Optical transitions of the ^{31}P bound exciton in ^{28}Si for reading and hyperpolarizing the donor electron and nuclear spins

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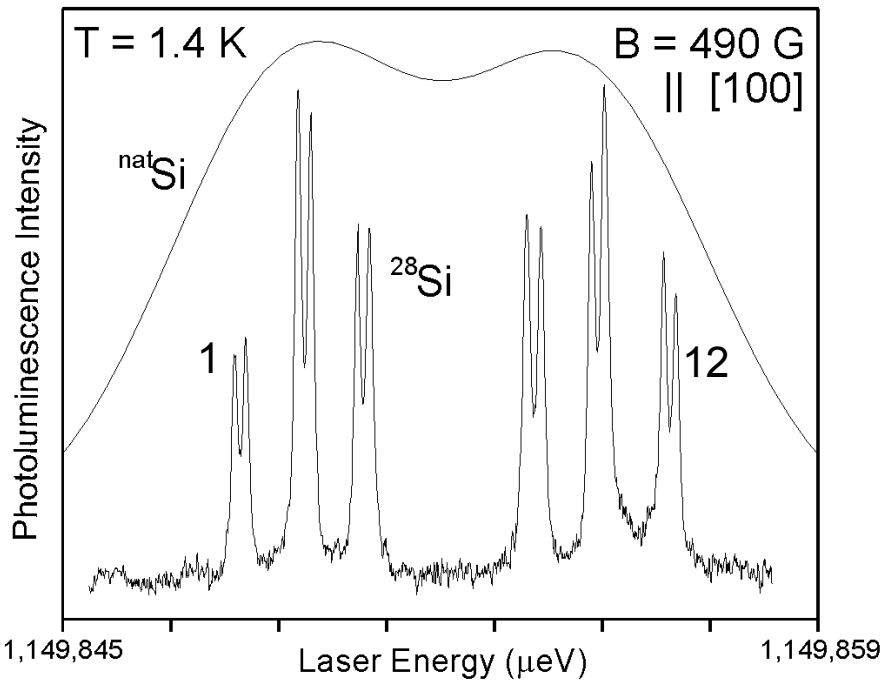
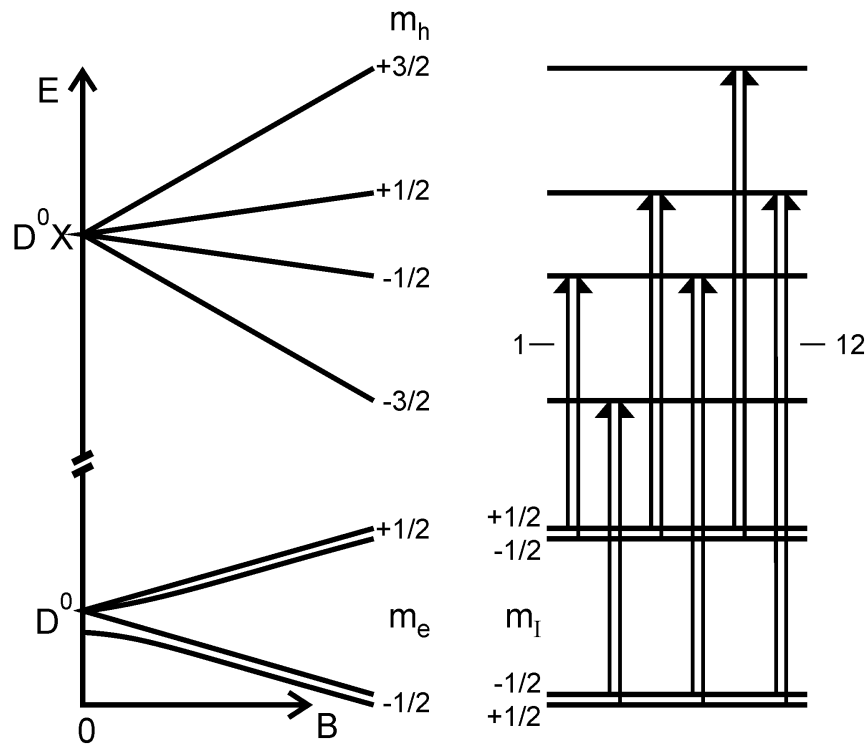
Avogadro Project

Improved shallow bound exciton linewidths – observation of the ^{31}P ground state hyperfine splitting in the donor bound exciton transition.

Phys. Rev. Lett. 97, 227401 (2006). Nuclear and electron spin readout…

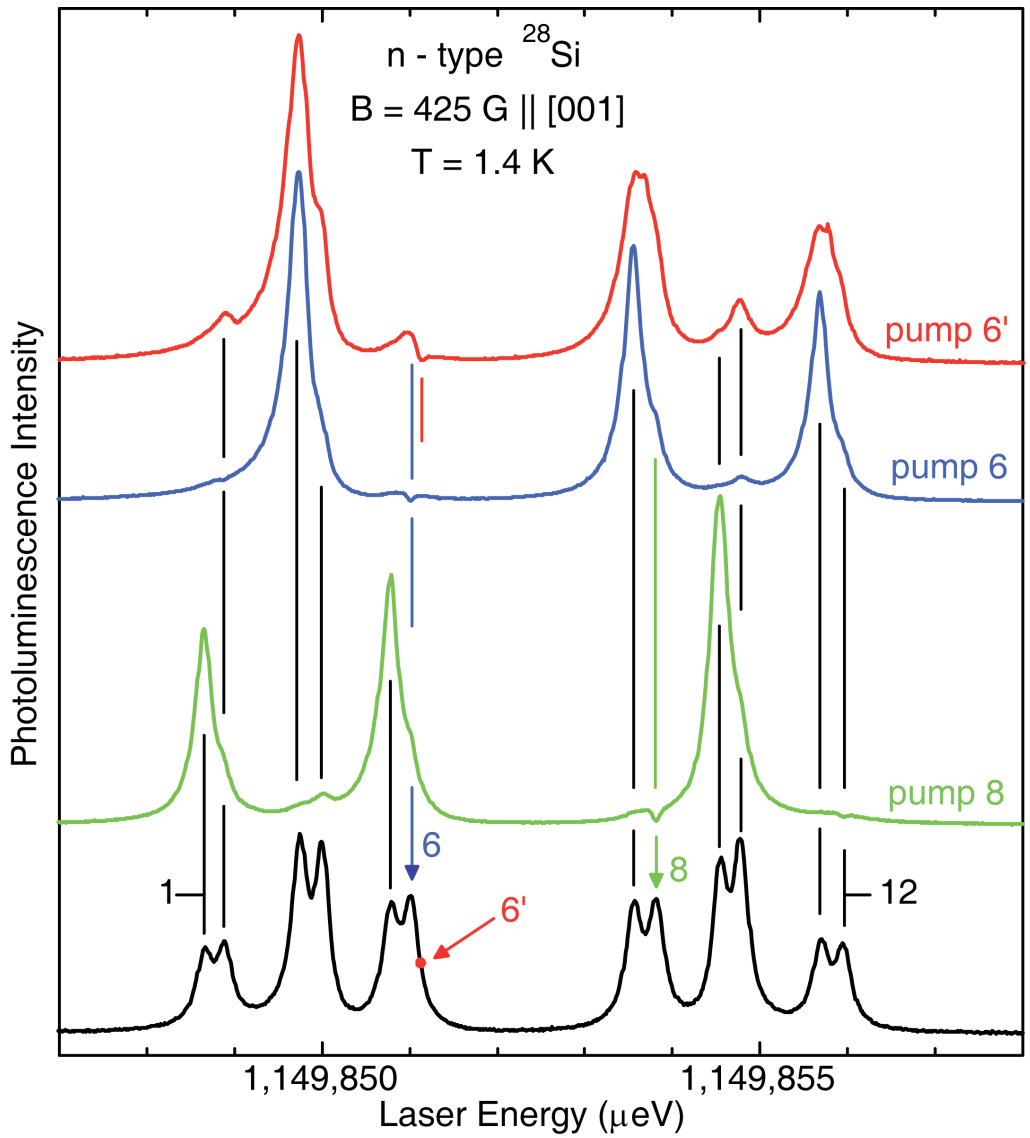
Also via BE Auger ionization – possibility of single donor readout

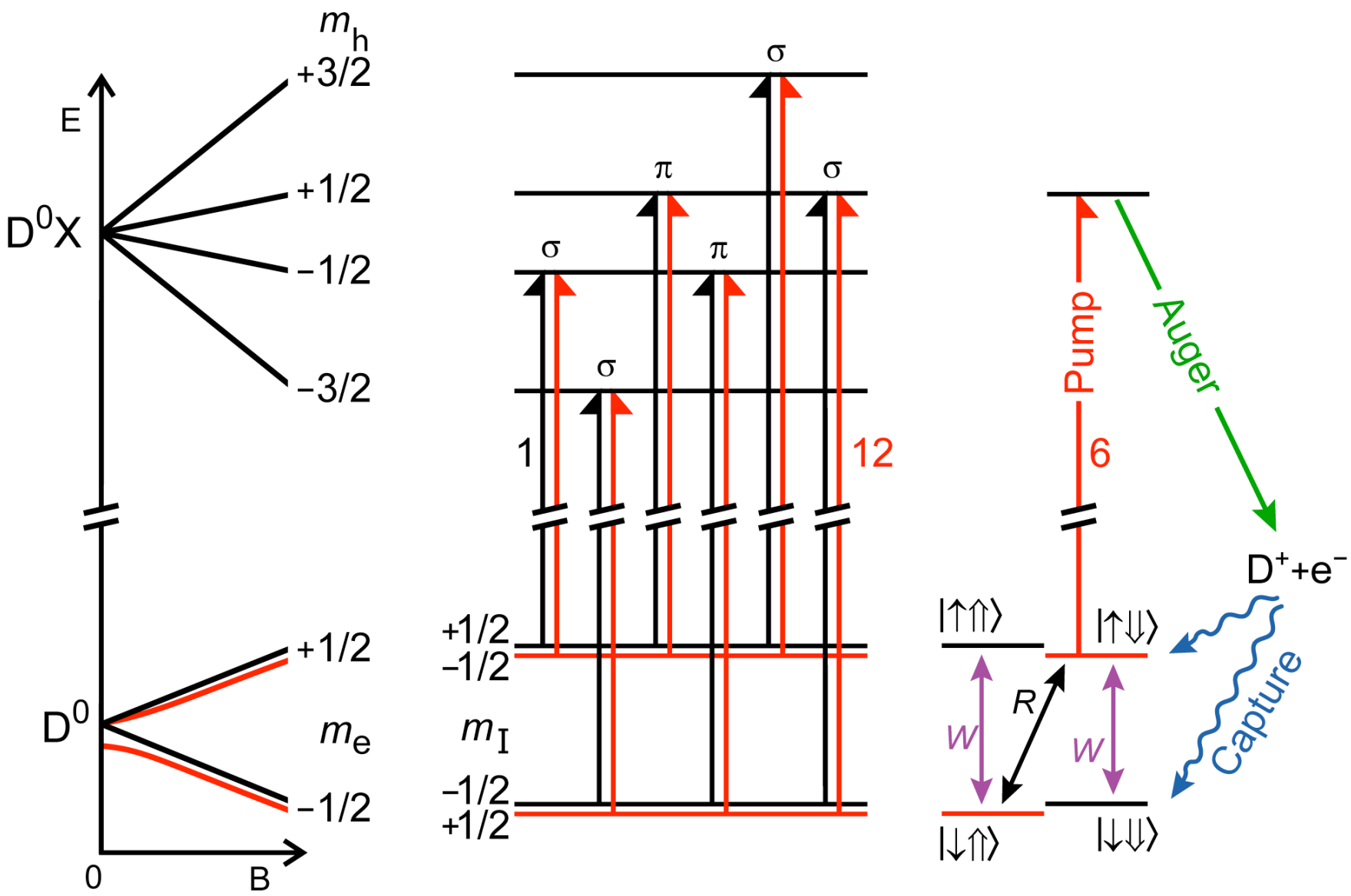




Electron and nuclear hyperpolarization by resonant dynamic pumping

(Phys. Rev. Lett. **102**, 257401 (2009))




m_h
+3/2
E
+1/2
D^0X
−1/2
−3/2
+1/2
D^0
m_e
−1/2
0
B
σ
π
σ
σ
π
σ
1
12
+1/2
−1/2
m_I
−1/2
+1/2
Pump
Auger
6
$D^+ + e^-$
|↑⇑⟩
|↑⇓⟩
R
w
w
Capture
|↓⇑⟩
|↓⇓⟩

Nuclear polarization of 76% and electronic polarization of 90% are achieved simultaneously, in less than one second

Higher polarization should be possible with reduced linewidths

Pump line	Populations (%) $\lvert\uparrow\Uparrow\rangle$	$\lvert\uparrow\Downarrow\rangle$	$\lvert\downarrow\Downarrow\rangle$	$\lvert\downarrow\Uparrow\rangle$	Polarization(%) Elec.	Nucl.
3 $\lvert\downarrow\Downarrow\rangle$	44	38	4	14	64	16
4 $\lvert\downarrow\Uparrow\rangle$	63	22	7	8	70	42
5 $\lvert\uparrow\Uparrow\rangle$	1	8	75	16	-82	-66
6 $\lvert\uparrow\Downarrow\rangle$	1	4	84	11	-90	-76
6′ $\lvert\uparrow\Downarrow\rangle$	2	11	64	23	-74	-50
7 $\lvert\downarrow\Downarrow\rangle$	64	26	1	9	80	46
8 $\lvert\downarrow\Uparrow\rangle$	76	18	2	4	88	60
9 $\lvert\uparrow\Uparrow\rangle$	3	15	43	39	-64	-16
10 $\lvert\uparrow\Downarrow\rangle$	4	5	70	21	-82	-50

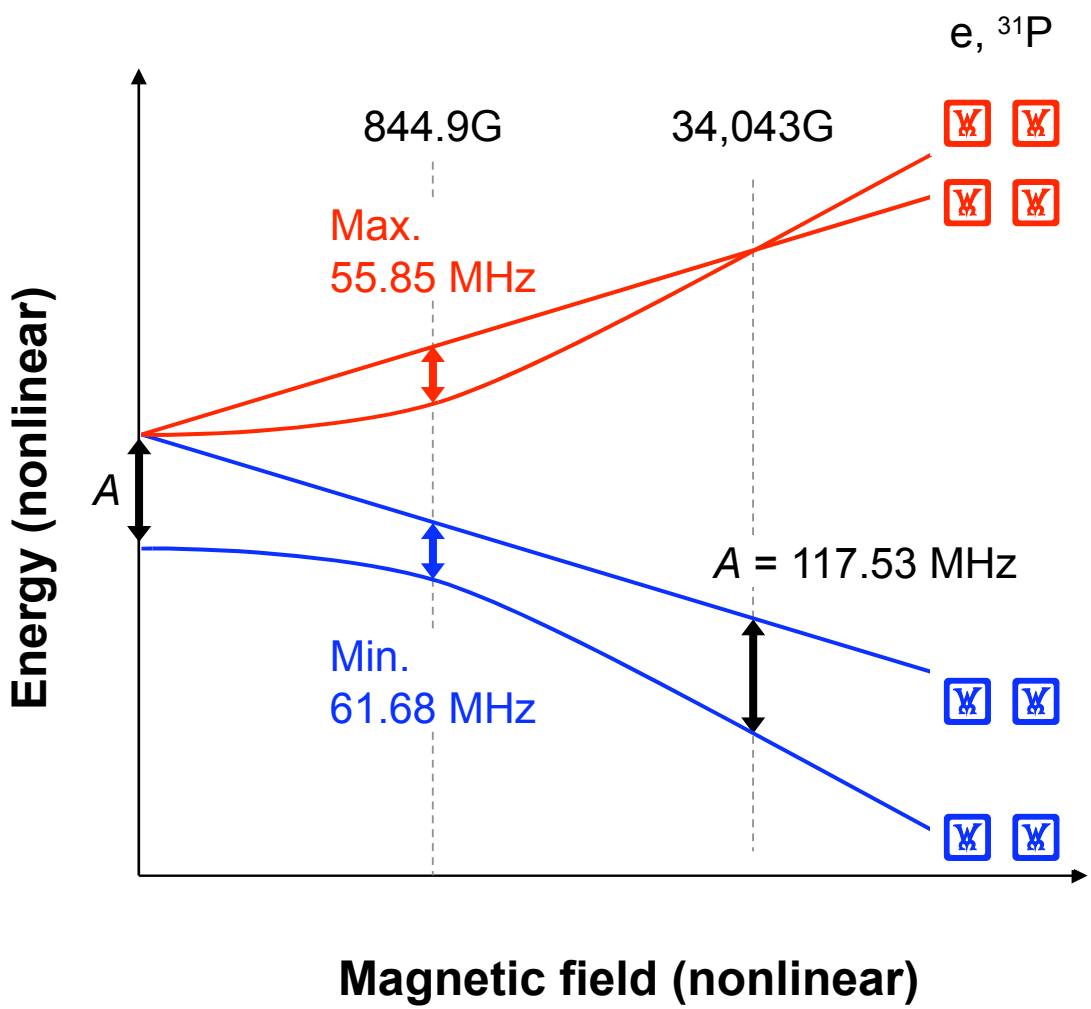
Putting these effects to some use:

Optically detected NMR of optically hyperpolarized ^{31}P in ^{28}Si at 845 Gauss

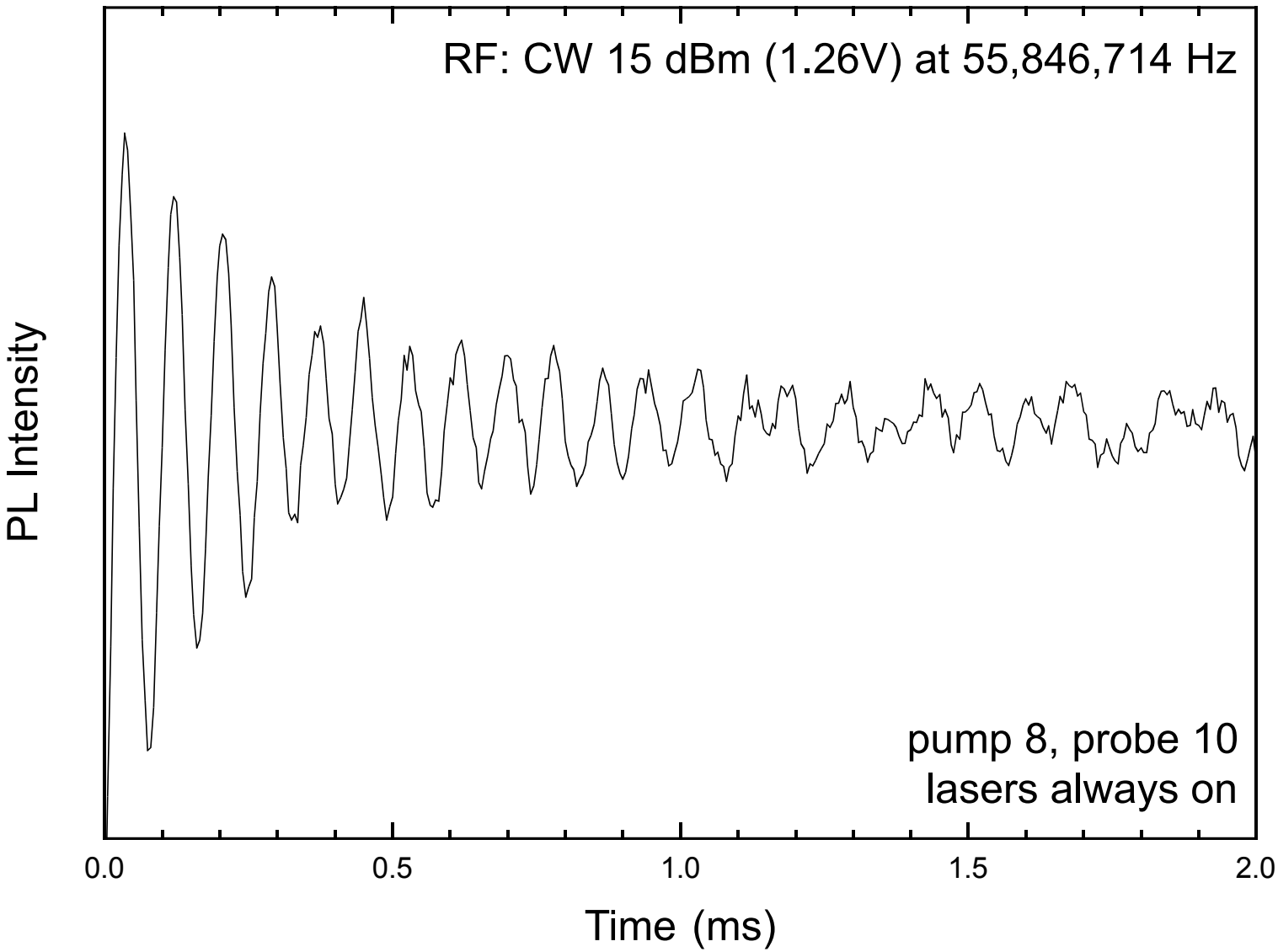
Why 845 Gauss?

Schematic energy diagram

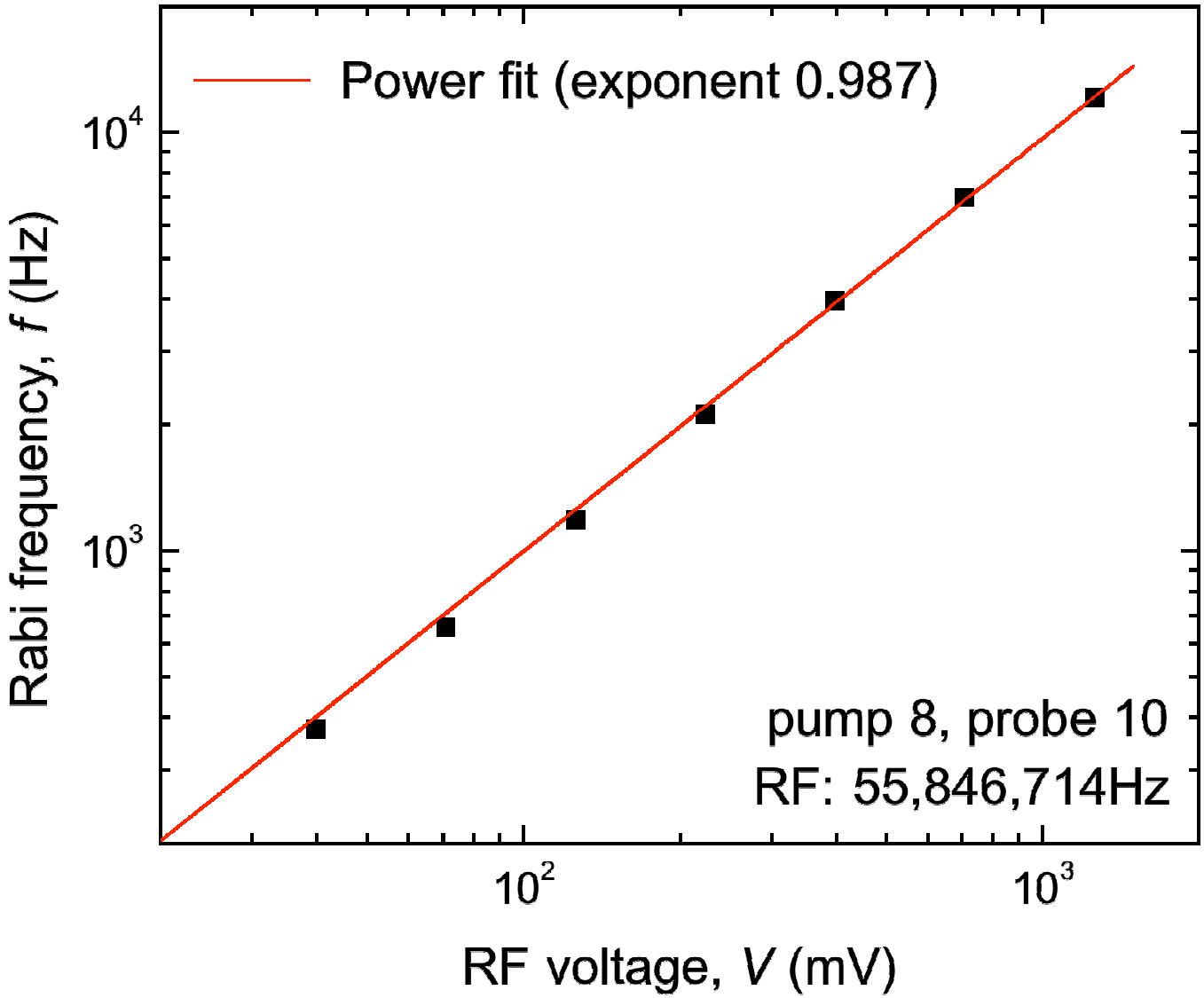
$g_e = 1.99850$
$g_{^{31}P} = 2.26320$



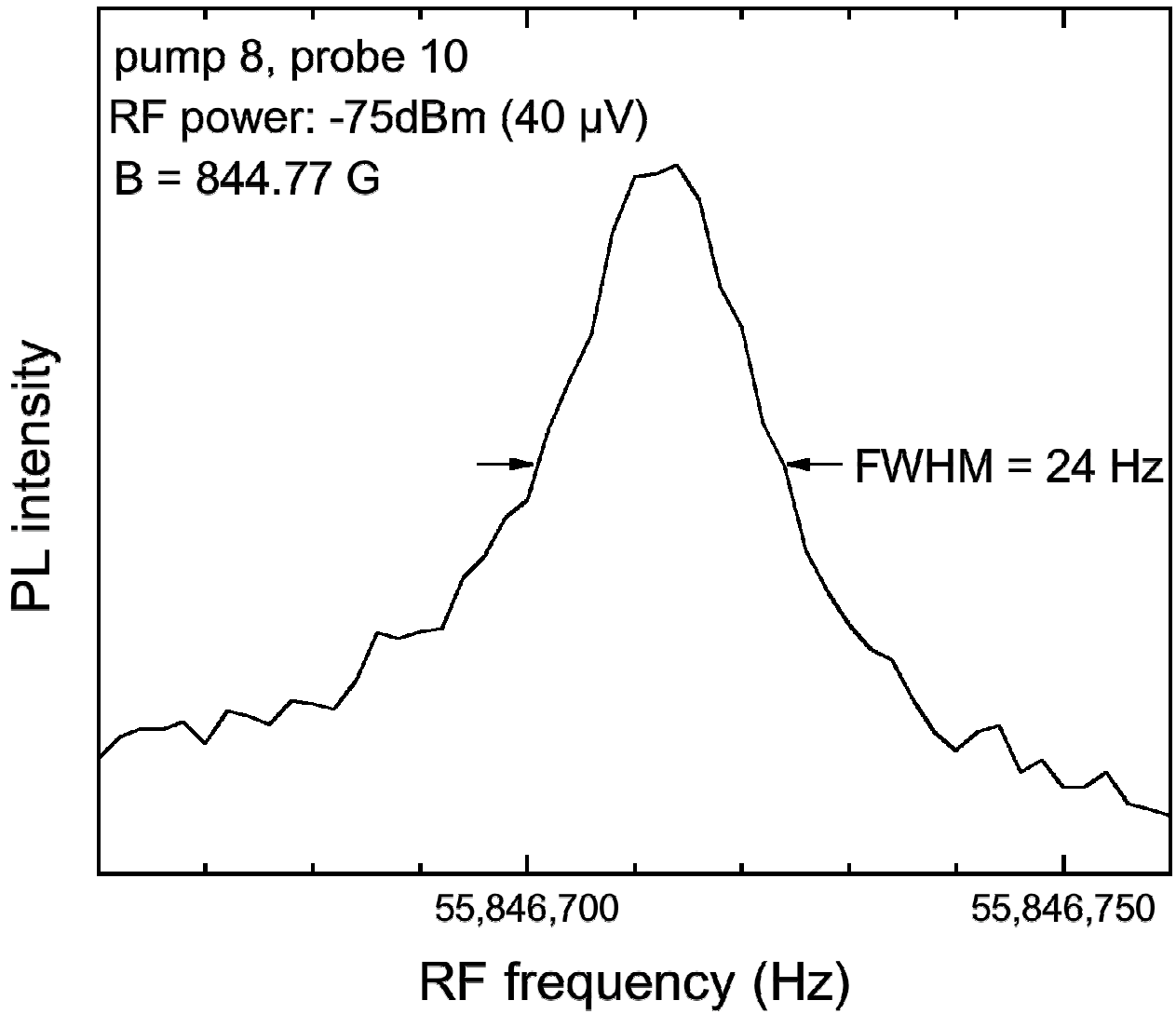
Rabi Oscillation



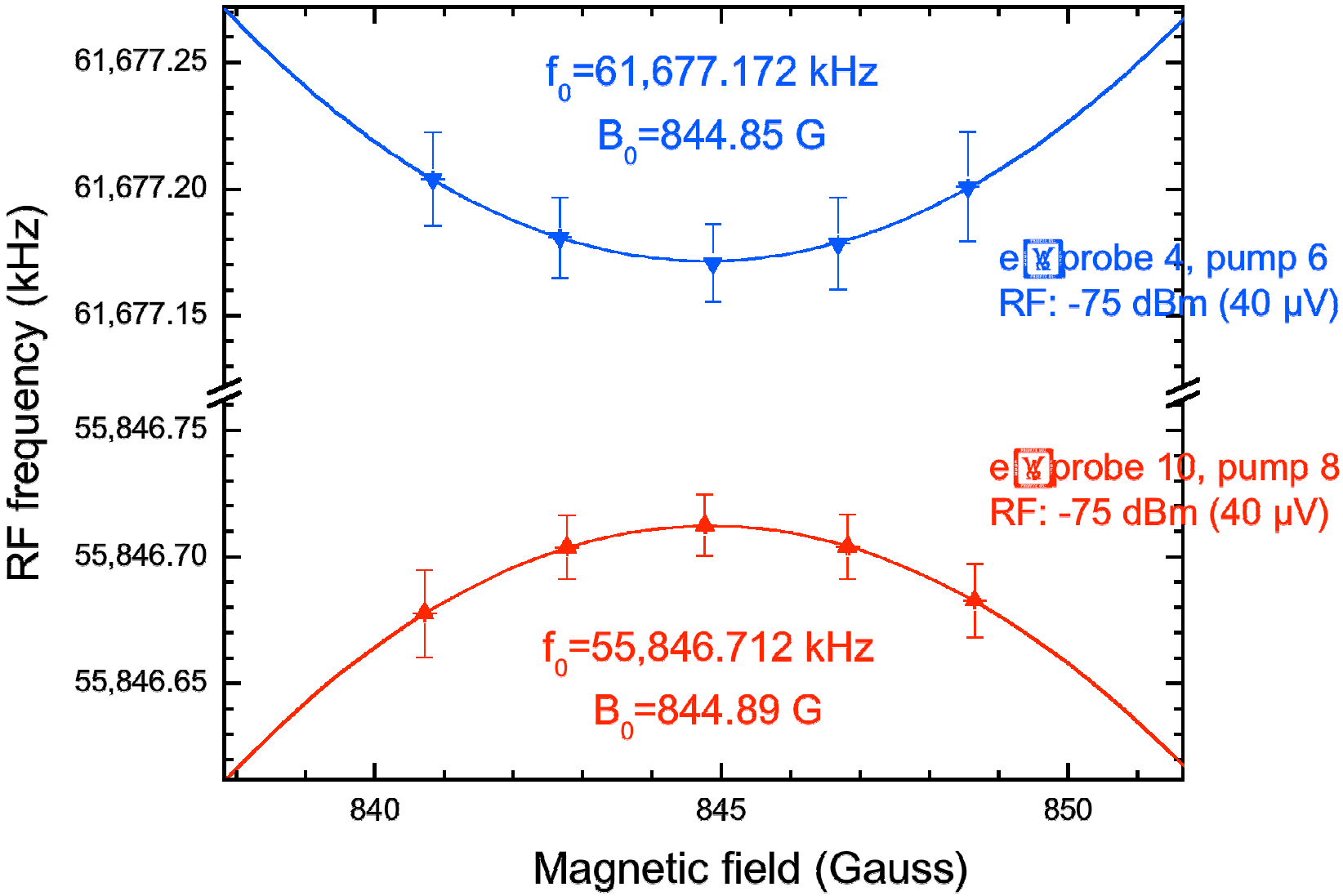
Rabi Frequency vs RF Amplitude



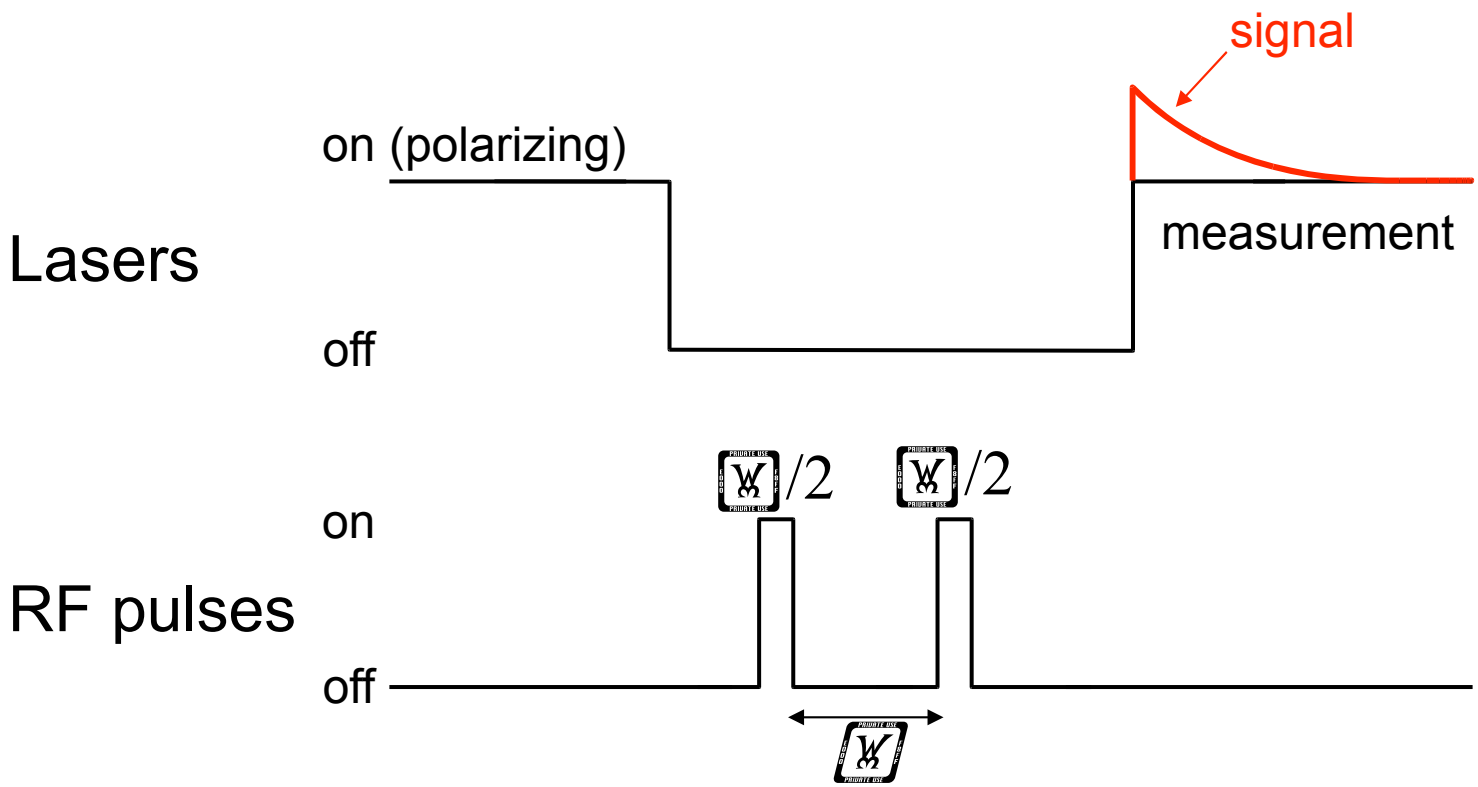
CW NMR


pump 8, probe 10
RF power: -75dBm (40 μV)
B = 844.77 G
FWHM = 24 Hz
PL intensity
55,846,700
55,846,750
RF frequency (Hz)

Magnetic Field Dependence



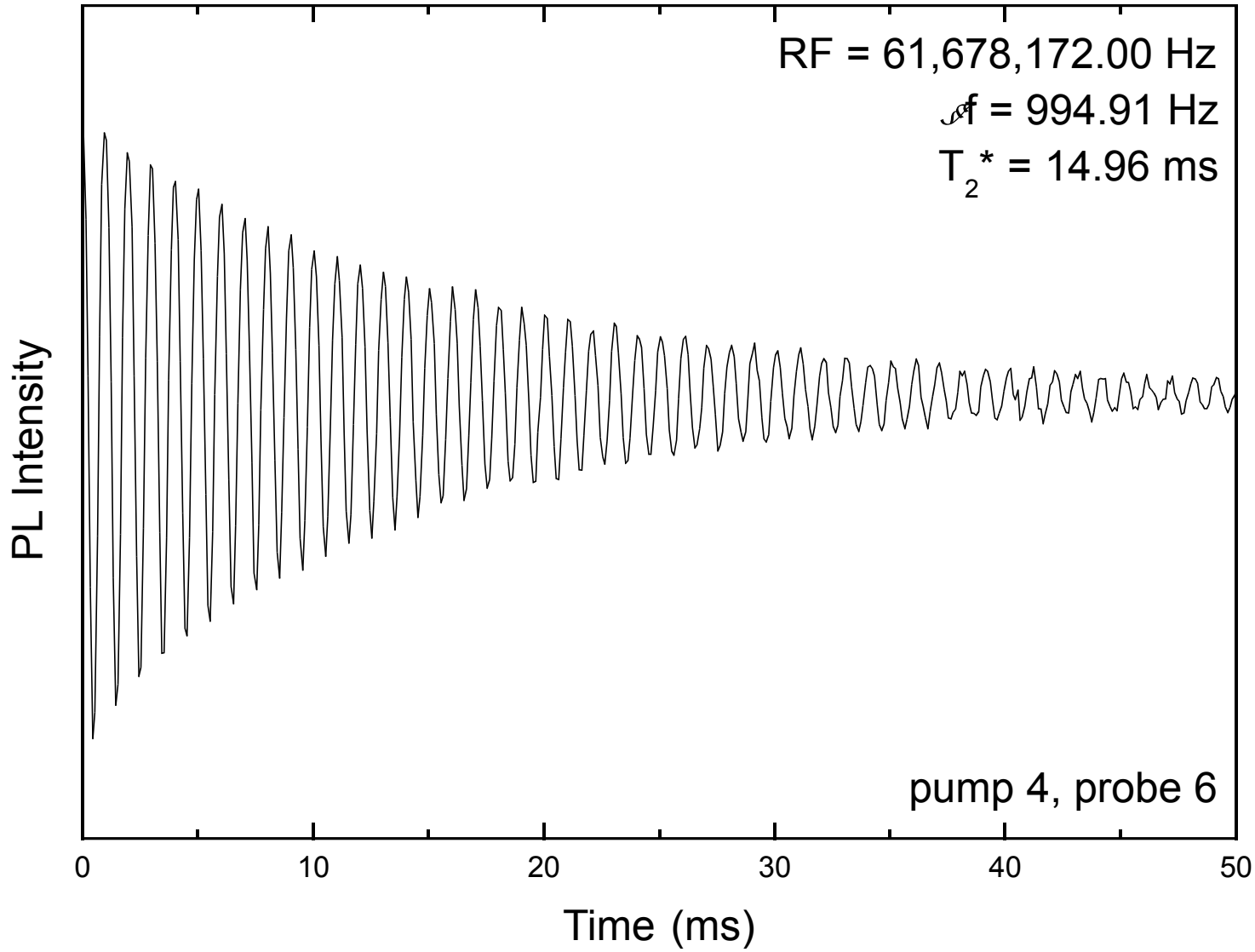
First pulsed NMR - Ramsey Fringe Experiment



RF freq. = Resonance freq. +/– 1 kHz ➔ fringes of 1 kHz

Ramsey Fringes

single shot – no averaging



^{31}P Hyperfine Constant

m_e	RF freq. (Hz)	Fringe freq. (Hz)	NMR freq. (Hz)
	55,845,712.00	1,008.22	55,846,720(5)
	55,847,712.00	992.41	
	61,676,172.00	1,004.51	61,677,177(5)
	61,678,172.00	995.68	

➔ Hyperfine constant A = 117,523,897(10) Hz

[existing value 117.53(2) MHz]