High Power Density Beam Measurement of a Single Beamlet from a Multi-Grid Prototype H- Negative Ion Accelerator

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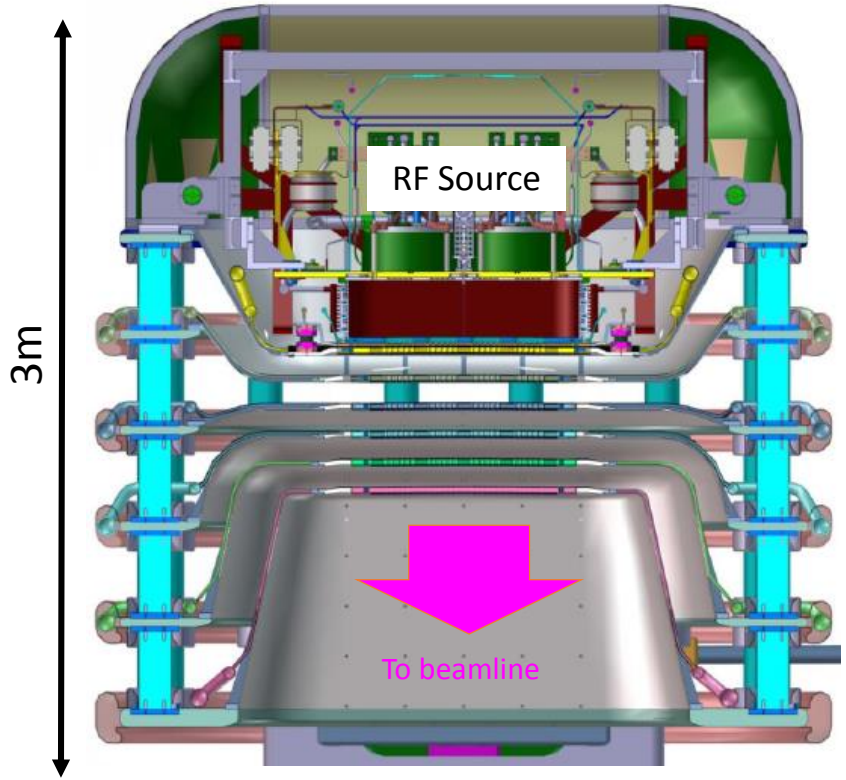
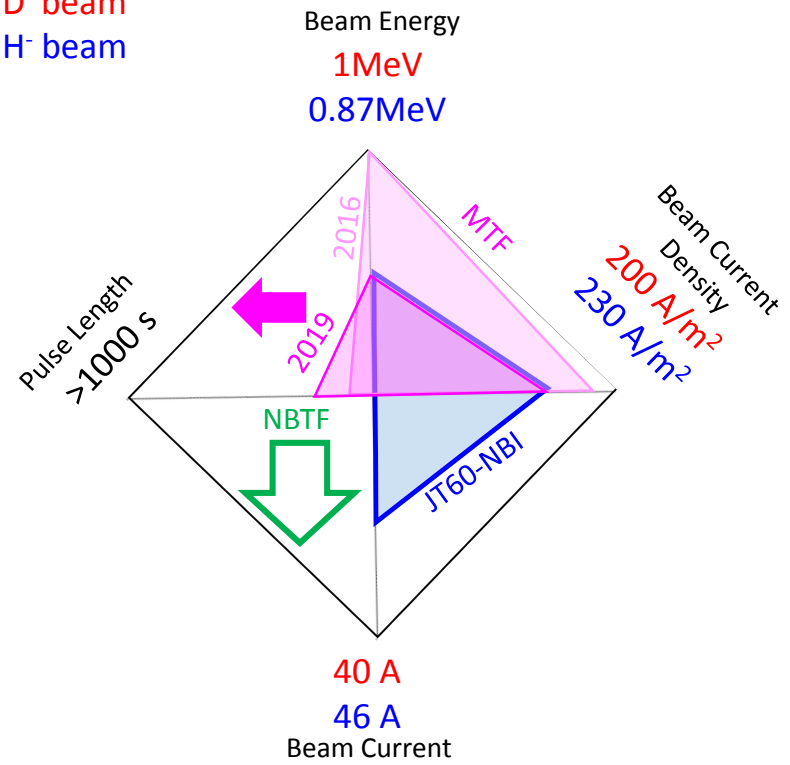
Toward ITER-relevant intense beam acceleration

ITER NBI Accelerator
3m

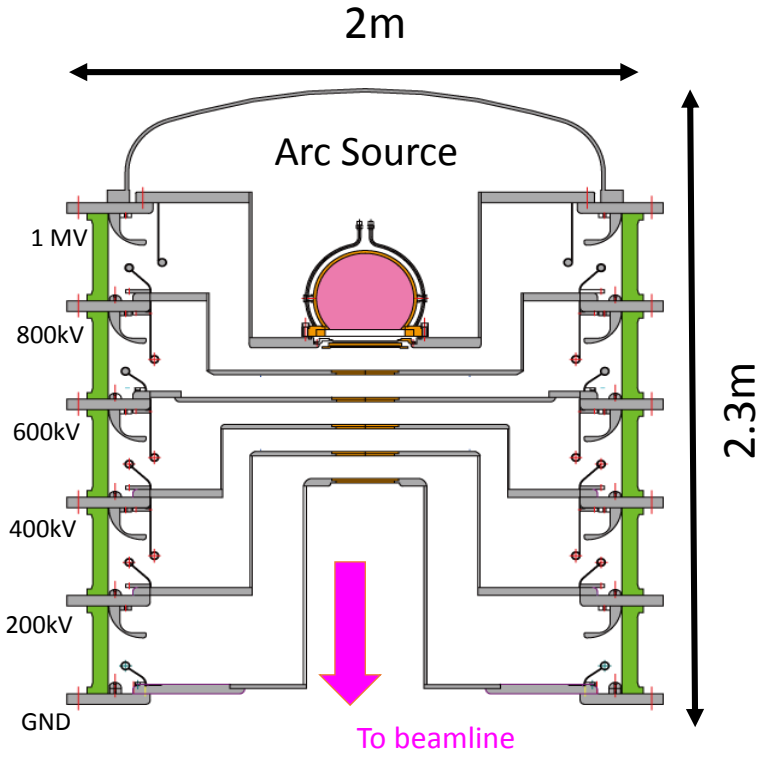


Accelerators for NBI systems:

ITER Requirement for:
D^- beam
H^- beam



MeV Test Facility
5-stage Multi-grid Accelerator

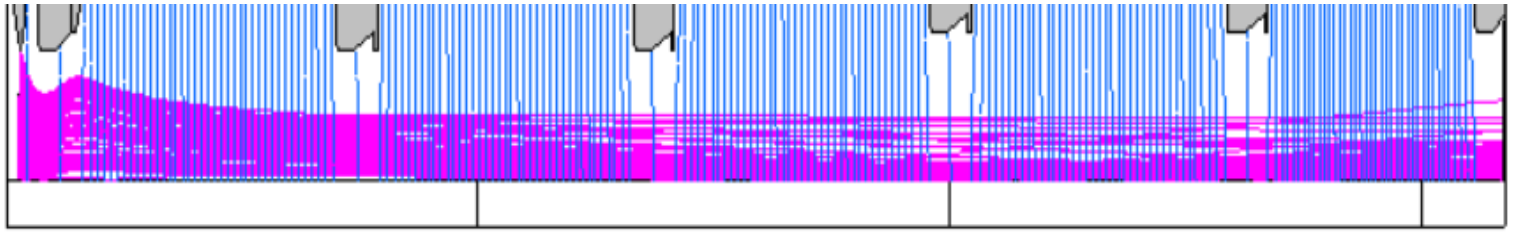


★ H- beam acceleration with 0.97 MeV, 190A/m^2 for 60s was achieved.
Next target is to generate 0.87 MeV, 230 A/m^2 for > 100 s H^- beam, which simulates the ITER target perveance.

1MeV Multi-Stage Accelerator Design

At first, the D- beam parameters were first realized and the pulse length was sucessfully extended up to 60s.

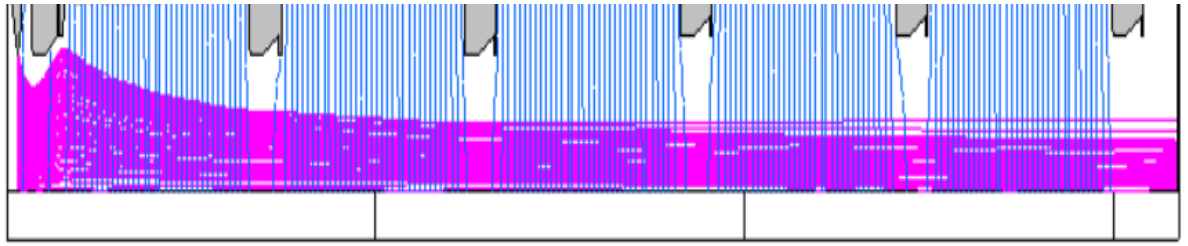
Accelerator Gap (109 mm)
Beam Energy: 1 MeV
Meniscus: 220 A/m^2
GND Grid: 200A/m^2

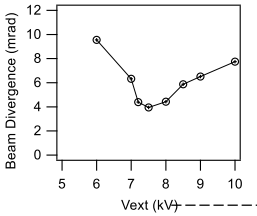


To achieve the next target beam conditions, the accelerator is matched to the ITER accelerator design where the gap length was reduced from 109mm to 88mm.

Using BEAMORBT, a 2D trajectory beam analysis code, the beam using the ITER-like accelerator (88mm gap) was calculated and showed a narrow beam with a divergence of 4mrad, which is within the required value.

Accelerator Gap (88 mm)
Beam Energy: 870 keV
Meniscus: 255 A/m^2
GND Grid: 230 A/m^2



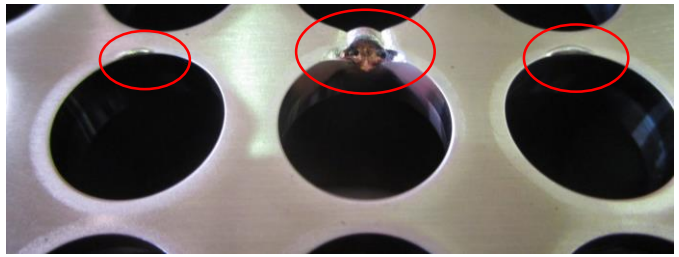


Shortening the gap length to 88 mm, the extracted current density at optimum beam optics should reach the ITER target perveance of 280 A/m^2/MV.

Issues for long pulse beam operation: Unclear physics of negative ion extraction

Current issues in the accelerator:

- Divergent beam components are intercepted on the grid apertures and melting the surface.

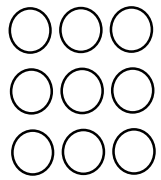


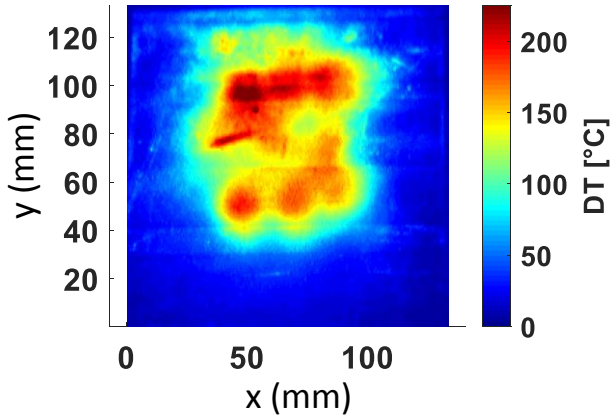
※Damages to the GND grid during the 60s beam pulse expt.

The beam pulse cannot be extended without resolving this issue.

- Peripheral region of the beam causes unwanted power loads on the accelerator.

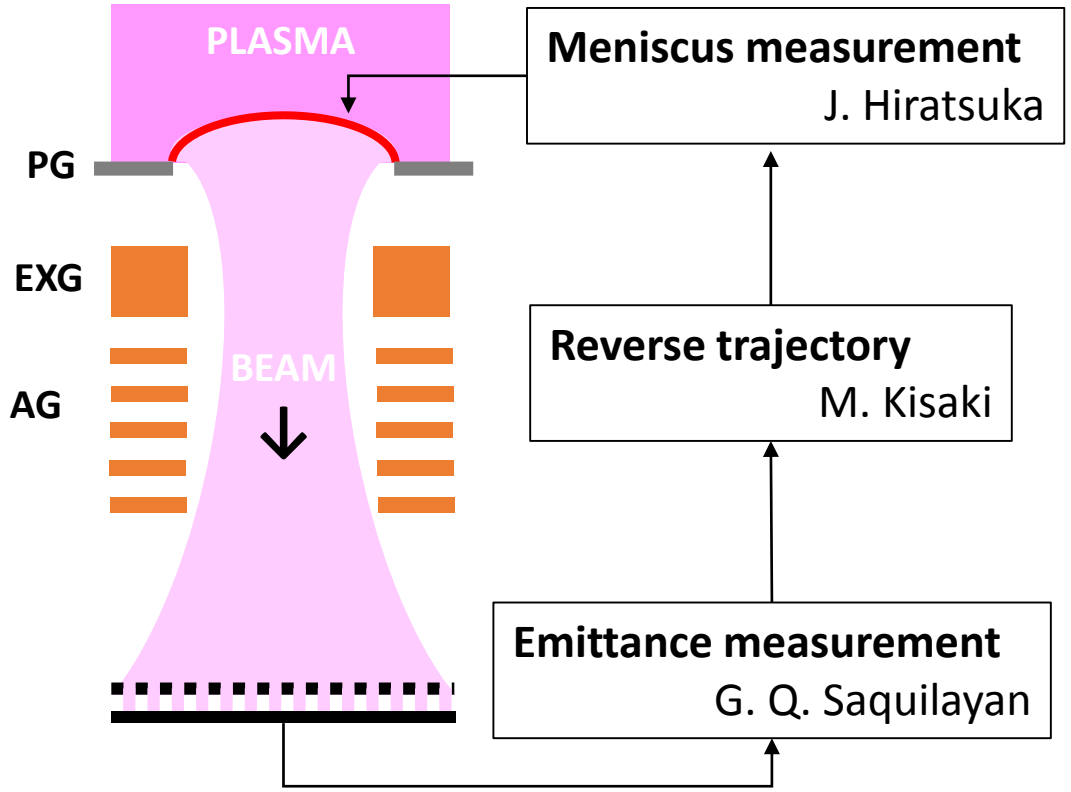
3x3 beam





To study the optics of multi-beams, the core and peripheral beam region for an H- beam should be investigated.

Reverse engineering of the Accelerator



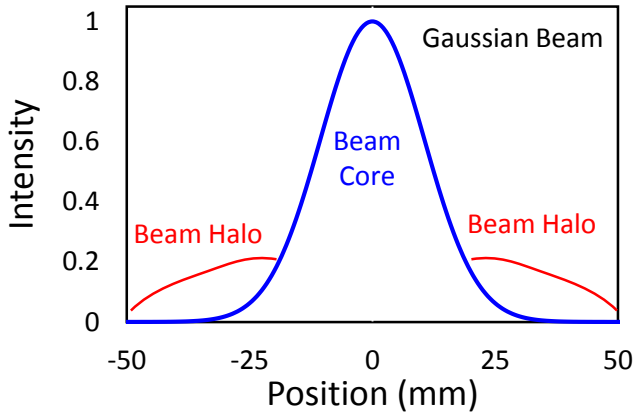
As part of the beam accelerator development, the overall beam is studied from the **Beam Emittance Measurement** to the **Reverse Trajectory Calculation** leading to the **Meniscus Measurement**.

Beam Diagnostics for High Power Beams

Beam Optics Study on the ITER-like beam:

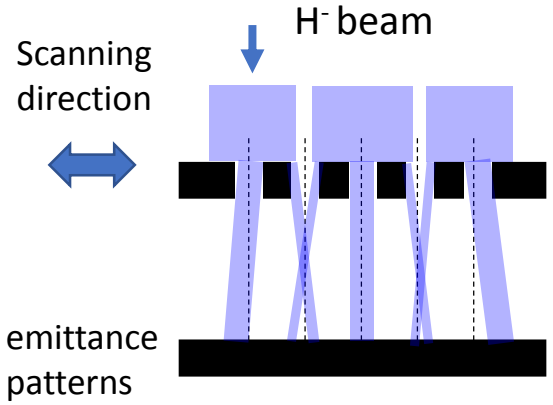
To investigate the beam optics and examine any possible beam abnormality that may be detrimental to the accelerator, we want to observe the core and halo region.

*The beam halo is considered to be outside the distribution of a gaussian beam.

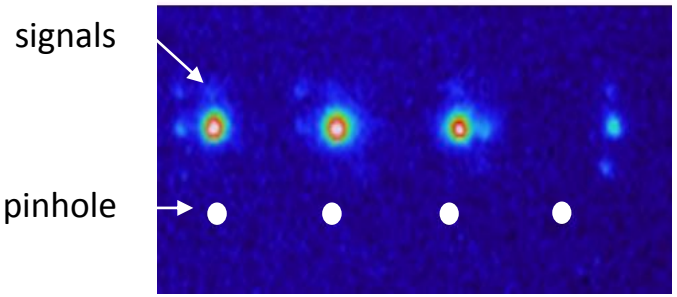


First, the measurement method was tested to distinguish the beam core and the halo region through a pepperpot beam emittance measurement of a 500keV multiple beam.

To withstand the high power load of 1MeV beams (~200 MW/m^2), IR imaging on a 1-D carbon fiber composite (CFC) target is selected due to its high heat resistance and low axial thermal conductivity.



IR image of the Emittance pattern



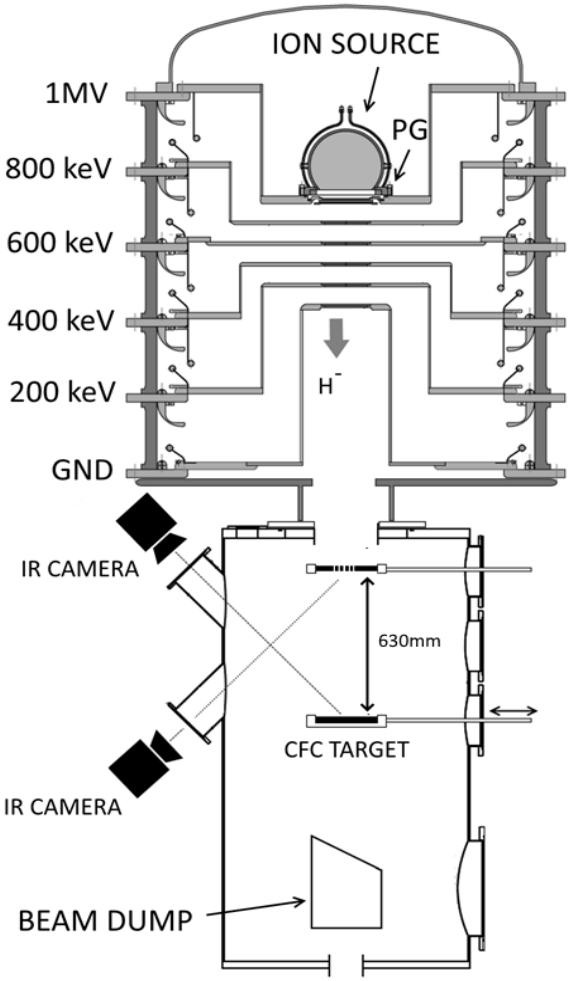
Measured patterns show multiple signals from different beamlets

*To reduce the contribution of thermal conductivity in the IR image, the frame in the IR video was extracted by examining the temperature variation rate was during the beam pulse.

However, the analysis of multiple beams is challenging due to the **superimposed signal patterns** and **weak intensities** on the beam edge.

⇒To investigate the core and halo regions carefully, a single beam is used to simplify the emittance analysis.

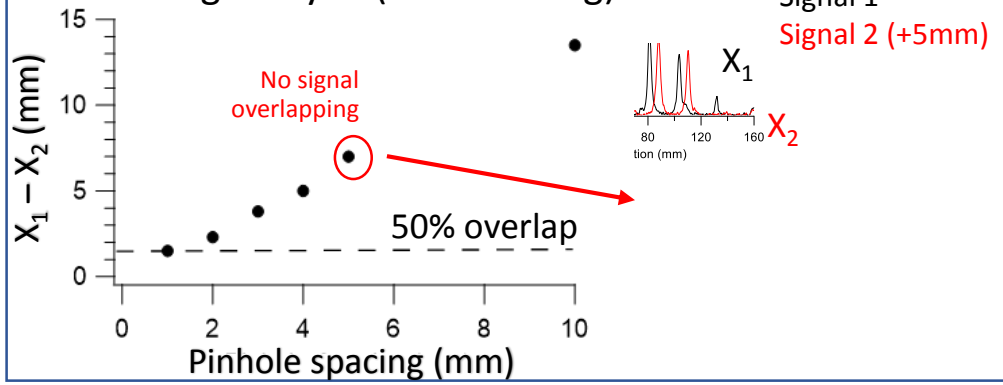
Development of an Emittance Measurement for High Power Beams



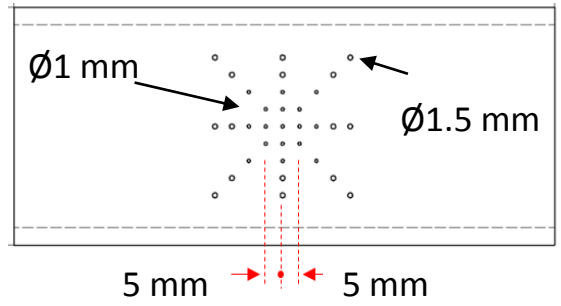
Ideas to improve the emittance measurement of the beam periphery:

① Reduce overlapping beamlet signals ⇒ Distance/spacing of the pinholes
② Measurement of divergent beam ⇒ Pinhole dimension (diameter size) and arrangement
③ Analysis of the beam trajectory ⇒ Simultaneous measurement of profile and emittance

① For 5mrad beams, the 5mm pinhole spacing allows the signals to be distinguished clearly during analysis (Gauss fitting).



② The pinhole diameter (outer edge of the beam) was enlarged to intensify the signals

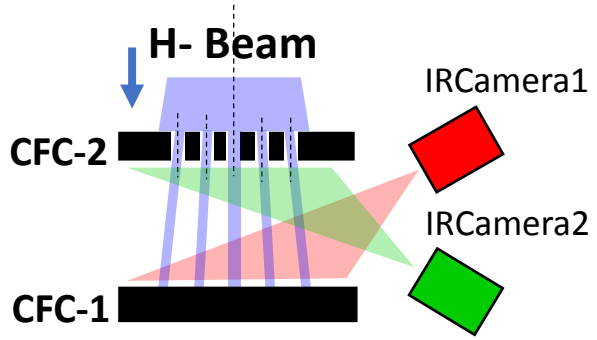


Design for the pinhole arrangement

③ In the measurement analysis, the location of the pinholes in reference to the beam axis is important.

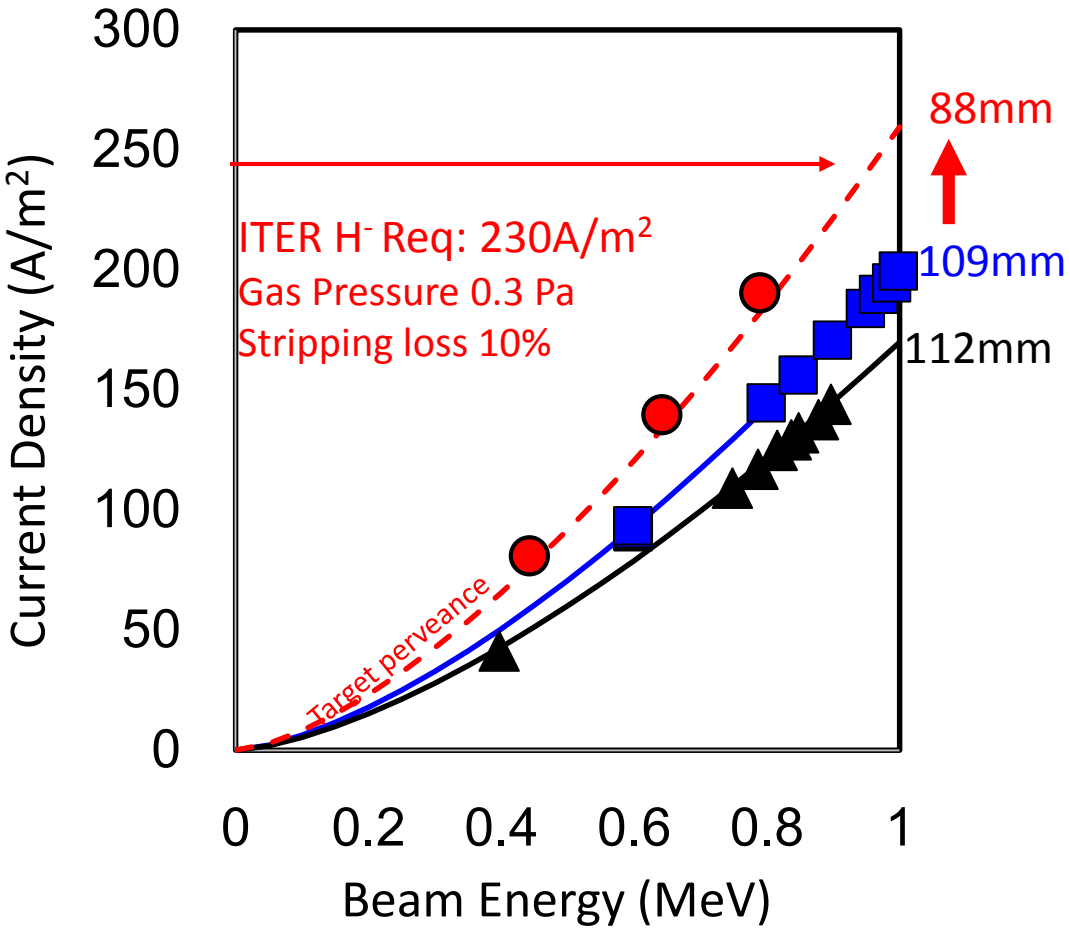
To ensure the alignment, the IR images are used to locate and correct the pinhole location centered to the beam.

Both beam profile and emittance pattern can be measured simultaneously

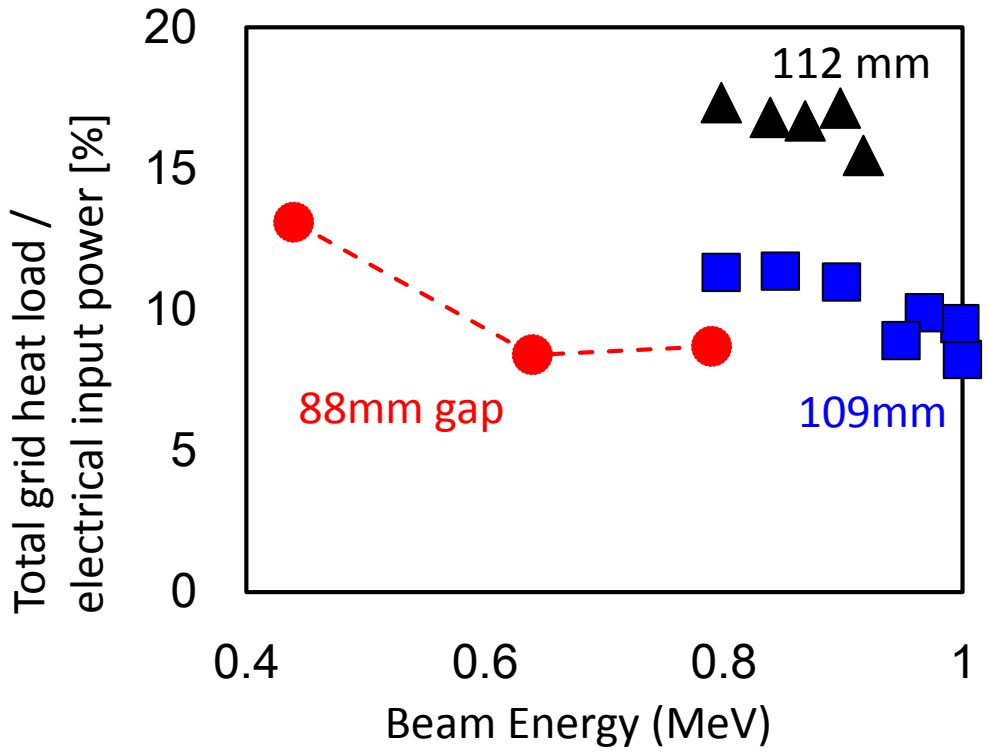


Experimental condition : ITER perveance matched condition

The performance of the ITER accelerator was tested through the beam acceleration test. The accelerated beam has reached the target perveance of 280A/m²/mV.



During the beam test, the accelerator grid heat loads for the accelerated beam energy was reduced to less than 10% of the total input power.

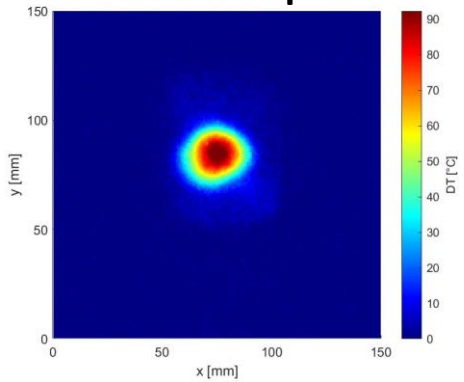


The grid heatloads for the 88mm accelerator gap and is within the allowable range for long pulse beams.

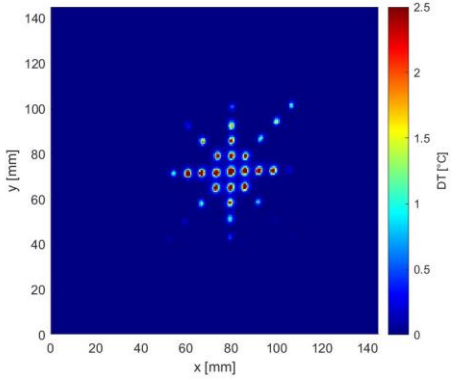
Emittance measurement of High Current Density Beam

The beam emittance of the 790keV H^- beam at the target perveance was measured for the first time.

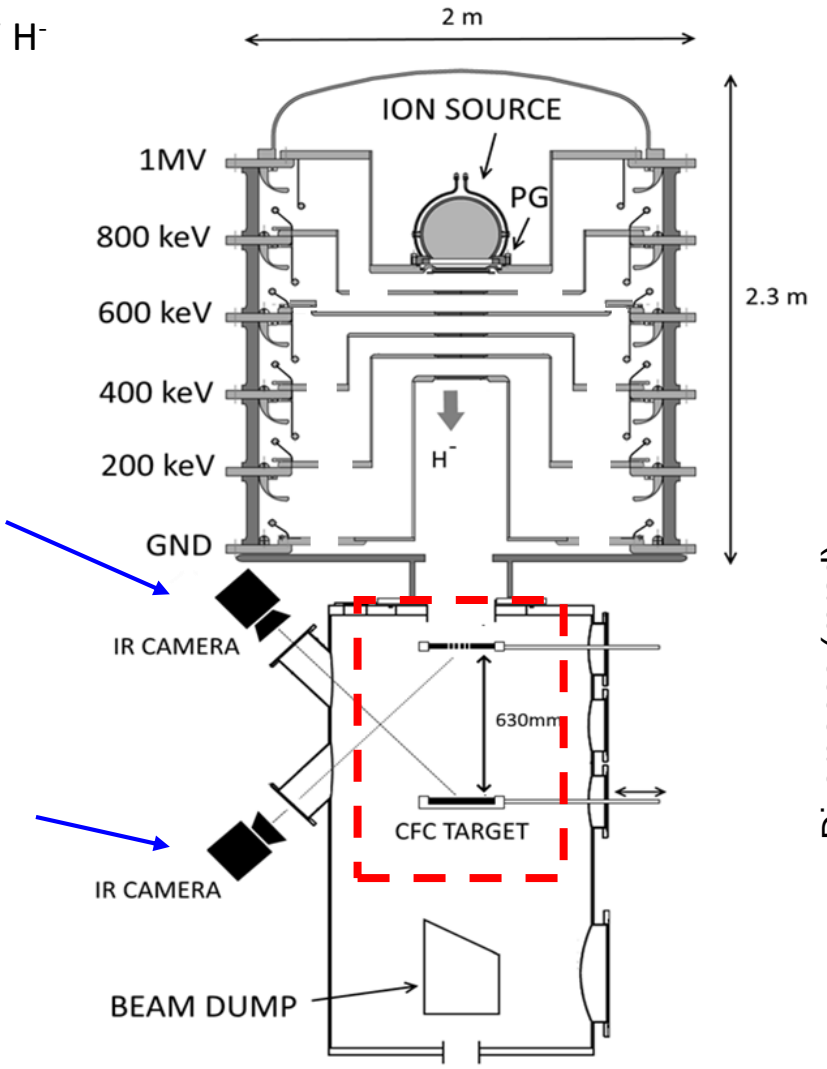
Beam Footprint



Emittance Pattern

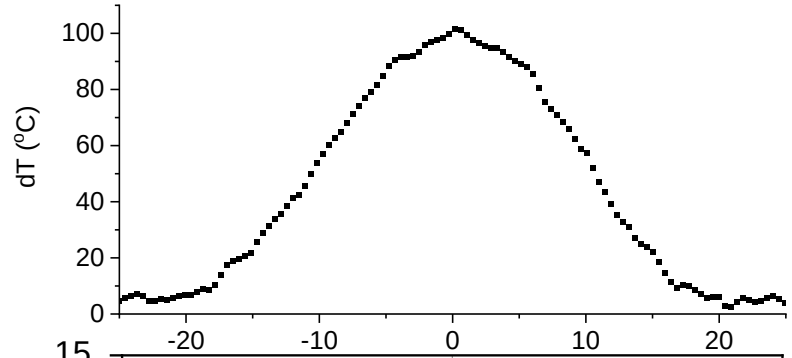


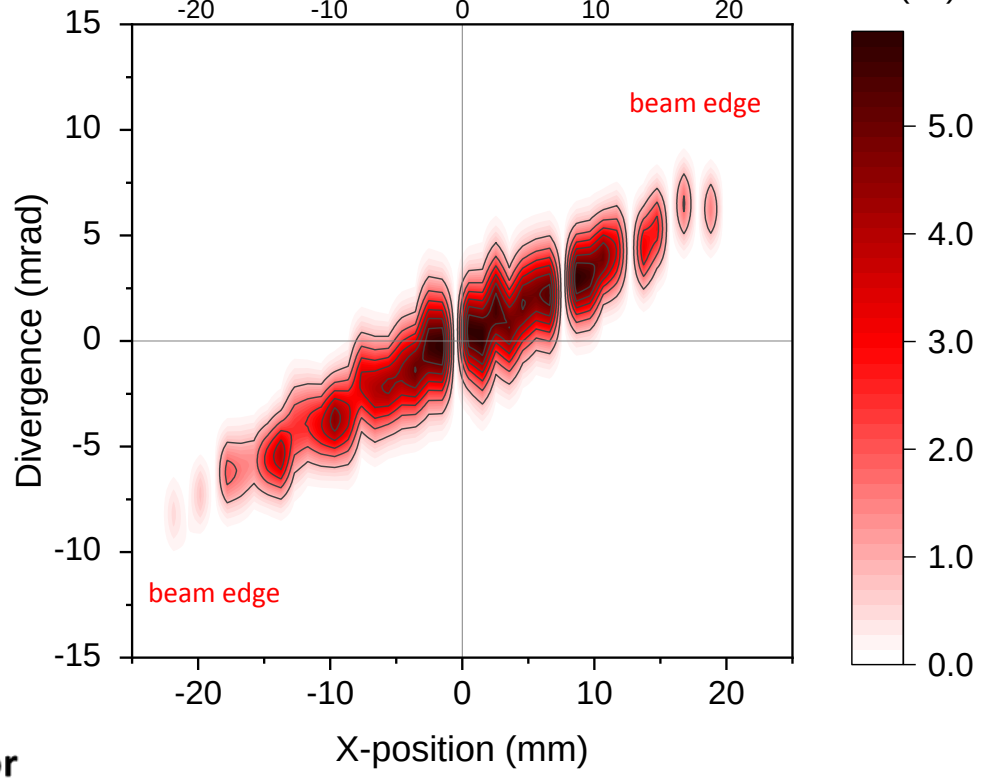
Both profile and emittance could be measured simultaneously.



Cross-section of the 5-stage accelerator

Beam Profile

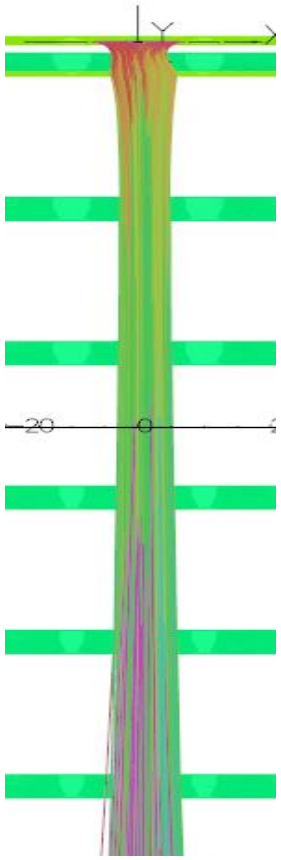




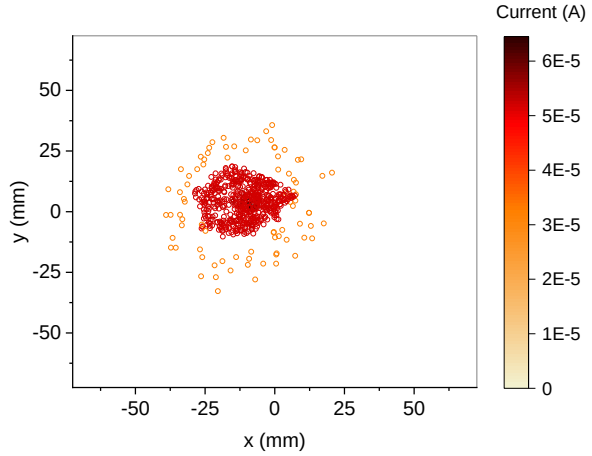
Beam Emittance

Emittance measurement of High Current Density Beam

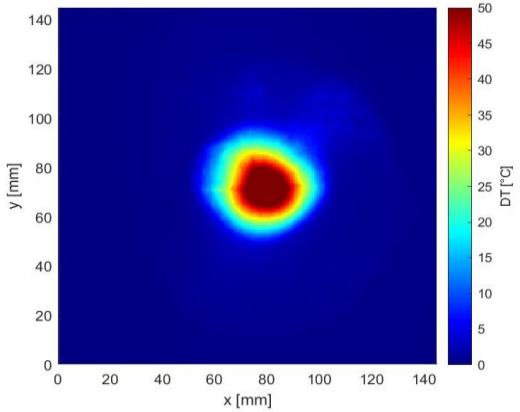
A finite element analysis software (3DOPERA) for beam analysis was used to simulate the 790keV H^- beam acceleration.

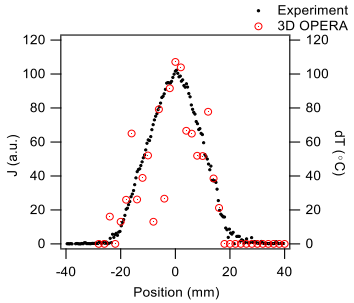


3D OPERA

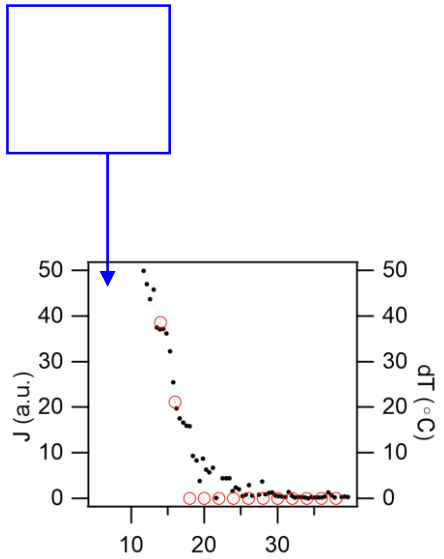


Experiment





Experiment:
Vext = 7.1kV
Beam Energy =790 keV
Current density = 195 A/m^2
(at beamdump)
3D Opera:
Vext = 7.1kV
Beam Energy =790 keV
Current density= 215 A/m^2
(at the meniscus)

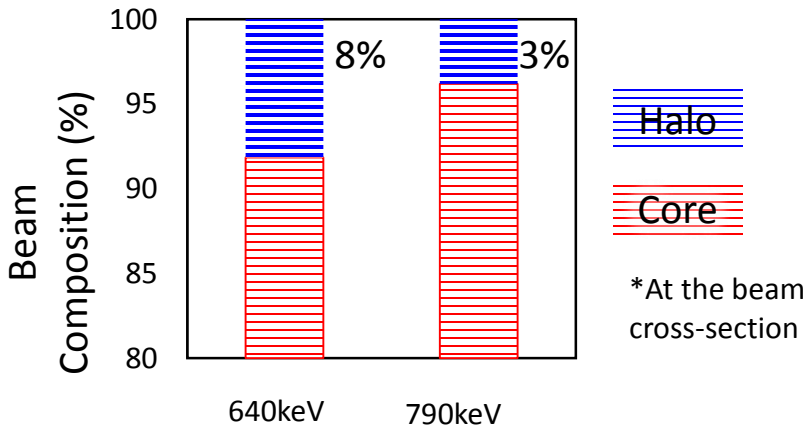


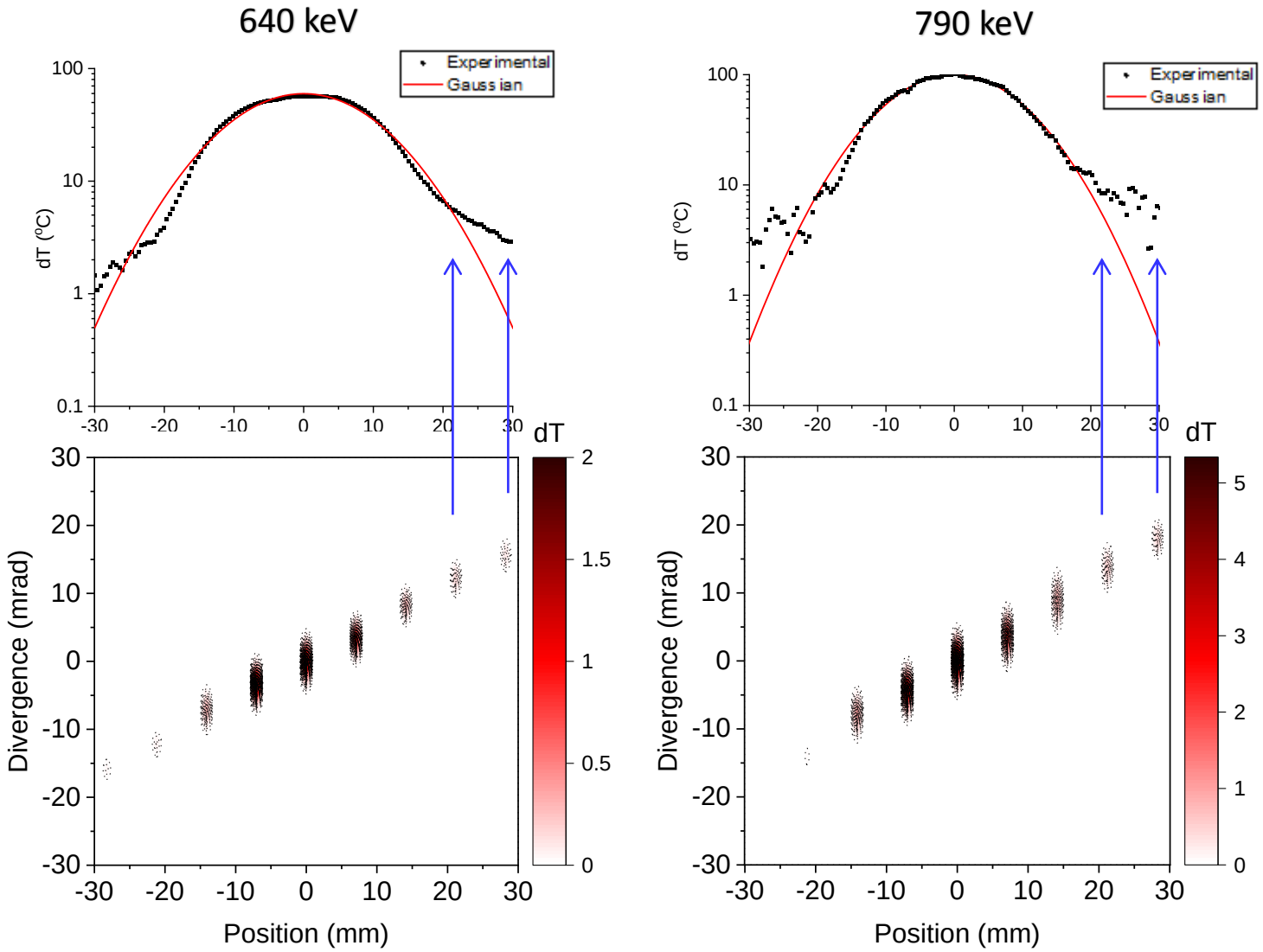
- Simulations of the H- beam with similar conditions to the experiment were analysed.
- The similar beam shape was observed with beam core diameter but with varying signal intensities.
  - Thermal Profile: 23 mm
  - Simulations: 24 mm
- Although the beam core is similar the beam edge is different in the experiment.

Investigation of the beam edge through emittance measurements

The beam emittance and profile was measured simultaneously to distinguish the beam edge.

- Weak intensities at the beam edge, are confirmed to be part of the beam as measured in the beam emittance.
- For 640keV and 790keV beam, the beam halo signals were both present with similar divergences of up to 20mrad.





Summary

→ Beam acceleration test for the ITER-like accelerator has demonstrated H- beam at the ITER target perveance.

→ Using the newly designed beam measurement method for high current density beams, the emittance of a single beamlet was successfully measured.

→ Beam emittance at the ITER perveance is within the requirement of 7mrad with divergences of up to 20mrad at less than 3% of the beam.

→ For the beam at ITER perveance, long pulse operation is possible due to the small beam halo component which resulted to low total accelerator grid heat loads.