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Status of the ITER Neutral Beam Injector Project and accelerator optimization

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ITER NBI requirements and functionalities

2 (+1) NBI Neutral Beam Injectors based on negative ions are foreseen in ITER

Each beam must provide:

P=16.5MW
I=40A
V=1MV
t_{pulse}=3600s

Main functionalities:

Plasma Heating
Plasma Rotation
Current drive
Plasma parameter profile control
Burn phase control

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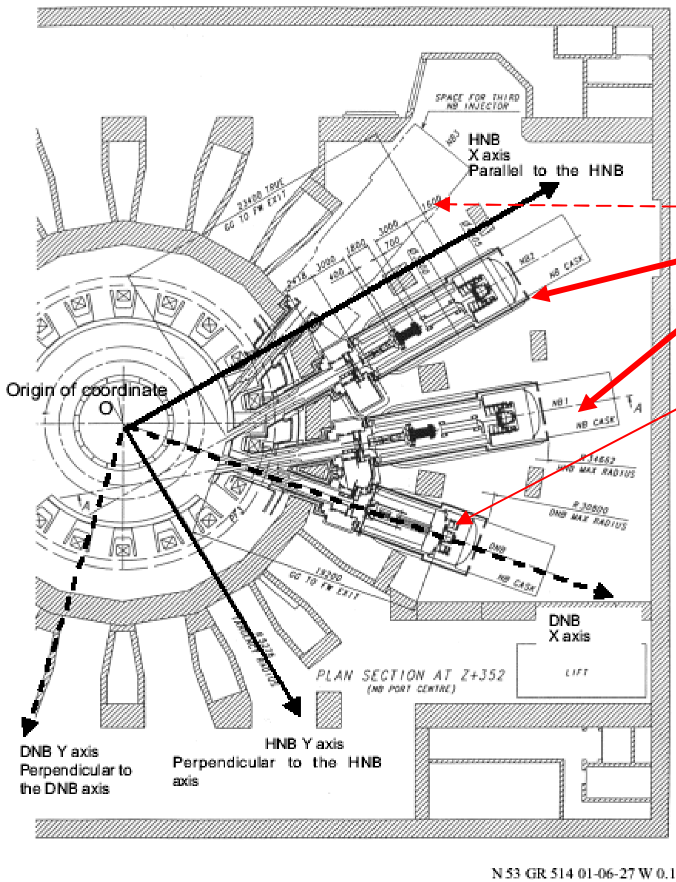
NBI in ITER

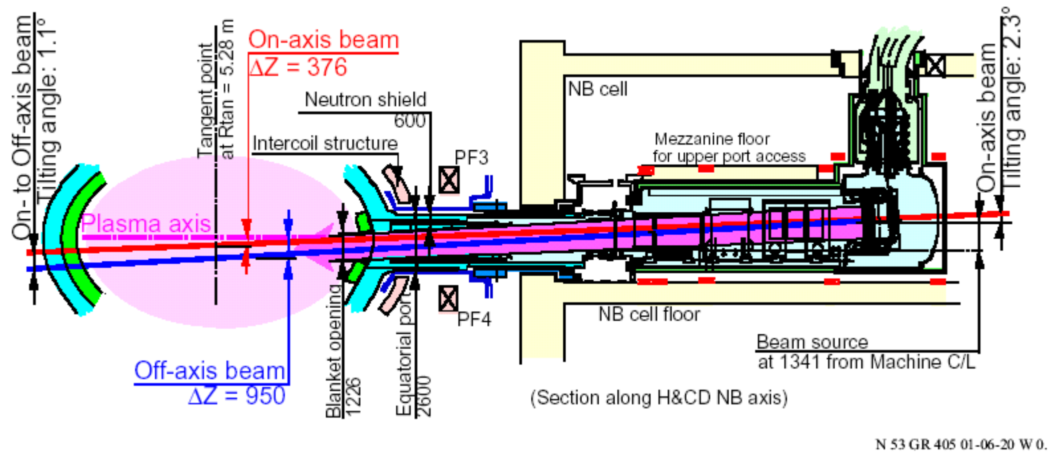
2+1 NBI

tangential injection

DNB



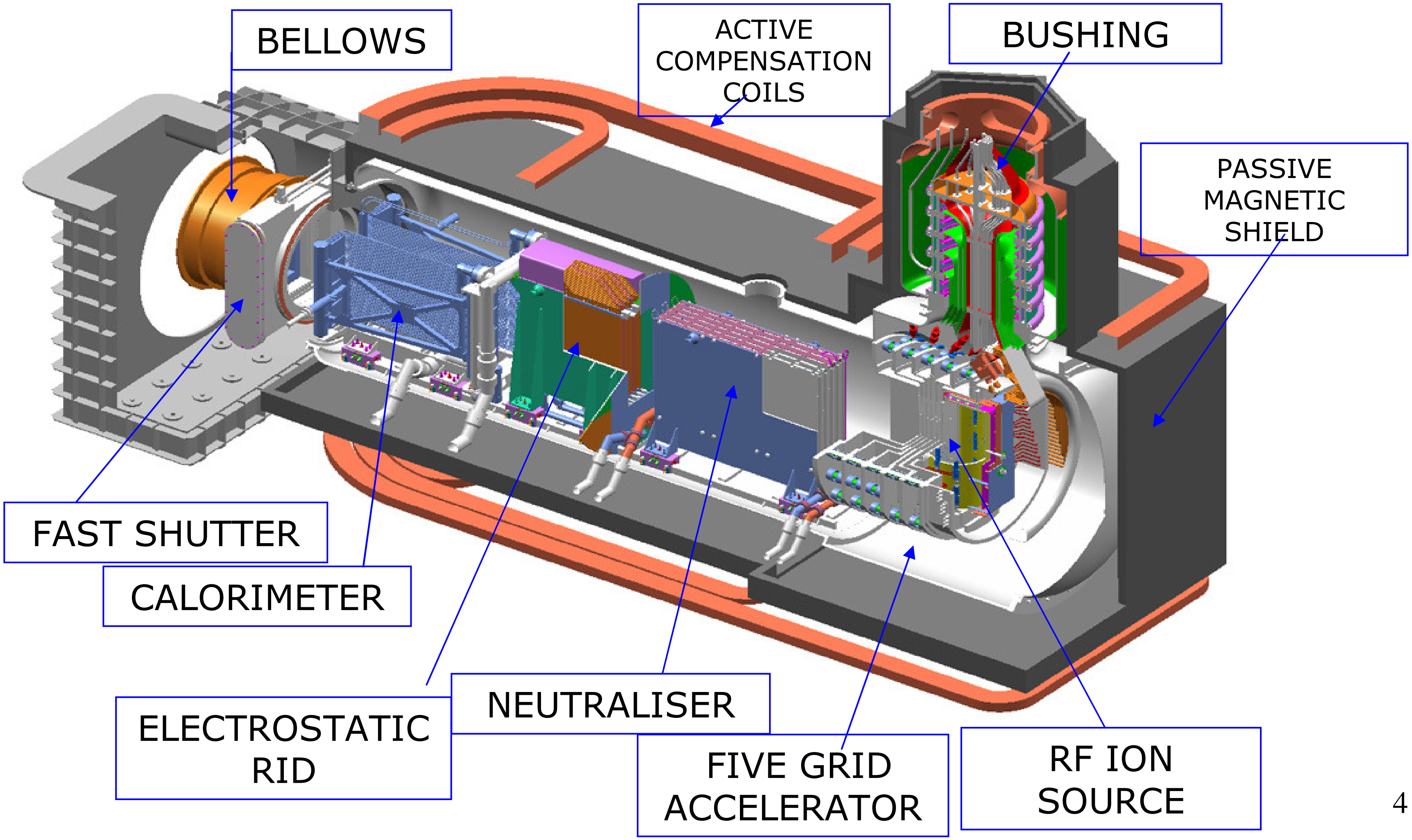
Plan view



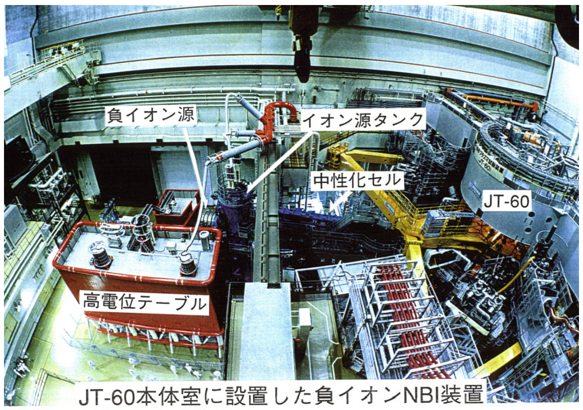
Vertical cross section view

On/off axis injection by tilting the beam axis vertically

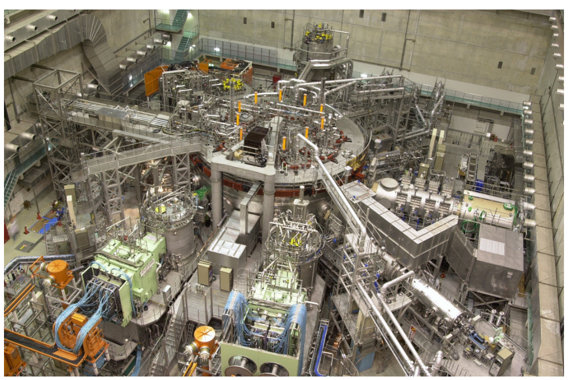
NBI Main components



Results in fusion experiments



JT-60U
N- NBI maximum parameters
Max Voltage 400 kV
Max power per beam 5.8MW
Pulse lenght 30 s (2MW, 360kV)
Upgrade up to 100s foreseen for JT60-SA



LHD
N- NBI maximum parameters
Max power per beam 6.4 MW
Max Voltage 190 kV
Pulse lenght 128 s (at 0.2MW)

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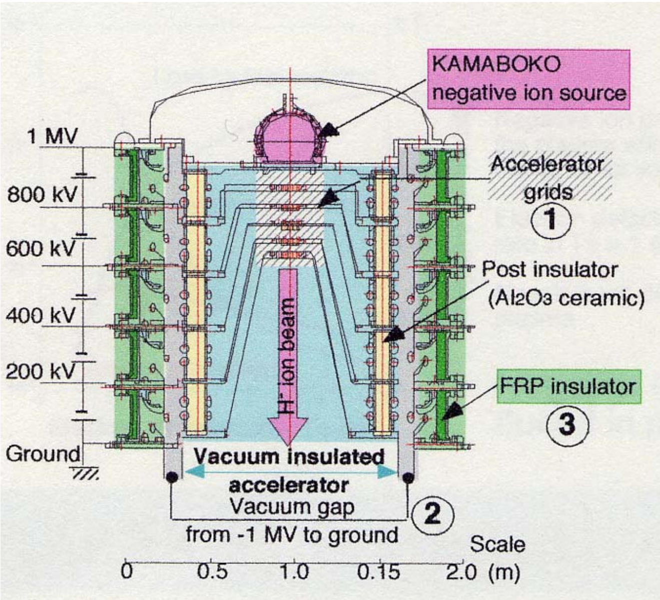
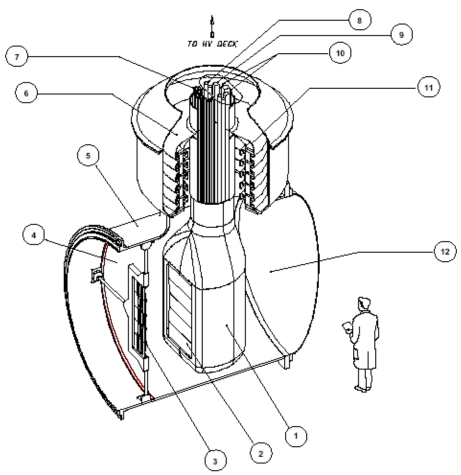
Results in 1 MV Test Facilities

R&D in progress to test Voltage Holding at 1MV.



MAMuG **(JAEA)** maximum parameters in H
Voltage 836 kV
Current density 146 A/m^2
Pulse length 0.2s



SINGAP **(CEA)** maximum parameters in D
Voltage 726 kV
Current density 126 A/m^2
Pulse length 0.2s
HV holding improved by Ultra HV techniques

Progress in NBI design and R&D

In recent years a close collaboration between EU and Japan has led to the complete revision of the NBI design. Several issues identified during the revision have been solved or a well defined program has been identified to tackle and solve them at the Neutral Beam Test Facility to be built in Padova (Italy) .

A robust and well coordinated R&D program carried out by EU (at 1MV CEA facility in Cadarache and RF ion source facilities at IPP Garching) and Japan (at JAEA 1MV facilty in Naka) has led to important results that have been applied to the choice of the ion source and accelerator

Main advances

Choice of the negative ion source now based on RF concept (it was arc driven in the reference design)

Choice of accelerator now five grid system (MAMuG concept) as in the reference design. *Crucial test and comparison of MAMuG and SINGAP concepts performed at JAEA this year*

HV bushing and construction of large bore ceramics *(Japanese industry and JAEA)*

Assessment of the electrostatic Residual Ion Dump (RID) *(no plasma formation in standard operation, UKAEA ,CIEMAT)*

Arc protection is now included in the design:

Passive:analysis of core snubber performed, additional damper resistance to ground the GG to control and mitigate arcs

Active: design complete (fast intervention)

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Main changes to the NBI design

Negative ion source based on RF concept

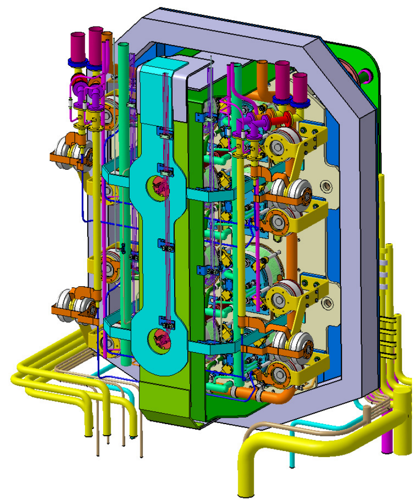
New vessel with vertical access for vertical assembling and maintenance

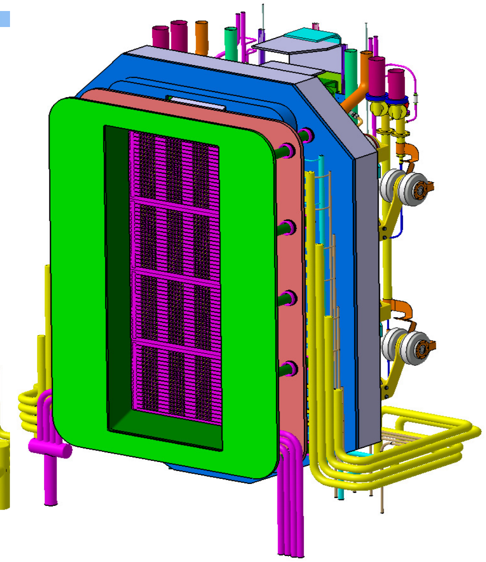
Absolute gate valve to separate the NBI from ITER (UKAEA)

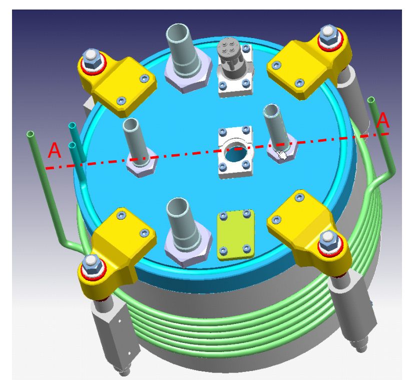
New air insulated HV deck

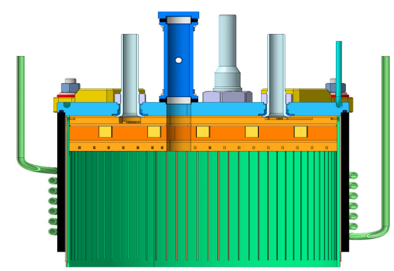
RF Negative Ion Source

- Plasma facing the grids ~ 1.5 m^2
- $P_{source} \approx 0.3$ Pa
- Plasma confined through permanent magnets
- Actively cooled source case to remove plasma heat load
- Actively cooled back plate to remove BPIs heat load
- 8 RF drivers
  - Diameter: 300 mm
  - Body: Ceramic cylinder
  - Water cooled 6 turns RF coils
  - 3 matching capacitances close to two RF coils
  - Copper Faraday shield water cooled









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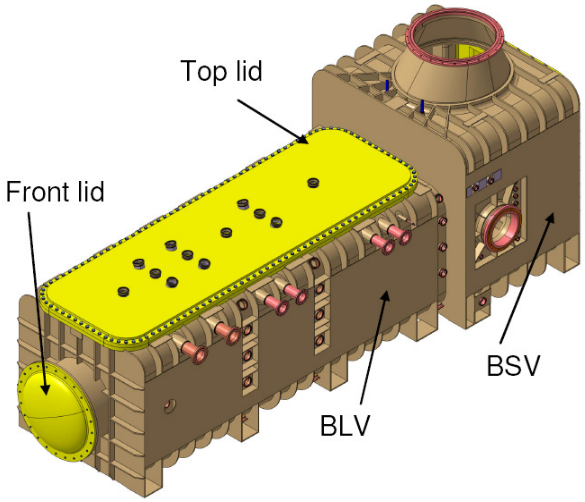
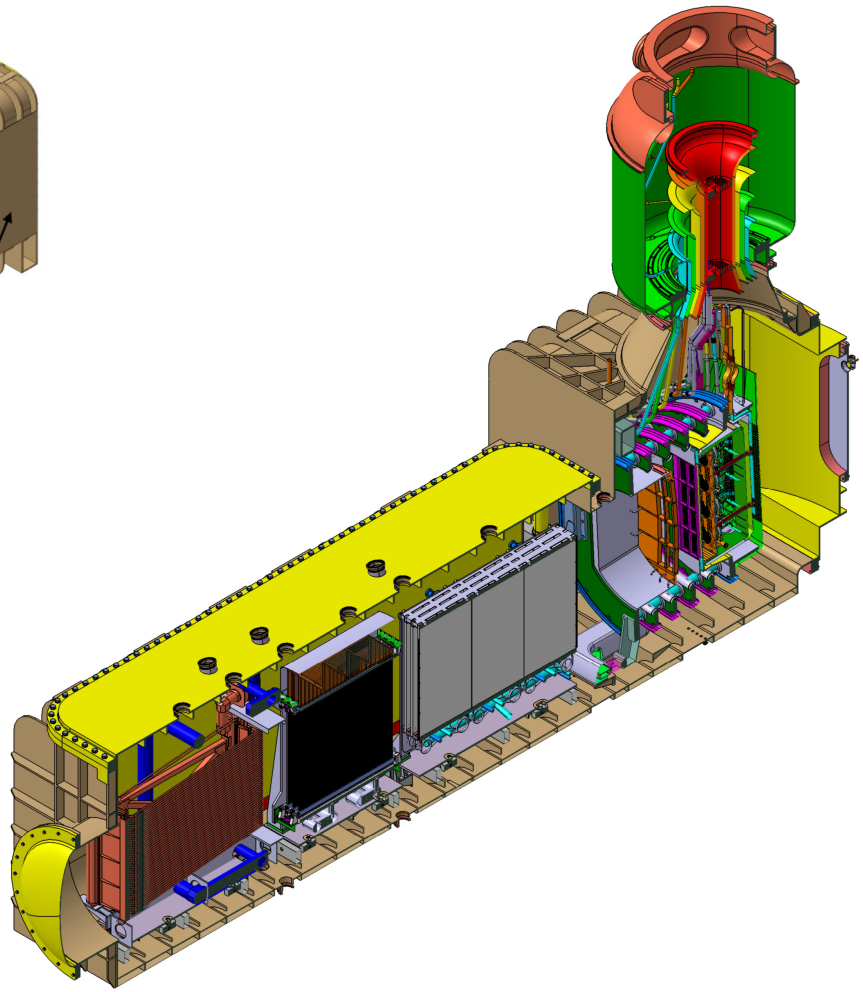
NBI Vessel





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Further advances in the project

1MV Transformer feasibility assessment

Preparation of the technical specifications for Power supply and RF Ion Source.

Development of passive and active systems to dump electrons and to steer the beam (see poster P2-04 on *Active steerer* by Cavenago)

Definition of an integrated diagnostic system for NBI and the Ion Source

The design of the NB Test Facility to be built in Padova is almost complete

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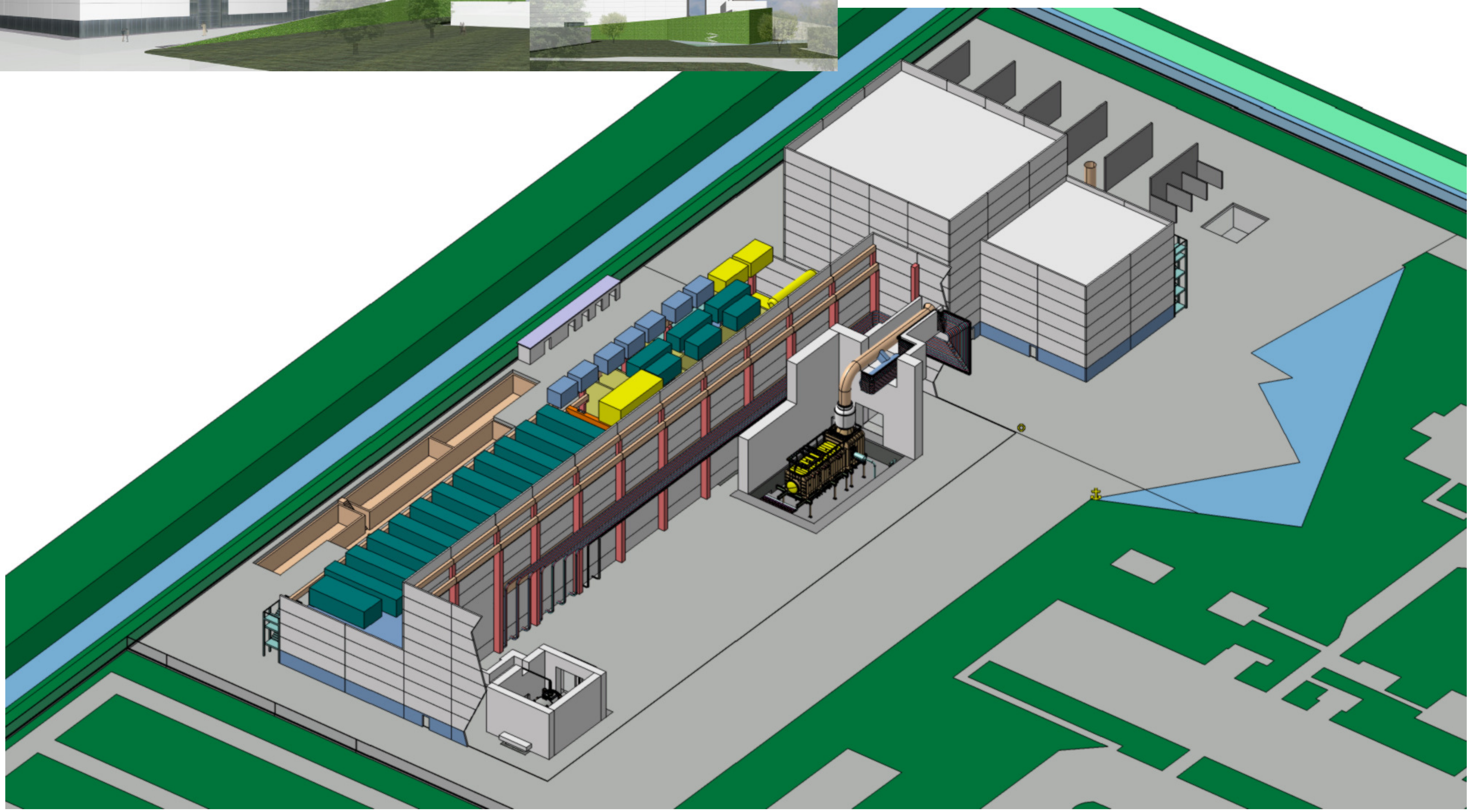
The NB Test Facility

The NB Test Facility is aimed to test and optimise the first prototype of the NBI for ITER and to assist ITER during the operation. Start of the operation is planned in five years from approval in order to test the NBI for five years before start of operation in ITER

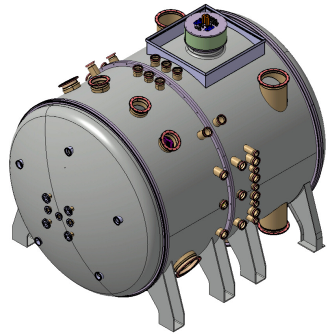
In order to speed up the test and optimisation of the NBI an Ion Source facility with 100kV extraction aimed to optimise the RF Ion Source in H and D.
Starting of operation is planned in 3 years from approval

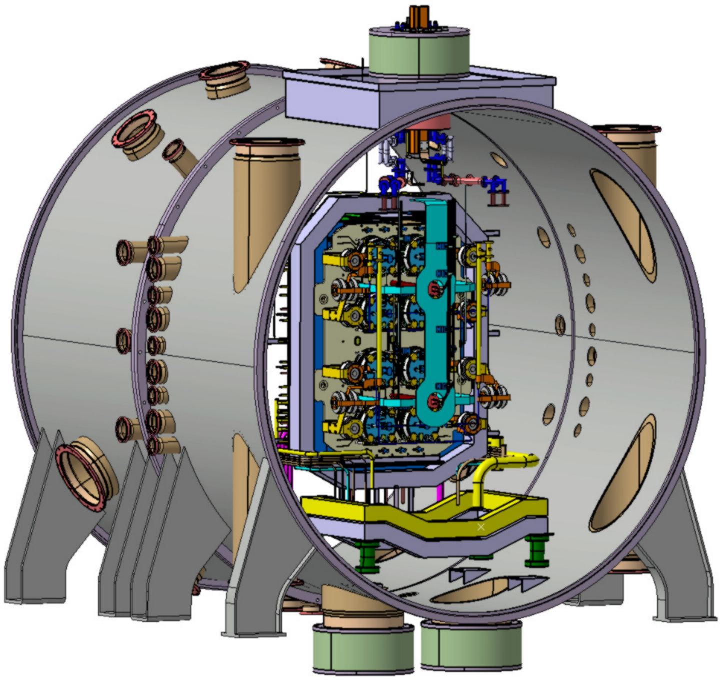
Buildings and layout



Ion Source facility: Status of design

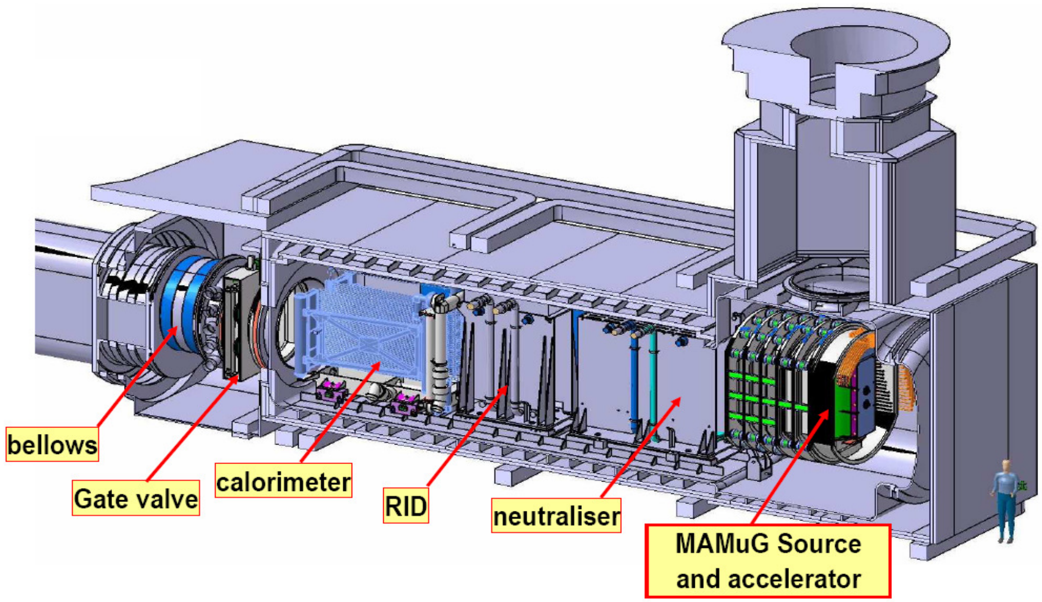
- Technical specifications foreseen in the 2008 for:
  - Power supplies and insulation transformer
  - HV Deck and transmission line
  - Vessel, including hydraulic and electrical bushings
  - Ion source, 3 grids system, support frame
  - Cooling, vacuum and gas injection plant





NB Test facility: Status of the design

- Calorimeter design in progress (UKAEA)
- Cryogenic pumps under final revision (FZK)
- Cryogenic plant under final revision
- Vacuum and gas injection system design ready for Technical Specifications
- Close contact EU-DA,JA-DA,ITER to keep the design updated
  - Power Supplies (PS)
  - Interfaces of PS, transmission line, bushing, vessel, internal connections, HVD1
  - Interfaces with ITER site and plants



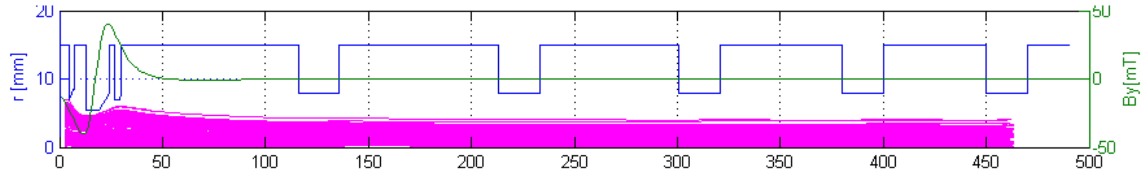
Further advances in beam physics

Better understanding of 1MV accelerator physics (backstreaming ions, generation of secondary particles, magnetic filter and uniformity) and beam transmission (neutralization, residual plasma, RID)

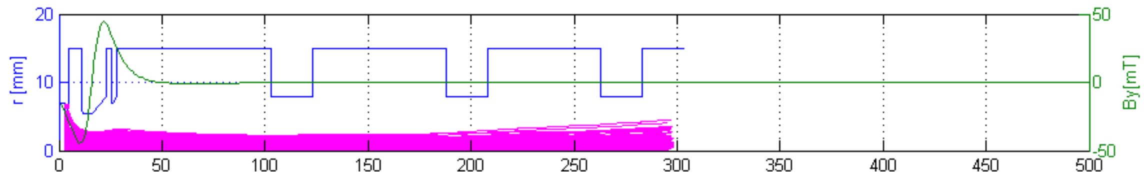
Optimization of accelerator geometry and cooling system to withstand and compensate for deformations and thermal stresses due to electron power load

Optimization of the accelerator design

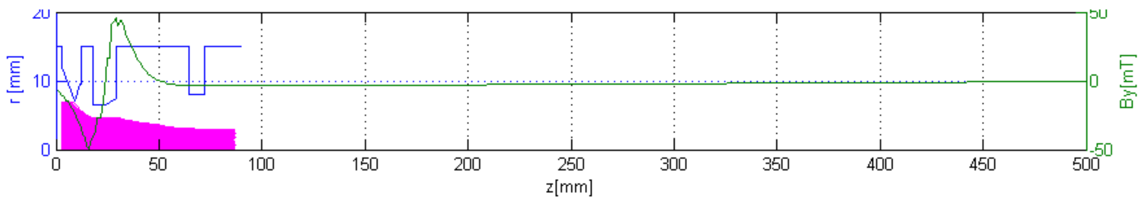
1MV five grids (MAMuG) *as in the reference design*



500kV three grids for initial ITER operation *(similar to JT60 system)*



100kV for Ion Source *(in collaboration with India for DNB)*



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Accelerator opimisation: numerical tools

Electric field distribution (SLACCAD 2D)

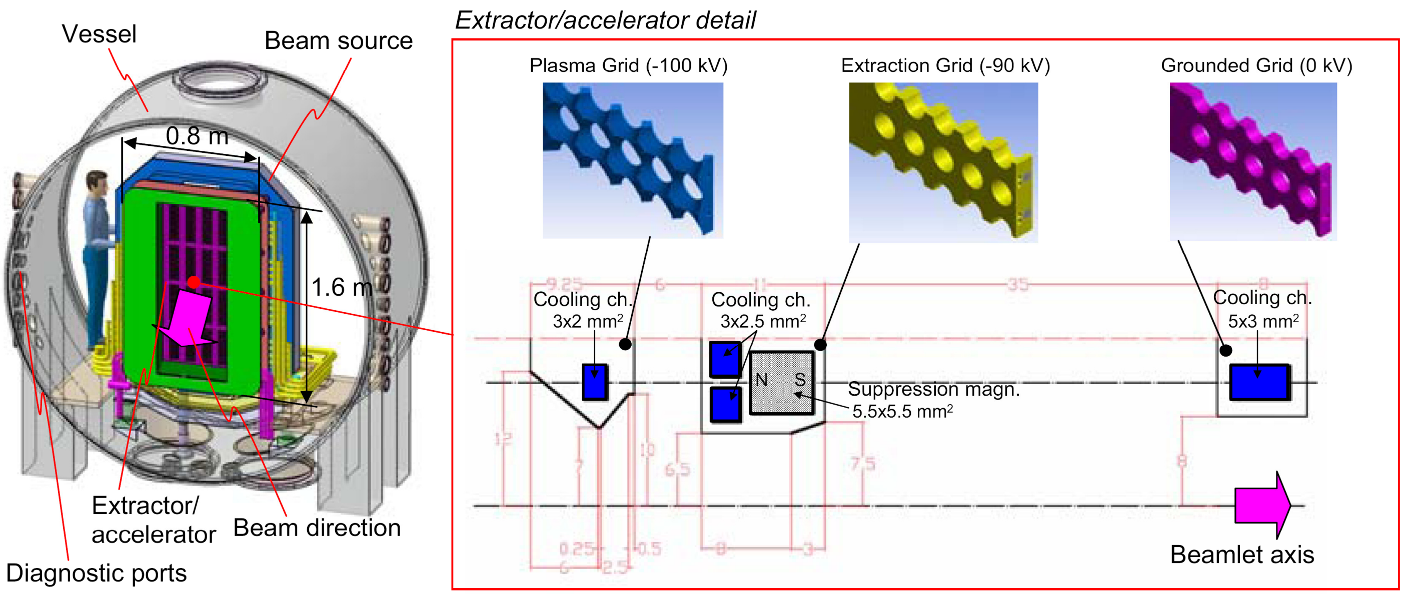
Particle trajectories and self consitsent electric fields in presence of magnetic fields (applied or stray) (EAMCC Montecarlo & SLACCAD single or two beamlets, , BYPO)

Interaction of particles with background gas (stripping and ionization) generation of secondary (electrons, positive ions,neutrals) and their interaction with materials (thermal load, emission of secondary particles) (EAMCC)

Beamlet-beamlet Interaction and optics (divergence) (OPERA 3D)

Thermal load and cooling system . Optimisation of grids with magnets and cooling channels to limit grid deformation and expansion. (ANSYS)

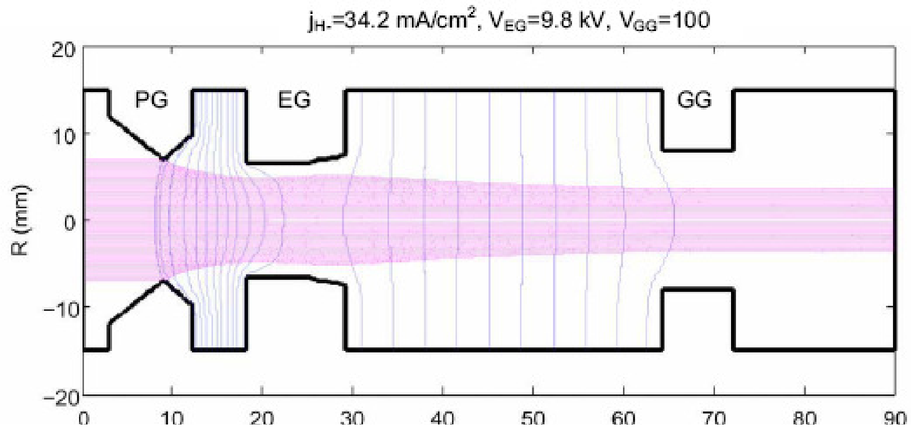
optimisation for 100kV

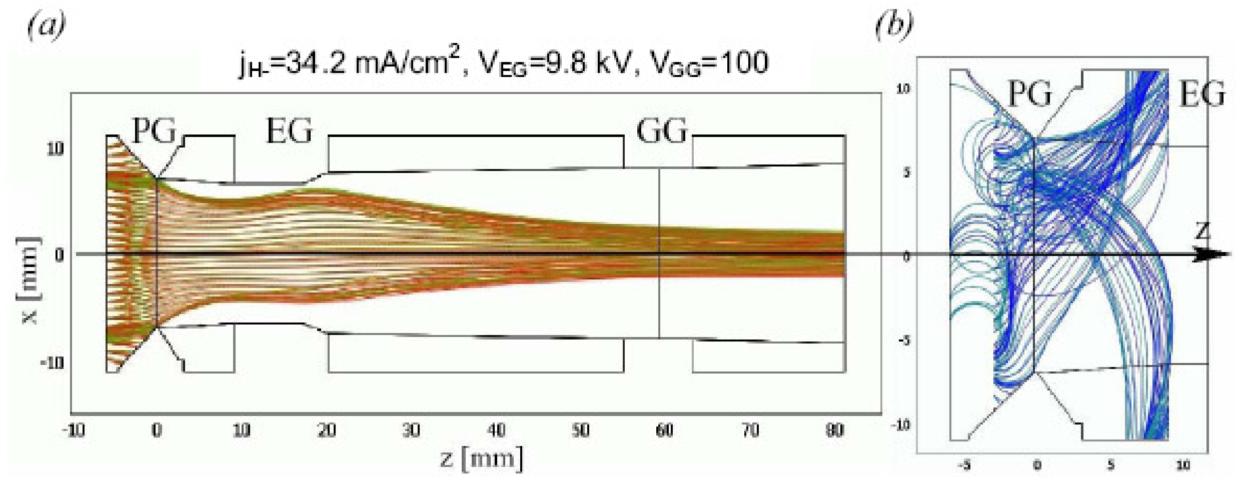


overview of the 100kV extractor accelerator system

E, B fields and particle trajectories

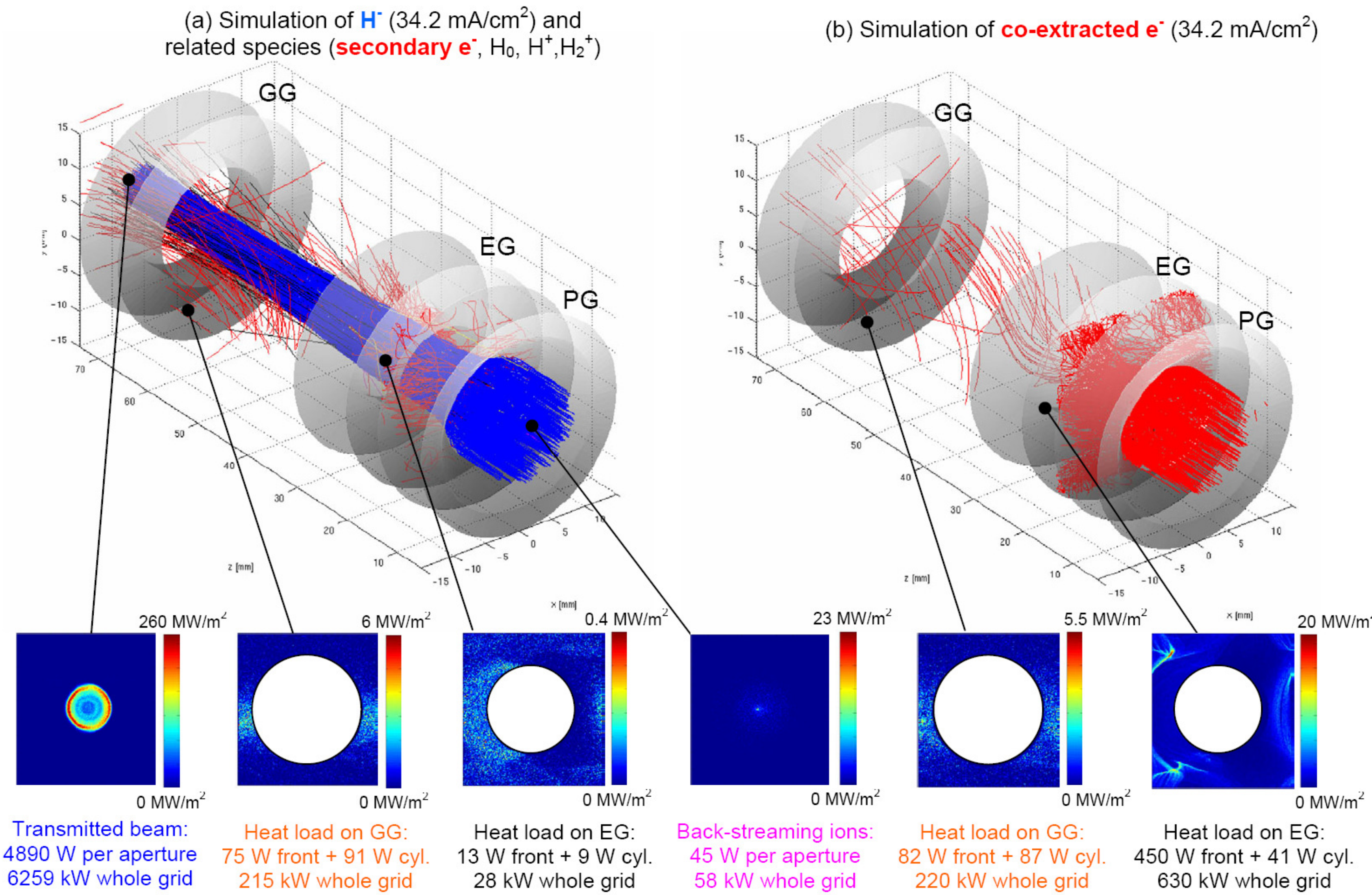
Self consistent E field and trajectory with SLACCAD





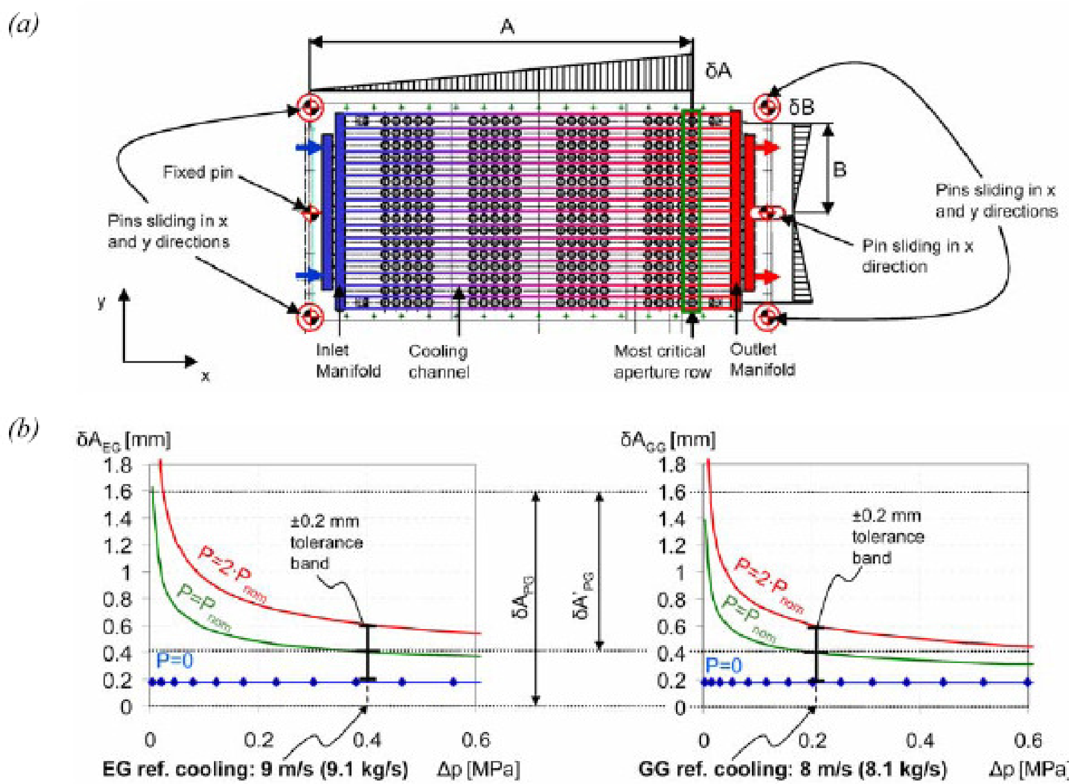
Self consistent E, B fields and trajectories with BYPO

Thermal load



Planar expansion

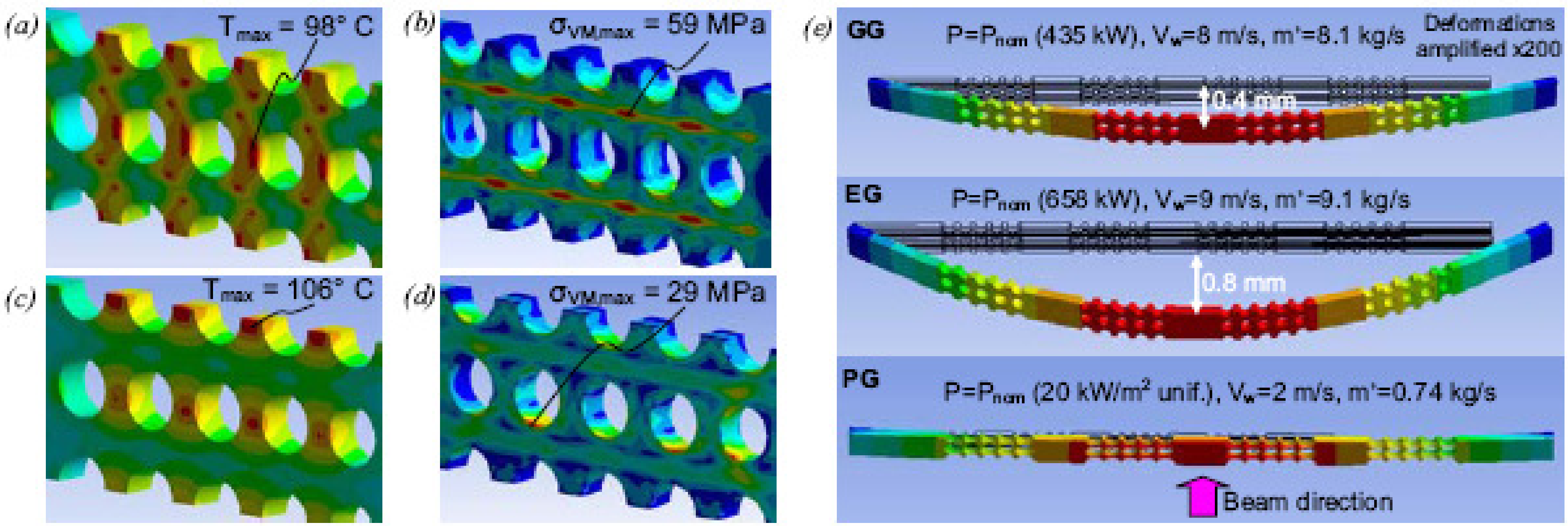
Planar thermal expansion in x-y direction for EG and GG due to thermal load



Plasma grid operates at 150 degrees to optimise Negative ion production
Mechanical offset (PG) and cooling (EG, GG) to keep disalignment within 0.2mm in a range of power from zero to twice the estimated max power

Out of plane deformation

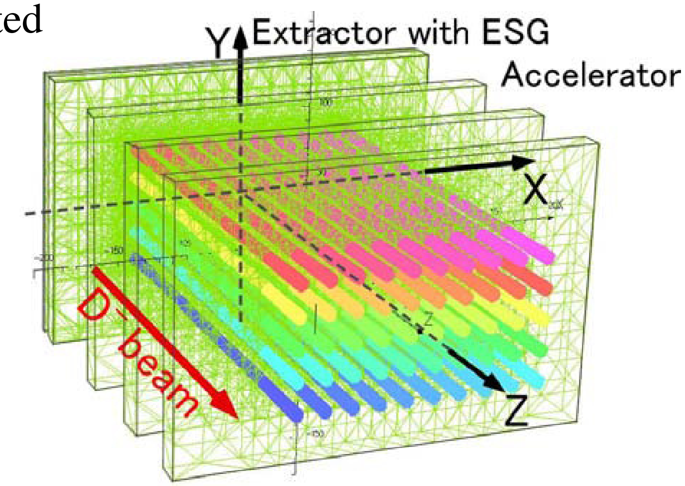
Out of plane deformation due to thermal gradients
Max bending on extraction grid
At nominal thermal load divergence increase by 50%

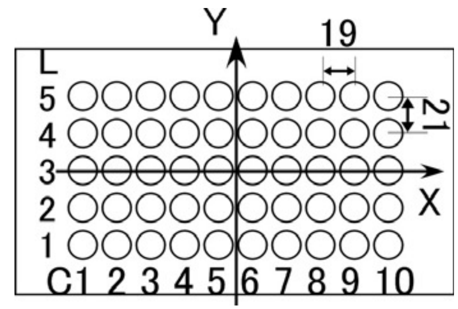


To reduce divergence on extraction grid: cooling and thermal load reduction by permanent magnet configuration
Further effects due to beam deflection caused by magnetic fields (see poster P2-11 *Optimisation of the magnetic field configuration …* by Agostinetti) and beamlet-beamlet interaction

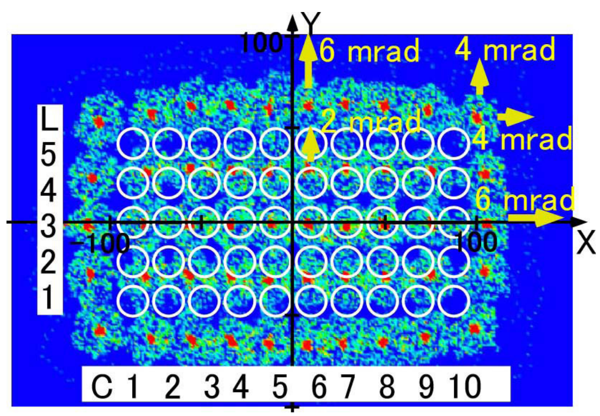
Compensation of beamlet repulsion in JT60U three grid system

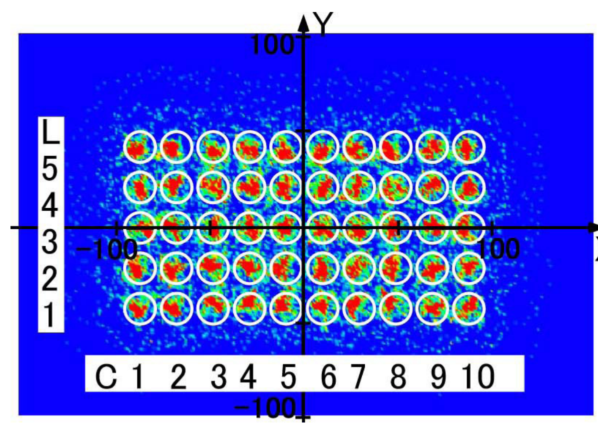
Additon of field shaping plates and aperture mechanical offset allow the deflection to be corrected





Beamlet-beamlet interaction and repulsion (OPERA 3D)





Beam footprint downstream the GRG before and after ESG aperture mechanical offset

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Conclusions

A design revision and a R&D program carried out by EU and Japan in close collaboration have led to significant changes and improvements of the ITER NBI design improving reliability and availability of the system

Most of the components of the NBI and the NB Test Facility are now in the final phase of optimization and integration and for some of them the technical specifications are expected to be ready within this year or early next year

Several issues have been solved and for the remaining ones a well co-ordinated R&D program can be carried out at present facilities and at the Neutral Beam Test Facility to be built in Padova in order to tackle and solve them before operation in ITER