Research activities of RF based negative ion source in the ASIPP

Yahong XIE, Chundong HU, Jianglong Wei, Yuming Gu, Caichao Jiang, Yongjian Xu, Lizhen Liang, Yuanzhe Zhao, Yuanlai Xie

xieyh@ipp.ac.cn

Neutral beam Injection Division，Institute of Plasma Physics, CAS

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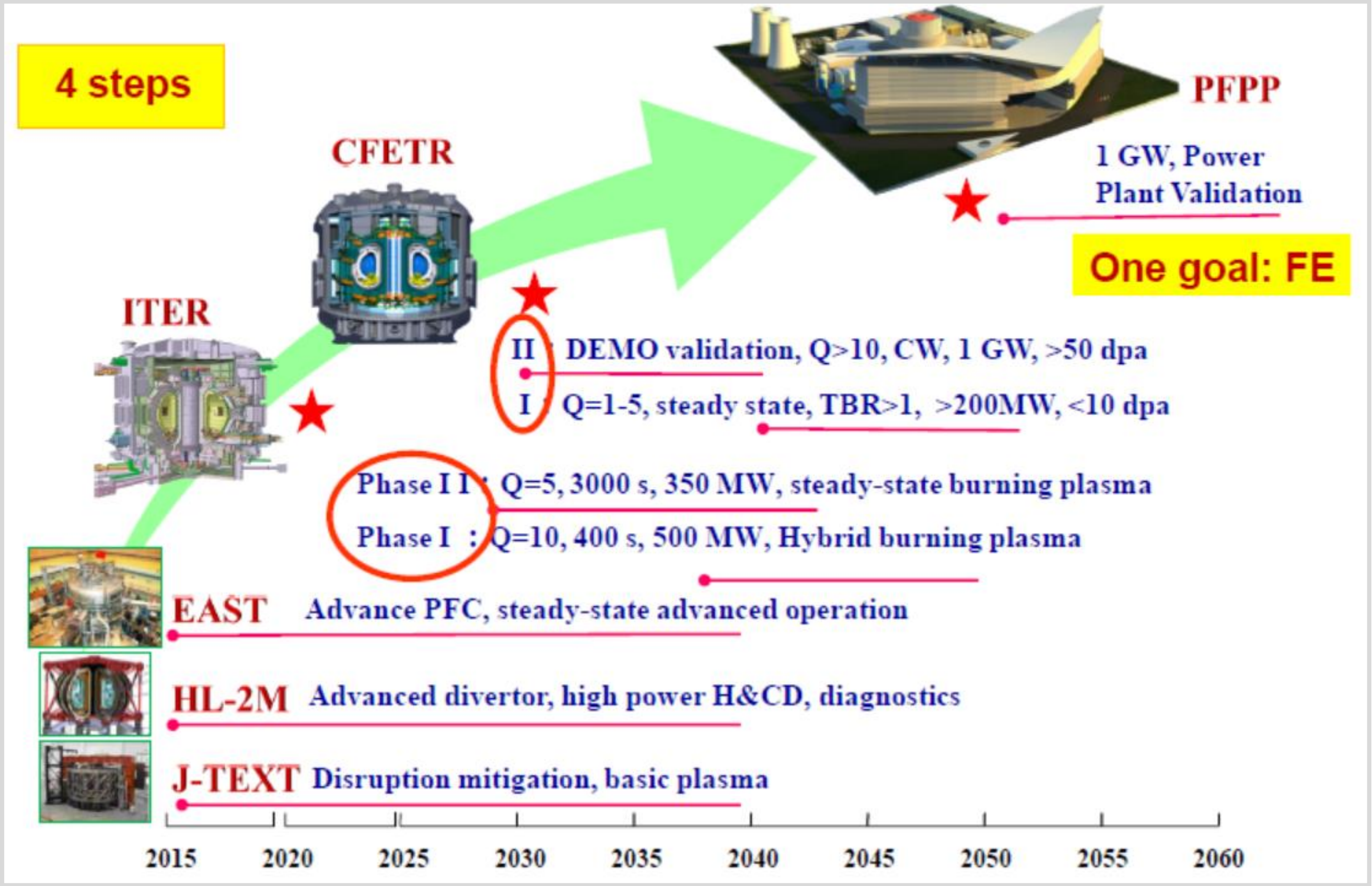
Outline

- Background
- Introduction of RF source test facility
- Research activities of RF N- beam source
  - RF plasma discharge
  - Negative ion beam extraction
- Summary and future plan

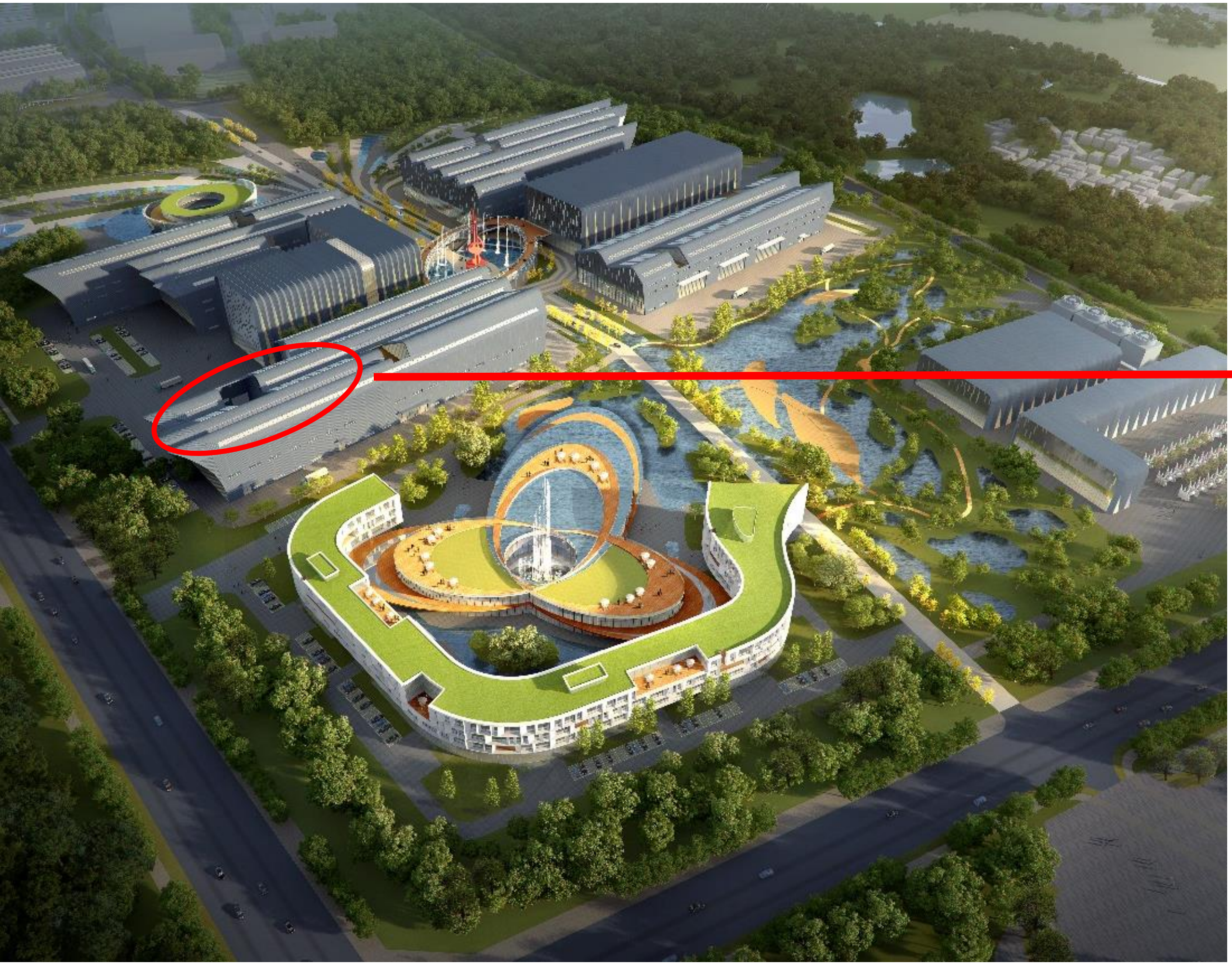
MFE development pathway in CHINA



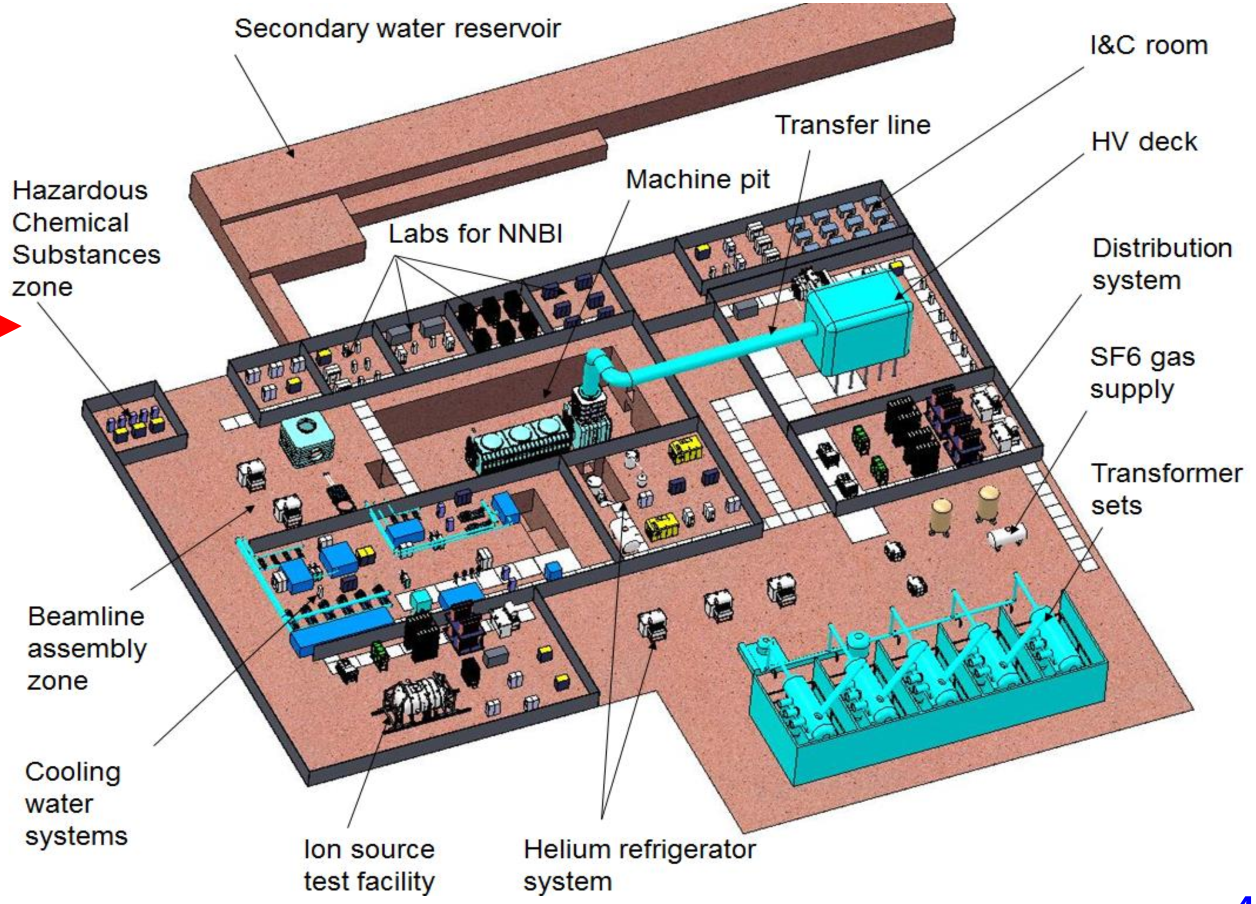
CRAFT Project

Comprehensive Research fAcility for Fusion Technology (CRAFT)

National big science facility (2019.9-2025.5)



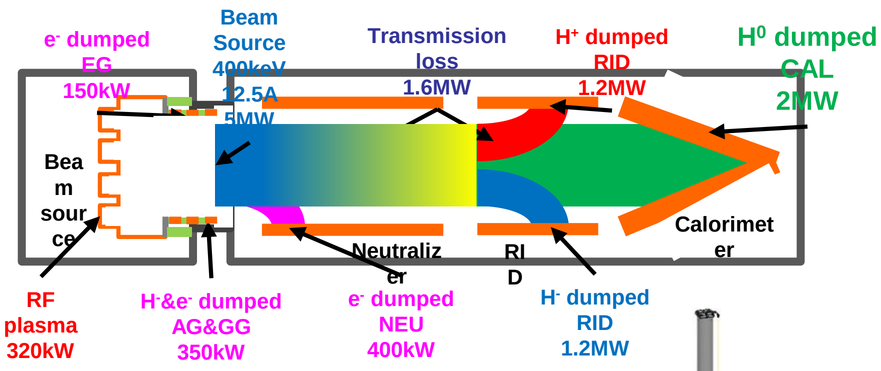
Layout of CRAFT NNBI system



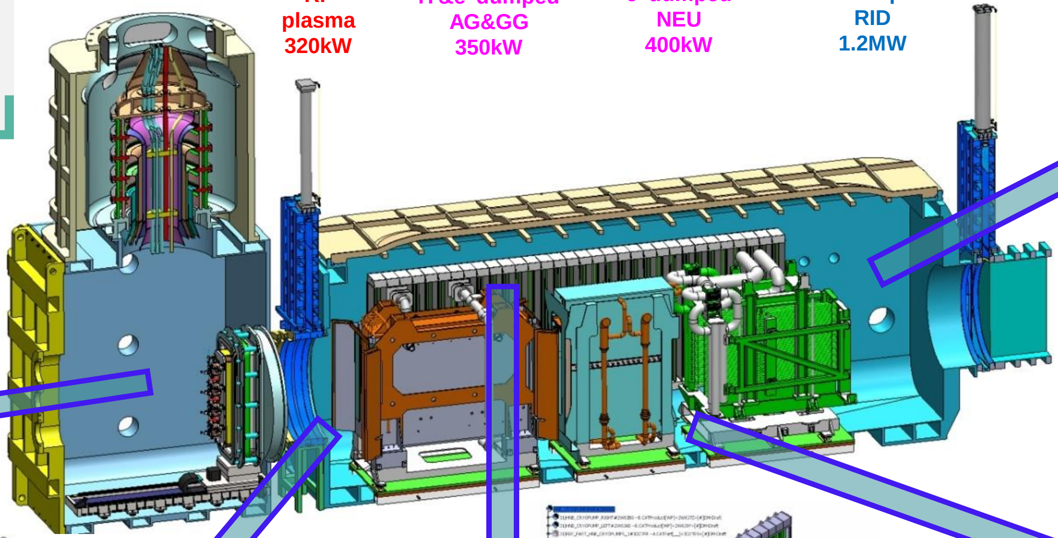
CRAFT NNBI system

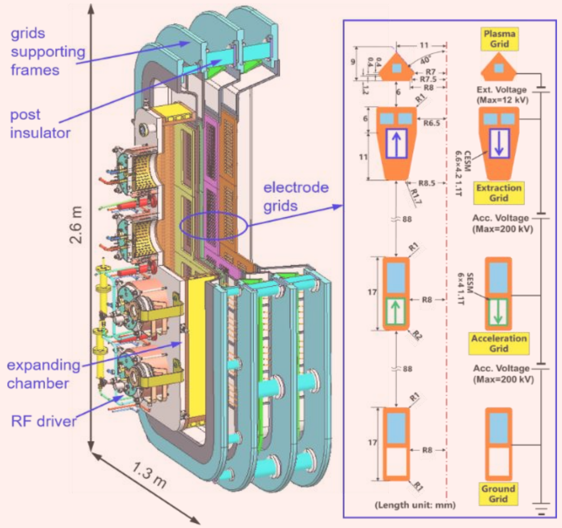
➢ Key technology

- Negative ions generation
- Negative beam acceleration
- HVPS and transmission
- High speed cryopump

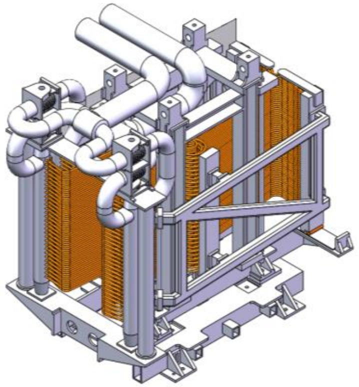


CRAFT NNBI components

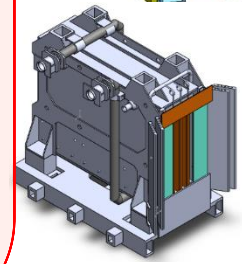




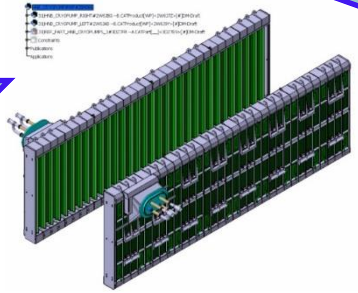
Giant negative beam source



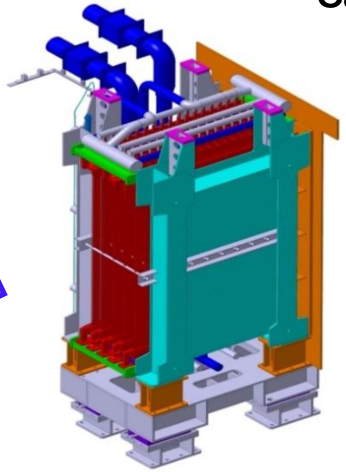
Calorimeter



Neutralizer



Cryopump panels



Electrostatic residual ion dump

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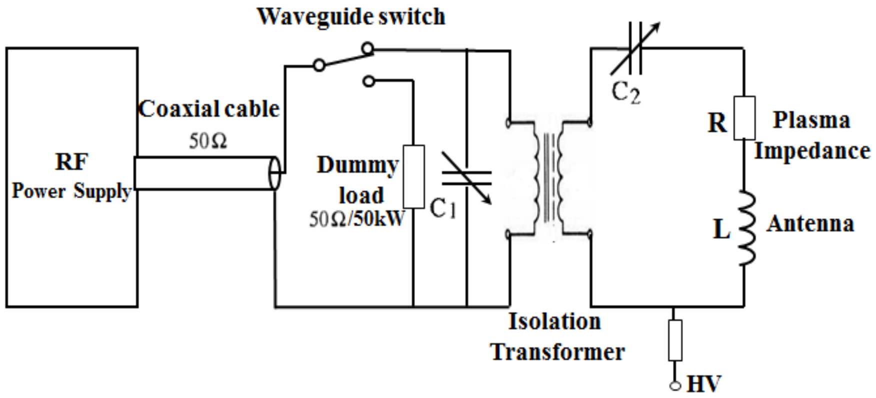
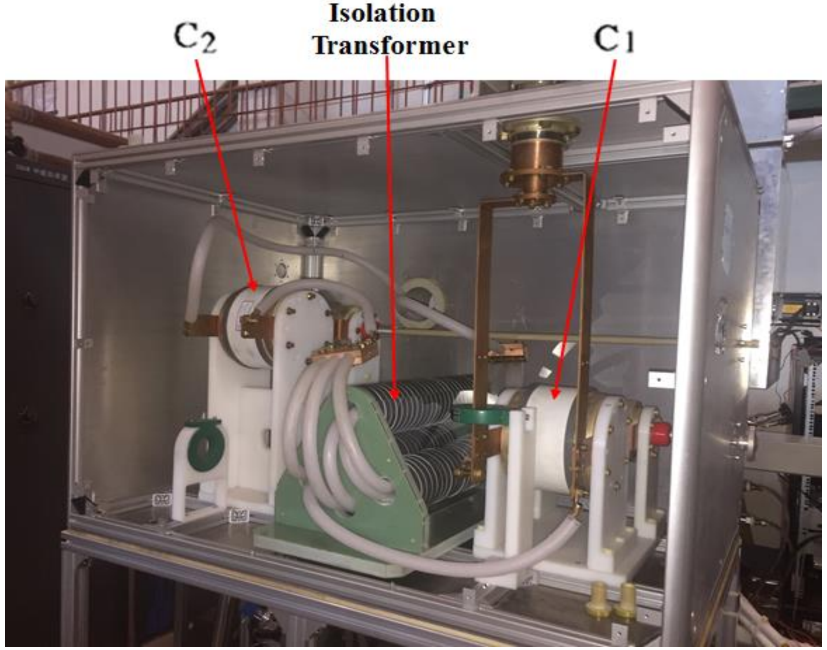
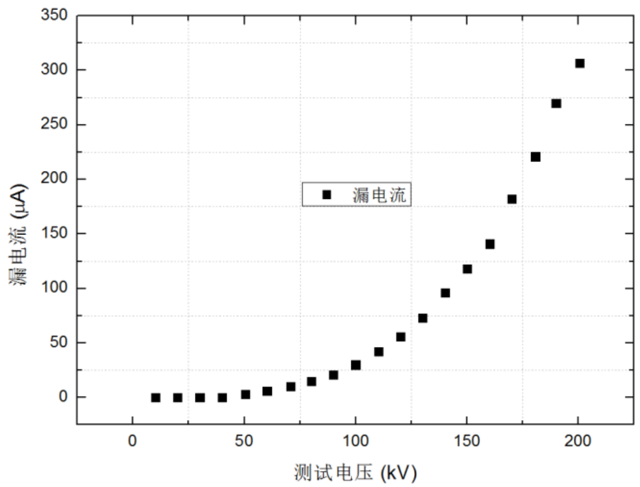
RF beam source test facility

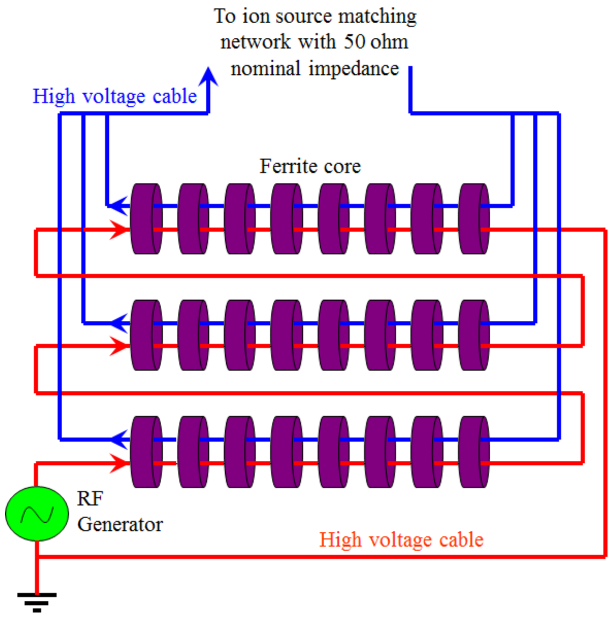
The matching network on test facility



C2=2.65nF±0.5nF   C1=1.1nF~5nF







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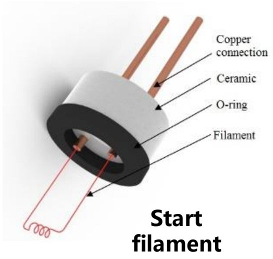
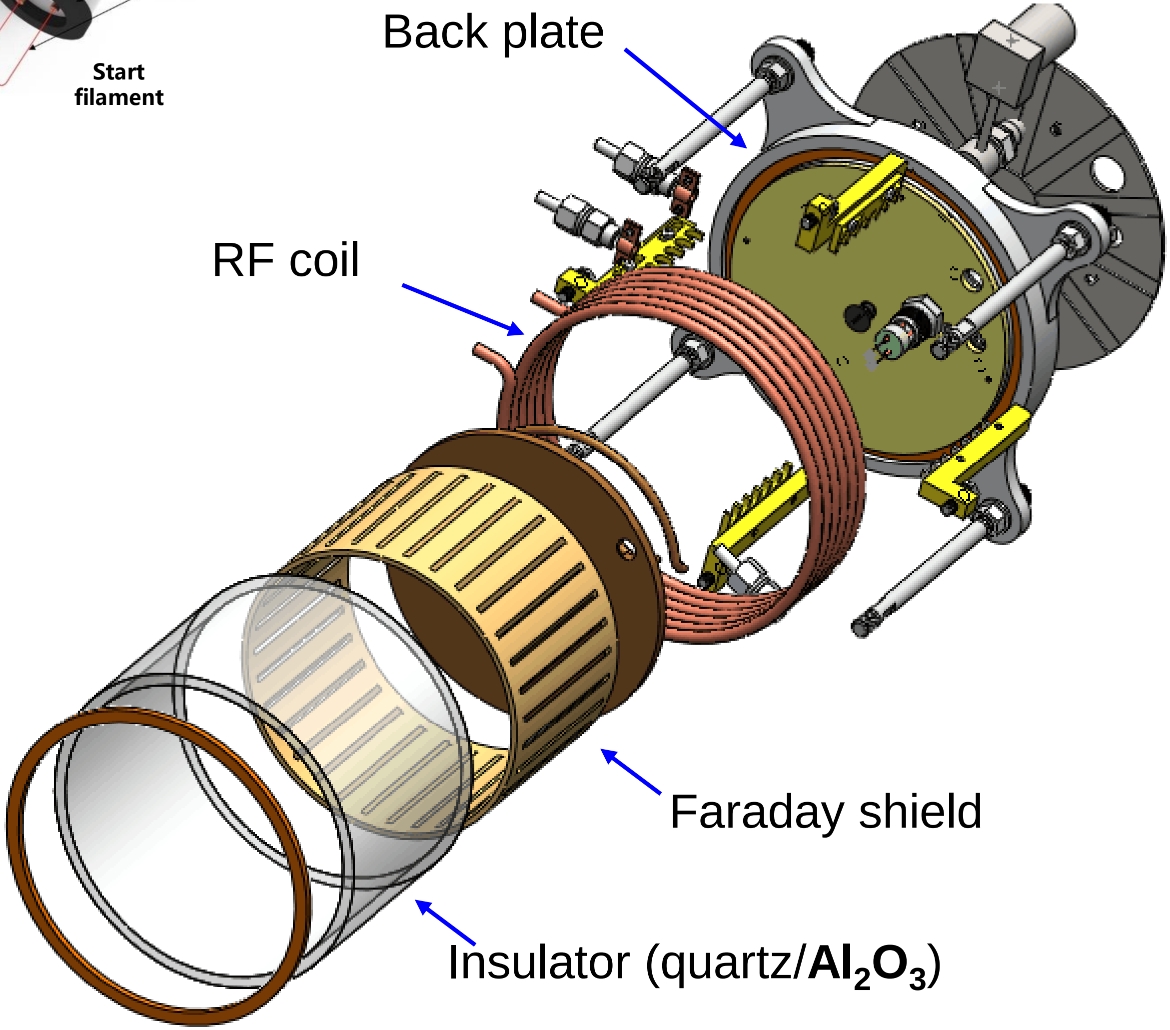
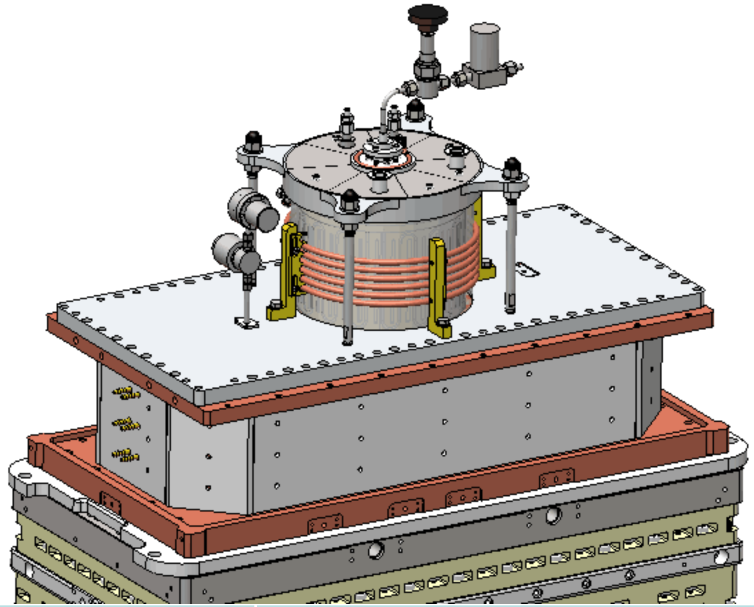
Design of RF plasma source



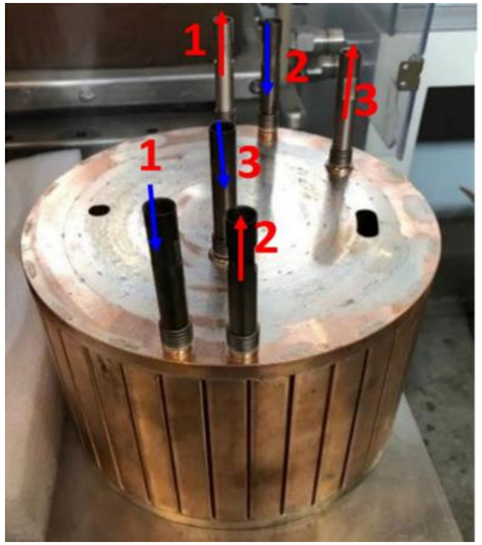


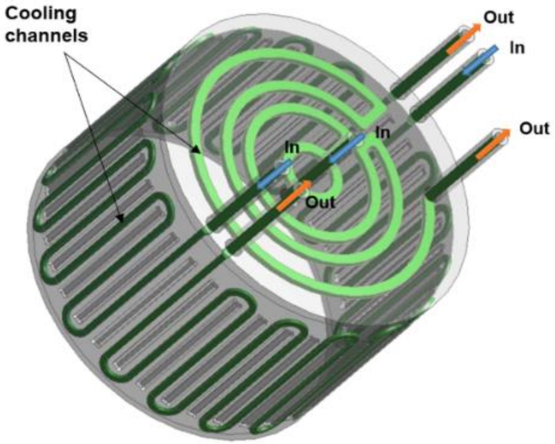


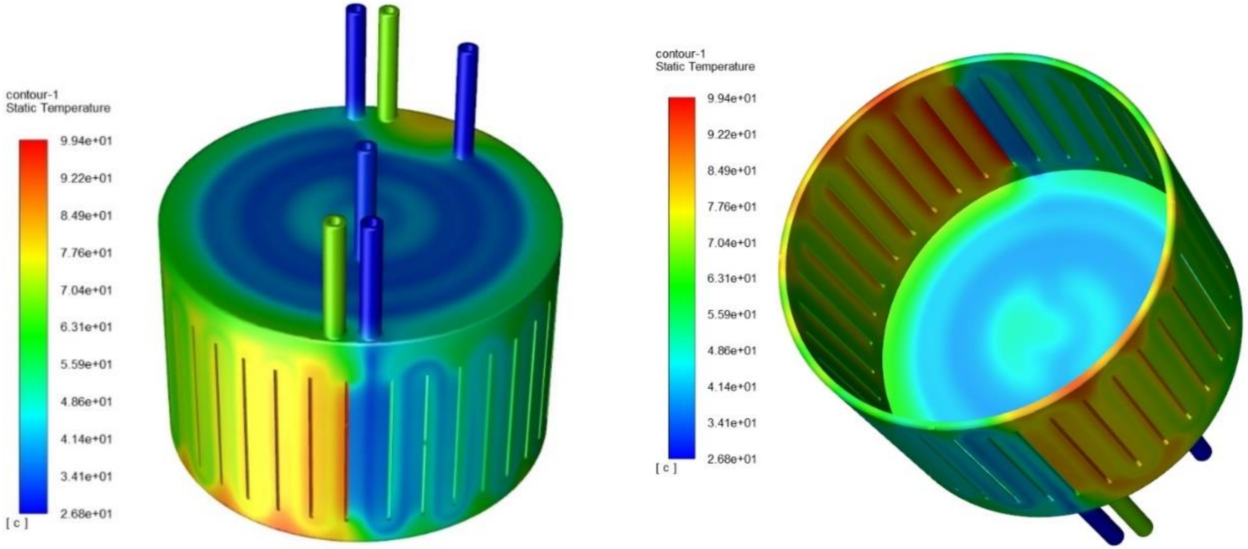
Item	specifications
faraday shield	ID=200mm height = 140mm thickness = 4 mm
Size of insulator	ID=210mm height = 156mm thickness = 8 mm
Expansion area	Length=650mm, height= 260mm, depth= 240 mm

R&D of RF driver

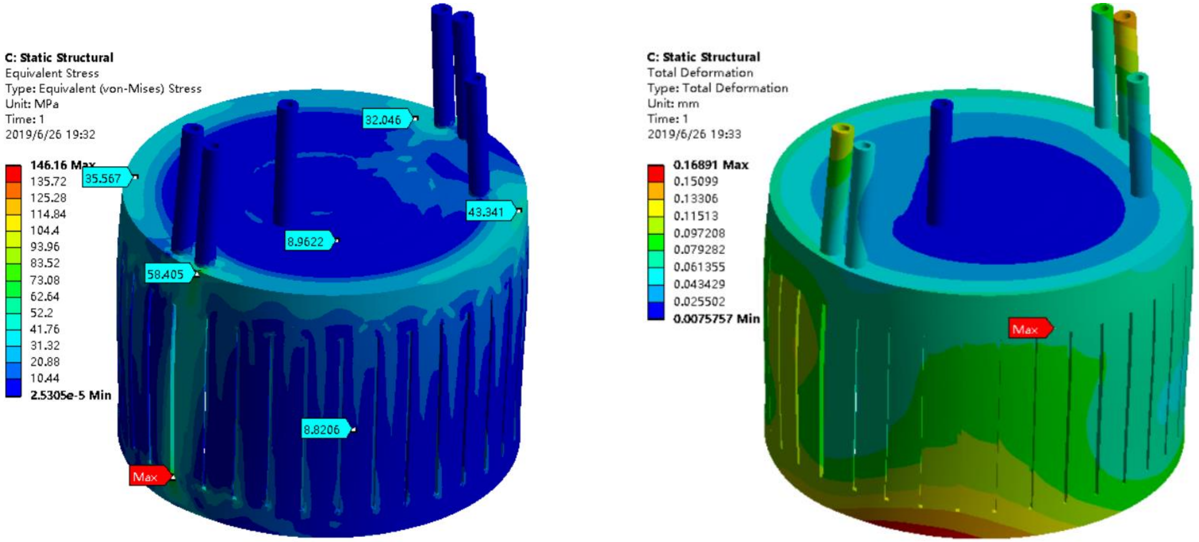
- Heat loading on FS is around 50% of total
- FS is very different to manufacture (by vacuum brazing)
- Active cooling FS with three pipes was developed







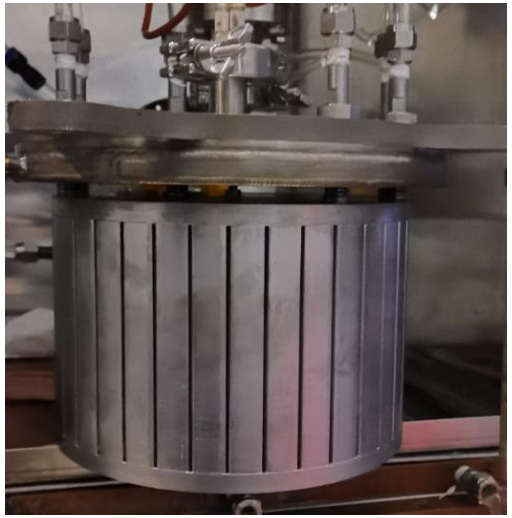
Temperature analysis

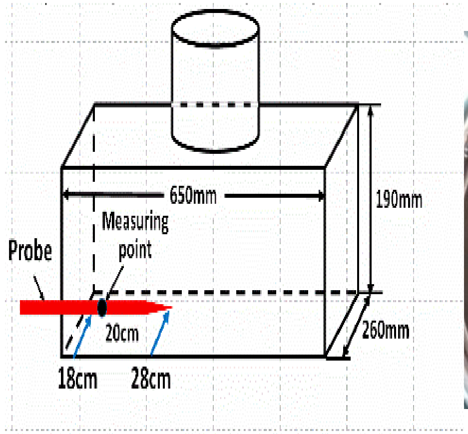


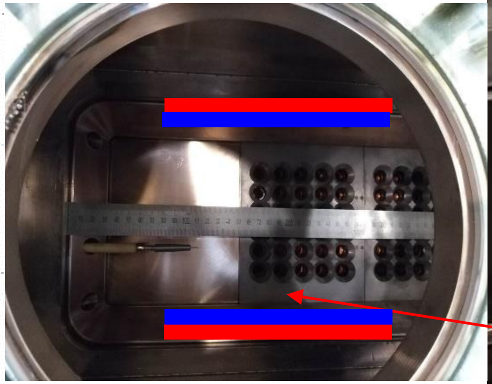
Stress and thermal displacement analysis

Single driver ion source

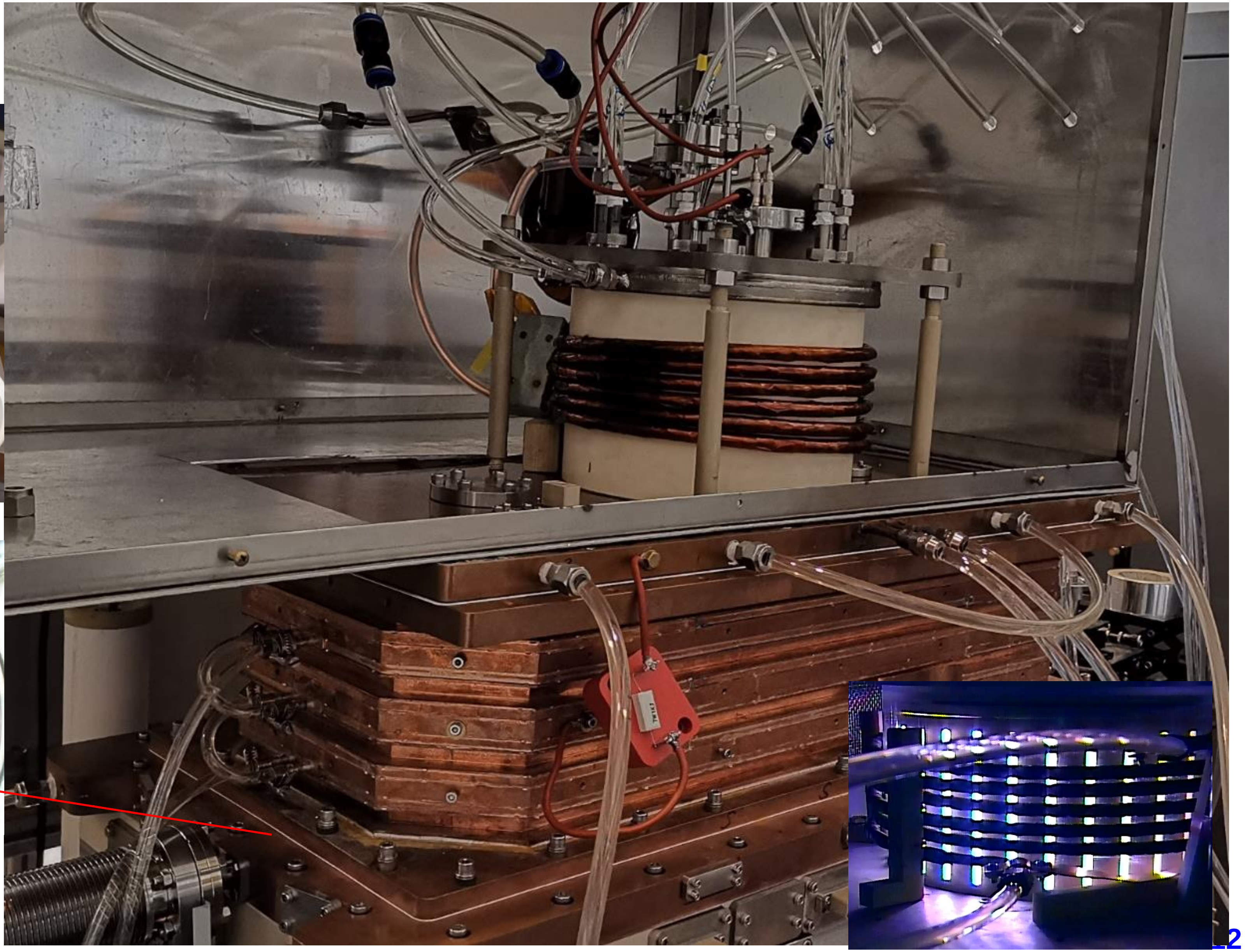
Picture of RF ion source



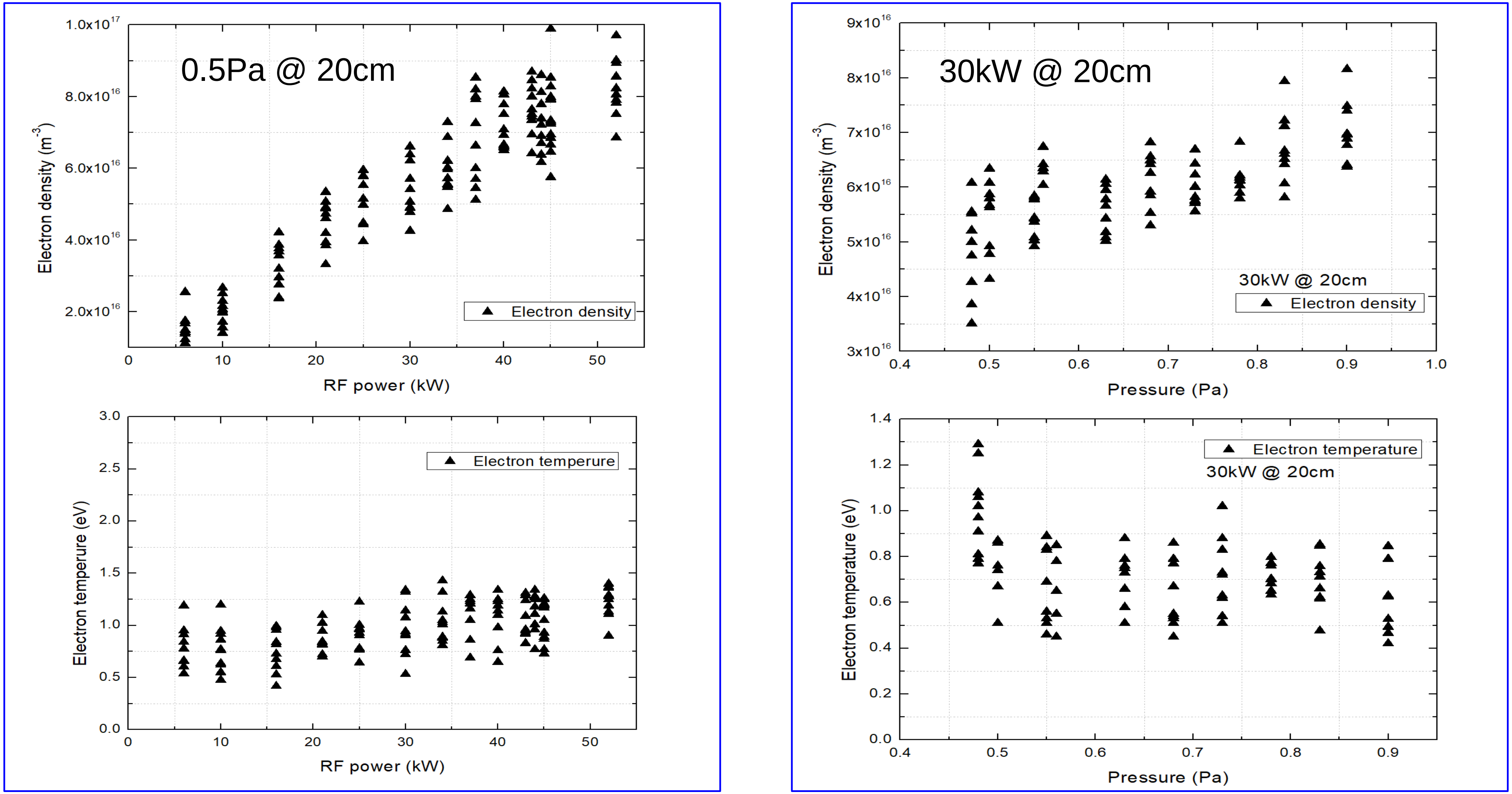




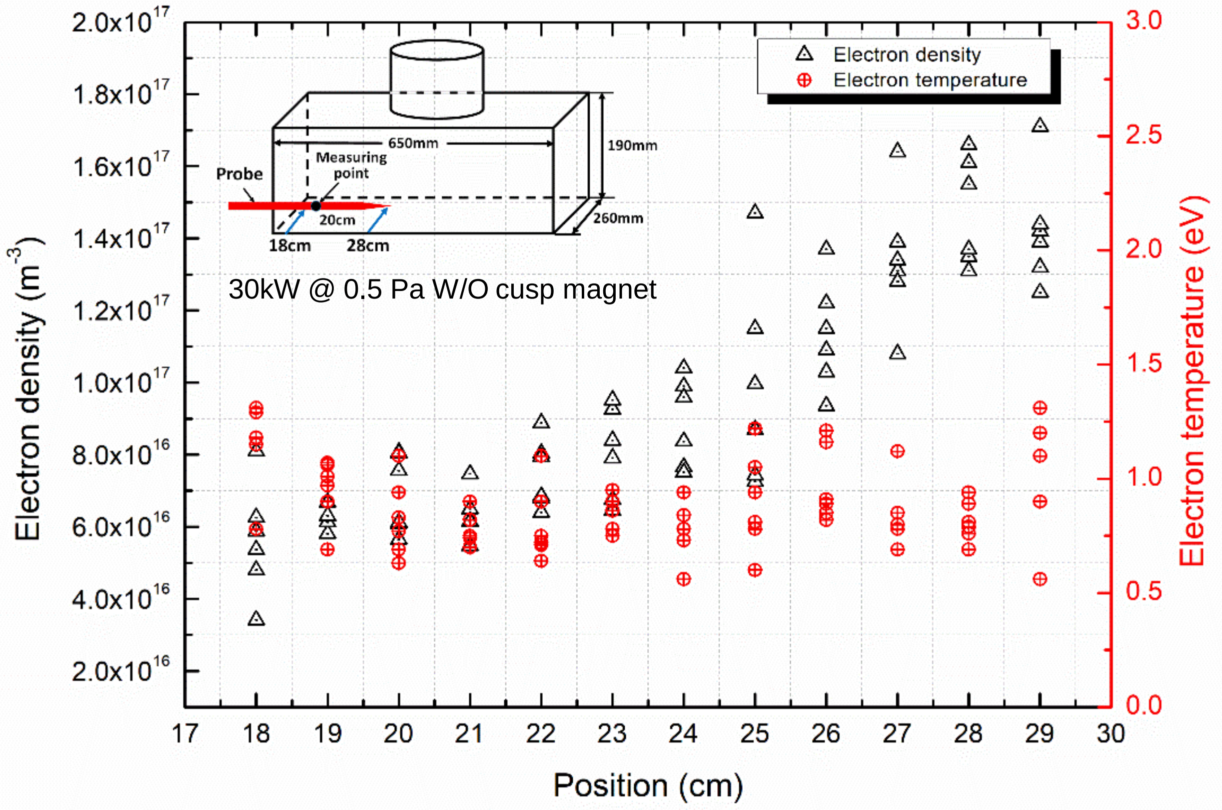
Position of movable probe

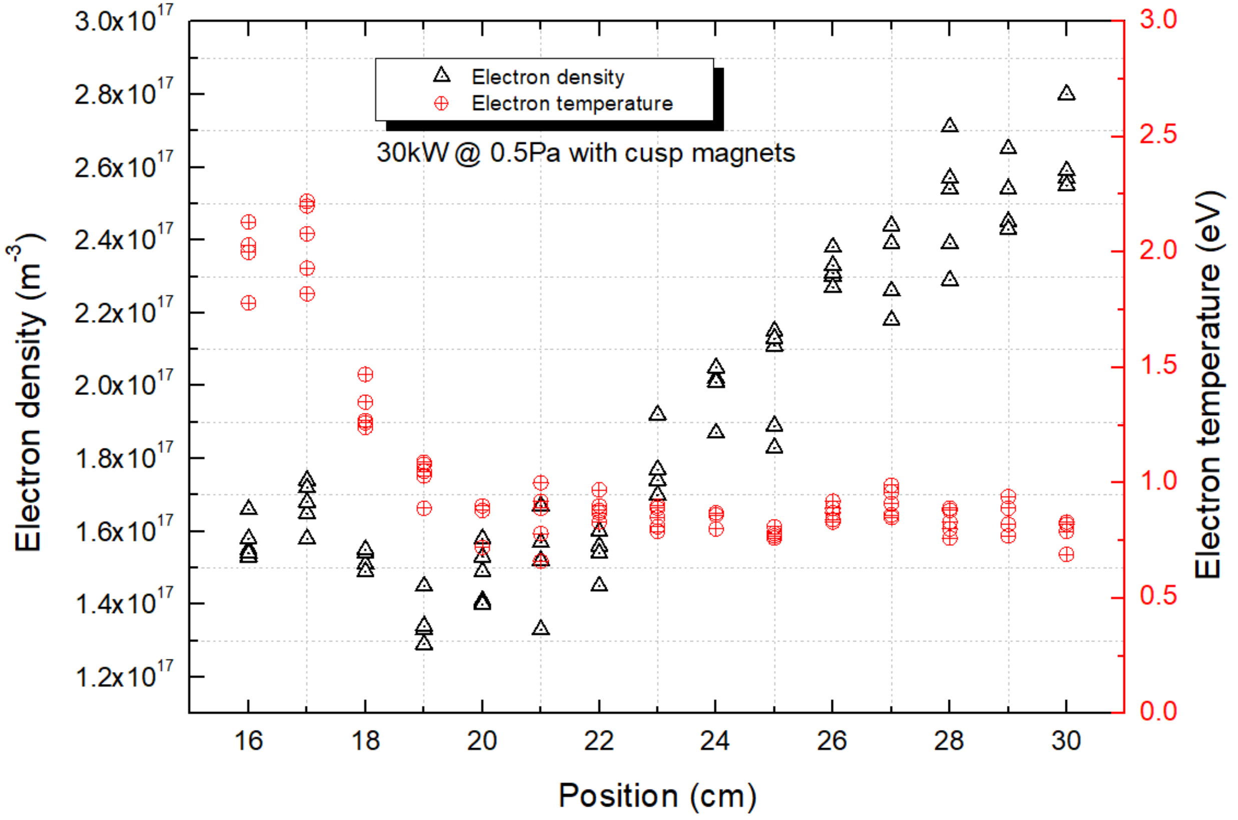


Plasma parameters measurement (w/o cusp mag.)

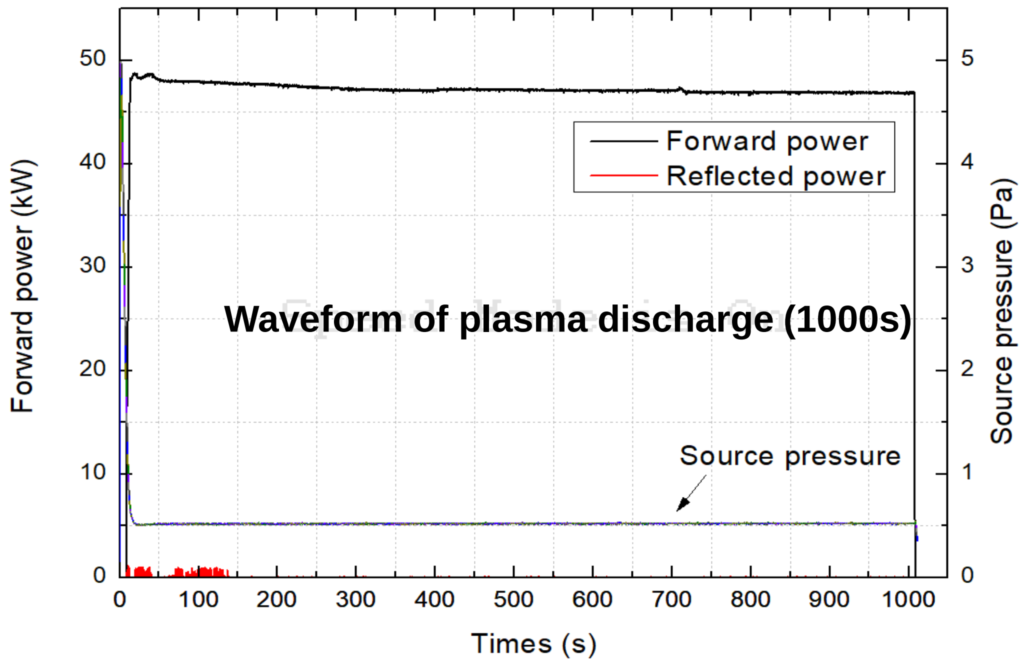


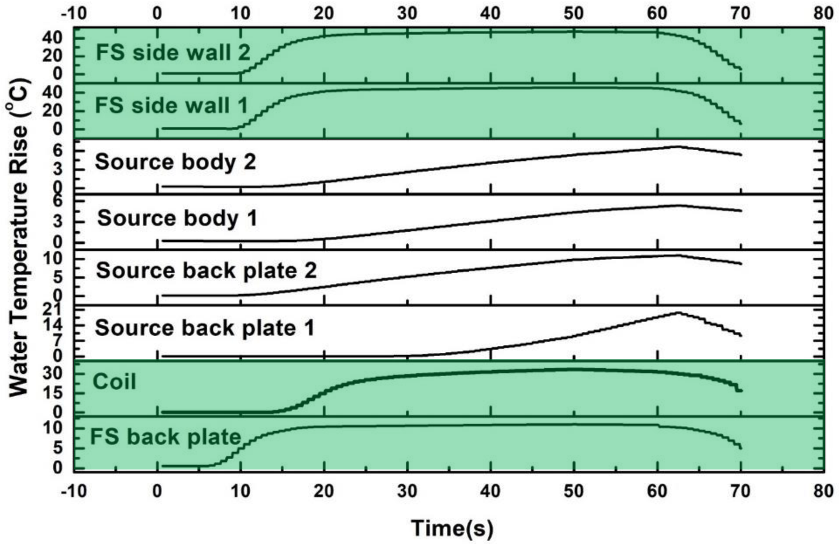
Plasma parameters with space distribution



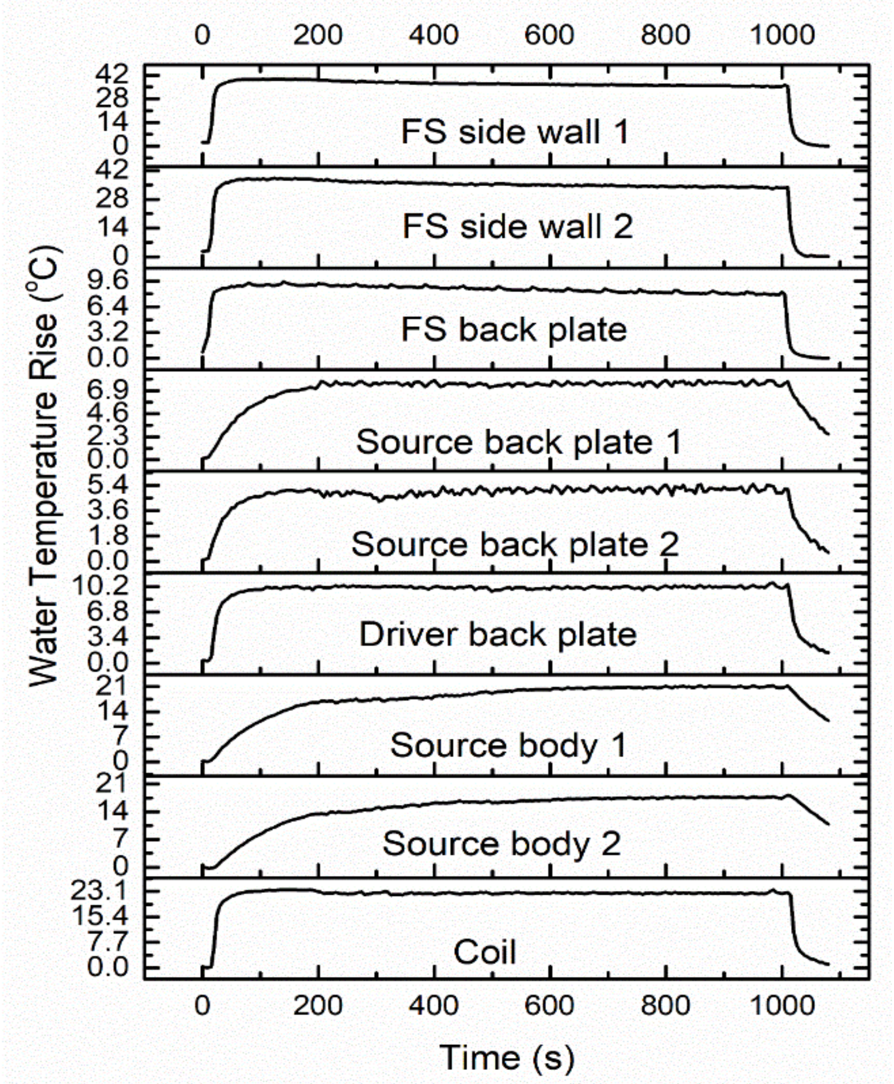


Long pulse operation（47kW@1000s）





80 kW RF discharge with 60s duration



Temperature rise of cooling water for each components

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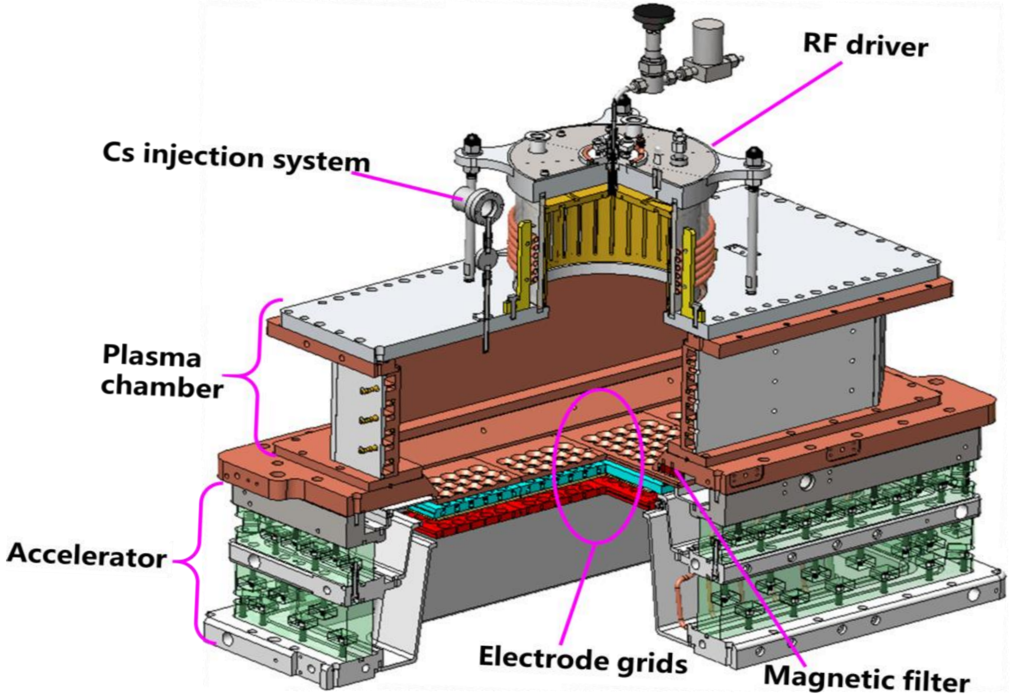
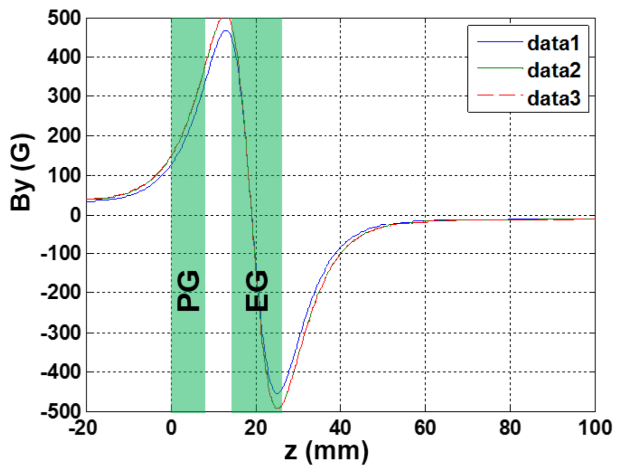
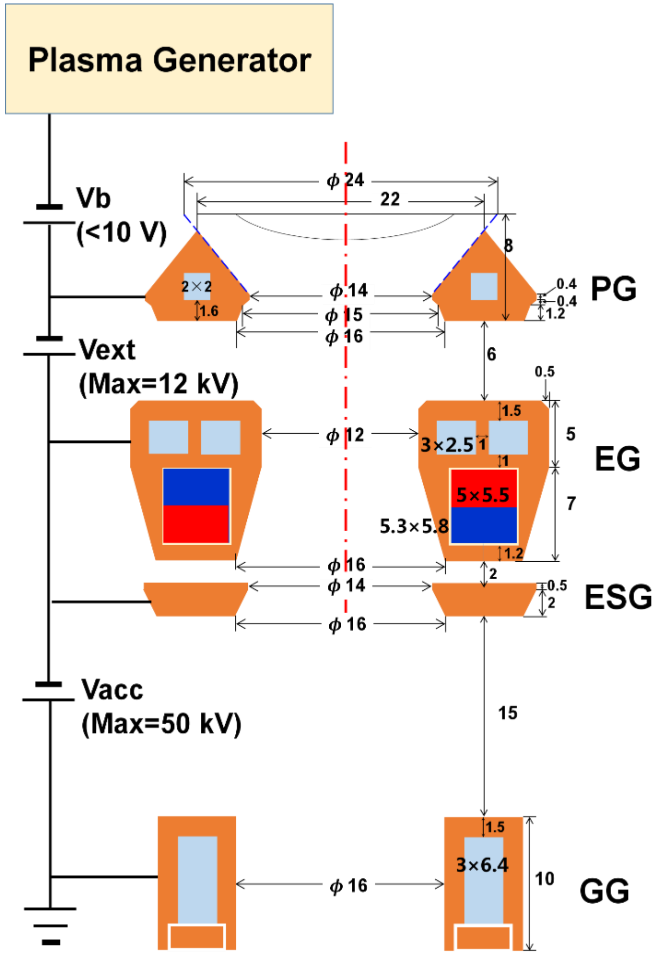
Design of negative ion accelerator





Center B_{ESM}



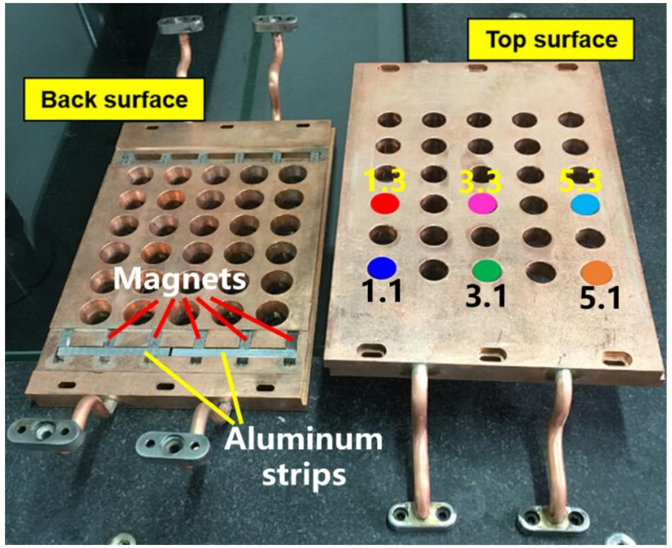
Electrode system

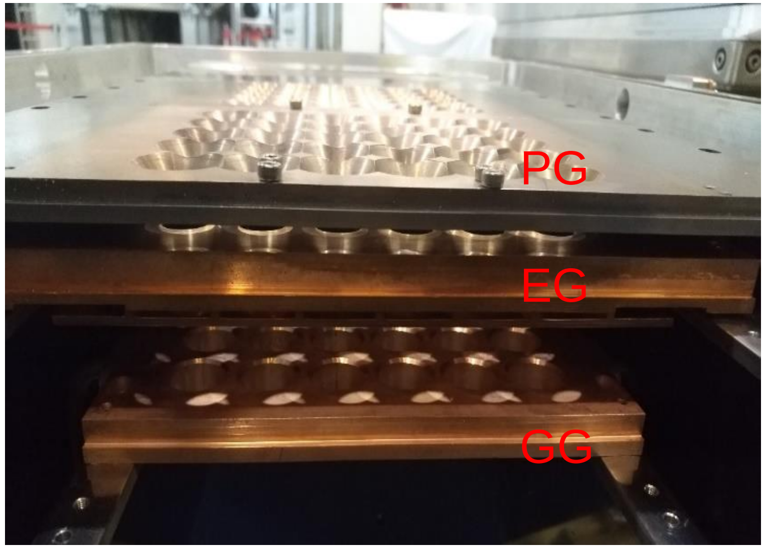
►**2** segments, **5×6 beamlets** for each, aperture separation **22mm and 20mm**

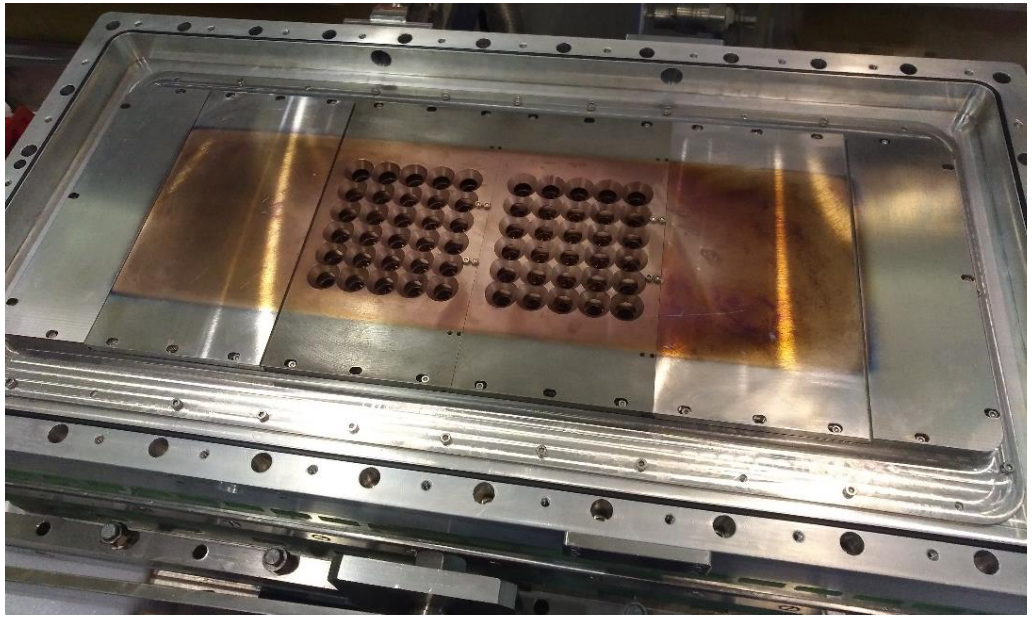
►Center of electron suppression magnetic field **~500G**

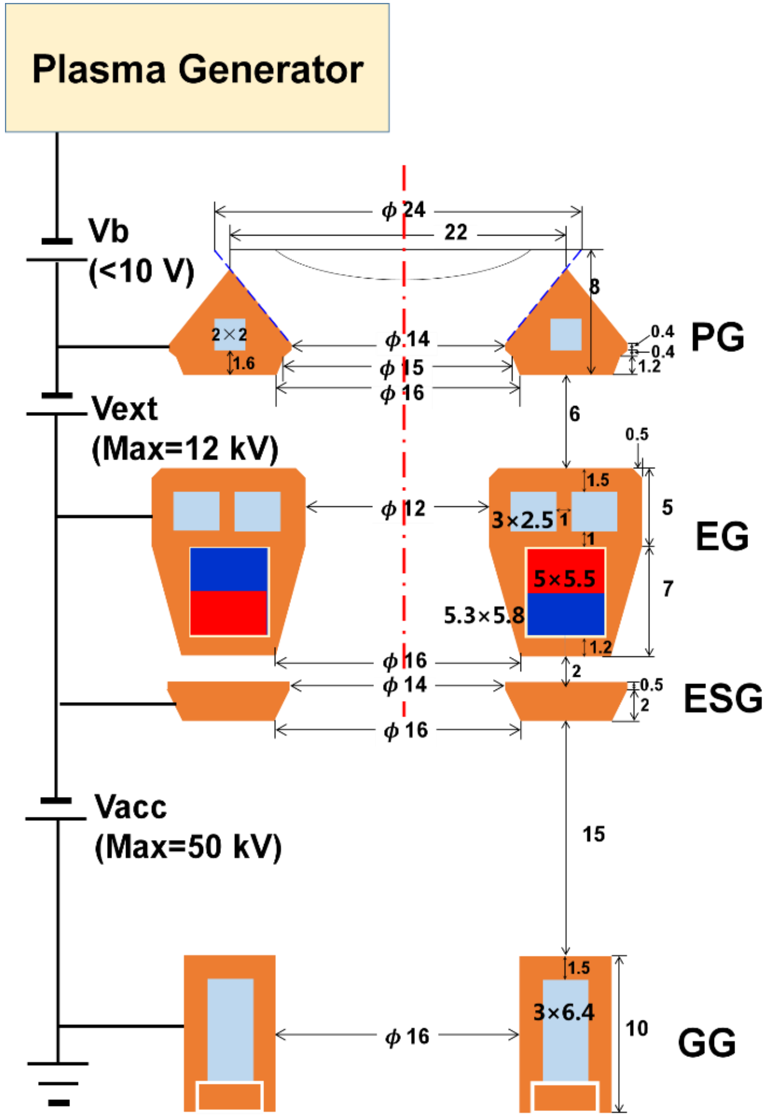
►Electron Suppression Magnet: **5mm×5.5mm**(cross section), **SmCo**, **1 T**

Development of negative ion accelerator



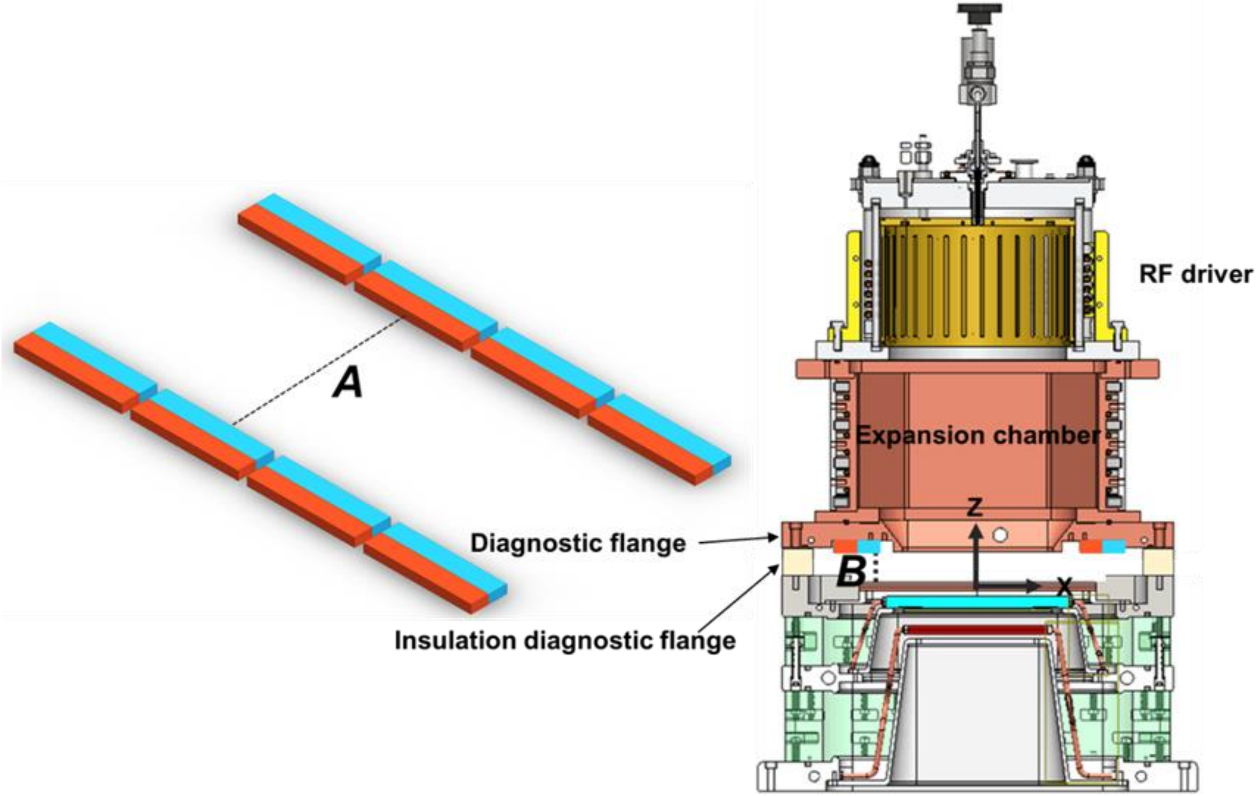


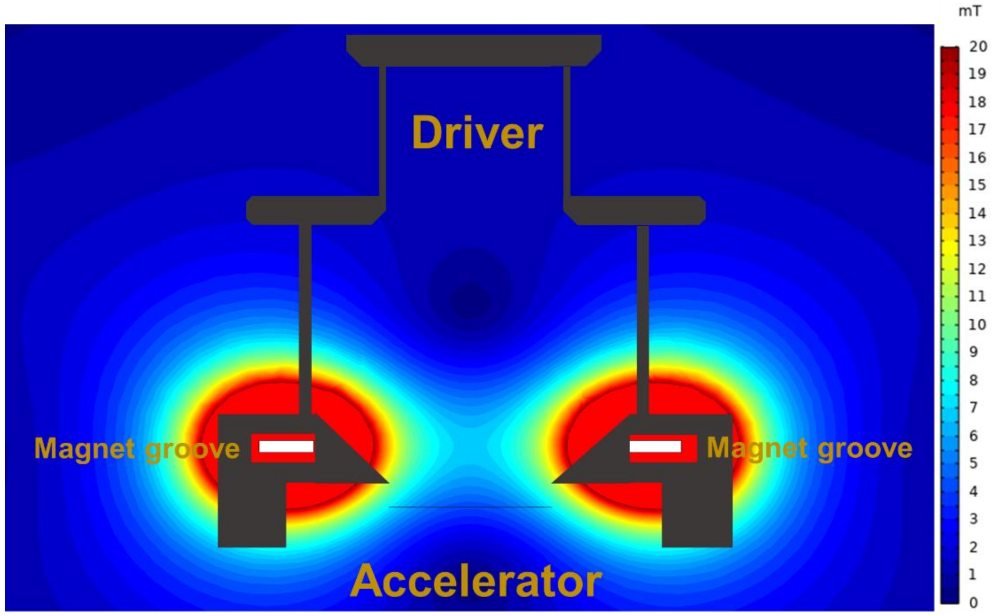




Magnetic filter on negative beam source

- 4×2 permanent magnets （Sm_2Co_{17}） installed 55mm before PG
- Magnetic intensity is 1T
- $\int|B_x|dz$ between 1.2 mTm-1.35 mTm

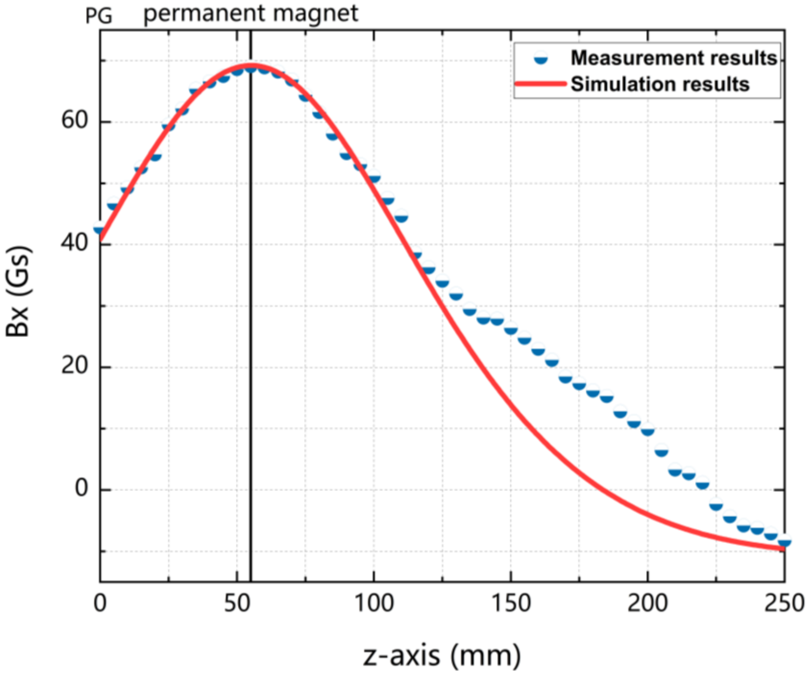


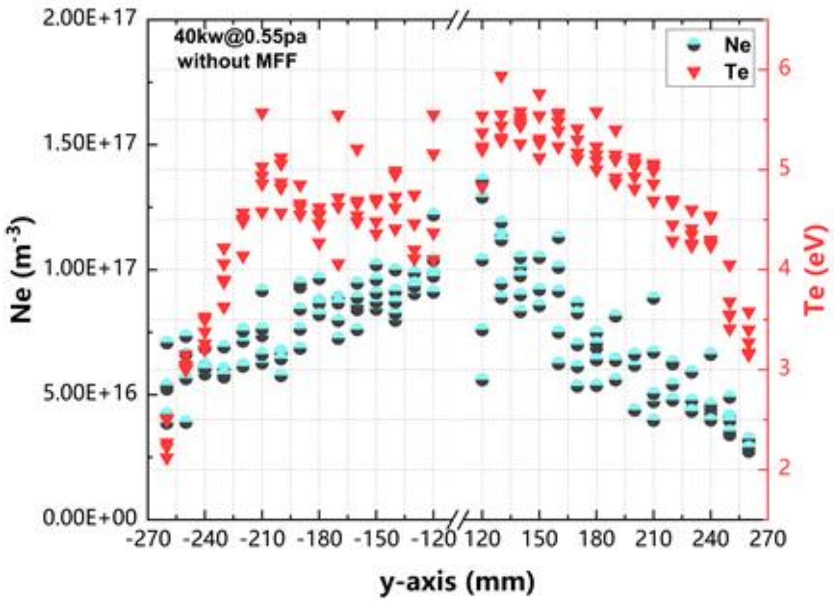


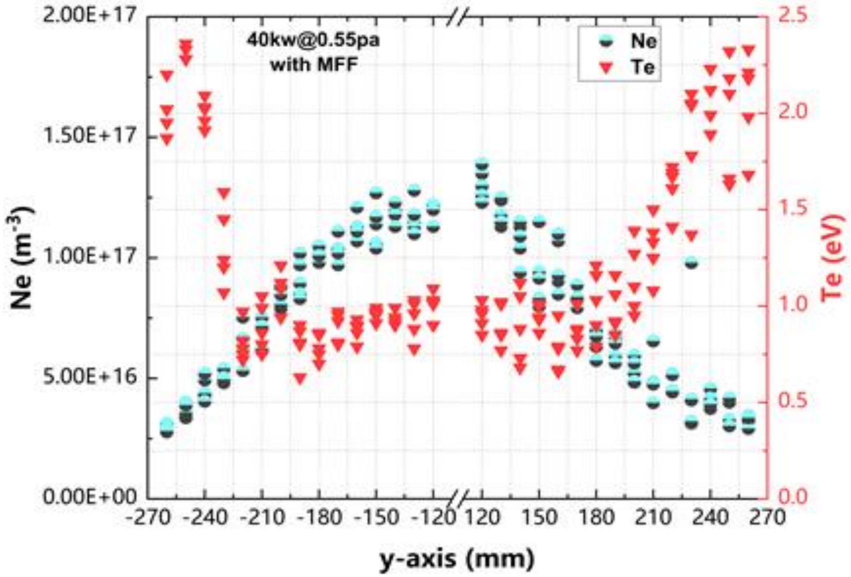
2D color map of permanent magnet filter

Magnetic filter on negative beam source

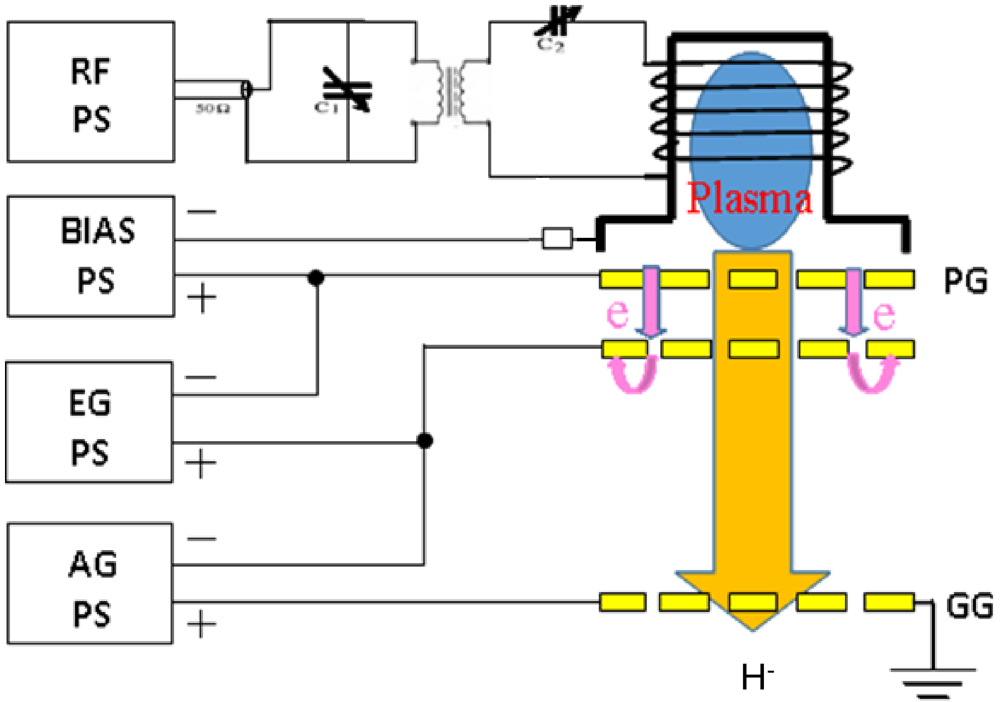
- The electron temperature decreased from 5.5eV to 1 eV with magnetic filter
- The magnetic filter effects on electron density can be neglected
- The results were good for the negative beam source

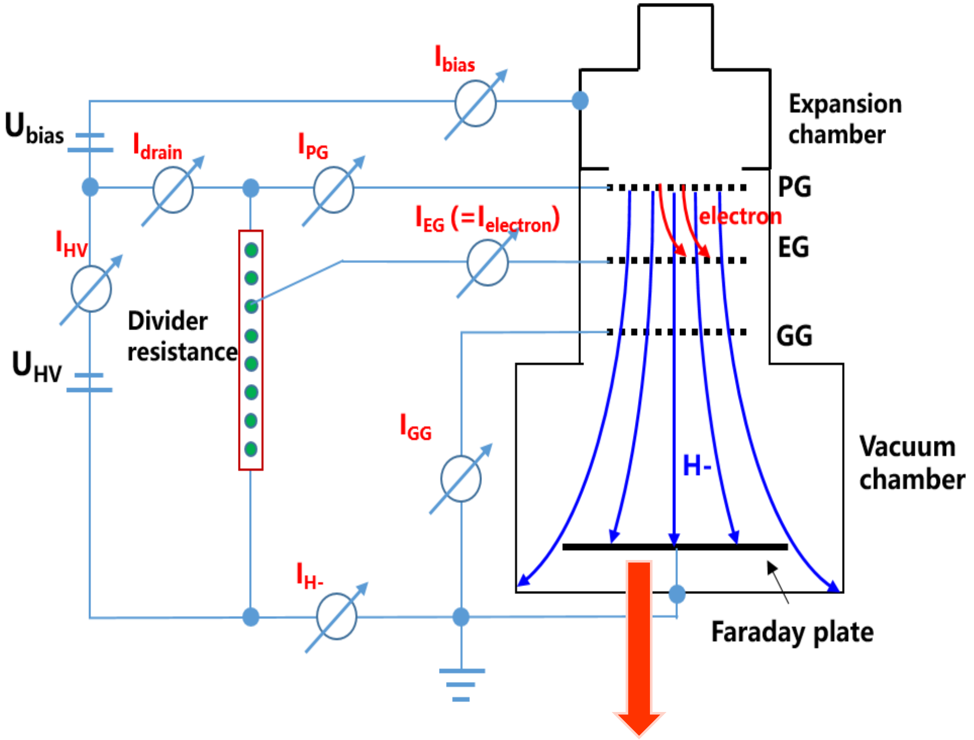


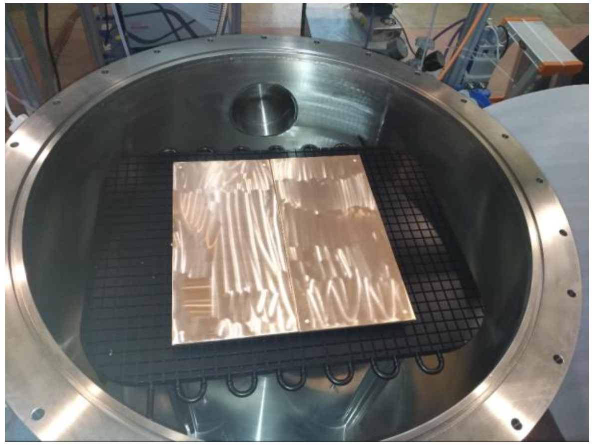




Negative ion extraction exp.



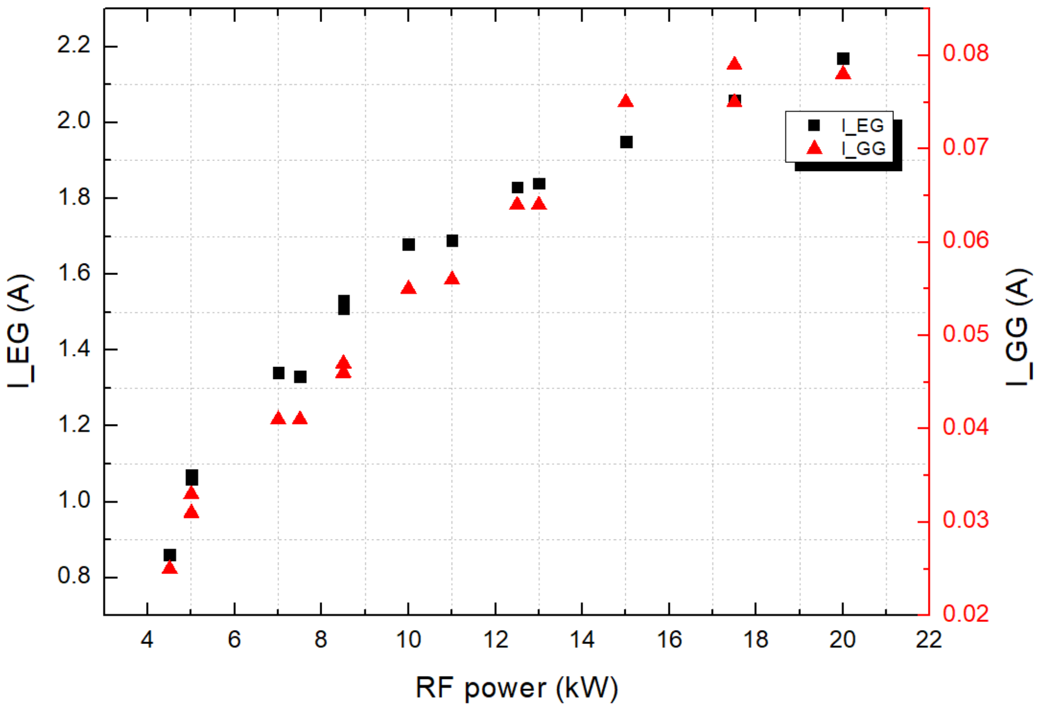




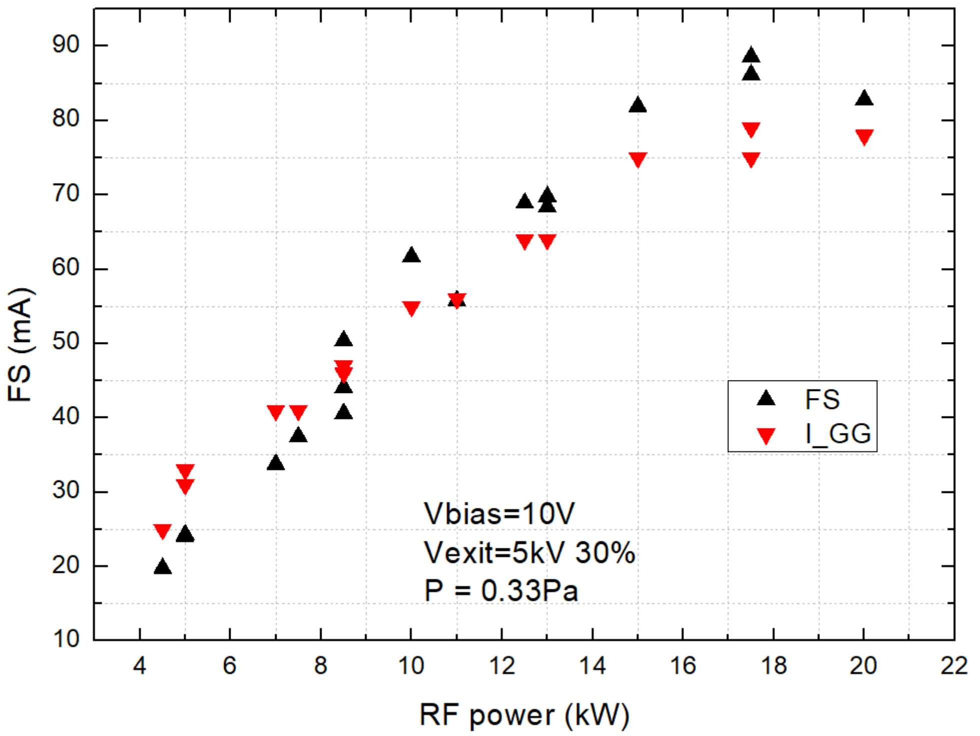
- ☐ Plasma grid current: I_{PG}
- ☐ Extraction grid current: I_{EG}
- ☐ Ground grid current: I_{GG}
- ☐ Faraday plate current: I_{FS}

Negative ion extraction W/O Cs

- The source pressure keeps 0.33 Pa
- Negative ion density realized 10 A/m^2（20kW）
- The ratio of electron to negative ion is around 25

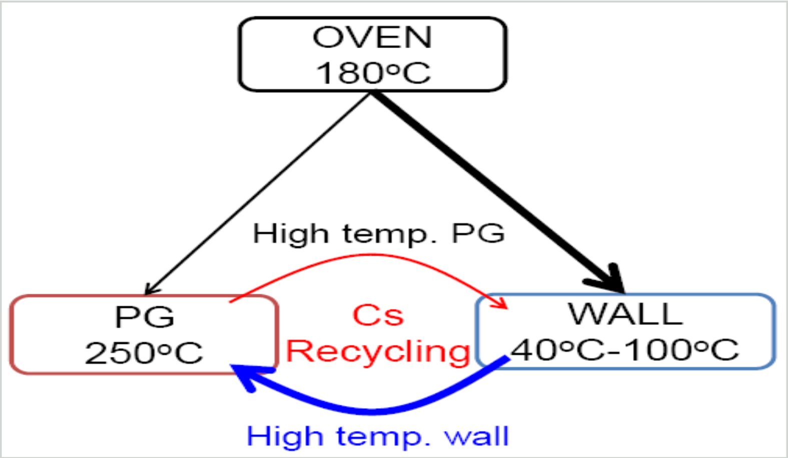


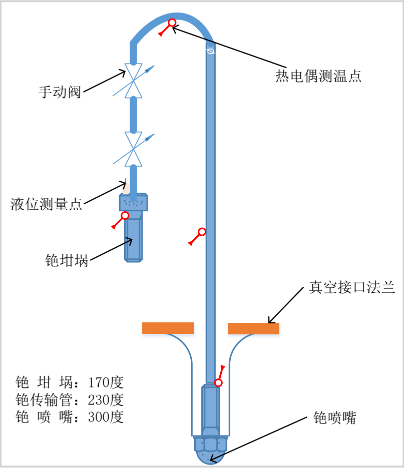
EG and GG current as a function of RF power

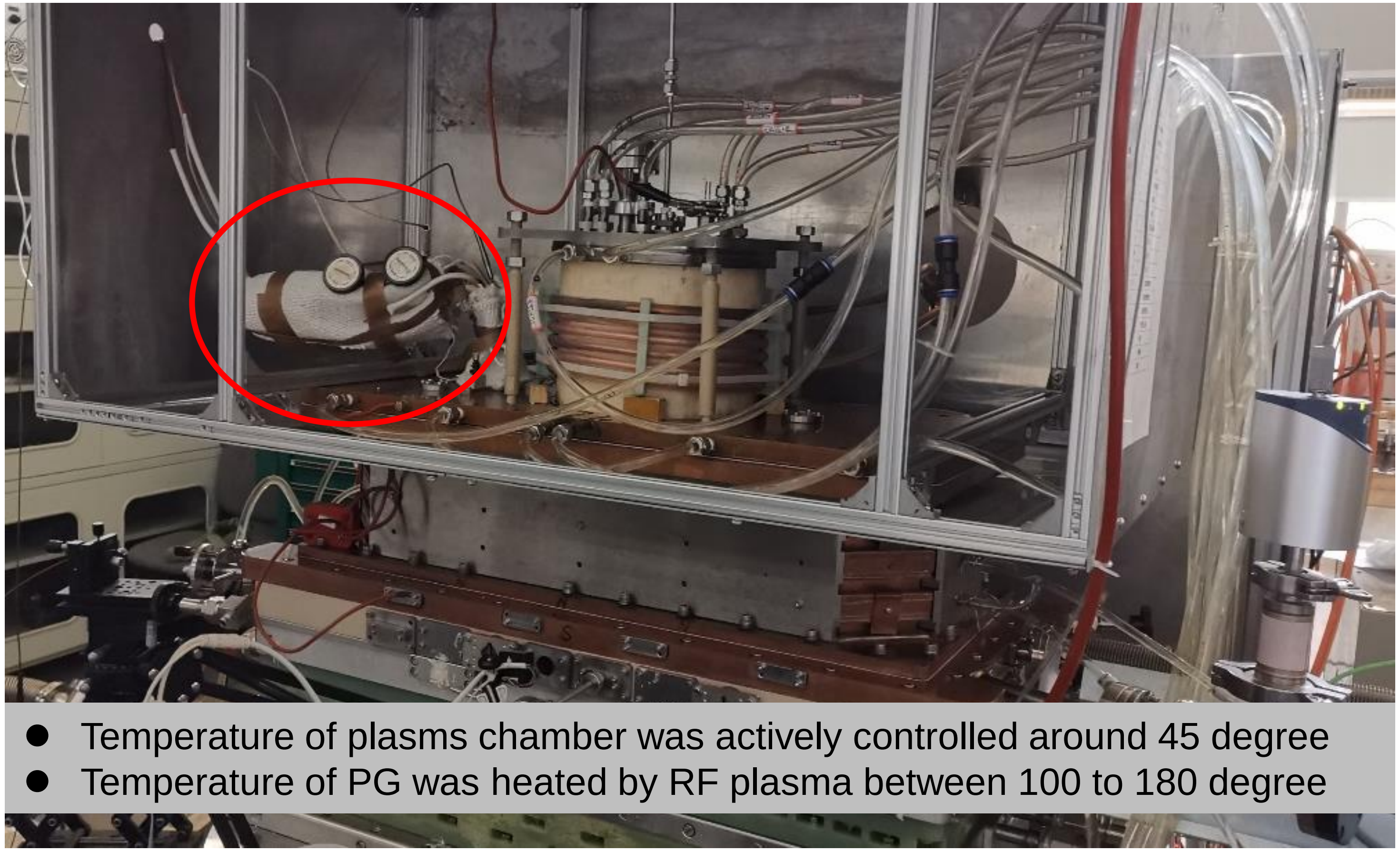


Faraday cup current and GG current as a function of RF power

Cs dispenser for negative ion production



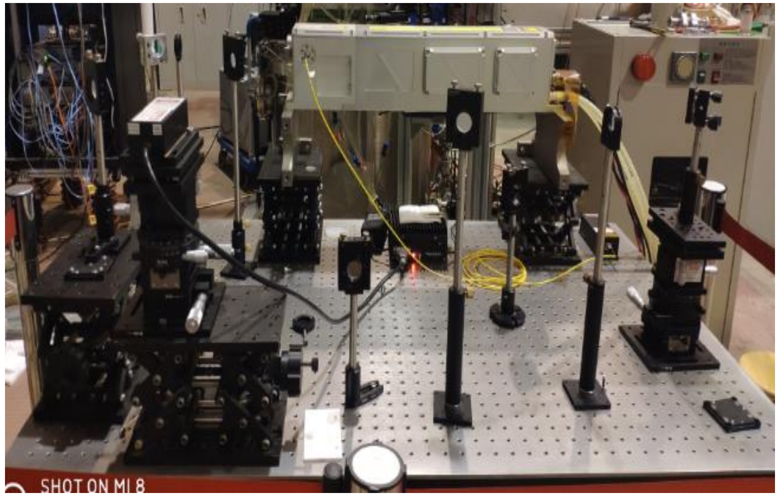




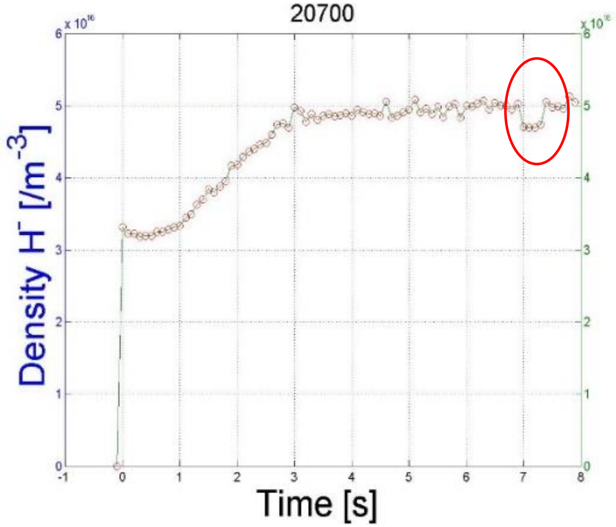
R&D of Cs dispenser to enhance the H- yield

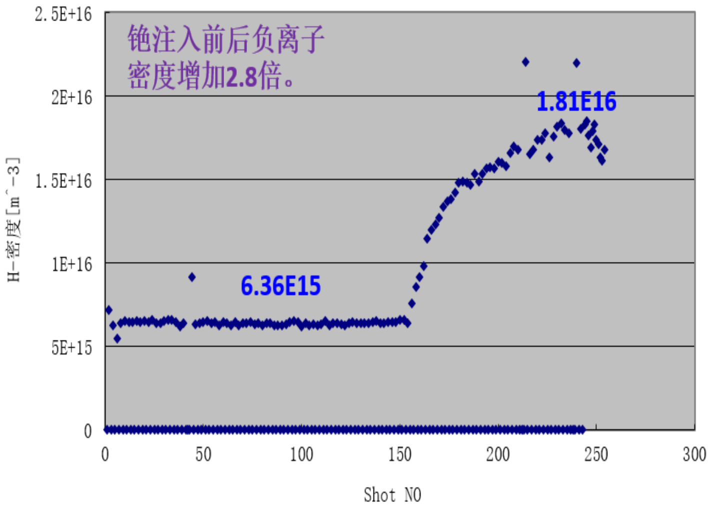
Cs dispenser installed on the beam source

Diagnosis of negative ion

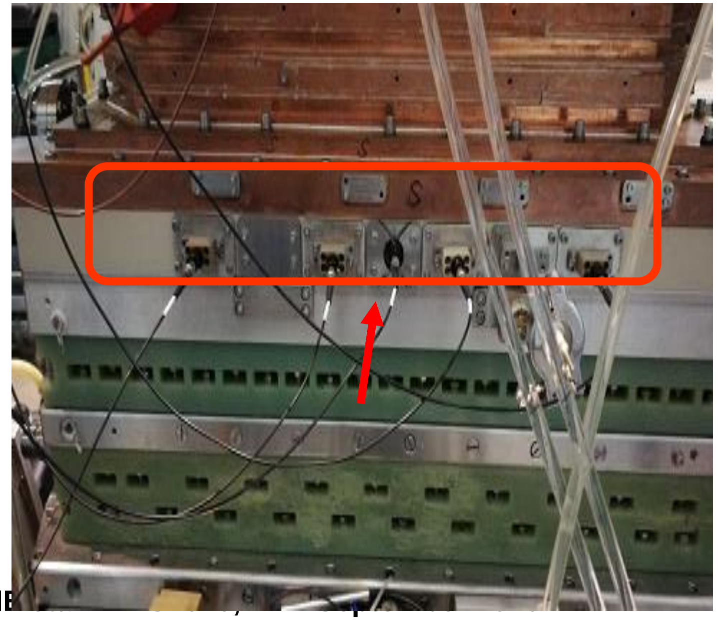


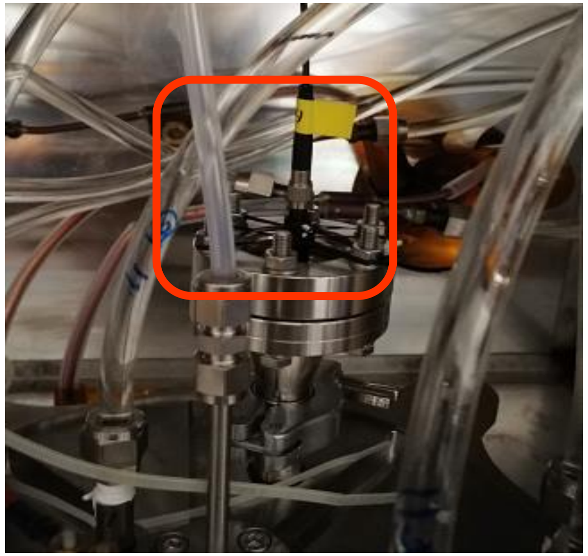
Picture of CRDS system



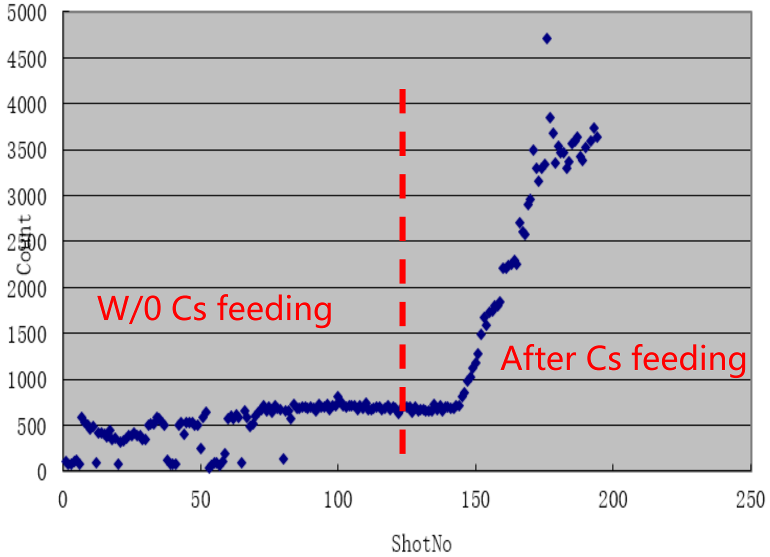


Measurement of H- density with CRDS



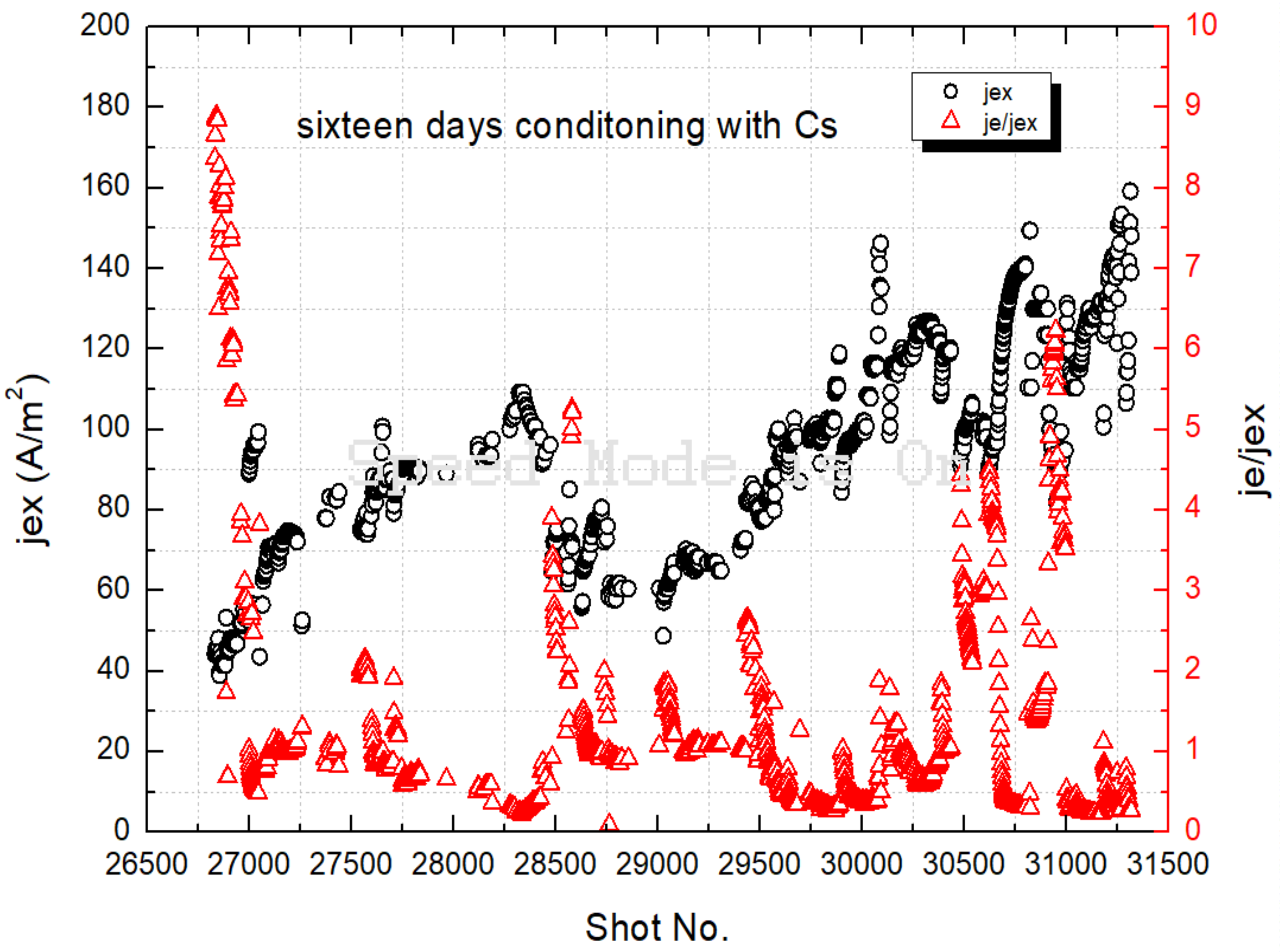


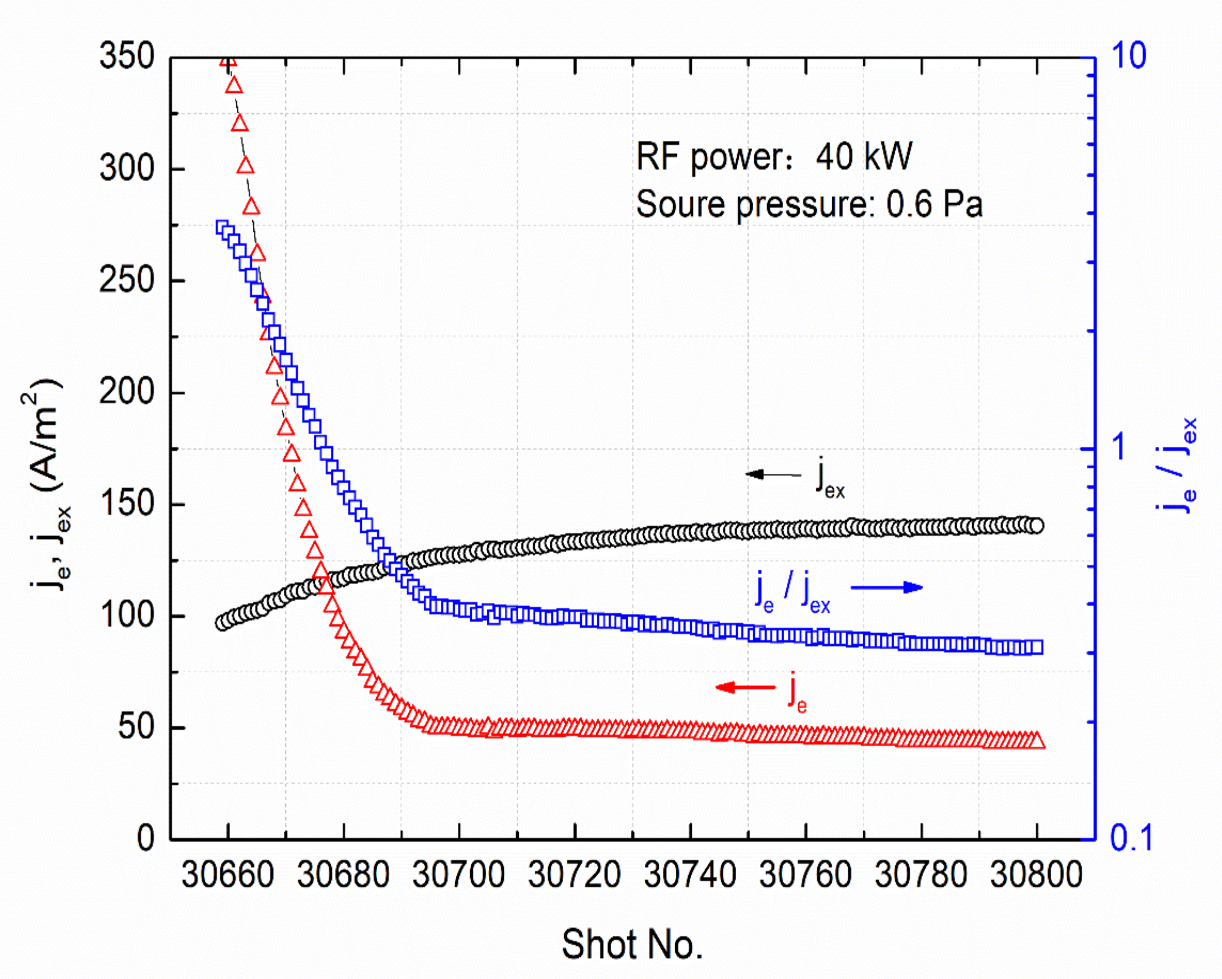
OES measurement points



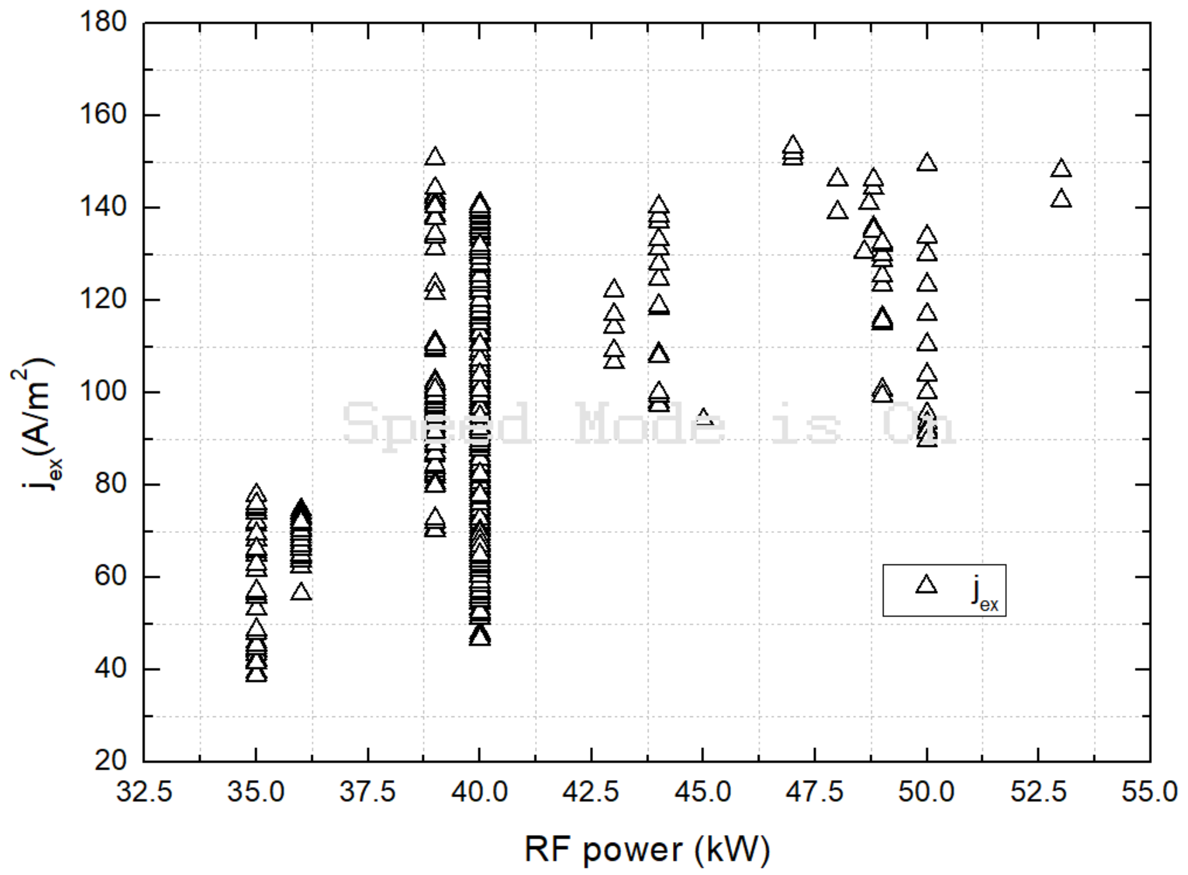
Intensity of 852nm line of Cs

Day by day conditioning

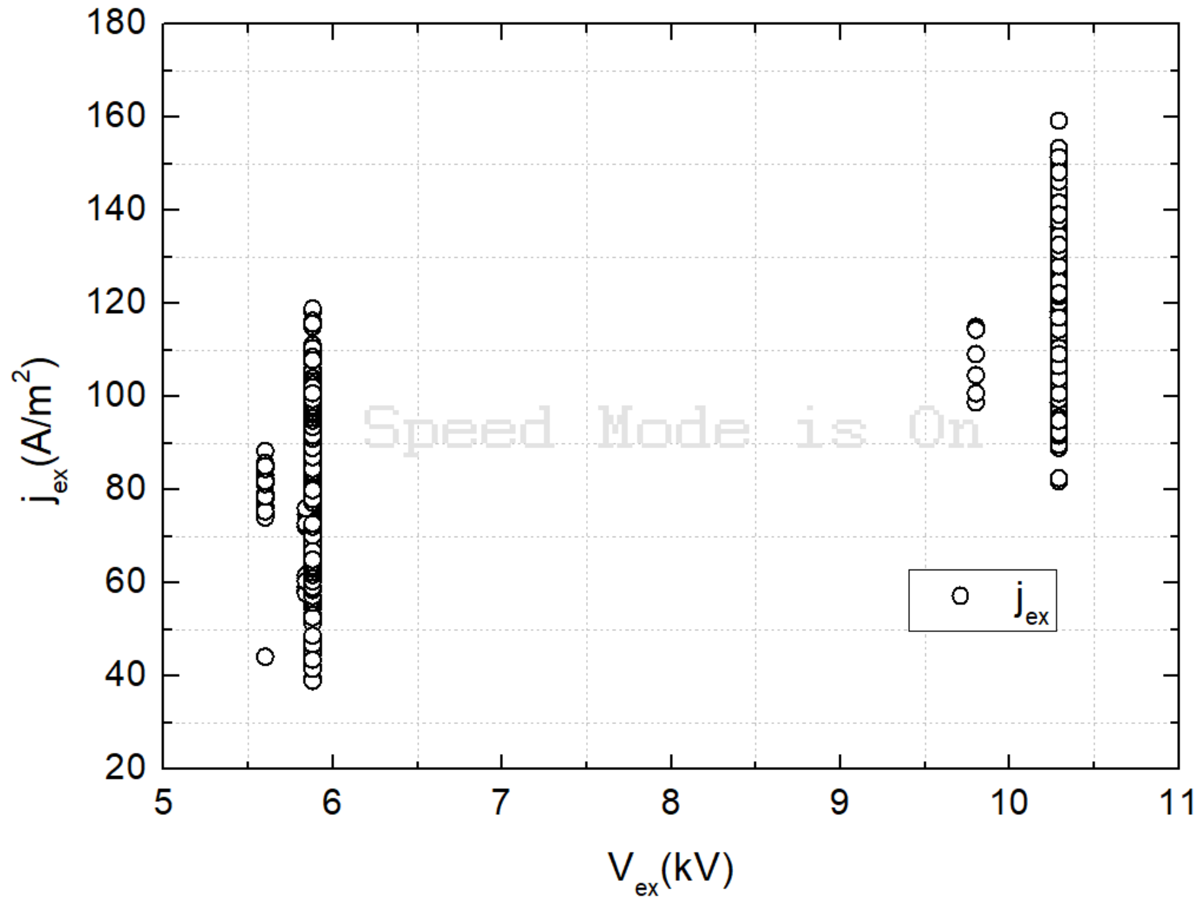




Conditioning results of negative ion extraction

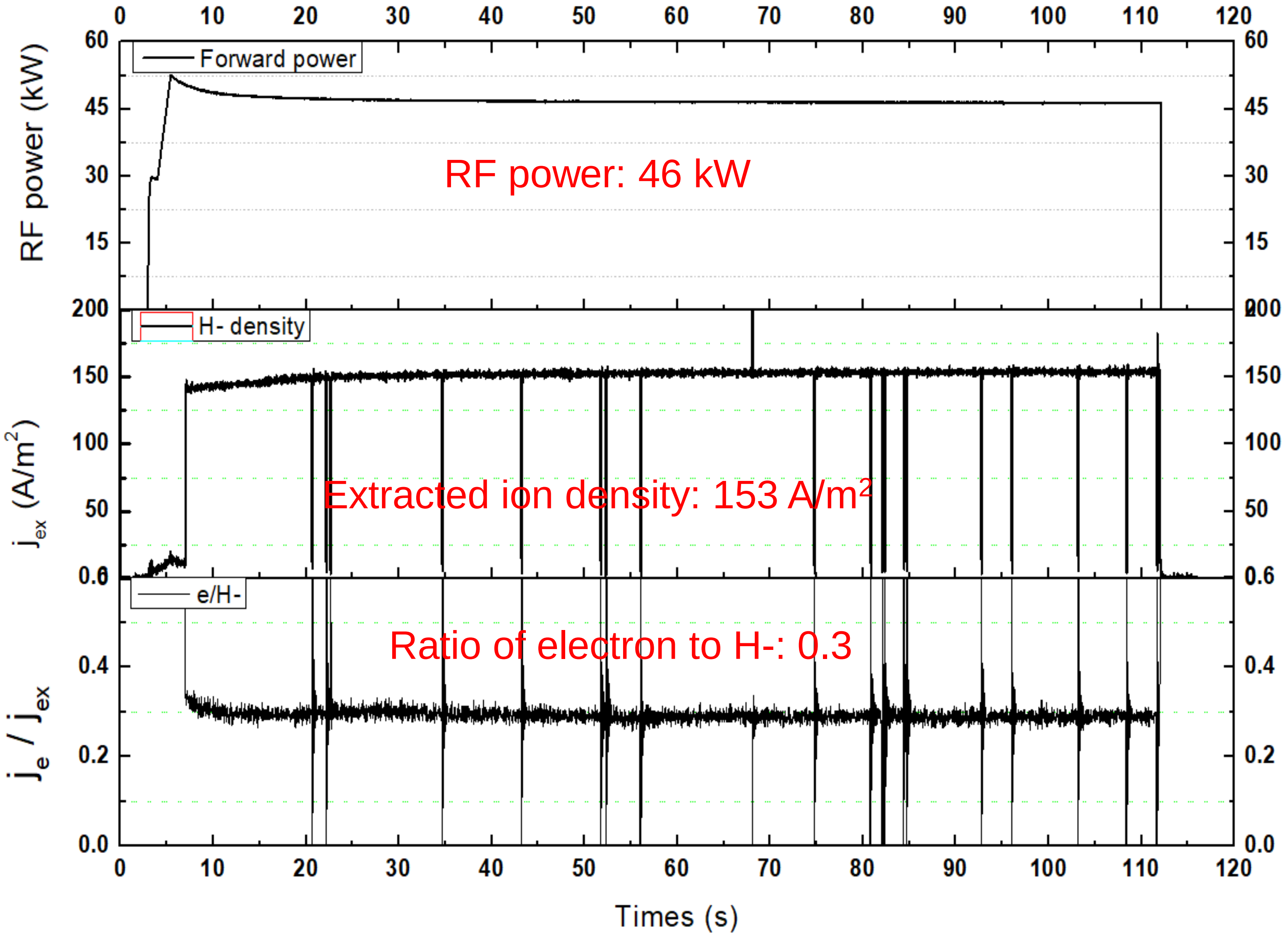


Extracted ion density vary with RF power



Extracted ion density with different extraction voltage

Long pulse negative ion extraction



Ten holes were left because of weak pump speed

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Summary

- High power negative ion based RF ion source was designed in ASIPP for CRAFT NNBI system
- A RF ion source test facility was developed for the performance testing at the first phase
- A negative source with singer driver and three layers grids was developed
- Long pulse plasma discharge of 1000s was achieved on with RF power of 47 kW (60s with 80 kW)
- The negative ion production and extraction was tested with Cs feeding
- Long pulse of 105 s beam extraction with density of 153 A/m^2 was achieved (the ratio of electron to ion was 0.3)

RF beam source test facility upgrade (Oct. 2020)

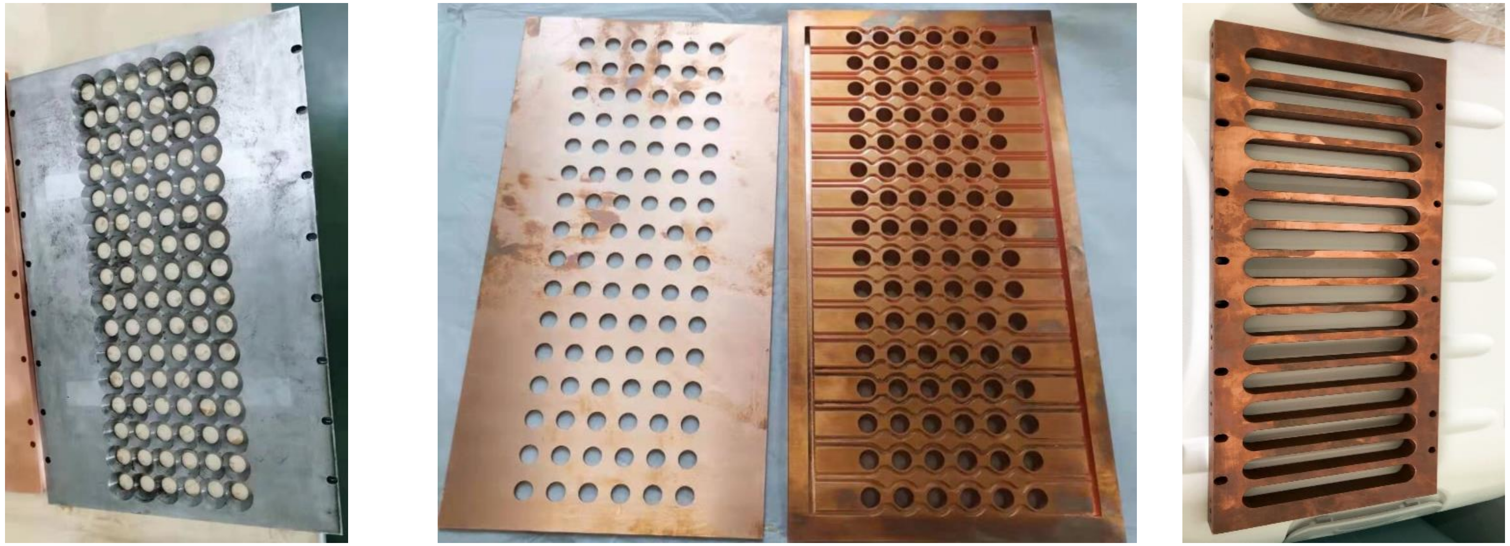
- RF P.S.：100kW @ 1MHz
- Extractor P.S.：-16kV@20A
- Acc. P.S.：-50kV@50A (Oct. 2020)

- TC/WFC
- Langmuir Probe
- Microwave interferometer
- OES & CRDS

Future plan

- Characteristic study of negative ion production and extraction（ Cs feeding, PG temperature control, beam optics …）
- Long pulse negative ion production and extraction with large size
- Increase source size (two drives, large extraction grid)
- …

ITER-like Faraday shield



Manufactured large size PG, EG and GG

Thanks for your attention ！