# CAN THE POLARIZATION OF THE STRANGE QUARK BE POSITIVE ?

AND

# WHY DOES IT MATTER ??

Elliot Leader
Imperial College London

understanding the spin structure of nucleons

1) The problem of flavour separation.

2) The HERMES SIDIS results

3) a) The "almost impossibility" of

$$\int_0^1 \Delta s(x) \geq 0$$

b) Misuse of Bjorken Sum Rule.

4) Lessons for COMPASS, RHIC, ...

[WORK WITH SIDOROV and STAMENOV
Phys. Rev. D67 (2003) 037503]

1) The problem of flavour separation.

In LO

$$g_1^p = \frac{1}{2}\left\{ \frac{4}{9}\left(\Delta u(x) + \Delta\bar{u}(x)\right) + \frac{1}{9}\left(\Delta d(x) + \Delta\bar{d}(x)\right) + \frac{1}{9}\left(\Delta s(x) + \Delta\bar{s}(x)\right)\right\}$$

MANIFESTLY CLEAR : CAN ONLY MEAURE

$$\Delta q(x) + \Delta\bar{q}(x)$$

∴ IN PRINCIPLE NO INFORMATION ABOUT

$\Delta\bar{u}(x)$, $\Delta\bar{d}(x)$, $\Delta\bar{s}(x)$ vs $\Delta s(x)$

---

Convenient to define

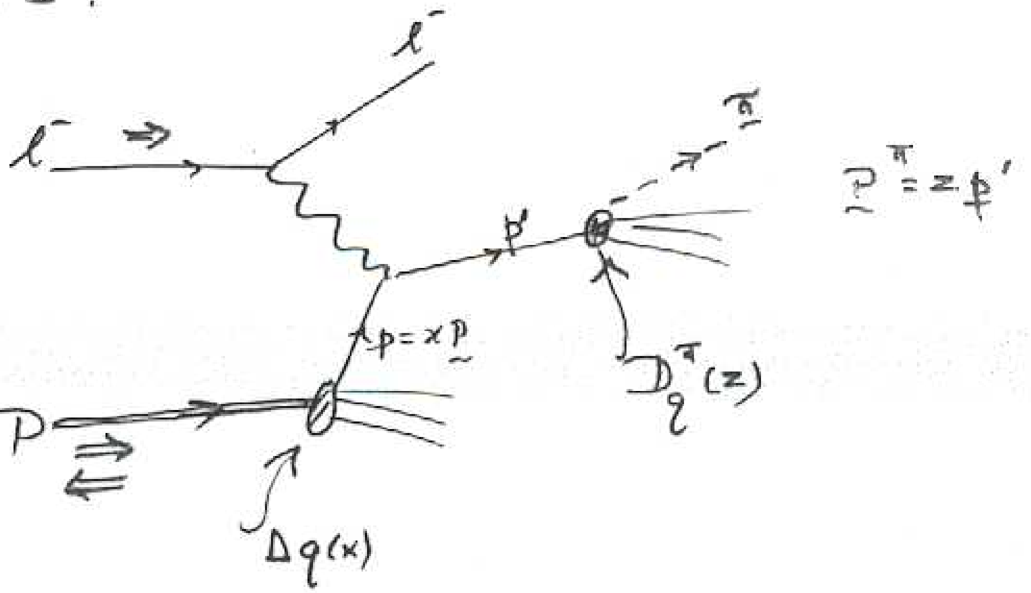
$$\Delta q_3(x) = \left[\Delta u(x) + \Delta\bar{u}(x)\right] - \left[\Delta d(x) + \Delta\bar{d}(x)\right]$$

$$\Delta q_8(x) = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} - 2(\Delta s + \Delta\bar{s})$$

$$\Delta\Sigma(x) = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$

How can we ever study $\Delta\bar{u}, \Delta\bar{d}$?

SIDIS:




$$\frac{d^2\Delta\sigma}{dx\,dz} \sim \frac{4}{9}\left[\Delta u\, D_u^\pi + \Delta\bar{u}\, D_{\bar{u}}^\pi\right]$$

$$+ \frac{1}{9}\left[\Delta d\, D_d^\pi + \Delta\bar{d}\, D_{\bar{d}}^\pi\right]$$

$$+ \frac{1}{9}\left[\Delta s\, D_s^\pi + \Delta\bar{s}\, D_{\bar{s}}^\pi\right]$$

$\Longrightarrow$ in principle can learn separately about $\Delta\bar{u}$, $\Delta\bar{d}$

<u>IF</u> we know Fragmentation Functions $D_q^\pi$

Some question about how well we know FRAG. FUNCTIONS, BUT GREAT HOPE for near future is polarized SIDIS — HERMES + COMPASS

ONLY HOPE FOR NEAR FUTURE

**SIDIS**

∴ very important that we understand SIDIS

and

that we can believe SIDIS results.

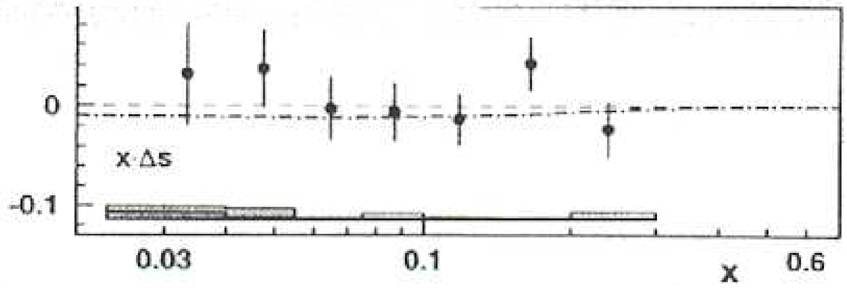
HERMES result on $\Delta s + \Delta \bar{s}$ (new) (2003)

and on $\Delta u$ and $\Delta d$ (old) (1999)

are problematic!

(Fig 1)

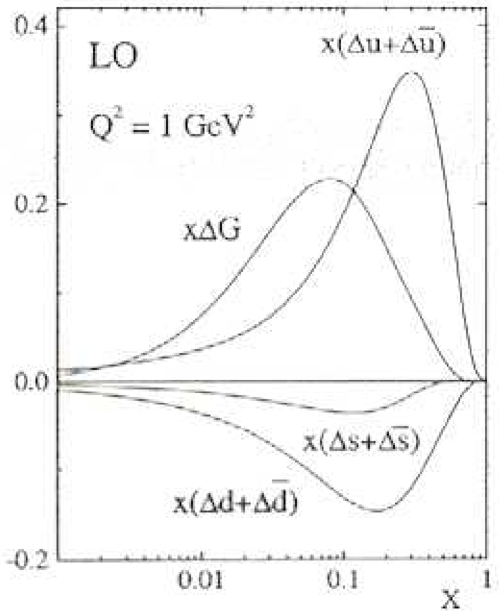
(Fig 2, 3)




HERMES : SEMI INCLUSIVE

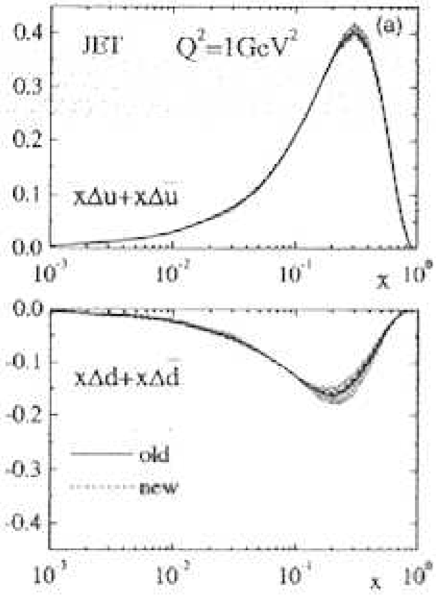
$\pi^{\pm} + K^{\pm}$

LO ANALYSIS




Inclusive DIS

LO




Inclusive DIS

NLO ANALYSIS.

Fig 3

Is it possible that, because of lack of flavour sensitivity the INCLUSIVE DIS analyses are incorrect ?

**NO** : IT IS "ALMOST IMPOSSIBLE" FOR THE FIRST MOMENT

$$\delta s(Q^2) \equiv \int_0^1 dx \left[\Delta s(x,Q^2) + \Delta \bar{s}(x,Q^2)\right]$$

TO BE POSITIVE.

In all analyses of DIS, to help with flavour separation, impose Bjorken Sum Rule (come back to this later)

$$a_3 \equiv \int_0^1 \Delta q_3(x,Q^2)\, dx = g_A/g_V = 1.2670 \pm 0.0035$$

$$\int_0^1 dx \left\{(\Delta u + \Delta \bar{u}) - (\Delta d + \Delta \bar{d})\right\}$$

Usually, also impose:

$$a_8 \equiv \int_0^1 dx\, \Delta q_8(x, Q^2) = 3F - D$$

$$= 0.585 \pm 0.025$$

Based on analysis of HYPERON $\beta$-DECAYS, ASSUMING $SU(3)_F$ IS A GOOD SYMMETRY.

No evidence AGAINST $SU(3)_F$ IN THESE DECAYS, BUT CANNOT BE AN EXACT SYMMETRY:

VARIOUS STUDIES SUGGEST BREAKING $\lessapprox$ 10%

NEW KTEV EXPT: $\Xi^0 \to \Sigma^+ e^- \bar{\nu}$ SUPPORTS THIS.

WE WILL DOUBLE THE UNCERTAINTY AND INSIST THAT

$$\boxed{0.47 \leq a_8 \leq 0.70}$$

NOW WRITE

$$\Gamma_1^p(Q^2) \equiv \int_0^1 g_1^p(x, Q^2)\, dx$$

$$= \frac{1}{6}\left\{ \frac{1}{2} a_3 + \frac{5}{6} a_8 + 2\delta_s(Q^2) \right\}$$

$$\Longrightarrow$$

$$a_8 = \frac{6}{5}\left\{ 6\Gamma_1^p(Q^2) - \frac{1}{2} a_3 - 2\delta_s(Q^2) \right\}$$

STRATEGY FOR RHS:

$a_3$ VERY WELL KNOWN

$\Gamma_1^p(Q^2)$ FROM EXPT (WITH CARE!)

THEN SHOW THAT $\delta_s(Q^2) \gtrsim 0$

$\Longrightarrow$ CRAZY VALUE FOR $a_8$

PROBLEM IS TO GET RELIABLE VALUE FOR $\Gamma_1^p$

---- DEPENDS ON EXTRAPOLATION OF DATA TO $x = 0$ AND $x = 1$

TWO EXTREMES:

Scenario $S_1$ : ASSUME PQCD AT SMALL $x$ :
(E155 etc) $(Q^2 \approx 5)$

$$\Gamma_1^p = 0.118 \pm 0.004 \pm 0.007 \qquad (S_1)$$

Scenario $S_2$ : ASSUME REGGE AT SMALL $x$ :
(E143 etc) $(Q^2 \approx 3)$

$$\Gamma_1^p = 0.133 \pm 0.003 \pm 0.009 \qquad (S_2)$$

THEN IN

$$a_8 = \frac{6}{5}\left\{6\,\Gamma_1^p - \frac{1}{2}a_3 - 2\delta_s\right\}$$

$$\delta_s \geqslant 0 \quad \Longrightarrow$$

$$a_8 \leq 0.089 \pm 0.058 \qquad (S_1)$$

$$a_8 \leq 0.197 \pm 0.068 \qquad (S_2)$$

RECALL FIRM CONVICTION THAT

$$0.47 \leq a_8 \leq 0.70$$

WITH $\pm 20\%$ BREAKING OF $SU(3)_F$ .

CONCLUSION :

$$\delta_s \equiv \int_0^1 dx \left[ \Delta s + \Delta \bar{s} \right] \geqslant 0$$

$\Rightarrow$ DRAMATIC BREAKING OF $SU(3)_F$

MANY TIMES OUTSIDE THE EXPECTED RANGE OF BREAKING.

$\therefore$ IT IS "ALMOST IMPOSSIBLE" FOR $\delta_s$ TO BE $\geqslant 0$.

## Implications.

1) Either: something is wrong with HERMES

2) Or: our understanding of these reactions is incomplete.

1) HERMES has NOT published their data (14 months!)

???

Is their data incorrect?

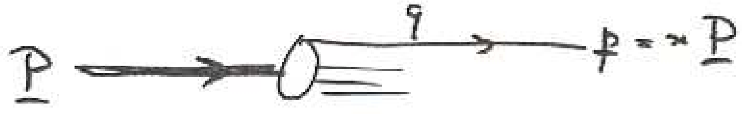
Is their analysis of their data incorrect?

Since only hope to learn about $\Delta\bar{u}, \Delta\bar{d}$ in near future is based on SIDIS this is extremely worrying.

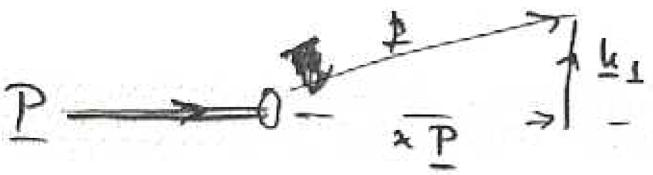
2) Possibly the theoretical treatment is incomplete — linked to aspects we are studying here with Anselmino, Murgia and d'Alesio — i.e. the rôle of INTRINSIC TRANSVERSE MOMENTUM

(13)

In standard picture kinematics is collinear:




Yet, by Uncertainty Relation $\langle \underline{k}_\perp \rangle \neq 0$




$p = x\underline{P} + \underline{k}_\perp$

Can introduce $\hat{q}(x, k_\perp^2)$

$$q(x) = \int_0^{Q^2} d^2\underline{k}_\perp \; \hat{q}(x, k_\perp^2)$$

Now in DIS, we don't measure any $p_\perp$.

i.e. we don't detect struck quark or its fragments.

$\therefore$ $q(x)$ is relevant.

But in SIDIS, we do detect struck quark or, at least, its fragments, but only out to some $p_T^{MAX}$ fixed by apparatus.

So maybe only

$$\int_0^{p_\perp^{max}} \vec{q}(x, k_T^2)\, d^2k_T \neq q(x)$$

is controlling the behaviour.

This is interesting per se

BUT

catastrophic to our hopes to use SIDIS to study $\Delta\bar{u}(x)$, $\Delta\bar{d}(x)$.

We await publication of HERMES data with much anticipation!

However, there are OTHER problems in HERMES analysis (1999 expt).

Look at Bjorken sum rule at NLO:

# Bjorken Sum Rule — A Reminder

1) $$\int_0^1 dx\left[g_1^p(x,Q^2) - g_1^n(x,Q^2)\right] = \frac{1}{6}\left(g_A/g_V\right)\delta C_{NS,1}(Q^2)$$

$\delta C_{NS,1}$ = 1st moment of Wilson coeff't function $\delta C_{NS}(x,Q^2)$

$$= 1 + \frac{\alpha_s(Q^2)}{\pi}\,\delta C^{(1)}_{NS,1} + \left(\frac{\alpha_s(Q^2)}{\pi}\right)^2 \delta C^{(2)}_{NS,1} \cdots$$

2) $$g_1^p(x,Q^2) - g_1^n(x,Q^2) = \frac{1}{6}\,\Delta q_3(x,Q^2) \otimes \delta C_{NS}(x,Q^2)$$

($\otimes$ ← convolution)

$$\int_0^1 dx\ \Delta q \otimes \delta C_{NS} = \int_0^1 dx\,\Delta q(x) \cdot \int_0^1 dx\,\delta C_{NS}$$

$$= \int_0^1 dx\,\Delta q(x) \cdot \delta C_{NS,1}$$

$\therefore$ LHS of BJORKEN SUM RULE

$$= \frac{1}{6} \int_0^1 dx \left\{ (\Delta u + \Delta \bar{u}) - (\Delta d + \Delta \bar{d}) \right\} \cdot \delta C_{NS,1}(Q^2)$$

$$= \text{RHS}$$

$$= \frac{1}{6} \left( g_A / g_V \right) \cdot \delta C_{NS,1}(Q^2)$$

Thus

$$a_3 \equiv \int_0^1 dx \left\{ (\Delta u + \Delta \bar{u}) - (\Delta d + \Delta \bar{d}) \right\}$$

$$= g_A / g_V \qquad \text{INDEP OF } Q^2$$

(Rigorous result linked to conservation of isotopic spin)

PROBLEMS IN THE OLD HERMES ANALYSIS FOR $\Delta u$, $\Delta d$.

( Sissakian, Shevchenko, Ivanov : hep-ph/0307189
BUT
ACTUALLY POINTED OUT SOME YEARS AGO
BY D. STAMENOV )

HERMES OBTAINS: LO ANALYSIS

$$a_3 = 0.82 \pm 0.06 \pm 0.06$$

INSTEAD OF

$$g_A / g_V = 1.2607 \pm 0.0035$$

THEY SAY THIS is OK ! WHY?

IN LO:

$$LHS_{Bj} = \int_0^1 dx \left[ g_1^p - g_1^n \right] = \frac{1}{6} \int_0^1 dx \left[ \Delta u + \Delta \bar{u} - \Delta d - \Delta \bar{d} \right]$$

$$= a_3$$

$$RHS_{Bj} = \frac{1}{6} \left( g_A / g_V \right) \left[ 1 - \frac{\alpha_s(Q^2)}{\pi} \dots \right]$$

IS COMPATIBLE WITH $0.82 \pm 0.06 \pm 0.06$
AT $\langle Q^2 \rangle \approx 2.5$

NONSENSE !

(15)

1) $a_3 = \int_0^1 dx\,[\Delta u + \Delta \bar{u} - \Delta d - \Delta \bar{d}]$

is INDEPENDENT of $Q^2$

to ALL ORDERS OF PQCD

2) IF, EXPERIMENTALLY, YOU FIND

$$\int_0^1 dx\,[g_1^p(x, Q^2) - g_1^n(x, Q^2)]$$

$$\neq \frac{1}{6}\, g_A/g_V$$

IT IS TELLING YOU THAT AT YOUR $Q^2$ a LO TREATMENT IS WRONG.

You CANNOT use LO on LHS of Bjorken and NLO on RHS!

# CONCLUSIONS

1) THE GREAT HOPE FOR UNDERSTANDING THE SPIN STRUCTURE OF THE NUCLEON IN THE NEAR FUTURE IS SEMI-INCLUSIVE DIS.

2) UNFORTUNATELY THE HERMES polarized parton densities are unreliable.

3) ASSUMING THE DATA is OK, problem may be use of LO analysis of $g_1$ without HIGHER TWIST CORRECTIONS. MAY ALSO BE linked to relatively small $p_T$ of the experiment.

4) WHAT ABOUT AN NLO ANALYSIS ??

Several groups are ready to do it, but they need the DATA !

So, please, publish or release the data.