# Model of Black Hole Formation in $2 + 1$ Dimensions

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As accelerators across the globe reach higher and higher energies, we may actually be able to create black holes in the laboratory. This raises the natural question: how difficult is it to create a black hole? Right now we are hovering near the energy threshold of black hole formation, but we do not know whether or not quantum effects could suppress black holes even if we have sufficient energy.

Part of the reason why this is a difficult question is that we do not have a full understanding of the physics that govern microscopic black holes. Right now in theoretical physics we are faced with a fundamental tension between our understanding of the very large (gravity) and our understanding of the very small (quantum mechanics). Until we have a theory of quantum gravity, we will be unable to fully understand black hole formation.

At the same time, many important results in physics can be derived from suitable approximations. Through an ad hoc application of quantum mechanics to black holes, Hawking was able to show that black holes could evaporate, an important ingredient in our understanding of black hole physics. This kind of quantum improvisation over a classical theme is known as the semi-classical approximation, and it has proved quite useful in understanding physics when a full quantum treatment is impossible.

In my thesis on black hole formation, I use the semi-classical approximation to determine how difficult it would be to create a black hole. This analysis could yield one of three results. Black hole formation could be exponentially enhanced, meaning that quantum effects actually increase the likelihood that black holes are formed in a given interaction. Or black hole formation could be exponentially suppressed, which is the result most often cited in the literature. But the result I found using an exactly solvable model was that black hole formation was neither suppressed nor enhanced, meaning that the semi-classical prediction is identical to the classical prediction.

If true, this result has profound implication for our understanding of black hole physics. Most calculations that try to predict whether black holes can be formed in accelerators use a geometric (read: classical) approach. These calculations are based on the assumption that a black hole will form when sufficiently energetic particles get close enough to each other to warp space-time into a black hole. Because I have shown in my model that there is neither suppression nor enhancement, it suggests that these geometric calculations should give the right predictions even without taking into account quantum effects.

The model I use is based on the head-on collision of two massless particles in $2 + 1$ dimensions (two space and one time) with negative cosmological constant. One universe seems to be $3 + 1$ dimensional, so my model is limited by the fact that it involves one fewer spacial dimension. On the other hand, two body motion in $3+1$ dimensions is not exactly solvable, so what my model lacks in realism it makes up for in mathematical certainty. As part of my thesis, I show that models of black hole formation that suggest exponential suppression may actually be based on faulty simplifications.

The other important part of my thesis is that it suggests a generic way of finding out whether a given model of black hole formation will imply suppression/enhancement or not at the semi-classical level. If the relative motion of the particles are known and if there is a so-called horizon effect when the particles approach each other, then it is a simple exercise in solving a first order differential equation and evaluating an integral to apply the semi-classical approximation. In future work, I hope to find other analytic — and hopefully more realistic — models of black hole formation to test my claim that there is no suppression/enhancement.