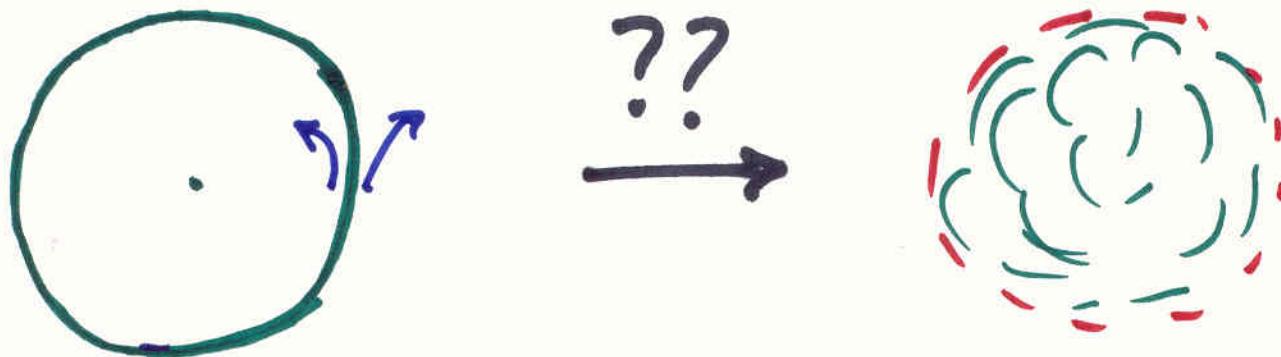


# WHAT IS INSIDE A BLACK HOLE?



Quantum Gravity effects  
 $\ell_p, \ell_s ??$        $N^{\ell_p} ??$

String theory : gives  $S_{\text{micro}} = \frac{A}{4G}$

Perhaps also "saves itself  
from inconsistency, by making  
"fuzz balls"

Work with:

Giusto, Park, Lunin, Saxena,  
Srivastava

Related developments:

Bena, Kraus, Warner ...

[supertubes + geometries]

Emparan et. al [Ring geometries]

Marolf - Palmer [Quantising  
Supertubes]

Gimon, Horava, Dyson, Drucker,  
Johnson [CTC's etc]

Balasubramanian [Counting states]

## 2 CHARGES: THE EXTREMAL D1-D5 SYSTEM<sup>3</sup>

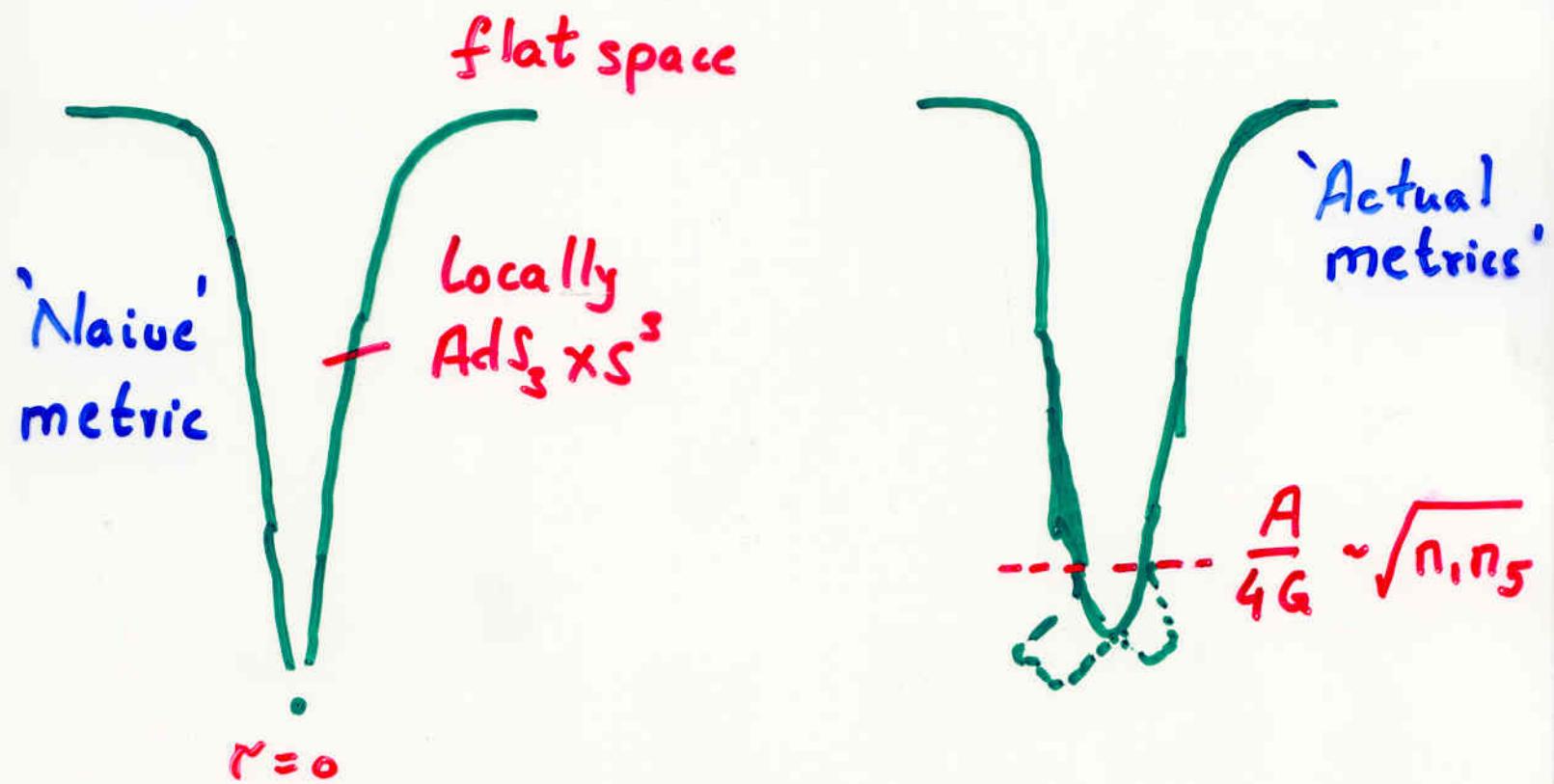
$$M_{q,1} \rightarrow M_{4,1} \times T^4 \times S^1$$

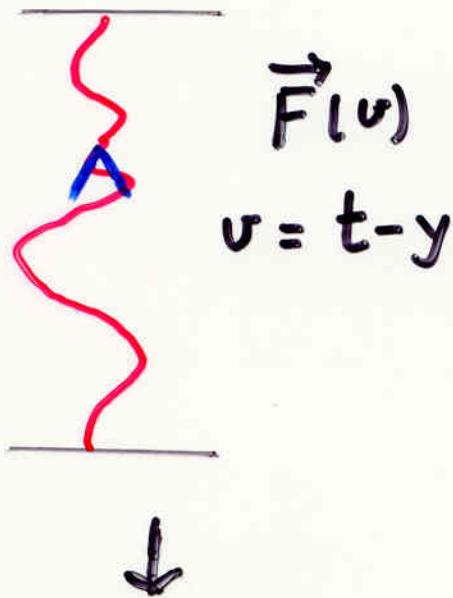
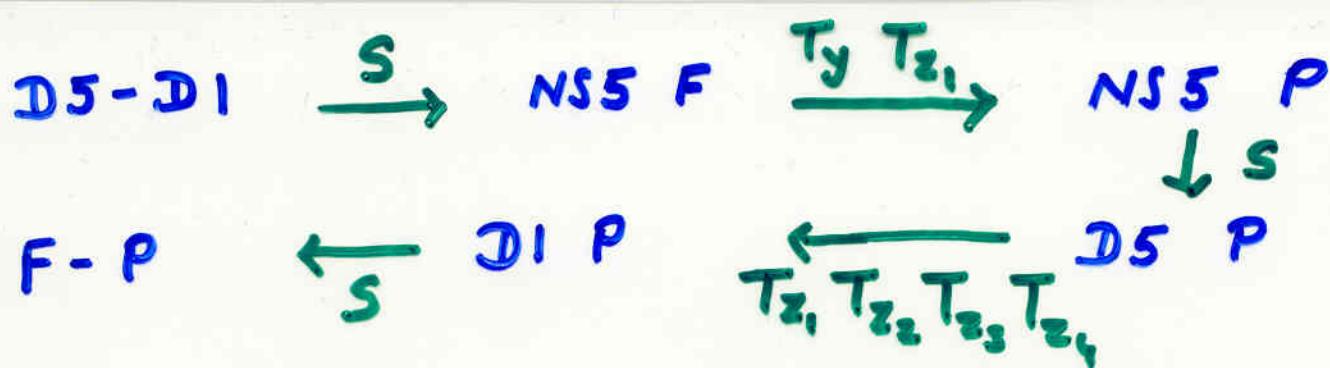
$t, r, \theta, \psi, \phi$        $z_1 \dots z_4 \quad y$   
 $\frac{D5}{\overbrace{\hspace{1cm}}}$        $\frac{D1}{\overbrace{\hspace{1cm}}}$

$$ds^2_{\text{naive}} = \frac{1}{\sqrt{(1 + \frac{Q_1}{r^2})(1 + \frac{Q_5}{r^2})}} [-dt^2 + dy^2]$$

$$+ \sqrt{(1 + \frac{Q_1}{r^2})(1 + \frac{Q_5}{r^2})} [dr^2 + r^2 d\Omega_3^2] + \sqrt{\frac{1 + \frac{Q_1}{r^2}}{1 + \frac{Q_5}{r^2}}} dz_a dz_a$$

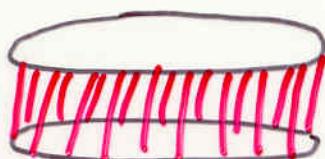
But there should be  $e^S = e^{2\pi\sqrt{2}\sqrt{n_1 n_5}}$  states!





F string has no longitudinal vibration mode

So F must bend away from central axis to carry P



$\rightarrow$  FP geometry by superposing strands

$\downarrow$  S,T dualities

D1-D5 geometries

[Classical limit: Continuous family labelled by  $\vec{F}'$ ]

$$ds^2 = \sqrt{\frac{H}{1+K}} [-(dt - A_i dx^i)^2 + (dy + B_i dy)^2] \\ + \sqrt{\frac{1+K}{H}} d\vec{x} d\vec{x} + \sqrt{H(1+K)} d\vec{z} d\vec{z}$$

$$e^{2\Phi} = H(1+K), \quad C_{ti} = \frac{B_i}{1+K}, \quad C_{ty} = -\frac{K}{1+K}$$

$$C_{iy} = -\frac{A_i}{1+K}, \quad C_{ij} = \tilde{C}_{ij} + \frac{A_i B_j - A_j B_i}{1+K}$$

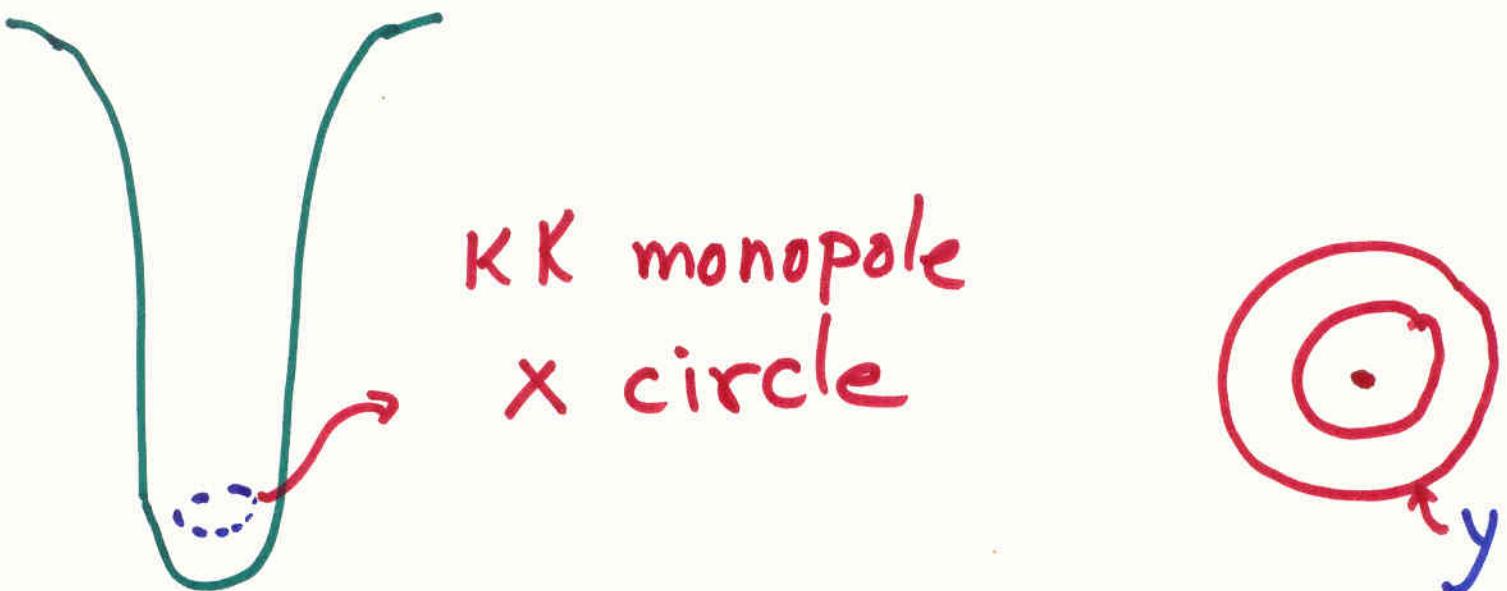
$$H^{-1} = 1 + \frac{Q}{L} \int_0^L \frac{dv}{|\vec{x} - \vec{F}(v)|^2}, \quad K = \frac{Q}{L} \int_0^L \frac{dv (\dot{F})^2}{|\vec{x} - \vec{F}(v)|^2}$$

$$A_i = -\frac{Q}{L} \int_0^L \frac{dv \dot{F}_i}{|\vec{x} - \vec{F}(v)|^2}$$

$$dB = -*dA, \quad d\tilde{C} = -*dH^{-1}$$

Lunin + SDM, hep-th 0109154

$\vec{x} = \vec{F}(v)$ : Coordinate  
 singularity, origin of KK  
 monopole. [Lunin, Maldacena, Mo03]



When  $y$  circle shrinks,  $\Rightarrow$   
 origin of plane polar coordinates

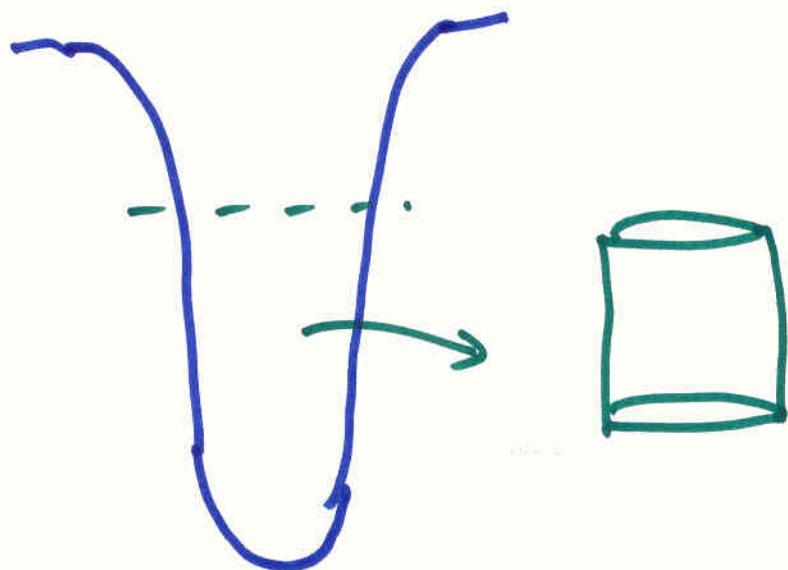
$$\overline{s^1 \leftarrow \circlearrowright s^3}$$

Matter picture:  
 $S^3$  shrinks

Gravity picture  
 $s'$  shrinks

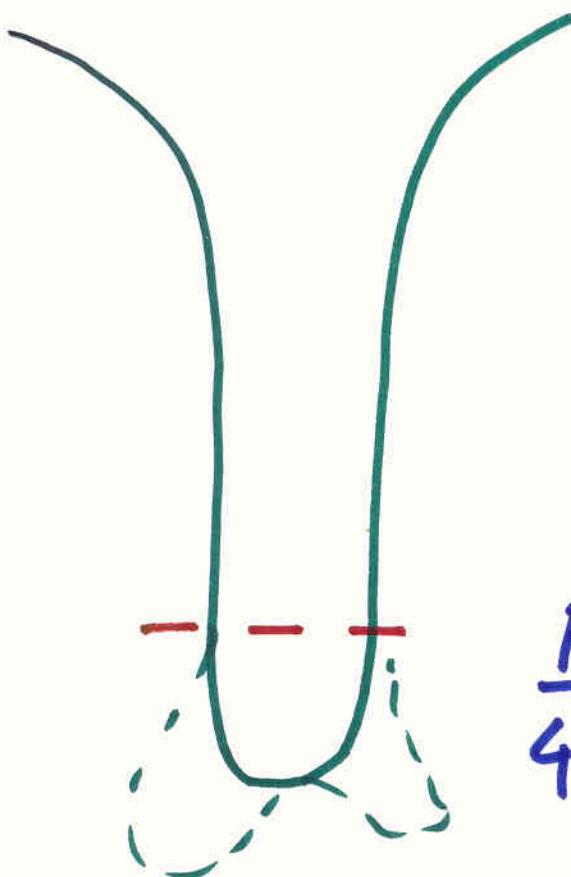
## A SIMPLE EXAMPLE:

FP: Uniform helix, 1 turn



- Balasubramanian, Keski-Vakkuri, de Boer, Ross
- Maldacena - Maoz

## SIZE



$$1 + \frac{Q_1}{r^2}, \quad 1 + \frac{Q_5}{r^2}$$

$$\Rightarrow r_f \sim \sqrt{Q} \sim \sqrt{n}$$

$$\frac{A}{4G} \sim \sqrt{n_1 n_5} \sim S$$

$$A \sim R_H^3 \Rightarrow R_H \sim \left[ \frac{g^2 \omega'^4}{\sqrt{4R}} \right]^{\frac{1}{3}} (n_1 n_5)^{\frac{1}{6}}$$

$$>> \ell_P, \ell_S$$

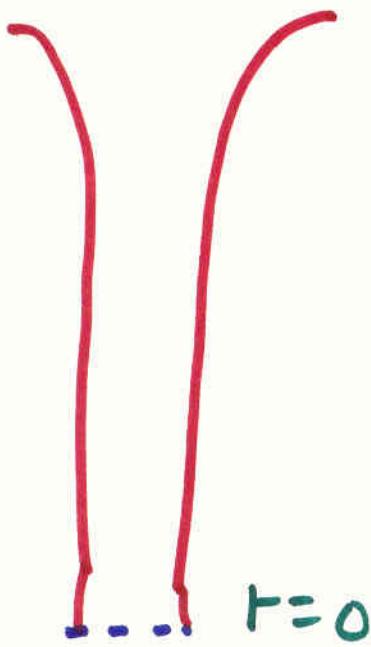
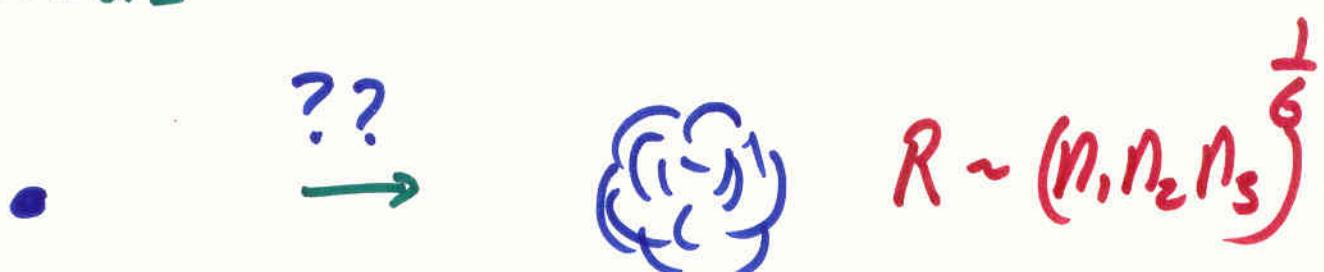
3 charge:  $r_f \sim \sqrt{n}, \quad R_H \sim \sqrt{n}$

So can save both in a classical limit

2 CHARGE



3 CHARGE



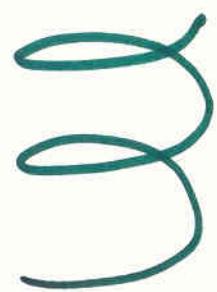
$$\begin{aligned} |-k\rangle^{total} &= (J_{-(2k-2)}^{+,total})^{n_1 n_5} (J_{-(2k-4)}^{+,total})^{n_1 n_5} \dots (J_{-2}^{+,total})^{n_1 n_5} (J_0^{+,total})^{n_1 n_5} |1\rangle^{total}, \quad k \geq 0 \\ |k\rangle^{total} &= (J_{-(2k-2)}^{-,total})^{n_1 n_5} (J_{-(2k-4)}^{-,total})^{n_1 n_5} \dots (J_{-2}^{-,total})^{n_1 n_5} |1\rangle^{total}, \quad k > 1 \end{aligned}$$

$$\begin{aligned} ds^2 &= -\frac{1}{h}(dt^2 - dy^2) + \frac{Q_p}{hf} (dt - dy)^2 + hf \left( \frac{dr_N^2}{r_N^2 + a^2\eta} + d\theta^2 \right) \\ &+ h \left( r_N^2 + (n+1)a^2\eta - \frac{(2n+1)a^2\eta Q_1 Q_5 \cos^2\theta}{h^2 f^2} \right) \cos^2\theta d\psi^2 \\ &+ h \left( r_N^2 - na^2\eta + \frac{(2n+1)a^2\eta Q_1 Q_5 \sin^2\theta}{h^2 f^2} \right) \sin^2\theta d\phi^2 \\ &+ \frac{a^2\eta^2 Q_p}{hf} (\cos^2\theta d\psi + \sin^2\theta d\phi)^2 \\ &+ \frac{2a\sqrt{Q_1 Q_5}}{hf} [-(n+1)\cos^2\theta d\psi + n\sin^2\theta d\phi] (dt - dy) \\ &- \frac{2a\eta\sqrt{Q_1 Q_5}}{hf} [\cos^2\theta d\psi + \sin^2\theta d\phi] dy \sqrt{\frac{H_1}{H_5}} \sum_{i=1}^4 dz_i^2 \\ C_2 &= \frac{a\sqrt{Q_1 Q_5} \cos^2\theta}{H_1 f} (ndt - (n+1)dy) \wedge d\psi \\ &+ \frac{a\sqrt{Q_1 Q_5} \sin^2\theta}{H_1 f} (-(n+1)dt + ndy) \wedge d\phi \\ &+ \frac{a\eta Q_p}{\sqrt{Q_1 Q_5} H_1 f} (Q_1 dt + Q_5 dy) \wedge (\cos^2\theta d\psi + \sin^2\theta d\phi) \\ &- \frac{Q_1}{H_1 f} dt \wedge dy - \frac{Q_5 \cos^2\theta}{H_1 f} (r_N^2 - na^2\eta Q_1) d\psi \wedge d\phi \tag{0.1} \\ e^{2\Phi} &= \frac{H_1}{H_5} \end{aligned}$$

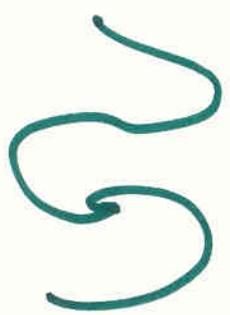
$$\begin{aligned} f &= r_N^2 + a^2\eta(n+1)\sin^2\theta - a^2\eta n \cos^2\theta \\ h &= \sqrt{H_1 H_5}, \quad H_1 = 1 + \frac{Q_1}{f}, \quad H_5 = 1 + \frac{Q_5}{f} \end{aligned}$$

[Giusto, SDM, Saxena '04]

## 2 CHARGE



HIGH  $J$   
AXIAL SYMM.

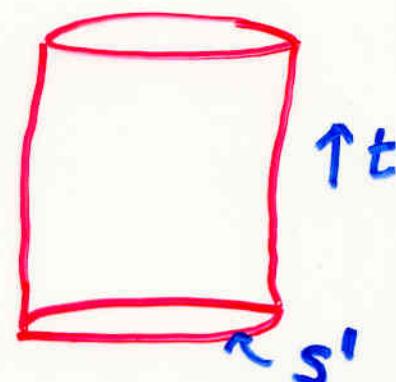


$J = 0$   
NO SYMMETRY

3 CHARGE: WE HAVE ALL  
AXISYMMETRIC SOLUTIONS,  
MAKING OTHERS COULD BE  
JUST A TECHNICAL PROBLEM

# THE D1-D5 CFT

$$M_{9,1} \rightarrow M_{4,1} \times \underbrace{T^4 \times S^1}_{D5 \cup D1}$$

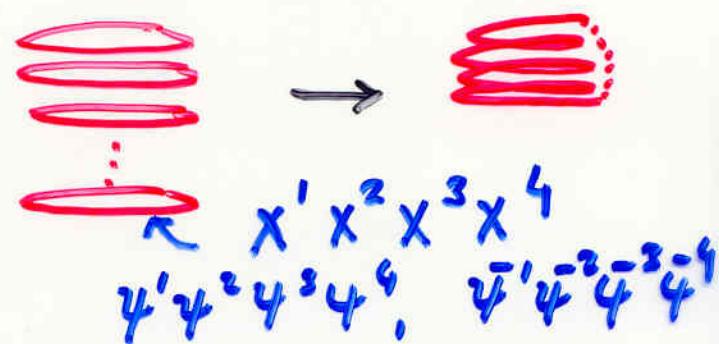


1+1 dim CFT:  $\sigma$  model  
with target space  $(T_4)^N / S_N$

$$N = n_1 n_5$$

Twist operators  $\sigma_K$ :

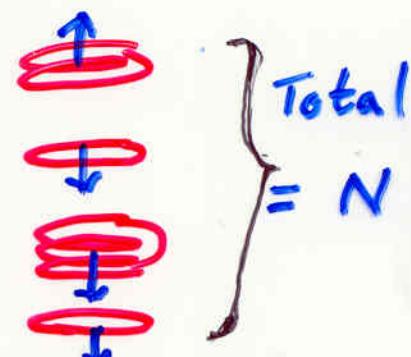
Link together  $K$   
copies of free  $c=6$   
CFT



Ramond ground states:

$$\sigma_{K_1}^{\pm}, \dots, \sigma_{K_n}^{\pm} |0\rangle \Big|_{NS \rightarrow R}$$

$$\sum K_i = N$$



$$\rightarrow e^{2\pi i \sqrt{2} \sqrt{n_1 n_5}} \text{ states}$$

# THE CFT STATE $\leftrightarrow$ GEOMETRY MAP

A diagram showing a red wire forming a loop. The wire starts from the bottom right, goes up and to the left, then turns back down and to the right, forming a U-shape. A small blue dot is placed on the wire at its highest point, located on the left side of the loop.

$$\vec{F}(v) \leftrightarrow (a_{k_1}^{i_1})^+ \cdots (a_{k_n}^{i_n})^+ |0\rangle$$

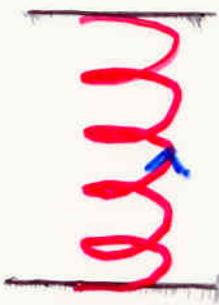
↓    ↓

$$y \leftrightarrow (a_{k_1}^{\pm\pm})^- \cdots (a_{k_n}^{\pm\pm})^- |0\rangle$$

[ Classical Geometries : many quanta in the same harmonic ]

### Example:

FP



$\kappa$  turns of uniform helix



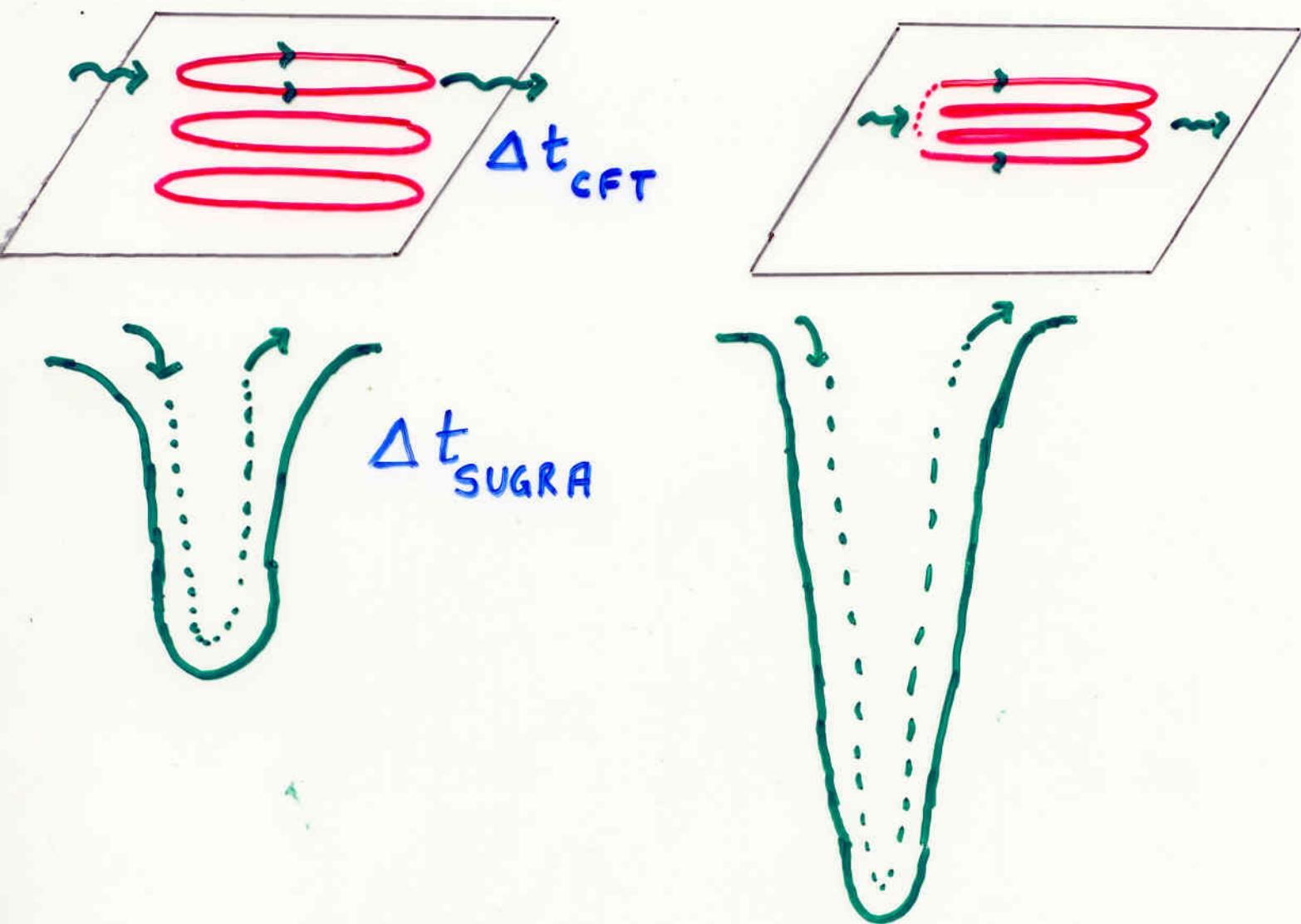
K circles  
linked by  $\sigma_K$

All spin's aligned

CFT state

# A DYNAMICAL EXPERIMENT

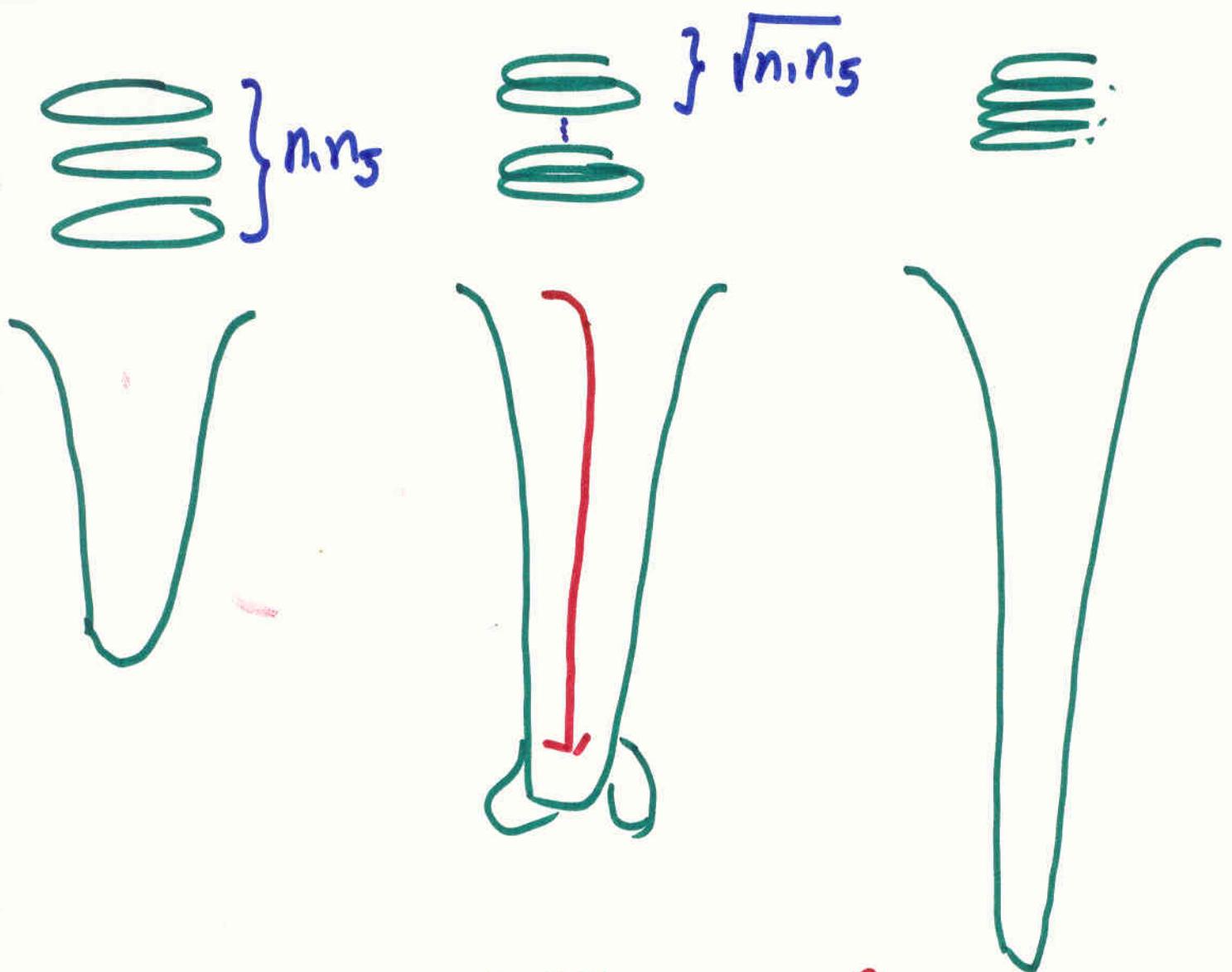
9.



$$\Delta t_{CFT} = \Delta t_{SUGRA} \text{ FOR EACH STATE}$$

$$\text{Backreaction} \sim (n, n_5)^{-\frac{1}{2}} \text{ for generic state}$$

 'Hair' makes sense since geometries can be distinguished by experiments



$\Delta T_{SUGRA} \sim \Delta T_{CFT}$  for  
generic state

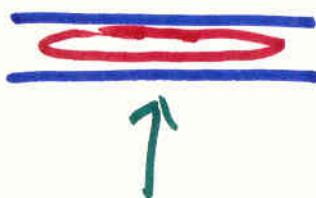
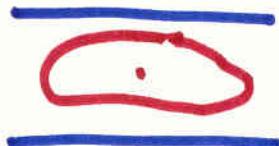
$$= \pi R \sqrt{n_1 n_5}$$

# 3 CHARGE: AN ARGUMENT

$$M_{4,1} \times T^4 \times S^1$$



$$M_{3,1} \times S^1_{\text{New}}$$

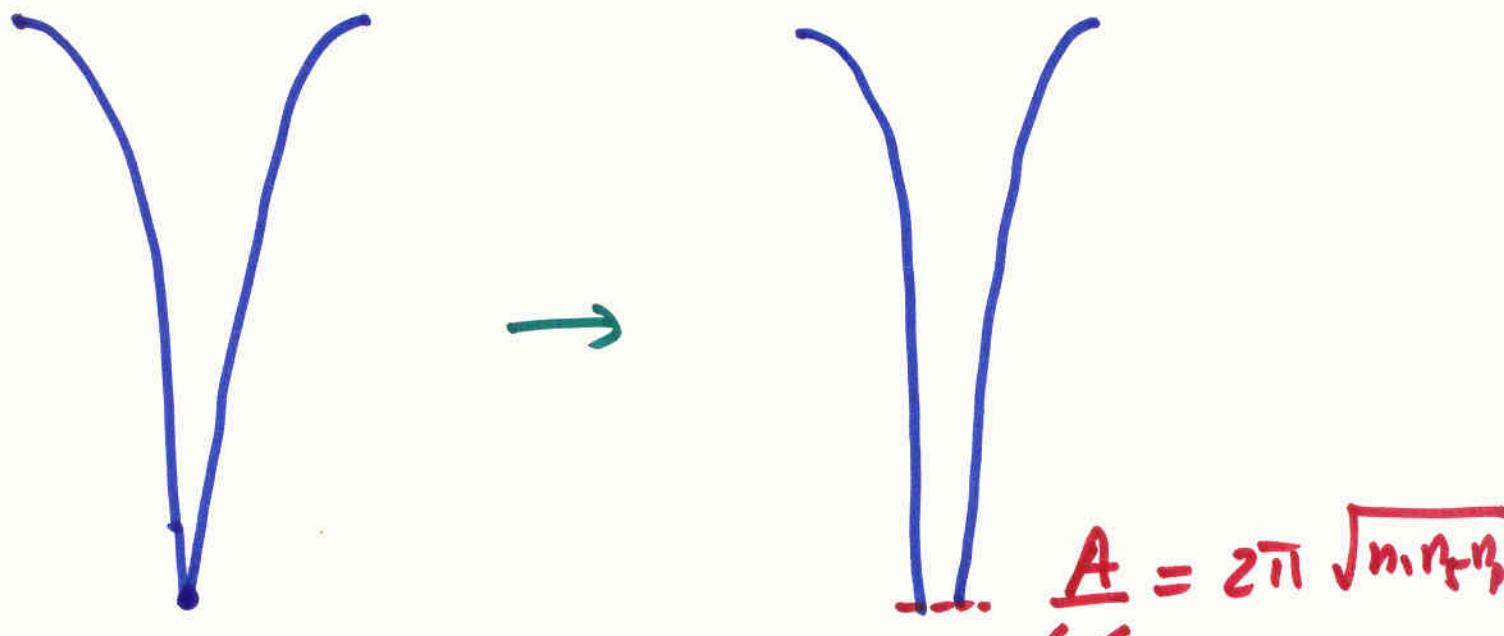


D1-D5-P

$$\frac{A}{4G} = 2\pi \sqrt{n_1 n_5 n_p}$$

3 CHARGE  
EXTREMAL  
IN 4-D

Expect:  $\frac{A}{4G} =$   
 $2\pi \sqrt{n_1 n_5 n_p}$



$$\frac{A}{4G} = 2\pi \sqrt{m_1 m_2}$$

Naive :  
3 charge in 4-D

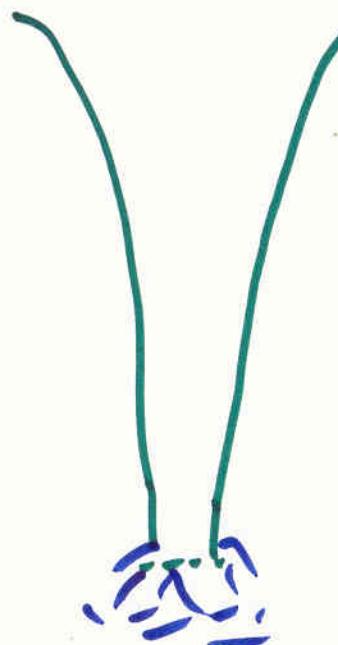
This suggests that we should have some location  $r = r_0$  (not  $r=0$ ) where a "horizon" should be placed.

[ Like 2 charges in 5-D ]

4-D:

D1-D5-P-KK

dualities  
permute



D1-D5-P

→ D1-D5-KK



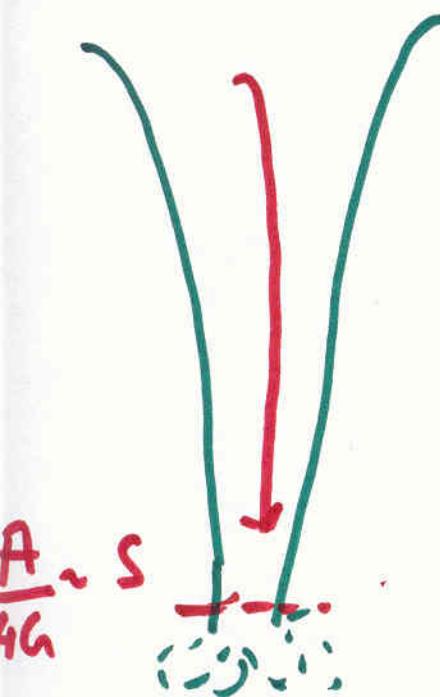
CFT with effective  
string, winding

$$N = n_1 n_2 n_3$$

Generic state.

$$\sim \sqrt{n_1 n_2 n_3}$$

# Dynamical Experiment



W W W W  
↓

$$\text{Length} \sim 2\pi R \sqrt{n_1 n_2 n_3}$$

$$\Delta t_{SUGRA}$$

$$\Delta t_{CFT} \sim R \sqrt{n_1 n_2 n_3}$$

$$\Delta t_{SUGRA} \sim \Delta t_{CFT} \quad !!$$

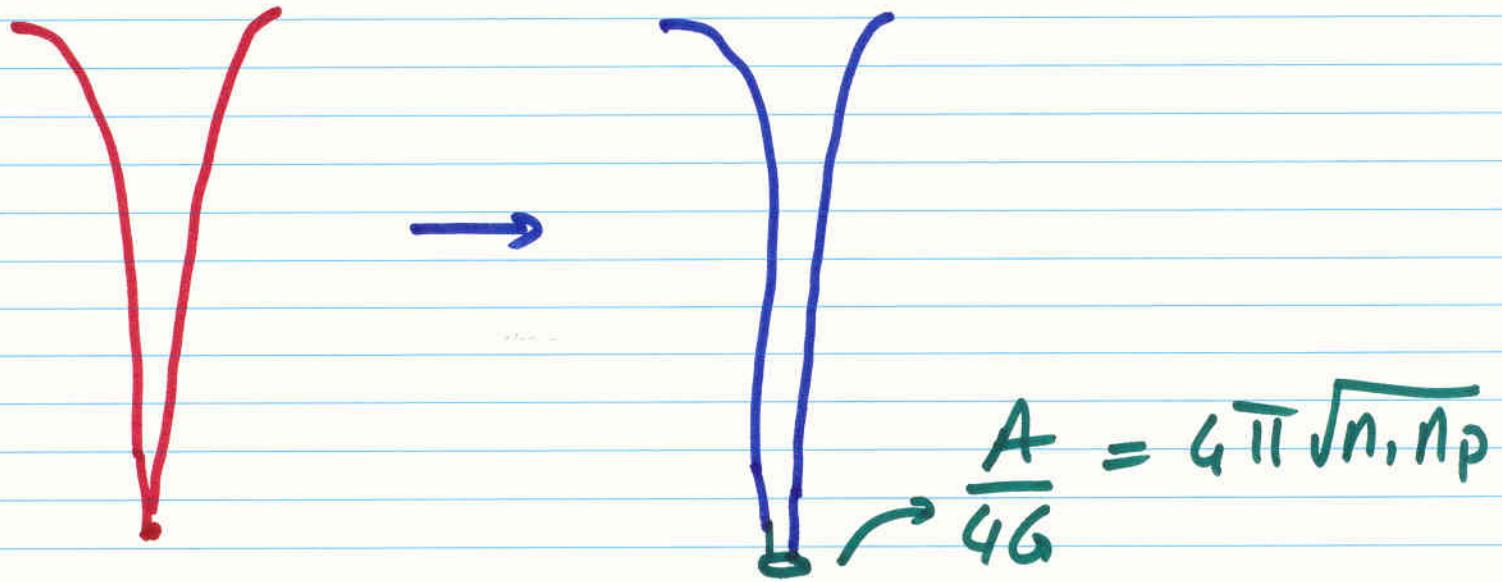
Dabholkar: 2-charge

extremal  $\rightarrow$  quantum corrections

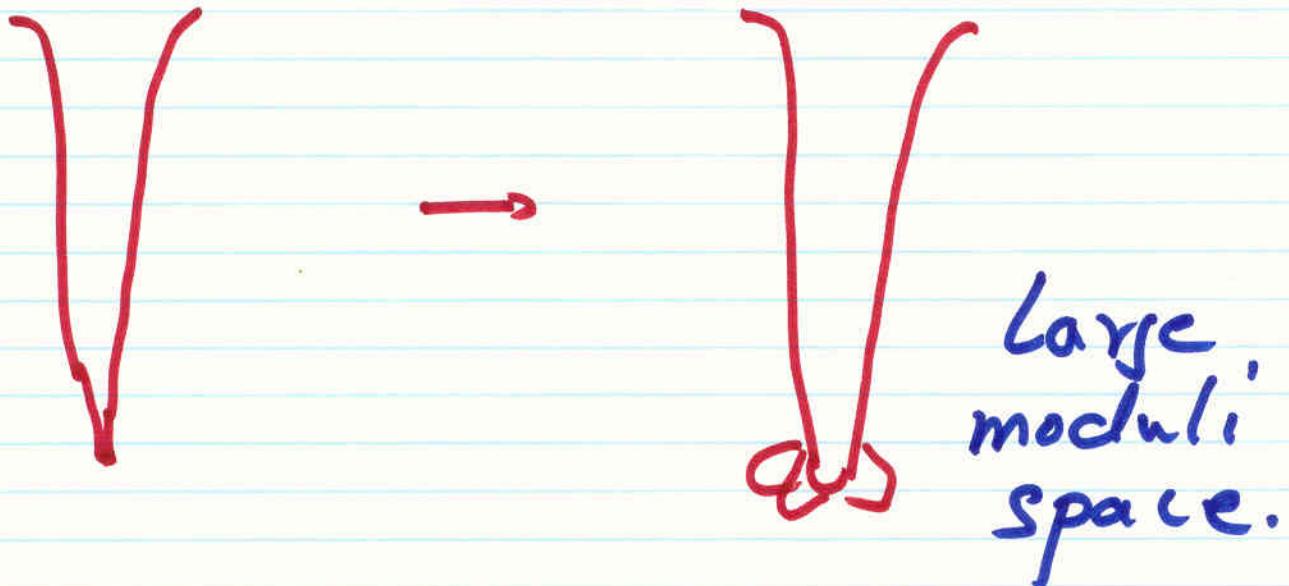
$\rightarrow$  Entropy from usual kind  
of gravity calculation

[Special geometry, Strominger etc]

Suggests

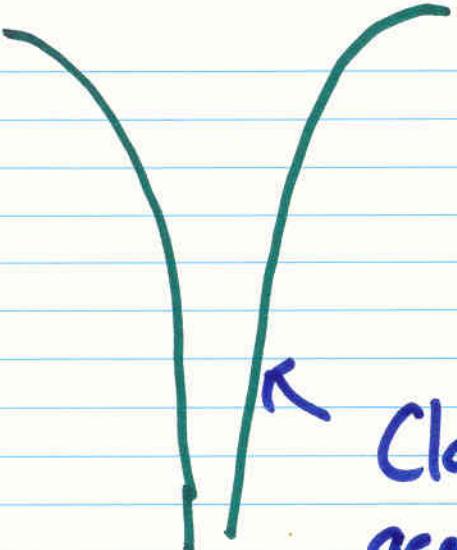


But we thought

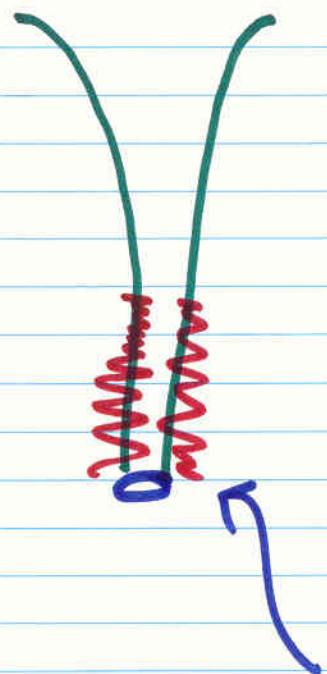


How can there be two solutions  
to the same problem?

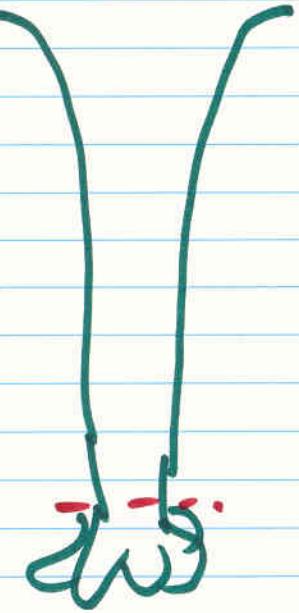
Moduli space  $\rightarrow$  Massless modes  
 $\rightarrow$  Cannot make a good  
"effective action" by integrating  
out quantum fluctuations.



Classical  
geom. from  
"corrected"  
action



Perhaps  
fluctuations  
are growing



Actual  
states

## Summary:

- Hawking argument (info loss)

→ Theorem:

- 1.) Unique vacuum
- 2.) All quantum gravity effects  $\lesssim \ell_P, \ell_s$

$\Rightarrow$  information loss

Perhaps 2.) breaks down

- 2 charge extremal, some 3 charge extremal, supporting arguments