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A technical description and request
for beam time for the proposal

Measurement of the Ratio between the Double- and Single-Ionization Cross Sections of Helium by Antiprotons

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INTRODUCTION

At the PSCC meeting on February 1, 1983, our Proposal CERN/PSCC 82-86, PSCC/P64, November 1982, was recommended, but technical clarification was needed. A more technical description is found below together with a request for beam time. In the proposal, we suggested an experimental investigation of the double-ionization cross section for 5-MeV antiprotons colliding with He atoms. However, it has become clear that a 5-MeV $\bar{p}$ beam from LEAR will not be available in the near future. Nevertheless, it will be possible to perform the measurement with a degraded 200-MeV/c (∿21-MeV kinetic energy) beam, which will be produced at LEAR in 1984. In the present brief report, the apparatus is described, the degraded 5-MeV $\bar{p}$-beam quality is discussed based on measurements on a Ni degrader, the background radiation is estimated, and test experiments are outlined.

Description of Apparatus

In Fig. 1 is shown a schematic drawing of the proposed apparatus. The 21-MeV $\bar{p}$ beam passes through a metallized scintillating degrader foil, in which the $\bar{p}$'s lose ∿16 MeV. They then interact with a dilute He gas (∿10^{-3} torr) in the target region, and the $\bar{p}$'s are detected by a ΔE scintillator counter which, in coincidence with the degrading scintillator, serves as a stop detector in a time-of-flight system.

Between the bottom of the target region and a thin, high-transparency mesh is an accelerating voltage of ∿800 V/cm, which directs the created singly and doubly charged He ions into a flight tube consisting of two cylindrical nets. The dimensions and the applied voltages are optimized so as to give the optimum time resolution for a broad $\bar{p}$ beam. The tube consists of nets to allow pumping of outstreaming He gas. The start detector is a low dark-current channel-electron multiplier, the cone of which is held at -3 kV. Vacuum is maintained by a diffusion pump. Although the drift time in this field is $\sim$400 ns, a beam intensity of up to 10^6 per sec can be tolerated since the difference in drift time between He^+ and He^{++} is 150 ns, and the time resolution is $\sim$10 ns (see Fig. 2 of Ref. 1).

Assuming the same double-ionization cross section for $\bar{p}$ as for p, a collection of 200 counts in the He^{++} peak requires an intensity of 10^6 $\bar{p}$/sec for $\sim$4 hrs of efficient running time. The content of the He^+ peak will be some 500 times higher.

Degraded Antiproton-Beam Quality

The degrading causes two main problems: energy straggling and angular deflection. At the 6-MeV Aarhus Tandem Van de Graaff, we have measured the energy and the angular distribution of 12-MeV p degraded to 4-MeV in a Ni foil, and the results are shown in Fig. 2a and b. The obtained distributions agree well with the results obtained from the energy-straggling theory of Tschalär[2)] and Molière's multiple-scattering theory[3)]. Hence we feel confident about the corresponding theoretical results obtained for 20-MeV $\bar{p}$ degraded to 5 MeV.

In Fig. 3 is shown our best estimate of the energy of antiprotons as a function of Ni-foil thickness. It is seen that a 656-mg/cm^2 foil should decelerate 20-MeV $\bar{p}$'s to 5 MeV. It is obvious, however, that the exit energy depends strongly on the foil thickness, and the actual thickness of the degrader foil to be used must be checked experimentally.

In Fig. 4a and b are shown the energy and angular distribution of 20-MeV p degraded to 5 MeV, as obtained from Tschalär and the Molière theory, respectively. If we compare the energy distribution with Fig. 1 of Ref. 1, it is seen that the energy spread does not cause any problem.

Assuming a geometrical cross section for annihilation or other processes that will cause a loss of $\bar{p}$'s of 1.3×10^{-24} cm^2, we estimate a loss of 0.85% of the $\bar{p}$'s in the foil. With 10^6 sec^{-1} in the primary beam, this gives a loss of 8.5×10^3 sec^{-1}, which is negligible with respect to the beam intensity. This also means that the present experiment transmits practically all antiprotons.

Along with the degraded $\bar{p}$'s, there will be electrons exiting from the foil surface. From Ref. 4, it can be estimated that some 3×10^{-6} electrons/antiprotons or less will exit, having the same velocity as the $\bar{p}$'s. They will cause no problem. However, from the same reference it can be deduced that also a relatively large number of very low-energy electrons will emerge. To avoid experimental errors due to these electrons, a positive voltage of ∿50 V should be applied to the metallized scintillator surfaces.

Background Radiation

The major source of background radiation will be the annihilation of the 5-MeV $\bar{p}$'s that are stopped downstream. This will give rise to emission of approximately 4 pions, each of ∿300 MeV per antiproton, together with α and γ radiation. These particles will be emitted when the $\bar{p}$ annihilates, which means that the emission is spread out over several microseconds after the arrival of the $\bar{p}$ to the beam dump. The annihilation radiation may cause two kinds of problems:

(1) Background counts in the start and stop detectors will generally give a background in the time-of-flight spectrum. Low-energy particle radiation (α's) will not emerge from the scintillator material, and the efficiency of the channeltron of detection of γ-radiation is probably negligible. Therefore, only the pion radiation need be estimated. Due to the solid angle of the start detector, as seen from the beam dump, only $\sim 10^{-6}$ of the pions will hit the start detector. The efficiency of this detector for pions of very high energy is unknown to us but is probably very low ($\lesssim 10^{-3}$) so that we shall have $4 \times 10^6 \times 10^{-6} \times 10^{-3} \sim$ a few 10^{-3} pion counts per second in the start detector, which is negligible.

(2) The actual target gas is also bombarded with annihilation radiation. Once again, we can forget about α and γ particles. The gas is traversed by ~ 10 pions/sec. However, having a kinetic energy of several hundred MeV, the cross sections for ionizing the He atoms are so small that they cause no problem.

Test Experiments

Test experiments and reference measurements with proton beams are performed as follows: (i) At the Aarhus EN Tandem, a 12-MeV p beam degraded to 5 MeV will be used to investigate the target-pressure dependence of the measured ratio between doubly and singly charged He-ion yield, to test the stop detectors, and to optimize the voltages on the flight-tube system to obtain the best time resolution. (ii) With a 21-MeV p beam, the energy- and angular distributions emerging from the degrader foil will be measured when a suitable thickness of the degrader foil has been established. This can be done by using an already existing apparatus. Further, with the apparatus of Fig. 1, a reference measurement of the ratio between double- and single-charged He ions will be performed. A request for a proton beam with kinetic energy up to 30 MeV at the Institute of Physics in Oslo, Norway, has already been approved for the spring of 1984.

Time Schedule and Beam Request

The construction of the experimental apparatus has started, and the test experiments will be performed within the next two months. This means that the experiment can be run at LEAR whenever the 200-MeV/c $\bar{p}$ beam has been prepared. The beam request is for 12 hours of running time with the full beam.

References

1. J. Bak et al., CERN/PSCC/82-86 PSCC/I65, Nov. 1982
2. C. Tschalär, Nucl.Instrum.Methods <u>61</u>(1968)141; ibid. <u>64</u>(1968)237
3. G. Molière, Z.Naturforsch. <u>3a</u>(1948)78
4. M. Breinig et al., Phys.Rev.A <u>26</u>(1982)3015

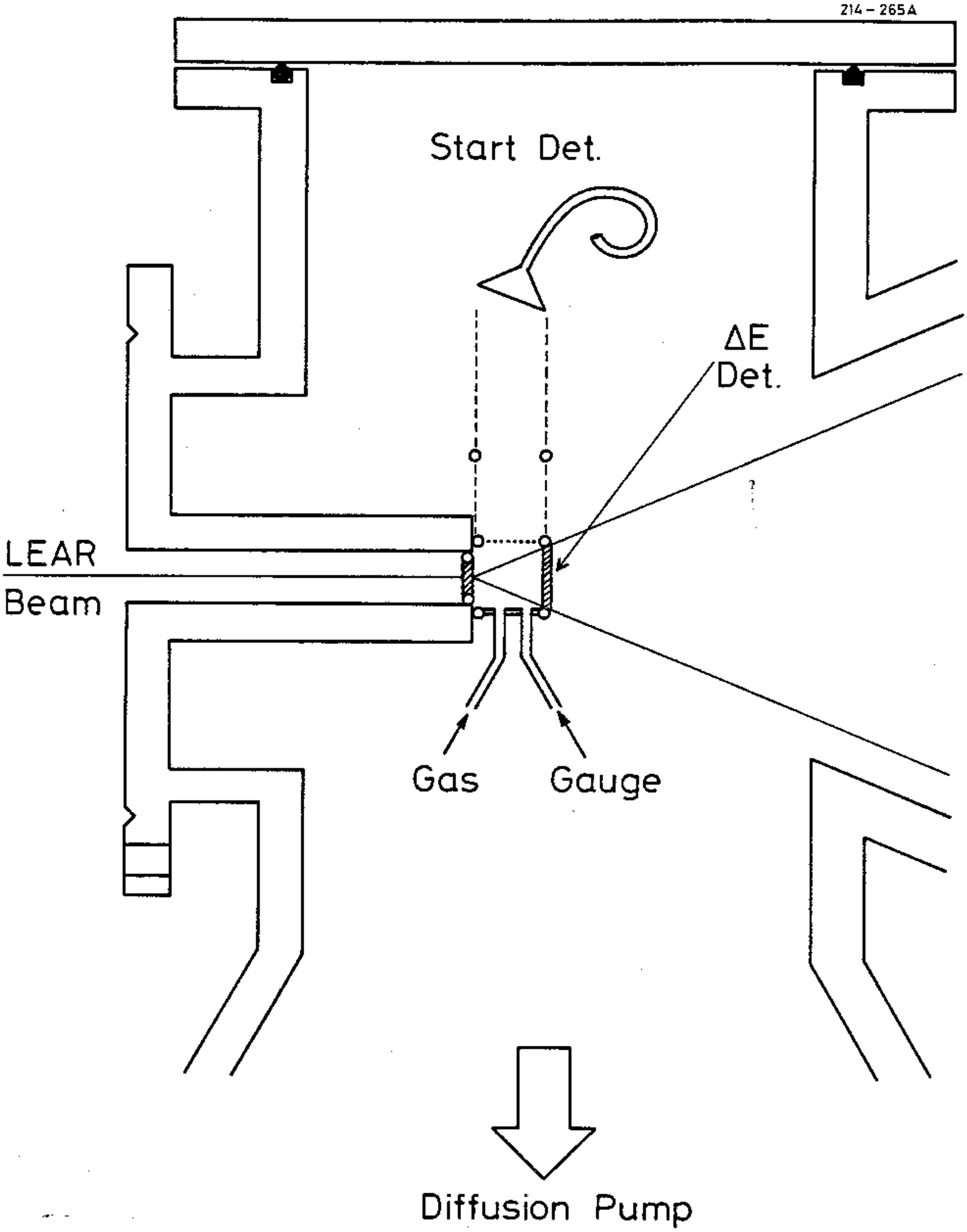


Fig. 1: Schematic of experimental setup.

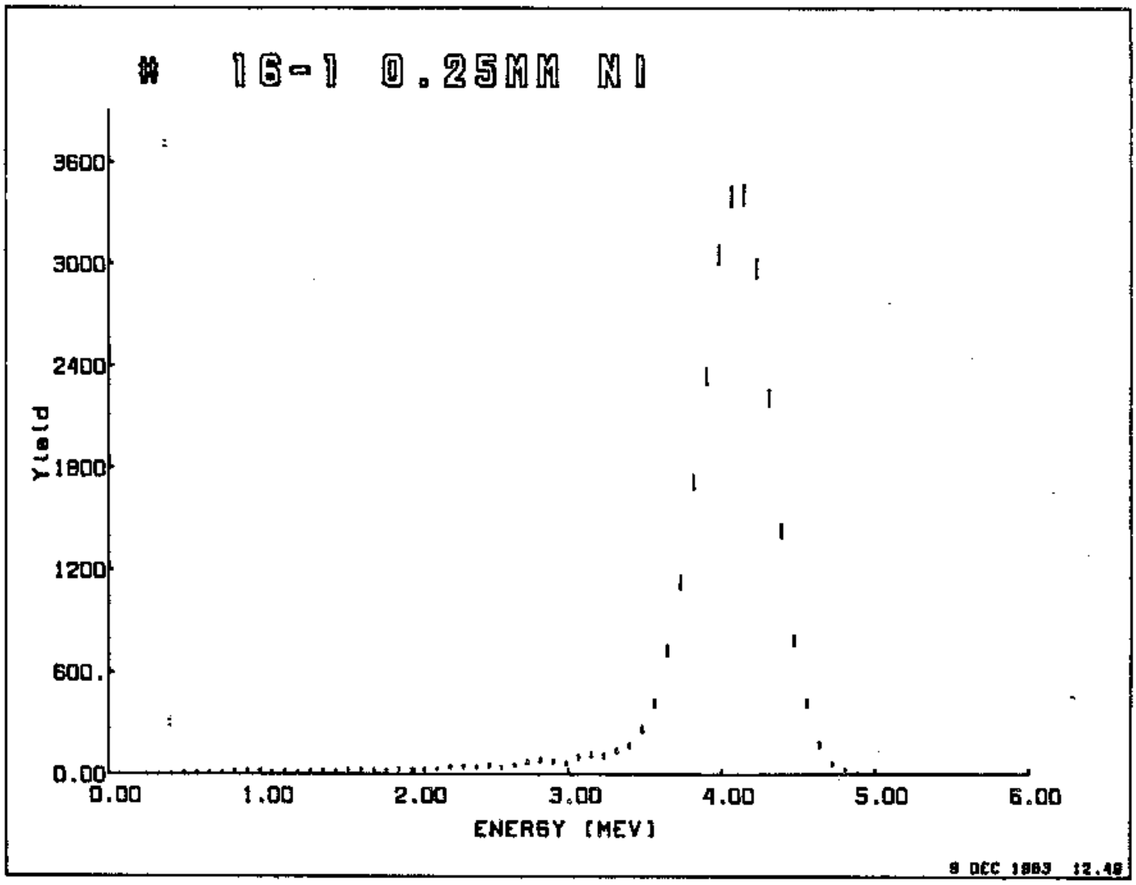
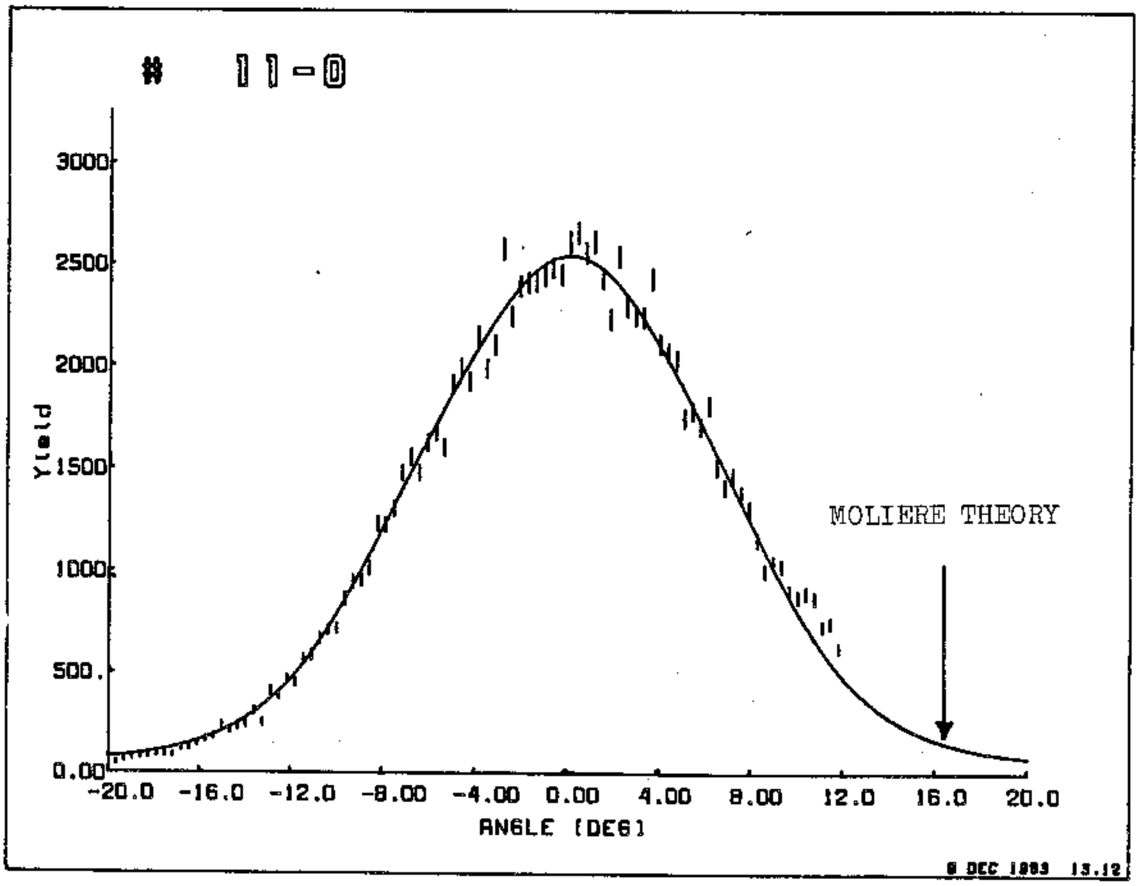


Fig. 2a. Energy distribution of 12-MeV protons after passage of 0.25 mm Ni.



MOLIERE THEORY

Fig. 2b. Angular distribution of 12-MeV protons after passage of 0.25 mm Ni.

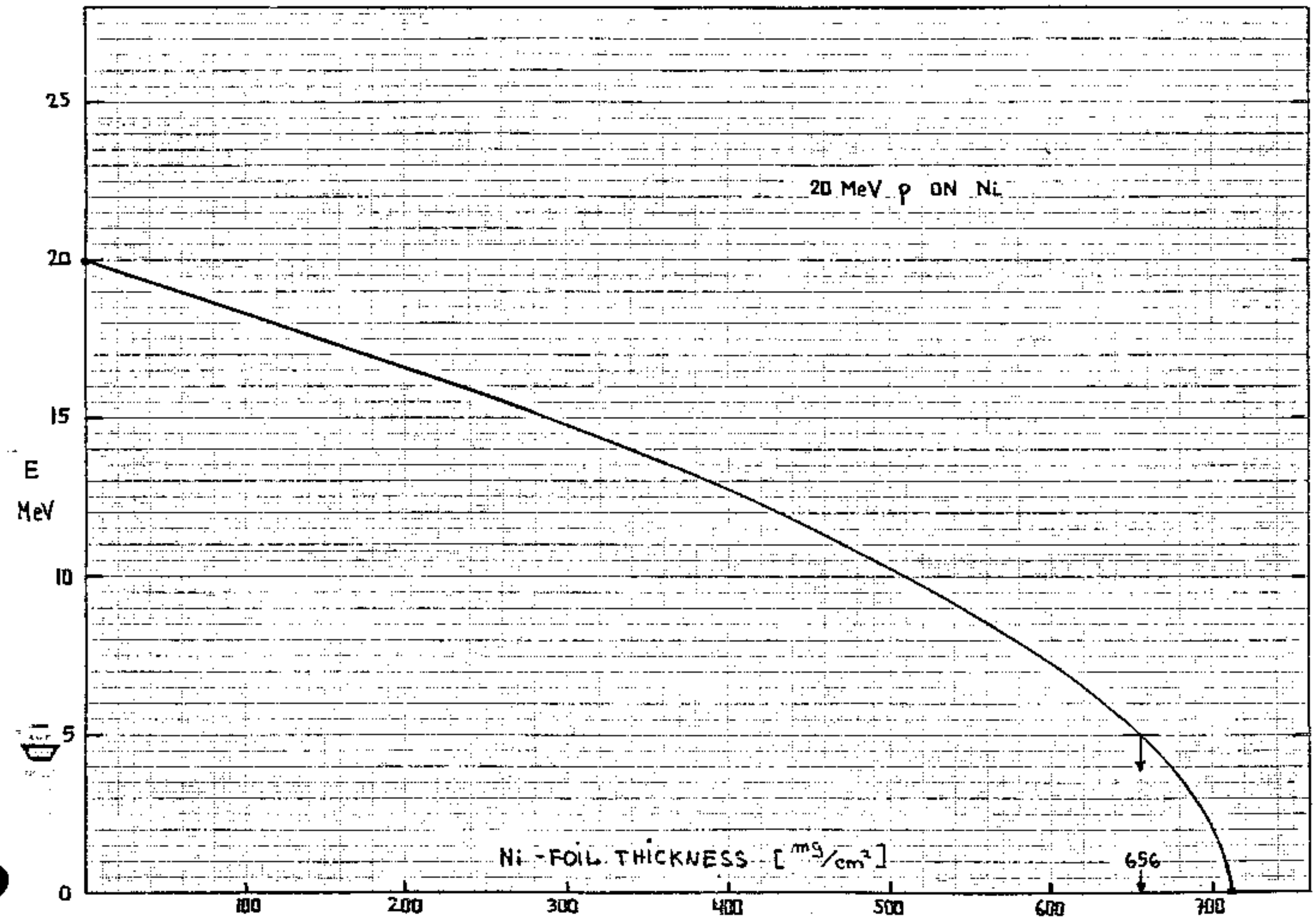


Fig. 3. Energy versus foil thickness. 20-MeV protons on Ni.

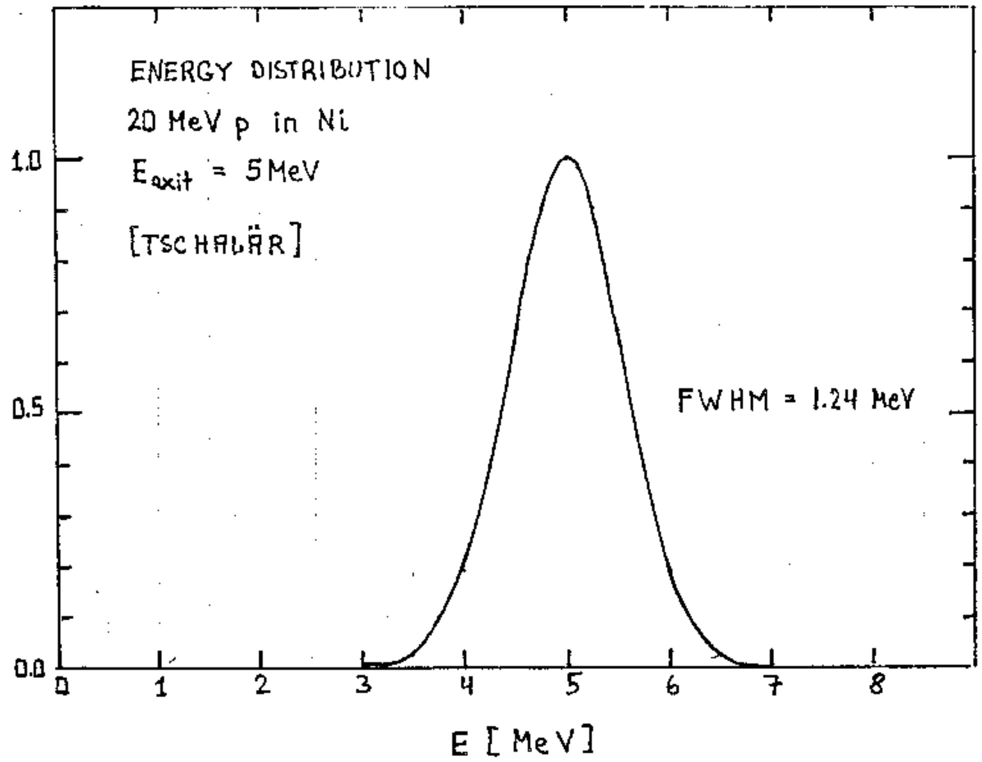


FIGURE 4a. Expected energy distribution of 2o MeV protons degraded to 5 MeV in Ni foil. Theory by Tschalär.

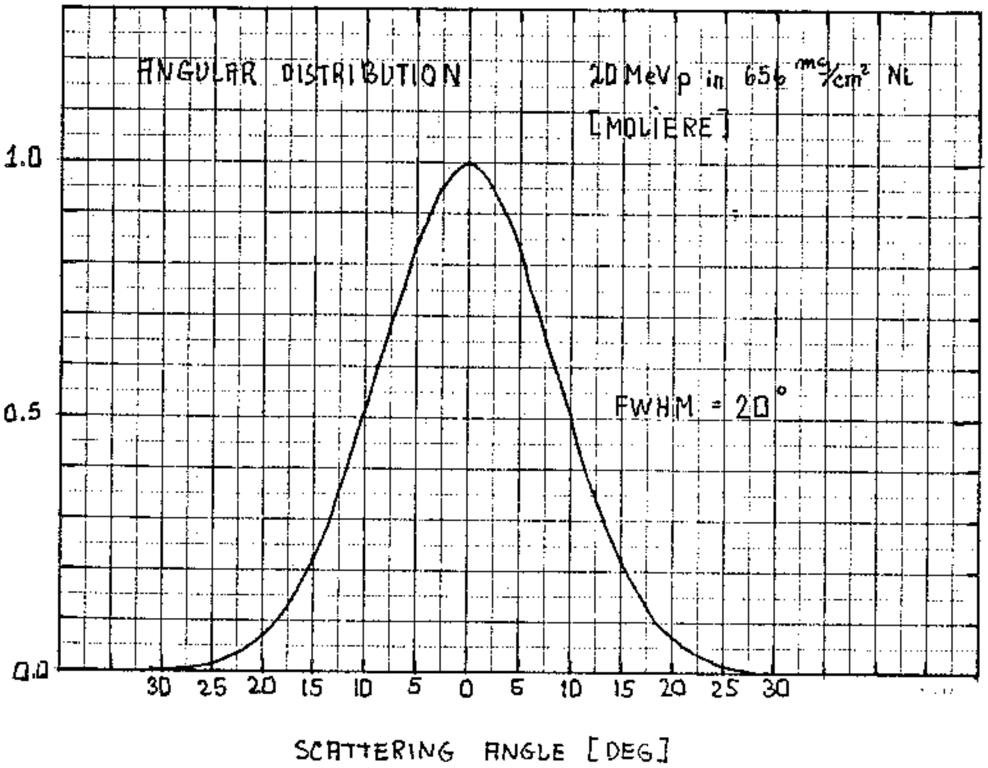


FIGURE 4b. Expected angular distribution of 2o MeV protons degraded to 5 MeV in Ni foil. Theory by Moliere.

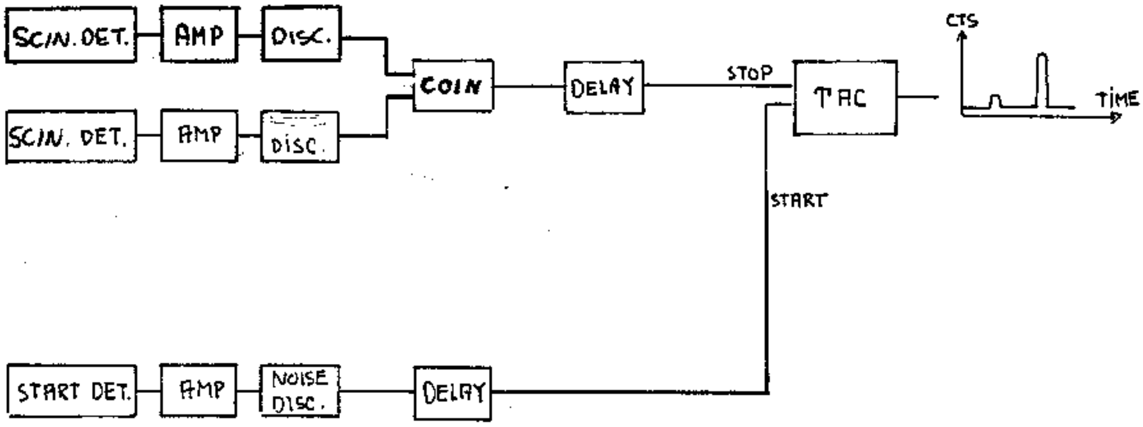


FIGURE 5. Possible electronic setup