Working group summary: Diffraction

Theory

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1. Overview
2. Theory of and around diffractive Higgs production
   - gluon distribution
   - rapidity gap survival
   - diffractive parton densities
3. QCD at high parton densities
   - Saturation, multiple interactions, AGK cutting rules
4. Conclusions

Warning and apologies:
very selective, often gloss over technical details

Topics and contributions

- Diffractive Higgs production J Forshaw, G Ingelman, A Kaidalov, P Landhsoff, L Lönnblad, A Martin, L Motyka, R Peschanski
- Diffractive structure functions and parton densities M Arneodo, M Groys, P Newman, A Proskuryakov, F-P Schilling, G Watt, G Wolf
- Diffractive factorization breaking ("rapidity gap survival") A Bruni, M Klasen, U Maor, A Mastroberardino, A Prygarin, S Schätzel, F-P Schilling
- Multiple interactions J Bartels, K Boreskov, A Kaidalov, H Kowalski, A Sabio-Vera, M Strikman
- Small-x theory (BFKL, nonlinear evolution, saturation) J Andersen, D Kharzeev, G Ingelman, E Levin, M Lublinski, C Marquet, S Munier, J Raufeisen, A Sabio-Vera, R Venugopalan

- Charged current exchange L Adamczyk, R Bellan, P Laycock, K Wichmann
- γp interactions at LHC J Nystrand, K Piotrzkowski
- Diffraction at LHC: generator studies M Boonekamp, B Cox, J Monk, A Pilkington, A Solol, M Tasevsky
- Diffraction at LHC: detectors and triggers B Cox, R Croft, A De Roeck, I Efthymiopoulos, K Eggert, F Ferro, P Grafström, M Grothe, C Hogg, D Macina, M Murray, K Österberg, R Orava, A Panagiotou, M Ryynanen, P v Mechelen
- Forward detectors at HERA V Andreev, A Bunyatyan, X Janssen, M Kapishin, H Kowalski, V Monaco, R Sacchi, K Vervink
- Diffraction at the Tevatron C Avila, D Goulianos

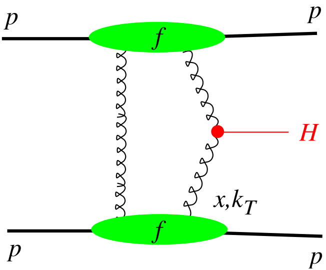
Exclusive Higgs production

Exclusive channel $p + p \to p + H + p$ has many attractive features

- mass resolution
- quantum number filter/discriminator J^{PC}
- scenarios beyond standard model

$\to$ J Ellis, B Cox, plenary talks

Exclusive Higgs production (very oversimplified)



$f(x, k_T) =$

unintegrated gluon distribution

$$\int^{\mu^2} \frac{d^2 k_T}{k_T^2} f(x, k_T^2) = x g(x; \mu^2)$$

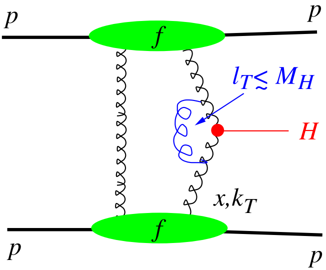
(roughly)

- appears as $\displaystyle\int \frac{d^2 k_T}{k_T^4} f(x_1, k_T^2) f(x_2, k_T^2)$

  $\rightarrow$ not dominated by $k_T \sim M_H$

  $\rightarrow$ bad infrared behavior

Exclusive Higgs production (oversimplified)



radiative corrections
$\rightarrow$ large Sudakov logarithms
$\rightarrow$ cancellations in infrared region
Khoze, Martin, Ryskin

- improves infrared behavior
  but retain sensitivity to lowish values of k_T
- appreciable dependence of cross section on precise implementation of resummation, choice of scales, ...
  $\rightarrow$ J Forshaw, L Motyka (Jan meeting)
  full NLO calculation would be useful

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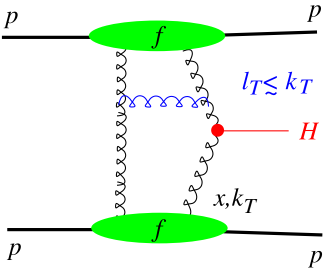

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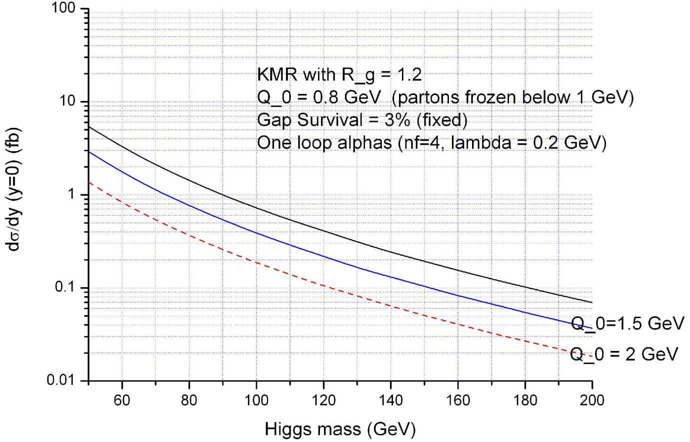
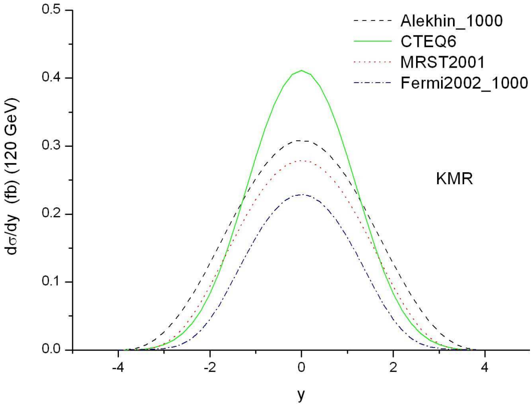
Sensitivity to infrared region:
Higgs cross section evaluated with cutoff $Q_0 \leq k_T$
J Forshaw (Jan meeting)



Need to know unintegrated gluon distribution

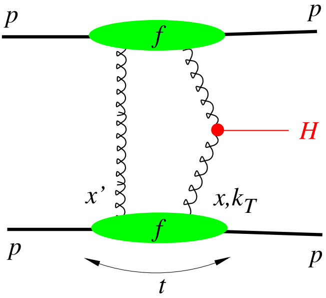
one strategy: obtain from integrated (DGLAP) distributions by differentiation $\int^{\mu^2} \frac{d^2 k_T}{k_T^2} f(x,k_T^2) = xg(x;\mu^2)$

J Forshaw (Jan)



more fundamentally: how to constrain unintegrated gluon distrib. from data L Lönnblad (March)

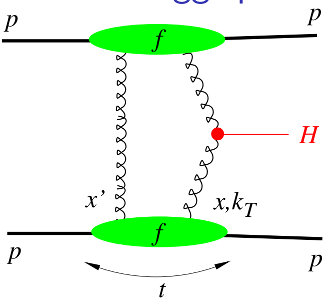
Exclusive Higgs production (less oversimplified)



need generalized gluon distribution $f(x, x', k_T^2, t)$

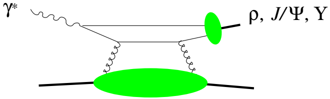
- skewness: $x \sim M_H^2/s \approx 10^{-2}$ for $M_H = 120$ GeV,
  $x' \sim k_T^2/s \ll x$
- t dependence
  interplay between t and x: shrinkage $f \sim x^{-\alpha'|t|}$
  transformed from t to impact parameter
  $\rightarrow$ distribution of gluons in transverse plane

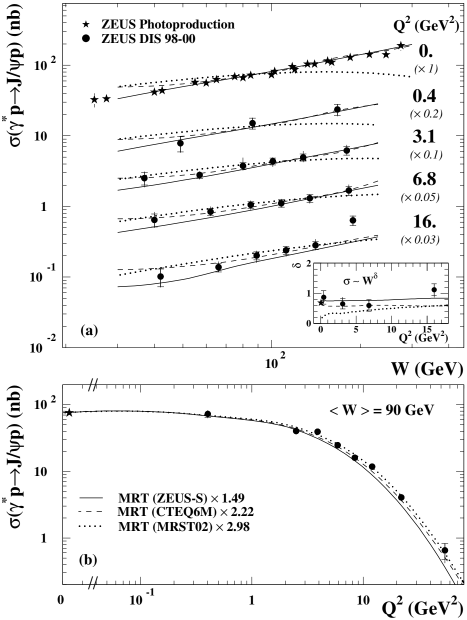
Exclusive Higgs production (less oversimplified)



need generalized gluon distribution $f(x, x', k_T^2, t)$

- can measure at HERA: vector meson production and DVCS $\gamma^* p \to \gamma$



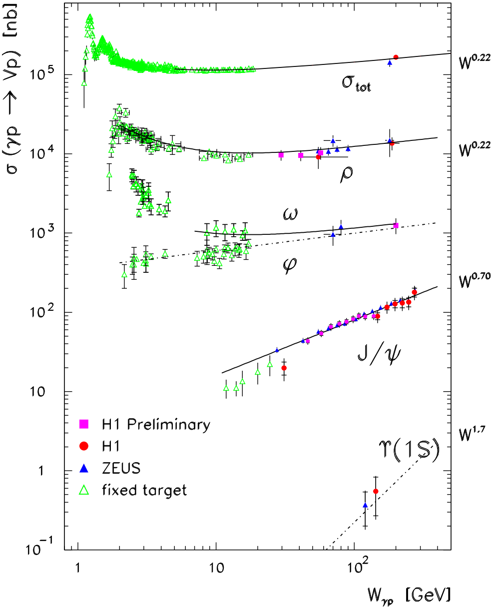


← ZEUS, NPB 695 (2004) 3

- data sensitive to gluon distrib. at

$$x = \frac{M_V^2 + Q^2}{W^2}$$

- but:
  theory uncertainties

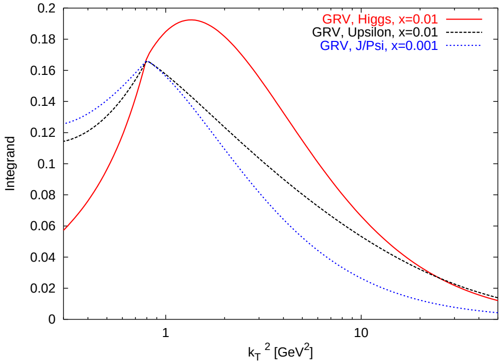


- smallest theory uncertainties:
  - Υ photoproduction
  - DVCS at large Q^2
- Υ photopr.: $x \sim 10^{-2}$ as for light Higgs

  small rate ⇝ HERA II

  A Bruni (this meeting)

vector mesons at HERA vs. light Higgs at LHC:



similar sensitivity to gluon k_T

← L Motyka (Jan)

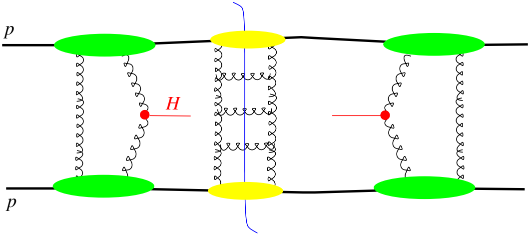
process amplitude $\propto \int d(\log k_T^2) \times$ Integrand

(J/Ψ and Υ curves: photoproduction)

(warning: curve for $k_T < 1$ GeV very dependent on infrared prescription)

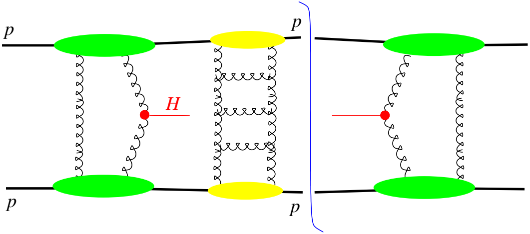
ongoing studies L Motyka, T Teubner

Exclusive Higgs production (simplified)



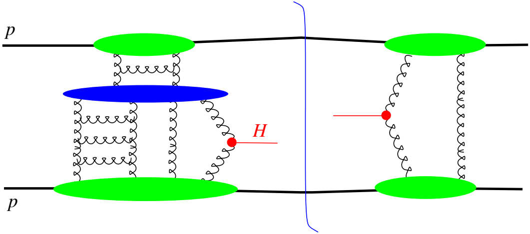
- in pp collisions no factorization for events with rapidity gap
  BIG effets
- culprit: interactions between spectator partons, mainly
  (but not only) soft

Exclusive Higgs production (simplified)



- in pp collisions no factorization for events with rapidity gap BIG effets
- culprit: interactions between spectator partons, mainly (but not only) soft
- current models based on data for pp elastic/diffractive scattering $\rightarrow$ U Maor (March, Oct), A Prygarin (Jan)

Exclusive Higgs production (less simplified)



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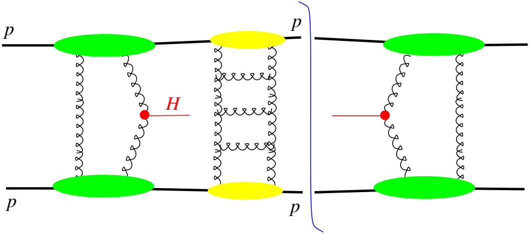
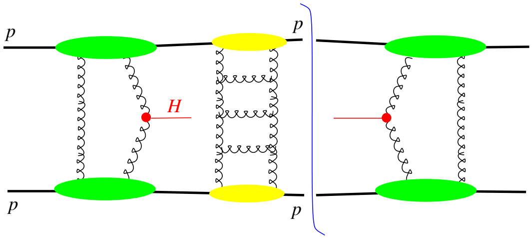
  BIG effets
- culprit: interactions between spectator partons, mainly (but not only) soft
- current models based on data for pp elastic/diffractive scattering $\rightarrow$ U Maor (March, Oct), A Prygarin (Jan)
- (is enough?) $\rightarrow$ L Motyka (Jan)

Exclusive Higgs production (simplified)



- in pp collisions no factorization for events with rapidity gap
  BIG effets
- culprit: interactions between spectator partons, mainly (but not only) soft
- further input: t dependence of hard subprocess
  (collision more central $\rightarrow$ more secondary interactions)
  $\rightarrow$ vector meson and DVCS data

Exclusive Higgs production (simplified)



I can only conclude that this unhappy situation needs a lot more expertise and detailed consideration than I can here provide. The best answer to this problem is to determine the survival probability experimentally.

J D Bjorken, Phys Rev D47 (1992) 101

Survival probability

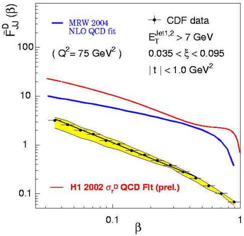
test models in a variety of processes → inclusive diffraction

- Tevatron $p\bar{p} \to p + \text{gap} + \text{jets} + X + \bar{p}$
  or $\bar{b}b$ or W instead of jets (looking forward to run II data)

CDF diffractive dijets

- Diffractive structure function of the antiproton:

$$\tilde{F}^D_{JJ}(\beta) = \frac{1}{\xi_{\max} - \xi_{\min}} \int_{\xi_{\min}}^{\xi_{\max}} \mathrm{d}\xi \left[\beta g^D(\xi,\beta,Q^2) + \frac{4}{9}\beta\Sigma^D(\xi,\beta,Q^2) \right]$$



- Fairly close to result presented by M. Arneodo (October meeting) ← G Watt (Jan)
- Results for 'survival probability' of the rapidity gap do not contradict calculation by Kaidalov-Khoze-Martin-Ryskin, 2000/1: $S^2 \simeq 0.12$–0.28

HERA-LHC Workshop, CERN, Geneva, January 2005 – p.32/35

Survival probability

test models in a variety of processes $\to$ inclusive diffraction

- Tevatron $p\bar{p} \to p + \text{gap} + \text{jets} + X + \bar{p}$
  or $\bar{b}b$ or W instead of jets (looking forward to run II data)
- essential input: diffractive parton densities from HERA
  $\gamma^* p \to X + p$, $\gamma^* p \to \text{jets} + X + p$, $\gamma^* p \to \bar{c}c + X + p$
  ongoing analyses and fits M Groys, P Newman, A Proskuryakov, G Wolf
  diffractive PDF library F-P Schilling
- diffractive structure function data:
  gobally good agreement between H1 and ZEUS
  but notable differences in detail
  $\to$ uncertainties on diffractive PDFs, especially on gluon
  P Newman, M Groys (this meeting)

  further data (high Q^2, jets, charm, tagged protons) will help

Survival probability

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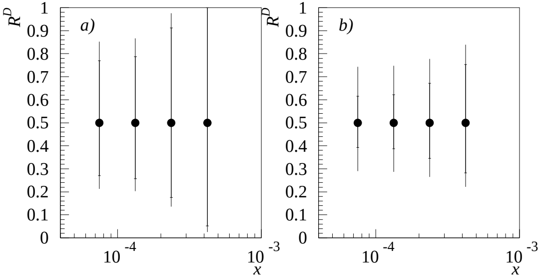
  diffractive PDF library F-P Schilling
- outstanding theory issues: → e.g. G Watt (June, Jan)
  - treatment of diffractive charm
  - kinematics where leading-twist description adequate
    at large β expect dominant twist-4 contribution from longitudinal γ^*

direct measurement of F_L^D would provide

- handle on diffractive gluon distribution
- information on twist-4 contamination at high β



projected errors with low-energy running

$$R^D = \frac{F_L^D}{F_2^D - F_L^D}$$

M Kapishin (this meeting)

left: 10 pb^{-1} at $E_p = 500$ GeV and 50 pb^{-1} at $E_p = 820$ GeV
right: 50 pb^{-1} at $E_p = 500$ GeV and 250 pb^{-1} at $E_p = 820$ GeV
cuts $Q^2 \geq 5$ GeV^2, $x_{I\!P} \leq 0.01$

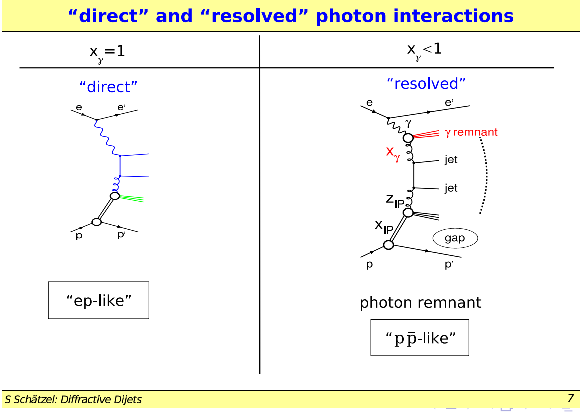
Survival probability at HERA

factorization breaking also expected in γp

$\rightarrow$ can test at HERA alone

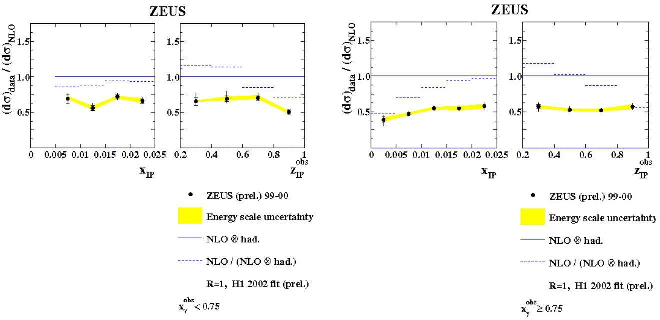
avoid extrapolation of diffractive PDFs to Tevatron kinematics

A Bruni, M Klasen, A Mastroberardino, S Schätzel, F-P Schilling



Ratio data / NLO (unsuppressed)

Resolved $x_\gamma < 0.75$ | Direct $x_\gamma > 0.75$



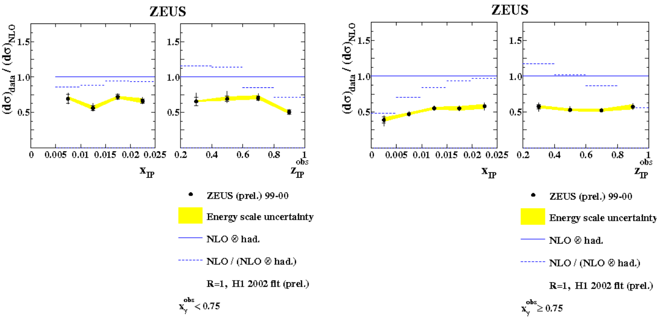
- Photon PDF uncertainties at high E_T, η^{jet}
- Data lower by a factor ~ 0.5 vs NLO QCD model

1

- for resolved photon suppression, as expected
- suppression also seen for $x_\gamma \to 1$, not understood

Ratio data / NLO (unsuppressed)

Resolved $x_\gamma < 0.75$ Direct $x_\gamma > 0.75$

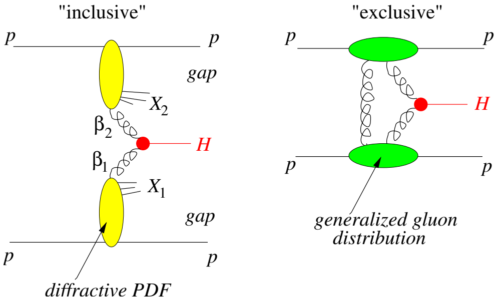


- Photon PDF uncertainties at high E_T, η^{jet}
- Data lower by a factor ~ 0.5 vs NLO QCD model

1

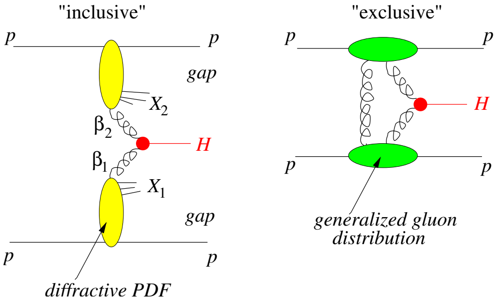
- found by both H1 and ZEUS
- further studies may help clarify:
  ratios diffractive/nondiffractive, diffractive $\bar{c}c$, leading baryons
  → A Kaidalov, this meeting

Non-exclusive background



- "inclusive" diffractive events become background to "exclusive" ones when remnant systems $X_{1,2}$ become soft
- relevant region for diffractive PDFs: $\beta_{1,2} \to 1$ and $Q^2_{1,2} \sim M^2_H$

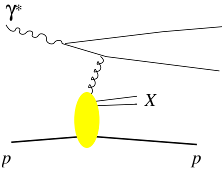
Non-exclusive background

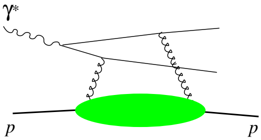


- for “exclusive” mechanism $b\bar{b}$ is suppressed compared with H, but not for “inclusive” one
  $\longrightarrow$ potentially dangerous background
  affects Higgs mass measurement, J^{PC} filtering

further studies:

- inclusive vs. exclusive dijets in pp or $p\bar{p}$ (Tevatron run II)
  jet finding algorithms → A Pilkington (Jun)
- possibility at HERA: inclusive vs. exclusive diffractive dijets





ongoing studies

QCD of high parton densities

Some (almost) trivialities:

In high-energy collisions multiple interactions are generally present

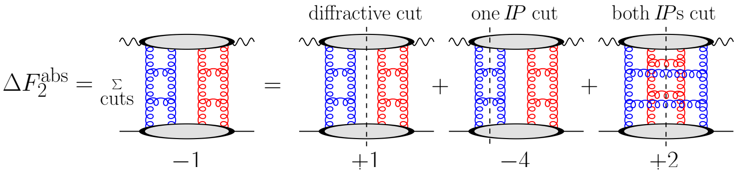
- modify event characteristics compared to single hard scattering → underlying event   Summary talk L Lönnblad
- effects cancel in sufficiently inclusive observables (rapidity gaps in pp not "sufficiently inclusive") if hard scale large enough
  - underlies leading-twist factorization
- "large enough" becomes more demanding at smaller x
  - breakdown of leading-twist factorization, parton saturation at high energies

Phenomena are related

- absorptive corrections to inclusive observables
- multiple interactions in single event
- rapidity gap events

can be generated by same diagrams, cut in different ways
$\rightarrow$ constraints for theory and modeling

absorptive corrections (to exchange of 1 gluon ladder) in $\gamma^* p$



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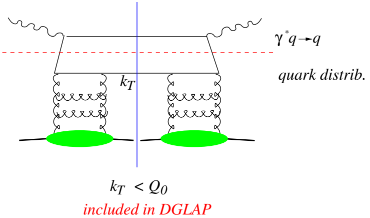
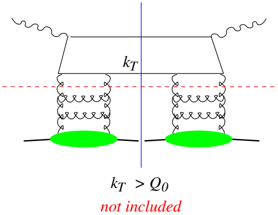
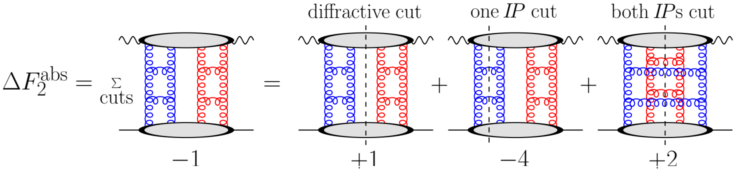




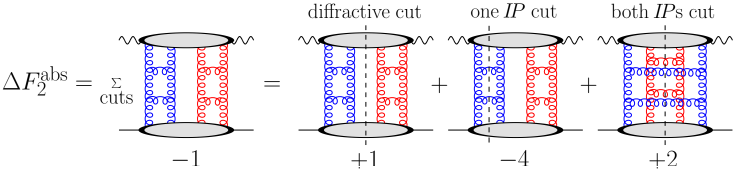
→ extraction of gluon density at low x and moderate Q^2

G Watt (Jun, Jan)



AGK (Abramovsky, Gribov, Kancheli) cutting rules
give relative weights of different cuts

- original rules modified in QCD J Bartels, A Sabio-Vera
  "two gluons=pomeron" too simple
- essential input: coupling of gluons to projectile
  can calculate for γ^*
  for p must model/extract from data



AGK (Abramovsky, Gribov, Kancheli) cutting rules
give relative weights of different cuts

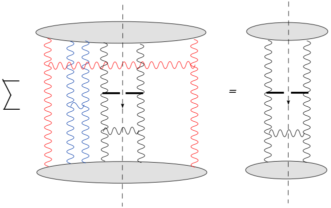
- numerical study in dipole model H Kowalski (Jun)
  simultaneously good description of inclusive and diffract. DIS
  F Eisele (plenary talk)

  → substantial fraction of multiple interactions at moderate Q^2

  at $Q^2 = 4$ GeV^2: $\sim \frac{3}{4}$ of events with 1 cut ladder
  $\sim \frac{1}{8}$ with ≥ 2 cut ladders
  $\sim \frac{1}{8}$ with no cut ladder (diffractive)

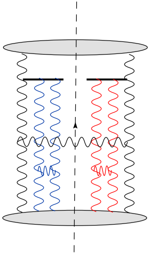
applications in pp scattering

J Bartels, this meeting



interactions between colliding protons cancel in 1-jet inclusive cross section (as in collinear factorization)

but still have interactions between jet and one proton



- more complicated results for 2-jet inclusive cross section first results obtained, but much theory remains to be worked out

perspectives:

- relations between different cuts (i.e. different observables)
- experimental information on final states
  $\rightsquigarrow$ information on absorptive corrections
- make contact with “DGLAP based approach” to multiple scattering as e.g. implemented in Pythia, Herwig
  $\rightarrow$ implement theory constraints in models/event generators
- theory of gap survival probability
- ep as “testing ground” for more complicated pp case

Nonlinear effects: from ep to pp

Theoretical framework for scattering at high parton densities:
color glass condensate → R Venugopalan (this meeting)

- strong nonlinear effects for processes with hardness $k_T < Q_s$
  saturation scale $Q_s(x)$ grows when x decreases
- in low-density limit recover standard BFKL, k_T factorization

Nonlinear effects: from ep to pp

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- strong nonlinear effects for processes with hardness $k_T < Q_s$
  saturation scale $Q_s(x)$ grows when x decreases
- recover color dipole formulation for DIS and ep diffraction
  same dipole cross section also appears in forward Drell-Yan production → J Raufeisen (Nov)
- dipole cross section not sufficient input for more complicated final states in pp collisions
  need more complicated gluon correlation functions
  color dipoles → color "multipoles"
  possibly can constrain with suitable diffractive final states (work in progress)

Conclusions

- To realize physics potential of diffractive Higgs production
  • optimize detectors/triggers • control backgrounds
  input from HERA:
  - generalized gluon distribution
  - diffractive parton distributions
  - rapidity gap survival (HERA→Tevatron and HERA→HERA)
- multiple interactions, absorptive corrections, rapidity gaps
  - become important at high energies and moderate scales
  - are interrelated
  - of fundamental and of practical interest
    e.g.: extraction of gluon density from $F_2(x_B, Q^2)$
- theoretical tools available

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- theoretical tools available
  but much remains to be done for theory and measurement

Special Thanks

- to my co-convenors
- to all those who have contributed to our working group
- to J Bartels, A Bruni, X Janssen, M Kapishin, A Mastroberardino, L Motyka, P Newman, T Teubner, R Venugopalan, G Watt for valuable input to this summary talk