4/4/12 Lecture outline

$\star$ Reading: Zwiebach chapters 1 and 2.

- Special relativity vs quantum mechanics. Led to quantum field theory (QFT) . All matter and interactions arise as fluctuations of fields. Light consists of photons, which are fluctuations of the field A_μ. Electrons and quarks are fluctuations of the electron and quark fields, etc. Such fluctuations can be created and/or destroyed, and can even exist only temporarily (virtually). Bizarre consequences, e.g. the existence of anti-matter, predicted by Dirac in 1928 and discovered by Anderson (at Caltech) in 1932.

Quantum field theory is one of humankind's most accurately tested theories! E.g. the magnetic moment of the electron, can compute using theory and compare with experiment, get better than 1 part in 10^{12} agreement. A particular model, the "Standard Model", describes the strong, weak, electromagnetic interactions. What about gravity? Gravity is very different from other forces. Other forces carried by spin 1 object: photon, $W^\pm$, Z, gluons. Gravity is carried by a spin 2 object: the graviton $\sim \delta g_{\mu\nu}$. Spin 2 is very different than spin 1, especially at high energies!

- Quantum mechanics (or QFT) vs general relativity. Long standing clash. Write $G = 1/M_{pl}^2$ in $\hbar = c$ units. Quantum effects $\sim (GE^2)^\ell$, blow up for $E \sim M_{pl}$ ($E_{pl} = (\hbar c^5/G)^{1/2} = 1.22 \times 10^{19} GeV$) . Also many conceptual problems; black holes, meaning of quantum ideas when the metric itself can have quantum fluctuations.

String theory is the only known theory for resolving this clash, i.e. which gives a "UV completion" of quantum gravity. In string theory, replace point particles with tiny ($\ell \sim \ell_p = (G\hbar/c^3)^{1/2} = 1.62 \times 10^{-33} cm$) bits or loops of string. Turns out to lead to some bizarre consequences, like extra dimensions. Is it right? We don't know. At the very least, it is the only known well-defined theoretical framework which can be used to explore the mysteries of quantum gravity. Lessons learnt should be useful even if string theory isn't the last word on the subject. Has led to many interesting spin-offs and insights into topics which can be divorced from string theory, e.g. susy, gauge theories.

Curious history of string theory: originally developed to explain observed spectrum of mesons, e.g. $M^2 = (J + a)/\alpha'$. But found that open strings always give massless spin 1 objects, and closed strings always give massless spin 2 objects. Mesons aren't like that. But massless spin 1 objects could be the photon and gluons – good! And massless spin 2 object could be the graviton – even better – Michael Green (Cambridge) and John Schwarz (Caltech) recycled the slightly off theory of mesons into a theory of quantum gravity! Mesons are described instead by QCD. (Still interest in QCD effective string theory.)

- $x^\mu = (ct, x, y, z)$, $x_\mu = (-ct, x, y, z) = \eta_{\mu\nu} x^\mu$, $\eta_{\mu\nu}\eta^{\nu\lambda} = \delta_\mu^\lambda$. $ds^2 = -dx^\mu dx_\mu$.

Lorentz vectors transform under boosts as $x'^\mu = \Lambda^\mu_\nu x^\nu$, e.g. $\begin{pmatrix} ct' \\ x' \end{pmatrix} = \begin{pmatrix} \gamma & -\gamma\beta \\ -\gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} ct \\ x \end{pmatrix}$. Can boost along any direction. Lorentz scalars, including in particular ds^2, are invariant, e.g. $ds^2 = ds'^2$.