

Model calculations of the Sivers function satisfying the Burkardt Sum Rule

CLAS12 Workshop
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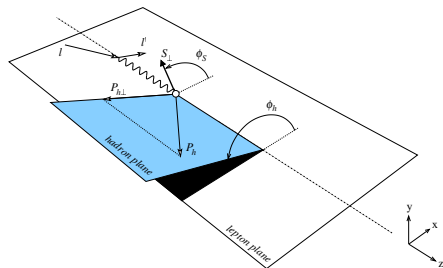
with S. Scopetta (Perugia) and V. Vento (Valencia)

27/02/09

Single Spin Asymmetries

SSA for transverse target polarization in SIDIS $\gamma^* p \rightarrow h X$

$$A(\phi_h, \phi_S) \equiv \frac{d\sigma(\phi_h, \phi_S) - d\sigma(\phi_h, \phi_S + \pi)}{d\sigma(\phi_h, \phi_S) + d\sigma(\phi_h, \phi_S + \pi)}$$



- ϕ_h = angle between **leptonic** and **hadronic** planes
- ϕ_S = angle between **leptonic** plane and **transverse spin** of the target

The number of emitted hadrons at a given ϕ_h depends on the orientation of \vec{S}_\perp , the transverse spin of the target

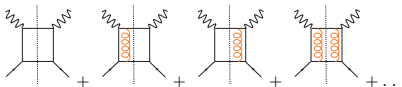
SSA due to the structure of the target \rightarrow **Sivers mechanism** (distribution functions)

Sivers Function $f_{1T}^{\perp Q}(x, k_T)$

Amplitude of modulation of the number density of **unpolarized quarks** in a **transversely polarized target**

Transverse Momentum Dependent PD \Rightarrow Correlation between the transverse spin of the target and the intrinsic transverse parton momentum

Importance of the gauge link



0th order, No gauge link $\rightarrow f_{1T}^{\perp Q}(x, k_T) = 0$

Existence of leading-twist FSI $\rightarrow f_{1T}^{\perp Q}(x, k_T) \neq 0$

Properties of the Sivers function

- From first principles: **Burkardt Sum Rule** (PRD 69 (2004) 091501)

$$\sum_{Q=q,g} \int_0^1 dx \text{ "1st moment of } f_{1T}^{\perp Q}(x, k_T)\text{"} = 0$$

- OAM, GPDs \leftrightarrow Sivers function, ...

Model Calculations with $SU(6)$ proton WF and perturbative OGE

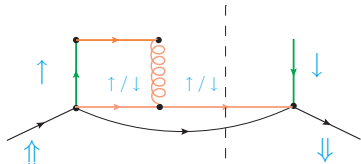
• MIT Bag Model \longrightarrow 1-body

[Yuan, PLB 575 (2003)]

- ▶ Proportionality u and d distribution
- ▶ **Large Violation** of the Burkardt SR

$$\frac{\langle k_x^u \rangle + \langle k_x^d \rangle}{\langle k_x^u \rangle - \langle k_x^d \rangle} \simeq 0.60$$

- ▶ **Only active** quark helicity-flip



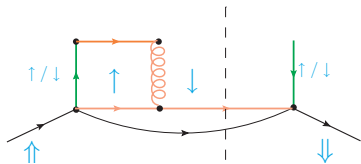
• NR Constituent Quark Model \longrightarrow 3-body

[A.C., Fratini, Scopetta and Vento, PRD 78:034002 (2008).]

- ▶ No proportionality u and d distribution
- ▶ **Small Violation** of the Burkardt SR

$$\frac{\langle k_x^u \rangle + \langle k_x^d \rangle}{\langle k_x^u \rangle - \langle k_x^d \rangle} \simeq 0.02$$

- ▶ **Both active** OR **non-active** quark helicity-flip



Model Calculations with $SU(6)$ proton WF and perturbative OGE

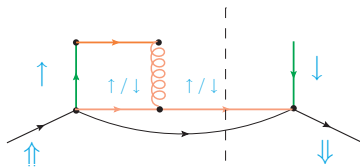
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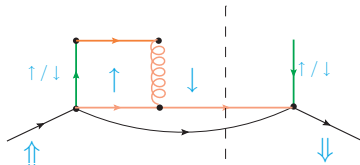
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Why such a difference between those 2 models?

Constituent Quark Model vs. MIT Bag Model

Solution

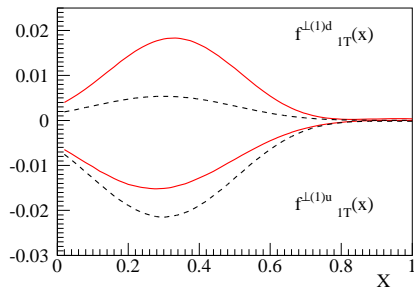
The "non-active quark" can also flip helicity in the MIT Bag Model!!!

[A. C., Scopetta & Vento, arXiv:0811.1191 [hep-ph]]

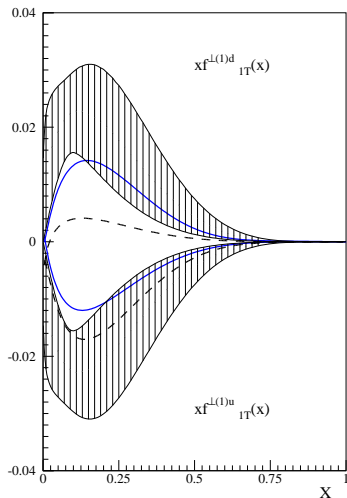
- **Before:** dashed curve
 - ▶ Missing term in the first calculation in the bag
 - ▶ Burkardt SR violated by 60%
- **After:** plain red curve
 - ▶ Helicity-flip of the "non-active quark" taken into account
 - ▶ Burkardt SR violated by 5%

The results in the MIT Bag Model fulfill the theoretical properties of the Sivers function

No proportionality between the u and d -distributions



Revised Results in the MIT Bag Model

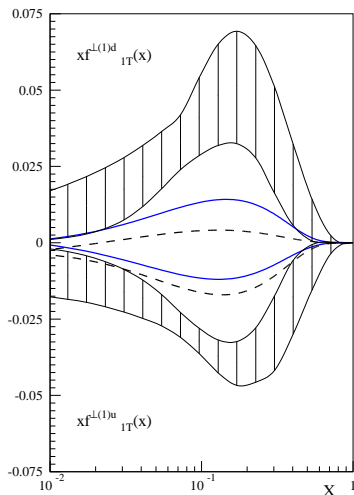


- **Shaded Area:** $1-\sigma$ region of the best fit of the Sievers function extracted from HERMES data, at $Q^2 = 2.5 \text{ GeV}^2$
[Collins et al., PRD 73 (2006) 014021]
- **Dashed Curve:** 1st result in the MIT Bag model after NLO-standard evolution
[Yuan, PLB 575 (2003)]
- **Plain blue Curve:** revised result in the MIT Bag model after NLO-standard evolution
[A. C., Scopetta & Vento, arXiv:0811.1191 [hep-ph]]

The results in the MIT Bag Model are in agreement with this extraction of the Sievers function

... up to correct Evolution of the Sievers function

Revised Results in the MIT Bag Model



- **Shaded Area:** **Sivers function extracted from HERMES and COMPASS data**
No assumption on the proportionality between the u - and d -distributions
[M. Anselmino et al., Eur. Phys. J. A39:89-100 (2009)]
- **Dashed Curve:** 1st result in the MIT Bag model after NLO-standard evolution
[Yuan, PLB 575 (2003)]
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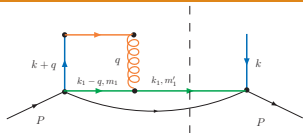
The results in the MIT Bag Model are now in a better agreement with this extraction of the Sivers function

Conclusions

- **Agreement between models**
 - ▶ More *physical* picture for **helicity-flip at the quark level**
⇒ either the *active* and *non-active* quark can flip
 - ▶ First Principles arguments ⇒ **Burkardt Sum Rule** fulfilled
- Much **better agreement** of the MIT Bag calculation with the actual **extractions**
- **... to the experiments**
 1. Need for Correct **evolution** of TMDs
 2. Relation between **GPDs in Impact Parameter Space** and **Sivers function????**
 3. **Improvement of the models** after experimental feedback

Let us know, please!

Calculation Details



$$f_{1T}^{\perp Q}(x, k_{\perp}) \propto 2\Re \left\{ \int \frac{d^2 q_{\perp}}{(2\pi)^5} \frac{i}{q^2} \sum_{\{m\}, \beta} C_{\{m\}}^{Q, \beta} \varphi_{m_1}^{\dagger}(\vec{k} - \vec{q}_{\perp}) \gamma^0 \gamma^+ \varphi_{m_2}(\vec{k}) \int \frac{d^3 k_3}{(2\pi)^3} \varphi_{m_3}^{\dagger}(\vec{k}_3) \gamma^0 \gamma^+ \varphi_{m_4}(\vec{k}_3 - \vec{q}_{\perp}) \right\}$$

$$\int \frac{d^3 k_3}{(2\pi)^3} \varphi_{m_3}^{\dagger}(\vec{k}_3) \gamma^0 \gamma^+ \varphi_{m_4}(\vec{k}_3 - \vec{q}_{\perp}) = F(\vec{q}_{\perp}) \delta_{m_3 m_4} + H(\vec{q}_{\perp}) \delta_{m_3, -m_4}$$

With the MIT Bag WF,

$$\varphi_m(\vec{k}) \propto \begin{pmatrix} t_0(|\vec{k}|) \chi_m \\ \vec{\sigma} \cdot \vec{k} t_1(|\vec{k}|) \chi_m \end{pmatrix}, \quad t_i(k) = \int_0^1 u^2 du j_i(ukR_0) j_i(u\omega)$$

$H(\vec{q}_{\perp})$ does not vanish in a basis for the gluon's momentum constrained by the DIS framework,
 \Rightarrow z-axis is the virtual photon's direction
 \Rightarrow operator structure: γ^+

Results in IK

