Hard diffraction/rapidity gap physics at the LHC (theory)

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Jochen Bartels, Hamburg University

Connection with other theory talks on diffraction: Maor, Ducati

hard diffraction:	soft diffraction:
small transverse distances	large transverse distances
d.o.f.: partons, multiple interactions	d.o.f.: Pomeron fields, reggeons
this talk	Uri's talk

LHC is:

- Discovery machine

  (waiting for discovery)
- QCD machine

  (QCD is always present)

(Hard) Diffraction is:

- Vital Aspect of QCD (Strong interactions)
- Place to look for New Physics

LHC data on hard diffraction have started to be analyzed
So far: mainly comparison with Monte Carlo

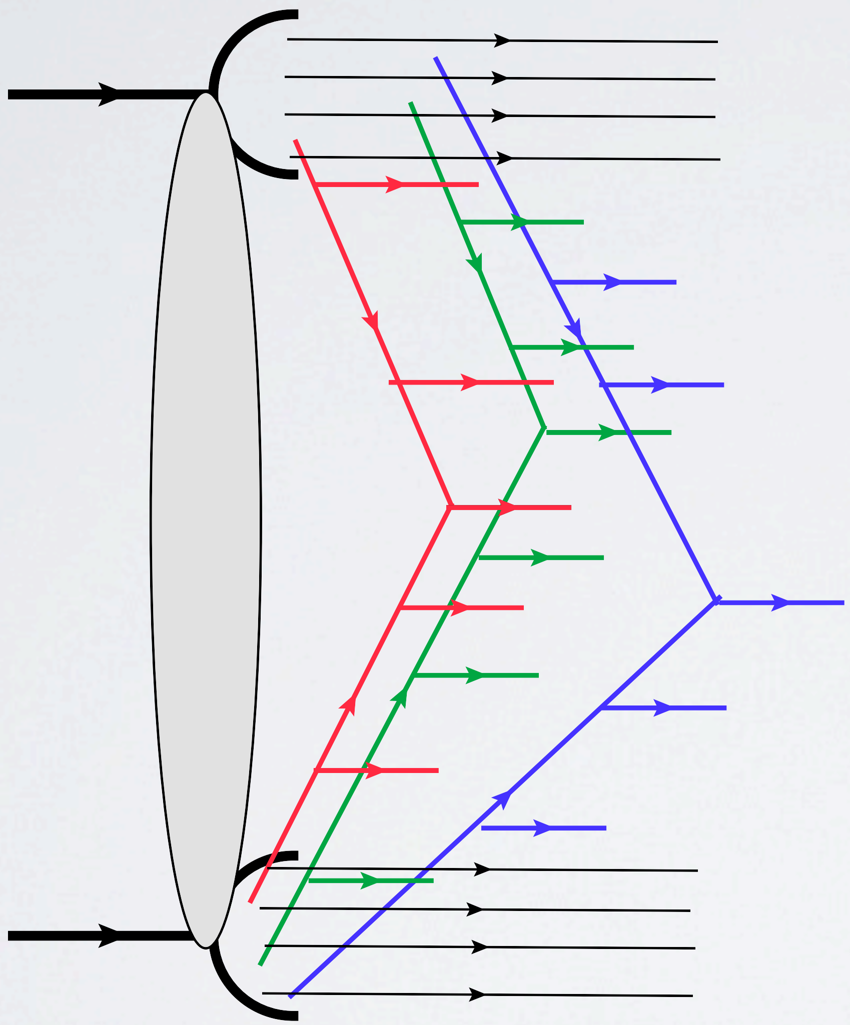
In recent years:
very intense cross talk between diffraction at HERA and Tevatron

This talk:
Overview of our current (theoretical) understanding

- Theory: multiparton physics
- Some particular final states (QCD)
- Some particular final states (new physics)

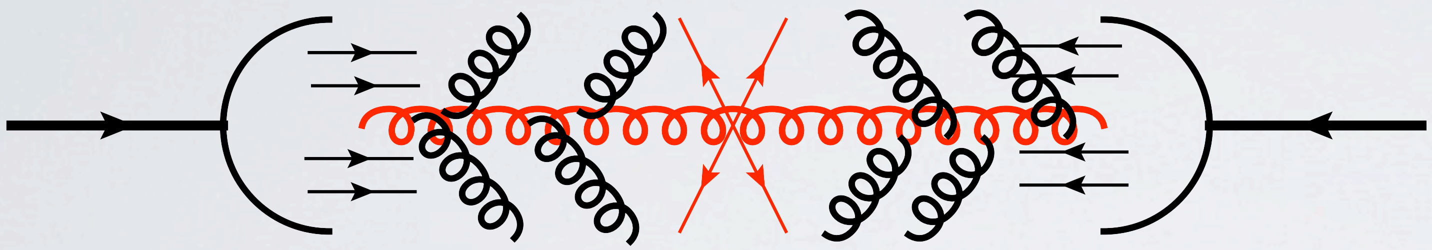
Introduction: physics of multiple interactions

'Definition' of hard diffraction:
a heuristic picture of an event structure in pp collisions:

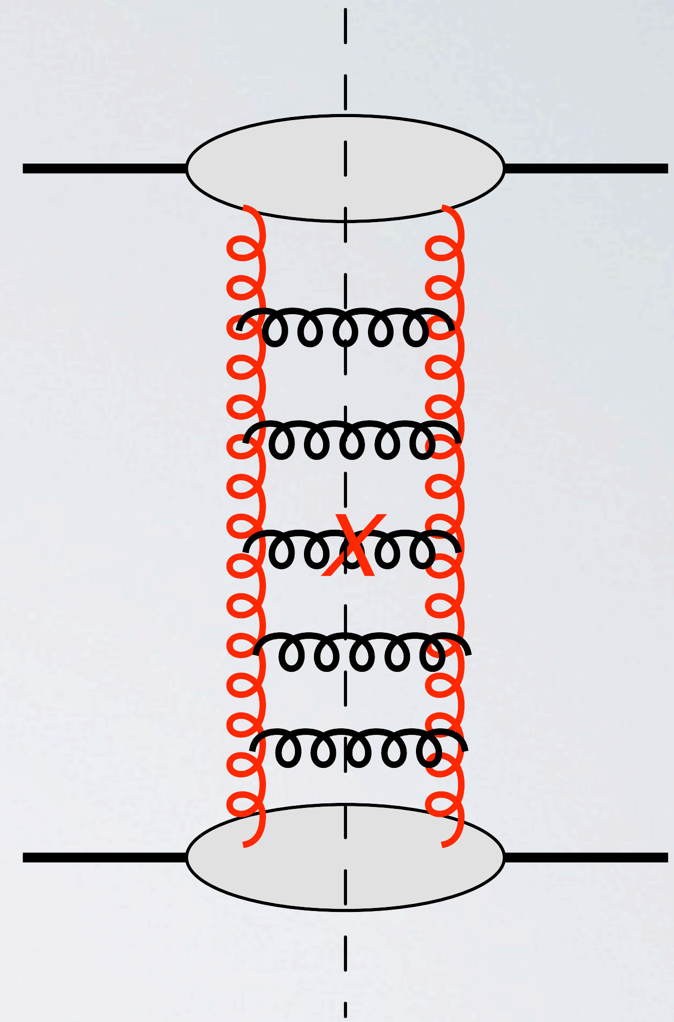


Valid only for 'hard' partons;
Ordering in scale and momentum fraction (rapidity)
Initial state interaction (absorption) tends to lower the cross section
Missing: final state hadronization

Notations:

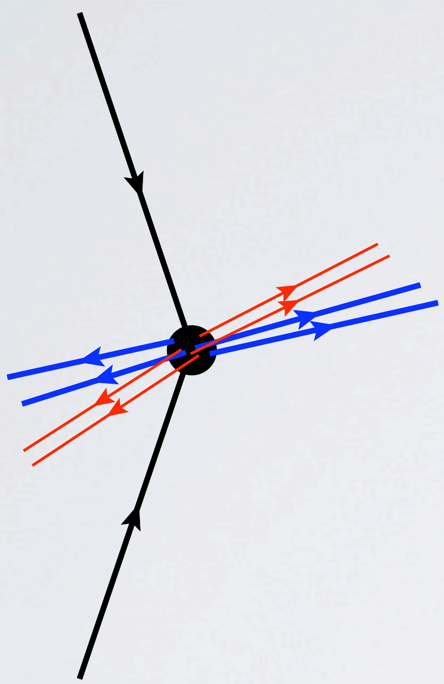


maybe more intuitive

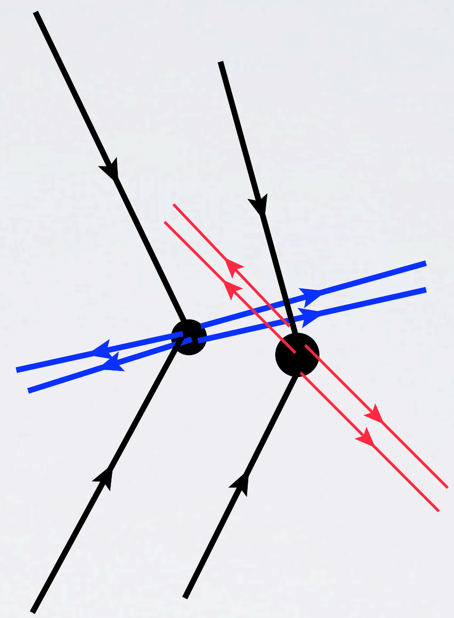


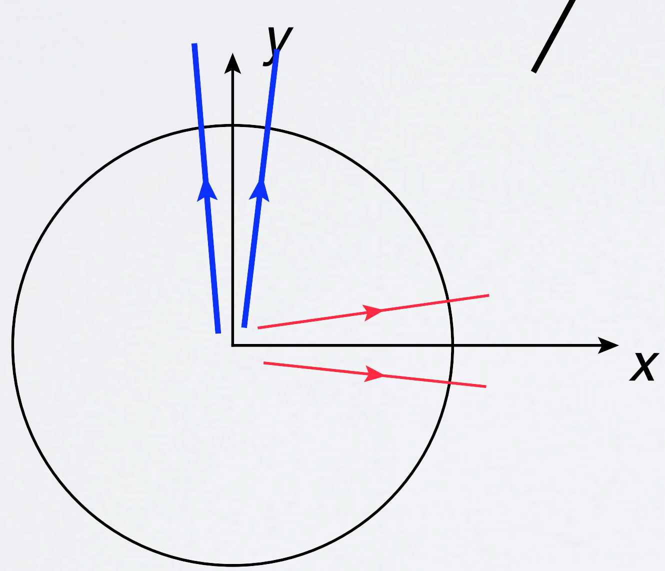
closer to Feynman diagrams, this talk

Number of chains varies from event to event.
Presence of second chain firmly established at the Tevatron (R.Field)
Confirmed at HERA, LHC.



or

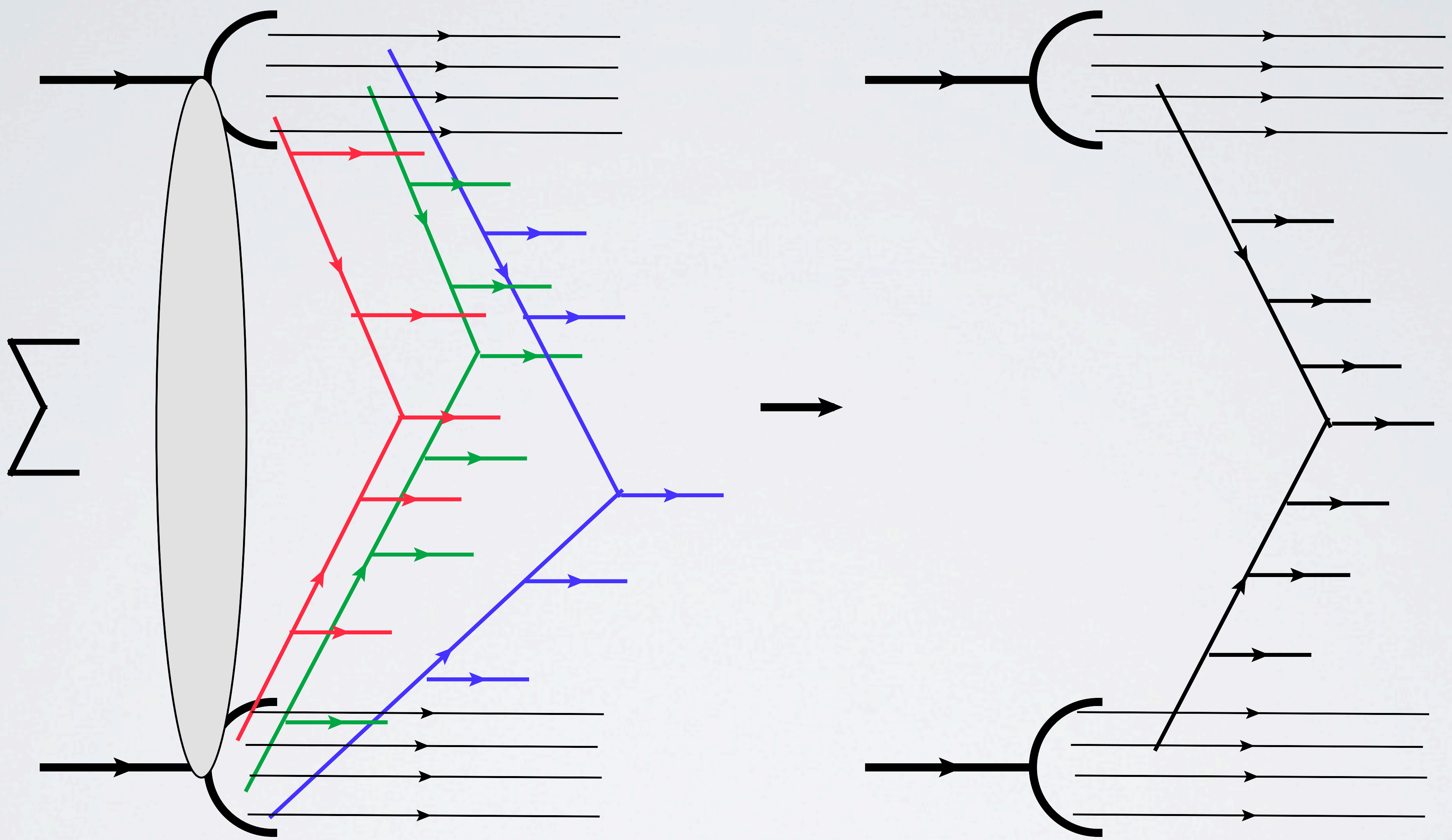




Number of chains grows with energy

How to get to the standard 'collinear factorization':

sum over events → single inclusive cross section

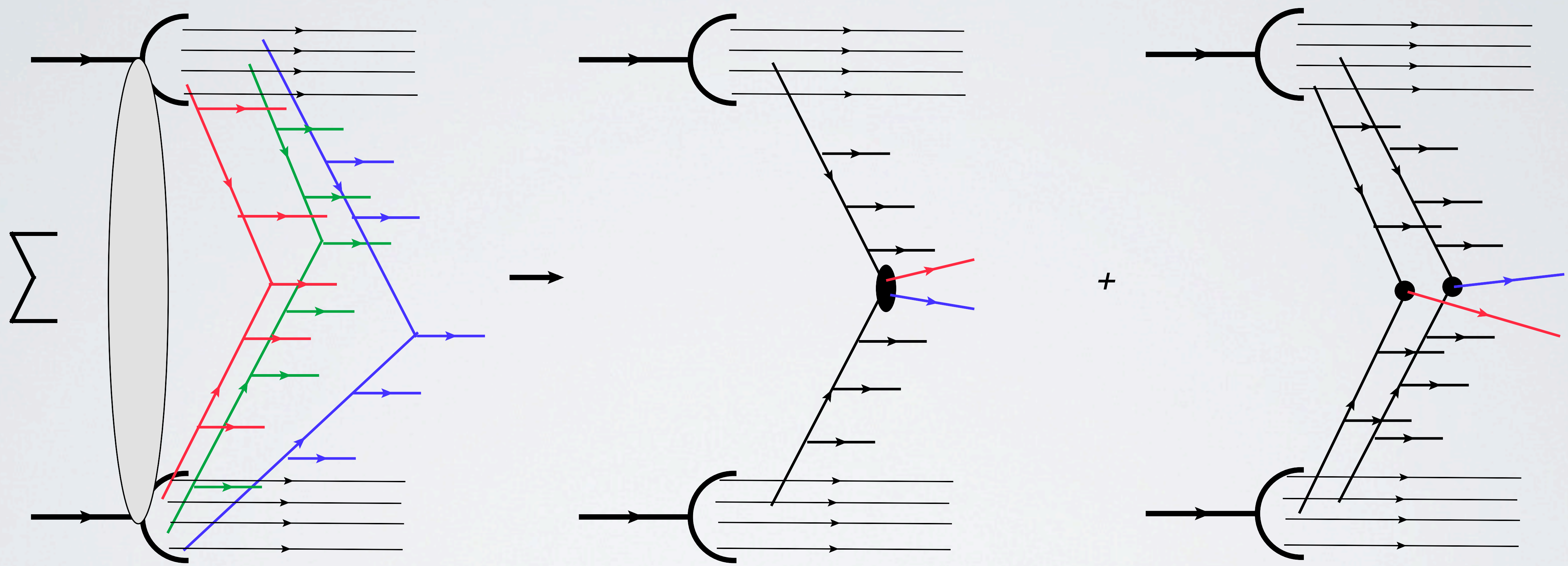


parton can come from any chain
sum over the number of chains
connection with initial state interaction

→ single chain
(factorization, AGK rules)

Double inclusive cross section:

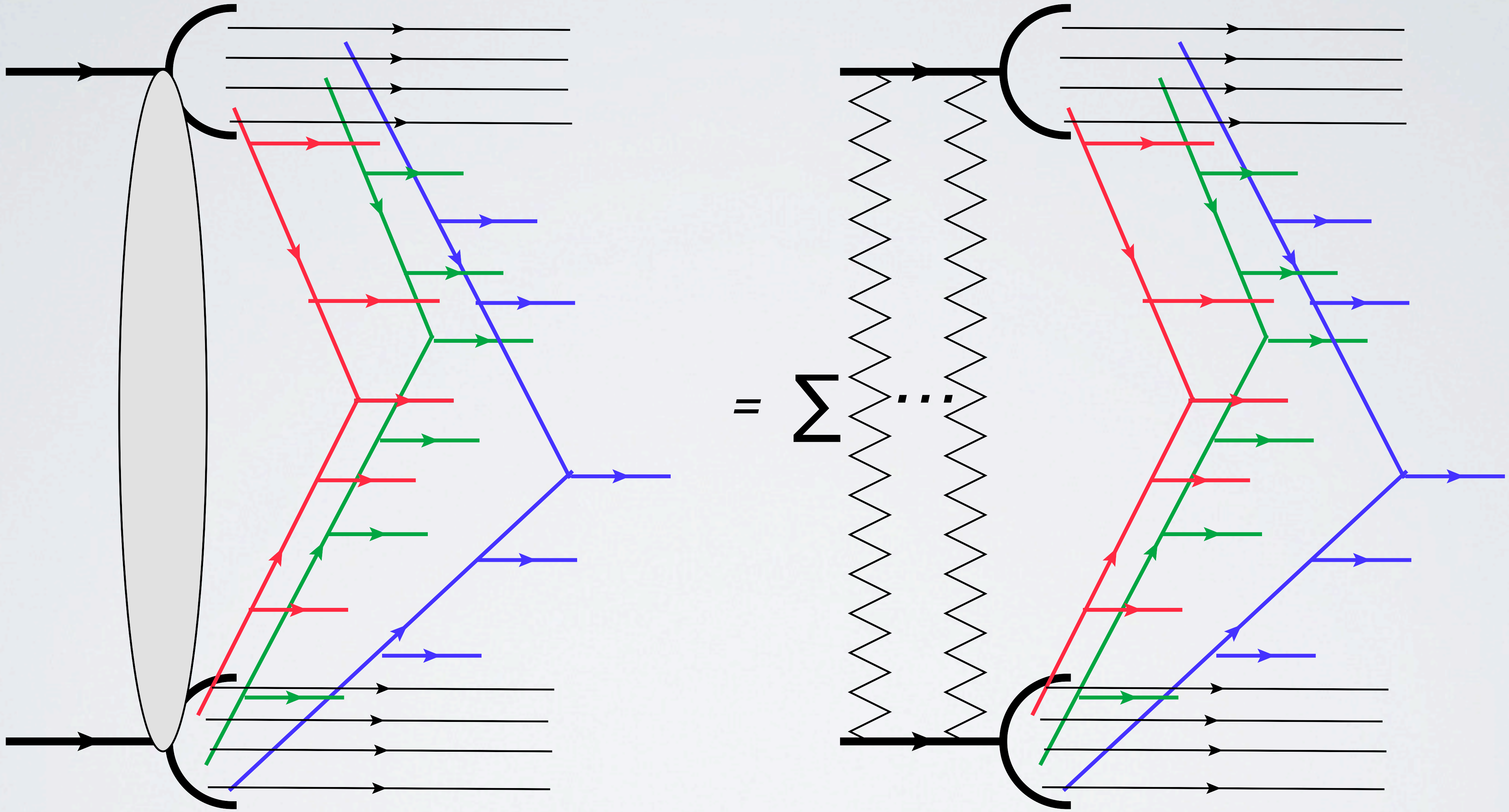
sum over events ➔ double inclusive cross section



Leads to corrections to multijet cross sections
Potentially important in search for new physics

(Treleani; Kulesza, Stirling; Diehl,Schaefer)

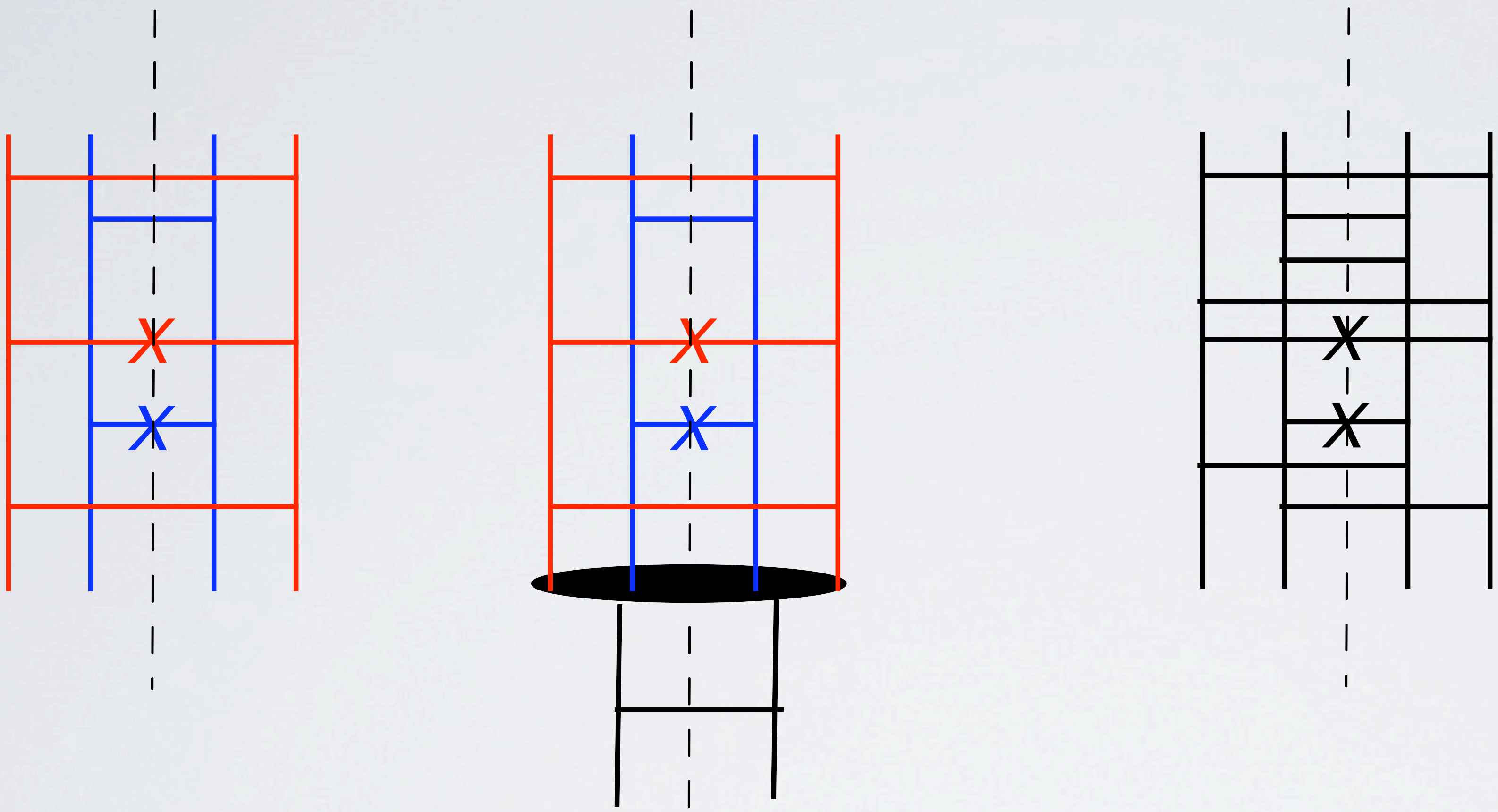
So far: simplified picture, eikonal model (elastic and quasi-elastic re-scattering) guideline for many MC's



Connection between 'cut' and 'uncut' ladder

Steps of improvements:
A. 'cross talk' between different chains, multiparton evolution

Flensburg,Gustafson
JB,Ryskin
B.Blok et al:
Kulesza, Stirling,
Golec-Biernat et al.
Diehl, Schaefer



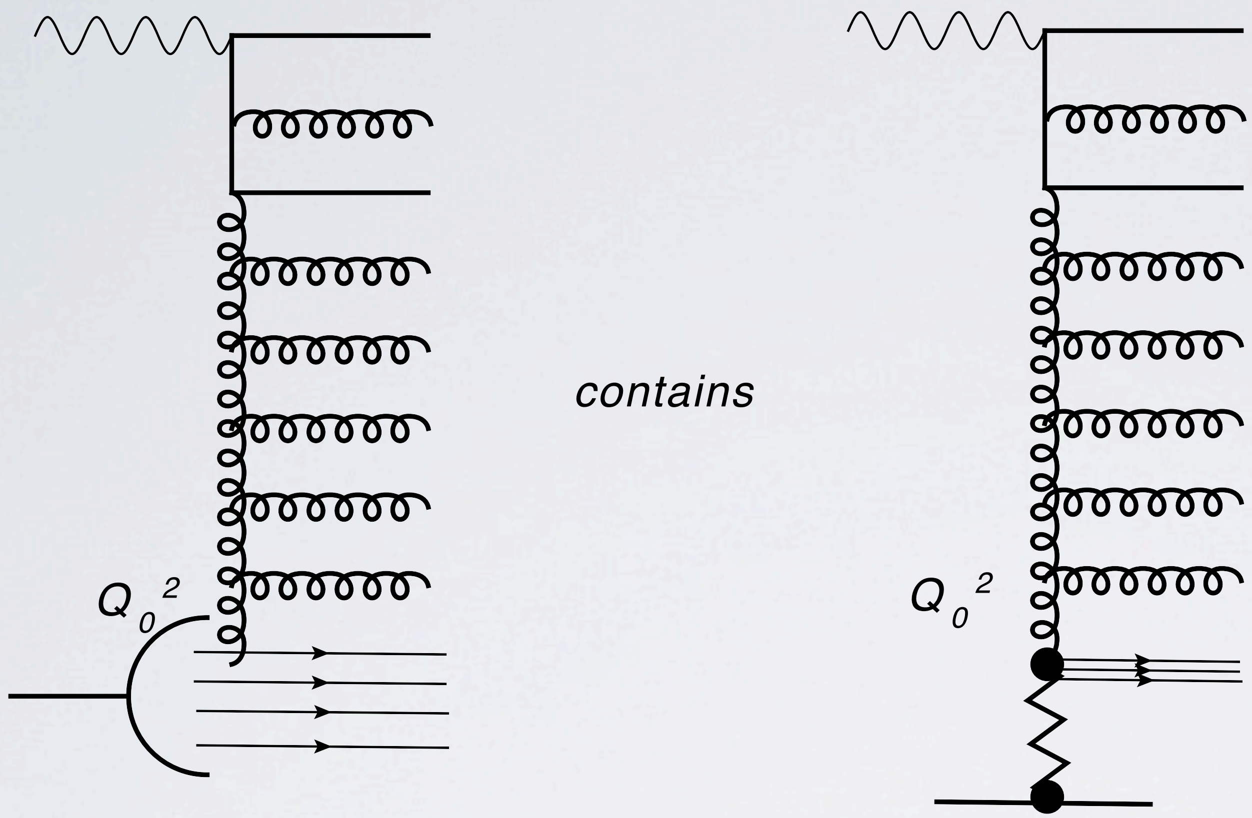
→ beyond the eikonal picture

no communication *number changing vertex* *recombination (swing)*

double DGLAP

B. Include hard diffraction

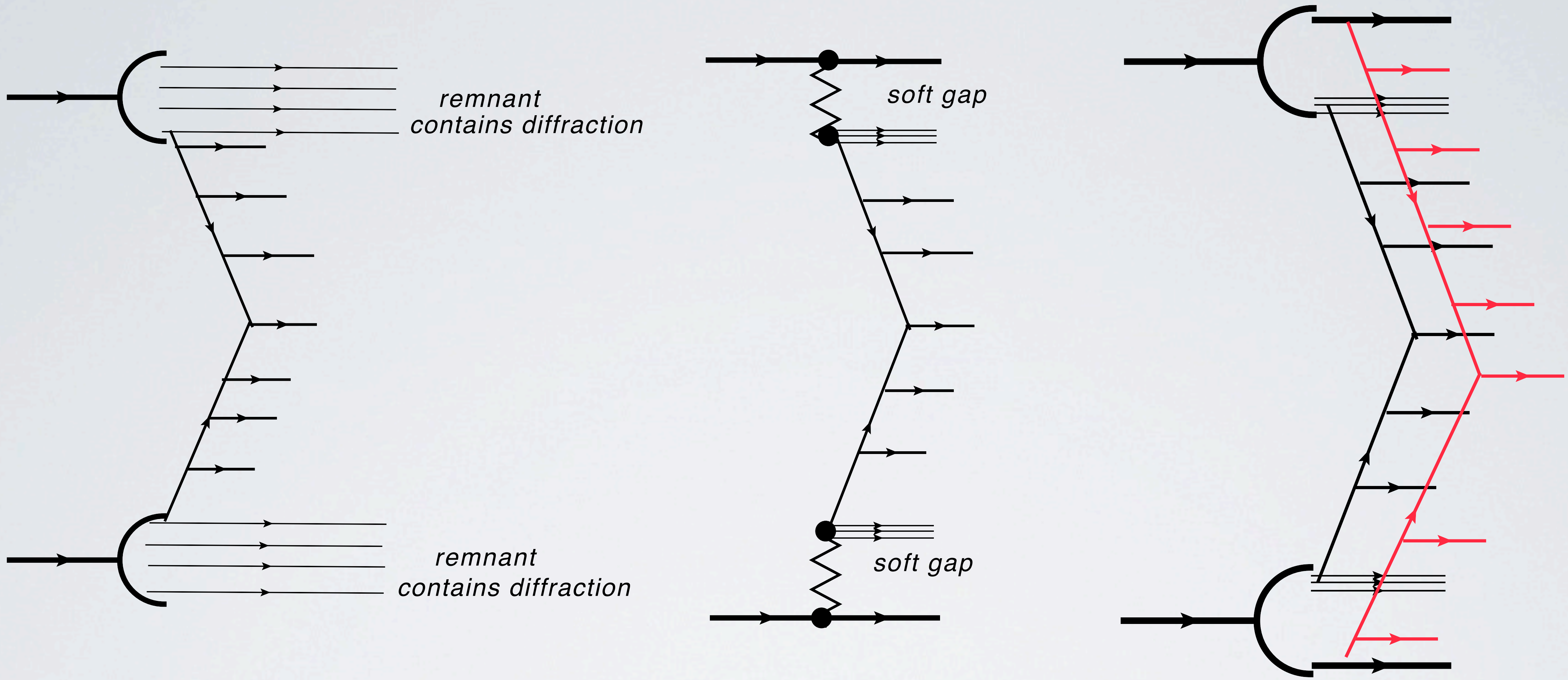
‘Soft’ diffraction is included but not visible : single chain, HERA



Collins et al.

Factorization theorem
‘Soft’ gap: below initial scale Q_0^2 of DGLAP-evolution
HERA: diffraction more than 10%

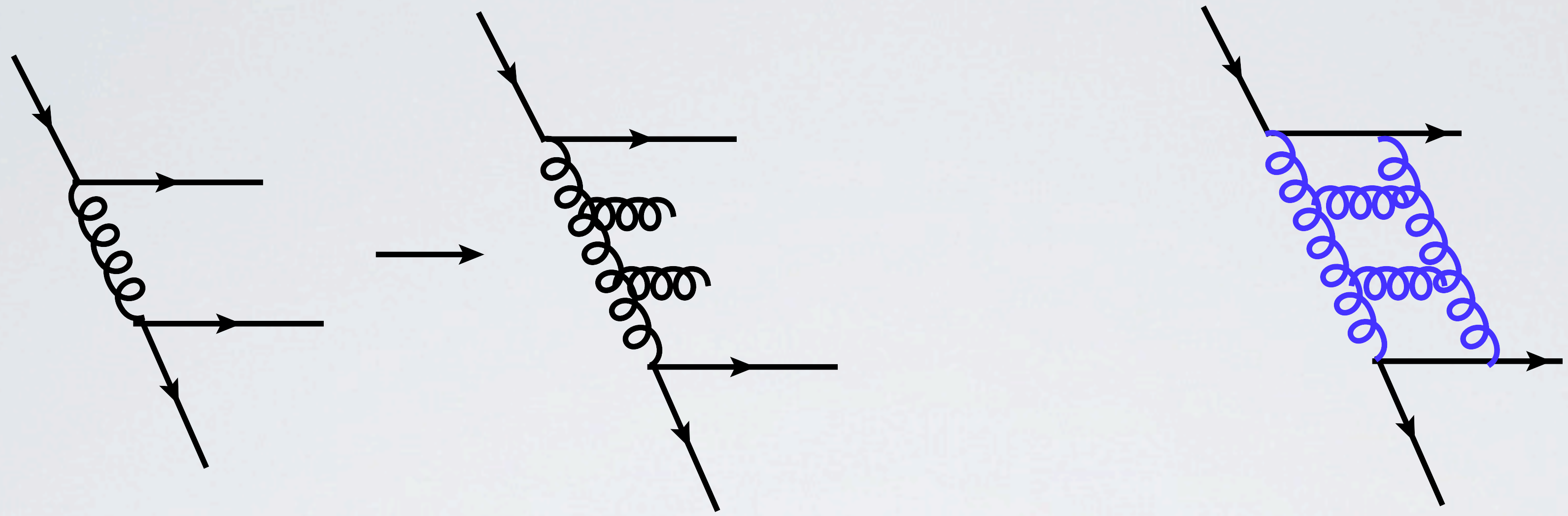
LHC, single chain is analogous to DIS:



BUT: second, third... chain may fill the gap, less diffraction

Hard diffraction is not included:

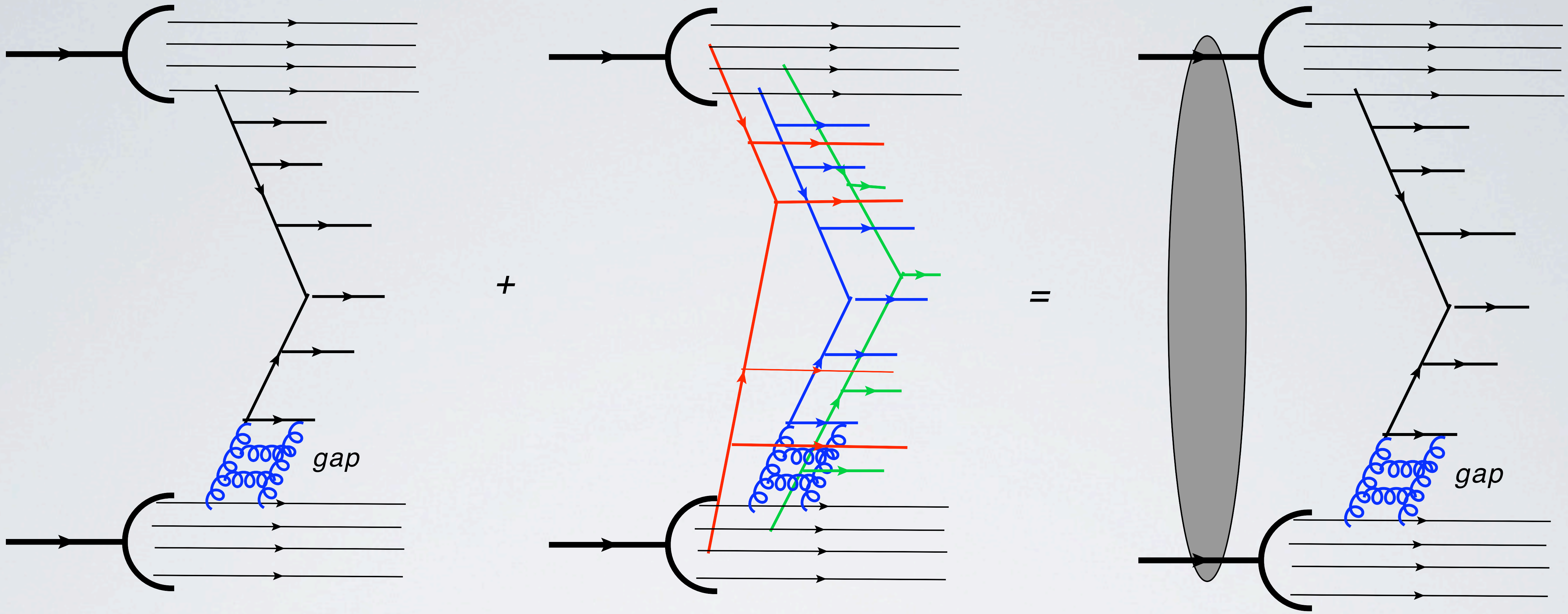
Radiation off a parton chain suppresses large rapidity gaps:



color octet:
radiation fills the gap

color singlet exchange favors gap

Need to include new contributions into the previous picture:



Sum over all rescattering effects: lowers the probability of rapidity gaps

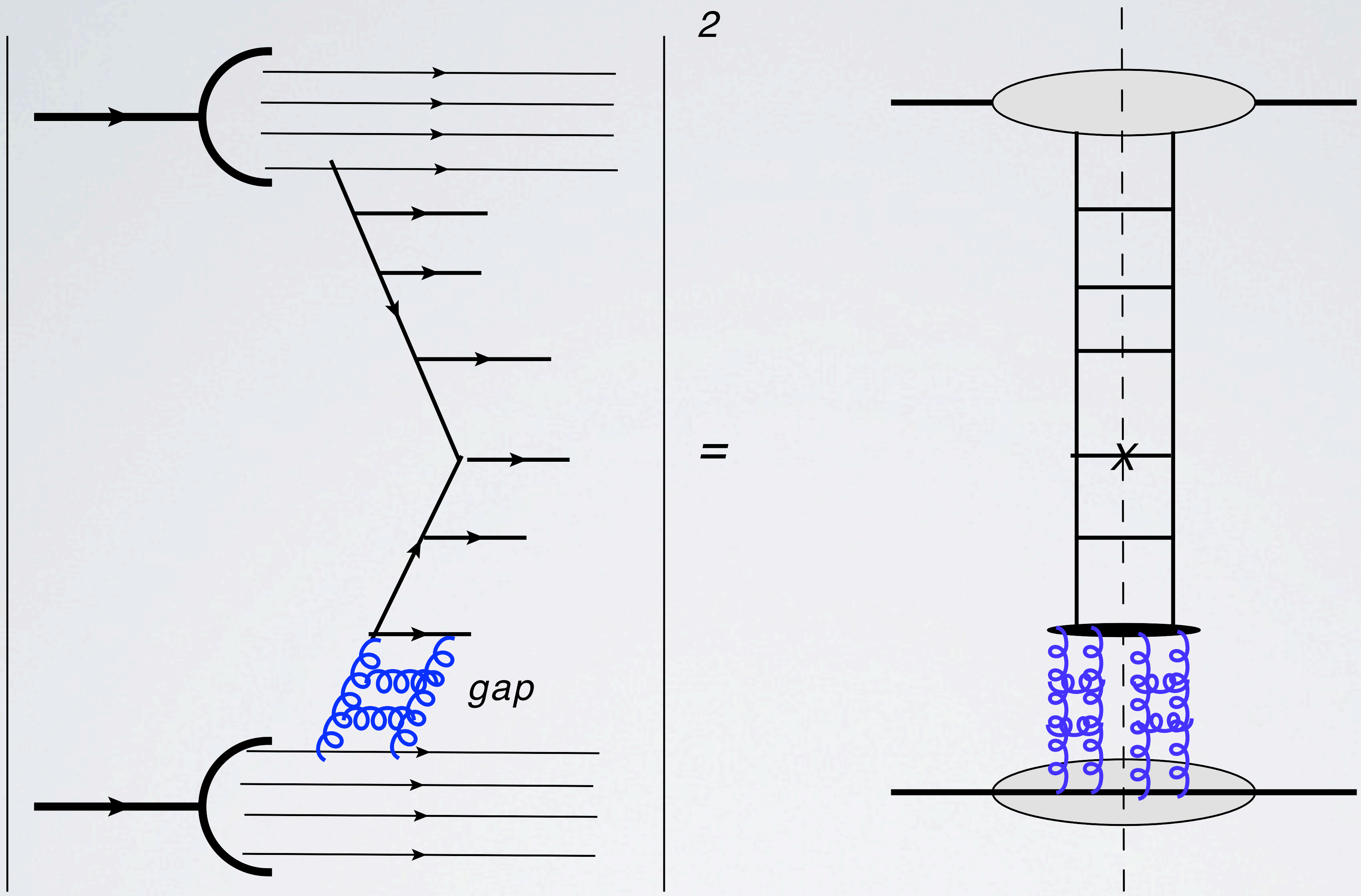
Define 'survival probability' as suppression factor:

diffract.cross section = S $\otimes$ hard cross section (in b-space)

S is 'effective' parameter. Formula works surprisingly well.

But: S is not universal (depends upon final state),
spoils the eikonal picture

After squaring: 'ladder graphs'



Beginning of 'Pomeron' graphs → soft diffraction

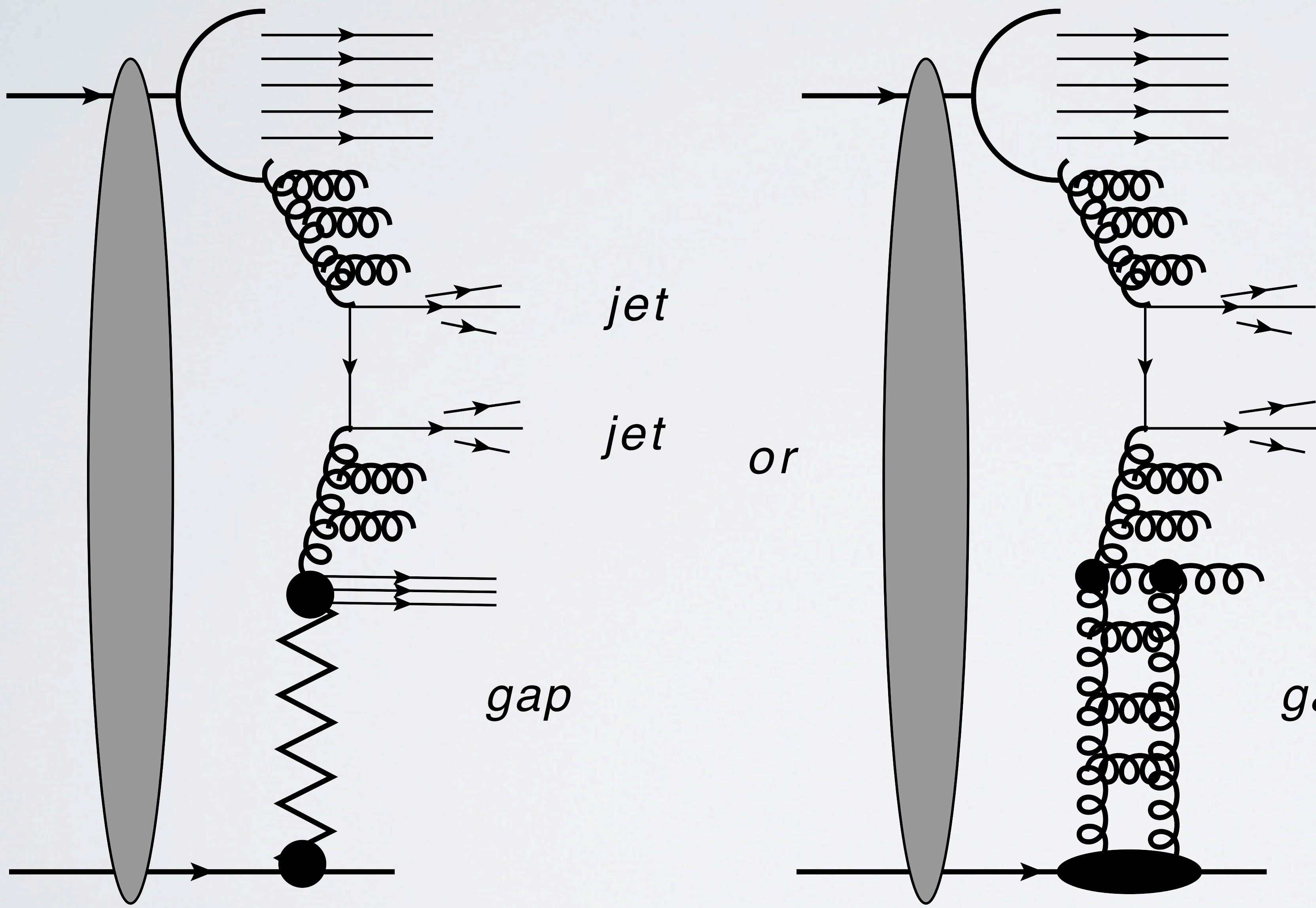
Conclusions of this 'introductory' part:

structure of a single (nondiffractive) event can be rather complex -
simplicity returns when inclusive cross sections are considered

Diffractive events:
experimentally attractive
'approximate simplicity': hard $\otimes$ soft rescattering (survival prob.)
but: subtleties are encoded in the survival probability - nonuniversal.
need to be measured!

Diffractive processes - QCD dynamics

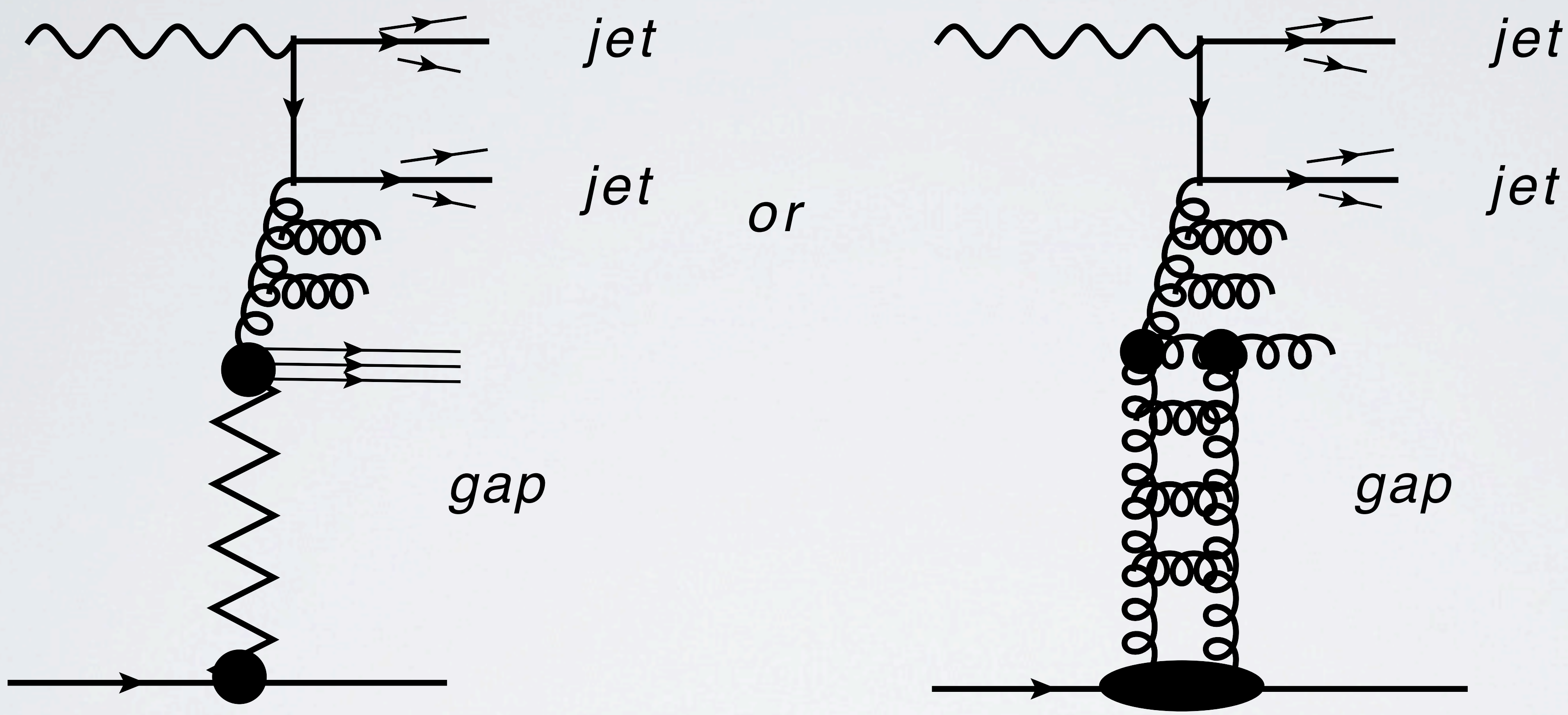
1. Diffractive parton densities



also called 'Pomeron' structure function

Ingelman, Schlein

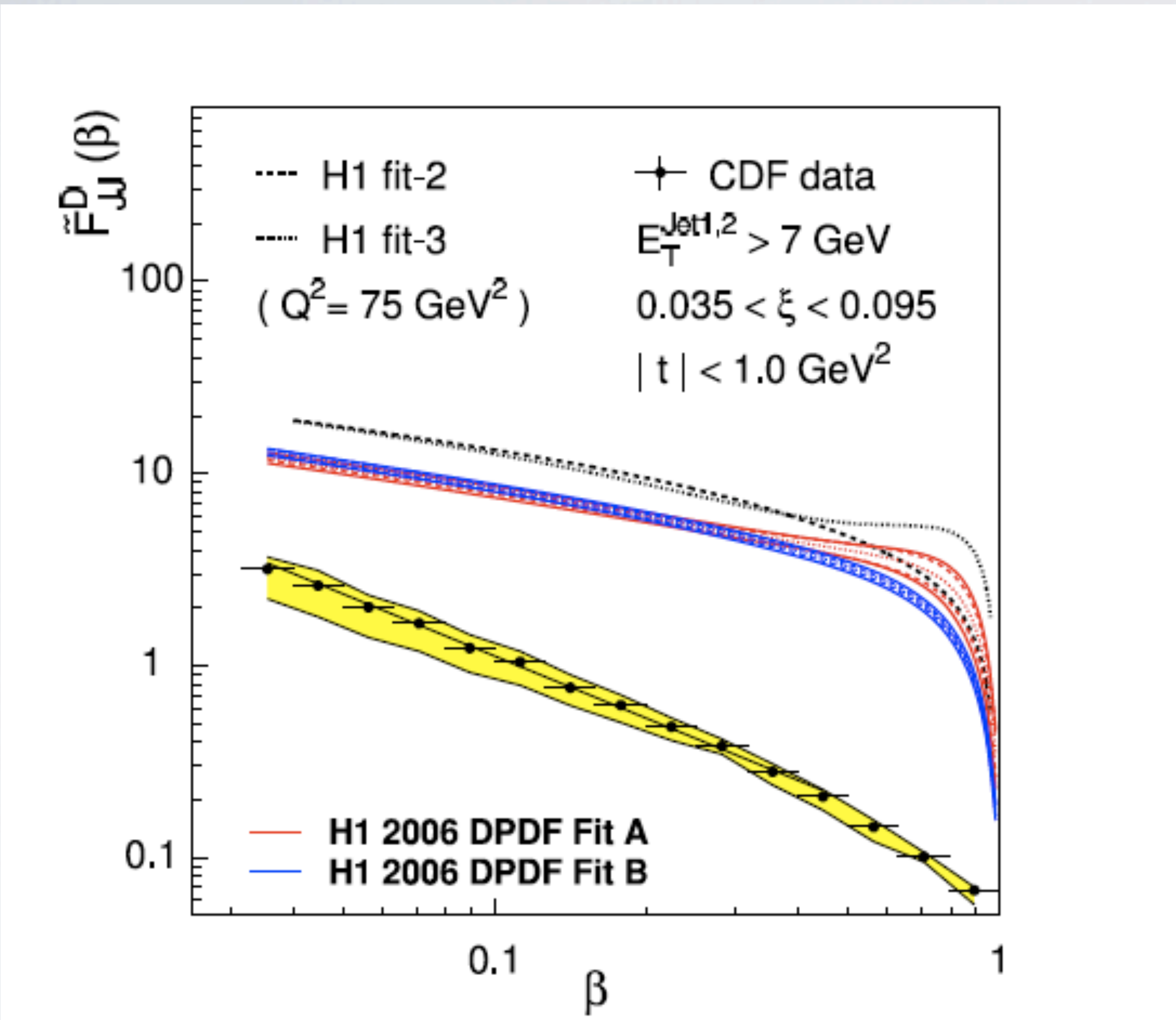
The analogue at HERA: diffractive parton densities

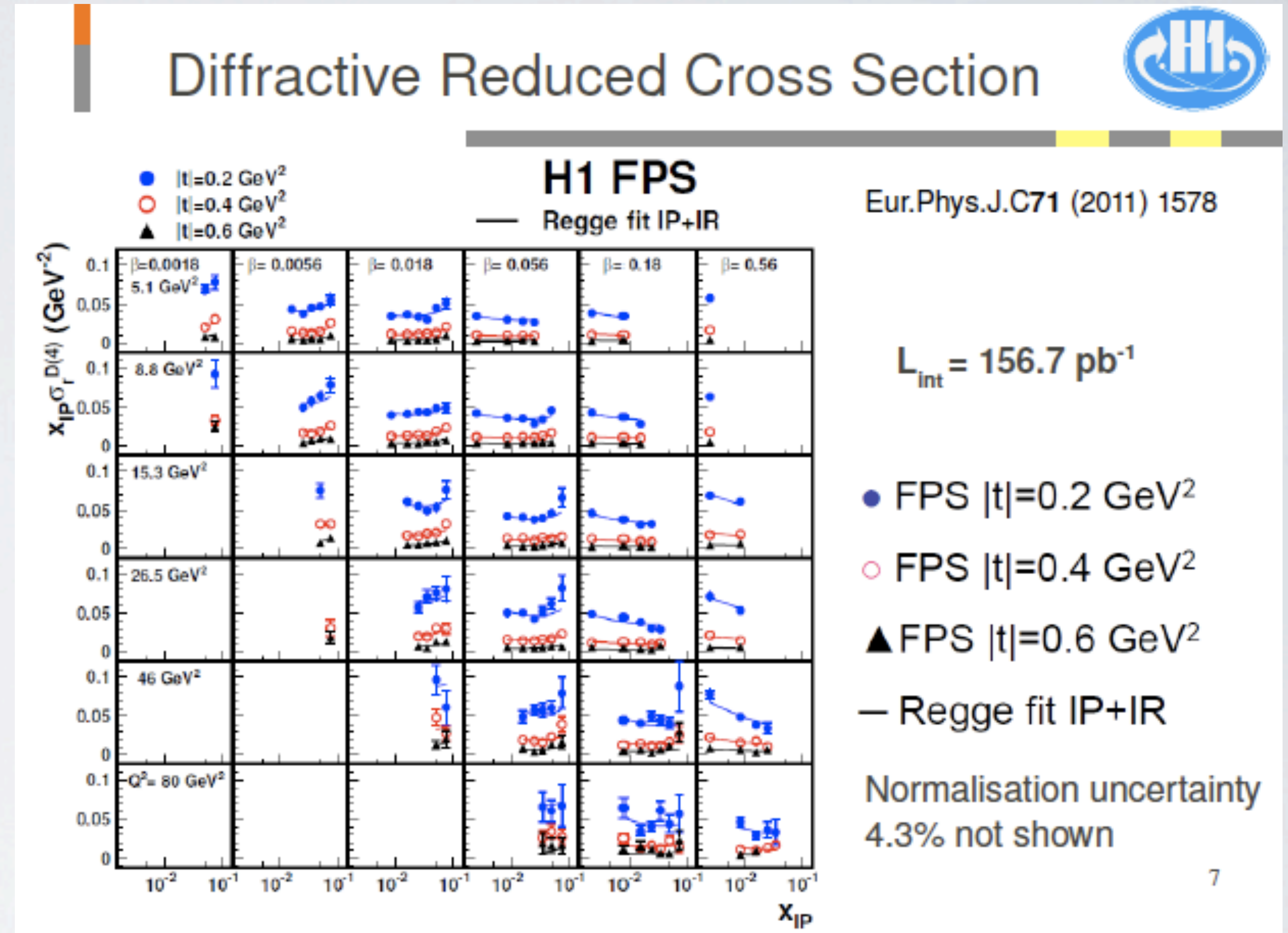


Diffractive parton densitites follow DGLAP evolution, are universal.

But: cannot be transported to pp-collisions (survival probability)

Comparison with HERA data:

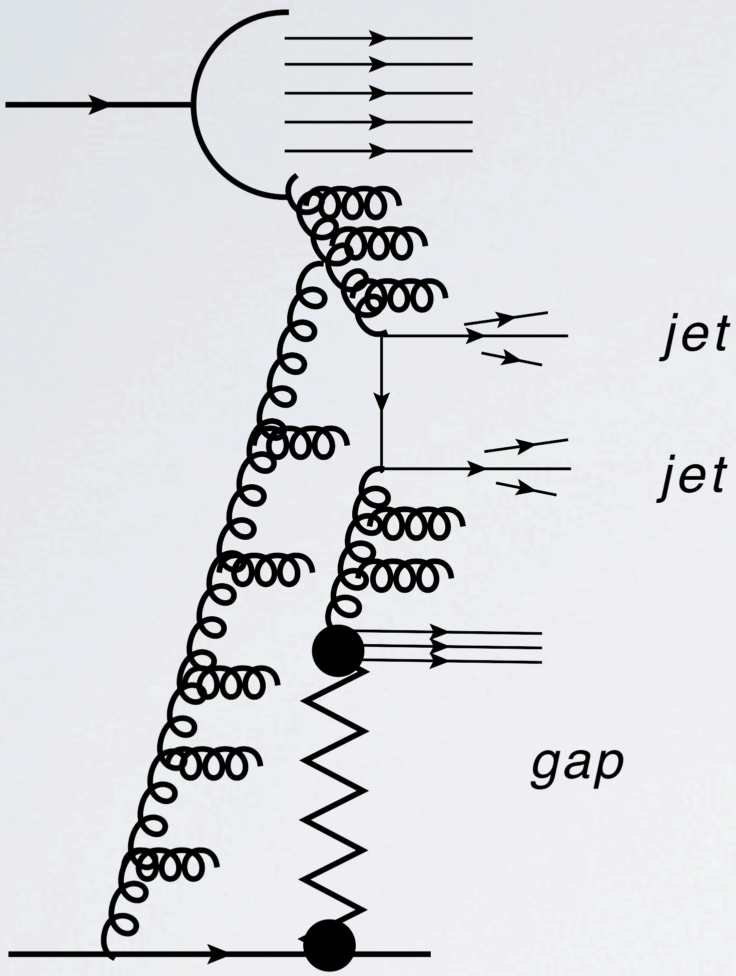


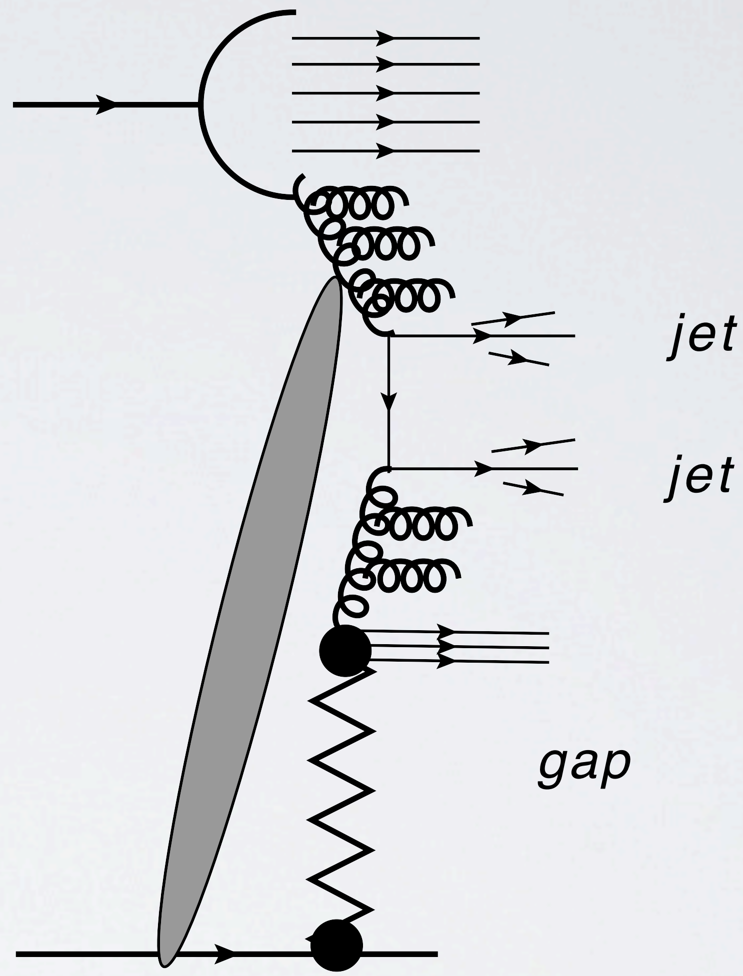


Is the survival probability simply a constant (in b-space)?
Does it depend upon

$$\beta,\ E_T\quad ?$$

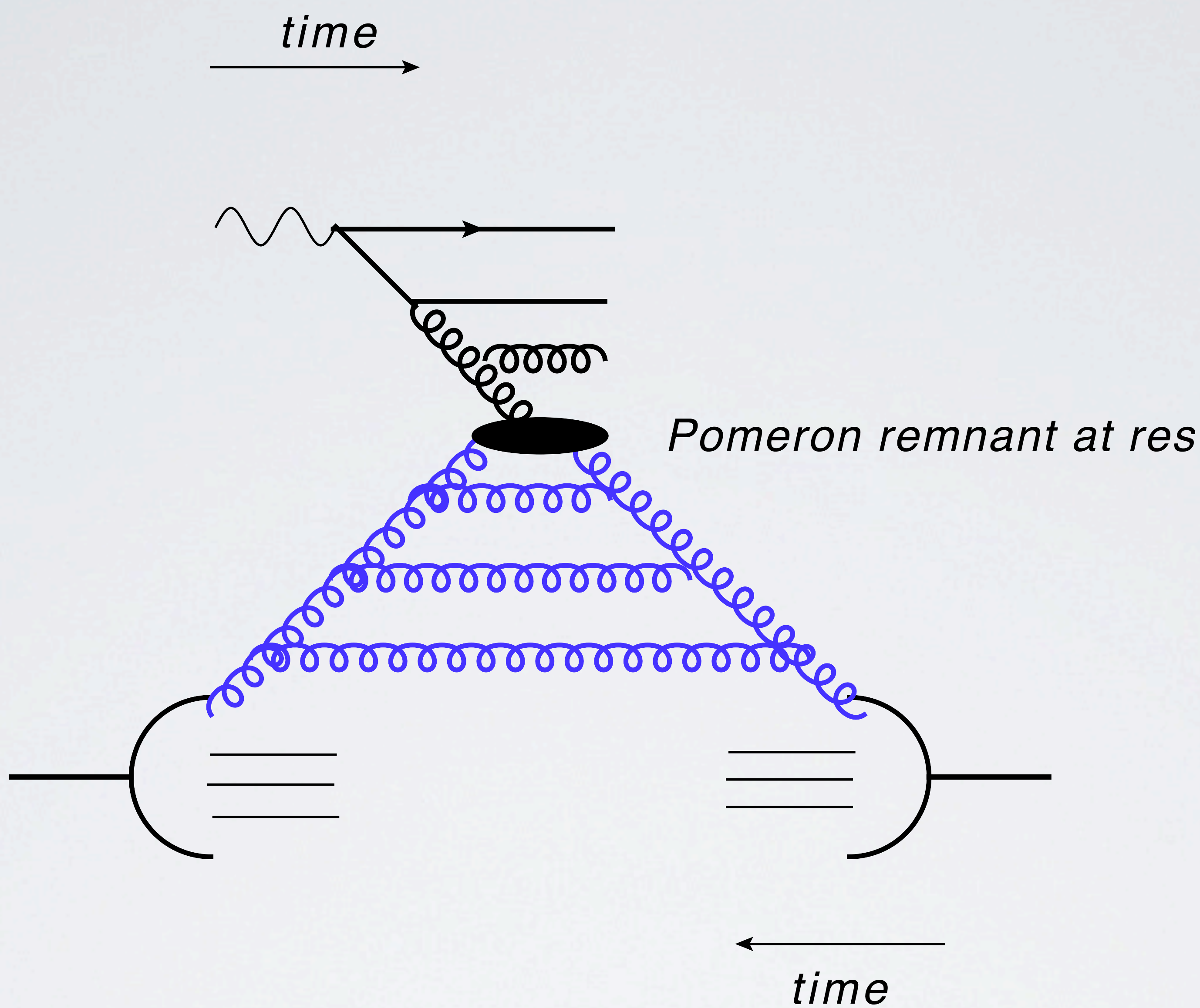
Survival probability could have other contributions:





‘Semihard’ rescattering corrections
(are not small)

Space-time picture of the 'Pomeron' structure function:



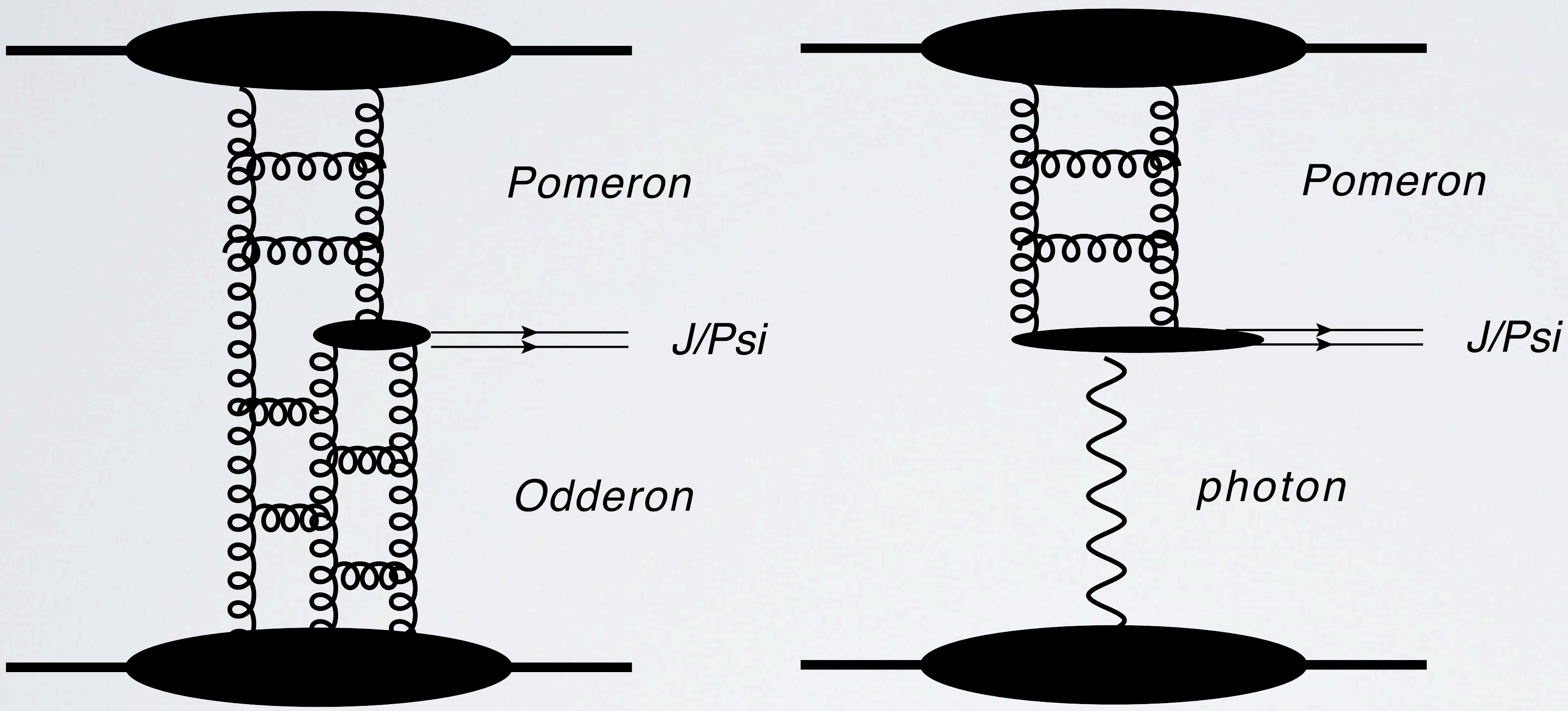
Pomeron is part of the proton

2. Double diffractive final states

'Production out of pure glue':

e.g. J/Ψ as signal for the odderon

$pp \to ppV,\ V = J/\Psi, \Upsilon$



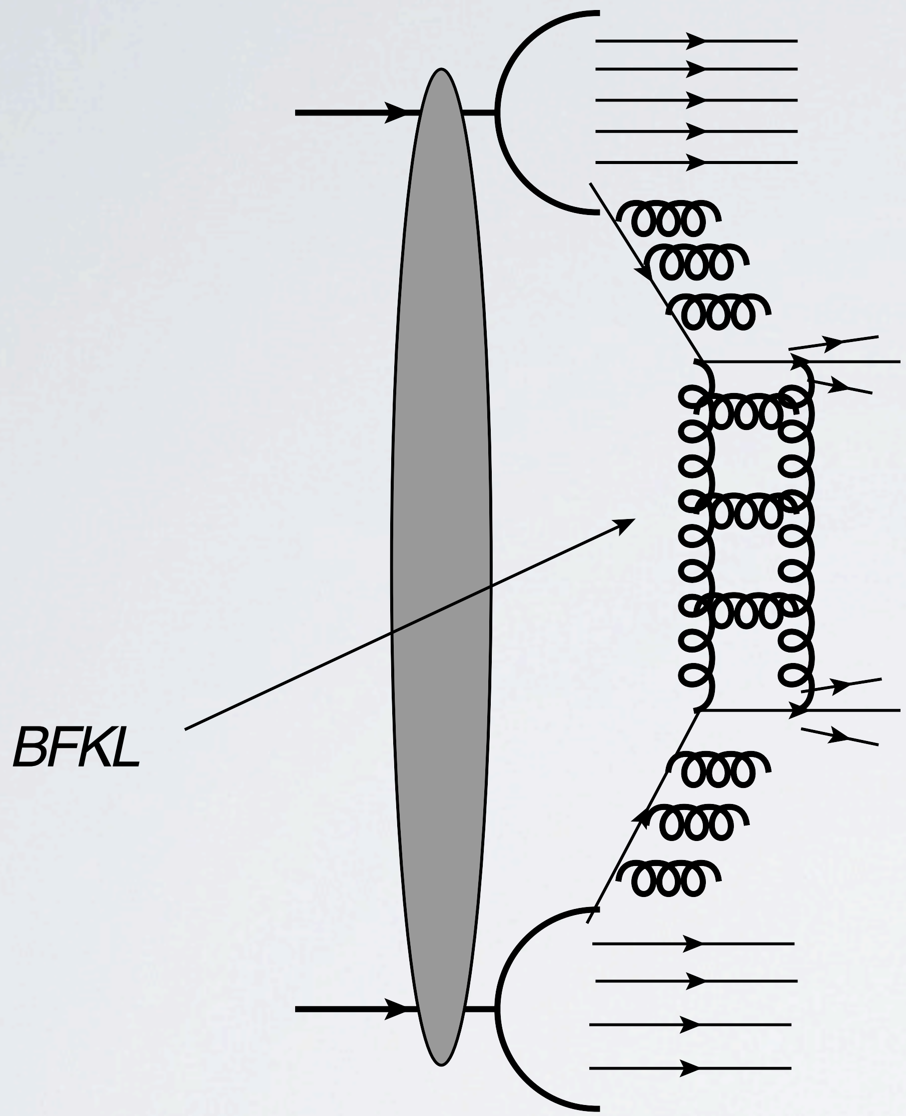
In SU(3) gauge theory: BFKL (2 gluons) and Odderon (3 gluons) are fundamental configurations.

$d\sigma^{\rm corr}/dy$	J/ψ		Υ	
	odderon	photon	odderon	photon
Tevatron	0.3–1.3–5 nb	0.8–5–9 nb	0.7–4–15 pb	0.8–5–9 pb
LHC	0.3–0.9–4 nb	2.4–15–27 nb	1.7–5–21 pb	5–31–55 pb

ble 1: Estimates of cross-sections $d\sigma^{\rm corr}/dy|_{y=0}$ given for the exclusive J/ψ and Υ pro-

3. Jet-gap-jet (hard color singlet exchange)

Cox,Forshaw,Lonnblad;
Enberg,Ingelman, Motyka;
Royon



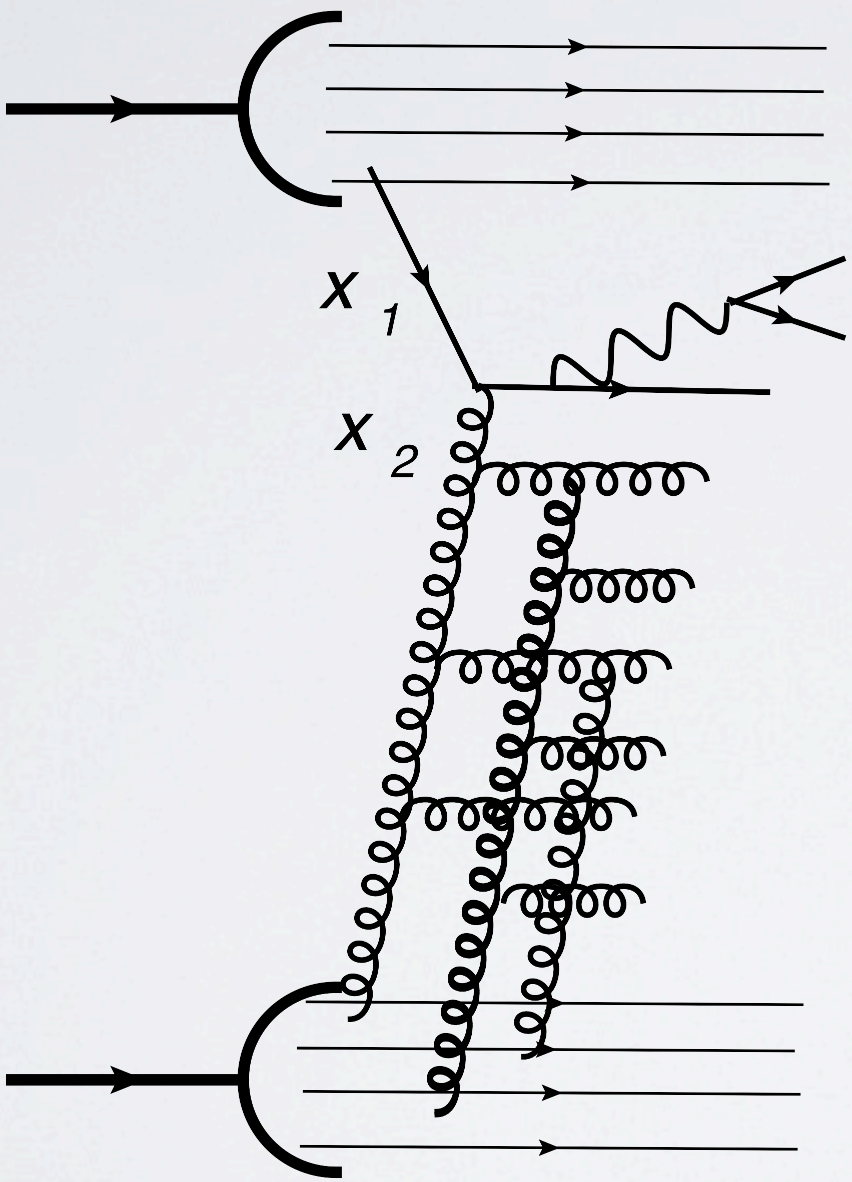
BFKL needs all conformal spins

$$\frac{d\sigma^{pp}}{dx_1 dx_2 dE_T^2} = S f(x_1, E_T) f(x_2, e_T) \frac{d\sigma^{qq\to JJ}(\eta, E_T)}{dE_T^2}$$

Survival factor S:
Modelled by Monte Carlo

4. Saturation: forward Drell-Yan

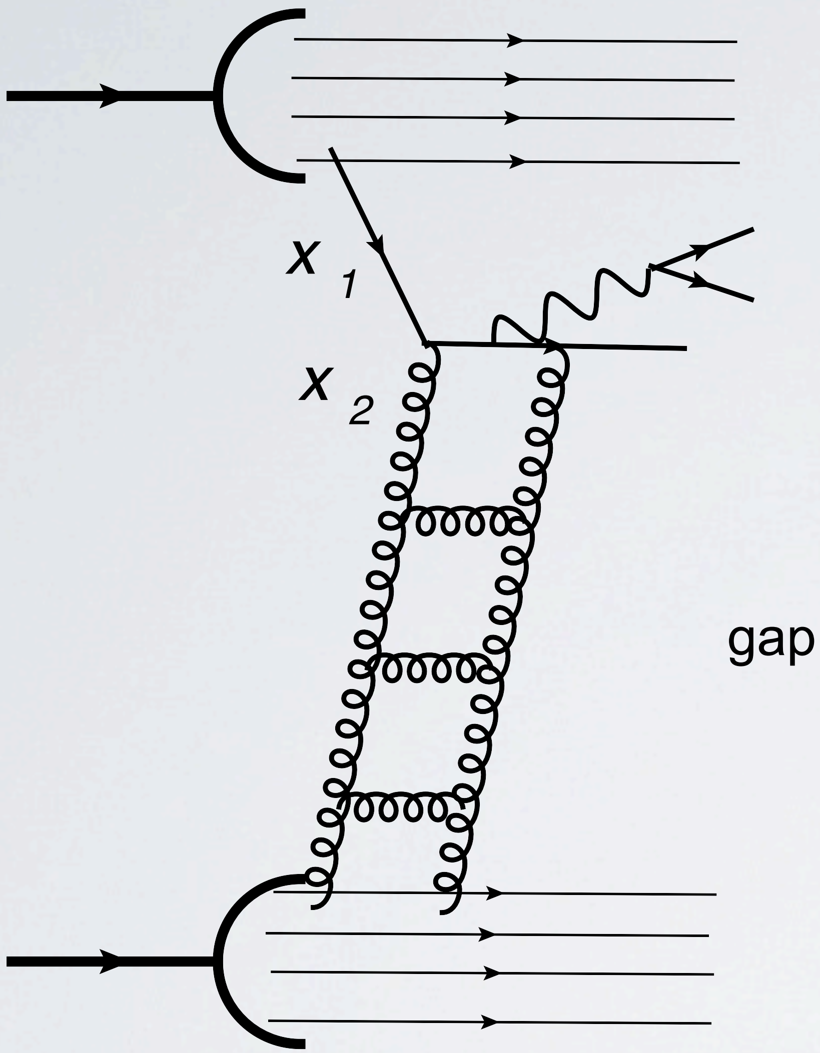
Motivation: parton densities at small-x.



Signals for saturation at the LHC:
- ridge effect,
- charged multiplicity,
- scaling in $\frac{dN}{dy dp_t^2} = \frac{F(p_t^2/Q_s^2)}{Q_0^2}$

$$x_2 \ll x_1$$

Motivation: HERA observation $\frac{\sigma_{diff}}{\sigma_{tot}}$:



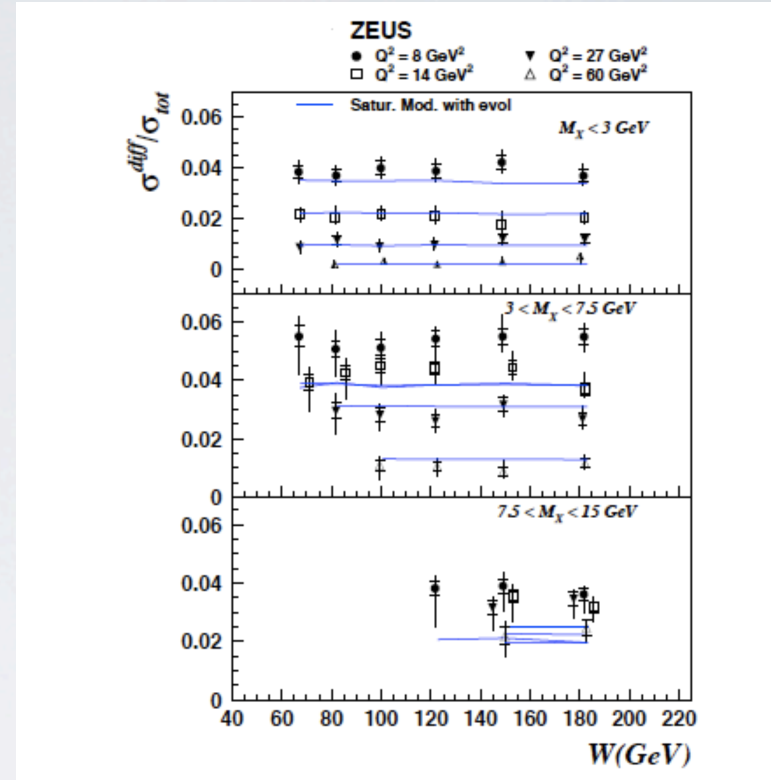
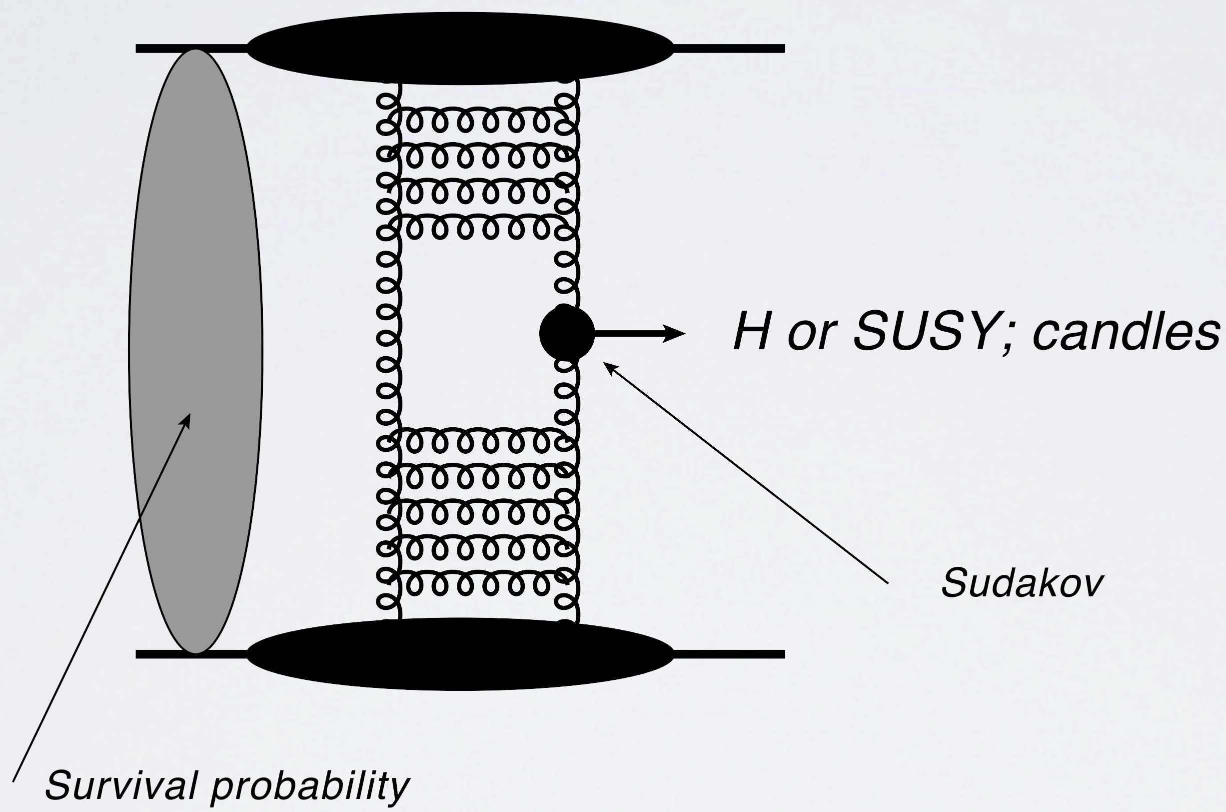


Figure 9. ZEUS data for the ratio $\sigma_{\rm diff}/\sigma_{\rm tot}$ together with the respective prediction of the saturation model in Ref. [55].

Diffractive/rapidity gap processes: new physics

1. Double diffractive production of Higgs, SUSY,....

Topic of intense discussion (Bialas,Landshoff; ... ;Durham group)

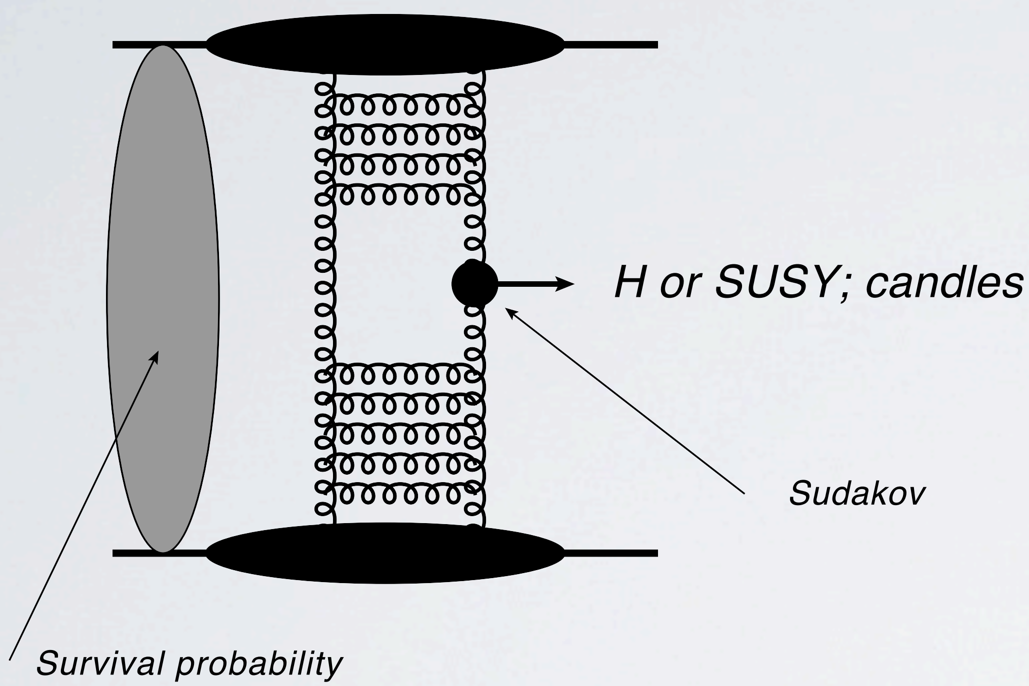


$$\sigma(pp \to p + H + p) \sim \frac{\langle S^2 \rangle}{B^2} \left| N \int \frac{dQ_t^2}{Q_t^4} f_g(x_1, x_1', Q_t^2, \mu^2) f_g(x_2, x_2', Q_t^2, \mu^2) \right|^2$$

Experimental aspects: clean signal, precise mass determination

Theoretical ingredients: parton densities, Sudakov factor, suppression rules survival probability

Theoretical uncertainty: survival probability
Standard calculation based upon eikonal approximation, however, it could be more complicated, e.g.:



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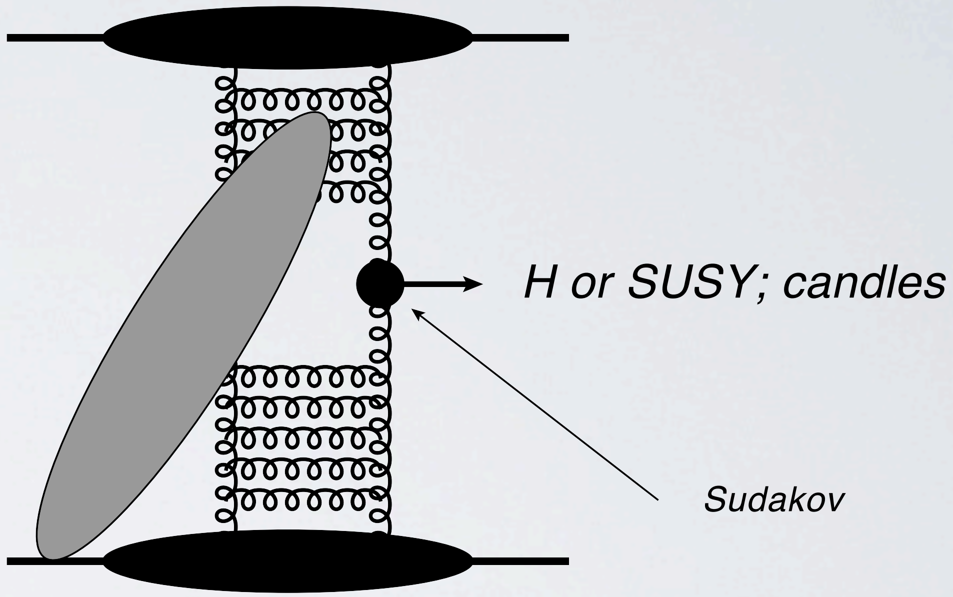


Corrections are large
and need to be resummed
Very difficult problem

Help from experiment: (Tevatron)
measure production of other final states (candles)
e.g. jet-jet, $\gamma\gamma,\ \chi_c$

Estimates (from Royon, 2010):

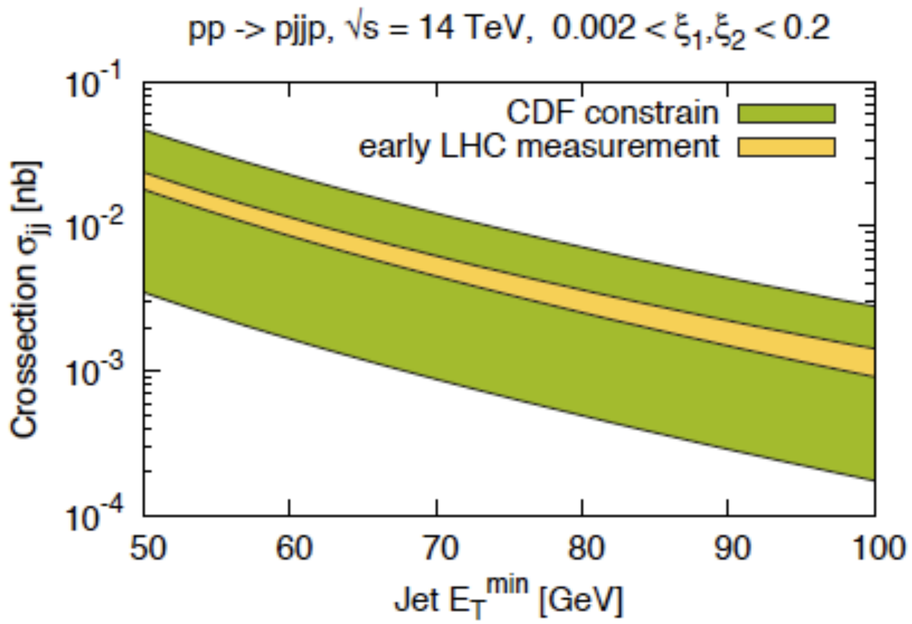


Figure 5: Total uncertainty for exclusive jets at the LHC: constraint provided by the CDF measurements and the potentail LHC measurement with a low luminosity of 100 pb^{-1}.

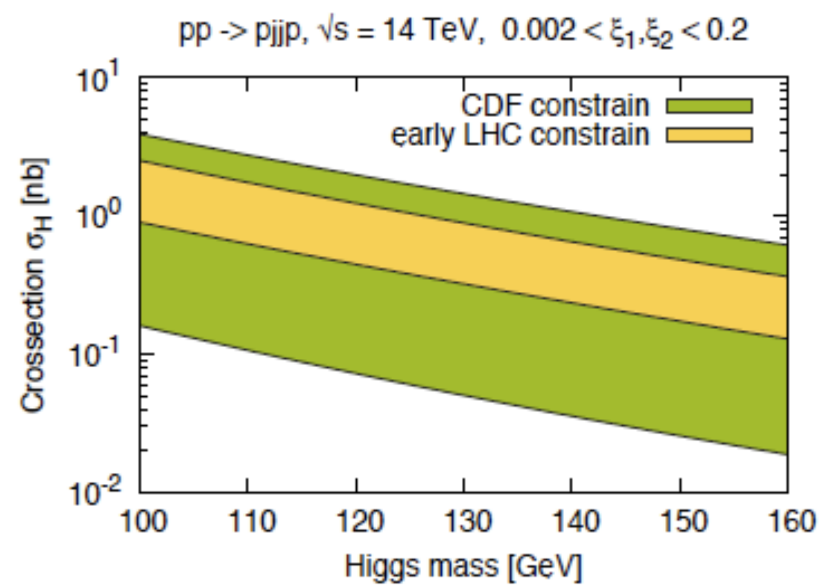
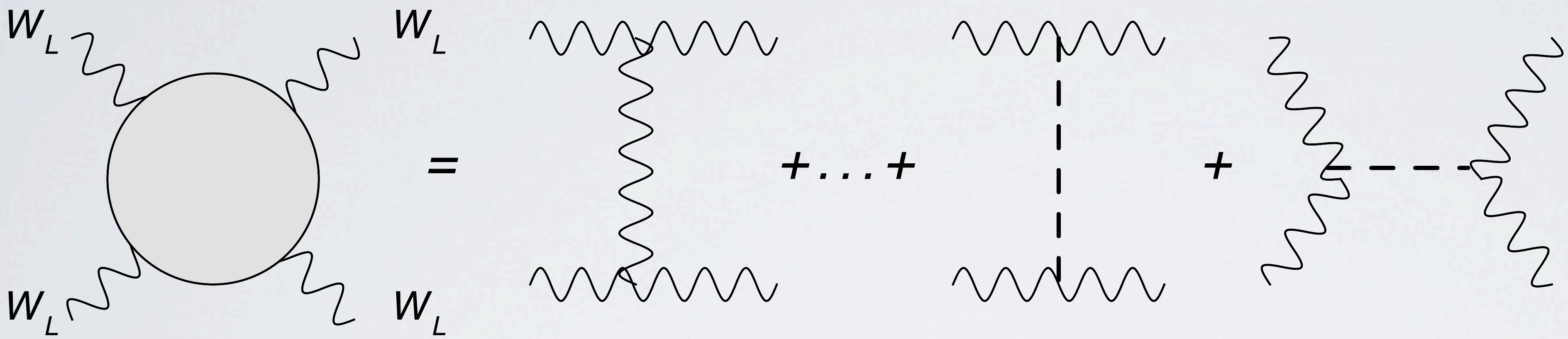


Figure 6: Total uncertainty for exclusive Higgs production at the LHC: constraint provided by the CDF measurements and the potentail LHC measurement with a low luminosity of 100 pb^{-1}.

2. Rapidity gaps and Electroweak physics

Why do we need a Higgs:
a) high energy behavior vector-vector scattering
b) renormalizability of electroweak theory



Bad high energy behavior (violation of unitartiy bounds), near 1 Tev:
'WW scattering is the primary place to search for Higgs bosons'

Similarly in other VV→VV processes, but at higher order (energies).

$$\gamma + \gamma \to WW,\ ZZ$$

New physics maybe encoded in anomalous coupling.

What can be done in pp-scattering: photon-photon induced interactions

(Pierzchala,Piotrzkowski,; Chapon,Kepka,Royon; D0)

$$W_{\gamma\gamma} \leq 1.8\, TeV$$

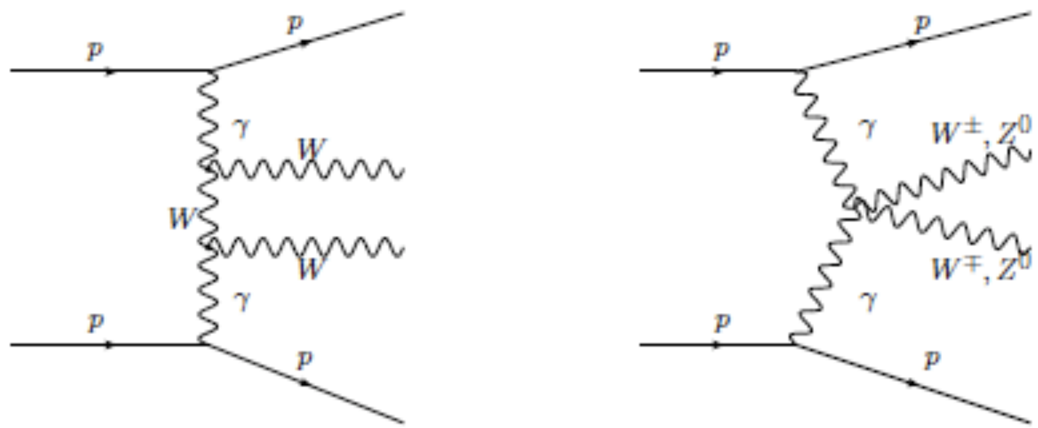


Figure 1: Feynman diagrams for the signal (triple gauge couplings on the left, quartic on the right)

Bounds on anomalous quartic gauge coupling can be improved
Unitarity violations in VV scattering around $W_{\gamma\gamma} = 2\; TeV$

Need to go to small t.

Conclusions

Theory of hard diffraction:

- theory of multiparton interactions (only at the beginning)
- convenient parametrization: survival probability (nonuniversal) S^2
- connection with soft (=long distance) diffraction

Specific final states:

- aspects of QCD dynamics
  diffractive parton densities
  jet gap jet (BFKL)
- search for new physics
  double diffractive Higgs
  electroweak