Liverpool Atom Interferometer Upgrade Progress

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Measurements using Atom Interferometry

- Local Gravity
- Fine Structure Constant
- Lorentz Invariance Violation
- Dark Matter
- Gravitational Waves
- Quantum Foam

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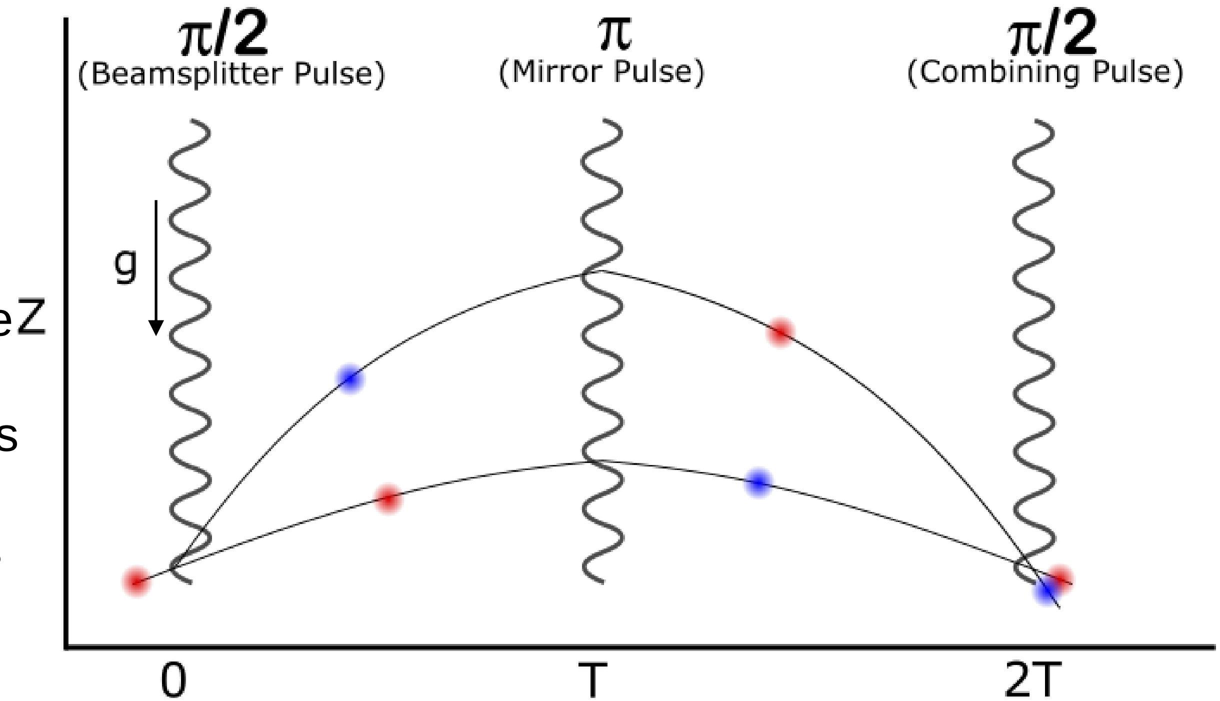
Atom Interferometry Overview

1. Atom cloud is cooled to near absolute zero
2. Atoms put into a specific state
3. A $\frac{\pi}{2}$ pulse acts as a beamsplitter and splits the atom cloud
4. Free propagation of atoms
5. A π pulse acts as a mirror to invert state populations
6. Another free propagation stage
7. A second $\frac{\pi}{2}$ pulse re-combines the beams
8. State populations are measured



Output Population Ratio

$$P = \frac{1}{2}(1 - \cos(\Delta\varphi))$$
$$\Delta\varphi = kg\boldsymbol{T}^{\boldsymbol{2}}$$

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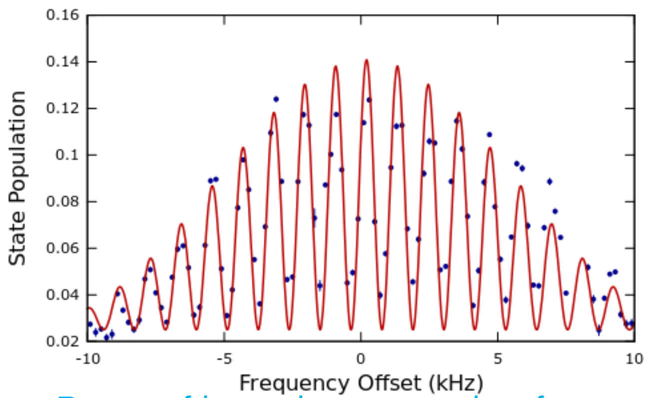
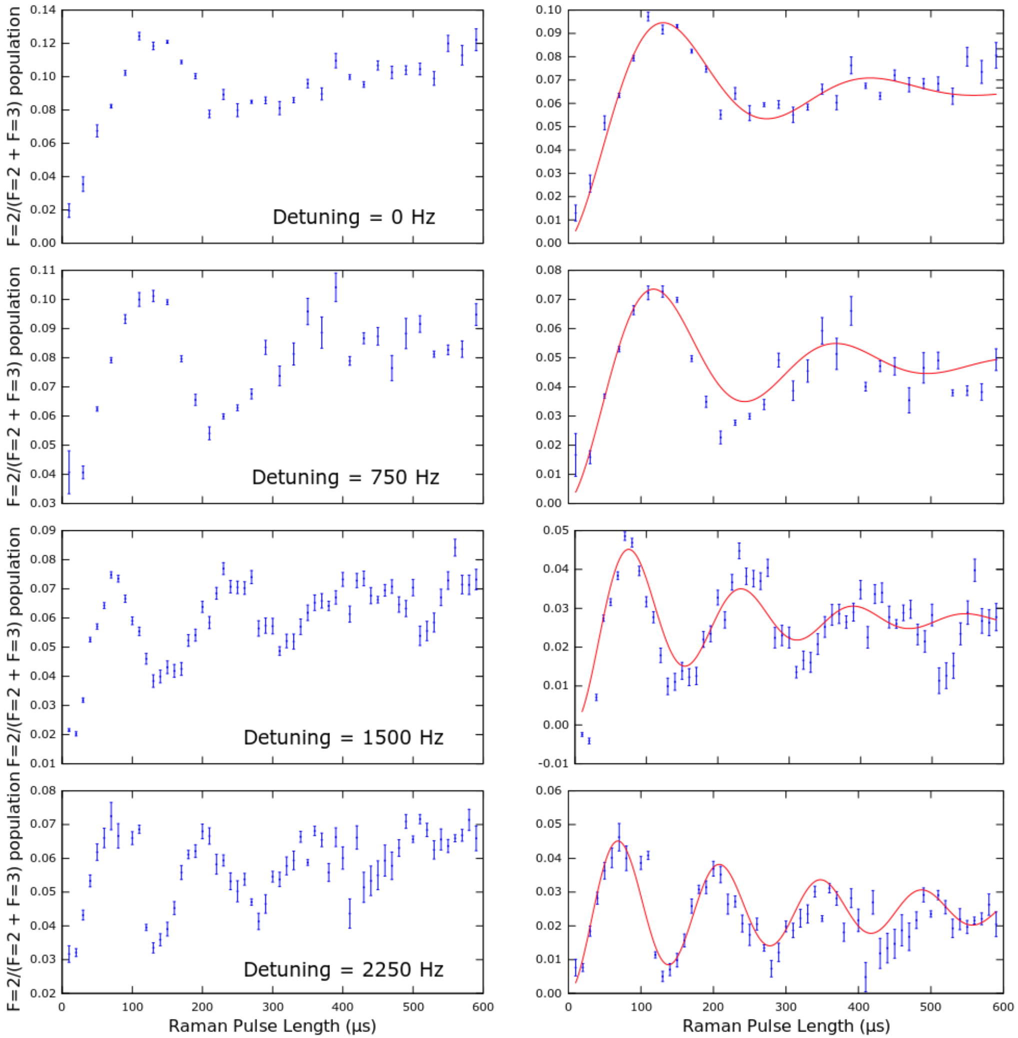
Current Measurements

- Current results for Liverpool Interferometer

- Raman beam improvements reduce noise
- Increase the Rabi frequency



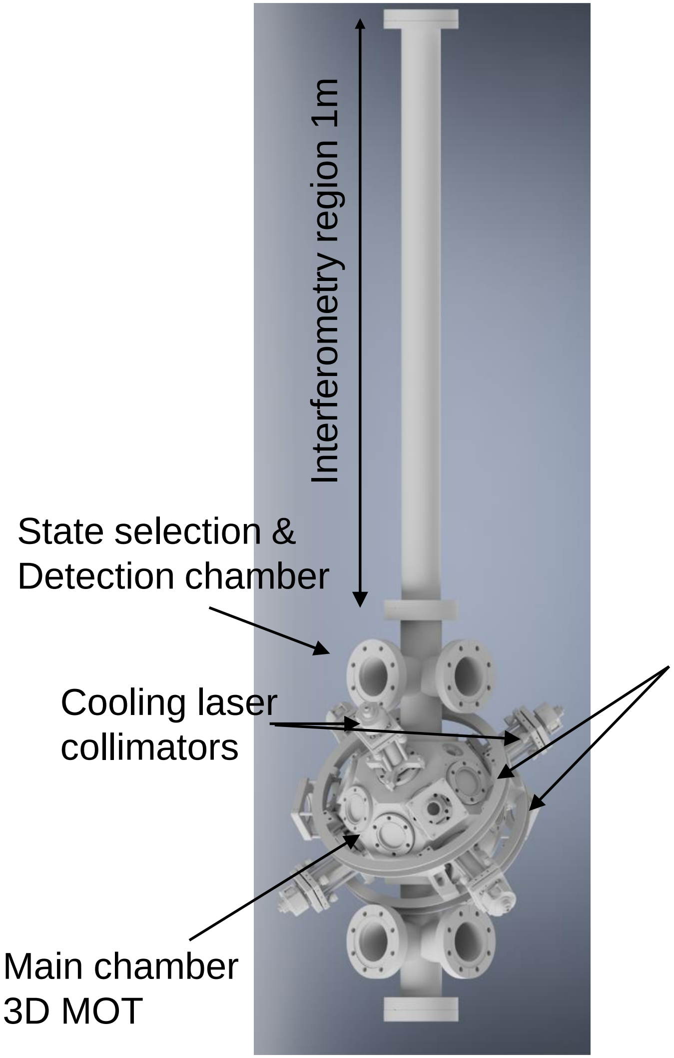
Ramsay fringes demonstrate interference



Rabi Oscillations with increasing detuning form atomic resonance

General Improvements

- More ports allow for more camera angles and use of dipole trap
- Fibre AOMs and switches allow for reduction in leaked light
- Larger, flatter Raman windows reduce wavefront distortion
- New detection system
- Cold atom source for faster loading times
- Vibration Isolation



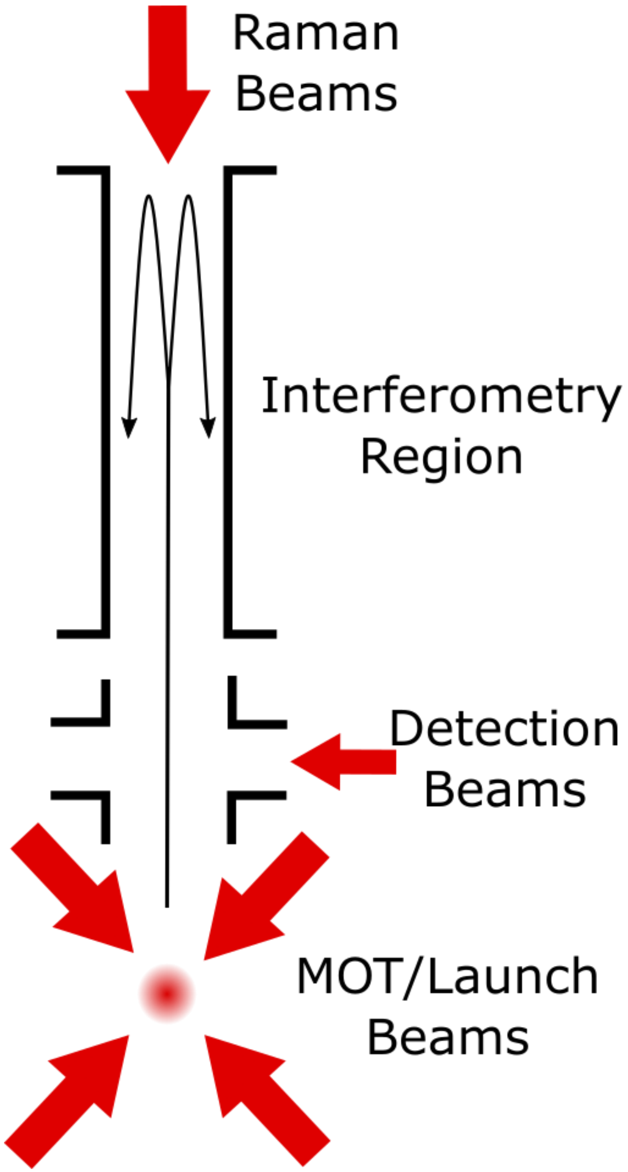
Designed by K. Bridges, A. Webber-Date

Launching Atoms

Output Population Ratio

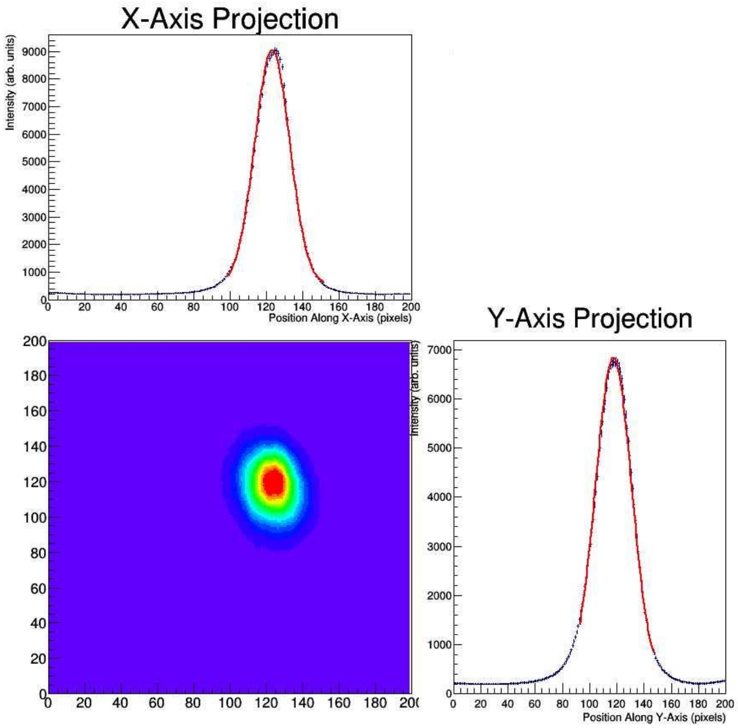
$$P = \frac{1}{2}(1 - \cos(\Delta\varphi))$$
$$\Delta\varphi = kg\boldsymbol{T^2}$$

- Sensitivity of atom interferometry depends on T
- Can effectively double the Interferometry Region by launching
- Leads to factor 4 increase in phase shift



Limitations in Power

- Upgrade includes larger windows for larger trapping beams
- Larger beams increase atom number
- Must increase power to compensate for larger beam diameter



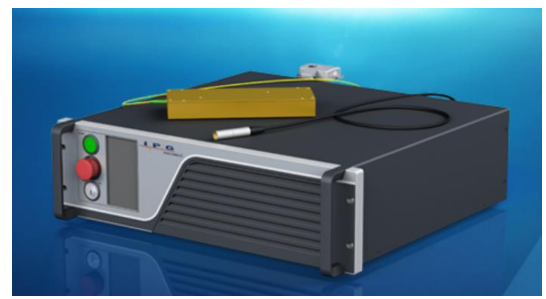
Current MOT Diameter = ~1 mm
Current Beam Size = 12 mm
Current Atom number $\sim 4 \times 10^7$

New MOT Beam Diameter = 25 mm
Possible Upgrade MOT Size = $>$ 2 mm
Upgraded Atom Number $> 3 \times 10^8$

Increasing Power

- New laser has been purchased to increase power
- Consists of 1560 nm seed laser and 30 W fibre amplifier
- Rubidium requires 780 nm light

40 mW @ 1560 nm

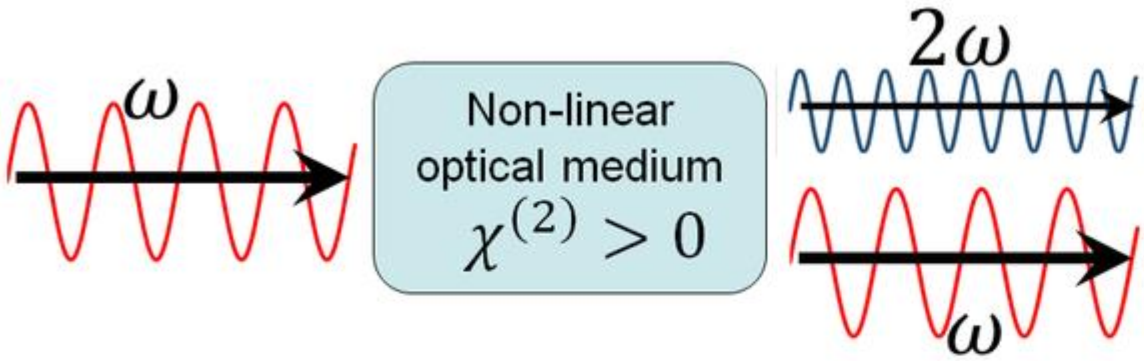


30 W @ 1560 nm

7 W @ 780 nm

Second Harmonic Generation (Frequency Doubling)

- Lithium Niobate crystal used change the wavelength of light (PPLN)
- Two 1560 nm photons interact with the PPLN to create one 780 nm photon
- Output is up to 7 W of 780 nm, 2.5 times the current power



- Residual 1560 nm light may be used in future dipole trap
- Dipole trap means colder atoms
- Colder atoms means a larger signal

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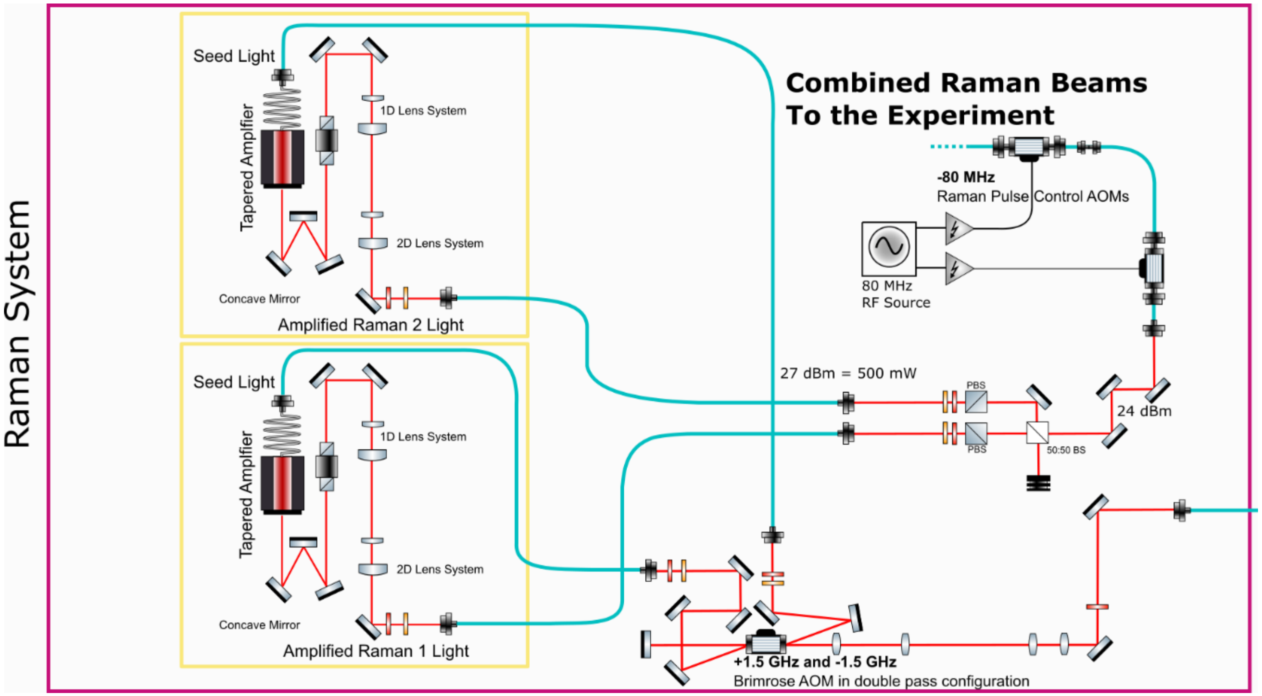
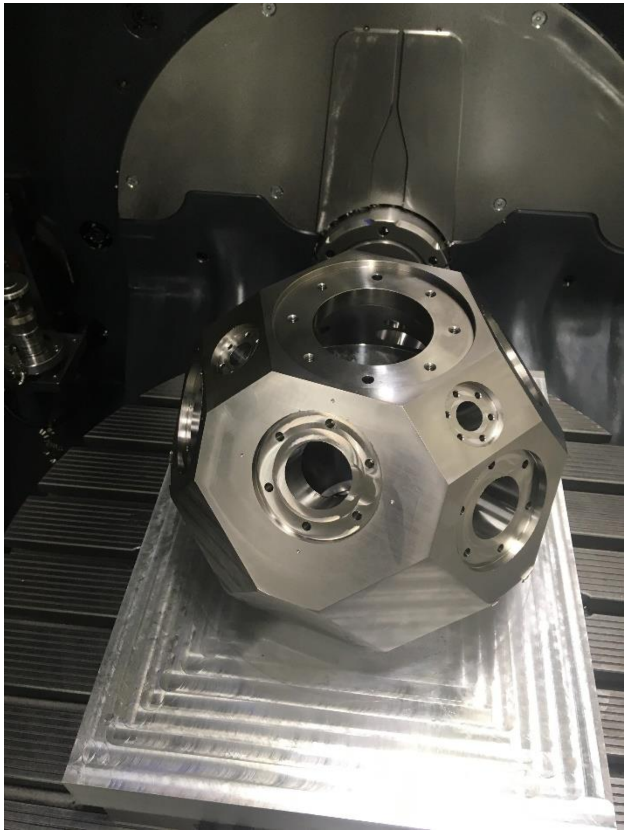
Raman Power Increase



- Power limited by damage threshold of ultra-fast AOM
- Amplification with Tapered Amplifier occurs after the frequency manipulation
- Means higher Raman beam power
- Allow for more momentum to be imparted on atoms

Chamber Progress



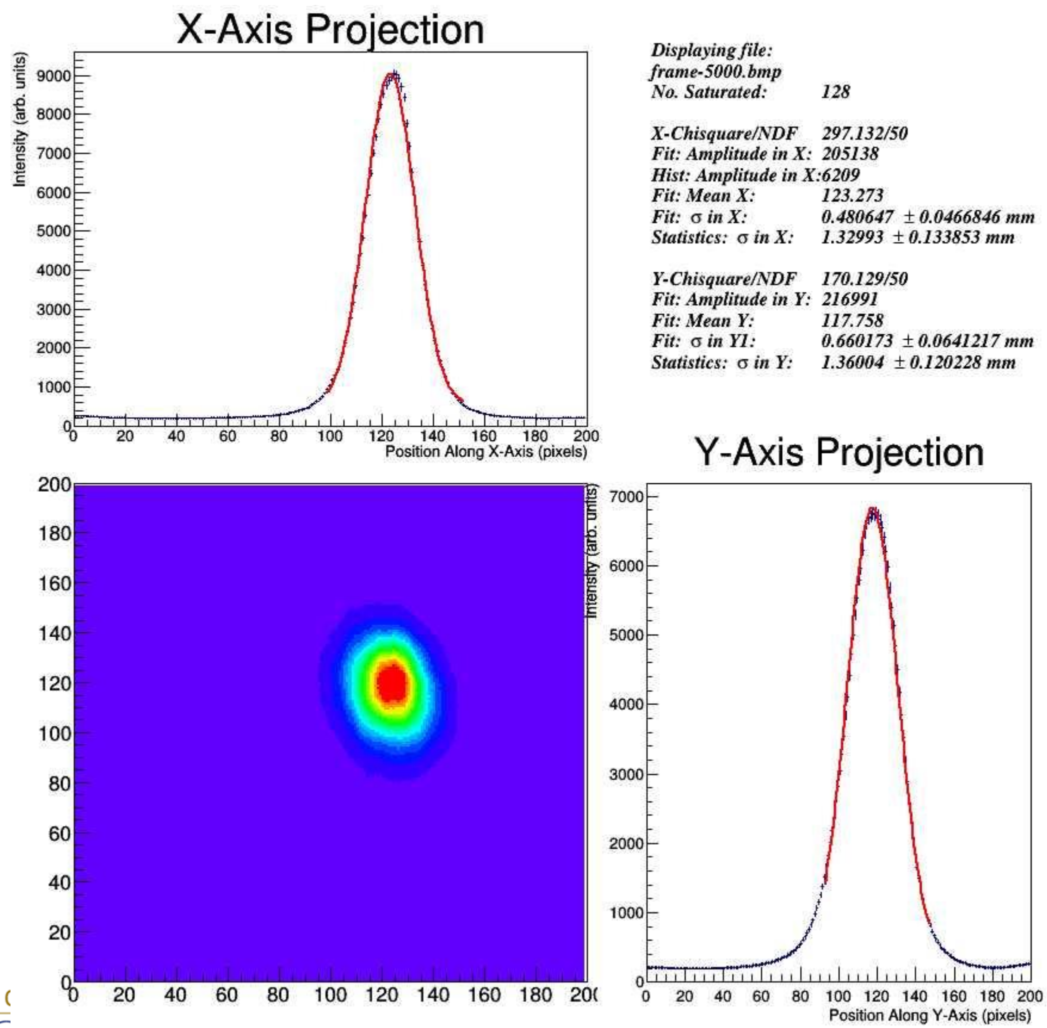
The main chamber is being made here at Liverpool Physics Workshop! Many thanks to them for everything they do for us.

Summary

- Upgrade is now underway
- New high power laser system has been designed
- Atom launch designed
- All upgrade components have been ordered

Questions?

Back Ups


X-Axis Projection
Intensity (arb. units)
Position Along X-Axis (pixels)
Displaying file:
frame-5000.bmp
No. Saturated: 128
X-Chisquare/NDF 297.132/50
Fit: Amplitude in X: 205138
Hist: Amplitude in X:6209
Fit: Mean X: 123.273
Fit: σ in X: 0.480647 ± 0.0466846 mm
Statistics: σ in X: 1.32993 ± 0.133853 mm
Y-Chisquare/NDF 170.129/50
Fit: Amplitude in Y: 216991
Fit: Mean Y: 117.758
Fit: σ in Y1: 0.660173 ± 0.0641217 mm
Statistics: σ in Y: 1.36004 ± 0.120228 mm
Y-Axis Projection
Intensity (arb. units)
Position Along Y-Axis (pixels)

Large Momentum Transfer

- Large Momentum Transfer (LMT) increases sensitivity
- Implementing LMT requires Raman beam detuning (Δ)
- Detuning reduces single photon interaction – causes decoherence
- Also decreases Raman transition

$$Single\ Photon\ Interaction \propto \frac{1}{\Delta^2} \qquad Raman\ Transition \propto \frac{1}{\Delta}$$

- Can suppress single photon interaction and maintain Raman transition by increasing Raman beam power

$$\Omega_{Raman} \propto \frac{I_1 I_2}{2\Delta}$$

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Atom Launching

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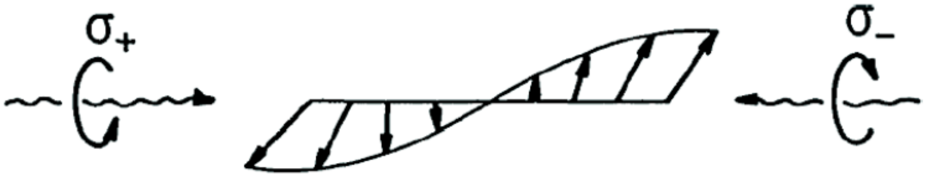
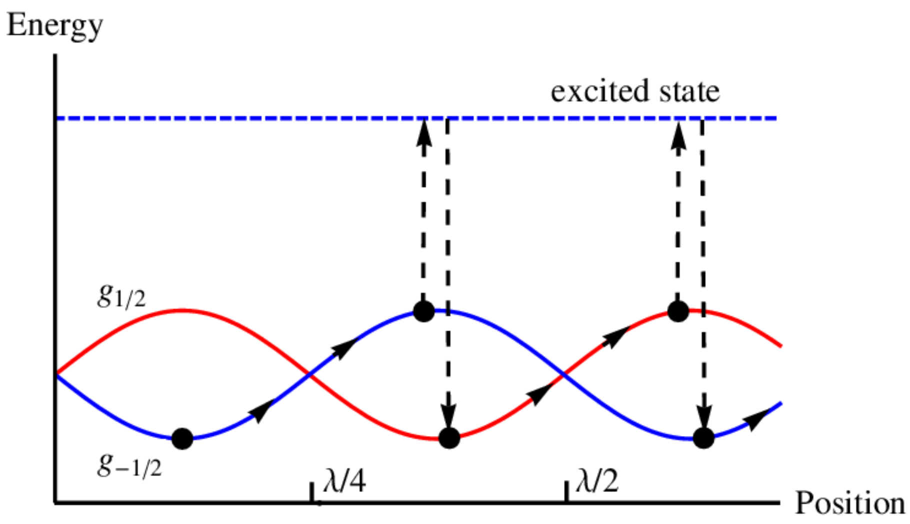
Polarisation Gradient Cooling

- PGC is used to cool below Doppler limit
- Two counter-propagating, circular polarised beams form standing wave



- Atoms moving in standing wave lose kinetic energy as they move toward potential maximum
- Optical pumping moves atoms to lower energy state, removing potential energy [5]



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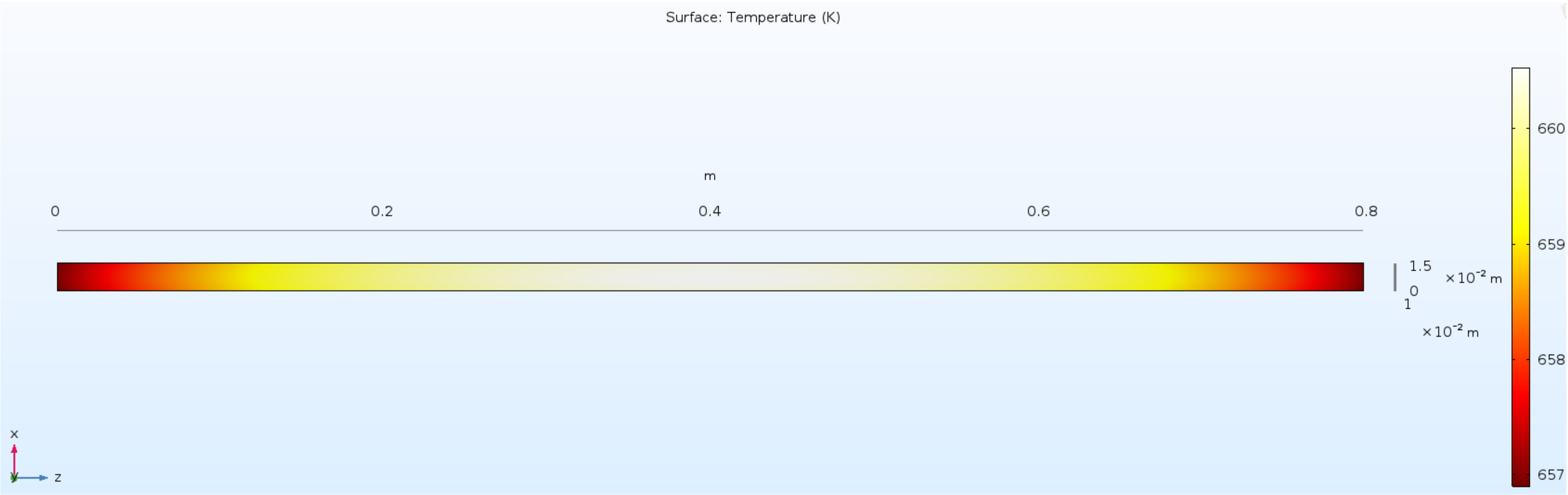
Coil Heating



- Simulation of Joule heating in the coil without cooling
- At equilibrium
- Max temperature is 660K

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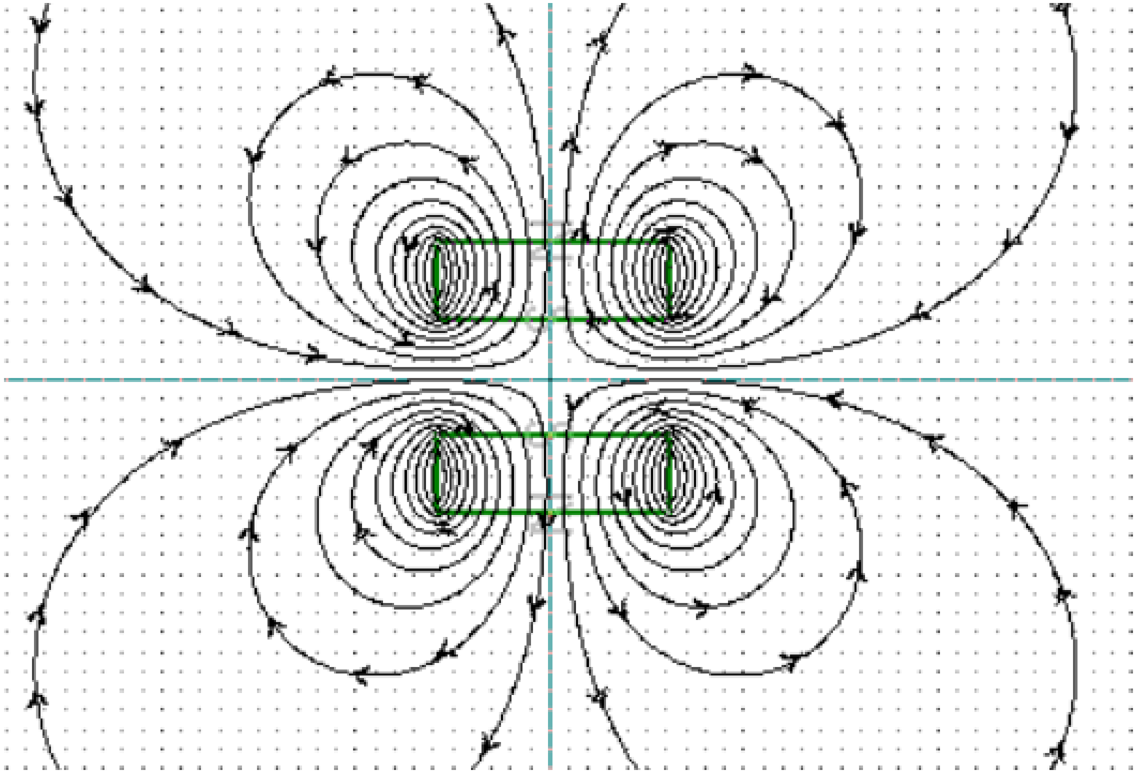
Field Lines



- 2D field simulation of two coils
- Anti-Helmholtz configuration
- Magnetic minimum in the centre

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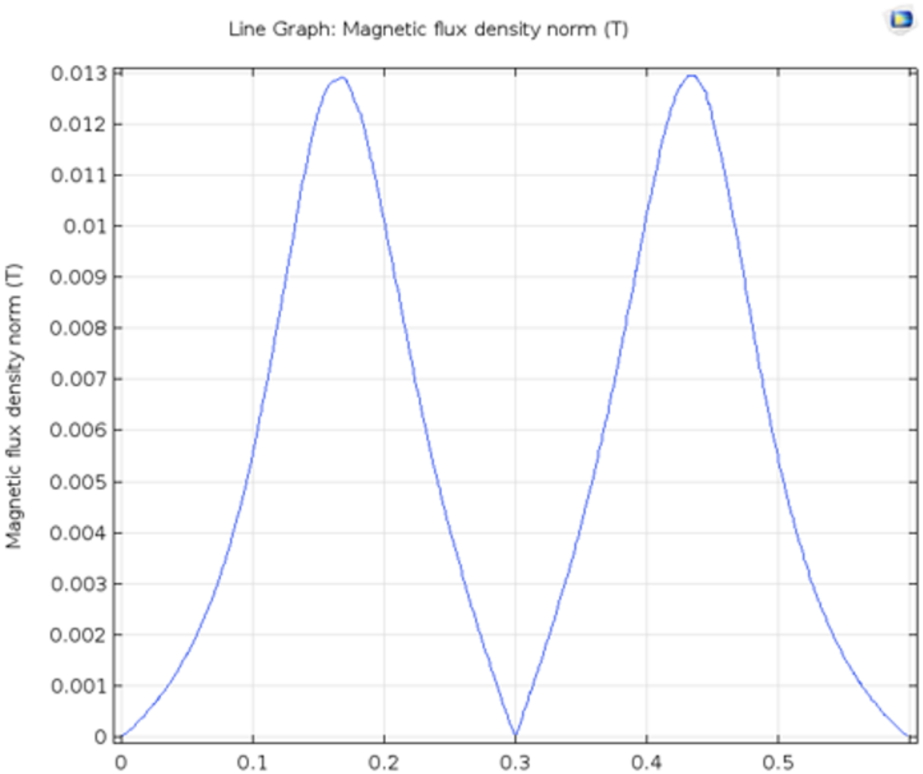
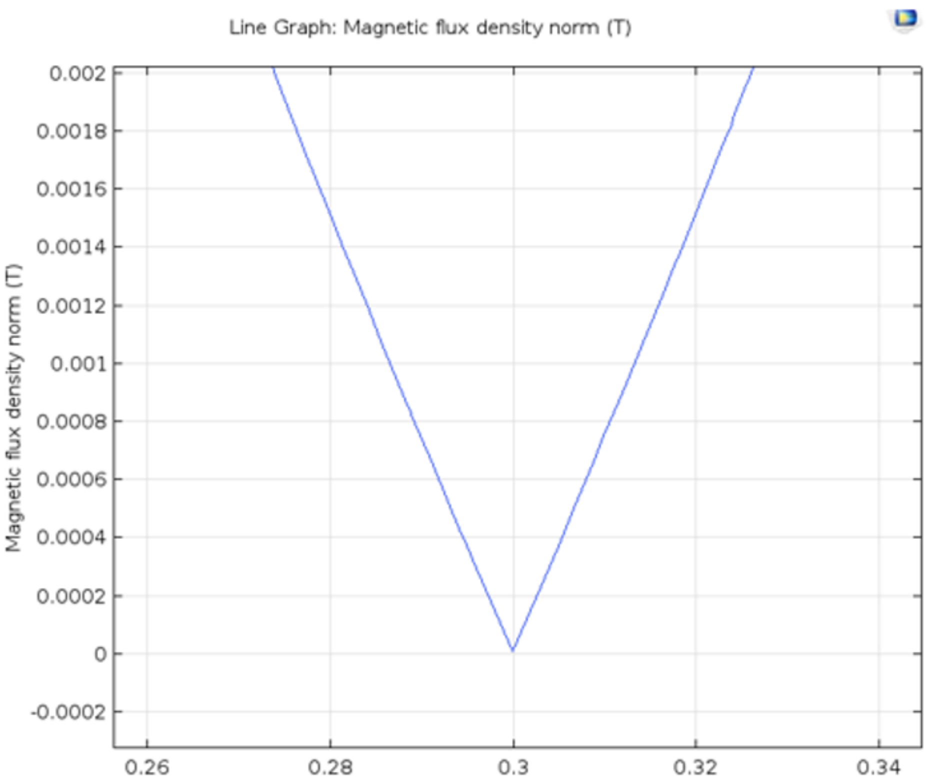
Perfect Helmholtz





- Less sloping at the magnetic minimum
- Larger field gradient

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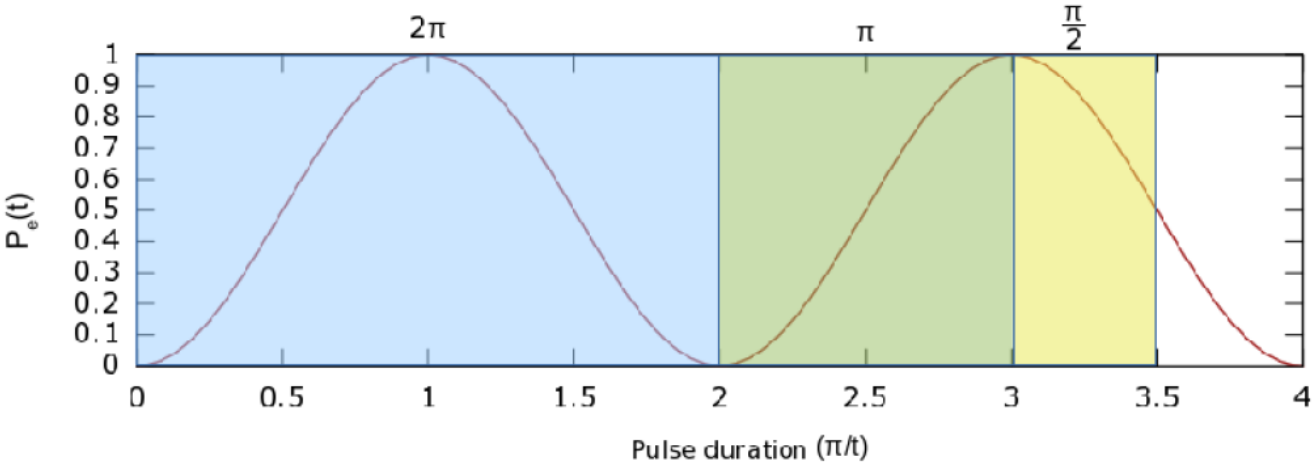
Two-Level Atom

- Atoms have two states, ground state $|g\rangle$ and excited state $|e\rangle$
- Atoms are prepared in a specific state
- They are split by introducing an electric field i.e. a laser pulse
- Depending on the properties of this field, the energy states of the atoms change
- Probability of states depends on pulse duration and Rabi frequency
- A π/2 pulse corresponds to a 50% probability the atom will be in a different state



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Quantum Decoherance

- Quantum foam permeates space-time
- Small chance it can interact with coherent matter
- Interactions would cause a transfer of momentum that would cause decoherence in spatially superimposed massive objects
- Massive objects prepared in a superposition of different positions would entangle with degrees of freedom of foam [4]

- In interferometer, atoms are coherently separated into superposition of states
- Quantum foam potentially scatters off cold atoms in interferometer
- There is momentum exchange between atoms and foam.
- Transfer will cause the decoherence of the atoms in the cloud

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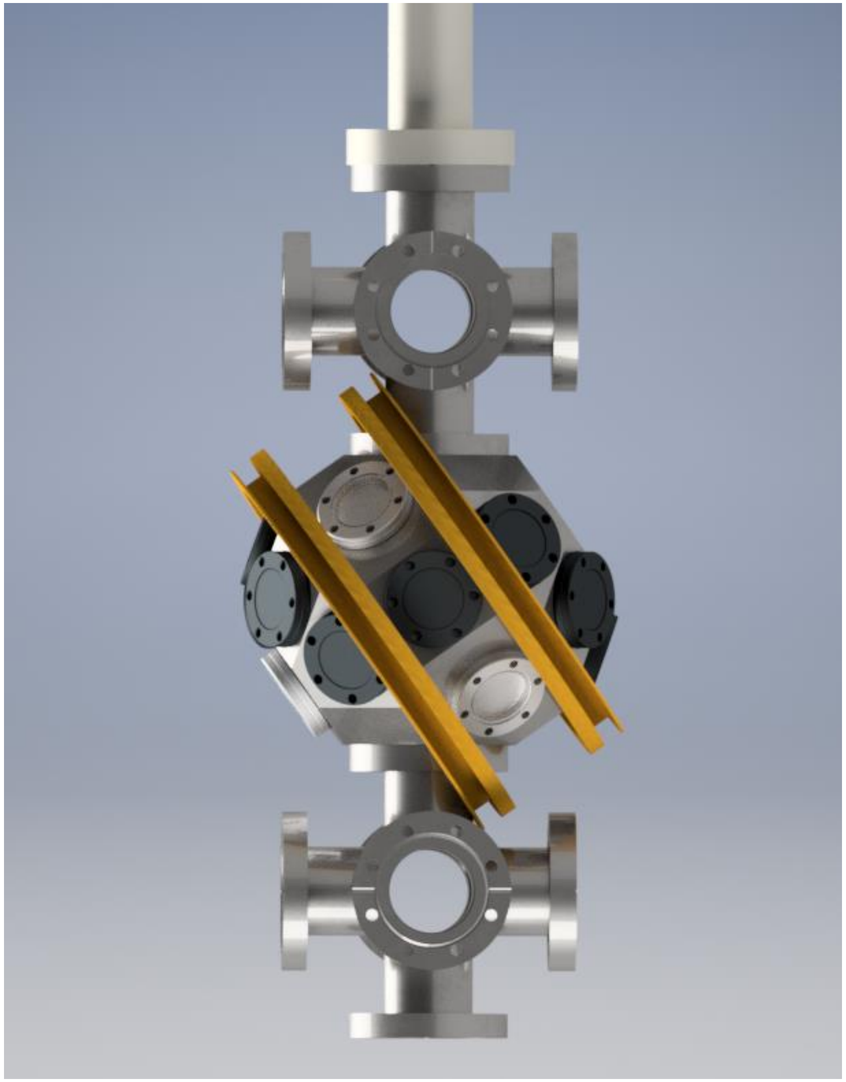
Assembled Interferometer

- **Set up as if launching**
- Interferometry region
- Detection and state selection
- Coils
- Chamber
- Another detection cross



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