# 110 mA Operation of J-PARC Cesiated RF-Driven $H^-$ Ion Source

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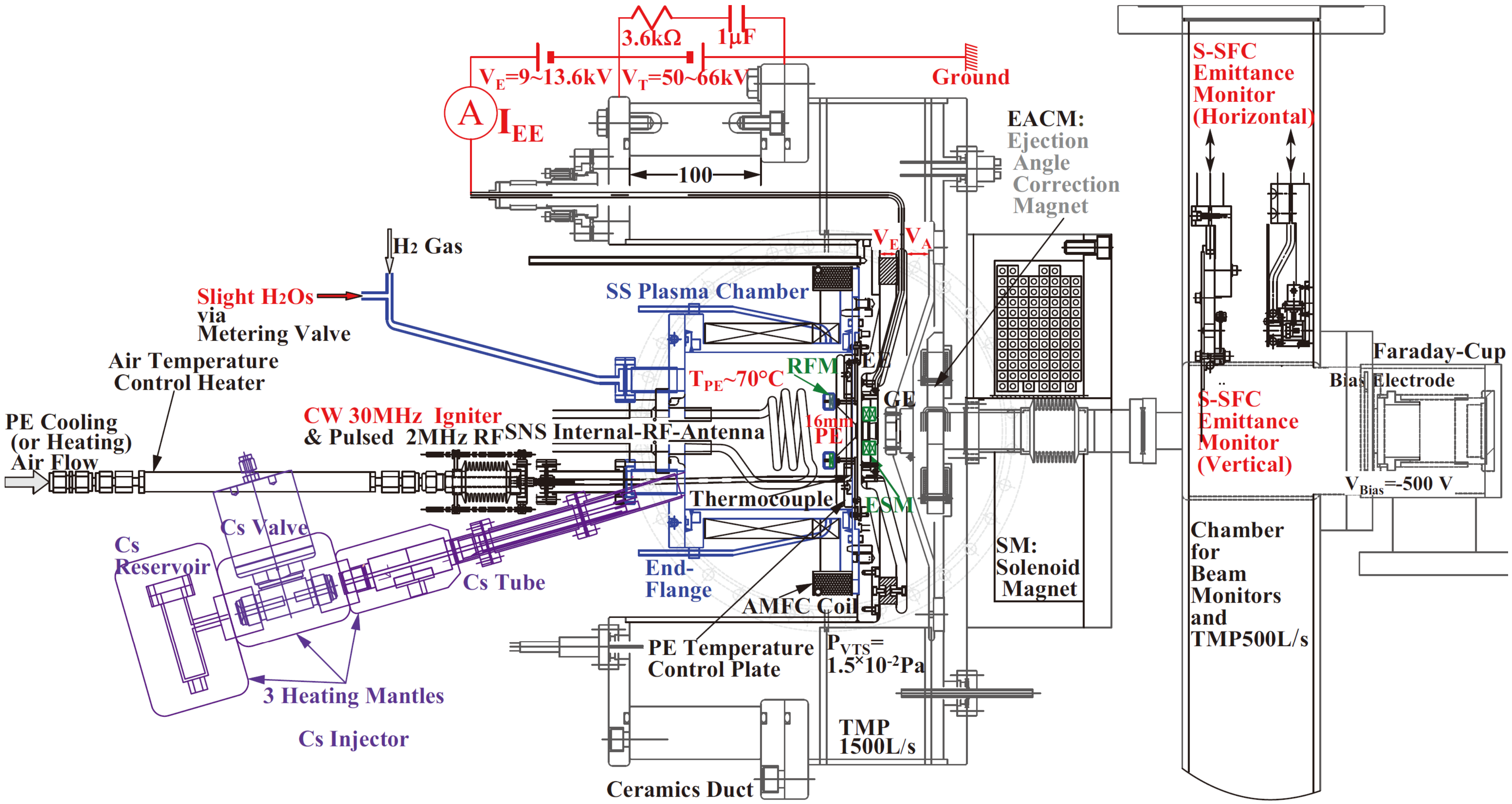
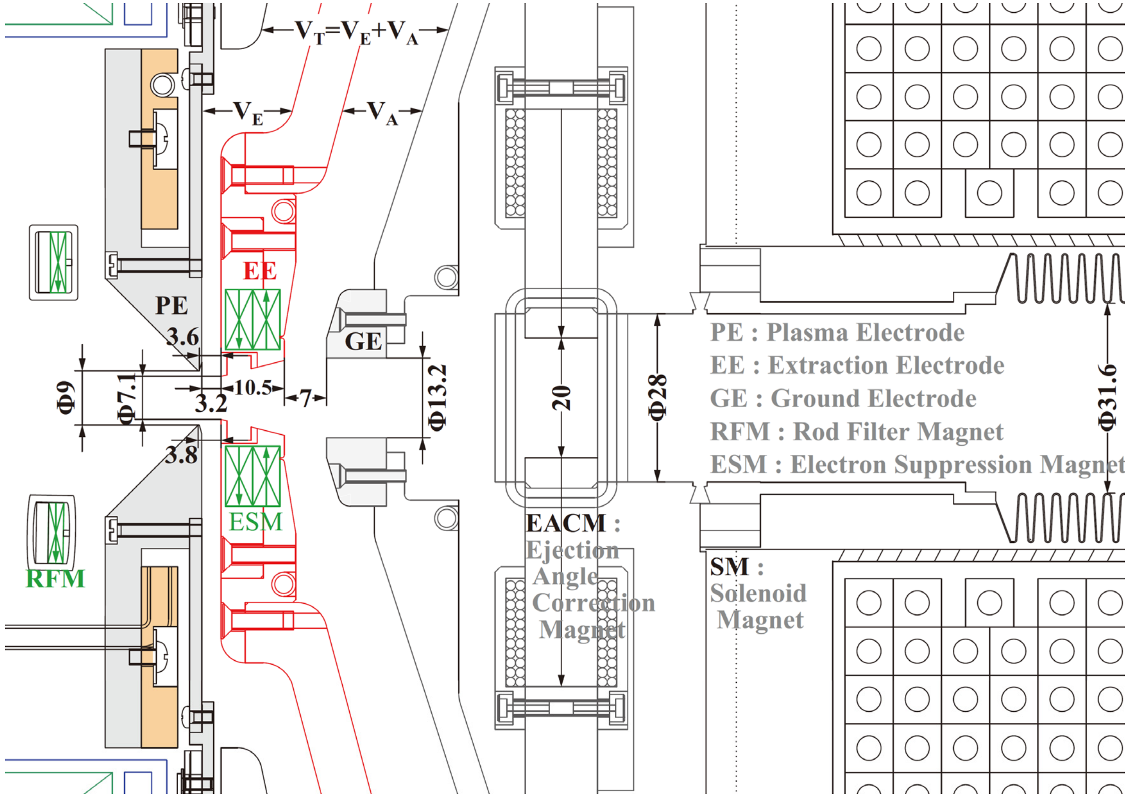
110mA H⁻ IS
2020/9/9
@NIB2020

# J-PARC RF-Driven H⁻ Ion Source Test-Stand




High $I_{H^-}$ & Brightness & RF power efficiency by Thick PE(16mm-45°:$1.5I_{H^-}$) , slight $H_2$Os Feeding($0.5\varepsilon_{nrsmx/y}$),
Low$T_{PE}$~70°C($0.75\varepsilon_{nrmsx/y}$), CW-30MHzRF igniter($1.2I_{H^-}$:17SCCMfor$\phi_{PE}$=9mm) : 94.3% RFQ accl. effi. for 72mA

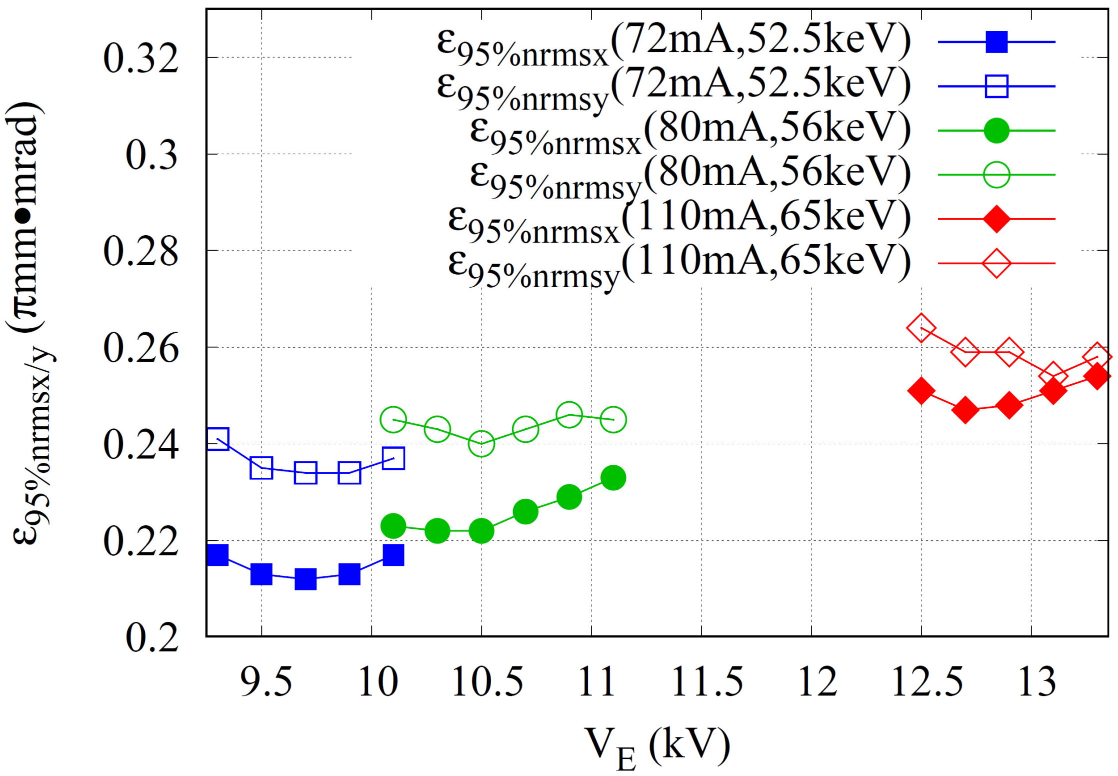
# Detailed dimensions of beam extraction region & 110 mA operation parameters



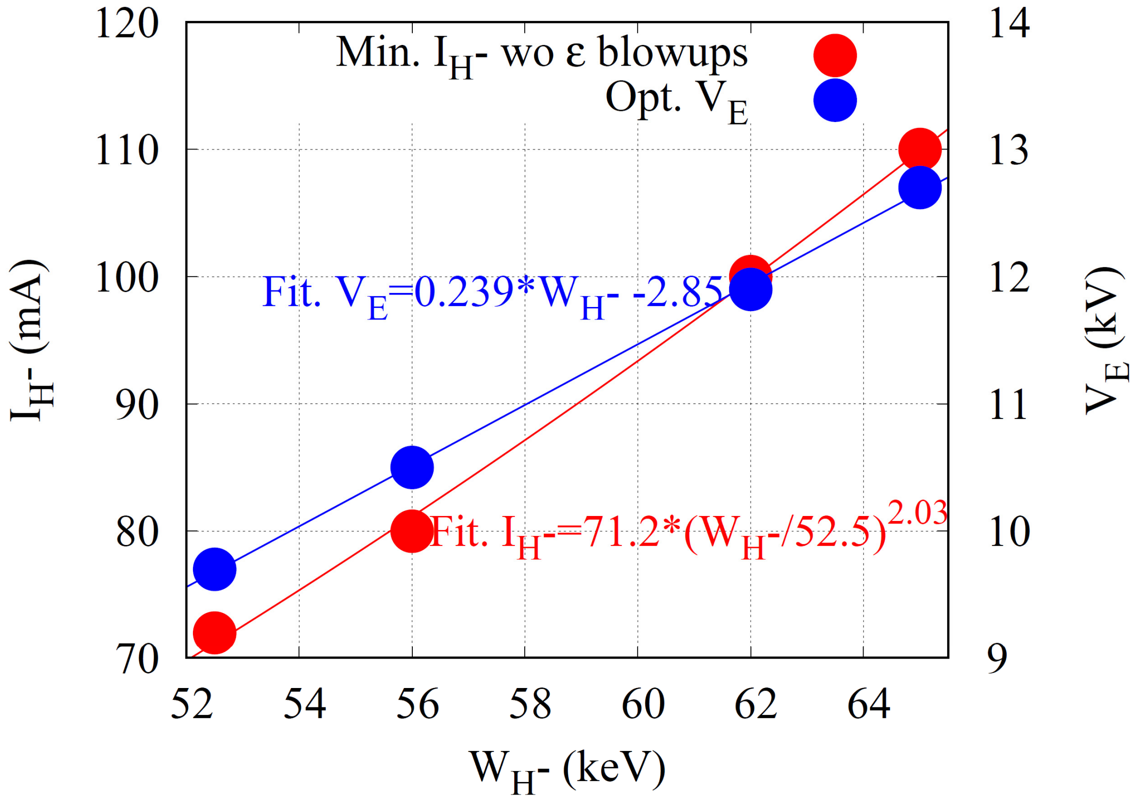

$\phi_{PE}$=9mm, $\phi_{EE}$=7.1mm, $\phi_{GE}$=13.2mm,
$V_T$=52.5~65.5kV, $W_{H^-}$=52.5~65 keV,
$G_E$=3.2mm, $V_E$=9.2~13.6kV,
$G_A$=7mm, $V_A$=42.4~52.4kV

| IS & test-stand paramametes for $I_{H^-}$ = 110 mA operation | Value |
|---|---|
| $H_2$ gas flow rate | 17 SCCM |
| CW 30 MHz RF igniter power | 50 W |
| 2 MHz RF duty factor ~ Beam duty factor *Limitted by radiation safety permission of averaged $I_{H^-}$ = 5 mA | 4.5 % (1 ms × 45 Hz) *110 mA × 4.5 % = 4.95 mA |
| 2 MHz RF power ($P_{2MHz}$) *tilt up | 40 ~ 41.6 kW |
| RF power efficiency ($I_{H^-}$ / $P_{2MHz}$) | 2.64 mA/kW |
| $H^-$ ion density at PE ($\phi_{PE}$=9mm) | 1729 A/m$^2$ |
| Plasma electrode temperature ($T_{PE}$) | ~70 ° C |
| Stationary state Cs injection rate *Mainly attached on low temp. part | 35.8 μg/hour *Not ejected |
| $H^-$ ion beam energy ($W_{H^-}$) = ($V_E$ + $V_A$) | 65 keV =(12.7 + 52.3) kV |
| 1st section vacuum pump & vacuum pressure | 1500 L/s TMP & 1.5 × 10$^{-2}$ Pa |
| 2nd section vacuum pump | 500 L/s TMP |
| Solenoid magnet current | 350 A(49000 AT) |

# $V_E$ vs $\varepsilon_{95\%nrmsx/y}$ & $W_{H^-}$ vs $I_{H^-}$ / $V_E$

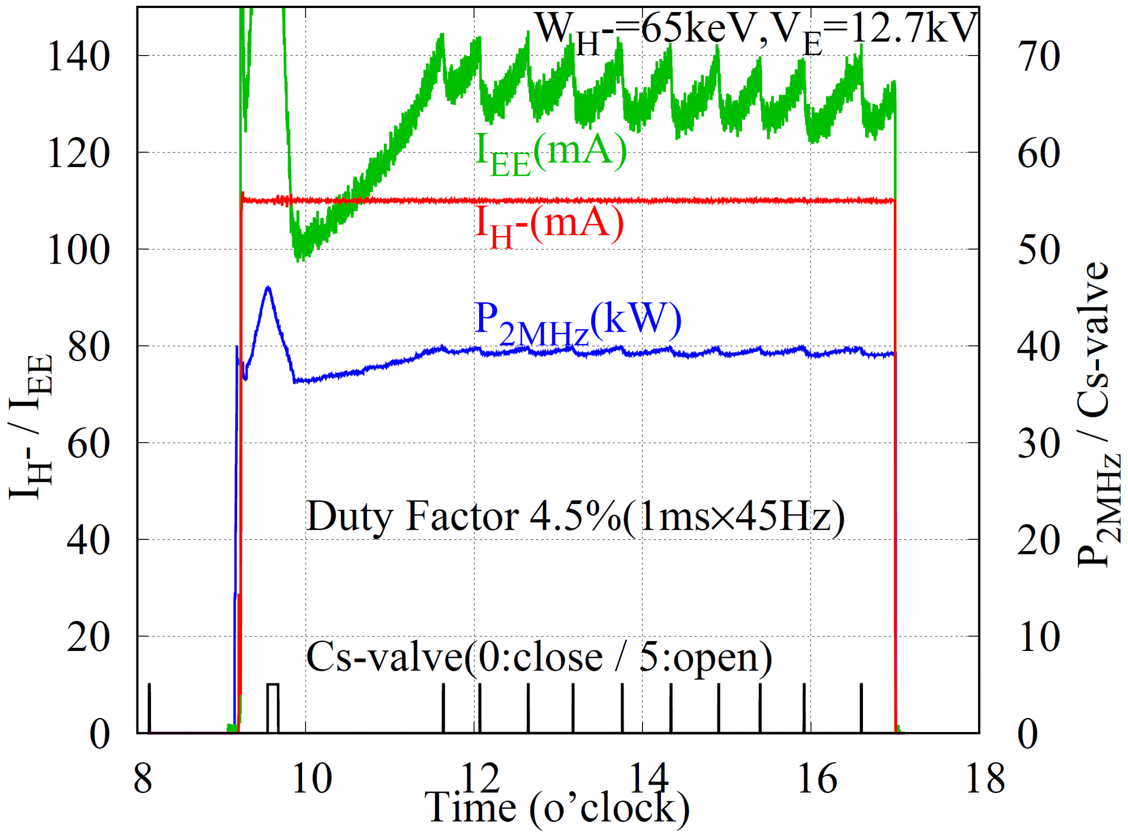



Measured relationships between $V_E$ and $\varepsilon_{95\%nrmsx/y}$ for conditions of ($W_{H^-}$, $I_{H^-}$) = (52.5 keV, 72 mA), (56 keV, 80 mA) and (65 keV, 110 mA), plotted with blue open or closed squares, green open or closed circles and red open or closed diamonds, respectively.

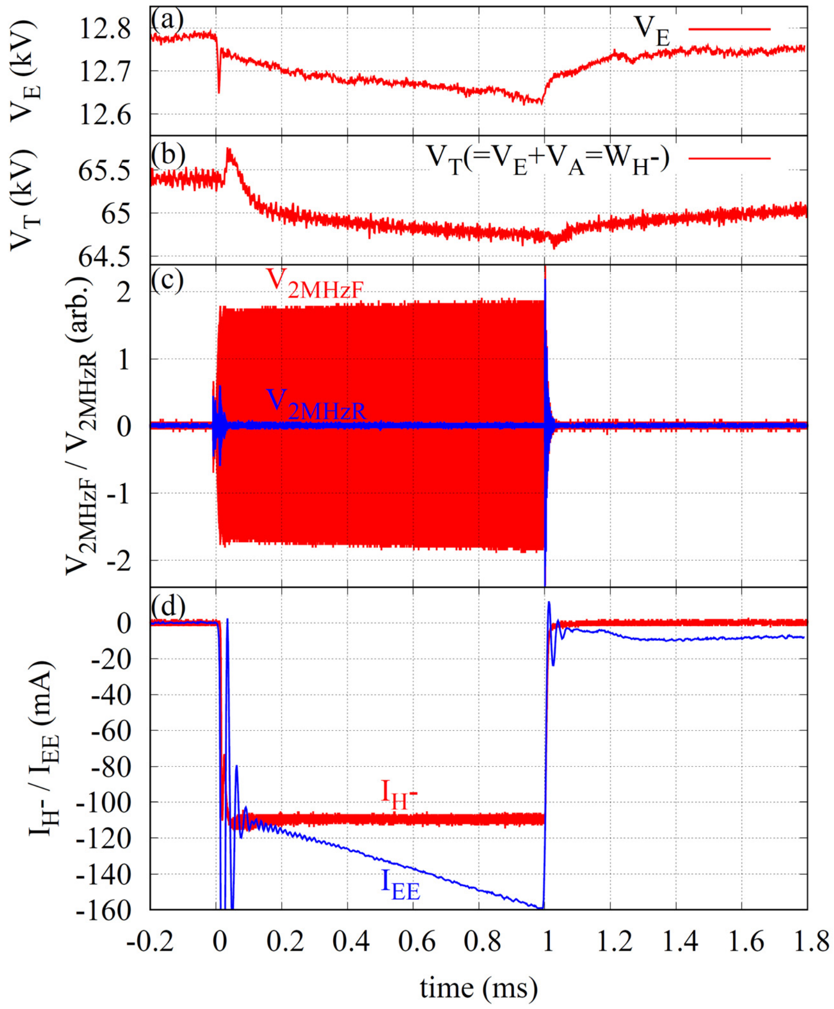



Measured relationships between $W_{H^-}$ & $I_{H^-}$ without any emittance blowups, $W_{H^-}$ & optimum $V_E$ plotted with red closed circles and blue closed circles, respectively. Fitted $I_{H^-}$ & $V_E$ equations are shown with red & blue lines, respectively. Square (not 3/2 power) dependence of $I_{H^-}$ on required $W_{H^-}$ is essential for next IS & RFQ design.

# 8 hours 110 mA operation & waveforms of one beam pulse

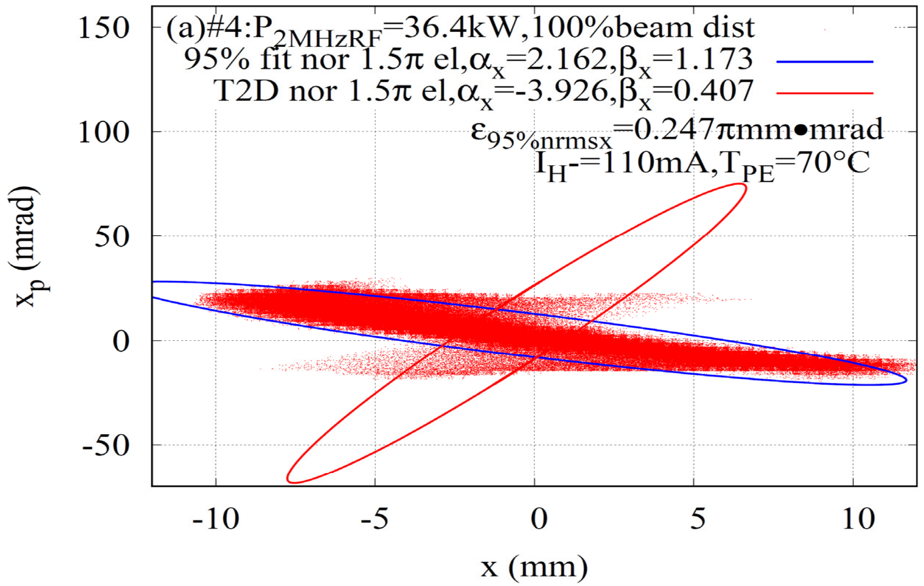


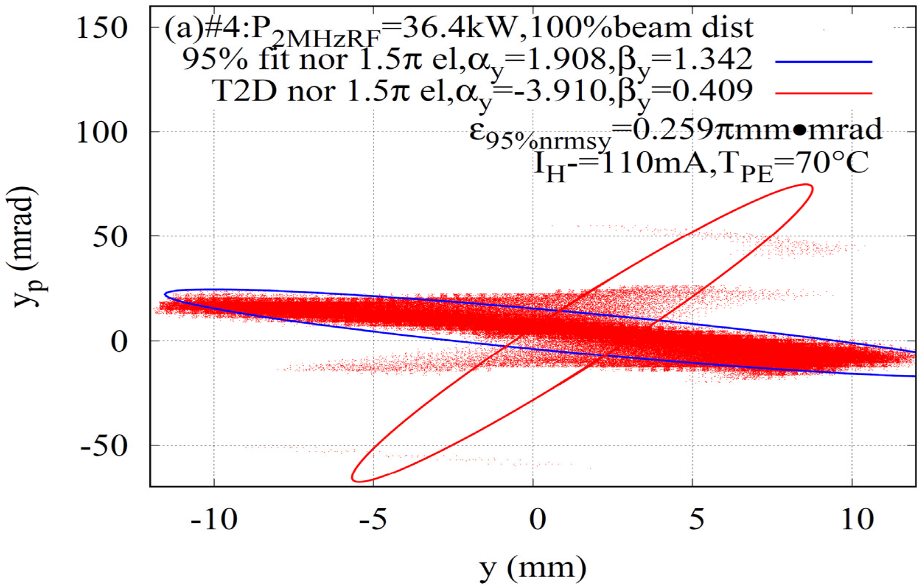

Trend graph of $I_{H^-}$, $I_{EE}$, $P_{2MHz}$ and Cs-valve close/open during 8 hours operation of well-conditioned IS after 88 hours shutdown, in which $I_{H^-}$, was feedbacked to 110 ±1 mA by $P_{2MHz}$, for $W_{H^-}$ and $V_E$ of 65 keV and 12.7 kV, respectively. In station. state, Cs inject. rate = 35.8 μg/hour.




Waveforms of $V_E$(a), $V_T$(b), $V_{2MHzF}$ and $V_{2MHzR}$(c) and $I_{H^-}$ and $I_{EE}$ (d) of one beam pulse. *Flat $I_{H^-}$ by tilting up $P_{2MHz}$ by 4% to comp. $V_E$&$V_T$ droops.

# Particle distributions in horizontal & vertical phase-planes for $(I_{H^-}, W_{H^-}, V_E$, duty factor$)=(110\text{mA}, 65\text{keV}, 12.7\text{kV}, 4.5\%)$

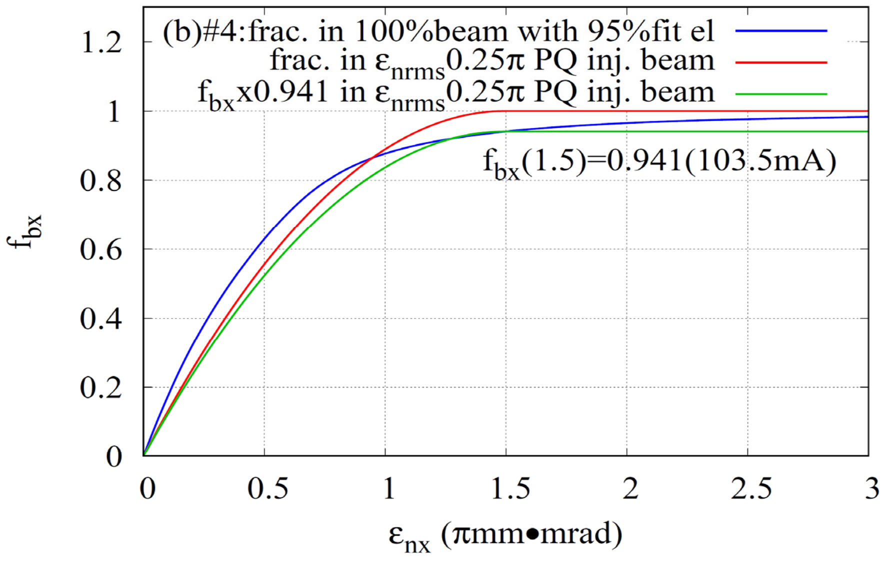


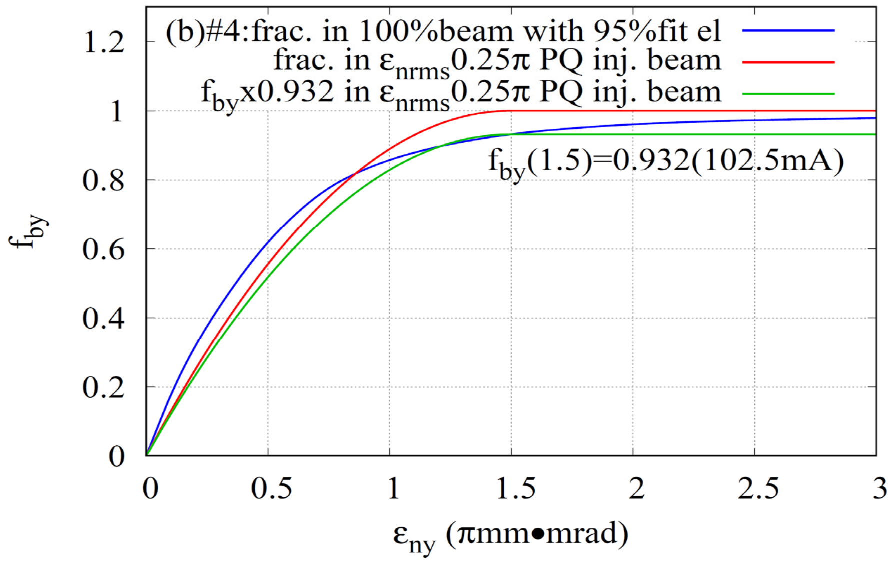




0.4 mega dots plots of H&V 100 % beam

1.5π ellipses fitting H&V 95% beam

1.5π ellipses at GE backward traced with Trace2d




$\varepsilon_{nx/y}$ vs beam fraction $f_{bx/y}$ : measured, PARMTEQ inject. & PARMTEQ inject. $\times f_{bx/y}(1.5)$

$\varepsilon_{nx/y}(1.5) < \varepsilon_{nPQx/y}$

PARMTEQ sim. acc. effi. is expected for 102.5mA beam.

# CONCLUDIONS

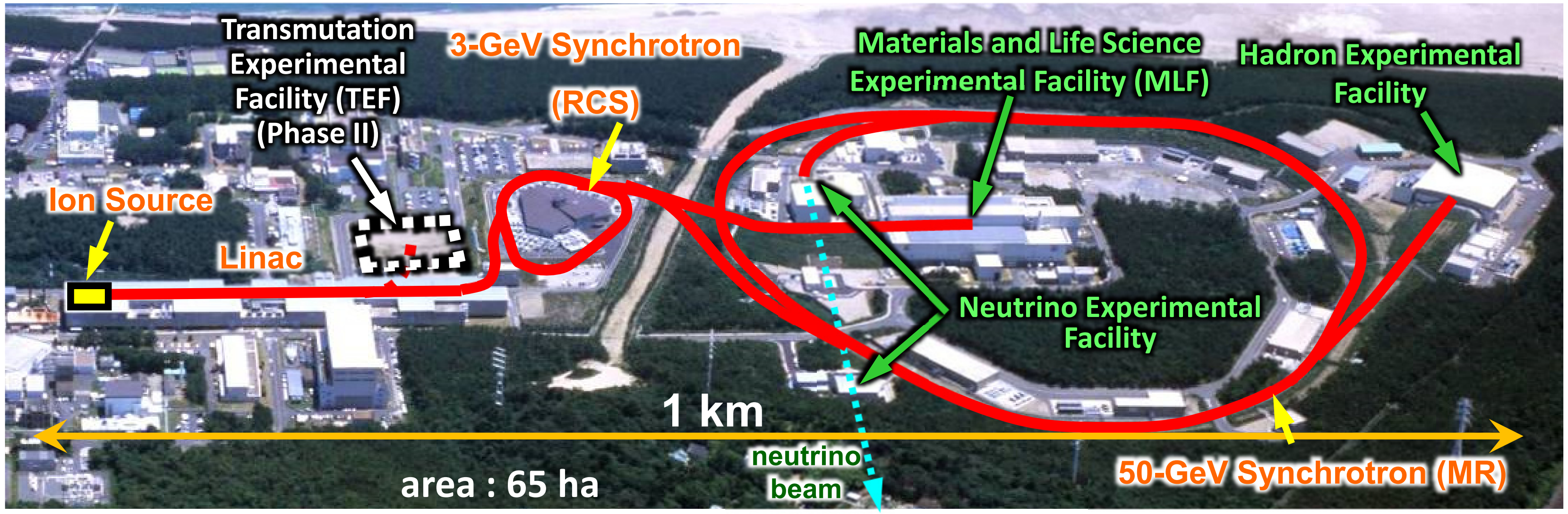
- Square (not 3/2 power) dependence of $I_{H^-}$ on $W_{H^-}$ required to avoide emittance blowup was measured : $I_{H^-}(W_{H^-}) = 71.2 \times (W_{H^-} / 52.5)^{2.03\ (>3/2)}$.
- 8 hours operation with ($I_{H^-}$, $W_{H^-}$, $V_E$, duty factor) = (110mA, 65keV, 12.7kV, 4.5%) was stable without high voltage sparking. In stationary state, $I_{H^-}$ was feedbacked to 110 ±1 mA by $P_{2MHz}$ & Cs injection rate was 35.8 μg/hour.
- Flat $I_{H^-}$ pulse was produced by 4 % titing up $P_{2MHz}$ during pulse.
- $\varepsilon_{95\%nrmsx/y}$ was measured as 0.247/0.259π mm•mrad for ($I_{H^-}$, $W_{H^-}$, $V_E$, duty factor) = (110mA, 65keV, 12.7kV, 4.5%). 102.5mA of beam is inside of PARMTEQ injection beam emittances with smaller $\varepsilon_{nrmsx/y}$.
- 132mA(=110mA×50kW/41.6kW $\because I_{H^-} \propto P_{2MHz}$) is possible with appropriately designed high voltage power supply & 2 MHz matching circuit for $V_T$=72 kV {$\because 71.2 \times (71.2\text{keV}/52.5\text{keV})^{2.03} = 132\text{mA}$}.

ACKNOWLEDGMENT
The authors wish to express their sincere thanks to Dr. Martin P. Stockli and SNS ion source group members for their support to purchase internal-RF-antennas and their information on the SNS RF-driven $H^-$ ion source.

"Thank you for your attention"

# Overview of the J-PARC
## (Japan Proton Accelerator Research Complex)

- J-PARC comprises a high-intensity proton accelerator and the experimental facilities that utilize the proton beam.
- The J-PARC accelerator consists of a linear accelerator (Linac), a Rapid Cycling Synchrotron (RCS) and a Main synchrotron Ring (MR).



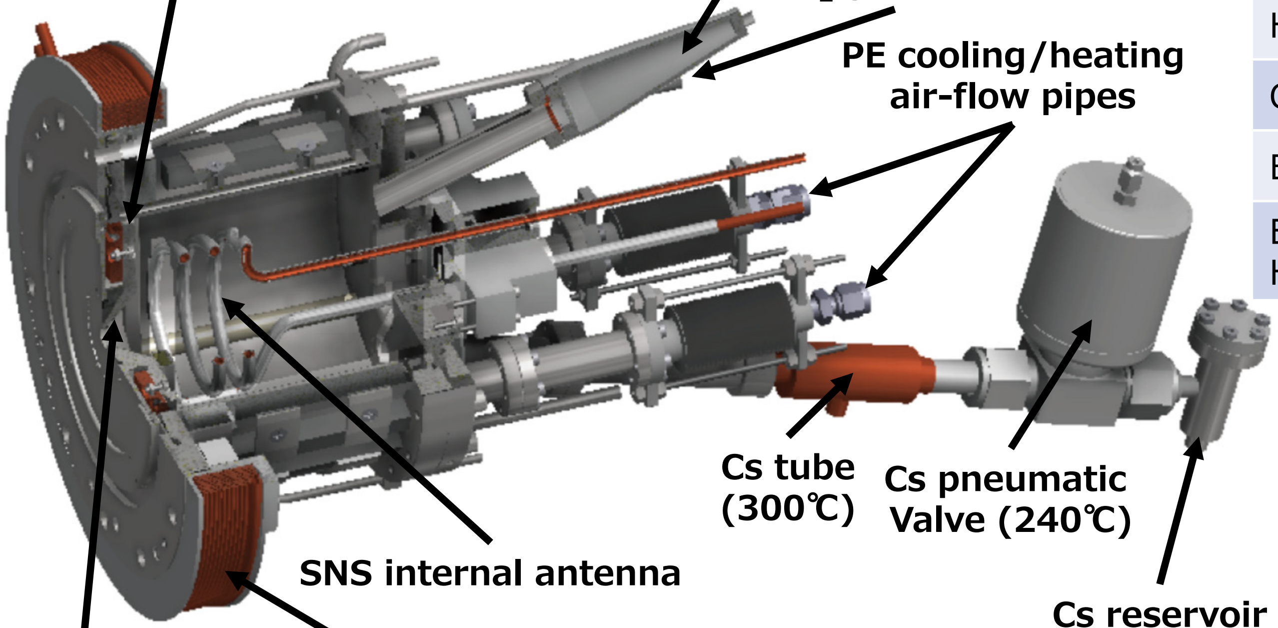

- The proton beams accelerated at the RCS are delivered to the Materials and Life Science Experimental Facility (MLF) and injected into the MR.
- After the proton beams accelerated at the MR, they are delivered to the Neutron Production Facility (NU) or to the Hadron beam Facility (HD).

### Linac
- $H^-$ **beam** acceleration
- Beam energy : **400 MeV**
- Beam current:
  **50 mA** for user operation
  **60 mA** for beam study
  (peak current at Linac exit)
- Pulse length : < 0.5 ms
- Repetition: 25 Hz

### Rapid Cycling Synchrotron(RCS)
- Charge-exchange injection $H^- \rightarrow H^+$
- Beam energy :**3 GeV**
- Injection into MR
- Delivery to MLF
- Beam supply to MLF with the beam power of **600 kW** (in 2020)

### Main Ring (MR)
- Beam energy :**30 GeV**
- Beam power
  - **500 kW** (in 2020) to NU
  - **50 kW** (in 2020) to HD

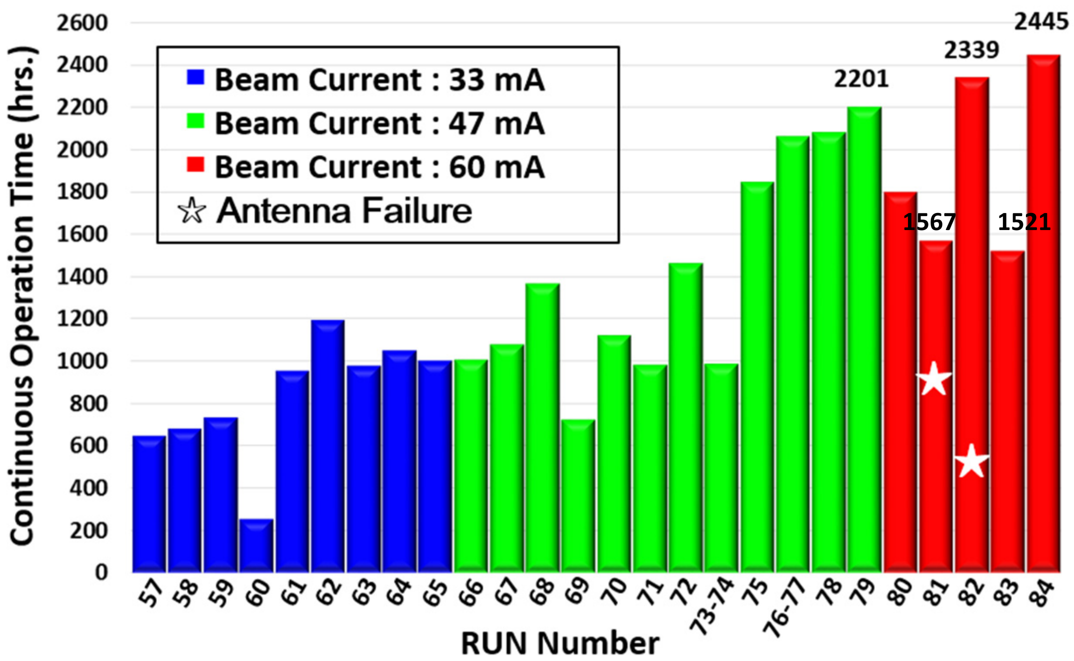
# J-PARC Cesiated RF $H^-$ ion source

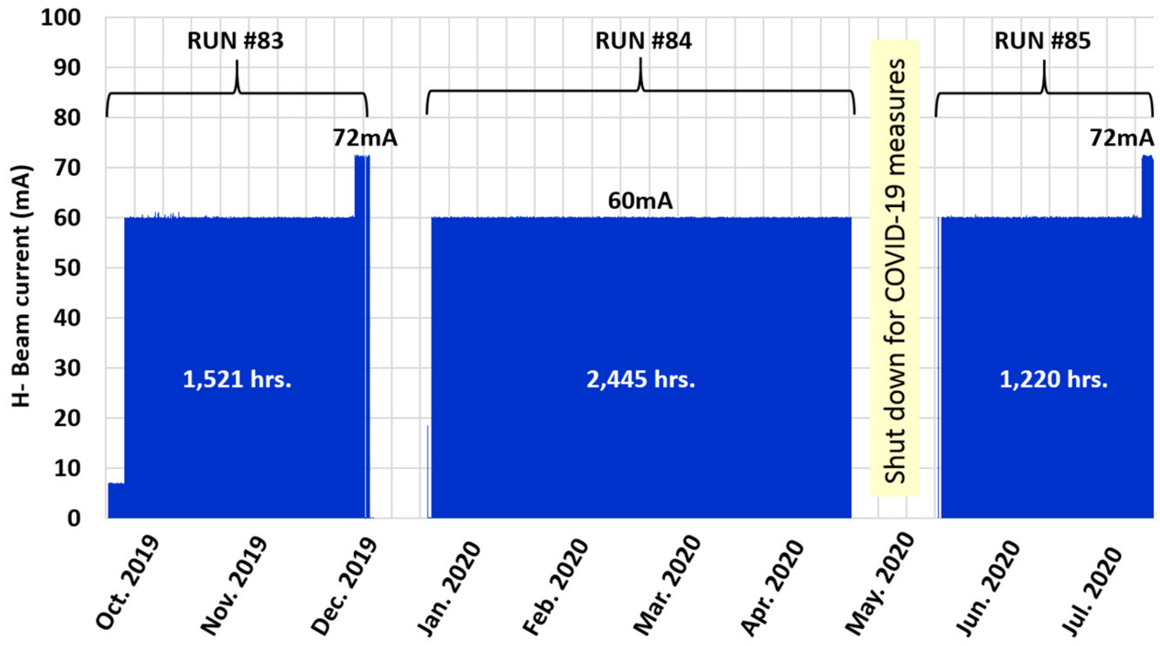



| Specifications | |
|---|---|
| Discharge type | Internal antenna RF discharge |
| Repetition rate | 25 Hz |
| RF frequency | 30 MHz (cw, ~ 50 W)<br>2 MHz (0.8 ms pulsed, ~ 35 kW) |
| $H_2$ gas flow rate | 21 sccm |
| Cs consumption | 0.28 g in 1,567 hrs (in 2019) |
| Beam energy | 50 keV |
| Extracted<br>$H^-$ beam current | 60 mA (for user operation)<br>72 mA (for accelerator beam study) |

- The inner volume of the plasma chamber is 100 mm in diameter and 120 mm in length.
- $H_2$ plasmas are confined by 18-pole cusp magnetic field.
- The aperture of the PE is 9 mm in diameter.

# Progress of J-PARC RF $H^-$ ion source




**<u>Continuous operation time prolonged :</u>**

~1.5 months →2.5 months (Run#75)

→3 months (2017 Autumn~) **→ 3.5 months (2020 Jan.- Apr.)**