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Spin Structure Function of the Neutron: SLAC E154 Results

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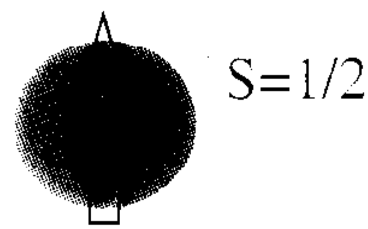
Temple University
for the E154 collaboration

- Motivation
- SLAC Experiment E154
- Results
- Future Implications

Motivation

- **Nucleon spin structure study.**
  - How much of the nucleon spin is carried by the valence quarks?
  - How much of the nucleon spin is carried by the strange sea?
  - How much of the nucleon spin is carried by the gluons?



$S = 1/2 = 1/2\Delta q + \Delta G + \Delta L$

- **Precision test of the Björken sum rule.**

↓

Precision data of the spin structure function are needed at higher Q^2 and lower x on both the proton and the neutron

SLAC Experiment E154

Oct-Nov `95

- High Beam and Target Polarizations
- First 50 GeV Physics in ESA
- Achieved Proposal Statistics

	E142	E154
• Beam Energy (GeV)	22.6	48.3
• Beam Polarization	0.35	0.82
• Target Polarization	0.33	0.38
• Target Window thickness	0.1mm	0.05mm
• Number of Events	300M	100M

The E154 Collaboration

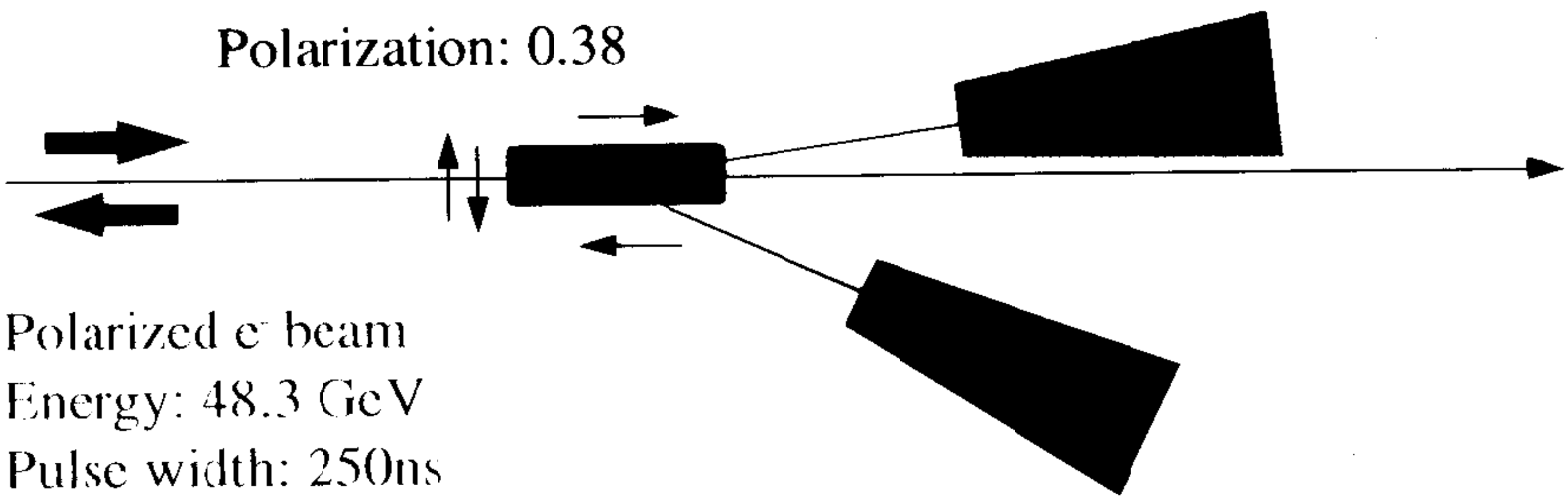
- American
- Berkeley
- Bonn
- Caltech
- Clermont-Ferrand
- Kent State
- Massachusetts
- Michigan
- NIST
- Old Dominion
- Northwestern
- Princeton
- Saclay
- SLAC
- Syracuse
- Temple
- Tohoku
- UCLA
- William & Mary
- Wisconsin

80 collaborators

Experimental Procedure

Polarized ^{3}He target
Effective length: 30cm
Pressure: 10 atm
Polarization: 0.38

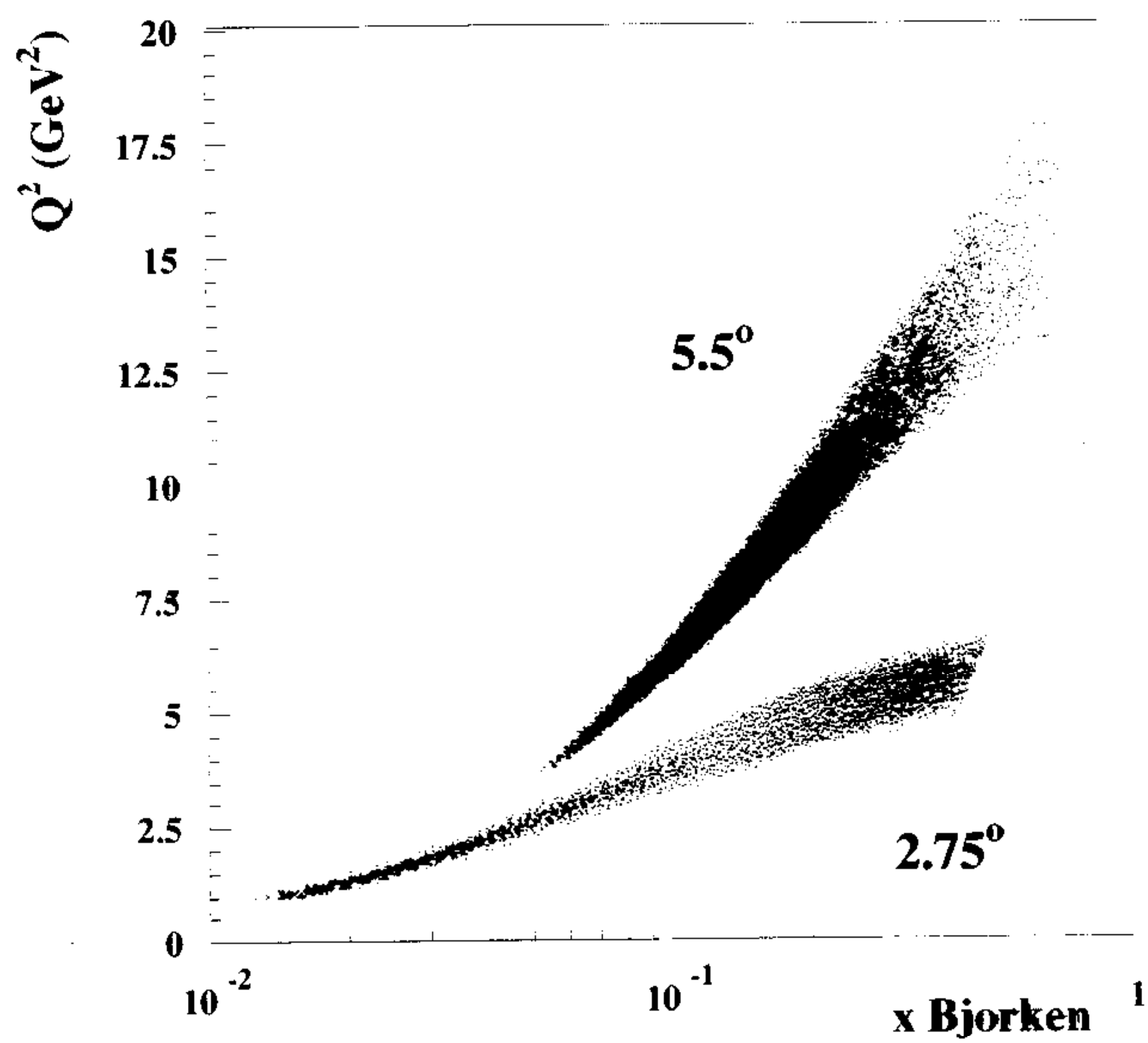
Mom. range: 10 to 43 GeV/c
Scattering angle θ: 2.75
0.5 e-/pulse
5 π/pulse



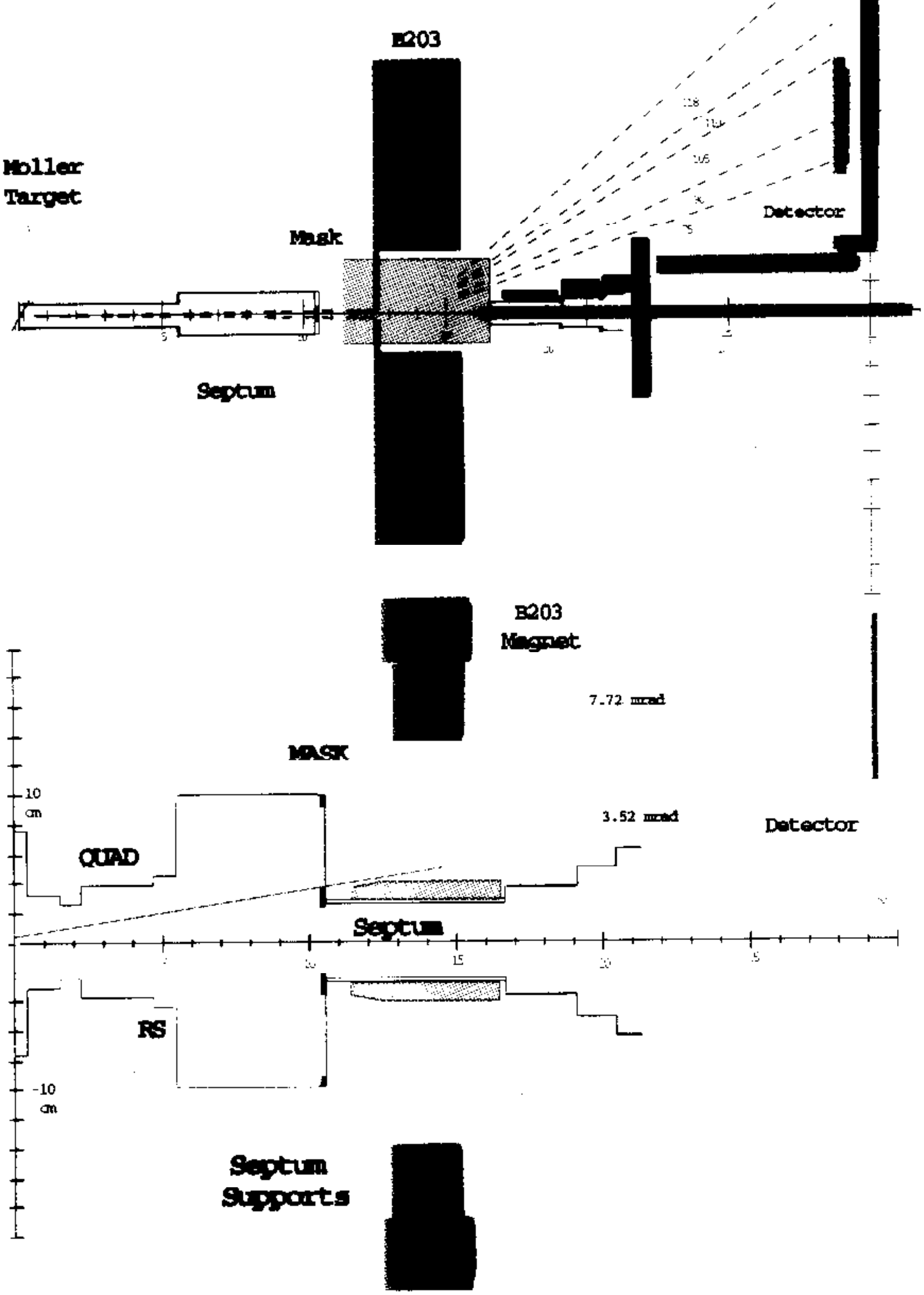
Polarized e^- beam
Energy: 48.3 GeV
Pulse width: 250ns
Rate : 120 Hz
Average current: 1μA
Polarization: 0.82

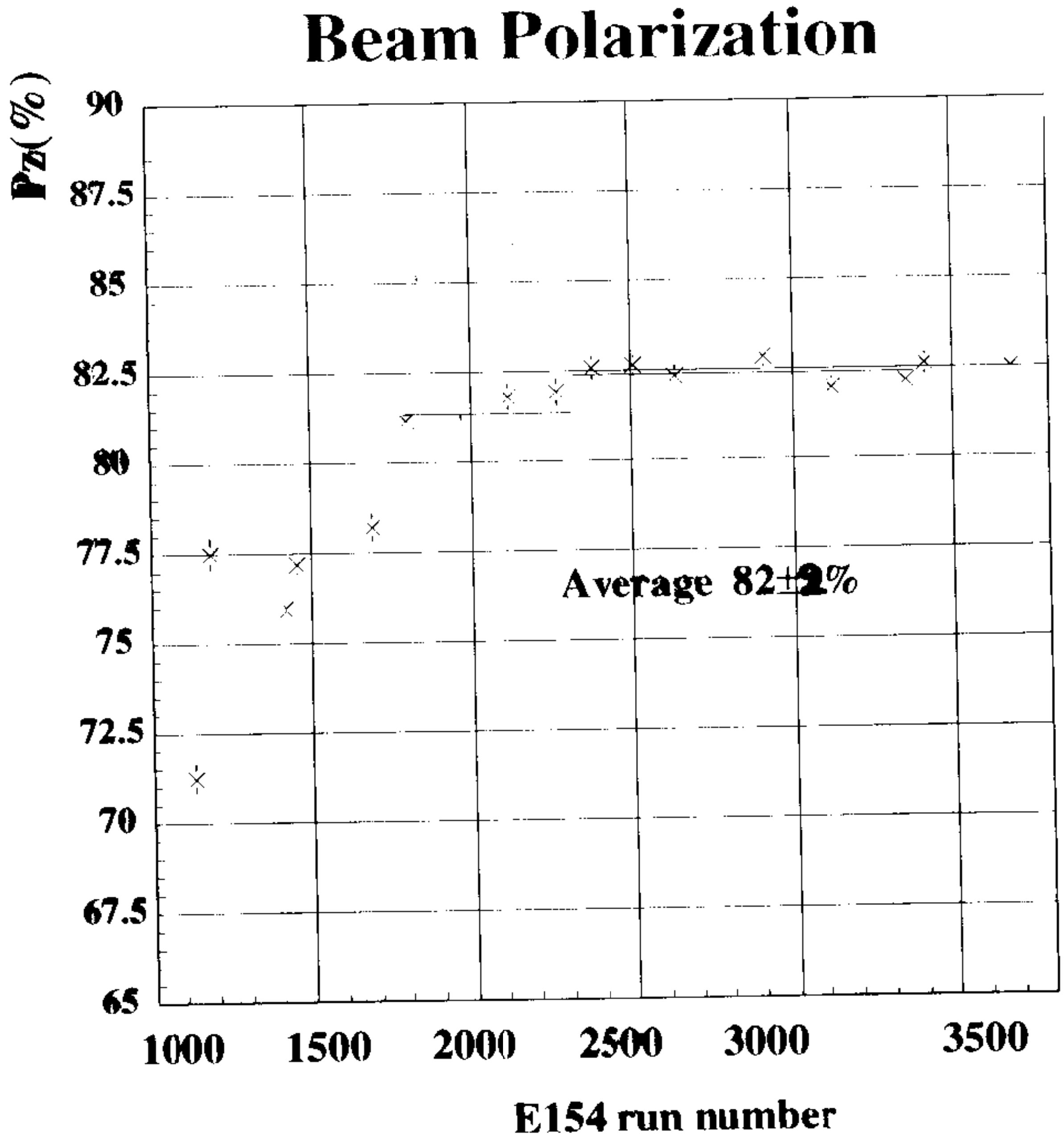
Mom. range: 10 to 35 GeV/c
Scattering angle θ: 5.5
0.1 e-/pulse
1-2 π/pulse

Q^2 versus x

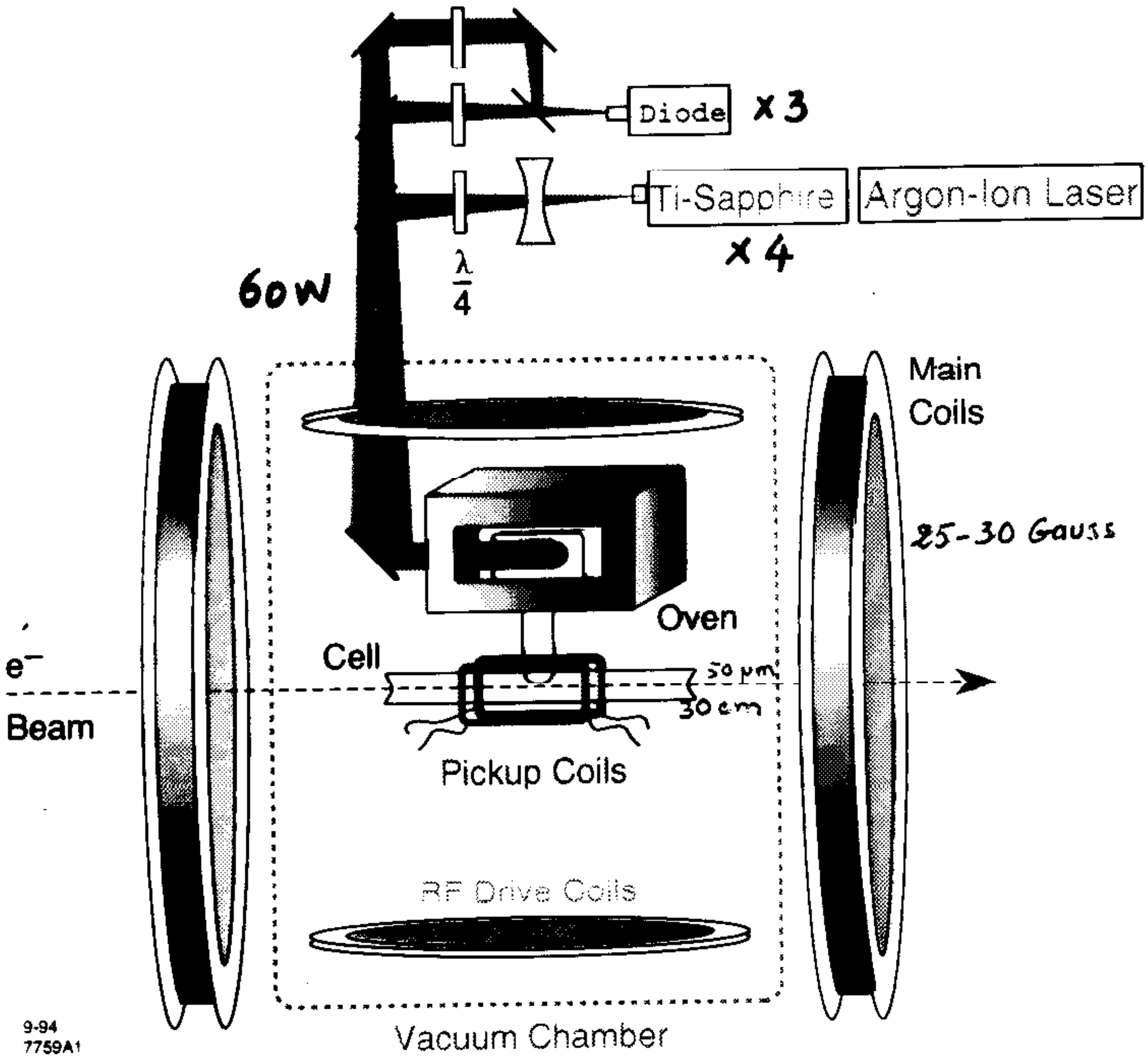


E 154 Moller Polarimeter

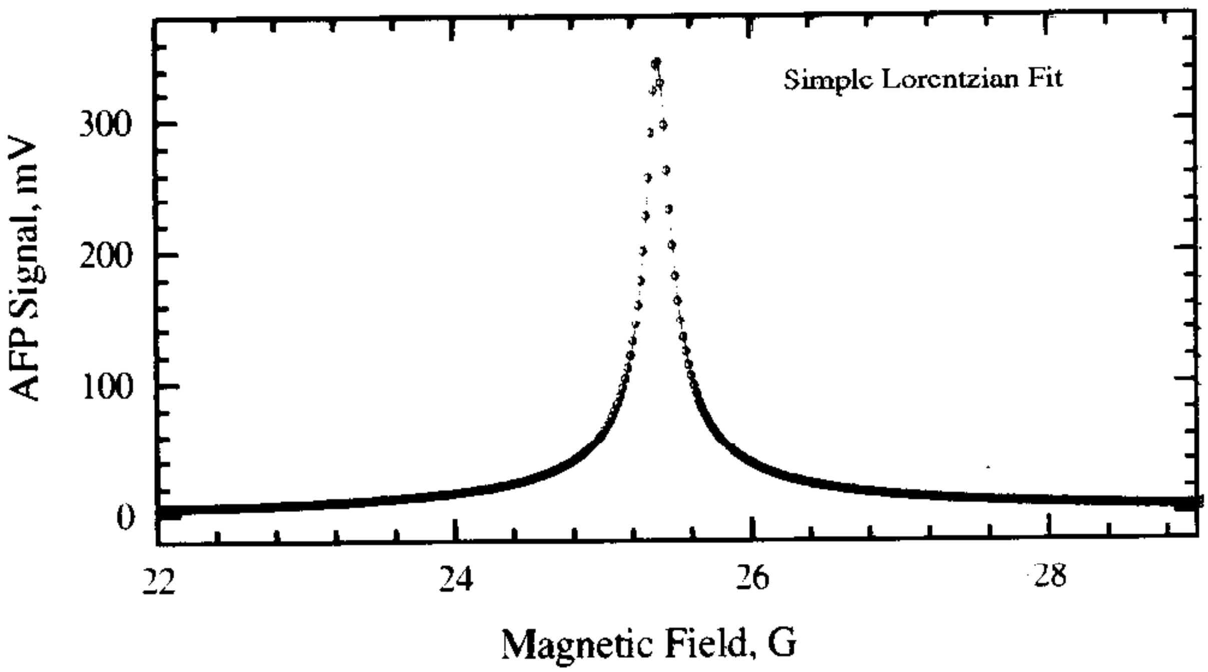



Beam Polarization
Pz(%)
90
87.5
85
82.5
80
77.5
75
72.5
70
67.5
65
1000
1500
2000
2500
3000
3500
Average 82±2%
E154 run number

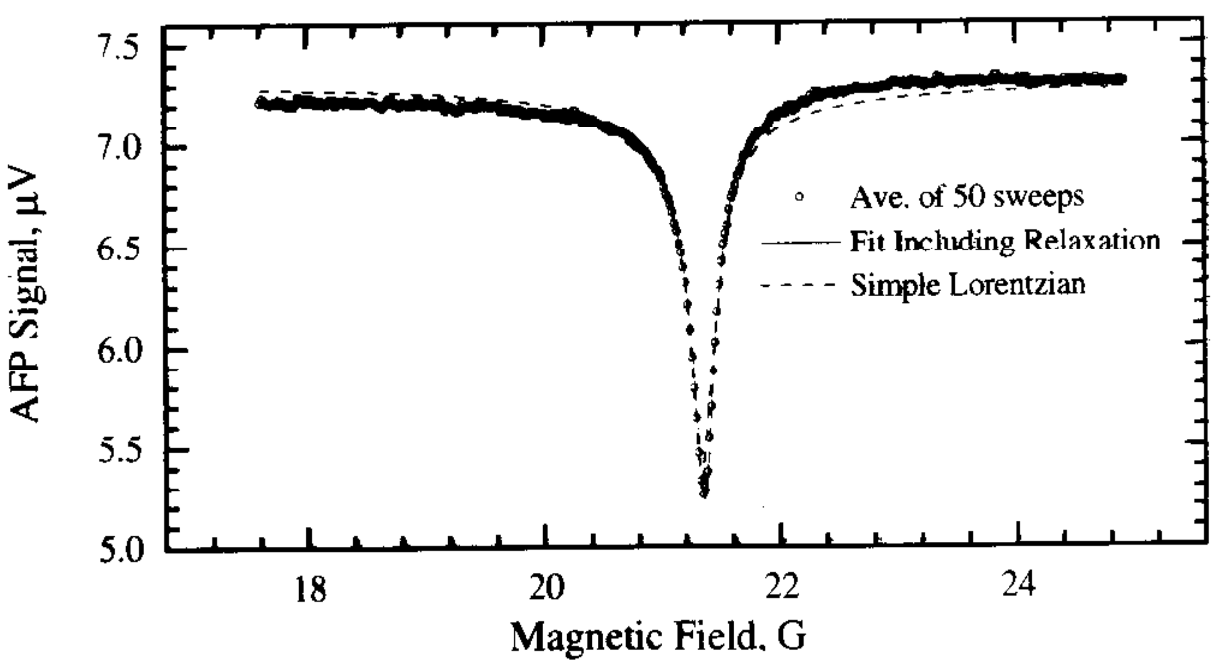
E154 Target Setup



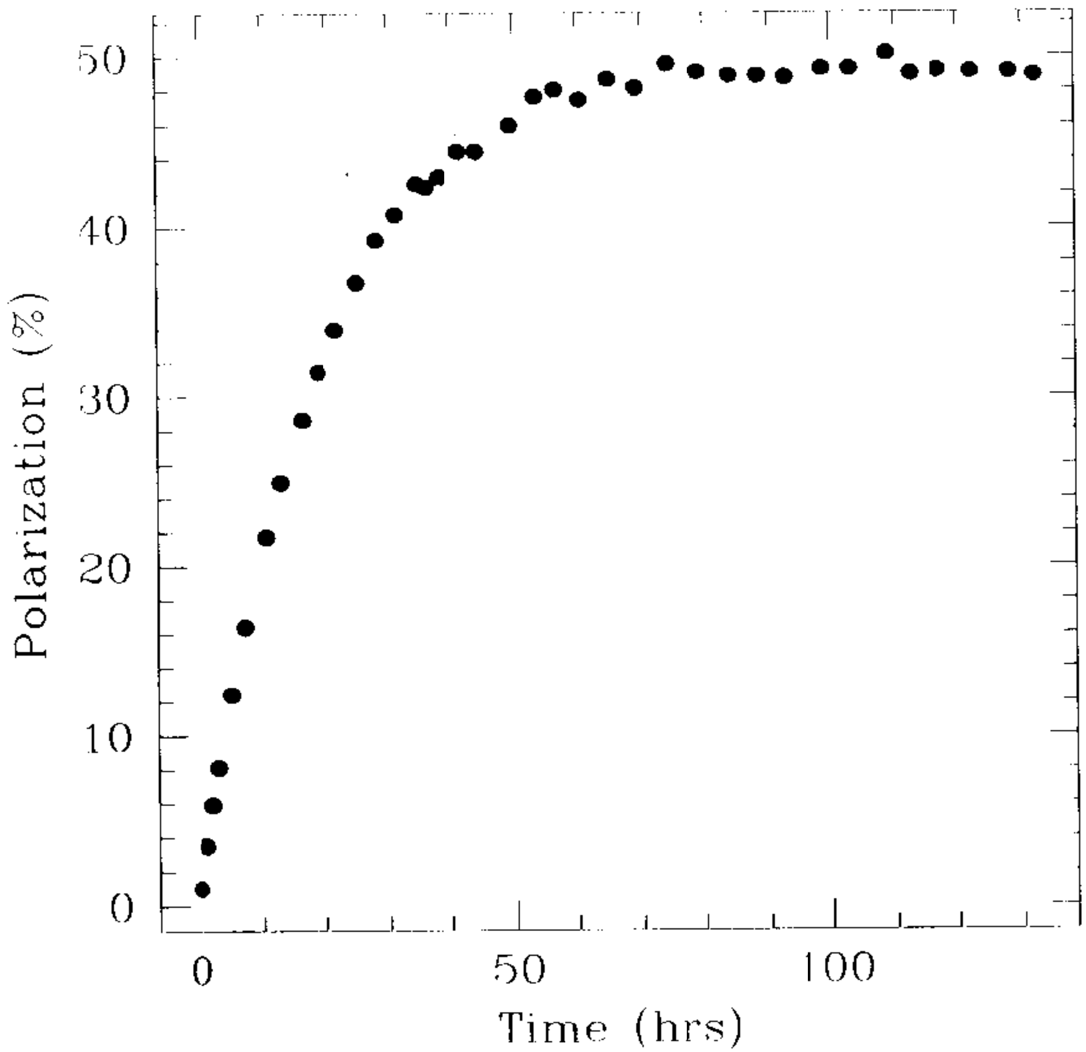
³He AFP Signal



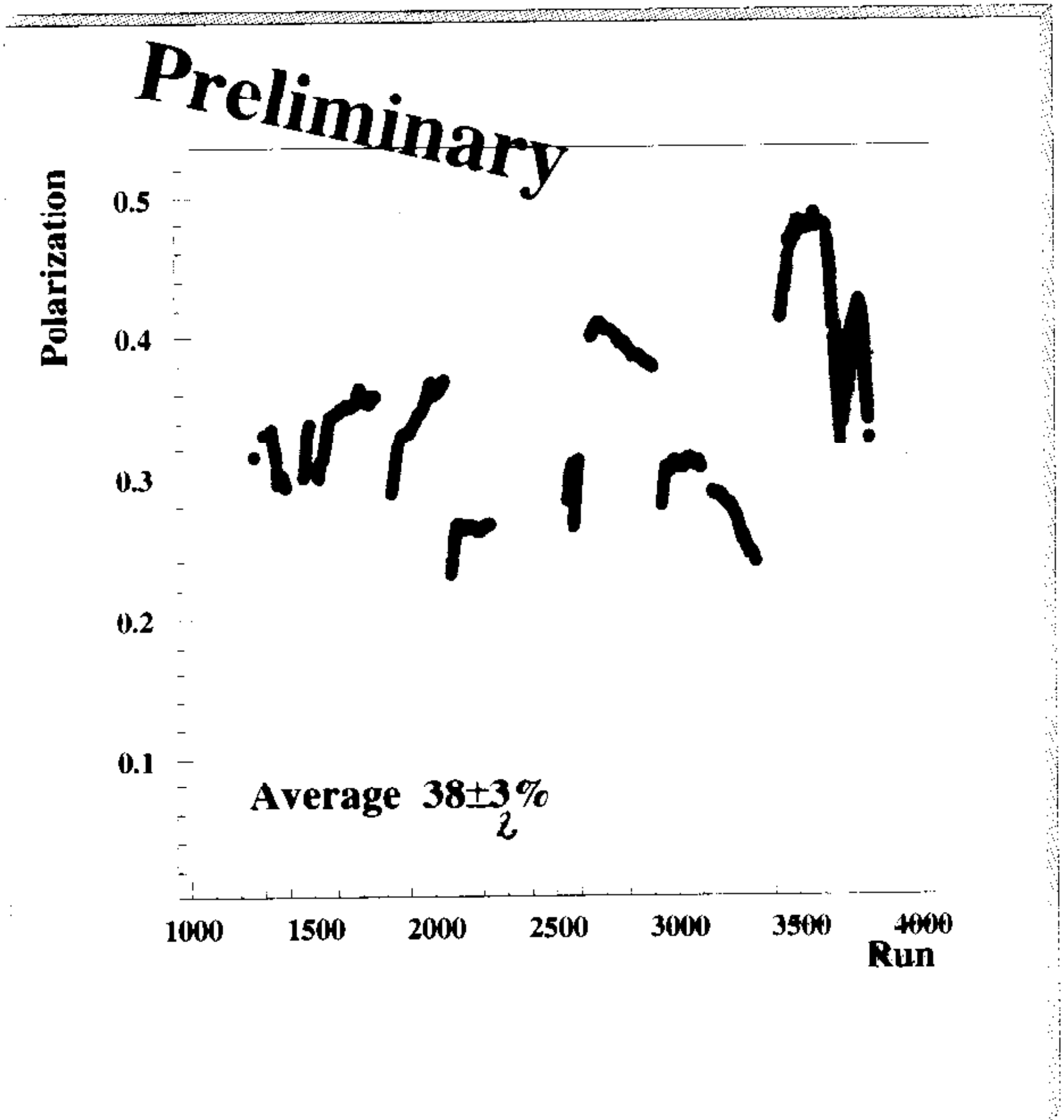
Water Calibration



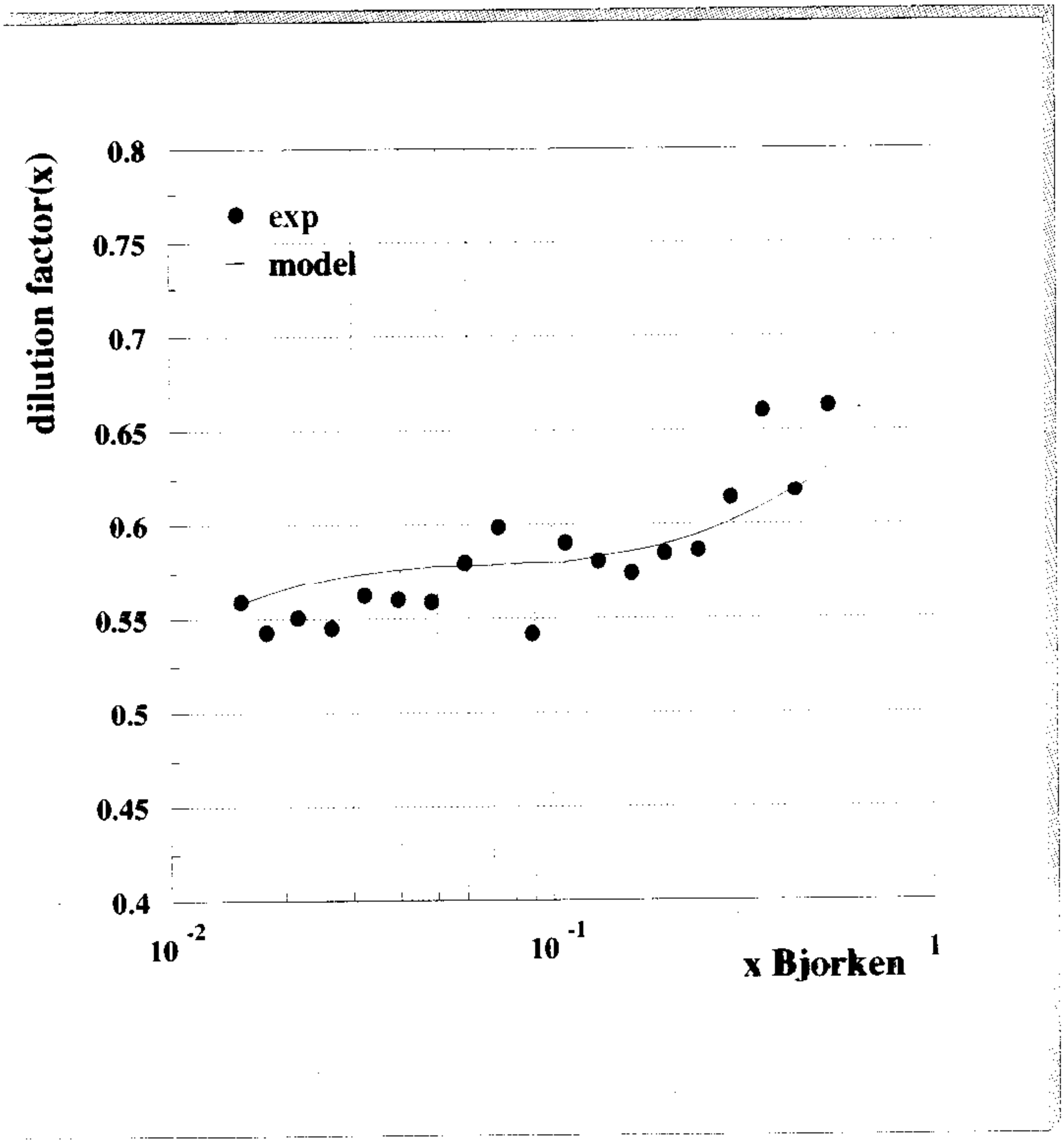
Spin-up of Picard



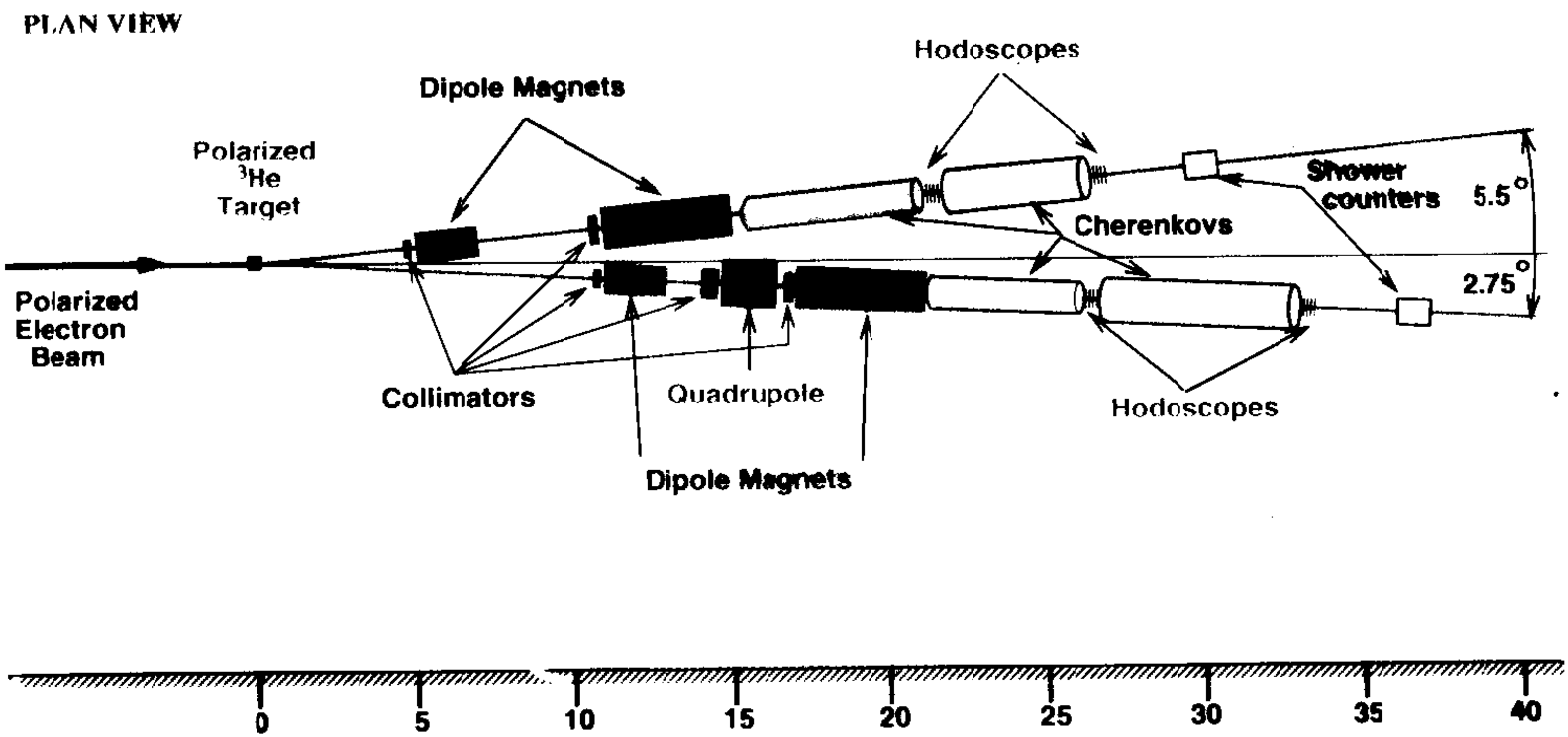
E-154 Target Polarization



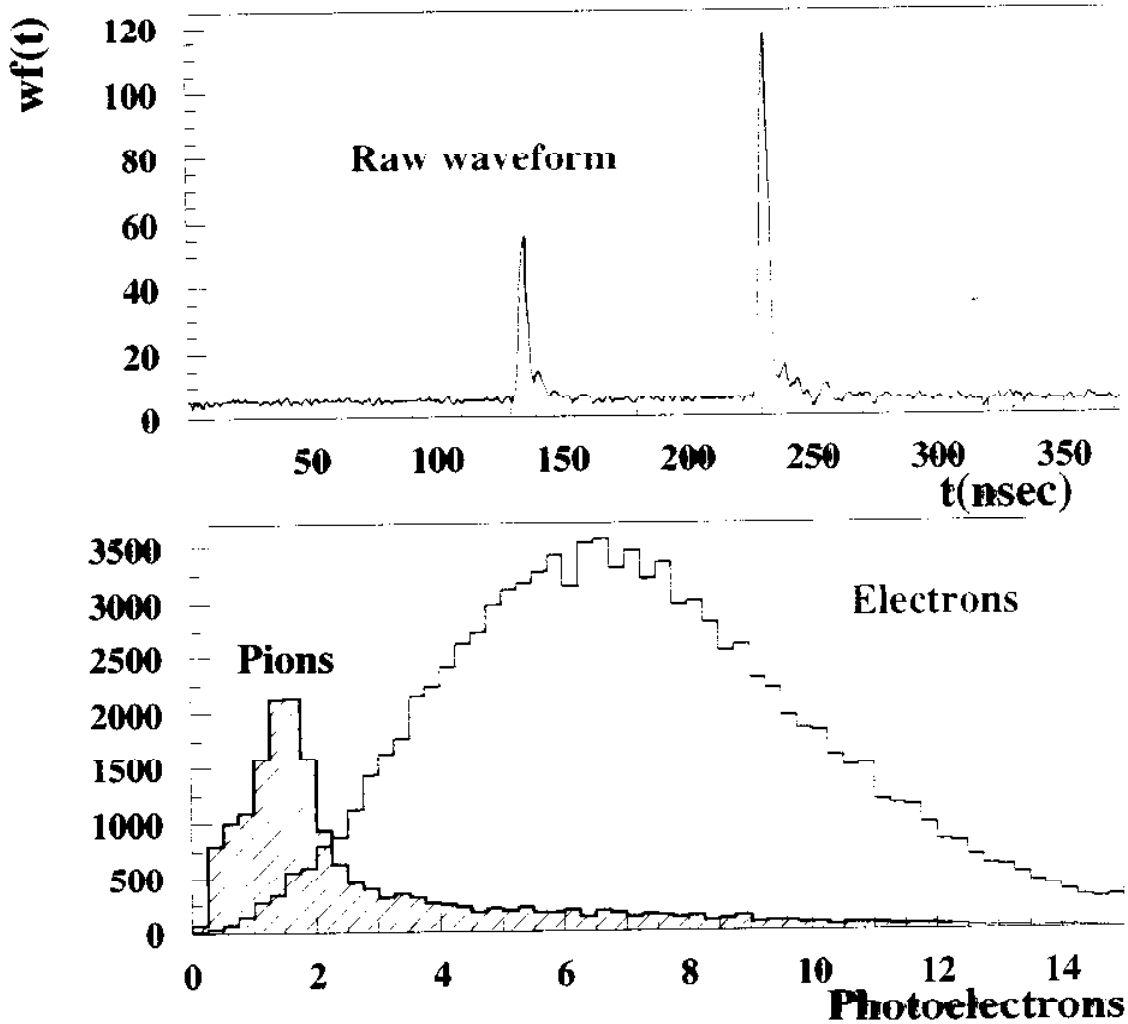
E154 dilution factor



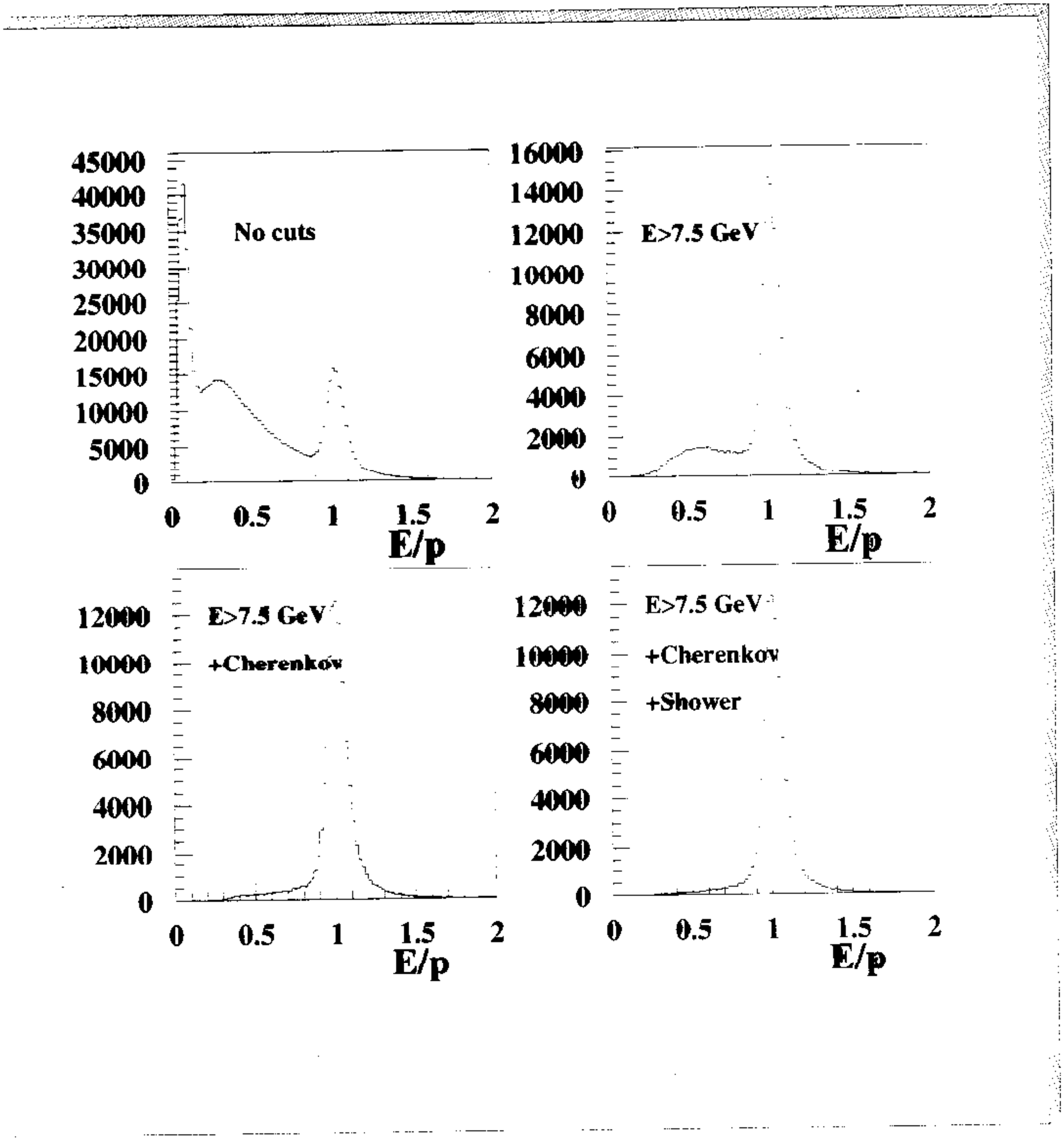
E154 Spectrometers Setup



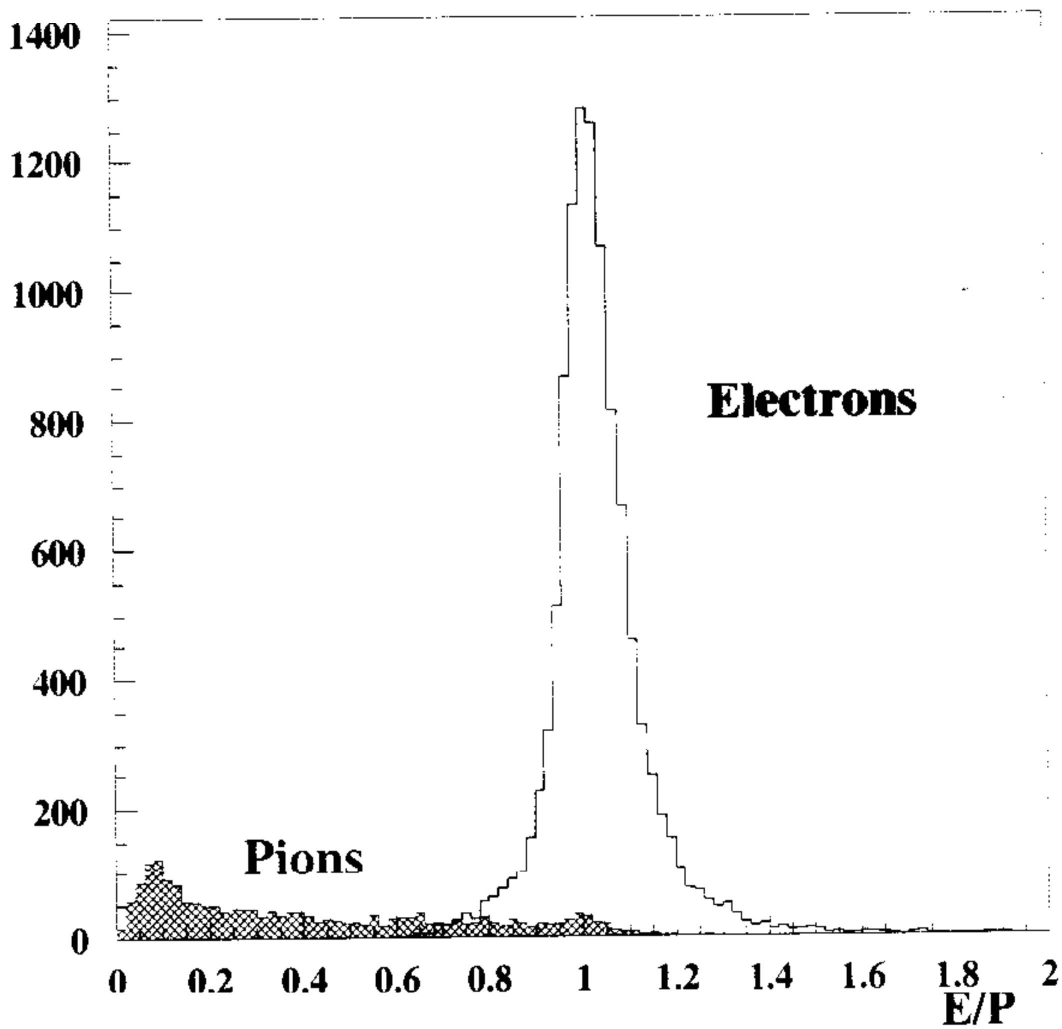
E154 Cherenkov Data



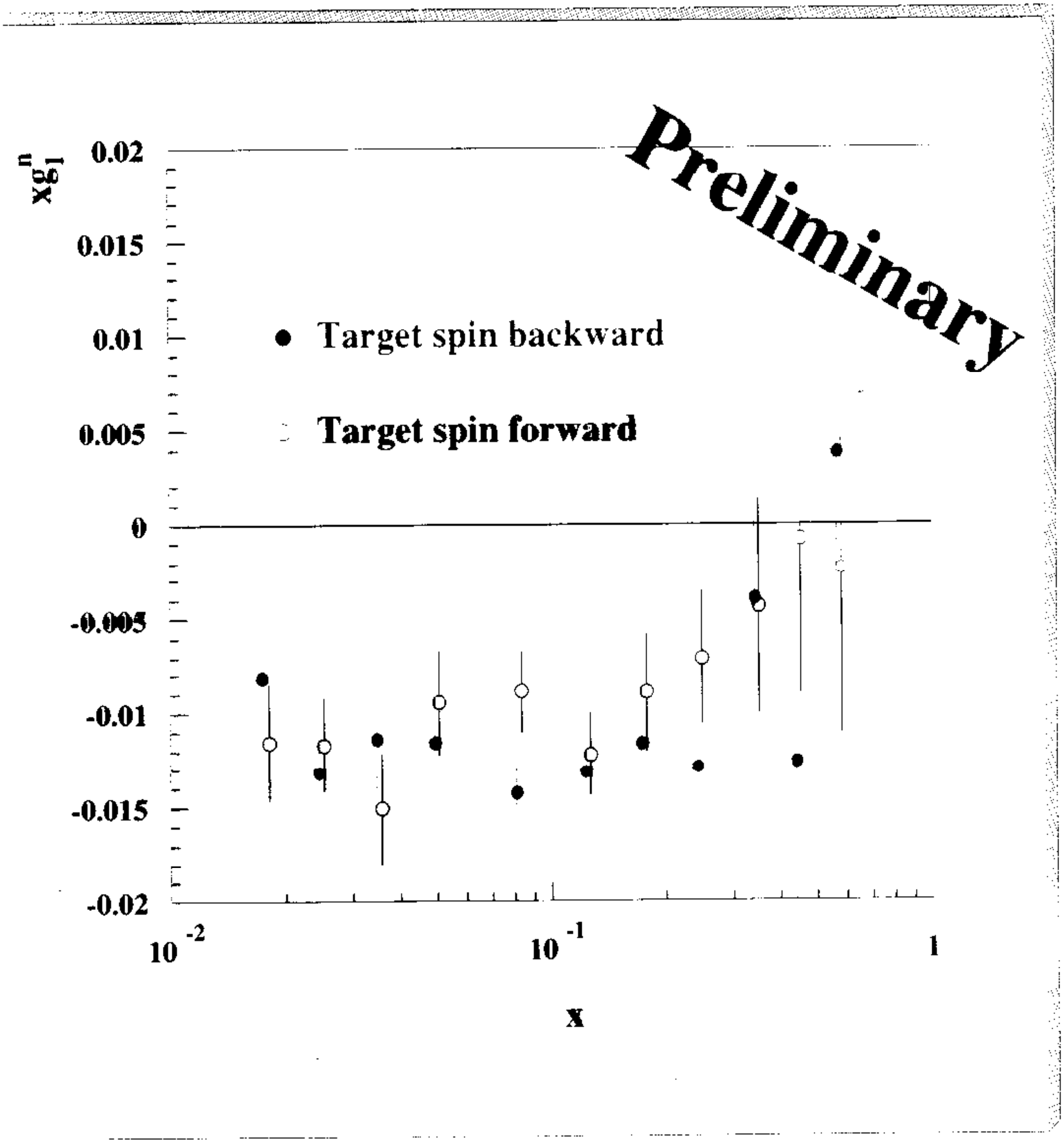
Particle ID: E/p



E/p for x = 0.017

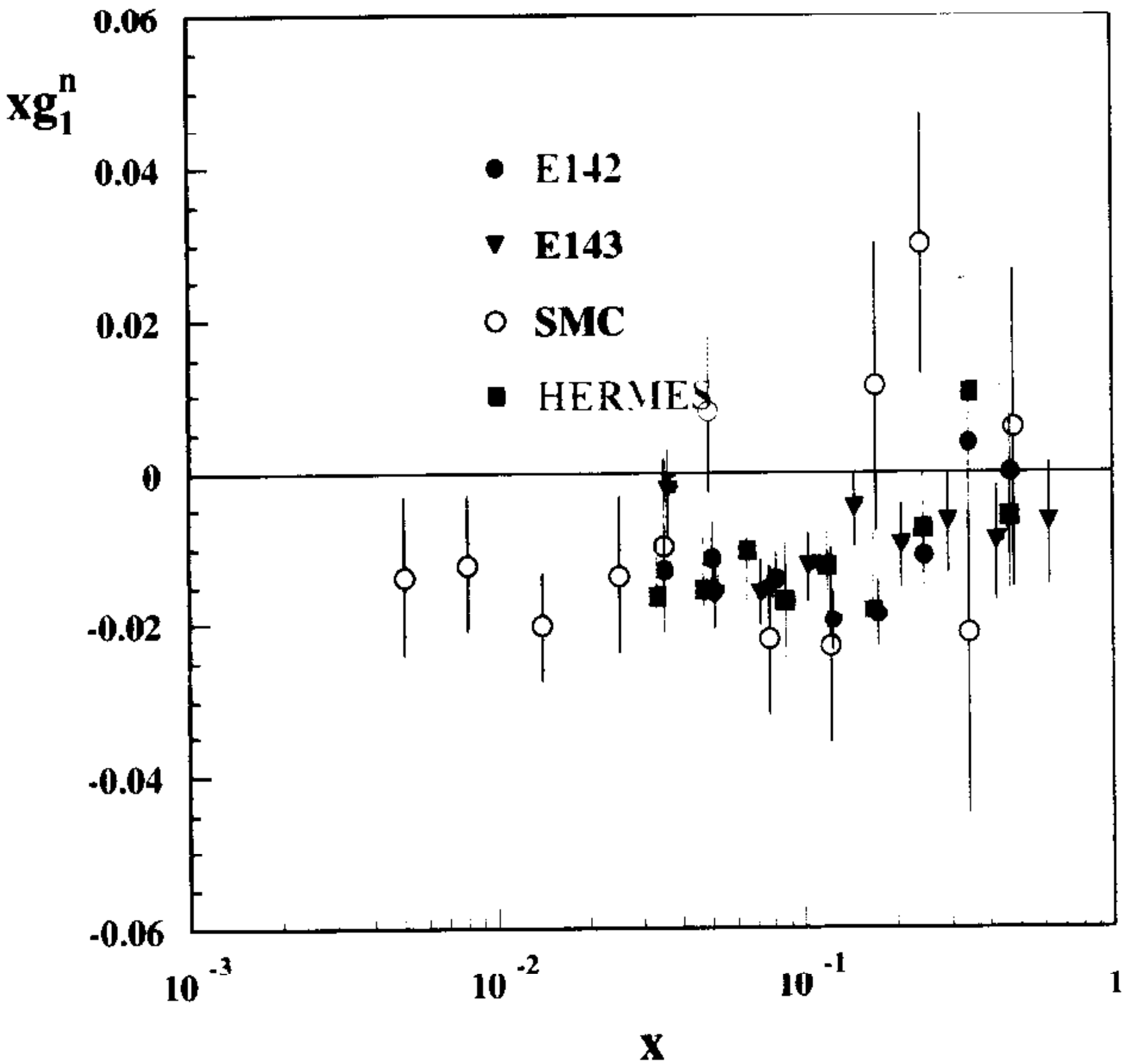

1400
1200
1000
800
600
400
200
0
Electrons
Pions
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
E/P

E154

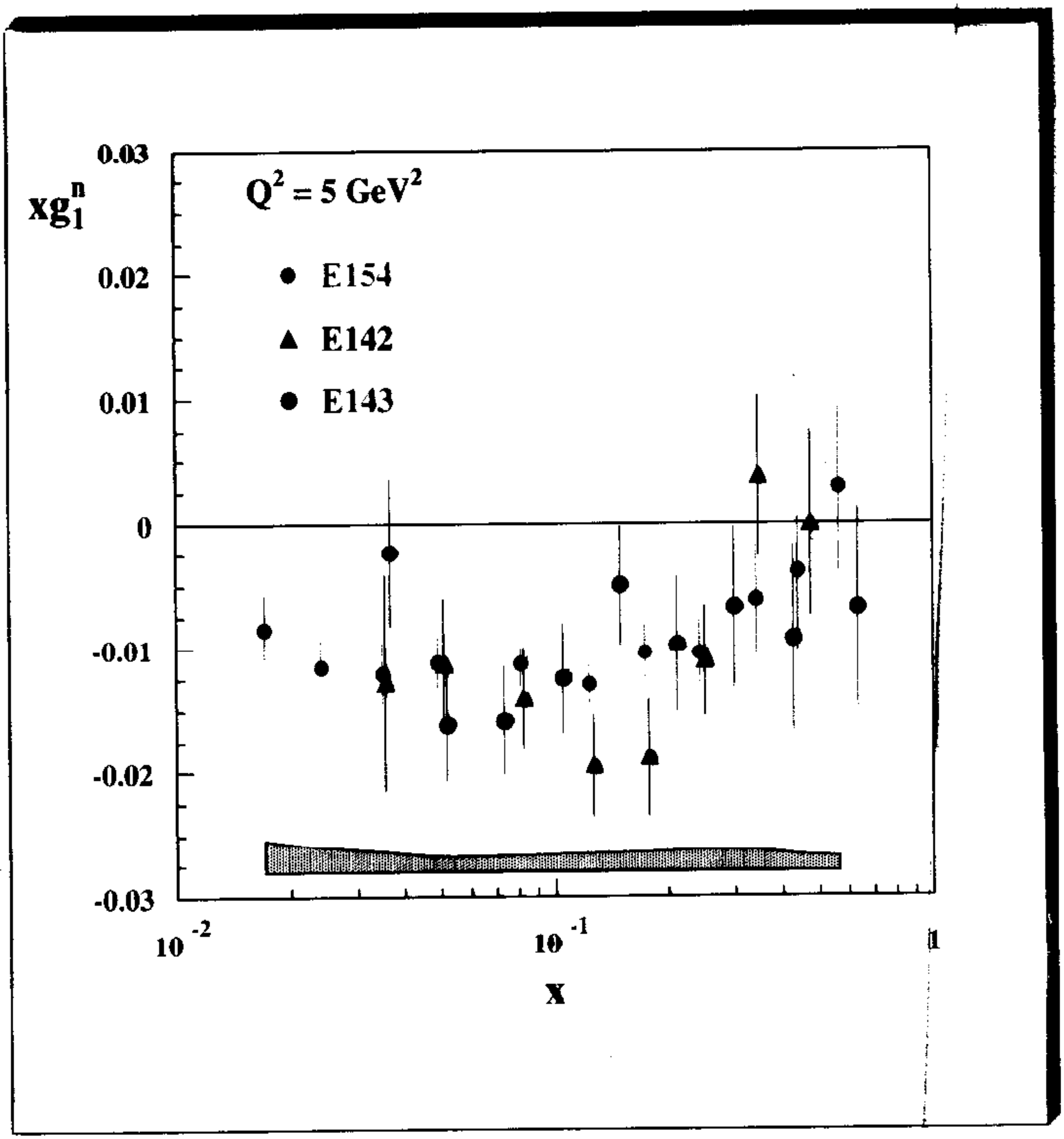


Preliminary
xg_1^n
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
Target spin backward
Target spin forward
10^{-2}
10^{-1}
1
x

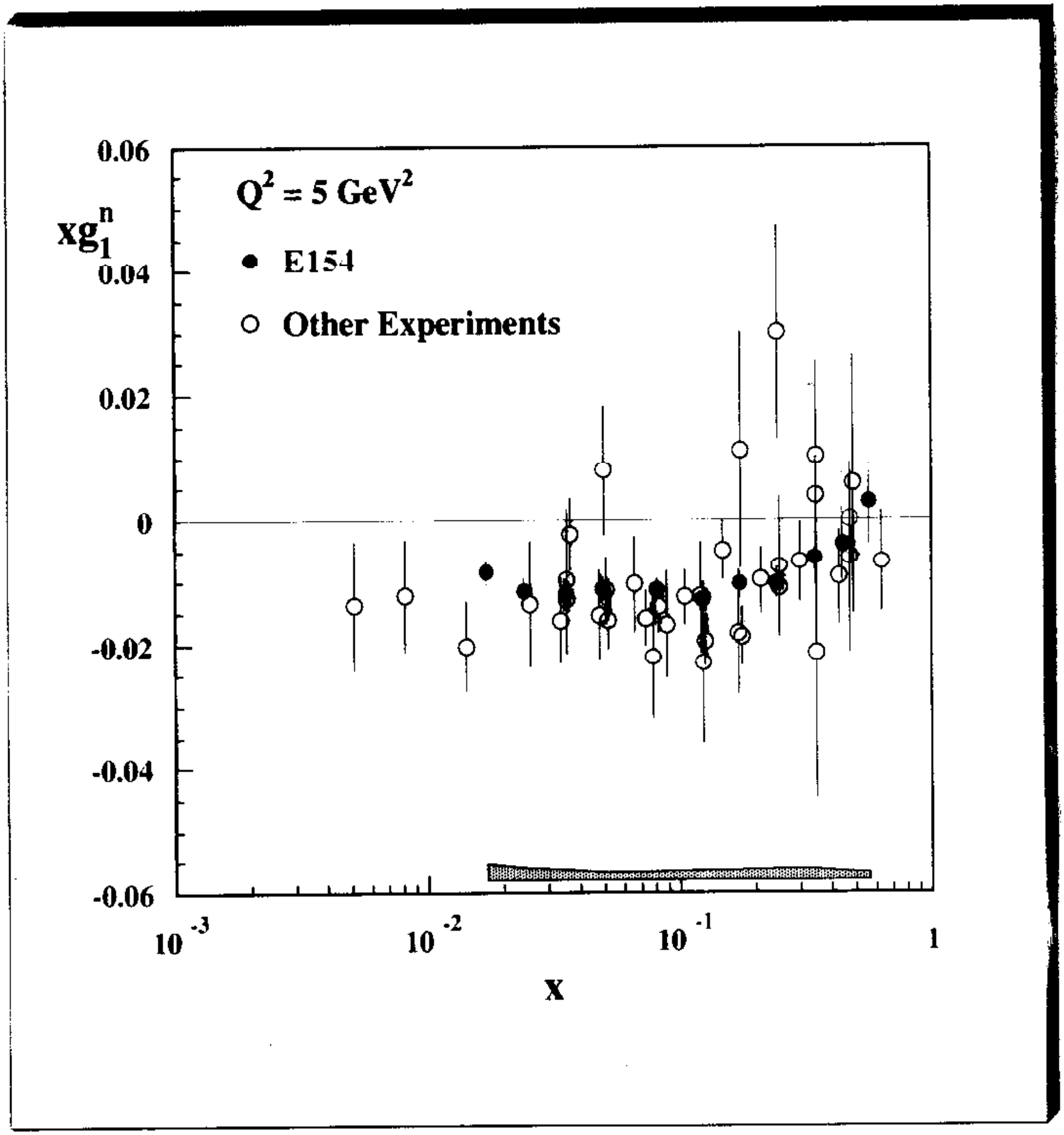
Neutron World Data



SLAC Experiments

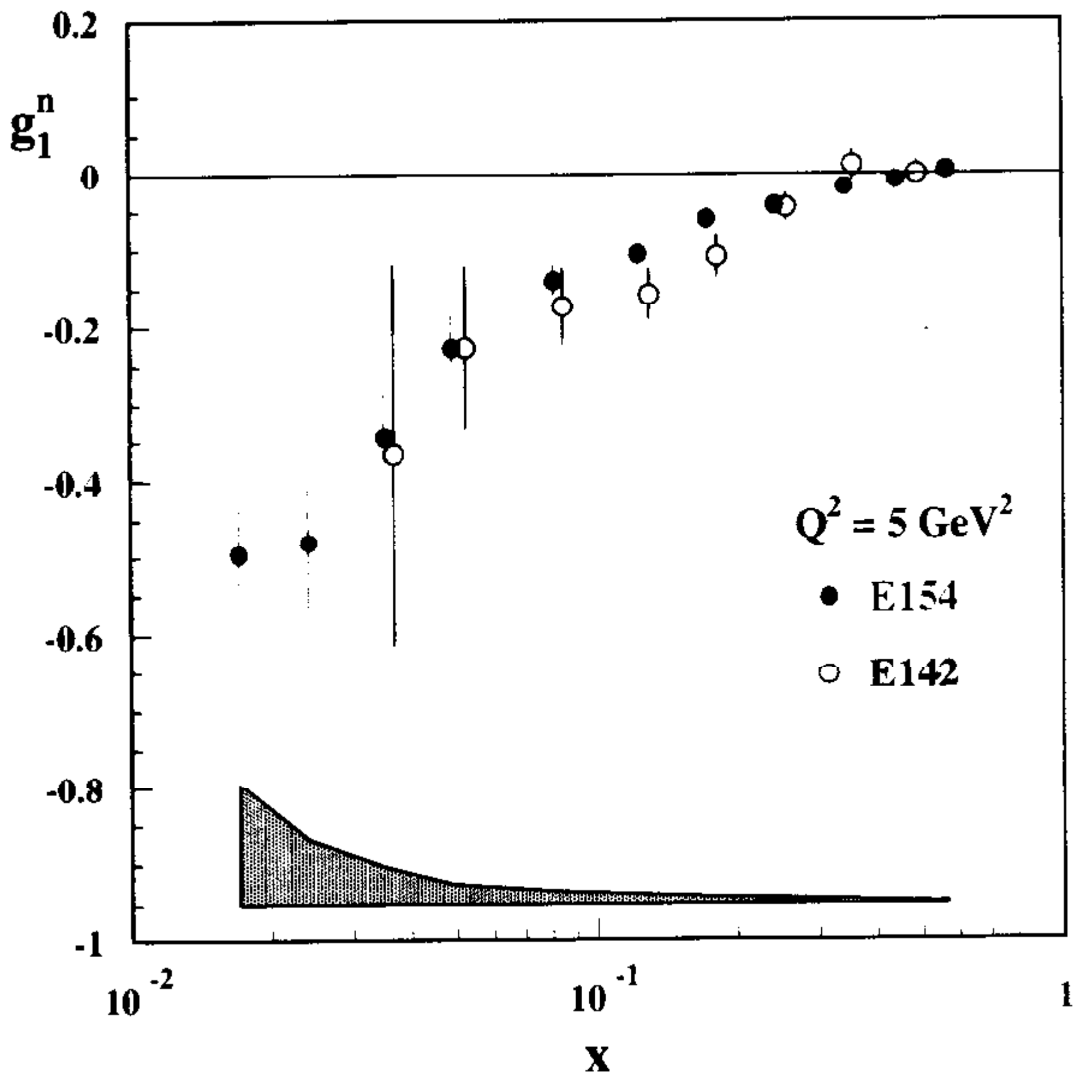


Neutron

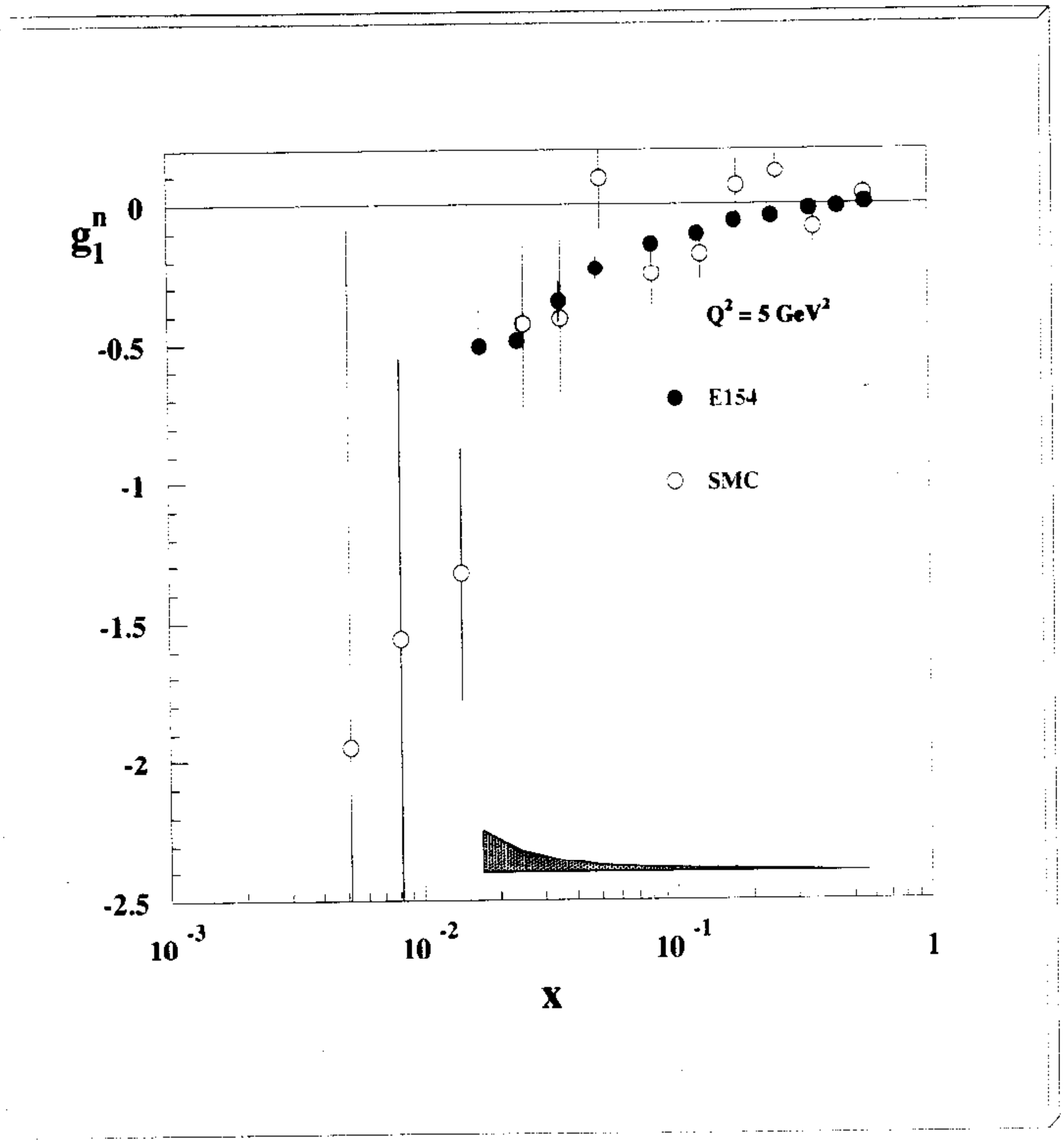


$Q^2 = 5\ GeV^2$
E154
Other Experiments
xg_1^n
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
10^{-3}
10^{-2}
10^{-1}
1
x

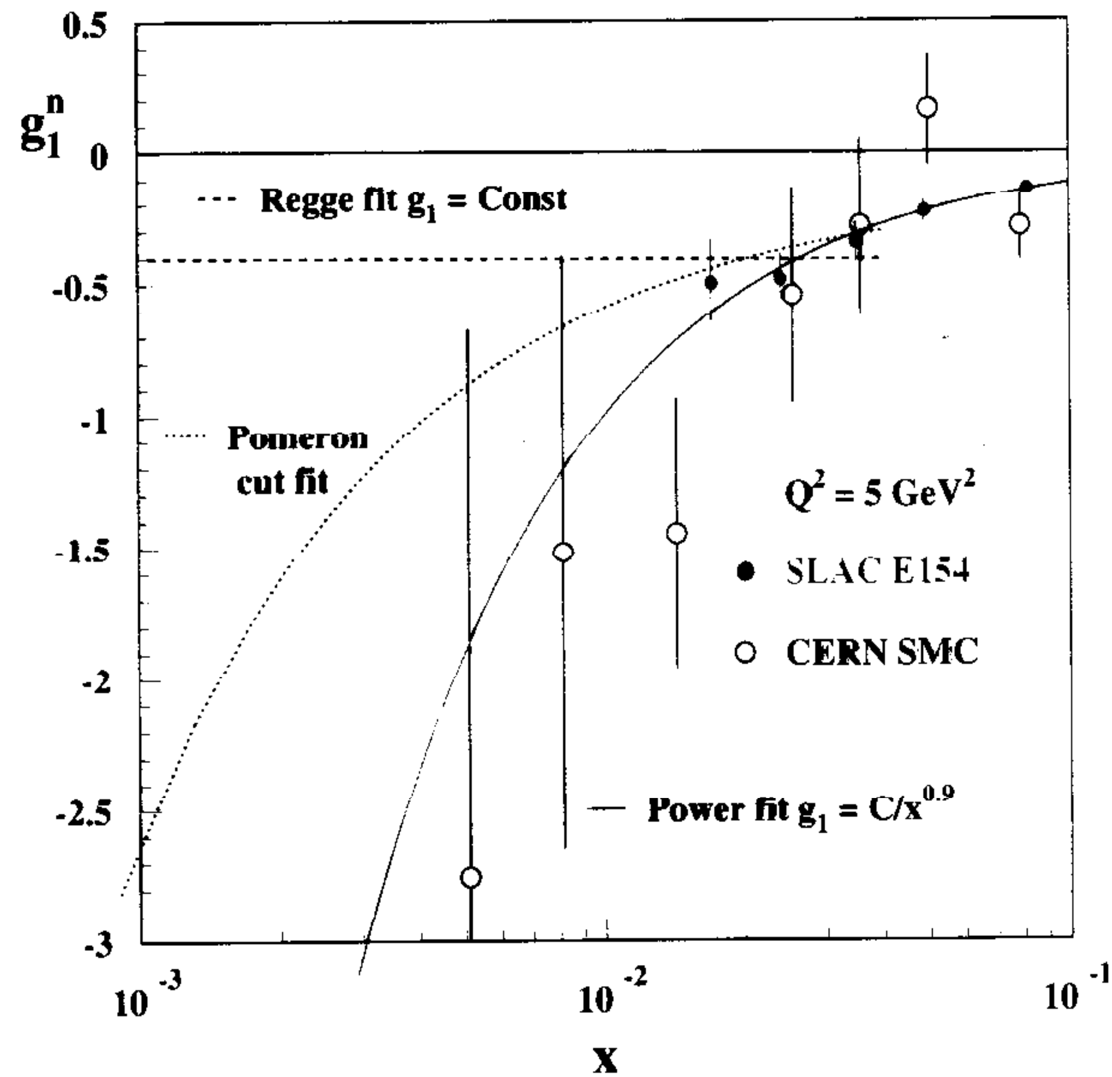
E154 versus E142



Neutron

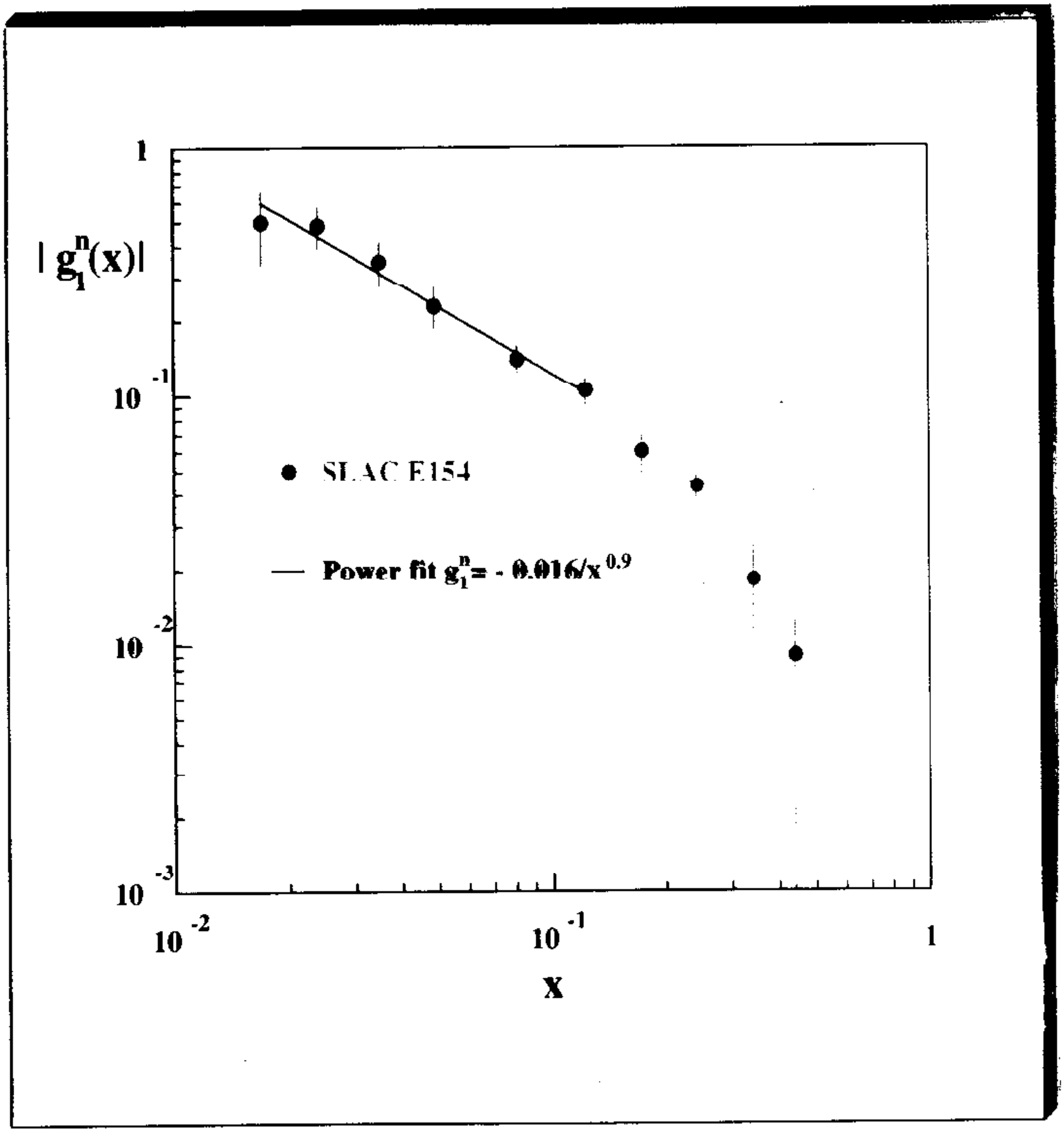


Low x fits

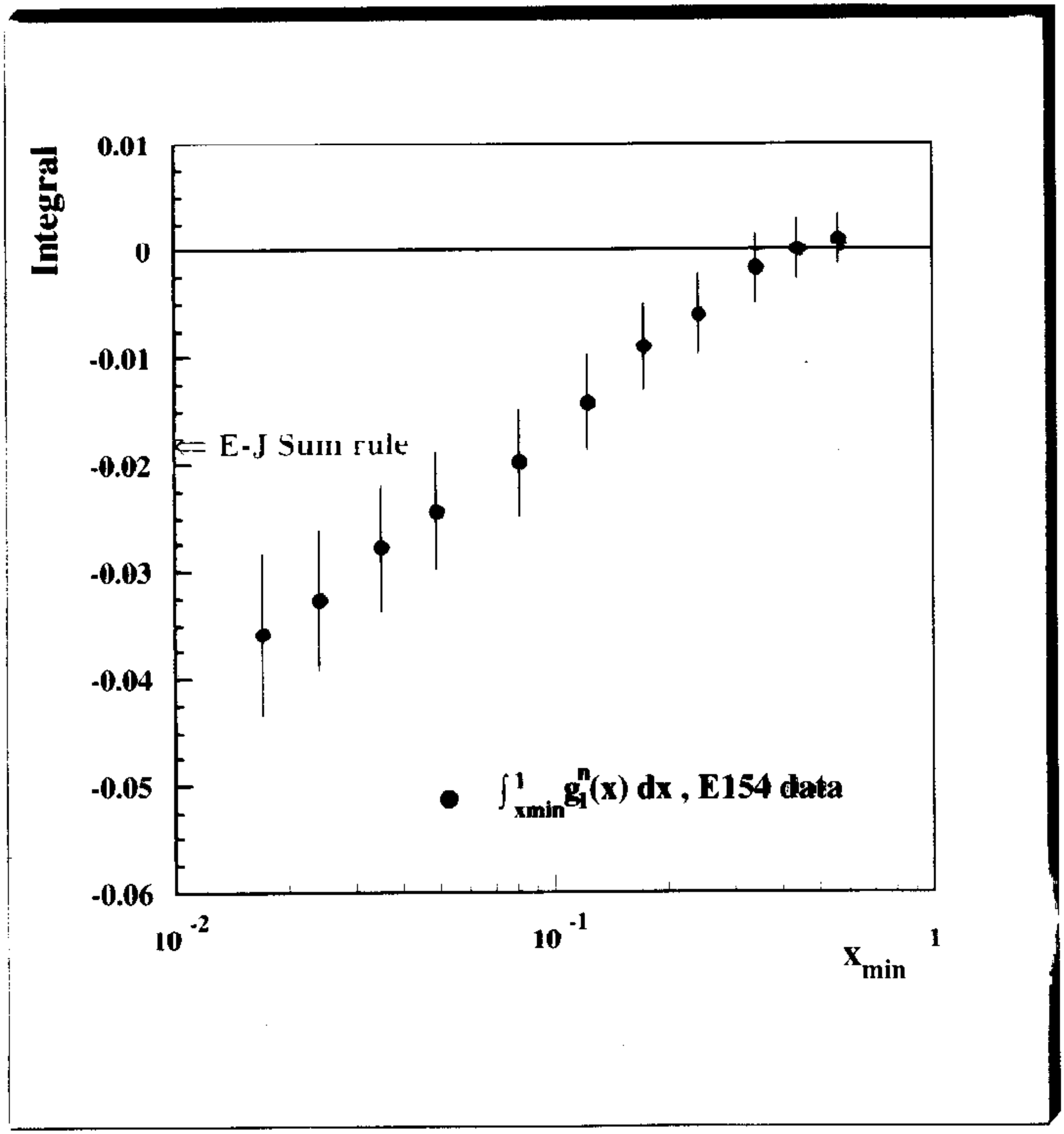


0.5
g_1^n
0
-0.5
-1
-1.5
-2
-2.5
-3
--- Regge fit g_1 = Const
...... Pomeron cut fit
$Q^2 = 5\ GeV^2$
SLAC E154
CERN SMC
— Power fit $g_1 = C/x^{0.9}$
10^{-3}
10^{-2}
10^{-1}
x

Low x



Neutron integral



Neutron Experimental Integral

at $Q^2 = 5\ GeV^2$

$$\Gamma^n_{exp}(Q^2) = \int_{0.014}^{0.7} g_1^n\,(x,Q^2)\,dx = -\,0.036 \pm 0.004(stat) \pm 0.005(syst)$$

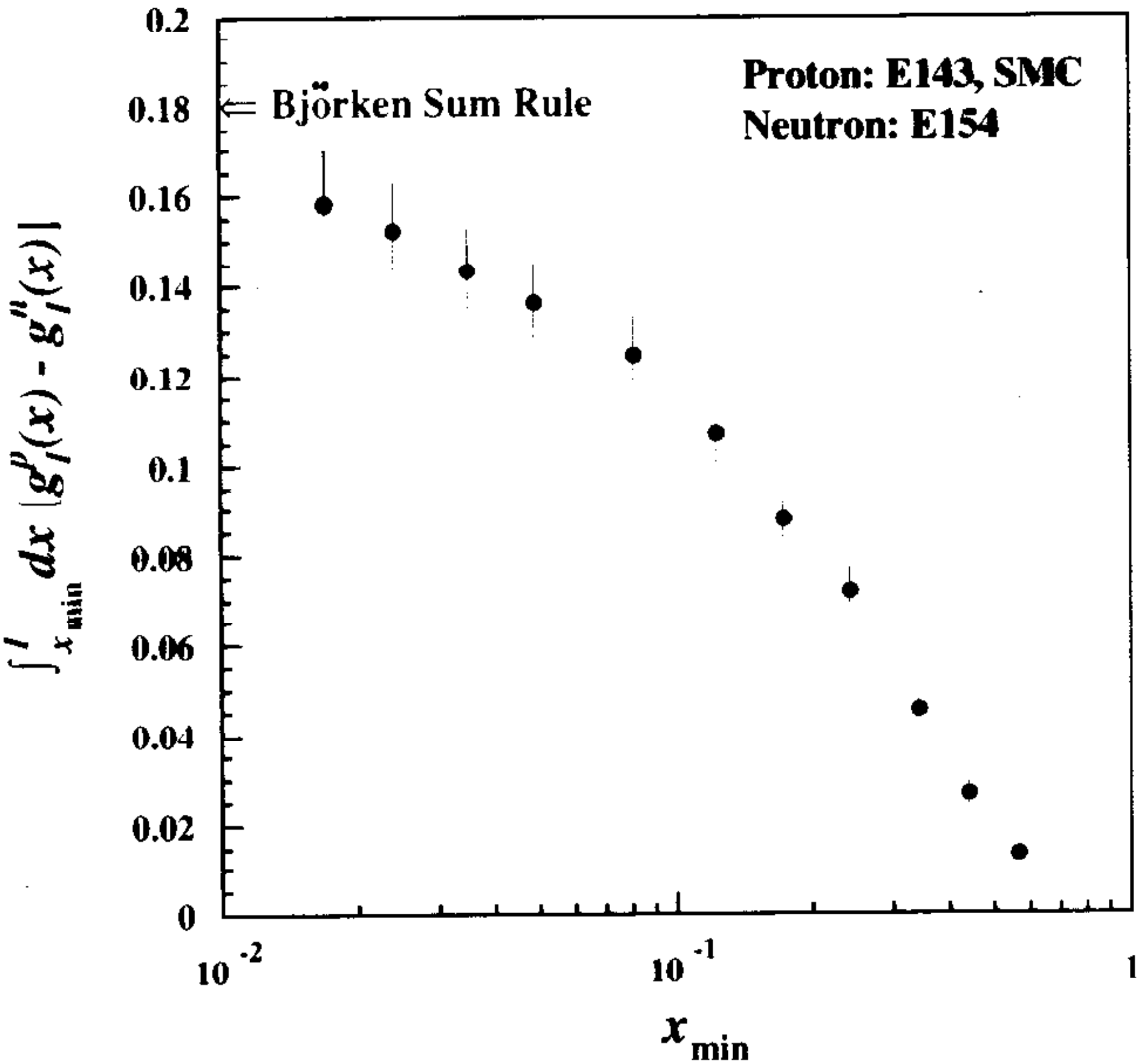
Regge theory extrapolation => $g^n \sim x^{-\alpha}$ with $-0.5 < \alpha < 0$

$$\Gamma^n(Q^2) = \int_0^1 g_1^n\,(x,Q^2)\,dx = -0.041 \pm 0.004(stat) \pm 0.006(syst)$$

Unconstrained Power Law => $g^n \sim x^{-\alpha}$, $\alpha = 0.9 \pm 0.2$

$$\Gamma^n(Q^2) = \int_0^1 g_1^n\,(x,Q^2)\,dx = -0.2 \ \text{for } \alpha \sim 0.9, \text{ diverges for } \alpha \sim 1$$

Björken Sum Rule



Physics Implications

- Divergent low x Behavior!
  - Estimate of Total Integral Unreliable.
  - Simple Regge Theory?
  - Strong Q^2 Dependence at low x?

- **Low x behavior may point to a major role for gluons inside nucleons.**

- Tremendous Motivation for More Data at New Facilities.

$g_2(x, Q^2)$ Structure Function

- Burkhardt-Cottingham (BC) sum rule $\int_0^1 g_2(x, Q^2) dx = 0$

→ Annals of Physics, **56**, 453 (1970).

- Wandzura-Wilczek g2 expression (twist-2 only)

$$g_2^{WW}(x, Q^2) = -g_1(x, Q^2) + \int_x^1 \frac{dy}{y} g_1(y, Q^2)$$

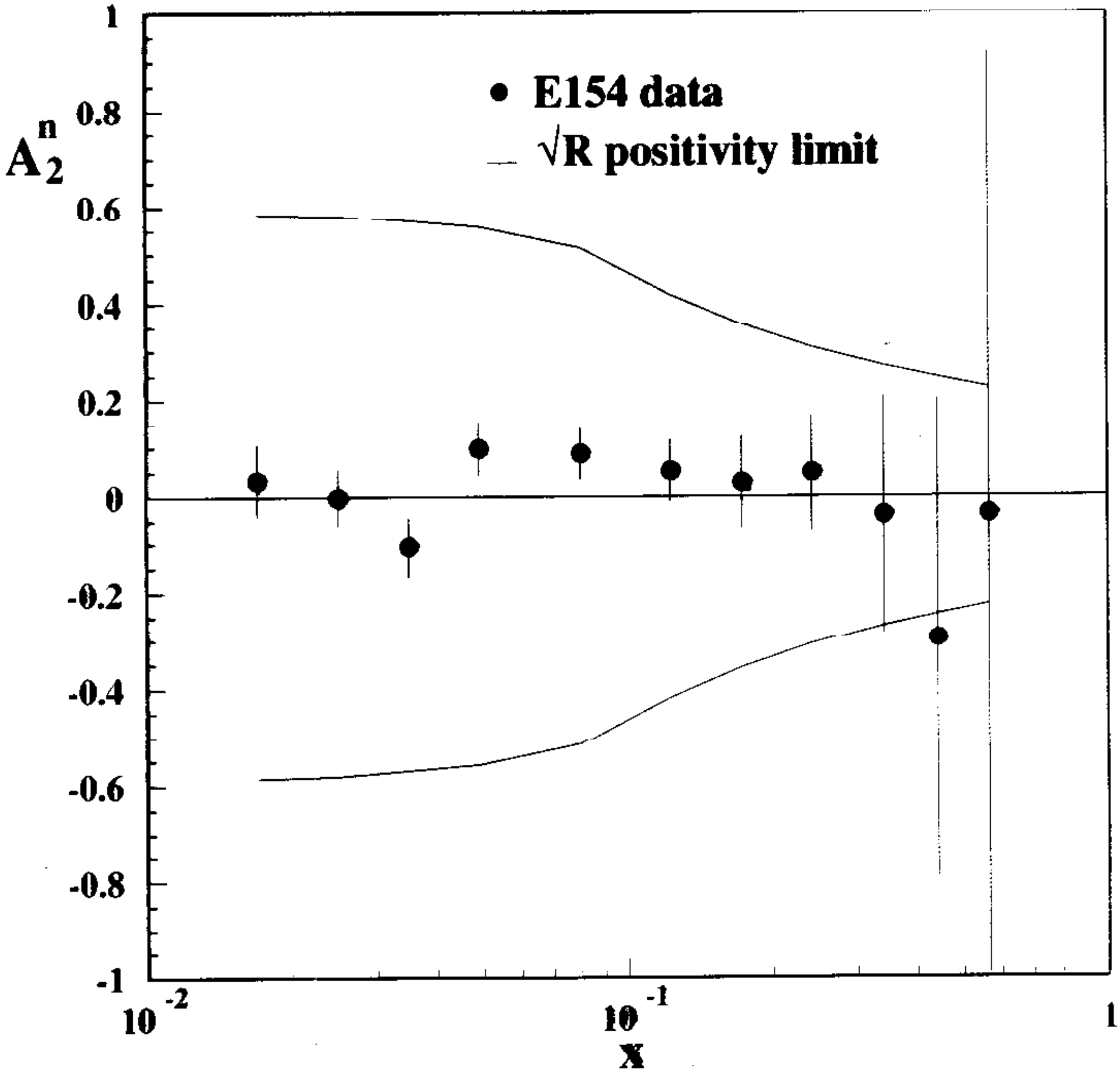
→ Wandzura and Wilczek, PL 72B, 195 (1977).

- g_2^{WW} obeys the Burkhardt-Cottingham sum rule
- In general there are additional contributions.

$$g_2(x, Q^2) = g_2^{WW}(x, Q^2) - \int_x^1 \frac{\partial}{\partial y}\left(\frac{m}{M} h_T(y, Q^2) + \xi(y, Q^2)\right)\frac{dy}{y}$$

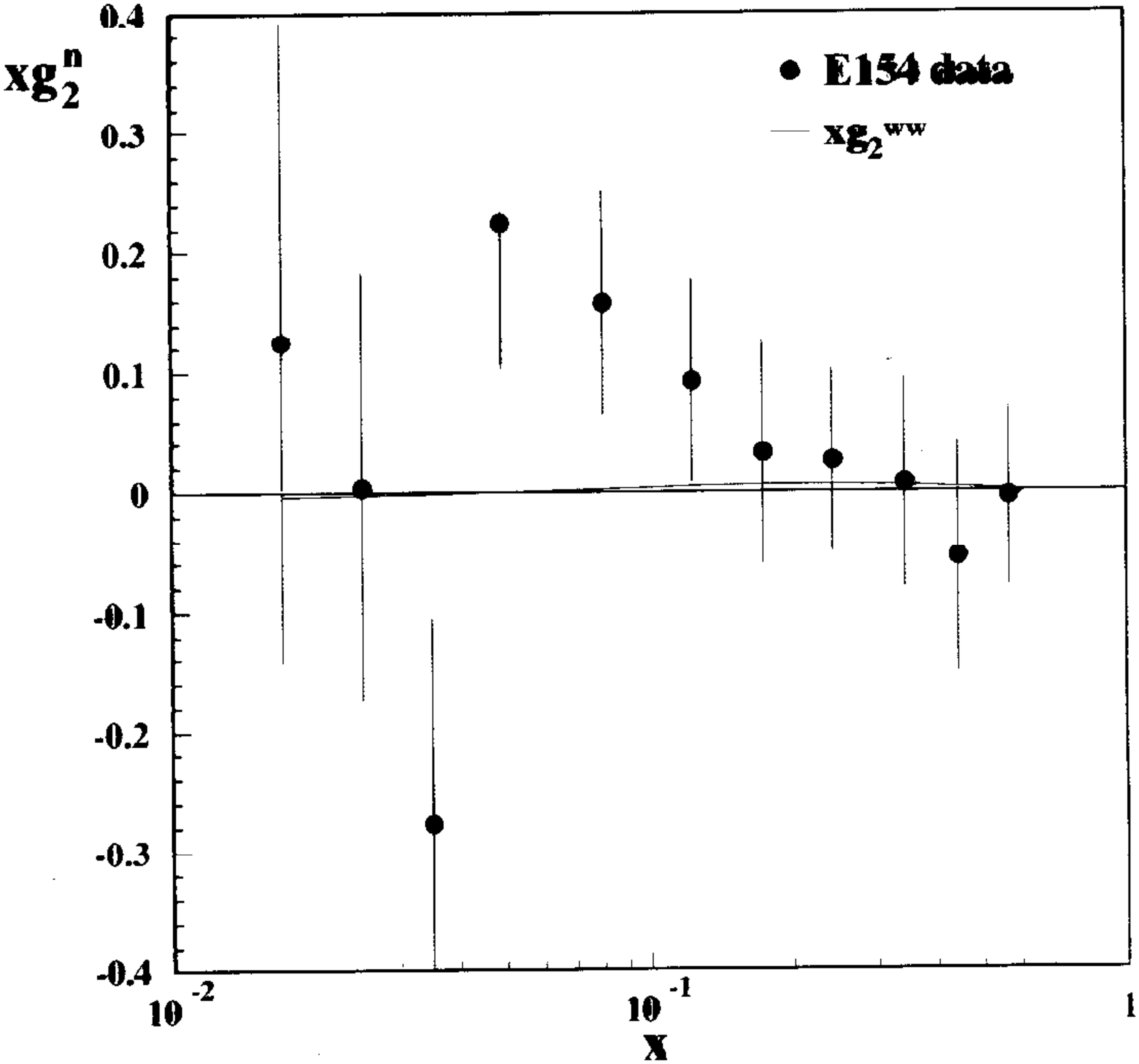
$$= g_2^{WW}(x, Q^2) + \overline{g_2(x, Q^2)}$$

- $\overline{g_2}$ measures quark-gluon correlations inside the nucleon and depends on quark masses and parton transverse momentum. It is especially interesting since it provides a new probe of QCD dynamics.

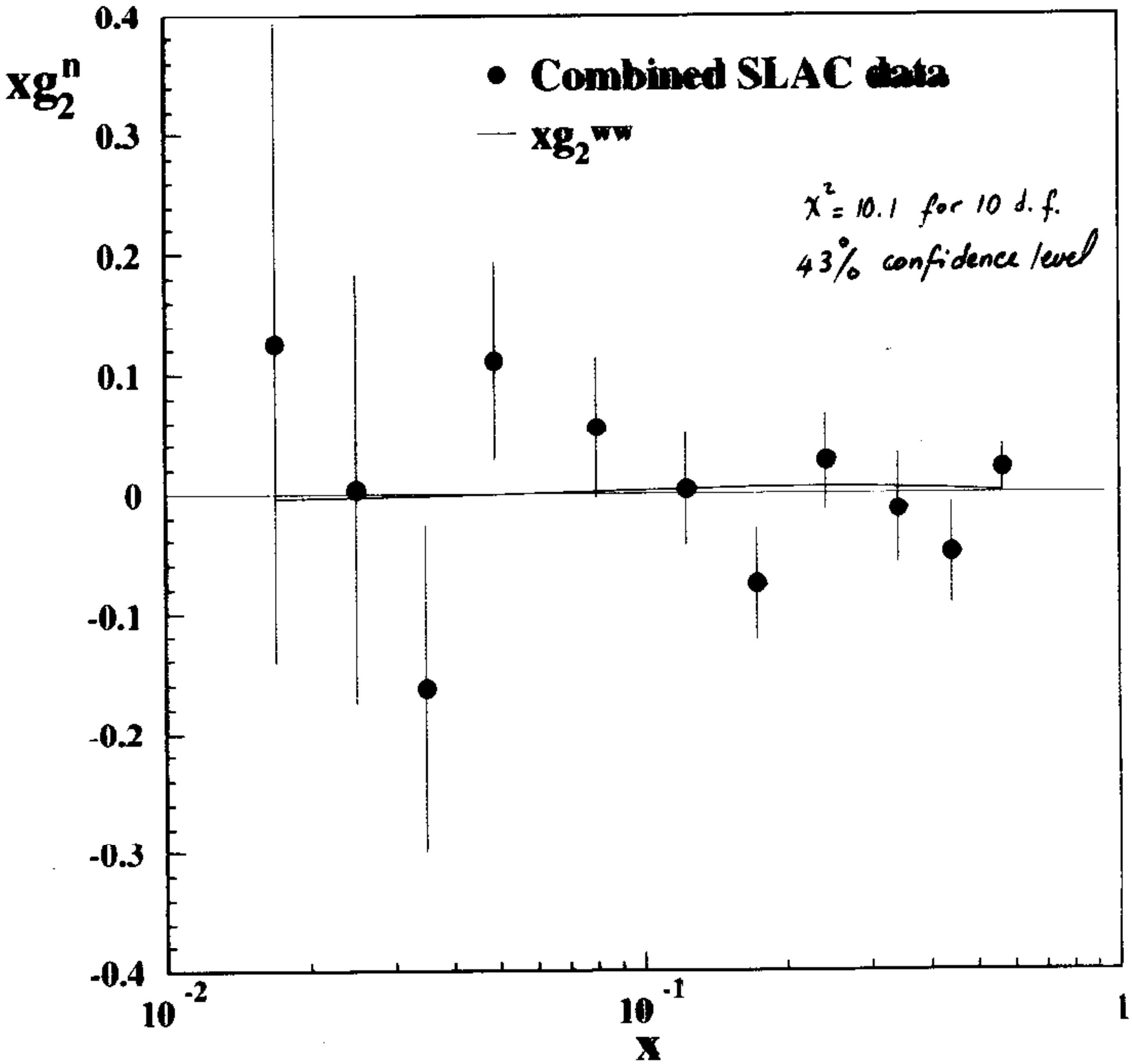


E154 data
√R positivity limit
A_2^n
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
10 -2
10 -1
1
x

NEUTRON xg_2



Neutron xg_2



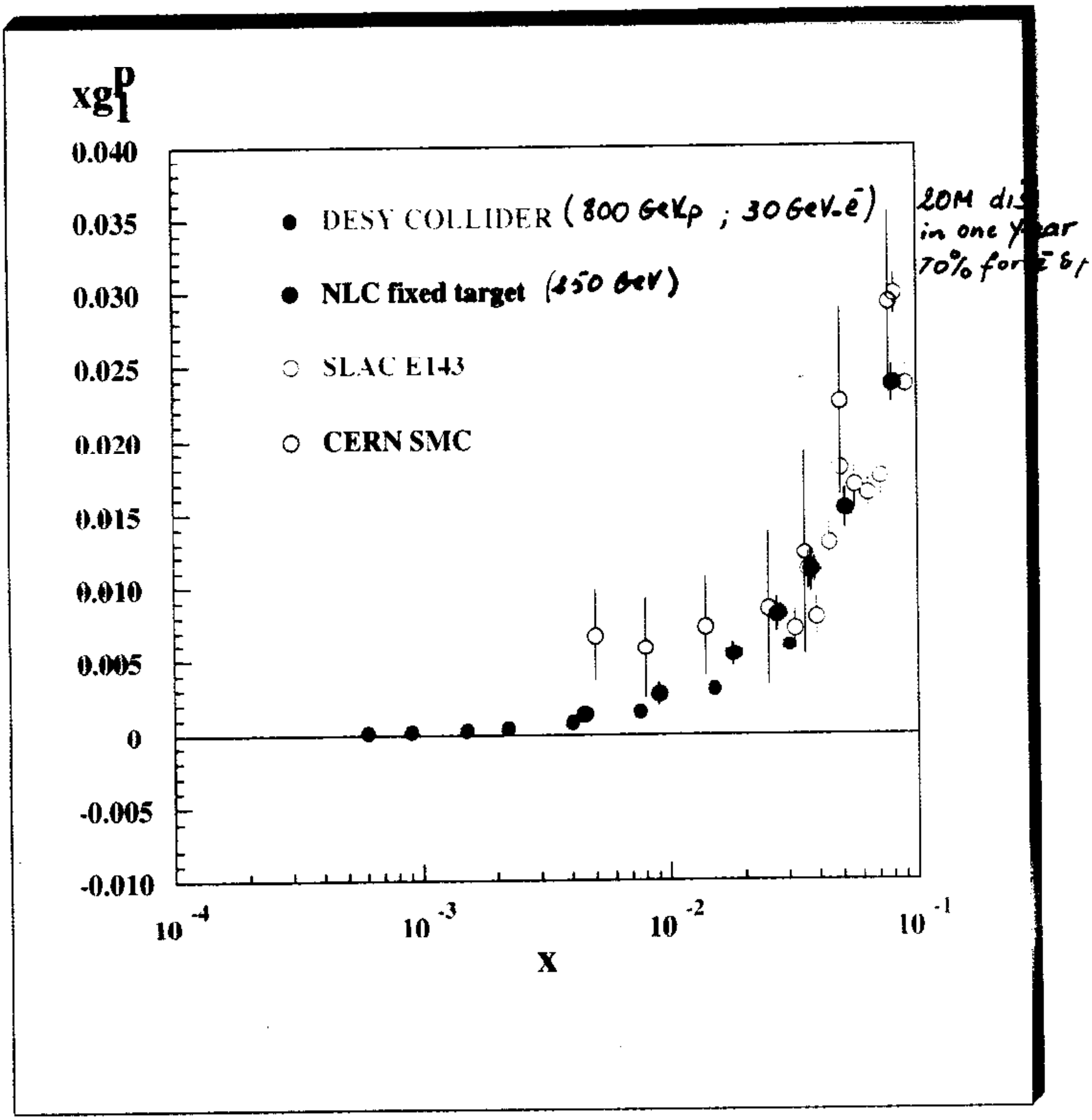
xg₂ⁿ
Combined SLAC data
xg₂ʷʷ
χ² = 10.1 for 10 d.f.
43% confidence level
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
10⁻²
10⁻¹
1
x

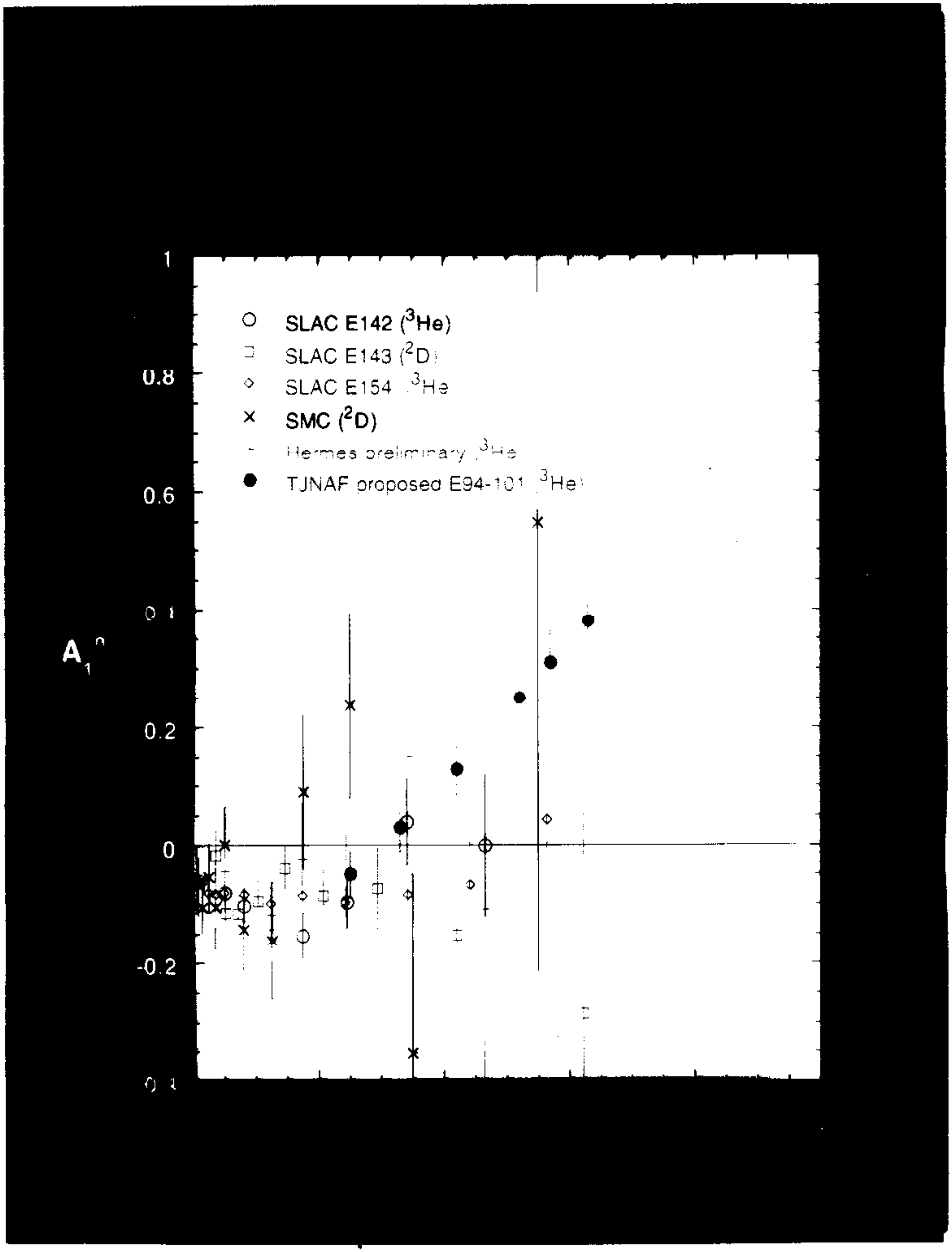
Comparison of Experimental and Theoretical Results for the Reduced Twist-3 Matrix Element

	$d_2^n \times 10^2$	$Q^2 (GeV/c)^2$
E154 result	-0.3±3.8	5.0
SLAC Average	-1.0±1.6	5.0
QCD sum rule [1]	-3±1	1.0
QCD sum rule [2]	-2.7±1.2	1.0
Bag Model [3]	0	5.0
Bag Model [4]	-0.253	5.0
Bag Model [5]	0.03	5.0
Lattice QCD [6]	-0.39±0.27	4.0

[1] E. Stein *et al.*, Phys. Lett. B 343 (1995) 369.
[2] I. Balitsky *et al.*, Phys. Lett. B 242 (1990) 245.
[3] X. Ji and P. Unrau, Phys. Lett B 333 (1994) 228.
[4] X. Song, Phys. Rev. D 54 (1996) 1955.
[5] M. Stratmann, Z. Phys. C 60 (1993) 763.
[6] M. Göckeler *et al.*, Phys. Rev. D 53 (1996) 2317.

Proton Spin Structure Function





SLAC E142 (3He)
SLAC E143 (2D)
SLAC E154 (3He
SMC (2D)
Hermes preliminary (3He
TJNAF proposed E94-101 (3He)
A1n
1
0.8
0.6
0.2
0
-0.2

FUTURE

- Polarize the Protons at HERA.
- Fixed Target Physics at the NLC could have a decisive impact.
- Measure the high x region of the neutron at CEBAF