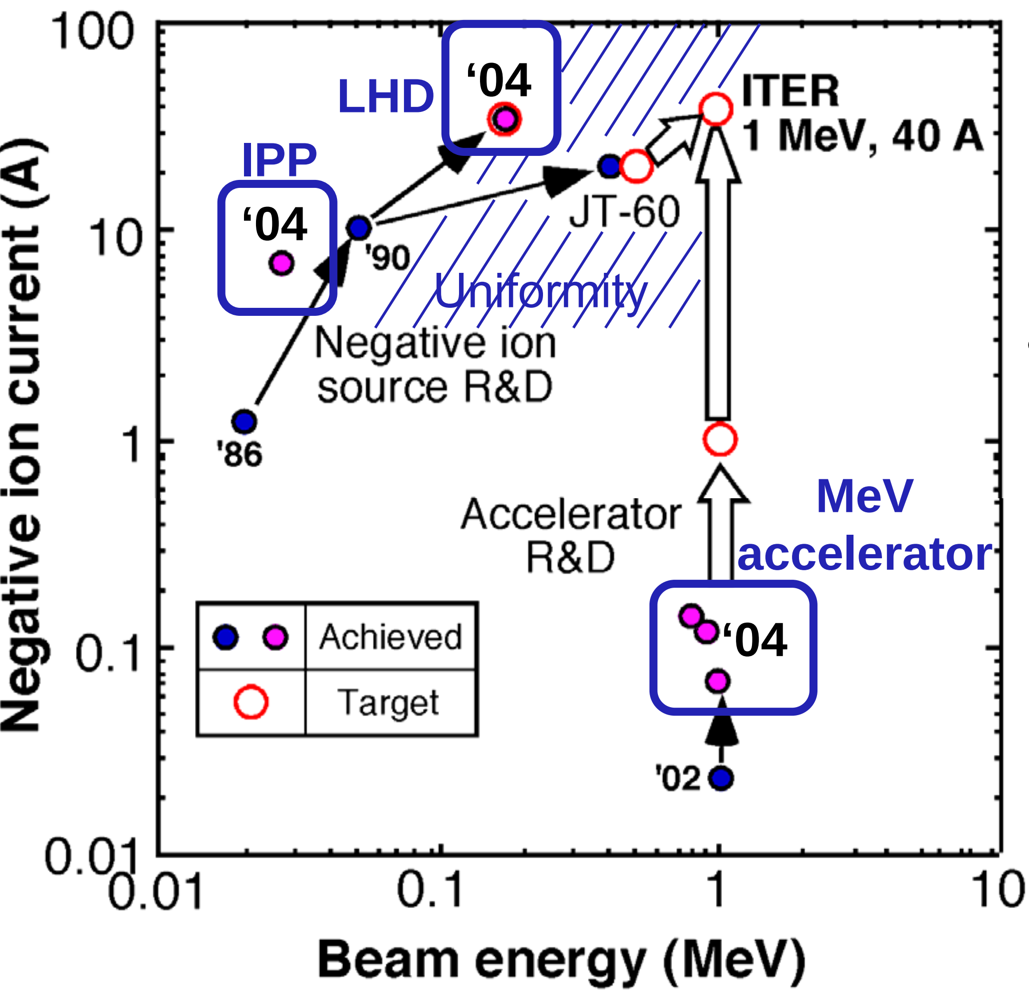
NEUTRAL BEAM INJECTION
R&D on Ion Sources and Accelerators

Rapporteur: T. Inoue, JAERI Naka

- FT/1-2Ra: 1 MeV accelerator and uniformity
  R&D on a High Energy Accelerator and a Large Negative Ion Source for ITER
  T.Inoue et al., JAERI Naka, Japan
- FT/1-2Rb: Status of existing negative-ion based NB system
  Improvement of Negative Ion Source with Multi-slot grids for LHD-NBI
  K. Tsumori et al., NIFS, Japan
- FT/1-2Rc: rf driven large negative ion source
  Status and Plans for the Development of an RF Negative Ion Source for ITER NBI
  H.D. Falter et al., IPP Garching, Garmany

FT/1-2Ra
FT/1-2Rb
FT/1-2Rc

Progress in 2002 - 2004



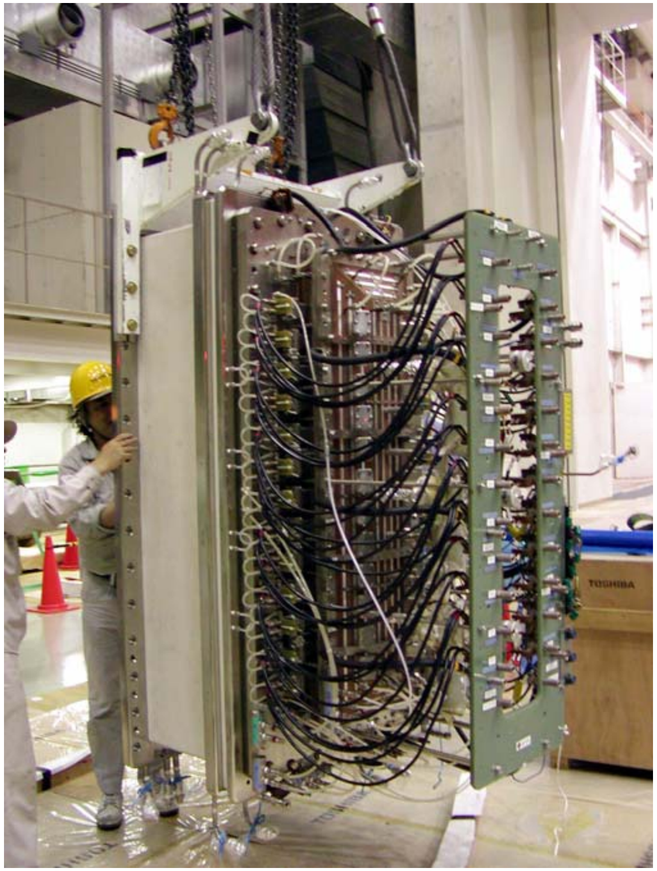
- Status of existing NB system
  - –LHD NBI: FT/1-2Rb
  - –JT-60 NBI

- R&D for ITER
  - –MeV accelerator
    - -JAERI Vacuum Insulated accelerator: FT/1-2Ra
    - -SINGAP at Cadarache
  - –Negative ion uniformity: FT/1-2Ra
  - –rf driven large source: FT/1-2Rc

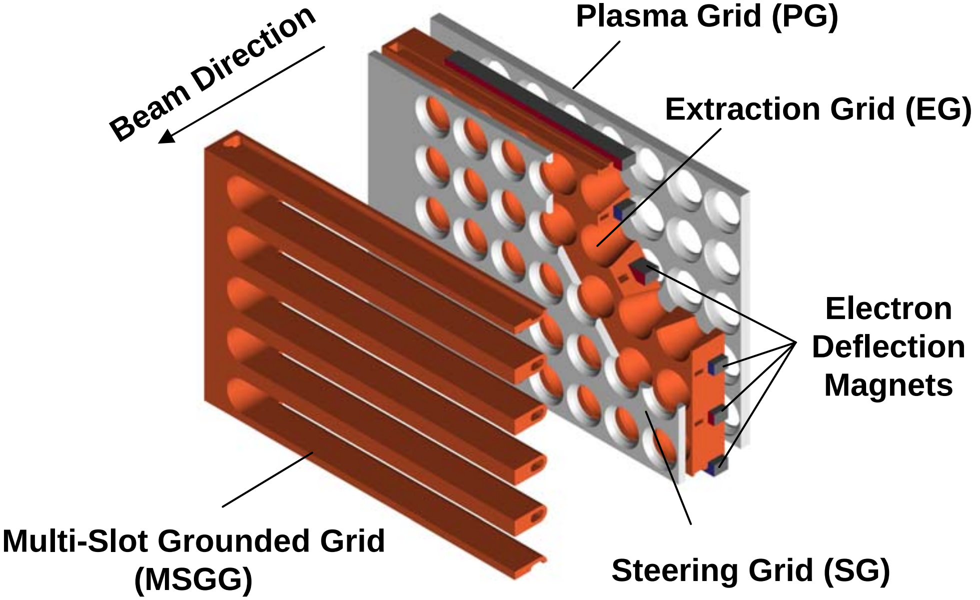
NIFS

Multislot grid in LHD NBI

Large negative ion source of LHD NBI



Accelerator structure

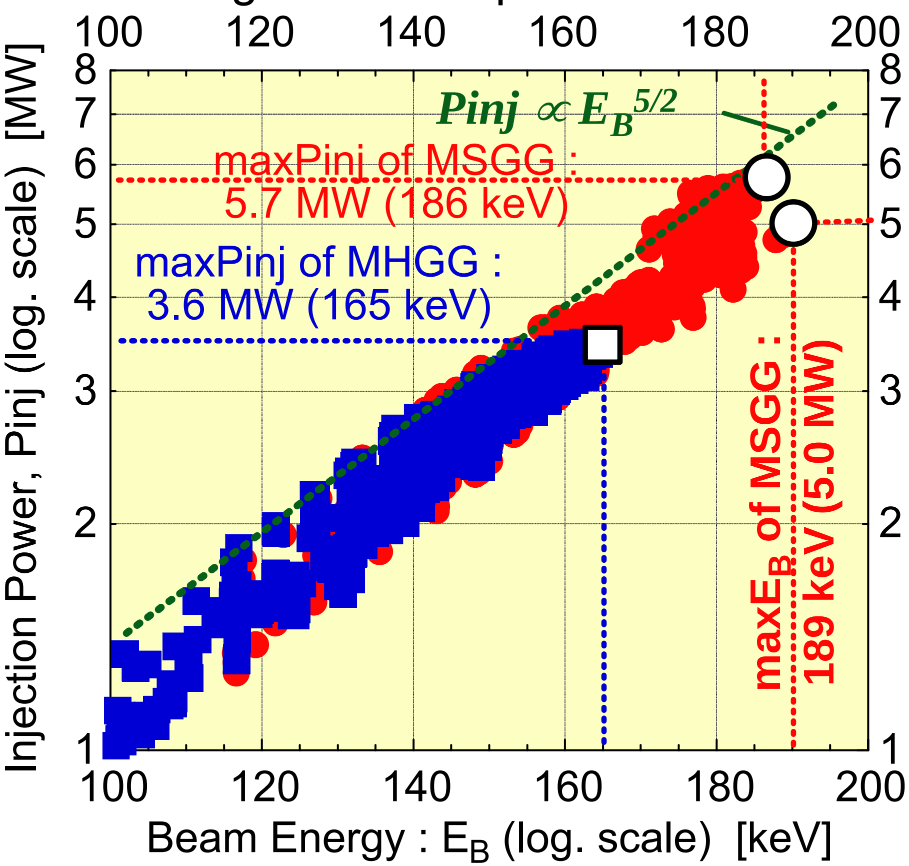


- Grounded gird in the accelerator was replaced from Multihole's to Multislot grid.
- Further tuning of the ion source
  - Plasma grid temperature: 240°C,
  - Arc discharge uniformity.

NIFS

NB power increased in NBIs

Progress of NB power in LHD



- Multislot grounded gird
  Improved voltage holding capability, from 160 kV to 180 kV,
- The LHD N-NB system achieved the design value of power and beam energy,
  –5.7 MW at 186 keV (H^0) for 1.6 s.

JAERI

- JT-60U N-NB system
  has progressed, in particular in the long pulse operation,
  –5.8 MW at 400 keV (D^0) for 0.86 s.
  –1.5 MW at 360 keV (D^0) for 25 s.

FT/1-2Ra
FT/1-2Rc

Issues for the ITER NB system

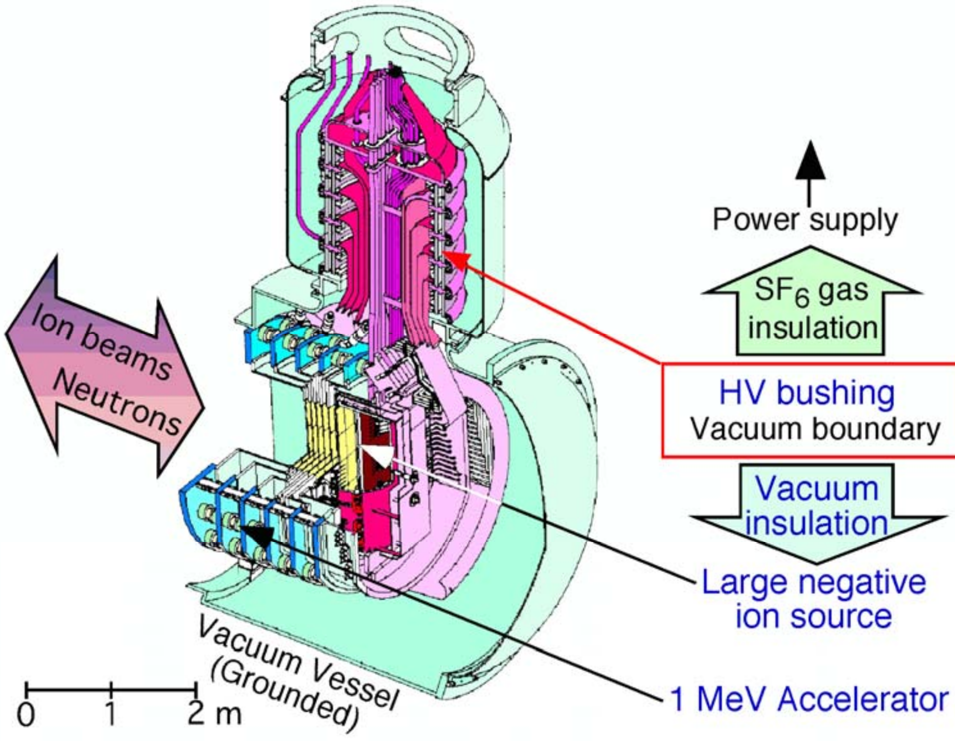
- **Vacuum insulation of 1 MV**
  Insulation gas (SF_6) is not applicable due to excess radiation induced conductivity (RIC).

- **Acceleration of 1 MeV beam**
  R&D target: 1 MeV,
  1 A class current
  200 A/m^2 D^-

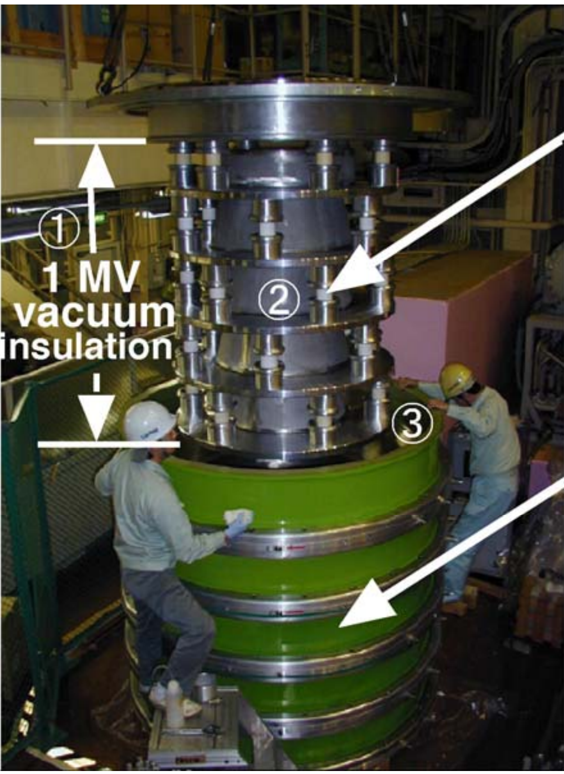
- **Negative ion uniformity**
  is still one of major issues in the existing large sources.

- **Complicated structure of HV bushing**
  and maintenance

ITER ion source, accelerator and HV bushing assy.



H^- current density increasing at MeV



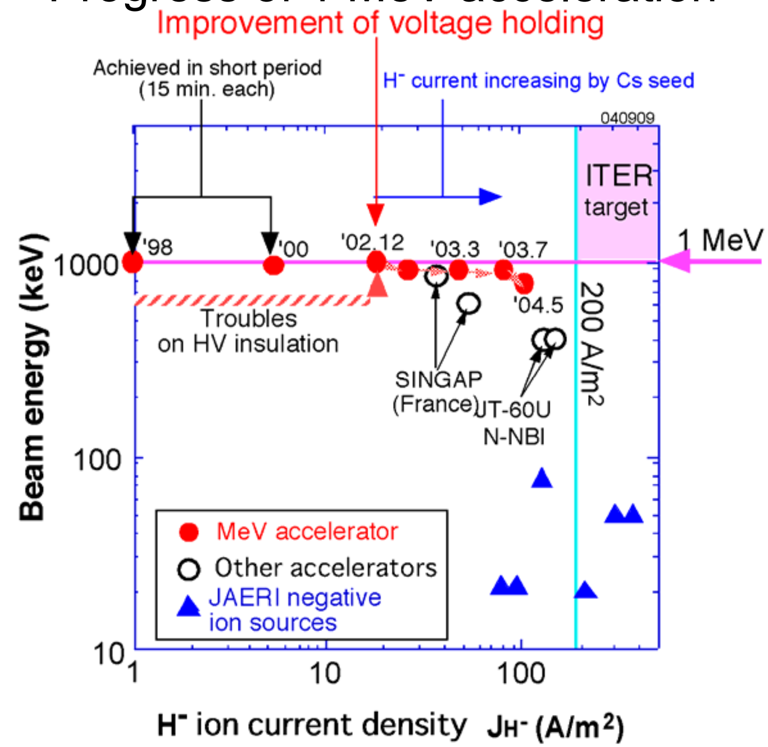
Vacuum Insulated Acclerator

Insulation design for
① glow discharge
② vacuum arc discharge

Insulator stack

- Five FRP insulator rings (each 33 cm^h, ϕ1.8 m)
- Simulating HV bushing
  ③ surface flashover

Progress of 1 MeV acceleration



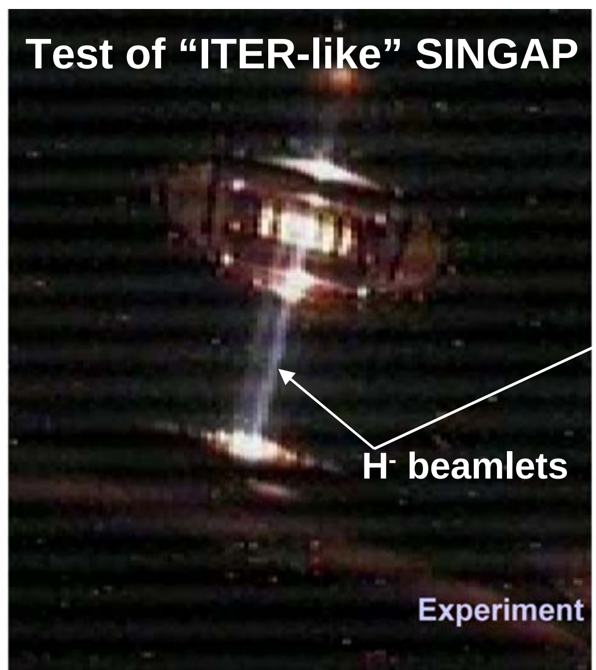
- 1 MV vacuum insulation technology has been developed by Dec. 2002.
- The H^- ion current density is increasing according to the source tuning.
  (Cs seeding, filaments, magnetic filter, etc.)

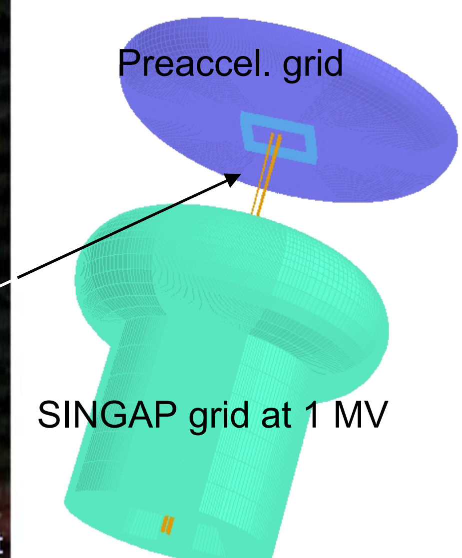
Progress of 1 MeV accelerators

- H^- ion current density has been increased to substantial level of 100 A/m^2 at the energy of ≈ 1 MeV.
  - 1 MeV, 70 mA (18 A/m^2) for 1.0 s (without Cs)
  - 900 keV, 110 mA (80 A/m^2) for 0.5 s (with Cs)
  - 800 keV, 140 mA (100 A/m^2) for 0.5 s (with Cs)

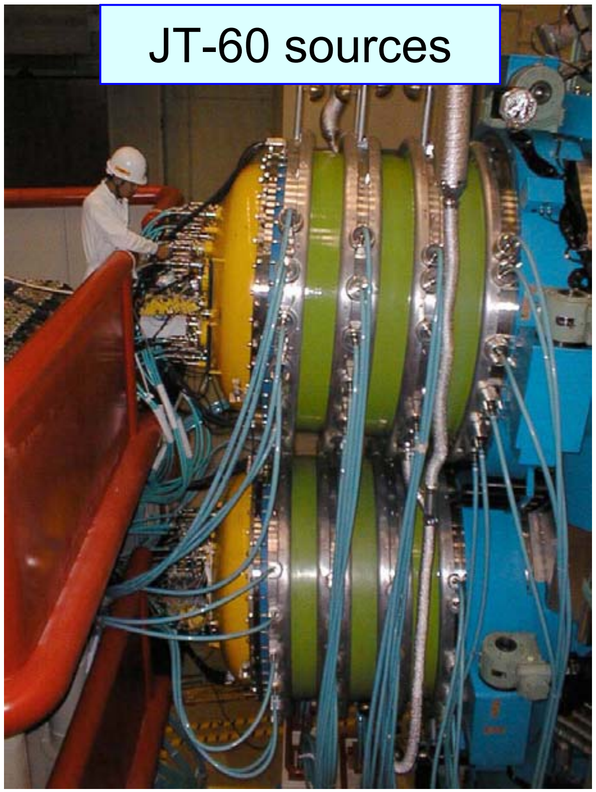
SINGAP accelerator
as an alternative
has modified to simulate the ITER relevant geometry.

The final test of the SINGAP is to be done in JAERI Naka, Japan under collaboration between JAERI and CE Cadarache.

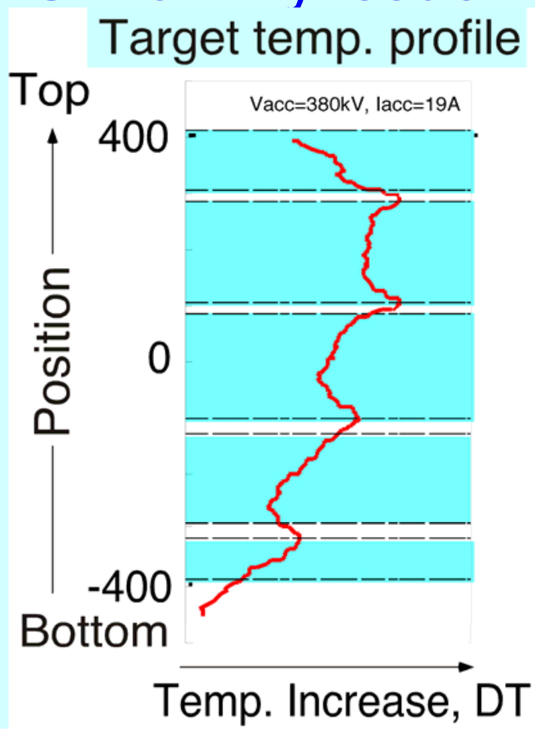


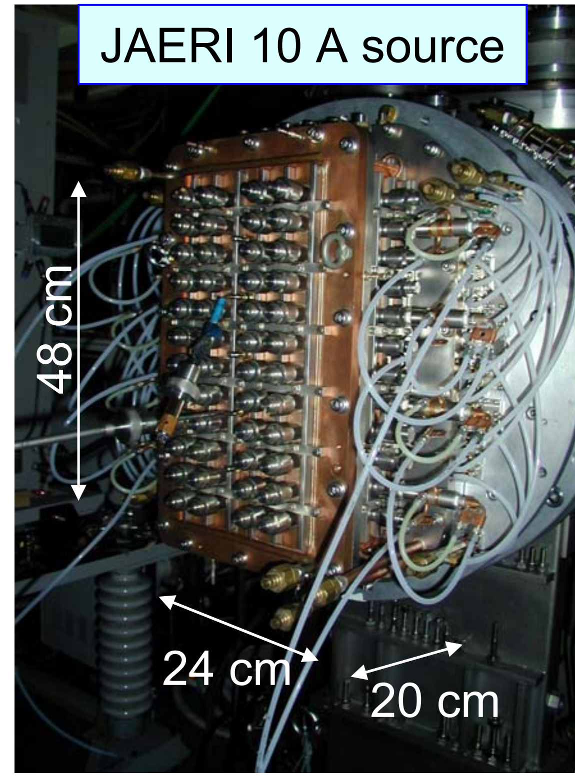


Negative ion uniformity issue



Uniformity issue

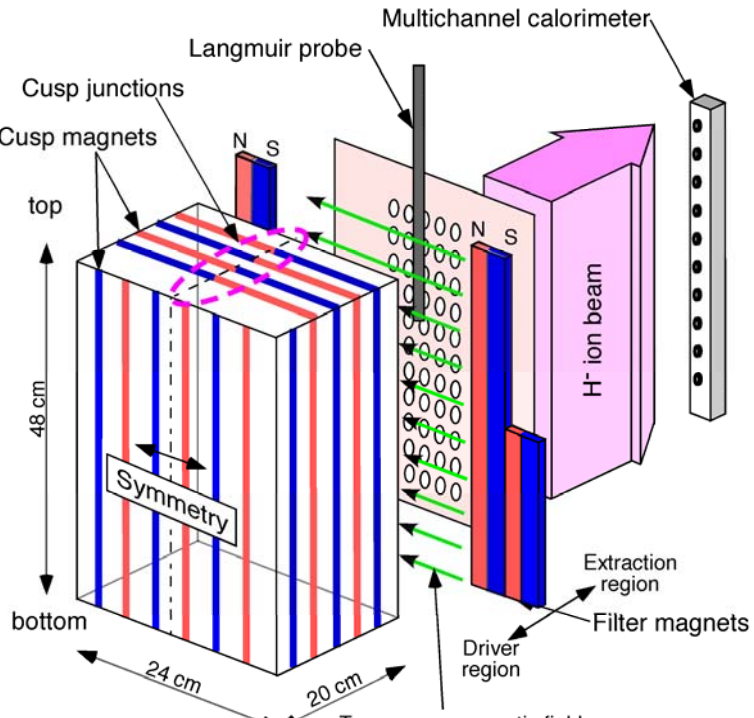


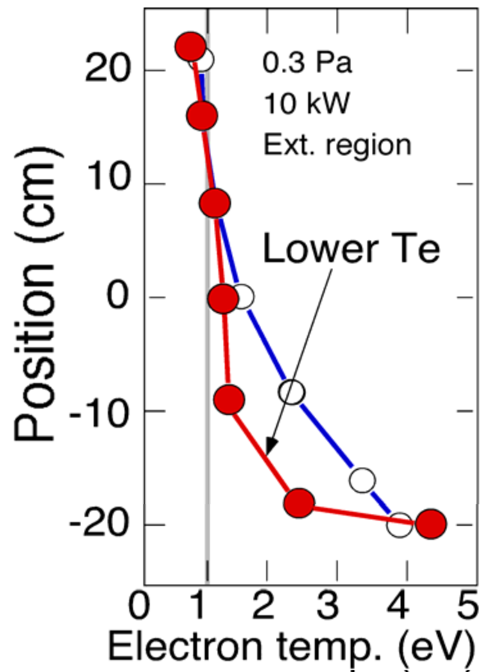


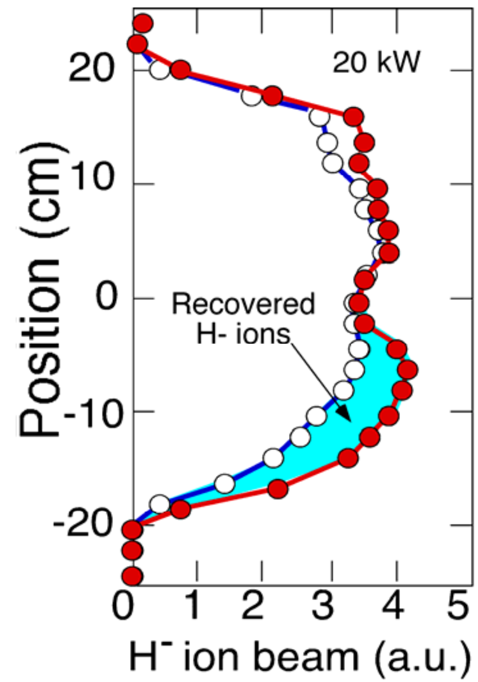
- The negative ions are less from the lower position of the JT-60 large negative ion source.
- The uniformity issue has not been solved due to poor accessibility to the source in JT-60.

The 10 A source has similar magnetic configuration to those of JT-60 and ITER.

Electron detachment and uniformity

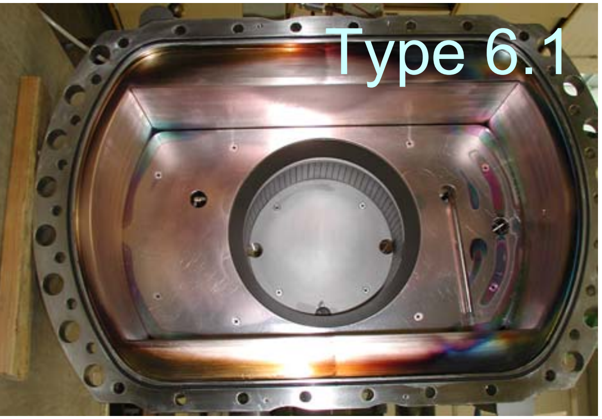


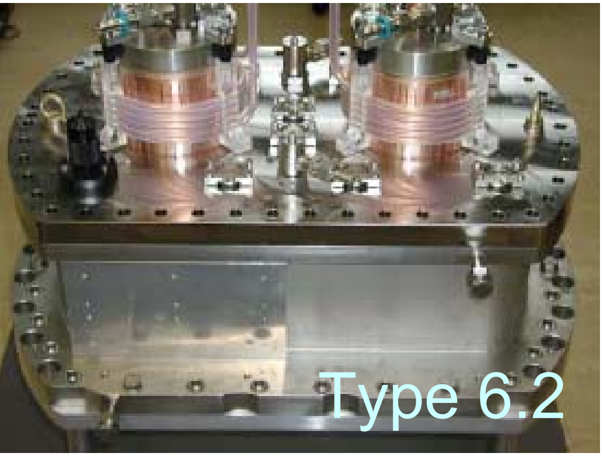




- Negative ion source is divided into 2 regions by a “magnetic filter” to reduce electron temperature (Te ≤ 1 eV) in the extraction region.
- However, Te > 1 eV was observed locally in the extraction region.
- Reduction of Te by stronger magnetic filter field or intercept of leaking fast electron was effective to achieve low Te, followed by H^- ion recovery.

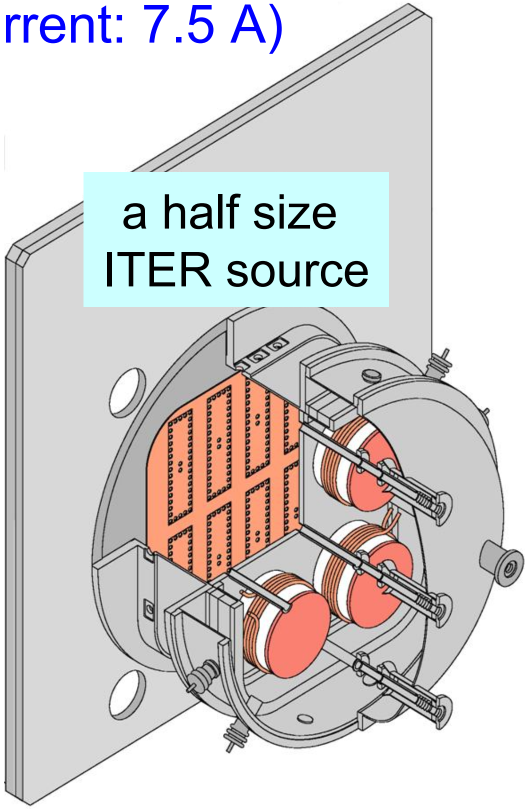
rf driven negative ion source





R&D on rf driven negative ion source has made remarkable progress at IPP, approaching the ITER requirement.

–260 A/m^2 (Power supply current: 7.5 A) at 0.4 Pa and 22 keV.



Attractive option for the ITER NB:

- Simple design,
  requires only rf connection,
  ⇒ simple structure of HV bushing
- Scalable with rf modules

Two test beds being upgraded:

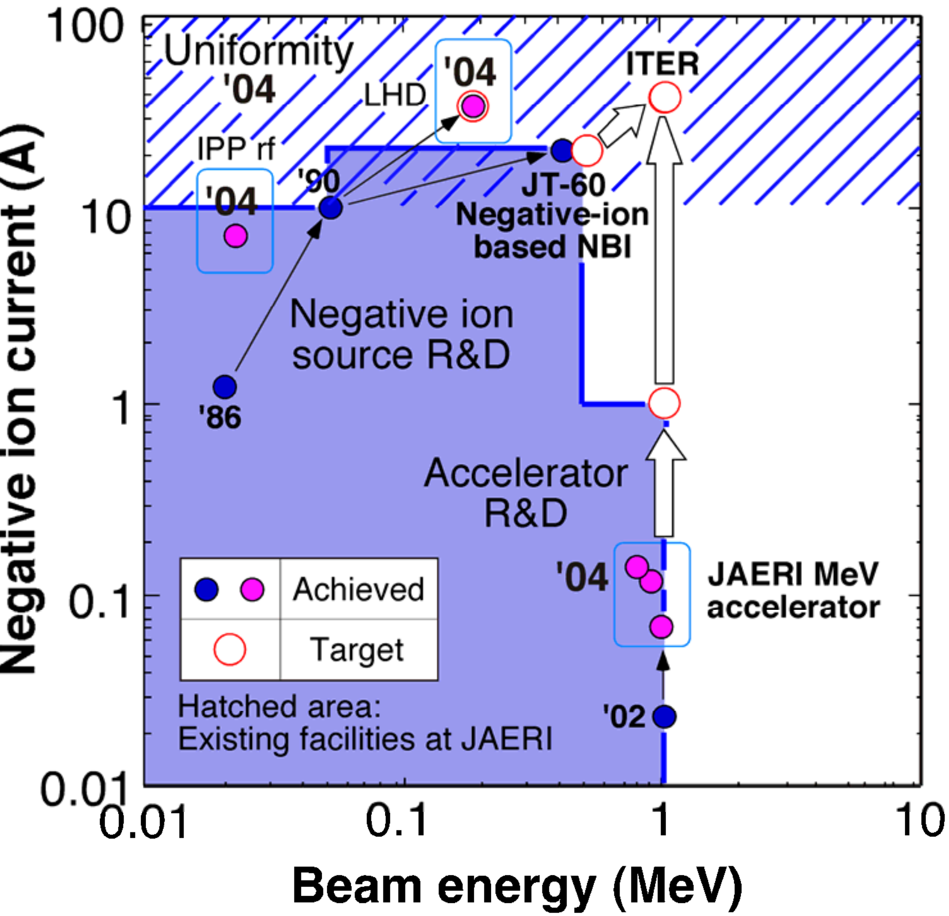
– for 1 hour pulses, and
– for scalability test with “a half size ITER source”.

FT/1-2Ra
FT/1-2Rb
FT/1-2Rc

Summary

	NB power	Current	Current density	Energy	Note
ITER (requirement)	16.5 MW	40 A	200 A/m^2 (D$^-$) (≈ 300 A/m^2 (H$^-$))	1 MeV	
LHD N-NB	5.7 MW	34.5 A	318 A/m^2 (H$^-$)	186 keV	Rated value achieved
JT-60 N-NB	5.8 MW	17.4 A	130 A/m^2 (D$^-$)	400 keV	1.5 MW for 25 s
KAMABOKO		2 A	300 A/m^2 (H$^-$)	50 keV	
rf type 6.1			260 A/m^2 (H$^-$)		
JAERI MAMuG accelerator		0.14 A	100 A/m^2 (H$^-$)	800 keV	
		0.07 A	18 A/m^2 (H$^-$)	1 MeV	
SINGAP accelerator	To be tested in JAERI Naka, Japan under collaboration of JAERI and CE Cadarache.				

Summary



- The world wide NB R&D is getting close to the ITER requirement.
- The R&D status is reaching almost on the envelope of the existing facilities.
    - Ion source R&D: ≤ 20 A, 500 keV,
    - Accelerator R&D: ≤ 1 A, 1 MeV.
- However, integration test at 40 A, 1 MeV would be necessary for ITER.
- Discussion on the full-scale testbed for the ITER NB system has been started among interested parties.

Conclusion

- LHD N-NB system achieved the design value of power and beam energy, 5.7 MW at 186 keV (H^0) for 1.6 s.

- In the 1 MeV accelerator R&D at JAERI, H^- ion current density has been increased to substantial level of 100 A/m^2 at the energy of ≈ 1 MeV.

- It was found that local reduction of H^- ions in large sources was due to electron temperature increase followed by loss of ions by electron detachment. Reduction of Te was effective to improve uniformity of the H^- ion production.

- R&D on rf driven negative ion source has made remarkable progress at IPP Garching, 260 A/m^2 (Power supply current: 7.5 A) at 0.4 Pa and 22 keV.