UNIVERSITY OF OXFORD

Holographic 3-jet events

Jorge Casalderrey Solana and Andrej Ficnar

INT Equilibration Workshop

August 21, 2015

Andrej Ficnar
University of Oxford

Towards Holographic 3-jet events

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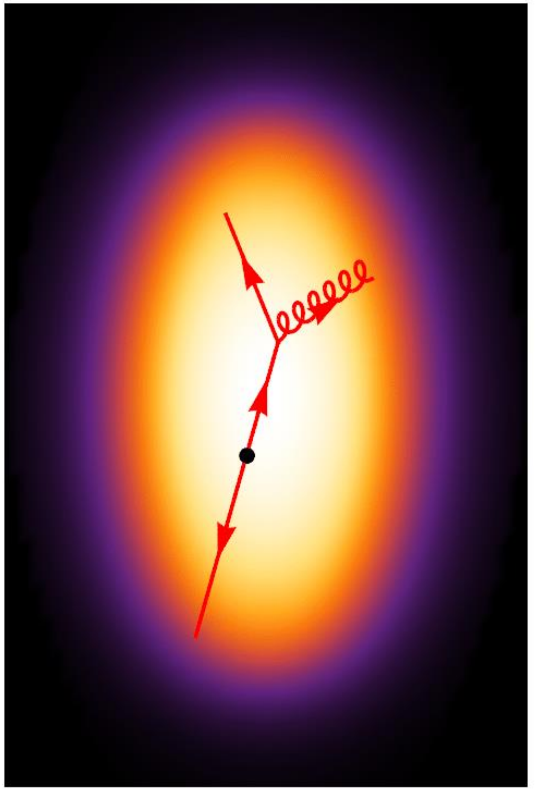
Outline

- Motivation
- Introduction
  - Quarks and gluons in holography
  - Holographic back-to-back jets
- Simulating a 3-jet event
  - Applying a transverse kick
  - Resolved vs. unresolved case
  - Resolution criterion
  - Comparison with perturbative estimate
- Towards analytical derivation
- Conclusions and prospects

Motivation

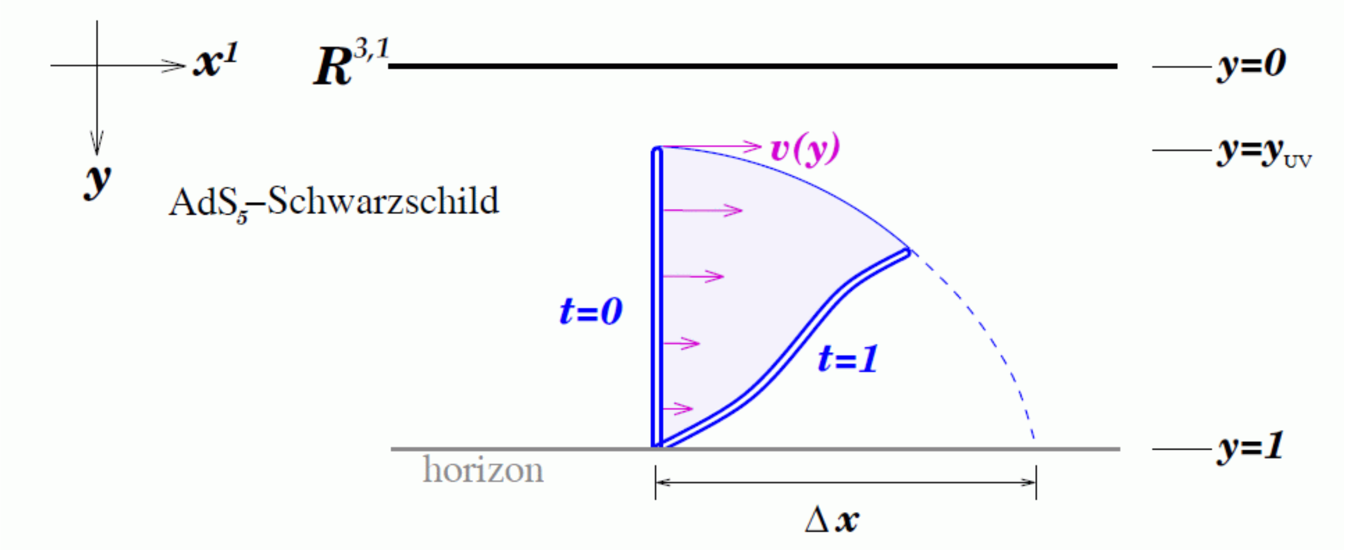
- Simulate a production of a **hard gluon** in a back-to-back jet event in a strongly coupled plasma
- Question of **resolution:**
  - When will the medium be able to resolve the emitted gluon from its parent quark?
- Phenomenological interest
  - Jet structure in heavy ion collisions
  - Energy distribution in 3-jet events



Gluons in holography

- Energetic gluons in a strongly coupled plasma naturally represented by a **doubled string** rising up out of the horizon

Gubser et al., 2008

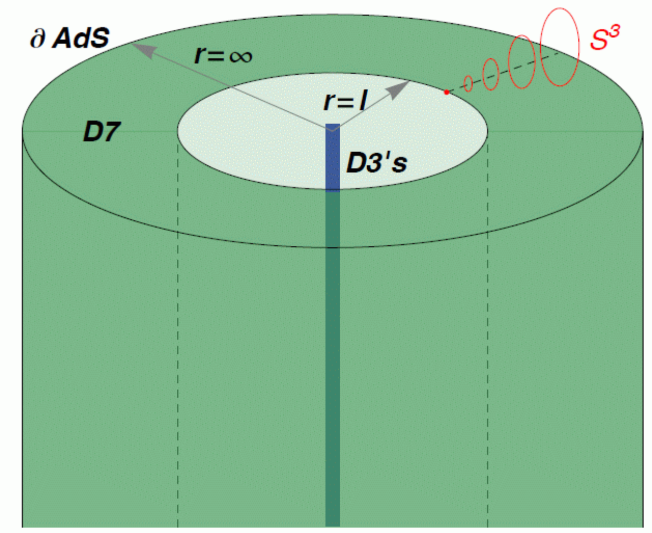


Quarks in holography

- Fundamental d.o.f. are introduced via **flavor branes**
  - D7 branes in AdS introduce $\mathcal{N}=2$ hypermultiplet to $\mathcal{N}=4$ SYM

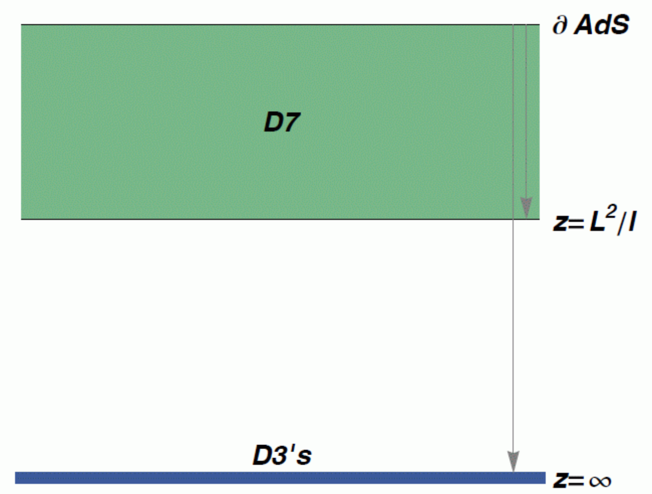
$$M_Q \propto l$$

Karch & Katz, 2002

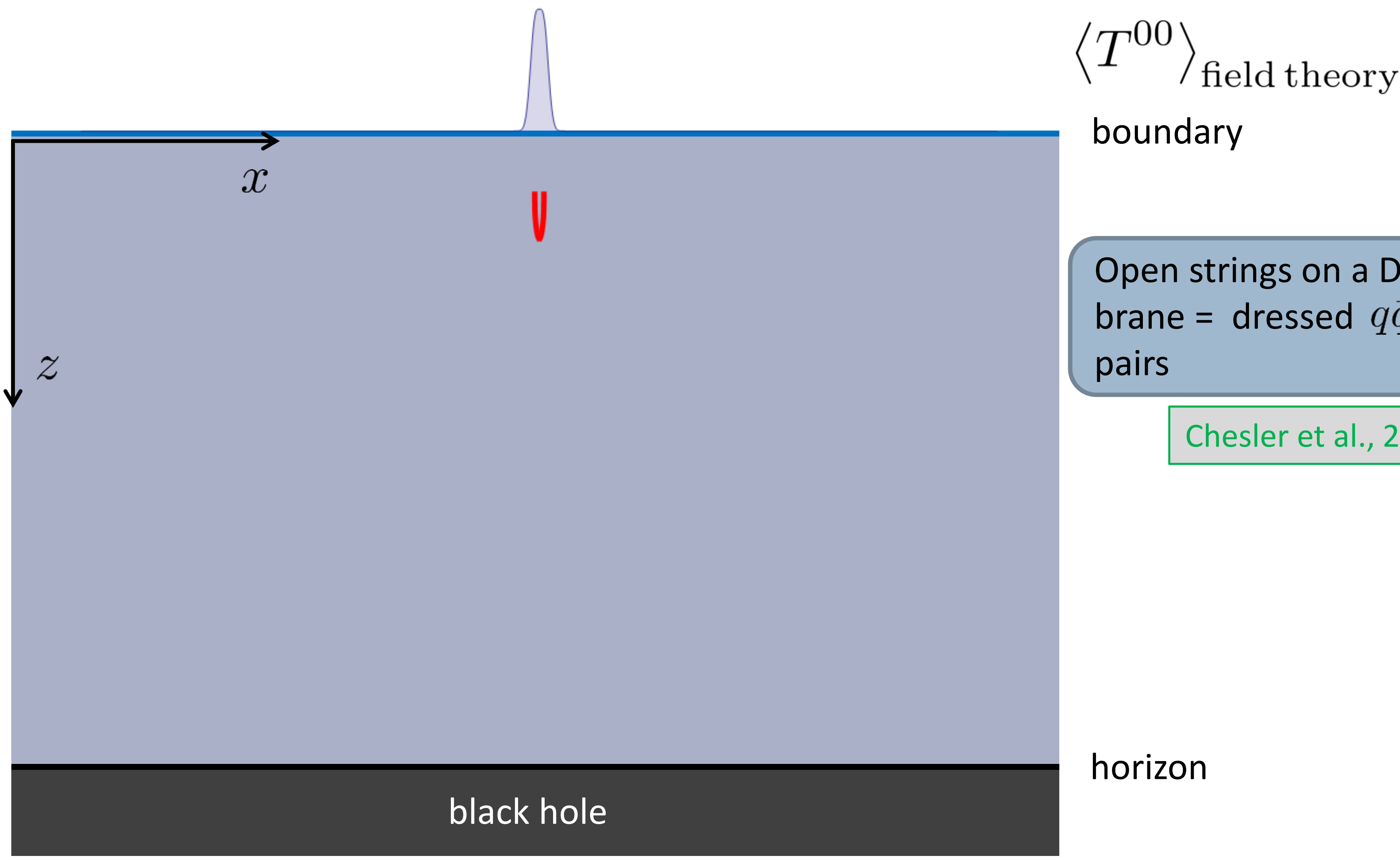


- We'll focus on **light quarks** at finite temperatures

$$z_Q \sim 1/M_Q \to \infty$$



Back-to-back $\bar{q}q$ "jets" as falling strings



Open strings on a D7 brane = dressed $q\bar{q}$ pairs

Chesler et al., 2009

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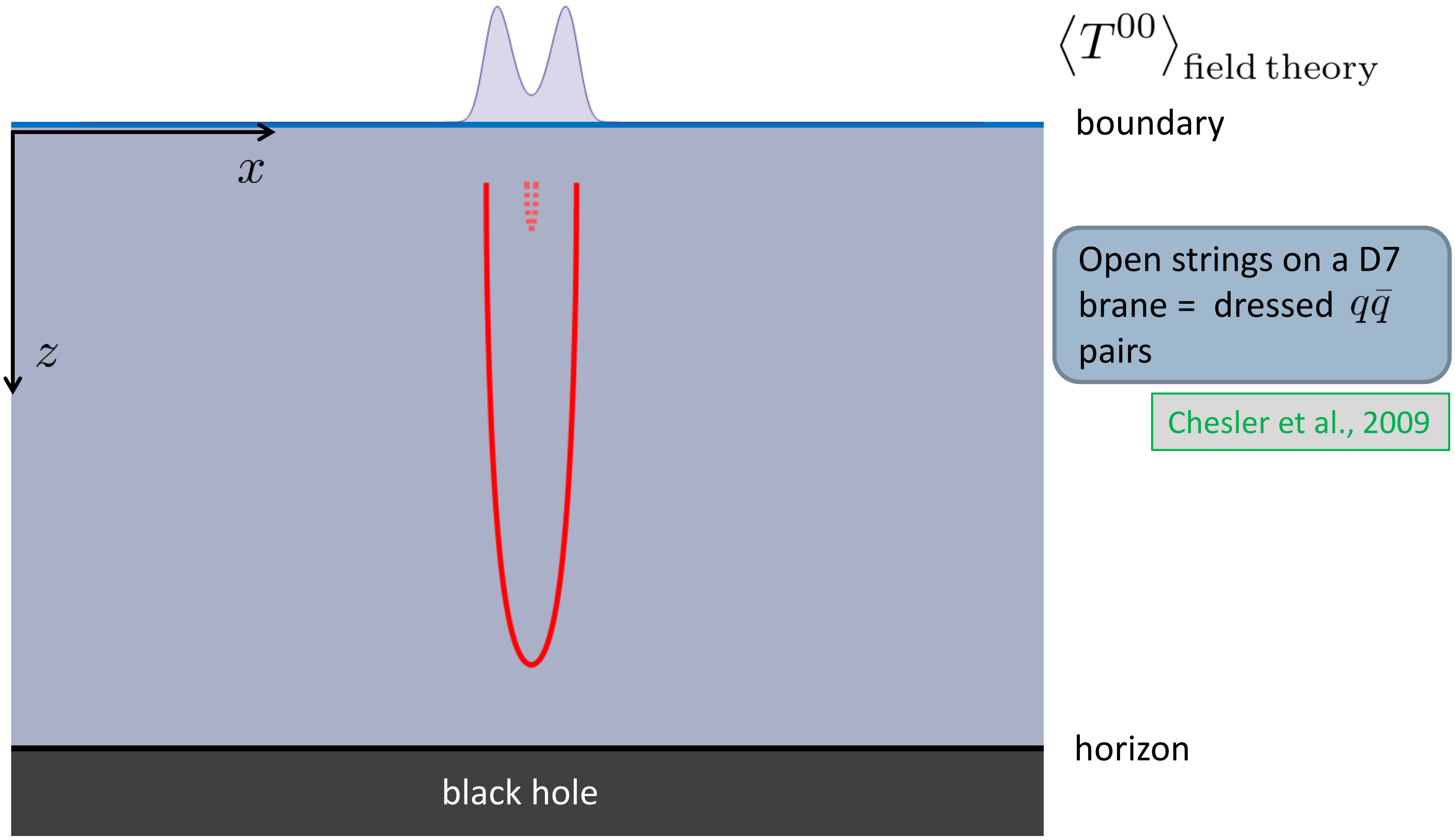

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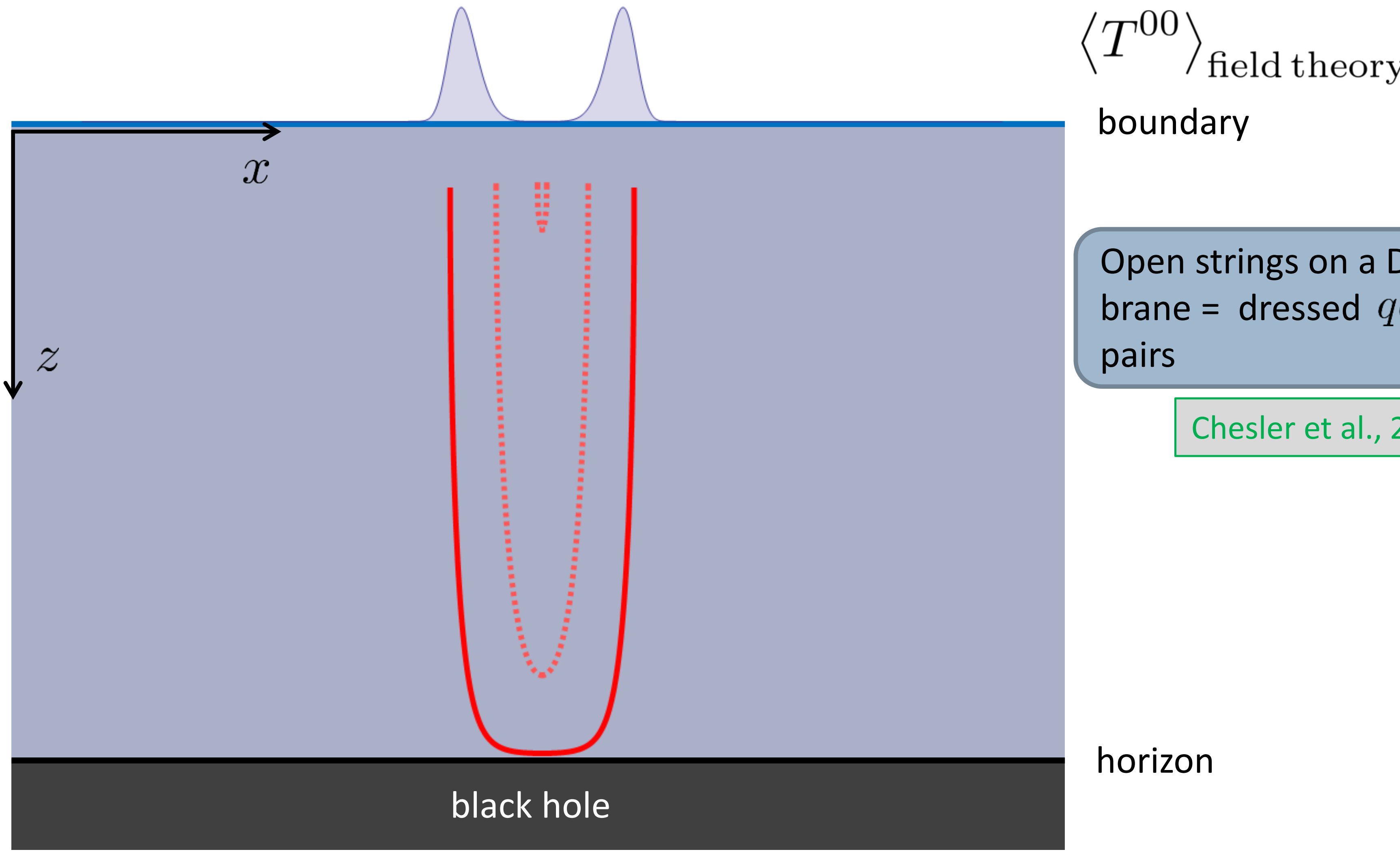

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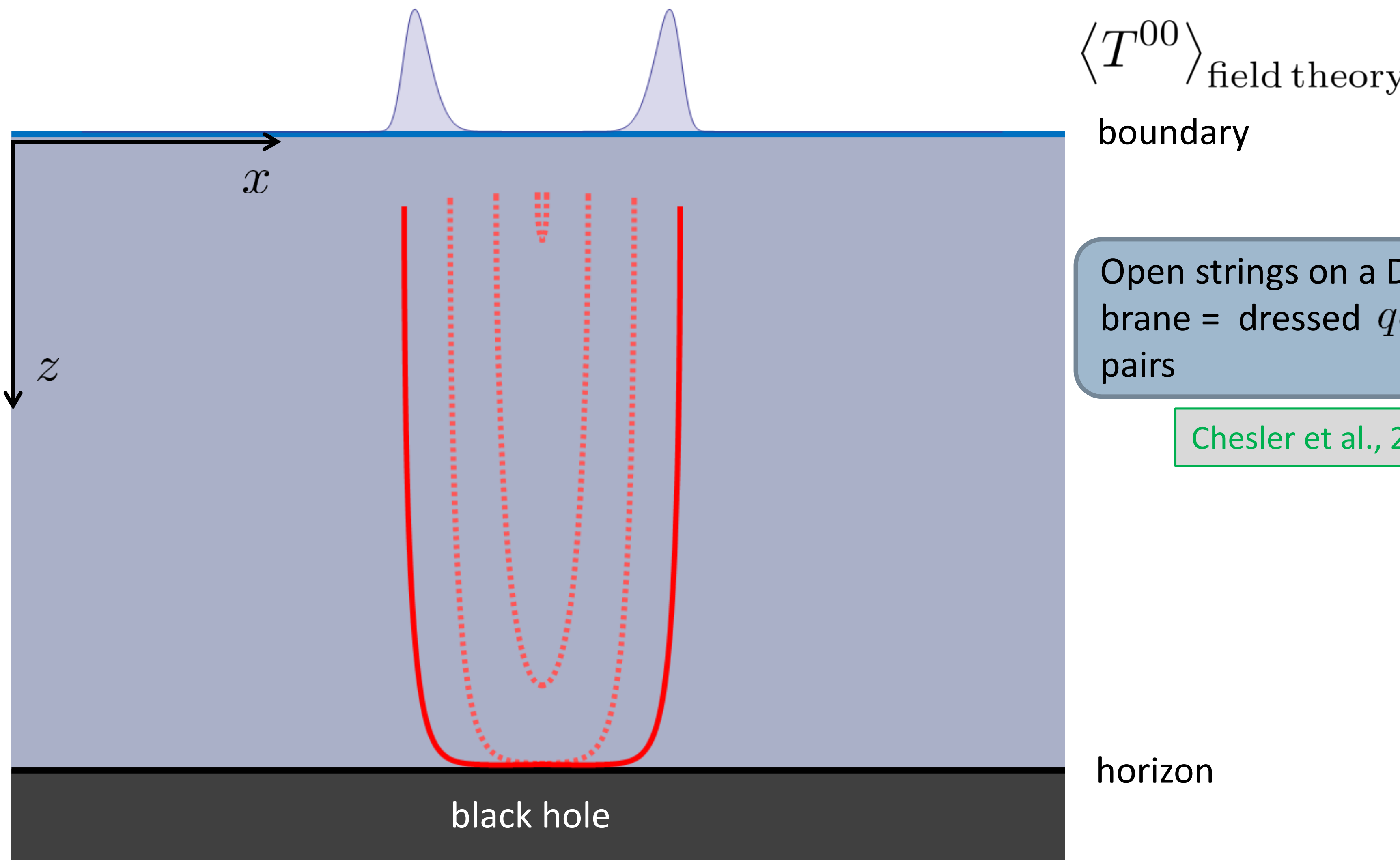

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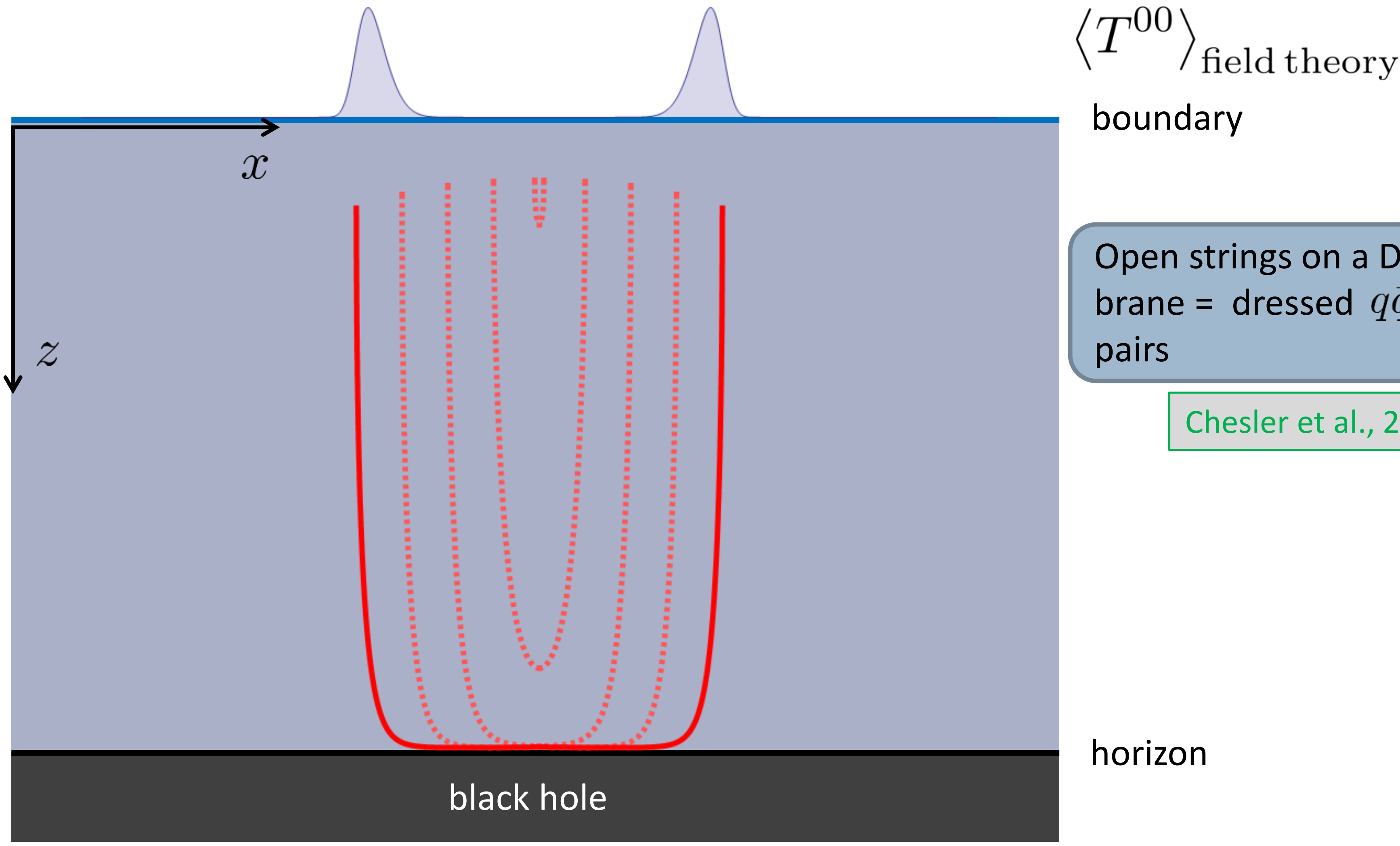

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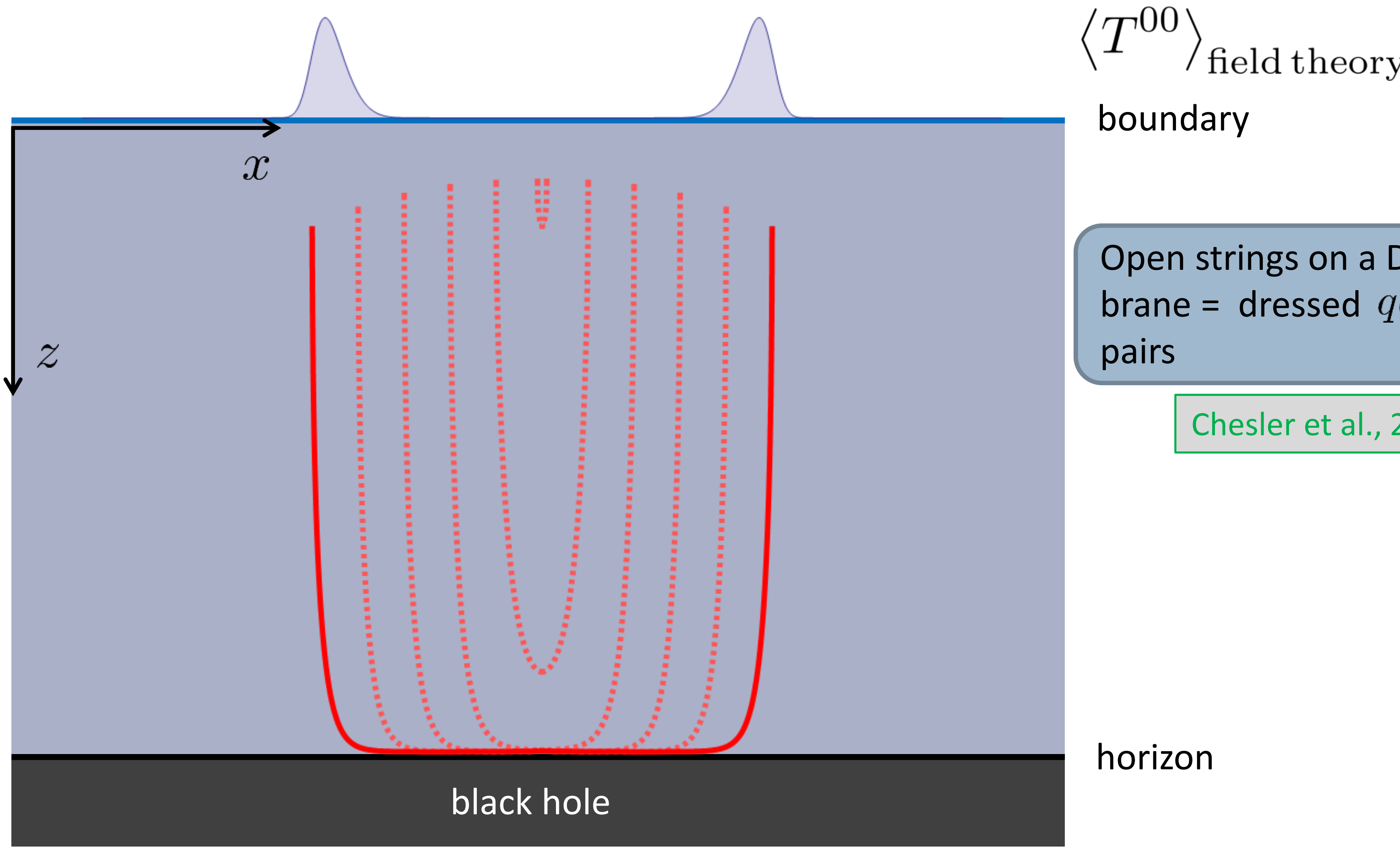

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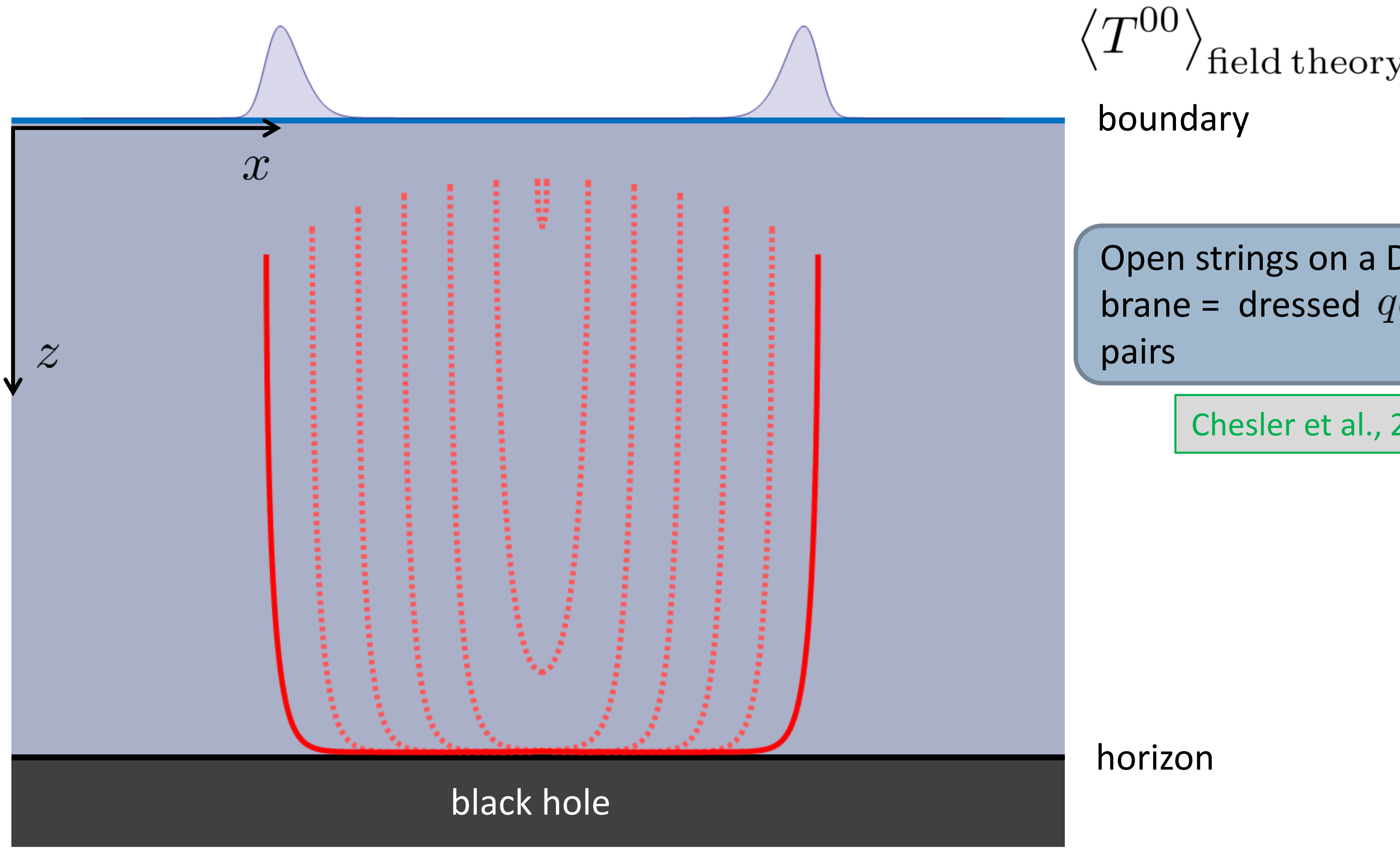

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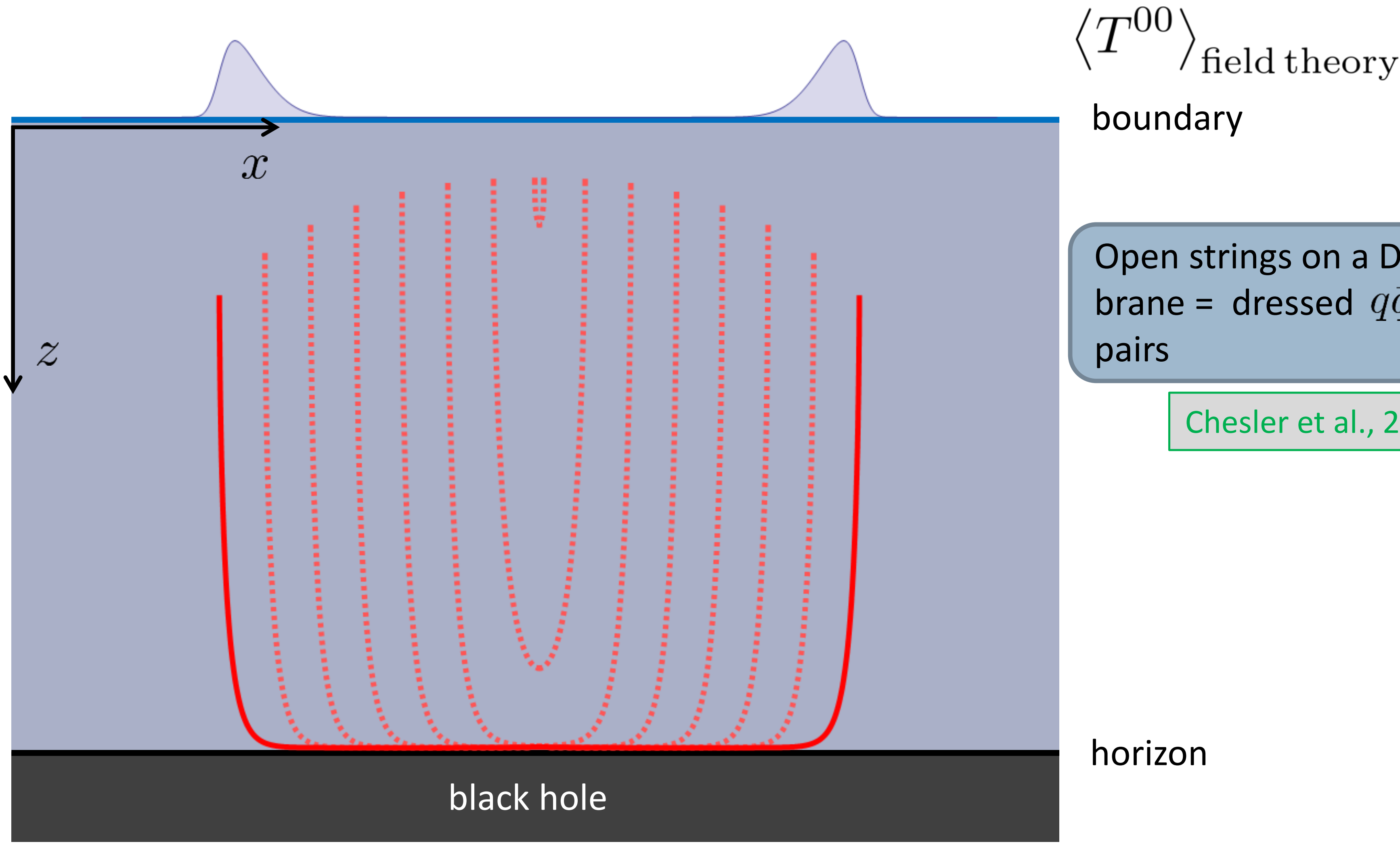

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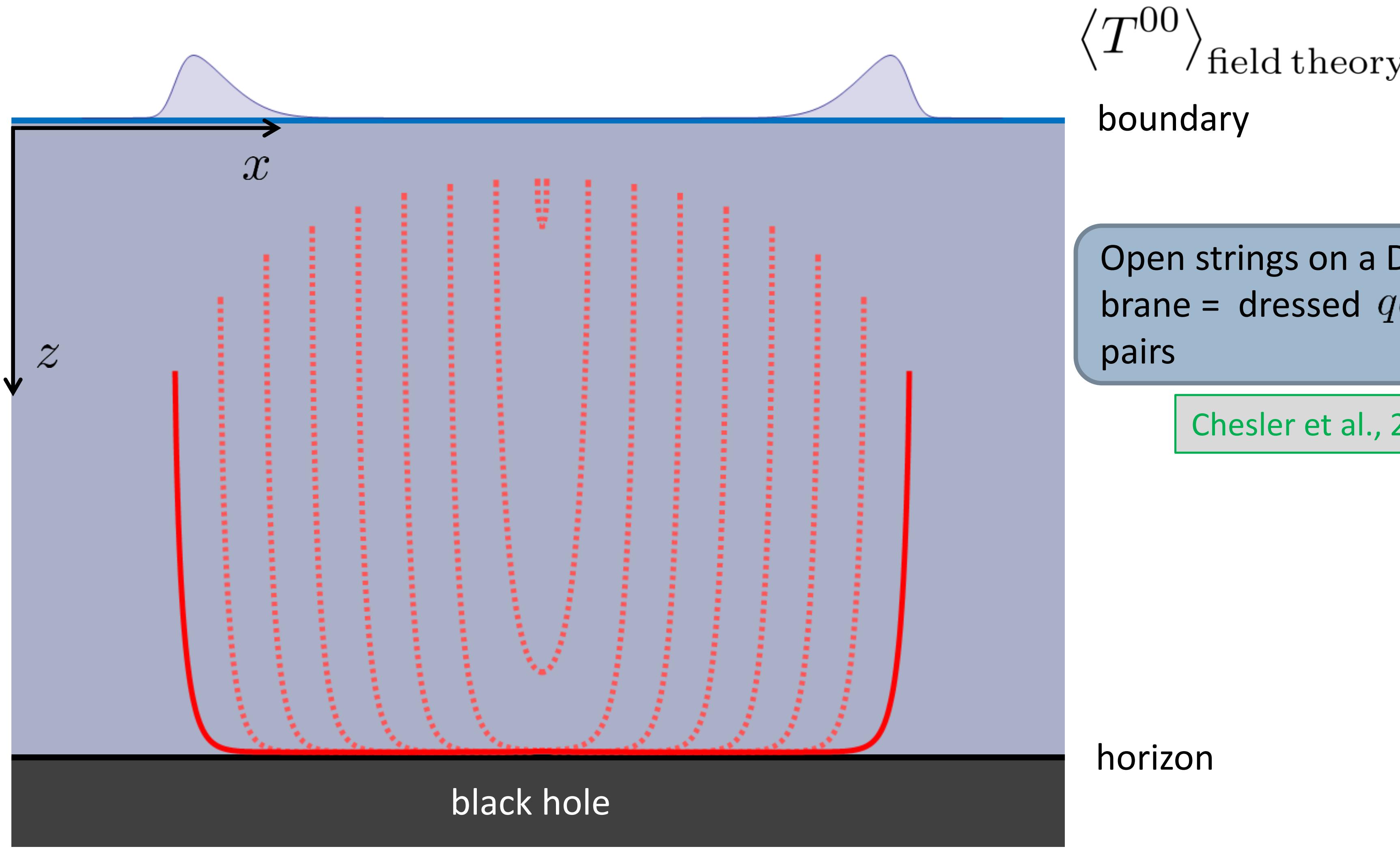

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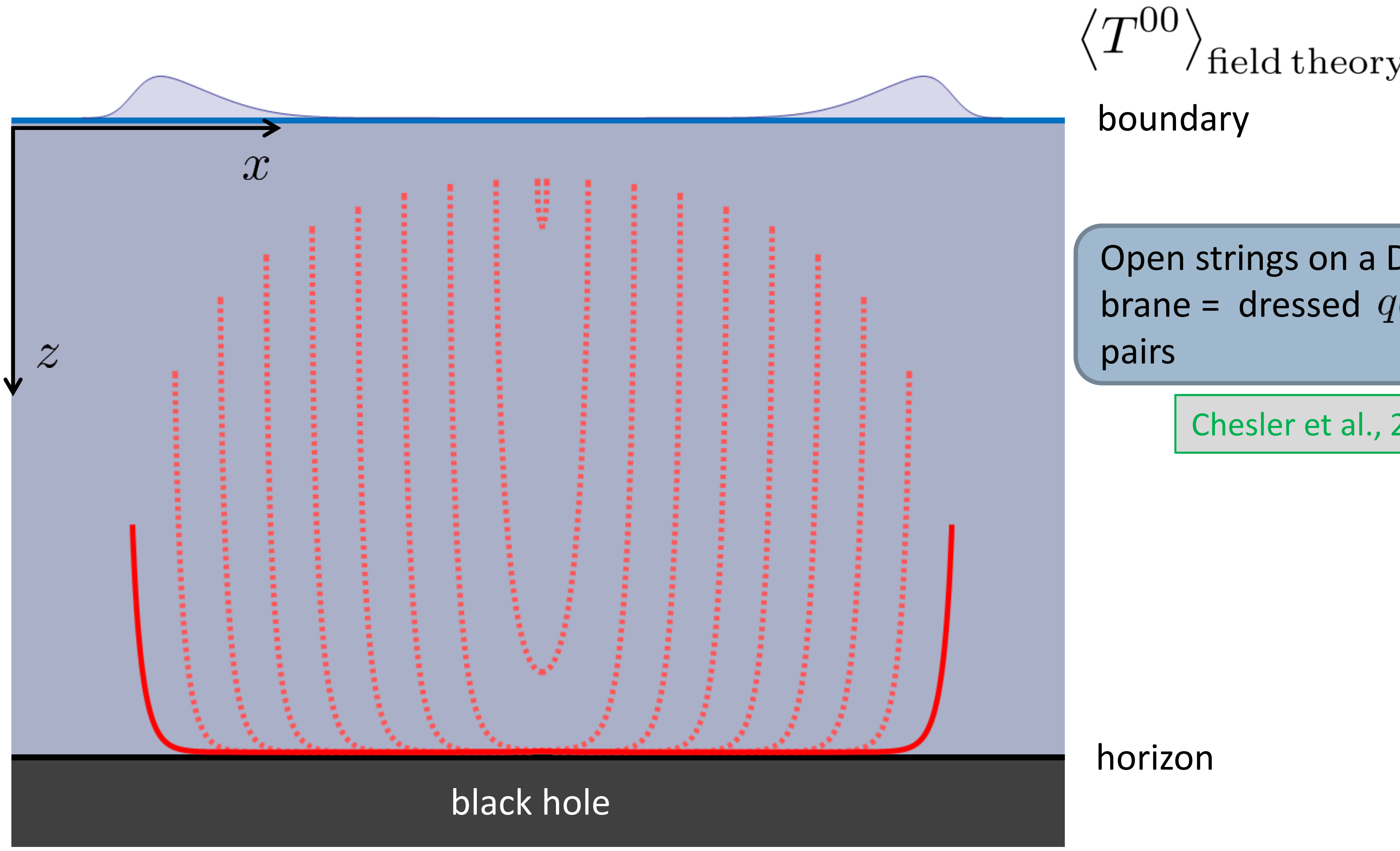

Open strings on a D7 brane = dressed $q\bar{q}$ pairs

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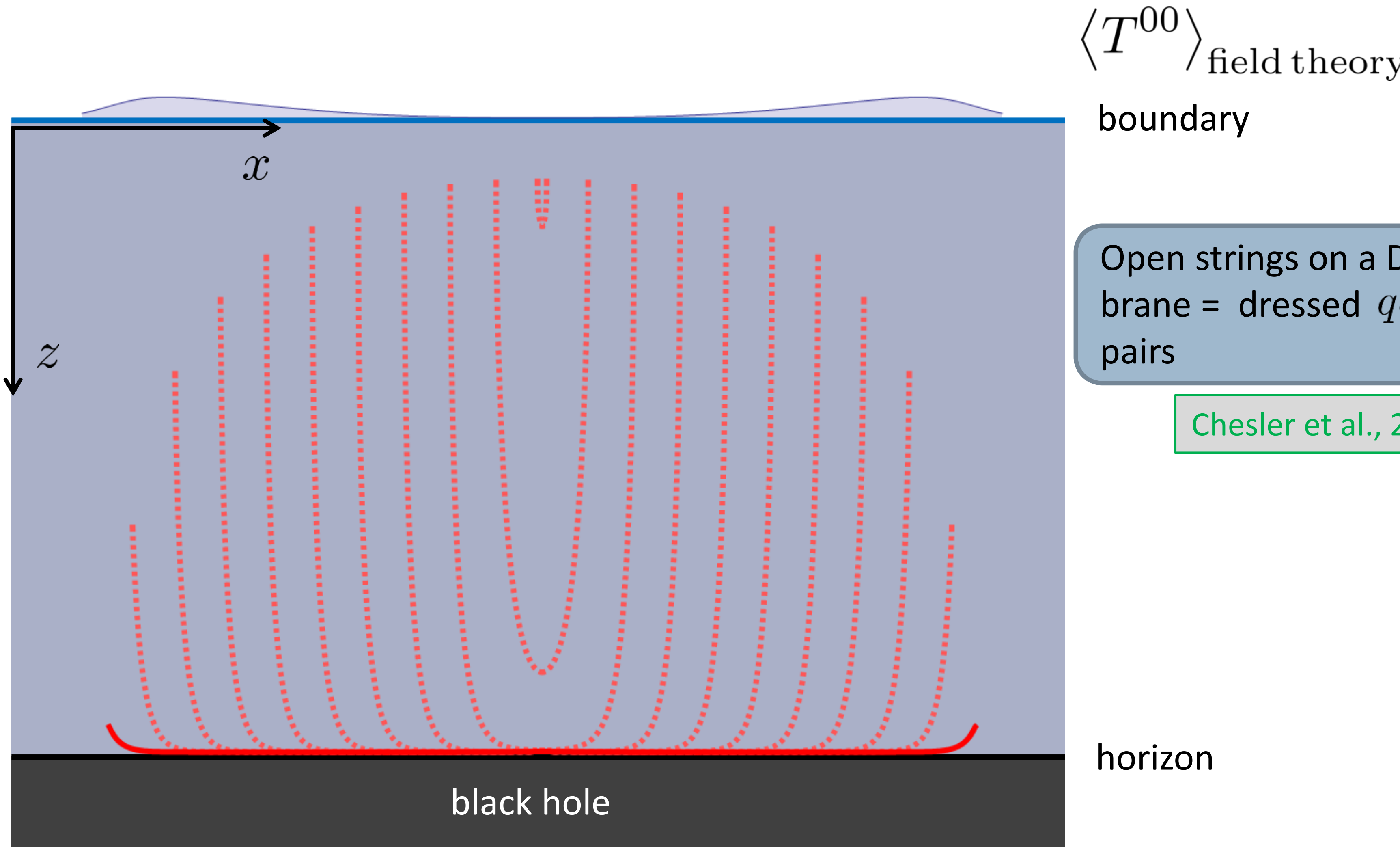

Open strings on a D7 brane = dressed $q\bar{q}$ pairs

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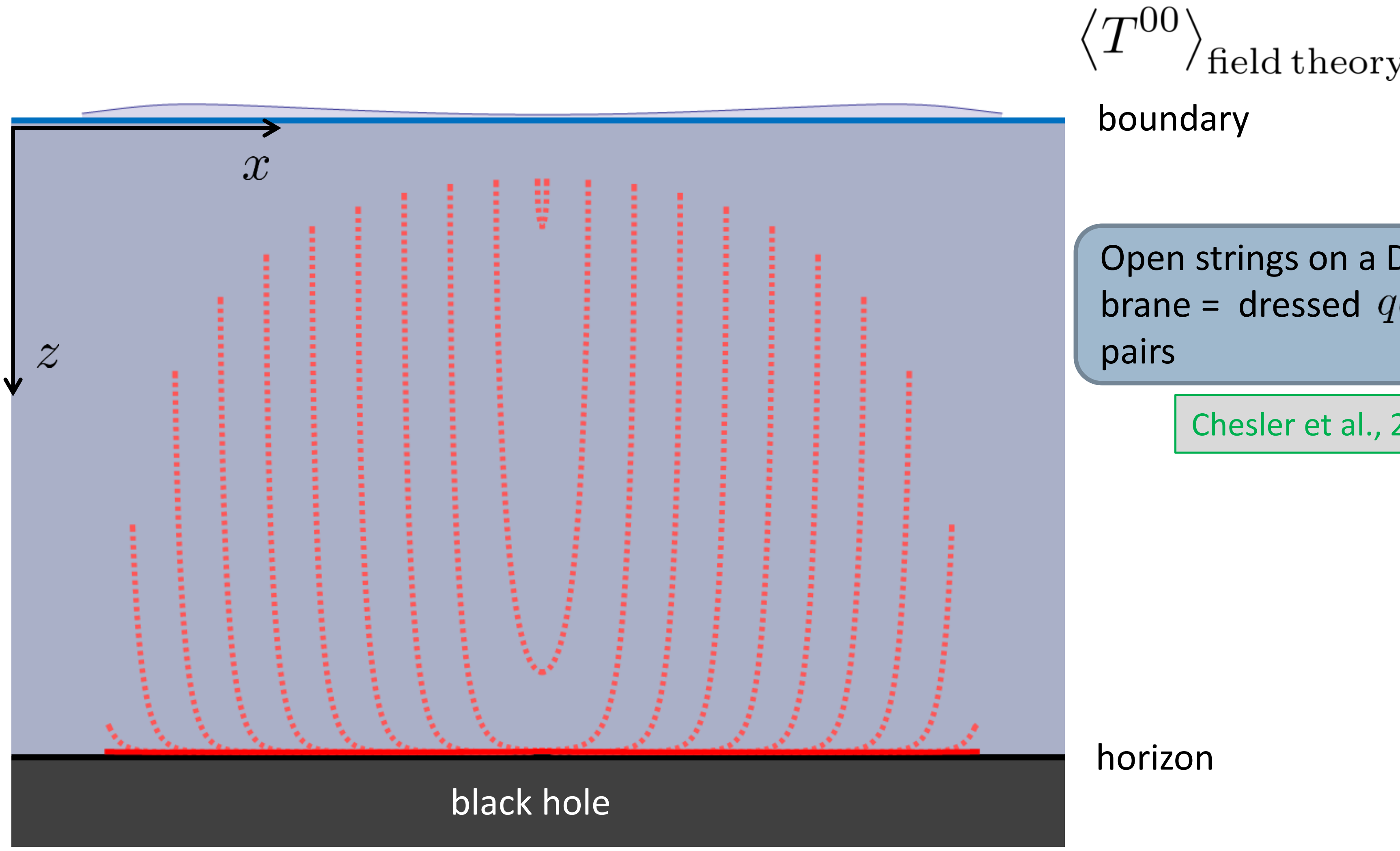
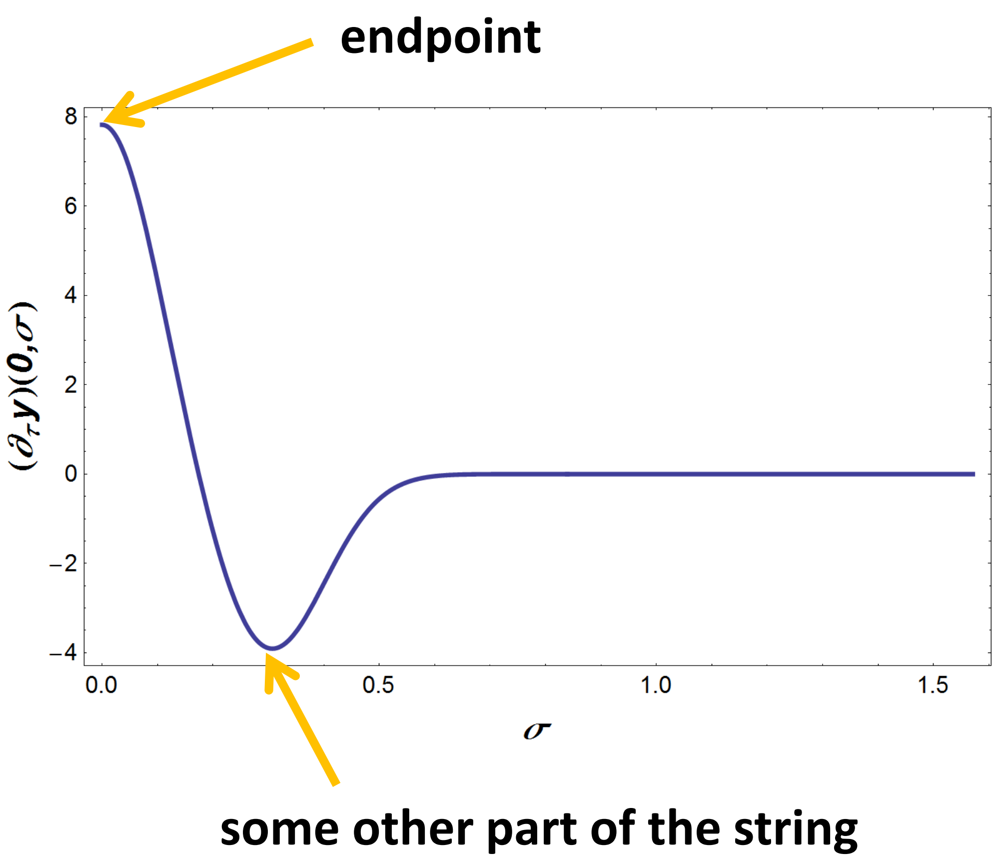


Open strings on a D7 brane = dressed $q\bar{q}$ pairs

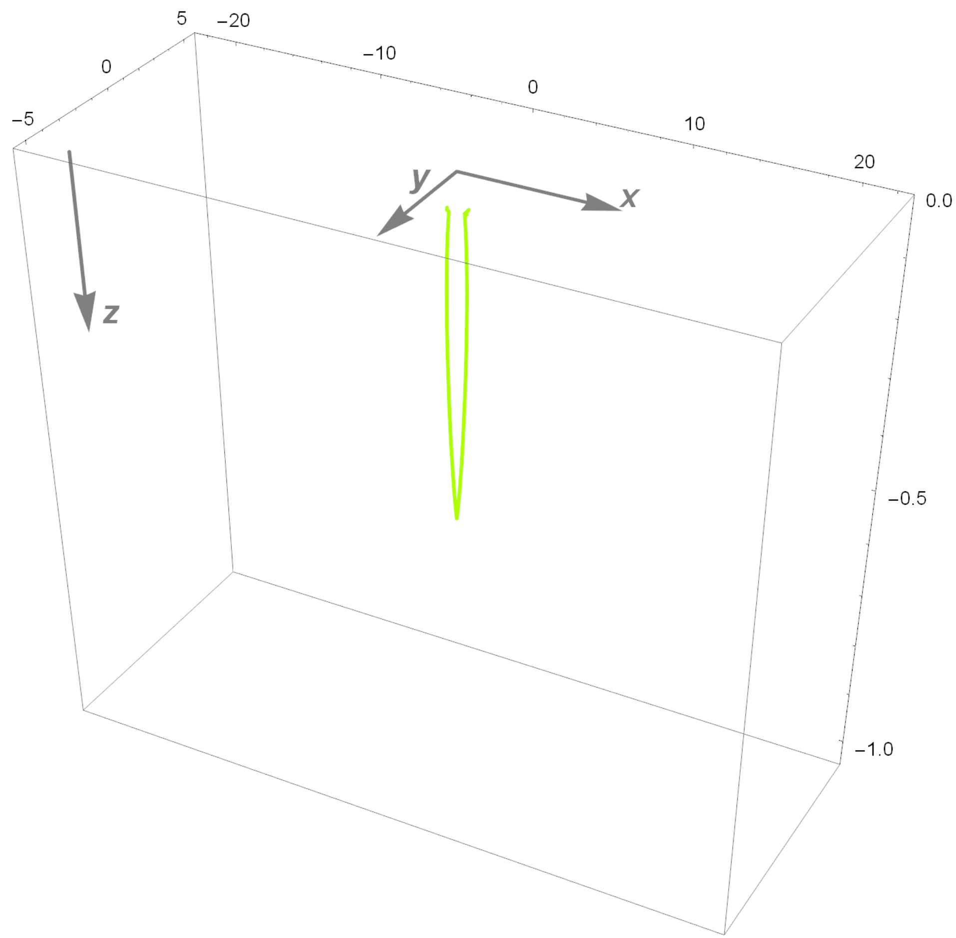
Chesler et al., 2009

Simulating 3-jet events

- Try simulating a 3-jet event by applying an initial **transverse kick** to the falling string



Simulation of a 3-jet event



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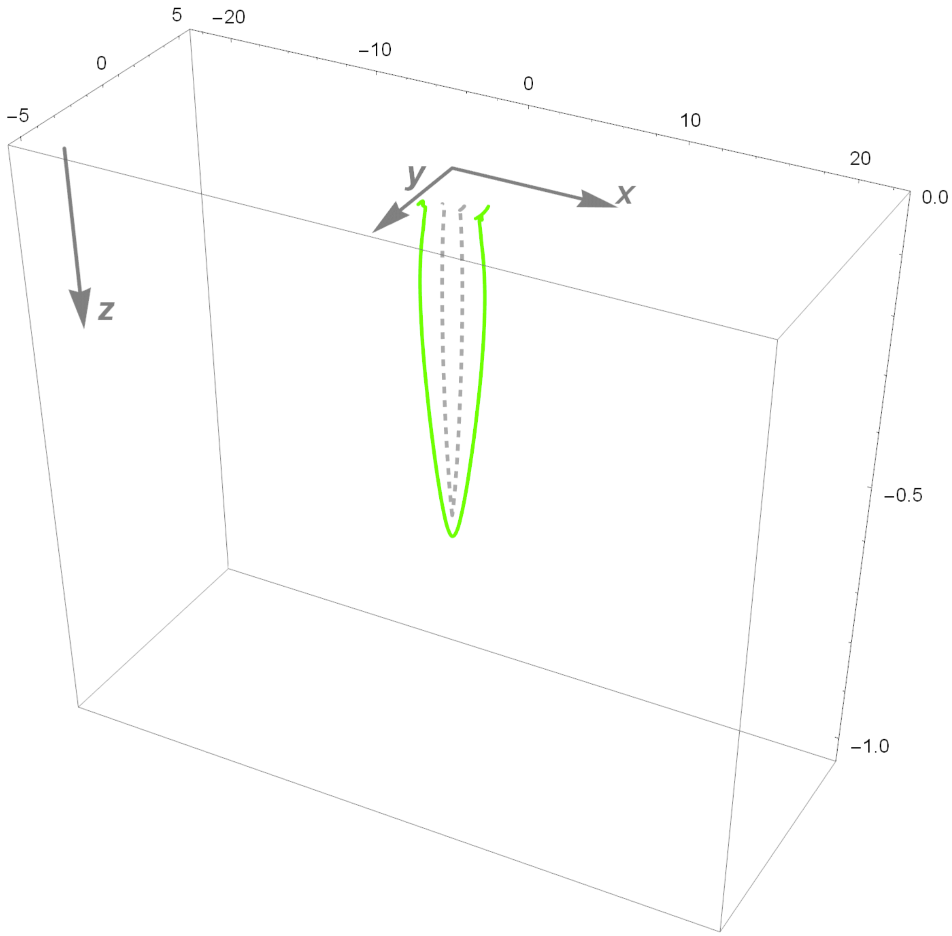

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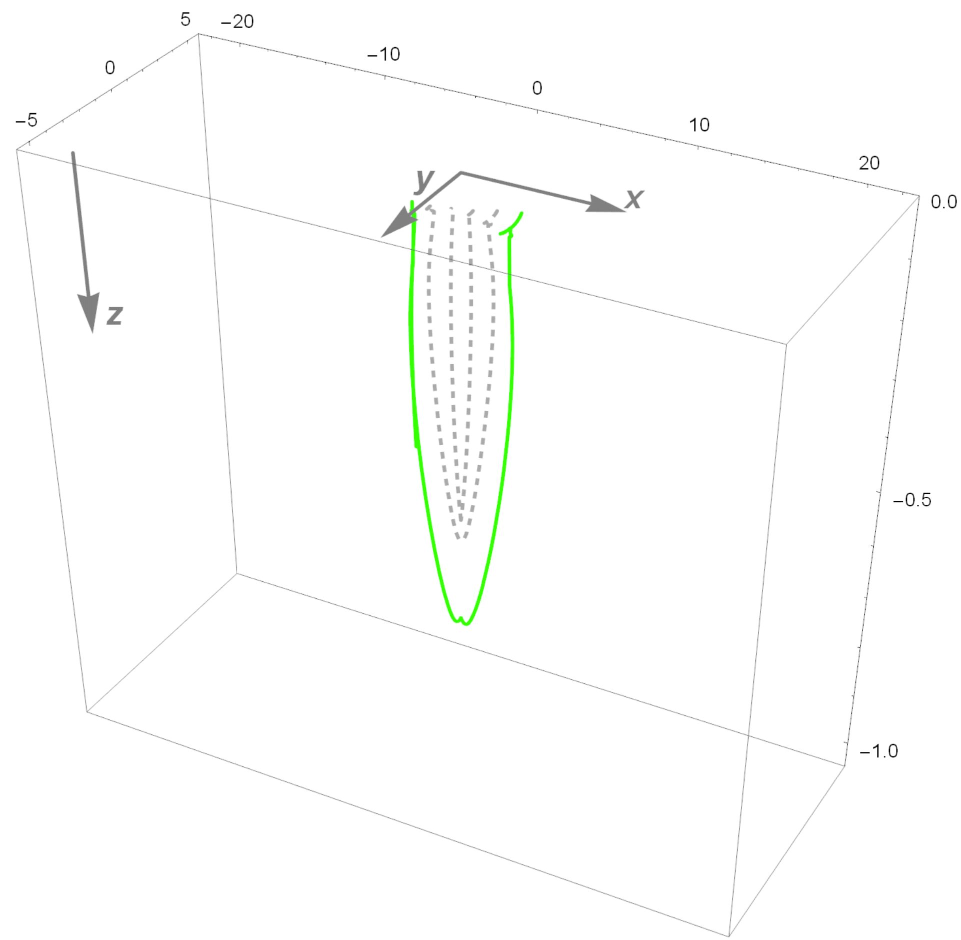

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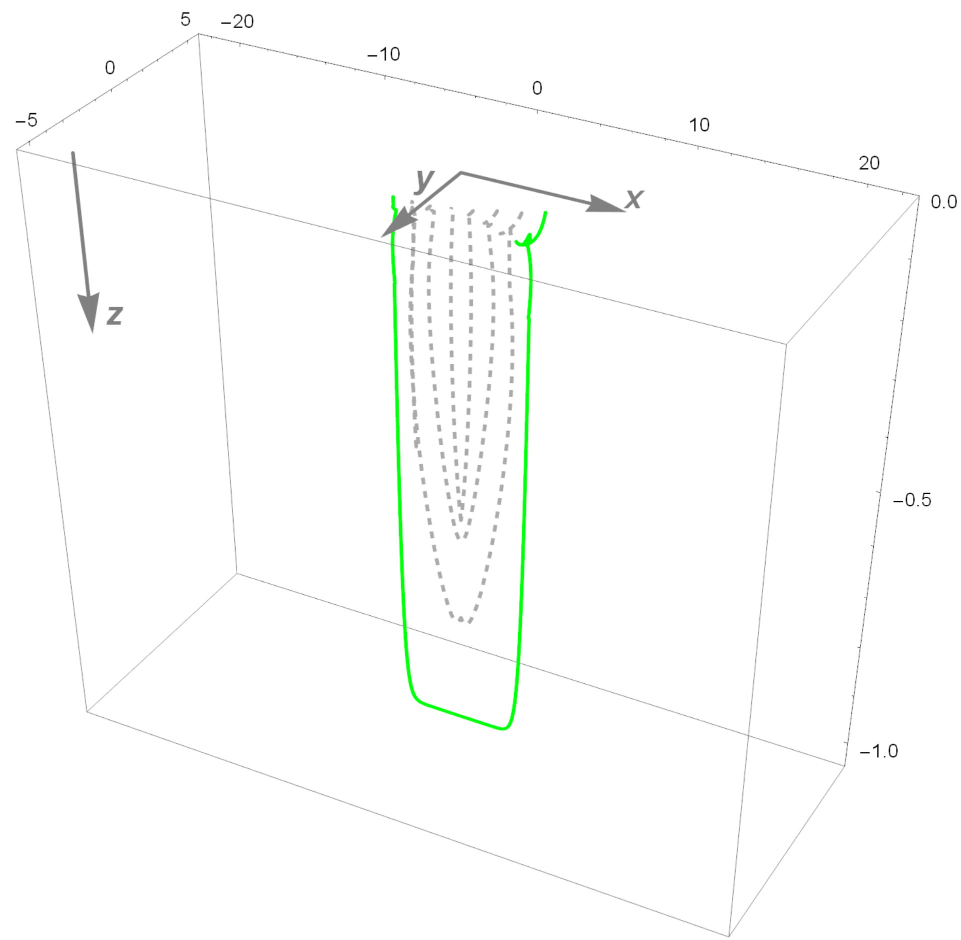

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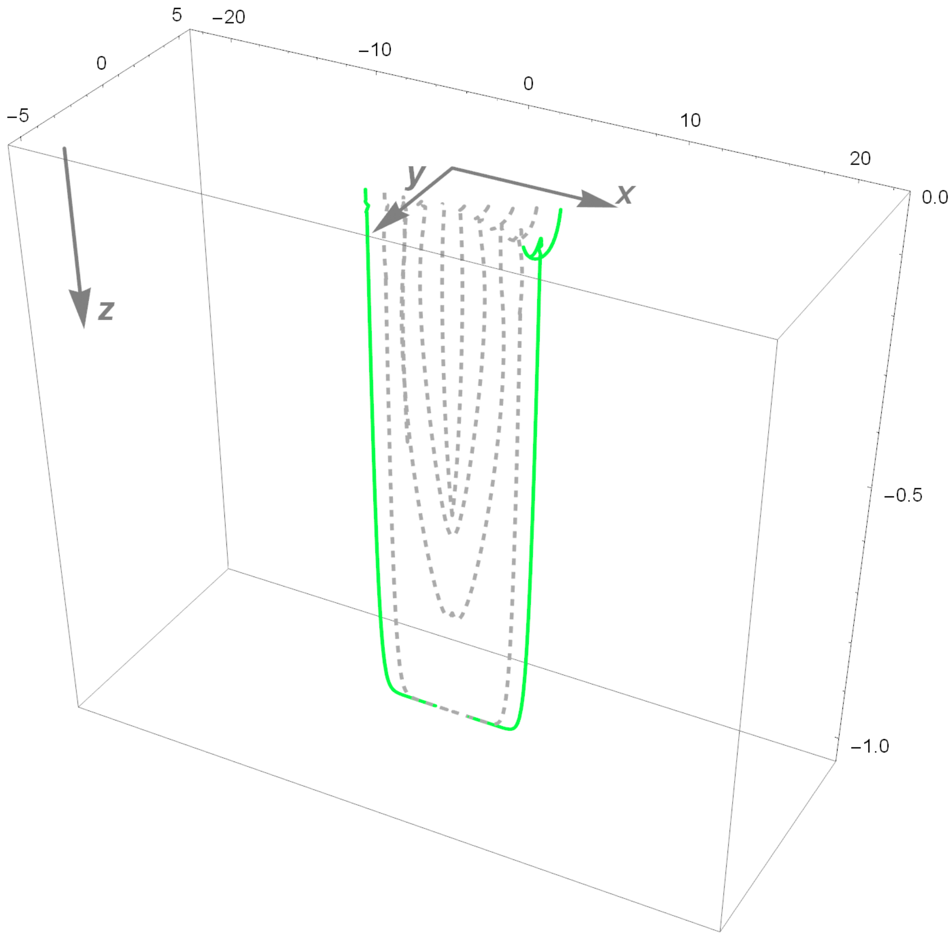

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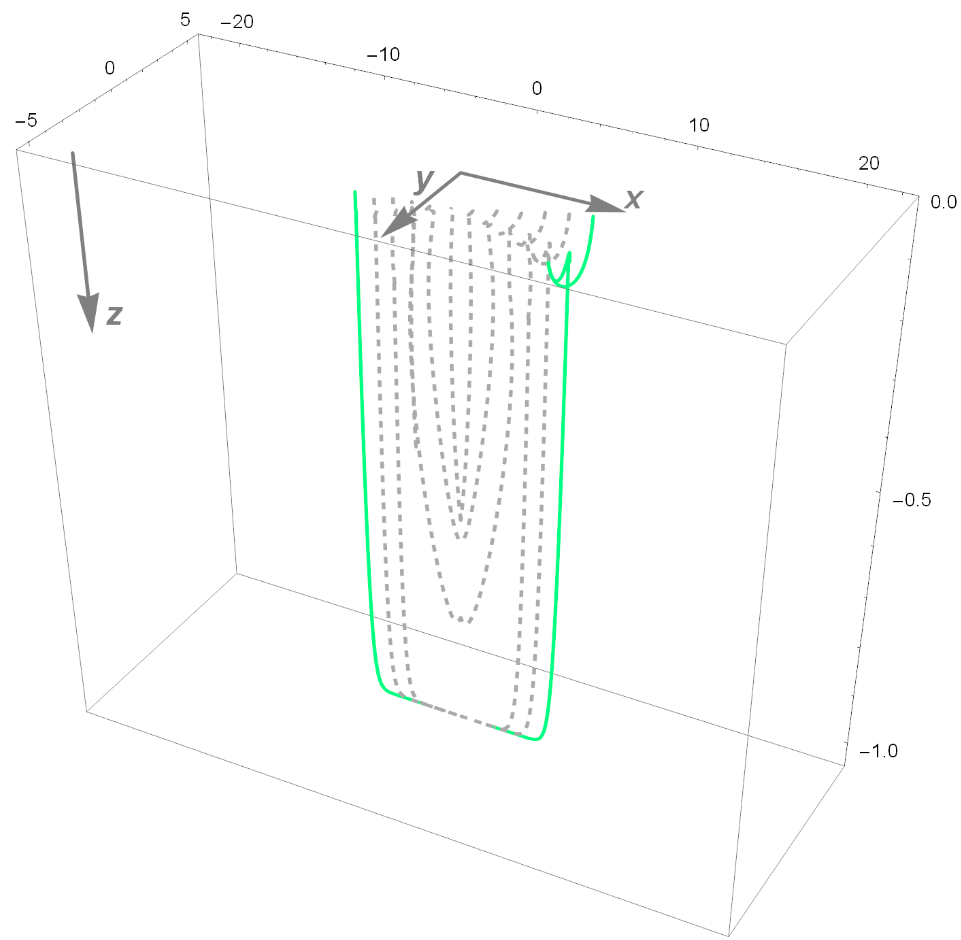

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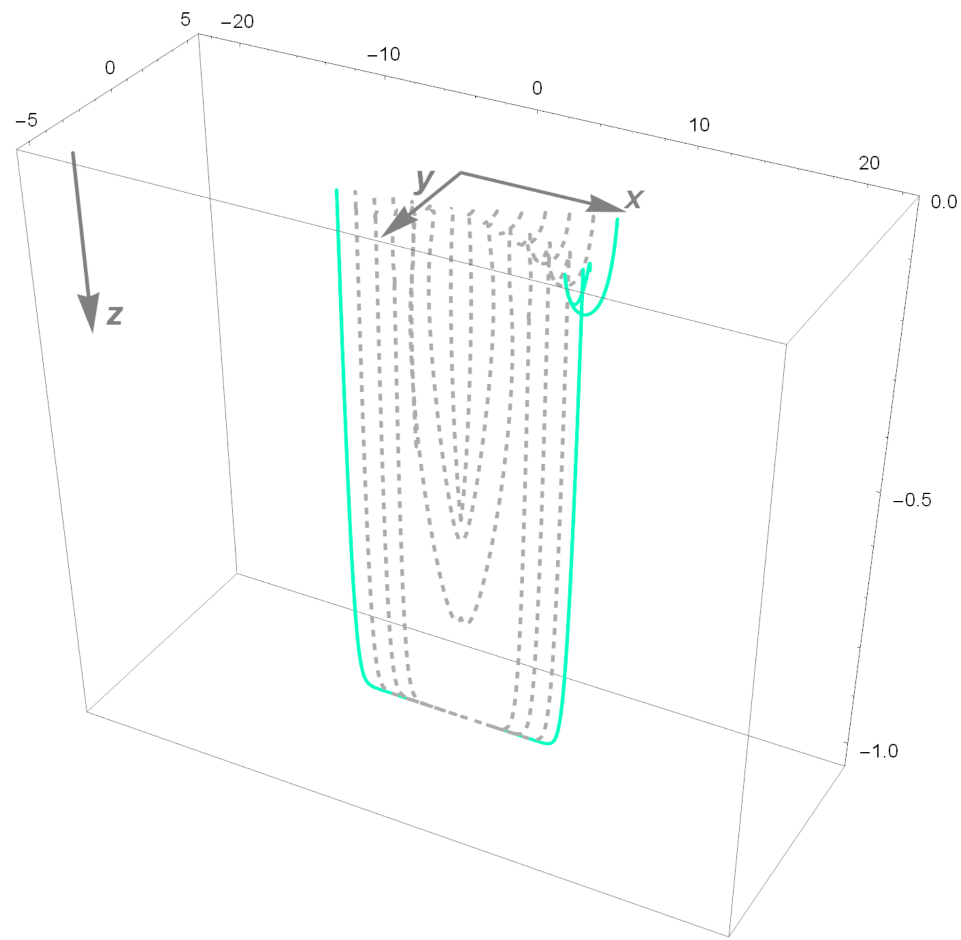

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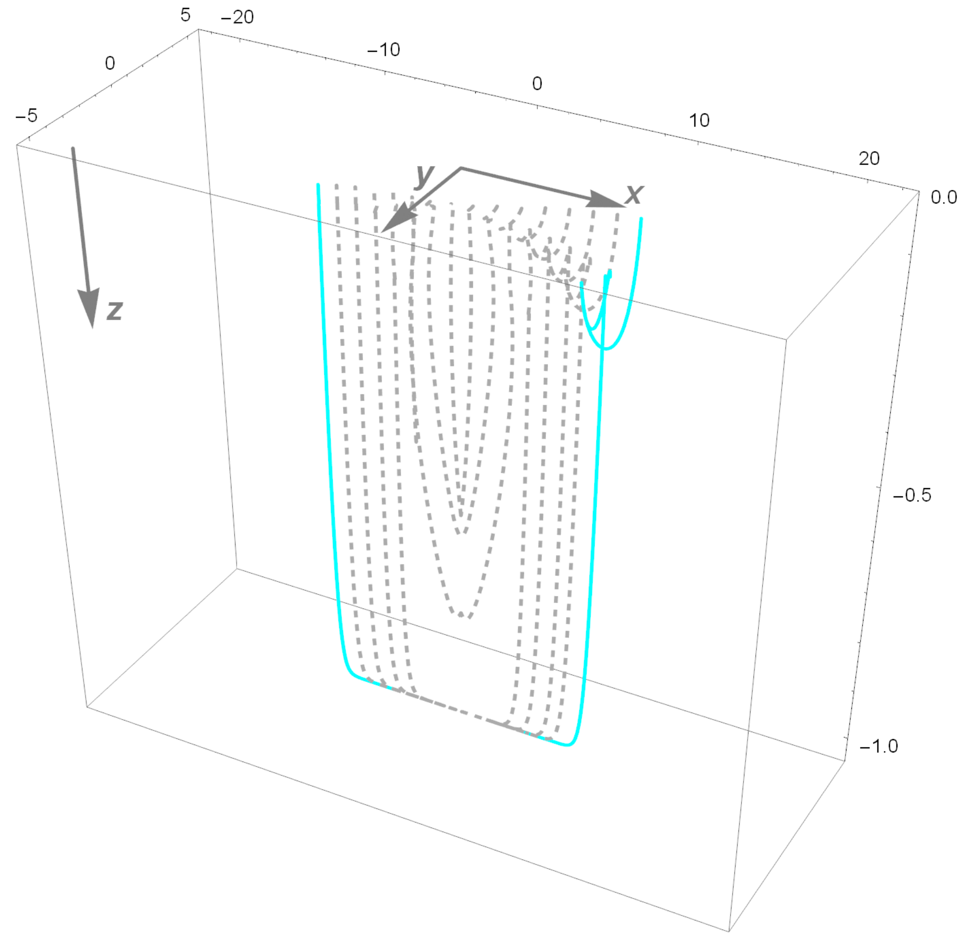

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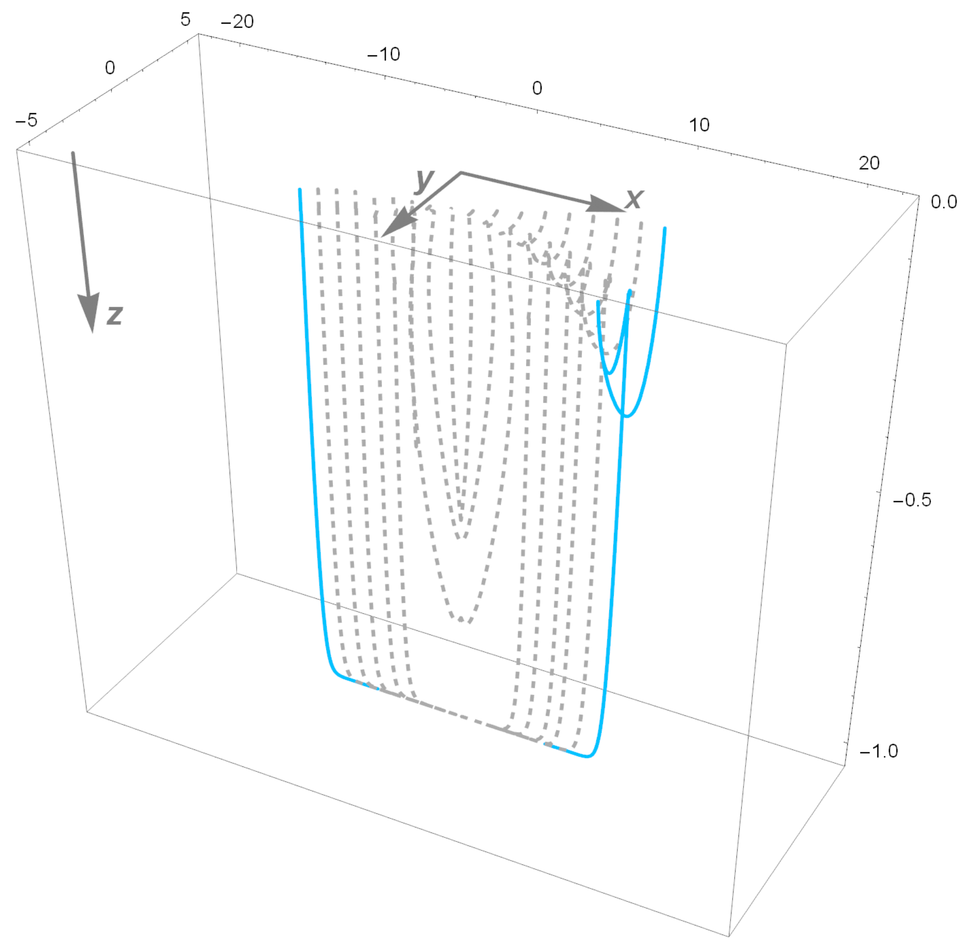

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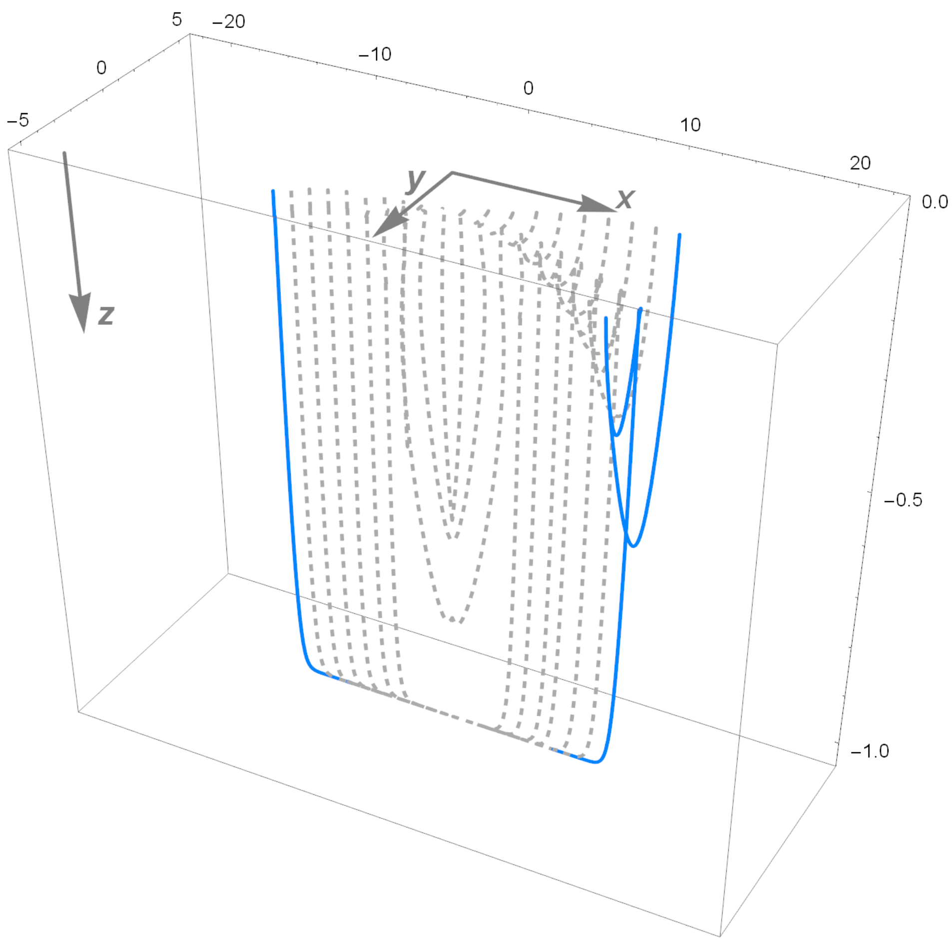

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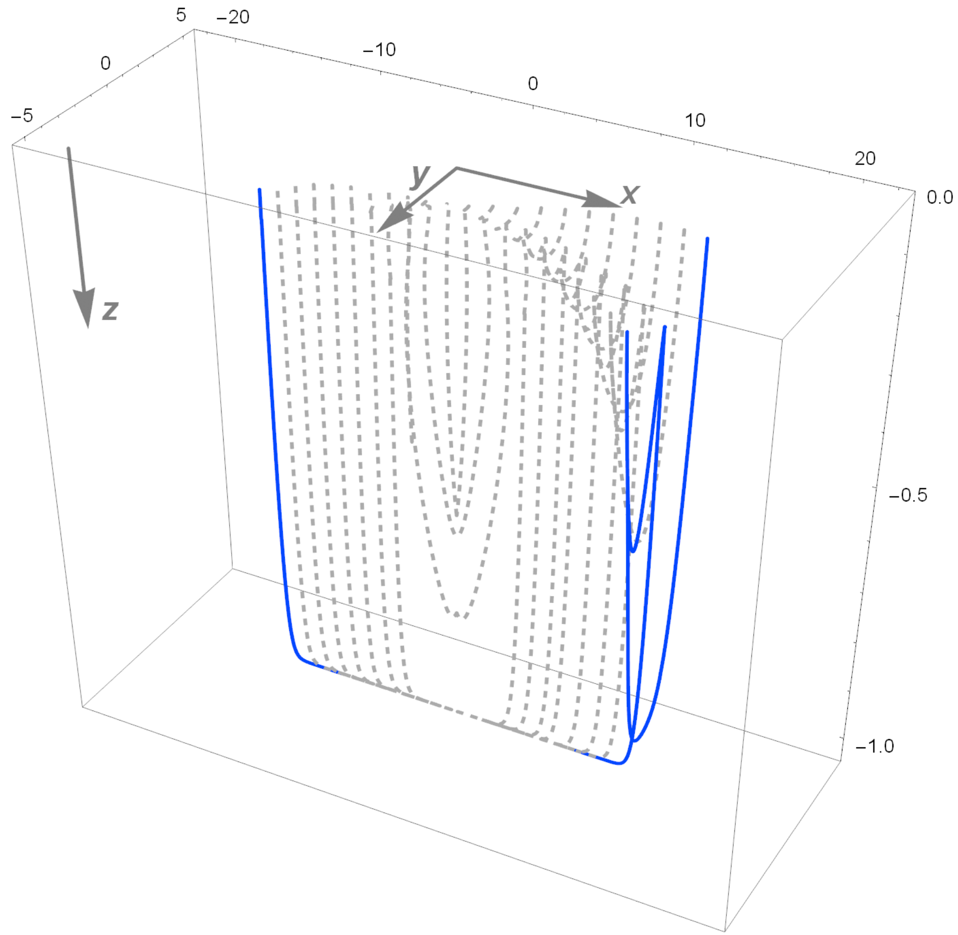

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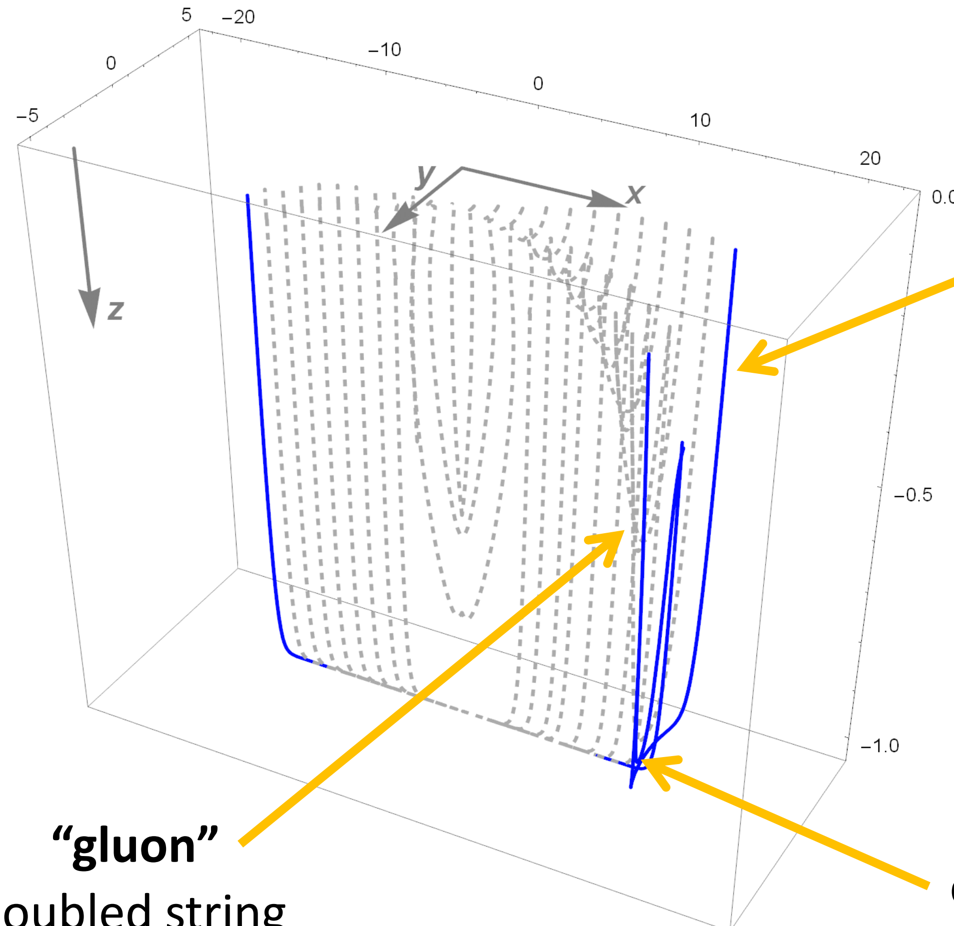
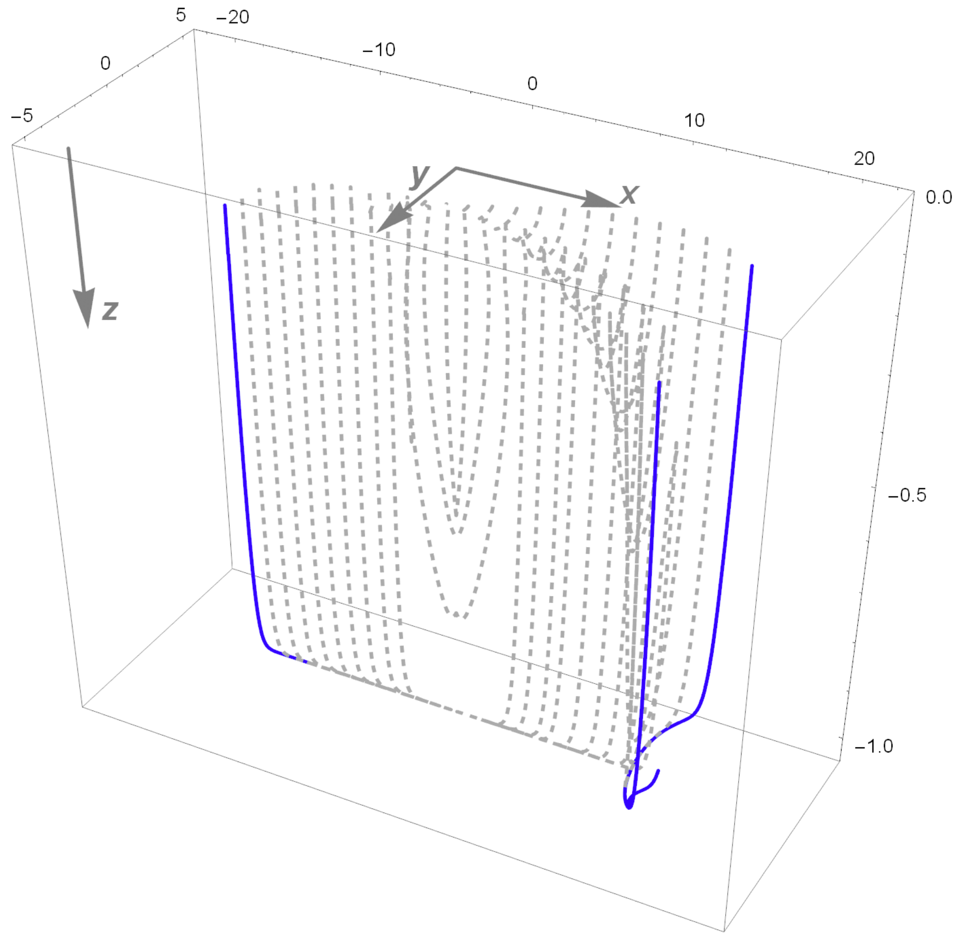


string with
an endpoint
"quark"

"gluon"
doubled string
with a kink

causal separation

Simulation of a 3-jet event



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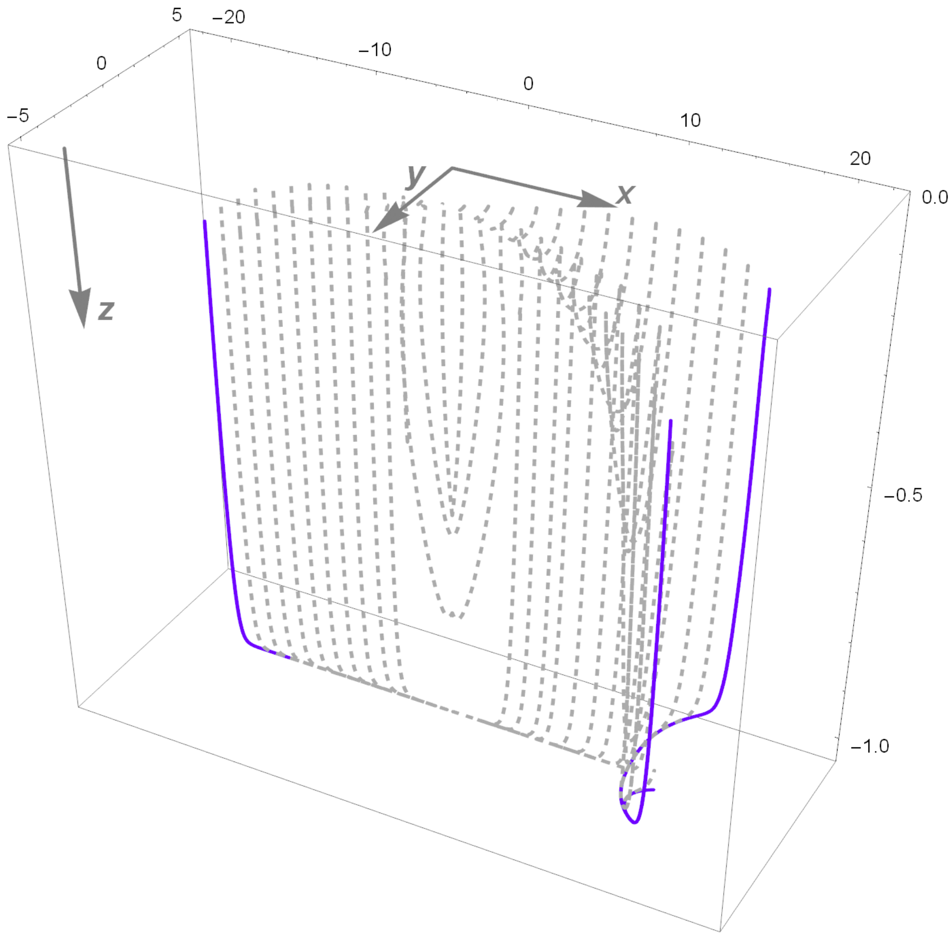

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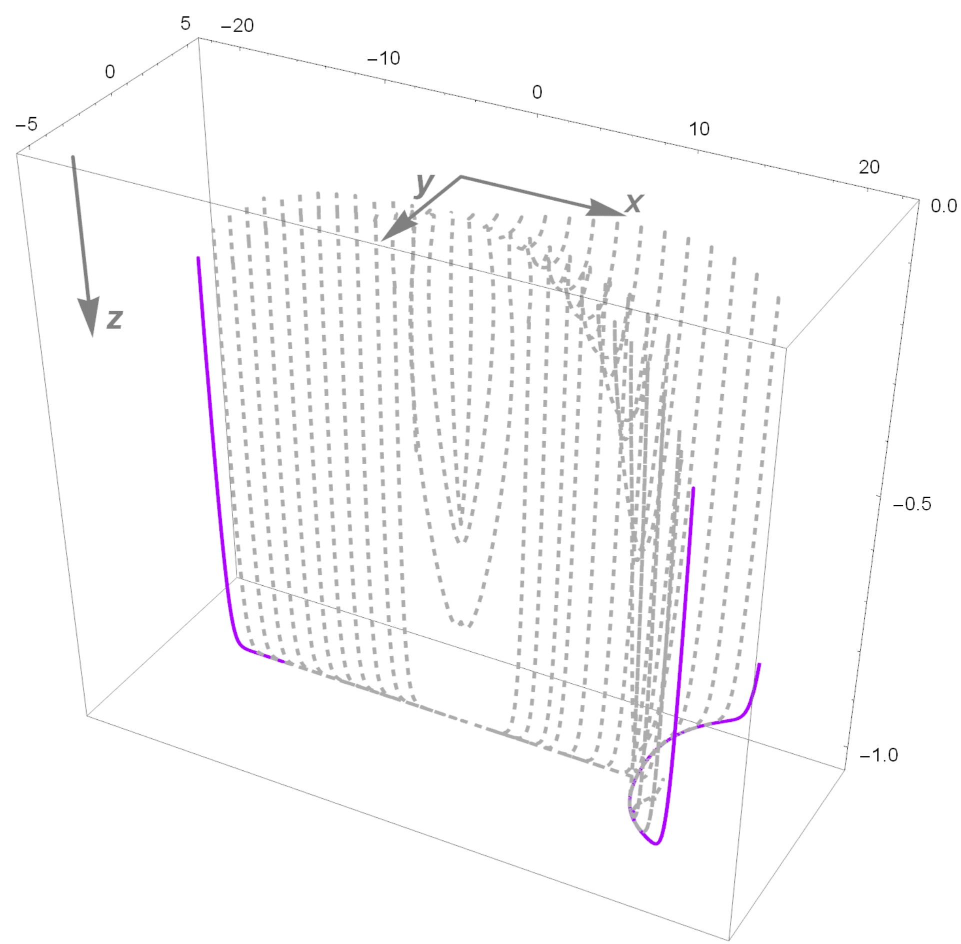

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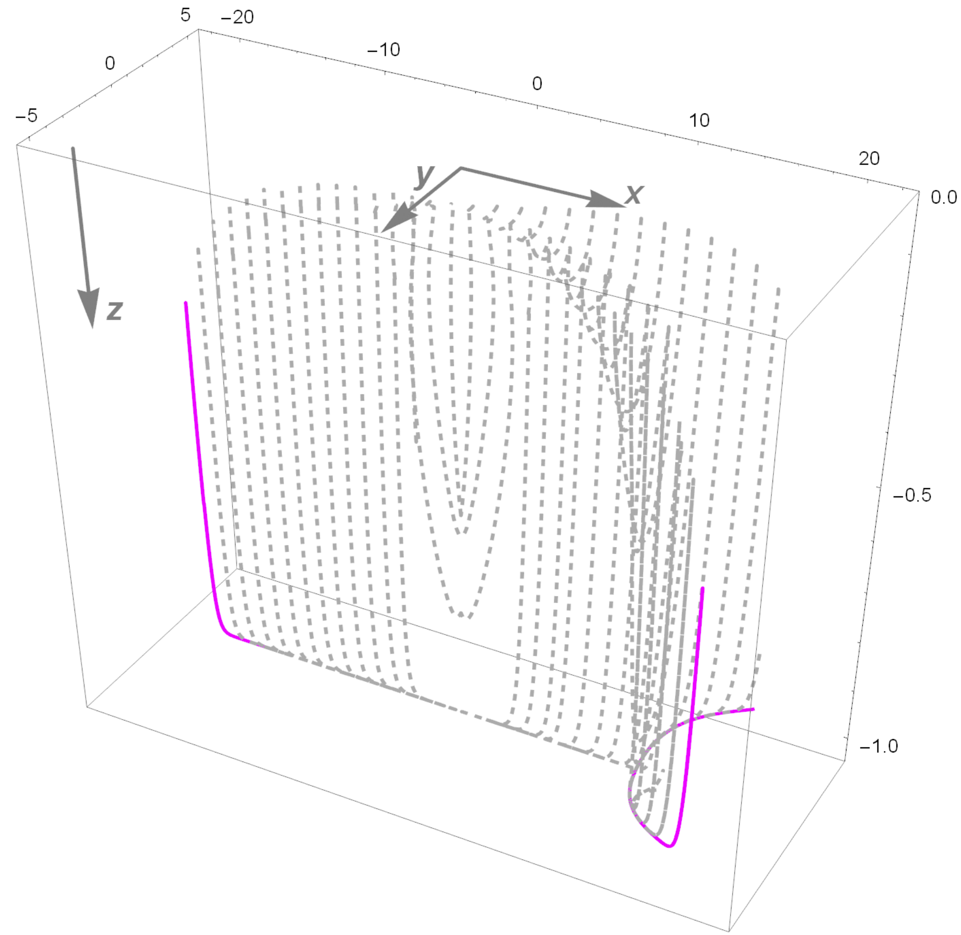

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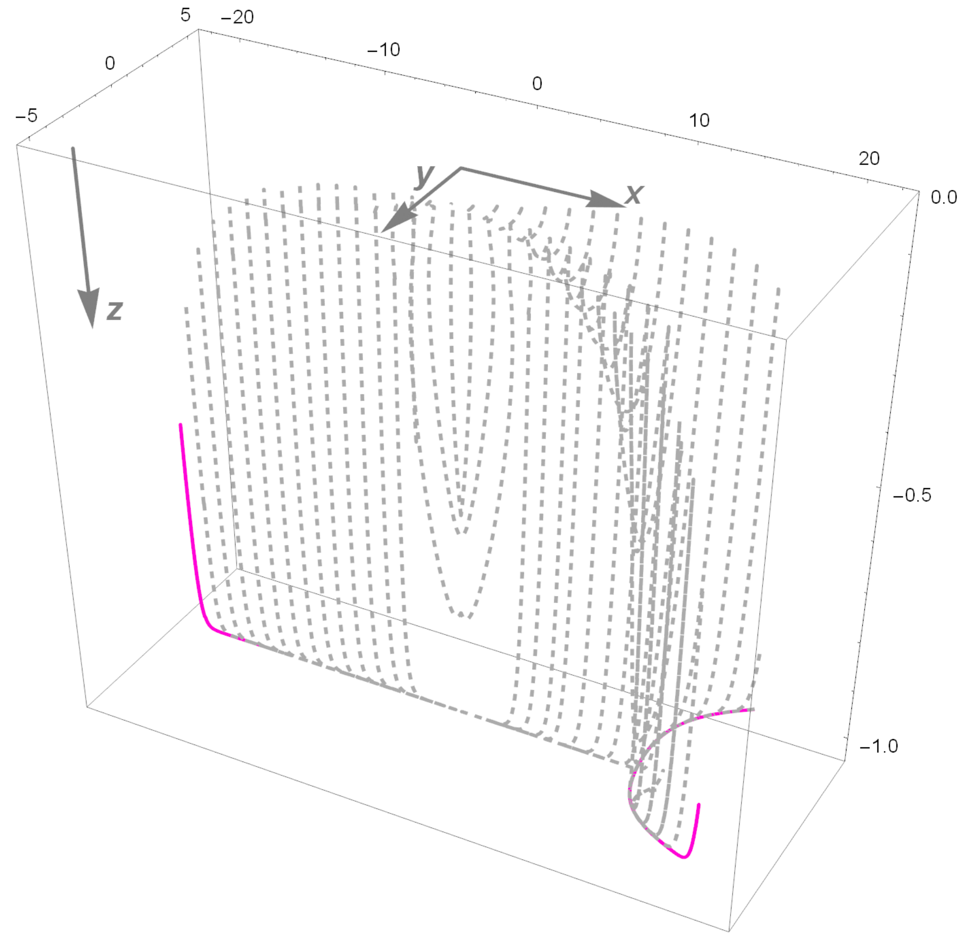

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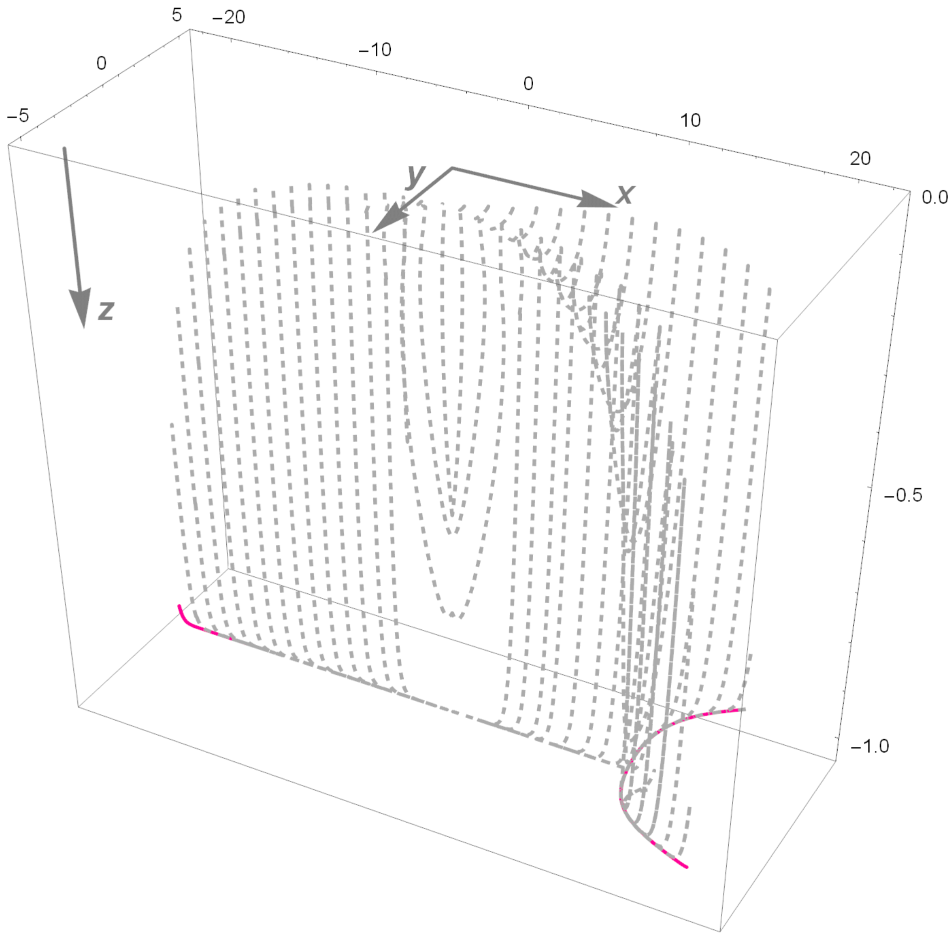
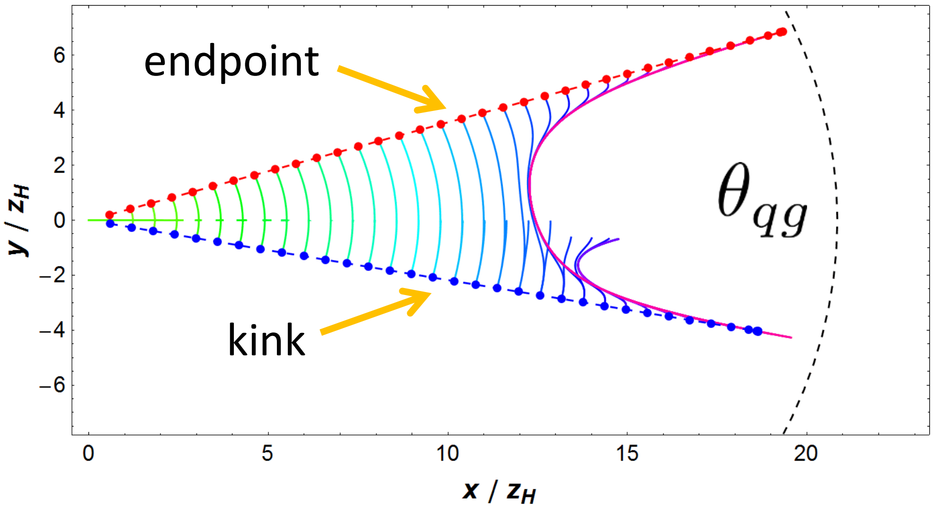


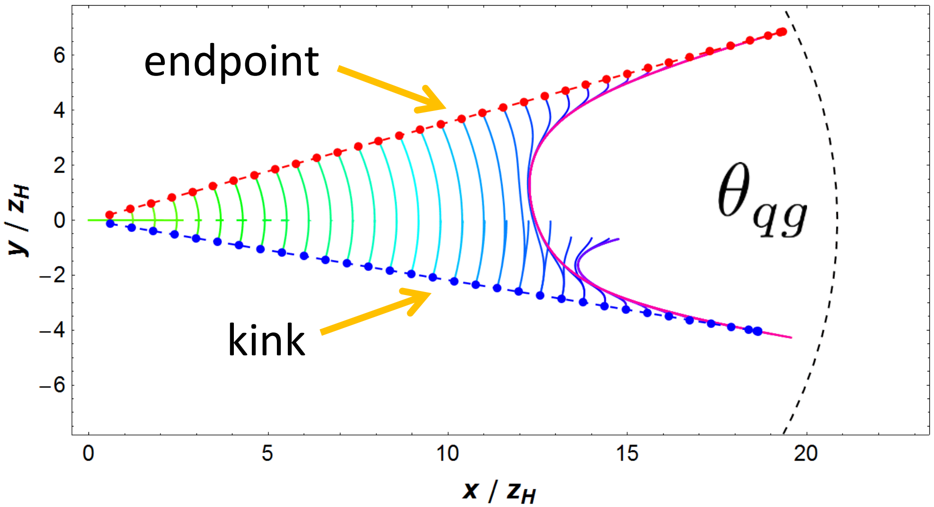
Resolved vs. unresolved case



resolved case

$$\frac{r_{\text{endpoint}}}{r_{\min}} > 1$$

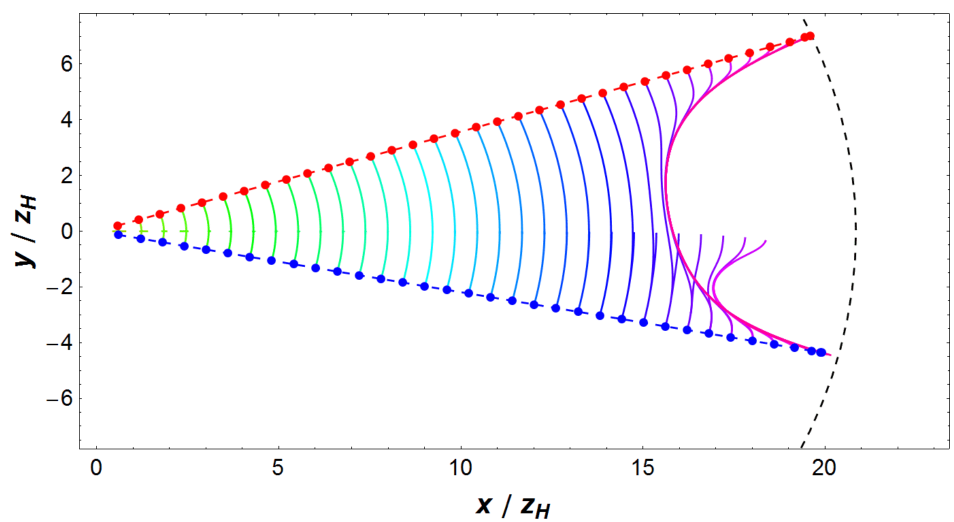
Resolved vs. unresolved case



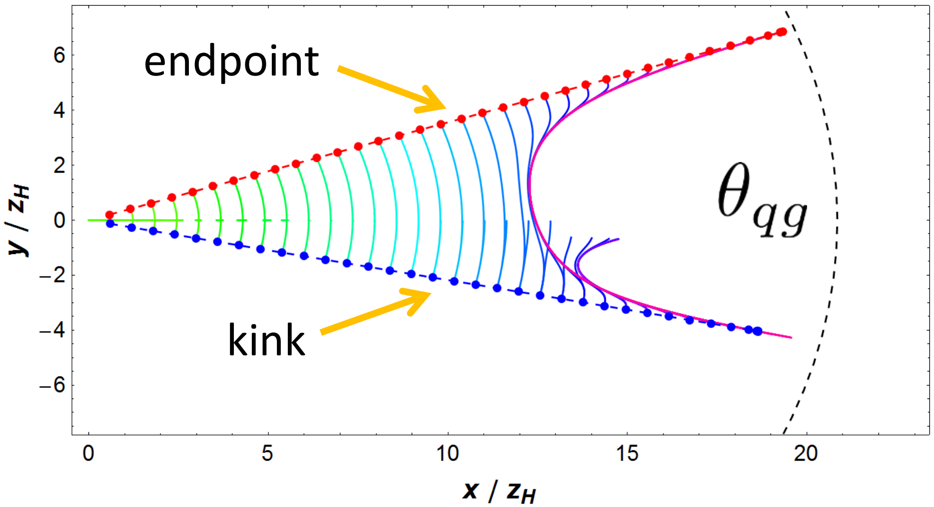
resolved case

$$\frac{r_{\text{endpoint}}}{r_{\min}} > 1$$

increase energy



Resolved vs. unresolved case



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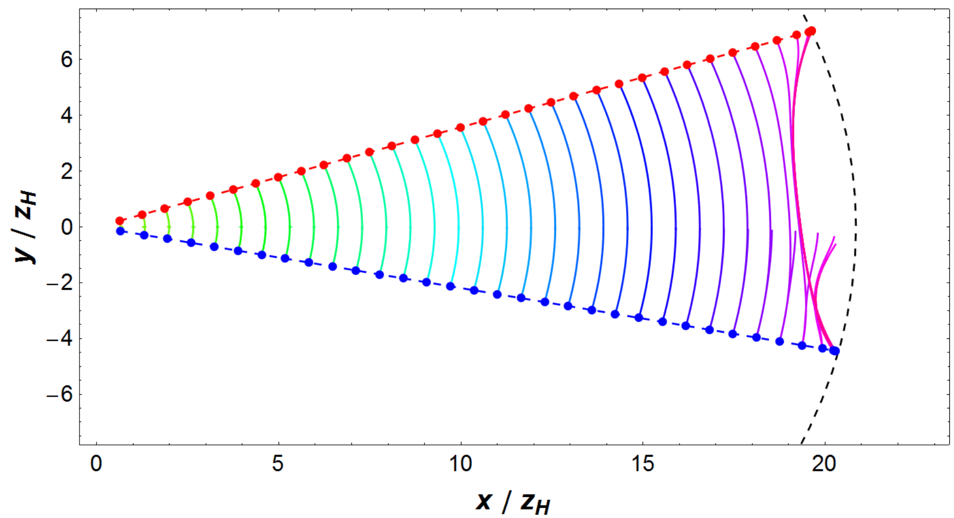

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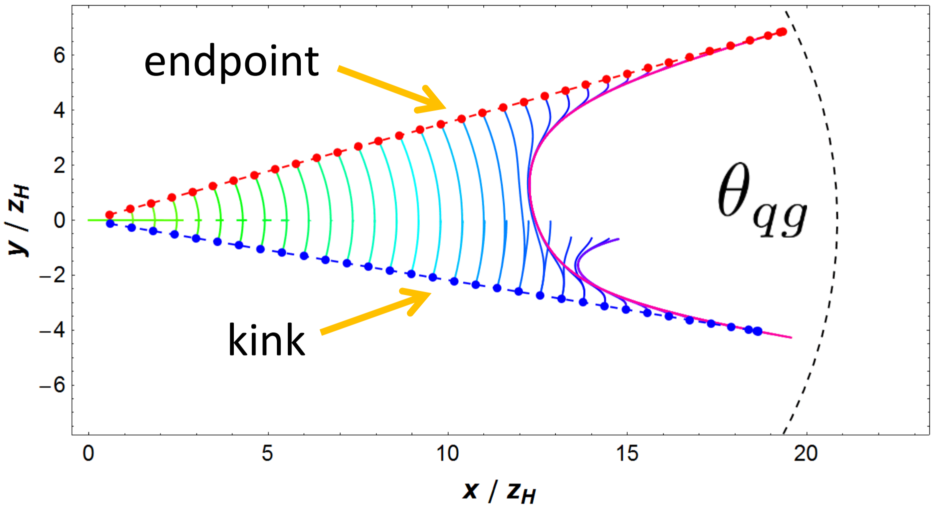

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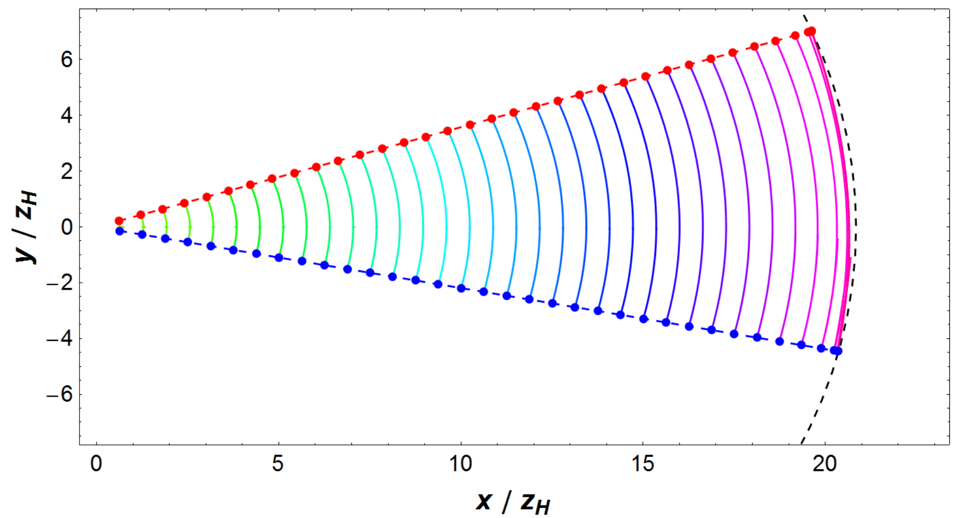
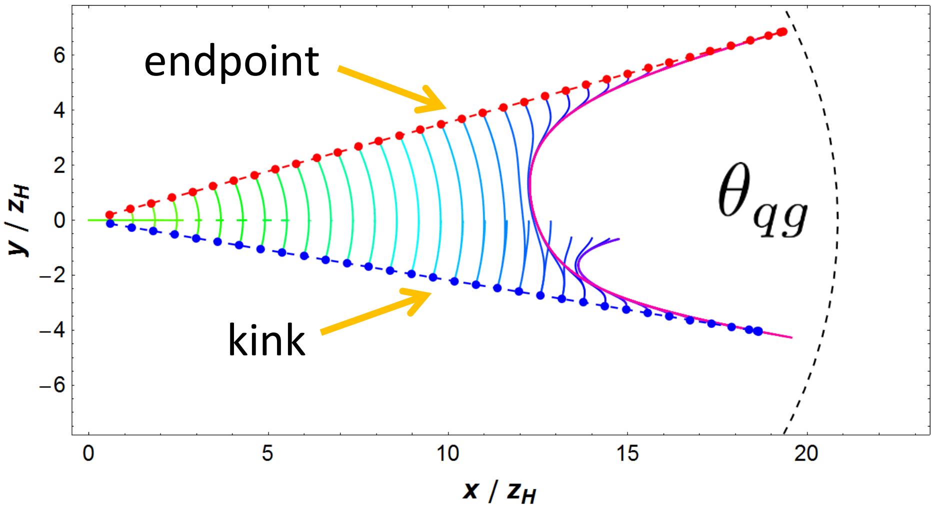


Resolved vs. unresolved case

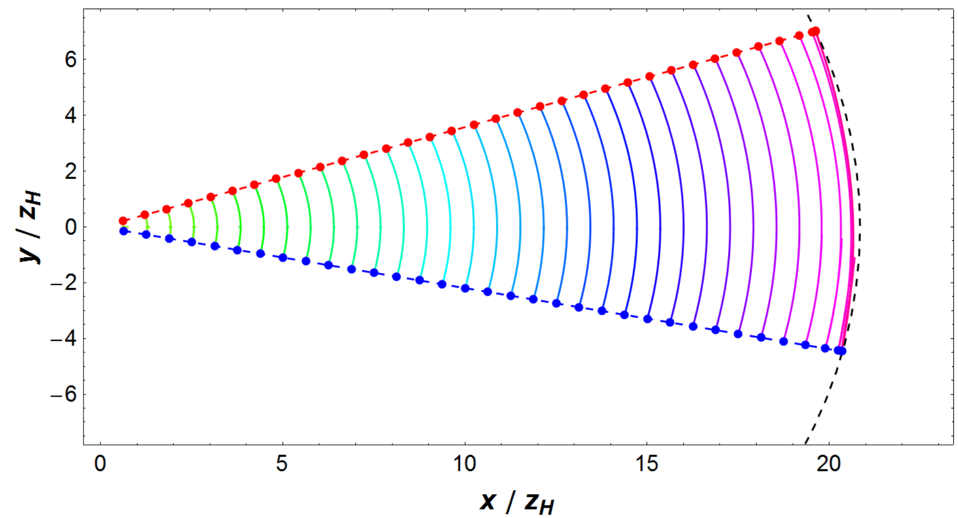


resolved case

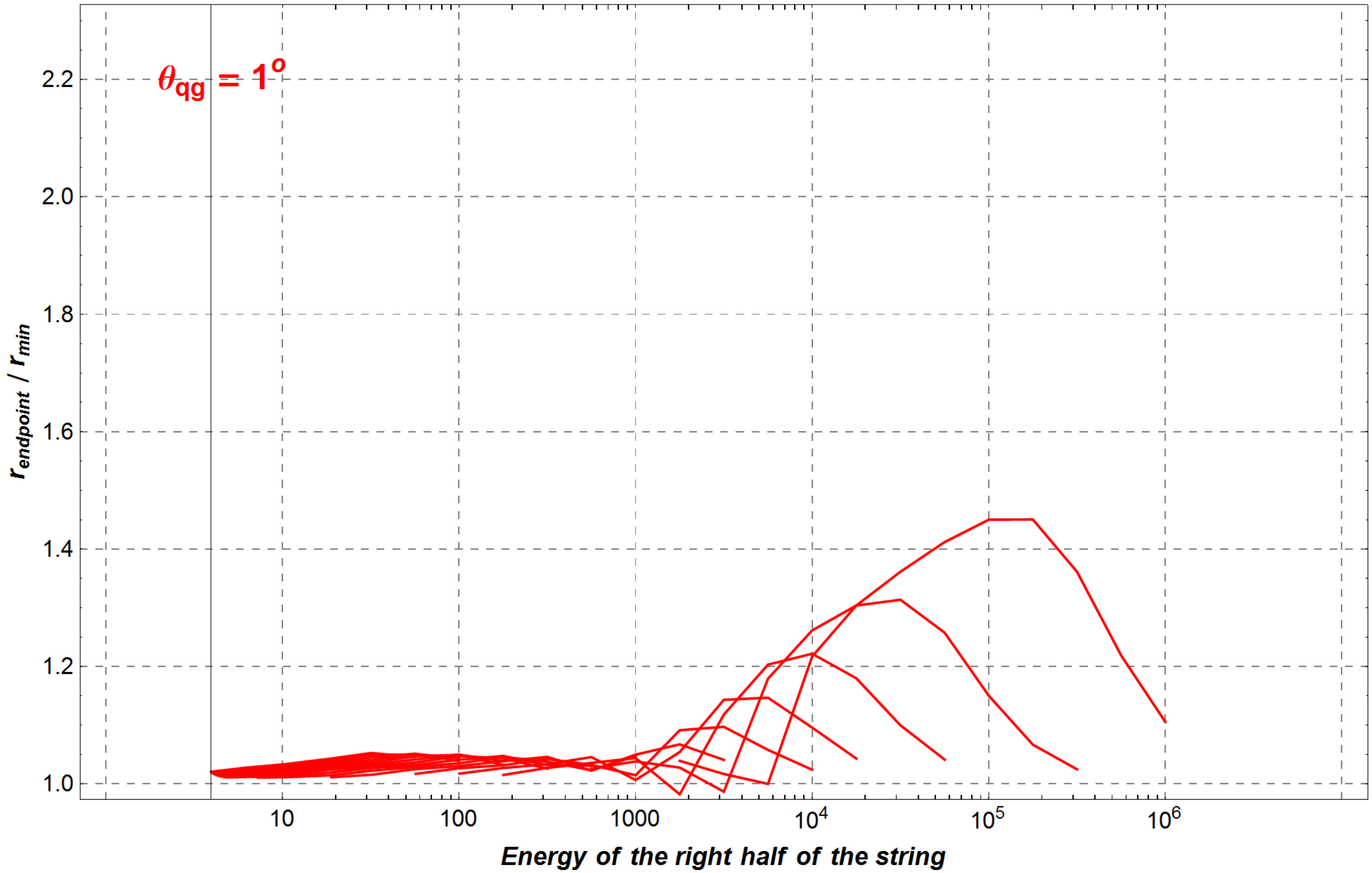
$$\frac{r_{\text{endpoint}}}{r_{\text{min}}} > 1$$

unresolved case

$$\frac{r_{\text{endpoint}}}{r_{\text{min}}} \sim 1$$



Minimal resolution energy



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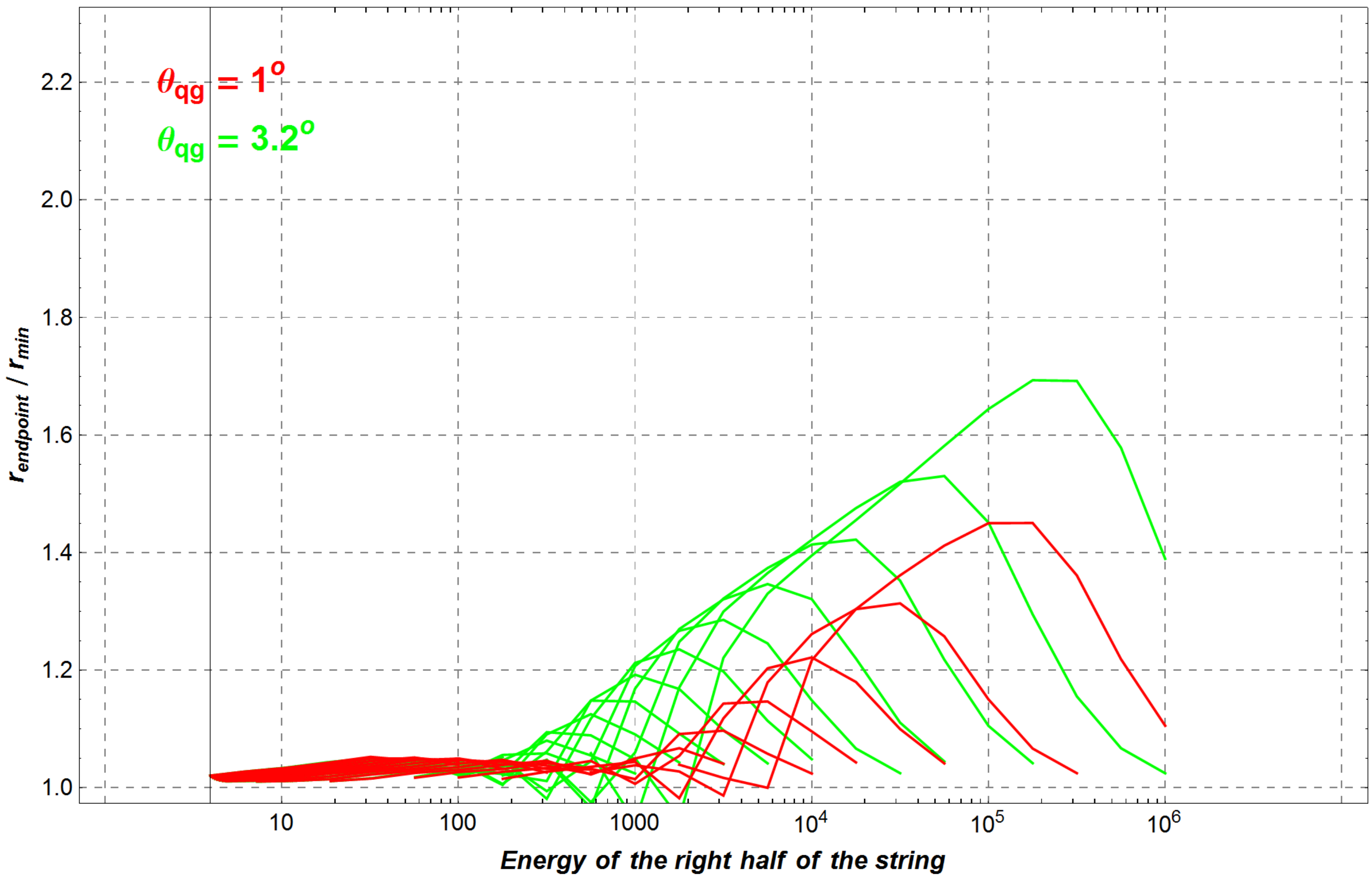

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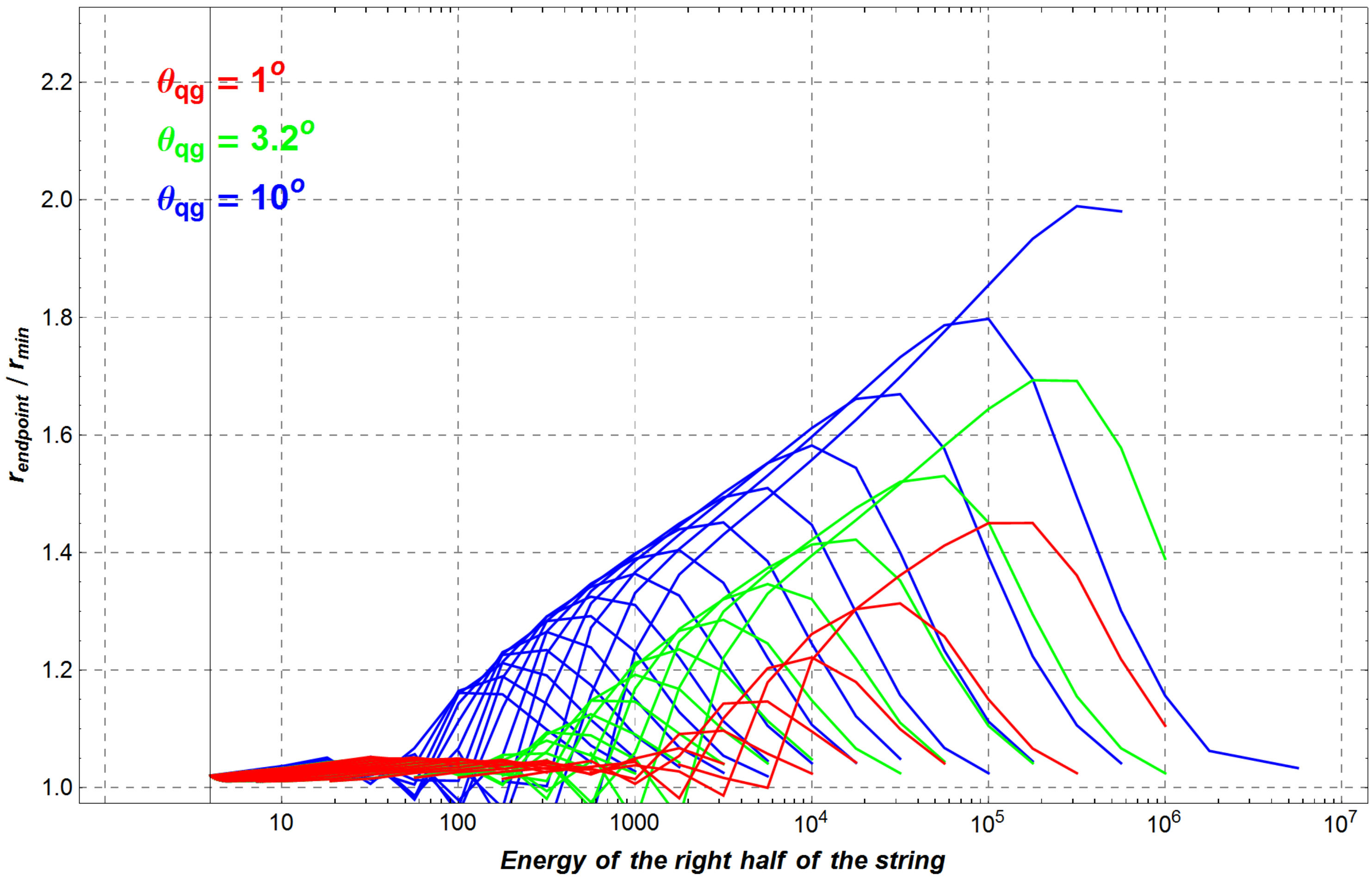
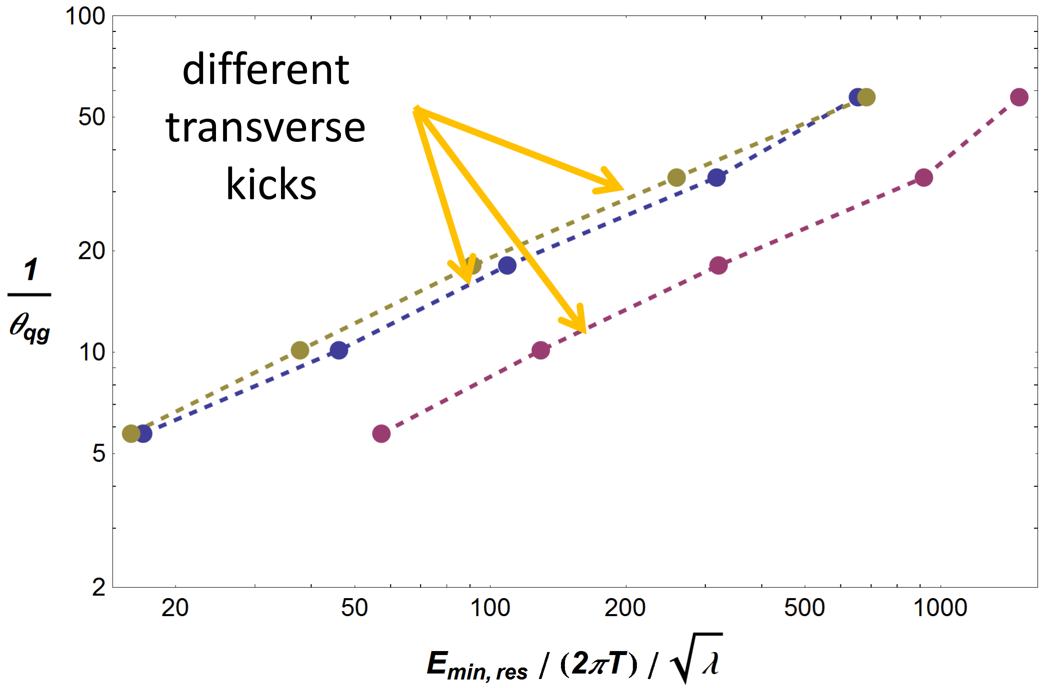


Resolution criterion



(preliminary)

$$\frac{1}{\theta_{qg}} \sim E_{\mathrm{min,res}}^{0.64}$$

Compare with perturbative estimate

- Consider the typical length dependence of the energy loss in pQCD (up to log corrections)

$$\Delta E_{\mathrm{BDMPS}} = \frac{1}{2}\alpha_s \hat{q} L^2$$

Baier et al., 1997

- Color decoherence for two color sources occurs at

$$\tau_{\mathrm{coh}} = \frac{2}{\left(\hat{q}\theta^2\right)^{1/3}}$$

Casalderrey-Solana & Iancu, 2011

- This yields a simple estimate

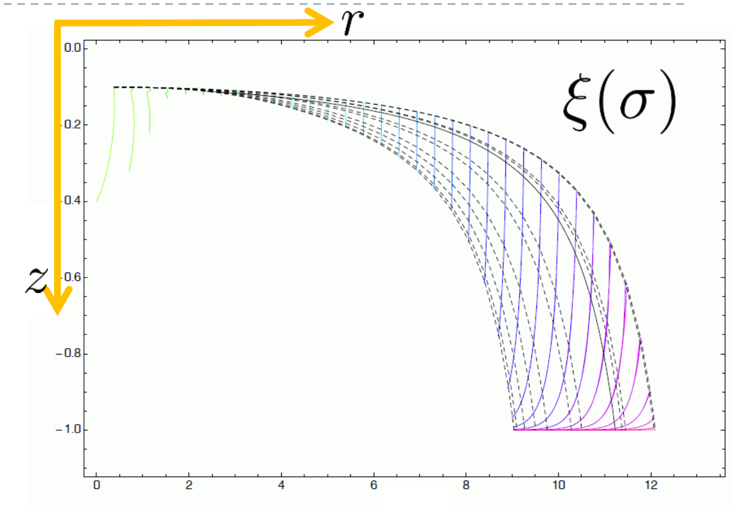
$$\frac{1}{\theta_{qg,\mathrm{pQCD}}} \propto E^{3/4}$$

Towards an analytical derivation

- Describe the energetic string as a congruence of null geodesics

$$X^\mu = X^\mu_{\text{geo}} + \varepsilon \delta X^\mu + \mathcal{O}(\varepsilon^2)$$

Chesler & Rajagopal, 2014



- Choosing a suitable gauge:

$$\Pi^0_0 = \frac{1}{2\pi\alpha'} \frac{1}{z^2_{\text{geo}}\xi(\sigma)^{3/2}} \sqrt{\frac{(\partial_\sigma z_{\text{geo}})^2 + (f r_{\text{geo}}\xi(\sigma)\theta'(\sigma))^2}{-2\varepsilon f\,(\partial_t \delta r)}} + \mathcal{O}(\sqrt{\varepsilon})$$

$$\Pi^\sigma_0 = \mathcal{O}(\sqrt{\varepsilon})$$

  - Energy is transported along $\sigma = \text{const.}$ $(\partial_t \Pi^0_0 + \partial_\sigma \Pi^\sigma_0 = 0)$
  - All the dynamics is in the radial direction
  - Two distinct regimes

Conclusions and prospects

- Numerical simulations of classical falling string configurations with non-trivial transverse dynamics
  - Kink-like structures ⇨ propagation of hard gluons produced in association with a quark-antiquark pair
- Two physically distinct regimes
  - Depending on whether the medium is able to resolve the transverse structure of the string prior to its total quench
- Transverse resolution angle θ_{qg} scales approximately as $E^{-2/3}$
  - As opposed to the perturbative result of $E^{-3/4}$
- Prospects
  - Analytic derivation via geodesic congruence
  - Holographic brick, phenomenological applications