Numerical evidence for firewalls

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How can we do an experiment on firewalls?

We need a microscopic theory of geometry

We then need to identify what is a horizon

Calculate what happens

Firewalls detail a time dependent experiment:

Throw someone into a black hole and ask what happens as time goes by and they cross the horizon.

Microscopic theory

Use gauge/gravity duality

Building a black hole

For technical reasons, BFSS matrix model black hole is ideal for simulations. Can also take large N.

(Finite number of degrees of freedom in matrices)

BFSS matrix model

Dimensional reduction of U(N) SYM in d=9+1 to 0+1

$$S_{BFSS} = \frac{1}{2g^2}\int dt \left((D_t X^I)^2 + \frac{1}{2}[X^I, X^J]^2 \right) + \text{fermions}$$

Banks, Fischler, Shenker, Susskind ‘96

There are 9 dynamical matrices and one matrix constraint.

Near Horizon of D0 branes

$$ds^2 = H^{-1/2}(r)(dx_{||}^2) + H^{1/2}(r)(dr^2 + r^2 d\Omega_{8-p}^2)$$

Horowitz-Strominger

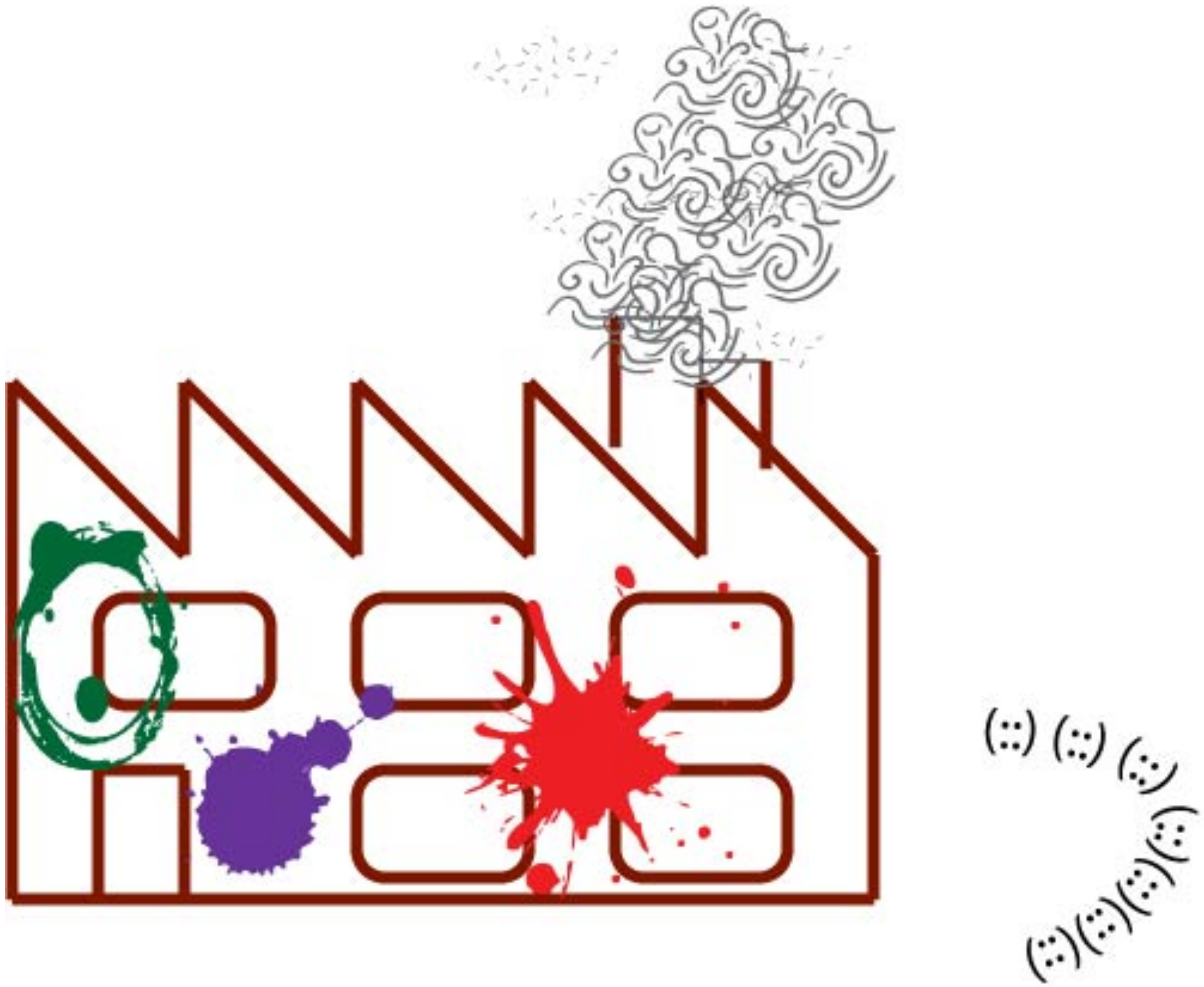
$$\int_0^{r_0} H^{1/4}(r)dr = \infty$$

There is an infinitely long throat for p <= 3

Effective curvature goes to zero as r goes to zero for p<3: gravity describes well IR, grows when r gets bigger - stringy UV.

Itzhaki-Maldacena-Sonnenschein-Yankielowicz

Put it on a computer



Factory that spits out lists of matrices ordered in time.

What we actually simulate

Classical dynamics of BFSS.

Wait and check for thermalization

w. C. Asplund,E. Dzienkowski, D. Trancanelli

Appropriate for ‘hot’ stringy black holes

Some qualitative aspects should be correct.

Once you have a typical matrix configuration, how do you probe it geometrically?

Add a D0 brane probe (extra eigenvalue)

The probe lives in $\mathbb{R}^9$

We can ask questions about the probe and locate information relative to this flat geometry.

Distance from probe to configuration

Compute masses of off-diagonal strings connecting probe to configuration.

Better with fermions.

Need to diagonalize ‘instantaneous’ effective Hamiltonian for od fermions.

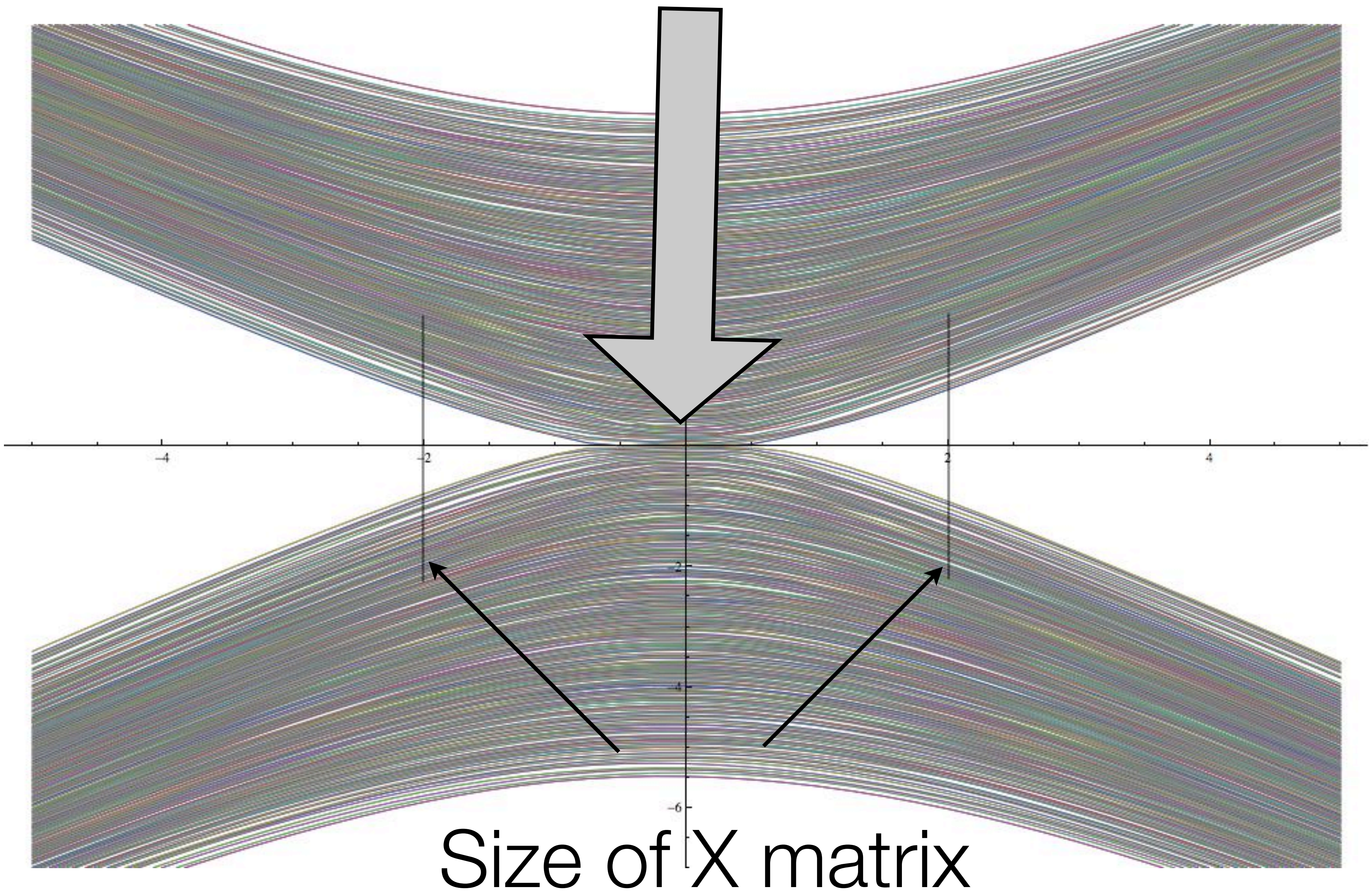
$$H_{eff} = \sum (X^i - x^i \otimes 1) \otimes \gamma^i$$

Define (spectral) distance as minimum eigenvalue (in absolute value)

w. E. Dzienkowski

Scan over a 1 parameter set at fixed time

Fermions are gapless in a region



Effective field theory breaks down in gapless region: can’t integrate out off-diagonal fermion modes.

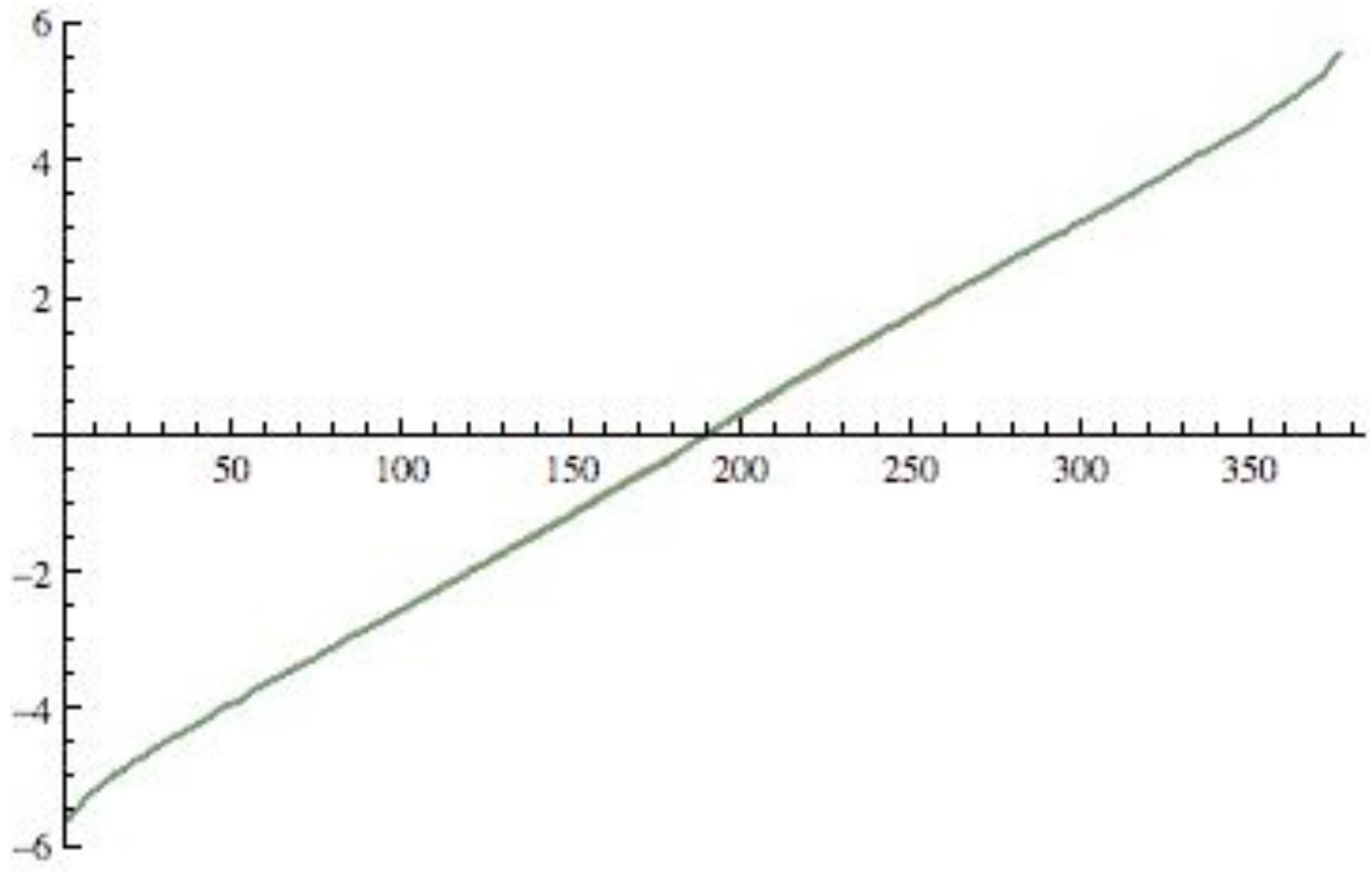
Fix position of probe inside gapless region

Define spectral dimension using density of states near zero

$$\frac{dn}{dE}|_{E\simeq 0} \simeq E^{\gamma-1}$$

$$\text{spectral dim} = \gamma$$

Same density of degrees of freedom as field theory in $\gamma+1$ dimensions



Spectral dimension = 1

Effective 1+1 field theory

A gas of D0 branes would have spectral dimension 9

A fuzzy sphere would have spectral dimension 2

Very non commuting configurations behave very different than ordinary D-branes: the IR is much richer.

Can not be both space filling and one-dimensional

$$1 \neq 9$$

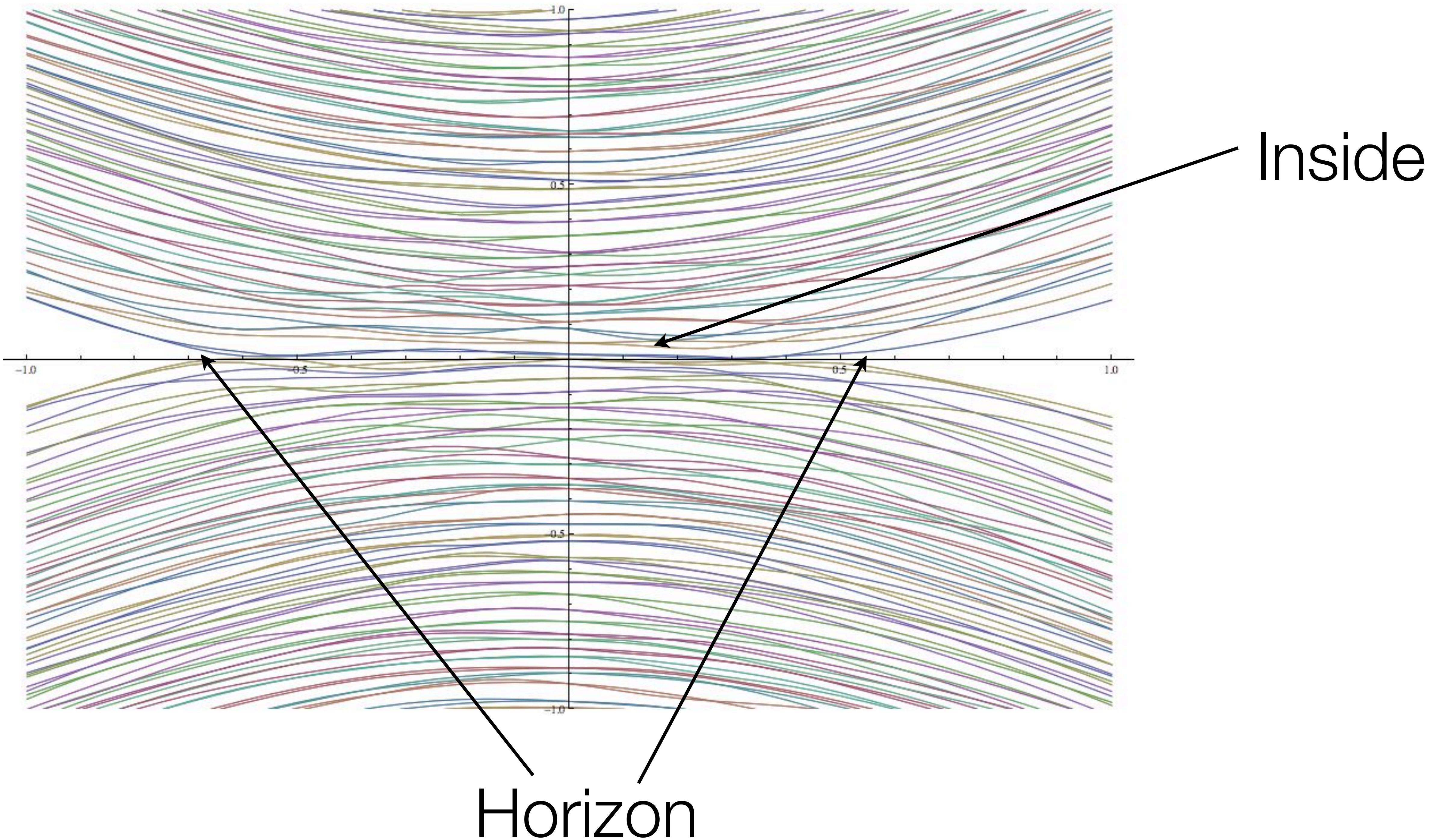
Physics can not be local in that region.

Interpretation (speculation)

Gapless region is ‘inside the black hole’

EFT breaks down as we get near black hole:
gap becomes smaller than naive distance (could be interpreted as redshift)

Coming from 2 directions



Inside region can not be characterized as ‘no drama’: an observer falling in there could not help notice that there is a very hot IR full of degrees of freedom. At fixed T, the number of such degrees of freedom grows with N.

$$\text{Number of IR states with } E < T \simeq N^{3/4}$$

Claim: this is evidence for the existence of firewalls.