HOLOGRAPHIC HIGGS PRODUCTION AND THE ADS GRAVITON (POMERON)

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Richard Brower, Marko Djurić, Ina Sarcević and Chung-I Tan: *String-Gauge Dual Description of DIS and Small-x*, 10.1007/JHEP 11(2010)051, arXiv:1007.2259

Richard Brower, Marko Djurić and Chung-I Tan: *Holographic Higgs Production by Pomeron Fusion*, (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), (e.g., Miguel’s talk)

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., work by Kovchegov et al., more recent work by Y. Bartel, et al., etc.)

Executive Summary:

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

Goals:

- Establishing "Pomeron" in QCD non-perturbatively,
- Unification of Soft and Hard Physics in High Energy Collision
- New phenomenology based on "Large Pomeron intercept", e.g., DIS at small-x: (DGLAP vs Pomeron); Central Diffractive Higgs Production.

Outline

- QCD High Energy Scattering with AdS/CFT
- Higher Order Effects: Froissart Bound, and Eikonal Sum
- Application: Deep Inelastic Scattering at Small-x: (universality) and Diffractive Higgs Production at LHC: (scale inv. breaking)
- Summary

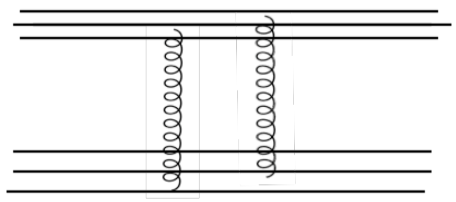
I. Gauge/String Duality

QCD Pomeron as “metric fluctuations” in AdS

- Strong <==> Weak duality
- Symmetry of CFT <==> Geometry of AdS
- High Energy Scattering
- Confinement

Two gluon exchange (Low-Nussinov Pomeron!)

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

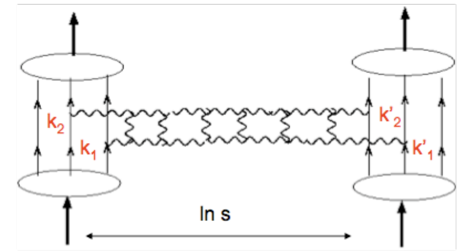


F.E. Low. Phys. Rev. D 12 (1975), p. 163.
S. Nussinov. Phys. Rev. Lett. 34 (1975), p. 1286.

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

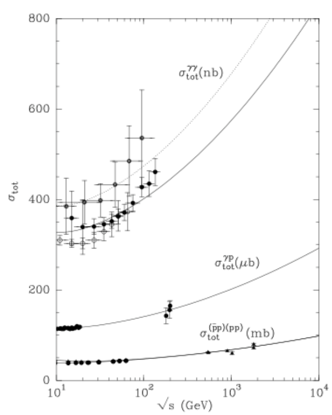
$t = -(k_1 + k_2)^2$ →

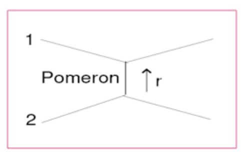
$\lambda = g^2 N_c \sim 0$



- ❑ Sum diagrams 1st order in $g^2 N_c$ & all orders $(g^2 N_c \text{ logs})^n$
- ❑ 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

AdS/CFT: degrees of freedom

Weak Coupling:

Gluons and Quarks: $A_\mu^{ab}(x), \psi_f^a(x)$

Gauge Invariant Operators: $\bar{\psi}(x)\psi(x), \;\; \bar{\psi}(x)D_\mu\psi(x)$

$S(x) = TrF_{\mu\nu}^2(x), \;\; O(x) = TrF^3(x)$

$T_{\mu\nu}(x) = TrF_{\mu\lambda}(x)F_{\lambda\nu}(x), \;\; etc.$

$$\mathcal{L}(x) = -TrF^2 + \bar{\psi}\not{D}\psi + \cdots$$

Strong Coupling:

Metric tensor: $G_{mn}(x) = g_{mn}^{(0)}(x) + h_{mn}(x)$

Anti-symmetric tensor (Kalb-Ramond fields): $b_{mn}(x)$

Dilaton, Axion, etc. $\phi(x), \; a(x), \; etc.$

Other differential forms: $C_{mn\cdots}(x)$

$$\mathcal{L}(x) = \mathcal{L}(G(x), b(x), C(x), \cdots)$$

$\mathcal{N} = 4$ SYM Scattering at High Energy

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

Bulk Degrees of Freedom from type-IIB Supergravity on AdS_5:

- metric tensor: G_{MN}
- Kalb-Ramond 2 Forms: B_{MN}, C_{MN}
- Dilaton and zero form: ϕ and C_0

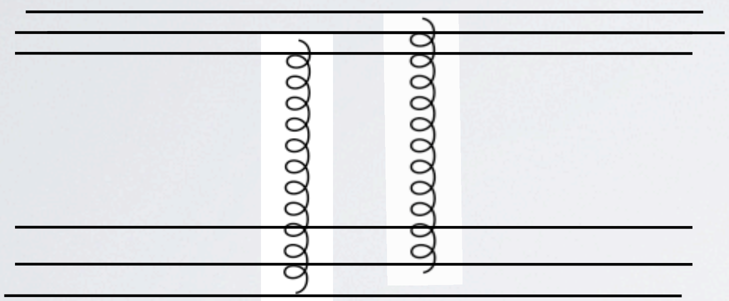
$$\lambda = g^2 N_c \to \infty$$

Supergravity limit

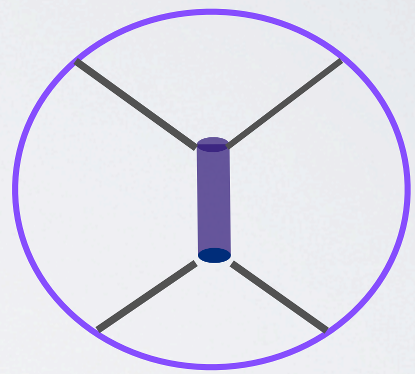
- Strong coupling
- Conformal
- Pomeron as Graviton in AdS

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

WEAK: TWO GLUON <=> STRONG: ADS GRAVITON



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

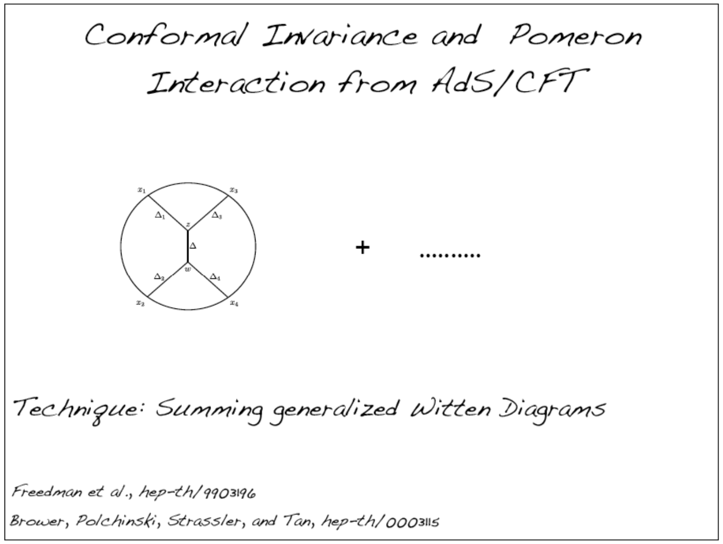


$$J = 2$$

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

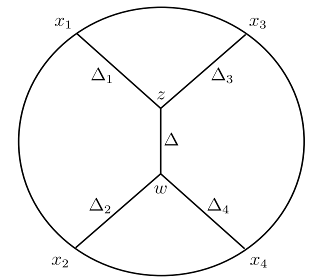
F.E. Low. Phys. Rev. D 12 (1975), p. 163.
S. Nussinov. Phys. Rev. Lett. 34 (1975), p. 1286.

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



- Draw all "Witten-Feynman" Diagrams in AdS_5,
- High Energy Dominated by Spin-2 Exchanges:

$$p_1 + p_2 \to p_3 + p_4$$



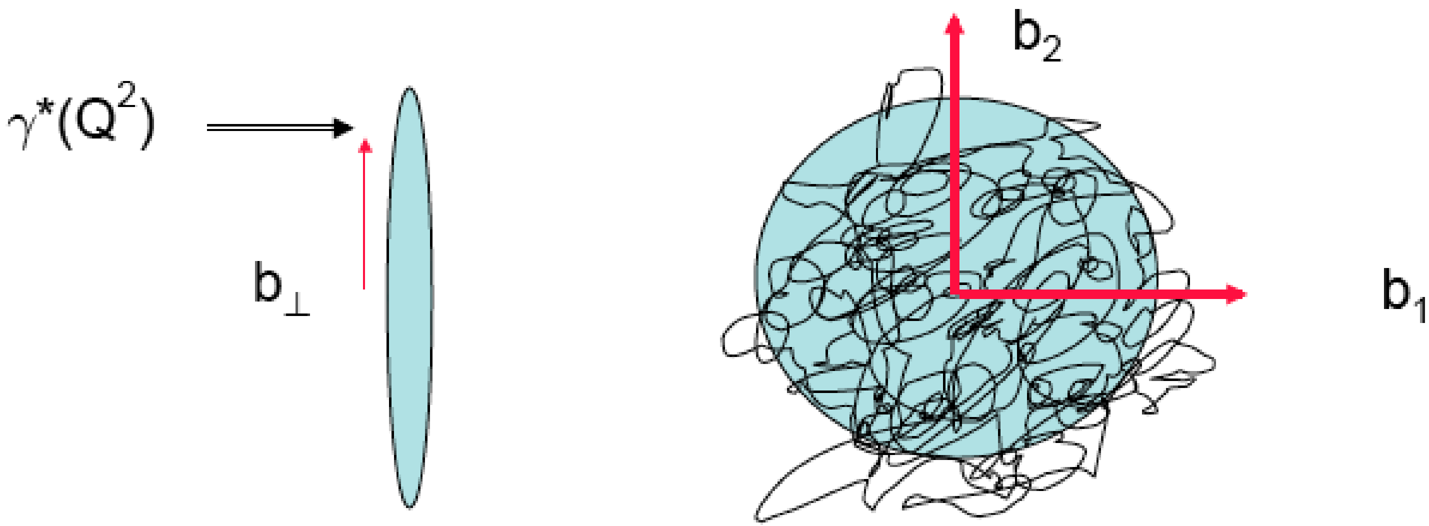
One Graviton Exchange at High Energy

$$T^{(1)}(p_1,p_2,p_3,p_4) = g_s^2 \int \frac{dz}{z^5} \int \frac{dz'}{z'^5}\, \tilde\Phi_\Delta(p_1^2,z)\tilde\Phi_\Delta(p_3^2,z)\mathcal{T}^{(1)}(p_i,z,z')\tilde\Phi_\Delta(p_2^2,z')\tilde\Phi_\Delta(p_4^2,z')$$

$$\mathcal{T}^{(1)}(p_i,z,z') = (z^2 z'^2 s)^2 G_{++,--}(q,z,z') = (zz's)^2 G^{(5)}_{\Delta=4}(q,z,z')$$

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 $z' = 1/Q'$)

Additional Steps for QCD:

- Spin-2 leads to too rapid an increase for cross sections

  Need to consider $\lambda = g^2 N$ finite.

- Confinement:

  Conformal, therefore no scale and no particles, etc.

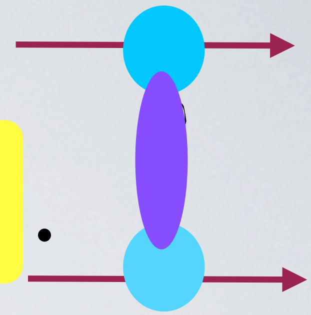
- Short-distance: Running Coupling

Brower, Polchinski, Strassler, and Tan: "The Pomeron and Gauge/String Duality," hep-th/063115

ADS BUILDING BLOCKS BLOCKS

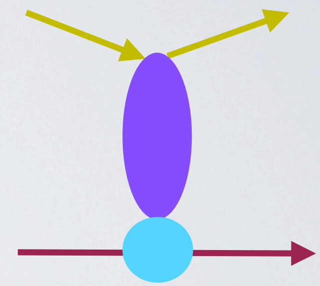
For 2-to-2

$$A(s,t) = \Phi_{13} * \widetilde{\mathcal{K}}_P * \Phi_{24}\,.$$



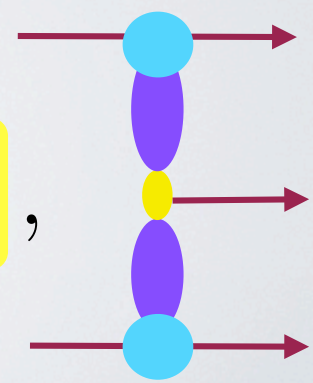
$$A(s,t) = g_0^2 \int d^3\mathbf{b}\, d^3\mathbf{b}'\; e^{i\mathbf{q}_\perp\cdot(\mathbf{x}-\mathbf{x}')}\; \Phi_{13}(z)\; \mathcal{K}(s,\mathbf{x}-\mathbf{x}',z,z')\; \Phi_{24}(z')$$

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

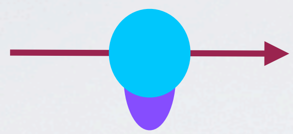


For 2-to-3

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



BASIC BUILDING BLOCK

- Elastic Vertex: 

- Pomeron/Graviton Propagator: 

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

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

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

confinement: $G_j(z,x^\perp,z',x'^\perp;j)$ → discrete sum

Diffusion in AdS: $(\lambda < \infty)$

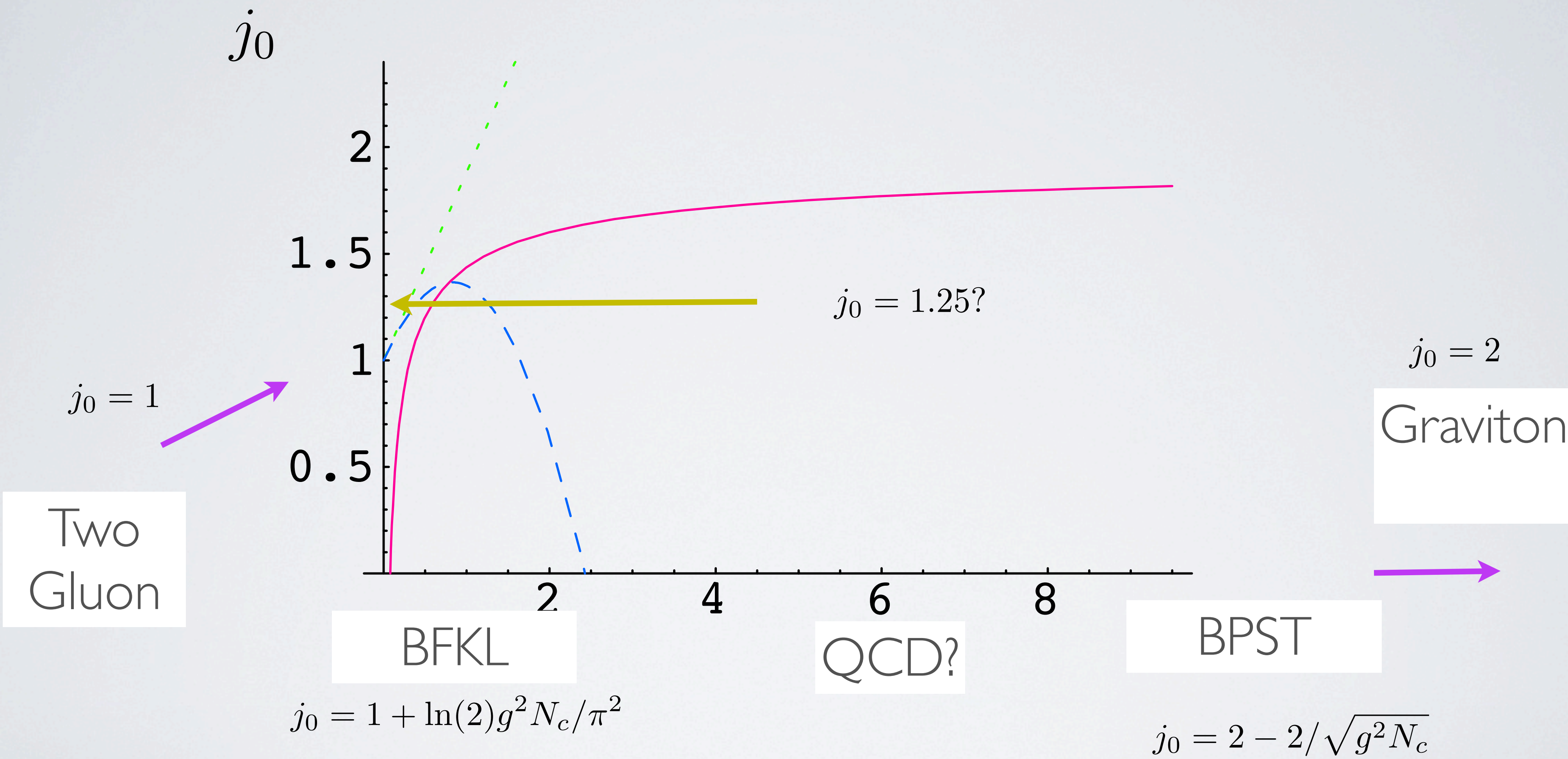
At finite λ, due to Diffusion in AdS

- Graviton (Pomeron) becomes j-plane singularity at

$$j_0 : \quad 2 \rightarrow 2 - 2/\sqrt{\lambda}$$

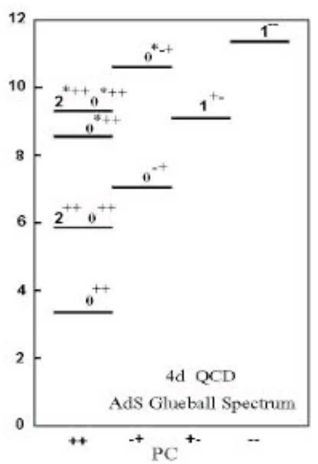
- Conformal: No scale and it is a branch cut, not a Regge trajectory

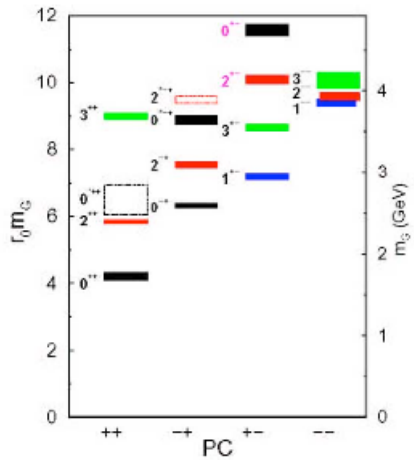
$\mathcal{N} = 4$ Strong vs Weak $g^2 N_c$

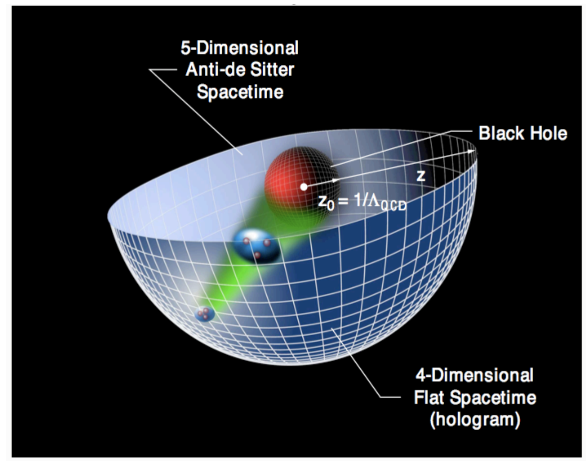


Confinement Deformation: Glueball Spectrum

$(\lambda = \infty)$







Four-Dimensional Mass:

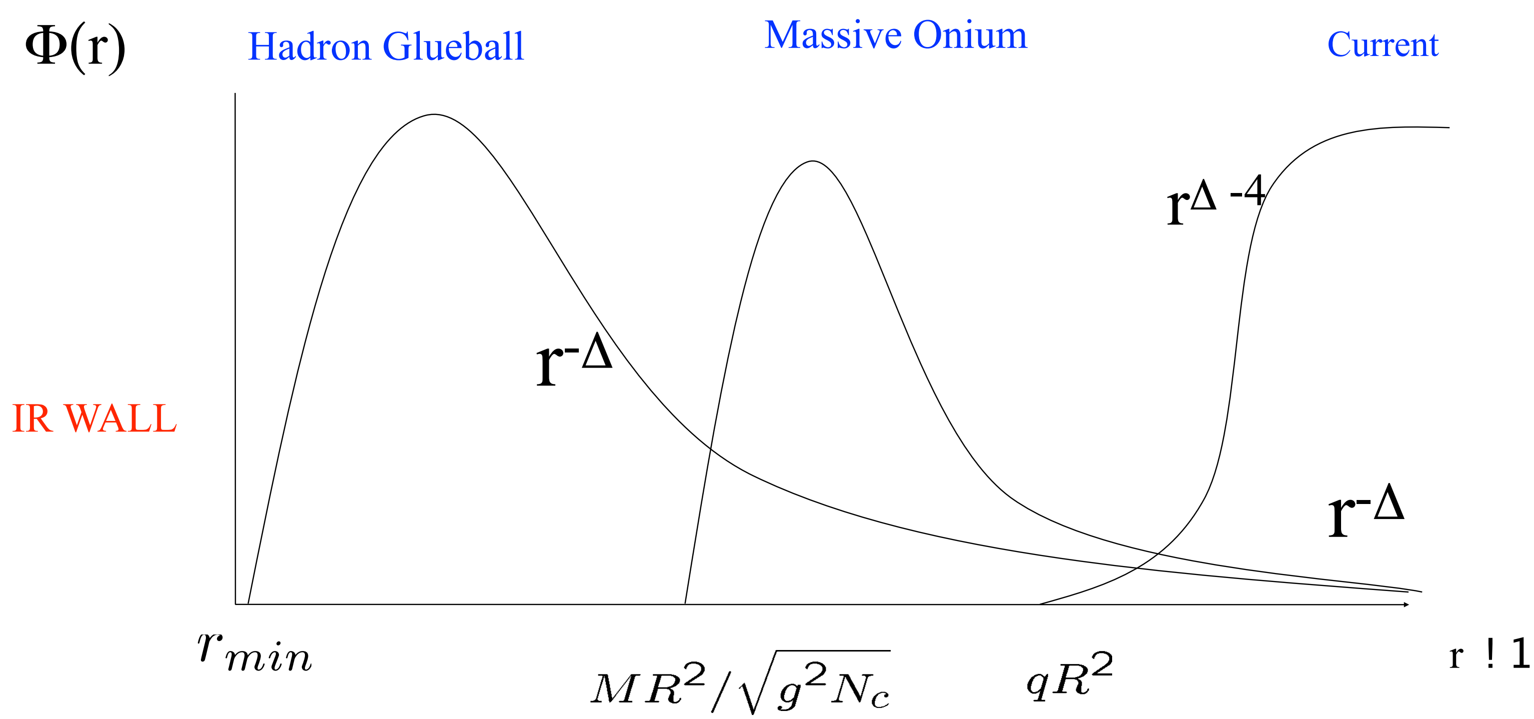
$$E^2 = (p_1{}^2 + p_2{}^2 + p_3{}^2) + M^2$$

5-Dim Massless Mode:

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

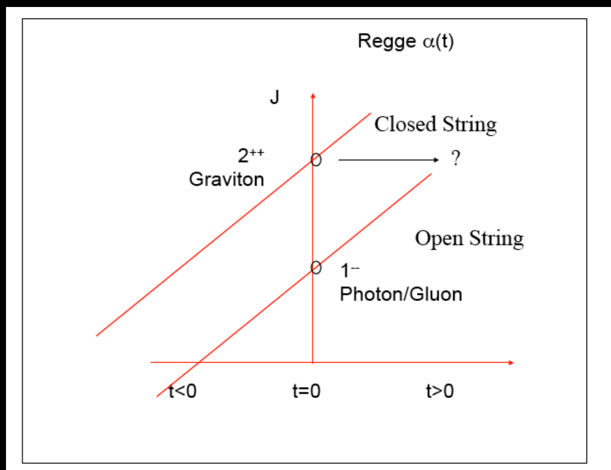
- Universality and Holographic:

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

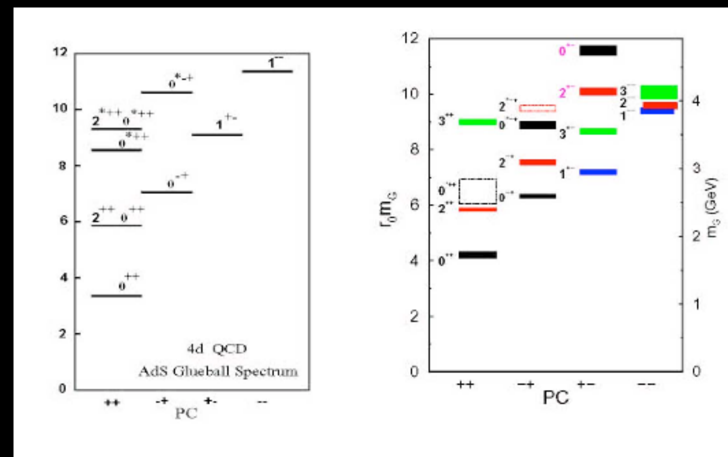


QCD Pomeron <===> Graviton (metric) in AdS

Flat-space String



Confinement



Conformal Invariance

Fixed cut in J-plane:

j_0

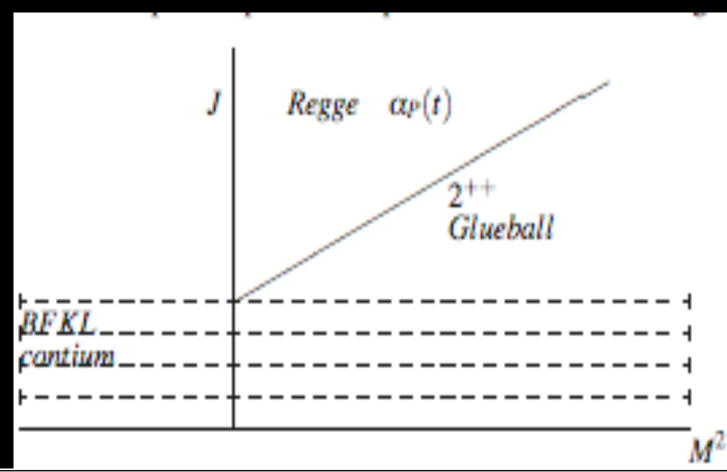
Weak coupling:
(BFKL)

$$j_0 = 1 + \frac{4\ln 2}{\pi}\alpha N$$

Strong coupling:

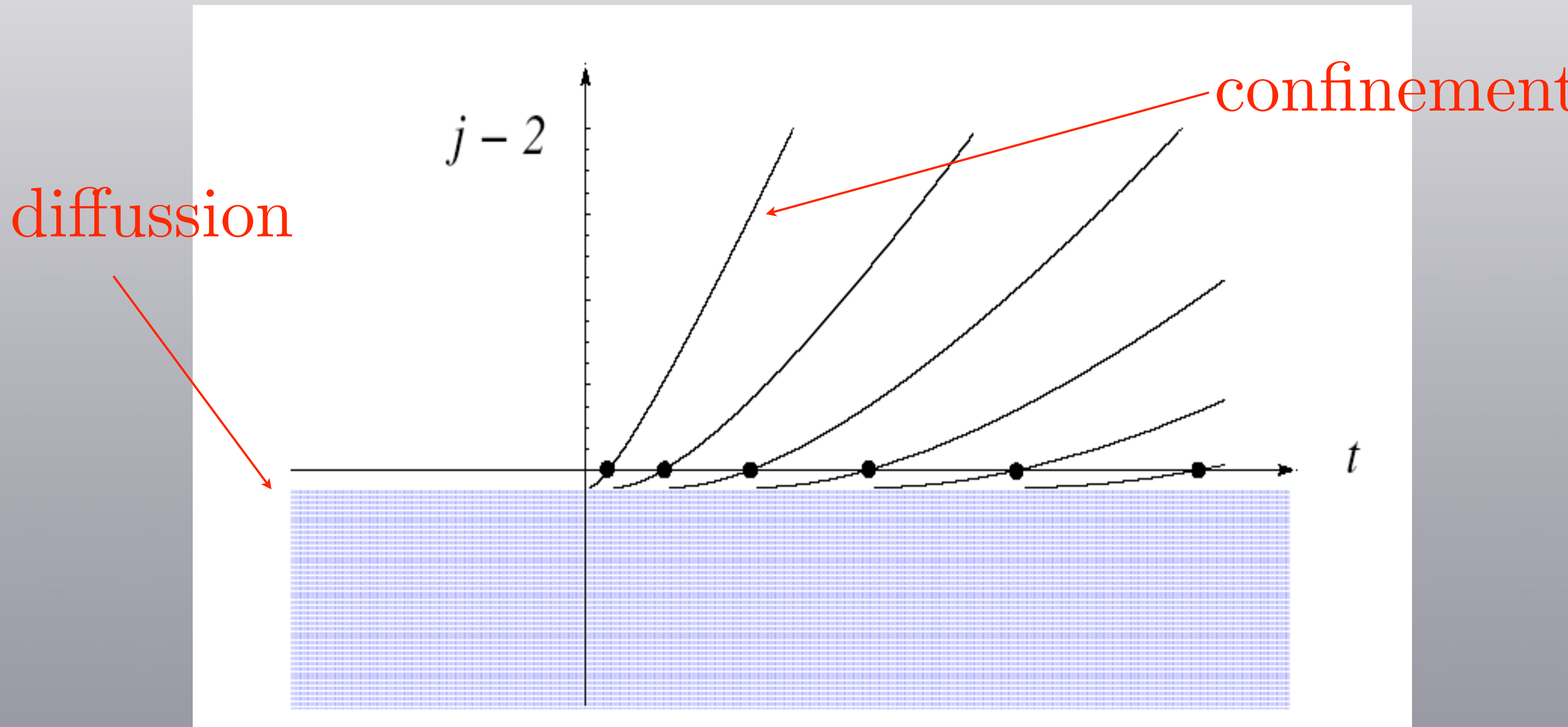
$$j_0 = 2 - \frac{2}{\sqrt{\lambda}}$$

Pomeron in AdS Geometry



Unified Hard (conformal) and Soft (confining) Pomeron

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



AdS/CFT ===>

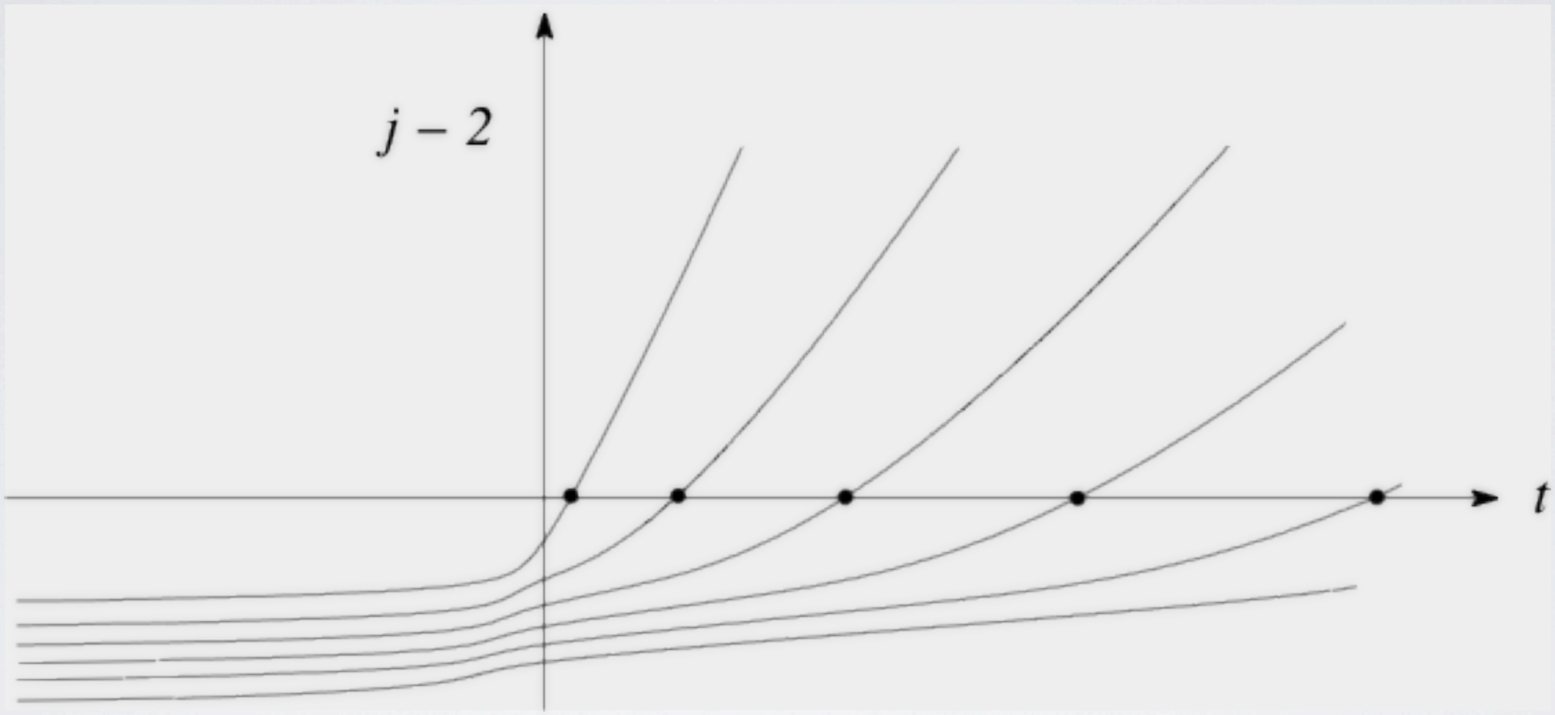
In gauge theories with string-theoretical dual descriptions, the Pomeron emerges unambiguously.

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.)

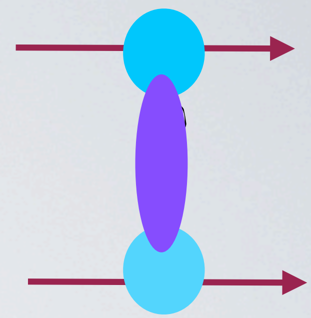
(STRONG) RUNNING



III. Double Diffractive Higgs Production

ELASTIC, DIS, DOUBLE HIGGS: ADS BUILDING BLOCKS

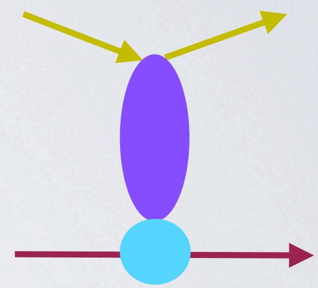
$$A(s,t) = g_0^2 \int d^3\mathbf{b} d^3\mathbf{b}' \, e^{i\mathbf{q}_\perp \cdot (\mathbf{x}-\mathbf{x}')} \, \Phi_{13}(z) \, \mathcal{K}(s, \mathbf{x}-\mathbf{x}', z, z') \, \Phi_{24}(z')$$



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

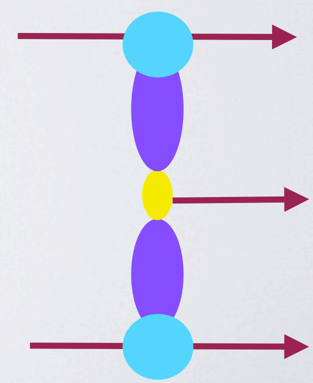
$$d^3\mathbf{b} \equiv dz d^2 x_\perp \sqrt{-g(z)} \quad \text{where} \quad g(z) = \det[g_{nm}] = -e^{5A(z)}$$

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

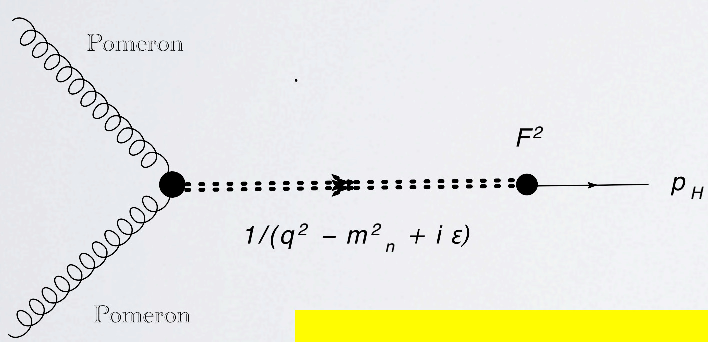


$$A(s_1, s_2, s, t_1, t_2) = \Phi_{13} * \mathcal{K}_1 * \mathcal{V}_H * \mathcal{K}_2 * \Phi_{24}$$

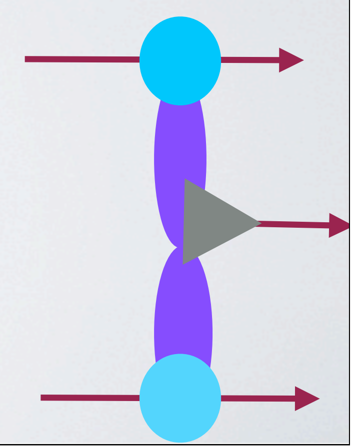
NEW FEATURE: POMERON-POMERON FUSION VERTEX

- 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: $$\mathcal{L} = \frac{\alpha_s g}{24\pi M_W} F^a_{\mu\nu} F^{a\mu\nu} \phi_H = L(m_H^2) F^a_{\mu\nu} F^{a\mu\nu} \phi_H$$



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



MODEL FOR CONFINEMENT DILATON GRAVITY

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

$$G_{mn} = g_{mn} + h_{mn}$$

$$\phi = \phi_{cl} + \varphi$$

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

- Constant Background: $\phi_{cl} = constant \qquad V_{PP\phi} = 0$
- Non-trivial background: $\phi_{cl} \neq constant \qquad V_{PP\phi} \neq 0$
- Asymptotic Freedom -- "coupling" running with "scale" in UV:

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: $V_{PP\phi} \neq 0$

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.

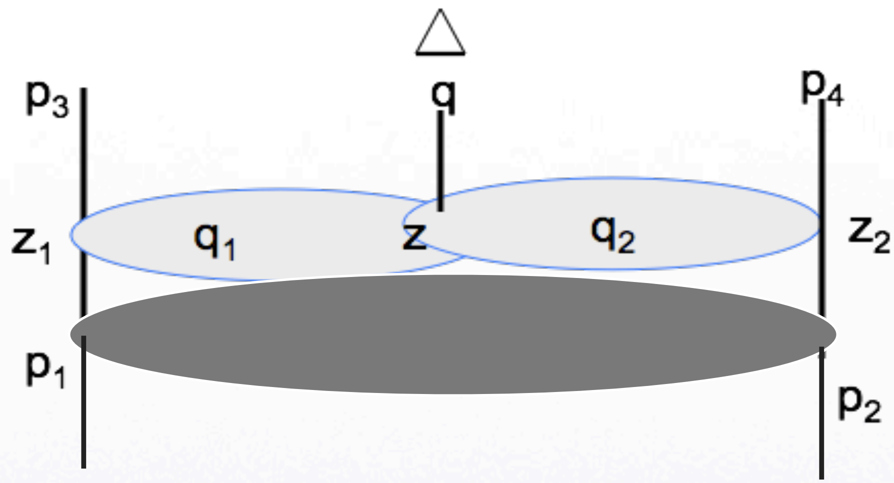
- Use phenomenological parametrization for diffraction peaks.

- Estimate double-Pomeron Higgs production:

$$\frac{d\sigma}{dy_H} \simeq (1/\pi)\times C' \times m_1^{-4} \times |\gamma_{GGH}(0)|^2 \times \frac{\sigma(s)}{\sigma(m_H^2)} \times R_{el}^2(m_H\sqrt{s}) \simeq .8 \sim 1.2 \ \ \text{pbarn}$$

Next Calculation: Survival Probability

Double Regge (Pomeron) exchange



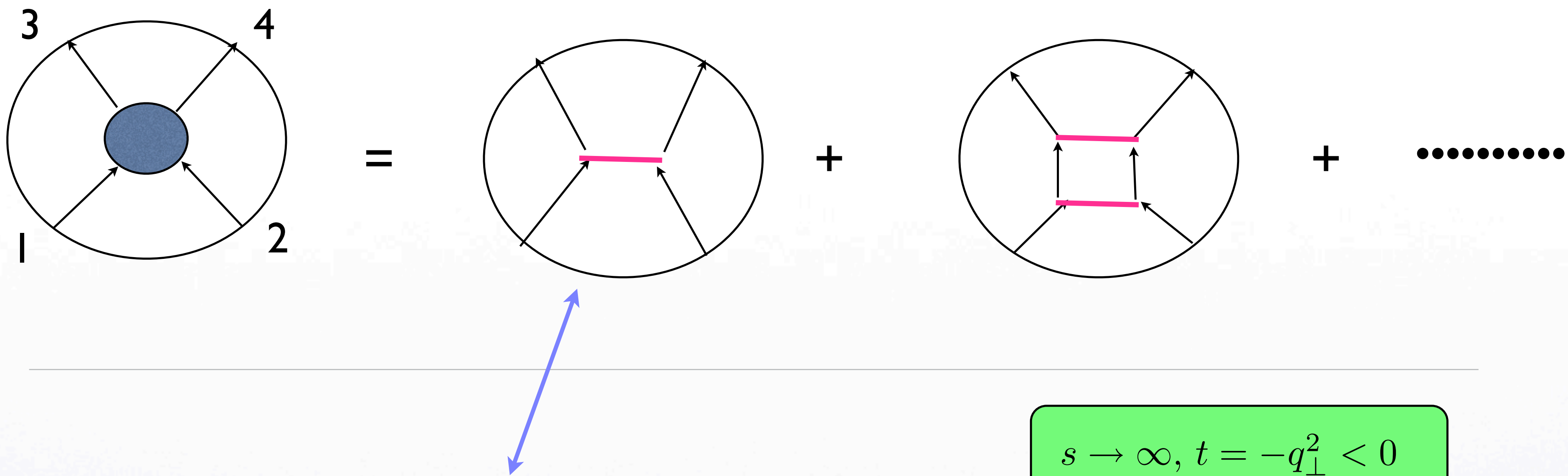
Competing factors in regions of importance, e.g., confinement, (

Reducing Cross Section to fbarn range.

II. 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?
- "non-perturbative" (e.g., blackhole production)

Higher Orders Witten Diagrams:



$s \to \infty,\ t = -q_\perp^2 < 0$

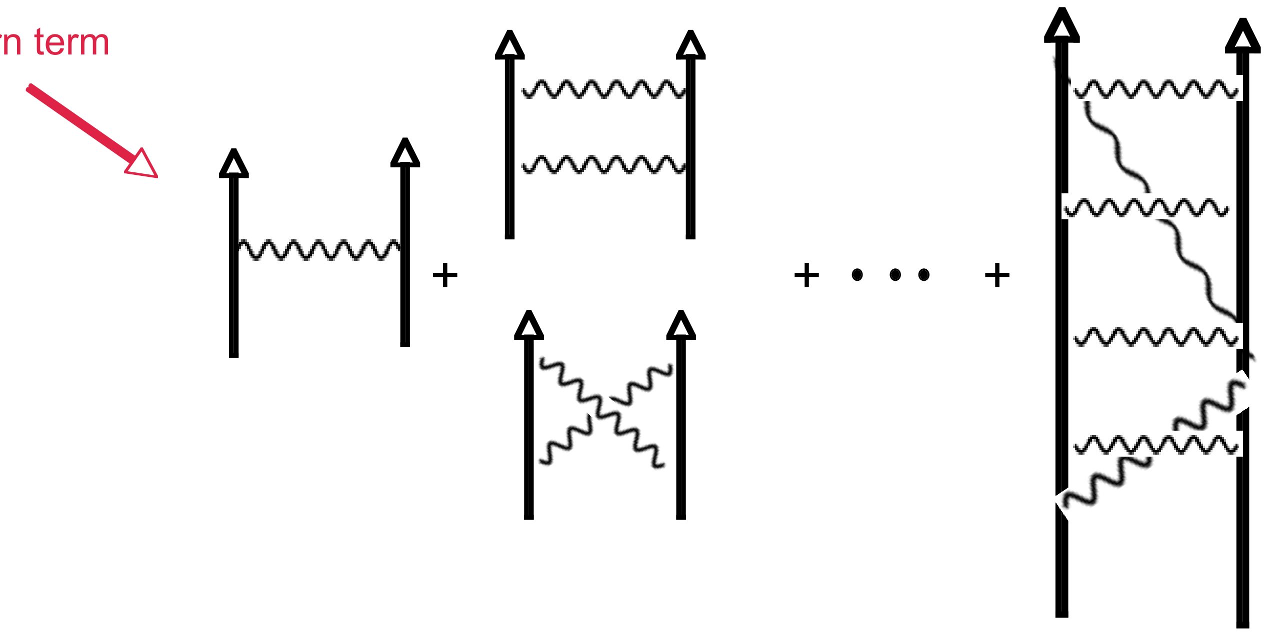
$$A_4(s,t) \simeq \int d^2b\, e^{-i\mathbf{b}\cdot\mathbf{q}_\perp} \int d\mu(z) \int d\mu(z')$$

$$\times \quad \phi_1(z,\mathbf{b})\phi_3(z,\mathbf{b})\mathcal{K}(s,\mathbf{b}-\mathbf{b}',z,z')\phi_2(z',\mathbf{b}')\phi_4(z',\mathbf{b}')$$

Eikonal Expansion

$$A_1(s, t = -q_\perp^2) \simeq 2s \int d^2 b e^{-iqb} \chi(s,b) = 2s\chi(s, q_\perp)$$

Born term



"sum" to get $$A_{eikonal}(s,t) = -2is \int d^2 b e^{-iqb} [e^{i\chi(s,b)} - 1] \,,$$

- # Eikonal Sum: derived both via Cheng-Wu or by Shock-wave method

$$A_{2\to 2}(s,t) \simeq -2is \int d^2b \, e^{-ib^\perp q_\perp} \int dz dz' P_{13}(z) P_{24}(z') \left[e^{i\chi(s,b^\perp,z,z')} - 1 \right]$$

$$P_{13}(z) = (z/R)^2 \sqrt{g(z)} \Phi_1(z) \Phi_3(z) \qquad P_{24}(z) = (z'/R)^2 \sqrt{g(z')} \Phi_2(z') \Phi_4(z')$$

Transverse AdS_3 space !!

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

- Saturation:

$$\chi(s, x^\perp - x'^\perp, z, z') \; = \; O(1)$$

Scattering in Conformal Limit:

Use the condition: $\chi(s, x^{\perp} - x'^{\perp}, z, z') = O(1)$

Elastic Ring: $b_{\rm diff} \sim \sqrt{zz'}\, (zz's/N^2)^{1/6}$

No Froissart $\sigma_{total} \sim s^{1/3}$

Inner Absorptive Disc:

$$b_{\rm black} \sim \sqrt{zz'}\ \frac{(zz's)^{(j_0-1)/2}}{\lambda^{1/4}N} \qquad b_{\rm black} \sim \sqrt{zz'}\ \left(\frac{(zz's)^{j_0-1}}{\lambda^{1/4}N}\right)^{1/\sqrt{2\sqrt{\lambda}}(j_0-1)}$$

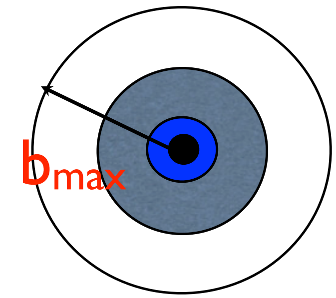
Inner Core: “black hole” production ?

Saturation of Froissart Bound

- The Confinement deformation gives an exponential cutoff for $b > b_{max} \sim c \log (s/s_0)$,
- Coefficient $c \sim 1/m_0$, m_0 being the mass of lightest tensor glueball.
- Froissart is respected and saturated.

$$\Delta b \sim \log(s/s_0)$$

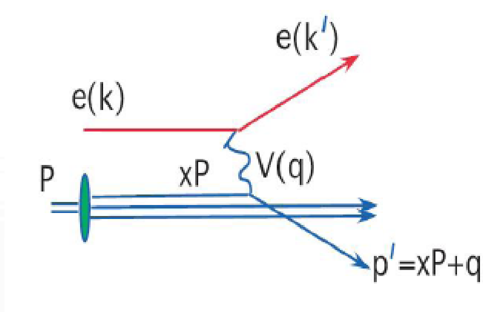
Disk picture



b_{max} determined by confinement.

III. Deep Inelastic Scattering (DIS) at small-x

Deep Inelastic Scattering (DIS)



$$F_2(x, Q2) = \frac{Q^2}{4\pi^2 \alpha_{em}} \left[\sigma_T(\gamma^* p) +_L (\gamma^* p)\right]$$

$$x \equiv \frac{Q^2}{s}$$

$$Small\ x: \ \frac{Q^2}{s} \to 0$$

Optical Theorem

$$\sigma_{total}(s, Q^2) = (1/s)\mathrm{Im}\ A(s, t = 0; Q^2)$$

- # Eikonal Sum: derived both via Cheng-Wu or by Shock-wave method

$$A_{2\to 2}(s,t) \simeq -2is \int d^2b\, e^{-ib^\perp q_\perp} \int dz dz' P_{13}(z) P_{24}(z') \left[e^{i\chi(s,b^\perp,z,z')} - 1\right]$$

$$P_{13}(z) = (z/R)^2 \sqrt{g(z)} \Phi_1(z) \Phi_3(z) \qquad P_{24}(z) = (z'/R)^2 \sqrt{g(z')} \Phi_2(z') \Phi_4(z')$$

transverse AdS_3 space !!

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

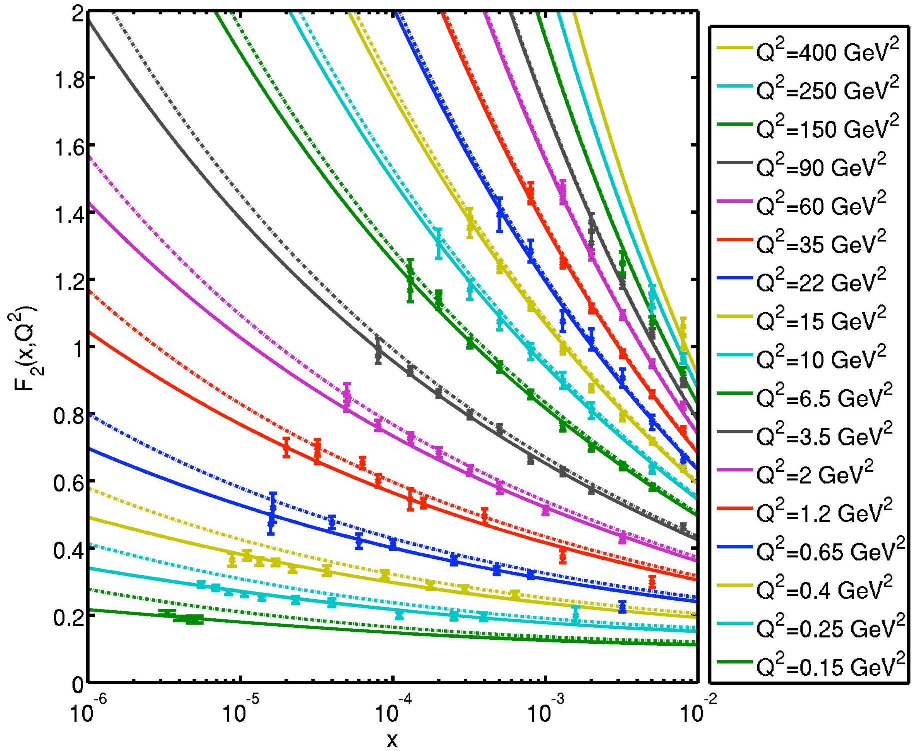
- Saturation:

$$\chi(s, x^\perp - x'^\perp, z, z') \;=\; O(1)$$

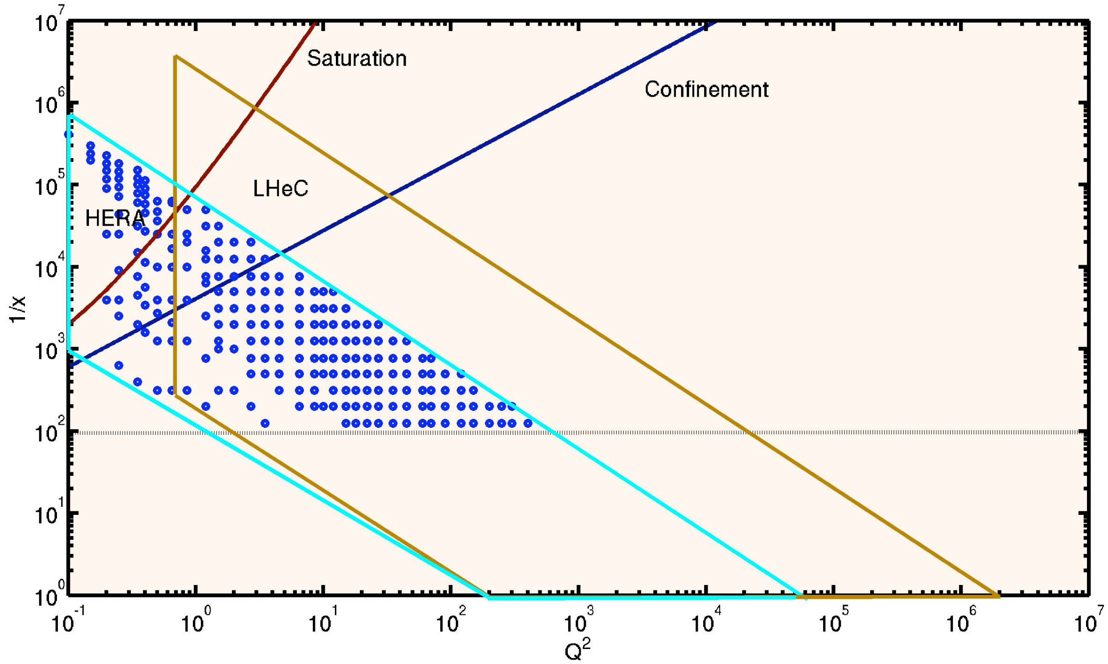
- Universality: e.g., Choose Φ_1 and Φ_3 for DIS.

Questions on HERA DIS small-x data:

- Confinement? (Perturbative vs. Non-perturbative?)
- Saturation? (evolution vs. non-linear evolution?)

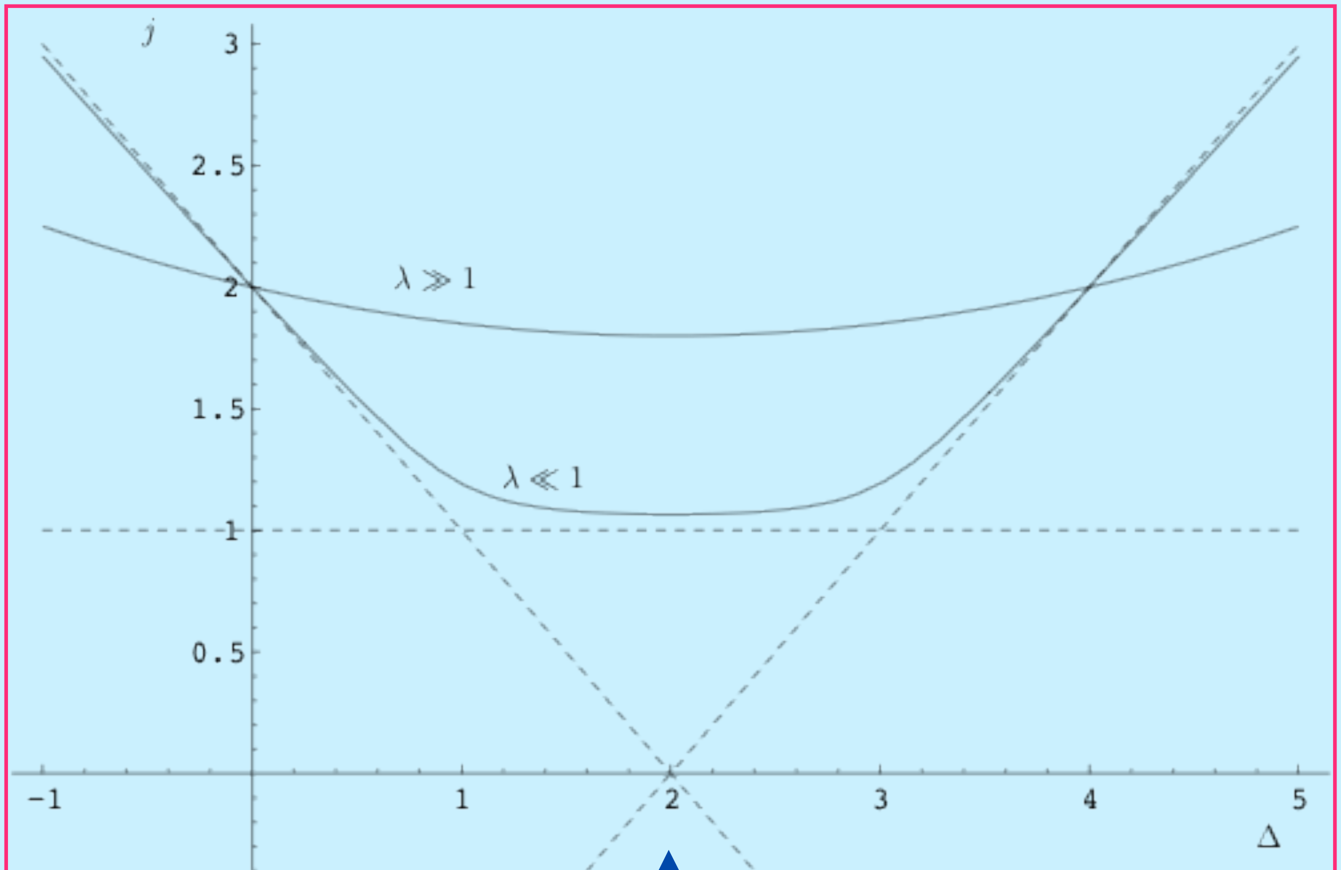


$F_2(x,Q^2)$
x
Q^2=400 GeV^2
Q^2=250 GeV^2
Q^2=150 GeV^2
Q^2=90 GeV^2
Q^2=60 GeV^2
Q^2=35 GeV^2
Q^2=22 GeV^2
Q^2=15 GeV^2
Q^2=10 GeV^2
Q^2=6.5 GeV^2
Q^2=3.5 GeV^2
Q^2=2 GeV^2
Q^2=1.2 GeV^2
Q^2=0.65 GeV^2
Q^2=0.4 GeV^2
Q^2=0.25 GeV^2
Q^2=0.15 GeV^2



Saturation
Confinement
LHeC
HERA
1/x
Q^2

$\mathcal{N} = 4$ SYM Leading Twist $\Delta(J)$ vs J: Anomalous Dimensions



$\lambda = 0$ DGLAP (DIS moments)

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

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

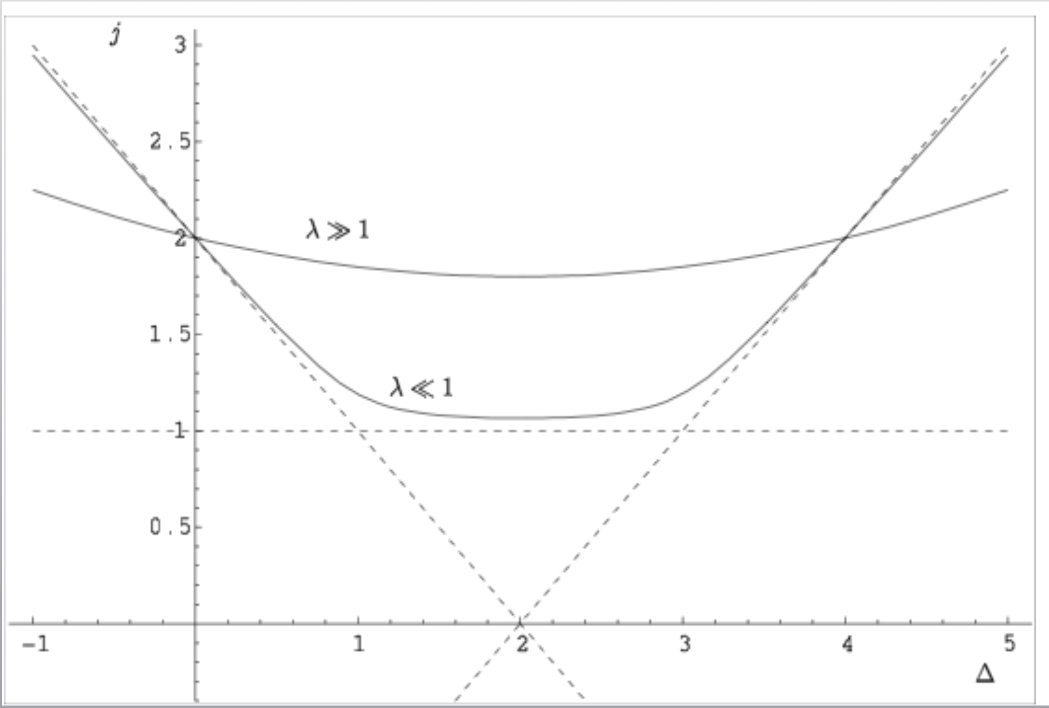
$\lambda = 0$, BFKL

$\lambda = g^2 N = 0$

$j = j_0$ @ min Δ

MOMENTS AND ANOMALOUS DIMENSION

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



$$\gamma_2 = 0$$

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

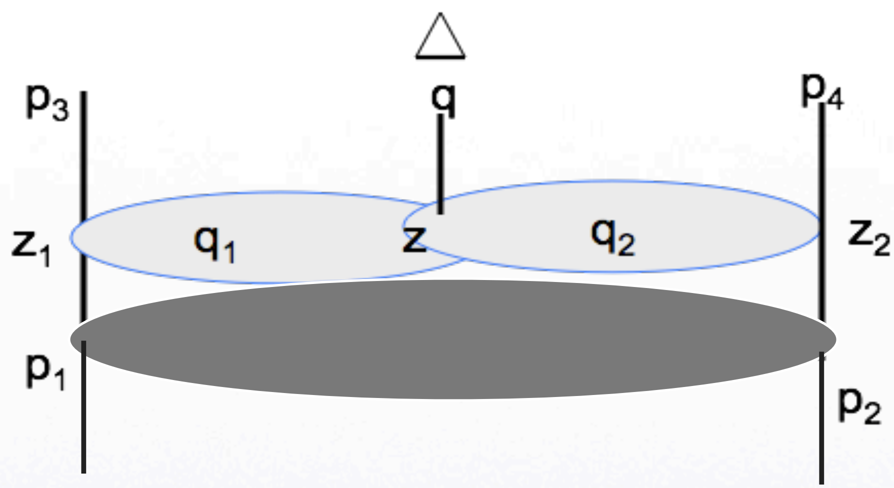
$$\gamma_n = 2\sqrt{1 + \sqrt{g^2 N}(n-2)/2} - n$$

Simultaneous compatible large Q^2 and small x evolutions!

Energy-Momentum Conservation built-in automatically.

IV: Survival Probability

Double Regge (Pomeron) exchange



Competing factors on region of importance.

Survival probabilty depends on Im $\chi(s, b, z, z')$

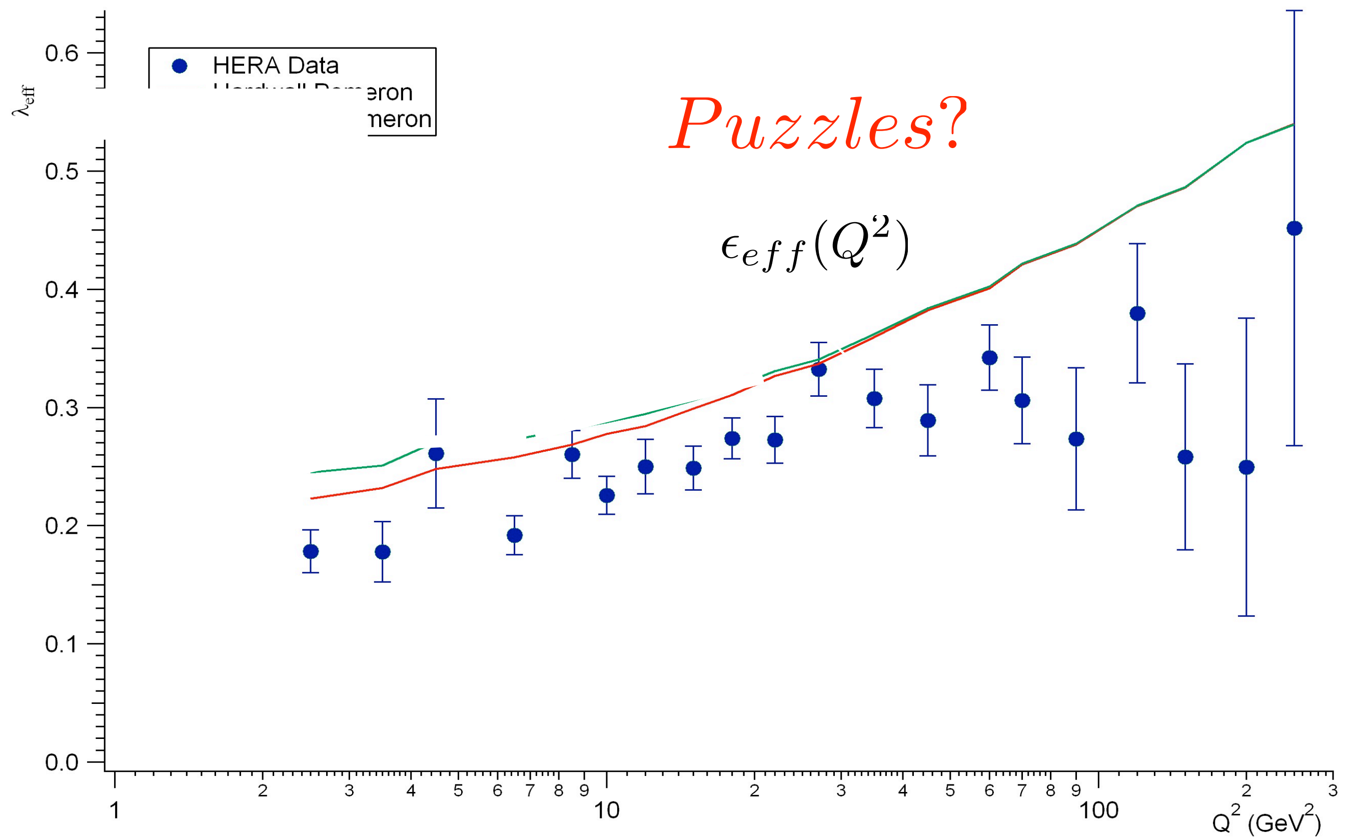
Confinement scale enters

V. Summary and Outlook

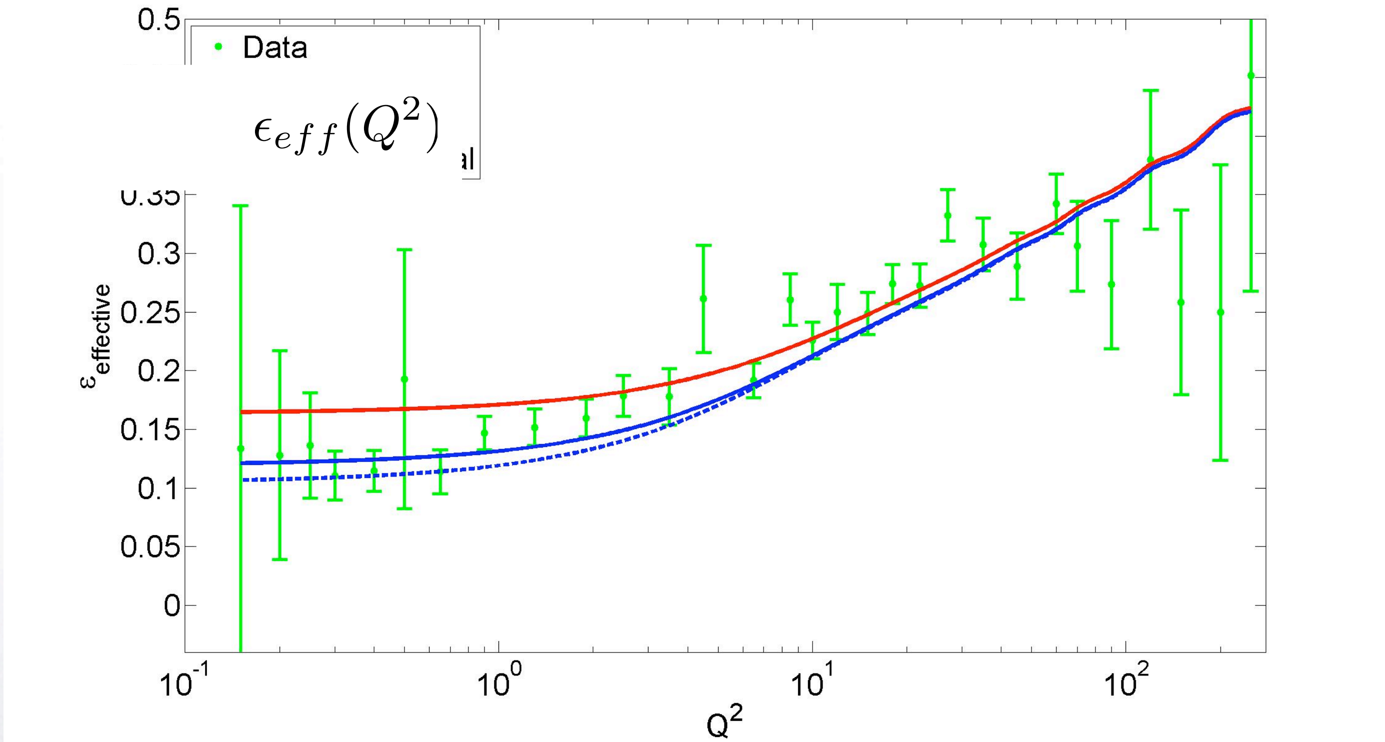
- Provide meaning for Pomeron non-perturbatively from first principles.
- Realization of conformal invariance beyond perturbative QCD
- New starting point for unitarization, saturation, etc.
- Phenomenological consequences, DIS at small-x, Diffractive Higgs production at LHC (in progress), etc.

Effective Pomeron Intercept from HERA data:

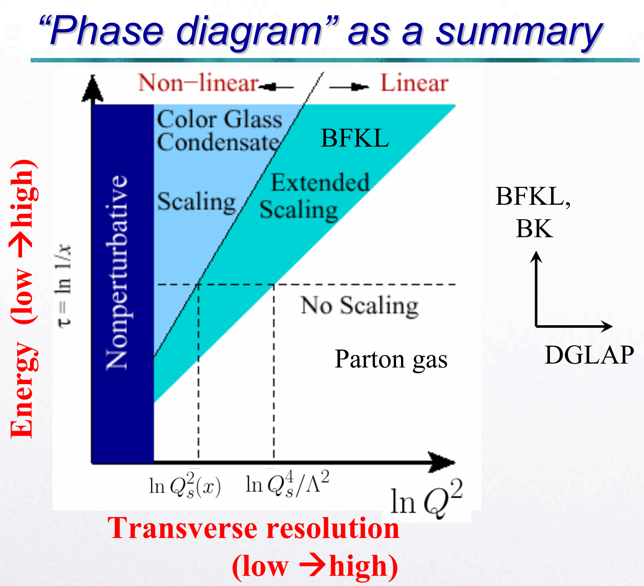
$$F_2 \simeq C(Q^2)\ x^{-\epsilon_{eff}}$$



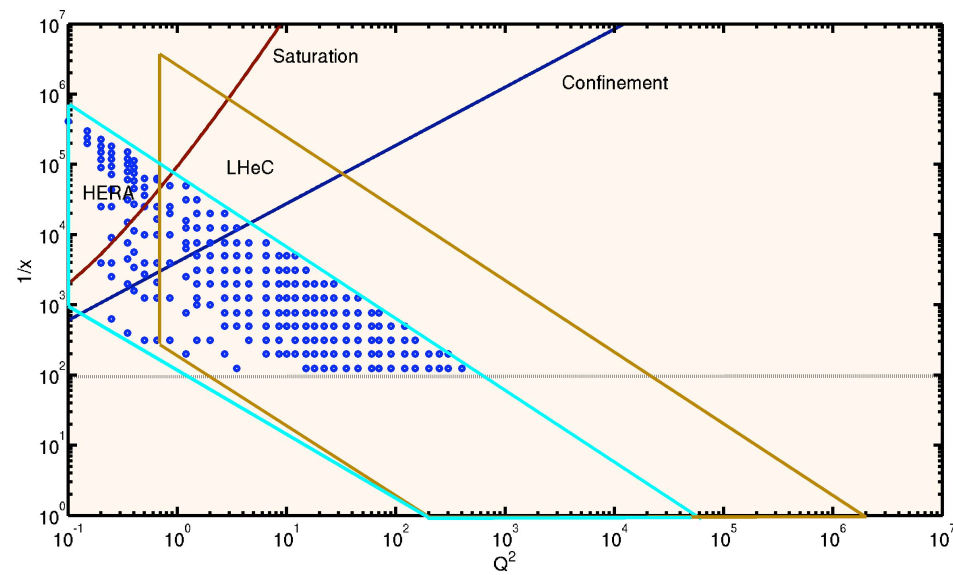
$$F_2(x, Q^2) \sim (1/x)^{\epsilon_{effecti}}$$



Standard expectation
(from Itakura's RIKEN lectures)



AdS/CFT expectation
(from BDST: hep-ph/1007.2259)



$\mathcal{N} = 4$ SYM Scattering at High Energy

AdS_5 boundary, $z \to 0$,

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

Bulk Degrees of Freedom from Supergravity:

- metric tensor: G_{MN}
- Kalb-Ramond 2 Forms: B_{MN}, C_{MN}
- Dilaton and zero form: ϕ and C_0

Born-Infeld Action

$$S = \int d^4x \det[G_{\mu\nu} + e^{-\phi/2}(B_{\mu\nu} + F_{\mu\nu})] + \int d^4x (C_0 F \wedge F + C_2 \wedge F + C_4))$$

Dimension	State J^{PC}	Operator	Supergravity
$\Delta = 4$	0^{++}	$Tr(FF) = \vec{E}^a \cdot \vec{E}^a - \vec{B}^a \cdot \vec{B}^a$	ϕ
$\Delta = 4$	2^{++}	$T_{ij} = E_i^a \cdot E_j^a + B_i^a \cdot B_j^a - \text{trace}$	G_{ij}
$\Delta = 4$	0^{-+}	$Tr(F\tilde{F}) = \vec{E}^a \cdot \vec{B}^a$	C_0
$\Delta = 6$	1^{+-}	$Tr(F_{\mu\nu}\{F_{\rho\sigma}, F_{\lambda\eta}\}) \sim d^{abc}F^aF^bF^c$	B_{ij}
$\Delta = 6$	1^{--}	$Tr(\tilde{F}_{\mu\nu}\{F_{\rho\sigma}, F_{\lambda\eta}\}) \sim d^{abc}\tilde{F}^aF^bF^c$	$C_{2,ij}$