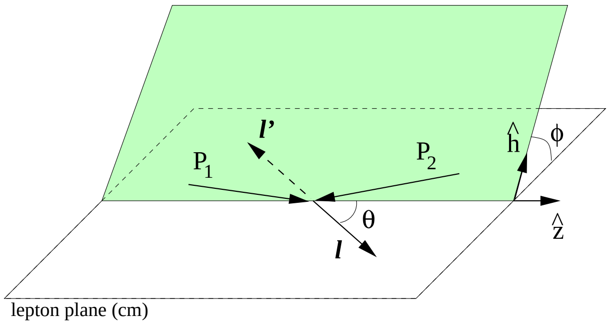
Sivers & Collins-Mulders Effect in DRELL YAN



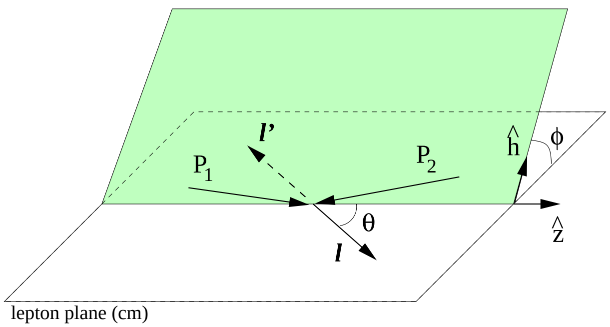
$$\bar{p} + p \to \mu^- \mu^+ + X$$

SSAs& T-odd Contribution in Drell Yan (RHIC-II, JPARC & GSI-FAIR)

$$\frac{d\Delta\sigma^{\uparrow}}{d\Omega dx_1 dx_2 d\mathbf{q}_T} \propto \sum_a e_f^2 \, |\mathbf{S}_{2_T}| \, \{ -B(y) \, \sin(\phi + \phi_{S_2}) \, \mathcal{F}\left[\hat{\mathbf{h}} \cdot \mathbf{p}_{1_T} \frac{\bar{h}_1^{\perp\, a} \, h_1^a}{M_1} \right]$$

$$+ A(y) \, \sin(\phi - \phi_{S_2}) \, \mathcal{F}\left[\hat{\mathbf{h}} \cdot \mathbf{p}_{2_T} \frac{\bar{f}_1^a \, f_{1T}^{\perp\, a}}{M_2} \right] \, \ldots \} \, ,$$

Unpolarized DRELL YAN $\cos 2\phi$



$$\bar{p} + p \to \mu^- \mu^+ + X$$

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} = \frac{3}{4\pi}\frac{1}{\lambda+3}\left(1 + \lambda\cos^2\theta + \mu\sin^2\theta\cos\phi + \frac{\nu}{2}\sin^2\theta\cos 2\phi\right) \qquad (1)$$

Angles refer to the lepton pair orientation in their rest frame relative to the boost direction and the initial hadron's plane. Asymmetry parameters, λ, μ, ν, depend on s, x, $m^2_{\mu\mu}$, q_T

Boer PRD: 1999, Boer, Brodsky, Hwang PRD: 2003 Collins SoperPRD: 1977 subleading twist

- Leading twist $\cos 2\phi$ azimuthal asymmetry depends on T-odd distribution $h_1^\perp$.

$$\nu = \frac{2\sum_a e_a^2 \mathcal{F}\left[\left(2\boldsymbol{p}_\perp\cdot\boldsymbol{k}_\perp - \boldsymbol{p}_\perp\cdot\boldsymbol{k}_\perp\right)\frac{h_1^\perp(x,\boldsymbol{k}_T)\bar{h}_1^\perp(\bar{x},\boldsymbol{p}_T)}{M_1 M_2}\right]}{\sum_{a,\bar{a}} e_a^2 \mathcal{F}[f_1\bar{f}_1]} \qquad (2)$$

Convolution integral

$$\mathcal{F} \equiv \int d^2\boldsymbol{p}_\perp d^2\boldsymbol{k}_\perp \delta^2(\boldsymbol{p}_\perp + \boldsymbol{k}_\perp - \boldsymbol{q}_\perp) f^a(x,\boldsymbol{p}_\perp)\bar{f}^a(\bar{x},\boldsymbol{k}_\perp)$$

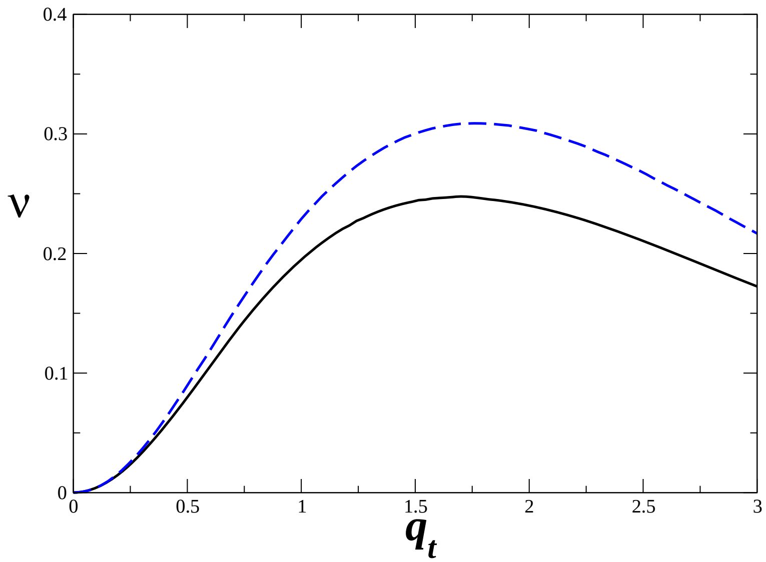
Higher twist comes

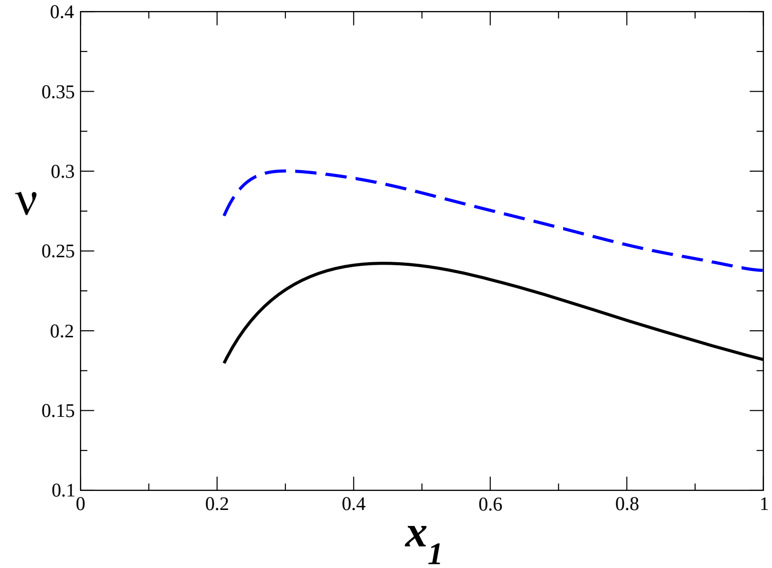
$$\nu = \frac{2\sum_a e_a^2 \mathcal{F}\left[(2\boldsymbol{p}_\perp \cdot \boldsymbol{k}_\perp - \boldsymbol{p}_\perp \cdot \boldsymbol{k}_\perp)\frac{h_1^\perp(x,\boldsymbol{k}_T^2)\bar{h}_1^\perp(\bar{x},\boldsymbol{p}_T)}{M_1 M_2}\right] + \nu_4[w_4 f_1 \bar{f}_1])}{\sum_{a,\bar{a}} e_a^2 \mathcal{F}[f_1 \bar{f}_1]}$$

where Collins Soper PRD: 1977 subleading twist

$$\nu_4 = \frac{\frac{1}{Q^2}\sum_a e_a^2 \mathcal{F}\left[w_4\, f_1(x,\boldsymbol{k}_\perp)\bar{f}_1(\bar{x},\boldsymbol{p}_\perp)\right]}{\sum_a e_a^2 \mathcal{F}\left(f_1(x,\boldsymbol{k}_\perp)\bar{f}_1(\bar{x},\boldsymbol{p}_\perp)\right)},$$

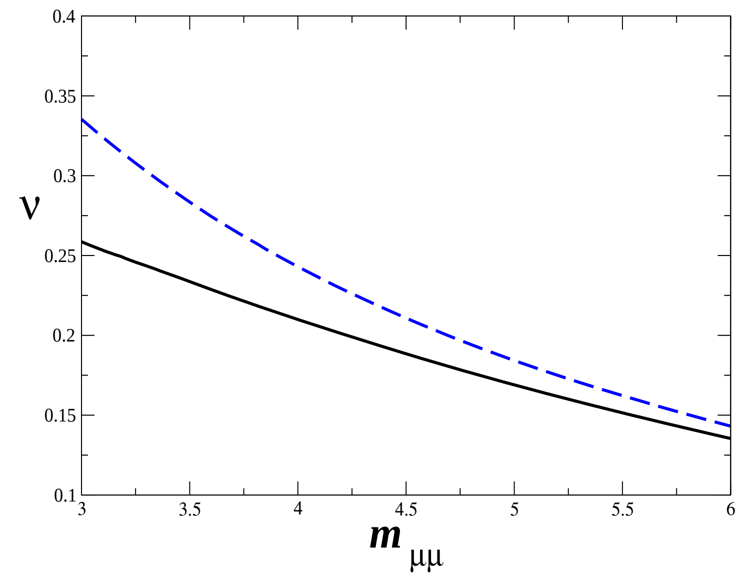
where the weight $w_4 = 2\left(\hat{\boldsymbol{h}} \cdot (\boldsymbol{k}_\perp - \boldsymbol{p}_\perp)\right)^2 - (\boldsymbol{k}_\perp - \boldsymbol{p}_\perp)^2$





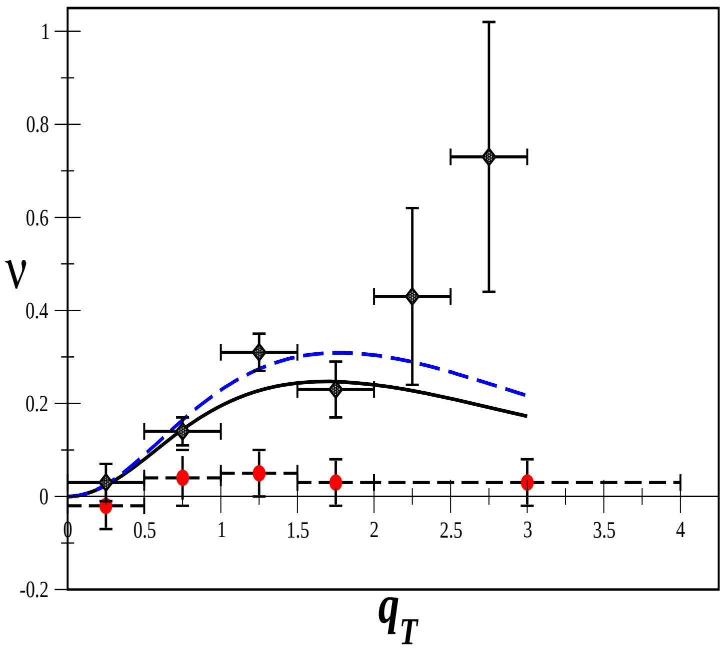
Perform Convolution integral L.G., Goldstein PLB: 2007
$s = 50\,\mathrm{GeV}^2$, $x = [0.2 - 1.0]$,
$q = [3.0 - 6.0]$ GeV, $\boldsymbol{q_T} = 0 - 2.0\,\mathrm{GeV}$

q_T^2/Q^2 corrections
$x_1 x_2 = \frac{Q^2(1+q_T^2/Q^2)}{s}$
q_T/Q can be order 0.5



Sea Quark Boer Mulders

Gamberg & Goldstein Plb 2007



- ν plotted as a function of q_T for $s = 50\ \mathrm{GeV}^2$, $x[0.2 - 1.0]$, and $Q[3 - 6]\ \mathrm{GeV}/c$. Solid line leading twist contribution ν_2, dashed line leading and sub-leading twist $(\nu_2 + \nu_4)$.
- Data: Diamonds are for E615 $\pi^- + p$ at 252 GeV/c. Circles are for E866 $p + d$ at 800 GeV/c Peng, Zu hep-ex/0609005.
- Horizontal bars refer to bin size, vertical error bars refer to statistical uncertainties.
- One of pair of structure functions in convolution involve sea anti-quarks, the $\bar{h}_1^{\perp(sea)}$ for $N \to \bar{u}$ or $\bar{d}$.
- Suppressed by another factor of α_s in our approach (as well as possible kinematic factors) w/ data suggest that sea structure BM function roughly $\frac{1}{3}$ of the magnitude of predicted valence quark structure function.