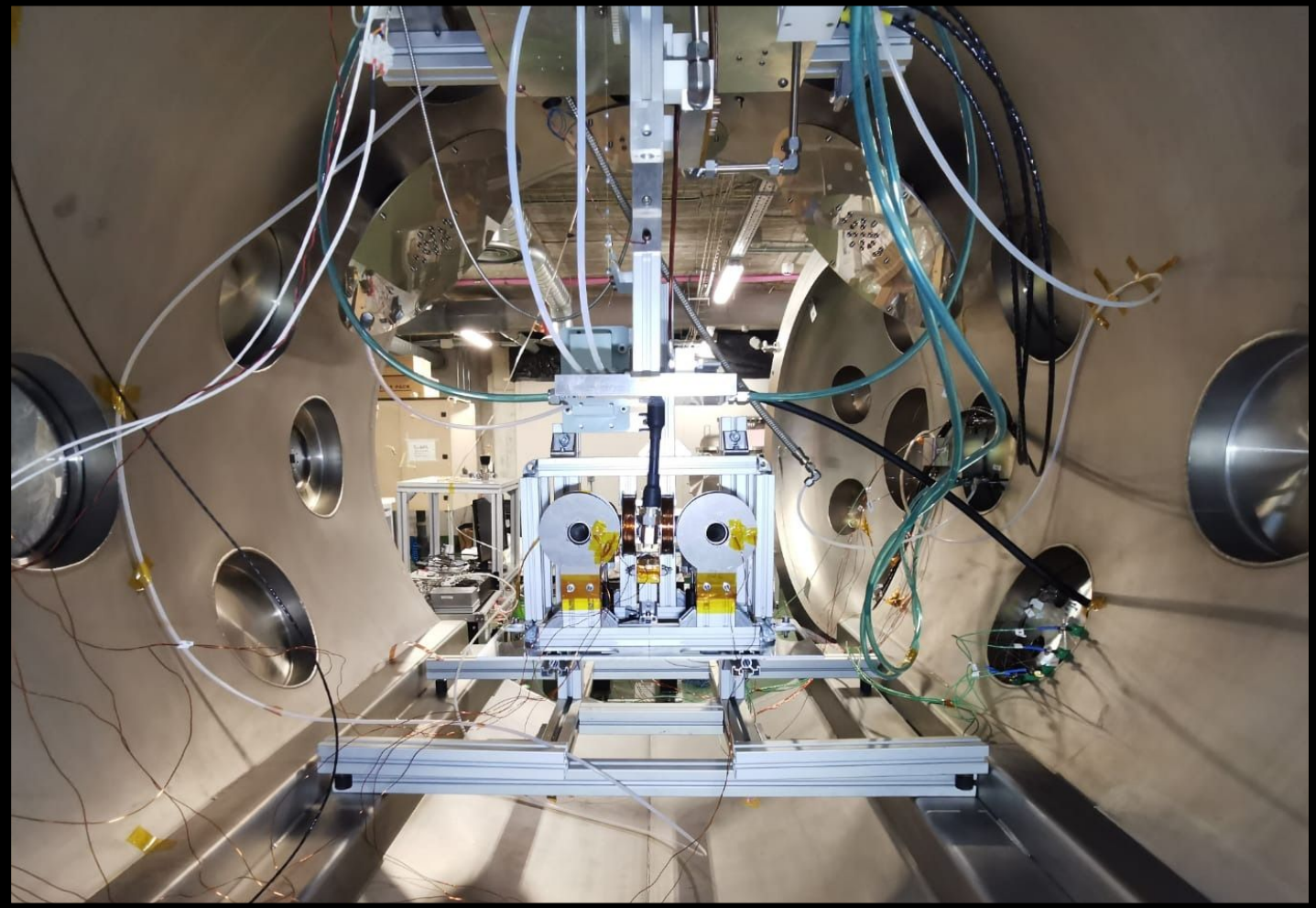
First Characterisation of a Dual ECR Thruster

Célian Boyé
Jaume Navarro, Mario Merino
Universidad Carlos III de Madrid, Spain

PLASMATECH 2023 – 27th April 2023

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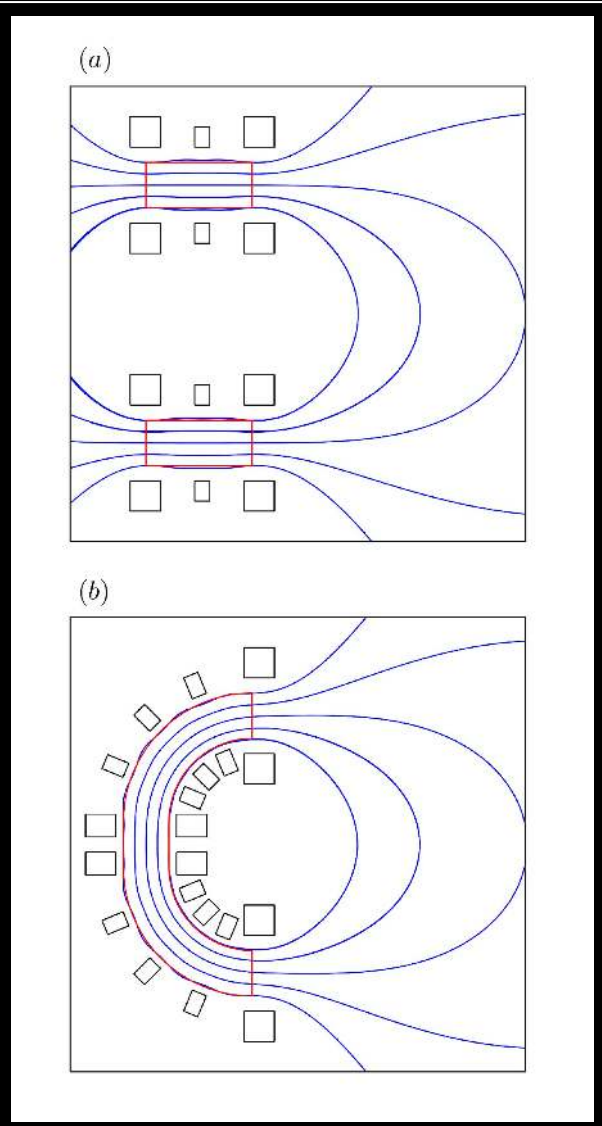


ZARATHUSTRA Motivation



MAT2 sources being assembled

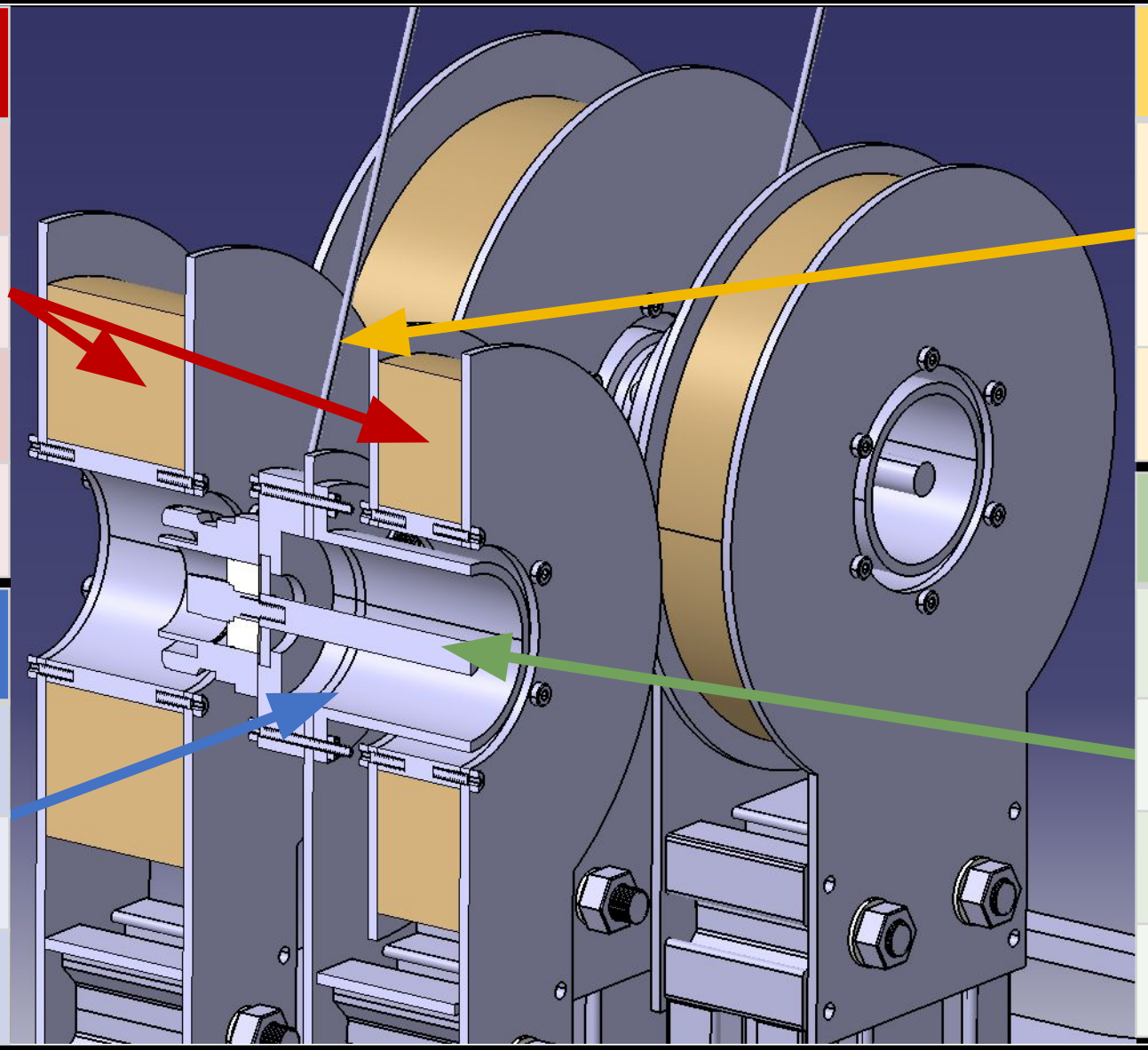
- Classic ***EPTs*** acts like total magnetic dipoles, coupling with the Earth's magnetic field and therefore producing secular torque.
- ***MAT2*** thruster is a dual coaxial ***ECR*** thruster (a) developing a magnetic arch with a closed-line topology to counter this effect.
- Interaction in between two ***ECR*** sources enables:
  - Closed-line magnetic field topology.
  - Lowering of the plume divergence.



MAT2 Architecture

Electromagnets	
Maximum total power per source	
Maximum magnetic field intensity	
ECR resonance field	
Total number of turns per source	

Ionisation chamber	
Length	
Diameter	
Material	Non-magnetic Stainless Steel

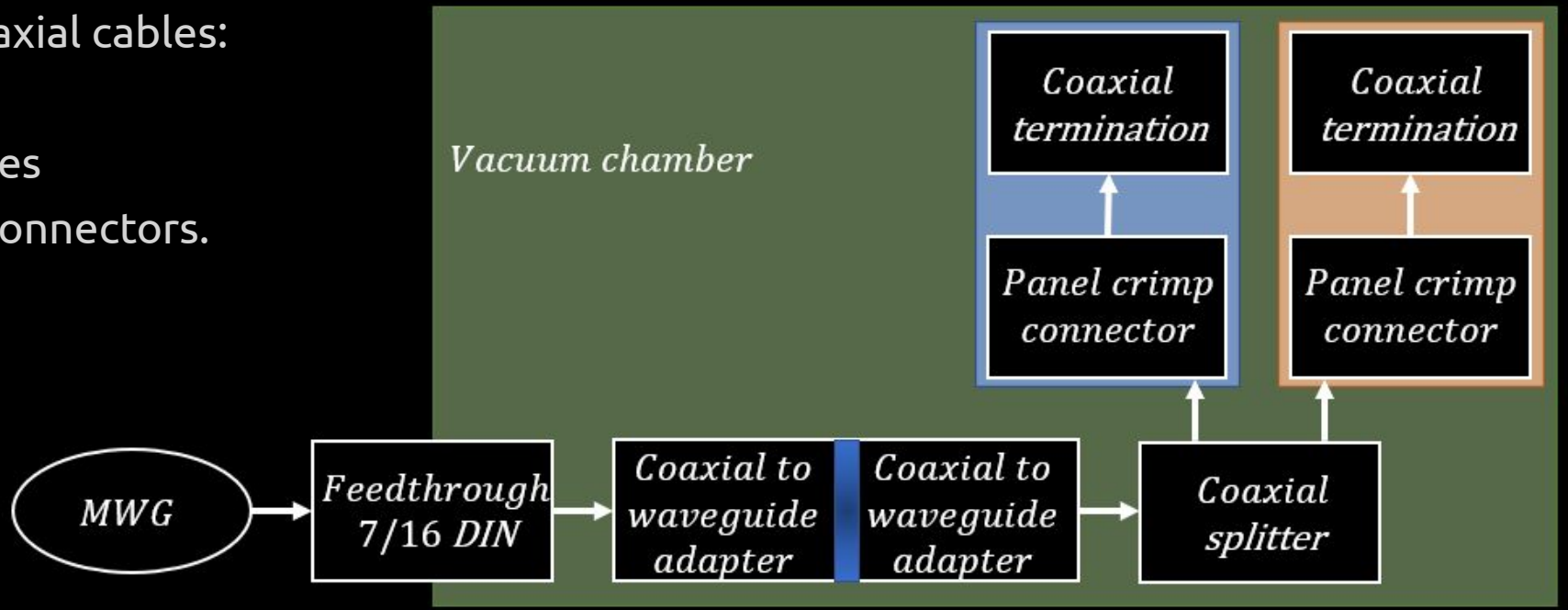


Gas feeding	
Gas	Krypton
Ignition mass flow rate	
Operation mass flow rate	

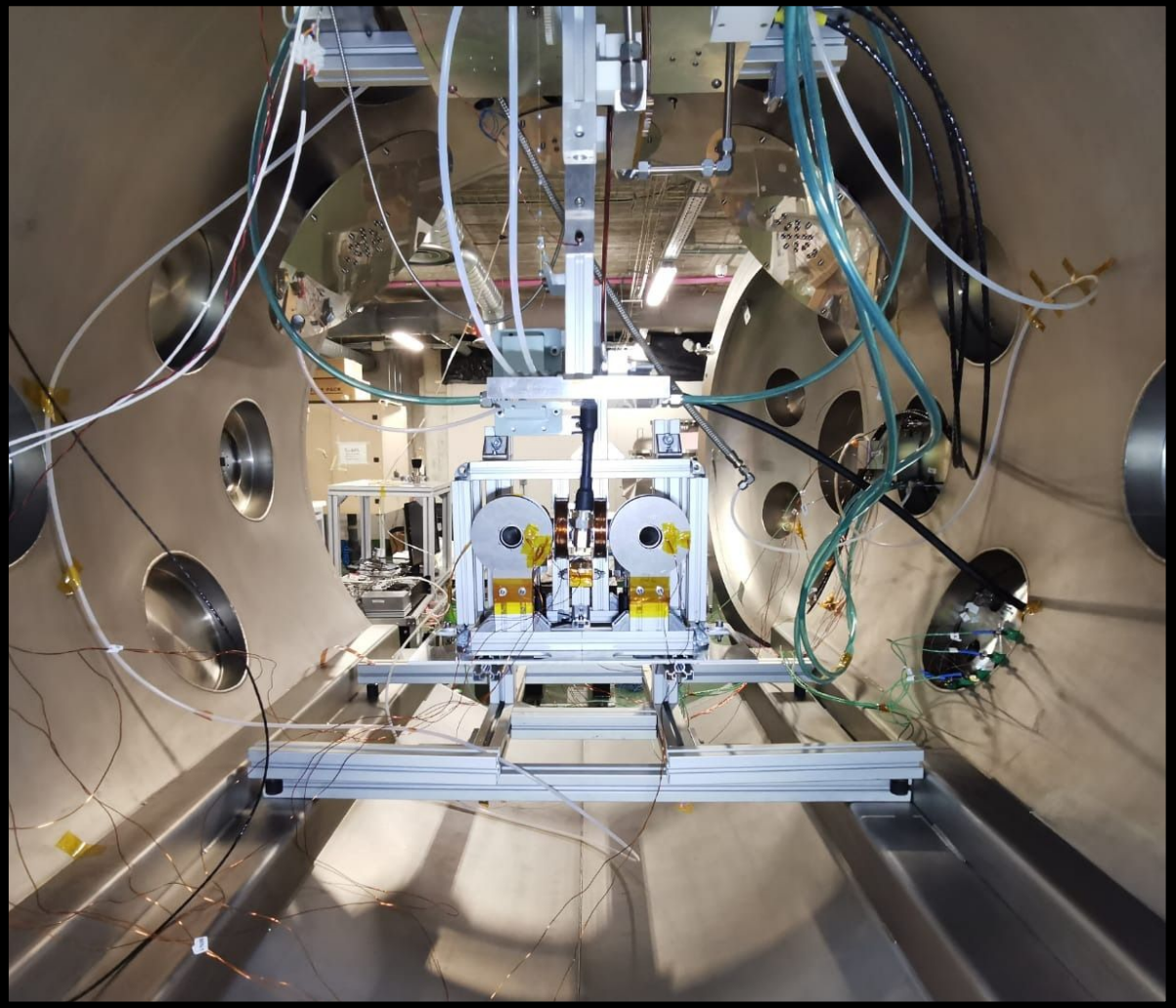
Inductor	
Length	
Diameter	
Frequency	
Power	

MAT2 Architecture

- $2.45GHz$ tunable (± 50 MHz) solid state microwave generator (***Muegge*** MR1000D-200ML).
- 7-16 DIN coaxial 2.45 GHz graded feedthrough (***Allectra*** 242-7_16-K50).
- Coaxial $2.45GHz$ graded all females three ways splitter (***Microlab*** D2-16FD).
- M3 termination 7-16 DIN panel crimp (***Telegartener*** J01121A0721).
- Elements connected with coaxial cables:
  - LMR-600-FR coaxial cables
  - TC-600-716M-X coaxial connectors.



Experimental Setup



MAT2 Thrutster installed in the EP2 group vacuum chamber

- Technology in use:
  - *Primary pump:* Leybold ***Leyvac LV 80*** $(80\ m^3/h)$
  - *Turbomolecular pumps:* 2 ***MAGW2.200iP*** $(2000\ l/s)$
  - *Cryopanels:* 3 Leybold ***Leyvac 140 T-V***
  - *Leak dectector:* Leybold ***L300i***

Vacuum chamber characteristics	
Length	
Diameter	
Operational pressure	
Pumping speed	

Experimental Setup - RPA

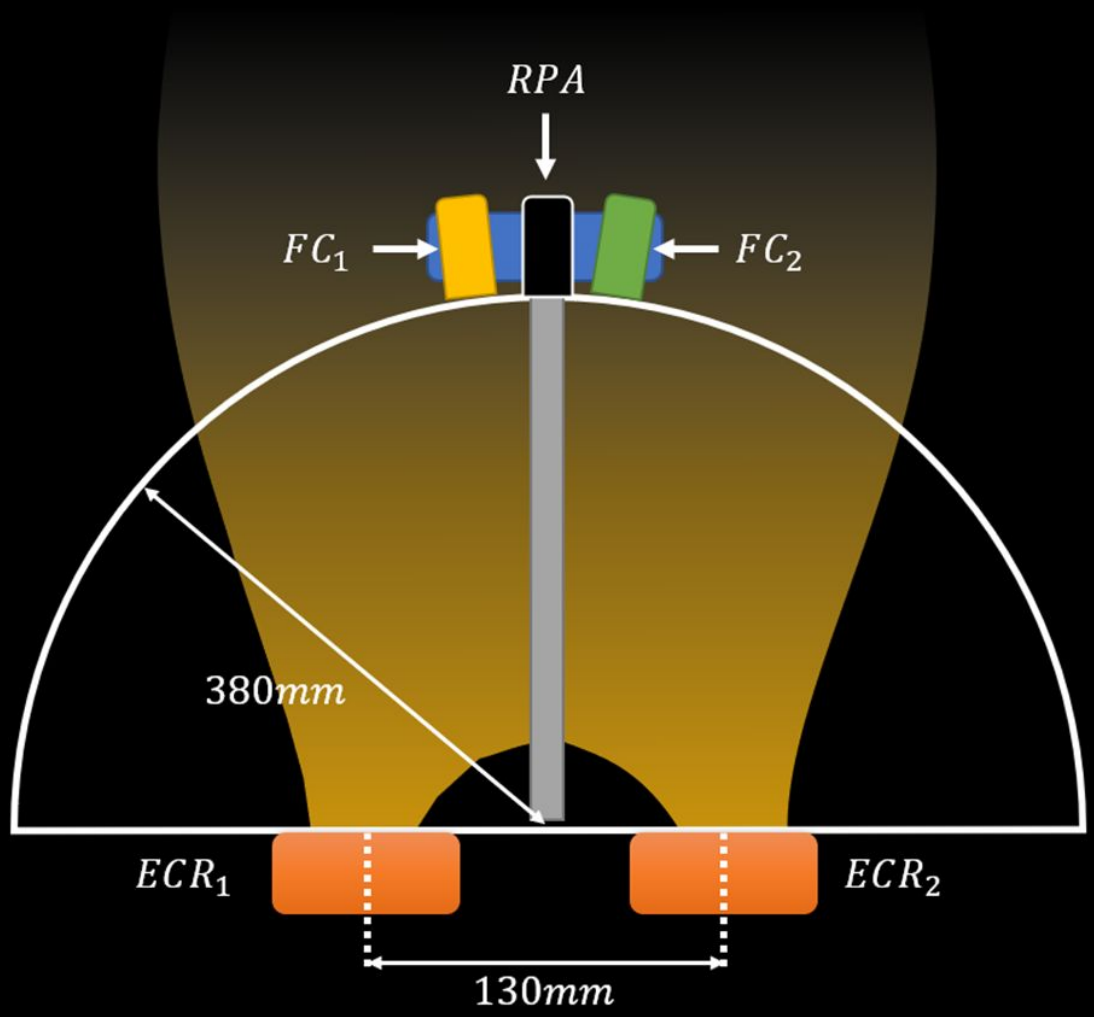
- Radial / Polar positioning system used in the vacuum chamber with a *Retarded Potential Analyzer* (***RPA***) and two *Faraday Cups* (***FC***).

- ***RPA*** characteristics:

  - *Distance to the thruster:* $380mm$
  - *Number of holes per grid:* 37
  - *Ion collection area:* $A = 1.86e-5$ m²
  - *Transmission factor:* $T = 0.0625$
  - *Set of angles:* $[-50°, -25°:5°:25°, 50°]$
  - $IEDF$, $\overline{E_i}$, $\overline{v_i}$, I_{Tot}

- ***FC*** characteristics:

  - *Distance to the thruster:* $380mm$
  - *Set of angles:* $[-90°:90°]$
  - I_{tot}



Experimental Setup - RPA

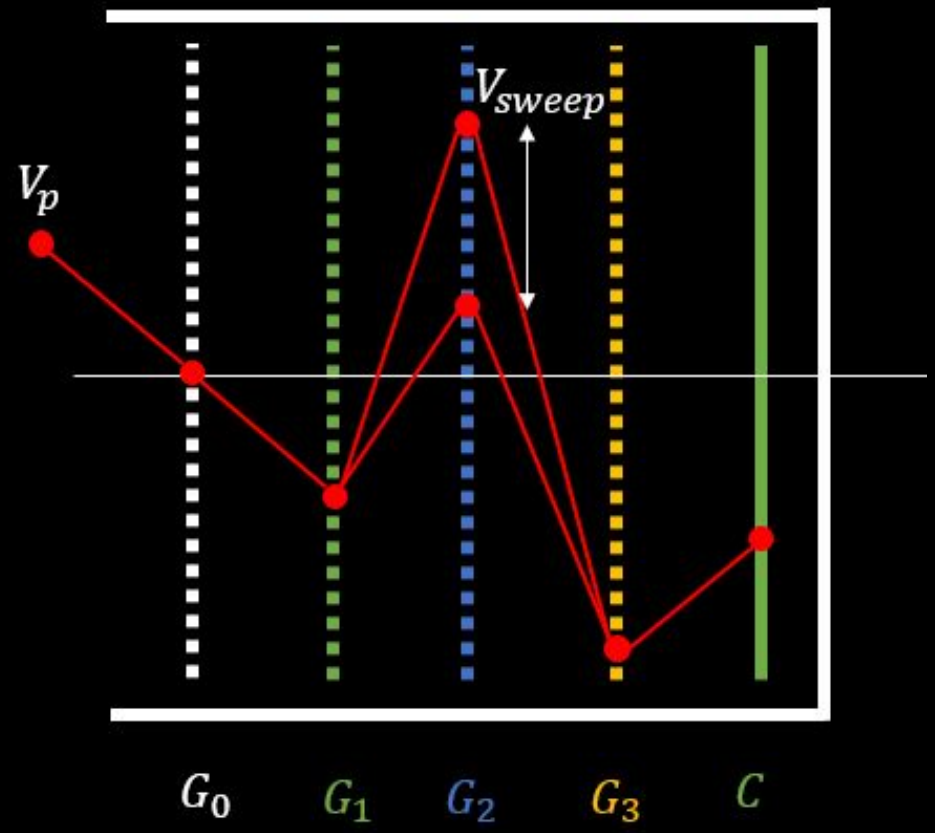
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  - I_{tot}

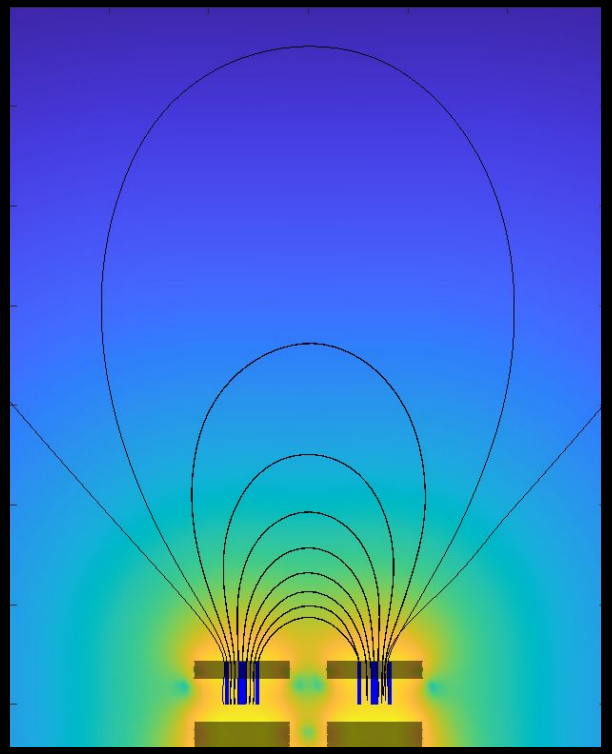


***RPA** functioning scheme*

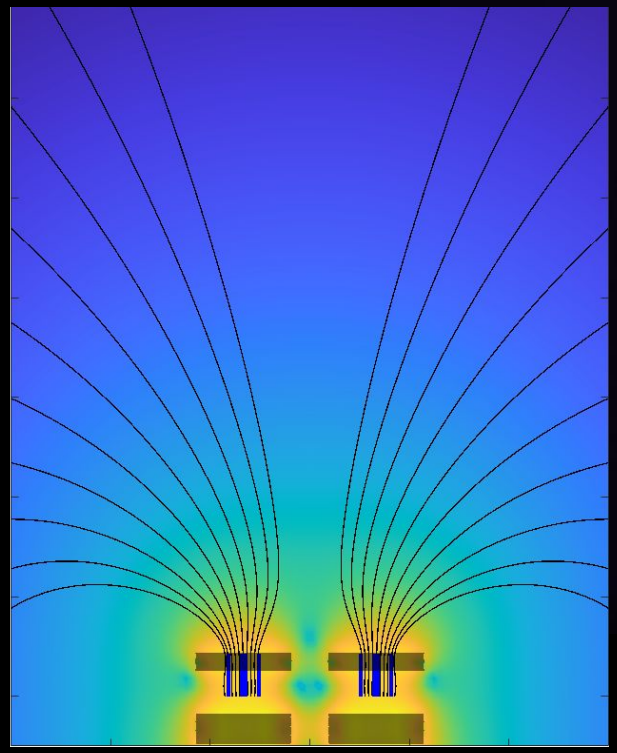
Experimental Setup

- Two magnetic topologies have been characterized.

*Magnetic field with "**MF ARCH**" configuration.*



*Magnetic field with "**MF SP**" configuration.*





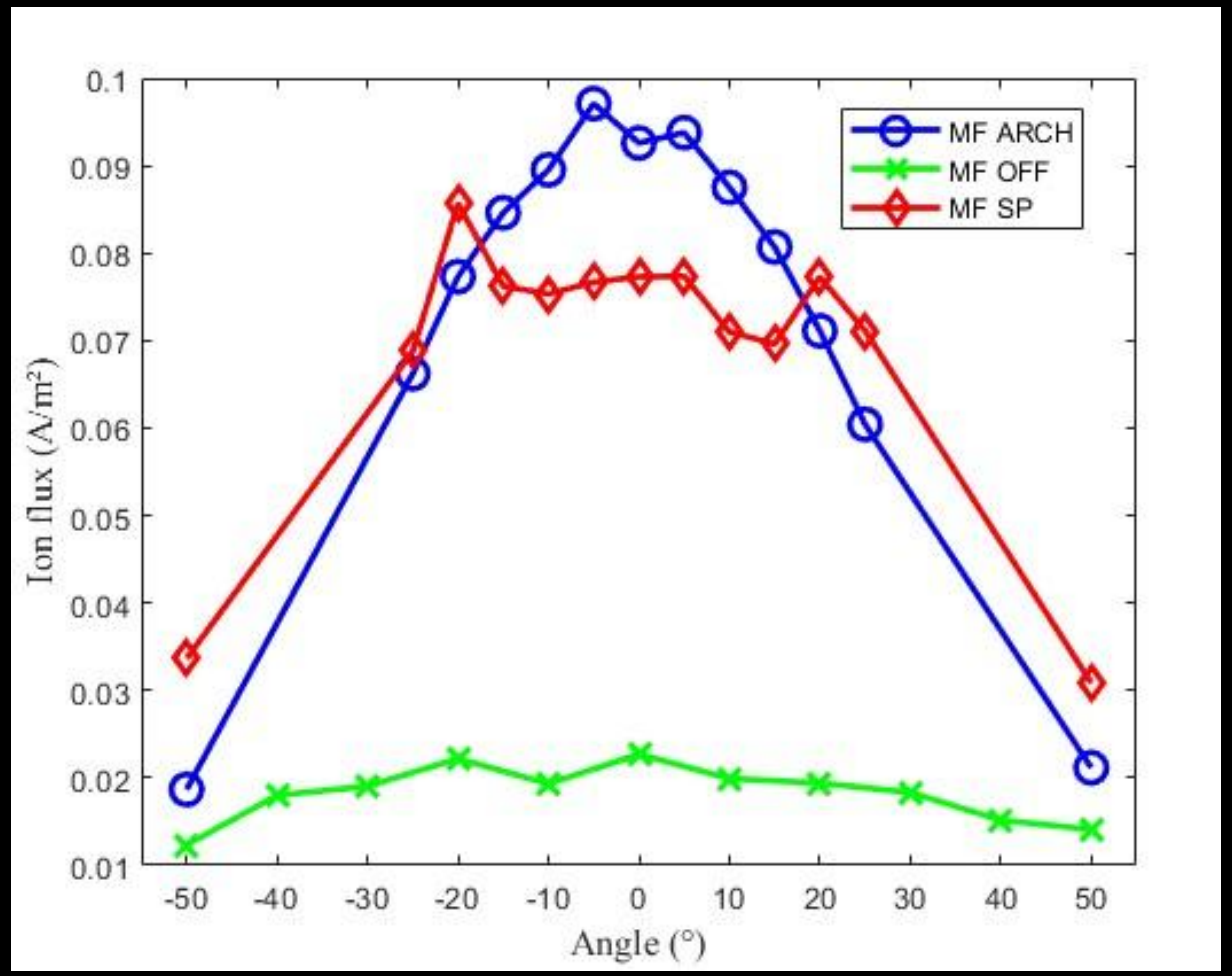
*Thruster in operation with Krypton in **MF ARCH** configuration.*

Results - Ion Flux

- Ion flux computed with data from the RPA:

$$I_{TOT} = \frac{\int_{E_{min}}^{E_{max}} IED \; dE}{AT}$$

- $MF\ OFF$ ion flux plot lies one order of magnitude lower than the other magnetic topologies.
- $MF\ REVERSE$ ion flux plot symmetry is coherent with the corresponding magnetic topology.
- Magnetic field intensity is strong enough for $MF\ ON$ to obtain a peak in ion flux around $0°$.



Results - Average Ion Energy and Velocity

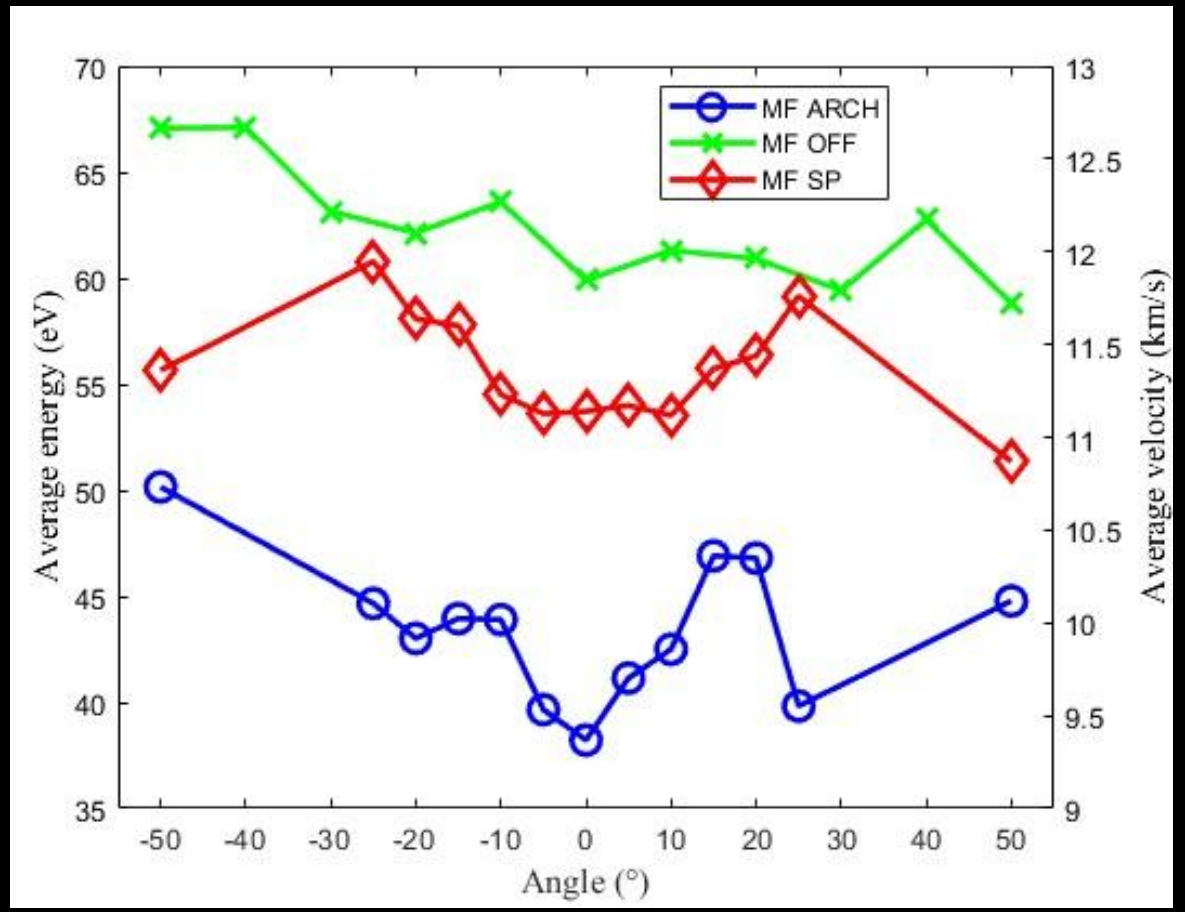
- Mean energy computed with data from the RPA:

$$\overline{E_i} = \frac{\int_{E_{min}}^{E_{max}} E\ f(E)\ dE}{\int_{E_{min}}^{E_{max}} f(E)\ dE}$$

- Same symmetry can seen for both $MF\ ARCH$ and $MF\ SP$ in the ion flux and the average energy plots.

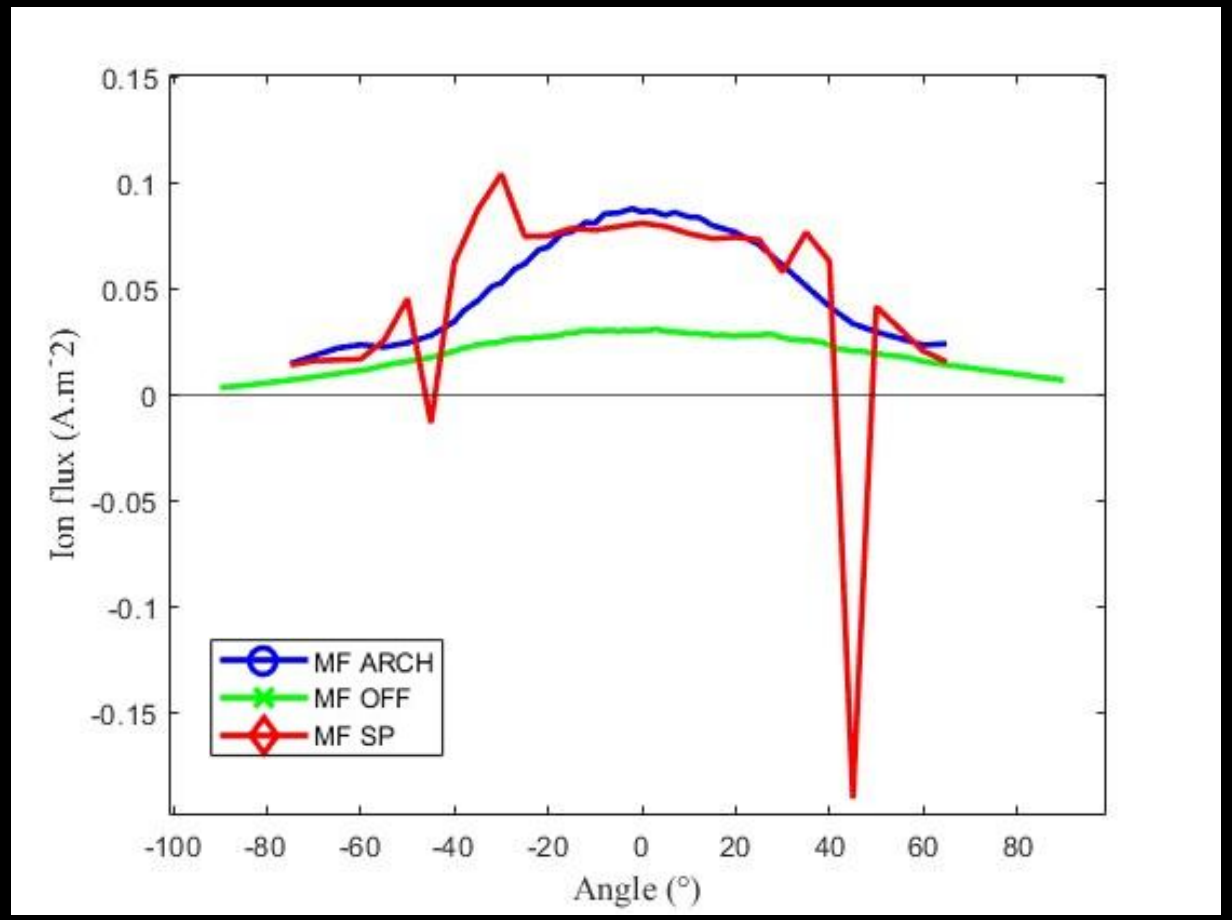
- Closed-line magnetic field might prevent the acceleration of ions close to $0°$.

- Differences in between the ion flux and the average energy plots could indicate the need to improve the probing setup.

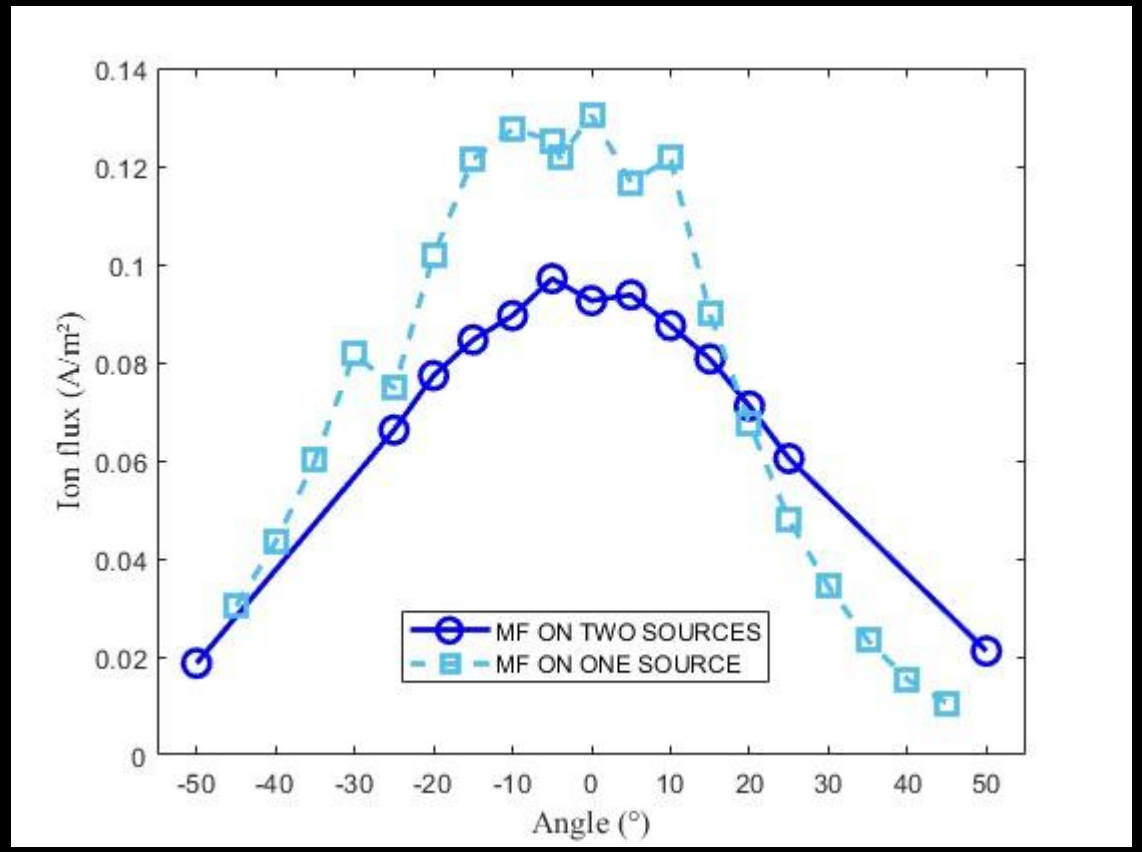


Results - Presence of Hot Electrons

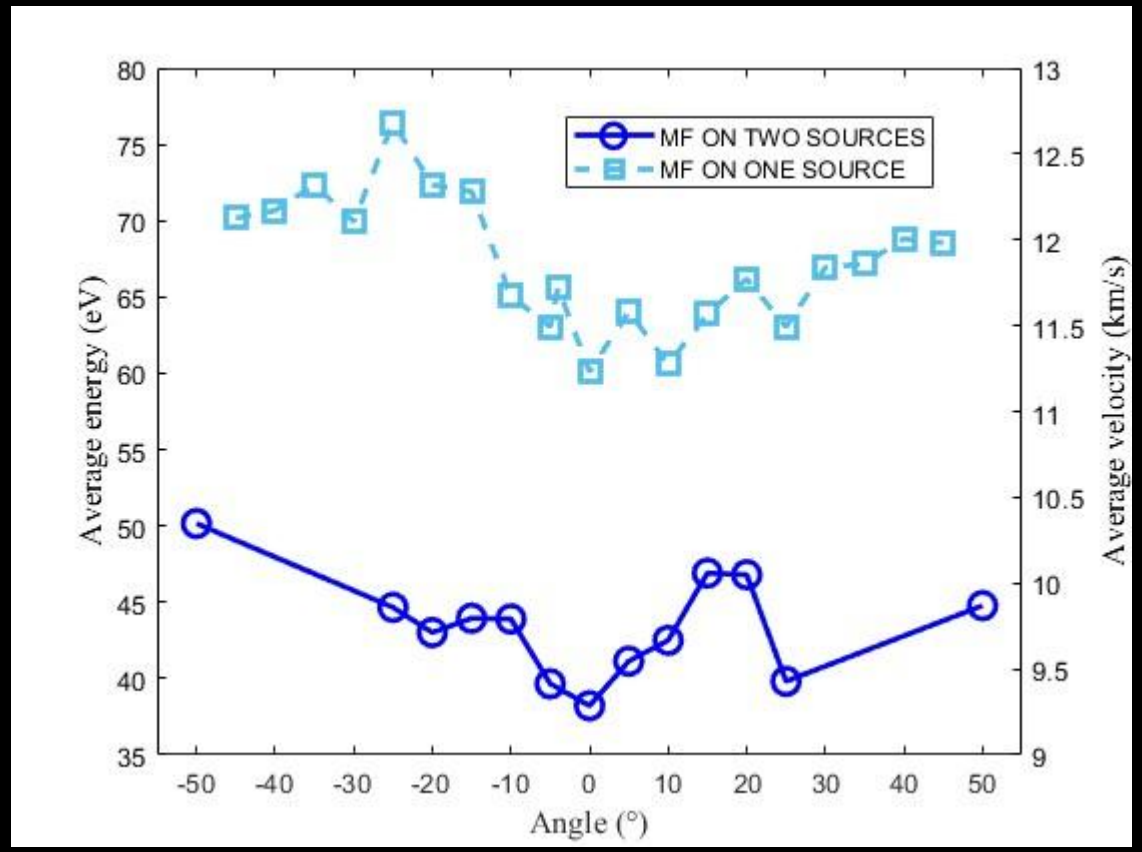
- Faraday cup measurements show the presence of high energy electrons, for a bias of 100 V.
- The angles for which they were collected ($|45°|$) matches with the intersection in between the magnetic field line coming from the inductor and the FC.
- Such phenomena have already been measured in various study, for waveguide and coaxial ECR thrusters.



Results - One source Thruster Comparison



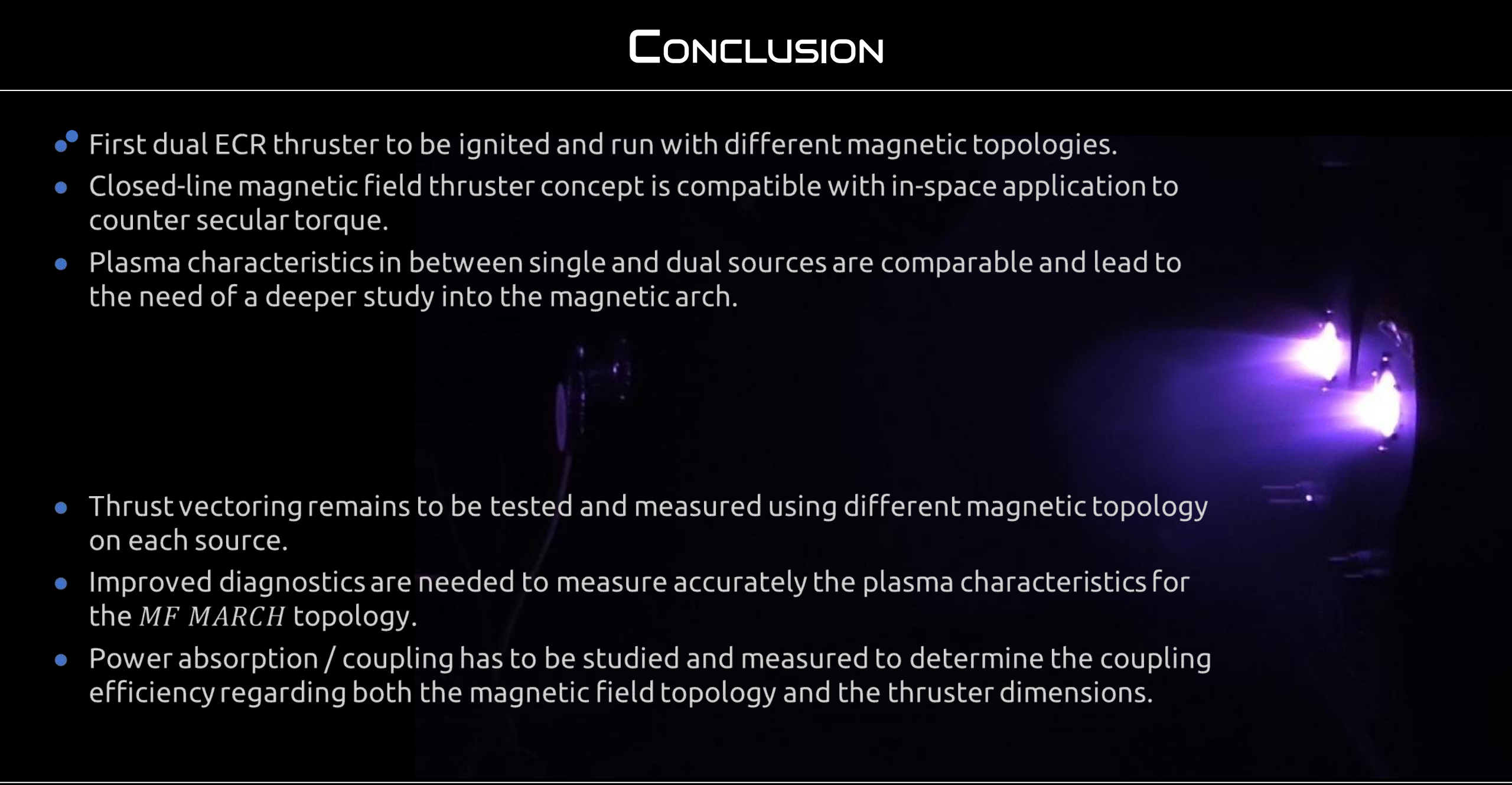
Comparison of the ion flux in between one and two sources.



Comparison of the average energy and velocity in between one and two sources.

Conclusion

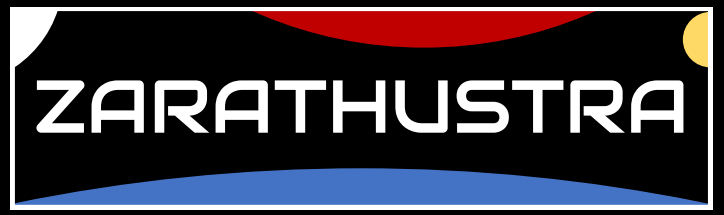
- First dual ECR thruster to be ignited and run with different magnetic topologies.
- Closed-line magnetic field thruster concept is compatible with in-space application to counter secular torque.
- Plasma characteristics in between single and dual sources are comparable and lead to the need of a deeper study into the magnetic arch.



- Thrust vectoring remains to be tested and measured using different magnetic topology on each source.
- Improved diagnostics are needed to measure accurately the plasma characteristics for the $MF\ MARCH$ topology.
- Power absorption / coupling has to be studied and measured to determine the coupling efficiency regarding both the magnetic field topology and the thruster dimensions.

Thank you!









Acknowledgments

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 950466)

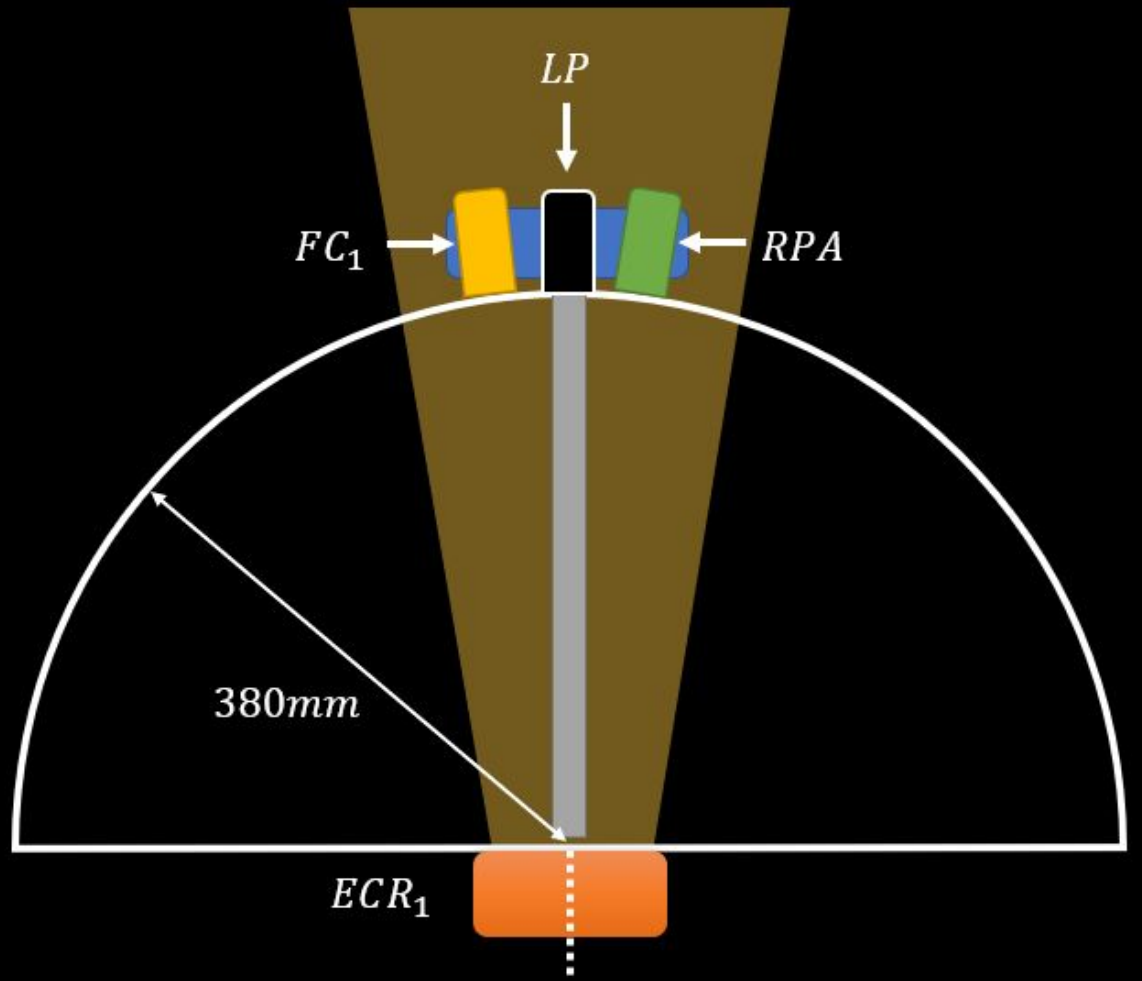


Experimental Setup

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  - *Measured quantities:* IED, $IEDF$, $\overline{E_i}$, I_{Tot}

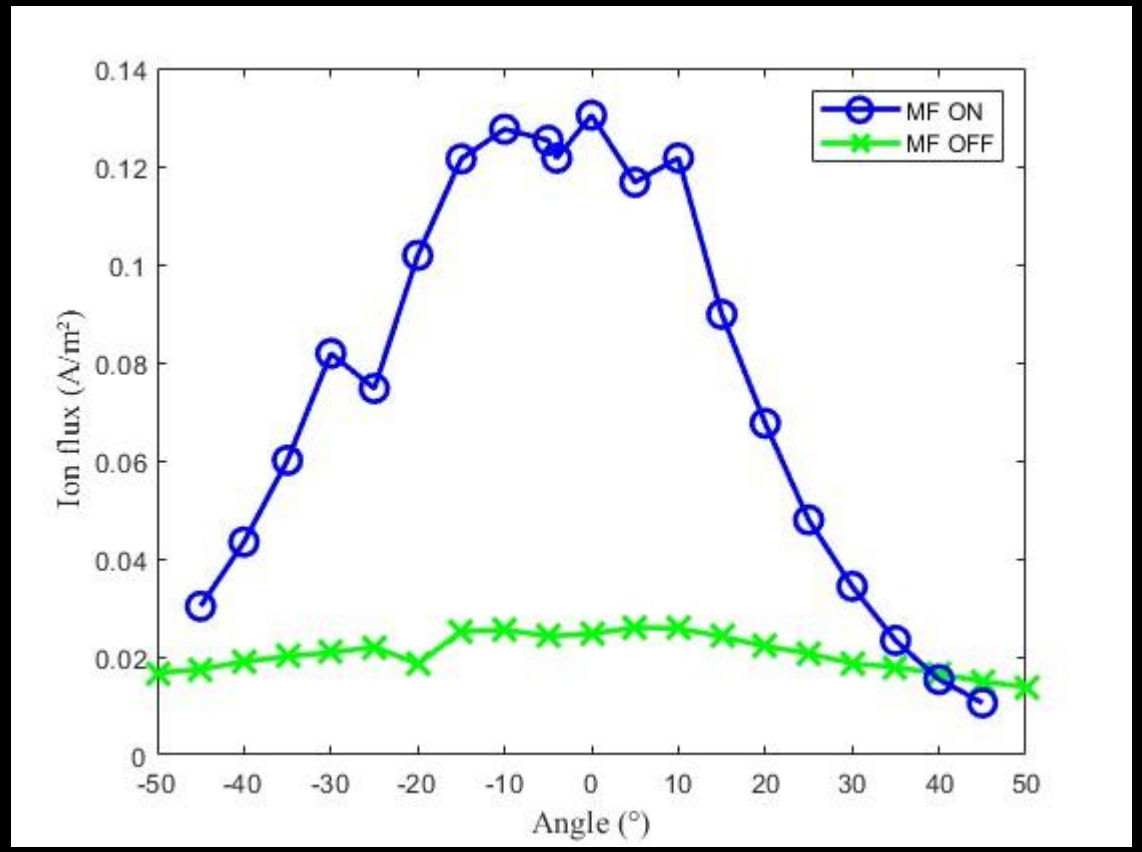
- ***FC*** characteristics:
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  - *Set of angles:* $[-90°:90°]$
  - *Measured quantities:* I_{tot}



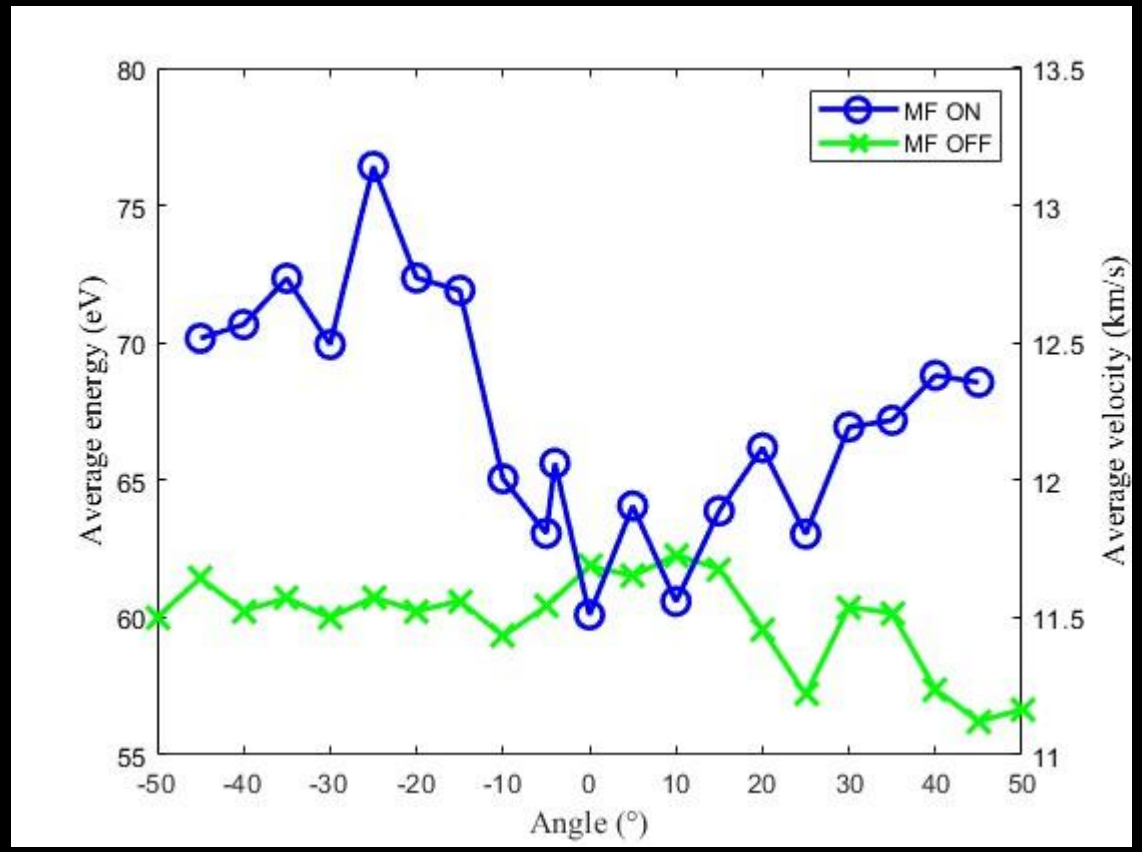
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- [3] J. Jarrige, P. Elias, F. Cannat, and D. Packan, “Characterization of a coaxial ECR plasma thruster,” in 44th AIAA Plasma Dynamics and Lasers Conference, San Diego (AIAA, 2013).
- [4] S. Peterschmitt and D. Packan, “Impact of the microwave coupling structure on an electron-cyclotron resonance thruster,” J. Propul. Power 37, 806–815 (2021).

Results - Presence of Hot Electrons



*Total ion flux of one source measured with the **RPA**.*



*Average energy and velocity of one source measured with the **RPA**.*