Max-Planck-Institut für Kernphysik

Towards a 3H/3He Mass-Ratio Measurement with THe-Trap

First IMPRS-PTFS Seminar

Jochen Ketter

February 4, 2011

Motivation

Mass of the Electron Antineutrino

- β-Decay of Tritium

$$^3\mathrm{H} \rightarrow {}^3\mathrm{He} + \mathrm{e}^- + \overline{\nu}_\mathrm{e}$$

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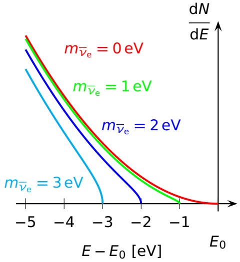
- KATRIN: electron kinematics near the endpoint



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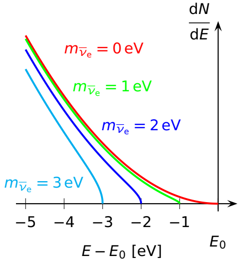

Penning Trap Contribution

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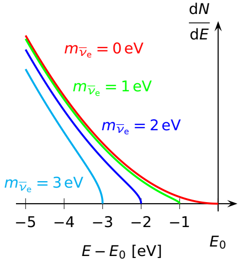

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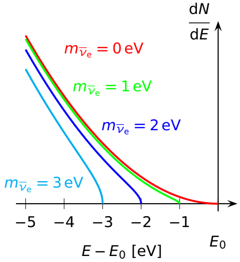

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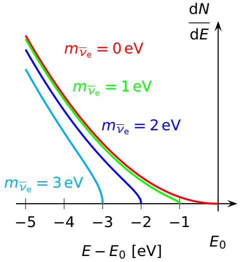

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- uncertainty of $30\,\mathrm{meV}$ in Q
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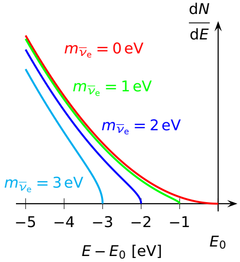

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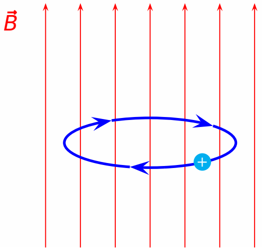
dedicated experiment, developed at the University of Washington in Seattle

A Penning Trap Primer

Charged Particle Confinement

- free-space cyclotron frequency

$$\omega_c = \frac{qB}{m}$$



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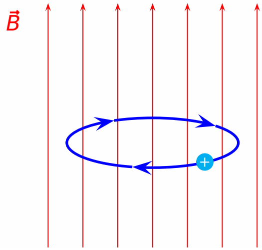

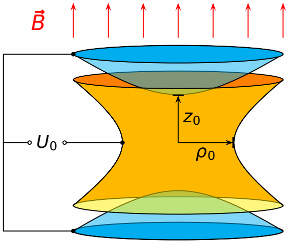

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- electrostatic quadrupole field
- three eigenmodes
  - axial $\omega_z = \sqrt{\frac{qU_0}{md^2}}$
  - modified cyclotron ω_+
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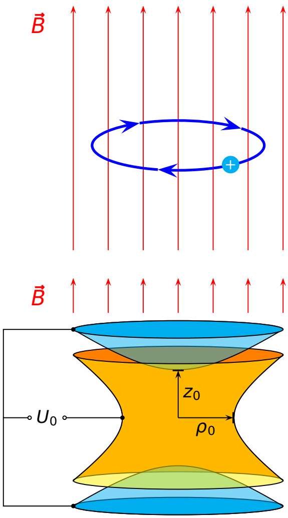
$$\omega_\pm = \frac{1}{2}\left[\omega_c \pm \sqrt{\omega_c^2 - 2\omega_z^2}\right]$$



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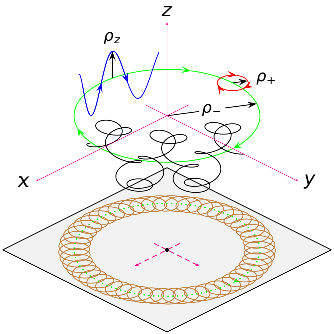

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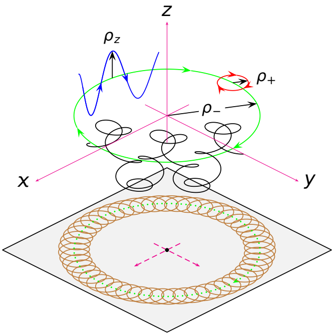
- Invariance Theorem

$$\omega_c^2 = \omega_+^2 + \omega_-^2 + \omega_z^2$$



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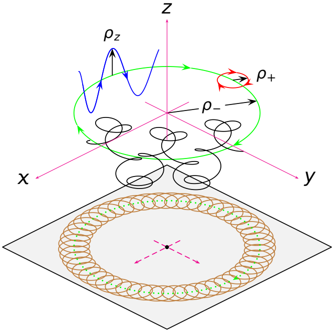


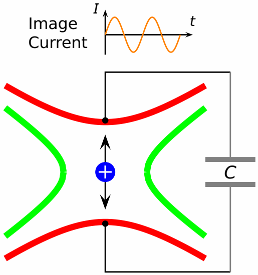
Mass-Ratio

$$R = \frac{m_{\mathrm{a}}}{m_{\mathrm{b}}} = \frac{q_{\mathrm{a}}}{q_{\mathrm{b}}} \cdot \frac{\omega_{\mathrm{c}}(\mathrm{b})}{\omega_{\mathrm{c}}(\mathrm{a})} \cdot \frac{B_{\mathrm{a}}}{B_{\mathrm{b}}}$$

Non-Destructive Ion Detection

Ion Electrode Interaction

- induced image charges
  ⇒ image currents
- goal: generate and amplify voltage drop



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- tune out trap capacitance at
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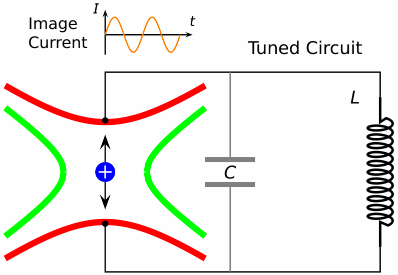

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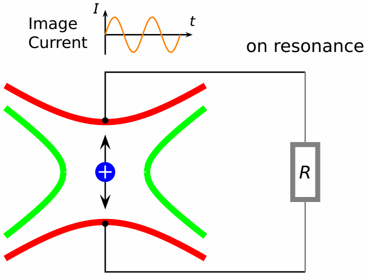

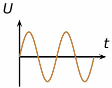

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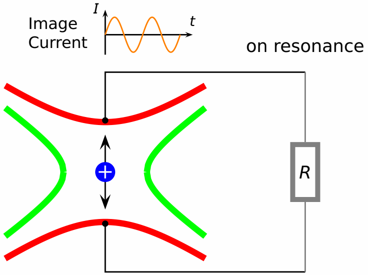

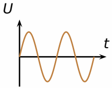

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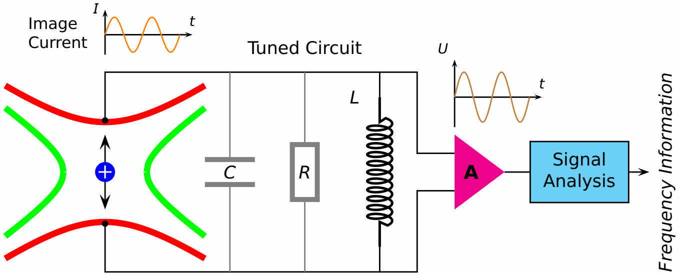

Anharmonic Frequency Detection

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Driven Harmonic Oscillator

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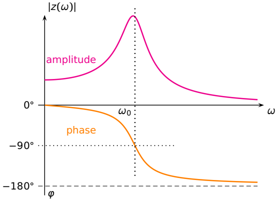

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- Error Signal for frequency lock
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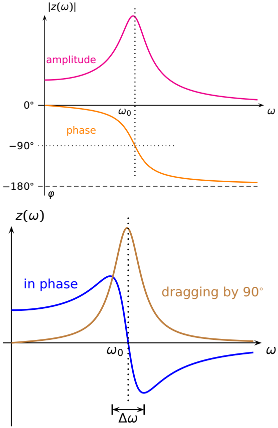

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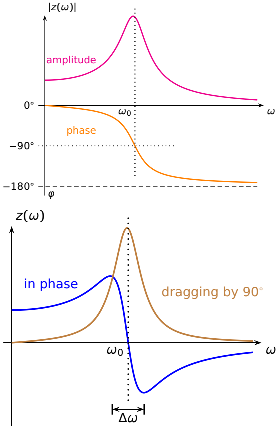
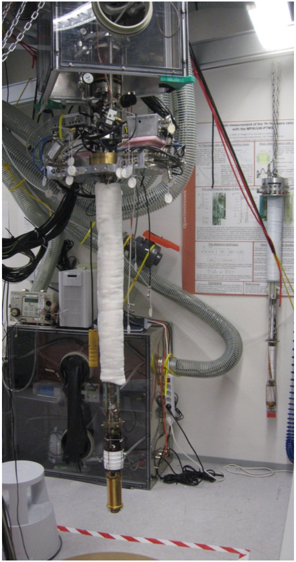
Radial Modes

- monitor excitations via higher-order effect on natural axial frequency



The Setup at MPIK



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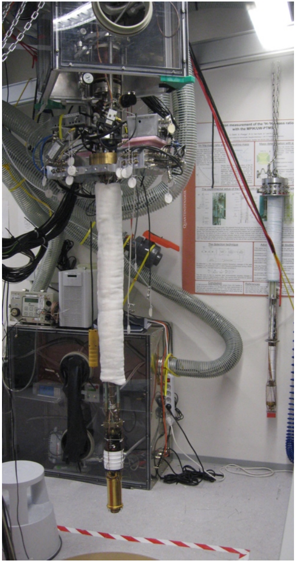

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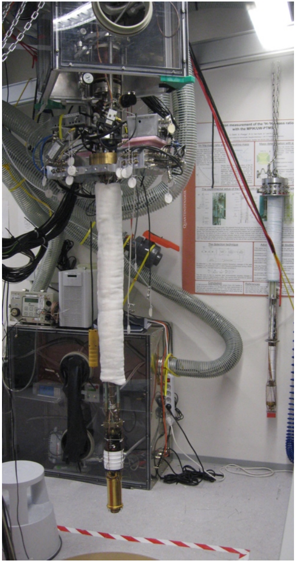

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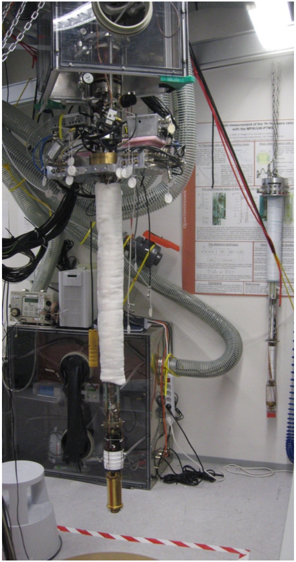

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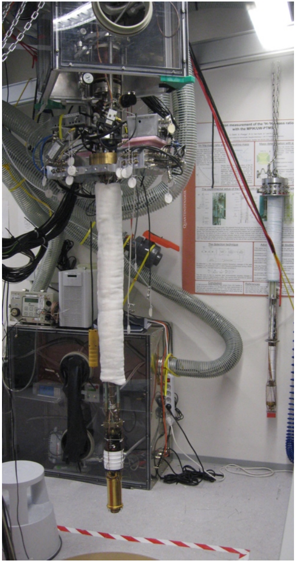

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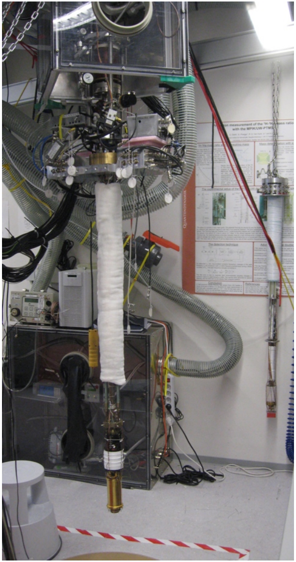

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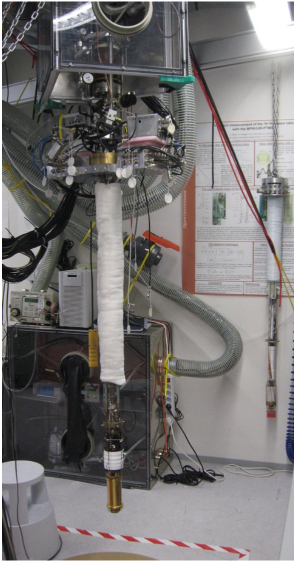

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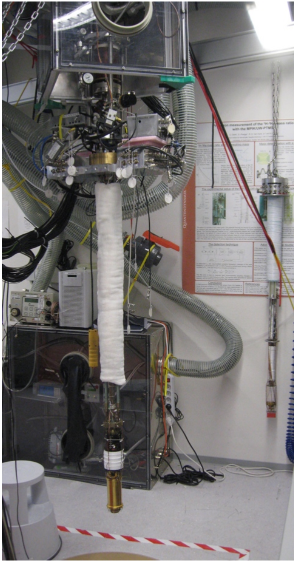

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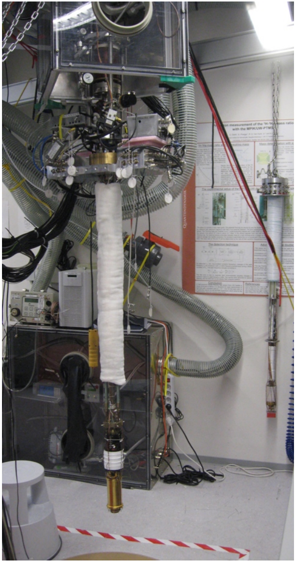

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- novel cascaded Zener-diode voltage-reference voltage-source

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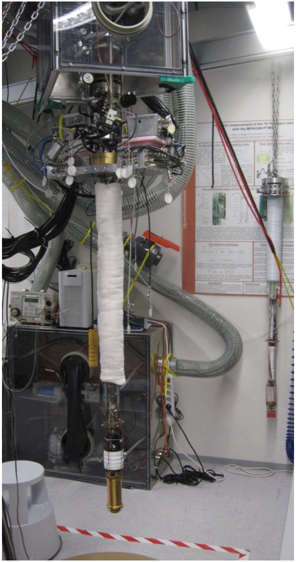

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The Control Room

The Magnet Room

External Influences

- room temperature
- external magnetic field changes
- vibration isolation

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Cold-Bore Magnet

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temperature-dependent magnetic susceptibility

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temperature-dependent magnetic susceptibility ⇒ stabilize:

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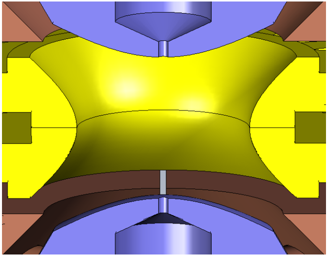
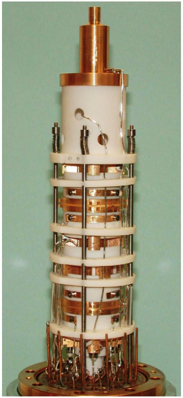
- liquid helium level
  ⇒ constant temperature distribution

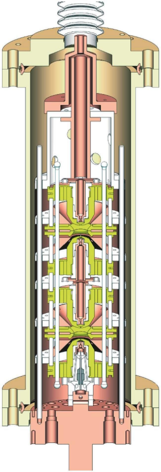
The Traps of THe-Trap

Inside Vacuum Envelope

- two hyperbolic traps with correction electrodes







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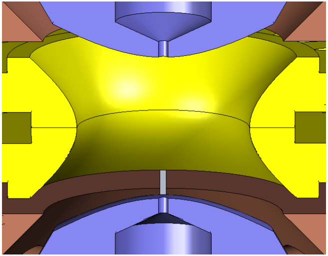
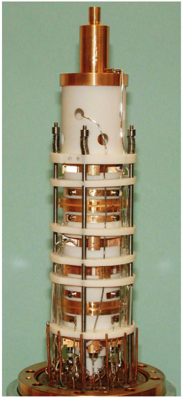
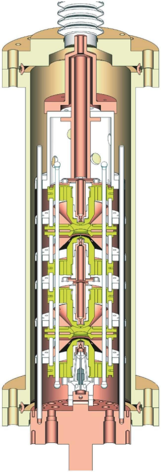
- transfer section
- capture section







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Inside Vacuum Envelope

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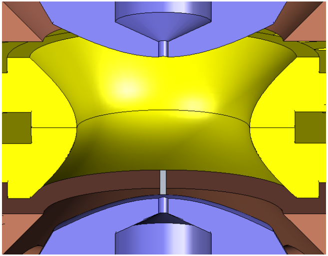
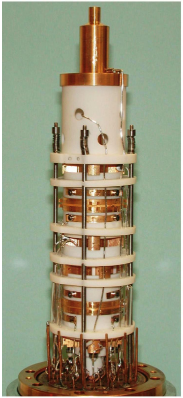
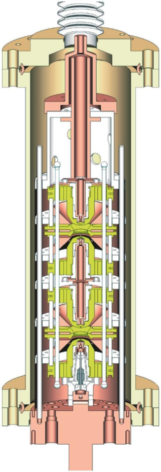
- capture section
- Field Emission Point







RF Ion Work

The Road to Ions

- load a cloud of ions

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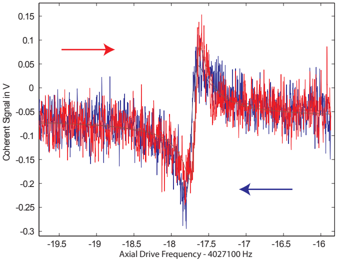

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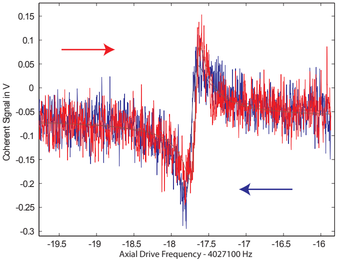

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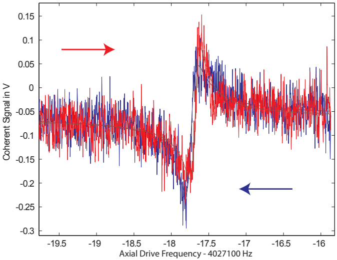

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- establish lock

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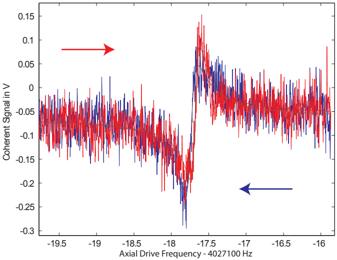

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Triggered Sweeps

- establish lock
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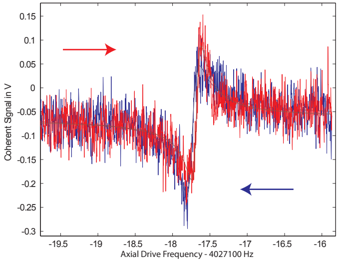

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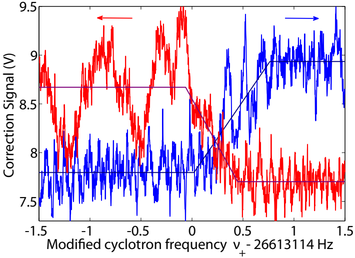

Triggered Sweeps

- establish lock
- run triggered sweeps

Summary and Outlook

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Achievements

- experiment moved to MPIK
- dedicated lab
- commissioning experiments
- single ion sensitivity

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- systematic studies
- external loading and ion transfer

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Achievements

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Long-term Goal

- $^{3}H/^{3}He$ Mass-Ratio Measurement