BEAM LOSS TRACK MEASUREMENTS BY A FAST TRIGGER SCHEME IN J-PARC LINAC*

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Abstract

In J-PARC Linac, highest beam loss has been observed at the ACS (Annular-Coupled Structure linac) section. The primary source of the beam loss is considered to be H^0 produced by an interaction of H^- beams with remnant gas. The H^0 hits the beam duct, converted to H^+, and escapes from the beam duct.

To detect the H^+'s and estimate the absolute magnitude of the beam loss, we constructed a detector system, which consists of 6 planes of hodoscopes made of 16 scintillation fibers with 64 x 64 mm^2 area. The scintillation light is measured by multi-anode photomultipliers. In the ACS section, two planes to measure horizontal positions are installed, and at about 1 m downstream positions, two planes for horizontal measurements and two for vertical measurements are placed. We will reconstruct charged particles passing through all the 6 planes, and measure the velocity by time-of-flight and energy loss to identify particle species.

We present new measurements since the recovery of the J-PARC after the earthquake started in April 2012 by a new fast trigger scheme using dynode signals of photomultipliers in order to improve signal-to-noise ratios.

INTRODUCTION

The H^0 ion produced by a beam H^- interacted with a remnant gas atom is considered to be the main source of the beam loss in the J-PARC ACS section. The primary goal of this work is to measure H^+'s converted from the H^0's through the beam duct. For this measurement, we constructed 6 planes of scintillating fiber detectors. Each plane consists of 16 4 x 4 x 64 mm^3 plastic scintillating fibers. There are 2 upstream horizontal-measuring planes (H0, H1), 2 downstream horizontal-measuring planes (H2, H3) 1130 mm apart from H0/H1, and 2 downstream vertical-measuring planes (V0, V1) 58 mm apart from H2/H3. 32 fibers in each pair of planes are connected to a multi-anode photo-multipliers (PMT's) Hamamatsu H8500C. This pairing is to reduce inefficiency when a charged particle passes through a boundary between adjacent fibers in a plane and also to suppress accidental background.

Charged particle tracks are reconstructed by combining hits at the fiber planes. Energy of each track is measured with the time-of-flight, and energy loss in each plane is measured by the amplitude of the signal. The energy and the amplitude are used to identify protons and reject other particle species such as electrons, X ray, gamma ray, and neutrons.

The second goal of this work is to measure beam loss source positions along the beam duct and identify hot spots, by projecting each track to the beam axis.

Since 2010, we have measured beam loss with these detectors in ACS section, where we already observed charged particle tracks by beam loss. Detailed description of the scintillating fiber counters and data acquisition system, see [1,2].

FAST TRIGGER SCHEME

In 2012 measurements, the trigger scheme was improved significantly. Until 2011, we used a scheduled timing of the beginning of the macro pulse as the start signal for TDC (Time-to-Digital Converter) CAEN V785 and the gate signal for QDC (charge (Q)-to-Digital Converter) CAEN V792. There were two serious problems with this scheme. First, since the TDC cannot record multiple hits, in case there is another hit before the interesting signal, a wrong timing was recorded, and therefore signal-to-background (S/N) ratio was significantly deteriorated. To solve this problem, we utilized final-stage dynode signals (DY) which are available for PMT H8500C. The polarity of DY signals is opposite to the negative anode signals. Since the PMT has multiple anodes, the DY signal serves as analog sum signal over all the anode channels. We discriminate the DY signals of the three PMT's (DY1 for H0/H1, DY2 for H2/H3, and DY3 for V0/V1), and form coincidence signal from discriminated signals of DY1 and DY3 for the start timing of TDC's and the timing gate of QDC's. The DY1 and DY3 coincidence signal (DY1&DY3) is used as a trigger of a charged particle track penetrating from H0 to V1. Timing and charge of individual anode signal can be measured with low accidental background by narrowing the duration from the start timing to the anode signals for TDC's, and the gate width for QDC's. We also formed a time gate (TG) from the scheduled beam start timing to define the timing within the macro pulse. The coincidence DY1&DY3&TG is used for the data taking. The timing offset and time interval per TDC channel for each fiber was calibrated by injecting a pulse generator signal split to all the detector signal cables end and measuring the timing with the data acquisition system.

RESULTS

The analysis shown here is based on the data taken from Apr. to Jun. 2012. The fiber geometry for H0, H1, H2, and H3 is shown in Fig. 1. By moving H2 and H3, we cover three different track angles, 3.6°-5.0°, 6.0°-7.0°, and 9.0°-11.0°.

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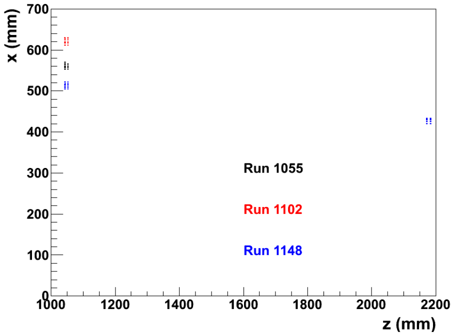

Figure 1: Fiber geometry is shown as a function of the z-position (mm) along the beam axis and the horizontal x-position (mm). The upstream fiber positions at z around 2170 mm are common, while there are three different downstream fiber positions at z around 1050 mm.

With TDC hits, we reconstruct a 3-dimensional track with the horizontal fiber position x^{hit}_i, the timing t^{hit}_i, and the z-position z_i at Plane H*i* (*i*=0, 1, 2, 3). The positive direction of z is upstream. We require TDC hits in all the 4 Planes H0-H3, and search for straight line tracks and fit with the following formulae in the *z*-*x* and the *z*-*t* planes simultaneously;

$$x^{track} = X_0 + X_1 z^{track}$$

$$t^{track} = T_0 + T_1 z^{track} \quad ,$$

where X_0, X_1, T_0, T_1 are fit parameters. Fig. 2 shows residuals of the horizontal position x^{hit}_p- x^{track}_p and the time t^{hit}_p- t^{track}_p, where t^{track}_p is t^{track} at $z=z_p$ (Plane H*p*, *p*=1,2). A sharp signal peak (colored small spot in the center) for charged tracks with very low background is seen. The width of the time residual of the Gaussian fit is 0.40 nsec in r.m.s.

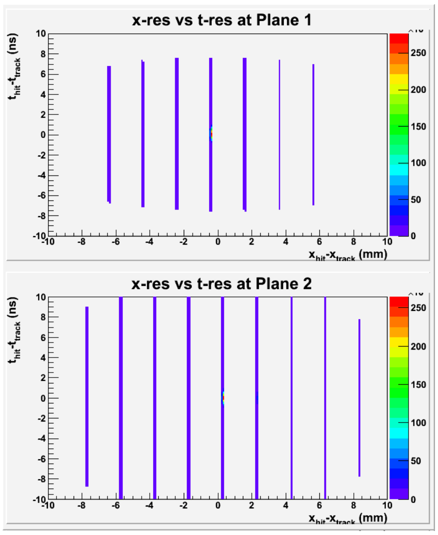

Figure 2: Residuals of hit timing (nsec) in the horizontal axis and horizontal hit positions (mm) in the vertical axis is plotted for H1 (top) and H2 (bottom) with respect to the projected timing from the track.

Fig. 3 shows TDC distributions at each fiber at Plane H2. The peaks at each fiber show protons. Before the calibration, the timing variations of ~100 TDC channel corresponding to ~3.2 nsec were observed. We calibrated the timing at each fiber by injecting pulse generator signals at the PMT signal outputs in the linac tunnel, and measured the timings with the DAQ system. We also changed used several known delay settings for generator signals. We corrected at each fiber both for timing offset and time per TDC channel. The resulting proton timing was adjusted within 1 TDC channel, namely 32 psec.

Fig. 4 shows two-dimensional distributions of time-of-flight and the track angle at different geometries. The signal peak is the highest at the lowest angle configuration. The energies at the peaks are 72.49 MeV at 3.6°-5.0°, 114.7 MeV at 6.0°-7.0°, and 79.05 MeV at 9.0°-11.0°, which are within the simulated H^+ energy ranges of 40-110 MeV. The observed energies have decreasing tendency at a higher angle, which may be due to higher energy loss with larger effective thickness of the beam duct.

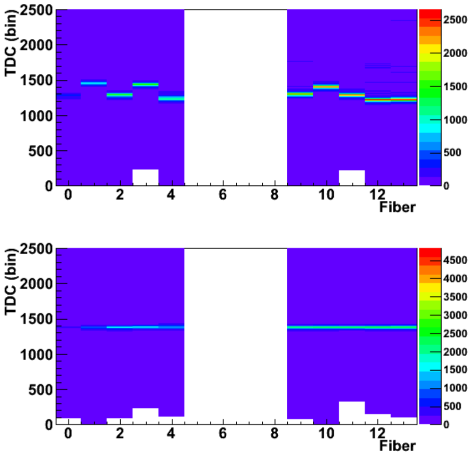

Figure 3: TDC distributions before (top) and after (bottom) the timing calibrations at Plane H2.

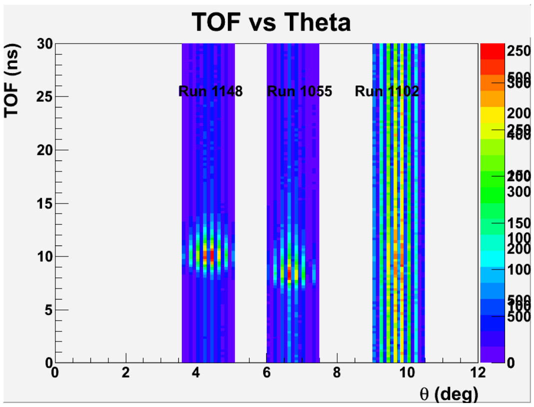

Figure 4: Time-of-flight (nsec) between H0 and H2 as a function of the track angle (degrees) at the three geometry configurations. Note that the z-scales of each geometry configurations are different.

Fig. 5 shows the projected z-position of each track to x=0, namely to the beam axis. The raw data (solid line) shows decreasing numbers of tracks toward upstream (larger z) positions.We estimated H^+ numbers from time-of-flight distributions at each geometry as shown with dashed lines in Fig. 5. After the correction, the H^+ peak heights are similar at 6.0^o-7.0^o and 3.6^o-5.0^o, and corresponding z-ranges of 5400-6300 mm and 6900-9000 mm, while lower by the factor of 6 at 9.0^o-11.0^o and 4400-5000 mm.

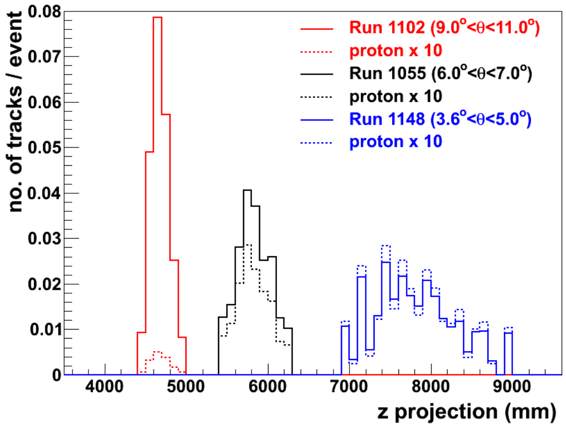

Figure 5: Projected z-positions of x-z tracks at three geometry configurations. Solid lines show raw numbers of tracks including accidental tracks, whereas the dashed lines are after the time-of-flight cuts and corrected to obtain proton numbers.

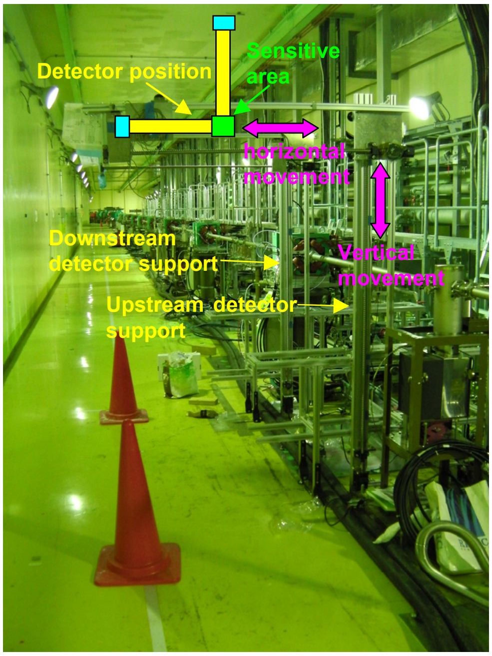

Figure 6: Remotely controlled detector moving system. The base plate for the detector moves in horizontal and vertical directions.

CONCLUSIONS

A clear time-of-flight signal consistent with H^+ has been observed with the fast trigger scheme with PMT dynode signals. Assuming H^+, the energy is 72.5-114.7 MeV, which is cosistent with simulation. In the measured angle ranges, the H^+ rate is highest at the lowest angle ranges of 3.6^o-5.0^o. The beam loss distributions along the beam axis are demonstrated.

In the summer shutdown period in 2012, we have been upgrading the detectors for the next beam operation starting from Oct. 2012. We are currently constructing two fiber planes for vertical position measurements at the upstream position, which enables both horizontal and vertical track reconstruction. Also, the new detector is expected to have better position resolutions by weighted mean positions of fibers in two planes with their amplitudes, since we adopt scintillating fibers with a 4 mm diameter circular cross section, instead of existing fibers with a 4 mm x 4 mm square cross section. We are installing a remotely-controlled detector moving supports in x- and y-positions as shown in Fig. 6. With these upgrades, we expect to increase acceptance of beam loss tracks significantly. We are also preparing detailed detector simulation in order to estimate detector acceptance for absolute beam loss rate estimation.

ACKNOWLEDGEMENT

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