Diamond sensor for EDM experiments

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In partnership with the Beck group

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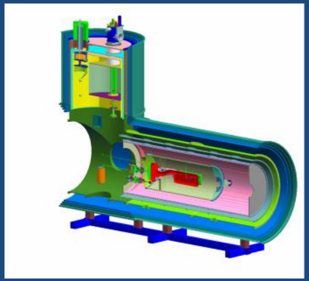
Spectroscopy of NV centers in diamond can be used for not-very-intrusive measurements of electric and magnetic fields in support of nEDM experiments

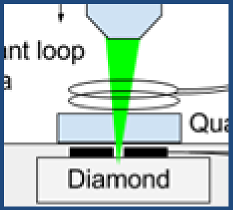
nEDM experiments and constraints



We use two spectroscopy methods:

- Electromagnetically-induced transparency
  - Issues with voltage-induced destruction

- Confocal ODMR measurements
  - Easier to perform, lots more data



Can measure fields to 5-10% (1-2 kV/cm).

Southwest Sciences performs research and develops technology in combustion, atmospheric chemistry, imaging, and optical sciences.

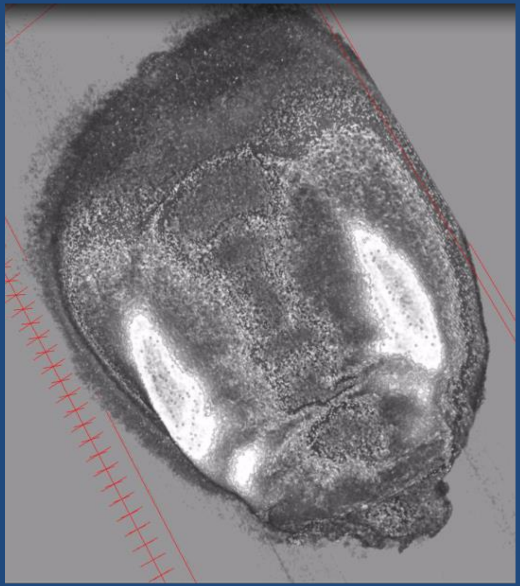
>30 patents
>200 papers
5 active licenses, $53M sales
Offices in Santa Fe and Cincinnati

1985 1995 2005 2015

We use spectroscopy to measure gas concentrations and other properties

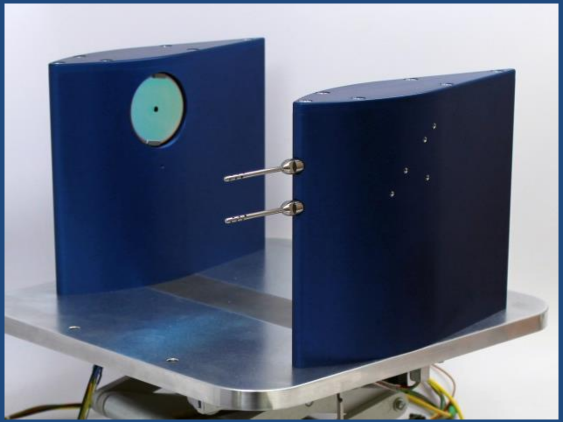
Formaldehyde detector for International Space Station

Multipass optics for Raman spectroscopy



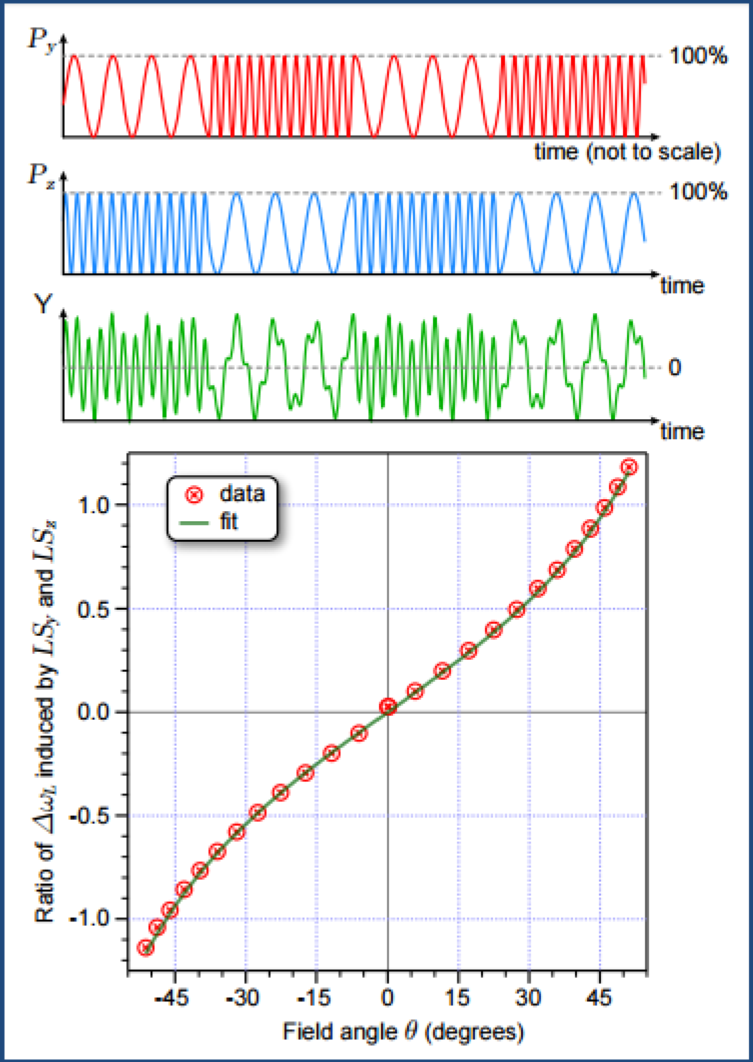
Optical coherence tomography for non-destructive imaging.

Gas sensing outside aircraft



Atomic magnetometry
(with Budker group at Berkeley)

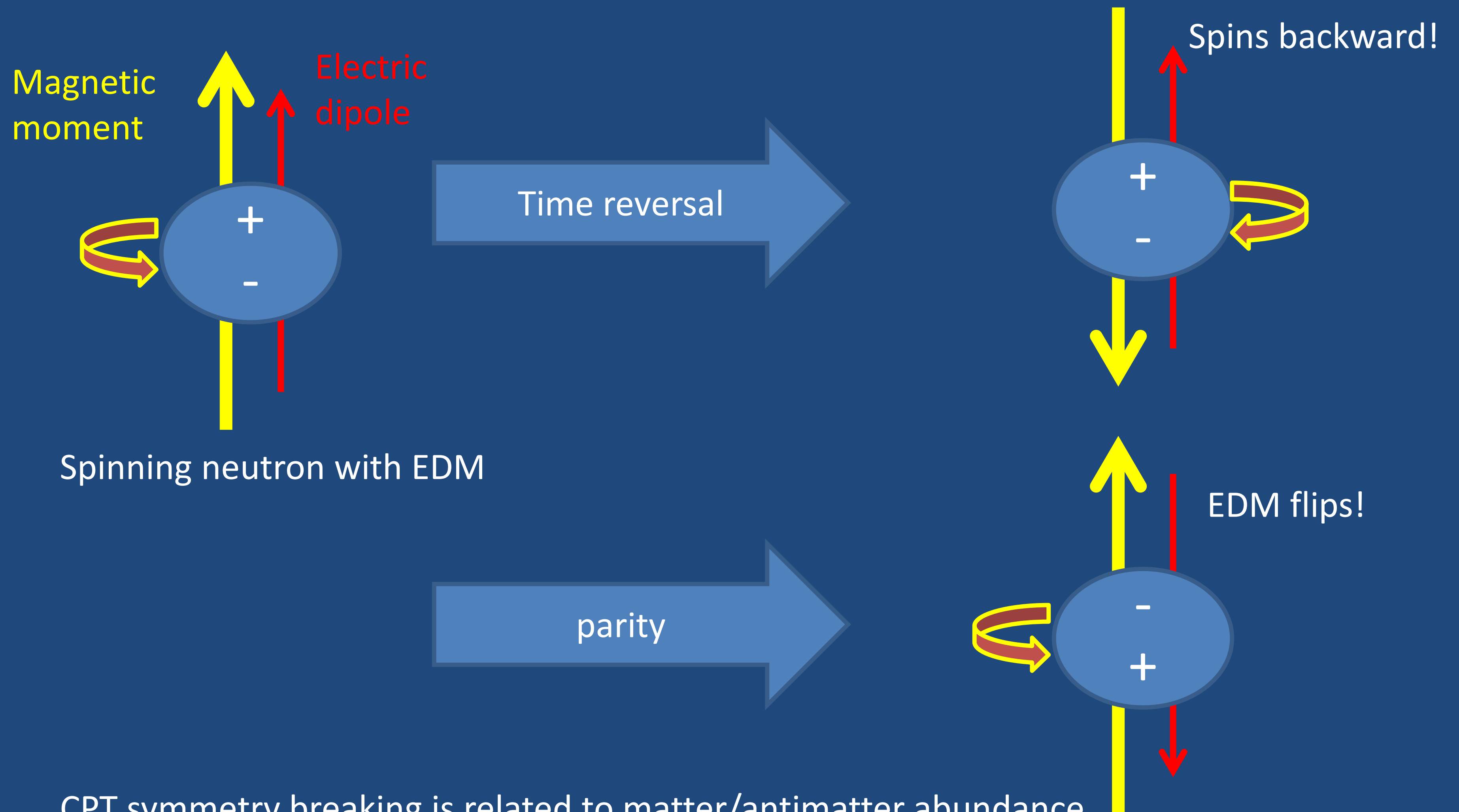
Vector mag using light shifts



Magnetometers for submarine detection

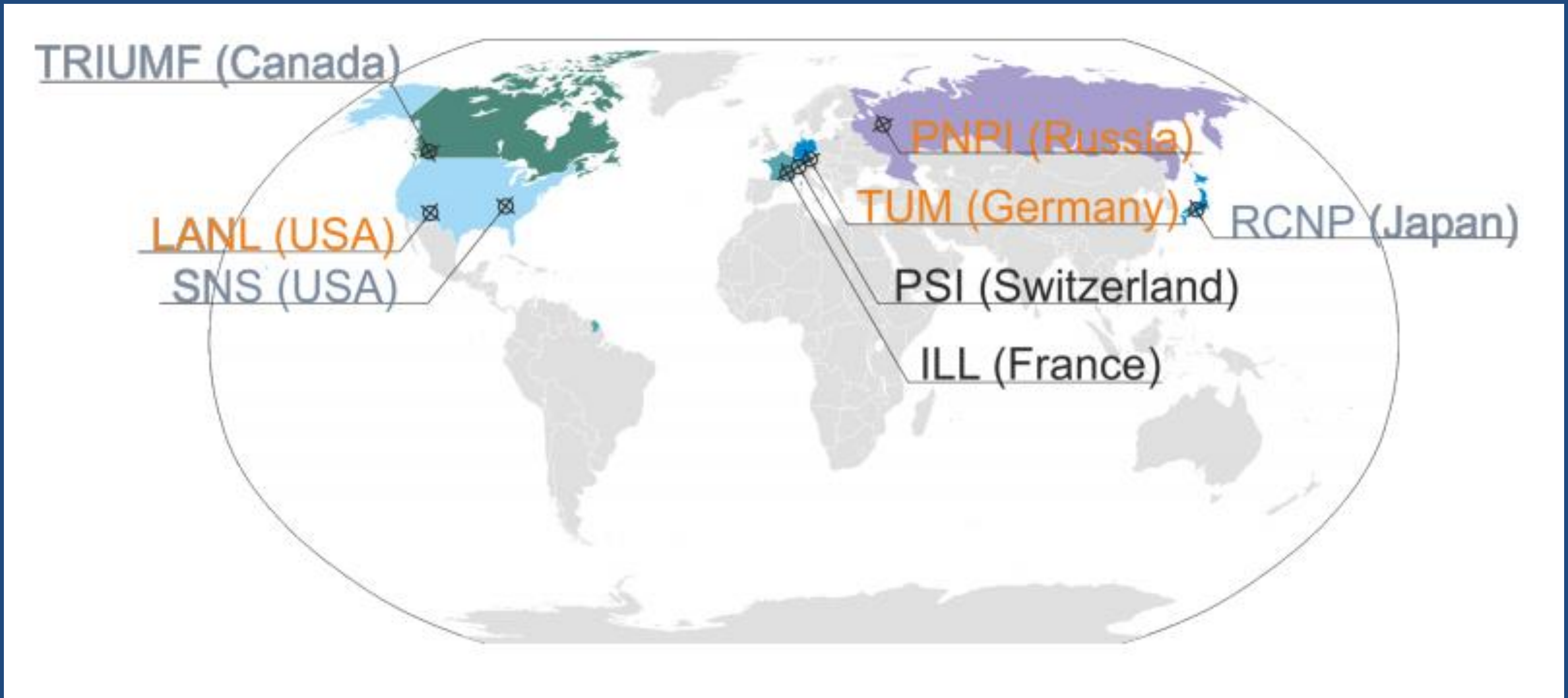
Fiberized magnetic field sensors(for nEDM experiments)

If the neutron has an electric dipole moment, it violates time reversal and parity symmetries



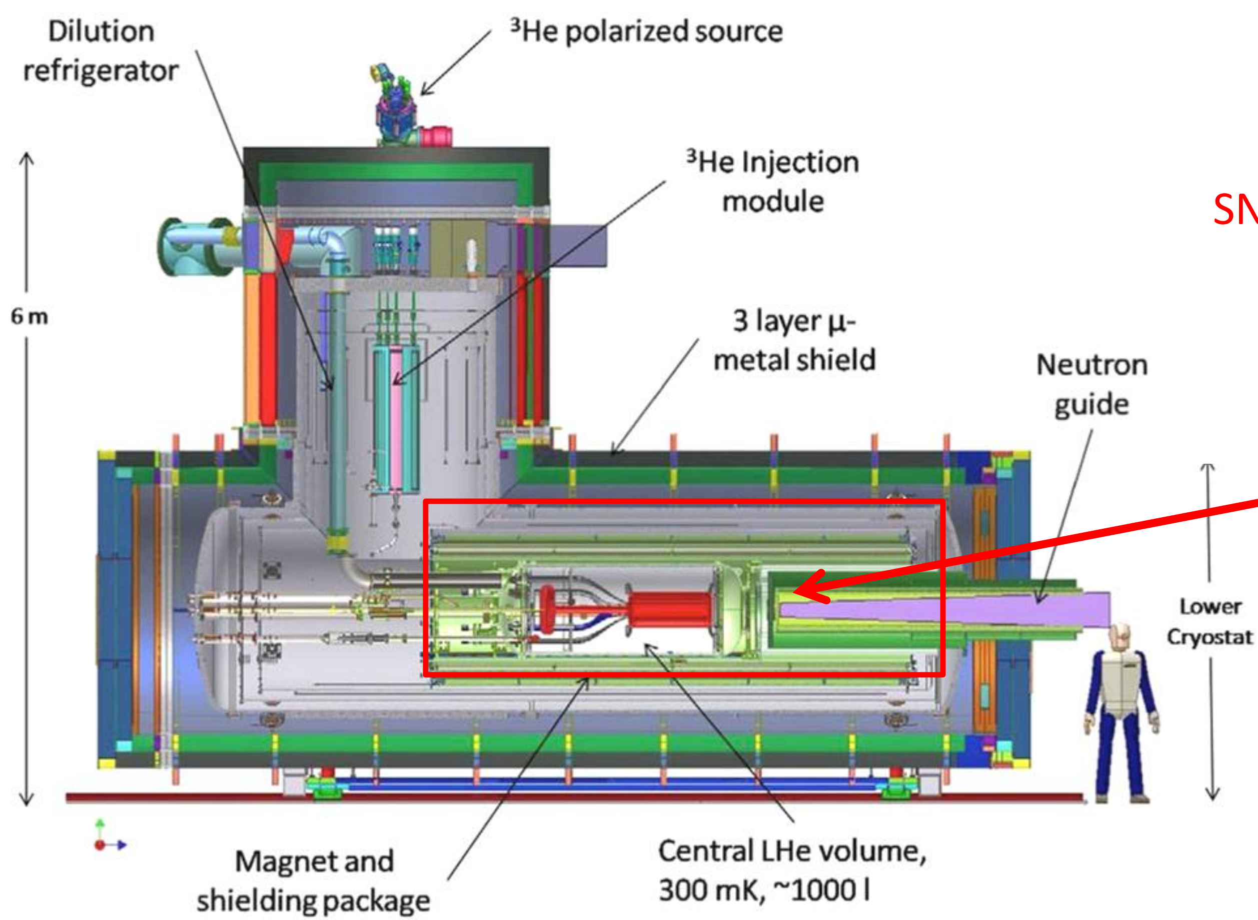
CPT symmetry breaking is related to matter/antimatter abundance

Many research groups are trying to measure the neutron EDM to find new physics



Map taken from Schmidt-Wellenburg, The quest to find an electric dipole moment of the neutron (ArXiV 2016).

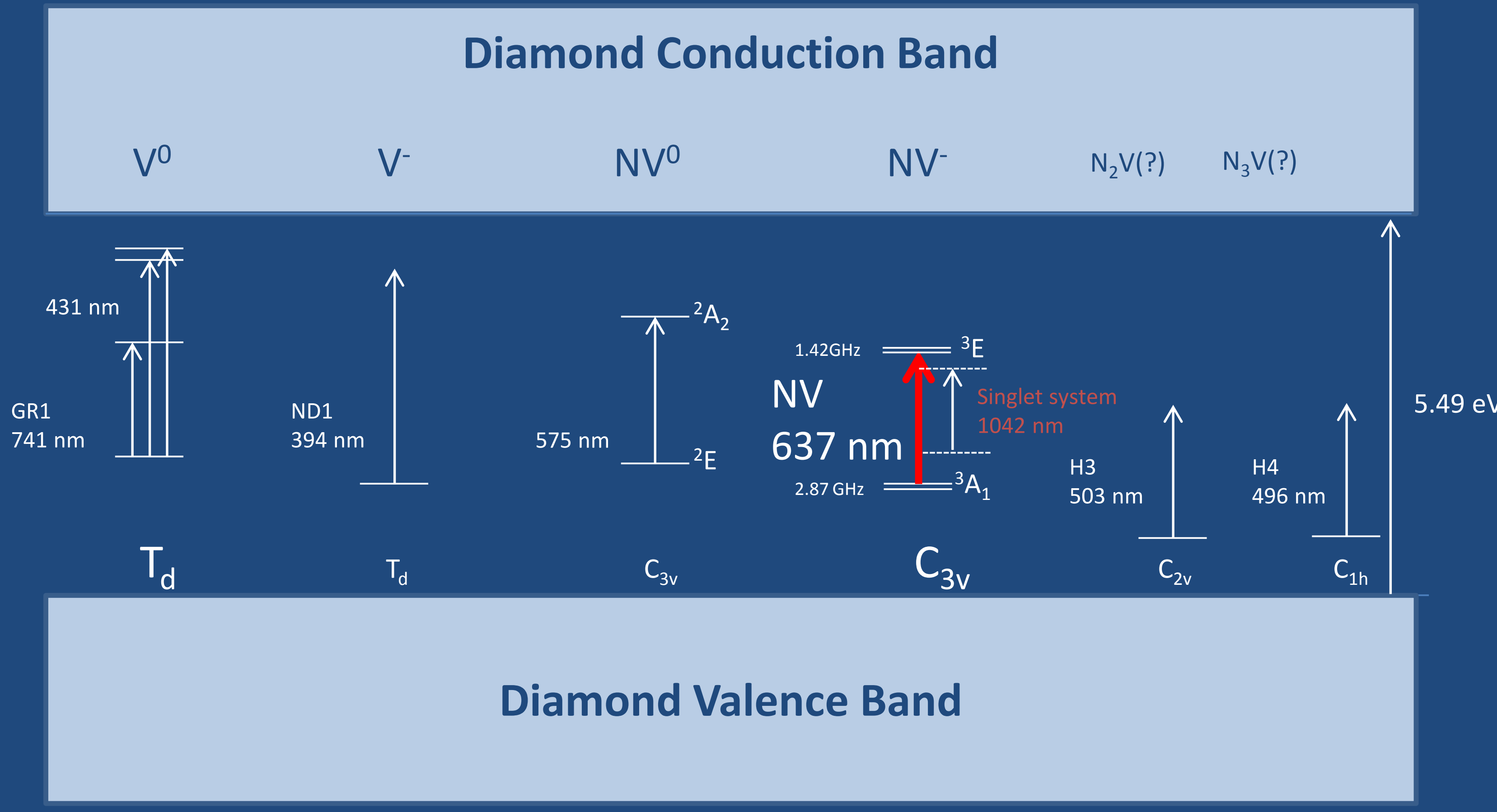
Searches for nEDM use neutrons in combined electric and magnetic fields



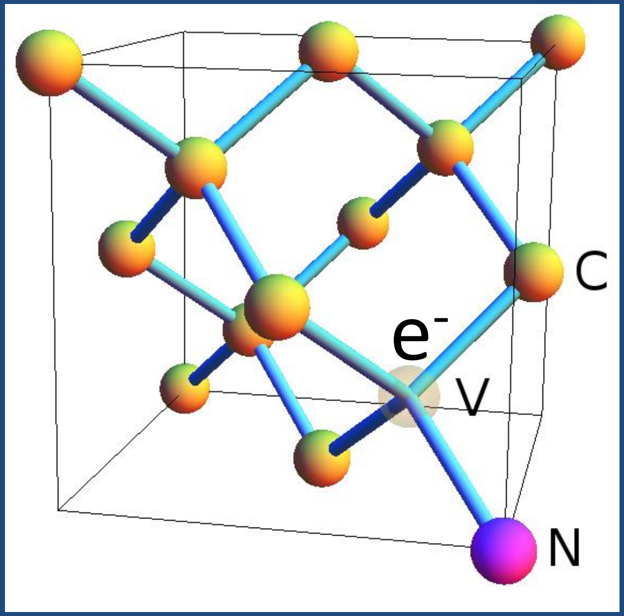
SNS APPROACH AT OAK RIDGE

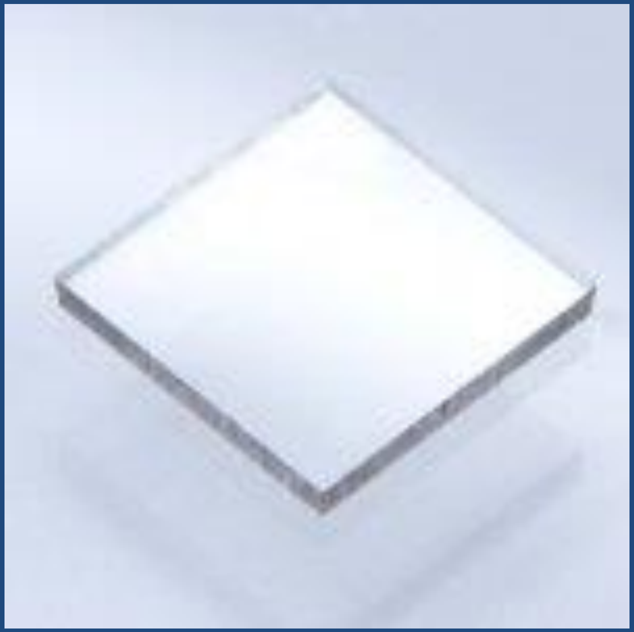
Need to measure fields inside cold, shielded volume

Diamond supports a large number of optically active impurity centers. The NV center is one.



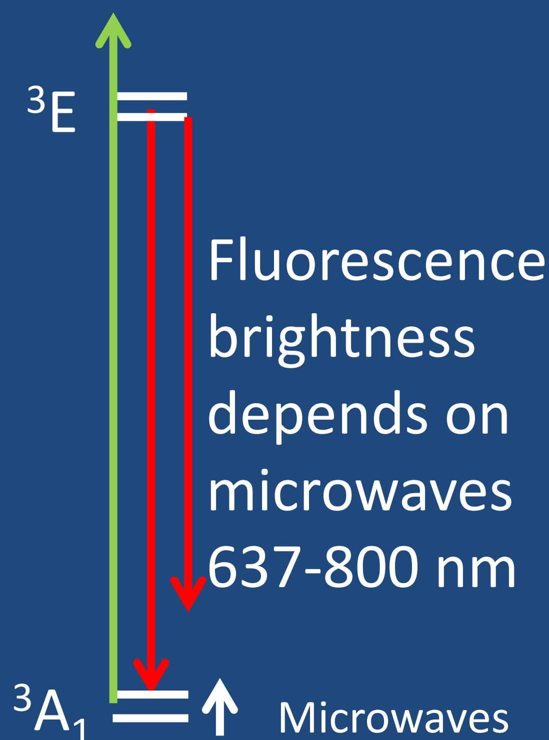
Diamonds produced by chemical vapor deposition feature high purity, controlled doping.





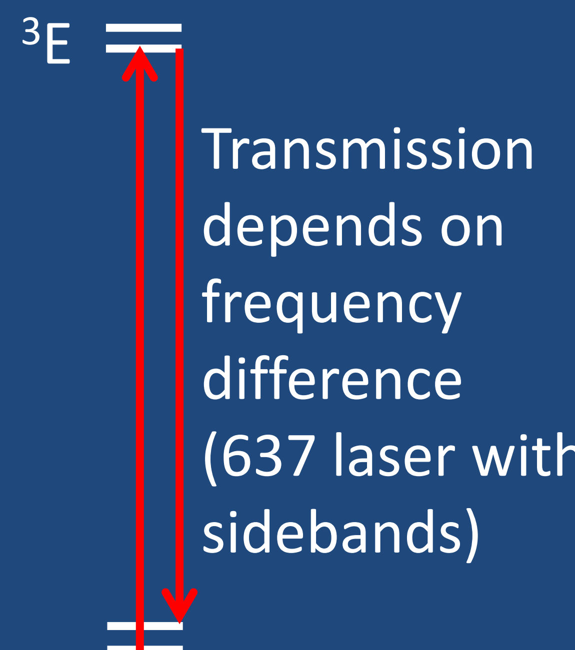
Start with ppm level of nitrogen. Bombard with electrons to make vacancies, then anneal to pair N and V. Add electron to form NV^-
Single crystal diamonds 5x5x0.5 mm cost about $600.

Two approaches to high resolution spectroscopy of the ground state: Optically-Detected Magnetic Resonance and Electronically-Induced Transparency



OMDR

Confocal
Can detect single NVs

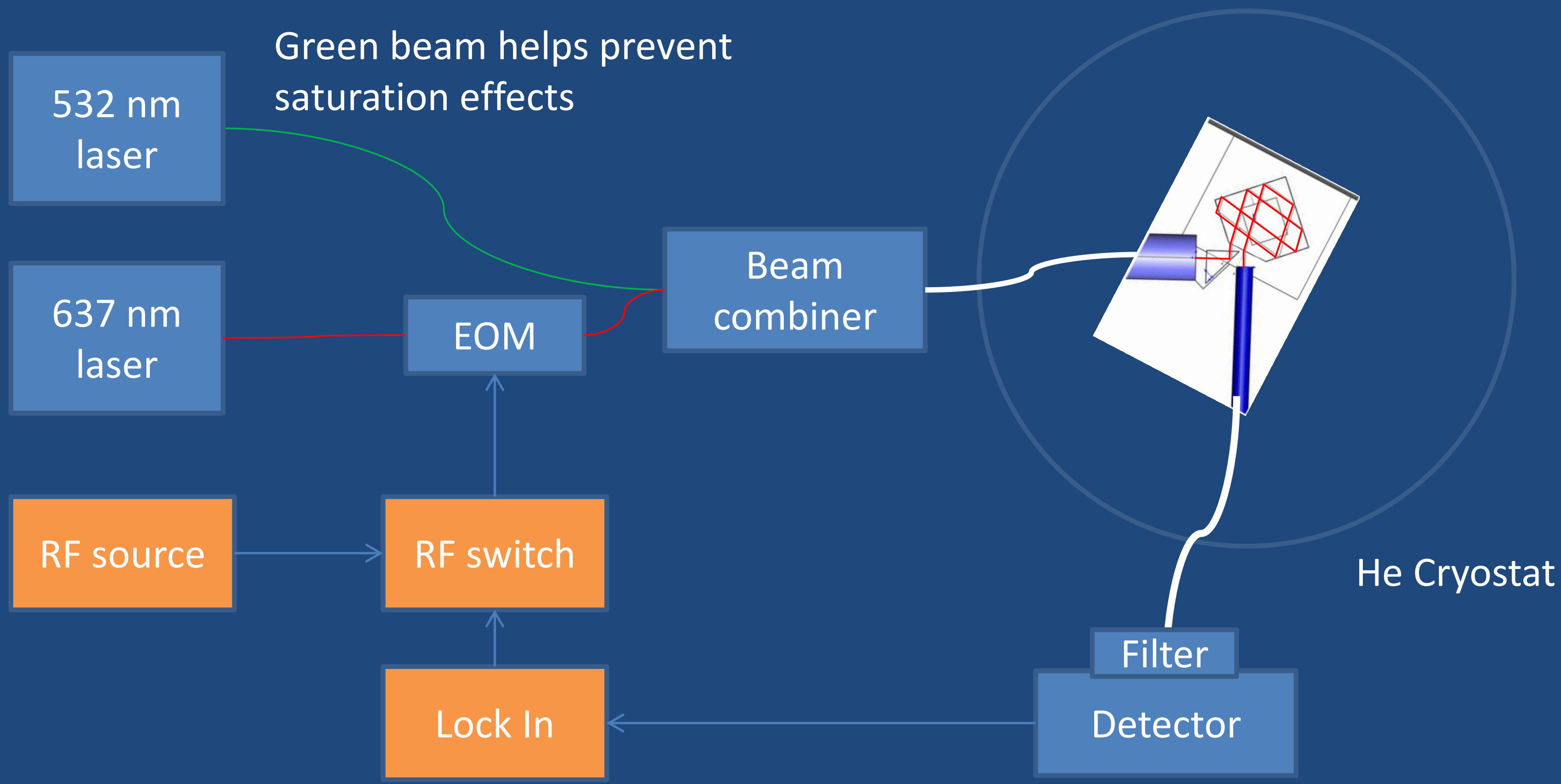


EIT

Requires cm path, cryogenics

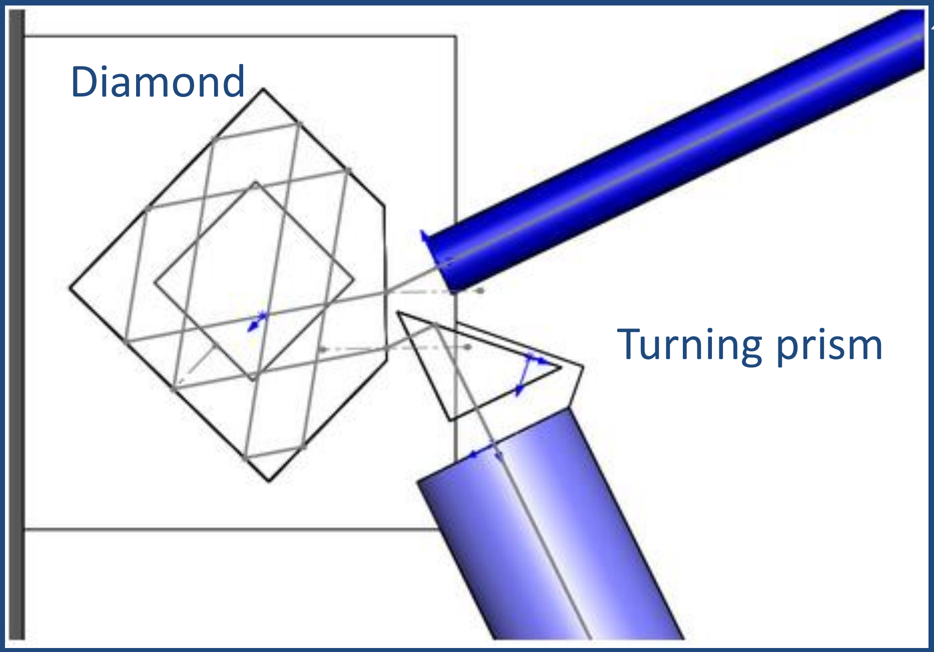
EIT layout combines Acosta, Clevenson and optical fibers

Most experiments haven't used fibers



A laser-machined quartz block holds elements together.

1 mm diameter optical fiber returns transmitted light



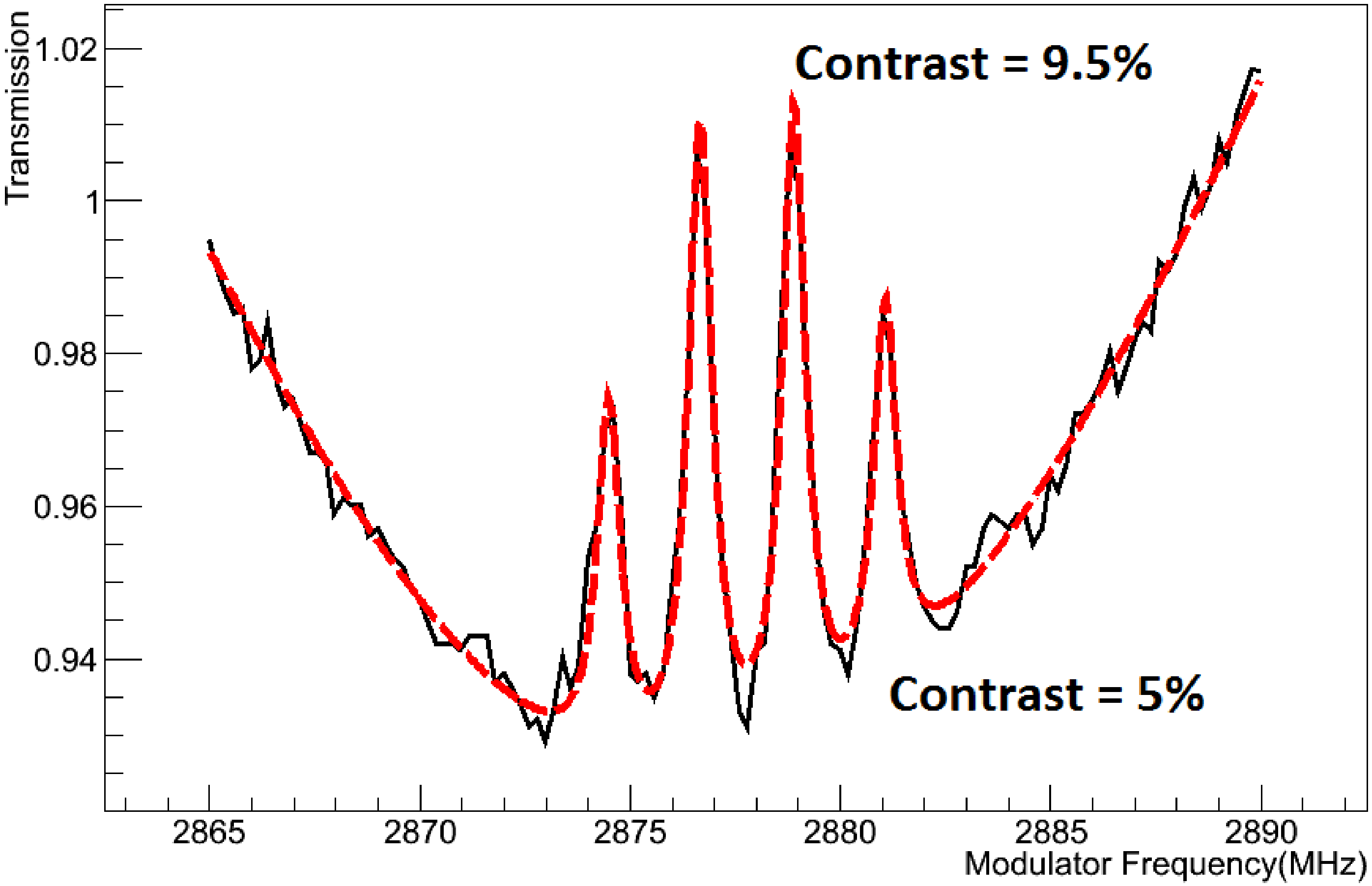
Laser-machined quartz mounting block

Polarization-maintaining fiber ending in GRIN lens delivers red and green beams

Diamond is mounted on a glass block with channels for optical fibers

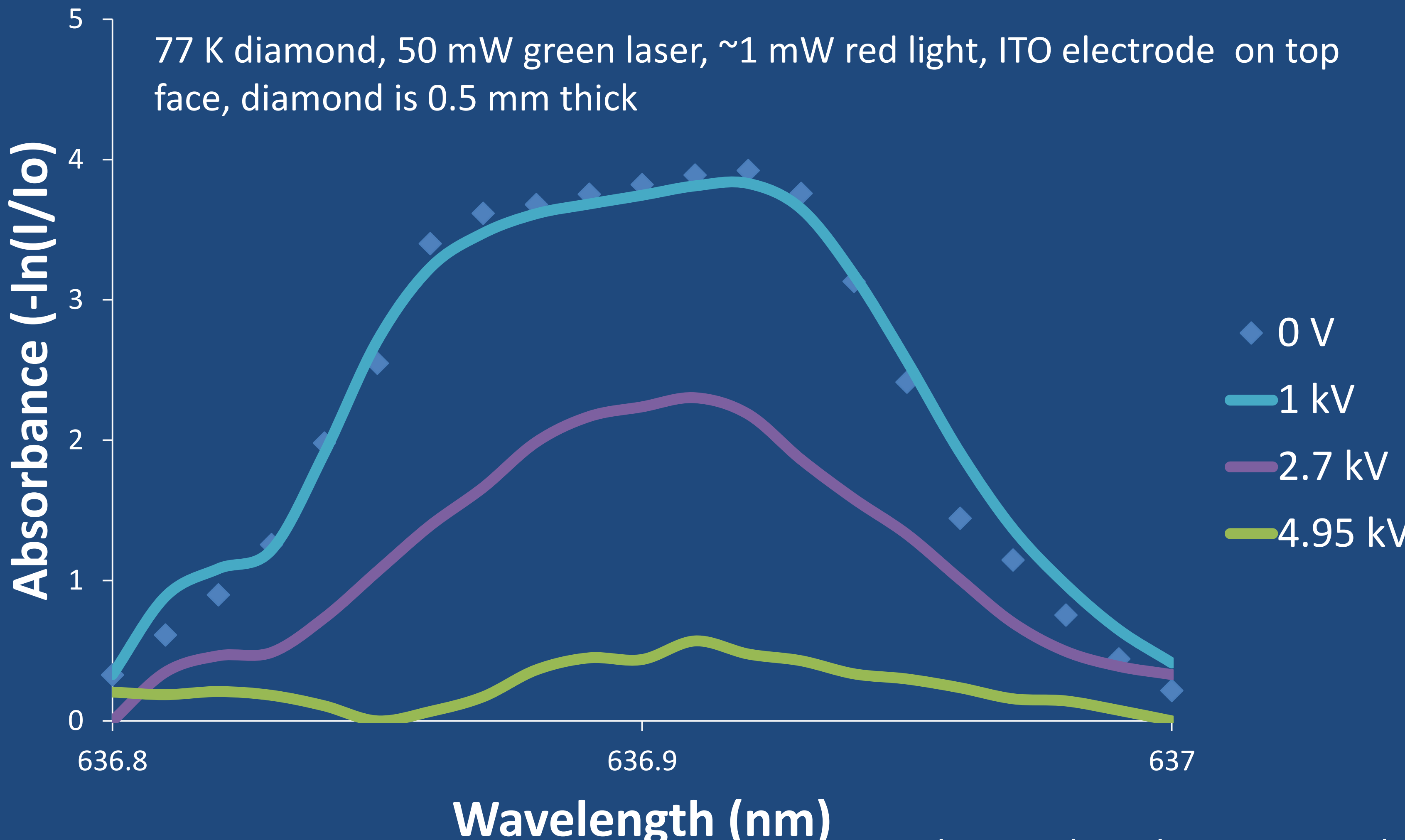
A free-space version is needed so we can apply electric fields

EIT measurements with 700 kHz line widths, line centers to 10 kHz precision.



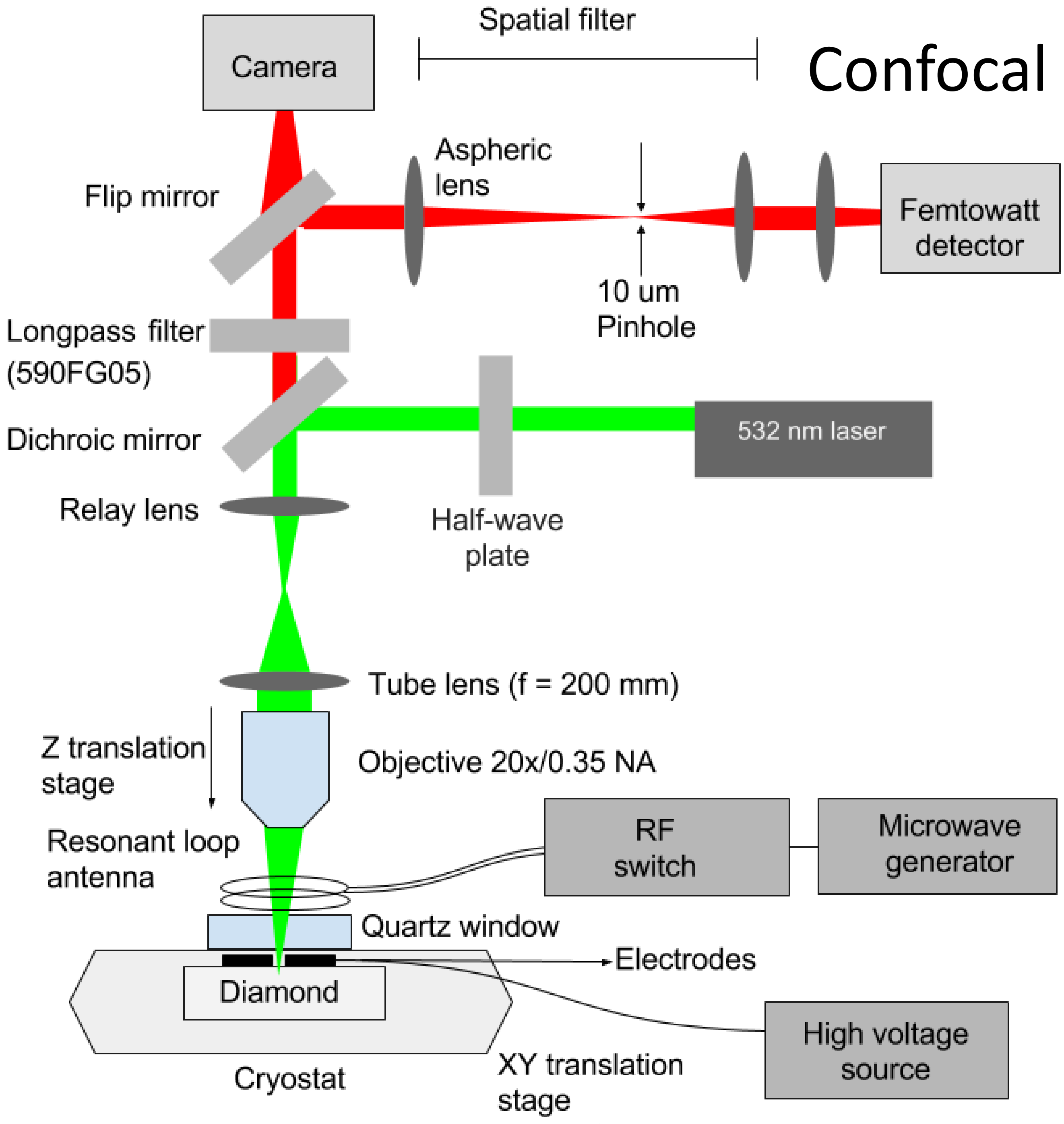
χ^2 / ndf	0.001048 / 110
Background Intercept	1.421 ± 0.002434
Background Slope	1.235e-005 ± 2.342e-005
antihole height	-49.28 ± 0.1468
antihole width	58.68 ± 0.118
antihole center	2877 ± 0.01314
1st EIT height	0.05 ± 7.329e-005
1st EIT width	0.681 ± 0.007668
1st EIT center	2874 ± 0.002077
2nd EIT height	0.09413 ± 0.00014
2nd EIT width	0.7057 ± 0.008483
2nd EIT center	2877 ± 0.01104
3rd EIT height	0.09005 ± 0.003452
3rd EIT width	0.6872 ± 0.03279
3rd EIT center	2879 ± 0.01126
4th EIT height	0.05253 ± 0.003443
4th EIT width	0.672 ± 0.0546
4th EIT center	2881 ± 0.01855

Increasing the voltage beyond 40 kV/cm destroys the NV- absorption signal!

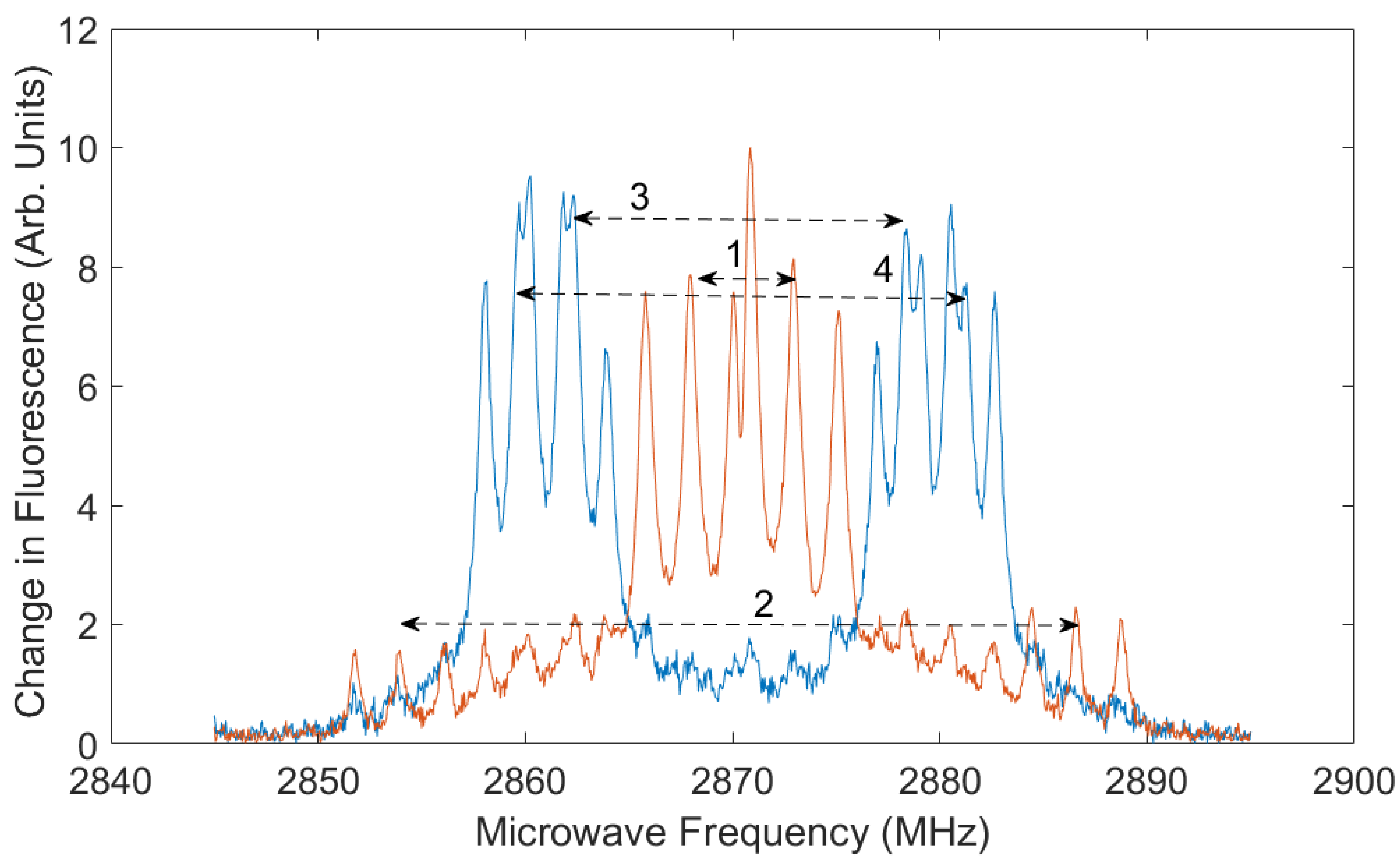


Chen et al used 1.8 W green laser

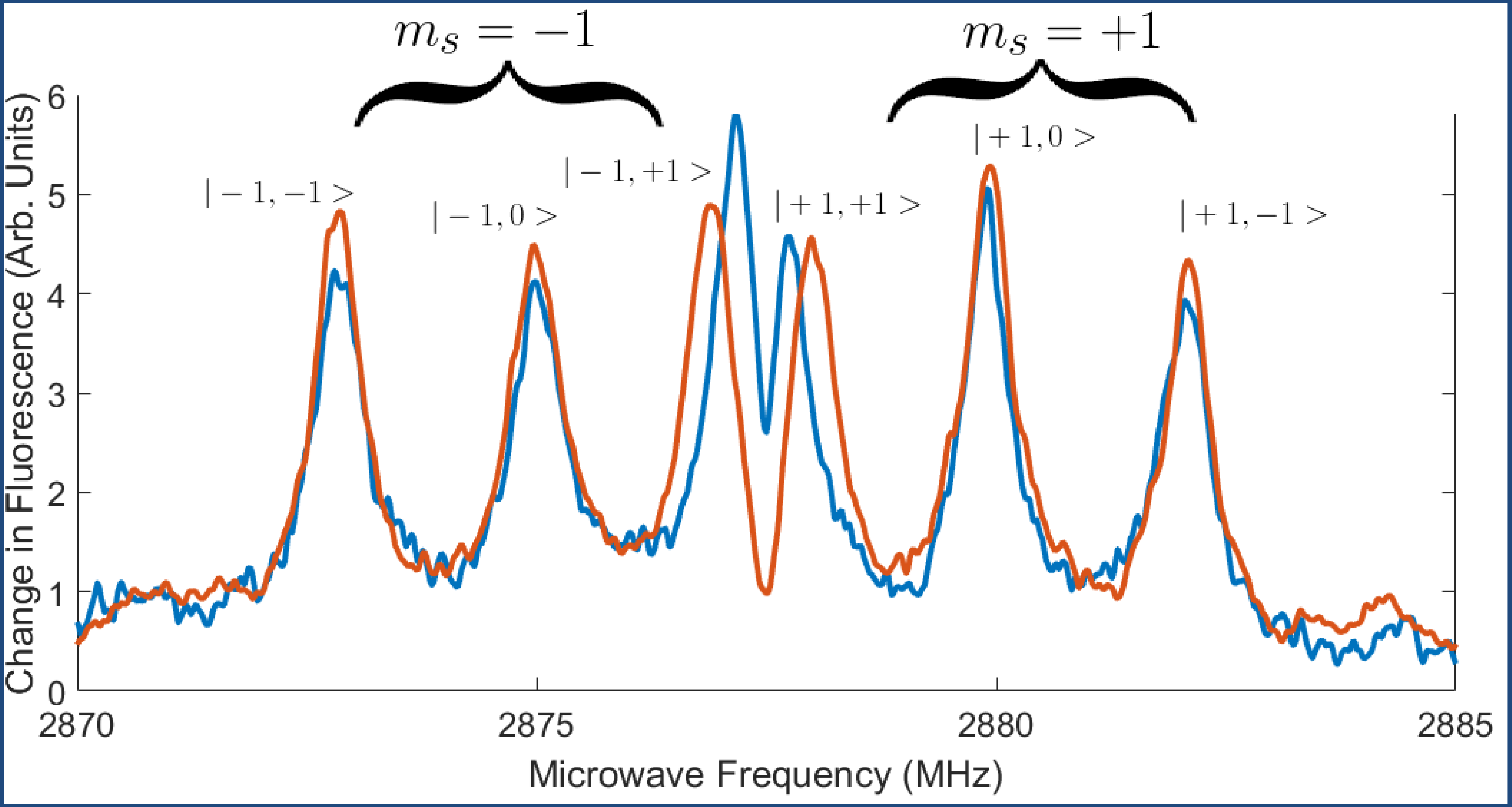
Confocal ODMR



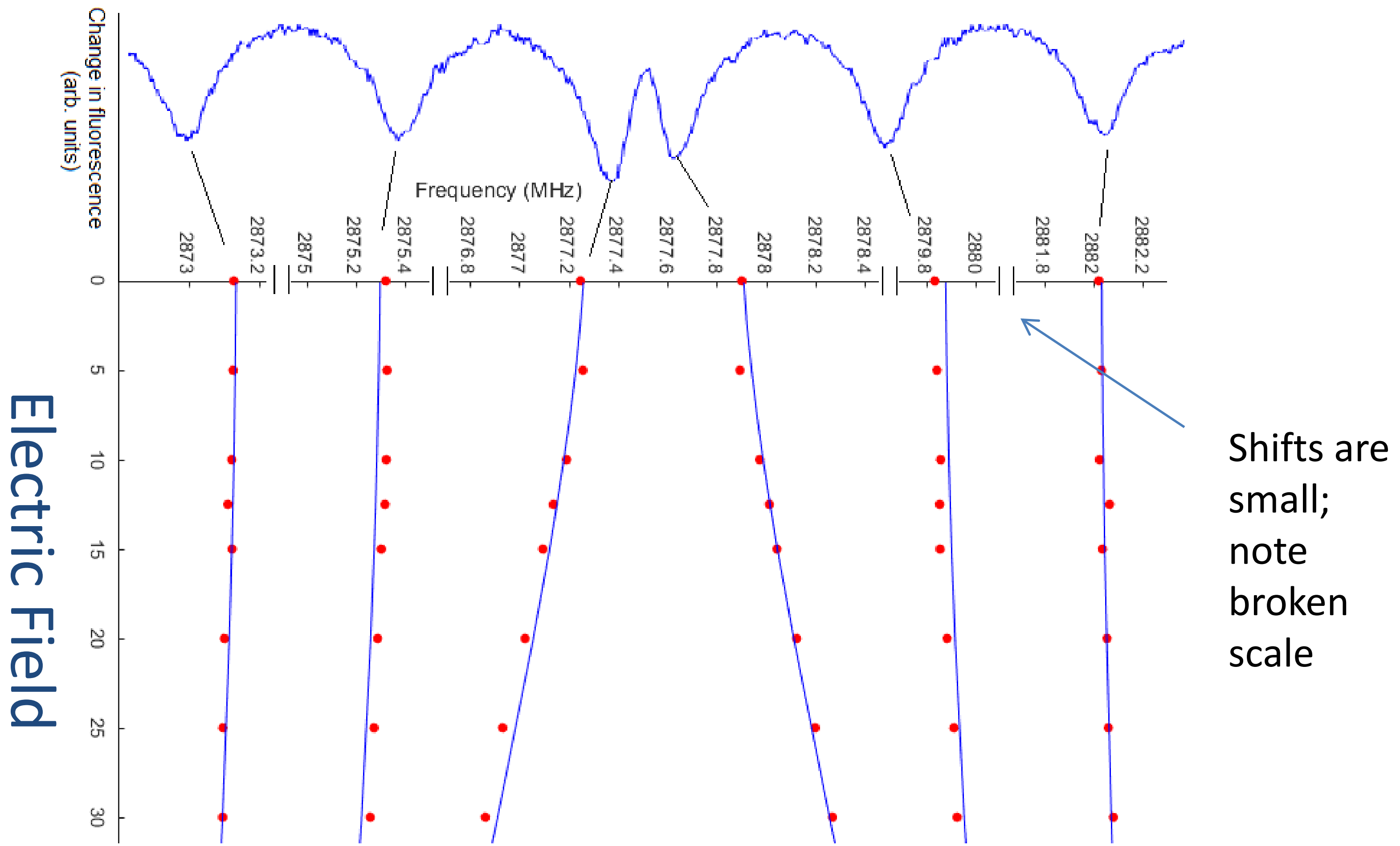
All 24 resonances observed by ODMR. Can fit peak positions to 5-10 kHz.



ODMR spectrum at two different voltages. Innermost peaks show clear shift.



Peak positions show clear dependence on electric field, shift of ~400 kHz at 30 kV/cm

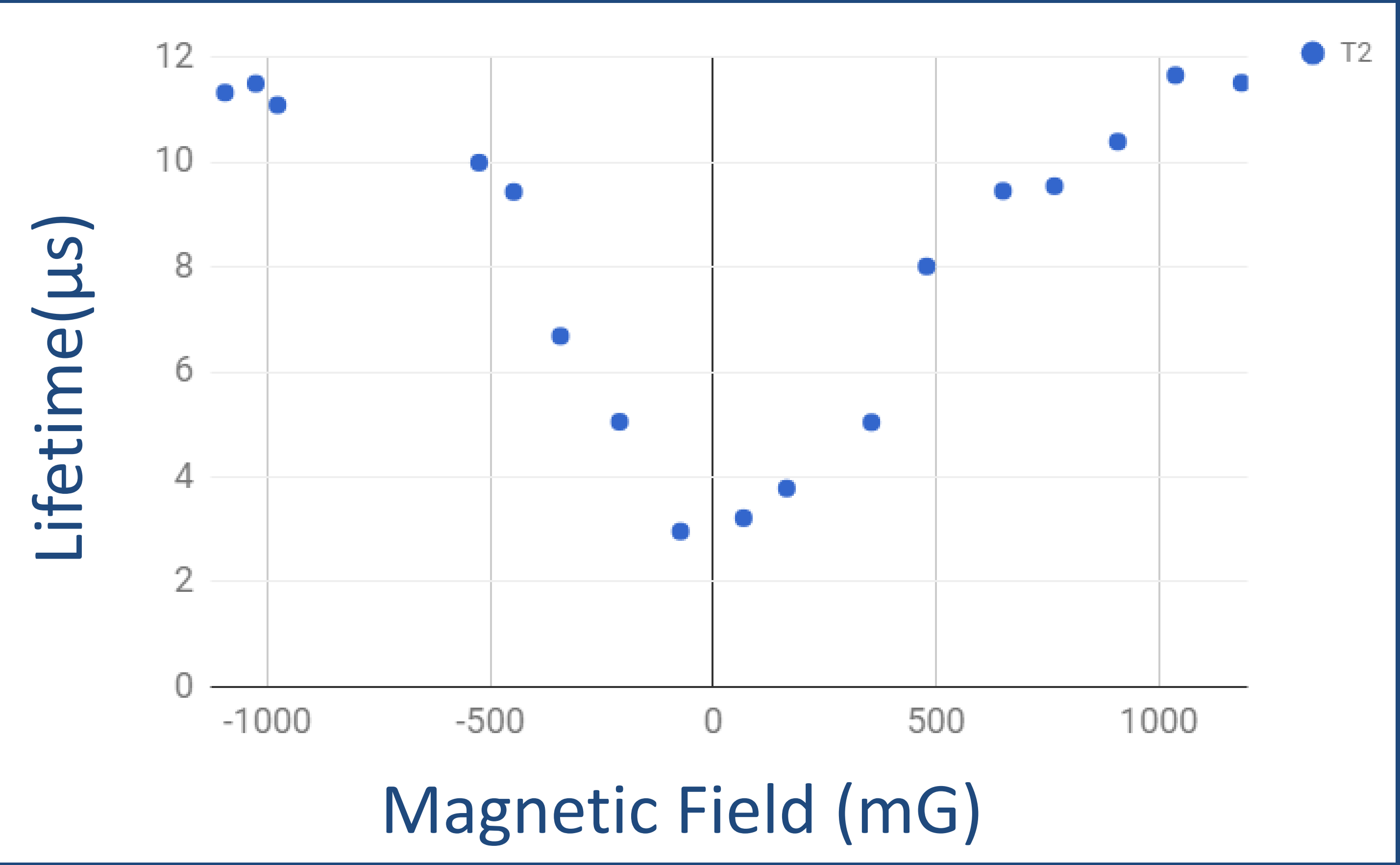


Dipole moment is 17 Hz cm/V. Field uncertainty ~ 10 kHz/17 Hz cm/V = 600 V/cm

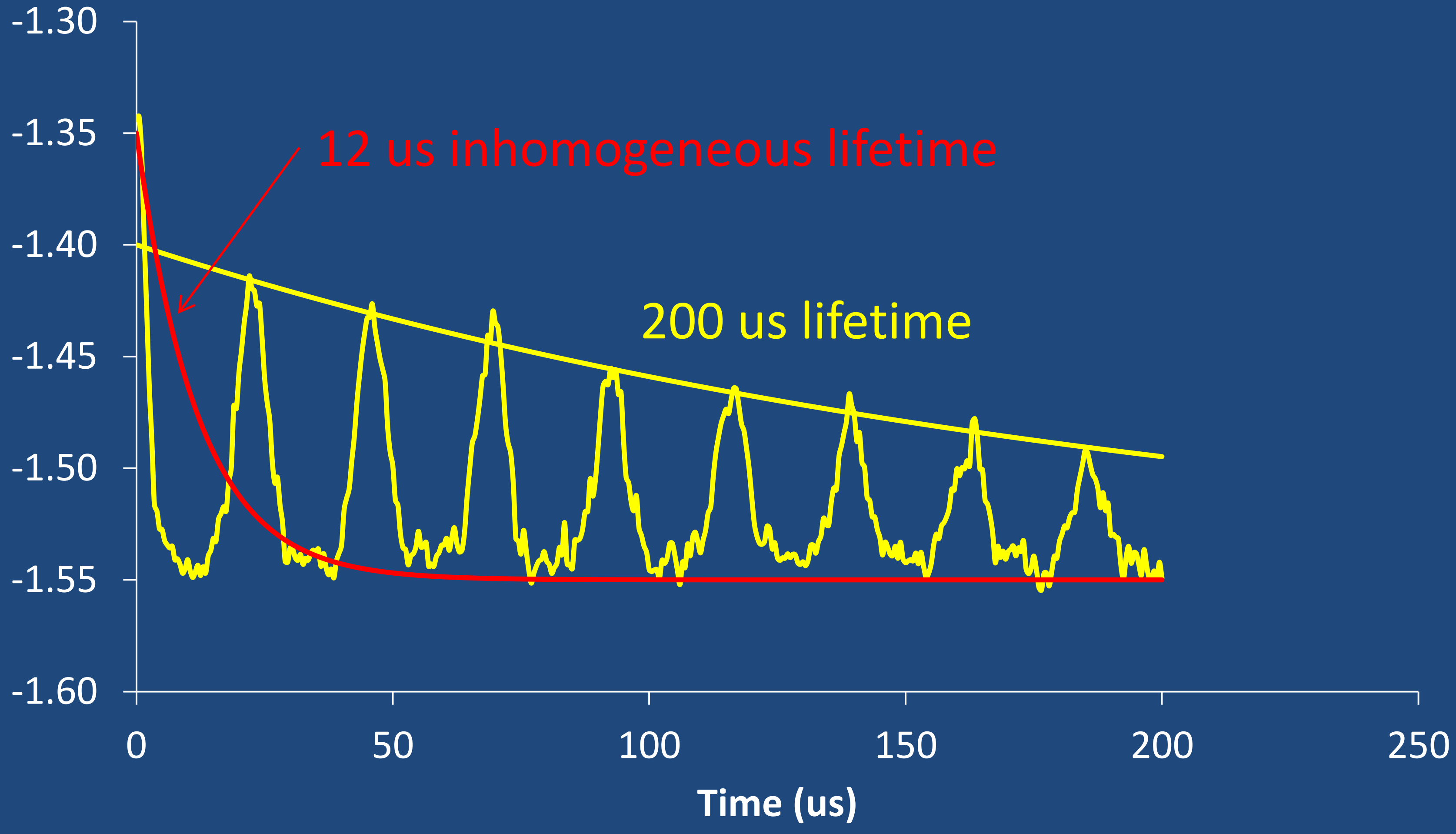
Determine electric fields with accuracy of 5 to 10%

Inhomogeneous lifetime depends on magnetic field, and we think we understand why

Lifetime measured using time-dependent spectroscopy (Rabi Oscillations)



Homogeneous lifetime is much longer. If limited by homogeneous lifetime, measurements would yield improved electric and magnetic sensitivity



CONCLUSIONS: NV Diamond sensors can measure electric fields to 5 to 10% accuracy when operated near an avoided crossing.

We found two new avoided crossings at ±80 uT.

Need to adjust magnetic field, laser and microwave polarization so that an avoided crossing is obtained and other NV signals don't get in the way—an issue in nEDM systems

EIT has comparable sensitivity but need much higher green power to operate at high voltages.

Need to test the window effect.

Homogeneous lifetime is 20x longer-more sensitive measurements are possible