4/3/13 Lecture outline

⋆ Reading: Zwiebach chapters 1 and 2.

• Last time: QFT works well for 3/4 of the forces, all those with spin 1 force carries. Gravity has a spin 2 force carrier, and that leads to mathematical difficulty with quantum field theory. Also conceptual difficulties about how to fit QFT with the general covariance symmetry, $x^\mu \to x^{\mu'}(x)$, of GR. Also conceptual challenges of quantum mechanics and black holes – Hawking radiation and the quantum information loss puzzle.

• 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.)

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