DEVELOPMENT OF THE BEAM LOSS MONITOR FOR BEAM HALO MEASUREMENT IN THE J-PARC RCS

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Abstract

In the J-PARC RCS, transverse beam profiles including both the beam core and halo at extraction beam transport line (3NBT) were measured by using a combination with a wire scanner type beam scraper and some beam loss monitors (BLMs). Our final goal of this halo monitor is to measure the intra-bunch beam halo of extracted two bunches from the RCS. Thus the plastic scintillator and photomultiplier (PMT) assemblages were adopted as the BLMs with quick time response. However, we found that the BLMs detected not only the radiation from the wire but also reflected one from other devices and wall. Therefore we tried to develop new-type BLMs, which are scintillation-type BLM of lead glass and Cherenkov-type BLM of quartz or UV acrylic. In this presentation, we will report on the overview and experimental results of the new-type BLMs together with the outline of halo monitor system.

INTRODUCTION

The 3-GeV Rapid Cycling Synchrotron (RCS) of the Japan Proton Accelerator Research Complex (J-PARC) is a MW class of high intensity proton accelerator [1]. In addition, the RCS has two functions as a proton driver for neutron/muon production at the Material and Life science experimental Facility (MLF) and as a booster of the 50-GeV Main Ring synchrotron (MR) injection. To provide such a high power proton beam for the MR with small injection beam loss or for the MLF with broad range and uniformity irradiation to the target using the octupole magnet [2], it is required to improve the extraction beam quality, namely to achieve the Low-Halo and High-Intensity beam by finer beam tuning in the RCS [3]. Therefore the measurement of the transverse beam profile including both of the beam core and the beam halo is one of the key issues for the high power beam operation in the RCS. Thus a new beam halo monitor was developed and installed at the 3GeV-RCS to Neutron source Beam Transport (3NBT) line as shown in Fig. 1 and Fig. 2 [4]. This new beam halo monitor was constructed by combining a wire scanner type beam scraper and some beam loss monitors (BLMs). The transverse beam profile including the beam core and beam halo can be reconstructed with the halo monitor. On the other hand, our final goal of the halo monitor is to measure not only the transverse beam halo but also the intra-bunch beam halo of the extracted two bunches from the RCS. However the beam experiments made clear that there are some issues for the intra-bunch beam halo measurement.

In this paper, we report the transverse beam halo measurement with the new beam halo monitor. In addition, we introduce the new BLMs which were developed for intra-bunch beam halo measurement.

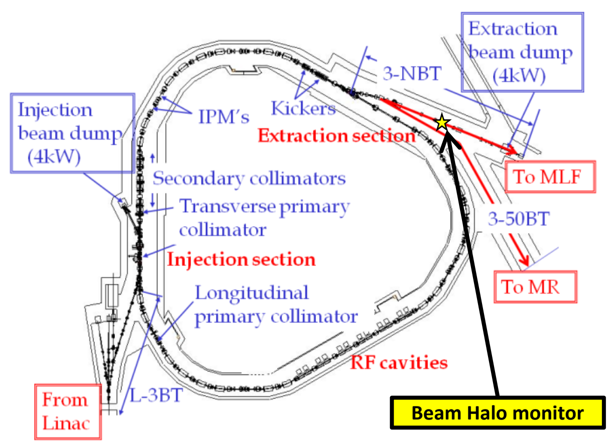

Figure 1: Top view of the RCS and location of the beam halo monitor installation.

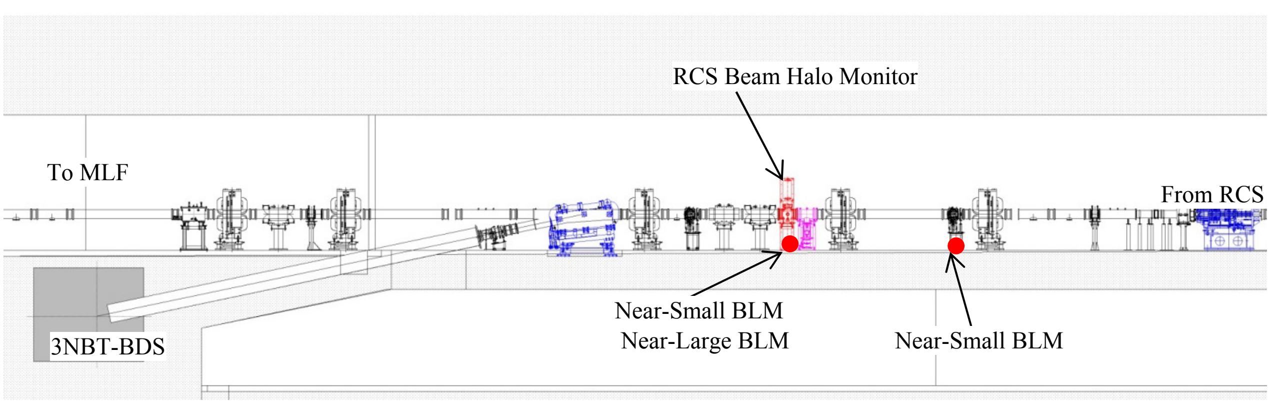

Figure 2: Side view of the 3NBT line and location of the beam halo monitor installation.

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TRANSVERSE BEAM HALO MEASUREMENT

Measurement Principle

The new beam halo monitor was constructed by combining a wire scanner type beam scraper and some BLMs as shown in Fig. 3. Popular wire beam profile monitor detects the secondary electron emitted from the wire due to irradiate the beam. In this case, the wire signal should be disturbed by the floating electrons in the vacuum chamber. Moreover it is difficult to achieve a wide dynamic range for the beam halo measurement by using only the electric circuits. In contrast, our monitor detects the radiation in order to suppress the signal disturbance due to floating electrons. And more the ultra-wide dynamic range can be achieved by using the several BLMs with the different sensitivities.

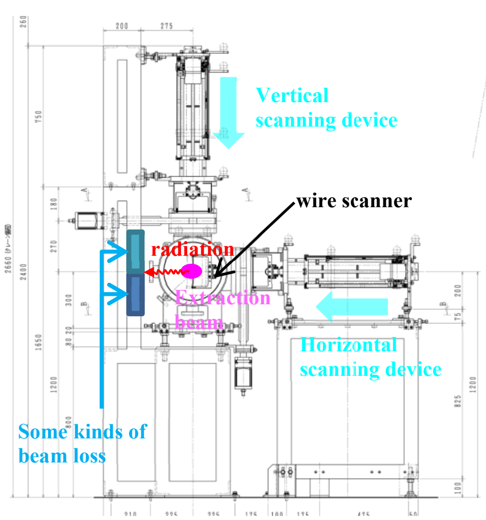

Figure 3: Schematic diagram of the new beam halo monitor.

Scintillator type BLMs (S-BLMs) are adopted for the halo monitor because they have good time responsiveness. We chose a common photomultiplier tube (PMT). And we controlled the sensitivities of the S-BLM by changing the volume size of the plastic scintillator or the distance from the wire scanner to the S-BLM. For the first trial test, two kinds of S-BLM were assembled. One is the small plastic scintillator type as shown in Fig. 4, and the other is the large plastic scintillator type in Fig. 5. The small type S-BLM has a light guide for a support of the thin plastic scintillator. Two large type S-BLMs were assembled. One wsa installed close to the wire scanner together with the small type S-BLM as shown in Fig. 2. The other was installed upstream of about 5m away from the wire scanner. The aim of the near large type S-BLM is a high sensitivity detector to measure beam halo elements. And the aim of both the near small type and the far large type S-BLMs are a low sensitivity detectors to measure beam core elements.

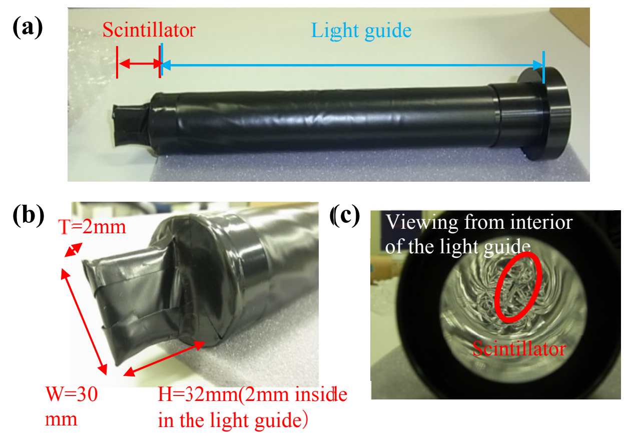

Figure 4: Photographs of the Small Scintillator type BLM. It has a light guide for a support of the thin plastic scintillator.

Figure 5: Photograph of the Large Scintillator type BLMs.

Reconstruction of the Transverse Beam Profile

In this system, BLMs can detect the only radiations caused by hitting the beam into the wire scanner. Thus BLMs signal should be proportional to the number of the hitting particles. Calibration formula ($N_{particle}$ / S_{BLM}) for each BLM can be obtained by using the matched beam intensity with the each sensitivity [4].

After completing each calibration curve acquiring, we demonstrated the transverse beam profile reconstruction with the new halo monitor. In this first trial beam test, the output beam power was 340kW equivalent. All PMTs were excited by a common power supply and the high voltage was fixed on -1kV. Fig. 6 shows the experimental result. Fig. 6 (a) shows the scanning raw data with three beam loss monitors and (b) shows the reconstructed profiles. Only by using each sensitivity calibration formula, we can reconstruct the transvers beam profile including both the beam core and beam halo can be reconstructed. Namely any other correction is not necessary to join together all measured plots. In this scheme, it is possible to expand the dynamic range by using the higher sensitivity beam loss monitors.

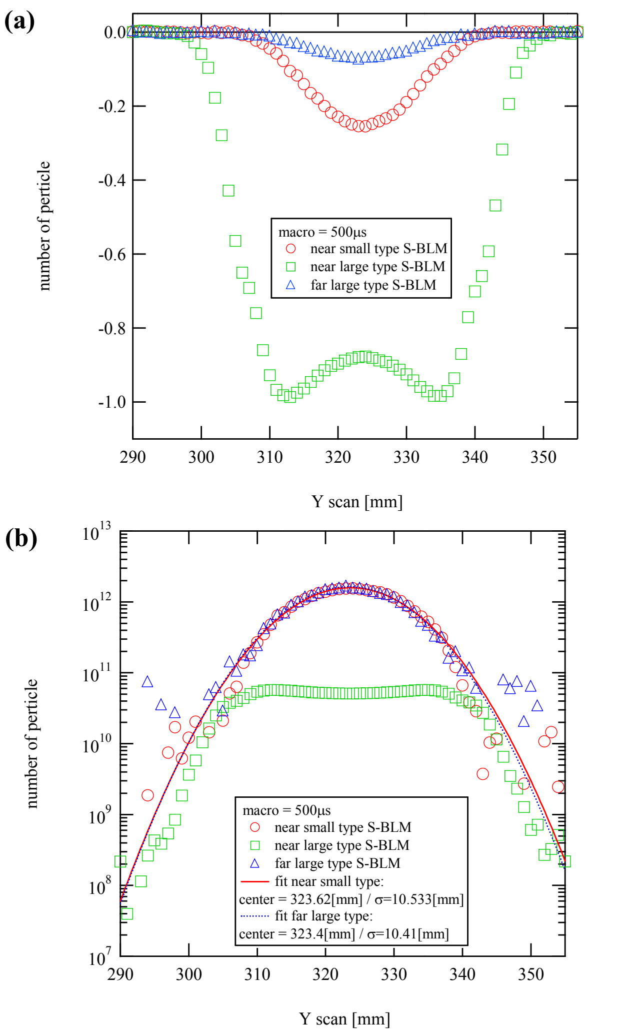

Figure 6: Demonstration of the transverse beam profile reconstruction with the output beam power of 320kW equivalent. (a) : Each S-BLM signal plots. (b) : Conversion data plots by using each sensitivity calibration curve formula.

NEW BLM DEVELOPMENT FOR THE INTRA-BUNCH BEAM HALO MEASUREMENT

Distortion of the Bunch Signal from the Plastic Scintillator BLM

We verified that the RCS Beam Halo Monitor has the ultra-wide dynamic range and can reconstruct the transverse beam profile including both the beam core and halo. But our final goal of this halo monitor is to measure the intra-bunch beam halo of extracted two bunches from the RCS. Then we reconstructed the two-dimensional profiles (bunch length vs beam size) from the two BLMs with low-sensitivity; Near-Small plastic scintillator and Far-Large plastic scintillator. Fig. 7 shows the comparison between two plastic scintillators. Uppers show the two-dimensional profile from the Near-Small type, and lowers show the one from the Small-Large type. These transverse distributions were consistent, but the time distributions were markedly different.

In order to investigate these differences in the time distribution, the raw signals from the two BLMs where the wire scanner inserted at the beam centre were compered as shown in Fig. 8. After the subtraction the background signal from the whole signal, pure beam loss signal at the wire scanner can be obtained. The tail component of the bunch signal from the Far-Large type increases more than one from the Near-Small type. The plastic scintillator BLMs detected not only the radiation from the wire but also reflected one from other devices and wall. This indelible tail component was caused the reflected radiation. Thus the bunch signal from the plastic scintillators was distorted as far from the wire scanner.

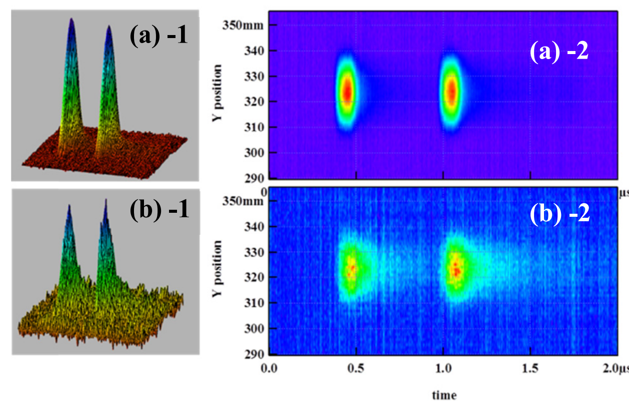

Figure 7: Reconstructed 2D-profile. (a): Near-Small type, (b): Far-Large type.

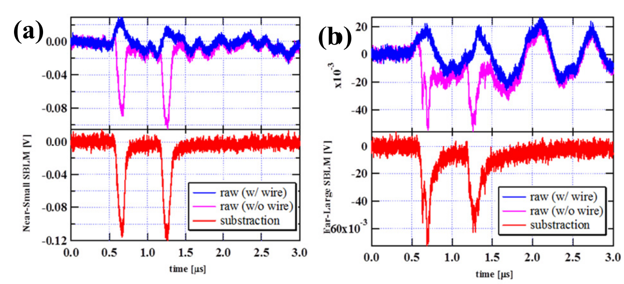

Figure 8: Typical result of the noise reduction of the S-BLM signal. (a): Near-Small type, (b): Far-Large type.

Upper plots show the comparison of the raw S-BLM signals between inserted and retracted the wire scanner. Lower plot shows pure beam loss signal at the wire scanner after the background noise reduction.

New-type BLM

To obtain the bunched beam structure from the BLM clearly, it is necessary to suppress these reflected radiations. The energy of the radiation decreases after the reflection generally. Therefore new-type BLM is required

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to have a high sensitivity toward the faster radiation particles. Then we develop new-type BLMs, which are scintillation-type BLM of lead glass and Cherenkov-type BLM of quartz or UV acrylic as shown in Fig. 9. The lead glass scintillator has a long bar structure and then it has the higher sensitivity toward the faster gamma-ray which approaches from the top of the long bar. On the other one, quartz and UV acrylic are short disk structure and then it has the higher sensitivity toward the faster electron to generate the Cherenkov light.

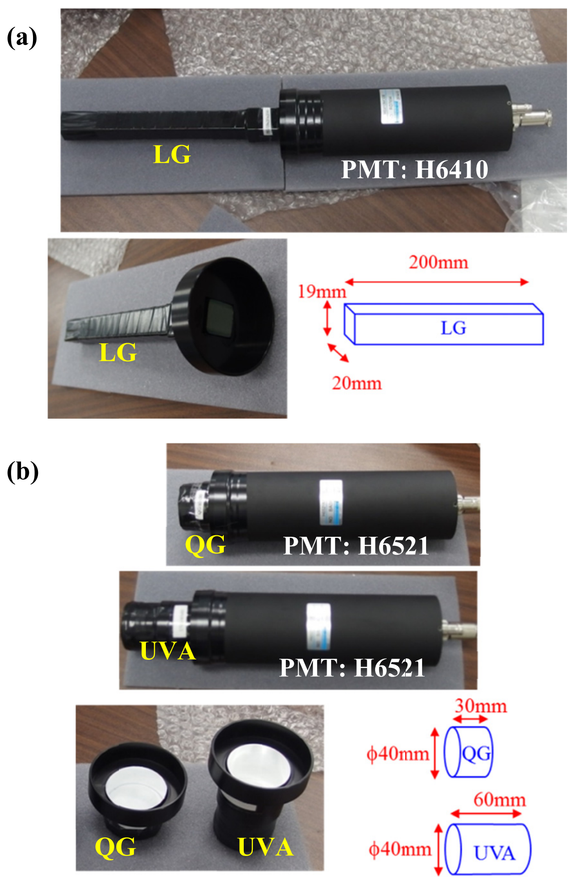

Figure 9: Photograph of the new-type BLMs. (a): scintillation-type BLM of the lead glass. (b): Cherenkov-type BLM of the quartz or UV acrylic.

Trial Beam Test

In order to see if the new-type BLMs work as they were expected to, they were installed near the wire scanner and trial beam tests were carried out. The beam destination for the extracted beam from the 3GeV-RCS switched from the MLF-target (MLF-TGT) to 3NBT-beam dump (3NBT-BD) because the effect of the reflected radiation can enhance dynamically.

At first, the ultra-low intensity beam was used to prevent the saturation of the BLM. The wire was fixed on the beam centre, and the beam destination switched between the MLF-TGT and 3NBT-BD. Fig. 10 shows the raw signals from the every BLM. The single intermediate bunched beam was injected into the RCS. Therefore the only one bunched beam was extracted. The plastic scintillator detected the reflected radiation from the 3NBT-BD as a result the bunch signal was distorted as shown in Fig.10 (a). On the other hand, all new-type BLMs can suppress the reflected radiation drastically. Offcuts these suppressions were not perfect until now and then they have to more progress to achieve the intra-bunch beam halo measurement. But we can probe the availability of the new-type BLMs.

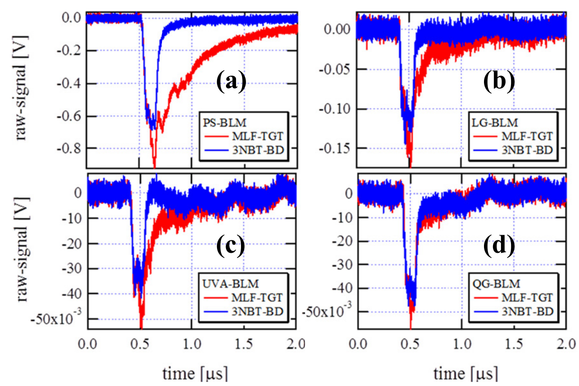

Figure 10: Raw signals of the BLMs compared between the MLF-TGT and the 3NBT-BD operation mode. (a): plastic scintillator, (b): lead glass, (c) UV acrylic, (d) quartz glass.

Next, the high intensity beam was used for the high power beam commissioning. In this time, the beam destination is fixed to the 3NBT-BD and the wire position changed between on centre of the beam and far from the beam. Fig. 11 shows the raw signals compared between two wire positions and the subtracted signal from the every BLM. Plastic scintillator signal was saturated due to the reflected radiation and subtracted signal was distorted. But all bunch signals measured by new-type BLM were almost not distorted. From these results, the transverse beam profile can be measured in the 3NBT-BD operation mode by using these new-type BLMs.

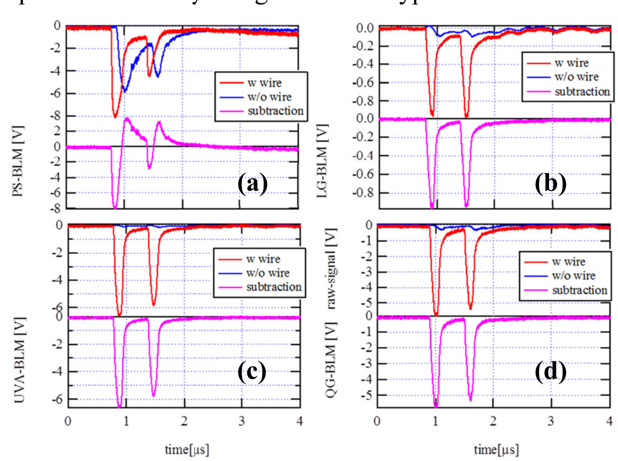

Figure 11: Raw signals of the BLMs compared between the inserted and retracted the wire. (a): plastic scintillator, (b): lead glass, (c) UV acrylic, (d) quartz glass.

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Then the beam profile measurements with various beam intensity were carried out in the 3NBT-BD operation mode. Fig. 12 shows the scanning result from every BLM. In the case of the plastic scintillator, the transverse profile was distorted as shown in the Fig. 12 (a), because the raw signals were saturated due to the reflected radiation from the 3NBT-BD. On the other hand, the new-type BLMs can measure the beam profiles. So we analysed and calculated the calibration formula for each new-BLM roughly, and tried to reconstruct the transverse beam profile as shown in Fig. 13.

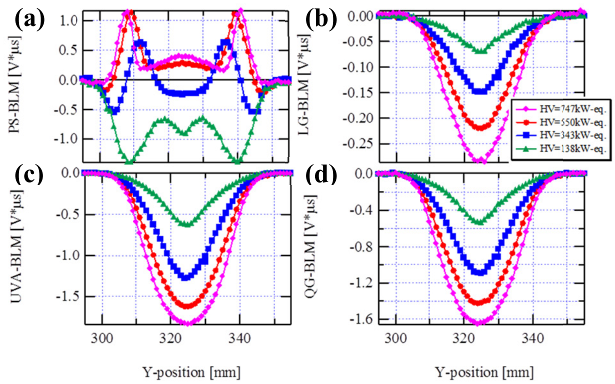

Figure 12: Scanning plot of the BLMs with various beam intensity. (a): plastic scintillator, (b): lead glass, (c) UV acrylic, (d) quartz.

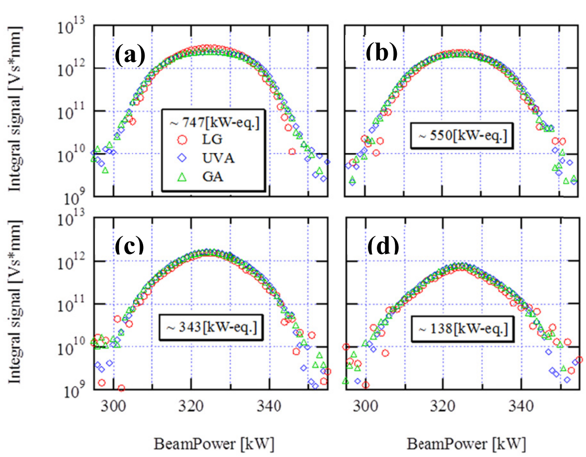

Figure 13: Demonstration of the transverse beam profile reconstruction from the new-type BLM. (a) : 747kW-eq.. (b) : 550kW-eq., (c) 343kW-eq., (d) 138kW-eq.

SUMMARY

In the J-PARC RCS, new beam halo monitor, which is combined a wire scanner and some beam loss monitors, was developed to measure the transverse profile of the extraction beam. This new halo monitor aims to achieve the ultra-wide dynamic range. By using several beam loss monitors of plastic scintillator type with different sensitivities, the transverse beam profile including the beam core and halo elements can be reconstructed.

The transverse beam profile including both the beam core and beam halo can be reconstructed by using the several BLMs with the various sensitivities. Only by using sensitivity calibration formula for the each BLM, transverse profile including both the beam core and beam halo can be reconstructed directly.

In this scheme, it is possible to expand the dynamic range by using the higher sensitivity BLMs. The time structure of the bunch signal measured by the plastic scintillator was distorted, because of the reflected the radiation. The new-type BLMs, which are scintillation-type BLM of lead glass and Cherenkov-type BLM of quartz or UV acrylic, can be reduced the reflected radiation drastically. In order to achieve the intra-bunch beam halo measurement, the new-type BLMs have to progress.

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