THE 6TH INTERNATIONAL SYMPOSIUM ON NEGATIVE IONS, BEAMS AND SOURCES
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Methods of Beam Emittance Measurements of High Power Negative Ion Beams for NBIs

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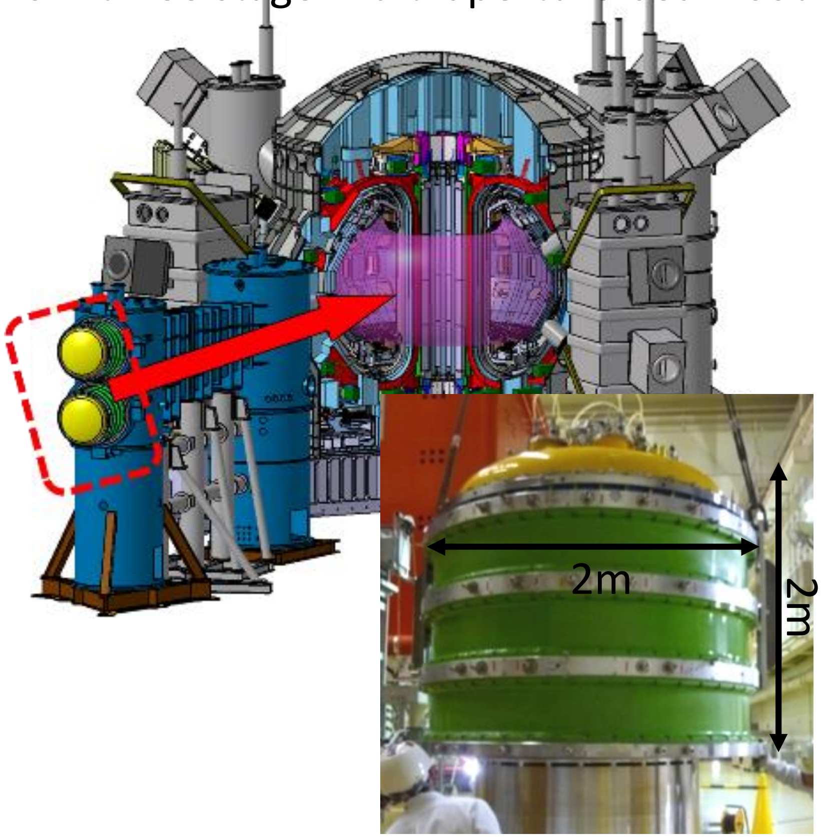
High power negative ion beam for NBIs

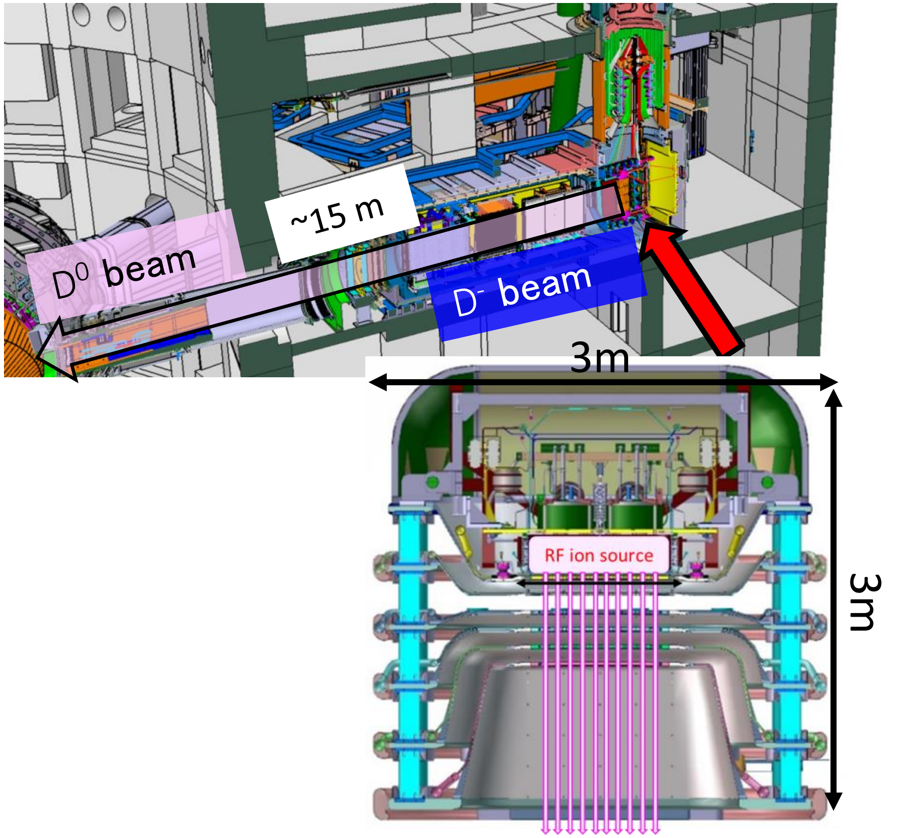
JT-60SA

0.5 MeV, 22 A (130 A/m^2) for 100s
from three stage-multi aperture beam source



ITER project

1 MeV, 40 A (200 A/m^2) for 3600 s
from five stage and multi aperture beam source

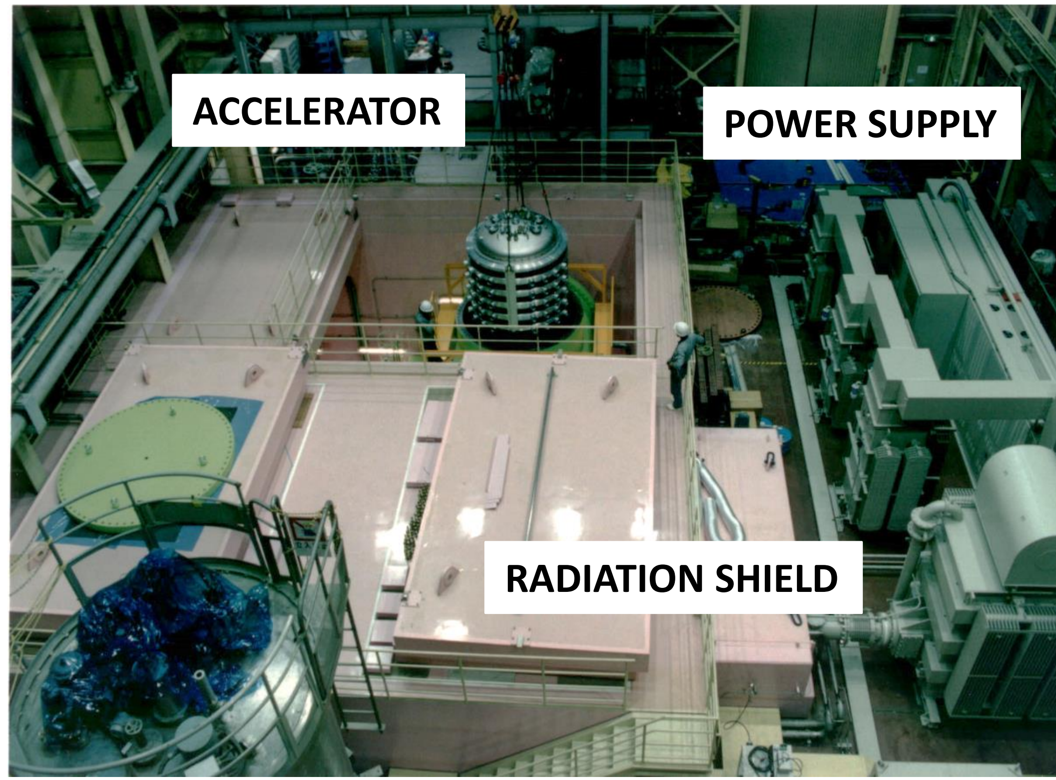


MeV ion source Test Facility (MTF) in QST

The test facility is developing the ion beam accelerator for the ITER NBI system.

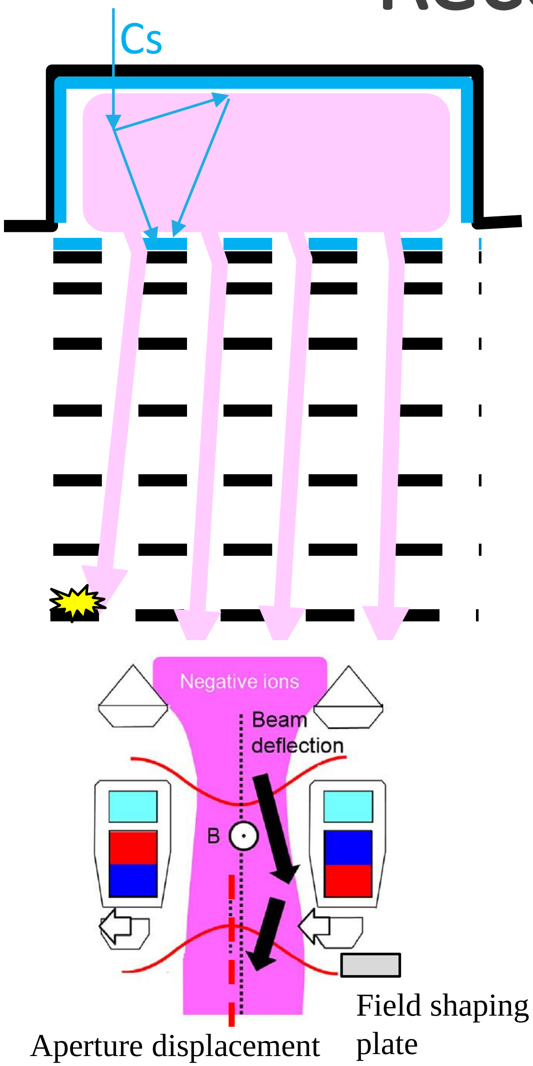
ITER REQUIREMENTS:
Beam Energy : 1 MeV
Beam Current : 40 A
Current Density : 200 A/m^2 (D^-)
Pulse Length : 3600 s

MTF specification
Beam Energy : 1 MeV
Beam Current : 1 A
Current Density : 200 A/m^2 (H^-)
Pulse Length : > 1000 s



MTF Facility in Naka Fusion Institute, Ibaraki

Recent issues and solutions



Negative ion production

Degradation of current for long pulse
→ Temperature control of chamber wall to suppress excess Cs deposition from wall to plasma grid (Dr. Yoshida (P1-09))

Negative ion acceleration

High power loading on acceleration grids due to beam deflection by magnetic field and space charge repulsion → Compensated

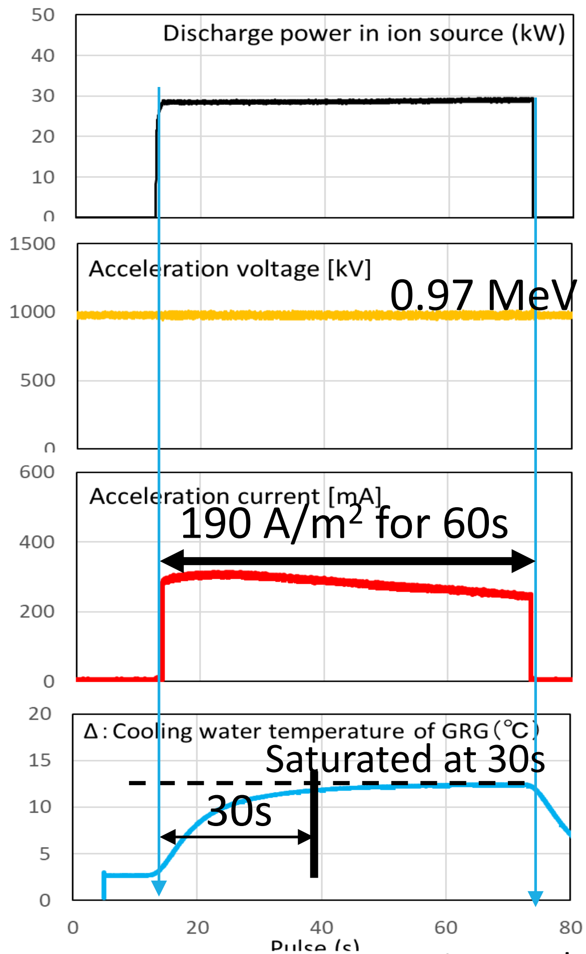
Insufficient voltage holding capability of large accelerator → Construction of experimental scaling to design large grid with multi apertures

Beam acceleration up to 60 s has been achieved.

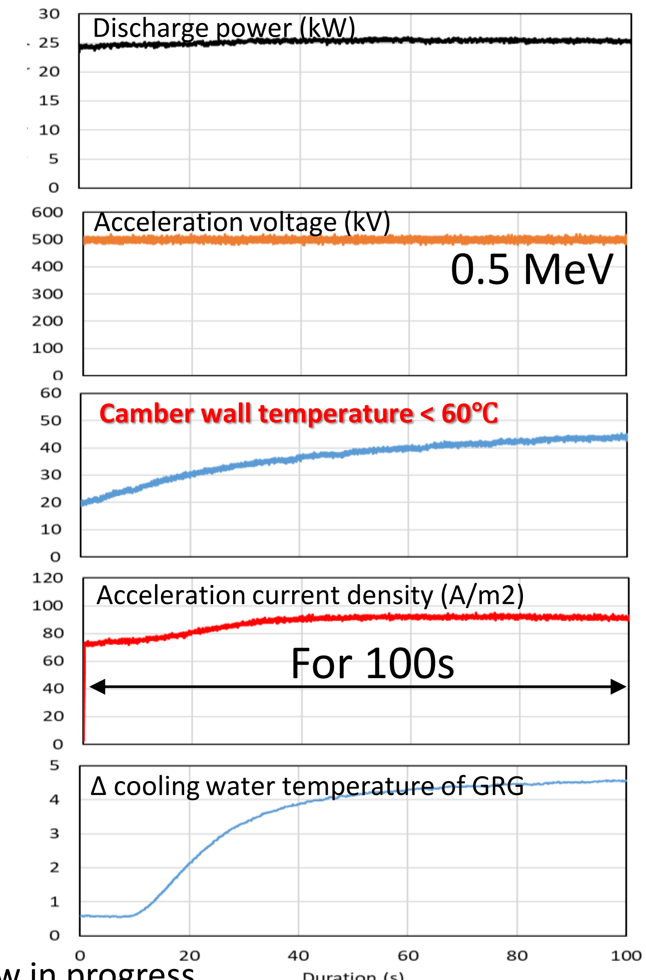
Beam acceleration over 100 s is now on-going.

Recent results

Result of five stage accelerator in 2015



Recent result using JT-60SA three stage accelerator



Long pulse tests over 100 s is now in progress.

However, precise study for this kind of high dense and large beams has not been performed yet.

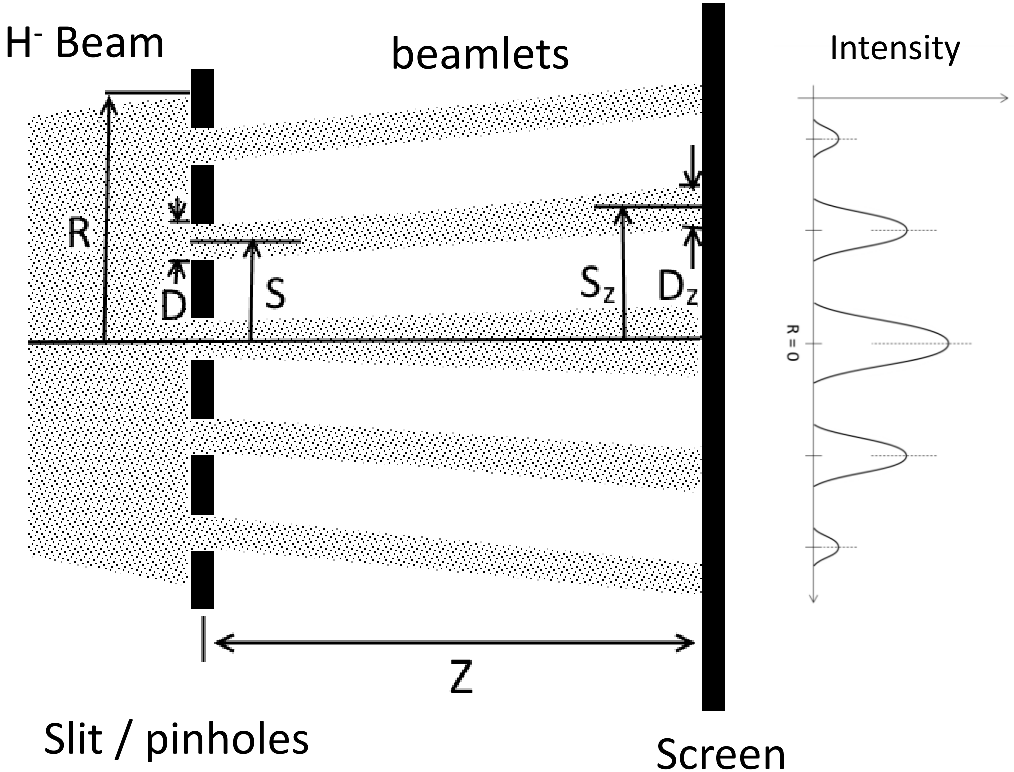
Beam Diagnostics
for 1 MeV High current density Beams

Common Measurement Methods:

Slit-and-Collector Method

Faraday cups and wire scanners.

Things to consider:
- electrical noise (i.e. secondary electrons)
- sensitivity/resolution



Imaging methods

Fluorescence due to particle beams.

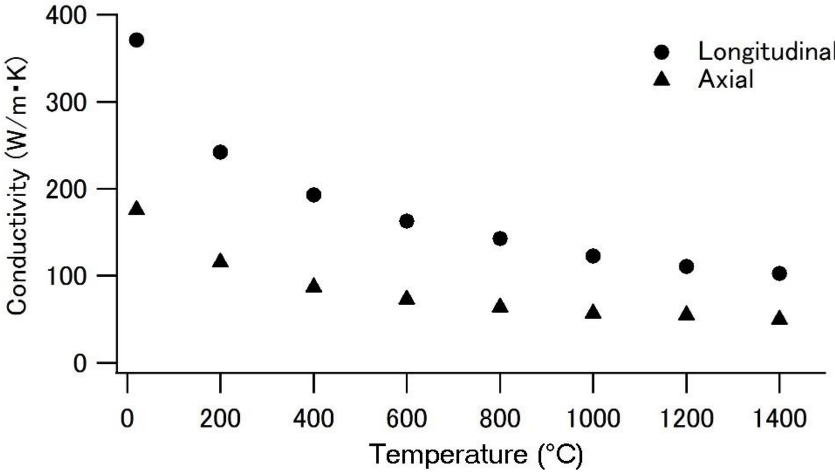
Things to consider:
- lifetime of scintillator screens

Thermal Measurement of Beam Emittance

Target Material

A one-dimensional carbon fiber composite (CFC) target is selected to measure the high power beam.

- **High heat resistance**
  (Melting Point: 2000ºC)
- **Good machining properties**
- **Low axial thermal conductivity**
- **Imaging form of measurement**



Low axial conductivity reduces the overestimation of the beam size.

Material	Thermal Expansion Coefficient (linear)	Melting Point (ºC)	Density (kg/m^3)	Specific Heat (J/kg K)
1D-CFC	**2.95**	**2000**	**1660**	**1140**
Cu	16.7	1085	8960	376.8
W	4.5	3410	19600	133.9
Mo	5	2623	10188	277.1

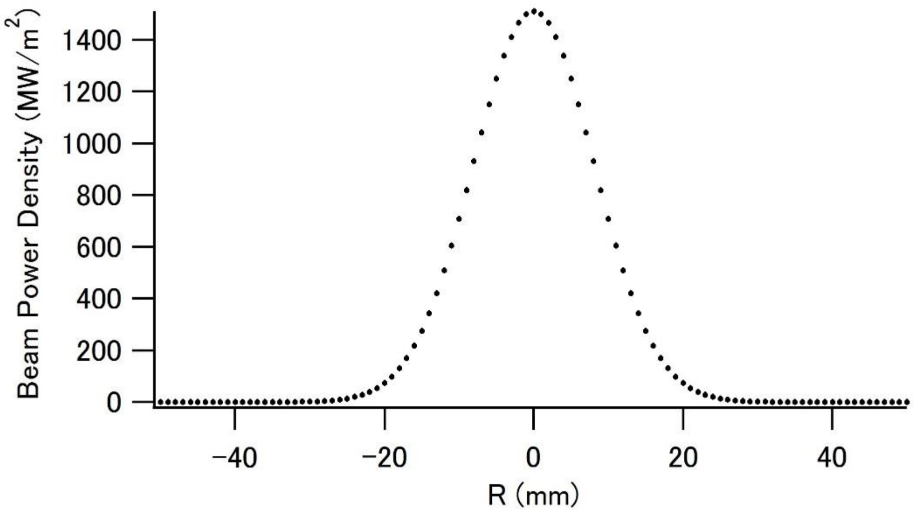
Thermal Measurement of Beam Emittance

Target Material

Previous thermal images that captured the beam footprint of a 1 MeV negative ion beam exhibited a Gaussian profile with the beam power density averaging to 200 MW/m^2.

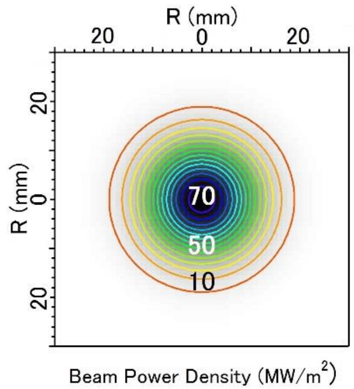
The exposure time of the beam to the CFC target will be limited when reproducing the beam footprint.

Calculation of a Gaussian profile beam
Total Beam Power Density in 1D



Peak Temp will be as high as 1400 MW/m^2

Beam Divergence : 5 mrad
Drift distance: 2.3 m
Aperture diameter: 14 mm

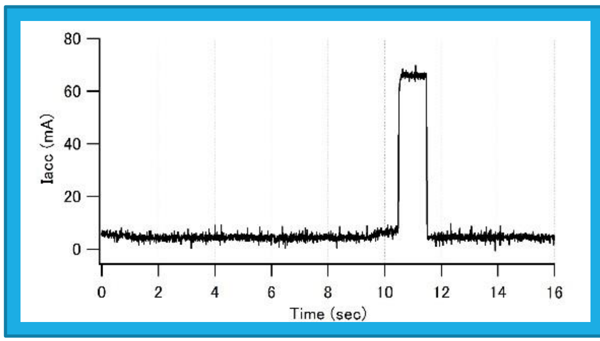


Spatial contour of the Gaussian beam

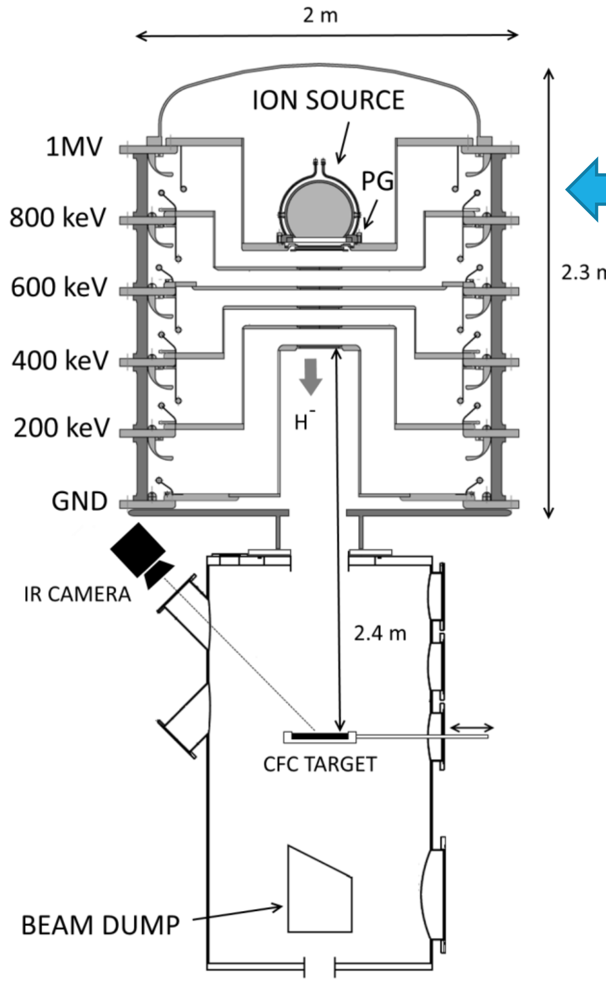
Material Parameters:
- Thickness / Dimensions
- Exposure time
- Thermal Expansion

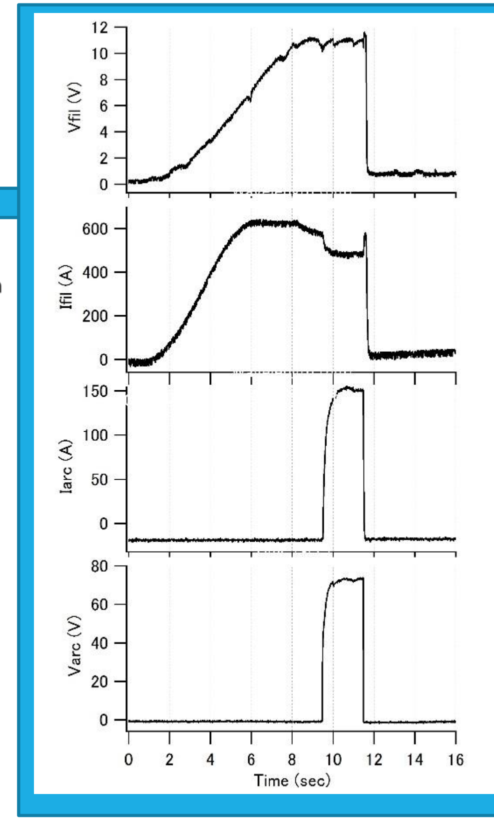
Operation of the 1 MeV Negative Ion Beam

The negative ions formed from a cesium seeded vacuum arc ion source are extracted to a multi-aperture multi-grid acceleration system.



Current measured in the accelerator

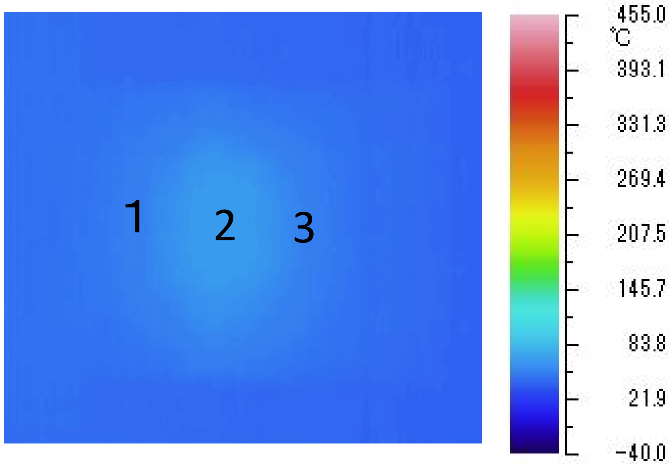




Timing sequence for operation

Operation of the 1 MeV Negative Ion Beam

Beam Profile



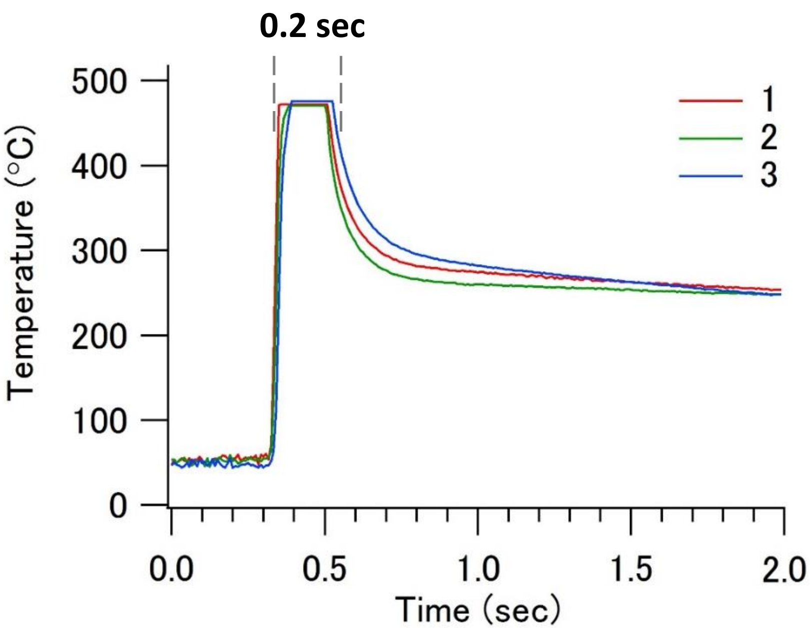
Thermal Imaging
Sampling Rate: 120 Hz
Beam Pulse: 0.2 sec

Broadening of the beam footprint at longer exposure times.

Tune to the stable beam operation

The multiple beamlet profiles of a 900 keV negative hydrogen ion beam was observed through the thermal images on the CFC target.

temperature progression in the central part → Max. Temperature Profile

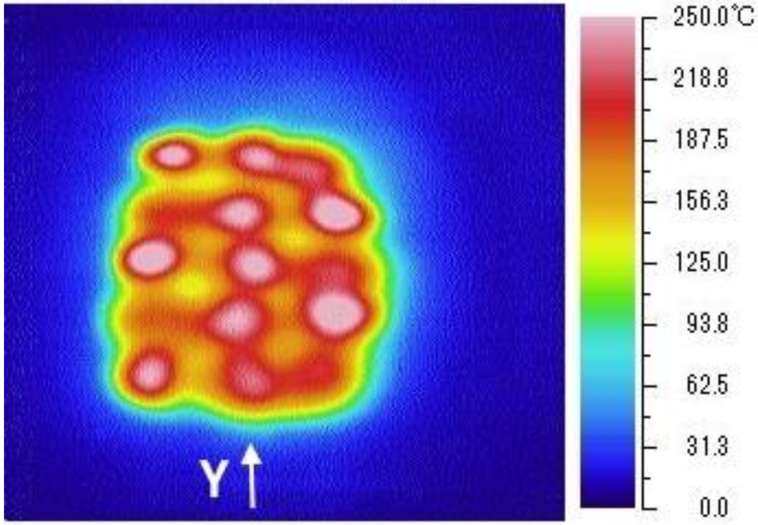


Operation of the 1 MeV Negative Ion Beam

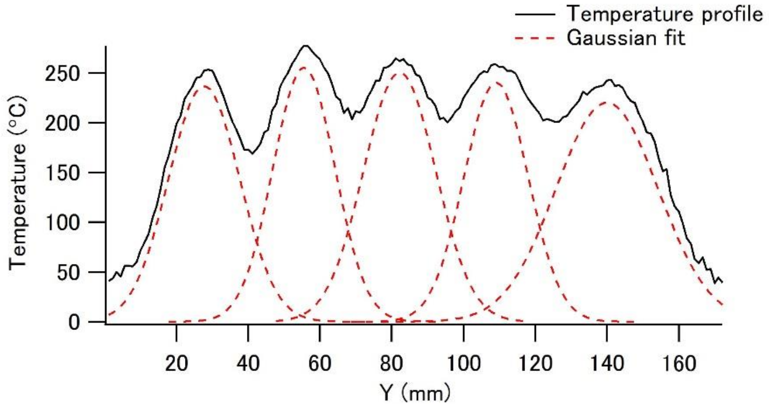
Beam Profile

Thermal images show the multiple beamlets.

Noise from the background temperature in the images were reduced.



Displacement on the beamlet alignment

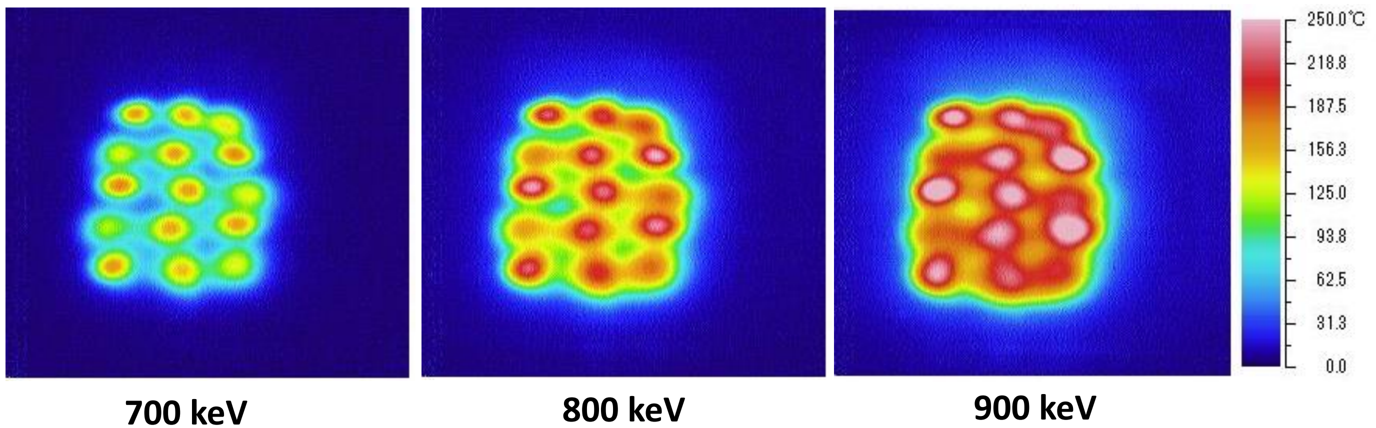


Possible reasons:

- Initial particle trajectories upon extraction
- Non-uniformity in the beam initializing phase

Operation of the 1 MeV Negative Ion Beam

Beam Profile



Vacc (keV)	Parc (kW)	Vext (kV)
700	24	3.7
800	34	4.3
900	43	4.8

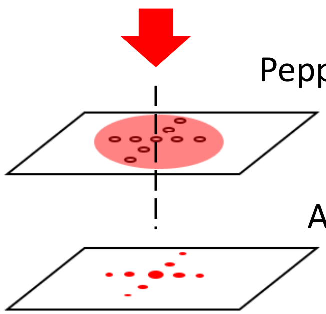
- Some parameters for beam optics

At 900 keV, the observed beamlet diameters became concentrated.

Increasing the beam energy also increased the temperature in the thermal images

This relation is important for image analysis

Intensity response determines the reliability of the beam emittance experiment

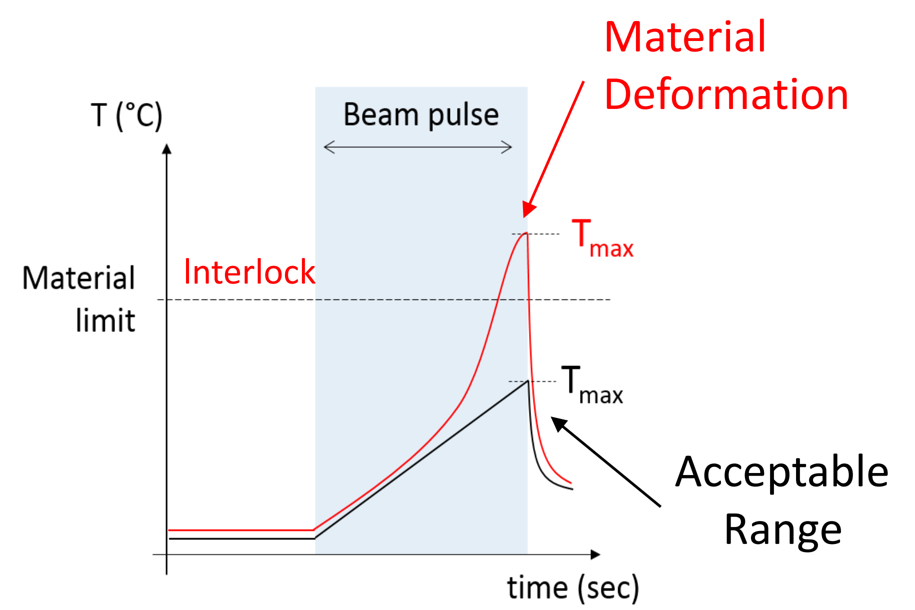


Diagnostics for 1 MeV Negative Ion Beam

Beam Emittance Application

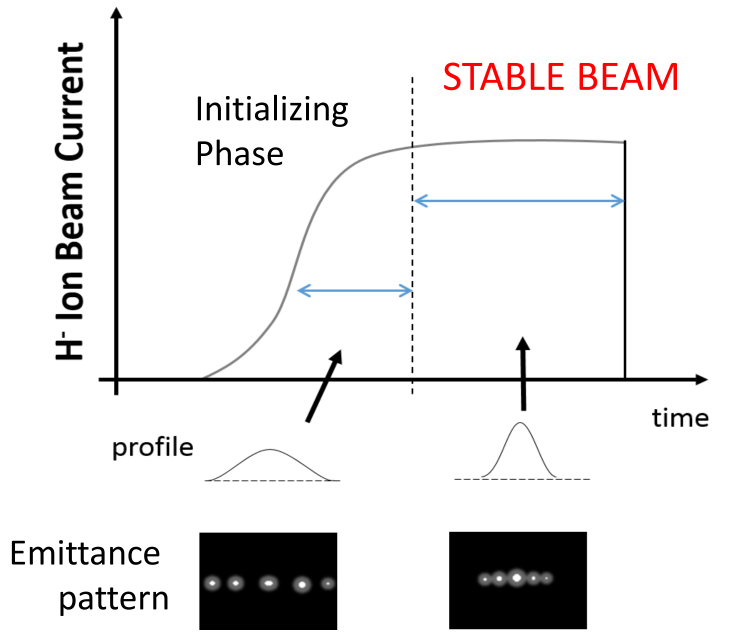
Main Concerns:

Temperature Range of the Measurement



Phases of the Beam

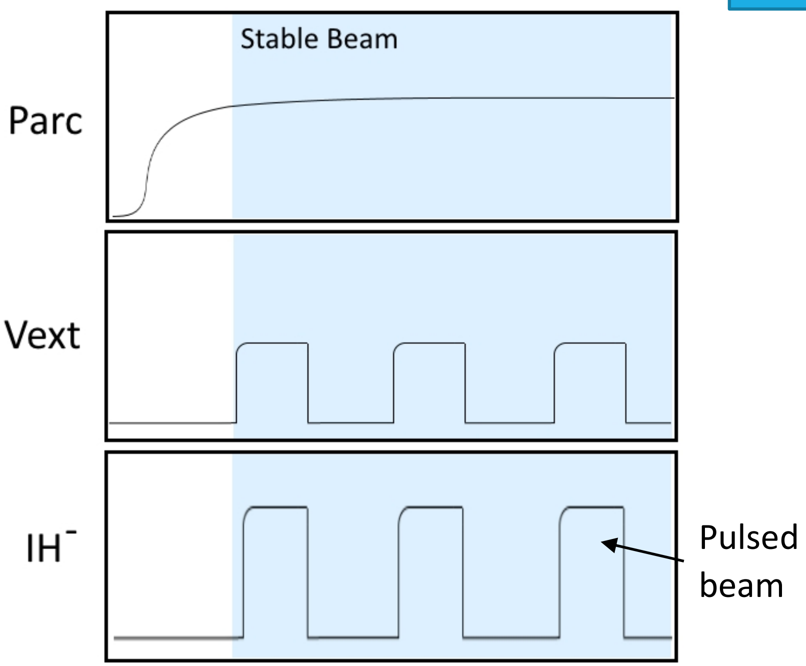
Tuning the measurement to match the stable beam phase



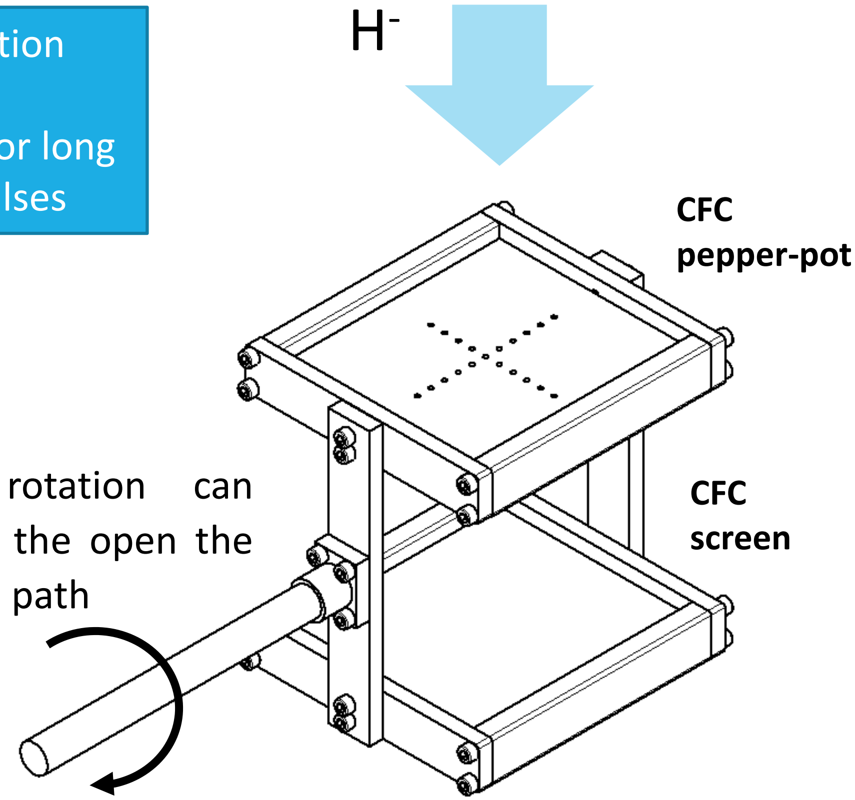
Diagnostics for 1 MeV Negative Ion Beam

Measurement Schemes

To assure that the measured beam is stable, the ion source will operate continuously.



Beam selection scheme is necessary for long H- beam pulses



90° rotation can allow the open the beam path

Possible mechanisms for continuous beam monitoring.

Summary

1 MeV High Power Beam

High Beam Power Densities

Challenge for Beam Diagnostics :

High voltage components of the accelerator

High temperature heat loading

(Long) Beam Pulse Operation

Thermal Beam Emittance Measurement Method

1D – Carbon-Fiber Composite

Advantages:

Imaging form of measurement

CFC has a high heat resistance

Measurement schemes are possible

Beam diagnostics of the 1MeV H^- beam is possible with the thermal beam emittance measurement. This method is being developed specifically for ITER class beams for NBI systems

Thank you for your attention