Quantum Black Holes

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Theoretical Particle Physics
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Outline

1. Semi-classical black holes and quantum black holes
2. Effective operators
   - Effective Field Theory (EFT)
   - Lagrangian
   - Matching of cross sections
3. Low energy contributions

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Semi-classical black holes and quantum black holes

Model of low scale quantum gravity:
Formation of small black holes (BH) at particle colliders

Semi-classical BH

- thermal object
- decay via Hawking radiation into many particle final state
- geometrical cross section:
$$\sigma = \pi r_s^2$$
- formation unlikely since $\mathrm{M_{BH}} \gg \mathrm{M_P}$

QBH

- non-thermal object
- decay into only a few particles
- cross section from semi-classical case
- interpretation as short-lived state

Effective Operators for QBHs

How to model these states in particle physics processes?
$\rightarrow$ suitable Effective Field Theory

QBH

- e.g. spinless QBH is represented by scalar field
- charges in accordance with gauge quantum numbers of Standard Model

Interaction

- defined by EFT
- matching of cross section with geometrical one

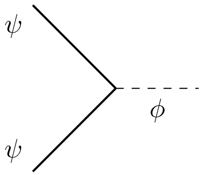
- conservation of gauge symmetries
- no equal assumption for global symmetries

Effective Operators for QBHs

Lagrangian

$$\mathcal{L}_6 = \frac{c}{\bar{M}_P^2} \Box \phi \bar{\psi} \psi + h.c.$$

- mass dimension 6 suitable for 4-dimensional cross section
- ϕ: neutral scalar field $\to$ QBH
- ψ: fermion field
- c: adjustable parameter to match cross section, depending on CoM energy and relevant masses



Matching of cross sections

Cross section for production of scalar field

$$\sigma\,(2\psi \to \phi) \;=\; \frac{\pi}{s}|\mathcal{A}|^2\,\delta(s - M_{BH}^2)$$

amplitude: $$|\mathcal{A}\,(2\psi \to \phi)\,|^2 \;=\; s^2\,\frac{c^2}{\bar{M}_P^4}\left[s - (m_1 + m_2)^2\right]$$

Geometrical cross section

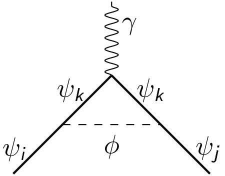
$$\sigma \sim \pi r_s^2 \quad , \quad 4\text{d} : r_s \;=\; \frac{\sqrt{s}}{4\pi \bar{M}_P^2}$$

thus: $$c^2 = \frac{1}{16\pi\left[s - (m_1 + m_2)^2\right]}\,\frac{\left[\left(s - M_{BH}^2\right)^2 + M_{BH}^2\Gamma^2\right]}{M_{BH}\Gamma}$$

Low energy contributions

Effective Lagrangian

$$L_{eff} = \frac{e}{32\pi^2} \sum_{ij} \frac{m_i}{\bar{M}_P^2} \bar{\psi}_i \left(A_{ij} + B_{ij}\gamma_5 \right) \sigma_{\mu\nu} \psi_j F^{\mu\nu}$$



1. anomalous magnetic moment (e.g. of μ: $\bar{M}_P > 266\,\mathrm{GeV}$)
2. “forbidden“ lepton flavor violating processes (e.g. $\mu \to e\gamma$: $\bar{M}_P > 3 \times 10^4\,\mathrm{GeV}$)
3. electric dipole moment (e.g. neutron: $\bar{M}_P > 5 \times 10^3\,\mathrm{GeV}$)

Thanks

Thanks for your attention!