POLARIZED BEAMS AT PSI

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Abstract

The PSI facilities for production of polarized protons, deuterons and neutrons at low and medium energies are described. Ongoing developments and plans for future imporvements are presented.

Introduction

Investigations with polarized particles have become an important part of the research programme at PSI, especially at low energy. More than 50% of the operation time of the PSI Philips cyclotron is dedicated to the acceleration of polaried protons and deuterons. With the development of two new facilities polarized neutron beams became available at low and medium energies. The beams are characterized by a high flexibility in the spin axis orientation, allowing measurements of complete sets of observables in analyzing power and spin correlation studies, and by intensities sufficient to perform double scattering experiments, e.g. for polarization transfer investigations.

The general layout of the polarized beams is as follows:

i) at low energy (Ep ≤ 72 MeV): after acceleration in the Philips Cyclotron, transportation of $\vec{p}$ and $\vec{d}$ to one of the three low energy experimental areas. Polarized neutron production in one area.

ii) at medium energy (Ep = 590 MeV): the Philips Cyclotron is used as injector into the Ring Accelerator. After acceleration, transportation of $\vec{p}$ through the 590 MeV proton beam line to the last target, which is used as π-production target. Experimentation in an area located behind the proton beam dump. A new nucleon area is projected.

Primary beams

Production and Acceleration

The PSI polarized hydrogen ion source is of the atomic beam type. It is equipped with a cold (~35 K) atomic beam [1,2], developped in collaboration with ETH Zurich, and an ANAC "superionizer". Nuclear polarization is generated by a set of strong and weak field rf-transitions. The theoretical polarizations obtainable with our scheme are for protons $p_Z = \pm 1$, and for deuterons a mixed polarization with $p_Z = \pm 1/3$ and $p_{ZZ} = \pm 1$, and a pure vector polarization with $p_Z = \pm 2/3$.

Selection of a particular polarization state or rapid sign reversal is achieved by switching on and off the rf power of the corresponding transition unit. Practical values of the polarization have been typically 85% of the theoretical maximum. Improvement of the vacuum system has recently led to a polarization of 90%. The correlations between polarization state and other beam parameters like intensity, phase space, energy are negligible for most experiments [3].

The beam extracted from the ionizer is axially injected into the Philips cyclotron. After acceleration to an energy of up to Ep = 72 MeV, the beam is transported either to the low energy experimental areas or to the Ring Accelerator. The highest intensity extracted to date was 6 μA of polarized protons at 72 MeV, in the first harmonic mode (17 MHz). The performances of the system are illustrated by the quotations given in tab.1.

Atomic beam flux into ionizer	$5\cdot10^{16}$ atoms/s
Beam current from ionizer	300 μA
Beam energy	≤ 13.5 keV
Beam quality	75μA in 80mm mrad √MeV
Beam at the end target of injection line (at 13.5 keV)	45 μA
Bunching factor	2 - 4
Beam after 1st accel. stage (72 MeV)	3 - 6 μA
Beam after 2nd accel. stage, at target (590 MeV)	5 μA

Table 1: Intensities of the polarized proton beam.

It is planned to double the intensity by the integration of an ECR-ionizer in the polarized ion source. Investigations of this new ionization technique have recently been performed in collaboration with KfK [4].

Spin handling

The beam extracted from the cyclotron has its spin orientation axis parallel to the magnetic field of the accelerator. Additional spin handling with solenoid and dipole fields is therefore required to generate selected spin orientations in the horizontal plane.

Longitudinally and transversally polarized low energy proton beams: The need of such beams for the experiments on parity violation performed at 50.7 MeV by the ETH group [5,6] led to a specific layout of one of the beam lines. The spin axis is aligned in the beam direction by means of a solenoid followed by a 47.6° deflection. Alternatively, a solenoid located in front of the target station is used for the production of a transverse polarization in the horizontal plane.

The high requirement of this experiment on the beam quality has induced a very detailed analysis of the beam properties [3,5,6]. For example, the experimental setup includes monitors [7] for the measurement of unwanted transverse polarization components in the longitudinally polarized beam. Particularly interesting is the behaviour of the component in the horizontal plane, p_X. While the average value is $p_X=0.001$, the actual distribution of the polarization across the beam shows a systematical variation from $p_X=-.025$ to $p_X=+.025$.

Investigations of the correlations between beam properties and polarization state revealed very small effects. For example, the intensity modulation observed as the sign of the polarization is reversed at the source is smaller than $5\cdot10^{-4}$ and the position modulations, measured with a precision of one tenth of a micrometer, are 0 [5,6].

Deuteron beam with a p_{XZ} component: A deuteron beam with a vertical polarization axis is not sufficient to determine completely the analysing power of a reaction. Only A_y, A_{XX} and A_{yy} can be measured. The quantity A_{XZ} (or T_{21} in spherical notation) is therefore generally missing in the results obtained at cyclotron laboratories. The component p_{XZ} of the beam polarization is given in the target coordinate system by

$$p_{XZ} = \frac{3}{2}\sin\alpha\cos\alpha\sin\beta\,\hat{p}_{ZZ}$$

where α is the angle between beam direction and spin axis and ß is the angle between the normal to the scattering plane and the projection of the spin axis on the plane perpendicular to the beam direction [8]. The quality $\hat{p}_{ZZ}$ is the tensor polarization in the source own coordinate system.

The maximum value is obtained with α = 45°, the

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spin axis lying in the horizontal scattering plane (β=90°). The technique used by the ETH group for the measurements of A_{xz} combines the rotation of the spin axis into the horizontal plane by a superconducting solenoid located close to the extraction from the cyclotron with the large deflection angle (170°) experienced by the beam during transportation to the experimental area [9]. For a deuteron beam of 24 MeV, the resulting angle α is 65.38°. In this case, the component p_{xz} reaches 75.8% of the maximum possible value.

Secondary beams

With the availability of several µA of polarized protons on target, production of polarized neutrons by polarization transfer becomes very attractive in the whole energy range covered by the PSI accelerators.

Monoenergetic polarized neutrons between 30 and 70 MeV

A facility delivering monoenergetic polarized neutrons below 72 MeV has been recently installed in collaboration with the Basel group [10]. The $^2H(\vec{p},\vec{n})$ 2p transverse polarization transfer at 0° is used as production reaction.

The general layout is illustrated in fig. 1. The vertically polarized protons from the Philips Cyclotron are focussed into a polarimeter (POL), where the polarization is measured. After passing through a solenoid (SOL) the beam hits the neutron production target (T) located inside the shielding (S). The dipole magnet (D) downstream from the production target purges the beam of charged particles produced in the target region and deflects the proton beam into a Faraday cup (FC) which monitors the proton beam intensity. The field is adjusted such that a spin orientation in the horizontal plane is precessed by 90°. The neutrons exit the dipole and shielding at 0° through the collimator (C). The TOF path available for neutron experiments is indicated in fig. 1. For extreme forward angles ($\theta \leqslant 20°$) TOF paths of up to 10 m from the collimator exit are available.

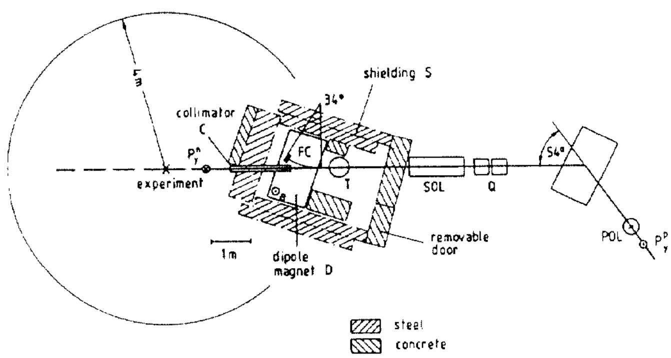

Fig. 1 Layout of the low energy polarized neutron facility.

The collimator consists of a 1.5 m long stainless steel piece with a cyclindrical bore in which brass cyclinders are filled to shape the beam according to the experimenter's need. Solid angles of $2.5\cdot10^{-5}$ and $7\cdot10^{-5}$ sr have been used. Best results in respect to the beam profile are obtained with a bore tapering from larger to smaller diameters over 0.3 m and then opening up with a cone apex exactly at the production target spot. Special attention was paid to the reduction of the background by means of a steel and concrete shielding as shown in fig. 4. Around the neutron target area the background due to fast correlated neutrons is of the order of 10^{-5} to 10^{-6}. The overall background, energy integrated, is about 10^{-3} at a neutron beam energy of 70 MeV.

A particular requirement on the design of the production target was set by the high thermal load from the primary beam. The liquid deuterium (LD_2) target is mounted on the cold head of a refrigerator with a nominal cooling power of 10 W at 20 K. Since the energy loss of 72 MeV protons in 1.0 cm of LD_2 is 1.9 MeV, the maximum permissible beam current is about 5 µA in order to operate the LD_2 target at these intensities without producing bubbles in the liquid. A two-stage refrigeration system is used, where the LD_2 is cooled by liquid hydrogen (LH_2) and the LD_2 is operated away from the equilibrium condition, and a rapid circulation of the LD_2 between the beam spot region and the LH_2 heat exchanger is enforced by operating a fan in the LD_2. With a 1 cm thick LD_2 target a peak-integrated neutron flux of $\sim1\cdot10^5$ n/s cm² per µA of proton beam current is obtained. In the near future beam currents of up to ~5 µA of polarized proton beam with a suitable time resolution can be expected. This would result in flux of up to $\sim5\cdot10^5$ n/s cm² of highly monoenergetic neutrons. With a 1 ns proton burst width, the monoenergetic peak of the neutron energy spectrum has a width of 2-3 MeV.

TOF spectra of parameters characterizing the neutron beam are shown in fig. 2 for a measurement at 54.5 MeV.

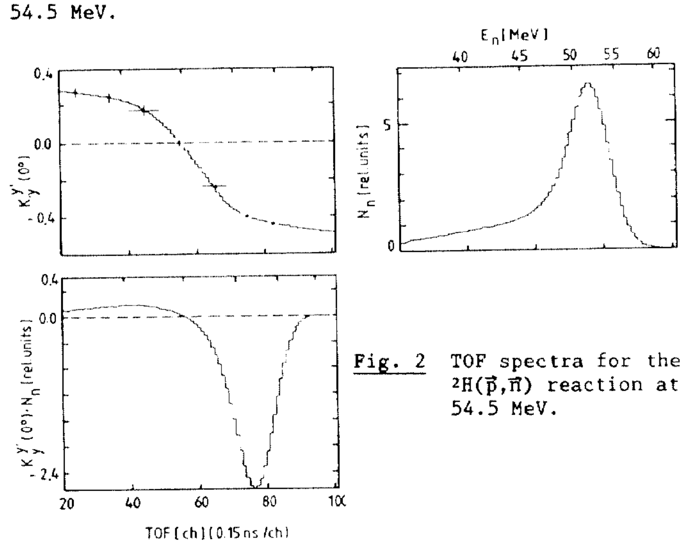

Fig. 2 TOF spectra for the $^2H(\vec{p},\vec{n})$ reaction at 54.5 MeV.

The transverse polarization transfer coefficient at 0° shows a strong dependence on the excitation energy. The experimentally interesting quantity polarization transfer times neutron flux, however, displays a clear monoenergetic behaviour. Based on a typical proton polarization of 0.85 a peak averaged neutron polarization of 0.30 to 0.35 is obtained for energies between 50 and 70 MeV.

Medium energy polarized neutrons

The production of polarized neutrons with energies between 200 and 580 MeV by longitudinal proton-neutron spin transfer on a carbon target at small emission angle has been investigated by a Freiburg-, Geneva- and PSI-collaboration. The last pion production target in the 590 MeV proton beam line is also used for neutron production. The neutron emitted at 3.4° enters an experimental area located behind the beamdump. Fig. 3 shows the energy spectrum of the neutrons above 200 MeV as measured at 60 m distance [11].

The longitudinal orientation of the proton polarization is obtained by means of a superconducting solenoid and the last bending magnet. The resulting longitudinal polarization of the neutrons can be transformed into a vertical one by passing the n-beam through a dipole magnet.

The polarization is measured with the (np) elastic scattering [11]. The polarization of the neutron beam is shown as a function of the energy in fig. 4.

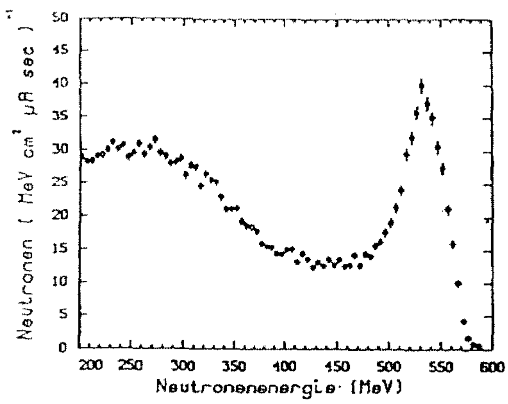

Fig. 3 Energy spectrum of the neutron beam produced on a carbon target.

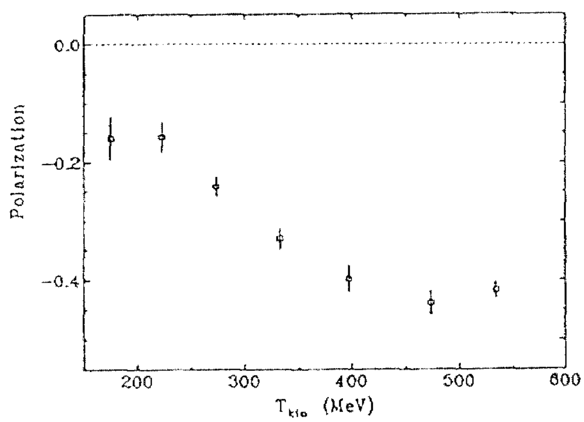

Fig. 4 Energy dependence of the neutron beam polarization.

It is seen that about 40% polarization is obtained above 300 MeV. These results demonstrate the suitability of the longitudinal polarization transfer on a carbon target to generate intense beams of polarized neutrons at higher energies. Ongoing developments to further improve the polarized neutron flux are based on this technique.

A new beam line is proposed for this purpose. Neutrons produced on a 12-20 cm thick target by quasi-free elastic and inelastic processes are collimated to achieve a beam at 0^{o} with a $4 \cdot 4$ cm^2 cross section at 12m distance. The reaction target will be 12-15 m downstream from the production target. This has two consequences:

- operating the Philips Cyclotron in the 1st harmonic mode (17 MHz), there will be no energy ambiguities from the time of flight measurements above 90 MeV (15m); in the 3rd harmonic mode the first ambiguity is still as low as 230 MeV.
- the polarized neutron beam produced with a intensity of 2-10 μA will have a flux which is similar to that of the present unpolarized beam at 60 m and at a full intensity [12].

The energy of the incident neutrons can be measured by time of flight to an accuracy of about 50 MeV (FWHM) at 560 MeV, and about 15 MeV (FWHM) at 300 MeV, assuming a proton bunch width $\leq$ 1 ns.

To obtain a longitudinally polarized proton beam, the vertical spin is first rotated into the horizontal plane by a superconducting solenoid, and then parallel to the beam direction by a 31^{o} bending magnet. Just after the production target the proton beam will be deflected into a beamdump. The polarization of the primary proton beam will be monitored permanently by scattering off a carbon target located upstream of the spin handling system. Two dipole magnets will allow to rotate the neutron polarization from the longitudinal into the two other orthogonal directions.

Conclusions

The performances summarized in table 2 show that competitive polarized particle facilities have been developped at PSI in close collaboration with the user groups. Up to 5 μA of polarized protons have been delivered on target at low and medium energies, and polarized neutron beams of up to $5 \cdot 10^5$ n/(s·cm²) have been observed. Polarizations in the three orthogonal directions can be produced at different target stations. Ongoing developments on the source will soon double the beam intensities. A ten times enhanced polarized neutron flux at medium energy can be achieved after construction of the proposed experimental area especially designed for this purpose.

Neutron energy (MeV)	30-70	200-580
Neutron polarization	~35%	~40%
Resolution FWHM (MeV)	2-3	11-50
Duty cycle	100%	100%
Neutron production target	LD_2	carbon
Present intensities		
Primary beam (μA protons)	3	5
Neutron flux (10^5 n/s·cm²)	3	5
Future intensities		
Primary beam (μA protons)	5	10
Neutron flux (10^5 n/s·cm²)	5	50

Table 2: Properties of the PSI polarized neutron beams.

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