HOLOGRAPHIC DOUBLE DIFFRACTIVE PRODUCTION OF HIGGS AND THE ADS GRAVITON (POMERON)

Chung-I Tan, Brown University
(with Richard Brower and Marko Djuric)
Paris-2011

R.C. Brower, Marko Djurić, Chung-I Tan
"Holographic Double Diffractive Higgs Production"
in preparation

Brower, Polchinski, Strassler, Tan (BPST) The Pomeron and Gauge/String Duality (2006)

References:

- R. Brower, J. Polchinski, M. Strassler, and C-I Tan, “The Pomeron and Gauge/String Duality”, hep-th/0603115.
- R. Brower, M. Strassler, and C-I Tan, hep-th/0707.2408; hep-th/0710.4378.
- R. Brower, M. Djuric, and C-I Tan, arXiv:0812.0354.
- R. Brower, M. Djuric, I. Sarcevic and C-I Tan, “DIS and Gauge/String Duality”, arXiv:1007.2259
- R. Brower, M. Djuric, and C-I Tan, “Diffractive Higgs Production and Gauge/String Duality”, (in preparation)

Other related work, e.g.,

L. Cornalba, et al., (hep-th/0710.5480),

- Y. Hatta, E. Iancu, and A. H. Mueller, (hep-th/0710.2148),
- E. Levin, et al. (arXiv:0811.3586) and (arXiv:0902.3122).
- Many others, (e.g., Kovchegov’s talk, more recent work by Y. Hatta, et al., etc.)

Executive Summary:

Gauge/String Duality (AdS/CFT) → 2-GLUONS $\simeq$ GRAVITON

Goals:

- Generality of "Pomeron" in QCD beyond perturbation theory,

- Unification of Soft and Hard Physics

- New phenomenology based on "Large Pomeron intercept", e.g., DIS at small-x: DGLAP vs Pomeron (talk by Marko Djuric)
- Diffractive Higgs Production

EXACT Weak/Strong EQUIVALENCE
N = 4 SYM is IIB string theory in AdS5 x S5

$$ds^2 = e^{2A(z)}[-dx^+dx^- + dx_\perp dx_\perp + dzdz] + ds^2(Y^5)$$

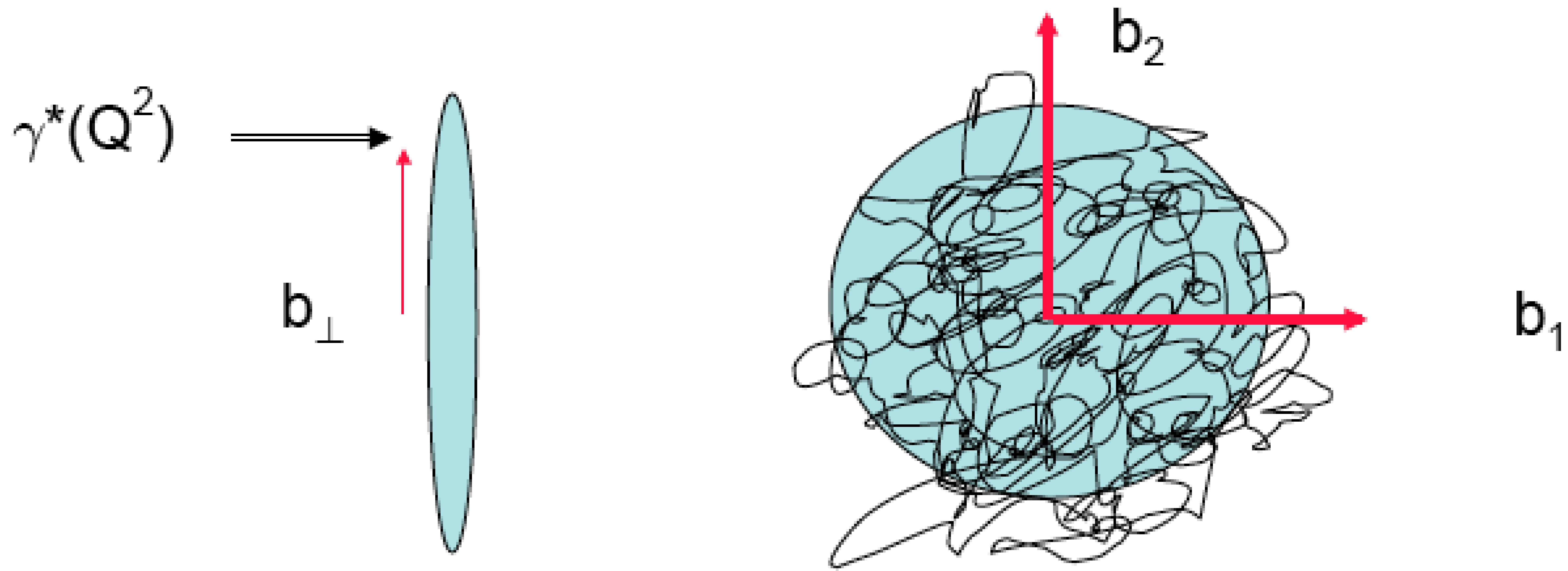
for AdS_5 $\quad e^{2A(z)} = \frac{R^2}{z^2}$ $\qquad R^2 d^2\Omega_5$

Overwhelming evidence for $\mathcal{N} = 4$ SYM
in the 'tHooft planar limit $N_c \to \infty$
at fixed $\lambda = g^2 N_c$

$$\langle e^{\int d^4x \phi_i(x) \mathcal{O}_i(x)} \rangle_{CFT} = \mathcal{Z}_{string}\left[\phi_i(x,z)|_{z\sim 0} \to \phi_i(x)\right]$$

QCD EMERGENCE OF 5-DIM ADS

"Fifth" co-ordinate is size z / z' of proj/target

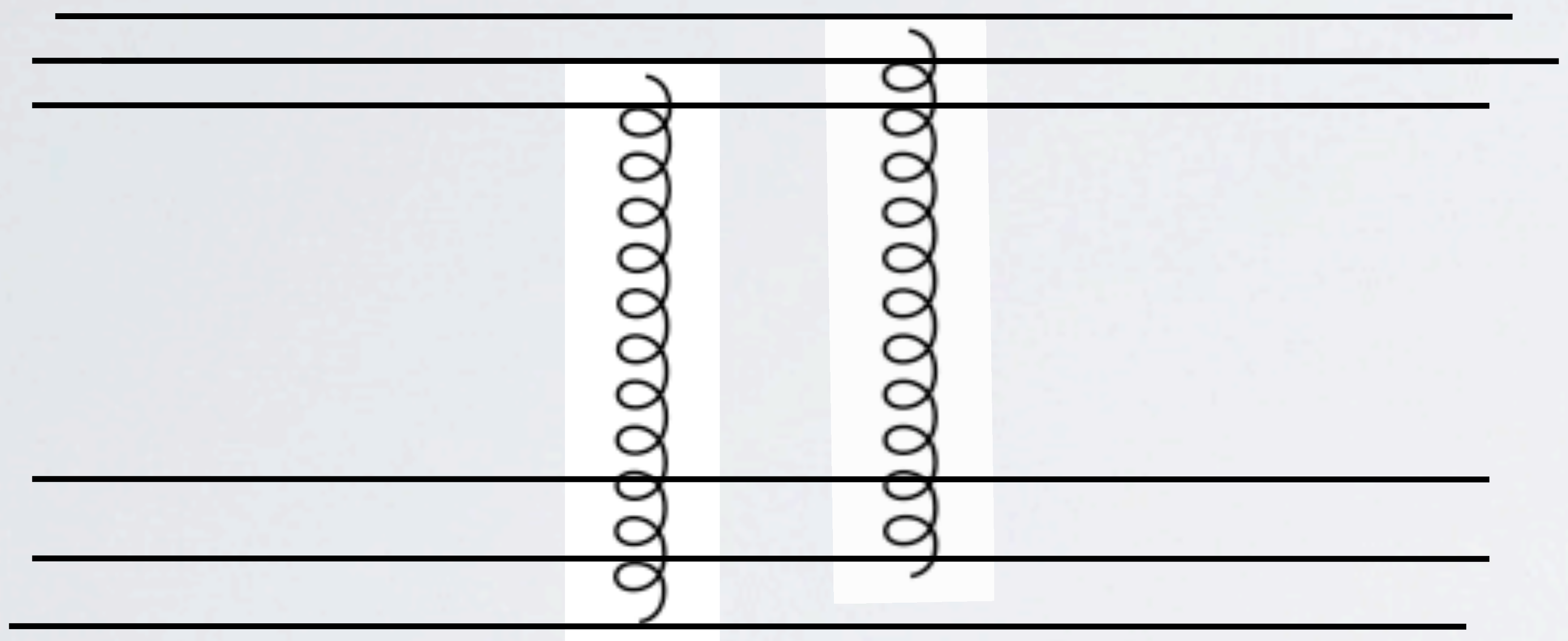


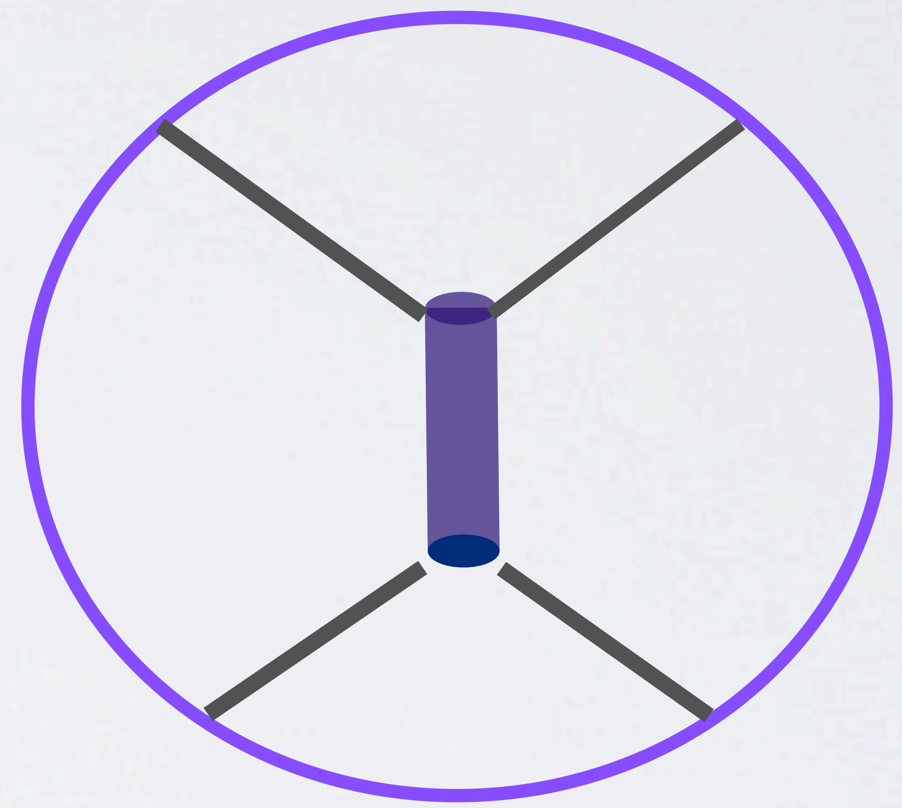
5 kinematical Parameters:

2-d Longitudinal	$p^\pm = p^0 \pm p^3 \simeq \exp[\pm \log(s/\Lambda_{qcd})]$
2-d Transverse space:	$x'_\perp - x_\perp = b_\perp$
1-d Resolution:	$z = 1/Q$ (or $z' = 1/Q'$)

WHAT IS THE BARE POMERON ? LEADING 1/N TERM CYLINDER EXCHANGE

WEAK: TWO GLUON <=> STRONG: ADS GRAVITON





$$J = 2$$

$$J_{cut} = 1 + 1 - 1 = 1$$

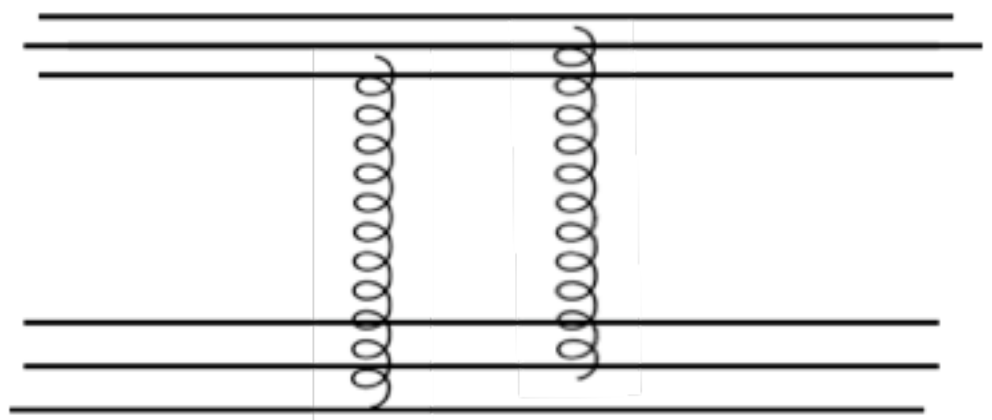
$$S = \frac{1}{2\kappa^2} \int d^4x dz \sqrt{-g(z)} \Big(-\mathcal{R} + \frac{12}{R^2} + \frac{1}{2} g^{MN} \partial_M \phi \partial_N \phi \Big)$$

F.E. Low. Phys. Rev. D 12 (1975), p. 163.
S. Nussinov. Phys. Rev. Lett. 34 (1975), p. 1286.

AdS Witten Diagram: Adv. Theor. Math. Physics 2 (1998)253

Two gluon exchange (Low-Nussinov Pomeron!)

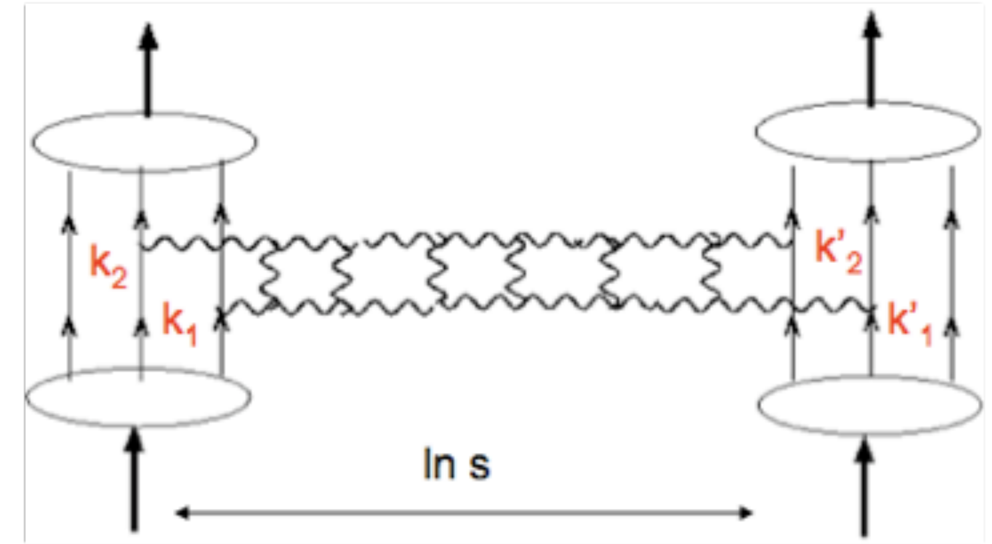
- $J_{cut} = 2\,(J-1) + 1 = 1$



F.E. Low. Phys. Rev. D 12 (1975), p. 163.
S. Nussinov. Phys. Rev. Lett. 34 (1975), p. 1286.

BFKL: Balitsky & Lipatov; Fadin,Kuraev,Lipatov'75

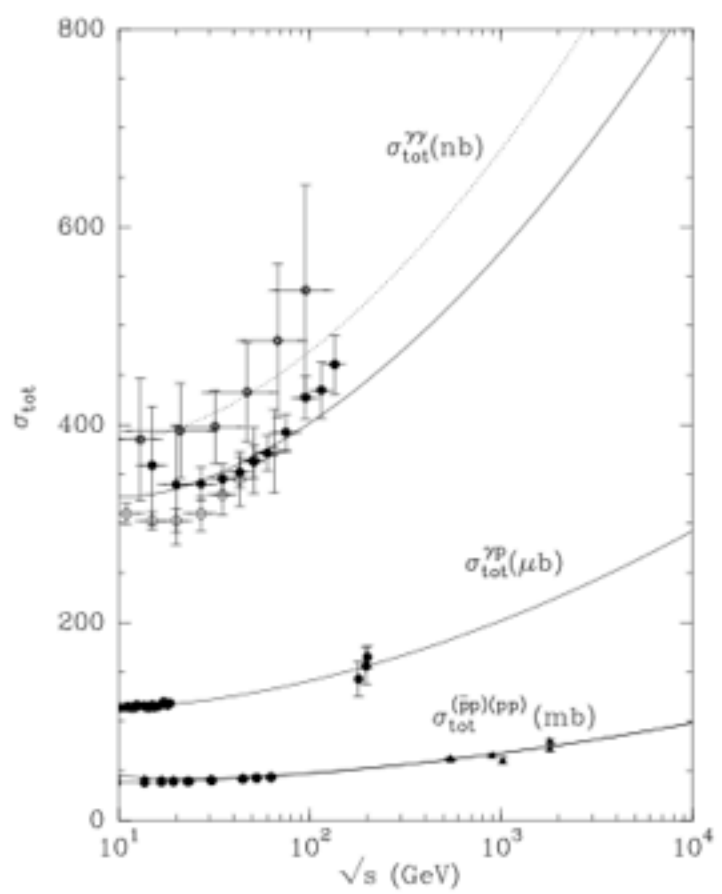
$t = -(k_1 + k_2)^2$

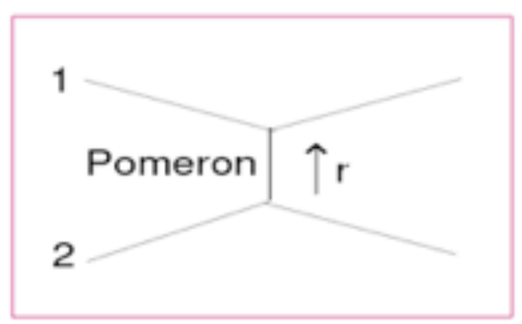


$\lambda = g^2 N_c \sim 0$

- ❑ Sum diagrams 1^{st} order in $g^2 N_c$ & all orders $(g^2 N_c \log s)^n$
- ❑ BKFL equation for 2 "reggized" gluon ladder is L = 2 SL(2,C) spin chain to one loop order.
- ❑ Accidentally "planar" diagrams (e.g. $N_c = 1$) and conformal.

Total Cross Sections





$$\mathcal{A} \sim s^{J(t)} = s^{\alpha(0)+\alpha' t}$$

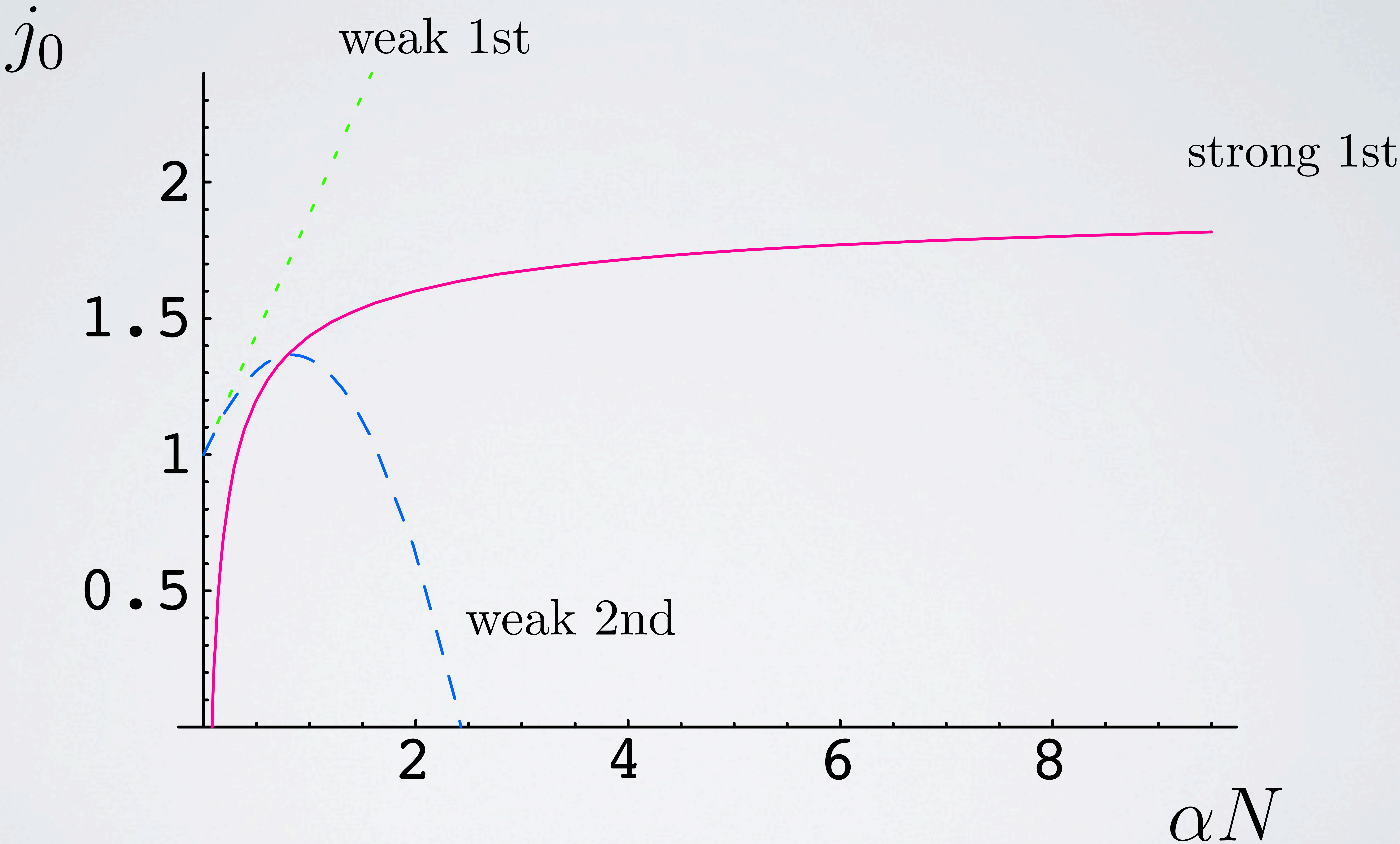
$$\sigma_{total} \sim \mathcal{A}(s,0)/s \sim S^{J(0)-1} \sim s^{\alpha(0)-1}$$

$$\alpha(0) > 1$$

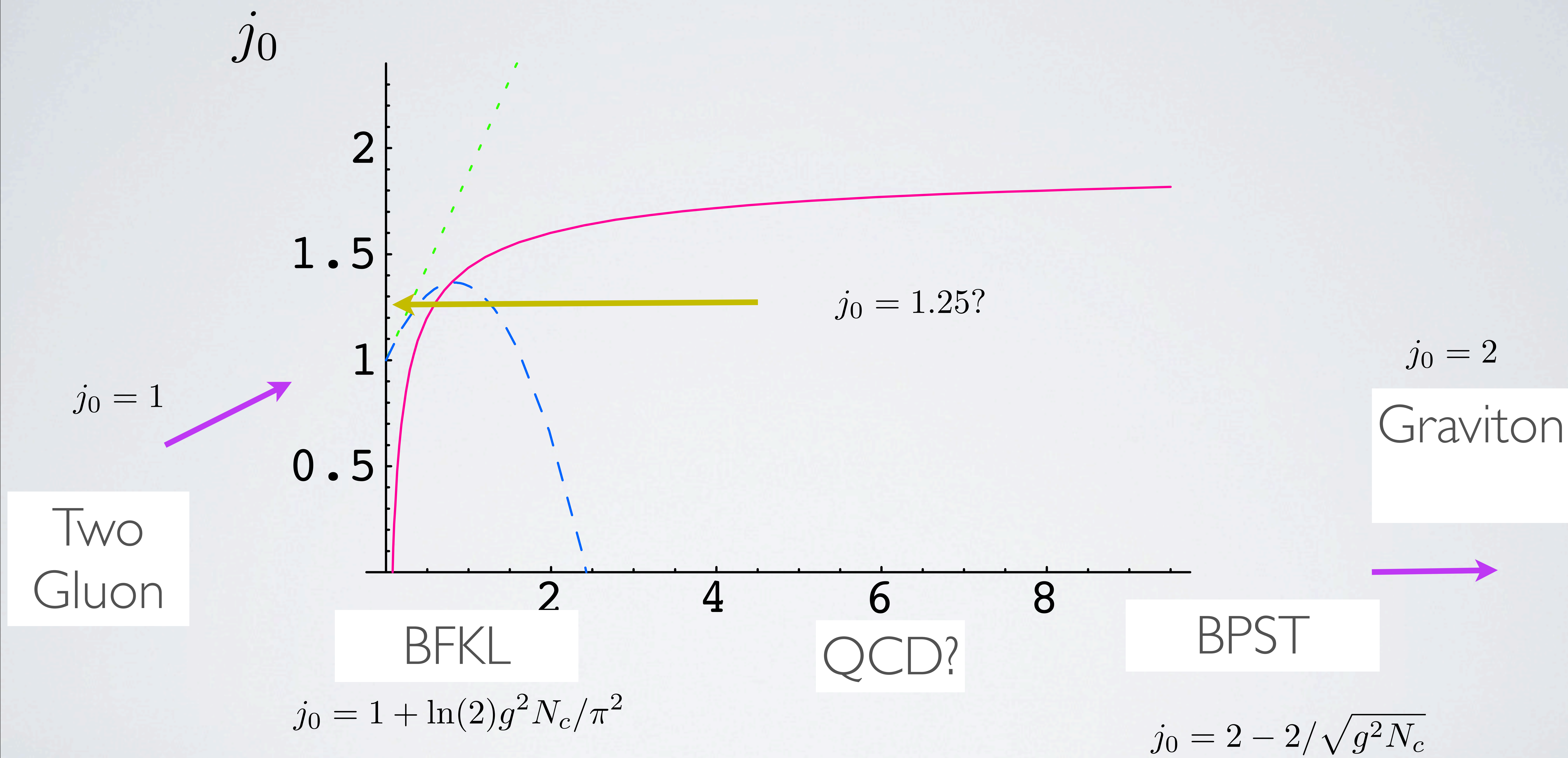
(IR) Pomeron as Closed String??

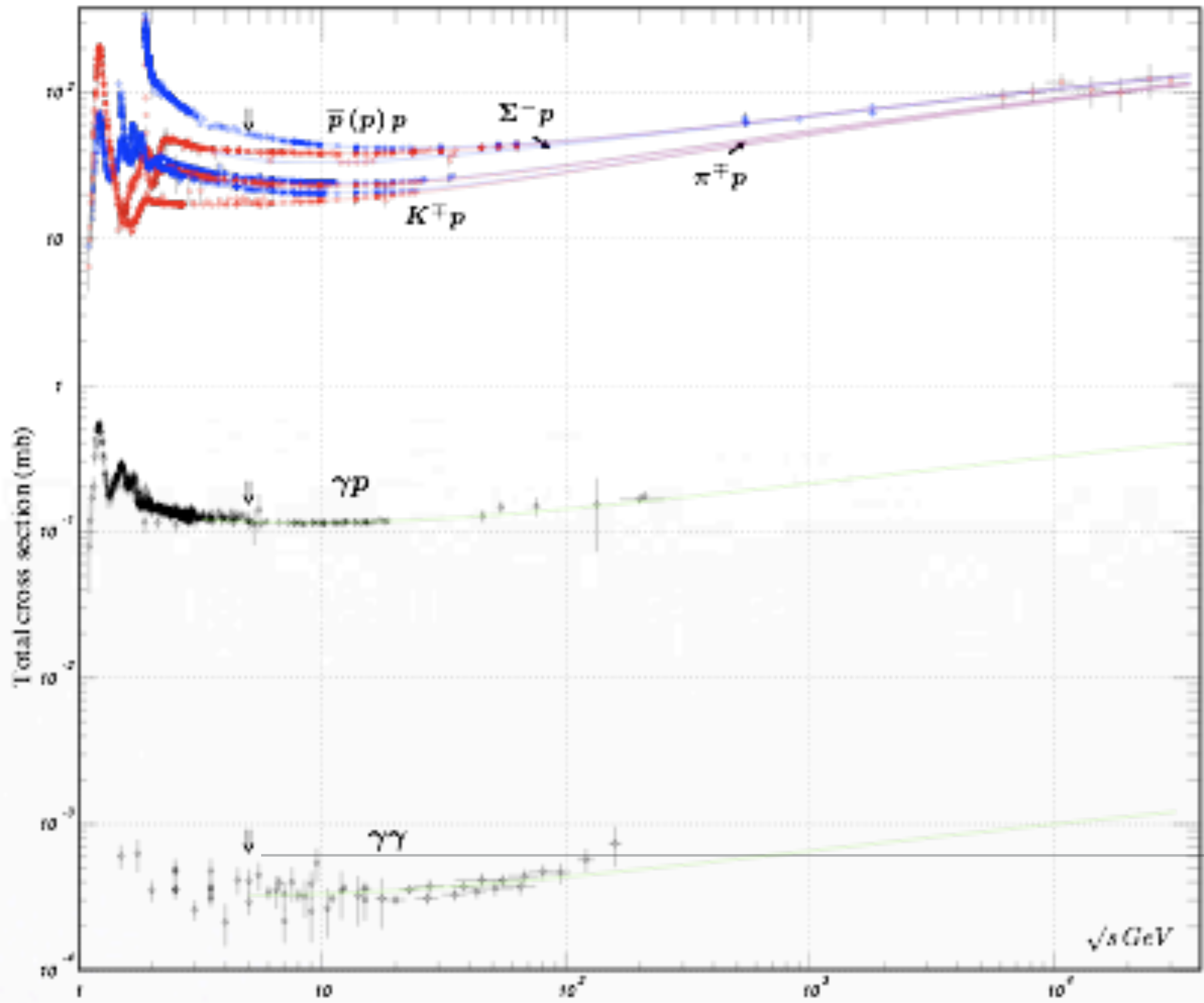
Using AdS/CFT to obtain a strong coupling, i.e., non-perturbative, treatment of high energy forward scattering

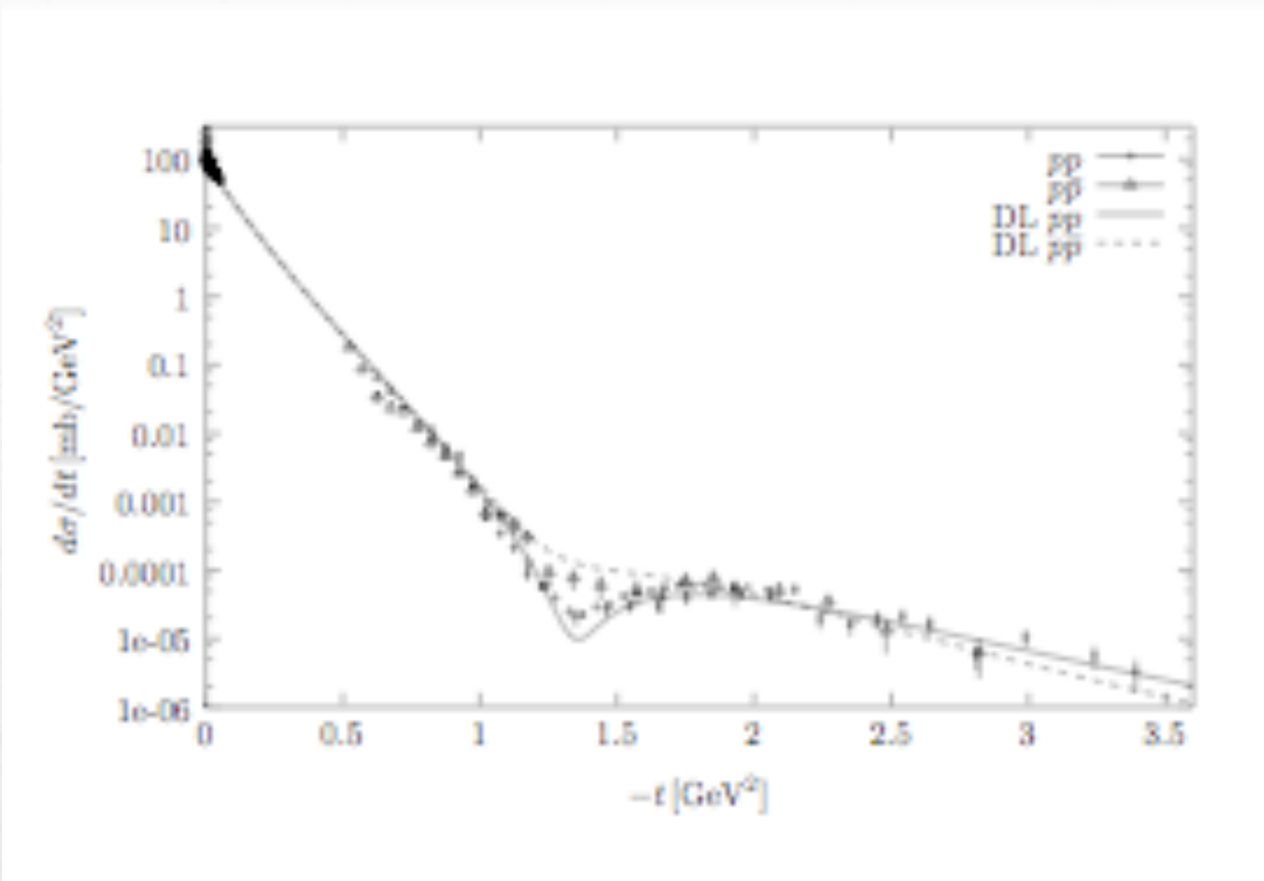
$\mathcal{N} = 4$ Strong vs Weak $g^2 N_c$



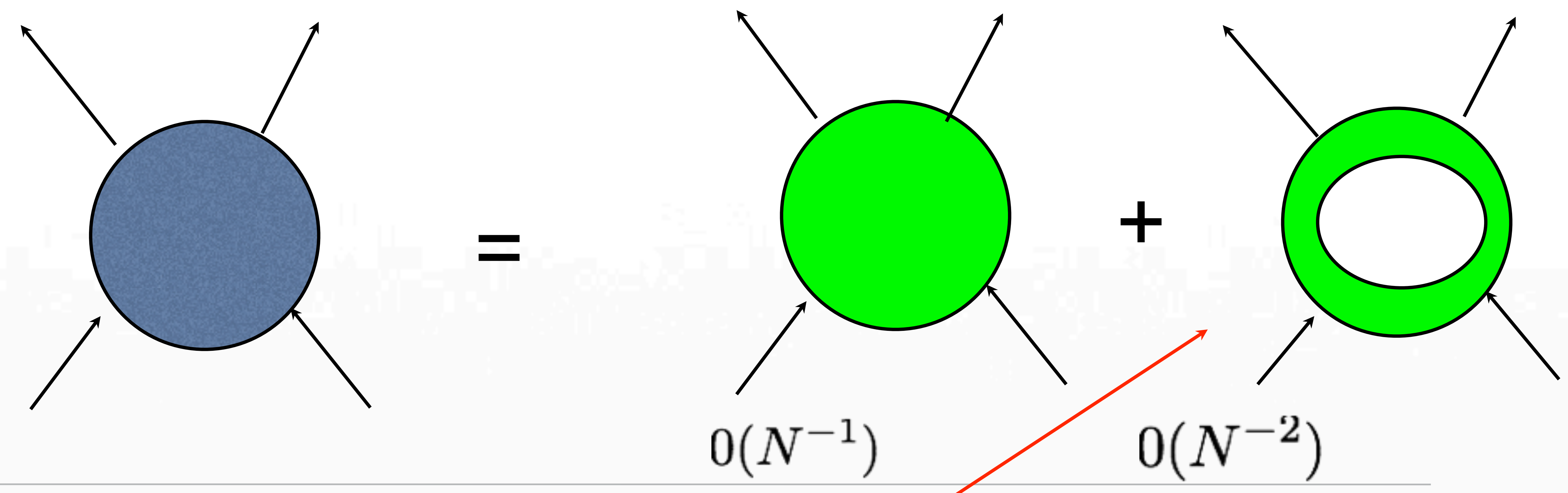
$\mathcal{N} = 4$ Strong vs Weak $g^2 N_c$



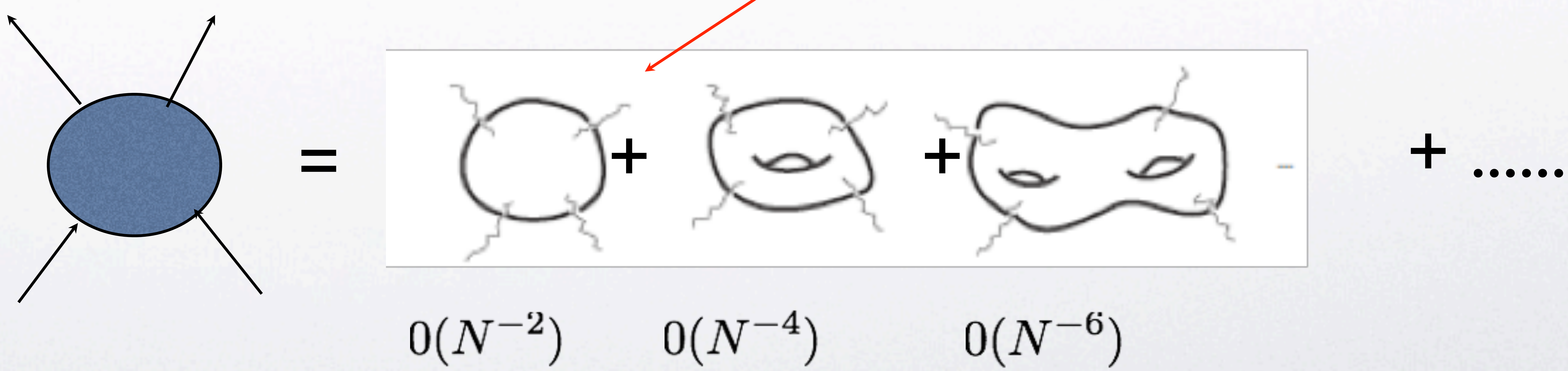




Open-string Scattering

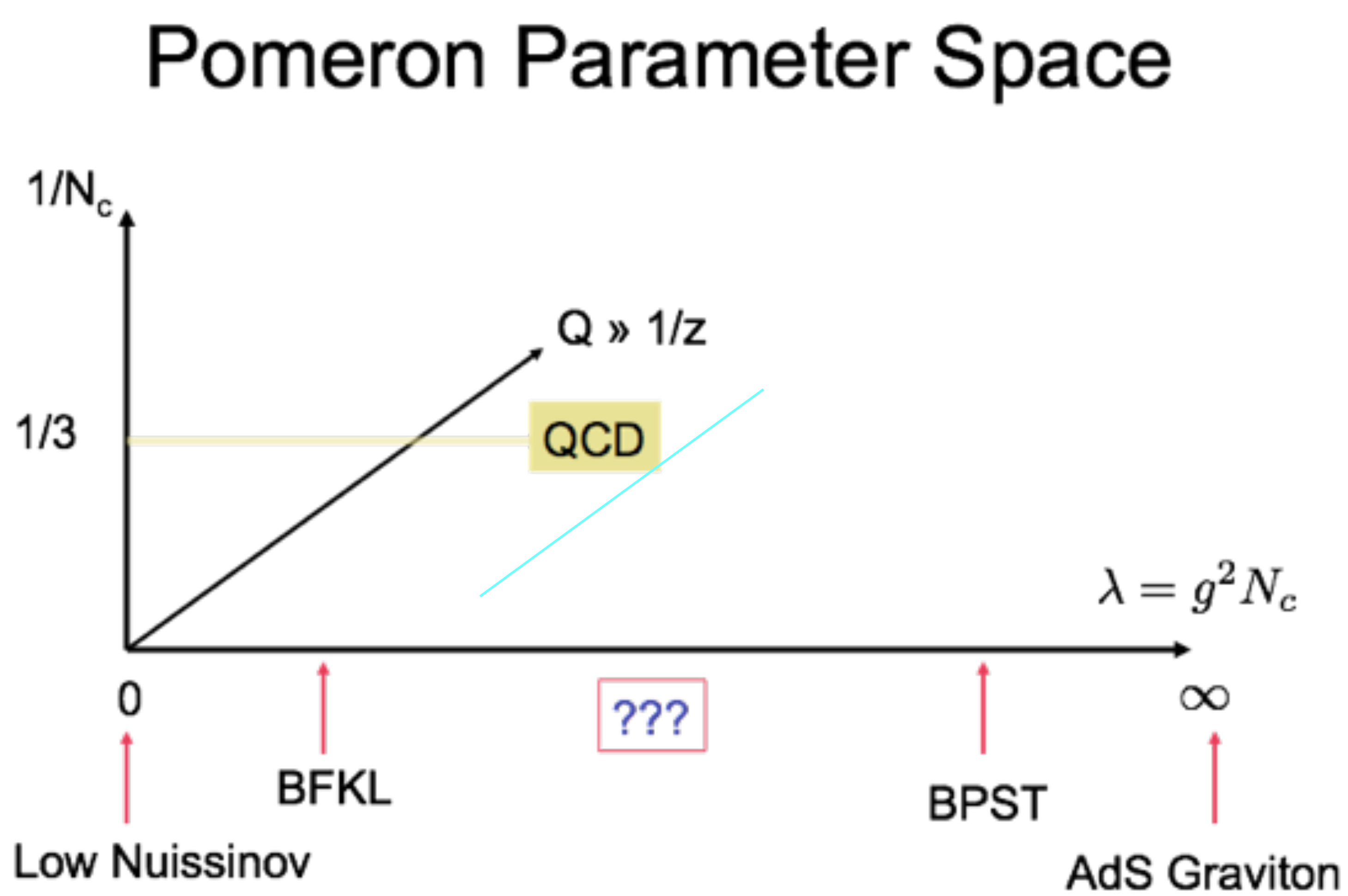


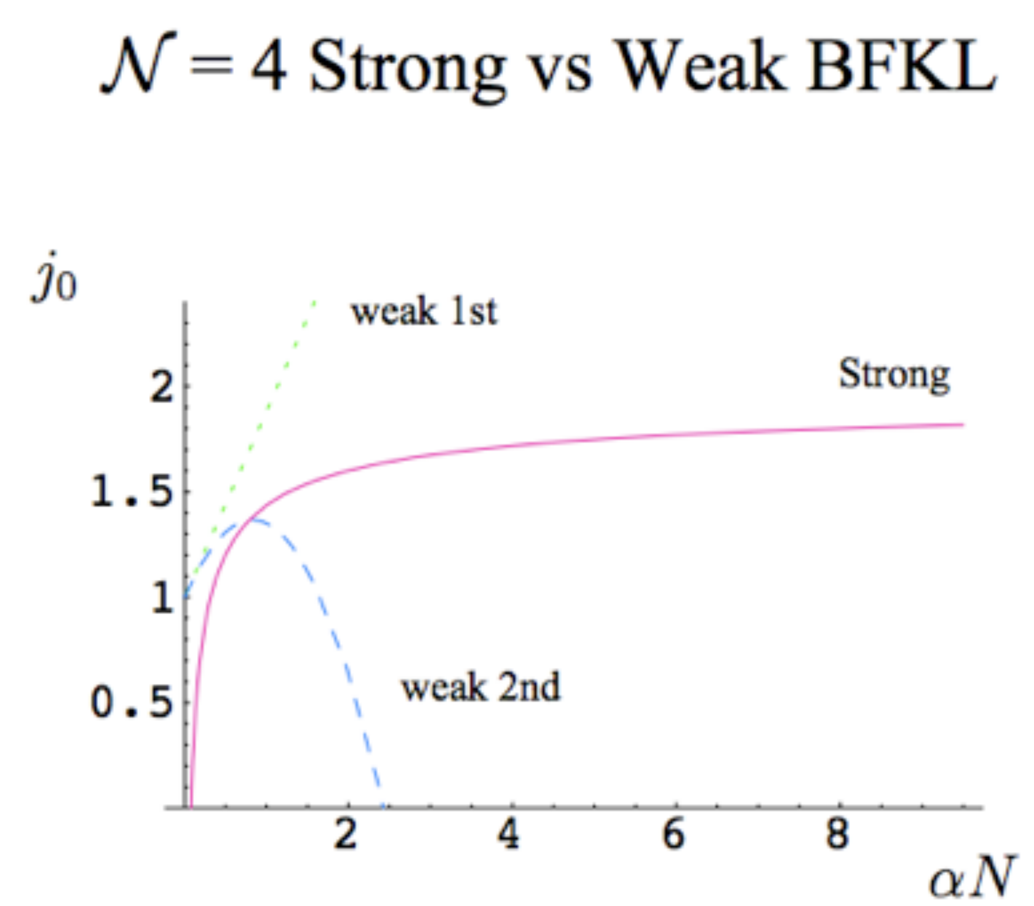
Closed-string Scattering



In this talk, will focus on "closed string" exchanges only. For DIS, applicable at x<<1.

Gauge/String Duality: QCD at Strong Coupling





- C=+1: Pomeron <=> Graviton:

$$\alpha_0^{(+)} = 2 - 2/\sqrt{\lambda} + O(1/\lambda)$$

$$(symmetric\, tensor : g_{\mu\nu})$$

- C=-1: Odderon <=> Kalb-Ramond

$$\alpha_0^{(-)} = 1 - m_{ads}^2/2\sqrt{\lambda} + O(1/\lambda)$$

$$(anti-symmetric\, tensor : b_{\mu\nu})$$

- Many New Questions:

Comparison of strong vs weak coupling kernel at t=0

Strong Coupling:

$$\mathcal{K}(r,r',s) = \frac{s^{j_0}}{\sqrt{4\pi\mathcal{D}\ln s}} e^{-(\ln r - \ln r')^2/4\mathcal{D}\ln s}$$

Diffusion in "warped co-ordinate"

$$j_0 = 2 - \frac{2}{\sqrt{g^2N}} + O(1/g^2N)$$

$$\mathcal{D} = \frac{1}{2\sqrt{g^2N}} + O(1/g^2N) \quad .$$

Weak Coupling:

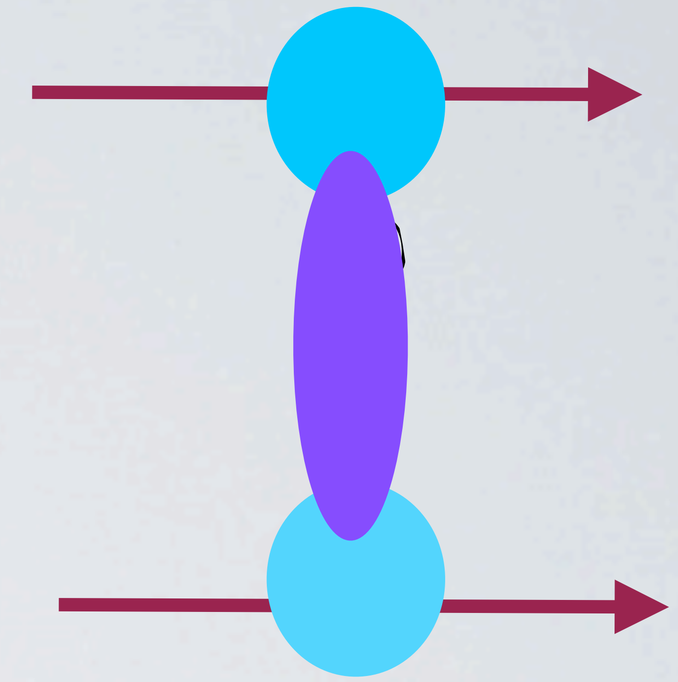
$$K(s,k_\perp,k'_\perp) \approx \frac{s^{\alpha(0)-1}}{\sqrt{\pi\ln s}} e^{-[(\ln k'_\perp - \ln k_\perp)^2/4\mathcal{D}\ln s]}$$

$$j_0 = 1 + \ln(2) g^2 N/\pi^2$$

$$\mathcal{D} = \frac{14\zeta(3)}{\pi} g^2 N/4\pi^2 .$$

ELASTIC, DIS, DOUBLE HIGGS: ADS BUILDING BLOCKS

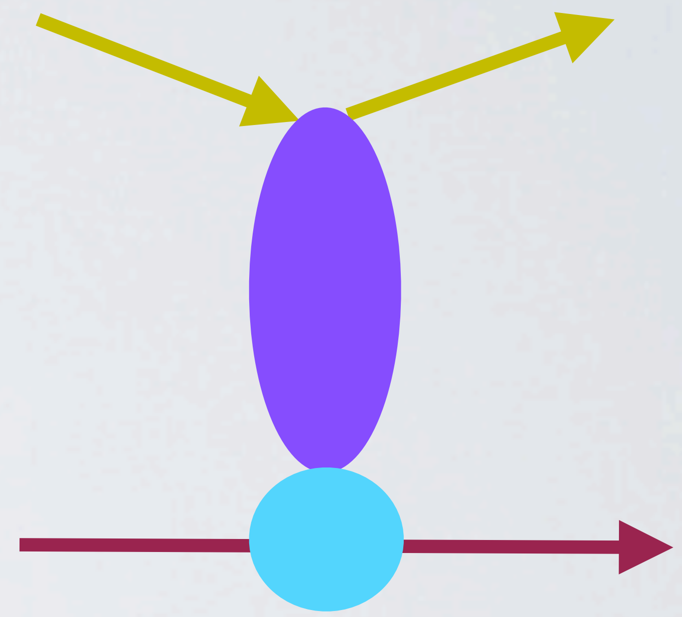
$$A(s,t) = g_0^2 \int d^3\mathbf{b} d^3\mathbf{b}' \; e^{i\mathbf{q}_\perp\cdot(\mathbf{x}-\mathbf{x}')} \; \Phi_{13}(z) \; \mathcal{K}(s, \mathbf{x}-\mathbf{x}', z, z') \; \Phi_{24}(z')$$



$$\sigma_T(s) = \frac{1}{s} Im A(s,0)$$

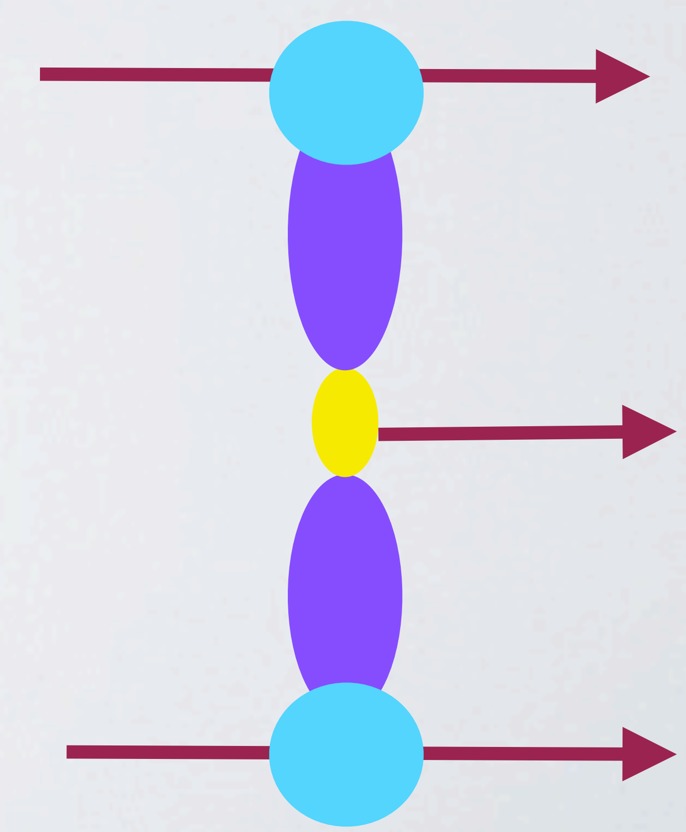
$$d^3\mathbf{b} \equiv dz d^2 x_\perp \sqrt{-g(z)} \quad \text{where} \quad g(z) = \det[g_{nm}] = -e^{5A(z)}$$

for $\quad F_2(x,Q)$



$$\Phi_{13}(z) \to \Phi_{\gamma^*\gamma^*}(z,Q) = \frac{1}{z}[Qz)^4(K_0^2(Qz) + K_1^2(Qz)]$$

For Double Diffractive Higgs

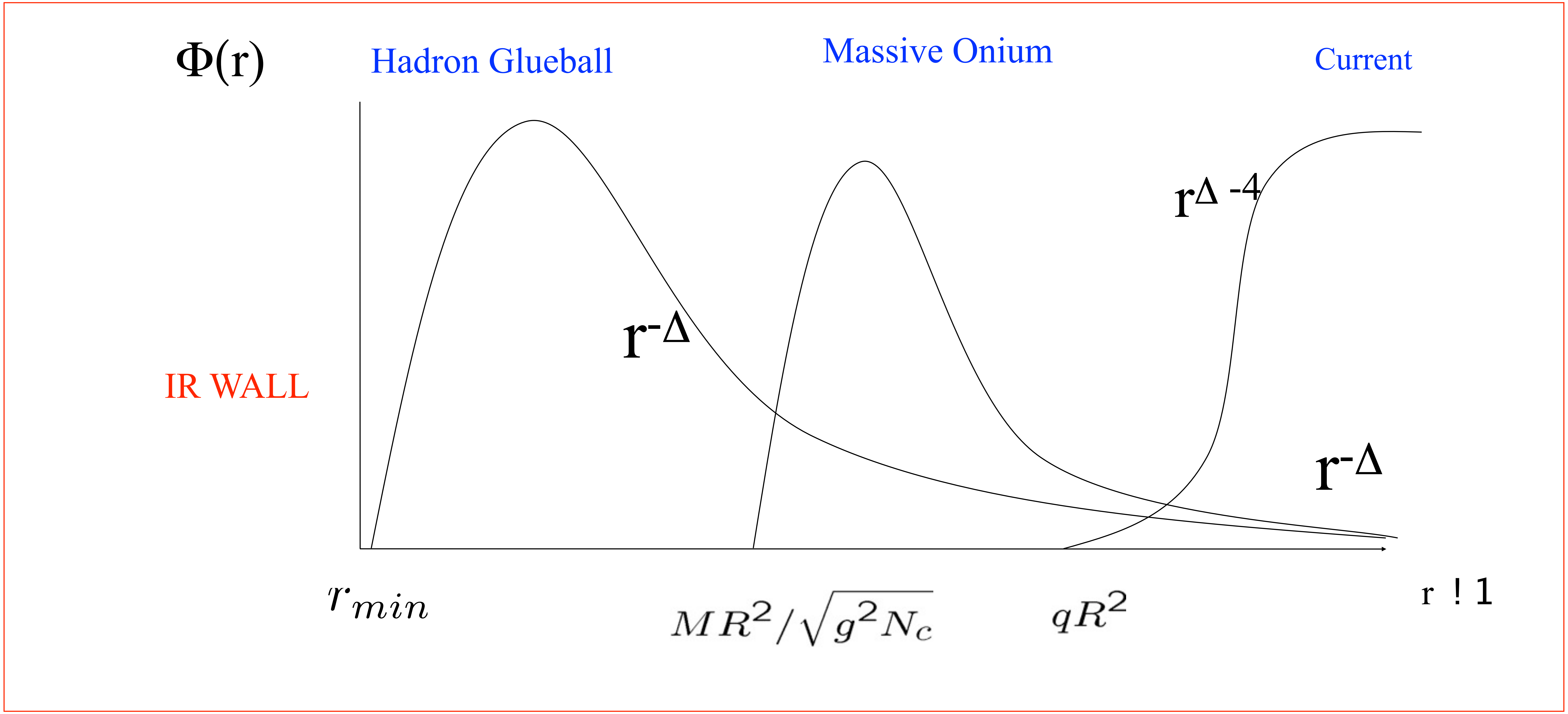


$$A(s_1, s_2, s, t_1, t_2) = \Phi_{13} * \mathcal{K}_1 * \mathcal{V}_H * \mathcal{K}_2 * \Phi_{24}$$

$$\mathcal{V}_H \to V_H \; \Phi_H = V_H \; (m_H z)^2 K_2(m_H z)$$

- Universality:

By choosing wave functions, Φ, can treat DIS, Higgs Production, Proton-Proton, etc., on equal footing.

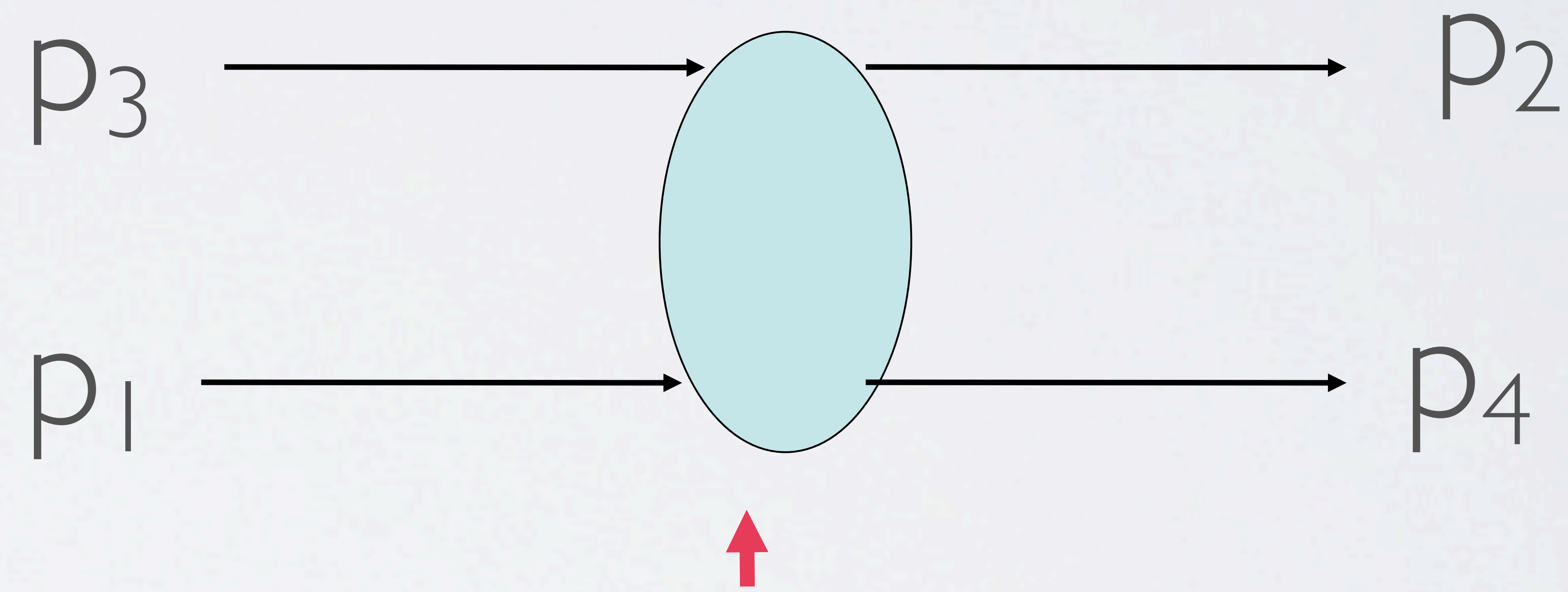


CLASSIC REGGE DIFFUSION IMPACT PARAMETER

$$A(s,t) \sim s^{\alpha' t + j_0} \rightarrow a(s, b_\perp) \sim s^{j_0} exp[-b_\perp^2 / 4\alpha' log(s)]$$

Diffusion in transverse (impact) space
rapidity = "time"

$s = (p_1 + p_3)^2$



$t = (p_1 + p_2)^2$

$$A(s, t = -q_\perp^2) = \int \frac{d^2 b_\perp}{4\pi^2} e^{-i q_\perp \cdot b_\perp} a(s, b_\perp)$$

SL(2,C) ADS3 J-PLAN SCHRÖDINGER EQU.

$$M_{+-}\psi = [-\partial_u^2 + e^{-2u}\nabla_\perp]\psi = 2\sqrt{g^2 N_c}\partial_y\psi$$

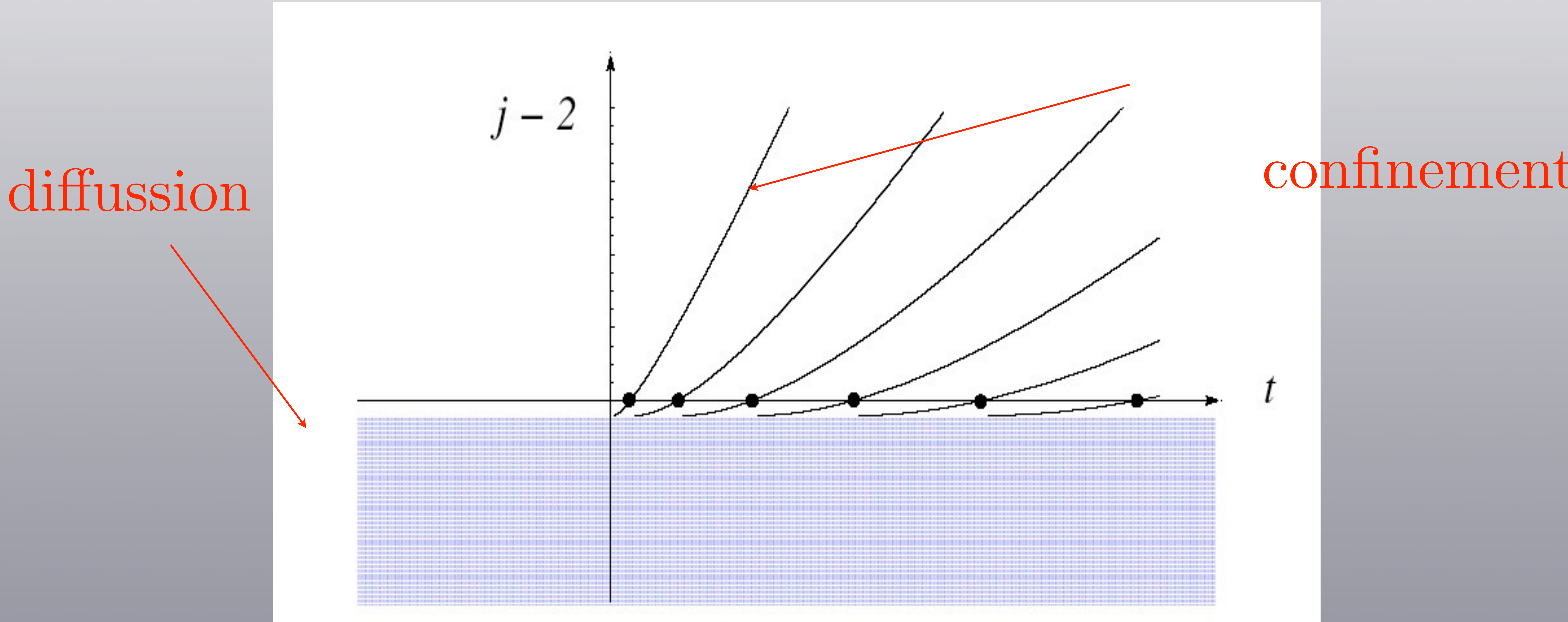
Eigenvalues: ν^2 $\quad t = -q_\perp^2$ $\quad E = 2 - j$

$$G_j(t, z, z') \sim \int q dq \frac{J_{(\Delta(j)-2)}(qz) J_{(\Delta(j)-2)}(qz')}{q^2 - t}$$

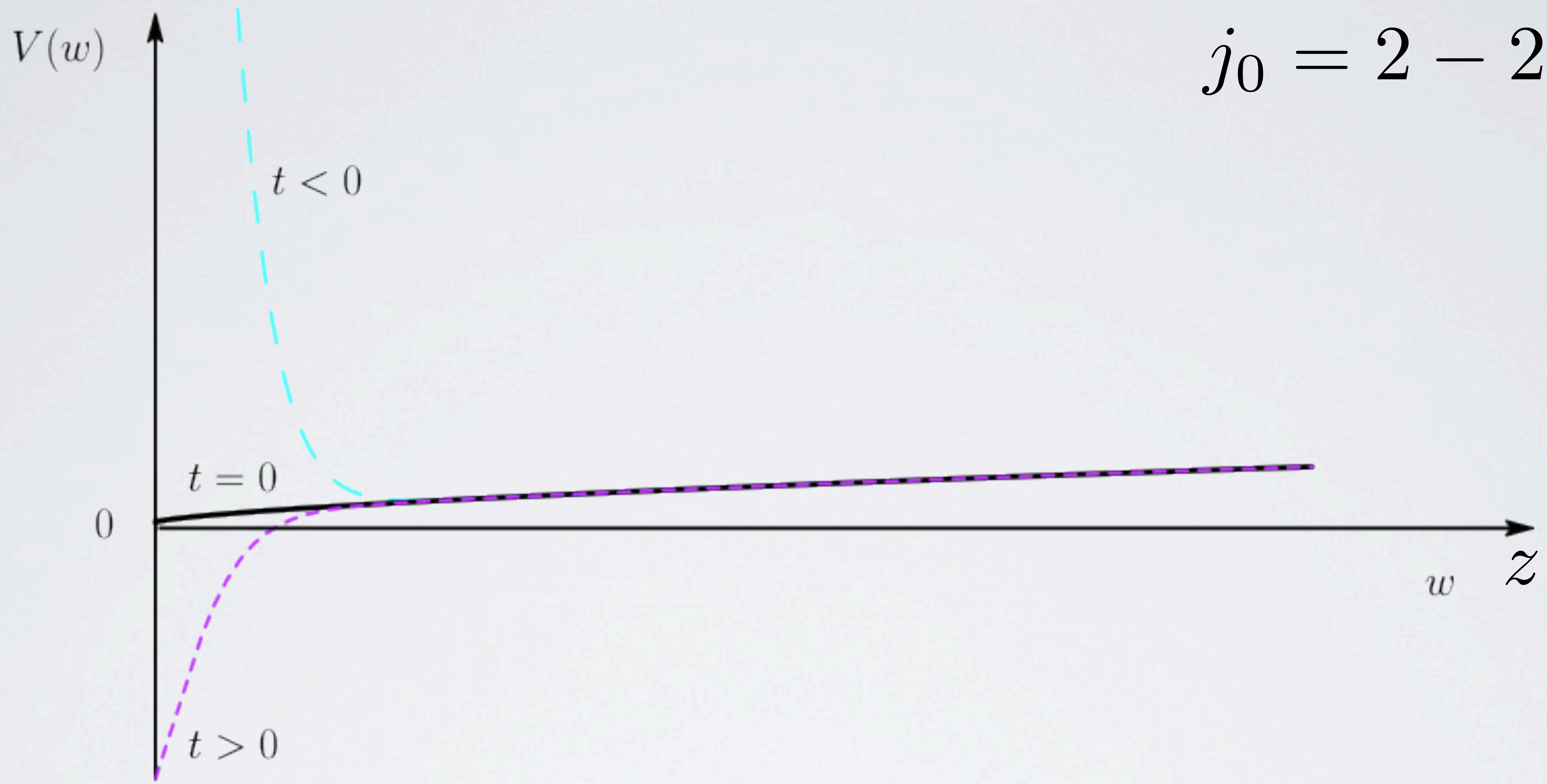
$$(\Delta(j) - 2)^2 = 2\sqrt{g^2 N_c}(j - j_0)$$

Unified Hard (conformal) and Soft (confining) Pomeron

At finite λ, due to Confinement in AdS, *at* $t > 0$
aymptotical linear Regge trajectories



ADS J-PLANE SCHEODINGER EQ

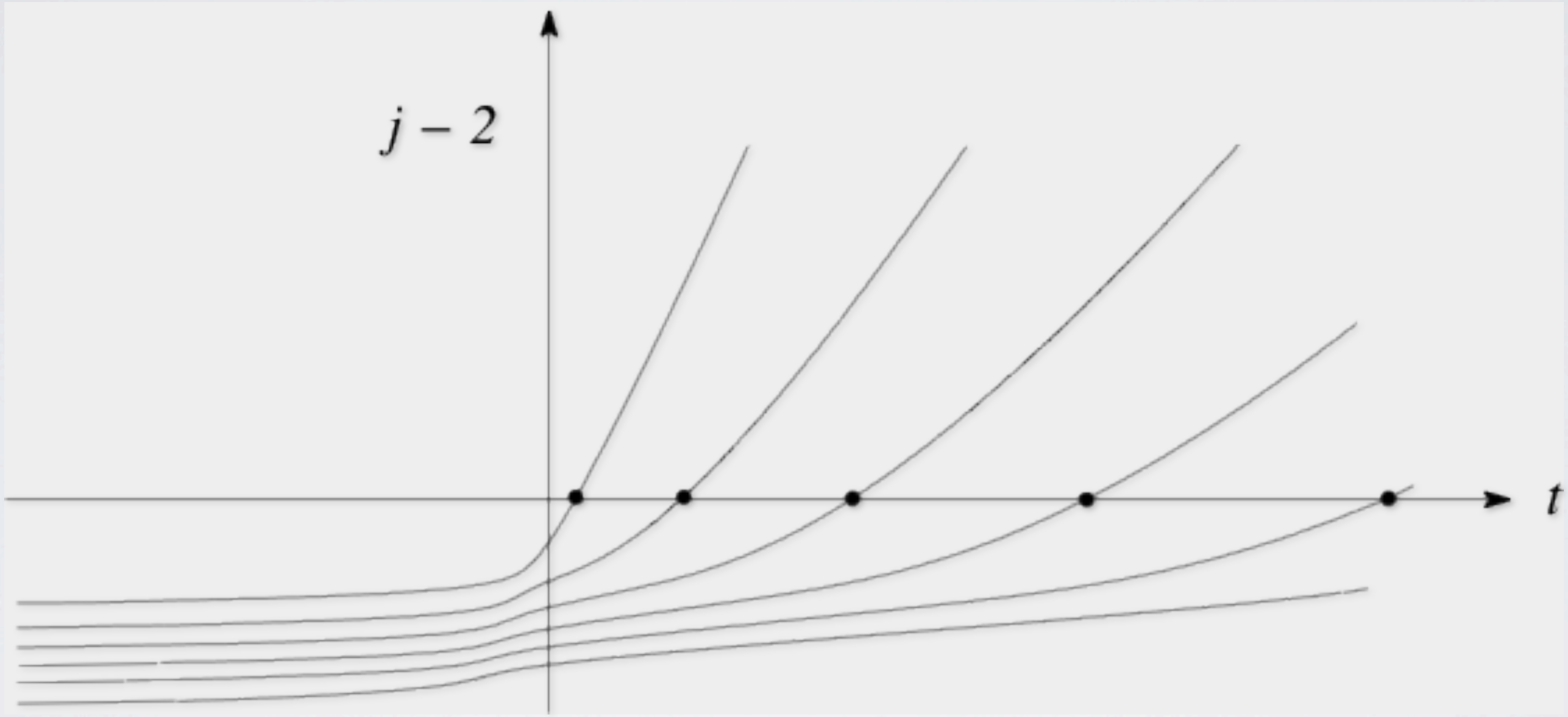


$$j_0 = 2 - 2/\sqrt{g^2 N}$$

$$z = e^{-w}$$

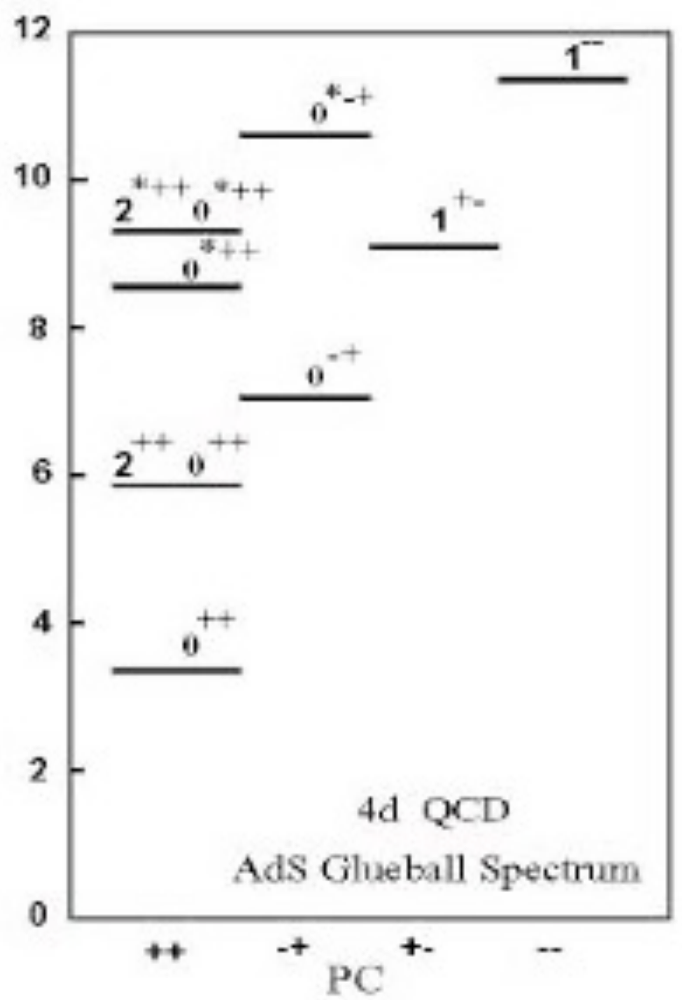
$$[-\partial_w^2 - te^{-2w} - cw)/2 + \sqrt{g^2 N}(j - j_0)]G_j(t, z, z') = \delta(w - w')$$

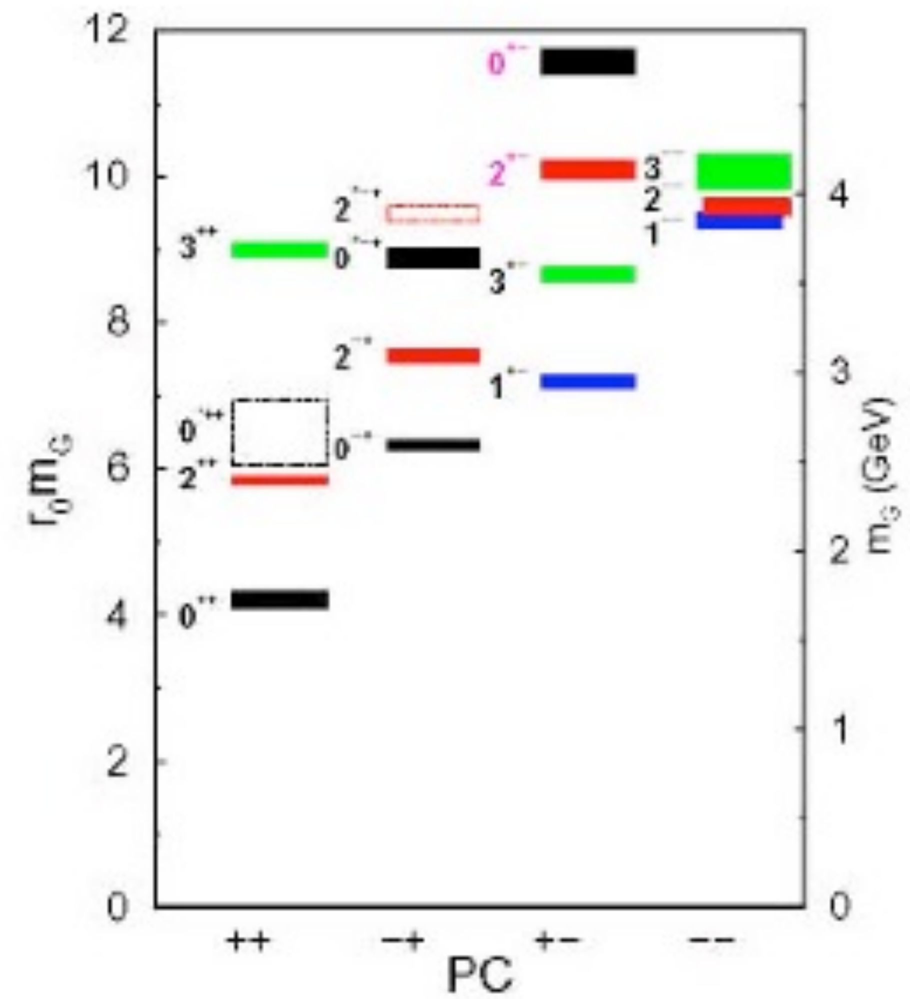
(STRONG) RUNNING

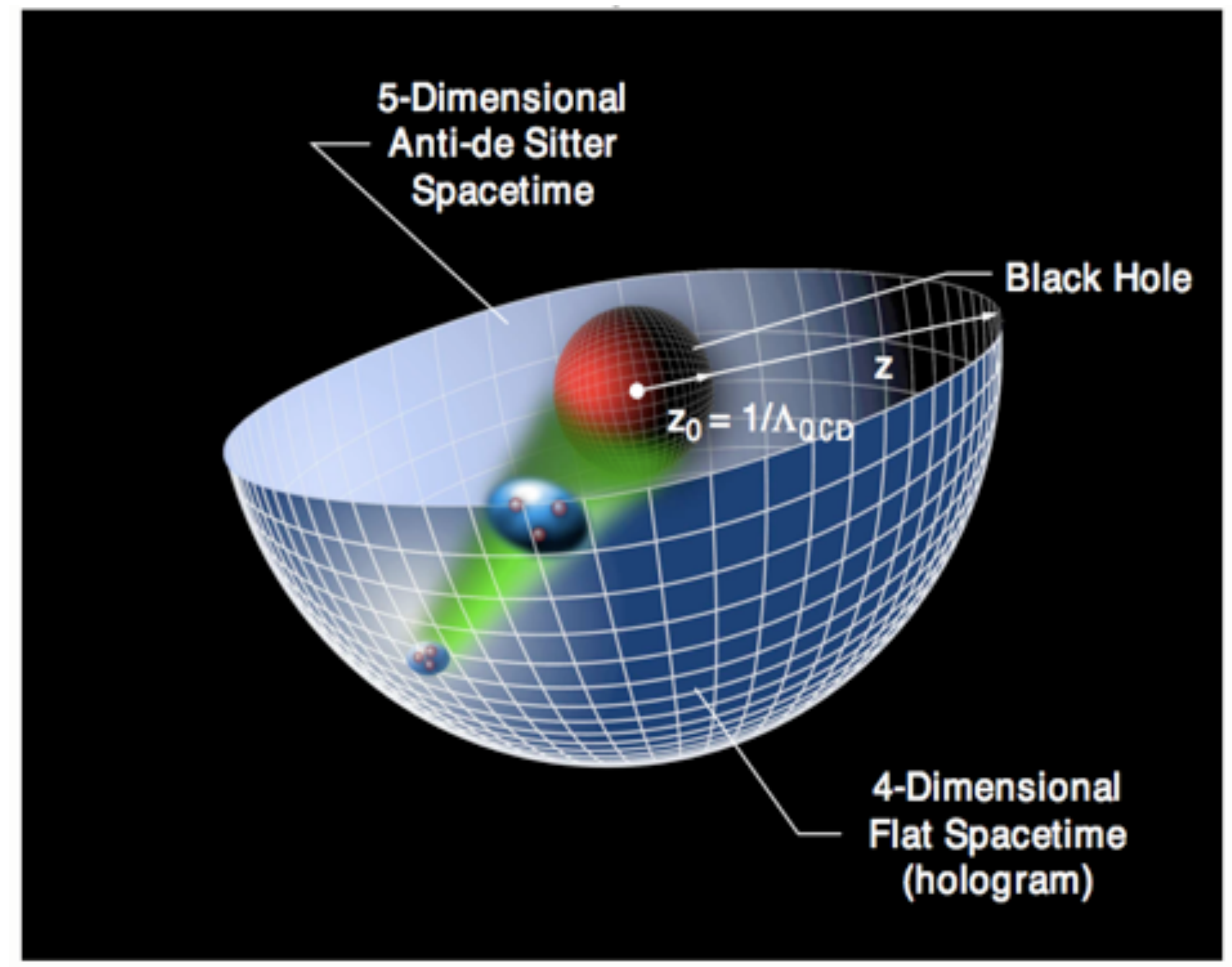


Confinement Deformation: Glueball Spectrum

$(\lambda = \infty)$







Four-Dimensional Mass:

$$E^2 = (p_1{}^2 + p_2{}^2 + p_3{}^2) + M^2$$

5-Dim Massless Mode:

$$0 = E^2 - (p_1{}^2 + p_2{}^2 + p_3{}^2 + p_r{}^2)$$

AdS/CFT ===>

In gauge theories with string-theoretical dual descriptions, the Pomeron emerges unambiguously.

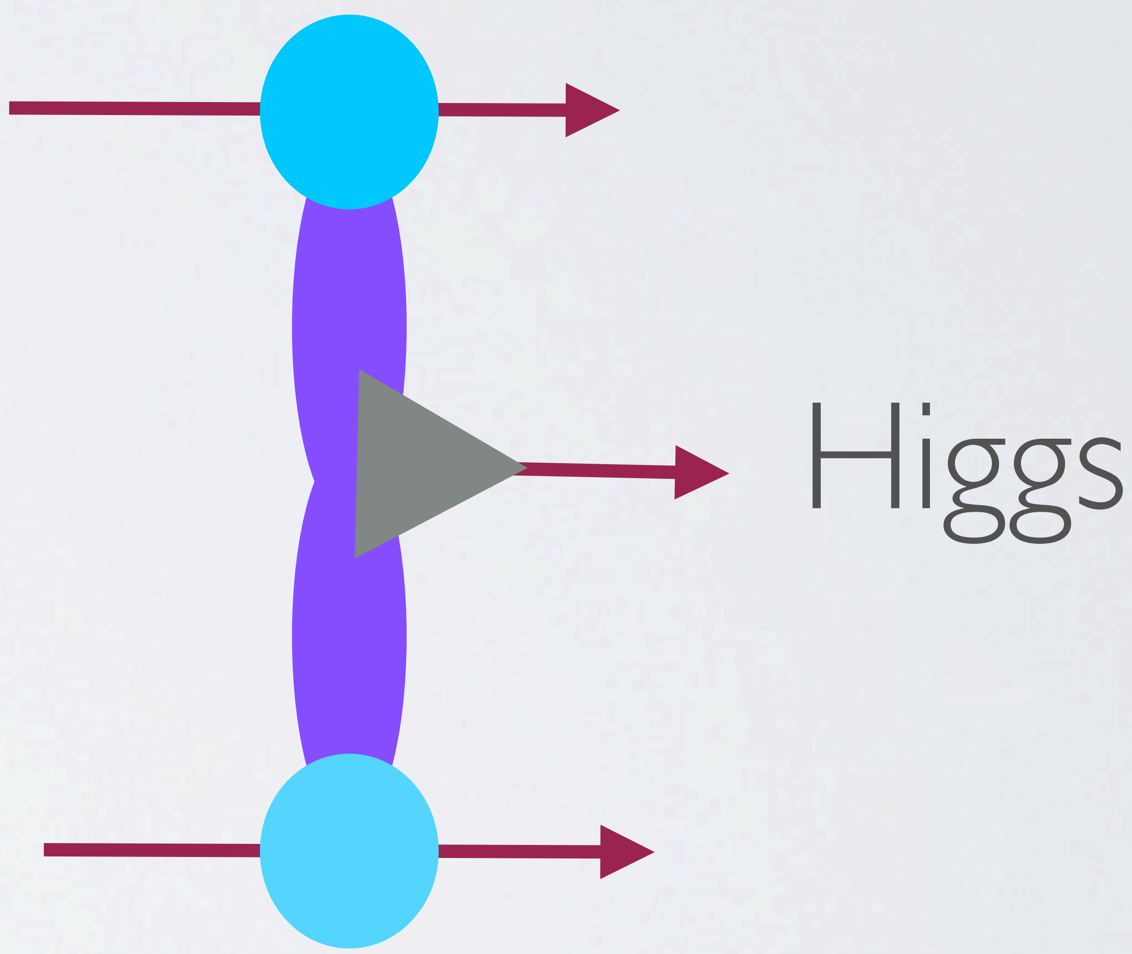
Pomeron can be associated with a Reggeized Graviton.

Both the IR (soft) Pomeron and the UV (BFKL) Pomeron are dealt in a unified single step.

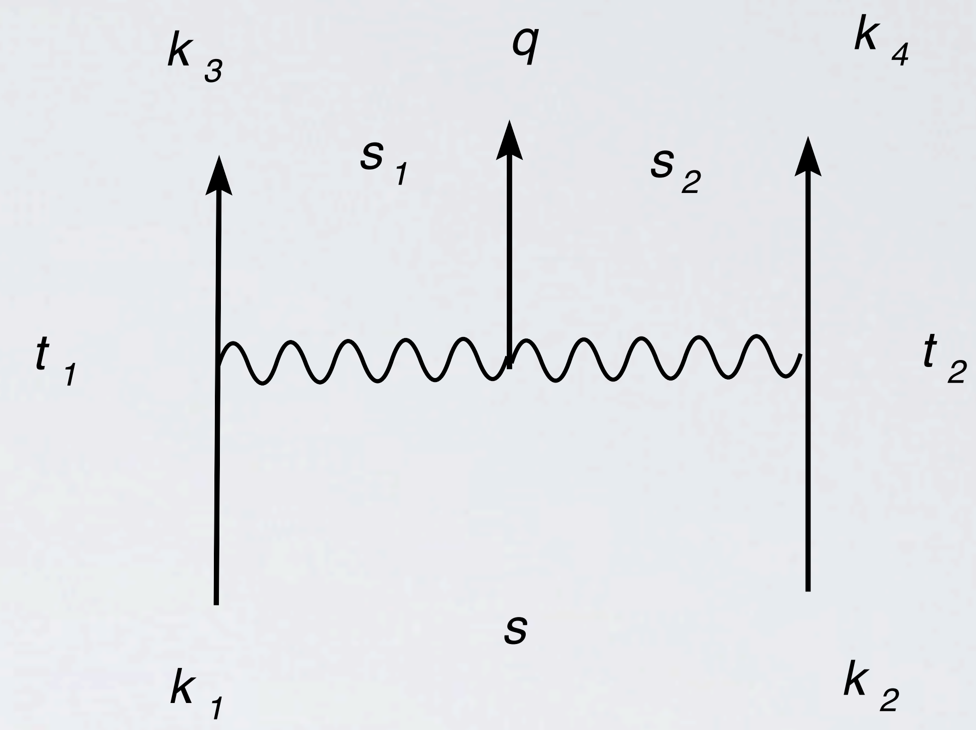
R. Brower, J. Polchinski, M. Strassler, and C-I Tan, "The Pomeron and Gauge/String Duality", (hep-th/0603115.)

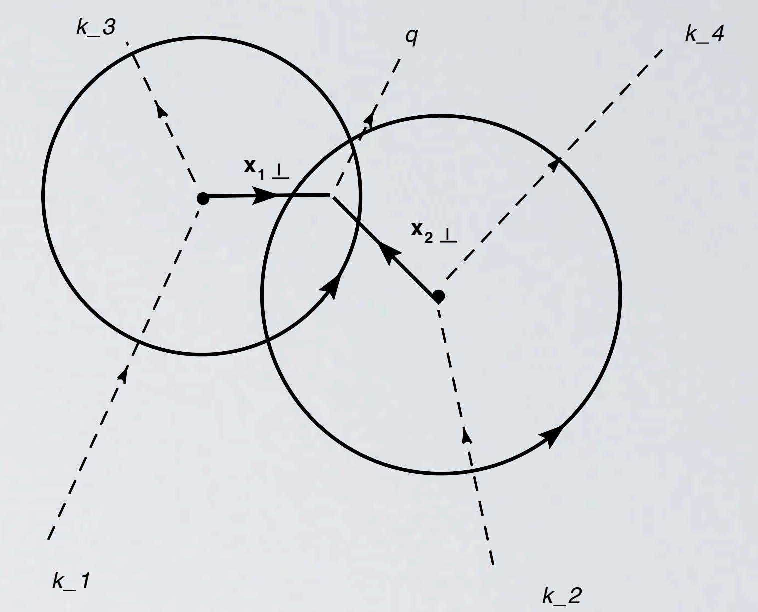
DOUBLE DIFFRACTIVE HIGGS PRODUCTION

- Kinematics:
- Basic Building Block:
- New Feature:



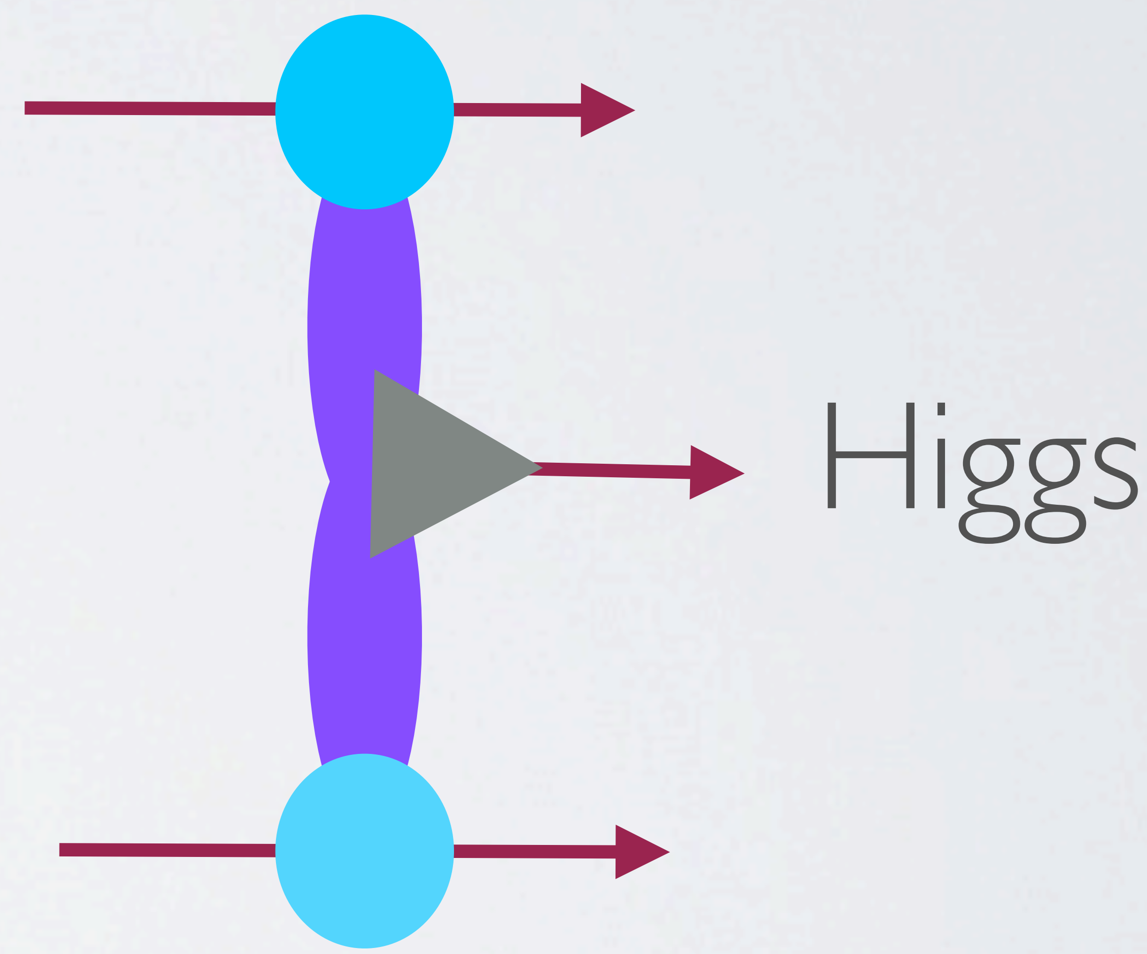
KINEMATICS:





- Longitudinal Phase Space:

$$s >> s_1, s_2 >> t_1, t_2$$



- Transverse Correlation:

$$t_1 \simeq -q_{3,\perp}^2, \quad t_2 \simeq -q_{4,\perp}^2$$

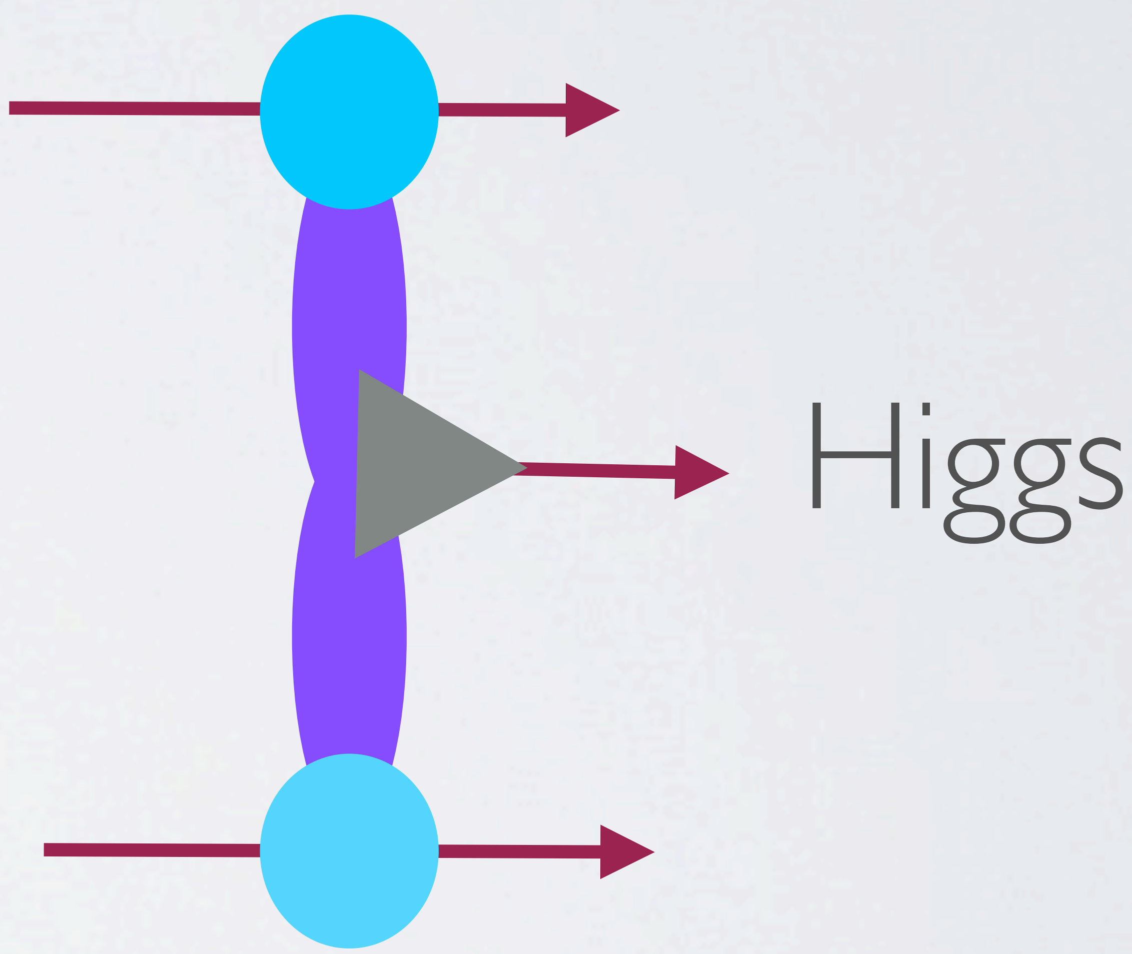
$$\kappa = \frac{s_1 s_2}{s} \simeq m_H^2 + q_{H,\perp}^2$$

BASIC BUILDING BLOCK

- Elastic Vertex:
- Pomeron/Graviton Propagator:

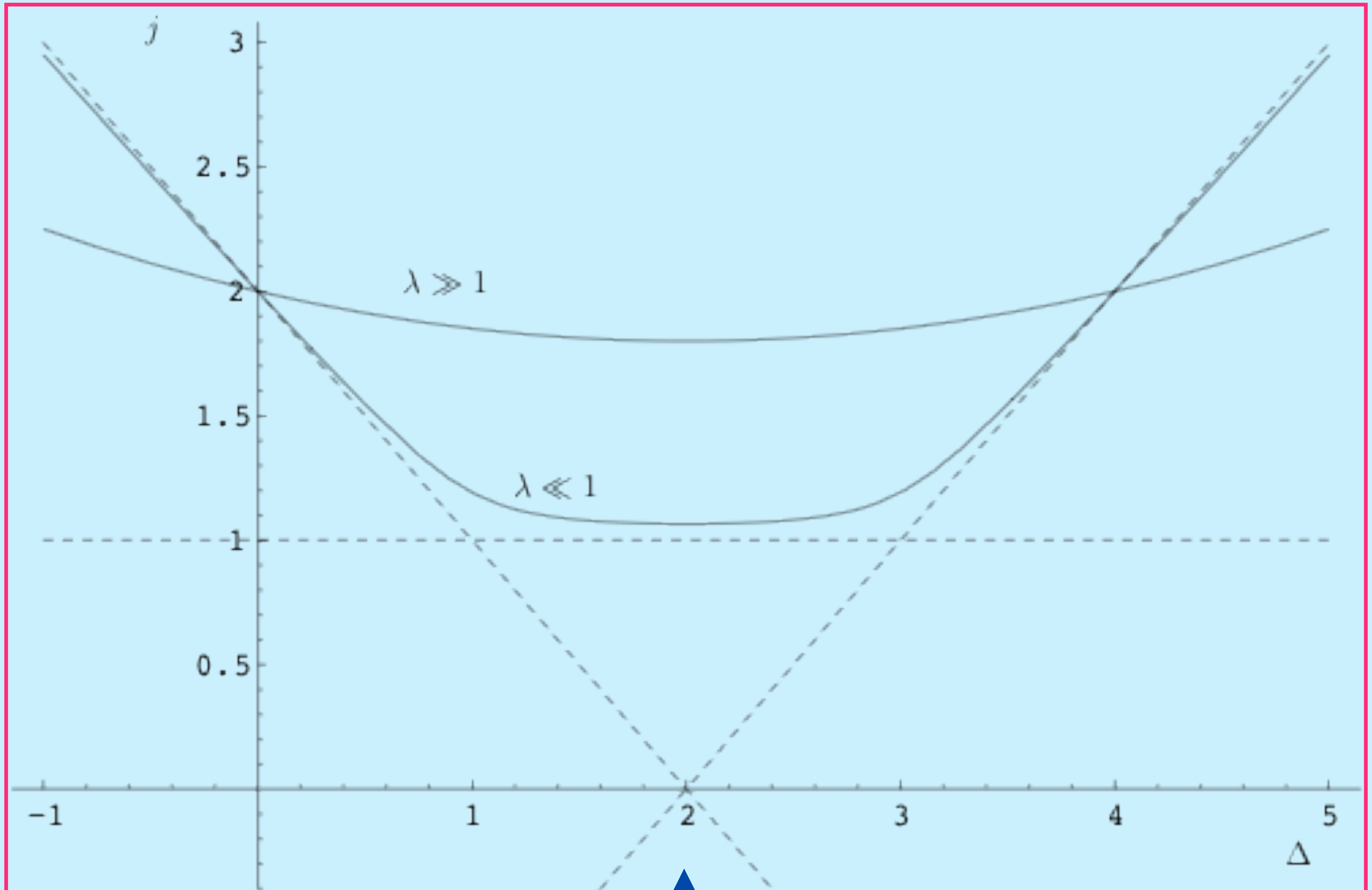
$$G_j(z, x^\perp, z', x'^\perp) = \frac{1}{4\pi z z'} \frac{e^{(2-\Delta(j))\xi}}{\sinh \xi} \;,$$

$$\Delta(j) = 2 + \sqrt{2}\, \lambda^{1/4} \sqrt{(j - j_0)}$$



$$\mathcal{K}(s, b, z, z') = -\left(\frac{(zz')^2}{R^4}\right) \int \frac{dj}{2\pi i} \left(\frac{1 + e^{-i\pi j}}{\sin \pi j}\right) \widehat{s}^j \, G_j(z, x^\perp, z', x'^\perp; j)$$

$\mathcal{N}$ = 4 SYM LEADING TWIST DELTA(J) VS J



$\lambda = 0$ DGLAP (DIS moments)

$Tr[F_{+\mu} D_+^{j-2} F_+^{\mu}]$

(0,2) $T_{\mu\nu}$ $\gamma = 0$

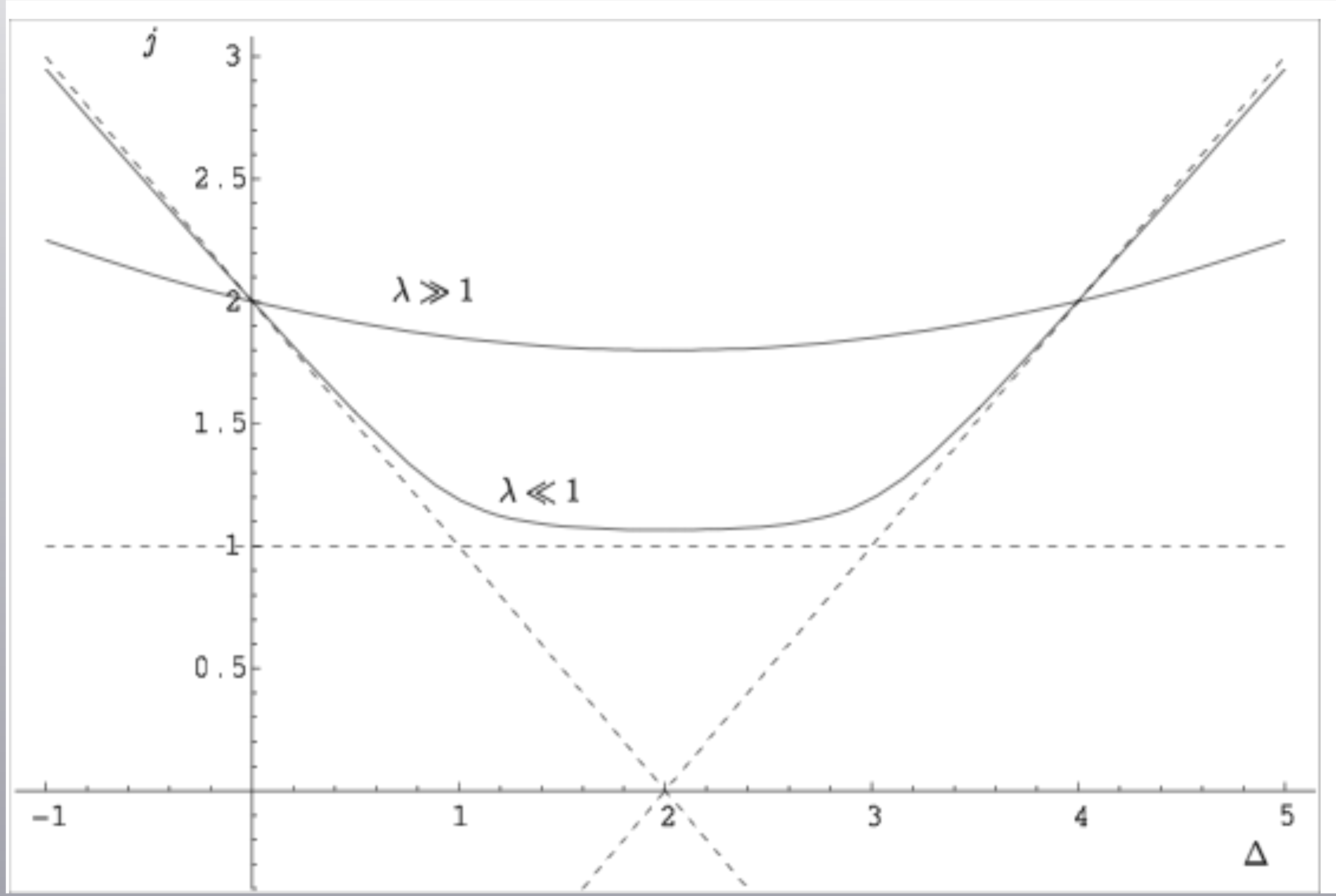
$\lambda = 0$, BFKL

$\lambda = g^2 N = 0$

$j = j_0$ @ min Δ

MOMENTS AND ANOMALOUS DIMENSION

$$M_n(Q^2) = \int_0^1 dx\, x^{n-2} F_2(x, Q^2) \to Q^{4-\Delta_n}$$



$$\gamma_2 = 0$$

$$\Delta(j) = 2 + \sqrt{2}\sqrt{\sqrt{g^2 N_c}(j - j_0)}$$

$$\gamma_n = 2\sqrt{1 + \sqrt{g^2 N}(n-2)/2} - n$$

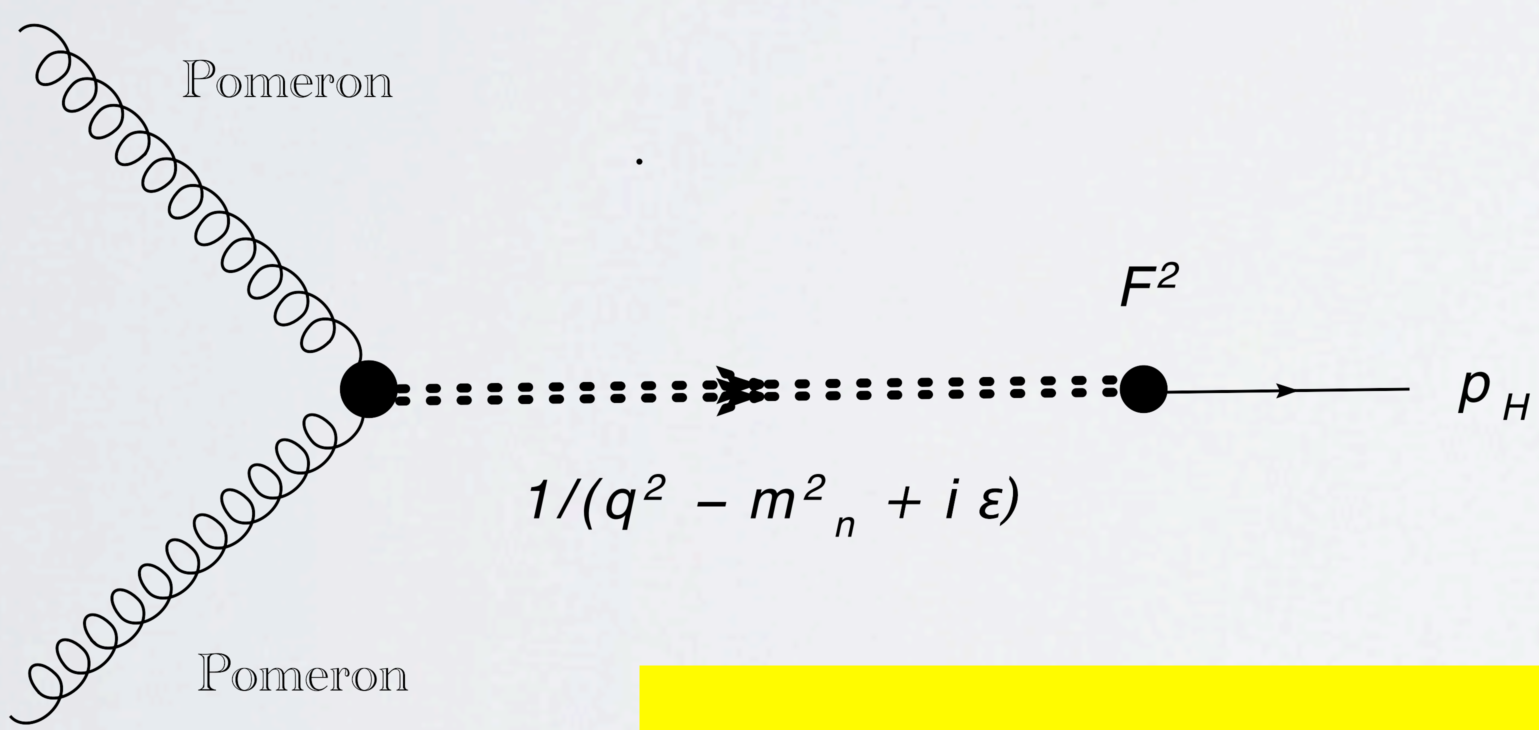
Simultaneous compatible large Q^2 and small x evolutions!

Energy-Momentum Conservation built-in automatically.

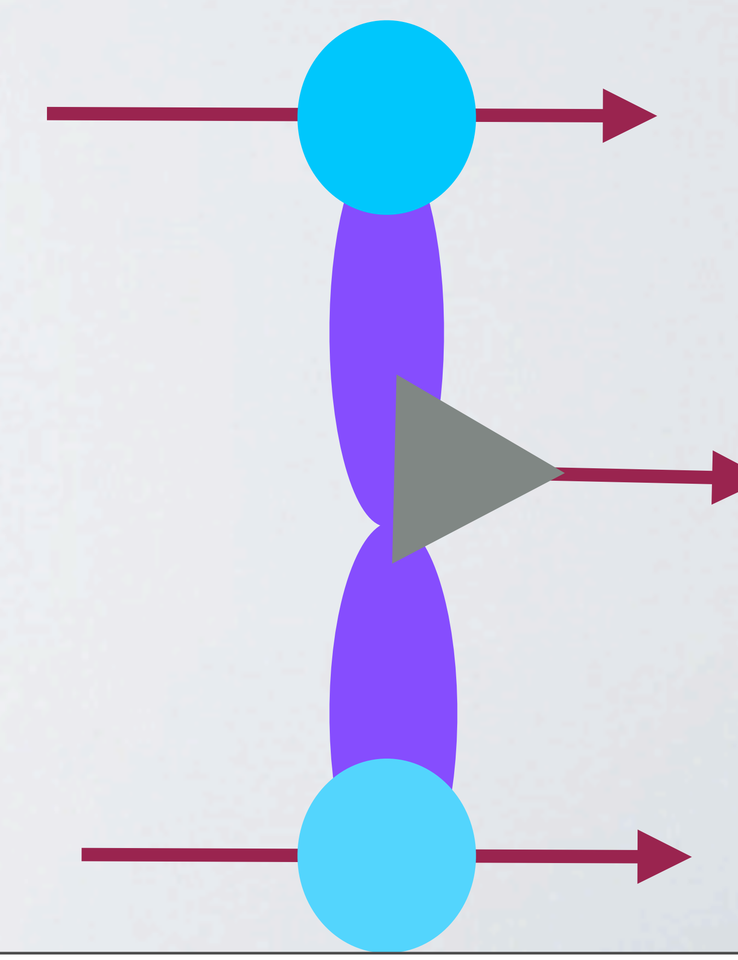
NEW FEATURE: POMERON-POMERON FUSION VERTEX

- Higgs coupled to Heavy quarks: $$\mathcal{L} = -\frac{g}{2M_W} m_t \, \bar{t}(x) t(x) \phi_H(x) \, .$$

- Integrating out heavy quarks leads to coupling to F^2: $$\mathcal{L} = \frac{\alpha_s g}{24\pi M_W} F^a_{\mu\nu} F^{a\mu\nu} \phi_H = L(m_H^2) F^a_{\mu\nu} F^{a\mu\nu} \phi_H$$



$$\mathcal{V}_H = V_{PP\phi} * K(m_H^2, z) * L(m_H^2)$$



CENTRAL VERTEX AND SCALAR INVARIANCE

- In scale invariance theory with exact AdS5-background, graviton-graviton-dilaton vertex vanishes identically
- To have non-vanishing expectation values for $\langle F^2\rangle, \langle F^2 T_{\mu\nu}\rangle, \langle F^2 T_{\mu\nu} T_{\mu'\nu'}\rangle,$ scale invariance must be broken.
- With Confinement deformation, will have non-vanishing

$$\langle F^2\rangle, \langle F^2 T_{\mu\nu}\rangle, \langle F^2 T_{\mu\nu} T_{\mu'\nu'}\rangle \neq 0,$$

- Will also have non-vanishing graviton-graviton-dilaton vertex: $V_{PP\phi} \neq 0$

MODEL FOR CONFINEMENT DILATON GRAVITY

$$S = M_P^2 \int d^5x \sqrt{g} \Big(-\mathcal{R} - V(\phi) + \frac{1}{2} G^{MN} \partial_M \phi \partial_N \phi - \lambda(\phi) T(z) \Big)$$

$$G_{mn} = g_{mn} + h_{mn} \qquad \phi = \phi_{cl} + \varphi$$

- Constant Background: $\phi_{cl} = constant \qquad V_{PP\phi} = 0$
- Non-trivial background: $\phi_{cl} \neq constant \qquad V_{PP\phi} \neq 0$

$$S_{int} = \frac{M_P^2}{4} \int dz d^4x \sqrt{-g} h^{nm} h_{mn} [V'(\phi_{cl})\varphi - g^{zz} \partial_z \phi_{cl}(z) \partial_z \varphi] \, .$$

- Asymptotic Freedom -- “coupling” running with “scale” in UV:

PHENOMENOLOGICAL ESTIMATES FOR DIFFRACTIVE HIGGS PRODUCTION

- Normalizing Pomeron-Pomeron-Higgs coupling by trace-anomaly by going on-shell

$$\gamma_{GGH}(q^2=0)=\frac{2M_G^2}{3vb}=2^{1/4}G_F^{1/2}\frac{2M_G^2}{27}$$

- Use Strong Coupling Pomeron/Graviton Kernel to continue back to scattering region where t<0.

- Use phenomenological parametrization for diffraction peaks.

- Estimate double-Pomeron Higgs production:

$$\frac{d\sigma}{dy_H}\simeq(1/\pi)\times m_1^{-4}\times|\gamma_{GGH}(0)|^2\times\frac{\sigma(s)}{\sigma(m_H^2)}\times R_{el}^2(m_H\sqrt{s})$$

III. Beyond Pomeron

- Sum over all Pomeron graph (string perturbative, $1/N^2$)
- Eikonal summation in AdS_3
- Constraints from Conformal Invariance, Unitarity, Analyticity, Confinement, Universality, etc.
- Froissart Bound?
- Other "non-perturbative"

It is convenient to introduce the "eikonal" $\chi(s, b, z, z')$ since we will show shortly that it is possible to express the amplitude in an eikonal sum as

$$A(s,t) = 2is \int d^2b e^{i\vec{q}\cdot\vec{b}} \int dz dz' P_{13}(z) P_{24}(z') \{1 - e^{i\chi(s,b,z,z')}\},$$

To first order in the eikonal,

$$A_4(s,t) \simeq \int d^2b e^{-i\mathbf{b}\mathbf{q}_\perp} \int dz dz' P_{13}(z) P_{24}(z') \left(2s\chi(s,b,z,z')\right),$$

where

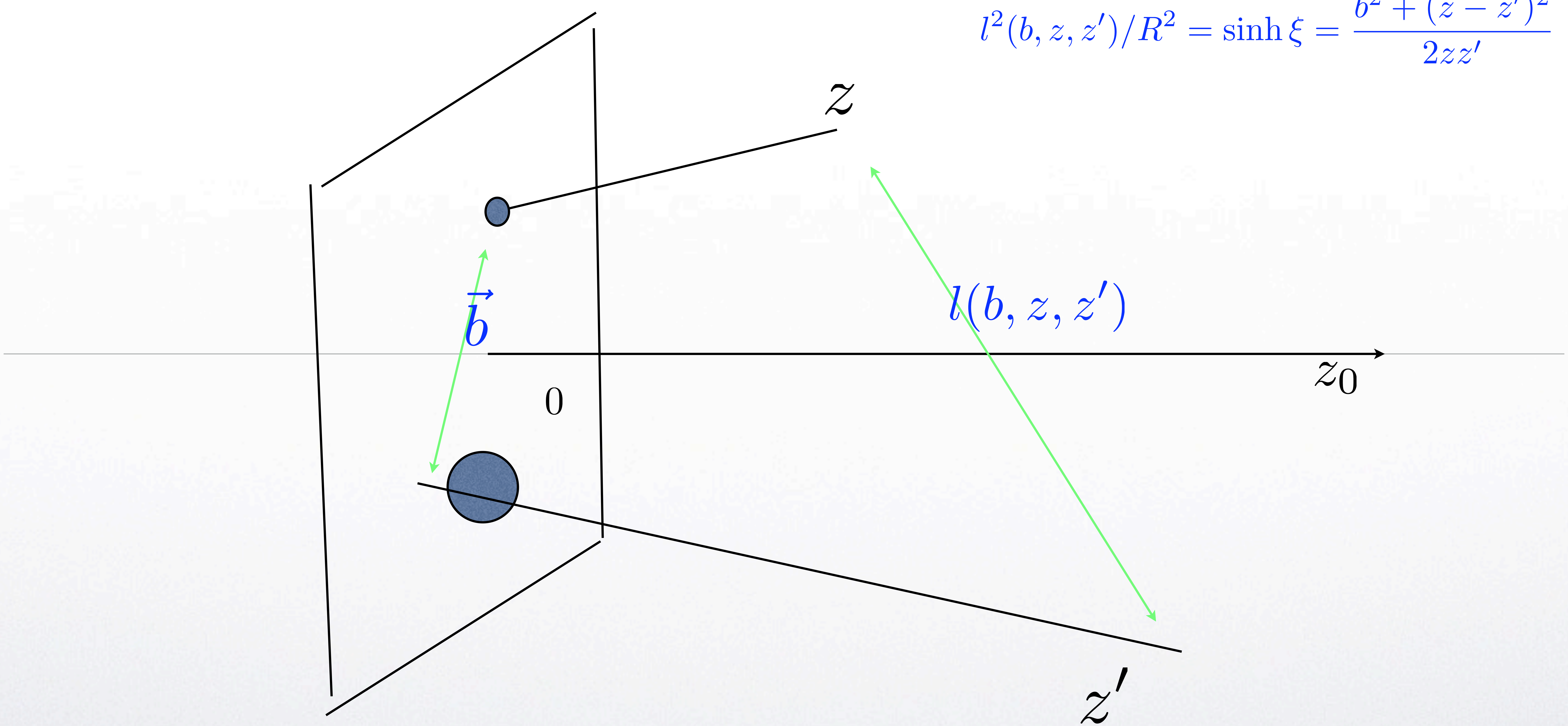
$$\chi(s,b,z,z') = \frac{g_0^2 R^4}{2(zz')^2 s} \mathcal{K}(s,b,z,z')$$

$\mathcal{K}$ is the BPST Pomeron kernel.

Geometry of Transverse AdS-3

chordal distance: $l(b, z, z')$

$$l^2(b, z, z')/R^2 = \sinh \xi = \frac{b^2 + (z - z')^2}{2zz'}$$



CONCLUDING COMMENTS

- Remarkable strong/weak correspondence
- Natural synthesis of near conformal & breaking:
  - IR (confinement) and UV (asymptotic freedom)
- By Non-pert. QCD-2013:
  - xsection for Double Diffractive Higgs observed,
  - Pomeron-Pomeron Higgs fusion better understood.
  - Constrained by
    - total cross section
    - DIS at small x, etc.