[ONE THEORIST'S PERSPECTIVE ON]
FOUR ERAS OF ELECTRON-PROTON SCATTERING

DRELL SYMPOSIUM
SLAC JULY 31, 1998

"ANCIENT EXPLORERS IN SEARCH OF DISTANT LANDS AND TREASURES HAD NO IDEA HOW GREAT THE CHALLENGE OR HOW DIFFICULT THE PASSAGE. THEY SAILED INTO UNCHARTED SEAS. THEIR ONLY SCALE OF DISTANCES CAME FROM PREVIOUS JOURNEYS STARTING FROM ANCIENT PHOENICIA AND... CRETE, THROUGH THE MEDITERRANEAN TO THE NORTH SEA.

"... WE CAN LOOK BACK TODAY WITH THE ANCIENT MARINERS AND VIEW HOW FAR WE HAVE PROGRESSED ... IN OUR EXPLORATIONS OF THE LEPTON-[HADRON] FRONTIERS OF NATURE *

* "KNOWN & UNKNOWN REGIONS IN LEPTON PHYSICS" S.D. DRELL PROC. 1973 LEPTON-PHOTON SYMPOSIUM, BONN.

A DRELL CREDO:

" I JUST WANT TO REMARK ABOUT THE USE OF THE DGS REPRESENTATION. WHEN I STARTED THIS PROBLEM, I STUDIED THIS REPRESENTATION IN DETAIL AND FOUND THAT IT WAS TO ME VOID OF ANY PHYSICS. THEREFORE I PUT THIS DGS REPRESENTATION ASIDE AND WILL NOT USE IT AGAIN, BECAUSE WITH PURE MATHEMATICAL JIGGLING AROUND YOU CAN'T SOLVE PHYSICS. I CAN'T UNDERSTAND HOW TO EVEN APPROXIMATELY INTRODUCE PHYSICS INTO THE DGS SPECTRAL FUNCTION AND SO I GIVE IT UP. *

* "INELASTIC ELECTRON SCATTERING, ASYMPTOTIC BEHAVIOR & SUM RULES" S.D. DRELL IN SUBNUCLEAR PHENOMENA, 1969 ERICE SCHOOL

"FOUR ERAS OF ELECTRON-PROTON SCATTERING" ?

★ TITLE BY PESKIN –

★ APOLOGIES

- NOT A REVIEW AND NOT A HISTORY
- A SINGLE PATH IN THE SUM OVER HISTORIES. IDEOSYNCRATIC, PERHAPS OCCASIONALLY PROVOKATIVE.

1 THE ARCHAIC ERA 1954 - 1966

THE EMERGENCE OF SIMPLE ELECTRON SCATTERING SOCIETIES ON THE SHORES OF SAN FRANCISCO BAY [SIMILAR TO CONTEMPORARY REMAINS IN CAMBRIDGE & HAMBURG.]

2 THE CLASSIC ERA 1966 - 1972

CREATION OF THE ARCHETYPES, RICH INTERACTION OF PRIESTLY & ARTISIAN CLASSES, BARBARIAN INVASION, CLIMAXING IN CREATION OF QCD.

3 HELLENISTIC ERA 1972-1980

ELECTRON SCATTERING CULTURE SPREADS THROUGHOUT THE CIVILIZED WORLD. THE DEEP INELASTIC RITUAL DOMINATES. WITH NOTABLE EXCEPTIONS, LOCAL CULTURE AT SLAC TURNS ELSEWHERE.

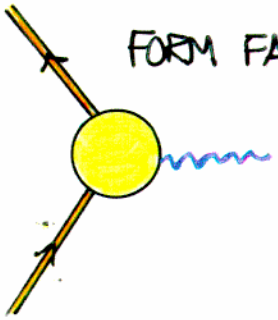
4 RENAISSANCE 1983 - ?

INTEREST IN DEEP INELASTIC PROCESSES IS REBORN AS A PROBE OF CONFINEMENT

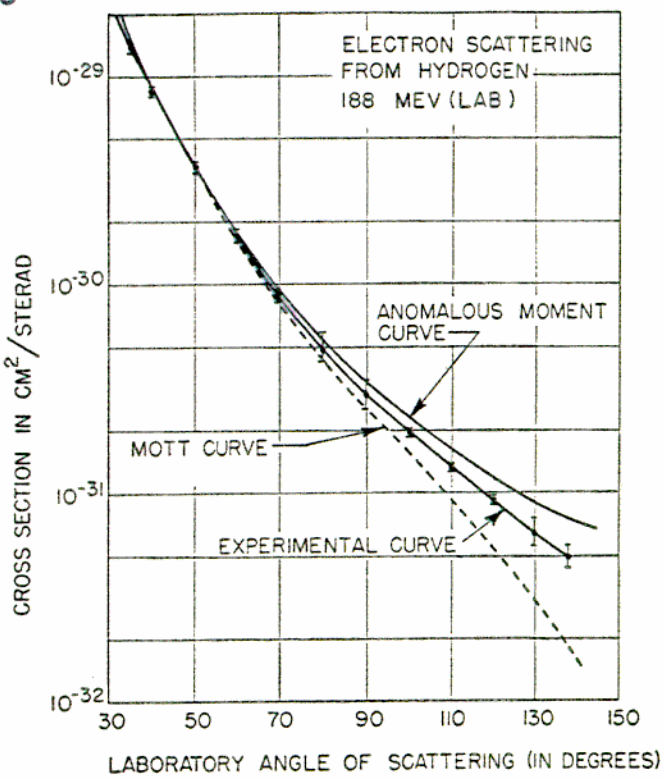
S. DRELL AT THE BEGINNING OF THE ARCHAIC PERIOD. BEFORE CALIFORNIAN MIGRATION

1 THE ARCHAIC ERA 1954 - 1966

$ep \to ep$ AT HEPL. HOFSTADTER & COLLABORATORS



FORM FACTORS $F(q^2)$



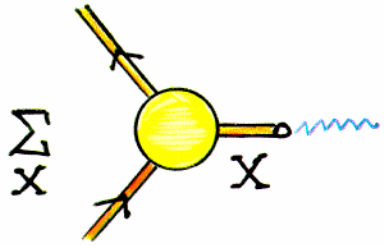
R. HOFSTADTER & R. McALLISTER
PHYS. REV. 98 (1955) 217

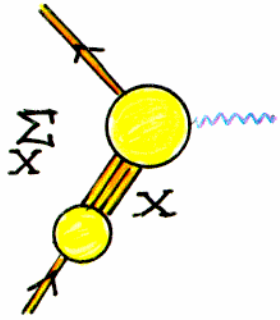
- ★ PROTON IS COMPOSITE
- ★ FORM FACTOR MEASURES CURRENT DISTRIBUTION AT LOW MOMENTUM TRANSFER.

- ★ DRELL & ZACHARIASEN "ELECTROMAGNETIC STRUCTURE OF NUCLEONS"

- NUCLEONS PROVED VERY COMPOSITE: DIPOLE FORM FACTOR, ABUNDANCE OF RESONANCES.

$$F(q^2) = \frac{1}{(1 + q^2/0.71)^2}$$





?

- INTERPRETATION OF $F(q^2)$

$$F(0) = Q \qquad dF/dq^2\Big| = \frac{1}{6}\langle r^2\rangle$$

NON-RELATIVISTIC CONNECTION: $F(q^2) \Longleftrightarrow \int d^3r\, e^{i\vec{q}\cdot\vec{r}}\rho(r)$
DIES IN RELATIVISTIC QFTy.

★ 1962 REVIEW OF INELASTIC ELECTRON SCATTERING (W. CARL BARBER) SPECIFICALLY EXCLUDES PARTICLE (ie PION) PRODUCTION

★ MAJOR EFFORT ⟹ HADRONIC DEMOCRACY, BOOTSTRAP NO PICTURE (COORDINATE SPACE). WHAT IS A PROTON? A NEUTRON + A PION. WHAT IS A NEUTRON? A PROTON PLUS A PION. WHAT IS A PION? A PROTON PLUS AN ANTINEUTRON. WHAT IS... ACTUALLY TAKEN SERIOUSLY!

★ SLAC & INELASTIC SCATTERING

- FRIEDMAN, KENDALL, TAYLOR PROPOSAL
  - ELASTIC
  - RESONANCE
  - CONTINUUM — EXPECTATIONS

  } OFT TOLD STORY PART OF HEP MYTHOLOGY

- BJORKEN, GOURDIN, DRELL & WALECKA*
  INELASTIC KINEMATICS, $W_{\mu\nu}$, PRODUCTION

* ANN PHYS 28 (1964) 18.

Proceedings of the

XIII th INTERNATIONAL CONFERENCE

ON HIGH-ENERGY PHYSICS

University of California
Held at Berkeley, California, August 31 - September 7, 1966

Introductory Session

CURRENT TOPICS IN PARTICLE PHYSICS

Murray Gell-Mann

We consider three hypothetical and probably fictitious spin 1/2 quarks,

Now what is going on? What are these quarks? It is possible that real quarks exist, but if so they have a high threshold for copious production, many BeV; if this threshold comes from their rest mass, they must be very heavy and it is hard to see how deeply bound states of such heavy real quarks could look like $q\bar{q}$, say, rather than a terrible mixture of $q\bar{q}$, $qq\bar{q}\bar{q}$, and so on. Even if there are light real quarks, and the threshold comes from a very high barrier, the idea that mesons and baryons are made primarily of quarks is difficult to believe, since we know that, in the sense of dispersion theory, they are mostly, if not entirely, made up out of one another. The probability that a meson consists of a real quark pair rather than two mesons or a baryon and antibaryon must be quite small. Thus it seems to me that whether or not real quarks exist, the q and $\bar{q}$ we have been talking about are mathematical; in particular, I would guess that they are mathematical entities that arise when we construct representations of current algebra, which we shall discuss later on. Their effective masses, to the extent that these have meaning, seem to be of the order of one-third the nucleon mass. One may think of mathematical quarks as the limit of real light quarks confined by a barrier, as the barrier goes to an infinitely high one.

If the mesons and baryons are made of mathematical quarks, then the quark model may perfectly well be compatible with the bootstrap hypothesis, that hadrons are made up out of one another.

Session 6

ELECTRODYNAMIC INTERACTIONS

S. D. Drell, Rapporteur

Drell: I have a remark to myself which I didn't make which says, "what would I like to see measured?" Let me just say briefly that I'd very much like to see inelastic electron or muon cross sections measured; they provide the inelastic nucleon form factors that are of great interest in their own right. Moreover they are also the necessary input that goes into neutron-proton mass-difference calculations, if their isovector structure can be measured, or into the hyperfine-structure calculation, if their spin structure can be determined. Also there are some sum rules, asymptotic statements derived by Bjorken and others, as to how these inelastic cross sections should behave in energy, some of which were mentioned in Dashen's talk on current algebra, and which can be checked experimentally.

★ PROPHETIC VOICES

- K. JOHNSON (1961)

  PHYSICAL AMPLITUDES ARE NOT T-PRODUCTS

  $$T(A(x)B(0)) \longrightarrow T^{\star}(A(x)B(0))$$

  THEY DIFFER BY LOCAL TERMS $\longrightarrow$ POLYNOMIALS IN q.

- BJORKEN & K. JOHNSON & F.E. LOW (1966)

  T-PRODUCTS, COMMUTATORS & THEIR PHYSICAL IMPLICATIONS CAN BE EXTRACTED FROM PHYSICAL AMPLITUDES IN THE $q^0 \to i\infty$ LIMIT. BJORKEN, JOHNSON, LOW LIMIT

- BJORKEN (1966)

  "APPLICATIONS OF THE CHIRAL $U(6) \otimes U(6)$ ALGEBRA OF CURRENT DENSITIES" PHYS REV 148 (1966) 1467

  - $q^0 \to i\infty \Longrightarrow$ DEEP INELASTIC LIMIT
  - $[J_\mu^a(\vec{x}), J_\nu^b(\vec{y})] = \cdots \delta^3(\vec{x}-\vec{y})\, \Theta^{ab}_{\mu\nu}$

LOCAL?

$$\left.\begin{array}{l}\text{BJ - YES}\\ \text{HEΦ (1966) - NO}\end{array}\right\} \text{QCD - ALMOST}$$

$$Z_p - Z_n = \frac{1}{3}\left(\frac{G_A}{G_V}\right). \tag{6.17}$$

Thus,

$$\int_0^\infty \frac{d\nu'}{\nu'} \frac{d}{dq^2 d\nu'} \times [\sigma_p{}^{\uparrow\uparrow} - \sigma_p{}^{\downarrow\uparrow} - \sigma_n{}^{\uparrow\uparrow} + \sigma_n{}^{\downarrow\uparrow}] \to \frac{-8\pi\alpha^2}{3q^4 E}\left(\frac{G_A}{G_V}\right). \tag{6.18}$$

Something may be salvaged from this worthless equation by constructing an inequality[18]:

$$\lim_{q^2 \to -\infty} \lim_{E \to \infty} q^4 E \int_0^\infty \frac{d\nu}{\nu'}\left[\frac{d\sigma_p}{dq^2 d\nu'} + \frac{d\sigma_n}{dq^2 d\nu'}\right] > \frac{8\pi\alpha^2}{3}\left|\frac{G_A}{G_V}\right|. \tag{6.19}$$

---

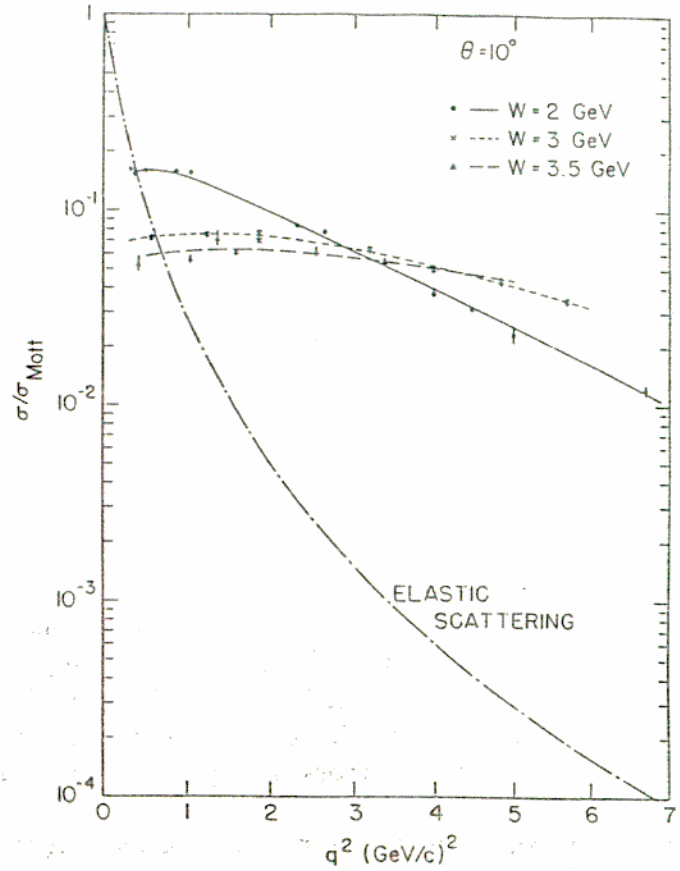
[17] Compare Eqs. (5.7)–(5.9).
[18] $\sigma_p = \sigma_p{}^{\uparrow\uparrow} + \sigma_p{}^{\uparrow\downarrow}$.

BJORKEN'S EQ (6.19) AND THE TURN-ON OF THE SLAC-MIT EXPERIMENT MARK THE END OF THE ARCHAIC ERA.

S. DRELL WITH W.K.H. PANOFSKY AT 1968 VIENNA CONFERENCE

2 THE CLASSICAL ERA

1966-1972

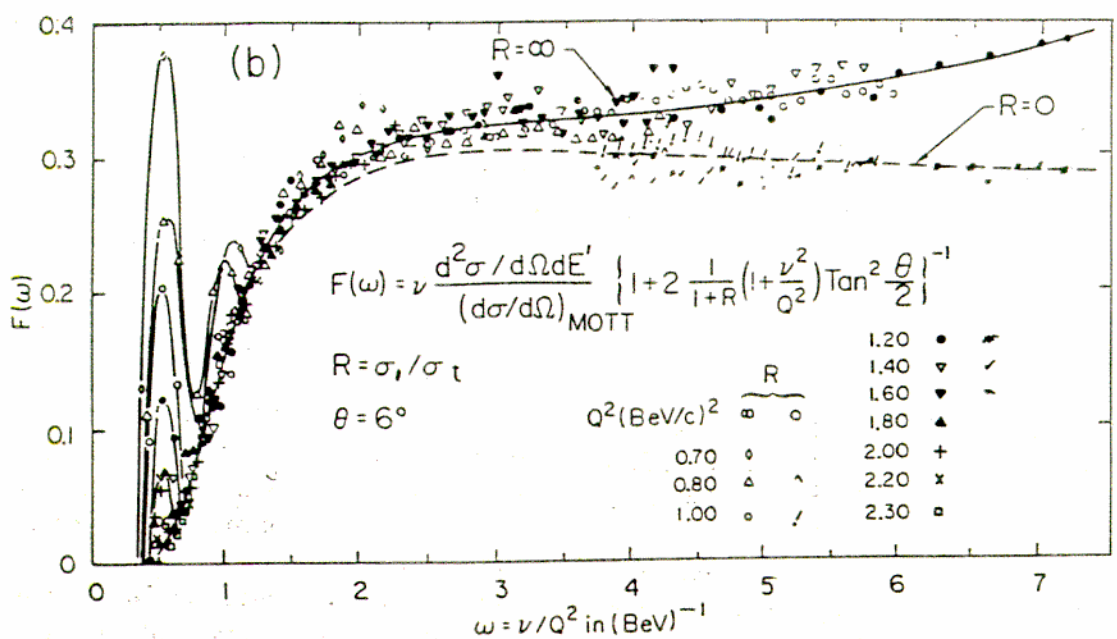


- ★ $\frac{\sigma}{\sigma_{MOTT}}$ ~ INDEPENDENT OF Q^2
- ★ STRUCTURE FUNCTIONS SCALE
- ★ STRUCTURE FUNCTIONS ARE NUMERICALLY SMALL (FAVOR FRACTIONAL CHARGE)

1968 VIENNA CONFERENCE

PARALLEL SESSION TALK BY J. FRIEDMAN

PLENARY TALK BY W.K.H. PANOFSKY



- BOOKS HAVE BEEN WRITTEN ABOUT THIS PERIOD IN SLAC'S HISTORY — I WILL LEAVE THE MAINSTREAM TO THE HISTORIANS.

- PERSPECTIVE OF A YOUNG (THEN) THEORIST —

  IF QCD WAS A "KUHNIAN" REVOLUTION IN THE HISTORY OF SCIENCE, THEN THESE WERE PRE-REVOLUTIONARY TIMES. PEOPLE WERE FREELY USING CONTRADICTORY IDEAS & KNEW IT.

- MURRAY GELL-MANN (1971 CORAL GABLES CONFERENCE)

  "NATURE READS BOOKS ON FREE FIELD THEORY"

- LIGHT-CONE CURRENT ALGEBRA (GELL-MANN, FRITZSCH)

$$\left[J_\mu^a(x), J_\nu^b(0) \right] \Big|_{x^+=0} = \text{ELEMENTARY FREE FIELD THEORY}$$

BUT

$\langle P | \Theta | P \rangle$ — OPERATOR MATRIX ELEMENTS WERE NOT TO BE TAKEN FROM F.F. Th.

CONSERVATIVE, COULD NOT BE APPLIED BEYOND DIS.

- PARTONS (FEYNMAN, BJORKEN, PASCHOS)

HARD PROCESSES $\Rightarrow$ FREE PROPAGATION

PROMISCUOUS, ONE DIDN'T KNOW WHERE TO STOP.

- THEORISTS FOUND THEMSELVES CALCULATING THE STRONG INTERACTIONS w/ FREE FIELD THEORY & GETTING THE RIGHT ANSWER.

- REACTIONS

  ★ THE DRELL-LEVY-YAN PROGRAM. P_∞ METHODS (SOON TO BECOME LIGHT-FRONT FIELD THEORY) + $\underset{\sim}{P_\perp}$ CUTOFF $\Longrightarrow$ EXPLICIT MODEL OF PARTON PHYSICS. NEW APPLICATIONS AND CLEARER LIMITS. THE VIRTUES OF AN EXPLICIT MODEL

  ★ "CANONICAL" FIELD THEORY $\longrightarrow$ THE BARBARIAN INVASION.

★ THE ENGLISH INVASION ~1970

D.J. BROADHURST
F.E. CLOSE
J. ELLIS
A.J. HEY +
C.H. LLEWELLYN SMITH

• MIXED INTELLECTUAL GENES WITH LOCAL POPULATION

J.D. BJORKEN
S.J. BRODSKY
S.D. DRELL
F.J. GILMAN
H. HARARI

• AND STUDENTS

MIKE CREUTZ
INGE KARLINER
JOHN KOGUT
JOEL PRIMACK
DAVE SOPER
JOE KISKIS

& BOB JAFFE

CANONICAL FIELD THEORY

OPERATOR QFOy IN COORDINATE OR MOMENTUM SPACE.

- IGNORE PERTURBATIVE ANOMALIES FROM RADIATIVE CORRECTIONS.
- QUARKS, COLOR, VECTOR GLUONS, SOFT ($\bar{q}Mq$) CHIRAL SYMMETRY BREAKING
  - AMOUNTS TO QCD WITH ZERO ANOMALOUS DIMENSION
  - MOMENT SUM RULES (SEE CHLS TALK)
    $\sigma_L/\sigma_T \to 0$, ν & $\bar{\nu}$ SCATTERING, $e^+e^- \to PX$, ETC.

NEGLECT OF SHORT DISTANCE PROBLEMS WAS JUSTIFIED A POSTERIORI BY ASYMPTOTIC FREEDOM IN 1973.

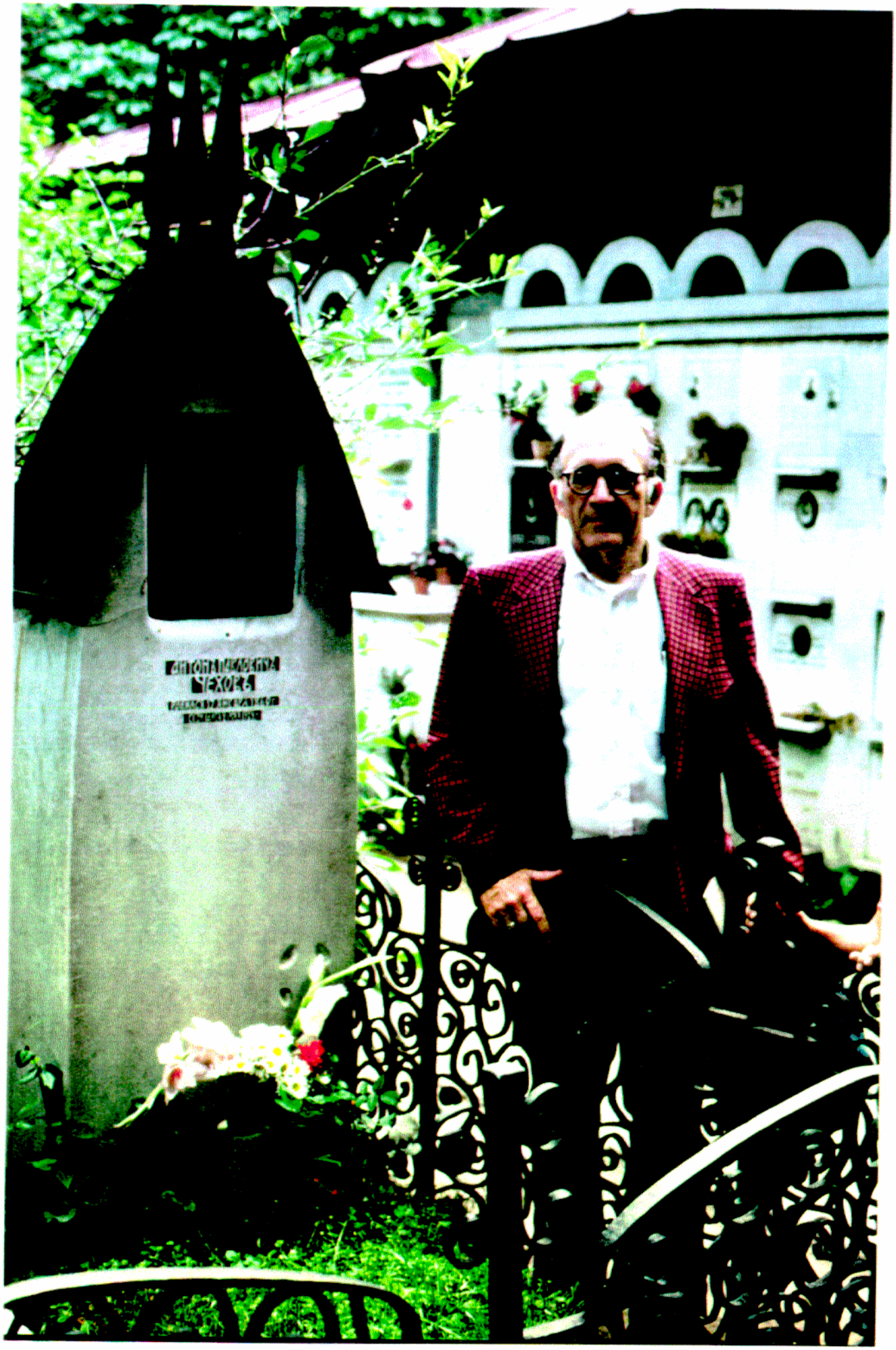
SOME FINAL OBSERVATIONS ON THE CLASSIC ERA —

- IT WAS BJL THAT DOMINATED ASYMPTOTIC ANALYSIS PRE-1972, NOT WILSON'S OPE.

- 1972 PAPER BY N. CHRIST, B. HASSLACHER & A. MUELLER ON OPE ANALYSIS OF DIS HAD A MAJOR IMPACT AT SLAC.

- THE CLASSICAL ERA HAD ALREADY ENDED — ie MAJOR THEORETICAL RESULTS WERE ALREADY IN PLACE — BEFORE DISCOVERY THAT QCD IS ASYMPTOTICALLY FREE.

SID DRELL IN ONE OF SLAC'S DISTANT COLONIES 1974



3 THE HELLENISTIC ERA 1972-1980

A PERIOD OF VAST ACTIVITY & GREAT DISCOVERIES

MIGRATION TO THE PROVINCES: DESY, CERN, FNAL

$\nu N \to \nu X$, $\mu N \to \mu X$

$\nu N \to \mu X$, $\nu N \to \mu\mu\bar{\mu} X$ ...

A COUPLE OF PERSONAL CHOICES:

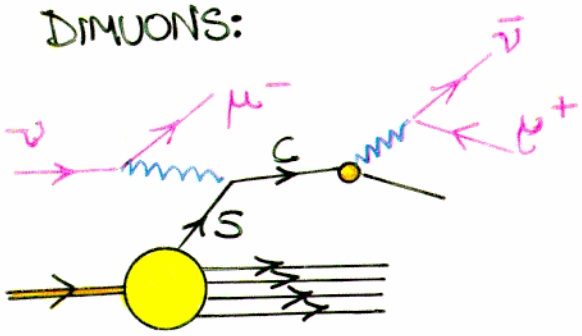
★ $\vec{e}\, d \to e X \not{P}$ @ SLAC

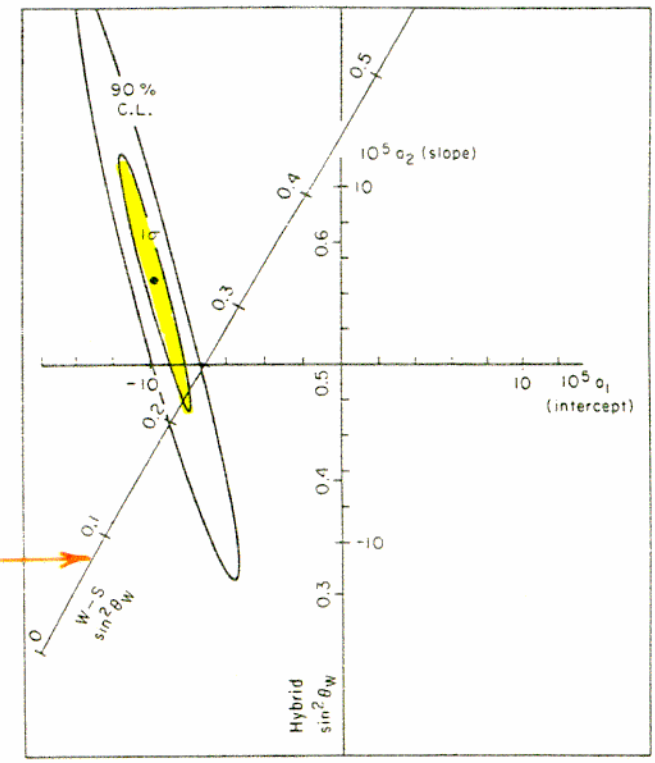
Z^0/γ INTERFERENCE

STRONG TEST OF THE STANDARD MODEL

★ MEASURING $S(x)$ & $\bar{S}(x)$ BY DIMUON PRODUCTION

AFTER THE DISCOVERY OF CHARM EXPLAINED DIMUONS:





W-S MODEL

C. PRESCOTT ET AL.

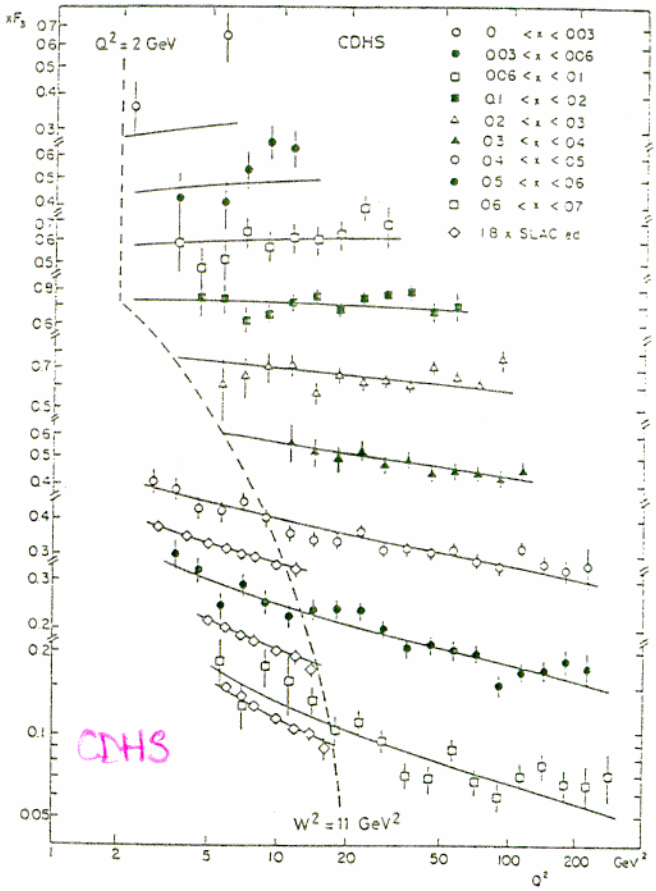
PHYS. LETT. 84B (1979) 524

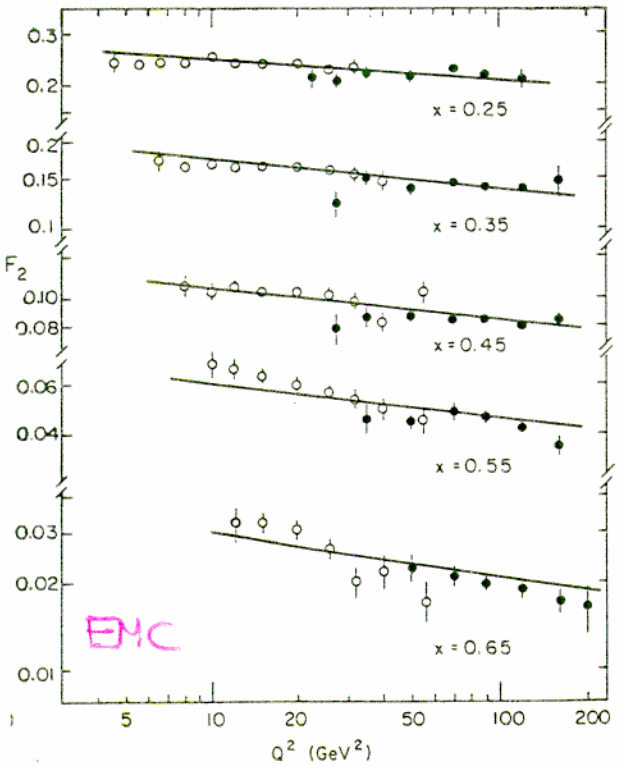
★ HOMAGE TO SCALING VIOLATION

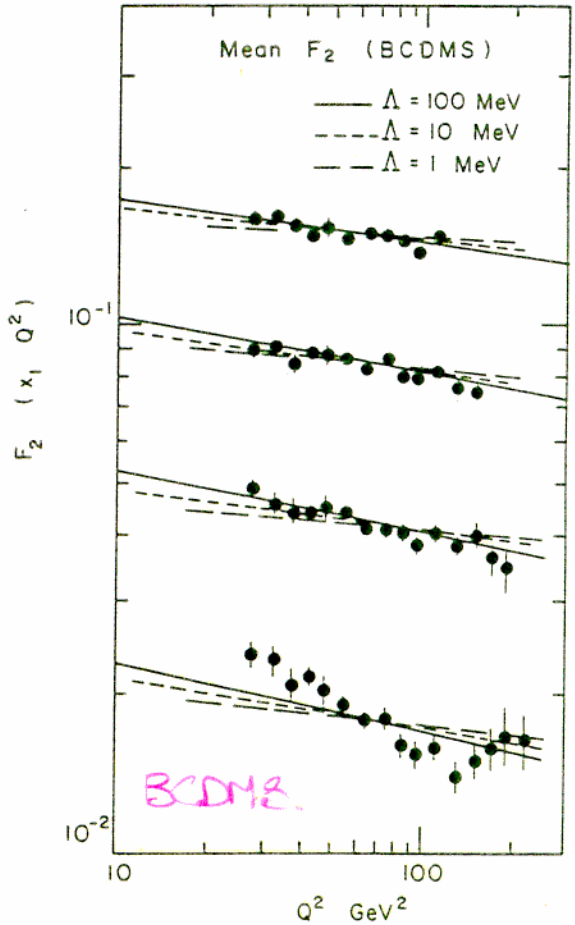
BY 1980 CONCLUSIVE EVIDENCE SUPPORTED QCD RADIATIVE CORRECTIONS

FACTORIZATION THEOREMS QUANTIFIED PARTON MODEL & CANONICAL FIELD THEORY

WE LEARNED WHAT THE P_T CUTOFF IN DRELL-LEVY-YAN REALLY MEANT.



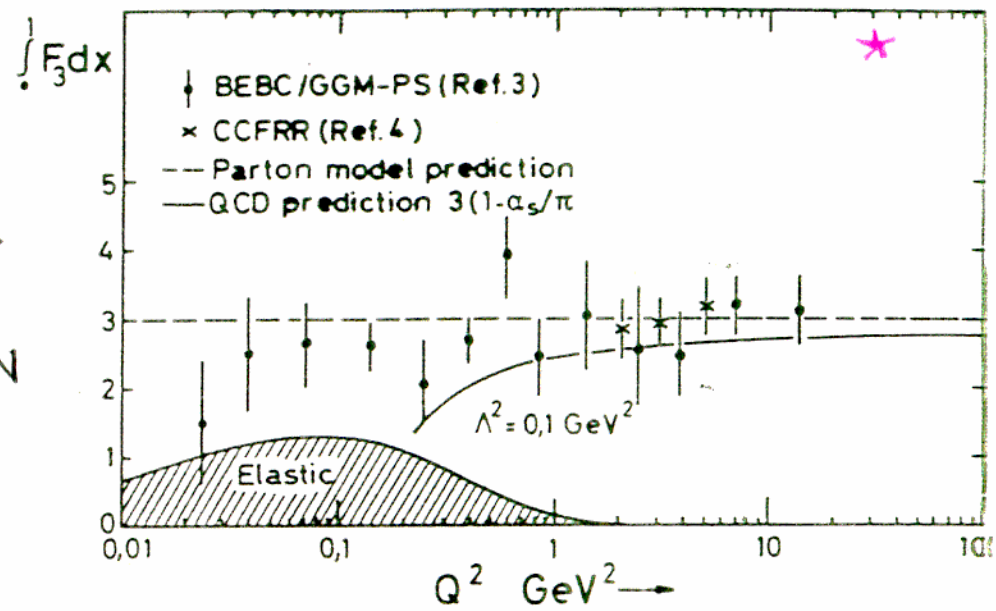




★ THREE REMARKABLE DEVELOPMENTS OF THE HELLENISTIC ERA.

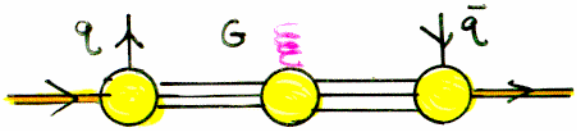
- ABSENCE OF HIGHER TWIST
  - SCALING WAS KNOWN FROM THE BEGINNING TO BE PRECOCIOUS
  - $\frac{P_G}{P_{TOT}} \cong \frac{P_Q}{P_{TOT}} \cong \frac{1}{2}$

    A VERY ASYMPTOTIC QCD PREDICTION ($\ln Q^2 \to \infty$), SEEN AT LOW-Q^2



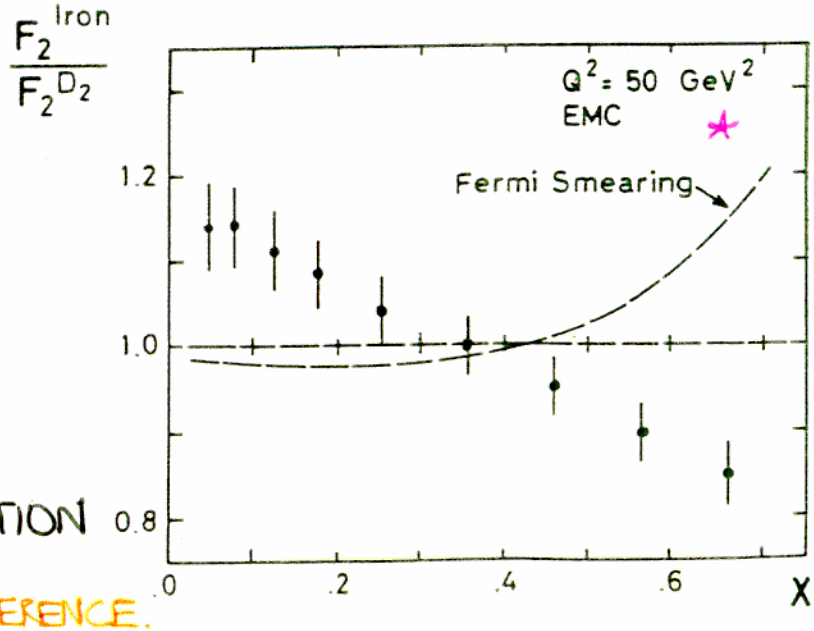
  - NO SIGN OF $\mathcal{O}(\Lambda^2/Q^2)$ CORRECTIONS

    WHERE ARE THE CORRELATIONS?



- FIRST LOOK @ NUCLEI

  IN 1980-1981 EMC RAN Fe & D_2. 1982 PARIS CONFERENCE RECORDED GRAPH AT RIGHT THAT ATTRACTED LITTLE ATTENTION



★ FROM D. HAIDT, 1982 PARIS CONFERENCE.

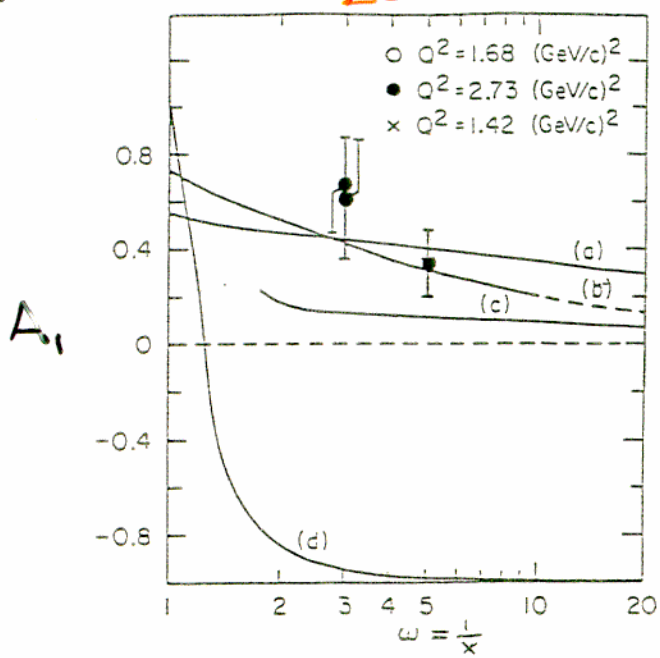
- SPIN DEPENDENT DIS

1970'S SAW A MODEST PROGRAM ON $\vec{e}\vec{p} \to eX$ AT SLAC WITH DEVELOPMENT OF POLARIZED TARGET & BEAM TECHNOLOGY.

VERNON HUGHES SLAC-YALE COLLABORATION OBTAINED FIRST MEASUREMENTS OF g_1^{ep}/f_1^{ep}

DATA ATTRACTED LITTLE INTEREST.

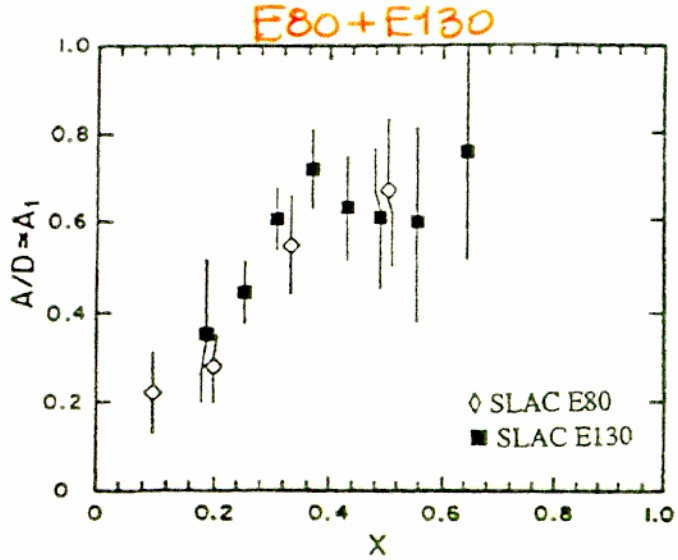
E80



SLAC'S PROGRAM TURNED TOWARD

- $\vec{e}p \to eX$ $\not{P}$
- e^+e^- COLLIDER PHYS.

E80 + E130



★ HELLENISTIC ERA CLOSES WITH

QCD SUPREME

DIS ROUTINE

VERNON HUGHES, A PROPHET CAST OUT...

4 RENAISSANCE 1983 - TODAY

INTEREST IN DIS & RELATED PHENOMENA INCLUDING ELASTIC FORM FACTORS REBORN AS A PROBE OF MYSTERIES OF CONFINEMENT

- NOBODY SERIOUSLY DOUBTS QCD IS THE CORRECT THEORY OF HADRONS

- LITTLE INTEREST IN QCD TESTS IN DIS
  SOME INTEREST IN HADRONIC-ENGINEERING

- HOWEVER: CONFINEMENT IS NOT UNDERSTOOD

CHALLENGE: $\mathcal{L} = -\frac{1}{4}\,\mathrm{Tr}\,F^2 + \bar{q}\,(i\not{D} - m)\,q$

DIAL-A-PROBE

OLD REFRAIN: "LEPTONS MAKE GREAT PROBES OF HADRONS BECAUSE LEPTONS ARE POINTLIKE"

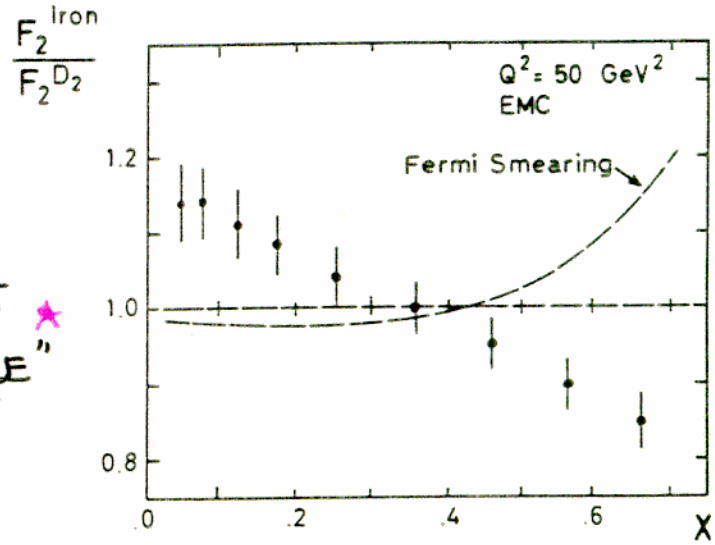
NEW VERSION: "QUARKS & GLUONS MAKE GREAT PROBES OF HADRONS (IN HARD PROCESSES) BECAUSE QUARKS & GLUONS ARE POINTLIKE"

- WE NOW UNDERSTAND PERTURBATIVE QCD AT SHORT DISTANCES SO WELL THAT WE CAN USE IT TO PROBE ASPECTS OF CONFINEMENT THAT REMAIN MYSTERIOUS

THIS OBSERVATION ORGANIZES THE INTERESTING ASPECTS OF D.I.S. SINCE MID-1980'S

1. QUARKS IN NUCLEI

"LOOKING FOR QUARKS IN THE NUCLEUS IS LIKE LOOKING FOR THE MAFIA IN SICILY: EVERYONE KNOWS THEY'RE THERE, BUT IT'S HARD TO FIND THE EVIDENCE" ★



- E.M.C. (1982/3) SAW FIRST EVIDENCE FOR NUCLEAR EFFECT IN D.I.S.

- BODER ET AL. ARCHAEOLOGY (APPROPRIATE TO RENAISSANCE!)

★ ANONYMOUS – CIRCA 1980

2A
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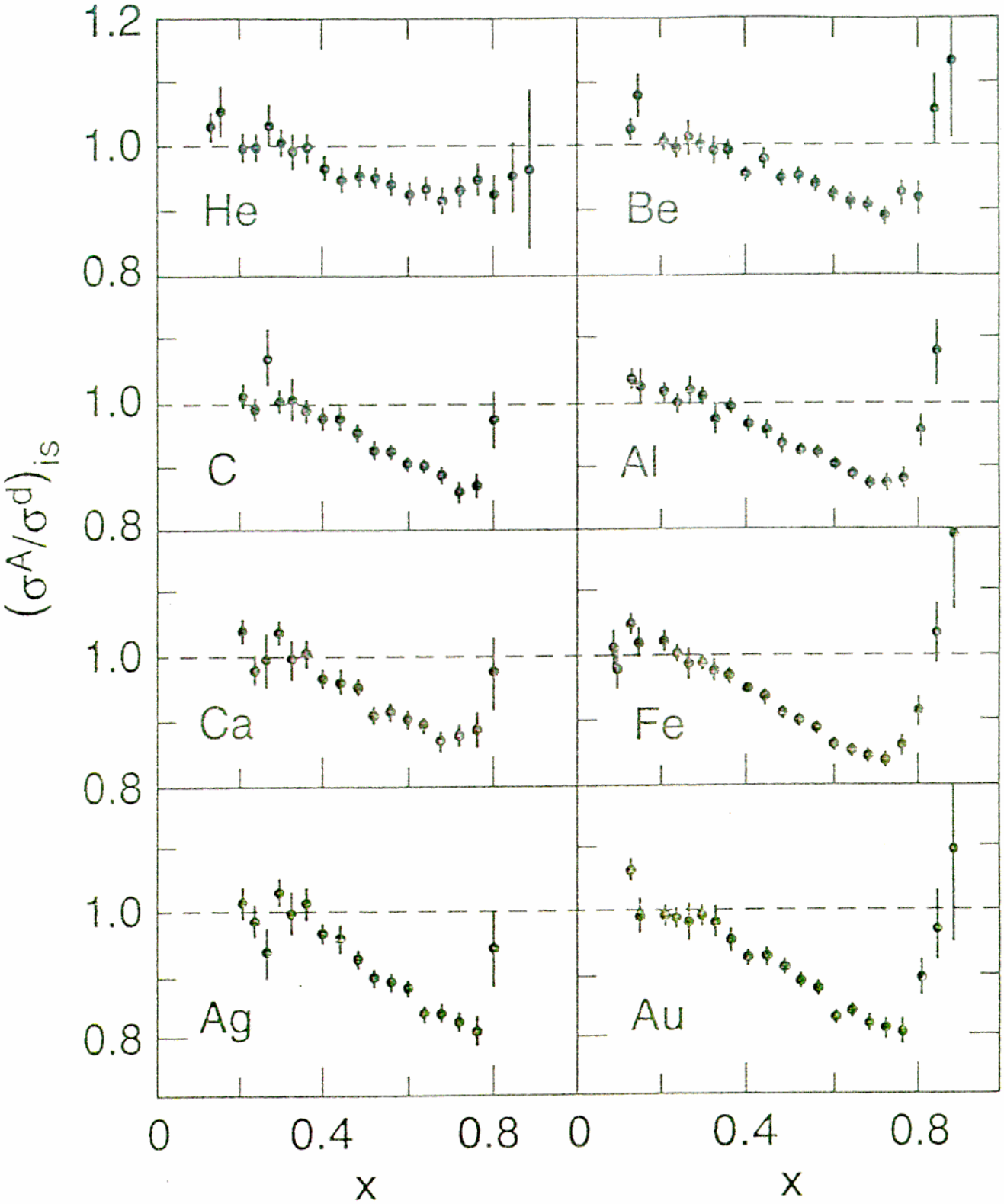
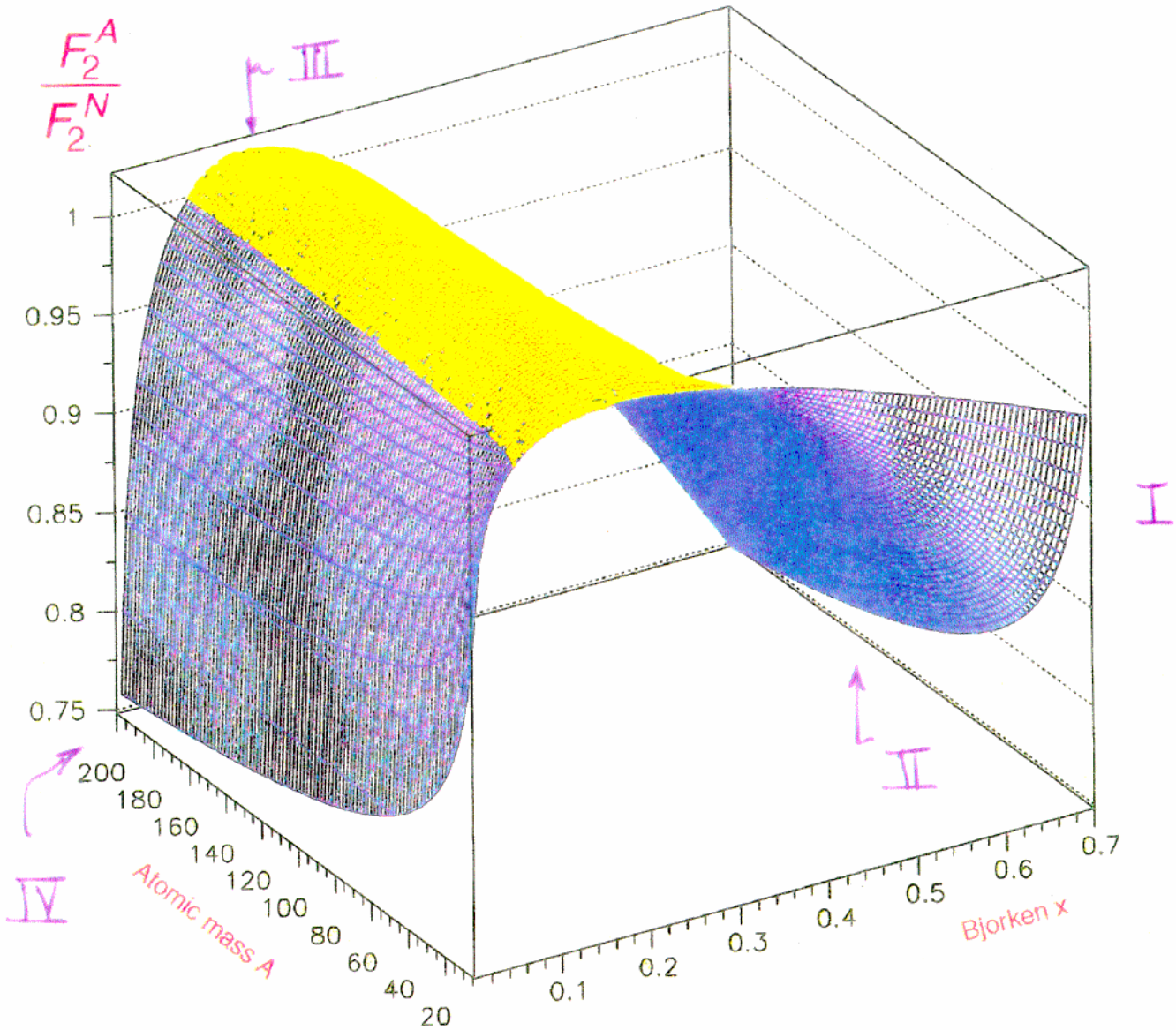


SLAC E139
PHYS. REV. D49
4349 (1994)



THANKS TO G. SMIRNOV

- INTERPRETATION

I WANT TO FOCUS ON REGION II

$$0.2 \lesssim x \lesssim 0.7$$

$$F_{2A}(x,Q^2)/F_2^N(x,Q^2) < 1$$

VALENCE QUARKS ARE SHIFTED TO LOWER x

⇒ LONGER CORRELATION LENGTH ALONG THE LIGHT-CONE (IOFFE)

⇒ QUARKS IN THE NUCLEUS ARE PARTIALLY DECONFINED

⇒ MANY PROPOSED MECHANISMS

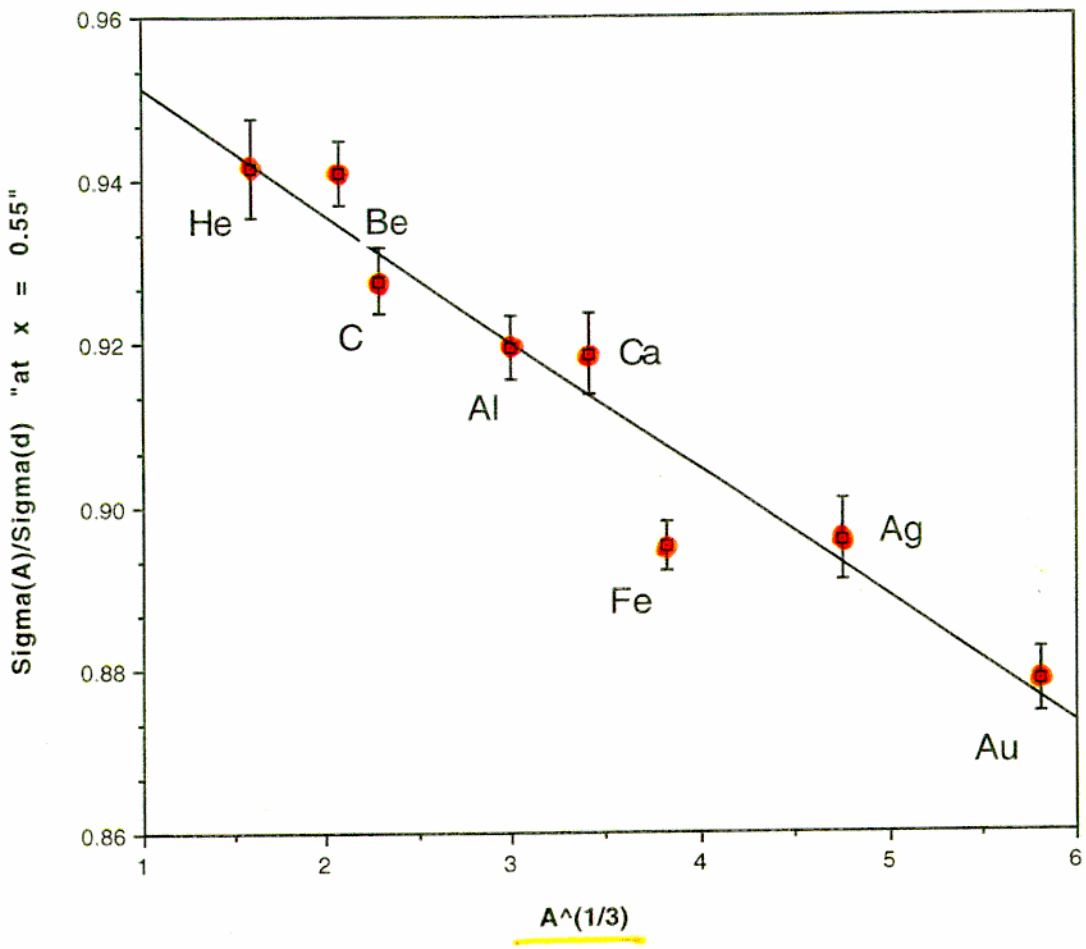
- CHANGE IN EFFECTIVE Λ_{QCD}.
- QUARK EXCHANGE
- ...

} HARD TO DISTINGUISH

⇒ MAGNITUDE OF NUCLEAR DEPLETION IN REGION II IS EXCELLENT MEASURE OF NUCLEAR ENVIRONMENT.

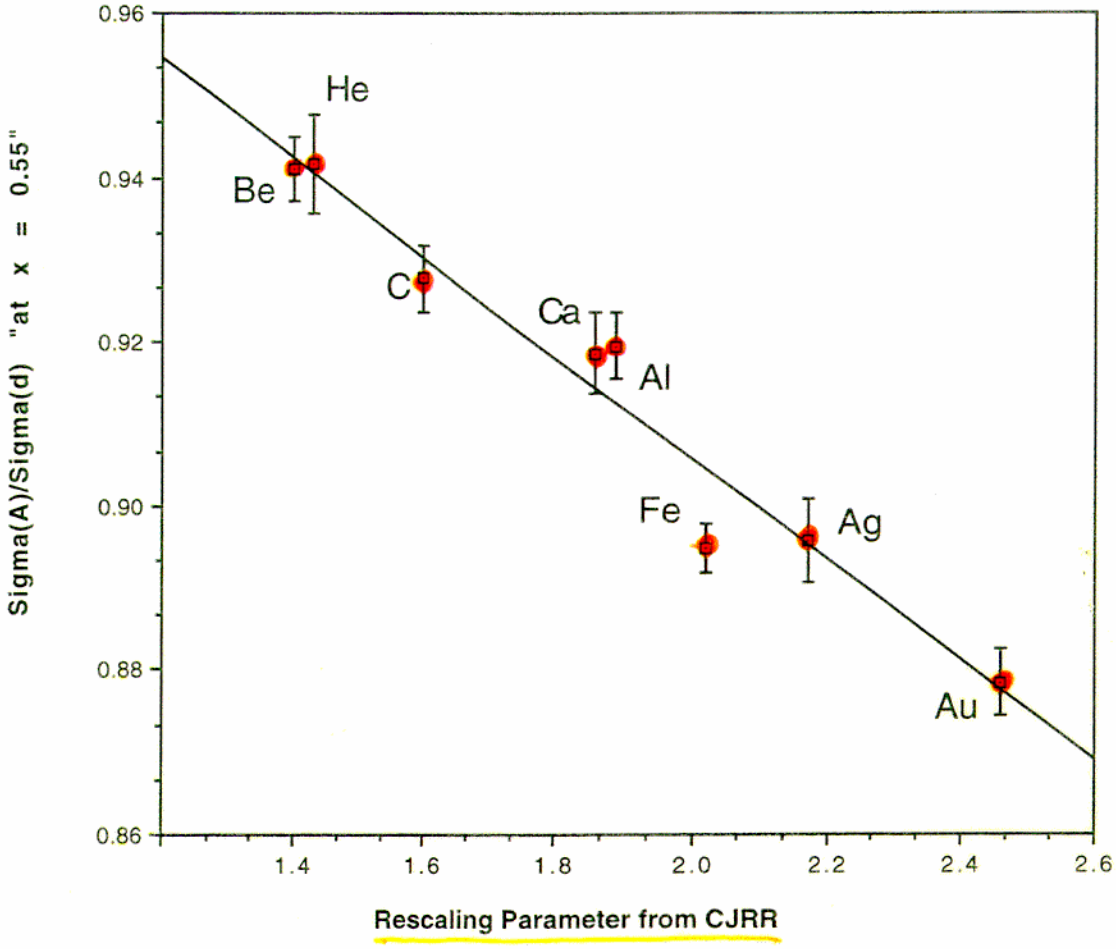
SLAC E139 Data versus A^(1/3)

[.40 < x < .68 / linear fit / evaluated at x = .55]



SLAC E139 Data versus Rescaling Parameter

[.40 < x < .68 / linear fit / evaluated at x = .55]



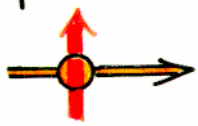
2. ANGULAR MOMENTUM IN THE NUCLEON

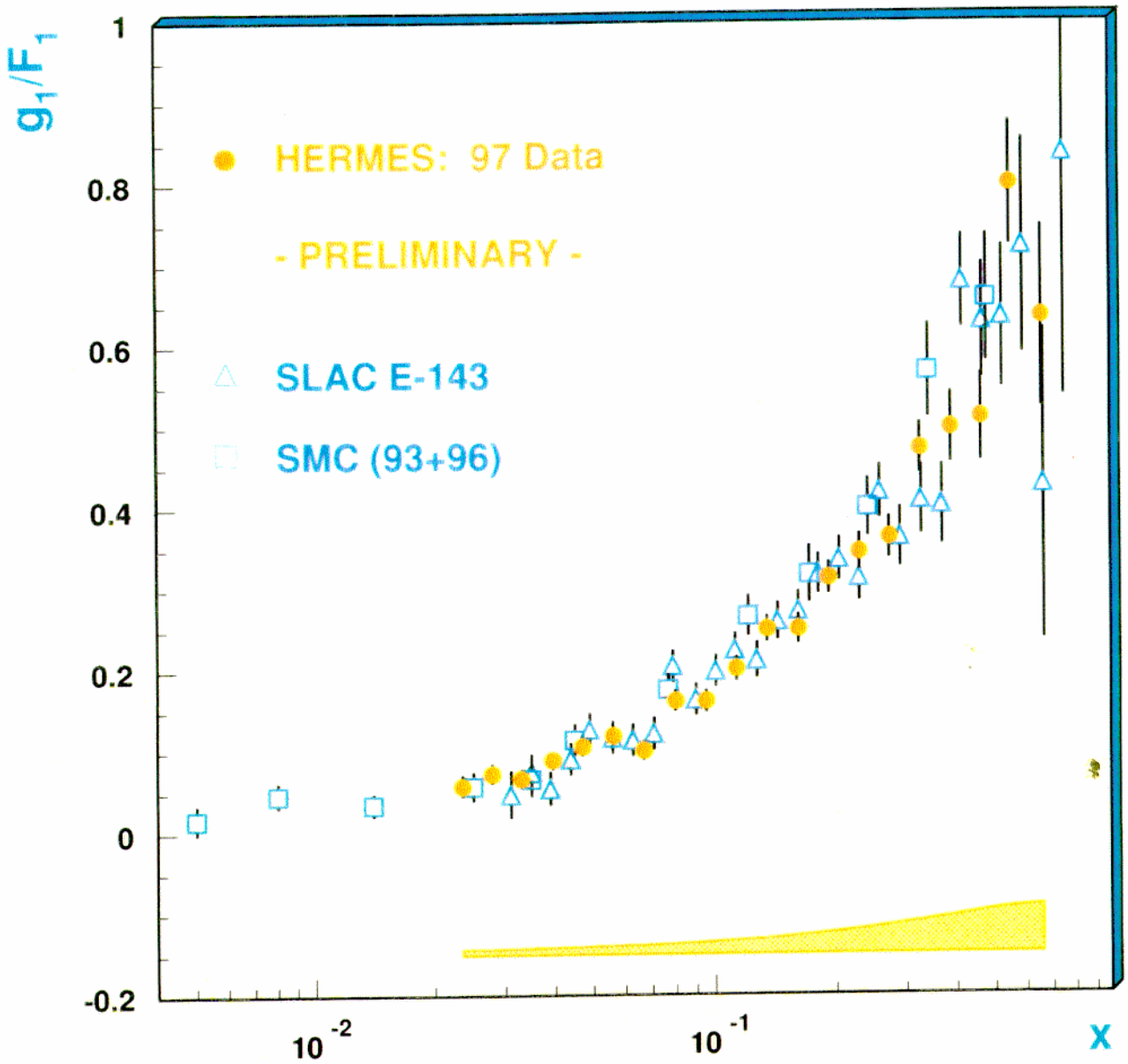
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_Q + L_G$$

★ $\Delta\Sigma \sim 0.2 - 0.3$ EMC 1987, SMC, SLAC E142, E143, SLAC E15X, HERMES

- SURPRISE $\Delta S = 0$ + β-DECAY $\Rightarrow \Delta\Sigma \sim 0.6$
- CONTROVERSY — WHAT IS $\Delta\Sigma$? NOW RESOLVED (SCHEME DEPENDENCE)

★ NEW PROGRAMS!

- ΔG $ep \to ec\bar{c}X$ (CERN, HERMES)
  $pp \to \gamma + X$, jets (RHIC)
- FLAVOR SEPARATION
  $ep \to ehX$ (CERN, HERMES)
  $pp \to W^{\pm}X$ (RHIC)
- TRANSVERSITY 
  $ep \to e\Lambda X$, $e(\pi\pi)X$ (HERMES)
  $pp \to \mu\bar{\mu}X$, $(\pi\pi)X$ (RHIC)
- L_Q, L_G WHAT ARE THEY? X-DISTRIBUTIONS
  HOW TO MEASURE?



HERMES

$\vec{e}+\vec{p}$ @ HERA

ELECTRON / MUON SCATTERING DATA SUMMARY

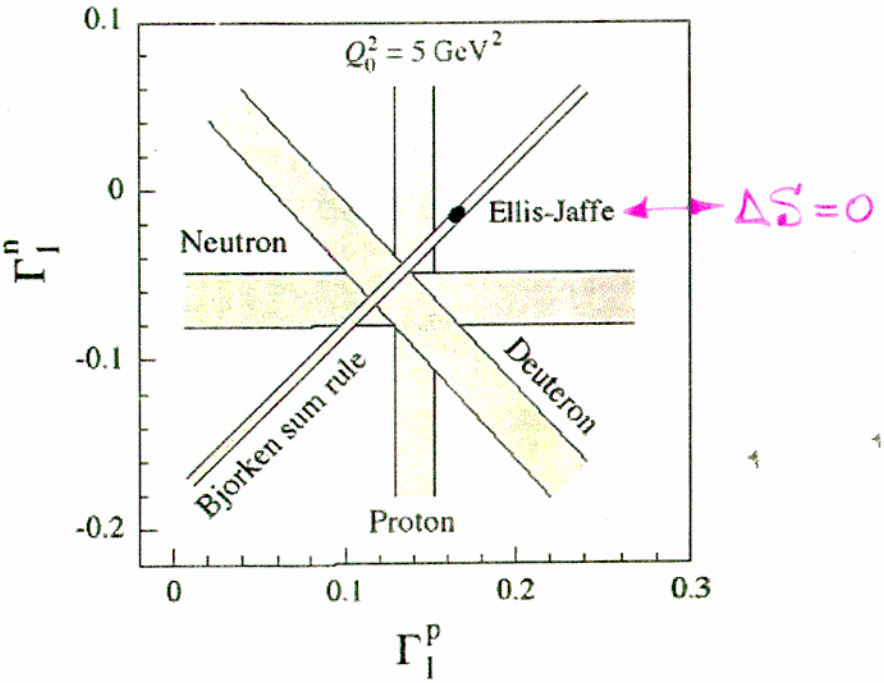
$Q_0^2 = 5\,\mathrm{GeV}^2$

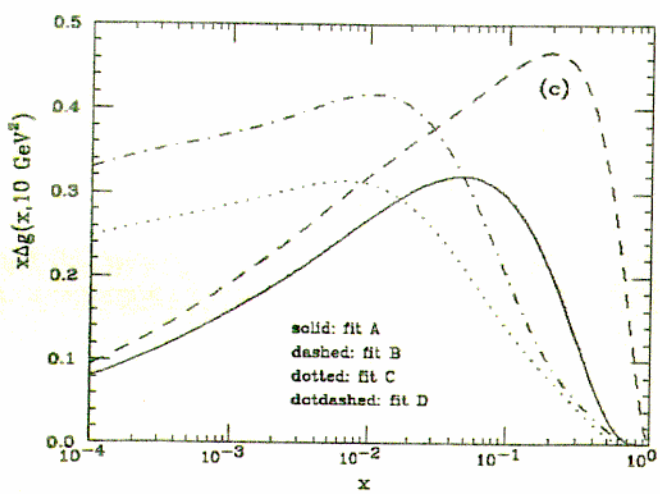
$\Delta U = \Delta u + \Delta\bar{u} = 0.82 \pm 0.02$ 1997 SMC REVIEW

$\Delta D = \Delta d + \Delta\bar{d} = -0.43 \pm 0.02$

$\Delta S = \Delta s + \Delta\bar{s} = -0.10 \pm 0.02$

$\Sigma = \sum_a \Delta Q_a = 0.29 \pm 0.06$





ATTEMPTS TO EXTRACT $\Delta g(x, Q^2)$ FROM QCD EVOLUTION OF $g_1(x, Q^2)$

(AB SCHEME)

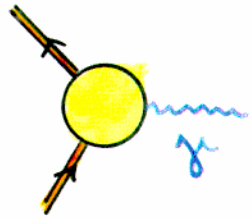
$\Delta g > 0 \quad \Delta g \sim 1$

ALTARELLI, BALL, FORTE, RIDOLFI

3. WEAK FORM FACTORS OF THE NUCLEON

A FITTING CONCLUSION.

(γ)



$j^{\mu}_{\gamma} \propto Q \propto \begin{pmatrix} 2/3 & & \\ & -1/3 & \\ & & -1/3 \end{pmatrix}$ IN LIGHT QUARK SECTOR

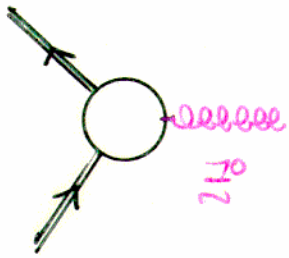
PURE OCTET. MEASUREMENTS OF E.M. FORM FACTORS CAN ACCESS $I_3 = \frac{1}{2}(u-d)$ & $Y = \frac{1}{3}(u+d-2s)$

NO WAY TO SEPARATE u, d, s.

(Z)

$j^{\mu}_{Z} \propto T_{3L} - \sin^2\theta\, Q$

$\hookrightarrow \begin{pmatrix} 1/2 & & \\ & -1/2 & \\ & & -1/2 \end{pmatrix}$ + HEAVY QUARK TERMS CALCULATE VIA pQCD



SO MEASURING Z^0 FORM FACTORS OF NUCLEONS CAN ⟹ STRANGE MATRIX ELEMENTS

★ AXIAL CHARGE $\bar{s}\gamma_\mu\gamma_5 s$ — INDEPENDENT CONFIRMATION OF D.I.S. MEASUREMENTS

★ MAGNETIZATION $\langle \frac{1}{2}\vec{r} \times \bar{s}\vec{\gamma}s \rangle$

RADIUS $\langle s^{+} r^2 s \rangle$

MAJOR PROGRAMS AT BATES, CEBAF IN FORM FACTOR MEASUREMENTS.