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COULD WE BUILD POLARIZED PROTON STORAGE RINGS ?

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A B S T R A C T

The importance of high energy polarization experiments, particularly with proton storage rings, is emphasized. It is suggested that strong interactions might be used to polarize proton beams, and three methods to achieve this are given. An order of magnitude estimate is given using the CERN-ISR as an example. The obtainable polarizations depend on the scattering parameters $L(S_a, S_b; S_c, S_d)$. An experiment is suggested to determine the most important combination of these. A positive result of that experiment alone could suffice to enable one to start detailed design studies.

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Polarization experiments play an important role in physics. They have been used to distinguish between competing theories, and to stimulate new research ¹⁾. They can be used to determine spins and parities ²⁾ and to test invariance principles without making any dynamical assumptions ³⁾. In fact, without polarization experiments, only the trace of the S matrix in spin space can be measured ⁴⁾.

At high energies, in the "asymptotic region", some simplification of the spin structure of the S matrix is expected. However, both the location of the asymptotic region and the nature of the simplification are model dependent ⁵⁾. Furthermore, at all observed energies, spin phenomena are significant ⁶⁾. Consequently, we are not entitled to ignore polarization experiments even at high energies. In fact, these experiments could yield valuable information concerning the validity of high-energy models.

In order to be able to determine experimentally the complete spin structure of the S matrix, one needs both a polarized beam and a polarized target. Both of these would be available at the same time, if proton beams in storage rings could be polarized. Furthermore, the experiments could then be done at the highest technically feasible cms energies.

Here we discuss the possibility of getting high-energy proton beams polarized via the strong interactions, using a gas target placed into the ring. The question of how to keep the beam from getting depolarized will not be discussed here, and we merely remark that it seems feasible to adjust the fields in the ring accordingly.

2.

We suggest the use of a H_2 gas target, which is the best from the point of view of reducing the effect of Coulomb scattering ⁷⁾. Further details will be given elsewhere ⁸⁾.

3. - EMPLOYING THE STRONG INTERACTIONS TO POLARIZE THE BEAM

Let us consider the elastic scattering of particles a and b on each other, where a and b are spin $\frac{1}{2}$ fermions. The spin states of the final particles can be different from that of the initial particles, and we denote them by a' and b' respectively. The polarization properties of the interaction can be characterized by the quantities ²⁾ $L(S_a, S_b; S_c, S_d)$, where the S_x form a complete set of linearly independent matrices ⁹⁾ in the spin space of particle x , in the rest frame of the particle.

$$L(S_a, S_b; S_c, S_d) \equiv \text{Tr}(M S'_a \otimes S_b M^\dagger S'_c \otimes S_d) \quad (1)$$

where M is the M matrix of the scattering, and depends on the cms energy E_c , and scattering angle θ_c .

The differential cross-section, when both particles are unpolarized, and no final polarizations are observed, are given by

$$\frac{d\sigma(0,0;0,0)}{d\Omega} = C L(1,1;1,1) = I \quad (2)$$

where C is some constant, a function of E_c and θ_c . When a has a polarization P_a , then the differential cross-section is

$$\frac{d\sigma(P_a,0;0,0)}{d\Omega} = C \left[L(1,1;1,1) + \sum_{k=1}^3 (P_a)^k (\sigma^k, 0; 0, 0) \right] \quad (3)$$

The polarization of b' along the unit vector $\hat{e}_j$ is

$$P_{b,j} = \frac{[L(1,1;1,\sigma^j) + \sum_{i=1}^3 P_a^i L(\sigma^i,1;1,\sigma^j)]}{[L(1,1;1,1) + \sum_{i=1}^3 P_a^i L(\sigma^i,1;1,1)]} \quad (4)$$

All spin-dependent cross-sections and polarizations can be expressed in this manner as a linear combination of the $L(S_a, S_b; S_c, S_d)$. In particular, the polarization which can be introduced into a circulating beam in a storage ring can also be expressed in terms of the L .

Often, the quantities P^i , D^{ij} , K^{ij} , C^{ij} , etc. are used instead of the $L(S_a, S_b; S_c, S_d)$. The conversion between that notation and ours is trivial. In fact, $L(\sigma^i, 1; 1, 1) = P^i$, $L(\sigma^i, \sigma^j; 1, 1) = C^{ij}$, $L(\sigma^i, 1; \sigma^j, 1) = D^{ij}$, $L(\sigma^i, 1; 1, \sigma^j) = K^{ij}$, etc.

We shall now outline three conceptually straightforward methods, which could conceivably be used separately or in combination to polarize a circulating proton beam.

Let a , b , a' , b' all be protons, and denote a unit vector pointing upwards, perpendicular to the plane of a circular machine, by $\hat{N}$. Let a be the target particle, and b the beam particle. In the cms of the scattering we define three unit vectors in terms of the momenta of a and a' : p_a, p_a' :

$$\hat{l} = \frac{p_a - p_a'}{|p_a - p_a'|}, \quad \hat{m} = \frac{p_a \times p_a'}{|p_a \times p_a'|}, \quad \hat{n} = \hat{l} \times \hat{m} \quad (5)$$

Denote by $(x)^i$ the component of the vector $\bar{x}$ in the frame defined by Eq. (5), and write $\sigma^N \equiv \sum_i \sigma^i (\hat{N})^i$.

1) - In the first method to be described, we introduce polarization into the beam "by transmission". By this we mean the following. We place a proton target, polarized along $\hat{N}$ into the circulating proton beam. We assume that

$$L(\sigma^N, \sigma^N; 1, 1) \neq 0, \quad (6)$$

so that the total cross-section for scattering a proton beam polarized along $\hat{N}$ on the target (also polarized along $\hat{N}$) will be different from the cross-section when the beam is polarized antiparallel to $\hat{N}$ (but the target polarization is still along $\hat{N}$). In fact, the difference of the cross-sections is just $2 \cdot L(\sigma^N, \sigma^N; 1, 1)$ integrated over all solid angles, and is non-zero whenever Eq. (6) holds. From this it follows that when passing through the target, protons with one of the two possible polarization states are scattered out of the beam more often than the others. Consequently, the transmitted beam will have left in it more protons in the latter polarization state. The result is that the transmitted beam becomes polarized. We refer to this phenomenon as "polarization by transmission".

If the interaction is such that spin flip is important when a beam passes through the target, then this could greatly reduce the above effect. Of course, as long as the target is thin enough, and/or the induced polarization of the beam small enough, such reduction can be neglected, unless the spin-flip effect is excessively large in that region of energy and angle, where it contributes to the observed effect. For the sake of simplicity, we shall assume in the following that spin-flip effects are negligible because the corresponding L are not too large. We denote this assumption schematically by saying that

$$|L(\sigma^N, \sigma^N; 1, 1)| \ll |L(1, \sigma^N; 1, \sigma^N)|, |L(\sigma^N, \sigma^N; 1, \sigma^N)| \quad (6a)$$

in the relevant ranges of cms scattering angles and energies.

Let us now calculate the polarization introduced into the transmitted beam. Assume that particles scattered at an angle θ_b or less in the lab., at the point where the target is placed into the beam, continue to circulate if the incoming particle is moving exactly along the axis of the beam. In addition, let us assume that θ_b is the same horizontally and vertically. Choose the target density so high that losses in the residual gas can be neglected, and a focusing factor F high enough ⁷⁾ to make losses due to Coulomb scattering negligible. Let us denote the lifetime of the beam in the target by $\tau_n(\uparrow)$ and $\tau_b(\downarrow)$ when its polarization in the rest frame of the particles is parallel and antiparallel to $\hat{N}$ respectively. Introduce

$$\Delta = \tau_b(\uparrow) - \tau_b(\downarrow) \equiv \tau_b(\uparrow) - \tau_b$$

The polarization of the transmitted beam, after the beam has been traveling in the target for a time τ , will be

$$P_b^N = \left\{ \exp\left(\frac{\tau \Delta}{\tau_b^2}\right) - 1 \right\} / \left\{ \exp\left(\frac{\tau \Delta}{\tau_b^2}\right) + 1 \right\} \quad (7)$$

When Eq. (6a) holds, then Δ is proportional to $L(\sigma^N, \sigma^N; 1, 1)$, and the target polarization P_a^N . In fact, one can write

$$\frac{\Delta}{\tau_b} = \frac{1}{2\pi(\cos\theta_b + 1)} \int_0^{2\pi} d\varphi \int_{\theta_b}^{\pi} d\theta \sin\theta \cdot \frac{2L(\sigma^N, \sigma^N; 1, 1) P_a^N}{L(1, 1; 1, 1) + L(\sigma^N, 1; 1, 1) P_a^N + L(\sigma^N, \sigma^N; 1, 1) P_a^N} \quad (8)$$

provided that

$$L(\sigma^N, \sigma^N; 1, \sigma^N) |P_a^N| \ll L(\sigma^N, \sigma^N; 1, 1) |P_a^N| \quad (9)$$

and that τ is small enough, so that most particles will not scatter more than once in the target. When, in addition, $\theta_b \ll 1$, and $L(\sigma^N, \sigma^N; 1, 1) \ll L(1, 1; 1, 1) + L(\sigma^N, 1; 1, 1) |P_a^N|$, then Eqs. (7) and (8) can be simplified to

$$P_b^N \approx \frac{\tau}{\tau_b} \frac{\Delta}{2\tau_b} \quad (7a)$$

$$\frac{\Delta}{\tau_b} \approx \frac{1}{4\pi} \int_0^{2\pi} d\varphi \int_0^\pi d\theta \sin\theta \frac{L(\sigma^N, \sigma^N; 1, 1) P_a^N}{L(1, 1; 1, 1) + L(\sigma^N, 1; 1, 1) P_a^N} \quad (8a)$$

When Eq. (6a) does not hold, then Eqs. (8) and (8a) do not either, and, instead, the expression for Δ/τ_b is somewhat more involved. Nevertheless, even in this case, Eqs. (7) and (7a) are valid, and P_b^N depends only on the parameter Δ/τ_b .

Note that the phenomenon of "polarization by transmission" does not contradict the theorem which states that when an unpolarized beam collides with a polarized target, then no polarization can be introduced, if one integrates over the azimuthal angle φ (provided that the usual invariance principles hold). That theorem refers to the scattered beam, while we are concerned here with the transmitted beam.

The next two cases will be discussed in less detail, since the arguments are analogous to those described above.

2) - Assume that in the relevant range of E_c and θ_c

$$L(1, 1; 1, \sigma^N) \neq 0 \quad (10a)$$

$$|L(1, 1; 1, \sigma^N)| \ll |L(1, \sigma^N; 1, \sigma^N)|, |L(\sigma^N, \sigma^N; 1, \sigma^N)| \quad (10b)$$

Place an unpolarized target into the beam. Construct the machine in such a manner that the particles scattered by the target to the right and to the left of the beam, within a certain angular range, are captured into

two separate satellite orbits respectively. To avoid stacking problems, we can assume that all orbits intersect at the target. Again assume that the effects of residual gas and Coulomb scattering can be neglected.

According to Eq. (10), the particles captured into the two satellite orbits will have opposite polarizations: parallel and anti-parallel to $\hat{N}$. The absolute value of the polarization will be

$$|P_b^N| = \left| \frac{1}{\Omega_s} \int_{\Omega_s} d\Omega \frac{L(1,1;1,\sigma^N)}{L(1,1;1,1)} \right| \quad (11)$$

and Ω_s is the range of solid angles, within which the scattered particles are accepted into the satellite orbit under question. Thus, in contrast to case 1), the $|P_b^N|$ is independent of τ .

Let f be the fraction of all scattered protons in the beam, which are captured into one of the satellite orbits. In the first approximation, let us neglect those protons which are scattered by the target from the satellite orbit back into that orbit or into the beam. Let us also assume that the main beam is not being continuously filled up, but once filled up at $\tau = 0$, it is left alone. Then the intensity of the satellite beam at time τ , $I_s(\tau)$, is governed by the differential equation

$$\frac{dI_s(\tau)}{d\tau} = \tau_b \left[f I_0(0) e^{-\tau/\tau_b} - I_s(\tau) \right] \quad (12)$$

Clearly, $I_s(\tau) < f I_0(0) e^{-\tau/\tau_b}$ implies increasing $I_s(\tau)$. On the other hand, if the main beam is continuously filled up, keeping its intensity at I_0 , then

$$\max [I_s(\tau)] = I_s(\infty) = f I_0(0) \quad (13)$$

The design can be simplified by providing for only one satellite orbit.

It can be made more sophisticated, by using a polarized target. This would be worth-while, if $L(1,1;1,\sigma^N) \lesssim L(\sigma^i,1;1,\sigma^N)$ in the solid angle range Ω_s .

3) - Assume that in the relevant E_c and θ_c range

$$|L(\sigma^N,1;1,\sigma^N)| \gg |L(\sigma^N,\sigma^N;1,\sigma^N)| \quad (14)$$

Those particles which are scattered into the solid angle range Ω_s around the forward direction are recaptured into the beam. We neglect the effects of residual gas and Coulomb scattering. The polarization along $\hat{N}$, in the total (original + recaptured) beam, at time τ , is

$$P^N = \frac{1}{\Omega_s} \int d\Omega_s \frac{L(\sigma^N,1;1,\sigma^N)}{L(1,1;1,1)} \frac{I_r(\tau)}{I_o(\tau) + I_r(\tau)} \quad (15)$$

where $I_o(\tau)$ and $I_r(\tau)$ are the intensity of the original and recaptured beam.

Let f be the fraction of all scattered protons which are recaptured. If the beam is not refilled after $\tau = 0$, then

$$\frac{dI_r(\tau)}{d\tau} = \tau_b [f I_o(0) e^{-\tau/\tau_b} - (1-f) I_r(\tau)] \quad (16)$$

We have $I_r(\tau) < [f/(1-f)] I_o(0) e^{-\tau/\tau_b}$ implies increasing I_r . When the intensity of the total beam is kept constant at $I_o(0)$, then again

$$\max [I_r(\tau)] = I(\infty) = f I_o \quad (17)$$

Up till now we discussed only elastic scattering of protons on each other. However, when E_c is several GeV, most proton-proton scattering events are inelastic. Although production of baryons can be neglected in the first approximation, meson production cannot. Since most mesons have spin zero, their presence does not affect the spin structure of the M matrix, and $L(S_a, S_b; S_c, S_d)$ can still be defined as before, except that these L will now be a function not only of E_c and θ_c , but also of the number, and cms energy and angle of the produced pions. Reinterpreting all the L in this manner, all equations are valid, even if any number of spin zero bosons are produced when a and b collide.

4. - AN EXAMPLE : THE CERN-ISR

The above considerations are not restricted to any particular storage ring. Nevertheless, to get an order of magnitude idea of the polarization which could be expected by these methods, we shall now consider as an example the CERN-ISR. The parameters are the accepted ones ¹⁰⁾. To avoid the technical difficulties connected with the second two possibilities mentioned in the previous section, we discuss the first case only.

We use a polarized H_2 gas target, and choose its density to be $3 \cdot 10^{17}$ atoms per cm^{-3} . Such densities are still technically feasible. We choose a linear focusing factor ¹¹⁾ $F \gtrsim 4$ at the position of the target. With these parameters ⁷⁾, the beam lifetime $\tau_b \approx 15$ min, and Eqs. (7) and (8) are applicable. This is so first because at such a target density, Coulomb scattering in the residual H_2 gas is negligible : this gas will have a density around $7 \cdot 10^{11} cm^{-2}$ integrated over the whole circumference of the ring ; second, when $F \gtrsim 4$, then in the gas target losses are predominantly caused by nuclear (as opposed to Coulomb) scattering.

Let us denote the polarization introduced into the circulating beam perpendicular (upwards) to the plane of the machine at time τ , by $P_b^N(\tau)$; the number of protons circulating in the beam at time τ by $N(\tau)$. Then, assuming that $|\Delta/\tau_b| = 10\%$, we find

$$|P_b^N(\tau)| \approx 5\% , \quad N(\tau) \approx 1.8 \cdot 10^{13} \quad \text{at } \tau = 10 \text{ minutes}$$

$$|P_b^N(\tau)| \approx 10\% , \quad N(\tau) \approx 6.7 \cdot 10^{12} \quad \text{at } \tau = 20 \text{ "}$$

$$|P_b^N(\tau)| \approx 15\% , \quad N(\tau) \approx 2.5 \cdot 10^{12} \quad \text{at } \tau = 30 \text{ "}$$

$$(\text{assuming } \Delta/\tau_b = 10\%) \quad (18)$$

When the desired level of polarization is reached, the gas target can be removed, and the polarized beams left to circulate.

It should be emphasized again that the value given for Δ/τ_b was assumed, and it is not known for high values of E_c . However, this value seems reasonable, if one compares it with measurements at the highest lab. energies available ^{6), 12)}.

Note that, when the polarized gas target is placed into an intersection region of two rings, then both rings can be polarized by the same target.

The same gas target (not placed into an intersection region) can be used to produce pions, and study $\pi^+ + p$ interactions ⁷⁾ with or without the other proton beam being also polarized.

5. - A SUGGESTED PRELIMINARY EXPERIMENT

Equations (7), (8), (11), (15) and (18) demonstrate that the polarization which can be achieved by strong interaction scattering depends on the scattering parameters $L(S_a, S_b; S_c, S_d)$. There are predictions for some of these, for lab. energies up to 200 GeV/c, based on the Regge model ¹³⁾, for p+p and p+ π elastic scattering. These predictions agree fairly well with all experiments done : up to 12.0 GeV/c lab. momentum. Unfortunately, for inelastic scattering there are no predictions concerning the L , and they are not easy to make in the energy range where quasi-two particle production is not expected to dominate. There exist no experimental data concerning the L for inelastic processes, in the energy range of interest. Under these circumstances, the only reasonable way to estimate the order of magnitude of the L which can be expected is to use the data and predictions for elastic scattering. In the range $-t \lesssim 0.1 \text{ (GeV/c)}^2$ the $|L(\sigma^i, \sigma^j; 1, 1)/L(1, 1; 1, 1)|$ teaches values around 20 %, and goes through a maximum near $-t \approx 0.05 \text{ (GeV/c)}^2$, for p-p elastic scattering, at lab. energies of 10 GeV/c, and somewhat lower for 30 GeV/c. Averaged over t up to $t = 0.1 \text{ (GeV/c)}^2$, (higher $|t|$ values are not important, because of the exponential drop of the differential cross-section ¹³⁾ as a function of t), we obtain $|L(\sigma^i, \sigma^j; 1, 1)/L(1, 1; 1, 1)| \approx 8 \%$ for elastic p-p scattering. Allowing for inelastic processes, it seems reasonable to assume for this ratio to be $\approx 5 \%$, which leads through Eq. (8a) to $|\Delta/\tau_b| \approx 10 \%$. This is in fact the value we used for purposes of an estimate, in the previous Section.

In order to decide definitely whether the strong interactions can indeed be used to produce useful polarized beams, one would have to have some experimental data concerning the $L(S_a, S_b; S_c, S_d)$. Because of its technical simplicity, method 1) discussed in Section 3 is perhaps the most elegant. For this reason, we shall concentrate our attention on it from now on. Although all the L appearing in Eq. (6) cannot be measured separately at this time for lack of high-energy polarized beams,

their relevant combinations can. In fact, the experiment to be suggested measures the L not only for elastic processes, but also for inelastic ones, and exactly the proper mixture of the two. The relevant quantity is Δ / τ_p appearing in Eq. (7), and the suggested experiment measures just that.

The experiment is shown schematically in Fig. 1. A full intensity proton beam from the accelerator (e.g. CERN-PS) is led onto a polarized solid state target ¹⁴⁾, with high polarizable H content ¹⁵⁾. The target should be about one collision length long. We do not measure the particles leaving the target sideways, and are not interested whether the protons were scattered in the target on polarized hydrogen, or other nuclei, elastically or not. Our aim is simply to measure the polarization of the transmitted beam. This polarization will be induced only by the scattering on polarized H atoms, because forward scattering on unpolarized nuclei cannot induce polarization in the forward direction. Furthermore, the polarization induced by the polarized H atoms is the same as that caused by a polarized H target: the elastic and inelastic processes contribute in the same way in both cases. On the other hand, the presence of the unpolarized nuclei in the target can have a depolarizing effect, and this has to be taken into account. This effect can be observed experimentally by a control experiment, placing between the two targets in Fig. 1 an unpolarized target which is composed (predominantly) of the same unpolarized nuclei as are present in the first target. The analyzing target may itself be a polarized target or an unpolarized one. The polarization of the beam transmitted by the first target can be measured in the first case by reversing the polarization of either target, and in the second case by reversing the polarization of the first target (the second target now being unpolarized). The angle θ is arbitrary and can be chosen so that the angle at which the analyzing power of the second target is highest.

Let us estimate the number of events in the detectors which would be needed to obtain a result of practical importance by this experiment. For purposes of this preliminary estimate, let us neglect

depolarization effects in the first target. (This is certainly justifiable if that target is thin.) Let us denote the distance which the beam travels in the first target by ℓ_1 ; the collision length of protons in this target by $\ell_{1(\text{coll})}$; the ratio of polarizable H nuclei to all nuclei in the first target by R_H ; the polarization of the polarizable atoms by P_H . We define $A(\theta)$ the analyzing power of the second target at angle θ by

$$A(\theta) = \frac{1}{P_b} \frac{N(+\theta) - N(-\theta)}{N(+\theta) + N(-\theta)} = \frac{1}{P_b} \frac{\Delta N(\theta)}{N(+\theta) - N(-\theta)} \quad (19)$$

where P_b is the polarization of the beam entering the second target, and $N(\theta)d\Omega$ is the number of protons scattered by the second target into the solid angle $d\Omega$ around θ . If depolarization effects in the first target are negligible, then the change in the number of counts at a fixed θ when reversing P_H will be, using Eq. (7) :

$$\Delta N(\theta) \approx A(\theta) R_H P_H \left\{ \left[\exp \frac{\Delta}{\tau_b} \frac{\ell_1}{\ell_{1(\text{coll})}} - 1 \right] / \left[\exp \frac{\Delta}{\tau_b} \frac{\ell_1}{\ell_{1(\text{coll})}} + 1 \right] \right\} \quad (20)$$

The quantity of interest is Δ/τ_b , and can be expressed from Eq. (20) in terms of known numbers¹⁶⁾. In particular, when

$$\frac{\Delta}{\tau_b} \frac{\ell_1}{\ell_{1(\text{coll})}} \ll 1$$

and $A \cdot P_b \ll 1$, then

$$\frac{\Delta}{\tau_b} = \frac{2 \ell_{1(\text{coll})}}{A(\theta) R_H P_H \ell_1} \frac{\Delta N(\theta)}{N(\theta)} \quad (21)$$

For purposes of our estimate let us take ¹⁵⁾ $R = 13 \%$, $P_H = 80 \%$, $A(\theta) = 10 \%$ for a suitably chosen θ , and $\ell_1 = \ell_1(\text{coll})$. Then we find from Eq. (21)

$$\frac{\Delta N(\theta)}{N(\theta)} \approx 5 \cdot 10^{-3} \frac{\Delta}{\tau_b}$$

Experimental observation of Δ / τ_b with an absolute accuracy of 2 % (relative accuracy is less important) would be a result of great importance. To achieve this, for statistical reasons, one would need about 10^8 events in the counters. On the other hand, even merely an order of magnitude confirmation that Δ / τ_b is not too far from 5 % would mean that method 1) in Section 3 can certainly be used. To obtain such a result about 10^7 events in the counters would suffice. Since we measure the transmitted beam (as opposed to the scattered one) after the first target, 10^8 or 10^7 counts are probably not too difficult to accumulate.

To reduce systematic errors, causing spurious asymmetries, the polarization of the first target can be switched several times for control purposes.

Other possible applications

The idea of polarizing a beam by transmission, i.e., by letting it pass through a polarized target, could be applied to other particles besides protons, such as neutrons, antiprotons or unstable baryons, etc. In fact, this could be used even in connection with non-circulating beams (i.e., those whose particles traverse the polarized target only once), provided that high density polarized hydrogen target become available. In this sense, developing polarized targets with hydrogen content of the order of 100 %, and densities of the order of solid H_2 , and a thickness of the order of one collision length, could then automatically solve the problem of producing high energy polarized beams.

Significance of the experiment

1) - When depolarization effects in the first target are negligible (automatically true if that target is thin), the experiment measures essentially $L(\sigma^i, \sigma^j; 1, 1)$, (which is often ¹³⁾ denoted by C^{ij}). It measures this not only for elastic p-p scattering, but for a known mixture of elastic and inelastic events. It measures this quantity not as a function of t , but its integral over t , that is its average for small $|t|$ (because contribution with high $|t|$ is negligible). Since the measurement of spin structure for small $|t|$ is difficult with the usual type of polarization experiments, it may be of interest to notice that this experiment is able to measure in just that region. The results could then be compared with theoretical predictions concerning inelastic p+p scattering, when such become available. It would certainly be of interest to have some data when attempting to make a model for such phenomena. Alternatively, one can use the existing theoretical predictions for elastic p-p scattering, together with the results of this experiment, and deduce from it the average of $L(\sigma^i, \sigma^j; 1, 1)$ (often called C^{ij}) for inelastic p-p scattering.

2) - Apart from the theoretical interest in the results, as described above, the main and primary interest of this experiment lies elsewhere. In fact, it could decide whether the first method described in Section 3 could indeed be used to build polarized storage rings. If yes, detailed design studies could start immediately. And if a polarized proton storage ring could eventually be built, that would certainly be an event of the greatest importance for the development of experimental physics.

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- 4) One could, perhaps, say that the physicist who is able to measure only total cross-sections, is like the man in an art gallery who is only told the total weight of each statue, but is kept in ignorance of all other parameters specifying their shapes. Most of us would agree that he is missing something.
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- 8) A joint communication is planned by the present author, together with T.W. Eaton, E. Jones and A.M. Sessler, where the technical problems in connection with such a project will also be investigated.
- 9) Of course, when all spins are $\frac{1}{2}$, then each set of $\{ S_x \}$ can be chosen to consist of the unit matrix, and the three Pauli matrices.
- 10) Design study of the intersecting storage rings (ISR), CERN-AR-SG/ 64-9 (1964).
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- 14) I am grateful to M. Borghini and L. di Lella for a discussion concerning this experiment.
- 15) M. Borghini is now developing a target in which the polarizable H content should reach 13 %.
- 16) If depolarization effects on the unpolarized nuclei in the first target are important, then instead of Eqs. (20) and (21), somewhat more complicated equations have to be used, but Δ/τ_b can still be determined by this experiment.