Multiple Interactions in Perturbative QCD

J.Bartels
II.Inst.f.Theor.Physik, Univ.Hamburg

DESY, October 16, 2006

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Introduction

Multiple interactions are present in high energy hadronic collisions:
HERA - $\gamma^* p$
Tevatron - $\bar{p}p$
LHC - pp
RHIC - pN, NN.

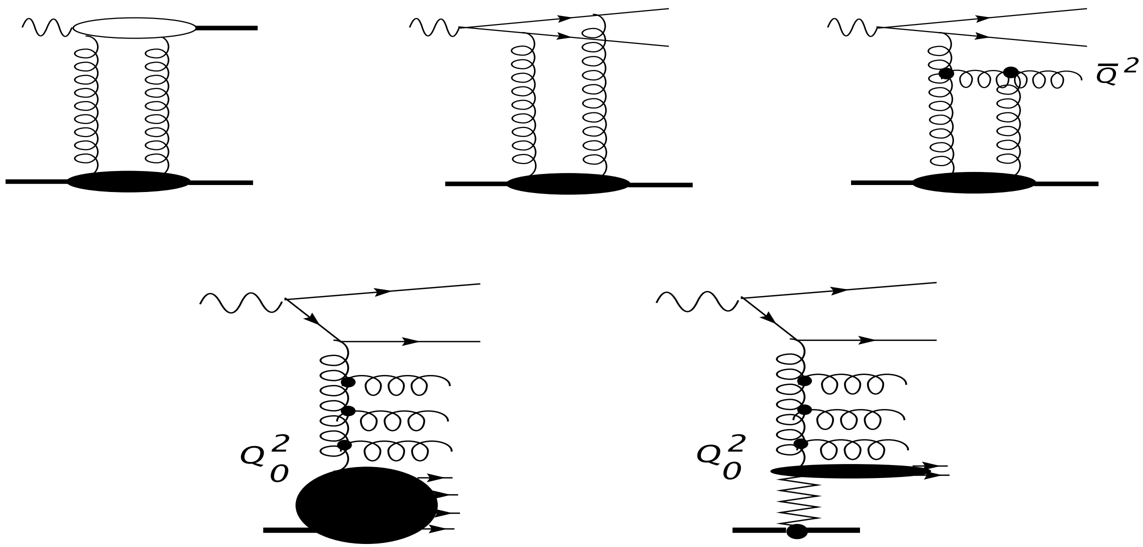
Multiple interactions in pQCD: need a hard scale,
e.g. double inclusive production of jets, heavy flavor etc; small x; underlying event structure

Enters the interface between pQCD (collinear factorization) and strong interactions.

In the following:
Discuss multiple interactions at HERA and at LHC.
(Close connection with heavy-ion physics, not this talk).
Theoretical remarks.

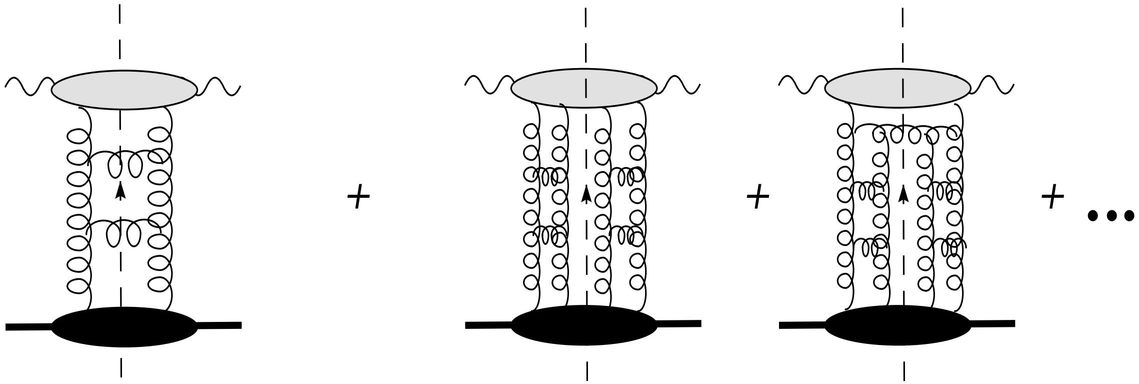
Multiple scattering at HERA

Direct evidence of multiple scattering at low Q^2, small x:
1) photoproduction, jets.
2) DIS diffraction at small x:
diffractive production of (heavy) vector mesons, of dijets,...: 'nothing below scale $\bar{Q}^2$':
cannot be part of DGLAP evolution (if initial scale $Q_0^2 < \bar{Q}^2$):



Consequence for F_2:

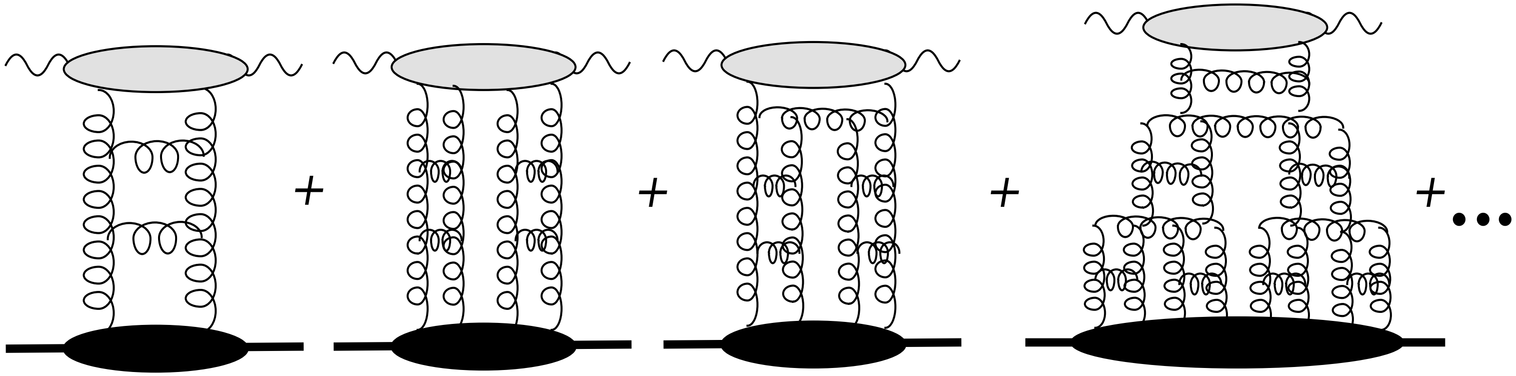
DGLAP is not enough, add this part of diffractive final states:



Example of multiple scattering. Higher twist, but:
two large momentum scales (Q^2, $\bar{Q}^2$), small-x enhancement).

How big? Studies/models based upon AGK cutting rules: Martin, Ryskin, Watts; Kowalski:
No quantitative conclusion,
but: worry about the accuracy of DGLAP at low Q^2 and small x.
Look for a theoretical framework where all contributions can be accomodated.

Saturation: continue summing multiple interactions



$\longrightarrow$ Nonlinear evolution equation (GLR,BK,JIMWLK...).
Coupling to proton is model-dependent (initial conditions).
Solutions exhibit saturation: scale $Q_s(x)$.

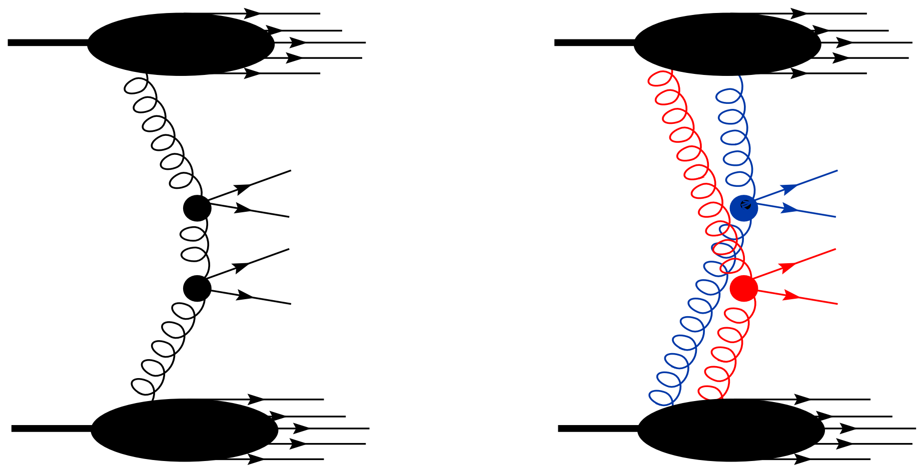
Signals at HERA (Golec-Biernat, Wüsthoff,...):
- Successful fits to F_2.
- Geometric scaling: $F_2(x, Q^2) = F_2(Q^2/Q_s^2(x)$, $Q_s^2(x) = Q_0^2(1/x)^\lambda$, $\lambda = 0.2...0.3$.
- constant ratio of cross sections: $\sigma_{diff}^{\gamma^* p}/\sigma_{tot}^{\gamma^* p}$.
Not a 'proof of saturation', but a 'strong hint'.

Multiple Interactions at the LHC

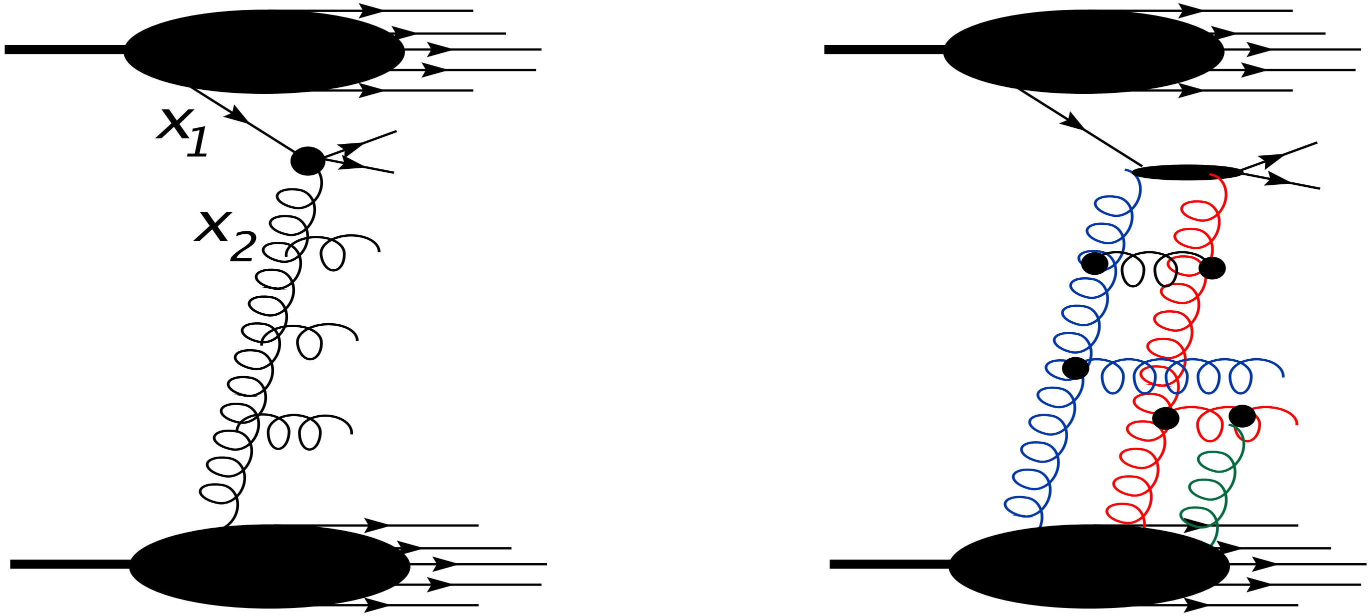
Where does one expect multiple interactions:

1) Underlying event (Monte Carlo)

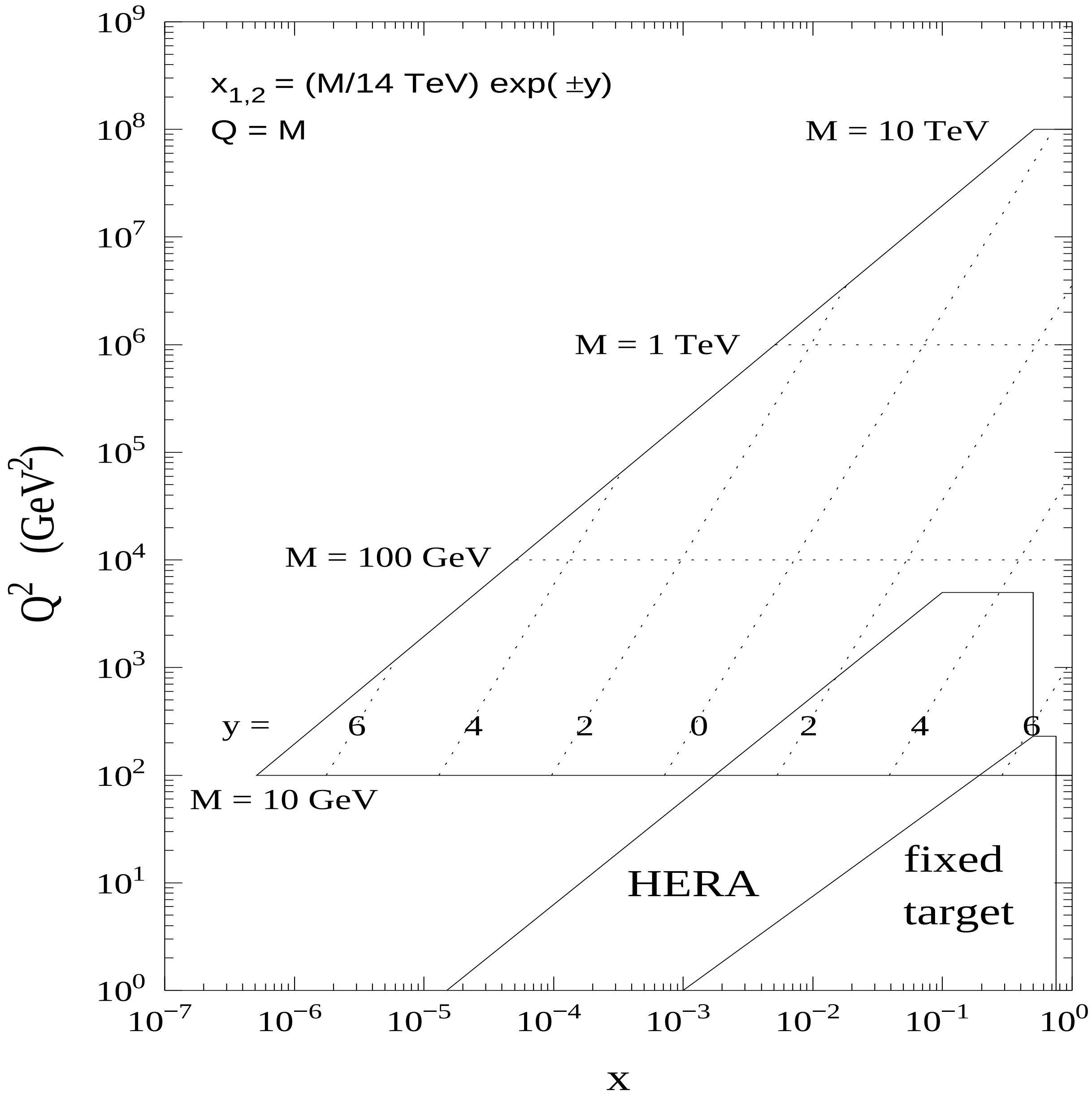
2) multi-jet final states (background to new physics), contributions from different chains to the same jet:



3) Jets (heavy flavour) close to the forward direction: $x_2 \ll x_1$:



Probes the small-x 'corner' in the LHC-kinematic plot:

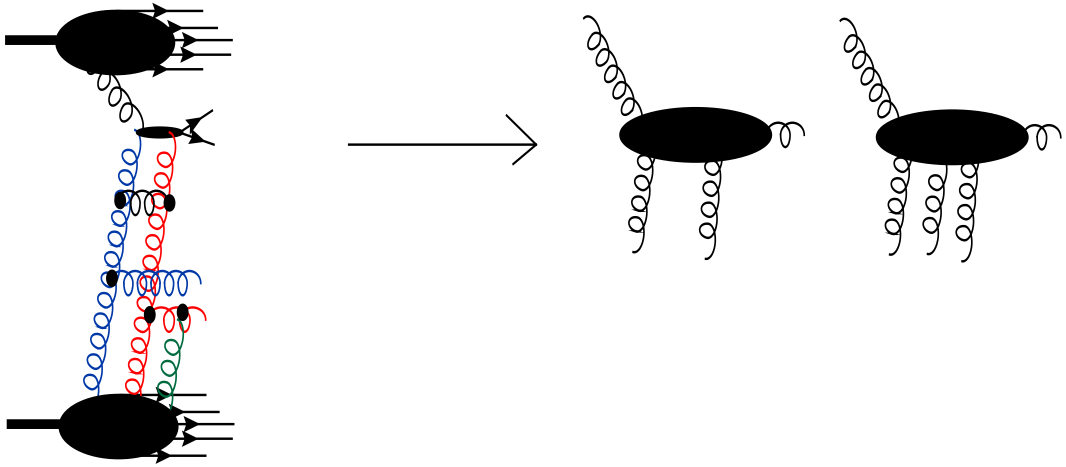


$x_{1,2}$ = (M/14 TeV) exp(±y)
Q = M
M = 10 TeV
M = 1 TeV
M = 100 GeV
M = 10 GeV
y = 6 4 2 0 2 4 6
HERA
fixed target
Q^2 (GeV^2)
x

Remarks about the theory of multiple scattering

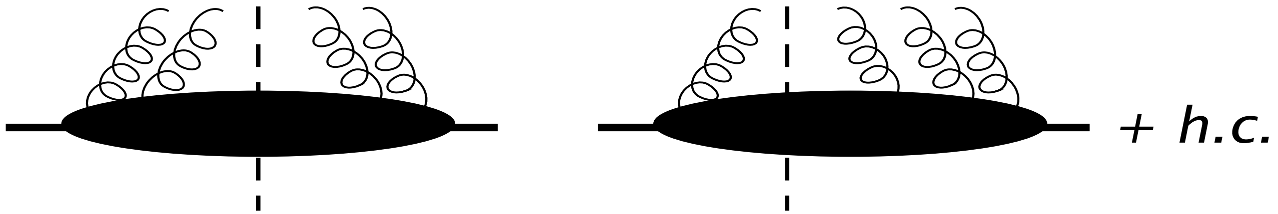
1) Perturbative part based upon QCD reggeon field theory (Gribov's reggeon calculus).

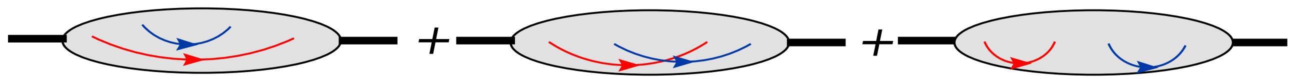
Known building blocks: reggeized gluons, BFKL kernels, $2 \rightarrow 4$ gluon vertex,...
New building blocks: production vertex (Braun; JB,Salvadore, Vacca)



DIS results cannot directly be used. Is there an anologue of the dipole picture?

2) Nonperturbative coupling to the proton:
correlators = double parton densities + interference terms;
symmetry (color connections):



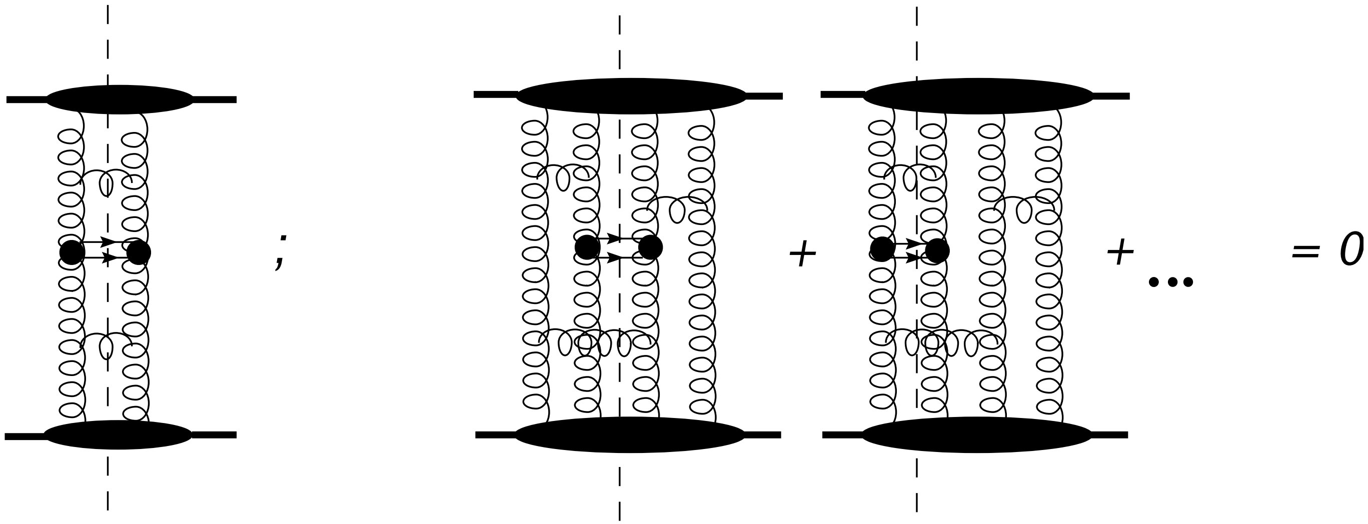


(Regge) factorization: couplings universal (consistency: HERA and LHC/Tevatron)

3) AGK rules in pQCD: (JB,Ryskin; JB,Salvadore,Vacca)

Mention a few results:

(a) in inclusive cross section (one jet-pair, two jet-pairs..):
rescattering corrections (soft and hard) cancel, e.g. one jet-pair:

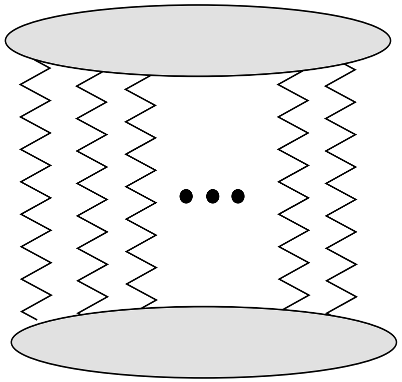


Consistent with collinear factorization. Generalize to two jet pairs.

b) Multiple Chains:

Simple model: eikonal type $\longrightarrow$ Poisson distribution of cut ladders

$$T_{el} = \sum \frac{1}{n!}$$



$$\sigma_k = 4is \int d^2 b e^{iqb} P_k(s,b)$$

$$P_k(s,b) = \frac{\Omega(s,b)^k}{k!} e^{-\Omega(s,b)}$$

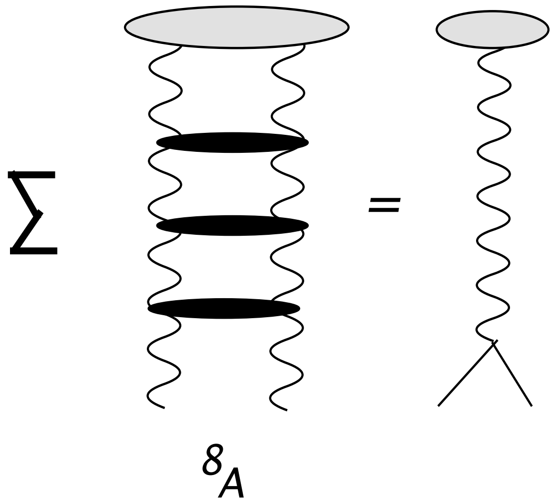
Consistency between cut ladder and rescattering function Ω.

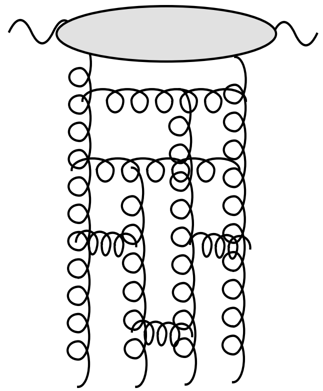
Different counting for jet-inclusice cross sections.

Symmetry requirement for cut ladders.

Deficiency of eikonal: no high mass diffraction

c) in a more general multi-chain diagram:
gluon reggeization makes life complicated (contained, but not foreseen in AGK paper).
Particularly disturbing in DIS:

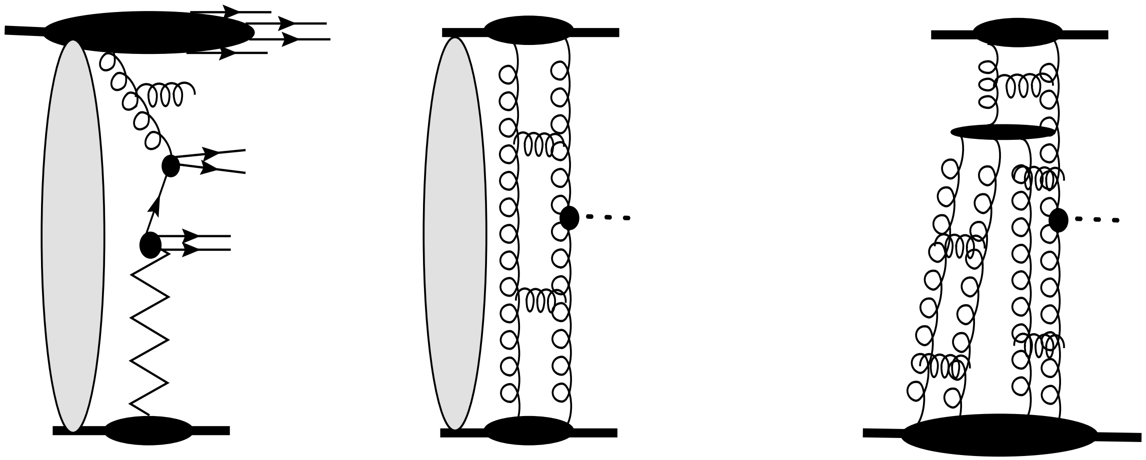




Diagrams contain 8_A channels, need to be separated, satisfy AGK for odd signature reggeons.
Consequence: cannot directly use the famous AGK rule $(1 + 2 - 4 = - 1)$ for DIS diffraction.

Next Step: Hard Exclusive Final state

Exclusive final states (rapidity gaps) in pp scattering need rescattering (survival factor).
Standard method: eikonal corrections (low mass diffraction of proton).
Examples: diffractive parton densities, diffractive Higgs production:



Rescattering goes across very large rapidity ($y > 12$),
could contain hard pieces (high mass diffraction) (JB,Bondarenko,Motyka).
Test: compare diffractive densities at HERA and Tevatron.

Conclusions

So far:

- multiple interactions are present at HERA and at LHC/Tevatron:
  lie on the interface between pQCD and strong interactions
- have to be taken into account
- include computable pQCD elements plus modelling.
  couplings/initial conditions: there are constraints which have to be observed.

What should/will be done in the future:

- presumably cannot stop at two chains (DIS: nonlinear equations; pp: new chapter)
- QCD reggeon field theory: identify sequence of approximations
- next step of complexity: exclusive production (e.g. diffractive Higgs)
- NLO calculations (fermions!)