Long Beam Pulse Extraction by the Laser Charge Exchange Method Using the 3-MeV Linac in J-PARC

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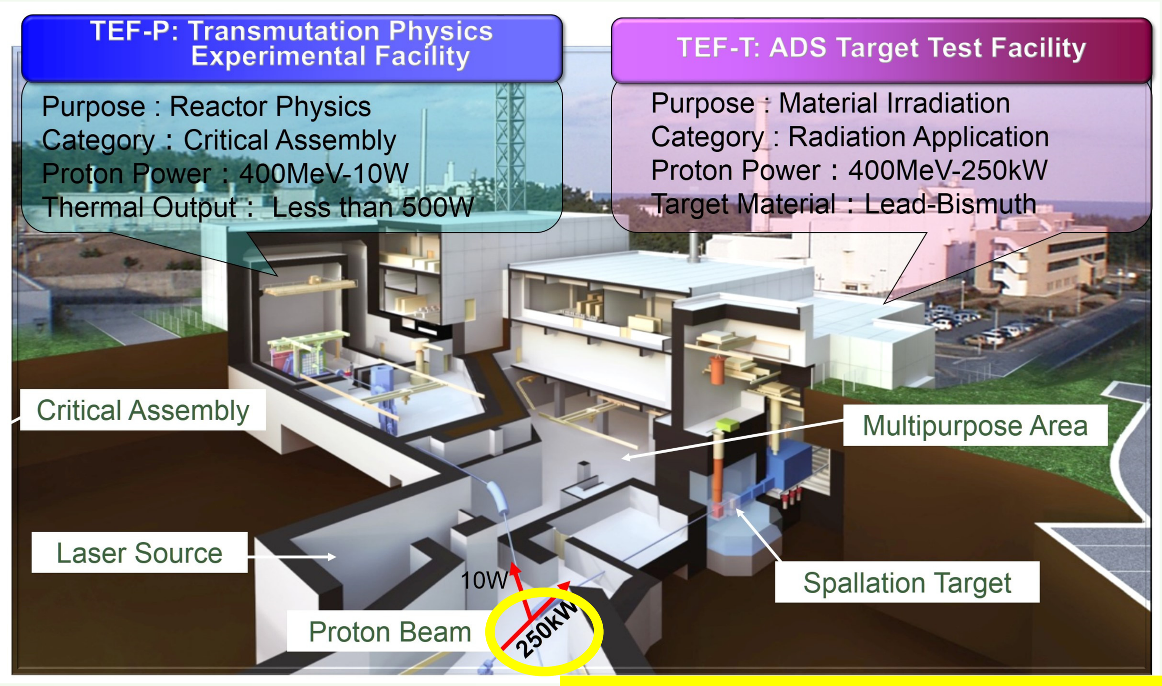
Introduction

- In the framework of J-PARC project, JAEA plans to be built a Transmutation Experimental Facility (TEF), which consists following two buildings;
    - ADS target test facility (TEF-T) for material irradiation tests using 250kW Pb-Bi spallation target, and
    - Transmutation Physics Experimental Facility (TEF-P), which set up a fast critical/subcritical assembly.
- Since the TEF-P requires a stable proton beam with a power of less than 10W, a stable and meticulous beam extraction method is required to extract a small amount of the proton beam from the high power beam using 250kW.
- To fulfil this requirement, the Laser Charge Exchange (LCE) method has been developed. The LCE strips the electron of the H^- beam and neutral protons will separate at the bending magnet in the proton beam transport.
- To demonstrate the charge exchange of the H^-, a LCE experiment was conducted using a linac with energy of 3 MeV in J-PARC.
- In this paper, the results using the **bright continuous laser source** are presented.

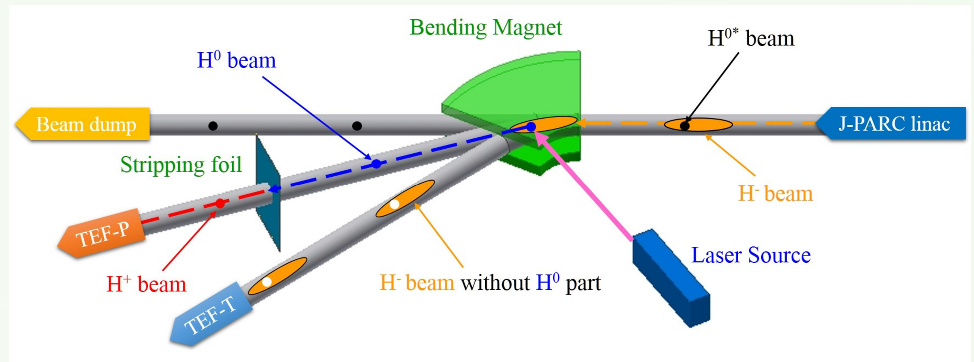
Transmutation Experimental Facility (TEF)



Laser Charge Exchange (LCE) Devices

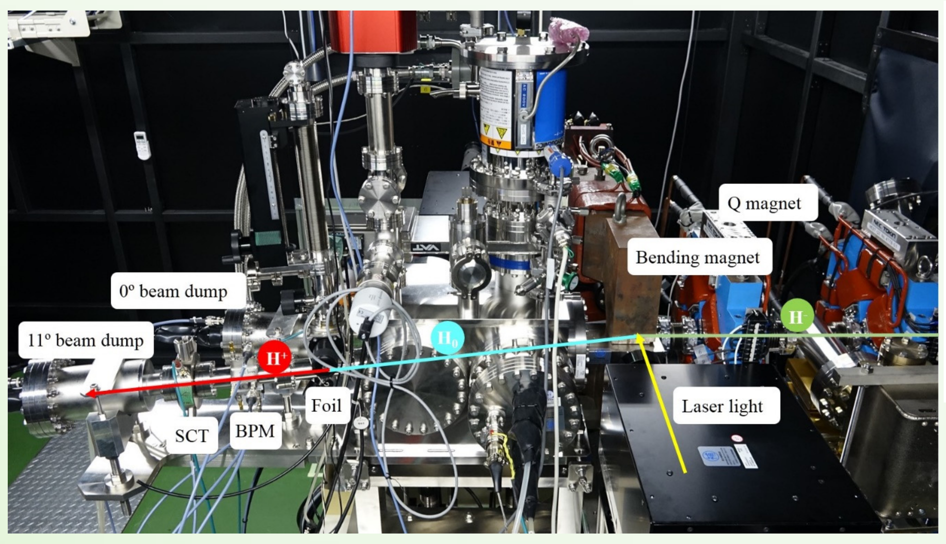
Laser Charge Exchange (LCE) Method to extract a small amount of the proton beam

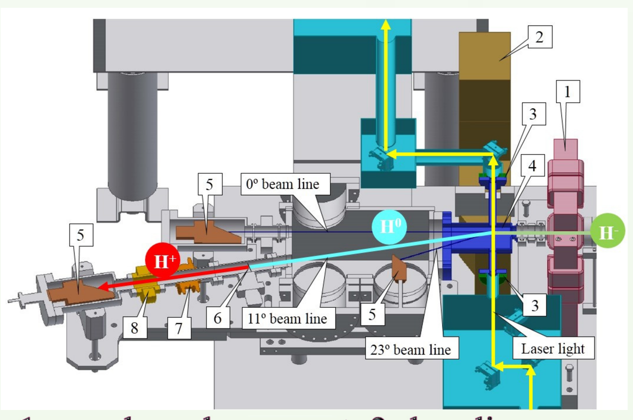
- TEF-P Critical Assembly simulates neutronic performance in very low thermal power.
- To simulate ADS neutronics very low power proton beam should be extracted from J-PARC intense proton accelerator.
- Using Laser Charge Exchange (LCE) Method, low power beam can be easily extracted by no influence of J-PARC accelerator operation.
- Since the outer electron of the H^- is very weakly bound to the atom, it can easily be stripped by a laser light in the wavelength range of 800~1100nm.
- To eliminate the pre-neutralized protons, we were trying to perform laser injection and beam bending simultaneously in one magnet.



The neutralized proton due to interaction by the laser light is written as "H^0", and the pre-neutralized proton due to interaction by the remaining gas in accelerator tubes is written as "H^{0*}".

LCE devices of the 3 MeV, 0.45kW linac





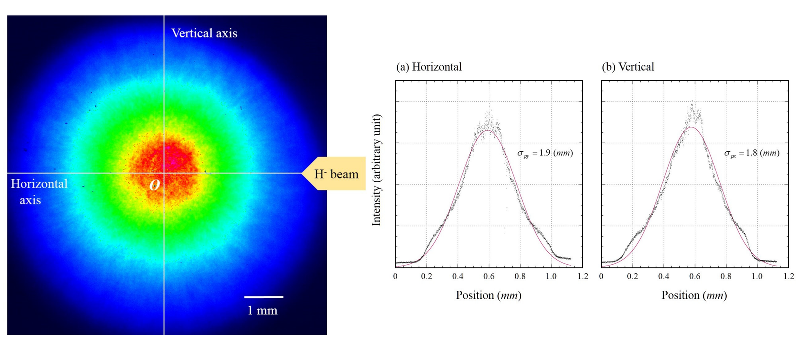
1- quadrupole magnet, 2- bending magnet, 3- quartz viewing port, 4- vacuum chamber, 5- beam dump, 6- stripping foil, 7- BPM, 8- SCT

- Beam width and emittance of the H^- beam were obtained with the beam emittance monitor placed 30 cm downstream of the quadrupole magnet by using Q-scan technique.
- The RMS width in the vertical and horizontal direction (σ_v, σ_h) at the collision point was estimated as about 2.0 and 4.3 mm, respectively.

Laser system

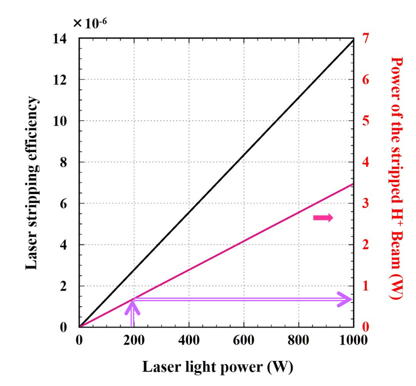
- The commercial diode laser from Lumics GmbH, module number LU1064C230, was selected. The laser light power at the exit of the diode laser module was 230 W, and the wavelength was 1064±3 nm. The time structure of the diode laser light was continuous.
- The measured laser light power was 198 W at the collision point, when the diode laser module was operated with the rated power of 230 W.

Two-dimensional profile of the laser light at the collision point.



The vertical RMS-radius of the laser light at the collision point was estimated to be 1.8 mm by fitting the data points with the normal distribution function.

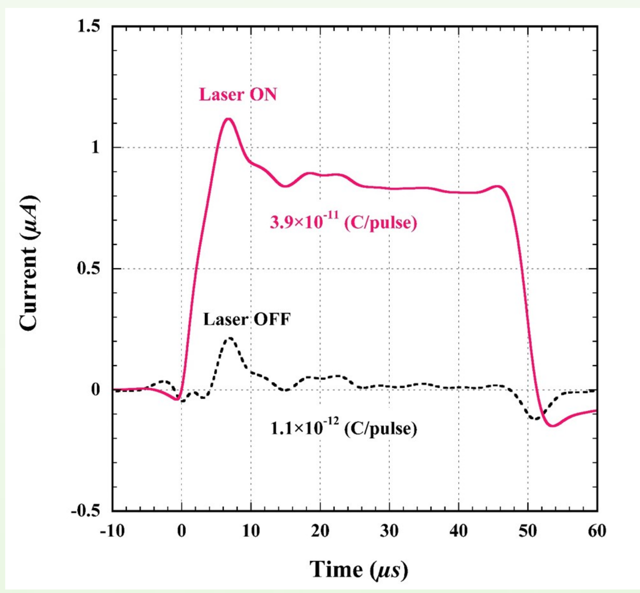
Laser stripping efficiency and the total number of the stripped H^+ beam as a function of the laser light power.



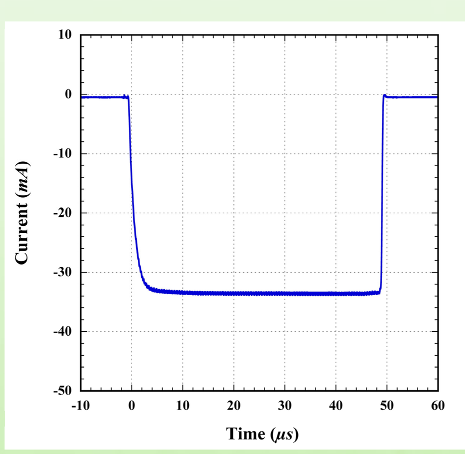
- If the laser light from this laser system collided with the H^- beam (400 MeV, 250 kW) delivered from the J-PARC linac, the stripped H^+ beam with a power of 0.70 W equivalent was extracted.

Preliminary results

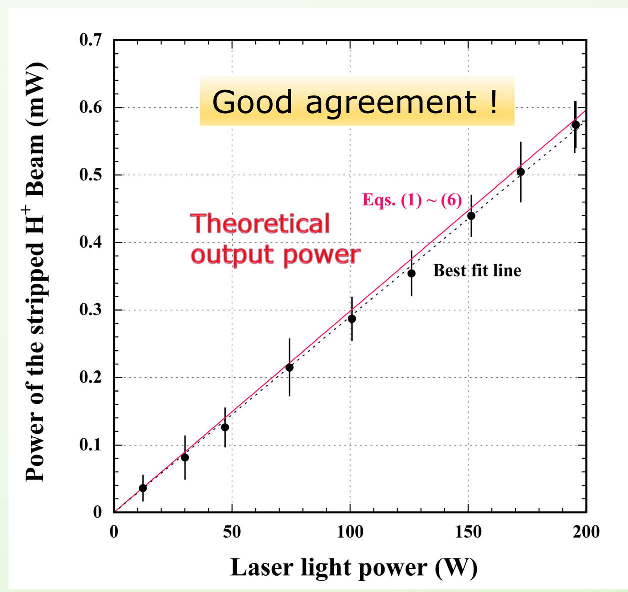
Current waveforms of the stripped H^+ beam with and without the laser light



Current waveform of the H^- beam



Change of the stripped H^+ beam power as a function of the laser light power



Theoretical estimation

Total numbers of the charge-exchanged H^0

$$N_0 = N_n P = N_n\left(1 - e^{-\sigma L}\right)$$

σ : cross-section $H^- \rightarrow H^0$
L : Luminosity

Luminosity L for the collision between the H^- beam and laser light

$$L = K\int_{-\infty}^{\infty} dx \int_{-\infty}^{\infty} dy \int_0^{\tau} dt \frac{N_n}{\beta c\tau}\frac{N_p}{c\tau}\rho_n\rho_p$$

$$L = \frac{1}{\sqrt{2\pi}}\frac{1+\beta\cos\theta}{\sin\theta}\frac{N_n}{\beta c\tau}N_p\frac{1}{\sqrt{\sigma_{nx}^2+\sigma_{px}^2}}$$

$N_n = I\tau/e \qquad N_p = E\tau\lambda/hc$
θ : Crossing angle
τ : Time width for the H^- beam
E : Power of the laser
λ : Wavelength of the laser
σ_{nx}, σ_{px} : Horizontal radius for H^- and laser

CONCLUSION

- To demonstrate the charge exchange of the H^-, a LCE experiment was conducted using a linac with energy of 3 MeV in J-PARC.
- In present experiment, we used the bright continuous laser source. As the result, the stripped H^+ beam with a pulse time width of 50 μs and a power of 0.57 mW was extracted.
- If the laser light from this LCE device collided with the H^- beam (400 MeV, 250 kW) delivered from the J-PARC linac, the stripped H^+ beam with a power of 0.70 W equivalent was extracted. This value almost satisfied the power requirement (less than 1 W) of the proton beam for the TEF-P.