strings?

We describe them only in terms of a fundamental tension – as for a rubber band

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How big are they?

A particle of energy E has a wavelength

$E = h c / \lambda = 1240$ eV-nm $/ \lambda$

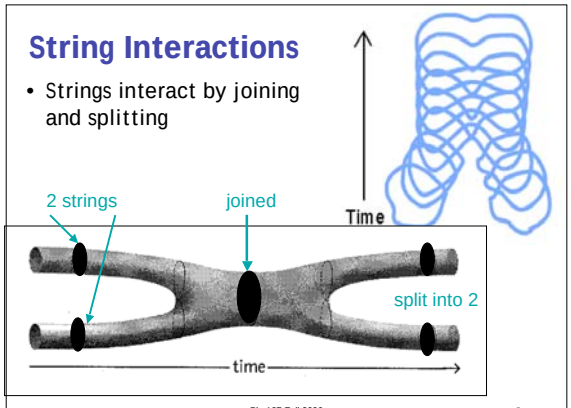
So can probe down to scales of order λ.∴

The Fermilab Tevatron operates at 1TeV and can probe 1.24 am, am, fm, pm, nm, um, mm, m

The nucleus is order fm, femto-meters. Current experiments can look for things 1000 times smaller than that. Strings could be up to 10^{19} smaller.

String Interactions

- Strings interact by joining and splitting



Results of the theory

- The first string excitation is a particle with *imaginary* mass — a tachyon (negative mass squared = negative energy)
  - Could go backwards in time: seems unlikely!
- But the next excitation is a massless spin-2 particle satisfying general relativity
  - The graviton!
- So string theory became a theory of gravity
- A Problem: for the math to work out we need 29 dimensions!

Superstrings

- Combine string theory with some of our other theories.
- Imposing supersymmetry on strings gets rid of the tachyon - it is no longer a solution.
- Additionally, the number of dimensions required for consistency drops from 26 to 10!
- Fundamental object is now a 'superstring'
- Get some of results of SuSy
  - Fix behavior at high energy
  - Dark matter

Extra dimensions in string theory

- Superstring theory has a 10 dimensional spacetime,
- How do we get from 10 dimensions down to 4?
- Introduce some of the ideas from Kalaza-Klein theory
  - Roll up the extra dimensions into some very tiny space of their own.
    Kaluza-Klein compactification.
- Add some of the advantages of Kaluza-Klein theory
  - Unification of electromagnetism force and gravity

Checklist String Theory

- Unify all the forces: strong force - gravity
- Quantize the forces - QFT very successful
- Unify the particles: quarks, leptons - 3 generations
- Explain all the different masses and strengths
- Explain dark matter
- Explain why universe is mostly matter
- Explain physics at very high energy - big bang