Low-x physics in AdS/CFT

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Motivations

- It's interesting !...though it may have little (if any) relevance to real experiments…

- Longstanding problems in the Regge regime of QCD (Froissart's theorem, soft vs. hard Pomerons, etc.)
  Theorists desperate for new ideas and insights from ``QCD—like" theories.

- Possible application to the ``sQGP" (Finite—T)

N=4 Super Yang-Mills

$$L = -\frac{1}{4}F^a_{\mu\nu}F^{\mu\nu}_a + i\bar{\psi}^i_a\bar{\sigma}^\mu D_\mu\psi^i_a + \frac{1}{2}\sum_{1\leq i<j\leq 4}(D_\mu\phi^a_{ij})^\dagger D^\mu\phi^a_{ij}$$

- SU(Nc) local gauge symmetry
- Maximally supersymmetric gauge theory in D=4.
- Conformal symmetry SO(4,2) $\beta = 0$

  The t\`Hooft coupling $\lambda = g^2_{YM} N_C$ doesn't run.
- Global SU(4) R-symmetry

Type IIB superstring

- Consistent superstring theory in D=10
- 256 massless states (supergravity modes)
- Admits the black brane solution which is asymptotically $AdS_5 \times S^5$

$$ds^2 = g_{\mu\nu} dX^\mu dX^\nu = \underbrace{\frac{r^2}{R^2}(-dt^2 + dx_1^2 + dx_2^2 + dx_3^2)}_{\text{Our universe}} + \frac{R^2}{\underbrace{r^2}_{\text{AdS `radius' coordinate}}} dr^2 + \overbrace{R^2 d\Omega_5^2}^{S^5}$$

The correspondence

Maldacena, `97

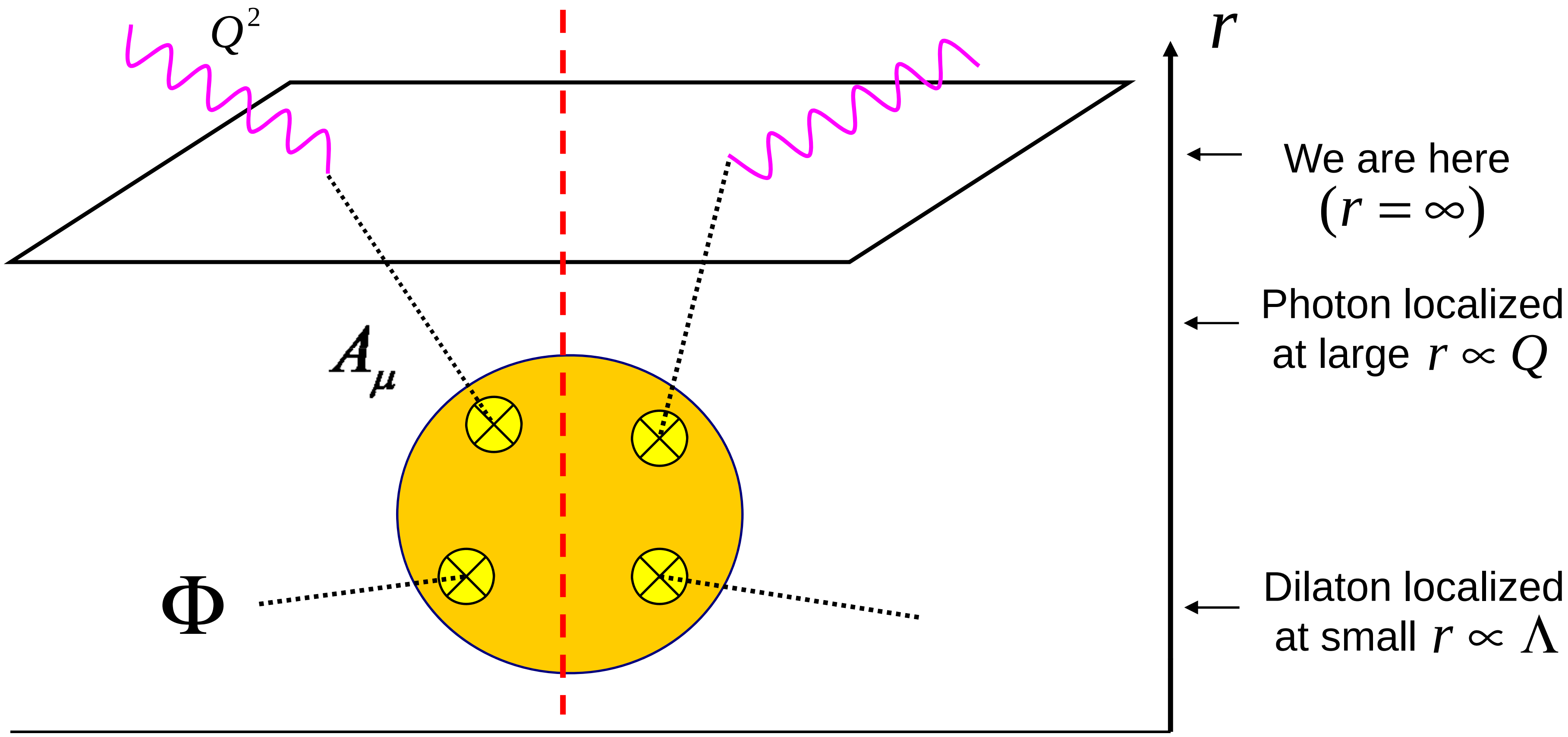
- Take the limits $N_C \to \infty$ and $\lambda = g_{YM}^2 N_C \to \infty$
- N=4 SYM at strong coupling is dual to weak coupling type IIB on AdS
- Spectrums of the two theories match

CFT		string
(anomalous) dimension	⟷	mass
t`Hooft parameter λ	⟷	curvature radius R^4/α'^2
number of colors $1/N_C$	⟷	string coupling constant g_s

Application to DIS

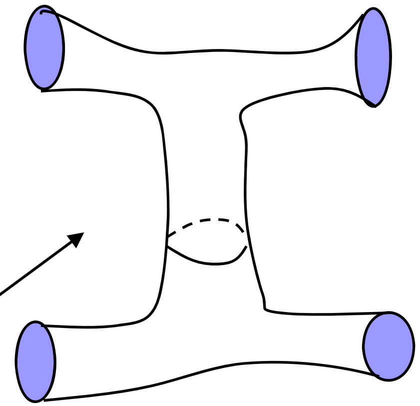
Polchinski, Strassler, `02

R-charge current excites metric fluctuations in the bulk, which then scatters off a dilaton (`glueball') via the super Virasoro-Shapiro amplitude.



Cut off the space at $r = r_0$ (mimic confinement)

The string S-matrix



Flat space Virasoro-Shapiro

$$A(s,t) \propto g_s^2 \frac{1}{t} s^{2+t}$$

t-channel graviton pole

AdS case

$$t \rightarrow t + \nabla_r^2$$

Laplacian in the 5th direction causes the shift of the intercept as well as diffusion. Gravitons become massive

$$j = 2 \rightarrow 2 - 2/\sqrt{\lambda}$$

c.f. BFKL

$$j = 1 + 4 \ln 2 \cdot \overline{\alpha}_s$$

Kotikov, Lipatov, Onishchenko, Velizhanin `04
Brower, Polchinski, Strassler, Tan `06

Beyond the single Pomeron approximation

- Graviton dominance — high energy behavior even worse than in QCD.

- No problem as long as

$$g_s^2 \propto \frac{1}{N_C^2} \to 0$$

- Keep Nc finite and study the onset of unitarity corrections.

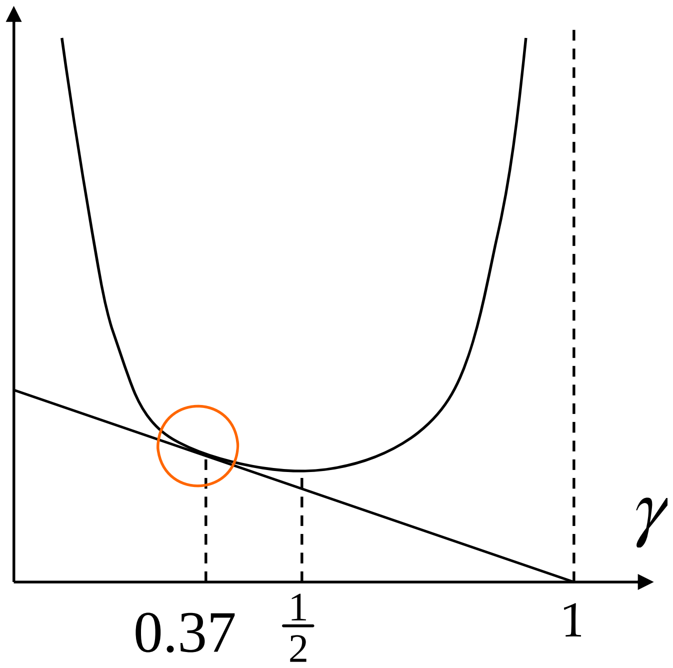
Multiple Pomeron exchange $\longleftrightarrow$ String loop diagrams

Saturation saddle point at weak coupling

Amplitudes factorize in the kt-space

$$\int d\gamma \exp\{\chi(\gamma)\ Y - (1-\gamma)\ln k_t^2/\Lambda^2\}$$

$$\chi(\gamma) = 2\psi(1) - \psi(\gamma) - \psi(1-\gamma)$$



BFKL saddle point

$$j = 1 + \chi(1/2) = 1 + 4\ln 2 \cdot \bar{\alpha}_s$$

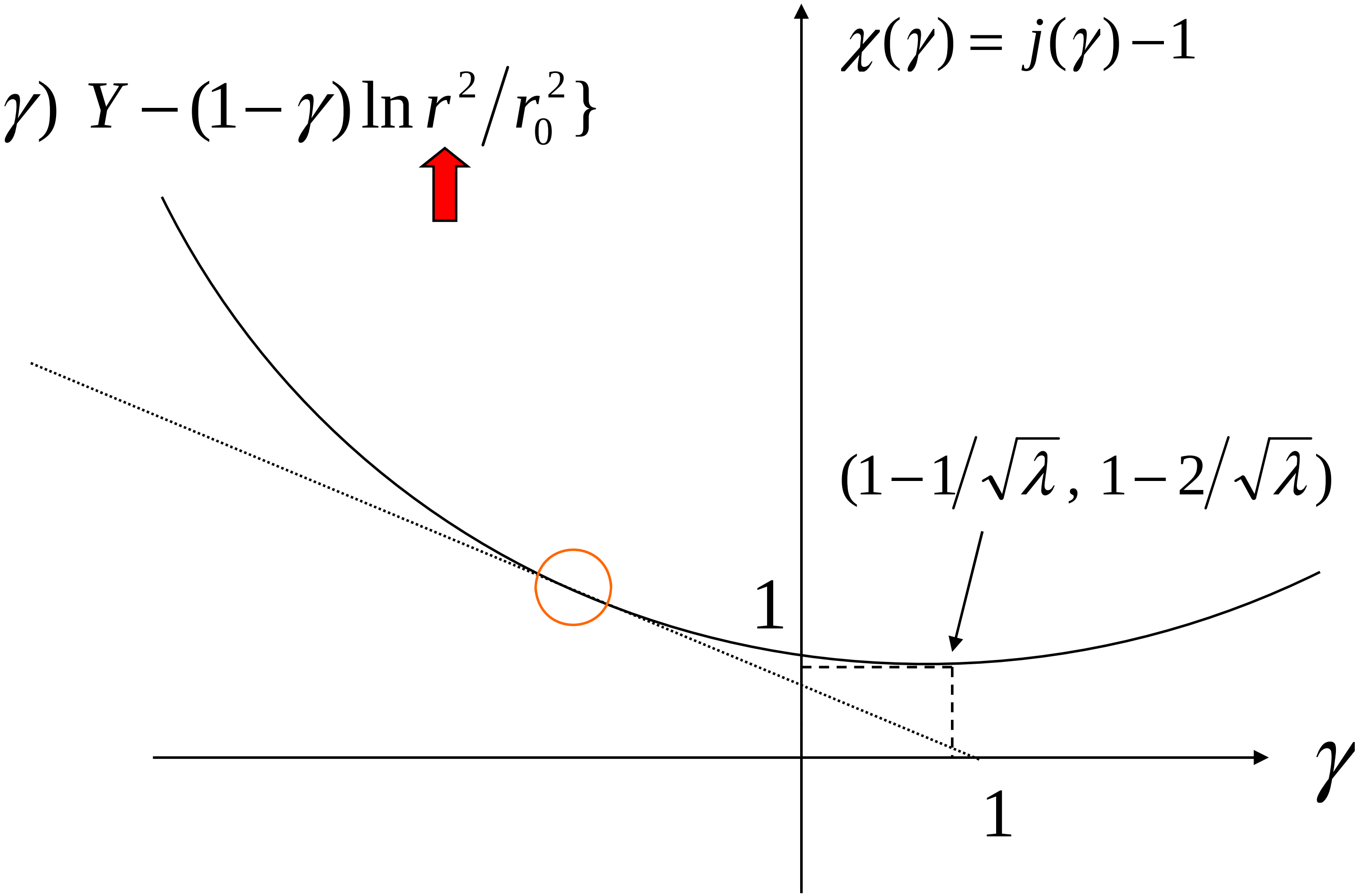
Saturation saddle point determined from

$$\chi'(\gamma) = -\frac{\chi(\gamma)}{1-\gamma}$$

``Saturation" saddle point at strong coupling

Amplitudes factorize in the r-space

$$\int d\gamma \exp\{\chi(\gamma)\ Y - (1-\gamma)\ln r^2/r_0^2\}$$



Anomalous dimension in N=4 SYM

The characteristic function extremely flat
``Saturation'' anomalous dimension huge

$$\gamma_s = -\frac{\lambda^{1/4}}{\sqrt{2}}$$

→ Anomalous dimension of the twist—two operator $\mathrm{Tr}[F_\mu^+ (D^+)^{j-2} F^{+\mu}]$

$$\gamma(j) \approx -\sqrt{\frac{j}{2}}\lambda^{\frac{1}{4}} \qquad 1 \ll j \ll \sqrt{\lambda}$$

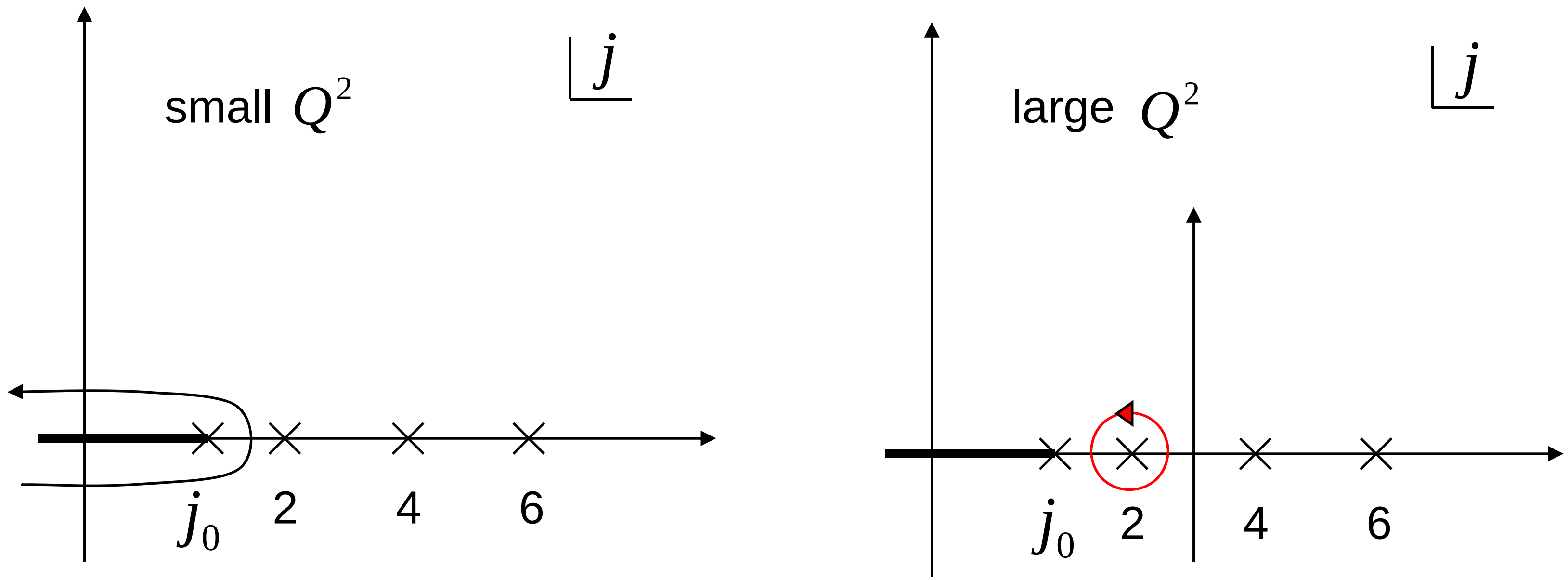
$$\gamma(j) \approx -\frac{\sqrt{\lambda}}{2\pi}\ln\frac{j}{\sqrt{\lambda}} \qquad j \gg \sqrt{\lambda}$$

Gubser, Klebanov, Polyakov, `02

``Diffusion approximation'' $j \propto \gamma^2$ is related to the Regge behavior $j \propto m^2$ of string excited states → Valid in a broad region, unlike BFKL !

The real part strikes back

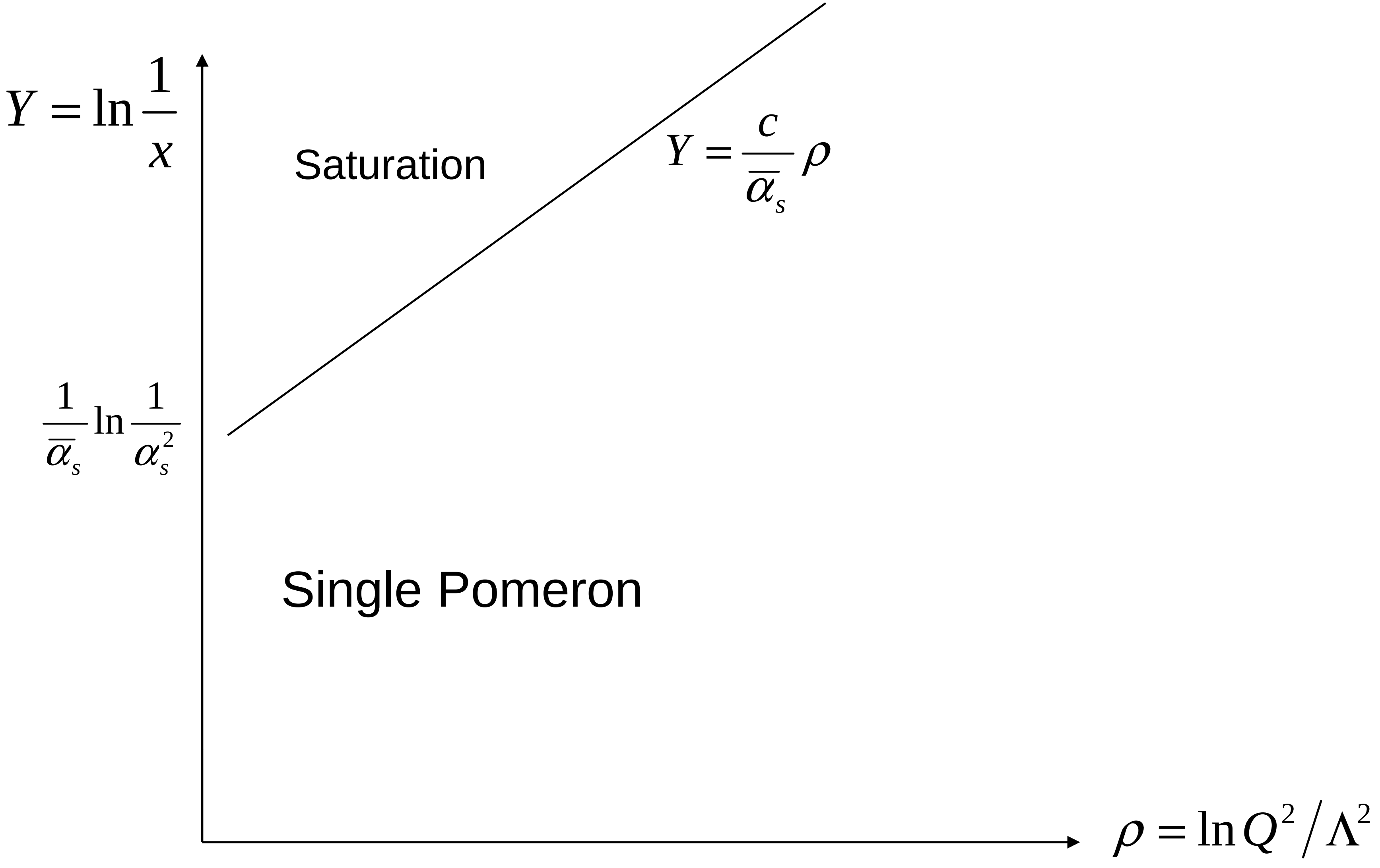
At large Q^2 massless gravitons reemerge.



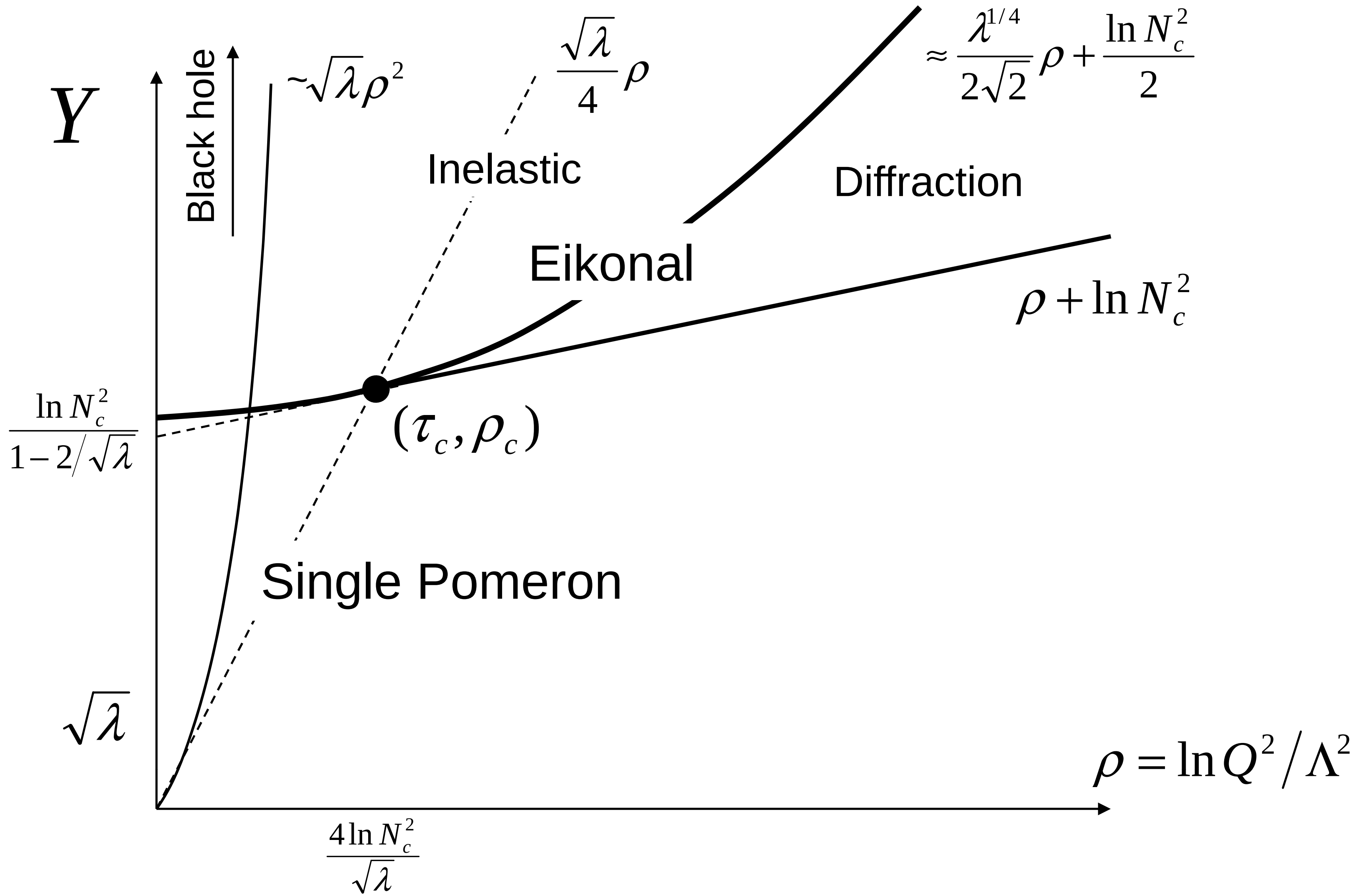
The real part reaches the unitarity limit first.

→ Resum by the eikonal approximation   t`Hooft, `87

Phase diagram at weak coupling

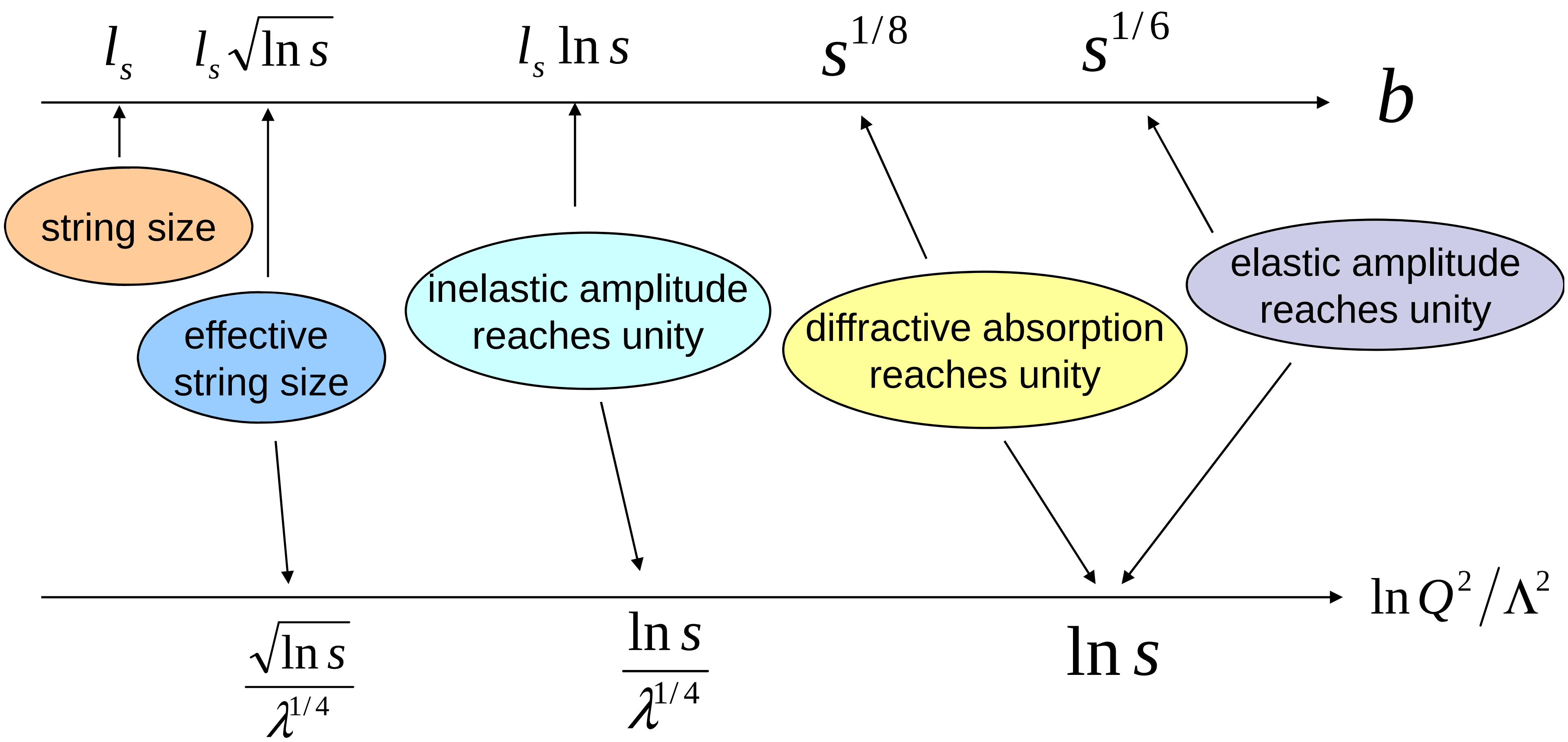


Phase diagram at strong coupling



Photon virtuality as an impact parameter

Compare our result with
Amati, Ciafaloni, Veneziano `87 (working in 10D string theory !)



Conclusions

- ❖ Regge regime in AdS/CFT largely unexplored.
- ❖ Some similarities, striking differences w.r.t. weak coupling QCD.
- ❖ Amati, Ciafaloni, Veneziano scenario realized in gauge theory
- ❖ Strong gravity and black hole creation
  - ➔ Reminiscent of the nonlinear effects in QCD in the saturation regime