Exclusive hard processes as the way to study transverse structure of the parton distribution in nuclei was reviewed by M. Diehl

Collinear factorization (not limited to small $x$)

- large $Q^2$ limit
- large $Q^2$ limit
- symmetric dipoles $\rightarrow$ small $r$
  $\rightarrow$ gluon distribution
  $xg(x, Q^2) = \int_0^{Q^2} dt^2 f(x, t^2)/t^2$
- asymmetric dipoles ($z \rightarrow 0$)
  $\rightarrow$ quark distribution

The $t$ dependence: measurements

- $\rho$ and $\phi$: $\gamma^* \rightarrow q\bar{q}$ “pointlike” for large $Q^2$
  smaller $Q^2$: $q\bar{q}$ dipole size contributes to $B$
  $\leftrightarrow$ large power corrections to collin. approx.
- $J/\Psi$: $\gamma \rightarrow c\bar{c}$ “pointlike” even for $Q^2 = 0$
From early studies - factorization theorem for exclusive processes has large higher twist corrections due to small but not negligible size of the quark antiquark pair - dipole model:

$$A_{\gamma^*+N\to V+N} \propto \int d^2d\psi_{\gamma^*}(z, b)\sigma_{q\bar{q}N}(d)\psi^*_{V}(z, b)$$

**HERA observes onset of the universal regime**

Curves are based on the model of Frankfurt, Koepf Strikman 97

H. Kowalski presented the dipole model which allows to fit simultaneously DIS data and vector meson production data.
Transverse distribution of gluons can be extracted from $\gamma + p \rightarrow J/\psi + N$.

HERA for the first time provided information about transverse size of the gluons distribution in a nucleon at small $x$ - it is smaller or comparable to e.m. size depending on $x$. 
Practical applications:

- Gap survival probability for Higgs production at LHC
  
  Talks of C. Hyde-Wright & A. Martin will discuss later

- Strong enhancement of the central impact parameters in \( pp \) collisions LHC with production of heavy particles.

- \( t \)-slope indicator of whether interaction of small dipoles dominate in the process

Need for better exclusive data for \( 0.05 > x > 0.01 \): low energy HERA run, recoil detector of COMPASS - F.H. Heinsius
Inelastic diffraction was discussed in the talks of E.Jancu & C.Marquet, H.Kowalski and G.Watt. Main issues - interplay of perturbative and nonperturbative dynamics of diffraction, effects of the approach to the black disk limit of the maximal strength of interaction

**soft mechanism**

energy dependence, t-slope as for soft diffraction

**hard mechanism** based on BFKL ladder applied at $x \leq 10^{-2}$

energy dependence, t-slope as for “$J/\psi$”-like exclusive production; increase of the energy dependence with $Q^2$
\( Q^2 \) dependence of effective Pomeron intercept

Previous data

P. Newman for H1

\( \alpha_{IP}(0) \) does not depend on \( Q^2 \) and close to soft value. Similar result from ZEUS

t-slope also close to the soft value - similar conclusion from CDF - M. Gallinaro. Much larger than for \( J/\psi \)
Current data seem to indicate that perturbative contribution is rather small.

In the presented saturation models dipoles sizes for which interaction is close to black dominate in diffraction. Numerical results correspond to dominance of sizes \( d \sim r_{\text{pion}} \) for \( x \sim 10^{-3} \) with \( d \) decreasing by a factor of \( \sim 0.7 \) for \( x \sim 10^{-4} \) - discussed scenario assumes that cross section becomes constant for large \( d \) and large \( s \), for HERA kinematics actually does not require BFKL.

How to test? Should lead to change of dependence of the cross section at small 

\[
\beta = \frac{x}{x_{IP}}
\]

Go to much smaller \( x \) - black spots, fluctuations,... multiple BFKL ladders, nonlinear evolution - E.lancu & C.Marquet
Diffraction lives after HERA

Hard diffraction at LHC - main focus of discussions production Higgs, WW,... at central rapidities

Experimental talks - C. Royon, J. Whitmore, B. Cox, M. Ruspa - reviewed by J. Whitmore at previous session -

Consensus: doable up to high luminosities, many interesting processes, Tevatron provides first hints that the cross section is of the order of magnitude predicted by the models.

C. Royon: first tests of dynamics of inclusive hard central diffraction at D0 using two Roman pot detectors -- will measure angular correlations of proton and antiproton.
C. Hyde-Wright - main focus - how to study transverse structure of nucleon exclusive hard diffraction via angular distribution of protons. Suggested asymmetry observable for study of $\alpha'$ effects.

Rapidity Dependence

- Rapidity $y$ of Higgs
  - $\xi_0 = [\xi_1 \xi_2]^{1/2} = M_H/\sqrt{s}$
  - $\xi_{1,2} = \xi_0 e^{\pm y}$
  - $B_g(\xi_{1,2}) \approx B_g(\xi_0) + \alpha_g' \ln[\xi_{1,2}/\xi_0]$
  - $B_g(\xi_{1,2}) \approx B_g(\xi_0) \pm y\alpha_g'$
- Forward backward asymmetry depends only on $\alpha_g'$

$$A = \frac{d\sigma(\xi_1, \xi_2) - d\sigma(\xi_2, \xi_1)}{d\sigma(\xi_1, \xi_2) + d\sigma(\xi_2, \xi_1)}$$

$$\propto y\alpha_g'$$

$r = (p_3 - p_4)$

$P = (p_3 + p_4)/2$
C.Hyde-Wright  Gap survival for Higgs: $P \approx 0.03$ if no correlations between soft and hard partons, correlations --> decrease of $P$.

A.Martin: $P \approx 0.026$ based on a different model (enhanced eikonal with different slope of the gluon form factor)

Bartels et al - large suppression due to A.M. - correction is less than 10%
Tevatron can check exclusive Higgs prod. formalism

Measure exclusive dijet and $\gamma\gamma$ cross sections to calibrate predictions for exclusive Higgs production at the LHC
\[ p\bar{p} \rightarrow p + \gamma \gamma + \bar{p} \]

KMR+Stirling
What is UPC? Collisions of nuclei (pA) at impact parameters \( b \geq 2R_A \) where strong interaction between colliding particles is negligible.

Trigger: One or both nuclei remain intact.

First data from RHIC on UPC production of \( \rho \)'s and \( J/\psi \)'s - Talk by M. Chiu

Counting rates are large up to

\[
S_{\gamma f}^A(LHC) \sim (1\text{TeV})^2, \sim 10s_{max}, \ HERA(\gamma p)
\]
Small $x$ physics with protons and nuclei in **a factor of ten** larger energy range though at higher virtualities both in inclusive and diffractive channels.

Diffraction off nuclei down to $x=10^{-4}$ at $Q^2 = 50$ GeV$^2$ - expectation

$\sigma_{\text{diff}}/\sigma_{\text{tot}} \geq 0.2$ (Guzey and MS)

Interaction of small dipoles at ultrahigh energies - approach to regime of black disk limit, color opacity.
**Pomeron Trajectory**

\[ \frac{d\sigma}{dt} \mid \gamma+p \rightarrow \rho+p = f(t) \left( \frac{s}{s_0} \right)^{2\alpha(t) - 2} \]

Is effective soft Pomeron trajectory nonlinear?

\[ \alpha_P(t) = (1.093 \pm 0.003 \pm 0.008) + (0.116 \pm 0.027 \pm 0.036) \text{GeV}^{-2} \cdot t \]

\( \alpha' \) is the measure of diffusion in the transverse space - universal in the Pomeron picture. However current wisdom that it that \( \alpha' = 0.25 \text{ GeV}^{-2} \) for pp case - how well we know \( \alpha'_{pp} \) for \(-t > 0.2 \text{ GeV}^2 \) ??

**Hard Pomeron - from J/psi production DIS05**

\[ \alpha_{IP} = (1.200 \pm 0.009) + (0.115 \pm 0.018)t \]

ZEUS photoproduction

\( (1.224 \pm 0.010 \pm 0.012) + (0.164 \pm 0.028 \pm 0.030) \text{GeV}^{-2}t \)

\( \alpha_{IP} = (1.20 \pm 0.03) + (0.07 \pm 0.05)t \)

ZEUS electroproduction

\( (1.183 \pm 0.054 \pm 0.030) + (0.019 \pm 0.139 \pm 0.076) \text{GeV}^{-2}t \)
Interesting test of the Regge factorization (no reason to be valid in the hard regime)

\[
\frac{d\sigma_{\text{inel diff}}(h+p\to X+p)}{dt} \bigg|_{t=0} = \frac{d\sigma_{\text{el diff}}(h+p\to h+p)}{dt} \bigg|_{t=0} = f(s)
\]

independent of h. Interestingly I find that the $\rho$-meson photoproduction data give similar value of f(s) as pp data with f(s) decreasing with increase of s. What is f(s) for $J/\psi$ production, for DVCS, ...? May help to separate hard and soft dynamics.