Recent developments in low-x physics

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- Low x physics in real life
- Theoretical low x physics
- Low x in AdS/CFT
- Conclusions

(selection, subjective: see sessions)

Low x physics in real life

Structure functions at small x: resummation at low x
(Forte, Altarelli, Ball); (Ciafaloni,Colferai,Salam,Stasto); (R.Thorne,C.White)

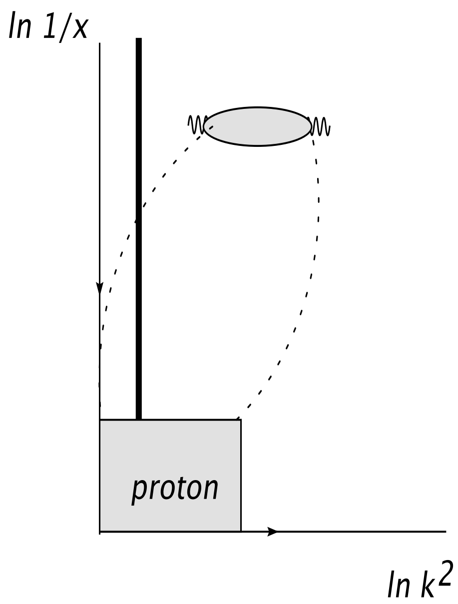
- different factorization schemes
- corrections large (comparable to NNLO in HERA kinematic region)
- resummed splitting function matrix
- coefficient functions (Higgs, Drell-Yan)

$\longrightarrow$ talk at this conference

Structure functions: discrete BFKL Pomeron (J.Ellis, H.Kowalski, D.Ross)

Idea (Lipatov): by imposing boundary conditions at the nonperturbative boundary, fixed cut singularity is resolved into a string of discrete poles.
Work out and compare with HERA data:

- need large number of poles
- k_t^2 dependence of unintegrated gluon density is very sensitive to choice of boundary conditions
- information on behavior at boundary

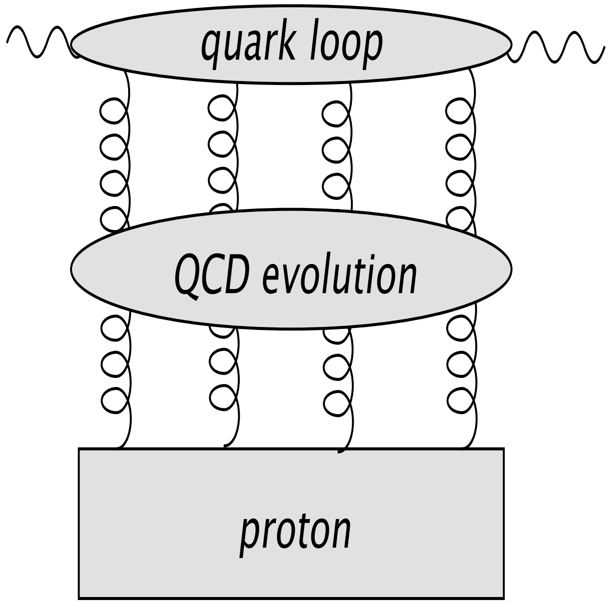


→ talk at this conference

Attempt to estimate size of higher twist in $F_2 = F_L + F_t$ and F_L at HERA:
(JB,K.Golec-Biernat,L.Motyka)

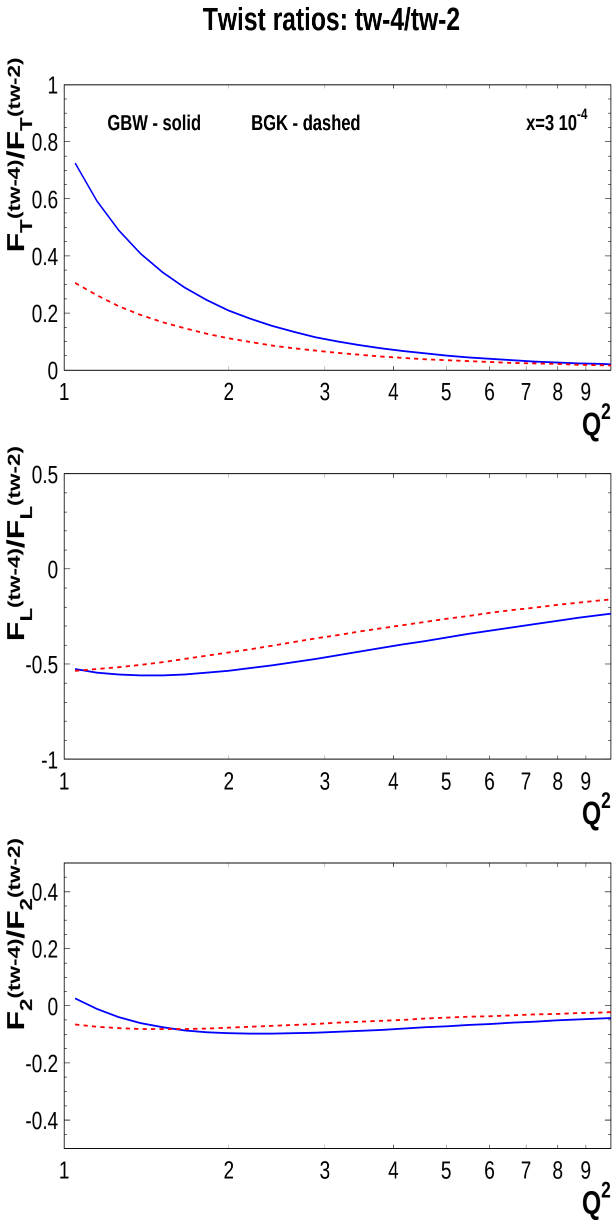
quark loop has peculiar features:

- twist-2 in F_t has log enhancement
- twist-2 in F_L has no log enhancement
- twist-4 corrections to F_t is positive, no log enhancement
- twist-4 corrections to F_L is negative, has logarithmic enhancement.
- potential compensation of twist-4 corrections in $F_2 = F_t + F_L$.



Evolution-improved version of GBW model allows to isolate twist-4 contribution

Almost complete cancellation of twist-4 corrections in F_2!
$\longrightarrow$ saturation in F_t and F_L expected to be stronger than in F_2



Saturation: standard arguments used for HERA data:

- flattening of the small-x rise of F_2 of $xg(x, Q^2)$.
  HERA: not seen. Likely: kinematic region too small, large errors in $xg(x, Q^2)$.
  LHeC: gain of factor 20 (compared to HERA). Current value of the saturation scale, obtained from F_2:

$$Q_s^2 \approx 0.8 \ at \ \ x = 10^{-4}, \ \ Q_s^2 \approx 3 \ at \ \ x = 10^{-6},$$

- Description of F_2 in the transition region phenomenological models (GBW), models inspired by nonlin
  evolution (BK) equation. Successful description with few parameters.
  Other successful models without saturation.

- geometric scaling: clear prediction of saturation

$$F_2(x, Q^2) = F_2(Q^2/Q_s^2(x))$$

  Seen in the data (refined analyis by Boef,Peschanski, Royon,Salek).
  Within DGLAP: also geometric scaling (Caola,Forte), at $Q^2 \geq 10\text{GeV}^2$. Test for saturation: $Q^2 \leq 5\text{Ge}$

- Diffraction: ratio of diffractive over constant cross section

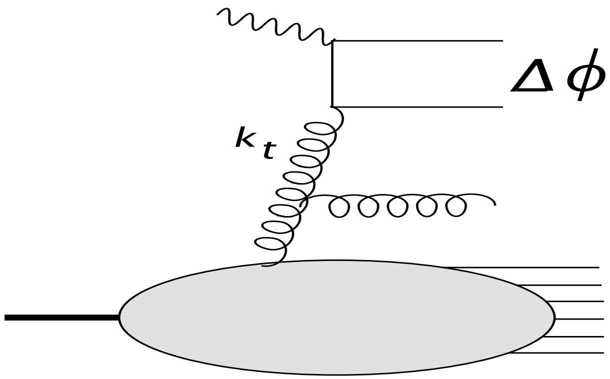
$$\sigma_{diff}^{\gamma^* p}/\sigma_{tot}^{\gamma^* p} \approx const$$

constant with energy (at fixed Q^2, M^2). Saturation model (GBW) for diffractive $q\bar{q}$ production provi
simple explanation.

Conclusion: inclusive measurements are not yet conclusive, need closer look into final states.

Example (F.Hautmann,H.Jung, K.Kutak):

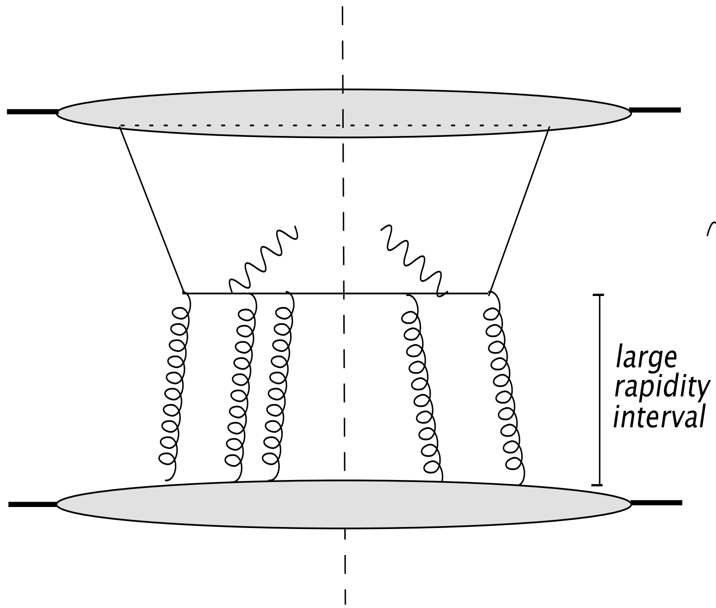
three jet events at HERA, azimuthal angle $\Delta\phi$ between hardest jets, sensitive to k_T dependence of unintegrated gluon.
Monte Carlo *with* saturation gives better description than *without*.

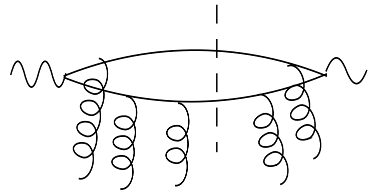


Saturation at the LHC: Drell-Yan, direct photon, jets... at forward rapidities.

Direct photon at large p_T (Kopeliovich,Levin,Rezaeian,Schmidt):

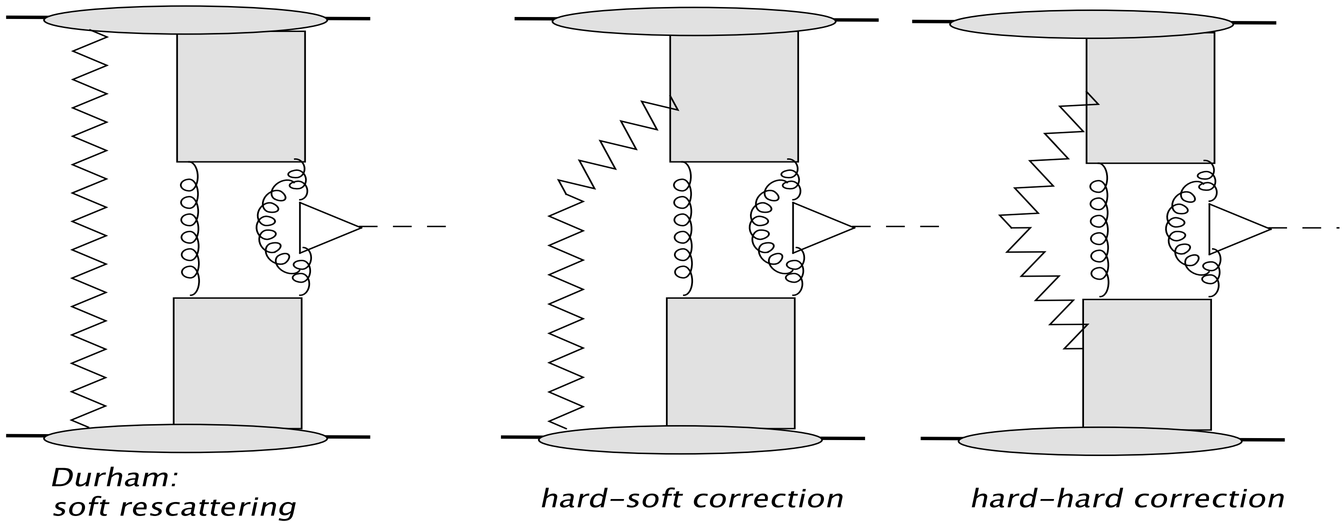
Use the dipole cross sections from DIS, CGC
p_T spectra, rapidity are quite sensitive to different models





Interesting: for virtual photon (Drell Yan) similar situation as in DIS, separate transverse and longitudinal part of the photon.
$\longrightarrow$ difference in the magnitude of saturation.

Diffractive Higgs production:
importance of rapidity gap physics at the LHC $\longrightarrow$ improve theoretical understanding of survival probability

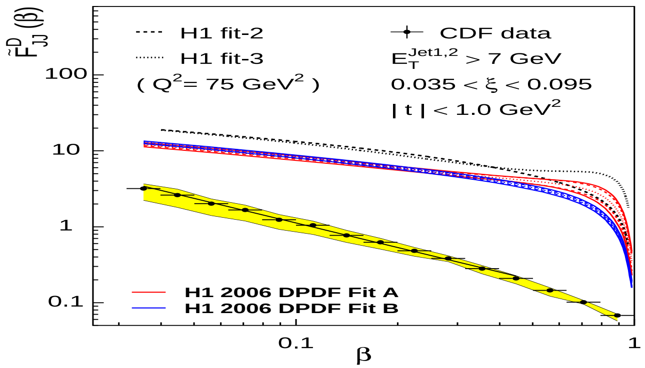


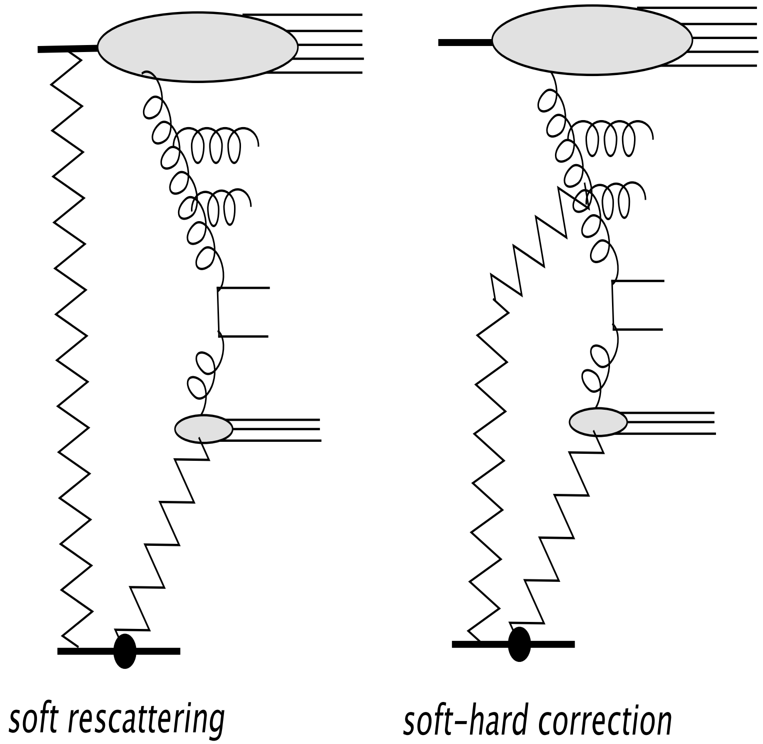
Diffractive dijet data from CDF seem to support the order of magnitude of the calculations.
But: hard corrections are found to be large (JB,Bondarenko,Kutak,Motyka),(Miller):
are they cancelled after *complete* summation?

Arguments supporting that hard corrections are small (Ryskin,Martin,Khoze)

Test: diffractive structure function at Tevatron, LHC:

No constant suppression factor. Does the soft-rescatttering model explain the Tevatron curve (β dependence, Q^2-evolution)?





Needed: more differential distributions from Tevatron/LHC

Desirable: complete higher order calculation (Cudell,Dechambre,Hernandez,Ivanov).

Theoretical low x physics

Higher order kernels in BFKL and BK (Fadin,Fiore,Grabovsky; Balitsky,Kyrilli)

1) Expect agreement between two approaches:

NLO BFKL kernel in momentum space,
Fourier transform + Möbius representation

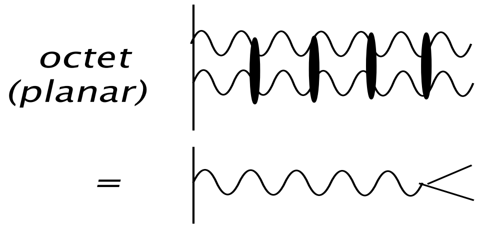
NLO BK kernel in coordinate representation,
take linear part

But: find disagreeement

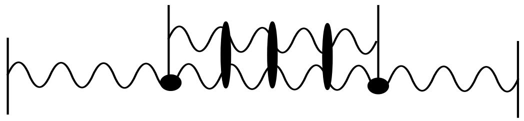
2) Möbius invariance of NLO BFKL kernel:
LO kernel is invariant under 2 dim Möbius transformations. NLO result in QCD cannot be invariant, but N=4 SYM should. Is it?

$\longrightarrow$ talks at this conference, hope to get an answer.

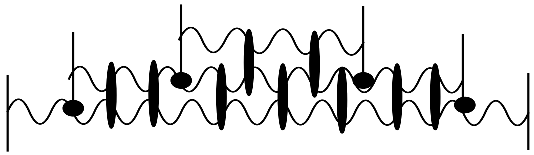
BFKL, color octet channel,LO (Lipatov)



bootstrap: gluon pole



gluon pole + cut



large N (planar)
BKP, open chain: integrable

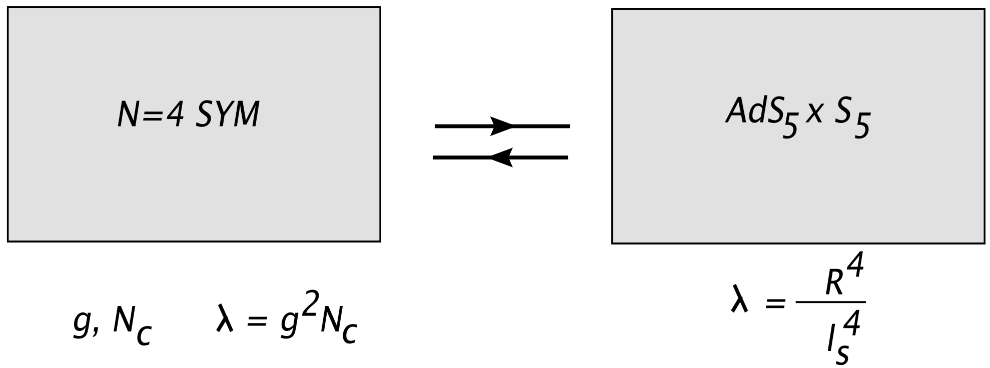
New:

- octet spectrum (contains more than poles) has been computed
- color octet BKP states (open chain) are integrable

Relevant for BDS formula (see below).

Low x physics in AdS/CFT

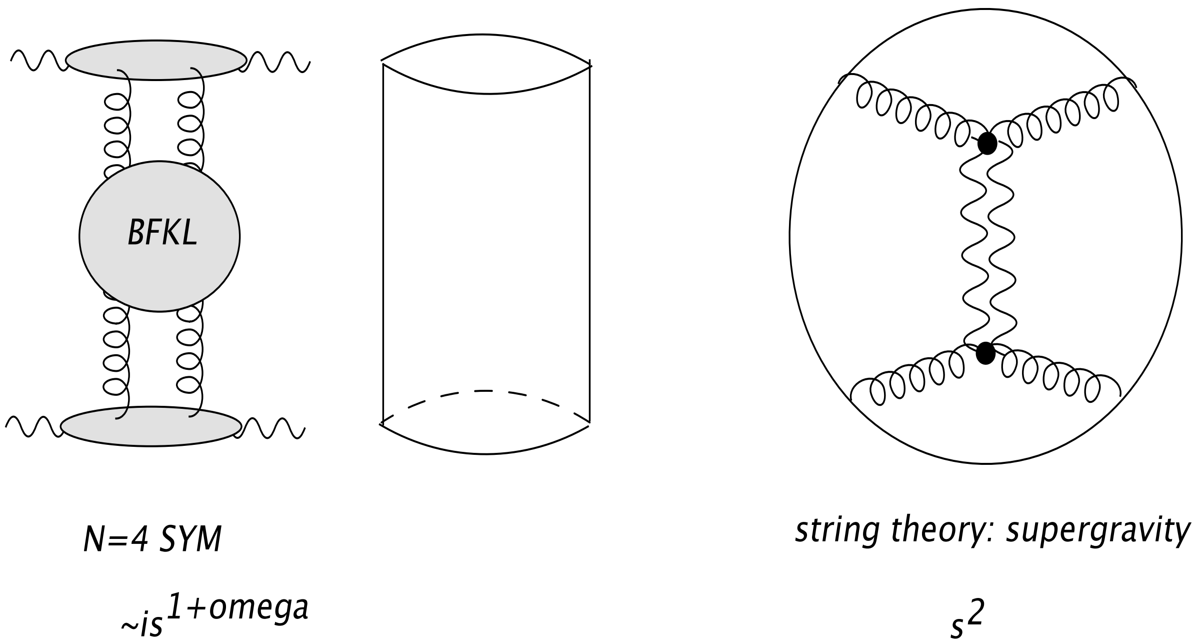
Interest in low-x QCD: compute high ernergy scattering at strong coupling. Use AdS/CFT hypothesis.
Most popular version:
N=4SYM: maximal symmetric, conformal symmetric, Yang Mills theory, no low energy phases, fixed coupl
constant.
Duality conjecture (AdS/CFT correspondence): gauge field theory is the same theory as a string theory in
dimensions with $AdS_5 \otimes S_5$ geometry:



Weak coupling on the string side gives strong coupling of N=4SYM gauge theory: t'Hooft coupling $\lambda = g^2$

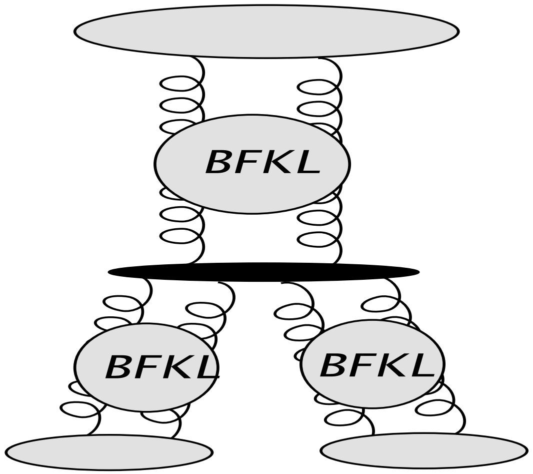
For low-x physics: central result is the Pomeron - Gravity duality.

Concrete: R-current scattering (global SU(4) symmetry in N=4SYM), analogue of $\gamma^*\gamma^*$ in QCD:

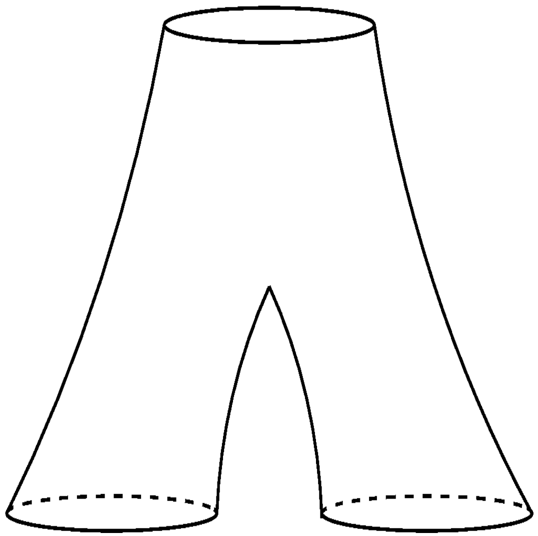


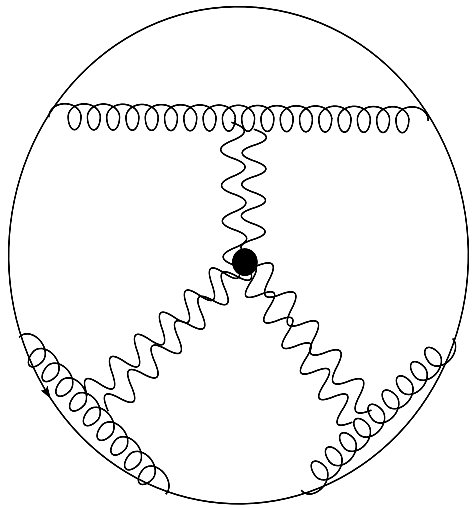
Witten diagram has been calculated (JB,Kotanski,Mischler,Schomerus): 'impact factor'
More accurately on the string side: $j_0 = 2 - \frac{2}{\sqrt{\lambda}}$, signature factor.

Other quantities of interest: strong coupling limit of BK kernel



N=4 SYM



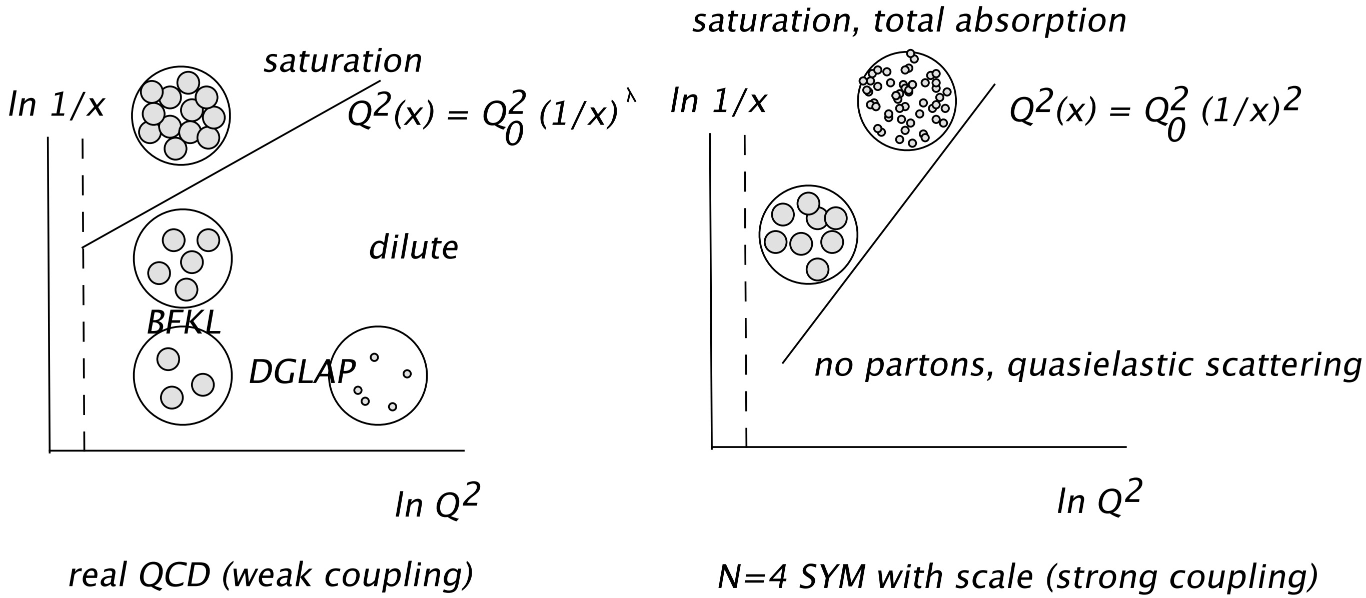


string theory

Integrable BKP states (closed chains): 8-point amplitudes

DIS in AdS/CFT (Polchinski,Strassler; Hatta,Iancu,Mueller):

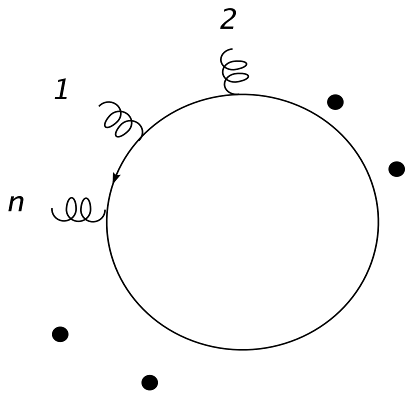
Complicated calculations, show only plot of E.Iancu:



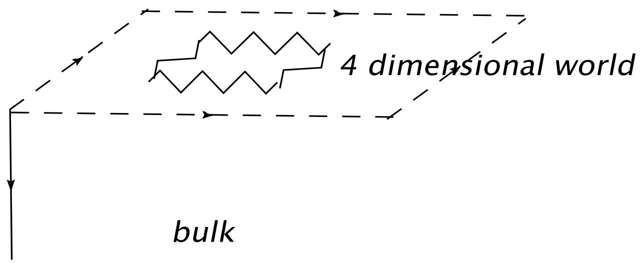
Quite different physics at strong coupling: at finite x no partons (lack of asymptotic freedom).

Another place where high energy behavior shows up: BDS formula (Bern,Dixon,Smirnow).

Conjecture: for n-gluon scattering amplitudes,
maximal helicity violating, large-N_c (planar), in $D = 4 - 2\epsilon$ dimensions



compute amplitudes



compute surfaces

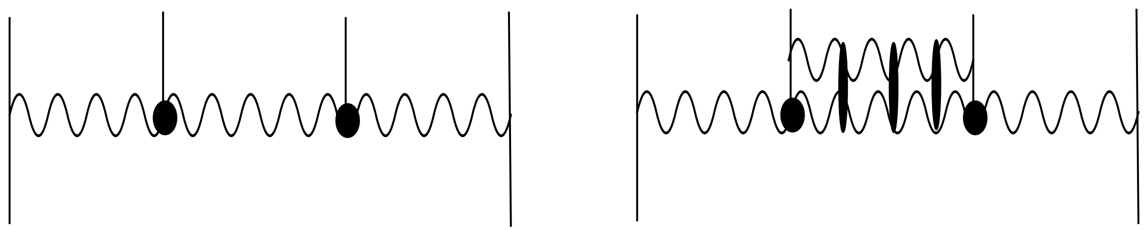
$$A_n = A_n^{Born} \times M_n, \ln M_n = \sum_{l=1}^{\infty} a^l \left(f^{(l)}(\epsilon) \left(I_n^{(l)}(l\epsilon) + F_n(0) \right) + C^{(l)} + E_n^{(l)} \right)$$

Interesting for multi-leg hard subprocesses at the LHC.

On the string side:
only few cases known (Alday, Maldacena): $n = 4$, $n = 8$, $n \to \infty$.

On the gauge theory side:
Discrepancy in M_n for $n > 5$, beyond one loop (Drummond et al; Alday, Maldacena)
Lifely/vehement discussions (Brower et al; Del Duca et al)

Comparison with known high energy calculations in QCD:
BDS misses Regge cut piece (JB,Lipatov,Sabio-Vera). The case of 6 gluons:



For $n > 8$: BKP states with > 2 gluons appear, are integrable (Lipatov)(see above).

Exponentiation of BDS not valid, but still hope for another simple expression.

Conclusions

- Low-x physics is active field: HERA, RHIC, LHC, theory.
- this talk: important issues have not been mentioned (multiple interactions)
- New tools have appeared: will be explored further

At the LHC we will be facing the problem of understanding the transition from pQCD to nonperturbative strong interactions at high energies (low x): low-x physics will stay with us.