



# Exclusive reactions with photons

## A powerful probe of the hadronic structure

Photon 2007 - LA SORBONNE

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# Exclusive reactions

Why exclusive reactions ?

Which exclusive reactions ?

Present and Future

The aim of this physics is

## TO UNDERSTAND THE CONFINEMENT DYNAMICS

→ What is the proton made of? and HOW?  
related and often easier : → What is a meson ...

We know that quarks and gluons are the basic fields  
A large scale  $Q^2$  is necessary

To be sensitive to specific hadronic states properties  
either average over everything else → totally inclusive  
or select a specific channel → exclusive

# Factorization of Hard Exclusive processes

- DIS : INCLUSIVE / Large vs Short distance

Structure Function = Pert. Coef. Funct.  $\times$  Parton distributions

- DVCS : EXCLUSIVE  $\gamma^* N \rightarrow \gamma N'$

Amplitude = Pert. Coef. Funct.  $\times$  Generalized Parton Distributions

- $\gamma^* \gamma \rightarrow M_1 M_2$  near threshold

Amplitude = Pert. Coef. Funct.  $\times$  Generalized Distribution Amplitude

## Successes of Factorized framework

- Consistent picture in QCD

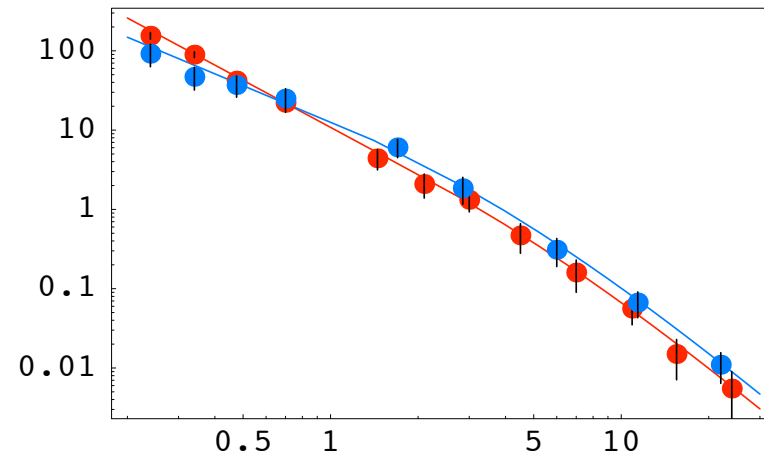
### Evolution DGLAP and ERBL Equations

- **Scaling**, e.g.

handbag dominance  $\equiv$  (generalized) Bjorken scaling

# When do we access the factorization regime ?

- LEP2 data : EARLY SCALING



$Q^2$  dependence of  $\gamma^*\gamma \rightarrow \rho^+\rho^-$  and  $\gamma^*\gamma \rightarrow \rho^0\rho^0$

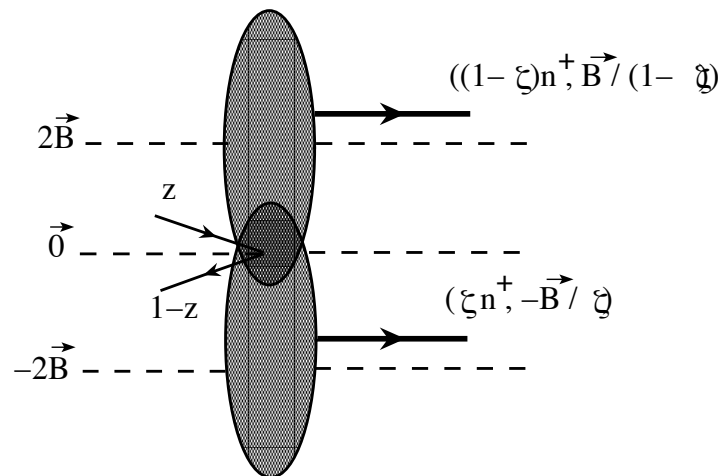
# Impact picture Representation

- $t$  dependence of GPDs maps transverse position of quarks in proton.

Fourier transform GPD at zero skewedness  $q(x, b_T) = (2\pi)^{-2} \int d^2\Delta e^{i\Delta \cdot b} H(x, \xi = 0, t)$

Generalize at  $\xi \neq 0 \rightarrow$  **Quantum femtophotography.**

- $W^2$  dependence of  $\gamma^* \gamma \rightarrow M_1 M_2$  maps impact representation of hadronization.



# Gauge invariance and exclusive processes

- Gauge inv. may be in apparent conflict with Factorization  
**1st example : dVCS on the photon**

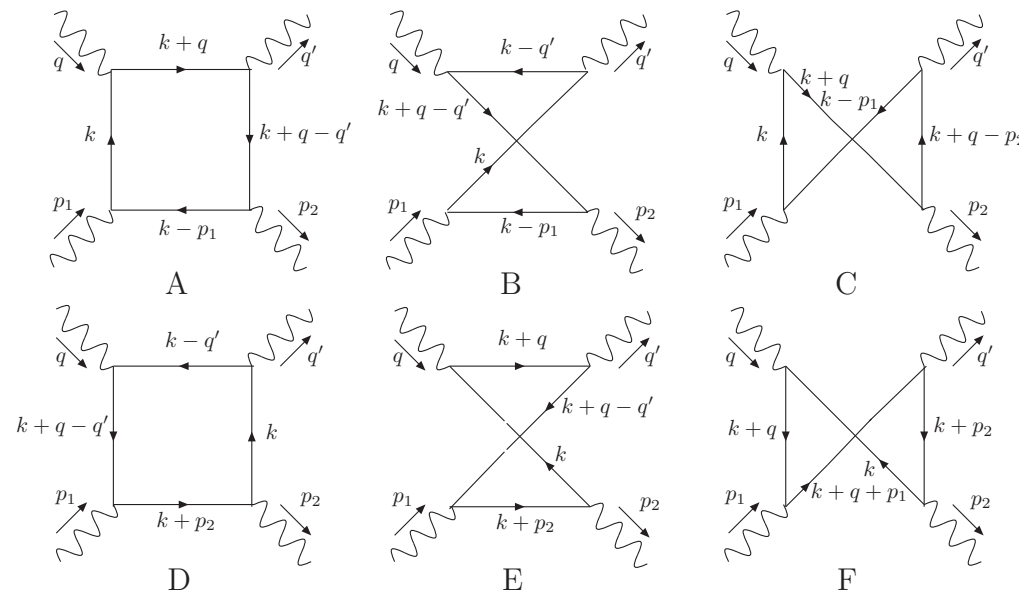


Figure 1: The Born order diagrams for  $\gamma^* \gamma \rightarrow \gamma \gamma$

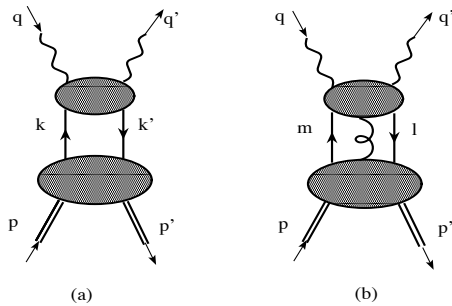
**ALL** diagrams needed for Gauge inv. Where is Factorization/handbag dominance? (cf. **S. Friot's presentation**)



# Gauge invariance

## 2nd example : dVCS on the pion

Gauge inv. requires to **add twist 3** part to the leading amplitude



$$T_{\mu\nu} = -\frac{1}{2P \cdot Q} \int dx \left( \frac{1}{x - \xi + i\epsilon} + \frac{1}{x + \xi - i\epsilon} \right) \mathcal{T}_{\mu\nu},$$

$$\begin{aligned} T_{\mu\nu} = & H_1(x) \left( -2\xi P_\mu P_\nu - P_\mu Q_\nu - P_\nu Q_\mu + \right. \\ & \left. g_{\mu\nu}(P \cdot Q) - \frac{1}{2} P_\mu \Delta_\nu^T + \frac{1}{2} P_\nu \Delta_\mu^T \right) - \\ & H_3(x) \left( \xi P_\nu \Delta_\mu^T + 3\xi P_\mu \Delta_\nu^T + \Delta_\mu^T Q_\nu + \Delta_\nu^T Q_\mu \right) + \\ & \frac{\xi}{x} H_A(x) \left( 3\xi P_\mu \Delta_\nu^T - \xi P_\nu \Delta_\mu^T - \Delta_\mu^T Q_\nu + \Delta_\nu^T Q_\mu \right). \end{aligned}$$

## Present and Future

- Nice results from BELLE, HERA, HERMES, JLAB ...

→ In this session

- future EXPERIMENTAL POSSIBILITIES  
→ medium energy AND large luminosities !

super BELLE , Jlab 6 GeV → 12 GeV

→ Very large energy ?

ILC , PLC + Ultraperipheral collisions at LHC

→ Many related presentations in other sessions  
Have a nice session !