Lifetime measurement summary

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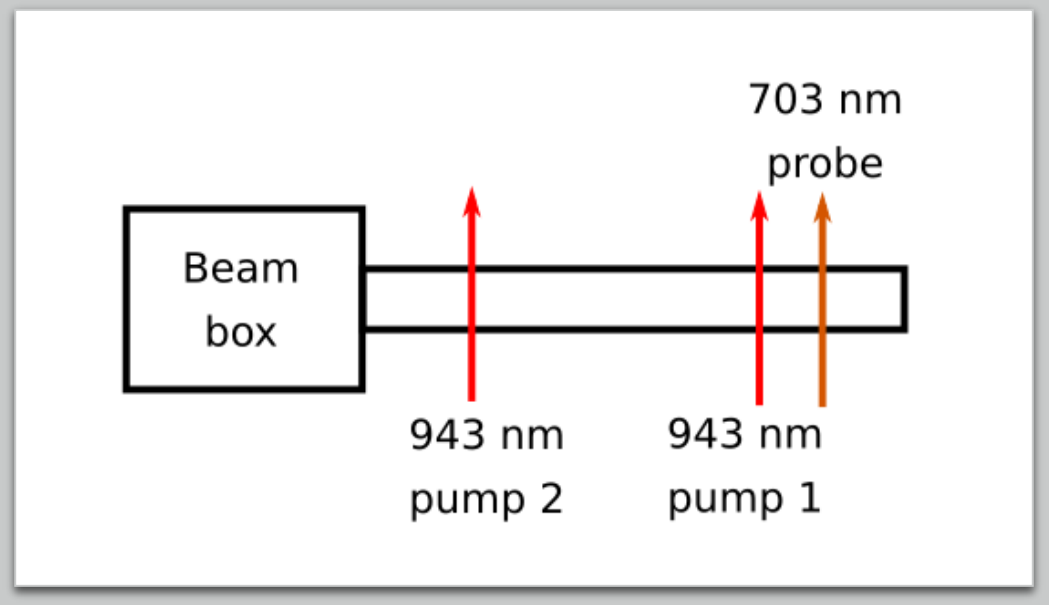
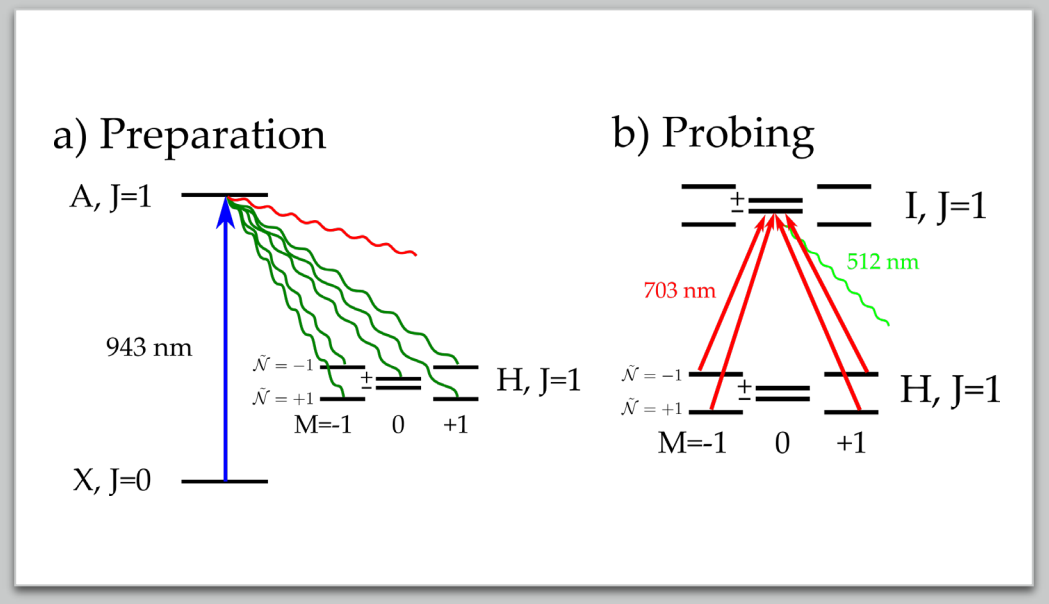
Structure of Presentation

1. Review of experimental setup & procedure
2. Statistics of main datasets
3. Systematic checks
4. Conclusion

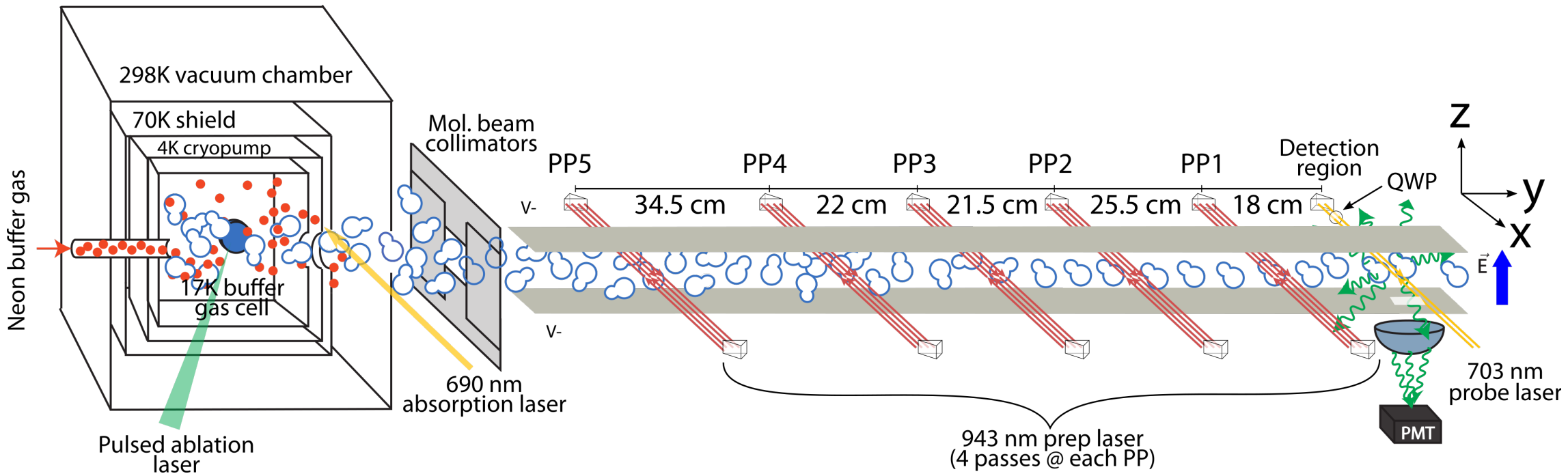
Review: experimental procedure

- Prepare molecular beam in H-state at 5 “prep points” (PP1-5)
- Detect remaining molecules in the same readout region
- ~38 V/cm Electric field along entire beam line
- Constantly switch between PP1 and PP2-5 every 7-9 s for normalization.
- PP1 -> closest to detection region





Review: experimental procedure

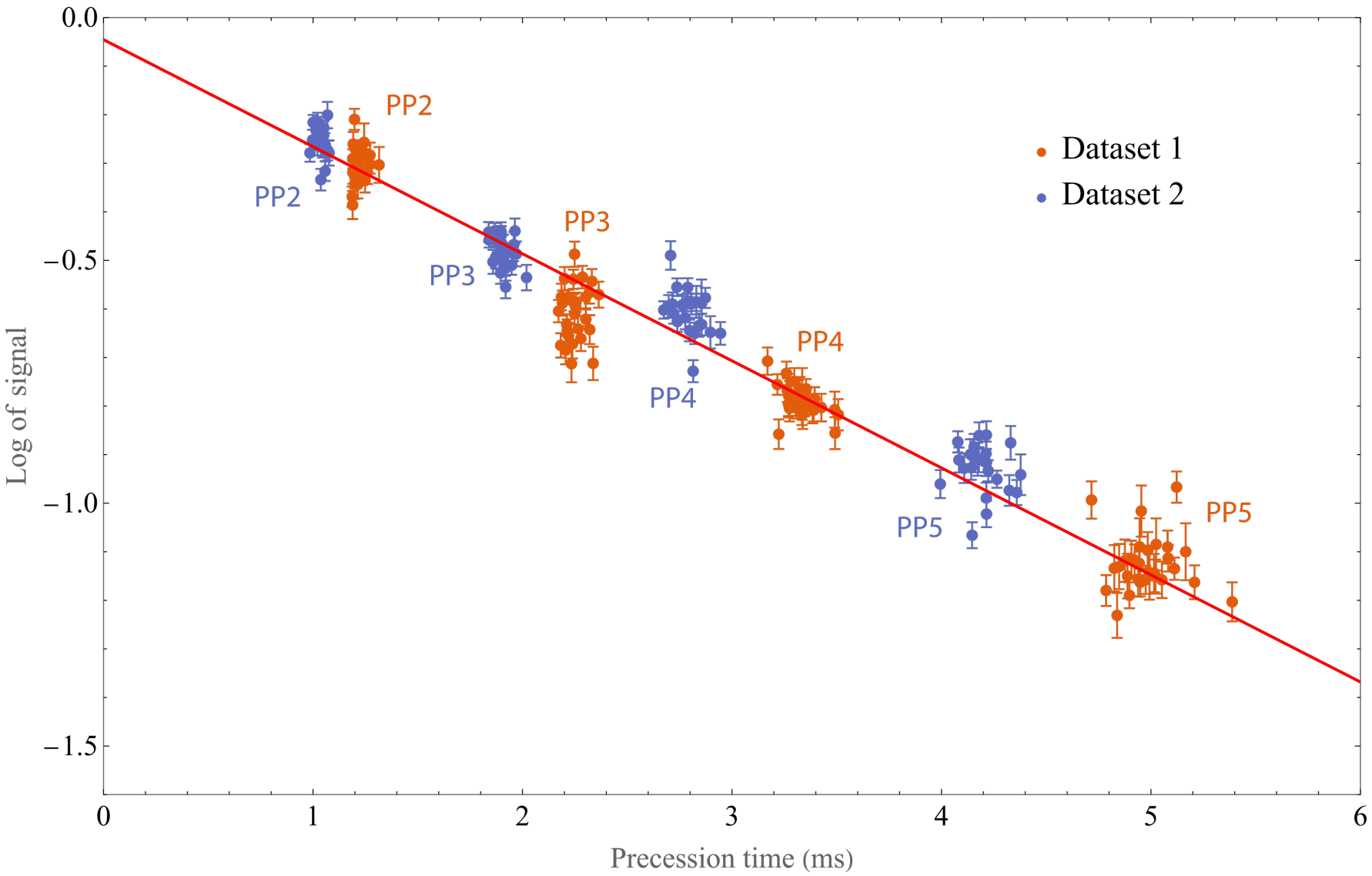


Review: analysis procedure

- After background subtraction and grouping of consecutive traces, normalize PP2-5 to PP1.
  - Suppresses effect of fluctuations in molecular beam
- Calculate beam velocity by comparing time of arrival of COM of fluorescence and upstream absorption regions
- Fit to exponential of the form $y = A\, e^{-t/\tau}$
  - Ideally should have just $y = e^{-t/\tau}$ if the prepared populations at PP1-5 are all the same
  - However, differences in laser and molecular beam size, orientation, alignment, etc. cause A to deviate from 1.

Data set	Velocity (m/s)	Fitted τ_H (ms)
1	208 (9)	4.48(7)
2	246 (10)	4.72(8)
1+2		**4.54(4)**

- Changed ablation target between datasets and realigned some optics (e.g. PP4)
- Reduced chi-squared is 4.2



Systematic error contributions

- Checked many sources of systematic errors
  - Amplify imperfection in system
  - Look for non-zero slopes with >2 sigma significance

So far only the following seem to warrant inclusion in systematic error budget:

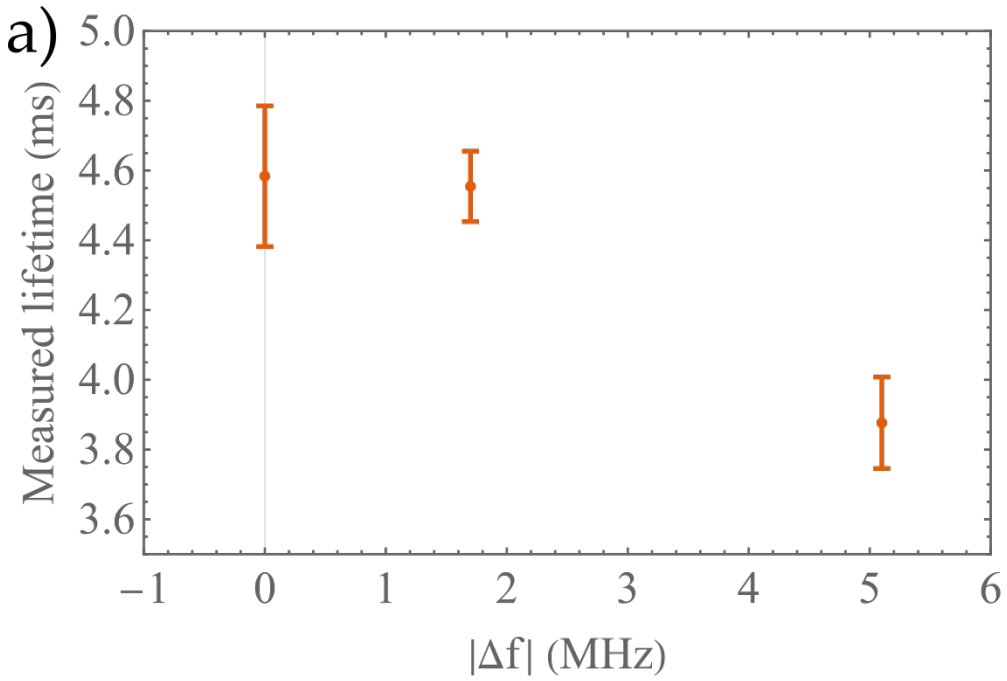
- 943 (pump) laser frequency shifts (single PP and simultaneously)
- Uncertainty in velocity calculation

Systematic: 943 prep laser detuning

- 943 laser lock typically has ~2 MHz stability
- The 5 PPs have X-A center line frequencies separated by <2 MHz (from Doppler scans)
- **Two checks:**
  - Shifted frequency of 943 laser for all PPs by up to 5 MHz
  - Shifted frequency of 943 laser for one PP at a time

Systematic: 943 prep detuning

Results of varying absolute detuning of ALL PPs



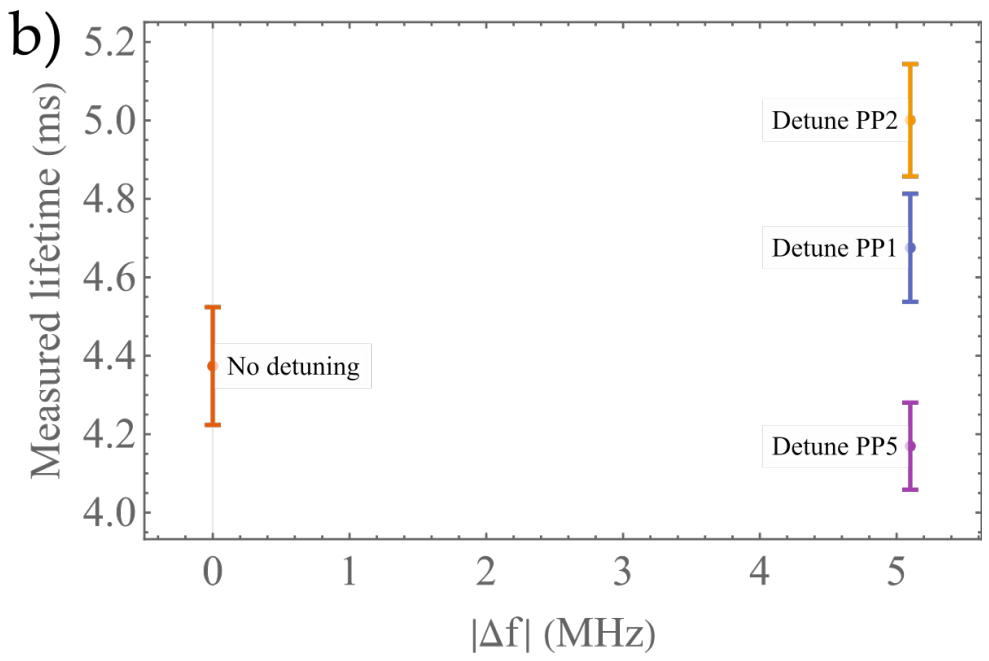
Possible systematic error mechanism:
943 prep laser has ~2 MHz linewidth due to slow cavity transfer lock.

- No discernable slope for 0-2 MHz
- Laser detuning varies no more than ±

2 MHz → take larger uncertainty of **0.2 ms**

Systematic: 943 prep detuning

Results of varying absolute detuning of single PPs



- Also ran tests detuning only **one** of the PPs at a time
- **Possible systematic error mechanism:**
  - Observed 1-2 MHz differences in X-A line center between different PPs from Doppler scans
  - Probably caused by different beam alignment and shape due to optics at each PP

- Detune PP1: 0.05(2) ms/MHz
- Detune PP2: 0.10(4) ms/MHz
- Take larger of these two slopes (0.14 ms/MHz) and multiply by 2 MHz to get **0.3 ms**

Systematic: velocity calculations

- Main method of calculating velocity was comparing arrival times of the center of mass of absorption and fluorescence signals
- However, we also tried a different method: fitting the mean of each group of traces to a function of the form

$$f(T) = \frac{S}{\sqrt{2\pi\sigma^2}} \frac{L}{T^2} \exp\left(-\frac{(L/T - \bar{v}_{mol})^2}{2\sigma^2}\right)$$

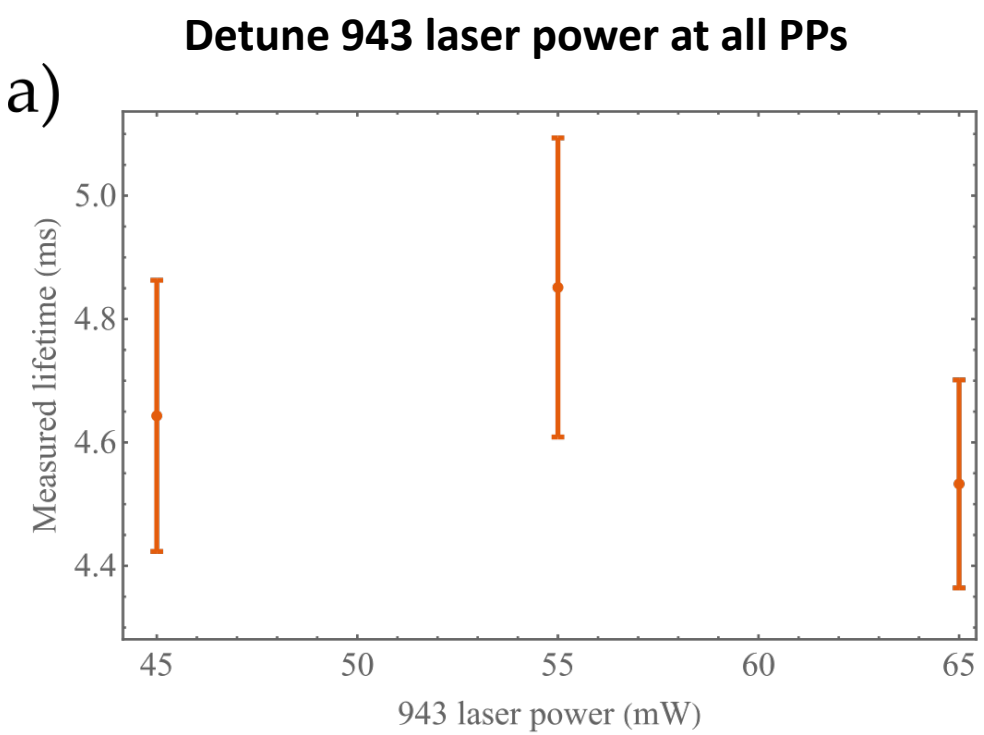
- This produced velocities which were ~2% faster.
- Decided to include a 2% uncertainty due to velocity calculation (0.1 ms)
- Also found that the average difference between the velocity of PP1 and PP2-5 is ~2%

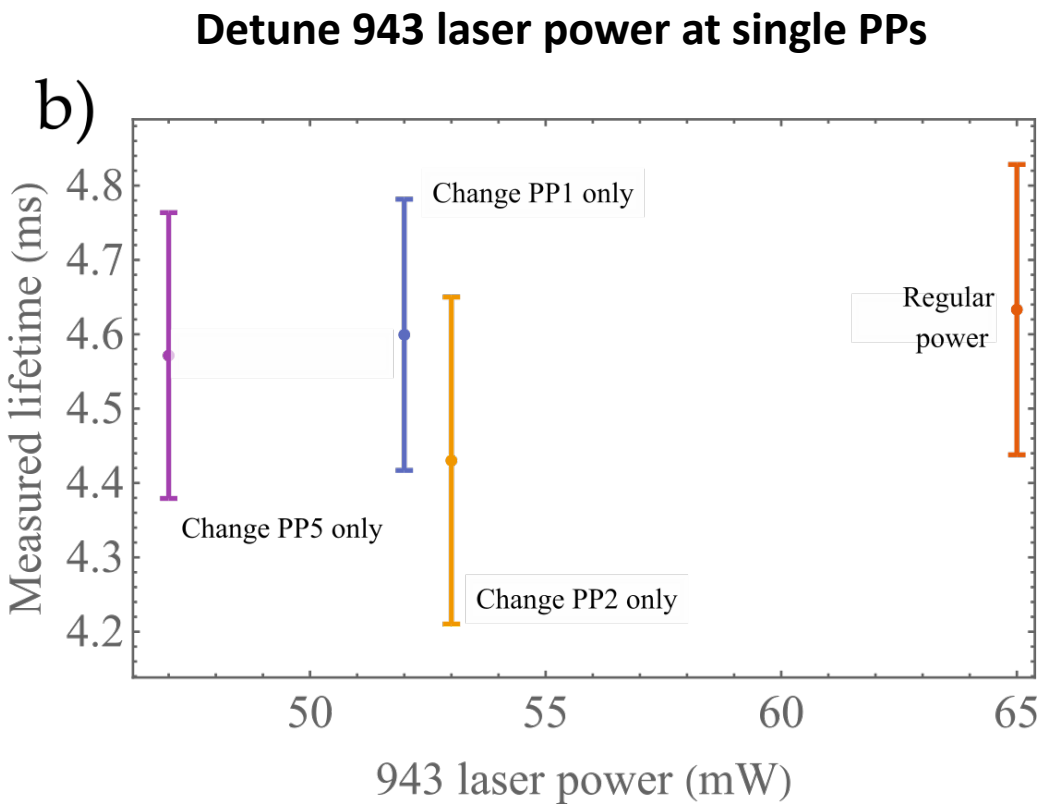
Other systematics explored

The following parameters were varied, resulting in no statistically significant non-zero slope in the lifetime:

- Power of 943 prep laser
- Power and detuning of 703 probe laser
- Position of vertical and horizontal collimators (width of molecular beam)
- E-field magnitude
- PP switch timing (from 7-9 s)
- Probe transitions (6 possible, due to substructure of H- and I-states)

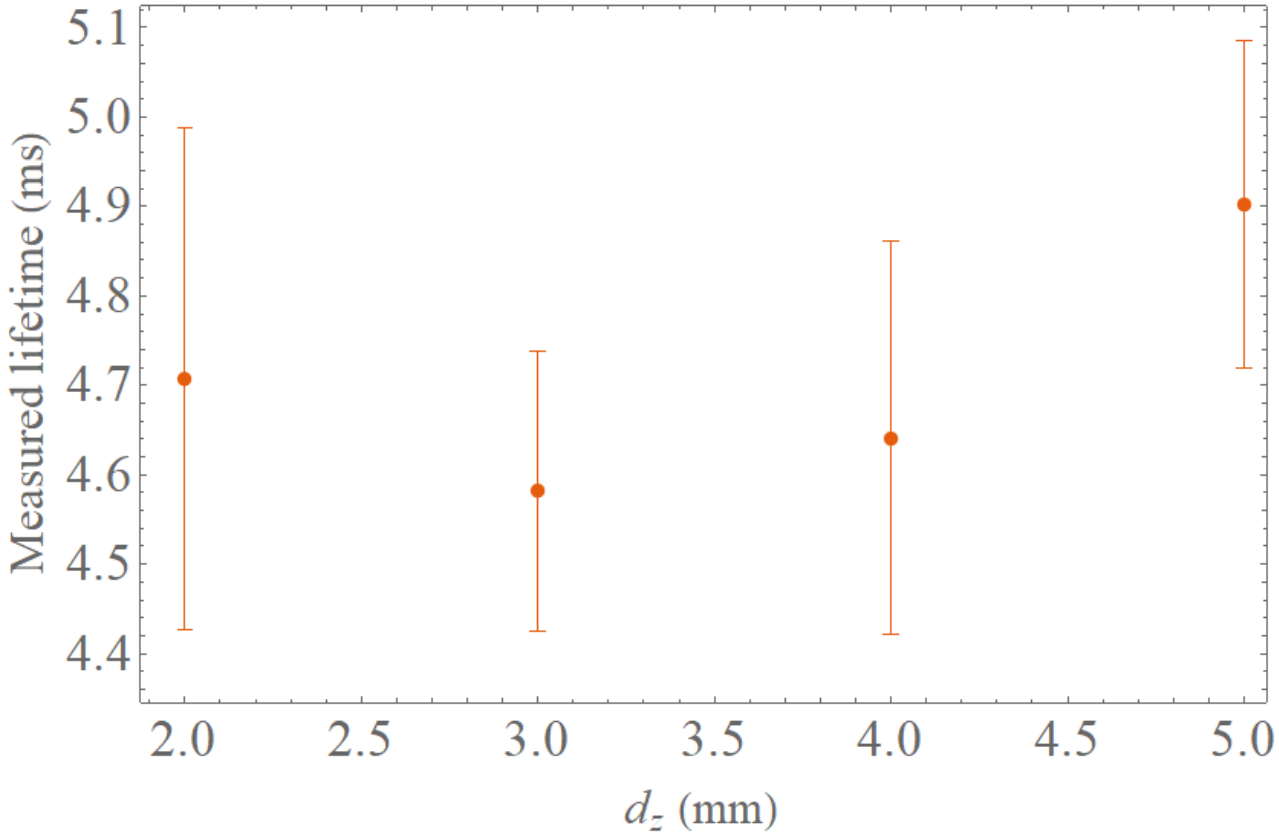
Systematic checks which did **not** result in an error contribution



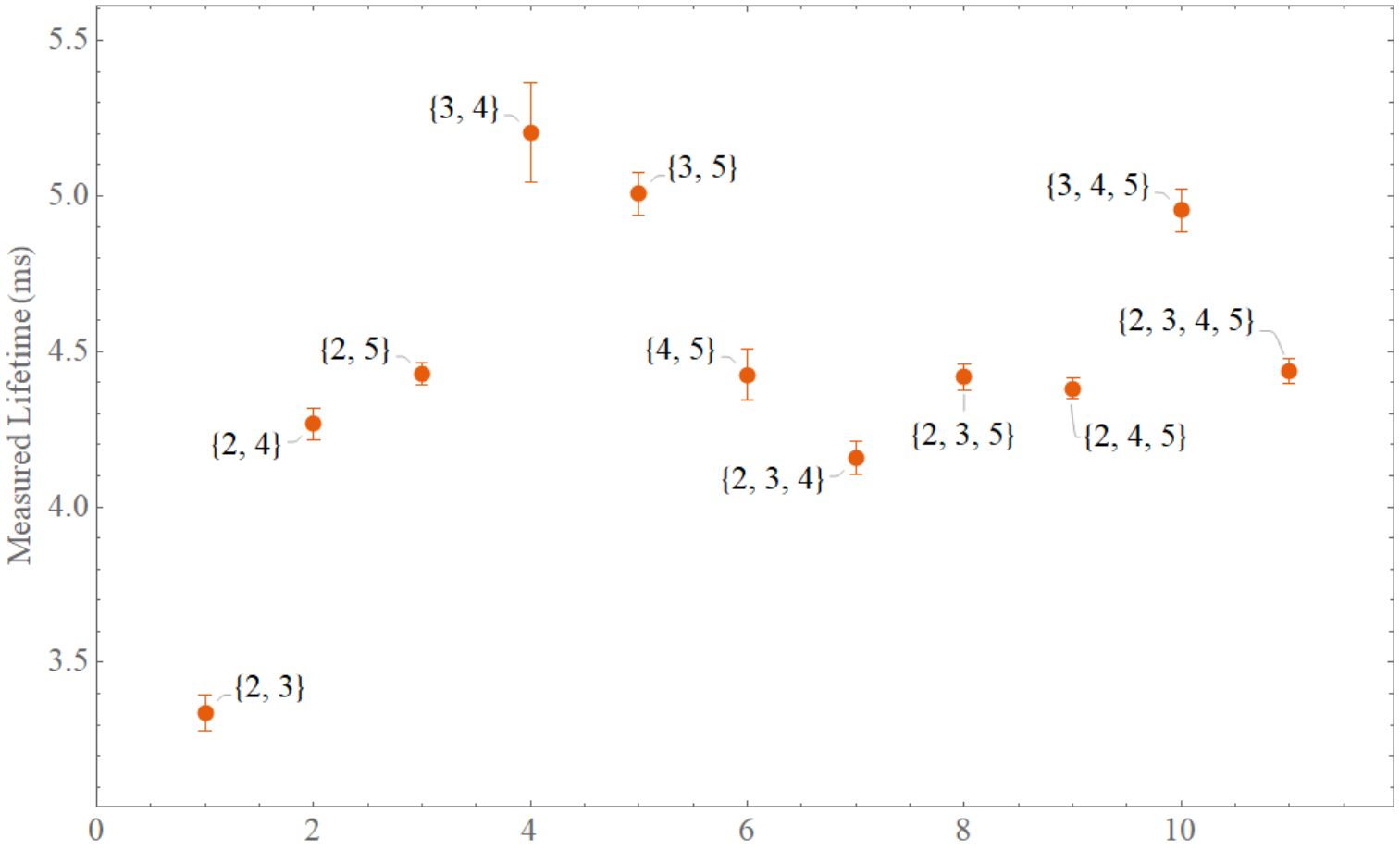


Systematic checks which did **not** result in an error contribution

Vary size of molecular beam vertical collimator opening (normal position: 3 mm)



Quick way to estimate systematic uncertainty by excluding certain PPs



- Mean (SD) of all PP combinations with 2+ PPs: **4.5(5) ms**
- Mean (SD) of all combinations with 3+ PPs: **4.5(3) ms**
- Close to result we arrived at by looking at individual PPs

Summary of uncertainties

Parameter	Error contribution (ms)
Prep laser detuning (all PPs)	0.2
Prep laser detuning (single PPs)	0.3
Velocity calculation uncertainty	0.1
Total systematic	**0.4**
Statistical	0.04
Total uncertainty	**0.4**

- Final result: $\boldsymbol{\tau = 4.5 \pm 0.4\ \mathrm{ms}}$
- Consistent with Cris' measurement in Jan 2019 (**4.3-7 ms**) and 2010 measurement **(>1.8 ms)**
- Very close to the value we have been working with for the lens and interaction region design

The End