REPORT OF GROUP VI

DEEP INELASTIC EXPERIMENTS

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1. INTRODUCTION

The study of lepton-hadron scattering has in the past disclosed fundamental features of the matter structure at short distances. It is a common belief that the complicated world confined in the proton volume will be "deeply" studied in any future machine. The working hypothesis for this study group is the future existence of a 20 TeV proton machine with a proton intensity $J_p = 10^{13}$p/sec. On this hypothesis a study has been done to extrapolate the current experimental and theoretical knowledge on the investigation of nuclear matter in deep inelastic experiments at distances corresponding to $Q^2 \simeq 3 \cdot 10^4$ GeV. This note will report on the results of this extrapolation from the deep inelastic experiments with the present proton machine to the multi-TeV region.

The main line of the study has been traced during an active week of study at Diablerets by the group working with an enthusiasm very "deep" considering the large distance in time of the multi-TeV machine. Many individual contributions have been completed later at home institutions and appear in the proceedings as well.

The material of this report is organized in the following way:

1) outlook on the physics of the lepton-proton scattering at $Q^2 = 3 \cdot 10^4$ GeV^2;

2) how will the neutrino and the muon beam be in the TeV region?

3) detectors for experiments with neutrinos and muons up to 15 TeV.

The purpose of the meeting was to find the scaling laws for the extrapolation of the present experiments to the TeV region and, maybe, to find out the limitations of this procedure. The working hypotheses common to all groups were $E_p = 20$ TeV and $J_p = 10^{13}$p/sec.

Our group has chosen, for the study of neutrino beams, an apparatus where the vertex is considered important (hybrid bubble chamber). The muon beams have been optimized for electronic experiments with many scattering centers having in mind the low scattering cross-section at the highest Q^2.

2. PHYSICS WITH 15 TeV MUONS AND 10 TeV NEUTRINOS

In the following we assume that the deep inelastic experiments will start some years after the completion of the LEP experimental programs. The e^+e^- physics being studied up to $\sqrt{s}$ = 200 will have taught us something about quark structure. The celebrated quantity

$$R = \frac{e^+e^- \rightarrow \text{hadron}}{e^+e^- \rightarrow \mu^+\mu^-}$$

in the conservative hypothesis of the existence of the Z_o will look as shown in Fig. 1. The quantity R after the "Z_o" tail will remain constant or will deviate from a constant indicating a possible quark structure.

In high statistic deep inelastic experiments the quark structure will appear as a fast change of the nucleon-parton distribution,i.e. $F(x,Q^2)$. The present theoretical "prejudice" tells us that the deviation from scaling of $F(x,Q^2)$ has a logarithmic dependence on Q^2, but if a new structure is reached at some distance, the parton distribution will show a faster rise at small x than that shown in Fig. 2.

Mu-meson and neutrino experiments can give important contributions to the understanding of the weak interactions either confirming the present predictions or extending the range for the search for higher mass weak bosons.

1) The 15 TeV ν beam can produce W up to a mass of 140 GeV.

2) If the charged gauge boson of the weak interaction is found in e^+e^- experiments and has a mass of 60 GeV, another charged boson W' is expected to have a higher mass. Deep inelastic experiments can show the effects of W' up to masses $M_{W'} \simeq 500$ GeV.

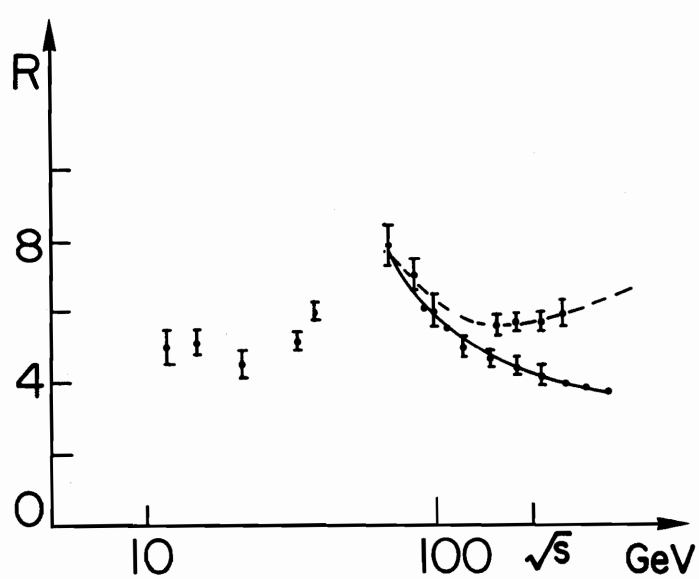

Fig. 1 Energy behaviour of the ratio $R = e^+e^- \rightarrow \text{hadron}/e^+e^- \rightarrow \mu^+\mu^-$.

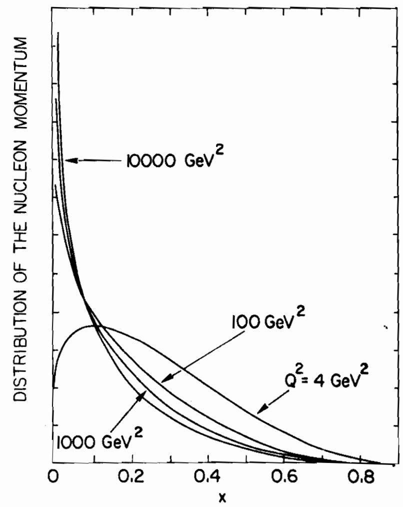

Fig. 2. Distribution of the nucleon momentum as predicted by QCD

In general, the experiments with ν and μ beams in the TeV region will be competitive with e^+e^- experiments for any rare process with cross-section $\sigma \lesssim 10^{-40}$ cm^2 (storage ring luminosities $\sim 10^{32}$ cm^{-2} sec^{-1}).

3. NEUTRINO BEAMS

What kind of ν beams and how to build them. This argument has been deeply studied by the Fermilab ν beam expert T. Mori and his contribution is published in the proceedings of this meeting. I will recall only the main results obtained by this extensive study.

1) Narrow Band Neutrino Beam (N.B.B.). The Proceedings of the 1978 ICFA working group contains a design of a N.B.B. Our group agrees with the conclusions reached with a warning on the difficulty of a π/K separation in the TeV region.

2) Wide Band Neutrino Beam (W.B.B.). The new fact in the TeV region compared to the GeV region is the fast rise of the radiation energy loss. So an important element of the W.B.B., the muon absorber (Fig. 3), does not scale linearly with energy and absorbers of 2 km of iron can absorb most of the decay muons. The very high gamma of the parent π also gives a naturally collimated beam. So a W.B. neutrino beam is conceptually very simple and, if the sign selection is not required, the beam elements are i) the target; ii) the decay tunnel; and the muon absorber as shown in Fig. 3.

If as reference detector we consider a bubble chamber, it is not very convenient to increase the decay tunnel since the flux per unit surface does not increase substantially (Fig. 3). A long cylindrical bubble chamber can be an ideal target vertex detector. The neutrino total cross-section is still rising linearly with energy in the TeV region and the rate for neutrino

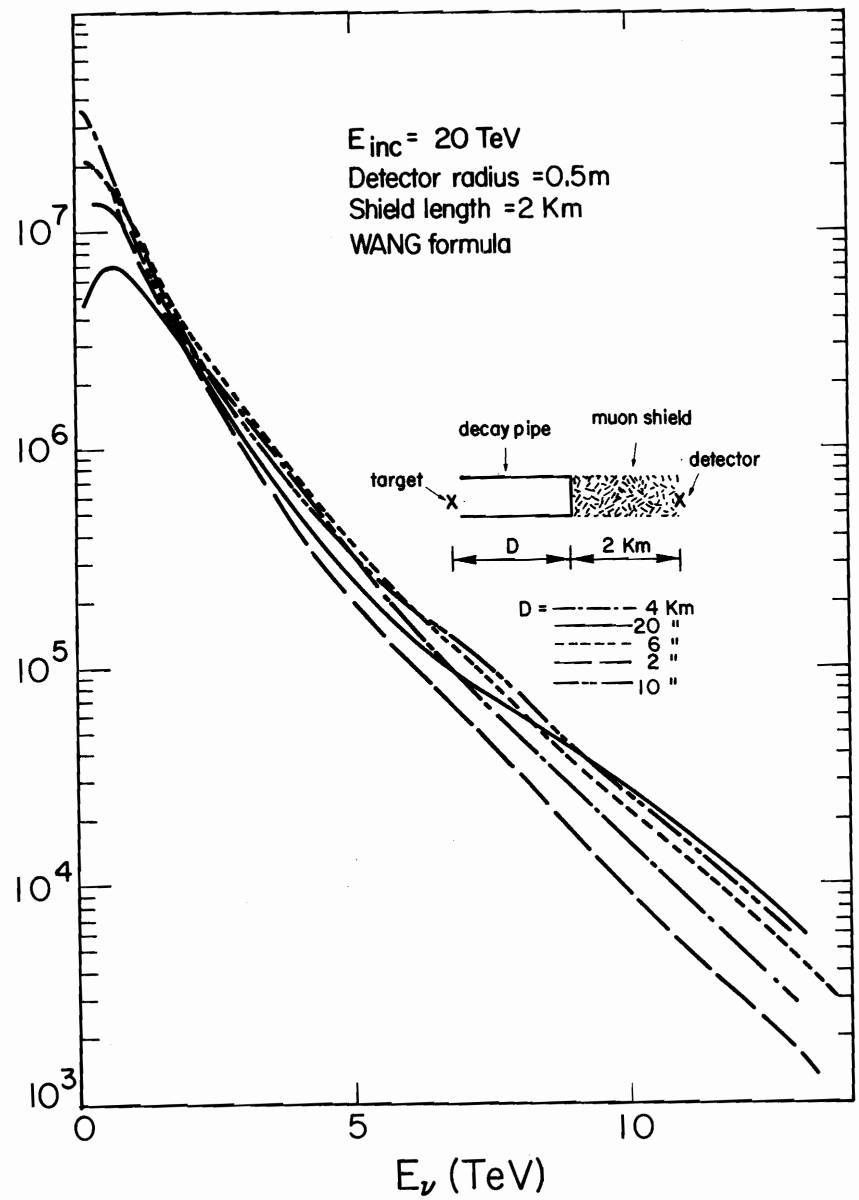

Fig. 3 Bare target ν_μ beam

experiments is relatively large (700 events/ton/10^{13}p). Neutrino experiments will look like the present hadron experiments with a target vertex detector (bubble chamber) and substantial external equipment.

An important feature of neutrino physics at high energy will be the possibility of studying reactions initiated by leptons of different flavours using beams of $\nu_{e,\mu,\tau}$. An important source of $\nu_{e,\tau}$ is the charmed particles. Neutrino beams with almost equal amounts of $\nu_{e,\mu,\tau}$ are produced in beam dump experiments (Figs 4,5). The possibility of having a tagged neutrino beam has been suggested by V. Kaftanov and the result of this work is published in the proceedings.

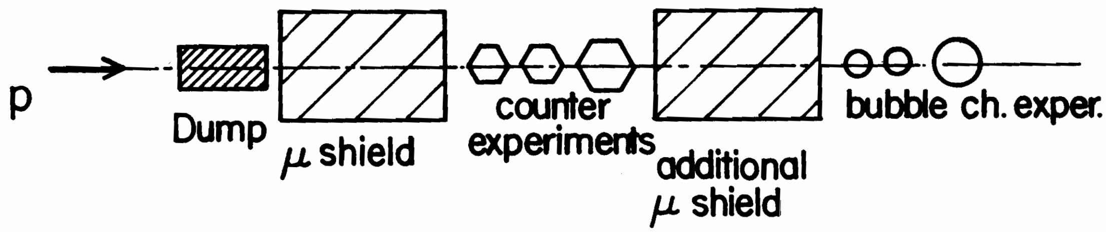

Fig. 4 Beam dump

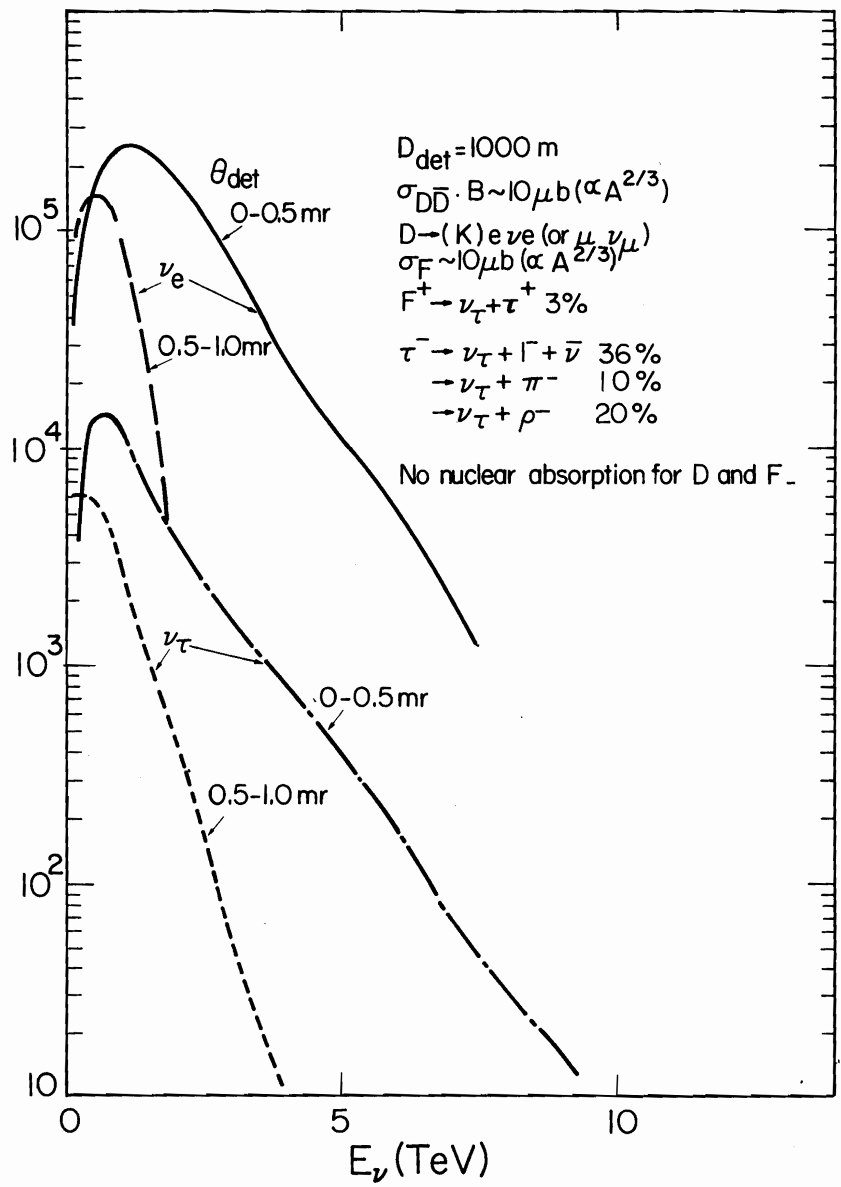

Fig. 5 Beam dump, 20 TeV

Conclusions on the ν beam

The N.B. and W.B. neutrino beam scaling law from the SPS to the 20 TeV machine is $E^{\leq 1}$. The beam dump technique will be a clear source of ν's with different flavours. In the Proceedings of the 1978 ICFA working group the possibility of a ν_e beam from the decay of μ stored in a ring has been considered. We believe that this expensive solution for a ν_e beam is justifiable if the μ storage ring is also used for $\mu\bar{\mu}$ collisions with luminosity $L \sim 10^{32}$ cm^{-2} sec^{-1}.

4. MUON BEAM FROM A 20 TeV PROTON MACHINE

The figures of merit to be optimized in a muon beam are:

1) high luminosity;
2) polarization;
3) monochromaticity, $\Delta p/p \sim 10\%$;
4) small transverse dimensions of the beam.

The building blocks for muon beams are shown in Fig. 6. The comparison between the existing muon beam at the SPS and the future muon beam is shown in the Table.

	SPS	20 TeV
L_1	0.6 km	30 km
L_2	0.3 km	2.5 km

The flux and luminosity for 1 m H_2 are:

E(TeV)	μ/sec	L(cm^{-2} sec^{-1}).
15	$2.3 \cdot 10^7$	10^{32}
10	10^8	$5 \cdot 10^{32}$

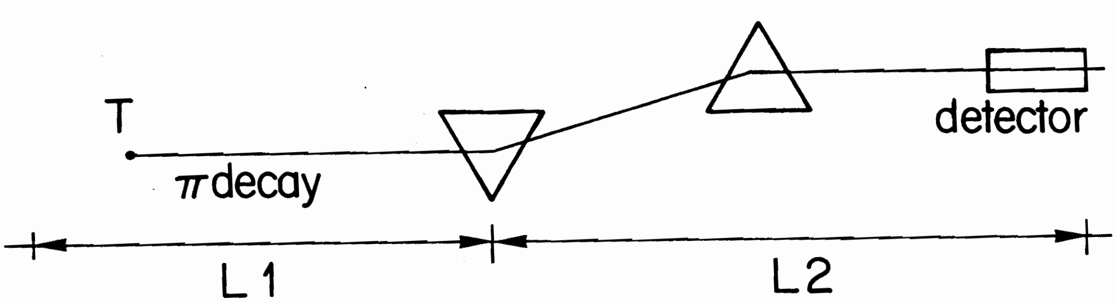

Fig. 6 Building blocks of the μ beam

5. DETECTOR FOR NEUTRINO BEAMS

The neutrino physics will be centered on the detailed study of the final states and strong emphasis will be placed on the quark flavour study. The possibility of seeing tracks of a few millimetres from short-lived particles produced at the vertex (τ, charm, beauty, etc.) makes the high spatial resolution bubble chamber an attractive vertex detector.

The requirement of one event per exposure implies a light chamber ($\sim$ 1/10 ton) of cylindrical shape, two to three metres long with a depth of $\sim$ 20 cm to allow $\Delta x \simeq 20\mu m$. The bubble chamber as target plus vertex detector requires heavy equipment to accomplish the complete reconstruction of the events. As shown in Fig. 7 the target bubble chamber is followed by:

1) an external particle identifier (EPI);

2) a hadron calorimeter for energy measurement;

3) an external muon identifier (EMI).

Some remarks regarding more specialized experiments are the following:

1) the decay products of the charged weak boson $W^{\pm}$ are at large angle $\theta \sim 10^{o}$;

2) the value of $\gamma\tau c$ for particles with charm and beauty are in the range of one cm;

3) an electronic detector that could have a space resolution comparable to the one of the bubble chamber ($\sim \Delta x \sim 20\mu m$) can study rare processes like $\nu_{\mu}e^{-} \rightarrow \nu_{\mu}e^{-}$ and $\bar{\nu}_{e}e^{-} \rightarrow \bar{c}s$ for center-of-mass energy $\sqrt{s} \sim 4$ GeV.

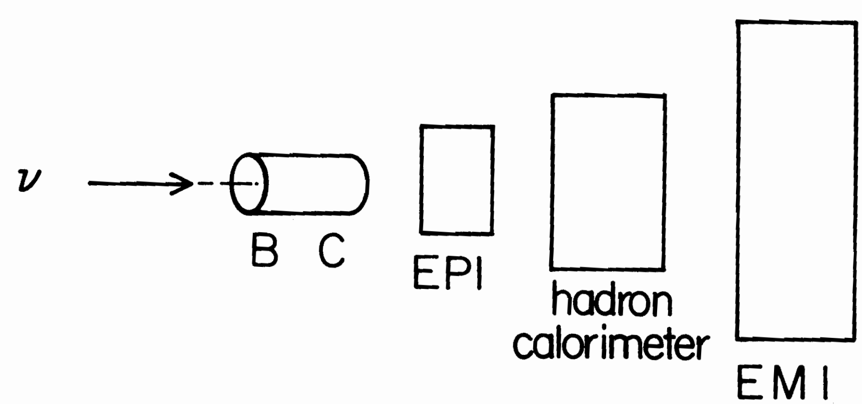

Fig. 7 Hybrid system bubble chamber + electronic detectors

6. EXPERIMENTS WITH MUON BEAMS

Physics with muon beams will be most likely devoted to:

1) deep inelastic scattering;
2) weak electromagnetic interference effects.

Beams and experiments will reach a very high luminosity ($L \sim 10^{38}$ $cm^{-2}day^{-1}$). In Fig. 8 is shown the typical deep inelastic diagram on the Q^2,ν plane for the 20 TeV machine.

The different kinematical regions will give interesting physical information on the proton world.

1) For $x < 0.1$ the experiments will study, with high statistics, the heavy quark sea ($\sim 3 \cdot 10^5$ events/day).
2) Weak interactions will take over on QED at high Q^2 ($Q^2 > 1000$ GeV^2).
3) Sizeable QCD effects and possible quark sturctures will be studied at the highest Q^2.

Experimental information to remember is the strong radiative effects of the muon (the critical energy in iron is 0.87 TeV and in H_2 11 TeV).

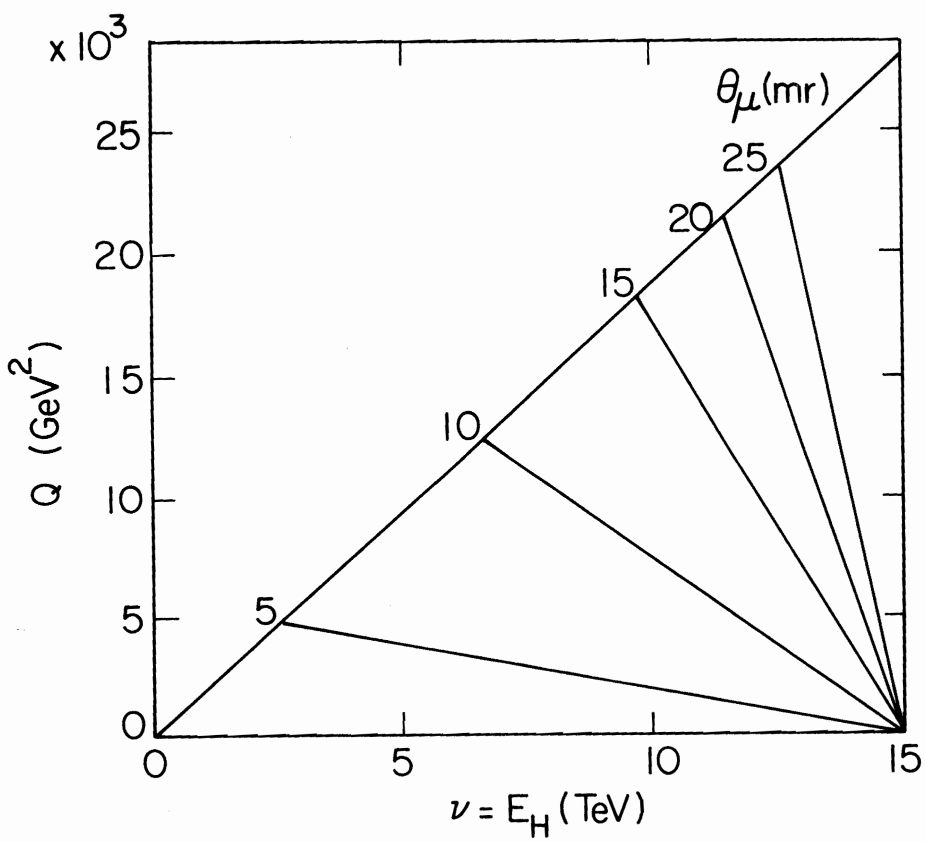

Fig. 8 Q^2, ν plot for deep inelastic scattering

Spectrometer for muon-proton scattering

A spectrometer using current technology that can be scaled at the multi-TeV muon beam has been presented at this meeting by Professor H. Anderson and is extensively described in the proceedings. The spectrometer is made of many cells, each cell consisting of a wide aperture magnet (magnetic field 2T) powered with superconducting core. Considering a space resolution $\sigma_x \sim \sigma_y \sim$ $\sim 100\mu m$ the angular and momentum resolution that can be obtained is $\sigma_\theta/\theta \sim$ $\sim \sigma_p/p \simeq 1\%$.

Calorimeters for deep inelastic muon experiments

In deep inelastic experiments the two measured quantities are:

$$Q^2 = 2E_\mu E'_\mu \sin^2 \frac{\theta}{2} \simeq E_\mu E'_\mu \theta^2$$

$$\nu = E_\mu - E'_\mu \simeq E_H$$

At very high energy the energy resolution of the calorimeters can be as good as $\Delta E_H/E_H \sim 1\%$ and the Q^2 and ν can be derived by the measurement of θ_μ and E_H. A sketch of a very high energy deep inelastic scattering using calorimeters is shown in Fig. 9. The tagging of the scattered muon is done with the equipped hadron absorber where the high value of the radiative losses of the muon can easily be detected giving also a rough indication of the scattered muon energy ($\Delta E'_\mu/E'_\mu \simeq 0.2$).

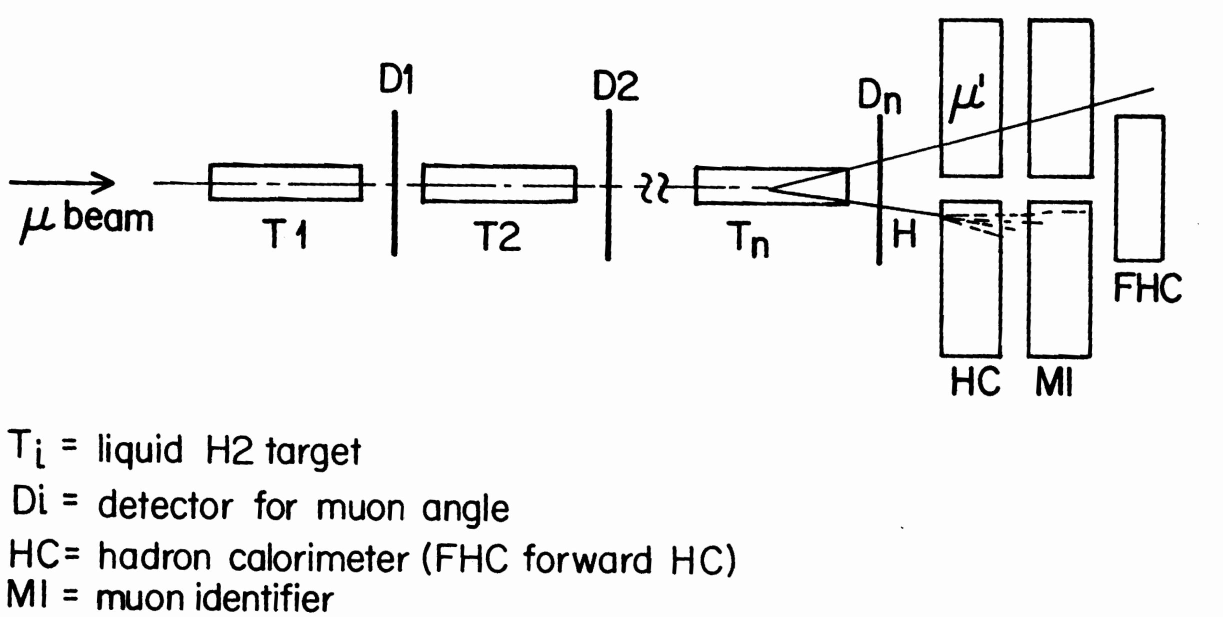

Fig. 9 Deep inelastic muon scattering with detection of the hadron shower energy

Calorimeters for muon-neutrino conversion experiments

The reaction

$$\mu \mathcal{N} \rightarrow \nu + X$$

gives physical information equivalent to that obtainable in the process

$$\nu \mathcal{N} \rightarrow \mu + X$$

The use of left-handed and right-handed muons will put limits on the existence of right-handed coupling of the lepton-hadron interaction. The possibility of experiments of this kind has been studied by H. Montgomery and the results are published in the proceedings of this meeting. A fine-grained calorimeter can detect the energy and the angle of the hadron jet with an accuracy $\Delta E_H/E_H \sim 1\%$ and $\theta_H/\theta_H \sim 10\%$. The monochromaticity of the muon beam will allow precise energy dependence measurement of the total cross-section.

7. CONCLUSIONS

The lepton beams of a 20 TeV proton machine will provide interesting physical information on the hadron structure function for Q^2 up to $3 \cdot 10^4$ GeV^2. The luminosity for a muon beam and a liquid H_2 target 100 metres long is $4 \cdot 10^{33}$ cm^{-2}sec^{-1}, more than one order of magnitude larger than the luminosity of colliding beams (e^+e^- and ep). Muon polarization will be an important tool for the study of the weak-electromagnetic interference. The possibility of producing ν beams of different leptonic flavours will allow tests of the universality of the interaction and will bring some understanding of the lepton flavours. The beams and the detectors for the multi-TeV machine can be scaled from what is done today at the SPS.