A Precise Measurement of the Stark Shift in the $6P_{1/2}$->$7S_{1/2}$ 378 nm Transition in Thallium

Final Thesis Talk

May 13, 2002

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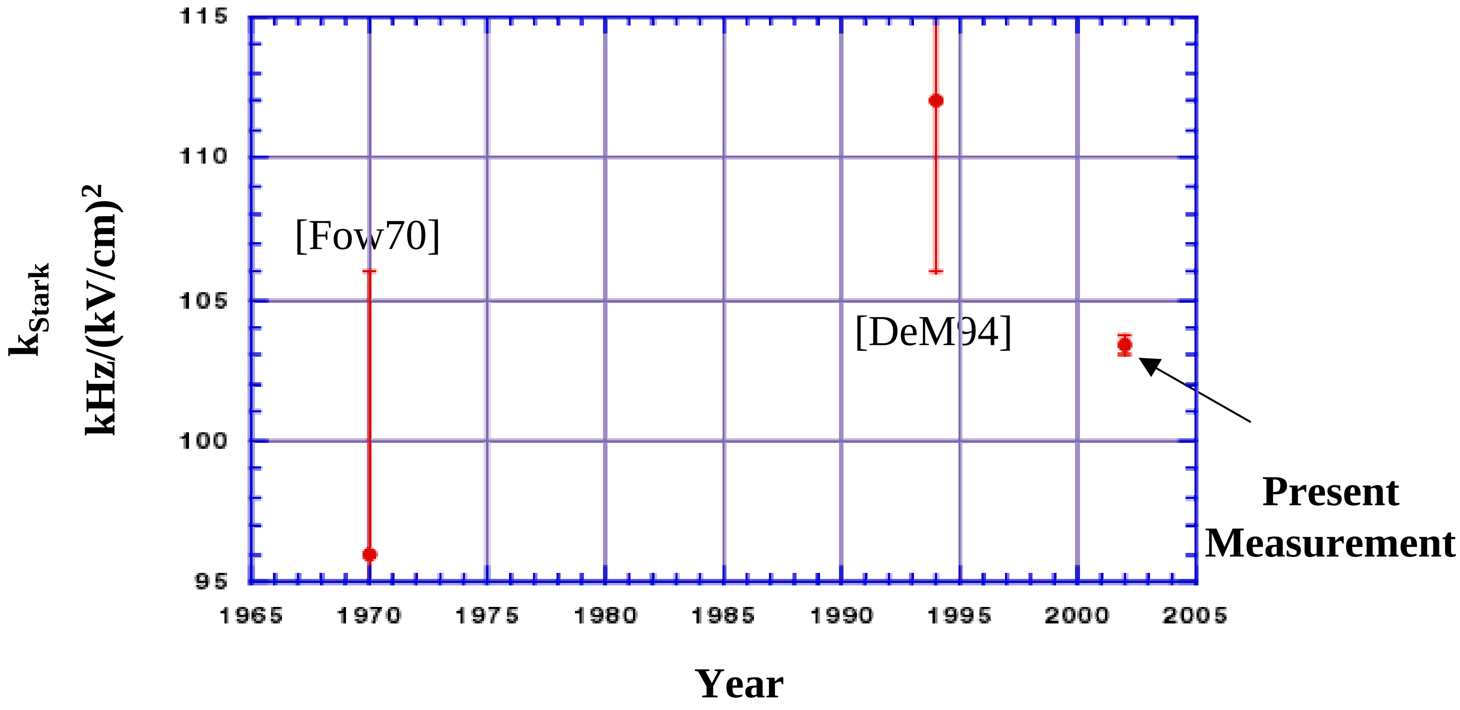
Previous work by Andrew Speck ’00, Paul Friedberg ’01,

D.S. Richardson, PhD

Summary of Stark Shift Measurements

$$\Delta\nu = k_{Stark}E^2$$



k_{Stark} = 103.34(37) kHz/(kV/cm)^2

Why Bother?

- Low energy AMO physics can be used to set stringent limits on fundamental physical quantities

- Parity non-conservation measurements give both evidence for and tests of fundamental physics

- Of interest here: Q_w , predicted by elementary particle theory

According to Atomic Physics:

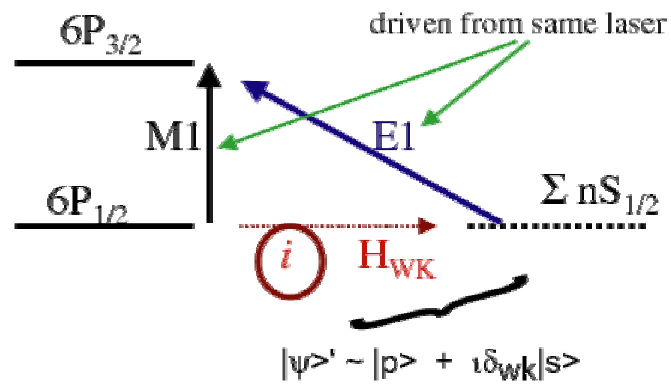
$$E_{PNC} = Q_w * C(Z)$$

Group	Element	Experimental Precision	Atomic Theory Precision
Colorado '88	**Cesium**	**2%**	**1%**
Oxford '91	**Bismuth**	**2%**	**8%**
UW '93	**Lead**	**1.2%**	**8%**
Berkeley	**Ytterbium**	**ongoing**	**Isotopic ratios…**
UW '95	**Thallium**	**1.2%**	**2.5% (new, 2001)**
Colorado '97	**Cesium**	**0.35%**	**~ 1% (or less)**

Where does k_{Stark} come into play?

- C(Z) based on an infinite sum of *E1* matrix elements*

$$\Psi_1^* e\vec{r}\,\Psi_2\, d^3\vec{r}$$



- k_{Stark} calculable from an infinite sum over <u>all</u> wavefunctions

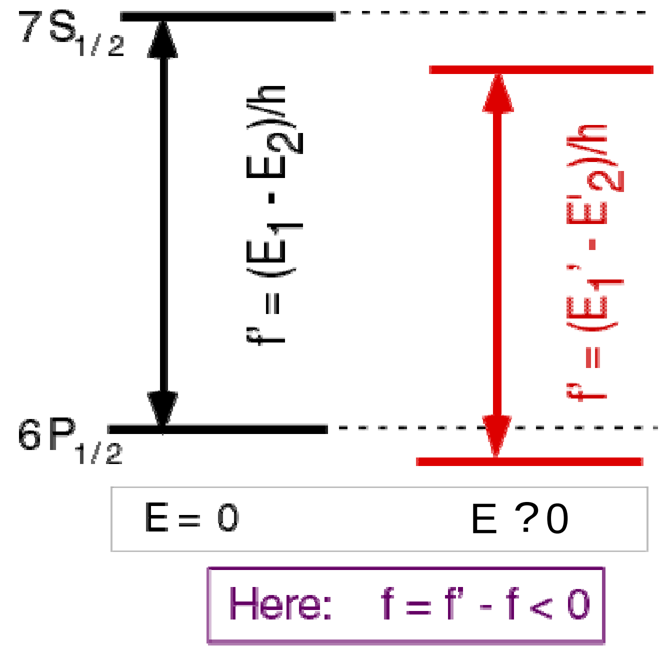
So, if your wavefunction approximations can accurately calculate k_{Stark}, they should be adequate for an accurate determination of C(Z) as well!

* details available upon request

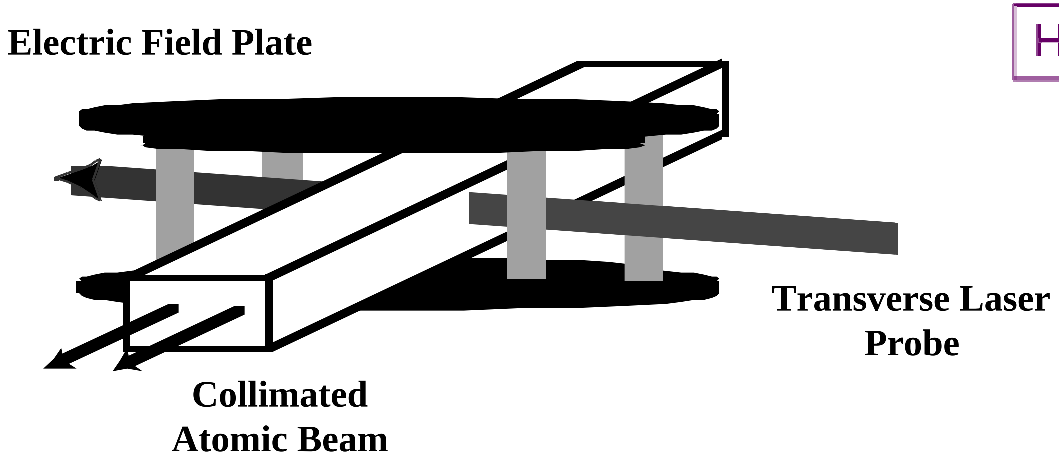
How to measure?

2nd order Perturbation Theory:

$$\Delta\nu = k_{Stark}E^2$$

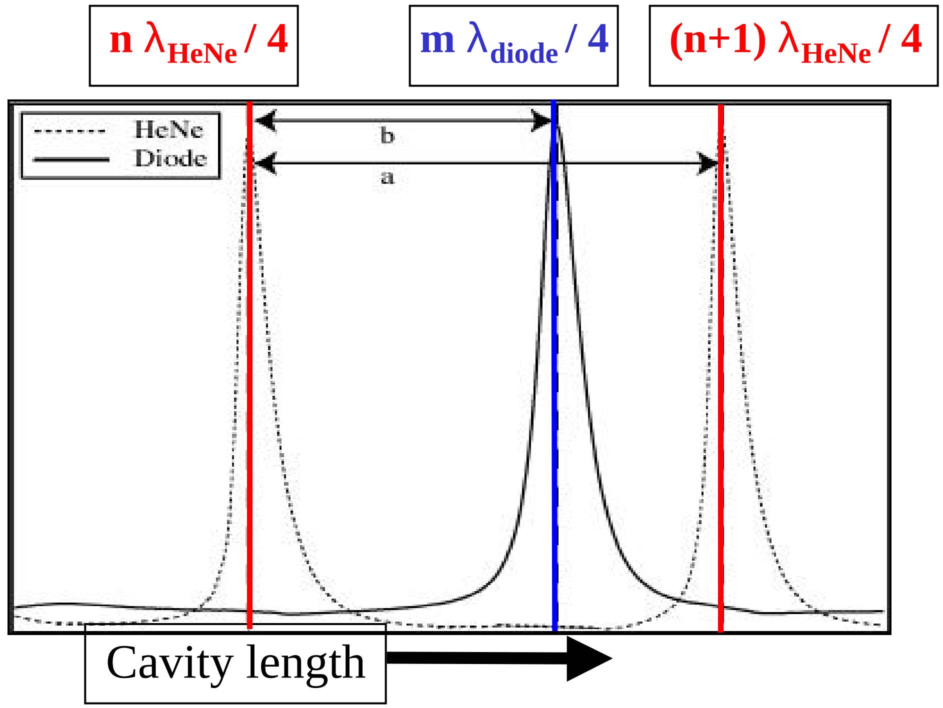


Interaction Region:



Optical System:

Frequency Stabilization:



$\rho = b/a$

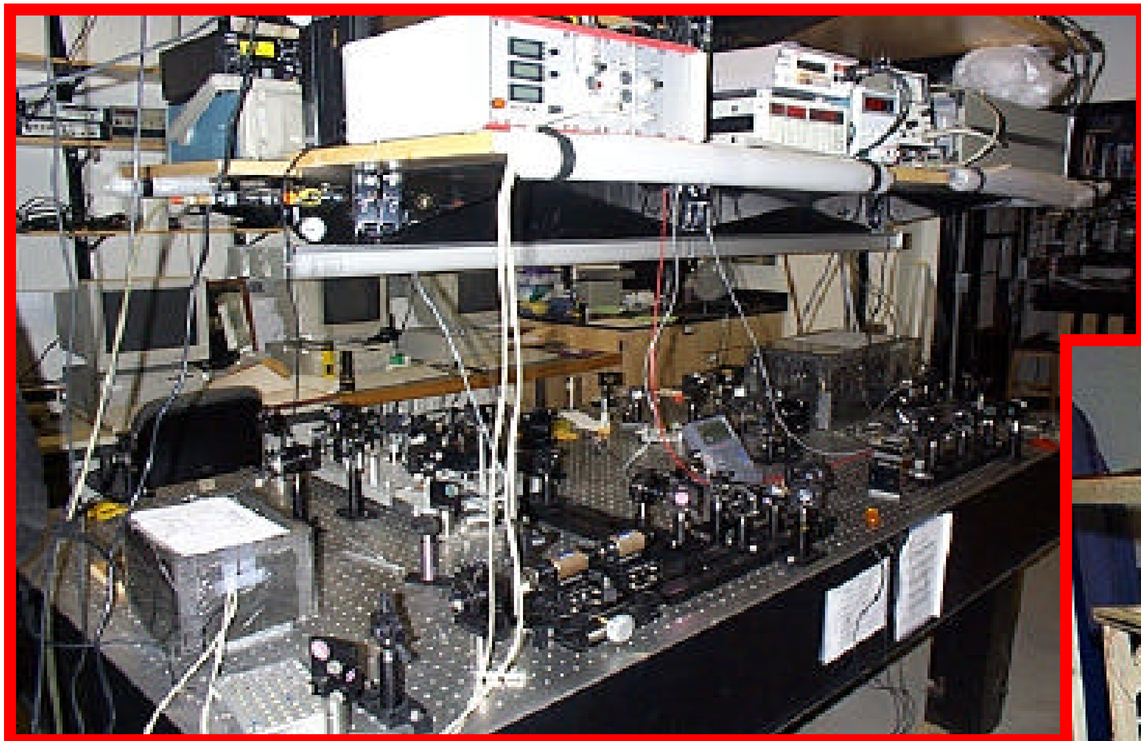
Frequency Tuning:

1) Adjust $0 < \rho < 1$ ~ 800 MHz range

-susceptible to mis-measurement of FSR, slow, manual

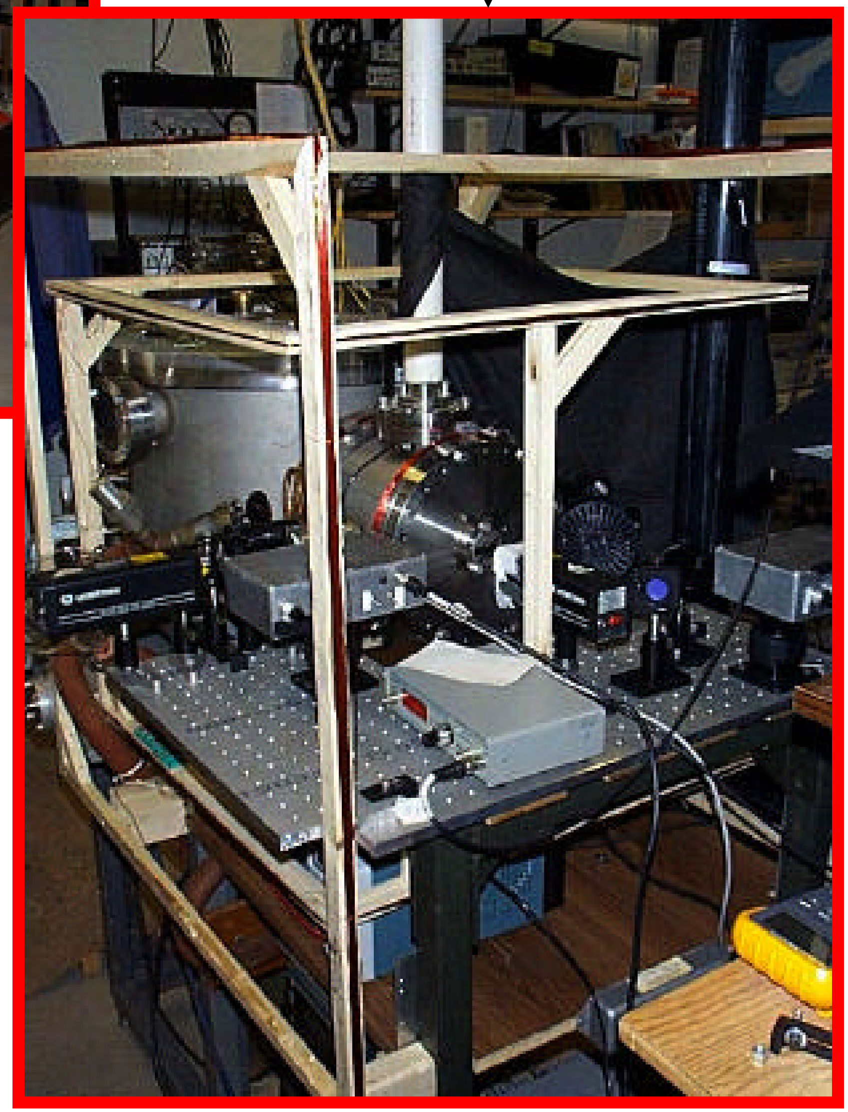
2) Acousto-Optic Modulator precisely shifts laser frequency at fixed ρ ~ 100 MHz range

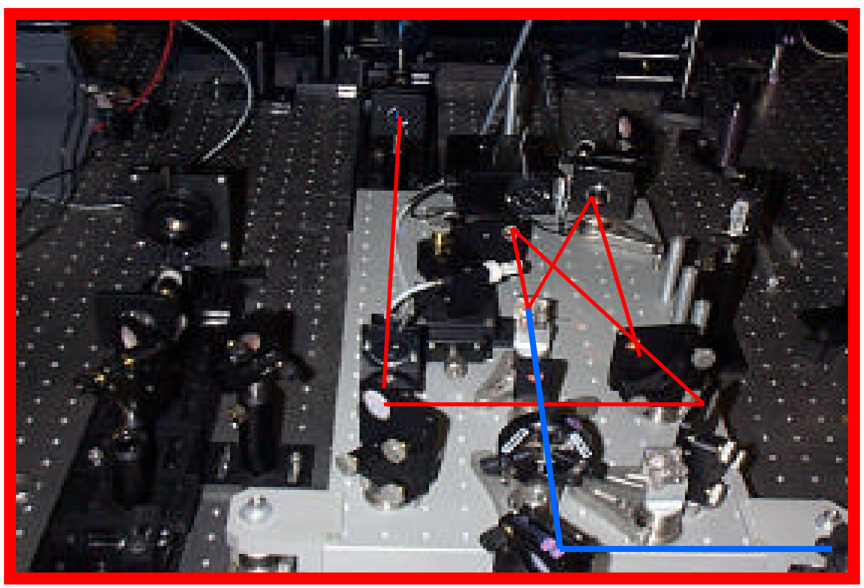
- synthesizer precision, instantaneous, computer control, steering problems



Optical Table

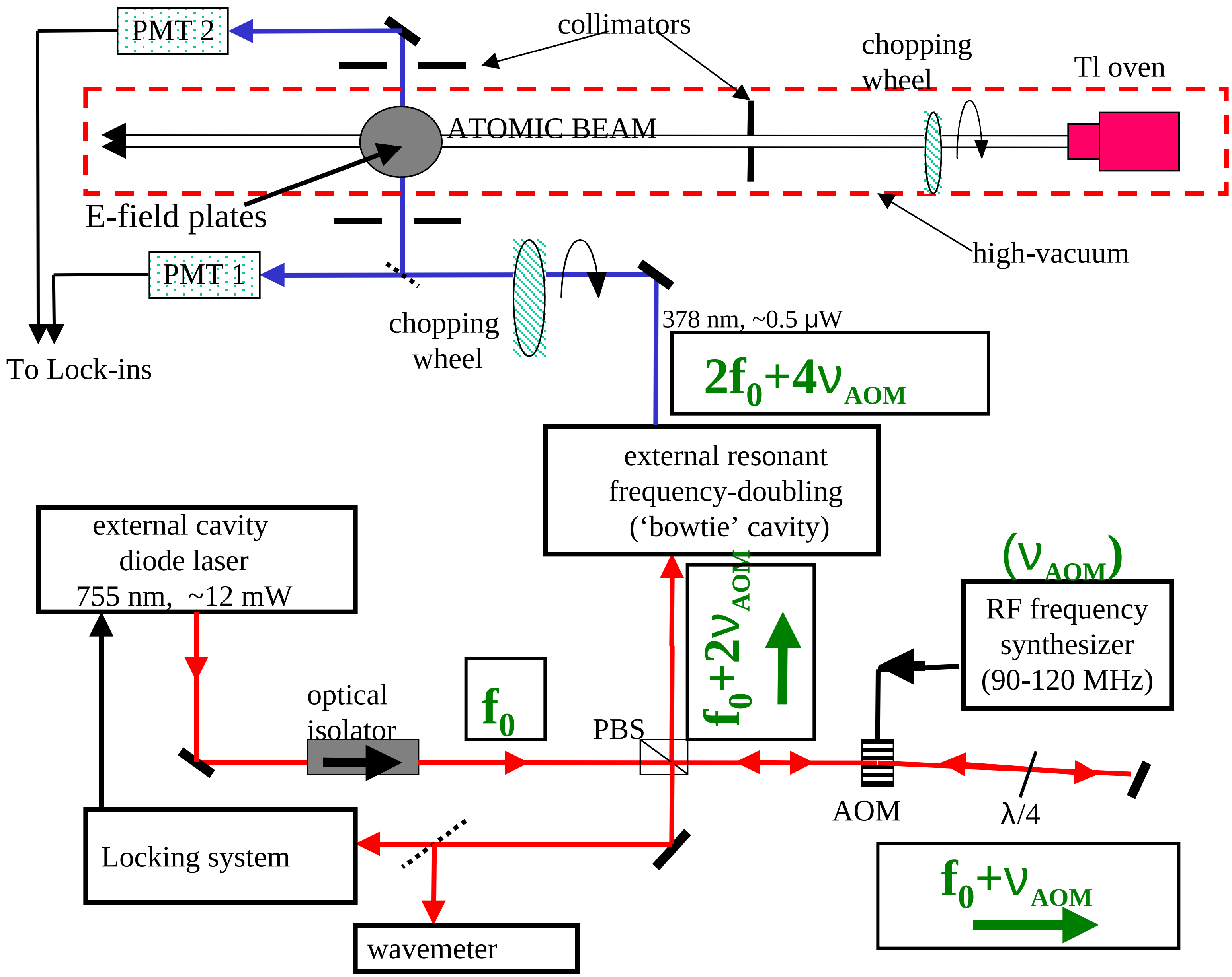
Interaction Region





Doubling Cavity

Atomic Beam and Optical System Layout



Data Collection/Signal Processing

Chopping System:

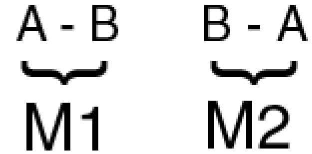
- Laser Beam chopping rejects any noise with frequency components other than the modulation frequency – 1400 Hz

- Atomic Beam chopping to correct for optical table drifts, beam density fluctuations, etc. – 1Hz

Division/Subtraction Schemes:

- Extra PMT for laser beam intensity normalization

- Interested in difference signal A-B

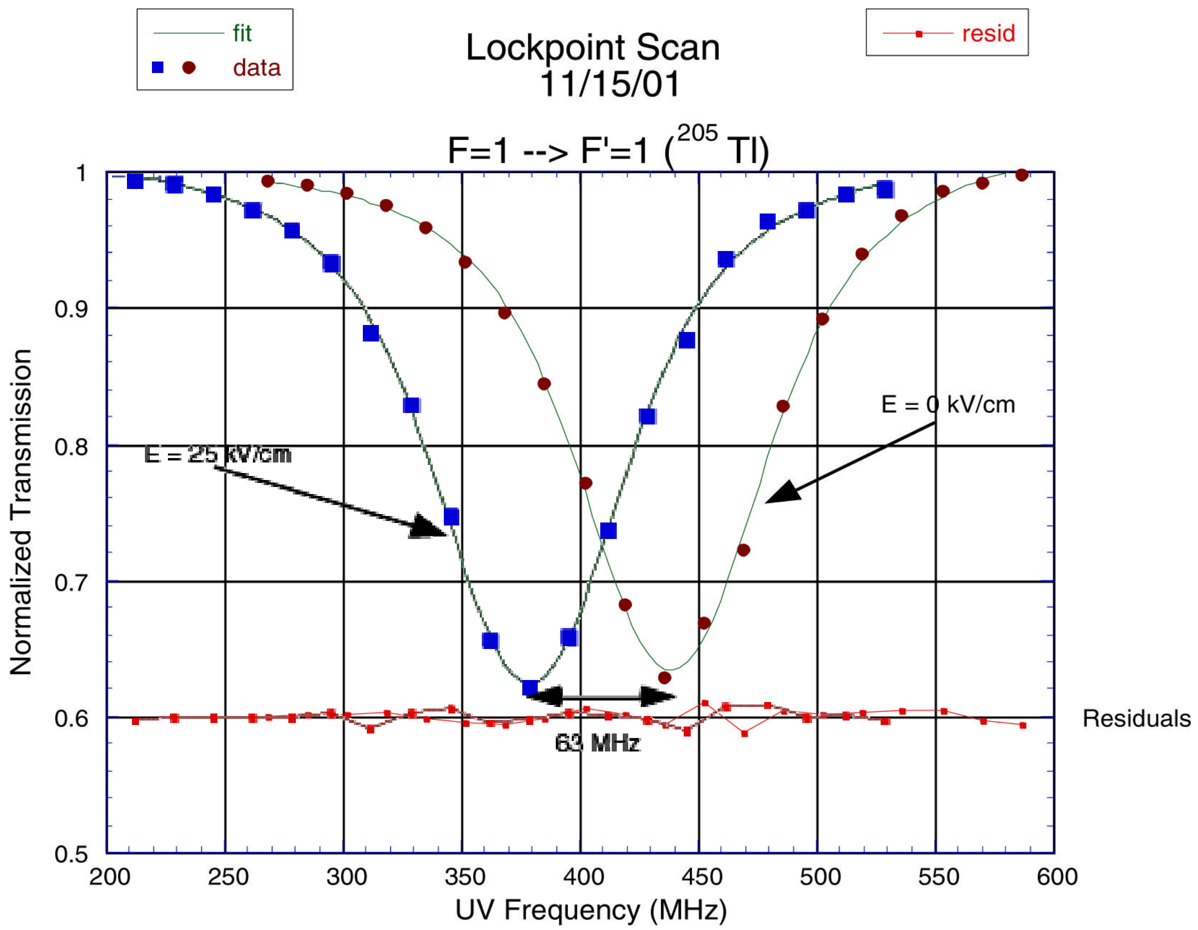


- Collect data in ABBA format to minimize the effects of linear drifts

Measurement Methods

ρ Frequency Scan:

- **Sequentially lock the diode laser, calibrate "ρ"**
- **Scan over single line of ^{205}Tl. Fit data to Voigt transmission profile**



$$k_{Stark} = \frac{63MHz}{(25kV/cm)^2}$$

$$= 101kHz/(kV/cm)^2$$

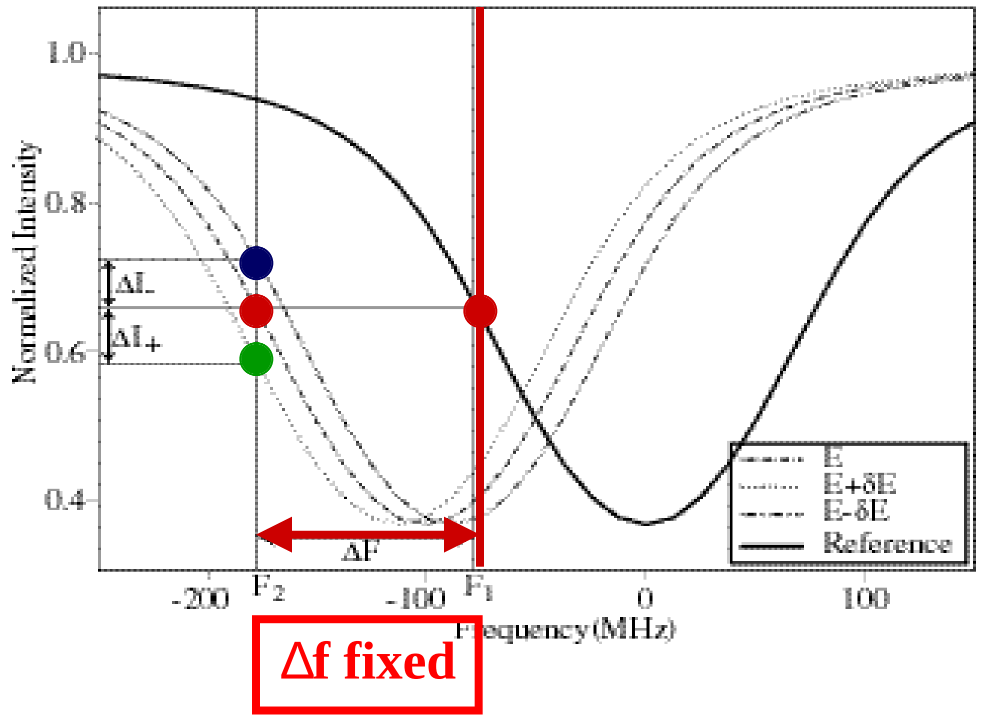
Transmission Change:

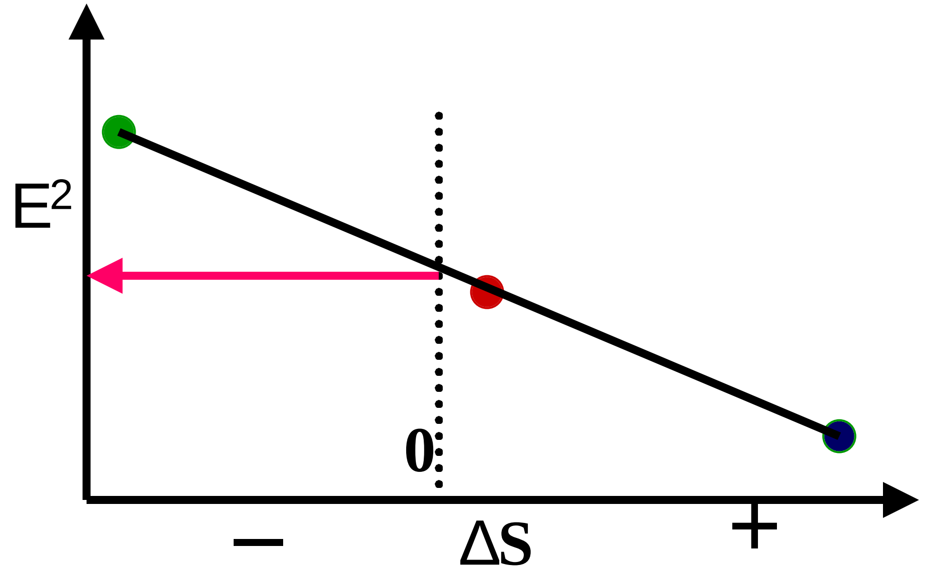
(1) Lock laser to inflection point of transmission curve (dip), measure S = T/N (E = 0)

(2) - Turn on Electric field ($E = E_0$)
- Shift AOM frequency by appropriate amount (Δf);
- Determine S' and ΔS = S' - S

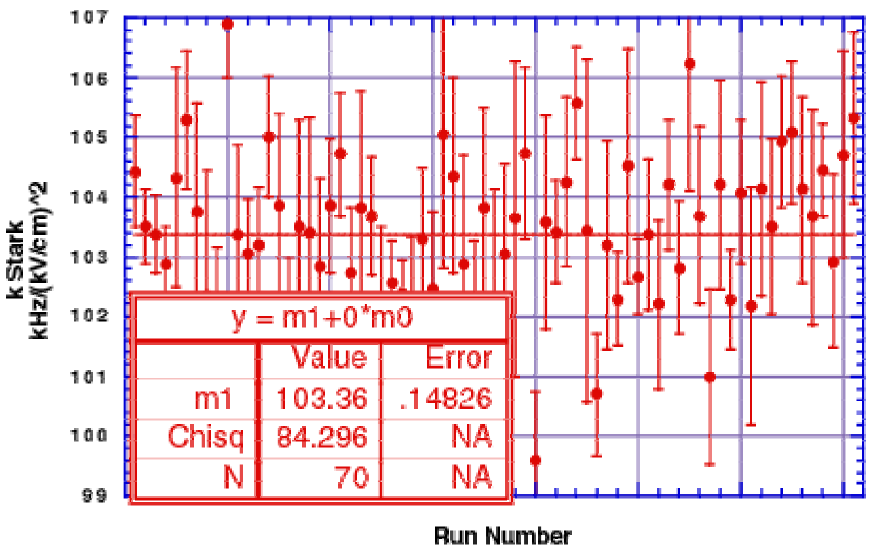
(3) Repeat sequence with altered Electric field values, <u>but same Δf</u>.

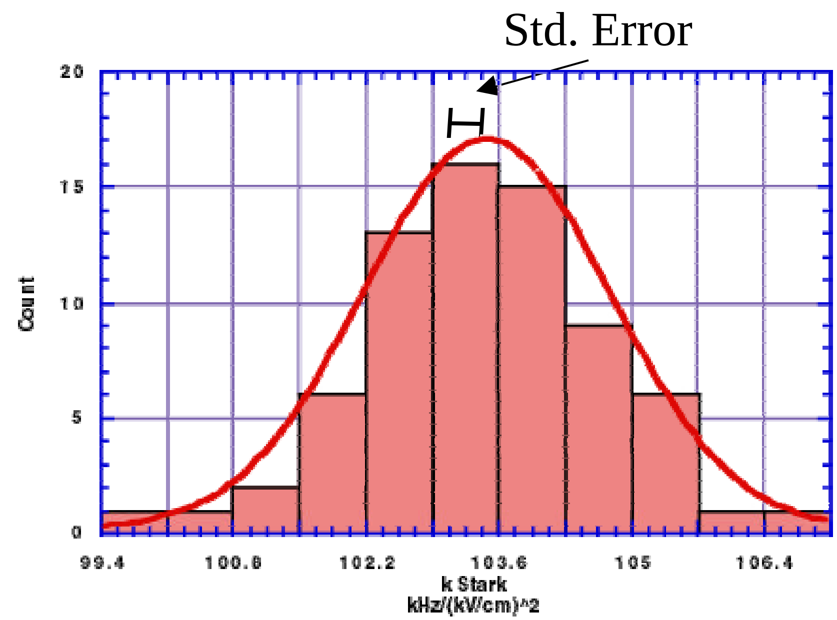
(4) Find y-intercept of linear fit -- value of E^2 which exactly matches Δf





Statistical Analysis





y = m1*Exp(-((m0-m3)/m2)^ 2)...		
	Value	Error
m1	16.315	0.58099
m2	1.6904	0.069543
m3	103.11	0.049158
Chisq	5.4446	NA
R	0.99225	NA

Final Statistical Error: 0.20 kHz/(kV/cm)^2 (0.19%)

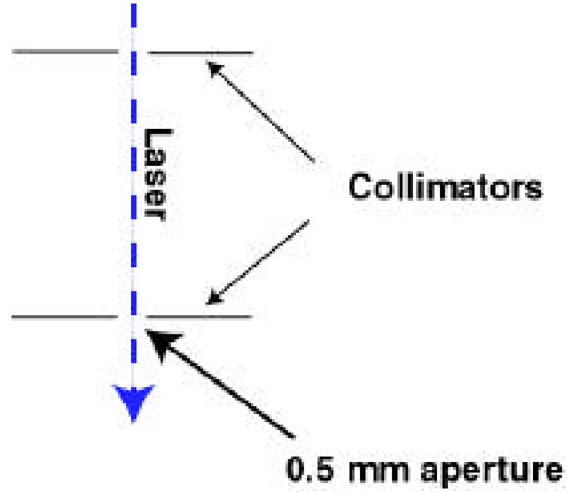
Systematic Error Analysis

Doppler Shifts:

$\delta f = f \quad v/c$

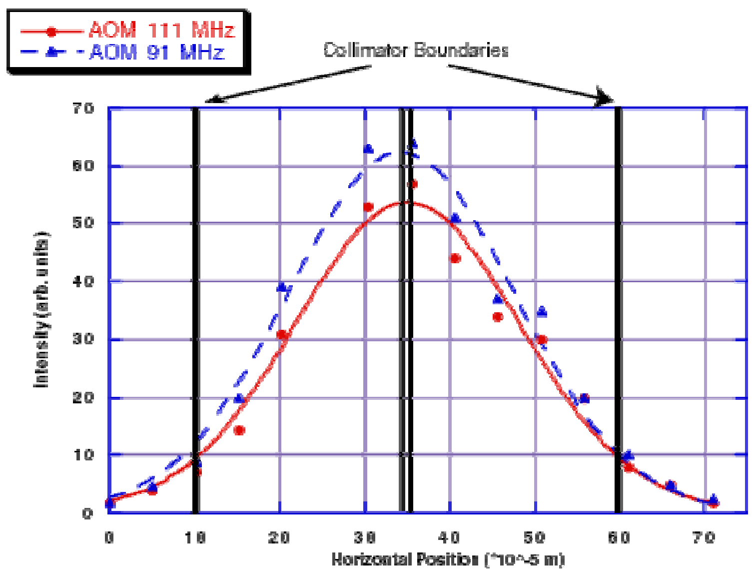
$= 4*10^{14}(300 \text{ m/s} / 3*10^{8} \text{ m/s}) * 10^{-3} \text{ rad}$

$= 0.4$ MHz (0.38%)



$\leq 4*10^{14}(300 \text{ m/s} / 3*10^{8} \text{ m/s}) * 10^{-4} \text{ rad}$

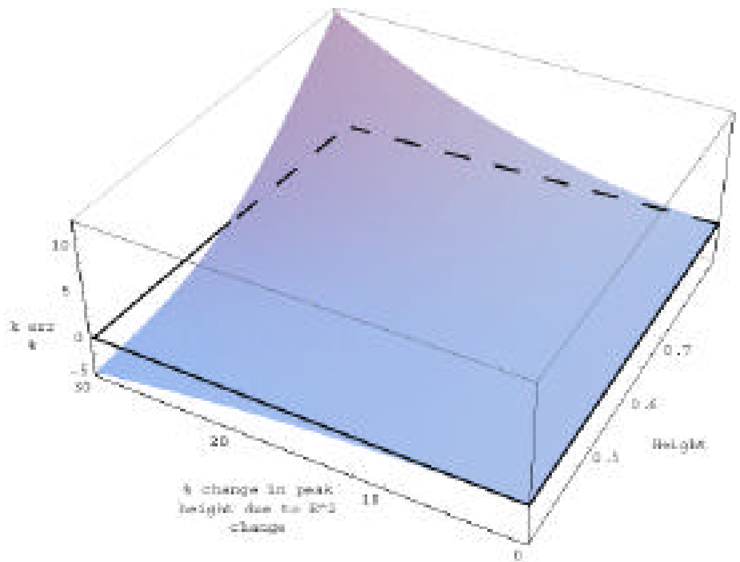
≤ 40 kHz (0.04 %)



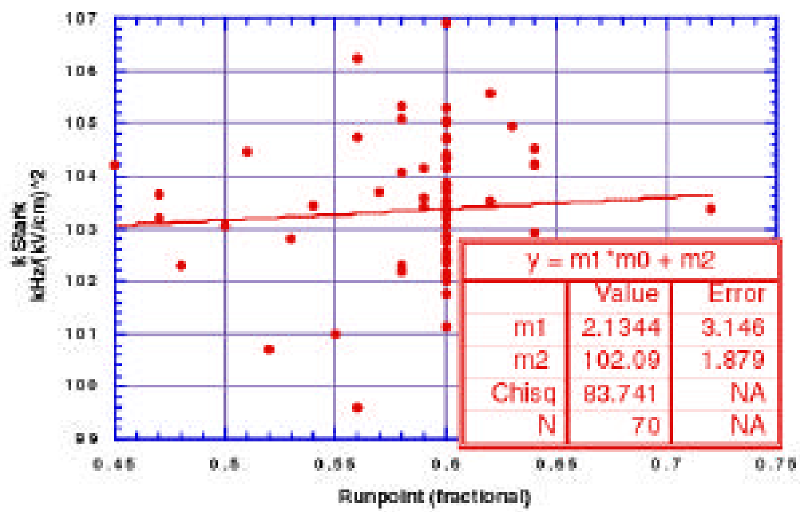
Correlation Plots

- Concerns about linear fit used to extract k_{Stark} with Transmission Change method

Simulation:

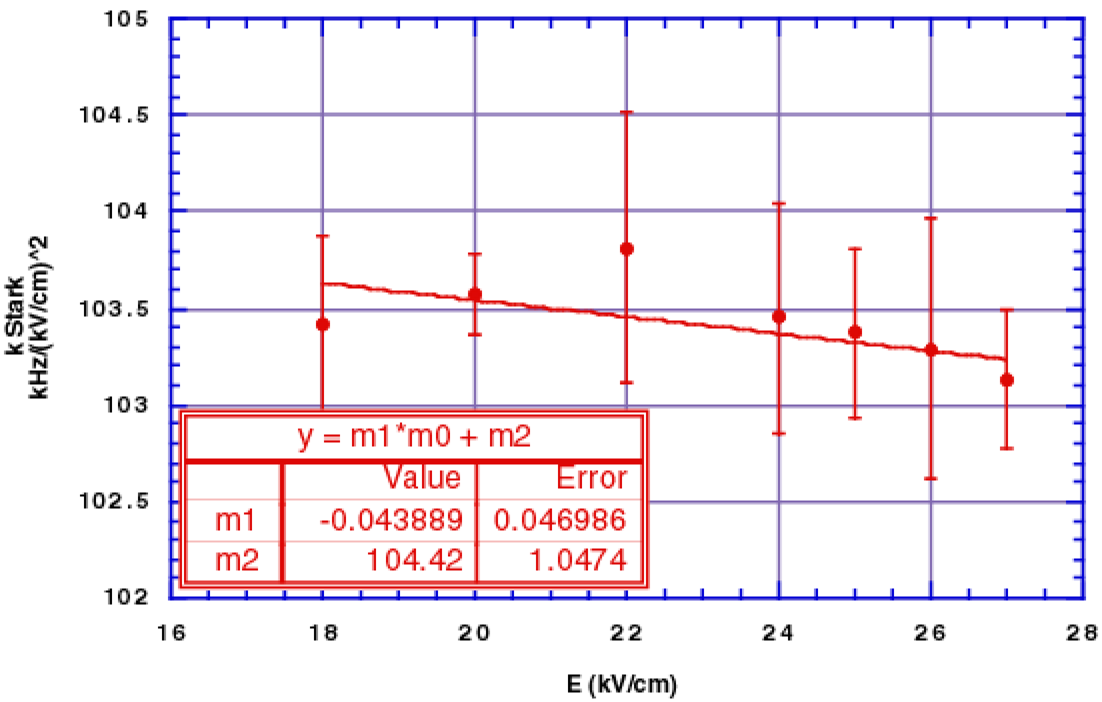


Measured:



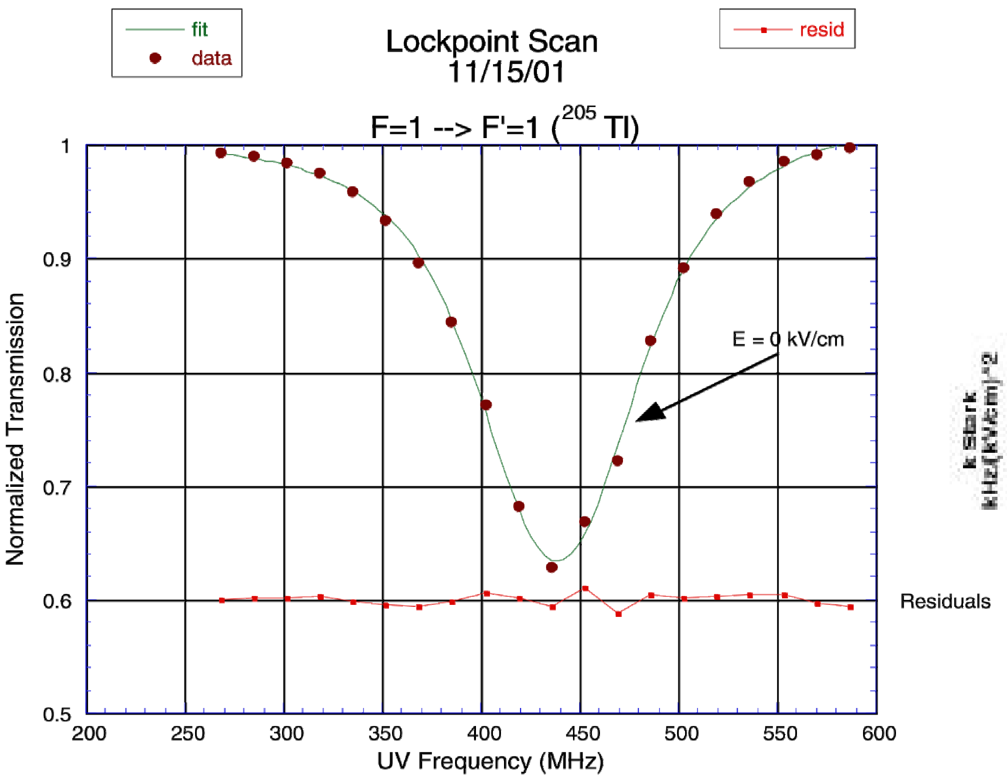
Symmetric data collection on both sides since opposite effect

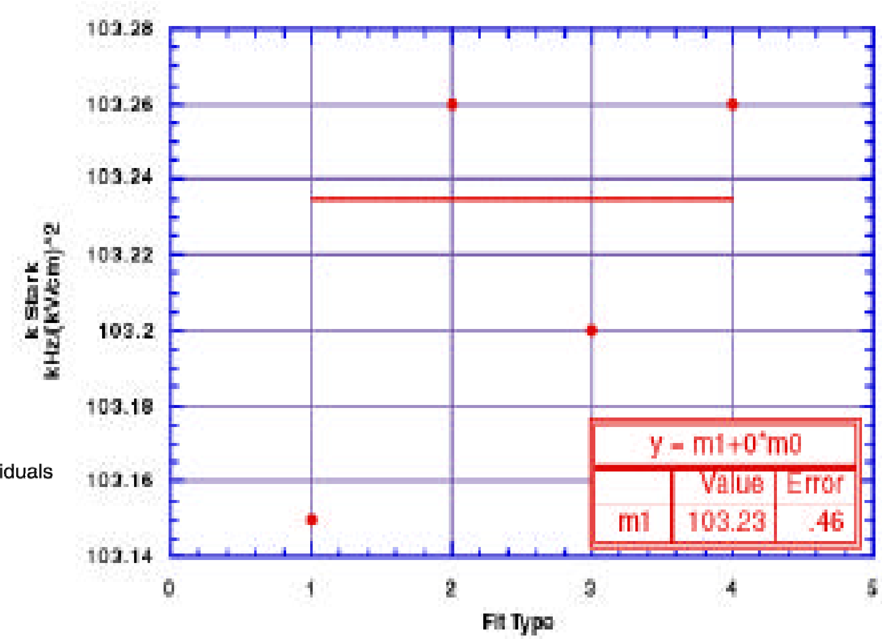
- Should be no relation between E and k_{Stark}, but we check anyhow . . .



ρ Scan Errors

Fitting Errors:





Conclusions

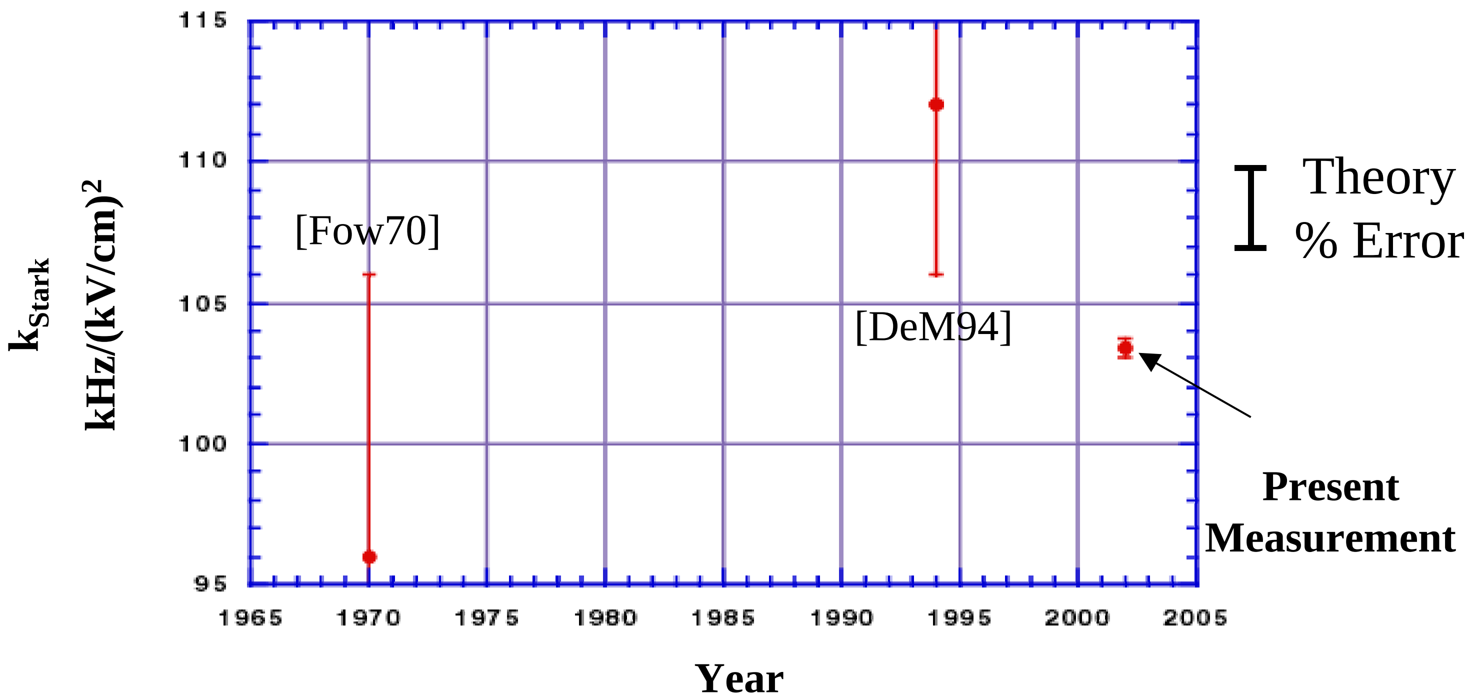
Final Values:

ρ Scan: 103.23(57) kHz/(kV/cm)^2

Transmission Change: 103.41(39) kHz/(kV/cm)^2

Combined Value: 103.34(37) kHz/(kV/cm)^2

-Modest amount of data required before submission for publication in June



Future

Stark Induced Amplitude at 1283 nm: