

# RF Helicon-based Plasma Thruster Design, Ignition and Characterization

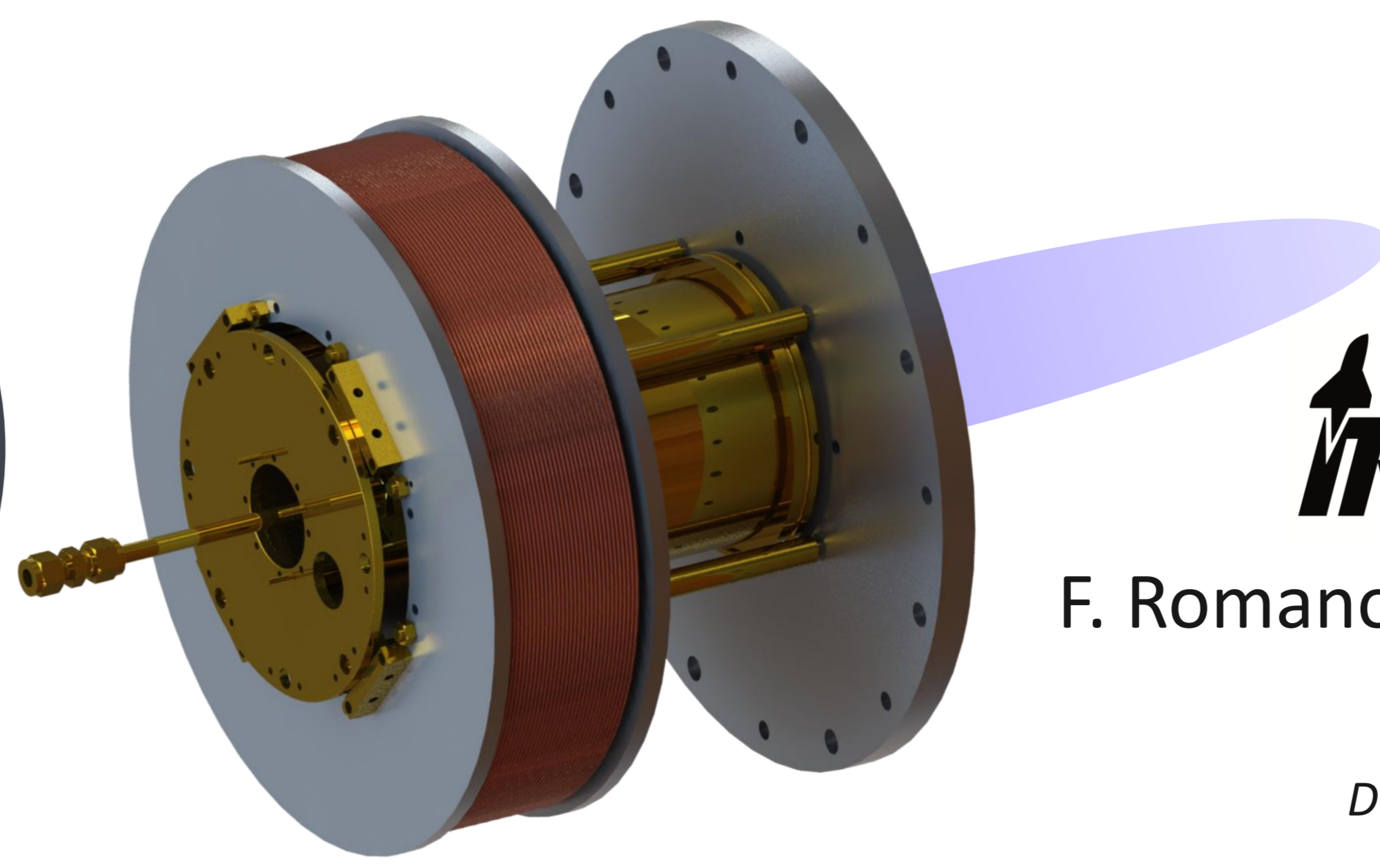


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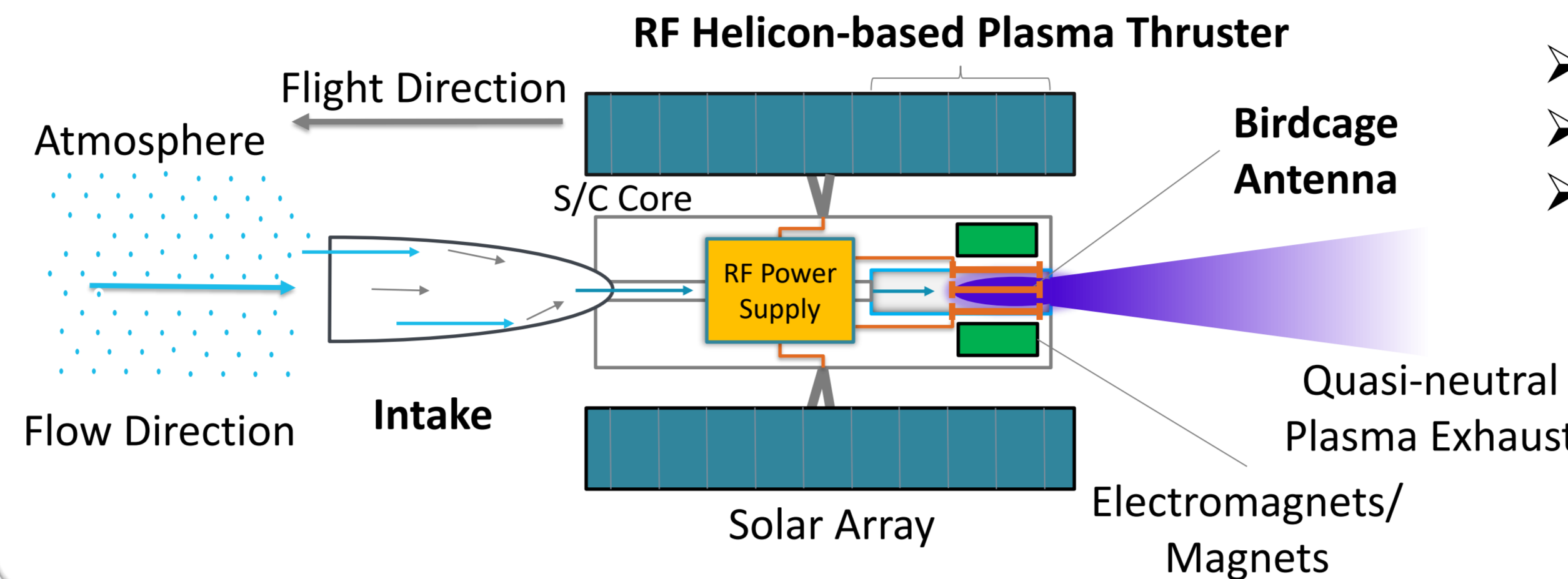


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## Atmosphere-Breathing Electric Propulsion

**Very Low Earth Orbit (VLEO)** offers a new range of space missions but drag compensation is required to extend their lifetime. A solution is Atmosphere-Breathing Electric Propulsion (ABEP):



- The intake collects the residual atmosphere
- The residual atmosphere is used as propellant
- Electric thruster compensates the drag

**RF Helicon-based Plasma Thruster (IPT):**

- RF antenna plus external magnetic field
- No parts in direct contact with the plasma
- Quasi-neutral plasma plume
- Use of different propellants

## IPT Design

- Design consists of: injector, discharge channel, birdcage antenna, electromagnet (EM), Faraday shield and support structure
- Birdcage Antenna: Correct resonance selection -> Linear polarization of E- and B- fields -> Provides **ExB** drift velocity
- Birdcage antenna + External axial magnetic field
  - Helicon wave-based discharge
  - Higher ionization degree and plasma density -> less input power required compared to inductive discharge
  - Enables EM acceleration due to high ionization (less neutrals)

## Plume Characterization

### Torsional pendulum

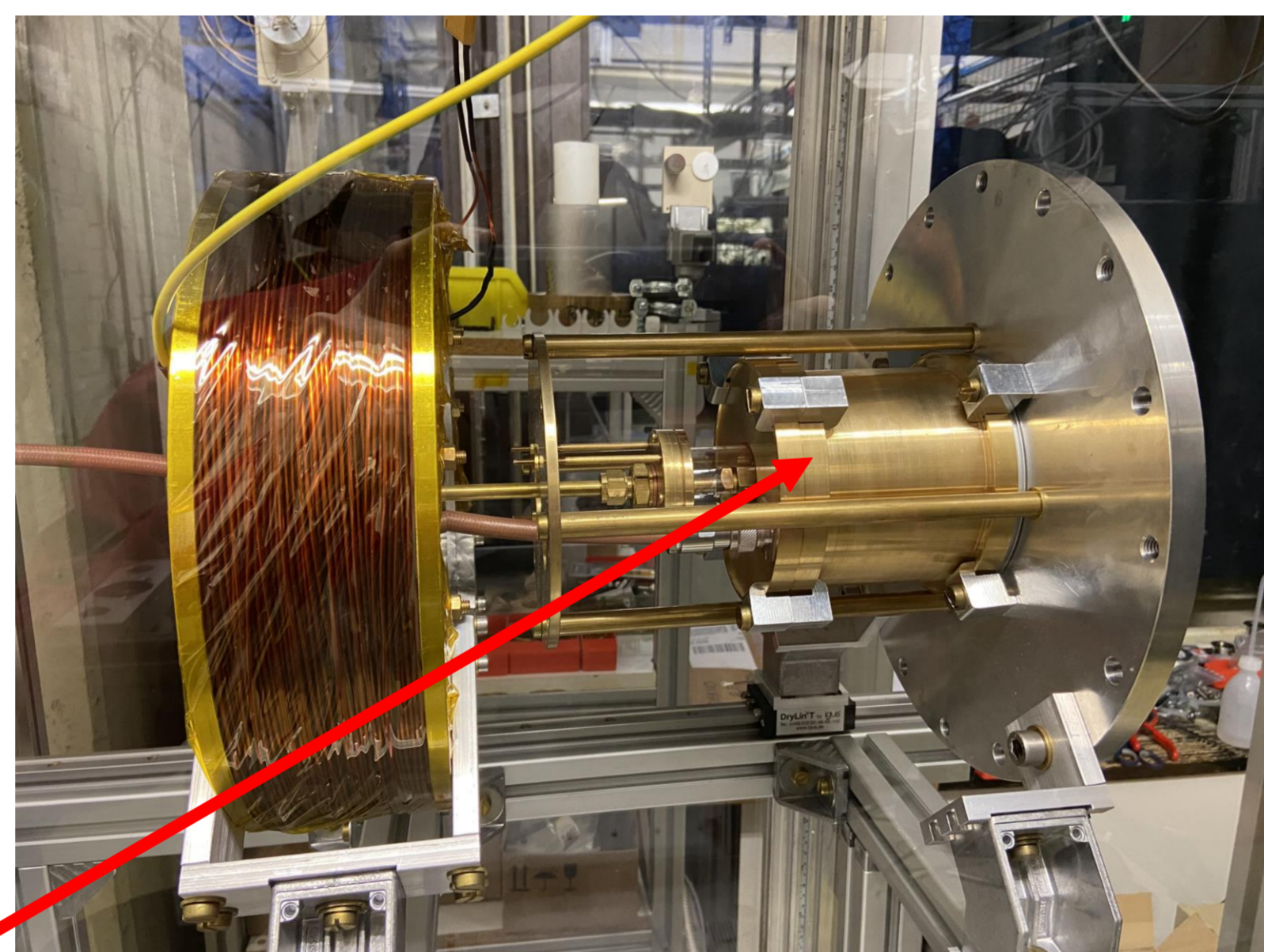
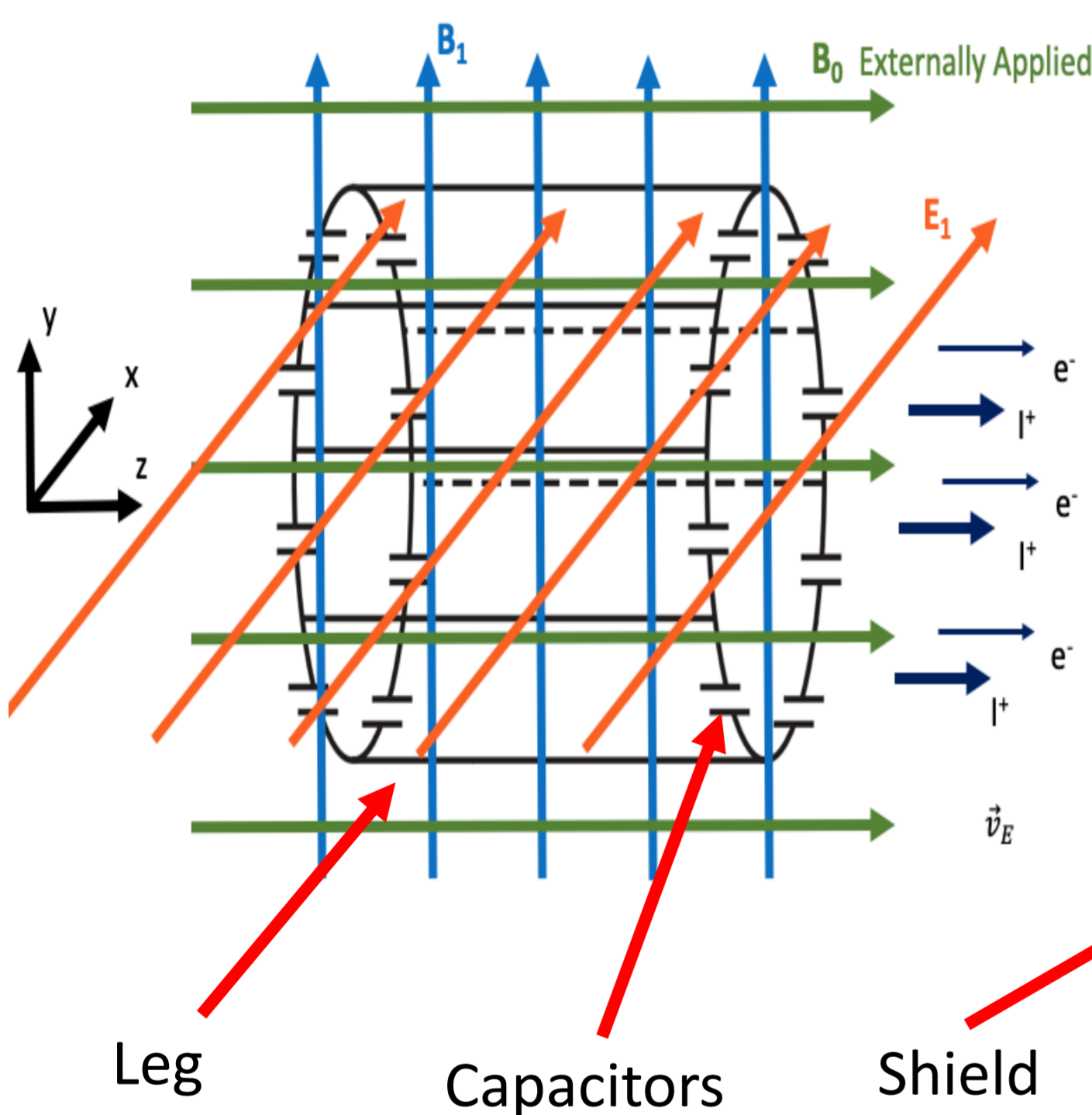
- Measurement of momentum flux in plume -> extract data on thrust, specific impulse, thrust efficiency
- Plate facing the thruster's exit plane
- Supported by a balance arm to counteract the plasma plume

### B-dot probe

- 3-axis of measurement
- Probe interfaces with 3 RF power combiners, vacuum feedthrough interface, oscilloscope
- Periodical rotating magnetic field measurement in the IPT plasma plume -> helicon wave detection in the IPT plasma plume -> confirmation of IPT as helicon plasma source

## Status

- IPT is based on a RF birdcage antenna at 40.68 MHz plus external magnetic field applied axially, 20-30 mT required for helicon waves.



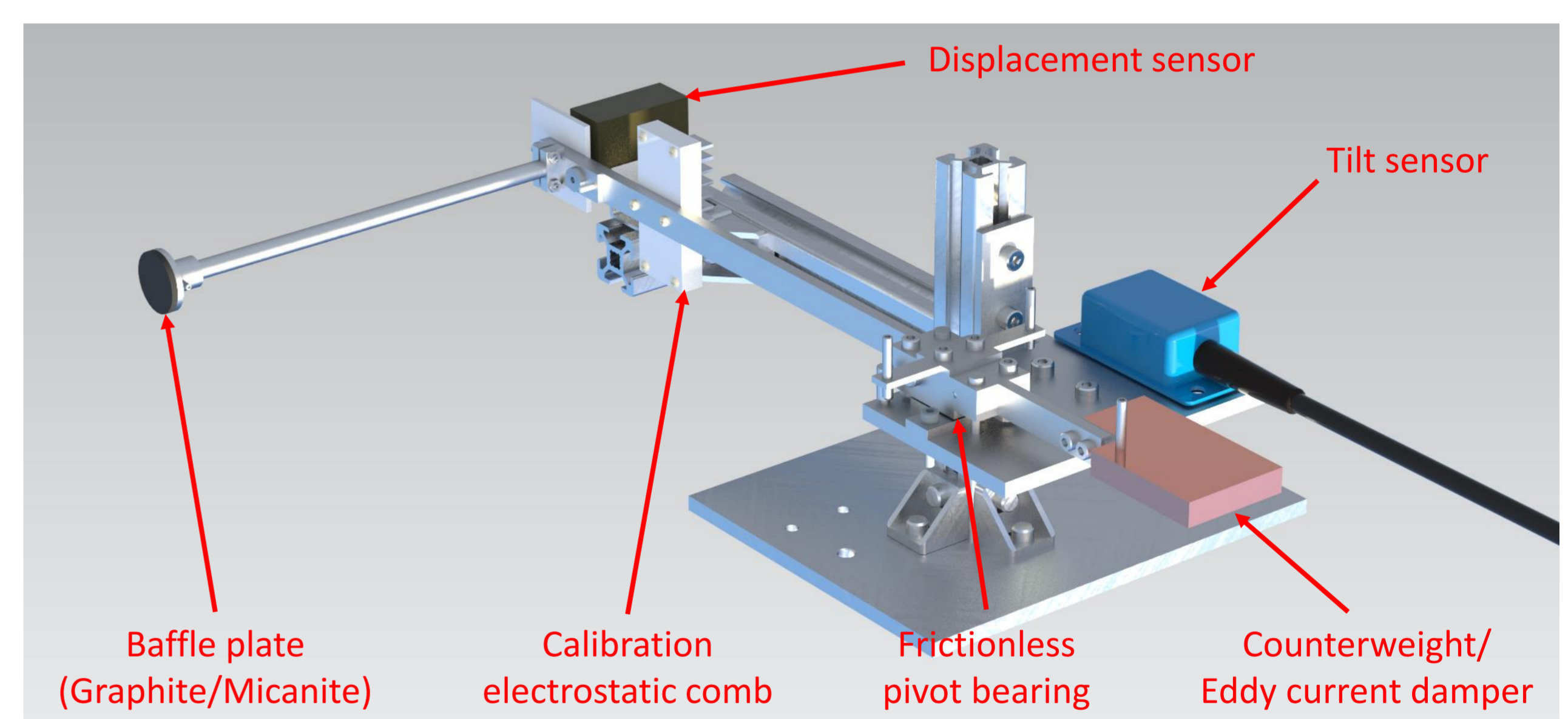
### Operational Envelope

Power	50-100 W
Mass flow	0.1-0.8 mg/s
Pressure	0.12-0.30 Pa
Magnetic field	14.7-44.5 mT, max: 70 mT
Current (Solenoid)	6-10 A, max: 15 A
Propellants	Ar, N <sub>2</sub> , O <sub>2</sub>

### Ignition & Operational Power

P <sub>IN, Ar</sub> [W]	P <sub>IN, N2</sub> [W]	P <sub>IN, O2</sub> [W]	$\dot{N}$ [1/s]
50-60	50-70	50-70	20.30
50-60	50-70	50-70	15.23
50-60	50-70	110	10.15
50-60	50-70	110	5.08
50-60	100	110	2.54

- ❖ Momentum flux probe to measure thrust
- ❖ Procurement completed, manufacturing and set-up in progress.



- ❖ B-dot probe head with 3 copper coils for 3-axis B-field measurements.
- ❖ Calibration set-up attached to IPT.

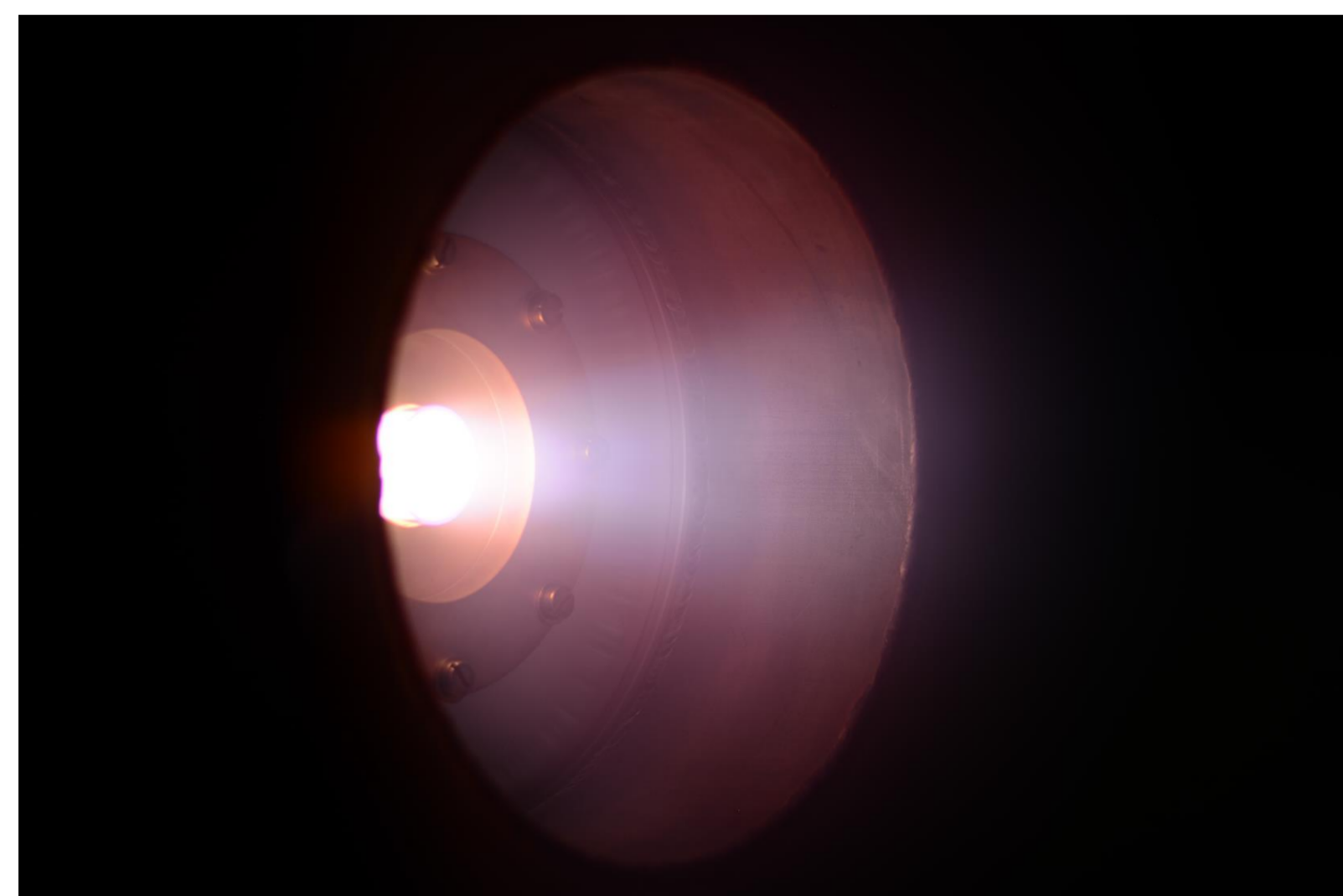
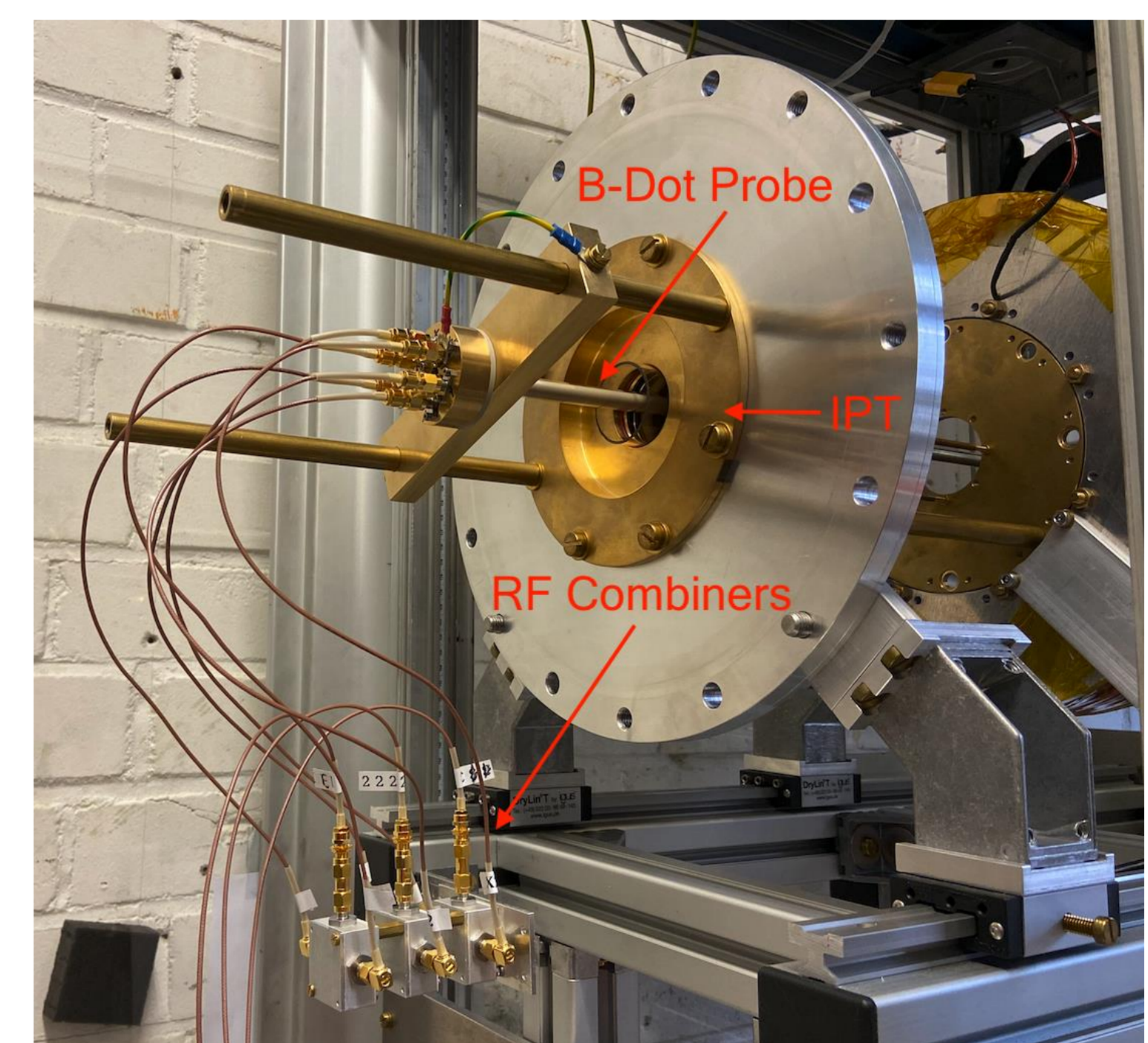


Fig: IPT operating with O<sub>2</sub>, P<sub>IN</sub>=60W, B<sub>EM</sub>≈30mT,  $\dot{m}$ =0.65mg/s

## Conclusions

- ✓ IPT & Birdcage antenna designed and built
- ✓ Stable IPT operation with N<sub>2</sub>, O<sub>2</sub>, and Ar was achieved over different power levels
- ✓ Thrust balance has been designed and under manufacturing
- ✓ B-dot probe designed and built

### Next:

- Plasma plume characterization
- Torsional pendulum set-up & calibration -> Momentum flux measurement -> Thrust
- B-dot probe calibration & measurement -> Helicon waves

## Selected references

- [1] F. Romano, "RF Helicon Plasma Thruster for an Atmosphere-Breathing Electric Propulsion System (ABEP)", PhD Thesis, University of Stuttgart, 2021. ISBN: 978-3-8439-4953-8
- [2] F. Romano., Y.-A. Chan, G. Herdrich et al., "Design, Set-Up, and First Ignition of the RF Helicon-based Plasma Thruster", Space Propulsion 2020+1, 17-19 March 2021.
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- [4] Kazunori Takahashi, Takeharu Sugawara, Hikaru Akahoshi, Yoshinori Takao, and Akira Ando, "Development of a momentum vector measurement instrument in steady-state plasmas", AIP Advances 8, 105117 (2018) <https://doi.org/10.1063/1.5050553>
- [5] Thomas Trottenberg, Alexander Spethmann, and Holger Kersten, "Interferometric Force Probes for Thruster Plume Diagnostics and Indirect Thrust Measurements", 35th International Electric Propulsion Conference, October 8-12, 2017.