

A LARGE SOLID ANGLE MAGNETIC DETECTOR
FOR ELECTRON-PROTON COLLIDING BEAMS

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Design Considerations

We have examined the properties of a magnetic detector designed to measure electron-proton deep inelastic scattering events in a colliding-beam experiment such as the proposed "electron target" for NAL. We have assumed the kinematics for 3 GeV on 400-GeV collisions; the conclusions for this case seem to us to be valid for a much wider energy range and could apply equally well to the case of 20-GeV electrons on 1000-GeV protons as studied at the 1973 Aspen Summer Study. Some scaling of the apparatus, appropriate to the higher energy, will be needed and will be commented on at the appropriate points in the text.

The detector design has been somewhat biased by a model of the interaction as shown in Fig. 1. From this model and the kinematics we have concluded that:

1. Detection of the scattered electron is necessary only in the backward hemisphere from $\approx 90^\circ$ to $\approx 10^\circ$ as measured from the initial proton direction. (The kinematics can be seen in Fig. 2.) We assume that a sign determination of the electron charge is essential to reduce backgrounds.

2. Measurement of the "beam jet" requires a transverse magnetic field in order to separate jet particles from the beam and to aid in separating the beam from the forward cone of neutral particles that must also be measured. A convenient experimental method for obtaining this transverse field is due to E. J. N. Wilson who points out that a "split field" magnet is a useful method of beam control in colliding beam machines and that such magnets are in a sense, a part of the machine lattice. Such a transverse field suffers the disadvantage in the proposed "electron target" for NAL that the transverse field must be ramped with the accelerator as the machine energy is increased.

Detector Description

The proposed detector is shown in Fig. 3. Its main components are a small split field magnet, the solenoidal magnet, the transverse magnet with smaller compensating magnets, shower counters and calorimeter around the solenoidal magnet, and shower counters and calorimeter in the "beam jet" detector downstream from the transverse magnet. We discuss each of these separately.

The Small Split Field Magnet

The small split field magnet of 2 kG-meter field provides colinear electron-proton collisions in a short region immediately upstream from the solenoidal magnet. It gives a 10-mrad bend to

the low-energy electrons in order to separate them from the proton beam; the perturbation on the proton trajectory is assumed to be small for the purpose of this discussion.

The Solenoidal Magnet

This magnet is chosen to magnetically measure wide-angle electrons and particles in the parton jet using spark chambers immersed in its volume. It aids in distinguishing such jet particles from the pionization cloud. Particles emerging from the interaction region from $\theta = 90^\circ$ to $\theta = 30^\circ$ are magnetically measured and, if they are electrons, have a more precise energy measurement as they shower in counters surrounding the solenoid. Particles between 30° and 40° are measured magnetically but with rather poor resolution if the momentum is high. Energy measurements for these angles are performed in shower counters and a calorimeter covering the downstream end of the solenoid. (At higher energies, i. e. 25×1000 GeV, it seems clear that a calorimeter must surround the entire solenoid.) Resolution of the solenoid can be conveniently parametrized by estimating the sagitta:

$$s = \frac{A \sin^2 \theta}{p_{\perp}}$$

where

$$A = \frac{L^2 B}{264 \text{ kGm}}$$

Here

θ = scattering angle

L = path length in the magnetic field, (L/c is the time spent in the magnetic field)

B = 33 kG.

The following table summarizes the kinematics and resolution for a 1-m radius by 2-m long solenoid of 33 kG measuring 3×400 GeV interactions.

Lab angle from proton	E_e^1 (max)	s (mm)	Q_{max}^2	Q_{min}^2 ($p_{\perp} > 5$ GeV)
10°	200	0.4	2400	360
20°	80	1.8	935	175
45°	19.5	17	200	72.5
90°	5.96	21	36	30

The final column follows from considerations by M. Strovink in the 1973 Aspen Summer Study who points out that π^0 backgrounds may be intolerable below $p_{\perp} = 5$ GeV. The magnetic field in this experiment will aid considerably in reducing these backgrounds but perhaps not enough to measure for significantly lower p_{\perp} than 5 GeV/c. We see that the sagitta is sufficiently large for a sign determination of the electron even for the highest energy electrons except perhaps near 10° . Particles in the beam jet will be measured more precisely than these elastic electrons since the momentum is shared among several particles.

The Transverse Magnet

The forward-going beam jet will have a typical longitudinal momentum of 200-300 GeV. If it shares this among 10 particles, the typical cone angle is 10 mrad. A transverse magnet aperture of 20-cm horizontal by 40-cm vertical seems adequate. (A vertical bend is chosen since the NAL vacuum chamber is smallest in this direction.) A $2 \text{ m} \times 6.5 \text{ kG}$ ramped field gives $\sim 1 \text{ GeV}/c$ transverse momentum to a particle. This impulse is clearly too large for the electron beam so that a superconducting pipe is needed to transport it through the magnet and back to the electron machine lattice. The 10-mrad bend to the electron beam from the small split-field magnets seems to result in adequate separation from the estimated 10-mrad cone angle of the beam jet. A superconducting tube of 5-cm diameter seems reasonable although 10-cm aperture could be tolerated. The 13 kG-m field separates 100-GeV particles by 3.2 cm from the main beam in 8 meters. Compensating magnets for this transverse field are needed elsewhere in the machine lattice.

Shower Counter and Calorimeter

Shower counters 2-m long with phototubes at each end surround the circumference of the solenoid and measure the electron energy (Q^2) of the event. A sandwich of 6-8 scintillators with 8-15 radiation lengths of lead might be sufficient. The end of the solenoid is capped with shower counters and a calorimeter to measure the total energy of the hadrons.

Beam Jet Calorimeter

A downstream shower counter and calorimeter is used to measure the energy content of the beam jet. Both the neutral component and the charged component are measured giving an overall energy balance to an event.

Conclusion

We have attempted a conceptual design of a detector that fits in a relatively small straight section yet collects all of the participating particles in an e-p deep inelastic collision. We conclude that such a detector is feasible although it is certainly not trivial and that a great deal of detailed design would be necessary before embarking on construction. The design of the detector is easily scaled to higher energy interactions, the solenoid will become larger, perhaps 2-m radius, and the transverse field must be stronger and would probably be a superconducting magnet since the 1000-GeV proton ring would be a true storage ring with fixed field. Our major conclusions are:

1. Only the backward hemisphere needs to be covered by the detector.
2. Only moderate straight section lengths are necessary if a transverse field is used to measure the beam jet.

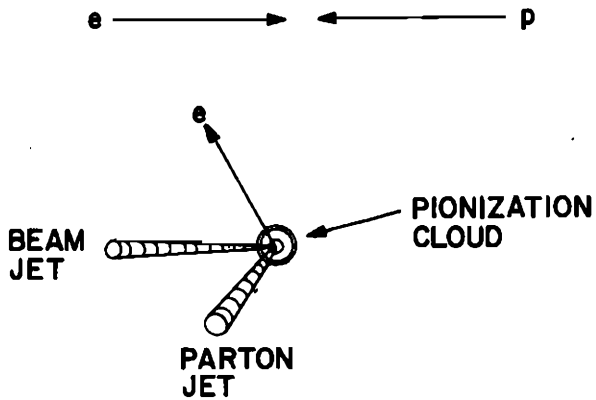
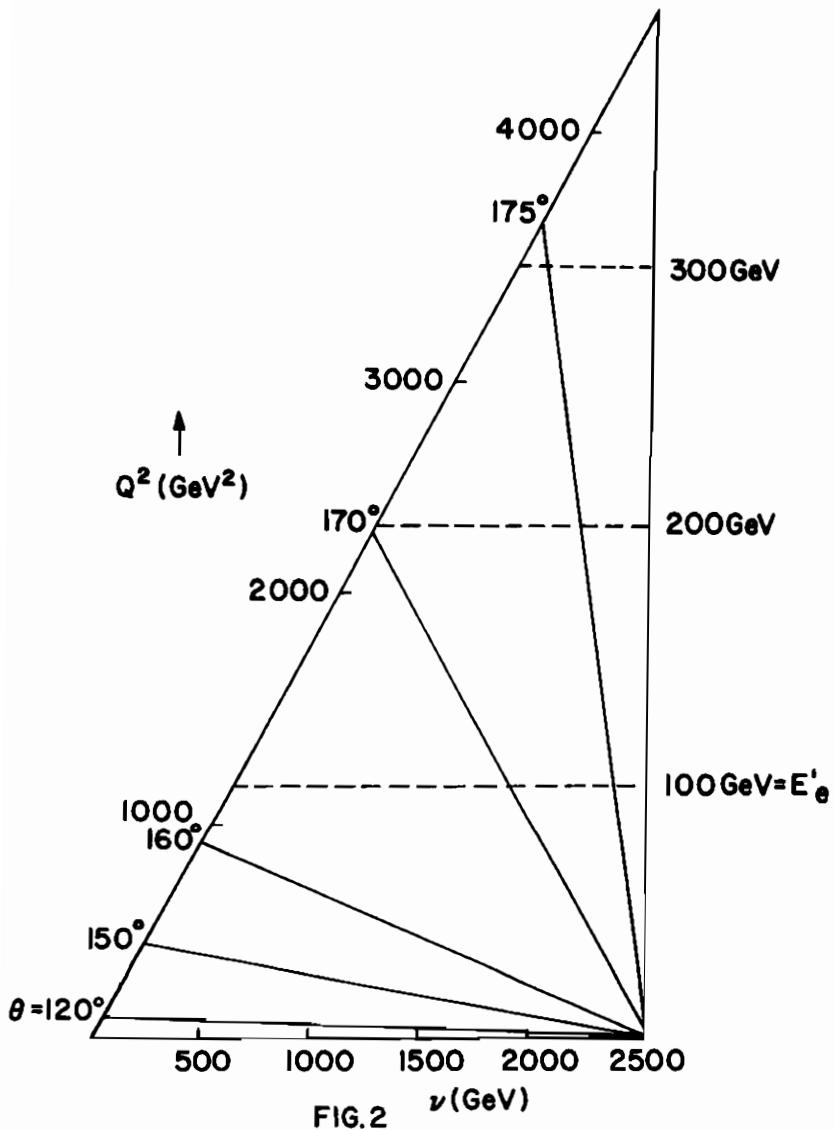


FIG.1



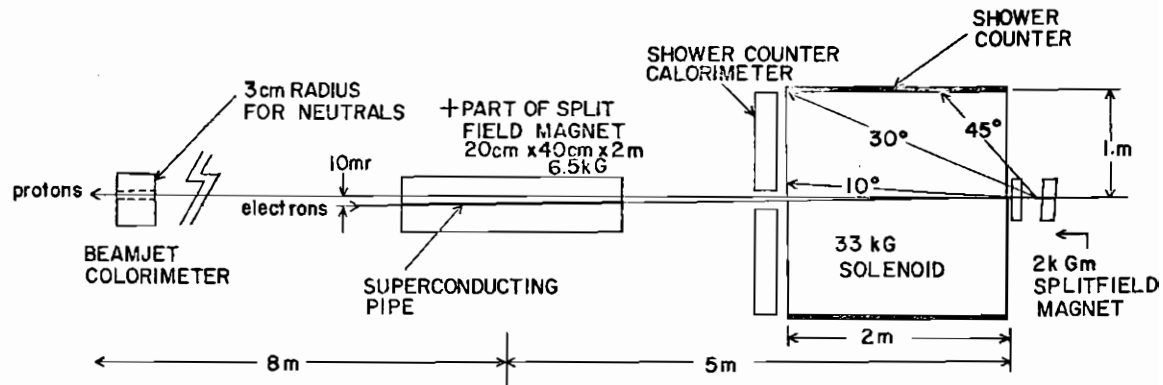


Fig. 3