# Simulation of microscopic black-hole production at the LHC

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# Trying to fix a problem in Physics...

- Gravity does not fit nicely into the Standard Model.
- Black-Holes $\rightarrow$ where gravity and quantum physics merge.
- New theories predict detectable gravitational effects at particle coliders.
- What do gravitational event signatures look like?
- How does field composition of the theory effect event signatures?

# Outline

# What is a Black-Hole?

This is a black-hole,

$$\mathrm{d}s^2 = \left(1 - \frac{\mu r^{4-D}}{\Sigma(r, a, \theta)}\right)\mathrm{d}t^2 - \sin(\theta)^2\left(r^2 + a^2 \sin(\theta)^2 \frac{\mu r^{4-D}}{\Sigma(r, a, \theta)}\right)\mathrm{d}\phi^2$$
$$+ 2a \sin(\theta)^2 \frac{\mu r^{4-D}}{\Sigma(r, a, \theta)}\mathrm{d}t\mathrm{d}\phi - \frac{\Sigma(r, a, \theta)}{\Delta(r, a, \mu, D)}\mathrm{d}r^2 - \Sigma(r, a, \theta)\mathrm{d}\theta^2$$
$$- r^2 \cos(\theta)^2 \mathrm{d}^{D-3}\Omega$$

where

$$\Sigma(r, a, \theta) = r^2 + a^2 \cos(\theta)^2$$

and

$$\Delta(r, a, \mu, D) = r^2 + a^2 - \mu r^{4-D}.$$

# Black-Hole Charge, Energy and Entropy

Adding entropy to a black-hole as a geometric quantity,

$$T\mathrm{d}S = \mathrm{d}M - \sum_i \Omega_i \mathrm{d}Q_i = \frac{\kappa}{8\pi}\mathrm{d}A$$

Entropy characterises the radiation emitted from the black-hole.

$$S_{total} = S_{black-hole} + S_{exterior}$$

# What is Black-Hole Radiation?

- Quantum fluctuations at the event-horizon introduce particle into the region outside the black-hole horizon.
- The space-time around the black-hole is a potential barrier for the particles near the horizon.
- Particles that escape the potential are seen as radiation at infinity.
- This radiation is commonly referred to as *Hawking radiation*.

# Radiation from an Action

Given the semi-classical action

$$S = \int_{\partial M} \mathrm{d}^N x \sqrt{g_M} \, (R + \mathcal{L}[\psi]),$$

we seek solutions to the following eigenvalue problem,

$$(\Delta + k^2)\psi = 0,$$

where $\Delta$ is the *Laplace-Beltrami* operator defined by the unperturbed metric $\mathbf{g}$ and $k \in \mathbb{C}$.

# Hawking Radiation as Total Flux

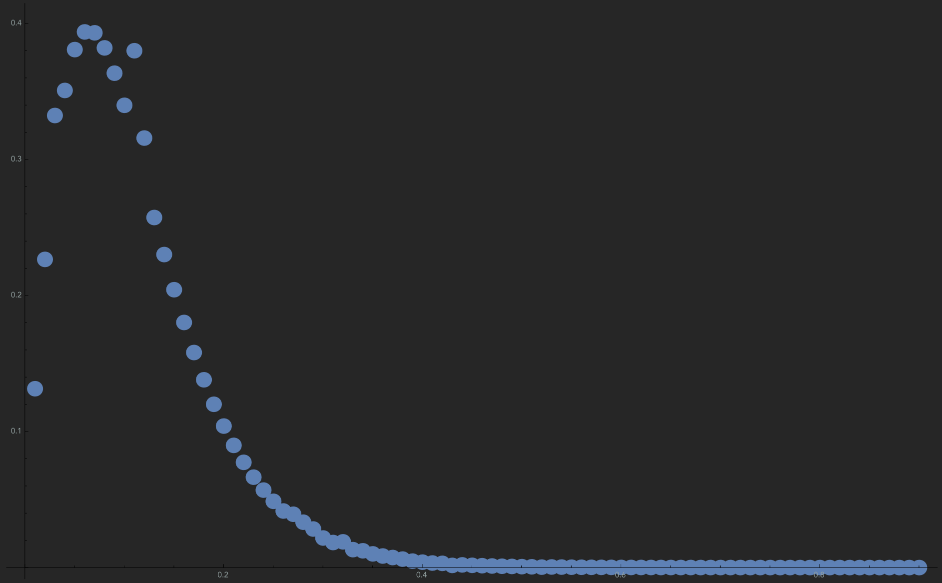
For a given background space-time geometry, the number of particles $\langle n(\omega)\rangle$ of a given species $\psi$, emitted in all modes $\omega$, is given by

$$\langle n\rangle = \int \mathrm{d}\omega \, \frac{\gamma(\omega)}{e^{\frac{\omega}{T_H}} - 1},$$

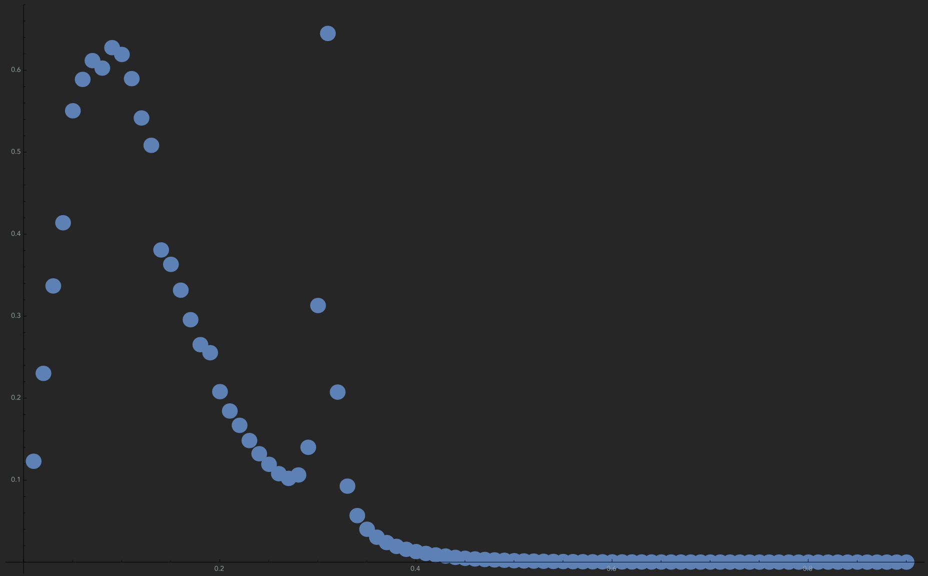
where $\gamma(\omega) \sim \, |\psi|^2 \times$ degeneracy, and

$$T_H = \frac{D-2}{4\pi r_h}.$$

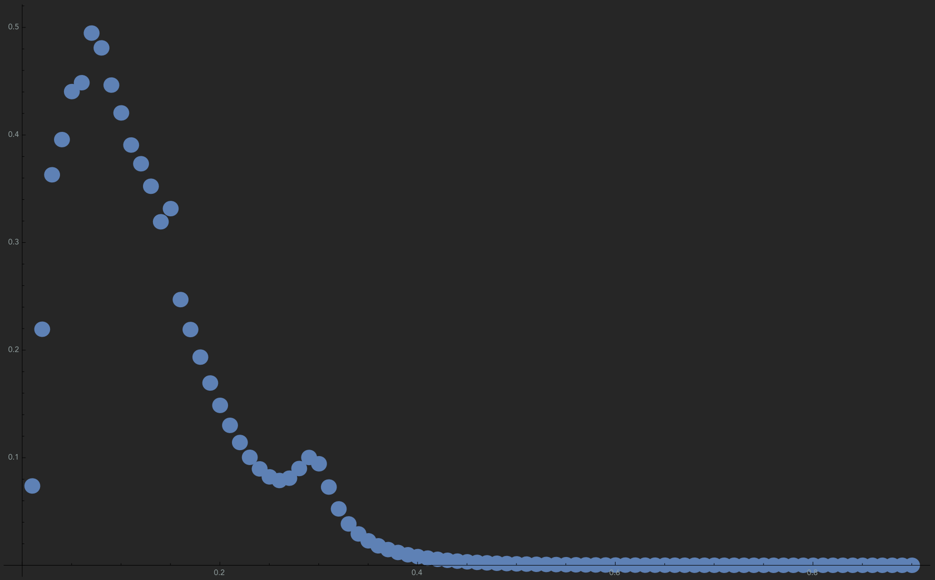
is the *Hawking temperature* of the black-hole.



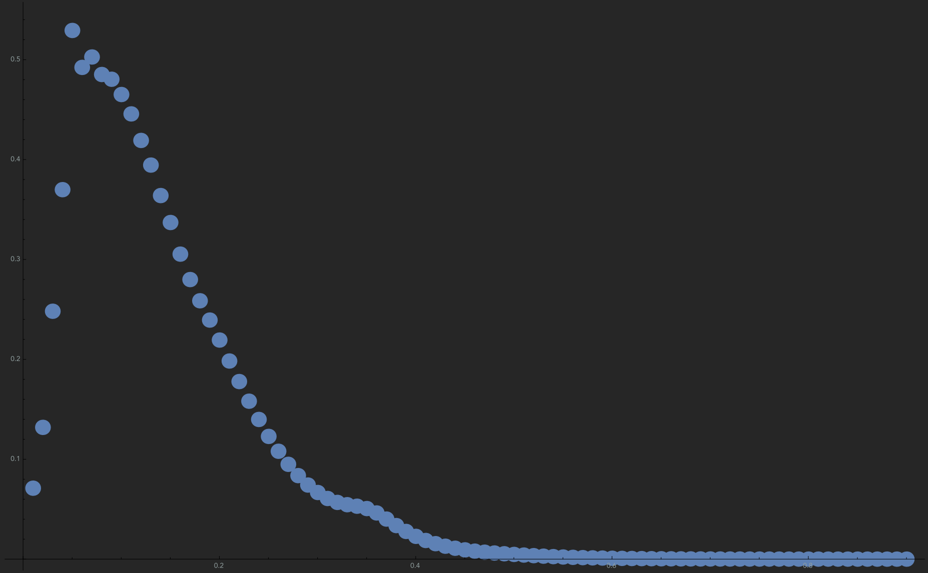

Graviton emission spectrum of rotating black hole $a = 0.001$ in 4 dimensions.




Graviton emission spectrum of rotating black hole $a = 0.5$ in 4 dimensions.




Graviton emission spectrum of rotating black hole $a = 0.9$ in 4 dimensions.




Graviton emission spectrum of rotating black hole $a = 0.99$ in 4 dimensions.

# Acknowledgements

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CERN