Construction of a Neutron Beam Line at the KEK 12-GeV PS

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Abstract: Primary proton beam line P1 of the KEK-Proton Synchrotron (KEK-PS) has been modified to the neutron beam line. Neutrons were produced by the proton-stripping reactions of deuterons in a 6 cm thick beryllium target. The deuteron beams of 2 $\sim$ 6 GeV provided the neutron beams of 1 $\sim$ 3 GeV. The neutron flux increases with an increase of the deuteron energy. Typical beam intensities were obtained to be roughly $(1 \sim 6) \times 10^8$ neutrons per 10^{11} deuterons of 2 $\sim$ 6 GeV.

The deuteron beam has been successfully accelerated since the end of 1991 at the KEK 12-GeV proton synchrotron (PS) [1]. This introduces a possibility for acceleration of light-to-heavy ions at the KEK PS. Ion-beams in multi-GeV/nucleon region are unique in the world, thus has yet to be realized.

The neutron beam line has been constructed, modifying the KEK-PS P1 beam line [2], for which the deuteron beam was utilized. This was designed for an experiment to measure the differential cross section of deuteron production by the (n, γ) reaction on liquid hydrogen (E235,Dγ [3]), which has been performed in April, 1993. Neutrons were produced by the proton-stripping reactions of deuterons in a beryllium target. The neutron beam line provided by the reactions has been existing at the Saclay/Saturne [4], where the deuteron energy region covers up to $\sim$2 GeV. Since the deuteron beams of 2 $\sim$ 11.2 GeV can be supplied by the KEK-PS, neutrons of 1 $\sim$ 5.6 GeV are available at the beam line. Monokinetic neutrons provided by the beam line would be quite useful for other field such as nuclear engineering as well as for physics. Interactions of a neutron with a nucleus have been estimated only approximately with those of a proton so far since no data are available in multi-GeV region. Systematic studies of the neutron-nucleus interaction have to be made in this beam line.

This article reports the features of the constructed beam line and the characteristics of the deuteron and the neutron beams obtained in the tuning for the Dγ experiment, where 2.0, 4.0, 4.7, 5.4 and 6.0 GeV deuterons were used.

Figure 1 illustrates the modified P1 beam line. The deuteron beam extracted from the KEK-PS is transported through the EP2 primary beam line to the P1 beam line, and focused on the neutron production (Be) target. The beam spot size on the target is controlled by the quadrupole triplet (Q1$\sim$3). The deuteron beam intensity are controlled by the collimators CH and CV placed behind the Q3 magnet. The steering magnets S1 and D1 are used to adjust the beam position at the target in vertical and horizontal directions, respectively. CH is installed in the gap of the S1 magnet so as to save the beam line space. The CH collimator is driven by a motor in the vacuum duct of the beam line.

The deuteron beam intensity was measured by the secondary emission chambers (SEC) [5]. The SEC was calibrated by the foil activation method with approximately 10% accuracy. Errors come most from the referred cross sections of the ^{24}Na production reaction by deuteron on ^{27}Al [6], detail of which is reported elsewhere [7, 8]. The beam profile was monitored by the segmented parallel plate ionization chambers (SPIC) [9]. The beryllium target of 3 cm diameter and 6 cm thick was used. Another targets of 3 cm and 10 cm thick were available as options. A target monitor (plastic scintillator telescope) was placed at 90 degrees to the beam line in order to confirm that the beam hits the right position.

A certain fraction of deuterons interact with beryllium and break up into a neutron and a proton. Charged particles were swept out in the vertical direction by the D2 bending magnet located just behind the Be target. Neu-

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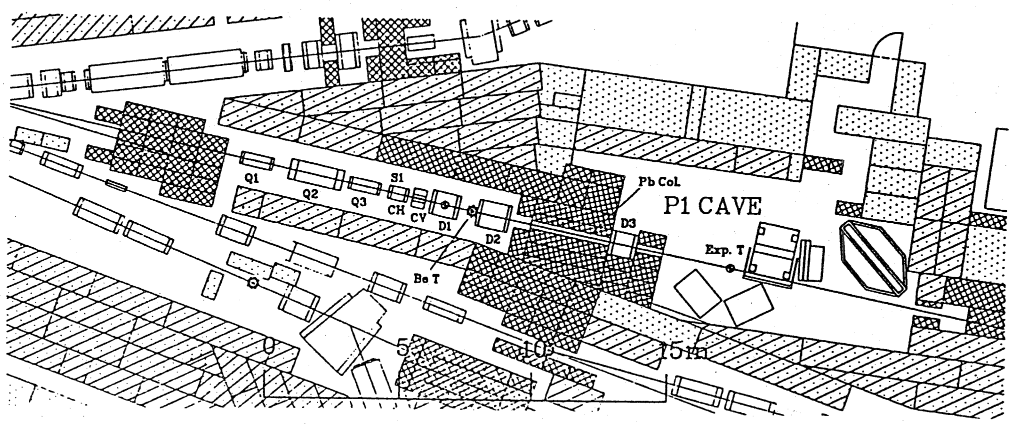

Figure 1: P1 beam line with the neutron beam course newly constructed at the KEK-PS.

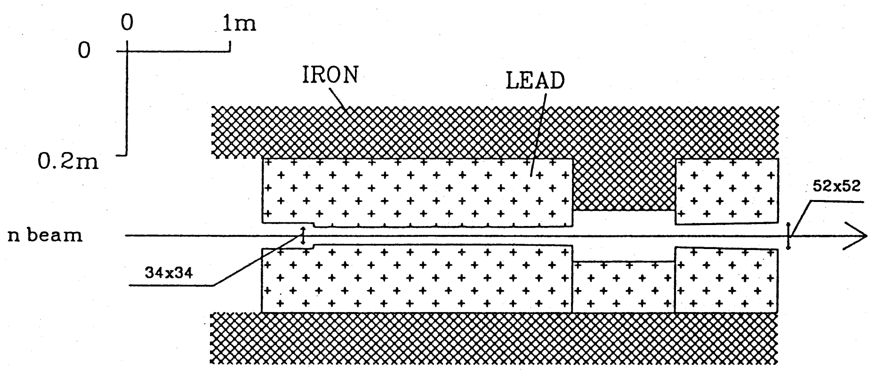

Figure 2: A schematic view of the cross section of the neutron collimator along the beam line.

trons produced at around 0 degree can pass through the collimator of 5 m long onto the experimental target. Figure 2 shows the cross section of the neutron collimator along the beam line. It consists of cast lead surrounded by iron. The loophole of the collimator is gradually widened, which is 3.4×3.4 cm^2 at the entrance and 5.2×5.2 cm^2 at the exit. The solid angle for the neutrons is approximately 50 μsr. The D3 magnet was placed as a secondary sweeping magnet. It was not used however as the neutron beam was already purified enough at this position.

The beam envelope is given as illustrated in figure 3-a, where the beam is focused with the last Q-triplet at the Be target. Since the neutron production from the stripping process is maximum at 0 degree, it was advantageous for the Dγ experiment to realize rather a parallel deuteron beam at the Be target even though the beam spot size was large. An another option of the beam optics was thus prepared, as shown in figure 3-b, where the final beam focusing was made with the Q1-Q2 doublet. Monitoring by the SPIC at the target the beam was tuned to be about 20 mm in diameter, which is almost as large as the target diameter.

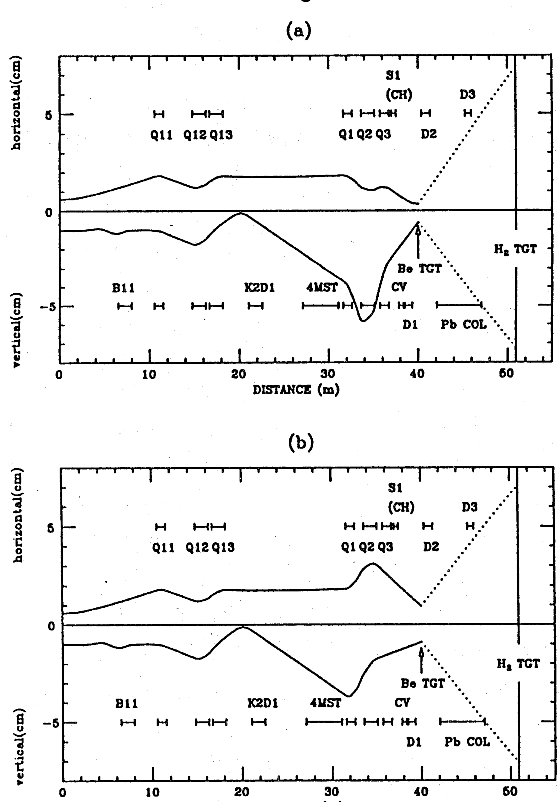

Figure 3: Beam envelopes in triplet mode (a) and doublet mode (b). See text for details.

A set of plastic scintillator hodoscopes was employed

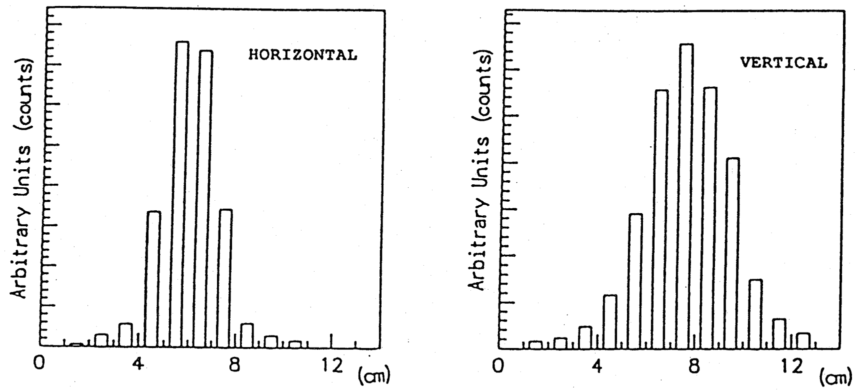

Figure 4: Neutron beam profiles obtained by a set of plastic scintillator hodoscopes.

as a neutron beam monitor (NBM). The NBM consists of 3 layers in beam direction. The first layer, divided into 16 slabs of 15 mm in width, is a veto of charged particles that remain in the neutron beam. The second and third ones are divided in vertical and horizontal directions into 13 slabs of 15 mm and two halves of 10 slabs of 20 mm in width, respectively. NBM provides a neutron beam profile, as shown in figure 4. The monitored envelope is consistent with the image of the neutron collimator.

The NBM can be used also for neutron beam intensity monitor. The neutron yields relative to the deuteron beam intensity are listed in table 1 as a function of the deuteron energy, with an assumption that the detection efficiency of the monitor for the neutrons is 1 %. One sees that the neutron flux increases with the deuteron energy. Typical beam intensities were obtained to be roughly $(1 \sim 6) \times 10^8$ neutrons per 10^{11} deuterons of $2 \sim 6$ GeV. Further studies of the detector response for neutrons are in progress in order to estimate the flux more precisely.

The energy distribution of the neutron beam is estimated by including the effects of (i) Fermi motion of a neutron in the deuteron, (ii) fluctuation of the deuteron energy loss in the beryllium target and (iii) energy spread of the deuteron beam (0.3 %). Employing the Monte Carlo simulation, the width of $\sigma \sim 3.5\%$ on the neutron energy distribution is obtained for the 6-GeV deuteron beam. The effects (i) and (ii) are of major importance on the energy spread. The energy distribution can be measured by analyzing the momentum distribution of recoiling protons by the Dγ spectrometer located behind the experimental target (liq. H_2), analysis of which is also in progress.

The authors thank Professor H. Sugawara, Professor S. Iwata, Professor K. Nakai and the crew of the KEK-PS experimental group for their support for this project. They are grateful to Professor M. Kihara and the members of the KEK-PS accelerator group for their great efforts on the successful acceleration of the deuteron beam. They thank Professor K. Kondo and the crew of the KEK radiation safety control center for their works in connection with the modification of the P1 beam line.

E_d (GeV)	n/d
2.0	1.0×10^{-3}
4.0	2.0×10^{-3}
4.7	2.6×10^{-3}
5.4	3.2×10^{-3}
6.0	6.0×10^{-3}

Table 1: Neutron yields relative to the deuteron beam intensity as a function of the deuteron energy. The values are preliminary as the detection efficiency of the NBM is not yet calibrated.

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