Recent status of negative Ion based NBI system for long pulse operation on JT-60U

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JAERI, *PPPL

1. Introduction
2. Progress of pulse duration
3. Beam steering
4. Stripping loss
5. Control of arc discharge
6. Summary

JT-60U NBI

1. Introduction

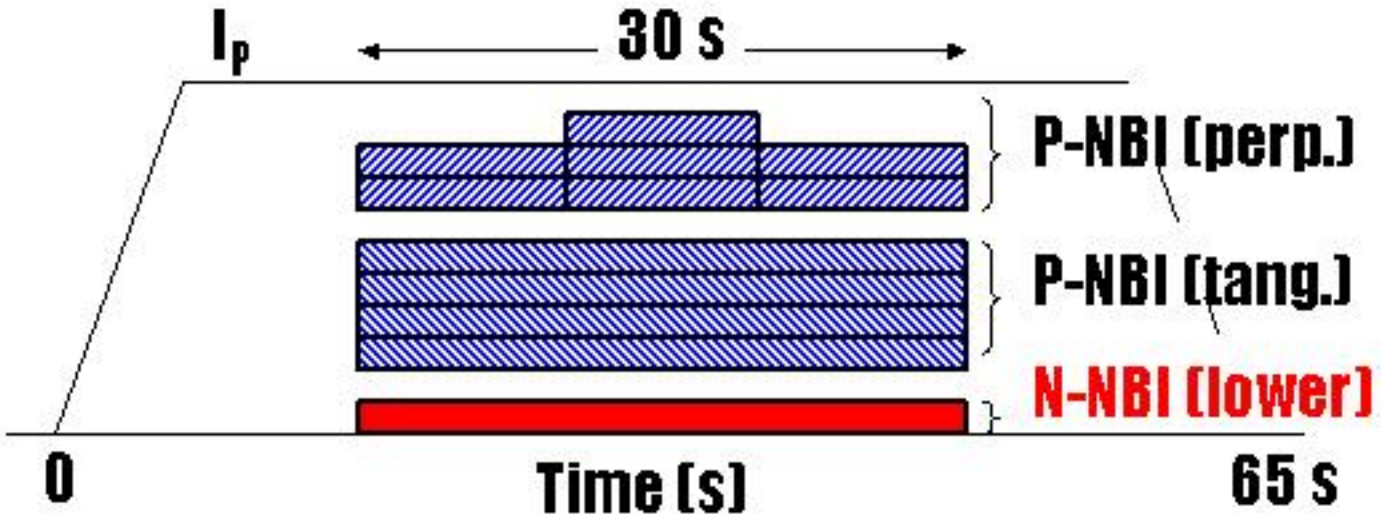
JT-60U : Long pulse operation of plasma current up to 65 s

NBI system : pulse extension from 10 s to 30 s

P-NBI : Tangential units (2MW × 30s,4units)

: Perpendicular units (2MW × 10s,7units)

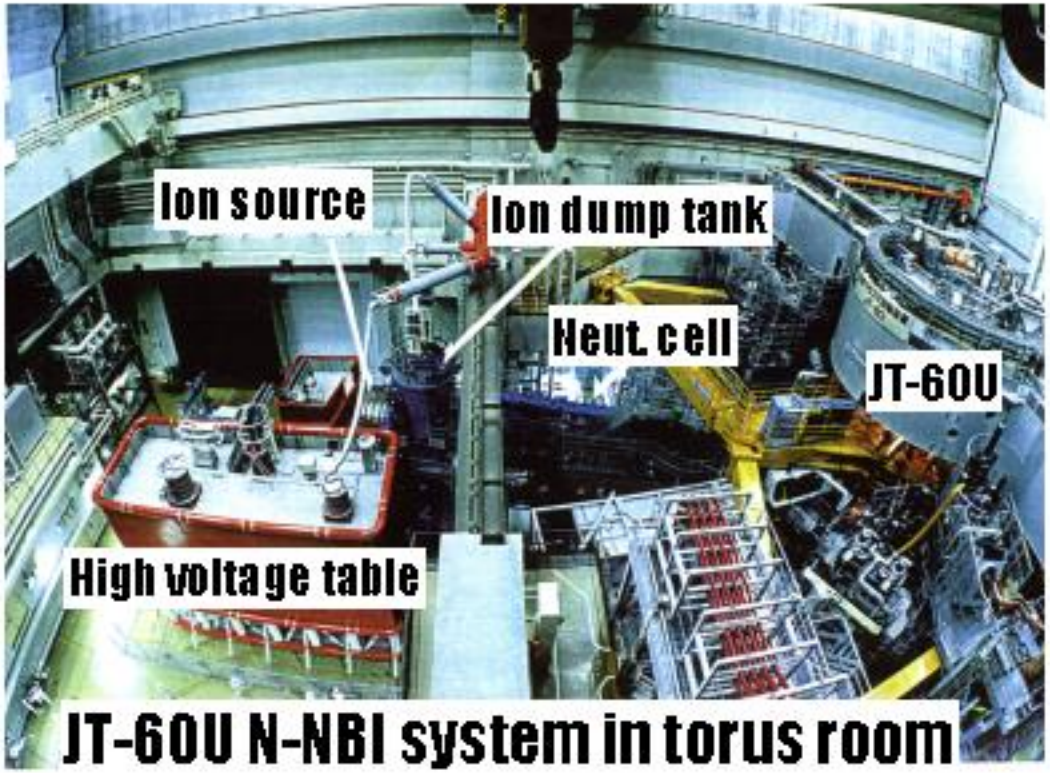
N-NBI : Lower ion source (2MW × 30s,1unit)



JT-60U NBI

Modification for long pulse operation

JT-60U N-NBI system has been modified to achieve long pulse operation up to 30 s.



JT-60U N-NBI system in torus room

Main modifications

- Ion source
- Beam line
- Power supply
- Control system

JT-60U NBI

Issues of Ion source

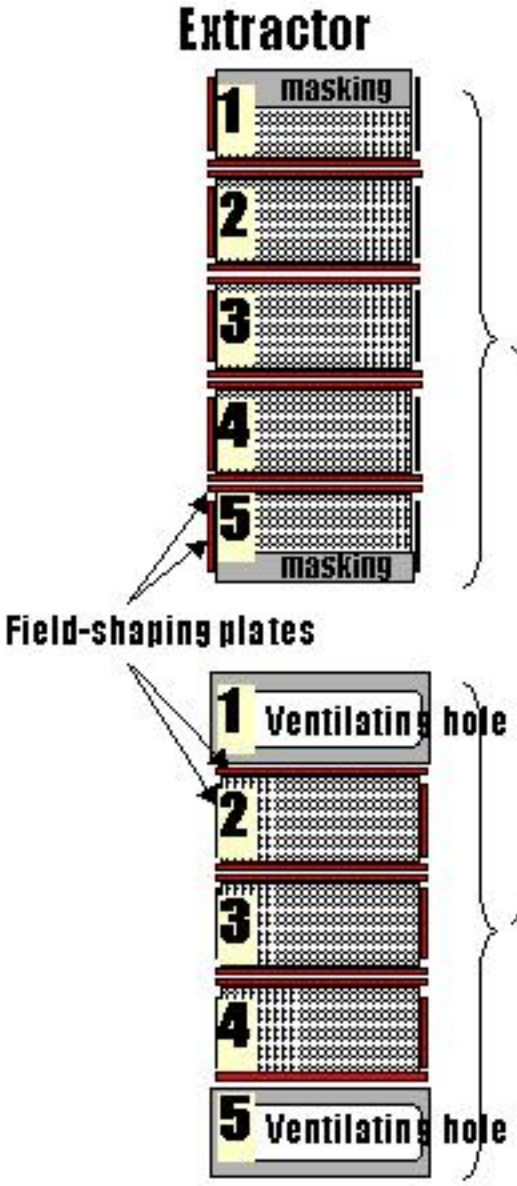
- Reduction of heat load on the grids
  - Beam Steering
  - Stripping loss
- Stable operation of Arc discharge
  - Control of Arc discharge
  - Damage of filament
- High power operation
  - Temperature of Plasma grid
  - High voltage holding
  - Uniformity of source plasma

4th IAEA TM

ITER R&D meeting

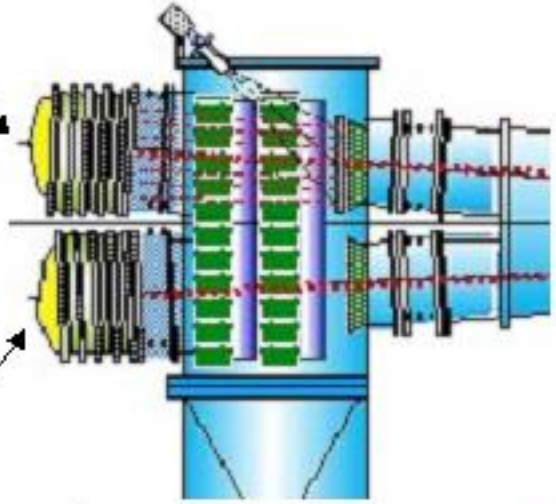
2. Progress of pulse duration

JT-60U NBI Ion sources for long pulse operation



Upper ion source

5segments
Locally masked of 1st,5th
Multi-aperture of 24x9
Field-shaping plate



10 s operation

Beam deflection measurement

Lower ion source

3segments
Ventilating hole at 1st,5th
Multi-aperture of 24x9
Field-shaping plate

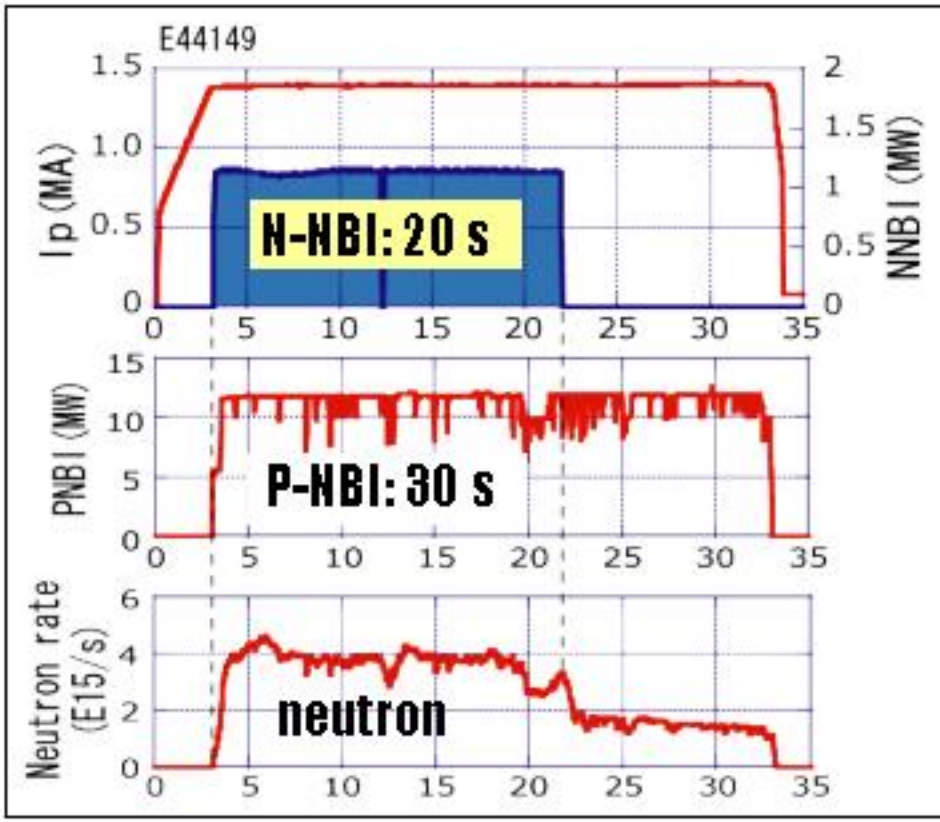
30 s operation

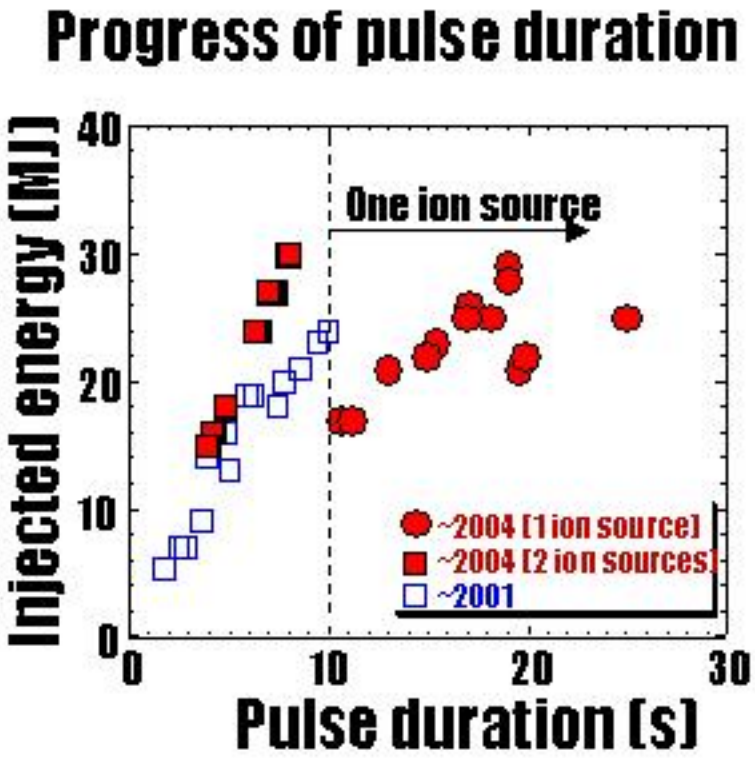
Long pulse operation

JT-60U NBI

Progress of long pulse operation

- N-NBI :Lower ion source (~1MW x 25 s, 1.6 MW x 17 s)
- P-NBI :Tangential units (4 units x 30s)
  Perp. Units (7units x 10s, 30 s in series)





3. Beam Steering

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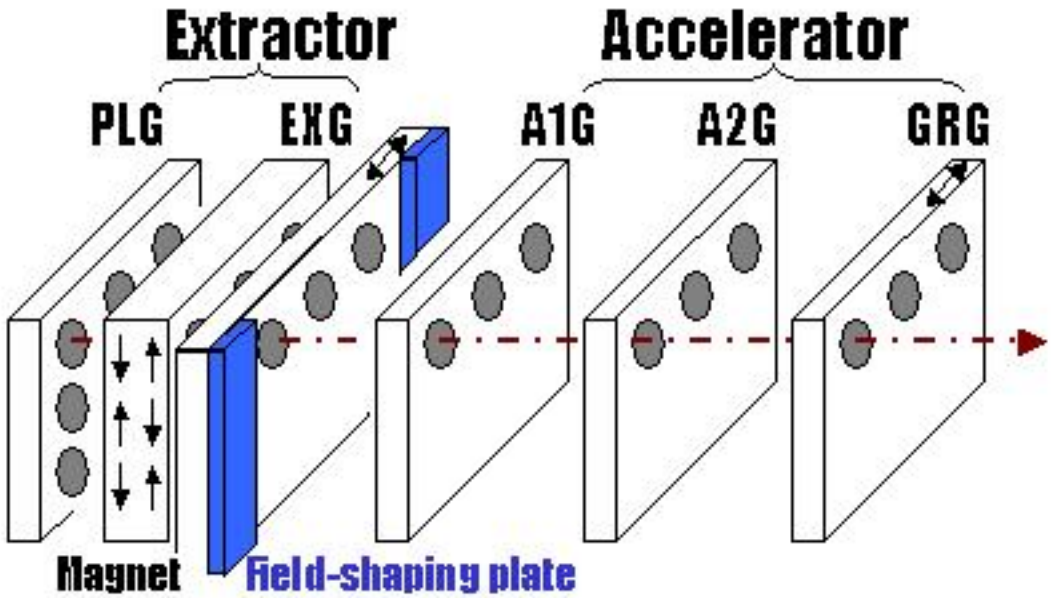
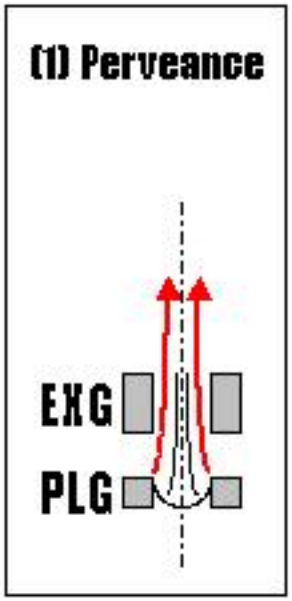
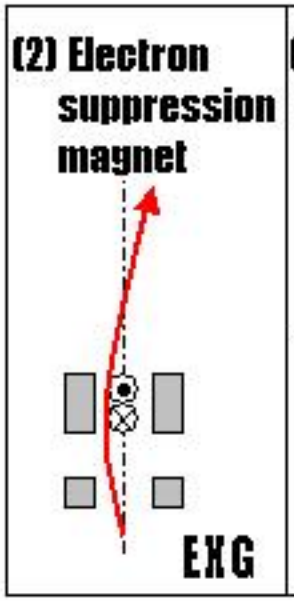
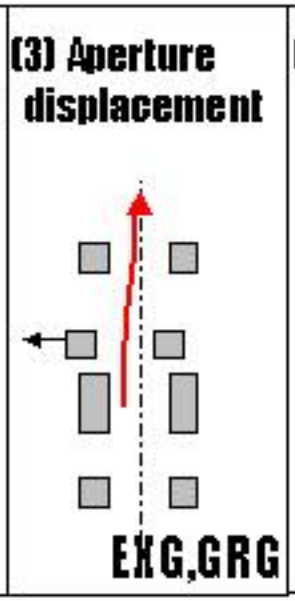
Steering of beam deflection

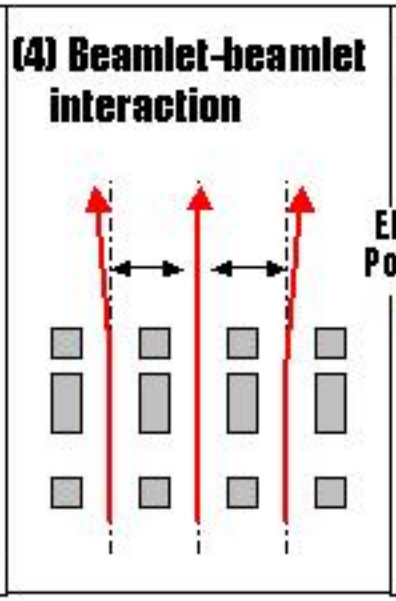


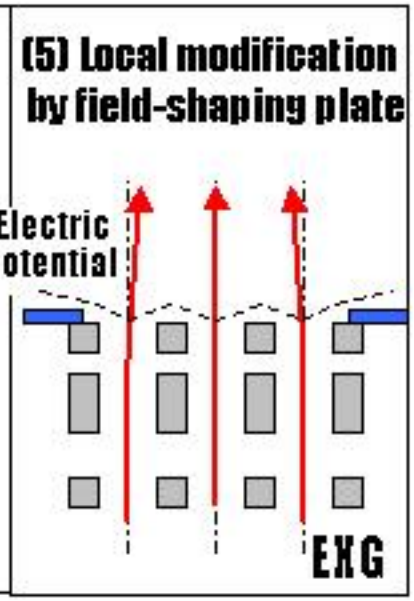
Grid structure was designed to pass and accelerate the negative ions through the multi-apertures grids.





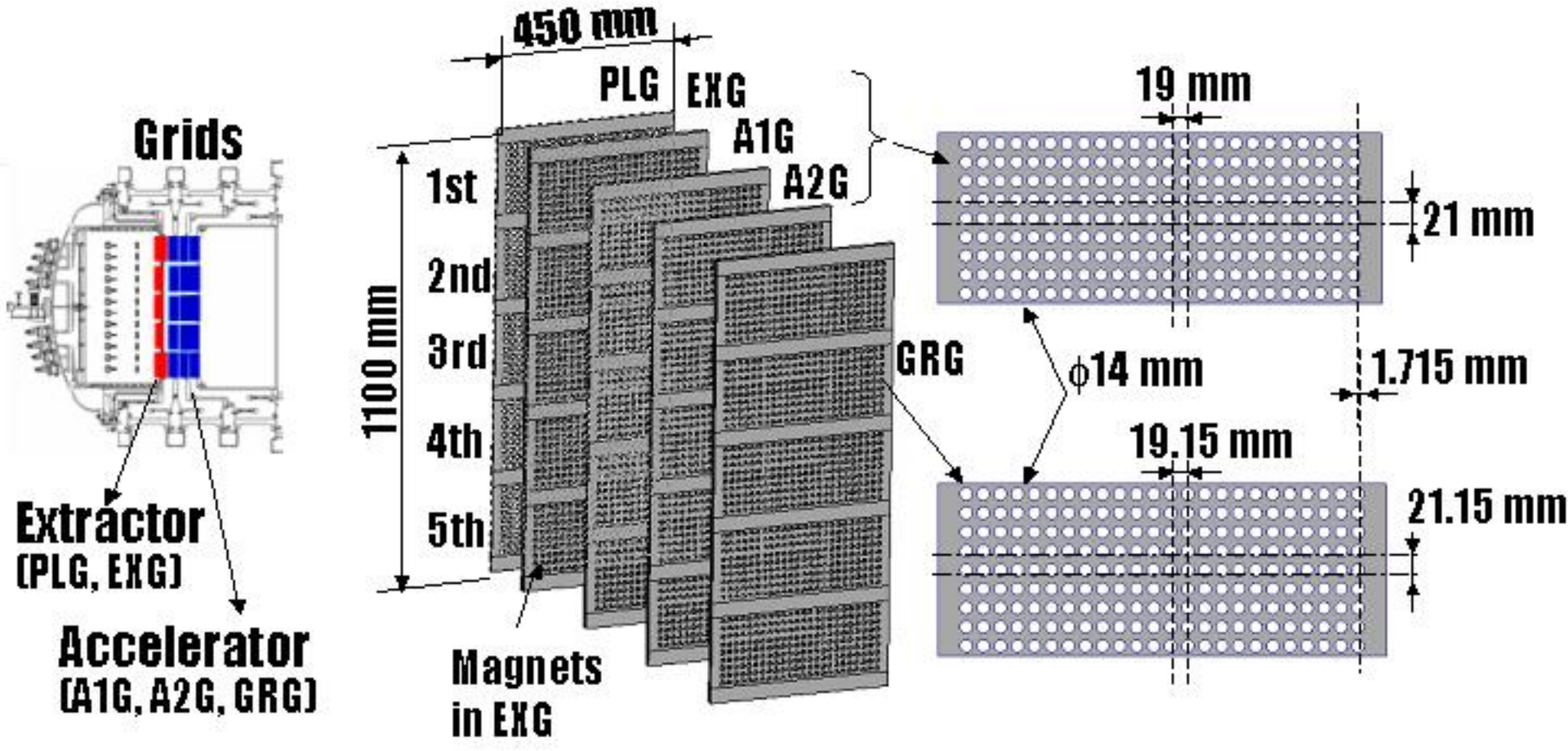






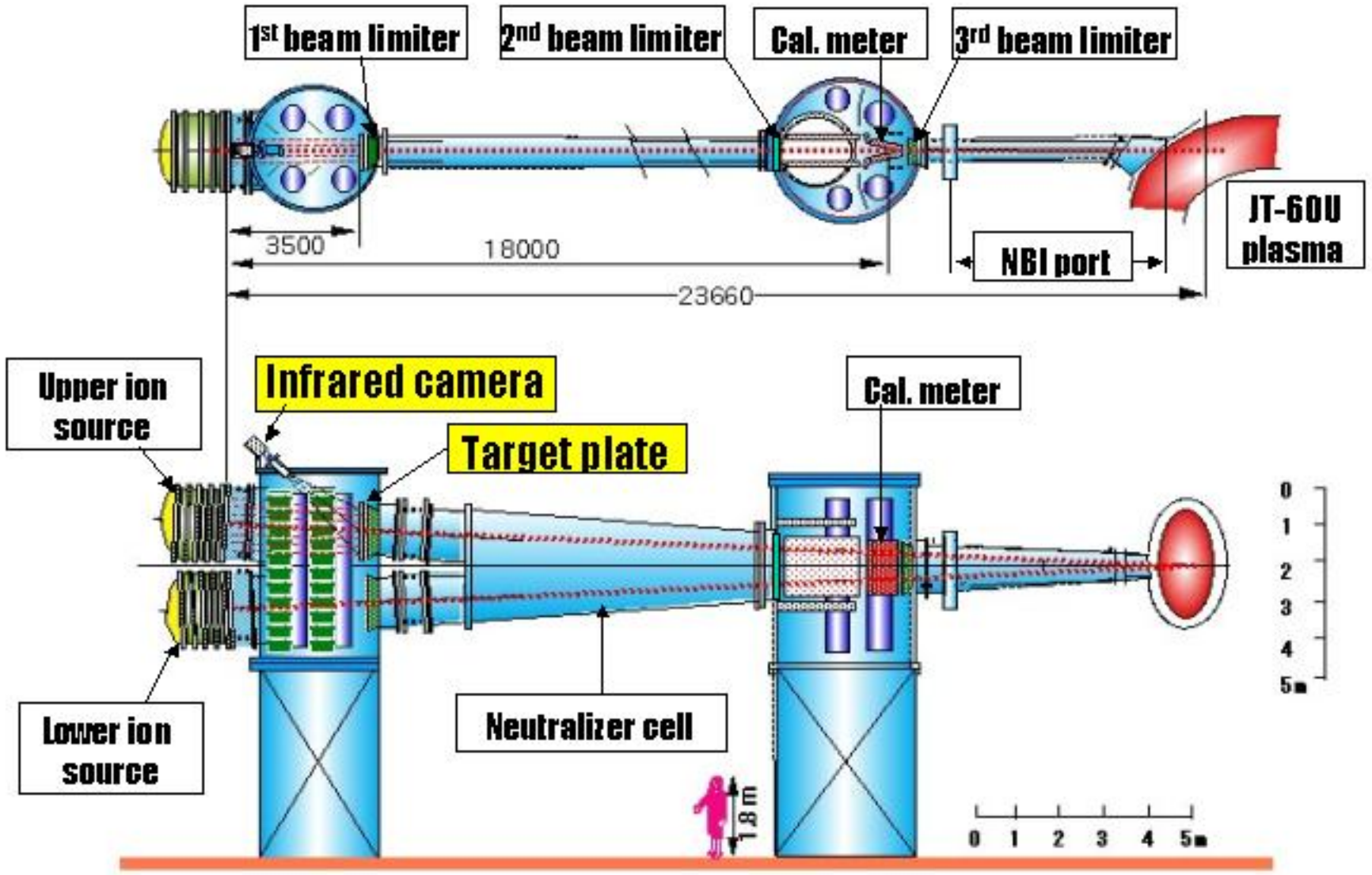
Grid structure of JT-60U N-NBI

- Extraction area : 450 x 1100 mm,
- Five segments composed of PLG, EXG, A1G, A2G and GRG,
- Multi-apertures grids (24 x 9) with aperture displacement,



JT-60U NBI

Measurement of beamlet deflection(1)



JT-60U N-NBI Beamline

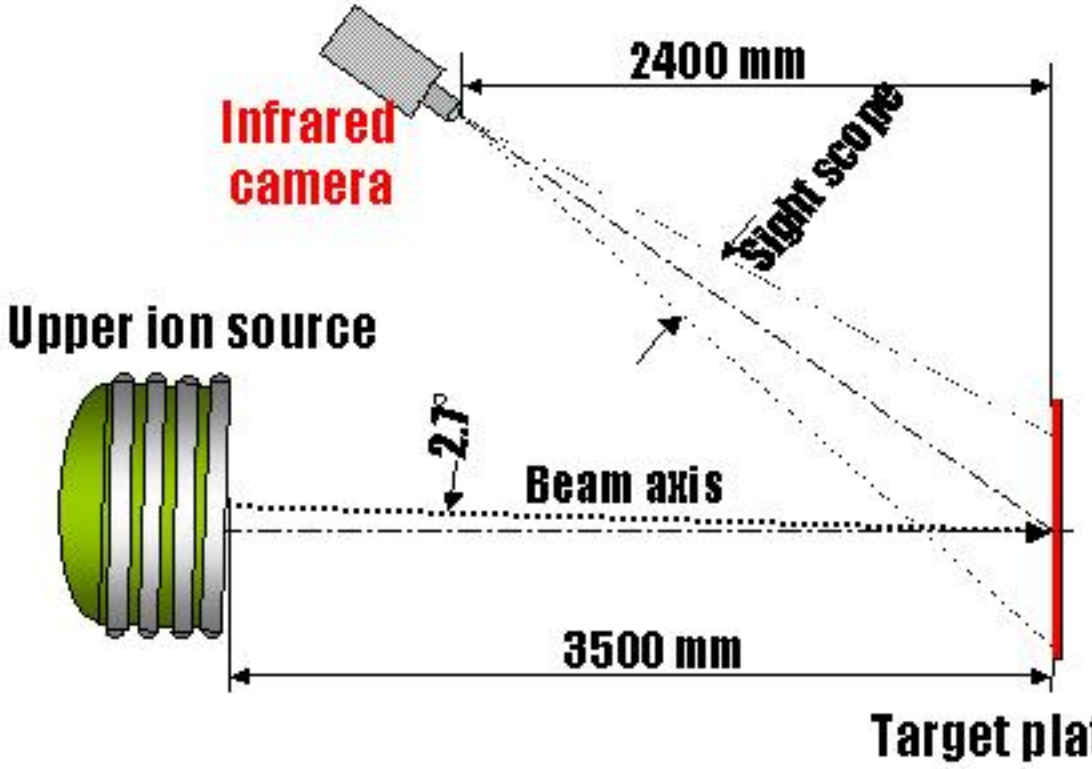
JT-60U NBI Measurement of Beam deflection(2)

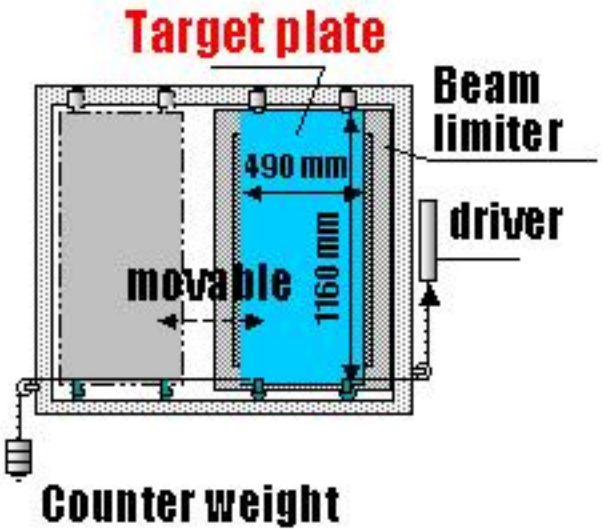
Infrared camera

Space resolution ; ~ 3 mm at target plate
time resolution; ~ 8.3 ms/ flame

Target plate

Material ; Mo
Size; 490 (W) x 1160 (H) x 12 (T)
Movable between shots





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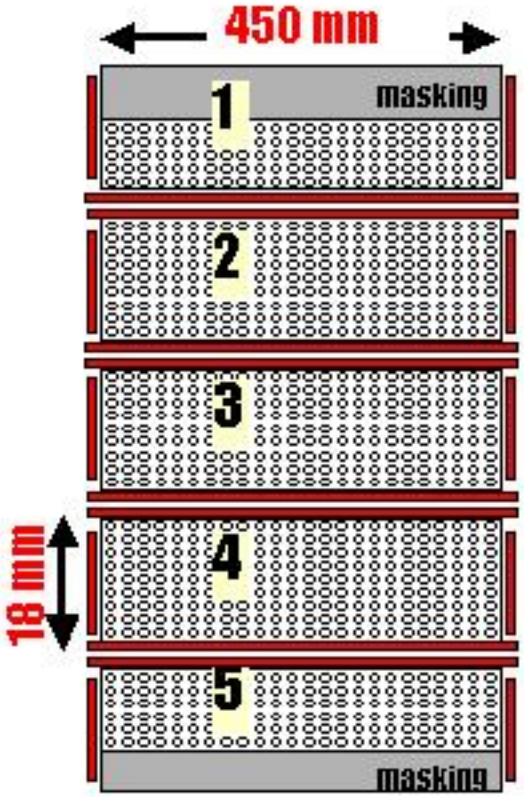
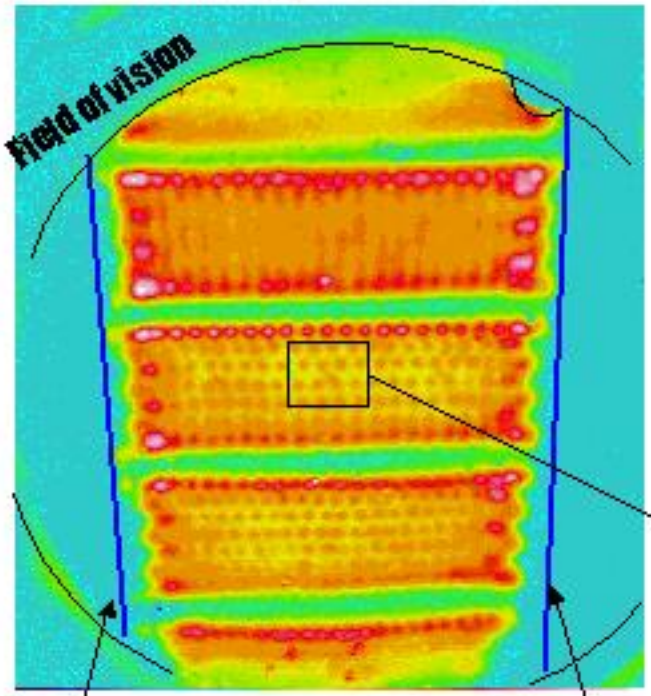
Typical infrared view of target plate

Extractor

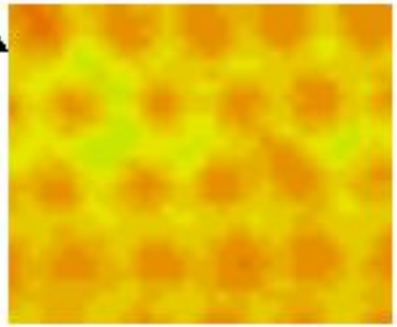


Infrared view
(at V_{ext}:5kV)



Segments
- five segments
- non-uniformity in Temp.

Multiple beamlets
- Lag between lines



Effect of Electron suppression magnet (Dipole magnetic field)

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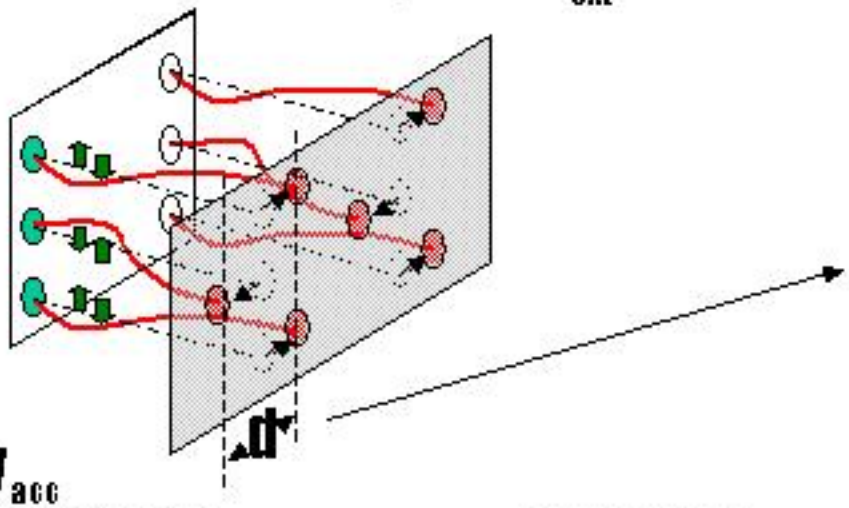
Effect of dipole magnetic field

- Lag at central beamlets of the segment decreases with extraction voltage (V_{ext}).
- Grid loss dose not depends V_{ext}.

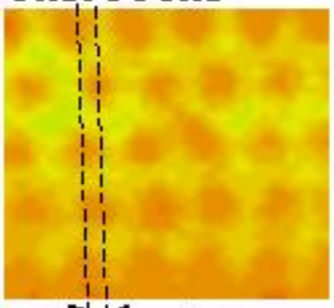
Beam steering at central beamlets may be well done at V_{ext}/V_{acc}~6kV/360kV .

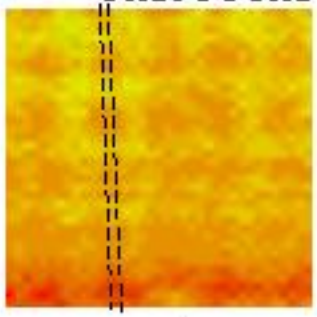


V_{ext}/V_{acc}

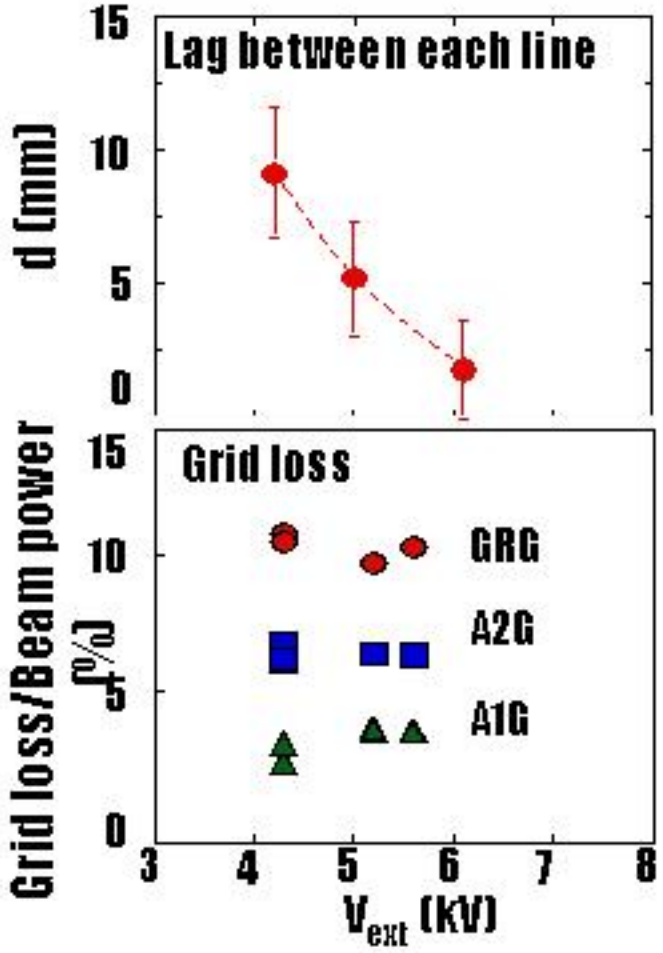
5kV/300kV

6kV/360kV





$I_{acc}/V_{ext}^{3/2}$~1.4, V_{ext}/V_{acc}~0.17-0.18



Effect of spread of beamlet-bandle (beamlet-beamlet interaction)

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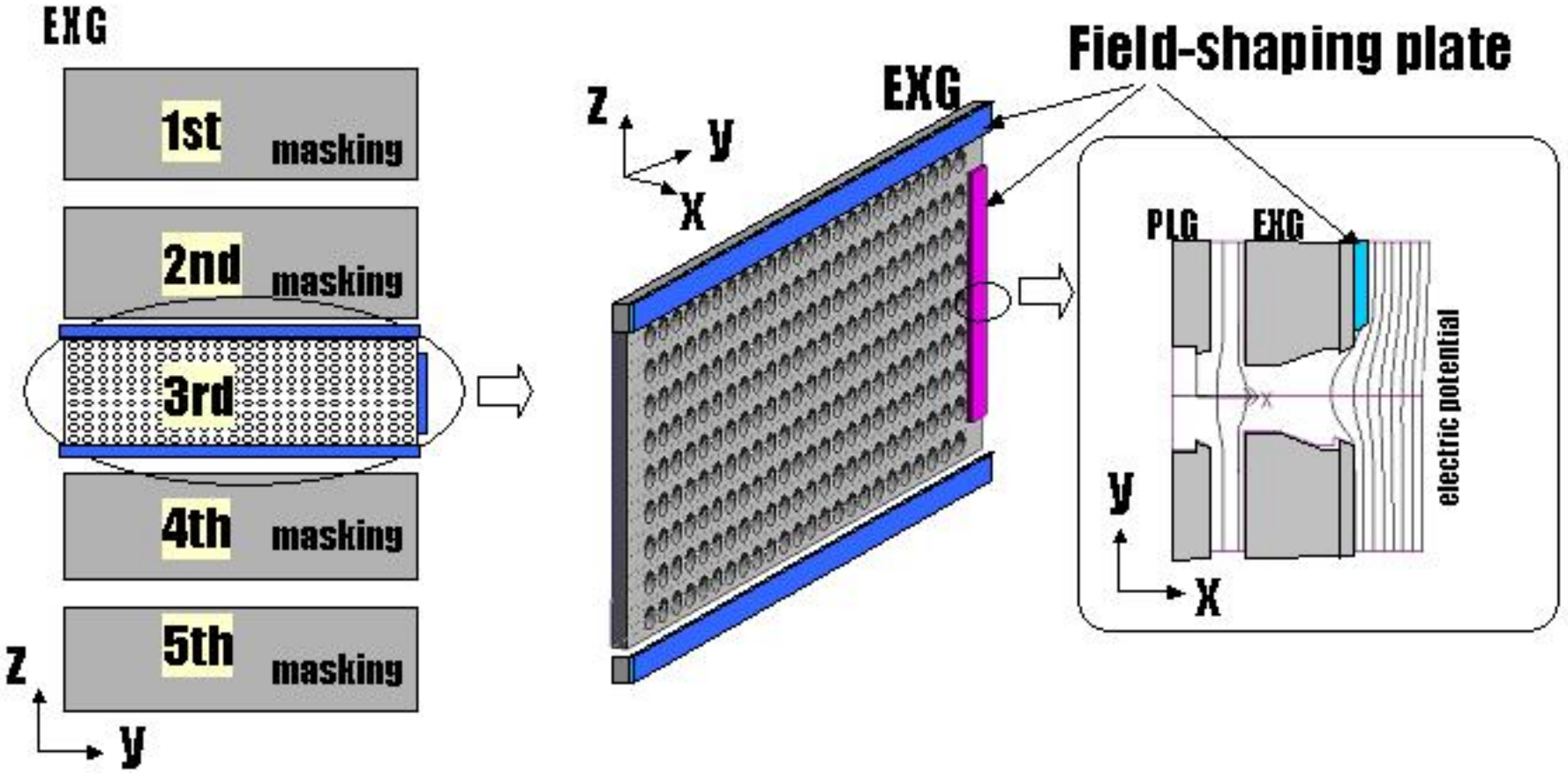
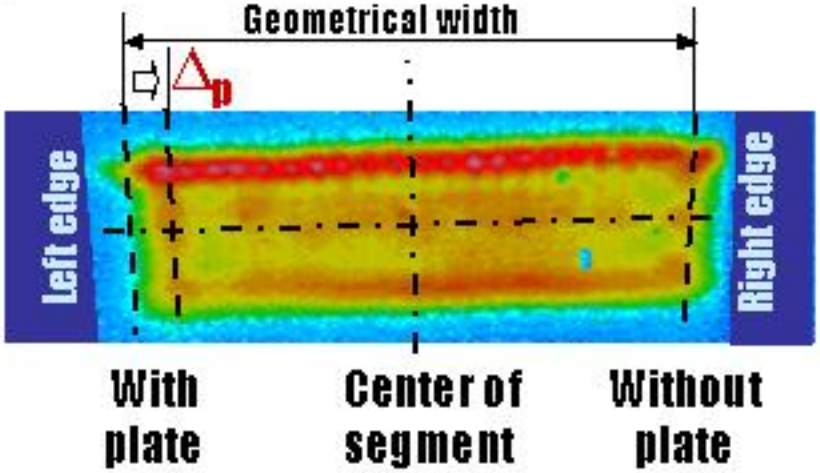
Field-shaping plate on EXG

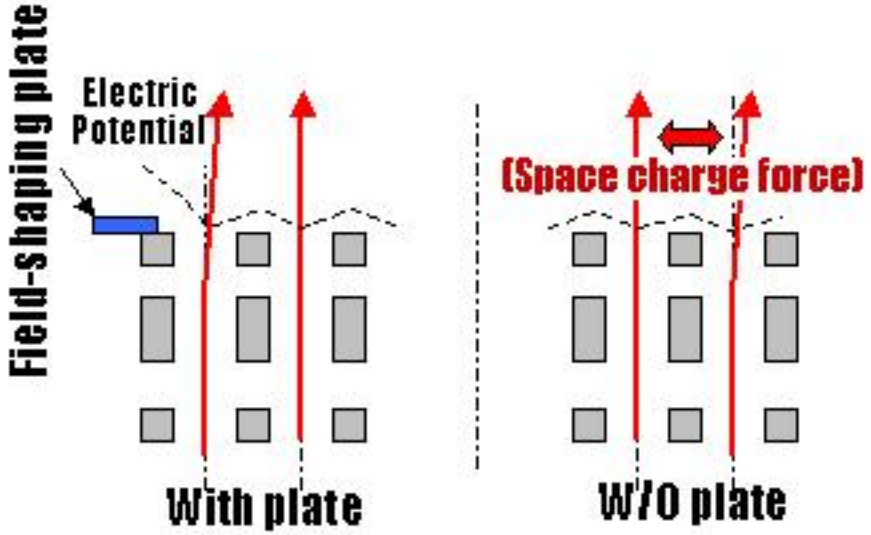
- Field-shaping plate is attached on EXG of 3rd segment to modify the local electric field.
- Other segments are masked so as to estimate accurately the current density.

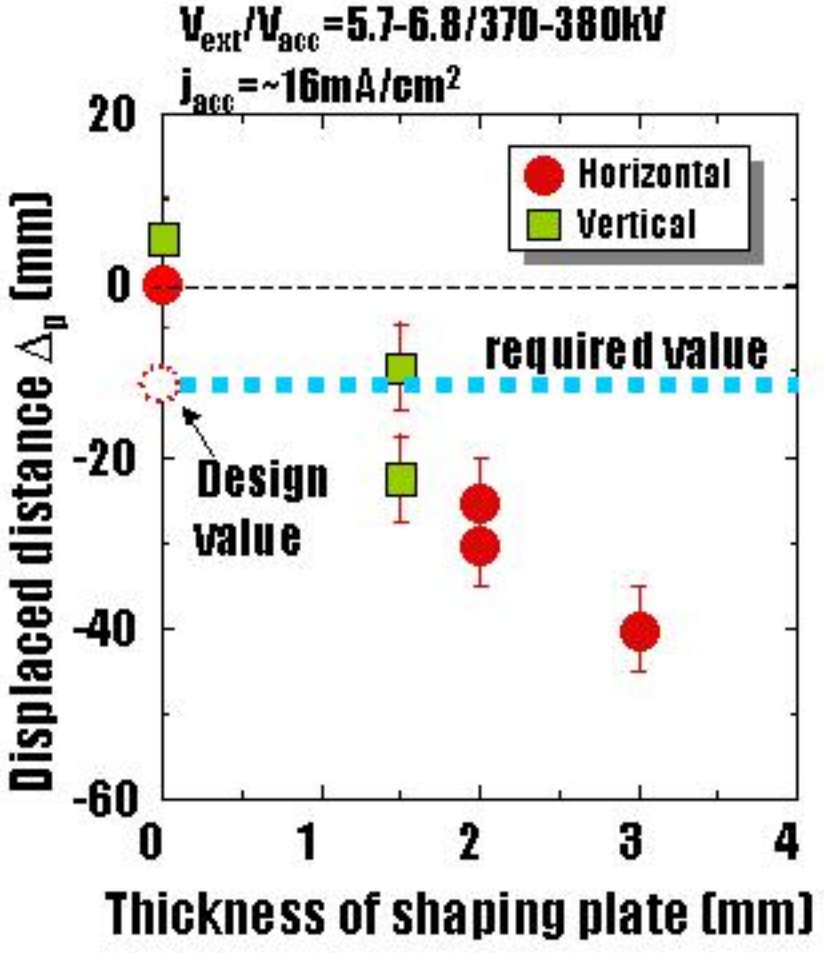


Effect of field-shaping plate

- Expansion of beamlet-bandle is observed.
- Expansion is suppressed by field-shaping plate.







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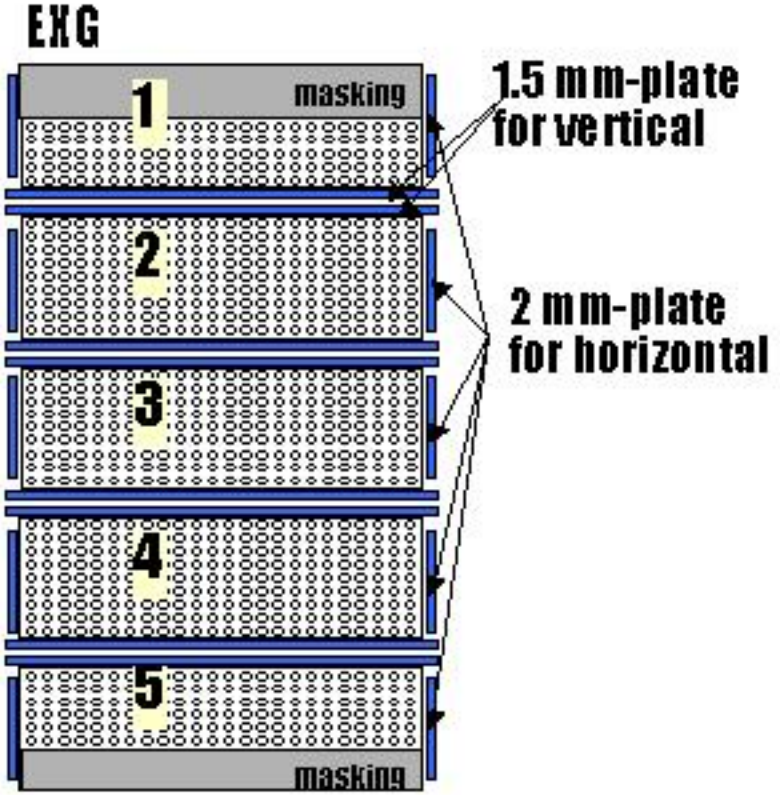
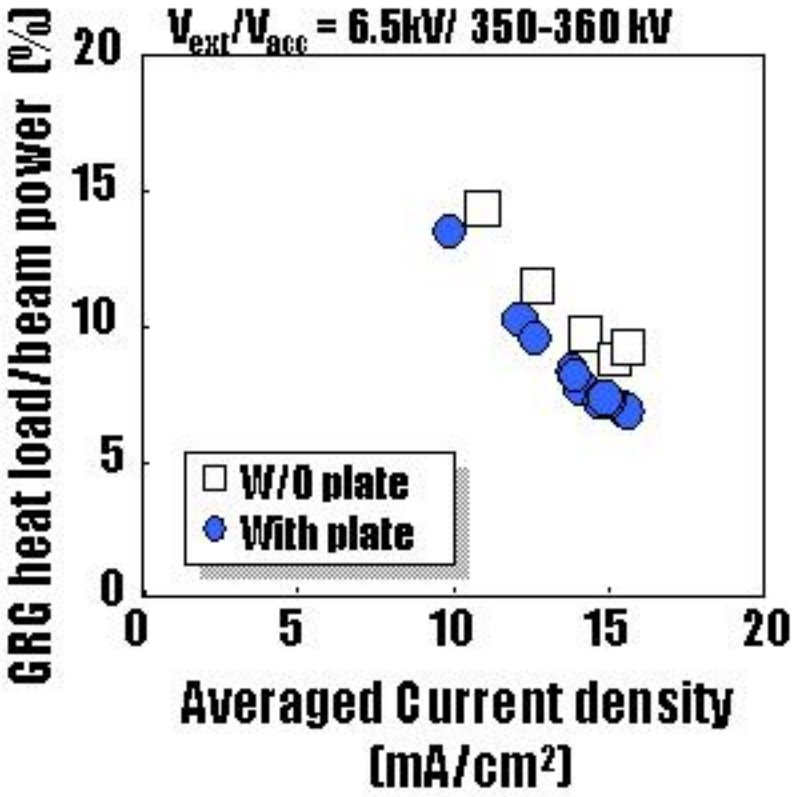
Heat load of GRG

- Field-shaping plates are attached around all segments of EXG.
- Heat load of GRG is reduced at the same operational condition of V_{ext}/V_{acc}.





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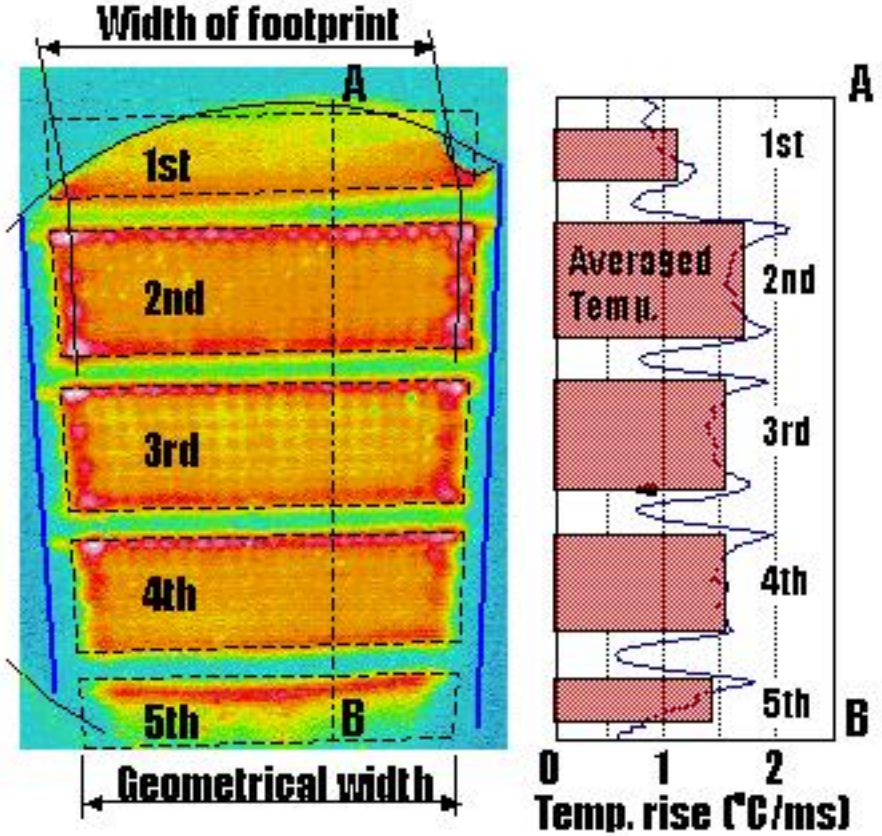
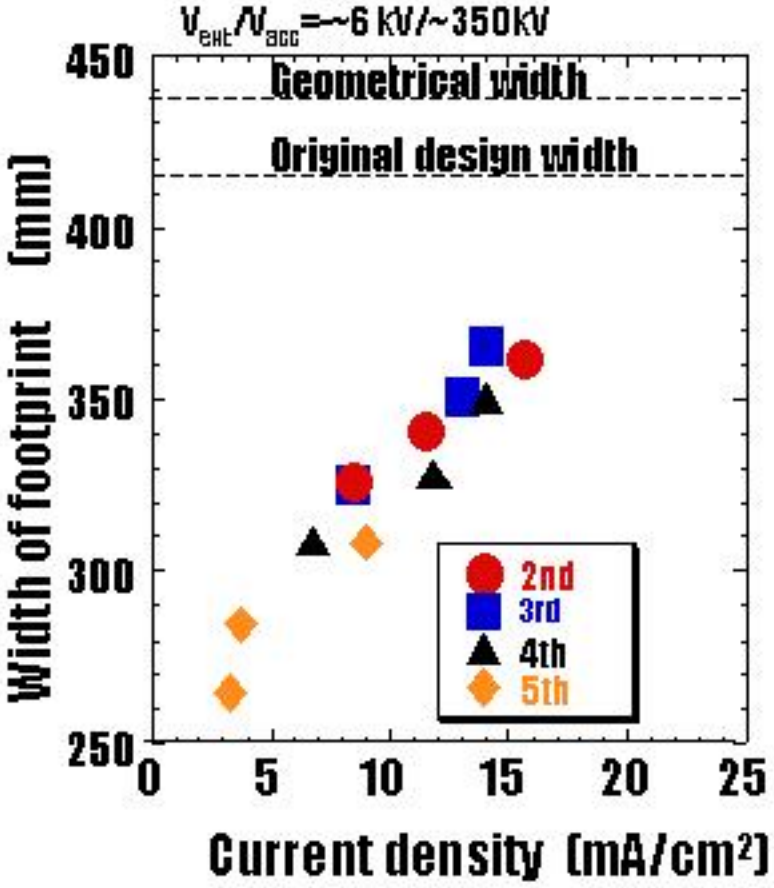
Effect of current density

- Non-uniformity of Temperature of footprints between segments,
- Wider footprint at higher temperature segment,
- Width of footprint increases with current density.



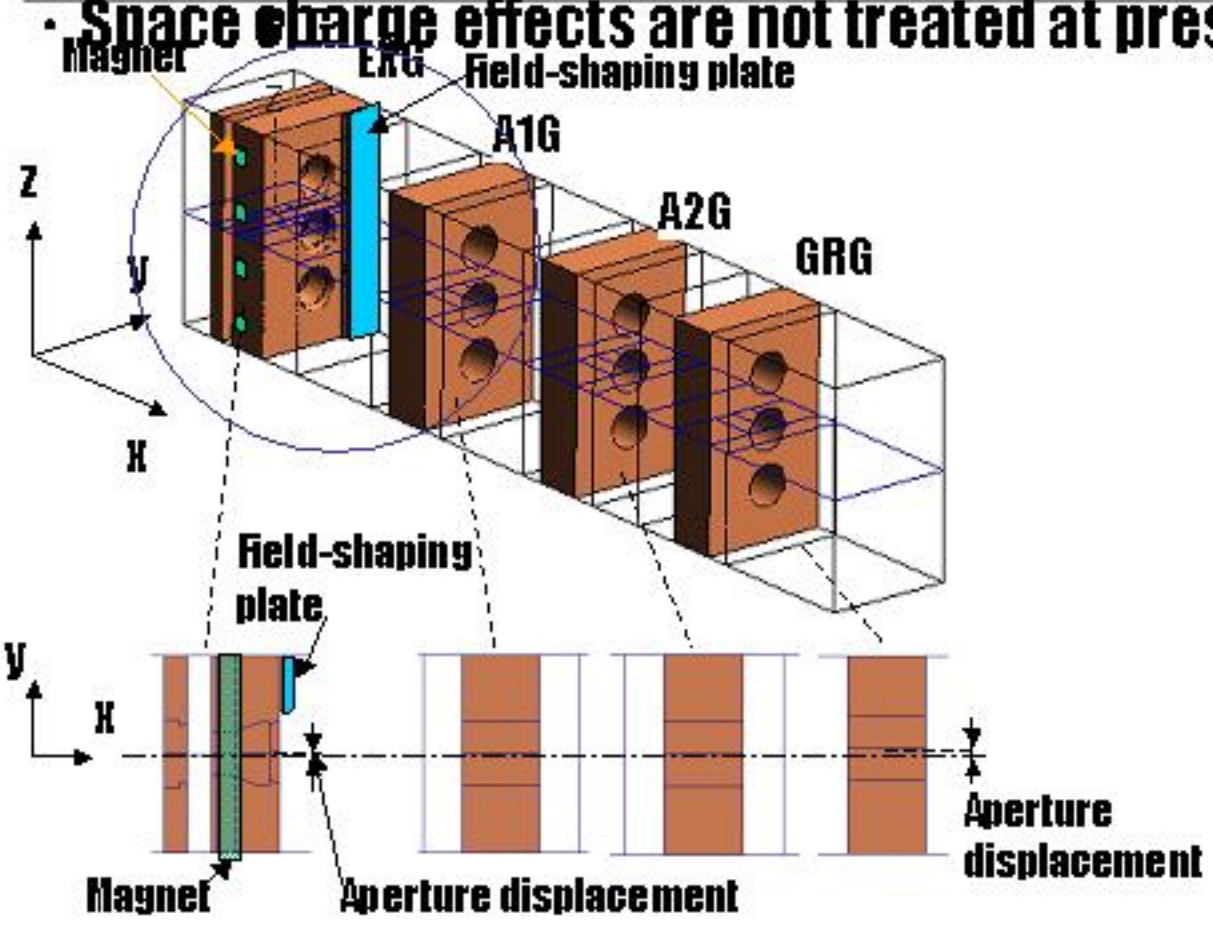


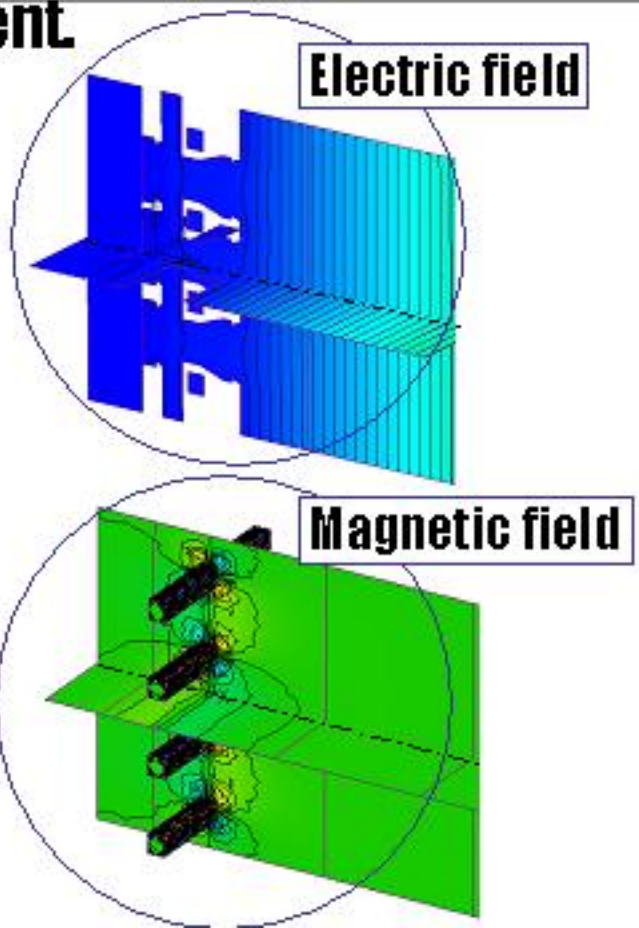
Each current density is assumed to be proportional to temperature rise of each segment.

Analysis of beamlet trajectory

Simulation model

- Single beamlet trajectory is calculated by 3D code, which can take the dipole magnetic field, field-shaping plate, and aperture displacement into account.
- Space charge effects are not treated at present.

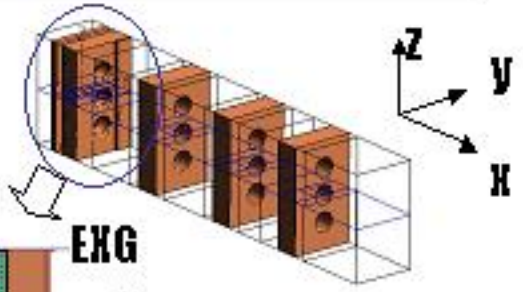


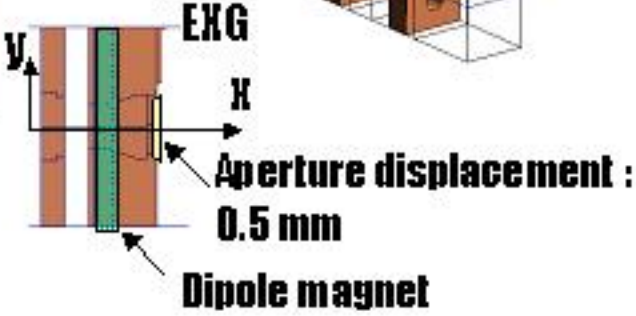


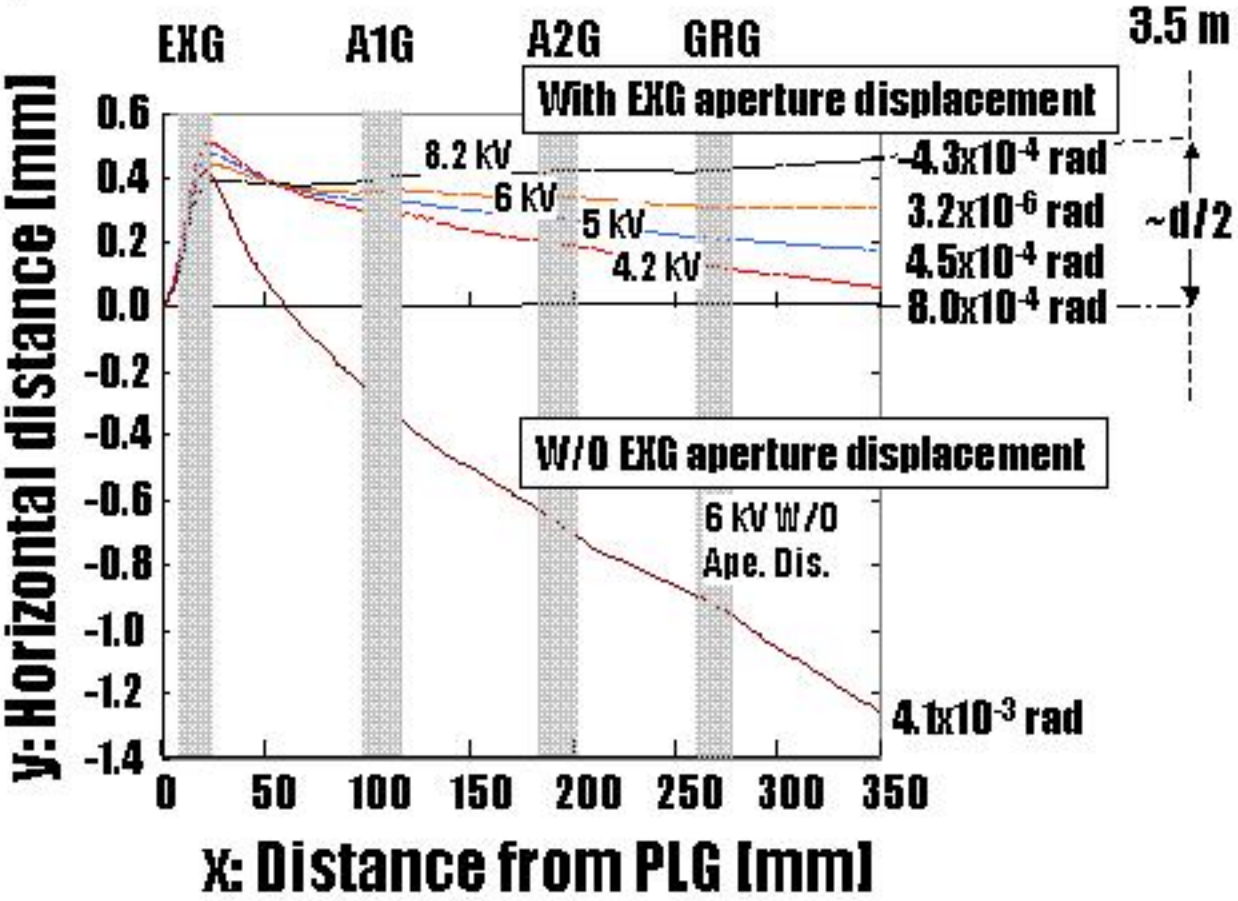
JT-60U NBI

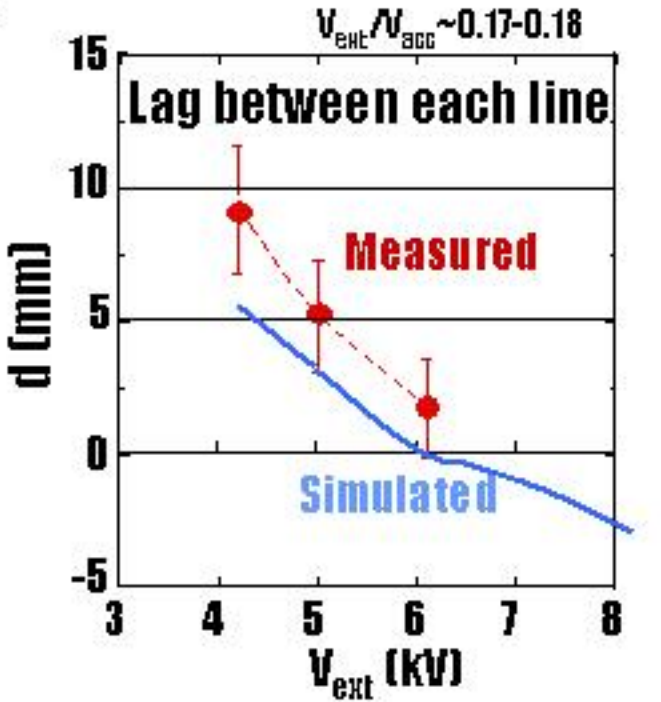
Effect of dipole magnetic field

- Beam deflection inside grids are suppressed within ~0.5 mm by the aperture displacement at outlet of EXG. (aperture diameter: 14 mm).
- Measured result is well simulated.









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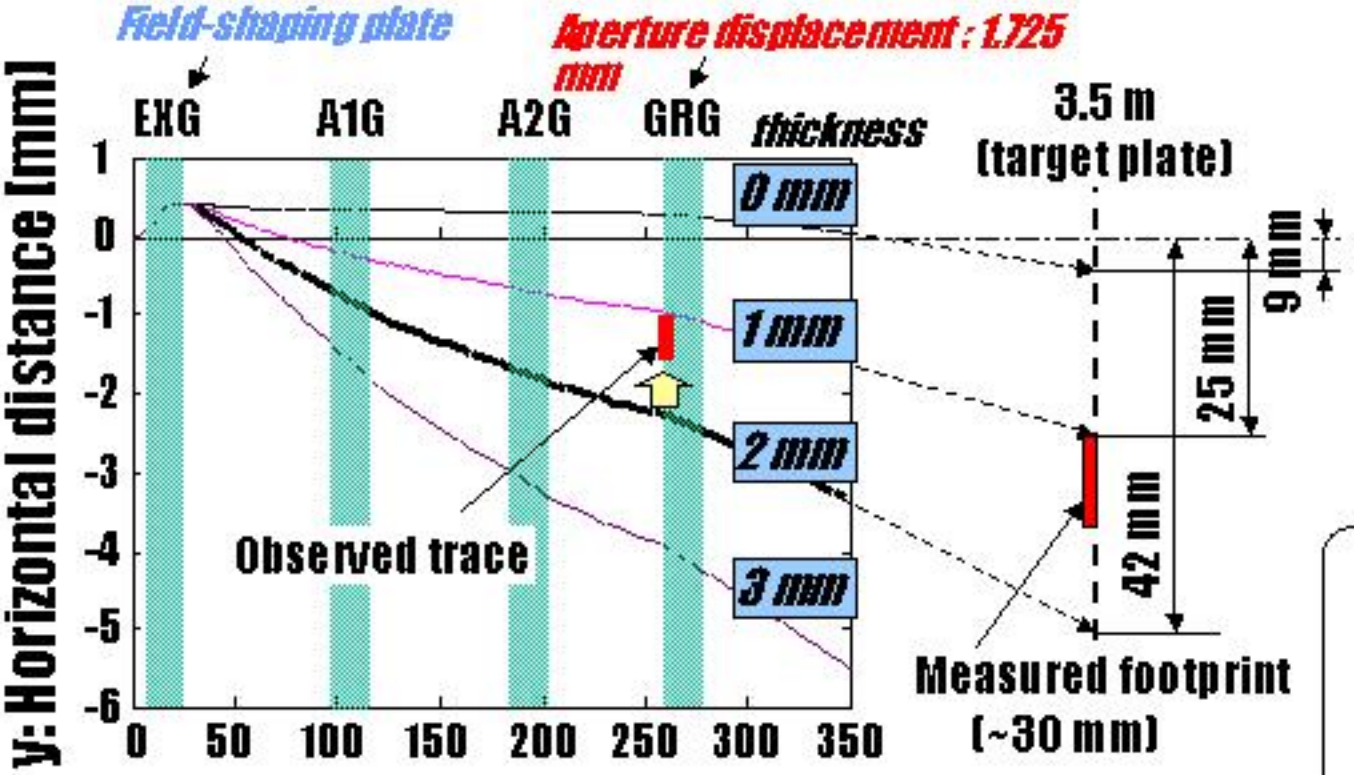
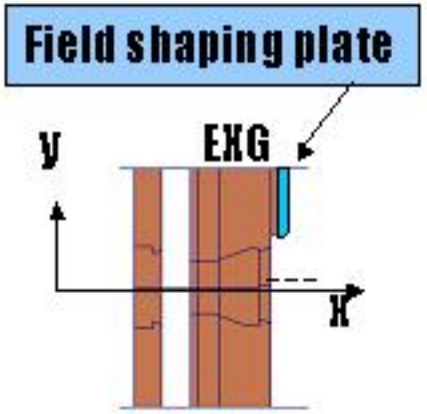
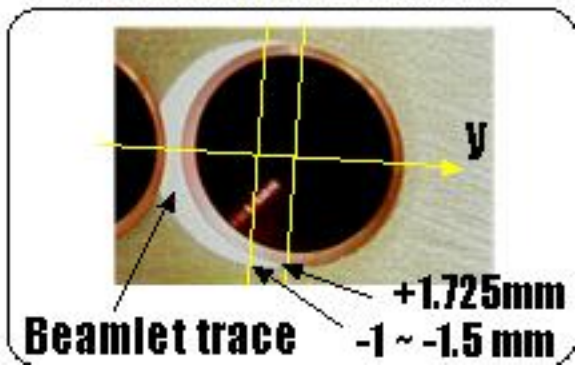
Effect of field shaping plate

- Displaced distance of the beamlet is almost in proportion to the thickness of field-shaping plate.
- Operational results with a 2 mm-thickness plate agree with the simulated one with a 1~1.5 mm thickness plate.





Observed trace on GRG

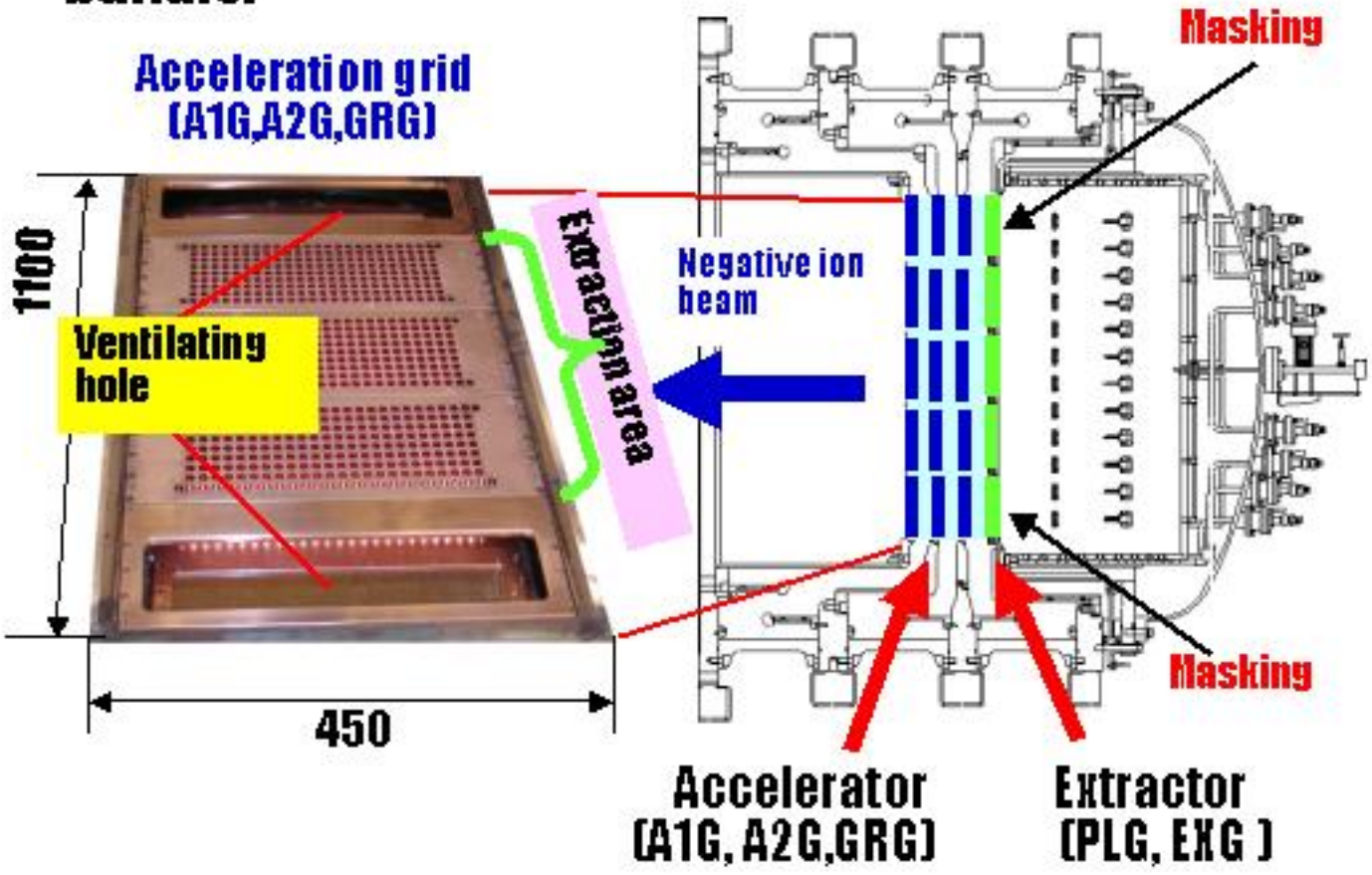


4. Stripping loss

JT-60U NBI

Reduction of Striping Loss

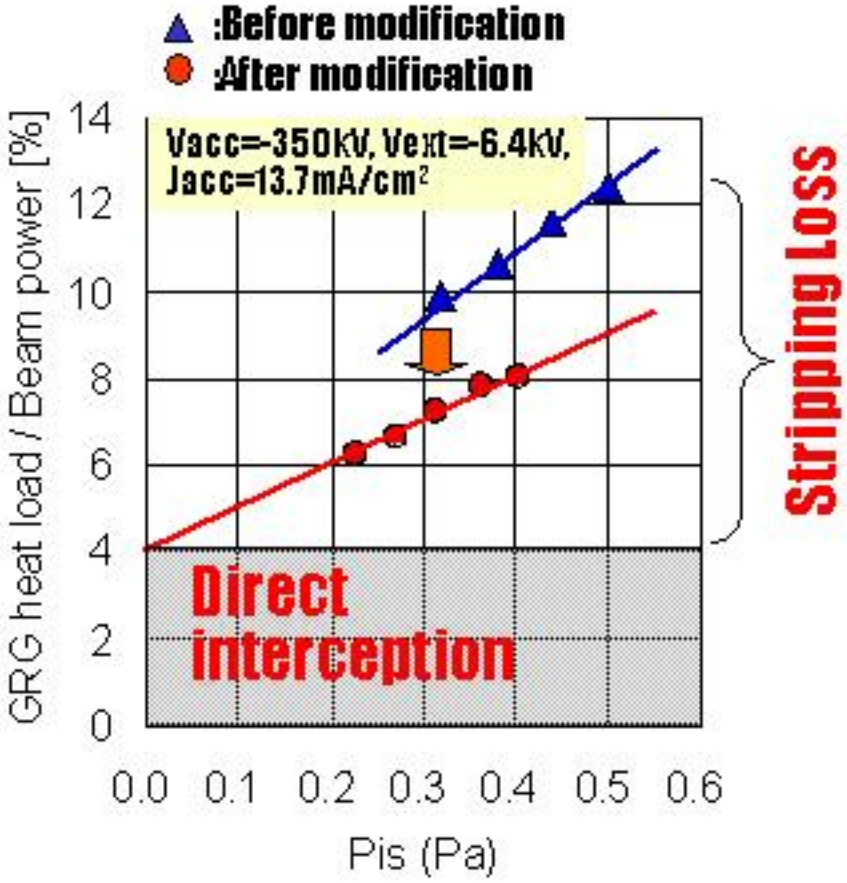
- Acceleration grids of top and bottom segments are ventilated to increase the vacuum conductance in acceleration column.
- Field-shaping plates are attached to compress the beamlet bundle.

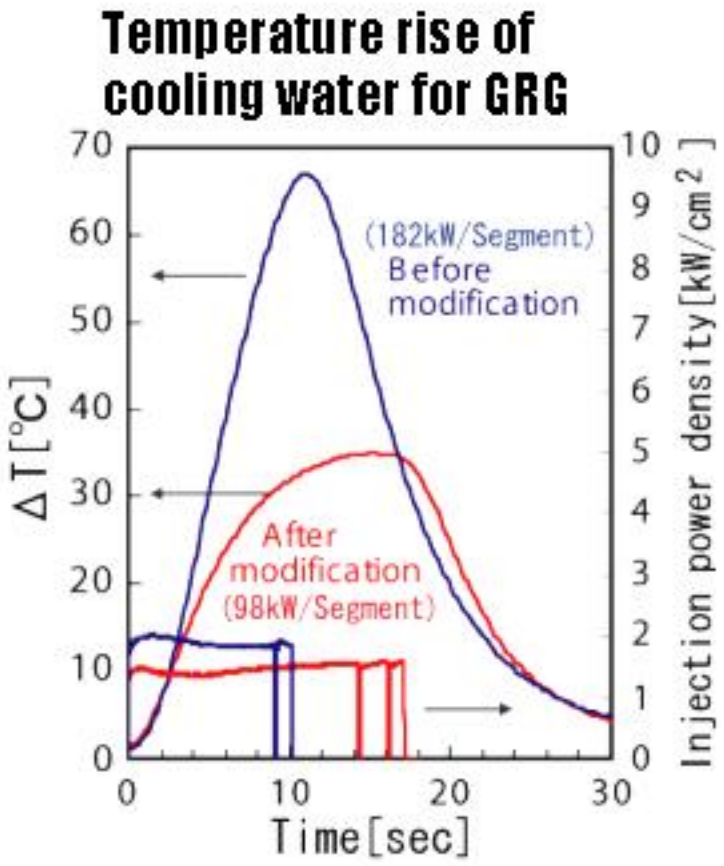


Pressure at EXG
before: ~0.16 Pa
after : ~0.1 Pa

Reduction of Heat load of GRG

- Heat load of GRG increases with the pressure at ion source [P_{is}].
- After modification, heat load is reduced from ~10 % to ~7 % at P_{is}~0.3Pa.
- Temperature of cooling water for GRG saturates with 20 s operation.



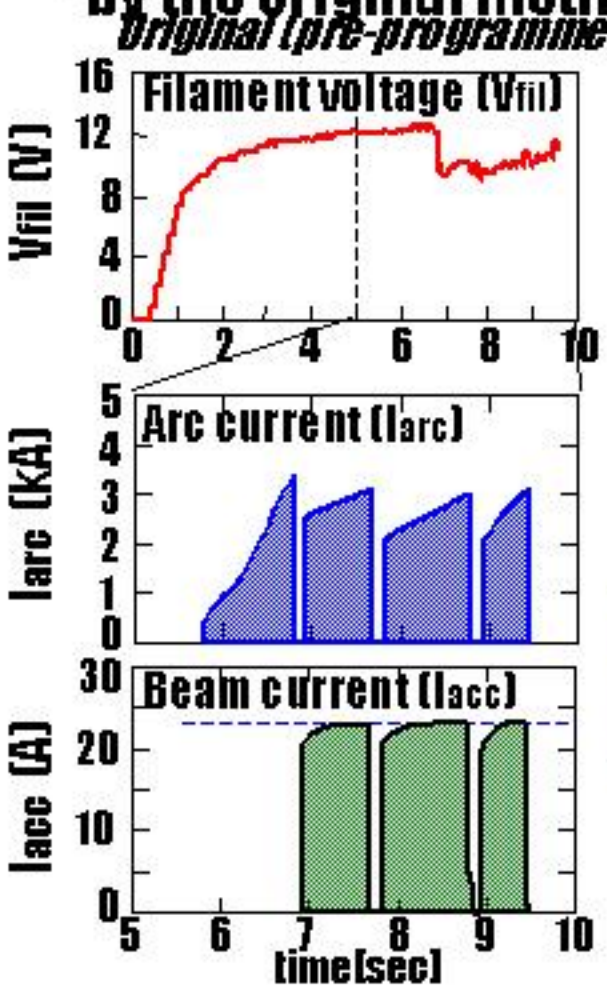


5. Control of Arc discharge

JT-60U NBI

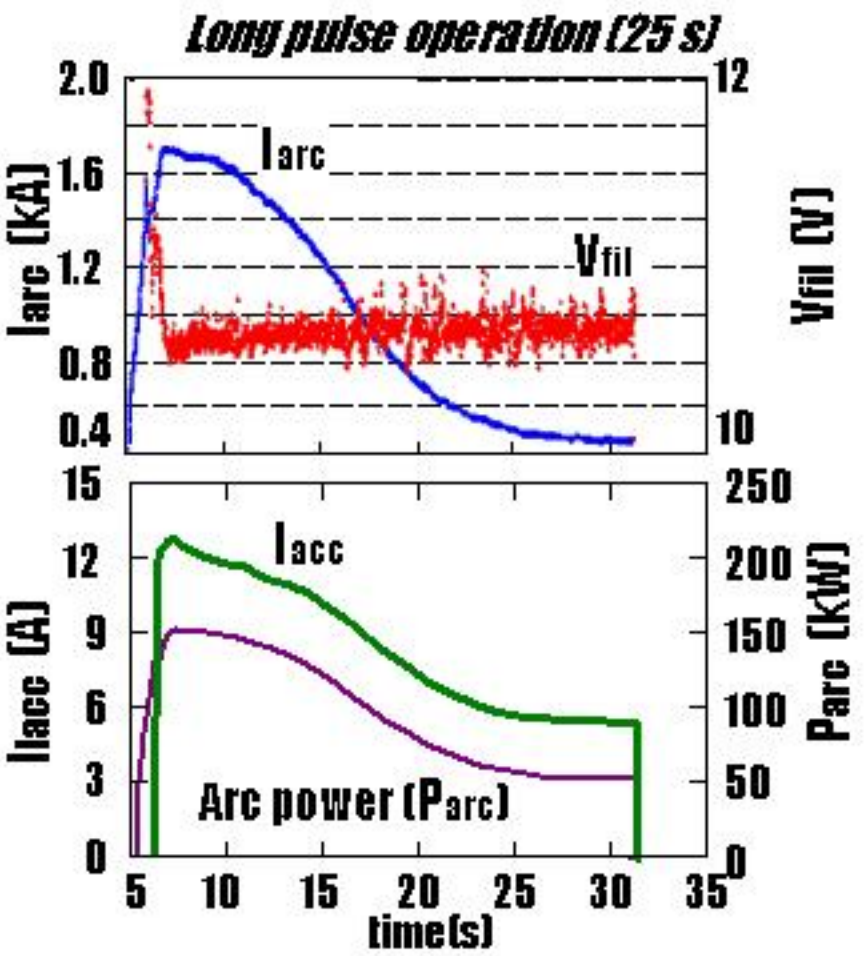
Change in arc power during long pulse operation

- Arc power was pre-programmatically controlled in the original.
- It is hard to obtain a stable arc discharge for long pulse operation by the original method.



Long pulse operation

Reduction of Parc results in a reduction of Iacc.

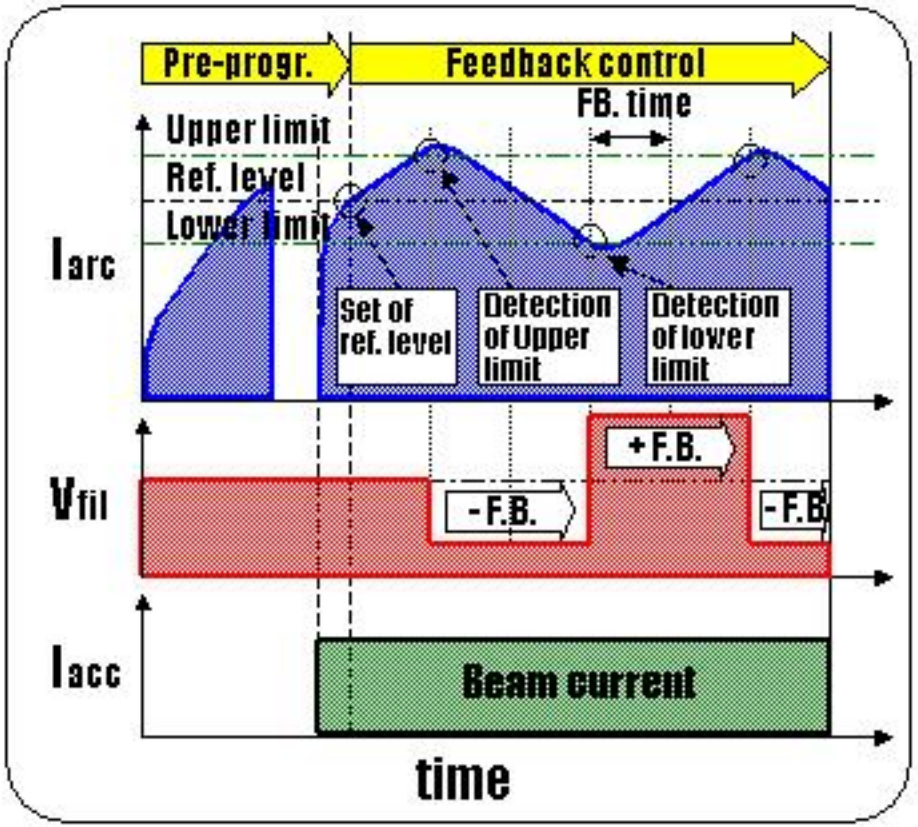


JT-60U NBI

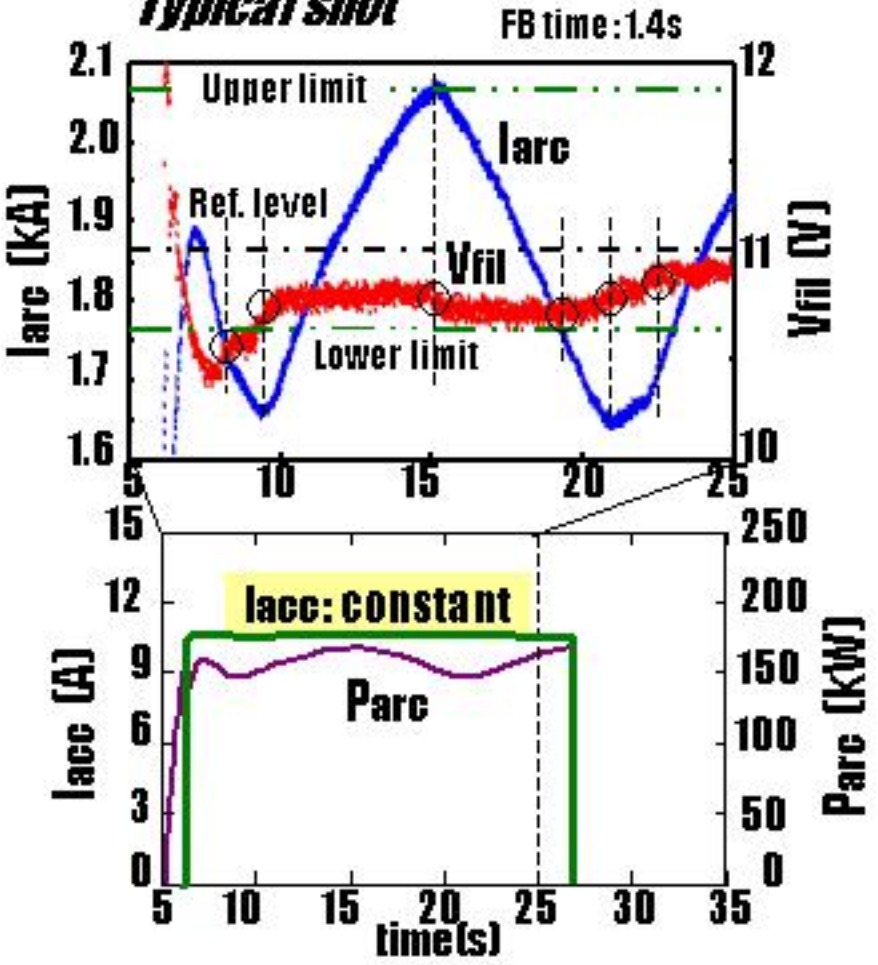
Feedback control of arc power

- Feedback control technique has been employed and succeeded to keep the arc power constant by controlling the filament voltage.

Feedback control of arc power



Typical shot



Fast feedback control with arc voltage has been tested for next campaign.

Summary

- Pulse duration has been extended up to 25 s at ~1 MW and 17 s at 1.6 MW with one ion source.
- A spread of beamlet-bundle, which depends on the current density, is observed in the multi-aperture grid.
- Field-shaping plate is useful to suppress the spread of beamlet-bundle, which may affect the heat load of grids.
- It is confirmed that the modification with a high vacuum conductance is effective in reducing the stripping loss.
- Feedback control with filament voltage has been employed to achieve a constant arc power for long pulse operation.
- Further modification of grid structure, taking better account of space charge interaction, may be expected to further improve the performance of multi-aperture grid.