Explaining the essentials (Lecture 2)

1) The Book Keeping Problem. Completeness in QM
2) Completeness in BH
3) Finding all states
4) Fundamental input: all physical states can be written as
   a: a flat or curved space-time background, with
   b: elementary particles with momenta $p_\mu$ such that all
   components $|p| < M_{\text{Planck}}$
5) The Penrose diagram slide 21
6) Consider time interval \( t_{\text{out}} - t_{\text{in}} = \mathcal{O}(M_{\text{BH}} \log M_{\text{BH}}) \).
Let a given in-state \( |\text{BH}_1\rangle_{\text{in}} \) at \( t = t_{\text{in}} \) evolve into a given out-state \( |\text{BH}_1\rangle_{\text{out}} \) at \( t = t_{\text{out}} \).

7) Now either add or remove one particle with momentum \( \delta p_{\text{in}} \).

8) Calculate how all outgoing particles are shifted by a shift \( \delta u_{\text{out}} \).

9) relation \( \delta u_{\text{out}} = f(\delta \theta) \delta p_{\text{in}} \) is linear
\( u^\pm \) and \( p^\pm \) are coordinates very close to the horizon.

10) \([u^\pm, p^\mp] = i\delta^2(\theta_1, \varphi_1, \theta_2, \varphi_2)\) generates simple algebra.
11) Diagonalize this algebra using $Y_{\ell,m}$

12) At any given $\ell, m$, get $\psi_{\text{in}}(u^+) \rightarrow \psi_{\text{out}}(u^-)$

13) Tortoise coordinates: $u = \pm e^\varrho, \quad = \sigma e^\varrho, \quad \sigma = \pm 1$

when $\varrho$ is very large, then ignore this particle (it is far from the BH), so the corresponding $p_{\text{in}}$ or $p_{\text{out}}$ can also be ignored. This justifies a posteriori the assumption that large $|p|$ can be ignored

14) plane waves in $\varrho$: $\psi(\sigma, \varrho) = \psi(\sigma) e^{-i\kappa \varrho}$

15) The role of regions I and II

16) Unitarity forces antipodal identification

Consequences:
17) BH has no interior! It all happens at the horizon (surface): holography

18) and Hawking particles are entangled

PROBLEMS

19) \( u^{\pm}(\theta, \varphi) \) CANNOT be second quantized. It is exactly one single “particle” going in, and one particle going out, either at \( \theta, \varphi \) or at the antipodal point \( \pi - \theta, \varphi + \pi \).

How to relate these particles with the 2\textsuperscript{nd} quantized particles in Fock space of the SM?

How to take SM quantum numbers into account?

Many elementary calculations still to be done!