Semester Summary: Trapped Anti-Hydrogen

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ALPHA Collaboration

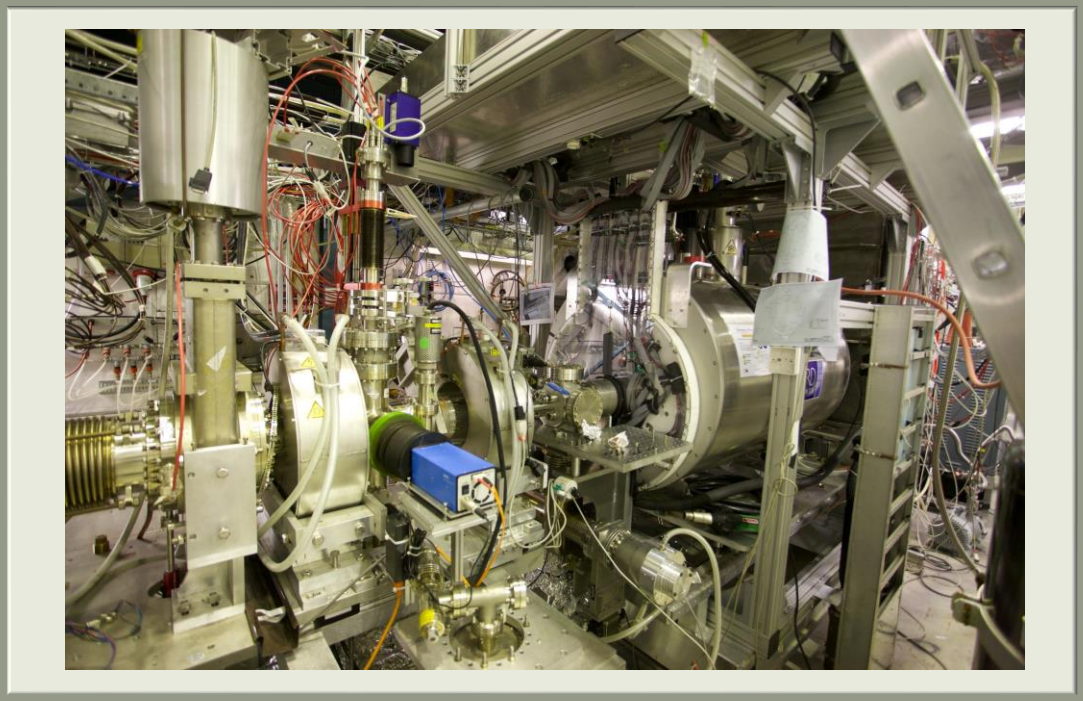
University of Michigan
Semester at CERN

What is ALPHA?

ALPHA:
Antihydrogen Laser Physics Apparatus

Goals:

- Create and trap antihydrogen
- Perform spectroscopy on antihydrogen
- Explore antisymmetries in matter and antimatter
- Test CPT violation



Summary of Projects

Projects:

- Heater and Bakeout Control
- Plasma Optimization
- Setting Up Microwave Hardware

Bakeout and Heater Control

Why Bakeout: Antimatter and Vacuums

Antimatter and Annihilations:

$$e^- + e^+ \rightarrow \gamma + \gamma$$

Need low pressure to in order to effectively trap antiprotons and positrons

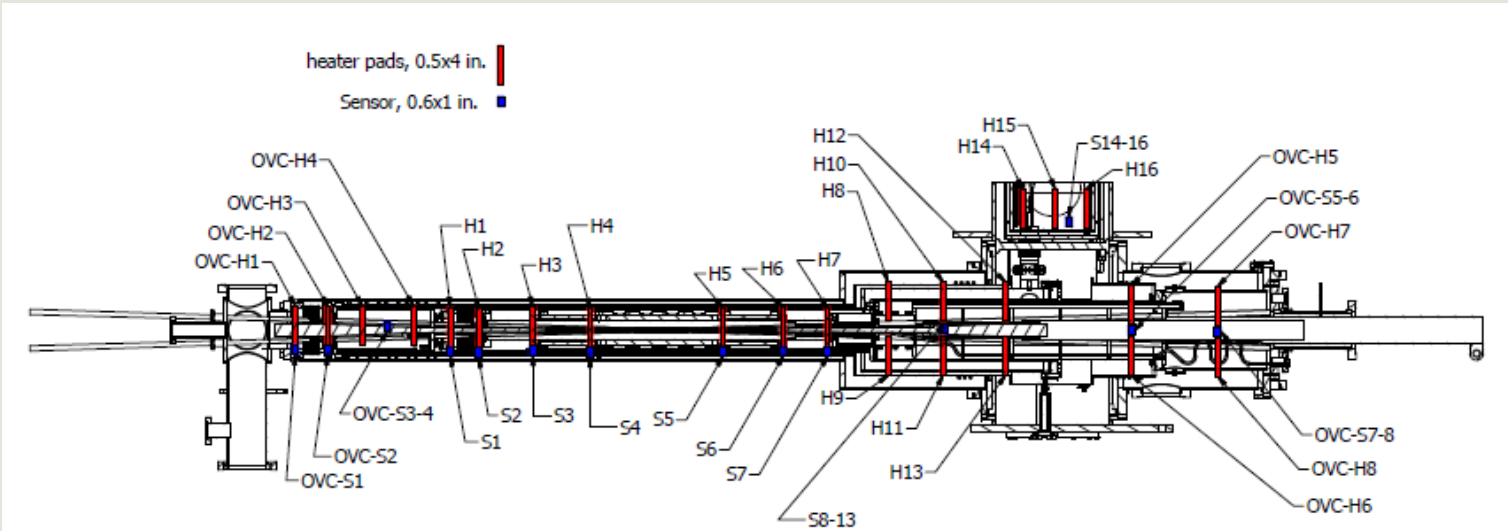
$$\sigma = 3\sqrt{2}\pi a_0^2 \sqrt{\frac{27.2\text{eV}}{E}}$$

$$\Gamma = \frac{1}{\tau} = n_{gas} v \sigma$$

$$P = \left(3\sqrt{2}\pi a_0^2 \sqrt{\frac{27.2\text{eV}}{m_{\bar{p}}}} \right)^{-1} \frac{k_B T}{\tau}$$

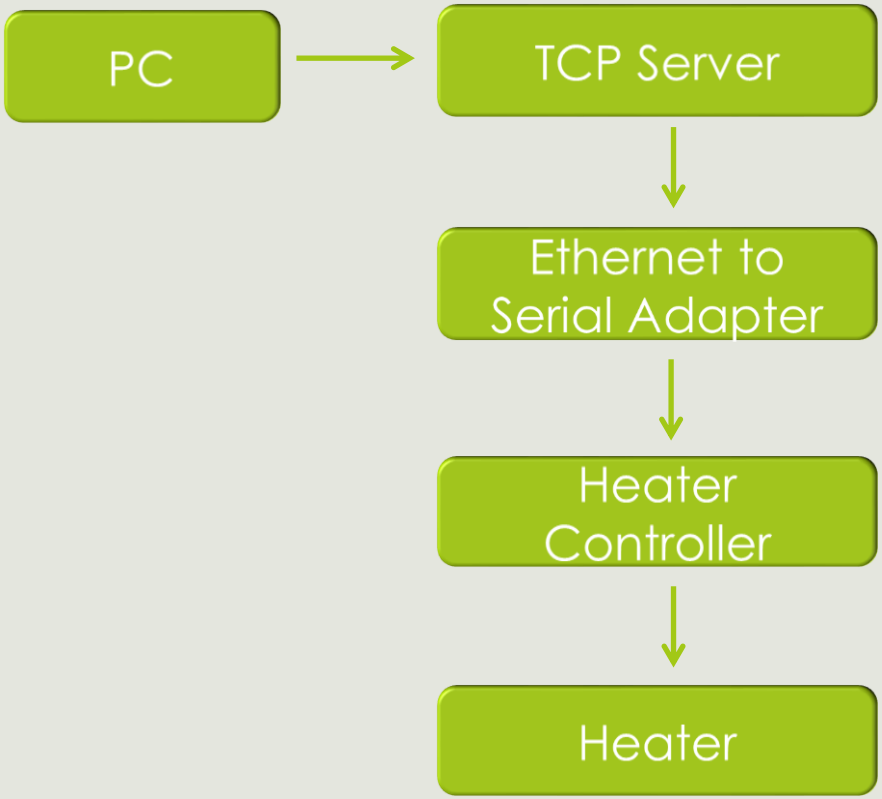
Given an estimated gas temperature of 10K and the length of of the experiment at 15 minutes, a pressure of better than 8e-13 mbar is needed.

Bakeout Hardware

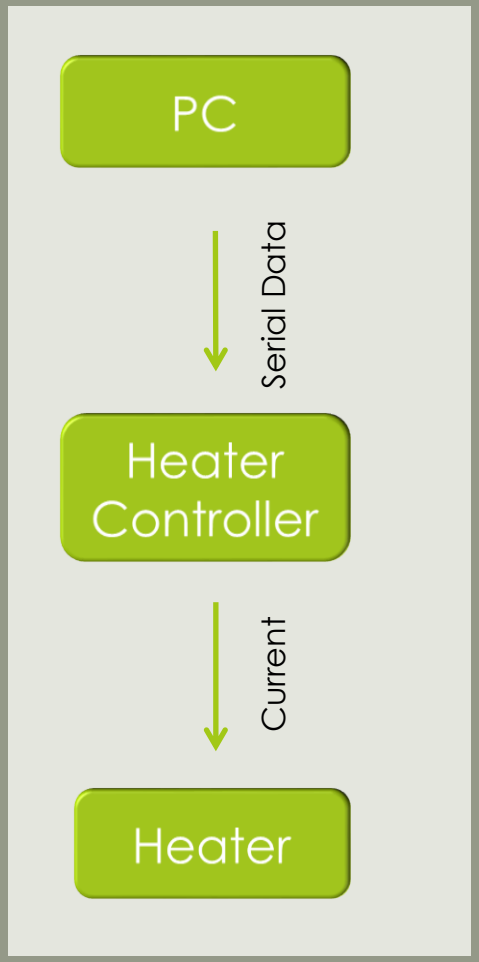


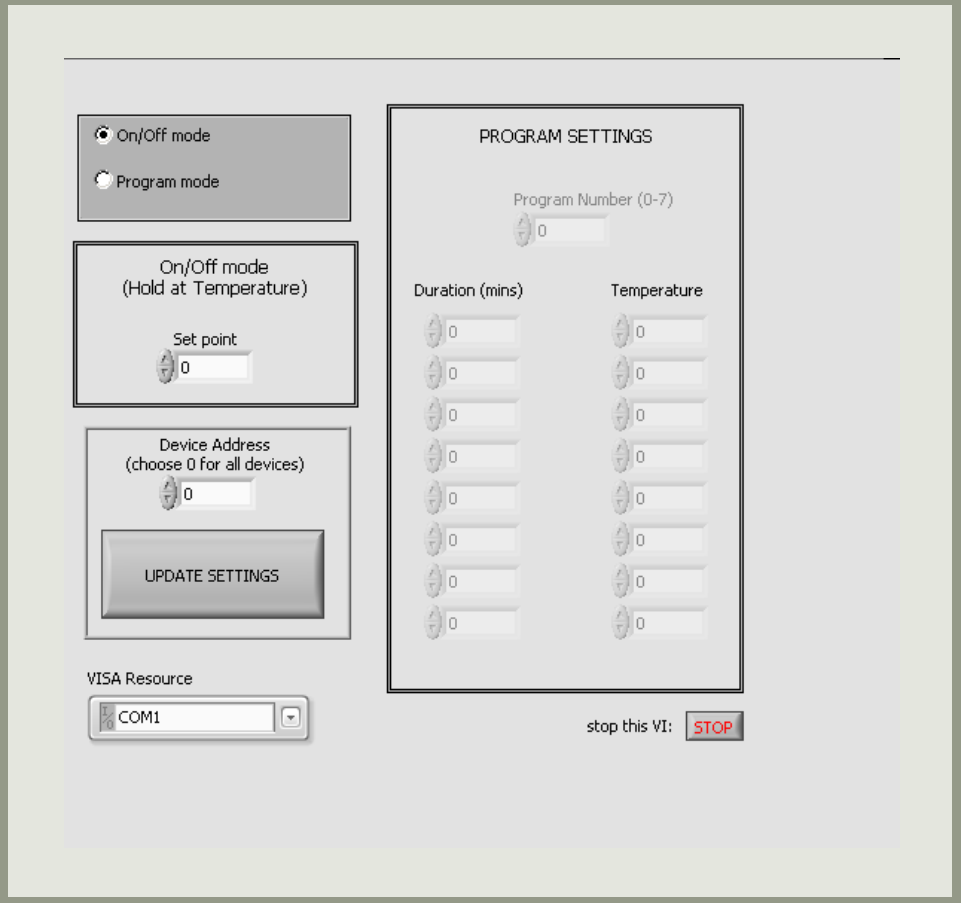
Heater and sensor placements.

Previous Heater Control Schematic



New System


PC
Serial Data
Heater Controller
Current
Heater


On/Off mode
Program mode
On/Off mode
(Hold at Temperature)
Set point
0
Device Address
(choose 0 for all devices)
0
UPDATE SETTINGS
VISA Resource
COM1
PROGRAM SETTINGS
Program Number (0-7)
0
Duration (mins)
Temperature
stop this VI:
STOP

Plasma Optimization

Anti-Hydrogen Formation

Radiative Recombination

$$\sigma_{\mathrm{RR}} = 2 \times 10^{-22}\ \mathrm{cm}^2\ \frac{\epsilon_0}{nE_e/\epsilon_0}$$

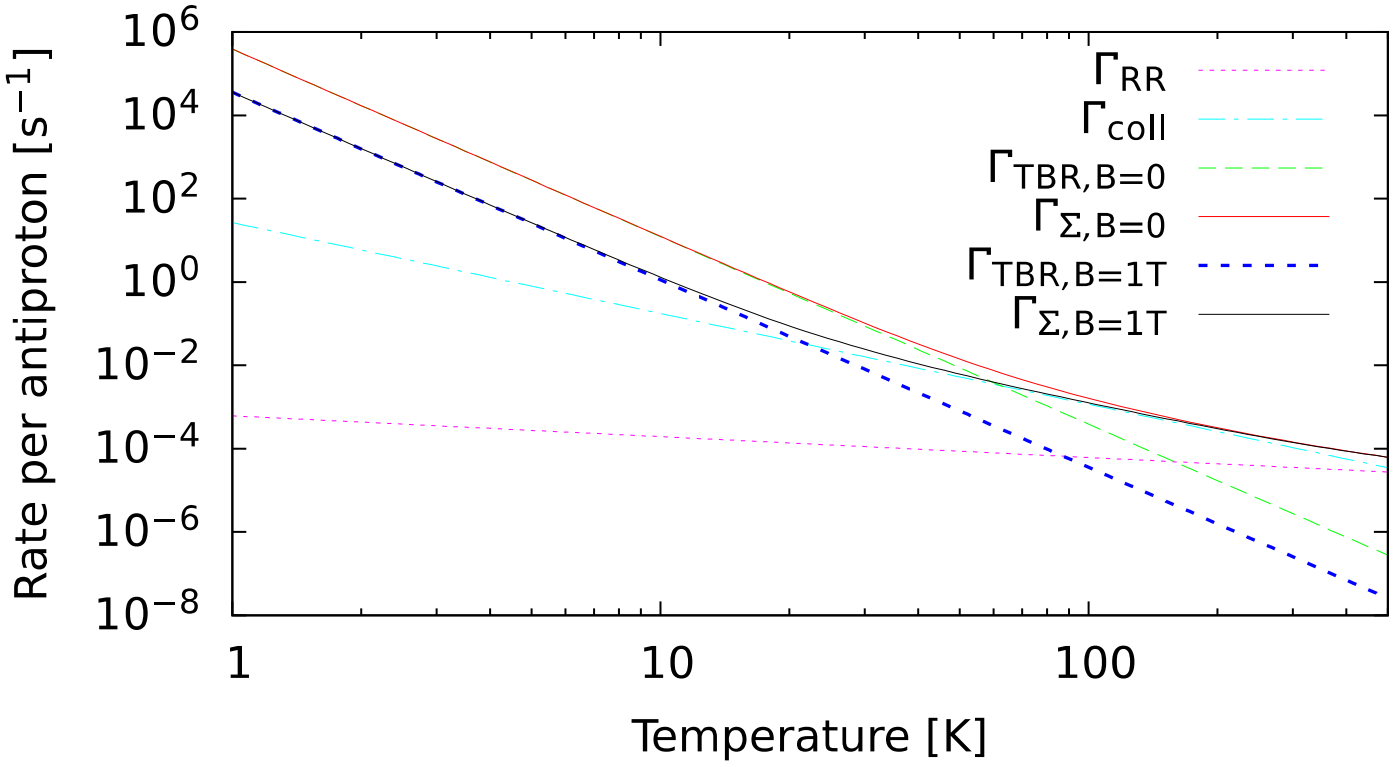
$$\Gamma_{\mathrm{RR}} = 3 \times 10^{-11} \sqrt{\frac{4.2\mathrm{K}}{\mathrm{T}}} \frac{n_e}{\mathrm{cm}^{-3}}\ \mathrm{s}^{-1}$$

Three Body Recombination

$$\Gamma_{\mathrm{TBR}} = 8 \times 10^{10} \left(\frac{4.2\mathrm{K}}{T}\right)^{2.18} \left(\frac{n}{\mathrm{cm}^3}\right)^{1.37} \mathrm{s}^{-1}$$

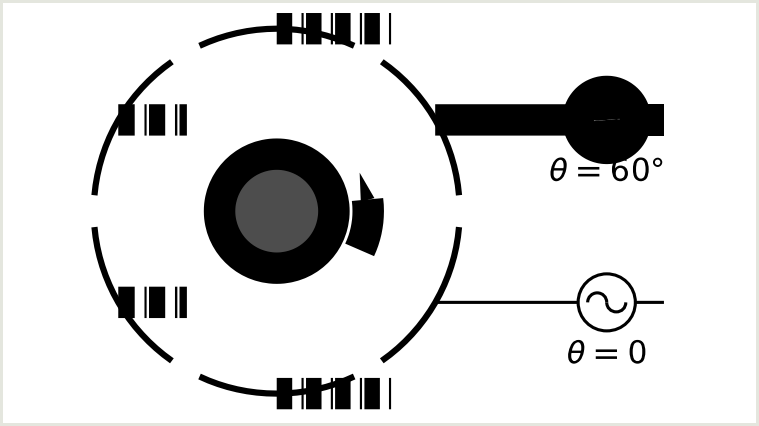
Small, dense, and cold plasmas will maximize anti-hydrogen formation rates

Formation Rates

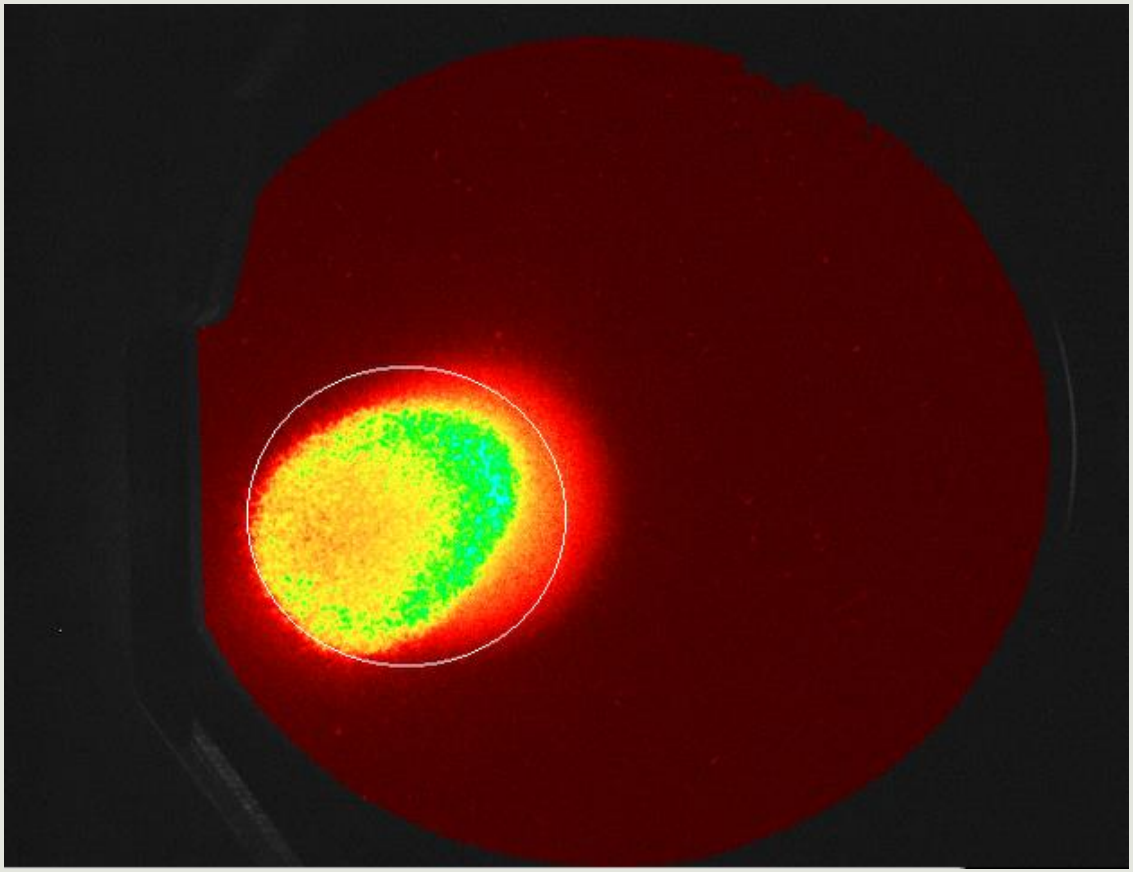


Rotating Wall

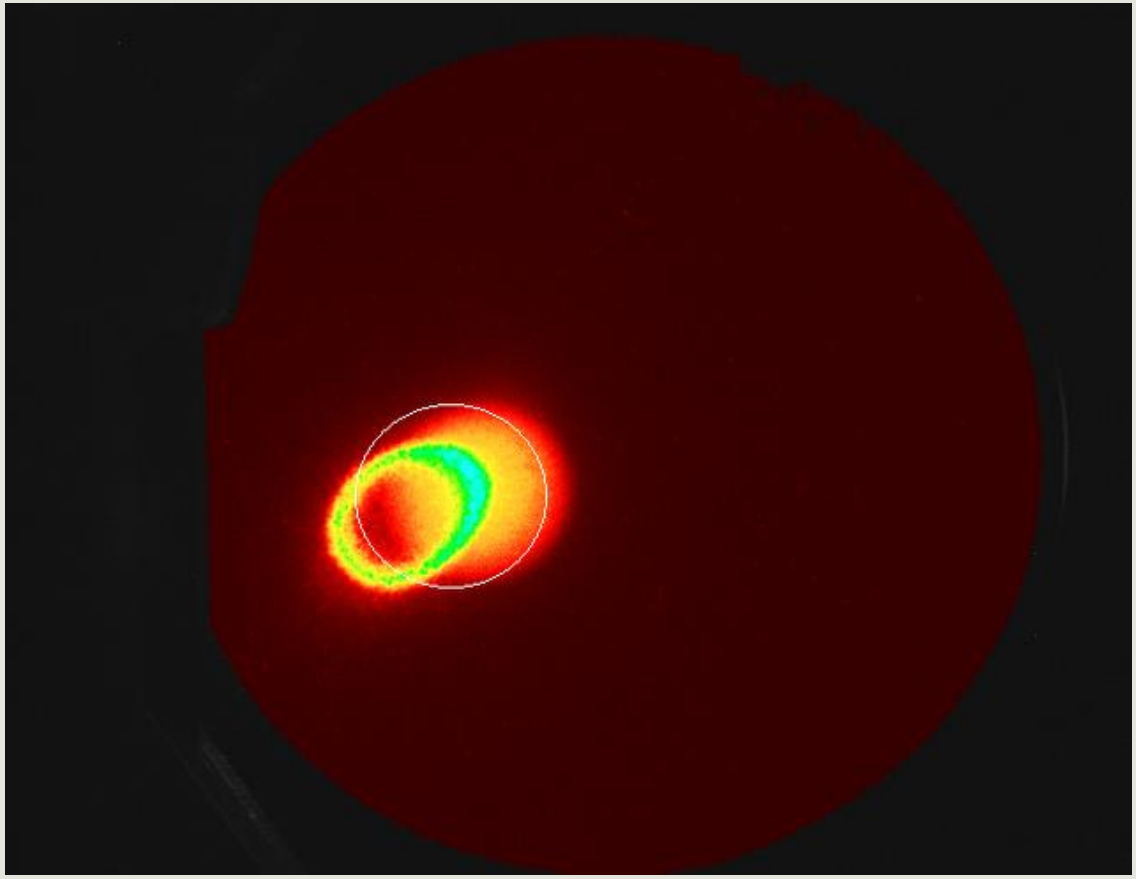
$$\omega_r = \frac{\mathbf{F} \times \mathrm{B}}{B^2} = \frac{en}{2\epsilon_0} \frac{r}{B_z}$$



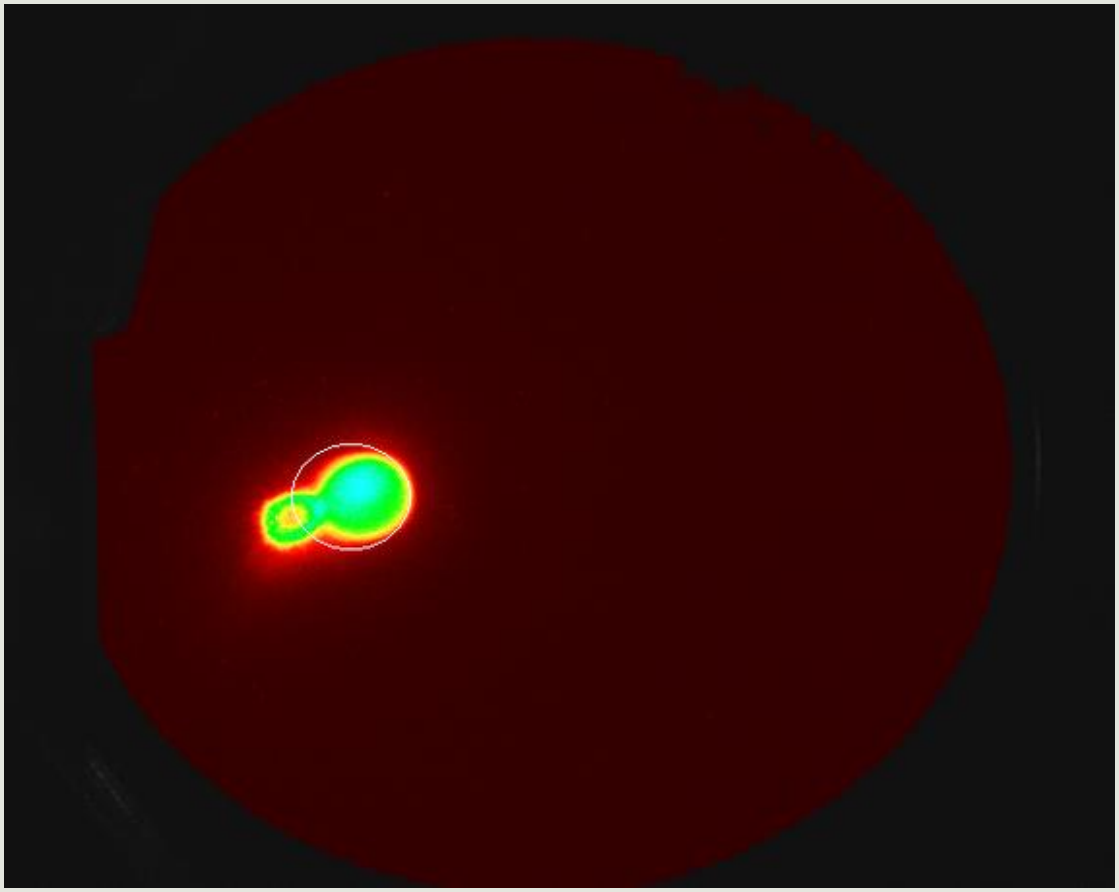
Uncompressed Plasmas



Partially Compressed, Centrifugally Separated



Fully Compressed Plasmas

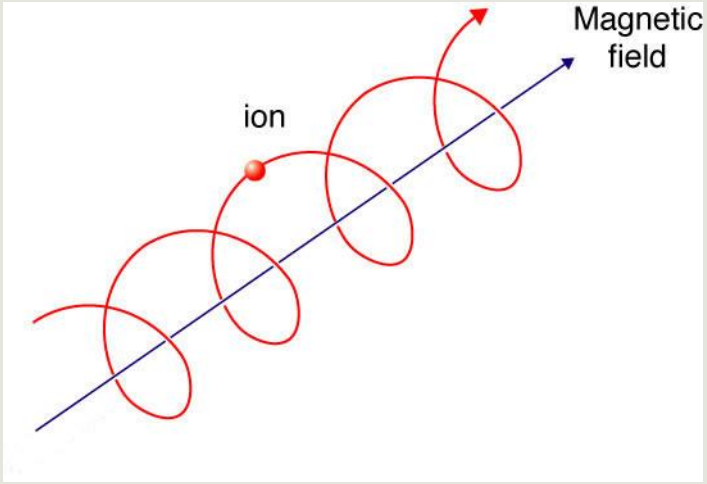


Cooling

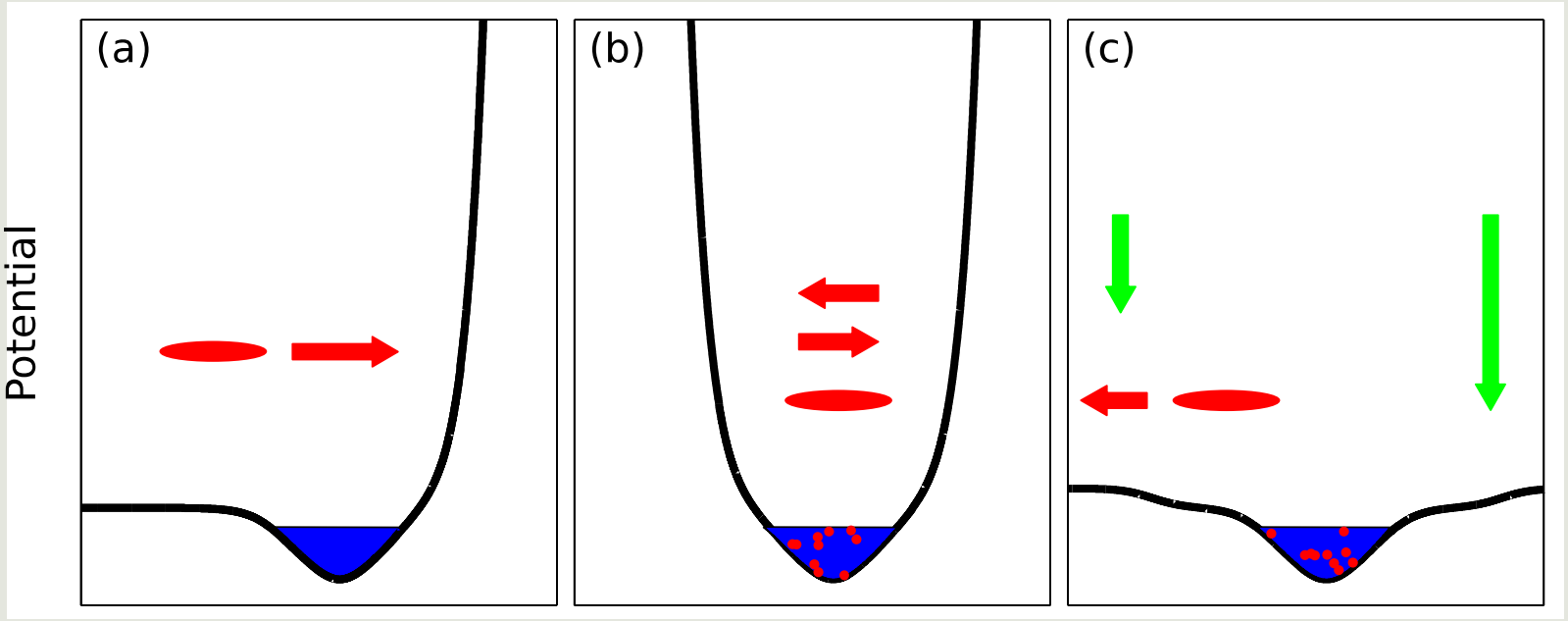
$$\mathbf{F} = q\left(\mathbf{E} + \mathbf{v} \times \mathbf{b}\right)$$

$$r_L = \frac{mv_\perp}{|q|B}$$

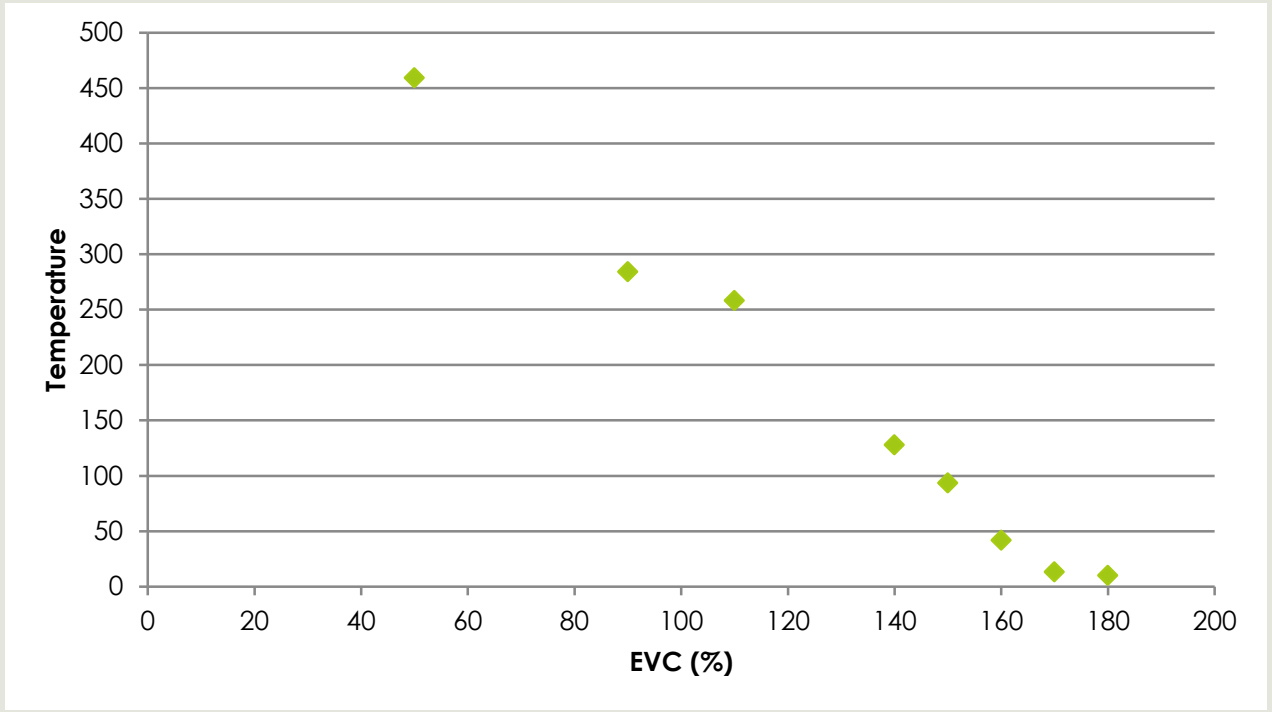
$$\frac{-dE}{dt} = \frac{\sigma_t B^2 v^2}{c\mu_0} \propto \frac{1}{m^4}$$



Evaporative and Sympathetic Cooling



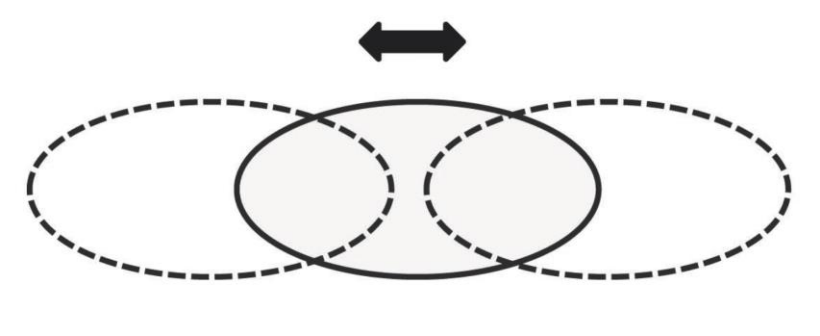
Evaporative Cooling



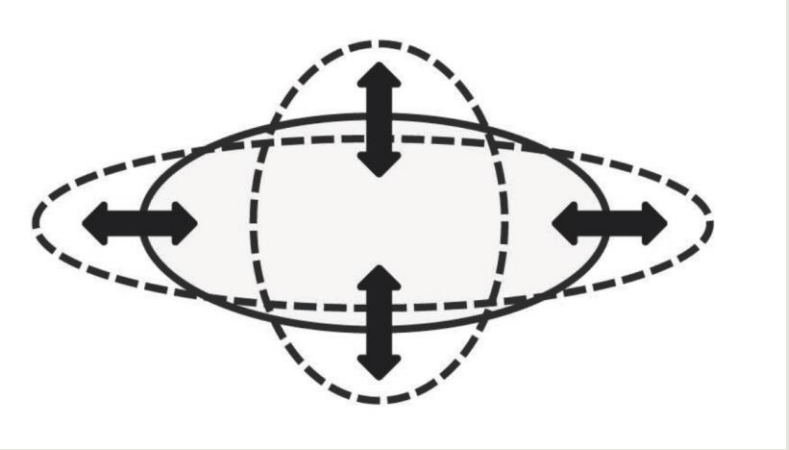
Plasma Modes and Microwaves

Dipole and Quadrupole Modes

Dipole



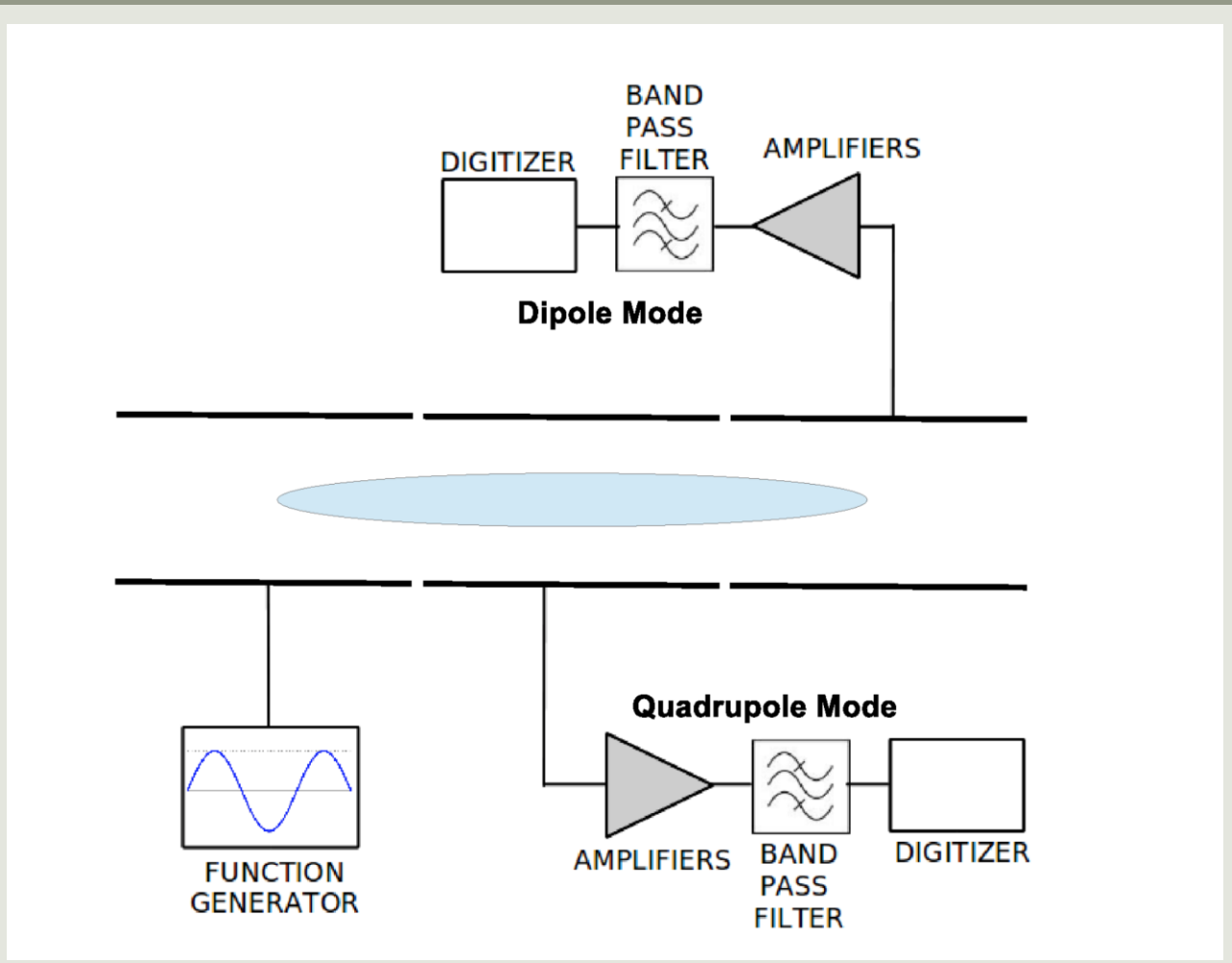
Quadrupole



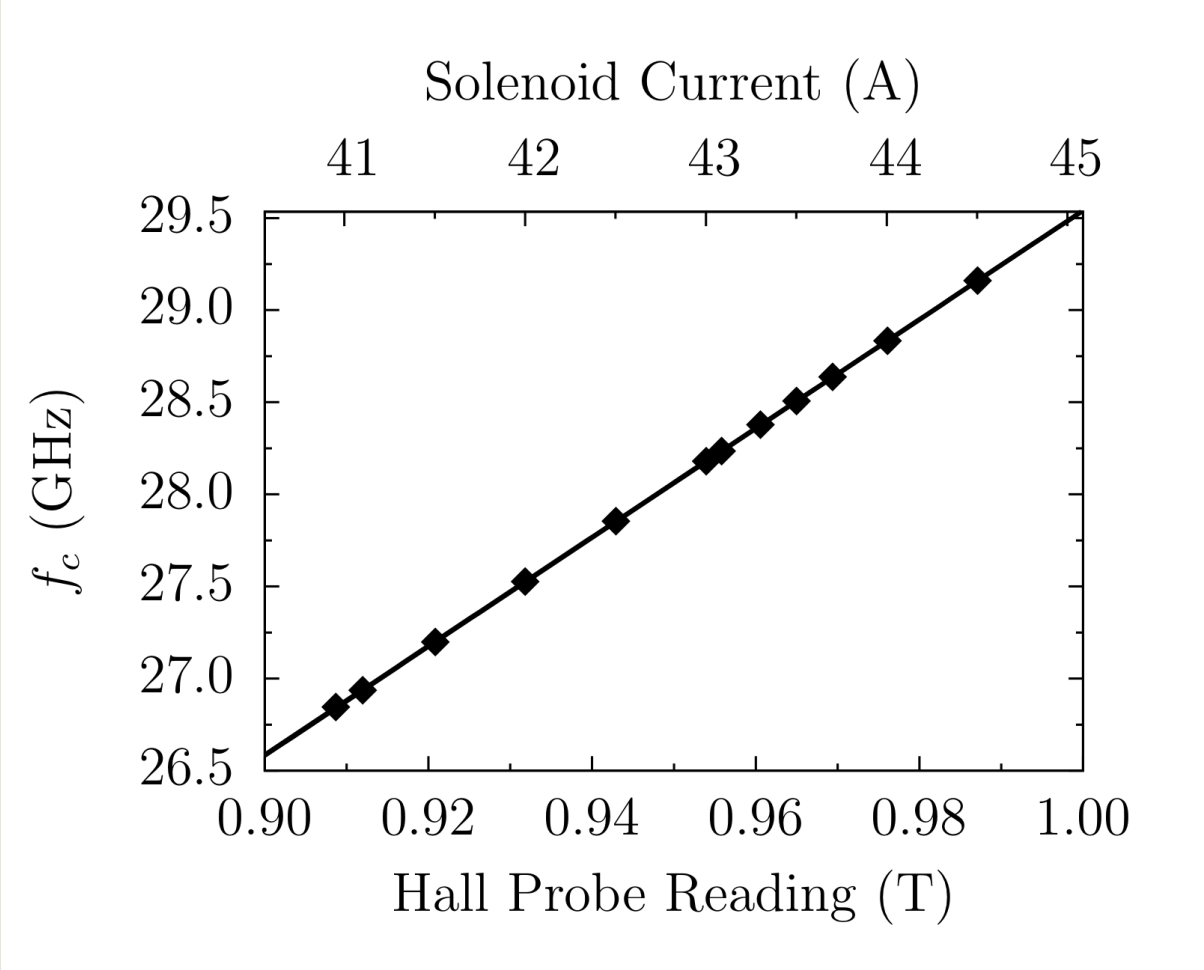
$$f_c = qB/2\pi m$$

$$\Delta f_{c,l} = \left[l - 1 - \left(\frac{r_p}{r_w} \right)^{2l} \right] f_r$$

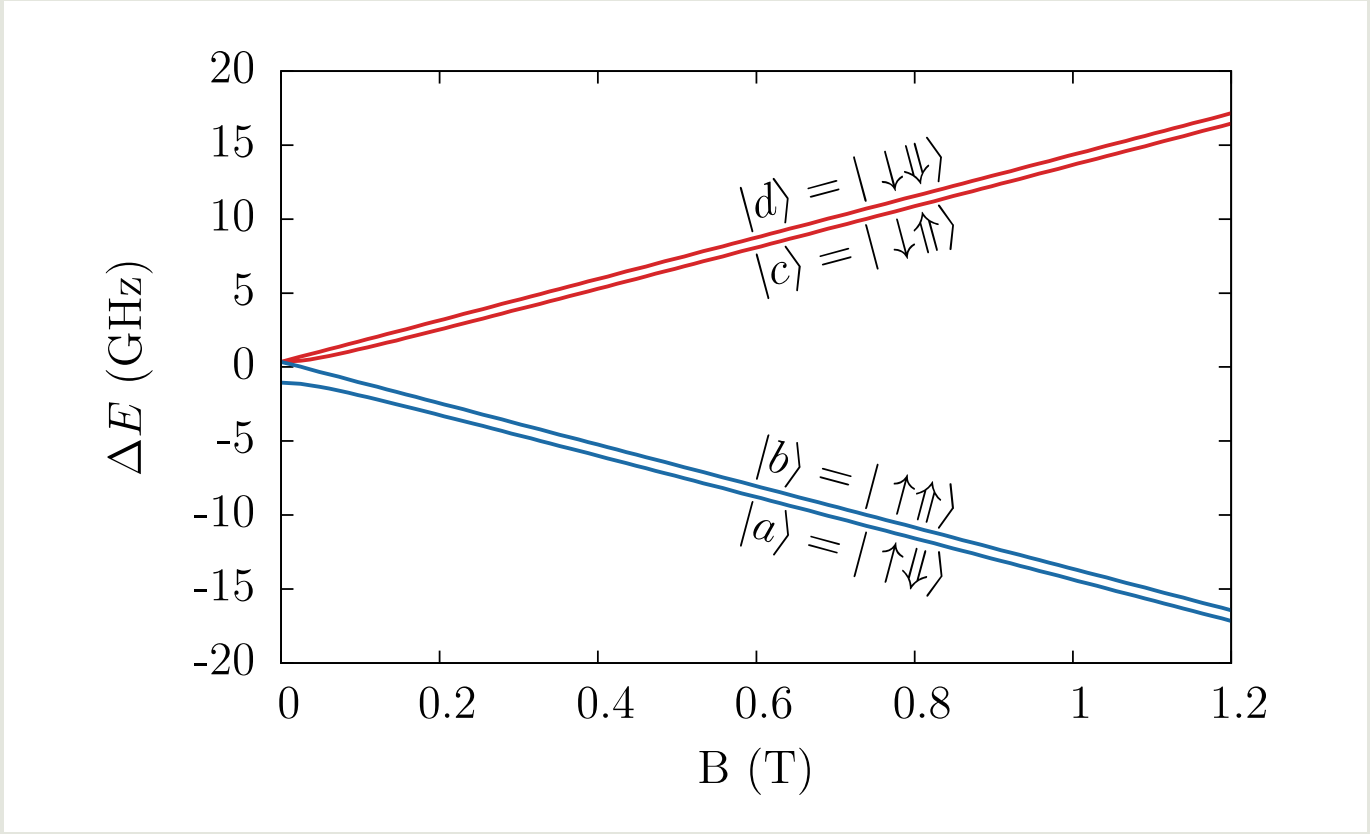
Nondestructive Plasma Measurement



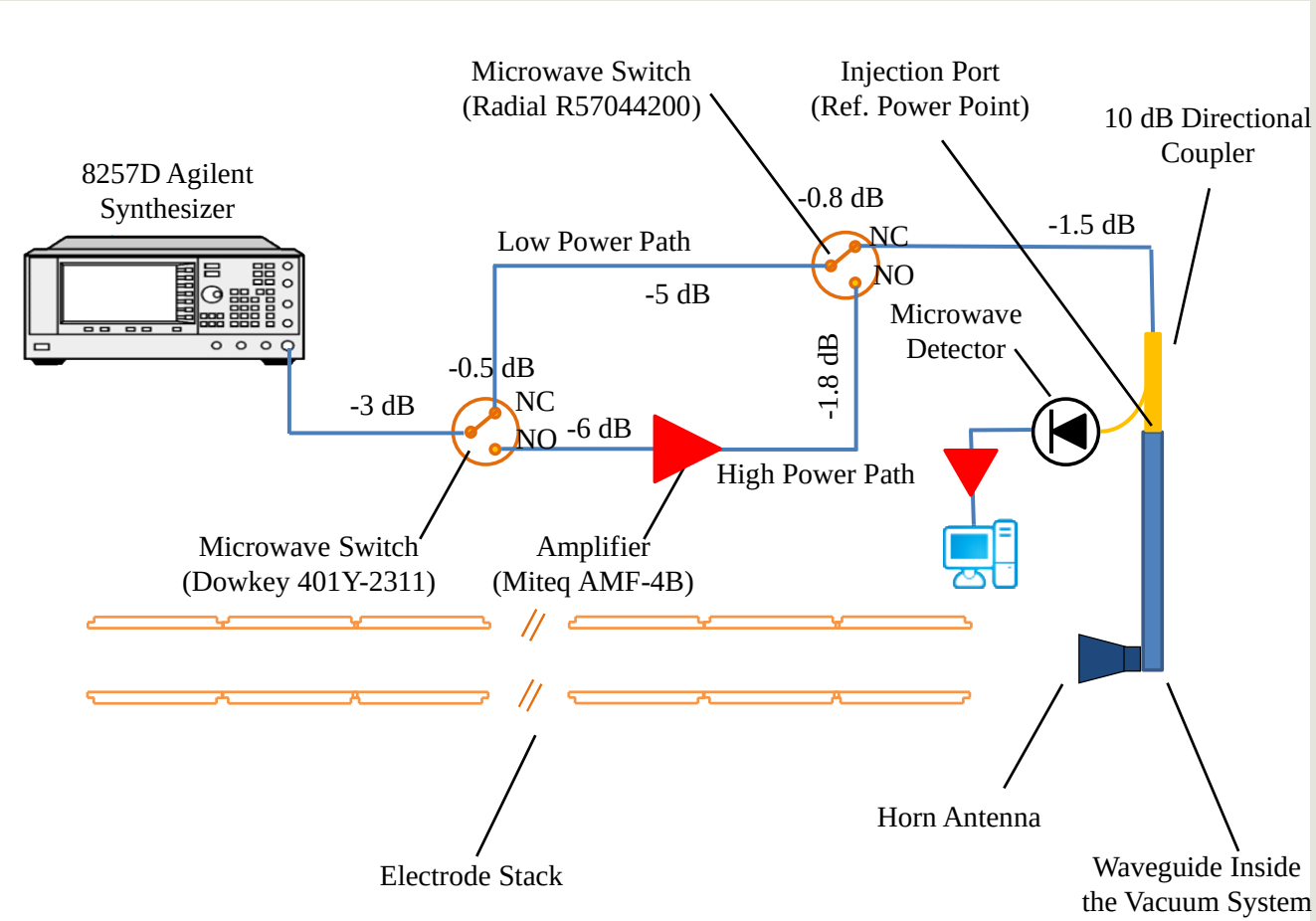
Magnetic Field Characterization



Positron Spin Flip



Microwave Hardware



Acknowledgements

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