THE INTERNAL SPIN STRUCTURE OF THE NUCLEON: PROGRESS IN OUR UNDERSTANDING.

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1) THE PRESENT STATUS: THEORY AND DATA IN POLARIZED DIS

2) THE NEAR FUTURE: POLARIZED SEMI-INCLUSIVE DIS — A MINI-BREAKTHROUGH.

3) THE DISTANT FUTURE: $\nu, \bar{\nu}$ BEAMS ON POLARIZED TARGETS.

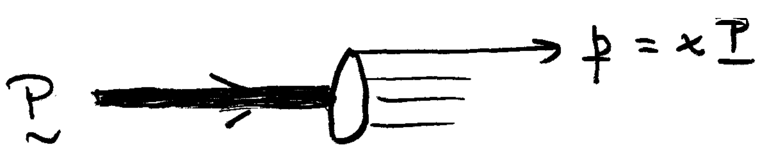
? 4) TRANSVERSELY POLARIZED HADRONIC REACTIONS $p^{\uparrow} p \to \pi X$

Internal spin structure of nucleon?

A modest interpretation ...

Just the 3 independent parton model densities:

1)



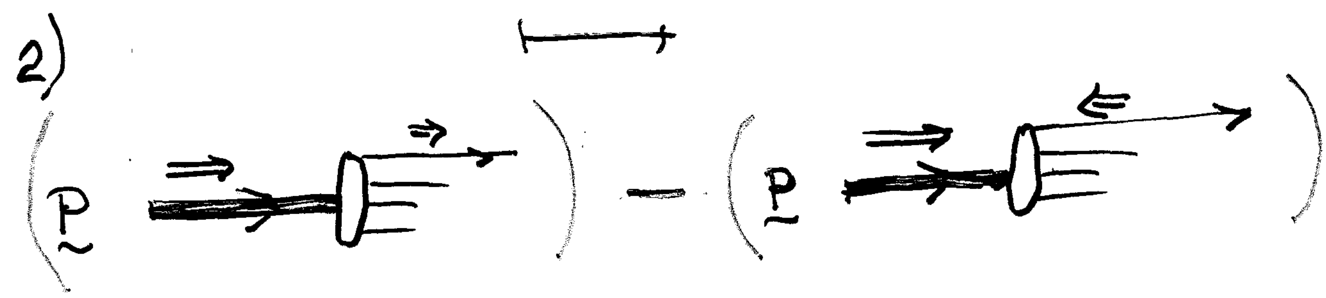
$q(x)$

Measure in DIS : NC <u>AND</u> CC

Large Q^2 - range

$\Longrightarrow$ good flavour separation

2)



$$\Delta q(x) = q_+(x) - q_-(x)$$

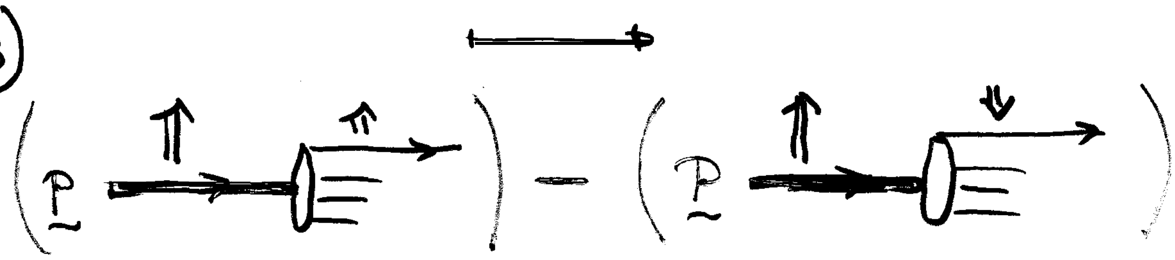
Measure: Longitudinally pol'd Lepton and Target.

No neutrino data.

Range of Q^2 small.

$\Longrightarrow$ poor flavour separation.

3)



$$\Delta_T q(x) = q_\uparrow(x) - q_\downarrow(x)$$

Measure?: CANNOT measure via DIS with TRANSVERSELY POLD. TARGET.

$g_2(x)$ DOES NOT tell you about $\Delta_T q(x)$.

Almost only information: SOFFER BOUND:

$$|\Delta_T q(x)| \leq \frac{1}{2}\left(q(x) + \Delta q(x)\right)$$

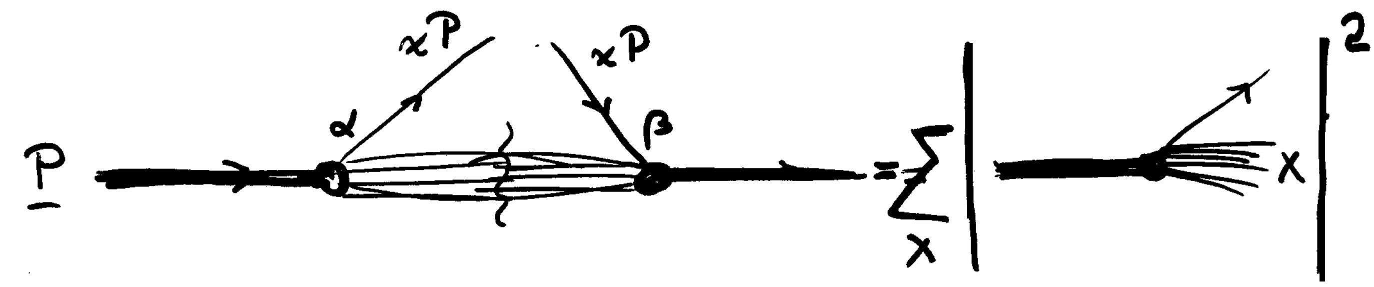
THREE INDEPENDENT FUNCTIONS, ALL OF FUNDAMENTAL IMPORTANCE:

$$q(x), \quad \Delta q(x), \quad \Delta_T q(x)$$

IS THIS ALL WE NEED ?

FAR FROM IT !

FIELD THEORETIC GENERALIZATION :



(α, β Dirac indices)

$$\Phi_{\alpha\beta}(x; P, S) = \int d\lambda\, e^{i\lambda x} \langle P, S | \bar{\psi}_\beta(0)\, \psi_\alpha(\lambda n) | P, S \rangle$$

n^μ = Gauge Fixing vector $A^a_\mu n^\mu = 0$; $n^2 = 0$

$$\Phi = \not{P} \left\{ q(x) - 2\lambda \Delta q(x) \gamma_5 + \Delta_T q(x) \gamma_5 \not{S}_T \right\} + M \left\{ e(x) I + f_T(x) \gamma_5 \not{S}_T + f_L(x) \lambda \gamma_5 [\not{P}, \not{n}] \right\}$$

+ - - - - - - -

This WITHOUT worrying about p_T !

Mainly discuss $\Delta q(x)$:

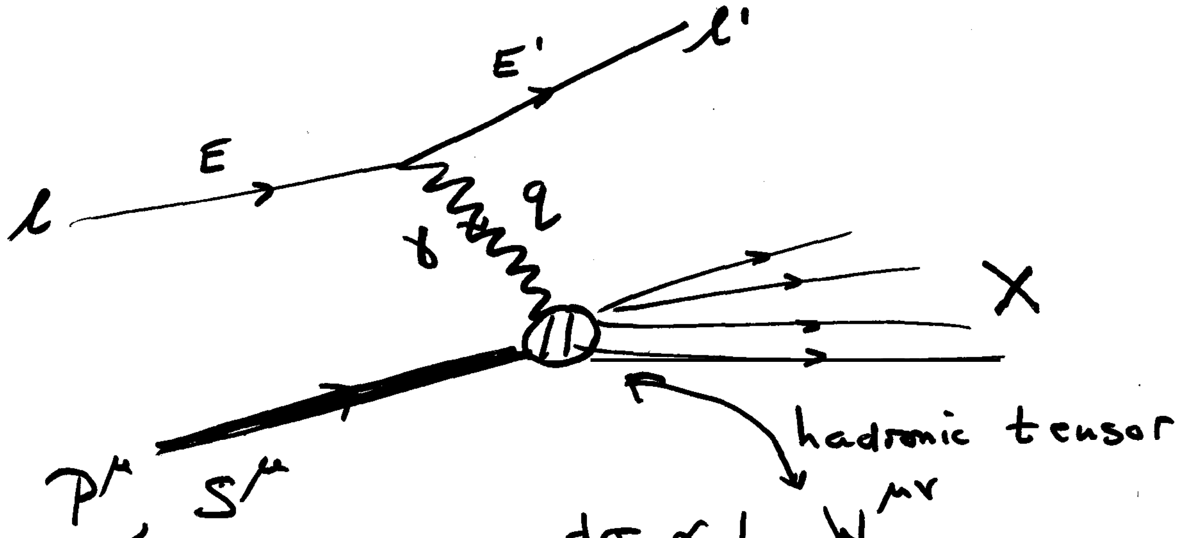
a) PRESENT STATUS

b) NEAR FUTURE (2-3 years)

c) LONG TERM FUTURE ($\gtrsim$ 2010)

IF TIME PERMITS, $\Delta_T q(x)$ — possibility of learning something about it.

The spin-dependent (NC) scaling functions



$$d\sigma \propto L_{\mu\nu} W^{\mu\nu}$$

Antisymmetric part ($\mu \leftrightarrow \nu$) is spin-dependent

$$\frac{1}{2m} W^{(A)}_{\mu\nu} = \frac{\epsilon_{\mu\nu\alpha\beta}\, q^\alpha}{(P.q)} \left\{ \frac{M\nu S^\beta}{P.q} g_1 + \frac{\left(P.q\, S^\beta - S.q\, P^\beta\right)}{m\nu} g_2 \right\}$$

Bjorken Scaling: $g_{1,2}(x)$

QCD : $g_{1,2}(x, Q^2)$

Brief history of theory of $g_1(x)$.

PRE 1987 :-

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

$$\Delta q(x) = q_+(x) - q_-(x)$$

$\Rightarrow$

PROTON

$q_\pm$ = Number density with spin along or opposite to $\Rightarrow$.

1987/88 EMC : "Crisis in parton model"

Aside from constants

$$\int_0^1 g_1^p(x)\,dx = a_0 + a_3 + a_8$$

$j = 1 \text{--} 8$; a_j = matrix elements of axial-vector currents

$a_{3,8}$ KNOWN FROM Weak INTS.

EMC + weak int data $\Longrightarrow$

$$a_0 \approx 0$$

BUT IN SIMPLE PARTON MODEL

$$a_0 = \int_0^1 \Delta\Sigma(x) \equiv \int_0^1 dx \sum_f \left[\Delta q_f(x) + \Delta \bar{q}_f(x)\right]$$

$$= 2 \langle S_z^{\text{quarks}} \rangle$$

Surprise this so small.....

"Spin crisis in the parton model"

(Anselmino + E.L)

EMC paper most cited experimental paper 3 years in succession!

POST 1988 : Influence of QCD ⇒

1) $\Delta q(x) \longrightarrow \Delta q(x, Q^2)$

2) $a_0(x, Q^2) = \Delta\Sigma(x) - \frac{3\alpha_s(Q^2)}{2\pi} \Delta G(x, Q^2) \otimes \delta C_{1}$

ANOMALOUS BEHAVIOUR :

$$\alpha_s(Q^2) \int_0^1 dx \, \Delta G(x, Q^2) \not\rightarrow 0$$

as $Q^2 \rightarrow \infty$.

⇒ POSSIBILITY OF SMALL

$\int a_0(x, Q^2)\, dx$

WITHOUT SMALL $\int \Delta\Sigma(x)\, dx$

NB! NB! NB! NB! NB! NB!

WHAT is $\{$MEASURED$\}$ is $a_0(x)$

NOT $\Delta\Sigma(x)$.

Very important to measure
$\Delta G(x, Q^2)$ independently
(RHIC, COMPASS, POLARIZED HERA, ...
E161

Recent Developments.

1) Vast improvement in DATA :
SMC, E142, E143, E154, E155,
HERMES.

2) Theory calculated to NLO
(Mertig, van Neerven; Vogelsang)

$\Longrightarrow$ Major effort to determine
$\Delta q(x)$, $\Delta G(x)$.

1) What can be determined <u>in principle</u>.

2) The polarized sea.

3) Scheme dependence; $SU(3)$ in β-decay

4) New results.

Based on A. Sidorov, D. Stamenov and E.L.

Phys. Rev. <u>D58</u> (1998) 114028

Phys. Lett. <u>B445</u> (1998) 232

Phys. Lett. <u>B462</u> (1999) 189

Phys. Lett. <u>B488</u> (2000) 283

Dubna — London — Sofia Collab.

What can be determined in principle

$$g_1^p(x,Q^2) = \frac{1}{9}\left\{ \delta C_{NS} \otimes \left[\frac{3}{4}\Delta q_3(x) + \frac{1}{4}\Delta q_8(x)\right] + \delta C_S \otimes \Delta\Sigma + \delta C_G \otimes \Delta G \right\}$$

$$g_1^n(x,Q^2) = \frac{1}{9}\left\{ \delta C_{NS} \otimes \left[-\frac{3}{4}\Delta q_3(x) \quad \cdots \right. \right\}$$

$$\Delta q_3 = (\Delta u + \Delta\bar{u}) - (\Delta d + \Delta\bar{d})$$

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

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

MANIFESTLY : ONLY INFORMATION ON $(\Delta q + \Delta\bar{q})$

Non-strange polarized sea : NO INFORMATION.

SOMETIMES USEFUL TO PARAMETRIZE

$\Delta q_V(x)$, $\overline{\Delta q}(x)$ with e.g.

$\Delta\bar{u} = \Delta\bar{d} = \Delta\bar{s}$ or $\Delta\bar{u} = \Delta\bar{d} = \lambda\Delta\bar{s}$ etc

MUST CHECK THAT MODEL OF SEA

DOES NOT BIAS RESULTS ✓

SCHEME DEPENDENCE

ALAS, IN POLARIZED CASE

DIS, MS, $\overline{MS}$ DO NOT uniquely

specify factorization scheme.

Trouble comes from γ_5

Three schemes in literature:

$\overline{MS}$ (Mertig, van Neerven, Vogelsang)

AB (favoured by Torino workers)

JET (we think is "best") (Carlitz, Collins, Mueller)

In both AB and JET $\int_0^1 \Delta\Sigma(x)dx$ does NOT

EVOLVE $\therefore$ meaningful to interpret it

a $2\times S_z^{quarks}$.

Fit To World Data

Because 1) range of Q^2 small

2) no neutrino data

to help flavour separation, usually

impose:

1) Bjorken Sum Rule:

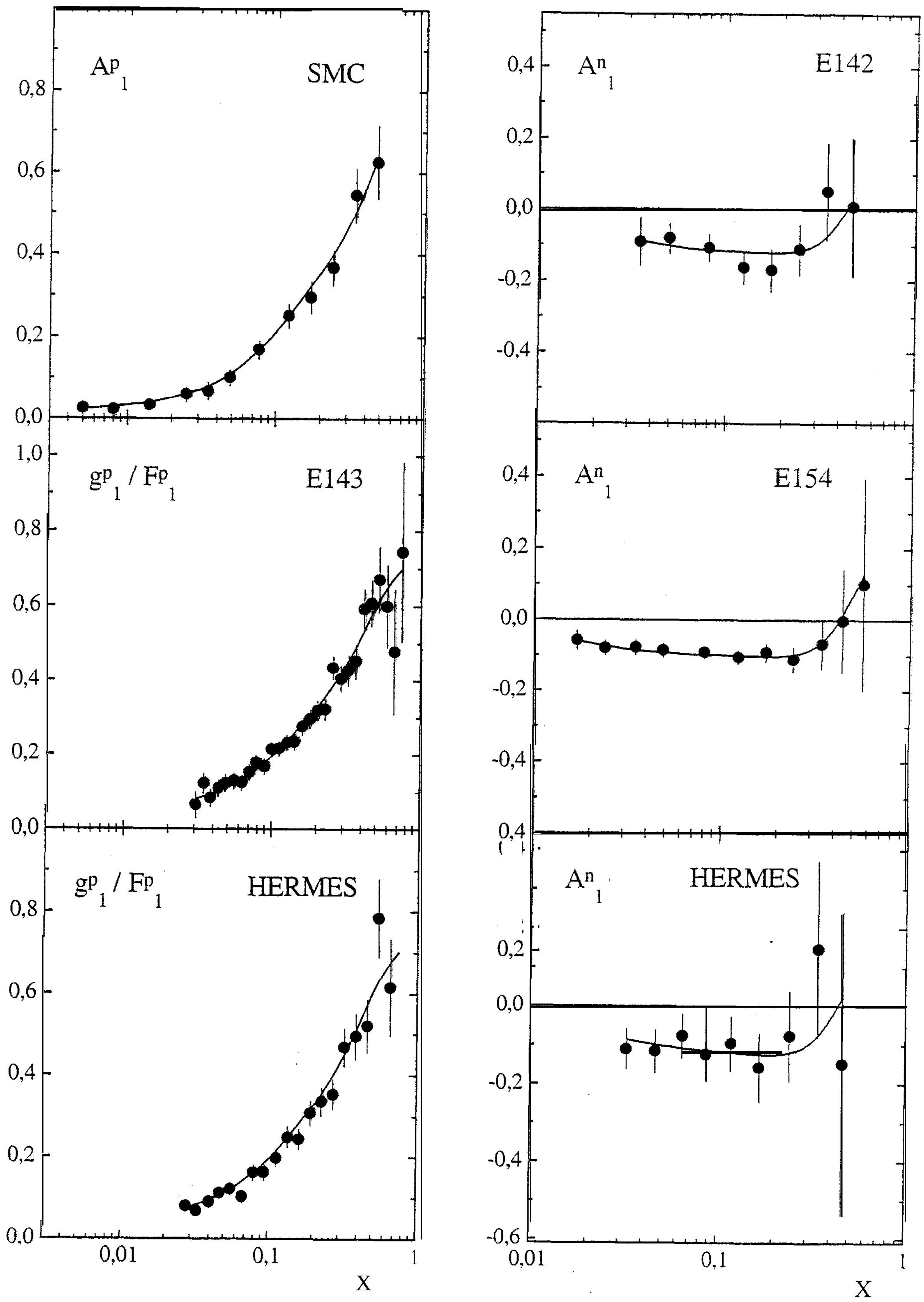
$$\int_0^1 a_3(x)\,dx = G_A/G_V \ldots$$

2) Connection to Cabibbo Weak Int. Theory

$$\int_0^1 a_8(x)\,dx = \underbrace{3F - D}$$

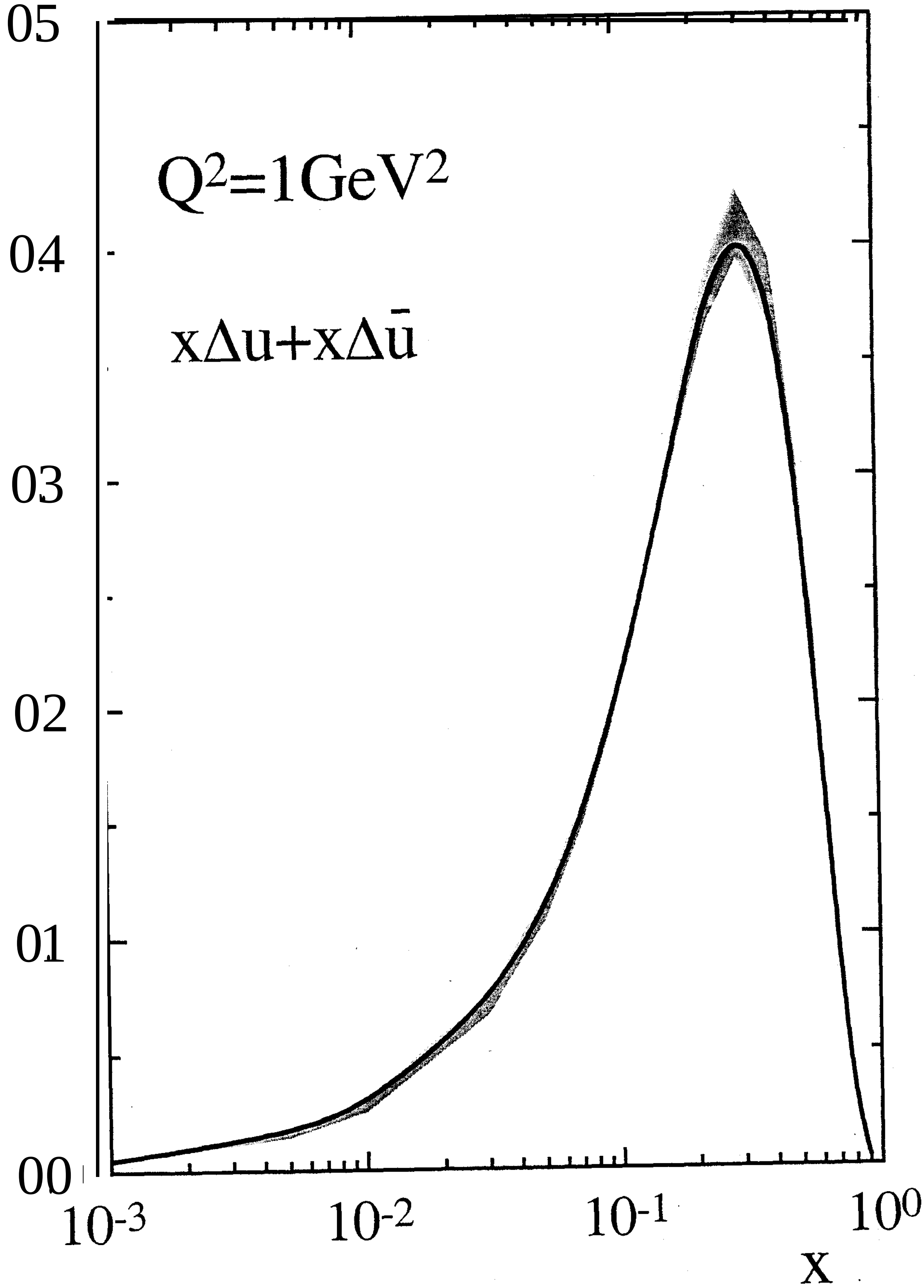
from SU(3) analysis of hyperon β- decay.

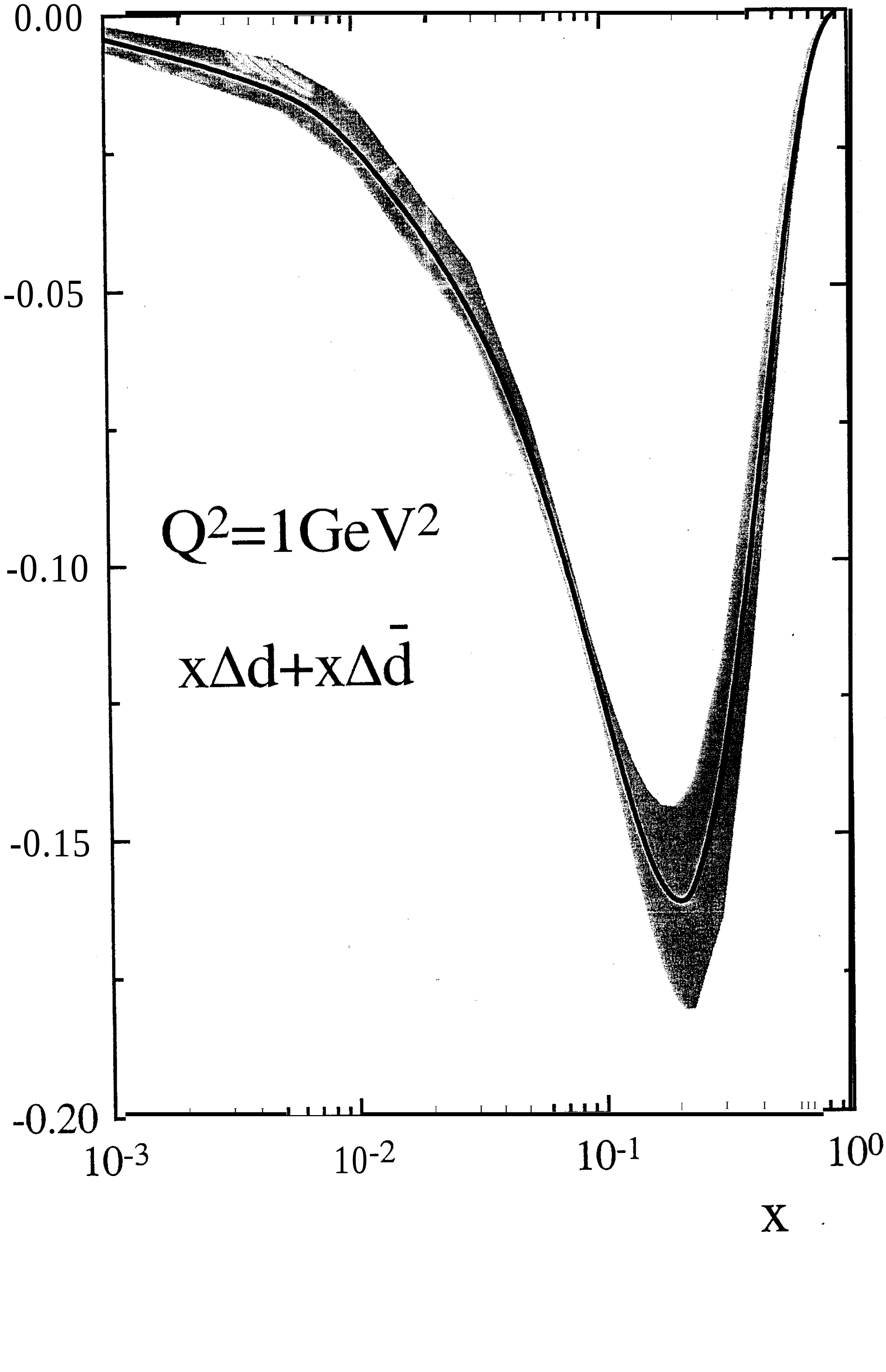
The data ...

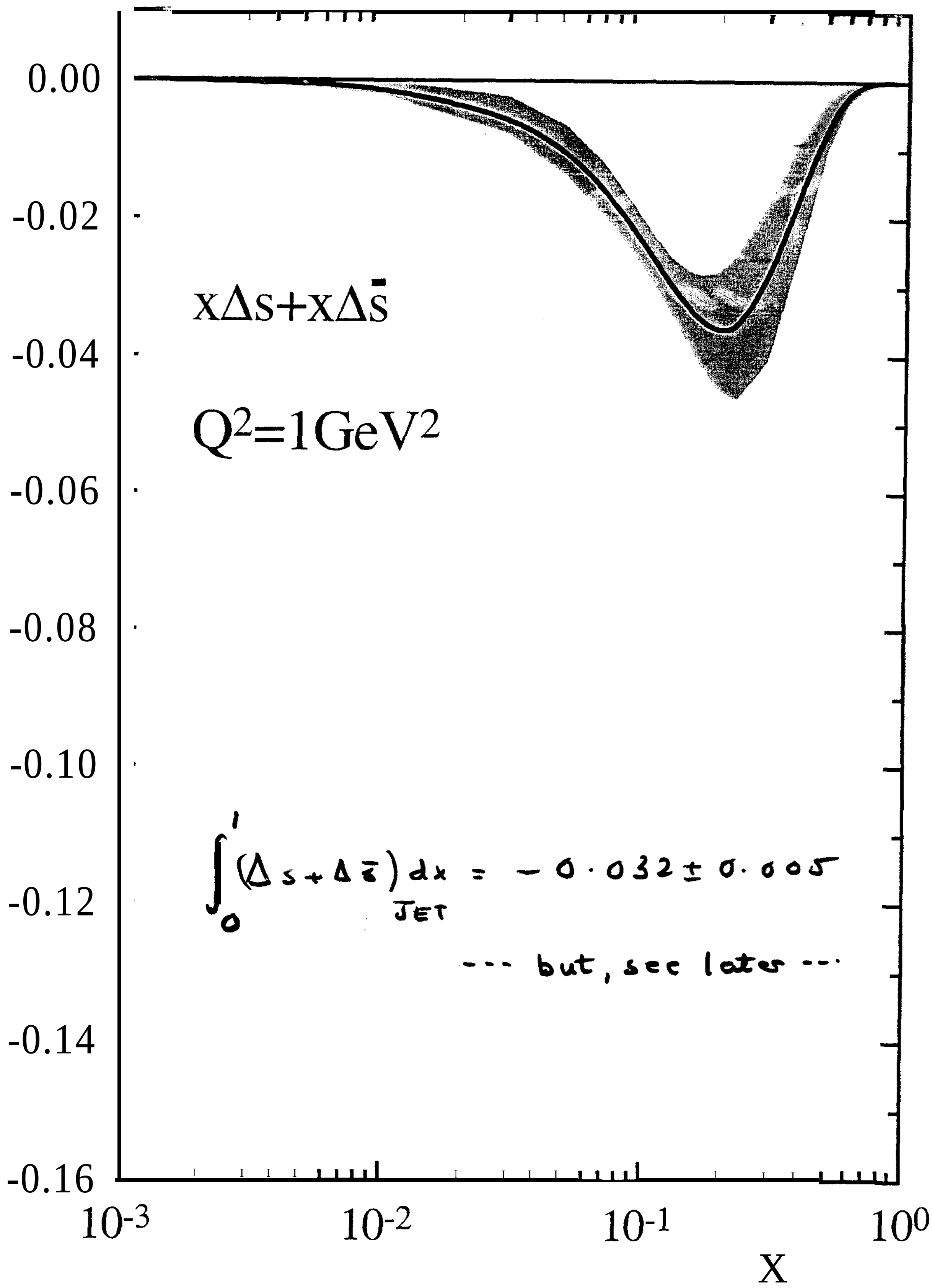


A^p_1
SMC
g^p_1 / F^p_1
E143
g^p_1 / F^p_1
HERMES
A^n_1
E142
A^n_1
E154
A^n_1
HERMES
0,01
0,1
1
X

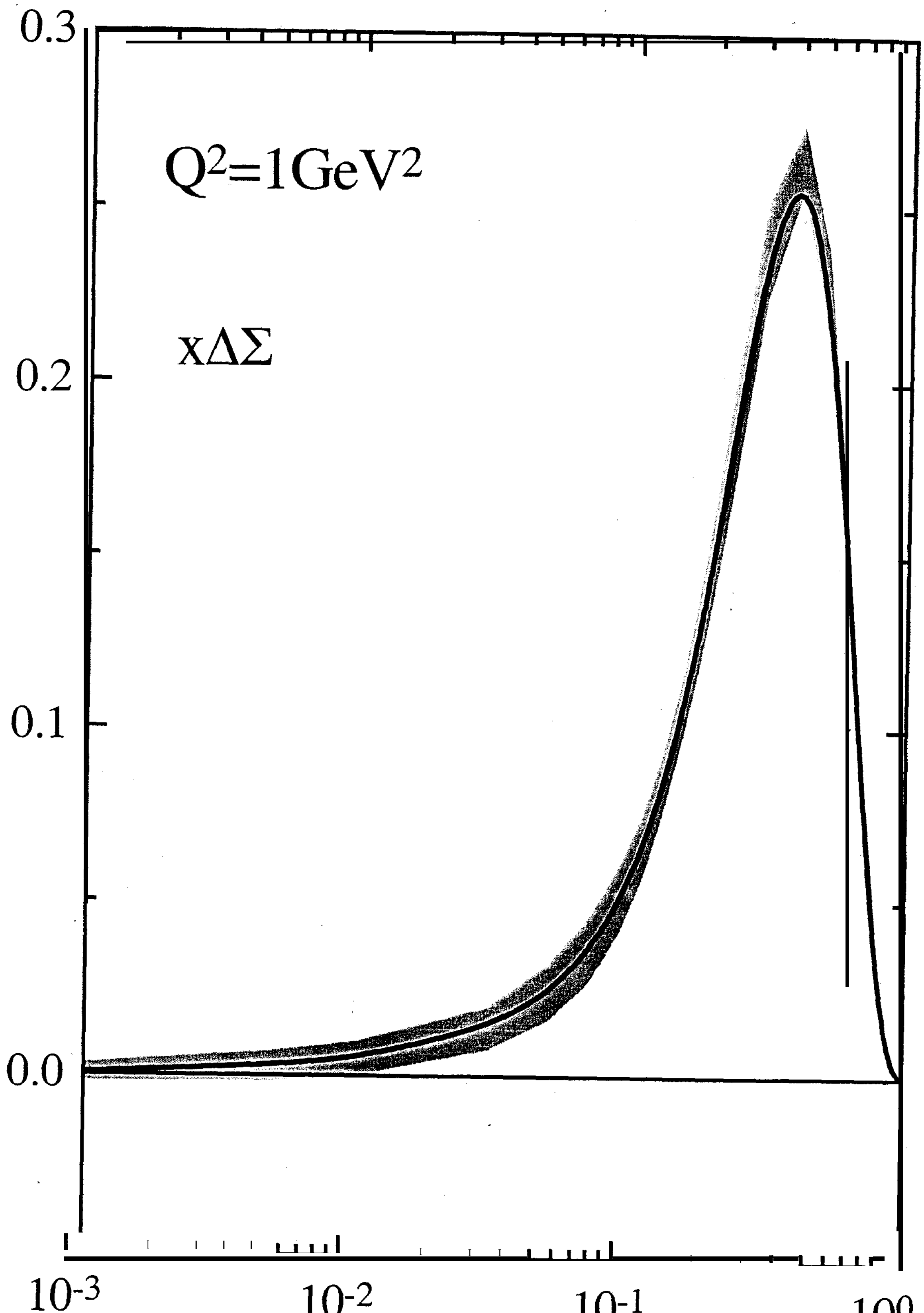
Fig 1a


05
04
03
02
01
00
Q^2=1GeV^2
$x\Delta u + x\Delta\bar{u}$
10^{-3}
10^{-2}
10^{-1}
10^{0}
x


0.00
-0.05
-0.10
-0.15
-0.20
Q^2=1GeV^2
$x\Delta d+x\Delta\bar{d}$
10^{-3}
10^{-2}
10^{-1}
10^{0}
x



0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
-0.14
-0.16
$x\Delta s+x\Delta\bar{s}$
$Q^2=1GeV^2$
$\int_0^1 (\Delta s+\Delta\bar{s})_{JET}\, dx = -0.032 \pm 0.005$
--- but, see later ---
10^{-3}
10^{-2}
10^{-1}
10^0
X


0.3
0.2
0.1
0.0
Q^2=1GeV^2
$x\Delta\Sigma$
10^{-3}
10^{-2}
10^{-1}
10^0
x