

FIP/1-3Ra

Long-pulse acceleration of 1MeV negative ion beams toward ITER and JT-60SA neutral beam injectors

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FIP/1-3Rb

Towards powerful negative ion beams at the test facility ELISE for the ITER and DEMO NBI system

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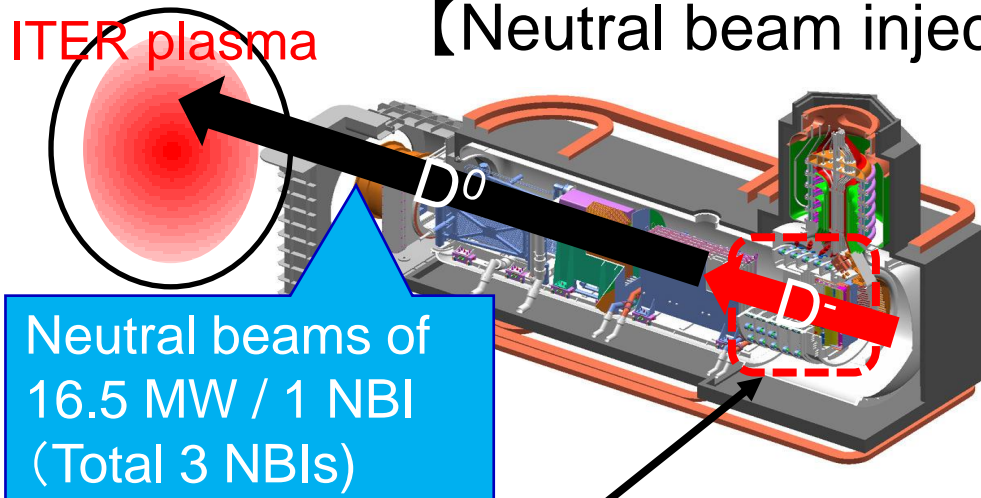


EUROfusion

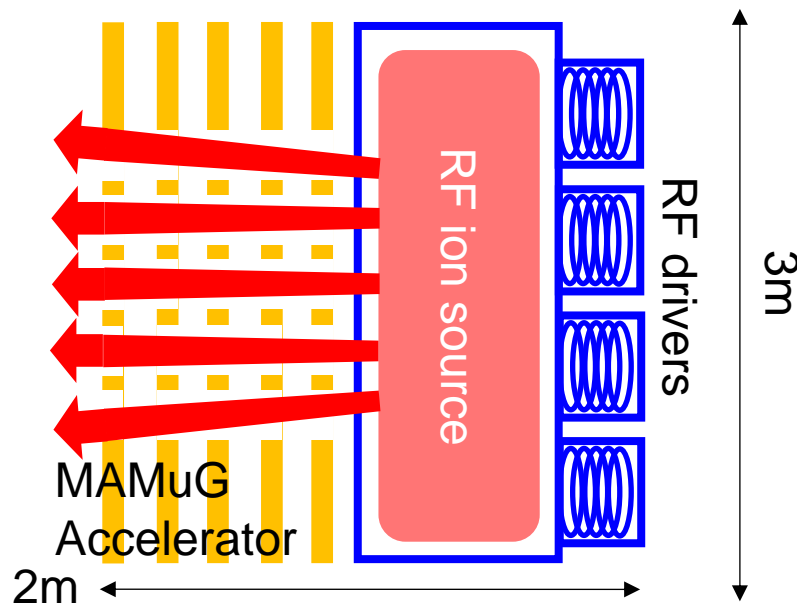


ITER plasma

【Neutral beam injector (NBI) for ITER】



D⁻ ion beam :
1 MeV, 40 A, 1 hour



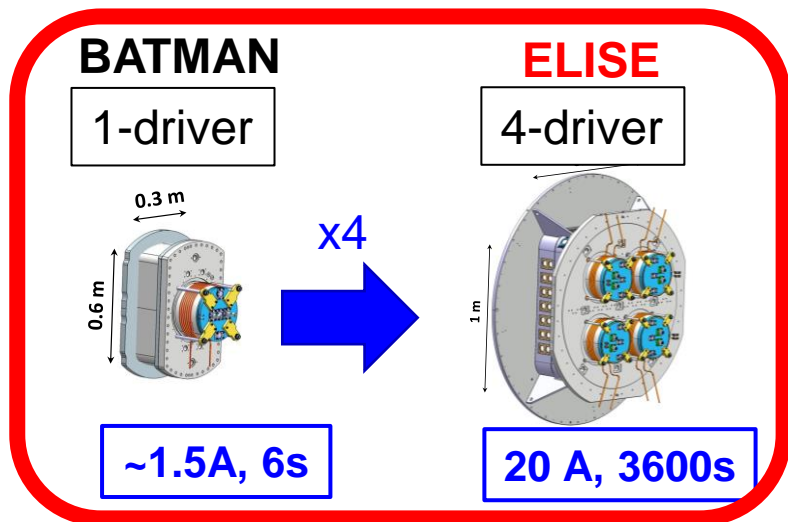
Issues in RF ion source

- High current negative ion production/extraction using multi-RF drivers
- Stable negative ion production/extraction for long pulse

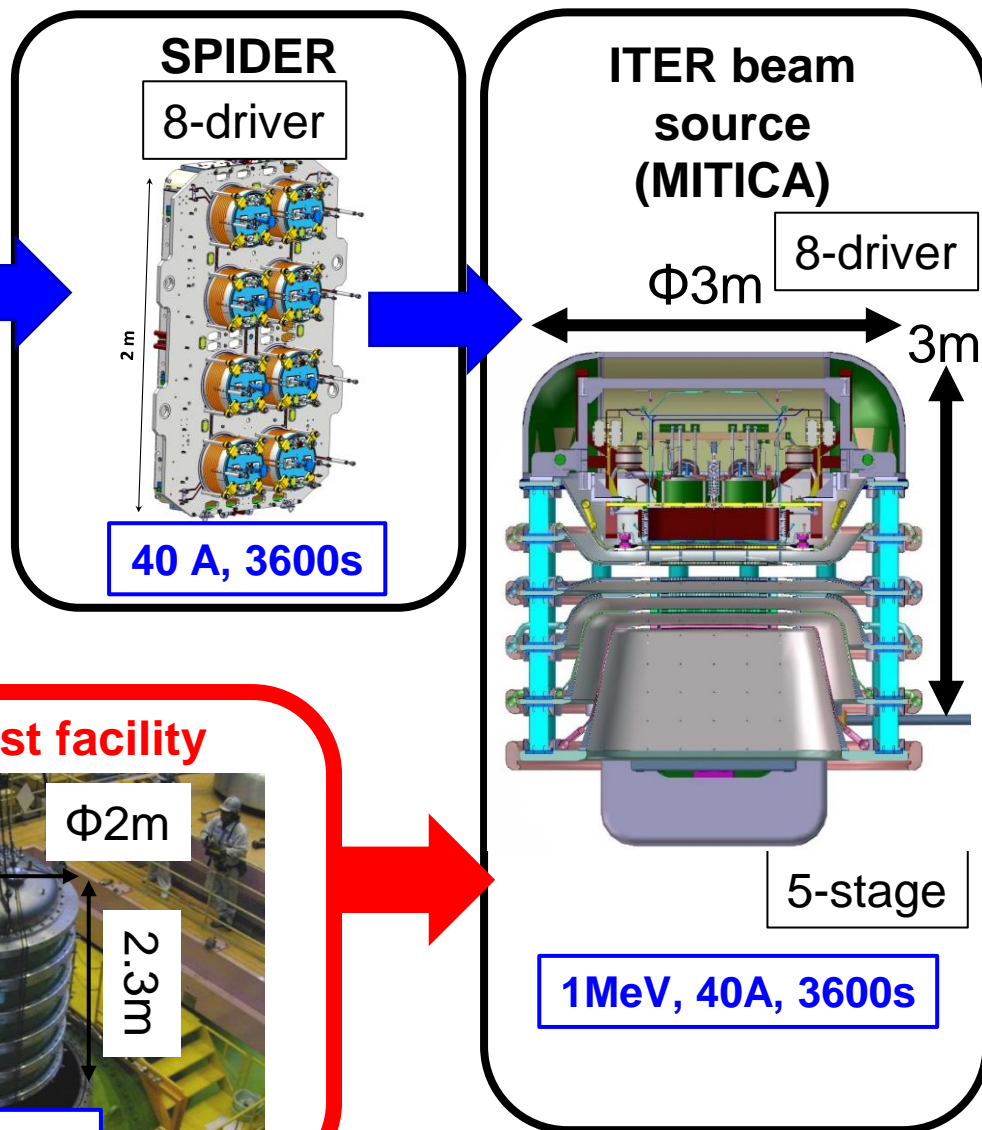
Issues in multi-aperture multi-Grid (MAMuG) accelerator

- Voltage holding with multi-grid
- Reduction of grid power load for long pulse

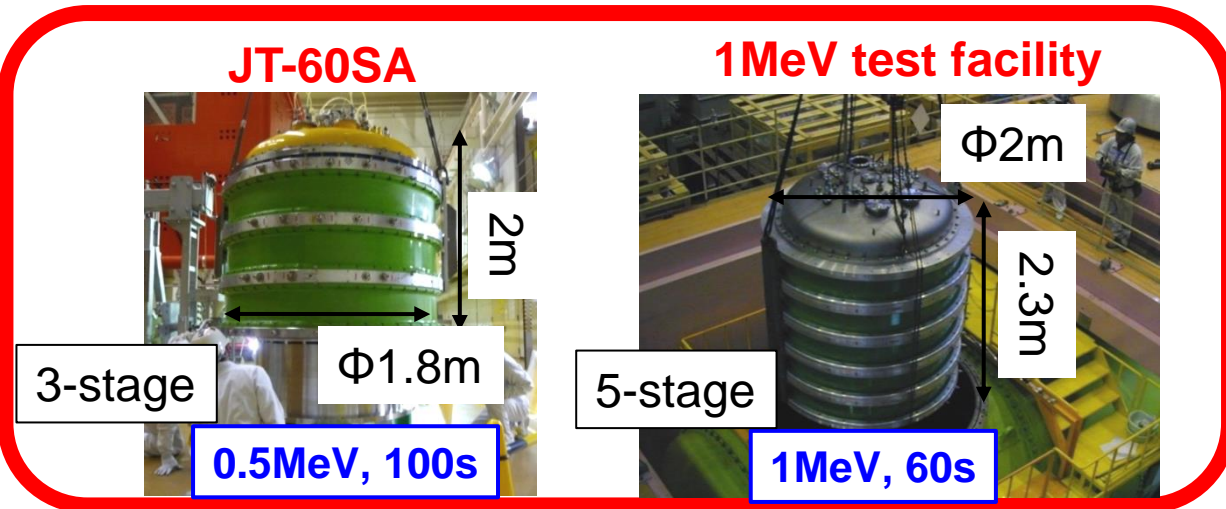
RF ion source (IPP, Garching)



ITER NB test facility (RFX, Padova)

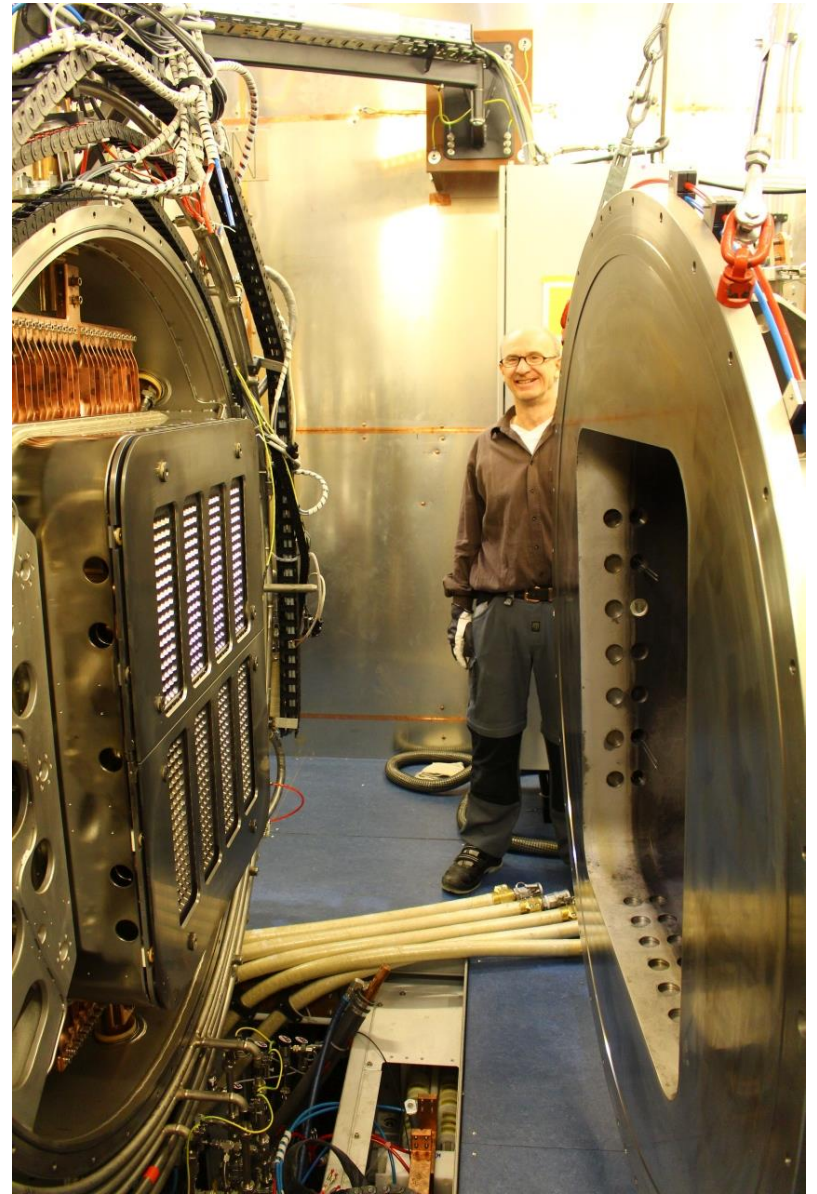


MAMuG accelerator (QST, Naka)



Progress in IPP

Towards powerful
negative ion beams
at the test facility ELISE
for the ITER and DEMO
NBI system



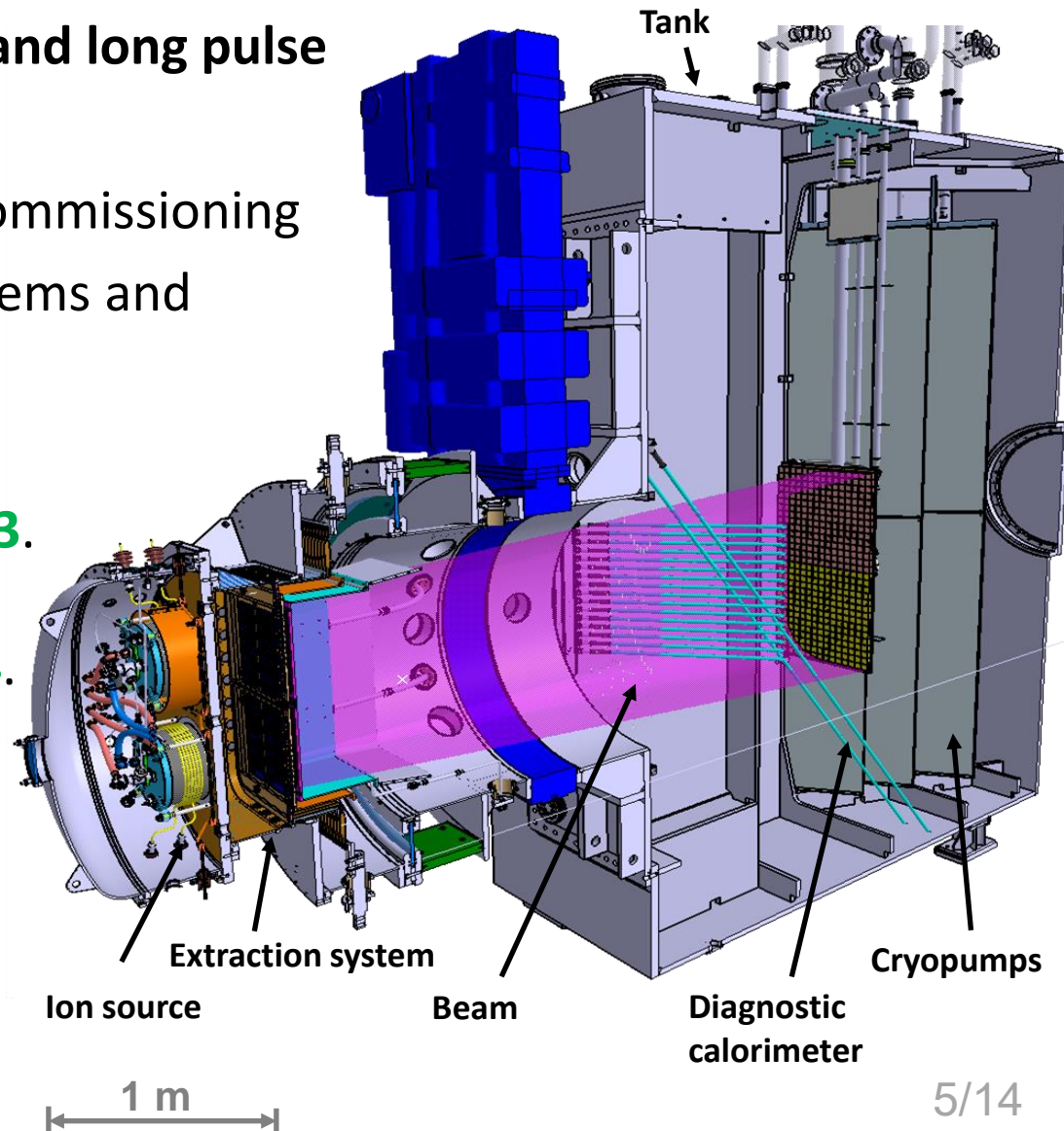
The ELISE test facility with a 1/2-size ITER RF ion source

4-driver in the ion source and ion extraction system.

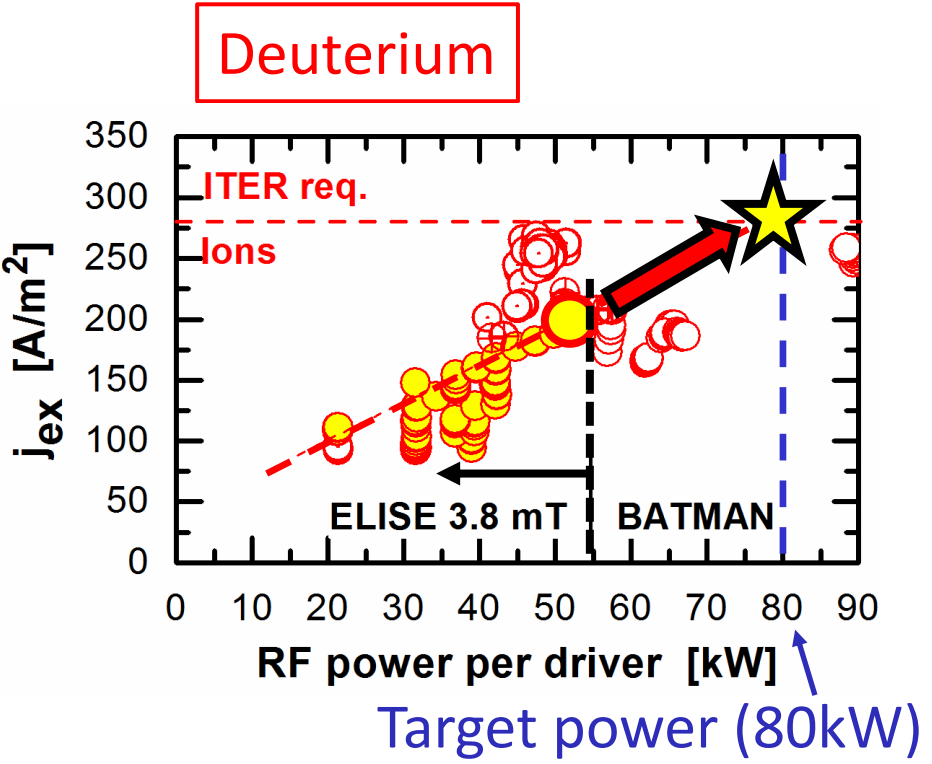
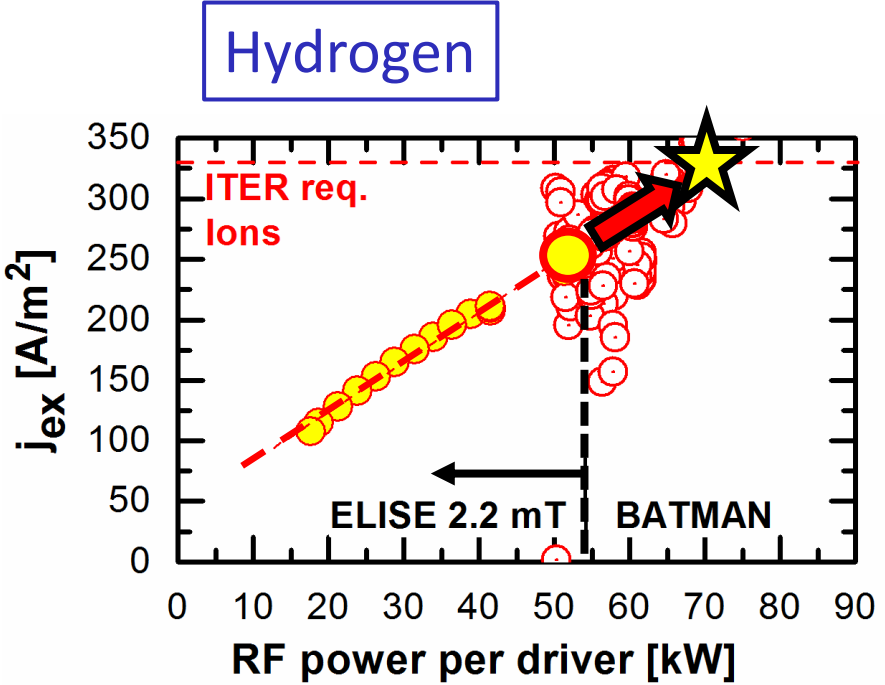
- **To demonstrate high current and long pulse operation**
- **To provide input** for design, commissioning and operation of ITER NBI systems and European test facilities
 - Operation :
Started since **February 2013**.
 - Long pulse test :
Started since **October 2014**.

Keys for long pulse ion extraction:

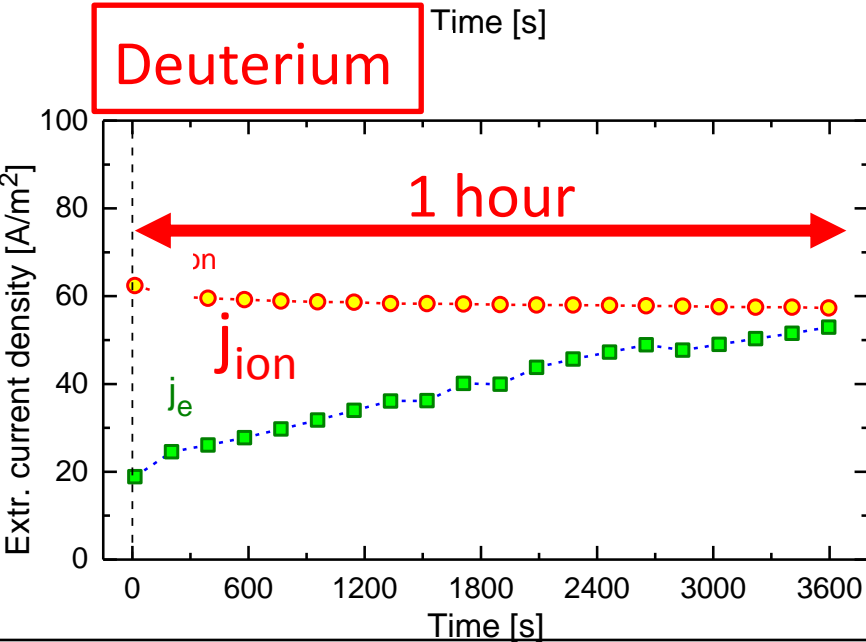
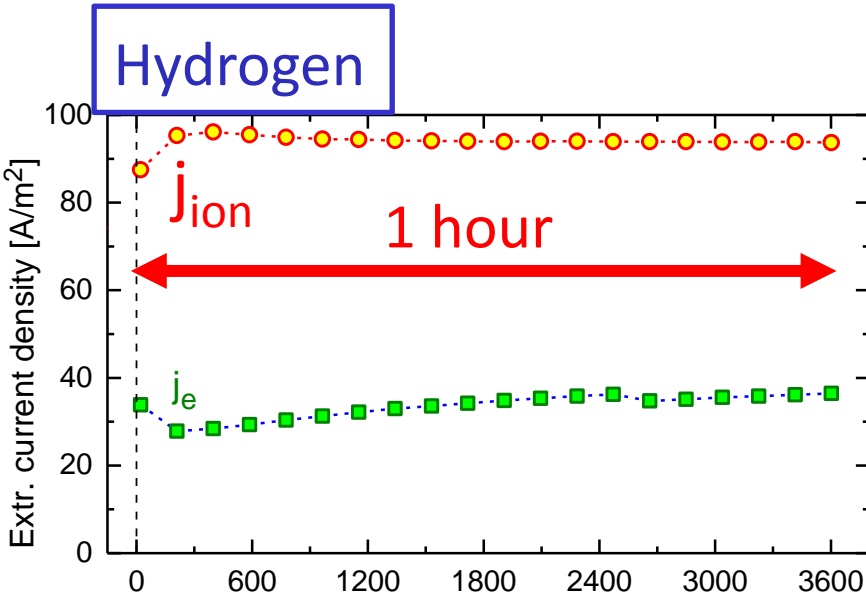
- **Beam homogeneity > 90 %**
- **Ratio of electron current for ion current < 1 at 0.3 Pa (ITER requirement)**



20 s plasma, 10 s beam



- Extracted current density j_{ex} linearly increases with RF power.
- ITER requirement could be satisfied with 80 kW per driver by considering the results from BATMAN.
- Long pulse operation was tested with this range of RF power.



Hydrogen	Achieved	Target
$I_{ion,ex}$	9.3 A	33 A
RF power per driver	20 kW	80 kW
$I_{ion,ex}/RF$ power	0.12 A/kW	0.10 A/kW

Deuterium	Achieved	Target
$I_{ion,ex}$	5.8 A	29 A
RF power per driver	20 kW	80 kW
$I_{ion,ex}/RF$ power	0.073 A/kW	0.091 A/kW

- 1 hour operation was successfully achieved.
- Ion current / RF power is almost satisfied with the target value.

- Experiments on ELISE test facility has been started since Feb 2013 and had several long pulse campaigns since last FEC.
- Input RF power was still $\frac{1}{4}$ of the target value. However, the H- and D- ion currents linearly increase with RF power and could satisfy the ITER requirement with 80 kW of RF power.
- Long pulse operation of the H⁻ and D⁻ ion production/extraction was performed for the first time. 1 hour operation as the ITER requirement was successfully achieved.
- Next campaign with larger current production/extraction is being planned by tuning RF ion source.

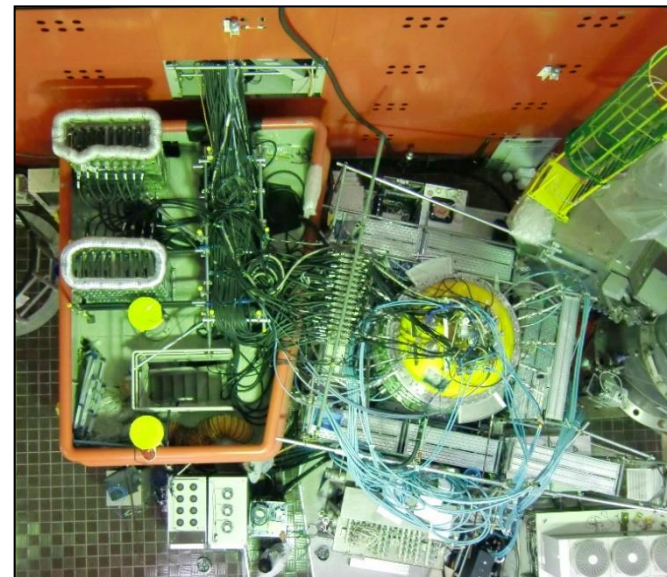
Progress in QST

Long pulse
beam acceleration
toward

ITER and JT-60SA NBI

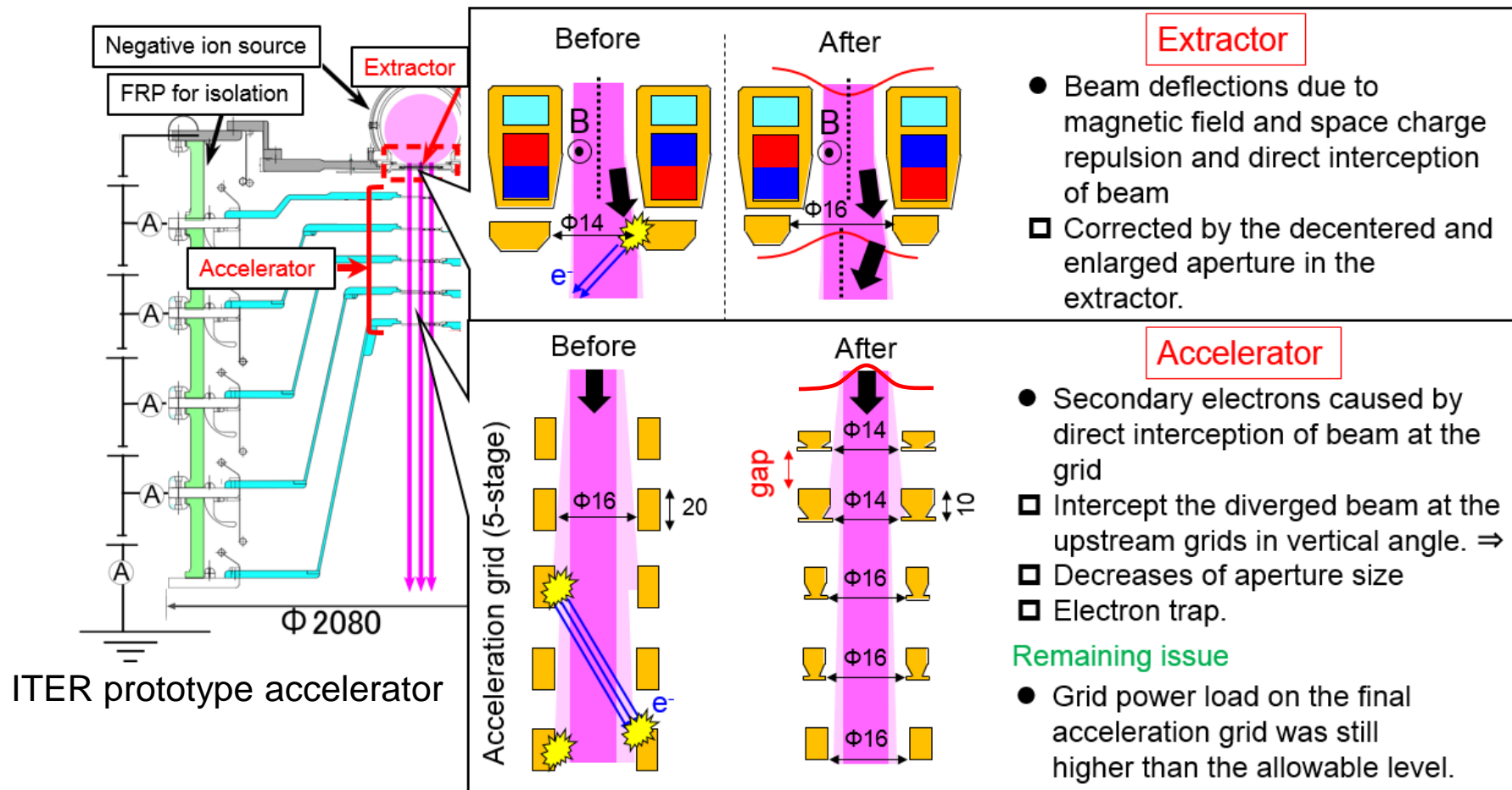


ITER prototype accelerator



N-NBI system for JT-60SA

Reduction of the grid power load has been performed as follows by FEC2014.



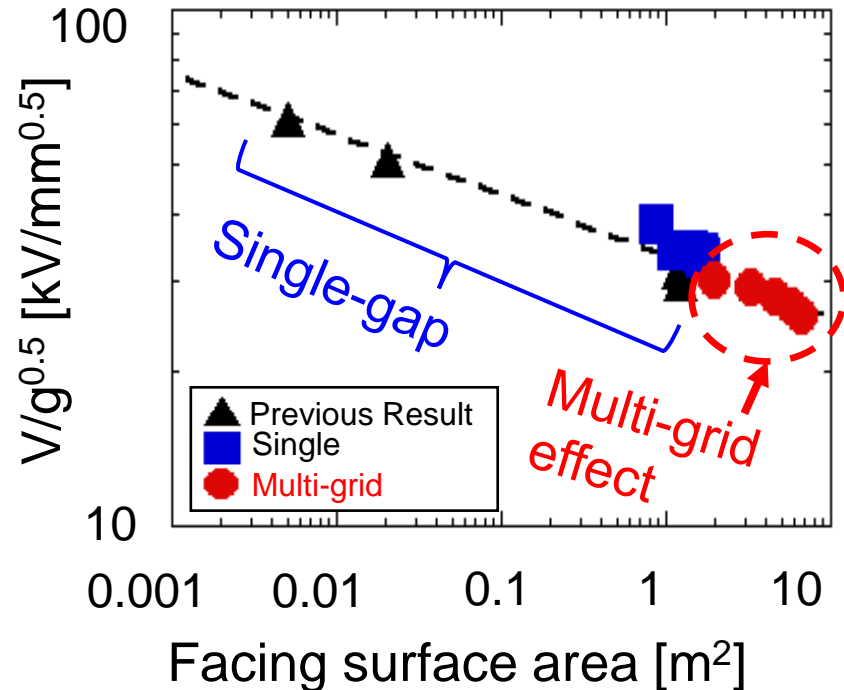
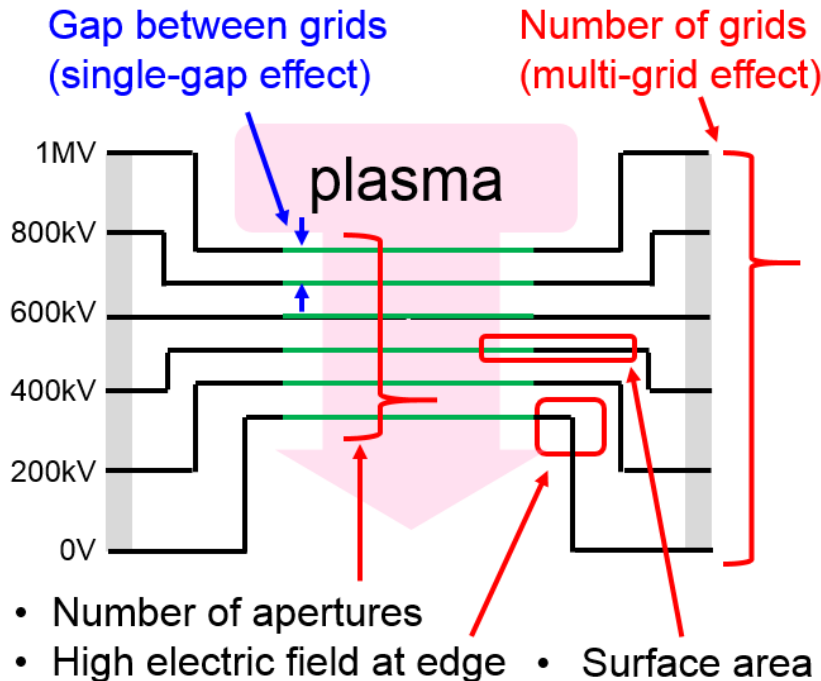
Achievement : 0.98 MeV, 0.4 s (FEC2012), 0.70 MeV, 60 s (FEC2014)

Remaining issue : 1 MeV, 60s beam acceleration.

Optimization of beam optics is required by shorter acceleration gap. For this, voltage holding capability in MAMuG accelerator was investigated.

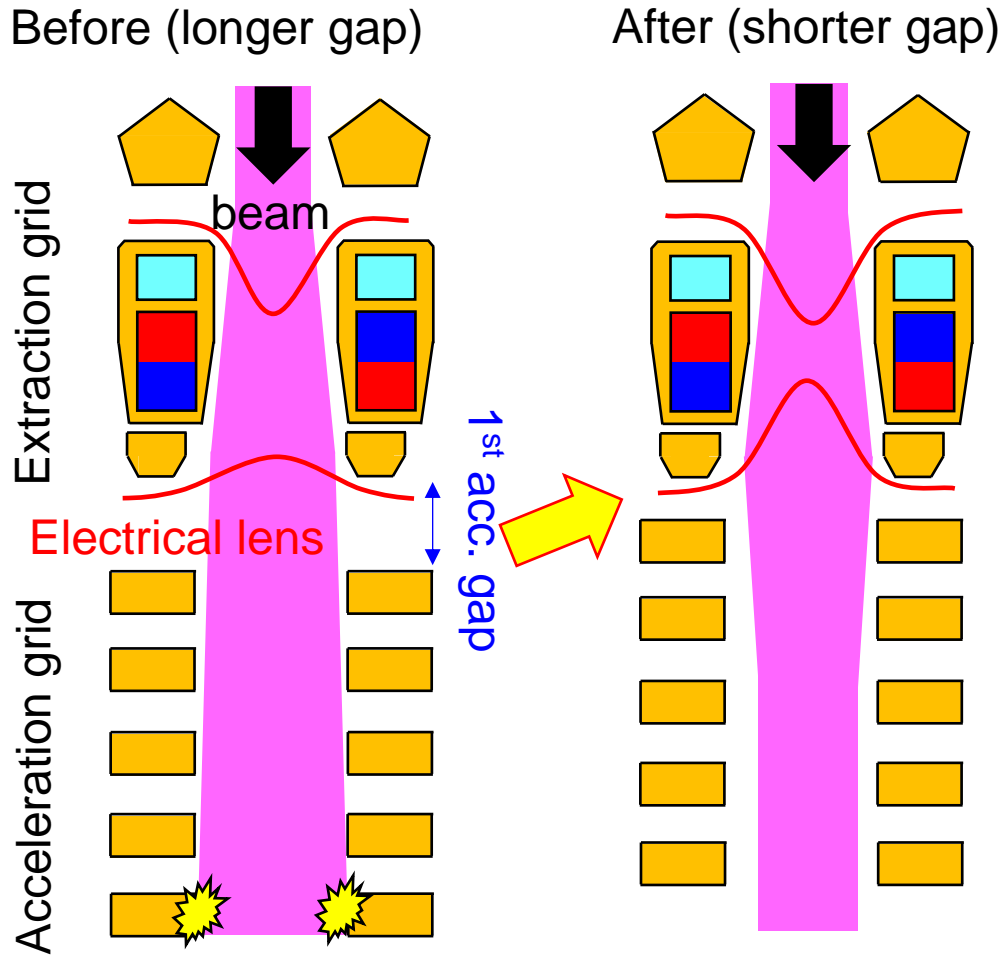
By FEC2014, experimental data of voltage holding capability was obtained for each part.

Newly obtained empirical scaling for multi-grid

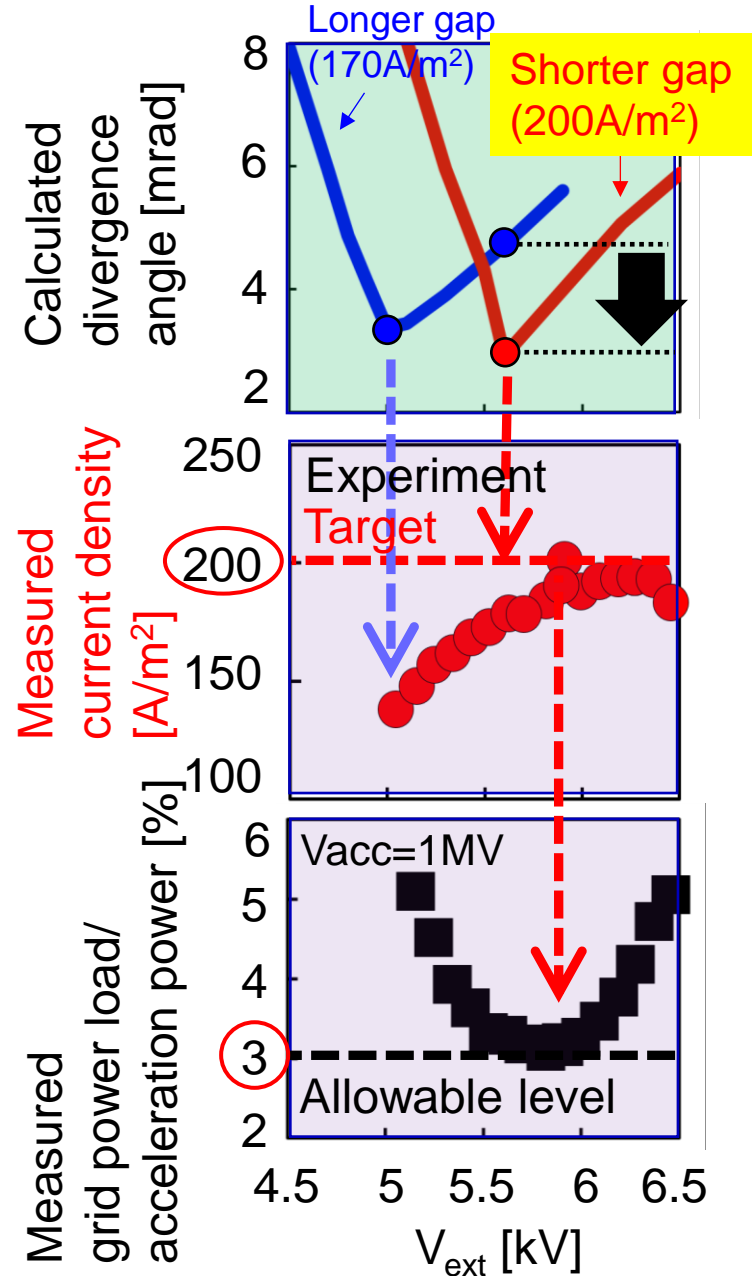


- This study clarified the voltage holding capability in multi-grid can be considered as that in the integrated surface area.
- By considering the empirical scaling, acceleration gap can be shortened to make electric field stronger and minimize the beam divergence.

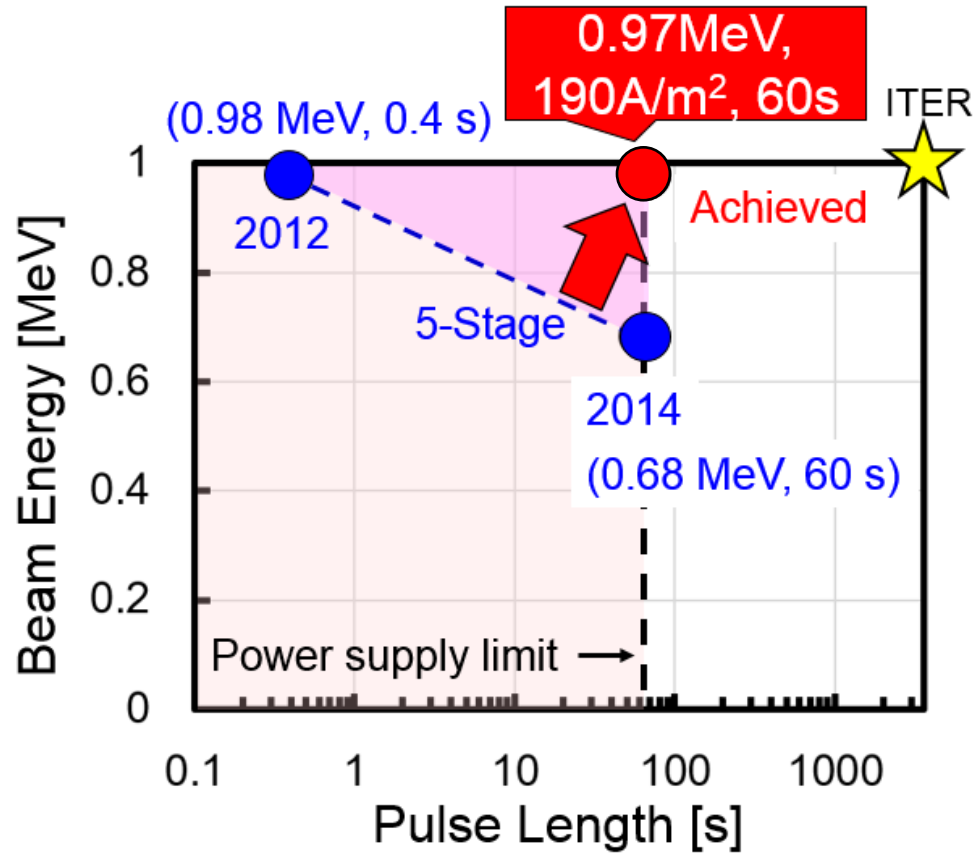
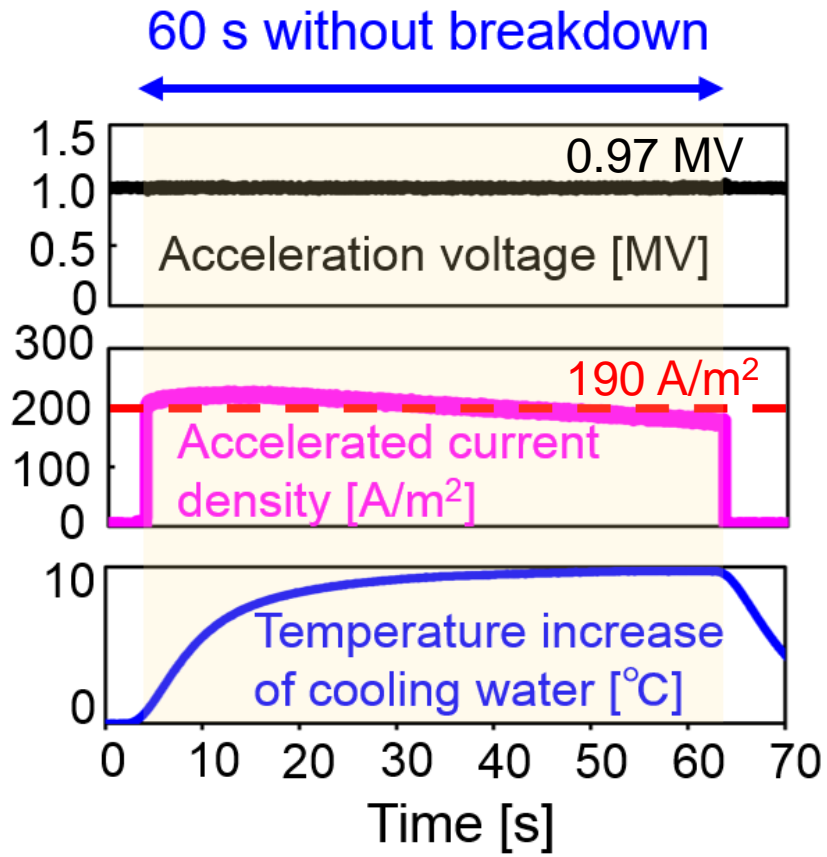
Tuning of acceleration gap length



- Beam optics was successfully tuned for 200 A/m^2 by increasing electric field by 14%.
- Power load on each acceleration grid was reduced to the allowable level (3%).



Achievement of 1MeV and long pulse beam



- Demonstration of long pulse acceleration with ITER-relevant energy and current density of 0.97 MeV, 190 A/m² up to 60 s (power supply limitation) was successfully achieved.
- Cooling water temperature was saturated. There were no breakdown and no thermal damage during 60 s.
 ⇒ Further long pulse acceleration is available.

Long pulse acceleration of ITER-relevant beams of 0.97 MeV, 190 A/m², 60 s was successfully demonstrated by the following R&D results in Japan.

- Multi-grid effect on voltage holding capability was experimentally investigated.
- Electric field in the first acceleration gap was tuned by satisfying the both requirements of voltage holding capability and beam optics.

Accelerator design of ITER and JT-60SA is being proceeded based on the R&D results.

Toward 1MeV, 40A, 1h beam : NB test facility (NBTF) in Italy

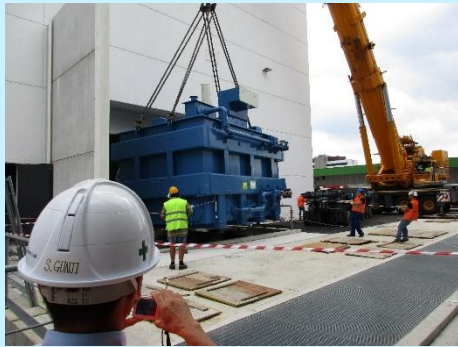
These achievements apply to the full size beam source in the NBTF for ITER.

In the NBTF site, construction of the 1MV system are in progress **under good collaboration with IO/F4E/RFX/IPP colleagues..**

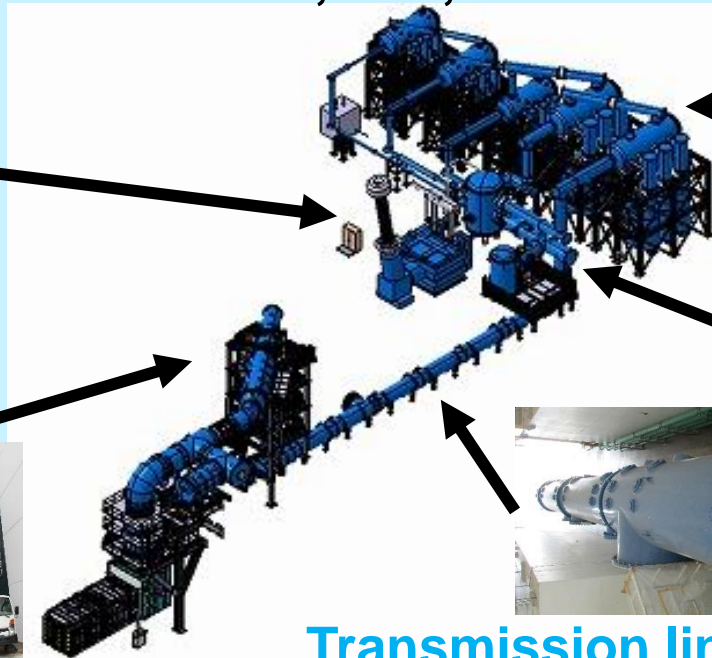
Installation of 1MV power supply delivered from Japan has **started from Dec/2015 as scheduled.**

Transformers : 100 %, Transmission line 60 % completed.

1MV insulating transformer



**HV power supply from Japan
1MV, 60A, 1h**



1MV DC generator



Transmission lines

