THE PROTON BEAM POLARIMETRY AT THE IHEP U70 FACILITY

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Abstract

The polarized proton beam is planned to be accelerated in the U70 accelerator of IHEP (Protvino, Russia). The polarized ion source feeds the chain: Linac Ural30 - Booster1.5 - U70. After acceleration up to 70 GeV the polarized beam is assumed to be extracted by fast or/and slow extraction systems and distributed over the several fixed target experimental set-ups. The main goal of this presentation is to analyze the possible means of measuring the proton beam polarization at the appropriate places in the chain.

1 Introduction

Long ago the proposal was made to accelerate the polarized proton beam in the IHEP U70 accelerator by using the " siberian snake " 'technique [1]. The Proposal was not accepted at that time due to the many other current deals. Now it seems the time is appropriate for renewing this program especially after the successful commissioning of the polarized RHIC at energy $\sqrt{s} = 200$ GeV and very promising progress towards the RHIC top energy $\sqrt{s} = 500$ GeV [2]. Two previous speakers gave in this Workshop the presentations on the acceleration of the polarized proton beam in U70 synchrotron [3] and about the possible physics program with use of this beam [4]. The small gap is available between these two subjects, this is a polarimetry. In following I'll try to fill this gap.

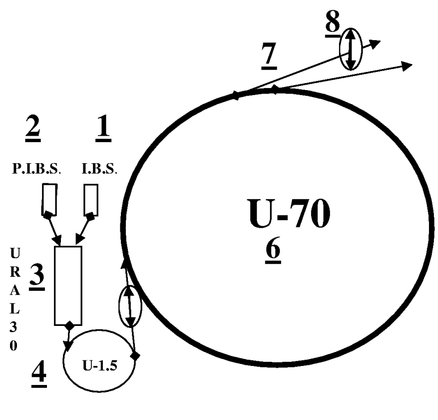

Figure 1: The layout of the polarized U70 complex.

2 The IHEP U70 facility

The scheme of the accelerator complex for 70 GeV polarized proton beam is presented in Fig.1. It consists of the following components: 1) unpolarized ion beam source, IBS, 2) the polarized ion beam source, PIBS, 3) RFQ Linac Ural-30, 4) Booster-1.5, 5) beam transport system from Booster -1.5 to U-70, 6) main accelerator U-70, 7) high energy polarized beam extraction and transportation systems, 8) fixed target experimental set-ups and the local polarimeters.

2.1 Local polarimeter for atomic beam source

The prototype of the polarized ion beam source (PIBS) is described in details in paper [5]. The low energy polarimeter of PIBS is based on the Lamb - shift effect and works in the following way. A beam of polarized protons is focused by an electrostatic lens into the cell containing a sodium vapor. The position of the beam in vertical plane is adjusted by electrostatic collector. Inside the sodium cell a portion of the polarized protons is converted into the metastable atoms in alpha and beta ($2S_{1/2}$) states. In the crossed magnetic and electric fields created by solenoid and a capacity the atoms in beta state are quenched. The beam of metastable atoms mostly in alpha state is recorded by detector with a secondary electron multiplier. The flux of the beam passing through polarimeter is controlled by the Faraday cup. Taking counting rates with different initial proton beam polarization one can find the beam polarization. It was 76 $\pm$2%. Such a precision may be achieved around 1 minute. Therefore it can be used as the absolute on-line polarimeter.

2.2 30 MeV relative polarimeter

In building the relative polarimeter for measuring the beam polarization at the exit of Linac Ural-30 we plan to use the rich experiences gained by physicists over the world. At this energy the polarization for elastic proton-carbon scattering was measured with precision of order 1%. According to these results the relative pC polarimeter may be built at 30 MeV by scattering protons at 65^0 angle at Lab. system. In this case the analyzing power is expected to be $A_N = (57.4 \pm 0.9)\%$. Assume we apply directly this technique in scale 1:1. Since Ural-30 transfers the current I=3 mA and duration of burst is 40 μs then we deal with number of protons in the burst equals $7.5{\cdot}10^{11}$. Suppose the thickness of target is 106.9 mg/cm^2 and width is of 3 mm (beam size is approximately 30 mm). For the useful solid angle of $\Omega = 10^{-3}$sr for scintillation telescope one expects 6,000 events per burst. Taking into account 16 bursts, 6 cycles per minute one gets $6{\cdot}10^6$ events per 10'. Such statistics will be enough to reach a precision of 5% in the beam polarization measurement.

2.3 1.3 GeV Polarimeter for booster-1.5

There are measurements of the analyzing power of the elastic pp- scattering in the wide energy region. The closest to the top booster energy experiment was done at the CERN PS [6]. At the kinetic energy of protons T=1.34 GeV the analyzing power at $\theta_L = 12^0$ laboratory angle is $A_N = (37 \pm 2)\%$. We found that the differential cross section is equal to 66 mb/sr with precision about 5%. We assumed that the simple two conjugated scintillation telescopes will be used with the solid angle of 0.7 msr. The booster may furnish about 30 bunches with $2{\cdot}10^{11}$ protons per bunch. The duration of bunch is very short approximately 80-100 ns. This condition puts severe restrictions on the rate of the data taking. For safety's sake we assumed that in passage of each bunch through target we can take only one event. This we can do with the polyethylene target of thickness around 50-100 μm. If we suppose that the beam polarization is 0.7 we expect to measure the beam polarization with precision of 5% during a couple hours.

2.4 70 GeV polarimeters for U70

The absolute and relative polarimeters, which we are planning to build for the main accelerator, must work from the injection energy of 1.3 GeV up to the top energy of 70 GeV. Polarimeters should control the internal beam polarization at all stages of beam circulation.

The basic criterium of getting the highest factor of merit (FOM) leads us to select the pp and pC CNI polarimeters as they were realized at RHIC [7], [8].

The additional approach to the polarimetry consists in applying the existing apparatus for measuring the beam polarization. This stems out from one advantageous which is relevant to the U70 facility - it has the beam extraction and transporting system, the beam lines and the equipments for detecting and identifying the secondary charged particles. The example is the beam channel number 2 which may transport the beam of highest energy up to 70 GeV/c to the experimental target. We can use this beam line and the existing there experimental set-up as the main basis of the inclusive pion relative polarimeter. The second appropriate apparatus is the PROZA set up using the polarized target. This set-up may be modified to measure the elastic pp-scattering at 45 GeV/c. The analyzing power of this reaction was measured at the indicated above energy long ago by the HERA Collaboration with appropriate precision [9]. There is one measurement of the analyzing power of the elastic pp-scattering at energy 77 ± 10 GeV. At the invariant momentum transfer -t=0.3$(GeV/c)^2$ $A_N = (2.0 \pm 1.3)\%$. The modified PROZA apparatus can be used as the absolute polarimeter.

Therefore in following we briefly describe two internal absolute polarimeters and two possible external polarimeters, namely, one is the relative inclusive pion polarimeter and second is the absolute elastic pp - scattering polarimeter.

2.4.1 CNI pp recoil polarimeter

The pp CNI polarimeter at 70 GeV has a large differential cross - section at around the CNI peak region $\frac{d\sigma}{dt}(-t \approx 3 \cdot 10^{-3}(GeV/c)^2) \approx 100\frac{mb}{(GeV/c)^2}$ [10], Its average analyzing power is around 2%. Therefore the factor of merit is around FOM $\approx 4 \cdot 10^{-2}\frac{mb}{(GeV/c)^2}$. The scheme of this polarimeter is presented in Fig.2.

It is just the RHIC polarimeter applied to U70 synchrotron. The polarized jet target (PJT) has an areal density of $10^{12} p \cdot cm^{-2}$, the polarization $P_T = (92 \pm 1.8)\%$, the jet size 5 mm(FWHM) and works in dc regime. 6 silicon strip detectors of size 72x64 mm^2 each are placed on the left and 6 on the right sides of beam at distance around 80 cm from PJT. Firstly in

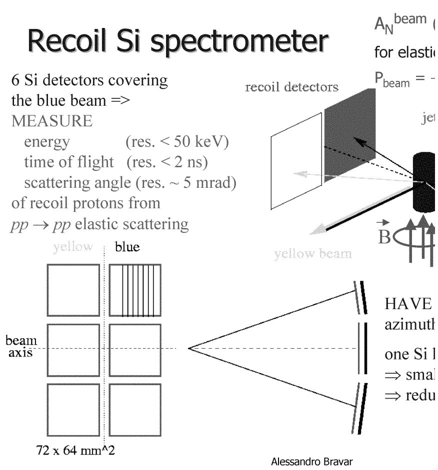

Figure 2: The RHIC CNI elastic pp- absolute polarimeter.

order to measure the analyzing power the unpolarized proton beam of 70 GeV strikes the PJT. Let us estimate the expected intensity per second for the polarized U70 beam assuming the following parameters. Internal beam flux per second is I=$5 \cdot 10^{12} \cdot f$, where f=20kHz, so one can find I=10^{18}protons/s. Since the duty factor for U70 is 0.2 we got the effective polarized beam intensity as $2 \cdot 10^{17}$p/s. For comparison we may estimate the same parameter for RHIC. RHIC at moment uses 55 bunches with $5 \cdot 10^{10}$ protons in bunch. The beam circulating frequency is of order 78 kHz. Therefore for RHIC the beam intensity is $2 \cdot 10^{17}$p/s. As we see the situation is the same for beam intensity in both U70 and RHIC facilities. For further estimate we take the RHIC PJT parameters as the basic ones for u70 too. So we should expect the same as at RHIC luminosity and counting rates. In order to estimate the counting rate we made the following assumptions. For pp-elastic differential cross section at 70 GeV/c we took the exponential form in function of t. Slope parameter is known experimentally B=11.3$(GeV/c)^{-2}$. The value of the differential cross section at t=0 we calculated from the optical theorem neglecting the real part of amplitude. The interval of measurement was taken as in RHIC, namely, $0.002 \leq |t| \leq 0.02, (GeV/c)^2$. The azimuthal coverage was taken as $\frac{\delta\phi}{\phi}$=0.086. So the effective cross section becomes 100μb. Multiplying this number by luminosity we got N=20 events/s. In order to reach the 5% precision in the analyzing power calibration one needs approximately $1.2 \cdot 10^6$ events. Such number of events may be accumulated in approximately 17 hours. In the case of beam polarization measurement this polarization can be measured with 5% precision in about 28 hours.

2.4.2 CNI pC recoil polarimeter

The use of absolute pC polarimeter will be useful due to very high luminosity and large cross section. Assume we shall use the same apparatus as at RHIC (see Fig.3). In this case the ribbon carbon target of the areal density $3.5\mu g/cm^2$ [8] contains $1.75 \cdot 10^{17} carbons/cm^2$ allowing to reach at U70 the luminosity of order L=$3.5 \cdot 10^{34} cm^{-2}s^{-1}$. With the accepted cross section for apparatus of order 9.5 mb one can expect the counting rate of order $3.3 \cdot 10^8 events/s$. Sure one needs to decrease this counting rate by factor $10^4 - 10^5$. This may be done by several means. One way, for example, is to use the target of very small width in comparison with the beam size. At RHIC the ribbon target has a width of $5\mu m$ while the beam size is around 1mm. Therefore the counting rate is expected to decrease by a factor of 200. Use of the same target at U70 having the beam size about 20mm leads to a suppression factor of order $4 \cdot 10^3$. Therefore the counting rate becomes around of $8 \cdot 10^4 events/s$ which is a suitable number. If we would like to measure the beam polarization with a precision of 5% and the pC average analyzing power is 1%, then we need to accumulate the statistics of order $8 \cdot 10^6 events$. Therefore the measurement in one point will take $100s$. For U70 top energy

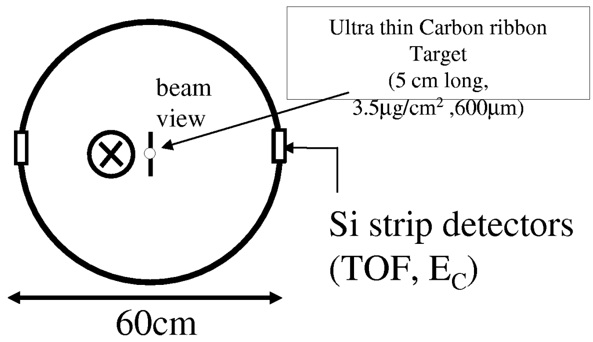

Figure 3: The RHIC elastic pC CNI recoil polarimeter.

with $2s$ plateau the result may be obtained in about $50s$. In energy ramp we may want to make measurements at 10 points. Then such measurements take approximately $1000s$. So the pC polarimeter is the fastest polarimeter. Such fast polarimeter might be very useful in tuning the accelerator, fighting the depolarizing resonances, etc.

There is another way of decreasing the counting rate directly by decreasing the beam intensity. In this case the essential problem will be the monitoring of the low intensity circulating beam. Optimum may be find by combining these two methods.

2.4.3 The external inclusive pion polarimeter

Just after commissioning of U70 accelerator the measurements were made of the inclusive particle yields by using the internal targets. The particle production angle varied from 0 to 15 mrad and their momenta were in the range 10-60 GeV/c. The particles were accepted by the beam line number 2. The useful solid angle and the momentum band were determined by the collimators, by the magnetic dipoles and quadrupoles. The particle selection and identification were made by the scintillation counters, threshold and differential Cherenkov counters. The momentum of particle was measured by the same Cherenkov counters. The monitoring of the initial beam intensity was made by two telescopes (Fig.4) [11].

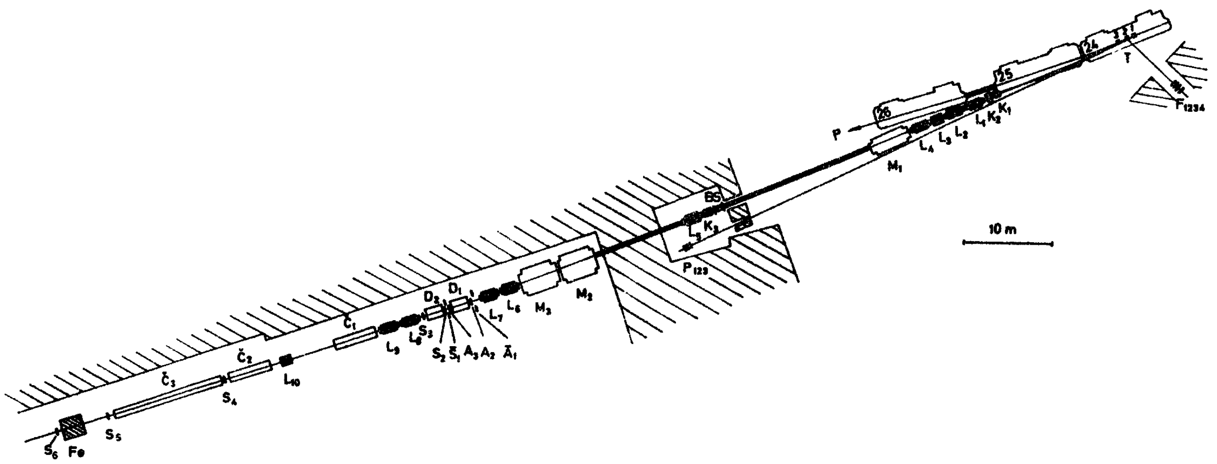

Figure 4: The scheme of the U70 beam transport channel number 2 which can be used with the indicated experimental set-up as the relative polarimeter for U70. P - circulating proton beam, T(1,2,3)- the internal targets, K_1, K_2, K_3 - collimators; M_1, M_2, M_3- bending magnets; $A_1 - A_3, S_1 - S_6$ - scintillation counters. $C_1 - C_3$ -threshold Cherenkov counters, D_1, D_2 - differential Cherenkov counters. P_{123} and F_{1234} - telescopes of the scintillating counters for monitoring the intensity of the internal proton beam.

Now we propose to use the channel 2 and the updated apparatus for measuring the beam polarization knowing the analyzing power in inclusive pion production. The polarized circulating proton beam with up and down polarizations strikes the internal carbon target as foil of sizes $50\mu(width) \times 20\mu(thickness) \times 5cm$ (height). Then we'll have the luminosity of order $10^{35} cm^{-2} \cdot s^{-1}$. Since the essential analyzing power is expected at the region of $p_T \geq 1.0 GeV/c$ and $x_F \geq 0.5$ the corresponding production angle and secondary particle momentum should be selected according to this requirement. In the paper [12] the measurement of the p+Be differential cross section was made at 67 GeV/c. The largest production angle reached was 20 mrad, and momentum of negative pions was 34 GeV/c. The differential cross section in laboratory system is $\frac{d\sigma}{d\omega \cdot dp} = 11 \frac{mb}{sr \cdot GeV}$. At the beam momentum acceptance 2% and useful solid angle $8\mu sr$ one expects $3 \cdot 10^4$ events/sec. Assuming that at the same angle we can extract negative pions of higher momentum (let say of 50 or 60 GeV/c) and yield becomes lower by two order of magnitude we still may be able to measure the beam polarization with desirable 5% precision in about 19 minutes. This will be fast, on-line, relative polarimeter.

Note there is no hitherto direct measurement of the π^- or π^+ analyzing power at 70 GeV/c. We took the interpolated value of the analyzing power between 22 and 200 GeV/c. However the precision of such interpolation is doubtful. Moreover the experimental data do not allow us to measure the beam polarization with necessary precision. Therefore we must make ourself the measurement with the required precision. For that we shall discuss in following the absolute elastic pp scattering polarimeter.

2.4.4 The external elastic pp polarimeter

At the 70 GeV there is only one experiment fulfilled at Fermilab which measured the polarization in elastic pp-scattering. The data serve as the indication that the P=2±1.3 at t=-0.3$(GeV/c)^2$. The more precise polarization measurement in elastic pp scattering was done by HERA Collaboration [9]. The average value of polarization for range 0.2$\leq -t(GeV/c)^2 \leq$ 0.3 was found to be P=2.23±0.15%. The cross section for this reaction was also measured with a good precision . So first we may extract the unpolarized beam at this energy (U70 should be tuned to this energy) and calibrate our apparatus. Then we have to go to 70 GeV and make the detailed measurement of analyzing power. If the analyzing power is close to 2% as was indicated by Fermilab experiment then we must reach the better than 5% measurement of the polarization, So we'll have the absolute polarimeter at 70 GeV. Then we can use the same target without polarization by extracting the polarized 70 GeV/c beam by bent crystal (as we are doing now with unpolarized 70 GeV/c proton beam) and we can measure the beam polarization at 70 GeV/c with the needed precision.

The counting rate may be estimated at the assumption that we are using the HERA collaboration apparatus [9] and measured by them differential cross section at -t=0.3 $(GeV/c)^2$. The 5% precision can be reached at approximately 10 hours assuming the beam intensity of I-$2 \cdot 10^7$ per cycle is available.

Summary

The program of acceleration of the polarized proton beam in U70 synchrotron will require the build-up of a set of the absolute and relative polarimeters. In this presentation an attempt was made to review the achievements of the other laboratories and to search for the efficient tools for polarimetry. Two internal absolute pp and pC CNI polarimeters were selected following the RHIC experience, Two new external polarimeters are proposed. For the Ural-30 and the Booster-1.5 the elactic pC and pp-scatterings are proved to be the suitable polarimeters. This is the first step for finding the optimum polarimetry for polarized U70 facility. Further study will be continued.

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