120 mA Operation of J-PARC Cesiated RF-Driven H^- Ion Source

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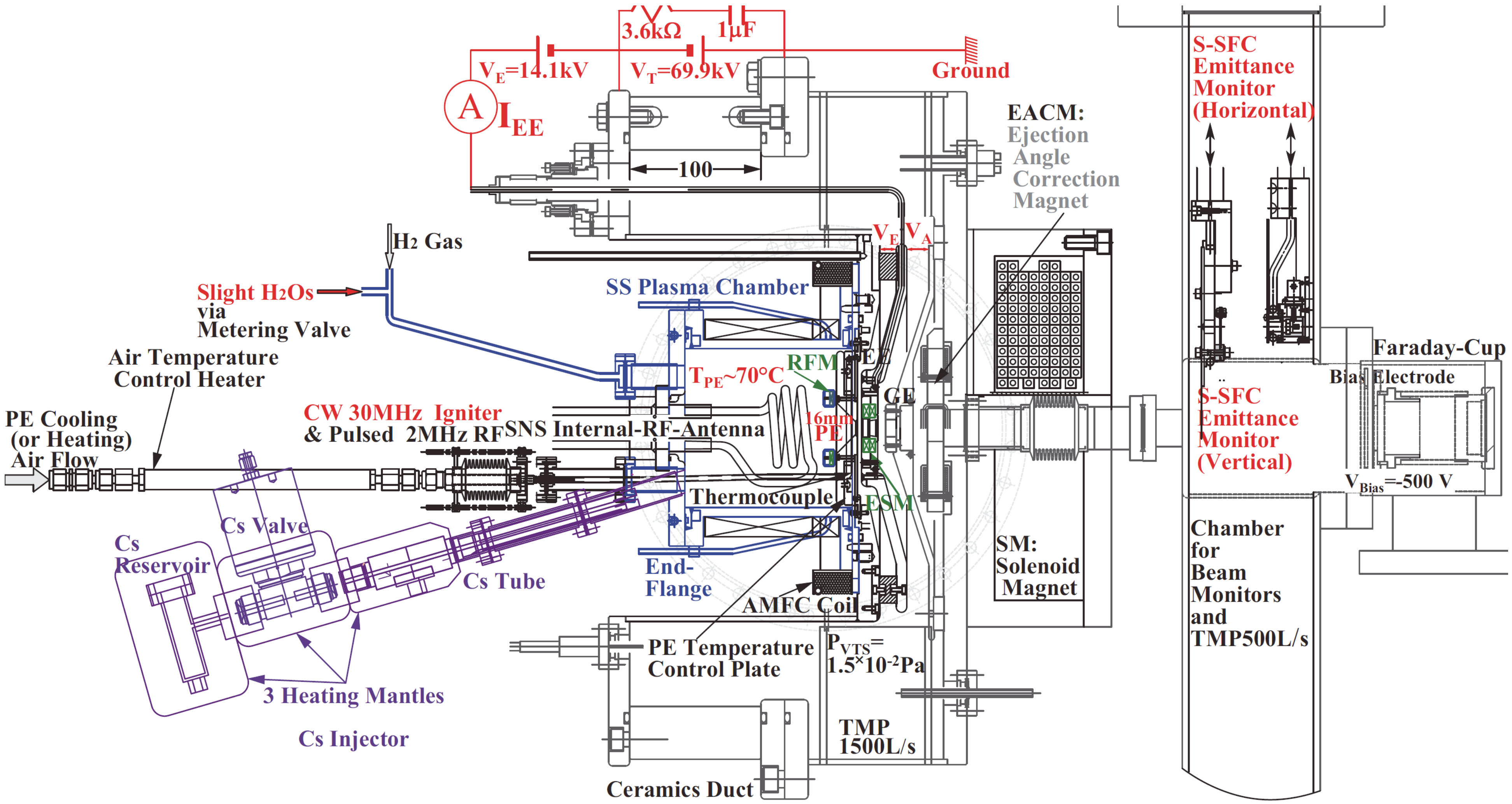
Contens

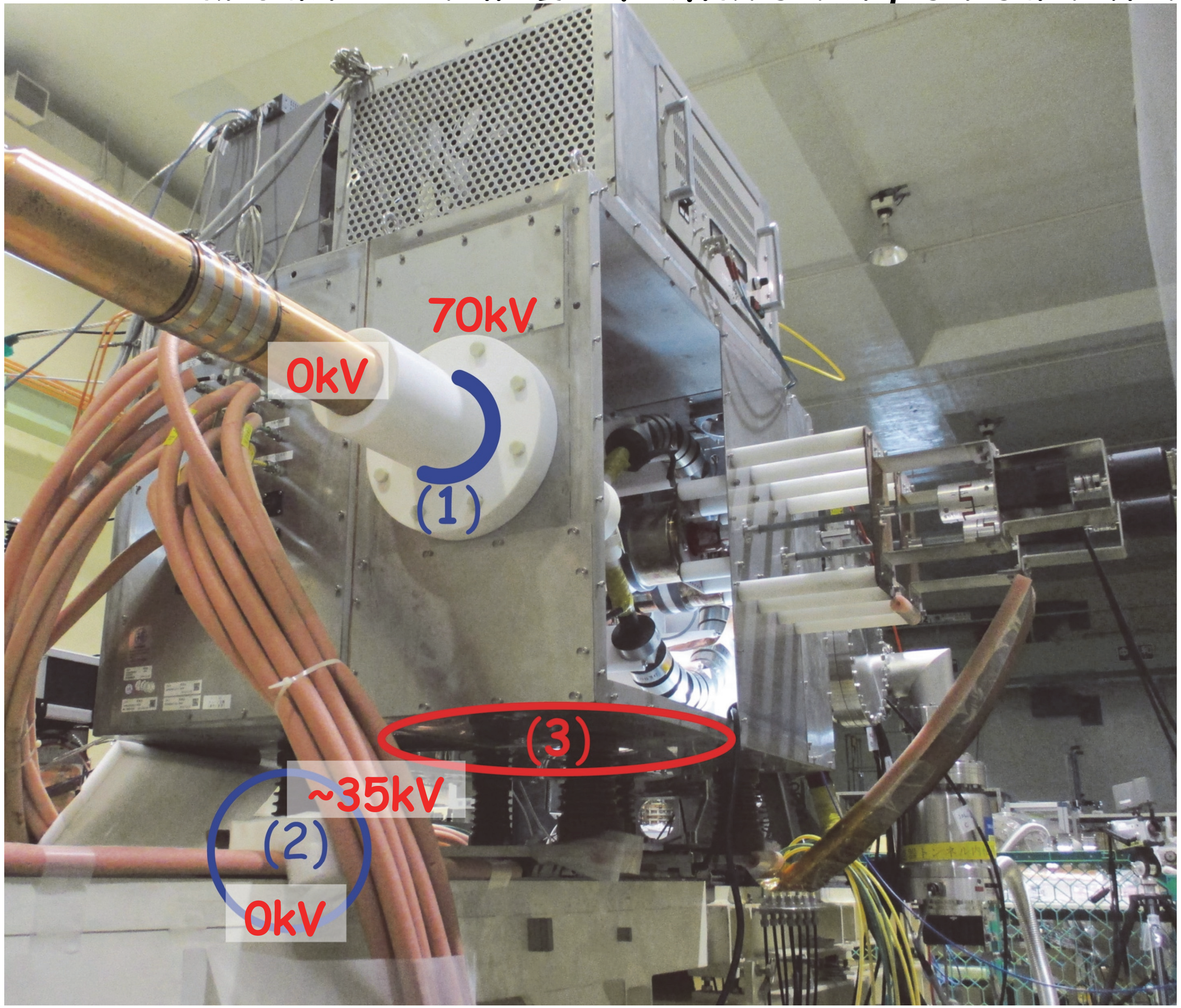
- Experimental Setup & Methods (J-PARC IS Test-stand)
- Withstand voltage improvements for W_{H^-} of 69.9keV around 2-MHz RF isolation transformer & matching circuit
- 8 hours operation
  with (I_{H^-}, W_{H^-}, V_E, duty factor) = (120mA, 69.9keV, 14.1kV, 4%)
- Measured waveforms of V_E, V_T, V_{2MHzF} & V_{2MHzR} and I_{H^-} & I_{EE}
  of one beam pulse
- Measured particle distributions in horizontal & vertical phase-planes
  for (I_{H^-}, W_{H^-}, V_E, duty factor) = (120mA, 69.9keV, 14.1kV, 4%)
- Parameters for 120 mA operation
- Conclusions

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_2Os Feeding(0.5$\varepsilon_{nrmsx/y}$), LowT_{PE}~70°C(0.75$\varepsilon_{nrmsx/y}$), CW-30MHzRF igniter(1.2I_{H^-}:17SCCMforϕ_{PE}=9mm) : 94.3% RFQ accl. effi. for 72mA, (I_{H^-}, W_{H^-}, V_E, duty factor) = (110mA, 66.6keV, 13.4kV, 4.5%)@NIBS2020 ⇒ (120mA, 69.9keV, 14.1kV, 4%)

Withstand voltage improvements for W_{H^-} of 69.9keV around 2-MHz RF matching circuit with isolation transformer



2MHz-RF perf. match. by FB C_S& C_P&f_{2MHz}(~2.03→2.025)

(1) Joint removal of teflon insulator around grounded 77D waveguide

(2) Insulation distance increase between cooling water nylon tubes & grounded mount

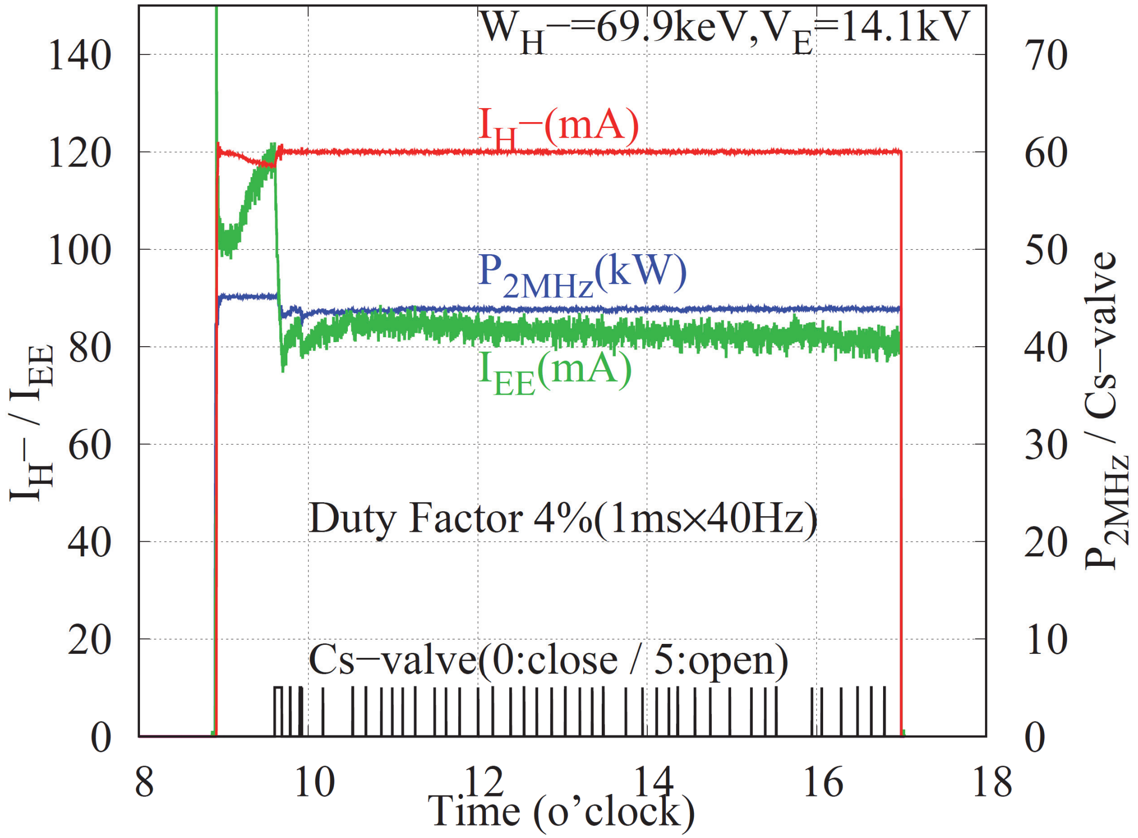
⇒ 120mA Ope. on Apr.

W_{H^-} < 69.9keV & I_{H^-} ~110 mA due to sparking & H^- pro. ef.↓ → various cesiation procedures (H_2O & Cs densities)

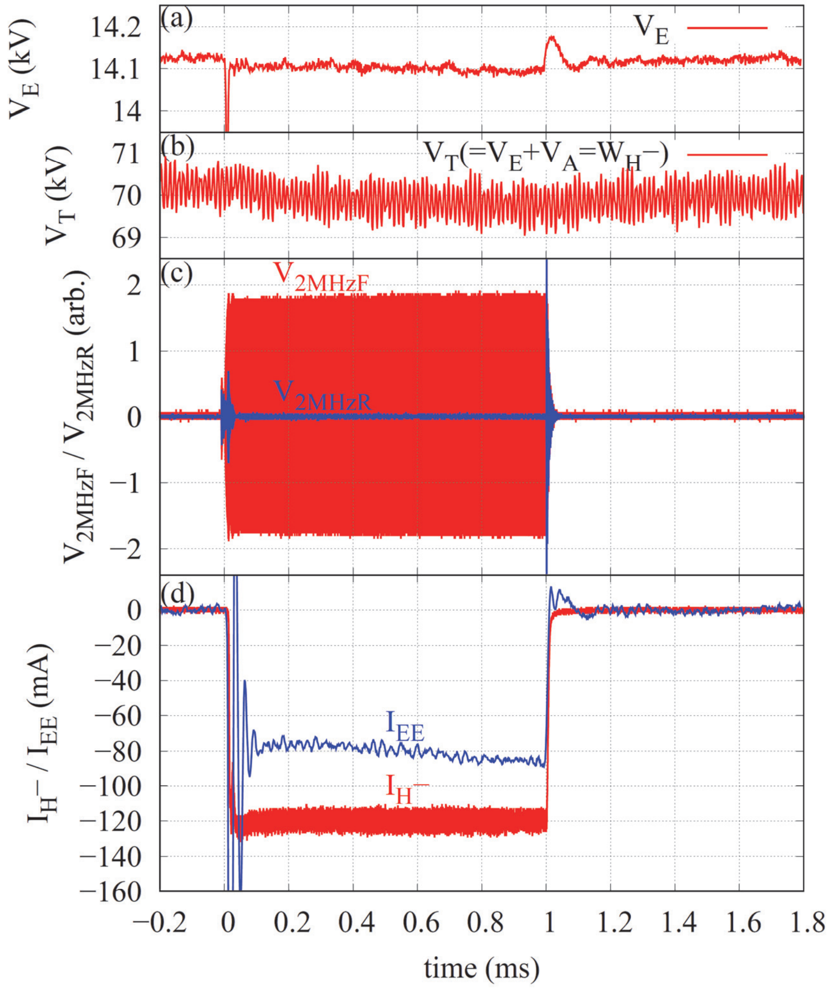
(3) Carbide dust removal from undersurface of matching circuit terminal

⇒ 120mA Ope. on Sep.

8 hours 120 mA operation & waveforms of one beam pulse



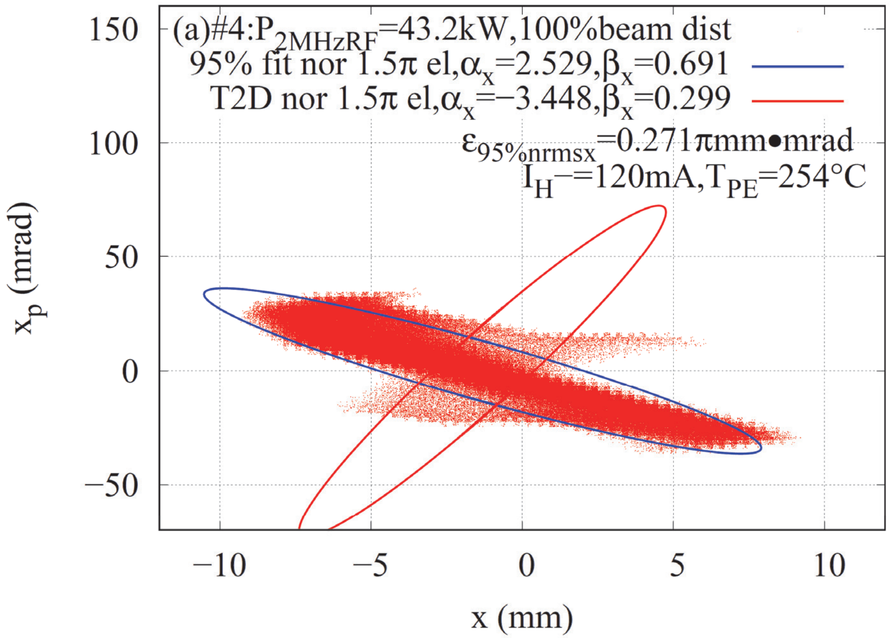
Trend graph of I_{H^-}, I_{EE}, P_{2MHz} and Cs-valve close/open during 8 hours operation, in which I_{H^-}, was feedbacked to 120 ±1 mA by P_{2MHz}, for W_{H^-} and V_E of 69.9 keV and 14.1 kV(pow. sup. max), respectively. In station. state, Cs inject. rate = 42.3 μg/hour.

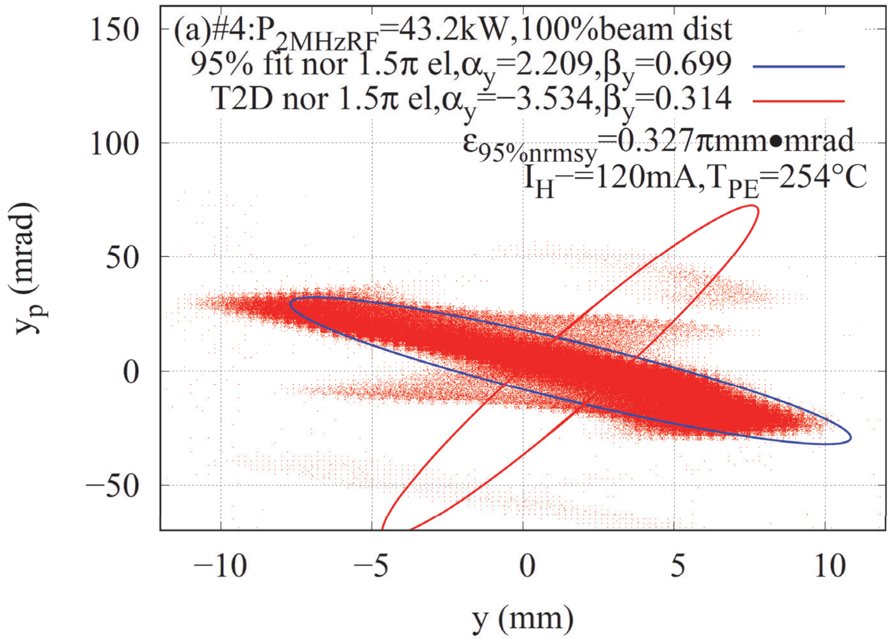


Waveforms of V_E(a), V_T(b), V_{2MHzF} & V_{2MHzR}(c) and I_{H^-} & I_{EE} (d) of one beam pulse.

Flat I_{H^-} by tilt. up P_{2MHz} by 9% to comp. V_E&V_T droops.
2MHz-RFperf.match.byFB C_S&C_P&f_{2MHz}(~2.03→2.025)

Particle distributions in horizontal & vertical phase-planes for $(I_{H^-}, W_{H^-}, V_E$, duty factor)=(120mA,69.9keV,14.1kV,4%)

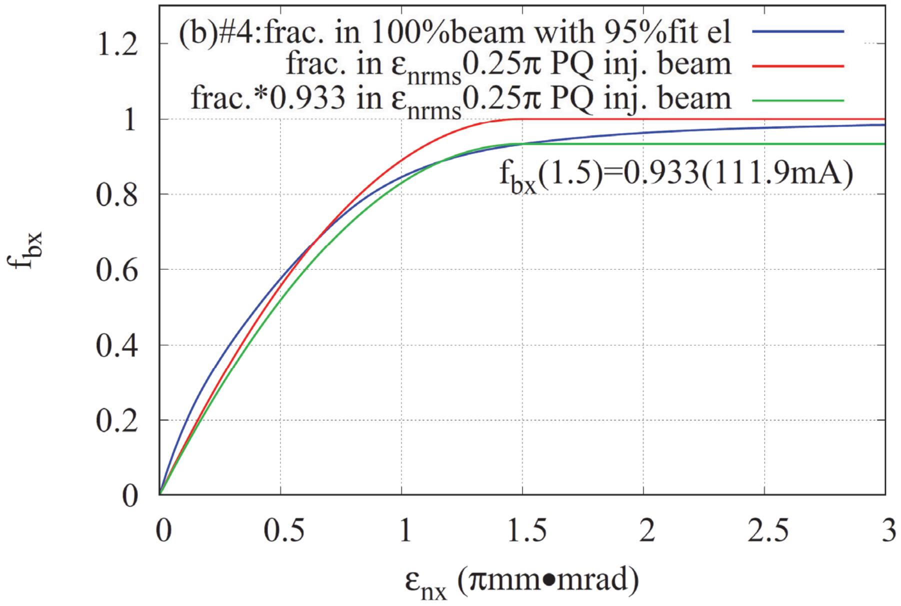


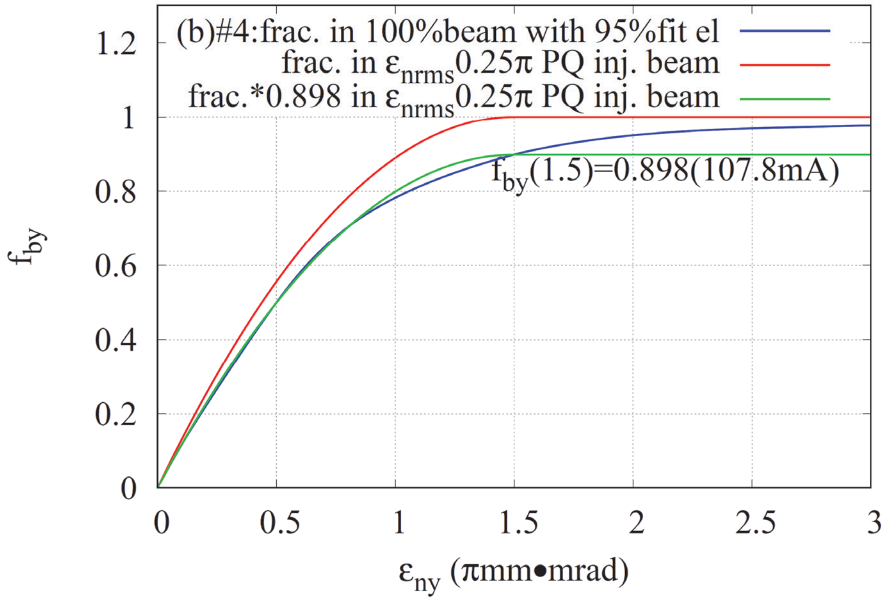


0.4 mega dots plots of H&V 100 % beam

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. × $f_{bx/y}(1.5)$

$\varepsilon_{nx/y}(1.5) < \varepsilon_{nPQx/y}$ PARMTEQ sim. acc. effi. is expected for 107.8mA beam.

Parameters for 120mA operation

IS & test-stand paramametes for I_{H^-} = 120 mA operation	Value
H_2 gas flow rate	17 SCCM
CW 30 MHz RF igniter power	43 W
2 MHz RF duty factor ~ Beam duty factor *Limitted by radiation safety permission of averaged I_{H^-} = 5 mA	4 % (1 ms × 40 Hz) *120 mA × 4 % = 4.8 mA
2 MHz RF power (P_{2MHz}) *tilting up 9% during pulse	42.9 ~ 46.8 kW
RF power efficiency (I_{H^-} / P_{2MHz})	2.68 mA/kW
H^- ion density at PE (ϕ_{PE}=9mm)	1886 A/m^2
Plasma electrode temperature (T_{PE})	254 °C
Stationary state Cs injection rate *Mainly attached on low temp. part	42.3 μg/hour *Not ejected
H^- ion beam energy (W_{H^-}) = (V_E + V_A)	69.9 keV =(14.1 + 55.8) 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	400 A (56000 AT)

CONCLUDIONS

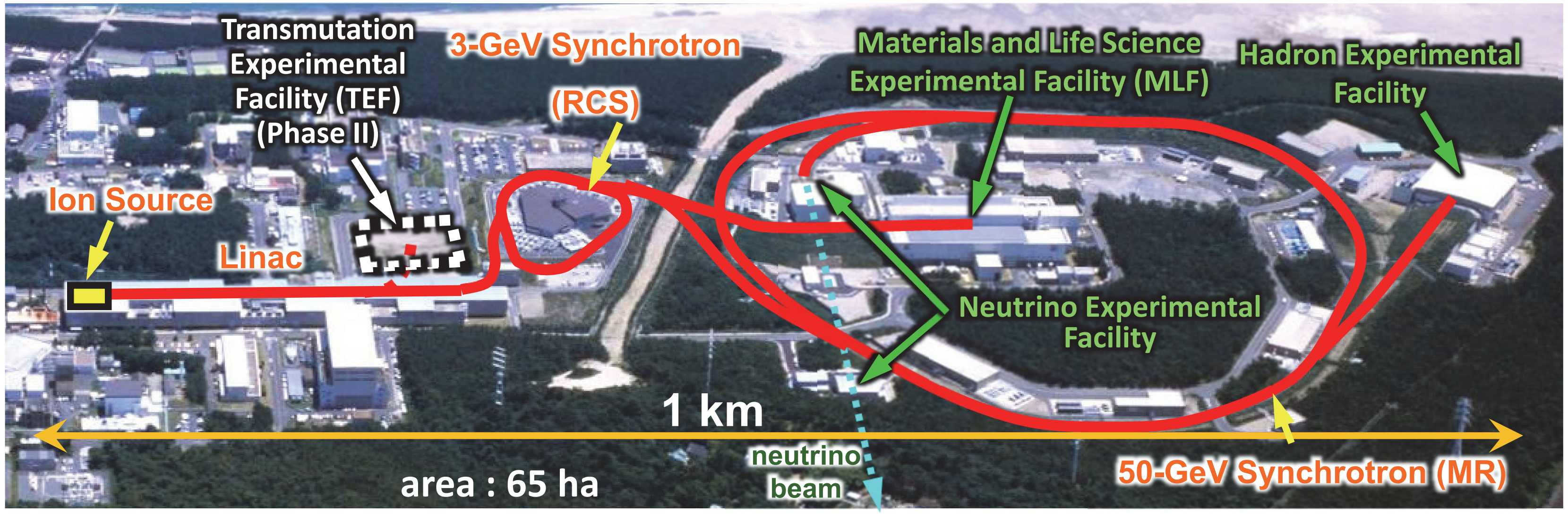
- 8 hours operation with (I_{H^-}, W_{H^-}, V_E, duty factor) = (120mA, 69.9keV, 14.1kV, 4%) was stable without any high voltage sparking. In stationary state, I_{H^-} was feedbacked to 120 ±1 mA by P_{2MHz} & Cs injection rate of 42.3 μg/hour.
- Flat I_{H^-} pulse was produced by 9% titing up P_{2MHz} during pulse.
- $\varepsilon_{95\%nrmsx/y}$ was measured as 0.271/0.327π mm•mrad for (I_{H^-}, W_{H^-}, V_E, duty factor) = (120mA, 69.9keV, 14.1kV, 4%). 107.8mA of beam is inside of PARMTEQ injection beam emittances with rather high T_{PE}=254 °C due to Cs compounds on PE surface accumulated during various cesiation procedures. 120mA beam with smaller emittances by T_{PE}~70 °C will be reported on 2023.

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).



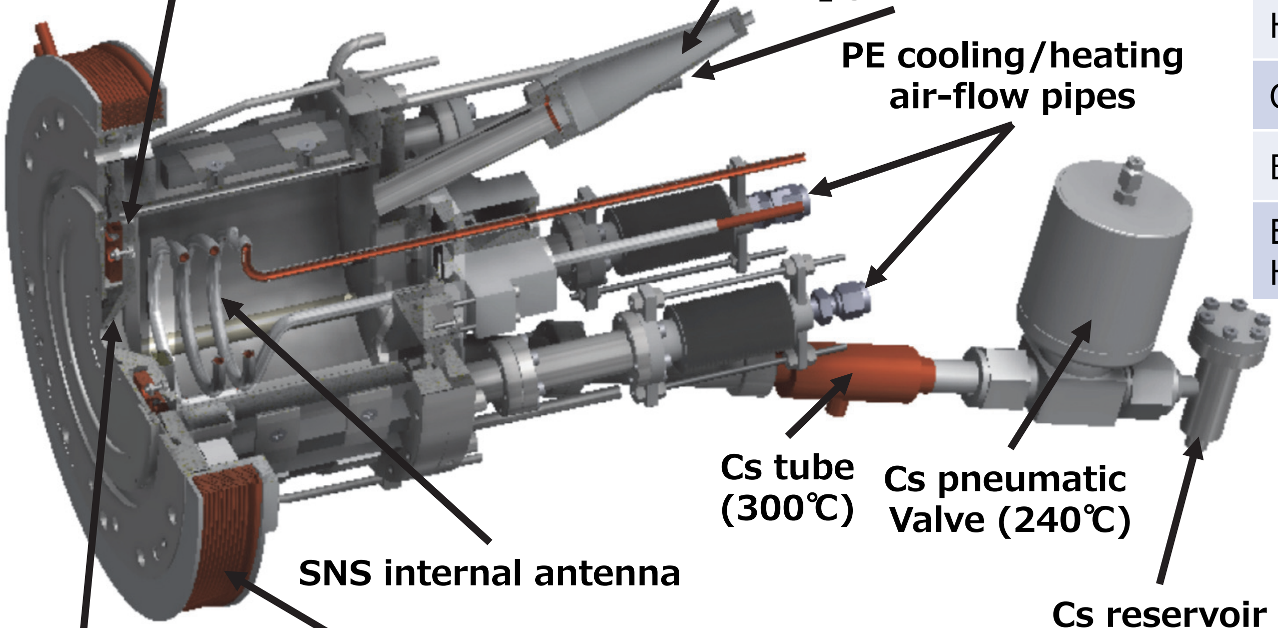
- The proton beams accelerated at the RCS are delivered to the Materials and Life Science Experimental Facility (MLF) and injected into the MR.
- After the proton beams accelerated at the MR, they are delivered to the Neutron Production Facility (NU) or to the Hadron beam Facility (HD).

● 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

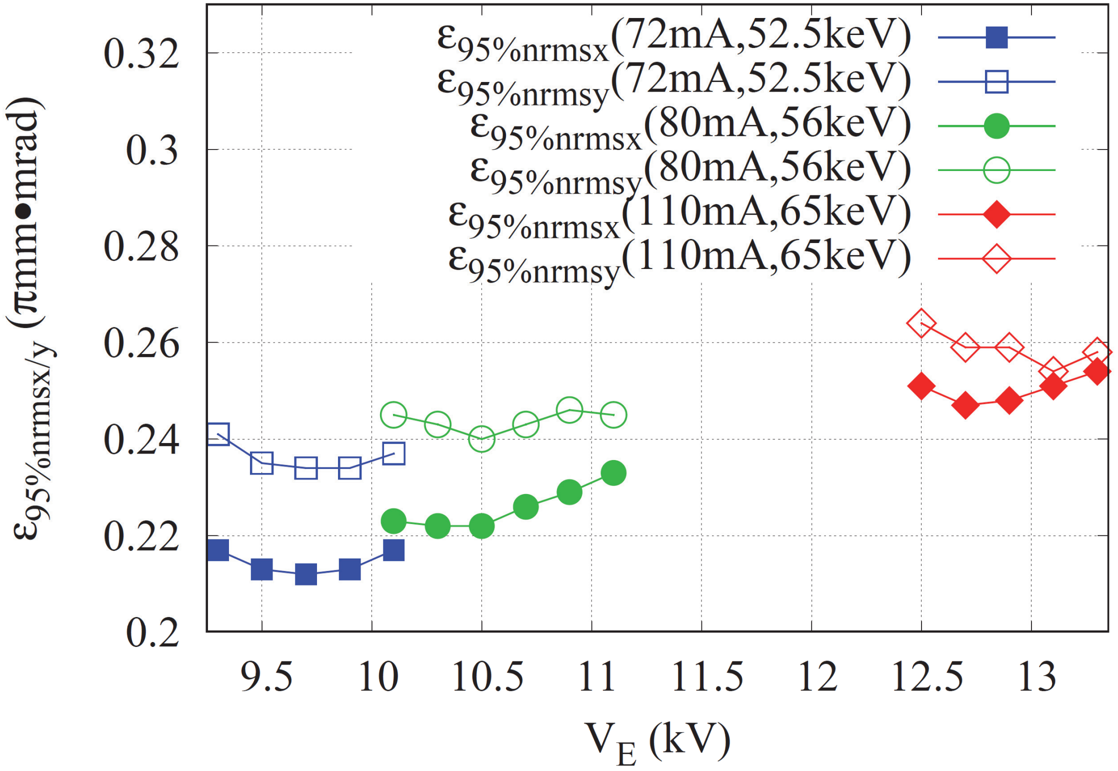
J-PARC Cesiated RF H^- ion source



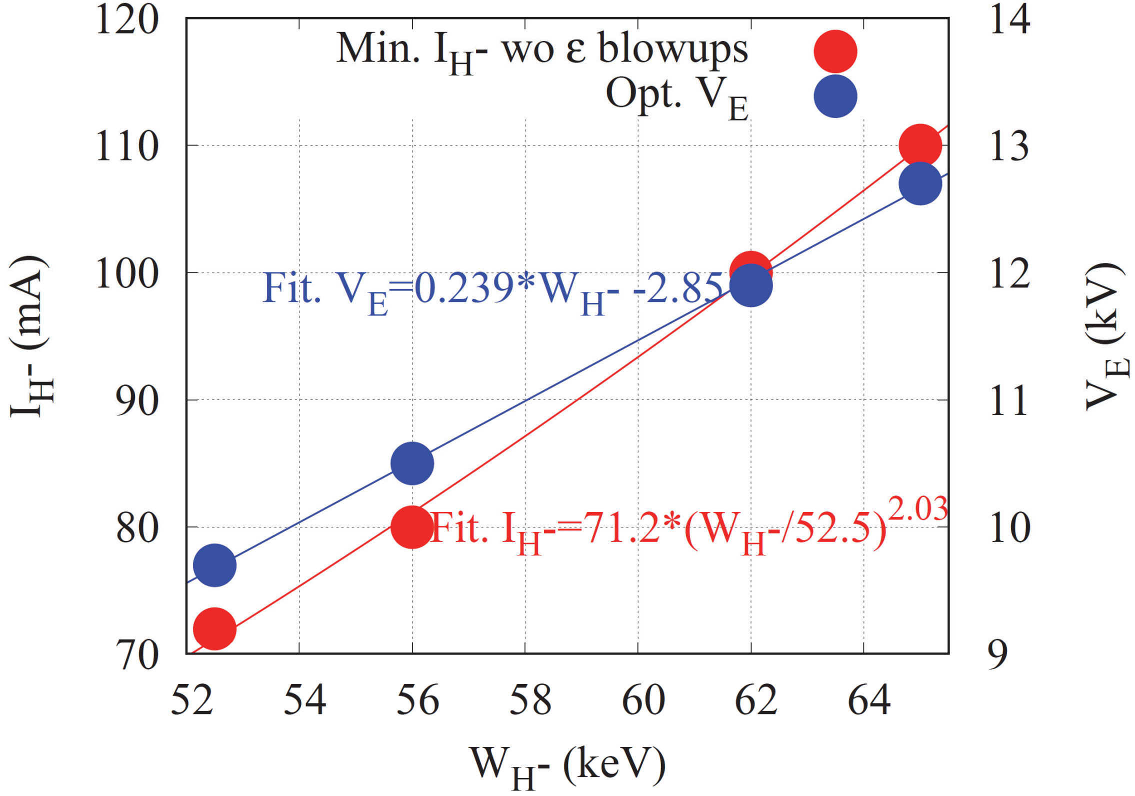
Specifications	
Discharge type	Internal antenna RF discharge
Repetition rate	25 Hz
RF frequency	30 MHz (cw, ~ 50 W) 2 MHz (0.8 ms pulsed, ~ 35 kW)
H_2 gas flow rate	21 sccm
Cs consumption	0.28 g in 1,567 hrs (in 2019)
Beam energy	50 keV
Extracted H^- beam current	60 mA (for user operation) 72 mA (for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

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.