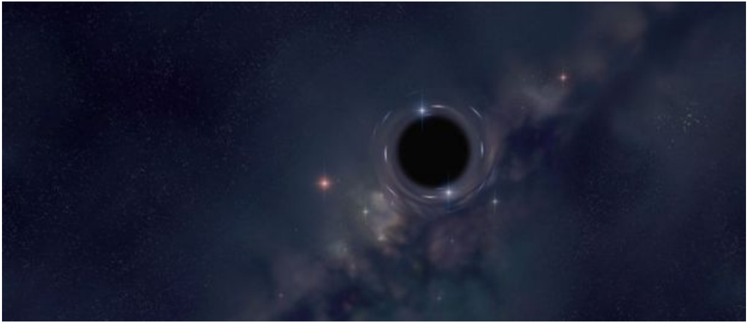
Probing the Constituent Structure of Black Holes

Sophia Müller



The usual Black Hole picture

The semi-classical approximation: $G_{\mu\nu} = \frac{8\pi G_N}{c^4} \hat{T}_{\mu\nu}$

- BH solely characeterized by: $r_g = 2G_N M$, Q, J
  $\rightarrow$ no hair theorem
- Hawking thermal radiation $T \propto \frac{1}{r_g}$
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Consequences

- $\Longrightarrow$ Tension with quantum mechanics: Information paradox
- ...

Core of the problem: intrinsic

Two choices: → general relativity / Riemann geomertry
→ quantum mechanics / Hilbert space geometry

Dvali / Gomez: Quantum N-Portrait of Black Holes

- BH as bound state of N gravitons embedded in graviton condensates
- individually weakly interacting: $\lambda \sim r_g$
- strong collective binding potential
- maximally packed
- defining features: $N \rightarrow$ no hair theorem
- $N \rightarrow \infty$, $L_P \rightarrow 0$, r_g finite → semiclassical limit
- leading corrections of order $\mathcal{O}(\frac{1}{N})$
  $\Longrightarrow$ **Resolution of Black Hole paradoxes!**

Our approach: N-portrait embedding in relativistic field theory
$\rightarrow$ scattering experiments on black holes

- Problem: A priori black hole states $|B\rangle$ are unknown ($|B\rangle \neq a^\dagger|0\rangle$)
- Solution from QCD: Non-zero overlap with kinematical states having the same quantum numbers and isometries ($J(0)|\Omega\rangle$)

$\rightarrow$ Auxiliary current description (ACD)

$$\langle B|J(0)|\Omega\rangle = \Gamma_B$$

e.g. in QCD: $\langle \pi|\bar{q}q|\Omega\rangle = f_\pi$

$$\rightarrow \quad |B\rangle \quad = \quad \Gamma_B^{-1} \int \frac{\mathrm{d}^4 p}{(2\pi)^4} B(p) \int \mathrm{d}^4 x e^{\mathrm{i}px} J(x)|\Omega\rangle$$

Current construction

Generic spacetime

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Consistency: For free states the ACD reduces to the LSZ reduction formalism

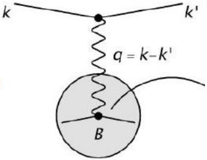
Constituent number density $\langle B|n(k)|B\rangle$
$\rightarrow$ number of constituents $N_c \propto N^4$

Energy density

$$\mathscr{E}(x) = (N/M_{\mathscr{B}})^2 |\mathscr{B}(x)|^2 \, \Gamma^{-2} \langle \Phi^{2(N-1)} \rangle$$

Mass

$$M_{\mathscr{B}}^2 = \frac{\langle \Phi^{2(N-1)} \rangle}{\langle \Phi^{2(N-2)} \rangle} \frac{N_c^2}{N^2} \implies M_{\mathscr{B}}^2 = \underbrace{\frac{\langle \Phi^{2(N-1)} \rangle}{\langle \Phi^{2(N-2)} \rangle}}_{1/r_g^2} N^2$$



Light-cone constituent distribution

$$\mathscr{D}(r) = 2\left(\frac{N}{M}\right)^4 \Gamma_{\mathscr{B}}^{-2} \langle \Phi^{2(N-2)} \rangle \frac{1}{4\pi^2 r^2} \int d^3P \cos(Pr/2) |\mathscr{B}(P)|^2$$

Differential cross section

$$k'^0 \frac{\mathrm{d}\sigma}{\mathrm{d}^3 k'} = \frac{2}{\mathscr{F}(\Phi)} \left|\alpha_g \Delta(k'-k)\right|^2 \mathscr{E}^{\alpha\beta\mu\nu}(k,k') \mathscr{A}_{\alpha\beta\mu\nu}(\mathscr{B};k,k')$$

Scattering Experiments I: Parton level

All calculations in “double scaling limit”: $M_B, N \to \infty$,
$M_B/N = const.$

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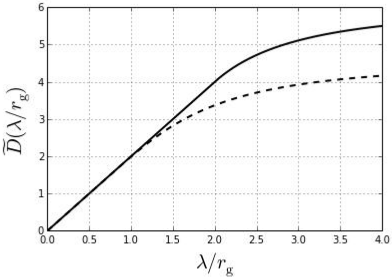
- spacetime dependence reduces to r-dependence
- finite in double scaling limit / corrections are $\mathscr{O}(\frac{1}{N})$-suppressed
- For $B(P)$ a gaussian wave packet repsectively a Heaviside function



→ Black hole interiors dominated by soft physics

Energy density

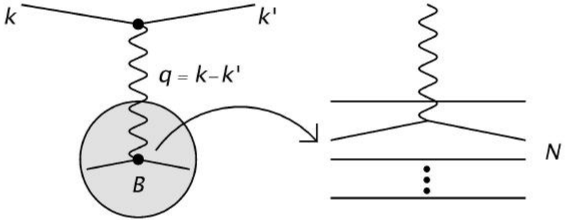
$$\mathcal{E}(x) = (N/M_{\mathscr{B}})^2 |B(x)|^2 \, \Gamma^{-2} \langle \Phi^{2(N-1)} \rangle$$

Mass

$$M_{\mathscr{B}}^2 = \frac{\langle \Phi^{2(N-1)} \rangle}{\langle \Phi^{2(N-2)} \rangle} \frac{N_c^2}{N^2} \quad \Longrightarrow \quad M_{\mathscr{B}}^2 = \underbrace{\frac{\langle \Phi^{2(N-1)} \rangle}{\langle \Phi^{2(N-2)} \rangle}}_{?1/r_g^2?} N^2$$

- scaling as in Witten's “Baryons in the 1/N-expansion”

Scattering Experiments II: 1-graviton exchange



resolve interior $\rightarrow$ $r_g^{-2} < -q^2 < M_{Pl}^2$ $\leftarrow$ weakly coupled

1-graviton exchange amplitude at tree level:

$$a^{(2)}(x_1, x_2) \propto \int \mathrm{d}^4 z_1 \mathrm{d}^4 z_2 \, \langle 0 | \mathrm{T}\Phi(x_2) \mathscr{T}_{\alpha\beta}(z_1) \Phi(x_1) | 0 \rangle \, \Delta^{\alpha\beta\mu\nu}(z_1, z_2) \times \langle B' | \mathscr{T}_{\mu\nu}(z_2) | B \rangle$$

Consider $\langle B|\mathscr{T}_{\mu\nu}(z_2)|B\rangle$

- condensate term involved
  $\rightarrow$ Wick's theorem:
  $\langle\Omega|\mathrm{T}\phi(x)\phi(y)|\Omega\rangle = \mathrm{i}\triangle(x-y) + \underbrace{\langle\Omega| : \phi(x)\phi(y) : |\Omega\rangle}_{\text{condensate}}$
- localized in the interior $\rightarrow$ information about internal structure

Differential cross section

$$k'^0 \frac{\mathrm{d}\sigma}{\mathrm{d}^3 k'} = \frac{2}{\mathscr{F}(\Phi)} \left|\alpha_\mathrm{g}\Delta(k'-k)\right|^2 \mathscr{E}^{\alpha\beta\mu\nu}(k,k')\mathscr{A}_{\alpha\beta\mu\nu}(B;k,k')$$

$$\Longrightarrow \quad \frac{\mathrm{d}\sigma}{\mathrm{d}^3 k} \propto \mathscr{D}(r)$$

Future work:

- application to other space-time geometries: dS, AdS,...
- finite-N-effects
- ...