Microwave Transitions Between Pair States Composed of Two Rb Rydberg Atoms

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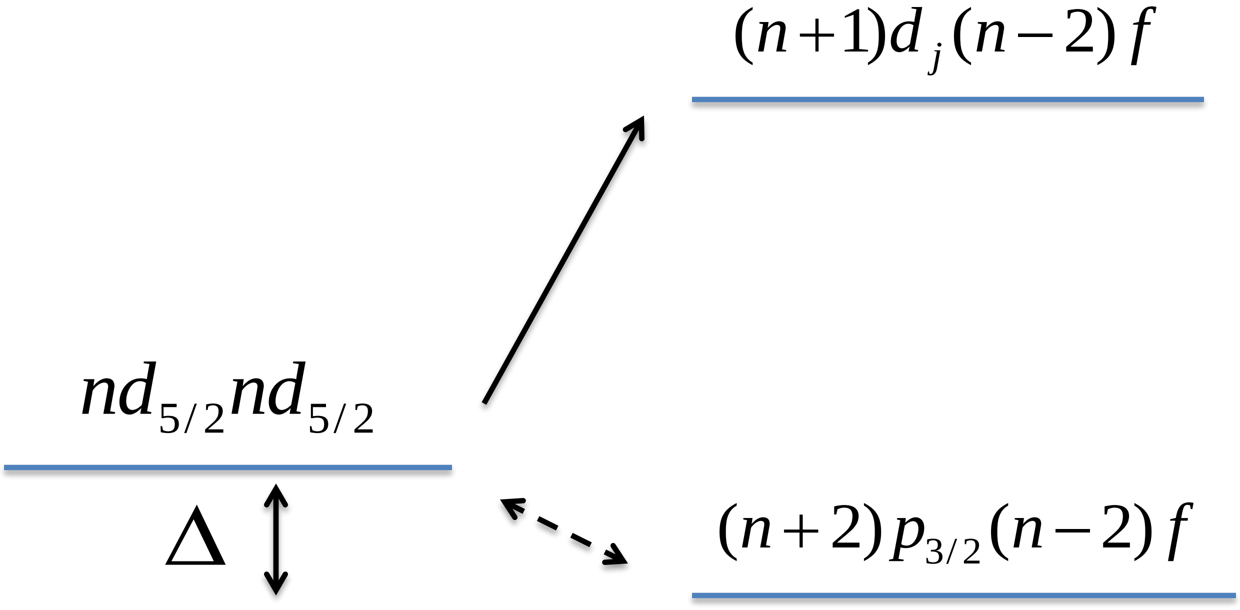
Overview

- Investigating a microwave transition

$$nd_{5/2}nd_{5/2} \rightarrow (n+1)d_j(n-2)f$$



Outline

- Rydberg Atoms
- Experiment (Theory)
- Experimental Setup
- Experiment
- Results

Rydberg Atoms

Rydberg Atoms

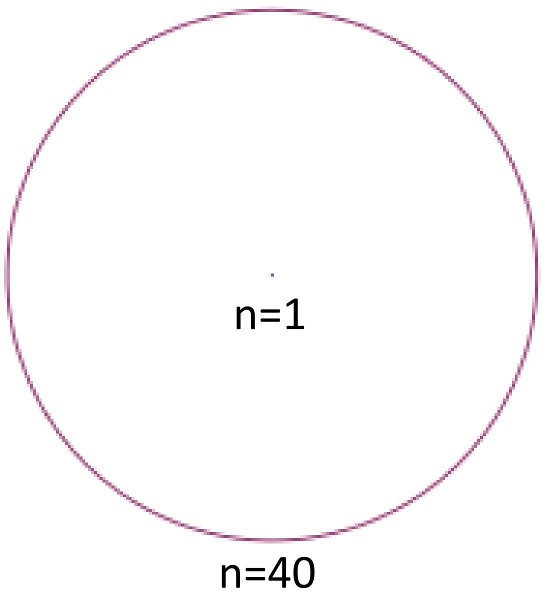
- A Rydberg atom is a highly excited atom

- They have exaggerated characteristics such as:
  - large size
  - low binding energy
  - large dipole moment
  - and so on

  which make them an interesting object to study

Properties of Rydberg Atoms

Bohr model of H atom



$$\text{Binding Energy} \propto n^{-2}$$

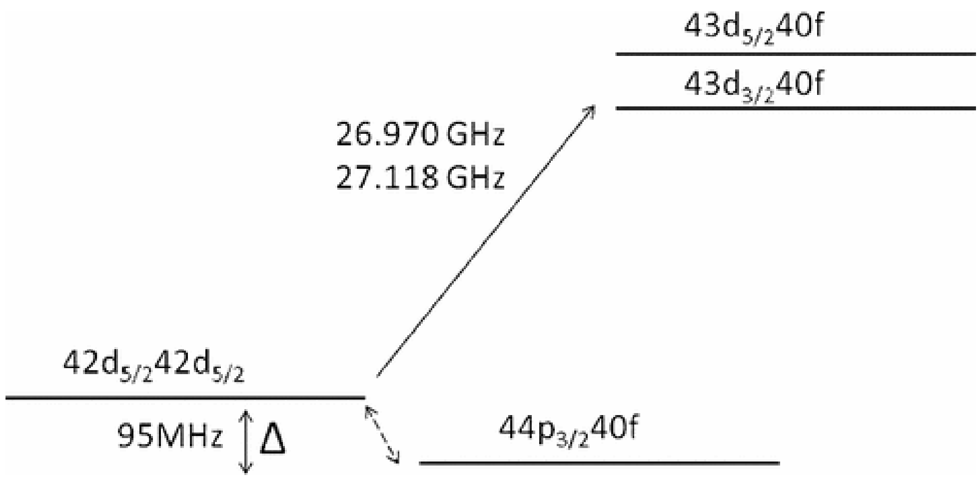
$$\text{Radius} \propto n^{2}$$

$$\text{Dipole Moment} \propto n^{2}$$

The experiment (Theory)

Background

- $nd_{5/2}nd_{5/2} \rightarrow (n+1)d_j(n-2)f$ was recently observed



- The transition is allowed because dipole-dipole induced configuration interaction between $nd_{5/2}nd_{5/2}$ and $(n+2)p_{3/2}(n-2)f$ states admixes some of the latter state into the former

- With configuration interaction, $nd_{5/2}nd_{5/2}$ state for R<∞ can be written as

$$\left|nd_{5/2}nd_{5/2R}\right\rangle = \left|nd_{5/2}nd_{5/2}\right\rangle + \varepsilon\left|(n+2)p_{3/2}(n-2)f\right\rangle$$

where

$$\varepsilon = \frac{\left\langle nd_{5/2}nd_{5/2}\right|\frac{\mu_1\mu_2}{R^3}\left|(n+2)p_{3/2}(n-2)f\right\rangle}{\Delta}$$

$$\Delta = W_{nd_{5/2}nd_{5/2}} - W_{(n+2)p_{3/2}(n-2)f}$$

- The coupling between $nd_{5/2}nd_{5/2}$ and $(n+1)d_j(n-2)f$ states in lowest order is:

$$V = \varepsilon\left\langle (n+2)p_{3/2}(n-2)f \left| \mu_1 E \right| (n+1)d_j(n-2)f \right\rangle$$

- Since $\frac{1}{R^3} \propto \rho_{Ryd}$ and the dipole matrix elements are proportional to n^2,

$$V \approx \frac{\rho E n^6}{\Delta}$$

- Our primary experimental interest is to verify the expression: $$V \approx \frac{\rho E n^6}{\Delta}$$

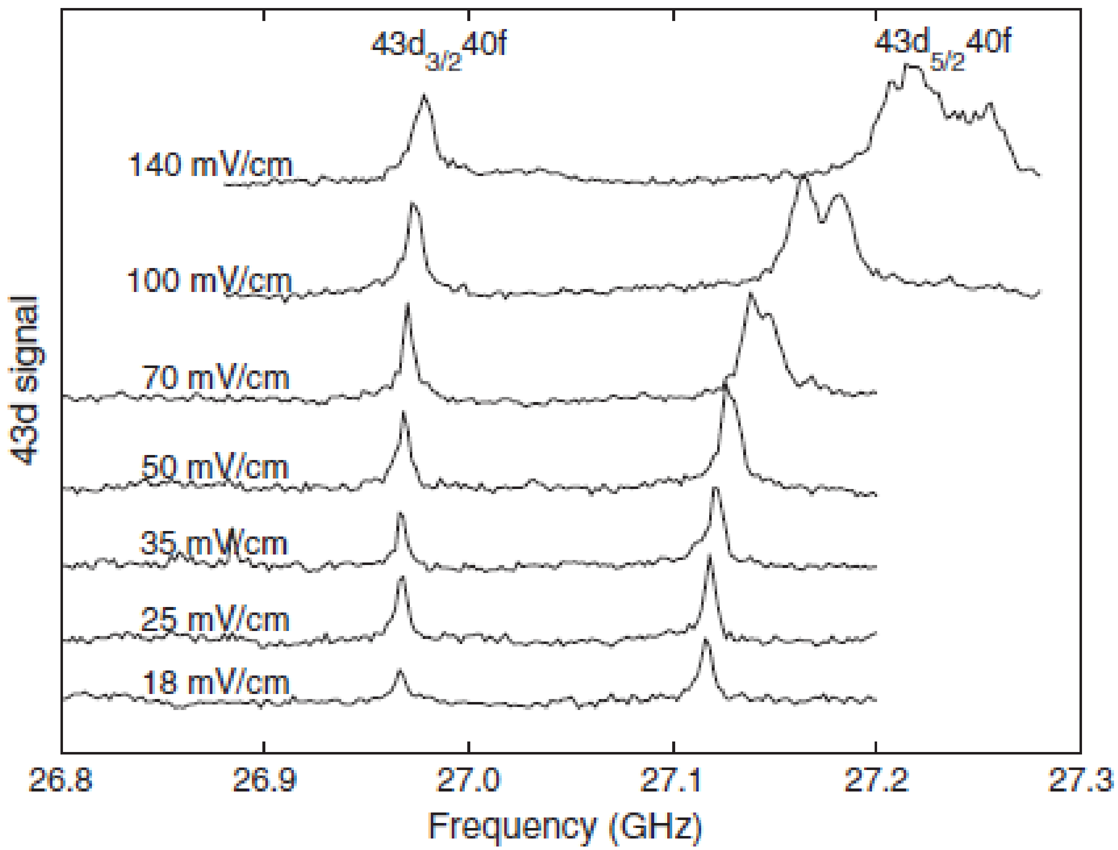
- As n is changed from 42 to 35

$$\left(\frac{n^6}{\Delta}\right)_{n=42} \Big/ \left(\frac{n^6}{\Delta}\right)_{n=35} \approx 47$$

- Is it possible to compensate this by adjusting the microwave field strength?

Previous Result

$$42d_{5/2}42d_{5/2} \rightarrow 43d_j 40f_{7/2}$$



Yinan Yu, Hyunwook Park, and T. F. Gallagher
Phys. Rev. Lett. **111**, 173001 (2013)

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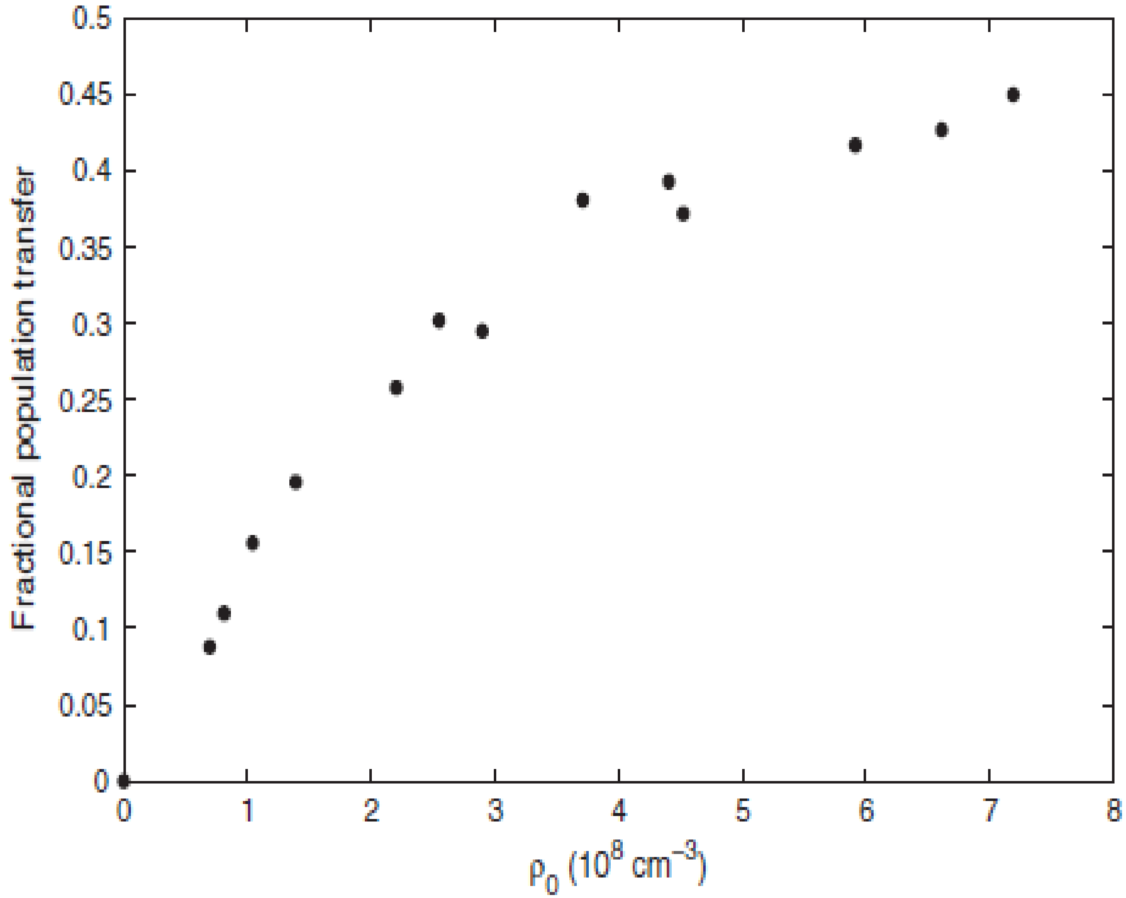

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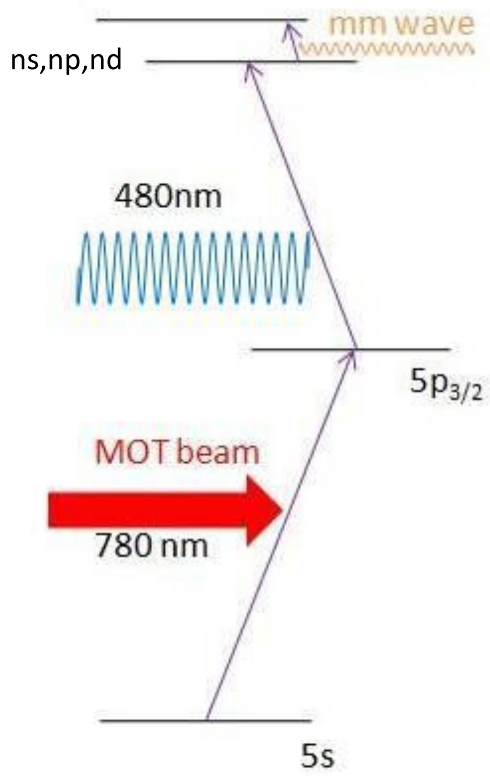
Experimental Setup

Experiment Overview



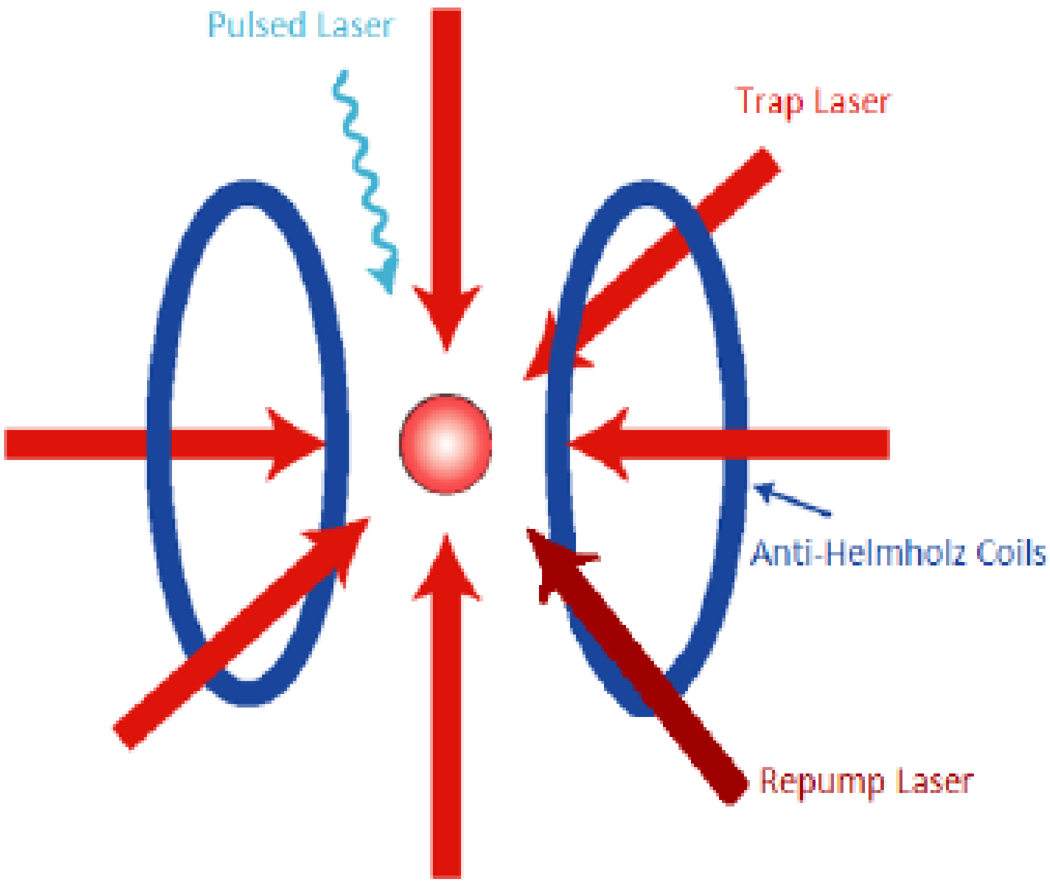
Energy level diagram

- We use magneto-optical trap and optical excitation to make a cold sample of Rb Rydberg atoms
- We use microwave to excite Rydberg atoms to different states
- We use Field ionization ionize the Rydberg atoms and MCP detector collect data

Experimental Setup

- Magneto-Optical Trap (MOT)
- Optical Excitation Laser
- Microwave Setup & Field Ionization
- Data Acquisition

MOT Basics



MOT uses

laser cooling with

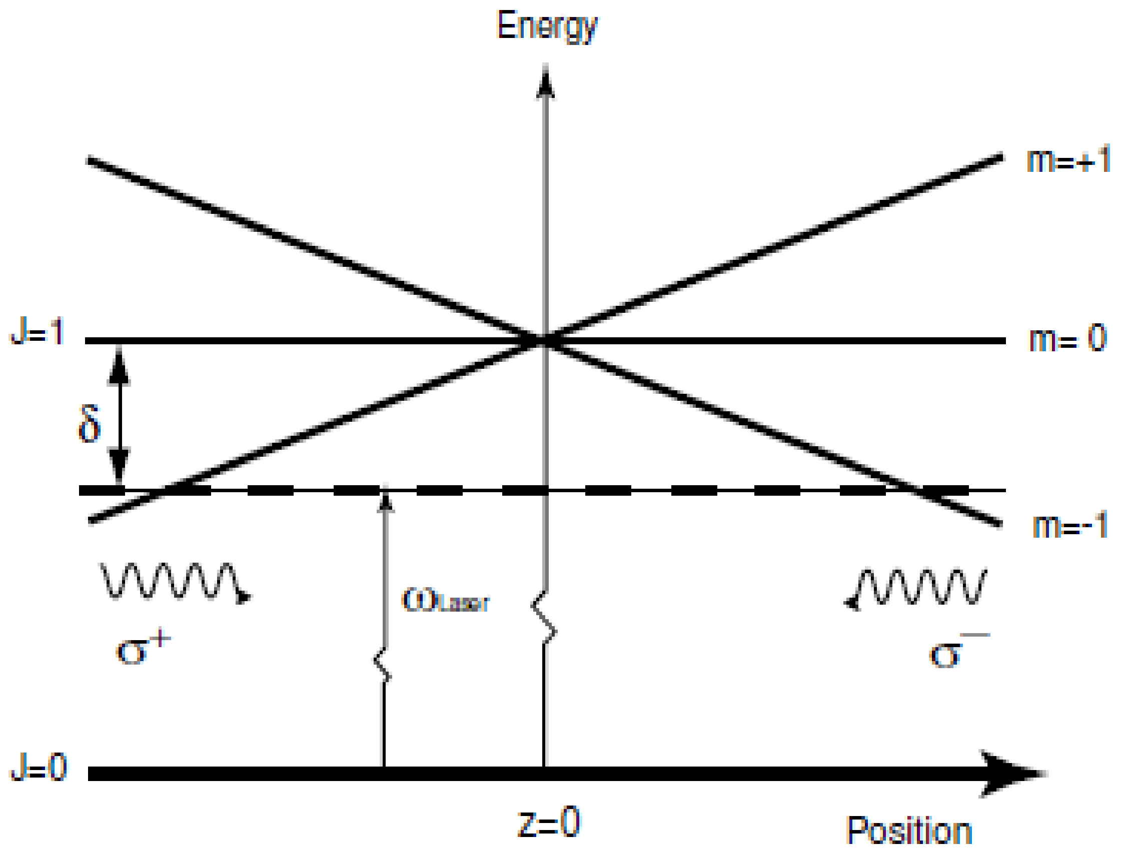
magneto-optical trapping

to produce

Samples of cold, trapped, neutral atoms

Lauren Levac, Observation of the Dipole-Dipole Interaction in Dressed State Rydberg Atoms by Microwave Spectroscopy, MS thesis, Univesity of Virginia, 2013

Magneto Optical Trapping



Wenhui Li. Probing Dipole-Dipole Interactions in a Frozen Rydberg Gas with Millimeter Waves. PhD thesis, University of Virginia, 2005.

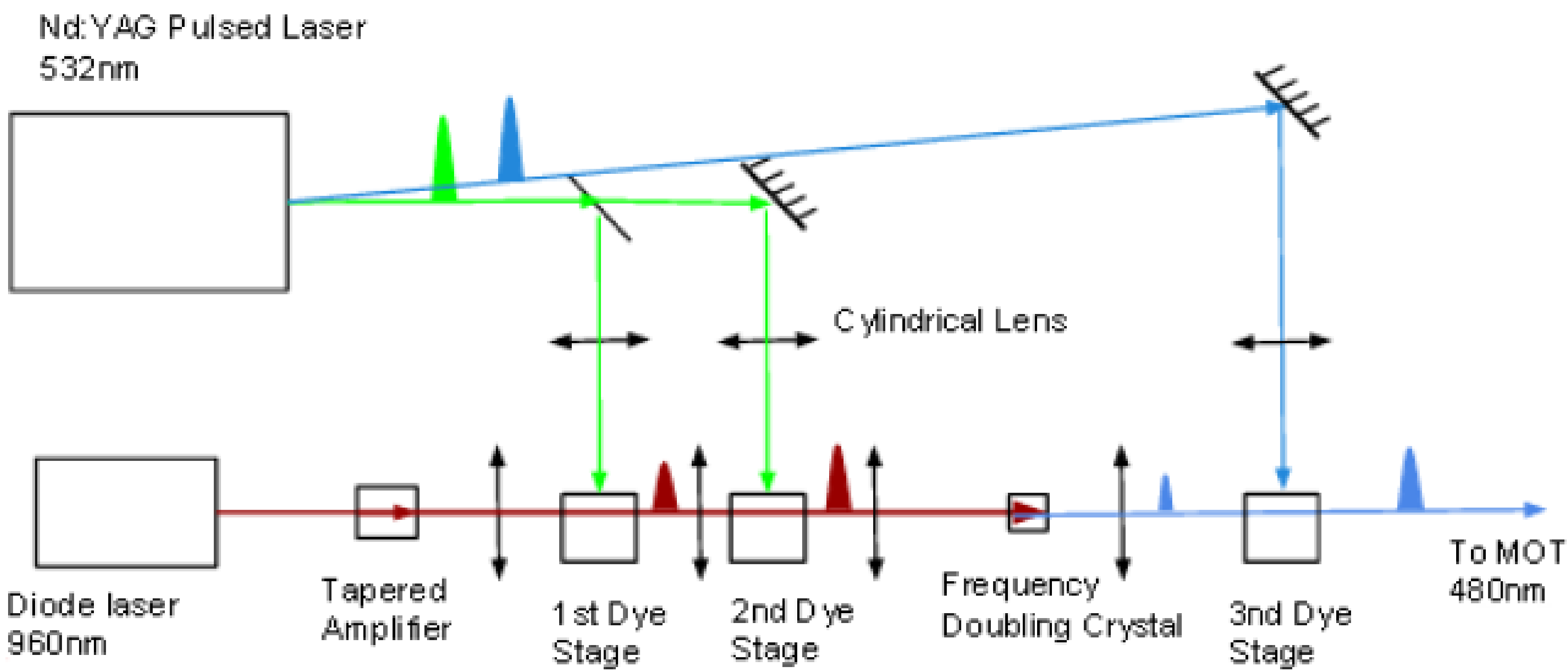
Typical Parameters for Our MOT

- # of trapped atoms: 10^5 ~ 10^6
- Diameter: ~1mm
- Density: $10^9/cm^3$

- # of Rydberg atoms: 10^4
- Density of Rydberg atoms (max): $10^8/cm^3$

Optical Excitation Laser

Excites Rb atoms to Rydberg state



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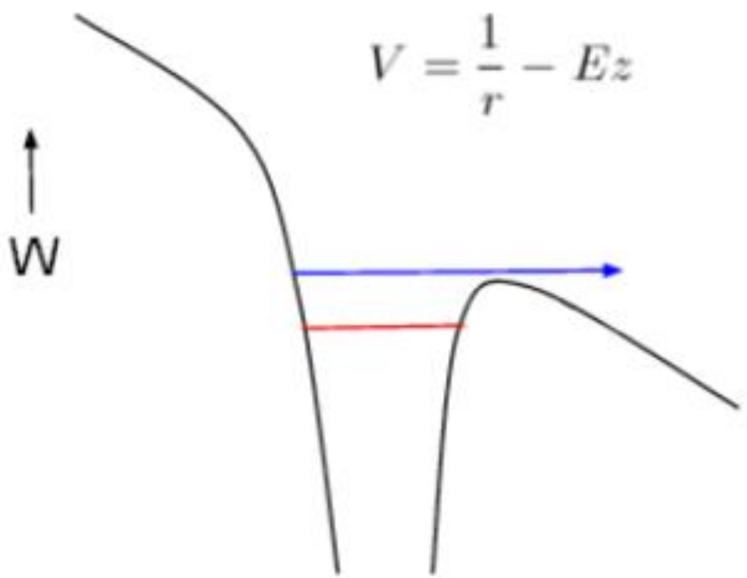
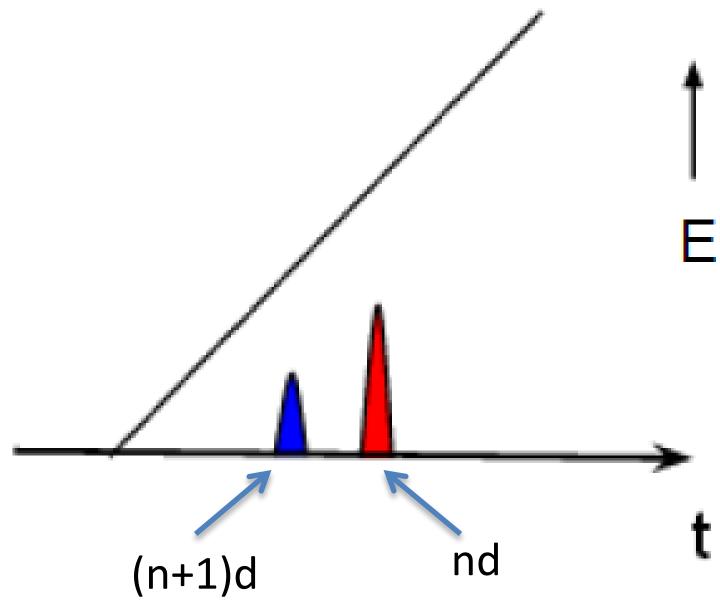
Field Ionization

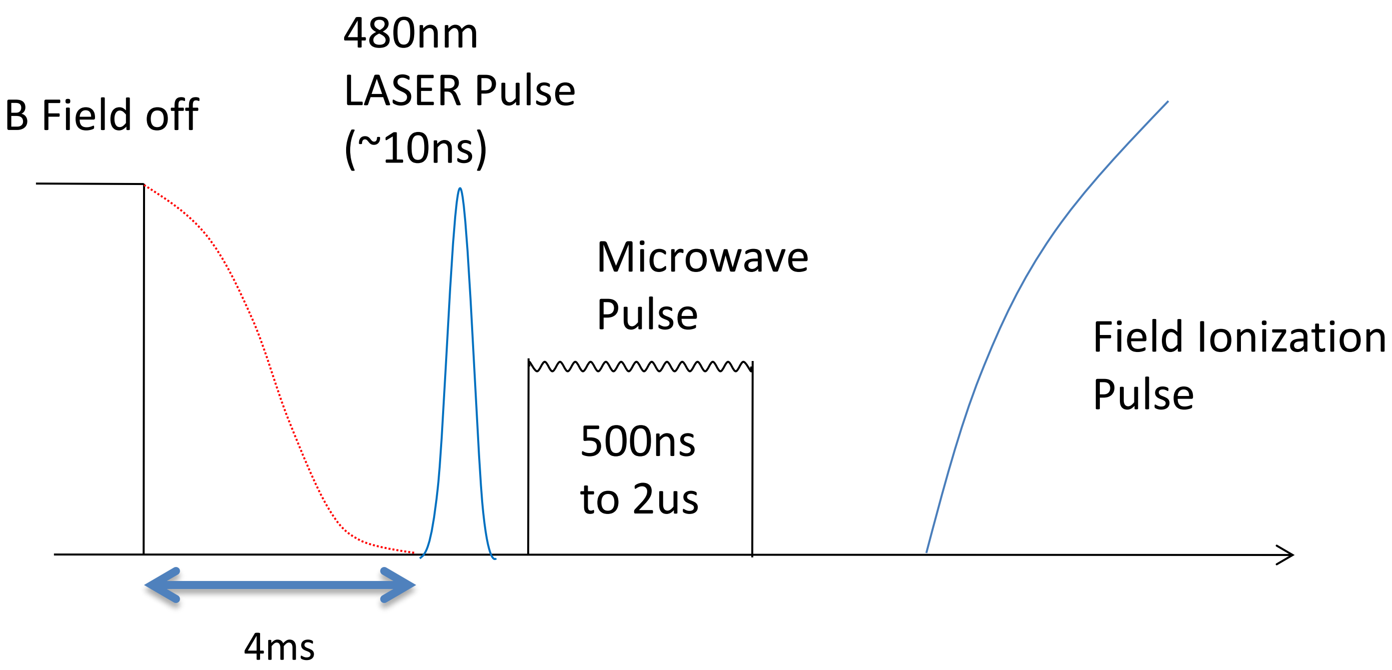


(a) An electric field applied to the atoms tips the potential well such that loosely bound electrons are able to escape.



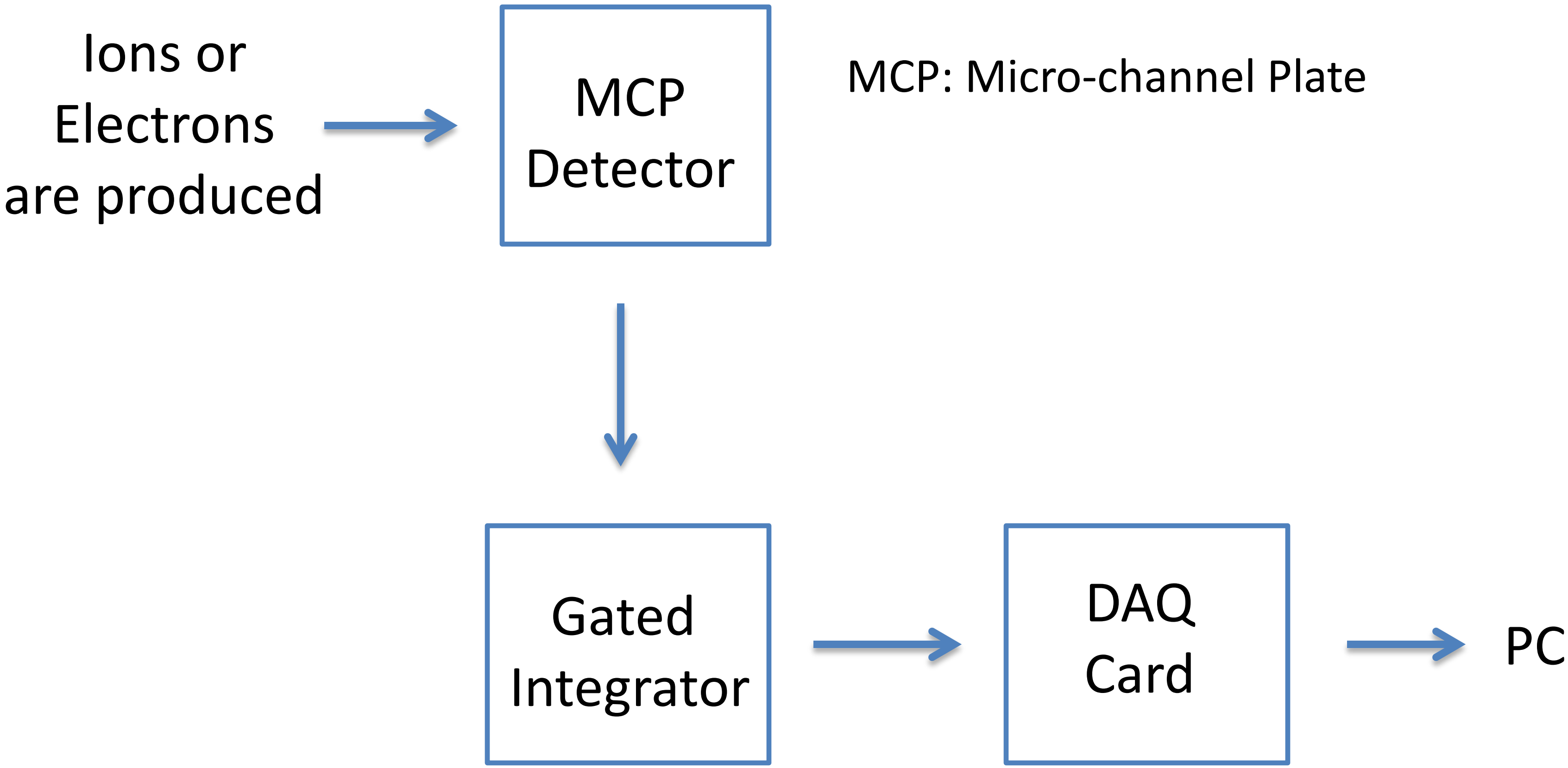
(b) Timing diagram for Field Ionization pulse.

Timing diagram



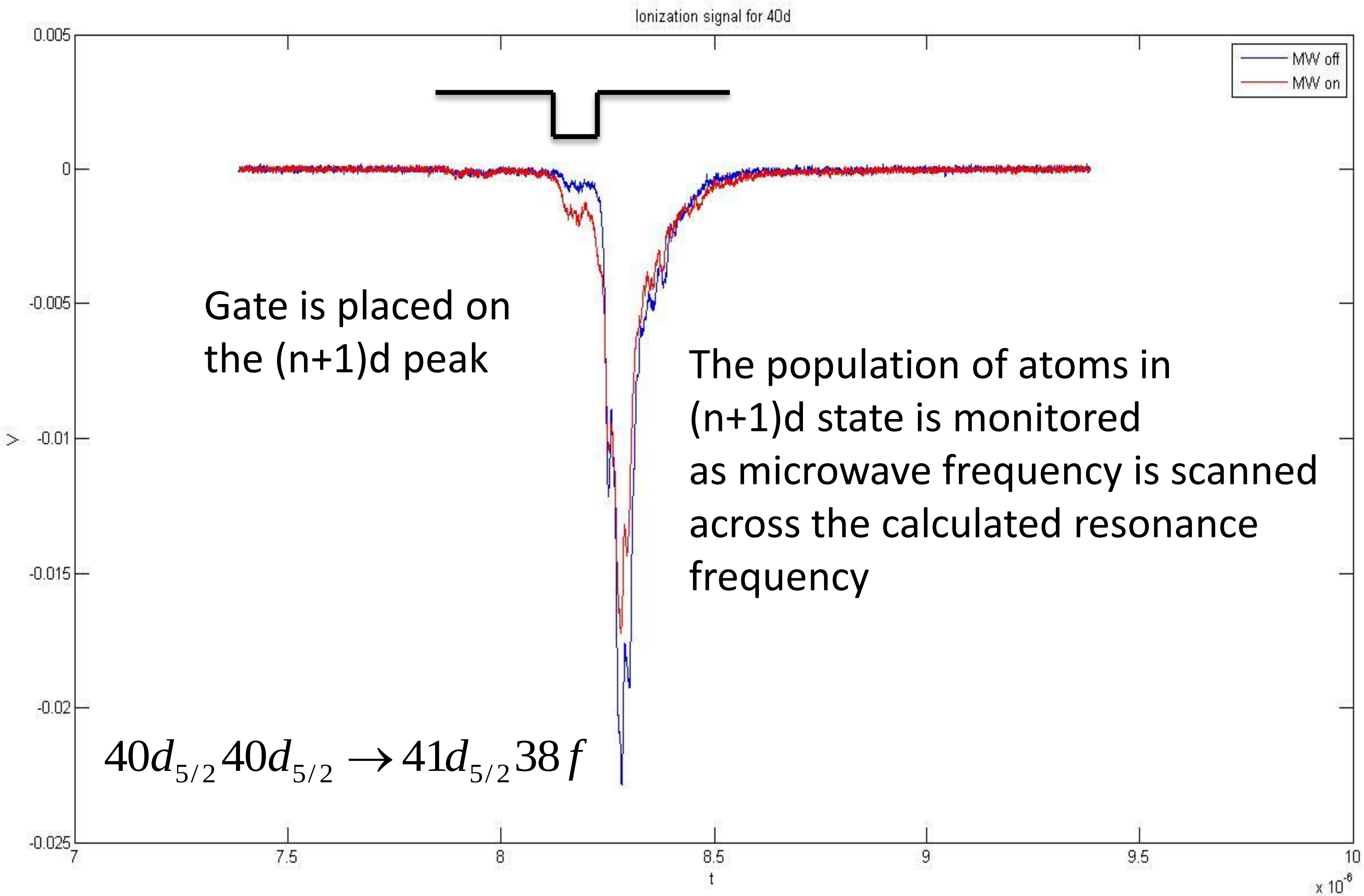
The Experiment
(experimental technique)

Data Acquisition



MCP: Micro-channel Plate

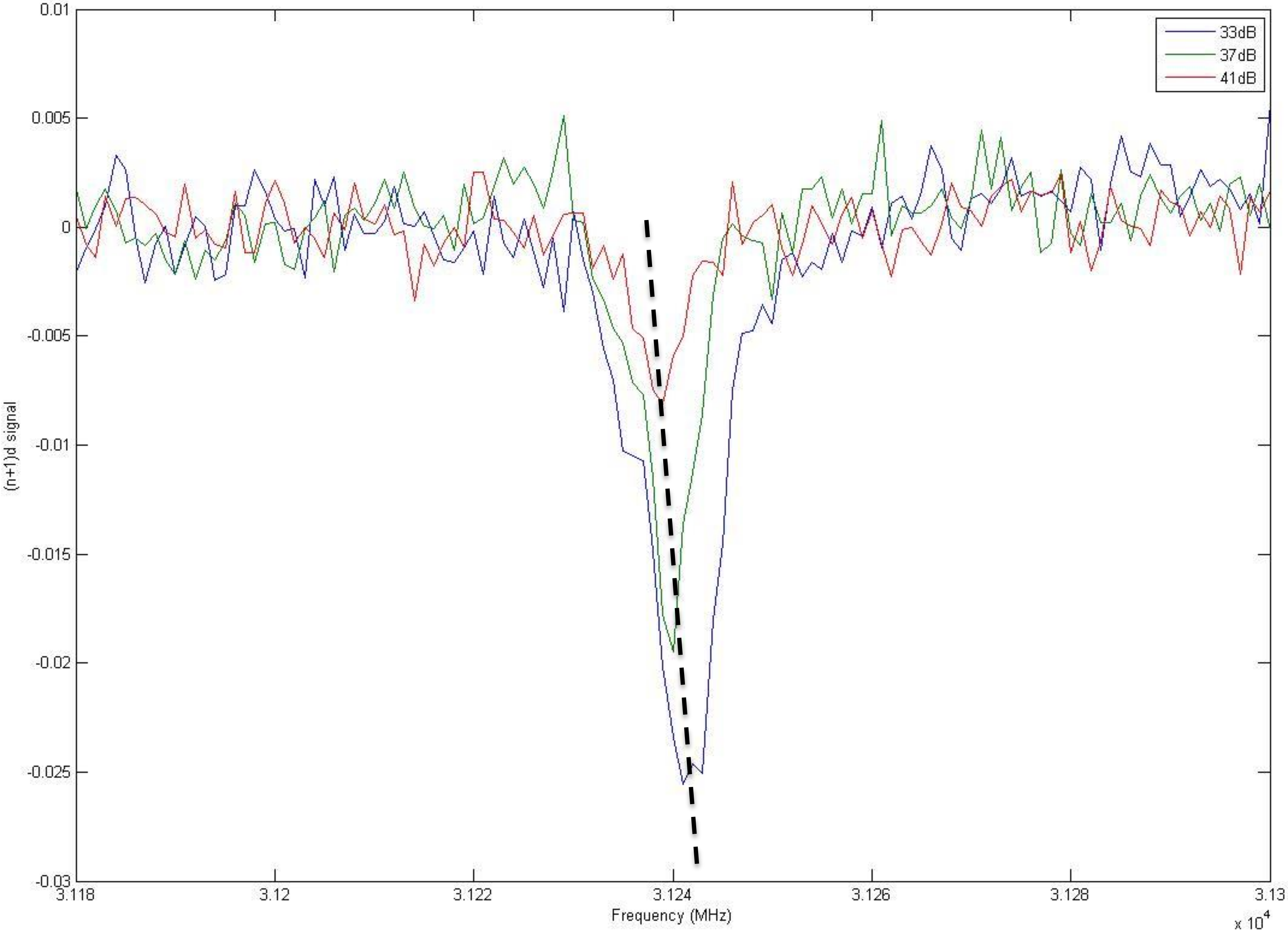
Measuring resonance frequency & Measuring power shift



Gate is placed on the (n+1)d peak

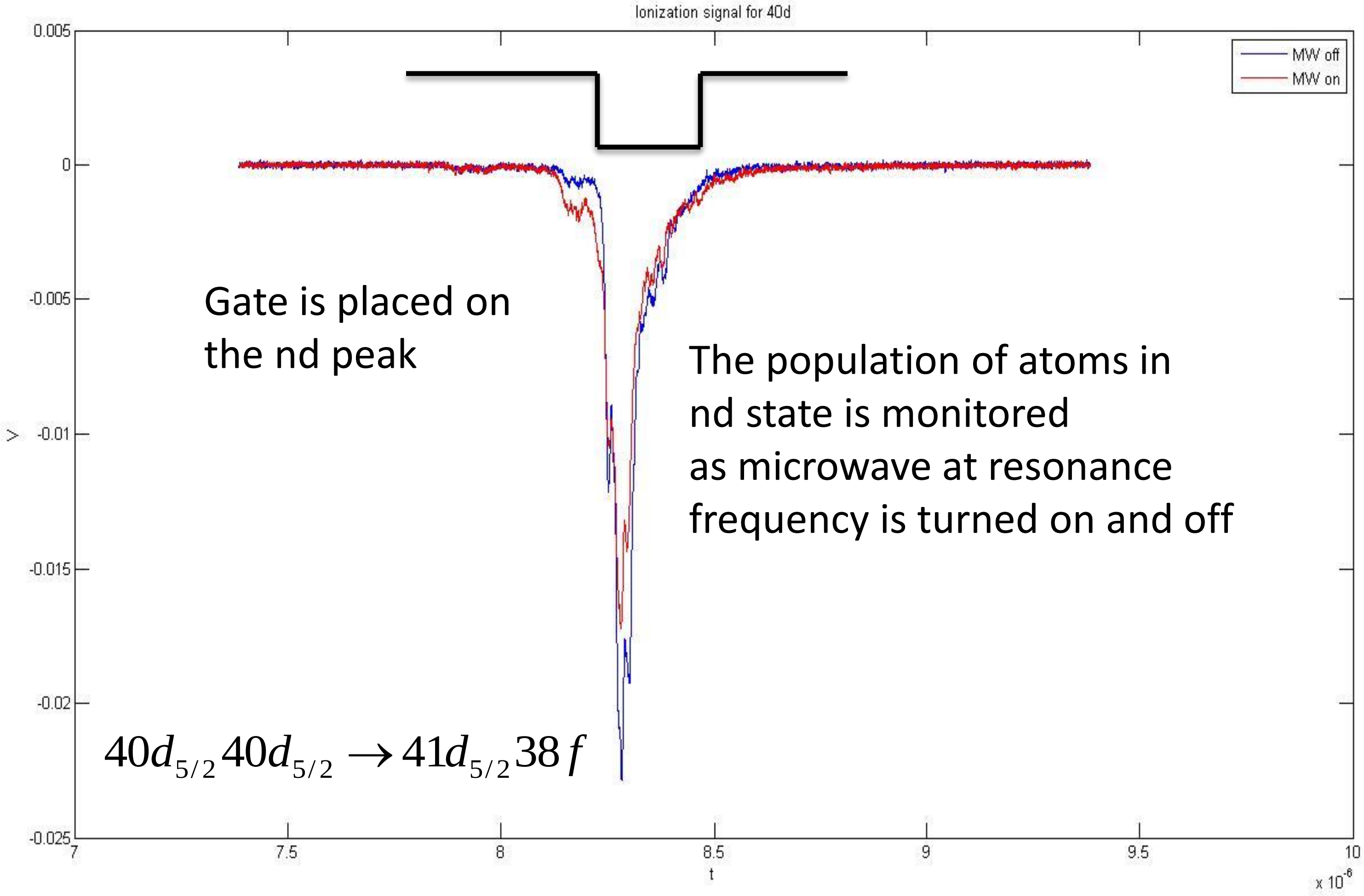
The population of atoms in (n+1)d state is monitored as microwave frequency is scanned across the calculated resonance frequency

$$40d_{5/2}40d_{5/2} \rightarrow 41d_{5/2}38f$$



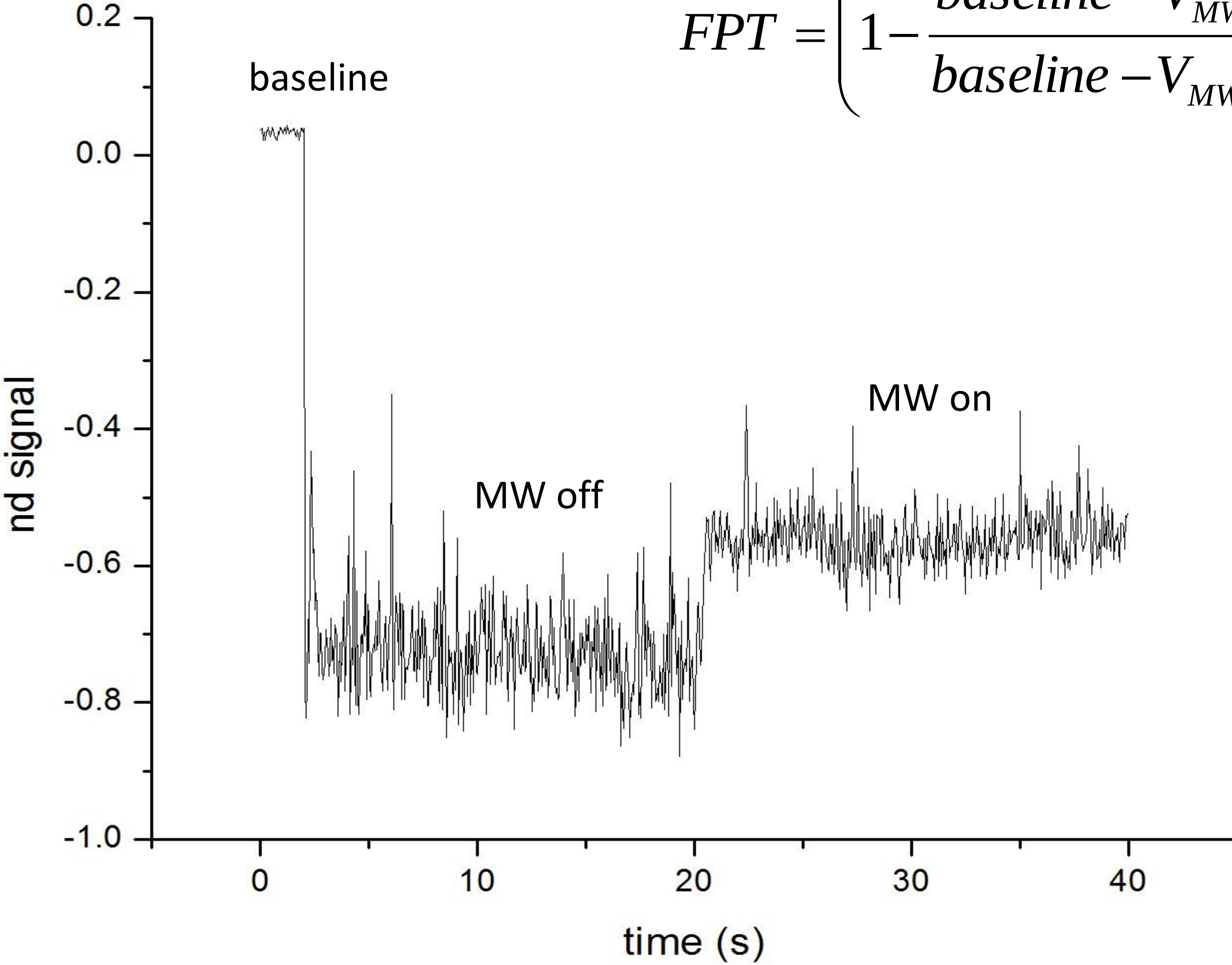
$$40d_{5/2}40d_{5/2} \rightarrow 41d_{5/2}38f$$

Measuring Fractional Population Transfer (FPT)



$$40d_{5/2}40d_{5/2} \rightarrow 41d_{5/2}38f$$

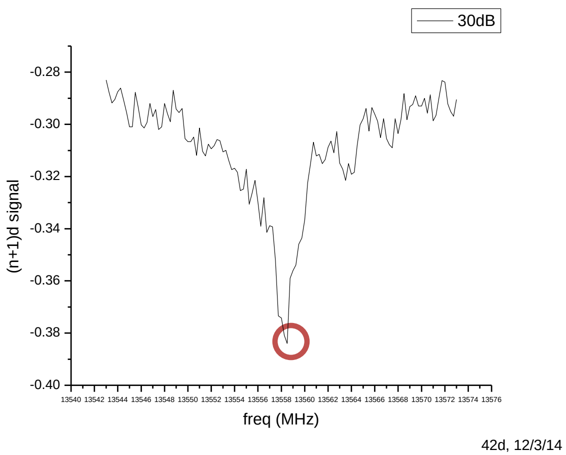
$$FPT = \left(1 - \frac{baseline - V_{MW\_on}}{baseline - V_{MW\_off}}\right) \times 100$$

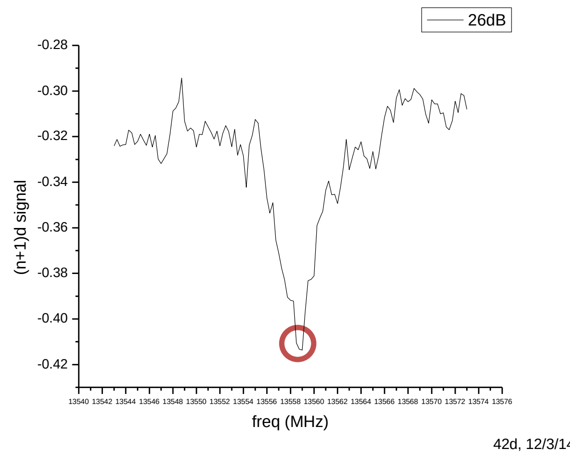


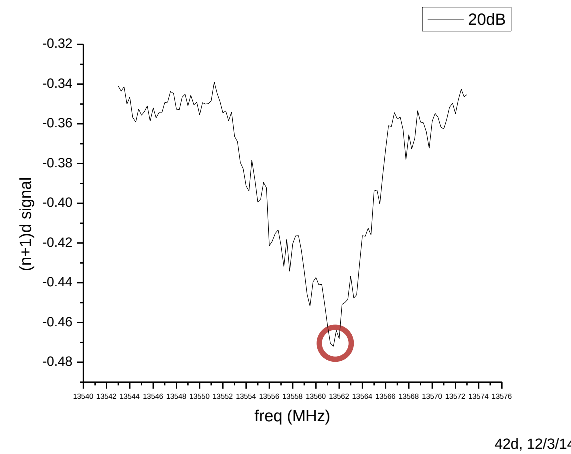
37d, 6dB, 9/25/14

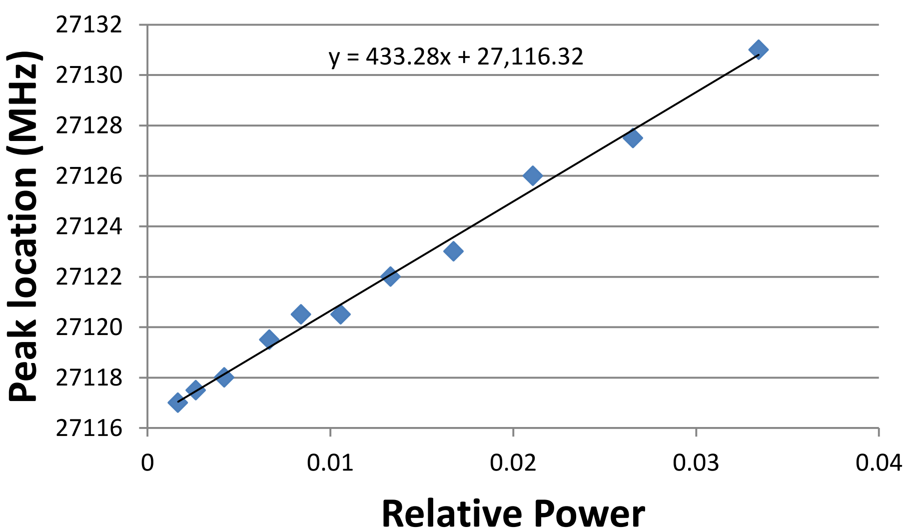
Results

Resonance frequency &
Power shift of the resonance frequency









$$42d_{5/2}42d_{5/2} \rightarrow 43d_{5/2}40f_{7/2}$$

Extrapolating the points back to zero microwave power allows us to determine resonance frequency of the transition

Transition frequency for

$$nd_{5/2}nd_{5/2} \rightarrow (n+1)d_{5/2}(n-2)f$$

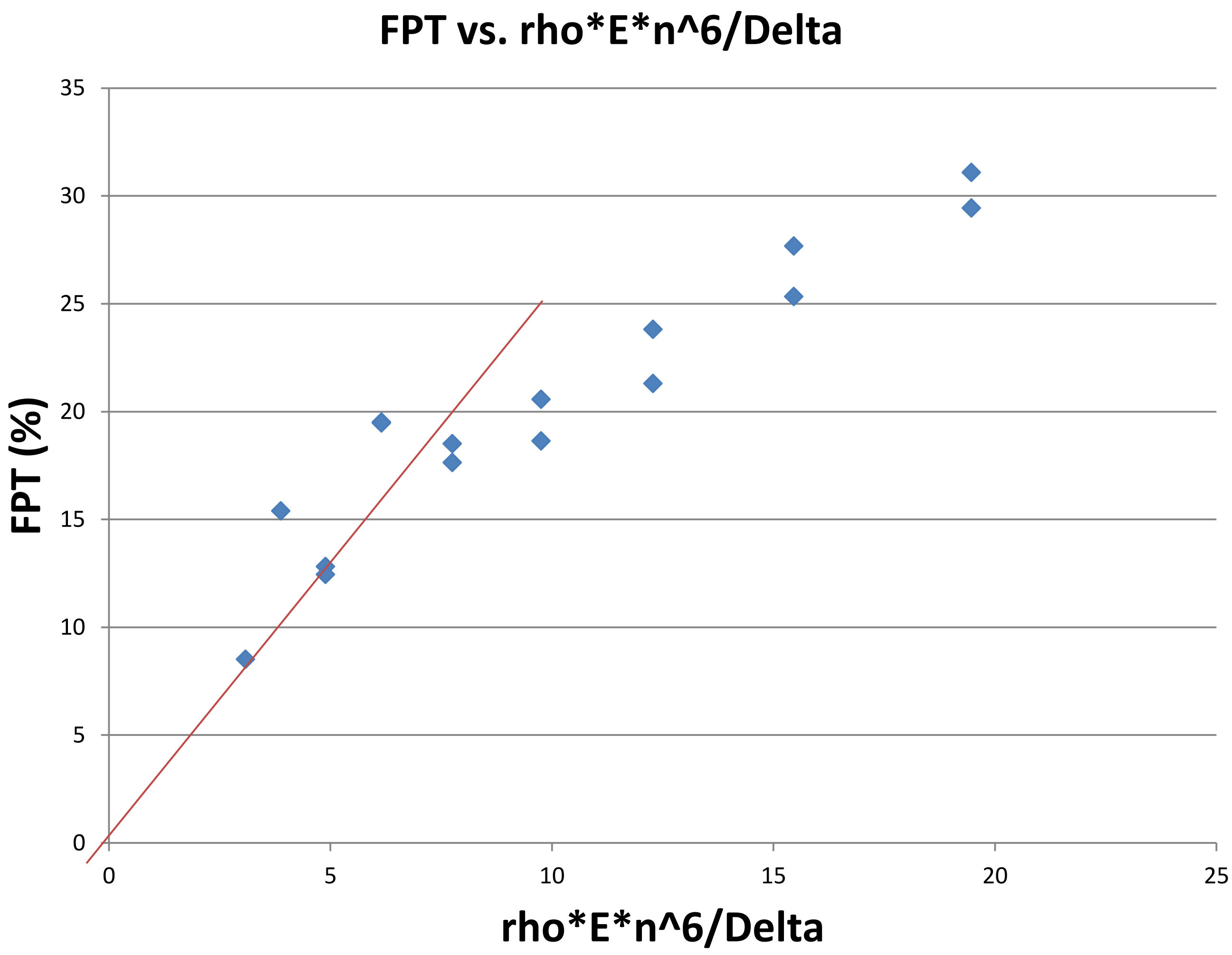
n	Calculated (GHz)	Meausred (GHz)	Percent Error (%)
34	49.898	49.898	<0.01
35	45.916	45.915	<0.01
36	42.344	42.341	<0.01
37	39.131	39.129	<0.01
38	36.233	36.231	<0.01
39	33.613	33.612	<0.01
40	31.239	31.236	<0.01
41	29.082	29.079	<0.01
42	27.118	27.113	0.017

Transition frequency for

$$nd_{5/2}nd_{5/2} \rightarrow (n+1)d_{3/2}(n-2)f$$

n	Calculated (GHz)	Meausred (GHz)	Percent Error (%)
34	49.618	49.617	<0.01
35	45.660	45.660	<0.01
36	42.109	42.106	<0.01
37	38.914	38.912	<0.01
38	36.033	36.031	<0.01
39	33.429	33.428	<0.01
40	31.068	31.066	<0.01
41	28.923	28.921	<0.01
42	26.970	26.968	<0.01

FPT data



42d data from 1/13/15

Normalizing MW power using Stark Shift

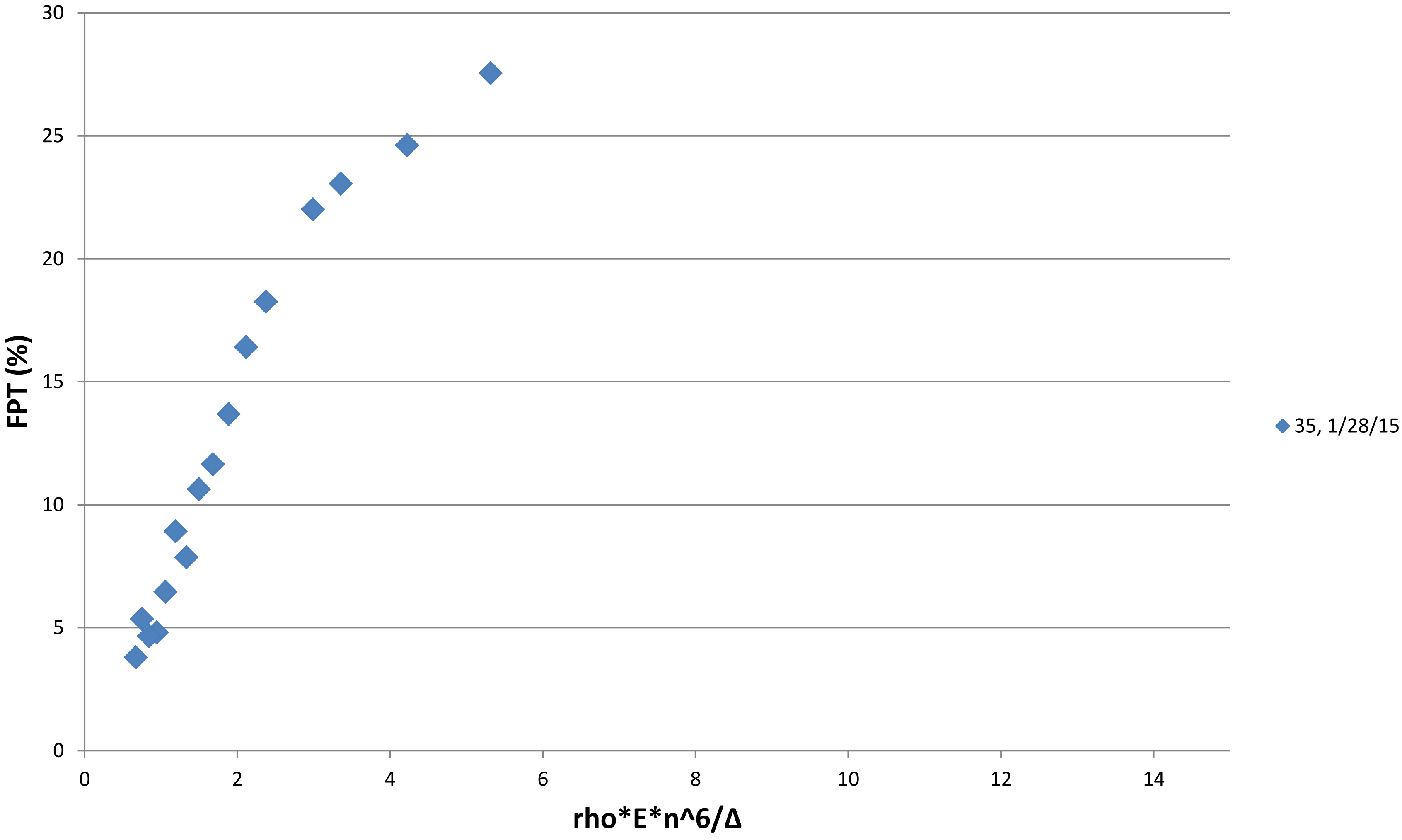
- MW power output changes

→ Need to normalize MW power

- Use the fact that the Stark shift

$$\Delta\omega \propto \frac{\left|\langle\varphi|\mu|\psi\rangle E\right|^2}{\Delta} \approx \frac{n^4 E^2}{\Delta}$$

FPT vs. rho*E*n^6/Δ



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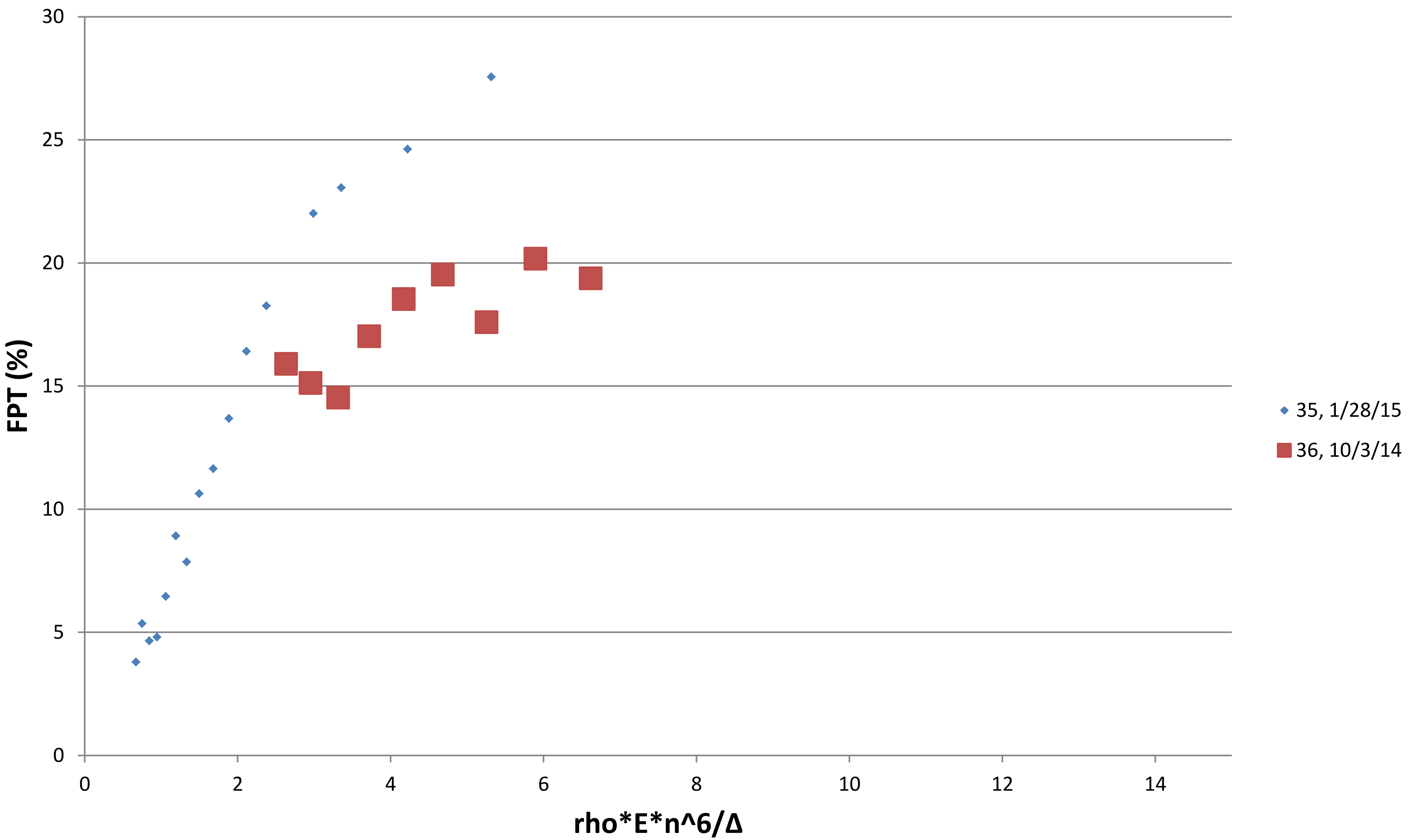

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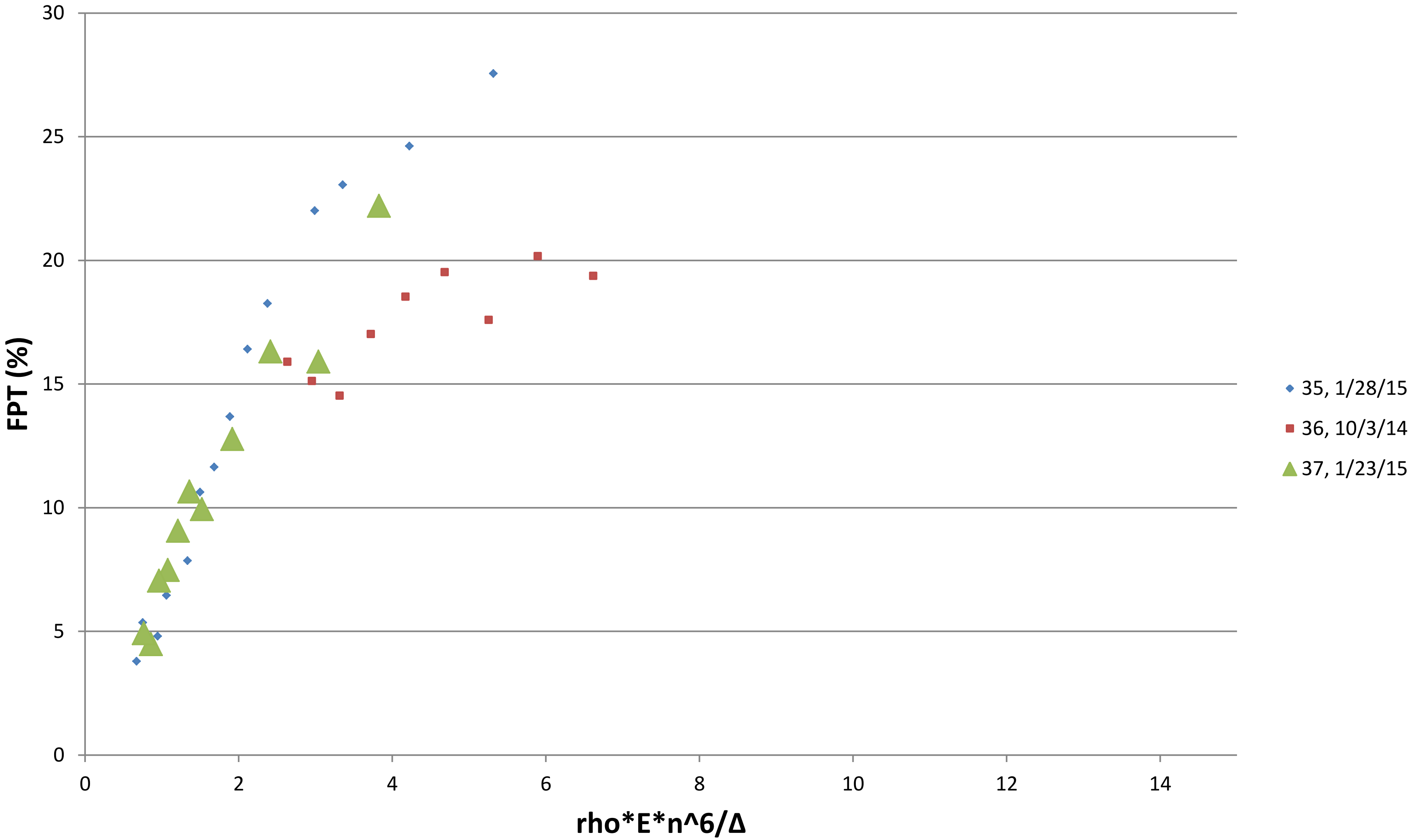

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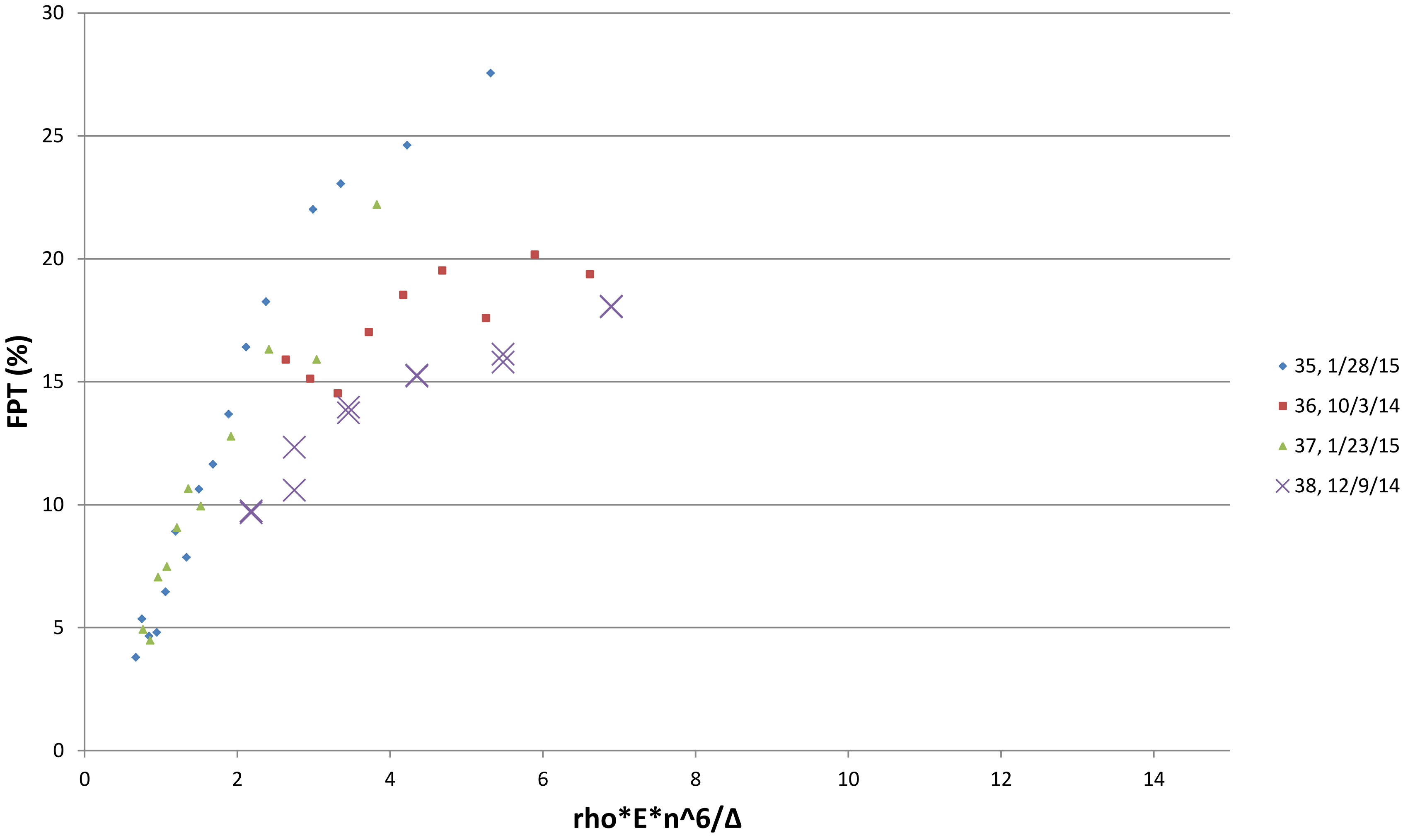

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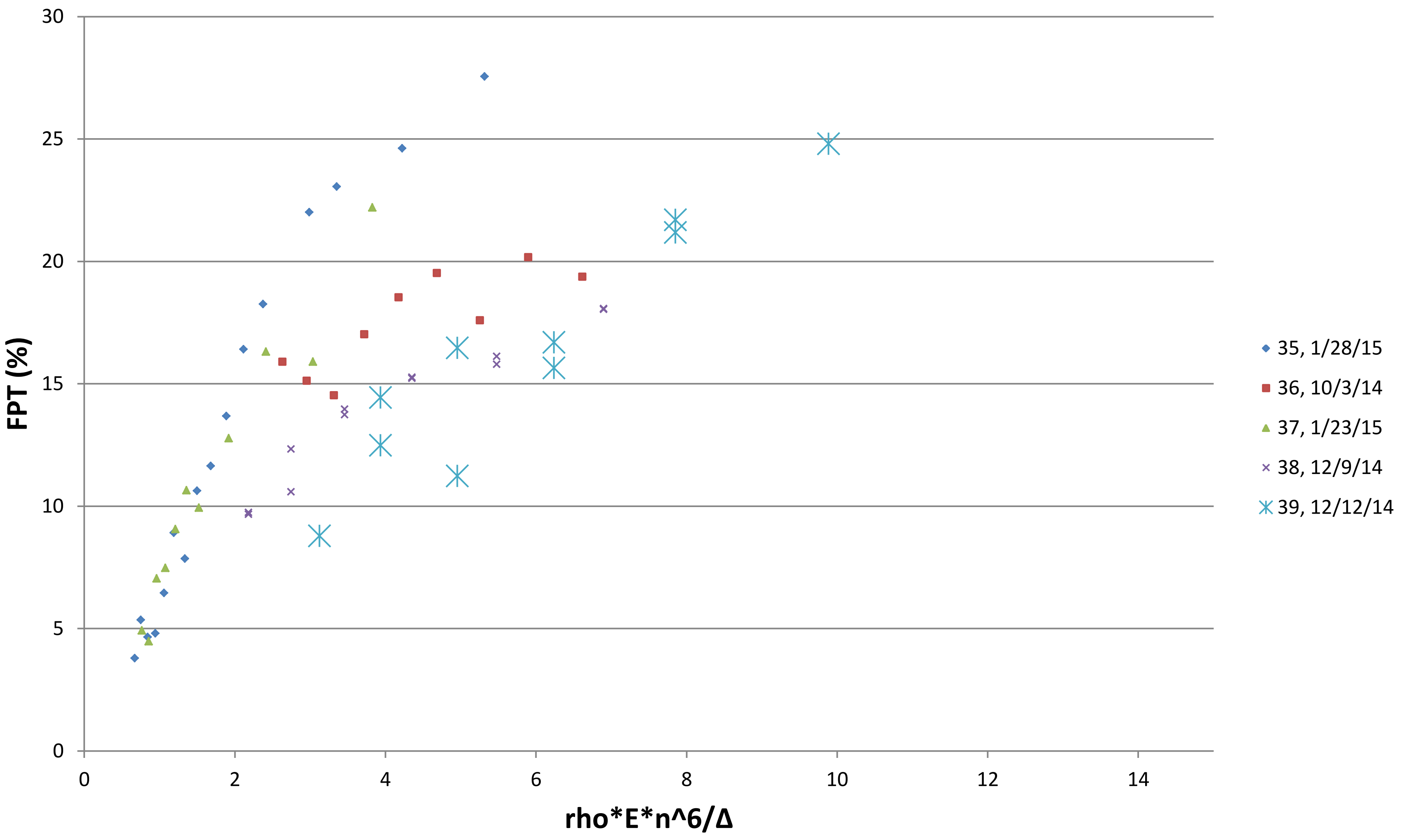

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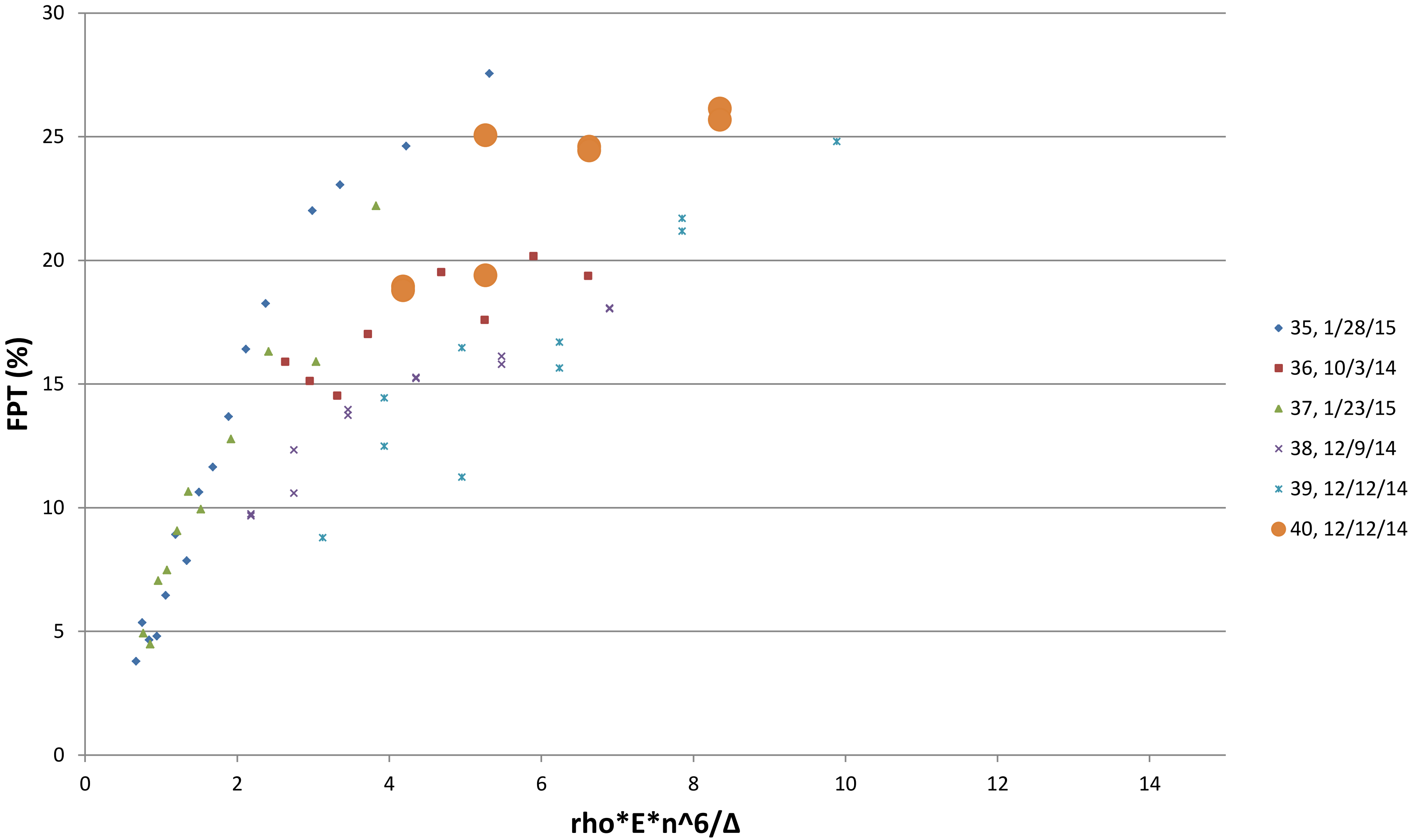

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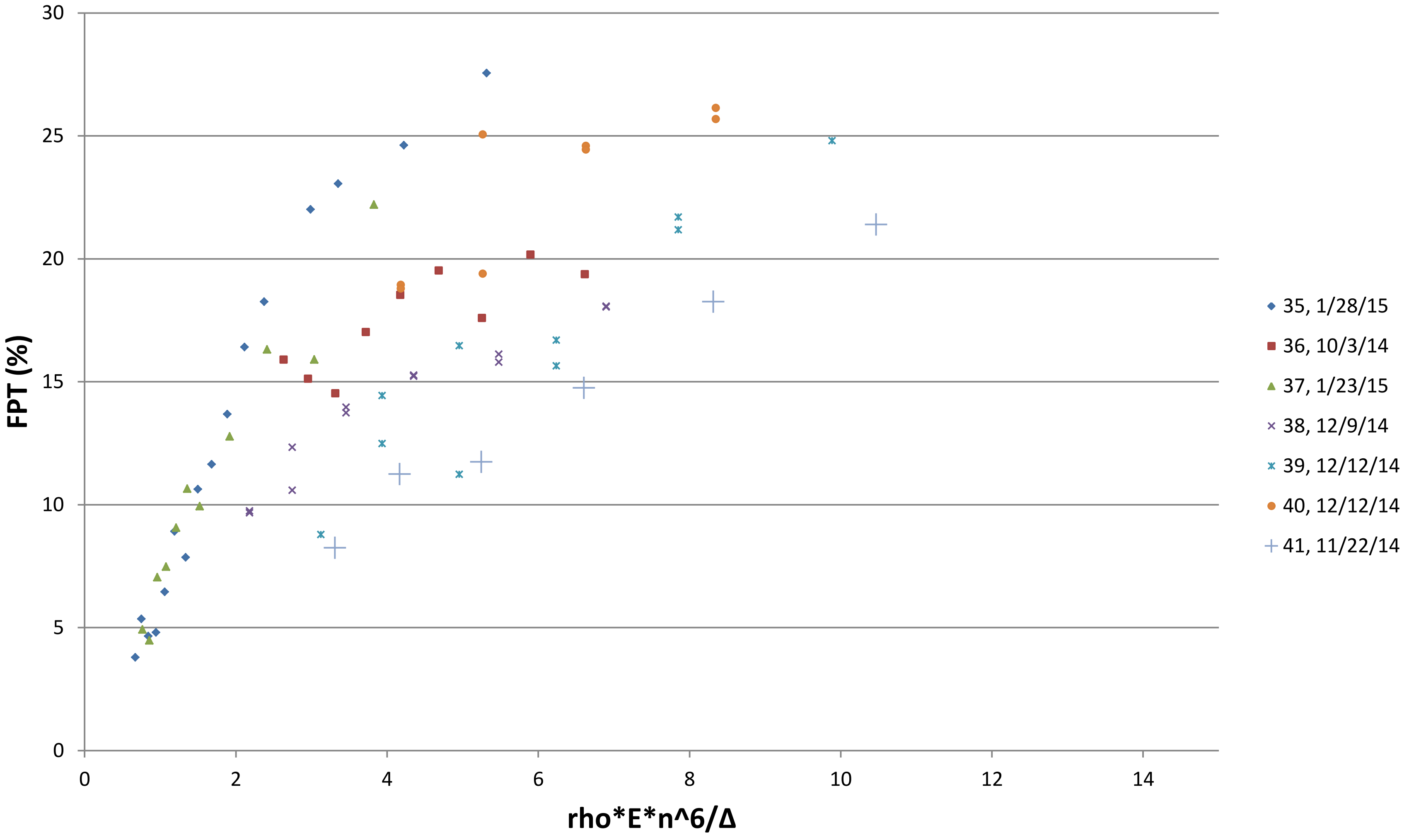

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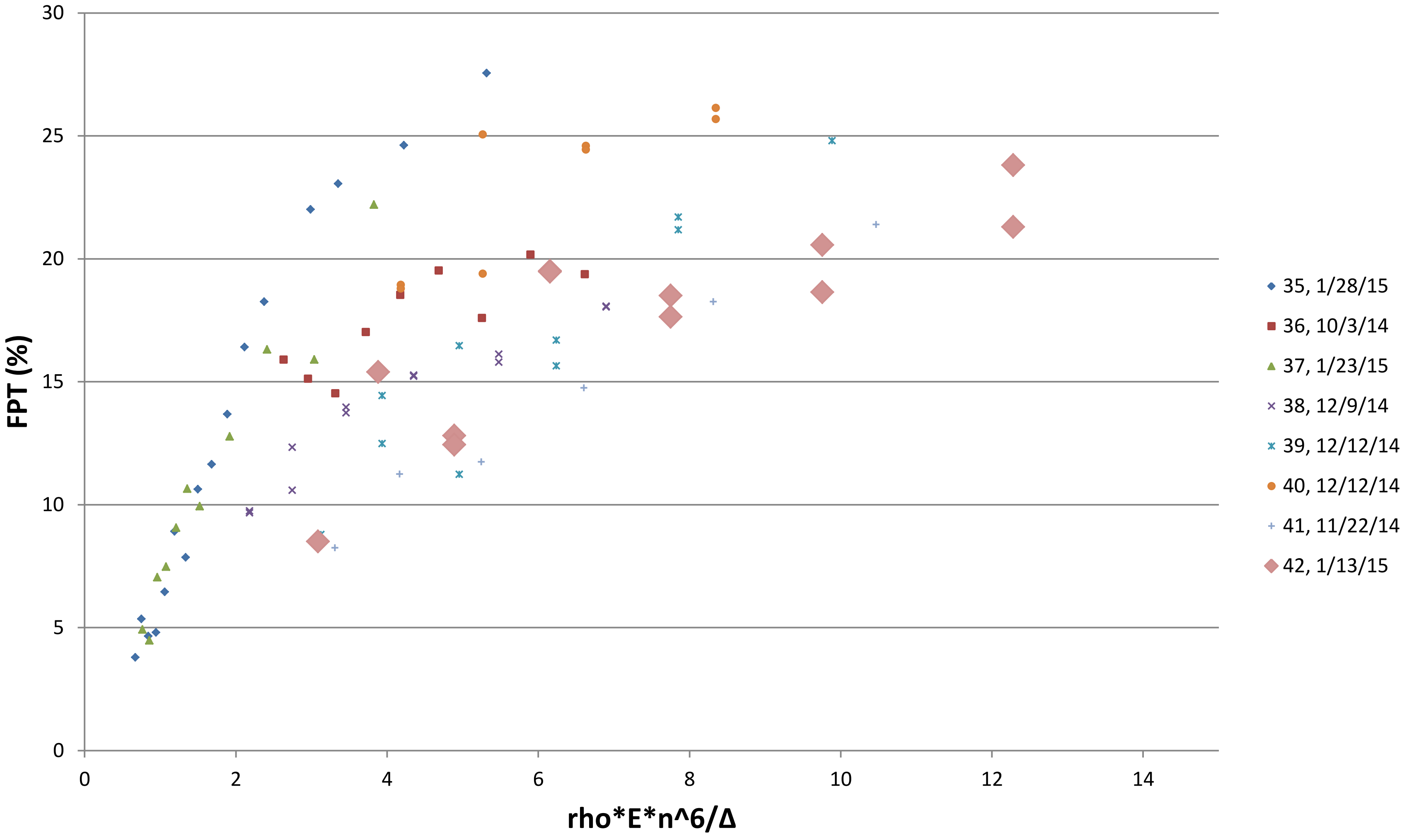

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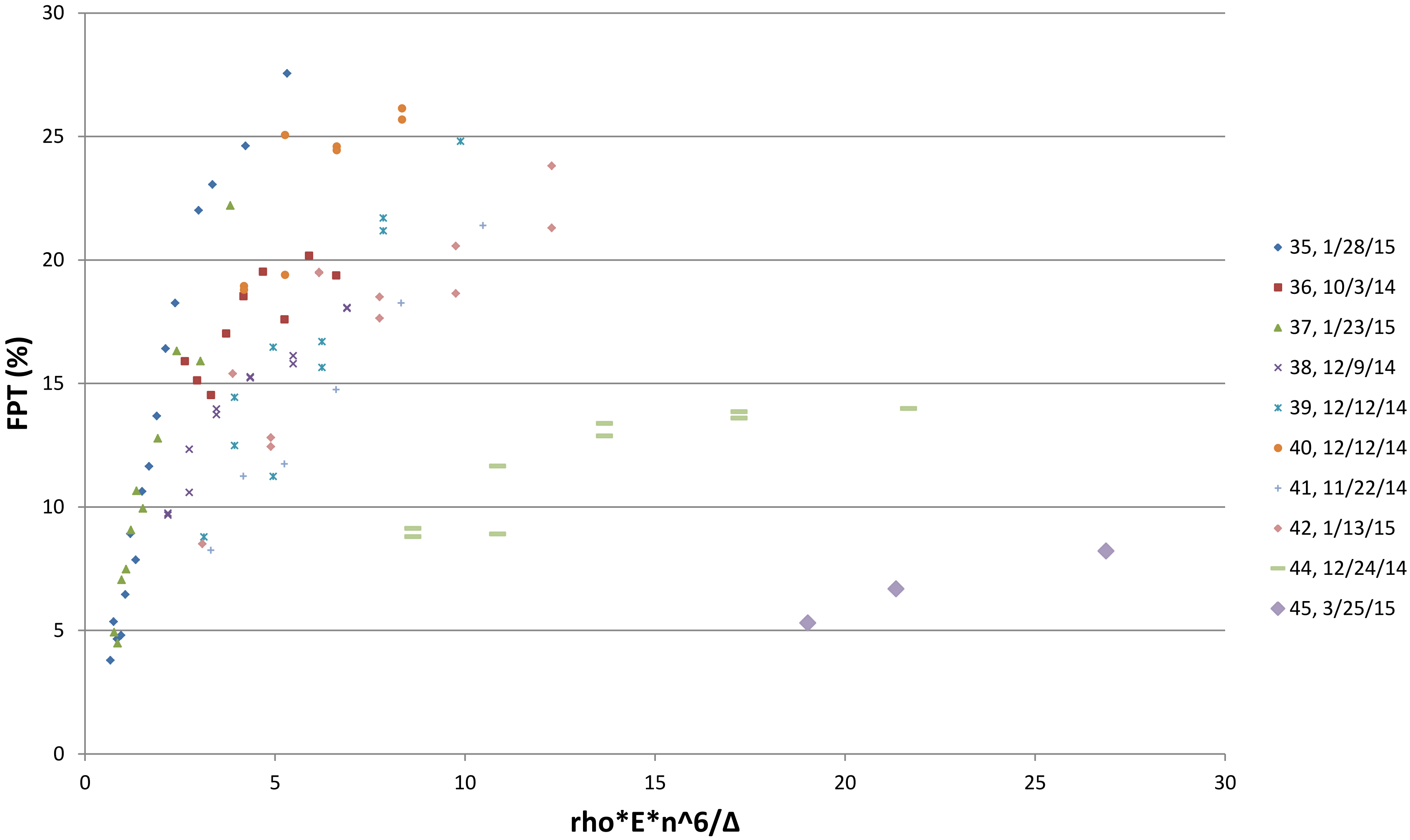

Conclusion

- The resonance frequencies of the ndnd-(n+1)d(n-2)f transitions for n=35 to 42 have been measured
- power shifts of the resonance frequencies have been measured for n=35 to 42.
- The dependence of the fractional population transfer from the ndnd to (n+1)d(n-2)f states on the microwave field strength and atomic density has been measured and can be compared to a simple theoretical model.

Acknowledgement

- My lab mates: Vincent, Alexandr, Eric, Safra, Kapila, Jirakan
- Dr. Gallagher

- This research is supported by Air Force Office of Scientific Research