Microwave Spectroscopy

Adam West

Outline:

Introduction:
- Motivation
- Current knowledge

Experimental setup:
- Measurement procedure
- Microwaves setup
- Initial measurements

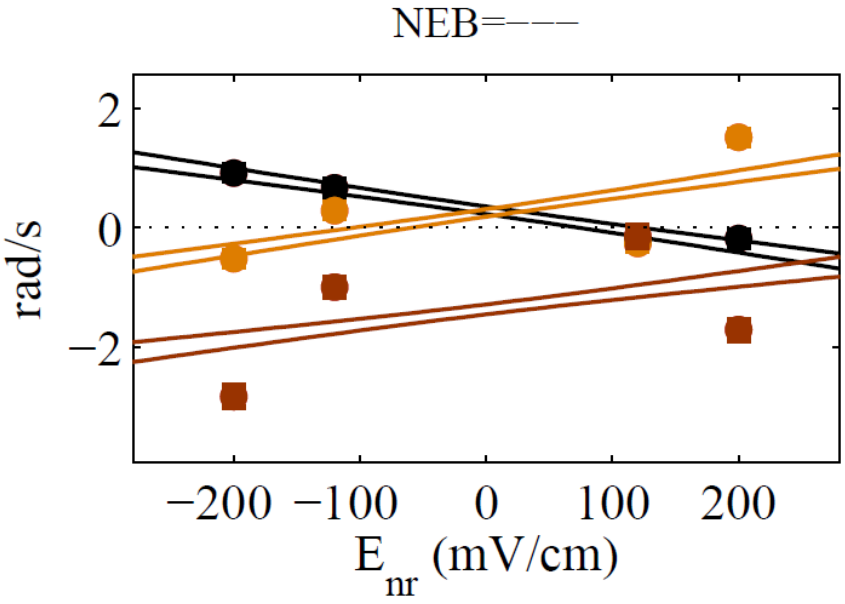
Results:
- Measured lines
- Estimate of E-field distribution
- Estimate of non-reversing E-field

Mysteries and Future Work

Motivation:

Why measure our electric field?

- It's good to accurately know the field we apply to our molecules.
- We believe that things like patch potentials could possibly explain data in the EDM experiment we currently don't understand.

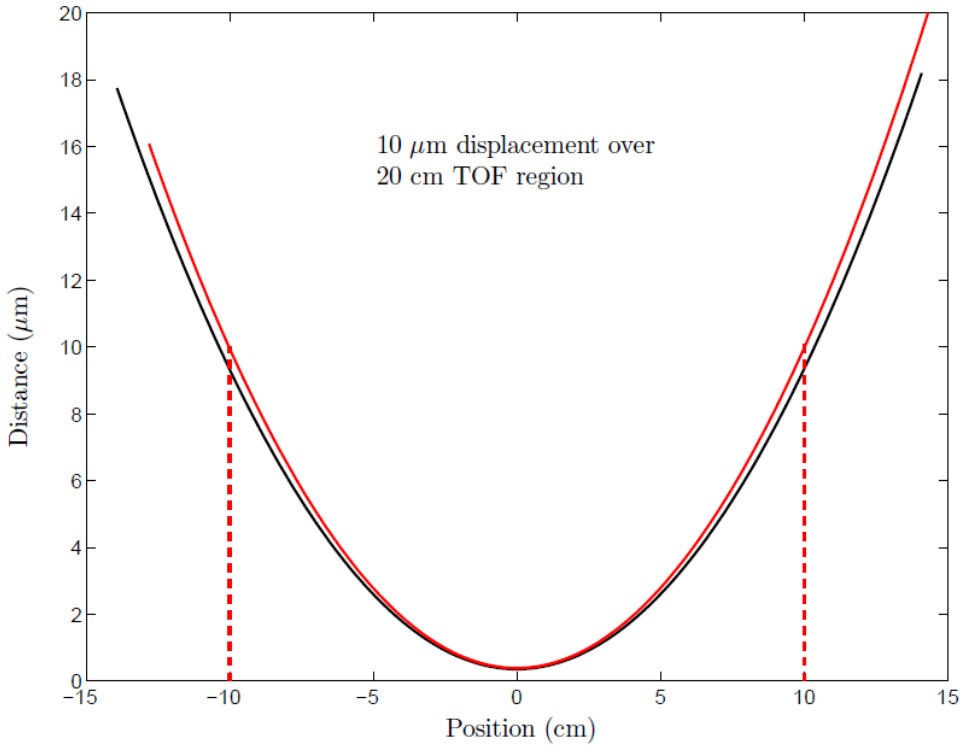


- Paranoia: 'You only have to be right once to make it all worthwhile'

Current Knowledge:

Interferometry:

An interferometer was used when the plates were installed to measure the spacing between the plates.



Applied voltage = ±177 V

This gives a field of 140 V/cm.

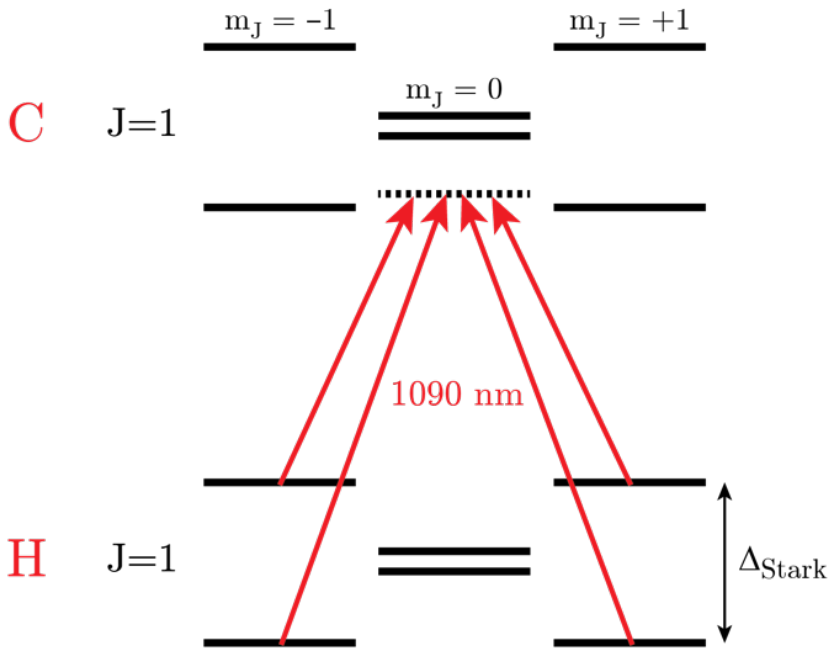
A 10 micron change in displacement corresponds to an E-field change of 56 mV/cm.

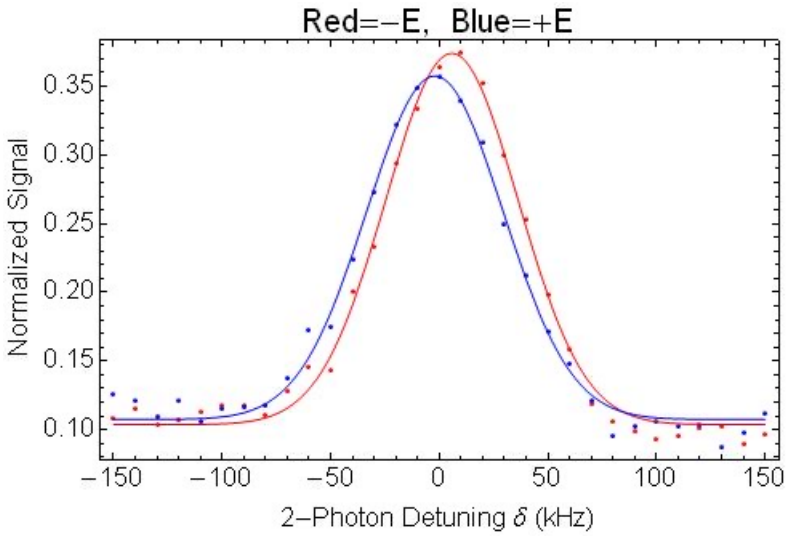
This corresponds to a change in Stark shift of ± 58 kHz.

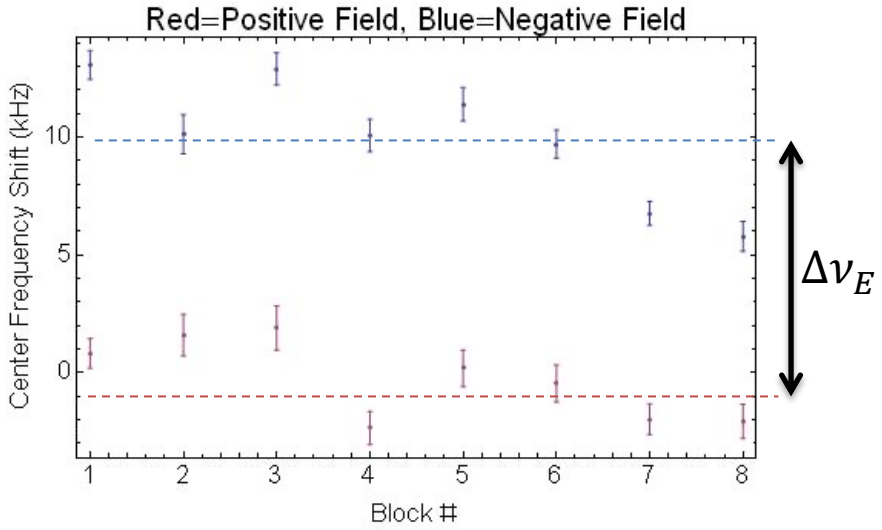
Current Knowledge:

Raman spectroscopy:
Limited to pump and probe regions.

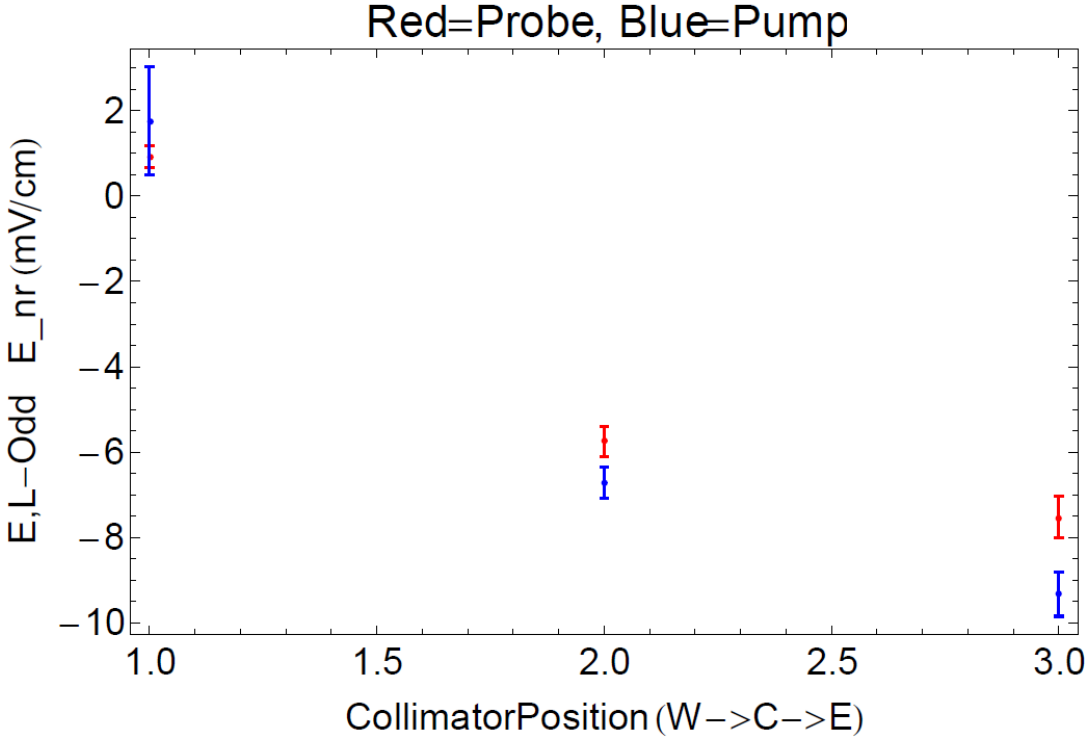
Very sensitive (10 ppm) measurement of Stark shift.







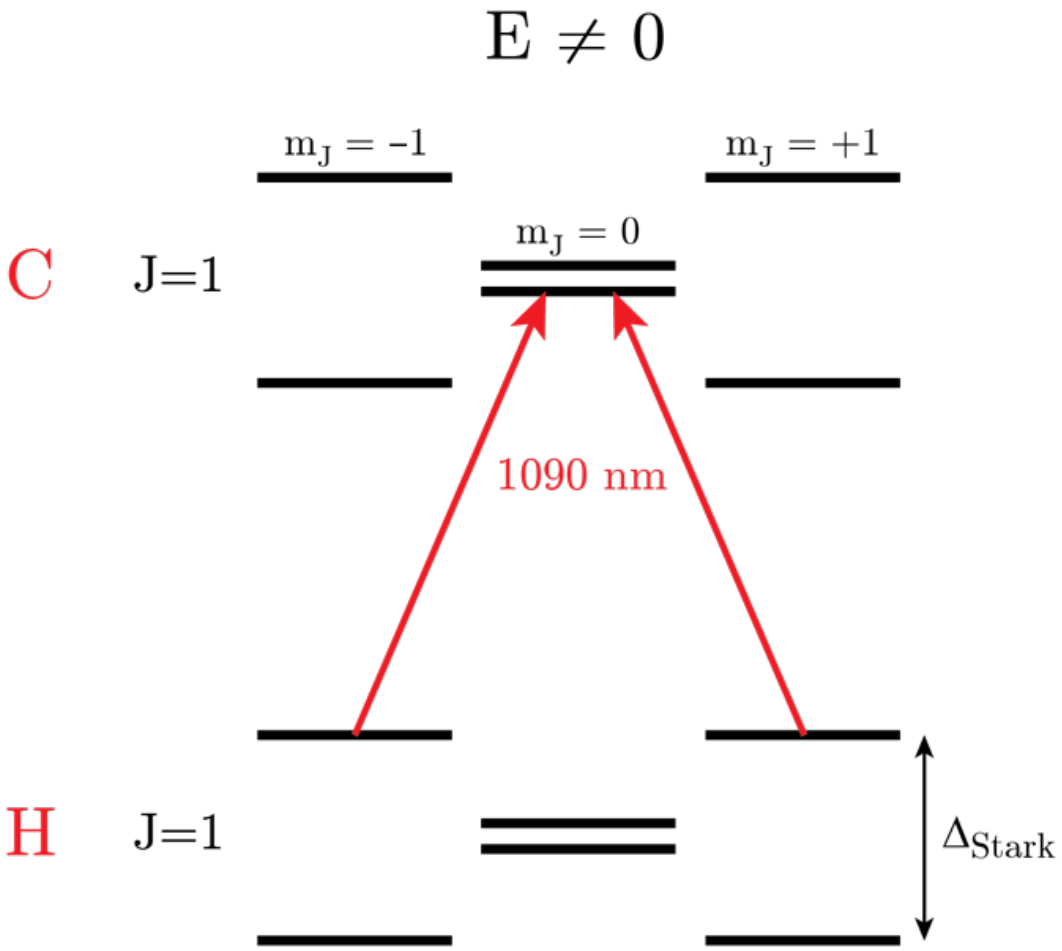
Current Knowledge:



Conclusions:

- Transition linewidth of around 65 kHz.
- Non-reversing E-field of around 5 mV.
- Dependence of the non-reversing E-field on adjustable collimator position.

Measurement Procedure:



Pump:

$$|+\rangle = 1/\sqrt{2}(|-1\rangle + |+1\rangle)$$

Phase precession:

$$1/\sqrt{2}(|-1\rangle + e^{i\phi}\,|+1\rangle)$$

Probe:

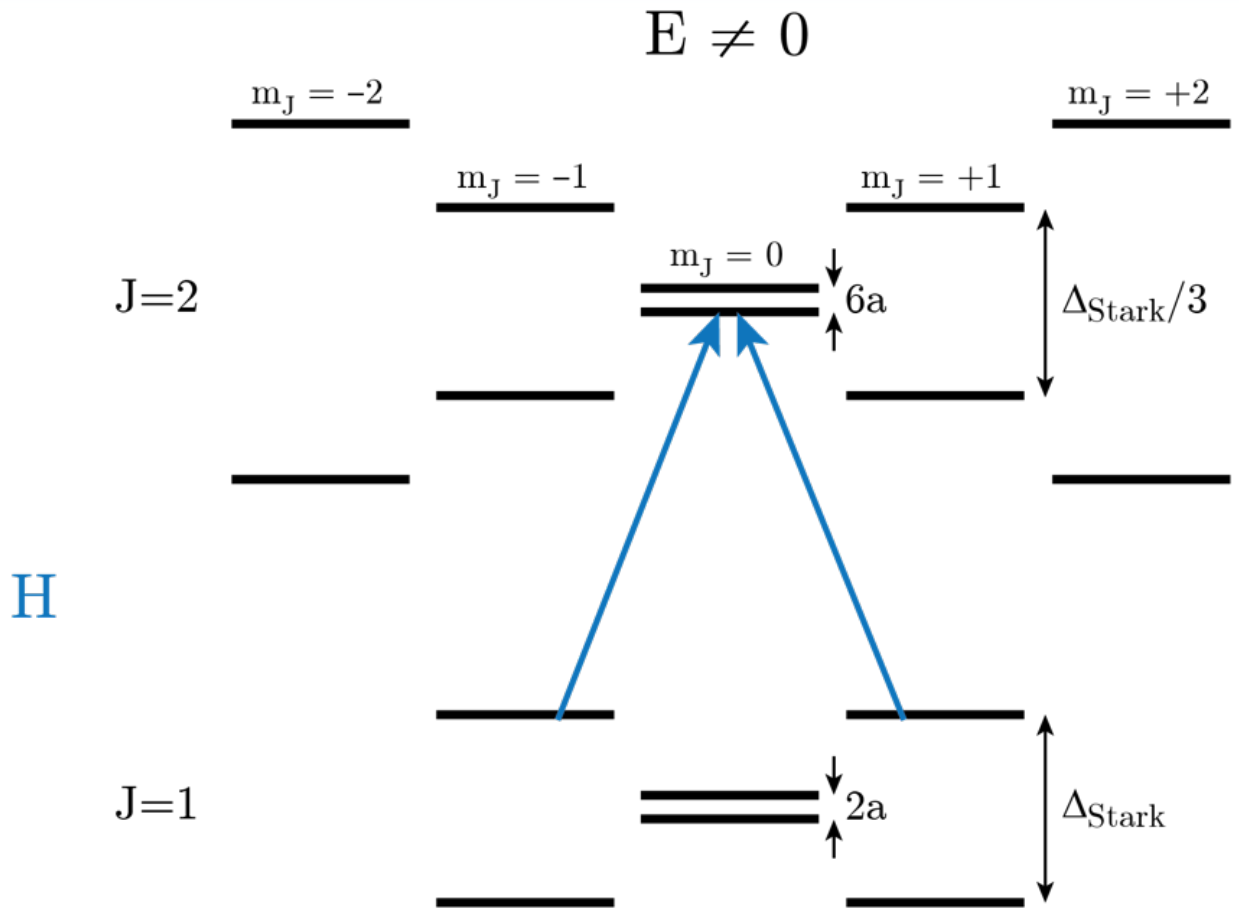
$$|-\rangle = 1/\sqrt{2}(|-1\rangle - |+1\rangle)$$

$$|+\rangle = 1/\sqrt{2}(|-1\rangle + |+1\rangle)$$

Asymmetry:

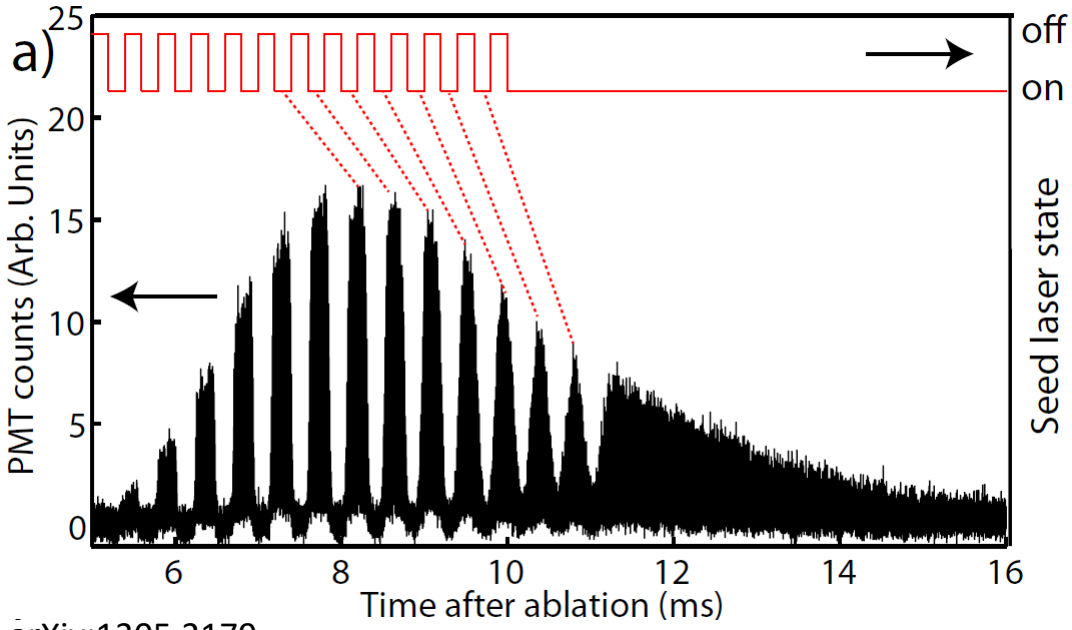
$$\mathcal{A} = \frac{S_- - S_+}{S_- + S_+}$$

Measurement Procedure:



CW: Longer interaction time, less microwave power needed.
Pulsed: Higher asymmetry, spatial resolution.

Measurement Procedure:



arXiv:1305.2179

We also wish to pulse our optical pumping laser.

This could provide even better spatial resolution.

Demonstrated by Emil previously.

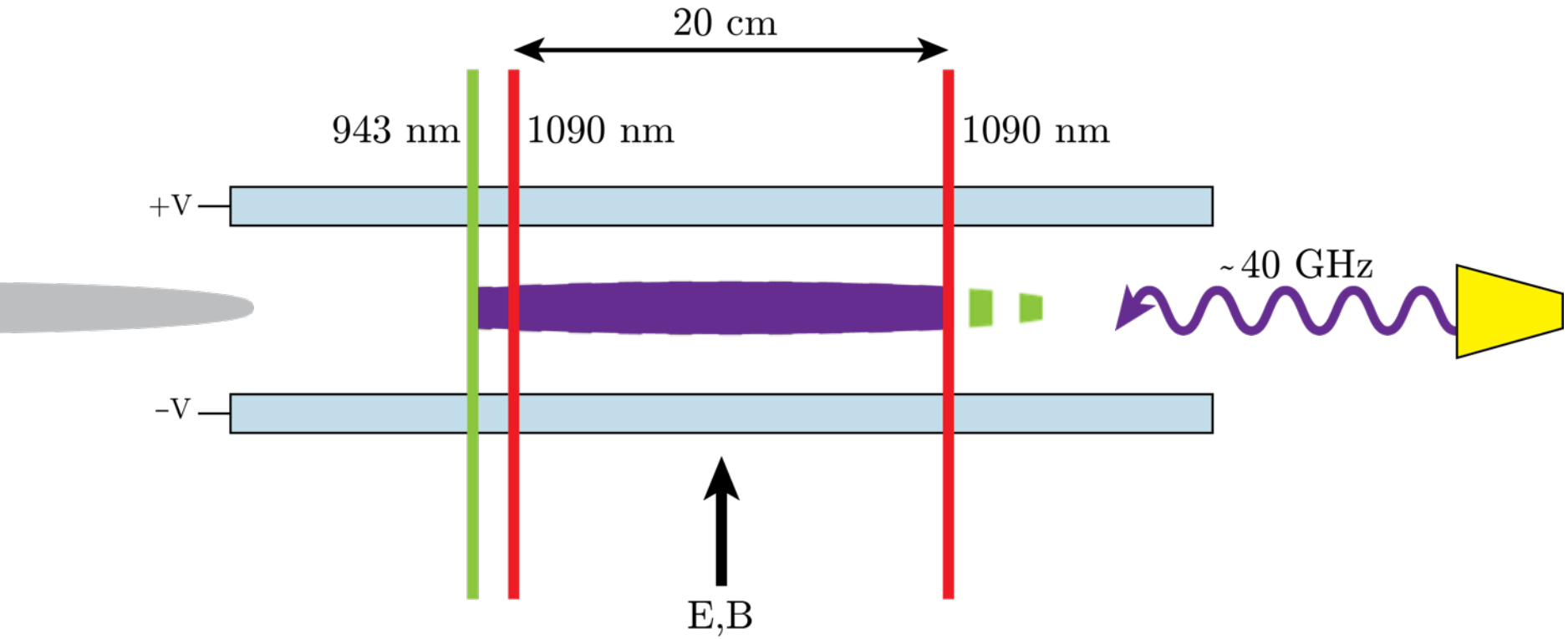
Require short pulse so contained molecules approximated by single velocity class.

Require separated pulse so no overlap during time of flight.

Typical pulse duration (separation) = 100 us (200 us).

Will allow for mapping of the velocity distribution/dispersion.

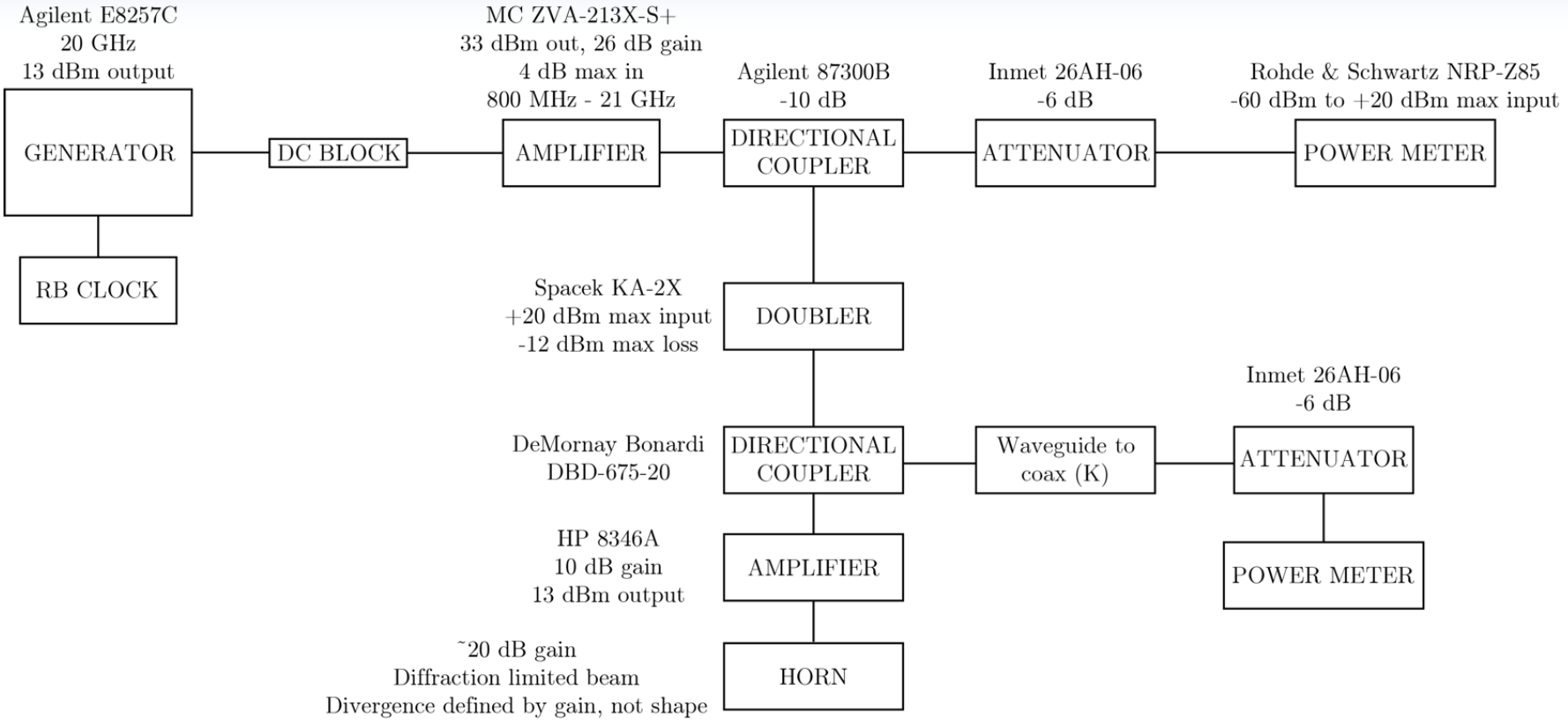
Measurement Procedure:



1. Prepare molecule pulse
2. Optically pump into H
3. Apply microwave pulse

2b. Apply multiple optical pumping pulses

Microwaves Setup:



Power measured through system.

Power from horn measured via collection in second horn.

Vacuum chamber and guard ring simulated in test rig.

Microwaves Setup:

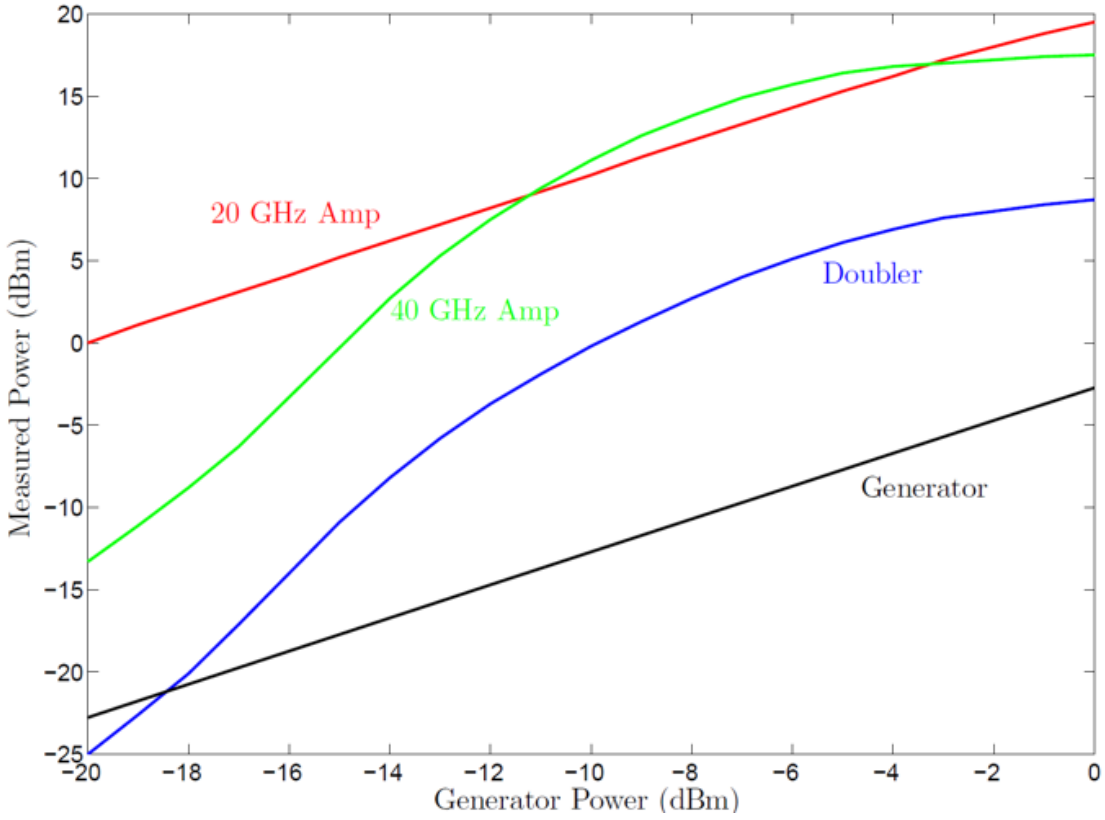
Microwave power measured throughout setup.

Observe 1 to 3 dB loss per 6 inch of SMA cable.

20 GHz amplifier provides around 20 dB of gain and is very linear.

Doubler shows (expected) non-linear behaviour with around 8 dB of loss.

40 GHz amp shows linear behaviour with around 10 dB of gain.

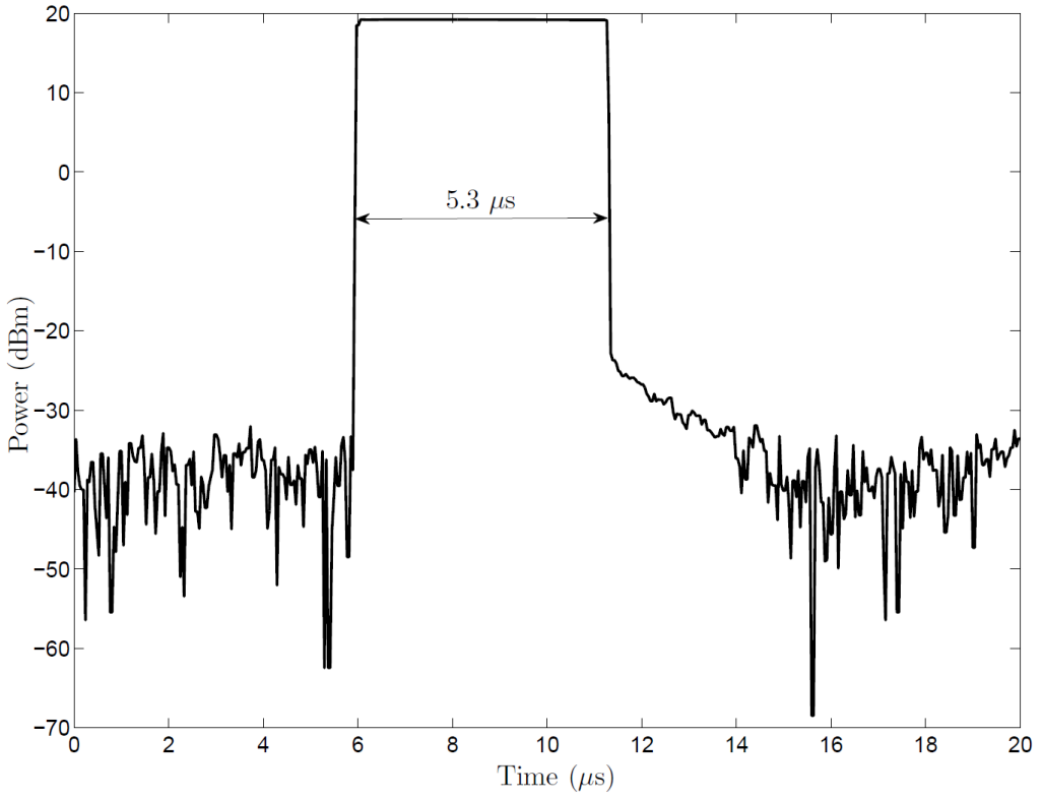


Microwaves Setup:

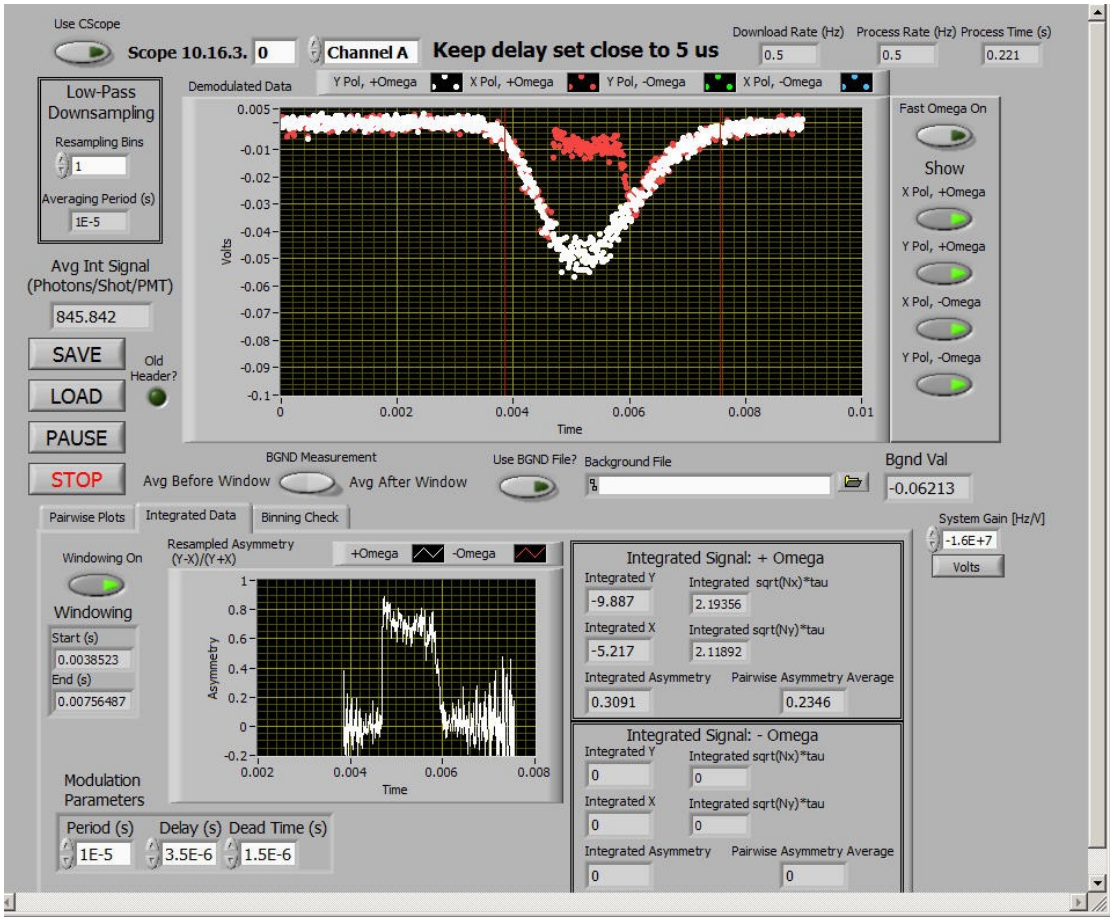
Microwave pulse measured using power meter.

Observe over 40 dB (10,000) suppression of power over pulse length.

In practice, tune pulse length and microwave power to achieve a pi pulse.



Initial Measurements:

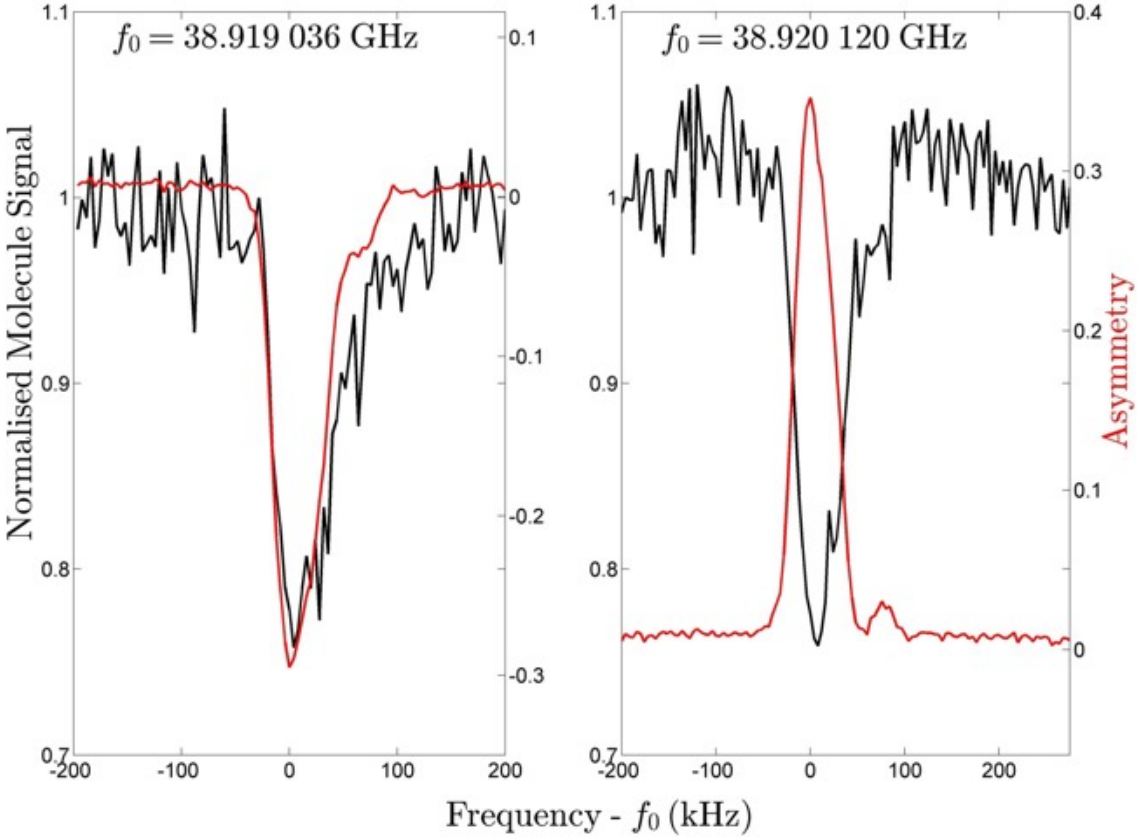


Red/white traces show orthogonal probe polarisations.

Clear region where molecule population is depleted.

Depletion is polarisation dependent – clearly produces an asymmetry.

Initial Measurements:



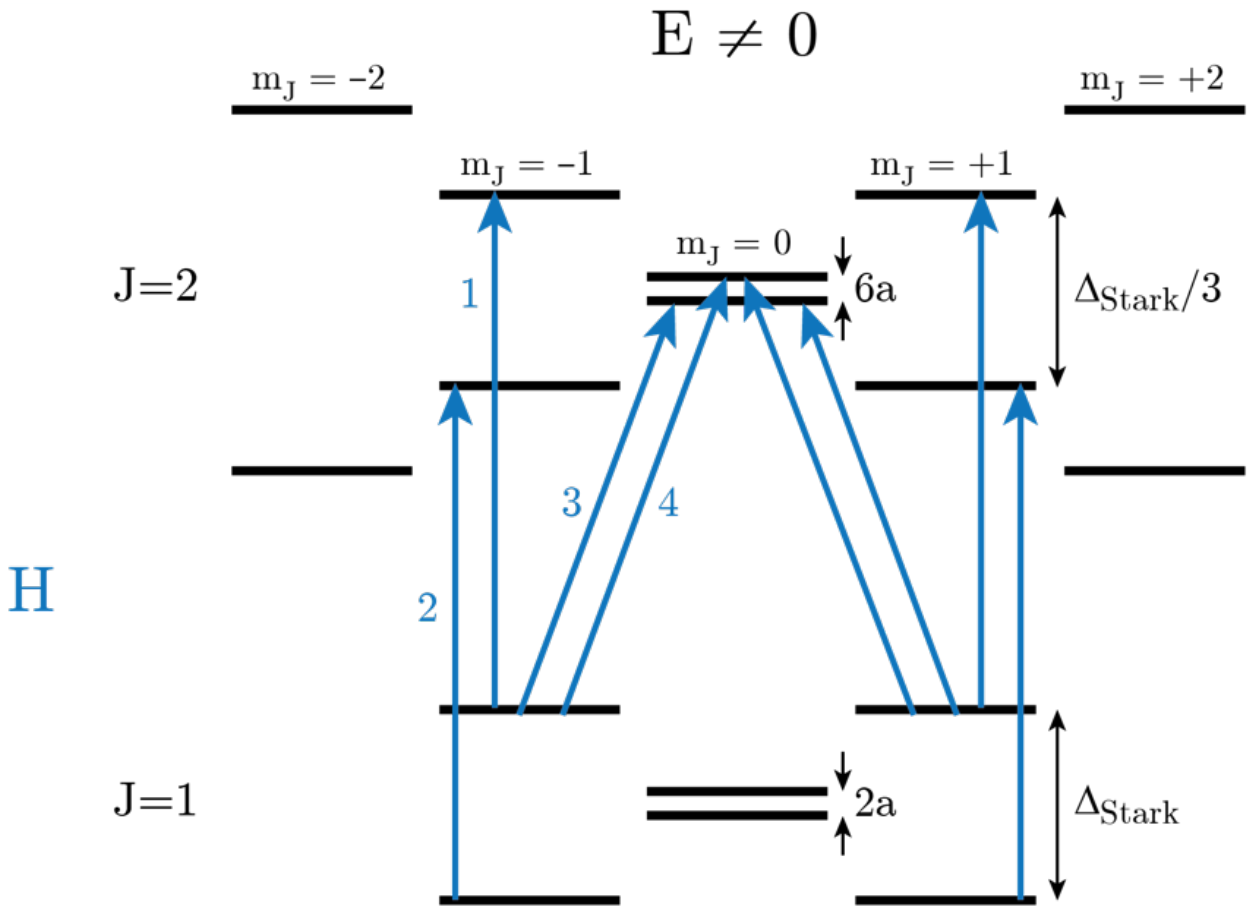
Observe significant variation in molecule signal.

Using asymmetry cancels this variation giving greater signal-to-noise.

Evidence for reflected signal.

Resonant frequency found to within a few kHz.

Measured Lines:



1 = 38.968,168 GHz 2 = 39.162,900 GHz

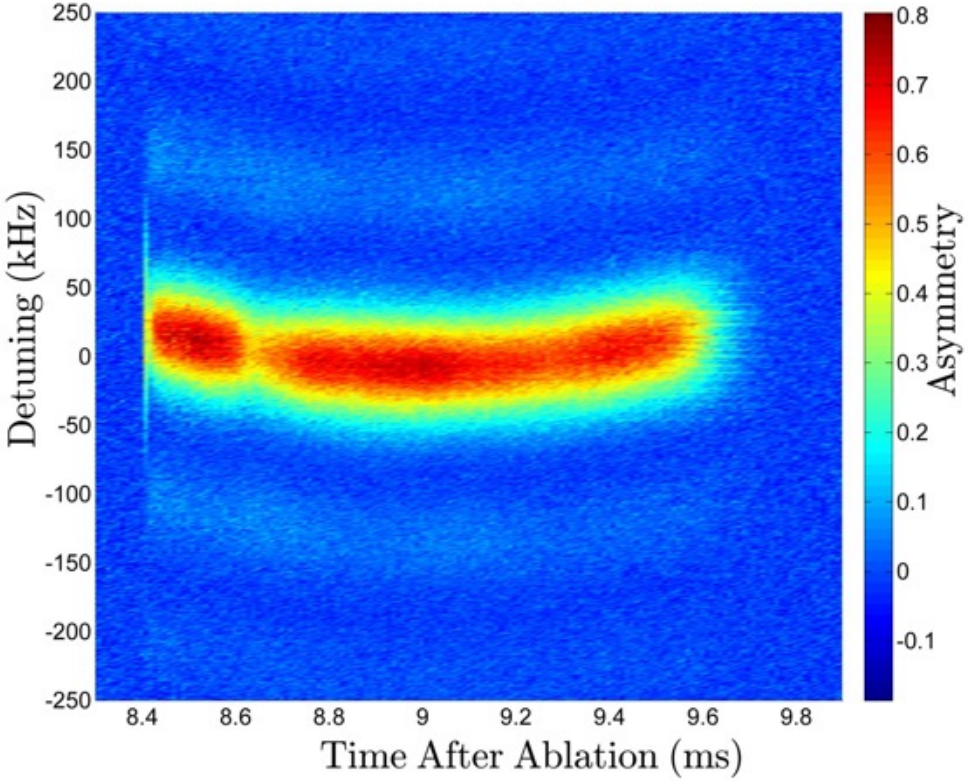
3 = 38.919,036 GHz 4 = 38.920,120 GHz

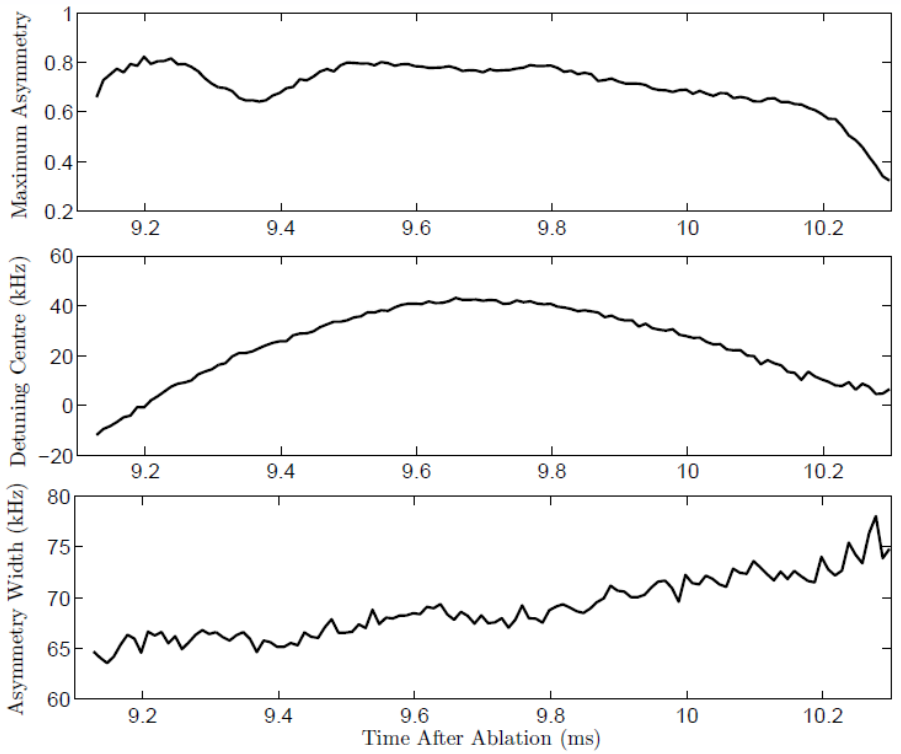
a = (4 – 3)/6 = 181 kHz

Microwave Spectroscopy

Adam West, 07/10/13

E-field Distribution:



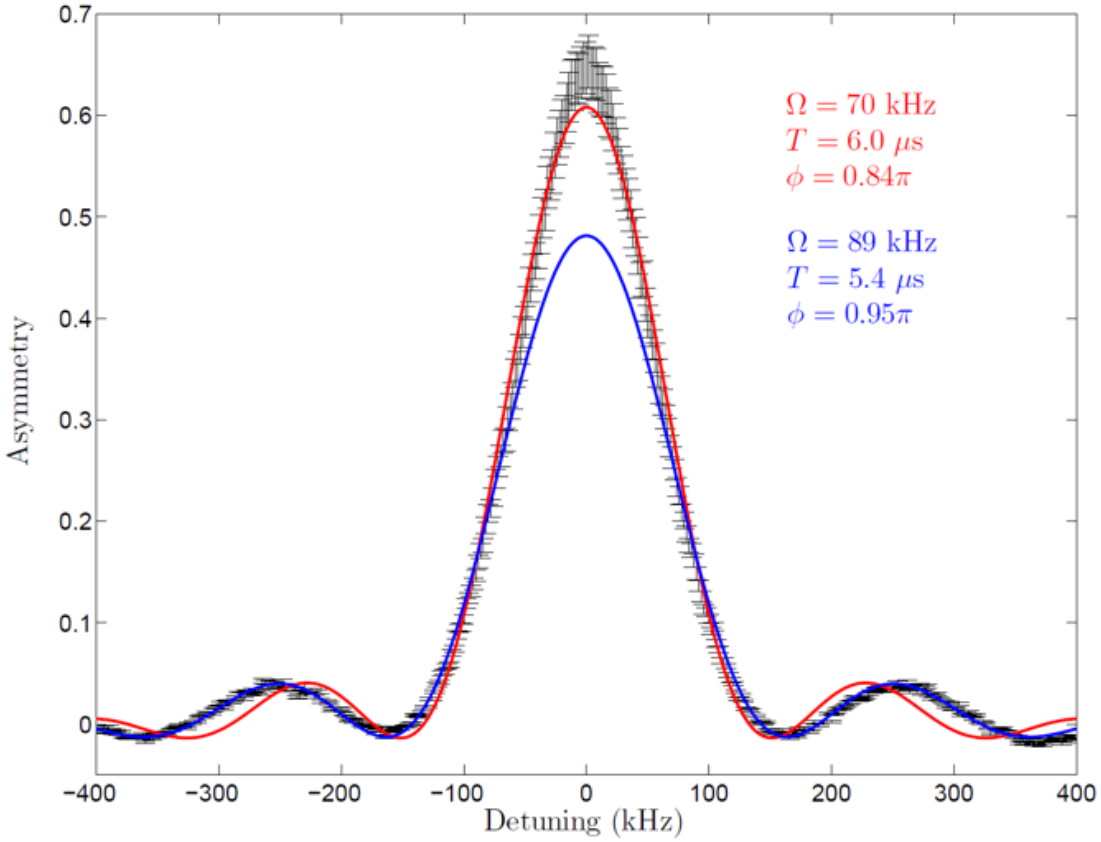


Spatial resolution limited by:

- Molecule movement during microwave pulse – 0.7 mm
- Time for two probe polarisations – 1 mm
- Velocity dispersion – 1 cm

Gaussian fits central feature well.
Sinc fits wings well.

E-field Distribution:



Weighted fit more accurate in wings.

Also provides more accurate value of pulse duration.

Molecules are subject to effective transit-time broadening.

$$\mathcal{E}(t) = \mathrm{rect}\left(\frac{t-t_0}{T}\right)\mathcal{E}_0\cos(\omega_0 t)$$

Uncertainty relation dictates a non-zero linewidth:

$$\mathcal{E}(\omega) = \int_{t_0-T/2}^{t_0+T/2} \mathcal{E}_0\cos(\omega_0 t')e^{-i\omega_0 t'}\ \mathrm{d}t'$$

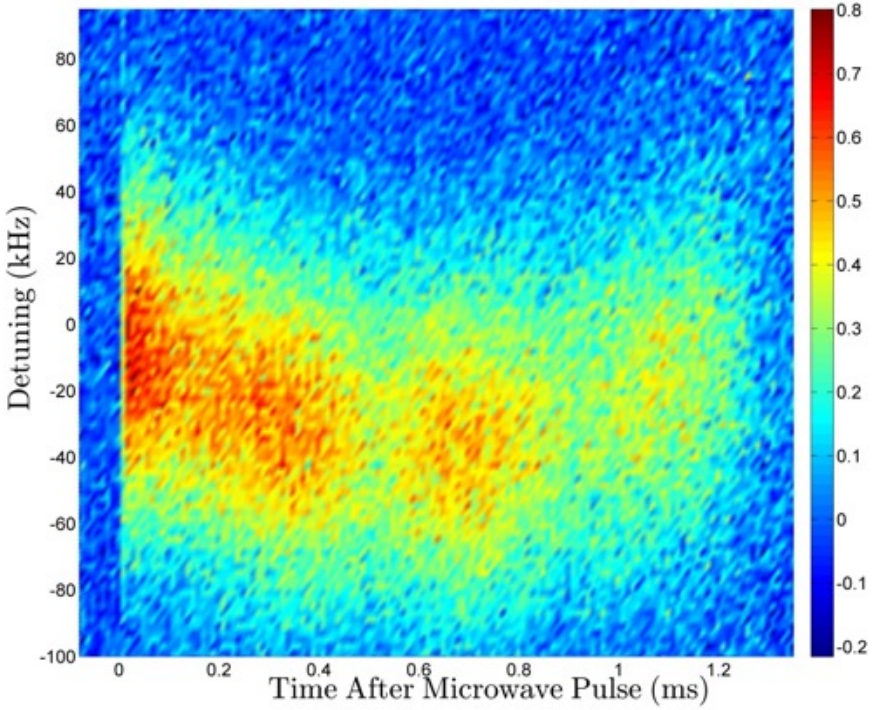
$$I(\omega) = |\mathcal{E}(\omega)|^2 = \frac{2}{T\pi}\mathrm{sinc}^2[(\omega-\omega_0)T/2]$$

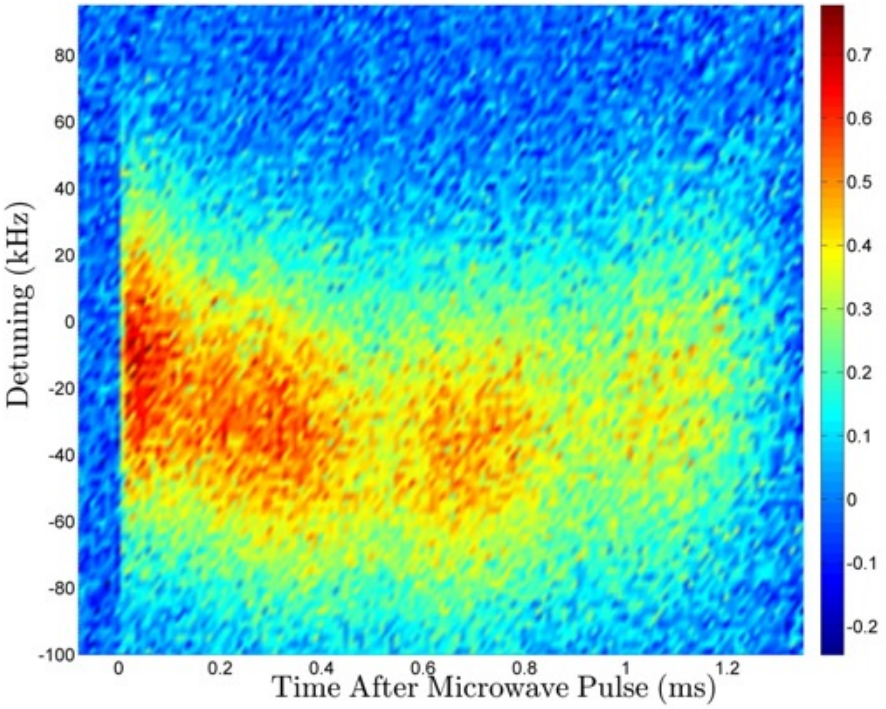
Using this treatment can derive population during Rabi flopping:

$$P(\omega) = \frac{\Omega^2}{\Omega^2+\Delta^2}\mathrm{sinc}^2\left(T/2\sqrt{\Omega^2+\Delta^2}\right)$$

Spectra of Atoms and Molecules, Bernath
Atomic Physics, Budker et al.

Non-reversing E-field:

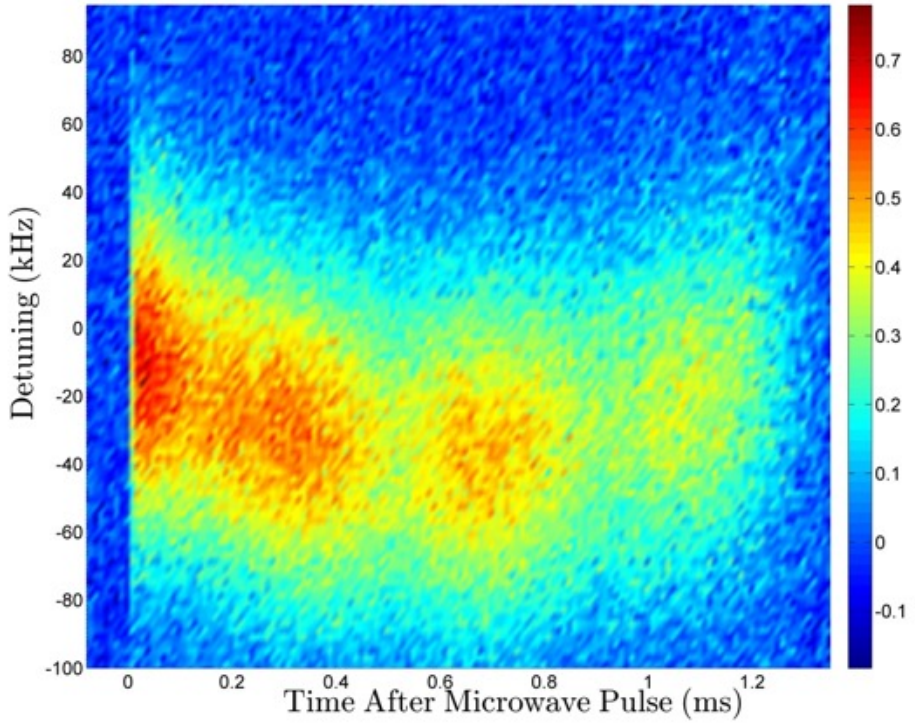


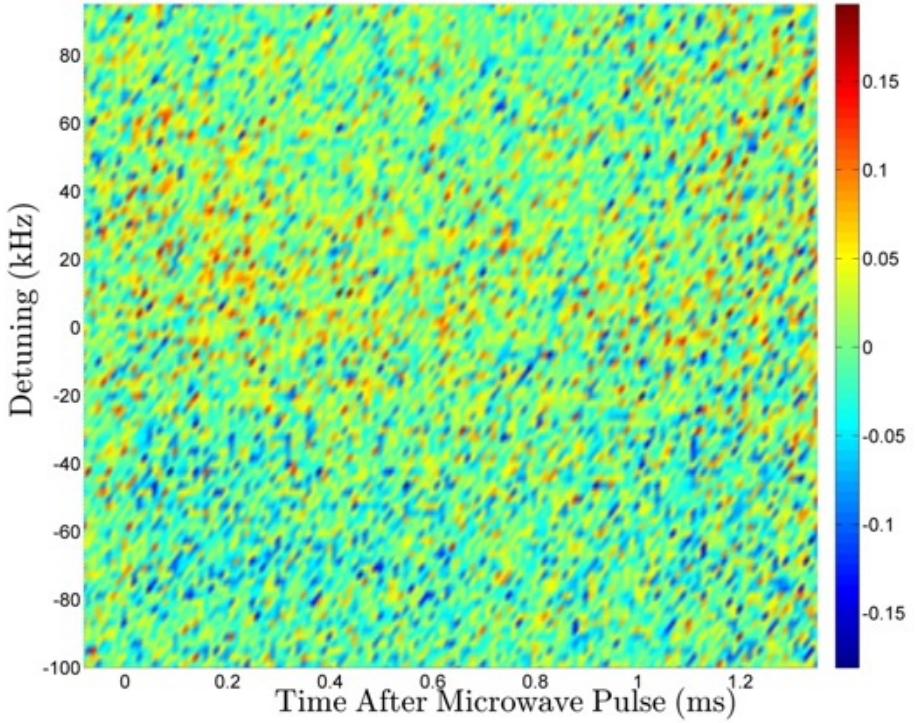


Perform same procedure for E orientated along +z and along –z.

Switch E-field using leads; reversing the voltage also introduces a non-reversing voltage.

Non-reversing E-field:





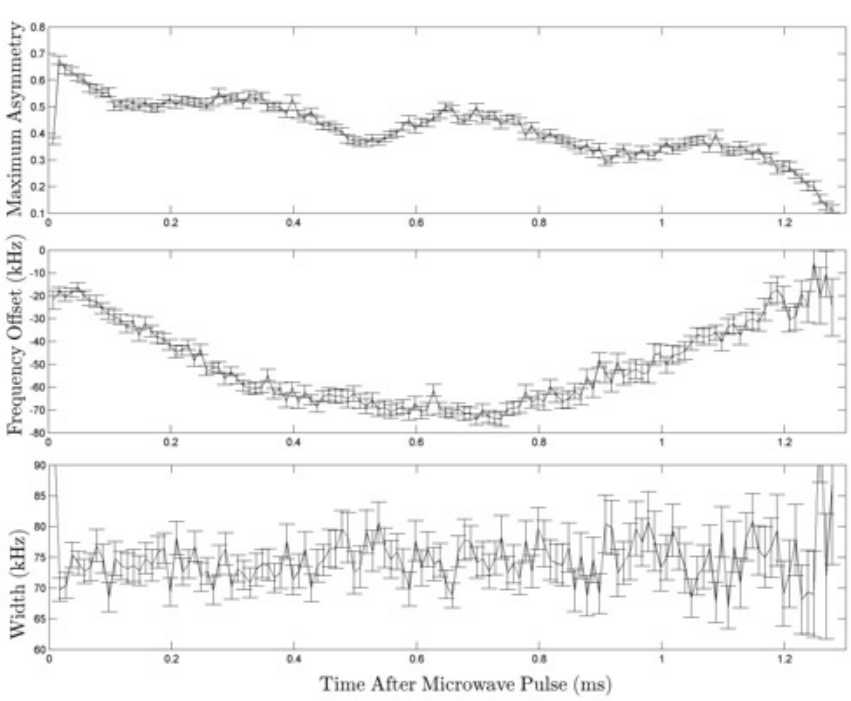
Perform parity sum of the asymmetry over the E-field state.

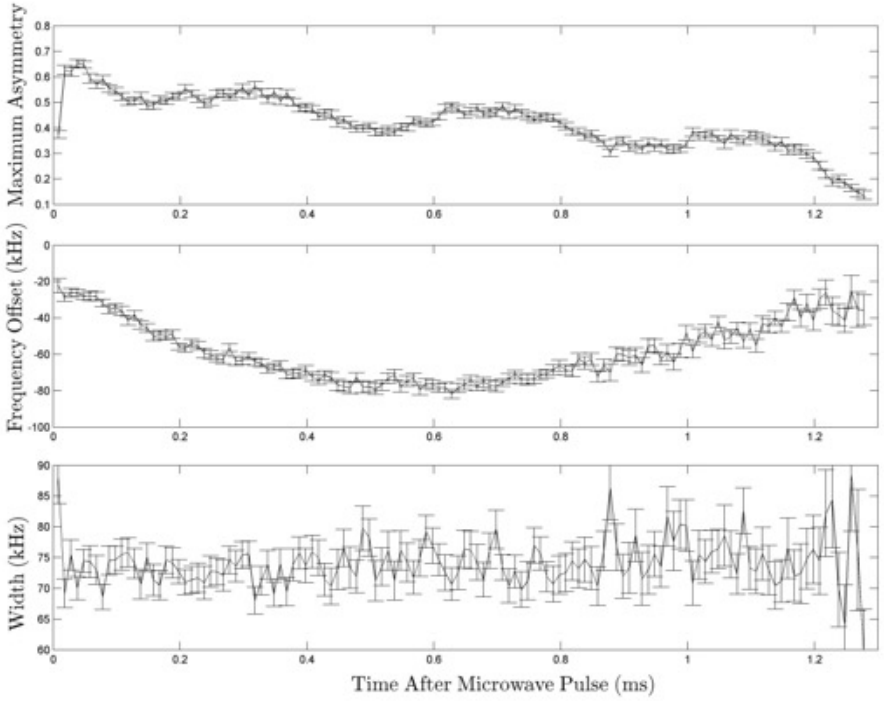
+ parity sum shows the reversing component – very familiar!

– parity sum shows the non-reversing component – a general trend can be discerned.

Non-reversing E-field:

It is more instructive to perform parity sums over the fitting parameters for the frequency spectrum.





In particular we want to see how the ‘frequency offset’ changes.

Recall the microwave transition resonance is Stark shifted by electric fields.

Non-reversing E-field:

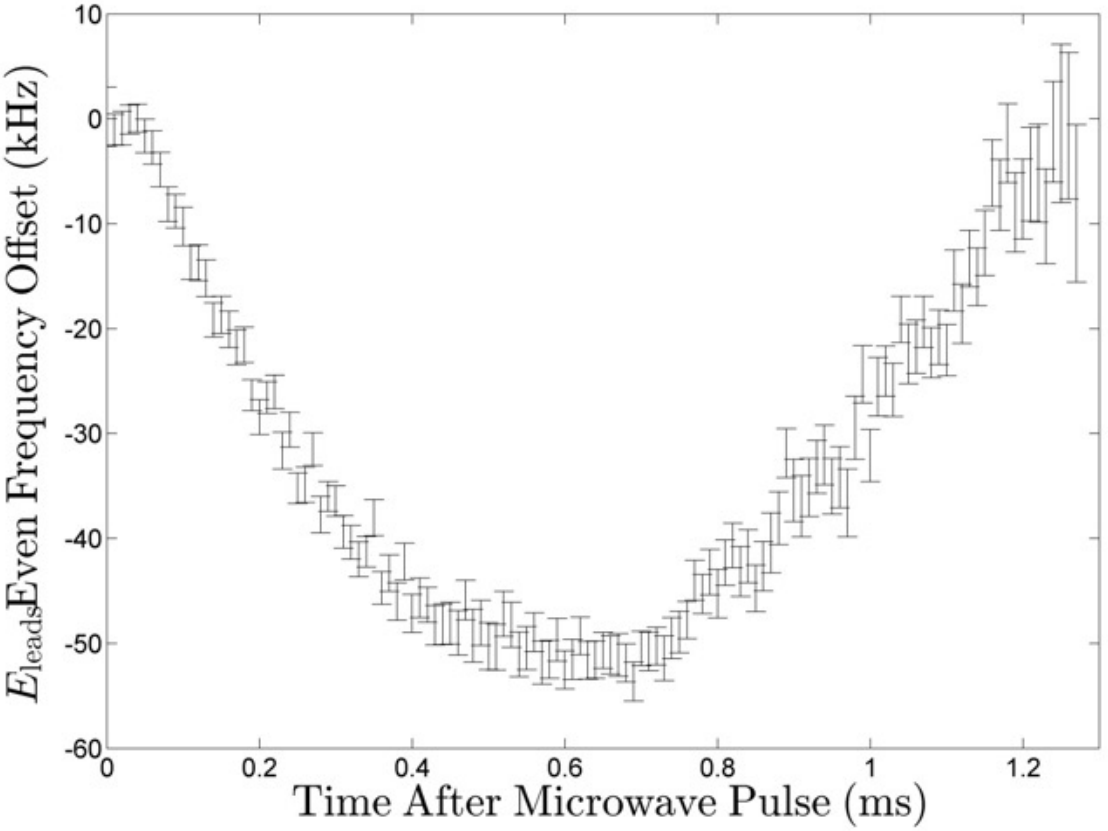
The even parity sum reveals the reversing E-field.

This shows the overall spatial variation of our E-field.

Recall the spatial resolution is limited to about 5% in places.

We see a roughly 50 kHz shift.

This compares to 58 kHz from interferometery and corresponds to around 50 mV variation.



Other measurements have also measured the variation in the y direction.

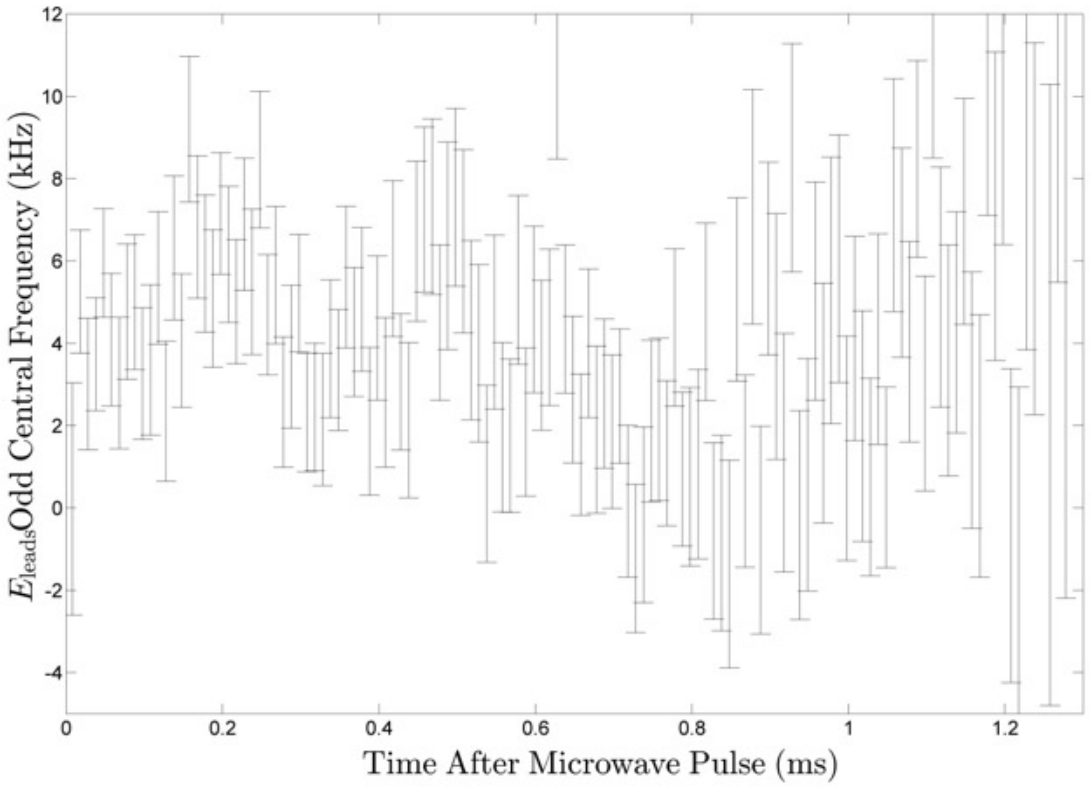
Non-reversing E-field:

The odd parity sum reveals the non-reversing E-field.

We observe a non-reversing field of around 4 mV – agrees well with Raman spectroscopy.

There is significant and reproducible spatial structure.

The variation is smeared out over around 1cm, but plate separation is 2.5 cm.



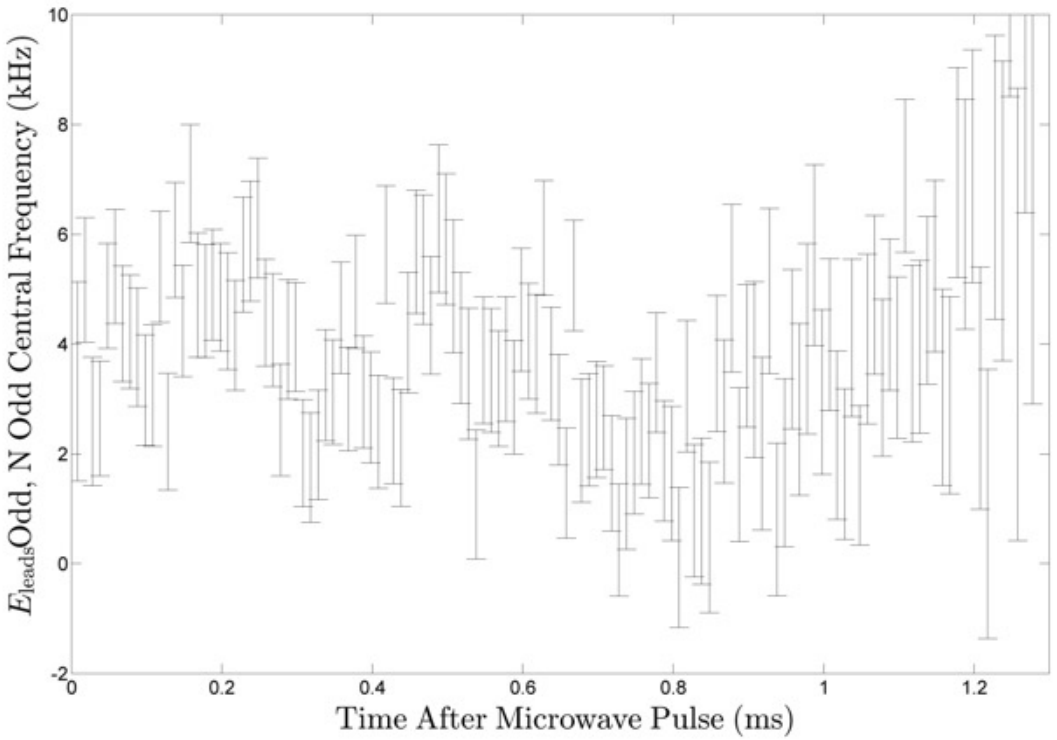
By using a longer microwave pulse we can achieve greater frequency resolution and thus better resolution of the spatial variation.

Non-reversing E-field:

We have also formed parity sums over the two omega doublets.

The odd sum displays almost an almost identical result (right).

The even sum is consistent with zero.



Non-reversing E-field:

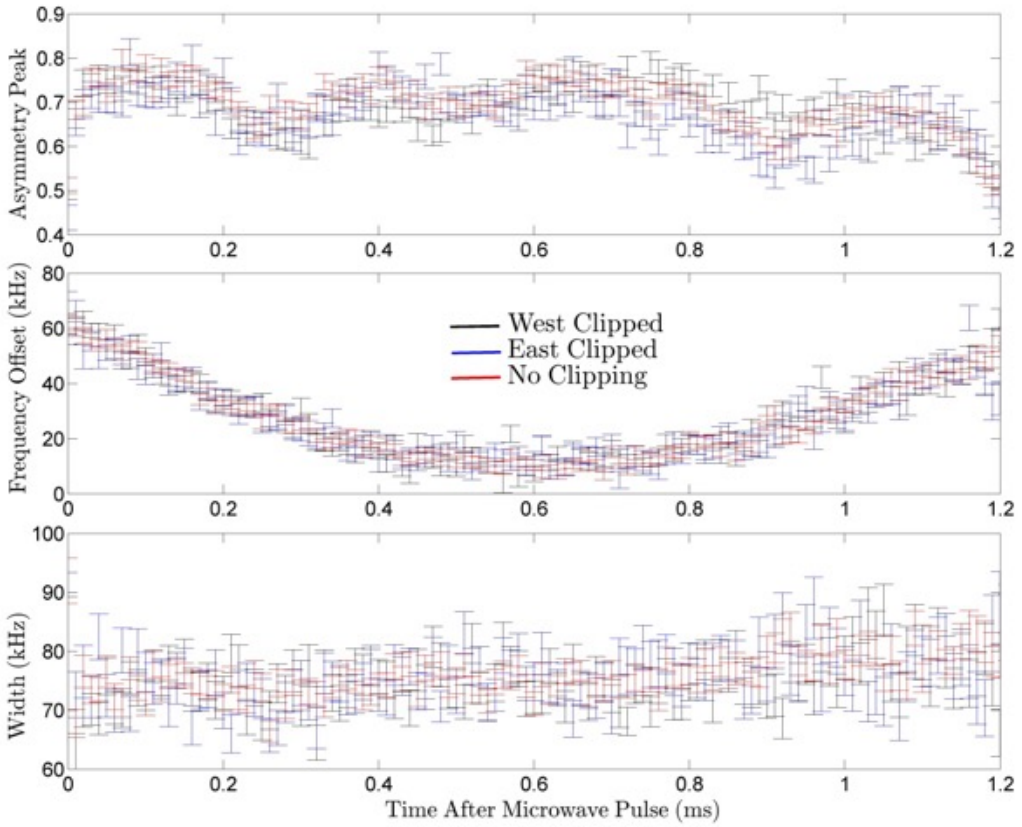
Dependence of the non-reversing field on collimator position was also investigated.

These collimators move transverse to the molecular beam.

The collimators are outside the interaction region.

Just analysing the asymmetry map does not yield any obvious trends.

Again we must use parity sums to gain insight.



Non-reversing E-field:

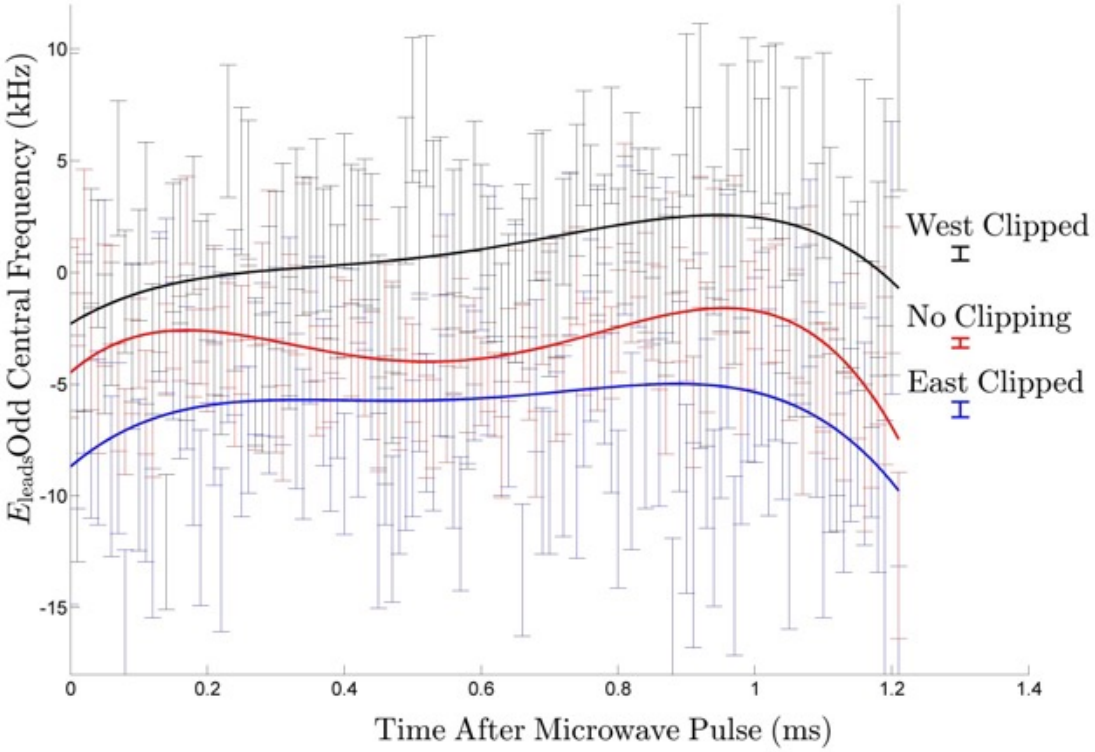
We see reproducible structure in the non-reversing E-field.

We also see variation in the non-reversing field as the collimators are moved.

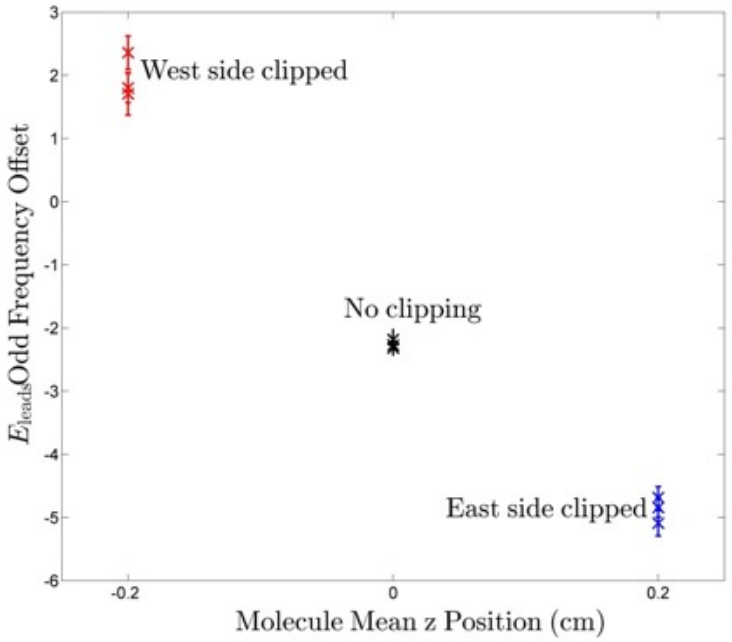
What is causing this?

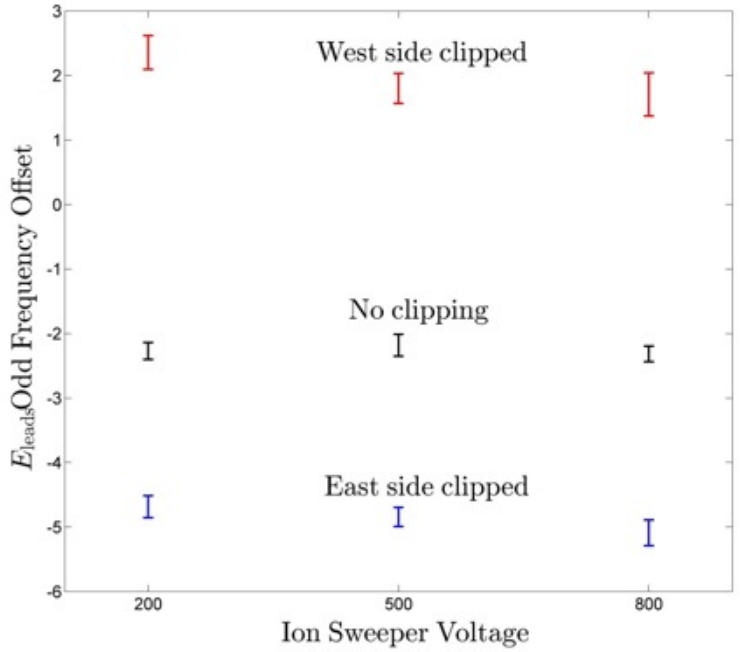
- E-field from collimator
- Deflected ions

To investigate the latter, try varying the ion sweeper voltage.



Non-reversing E-field:





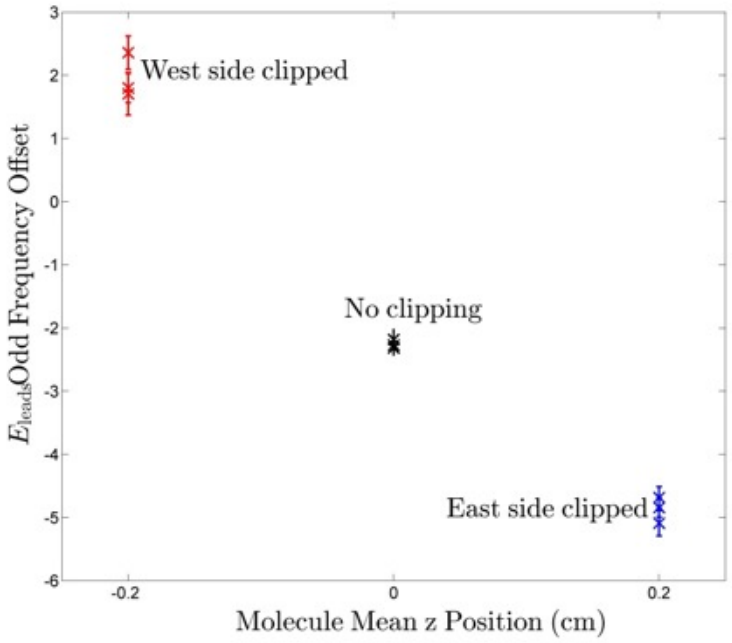
Here we take mean values of the non-reversing E-field.

Again we see variation in the non-reversing field with collimator position.

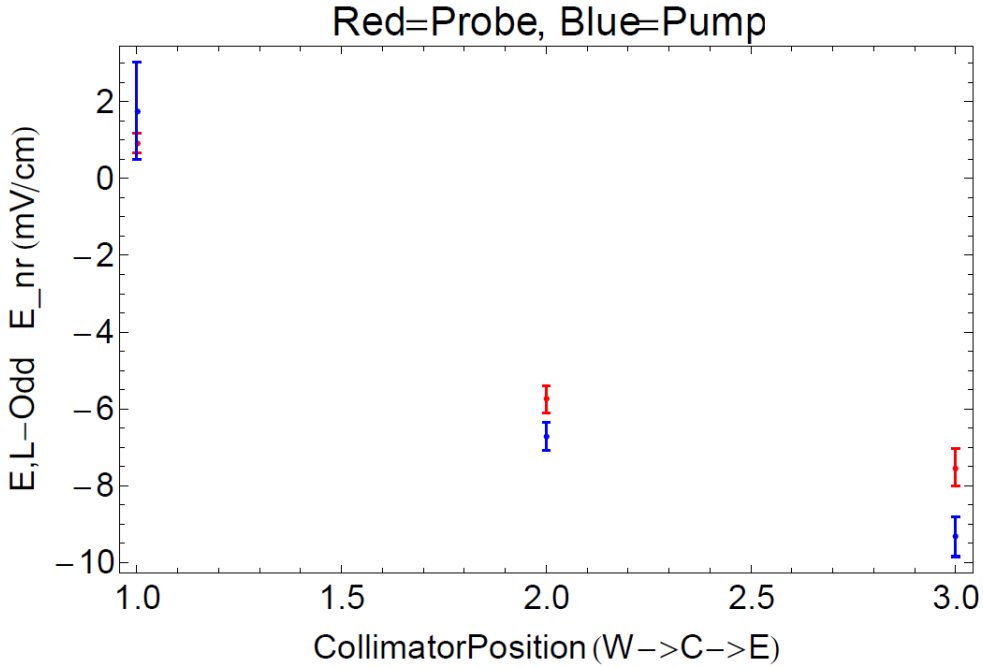
It is dubious as to whether we see significant variation with ion sweeper voltage.

Non-reversing E-field:

Microwave spectroscopy



Raman spectroscopy



Observe very similar general trend.
Also get quantitative agreement.

Mysteries/Future Work:

- Changes in spatial variation of asymmetry.
- Variation of non-reversing E-field with collimator position.
  - Ground collimators
  - Use collimators as sweeper
  - Install electron multiplier
- Quantitative comparison with Raman spectroscopy
- Perform measurements with pulsed optical pumping
- Achieve better spatial resolution
- Turn more knobs