ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
ДУБНА

E2 - 11271

M.Klein, T.Riemann

DEEP INELASTIC MUON SCATTERING AS A TEST OF GAUGE THEORIES

1978

E2 - 11271

M.Klein, T.Riemann *

DEEP INELASTIC MUON SCATTERING AS A TEST OF GAUGE THEORIES

Submitted to "Physics Letters"

*On leave of absence from: Institut fur Hochenergiephysik der Akademie der Wissenschaften der DDR, Berlin-Zeuthen

Кляйн М., Риман Т. E2 - 11271

Глубоконеупругое рассеяние мюонов и калибровочные теории

В работе показано, что асимметрии при рассеянии поляризованных лептонов зависят от мультиплетной структуры лептонов и валентных кварков в калибровочных теориях. Следовательно, эксперименты по глубоконеупругому рассеянию мюонов при энергиях SPS могут внести значительный вклад в вопрос о структуре нейтральных токов.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1978

Klein M., Riemann T. E2 - 11271

Deep Inelastic Muon Scattering as a Test of Gauge Theories

Different asymmetries in polarized lepton scattering are shown to be remarkably dependent on the valence quark and lepton multiplet structure in currently discussed gauge theories. Therefore deep inelastic muon experiments at SPS energies can contribute significantly to the investigation of neutral currents.

The investigation has been performed at the Laboratory of High Energy, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1978

In the near future high energy deep inelastic muon experiments will be performed probing the nucleon structure at momentum transfers, Q^2, of a few hundreds $(GeV/c)^2$ /1/. For muons and electrons both having electromagnetic and weak interactions, neutral current effects are expected to be of the order of

$$\varkappa = \frac{G}{\sqrt{2}} \cdot \frac{1}{2\pi\alpha} \cdot Q^2 \simeq 1.8 \cdot 10^{-4} Q^2 \qquad (1)$$

resulting from the interference of the one-photon exchange with the Z-boson exchange /2,3/. A measurement of these effects yields new and independent information on the neutral current structure which is very desirable considering the rather ambiguous experimental situation /4/. Therefore we perform a comprehensive quark parton model evaluation of different observables in polarized $\ell^{\pm}$ scattering for various gauge theories+. The main question involved concerns the extent to which the predictions of currently discussed gauge models differ from one another.

Assuming natural flavour conservation, any neutral current process in the valence quark approximation is sensitive only to the ℓ, u, d sector of corresponding models. Based on $SU(2)xU(1)$ invariance, there are eight possibilities to arrange ℓ, u,d in right-handed (r.h.) singlets or doublets, respectively, which are included in the following discussion. The contradiction between neutral current results from neutrino and atomic experiments could require to extend the gauge group. As corresponding examples, we consider $SU(2)_L xSU(2)_R xU(1)$ theories which predict the absence /6/ or a reduced size of parity violation /7/ in atoms although having a rich V, A structure.

+ See ref. /5/ for a recent investigation of the influence of electromagnetic corrections.

The weak current coupling to the Z-field is given by

$$g_Z \bar{\psi} \gamma^m (v_\psi - a_\psi \gamma_5) \psi \cdot Z_m . \tag{2}$$

Here ψ is μ(e), u or d and g_Z is the coupling constant. In the SU(2)xU(1) theories under consideration

$$g_Z^2 = \frac{g^2}{4\cos^2\theta} = 2 M_Z^2 \frac{G}{\sqrt{2}} \tag{3}$$

and

$$v_\psi = I_3^L + I_3^R - 2Q\sin^2\theta \tag{4}$$

$$a_\psi = I_3^L - I_3^R , \tag{5}$$

where $I_3^{L(R)}$ denotes the third component of the weak SU(2) in the corresponding l.h. (r.h.) doublet.

Using the above definitions, we can calculate $d\sigma^\mp$, the deep inelastic cross section of scattering leptons with charge $\mp$, and an averaged beam helicity ξ off nucleons. Normalizing to the one-photon exchange cross section $d\sigma_0$, we get[2,3]

$$\frac{d\sigma^\mp}{d\sigma_0} = 1 - \varkappa \left[v_\mu V(x) \mp a_\mu A(x) g(y) + \xi \left(\mp a_\mu V(x) + v_\mu A(x) g(y) \right) \right] \tag{6}$$

with $\varkappa = Q^2 g_Z^2/(4\pi\alpha M_Z^2)$ and $g(y)=y(2-y)/(1+(1-y)^2)$. Here V(x) and A(x) are ratios of structure functions defined as in ref.[3], which are independent of x for an isoscalar target

$$V = \frac{6}{5}(2v_u - v_d) \qquad A = \frac{6}{5}(a_d - 2a_u) \tag{7}$$

According to (6) several asymmetry parameters can be measured:

i) parity violation asymmetries varying only the polarization ξ

$$A^\mp = \frac{d\sigma^\mp(\xi>0) - d\sigma^\mp(\xi<0)}{d\sigma^\mp(\xi>0) + d\sigma^\mp(\xi<0)} = -\varkappa|\xi|(\mp a_\mu V + v_\mu A g(y)), \tag{8}$$

ii) a "beam conjugation" asymmetry varying both ξ and the beam charge

$$B = \frac{d\sigma^+(\xi>0) - d\sigma^-(\xi<0)}{d\sigma^+(\xi>0) + d\sigma^-(\xi<0)} = -\varkappa(a_\mu + |\xi| v_\mu) A \cdot g, \tag{9}$$

iii) charge asymmetries varying only the beam charge

$$D = \frac{d\sigma^+(\xi) - d\sigma^-(\xi)}{d\sigma^+(\xi) + d\sigma^-(\xi)} = -\varkappa a_\mu (A\cdot g + \xi V) , \; C = D(\xi = 0). \tag{10}$$

Note that certain ratios of asymmetries measure purely leptonic or purely hadronic couplings, i.e.,

$$\frac{C}{B} = \frac{a_\mu}{a_\mu + |\xi| v_\mu} \qquad \frac{C}{D} = \frac{A\cdot g(y)}{A\cdot g(y) + \xi \cdot V} . \tag{11}$$

The $SU(2)_L x SU(2)_R x U(1)$ model of Mohapatra and Sidhu[6] predicts $A^+ = A^- = 0$ and

$$B = C = D = -\frac{2\varkappa}{1+\varepsilon} a_\mu^{(1)} A^{(1)} \cdot g(y) \tag{12}$$

($a_\mu^{(1)} = -1/2$, $A^{(1)} = -9/5$, $\varepsilon \approx 0.1$) because Z^1 has only axial couplings and Z^2 only vector couplings to massive particles. In the model of De Rújula, Georgi and Glashow[7], Z^1 corresponds to Z in the Salam-Weinberg/GIM-theory (SW) and Z^2 has again only vector couplings. Asymmetries A-D arise which are about one half of those predicted by SW.

Deep inelastic muon experiments at the CERN SPS will reach a Q^2 of about 200 $(GeV/c)^2$ within an accuracy of 1% for the parameters A-D using a 50m carbon target[8]. Adopting this Q^2 as a reasonable value for illustration, we study A-D as functions of the relative energy transfer y, the polarization ξ , and the unification angle.

In fig.1 the y-dependence of A-D is shown at $\sin^2\theta=1/4$ /4/ and $\xi=1$ for the gauge models considered disregarding the pure vector model where all asymmetries are zero ⁺. The SU(2)xU(1) curves are denoted by the particles occuring in r.h. doublets. As can be seen, different models yield remarkably different predictions all being only weakly dependent on y. The strongest differences are revealed by the parity violation asymmetry A^+ and by the charge asymmetry D. Evidently, experimental errors smaller or about 1% are necessary to decide whether the lepton is in a r.h. doublet or not. If it occurs only in l.h. doublets (solid curves), the quark couplings can be determined from the asymmetry D. On the other hand, one easily realizes that an improved accuracy of at least 1/2 % is required to resolve the quark coupling structure if there is a r.h. lepton doublet (dashed curves). The behaviour of the $SU(2)_L xSU(2)_R xU(1)$ models considered is shared by none of the SU(2)xU(1) models.

Additional information arises from the slope and intercept of the lines $a + b/|\xi|$ which can be determined by varying the polarization, i.e. varying the momentum of the π,K parent beam and keeping the muon momentum fixed/9/ (see fig.2).

The asymmetries depend linearly on $\sin^2\theta$. Therefore in fig.3 the angular dependence of A-D is given for y=3/4 and $\xi=1$. One can distinguish three groups of asymmetry parameters. The information being extractable from A^- is nearly independent of $\sin^2\theta$. For A^+ and B the mean spacing between different predictions decreases with increasing $\sin^2\theta$. Note, however, that even the exotic value of $\sin^2\theta \approx 0.5$ would allow one to determine the lepton coupling in SU(2)xU(1) models from A^+. Finally, the usefulness of C and D is the same for any $\sin^2\theta$ fixed. Thus, if nature prefers another unification angle than 1/4, analogous conclusions from corresponding figures 1 and 2 can be drawn.

⁺ The value of $\sin^2\theta=1/4$ implies that the lepton has only an axial coupling in the standard model (eq.4). Thus, in the framework of SU(2)xU(1) theories, the recent CDHS neutrino experiment/4/ is most contradictory to atomic parity experiments indicating $a_\ell=0$.

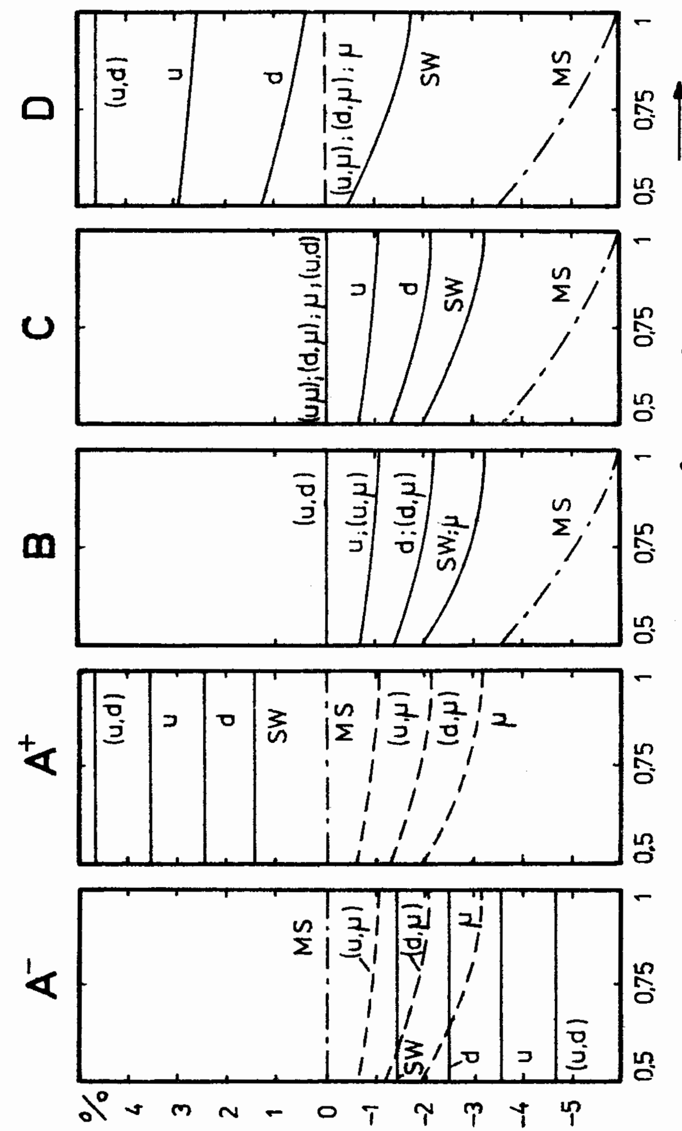
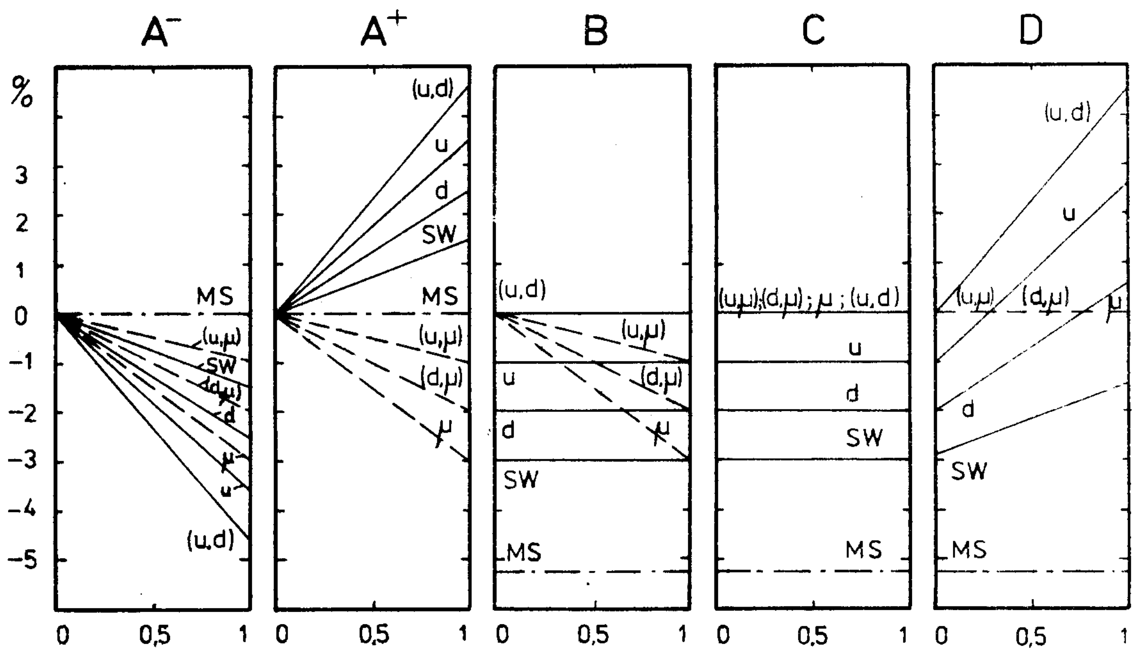


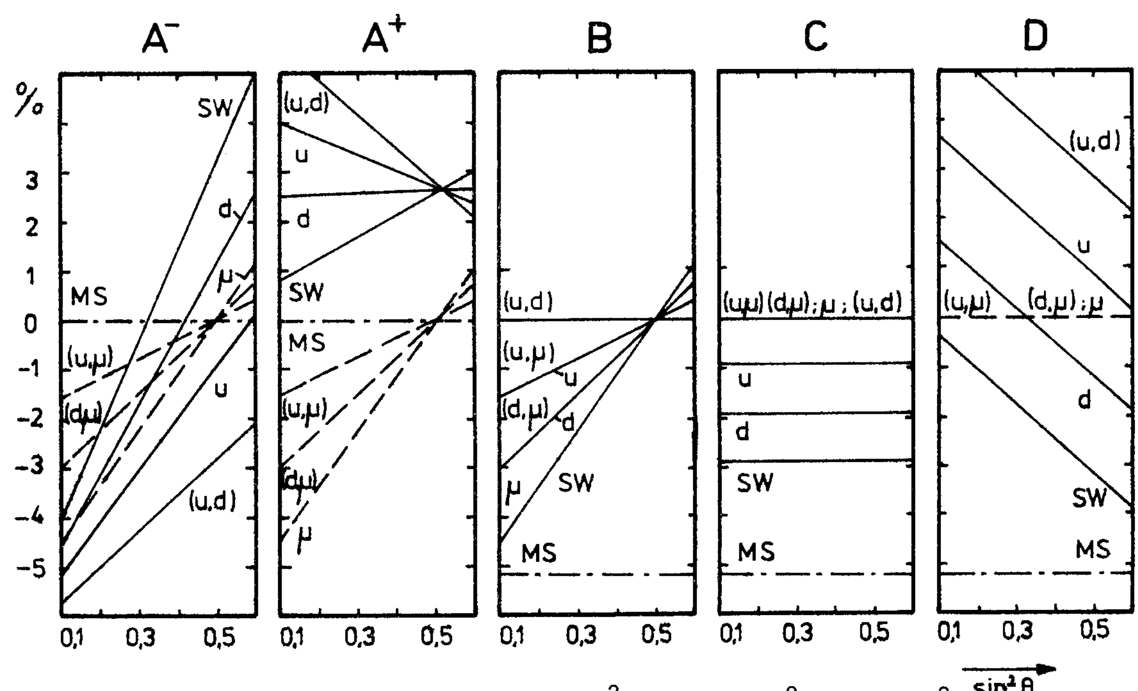
Fig. 1

Asymmetries (eqs.8-10) as a function of y at $\sin^2\theta=1/4$, $Q^2=200(GeV/c)^2$ and $\xi=1$ for various gauge theories (SW: Salam-Weinberg/GIM; solid curves: SU(2)xU(1), $a_\mu \neq 0$; dashed curves: SU(2)xU(1), $a_\mu=0$; MS: Mohapatra/Sidhu/6/; DGG/7/ is about one half of SW)



Asymmetries (eqs.8-10) as a function of ξ at $\sin^2\theta=1/4$, $Q^2=200(\mathrm{GeV}/c)^2$ and $y=3/4$ for various gauge theories (SW: Salam-Weinberg/GIM; solid curves: SU(2)xU(1), $a_\mu \neq 0$; dashed curves: SU(2)xU(1), $a_\mu=0$; MS: Mohapatra/Sidhu/6/; DGG/7/ is about one half of SW)

Fig. 2



Asymmetries (eqs.8-10) as a function of $\sin^2\theta$ at $y=3/4$, $Q^2=200(\mathrm{GeV}/c)^2$ and $\xi=1$ for various gauge theories (SW: Salam-Weinberg/GIM; solid curves: SU(2)xU(1), $a_\mu \neq 0$; dashed curves: SU(2)xU(1), $a_\mu=0$; MS: Mohapatra/Sidhu/6/; DGG/7/ is about one half of SW)

Fig. 3

It is evident, that the complete set of asymmetries can only be studied for muons, where positively and negatively charged polarized beams are available. Deep inelastic electron experiments measure only A^- and must be combined with other reaction channels to draw definite conclusions on the weak couplings[/10/].

To summarize, deep inelastic polarized muon experiments reaching momentum transfers, Q^2, of several hundreds $(GeV/c)^2$ can be considered as a new and independent source of information on the structure of weak neutral currents of leptons and hadrons. They are expected to be able to distinguish between currently discussed classes of gauge theories provided the experimental accuracy for corresponding observables is smaller than $5\cdot 10^{-5}Q^2$ which appears to be reachable at the CERN SPS.

Acknowledgement

We are indepted to D.Yu. Bardin, S.M. Bilenky, A. De Rújula, W.-D. Nowak, I.A. Savin, and N.M. Shumeiko for valuable discussions and suggestions.

References

/1/ CERN-Dubna-Munich-Saclay Collaboration NA4, CERN/SPSC/74-79, P19(1974) and 77-12, P19/Add.4(1977).

/2/ E. Derman, Phys.Rev., D7(1973)2755.
S.M. Bilenky, S.T. Petcov, JINR, E2-10809(1977).
M. Gourdin, Paris, LPTHE 77/08(1977) and ref. therein.

/3/ S.M. Berman, J.R. Primack, Phys.Rev., D9(1974)2171.

/4/ For recent neutrino and atomic physics results see:
P. Musset, CERN/EP/PHYS 77-48, Inv. Talk at the Lepton-Photon Symposium, Hamburg(1977)

/5/ D.Yu. Bardin, N.M. Shumeiko, JINR, P2-10873(1977).

/6/ R. Mohapatra, D. Sidhu, Phys.Rev.Lett., 35(1977)667.
(Note some printing errors in this article)

/7/ A. De Rújula, H. Georgi, S. Glashow, Ann.Phys., 109(1977)242.

/8/ Meeting of the Collaboration NA4, Dubna, June 2-3, 1977, unpublished.

/9/ K. Winter, Phys.Lett., 67B(1977)236.

/10/ R.N. Cahn, F.J. Gilman, SLAC-PUB-2002(1977).

Received by Publishing Department
on January 19, 1978.