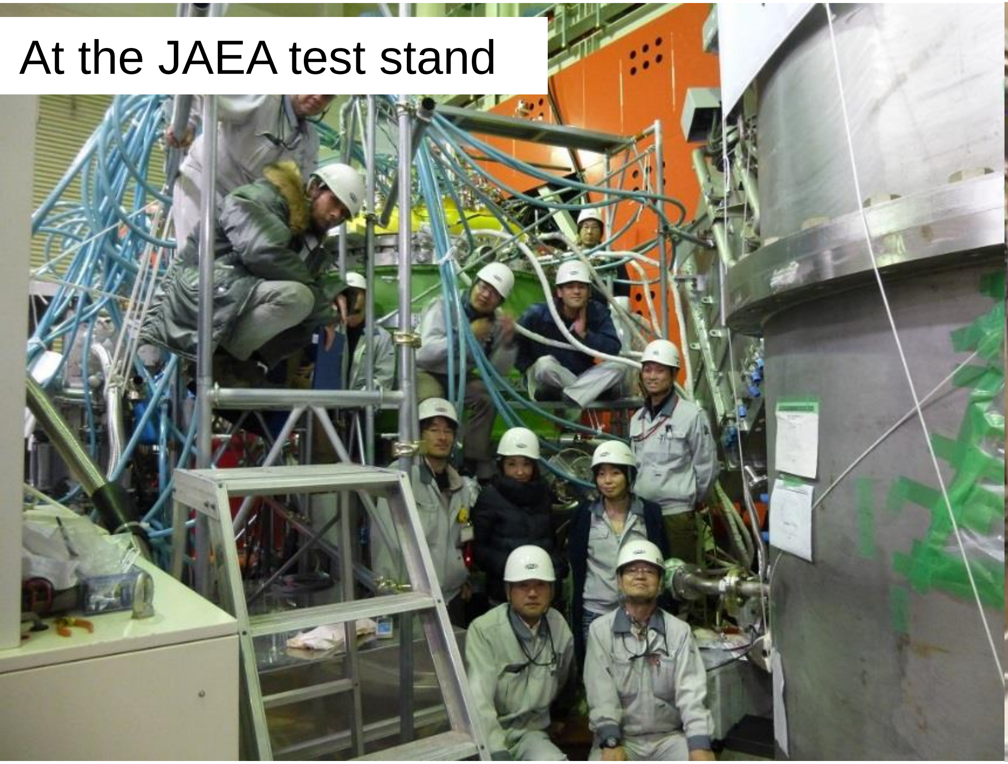
Development of a 1 MeV electrostatic accelerator for fusion application at JAEA


At the JAEA test stand


Joint research with RFX in JAEA

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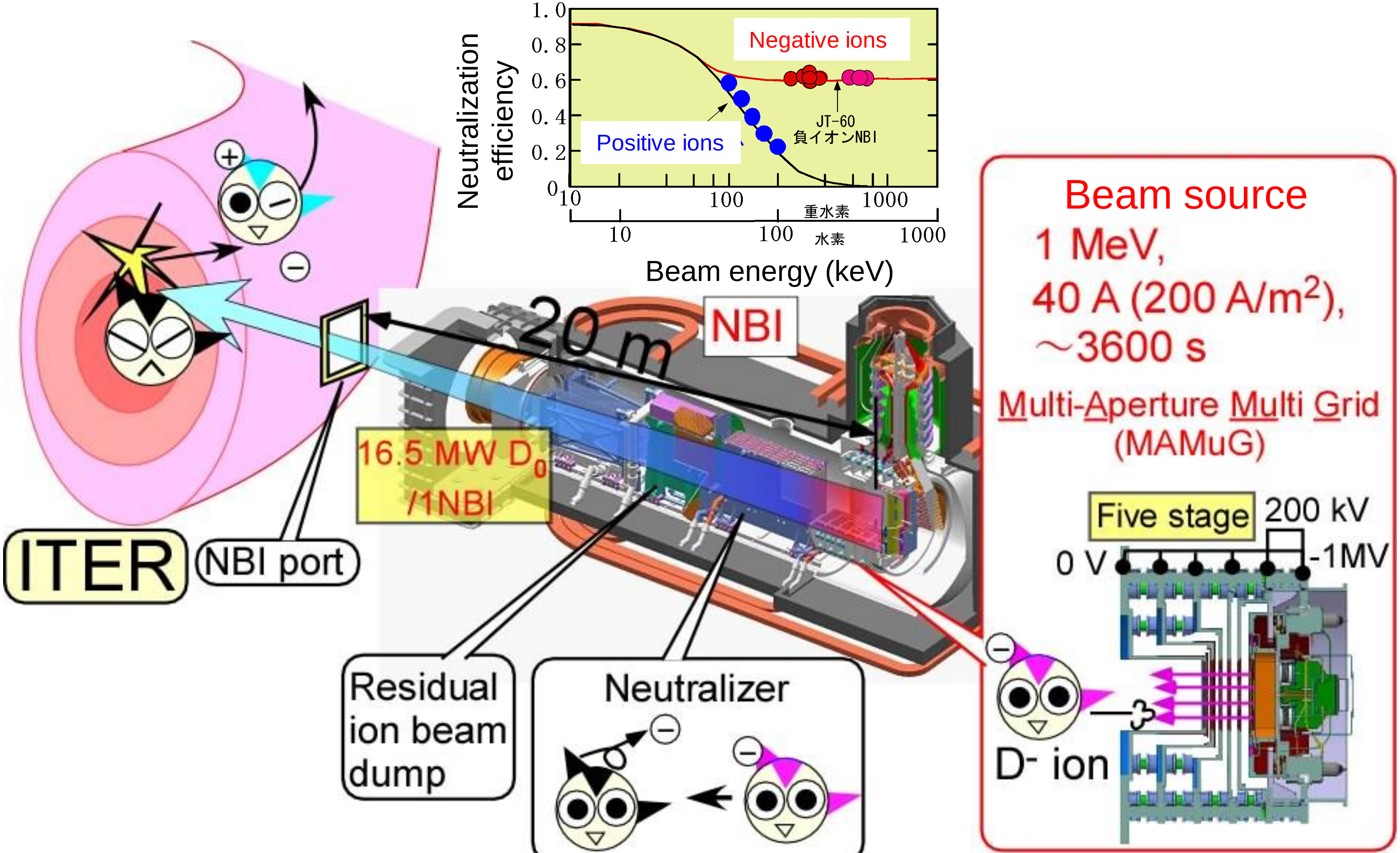
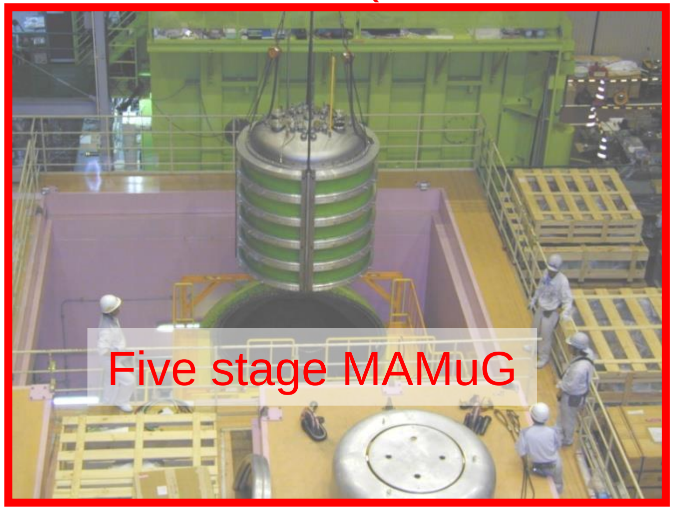
Beam source for Neutral Beam injection system of ITER

High energy and high current negative ion beam is required for heating and current drive for fusion plasma.

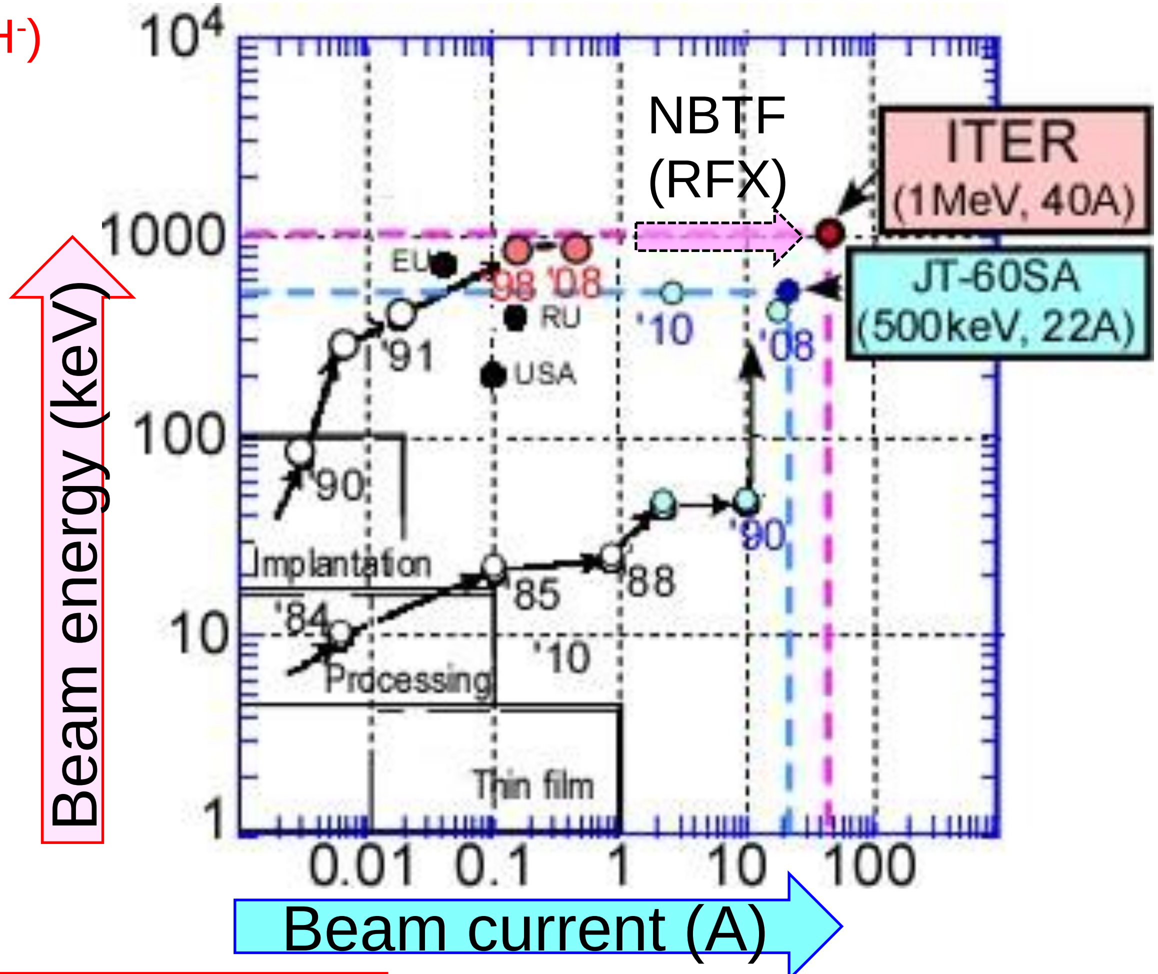


Development of negative ion source for ITER

MeV accelerator (1 MeV, 0.5 A, H^-)



Accelerator of JT-60U NBI
(500 keV, 22 A, D^-)

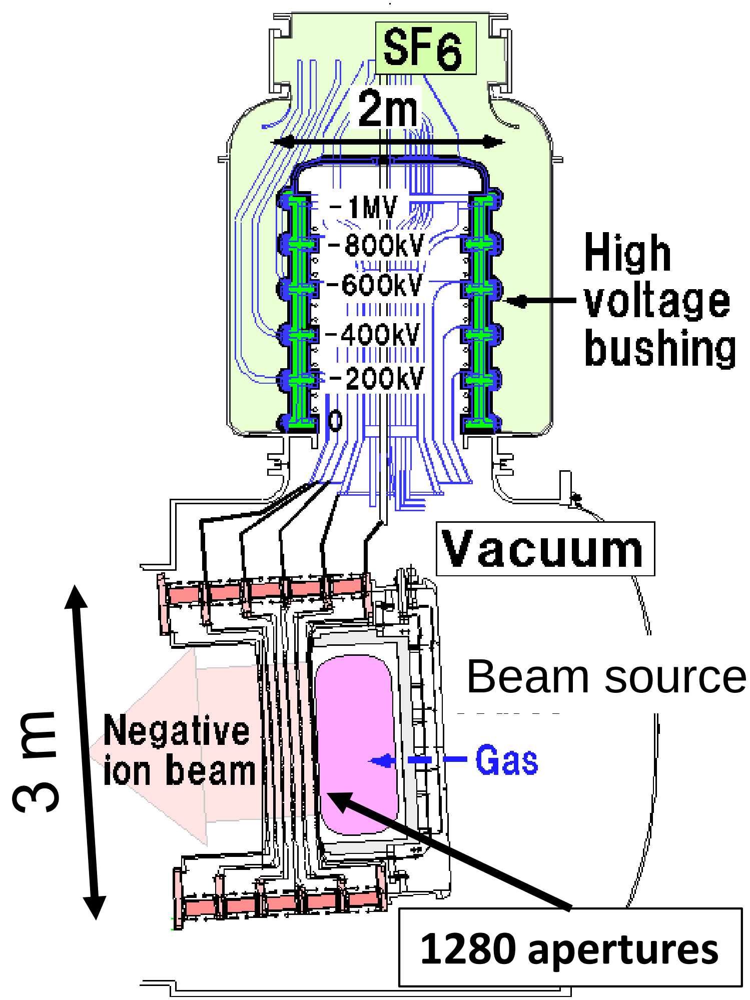


1 MeV beam with ITER-relevant current density

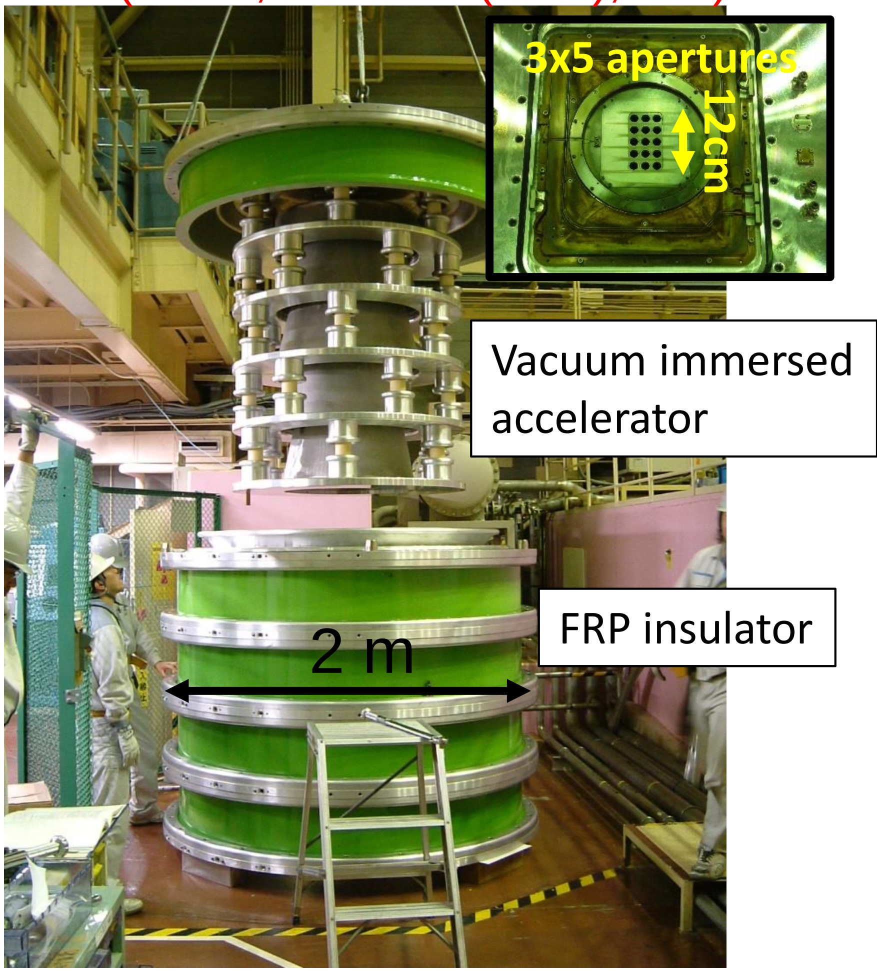
High current from large extraction area

Prototype accelerator for ITER

ITER accelerator
(1MeV, 200A/m^2 (40A), 3600 s)

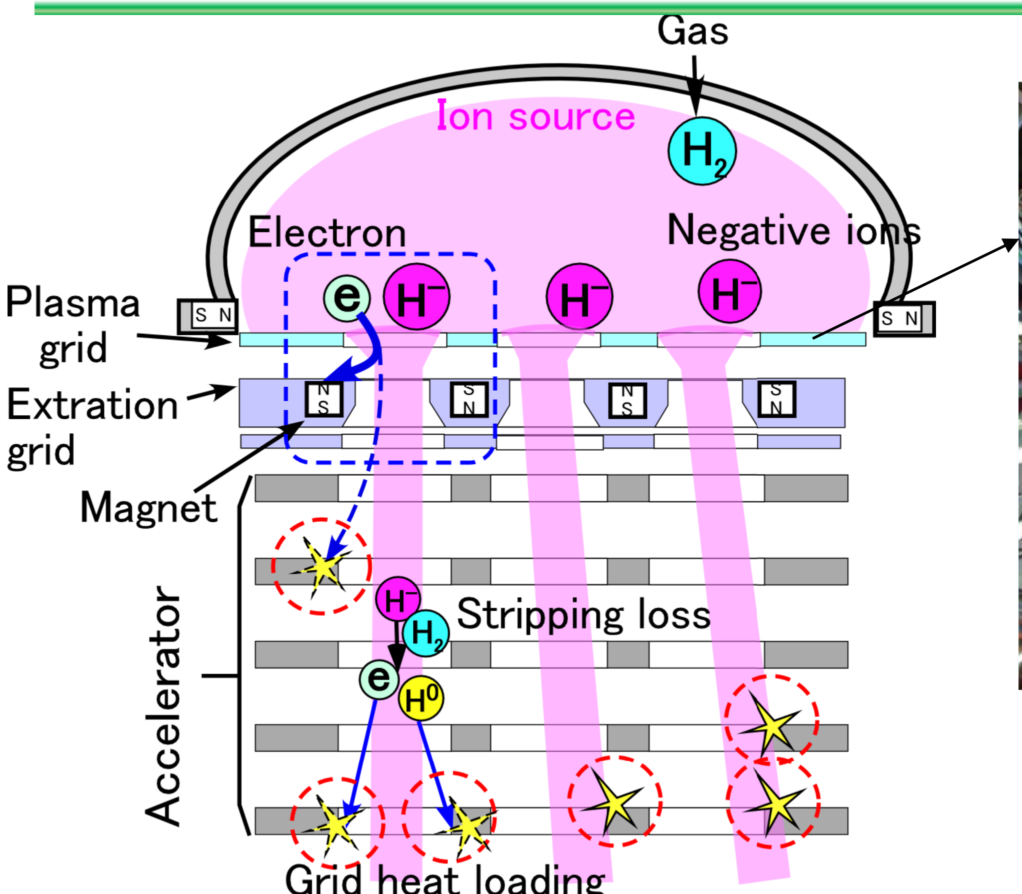


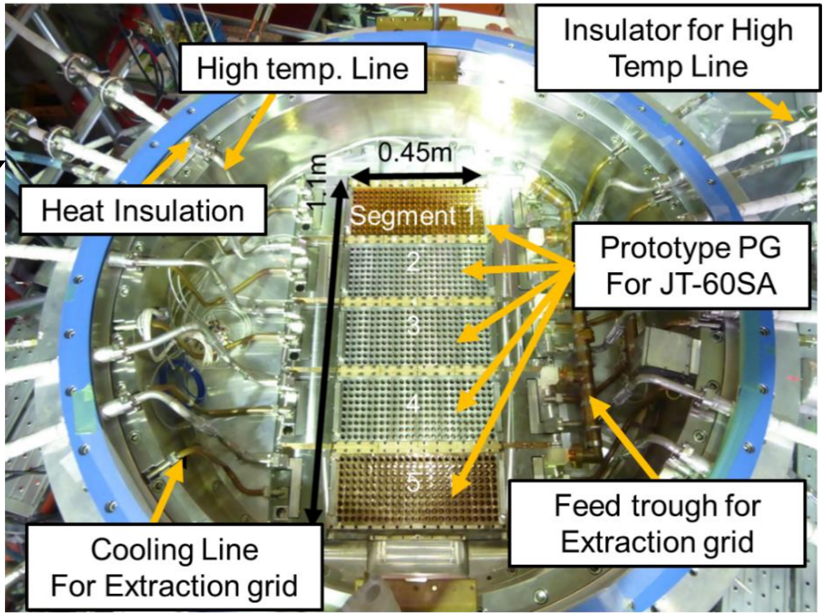
MeV accelerator
(1MeV, 200A/m^2 (0.5A), 60s)



R&Ds for 1MeV beam acceleration has been performed by using a multi-aperture multi-grid (MAMuG) accelerator, that was proposed by JAEA.

Features of negative ion source for fusion application





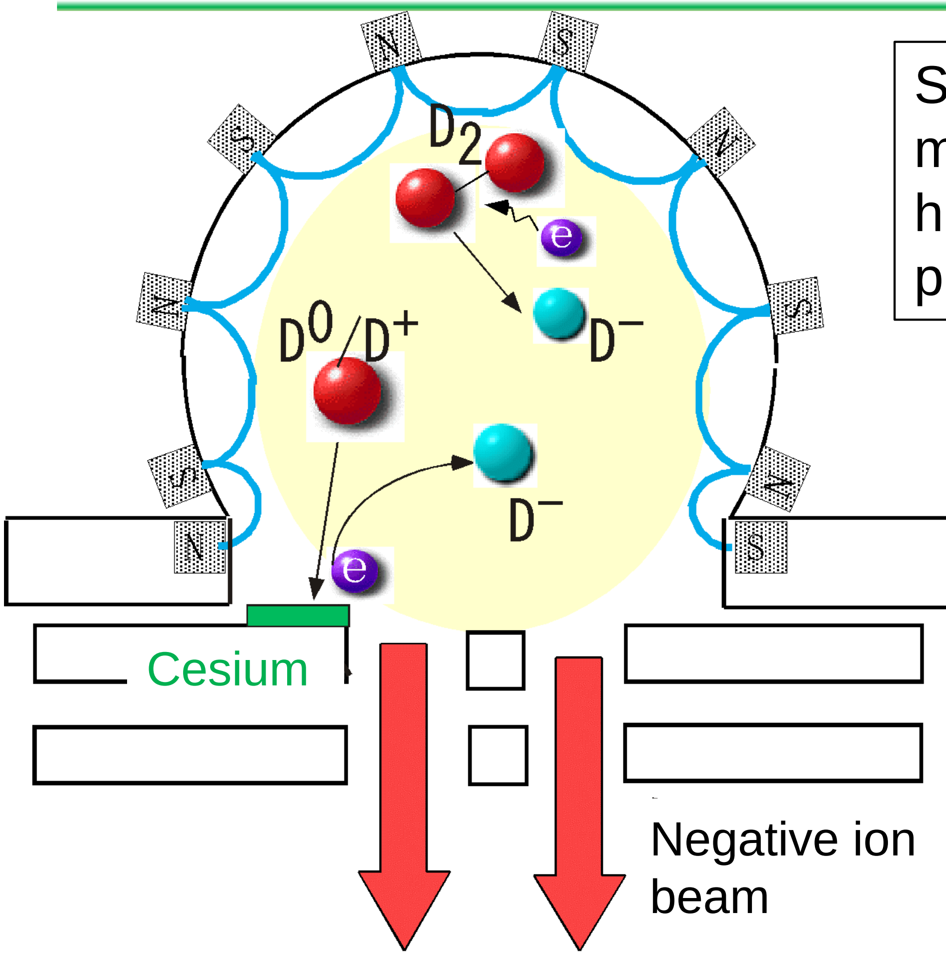
ITER-class grid with multi-apertures in JT-60U negative ion source

①Highly negative ion production (200A/m^2) at lower gas pressure (< 0.3Pa in the ion source) to suppress stripping loss

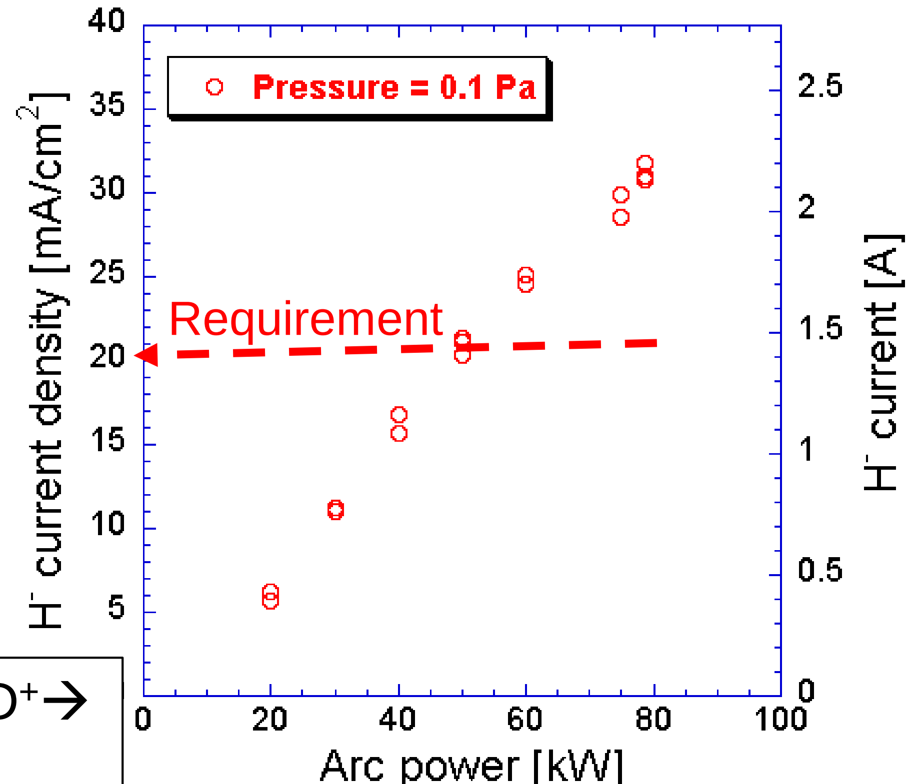
②High voltage vacuum insulation (1.2MV in total / 240 kV in one gap) at insulators and grids/grid support frames with large area with >1m^2.

③Suppression of grid loading by negative ions and electrons (<15% of total beam acceleration power)

①Highly negative ion production at lower gas pressure



Semi-cylindrical source with multi-cusp magnetic field (KAMABOKO) achieves high dense plasma (D/D^+) in lower gas pressure of < 0.3 Pa.



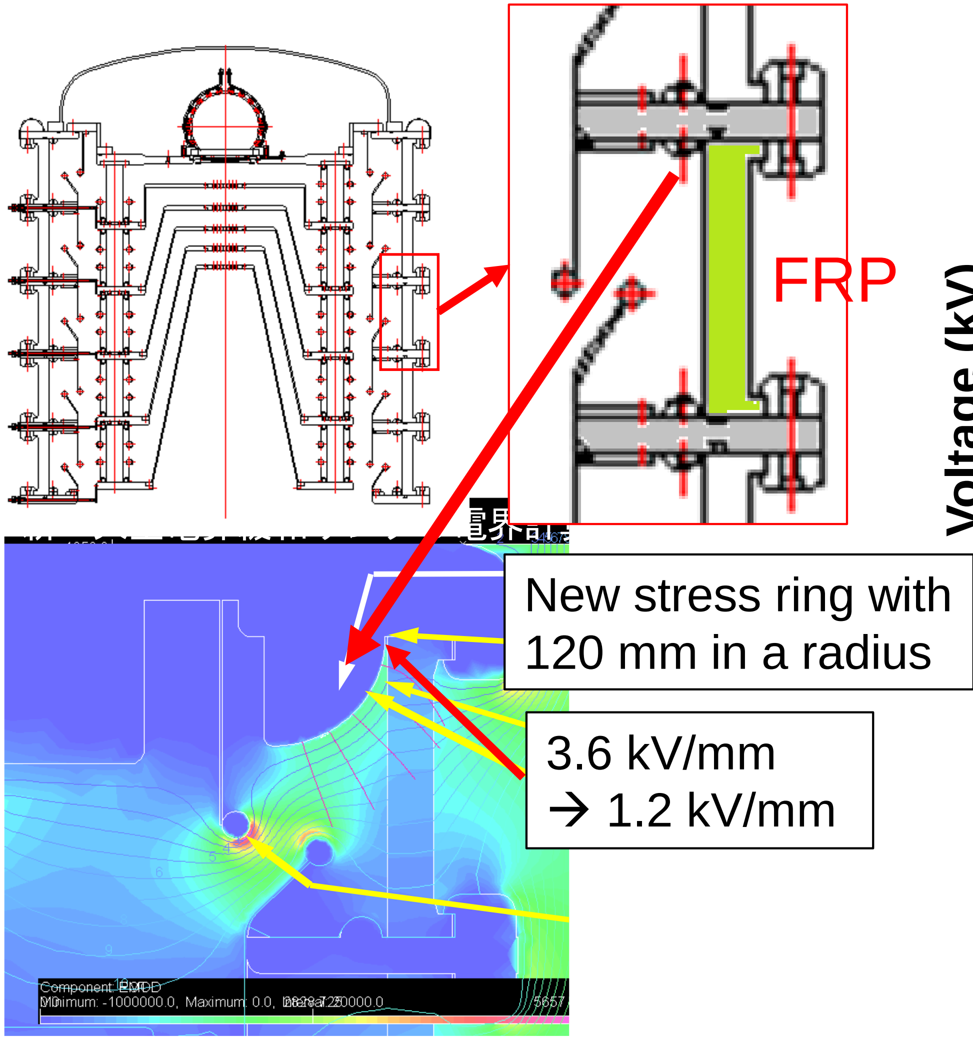
Surface production of negative ions ($D/D^+ \rightarrow D^-$) at low work function grid surface is enhanced by seeding a small amount of Cs.

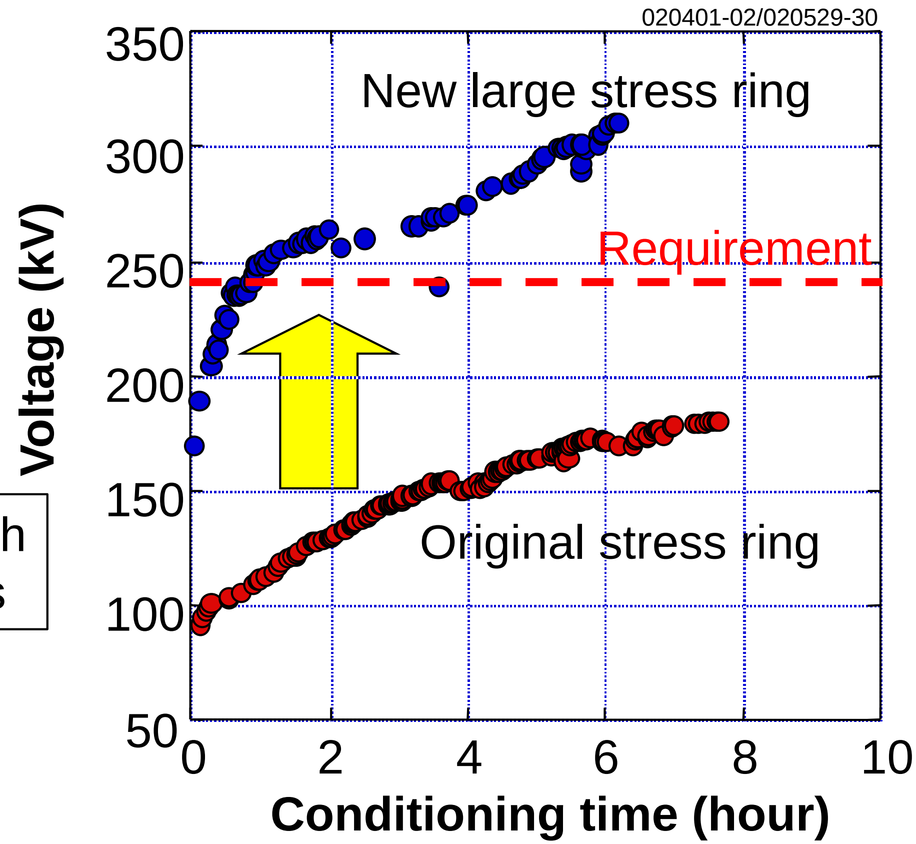
The negative ion current density of 310 A/m^2 was achieved at 0.1 Pa.

②High voltage insulation in a vacuum : Insulators

High electric field at triple junction between metal/dielectric material /vacuum caused creeping discharge and limited the voltage.

The electric field concentration was suppressed by installing large stress ring.

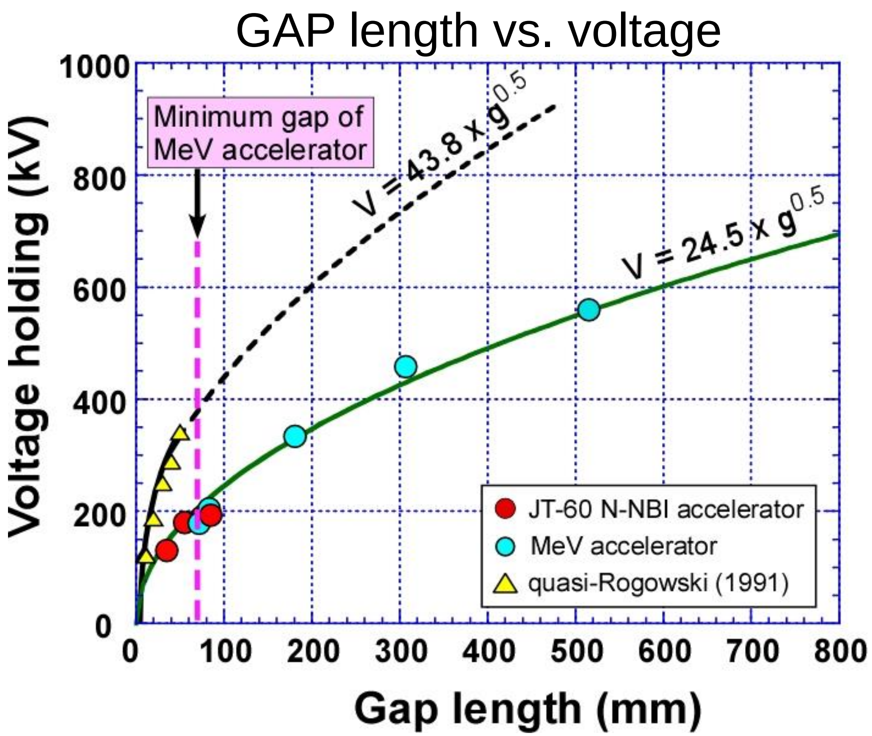


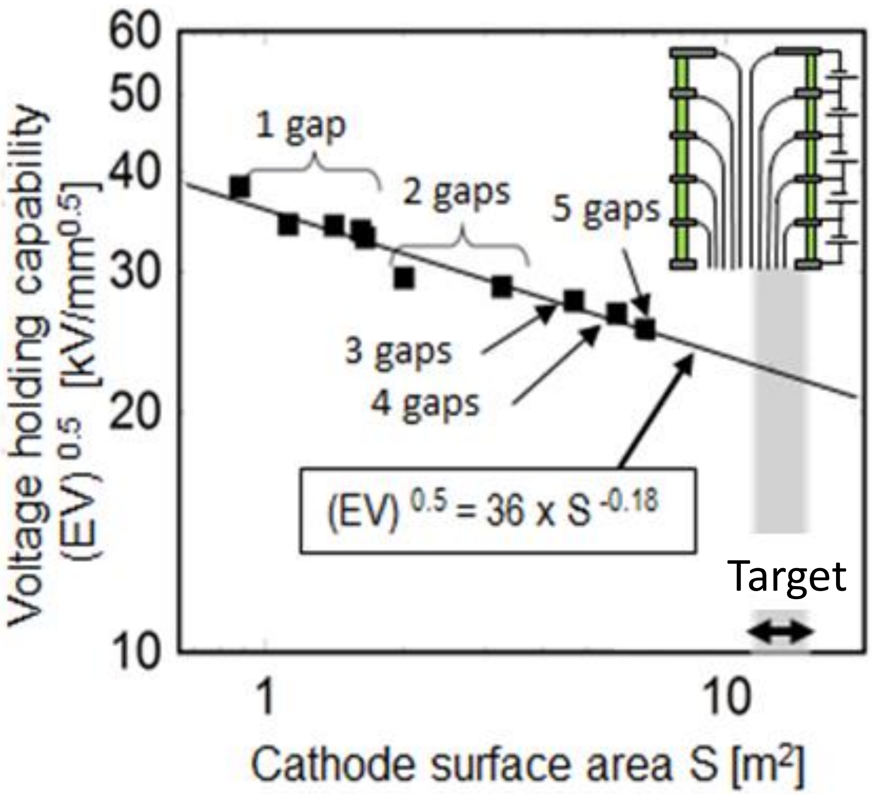


Voltage holding of the insulator satisfies with the ITER requirement.

②High voltage insulation in a vacuum : Metal part

The gap between grids was designed based on the results of small electrodes. However, the required voltage (240kV/1gap) has not been achieved.



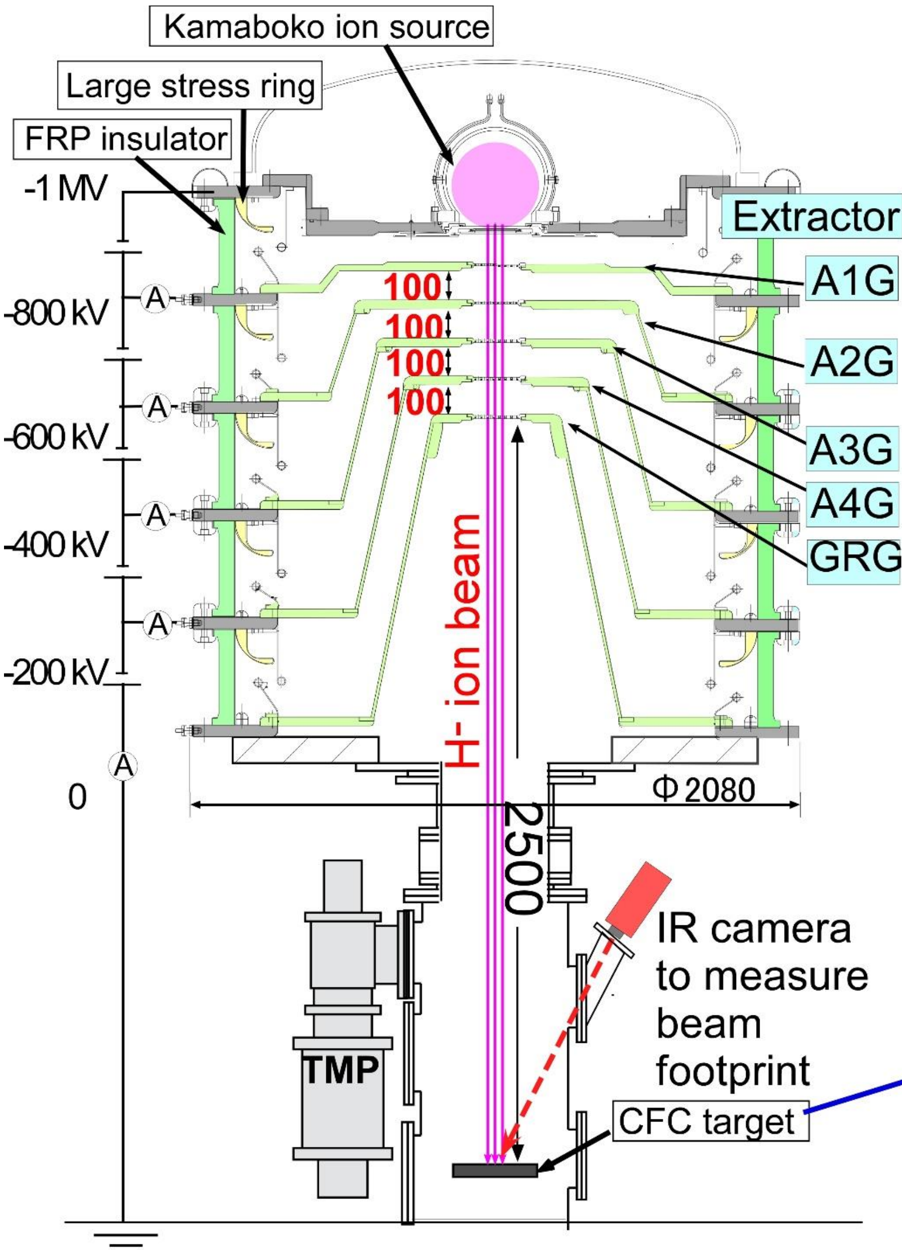


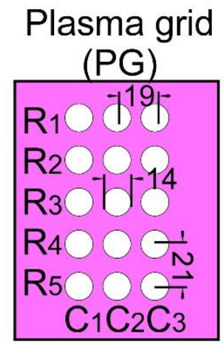
The withstand voltage in the large accelerator grid is 55% of that in the small electrodes.

The withstand voltage is decreased with the surface area.

The database to design the large accelerator has been established for the ITER.

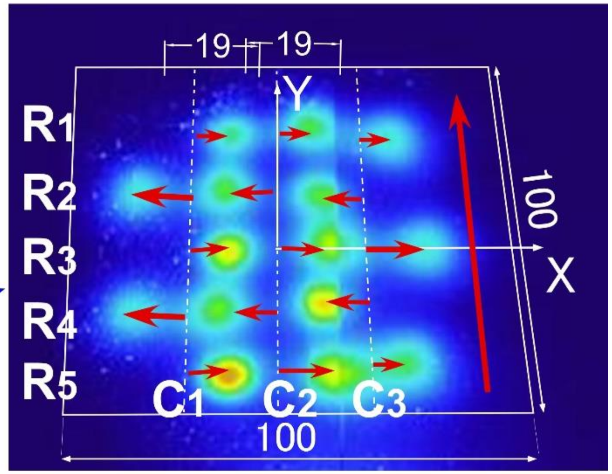
③ Suppression of grid power loading



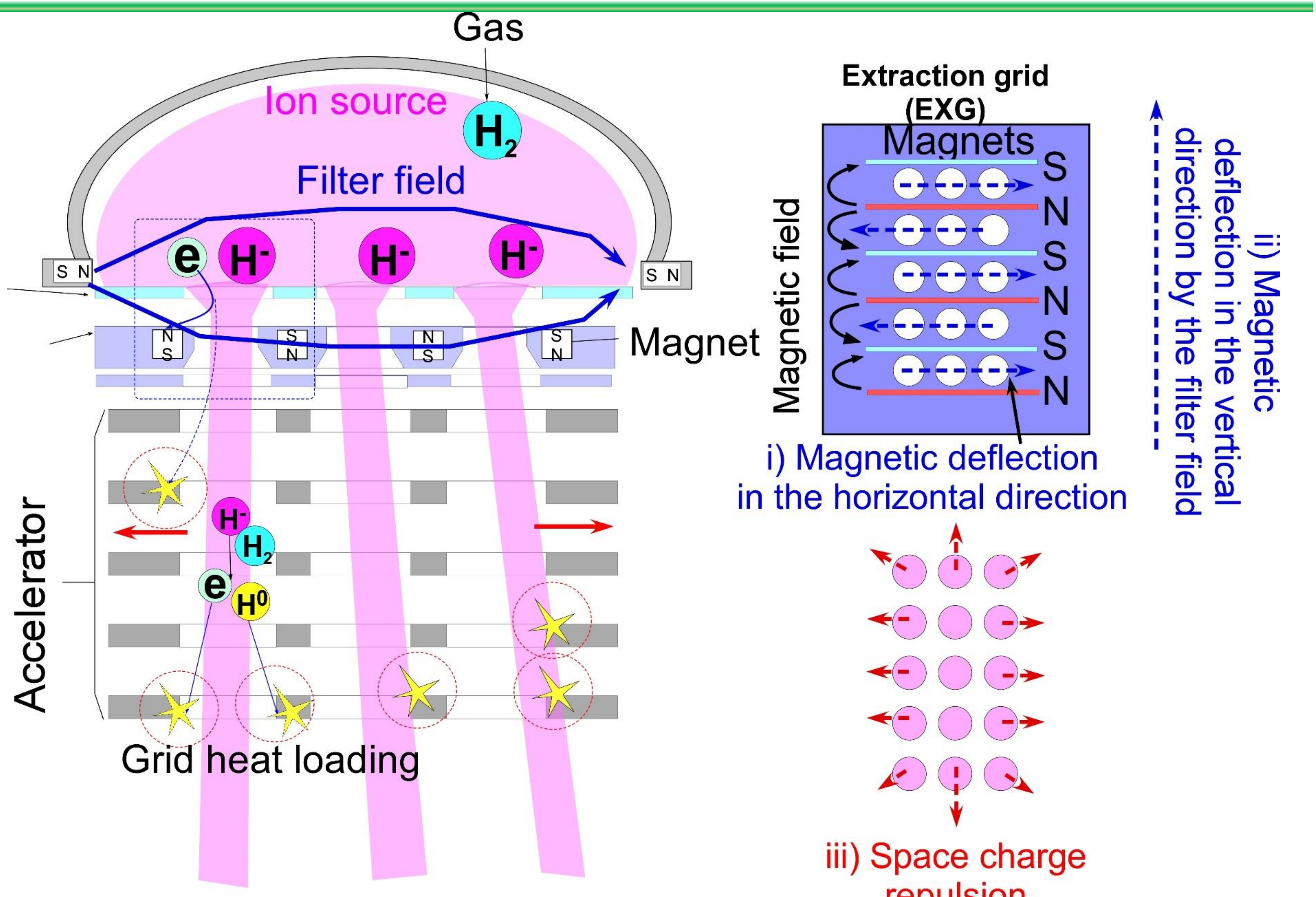


Some part of grid was melted.

Beam footprint intercepted at grid becomes weaker.



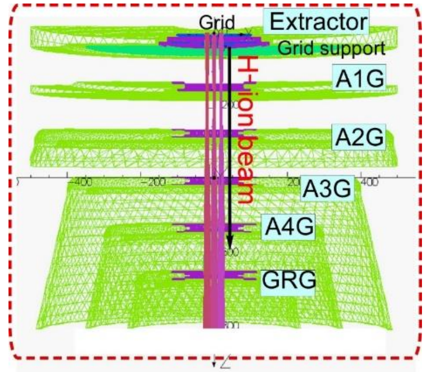
③ Suppression of grid power loading

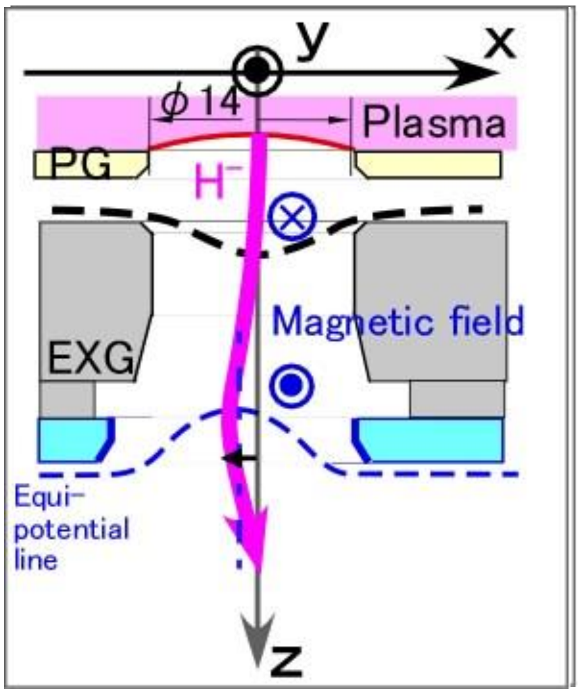


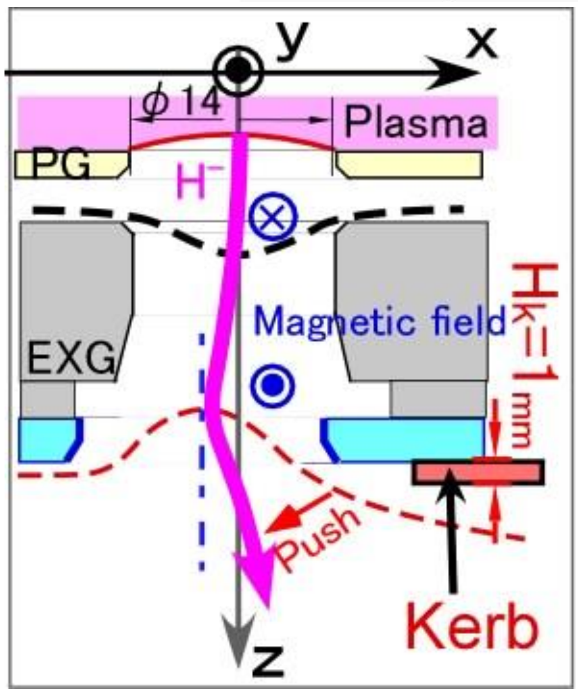
Superimpotion of the beam deflections i), ii), iii) caused the large beam deflection and cause the grid melting.

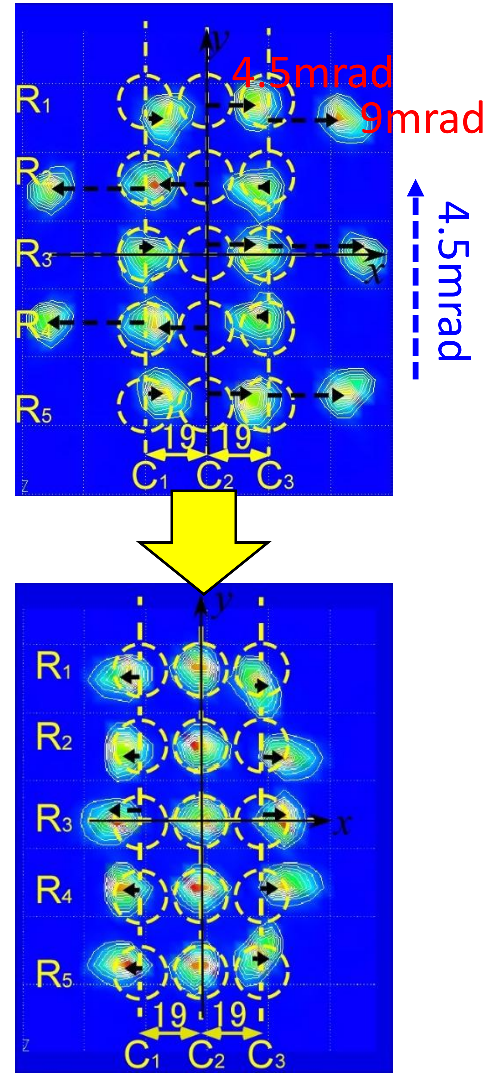
Compression of beam deflections

Beam trajectories and compression of beam deflection are examined by using a 3D beam analysis .



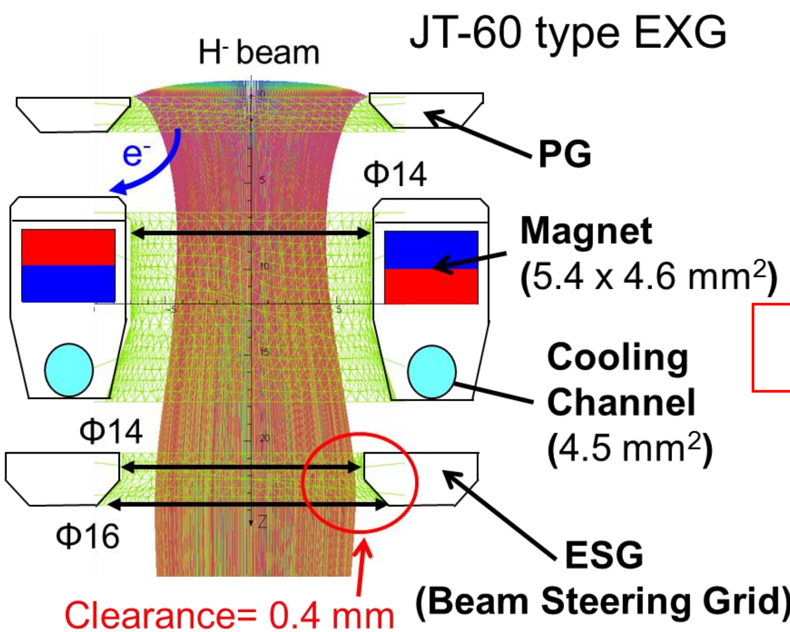


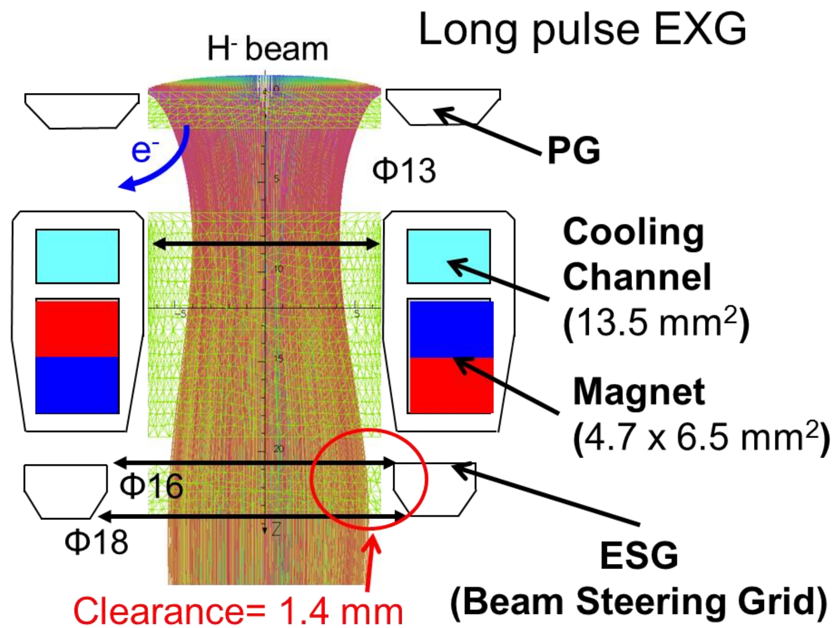


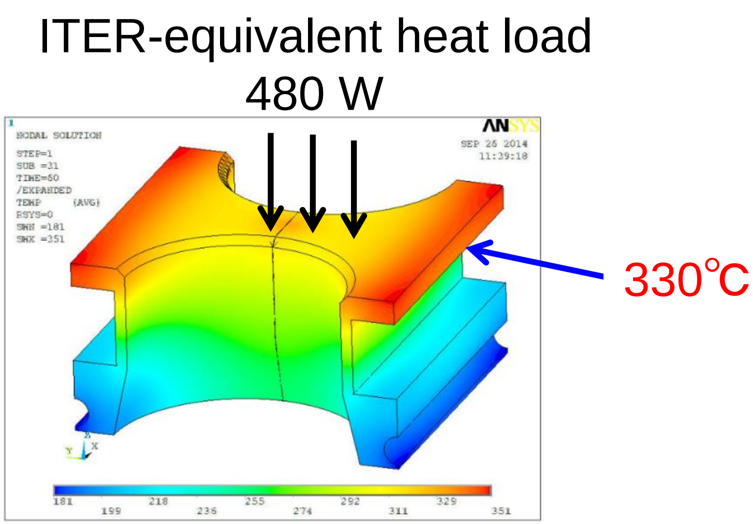


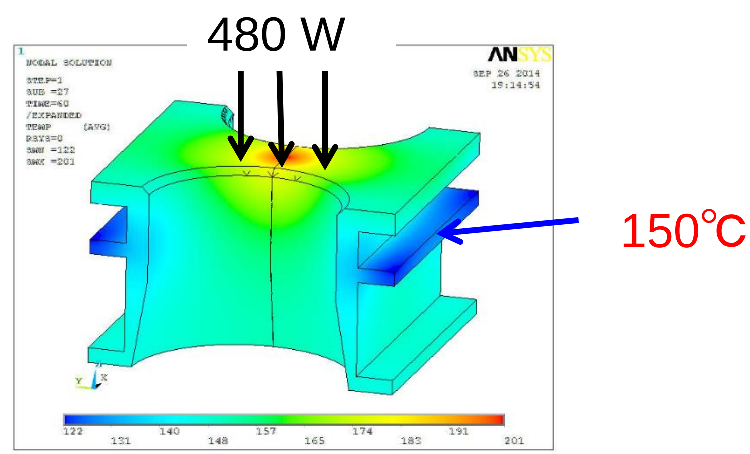
①Aperture offset of < 1 mm at the exit of the extraction grid
②Kerb with 1 mm in the thickness around the aperture area

Extraction grid for long pulse operation



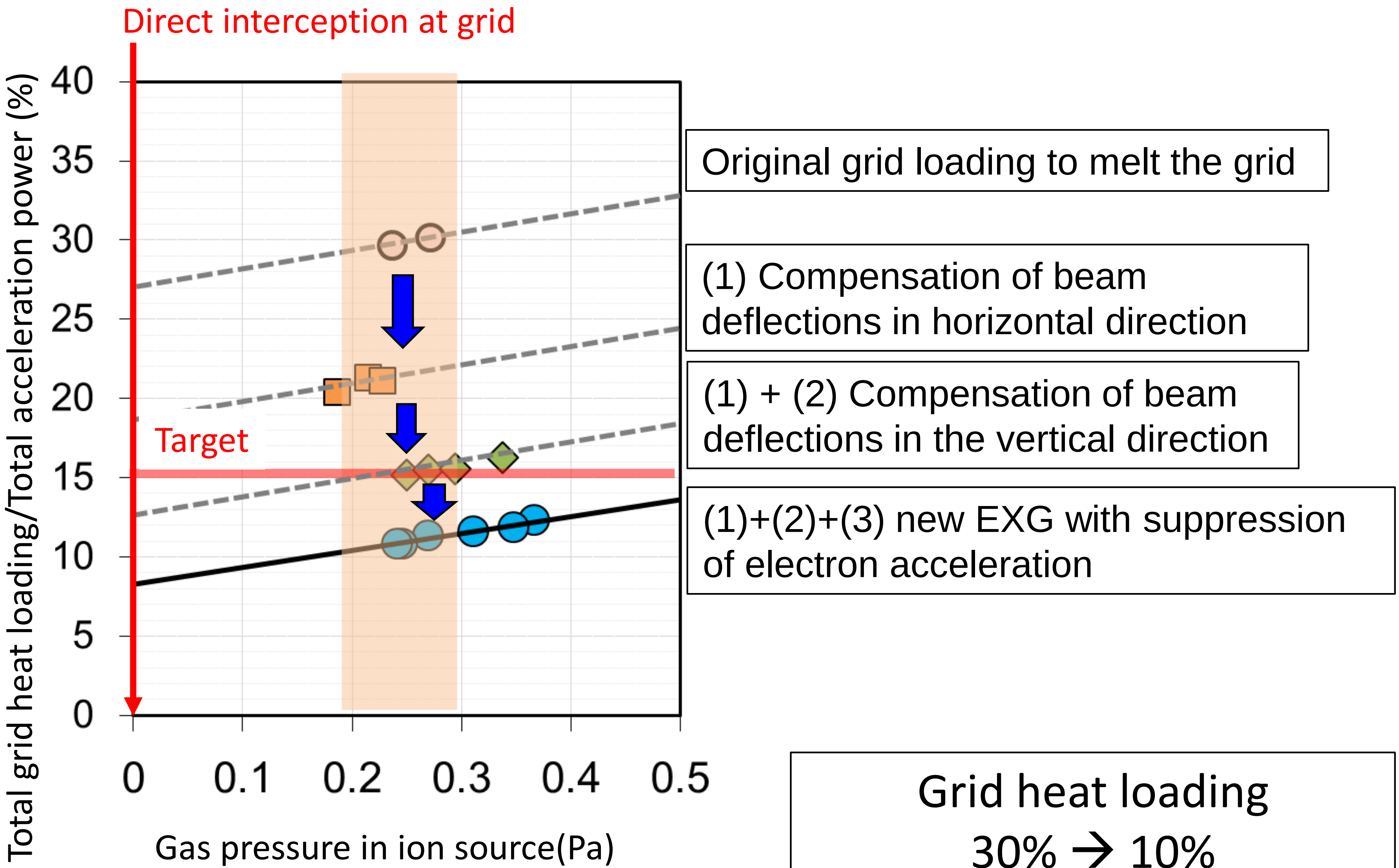






The new extraction grid has been demonstrated for the ITER beam source.

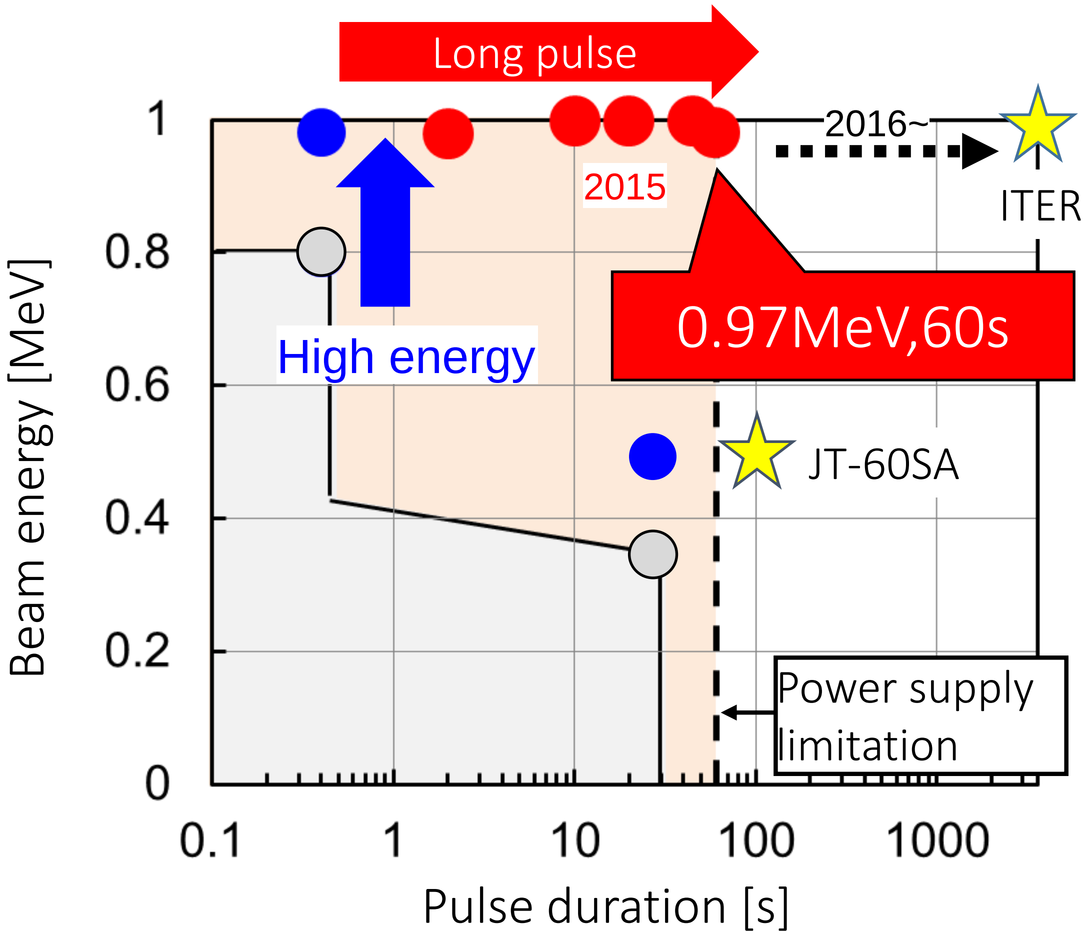
Reduction of grid heat loading



Grid heat loading

30% → 10%

Expansion of pulse length



During the long pulse operation with 1MV,

- no degradation of voltage holding capability.
- no damage on the grids.

No limitation for more longer pulse operation.

The long pulse acceleration of 60 s with the ITER-relevant beam (0.97MeV, 190A/m^2) has been successfully demonstrated for the first time.

Summary

To achieve the ITER requirement (1MeV, 200A/m^2 (40A),3600 s), R&Ds have been proceeded in JAEA.

①High current negative ion beam current (200A/m2) <0.3Pa was achieved in KAMABOKO source.
②Database to design the high voltage insulation in the ITER-class large accelerator has been established. Then, high voltage holding of 1MV was achieved.
③Grid loading has been successfully suppressed from 30% to 10 % by the compensation of beam deflections and optimization of extraction grid.

Finally, the long pulse acceleration of 60 s with the ITER-relevant beam (0.97MeV, 190A/m2) has been successfully demonstrated for the first time.