RADIATIVE CORRECTIONS TO THE DEEP INELASTIC μN SCATTERING IN THE TeV REGION

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ABSTRACT

The contributions to the deep inelastic cross section resulting from other than one photon but radiative and weak diagrams are estimated up to the energy of 30 TeV.

1. INTRODUCTION

The reaction

$$\ell + N \rightarrow \ell' + \text{hadrons} \tag{1}$$

is one of the main sources of information on the nucleon structure. Double differential cross sections of the reaction (1), $d^2\sigma_0 \equiv d^2\sigma_0/dxdQ^2$, calculated by one-photon exchange diagram (a) is simply expressed through nucleon inelastic structure functions $W_1(x,Q^2)$, $W_2(x,Q^2)$ and others. But from experiments we obtain the cross sections $d^2\sigma_{meas}$ which correspond to the diagram (b) containing other processes, in particular, some radiative ones:

$$\ell + N \rightarrow \ell' + \gamma + N \tag{2}$$

$$\ell + N \rightarrow \ell' + \gamma + N^* \tag{3}$$

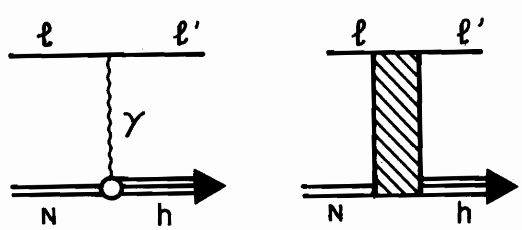
$$\ell + N \rightarrow \ell' + \gamma + \text{hadrons} \tag{4}$$

where γ is not detected.

One can assume that the procedure of the W_1 and W_2 determination from $d^2\sigma_{meas}$ is systematically unbiased when the ratio

$$\frac{d^2\sigma_{meas}}{d^2\sigma_0} = 1 + \delta(x, Q^2, E) \tag{5}$$

is close to 1 and the $\delta(x, Q^2, E)$ so called radiative corrections (RC) to the one-photon exchange, are small enough.



(a) (b)

The gauge invariance allows one to separate from the total RC a part of it, δ_ℓ, originating from diagrams with additional γ coupled to lepton lines (RC to the lepton current). So one can write

$$\delta(x, Q^2, E) = \delta_\ell(x, Q^2, E) + \delta_h(x, Q^2, E) \tag{6}$$

where δ_h is the rest of the radiative corrections which we will call as RC's to the hadron current.

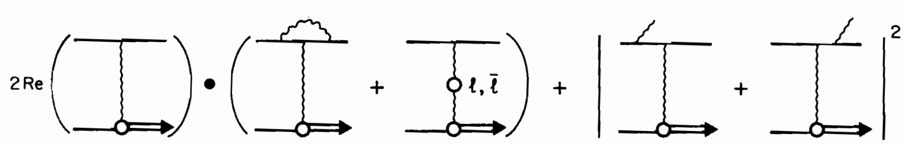
In a number of theoretical papers the methods and results of RC calculations are described. The method of the δ_ℓ calculation developed by Mo and Tsai[1,2] has been used in most of SLAC electron-nucleon deep inelastic experiments and with some modifications in Fermilab muon-nucleon experiments.

An alternative method of RC calculations has been developed by Akhundov, Bardin and Shumeiko[3] for the CERN muon experiment NA4 designed to study the deep inelastic scattering at the now highest possible energy and 4-momentum transfers. It is free of the so-called "photon softness" unphysical parameter used by Mo and Tsai. It permits also the faster calculations of RC's on computers[4].

Apart from the RC to the lepton current the number of graphs contributing to diagram (b) and giving the RC to hadron current have been considered[5]. The processes like the hadron polarization of vacuum[6], e.m. interactions between hadrons in a final state[7], e.m. lepton pairs production[8] and Z^0-boson exchange[9,10] are found to be important at high energies. Basing on these calculations we try to estimate the possible size of corrections to one-photon exchange up to incident muon energies of E = 30 TeV.

2. CORRECTIONS TO THE LEPTON CURRENT

The RC's to the muon-nucleon cross section, $\delta_\ell^{(1)}(x,y,E)$, arising from virtual and real photon emission and absorption diagrams (c) have been calculated in the lowest (first) α-order at the muon incident energies E = 50, 300 and 3000 GeV. The method of reference[3] has been used.



(c)

The main features of $\delta_\ell^{(1)}(x,y,E)$ are seen from fig. 1(a):

- for the large part of the kinematical region $\delta_\ell^{(1)}$ is small ($\lesssim$ 30%);
- there is a rapid increase of $|\delta_\ell^{(1)}|$ in the boundary regions $W^2 \to (M_p + M_\pi)^2$ and $W^2 \to W^2_{max}$ dominated by "soft" photon emission in the first one and by hard photons in the second one;
- the energy dependence of $\delta_\ell^{(1)}$ is very slow.

The most prominent energy dependence of $\delta_\ell^{(1)}$ at $y \simeq 0.5$ and $v = 0.43$ one can parametrize by formula

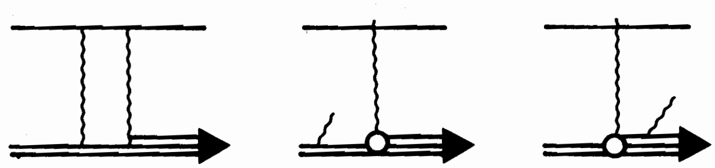
$$\delta_\ell^{(1)}(E) = \delta_\ell^{(1)}(50) \cdot \log(E/50) \tag{7}$$

which gives $\delta_\ell^{(1)} = -19\%$ at E = 30 TeV.

The "forbidden" regions where $\delta_\ell^{(1)} > 30\%$ are shown in fig. 1(b) for different energies in variables x, y. The curve III is obtained assuming that the boundary of the forbidden region will expand with energy increase from 3000 to 30 000 GeV as fast as it expands from 300 to 3000 GeV. It is evident that before drawing any conclusion about RC's inside of these regions one needs to calculate second order corrections $\delta_\ell^{(2)'}$ (two loops diagrams, double bremsstrahlung etc.).

3. CORRECTIONS TO THE HADRON CURRENT

The lowest α-order corrections arising from the two-photon exchange and photon emission from hadron vertex processes (d) have been calculated at E = 50, 300 and 3000 GeV for μ^+ and μ^- in the framework of the parton model[5]. They are shown in fig. 2. For the bigger part of the x,y plot $\delta_h^{(1)}$ is of the order of 1 to 3% both for μ^+ and μ^-.



(d)

The energy dependence of $\delta_h^{(1)}(x,y,E)$ is very slow. For example, the extrapolation of $\delta_h^{(1)}(v = 0.43, y = 0.6, E = 3000)$ to the energy E = 30 TeV gives $\delta_h^{(1)} = 4\%$.

The difference of $\delta_h^{(1)}$ for μ^+ and μ^- is almost energy independent and increases with increasing of y. One can use these properties of $\delta_h^{(1)}$ for their experimental measurement at present energies. This measurement will provide also a check of the parton model validity for such a calculation.

The RC arising from the hadron vacuum polarization, δ_{vac}, is also the first order correction. Berends and Komen[6] have shown that this correction increases logarithmically with increasing of Q^2. The extrapolation (see fig. 3) of calculations done up to $\sqrt{s} = 30$ GeV to the energy of E = 30 TeV ($\sqrt{s} = 250$ GeV) gives for $\delta_{vac} = 8\%$.

Corrections δ_f arising from e.m. interactions of final state hadrons are estimated[7] not better than by an order of magnitude. The energy dependence of δ_f is shown in fig. 3. One can see that at E = 30 TeV δ_f reaches the value of about 30%. It proves the necessity of more detailed and precise theoretical study of the hadronic final states in deep inelastic interactions.

4. WEAK NEUTRAL CURRENT CORRECTIONS

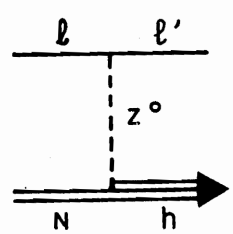
The lowest order correction due to lepton-nucleon weak interaction (diagram (e)) comes from γ - Z^0 interference term. The maximal size of this correction, $\delta_W^{(1)}$, as is known proportional to Q^2

$$\delta_W^{(1)} \sim 1.8 \cdot 10^{-4} \frac{Q^2 M_Z^2}{(M_Z^2 + Q^2)\, M_p^2} \tag{8}$$

At the energy E = 30 TeV the realistic Q^2 up to which one can measure the deep inelastic cross sections will be about 20 000 $(\mathrm{GeV}/c)^2$. As is seen from (8) the correction $\delta_W^{(1)}$ is about 40% at this point.

As far as $Q^2 \gg M_Z^2$ the one-loop weak corrections may be also significant at such momentum transfers.

As shown in the paper[10] the weak corrections are very important also for cross section asymmetry measurements. For example, the weak correction to the P-odd asymmetry A^- (of SLAC type) can reach 20% already at present muon beam energies.



(e)

5. PRODUCTION OF LEPTON PAIRS

Processes like (2) ÷ (4) where γ is replaced by $\ell^+\ell^-$ - pair (diagrams (f)) can also contribute to the measured inclusive deep inelastic cross section. The comprehensive study of corrections $\delta_{\ell\ell}$ arising from these processes has been performed in the paper[8]. It is shown that up to energy of 2 TeV $\delta_{\ell\ell} \leq 0.5\%$ for $Q^2 > 1$ $(GeV/c)^2$. At lower Q^2 $\delta_{\ell\ell}$ may reach a few percents. The energy dependence of $\delta_{\ell\ell}$ is very slow. For example at E = 30 TeV $\delta_{\ell\ell}$ is still less than 1% almost everywhere inside of the kinematical plot.

6. CONCLUSIONS

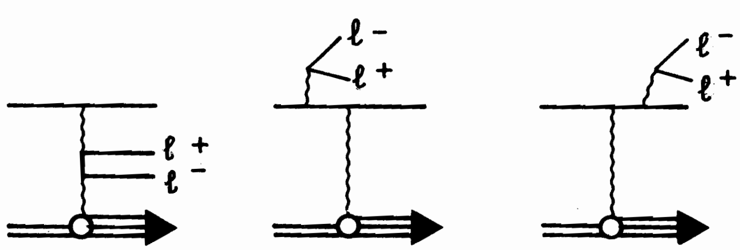
6.1 For the large part of the kinematical plot of the muon-nucleon deep inelastic scattering the first order radiative corrections to the lepton current, $\delta_\ell^{(1)}$ (x,y,E), one can calculate quite reliably up to considered energy E = 30 TeV.

6.2 The part of this plot, where $\delta_\ell^{(1)}$(x,y,E) exceeds 30% (at large y and small x), is logarithmically increased with increasing of E. Inside of this region one needs to estimate the second order corrections, $\delta_\ell^{(2)}$, in order to prove the correctness of the whole procedure of RC calculations at energies above 1 TeV.

6.3 The RC's to the hadron current grow with an energy increasing but its magnitude is still of an order of a few percents up to E = 30 TeV. These estimations are model dependent and should be checked experimentally at present energies.

6.4 The effects of lepton-hadron weak interactions grow with energy and at E = 30 TeV could reach the level of about 40% of electromagnetic ones.

6.5 The lepton pairs production by muons can not give sizeable corrections to the deep inelastic cross section up to energies higher than 30 TeV.



(f)

REFERENCES

1) L.W. Mo and Y.S. Tsai, Rev. Mod. Phys. 41 (1969) 205.

2) Y.S. Tsai, SLAC-PUB-848 (1971).

3) A.A. Akhundov, D. Yu. Bardin and N.M. Shumeiko, JINR Reports E2-10147, 10205 (1976), Jad. Fiz. 26 (1977) 1251.

4) N.M. Shumeiko, JINR Rep. P2-11744 (1978), Jad. Fiz. 29 (1979) 1571.

5) D.Yu Bardin and N.M. Shumeiko, JINR Rep. P2-10872 (1977).

6) F.A. Berens and G.J. Komen, Phys. Lett. 63B (1976) 432.

7) A.D. Dolgov, Ref. TH 1944-CERN (1974).

8) A.A. Akhundov, D.Yu Bardin and N.M. Shumeiko, JINR Rep. P2-12814 (1979).

9) D.Yu Bardin and N.M. Shumeiko, JINR Rep. P2-10873 (1977), Jad. Fiz. 29 (1979) 969.

10) D. Bardin, O. Fedorenko and J. Shumeiko, JINR Rep. E2-12564, 12761 (1979).

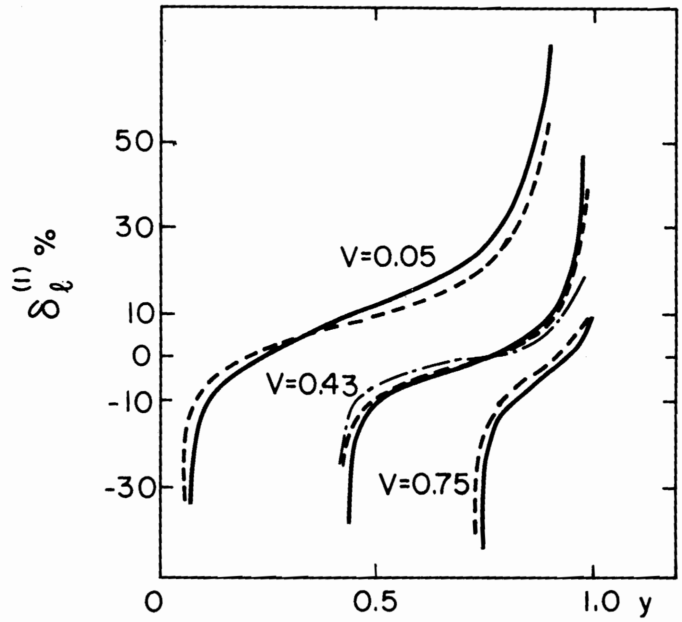


Fig. 1(a) Radiative corrections to the lepton current $\delta_\ell^{(1)}$ (%), as a function of y for different values of $v = x \cdot y$. The solid, dashed and dashed-dotted lines correspond to E = 3000, 300 and 50 GeV, respectively.

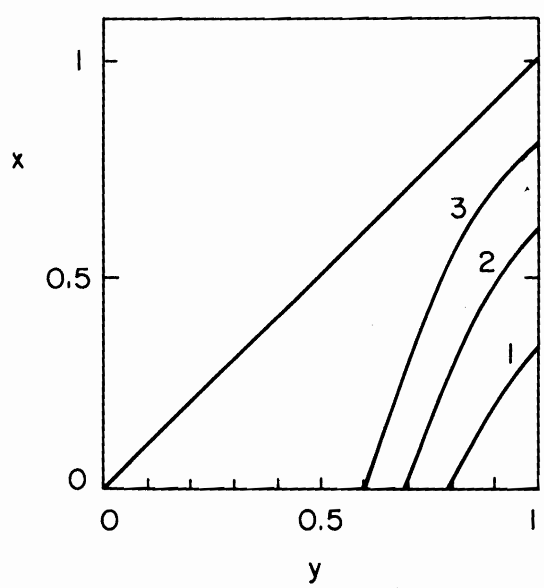


Fig. 1(b) Kinematical plot of the deep inelastic muon-nucleon scattering. Below the curves 1, 2, and 3 the $\delta_\ell^{(1)}$ is bigger than 30% at energies 300, 3000 and 30 000 GeV respectively.

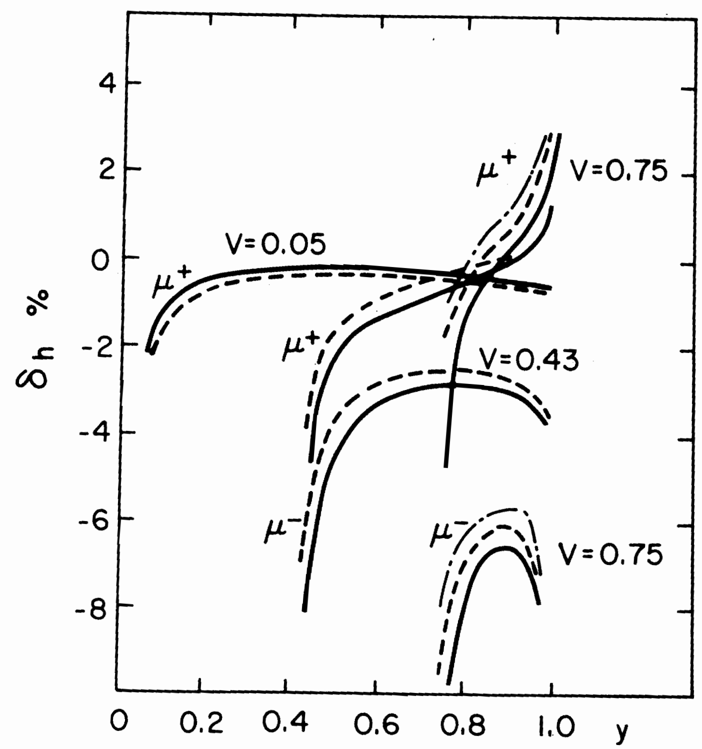


Fig. 2 Radiative corrections to the hadron current, $\delta_h^{(1)}$ (%), as a function of y for μ^+ and μ^- at different values of $v = x \cdot y$ and energies as in fig. 1(a).

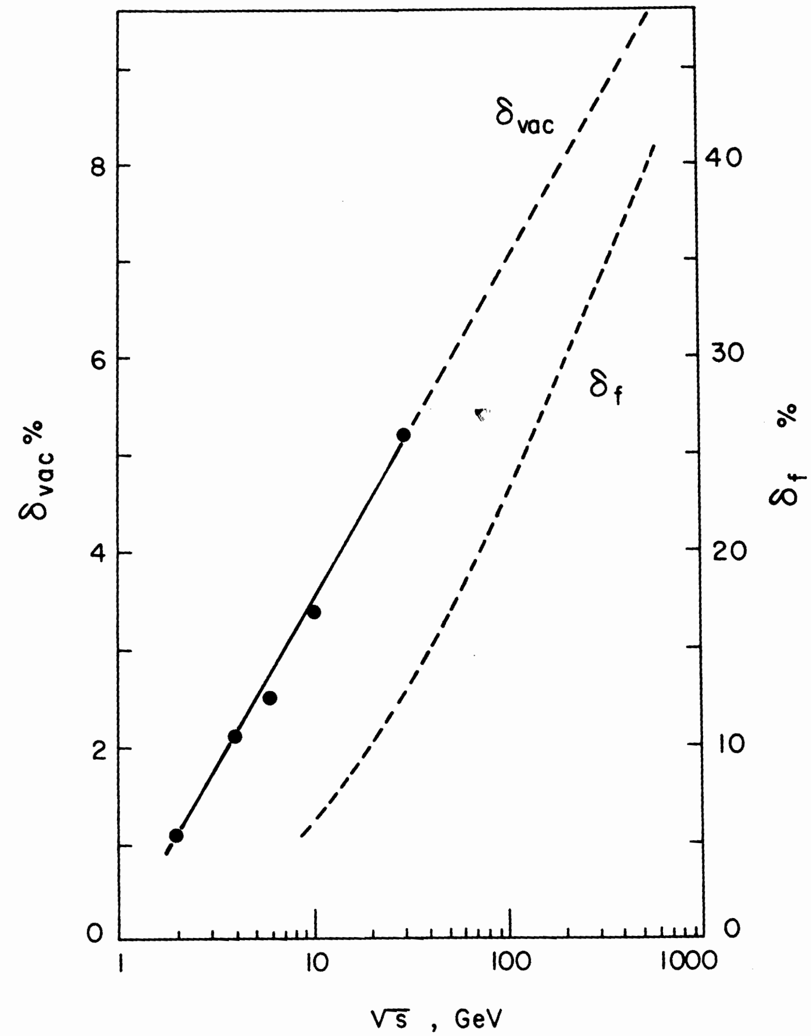


Fig. 3 Corrections due to hadron vacuum polarization, δ_{vac} (%), and e.m. interactions between hadrons in final states, δ_f(%), as a function of $\sqrt{s}$.