Strong interactions at HERA and LHC beyond collinear approximation

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Overview

Motivation

k_T factorisation

Multiple interactions

Diffractive processes in pp collisions

Summary

Understanding events at HERA and LHC

⟶ LHC: the experiment designed to discover Higgs boson and (we wish!) New Physics

⟶ Shape of the signal in LHC is strongly affected by strong interactions

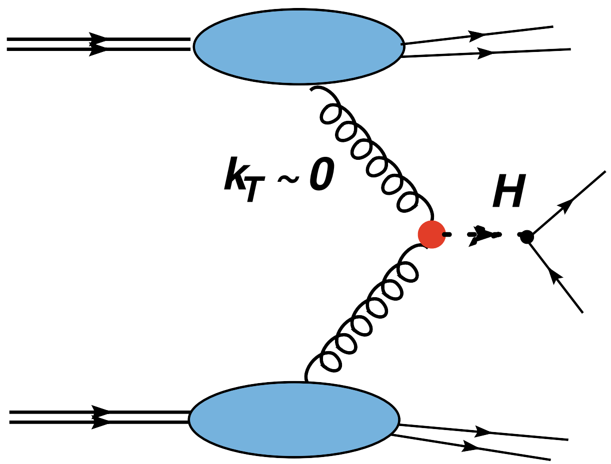
⟶ Discovery channels typically contain complicated multi-particle event topologies which may easily drown in QCD driven background

⟶ We need good understanding of strong interactions:
HERA — excellent QCD laboratory that provides invaluable input into the LHC program

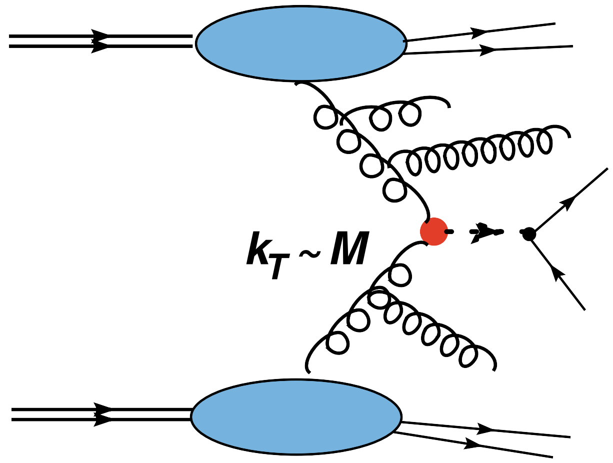
k_T factorisation

Collinear approach:

parton transverse $k_T \sim 0$



QCD radiation generates parton k_T



Strong kinematic effects of non-zero parton k_T

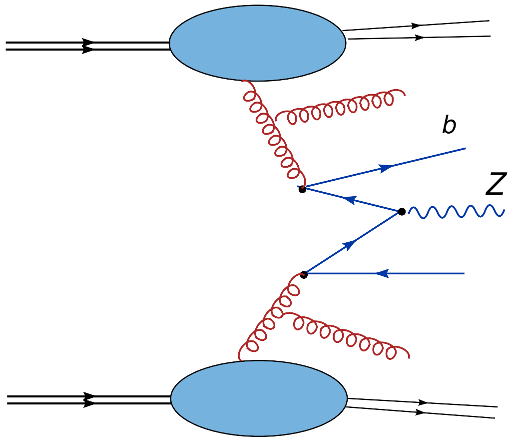
Price to pay: collinear parton densities $f(x,\mu^2)$ replaced by more complex unintegrated parton densities $F(x,k_T^2,\mu^2)$, also evolution and matrix elements require new calculations

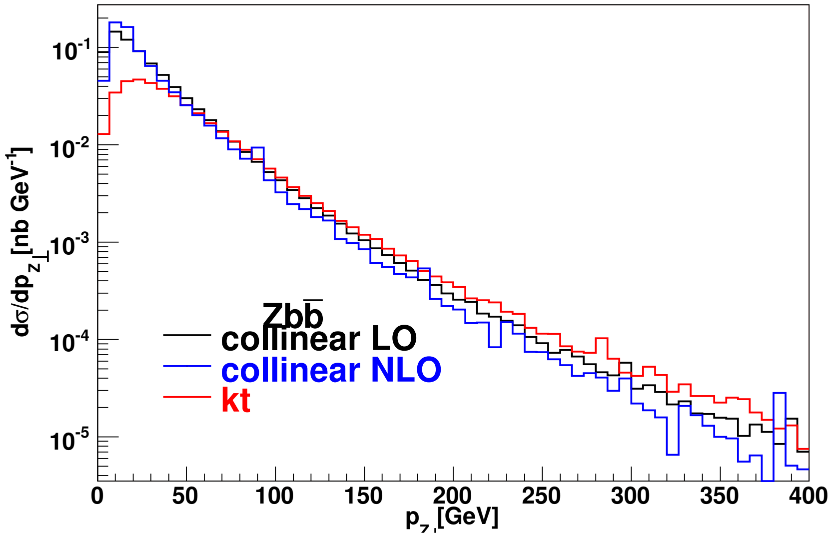
HERA contribution: constraints on $F(x,k_T^2,\mu^2)$ and Monte Carlo implementation of k_T-factorisation: Hannes Jung's CASCADE

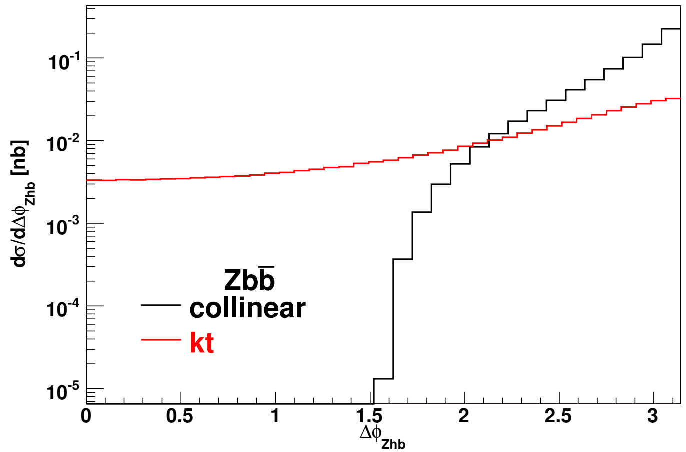
k_T effects at the LHC: $Z^0 b\bar{b}$ production

[M. Deak, F.Schwennsen], [S. Baranov, A. Lipatov, N. Zotov]

Recent improvement: inclusion of 'sea quarks' in $Z^0 b\bar{b}$ and $\gamma b\bar{b}$ production







Significant kinematical effects found in

⟶ p_T spectrum of the Z^0 boson

⟶ the azimuthal angle between more energetic jet and Z^0

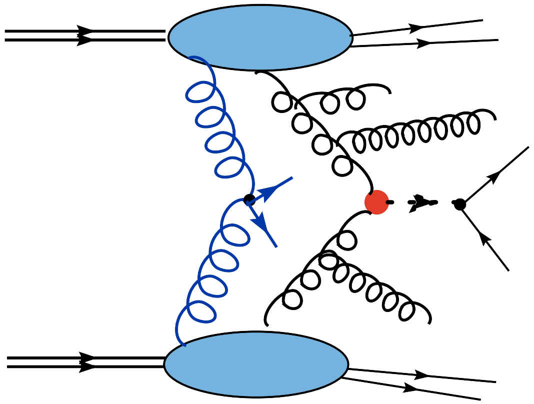
Future: more processes and NLO calculations (e.g. for heavy quark hadroproduction)

Multiple interactions

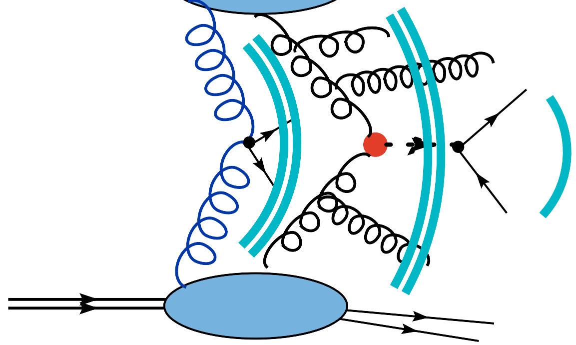
Fast growth of parton densities with energy $\longrightarrow$ dense partonic system

$\longrightarrow$ multiple hard interaction within one pp or γp collision

Secondary hard interactions



Hadron production



Notion of multi-parton densities emerges $\sim$ probabilities of finding n-partons in the proton

Multiple interactions $\longrightarrow$ additional particle production in hard and soft domain

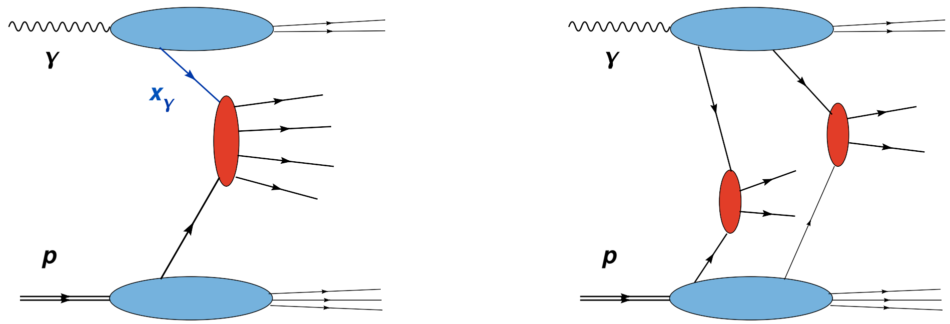
$\longrightarrow$ essential for underlying event structure

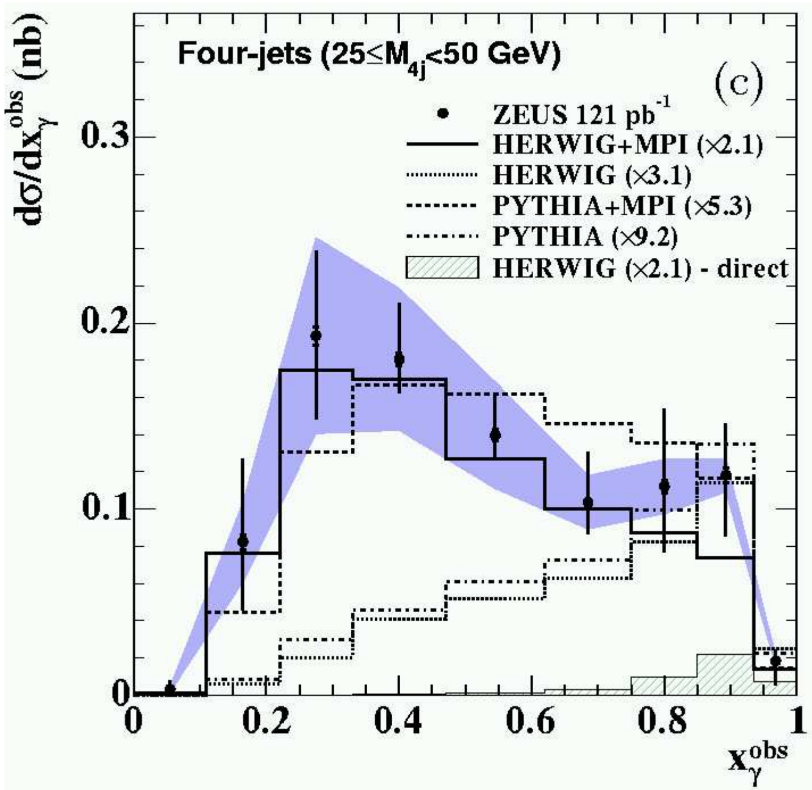
Evidence for multiple interactions in mini-jet photo-production at HERA

ZEUS: $\gamma p \longrightarrow$ four jets with $M_{4j} < 50$ GeV

Production mechanisms:

single and multiple chains





Real photon:

$x_\gamma \sim 1 \longrightarrow$ point-like $\longrightarrow$ no MI

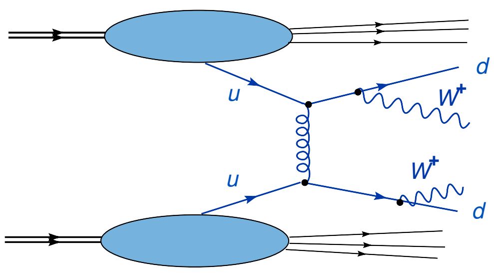
$x_\gamma \ll 1 \longrightarrow$ hadron-like $\longrightarrow$ MI

Data compared to MC predictions with and without Multiple Interactions **[B6]**

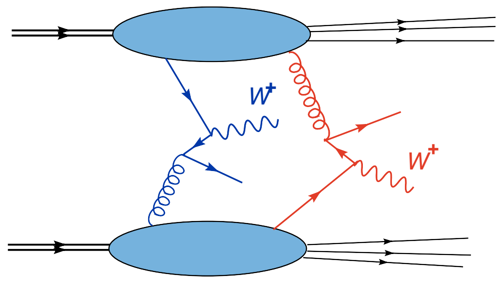
$\longrightarrow$ Multiple interactions needed to get event shapes right

Relevance of multiple interactions for hard processes [A. Kulesza and J. Stirling]

Like-sign W: single scattering



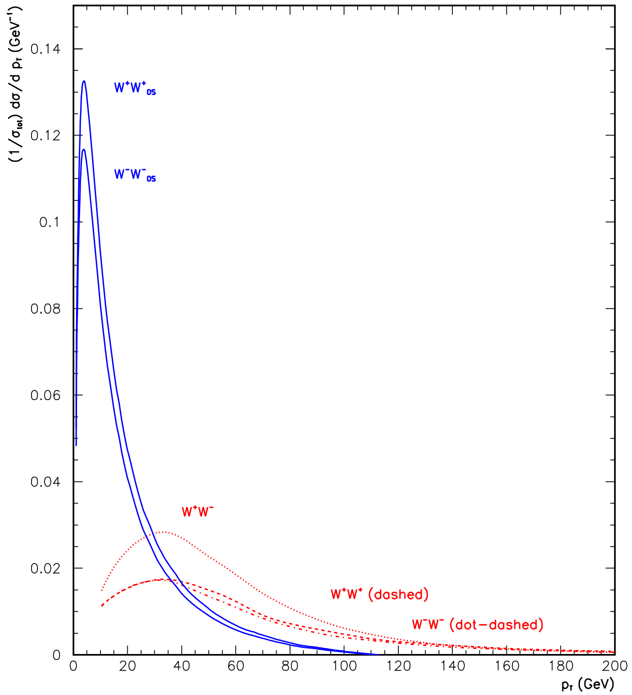
double scattering



Like-sign W production from double scattering only slightly smaller than single scattering production

Double scattering important for processes at electroweak scale!

$\longrightarrow$ Other channels? Background shape?



$\longrightarrow$ Systematic analysis of double scattering contribution to interesting channels:

background estimates and measurement of double parton distributions $\longrightarrow$ [B6]

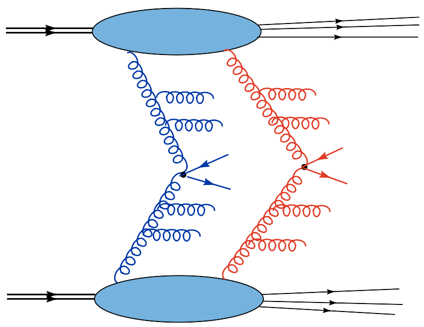
Multi-parton evolution

Independent secondary interactions

⟶ increase of multiplicity but not $\langle p_T \rangle$

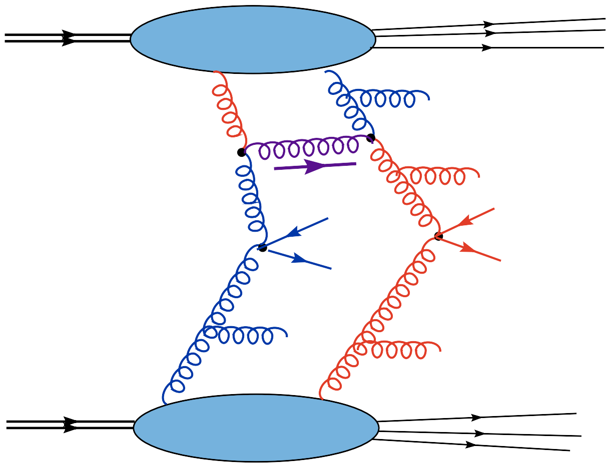
⟶ difficult to describe both n and $\langle p_T \rangle$

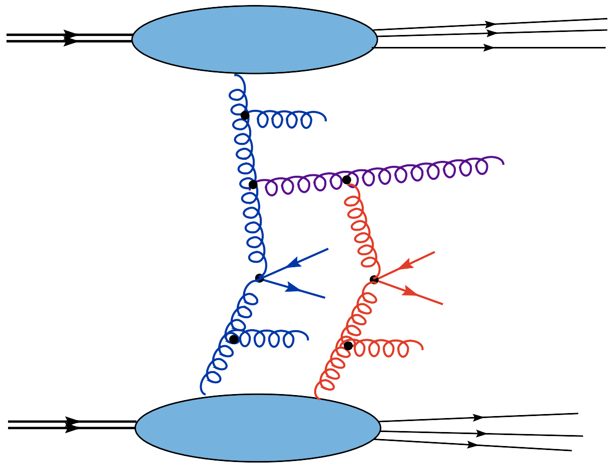
[G. Gustafsson]



Need to understand interaction between chains and effects on color flow

Chain swing: done for DIS **[Bartels, Ryskin]** ⟶ much more important for pp



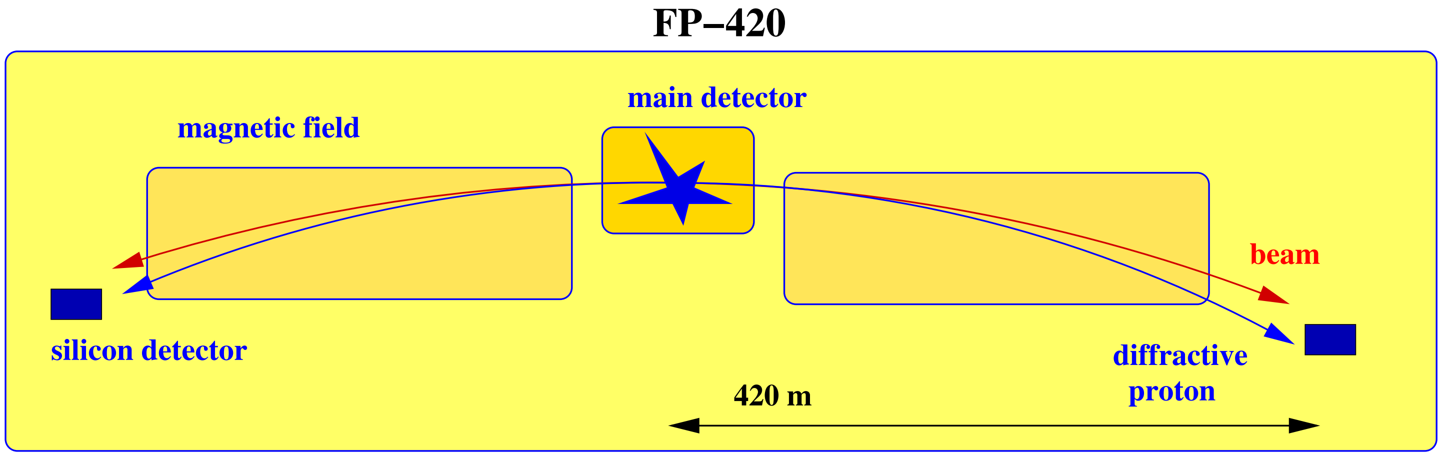


Ongoing: **[Bartels, Gustafsson, LM]**

Chain splitting ⟶ future

Central exclusive diffraction

Concept: complement conventional measurement with forward detectors



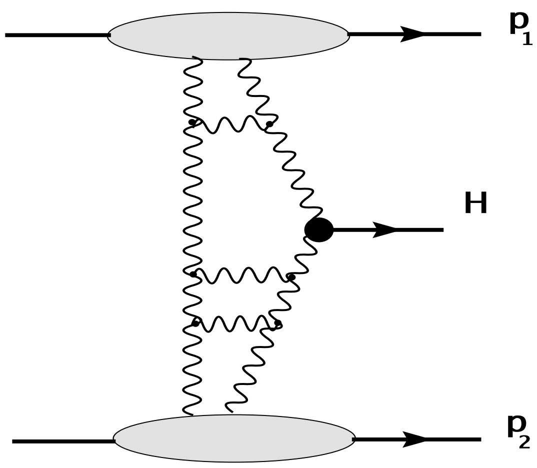
Magnetic spectrometer: small loss of proton energy $\longrightarrow$ drift outside the beam

Forward Proton measurement — precision trackers 420 meters downstream and a few millimeters from the beam

Complete event coverage and excellent mass resolution — up to $O(1\ \text{GeV})$ accuracy

Exclusive Higgs boson production $pp \to p\, H\, p$

[V. Khoze, A. Martin, M. Ryskin, A. Kaidalov, J. Stirling,...]



$\longrightarrow$ Protons stay intact and are measured in forward detectors

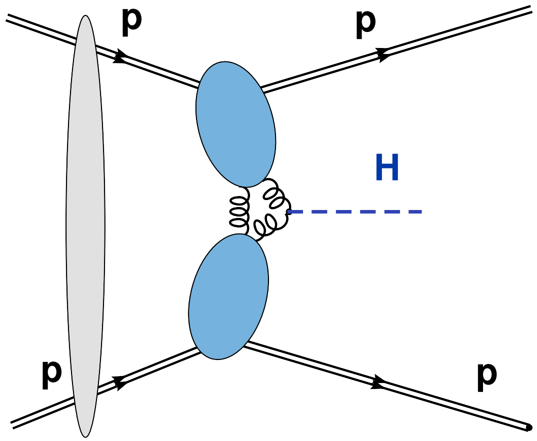
$\longrightarrow$ Higgs boson decay products seen cleanly in main detector

$\longrightarrow$ Precise information about final state: mass, decay width, quantum numbers

$\longrightarrow$ Favorable in case of SUSY scenarios: almost full coverage of $(M_A, \tan\beta)$-plane at 3σ level [S. Heinemeyer et. al. , hep-ph:0708.3052]

$\longrightarrow$ Potential to resolve almost degenerate resonances

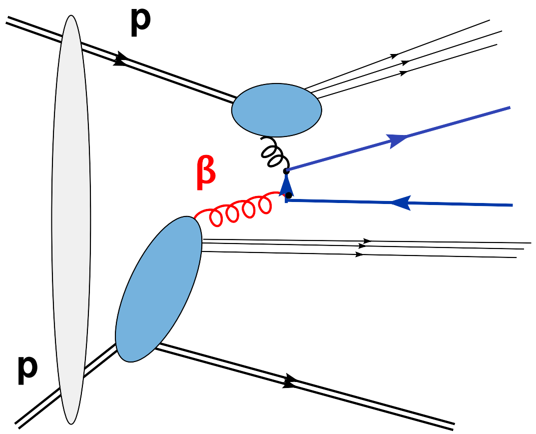
Main problem in exclusive diffractive Higgs: rescattering effects



Hard part calculable perturbatively but...

Secondary interactions may destroy

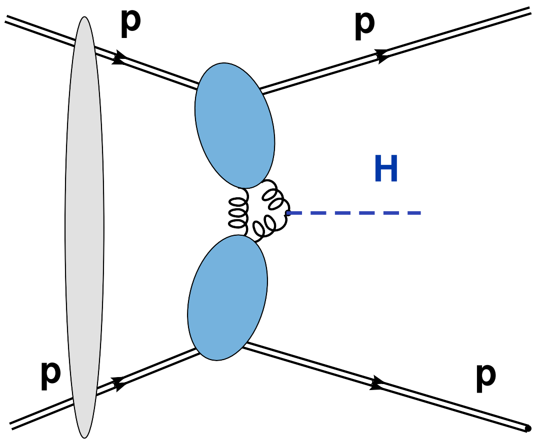
the exclusive signature

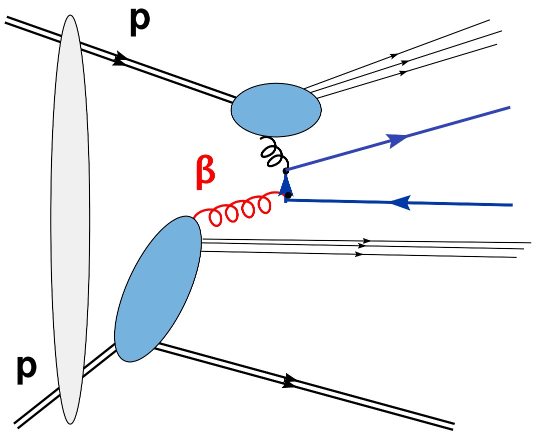


HERA and Tevatron $\longrightarrow$

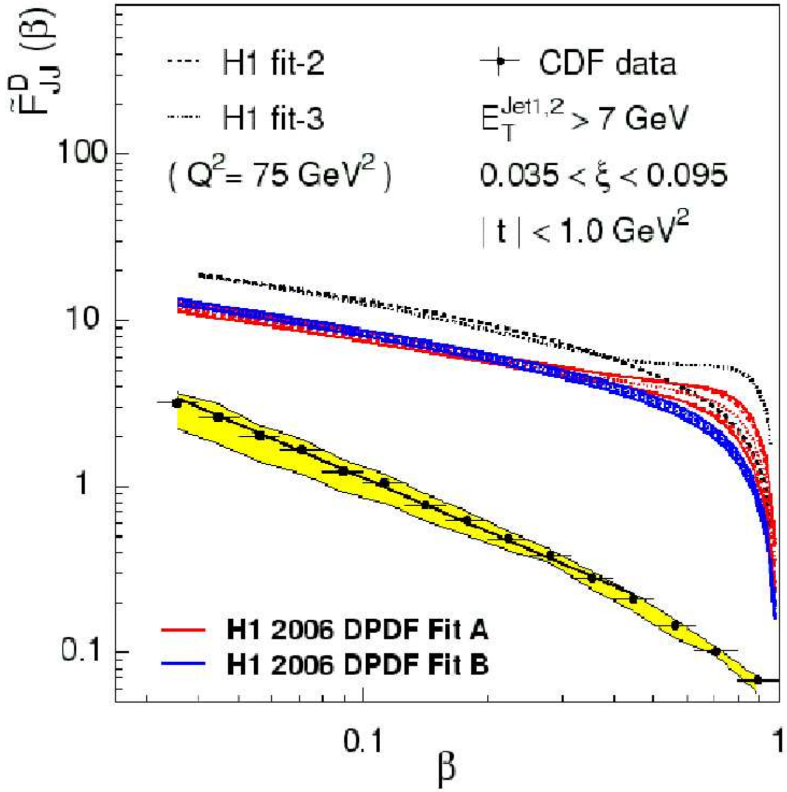
test case: diffractive dijets

Test of rescattering effects





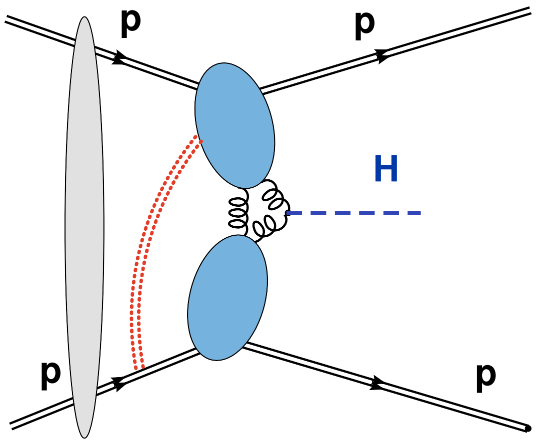
Diffractive dijet production at Tevatron

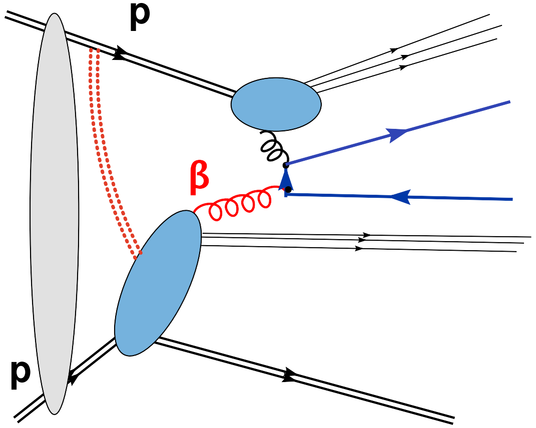


Large rescattering corrections:

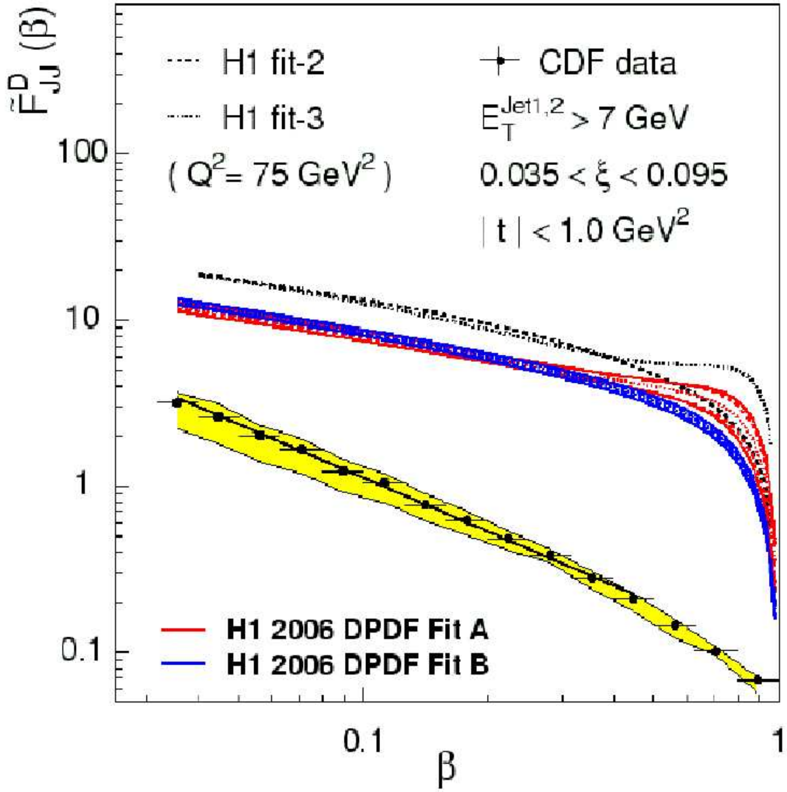
factor of 10 suppression!

Non-universal rescattering effects





Rescattering affects the shape



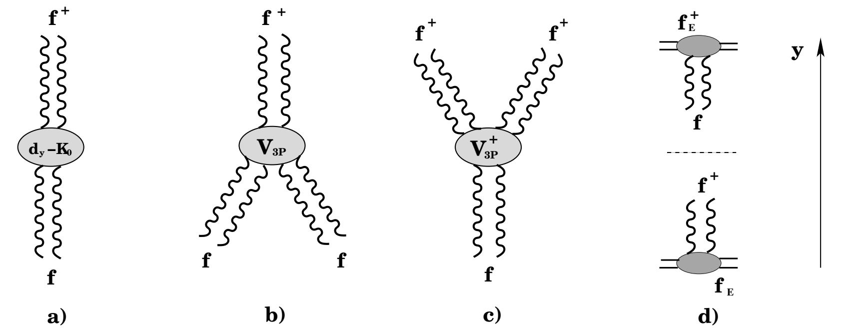
Hard rescattering is important

[J. Bartels, S. Bondarenko, K. Kutak, LM]

Approach to resum multiple scattering corrections

Use gluonic ladders as effective degrees of freedom

QCD provides Feynman rules for emerging effective field theory



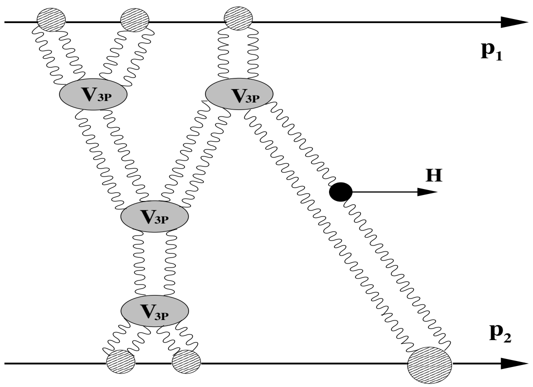
Define effective action in terms of effective fields $\mathcal{A}[f, f^\dagger; Y]$

Solve classical equations of motion to find classical field trajectories $\bar{f}(y, k^2)$ and $\bar{f}^\dagger(y, k^2)$
[S. Bondarenko, LM]

Scattering amplitudes in semi-classical limit: $S(Y; f_A, f_B^\dagger) \; = \; \sum_\alpha \Delta_\alpha \; \exp(-\mathcal{A}[\bar{f}_\alpha, \bar{f}^\dagger{}_\alpha; Y])$

$\longrightarrow$ Possible to define exclusive Higgs boson production in semi-classical limit

$\longrightarrow$ Ongoing activity: apply this formalism to DIS and $p\bar{p}$ data and apply to LHC physics
[S. Bondarenko, LM]



B6 Summary

Main goals: ⟶ discover details of proton structure (F_L!)

⟶ understand better strong interactions

⟶ obtain precise description of hard events at LHC

Task	Ongoing	Aim
Collinear parton distributions	Parton distribution fits: total cross sections, heavy quarks, jets ⟶ gluon density F_L measurement Higher twist corrections	Optimal use of HERA data ⟶ precise parton densities
k_T-factorisation	Evaluation of matrix elements and cross sections with $k_T \neq 0$	More processes: accurate description of kinematics
Multi-parton interactions	HERA measurements of multiple interactions Perturbative estimates of color reconnection Multiple scattering background to discovery channels	Parametr tuning of MC Improved color flow ⟶ MC Systematic understanding and subtraction of MI background
Diffraction	HERA measurements ⟶ diffractive partons Effective field theory at high energies	Diffractive processes at LHC: understanding and applications to Higgs boson physics