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Spokesman: C. N. Brown
Fermilab
(312)840-3158

A CRITICAL TEST OF THE QUARK CONFINEMENT MODEL

J.A. Appel, B.C. Brown, C.N. Brown, T. Yamanouchi

Fermi National Accelerator Laboratory

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I. Introduction

Elementary Particle Phenomenology is very conveniently described by Quark Model descriptions of the conservation laws governing the collisions and by parton model calculations of the dynamical properties of these interactions. Many experiments have tried to search for new particles which might be identified with the elementary quarks or partons, these searches have been carried to large masses at the ISR and to small cross sections at CERN PS, Serpukhov, and FNAL (e.g. E75). The negative results of these searches have led to much theoretical speculation (usually given the rubric "quark confinement models") on the binding of the constituents of a hadron. It is an element of an experimentalist's faith that the search for free constituent particles must be pushed to as high a mass and as small a cross-section as is accessible with the current generation of accelerators.

With the Fermilab synchrotron now capable of running at 500 GeV and with the prospect of 1000 GeV protons when the doubler is constructed, the mass range searched by E75 can now be extended. The soon to be completed P-West pion beam is designed to have a very large acceptance, very high intensity capabilities, and very flexible choice of targetting conditions. We propose to search for fractionally charged long-lived particles ($t \gtrsim 10^{-9}$ sec) in the P-West pion beam both at 500 GeV and at 1000 GeV. This search will improve the limits established by E75 by more than two orders of magnitude in cross section and by a factor of 2 in mass.

II. Kinematical Considerations

The optimum choice of the secondary momentum and production angle at which to search for heavy objects depends on the mechanism of their production. It is assumed that small production angles are favored (the most massive object which can be produced must go exactly forward in the lab). On the other hand, recent results on the production dynamics of J/ψ particles and also Drell-Yan-like lepton pairs indicate a much less steep p_T dependence than the limited 300 MeV/c of transverse momentum seen for light hadrons. One might interpret this as suggesting that massive constituents of a hadron would be produced with a flat p_t spectrum. Therefore, it is proposed to search at 0^o with the large angular aperture of the P-west pion beam ensuring a good acceptance for particles produced with a flat spectrum in p_t. If the muon background should prove severe, it will be possible to steer muons away from the apparatus by targetting the beam a few mrad opposite the direction of the pion beam bends. This will decrease the sensitivity very little, if the p_t spectrum is relatively flat.

Studying the kinematics of possible production mechanisms gives the optimum secondary momentum setting. The most massive particle that can be produced would occur thru simple pair production

$$N + N \rightarrow N + N + Q + \bar{Q} \qquad (1)$$

In this reaction it is kinematically possible to produce a 14.4 GeV object at 500 GeV and a 20.7 GeV object at 1000 GeV. If these particles had a charge of -1/3 they would have apparent laboratory momenta of 706 GeV and 1434 GeV respectively. These momenta are the super-momentum settings that lead to the most sensitive new particle search possible. For particles with masses less than the kinematical limit it is assumed that a rising production cross-section above energy threshold and a relatively flat production spectrum in both X and p_t would make them easily observable even though the secondary momentum was not quite optimum. This is evident from the four body phase space calculations shown in figure 1.

for 1000 GeV incident momentum. It should be pointed out that the super-momentum mode is a unique and powerful way of rejecting background particles, thus it is essential in achieving the highest sensitivity.

A simple comparison of the relative sensitivity of E-75 and this proposal is given in the following table.

	E-75 (M2)	P-West Beam
Total integrated beam	$< 10^{17}$	$> 10^{17}$
Secondary beam acceptance	.4 μster. %	60 μster %
Kinematical mass limit	8.7 GeV	14.4 GeV at 500
		20.7 GeV at 1000

This greater than two order of magnitude increase in the sensitivity of this proposal will result in a search down to cross-sections less than $10^{-39}cm^2$ at the highest masses kinematically allowed at Fermilab.

Constituents might also be produced through dissociation as in the following reaction,

$$N + N \rightarrow N + Q\ (\tfrac{2}{3}) + Q\ (\tfrac{2}{3}) + Q\ (-\ \tfrac{1}{3}) \qquad (2)$$

The most massive object kinematically observable thru this reaction is less than for reaction (1).

A search for charge $+\frac{2}{3}$ objects is necessarily less sensitive than for -1/3 objects as the optimum momentum setting of the beam is less than the incident proton energy. For 500 GeV and 1000 GeV the optimum settings would be 353.0 GeV and 717.3 GeV respectively. Assuming 10^6 integrally charged particles per spill such a sub-momentum search would have a sensitivity of the order of 10^{-10} of the ordinary hadron flux.

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III. Apparatus

Fig. 2 shows a layout of the proposed apparatus V_o, V_1 and V_2 are anti-counters, E_1 to E_8 are 1/2 in. thick scintillation counters, all are set to detect .07 times minimum ionizing particles. C_1 and C_2 are simple threshold Cherenkov counters used to help reduce low mass single ionizing backgrounds in the sub-momentum running. The apparatus could be located anywhere downstream of the momentum slit in the P-west pion beam. The final size of the counters will depend on the exact location in the beam but is expected to be less than 2 in. x 2 in.

Reading of all pulse heights will be triggered by the passage of any charged particle in the supermomentum mode. In the sub-momentum mode different triggers are possible including triggering on 2 of the scintillators S1-S8 less than minimum ionizing or triggering on an absence of a signal in both Cherenkov counters. A simple compact read-in system based on a small PDP 11/20 will be quite sufficient.

IV. Run Time Estimates and Schedule

We assume conservatively 3 pulses per minute at 500 GeV i.e. 10^4 pulses per 50 hours. At an intensity of $> 5 \times 10^{12}$ pulse this gives $> 10^{17}$ protons in 100 hours for the supermomentum search. In the sub-momentum mode 100 hours at 10^6 per pulse will give a search sensitive at 1 part in 10^{10}.

We request 100 additional hours for tune-up time for a total request of 300 hours at 500 GeV. We realize that many more hours will be required to commission the P-west pion beam. We believe this experiment should be run as soon as possible and can be run even before the downstream portion of the beam-line and the experimental set-ups are complete. If approved we will commit ourselves to helping in the original installation and tuning work for the beam.

To estimate the running time at 1000 GeV is difficult due to the uncertainty of the machine cycle. If we assume that the same integrated intensity will be available per day and a duty cycle not too different from present then the request will again be 300 hours.

V. Conclusion

Even for a relatively light, strongly produced particle such as the J/ψ it is clear that the increased luminosity at FNAL more than compensates the total center of mass energy advantage enjoyed by the ISR. For particles heavier than the J/ψ this advantage is overwhelming for any reasonable S dependence of the cross-section at threshold. Therefore it is important to make a search at FNAL for heavy fractionally charged particles using the super-momentum technique as this method alone reaches the greatest sensitivities near the kinematical limits at 500 or 1000 GeV. We thank Dr. R. R. Wilson for his continuing interests and encouragements.

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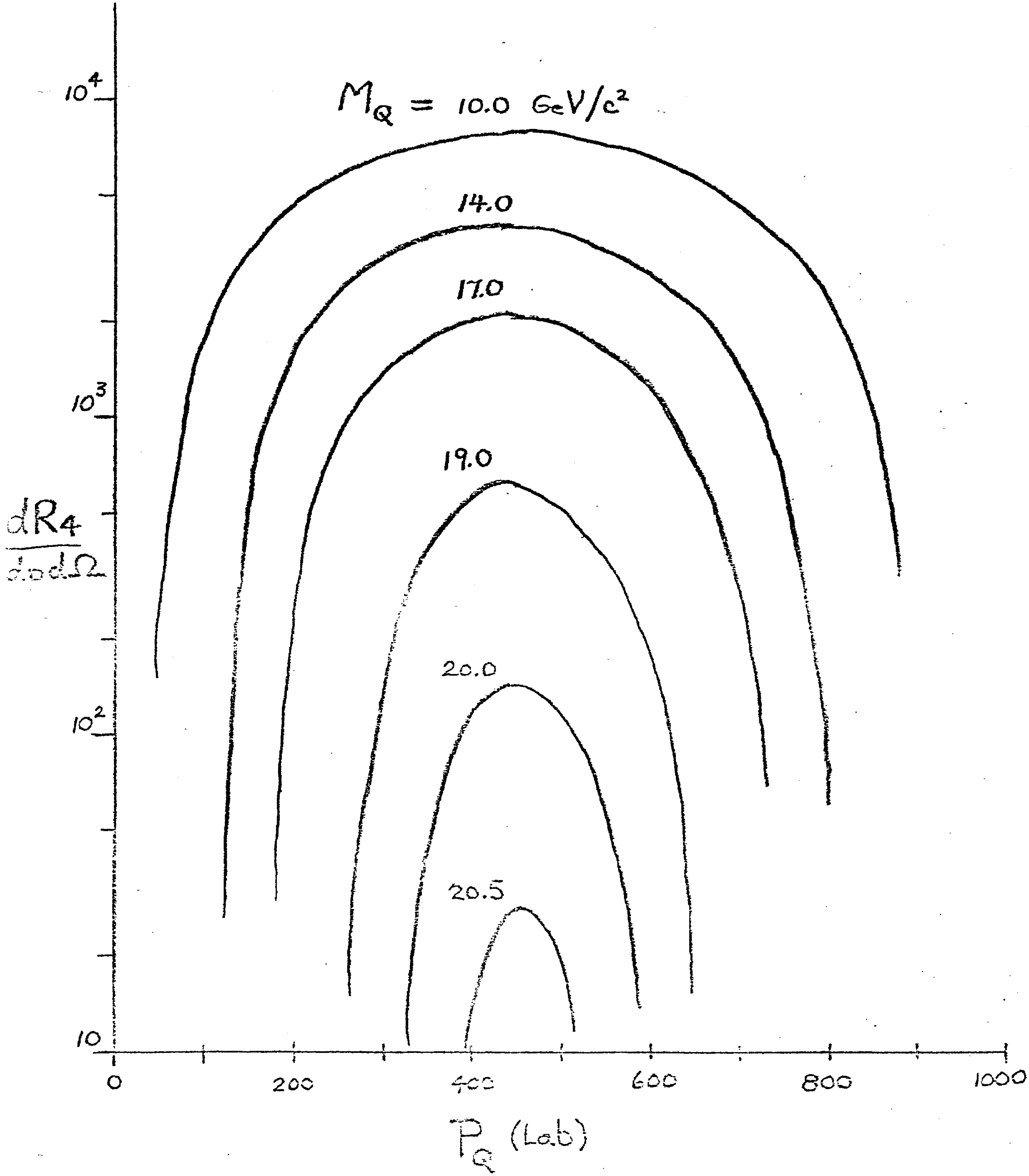
FIGURE CAPTIONS

1. Four-body phase space for the pair production of heavy particles of mass M_q for 1000 GeV incident protons.

2. Diagram of proposed apparatus. A coincidence of counters E1 and B coupled with an absence of a veto-signal triggers the readin of the pulse height scintillators E1-E8 and the Cerenkov counters C1, C2.



M_Q = 10.0 GeV/c²
14.0
17.0
19.0
20.0
20.5
10⁴
10³
10²
10
dR4 / dΩ dΩ
0
200
400
600
800
1000
P_Q (Lab)

Fig 1

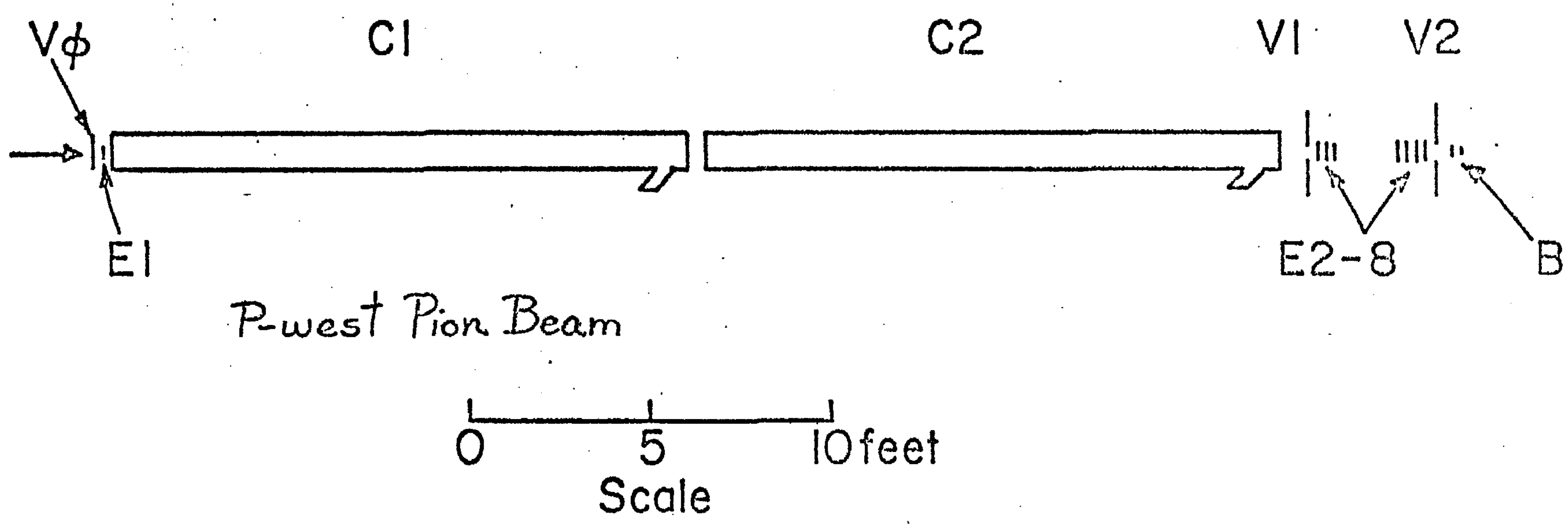


Fig. 2

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ADDENDUM TO PROPOSAL 532

Despite extensive searches for quarks at high energy accelerators, they remain an elusive quarry. Possible explanations why they have not been observed include:

1) They are integrally charged: (Han-Nambu quarks) or they are fractionally charged but
2) They are relatively light but strongly confined within ordinary hadronic matter; or
3) They are very massive and hence their production is suppressed in ordinary hadronic collisions.

We would like to emphasize that our proposal tests possibilities 2) and 3) by pushing the current mass and sensitivity limits considerably beyond previous searches.

The recent tantalizing report by Fairbank's group at Stanford encourages us to push harder to mount experiment P532 and investigate possibilities 2) and 3) above as soon as possible. We therefore propose as an addendum to P532 a conventional front end for the new high intensity P-West pion beam that would enable us to mount P532 within nine months and utilize the full 10^{13} protons/sec at 450-500 GeV that the Fermilab accelerator is now capable of delivering.

We believe this conventional first section of a P-West pion beam fits easily within the current design parameters of the Target Service Building utilities for the P-West area. We also believe such a temporary installation will not slow down the eventual delivery of intense high quality pion beams to the pion lab. On the contrary, we believe this conventional front end and first experiment will help hasten the time when a full design 1000 GeV beam will be available.

Within the context of our specific proposal to do a supermomentum search for charge 1/3 particles it is important to note that our design is capable of transporting 700 GeV secondary particles as far as the momentum slit in the pion lab. The acceptance of the beam is also as large as the design value for the superconducting pion beam. This will enable the supermomentum search to reach the mass and sensitivity quoted in the original proposal.

A. Proposed Beam

Figure 1 diagrams a sequence of 5 quadrupoles and 3 bending magnets which compose a first stage of the P-West pion beam transporting the secondary particles to the momentum slit enclosure. The quads could be either 4Q120's or 3Q120's. The bending magnets are 3 main ring B1 magnets run in series with the target box dispersing bend magnet. With one transrex power supply running at full voltage the dipoles will be limited to about 4000 amps. This corresponds to about 700 GeV at the center of the momentum slit. The quadrupoles capture 700 GeV particles and transport them to within a 10 cm by 5 cm spot at the momentum slit. With 4Q120 quads the acceptance at 700 GeV is about 100 μster% and with 3Q120's about 50 μster%. This is to be compared with the design value of 60 μster% for the full superconducting pion beam. The planned electrical and cooling water capacity in the target service building will easily handle this load.

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B. Possible Schedule

It is anticipated that 3 B1 magnets and 5 quadrupoles could be made available by this summer. Installation of the conventional first stage beam and P532 could proceed simultaneously with the installation of the target box and the momentum slit. The equipment would sit a few meters downstream of the momentum slit and would presumably run only on weekends. On weekdays the installation and testing of a superconducting second stage of the beam and the installation of experiments in the P-West pion area would proceed.

Since our requested 300 hours of running would be satisfied in 2 or 3 months of weekend running, we would vacate in time for the conversion of the first stage to superconducting elements and the full commissioning of the pion beam in FY 78.

P-West Pion Beam, First Stage

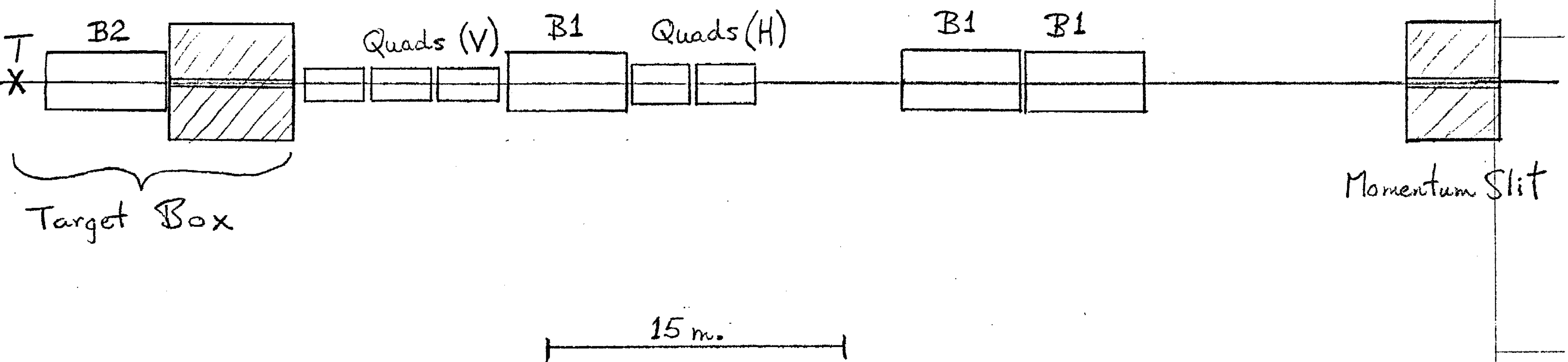

Figure 1.