Ultrahigh-energy scattering and locality in string theory

Steven B. Giddings

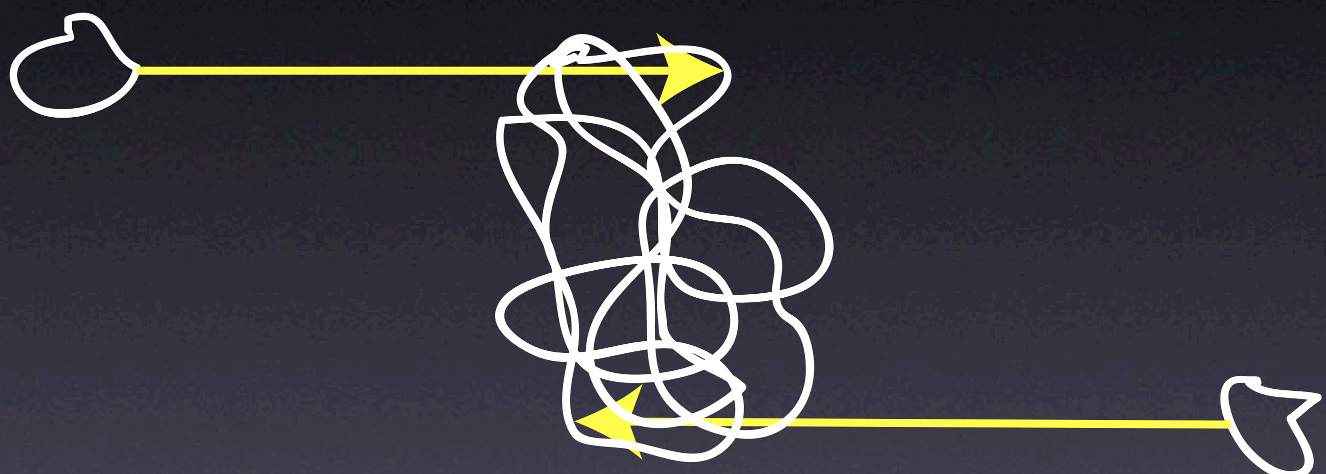
Based on:

hep-th/0604072;

arXiv:0705.1816, w. Gross and Maharana

Is there evidence for nonlocality in high-energy scattering?

Does string extendedness provide the mechanism for nonlocality?



What does this have to do w/BH formation?

(Does it prevent? Or is this BH formation?)

(Q's: Strominger, Gross, ...;

string spreading - Susskind)

Long strings? $L \sim E/M_s^2$

String uncertainty principle? $\Delta X \geq \frac{1}{\Delta p} + \alpha' \Delta p$

(Veneziano, Gross)

($\longleftrightarrow$ nonlocality)

(Proposed app. to BH info: LPSTU)

Indeed, stringy modifications to scattering:

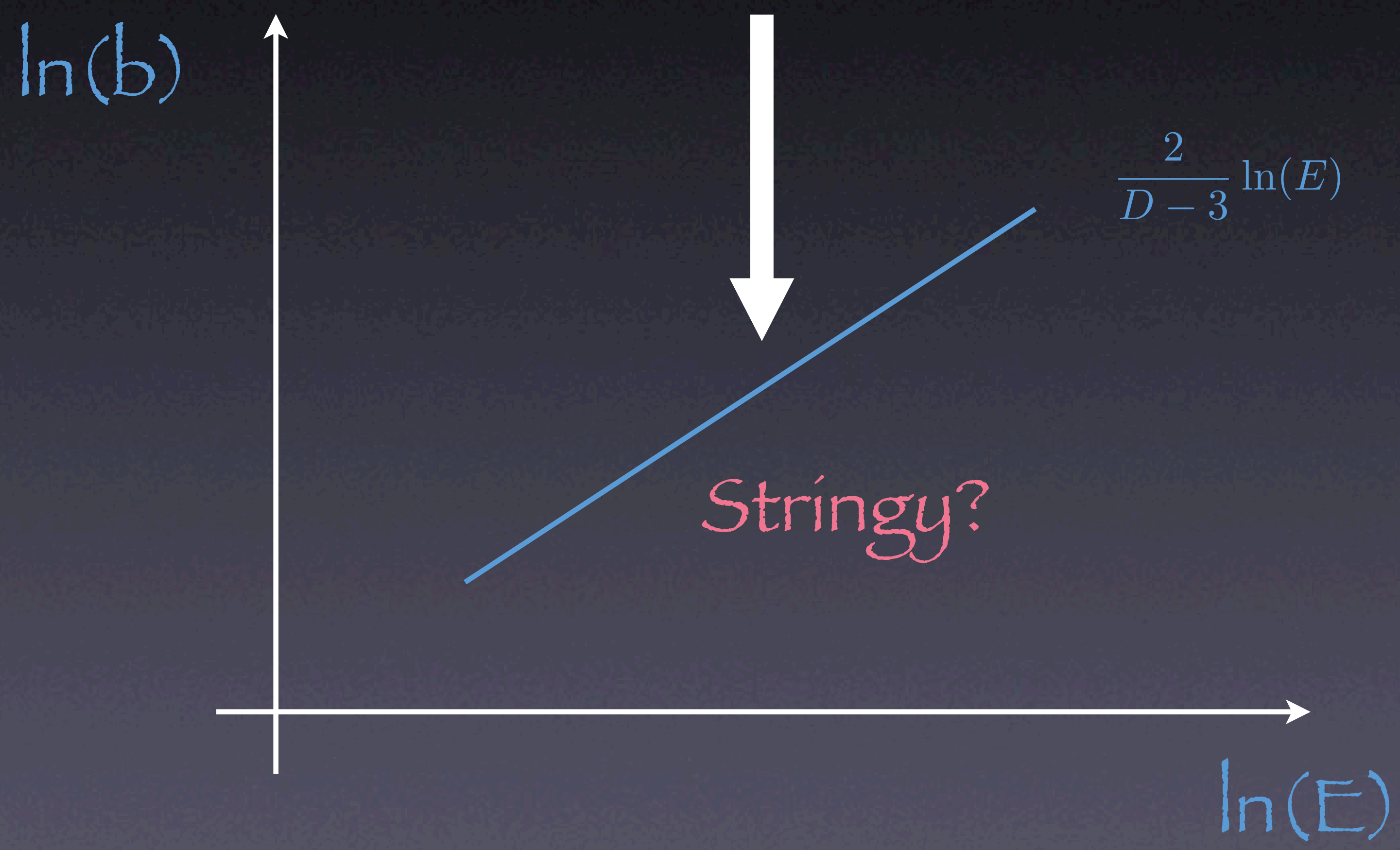
$$\mathcal{A}_0^{\rm string}(s,t) \propto g_s^2 \frac{\Gamma(-t/8)}{\Gamma(1+t/8)} s^{2+t/4} e^{2-t/4}$$

vs.

$$\mathcal{A}_0^{\rm grav}(s,t) \propto G_D \frac{s^2}{t}$$

To investigate: (s,t) $\longrightarrow$ (E,b) $E \ggg M_P$

e.g. $t \sim -1 \Leftrightarrow b \sim E^{2/D-3}$ (D noncmpct dims)

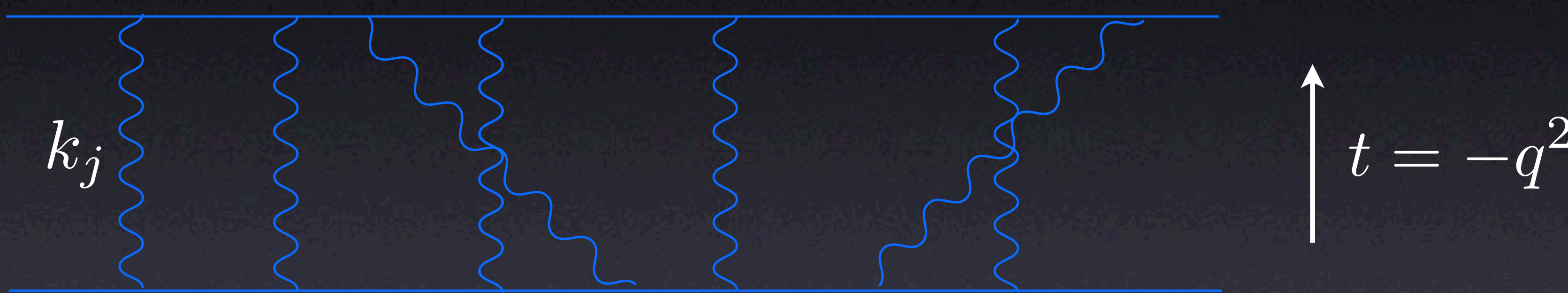


Fix E -- lower b

To check, compare loops:

(Following Amati, Ciafaloni, Veneziano; Muzinich-Soldate; SBG, Gross, Maharana)

Ultrahigh-E: Eikonal



$$iA_N^{\rm string} = \frac{2s}{(N+1)!}\int \left[\prod_{j=1}^{N+1} \frac{d^{D-2}k_j}{(2\pi)^{D-2}} \frac{iA_0^{\rm string}(s, -k_j^2)}{2s}\right] (2\pi)^{D-2}\delta^{D-2}\left(\sum_j k_j - q_\perp\right)$$

$$\prod_{j=1}^{N+1} \frac{E^{2-\alpha' k_j^2}}{k_j^2}$$

1) $k_j \approx q/(N+1)$

2) $E^{-\alpha' q^2/(N+1)}$

Thus at large N, string corrections get smaller

Which N dominates?

Can sum eikonal series:

$$iA_{\rm eik}(s,t) = 2s\int d^{D-2}\mathbf{b}\, e^{-iq_\perp\cdot\mathbf{b}}(e^{i\chi(b)}-1)$$

with $\chi(b) \sim G_D \frac{E^2}{b^{D-4}}$

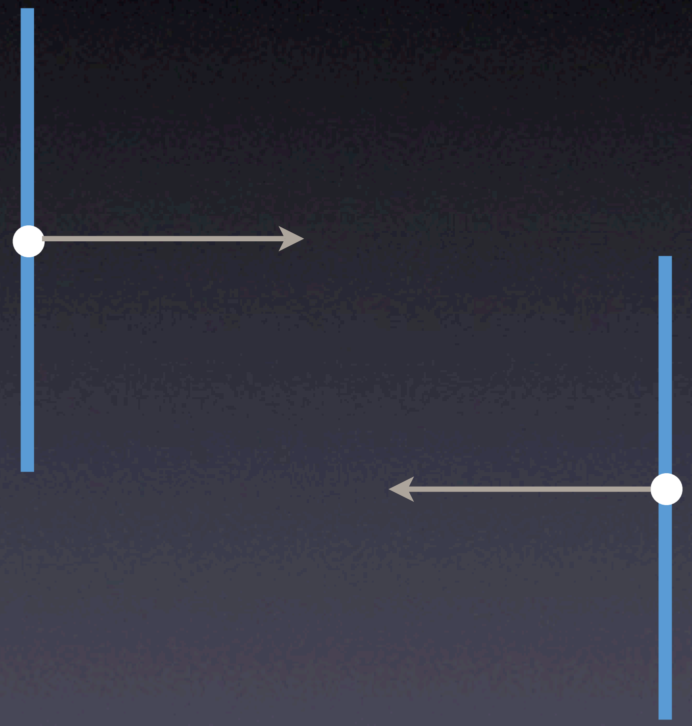
$\Leftrightarrow$ Dominant N: $N \sim \frac{G_D E^2}{b^{D-4}}$;

At $t \sim -1$: $N \sim (G_D E^2)^{\frac{1}{D-3}}$

$\therefore$ Large loop order dominates.

Eikonal ⟷ classical scattering

Two Aichelburg-Sexl shocks (ACV: checks)



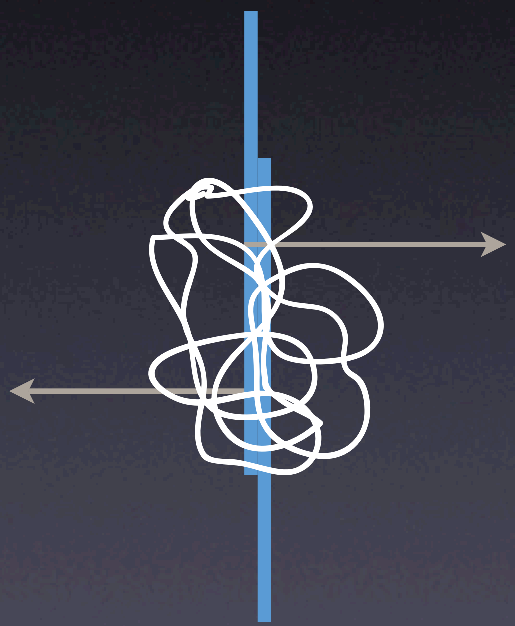
Black hole formation?

But - can excite strings: “diffractive excitation” (ACV)

Indeed, unexcited (elastic) amplitude, near Schwarzschild radius:

$$\mathcal{A}_{el} \sim \exp\left\{-E^{(D-4)/(D-3)}\right\} \qquad !!$$

So:



??

No black hole??

Info carried away?

(Veneziano, 2004)

Intuition: string only "spread out" "after" collision??

But: string spreading is a notoriously fuzzy concept...

Where is the string?

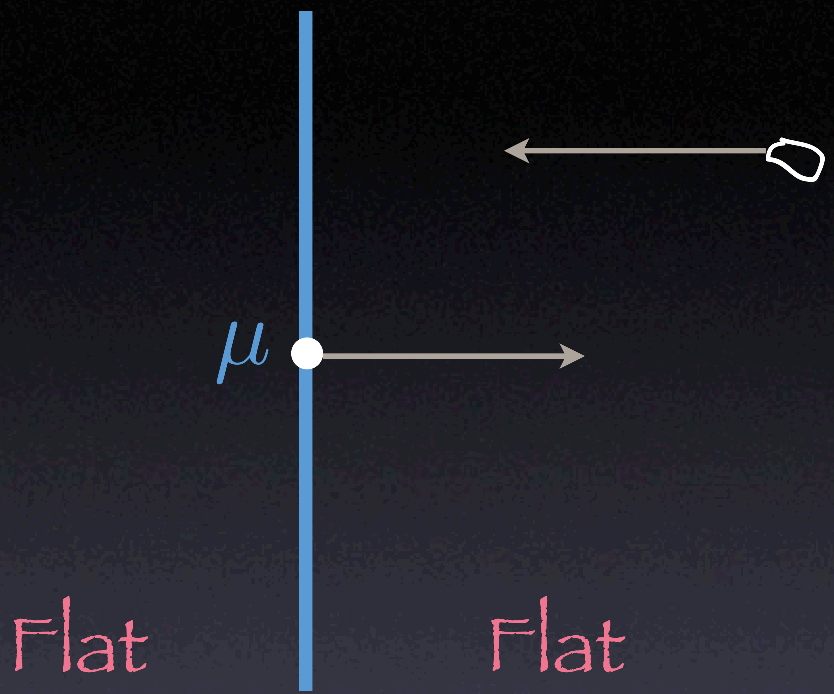
Karliner, Klebanov, Susskind: it depends

“low resolution”

“high resolution”

So: need to check for process in question ...

A test:



$$ds^2 = -du dv + dx^i dx^i + \Phi(\rho)\delta(u) du^2$$

$$\Phi(\rho) = -8G\mu \ln \rho \quad , \quad D = 4$$

$$\Phi(\rho) = \frac{16\pi G\mu}{\Omega_{D-3}(D-4)\rho^{D-4}} \quad , \quad D > 4$$

Scattering in a plane-wave metric:

de Vega and Sanchez; Horowitz and Steif

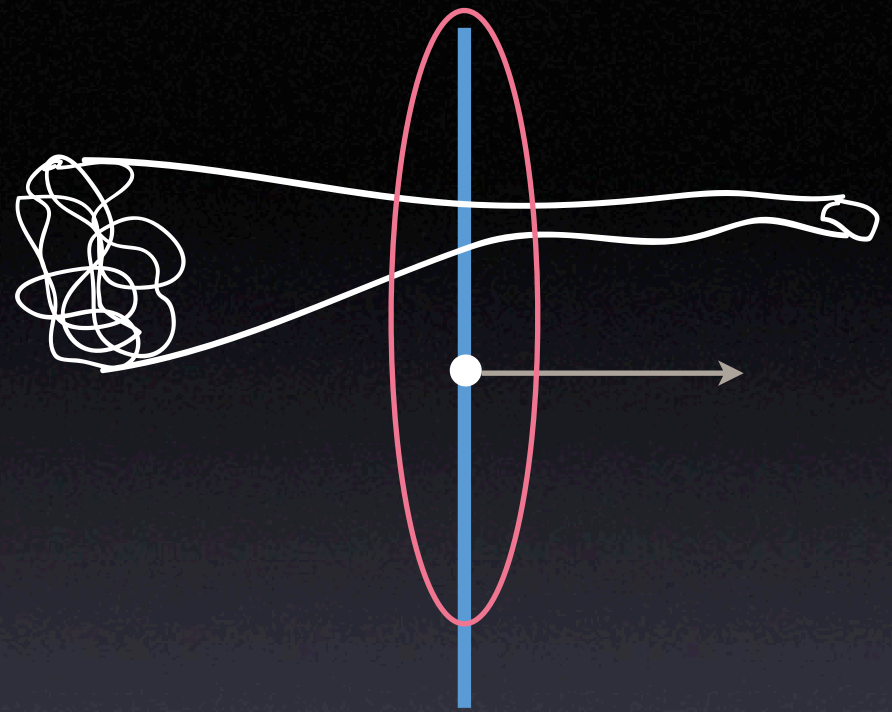
Light cone quantization

Compute for incoming unexcited string:

$$\langle \hat{X}^i_\epsilon(\tau,\sigma)\hat{X}^i_\epsilon(\tau,\sigma)\rangle$$

Where $\hat{X}^i_\epsilon(\tau,\sigma)$ is deviation from CM of string, w/world sheet regulator ϵ

Find:



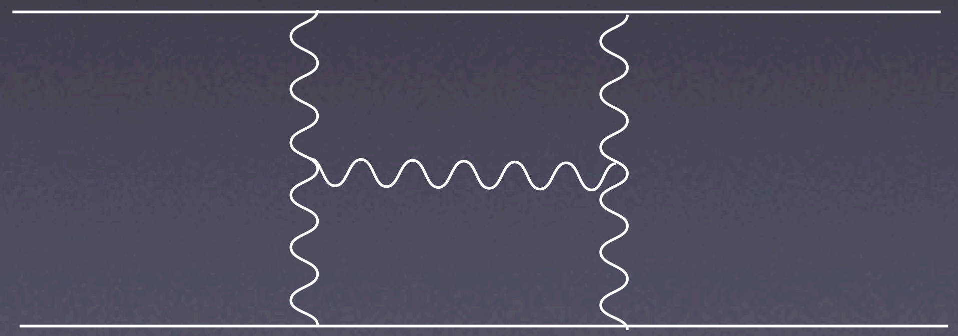
Indeed, origin of effect is “tidal string excitation”

$$(\Delta X)^2 \sim |\ln \epsilon| + \left[\frac{G_D E^2}{b^{D-2}}\tau\right]^2 |\ln \tau| \qquad \epsilon \ll \tau$$

For small tau: inside trapped surface

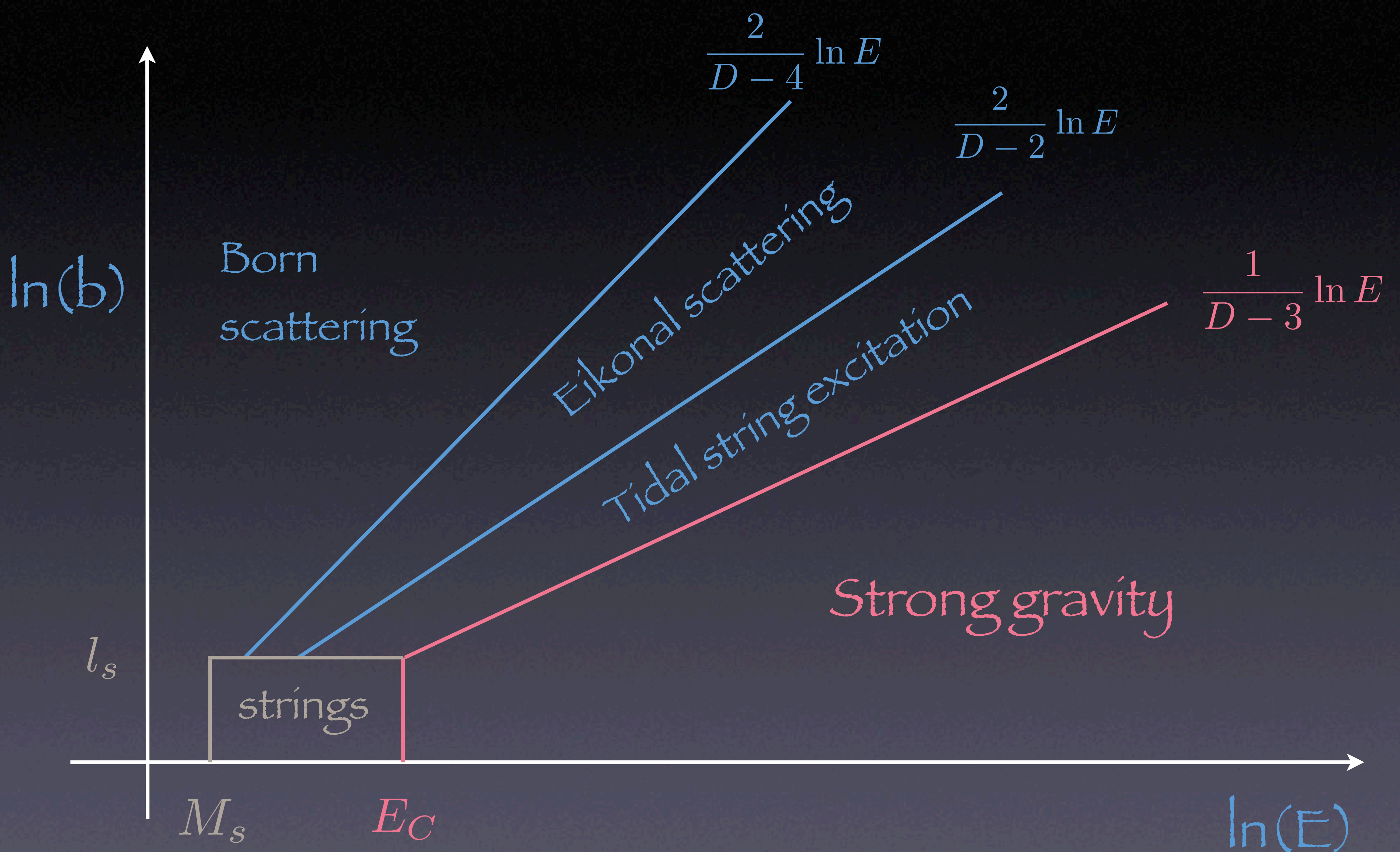
Thus:

- String appears to behave ~locally during collision
- Trapped surface appears to form
- This corresponds to breakdown of the gravitational loop expansion



$$\mathcal{O}(R_S/b)$$

Suggested "phase diagram:"



Locality?

Strong gravity/
black hole regime:

$$\sigma_T(E) \sim [R_S(E)]^{D-2} \sim E^{\frac{D-2}{D-3}}$$

$$\mathcal{A}_{el}(s,t) \sim e^{-S_{BH}}$$

$$\sim e^{-ER_S(E)} \sim e^{-E^{(D-2)/(D-3)}}$$

Local QFT
bounds

$$\sigma_T \leq c(\ln E)^{D-2}$$

Froissart

$$|\mathcal{A}_{el}(s,t)| \geq e^{-f(\theta)E\ln E}$$

Cerulus-Martin

No clear role for strings

... just strong gravity