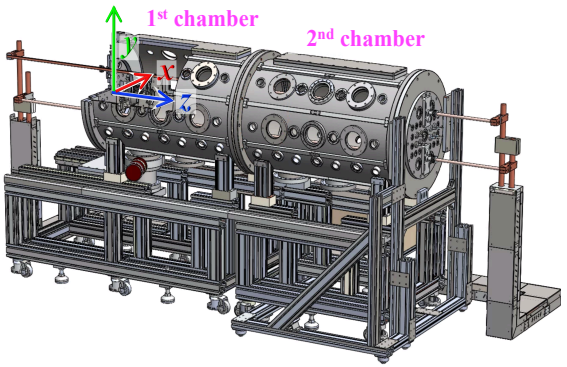
New low temperature multidipole plasma device with a magnetic X-point and its properties

[Plasma Sources Sci. Technol. 29, 115012 (2020)]

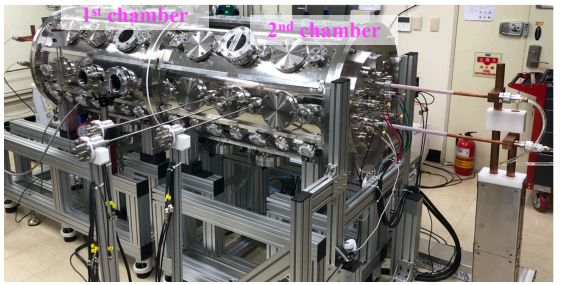
Young-chul GHIM

Department of Nuclear & Quantum Engineering, KAIST, S. Korea



28th January 2021

@ International Online Plasma Seminar



NFP Lab.
Nuclear Fusion&Plasma Lab

NQe Nuclear & Quantum Engineering
KAIST

Co-authors and acknowledgements

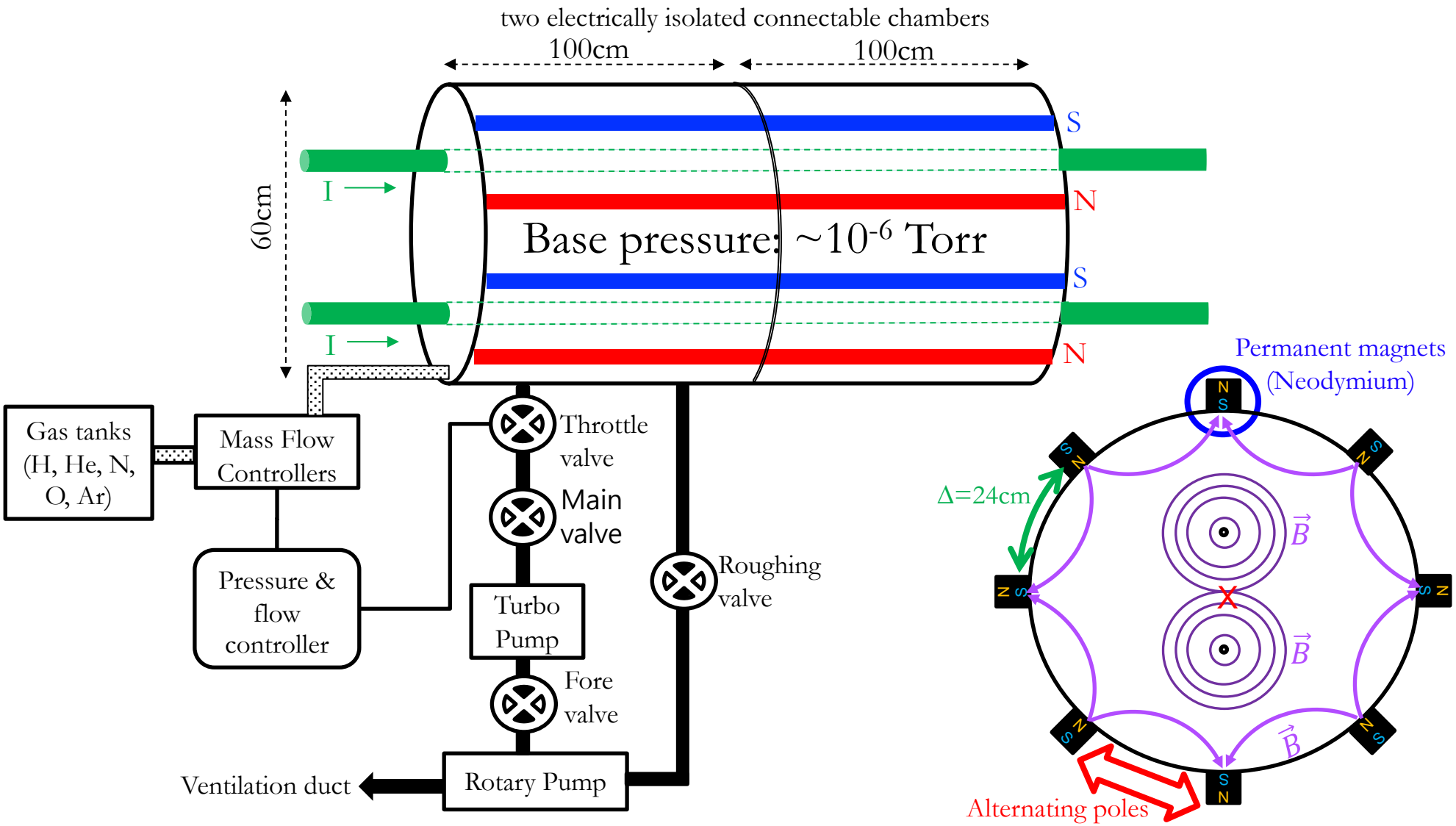
- Co-authors
  - ✓ KAIST: Yegeon Lim (1st author), Yong Sung You, Wonjun Lee, Wonho Choe
  - ✓ Jeonbuk National Univ.: Se Youn Moon
  - ✓ Korea Institute of Fusion Energy (National Fusion Research Institute): Taihyeop Lho
  - ✓ Agency for Defense Development: HJ Woo
  - ✓ I.T.S.: Bosung Kim

- Acknowledgements

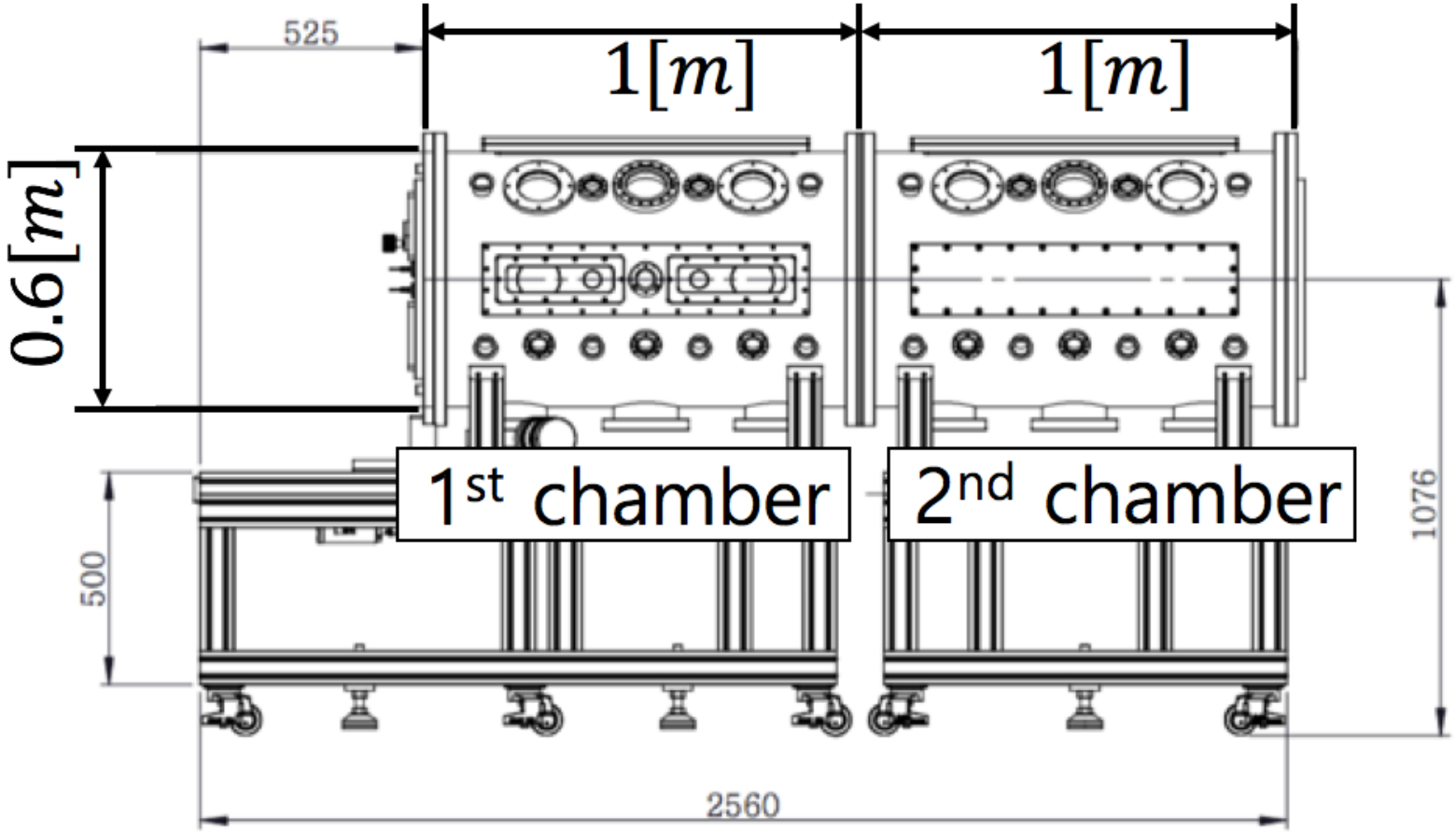
  - ✓ National Research Foundation of Korea funded by the Ministry of Science and ICT
    - NRF-2017M1A7A1A01015892
    - NRF-2020M1A7A1A03016161
    - NRF-2017R1C1B2006248
  - ✓ KAI-NEET, KAIST

- Many of the data and pictures presented here are from [Plasma Sources Sci. Technol. 29, 115012 (2020)]

Prologue: Introducing MAXIMS *(Magnetic X-point simlator system)*

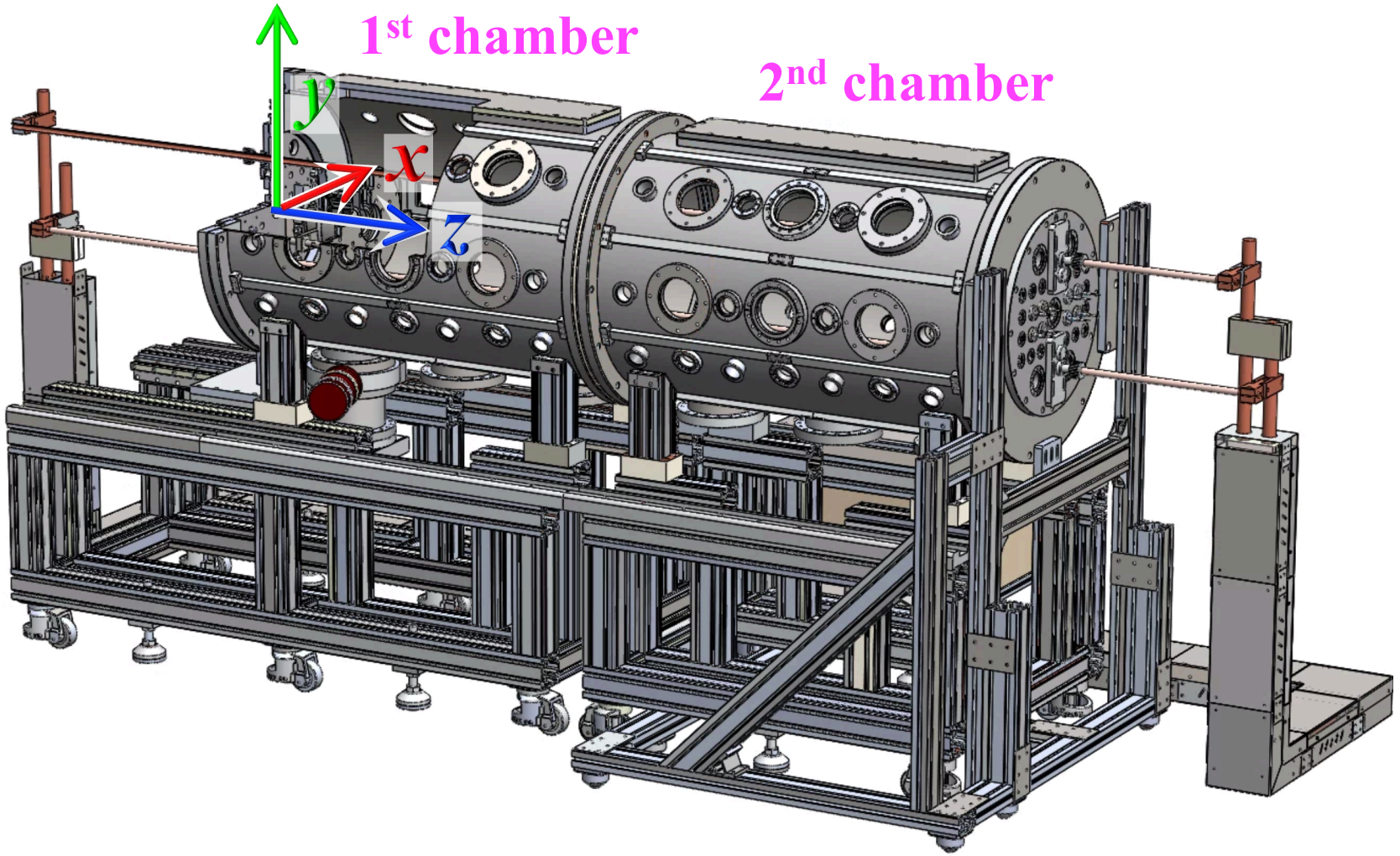


MAXIMUS – CAD drawing

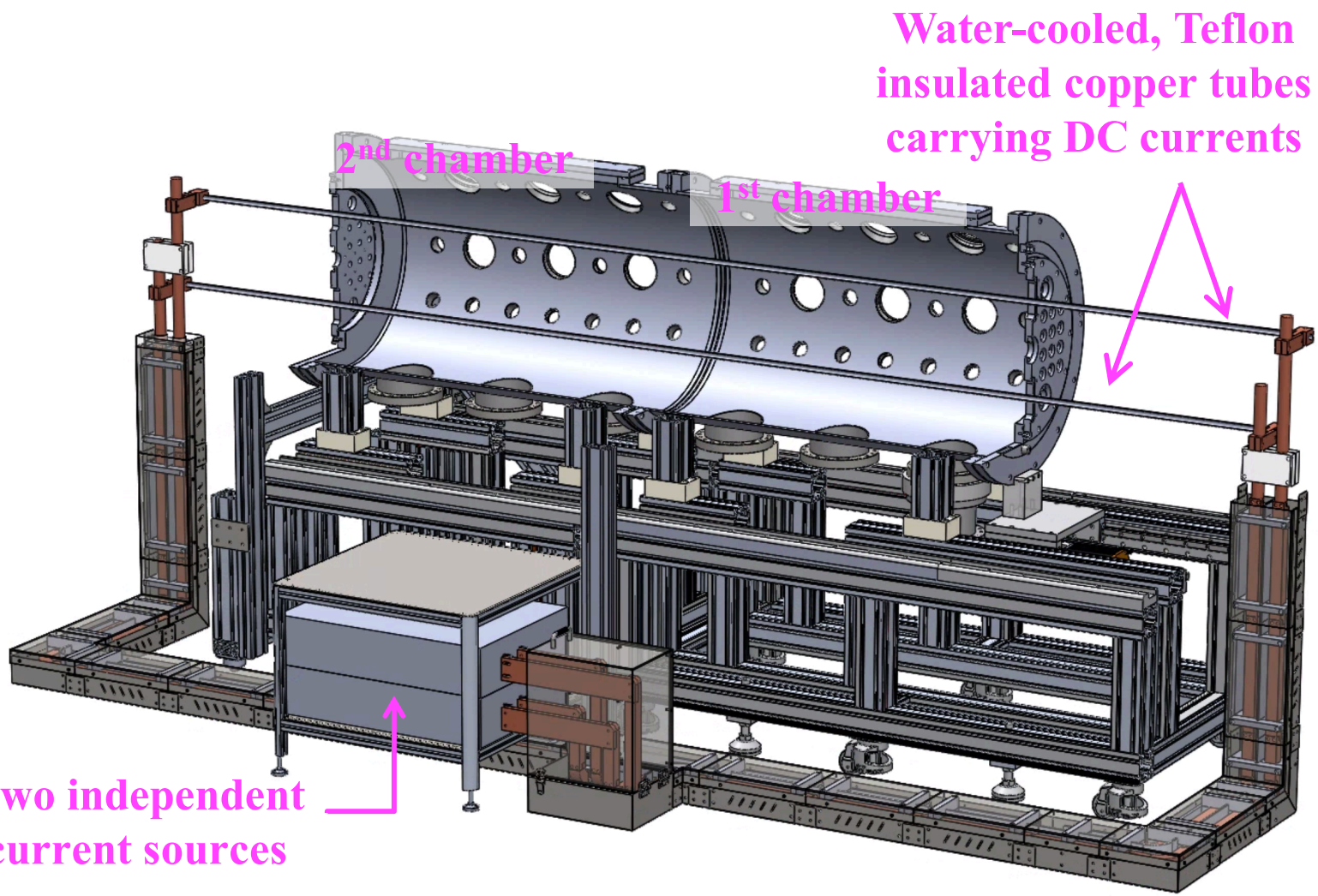


- 60 [cm] Diameter and 2 x 100 [cm] chambers
- 1st chamber is grounded; while 2nd chamber is electrically isolated
- Total 110 ports for various diagnostics and control purposes

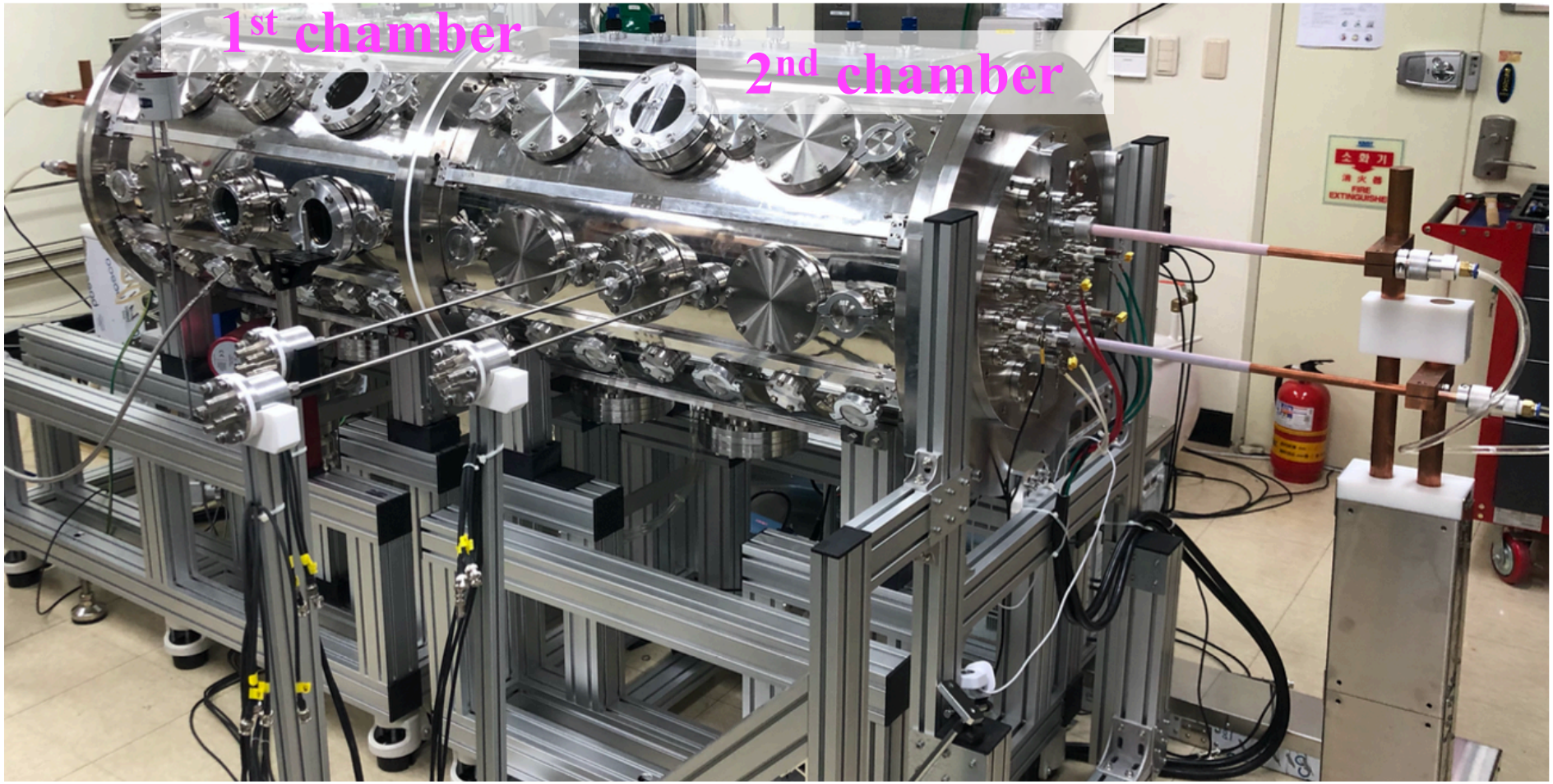
MAXIMUS – CAD drawing



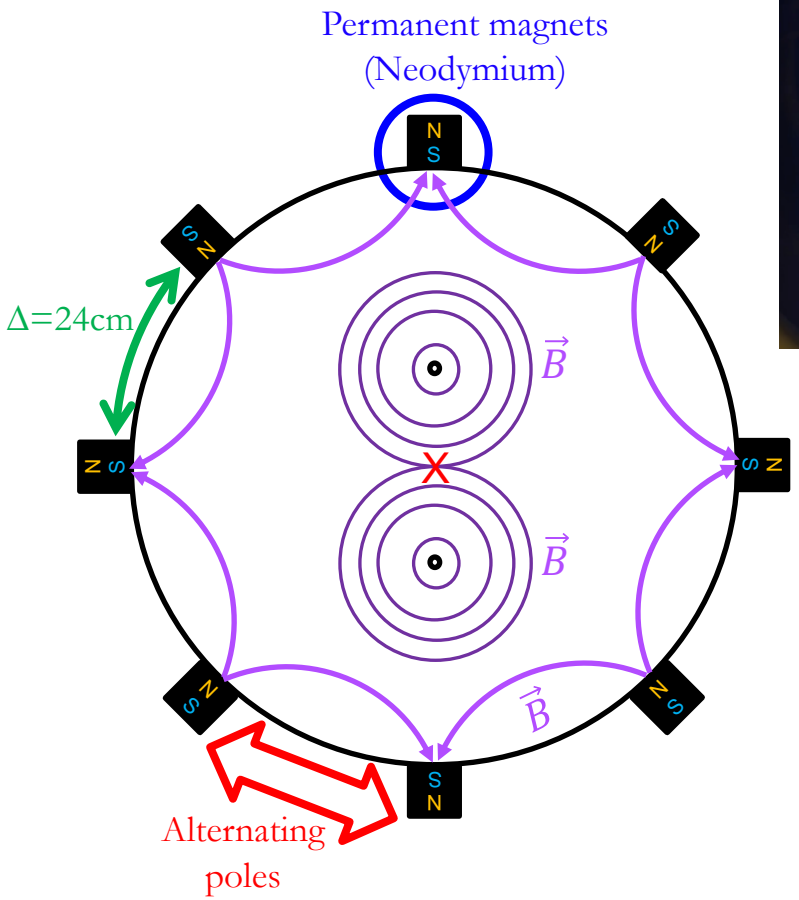
MAXIMUS – CAD drawing (half-cut)

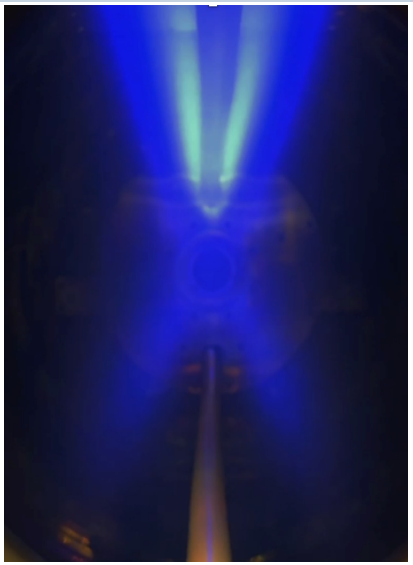


MAXIMUS – Picture

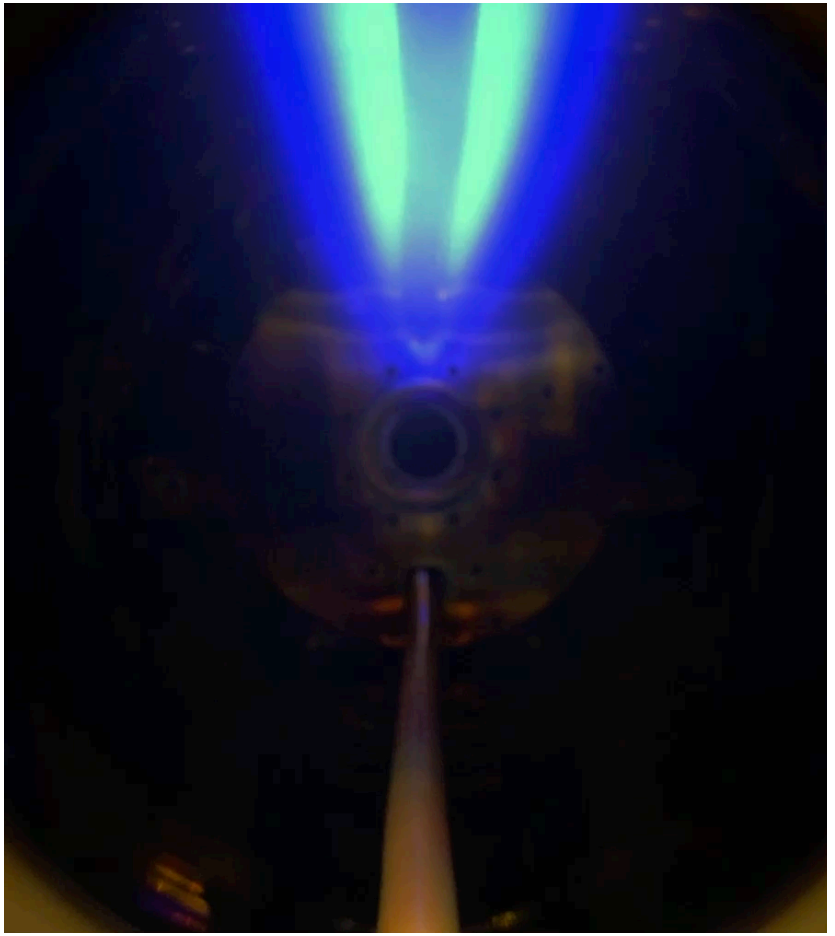


Prologue: An example of low temperature plasmas with tokamak-like poloidal B-fields





By varying (decreasing) the strength of "poloidal magnetic fields"



Contents

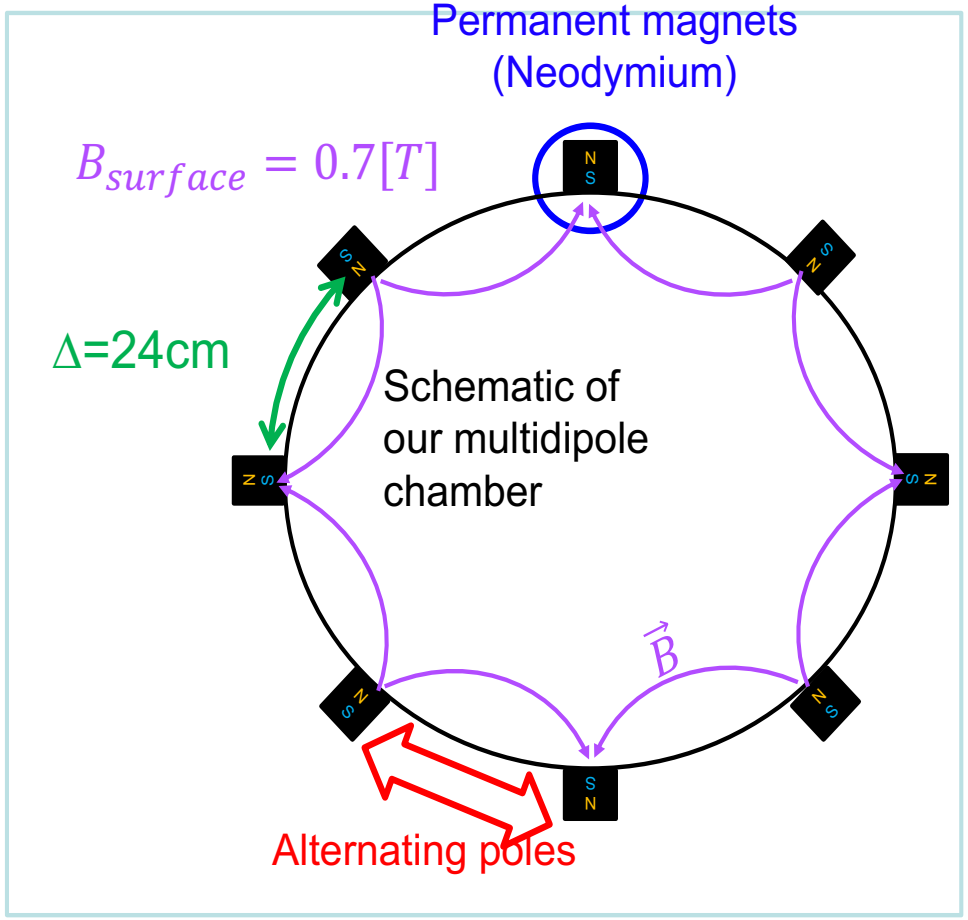
- General descriptions of MAXIMUS
  - ✓ Structures of magnetic fields: 1) permanent magnets; 2) axial current
  - ✓ DC plasma sources: 1) end-plate ThW filaments; 2) core ThW filaments; 3) end-plate LaB_6 disk;
- Basic properties of MAXIMUS plasmas
  - ✓ Under the multidipole configuration
  - ✓ Under the poloidal magnetic fields configuration with X-point
- Motivation of building MAXIMUS
- Summary

Contents

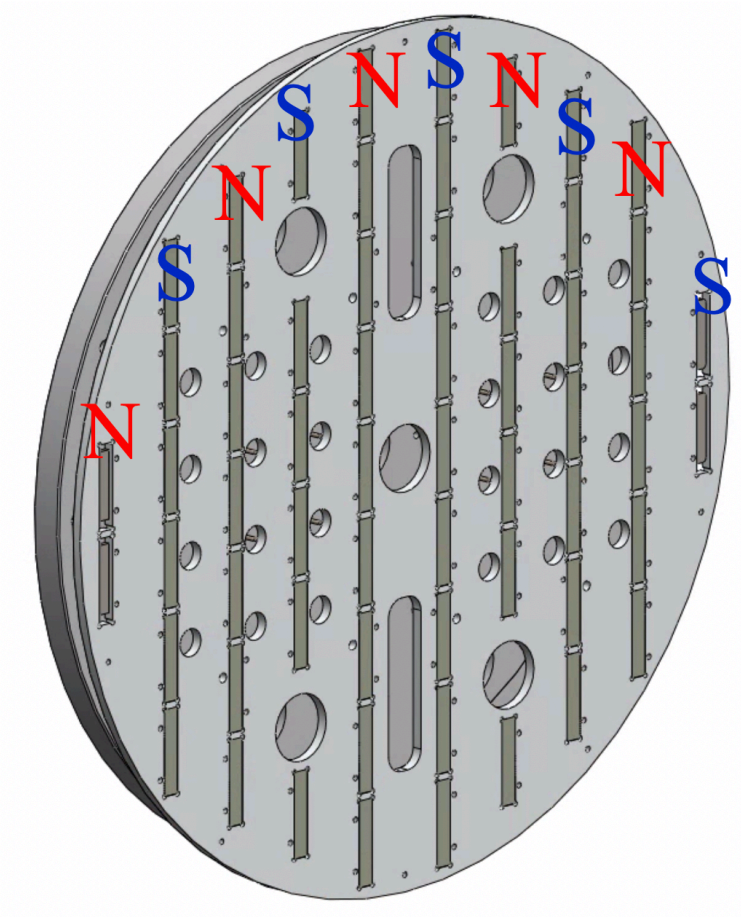
- General descriptions of MAXIMUS
  - ✓ Structures of magnetic fields: 1) permanent magnets; 2) axial current
  - ✓ DC plasma sources: 1) end-plate ThW filaments; 2) core ThW filaments; 3) end-plate LaB_6 disk;
- Basic properties of MAXIMUS plasmas
  - ✓ Under the multidipole configuration
  - ✓ Under the poloidal magnetic fields configuration with X-point
- Motivation of building MAXIMUS
- Summary

MAXIMUS: Permanent magnets create multidipole configuration

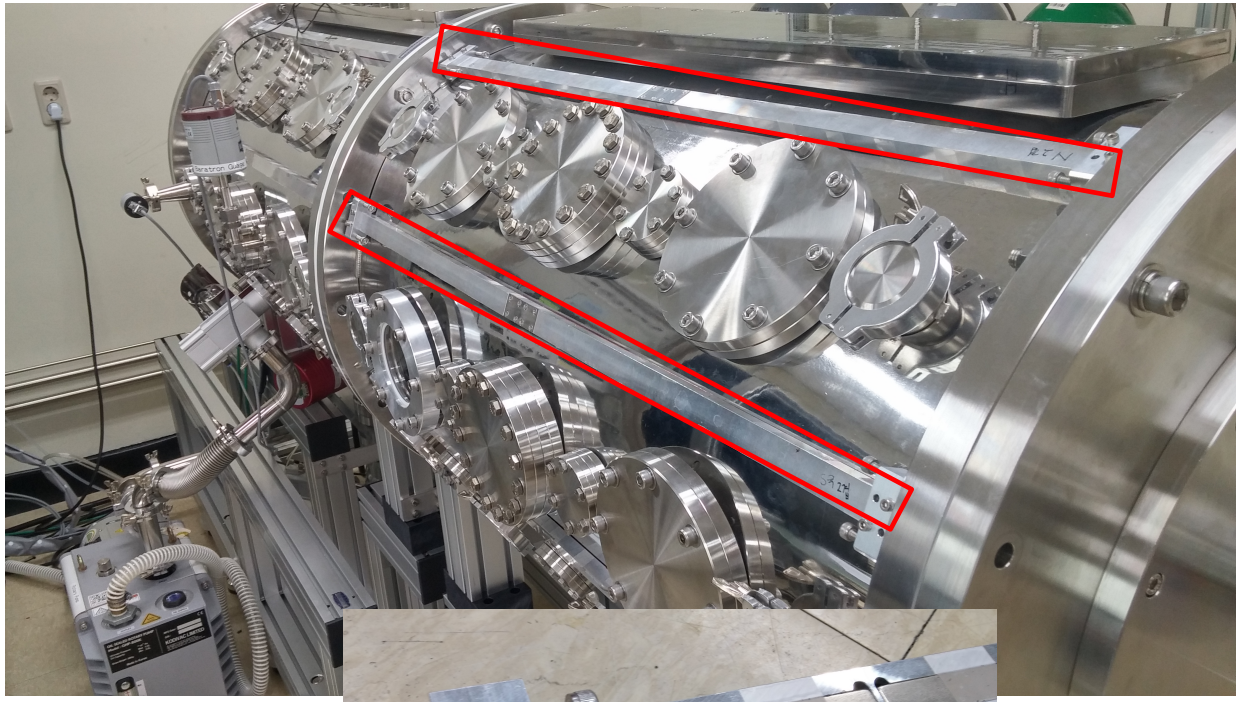
<Side wall>

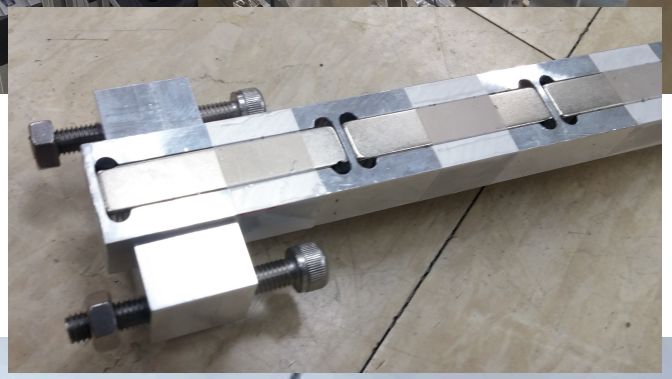


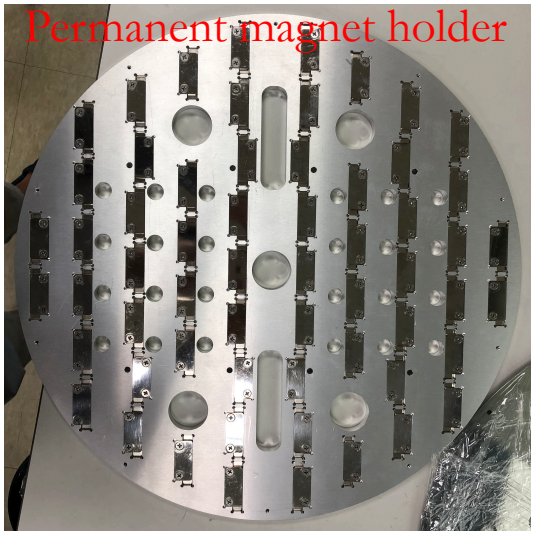
<End-plate wall>

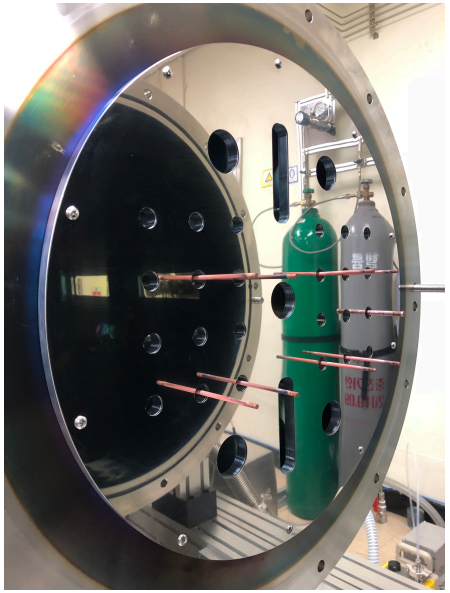


MAXIMUS: Permanent magnets create multidipole configuration

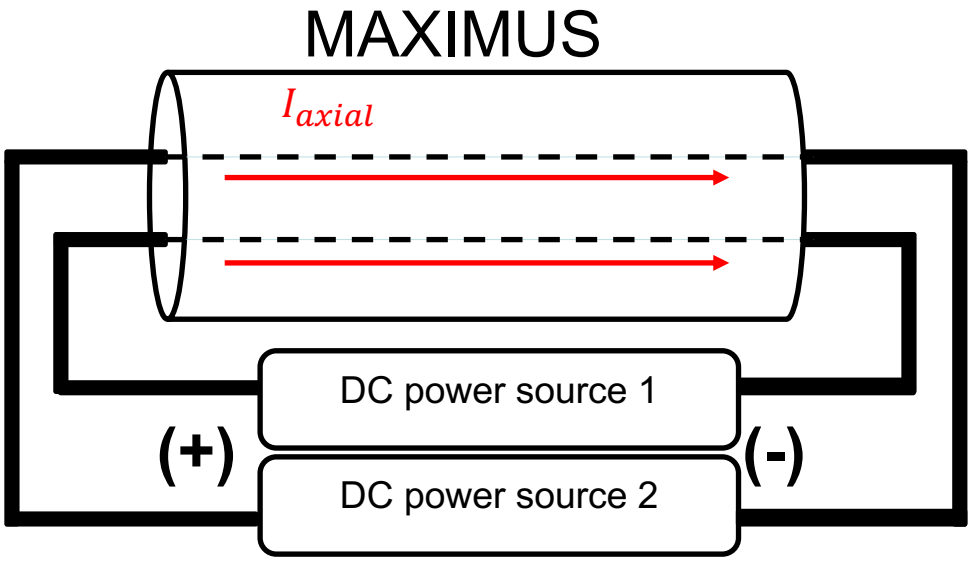






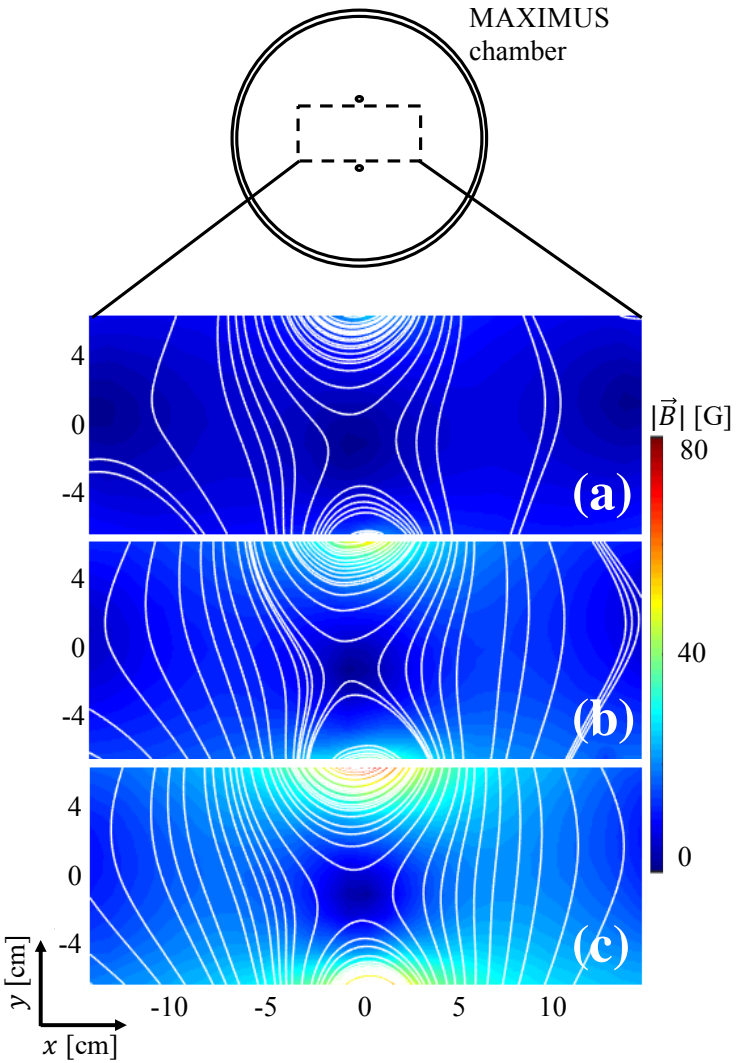


MAXIMUS: A pair of axial currents create X-point configuration



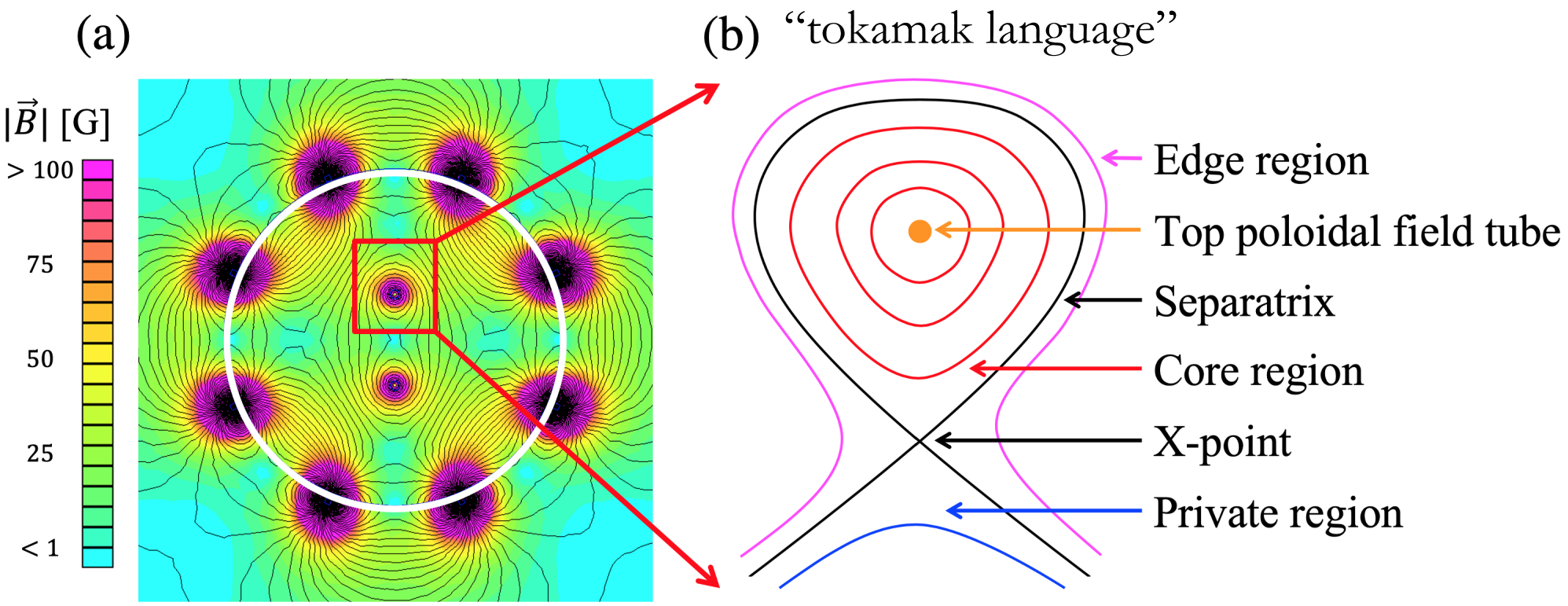
- Two axial copper tubes cooled by running water can move in vertical direction
  - ✓ $I_{axial} \leq 1.0\ kA$
  - ✓ Currents: either parallel or anti-parallel

MAXIMUS: Measured (hall probe) total magnetic fields

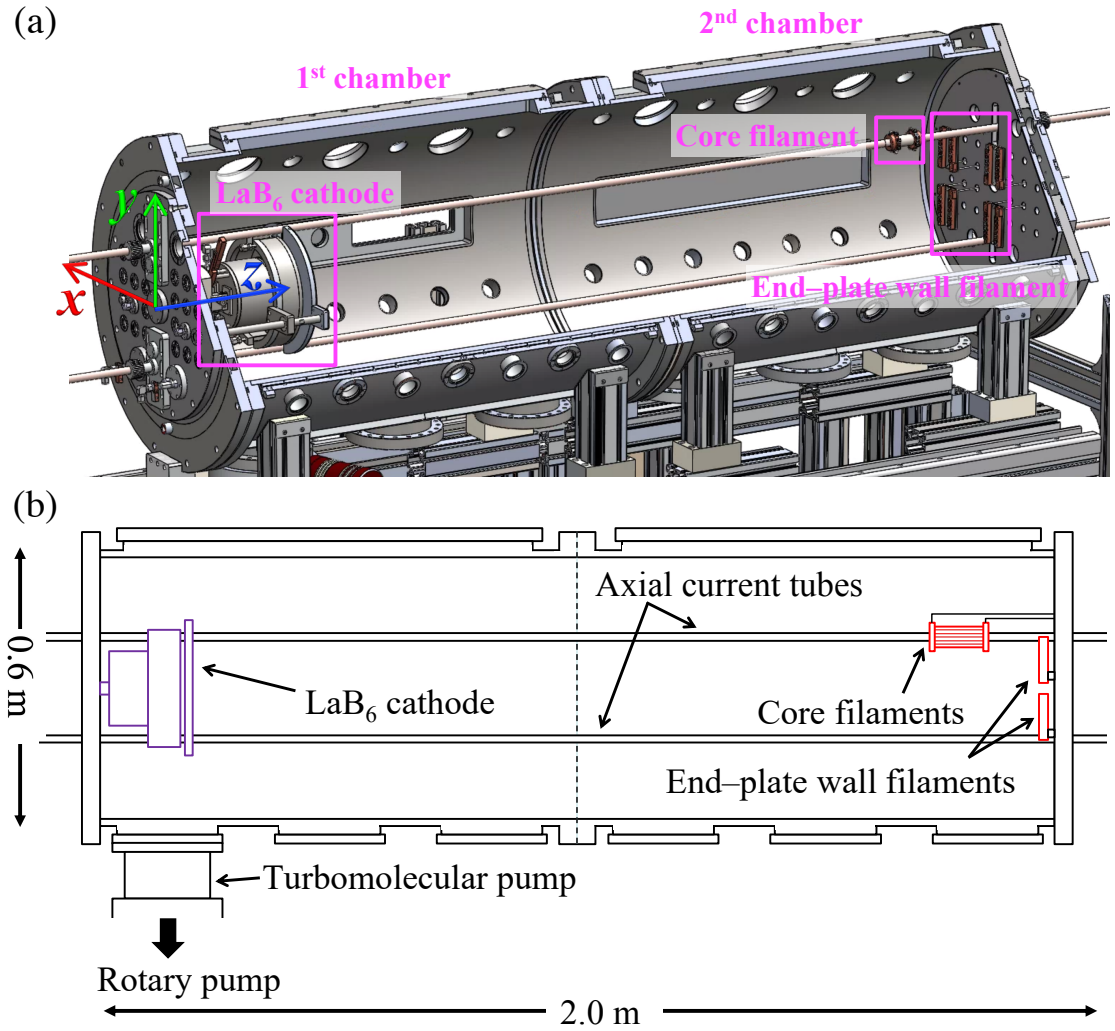


- (a) $I_{axial}^{top} = I_{axial}^{bottom} = 0.30$ [kA]
- (b) $I_{axial}^{top} = I_{axial}^{bottom} = 0.60$ [kA]
- (c) $I_{axial}^{top} = I_{axial}^{bottom} = 0.90$ [kA]

MAXIMUS: Calculated total magnetic fields

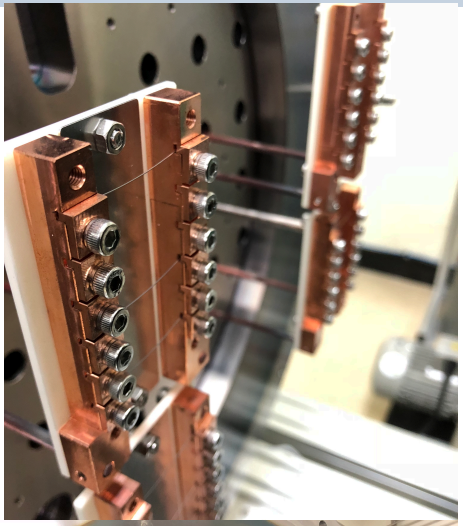


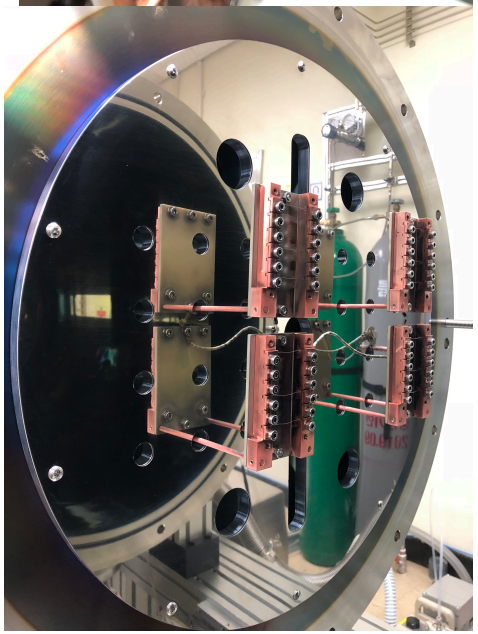
MAXIMUS: Available DC plasma source



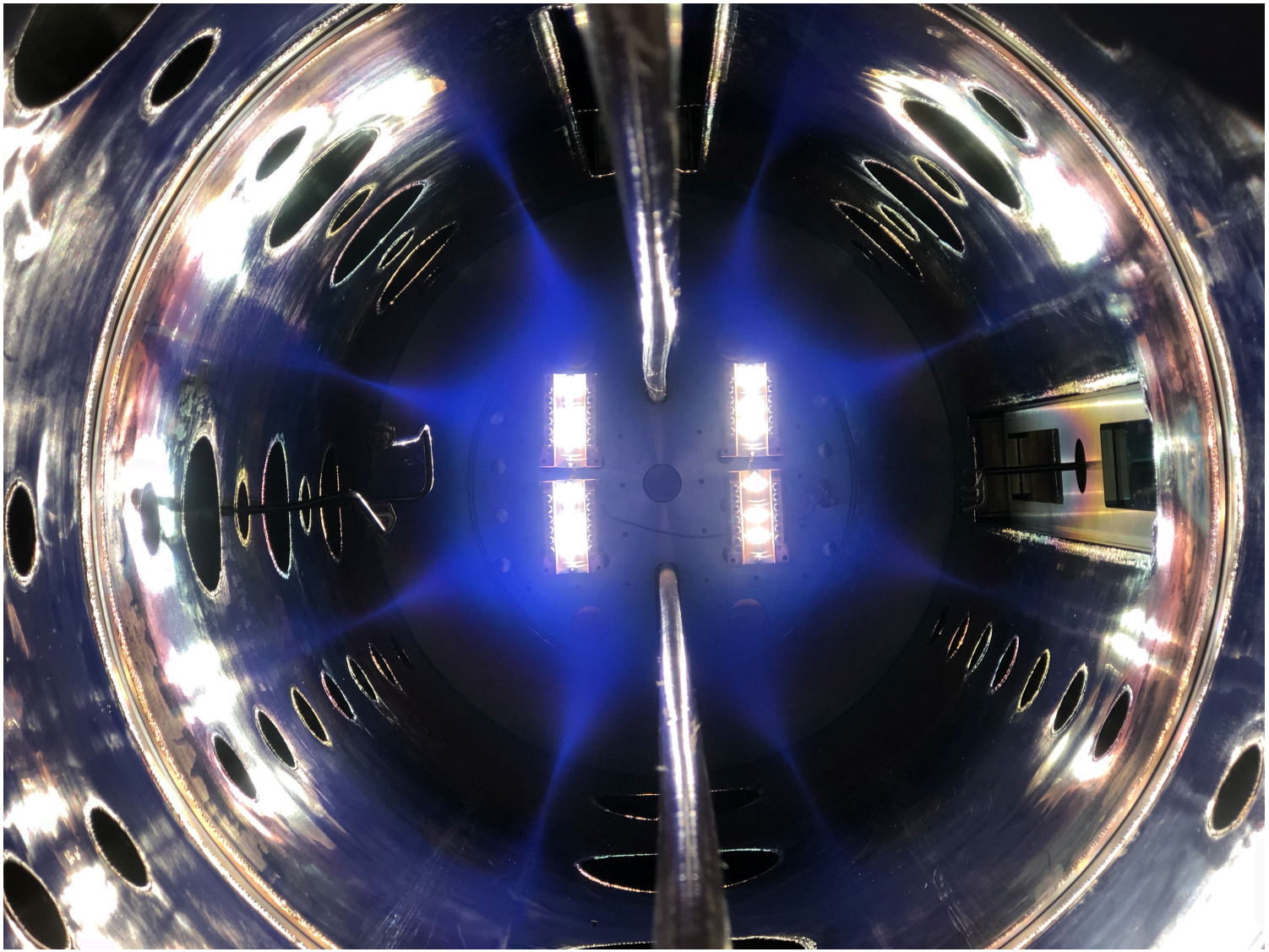
- Three types of sources
  1) End-plate wall ThW filaments
  2) Core ThW filaments
  3) LaB6 cathode (disk)

Plasma sources: 1) End-plate ThW filaments

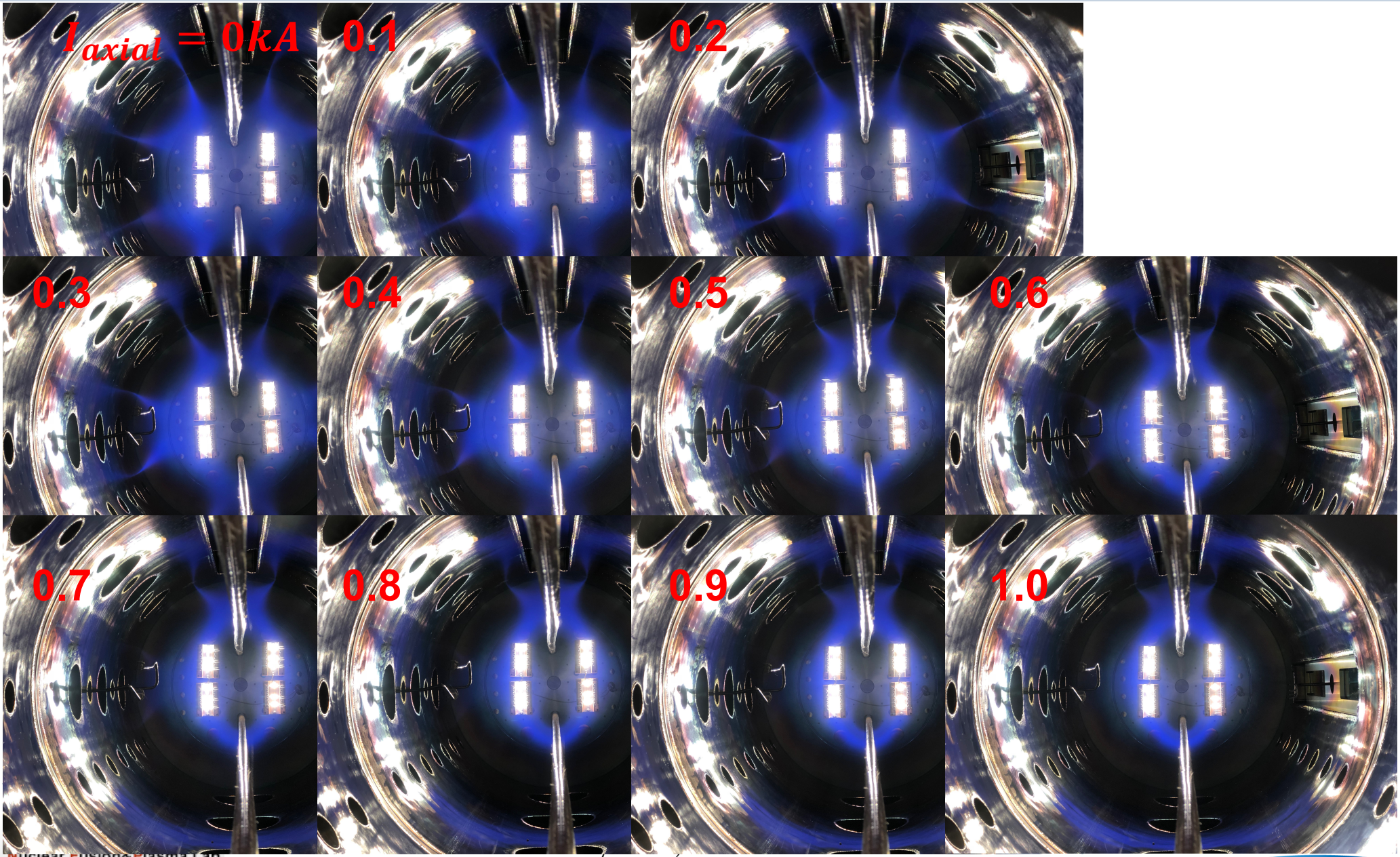




Plasma sources: 1) An example of plasmas with the end-plate ThW filaments

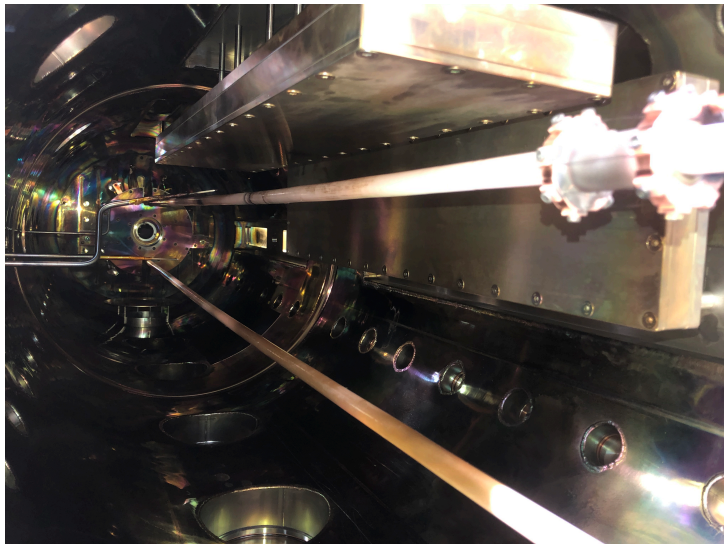


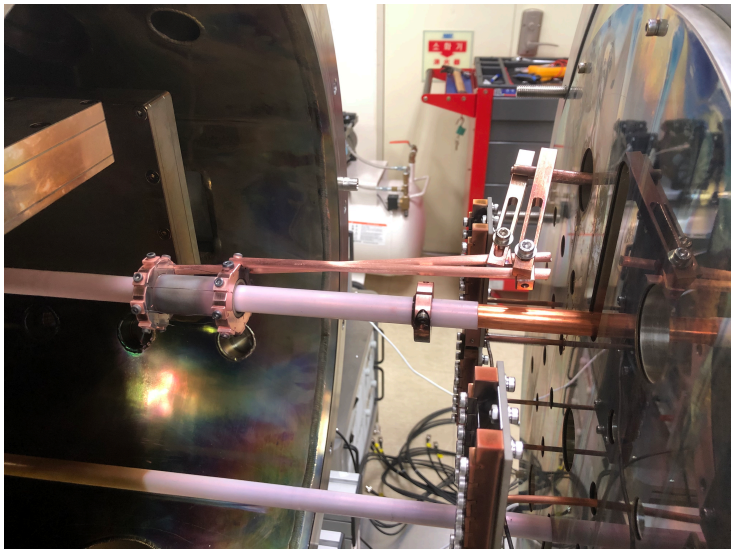
Plasma sources: 1) Examples of plasmas with the end-plate ThW filaments

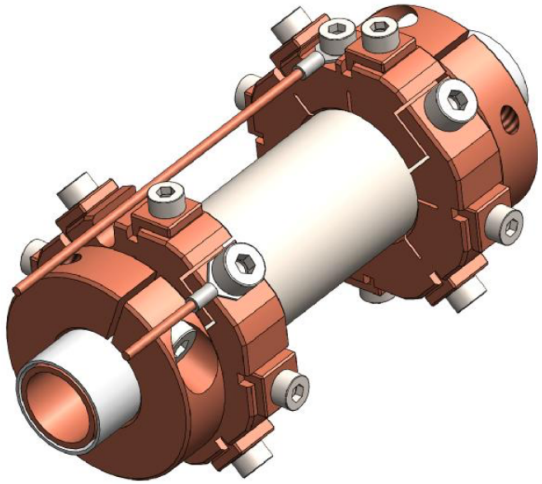


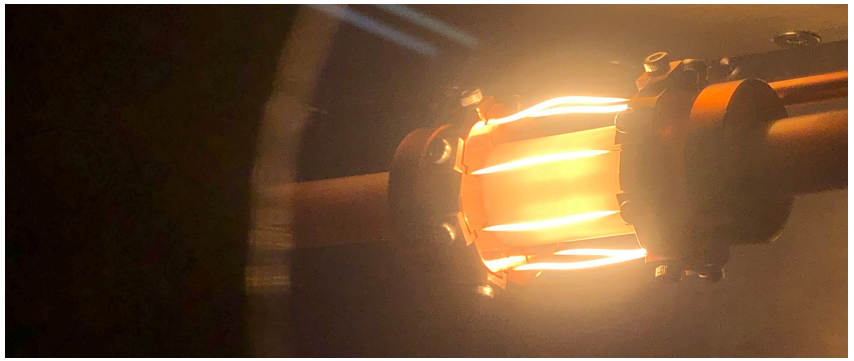
Plasma sources: 2) Core ThW filaments

- A problem with the end-plate ThW filaments: plasmas were not able to penetrate into the "core" region when the X-point configuration is generated.
- Change the source region: Install a plasma source in the "core" region, then the plasmas will be "confined."

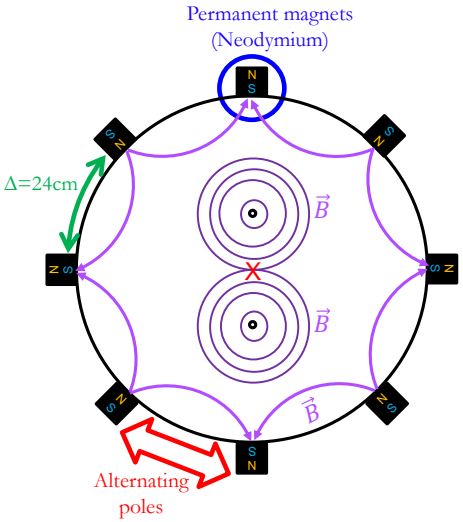


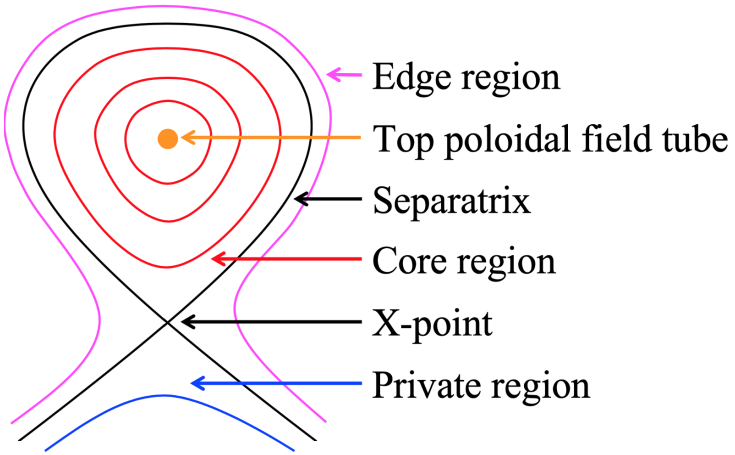


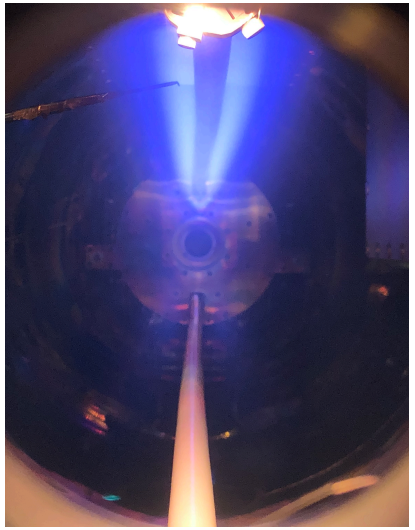


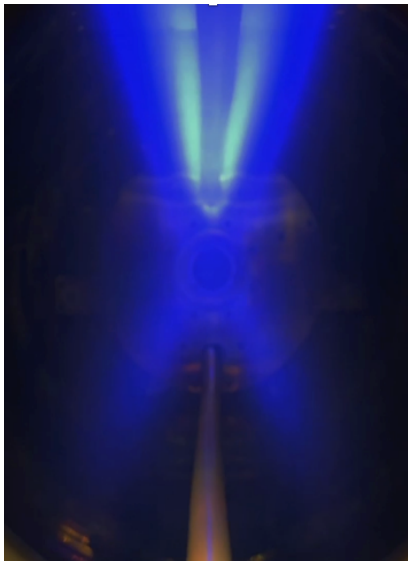


Plasma sources: 2) A movie of plasmas with the core ThW filaments

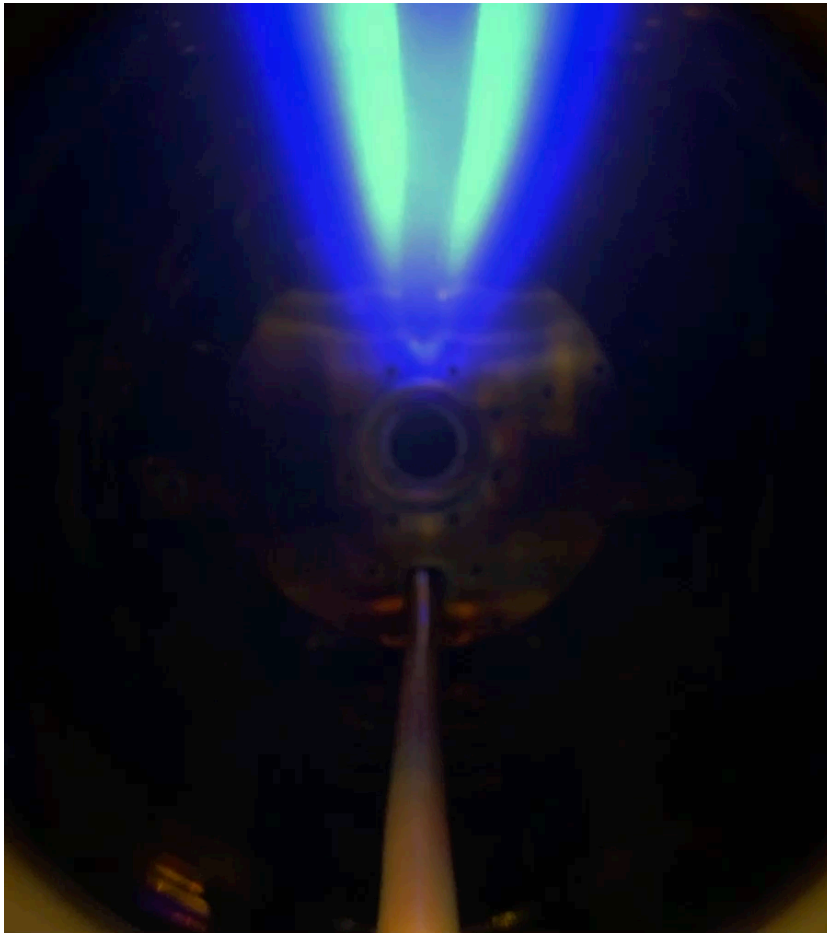




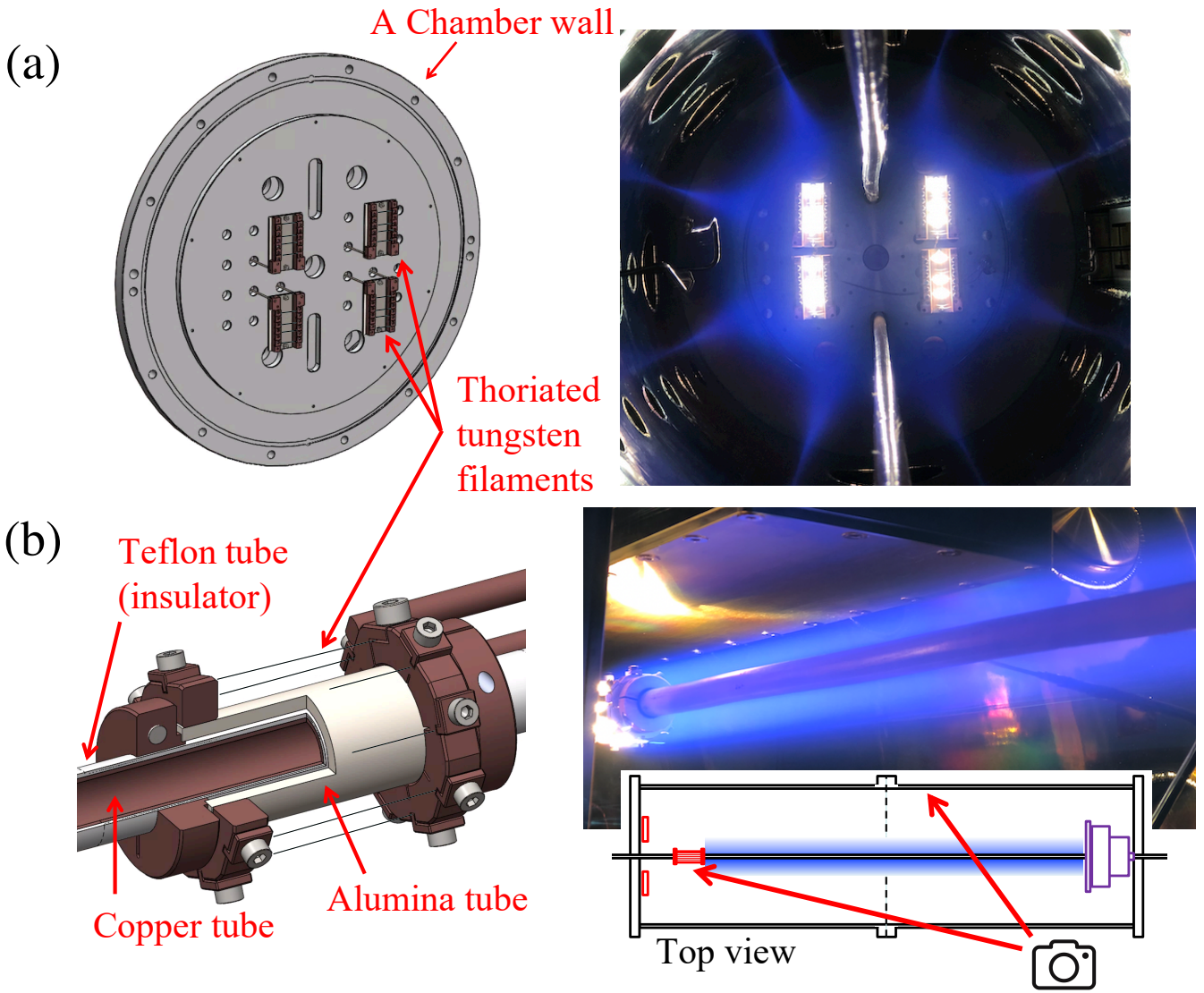




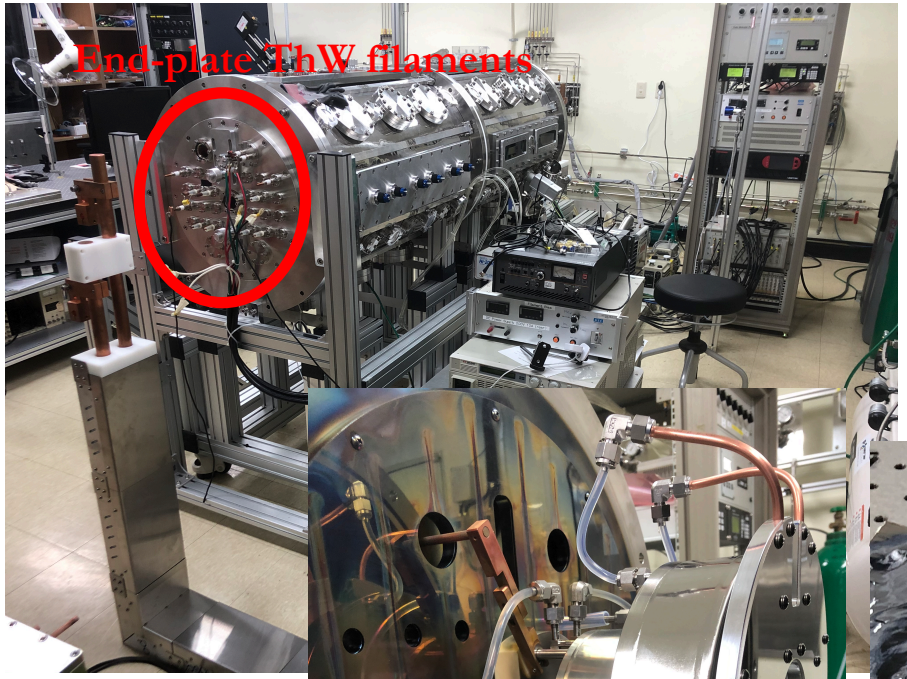
By varying (decreasing) the strength of "poloidal magnetic fields"
Iaxial (top) = 1.0 → 0 kA (varied)
Iaxial (bottom) = 1.0 kA (fixed)

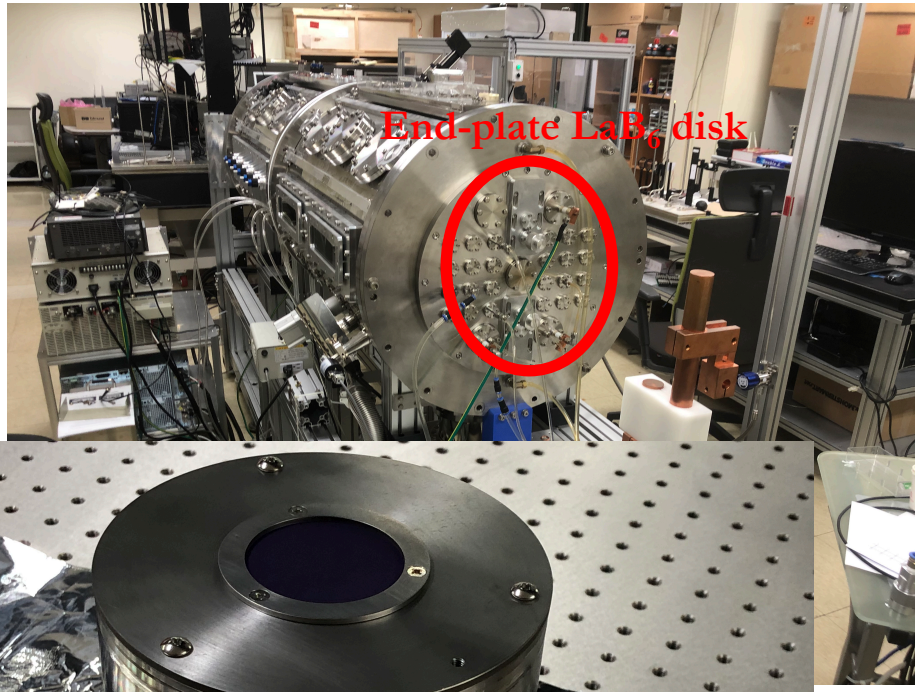


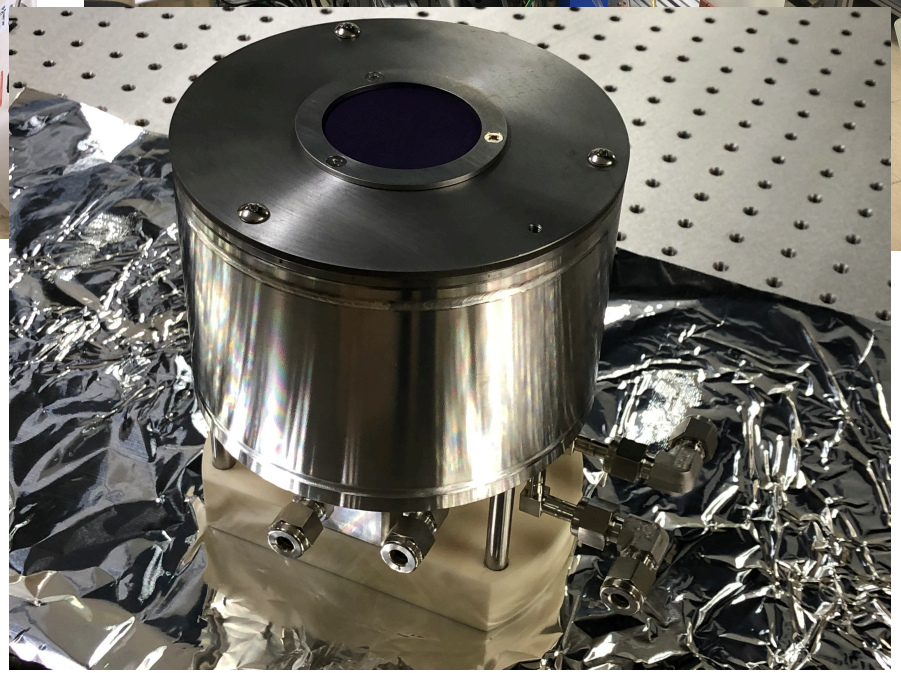
Comparison between the end-plate and core filaments



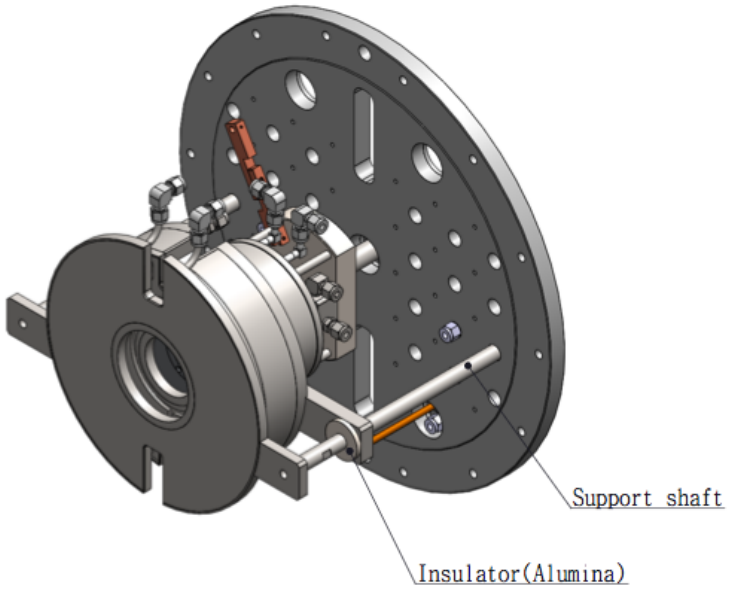
Plasma sources: 3) End-plate LaB_6 disk

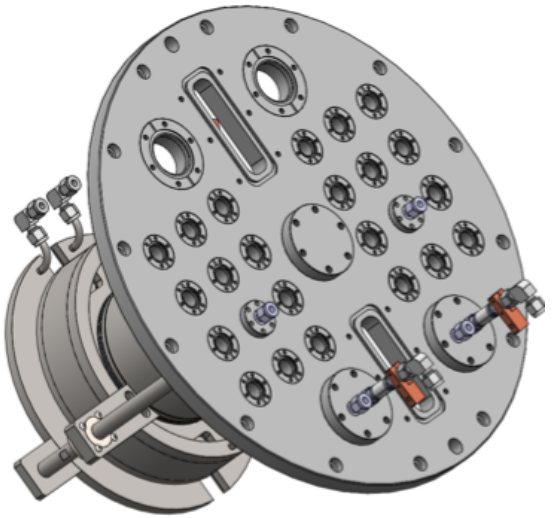




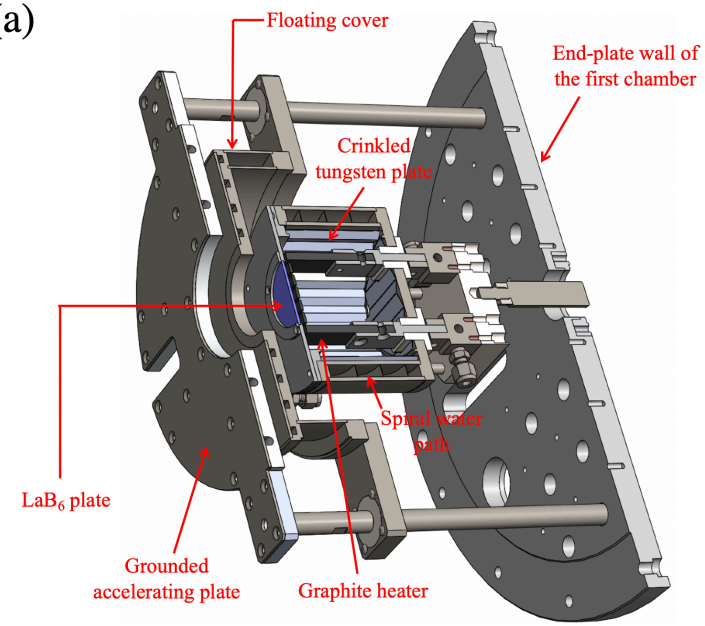


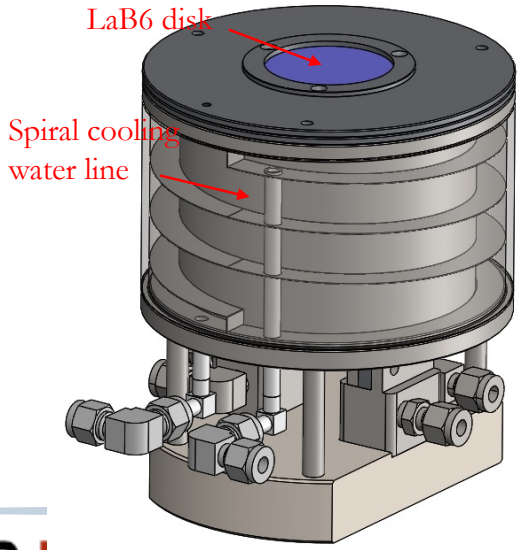
Plasma sources: 3) End-plate LaB_6 disk

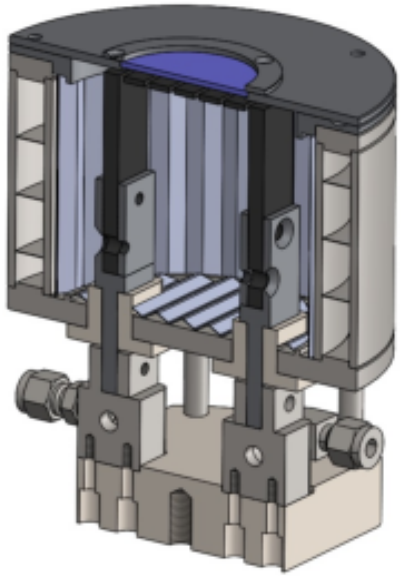


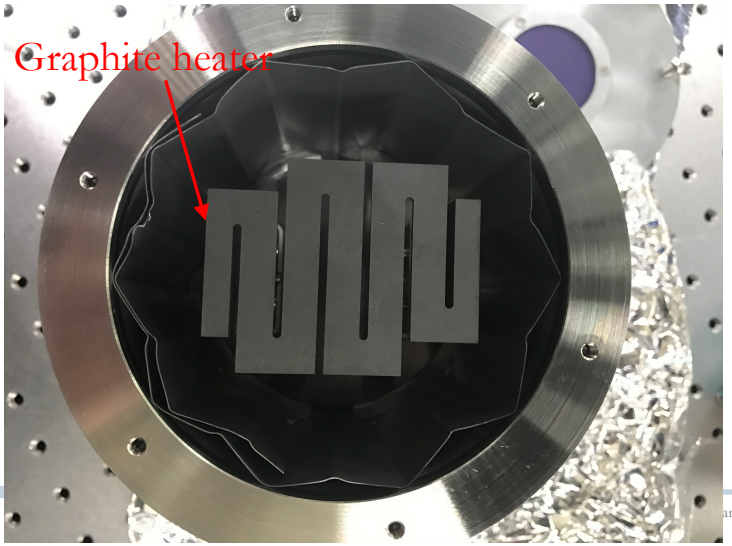


(a)

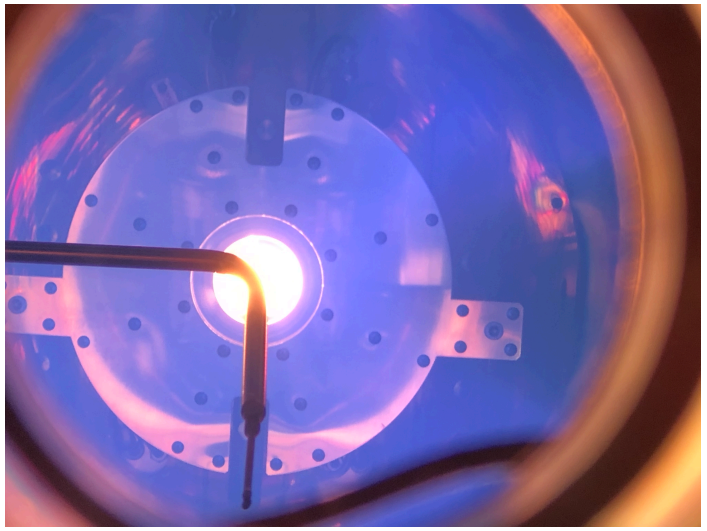


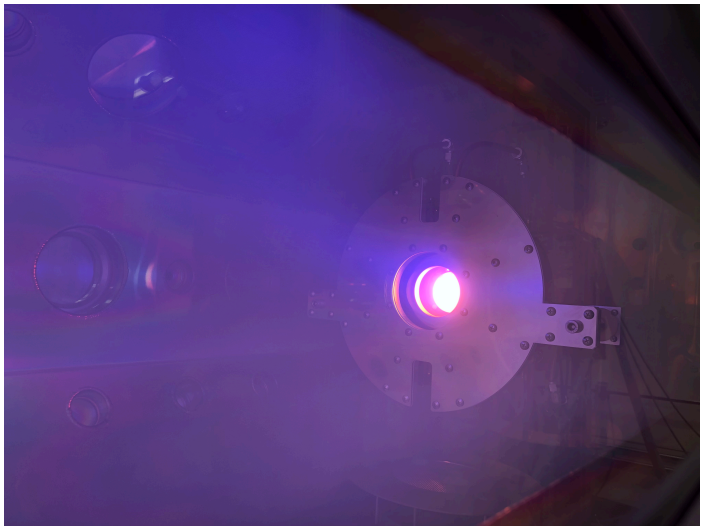




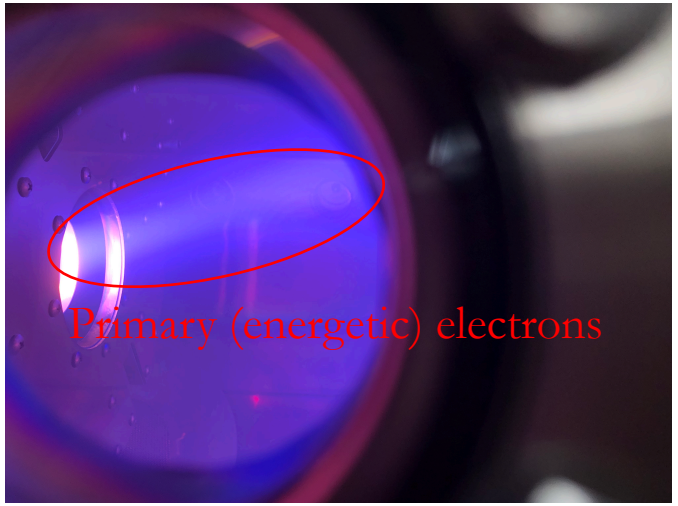


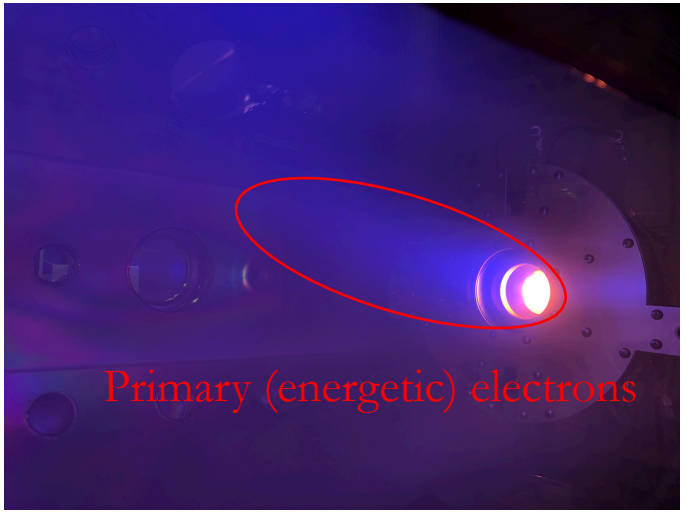
Plasma sources: 3) Example of plasmas with the end-plate LaB_6 disk

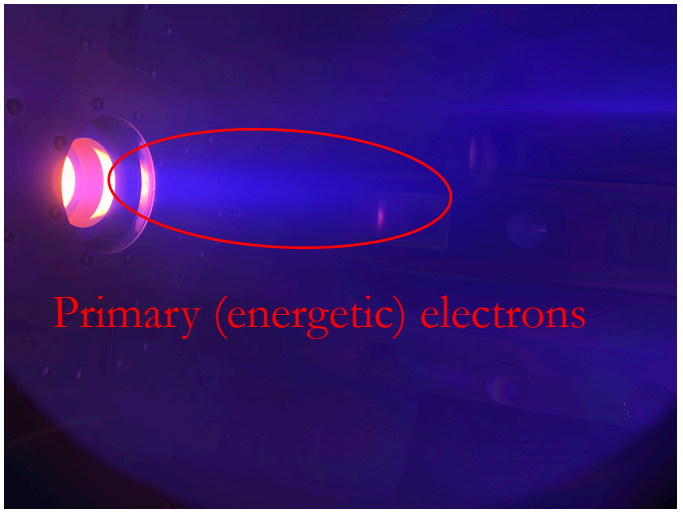




- ✓ Operation limit
  - Heating power
    - $P_h = 5kW$
  - Discharge condition
    - $I_d = 50A, V_d = -200V$





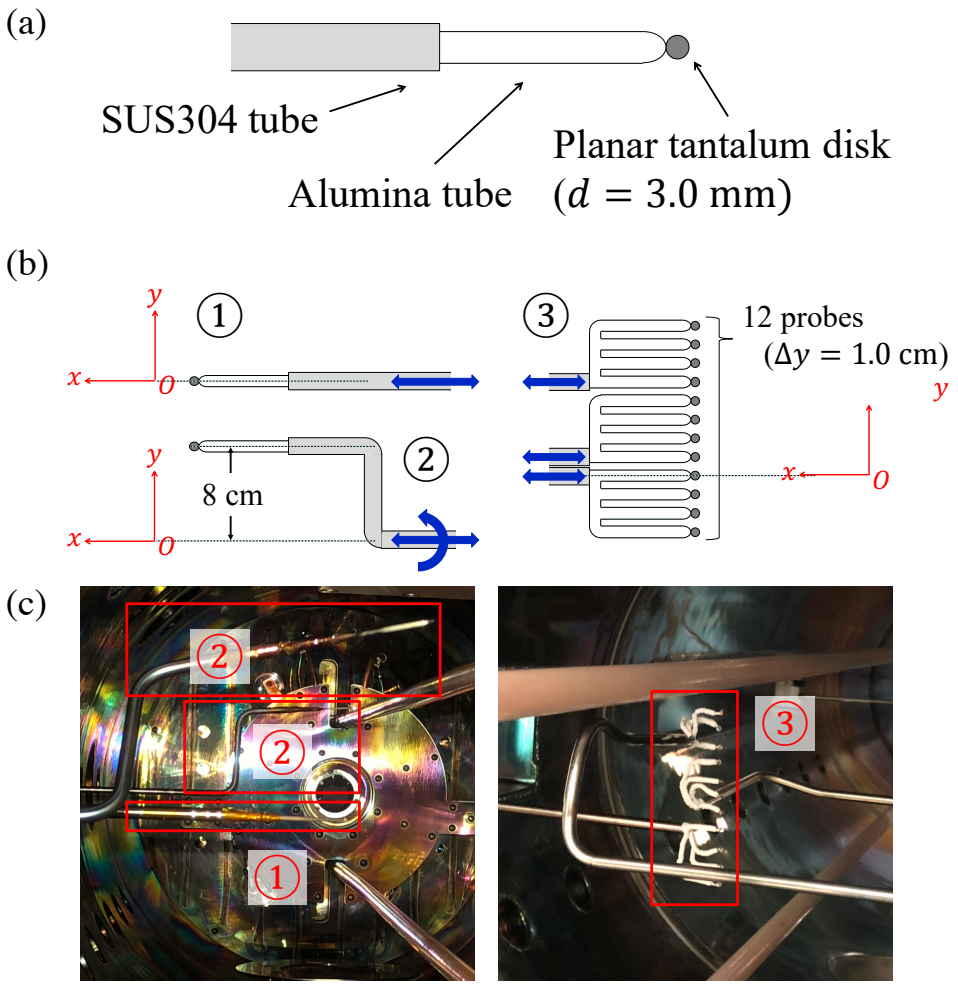


Contents

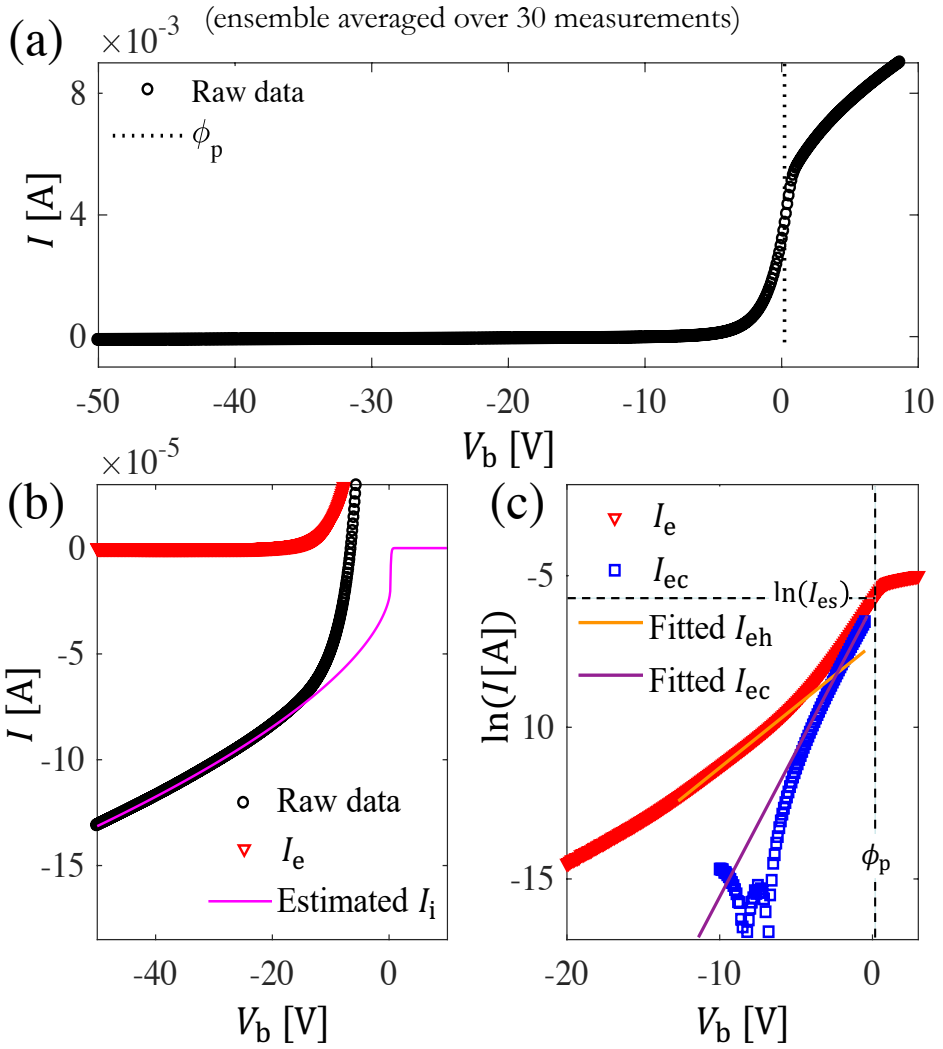
- General descriptions of MAXIMUS
  - ✓ Structures of magnetic fields: 1) permanent magnets; 2) axial current
  - ✓ DC plasma sources: 1) end-plate ThW filaments; 2) core ThW filaments; 3) end-plate LaB_6 disk;
- Basic properties of MAXIMUS plasmas
  - ✓ Under the multidipole configuration
  - ✓ Under the poloidal magnetic fields configuration with X-point
- Motivation of building MAXIMUS
- Summary

Langmuir probes measure plasma properties

<Three sets of Langmuir probes>



<An example of IV curve from MAXIMUS plasmas>

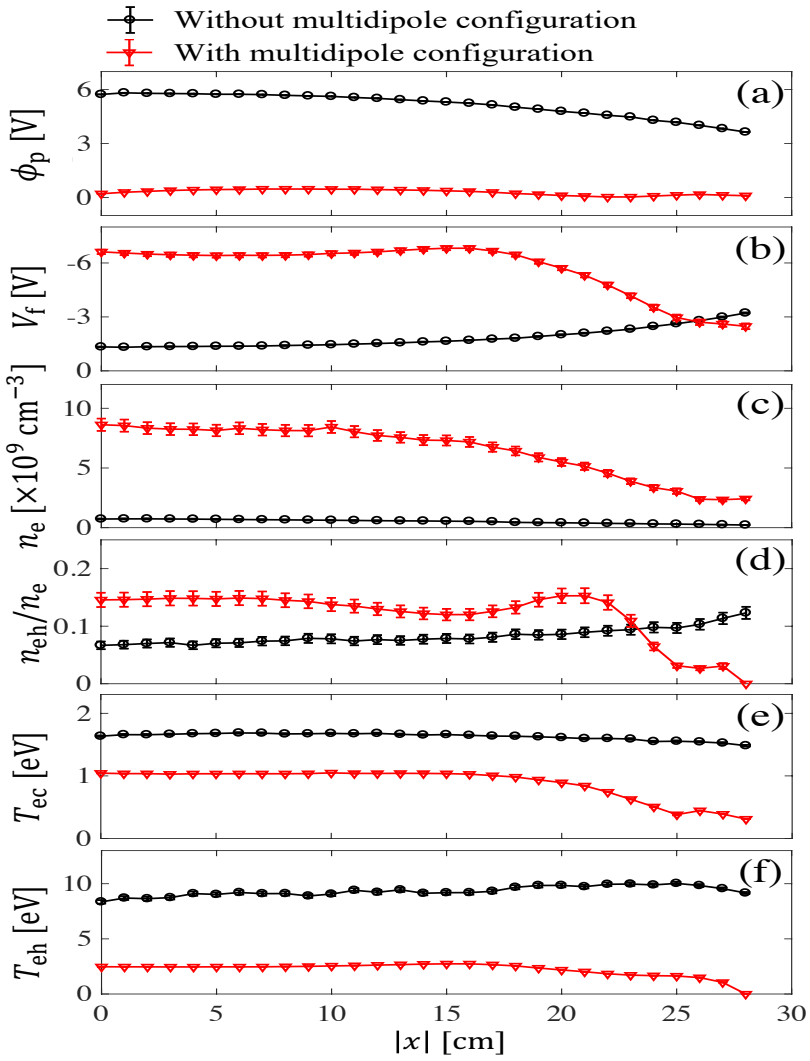


Data obtained with the end-plate ThW filaments

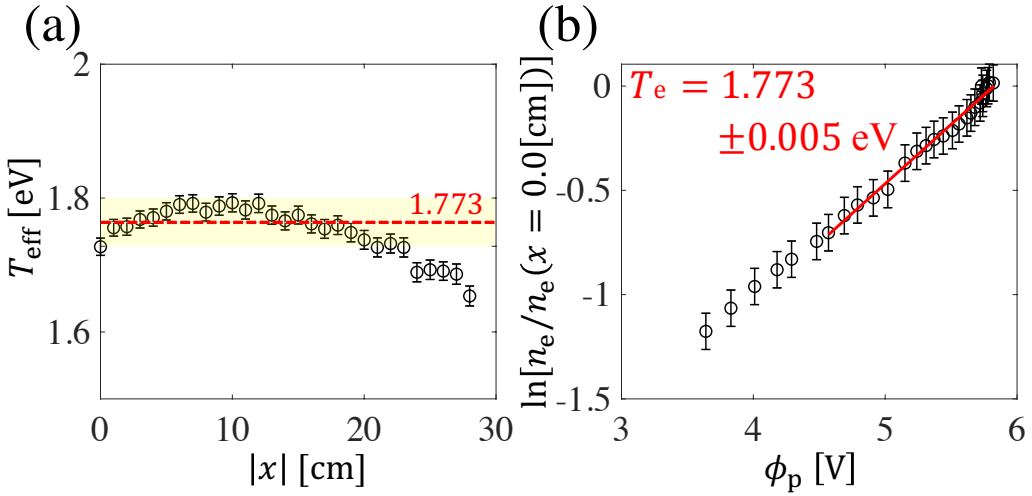
Multidipole vs non-multidipole plasmas (I_{axial} = 0.0 kA)

Ar neutral pressure : 1.00 mTorr; Discharge (bias) voltage: -80.0 V; Discharge current = 0.5 A

<Radial profile>



<Verifying the Boltzmann electrons>



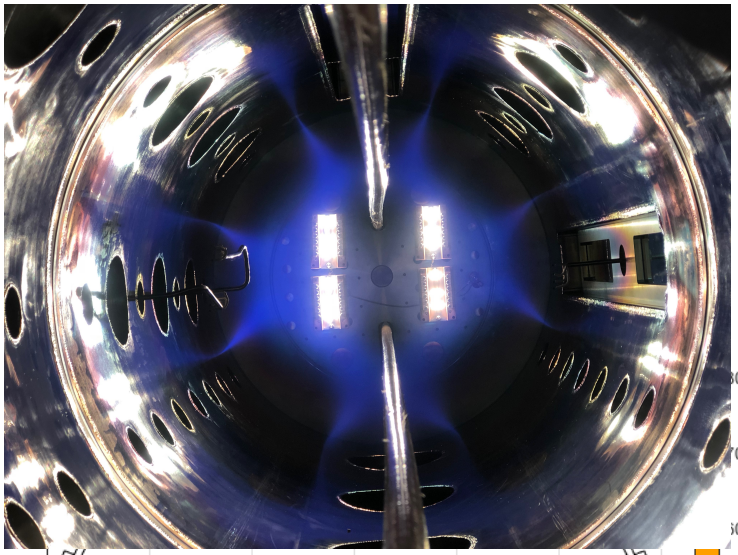
$\langle T_{eff} \rangle_{|x|<22.0cm} = 1.764 \pm 0.036$ eV

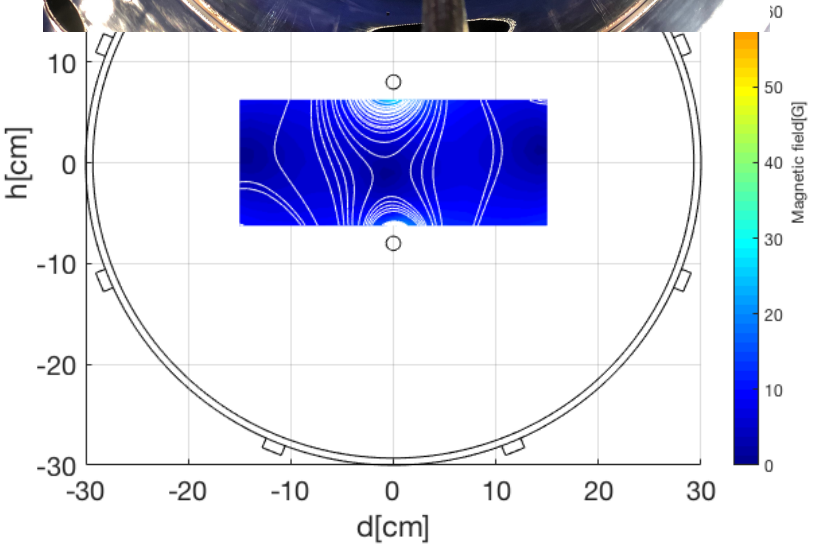
$T_e^{Boltzmann} = 1.773 \pm 0.005$ eV

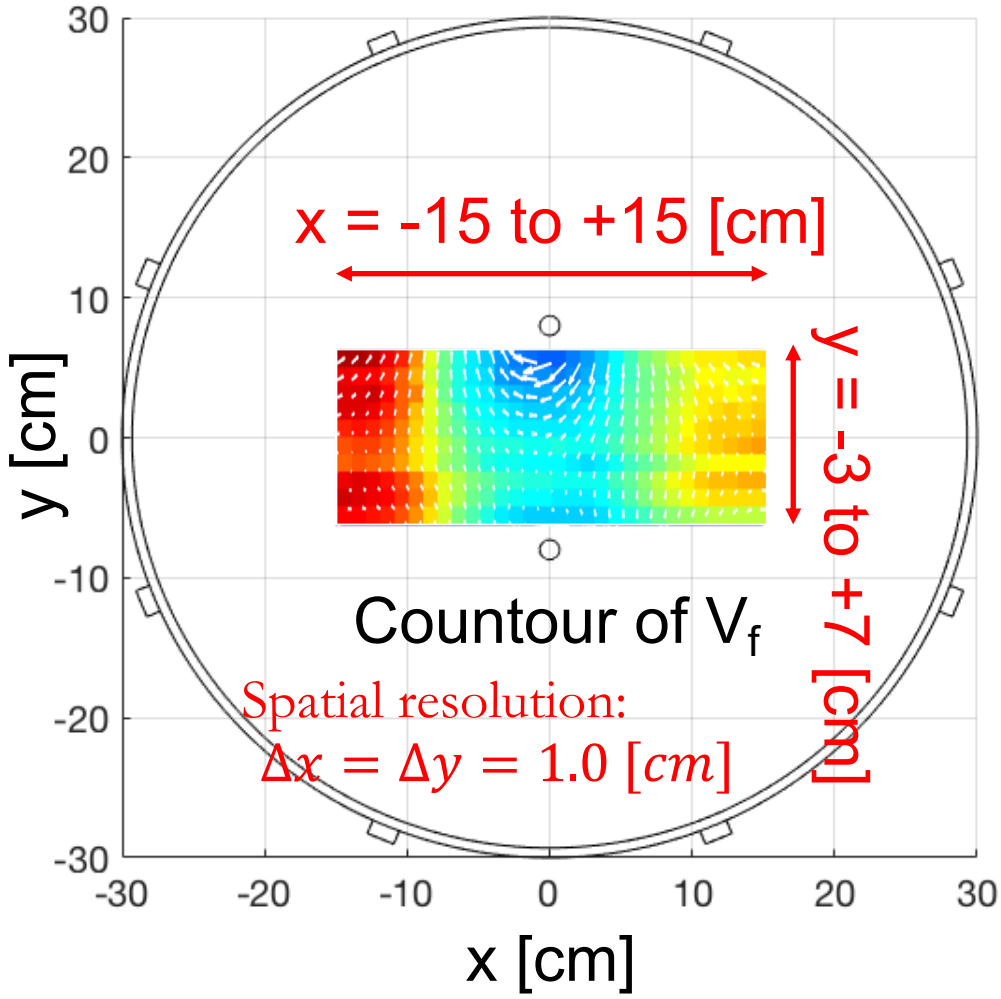
→Indicating that measurements of ϕ_p, n_e and T_{eff} are consistent.

2D profiles of plasmas are obtained at z=50 [cm]

$$I_{axial} = 0.3\ [kA]$$

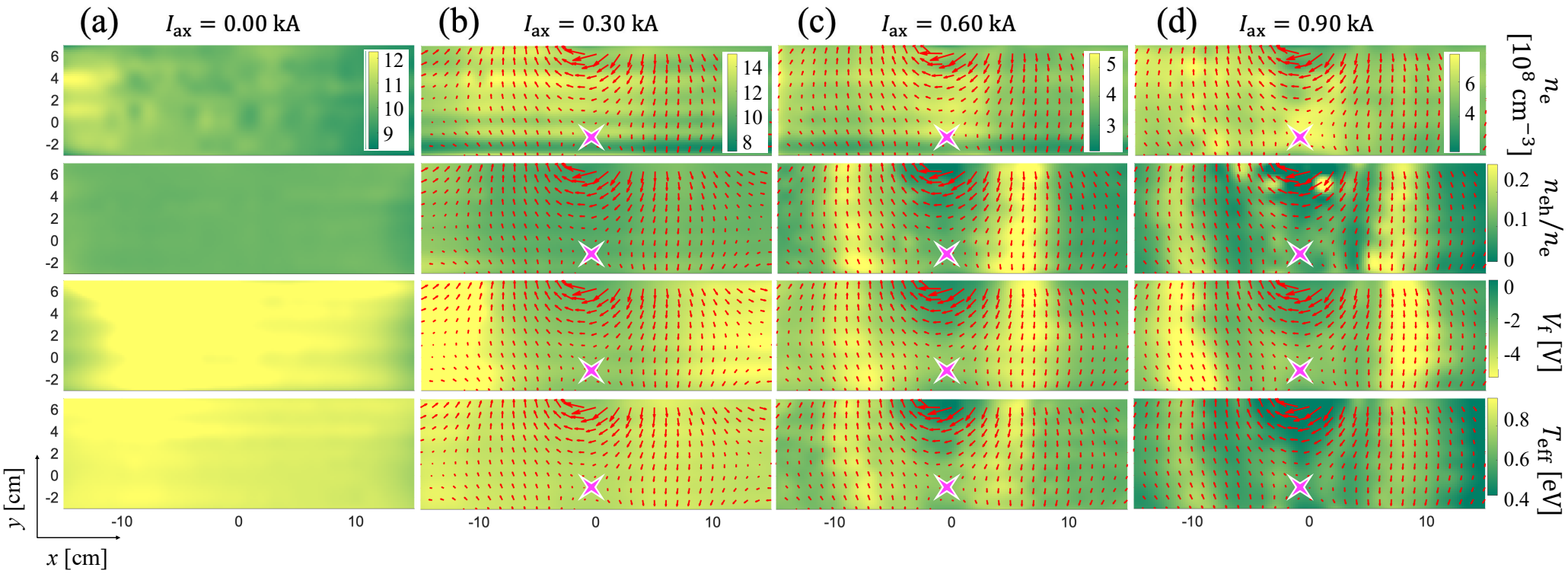






Plasma properties are correlated with the poloidal B-fields

Ar neutral pressure : 1.00 mTorr; Discharge (bias) voltage: -100.0 V; Discharge current = 0.2 A



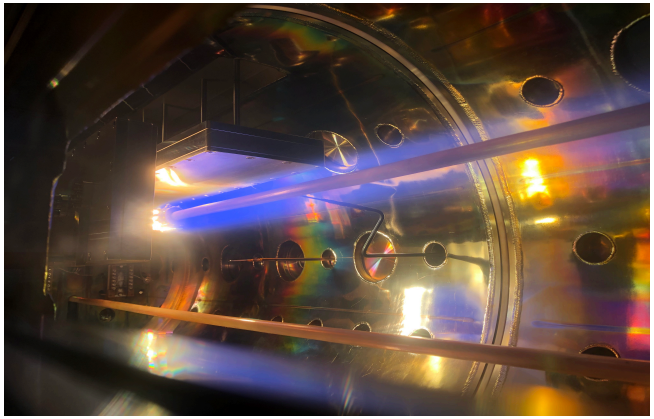
- Densities, temperatures and absolute values of floating potentials are smaller in the core region (consistent with the visual pictures, i.e., no plasmas in the 'core' region as B-fields increase)
- As plasmas are produced in the 'edge' region, it becomes more difficult for plasmas to penetrated into the 'core' region as B-field increases as if there exists a transport barrier.

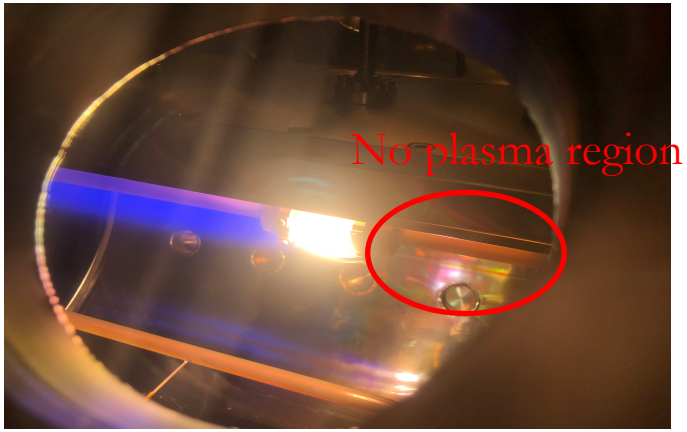
Data obtained with the core ThW filaments

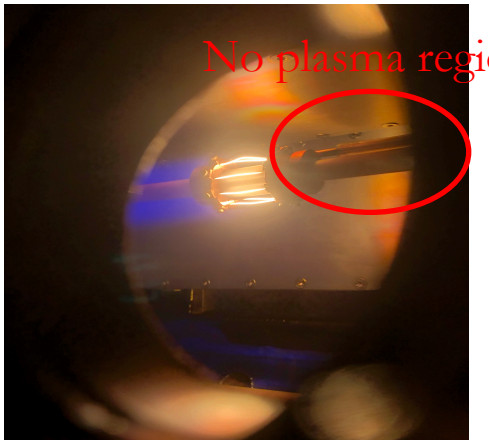
Note:

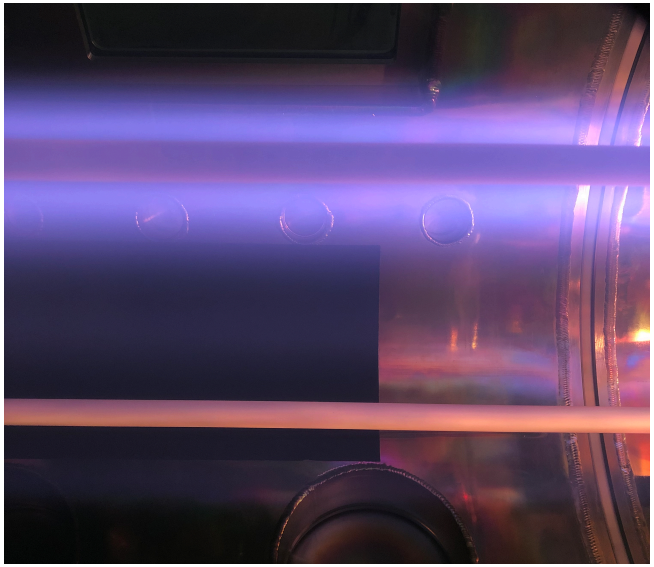
- Some of the data we show are not fully validated, thus credibility of the analyzed data may be questionable.
- Consider what I show is just preliminary results to stimulate further discussions.

Electrons are strongly drifting in the e⁻ grad-B and curvature drift direction







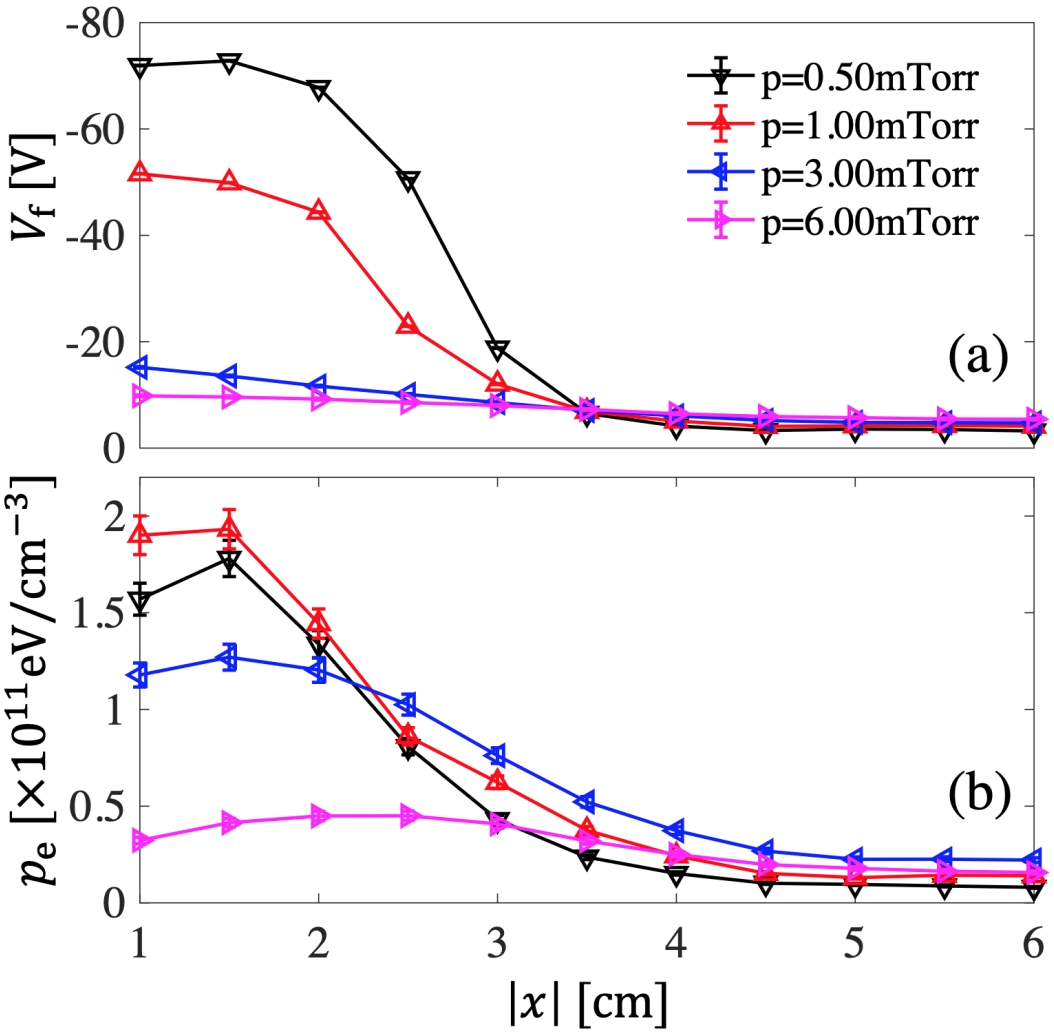


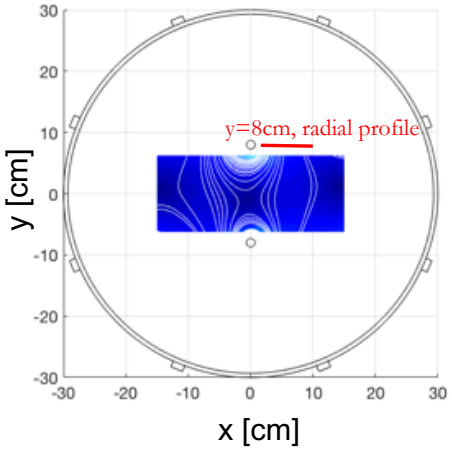
- Plasmas are only generated in one side of the core ThW filaments
  - ✓ As the bias voltage on the filaments increase, the size of plasma column in axial direction increases.
  - ✓ The direction corresponds to the electron grad-B and curvature drift. (Note: electrons are most likely to be magnetized while ions are not.)

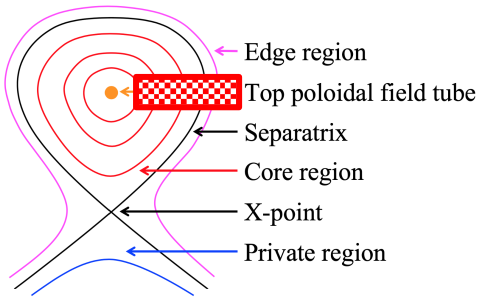
B=10G; $L_{\nabla B}$=10cm	Thermal e⁻	Primary e⁻	Ar⁺
Temperature [eV]	~1	~100	~0.025
v_{th} [m/s]	~4.2x10^5	~4.2x10^6	~250
f_{ce} [Hz]	~28M	~28M	~400
r_L [cm]	~0.24	~2.4	~10
$v_{\nabla B} + v_{curv}$ [m/s]	~10^4	~10^6	~250

Radial profiles (in the core region) depend on neutral pressures

Varying Ar neutral pressure; Discharge (bias) voltage: -100.0 V; Discharge current = 1.0 A; $I_{ax}^{top} = I_{ax}^{bottom} = 0.50$ kA



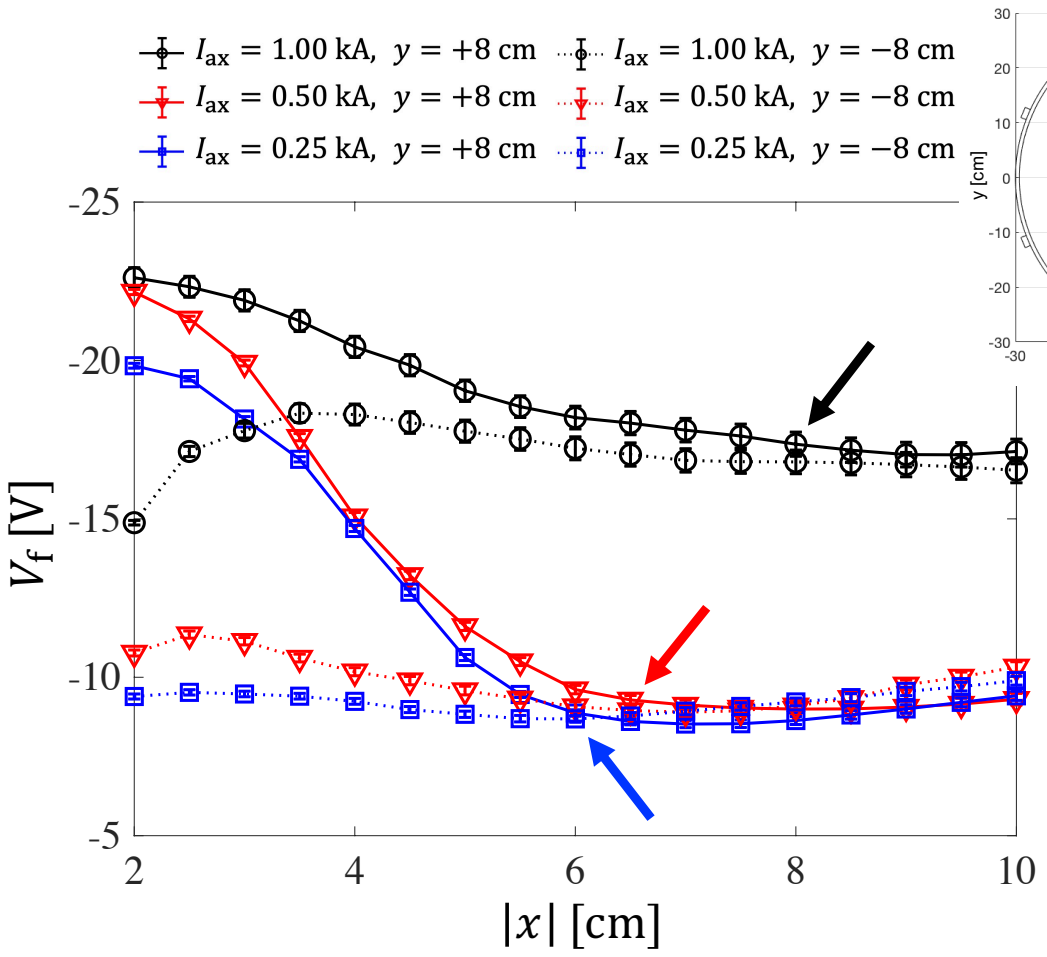


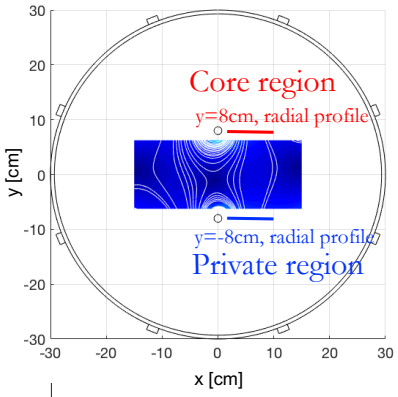


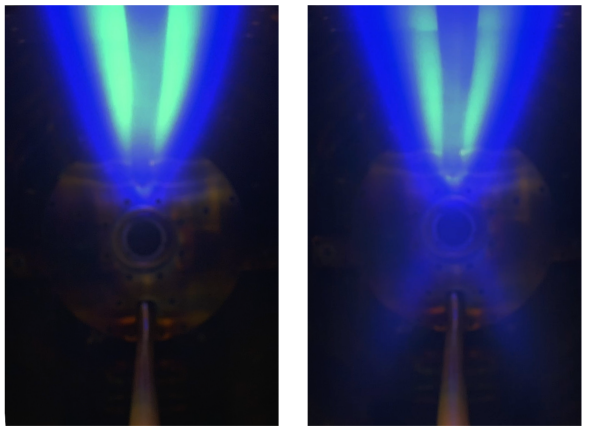
- Stiff gradients are observed for small neutral pressures (less collisions leading smaller diffusivity allows the gradient to be sustained by the B-fields).
- Unusually (absolute) large floating potentials (compared to no poloidal B-field) are observed which can be explained by large amount of high energy electrons due to the drifting motions.

Up-down symmetry at smaller radial position with smaller poloidal B-fields

Ar neutral pressure: 1.00 mTorr; Discharge (bias) voltage: -80.0 V; Discharge current = 1.0 A



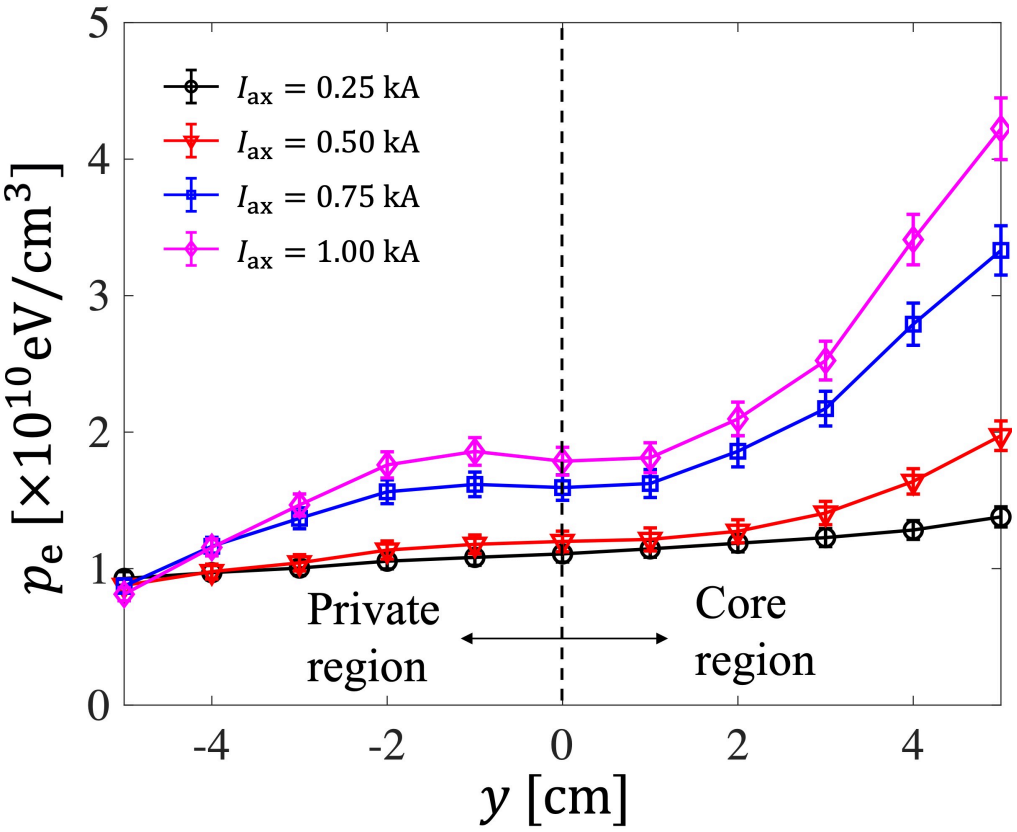


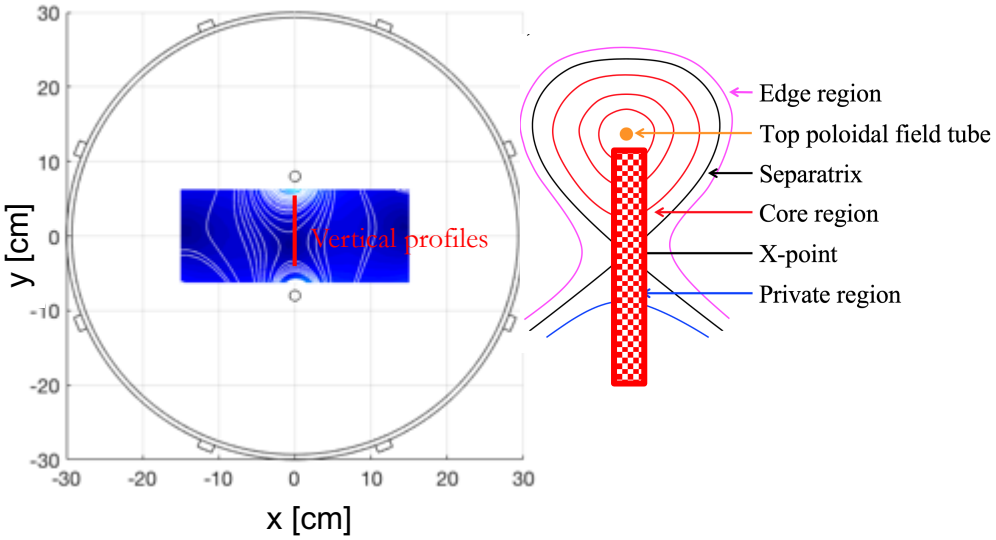


- Plasma source only exists in the core region (around the top copper tube)
  - ✓ Top (y=8cm) and bottom(y=-8cm) plasmas become 'similar' at the smaller radial location when the poloidal B-fields are smaller
  - ✓ This may be explained by easier diffusion with smaller B-fields.
  - ✓ Perhaps, this can be used to measure the particles (or heat) diffusivity.

Flattened plasma profiles around the magnetic X-point

Ar neutral pressure: 1.00 mTorr; Discharge (bias) voltage: -150.0 V; Discharge current = 1.0 A



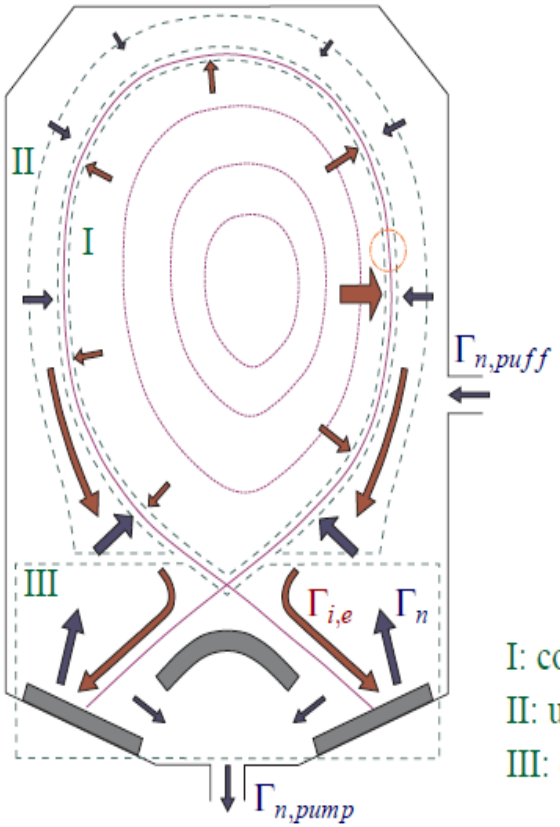


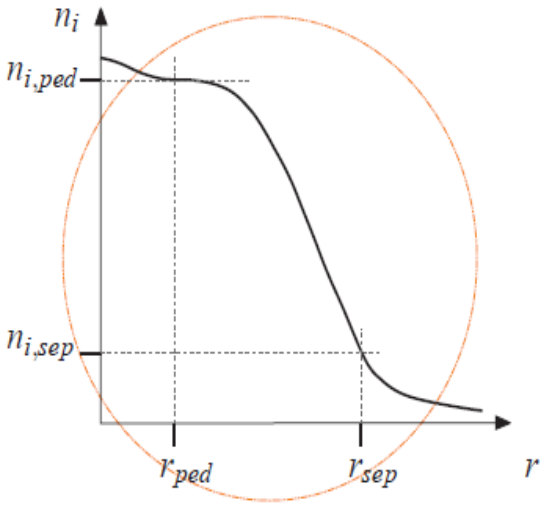
- As we've seen consistently, profiles are stiffer for stronger poloidal B-fields.
- Profiles are flattened around the X-point indicating increased transport levels around the X-point. (B-fields are weak around the X-point.)

Contents

- General descriptions of MAXIMUS
  - ✓ Structures of magnetic fields: 1) permanent magnets; 2) axial current
  - ✓ DC plasma sources: 1) end-plate ThW filaments; 2) core ThW filaments; 3) end-plate LaB_6 disk;
- Basic properties of MAXIMUS plasmas
  - ✓ Under the multidipole configuration
  - ✓ Under the poloidal magnetic fields configuration with X-point
- Motivation of building MAXIMUS
- Summary

To investigate role of neutrals in a tokamak scrape-off layer





I: core plasma
II: upper scrape-off layer (SOL)
III: divertor SOL

- Neutrals in the scrape-off layer (SOL)
  - ✓ act as sources/sinks of particles, momentum and energy
  - ✓ are correlated with shear flow which is a widely accepted key parameter for low and high confinement mode transitions
  - ✓ plays an important role for generating detached plasmas (from divertors) which reduces heat loads to the divertor
  - ✓ may cause (through sudden H-L back transition) or mitigate/prevent disruption events through recycling processes
  - ✓ are considered to be a hidden variable

To investigate fundamental physics of non-Maxwellian electrons

- ∇B and curvature drifts not only shifts the EVDF, but they also generate skewness and excess kurtosis.
  - ✓ This is because these drifts depend on a speed of an individual particle.
  - ✓ We can control levels of skewness and excess kurtosis in some degrees.
  - ✓ We are interested in investigating how various physics such as diffusion process, plasma waves and nonlinear physics (solitons, shock-wave, etc.) depend on skewness and excess kurtosis of EVDF.

- Some of interesting phenomena observed in solar corona, solar wind, space plasmas, magnetic reconnection are high energy density plasmas are theoretically explained with non-Maxwellian EVDFs.
  - ✓ We plan to design experiments to investigate such interesting phenomena with MAXIMUS.

Summary

- We have introduced our linear plasma system MAXIMUS which can generate
  - ✓ Tokamak-like poloidal magnetic fields with an X-point configuration
    - Thus, MAgnetic X-point sIMUlator System
- We have introduced you three types of plasma sources with characteristics of generated plasmas
  1) End-plate ThW filaments
  2) Core ThW filaments
  3) End-plate LaB_6 disk
- We have presented how plasma profiles are affected by poloidal magnetic fields.

Thank YOU!