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PHYSICS I

ELECTRONICS EXPERIMENTS COMMITTEE

PROPOSAL
TO INVESTIGATE SPIN-DEPENDENT EFFECTS IN HIGH-ENERGY PROTON-PROTON INTERACTIONS AT RHEL AND CERN

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1. INTRODUCTION

The CERN-IPN Orsay-Oxford Collaboration proposes to continue the study of spin-dependence effects in high-energy hadronic interactions. In recent years the polarization in hadron-proton forward elastic scattering (pp, $\pi^{\pm}p$, $K^{\pm}p$) was extensively measured from 6 GeV/c up to the highest energy available in a CERN secondary beam[1]. Also, we have recently completed an experiment at CERN (S106) studying the polarization in baryon exchange mechanisms[2] (backward $\pi^{\pm}p$ elastic scattering).

We wish now to extend our investigations to large momentum-transfer elastic pp scattering and to inelastic processes ($p + p \to \pi^{\pm}, K^{\pm}, \bar{p}, p$) on a polarized proton target. Because of the smallness of most of the cross-sections, a very intensive beam is needed -- 10^9 to 10^{10} protons per burst -- which corresponds to a small fraction of a slow-extracted proton beam (SEPB). The measurements must be performed at least at two energies.

It is obvious that the existence of spin effects in inclusive reactions depends on the nature of the reaction involved and the choice of the kinematical variables (X and p_T). In this way a conventional PS secondary beam (a few 10^6 π/cycle) also gives the possibility, at a first glance, to study some inclusive reactions on polarized targets.

To summarize, we propose:

i) on a CERN secondary beam (with same characteristics as p_8) at 8 GeV/c, to measure the asymmetry in the inclusive processes:

$$\left.\begin{array}{l} \pi^{\pm} + p \to \pi^{\pm} + \text{anything} \\ p + p \to p + \text{anything} \end{array}\right. \quad \text{at } X = 0.5 \pm 0.1$$

ii) on slow-extracted proton beams at 8 and 24 GeV/c, to measure

a) the polarization parameter P_0 in pp elastic scattering for $1.0 < |t| < 6\ (\text{GeV/c})^2$ with a precision of a few per cent, and

b) in the fragmentation region, the asymmetry in the inclusive process:

$$p + p \to \pi^{\pm} + \text{anything}$$

(the interesting $p + p \to p + X$ reaction can also be studied, with a similar set-up but will not be discussed in this proposal).

These two types of interactions can be measured with similar experimental arrangements, and the most suitable beams are:

- a low-intensity Nimrod SEPB at 8 GeV/c (10^9 protons/pulse)
- a low-intensity CERN SEPB at 24 GeV/c (5×10^9 to 10^{10} protons/pulse)

A 24 GeV/c CERN beam corresponds to the highest available CERN PS momentum and an 8 GeV/c Nimrod beam is, from a practical point of view, the only one available in Europe with such an intensity at lower energy. At 8 GeV/c a by-product of our measurements would be the exclusive reaction $p + p \rightarrow \pi^+ + d$. Compared with the two-body reactions it is obvious that in inclusive reactions on polarized targets the ratio signal/background (free protons/bound nucleons) is smaller, so that the measurements will require very high statistics and, especially, a good monitoring system.

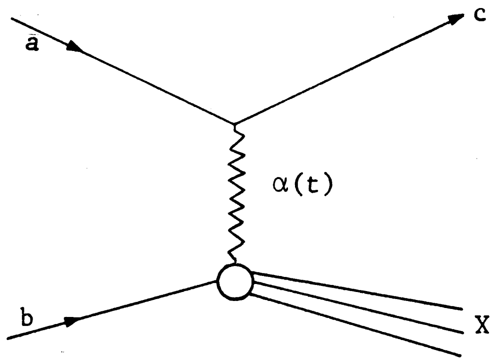
2. SPIN-DEPENDENCE IN HIGH-ENERGY HADRONIC INTERACTIONS

2.1 Inclusive processes

By observing only a specified subset of products in many particle production reactions, a simplified view of the underlying hadron dynamics may be gained. In such so-called inclusive experiments, of the type $a + b \rightarrow c + X$, where X represents the particles not observed, the ideas of limiting fragmentation[3)] and scaling[4)], which are common to many models[5)] for strong interactions at high energy, are supported by the data.

Although much theoretical work has been done in the field of inclusive reactions, ideas are only now beginning to emerge on the spin-dependence of such processes[6-10)]. Although some data on the polarization of the lambda in $K^- + p \rightarrow \Lambda^0 + X$ exists[11)] and shows negative Λ^0 polarization in the kaon fragmentation region but none in the proton fragmentation region, no experiment has yet been performed using a polarized target to investigate the spin dependence of processes such as $p + p \rightarrow \pi + X$.

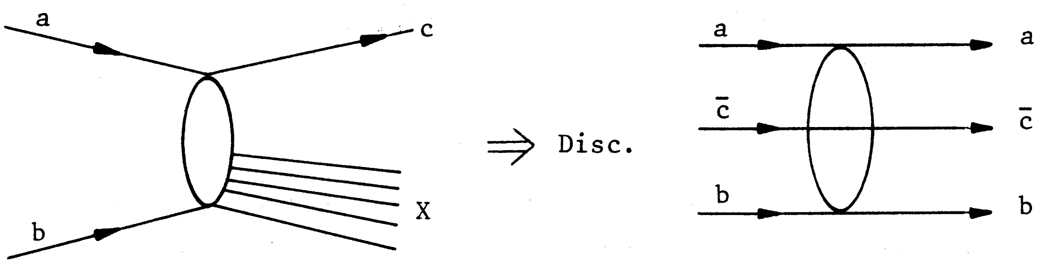
In the case where the energy s_{ab} is large and the momentum transfer t_{ac} is small it might be expected that exchange diagrams of the following type dominate the production process:



Such diagrams lead naturally to the idea of a spin dependence on the production process and further assumptions as to the nature of the exchange (e.g. Reggeized baryon or meson exchange) allow more detailed predictions to be made.

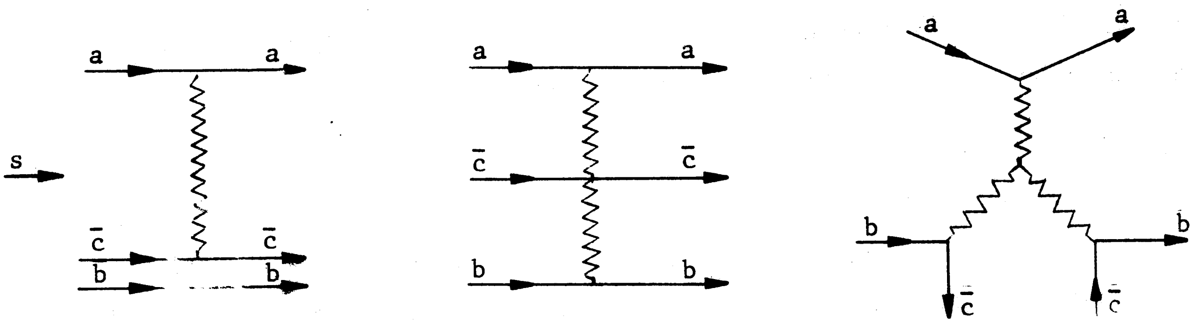
In the reaction $p + p \to \pi + X$, it has been pointed out[12] that, because of the difference in the pion and proton mass, the four-momentum transfer squared, t, to the outgoing pion can be positive [maximum 0.64 $(\mathrm{GeV}/c)^2$ at X = 0.15, where X is the Feynman variable defined in Appendix A] and so can lie very close to the nucleon pole at $t \sim 0.8$; this lends weight to the conjecture that baryon exchange will contribute to, and may even dominate, meson production at relatively low primary proton energies. Figure 1 shows the pion production cross-section as a function of p_T^2 for X = 0.25 at an incident energy of 12 GeV/c. The similarity between the position of the break in the cross-section slope at $p_T^2 \sim 0.2$ $(\mathrm{GeV}/c)^2$ in $p + p \to \pi^+ + X$ and the dip in the differential cross-section[13] for $\pi^+ + p \to p + \pi^+$ at $u \sim 0.15$ $(\mathrm{GeV}/c)^2$ [$p_T^2 = 0.21$ $(\mathrm{GeV}/c)^2$] is suggestive of a common origin. The position of the dip in the latter is usually ascribed to the wrong signature nonsense point of the N_α trajectory. For the process $p + p \to \pi^- + X$ only the Δ_δ trajectory would contribute in such a model. Comparison of $p + p \to$ $\to \pi^\pm + X$ should therefore be especially interesting if baryon exchange is dominant, but irrespective of the particular exchange model will provide information on the factorization of the vertices when compared with similar data of proton fragmentation under the influence of other hadrons.

A more rigorous approach to the theoretical treatment of inclusive reactions has been suggested by Mueller[14], where the amplitude for the process a + b → c + X is related, by a generalization of the two-body optical theorem, to the discontinuity of the forward 3-3 body elastic amplitude $ab\bar{c} \to ab\bar{c}$

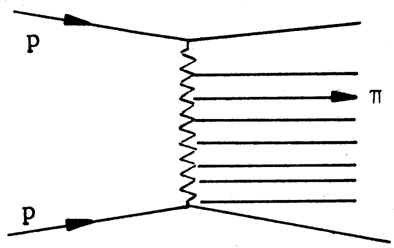


A Reggeized exchange treatment of this amplitude has been suggested by Chan[15] and others[16], and enables specific predictions to be made as to the energy dependence and the approach to a scaling limit of such inclusive reactions. Observations that such a model, together with the further constraints of s-channel helicity conservation and factorization of the Regge residues, leads to an expectation of no polarization effects, have been made by Abarbanel and Gross[6]. Absorptive corrections to such a model have been made by Ringland, Phillips and Worden[10] which lead to expected polarization effects of 10-15%. Further comments on spin dependence of inclusive processes have been made by Salin et al.[8], Berger[7] and Berman[17], the latter suggesting a $1/\sqrt{s}$ fall-off in the polarization (20 to 30%) on the basis of a QED analogy.

These ideas of Regge exchange to describe the inclusive production spectrum are expected to hold in restricted regions of momentum transfer and when the subenergies are large [say $s_{ab} > 10\ (\text{GeV})^2$]. As the total energy increases, so the regions of single Regge ($|X| \sim 1$), double Regge ($X \sim 0$) and triple Regge exchange (in all X values) are expected to be reached successively.



In the intermediate energy region [say s $\sim$ 10 (GeV)^2] only the single Regge limit is expected to have been reached ($|X| \sim 1$) and there is little guidance as to what to expect in the pionization region ($|X| \sim 0$). A diagram of the multiperipheral[18] type,



where the inclusively observed pion may have originated from any vertex, may be expected to carry little or no spin information to the observer.

Factorization of the Regge amplitudes is known not always to hold in exclusive processes and these non-factorizing amplitudes have been described by absorptive cuts[19]. It would be interesting to know whether such correction terms are also relevant in the case of inclusive reactions and hence give rise to non-zero polarization effects. Ringland, Phillips and Worden have proposed[10] such an absorptive mechanism and predict that the spin-dependent cross-section will be non-scaling with an energy dependence of $s^{-\frac{1}{2}}$ and that mirror symmetry $[A(\pi^+ + p \rightarrow \pi^+) = -A(\pi^- + p \rightarrow \pi^-)]$*) is to be expected for isospin symmetric particles. This mirror symmetry is well known to hold for the polarization of $\pi^\pm + p \rightarrow \pi^\pm + X$ at $m_X^2 = m_N^2$ (i.e. elastic scattering) and it will be of particular interest to see how polarization effects in this reaction depend upon m_X^2. Zero polarization would confirm the Regge pole factorization of Abarbanel and Gross[6] in a situation where analogous exclusive amplitudes are non-factorizing. Comparison of the fragmentation of the polarized proton under the influence

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*) A is a symbol to indicate the asymmetry.

of various incident particles (π's, p's, etc.) would provide further information on the factorization of these amplitudes.

Conclusion

It is the intention of this experiment to investigate spin-dependent effects in inclusive experiments, initially with an 8 GeV/c secondary beam at CERN and subsequently in proton beams of 8 GeV/c and 24 GeV/c at Nimrod and the CERN PS, respectively.

2.2 Polarization in pp elastic scattering

Polarization data has been obtained for pp elastic scattering at four momentum transfers t up to -2.5 $(\mathrm{GeV/c})^2$ and at beam momenta up to 17.5 GeV/c [1]. Figures 2, 3 and 4 show the existing data of the differential cross-section from 3 up to 24 GeV/c [20], the polarization parameter P at 10 and 17.5 GeV/c [1] and both $d\sigma/dt$ and P plotted at 10 GeV/c.

It is the intention of this proposal to remeasure the polarization data in the $|t|$ region $[1$ to 2.5 $(\mathrm{GeV/c})^2]$ with a good accuracy (1 to 2%) and to extend the data up to $|t| \sim 6$ $(\mathrm{GeV/c})^2$ at incident proton momenta of 8 and 24 GeV/c.

As is very well known, the polarization is a good probe of changes in the structures of the amplitudes of any two-body reactions, and especially in the slope of the cross-sections. In particular, in Fig. 4 we see a strong correlation between the differential cross-section $d\sigma/dt$ and the dip-bump structure in the polarization results, which show zeros near $t \sim -0.8$ $(\mathrm{GeV/c})^2$ (in fact double zero as in the π^+p scattering) and $t \sim -2.0$ $(\mathrm{GeV/c})^2$, and a maximum around $t = -1.3$ $(\mathrm{GeV/c})^2$.

At $t < -2.0$ $(\mathrm{GeV/c})^2$ there is some evidence that P becomes negative. At 10 GeV/c the mean value of P between $t = -1.94$ and -2.66 $(\mathrm{GeV/c})^2$ is $-4.6\% \pm 2.6\%$. But the precision is such that a zero polarization is not excluded and the degree of confidence for a negative non-zero value of P is of the order of 90%. So a precision of 1% between $t = -0.8$ and -2.4 $(\mathrm{GeV/c})^2$ will bring definitive conclusions on this point and will also fix the value of t where the polarization reaches its maximum, in the $t \sim -1.2$ $(\mathrm{GeV/c})^2$ region of the $d\sigma/dt$ shoulder-like structure. This structure becomes more and more pronounced when the energy increases. The choice of the two incident energies 8 and 24 GeV, suitable from the point of view of the beam intensity, is also extremely good regarding the evolution of this structure as a function of energy. As pointed out by

Allaby et al.[20] the structure develops between 7 and 10 GeV/c and becomes more and more pronounced up to 24 GeV/c, the highest energy measured up to now.

A detailed interpretation of P and also $d\sigma/dt$ in terms of quantitative models is difficult because of the complexity of the pp scattering amplitudes. However, the observed double zero at $t = -0.8\ (\text{GeV}/c)^2$ in pp polarization, which remains more or less the same[21] for $p_{lab} = 3$ to 17.5 GeV/c, is typical of pp scattering and is unlikely to be due to some fortuitous cancellation of amplitudes -- especially since there are five of them -- rather it is more likely to be some specific character of pp scattering. Conventional Regge-pole models[22] or dual absorptive models[23] were tried to explain the main features of the polarization data, and the optical model[24] of Cheng, Chu and Hendry with 13 free parameters reproduces P and $d\sigma/dt$ from 3 to 24 GeV/c and at all momentum transfers. Figure 5 shows samples of these fits to the cross-sections. The polarization is of the form $J_1^2(X)/X$ with $X = R\sqrt{-t}$ from which one obtains a sequence of double zeros at $t \sim -0.8, -2.6, \ldots\ (\text{GeV}/c)^2$ if $R = 0.8$ F. This point will be studied in detail with the proposed experiment as will the predictions of this model at very large t, up to $-6\ (\text{GeV}/c)^2$.

When s and t are large, another proposed way to explain the pp elastic scattering is based on an analogy with the ep scattering and a cross-section proportional to $G^4(t)$, the fourth power of the electromagnetic form factor of the proton[25]. The ratio $X/G^4(t)$, where X is the ratio of $d\sigma/dt$ to the calculated optical theorem value, shows very clearly[20] the importance of the structures in pp scattering and especially its increase with increasing incident momentum (something unlike a classical Regge structure). The factor $G^4(t)$ is an indication of what might be the distribution at infinite energy*). For present PS energies an interesting treatment is that followed by Abarbanel et al.[26] where $d\sigma/dt$ is parametrized with the following formula

$$\frac{d\sigma}{dt} \approx \left(\frac{d\sigma}{dt}\right)_{t=0} \left[aG^4(t) + R(s,t)\right]^2 ,$$

*) See, for example, Fig. 2.

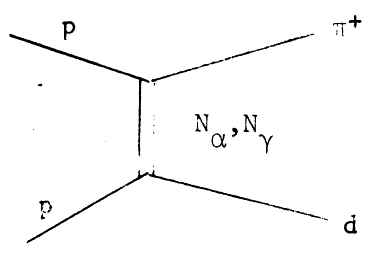
a is a parameter independent of s, and R(s,t) a term of Regge type. This expression as it stands is too qualitative to be compared with recent data of $d\sigma/dt$.

Experimentally t = -6.0 (GeV/c) represents a reasonable momentum transfer up to which measurements of the polarization can be made. At present the large t region has been poorly studied in hadronic interactions because of the smallness of the cross-section and of the luminosity. For example at $t = -4.5\ (\text{GeV}/c)^2$, $d\sigma/dt = 0.1\ \mu b/(\text{GeV}/c)^2$ in π^-p elastic scattering at 5 GeV/c [27] and $d\sigma/dt = 0.01\ \mu b/(\text{GeV}/c)^2$ in pp scattering at 24 GeV/c and the luminosity is of the order of $2 \times 10^{30}\ \text{cm}^{-2}\ \text{sec}^{-1}$ in conventional PS experiments. In the large t-differential cross-section experiments at the CERN PS the luminosity is increased by increasing the length of the target [2.0 m long hydrogen target in πp elastic scattering at 10 GeV/c] or increasing the beam intensity [to a few 10^{11} protons/pulse in the pp experiment[20]].

With a polarized target the only practical way to increase the luminosity is to increase the beam intensity. In the past PS elastic pp forward polarization measurement (Fig. 3)[1], the luminosity was about $2 \times 10^{30}\ \text{cm}^{-2}\ \text{sec}^{-1}$ and the result for a few weeks of PS time was of a poor statistical precision at large t. To have a better precision at comparable t values, and to extend the measurements to higher t, an increase of a factor of 10^2 in beam intensity at 8 GeV/c is needed, making 10^9 protons/pulse, and of a factor of 10^3 at 24 GeV/c making 10^{10} protons per pulse. The only way to build such beams is to take a small fraction of an extracted 8 GeV/c proton beam at Nimrod or of an extracted 24 GeV/c beam at CERN.

2.3 Polarization in the exclusive reaction $p + p \rightarrow \pi + D$

The presence of the deuteron in this exclusive reaction restricts the quantum numbers in the exchange channel to isospin $I = \frac{1}{2}$ baryons.



A description of this process $p + p \to \pi^+ + d$ has been given by Barger and Michael[28] in terms of Regge amplitudes. The expectation of the exchange degeneracy for N_α and N_γ trajectories leads to zero polarization effects. It also will be interesting to compare the observed polarization with other "effective" single particle exchanges, as for example in $\pi^- p$ forward charge exchange and $\pi^- p$ backward elastic scattering where a non-zero polarization is found*).

Differential cross-sections for $p + p \to \pi + d$ have been measured at several incident energies up to 24 GeV/c [29] and show the general features at high energy of exchange scattering with an exponential fall-off in t. The total cross-section falls rapidly with increasing incident energy from a value of 3 mb at 1.25 GeV/c to 1 μb at 8 GeV/c and 0.01 μb at 24 GeV/c. Polarization data have to date been limited to momenta below 1.45 GeV/c [30], where interpretation of the data has been made in terms of resonance production and final state interactions.

We have the intention to investigate the region where exchange processes dominate and to obtain polarization data at 8 GeV/c with a four-momentum transfer $|t| < 1.0\ (\mathrm{GeV/c})^2$.

3. EXPERIMENTAL DESIGN

We propose to use a single-arm spectrometer system for all phases of the experiment but the detailed layout will depend upon the various beam conditions in:

a) a secondary beam at CERN at 8 GeV/c (a few 10^6 π/pulse),
b) a slow-extracted proton beam at RHEL at 8 GeV/c ($\sim 10^9$ protons/pulse),
c) a slow-extracted proton beam at CERN at 24 GeV/c ($\sim 10^{10}$ protons/pulse).

We will present, in detail, in this proposal the set-up we expect to use at RHEL in an 8 GeV/c slow-extracted proton beam.

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*) This result comes from the present CERN-IPN Orsay-Oxford collaboration experiment, to be published.

3.1 The set-up in a CERN secondary beam at 8 GeV/c

It will be very simple and consist of four scintillation counter hodoscopes plus one analysing magnet of a CERN standard type. A 1-metre C-type magnet would be preferable, though a standard H-type magnet may be adequate with restrictions in the range of the transverse momentum covered. The measurements will be made at one setting of longitudinal momentum ($X = 0.5 \pm 0.1$) and the region of $|t| < 0.5$ $(\mathrm{GeV/c})^2$ will be covered in six settings of the counter hodoscope positions.

3.2 The experimental arrangement in an 8 GeV/c proton beam at Nimrod

We propose to use a simple single-arm spectrometer system for the measurement and detection of the inclusive process and this, together with detectors to record the conjugate particle, will be used for the exclusive scattering processes. The basic requirement of the spectrometer system is that it should be simple, and to avoid the complexity of multiparticle detection it should have less than 1% chance of accepting two particles from a given interaction. It should also have sufficient momentum resolution to define a small area on the inclusive kinematic plot (X, p_T) as shown in the Appendix. Such a system is shown in Fig. 6 and has the following characteristics:

Kinematic range covered:	$X = 0.2 \rightarrow X = 0.8$
	$t(\text{elastic}) = -1.0 \rightarrow t = -6.0$ $(\mathrm{GeV/c})^2$
Acceptance - momentum:	$\Delta p/p = 25\%$ at $X = 0.8$
- solid angle:	$\Delta\Omega = 0.6 \times 10^{-3}$ sr.
Momentum resolution:	$\delta p = \pm(1 \rightarrow 3)\%$.

Particle identification is made through threshold Čerenkov counters and particle trajectories determined in multiwire proportional chambers (MWPC) with 2 mm wire spacing and a scintillation counter hodoscope with 2 mm spacing in a horizontal plane only. This system allows the possibility of full coverage of the elastic scattering region $|t| = 2 \rightarrow 6$ $(\mathrm{GeV/c})^2$ in a few steps and of the inclusive scattering region $X = 0.2 \rightarrow 0.8$ and $p_T = 0 \rightarrow 1.0$ (GeV/c) in 50 steps. Each step necessitates the re-positioning of the proportional chambers and for the large transverse momentum

(p_T) events at small X the setting of the magnet current in M4(I). However, only the region around X = 0.8 will be extensively studied in the first instance. The C-magnet M4(II) can be either a Rutherford Laboratory type M5, fixed in place, or a type M4 which can be moved perpendicular to the beam line to cover the region of large transverse momentum as shown in Fig. 6.

The conjugate particle from the exclusive processes $p + p \to p + p$ and $p + p \to \pi + d$ will be detected in scintillation counter hodoscope arrays (50 cm × 20 cm) and (30 cm × 12 cm). The counter elements will be 5 mm wide and are based on existing counters from our previous experiment. Figure 6 shows the particle trajectories for the elastic pp reaction. The Cerenkov counters will be standard threshold devices which already exist at CERN.

The data acquisition system will be built around a Data General Nova computer with 16 K of store and interfaced to a CAMAC system. The scintillation counter hodoscopes will be read in either through parallel bit registers or through the commercial SEN SPADAC digitization system which has been used previously[2]. The planes of MWPC's (≃ 1000 wires) will be read into the computer using a system of either the RHEL or Orsay type.

A 'standard' CERN polarized proton target (PPT), of length 4.5 cm and diameter 1.5 cm, is to be used which produces 70% polarization of the free protons in butanol at 0.55°K. Such a target gives a 7% interaction probability with a 40 μb total cross-section, and 4% if an $A^{2/3}$ factor is used to allow for nuclear shielding in complex nuclei. The azimuthal angular acceptance of the spectrometer system described in the previous section is ±3°, and this leads to a scattering rate from the free protons (i.e. polarized protons) of the PPT of 4 events/μb/10^9 incident particles. The statistical accuracy, ΔP, on a polarization measurement, P, is given approximately by

$$\Delta P = \frac{1}{P_T} \frac{1}{\sqrt{N_{tot}}} ,$$

where P_T is the target polarization, and where $N_{tot} = N^+ + N^-$ is the total number of events for proton spin up, N^+, and down, N^-.

Therefore:

No. events to give $\Delta P_0 = 0.01$

$\Delta P_0 \simeq \frac{1.4}{\sqrt{N_{tot}}}$	for events from free protons	$N_{tot} = 2 \times 10^4$
$\simeq \frac{5.6}{\sqrt{N_{tot}}}$	" " " all "	$= 3 \times 10^5$
$\simeq \frac{10}{\sqrt{N_{tot}}}$	" " " all nucleons	$= 1 \times 10^6$
$\simeq \frac{5}{\sqrt{N_{tot}}}$	" " " all nucleons but assuming $A^{2/3}$ shielding	$= 2.5 \times 10^5$

3.3 Data rates

3.3.1 $p + p \to p + p$

The proposed system should, on the basis of previous experience at CERN, where pp elastic scattering was resolved out to $|t| \sim 2.5$ GeV/c [1)], be sufficient to resolve the events coming from free protons from inelastic and quasi-elastic background events. The proposed layout offers a momentum measurement plus good angular resolution of < 6 mrad in coplanarity and angular correlation. The differential pp elastic cross-section is shown in Fig. 2, and on the basis of this it is estimated that 4×10^{14} incident protons are necessary to obtain a statistical accuracy in the polarization measurement of 1% in each bin of four-momentum transfer $\Delta t = 0.1$ over the range $|t| = 1$ to 6 $(\text{GeV/c})^2$. This could be obtained in 400 hours of data-taking with 10^9 protons/pulse.

3.3.2 $p + p \to \pi + d$

The total cross-section for this process is 1.0 μb at 8 GeV/c incident proton momentum with a differential cross-section fall-off of approximately $e^{-3.5t}$ from a forward or backward point at 1.5 $\mu b/(\text{GeV/c})^2$. By collecting only half the total cross-section -- that where the deuteron is emitted backward and the pion forward in the laboratory -- we expect through time-of-flight measurements on the deuteron and momentum analysis on the pion to be able to resolve these small cross-sections. 10^{14} incident protons will give 3×10^5 $p + p \to \pi + d$ events with $|t| < 1.0\ (\text{GeV/c})^2$.

3.3.3 $p + p \to \pi^- + X$

The particle production cross-sections for 8 GeV/c incident protons are shown in Fig. 7. From these curves, and the parameters of the spectrometer system as discussed earlier, the following data acquisition rates are obtained for the various regions of the kinematic variables X and p_T, and are displayed graphically in Fig. 8. In the region of particular interest ($X \sim 0.8$) the data rate is of the order of 100 events/pulse.

3.4 The experimental arrangement with the SEPB at CERN

It will be similar to that used at Nimrod and will differ primarily in the analysing magnets or the detectors used.

4. BEAMS

Discussion in the previous section has shown the need for integrated incident proton intensities in excess of 10^{14} in order to obtain polarization accuracies of a few per cent in regions of low cross-sections. Such a flux can be most conveniently obtained in a few hundred hours of data-taking with a beam of intensity $\sim 10^9$ protons/pulse at 8 GeV/c (and 10^{10} protons/pulse at 24 GeV/c). Conventional particle-detecting devices (scintillation counters, multiwire chambers) cannot be used in beams of this intensity and therefore severe constraints of divergence (±1 mrad) and full size (< 10 mm) must be placed on the beam if two-particle final states are to be effectively resolved. Extracted proton beams can provide these conditions using septum magnets at the CERN PS and with suitable collimation to restrict the divergence at Nimrod.

4.1 The 8 GeV/c proton beam at RHEL

A possible design for such a beam is shown schematically in Fig. 9. It is basically an extension of the X3X extracted beam line in Hall 3 and uses the existing hole through the shielding (N4 beam line) to limit the beam divergence and reduce its intensity to ≃ 0.6% of SEPB intensity after the target station in X3X. Additional movable collimators will be required before the shielding wall to provide further control over the intensity transmitted. Four quadrupoles following the X3X focus will produce a parallel beam in both vertical and horizontal planes and this beam after collimation (1.1 cm exit aperture) will be bent through 5° by a two-metre (M2) magnet, to separate the charged and neutral components, and focused by a quadrupole pair onto the polarized target placed ∿ 20 metres beyond the shielding wall. The acceptance phase space of the beam is:

Horizontally:	11.8 mm/mrad
Vertically:	2.6 mm/mrad

and if (90 × 60) mm/mrad is taken as the phase space of the X3X SEPB then the intensity transmitted is ∿ 0.6%.

The proposed beam appears to be compatible with the other uses of the X3 SEPB once the neutron test work in the neutral beam N4 is complete, and involves no major rebuilding of the main shielding and beam dump. However, the beam, with its wide momentum acceptance and single bending magnet, may well prove to produce excessive beam halo and thereby an environment unsuitable for the operation of counters. If this is so then a second bending magnet, before the shielding, and an intermediate momentum focus, at the end of the shielding wall, should give a more acceptable beam (Fig. 10). Such a beam, although having the advantage of additional use as a secondary beam channel with π's, K's, etc., does require major rebuilding of the X3X shielding area and as such may be unacceptable at this stage to the other SEPB users. For this reason we suggest the initial (and perhaps final for our purposes) installation of a beam based on the existing shielding arrangements and with a single bending magnet as discussed earlier and drawn schematically in Fig. 9. We would propose to investigate the quality of this beam once installed, and if satisfactory for our purposes, use it for the experiments discussed in this proposal.

4.2 The 24 GeV/c proton beam at CERN

The parameters of such a beam at 24 GeV/c according to our plans are the following:

Energy : the energy of a slow-ejected proton beam (∿ 24 GeV/c).

Spot on the target :	$\leq$ 5 mm in both planes.
Divergence :	$\leq$ 1 mrad in both planes.
Intensity :	adjustable from 10^9 to 10^{10} protons/pulse.
Intensity of the halo:	$10^{-5}/cm^2$ of the full beam at distances $>$ 1 cm from the beam axis.

Very preliminary ideas seem to indicate that such a beam could be built in the East Hall in a reasonable time using one or two septum magnets. But the design of such a beam, and the study of the shielding problems around the beam line and the experimental zone, have to be carried out.

5. RADIATION DAMAGES OF THE POLARIZED TARGET

The radiation damage to the butanol polarized targets at 1°K has been measured on an electron beam[31]. The polarization of the target decreases as an exponential law as a function of the radiation dose and is reduced by a factor e^{-1} after the passage of 5×10^{14} minimum-ionizing particles/cm^2. So the lifetime defined by this factor e^{-1} will be of the order of 10^5 pulses ($\sim$ 3 days) at the PS for 5×10^9 protons/pulse/cm^2.

At Nimrod (10^9 protons/pulse, beam spot $\sim$ 0.2 cm^2) the radiation damage will not be a problem. For CERN with 10^{10} protons/pulse and a beam spot $\sim$ 0.2 cm^2 the lifetime will be of the order of 7 hours, and in that case the radiation damage is a serious problem. But possible solutions are the following:

i) to reduce the beam intensity up to 5×10^9 protons/pulse,

ii) to have a beam spot of 0.5 cm^2,

iii) to use the technique of regeneration of the polarization by heating the butanol sample during a short time[31] (expected dead-time $\simeq \frac{1}{2}$ hour),

iv) use the technique which consists of irradiating different zones of the target at different times.

Measurements with a proton beam will be done during the Nimrod part of this experiment, and especially with the present polarized target at 0.55°K. A definitive solution for the CERN part of this proposal will be found at this time.

6. PROPOSED SCHEDULE AND REQUESTS

We suggest the following machine time for the over-all programme:

i) 5 weeks (+ 1 test week), at CERN in an 8 GeV/c secondary beam, to start in October 1972. p_8 is the most suitable for its intensity and the easy possibility to get positive and negative particles.

ii) 3 cycles (+ 1 set-up cycle), at RHEL in an 8 GeV/c SEPB, to start in early 1973.

iii) 10 weeks (+ 2 set-up weeks), at CERN in a 24 GeV/c SEPB, to start in late 1973.

From RHEL we request the installation of a reduced intensity slow-extracted proton beam, as soon as possible after October 1972, with a view to completing investigations of the beam before installation of the polarized target in 1973. We further request the use of two C-type bending magnets of either the M4 or M5 type for the duration of the experiment at RHEL.

From EEC and CERN we require the availability of a CERN 1-metre bending magnet for the part of the experiment in a secondary beam. We wish to have the possibility to use a standard CERN polarized target for all the proposed experimental programme (3-5 months in a CERN secondary beam, 6 months at RHEL and 6 months in a CERN 24 GeV/c SEPB). We request and ask that a 24 GeV/c proton beam of 10^9 to 10^{10} protons/pulse be built at CERN for use during 10 weeks of PS time in late 1973.

The proposed run at RHEL is of course dependent upon agreement with CERN for the use of a CERN proton polarized target and suitable arrangements for its installation at Nimrod for approximatively 6 months in early 1973.

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APPENDIX

INCLUSIVE KINEMATICS

For the process

$$a + b \rightarrow c + X$$

we define the momentum of c in the centre of mass as p^* with longitudinal and transverse components $p_\parallel^*$ and p_T^*.

The Feynman variable X is defined by

$$X = \frac{p_\parallel^*}{p_{max}^*} \rightarrow \frac{2p_\parallel}{\sqrt{s}} \quad \text{as } s \rightarrow \infty ,$$

where

$$p_{max}^* = \gamma_c \beta_c m_b$$

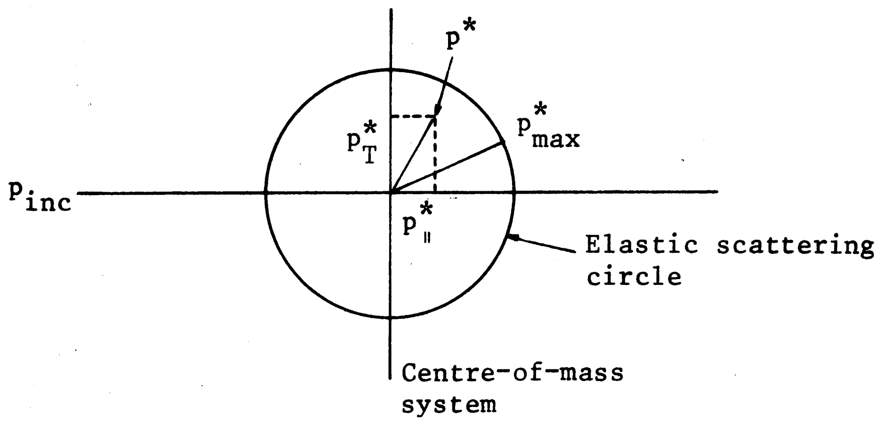
and

γ_c = Lorentz factor of c.m.

β_c = velocity of c.m.

m_b = mass of b .

In the diagram below we illustrate these quantities



In the approximation $p_T^* << p^*$, which holds for $|X| > 0.2$, we can write the laboratory momentum of c as

$$p^{lab} \simeq p_\parallel^{lab}$$

and

$$p_\parallel^{lab} = \gamma_c\{p_\parallel^* + \beta_c E^*\}$$

$$= \frac{\beta_c}{1 - \beta_c} m_b X \quad \text{for } X > 0$$

$$= - \frac{\beta_c}{1 + \beta_c} m_b X \quad \text{for } X < 0$$

Figure 11 shows a plot of p^{lab} as a function of X for 8 GeV/c

$$p + p \rightarrow \pi + X$$
$$\rightarrow p + X \ .$$

Figure captions

Fig. 1 : Inclusive production cross-section $p + p \to \pi^{\pm}$ at 12 GeV/c, X = 0.25.

Fig. 2 : Differential cross-section for elastic pp scattering, $d\sigma/dt$, at various momenta from Ref. 20.

Fig. 3 : Some existing data on the polarization parameter in pp elastic scattering from Ref. 1.

Fig. 4 : Differential cross-section and polarization for elastic pp scattering at 10 GeV/c.

Fig. 5 : Differential cross-section for pp elastic scattering with the fitted curve of Ref. 24.

Fig. 6 : Layout of the spectrometer system for pp exclusive measurements.

Fig. 7 : Particle production spectra at 8 GeV/c in pp interactions.

Fig. 8 : Rates for the inclusive process $p + p \to \pi + X$

Fig. 9 : Possible beam layouts for SEPB at Nimrod (first version).

Fig. 10 : Possible beam layouts for SEPB at Nimrod (second version).

Fig. 11 : Inclusive kinematics for $p + p \to \pi$ at 8 GeV/c.

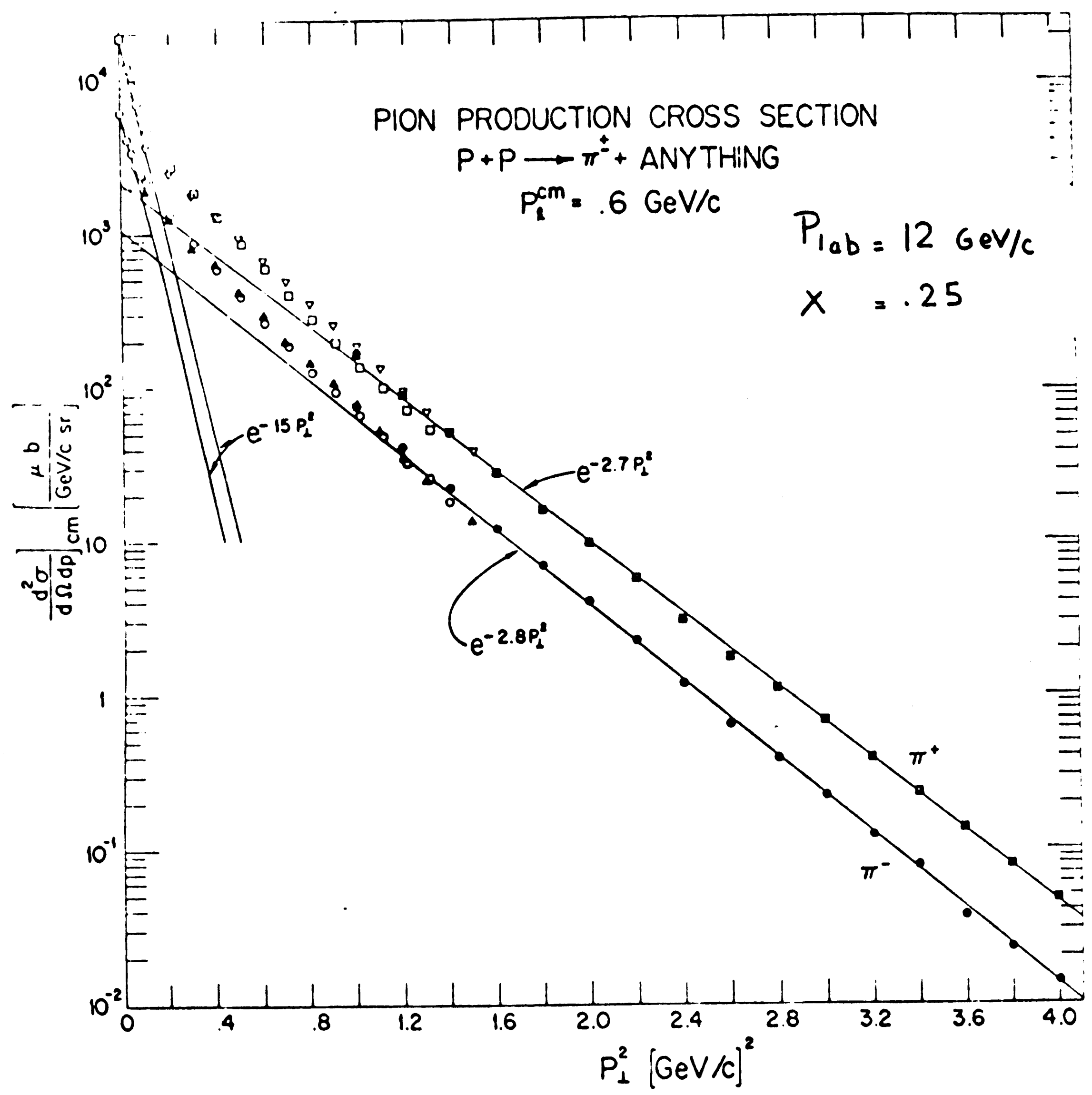
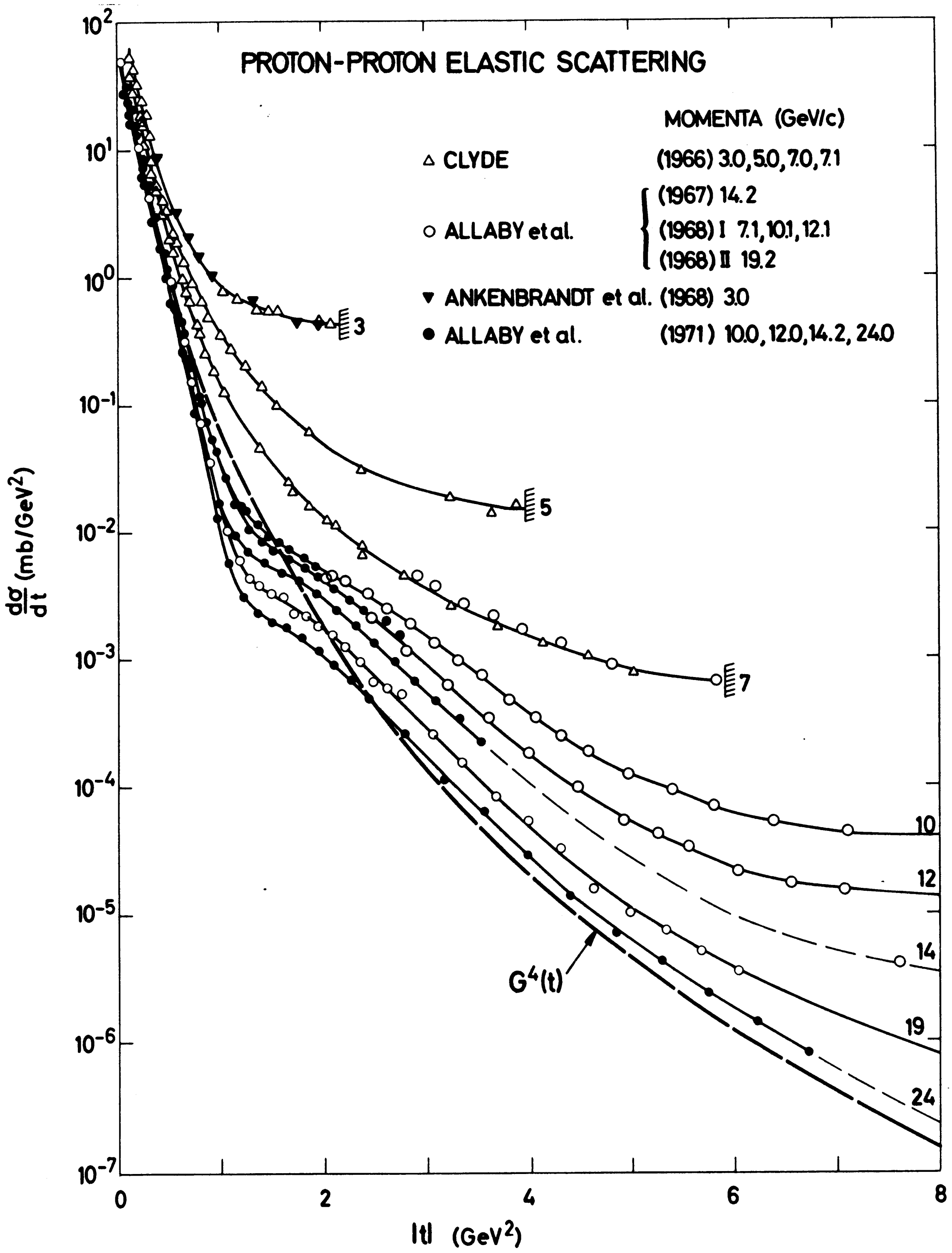

PION PRODUCTION CROSS SECTION
P + P ⟶ π± + ANYTHING
P_ℓ^{cm} = .6 GeV/c
P_{lab} = 12 GeV/c
X = .25
$e^{-15 P_\perp^2}$
$e^{-2.7 P_\perp^2}$
$e^{-2.8 P_\perp^2}$
π+
π−
$\frac{d^2\sigma}{d\Omega\, dp}\Big|_{cm}$ $\left[\frac{\mu b}{GeV/c\ sr}\right]$
$P_\perp^2$ [GeV/c]^2
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
.4
.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0

Fig. 1



PROTON-PROTON ELASTIC SCATTERING
MOMENTA (GeV/c)
△ CLYDE (1966) 3.0, 5.0, 7.0, 7.1
○ ALLABY et al. (1967) 14.2
(1968) I 7.1, 10.1, 12.1
(1968) II 19.2
▼ ANKENBRANDT et al. (1968) 3.0
● ALLABY et al. (1971) 10.0, 12.0, 14.2, 24.0
3
5
7
10
12
14
19
24
G⁴(t)
dσ/dt (mb/GeV²)
|t| (GeV²)

Fig. 2

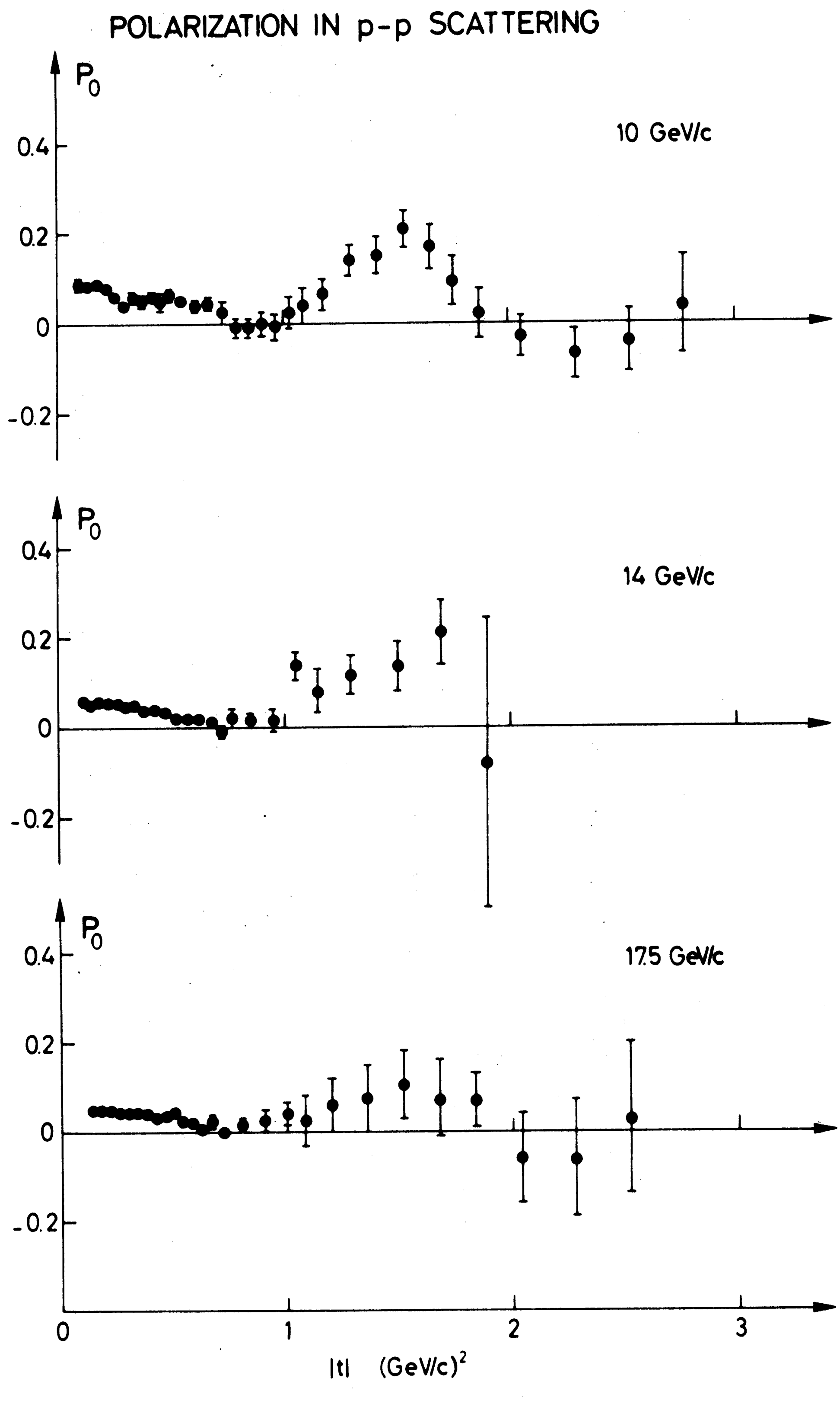
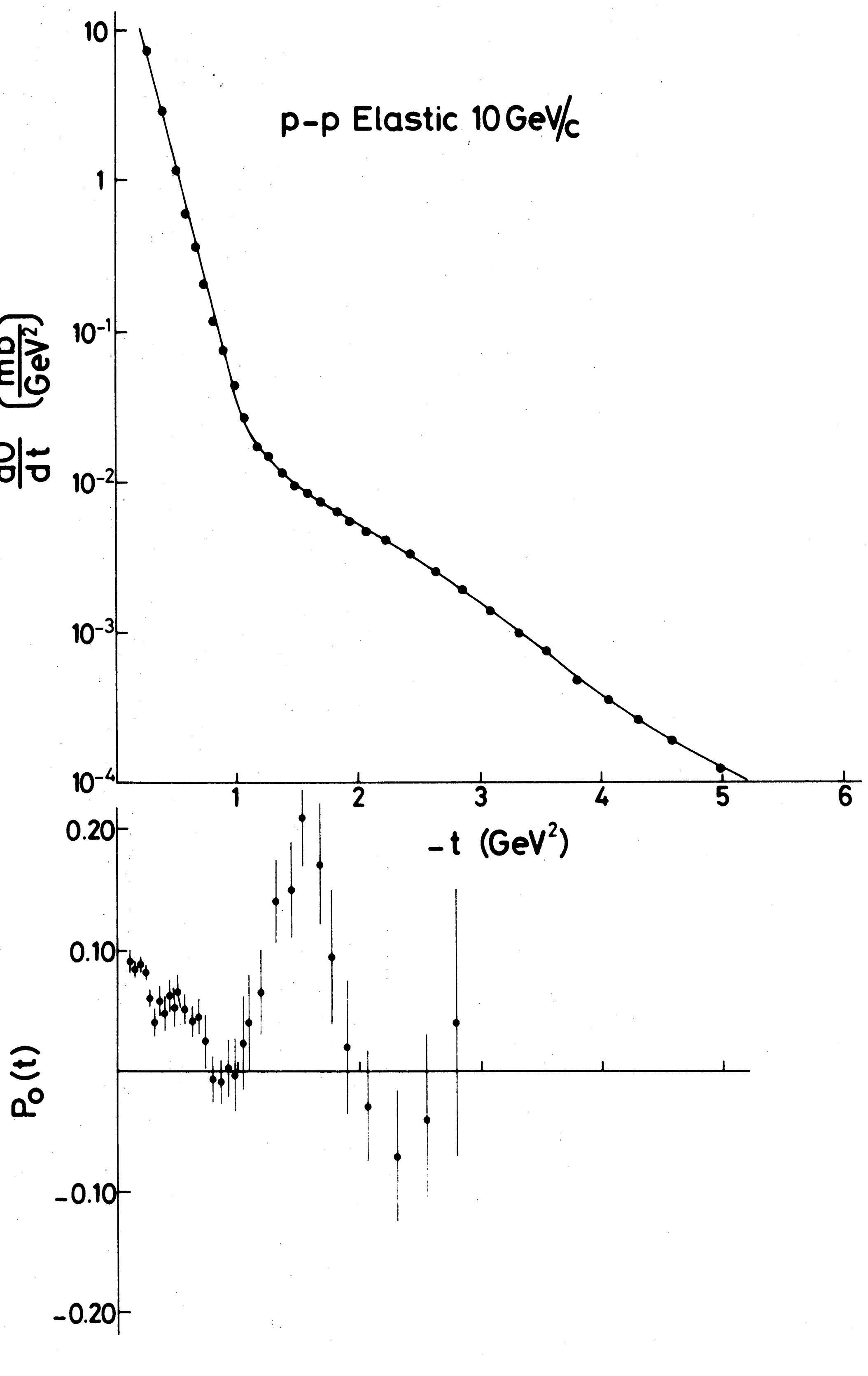

POLARIZATION IN p-p SCATTERING
P0
0.4
0.2
0
-0.2
10 GeV/c
14 GeV/c
17.5 GeV/c
0
1
2
3
|t| (GeV/c)2

Fig. 3



p-p Elastic 10 GeV/c
dσ/dt (mb/(GeV²))
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
1
2
3
4
5
6
-t (GeV²)
0.20
0.10
-0.10
-0.20
P₀(t)

Fig. 4

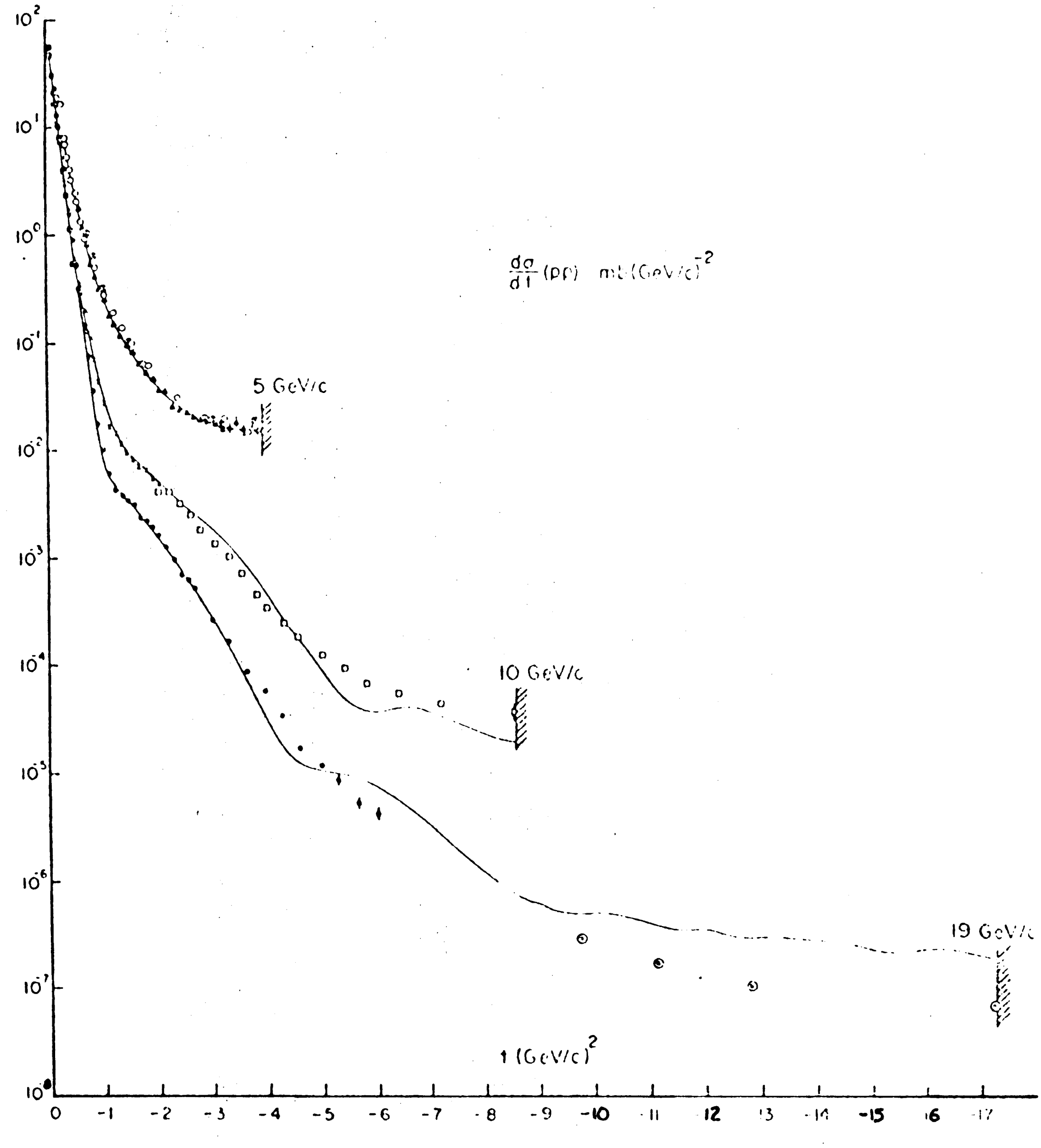


Fig. 5

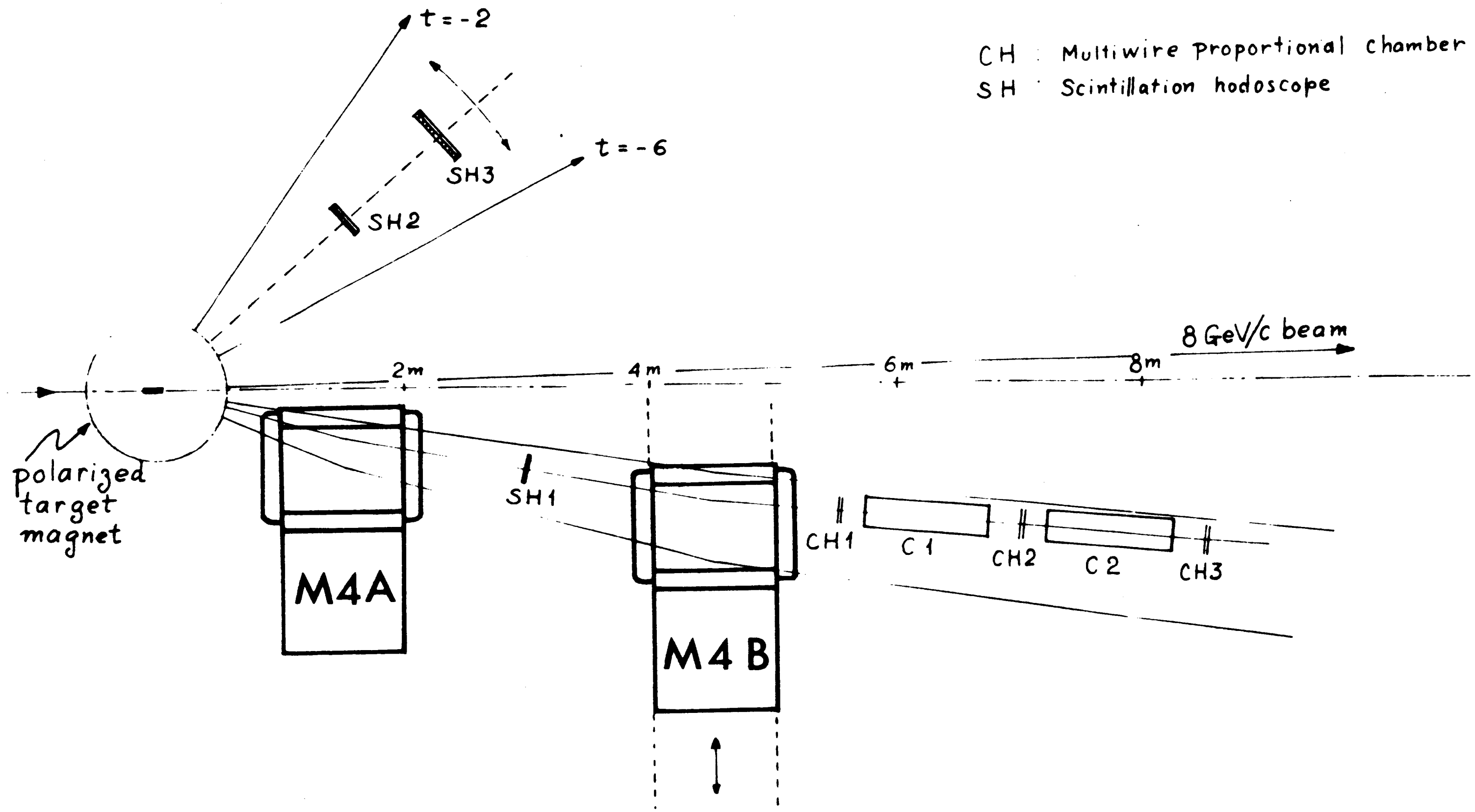

t = -2
t = -6
SH3
SH2
CH : Multiwire proportional chamber
SH : Scintillation hodoscope
8 GeV/c beam
2m
4m
6m
8m
polarized target magnet
SH1
M4A
M4 B
CH1
C 1
CH2
C 2
CH3

Fig. 6

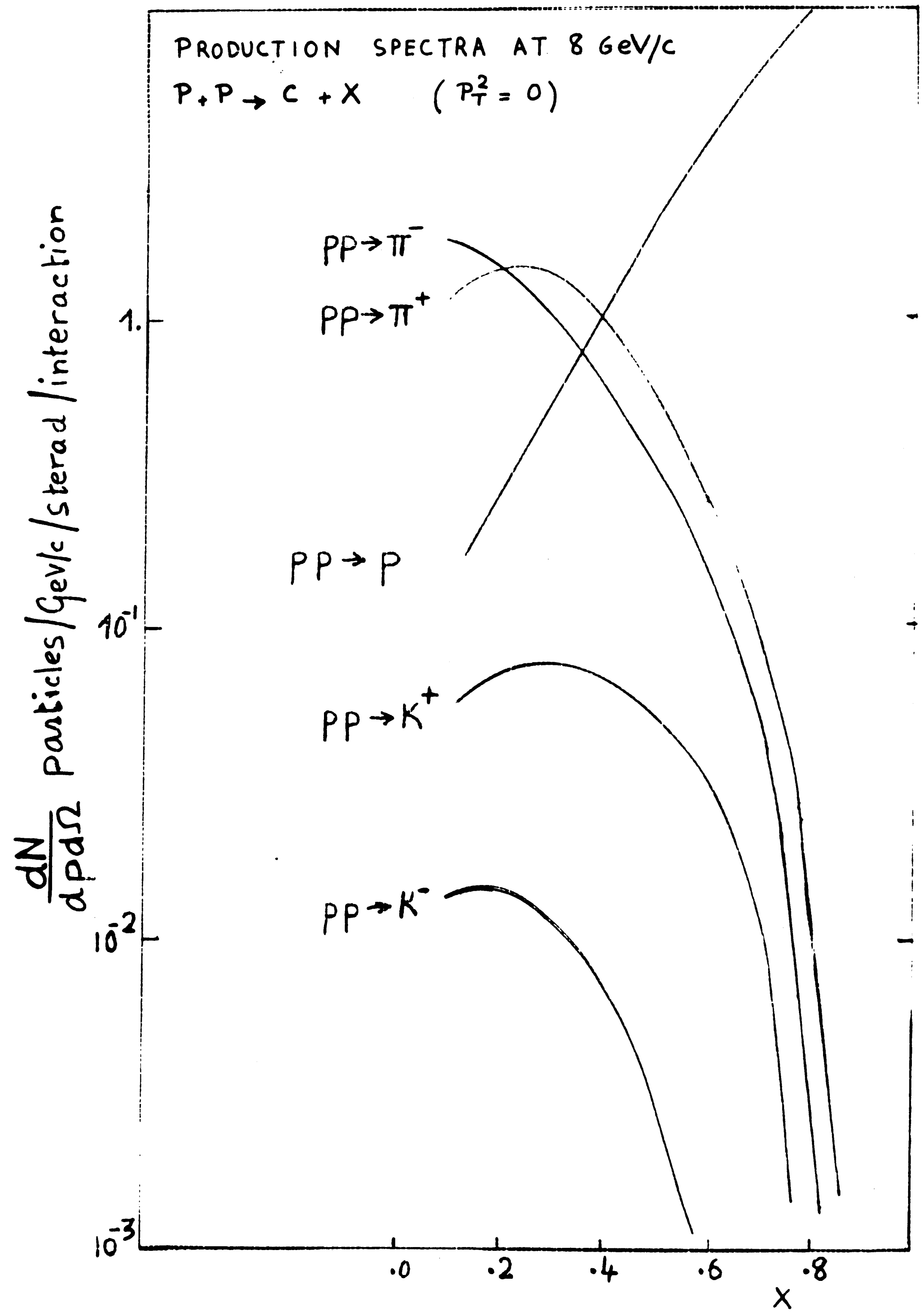
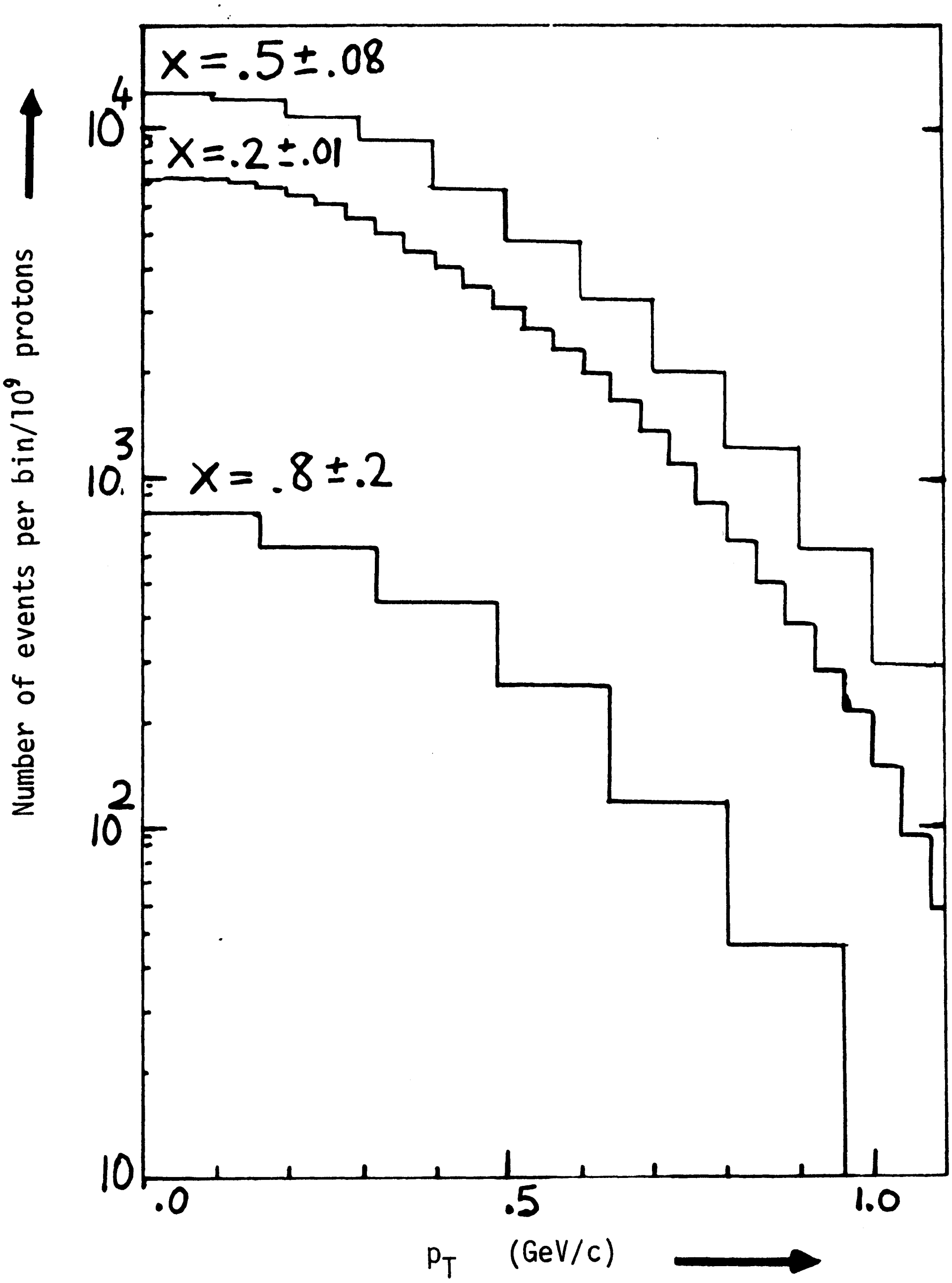

PRODUCTION SPECTRA AT 8 GeV/c
P+P → C + X (P_T^2 = 0)
PP→π⁻
PP→π⁺
PP → P
PP→K⁺
PP→K⁻
1.
10⁻¹
10⁻²
10⁻³
dN/dpdΩ particles/GeV/c/sterad/interaction
·0
·2
·4
·6
·8
X

Fig. 7



X = .5 ± .08
X = .2 ± .01
X = .8 ± .2
10^4
10^3
10^2
10
.0
.5
1.0
Number of events per bin/10^9 protons
p_T (GeV/c)

Fig. 8

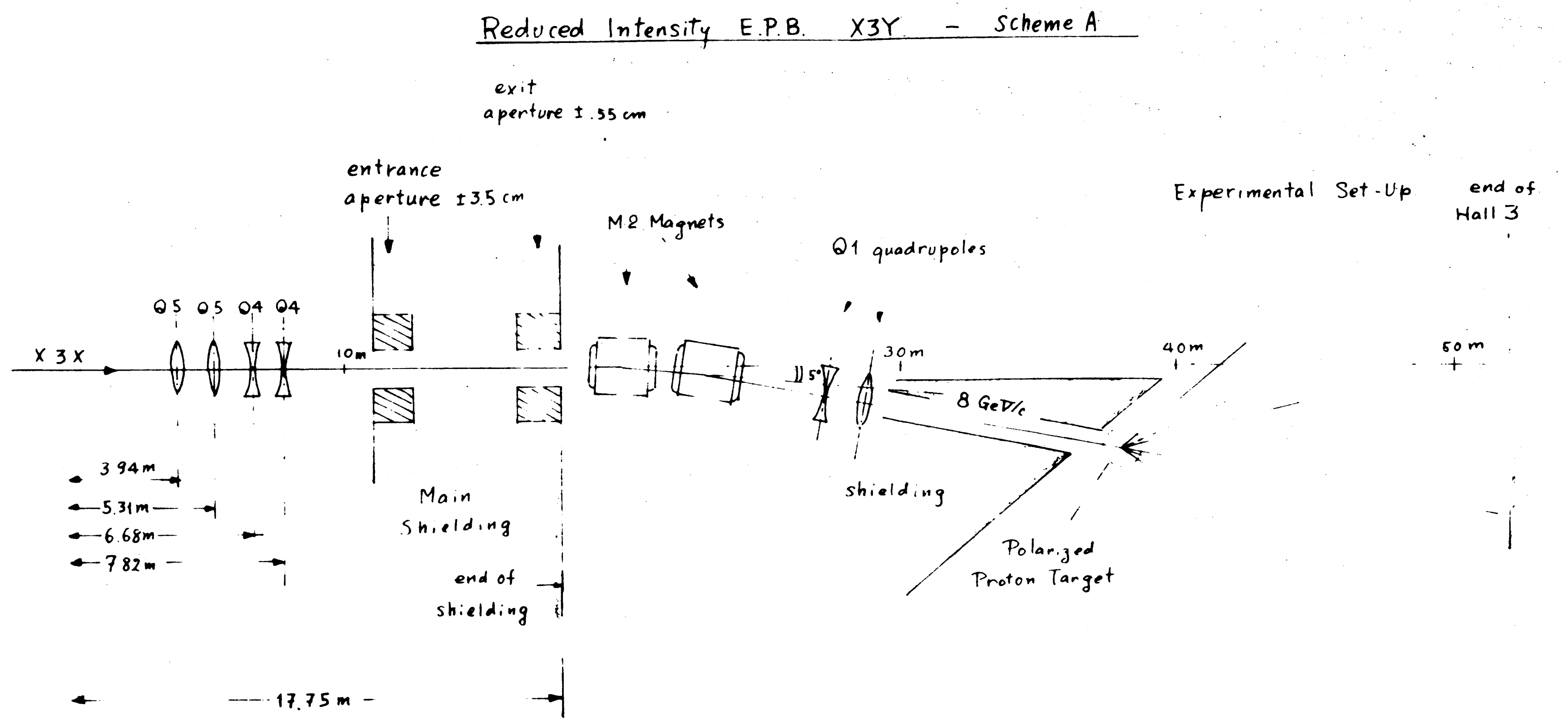

Reduced Intensity E.P.B. X3Y - Scheme A
exit
aperture ± .55 cm
entrance
aperture ± 3.5 cm
M2 Magnets
Q1 quadrupoles
Experimental Set-Up
end of
Hall 3
Q5 Q5 Q4 Q4
X 3 X
10m
30m
40m
50m
5°
8 GeV/c
3.94m
5.31m
6.68m
7.82m
Main
Shielding
end of
shielding
shielding
Polarized
Proton Target
17.75 m

Fig. 9

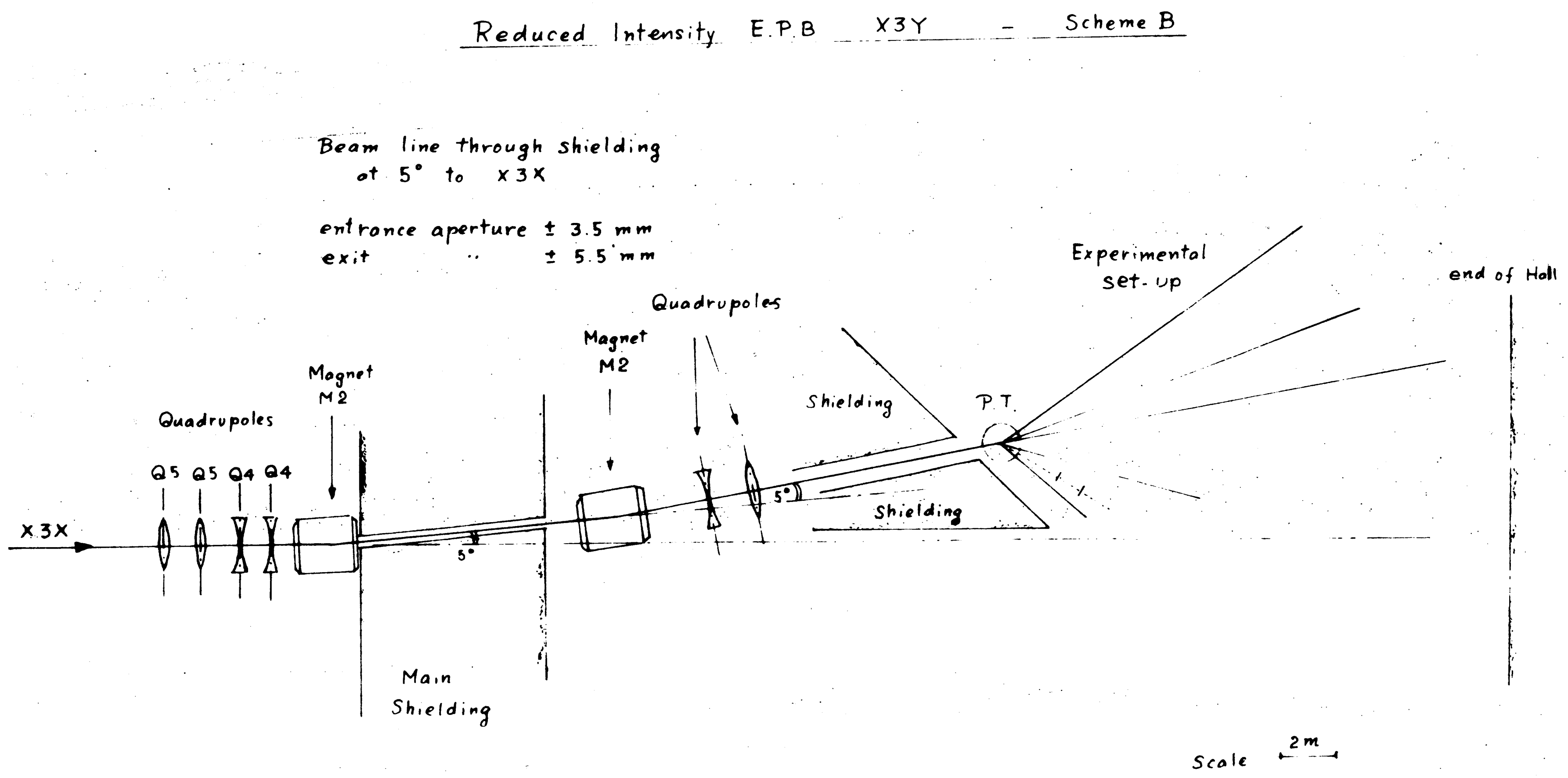

Reduced Intensity E.P.B X3Y - Scheme B
Beam line through shielding at 5° to X3X
entrance aperture ± 3.5 mm
exit " ± 5.5 mm
Experimental set-up
end of Hall
Quadrupoles
Magnet M2
Magnet M2
Quadrupoles
Q5 Q5 Q4 Q4
X3X
Shielding
P.T.
5°
Shielding
5°
Main Shielding
Scale 2m

Fig. 10

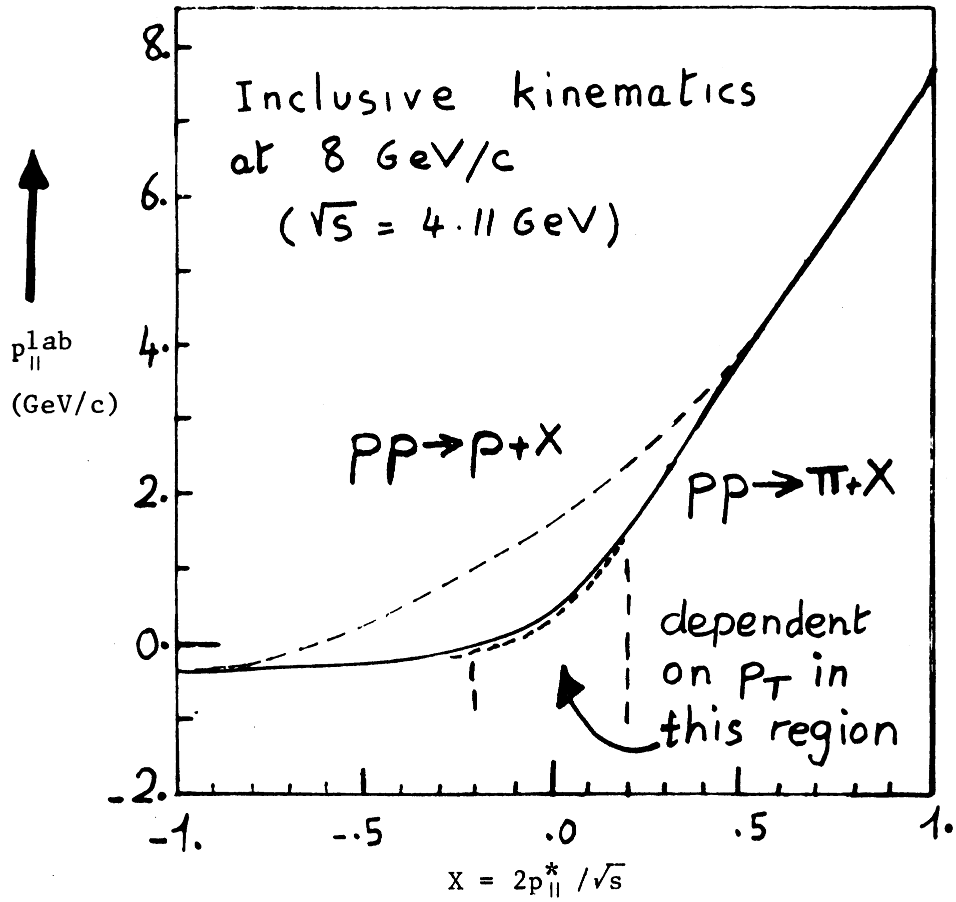

Inclusive kinematics
at 8 GeV/c
($\sqrt{s}$ = 4.11 GeV)
$p_{\parallel}^{lab}$
(GeV/c)
8.
6.
4.
2.
0.
-2.
$pp \to p + X$
$pp \to \pi + X$
dependent
on p_T in
this region
-1.
-.5
.0
.5
1.
$X = 2p_{\parallel}^{*}/\sqrt{s}$

Fig. 11