Transverse momentum dependent parton distributions in semi-inclusive DIS

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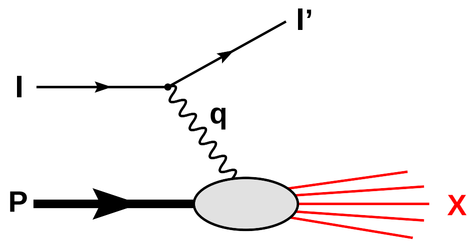
Hadronic hard processes

Strategy of perturbative QCD:

- Reduce complicated hadronic interactions to elementary partonic interactions.
- "Hard" scale $\mu \gg \Lambda_{QCD} \longrightarrow$ separation into "perturbative" part and "non-pert." parts.
- Dependence on the hard scale $\longrightarrow$ evolution equations.

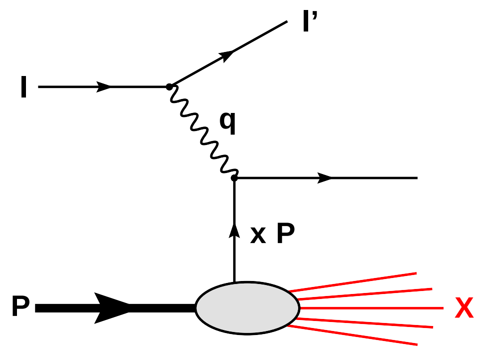
Inclusive Deep-Inelastic Scattering (DIS)

Deep-Inelast. $e^- N$ Scattering:

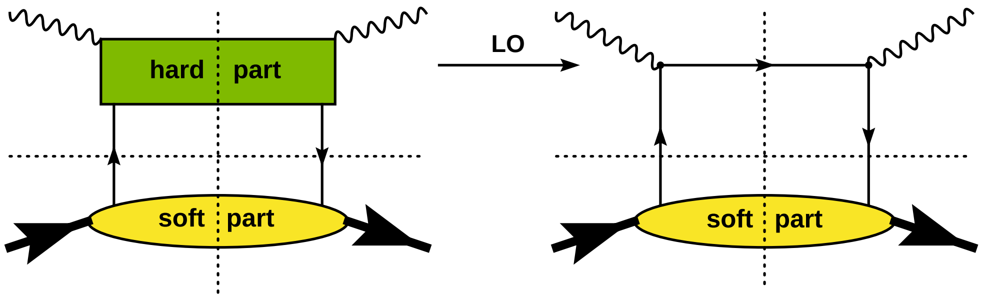


$\Longrightarrow$

DIS in the Parton Model:



Factorization of the cross section:



$$\sigma_{\text{DIS}} = (\text{hard}) \otimes (\text{soft})$$

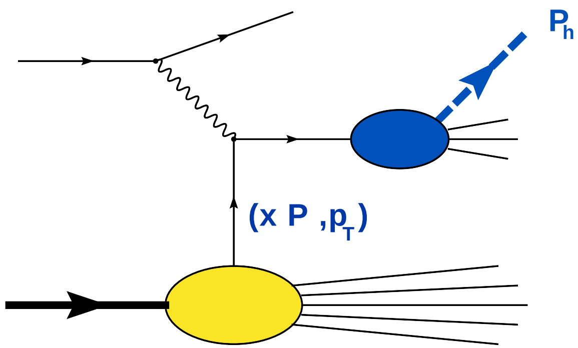
Hard part:

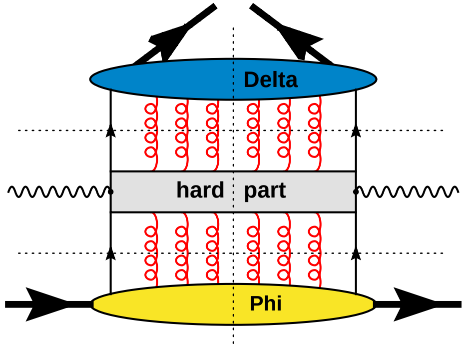
- Lepton-Parton scattering $\Longrightarrow \sigma_{\text{Parton}}$
- asymptotic freedom $\Longrightarrow$ $\alpha_s(Q)$
- perturbatively calculable.

Soft part:

- non-perturbative
  $\Longrightarrow$Experiments, Models, Lattice-QCD
- Parton Distributions: $f_1(x)$, $g_1(x)$, $h_1(x)$
- collinear picture

Semi-inclusive deep-inelastic scattering





quark-quark correlators:

$$\Phi_{ij}(x,\vec{p}_T) = \int \frac{d\xi^- d^2\vec{\xi}_T}{(2\pi)^3}\, \mathrm{e}^{ixP^+\xi^- - i\vec{p}_T\cdot\vec{\xi}_T} \langle P|\,\bar{\psi}_j(0)\,\mathcal{W}[0|\xi]\,\psi_i(\xi)\,|P\rangle\Big|_{\xi^+=0}$$

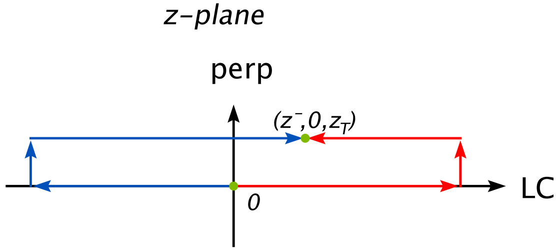
$$\Delta_{ij}(z,\vec{k}_T) = \mathcal{FT}\sum_X \langle 0|\mathcal{W}[\infty|\xi]\,\psi_i(\xi)\,|P_h;X\rangle\langle P_h;X|\,\bar{\psi}_j(0)\,\mathcal{W}[0|\infty]|0\rangle\Big|_{\xi^-=0}$$

- $\Phi \longrightarrow$ p_T-dependent parton distributions.
- $\Delta \longrightarrow$ k_T-dependent fragmentation functions.

Choice of the Wilson line: process dependent:

$$\mathcal{W}[0,x|\text{path}] = \mathscr{P}\exp\left\{-ig\int_0^x ds_\mu\, A^\mu(s)\right\}$$

SIDIS, DY: p_T-dependence



Twist-2 TMD parton distributions, parameterization, $f = f(x, \vec{p}_T^2)$

$$\mathcal{FT}\left[\langle P,S|\bar\psi\gamma^+\mathcal{W}\psi|P,S\rangle\right] = f_1 - \frac{\epsilon_T^{ij}p_T^iS_T^j}{M}\underbrace{f_{1T}^\perp}_{\text{Sivers}}$$

$$\mathcal{FT}\left[\langle P,S|\bar\psi\gamma^+\gamma_5\mathcal{W}\psi|P,S\rangle\right] = \lambda g_{1L} + \frac{\vec{p}_T\cdot\vec{S}_T}{M}g_{1T}$$

$$\mathcal{FT}\left[\langle P,S|\bar\psi i\sigma^{i+}\gamma_5\mathcal{W}\psi|P,S\rangle\right] = \underbrace{S_T^j\left(\delta^{ij}h_{1T} + \frac{p_T^ip_T^j}{M^2}h_{1T}^\perp\right)}_{\text{transversity } h_1(x,\vec{p}_T^2)} + \lambda\frac{p_T^i}{M}h_{1L}^\perp + \frac{\epsilon_T^{ij}p_T^j}{M}\underbrace{h_1^\perp}_{\text{Boer-Mulders}}$$

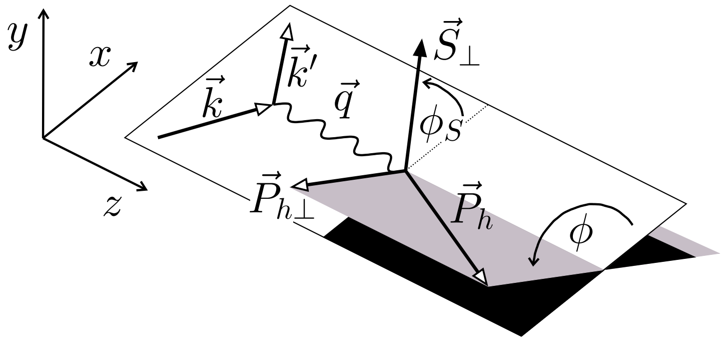
- TMD parton distributions are interpreted as *probability densities*.
- $f_{1T}^\perp$ and $h_1^\perp$ (naive) time-reversal odd (T-odd) $\longrightarrow$ Consequence of the gauge link.

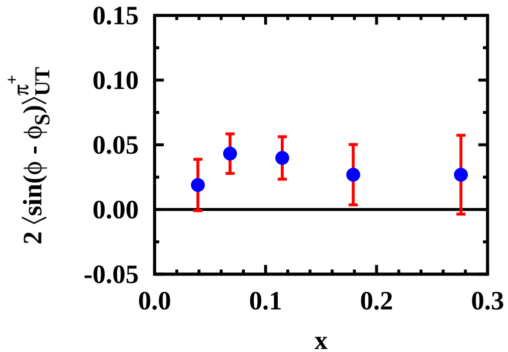
Experiments and observables in semi-inclusive DIS

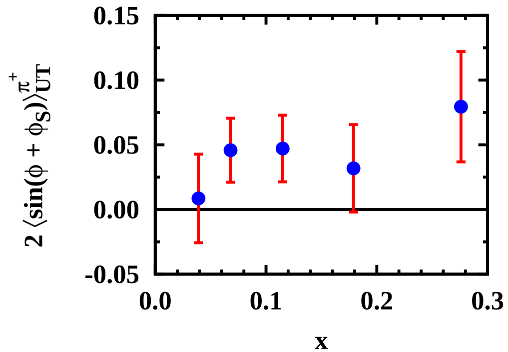
- SSA for transv. pol. target:

$$A_{UT}^{\mathrm{Sivers}} \propto \sin(\phi_h - \phi_s) f_{1T}^{\perp} \otimes D_1$$
$$A_{UT}^{\mathrm{Collins}} \propto \sin(\phi_h + \phi_s) h_1 \otimes H_1^{\perp},$$

Experiments by HERMES and COMPASS:







- SIDIS is sensitive to transversity h_1 through Collins effect! Sivers effect exist!

- Boer-Mulders-Effect: (unpolarized processes)

$$F_{UU}^{\cos(2\phi_h)} \propto \cos(2\phi_h) h_1^{\perp} \otimes H_1^{\perp}$$

also in DY: $\cos(2\phi_h)$-distribution $\propto h_1^{\perp} \otimes \bar{h}_1^{\perp}$

Own contributions

1.) Subleading twist:

- Model calculations of *longitudinal* SSA in a diquark-spectator-model.
- Classification of higher twist parton distributions $\longrightarrow$ additional T-odd PDFs.
- Tree-level formalism: Update of existing parton model descriptions.
- Model calculation of higher twist T-odd PDFs $\longrightarrow$ Modification of tree-level formalism is needed.

2.) Leading twist:

- Check of predictions in perturbative models, in particular sum rule for the Sivers-function.
- Flavor dependence of the Boer-Mulders function $h_1^\perp$ $\longrightarrow$ phenomenology for azimuthal asymmetries.