# ASYMMETRIES IN SEMI-INCLUSIVE DEEP INELASTIC SCATTERING

E. DI SALVO
DIPARTIMENTO DI FISICA
UNIVERSITA' DI GENOVA
INFN - SEZ. DI GENOVA

16th INTERNATIONAL SPIN PHYSICS SYMPOSIUM
TRIESTE, OCT. 14, 2004

SUMMARY

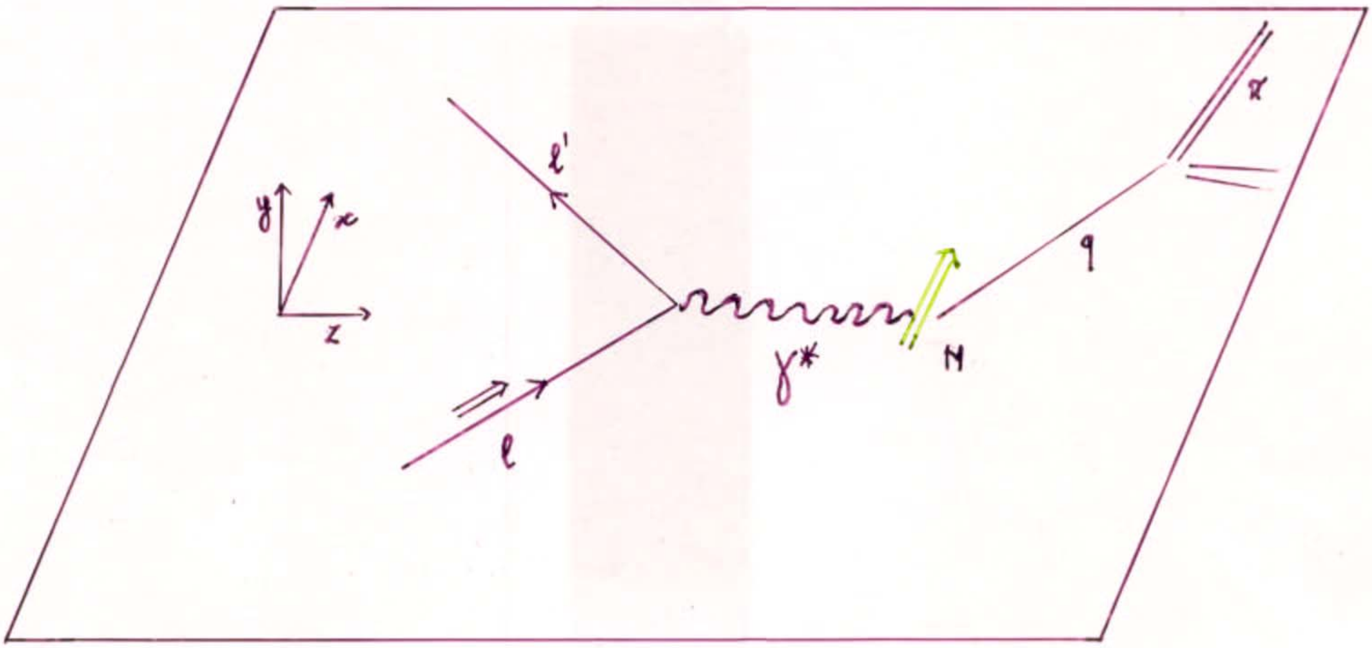
1. SIDIS CROSS SECTION
2. LEADING TWIST QCD RESULTS
3. MOMENTS
4. SYMMETRY PROPERTIES
5. NEW THEORETICAL RESULTS
6. CONCLUSION

# 1. SIDIS CROSS SECTION

$\vec{\ell}\ \vec{N} \longrightarrow \ell'\ \pi\ X$

LONGITUDINALLY POLARIZED LEPTON $\vec{\ell}$

TRANSVERSELY POLARIZED NUCLEON $\vec{N}$




## AZIMUTHAL ANGLES

LEPTON MOMENTUM $\rightarrow \boxed{\varphi_\ell}$

NUCLEON POLARIZATION $\rightarrow \varphi_{Pol}$ $\qquad \boxed{\varphi_S = \varphi_{Pol} - \varphi_\ell}$

PION MOMENTUM $\rightarrow \varphi_\pi$ $\qquad \boxed{\varphi = \varphi_\pi - \varphi_\ell}$

# SIDIS DIFFERENTIAL CROSS SECTION:

$$\frac{d\sigma}{d\Gamma} \qquad d\Gamma = \underbrace{d\Omega_{\ell'}\, dx}_{\downarrow \atop \ell'} \; \underbrace{dz\, d^2 q_\perp}_{\downarrow \atop \pi}$$

FOUR POLARIZATION COMBINATIONS:

$$\frac{d\sigma_{\rightarrow\uparrow}}{d\Gamma}, \qquad \frac{d\sigma_{\rightarrow\downarrow}}{d\Gamma}, \qquad \frac{d\sigma_{\leftarrow\uparrow}}{d\Gamma}, \qquad \frac{d\sigma_{\leftarrow\downarrow}}{d\Gamma}$$

NOTATION: $d\sigma_{AB}$

A = LEPTON POL.

B = NUCLEON POL.

MOREOVER

$$\frac{d\sigma_{\rightarrow\uparrow}}{d\Gamma} = \frac{d\sigma_{UU}}{d\Gamma} + \frac{d\sigma_{UT}}{d\Gamma} + \frac{d\sigma_{LU}}{d\Gamma} + \frac{d\sigma_{LT}}{d\Gamma}$$

U = UNPOLARIZED

L = LONG. POLARIZED (LEPTON)

T = TRANSV. POLARIZED (NUCLEON)

# 2. LEADING TWIST QCD RESULTS

MULDERS ET AL. : PHYS. REV. D **54** (1996) 1229 ; **57** (1998) 5780

$$\frac{d\sigma_{UU}}{d\Gamma} = A_{SYM} + A_{ANIS}\cos 2\varphi + O(q/Q)$$

$$\frac{d\sigma_{UT}}{d\Gamma} = B_{COL}\sin(\varphi+\varphi_S) + B_{SIV}\sin(\varphi-\varphi_S) + $$

$$+ B_{\perp}\sin(3\varphi-\varphi_S) + B_{\parallel}\sin 2\varphi\cos\varphi_S + O(q/Q)$$

$$\frac{d\sigma_{LU}}{d\Gamma} = O(q/Q)$$

$$\frac{d\sigma_{LT}}{d\Gamma} = C_{\parallel}\cos\varphi_S + C_{\perp}\cos(\varphi-\varphi_S) + O(q/Q)$$

$$\boxed{A_{SYM} \propto f_1 \otimes D}$$

$$\boxed{A_{ANIS} \propto \frac{\vec{q}_\perp^{\,2}}{\mu_N \mu_\pi} h_1^\perp \otimes H_1^\perp \otimes w_A}$$

$$\boxed{B_{col} \propto \frac{|\vec{q}_\perp|}{\mu_\pi} h_{1T} \otimes H_1^\perp \otimes w_{col}}$$

$$\boxed{B_{siv} \propto \frac{|\vec{q}_\perp|}{\mu_N} f_1^\perp \otimes D \otimes w_{siv}}$$

$$\boxed{B_\perp \propto \frac{|\vec{q}_\perp|^3}{\mu_N^2 \mu_\pi} h_{1L}^\perp \otimes H_1^\perp \otimes w_{B_\perp}}$$

$$\boxed{B_\parallel \propto \frac{M_N \vec{q}_\perp^{\,2}}{Q \mu_N \mu_\pi} h_{1L}^\perp \otimes H_1^\perp \otimes w_{B_\parallel}}$$

$$\boxed{C_\parallel \propto \frac{M_N}{Q} g_{1L} \otimes D}$$

$$\boxed{C_\perp \propto \frac{|\vec{q}_\perp|}{\mu_N} g_{1T} \otimes D \otimes w_{C_\perp}}$$

# 3. MOMENTS

## FOURIER COMPONENTS

MULDERS ET AL.:
NUCL. PHYS. B 564 (2000) 471

WEIGHT FUNCTIONS:

$$\langle W \rangle_{\rightarrow\uparrow} = \int \frac{d\sigma_{\rightarrow\uparrow}}{d\Gamma} \, W \, d\vec{q}_\perp^{\,2} \, d\varphi \, d\varphi_s$$

$$\left\langle \frac{\vec{q}_\perp^{\,2}}{M_N m_\pi} \cos 2\varphi \right\rangle_{\rightarrow\uparrow} \propto \frac{M_N m_\pi}{\mu_N \mu_\pi} h_1^{\perp(1)}(x) \, H_1^{\perp(1)}(z)$$

$$h_1^{\perp(1)}(x) = \int d^2p_\perp \, \frac{\vec{p}_\perp^{\,2}}{2M_N^2} \, h_1^\perp(x, \vec{p}_\perp^{\,2})$$

$$\left\langle \frac{|\vec{q}_\perp|}{m_\pi} \sin(\varphi + \varphi_s) \right\rangle_{\rightarrow\uparrow} \propto \frac{m_\pi}{\mu_\pi} h_1(x) \, H_1^{\perp(1)}(z)$$

$$\left\langle \frac{|\vec{q}_\perp|}{M_N} \sin(\varphi - \varphi_s) \right\rangle_{\rightarrow\uparrow} \propto \frac{M_N}{\mu_N} f_1^{\perp(1)}(x) \, D(z)$$

$$\left\langle \frac{|\vec{q}_\perp|}{M_N} \cos(\varphi - \varphi_s) \right\rangle_{\rightarrow\uparrow} \propto \frac{M_N}{\mu_N} g_{1T}^{(1)}(x) \, D(z)$$

IN PRINCIPLE: INFORMATION MAY BE INFERRED FROM $d\sigma_{\rightarrow\uparrow}$

HOWEVER: **BIASES:**

- FICTITIOUS ASYMMETRIES FROM EXPERIMENTAL SETUP
- FINITE STATISTICS → OVERLAPS IN F. C.

1st IMPROVEMENT:

$$4\,\frac{d\sigma_{UU}}{d\Gamma} = \frac{d\sigma_{\rightarrow\uparrow}}{d\Gamma} + \frac{d\sigma_{\leftarrow\uparrow}}{d\Gamma} + \frac{d\sigma_{\rightarrow\downarrow}}{d\Gamma} + \frac{d\sigma_{\leftarrow\downarrow}}{d\Gamma}$$

$$4\,\frac{d\sigma_{UT}}{d\Gamma} = \frac{d\sigma_{\rightarrow\uparrow}}{d\Gamma} + \frac{d\sigma_{\leftarrow\uparrow}}{d\Gamma} - \frac{d\sigma_{\rightarrow\downarrow}}{d\Gamma} - \frac{d\sigma_{\leftarrow\downarrow}}{d\Gamma}$$

. . . . . . . . . . . . . . . . . . . . .

$$\left\langle \frac{|\vec{q}_\perp|}{m_\pi} \sin(\varphi+\varphi_S) \right\rangle_{UT} \propto \frac{m_\pi}{\mu_\pi}\, h_1(x)\, H_1^{\perp(1)}(z)$$

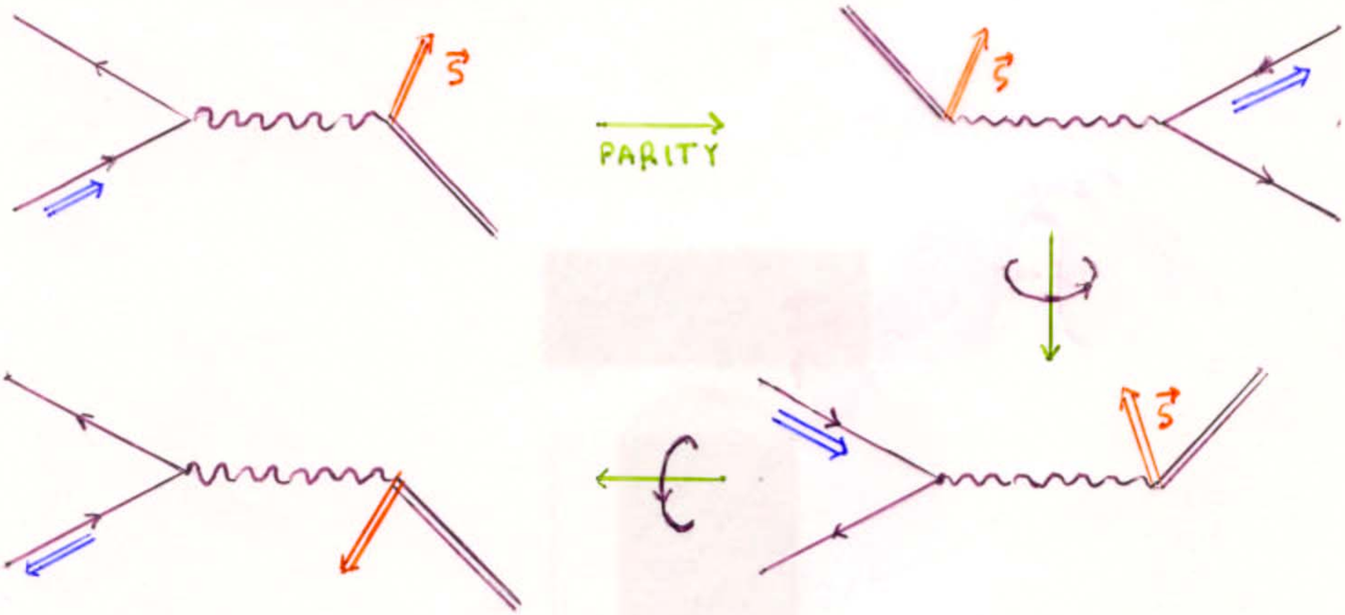
. . . . . . . . . . . . . . . . . . . . .

NOT ALL POLARIZATIONS AVAILABLE

E. G. COMPASS EXP., MUONS

2nd IMPROVEMENT: **SPACE SYMMETRIES**

# 4. SYMMETRY PROPERTIES




PARITY AND ROTATIONAL INVARIANCE IMPLY

$$\boxed{\frac{d\sigma_{\leftarrow\downarrow}}{d\Gamma}(\varphi, \varphi_s) = \frac{d\sigma_{\rightarrow\uparrow}}{d\Gamma}(-\varphi, \pi-\varphi_s)}$$

THEREFORE, E. G.,

$$\frac{d\sigma_{UT}}{d\Gamma}(\varphi, \varphi_s) = \frac{d\sigma_{\rightarrow\uparrow}}{d\Gamma}(\varphi, \varphi_s) + \frac{d\sigma_{\rightarrow\downarrow}}{d\Gamma}(-\varphi, \pi-\varphi_s)$$

$$- \frac{d\sigma_{\rightarrow\downarrow}}{d\Gamma}(\varphi, \varphi_s) - \frac{d\sigma_{\rightarrow\uparrow}}{d\Gamma}(-\varphi, \pi-\varphi_s)$$

HELPS TO REDUCE BIASES

# DISENTANGLING THE SIVERS EFFECT:

$$\varphi = \varphi_\pi - \varphi_e$$

$$\varphi_S = \varphi_{Pol} - \varphi_e$$

$$\varphi - \varphi_S = \varphi_\pi - \varphi_{Pol} \quad : \quad \varphi_e\text{-INDEP.}$$

BUT

$$\frac{d\sigma_{UT}}{d\Gamma} = B_{COL} \sin(\varphi + \varphi_S) + B_{SIV} \sin(\varphi - \varphi_S) +$$

$$+ B_\perp \sin(3\varphi - \varphi_S) + B_\parallel \sin 2\varphi \cos\varphi_S + O(q/Q)$$

THEN

$$\int \frac{d\sigma_{UT}}{d\Gamma} d\varphi_e = 2\pi B_{SIV} \sin(\varphi - \varphi_S)$$

ANALOGY WITH SINGLY POLARIZED DRELL-YAN:

ANSELMINO ET AL.: PHYS. REV. D 67 (2003) 074010

# 5. NEW THEORETICAL RESULTS

E. D. S. : hep-ph/0408108, 0407208

- $\boxed{\mu_N = \mu_\pi = Q/2}$

$\langle \cos 2\varphi \rangle \longrightarrow A_{ANIS} \propto \frac{\vec{q}_\perp^{\,2}}{Q^2} \longleftrightarrow$ ANALOGY WITH DRELL-YAN

$\langle \sin(\varphi + \varphi_s) \rangle \longrightarrow A_{COL} \propto \frac{|\vec{q}_\perp|}{Q}$ COLLINS ASYMM.

$\langle \sin(\varphi - \varphi_s) \rangle \longrightarrow A_{SIV} \propto \frac{|\vec{q}_\perp|}{Q}$ SIVERS ASYMM.

$\langle \cos(\varphi - \varphi_s) \rangle \longrightarrow C_\perp \propto \frac{|\vec{q}_\perp|}{Q}$ DOUBLE SPIN ASYMM.

- $\boxed{g_{1T} = h_{1T}(1-\varepsilon)}$

$C_\perp \propto g_{1T} \otimes D \otimes w_{C_\perp}$

USEFUL FOR DETERMINING TRANSVERSITY

# 6. CONCLUSION

- IMPORTANCE OF SPACE SYMMETRIES IN REDUCING BIASES

- DISENTANGLING SIVERS EFFECT:

$$A_{SIV} \sin(\varphi - \varphi_s) \propto \int \frac{d\sigma_{UT}}{d\Gamma} \, d\varphi_\ell$$

- PREDICTIONS ON $Q^2$-DEPENDENCE OF ASYMMETRIES:

$$A_{ANIS} \propto Q^{-2} \qquad A_{COL},\ A_{SIV},\ \langle \cos(\varphi - \varphi_s) \rangle \propto Q^{-1}$$

- DETERMINING $\langle \cos(\varphi - \varphi_s) \rangle$ (D. S. ASYM.)

$\Rightarrow$ METHOD FOR DETERMINING TRANSVERSITY