Innovative Cesiation Deriving Incredible 145 mA Beam from J-PARC Cesiated RF-Driven H^- Ion Source

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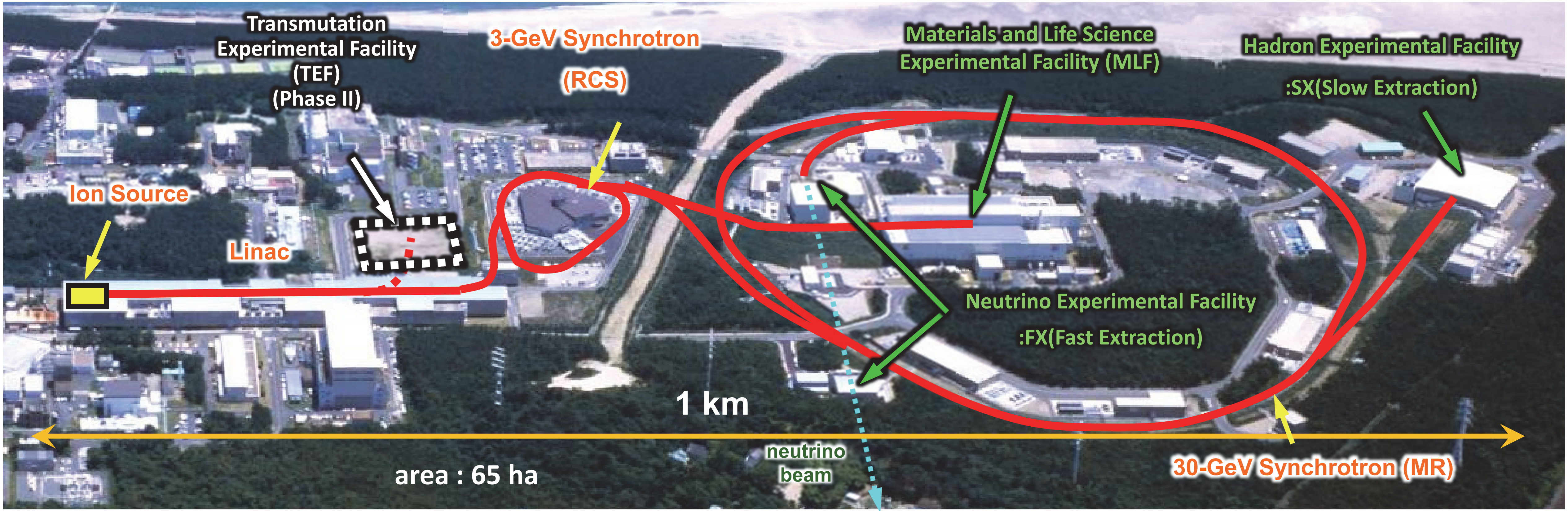
Overview of the J-PARC Accelerators



400 MeV LINAC (25 Hz)

- Macro Beam Pulse Width ≦0.6ms
- Steady Operation : 50mA & 0.5ms
- LINAC & RCS Study : 60mA & 0.6ms for RCS 1.5MW Operation
- Supe. IS $\varepsilon_{x/y}$:High RFQ Trans. 94.3% (67.9/72) in LINAC 60 mA Ope.

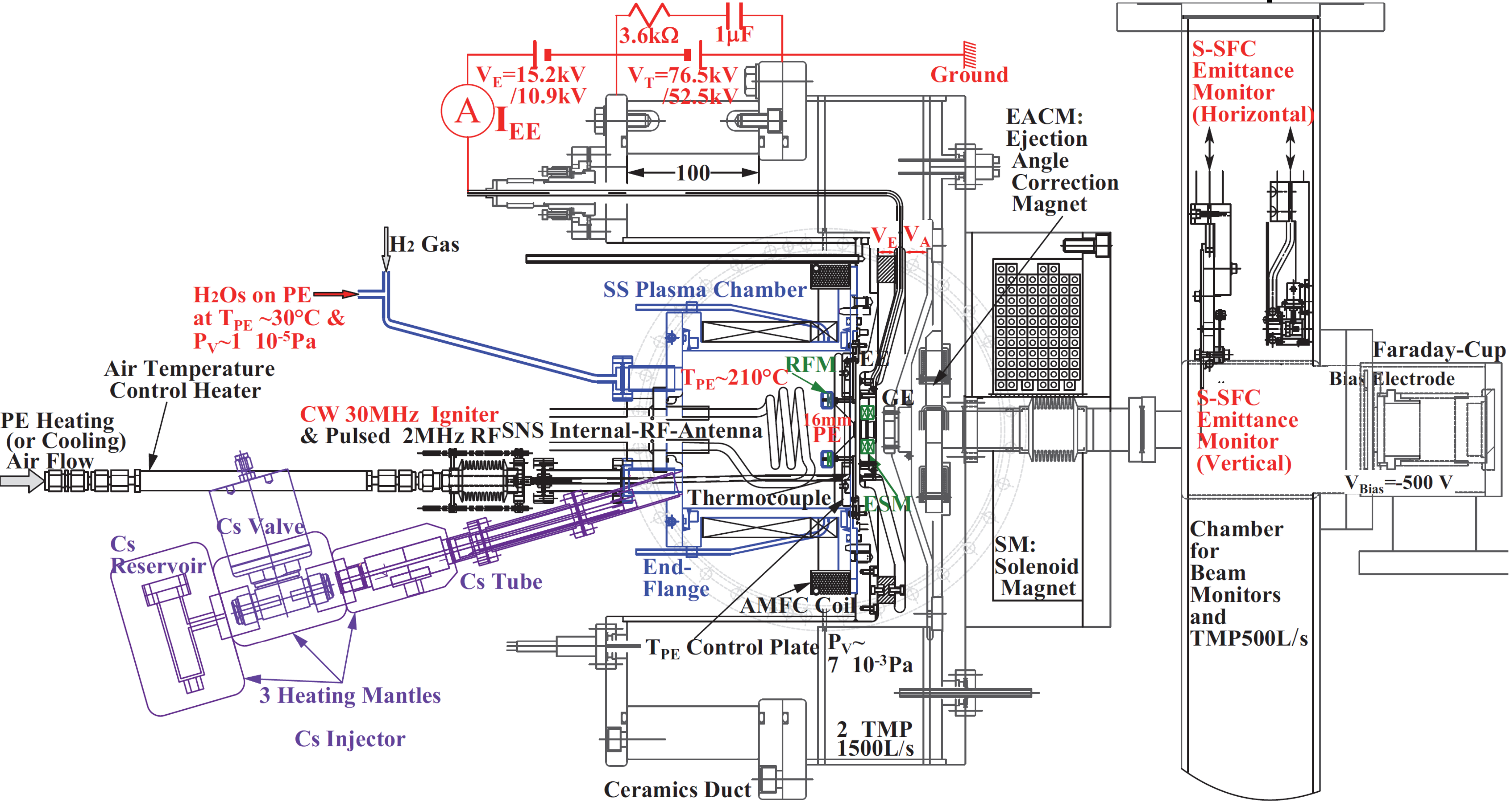
3 GeV RCS (25 Hz)

- Steady Operation 0.95MW(0.85MW for MLF)
- 2028~>1.2MW

30 GeV MR

- Stesdy Operation ~June 2021 FX0.52MW:2.52sCy. & SX64kW:5.2sCy.
- July 2021 ~ Jan. 2023 UG Shutdown
- 2024~FX0.75MW:1.32sCy. & SX80kW:4.24sCy.
- 2028~FX1.3MW:1.16sCy.(RCS>1.2MW)

Experimental set-up and differences between 65 keV 110 mA & 69.9 keV 120 mA operations



High Brightness & RF power effi. by

(1) 16mm 45° PE $\rightarrow 1.5 I_{H^-}$

(2) CW 30MHz RF igniter $\rightarrow$ 17SCCM (ϕ_{PE} 9mm) & $1.14 I_{H^-}$

(3) $T_{PE} \sim 70°C \rightarrow 0.84 \varepsilon_{nrmsx/y}$

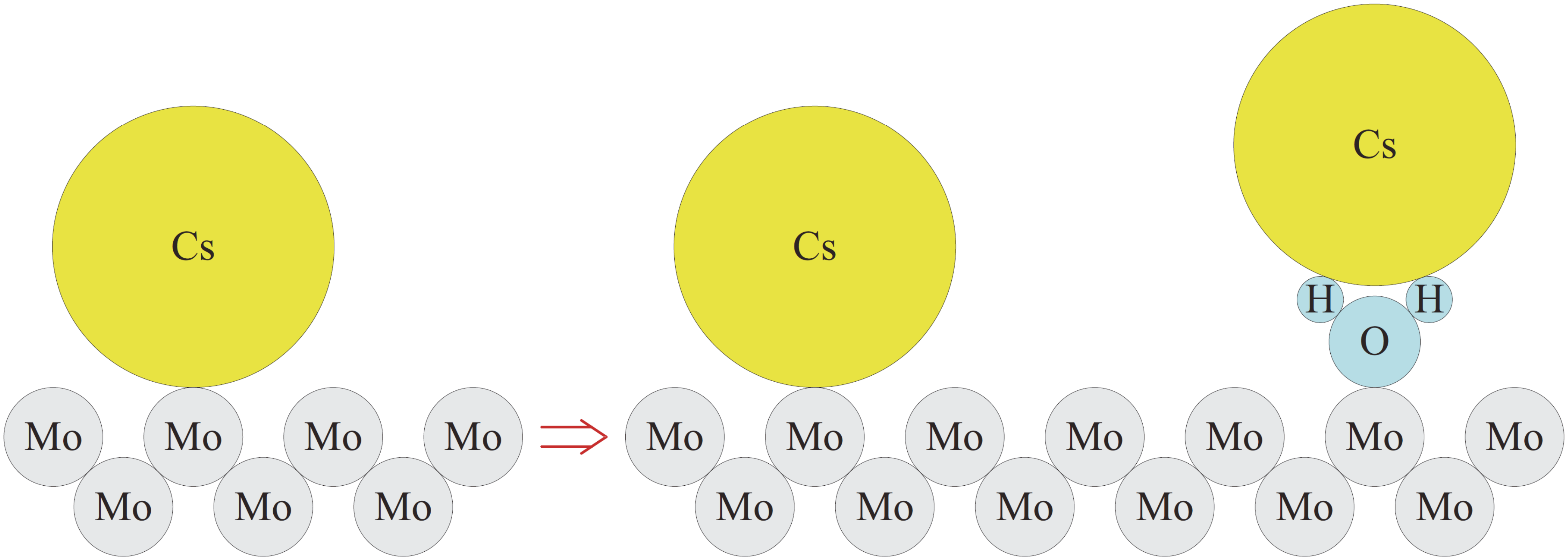
(4) Slight $H_2Os \rightarrow 0.5 \varepsilon_{nrsmx/y}$ & 0.67 Divergence Angle

(5) $T_{PE} = 254°C \rightarrow 1.1 * 0.84 \varepsilon_{nrmsx/y}$ after large amount of Cs and H_2O injections

Both of W_{H^-} & H^- production efficiency (HPE) should be increased for $I_{H^-} >= 120mA$.

HPE can be increased by cesiation with H_2O.

Hypothesis of H_2O (chemically bound with Mo) mediated cesiation

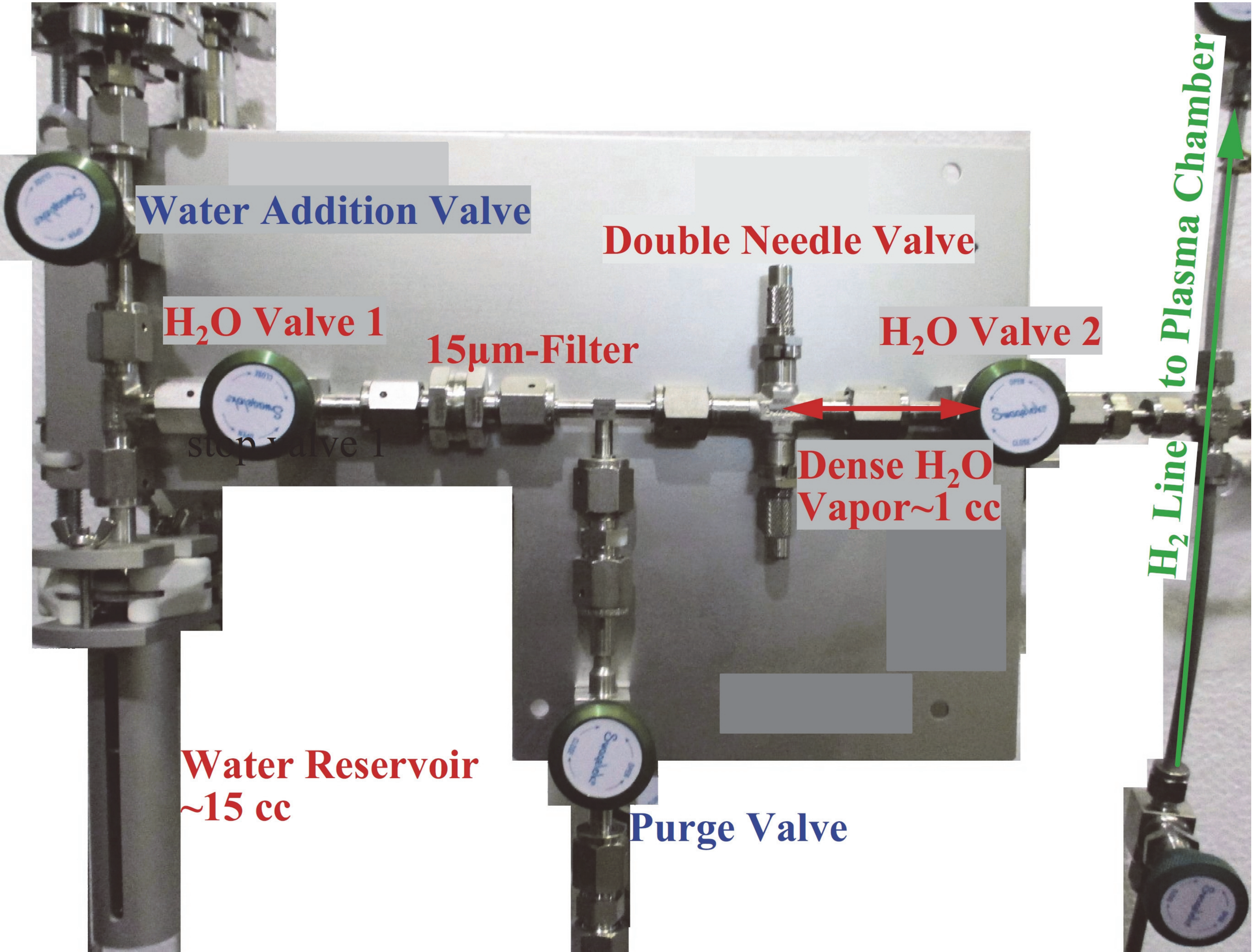


Uniform Cs half monolayer on Mo is difficult to be attained over large PE surface against non-uniform high energy plasm bombardments

Sub monolayer H_2O (chemically bounded with Mo) mediated cesiation surviving against high T_{PE} & high energy plasma bombardments cooperate with Cs half monolayer on remaining surface (with almost same work function as Cs half monolayer)

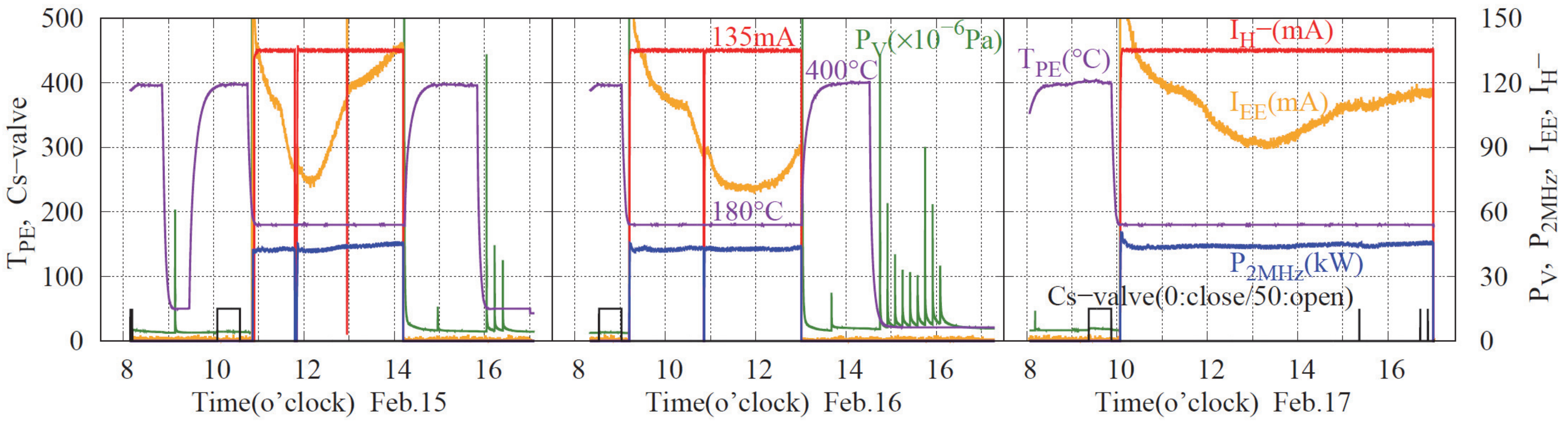
Ratio of H_2O mediated cesiation to conventional cesiaton had to be increased for I_{H^-} >= 120 mA.

H_2O injector



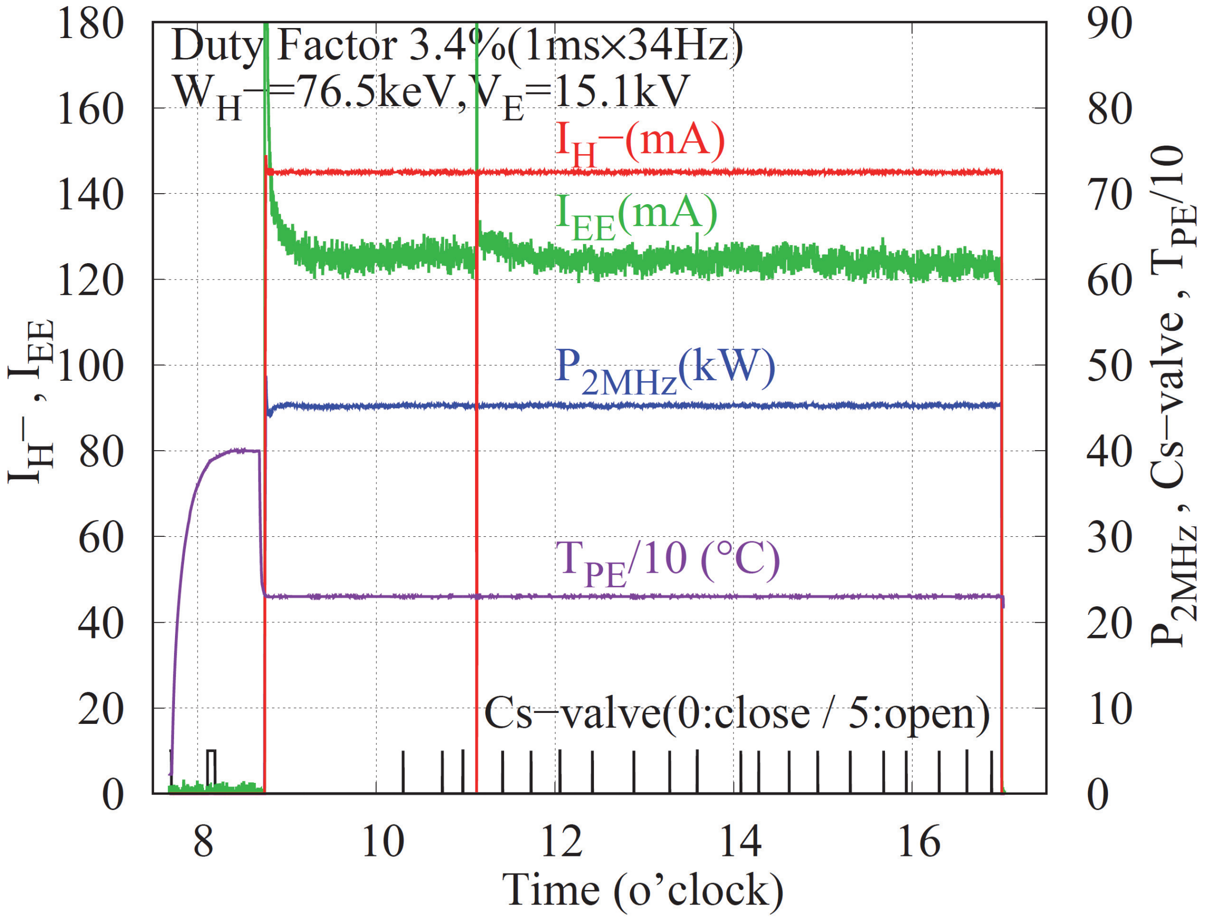
One H_2O injection is defined as opening of H_2O valve 2 for 5 min. and ejecting dense H_2O vapor in the pipe with about 1 cc between the double needle valve and it stored by opening H_2O valve 1 and the double needle valve for 5 min..

H_2O (chemically bound with Mo) mediated cesiation

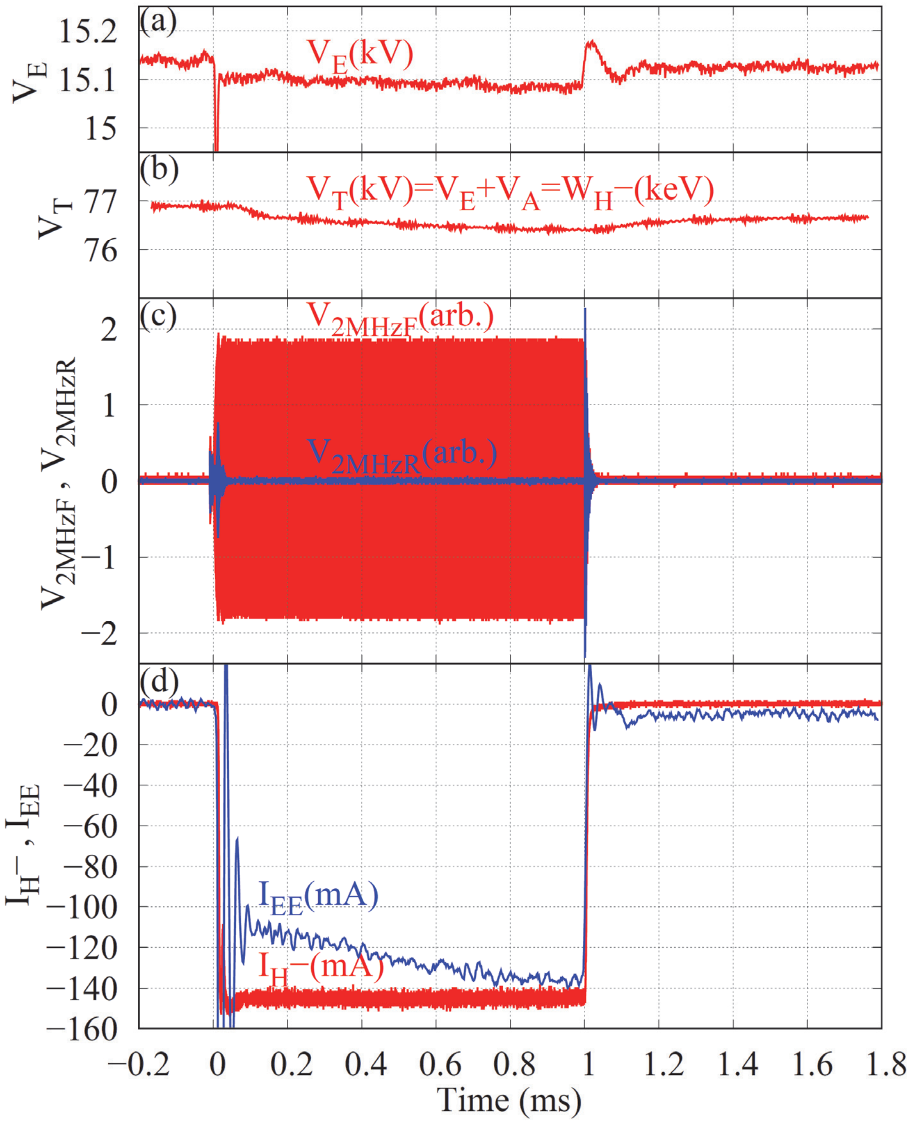


H_2O mediated cesiation procedure : (1) T_{PE} was increased to 400 °C and keeping it about 1 hour, (2) T_{PE} was decreased to 30~50 °C, (3) Every 10 min., H_2O injection was introduced 3 or 9 times, (4) Some of H_2O on PE was chemically bound with Mo in 16 hours, (5) after T_{PE} was increased to 400 °C, Cs valve was opened for 30 min. at the T_{CsR} of 180 °C (1.7 mg). (6) degree of H_2O mediated cesiation was examined by 72.5 keV 135 mA operation feedbacking P_{2MHz} at T_{PE} of 180 °C.

8 hours 145 mA operation & waveforms of a beam pulse

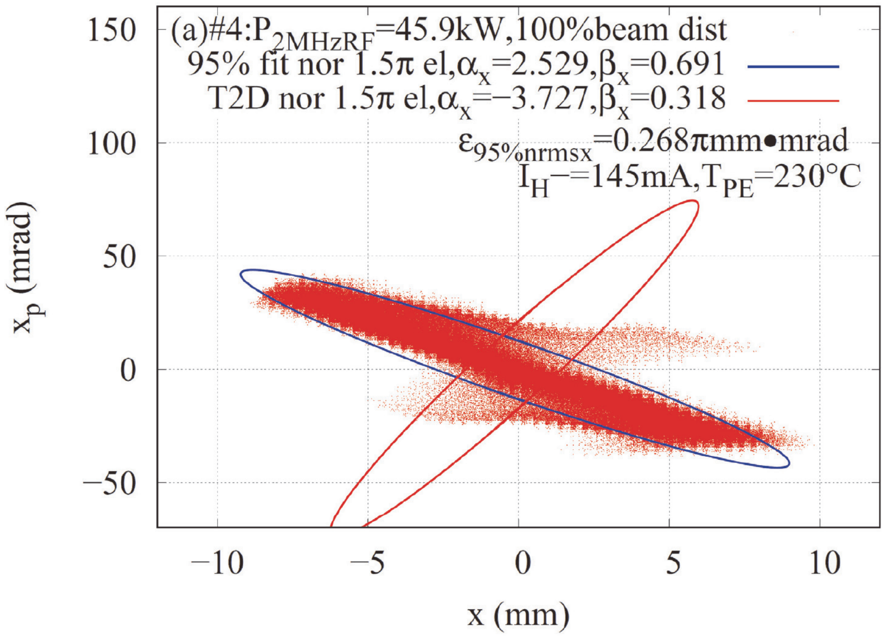


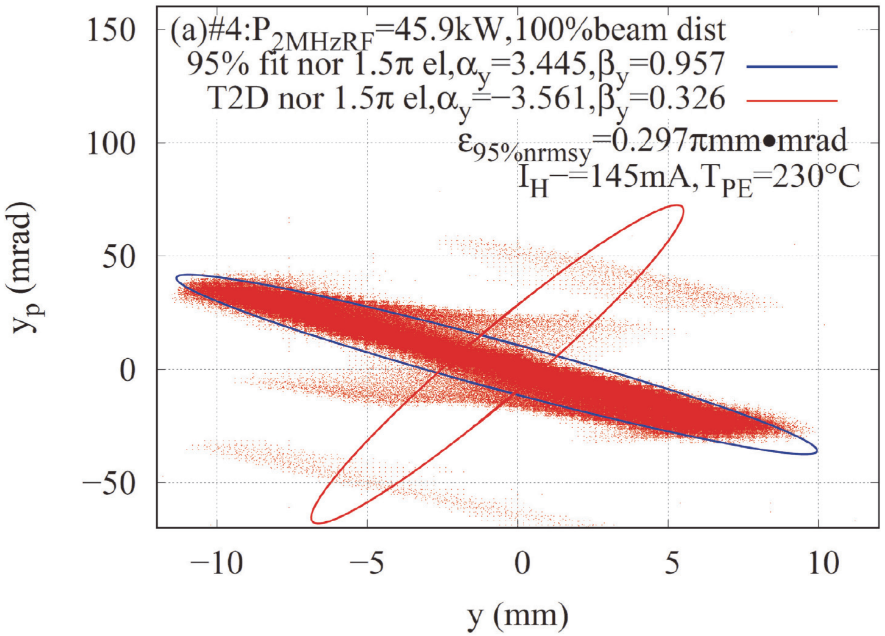
Trend graph of I_{H^-}, I_{EE}, P_{2MHz}, T_{PE} and Cs-valve close/open during 8 hours operation, in which I_{H^-}, was feedbacked to 145 ±1 mA by P_{2MHz}, for (W_{H^-}, V_E, T_{PE}) of (76.5 keV, 15.1 kV, 230 °C). In stational state, Cs inject. rate = 14 μg/hour <42 μg/hour for 69.9 keV 120 mA @ T_{PE}=245 °C.

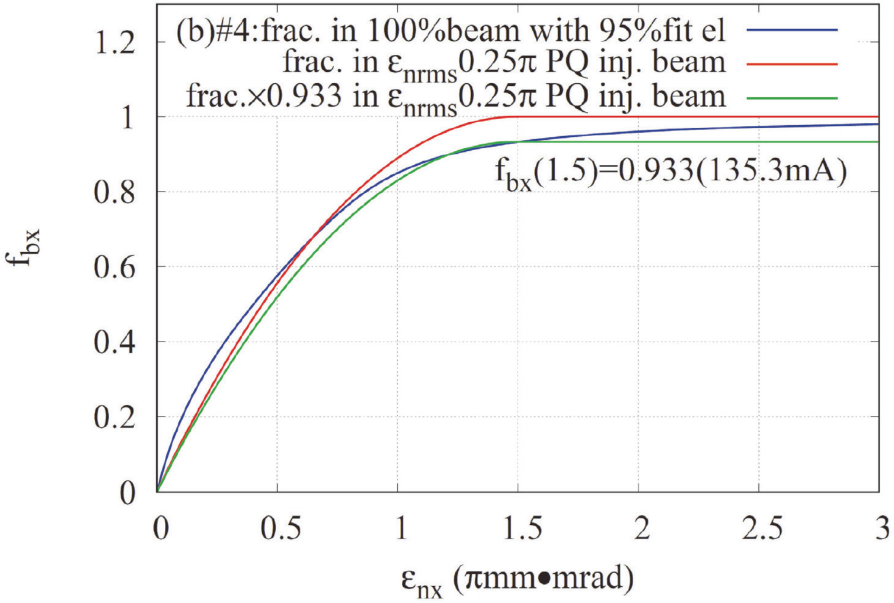


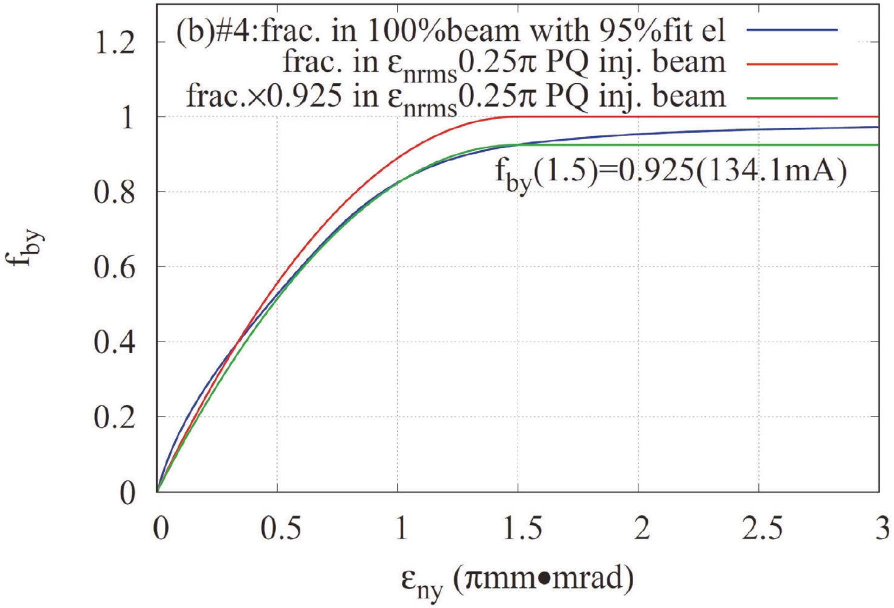
Waveforms of V_E(a), V_T(b), V_{2MHzF} and V_{2MHzR}(c) and I_{H^-} and I_{EE} (d) of one beam pulse. *Flat I_{H^-} of 145 mA was produced with 0.9% tilting up P2MHz.

Particle distributions in horizontal & vertical phase-planes for $(I_{H^-}, W_{H^-}, V_E, T_{PE}$, duty factor)=(145mA,76.5keV,15.1kV,230°C,3.4%)









100 % beam H^- ion distribution (red dots), fitted normalized 1.5 πmm·mrad ellipses fitting 95% beam (blue line) and ellipse backward traced to GE downstream surface with TRACE2D (T2D) (red line) in horizontal (a) or vertical (c) phase-plane.

Relationships between $\varepsilon_{nx/ny}$ and included beam fraction $f_{bx/by}$ in 100 % beam with ellipse fitting 95 % beam (blue line), $\varepsilon_{nx/ny}$ and included $f_{bx/by}$ in common PARMTEQ (PQ) injection beam with $\varepsilon_{nxrms/nyrms}$ of 0.25 πmm·mrad (red line) and $\varepsilon_{nx/ny}$ and included $f_{bx/by}$×0.933/0.925 in PQ beam (green line) in horizontal (c) or vertical (d) phase-plane for W_{H^-}, I_{H^-} and V_E of 76.5 keV, 145 mA and 15.1 kV, respectively.

Table 1. Parameters of J-PARC RF-driven H^- ion source test-stand in 145 mA / 83 mA operation.

H_2 gas flow rate	17 SCCM
CW 30 MHz RF igniter power	43 W
2 MHz RF duty factor ~ Beam duty factor *Limited by radi. safety permis.: I_{H-AV}=5mA	3.4%(1ms × 34 Hz) / 5%(1ms × 50 Hz) *145 mA × 3.4 % = 4.93 mA
2 MHz RF power (P_{2MHz}) *Tilting during pulse for flat beam pulse	45.9~46.3kW / 31.3~30.4kW
RF power efficiency (I_{H-} / P_{2MHz})	145/46.1=3.15mA/kW / 83/30.9=2.69mA/kW
H^- ion density at PE (ϕ_{PE} = 9mm)	2279A/m^2 / 1305A/m^2
Plasma electrode temperature (T_{PE})	230°C
Stationary state Cs injection rate *Mainly attached on low temp. part	14 / - μg/hour *Mainly not ejected
H^- ion beam energy (W_{H-}) = (V_E + V_A)	76.5(15.1+61.4)keV / 52.5(10.9+41.6)keV
1st sec. vacu. pumps & vacu. pressure	1500 L/s TMP × 2 & ~7 × 10^{-3} Pa
2nd section vacuum pump	500 L/s TMP
Solenoid magnet current	437A(61180AT) / 350A(49000AT)
Trans. emittances : $\varepsilon_{95\%nrmsx}$ & $\varepsilon_{95\%nrmsy}$	0.268&0.297πmm·mrad / 0.239&0.272πmm·mrad *0.268/0.239=1.12 ~ βγ(76.5keV)/βγ(52.5keV)=1.21

Improved I_{H-}(52.5keV) of 83mA (from 72mA) is indispensable to keep 60mA at LINAC exit for about 6 months of one J-PARC operation period before LINAC upgrade to reduce about 12 % beam loss downstream of RFQ.

Conclusions

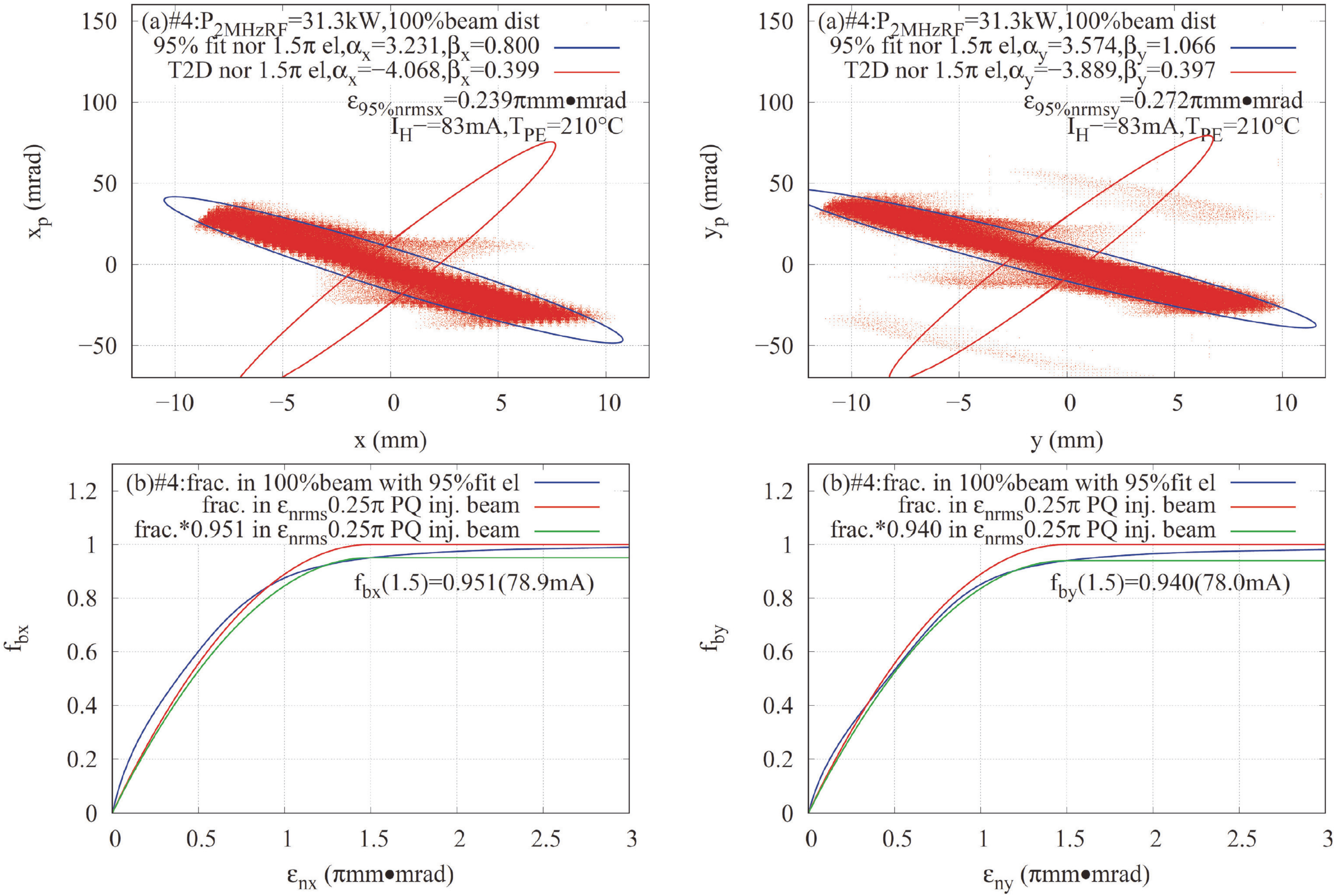
- With novel cesiation based upon hypothesis of H_2O (chemically bound with Mo) mediated cesiation, J-PARC IS produced I_{H^-}(76.5/52.5keV) of 145/83mA.
- 8 hours operation with (I_{H^-}, W_{H^-}, V_E, T_{PE}, duty factor) = (145mA, 76.5keV, 15.1kV, 230°C, 3.4%) was succeeded with only one sparking probably around 2MHz RF matching circuit. In stationary state, I_{H^-} was feedbacked to 145 ±1 mA by P_{2MHz} & Cs injection rate of 14 μg/hour.
- Flat I_{H^-} of 145mA/83mA pulse was produced by 0.9%/-3% tilting P_{2MHz} during pulse.
- Superior $\varepsilon_{95\%nrmsx/y}$($I_{H^-}$,$W_{H^-}$) of 0.268/0.297(145mA,76.5keV) & 0.239/0.272(83mA,52.5keV) π mm•mrad were attained. 134.1(76.5keV)/78.0(52.5keV) mA of beam is inside of PARMTEQ injection beam emittances. T_{PE} of 230°C rather higher than world standard does not affect to $\varepsilon_{95\%nrmsx/y}$.

ACKNOWLEDGMENTS

The author wishes to expres his sincere thanks to Dr. Martin P. Stockli ans SNS ion source group members for their support to purchase internal-RF-antennas and their information on the SNS RF-driven H^- ion source. The author also wishes to express his sincere thanks to Mr. Kiyonori Ohkoshi of J-PARC for preparing the experiments.

"Thank you for your attention"

Emittance Improvements with Shortest Beam Extracotor



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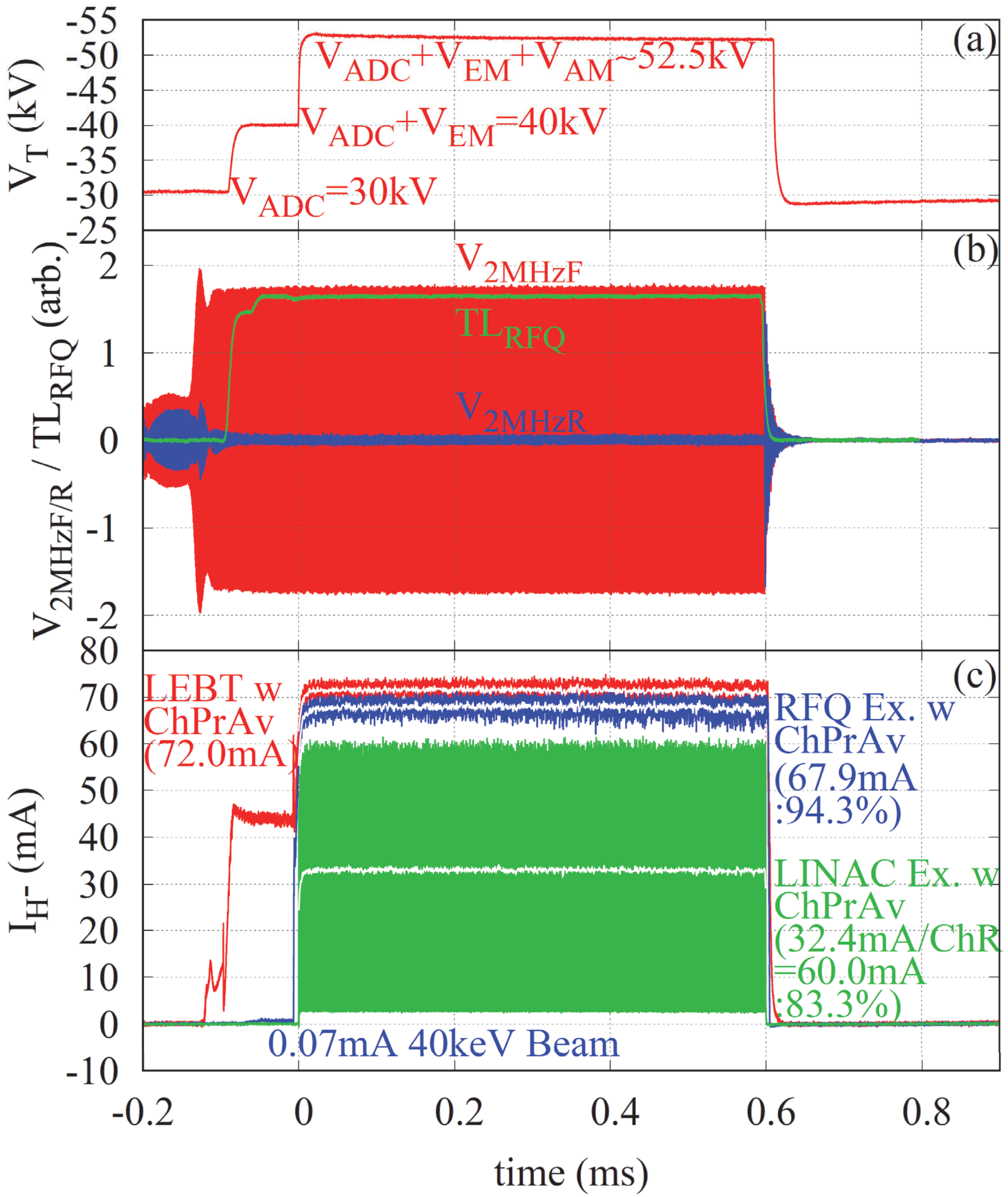
Relationships between $\varepsilon_{nx/ny}$ and included beam fraction $f_{bx/by}$ in 100 % beam with ellipse fitting 95 % beam (blue line), $\varepsilon_{nx/ny}$ and included $f_{bx/by}$ in common PARMTEQ (PQ) injection beam with $\varepsilon_{nxrms/nyrms}$ of 0.25 πmm·mrad (red line) and $\varepsilon_{nx/ny}$ and included $f_{bx/by}\times 0.944/0.928$ in PQ beam (green line) in horizontal (c) or vertical (d) phase-plane for W_{H^-}, I_{H^-} and V_E of 62 keV, 100 mA and 12 kV, respectively.

J-PARC LINAC 60 mA 1.5%(0.6ms×25Hz)BDF Operation



Macro Pulse Chopping with W_H- Mod.& RFQ Long.Acce.

(a) Terminal Voltage V_T

-30kV(V_{ADC})→-40kV($V_{ADC}+V_{EM}$)

→-52.5kV($V_{ADC}+V_{EM}+V_{AM}$) →-30kV(V_{ADC})

(b) Plasma Production Forward & Reflected 2MHz RF Voltages V_{2MHzF} & V_{2MHzR} and RFQ Tank Level TL_{RF}

(C) I_H-@LEBT, I_H-@RFQ Exit, I_H-@LINAC Exit

*Intermediate Chopper Period (812.5ns) Averaged IH- are ploted with white lines.

*Space Char. Neu. Satura. by 40 keV 0.1 ms H^- beam

→ Succession to 52.5 keV H^- beam

→I_H-&I_H-&I_H- Rapid Rise Time responding to V_{AM}

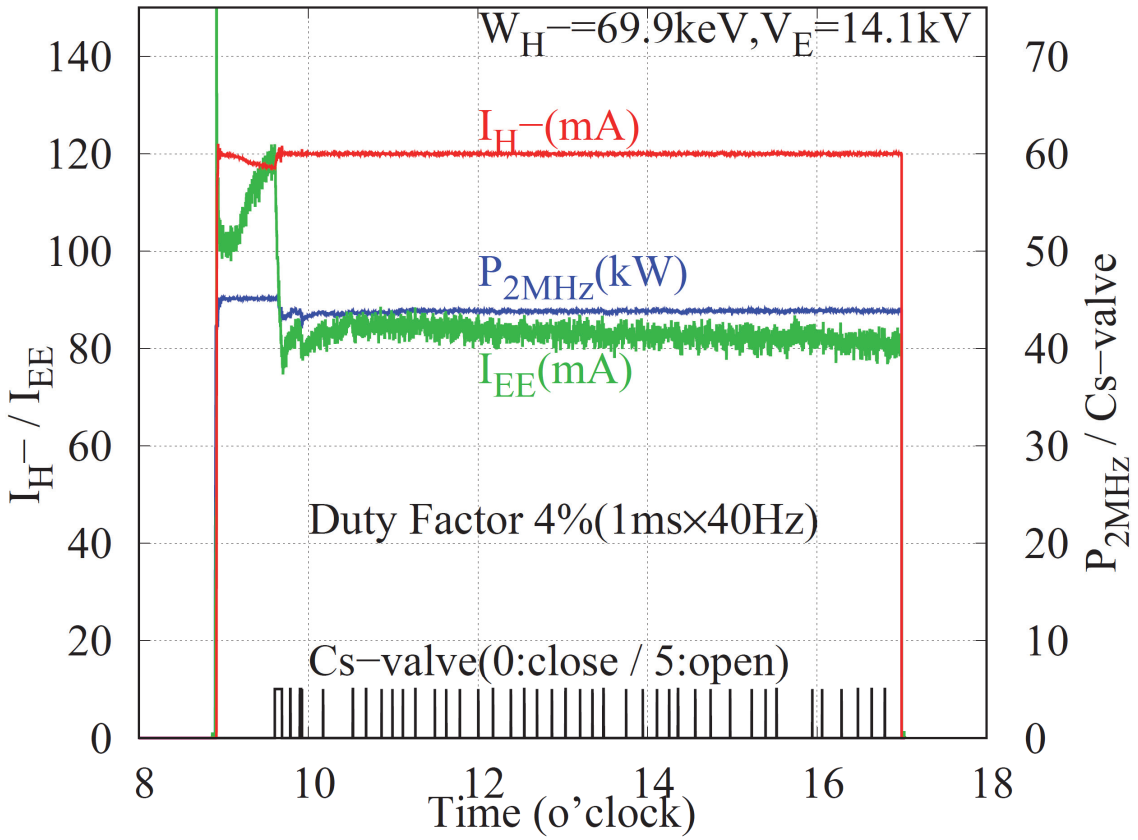
*High RFQ Transmission of 94.3%(67.9/72)

*0.07mA 40keV H^- beam was detected with RFQ exit CT at downstream surface of QM1 with design TL_{RFQ}

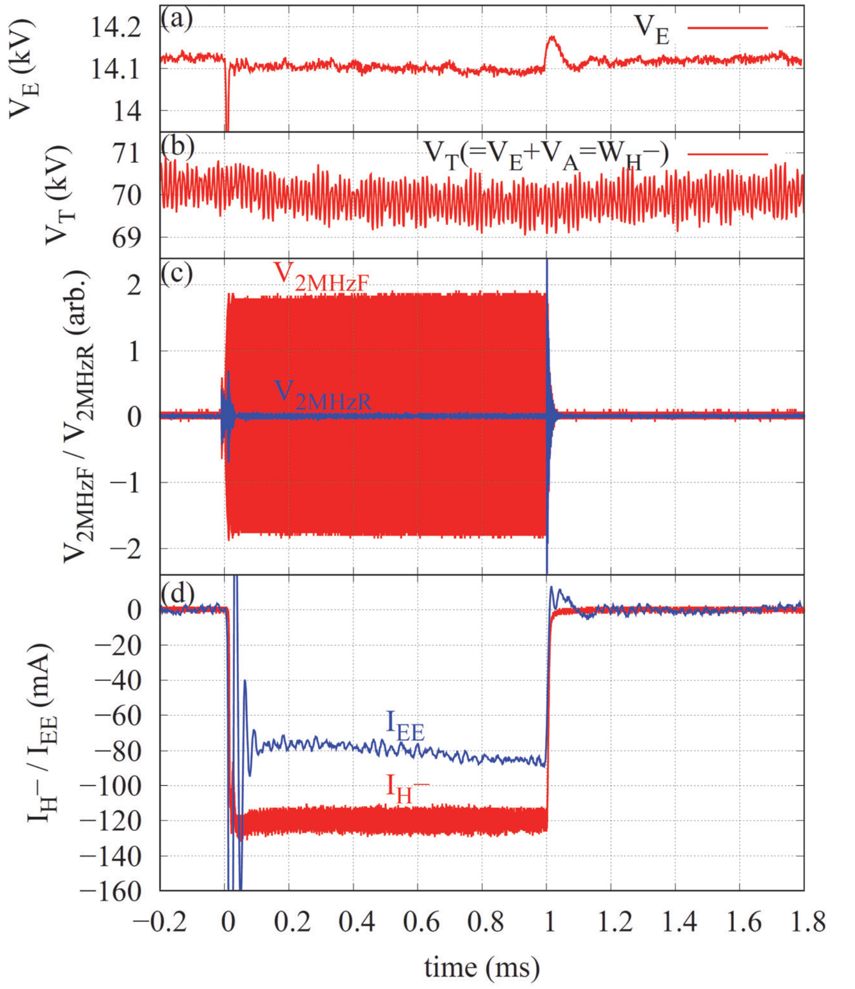
→ >>0.07mA 40keV H^- beam transmits through RFQ

*Low MEBT1 Transmission of 88.34%(60/67.9) due to space charge limited current of MEBT1

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, respectively. In station. state, Cs inject. rate = 42.3 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 9% to comp. V_E&V_T droops.

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

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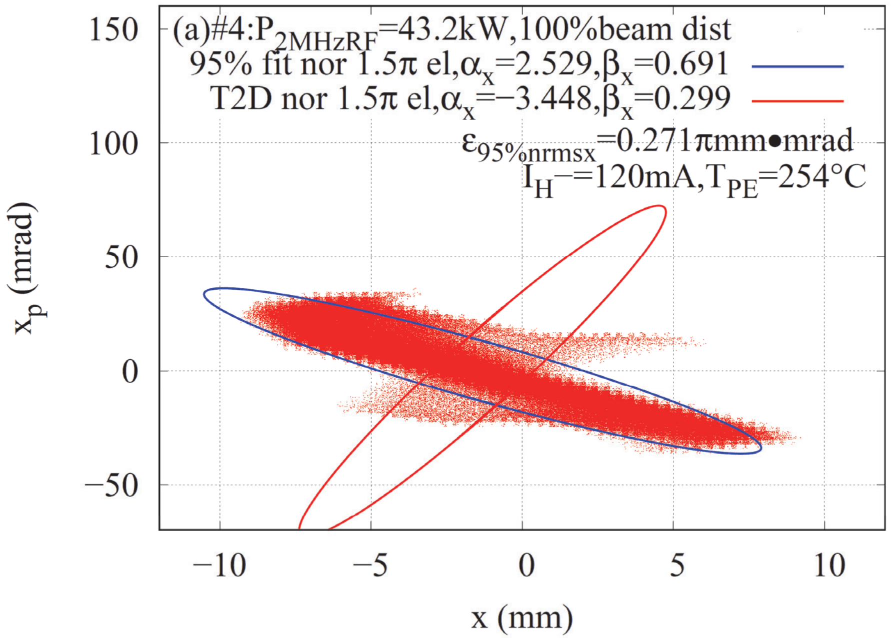

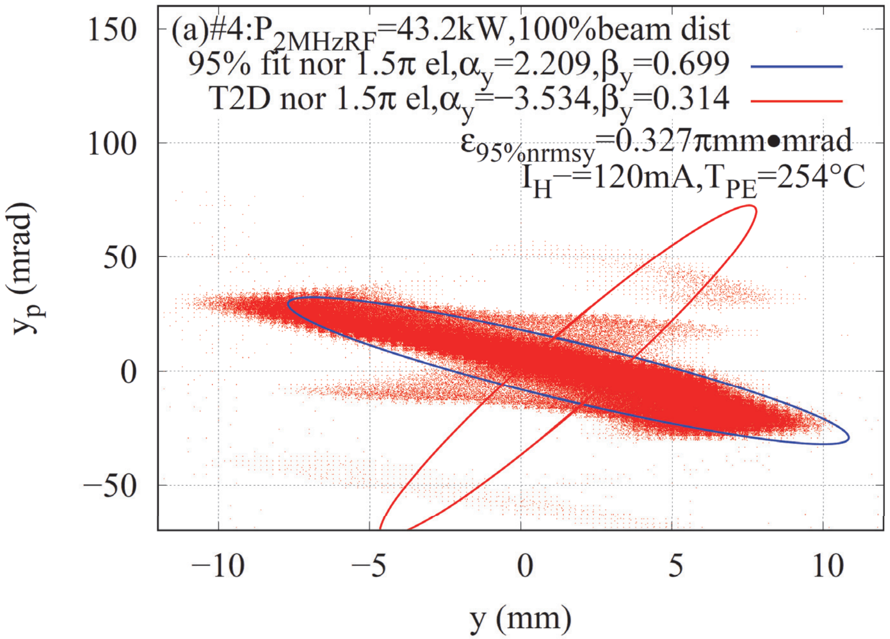

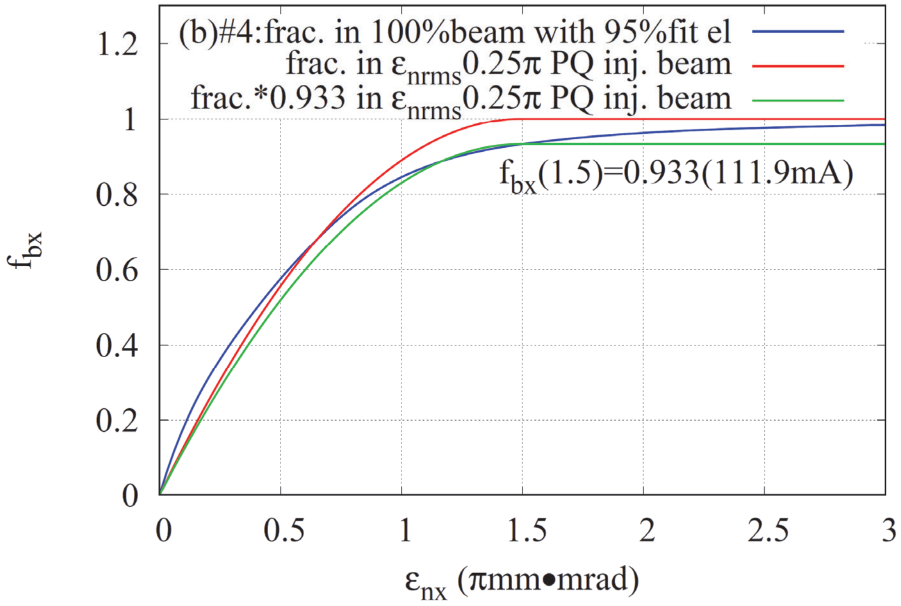

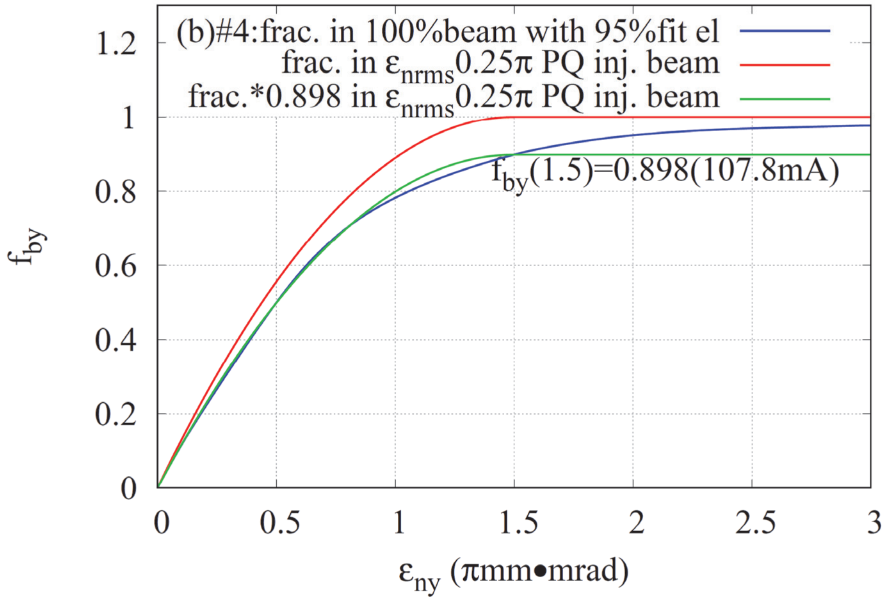

0.4 mega dots plots of H&V 100 % beam

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.