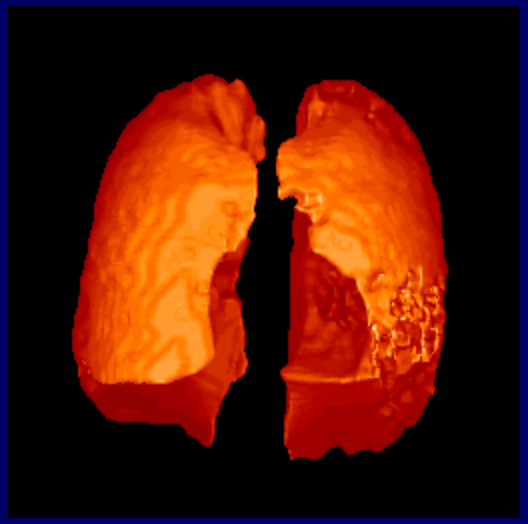
Design of a Hybrid ^{3}He Polarizer:
Measurement Techniques and Construction

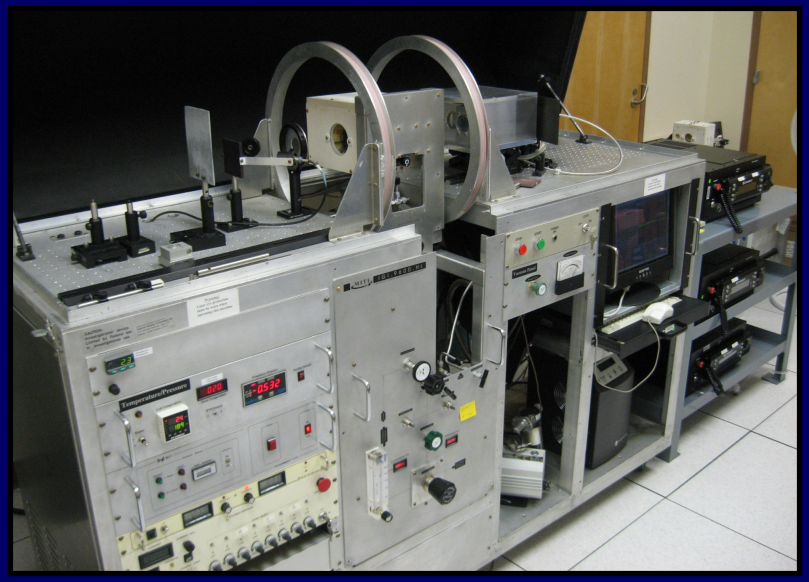


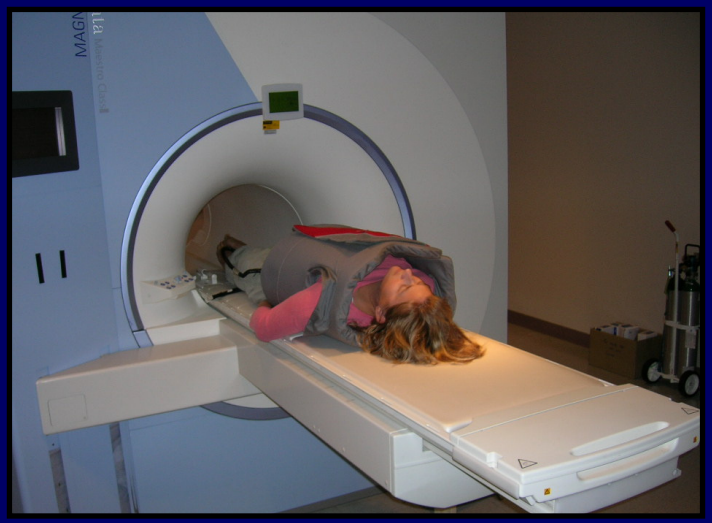
Karen Mooney

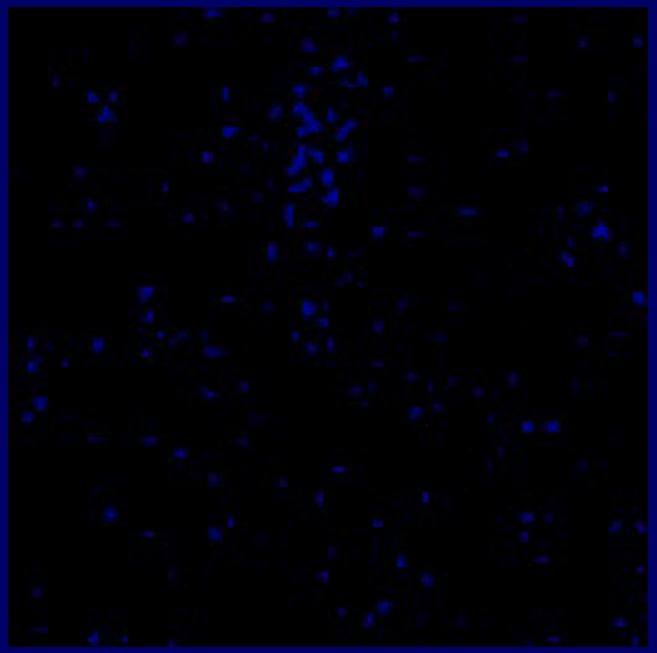
University of Virginia

March 25, 2008

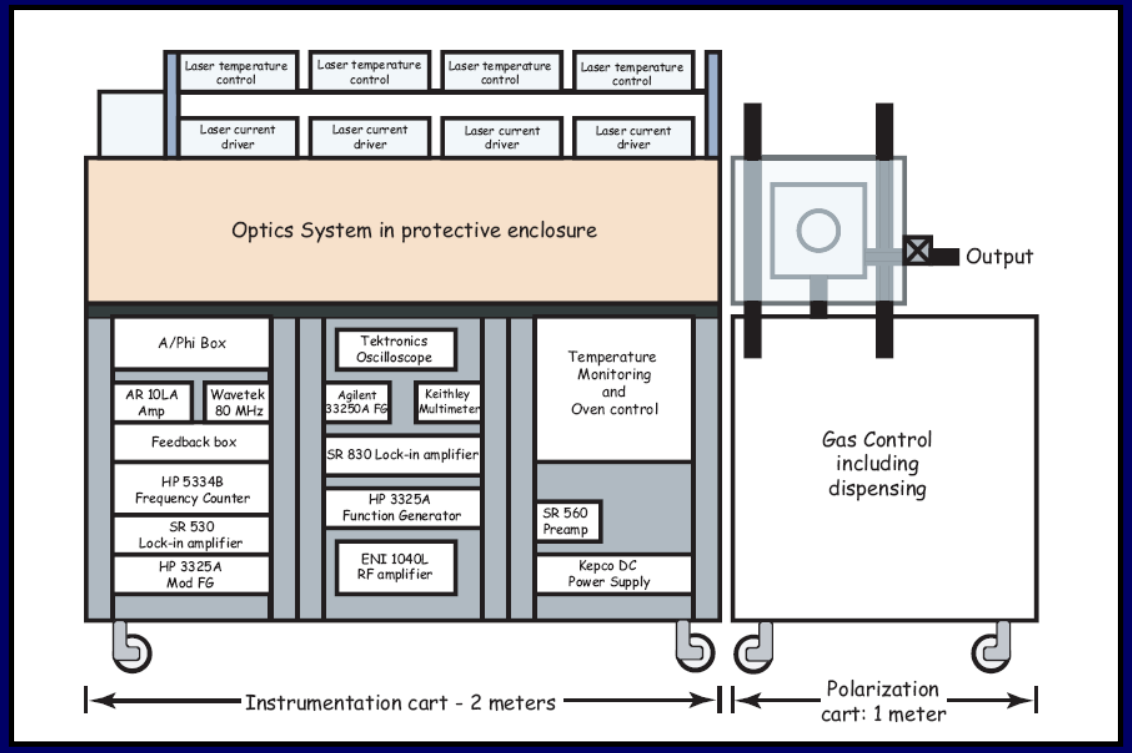
Polarizer Basics







New Polarizer Advancements



More Gas

- 3.0L/day Vs 1.0L/day

Higher Polarization

- 60% Vs 40%
- Rb-K Hybrid Cell
- Narrowed Diode Lasers

Enhanced Diagnostics

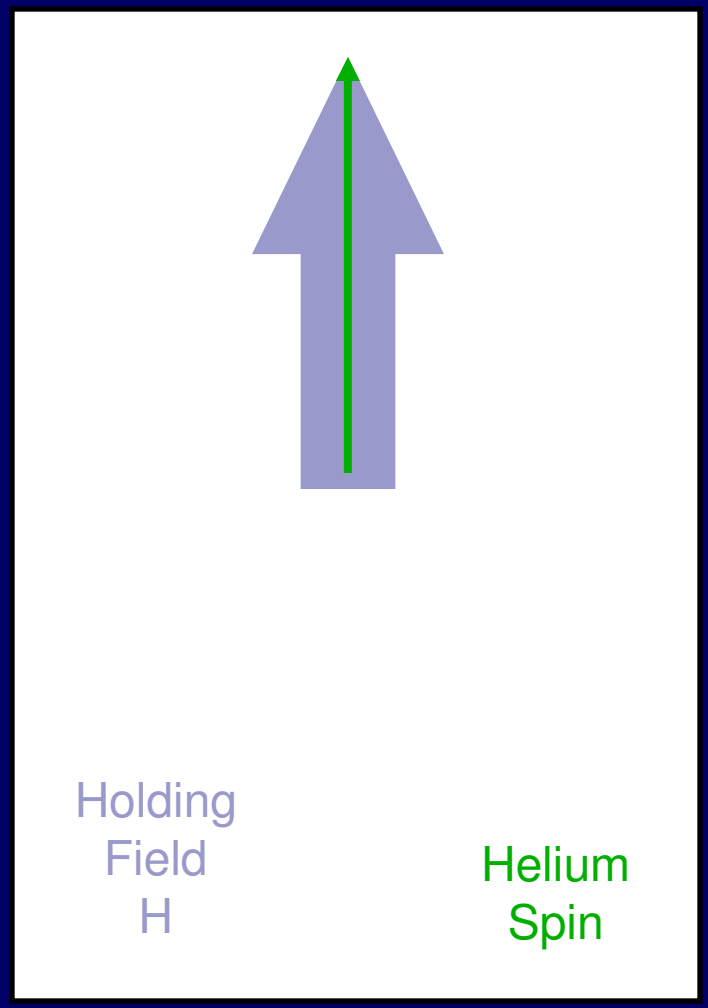
- AFP NMR w/ EPR calibration

Vs

Pulse NMR w/ Water calibration

Nuclear Magnetic Resonance (NMR)

- Polarized ^{3}He nuclei are aligned with an external magnetic field
- He Nuclear Spins are “flipped” by applying a transverse RF Field
- Faraday Induction signal detected in mutually perpendicular coils
- Signal detected is proportional to ^{3}He polarization



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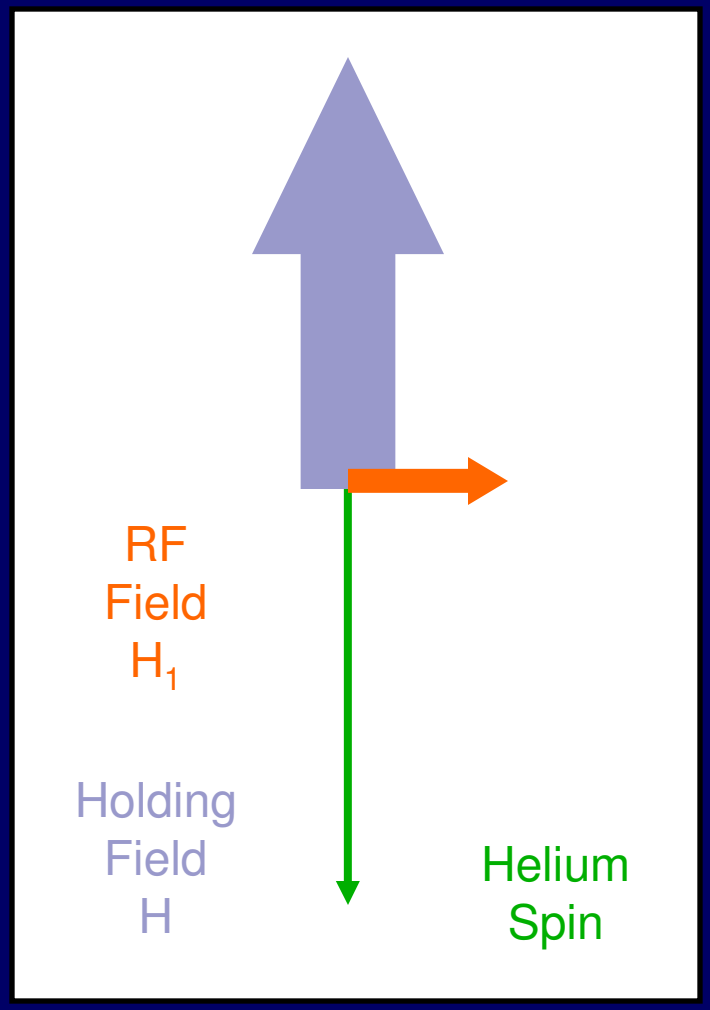


Adiabatic Fast Passage

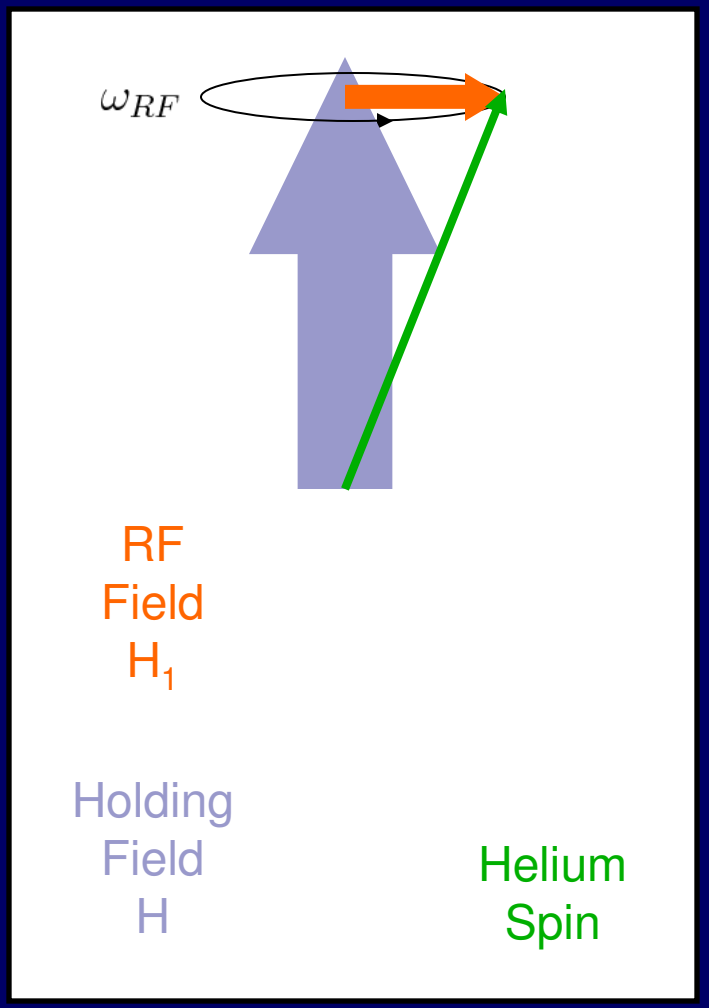
$$\overrightarrow{H}_{eff} = (H(t) - H_0)\hat{z} + H_1(\omega_{RF})\hat{x}$$

$$H_0 = \gamma\omega_{RF}$$

ω_{RF} is fixed, H is swept through H_0

Field Sweep

$12.6 \leftrightarrow 21.5$ Gauss



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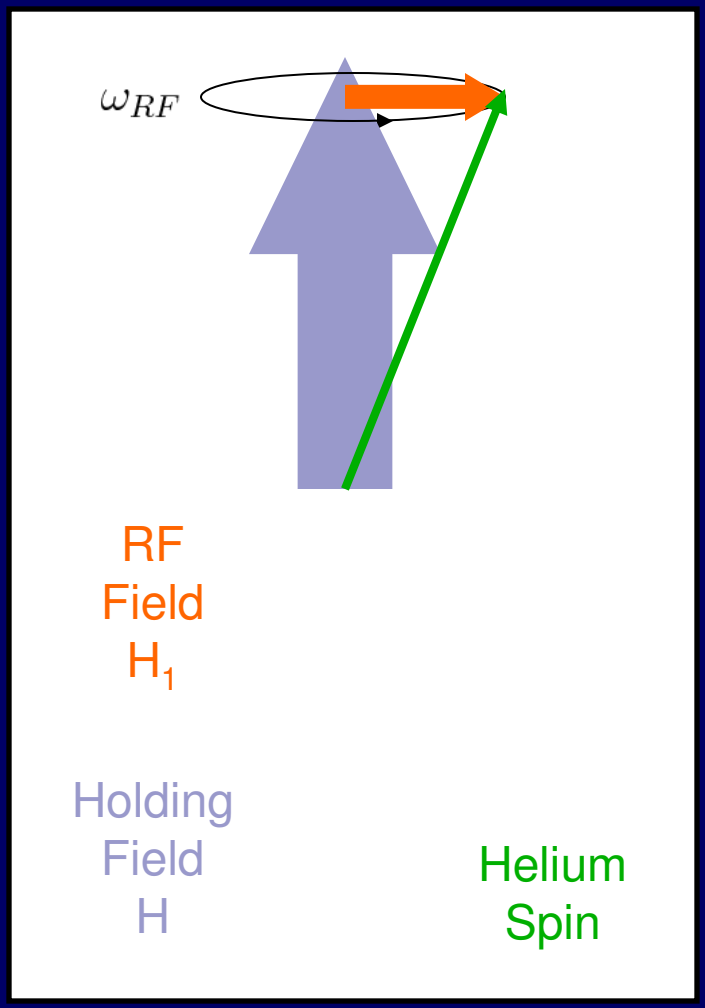
$$H_0 > H$$



AFP

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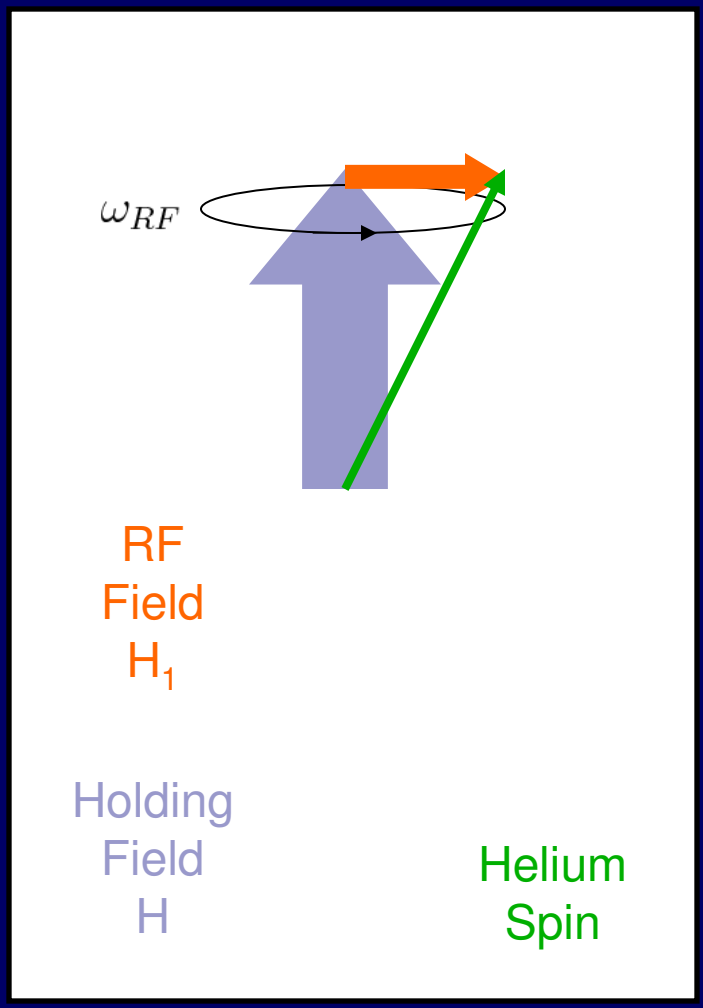

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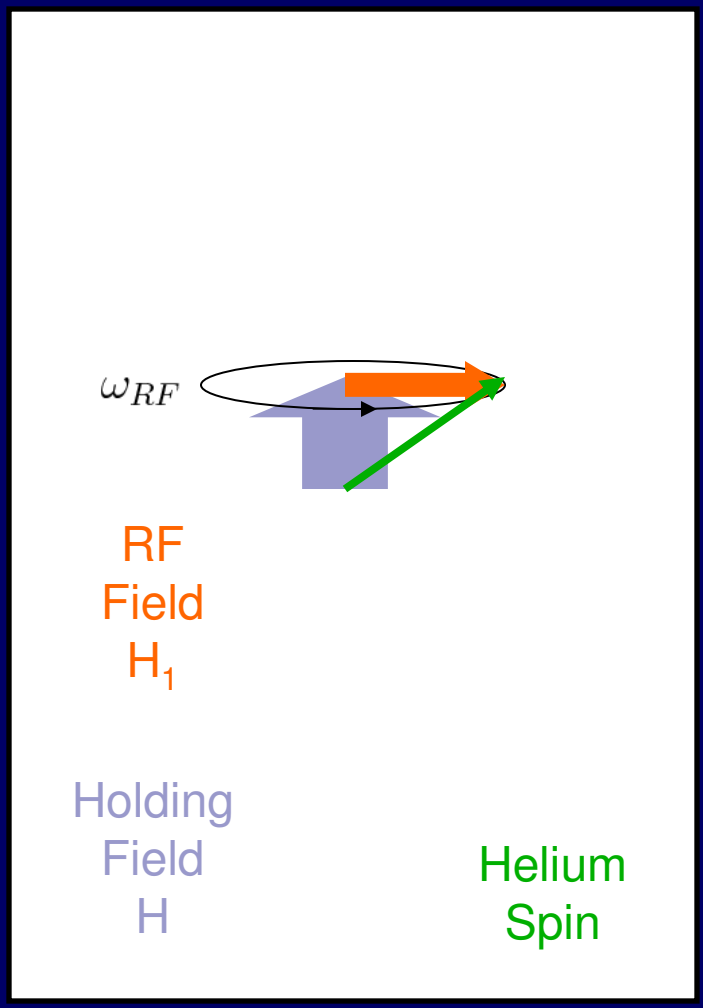

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$$\vec{H}_{eff} = (H(t) - H_0)\hat{z} + H_1(\omega_{RF})\hat{x}$$

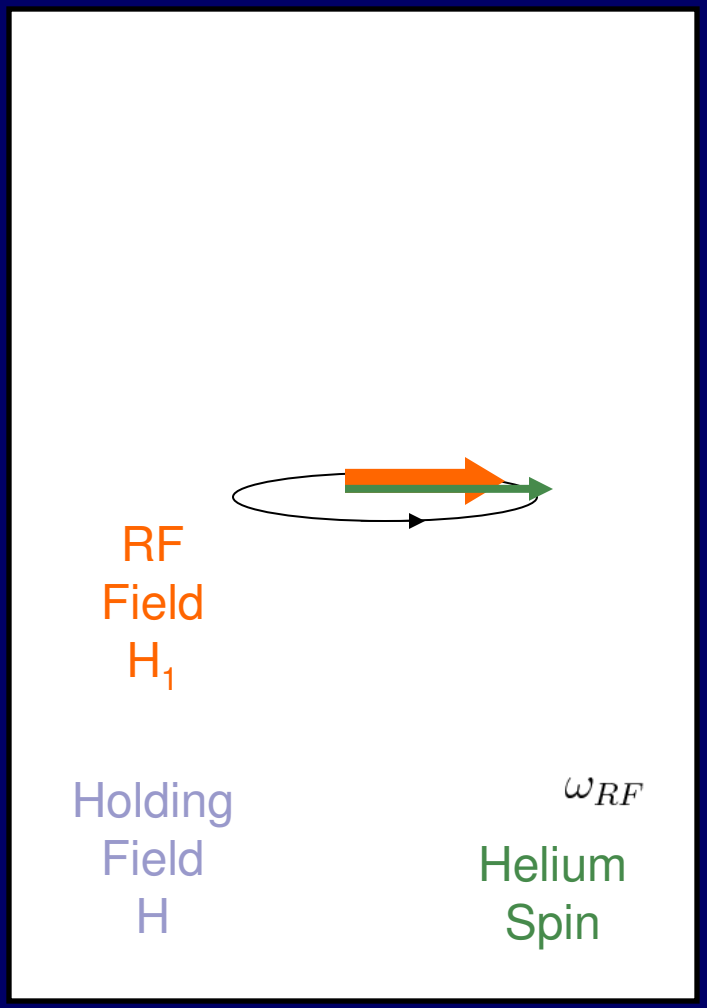
$$H_0 > H$$

$$H_0 = H$$

Typical Lab Values

$\omega_{RF} = 56.6$ kHz

$B_0 \approx 17$ Gauss



AFP

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$H_0 > H$

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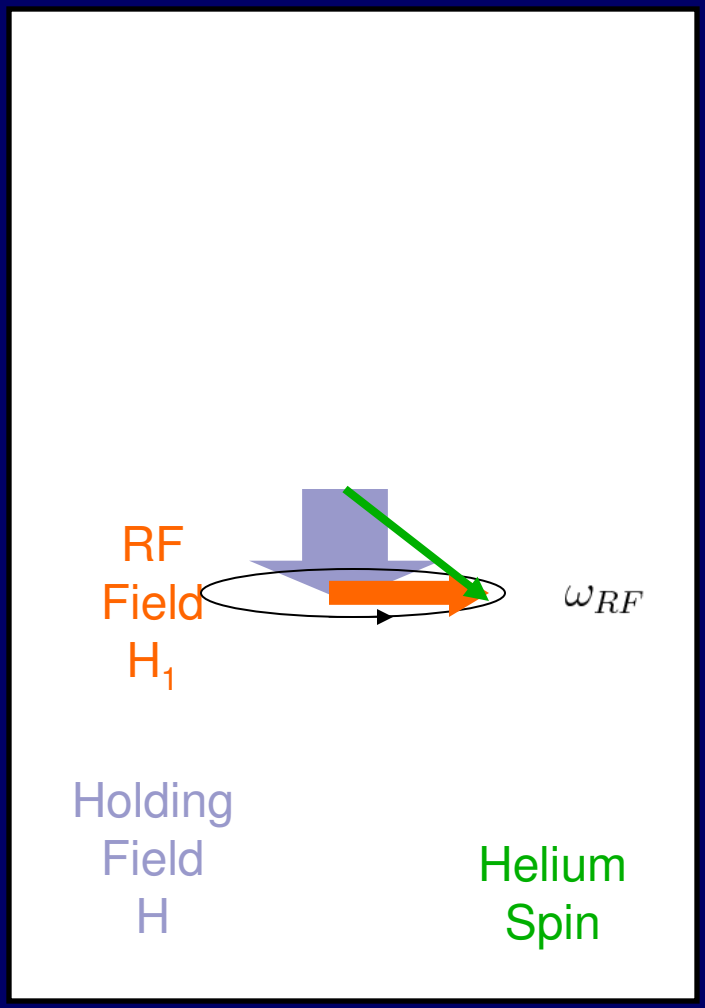

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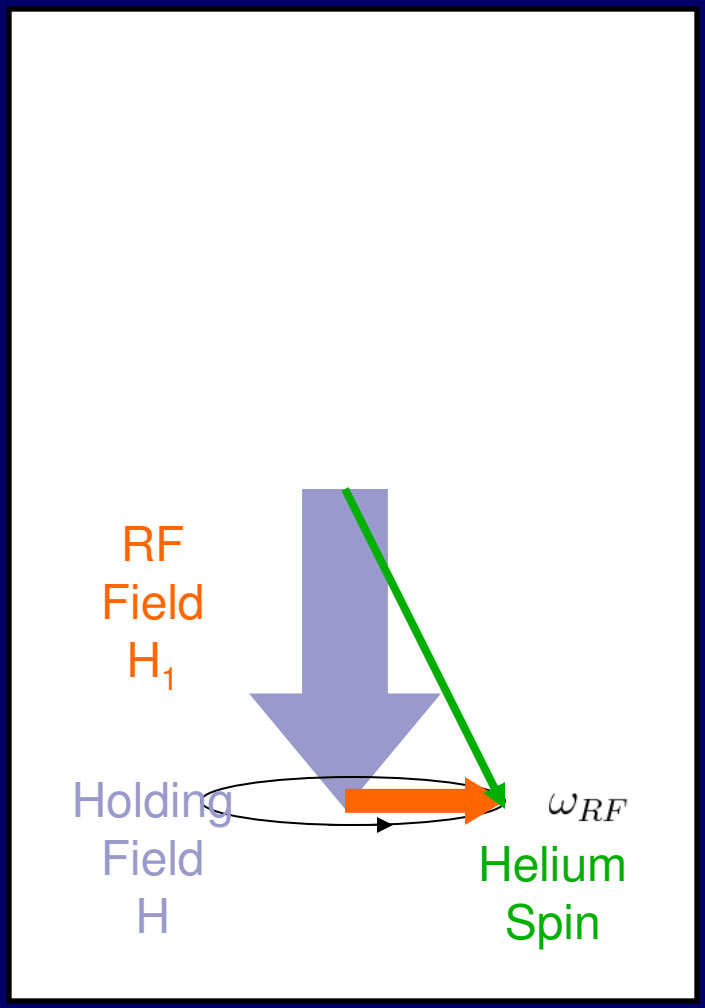

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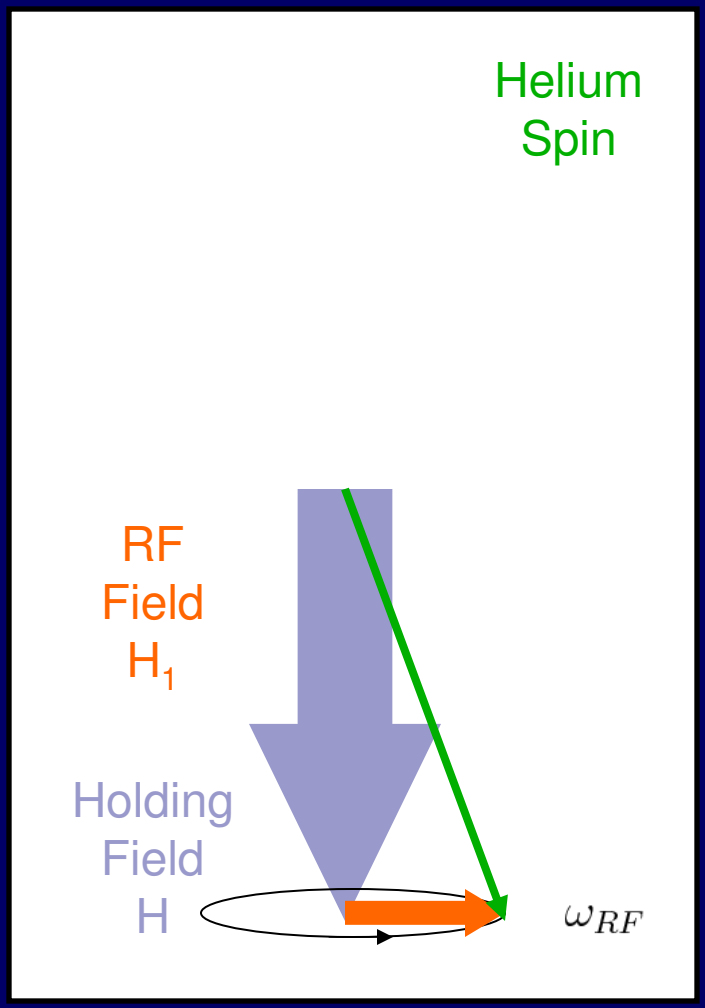

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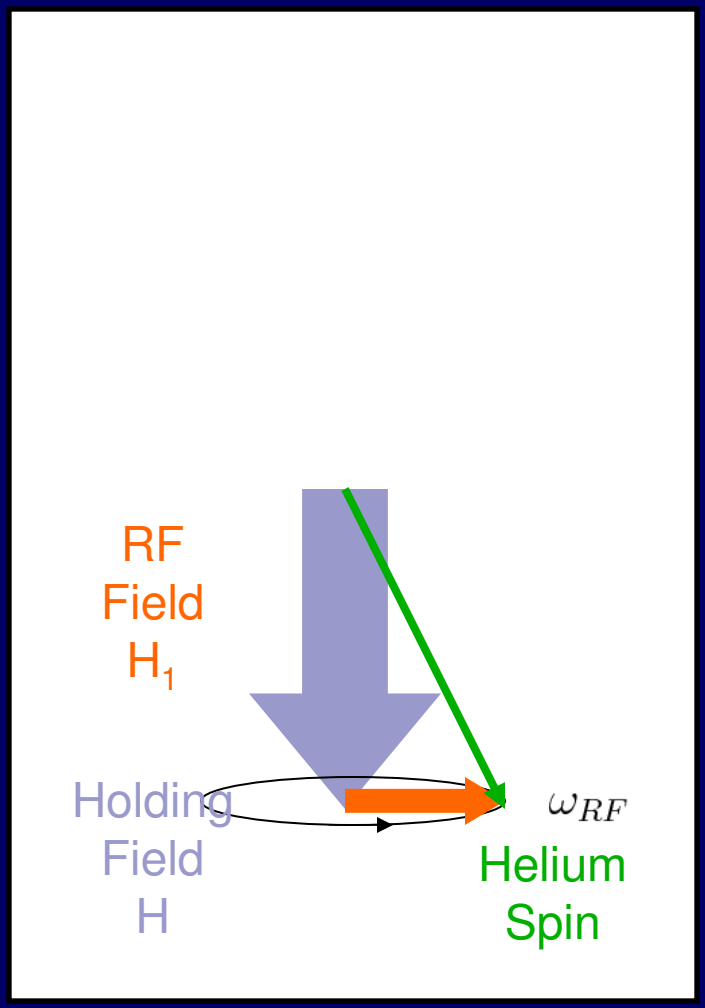

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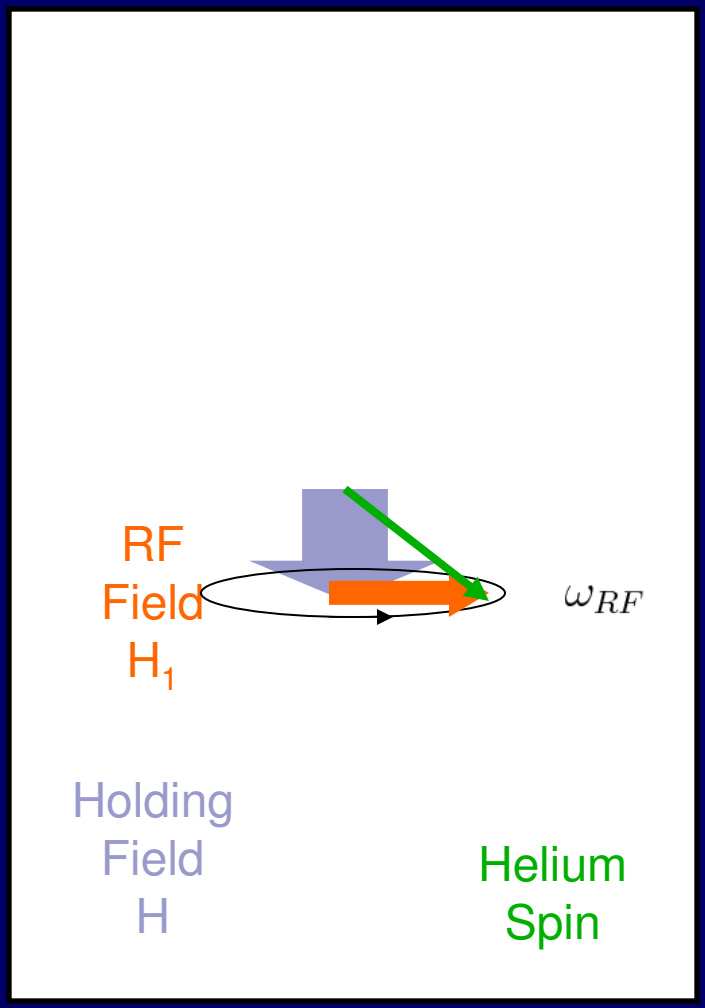

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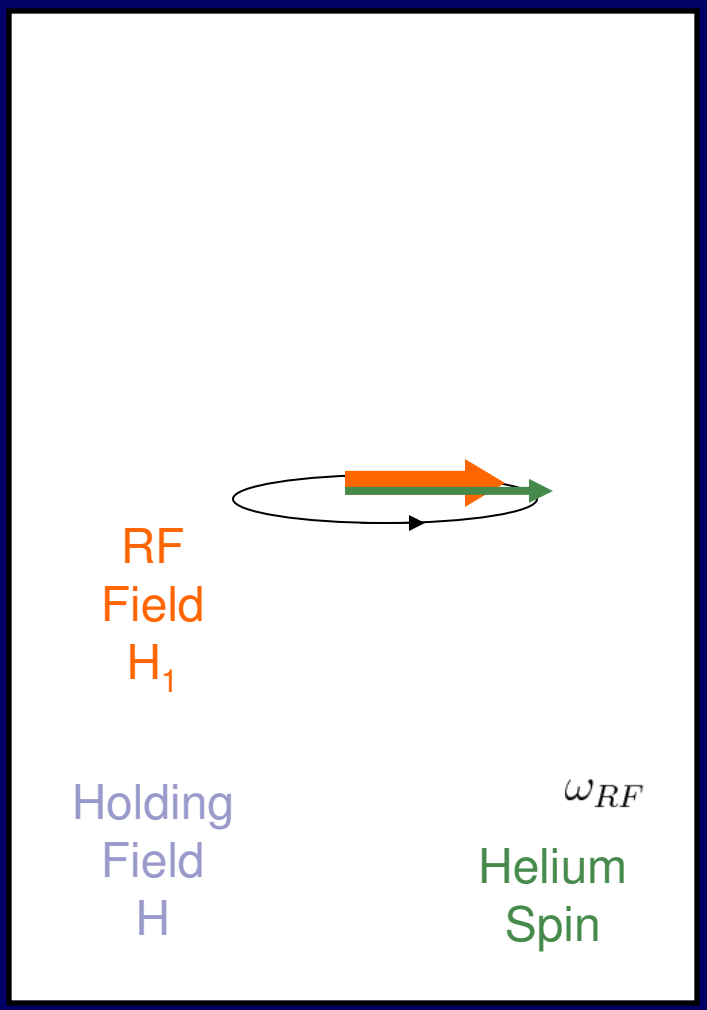

AFP

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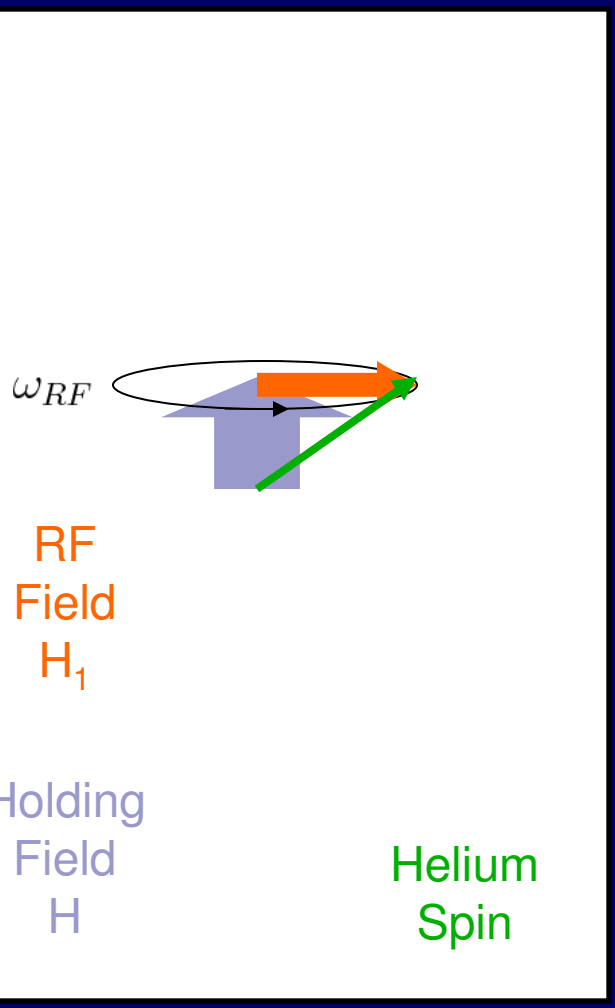

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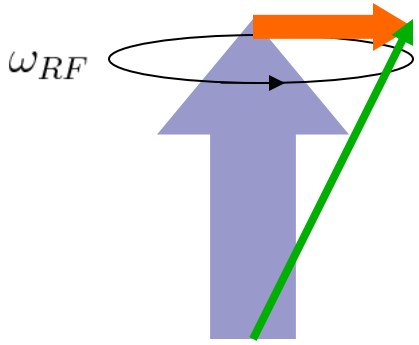

RF
Field
H_1

Holding
Field
H

Helium
Spin

AFP

$$\vec{H}_{eff} = (H(t) - H_0)\hat{z} + H_1(\omega_{RF})\hat{x}$$

$H_0 > H$

$H_0 = H$

$H_0 < H$

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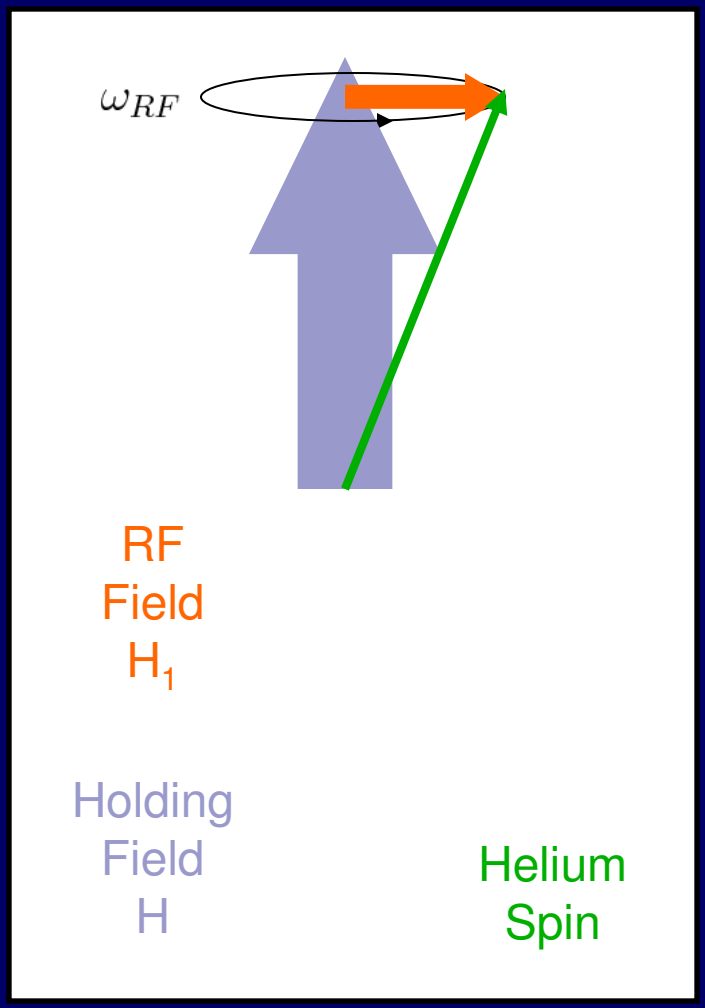


AFP

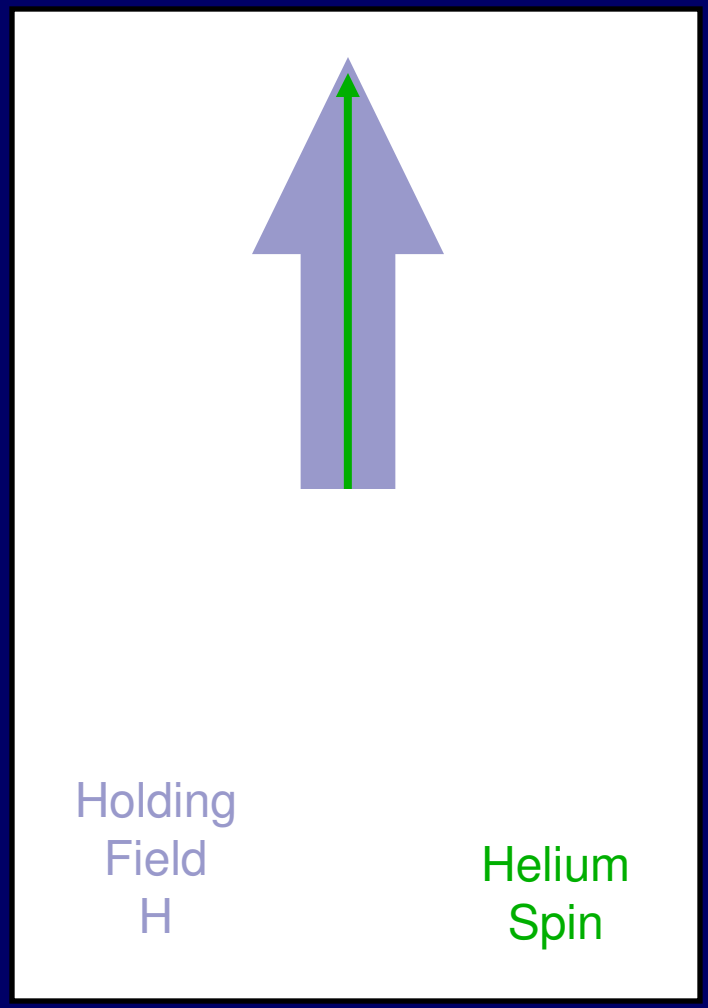
$$P_f \approx 0.99 * P_i$$

$$\vec{H}_{eff} = (H(t) - H_0)\hat{z} + H_1(\omega_{RF})\hat{x}$$

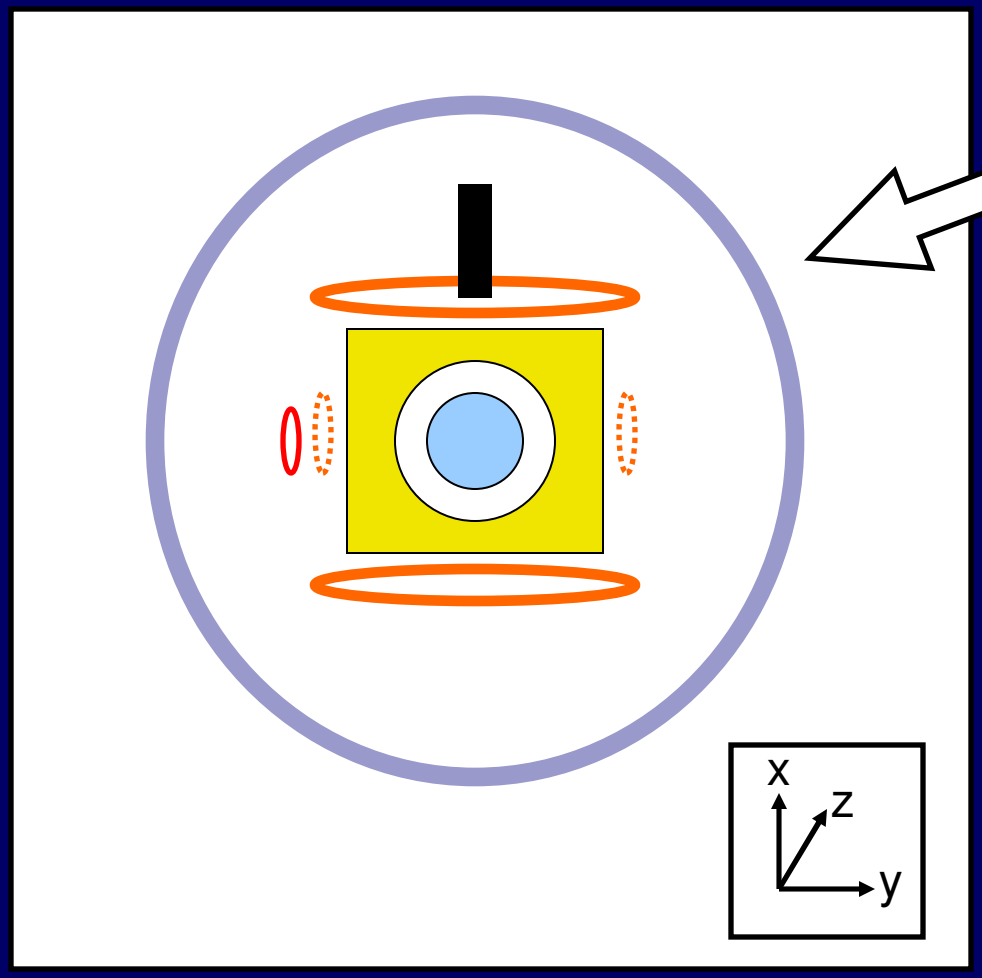
Adiabatic- Field is swept slowly so that the spin can follow it

$$D\frac{|\vec{\nabla}H_z|^2}{H_1^2} \ll \frac{\dot{H}}{H_1} \ll \omega_{RF}$$

Fast- The Field is swept quickly enough so that the spins do not relax in the low field region.



AFP Schematic



- Holding Field (H)

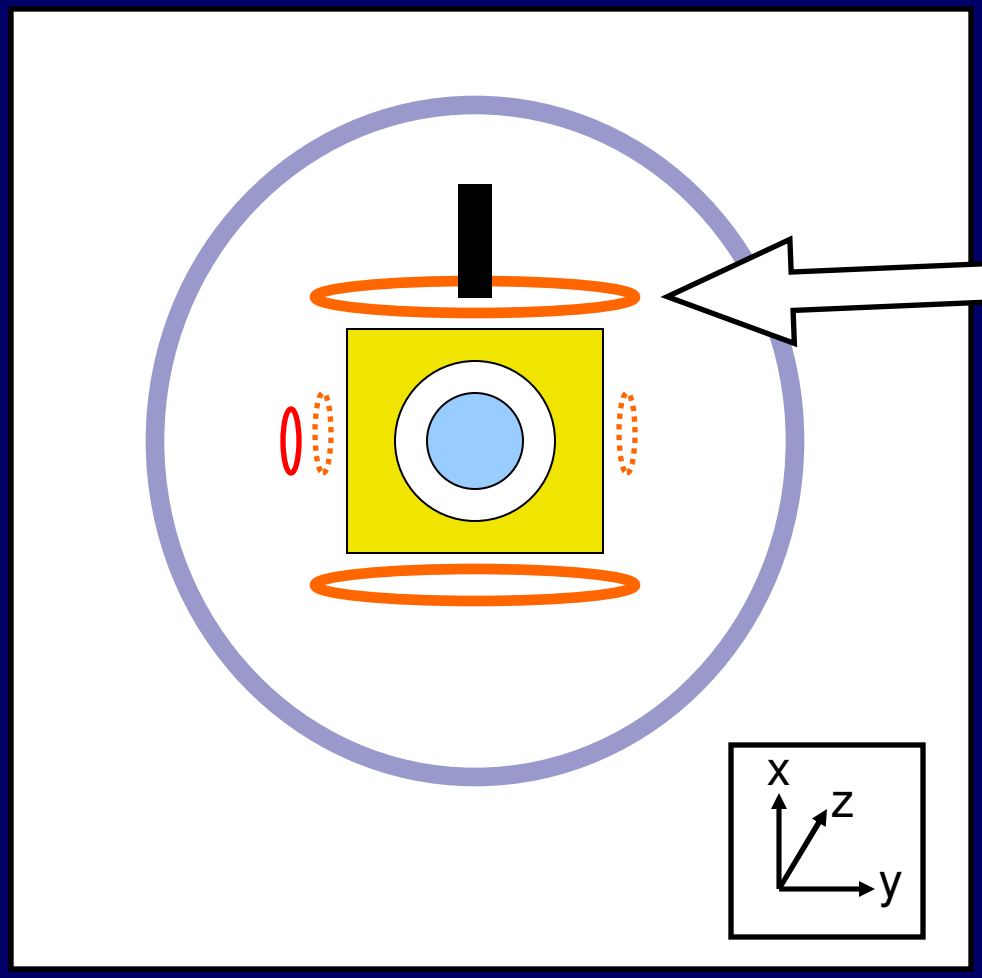
- RF Field $H_1(\omega)$

- - Pick Up Coils

-EPR Coil

EPR Photo Diode

AFP Schematic



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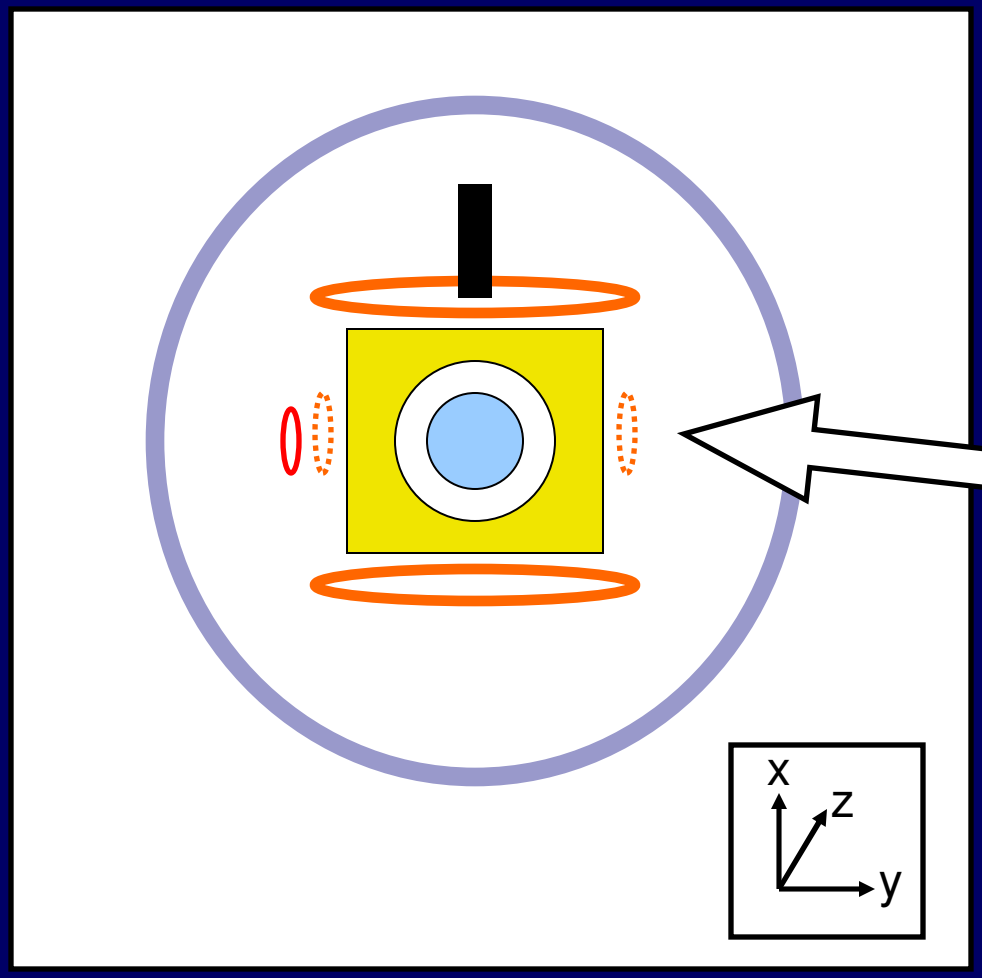
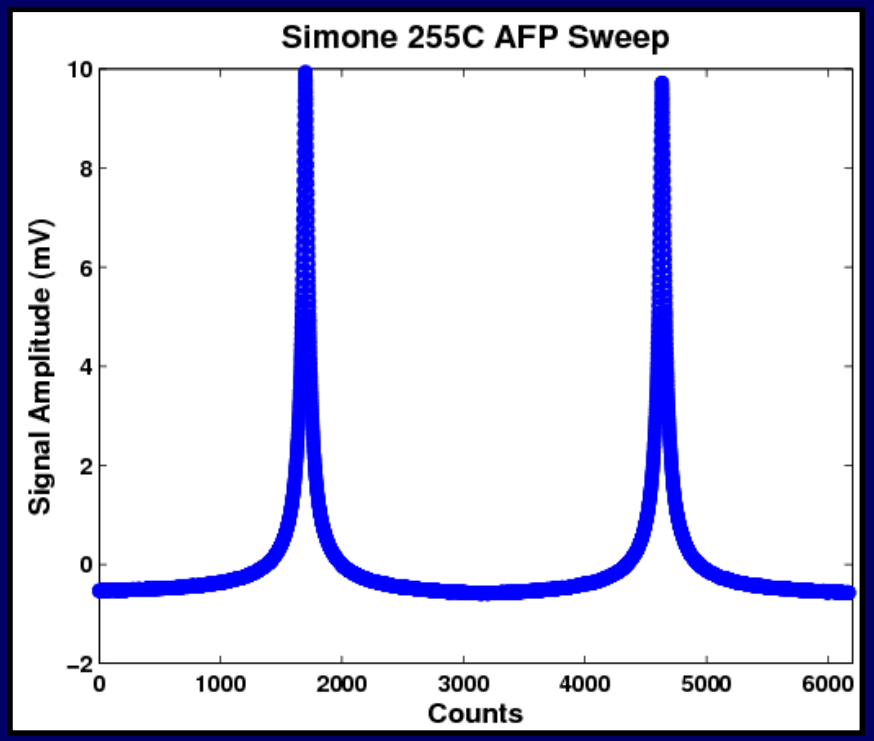


- Holding Field (H)
- RF Field $H_1(\omega)$
- - Pick Up Coils
-EPR Coil
EPR Photo Diode

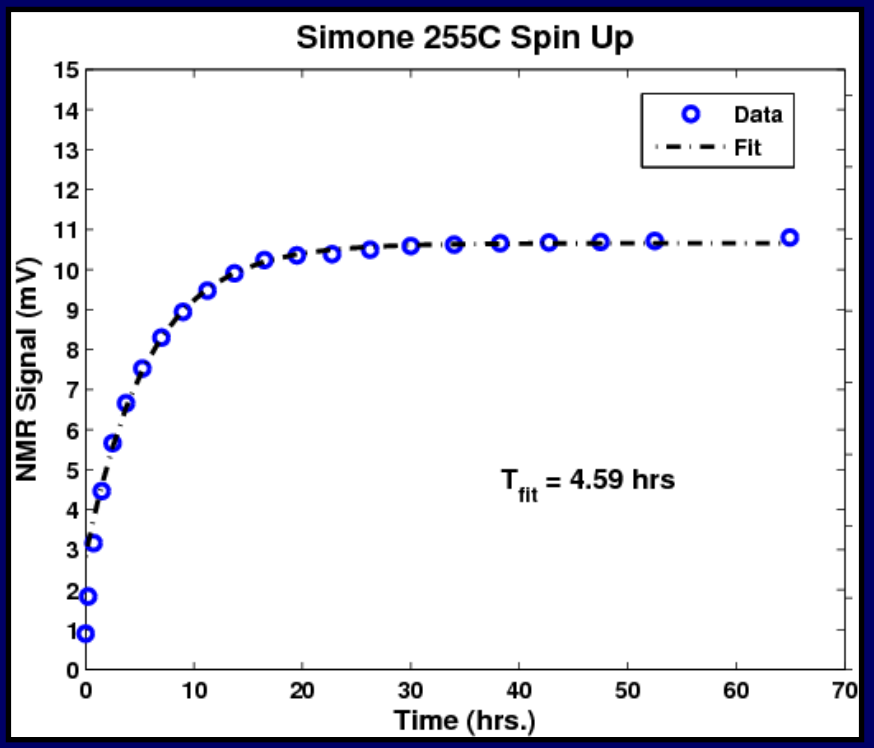
AFP Signal

Lock-In Signal



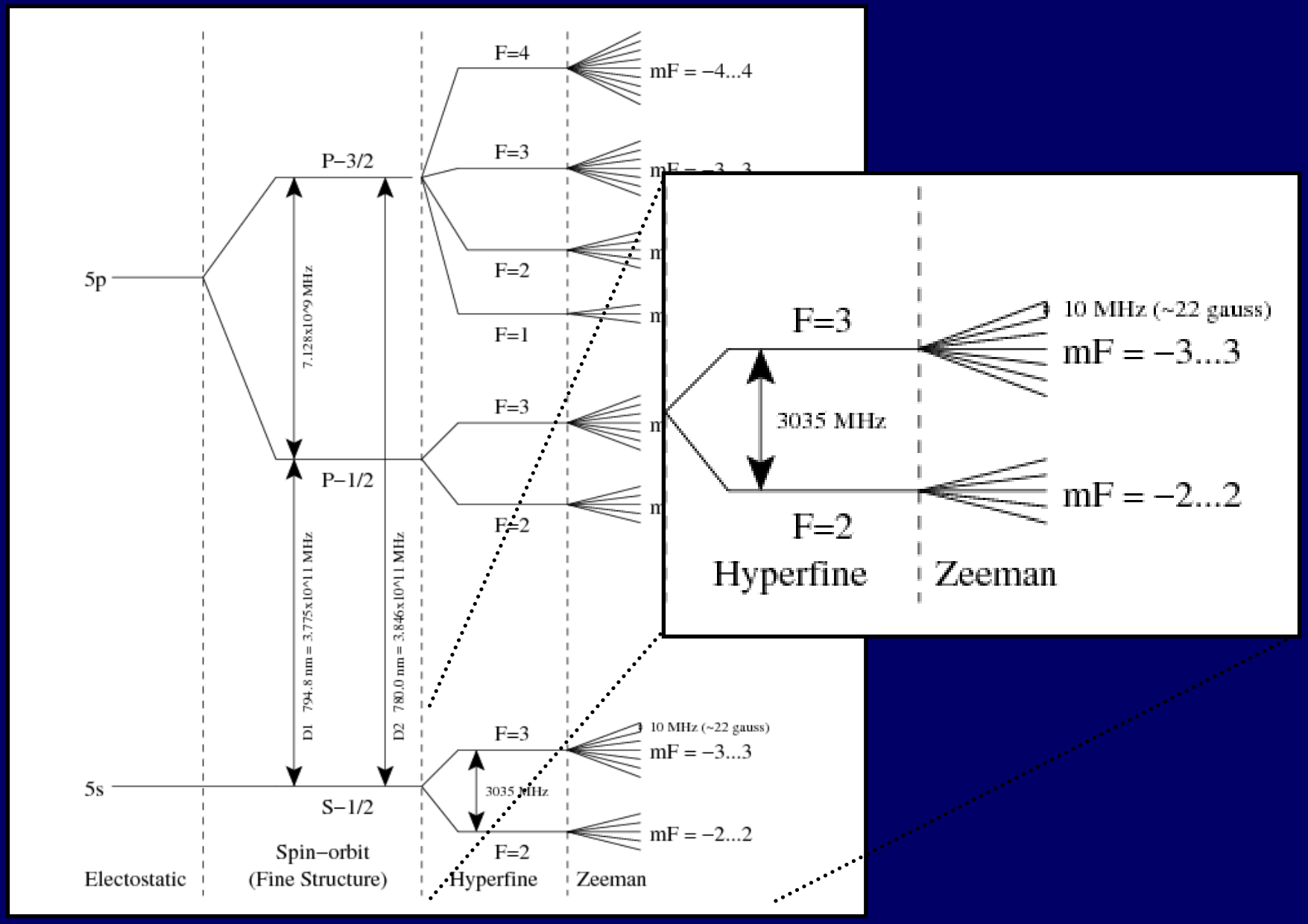
Sample NMR Signal

A “Spin Up” Fit

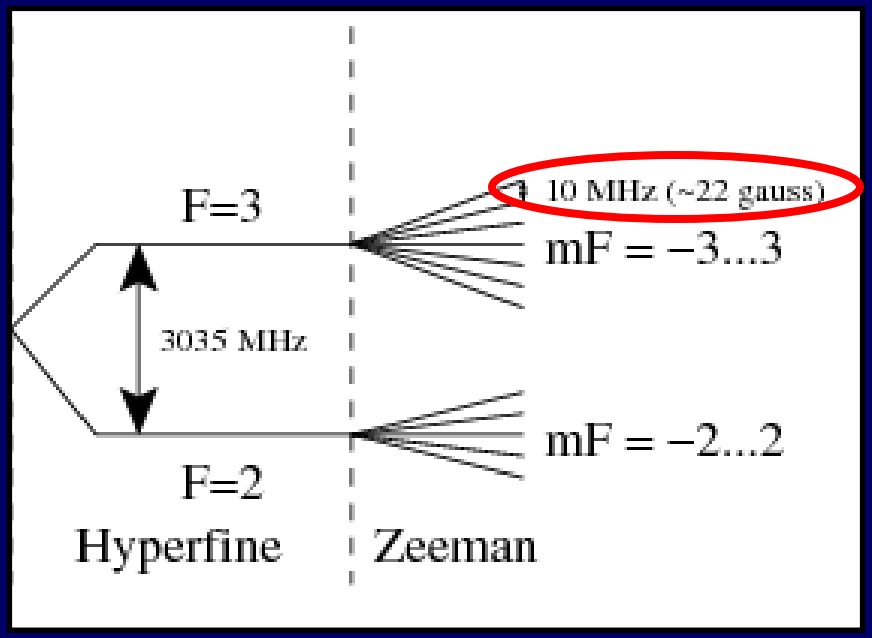


Sample Spin Up Taken 01/2008

Electron Paramagnetic Resonance

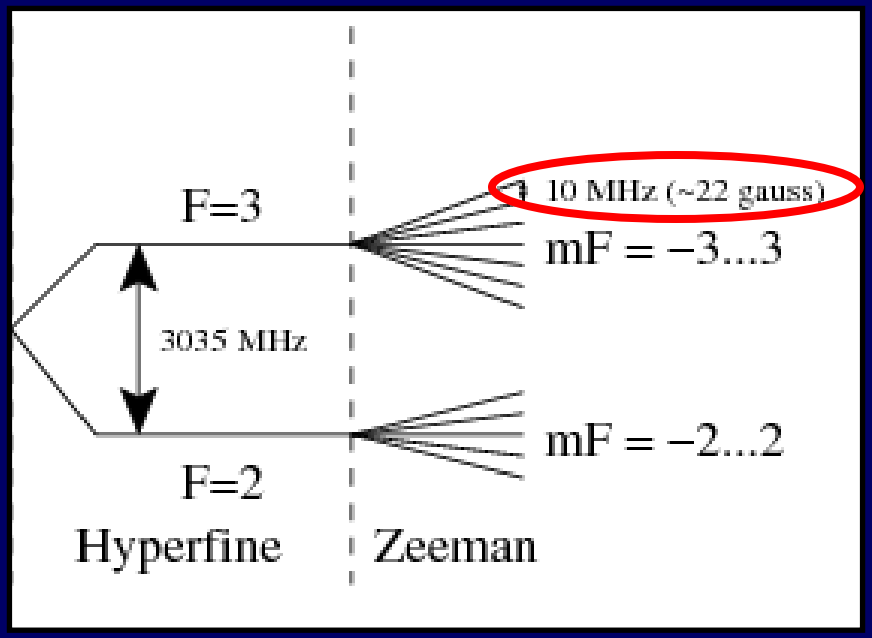


EPR- Measuring Frequency Shift



$$\nu(B)$$

EPR- Measuring Frequency Shift



$$\nu(B)$$

$$\overrightarrow{B_{Tot}} = \overrightarrow{B_{other}} + \overrightarrow{B_{He}}$$

$$B_{Tot} \approx 13\ \mathrm{G}, B_{He} \approx 20\ \mathrm{mG}$$

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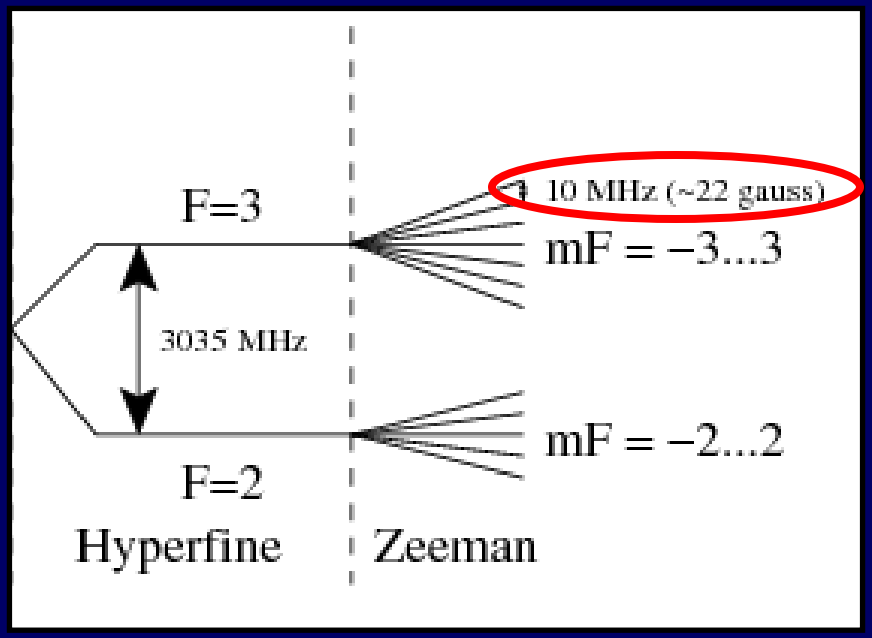

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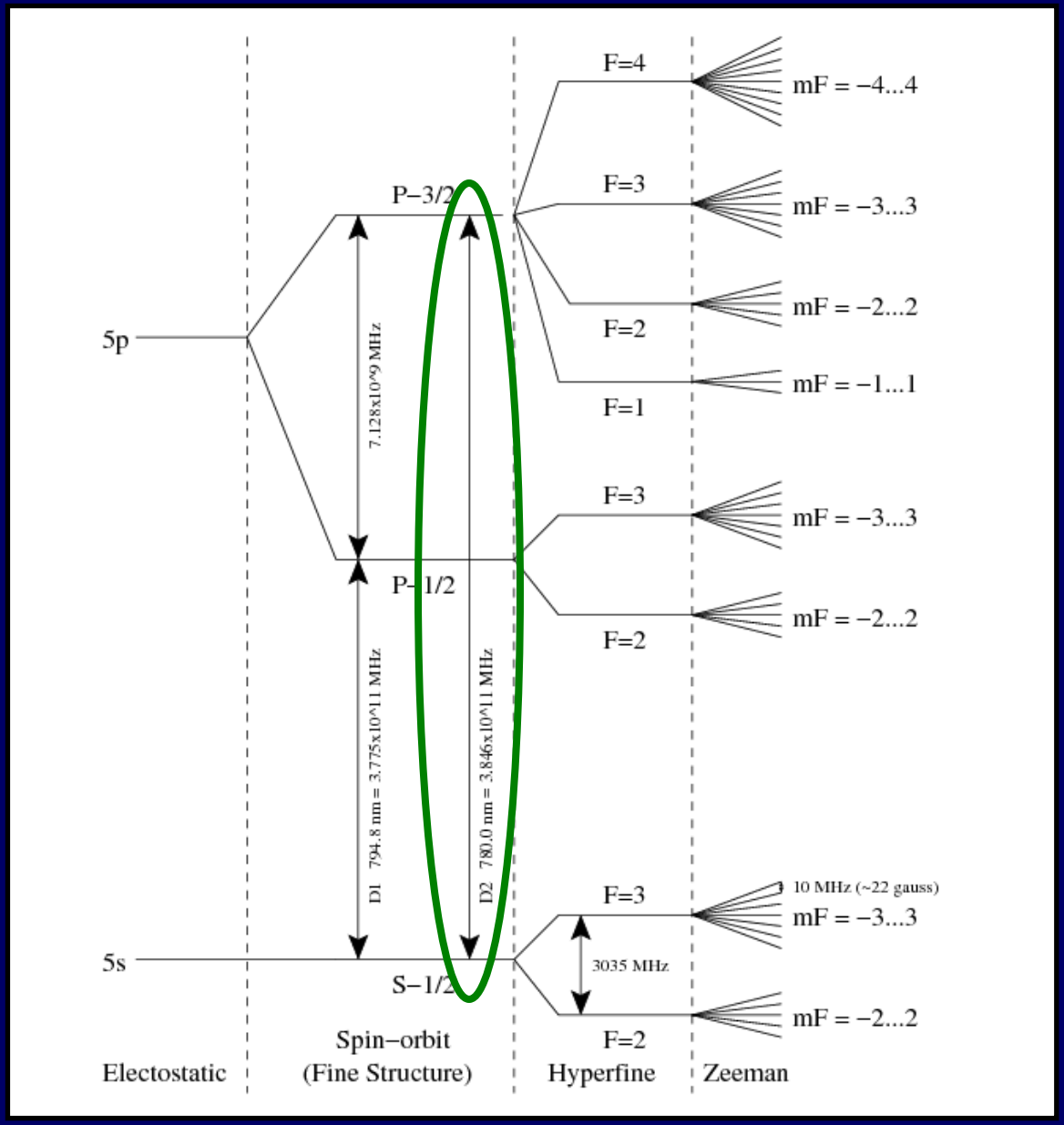
$$B_{Tot} \approx 13\ \mathrm{G}, B_{He} \approx 20\ \mathrm{mG}$$

$$\Delta\nu \approx 20\ \mathrm{kHz}$$

EPR- Monitoring Frequency



EPR- Reversing ^{3}He Polarization

$$\vec{H}_{eff} = (H(t) - H_0)\hat{z} + H_1(\omega_{RF})\hat{x}$$

$$H_0 = \gamma\omega_{RF}$$

H_0 is fixed, ω is swept through ω_{RF}

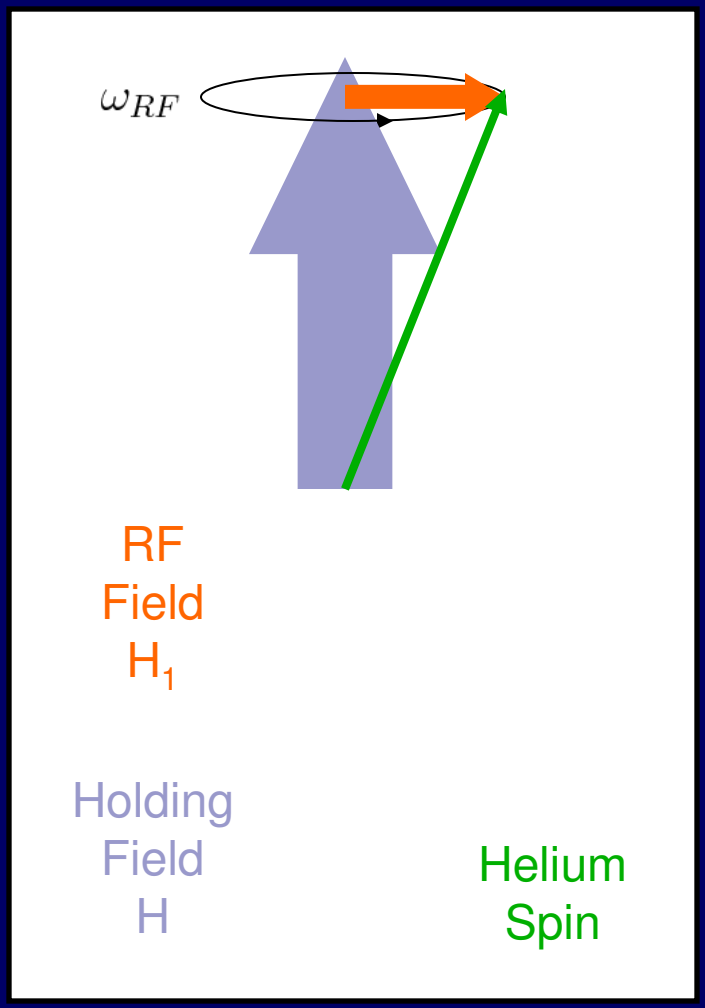
^{3}He RF Sweep

56.6 kHz $\leftrightarrow$ 30 kHz

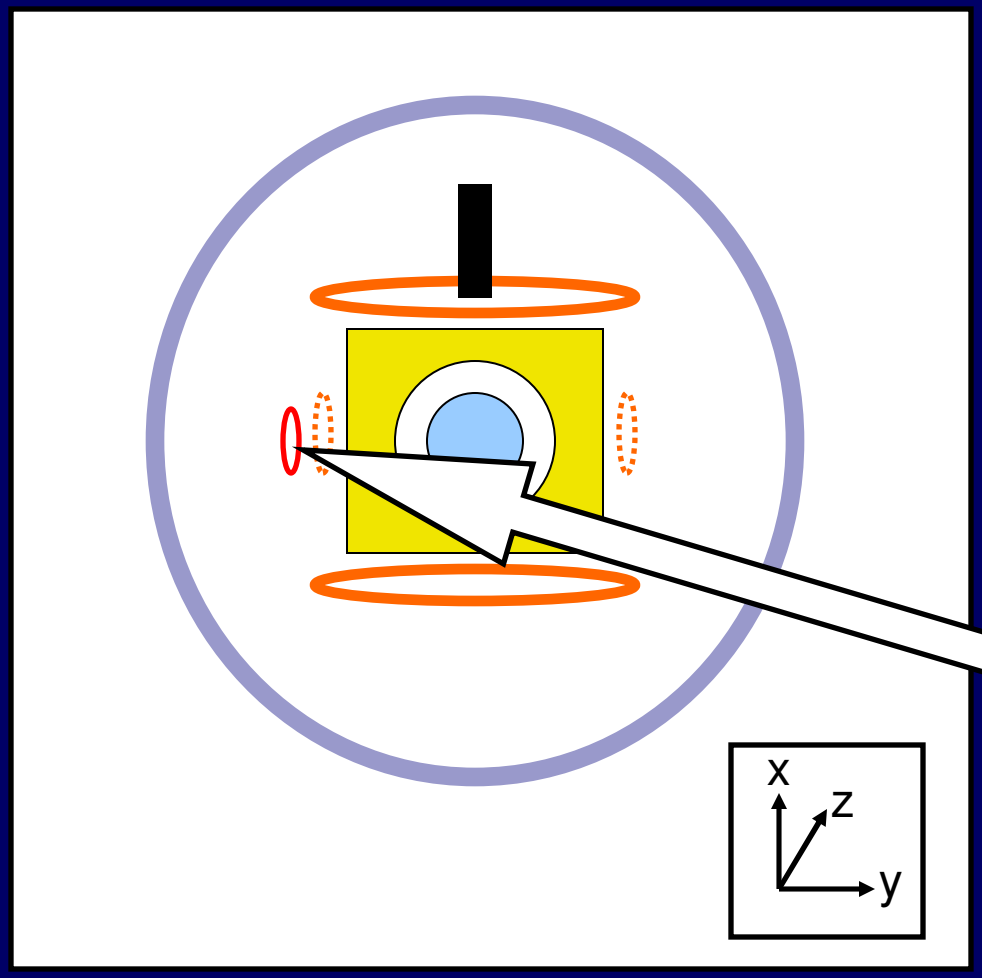
Typical Lab Values

$B_0 = 12.6$ Gauss

$\omega_{RF} \approx 42$ kHz



EPR Schematic



- Holding Field (H)

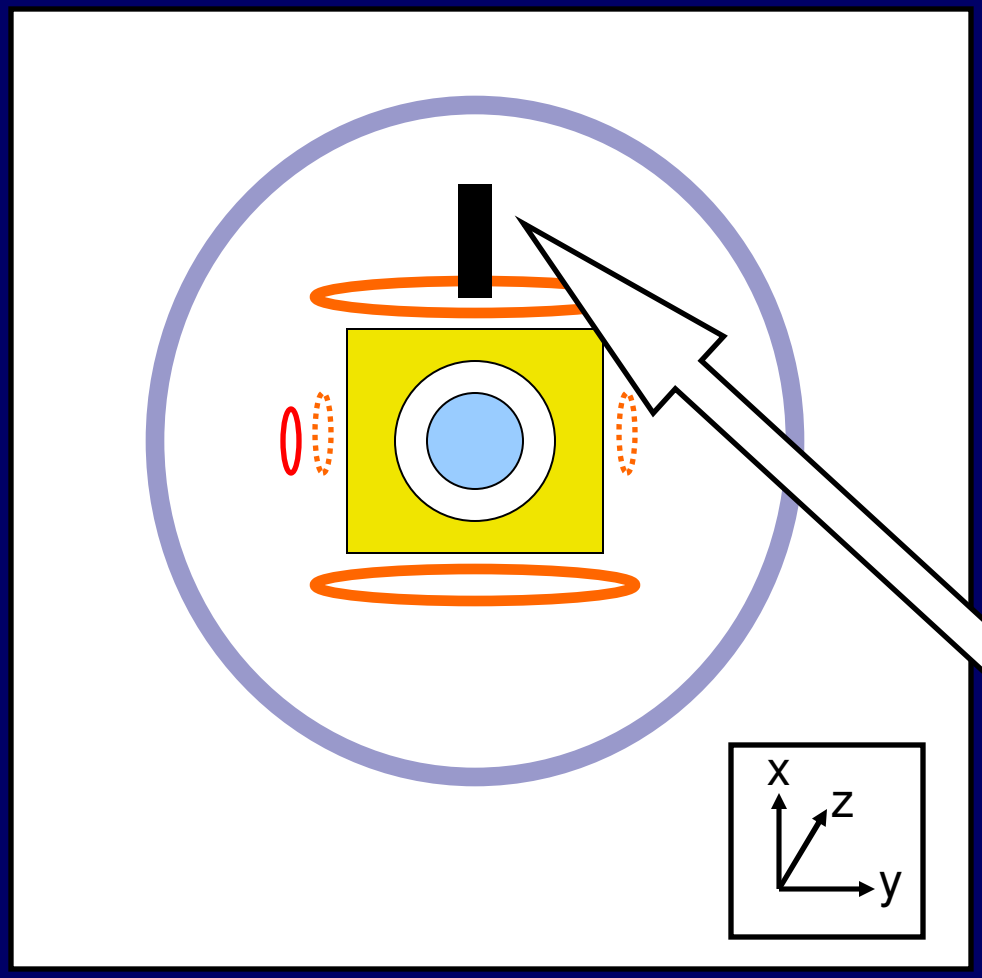
- RF Field $H_1(\omega)$

- - Pick Up Coils

-EPR Coil

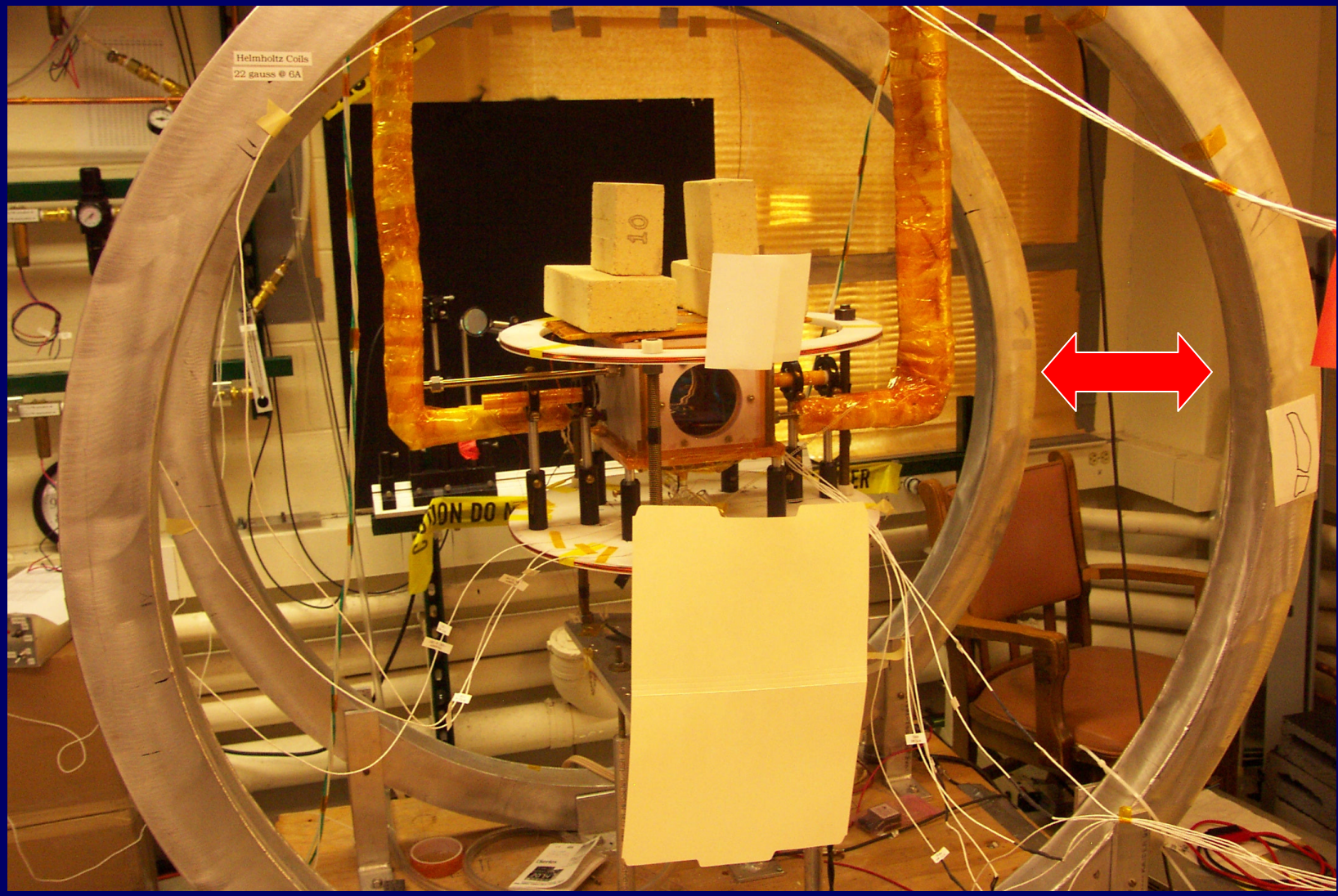
EPR Photo Diode

EPR Schematic

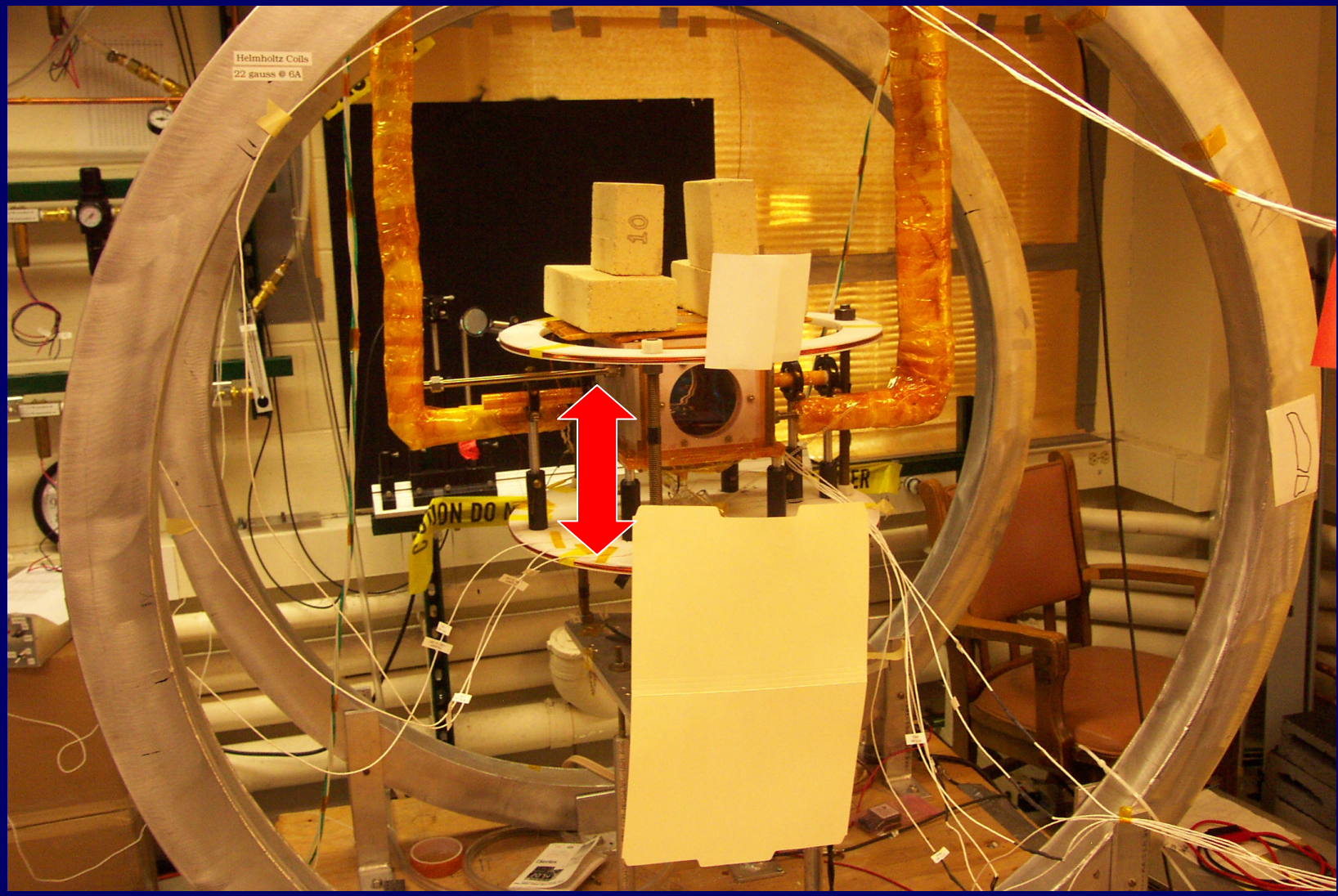


- Holding Field (H)
- RF Field $H_1(\omega)$
- - Pick Up Coils
-EPR Coil
EPR Photo Diode

Main Optical Pumping Oven



Main Optical Pumping Oven



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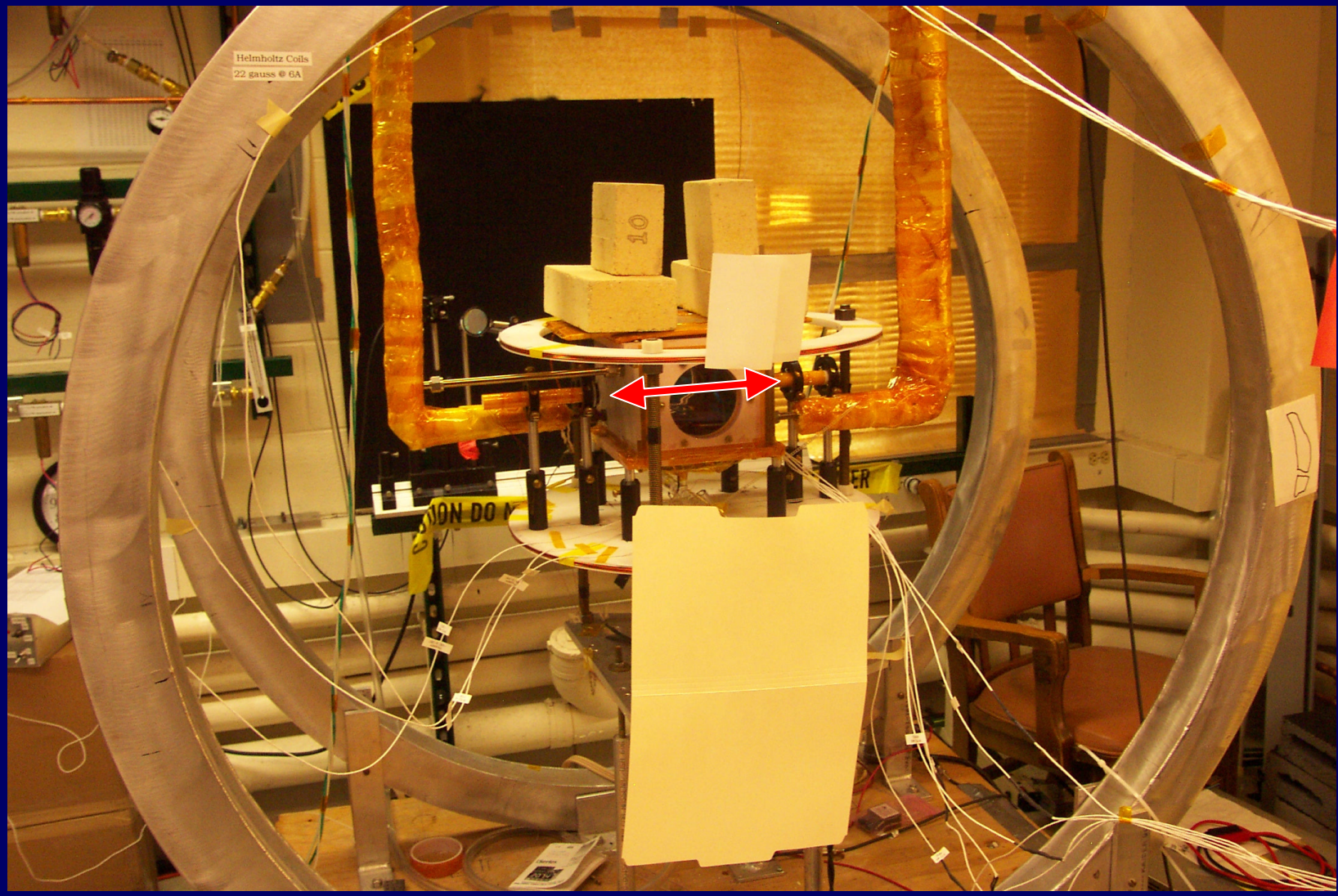

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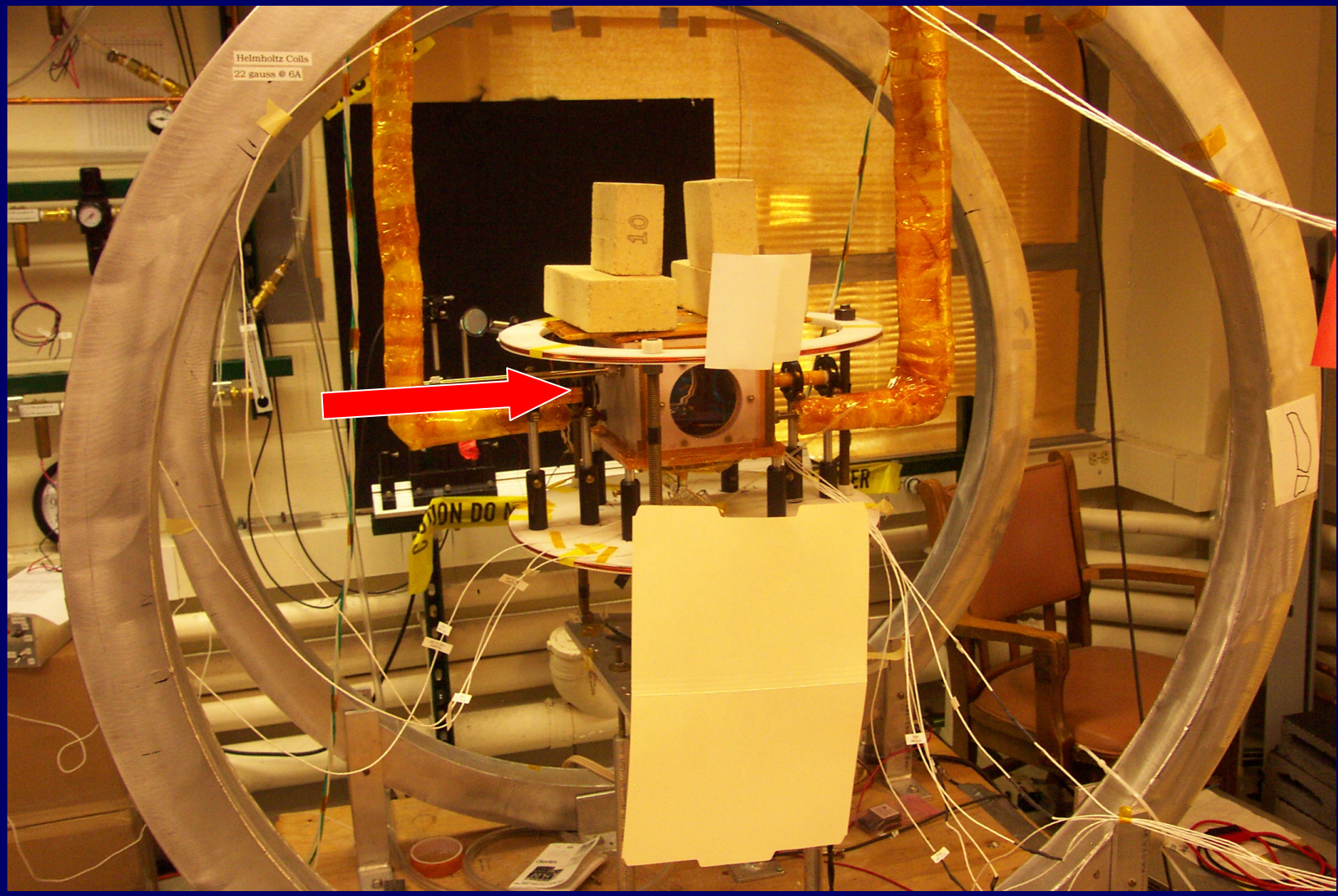

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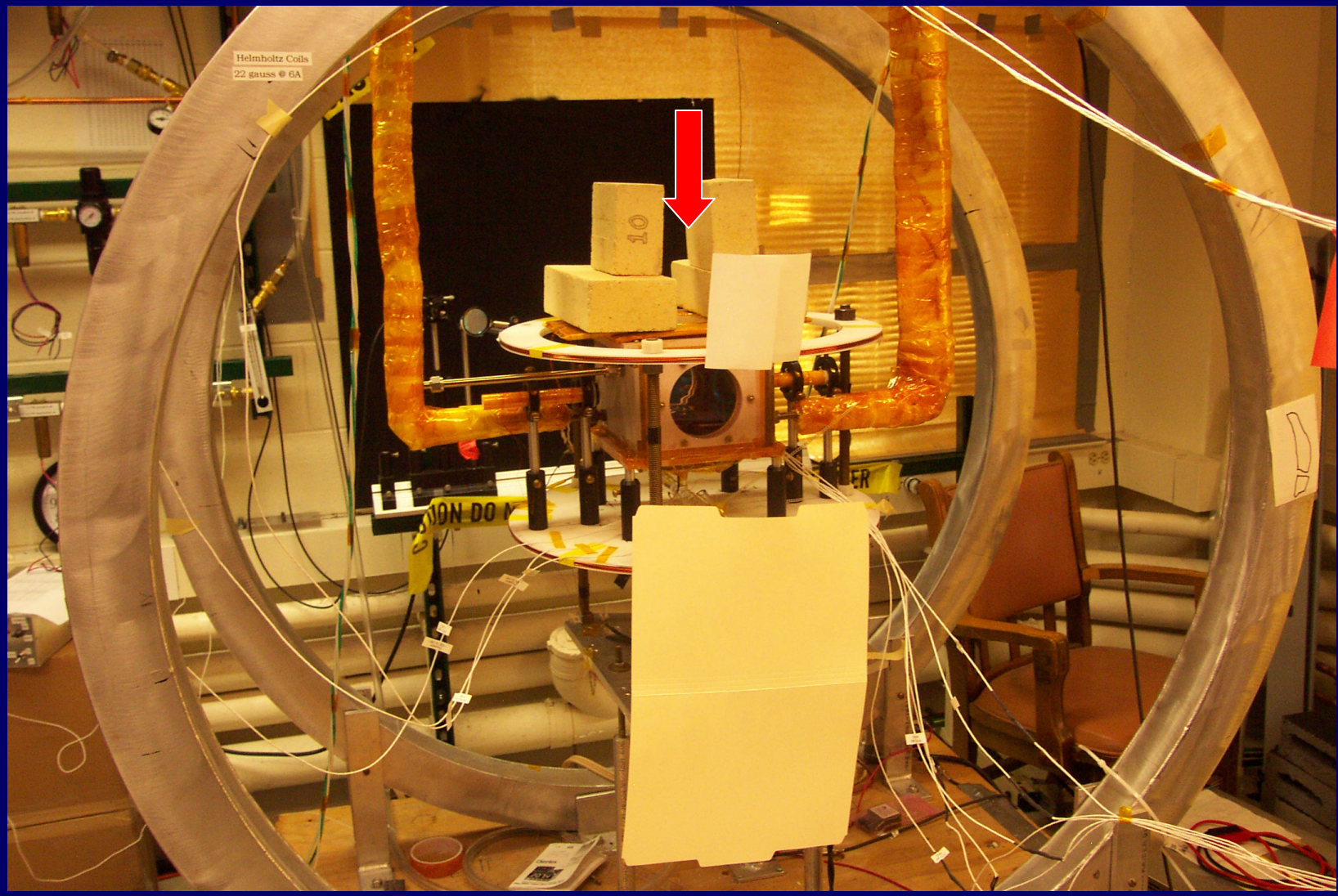
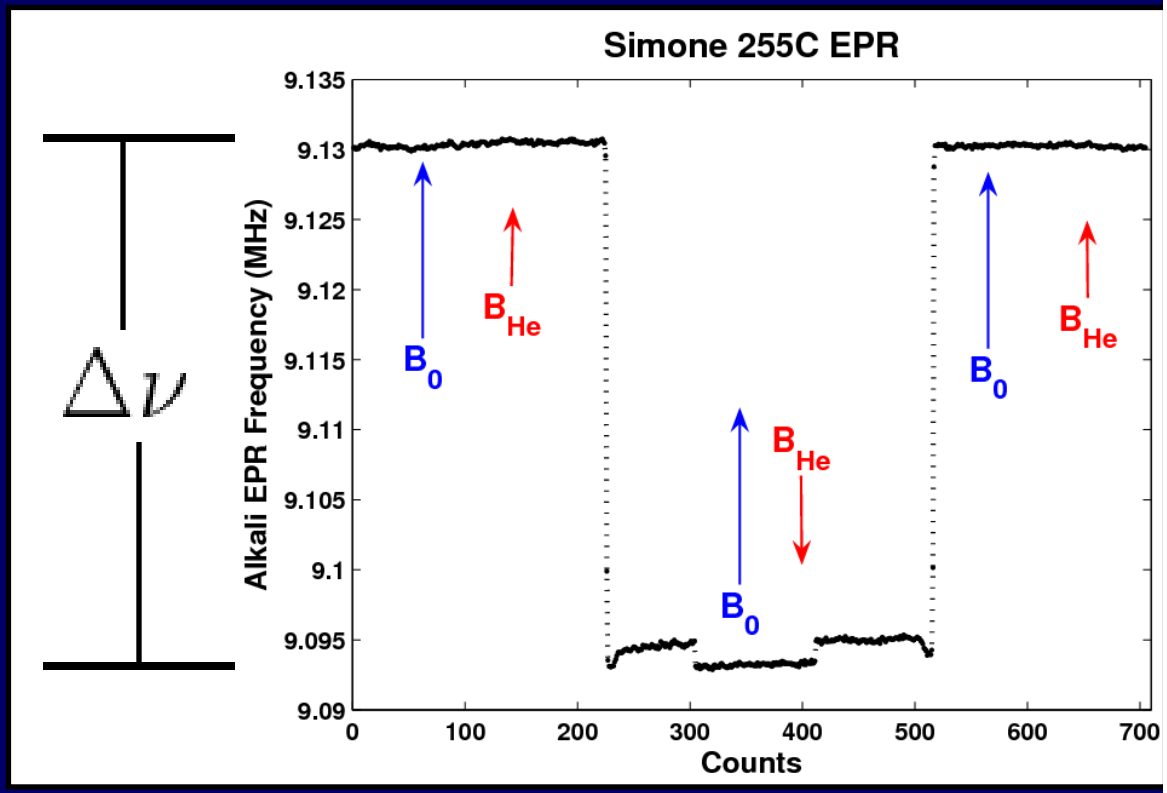


Calculating Polarization

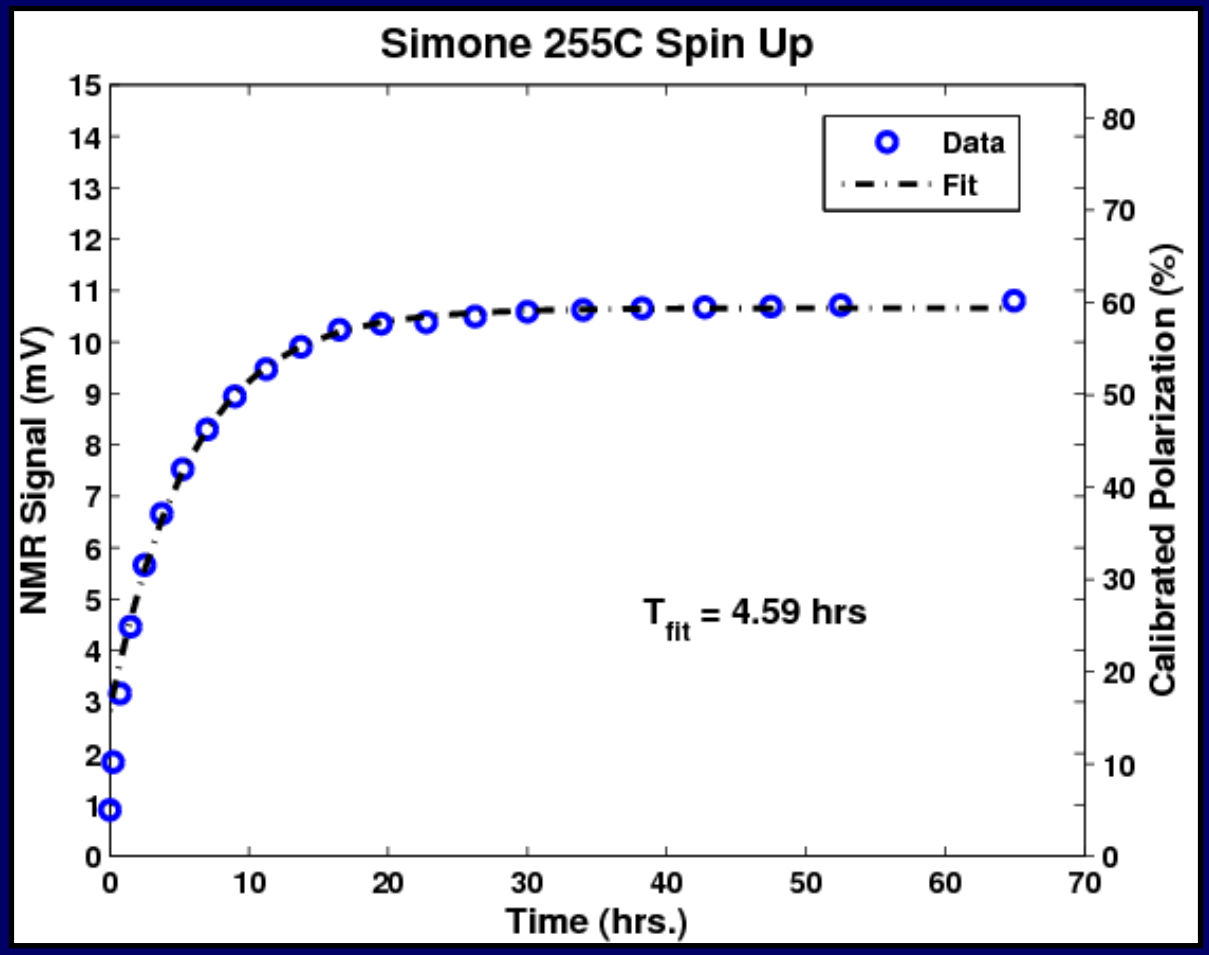
Calibration Procedure

- Take NMR
- Do EPR
- Take NMR
- Calculate P_{He}
- Average NMR Signals
- Get %/mV Calibration



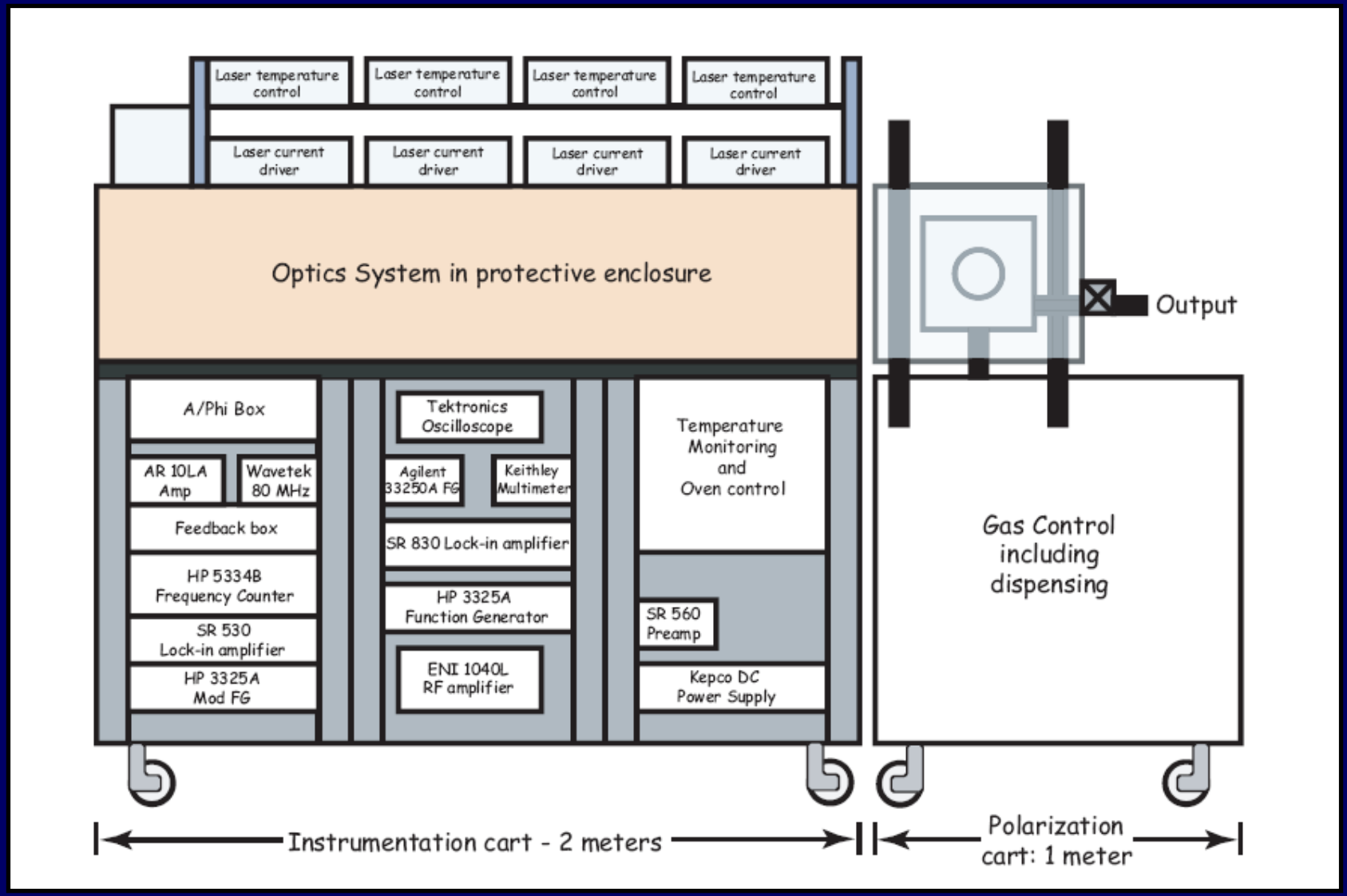
$$P_{He} = \frac{3}{8\pi} \frac{(2I+1)}{\mu_B \mu_{He} g_e [1 - 4I(\nu_{epr}/\nu_{hfs}] \kappa_0 [He] V_{pc}} \Delta\nu_{epr}$$

Calibrated Data



- Calibration usually performed once per cell installation
- Changes with cell movement, coil movement, gain adjustments, etc.
- Recommended every few months for new Hybrid Polarizer.

Initial Proposal: 07/07



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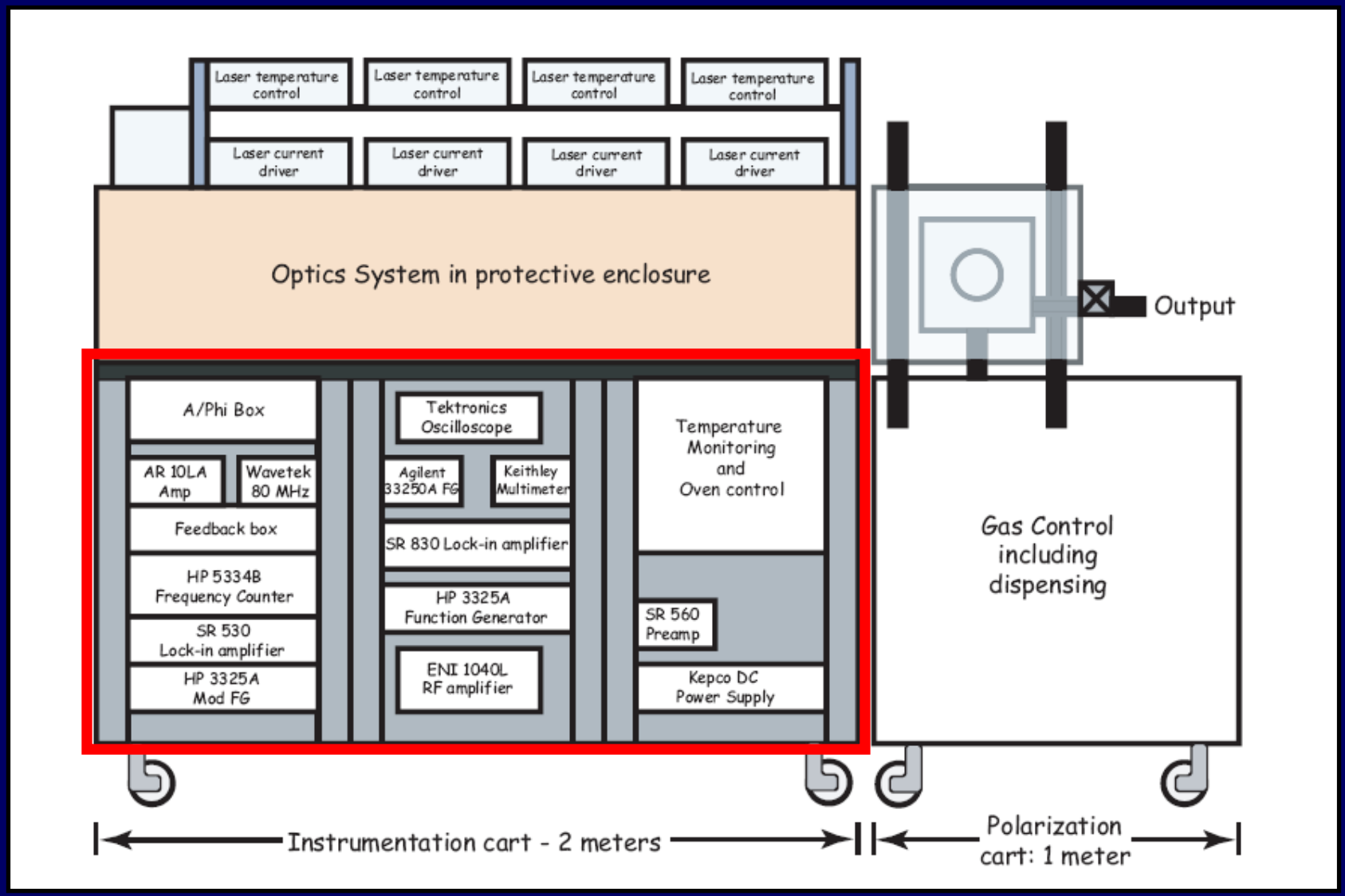

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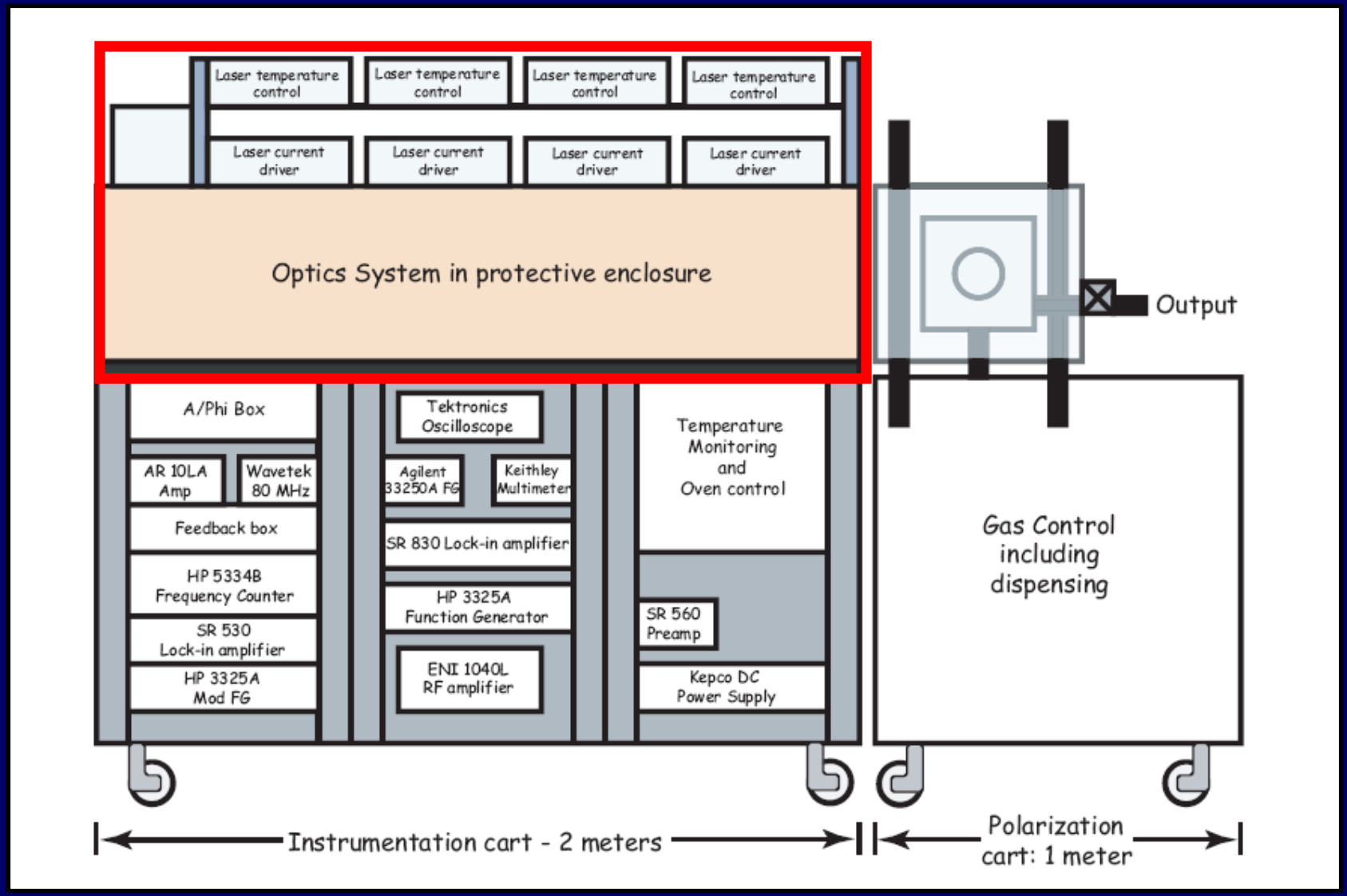
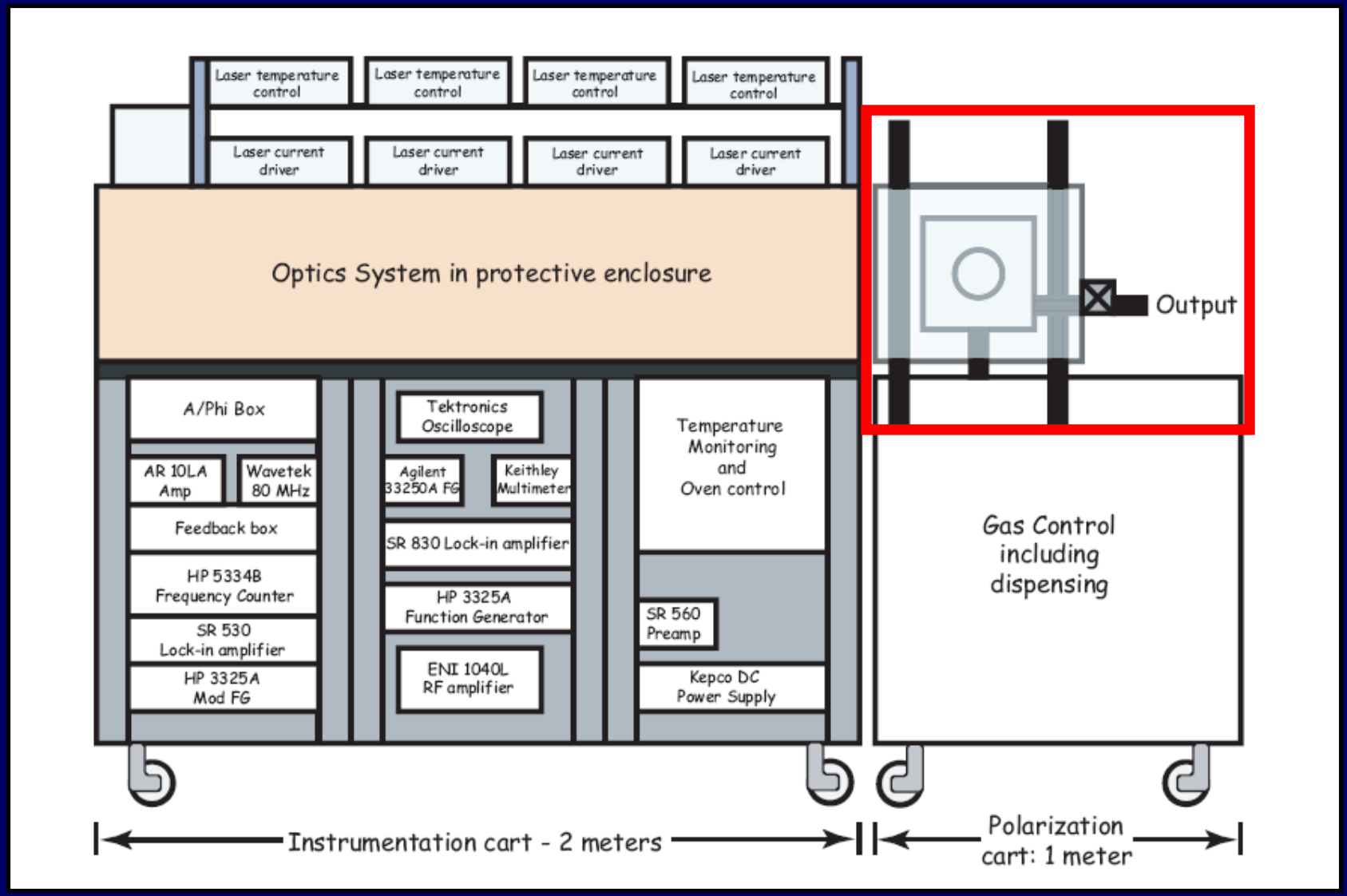
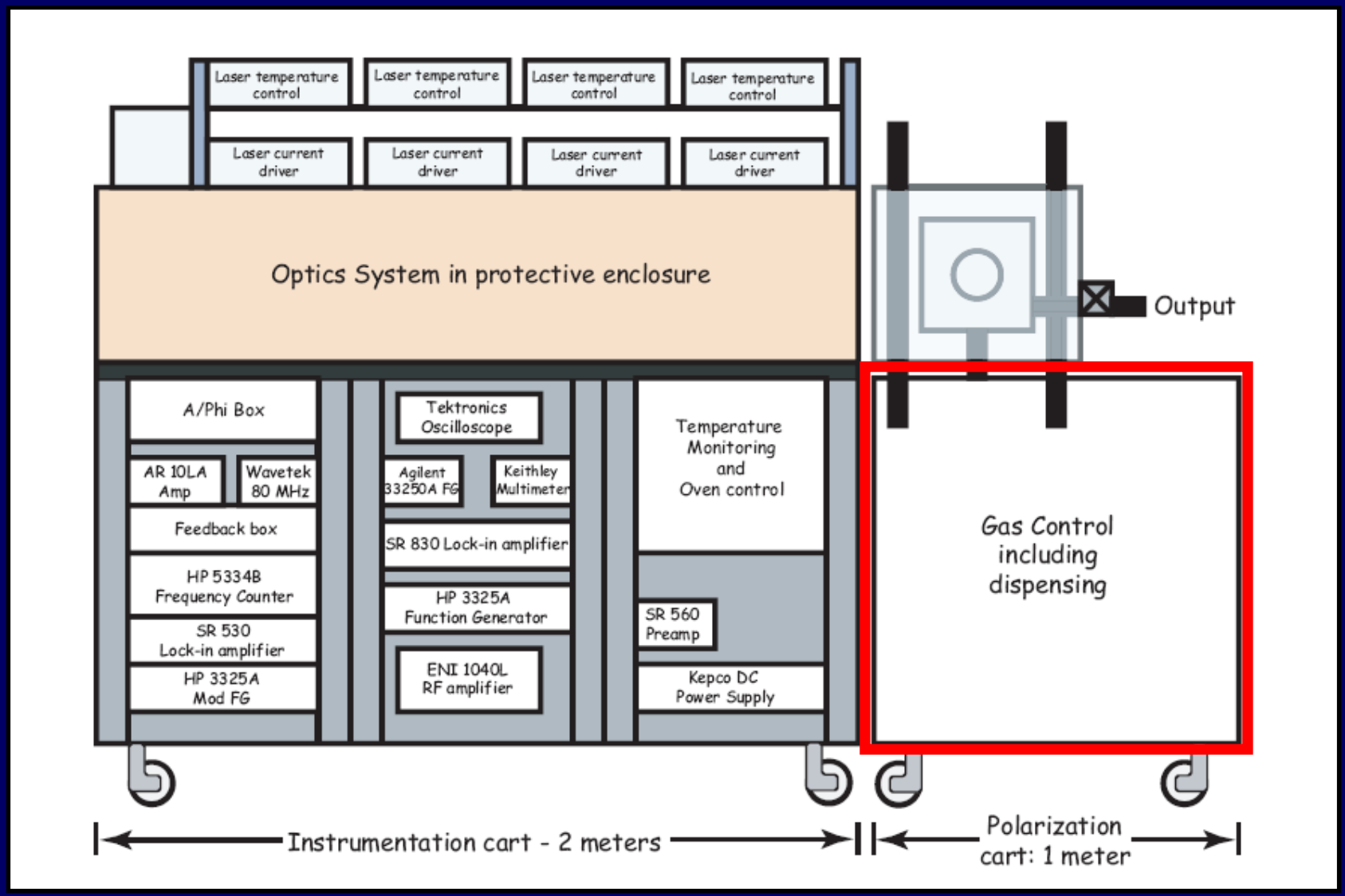


Initial Proposal: 07/07

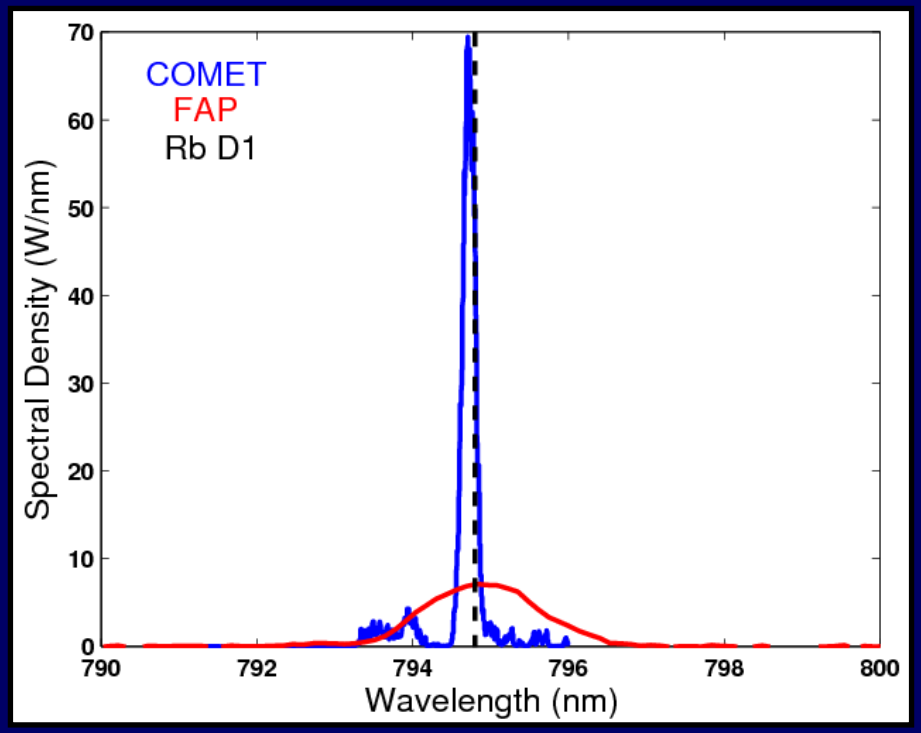


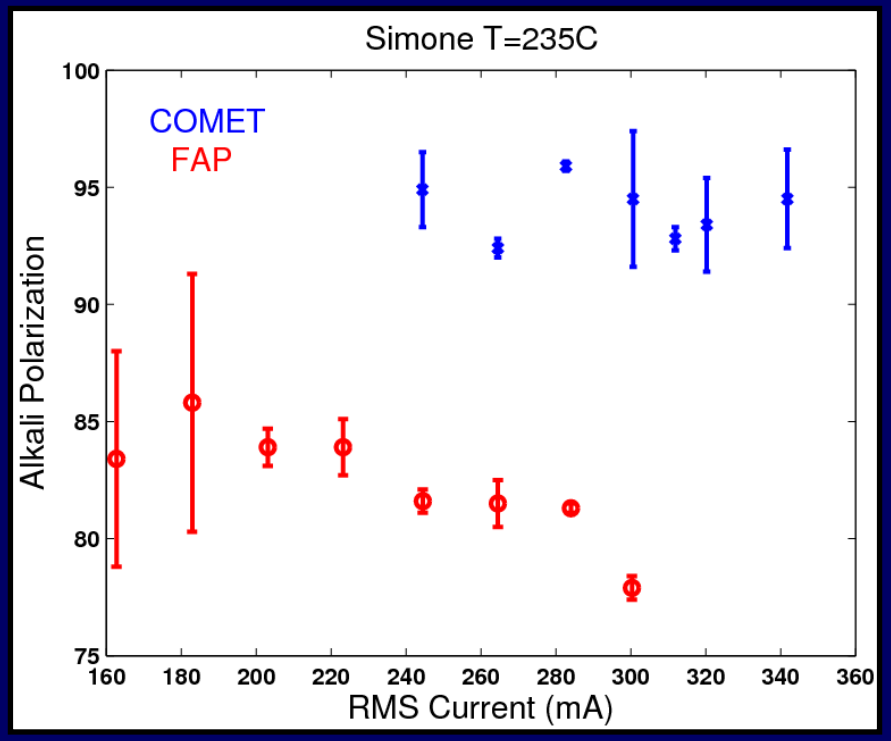
Initial Proposal: 07/07



Cart Constructed: 12/07

Laser Comparison: 11/07



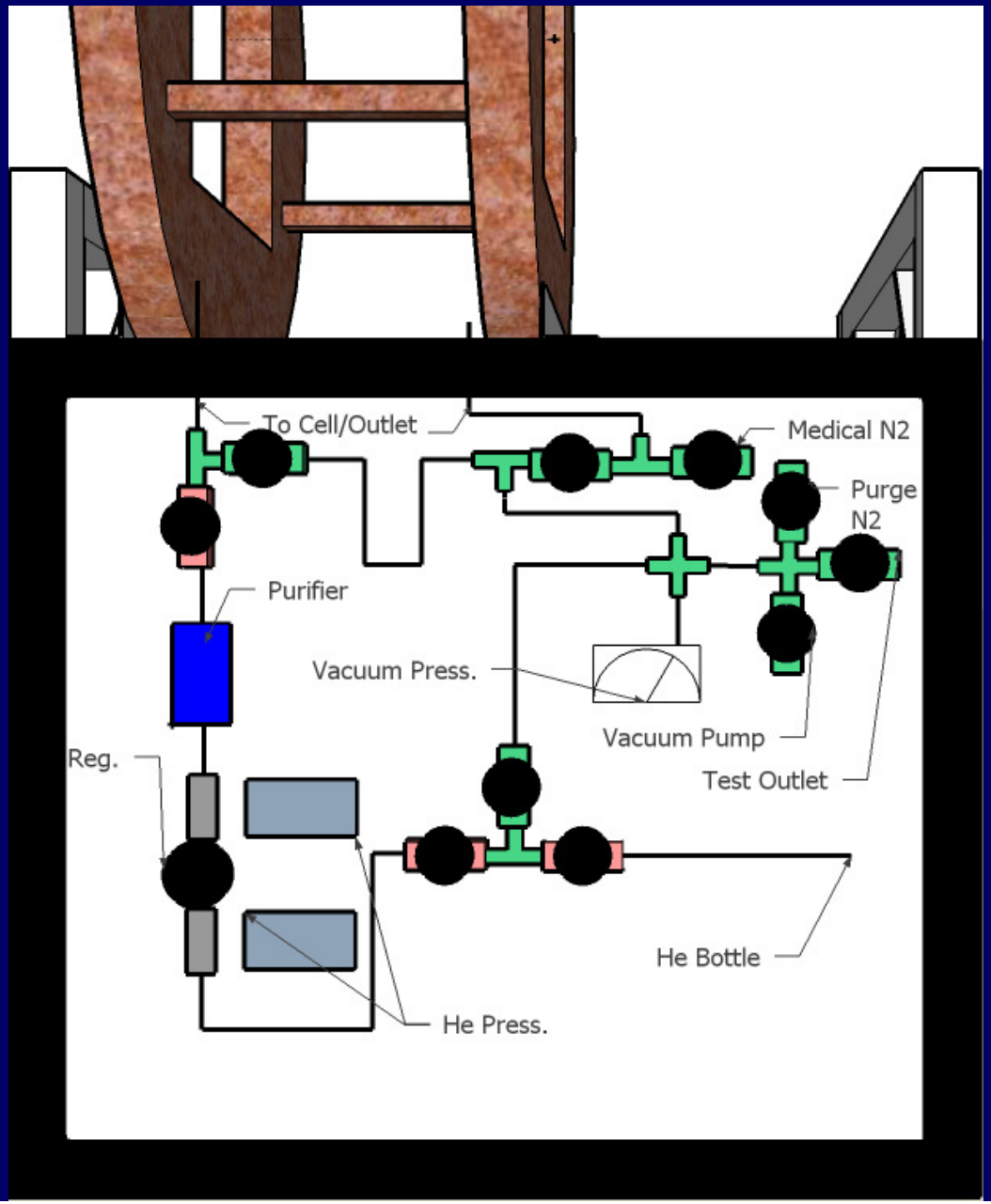


FAP

COMET

Lower Gas System: 02/08

Lasers

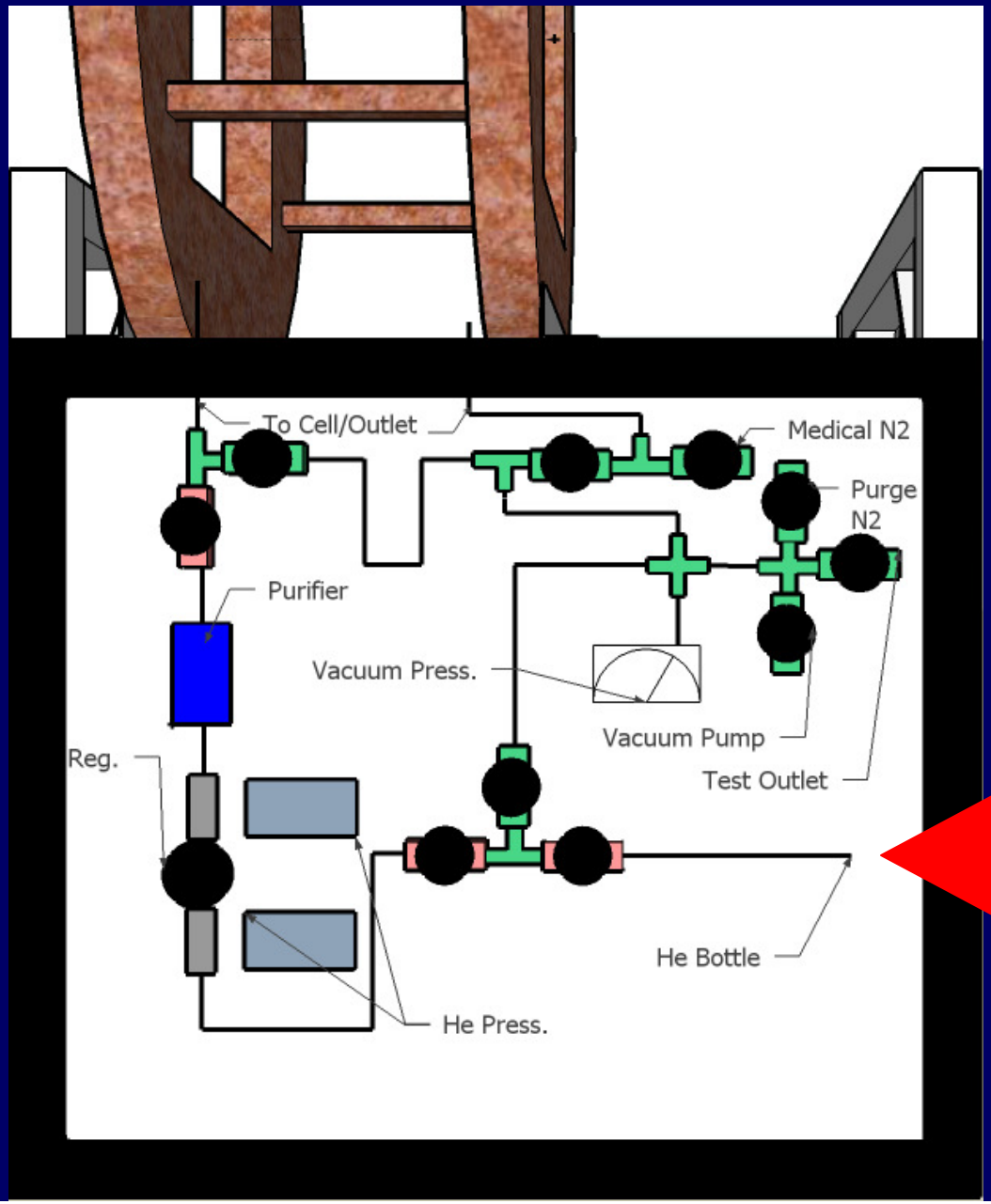


Construction

Mooney

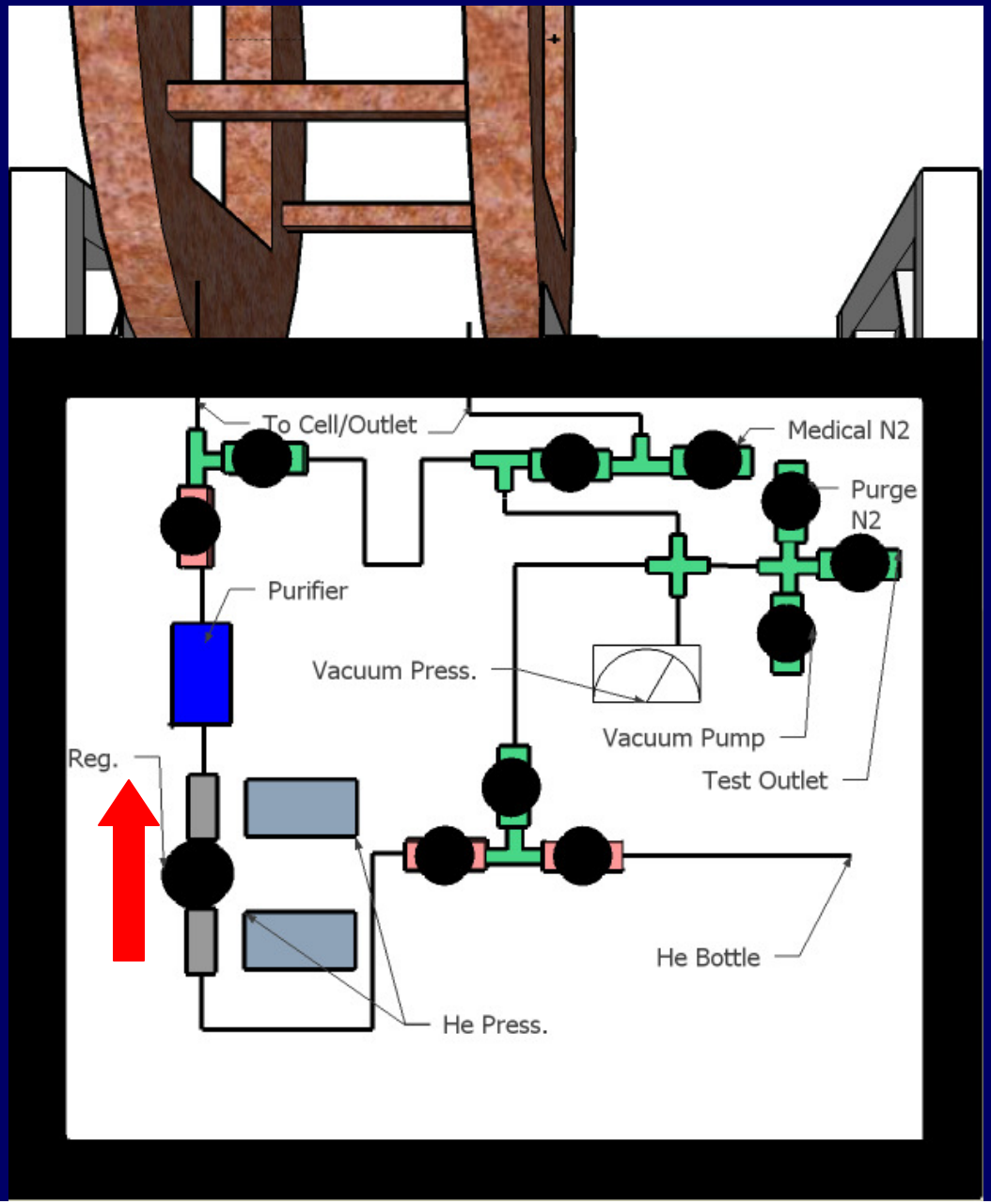
Lower Gas System: 02/08

Lasers



Lower Gas System: 02/08

Lasers



Reduces Pressure from 3000 psi to 150 psi

Construction

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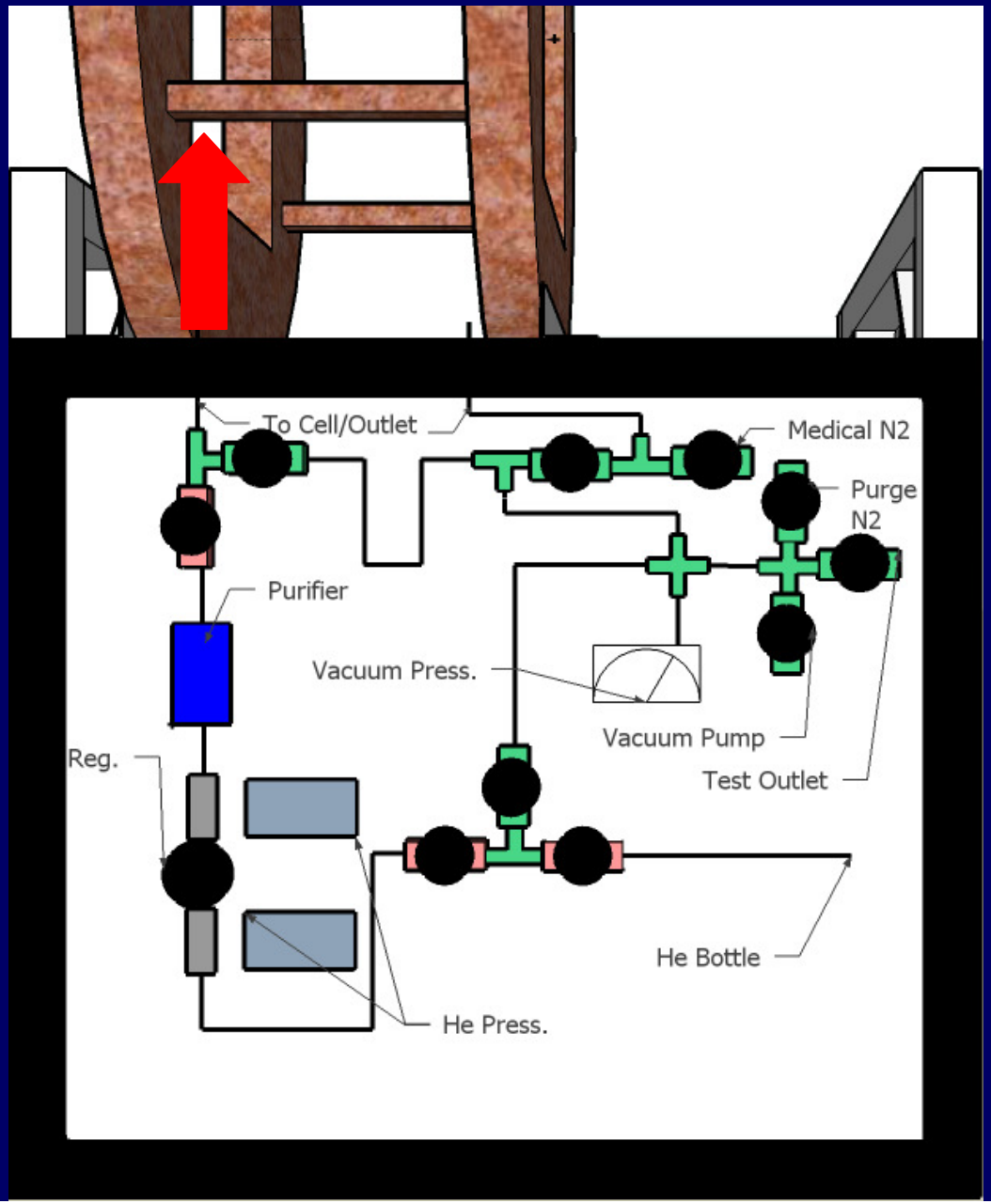
Lower Gas System: 02/08

Lasers



Construction

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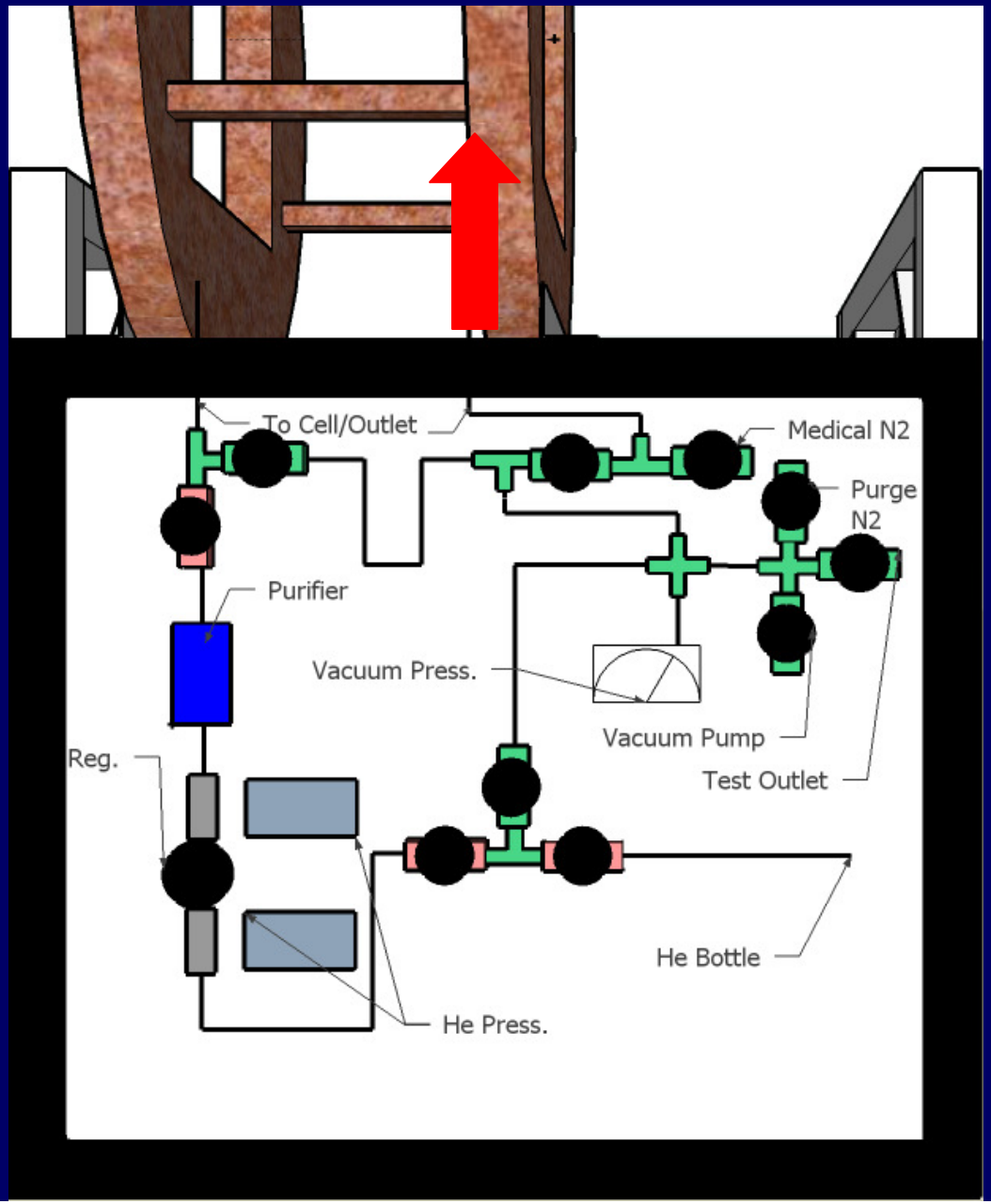
Lower Gas System: 02/08

Lasers



Construction

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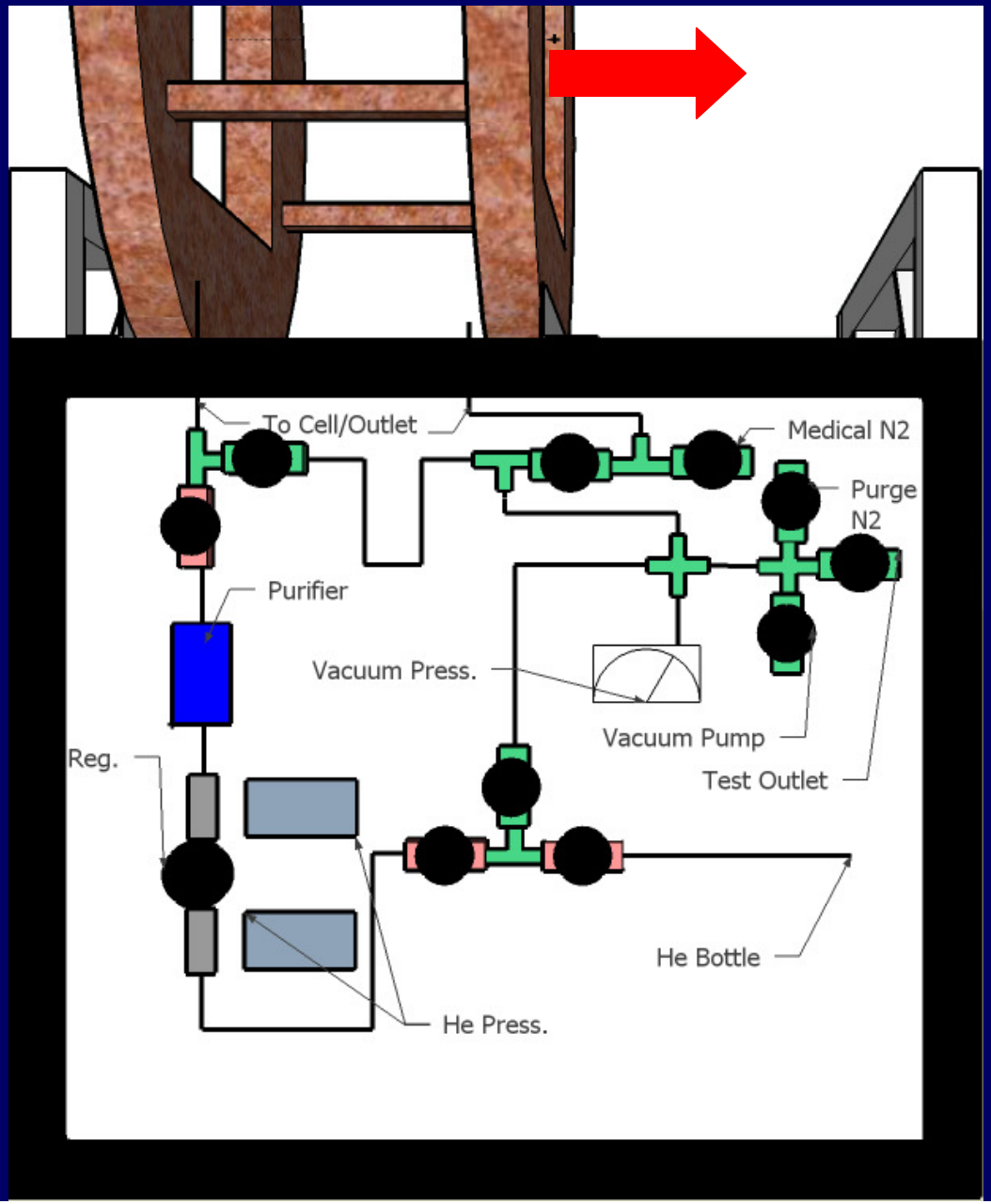
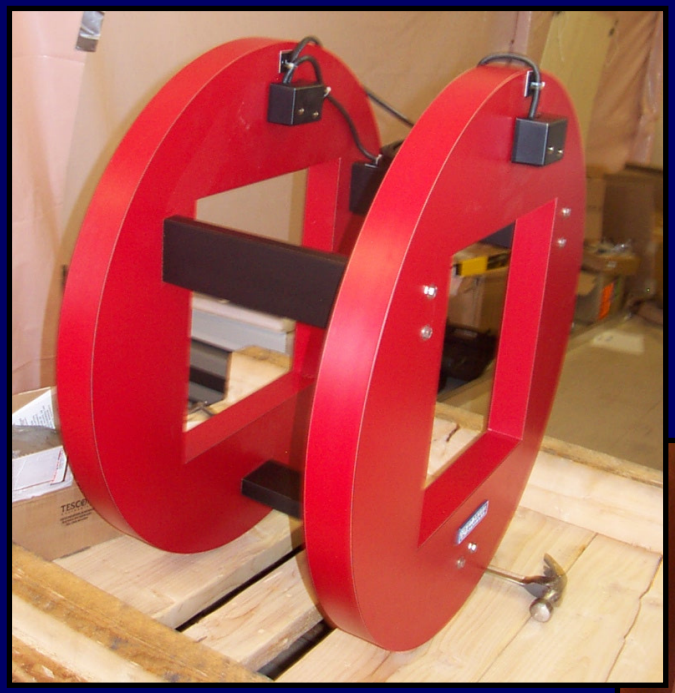
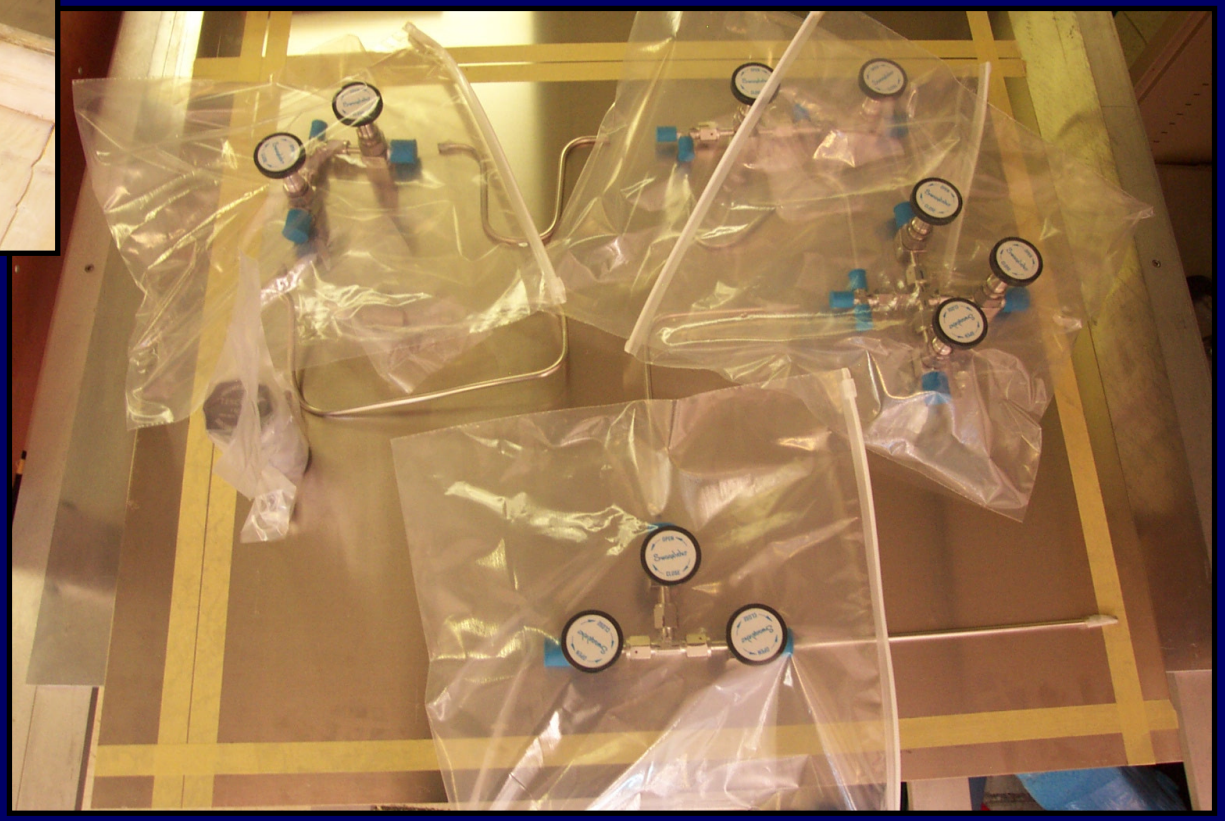
Lower Gas System: 02/08

Lasers



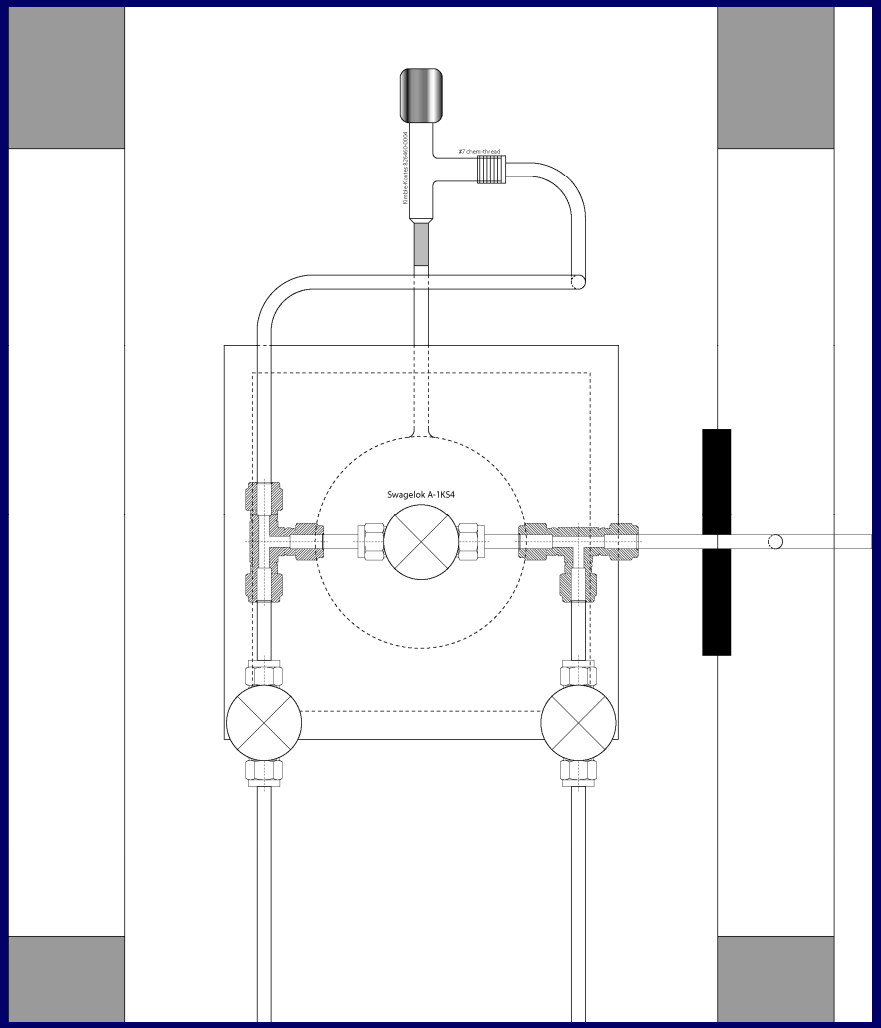
Lower Gas System: 03/08





Upper Gas System: 02/08

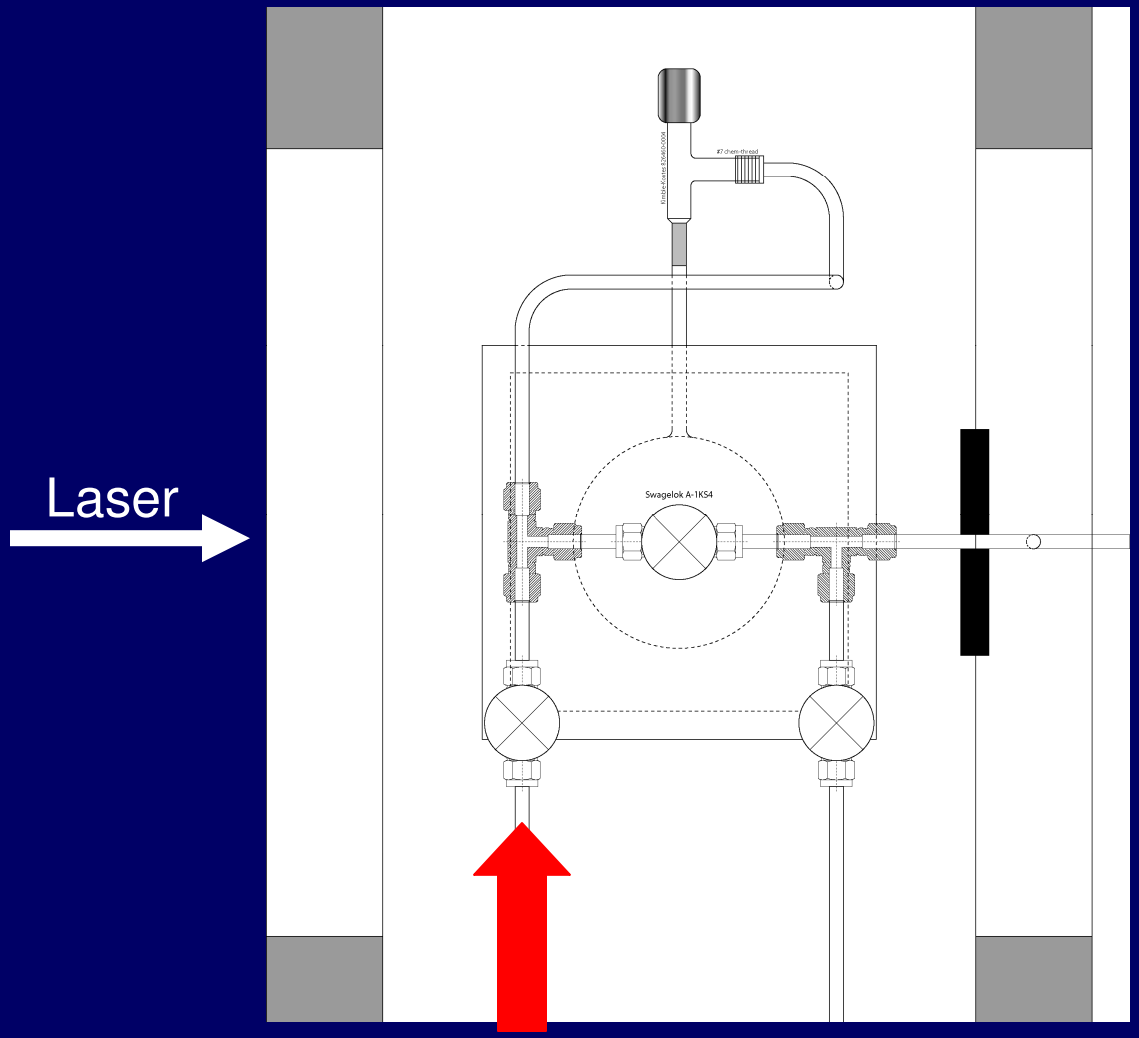
Laser



^{3}He fill

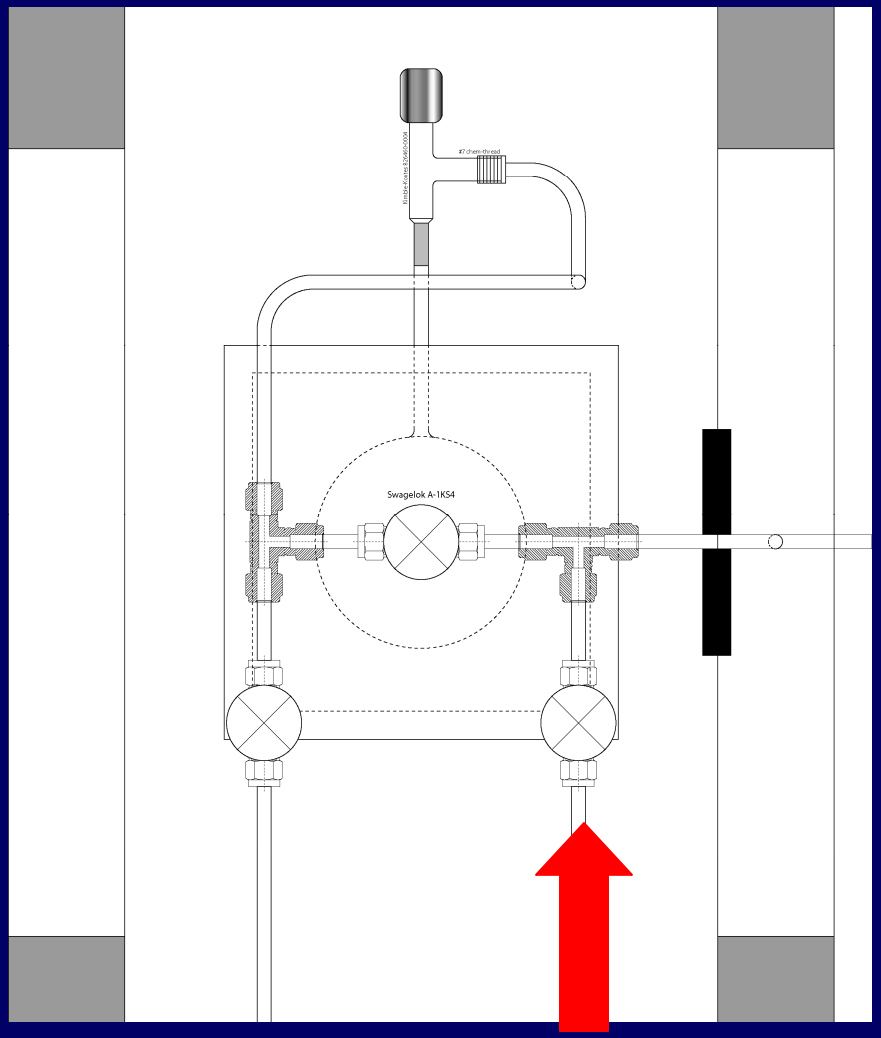
N_2 / Vacuum

Upper Gas System: 02/08



Upper Gas System: 02/08

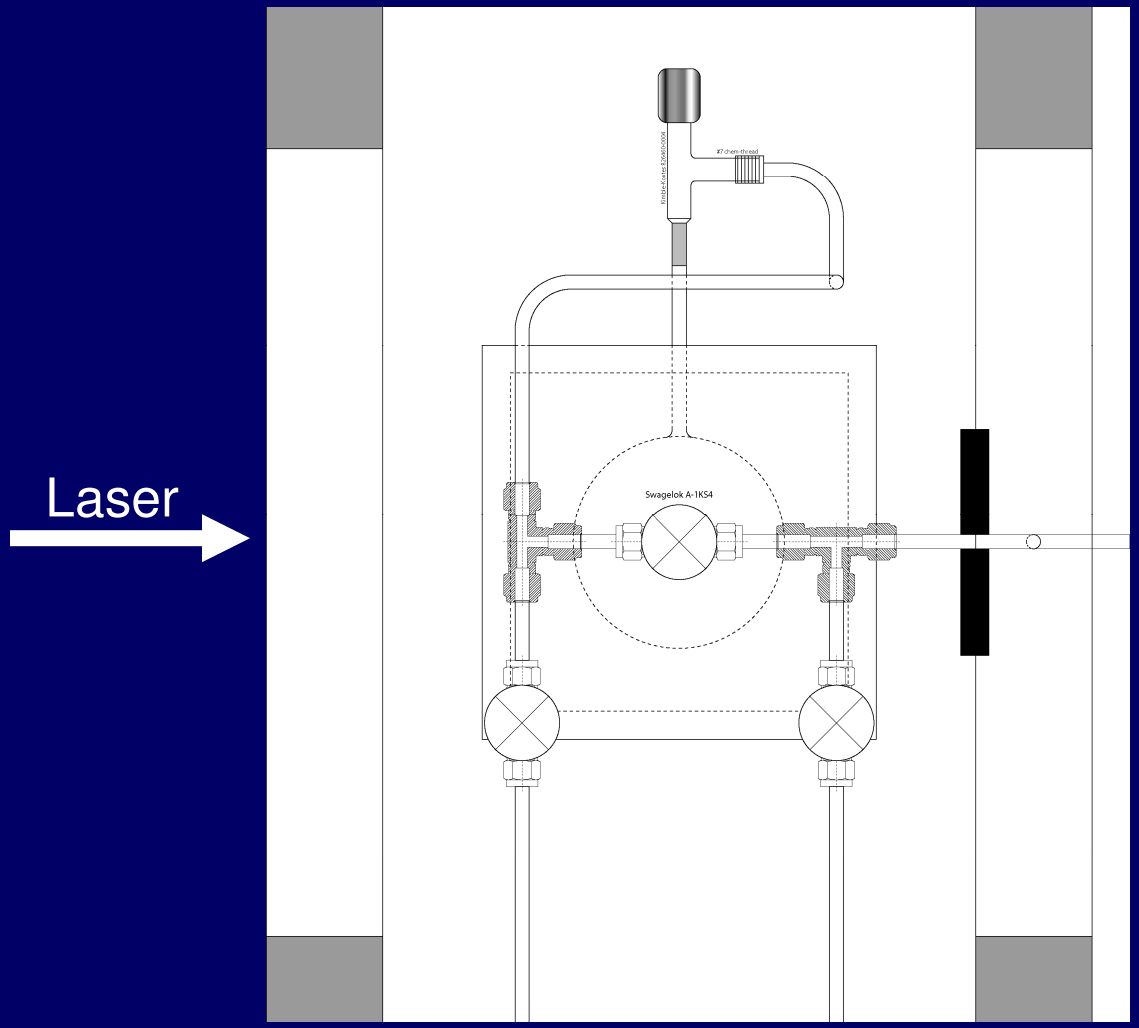
Laser



^{3}He fill

N_2 / Vacuum

Upper Gas System: 02/08



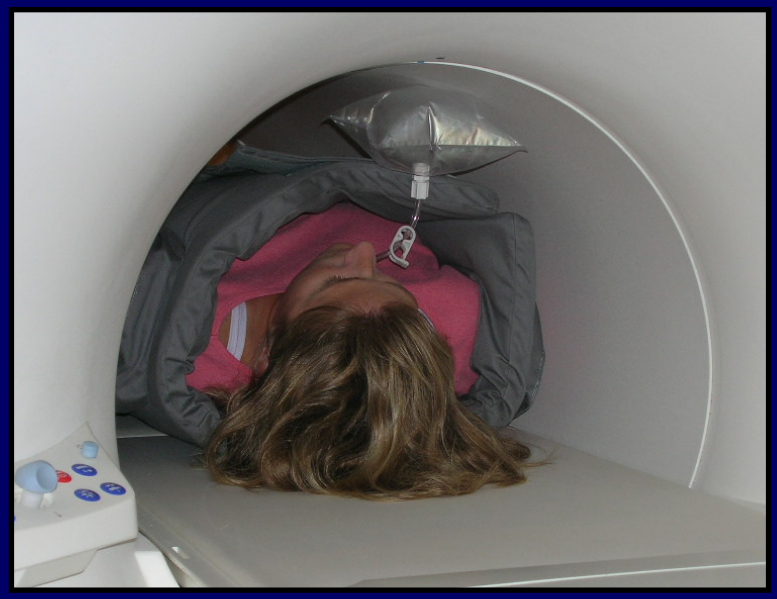
Laser

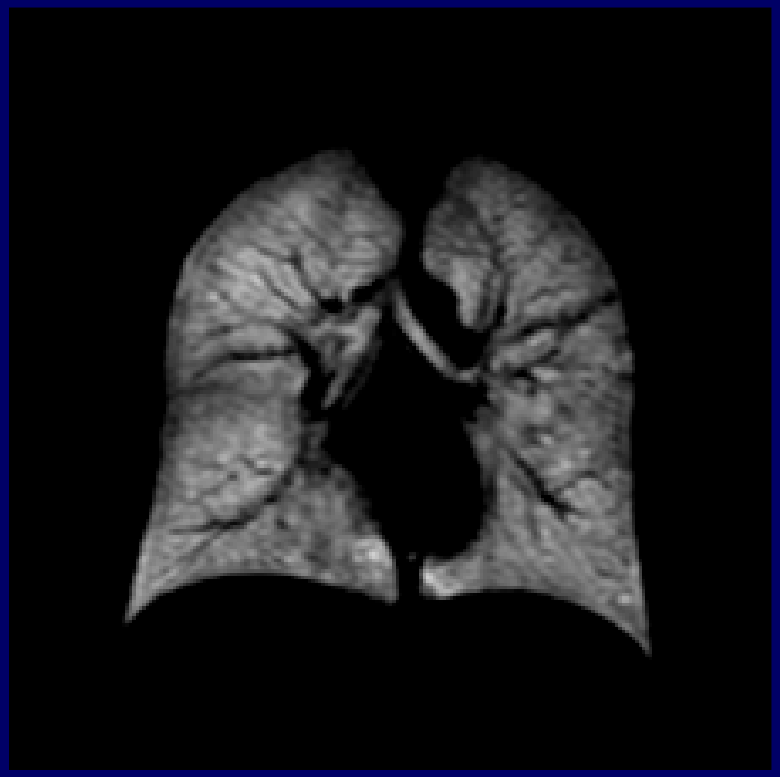
To Bag

^{3}He fill

N_2 / Vacuum

Operational Target: 04/2008





Acknowledgements

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Jaideep Singh

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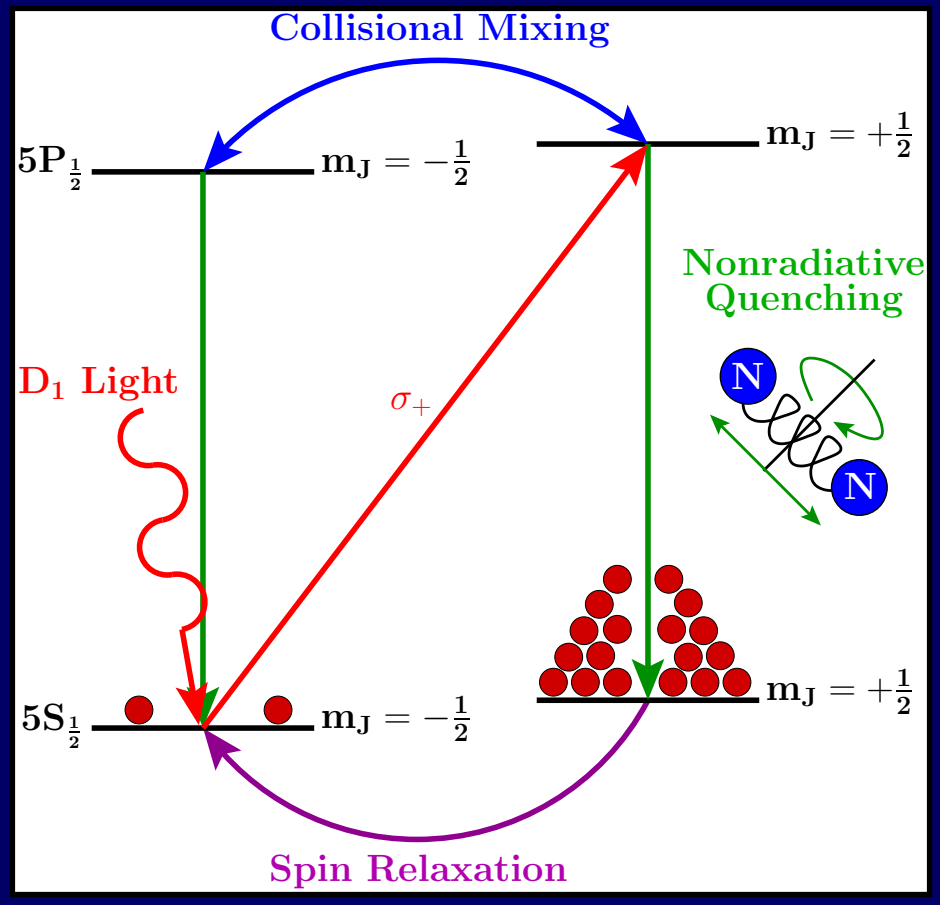
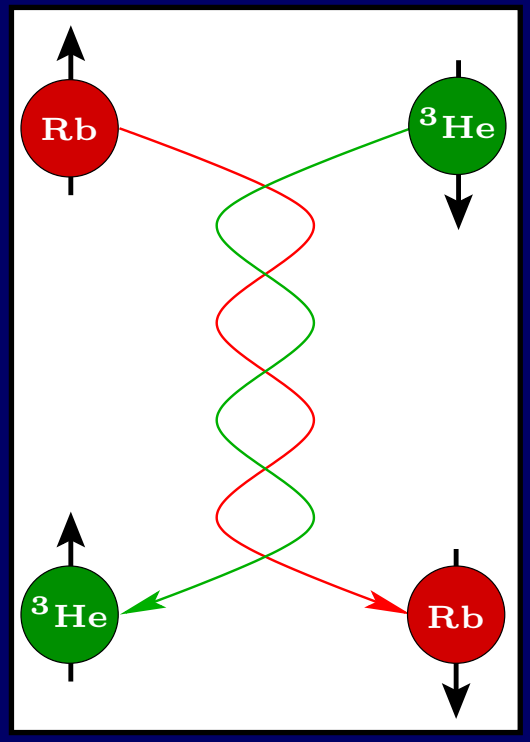
Spin Exchange Optical Pumping (SEOP)



Rubidium energy level diagram which details optical pumping. Source: Singh, 2004

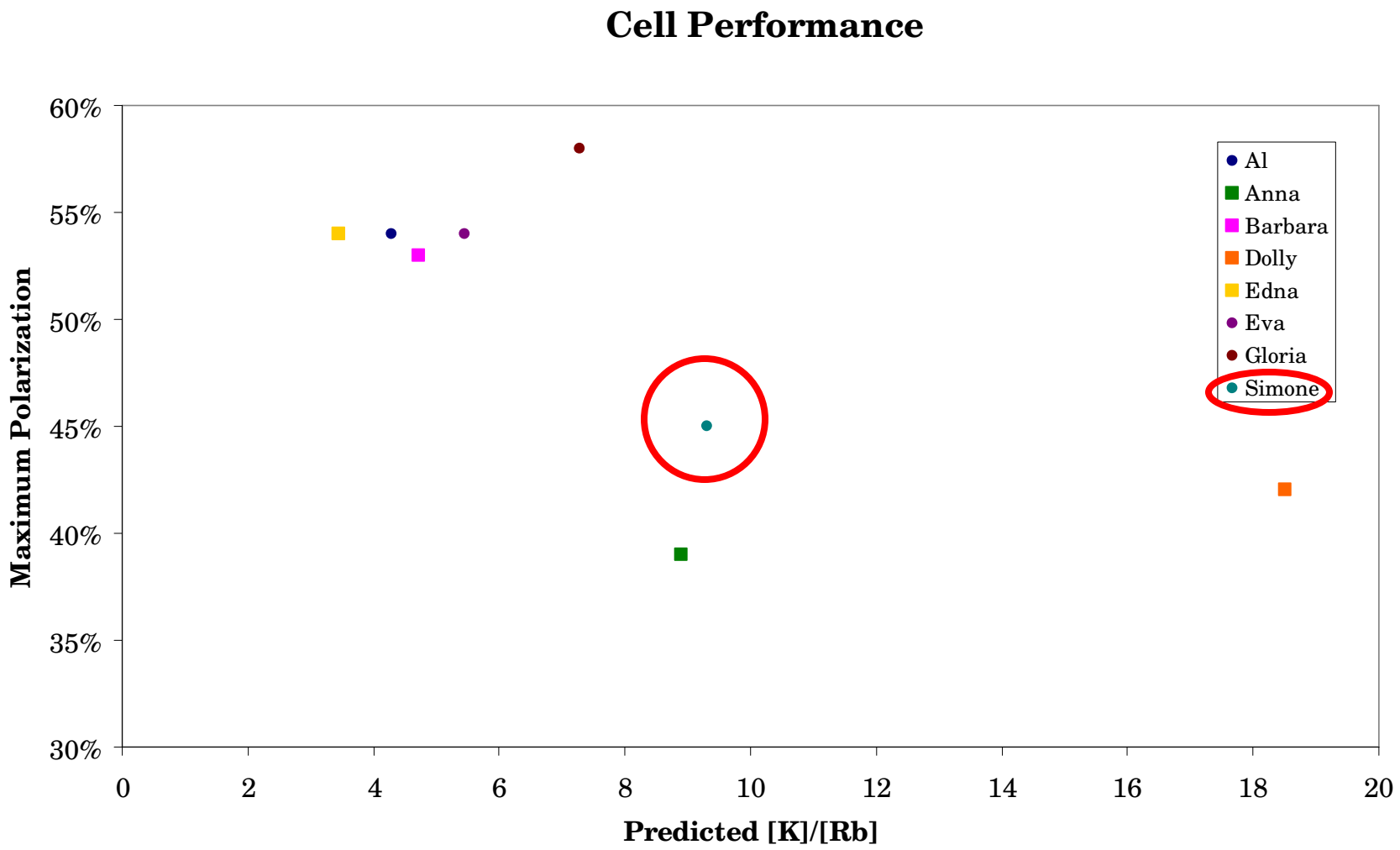


Spin Exchange diagram Source: Singh, 2004

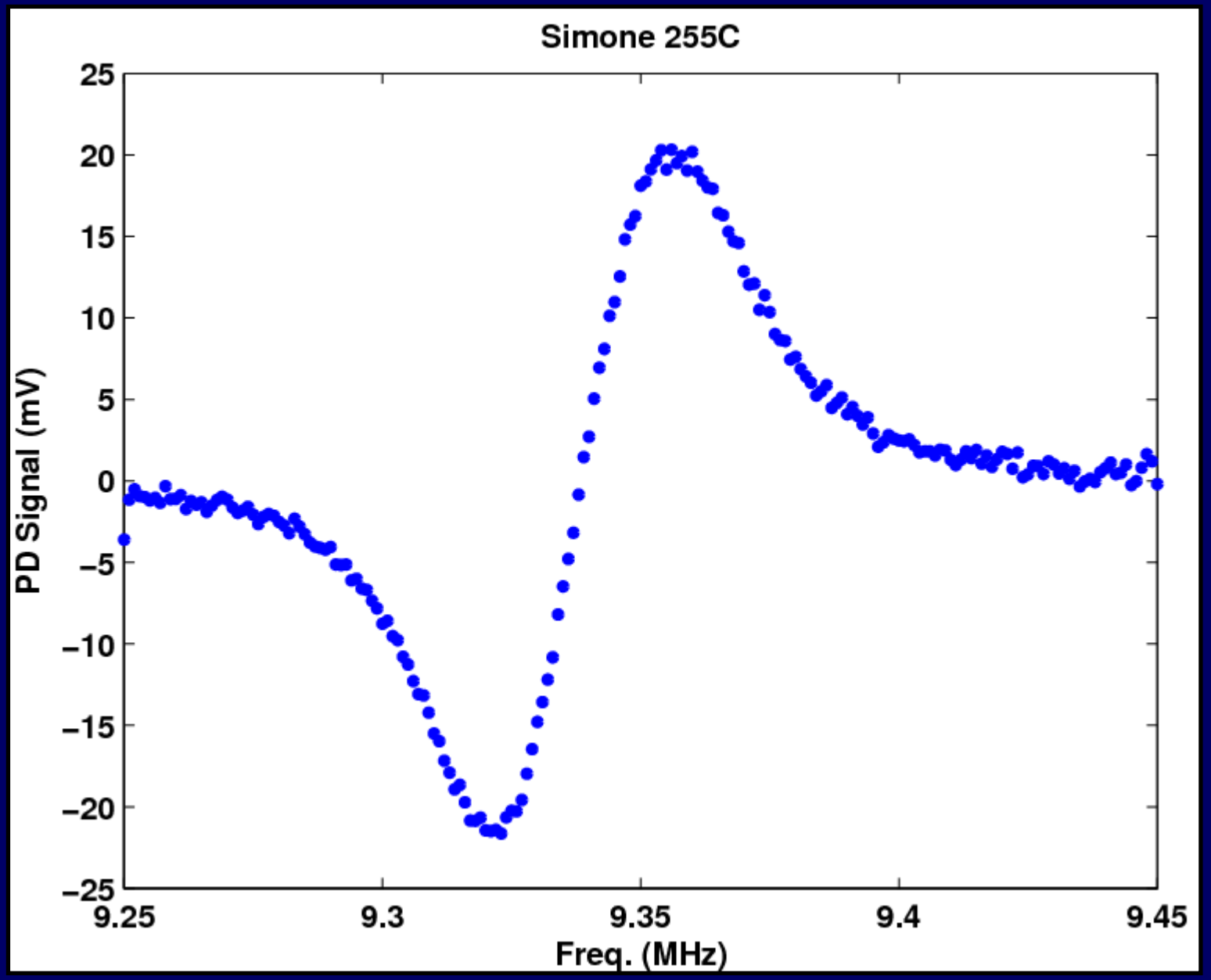
$$\langle P_{Rb} \rangle = \frac{R}{R+\Gamma_{SD}}$$

$$P_{^3He} = \langle P_{Rb} \rangle \left(\frac{\gamma_{SE}}{\gamma_{SE}+\Gamma} \right)$$

Simone- Previous Performance



Finding the Transition Frequency



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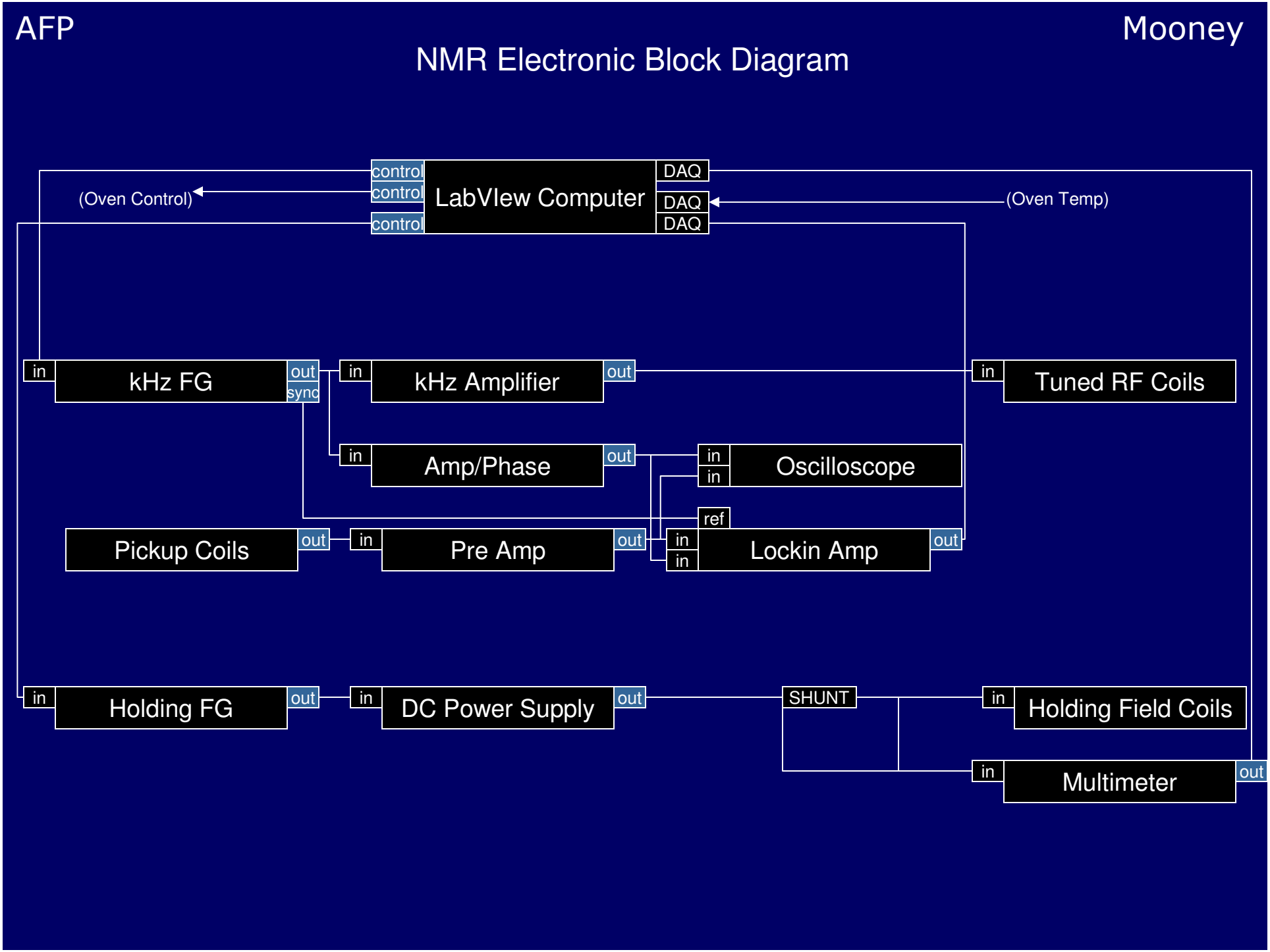
NMR Electronic Block Diagram



EPR

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EPR Electronic Block Diagram