Unpolarised Azimuthal Modulation

The full cross section for the unpolarised case is written as:

Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007)

$$\frac{d\sigma}{dx\,dy\,dz\,dP_{hT}^2\,d\phi_h\,d\psi} = \left[\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\left\{1+\cos\phi_h\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\right.$$

$$A_{UU}^{x}\left(x,z,dP_{hT}^2,Q^2\right) = \frac{F_{UU}^{x}}{F_{UU,T}+\varepsilon F_{UU,L}}$$

$$\varepsilon = \frac{1-y-\frac{1}{4}y^2\gamma^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}y^2\gamma^2} \quad and \quad \gamma = \frac{2xM}{Q}$$

$$F_{UU} = C[f_1D_1] = x\sum_q e_q^2 \int d\vec{p}_\perp d\vec{k}_\perp\, \delta^2\left(z\vec{k}_\perp+\vec{p}_\perp-\vec{P}_{hT}\right) f_1^q(x,k_\perp^2,Q^2)\,D_{1,q}^h(z,p_\perp^2,Q^2)$$

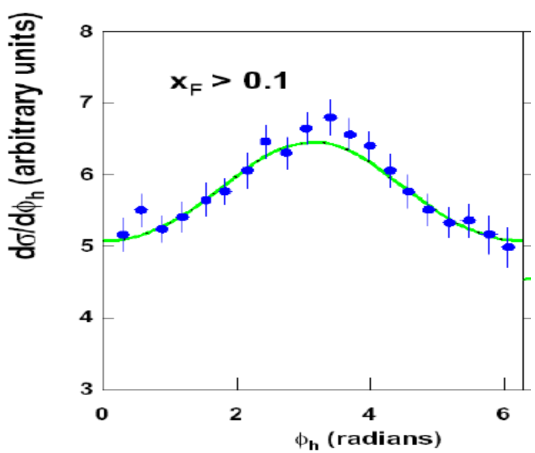
Unpolarised Azimuthal Modulation

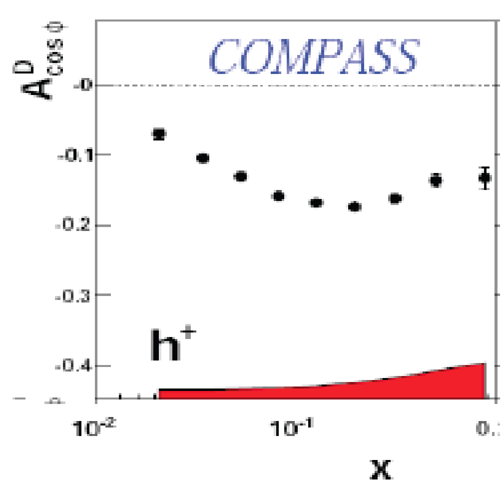
The full cross section for the unpolarised case is written as:

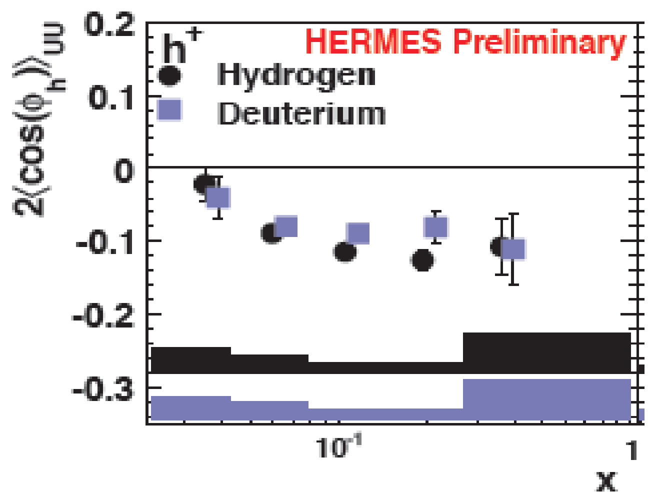
$$\frac{d\sigma}{dx\,dy\,dz\,dP_{hT}^2\,{\color{green}d\phi_h}\,d\psi}$$

Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007)

$$= \left[\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)\left\{1+{\color{red}\cos\phi_h}\sqrt{2\varepsilon(1+\varepsilon)}{\color{red}A_{UU}^{\cos\phi_h}}\right.$$







Unpolarised Azimuthal Modulation

When looking at the content of the structure functions/modulations in terms of TMD PDFs for the $\cos\phi_h$ and $\cos 2\phi_h$ we can write:

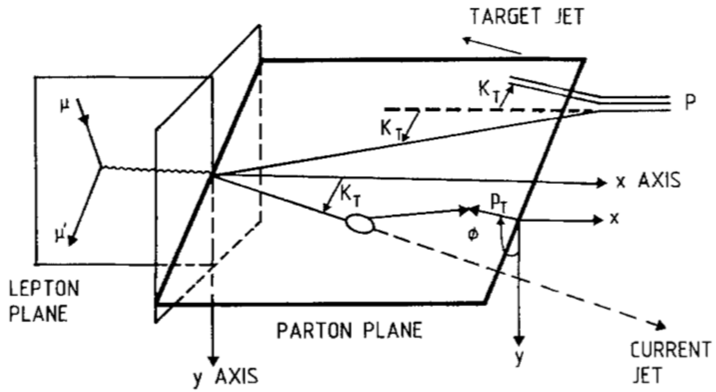
$$F_{UU}^{\cos\phi_h} = -\frac{2M}{Q} C\left[\frac{\hat{h}\cdot\vec{k}_\perp}{M} f_1 D_1 - \frac{p_\perp k_\perp}{M}\frac{\vec{P}_{hT} - z\left(\hat{h}\cdot\vec{k}_\perp\right)}{zM_h M} h_1^\perp H_1^\perp\right] + \text{twists} > 3$$

$$F_{UU}^{\cos 2\phi_h} = C\left[\frac{\left(\hat{h}\cdot\vec{k}_\perp\right)\left(\hat{h}\cdot\vec{p}_\perp\right) - \vec{p}_\perp\cdot\vec{k}_\perp}{MM_h} h_1^\perp H_1^\perp\right] + \text{twists} > 3$$

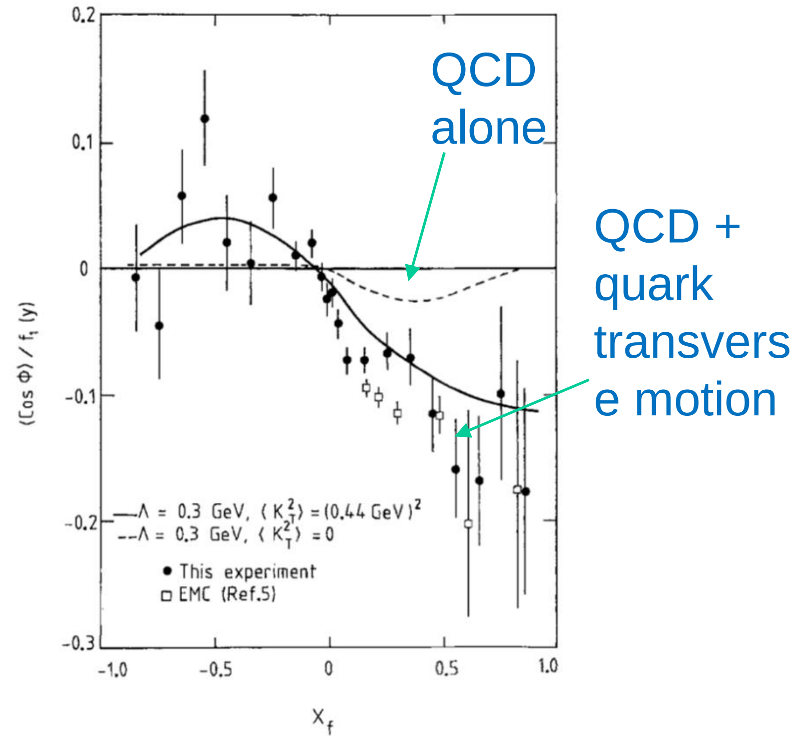
In the $\cos 2\phi_h$ Cahn effects enters only at twist4

$$F_{\text{Cahn}}^{\cos 2\phi_h} \approx \frac{2}{Q^2} C\left[\left\{2\left(\hat{h}\cdot\vec{k}_\perp\right)^2 - k_\perp^2\right\} f_1 D_1\right]$$

Partonic intrinsic transverse motion



- Cross section for SIDIS process expected to be
  $$d\sigma \sim \sigma_0[1 + A\cos\phi_h + B\cos 2\phi_h]$$
- Georgi and Politzer [1978]: azimuthal modulations of hadrons around the jet axis due to gluon radiation. Effect regarded as a clean QCD test.
- R.N. Cahn [1978]: same modulations can arise due to the quark intrinsic motion ($k_\perp$)



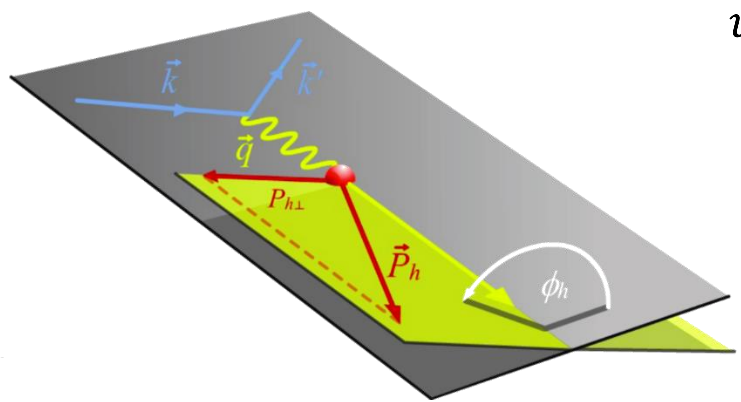
EMC experiment [1987]
Fit: Konig-Kroll model [1982] + Lund String

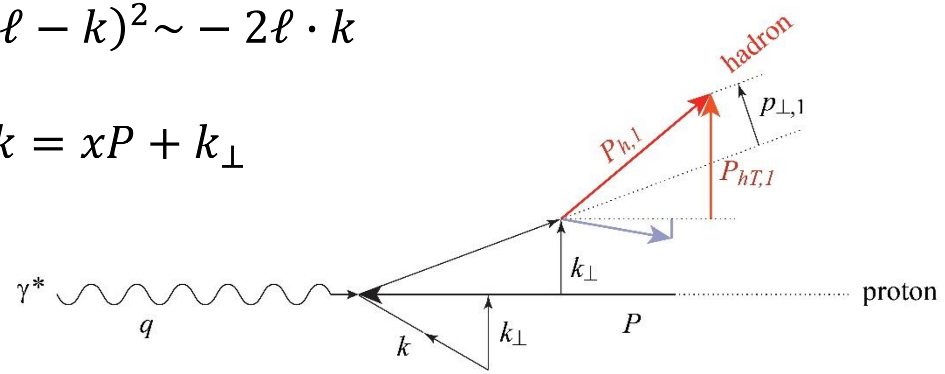
Unpolarised Azimuthal Modulation

The semi inclusive cross-section for $\ell p \to \ell' h X$ is given by $d\sigma^{\ell p \to \ell' h X} = \sum_q f_q(x, Q^2) \otimes d\sigma^{\ell q \to \ell' q} \otimes D_q^h(z, Q^2)$. The cross section for the partonic process is simply given by $d\sigma^{\ell q \to \ell' q} = \hat{s}^2 + \hat{u}^2$

$$s := (\ell + k)^2 \sim 2\ell \cdot k$$
$$u := (\ell - k)^2 \sim -2\ell \cdot k$$

$$k = xP + k_\perp$$

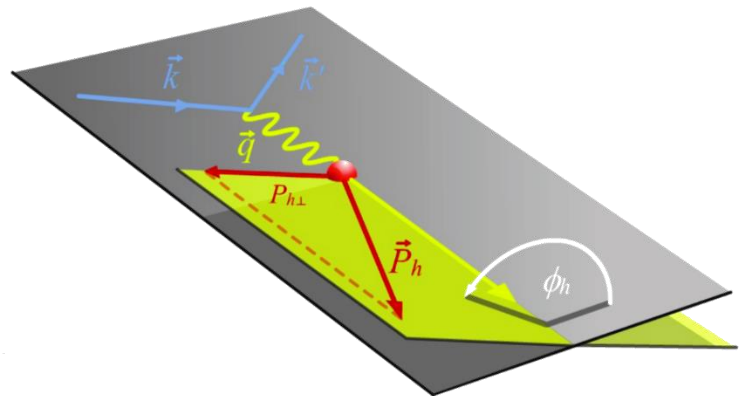




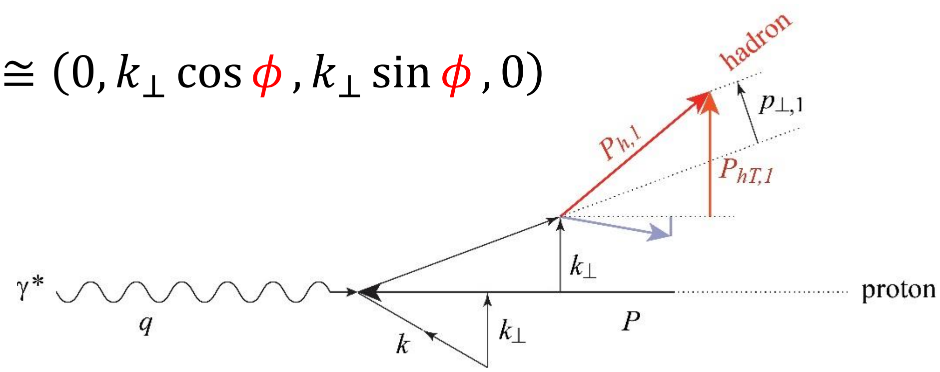
In collinear PM $d\sigma^{\ell q \to \ell' q} = \hat{s}^2 + \hat{u}^2 = x[1 + (1 - y)^2]$, i.e. no ϕ_h dependence.

Unpolarised Azimuthal Modulation

$k_\perp$ has only components outside the lepton scattering plane:



$$k_\perp \cong (0, k_\perp \cos\phi\,, k_\perp \sin\phi\,, 0)$$



Taking into account the parton transverse momentum in the kinematics leads to:

$$\hat{s} = sx\left[1 - \frac{2k_\perp}{Q}\sqrt{1-y}\cos\phi_h\right] + \mathcal{O}\left(\frac{k_\perp^2}{Q}\right) \quad \hat{u} = sx(1-y)\left[1 - \frac{2k_\perp}{Q\sqrt{1-y}}\cos\phi_h\right] + \mathcal{O}\left(\frac{k_\perp^2}{Q}\right)$$

Resulting in the $\cos\phi_h$ and $\cos 2\phi_h$ modulations observed in the azimuthal distributions