Holographic Pomeron in low-x QCD

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1804.07778 [hep-ph] with Amorim & Quevedo

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(Soft) Pomeron

- Elastic scattering in QCD dominated by exchange of Regge trajectory with vacuum quantum numbers.

$$\boxed{A(s,t) \sim s^{j(t)}}$$

$$j(t) = 1.08 + 0.25\,t \quad (\text{GeV units})$$

[Donnachie, Landshoff 92]

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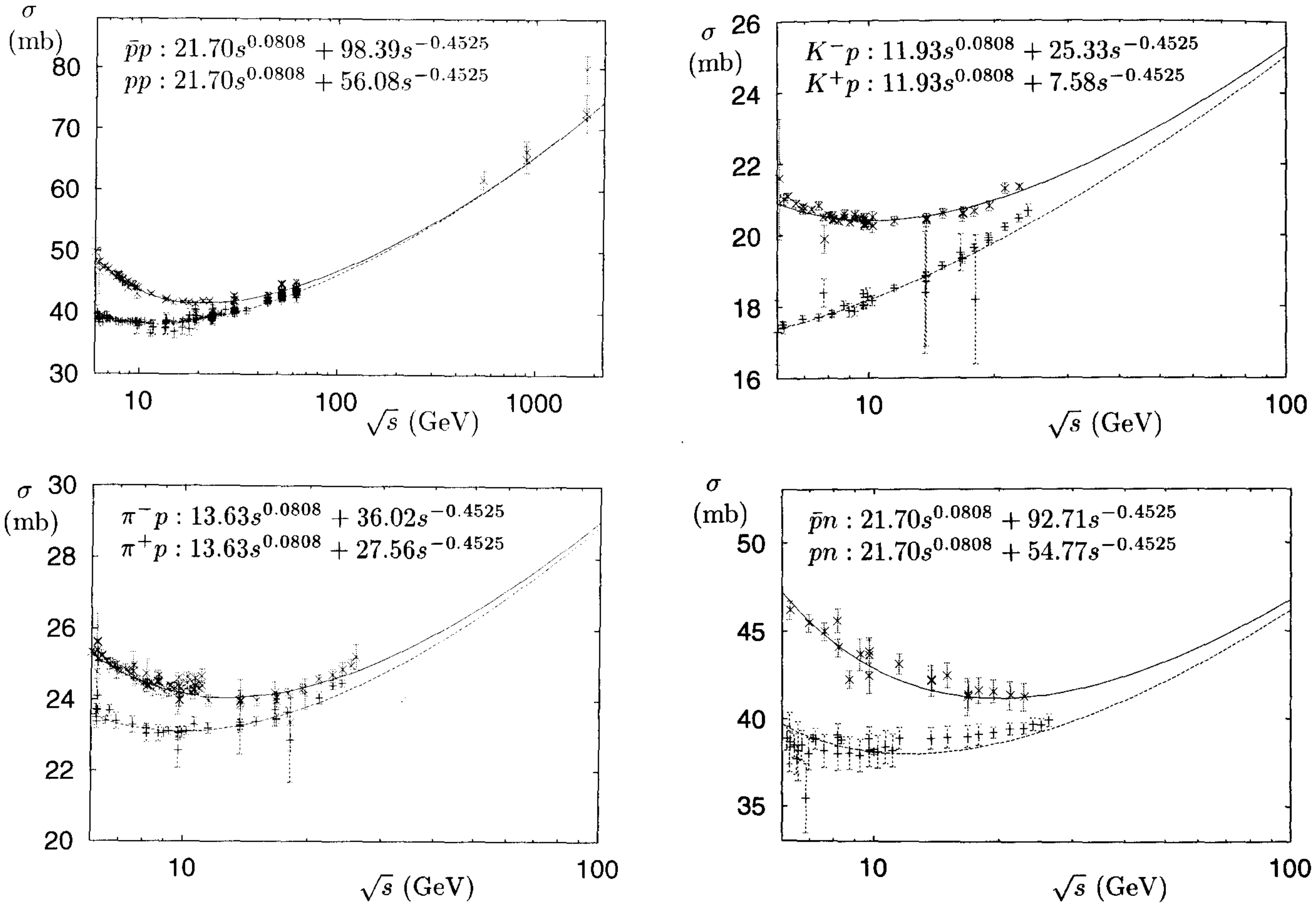
[Donnachie, Landshoff 92]

Total cross sections in QCD

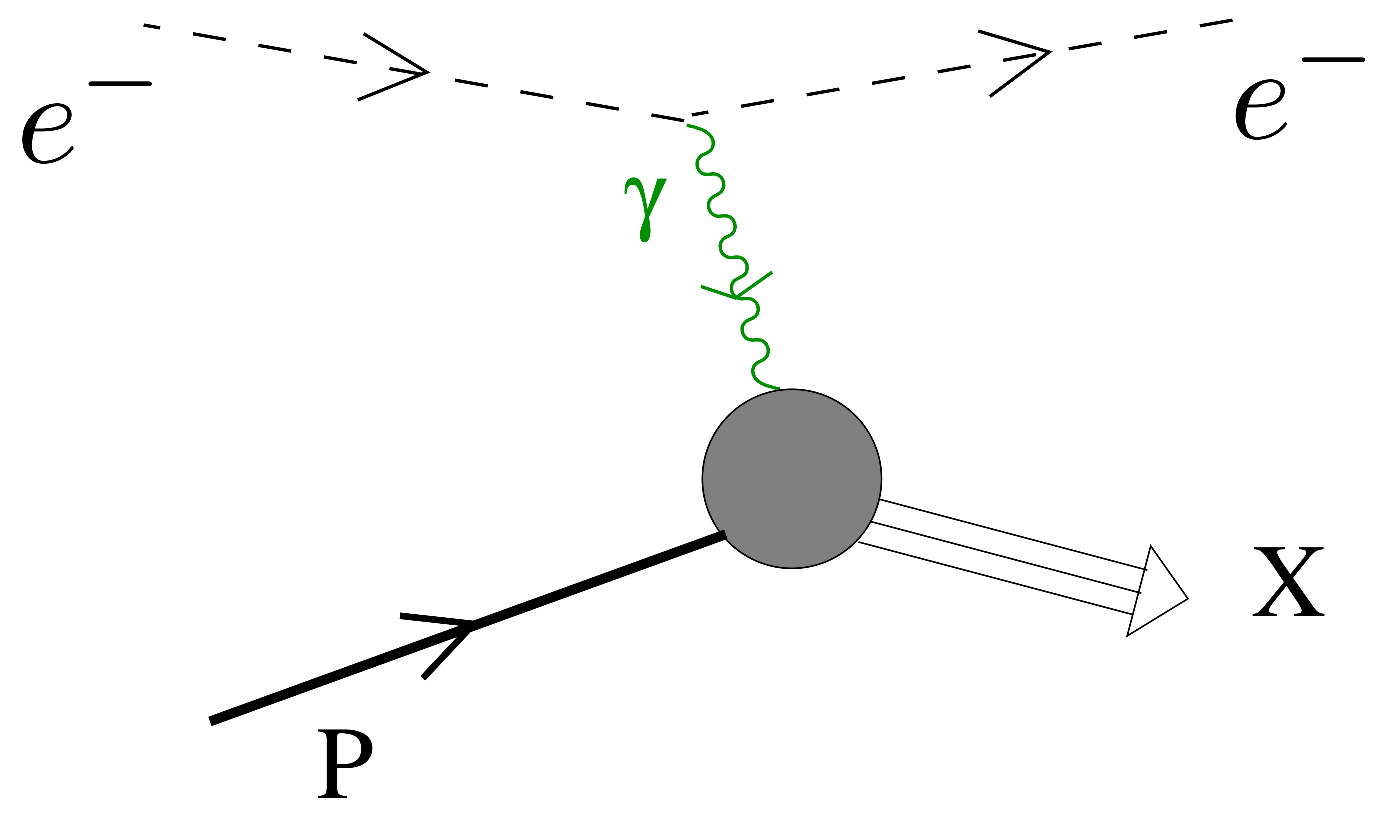
$$\boxed{\sigma \sim s^{j(0)-1} \sim s^{0.08}}$$

Evidence from lattice QCD that there are glueballs on this trajectory with $J \geq 2$.



Deep Inelastic Scattering (DIS)

- Pomeron also enters in diffractive processes, e.g. DIS



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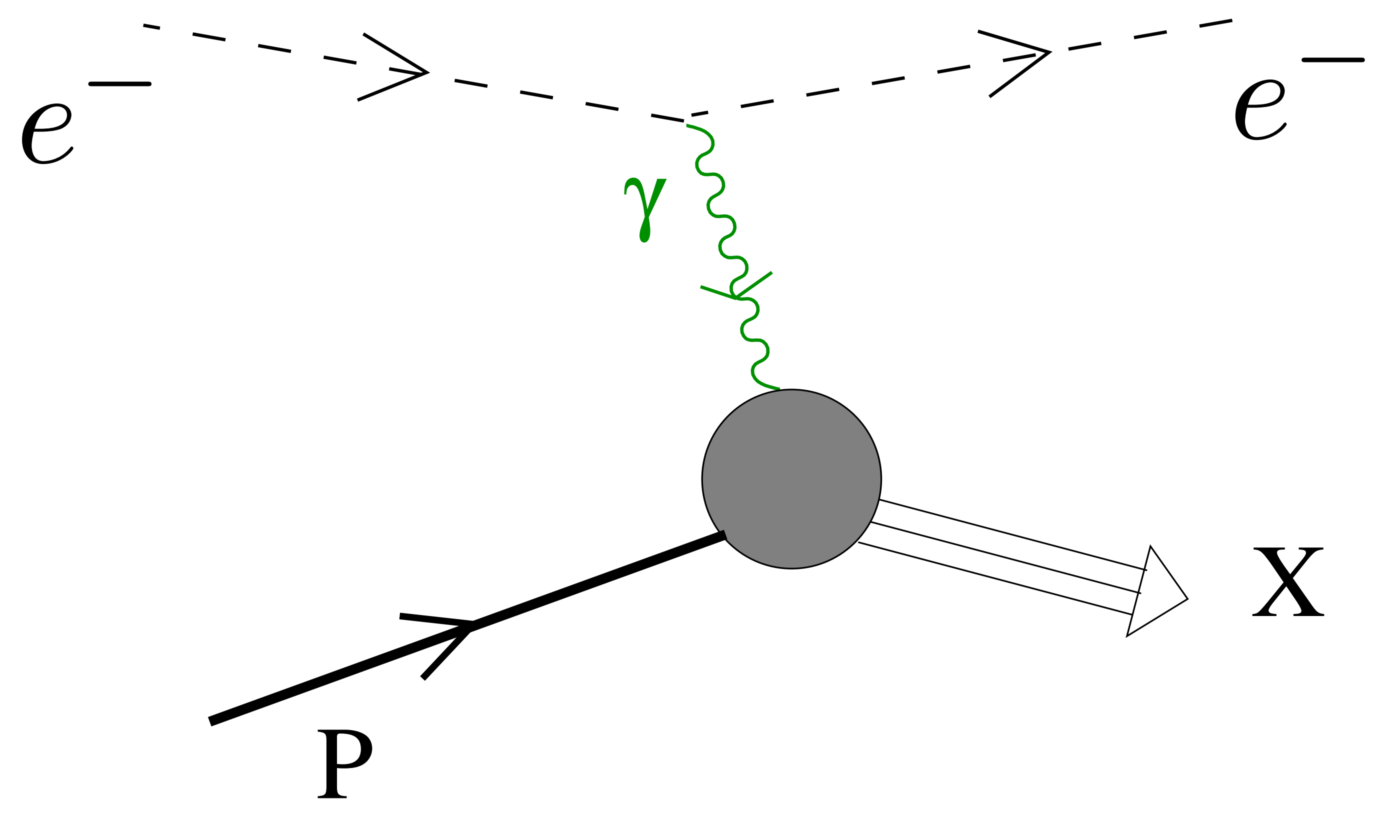
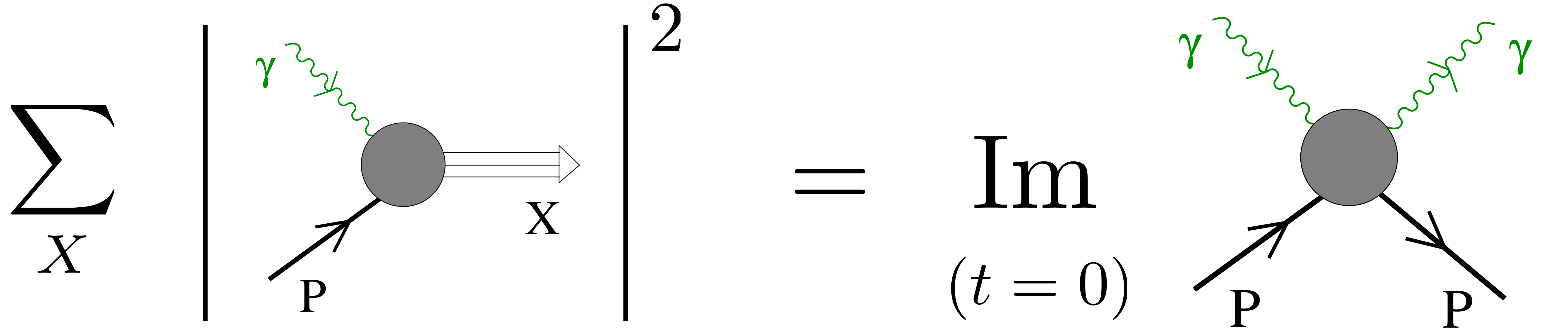


- Optical theorem



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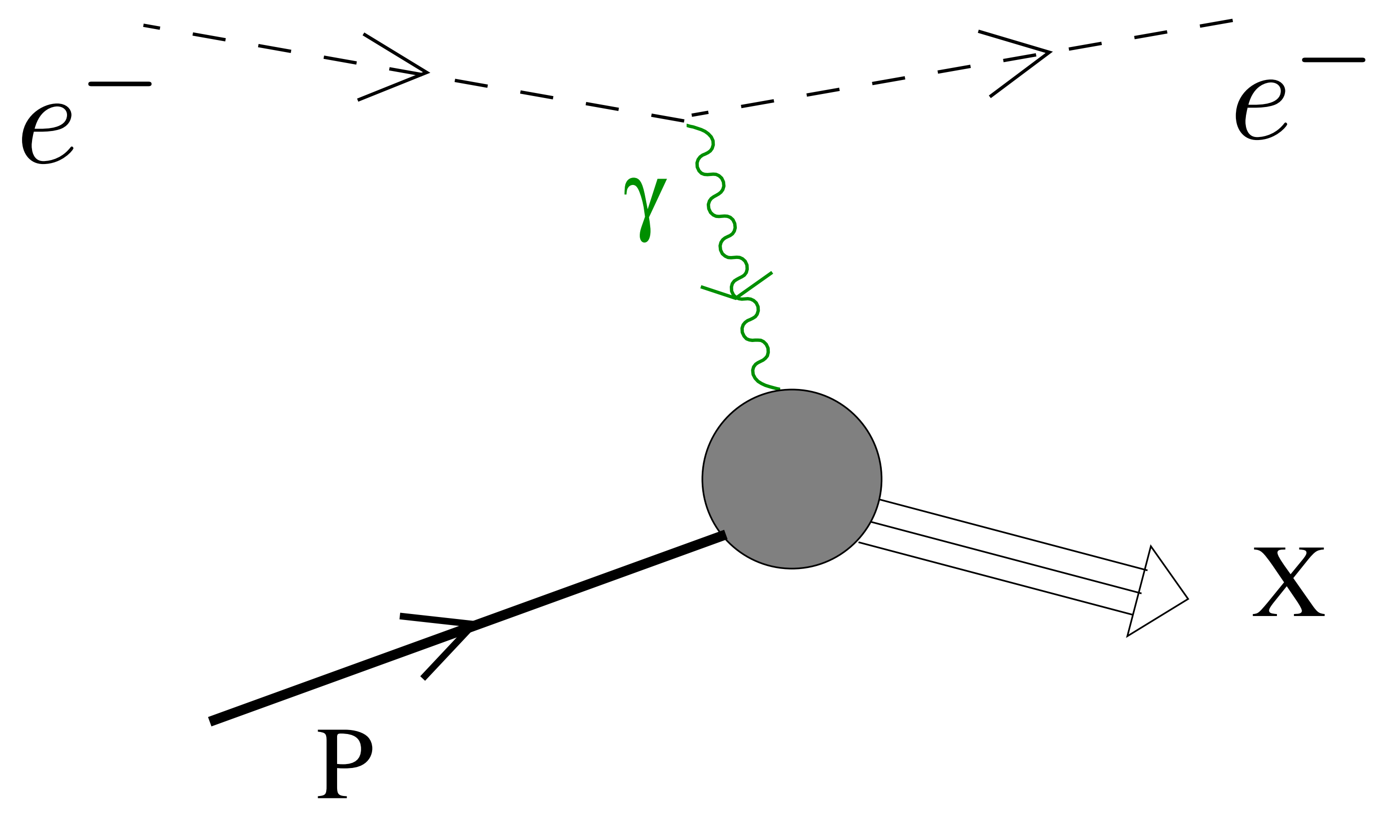

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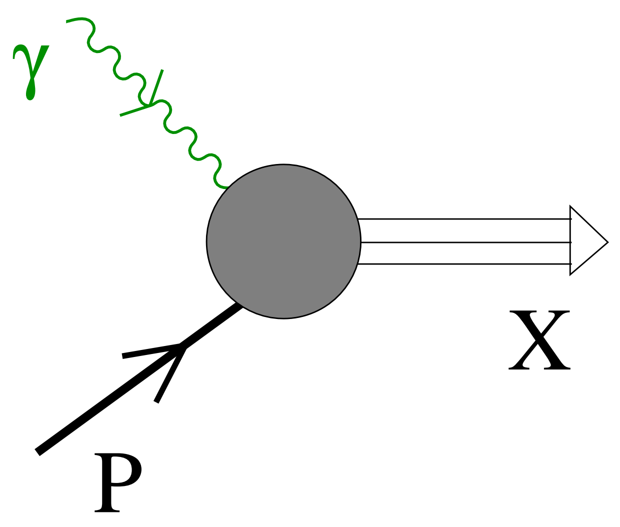
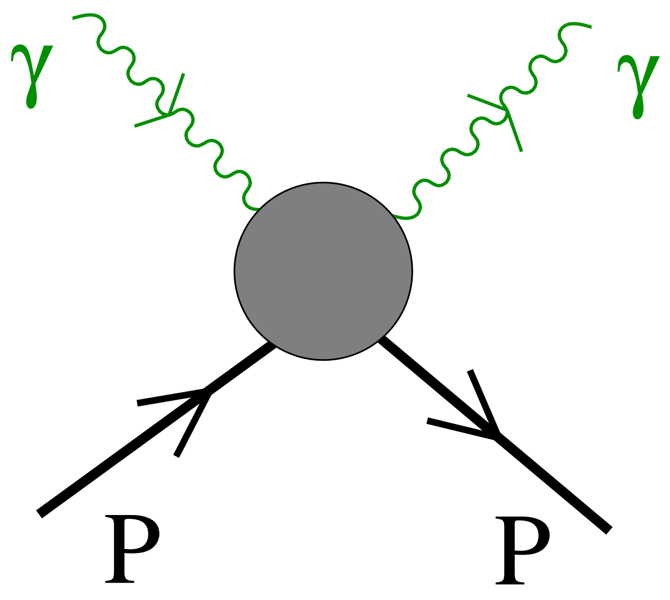
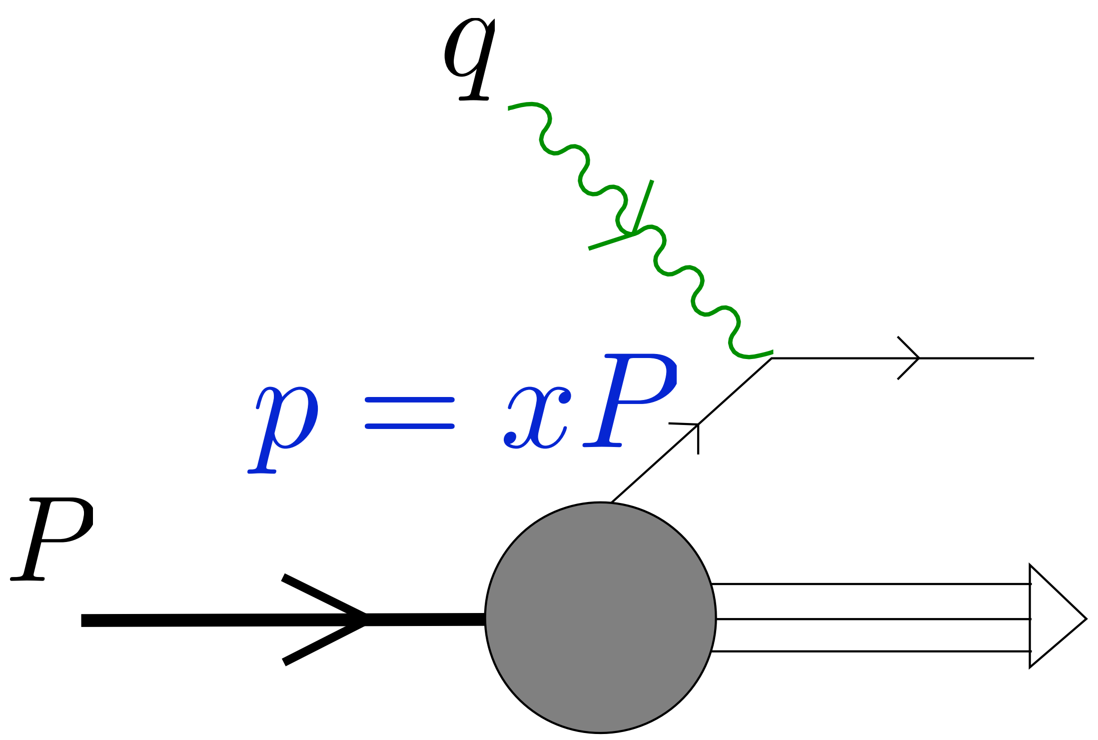
$\sum_X \Big|$ 

$\Big|^2 = \underset{(t=0)}{\mathrm{Im}}$ 

- Bjorken x

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



large s $\Rightarrow$ small x

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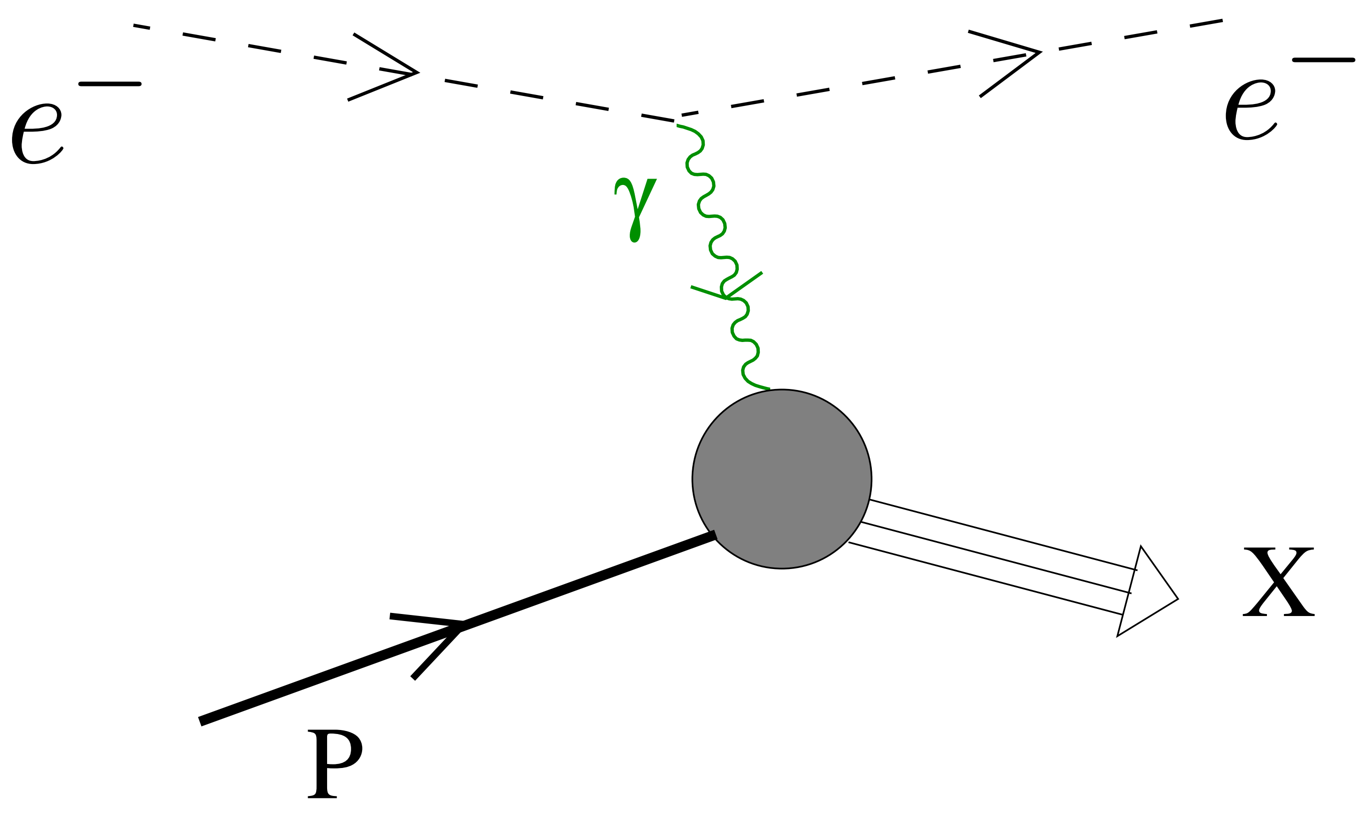

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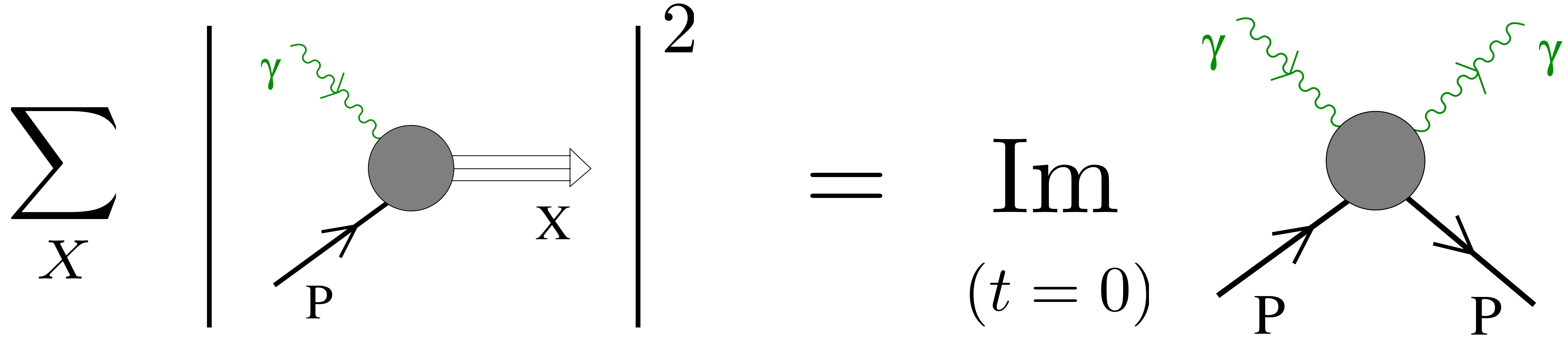

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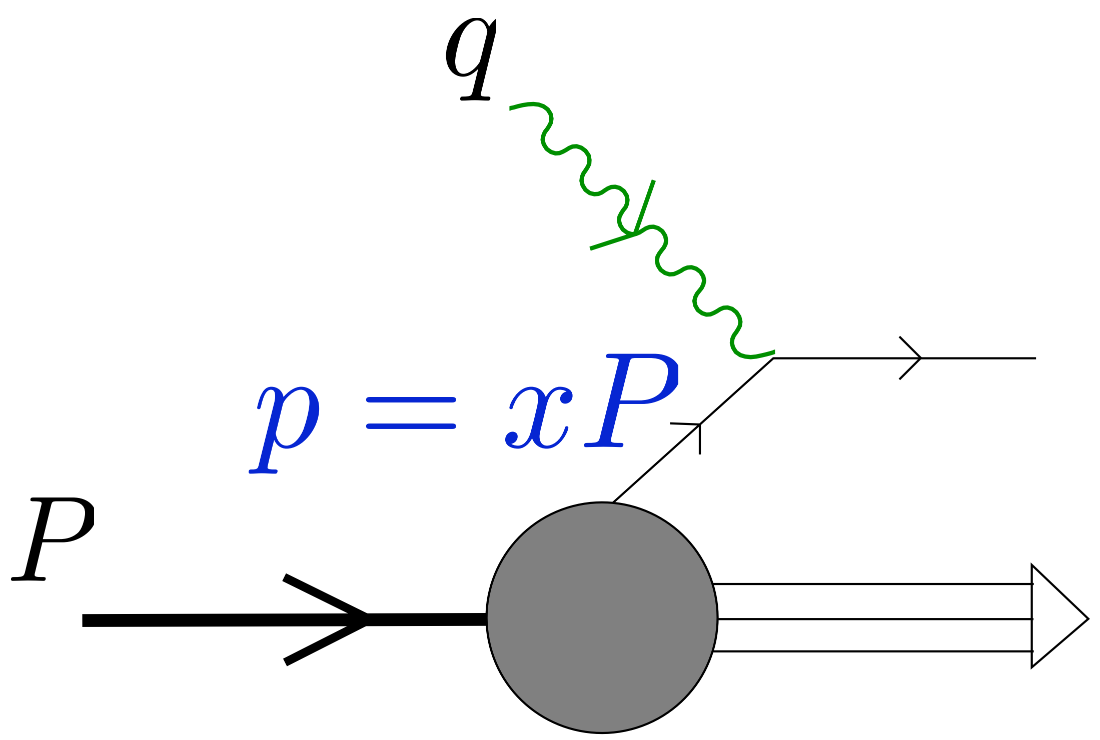

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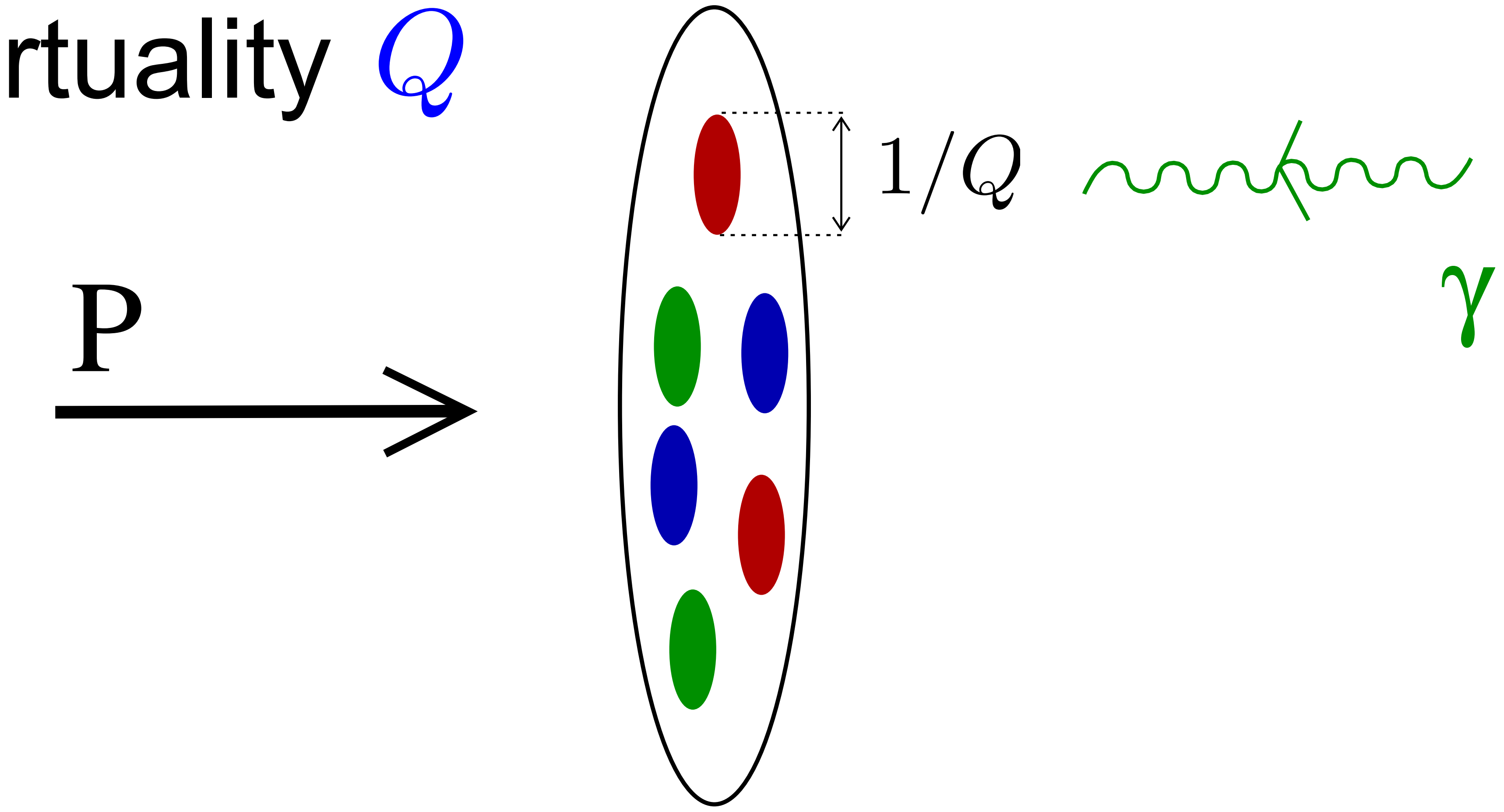
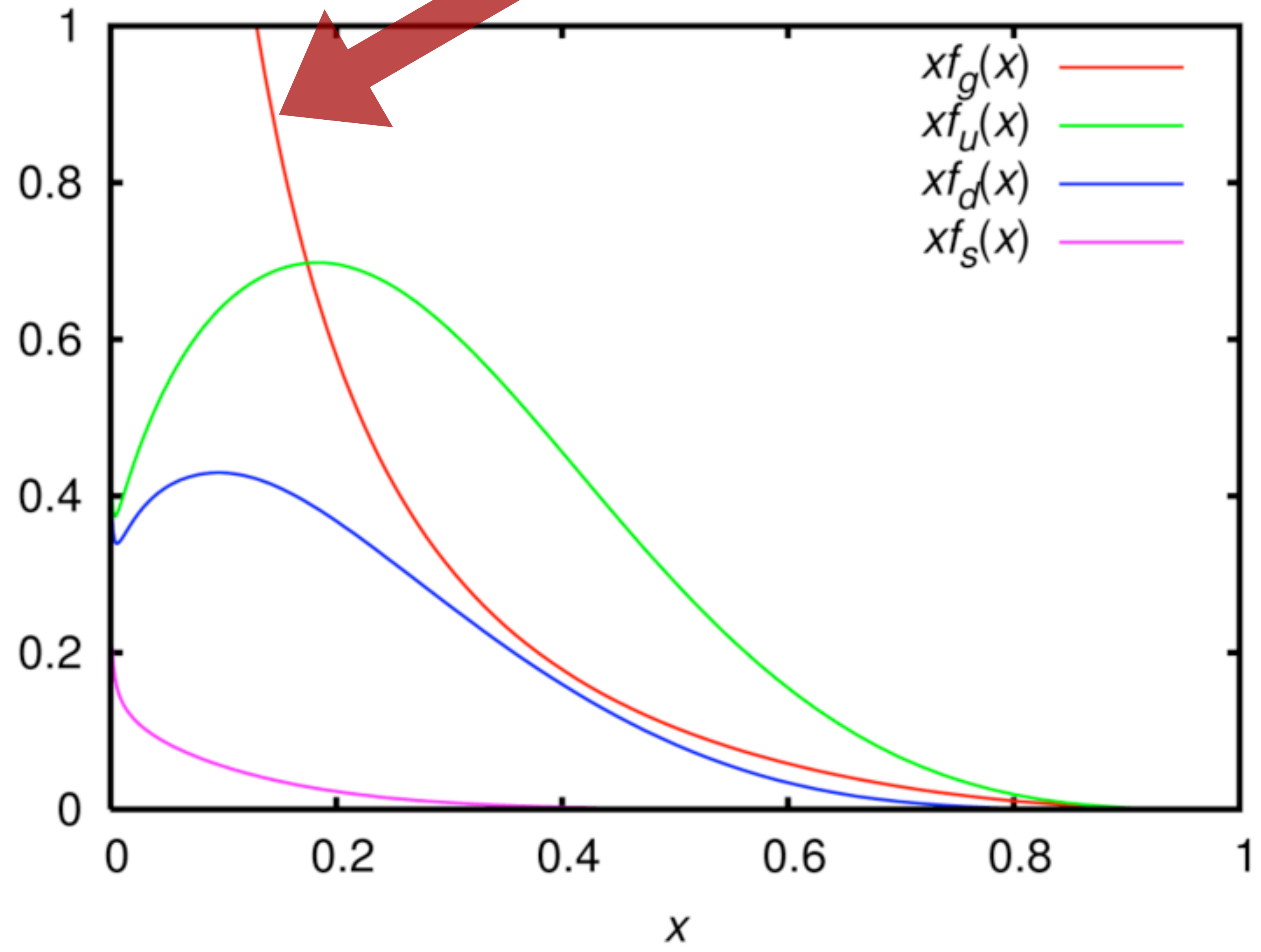
- Photon virtuality Q



- At low $x \lesssim 10^{-2}$ a steep x - dependence is observed $\sigma \sim x^{1-j_0}$

$f_i\left(x, Q^2\right)$

Gluons dominate at small x



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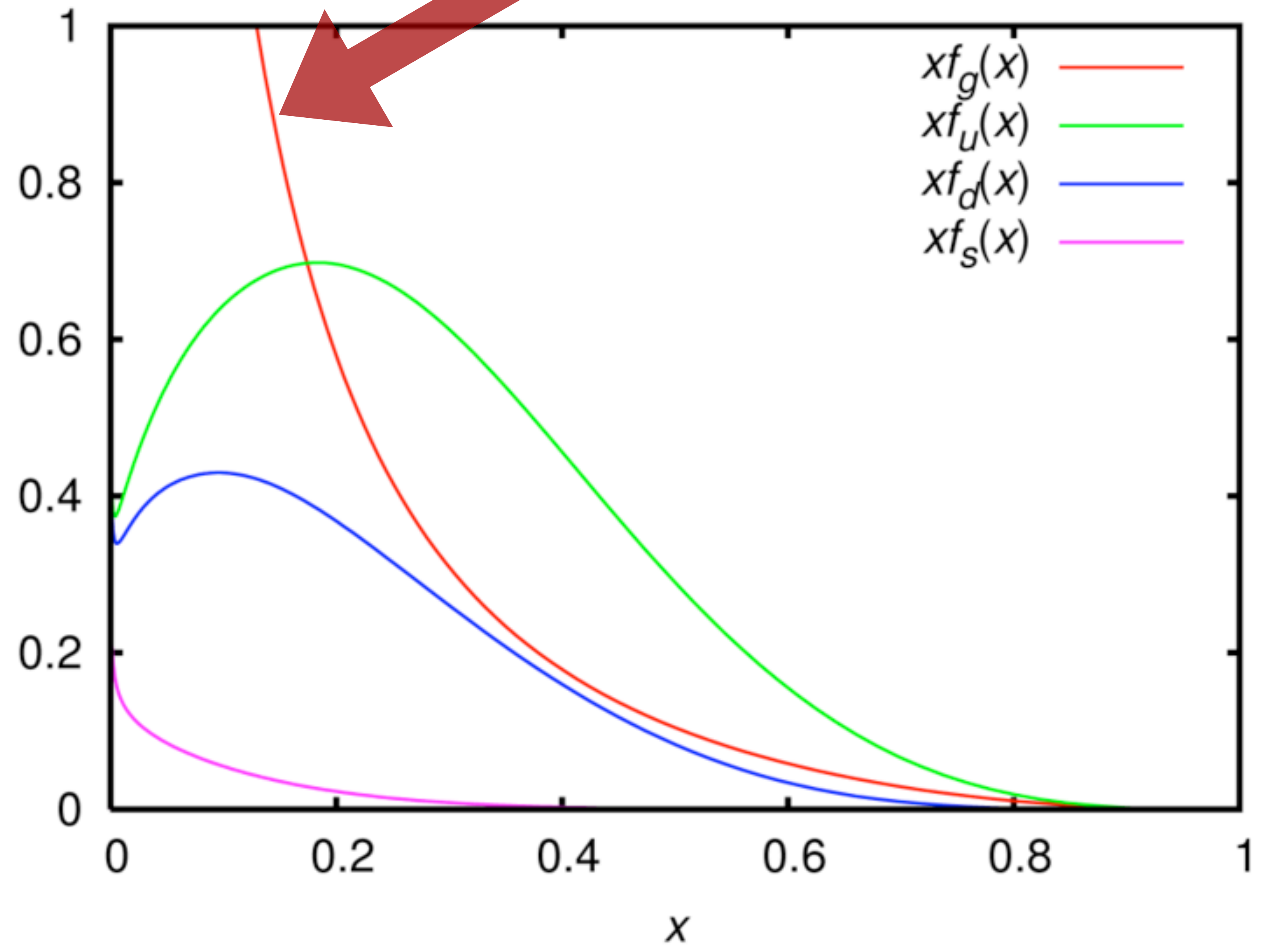
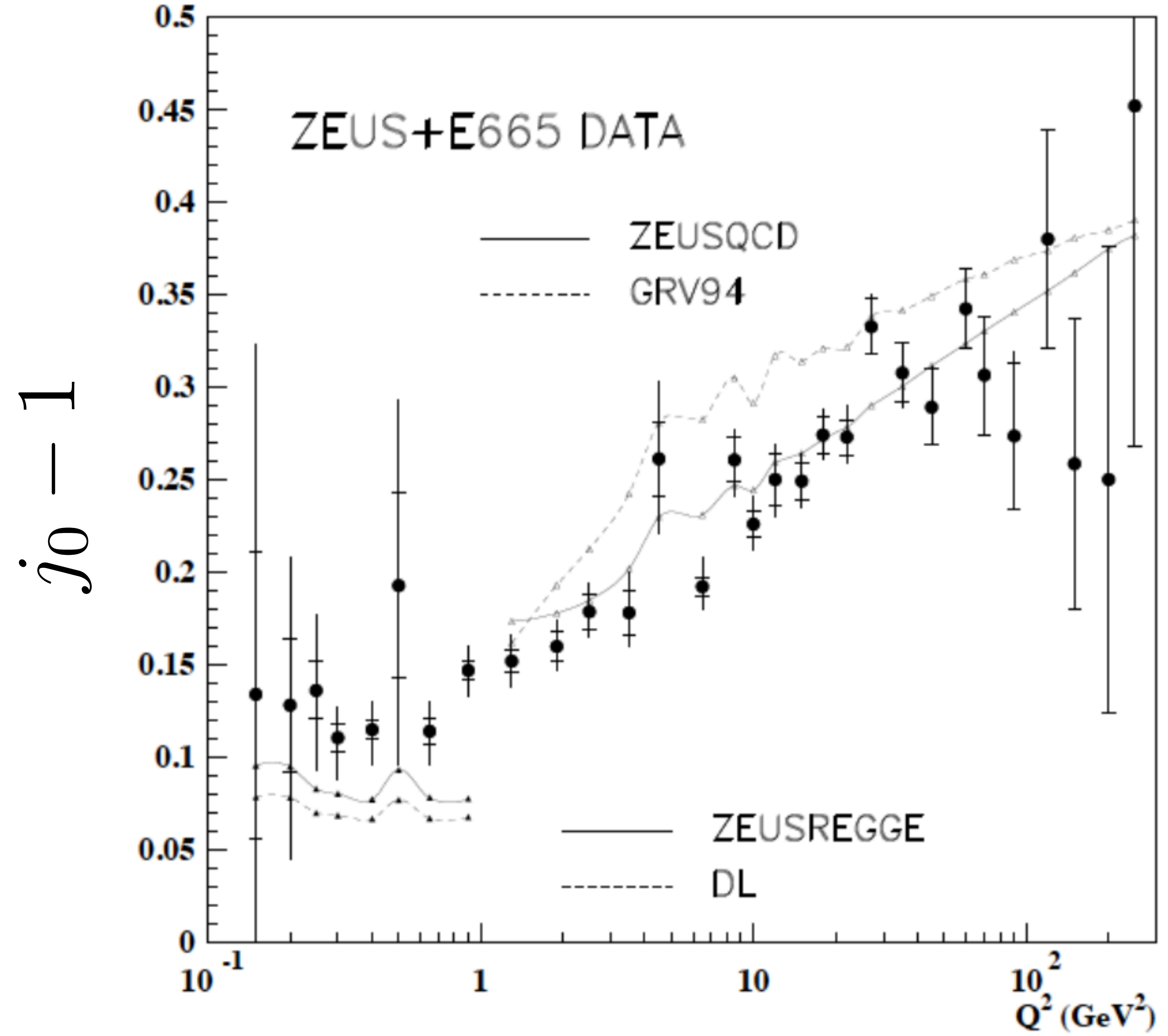


Effective slop varies with Q



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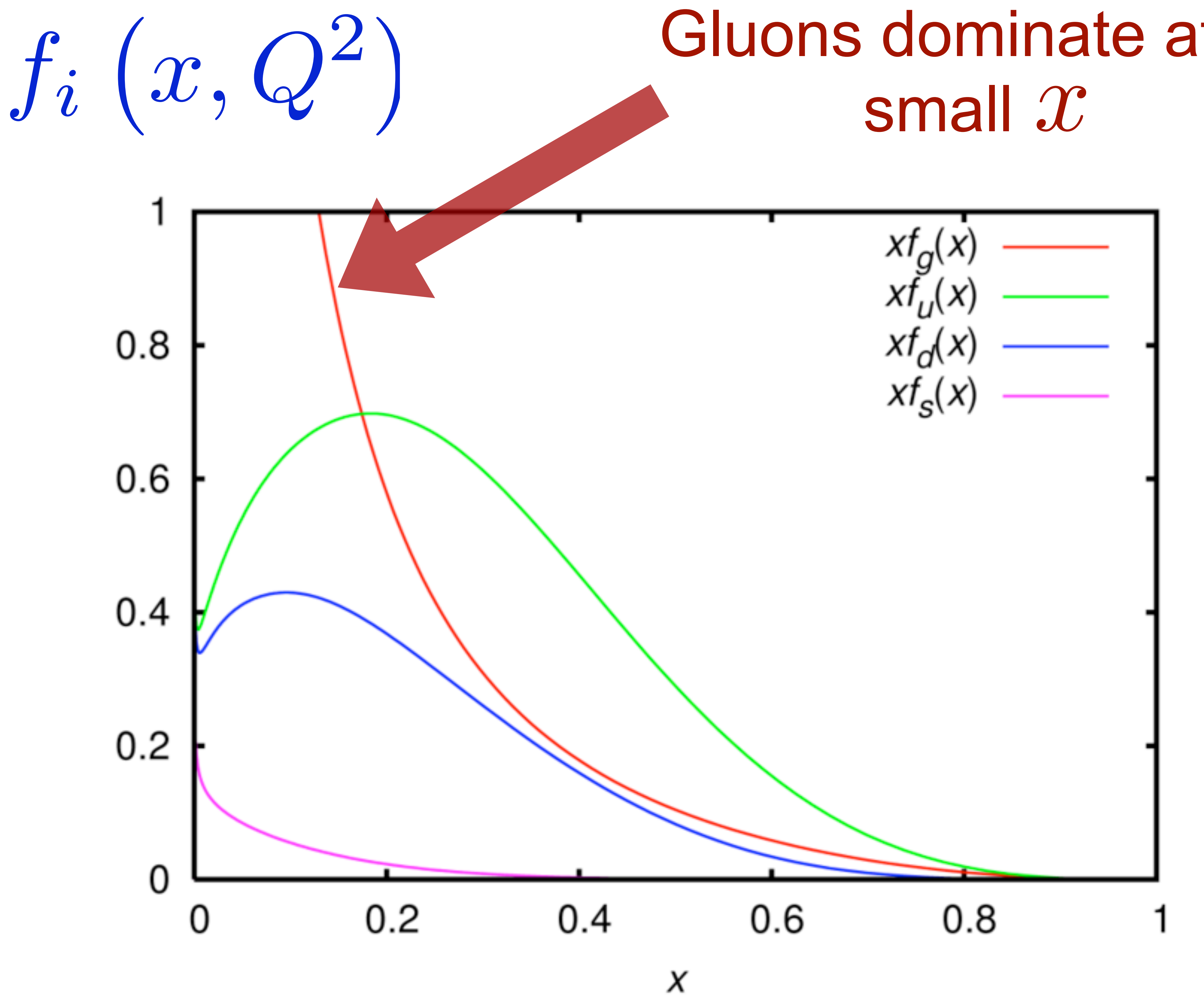

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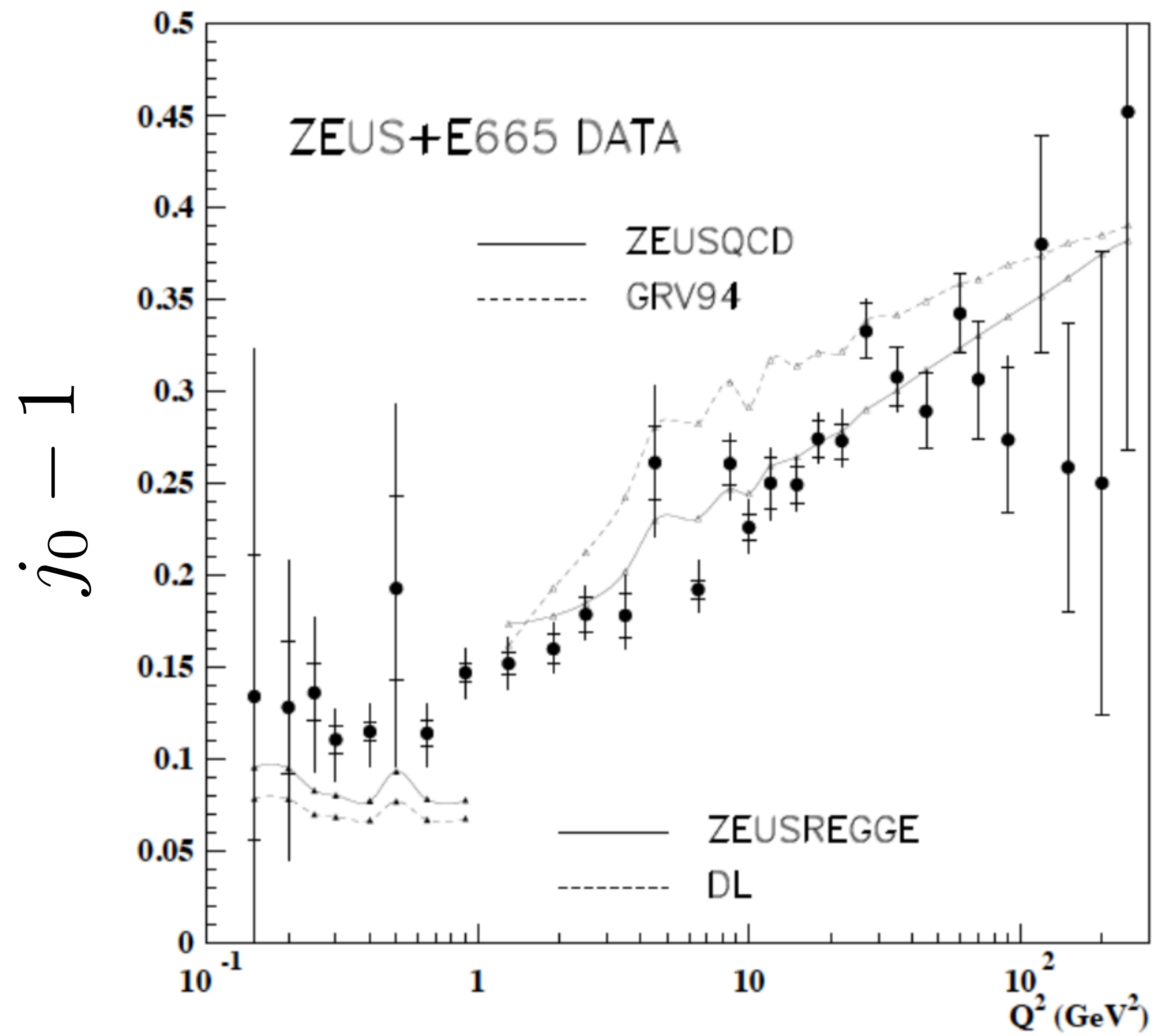

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One or two pomerons (soft and hard)?

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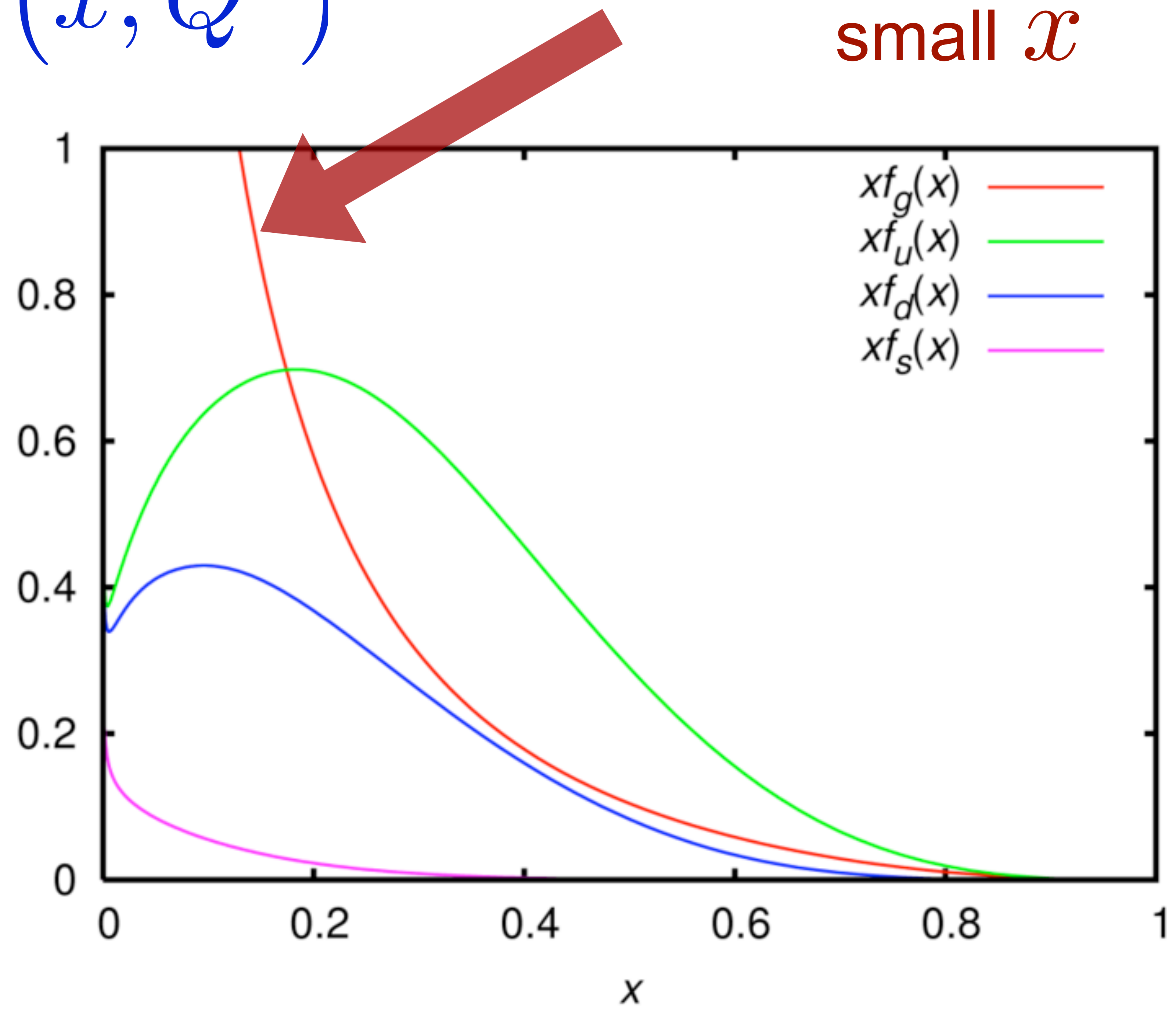

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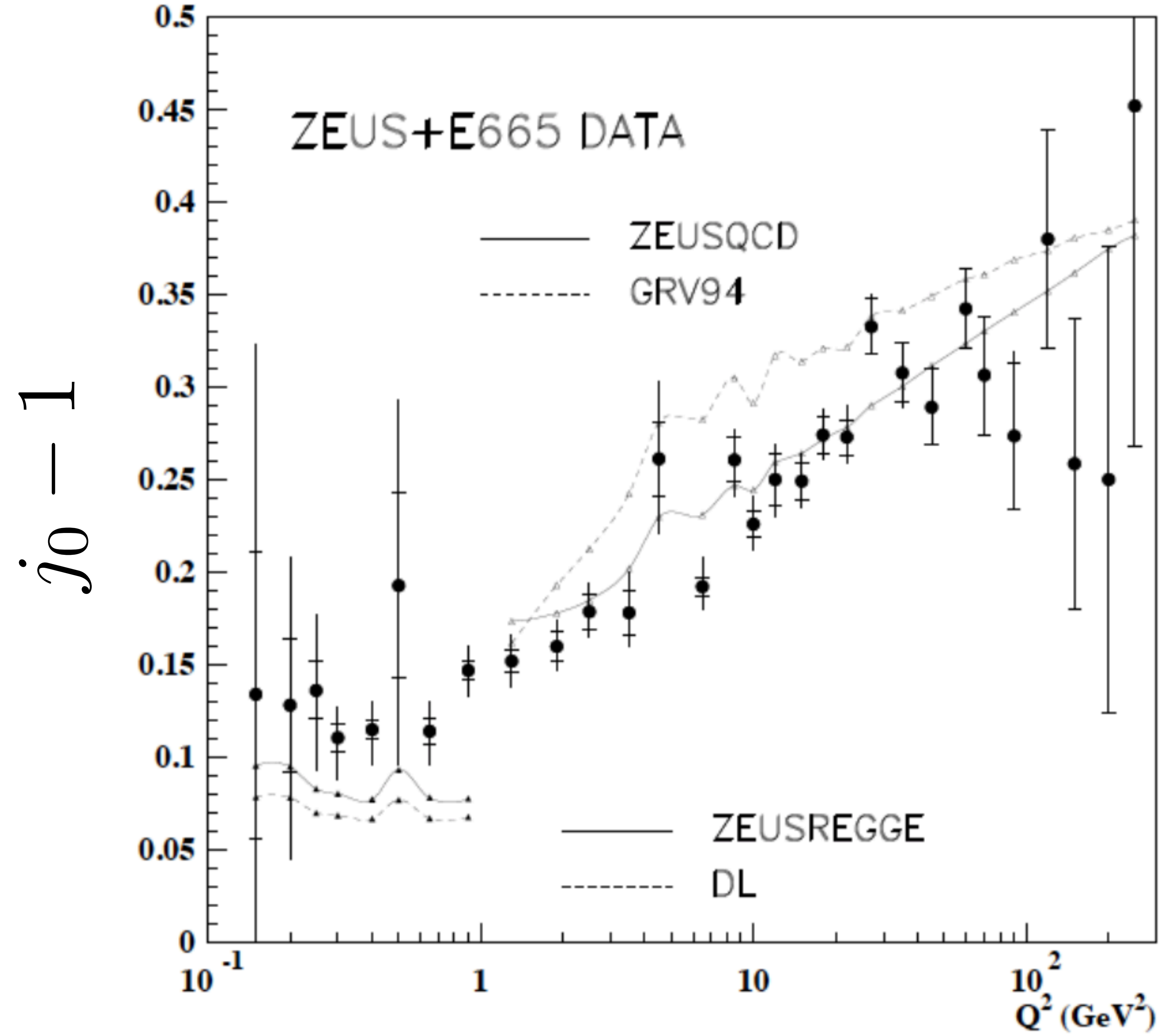

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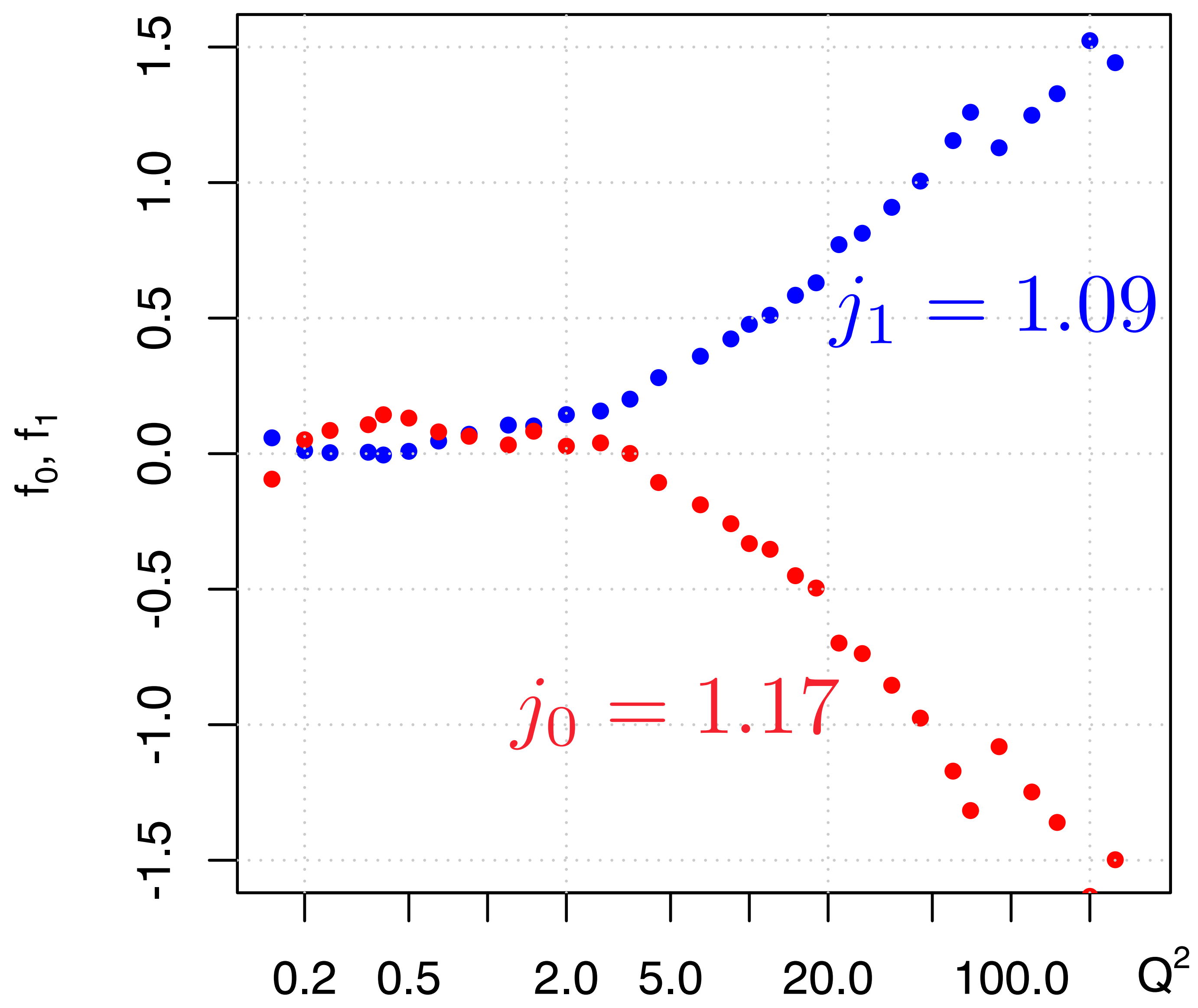
This talk:

Graviton Regge trajectory dual to pomeron trajectory [Brower, Polchinski, Strassler, Tan 06]

Hard and soft pomeron are distinct Regge trajectories

- Explain DIS data with two Regge trajectories
  [Donnachie, Landshoff 01]

$$\sigma(Q^2, x) \propto f_0(Q^2)\, x^{-j_0} + f_1(Q^2)\, x^{-j_1}$$



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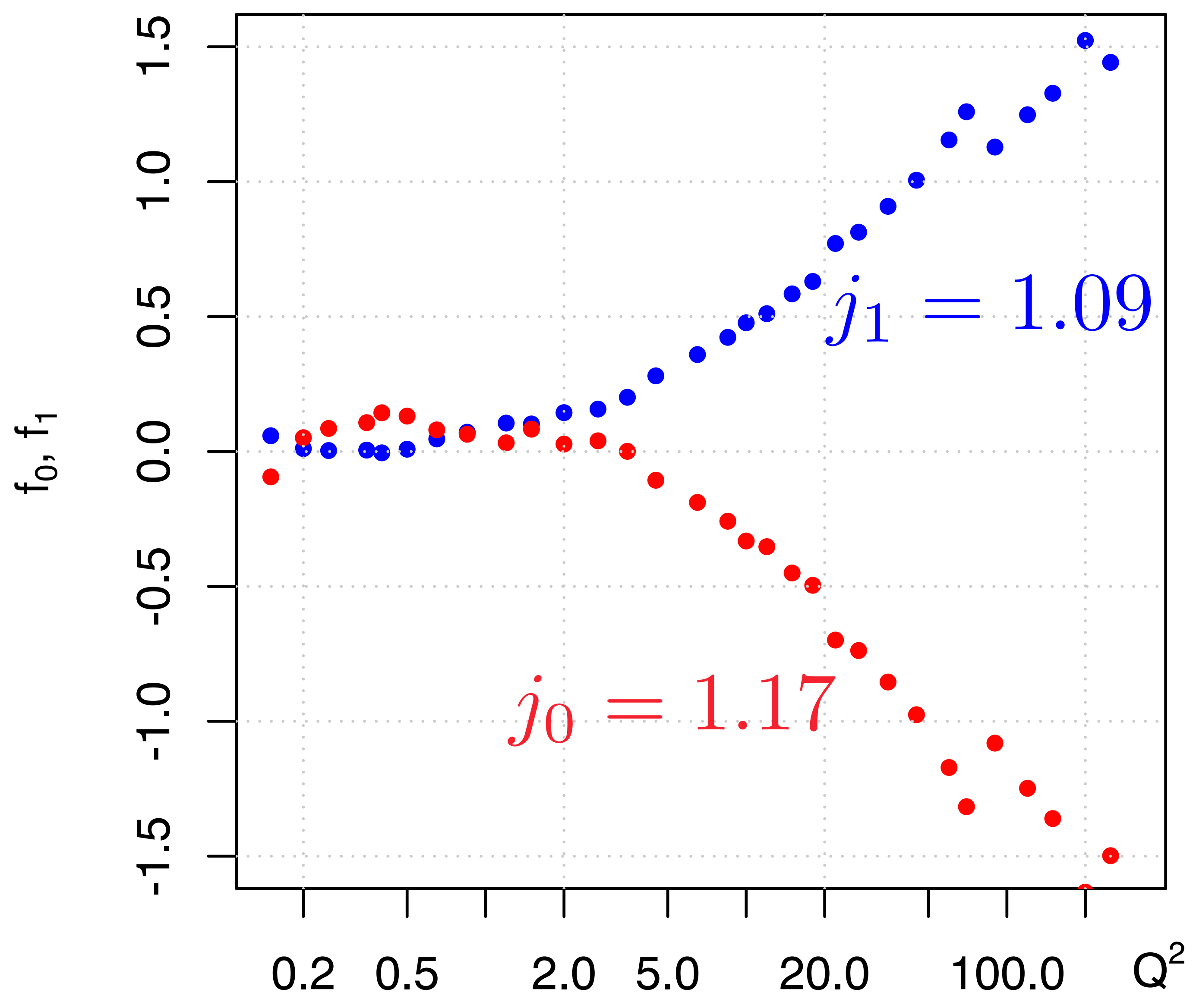
- Let us apply this idea to gauge/string duality
  [Bayona, MSC, Quevedo 17]

Holographic direction $z \sim 1/Q$

$$f_k(Q^2) = P_k(Q^2)\,\psi_k(Q^2)$$

Known function of Q^2 and j_k

Wave function of a 1D Schrodinger problem in holographic direction



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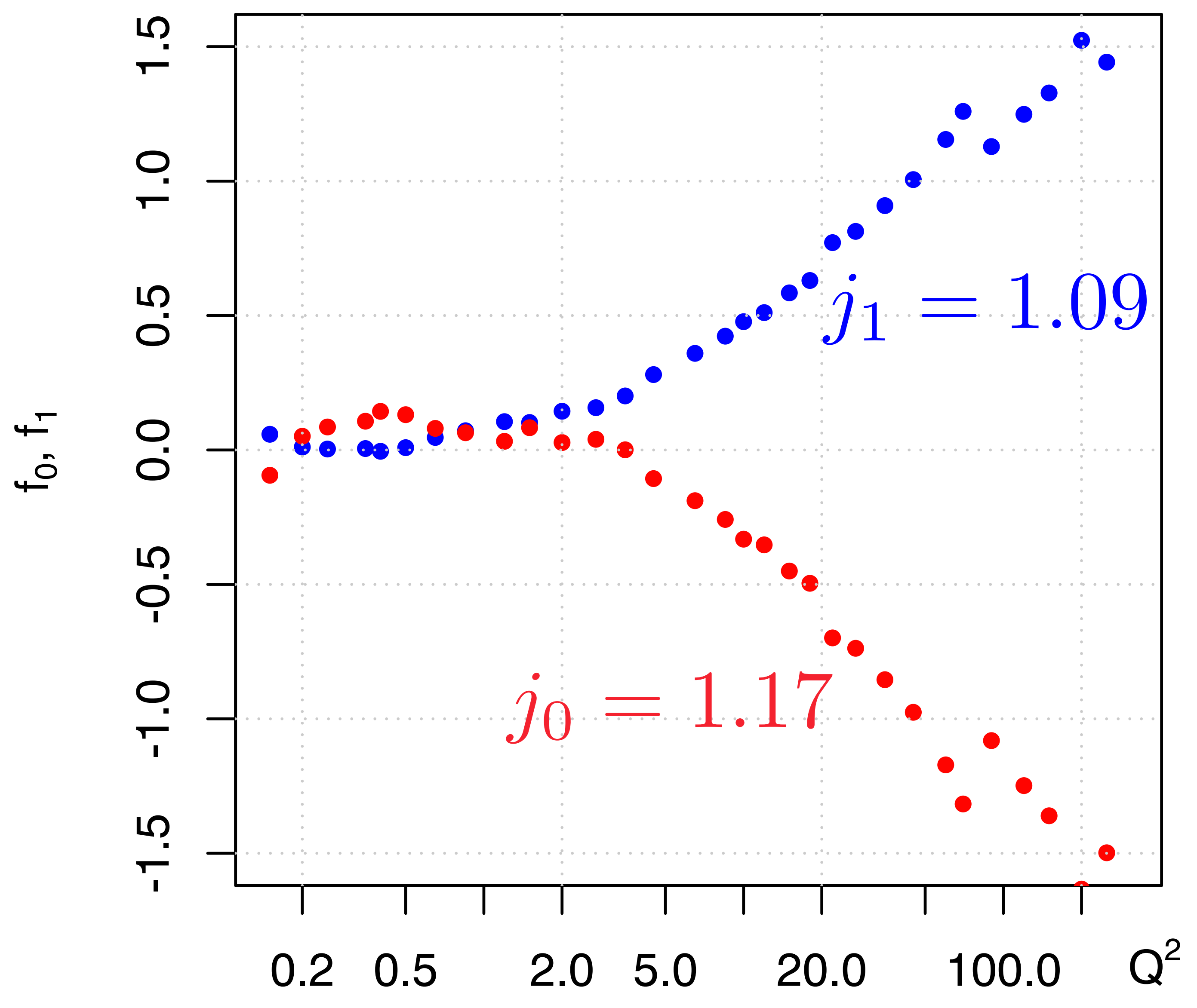
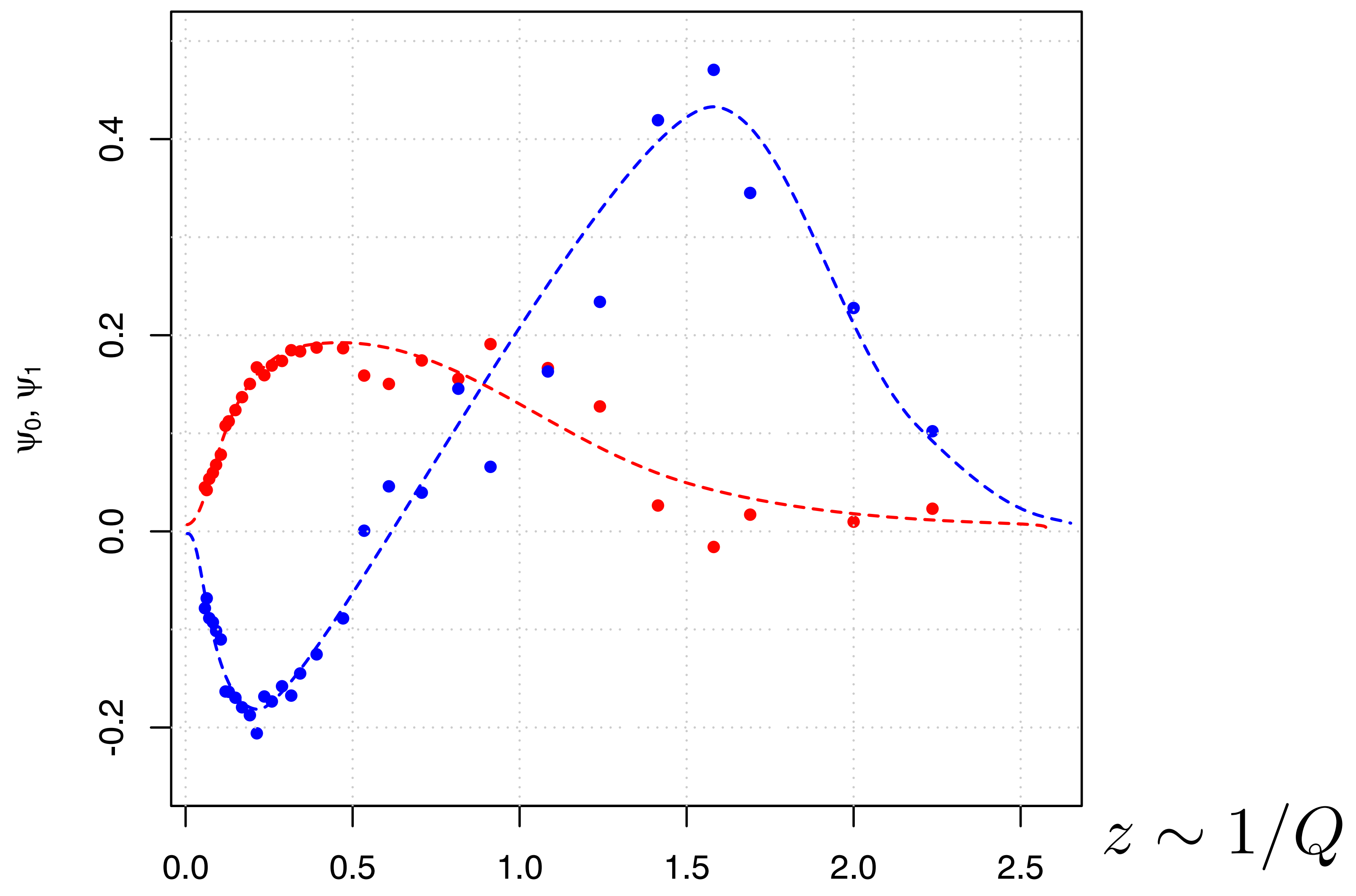
It seems data “knows” about holographic QCD!!





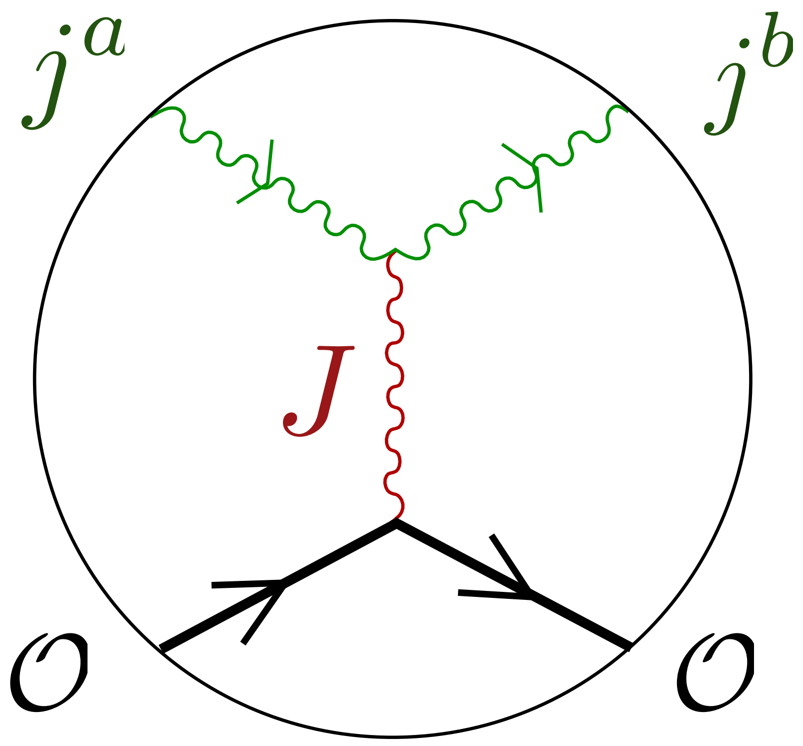
Graviton/Pomeron Regge trajectory at strong coupling [BPST 06]

- Exchange of spin J field in AdS

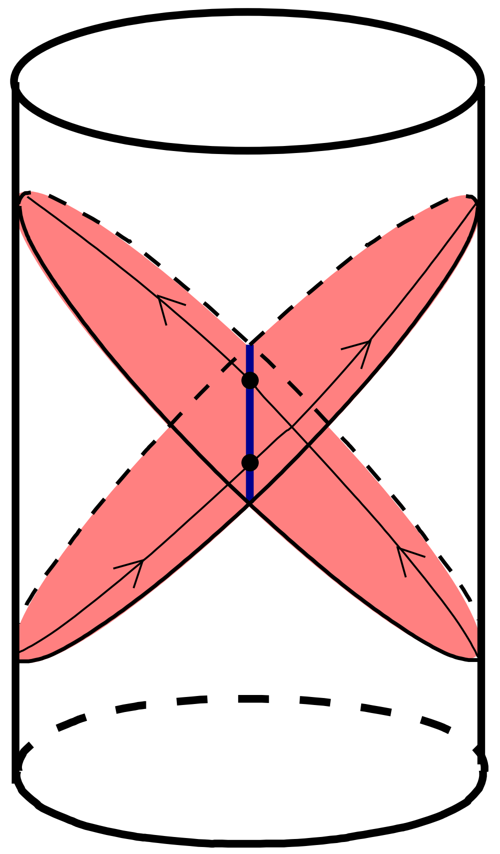
  (symmetric, traceless and transverse)

$$\left(D^2 - m^2\right) h_{a_1 \ldots a_J} = 0$$

with $m^2 = \Delta(\Delta - 4) - J$



AdS scattering process



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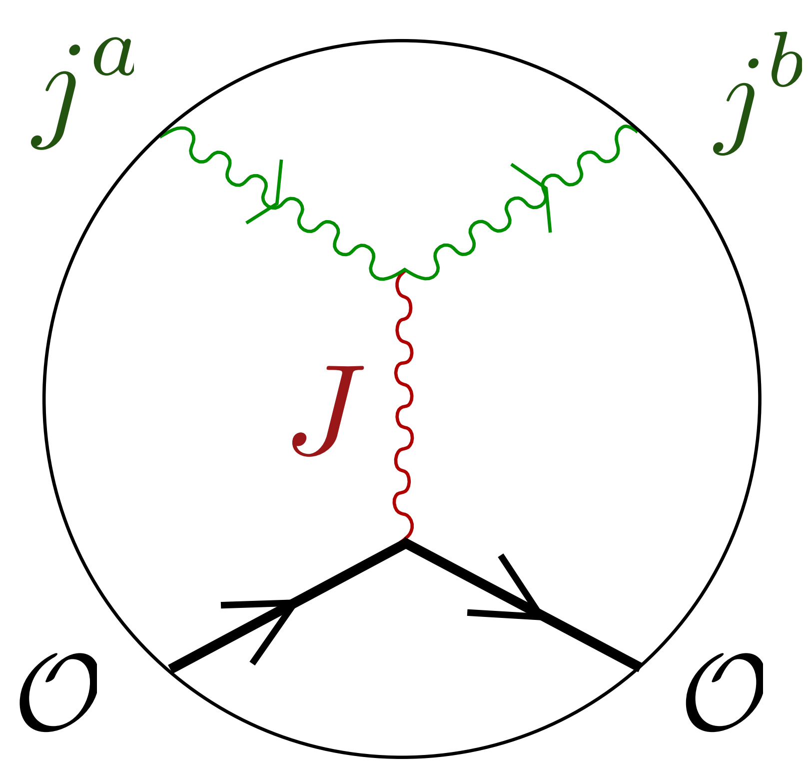

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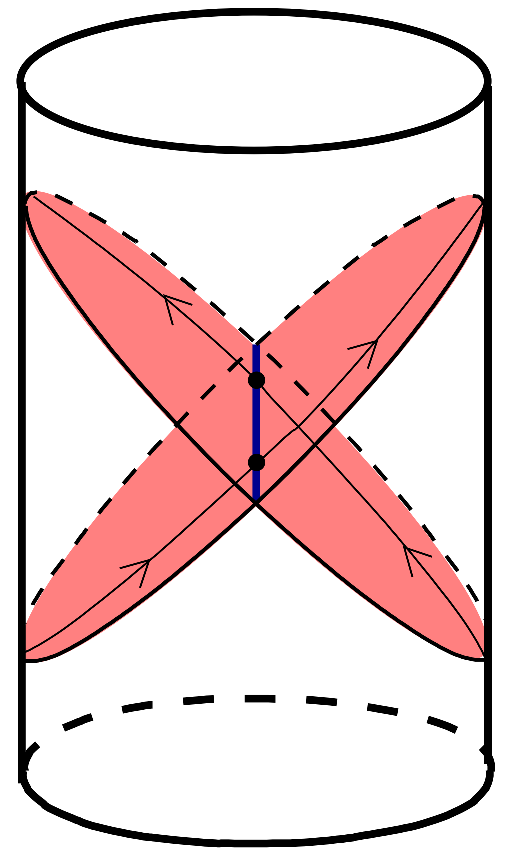
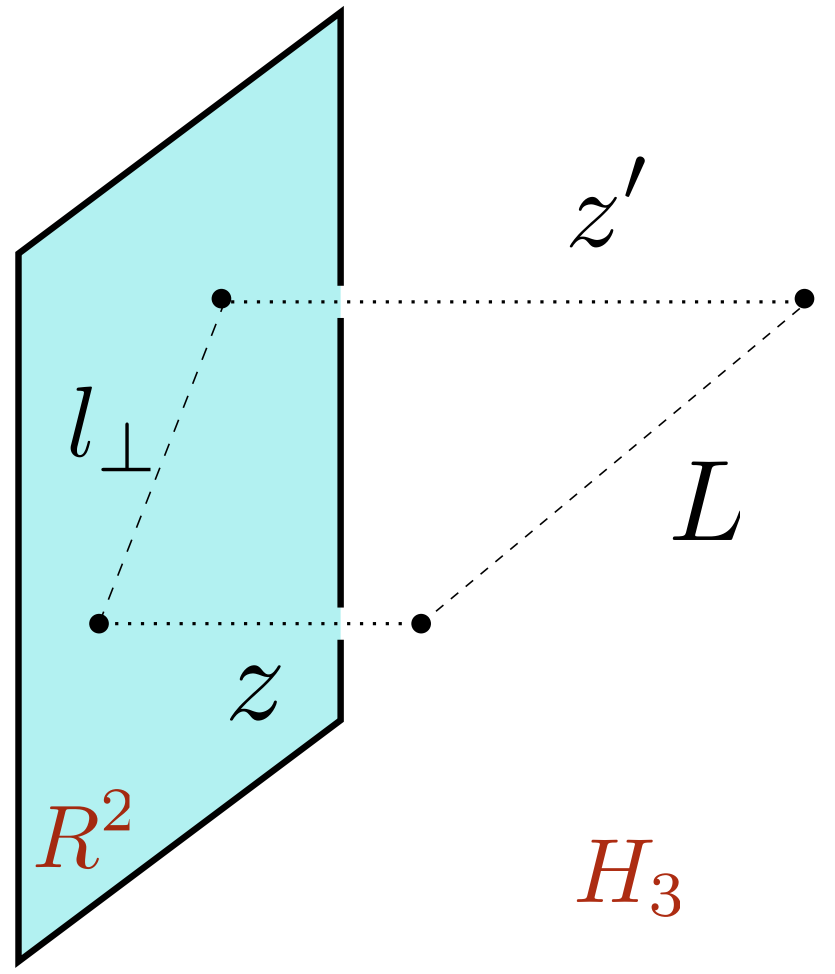


- AdS impact parameter repres. In Regge limit [Cornalba, MSC, Penedones, Schiappa 07]

$$A_J(s,t) \approx i V \kappa_J \kappa'_J \, s \int dl_\perp e^{i q_\perp \cdot l_\perp} \int \frac{dz}{z^3}\frac{dz'}{z'^3} \Phi_1(z)\Phi_3(z)\Phi_2(z')\Phi_4(z') S^{J-1} G_J(L)$$

$S = zz's$, AdS energy squared

$$\cosh L = \frac{z^2 + z'^2 + l_\perp^2}{2zz'}$$, impact parameter



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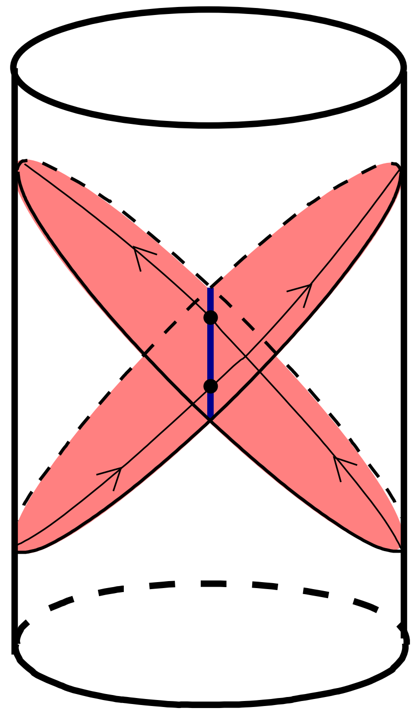

- $G_J(L)$ is the integrated propagator along light rays.

Obeys scalar propagator equation in transverse space

$$\Big[\Box_{H_3} - 3 - \Delta(\Delta - 4)\Big]G_J(L) = -\delta_{H_3}(y,y')$$

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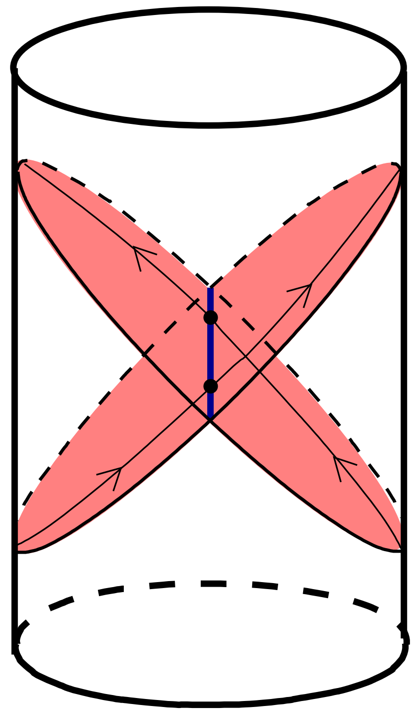

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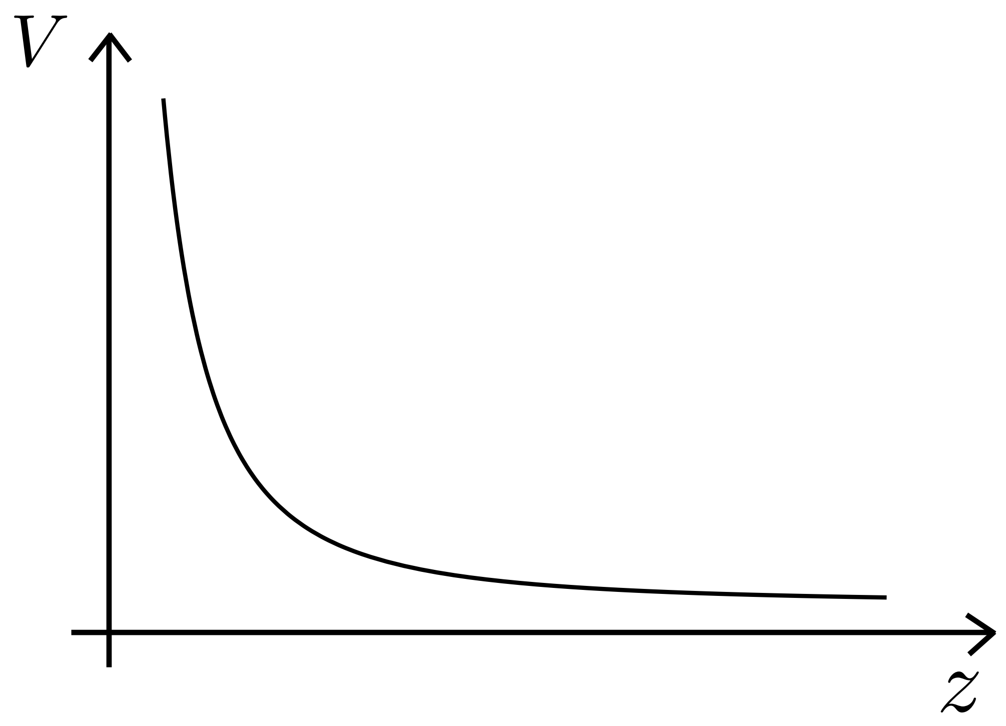
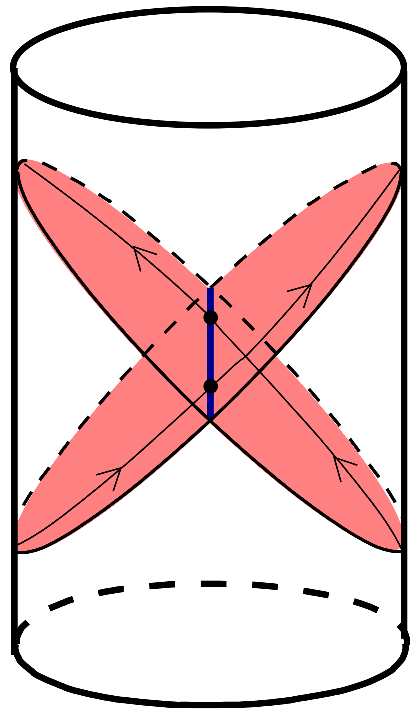


$$\left(-\frac{d}{dz^2} + V(z)\right) = t\,\psi(z)\ ,\ \text{with}$$

$$V = \left(\frac{15}{4} + \Delta(\Delta-4)\right)\frac{1}{z^2}$$

$$A_J(s,t) \approx iV\kappa_J\kappa_J'\, s \int dl_\perp e^{iq_\perp \cdot l_\perp} \int \frac{dz}{z^3}\frac{dz'}{z'^3}\Phi_1(z)\Phi_3(z)\Phi_2(z')\Phi_4(z) S^{J-1} G_J(L)$$



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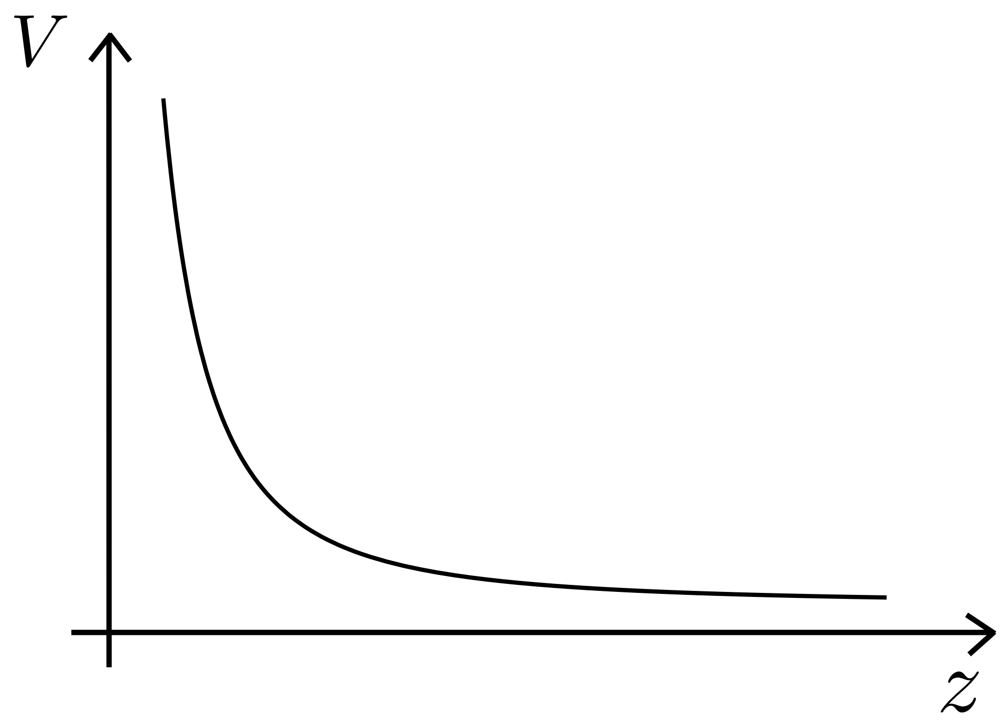

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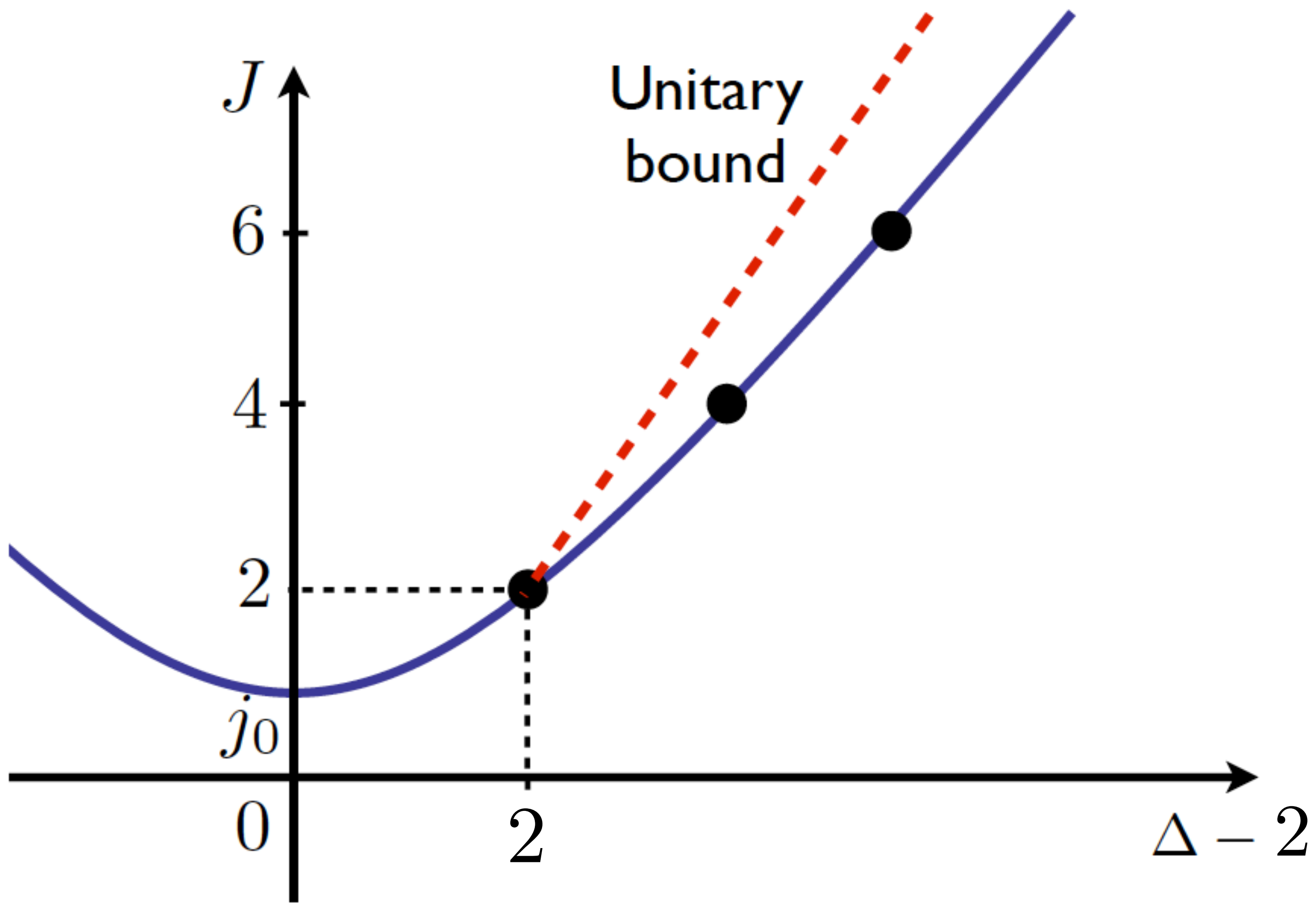


Holographic QCD

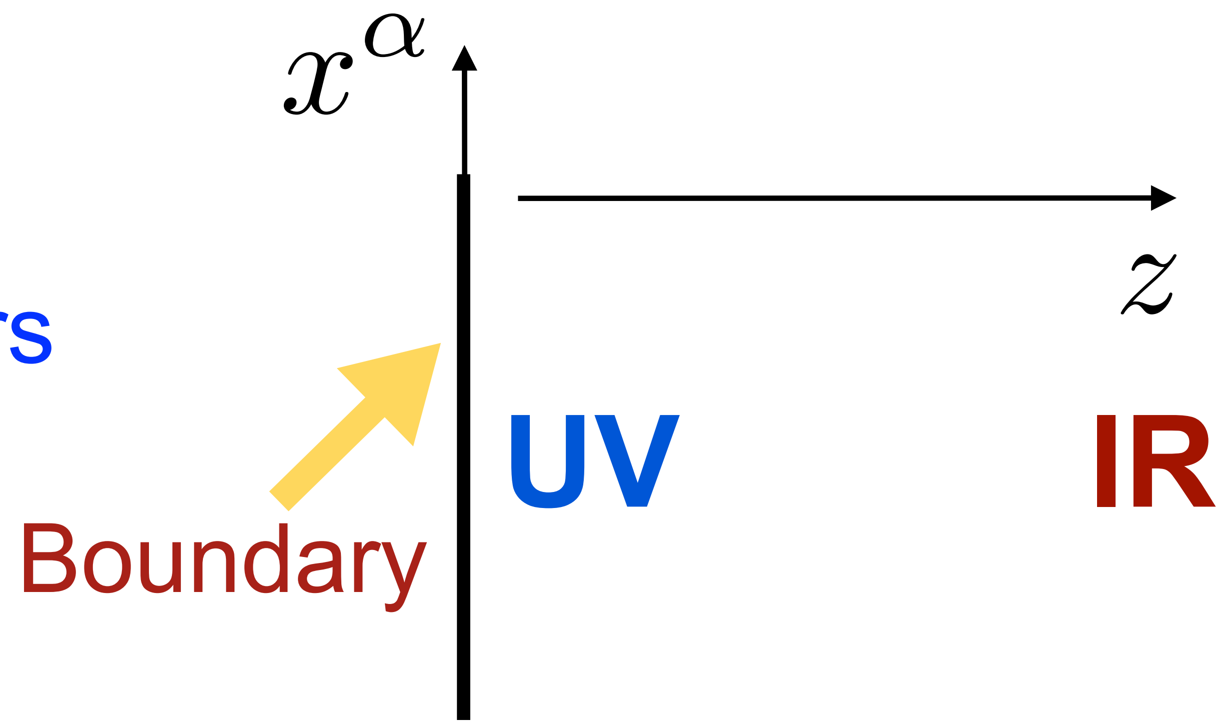
- QCD dual is a 5D theory with a graviton and a dilaton

$$\boxed{\begin{aligned} ds^2 &= e^{2A(z)}\left(dz^2 + \eta_{\alpha\beta}dx^\alpha dx^\beta\right) \\ \Phi &= \Phi(z) \end{aligned}}$$

AdS fields $\longleftrightarrow$ single trace operators

$$g_{ab} \leftrightarrow T_{\alpha\beta}$$

$$\Phi \leftrightarrow F^2$$



- Test our ideas with a 5D dilaton-gravity model [Gursoy, Kiritsis, Nitti 07]

$$S = \frac{1}{2\kappa^2}\int d^5x\sqrt{-g}\,e^{-2\Phi}\left[R + 4(\partial\phi)^2 + V(\phi)\right]$$

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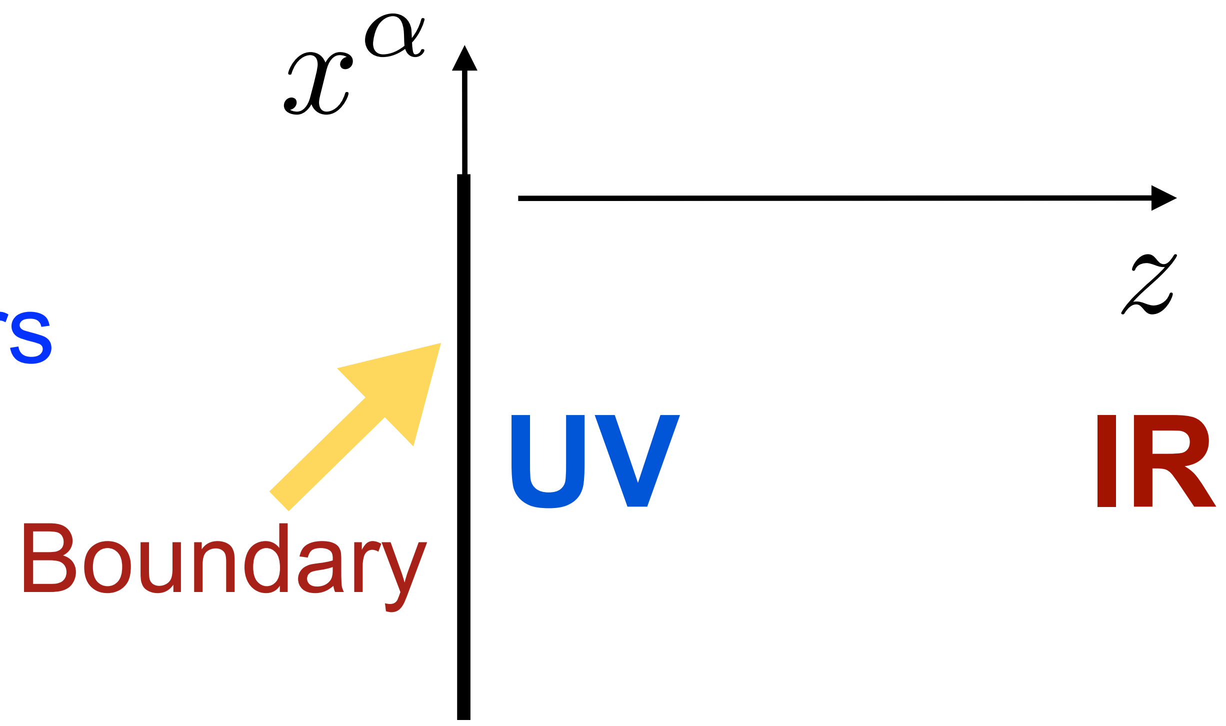

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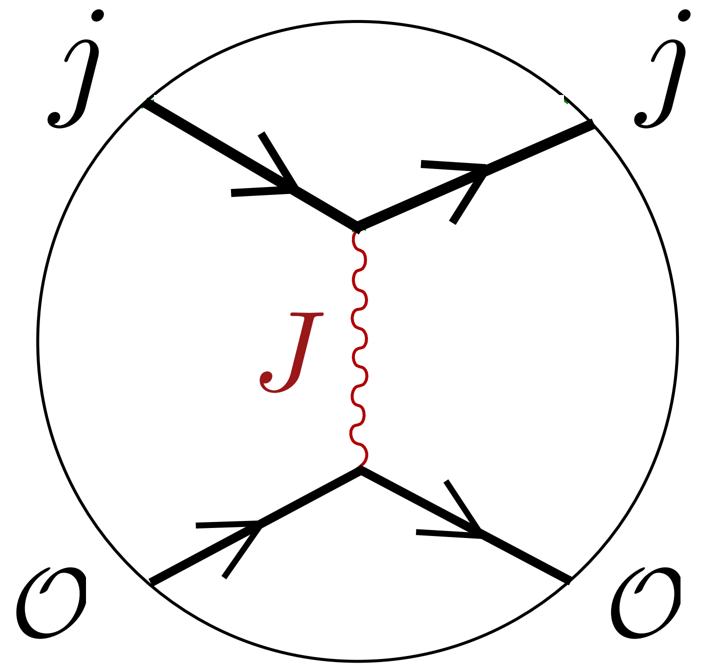

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- Considered non-minimal coupling between U(1) gauge field and graviton trajectory. Recall case of graviton in AdS

$$\int d^5X\sqrt{-g}\,e^{-\Phi}\left(F_{ab}F^{ab} + \beta R_{abcd}F^{ab}F^{cd}\right) \longrightarrow F^{ac}F^{b}{}_{c}h_{ab}\,, \quad F^{ac}F^{bd}\nabla_c\nabla_d h_{ab} \longrightarrow$$

$$\longrightarrow F^{ba_1}\nabla^{a_2}\dots\nabla^{a_{J-1}}F^{a_J}{}_{b}h_{a_1\dots a_J}\,, \quad F^{ba_1}\nabla^{a_2}\dots\nabla^{a_{J-1}}F^{a_Jc}\nabla_b\nabla_c h_{a_1\dots a_J}$$

Spin J field in holographic QCD [Bayona, MSC, Djuric, Quevedo 15]

- Spin J field dual to gluon operator $\mathcal{O}_J \sim \mathrm{Tr}\left(F_{\alpha\beta_1} D_{\beta_2} \dots D_{\beta_{J-1}} F_{\beta_J}{}^{\alpha}\right)$

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Decompose symmetric, traceless, transverse field $h_{a_1 \dots a_J}$ with respect to global $SO(1,3)$ boundary symmetry. Propagating modes have boundary indices $h_{\alpha_1 \dots \alpha_J}$

- In AdS limit reduce to $\left(\nabla^2 - m^2\right) h_{a_1 \dots a_J} = 0$

$$m^2 = \Delta(\Delta - 4) - J\,, \quad \Delta = \Delta(J)$$

- For $J = 2$ reproduce TT metric fluctuations

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Equation for propagating mode
in effective field theory

$$\Big(\nabla^2 - 2\dot\Phi\nabla_z + J\dot A^2 e^{-2A} - \Delta(\Delta-4) +$$
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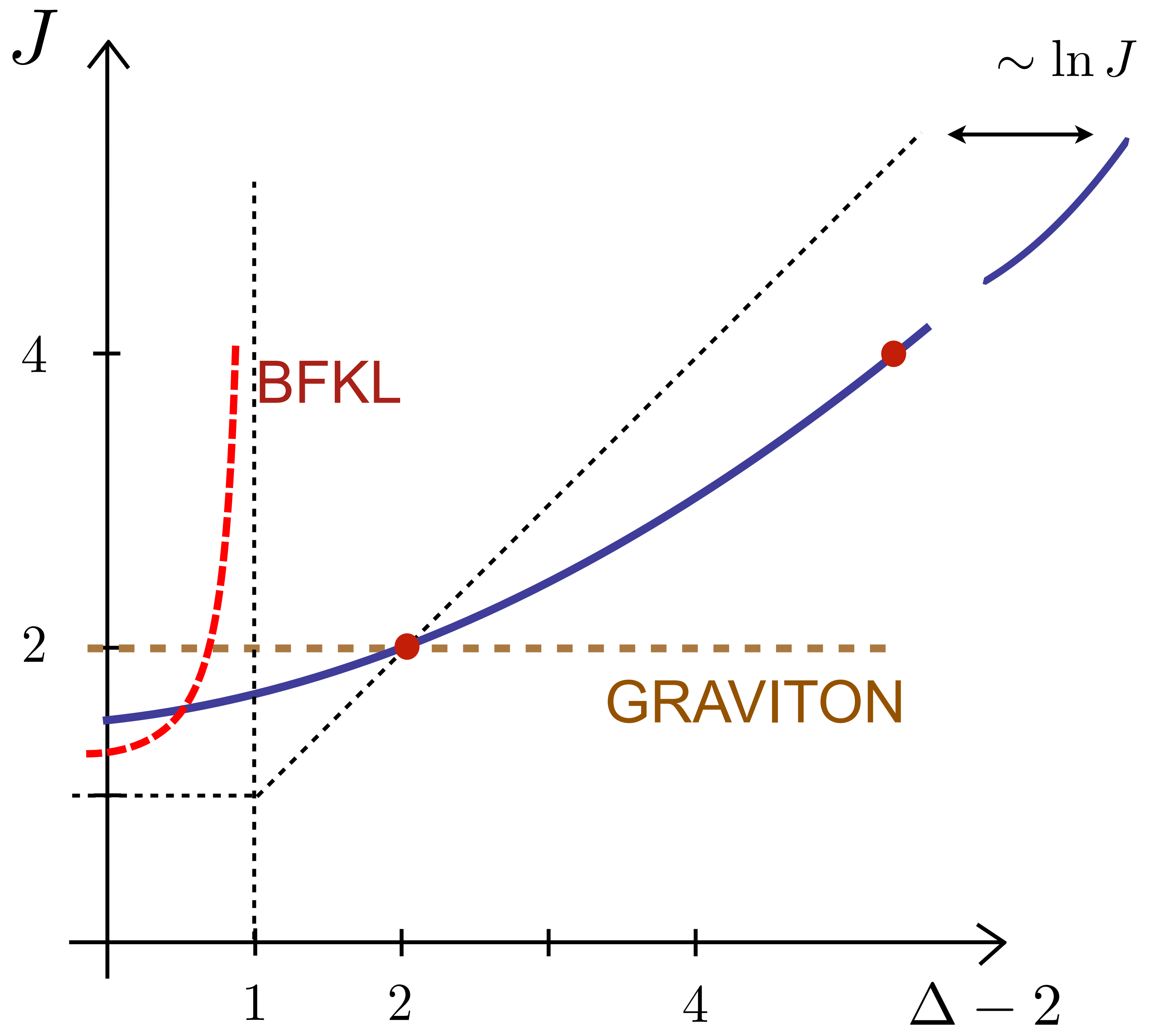

Equation for propagating mode in effective field theory

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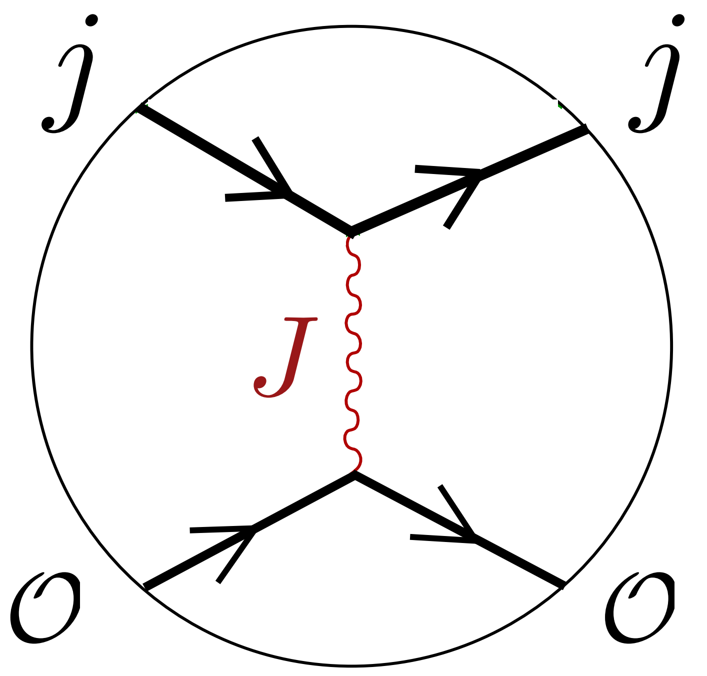
$$\left. +(J-2)e^{-2A}\left[a\ddot{\Phi} + b\dot{\Phi}^2 + c\left(\ddot{A} - \dot{A}^2\right)\right]\right) h_{\alpha_1 \dots \alpha_J} = 0$$

$$\Delta(\Delta-4) \approx \underbrace{\frac{2}{l_s^2}(J-2)\left(1 + d\,e^{-\Phi/2}\right)}_{\text{IR described by graviton trajectory}} + \underbrace{e^{-4\Phi/3}\left(J^2-4\right)}_{\text{UV free theory unitarity bound}}$$

Many Regge trajectories

- Consider 5D exchange of spin J field in the Regge limit



$$A_J(s,t) = iV \frac{\kappa_J \kappa'_J}{(-2)^J}\, s \int dz dz' e^{3A+3A'-\Phi-\Phi'}$$

$$|v_1|^2 |v'_2|^2 \left(s e^{-A-A'}\right)^{J-1} G_J(z,z',t)$$

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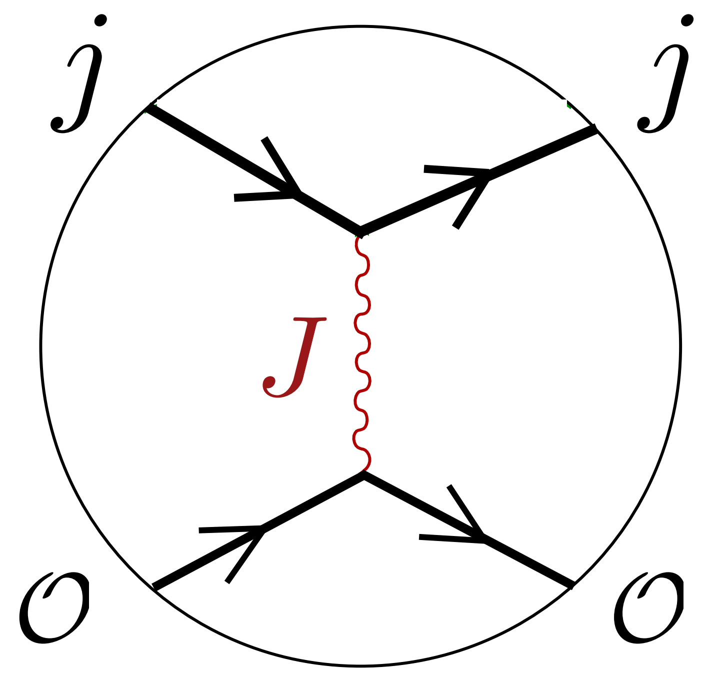

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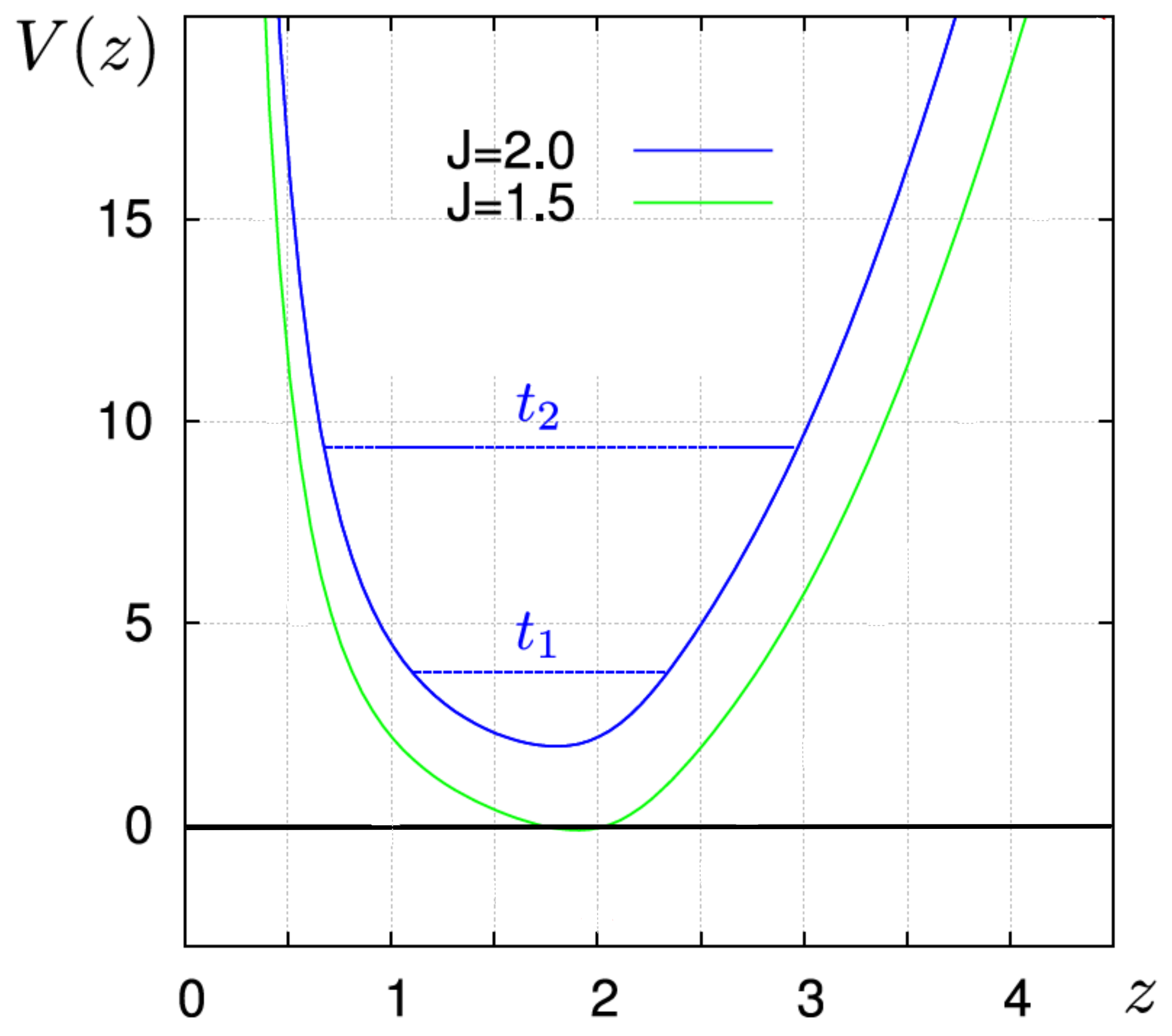

Reduces to a Schrodinger problem (spectral representation)

$$G_J(z,z',t) = e^{\Phi - \frac{A}{2} + \Phi' - \frac{A'}{2}} \sum_n \frac{\psi_n(z)\psi_n^*(z')}{t_n(J) - t}$$

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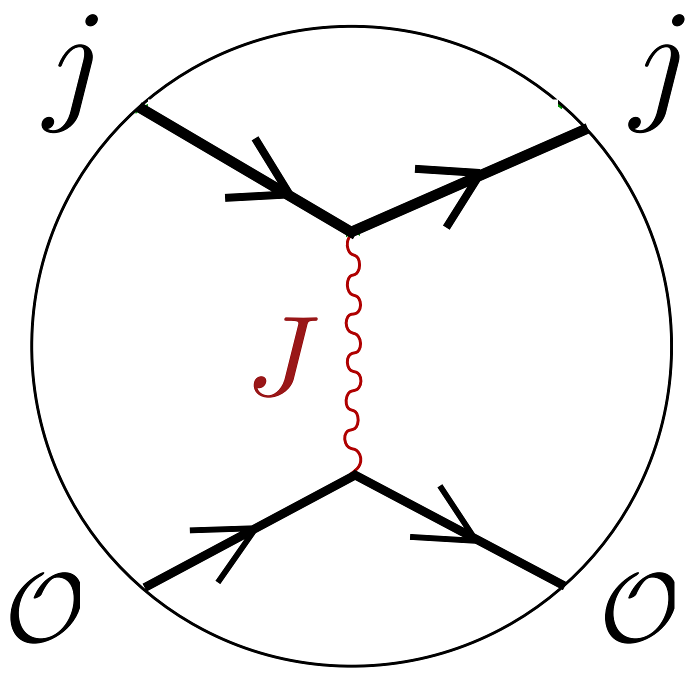

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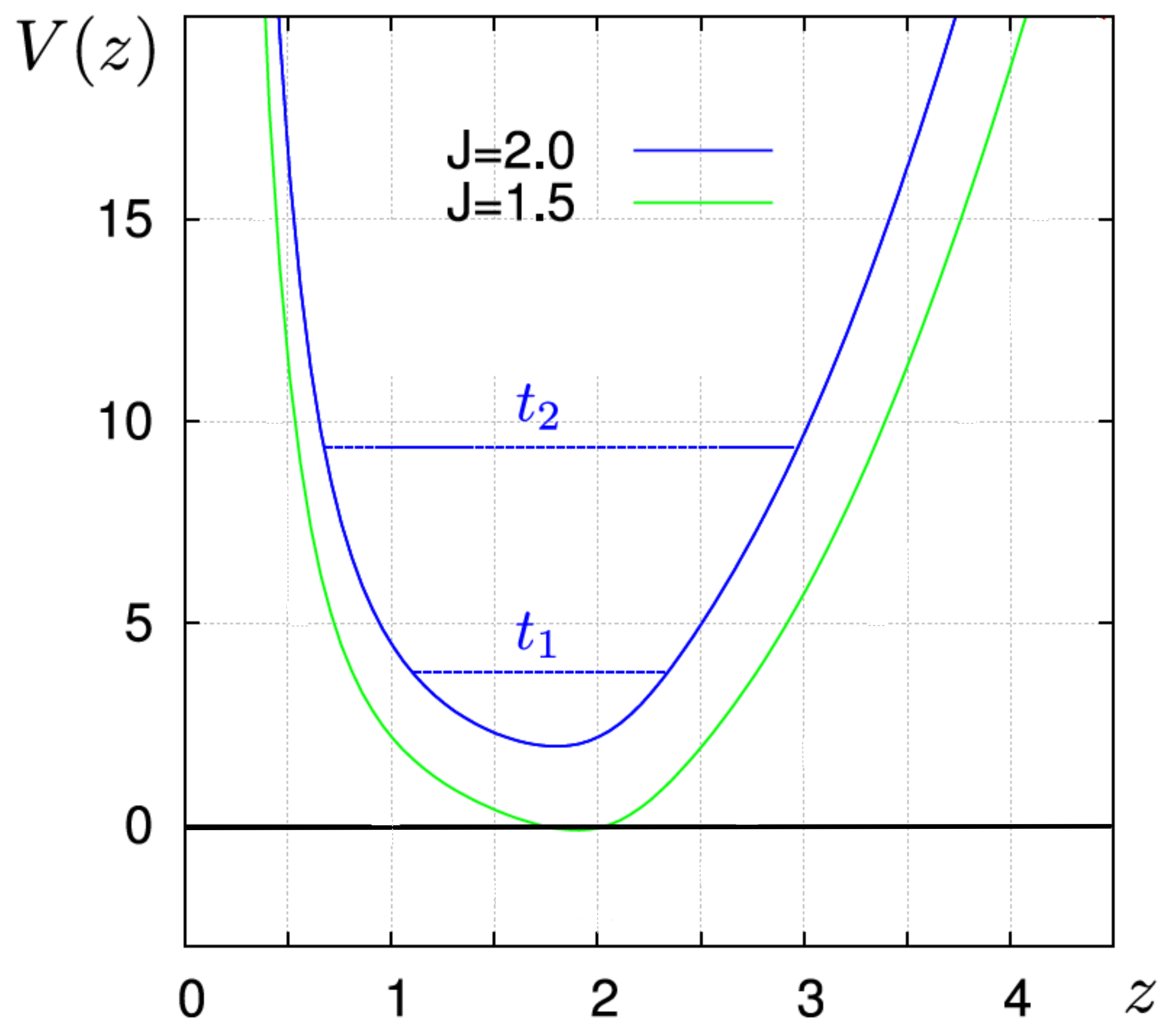

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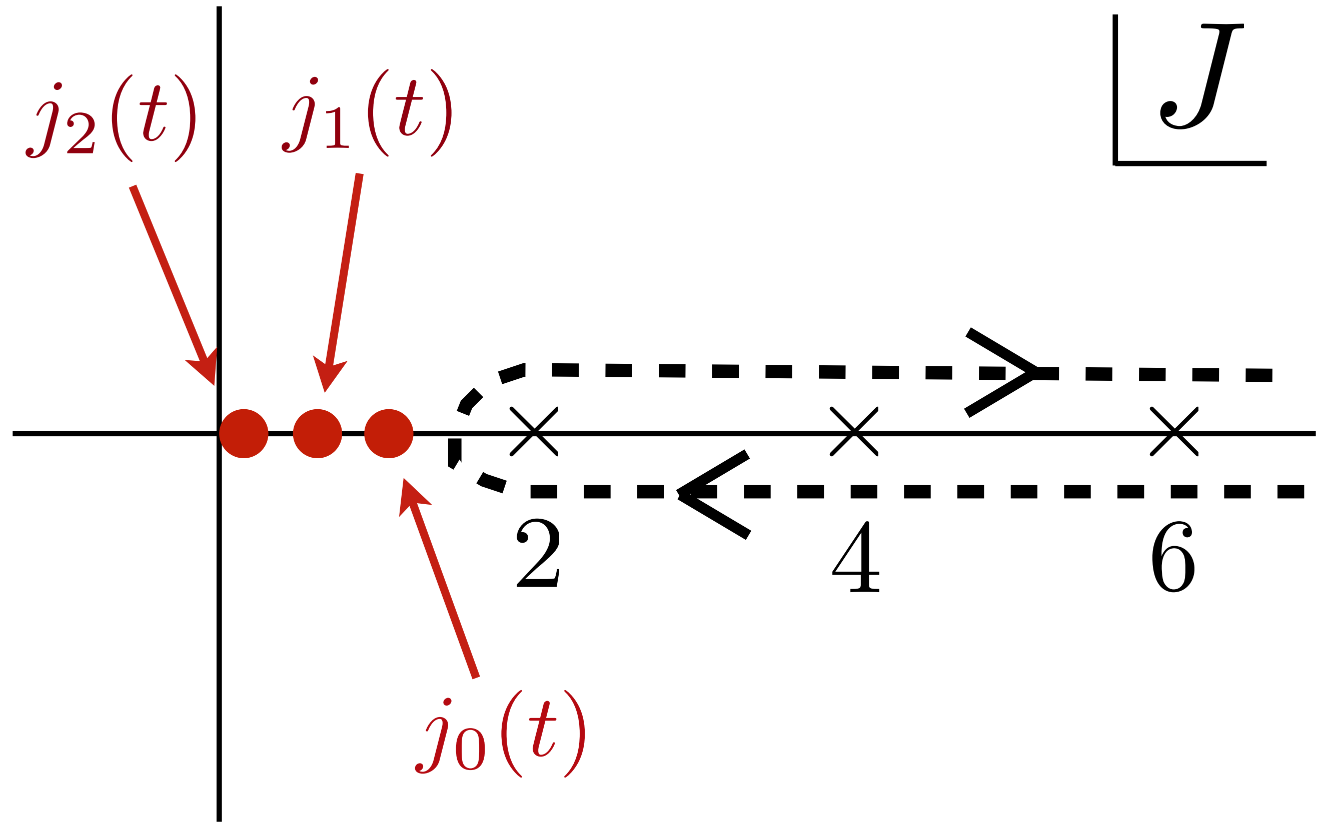
- Sum over spin J exchanges $\sum_J \to \int \frac{dJ}{\sin \pi J}$

Poles in the J-plane at $t = t_n(J) \;\Rightarrow\; J = j_n(t)$



$$F_2(x,Q^2) = \sum_n \left(f_n^{\mathrm{MC}}(Q^2) + f_n^{\mathrm{NMC}}(Q^2) \right) x^{1-j_n}$$

- Dependence on virtual photon wave function

$$f_n^{\mathrm{MC}}(Q^2) = g_n Q^{2j_n} \int dz\, e^{-(j_n - \frac{3}{2})A} \left(f_Q^2 + \frac{\dot{f}_Q^2}{Q^2} \right) \psi_n$$

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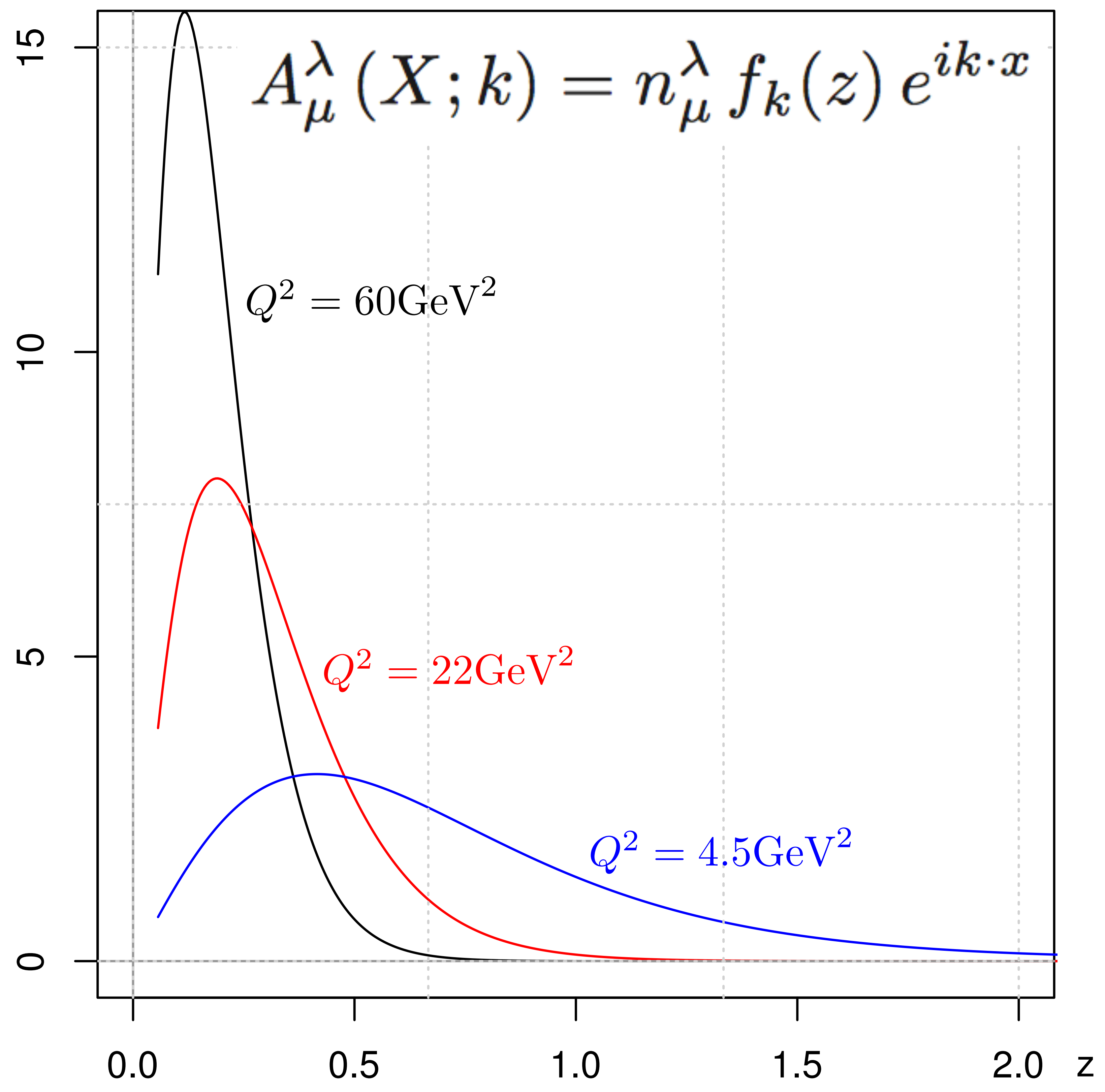

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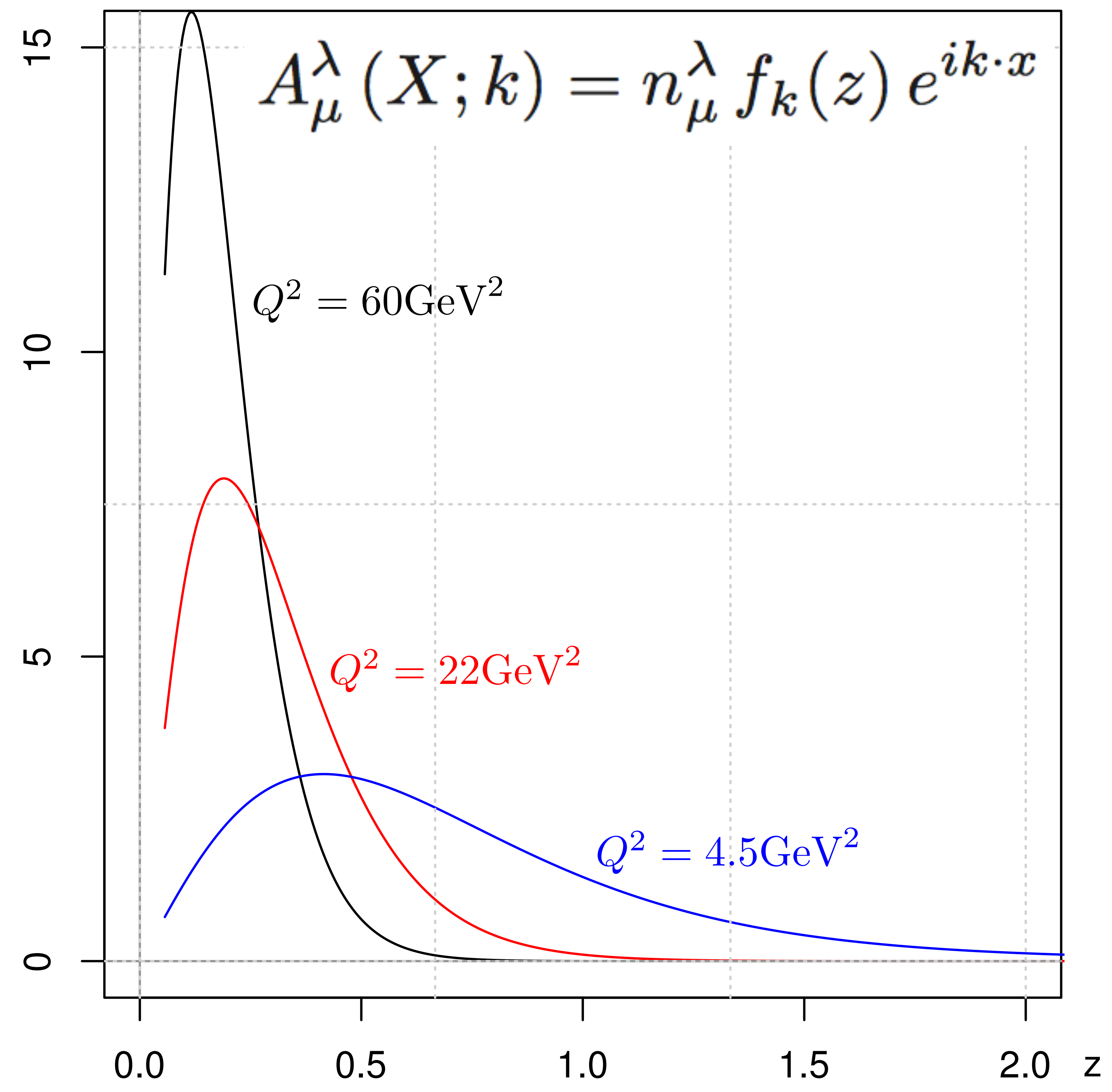
$$\tilde{\mathcal{D}}_\parallel = e^{-2A} \left(\partial_z^2 - (\dot{A} - 2\dot{B})\partial_z + \ddot{B} + \ddot{A} + \dot{B}^2 - \dot{A}\dot{B} \right)$$



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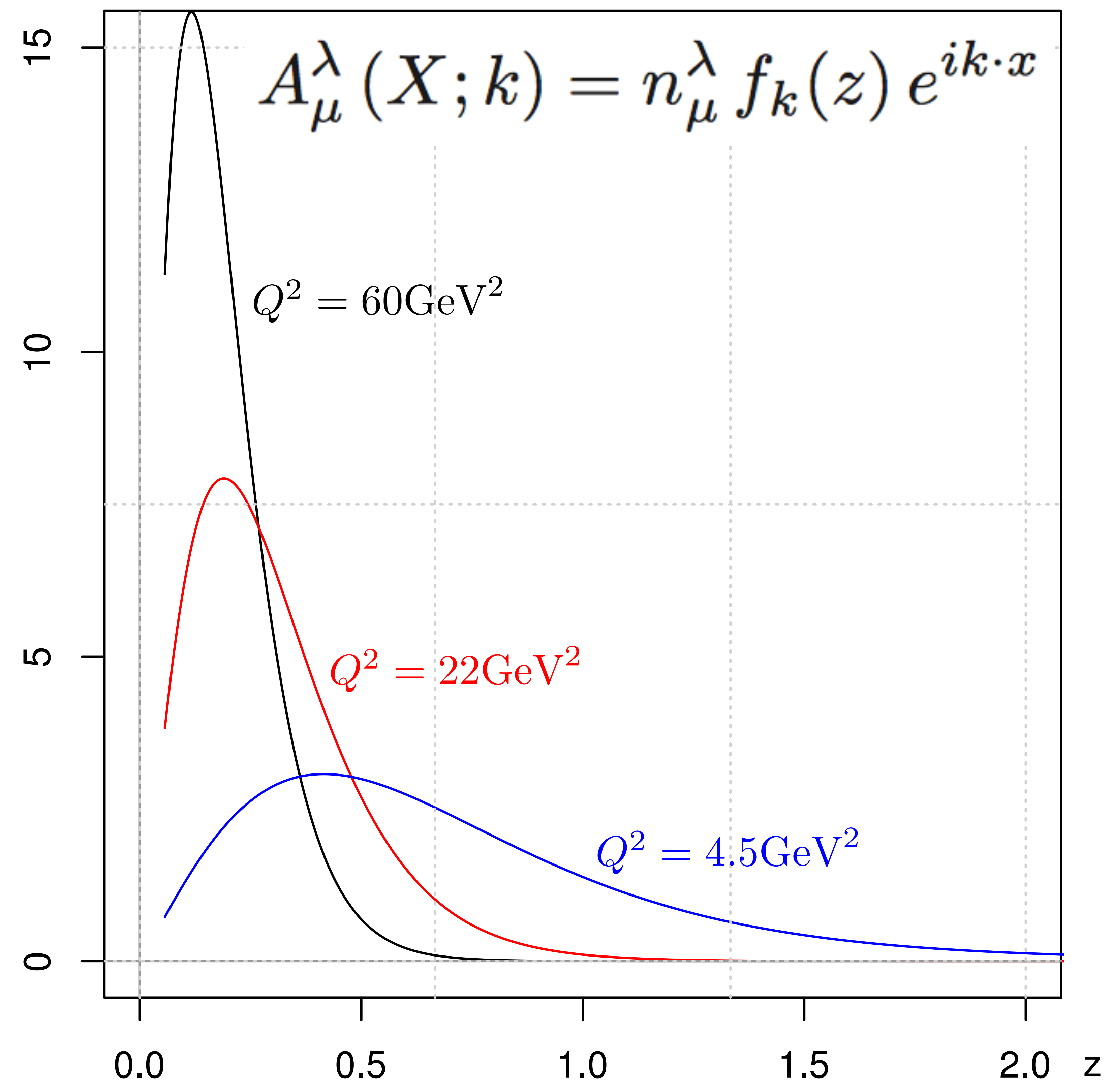
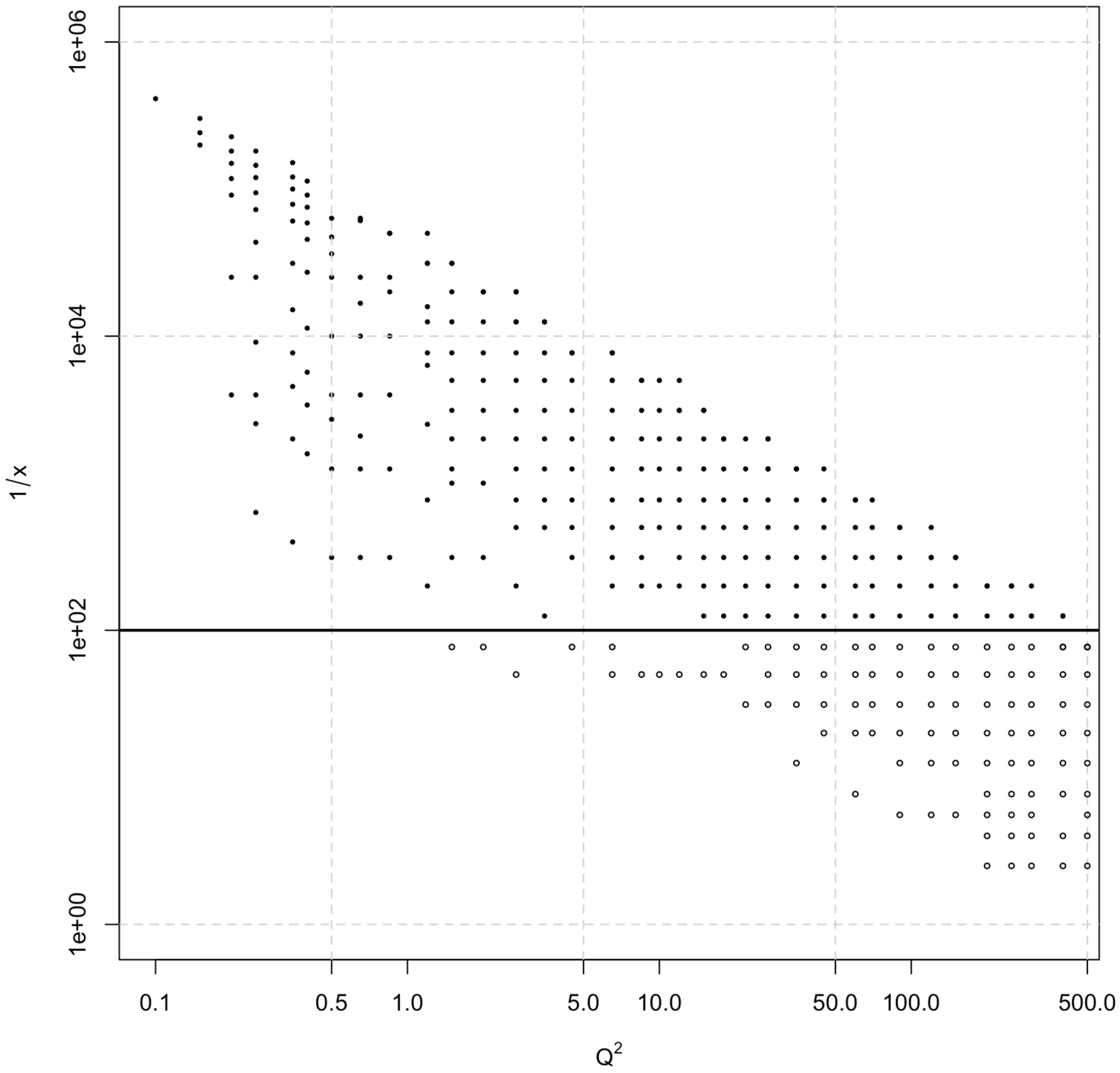
$$\boxed{\begin{aligned} \tilde{\mathcal{D}}_\perp &= e^{-2A}\left(\dot A \partial_z + \dot A^2 + \dot A \dot B\right) \\ \tilde{\mathcal{D}}_\parallel &= e^{-2A}\left(\partial_z^2 - (\dot A - 2\dot B)\partial_z + \ddot B + \ddot A + \dot B^2 - \dot A \dot B\right) \end{aligned}}$$



- Dependence on fixed target absorbed in coupling

$$g_n = -2\pi^2 \frac{\kappa_{j_n(0)} \bar\kappa_{j_n(0)}}{2^{j_n(0)}} j_n'(0) \int dz\, P_{24}(P^2,z)\, e^{(1-j_n(0))A(z)} e^{B(z)} \psi_n^*(j_n(0),z)$$

Test model agains low x DIS data from HERA



Truncated data to $x < 0.01$ region.
Has 249 data points and large range in Q

$$\left(0.1 < Q^2 < 400 \text{ GeV}^2\right)$$

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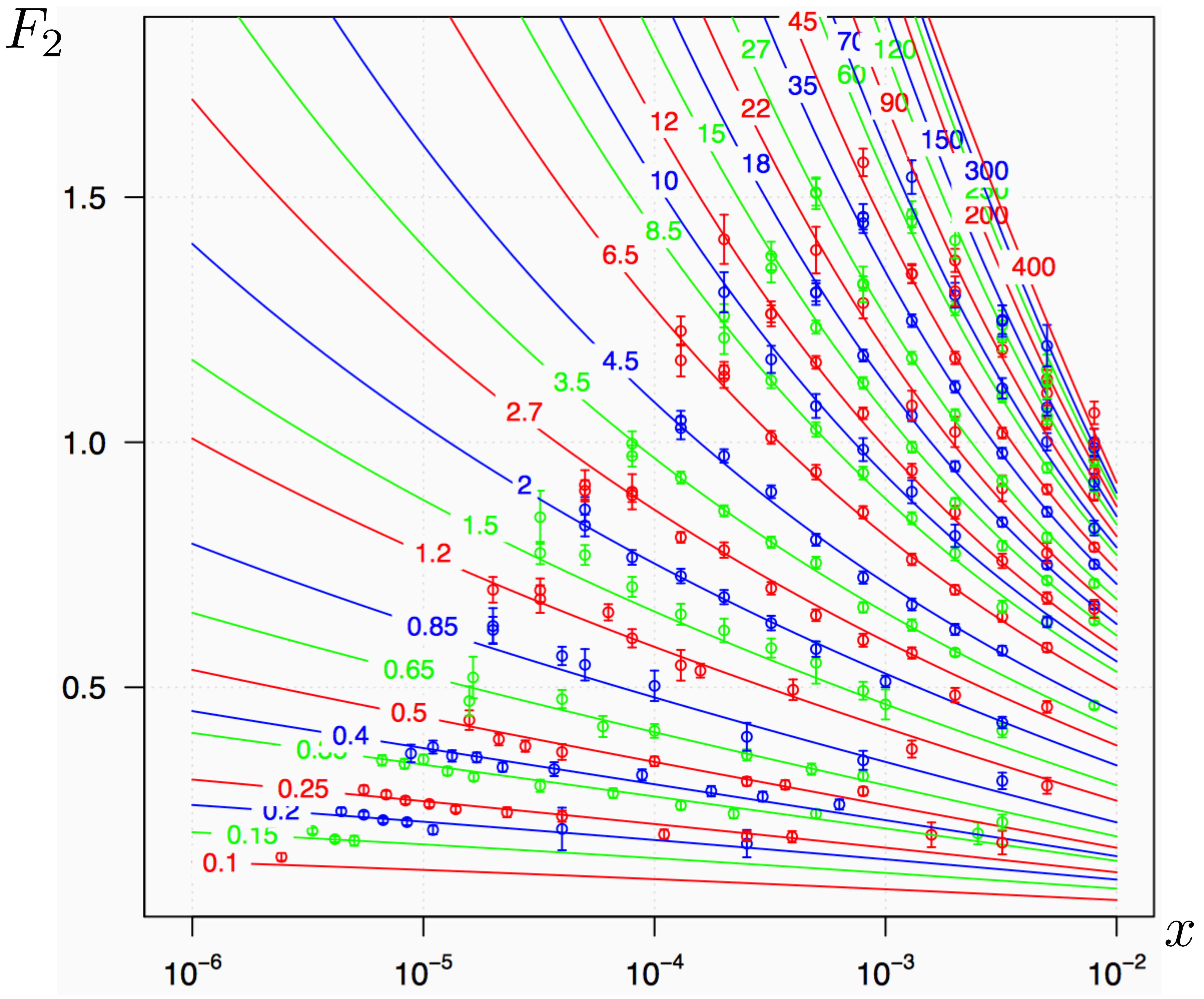

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Kept the first 4 Regge trajectories
(up to intercept of meson trajectory
that will also contribute)

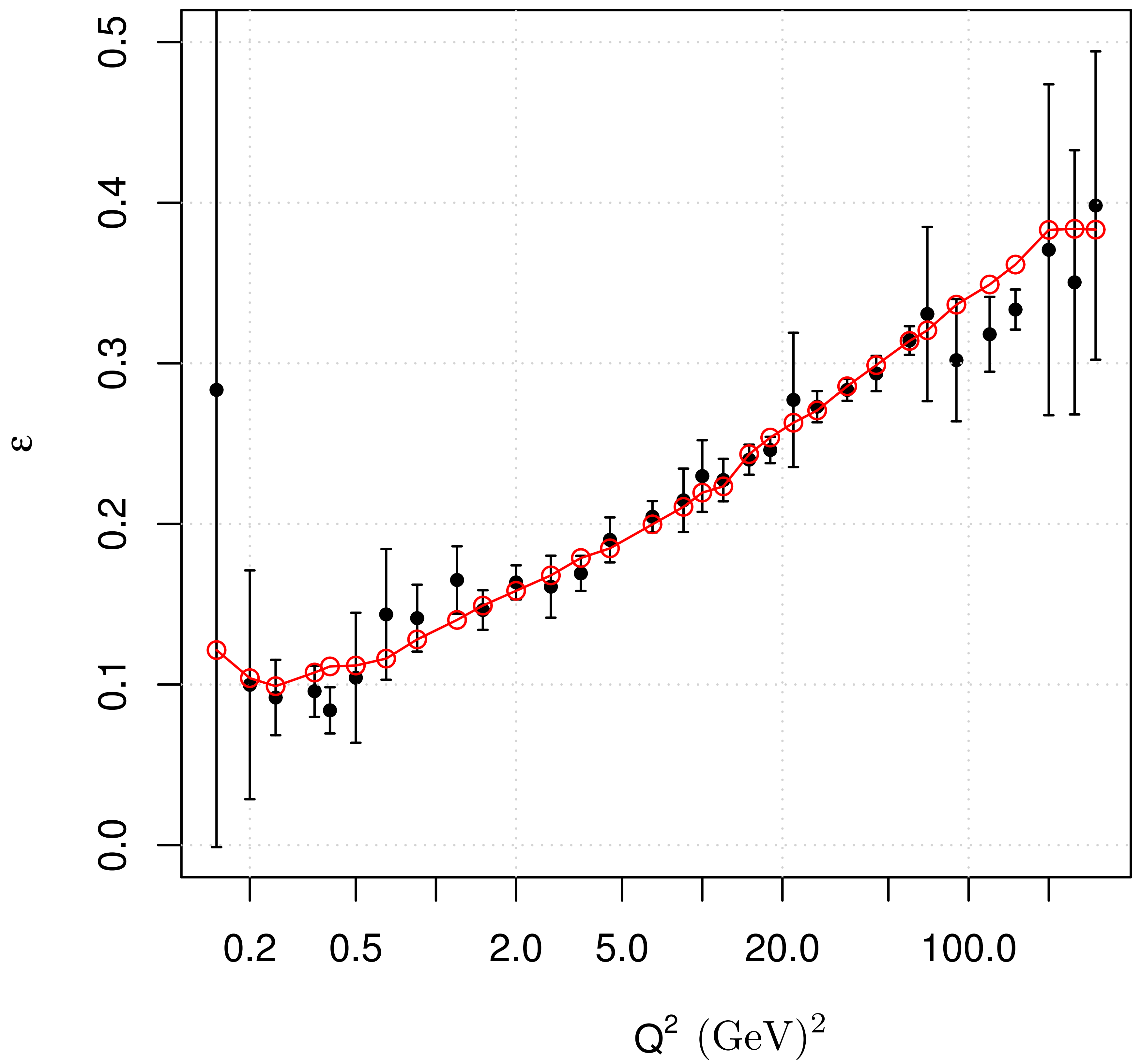
5 parameters from spin J equation;
4x2 parameters from coupling of each pomeron

Parameters fixed with $\chi^2_{\text{d.o.f.}} = 1.1$

$$l_s^{-1} = 6.93 \text{ GeV}\,, \quad \beta^{-1/2} = 6.20 \text{ GeV}$$

parameter	value	couplings	value	couplings	value
a	-4.68	g_0	-0.154	$\tilde{g}_0$	0.0707
b	4.85	g_1	-0.424	$\tilde{g}_1$	-0.0378
c	0.665	g_2	2.12	$\tilde{g}_2$	-0.248
d	-0.328	g_3	-0.721	$\tilde{g}_3$	0.363

• Reproduced long sought running of effective exponent $\sigma \sim f(Q)\left(\frac{1}{x}\right)^{\epsilon_{eff}(Q)}$



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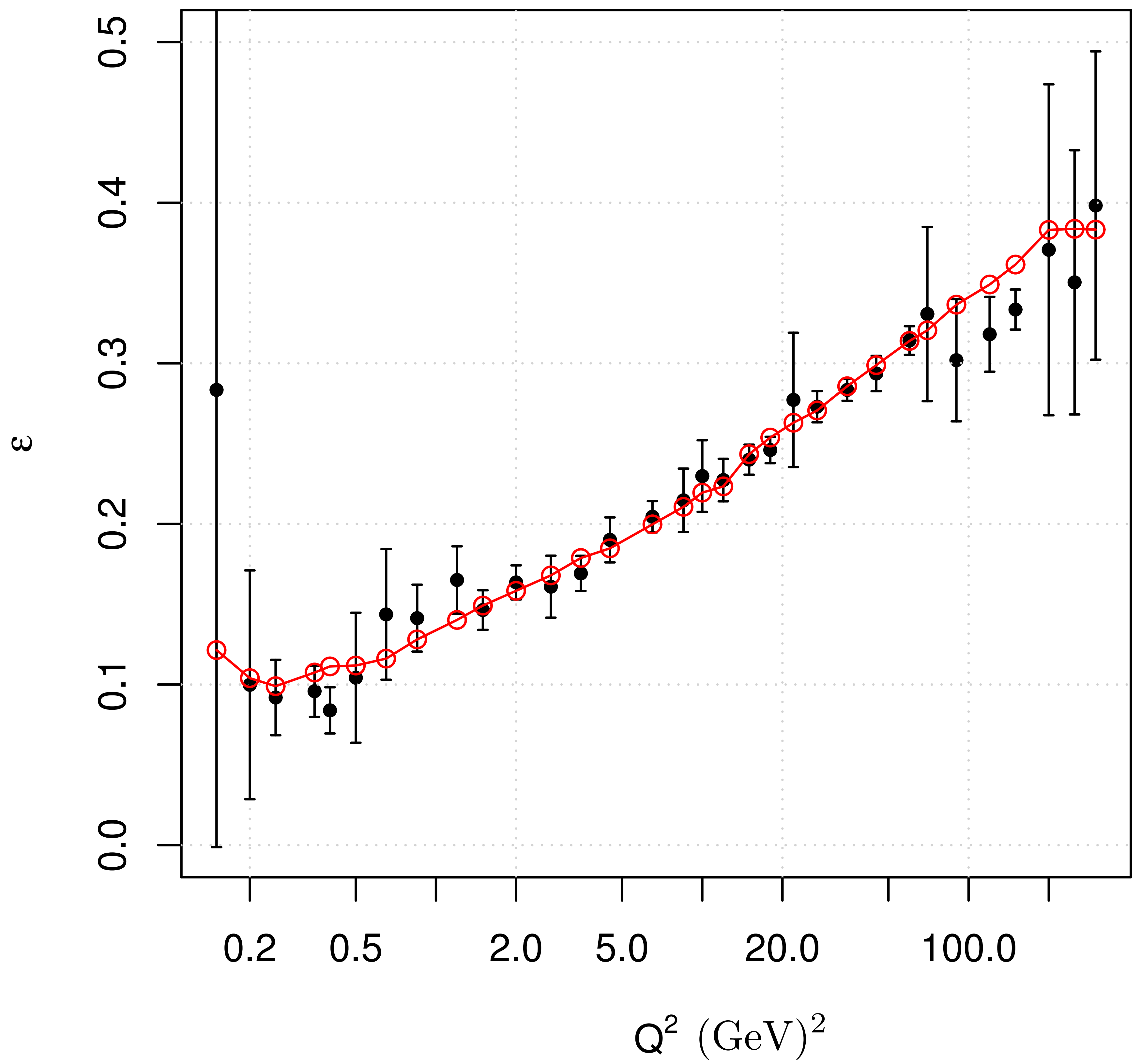

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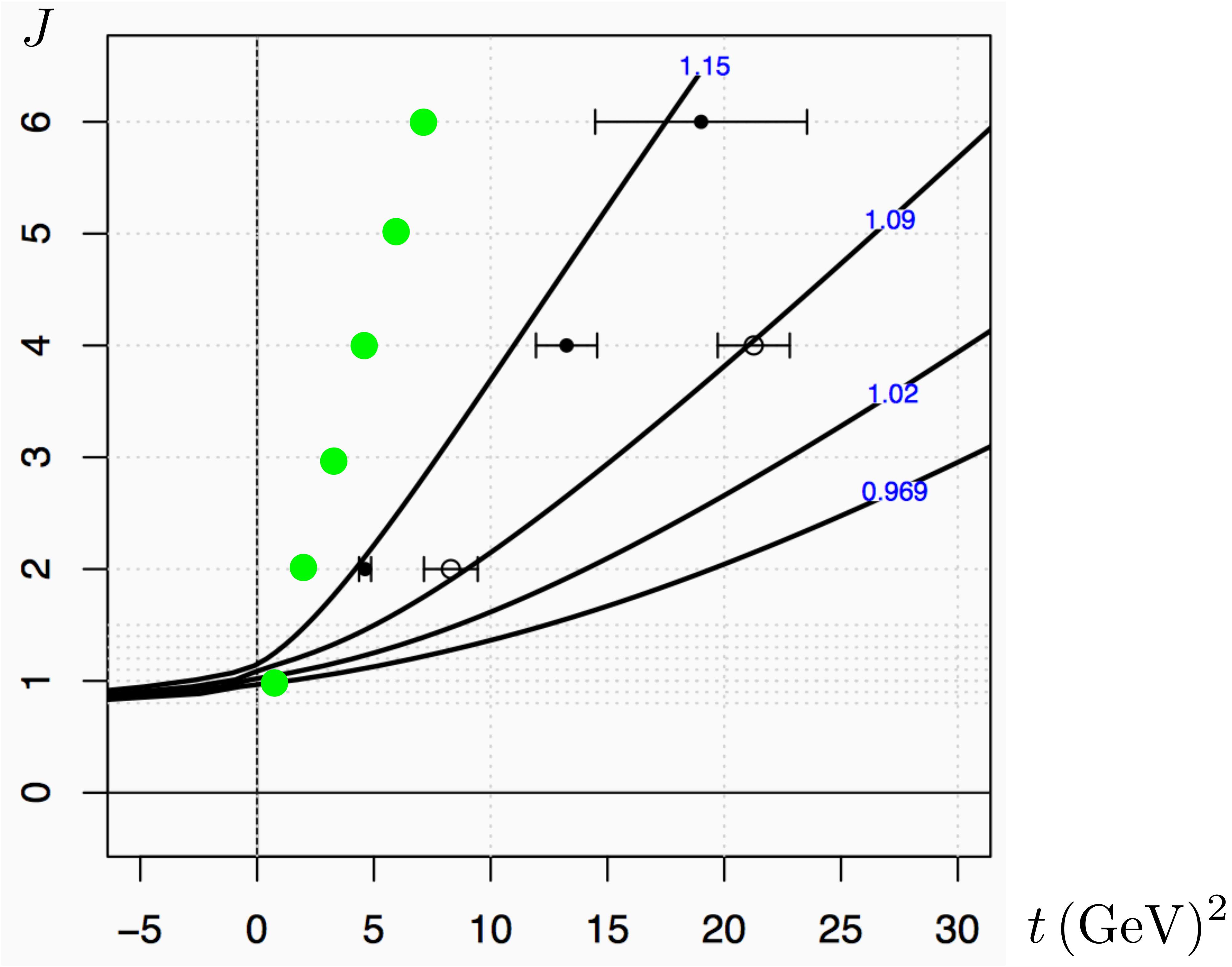
• Regge trajectories consistent with lattice [Meyer 05] QCD glueball spectrum!



In green meson trajectories

Non-minimal coupling defines scale of 1-10 GeV; matches order of magnitude of gap between spin 4 and 2 glueballs [CMEZ 14]

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- How generic are our results? Should try other holographic QCD models...

THANK YOU