Nickel-Catalyzed Cross-Electrophile Coupling of Aryl Chlorides with Primary Alkyl Chlorides

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Supporting Information

1. General Information

1.1 Reagents

Metals

Zinc flake (-325 mesh) was purchased from Alfa Aesar, stored in a nitrogen filled glovebox, and used as received.

Nickel(II) bromide ethylene glycol dimethyl ether ($NiBr_2$(dme)) was synthesized according to the literature procedure and stored in a nitrogen filled glovebox.[1] The amount of dme present in the $NiBr_2$(dme) was determined by elemental analysis and the mass of $NiBr_2$(dme) was calculated accordingly.

Nickel(II) iodide hydrate was purchased from Strem, stored in a nitrogen filled glovebox, and used as received. The amount of hydrate present in the $NiI_2 \bullet xH_2O$ was determined by elemental analysis and the mass of $NiI_2 \bullet xH_2O$ was calculated accordingly.

Ligands

Pyridine-2-carboxamidine•HCl (PyCam•HCl, **L8**•HCl) was synthesized according to the literature procedure.[2]

[2,2′-Bipyridine-6-carboximidamide•HCl (BPyCam•HCl, **L9**) was synthesized according to the literature procedure.[3]

Pyridine-2,6-bis(carboximidamide)•2HCl (PyBCam•2HCl, **L10**) was synthesized according to the literature procedure.[4]

Pyridine-2,6-bis(*N*-cyanocarboxamidine) (PyBCam^{CN}, **L11**) was synthesized according the literature procedure.[5]

All other ligands tested were purchased from commercial suppliers and used as received.

Solvents

1-Methyl-2-pyrrolidinone (NMP, anhydrous) was purchased from Sigma Aldrich, stored in a nitrogen filled glovebox, and used as received.

Other Reagents

tert-Butyl-3-chloropropylcarbamate was synthesized according to the literature procedure and characterization data matched those reported in the literature.[6]

Boc-3-chloropropylbenzylamine was synthesized according to the literature procedure and characterization data matched those reported in the literature.[7]

All other starting materials were purchased from commercial suppliers and were used as received unless otherwise noted.

1.2 Methods

NMR Spectroscopy

^{1}H and ^{13}C NMR spectra were acquired on 400 and 500 MHz Bruker NMR instruments. NMR chemical shifts are reported in ppm and are referenced to the residual solvent peak for $CDCl_3$ (δ = 7.26 ppm, ^{1}H NMR; δ = 77.16 ppm, ^{13}C NMR. Coupling constants (*J*) are reported in Hertz. In the ^{13}C NMR spectra of aryl compounds containing boron (**3o-3q**) the resonance corresponding to the carbon adjacent to boron was not observed.[8]

Gas Chromatography

GC analyses were performed on an Agilent 7890A GC equipped with dual DB-5 columns (20 m × 180 µm × 0.18 µm), dual FID detectors, and hydrogen as the carrier gas. A sample volume of 1 µL was injected at a temperature of 300 °C and a 100:1 split ratio. The initial inlet pressure was 20.3 psi but varied as the column flow was held constant at 1.8 mL/min for the duration of the run. The initial oven temperature of 50 °C was held for 0.46 min followed by a temperature ramp of 65 °C/min up to 300 °C. The total run time was 5.0 min and the FID temperature was 325 °C.

GC/MS Analysis

GC/MS analyses were performed on a Shimadzu GCMS-QP2010 equipped with an RTX-5MS column (30 m × 0.25 mm × 0.25 µm) with a quadrupole mass analyzer using helium as the carrier gas. The analysis method used in all cases was 1 µL injection of sample, an injection temp of 250 °C, and a 20:1 split ratio. The initial inlet pressure was 8.1 psi, but varied as the column flow was held constant at 1.0 mL/min for the duration of the run. The interface temperature was held at 275 °C, and the ion source (EI^{+}, 30 eV) was held at 200 °C. The initial oven temperature was held at 60 °C for 1 min with the detector off, followed by a temperature ramp, with the detector on, to 300 °C at 20 °C/min. Total run time was 13.00 min.

Infrared Spectroscopy

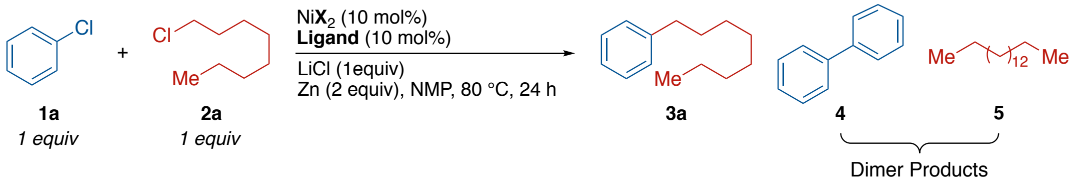
Infrared (IR) spectra were recorded on a Bruker Alpha Platinum ATR FT-IR spectrometer and are reported in wavenumbers (cm^{-1}).

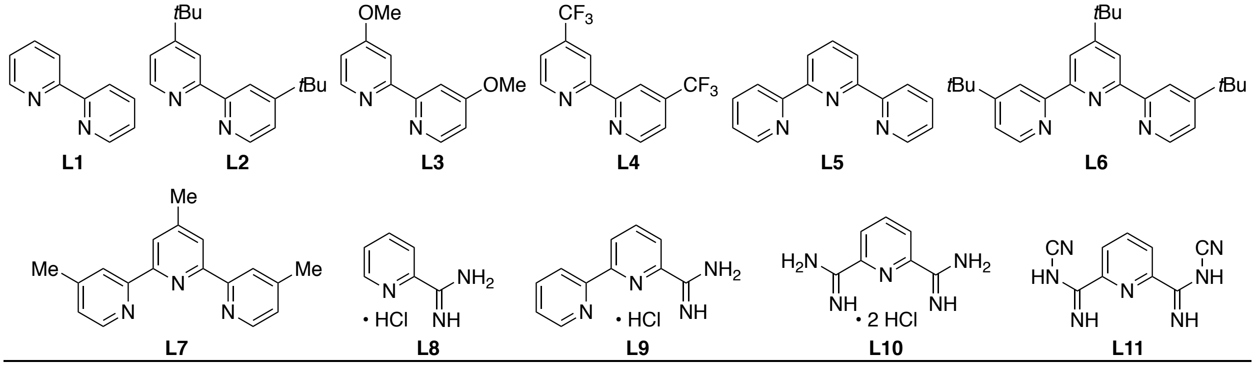
Chromatography

Chromatography was performed on silica gel (EMD, silica gel 60, particle size 0.040-0.063 mm) using standard flash techniques, on a Teledyne Isco Rf-200 (detection at 210 nm and 280 nm), or on a Biotage Isolera One (detection at 210 nm and 400 nm, on KPsil columns). Products were visualized by UV, PMA stain, or fractions were analyzed by GC.

2. Additional Optimization Tables

2.1 Figure S1. Ligand and Halide Effect on Selectivity.





Entry	Ligand	X	**3a** (%)	**4** (%)	**5** (%)
1	**L1**	Cl	2	48	1
		Br	10	43	6
		I	17	39	17
2	**L2**	Cl	2	50	3
		Br	8	41	4
		I	9	45	3
3	**L3**	Cl	3	37	9
		Br	10	35	10
		I	33	8	20
4	**L4**	Cl	1	49	0
		Br	2	42	1
		I	8	17	6
5	**L5**	Cl	10	0	25
		Br	6	1	36
		I	1	0	16
6	**L6**	Cl	38	28	16
		Br	22	26	19
		I	4	33	8
7	**L7**	Cl	9	9	28
		Br	31	20	8
		I	1	10	13
8	**L8**	Cl	16	19	6
		Br	43	11	4
		I	19	2	3
9	**L9**	Cl	10	0	4
		Br	19	0	32
		I	5	0	22

10	**L10**	Cl	11	0	0
		Br	62	0	2
		I	18	0	23
11	**L11**	Cl	46	1	7
		Br	65	0	9
		I	87	0	6

Reactions are carried out following the procedure described in **5.1 General Procedure for Reaction Optimization** (vide infra). A number of bidentate and tridentate amine ligands are tested along with different nickel precatalysts to examine the selectivity for the cross coupled product. Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

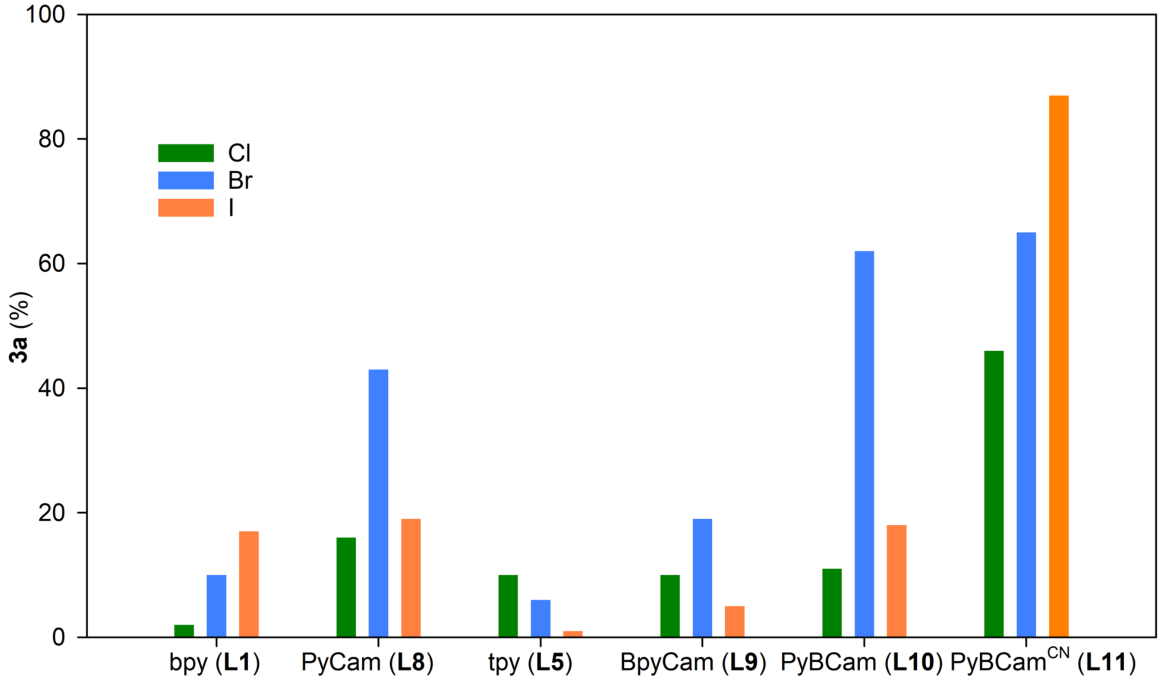
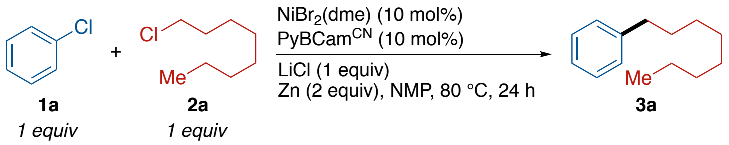


Chart S1. Bidentate and tridentate ligands on selectivity

A different representation of PyBcam and PyBCam^{CN} selectivity towards the cross-coupled product compared to bidentate and tridentate ligands. The numerical yields are reported in the table above.

2.2 Figure S2. Deletion Control Experiments.

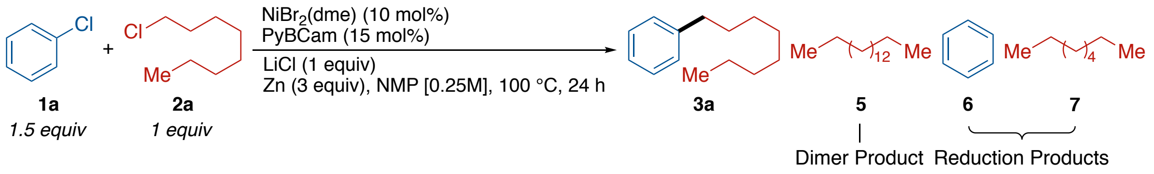


Entry	Deviation	Product (%)	Returned **1a** (%)	Returned **2a** (%)
1	No NiBr$_2$(dme)	0	99	86[a]
2	No Zn	0	105	107
3[a]	No LiCl	3	92	96

[a]We can not account for the small loss of chlorooctane in this reaction. Neither octane (hydrodehalogenation) or hexadecane (dimerization) could be detected by GC analysis. [b]Hydrodehalogenated arene **6** was observed in 7 %.

Reactions are carried out following the procedure described in **5.1 General Procedure for Reaction Optimization**. Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

2.3 Figure S3. Examination of Alternative Reductants and Additives.

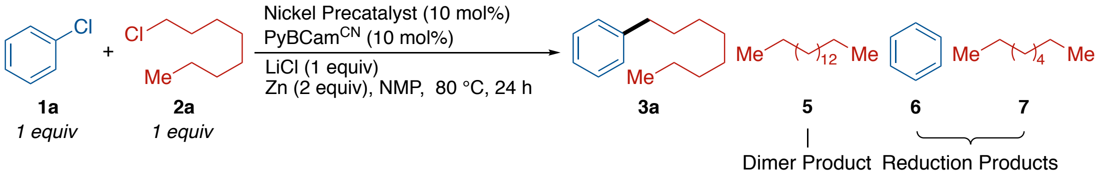


Entry	Deviation from above	**3a** (%)	**5** (%)	**6** (%)	**7** (%)	Returned **1a** (%)[a]	Returned **2a** (%)
1	TDAE instead of Zn	0	0	4	0	73	0
2	Mn instead of Zn	14	1	12	33	111	8
3	Mn and LiBr instead of Zn and LiCl[b]	4	13	8	30	80	0
4	LiBr instead of LiCl	42	24	24	8	68	0
5	MgCl$_2$ instead of LiCl	41	1	13	20	66	22

[a]Calculated with respect to mmole of alkyl chloride used. [b]Chlorobenzene (1 equiv) was used along with DIPEA (20 mol%). DIPEA had no effect on reaction outcome.

Reactions are carried out following the procedure described in **5.1 General Procedure for Reaction Optimization**. Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

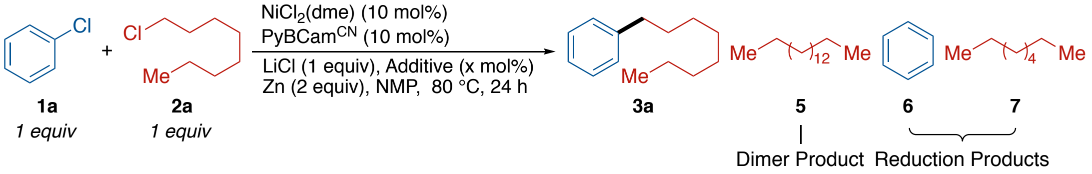
2.4 Figure S4. Halide Effect from Nickel Precatalyst.



Entry	Ni Precatalyst	**3a** (%)	**5** (%)	**6** (%)	**7** (%)	Returned **1a** (%)	Returned **2a** (%)
1	$NiCl_2$(dme)	44	7	30	0	21	40
2	$NiBr_2$(dme)	64	8	15	0	16	12
3	$NiBr_2$•$3H_2O$	68	8	22	0	7	12
4	$NiBr_2$ (anhydrous)	68	8	13	4	26	11
5	NiI_2•$4H_2O$	89	6	10	2	4	0
6	NiI_2 (anhydrous)	80	7	5	5	18	0

Reactions are carried out following the procedure described in **5.1 General Procedure for Reaction Optimization**. Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

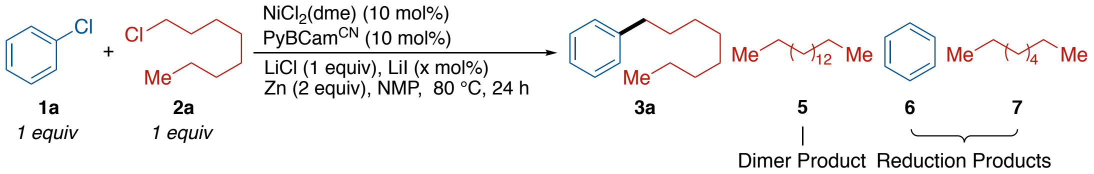
2.5 Figure S5. Effect of Various Halide Additives.



Entry	Additive (x mol%)	**3a** (%)	**5** (%)	**6** (%)	**7** (%)	Returned **1a** (%)	Returned **2a** (%)
1	No Additive	43	6	25	1	22	40
2	LiBr (20 mol%)	72	10	18	1	8	7
3	$ZnBr_2$ (10 mol%)	64	7	16	2	21	21
4	NBu_4Br (20 mol%)	72	10	19	2	11	8
5	LiI (20 mol%)	83	8	10	1	14	0
6	ZnI_2 (10 mol%)	79	7	4	4	21	1
7	NBu_4I (20 mol%)	83	8	10	2	12	0

Reactions are carried out following the procedure described in **5.1 General Procedure for Reaction Optimization**. Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

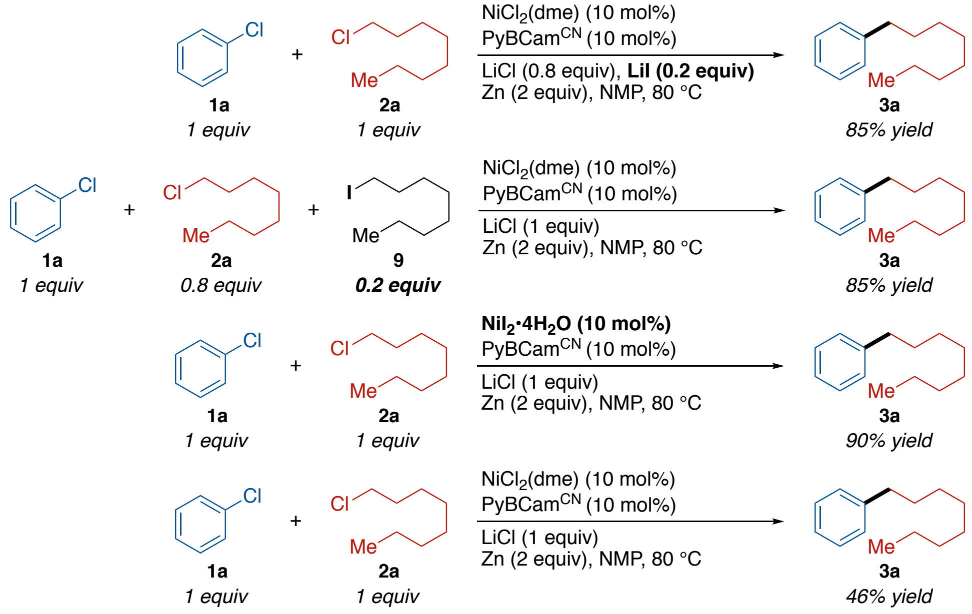
2.6 Figure S6. Optimization of Iodide Concentration.



Entry	LiI (x mol%)	**3a** (%)	**5** (%)	**6** (%)	**7** (%)	Returned **1a** (%)	Returned **2a** (%)
1	10	89	6	10	1	3	0
2	20	83	8	11	1	4	0
3	30	85	8	13	2	4	0
4	40	82	10	15	1	3	0
5	50	78	11	18	1	2	0
6	100	59	15	25	2	4	0

Reactions are carried out following the procedure described in **5.1 General Procedure for Reaction Optimization**. Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

2.7 Figure S7. Further Evidence for Iodide Co-Catalysis.



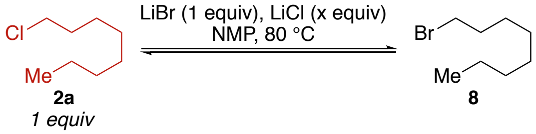
Reactions are carried out following the procedure described in **5.1 General Procedure for Reaction Optimization**. After 24 h of stirring the yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

3. Equilibrium Between Chlorooctane and Bromooctane

3.1 General procedure for equilibrium study

Reactions were set up in a N_2 filled glove box. To a 1-dram vial containing a PTFE-coated stirar was added the listed additives, alkyl halides, and NMP (1 mL). The reaction vials were sealed with a screw cap fitted with a PTFE-faced silicone septum. The reaction vials were then removed from the glovebox and allowed to stir (1250 RPM) in a reaction block at 80 °C. After stirring for the amount of time listed, 10 μL aliquots of reaction mixture were removed with a 50 μL gas-tight syringe and quenched with 200 μL of 1 M aqueous $NaHSO_4$, diluted with ether (1.5 mL), and filtered through a short silica pad in a pipette packed with glass wool. The filtrate was analyzed by GC.

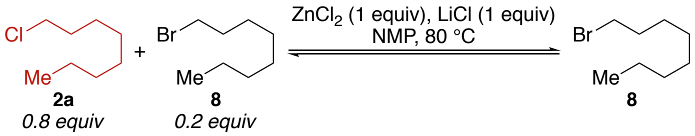
3.2 Figure S8. Effect of LiCl on the Equilibrium Between Chlorooctane and Bromooctane in the Presence of LiBr.



Entry	LiCl (x mol%)	Time	**2a** (%)	**8** (%)	**2a/8**
1	1	20 min	105	1	143
		40 min	107	1	126
		1 h	106	1	141
		2 h	108	1	136
		5 h	105	1	139
2	0	20 min	100	4	16
		40 min	100	4	15
		1 h	99	4	15
		2 h	100	4	15
		5 h	98	4	15

3.1 General procedure for equilibrium study was followed with LiBr (43.5 mg, 0.50 mmol, 1.0 equiv), LiCl (21.2 mg, 0.50 mmol, 1.0 equiv), and 1-chlorooctane (85.0 μL, 0.50 mmol, 1.0 equiv). Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

3.3 Figure S9. Effect of LiCl and $ZnCl_2$ on the Equilibrium Between Chlorooctane and Bromooctane.

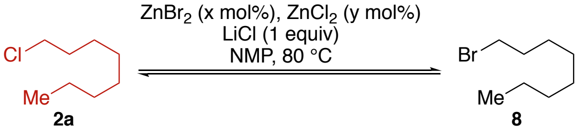


Entry	Conditions	Time	**2a** (%)[a]	**8** (%)[a]	**2a**/**8**	
1	Omit LiCl	20 min	86	13	4	Equilibrium established slowly
		40 min	86	13	4	
		1 h	85	12	4	
		2 h	86	12	5	
		8 h	81	10	5	
2	Omit $ZnCl_2$	0 min	110	2	45	Fast equilibration
		5 min	108	0	n/a	
		10 min	111	0	n/a	
		15 min	107	0	n/a	
		20 min	110	0	n/a	
		40 min	106	0	n/a	
		1 h	107	0	n/a	
		2 h	107	0	n/a	
		8 h	108	0	n/a	
3	No deviations	0 min	94	15	4	Equilibration takes >20 min
		5 min	94	8	7	
		10 min	99	5	12	
		15 min	99	4	16	
		20 min	104	3	22	
		40 min	107	1	63	
		1 h	105	1	105	
		2 h	104	1	128	
		8 h	102	<1	132	

[a] Calculated based on the overall mmol of halooctane (0.5 mmol total).

3.1 General procedure for equilibrium study was followed with $ZnCl_2$ (68.2 mg, 0.50 mmol, 1.0 equiv), LiCl (21.2 mg, 0.50 mmol, 1.0 equiv), 1-chlorooctane (68.0 μL, 0.4 mmol, 0.8 equiv), and 1-bromooctane (17.3 μL, 0.1 mmol, 0.2 equiv). Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

3.4 Figure S10. Equilibrium Between Chlorooctane and Bromooctane Under Mock Catalytic Conditions at Different Levels of Conversion.



2a
1 equiv

8

TON	Analytical Additive Amounts	Experimental Additive Amounts
0^a	100 mol% LiCl	LiCl (21.2 mg, 0.50 mmol)
0^b	10 mol% $ZnBr_2$	$ZnBr_2$ (11.3 mg, 0.05 mmol)
	100 mol% LiCl	LiCl (21.2 mg, 0.50 mmol)
1	10 mol% $ZnBr_2$	$ZnBr_2$ (11.3 mg, 0.05 mmol)
	10 mol% $ZnCl_2$	$ZnCl_2$ (6.9 mg, 0.05 mmol)
	100 mol% LiCl	LiCl (21.2 mg, 0.50 mmol)
10	10 mol% $ZnBr_2$	$ZnBr_2$ (11.3 mg, 0.05 mmol)
	90 mol% $ZnCl_2$	$ZnCl_2$ (61.4 mg, 0.45 mmol)
	100 mol% LiCl	LiCl (21.2 mg, 0.50 mmol)

[a]Prior to the reduction of $NiBr_2$(dme) pre-catalyst to Ni(0) by Zn. [b]Following the $NiBr_2$(dme) pre-catalyst reduction by Zn

3.1 General procedure for equilibrium study was followed with 1-chlorooctane (85.0 μL, 0.50 mmol, 1.0 equiv) and the experimental additive amounts given in Figure S10. The amounts of LiCl, $ZnBr_2$, and $ZnCl_2$ used in this experiment are based on the proposed catalytic cycle below in Figure S17. Only LiCl is present before the reduction of $NiBr_2$(dme) pre-catalyst by Zn. The use of 10 mol% of $ZnBr_2$ mimicks the catatlytic conditions after the initial reduction of 10 mol% of $NiBr_2$(dme) pre-catalyst to Ni(0) by Zn before the first turnover. After the first turn over, 10 mol% of $ZnBr_2$ and 10 mol% $ZnCl_2$ would be present following the reduction of (**L**)$NiCl_2$. At the usual catalyst loading, complete product formation would be at ten turnovers.

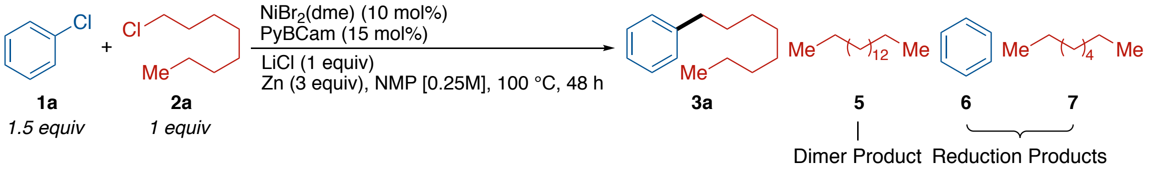
Entry	TON		20 min	40 min	1 h	2 h	5 h	7 h
1	0^a	**2a** (%)	109	107	101	105	109	105
		8 (%)	0	0	0	0	0	0
		2a/**8**	n/a	n/a	n/a	n/a	n/a	n/a
2	0^b	**2a** (%)	102	101	101	102	103	102
		8 (%)	0	0	0	0	0	0
		2a/**8**	n/a	n/a	n/a	n/a	n/a	n/a
3	1	**2a** (%)	104	102	99	101	101	100
		8 (%)	0	0	0	0	0	0
		2a/**8**	n/a	n/a	n/a	n/a	n/a	n/a
4	10	**2a** (%)	104	104	103	103	101	103
		8 (%)	1	1	1	1	1	1
		2a/**8**	177	126	109	96	96	96
5	0^b	**2a** (%)	105	105	105	107	106	96^c
	(Omit LiCl)	**8** (%)	0	0	0	0	0	0^c

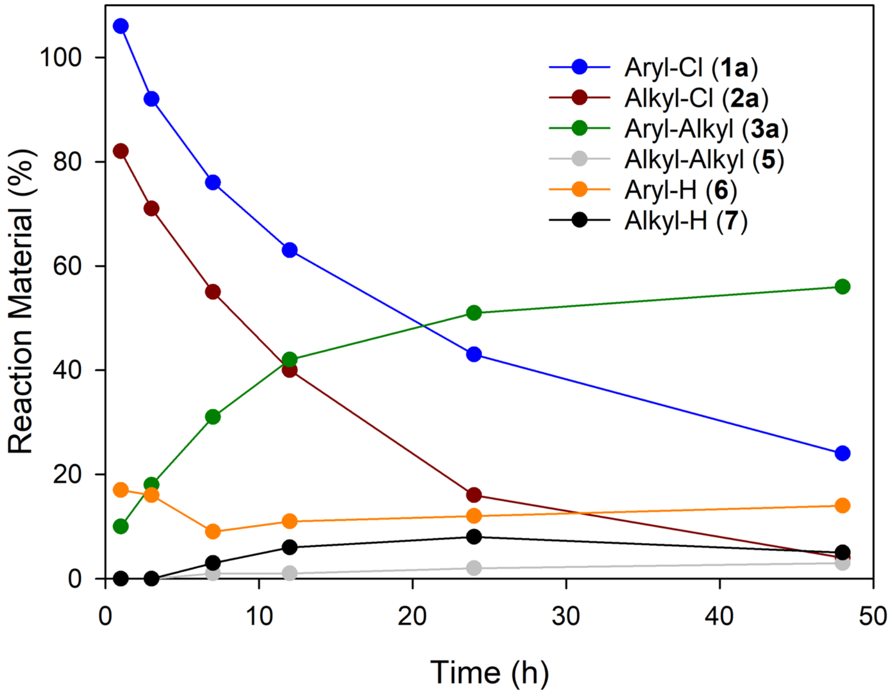
		2a/8	n/a	n/a	n/a	n/a	n/a	n/a
6	1 (Omit LiCl)	**2a** (%)	107	106	106	108	105	97[c]
		8 (%)	0	0	0	0	0	0[c]
		2a/8	n/a	n/a	n/a	n/a	n/a	n/a
7	10 (Omit LiCl)	**2a** (%)	106	107	107	108	105	93[c]
		8 (%)	0	0	0	0	0	0[c]
		2a/8	n/a	n/a	n/a	n/a	n/a	n/a

[a]Prior to the reduction of $NiBr_2$(dme) pre-catalyst to Ni(0) by Zn.[b]Following the $NiBr_2$(dme) pre-catalyst reduction by Zn. [c]Recorded at 24 h.

Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

3.5 Figure S11. Reaction Timecourse with Catalytic Amount of Bromide.

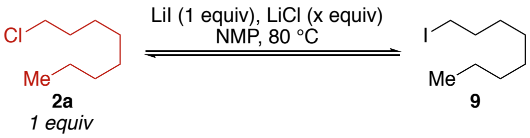




Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

4. Equilibrium Between Chlorooctane and Iodooctane

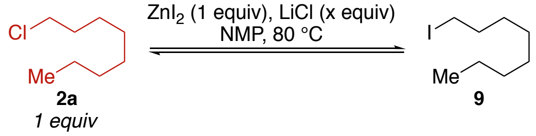
4.1 Figure S12. Effect of LiCl on the Equilibrium Between Chlorooctane and Iodooctane in the Presence of LiI.



Entry	LiCl (x mol%)	Time	**2a** (%)	**9** (%)	**2a/9**
1	1	1 min	100	0	n/a
		20 min	104	0	n/a
		40 min	104	0	n/a
		1 h	104	0	n/a
		2 h	106	0	n/a
		7 h	98	0	n/a
2	0	1 min	95	1	118
		20 min	95	1	100
		40 min	98	1	106
		1 h	98	1	99
		2 h	100	1	95
		7 h	97	1	96

3.1 General procedure for equilibrium study was followed with LiI (67.0 mg, 0.50 mmol, 1.0 equiv), LiCl (21.2 mg, 0.50 mmol, 1.0 equiv), and 1-chlorooctane (85.0 μL, 0.50 mmol, 1.0 equiv). Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

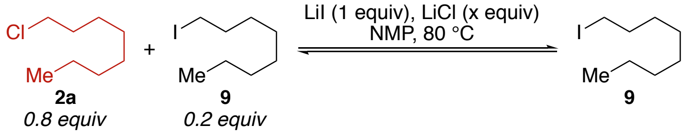
4.2 Figure S13. Effect of LiCl on the Equilibrium Between Chlorooctane and Iodooctane in the Presence of ZnI₂.



Entry	LiCl (x equiv)	Time	**2a** (%)	**9** (%)	**2a/9**
1	1	1 min	97	2	64
		20 min	86	12	7
		40 min	83	22	4
		1 h	75	27	3
		2 h	68	32	2
		7 h	69	33	2
2	0	1 min	100	0	n/a
		20 min	103	0	n/a
		40 min	104	1	195
		1 h	100	1	122
		2 h	102	2	65
		7 h	96	4	22

3.1 General procedure for equilibrium study was followed with ZnI_2 (159.6 mg, 0.50 mmol, 1.0 equiv), LiCl (21.2 mg, 0.50 mmol, 1.0 equiv), and 1-chlorooctane (85.0 μL, 0.50 mmol, 1 equiv). Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

4.3 Figure S14. LiCl Effect on the Equilibrium Between Chlorooctane and Iodooctane in the Presence of LiI.

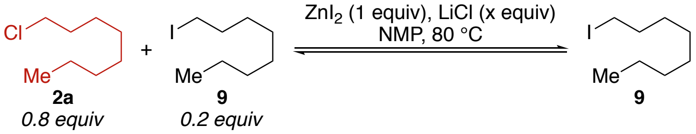


Entry	LiCl (x equiv)	Time	**2a** (%)[a]	**9** (%)[a]	**2a**/**9**
1	1.0	1 min	100	0	n/a
		20 min	99	0	n/a
		40 min	102	0	n/a
		1 h	110	0	n/a
		2 h	101	0	n/a
		7 h	92	0	n/a
2	0	1 min	80	20	4
		20 min	78	18	4
		40 min	80	20	4
		1 h	77	17	4
		2 h	78	20	4
		7 h	76	18	4

[a] Calculated based on the overall mmol of halooctane (0.5 mmol total).

3.1 General procedure for equilibrium study was followed with LiI (67.0 mg, 0.50 mmol, 1.0 equiv), LiCl (21.2 mg, 0.50 mmol, 1.0 equiv), 1-chlorooctane (68.0 μL, 0.4 mmol, 0.8 equiv), and 1-iodooctane (18.1 μL, 0.1 mmol, 0.2 equiv). Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

4.4 Figure S15. LiCl Effect on the Equilibrium Between Chlorooctane and Iodooctane in the Presence of ZnI_2.

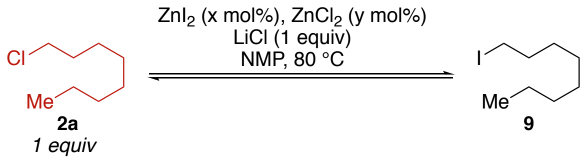


Entry	LiCl (x equiv)	Time	**2a** (%)[a]	**9** (%)[a]	**2a/9**
1	1.0	1 min	79	19	4
		20 min	71	22	3
		40 min	68	28	2
		1 h	62	27	2
		2 h	61	34	2
		7 h	56	32	2
2	0	1 min	80	20	4
		20 min	80	18	4
		40 min	82	19	4
		1 h	78	16	5
		2 h	79	18	4
		7 h	72	18	4

[a] Calculated based on the overall mmol of halooctane (0.5 mmol total).

3.1 General procedure for equilibrium study was followed with ZnI_2 (159.6 mg, 0.50 mmol, 1.0 equiv), LiCl (21.2 mg, 0.50 mmol, 1.0 equiv), 1-chlorooctane (68.0 μL, 0.4 mmol, 0.8 equiv), and 1-iodooctane (18.1 μL, 0.1 mmol, 0.2 equiv). Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

4.5 Figure S16. Equilibrium Between Chlorooctane and Iodooctane Under Mock Catalytic Conditions at Different Turnover Numbers (TON).



TON	Analytical Additive Amounts	Experimental Additive Amounts
0[a]	100 mol% LiCl	LiCl (21.2 mg, 0.50 mmol)
0[b]	10 mol% ZnI_2 100 mol% LiCl	ZnI_2 (16.0 mg, 0.05 mmol) LiCl (21.2 mg, 0.50 mmol)
1	10 mol% ZnI_2 10 mol% $ZnCl_2$ 100 mol% LiCl	ZnI_2 (16.0 mg, 0.05 mmol) $ZnCl_2$ (6.9 mg, 0.05 mmol) LiCl (21.2 mg, 0.50 mmol)
10	10 mol% ZnI_2 90 mol% $ZnCl_2$ 100 mol% LiCl	ZnI_2 (16.0 mg, 0.05 mmol) $ZnCl_2$ (61.4 mg, 0.45 mmol) LiCl (21.2 mg, 0.50 mmol)
20	10 mol% ZnI_2 190 mol% $ZnCl_2$ 100 mol% LiCl	ZnI_2 (16.0 mg, 0.05 mmol) $ZnCl_2$ (129.5 mg, 0.95 mmol) LiCl (21.2 mg, 0.50 mmol)

[a] Prior to the reduction of $NiI_2•4H_2O$ pre-catalyst to Ni(0) by Zn. [b] Following the $NiI_2•4H_2O$ pre-catalyst reduction by Zn

3.1 General procedure for equilibrium study was followed with 1-chlorooctane (85.0 μL, 0.50 mmol, 1.0 equiv) and the experimental additive amounts given in Figure S16. The amounts of LiCl, ZnI_2, and $ZnCl_2$ used in this experiment are based on the proposed catalytic cycle below in Figure S17. Only LiCl is present before the reduction of $NiI_2•4H_2O$ pre-catalyst by Zn. The use of 10 mol% of ZnI_2 mimicks the catatlytic conditions after the initial reduction of 10 mol% of $NiI_2•4H_2O$ pre-catalyst to Ni(0) by Zn before the first turnover. After the first turn over, 10 mol% of ZnI_2 and 10mol% $ZnCl_2$ would be present following the reduction of (**L**)$NiCl_2$. At the usual catalyst loading, complete product formation would be at ten turnovers. To probe how excess $ZnCl_2$ affects the equilibrium, 190 mol% of $ZnCl_2$ was employed.

Entry	TON		1 min	20 min	40 min	1 h	2 h	7 h
1	0[a]	**2a** (%)	102	111	105	104	104	106
		9 (%)	0	0	0	0	0	0
		2a/9	n/a	n/a	n/a	n/a	n/a	n/a
2	0[b]	**2a** (%)	103	102	103	104	103	102
		9 (%)	0	0	0	0	0	0
		2a/9	n/a	n/a	n/a	n/a	n/a	n/a
3	1	**2a** (%)	107	106	104	104	105	102
		9 (%)	0	0	0	0	0	0
		2a/9	n/a	n/a	n/a	n/a	n/a	n/a
4	10	**2a** (%)	95	97	98	97	99	94

		9 (%)	1	1	1	1	1	1
		2a/9	157	70	68	67	67	66
5	20	**2a** (%)	105	102	105	104	104	99
		9 (%)	0	1	1	1	2	2
		2a/9	n/a	181	113	85	66	60

[a]Prior to the reduction of NiI_2•$4H_2O$ pre-catalyst to Ni(0) by Zn. [b]Following the NiI_2•$4H_2O$ pre-catalyst reduction by Zn.

Yields are determined by GC analysis calibrated against 1,3,5-trimethoxybenzene as an internal standard.

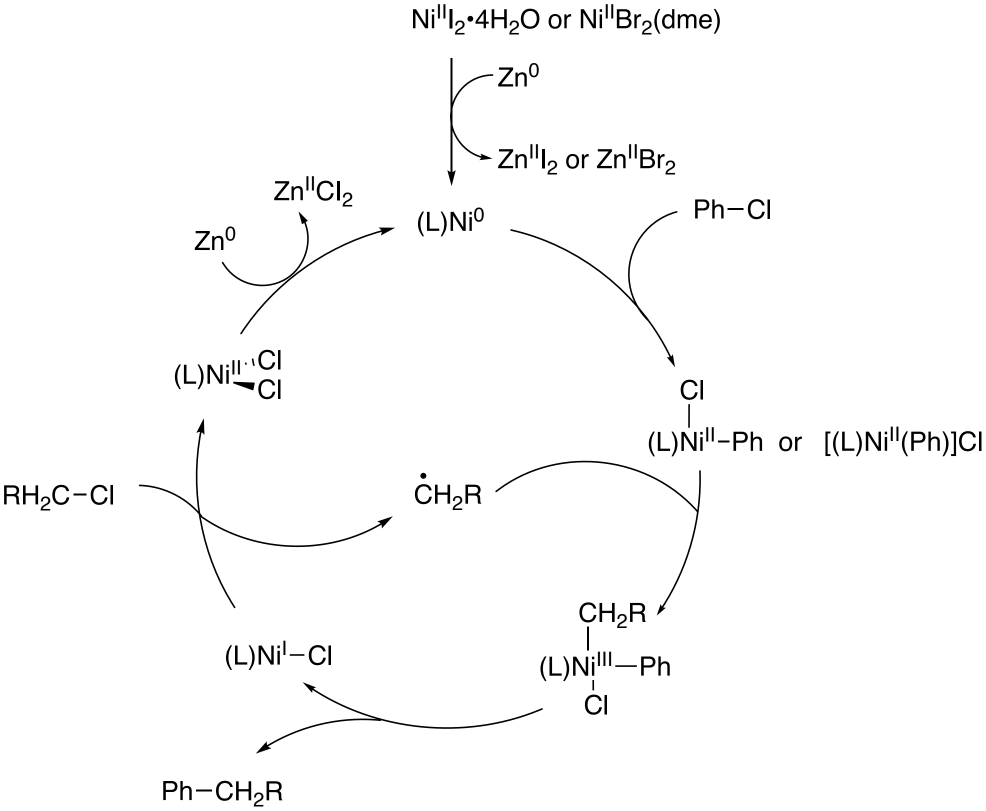
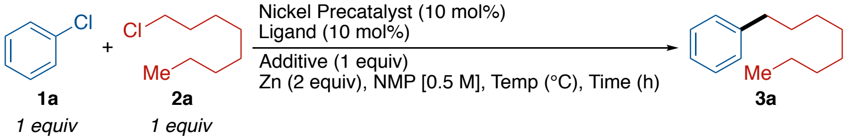


Figure S17. Proposed catalytic cycle based on previous work on cross-electrophile coupling of aryl halides with alkyl halides.[9] At this time we do not have evidence that nickel(0) is formed under these reactions. An alternative mechanism based upon nickel(I) could also be proposed, for example as recently reported by Diao.[10]

5. General Procedures

5.1 General Procedure for Reaction Optimization.



Reactions were set up in a N_2 filled glove box. A catalyst solution was prepared by charging an oven dried scintillation vial with a PTFE-coated stirbar, the listed nickel source (0.05 mmol, 10 mol%) and the listed ligand (0.05 mmol, 10 mol%). The solids were dissolved in NMP (1 mL) and allowed to stir for one hour. A second oven-dried 1-dram vial with a PTFE-coated stirbar was charged with the listed additive (0.50 mmol, 1.0 equiv), chlorobenzene (51.0 μL, 0.50 mmol, 1.0 equiv), 1-chlorooctane (85.0 μL, 0.50 mmol, 1 equiv), and 1,3,5-trimethoxybenzene (7.4 mg, 0.044 mmol) as an internal standard. This was dissolved in 1 mL of the prepared catalyst solution before the zinc (65.4 mg, 1.0 mmol, 2.0 equiv) was added. The reactions were sealed with a screw cap fitted with a PTFE-faced silicone septum. The reaction vial was then removed from the glovebox and allowed to stir (1250 RPM) at the listed temperature for the listed reaction time.

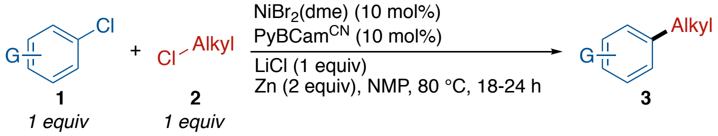
GC Analysis

The reactions were monitored by GC analysis, by taking a 10 μL aliquot of the crude reaction mixture with a gas-tight syringe. The aliquot was diluted with Et_2O (0.50 mL), quenched with 200 μL $NaHSO_4$, filtered through a 2-cm silica plug in a Pasteur pipette, and collected in a GC vial. The resulting solution was analyzed by GC and yields were determined based on the peak area of the analyte compared to 1,3,5-trimethoxybenzene as an internal standard.

Isolation and Purification

Reactions were isolated on a 0.5 mmol scale of chlorobenzene and 1-chlorooctane. The crude reaction mixture was filtered through celite, the celite was washed with acetone (3 × 4 mL), and the combined filtrate was concentrated by rotary evaporation. The crude mixture was diluted with Et_2O (40 mL) and washed with DI water (40 mL). The aqueous layer was extracted with Et_2O (3 × 20 mL), the organic layers were combined, dried over $MgSO_4$, filtered, and the filtrate was concentrated by rotary evaporation. The crude mixture was purified by column chromatography (80:1 pentane/Et_2O) to provide octylbenzene as a clear oil.

5.2 General Procedure A.



Reactions were set up in a N_2 filled glove box. For a preparative-scale benchtop procedure, see **5.4. Preparative-Scale Benchtop Procedure**. A catalyst solution was prepared by charging an oven dried scintillation vial with a PTFE-coated stirbar, $NiBr_2$(dme) (15.4 mg, 0.05 mmol, 10 mol%) and PyBCam^{CN} (10.7 mg, 0.05 mmol, 10 mol%). The solids were dissolved in NMP (1 mL) and allowed to stir for 30 min-1 h forming a homogenous, forest green solution. However, omitting the $NiBr_2$(dme) and ligand pre-stir did not impact productive catalysis. A second oven-dried 1-dram vial with a PTFE-coated stirbar was charged with LiCl (21.2 mg, 0.50 mmol, 1.0 equiv), the appropriate aryl chloride (0.50 mmol, 1.0 equiv), alkyl chloride (0.125 mmol, 0.25 equiv), and 1,3,5-trimethoxybenzene (7.4 mg, 0.044 mmol) as an internal standard. This was dissolved in 1 mL of the prepared catalyst solution before the zinc (65.4 mg, 1.0 mmol, 2.0 equiv) was added. The reactions were sealed with a screw cap fitted with a PTFE-faced silicone septum before being removed from the glovebox. The reaction was allowed to stir at 80 °C for 1 h. Using a syringe, N_2 sparged alkyl chloride (0.125 mmol, 0.25 equiv) was added every hour until a total of 0.5 mmol (1.00 equiv) of alkyl chloride was added to the reaction. After these additions the reaction was allowed to stir (1250 RPM) at 80 °C for a total of 18-24 h.

GC Analysis

The reactions were monitored by GC analysis, by taking a 10 μL aliquot of the crude reaction mixture with a gas-tight syringe. The aliquot was diluted with Et_2O (0.50 mL), quenched with 200 μL $NaHSO_4$, filtered through a 2-cm silica plug in a Pasteur pipette, and collected in a GC vial. The resulting solution was analyzed by GC and yields were determined based on the peak area of the analyte compared to 1,3,5-trimethoxybenzene as an internal standard.

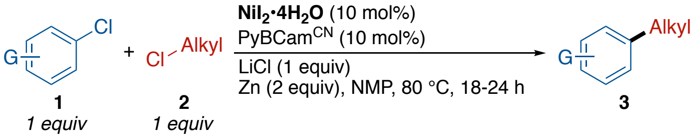
Isolation and Purification

Purification A. Reactions were isolated on a 0.5 mmol scale of aryl chloride and alkyl chloride without the addition of an internal standard to avoid difficulties in separating 1,3,5-trimethoxybenzene from the desired product. The crude reaction mixture was diluted with EtOAc (5 mL) and slurried with 1-3 g of silica gel before the volatile solvents were removed by rotary evaporation. The resulting dry-loaded product was purified by column chromatography on silica to provide the desired products.

Purification B. Reactions were isolated on a 0.5 mmol scale of aryl chloride and alkyl chloride without the addition of an internal standard to avoid difficulties in separating 1,3,5-trimethoxybenzene from the desired product. The crude reaction mixture was filtered through celite, the celite was washed with acetone (3 × 4 mL), and combined filtrate was concentrated by rotary evaporation. The crude mixture was diluted with Et_2O (40 mL) and washed with DI water (40 mL). The aqueous layer was extracted with Et_2O (3 × 20 mL), the organic layers were combined, dried over $MgSO_4$, filtered, and the filtrate was concentrated by rotary evaporation. The crude mixture was purified by column chromatography on silica to provide the desired products.

NOTE: There was no difference in yield when comparing **Purification A** and **Purification B**.

5.3 General Procedure B.

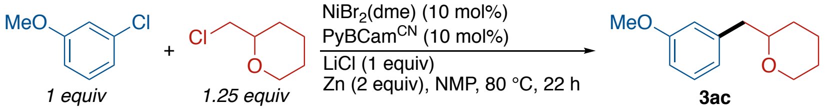


Reactions were set up in a N_2 filled glove box. A catalyst solution was prepared by charging an oven dried scintillation vial with a PTFE-coated stirbar, $NiI_2\bullet 4H_2O$ (19.3 mg, 0.05 mmol, 10 mol%) and PyBCam^{CN} (10.7 mg, 0.05 mmol, 10 mol%). The solids were dissolved in NMP (1 mL) and allowed to stir for 30 min-1 h forming a homogenous, dark yellow solution. A second oven-dried 1-dram vial with a PTFE-coated stirbar was charged with LiCl (21.2 mg, 0.50 mmol, 1.0 equiv), the appropriate aryl chloride (0.50 mmol, 1.0 equiv), alkyl chloride (0.50 mmol, 1.0 equiv), and 1,3,5-trimethoxybenzene (7.4 mg, 0.044 mmol) as an internal standard. This was dissolved in 1 mL of the prepared catalyst solution before the zinc (65.4 mg, 1.0 mmol, 2.0 equiv) was added. The reactions were sealed with a screw cap fitted with a PTFE-faced silicone septum before being removed from the glovebox. The reaction was allowed to stir (1250 RPM) at 80 °C for 18-24 h.

GC Analysis
Same as **Procedure A** as noted above.

Isolation and Purification
Purification B as noted above.

5.4 Preparative-Scale Benchtop Procedure.



A catalyst solution was prepared on the benchtop by charging a scintillation vial with a PTFE-coated stirbar, $NiBr_2$(dme) (216 mg, 0.701 mmol, 10 mol%), PyBCam^{CN} (149.4 mg, 0.701 mmol, 10 mol%) with no effort to avoid exposure to air. The scintillation vial was capped with a septa and evacuated before being backfilled with N_2. N_2 sparged NMP (9 mL) was added to the scintillation vial and the solution allowed to stir at rt for 10 min resulting in a clear, homogeneous, forest green solution. A Schlenk flask was fitted with an addition funnel and flame dried under vacuum before being backfilled with N_2. The addition funnel was removed and LiCl (297 mg, 7.01 mmol, 1.0 equiv), 3-chloroanisole (1.00 g, 7.01 mmol, 1.0 equiv), and zinc (917 mg, 14.0 mmol, 2.0 equiv) were added to the Schlenk flask. The addition funnel was replaced and the reaction evacuated and backfilled with N_2. The catalyst solution was transferred to the reaction via syringe under N_2 and the addition funnel was charged with 2-(chloromethyl)tetrahydropyran (1.18 g, 8.76 mmol, 1.25 equiv), and NMP (5 mL). The reaction vessel was lowered into a pre-heated 80 °C oil bath resulting in a color change from forest green to dark brown and the alkyl chloride solution was added dropwise to the stirring solution over 2 h. After this addition, the reaction was allowed to stir (500 RPM) at 80 °C for an additional 20 h.

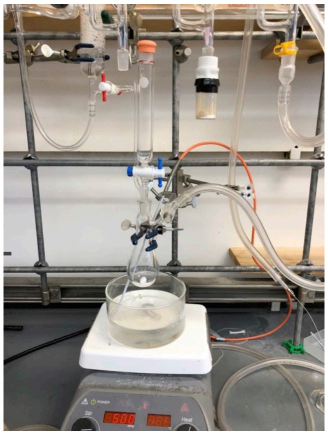


Image 1. Reaction setup with solids weighed into flask to form catalyst

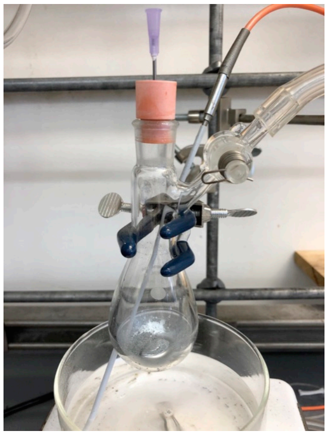


Image 2. Addition of LiCl, aryl chloride, and zinc flake.

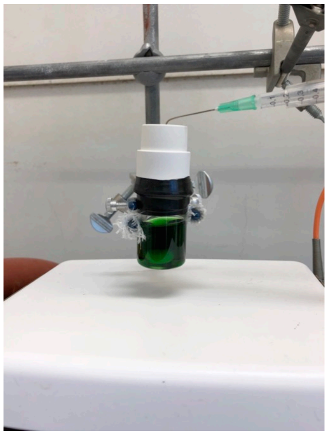


Image 3. Completed catalyst solution.


Image 4. Reaction after addition of the catalyst solution via syringe under N_2.


Image 5. Reaction setup prior to dropwise addition (11:30 am).

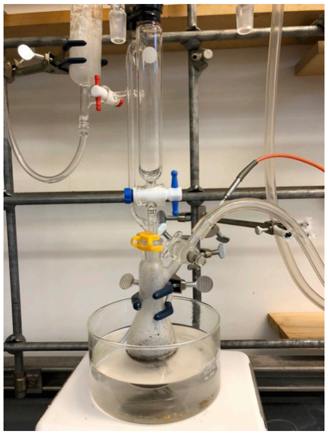
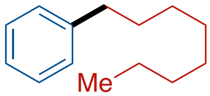


Image 6. Reaction after completion of the dropwise addition (1:35 pm).

The reaction was cooled to room temperature and diluted with Et_2O (60 mL) before being washed with a solution of saturated brine (60 mL). The Et_2O layer collected and the aqueous layer was extracted with Et_2O (3 × 30 mL). The combined organic layers were dried over $MgSO_4$, filtered, and the filtrate was concentrated by rotary evaporation. The resulting crude material was diluted with EtOAc and slurried with silica gel before the volatile solvents were removed by rotary evaporation. The resulting dry-loaded product was purified by column chromatography on silica to afford 2-(3-methoxybenzyl)tetrahydropyran (**3ac**) as a clear, colorless oil (915 mg, 63% yield).

6. Specific Procedures and Product Characterization



Octylbenzene (3a) [CAS: 2189-60-8]

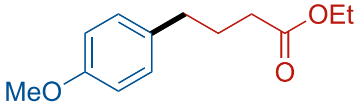
General Procedure A was followed with chlorobenzene (54.8 mg, 0.49 mmol, 1 equiv) and 1-chlorooctane (72.5 mg, 0.49 mmol, 1.0 equiv). After 24 h, the reaction was quenched following Purification B and the crude material was purified by chromatography (hexanes) to afford the product (76.1 mg, 82% yield) as a colorless oil. Characterization data matched those reported in the literature.[11]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.28 (m, 2H), 7.18 (m, 3H), 2.61 (t, J = 7.8 Hz, 2H), 1.62 (quint, J = 7.4 Hz, 2H), 1.38 – 1.21 (m, 10H), 0.89 (t, J = 6.3 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 143.0, 128.4, 128.2, 125.5, 36.0, 31.9, 31.5, 29.5, 29.4, 29.3, 22.7, 14.1.

HRMS (ESI) $[M]^+$ m/z calcd for $C_{14}H_{22}^+$ 190.1716, ASAP-MS found 190.1715.

IR (cm^{-1}) 3061, 2923, 2853, 1494, 741, 696.



Ethyl 4-(4-anisole)butyrate (3b) [CAS: 4586-89-4]

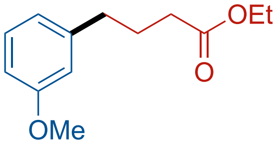
A modified General Procedure A was followed with 4-chloroanisole (71.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (17.5 μL/h (0.125 mmol/h), 0.625 mmol in total, 1.25 equiv). After a total of 19 h, the reaction mixture was filtered through silica gel with 5:1 pentane/Et_2O and the filtrate was concentrated by rotary evaporation. The resulting residue was purified by column chromatography (gradient from 40:1 pentane/Et_2O to 20:1 pent/Et_2O) to afford the product (70.6 mg, 64% yield) as a colorless oil. This procedure was repeated to establish its reproducibility and the second reaction provided the product (76.8 mg, 69% yield) in similar yield. Characterization data matched those reported in the literature.[12]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.10 (d, J = 8.6 Hz, 2H), 6.83 (d, J = 8.6 Hz, 2H), 4.13 (q, J = 7.1 Hz, 2H), 3.78 (s, 3H), 2.60 (t, J = 7.6 Hz, 2H), 2.31 (t, J = 7.5 Hz, 2H), 1.92 (quint, J = 7.5 Hz, 2H), 1.25 (t, J = 7.1 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 173.6, 158.0, 133.6, 129.5, 113.9, 60.3, 55.3, 34.3, 33.7, 26.9, 14.3.

HRMS (ESI) $[M+Na]^+$ m/z calcd for $C_{13}H_{18}O_3Na^+$ 245.1148, found 245.1145.

IR (cm^{-1}) 2937, 2835, 1730, 1612, 1512, 1243, 1176, 1034, 811.



Ethyl 4-(3-anisole)butyrate (3c) [CAS: 57816-01-0]

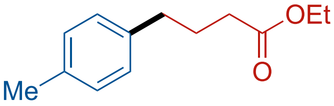
A modified General Procedure A was followed with 3-chloroanisole (71.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (17.5 μL/h (0.125 mmol/h), 0.625 mmol in total, 1.25 equiv). After a total of 24 h, the reaction mixture was filtered through silica gel with 10:1 pentane/EtOAc and the filtrate was concentrated by rotary evaporation. The resulting residue was purified by column chromatography (50:1 pentane/EtOAc) to afford the product (96.8 mg, 87% yield) as a colorless oil. Characterization data matched those reported in the literature.[12]

^{1}H NMR (500 MHz, CDCl$_3$) δ 7.20 (td, *J* = 7.3, 1.9 Hz, 1H), 6.83 – 6.68 (m, 3H), 4.13 (q, *J* = 7.2 Hz, 2H), 3.80 (s, 3H), 2.63 (t, *J* = 7.6 Hz, 2H), 2.32 (t, *J* = 7.5 Hz, 2H), 1.96 (quint, *J* = 7.5 Hz, 2H), 1.26 (t, *J* = 7.1 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, CDCl$_3$) δ 173.6, 159.7, 143.2, 129.4, 121.0, 114.3, 111.4, 60.3, 55.2, 35.3, 33.7, 26.5, 14.3.

HRMS (ESI) [M+Na]$^+$ m/z calcd for $C_{13}H_{18}O_3Na^+$ 245.1148, found 245.1144.

IR (cm^{-1}) 2941, 1730, 1258, 1151, 1038, 776, 695.



Ethyl 4-(4-tolyl)butyrate (3d) [CAS: 36440-63-8]

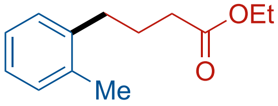
General Procedure A was followed with 4-chlorotoluene (63.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (4 × 17.5 μL, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total of 24 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (50:1 pentane/EtOAc) to afford the product (63.4 mg, 61% yield) as a colorless oil. Characterization data matched those reported in the literature.[13]

^{1}H NMR (500 MHz, CDCl$_3$) δ 7.14 – 7.06 (m, 4H), 4.14 (q, *J* = 7.1 Hz, 2H), 2.63 (t, *J* = 7.6 Hz, 2H), 2.36 – 2.29 (m, 5H), 1.95 (quint, *J* = 7.5 Hz, 2H), 1.27 (t, *J* = 7.1 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, CDCl$_3$) δ 173.6, 138.4, 135.5, 129.1, 128.5, 60.3, 34.8, 33.8, 26.8, 21.1, 14.4.

HRMS (ESI) [M+Na]$^+$ m/z calcd for $C_{13}H_{18}O_2Na^+$ 229.1199, found 229.1196.

IR (cm^{-1}) 2925, 1732, 1515, 1143, 782.



Ethyl 4-(2-tolyl)butyrate (3e) [CAS: 105986-51-4]

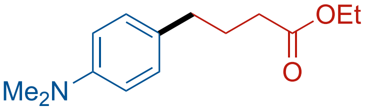
General Procedure A was followed with 2-chlorotoluene (63.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (4 × 17.5 μL, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total 24 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (50:1 pentane/EtOAc) to afford the product (15.6 mg, 15% yield) as a colorless oil. Characterization data matched those reported in the literature.[12]

^{1}H NMR (500 MHz, CDCl$_3$) δ 7.19 – 7.07 (m, 4H), 4.14 (q, J = 7.1 Hz, 2H), 2.69 – 2.59 (m, 2H), 2.37 (t, J = 7.4 Hz, 2H), 2.32 (s, 3H), 1.91 (dq, J = 9.7, 7.5 Hz, 2H), 1.26 (t, J = 7.1 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, CDCl$_3$) δ 173.7, 139.8, 136.1, 130.4, 129.1, 126.2, 126.1, 60.4, 34.1, 32.7, 25.5, 19.4, 14.4.

HRMS (ESI) [M+NH$_4$]$^+$ m/z calcd for $C_{13}H_{22}O_2N^+$ 224.1645, found 224.1642.

IR (cm^{-1}) 2938, 2868, 1731, 1148, 740.



Ethyl 4-(4-(dimethylamino)phenyl)butanoate (3f) [CAS: 1365610-67-8]

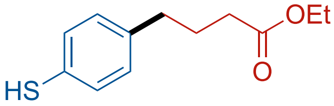
General Procedure A was followed with 4-chloro-*N*,*N*-dimethylaniline (77.8 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (4 × 17.5 μL, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total of 24 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (20:1 pentane/EtOAc) to afford the product (85.0 mg, 72% yield) as a colorless oil. Characterization data matched those reported in the literature.[12]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.07 (d, *J* = 8.6 Hz, 2H), 6.71 (d, *J* = 8.6 Hz, 2H), 4.13 (q, *J* = 7.1 Hz, 2H), 2.92 (s, 6H), 2.57 (t, *J* = 7.6 Hz, 2H), 2.32 (t, *J* = 7.6 Hz, 2H), 1.92 (quint, *J* = 7.7 Hz, 2H), 1.26 (t, *J* = 7.1 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 173.8, 149.2, 129.7, 129.2, 113.1, 60.3, 41.0, 34.2, 33.8, 27.0, 14.4.

HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{14}H_{22}NO_2^+$ 236.1645, found 236.1641.

IR (cm^{-1}) 2979, 2936, 2800, 1730, 1615, 1520, 1143, 824.



Ethyl 4-(4-mercaptophenyl)butanoate (3g)

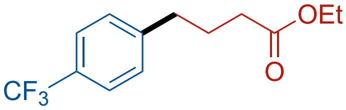
General Procedure A was followed with 4-chlorothiophenol (72.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (4 × 17.5 μL, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total of 24 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (gradient from 20:1 pentane/EtOAc to 10:1 pentane/EtOAc) to afford the product (78.7 mg, 70% yield) as a clear oil.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.28 – 7.20 (m, 4H), 4.11 (q, *J* = 7.1 Hz, 2H), 2.92 (t, *J* = 7.2 Hz, 2H), 2.43 (t, *J* = 7.2 Hz, 2H), 1.92 (quint, *J* = 7.2 Hz, 2H), 1.23 (t, *J* = 7.2 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 172.9, 134.7, 132.0, 130.7, 129.1, 60.5, 33.2, 32.9, 24.3, 14.3.

HRMS (ESI) $[M+Na]^+$ m/z calcd for $C_{12}H_{16}O_2SNa^+$ 247.0763, found 247.0760.

IR (cm^{-1}) 2980, 1728, 1477, 1204, 1095, 811.



Ethyl 4-(4-(trifluoromethyl)phenyl)butanoate (3h) [CAS: 1235271-20-1]

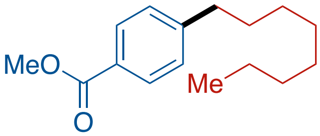
General Procedure A was followed with 4-chlorobenzotrifluoride (90.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (4 × 17.5 μL, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total of 24 h, the reaction was quenched following Purification B and the crude material was purified by chromatography (50:1 pentane/EtOAc) to afford the product (76.8 mg, 59% yield) as a colorless oil. Characterization data matched those reported in the literature.[12]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.53 (d, *J* = 7.9 Hz, 2H), 7.29 (d, *J* = 7.9 Hz, 2H), 4.13 (q, *J* = 7.1 Hz, 2H), 2.71 (t, *J* = 7.7 Hz, 2H), 2.32 (t, *J* = 7.4 Hz, 2H), 1.97 (quint, *J* = 7.5 Hz, 2H), 1.25 (t, *J* = 7.1 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 173.3, 145.7 (q, *J* = 1.5 Hz), 128.9, 128.4 (q, *J* = 32.1 Hz), 125.4 (q, *J* = 3.8 Hz), 124.4 (q, *J* = 271.8 Hz), 60.4, 35.0, 33.6, 26.3, 14.3.

HRMS (ESI) $[M+Na]^+$ m/z calcd for $C_{13}H_{15}F_3O_2Na^+$ 283.0916, found 283.0914.

IR (cm^{-1}) 2939, 1731, 1322, 1115, 843.



Methyl 4-octylbenzoate (3i) [CAS: 54256-51-8]

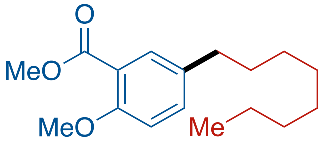
General Procedure A was followed with methyl 4-chlorobenzoate (85.3 mg, 0.5 mmol, 1 equiv) and 1-chlorooctane (4 × 21.2 μL, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total of 24 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (40:1 pentane/EtOAc) to afford the product (65.2 mg, 53% yield) as a colorless oil. Characterization data matched those reported in the literature.[14]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.95 (d, J = 8.3 Hz, 2H), 7.24 (d, J = 8.1 Hz, 2H), 3.90 (s, 3H), 2.68 – 2.62 (m, 2H), 1.62 – 1.59 (m, 2H), 1.33 – 1.24 (m, 10H), 0.88 (t, J = 6.9 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 167.3, 148.7, 129.7, 128.6, 127.7, 52.1, 36.2, 32.0, 31.3, 29.6, 29.4, 29.4, 22.8, 14.2.

HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{16}H_{25}O_2^+$ 249.1849, found 249.1845.

IR (cm^{-1}) 2925, 2855, 1721, 1610, 1274, 1107, 762.



Methyl 2-methoxy-5-octylbenzoate (3j)

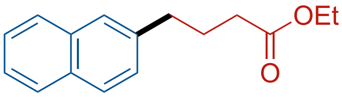
General Procedure A was followed with methyl 5-chloro-2-methoxybenzoate (100.3 mg, 0.5 mmol, 1 equiv) and 1-chlorooctane (4 × 21.2 μL, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total of 23 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (gradient from 20:1 pentane/EtOAc to 10:1 pentane/EtOAc) to afford the product (81.9 mg, 59% yield) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.60 (d, J = 2.3 Hz, 1H), 7.26 (dd, J = 8.5, 2.4 Hz, 1H), 6.88 (d, J = 8.5 Hz, 1H), 3.88 (s, 3H), 3.87 (s, 3H), 2.55 (t, J = 7.7 Hz, 2H), 1.57 (quint, J = 7.3 Hz, 2H), 1.32 – 1.22 (m, 10H), 0.87 (t, J = 7.0 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 167.0, 157.3, 134.7, 133.5, 131.5, 119.7, 112.1, 56.2, 52.1, 34.9, 32.0, 31.6, 29.6, 29.4, 29.3, 22.8, 14.2.

HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{17}H_{27}O_3^+$ 279.1955, found 279.1951.

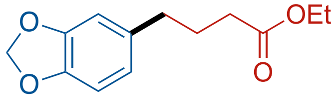
IR (cm^{-1}) 2925, 2854, 1729, 1254, 1082, 731.



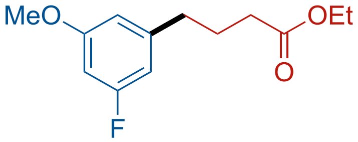
Ethyl 4-(3-naphthyl)butyrate (3k) [CAS: 6326-90-5]

General Procedure A was followed with 3-chloronaphthalene (81.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (4 × 17.5 μL, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total of 22 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (gradient from 40:1 pentane/EtOAc to 20:1 pentane/EtOAc) to afford the product (95.8 mg, 79% yield) as a colorless oil. Characterization data matched those reported in the literature.[13]

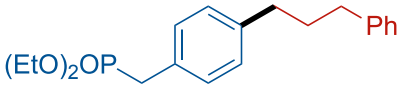
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.84 – 7.77 (m, 3H), 7.63 (s, 1H), 7.45 (dqd, *J* = 8.1, 6.8, 1.4 Hz, 2H), 7.35 (dd, *J* = 8.3, 1.8 Hz, 1H), 4.14 (q, *J* = 7.1 Hz, 2H), 2.84 (t, *J* = 7.6 Hz, 2H), 2.37 (t, *J* = 7.5 Hz, 2H), 2.12 – 2.02 (m, 2H), 1.27 (dt, *J* = 7.1, 4.1 Hz, 3H).
$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 173.6, 139.0, 133.7, 132.1, 128.1, 127.7, 127.5, 127.3, 126.7, 126.0, 125.3, 60.4, 35.4, 33.7, 26.5, 14.3.
HRMS (ESI) $[M+Na]^+$ m/z calcd for $C_{16}H_{18}O_2Na^+$ 265.1199, found 265.1194.
IR (cm^{-1}) 2935, 1729, 1600, 1179, 817, 746.



Ethyl 4-(3,4-benzodioxole)butyrate (3l) [CAS: 99557-75-2]
A modified General Procedure A was followed with 5-chloro-1,3-benzodioxole (78.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (17.5 μL/h (0.125 mmol/h), 0.625 mmol in total, 1.25 equiv). After a total of 24 h, the reaction mixture was filtered through silica gel with 10:1 pentane/EtOAc and the filtrate was concentrated by rotary evaporation. The resulting residue was purified by column chromatography (gradient from 50:1 pentane/EtOAc to 10:1 pentane/EtOAc) to afford the product (73.1 mg, 62% yield) as a colorless oil. ^{1}H NMR matches literature,[15] but no ^{13}C NMR has been reported to date.
^{1}H NMR (500 MHz, $CDCl_3$) δ 6.71 (d, *J* = 7.9 Hz, 1H), 6.66 (d, *J* = 1.7 Hz, 1H), 6.61 (dd, *J* = 7.8, 1.7 Hz, 1H), 5.90 (s, 2H), 4.12 (q, *J* = 7.1 Hz, 2H), 2.56 (t, *J* = 7.6 Hz, 2H), 2.29 (t, *J* = 7.5 Hz, 2H), 1.90 (quint, *J* = 7.5 Hz, 2H), 1.24 (t, *J* = 7.2 Hz, 3H).
$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 173.6, 147.7, 145.8, 135.3, 121.3, 109.0, 108.2, 100.9, 60.3, 34.9, 33.6, 26.9, 14.3.
HRMS (ESI) $[M+Na]^+$ m/z calcd for $C_{13}H_{16}O_4Na^+$ 259.0941, found 259.0936.
IR (cm^{-1}) 2936, 1729, 1489, 1243, 1035, 808.



Ethyl 4-(3-fluoro-5-methoxyphenyl)butanoate (3m)
General Procedure B was followed with 1-chloro-3-fluoro-5-methoxybenzene (80.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (75.3 mg, 0.5 mmol, 1 equiv). After 18 h, the reaction was quenched following Purification B and the crude material was purified by chromatography (gradient from hexanes to 2:23 EtOAc/hexanes) to afford the product (81.0 mg, 67% yield) as a colorless oil.
^{1}H NMR (500 MHz, $CDCl_3$) δ 6.53 – 6.47 (m, 2H), 6.45 (dt, *J* = 10.7, 2.3 Hz, 1H), 4.13 (q, *J* = 7.1 Hz, 2H), 3.78 (s, 3H), 2.61 (t, *J* = 7.5 Hz, 2H), 2.31 (t, *J* = 7.4 Hz, 2H), 1.94 (quint, *J* = 7.6 Hz, 2H), 1.26 (t, *J* = 7.1 Hz, 3H).
$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 173.3, 163.6 (d, *J* = 245.7 Hz), 160.9 (d, *J* = 11.3 Hz), 144.5 (d, *J* = 8.8 Hz), 110.1 (d, *J* = 2.5 Hz), 107.6 (d, *J* = 21.4 Hz), 99.1 (d, *J* = 25.2 Hz), 60.3, 55.4, 35.1 (d, *J* = 2.5 Hz), 33.5, 26.1, 14.24.
HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{13}H_{18}FO_3^+$ 241.1235, ASAP-MS found 241.1231.
IR (cm^{-1}) 2939, 1729, 1590, 1461, 1134, 1034, 838.



Diethyl (4-(3-phenylpropyl)benzyl)phosphonate (3n)

General Procedure B was followed with diethyl 4-chlorobenzylphosphonate (131.4 mg, 0.5 mmol, 1 equiv) and 1-chloro-3-phenylpropane (77.4 mg, 0.5 mmol, 1 equiv). After 18 h, the reaction was quenched following Purification B and the crude material was purified by chromatography (gradient from 3:7 EtOAc/hexanes to 4:1 EtOAc/hexanes) to afford the product (88.3 mg, 51% yield) as a colorless oil.

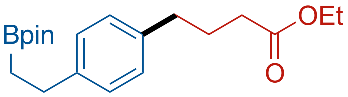
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.32 – 7.25 (m, 3H), 7.21 (dd, *J* = 8.1, 2.5 Hz, 2H), 7.18 (d, *J* = 8.0 Hz, 2H), 7.13 (d, *J* = 7.8 Hz, 2H), 4.05 – 3.96 (m, 4H), 3.12 (d, *J* = 21.5 Hz, 2H), 2.66 – 2.60 (m, 4H), 1.98 – 1.90 (m, 2H), 1.24 (t, *J* = 7.1 Hz, 6H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 142.3, 140.3 (d, *J* = 3.8 Hz), 129.7 (d, *J* = 7.6 Hz), 128.8 (d, *J* = 8.8 Hz), 128.6 (d, *J* = 2.5 Hz), 128.4, 128.3, 125.7, 60.0 (d, *J* = 7.6 Hz), 35.4, 35.0, 33.4 (d, *J* = 138.6 Hz), 32.9 (d, *J* = 1.3 Hz), 16.4 (d, *J* = 5.0 Hz).

^{31}P NMR (162 MHz, $CDCl_3$) δ 26.7.

HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{20}H_{28}O_3P^+$ 347.1771, ASAP-MS found 347.1766.

IR (cm^{-1}) 3024, 2981, 1507, 1245, 1022, 956, 847.



Ethyl 4-(4-(2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)phenyl)butanoate (3o)

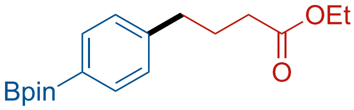
General Procedure A was followed with 2-(4-chlorophenethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (133.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (4 × 17.5 *μ*L, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total of 22 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (gradient from 50:1 pentane/EtOAc to 20:1 pentane/EtOAc) to afford the product (85.1 mg, 49% yield) as a colorless oil. ^{13}C NMR spectrum of **3o** is missing the resonance corresponding to the carbon adjacent to boron, consistent with other reports.[16]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.13 (d, *J* = 7.7 Hz, 2H), 7.06 (d, *J* = 7.7 Hz, 2H), 4.11 (q, *J* = 7.1 Hz, 2H), 2.71 (t, *J* = 8.2 Hz, 2H), 2.60 (t, *J* = 7.6 Hz, 2H), 2.30 (t, *J* = 7.7 Hz, 2H), 1.92 (quint, *J* = 7.6 Hz, 2H), 1.29 – 1.19 (m, 15H), 1.12 (t, *J* = 7.8 Hz, 2H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 173.7, 142.1, 138.6, 128.4, 128.1, 83.2, 60.3, 34.8, 33.8, 29.6, 26.7, 24.9, 14.4.

HRMS (ESI) $[M+NH_4]^+$ m/z calcd for $C_{20}H_{35}BNO_4^+$ 363.2690, found 363.2691.

IR (cm^{-1}) 2979, 2936, 1733, 1371, 1143, 733.



Ethyl 4-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)butanoate (3p) [CAS: 1365610-75-8]

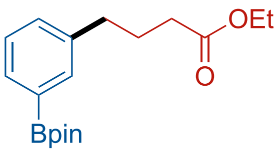
General Procedure B was followed with 4-chlorophenylboronic acid pinacol ester (119.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (75.3 mg, 0.5 mmol, 1 equiv). After 18 h, the reaction was quenched following Purification B and the crude material was purified by chromatography (gradient from hexanes to 2:23 EtOAc/hexanes) to afford the product (116.2 mg, 73% yield) as a colorless oil. Characterization data matched those reported in the literature.[12] ^{13}C NMR spectrum of **3p** is missing the resonance corresponding to the carbon adjacent to boron, consistent with other reports.[16]

^{1}H NMR (500 MHz, CDCl$_3$) δ 7.73 (d, *J* = 7.9 Hz, 2H), 7.19 (d, *J* = 7.9 Hz, 2H), 4.12 (q, *J* = 7.1 Hz, 2H), 2.66 (t, *J* = 7.6 Hz, 2H), 2.30 (t, *J* = 7.5 Hz, 2H), 1.95 (quint, *J* = 7.7 Hz, 2H), 1.34 (s, 12H), 1.25 (t, *J* = 7.1 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, CDCl$_3$) δ 173.4, 144.8, 134.9, 127.9, 83.7, 60.2, 35.3, 33.6, 26.4, 24.9, 14.2.

HRMS (ESI) [M+Na]$^+$ m/z calcd for $C_{18}H_{27}BO_4Na^+$ 341.1895, found 341.1893.

IR (cm^{-1}) 2978, 2933, 1731, 1610, 1357, 1141, 1088, 856.



Ethyl 4-(3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)butanoate (3q)

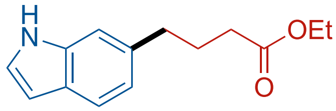
General Procedure A was followed with 2-(3-chlorophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (119.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (4 × 17.5 *μ*L, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total of 24 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (20:1 pentane/EtOAc) to afford the product (104.0 mg, 65% yield) as a clear oil. ^{13}C NMR spectrum of **3p** is missing the resonance corresponding to the carbon adjacent to boron, consistent with other reports.[16]

^{1}H NMR (500 MHz, CDCl$_3$) δ 7.65 – 7.63 (m, 2H), 7.33 – 7.26 (m, 2H), 4.12 (q, *J* = 7.1 Hz, 2H), 2.65 (t, *J* = 7.6 Hz, 2H), 2.31 (t, *J* = 7.5 Hz, 2H), 1.96 (quint, *J* = 7.6 Hz, 2H), 1.35 (s, 12H), 1.25 (t, *J* = 7.1 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, CDCl$_3$) δ 173.7, 140.9, 135.0, 132.6, 131.6, 128.0, 83.9, 60.4, 35.2, 33.9, 26.8, 25.0, 14.4.

HRMS (ESI) [M+Na]$^+$ m/z calcd for $C_{18}H_{27}BO_4Na^+$ 340.1931, found 340.1926.

IR (cm^{-1}) 2979, 2934, 1733, 1355, 1143, 709.



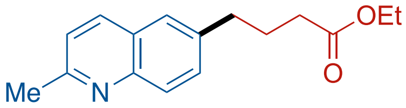
Ethyl 4-(1*H*-indol-6-yl)butanoate (3r)

General Procedure A was followed with 6-chloro-1H-indole (75.8 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (4 × 17.5 *μ*L, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total of 23 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (gradient from 10:1 pentane/EtOAc to 8:1 pentane/EtOAc) to afford the product (81.6 mg, 71% yield) as a pale yellow oil.

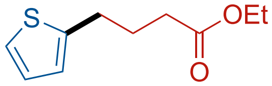
^{1}H NMR (500 MHz, CDCl$_3$) δ 8.10 (s, 1H), 7.56 (d, *J* = 8.1 Hz, 1H), 7.19 (s, 1H), 7.15 (dd, *J* = 3.2, 2.4 Hz, 1H), 6.97 (dd, *J* = 8.0, 1.5 Hz, 1H), 6.52 (ddd, *J* = 3.1, 2.0, 1.0 Hz, 1H), 4.13 (q, *J* = 7.1 Hz, 2H), 2.77 (t, *J* = 7.5 Hz, 2H), 2.35 (t, *J* = 7.5 Hz, 2H), 2.02 (quint, *J* = 7.6 Hz, 2H), 1.26 (t, *J* = 7.1 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, CDCl$_3$) δ 173.9, 136.3, 135.6, 126.2, 123.9, 121.1, 120.6, 110.7, 102.5, 60.4, 35.5, 33.9, 27.2, 14.4.

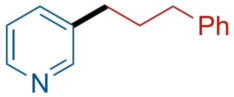
HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{14}H_{18}NO_2^+$ 232.1332, found 232.1328.
IR (cm^{-1}) 3400, 2932, 2858, 1712, 1250, 721.



Ethyl 4-(2-methylquinolin-6-yl)butyrate (3s)
A modified General Procedure A was followed with 6-chloro-2-methylquinoline (88.8 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (17.5 μL/h (0.125 mmol/h), 0.625 mmol in total, 1.25 equiv). After a total of 24 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (gradient from 50:1 pentane/EtOAc to 10:1 pentane/EtOAc) to afford the product (81.7 mg, 63% yield) as a slightly yellow oil.
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.94 (dd, J = 13.5, 8.4 Hz, 2H), 7.50 (d, J = 8.9 Hz, 2H), 7.23 (d, J = 8.4 Hz, 1H), 4.10 (q, J = 7.1 Hz, 2H), 2.80 (t, J = 7.6 Hz, 2H), 2.71 (s, 3H), 2.33 (t, J = 7.4 Hz, 2H), 2.07 – 1.98 (m, 2H), 1.23 (t, J = 7.2 Hz, 3H).
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 173.5, 158.4, 146.8, 138.9, 135.8, 130.8, 128.7, 126.5, 126.2, 122.1, 60.4, 35.1, 33.7, 26.4, 25.4, 14.3.
HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{16}H_{20}NO_2^+$ 258.1489, found 258.1485.
IR (cm^{-1}) 2939, 1728, 1601, 1374, 1179, 1026, 827.



Ethyl 4-(thiophen-2-yl)butanoate (3t) [CAS: 91950-17-3]
General Procedure B was followed with 2-chlorothiophene (59.3 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (75.3 mg, 0.5 mmol, 1 equiv). After 18 h, the reaction was quenched following Purification B with 5% aq NH_4OH instead of brine and the crude material was purified by chromatography (gradient from hexanes to 2:23 EtOAc/hexanes) to afford the product (32.7 mg, 33% yield) as a colorless oil. A ^{1}H NMR for **3t** was reported in $CDCl_3$ (example 17),[17] but it appears to actually be of the methyl ester according to the experimental (esterification in methanol) and the reported spectrum: it is missing the expected ethyl CH_3 at 1.26 ppm and the 2H signal at 4.13 ppm and has an unexpected 3H singlet at 3.67 ppm.
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.12 (dd, J = 5.1, 1.2 Hz, 1H), 6.92 (dd, J = 5.1, 3.4 Hz, 1H), 6.80 (dd, J = 3.5, 1.1 Hz, 1H), 4.13 (q, J = 7.1 Hz, 2H), 2.88 (t, J = 7.5 Hz, 2H), 2.36 (t, J = 7.4 Hz, 2H), 2.01 (quint, J = 7.5 Hz, 2H), 1.26 (t, J = 7.1 Hz, 3H).
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 173.2, 144.1, 126.8, 124.5, 123.2, 60.3, 33.4, 29.1, 26.9, 14.2.
HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{10}H_{15}O_2S^+$ 199.0787, ASAP-MS found 199.0785.
IR (cm^{-1}) 2934, 1729, 1163, 1026, 847, 823, 694.



3-(3-phenylpropyl)pyridine (3u) [CAS: 1802-34-2]
General Procedure B was followed with diethyl 3-chloropyridine (56.8 mg, 0.5 mmol, 1 equiv) and 1-chloro-3-phenylpropane (77.4 mg, 0.5 mmol, 1 equiv). After 16 h, the reaction was quenched following Purification B with 5% aq NH_4OH instead of brine and the crude material was

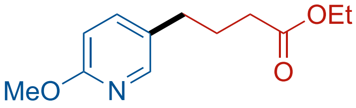
purified by chromatography (2:3 EtOAc/cyclohexane) to afford the product (65.0 mg, 66% yield) as a pale yellow oil. Characterization data matched those reported in the literature.[5]

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.47 – 8.42 (m, 2H), 7.49 (dt, *J* = 7.8, 2.0 Hz, 1H), 7.29 (dd, *J* = 8.2, 6.8 Hz, 2H), 7.22 – 7.16 (m, 4H), 2.66 (q, *J* = 8.1 Hz, 4H), 2.01 – 1.92 (m, 2H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 150.0, 147.4, 141.7, 137.4, 135.7, 128.4, 125.9, 123.2, 35.3, 32.6, 32.4.

HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{14}H_{16}N^+$ 198.1277, found 198.1276.

IR (cm^{-1}) 3025, 2930, 2855, 1598, 1485, 1075, 744, 703.



Ethyl 4-(6-methoxypyridin-3-yl)butanoate (3v)

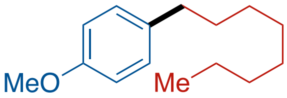
General Procedure B was followed with 5-chloro-2-methoxypyridine (71.8 mg, 0.5 mmol, 1 equiv) and ethyl 4-chlorobutyrate (75.3 mg, 0.5 mmol, 1 equiv). After 16 h, the reaction was quenched following Purification B with 5% aq NH_4OH instead of brine and the crude material was purified by chromatography (10:1 DCM/MeOH) to afford the product (81.5 mg, 73% yield) as a yellow oil. Characterization data matched those reported in the literature.[5]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.96 (d, *J* = 2.4 Hz, 1H), 7.40 (dd, *J* = 8.5, 2.5 Hz, 1H), 6.68 (d, *J* = 8.5 Hz, 1H), 4.12 (q, *J* = 7.2 Hz, 2H), 3.91 (s, 3H), 2.57 (t, *J* = 7.6 Hz, 2H), 2.31 (t, *J* = 7.4 Hz, 2H), 1.91 (quint, *J* = 7.5 Hz, 2H), 1.25 (t, *J* = 7.1 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 173.3, 162.8, 146.1, 138.9, 129.2, 110.5, 60.3, 53.3, 33.4, 31.3, 26.5, 14.2.

HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{12}H_{18}NO_3^+$ 224.1281, found 224.1279.

IR (cm^{-1}) 2940, 1729, 1606, 1489, 1387, 1283, 1252, 1176, 1142, 1023, 828.



4-octylanisole (3w) [CAS: 3307-19-5]

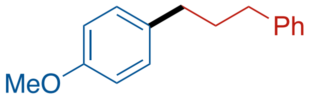
General Procedure A was followed with 4-chloroanisole (71.3 mg, 0.5 mmol, 1 equiv) and 1-chlorooctane (74.3 mg, 0.5 mmol, 1.0 equiv) added in one portion. After 24 h, the reaction mixture was loaded directly onto a silica gel column and purified by column chromatography (40:1 pentane/Et_2O) to afford the product (72.2 mg, 66% yield) as a colorless oil. Characterization data matched those reported in the literature.[11]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.10 (d, *J* = 8.5 Hz, 2H), 6.83 (d, *J* = 8.6 Hz, 2H), 3.79 (s, 3H), 2.54 (t, *J* = 7.2 Hz, 2H), 1.68 – 1.49 (m, 2H), 1.37 – 1.09 (m, 10H), 0.88 (t, *J* = 6.8 Hz, 3H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 157.7, 135.2, 129.4, 113.8, 55.4, 35.2, 32.0, 31.9, 29.6, 29.5, 29.4, 22.8, 14.3.

HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{15}H_{25}O^+$ 221.1900, ASAP-MS found 221.1900.

IR (cm^{-1}) 2922, 2852, 1611, 1510, 1459, 1242, 1038, 818.



1-methoxy-4-(3-phenylpropyl)benzene (3x)

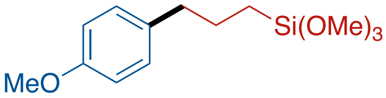
A modified General Procedure A was followed with 4-chloroanisole (71.3 mg, 0.5 mmol, 1 equiv) and 1-chloro-3-phenylpropane (17.9 μL/h (0.125 mmol/h), 0.625 mmol in total, 1.25 equiv). After a total of 19 h, the reaction mixture was filtered through silica gel with 5:1 pentane/Et_2O and the filtrate was concentrated by rotary evaporation. The resulting residue was purified by column chromatography (50:1 pentane/Et_2O) to afford the product (94.6 mg, 84% yield) as a colorless oil. Characterization data matched those reported in the literature.[18]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.36 – 7.29 (m, 2H), 7.26 – 7.19 (m, 3H), 7.17 – 7.12 (d, J = 8.6 Hz, 2H), 6.90 – 6.85 (d, J = 8.6 Hz, 2H), 3.82 (s, 3H), 2.68 (t, J = 7.7 Hz, 2H), 2.64 (t, J = 7.7 Hz, 2H), 1.97 (tt, J = 9.3, 6.8 Hz, 2H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 157.8, 142.5, 134.5, 129.4, 128.6, 128.4, 125.8, 113.8, 55.4, 35.5, 34.6, 33.3.

HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{16}H_{19}O^+$ 227.1430, ASAP-MS found 227.1428.

IR (cm^{-1}) 3027, 2933, 2856, 1611, 1511, 1243, 1036, 731.



Trimethoxy-[3-(4-methoxyphenyl)propyl]silane (3y) [CAS: 40715-68-2]

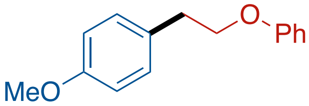
General Procedure A was followed with 4-chloroanisole (71.3 mg, 0.5 mmol, 1 equiv) and (3-chloropropyl)trimethoxysilane (4 × 22.8 μL, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total of 24 h, the reaction was quenched following Purification B and the crude material was purified by chromatography (9:1 hexanes/EtOAc) to afford the product (43.3 mg, 32% yield) as a colorless oil.

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.09 (d, J = 8.6 Hz, 2H), 6.82 (d, J = 8.6 Hz, 2H), 3.78 (s, 3H), 3.55 (s, 9H), 2.58 (t, J = 7.6 Hz, 2H), 1.76 – 1.64 (m, 2H), 0.72 – 0.63 (m, 2H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 157.8, 134.5, 129.5, 113.8, 55.4, 50.7, 38.4, 24.9, 8.9.

HRMS (ESI) $[M+Na]^+$ m/z calcd for $C_{13}H_{22}O_4SiNa^+$ 293.1180, found 293.1176.

IR (cm^{-1}) 2934, 2838, 1510, 1460, 1243, 1183, 1077, 1037, 806.



1-methoxy-4-(2-phenoxyethyl)benzene (3z) [CAS: 127294-20-6]

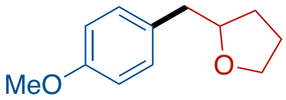
A modified General Procedure A was followed with 4-chloroanisole (71.3 mg, 0.5 mmol, 1 equiv) and (2-chloroethoxy)benzene (17.3 μL/h (0.125 mmol/h), 0.625 mmol in total, 1.25 equiv). After a total of 19 h, the reaction mixture was filtered through silica gel with 5:1 pentane/Et_2O and the filtrate was concentrated by rotary evaporation. The resulting residue was purified by column chromatography (gradient from 40:1 pentane/Et_2O to 30:1 pentane/Et_2O) to afford the product (73.3 mg, 64% yield) as a colorless oil. Characterization data matched those reported in the literature.[19]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.34 (t, J = 7.9 Hz, 2H), 7.28 (d, J = 8.9 Hz 2H), 7.04 – 6.90 (m, 5H), 4.20 (t, J = 7.1 Hz, 2H), 3.86 (s, 3H), 3.11 (t, J = 7.1 Hz, 2H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 158.9, 158.4, 130.4, 130.1, 129.5, 120.8, 114.6, 114.0, 68.9, 55.3, 35.0.

HRMS (ESI) $[M-OPh]^+$ m/z calcd for $C_9H_{11}O^+$ 135.0804, found 135.0803.

IR (cm^{-1}) 2937, 2836, 1513, 1241, 1033, 906, 727.



2-(4-methoxybenzyl)tetrahydrofuran (3aa) [CAS: 859999-32-9]

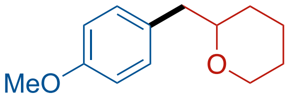
A modified General Procedure A was followed with 4-chloroanisole (71.3 mg, 0.5 mmol, 1 equiv) and 2-(chloromethyl)tetrahydrofuran (13.6 μL/h (0.125 mmol/h), 0.625 mmol in total, 1.25 equiv). After a total of 22 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (gradient from 50:1 pentane/EtOAc to 20:1 pentane/EtOAc) to afford the product (66.3 mg, 69% yield) as a colorless oil. Characterization data matched those reported in the literature.[20]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.15 (d, J = 8.4 Hz, 2H), 6.84 (d, J = 8.6 Hz, 2H), 4.03 (quint, J = 6.6 Hz, 1H), 3.89 (q, J = 7.2 Hz, 1H), 3.78 (s, 3H), 3.74 (td, J = 7.9, 6.3 Hz, 1H), 2.86 (dd, J = 13.7, 6.5 Hz, 1H), 2.70 (dd, J = 13.7, 6.4 Hz, 1H), 1.96 – 1.79 (m, 3H), 1.55 (dq, J = 11.5, 8.0 Hz, 1H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 158.1, 131.1, 130.2, 113.8, 80.3, 68.0, 55.3, 41.1, 31.0, 25.7.

HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{12}H_{17}O_2^+$ 193.1223, ASAP-MS found 193.1221.

IR (cm^{-1}) 2935, 2835, 1612, 1512, 1244, 1177, 1034.



2-(4-methoxybenzyl)tetrahydropyran (3ab) [CAS: 1408141-63-8]

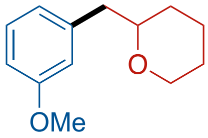
General Procedure A was followed with 4-chloroanisole (71.3 mg, 0.5 mmol, 1 equiv) and 2-(chloromethyl)tetrahydropyran (4 × 15.7 μL, 0.5 mmol, 1.0 equiv) added portionwise in 4 equal portions over 3 h. After a total of 24 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (gradient from 20:1 pentane/EtOAc to 15:1 pentane/EtOAc) to afford the product (93.0 mg, 90% yield) as a colorless oil. Characterization data matched those reported in the literature.[19]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.13 (d, J = 8.6 Hz, 2H), 6.83 (d, J = 8.7Hz, 2H), 3.98 (ddt, J = 11.5, 4.1, 1.8 Hz, 1H), 3.79 (s, 3H), 3.48 – 3.36 (m, 2H), 2.82 (dd, J = 13.8, 6.6 Hz, 1H), 2.59 (dd, J = 13.8, 6.5 Hz, 1H), 1.80 (dq, J = 12.4, 2.7 Hz, 1H), 1.56 (tt, J = 12.1, 4.1 Hz, 2H), 1.52 – 1.36 (m, 2H), 1.27 (tdd, J = 12.9, 10.9, 4.0 Hz, 1H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 158.1, 131.0, 130.4, 113.7, 79.1, 68.7, 55.3, 42.4, 31.5, 26.2, 23.6.

HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{13}H_{19}O_2^+$ 207.1380, ASAP-MS found 207.1377.

IR (cm^{-1}) 2934, 2835, 1612, 1511, 1243, 1036.



2-(3-methoxybenzyl)tetrahydropyran (3ac) [CAS: 1258063-60-3]

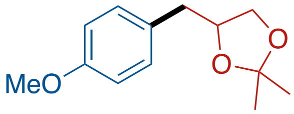
The preparative-scale benchtop procedure was followed with 3-chloroanisole (1.0 g, 7.01 mmol, 1 equiv) and 2-(chloromethyl)tetrahydropyran (1.18 g, 8.76 mmol, 1.25 equiv) added dropwise via addition funnel over 2 h. After stirring at 80 °C for a total of 24 h, the reaction was cooled to room temperature and diluted with Et_2O (20 mL). The reaction was washed with a solution of saturated brine (4 × 50 mL). The combined aqueous layer was extracted with Et_2O (20 mL) and the organic layers were combined, dried over $MgSO_4$, and concentrated by rotary evaporation to provide a yellow oil. The resulting crude was dry-loaded and purified by column chromatography (gradient from 20:1 pentane/EtOAc to 10:1 pentane/EtOAc) to provide the product (915 mg, 63% yield) as a clear, colorless oil. Characterization data matched those reported in the literature.[21]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.20 (t, *J* = 7.8 Hz, 1H), 6.83 – 6.73 (m, 3H), 4.01 – 3.95 (m, 1H), 3.80 (s, 3H), 3.49 (dtd, *J* = 10.8, 6.6, 2.0 Hz, 1H), 3.42 (td, *J* = 11.8, 2.4 Hz, 1H), 2.86 (dd, *J* = 13.6, 6.6 Hz, 1H), 2.62 (dd, *J* = 13.6, 6.5 Hz, 1H), 1.85 – 1.77 (m, 1H), 1.65 – 1.53 (m, 2H), 1.52 – 1.38 (m, 2H), 1.34 – 1.24 (m, 1H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 159.6, 140.6, 129.3, 121.9, 115.3, 111.5, 78.8, 68.8, 55.3, 43.4, 31.6, 26.2, 23.6.

HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{13}H_{19}O^+$ 207.1380, ASAP-MS found 207.1378.

IR (cm^{-1}) 2935, 2836, 1256, 1087, 1041, 696.



4-(4-methoxybenzyl)-2,2-dimethyl-1,3-dioxolane (3ad)

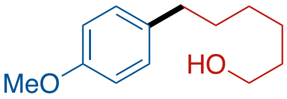
General Procedure A was followed with 4-chloroanisole (71.3 mg, 0.5 mmol, 1 equiv) and 4-(chloromethyl)-2,2-dimethyl-1,3-dioxolane (4 × 17.7 *µ*L, 0.5 mmol, 1.0 equiv) added portionwise in 4 equal portions over 3 h. After a total of 24 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (gradient from 20:1 pentane/EtOAc to 10:1 pentane/EtOAc) to afford the product (59.7 mg, 54% yield) as a colorless oil. Characterization data matched those reported in the literature.[22]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.13 (d, *J* = 8.6 Hz, 2H), 6.84 (d, *J* = 8.6 Hz, 2H), 4.33 – 4.24 (m, 1H), 3.95 (dd, *J* = 8.1, 5.9 Hz, 1H), 3.79 (s, 3H), 3.63 (dd, *J* = 8.1, 6.9 Hz, 1H), 2.96 (dd, *J* = 13.8, 6.1 Hz, 1H), 2.72 (dd, *J* = 13.8, 7.2 Hz, 1H), 1.43 (s, 3H), 1.35 (s, 3H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 158.4, 130.2, 129.7, 114.0, 109.2, 77.0, 69.1, 55.3, 39.3, 27.1, 25.8.

HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{13}H_{19}O_3^+$ 223.1329, ASAP-MS found 223.1327.

IR (cm^{-1}) 2986, 2936, 2836, 1613, 1513, 1245, 1035.



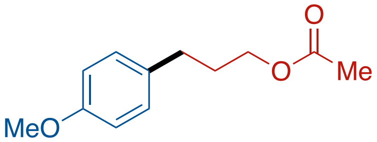
6-(4-methoxyphenyl)hexan-1-ol (3ae) [CAS: 102831-36-7]

A modified General Procedure A was followed with 4-chloroanisole (71.3 mg, 0.5 mmol, 1 equiv) and 6-chlorohexan-1-ol (16.7 *µ*L/h (0.125 mmol/h), 0.625 mmol in total, 1.25 equiv). After a total of 22 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (gradient from 20:1 pentane/EtOAc to 5:1 pentane/EtOAc) to afford the product (69.6 mg, 67% yield) as a colorless oil. Characterization data matched those reported in the literature.[23]

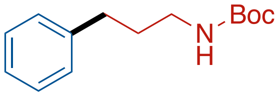
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.09 (d, *J* = 8.8 Hz, 2H), 6.82 (d, *J* = 8.1 Hz, 2H), 3.79 (s, 3H), 3.63 (t, *J* = 6.6 Hz, 2H), 2.55 (t, *J* = 7.7 Hz, 2H), 1.61 (s, 1H), 1.57 (tq, *J* = 12.8, 7.2 Hz, 4H), 1.36 (tq, *J* = 11.0, 5.8, 5.0 Hz, 4H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 157.7, 135.0, 129.4, 113.8, 63.1, 55.4, 35.1, 32.9, 31.8, 29.1, 25.7.

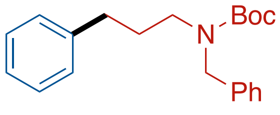
HRMS (ESI) $[M+H]^+$ m/z calcd for $C_{13}H_{21}O_2^+$ 209.1536, $[M-OH]^+$ m/z calcd for $C_{13}H_{19}O^+$ 191.1430, ASAP-MS found 209.1534, 191.1428.
IR (cm^{-1}) 3338, 2929, 2855, 1612, 1511, 1243, 1035, 731.



3-(4-methoxyphenyl)propyl acetate (3af)
A modified General Procedure A was followed with 4-chloroanisole (71.3 mg, 0.5 mmol, 1 equiv) and 3-chloropropyl acetate (15.4 μL/h (0.125 mmol/h), 0.625 mmol in total, 1.25 equiv). After a total of 22 h, the reaction was quenched following Purification A and the crude material was purified by chromatography (gradient from 40:1 pentane/EtOAc to 15:1 pentane/EtOAc) to afford the product (54.4 mg, 52% yield) as a colorless oil. Characterization data matched those reported in the literature.[24]
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.10 (d, *J* = 8.5 Hz, 2H), 6.83 (d, *J* = 8.3 Hz, 2H), 4.07 (t, *J* = 6.6 Hz, 2H), 3.79 (s, 3H), 2.63 (t, *J* = 7.7 Hz, 2H), 2.05 (s, 3H), 1.97 – 1.88 (m, 2H).
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 171.3, 158.0, 133.3, 129.4, 113.9, 63.9, 55.4, 31.3, 30.5, 21.1.
HRMS (ESI) $[M+NH_4]^+$ m/z calcd for $C_{12}H_{20}NO_3^+$ 226.1438, found 226.1434.
IR (cm^{-1}) 2953, 2836, 1735, 1612, 1512, 1236, 1034, 810.

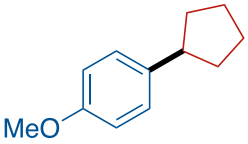


***Tert*-butyl (3-phenylpropyl)carbamate (3ag) [CAS: 147410-39-7]**
General Procedure B was followed with chlorobenzene (56.3 mg, 0.5 mmol, 1 equiv) and *tert*-butyl (3-chloropropyl)carbamate (92.3 μL, 0.5 mmol, 1 equiv) added in one portion. After 42 h, the reaction was quenched following Purification B and the crude material was purified by chromatography (gradient from hexanes to 4:1 hexanes/EtOAc) to afford the product (72.9 mg, 62% yield) as a colorless oil. Characterization data matched those reported in the literature.[12]
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.34 (t, *J* = 7.6 Hz, 2H), 7.25 (t, *J* = 7.2 Hz, 3H), 4.70 (s, 1H), 3.26 – 3.10 (m, 2H), 2.70 (t, *J* = 7.8 Hz, 2H), 1.87 (quint, *J* = 7.3 Hz, 2H), 1.52 (s, 9H).
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$) δ 156.1, 141.6, 128.5, 128.4, 126.0, 79.1, 40.3, 33.2, 31.8, 28.5.
HRMS (ESI) $[M+Na]^+$ m/z calcd for $C_{14}H_{21}NO_2Na^+$ 258.1465, found 258.1463.
IR (cm^{-1}) 3345, 2972, 2928, 2861, 1689, 1505, 1451, 1363, 1246, 1165, 740, 697.



***tert*-butyl benzyl(3-phenylpropyl)carbamate (3ah)**
General Procedure A was followed with chlorobenzene (56.3 mg, 0.5 mmol, 1 equiv) and tert-butyl benzyl(3-chloropropyl)carbamate (4 × 36.1μL, 0.5 mmol, 1 equiv) added portionwise in 4 equal portions over 3 h. After a total of 24 h, the reaction was quenched following Purification B procedure and the crude material was purified by chromatography (gradient from hexanes to 9:1 hexanes/EtOAc) to afford the product (100.7 mg, 62% yield) as a colorless oil.
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.38 – 7.13 (m, 10H), 4.46 (d, *J* = 24.8 Hz, 2H), 3.26 (d, *J* = 62.4 Hz, 2H), 2.60 (s, 2H), 1.84 (s, 2H), 1.50 (s, 9H).

^{13}C{^{1}H} NMR (126 MHz, CDCl$_3$) δ 156.1, 155.7, 141.9, 141.7, 138.8, 138.6, 128.6, 128.5, 128.4, 128.4, 127.8, 127.2, 125.9, 79.7, 50.7, 50.1, 46.6, 46.3, 33.3, 29.8, 28.5.
HRMS (ESI) [M+Na]$^+$ m/z calcd for $C_{21}H_{27}NO_2Na^+$ 348.1934, found 348.1931.
IR (cm^{-1}) 3061, 3027, 2972, 2928, 1688, 1455, 1412, 1363, 1156, 882, 735, 697.



1-cyclopentyl-4-methoxybenzene (3ai) [CAS: 1507-97-7]
A modified General Procedure A was followed with 4-chloroanisole (71.3 mg, 0.5 mmol, 1 equiv) and chlorocyclopentane (15.1 μL/h (0.125 mmol/h), 0.625 mmol in total, 1.25 equiv). After a total of 22 h, the reaction was quenched following Purification A procedure and the crude material was purified by chromatography (100:1 pentane/EtOAc) to afford the product (31.0 mg, 35% yield) as a colorless oil. Characterization data matched those reported in the literature.[25]
^{1}H NMR (500 MHz, CDCl$_3$) δ 7.17 (d, *J* = 8.6 Hz, 2H), 6.84 (d, *J* = 8.5 Hz, 2H), 3.80 (s, 3H), 2.95 (tt, *J* = 9.9, 7.4 Hz, 1H), 2.10 – 2.00 (m, 2H), 1.80 (ddd, *J* = 9.9, 7.1, 4.9 Hz, 2H), 1.74 – 1.63 (m, 2H), 1.61 – 1.50 (m, 2H).
^{13}C{^{1}H} NMR (126 MHz, CDCl$_3$) δ 157.6, 138.5, 127.9, 113.6, 55.3, 45.1, 34.7, 25.4.
HRMS (ESI) [M+H]$^+$ m/z calcd for $C_{12}H_{17}O^+$ 177.1274, ASAP-MS found 177.1272.
IR (cm^{-1}) 2951, 2866, 2834, 1612, 1512, 1242, 1038, 824.

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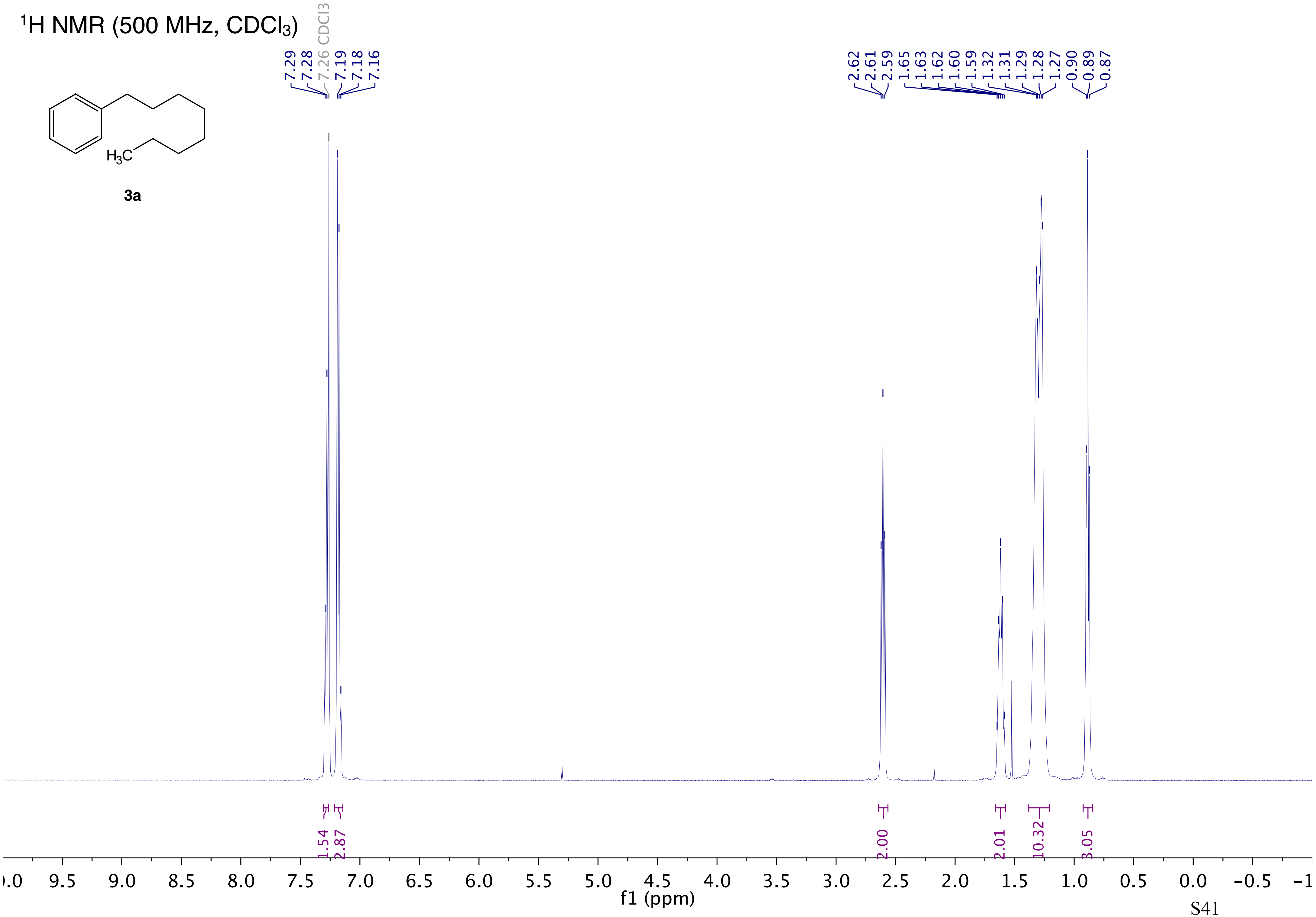
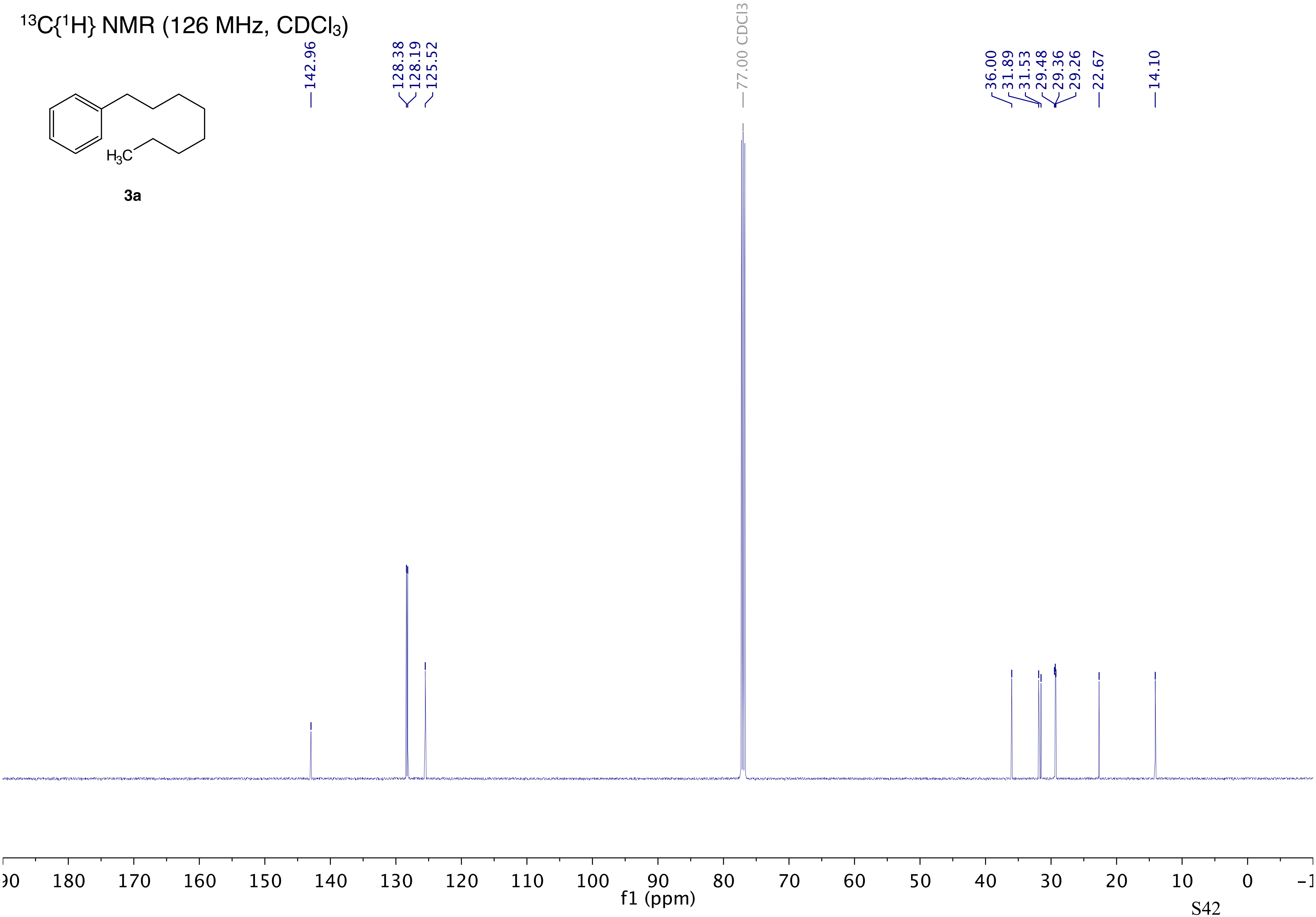
9. ^{1}H, ^{13}C NMR Spectra

^{1}H NMR (500 MHz, $CDCl_3$)



3a

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)



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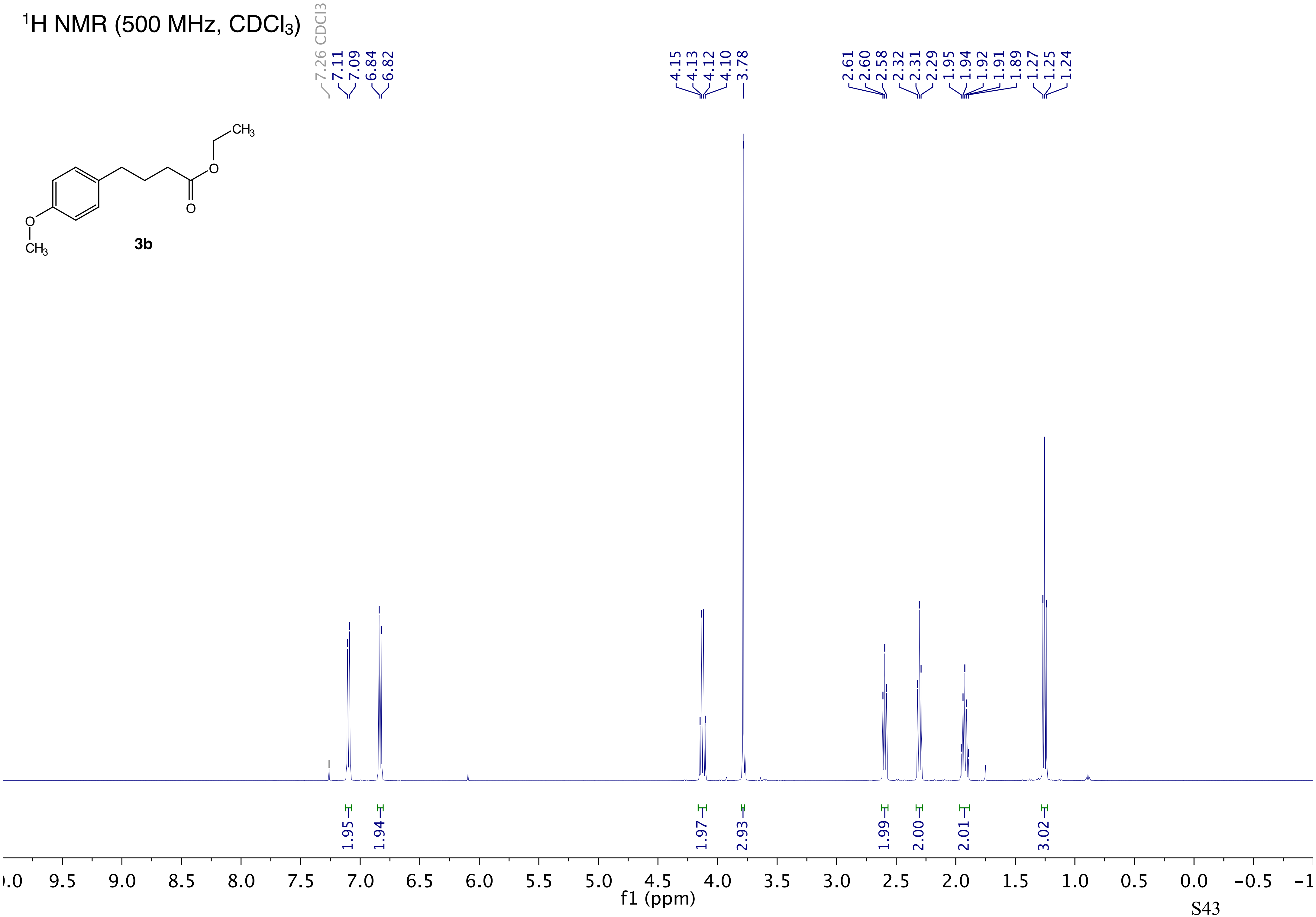

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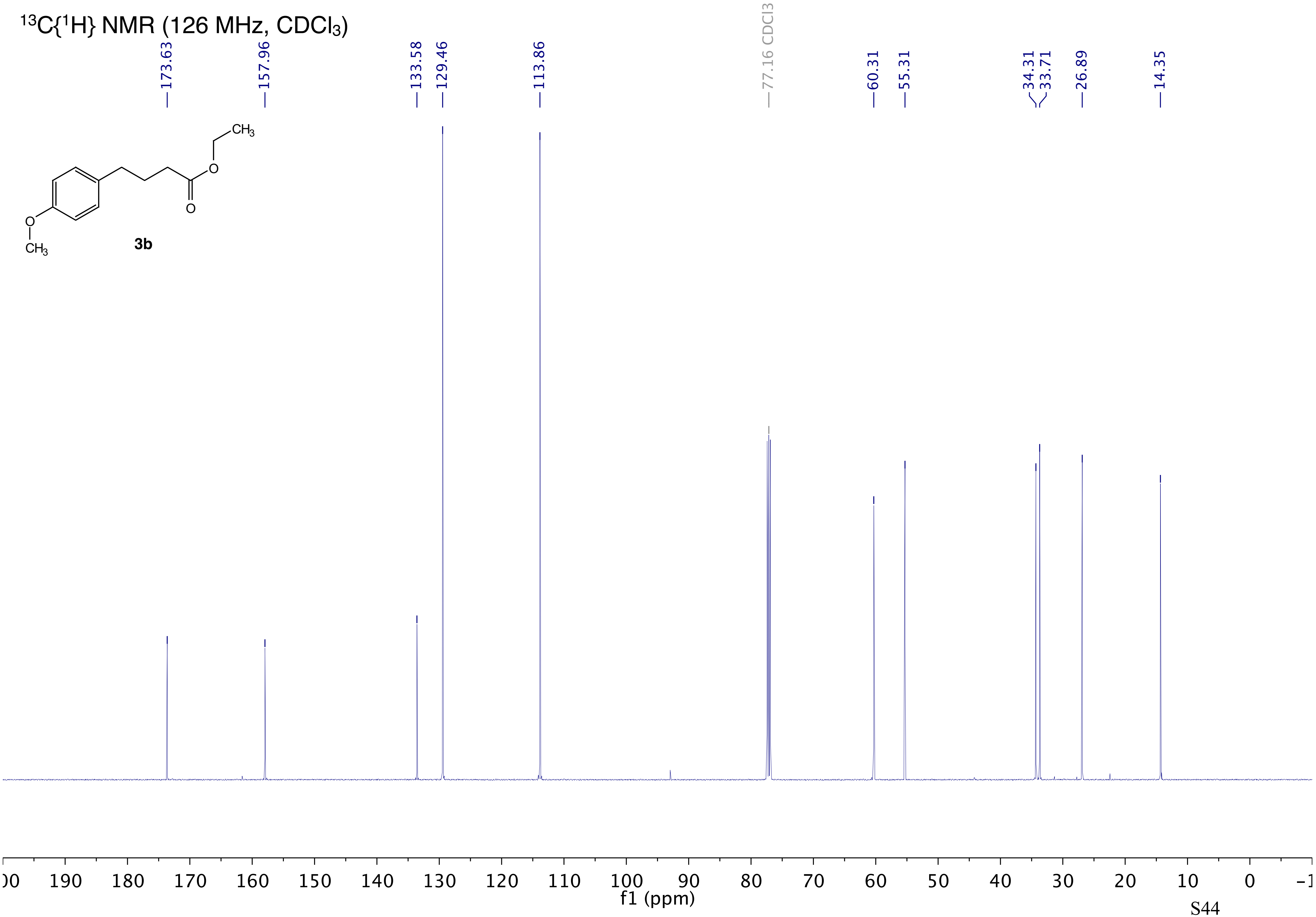

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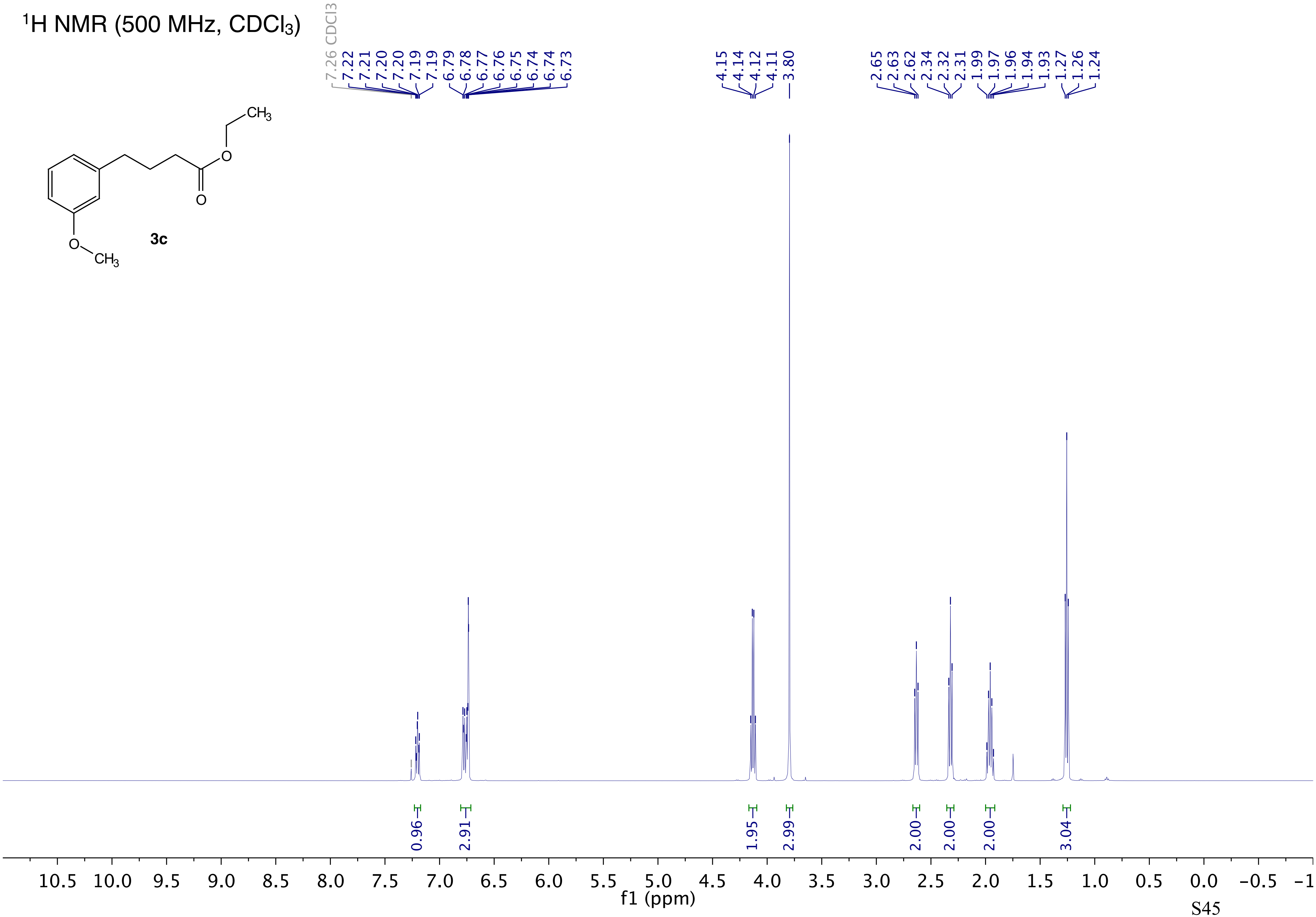

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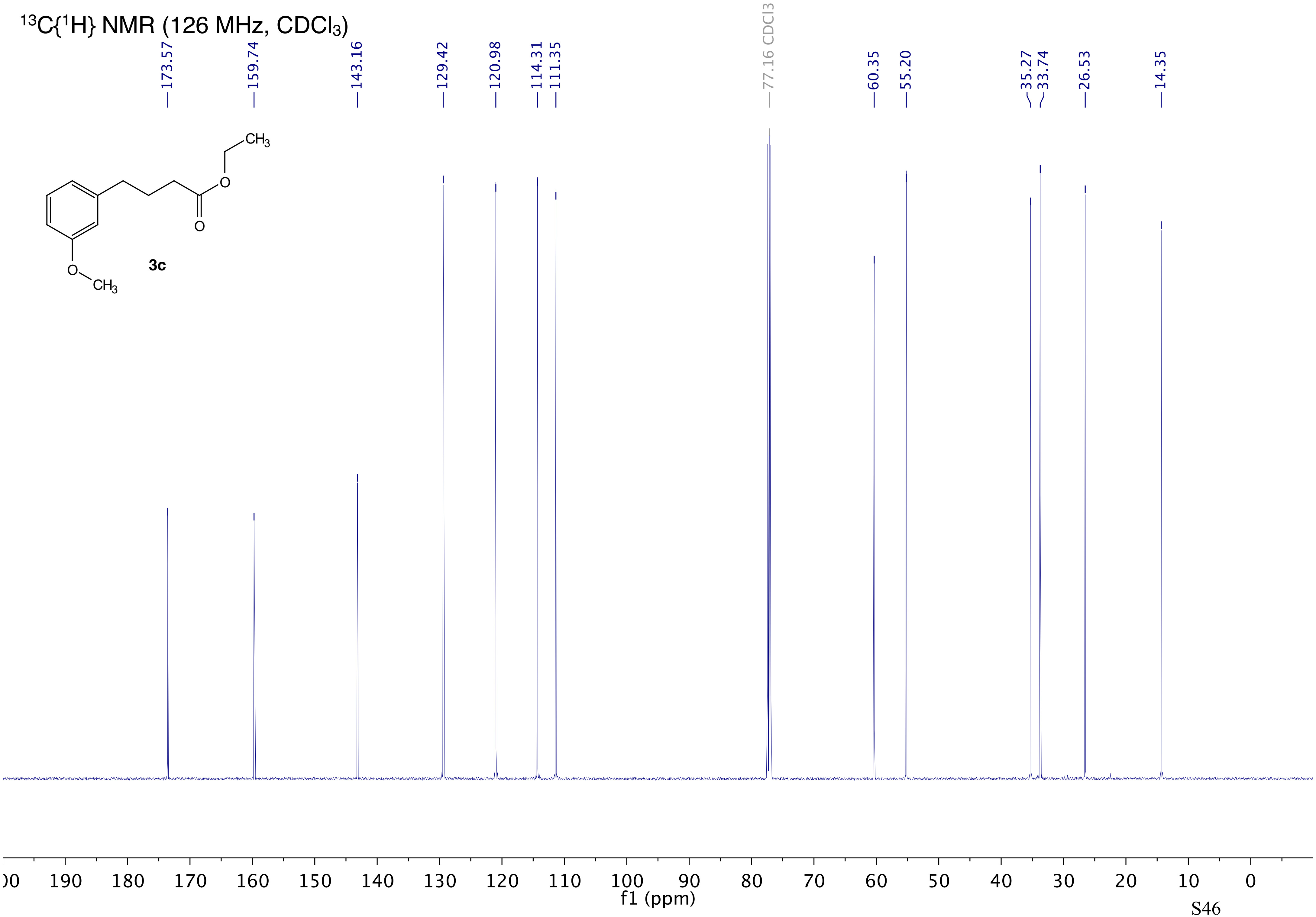

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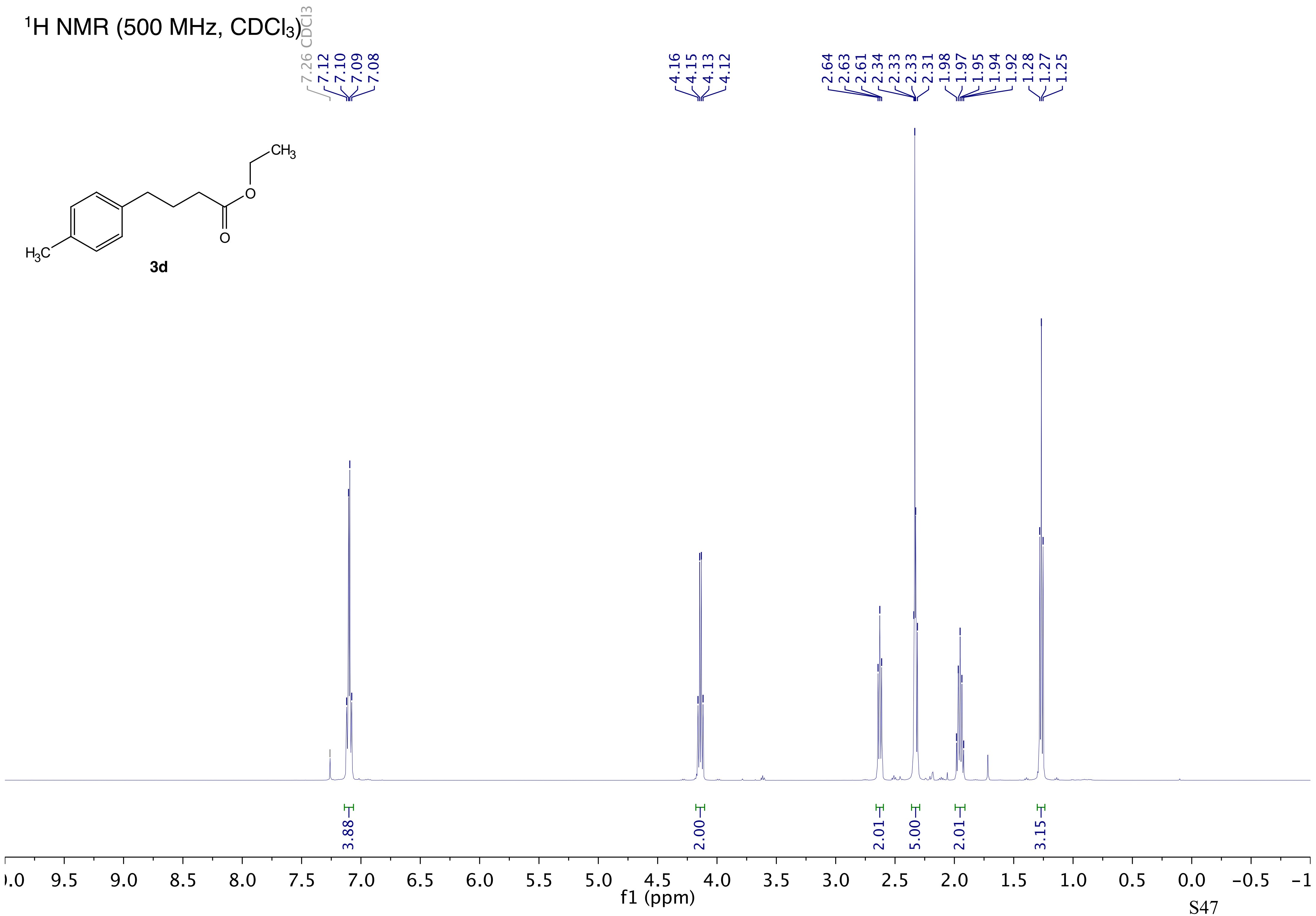

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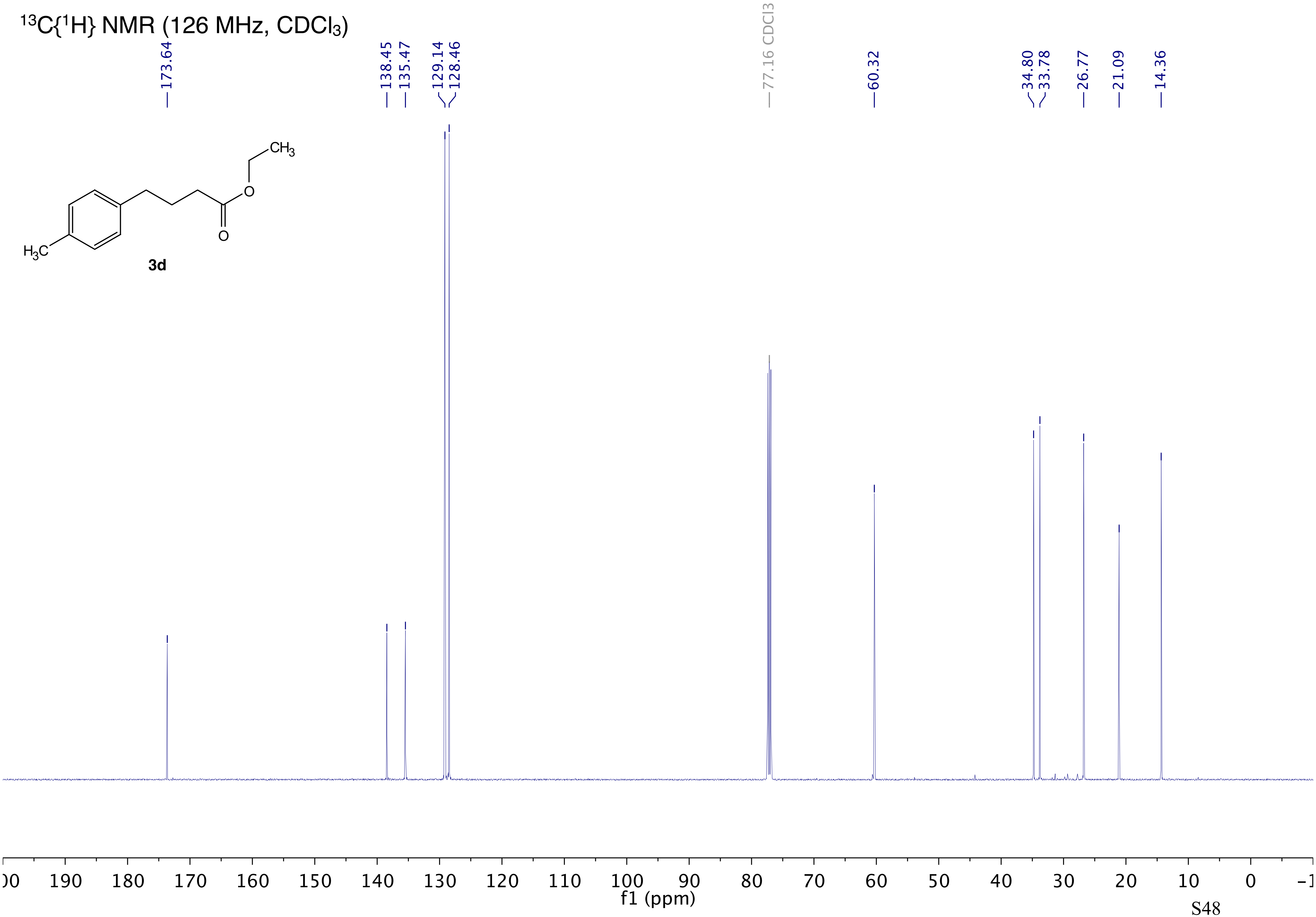

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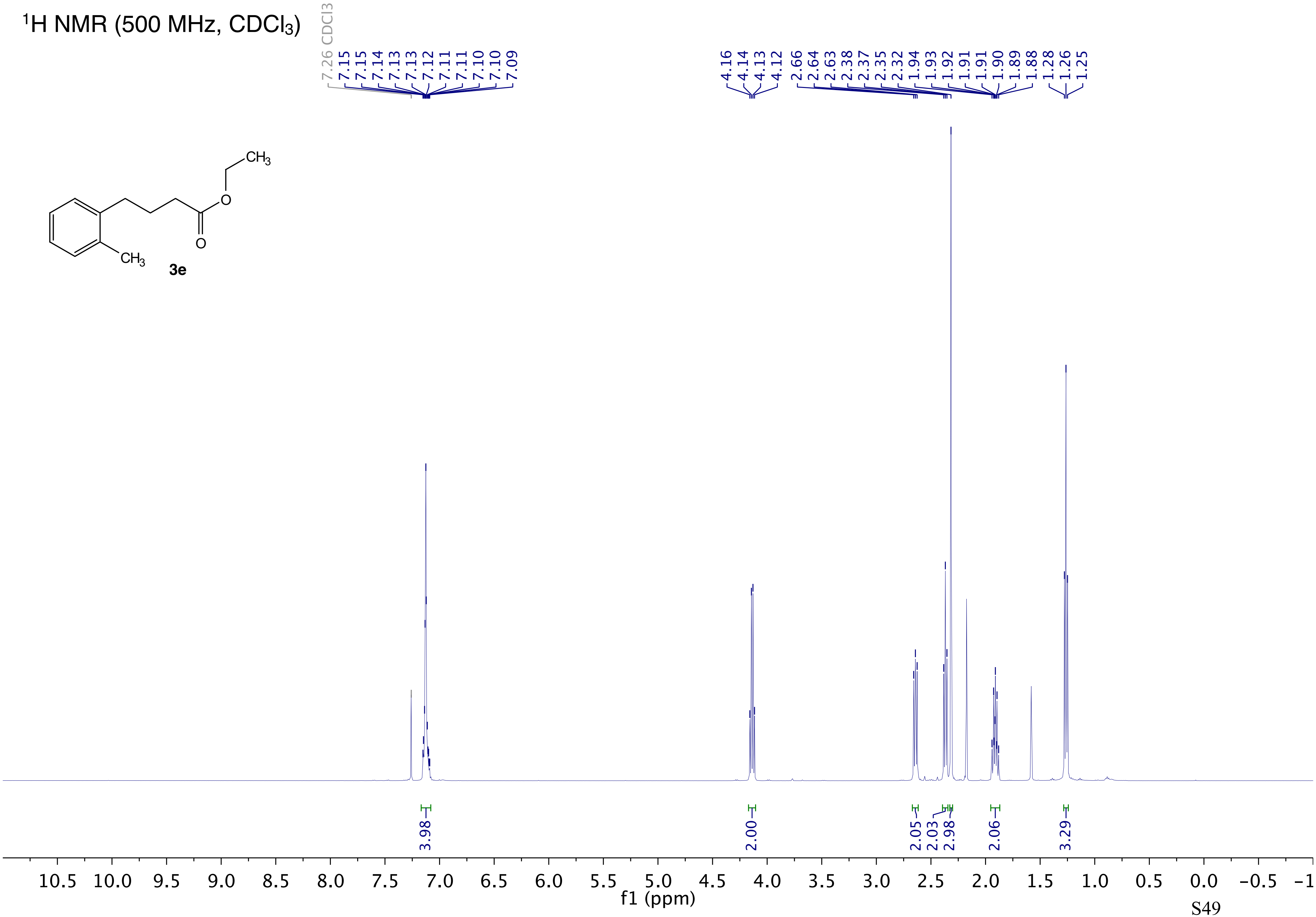

3e

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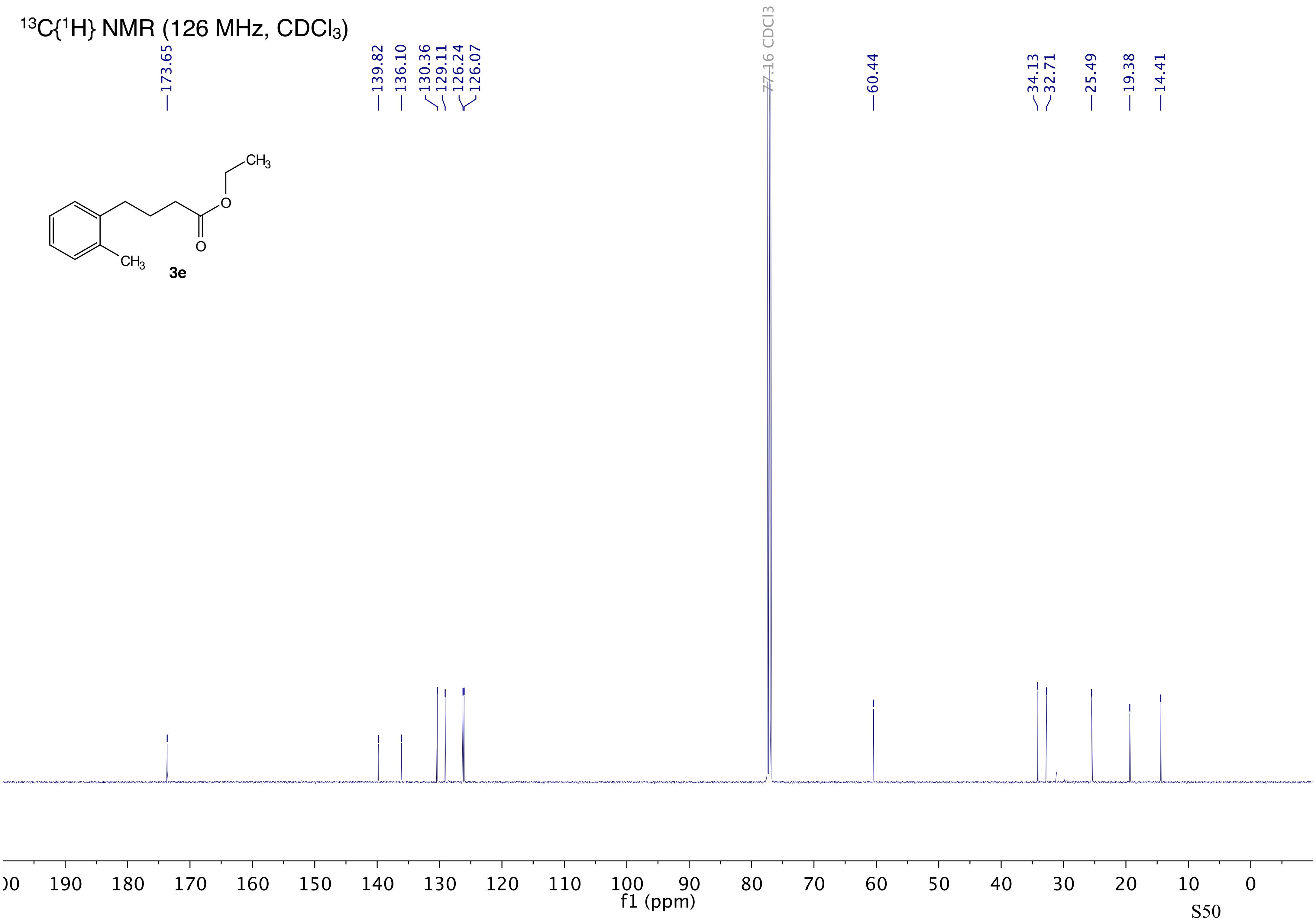

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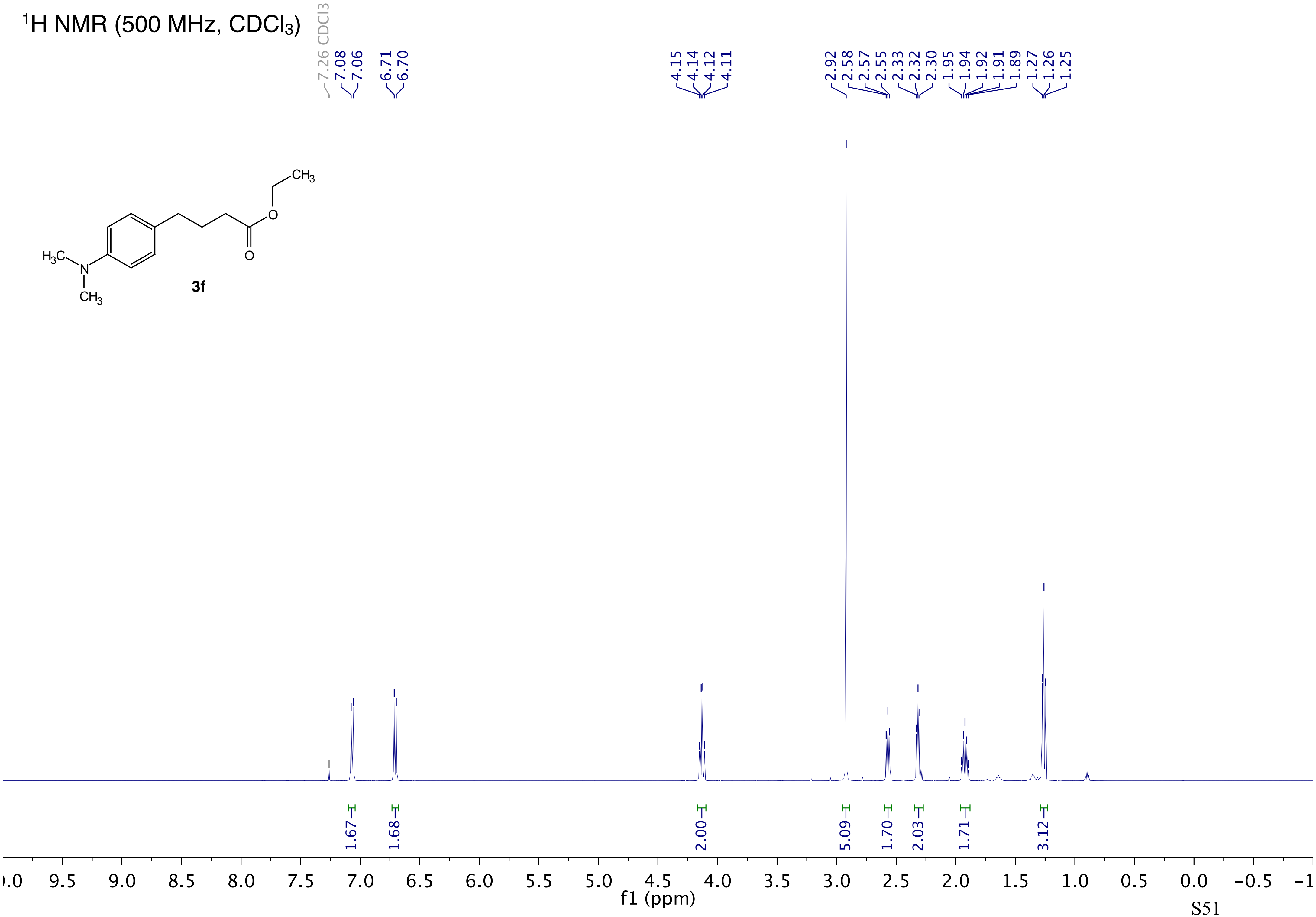

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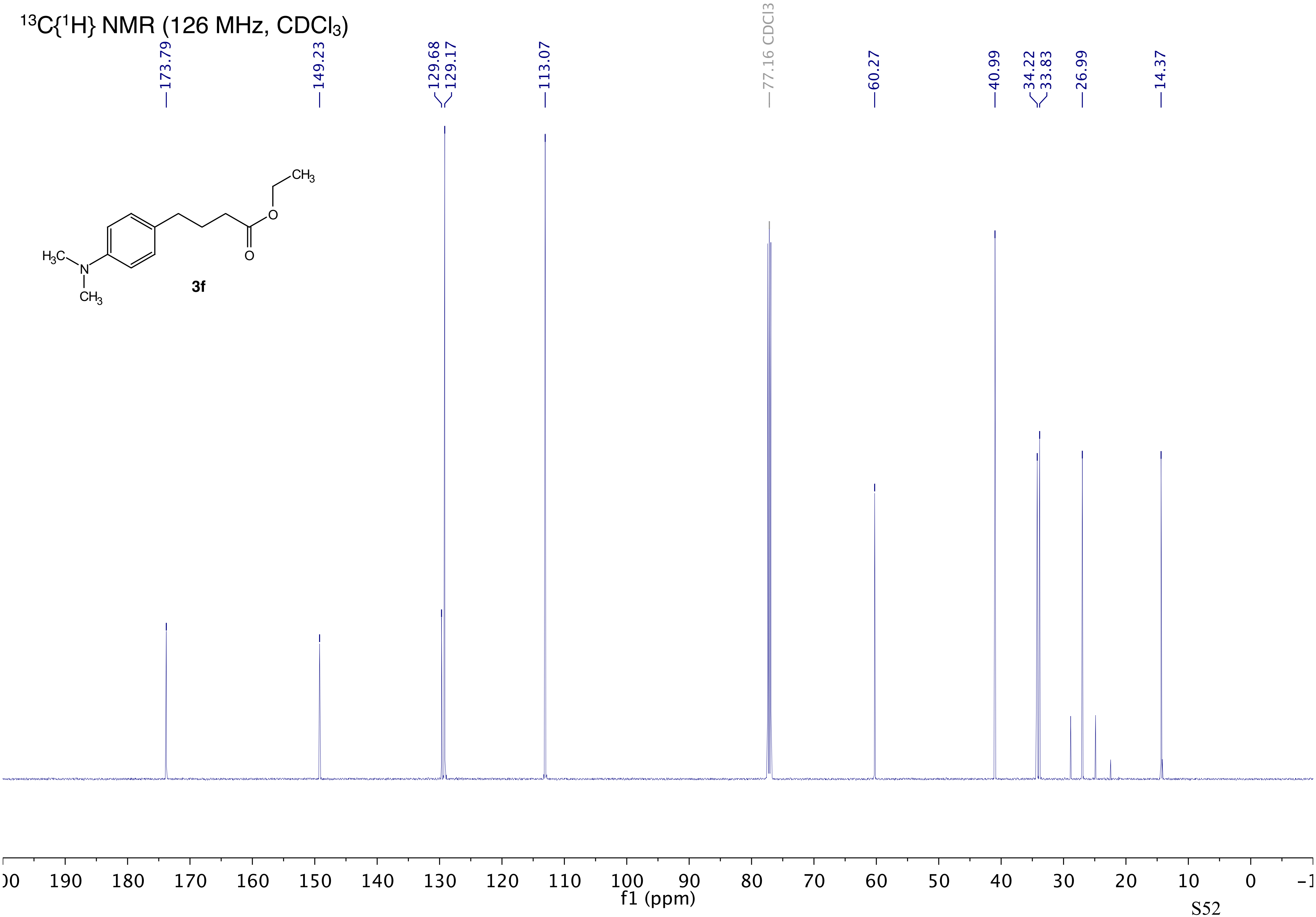

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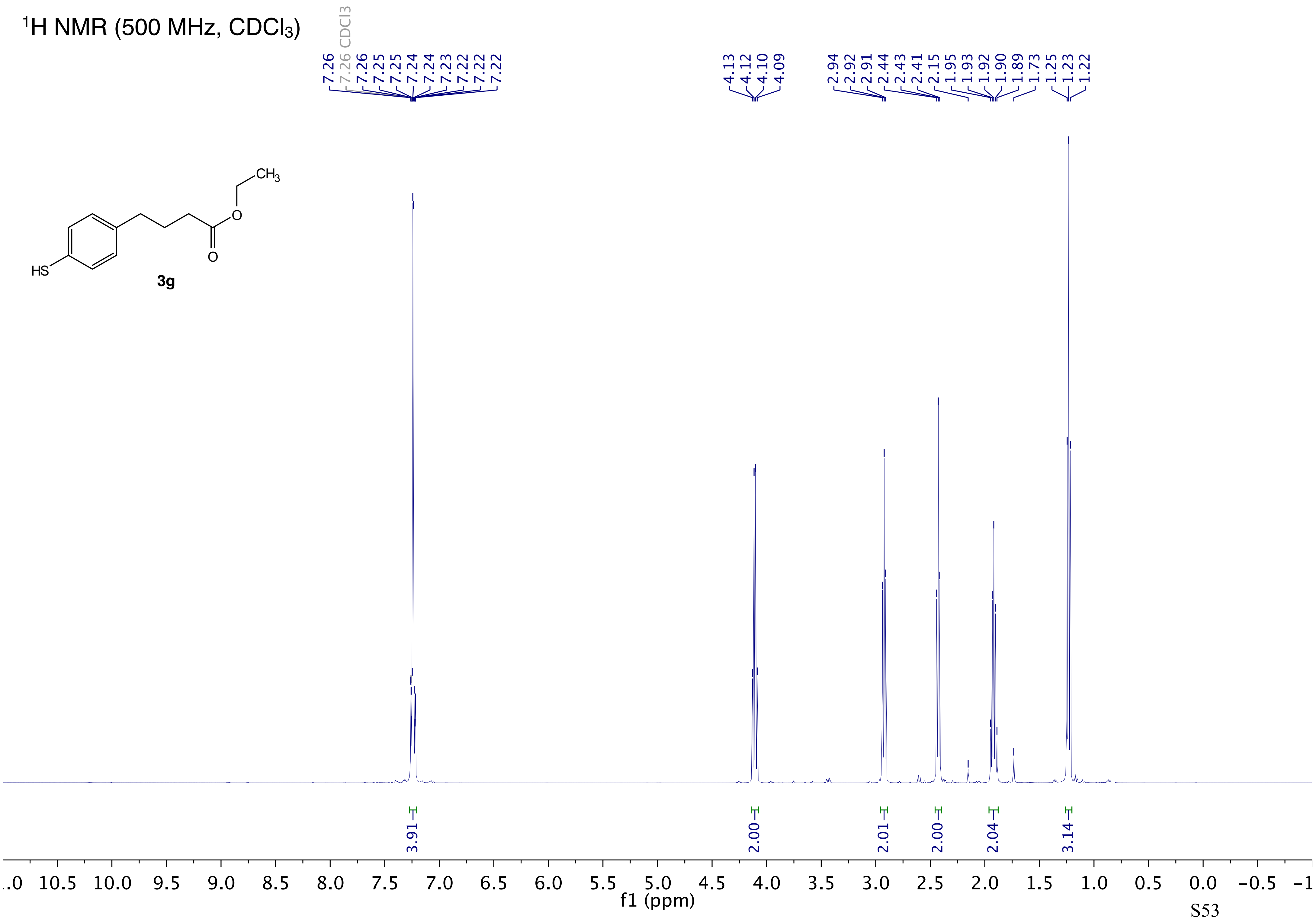

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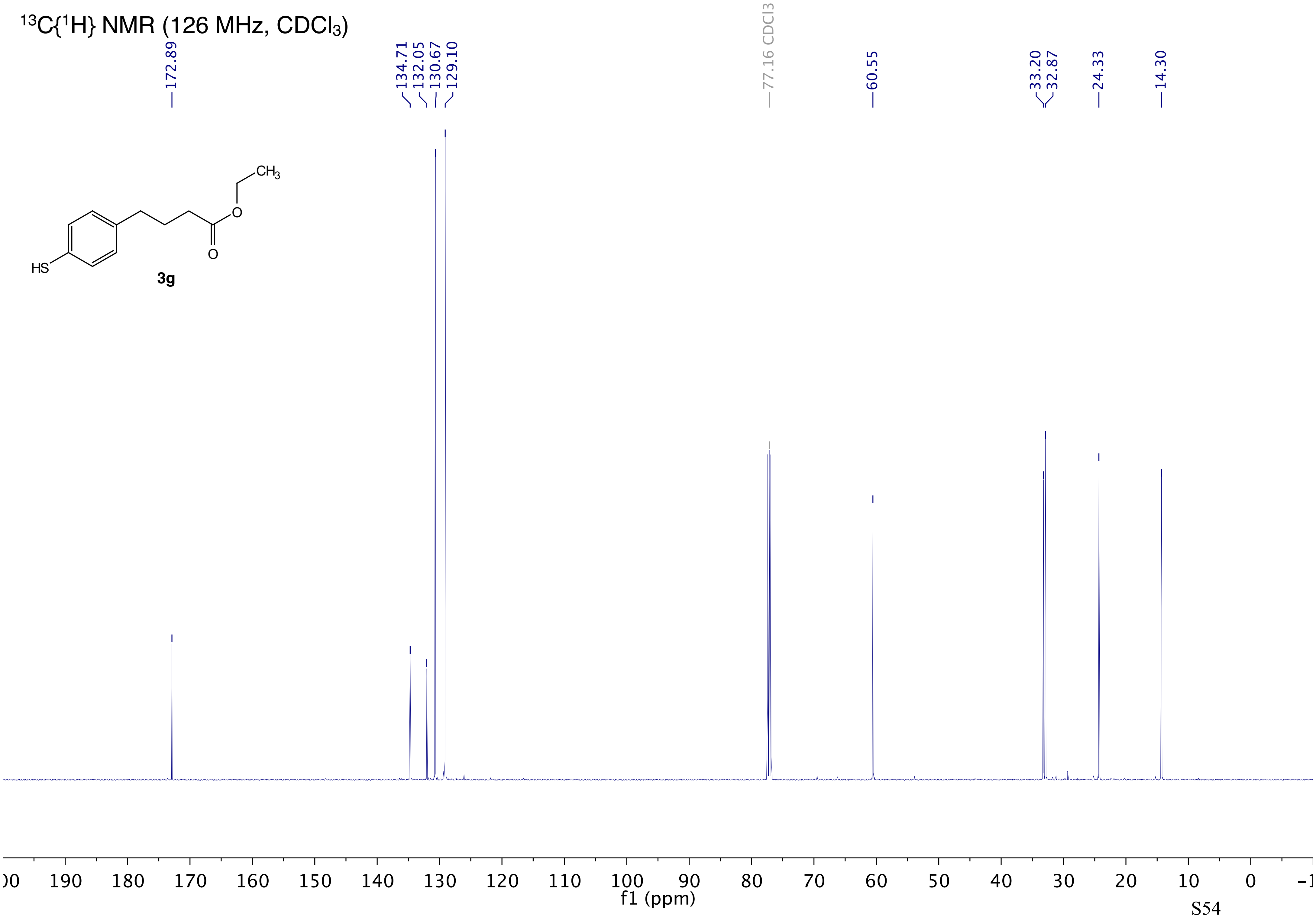

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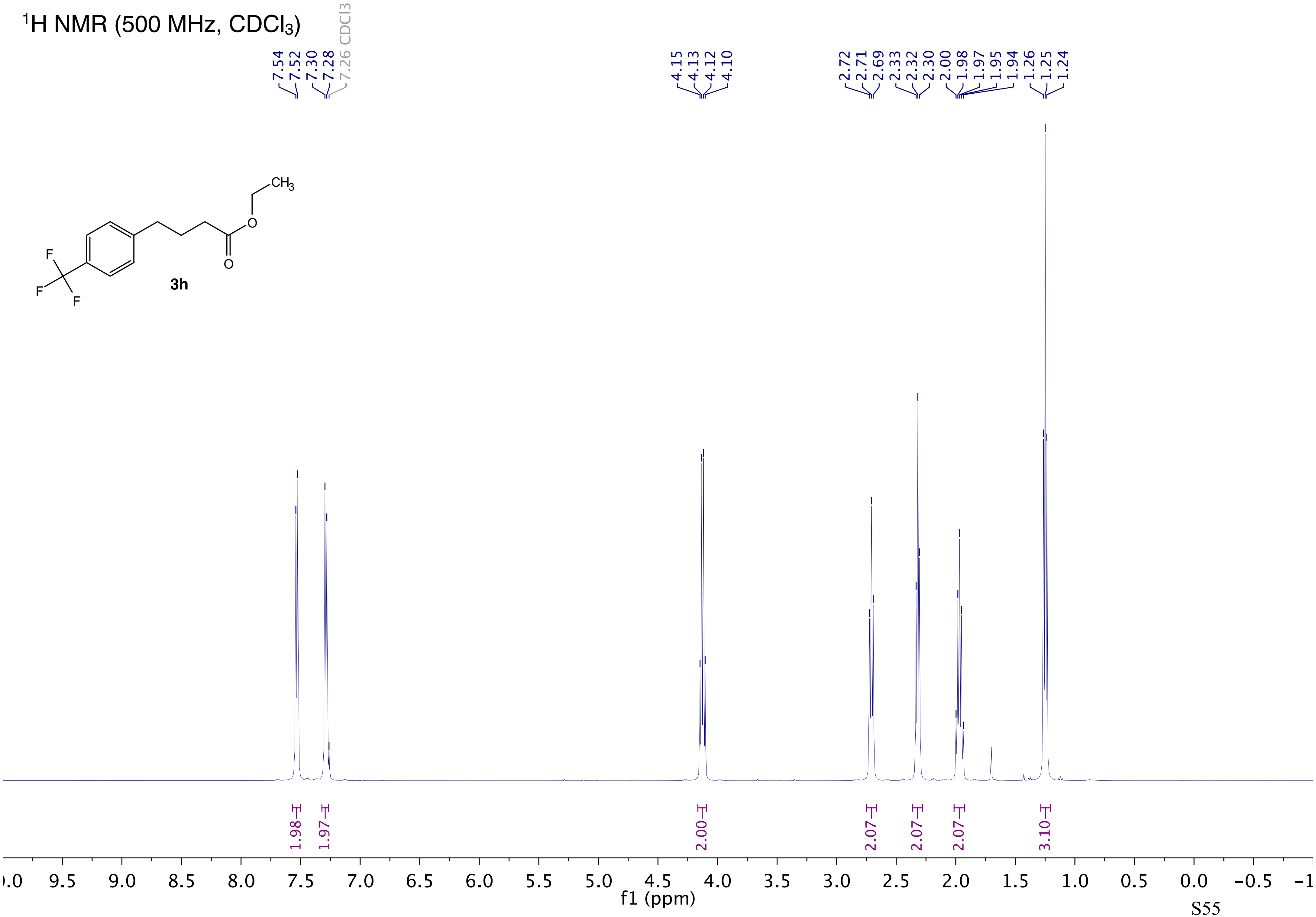

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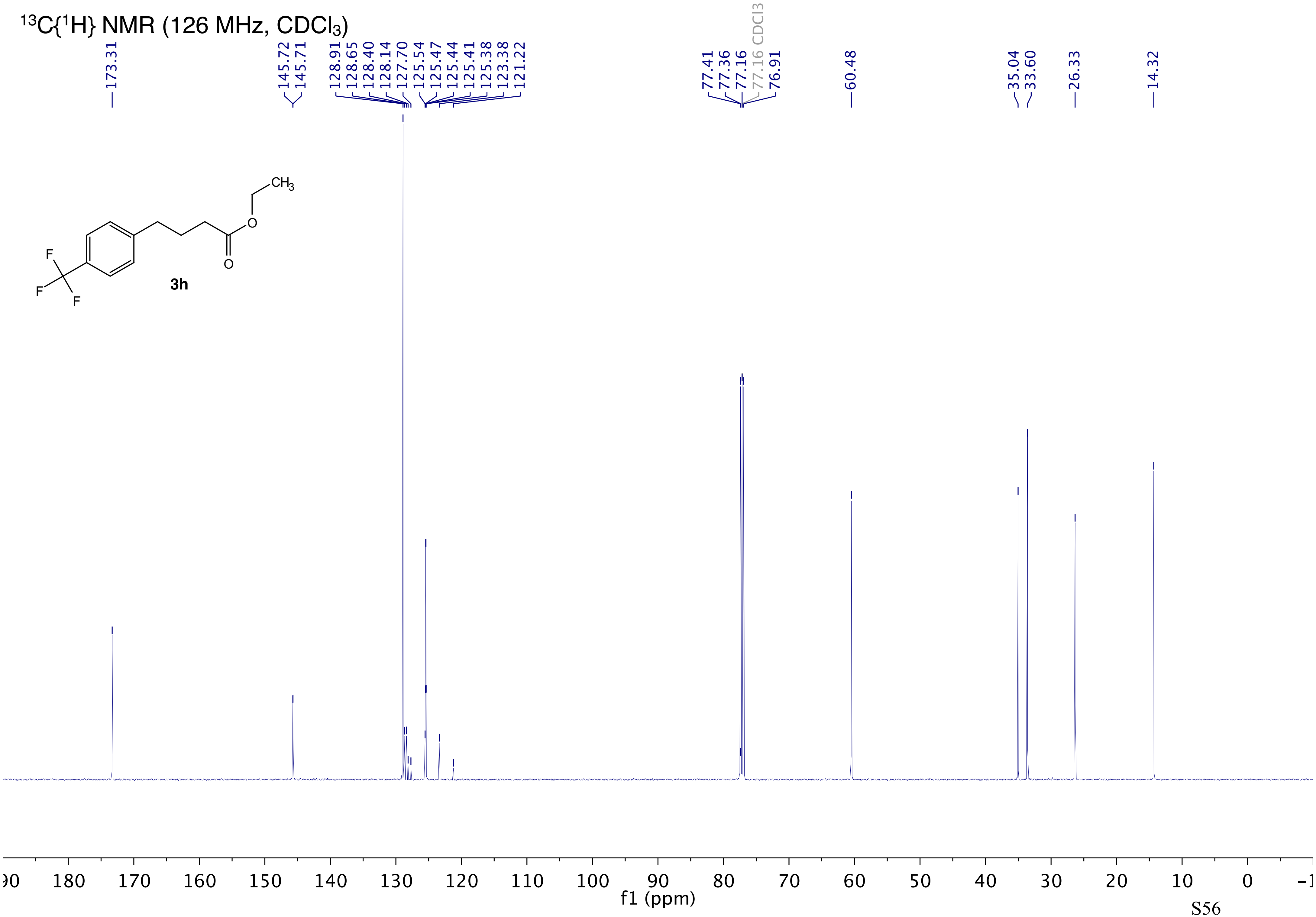

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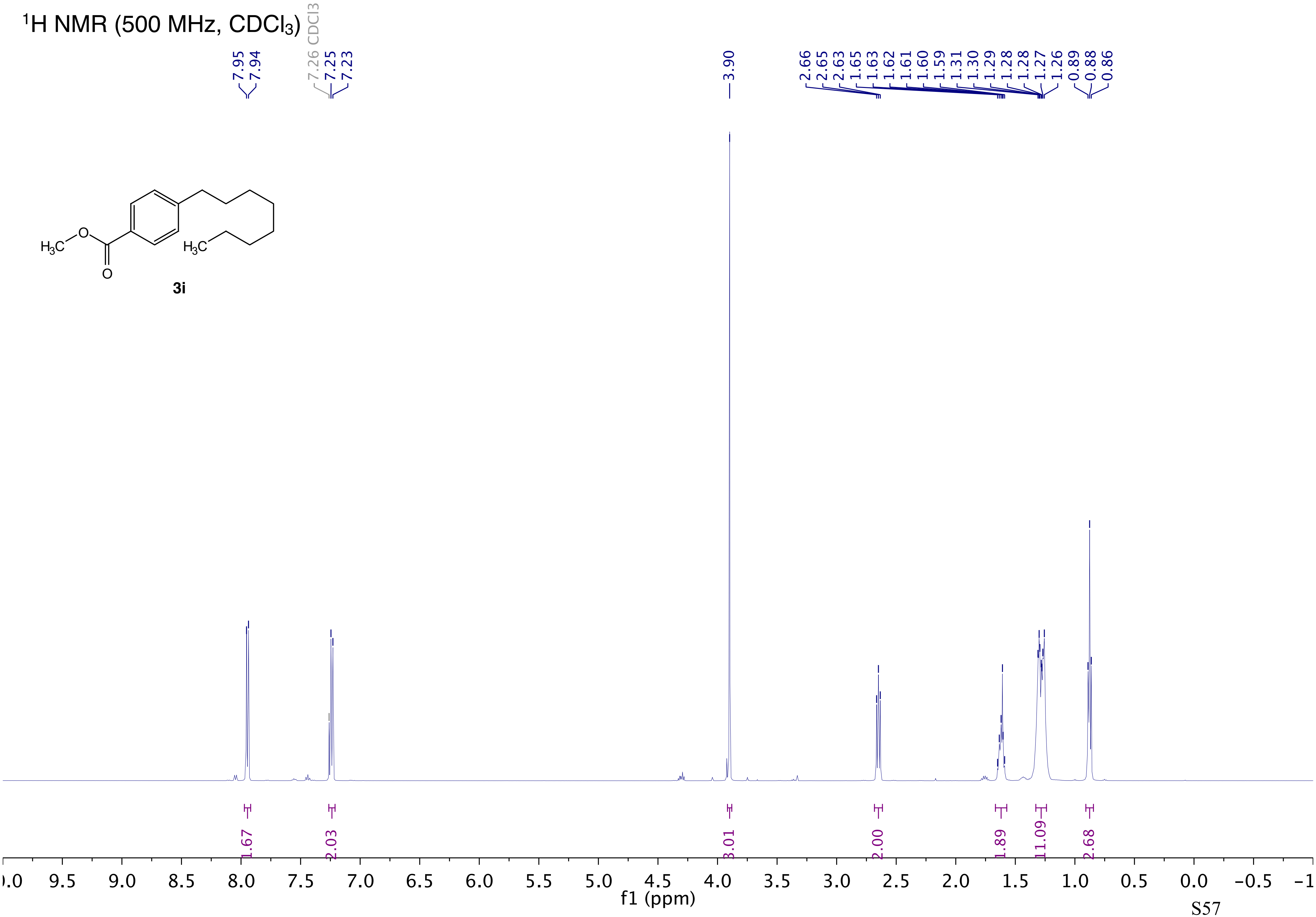
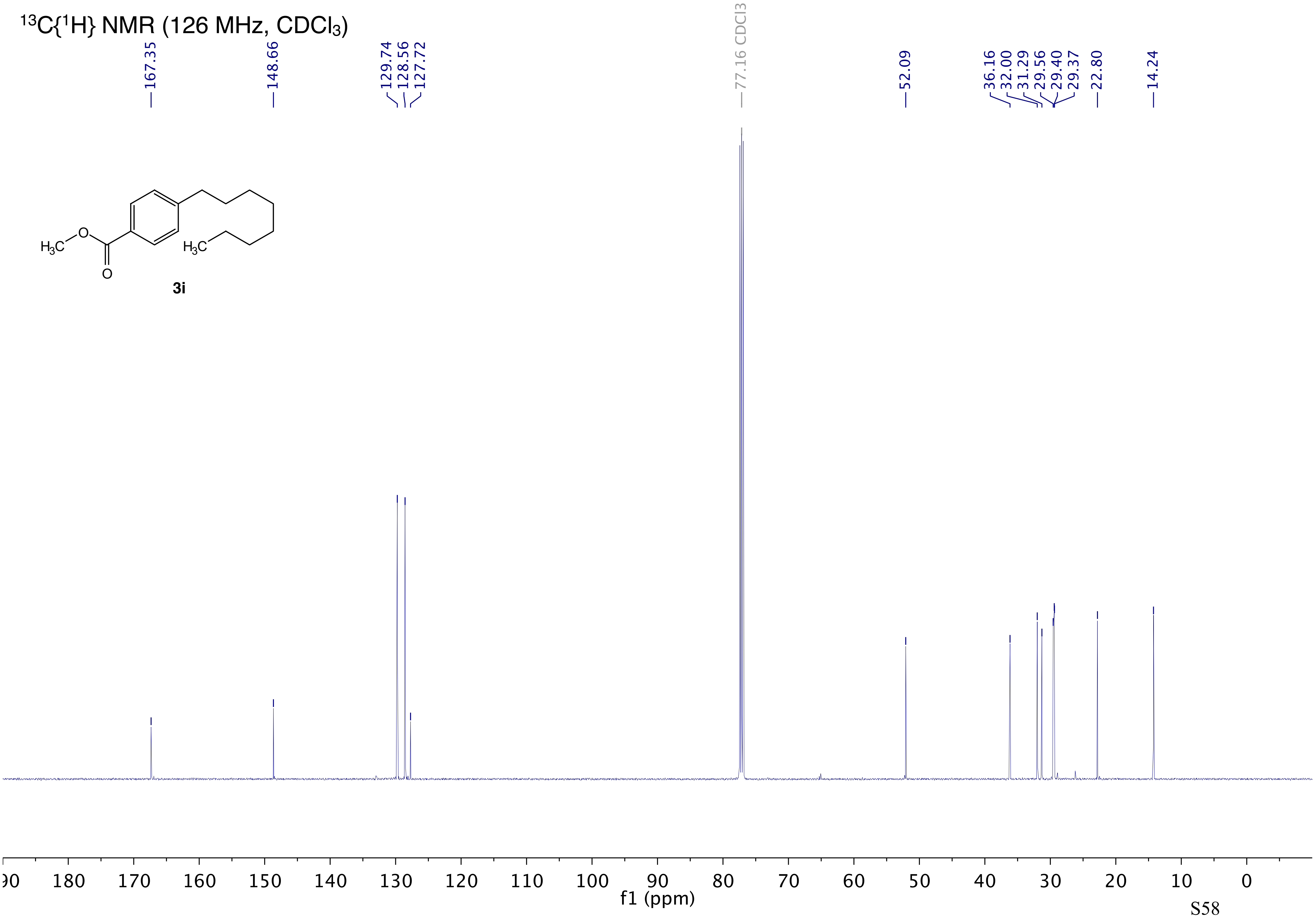
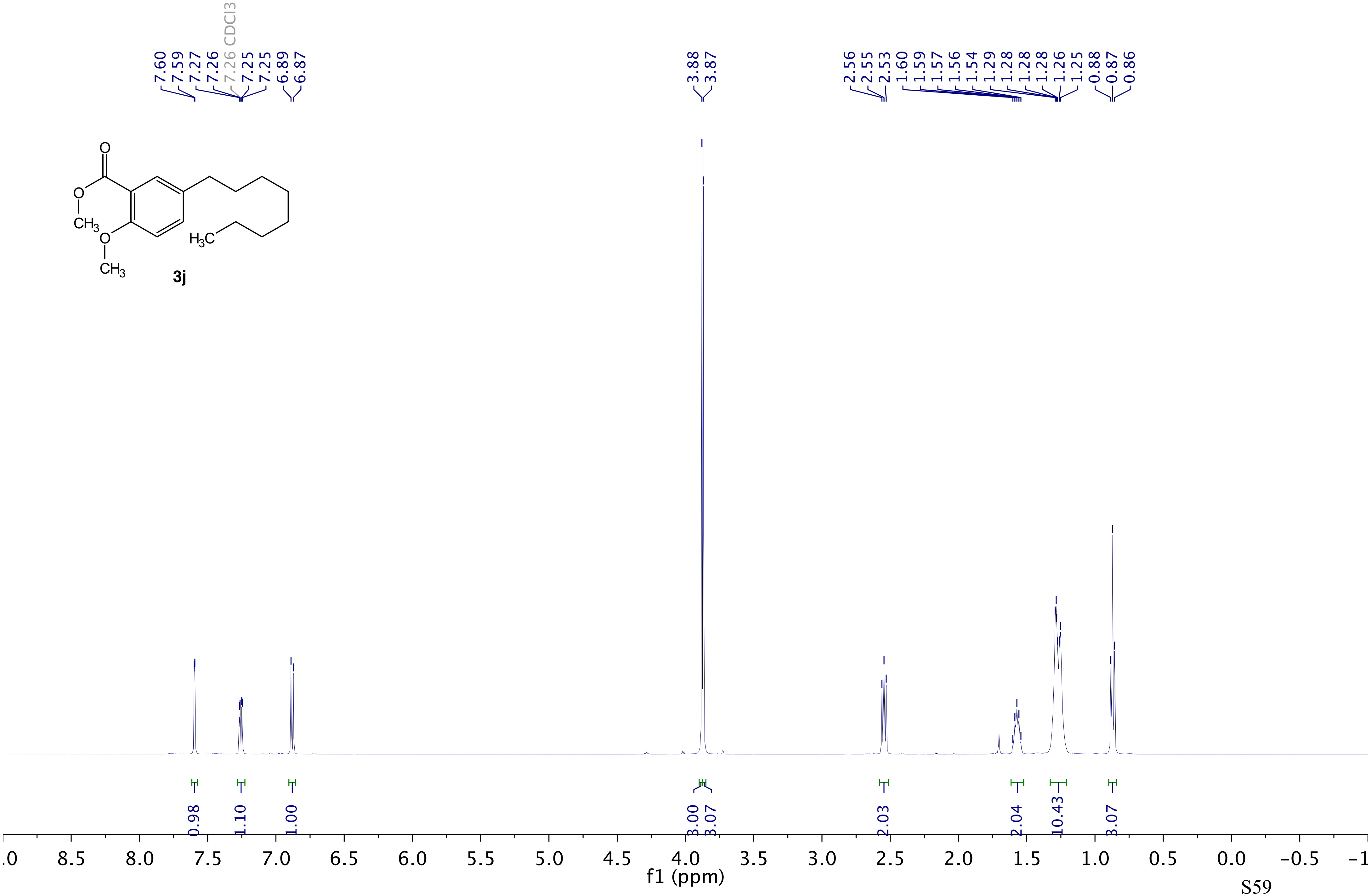


3i

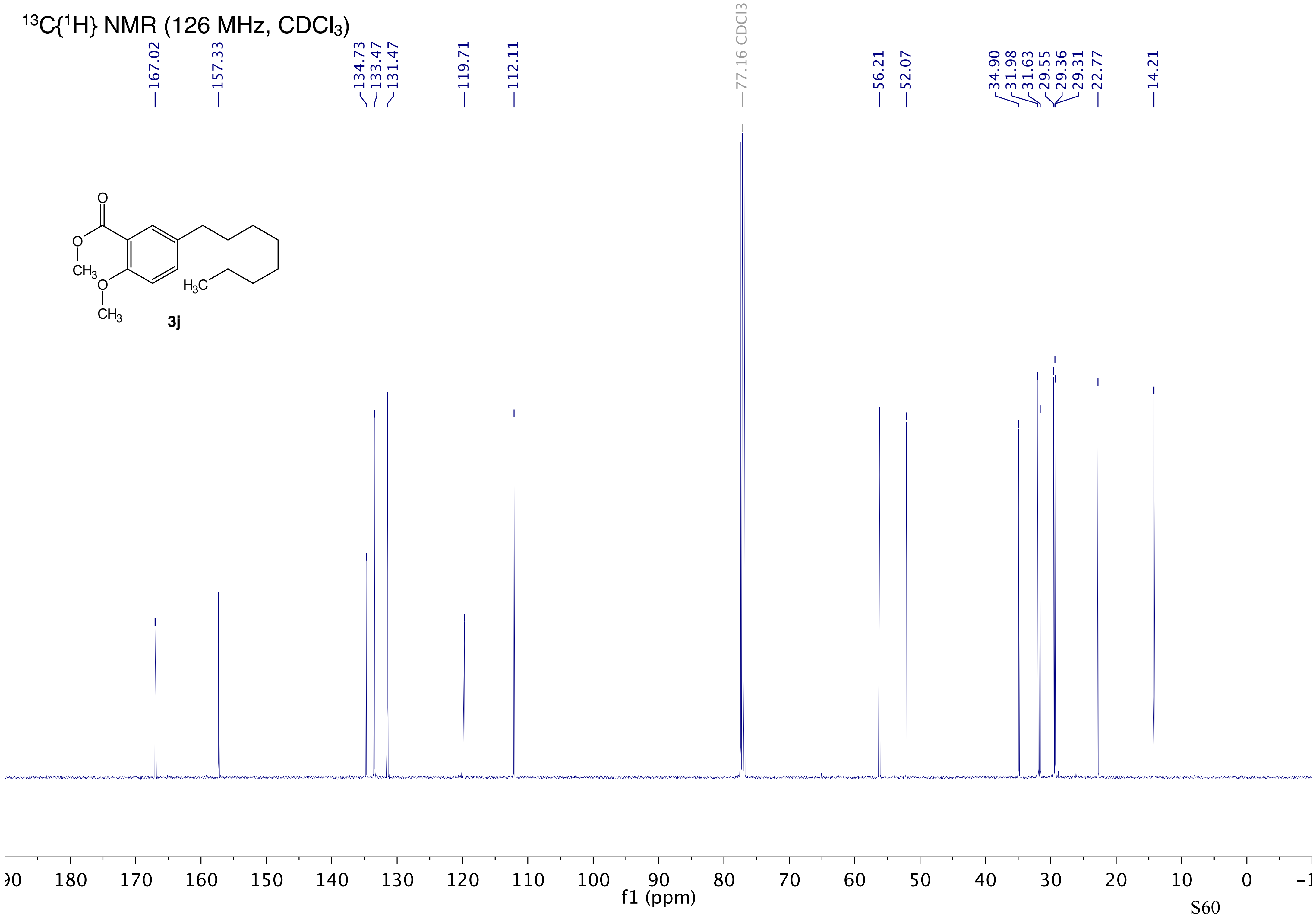
$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)



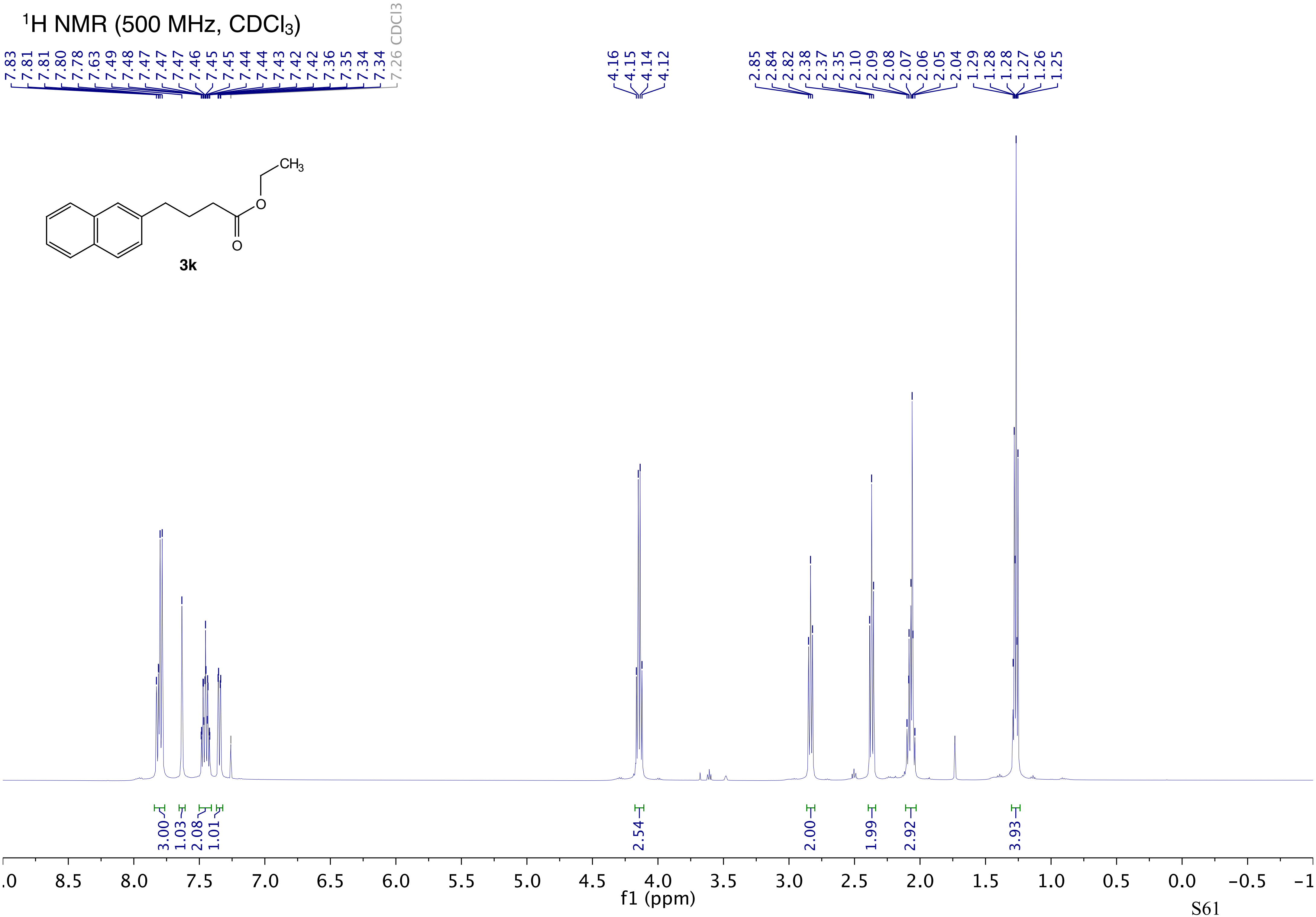
^{1}H NMR (500 MHz, $CDCl_3$)



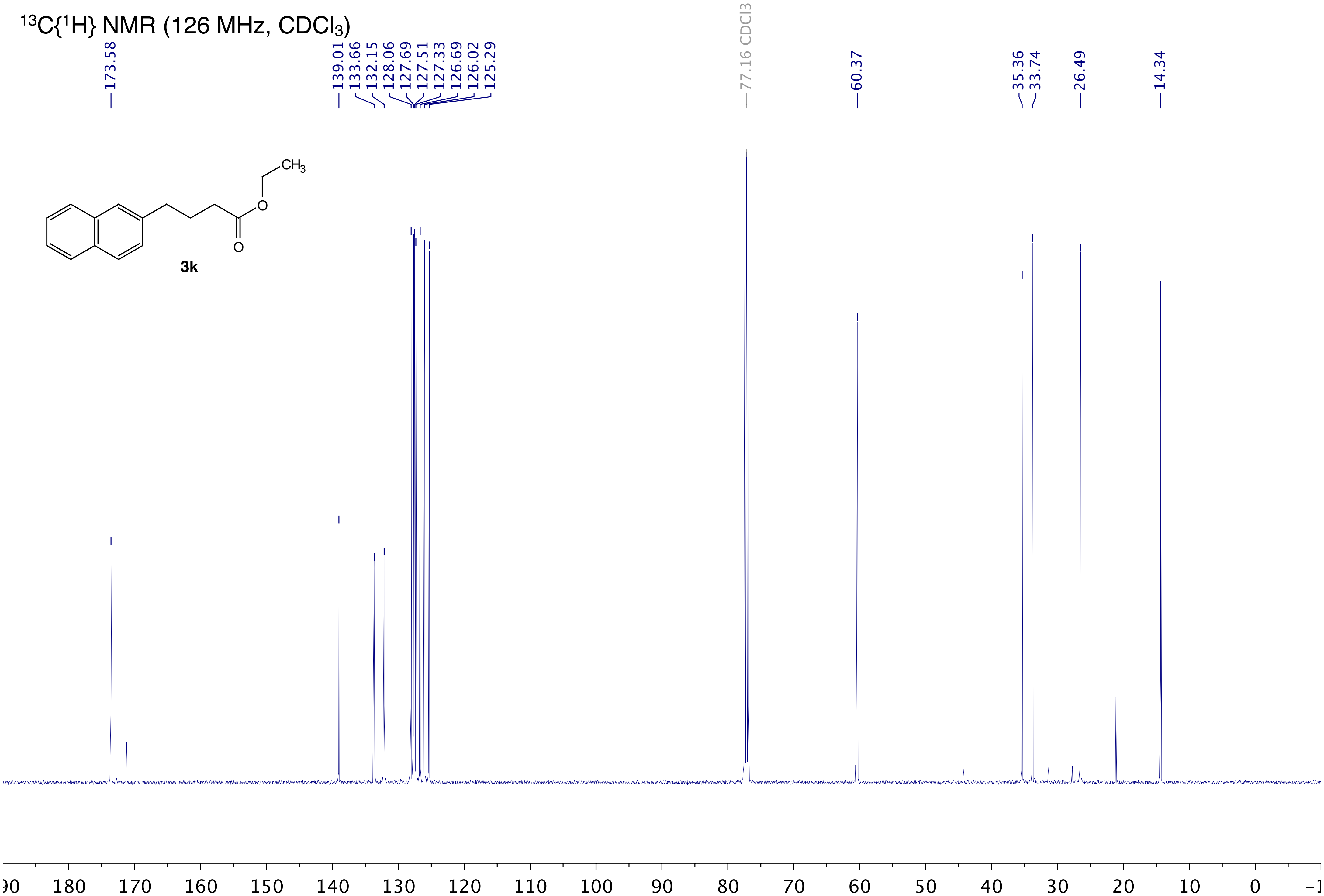
$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$)

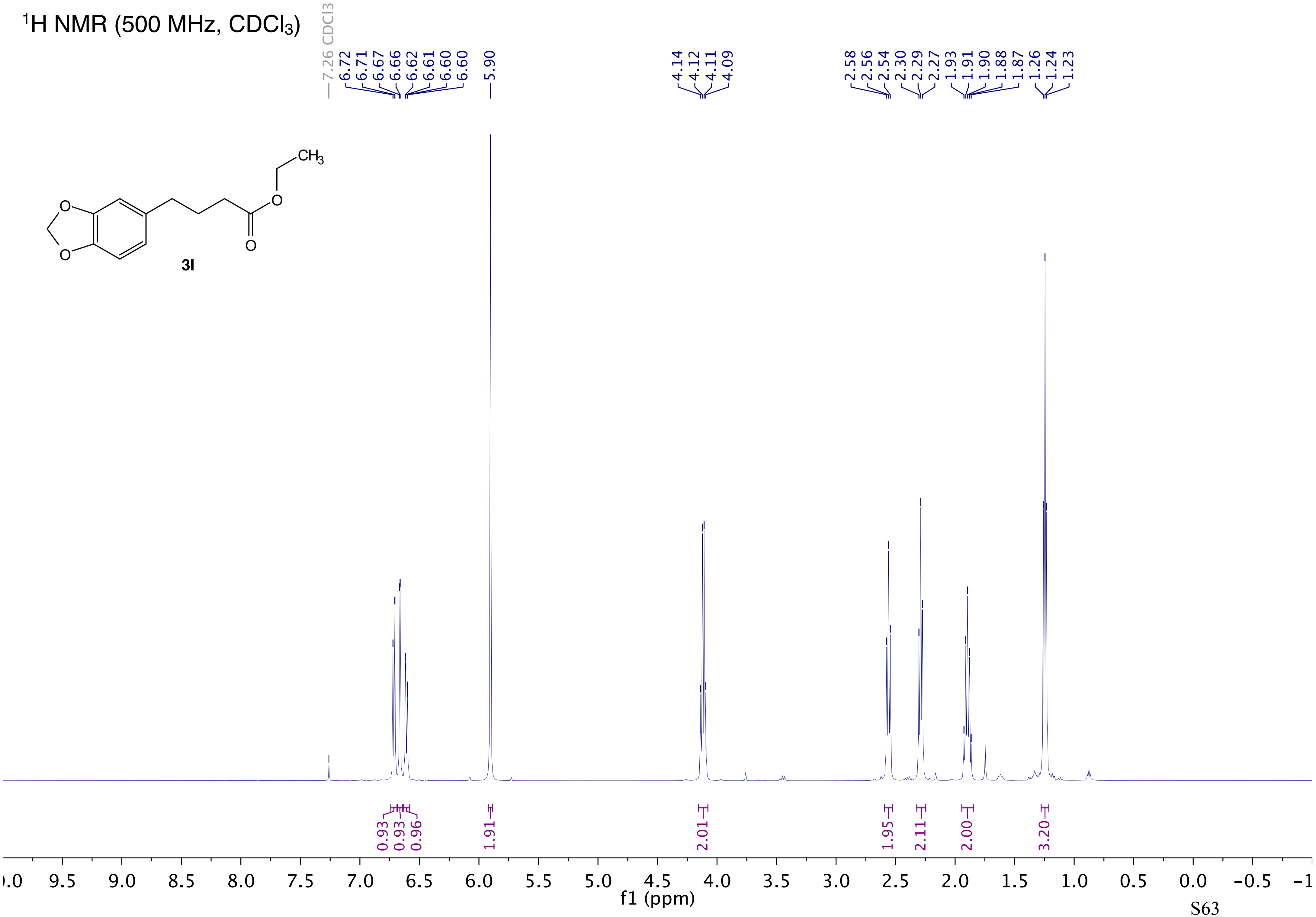


^{1}H NMR (500 MHz, $CDCl_3$)



$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)




1H NMR (500 MHz, CDCl3)
7.26 CDCl3
6.72
6.71
6.67
6.66
6.62
6.61
6.60
6.60
5.90
4.14
4.12
4.11
4.09
2.58
2.56
2.54
2.30
2.29
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1.93
1.91
1.90
1.88
1.87
1.26
1.24
1.23
CH3
O
O
O
O
3l
0.93
0.93
0.96
1.91
2.01
1.95
2.11
2.00
3.20
10.0
9.5
9.0
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7.5
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4.5
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2.5
2.0
1.5
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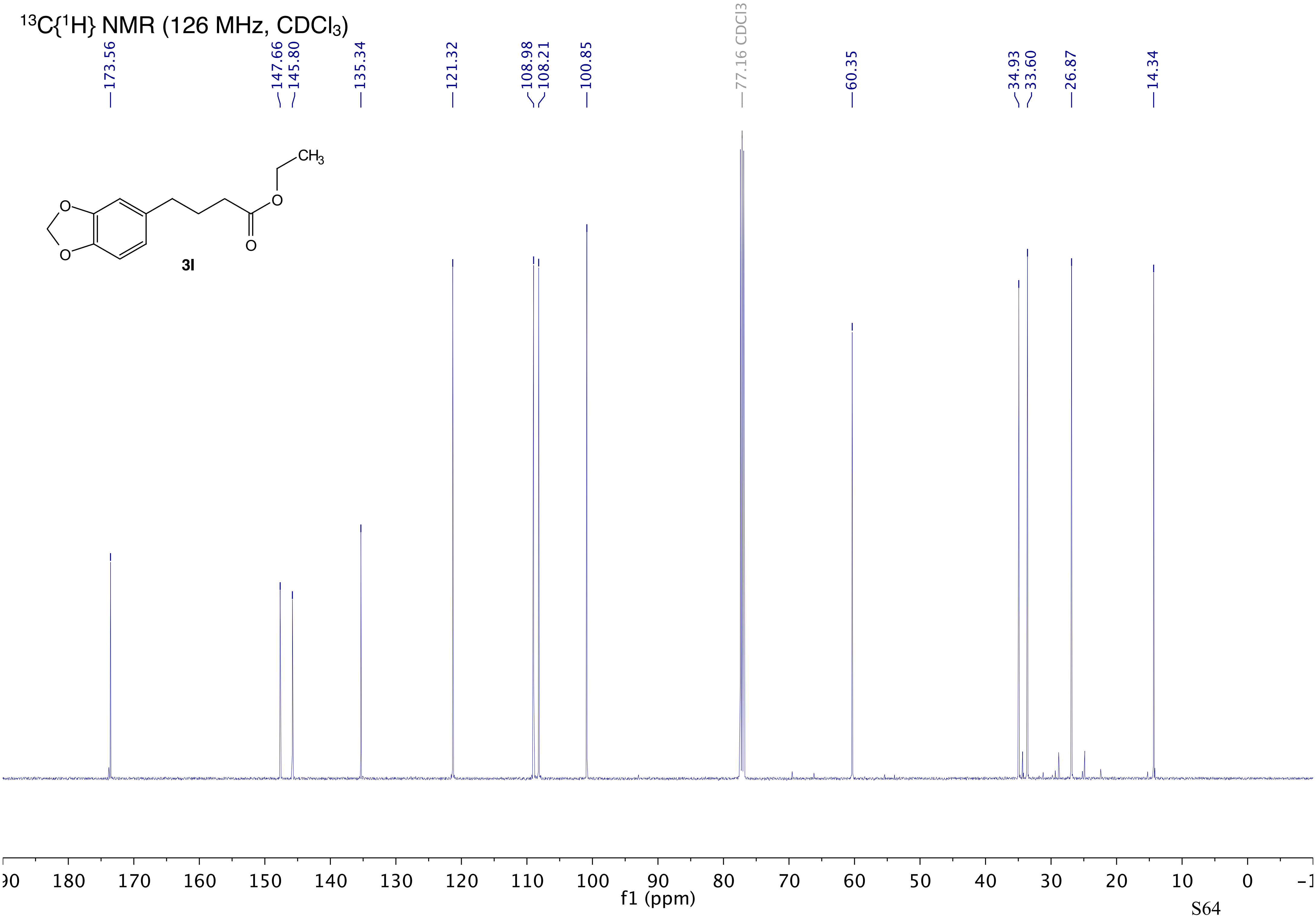
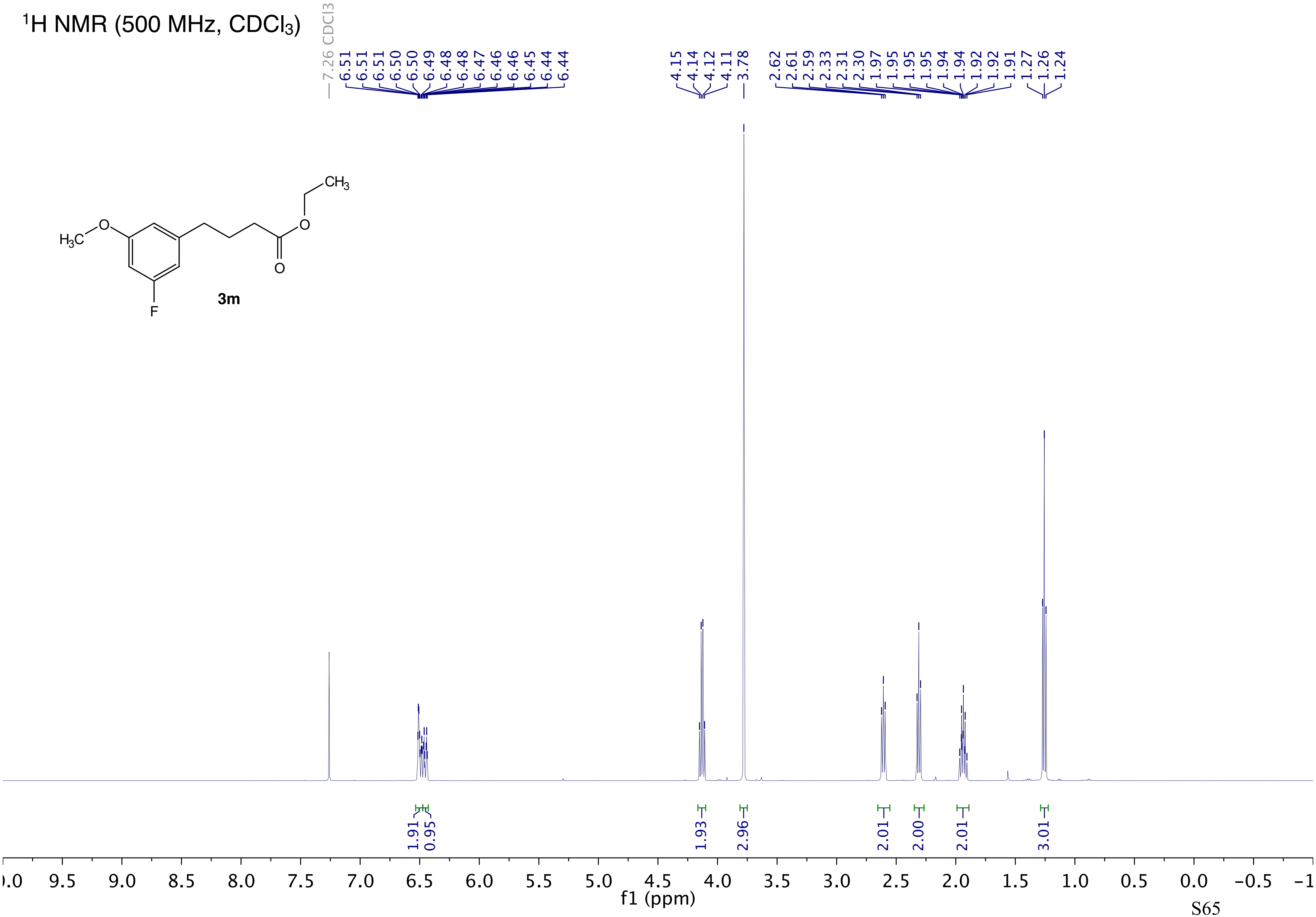
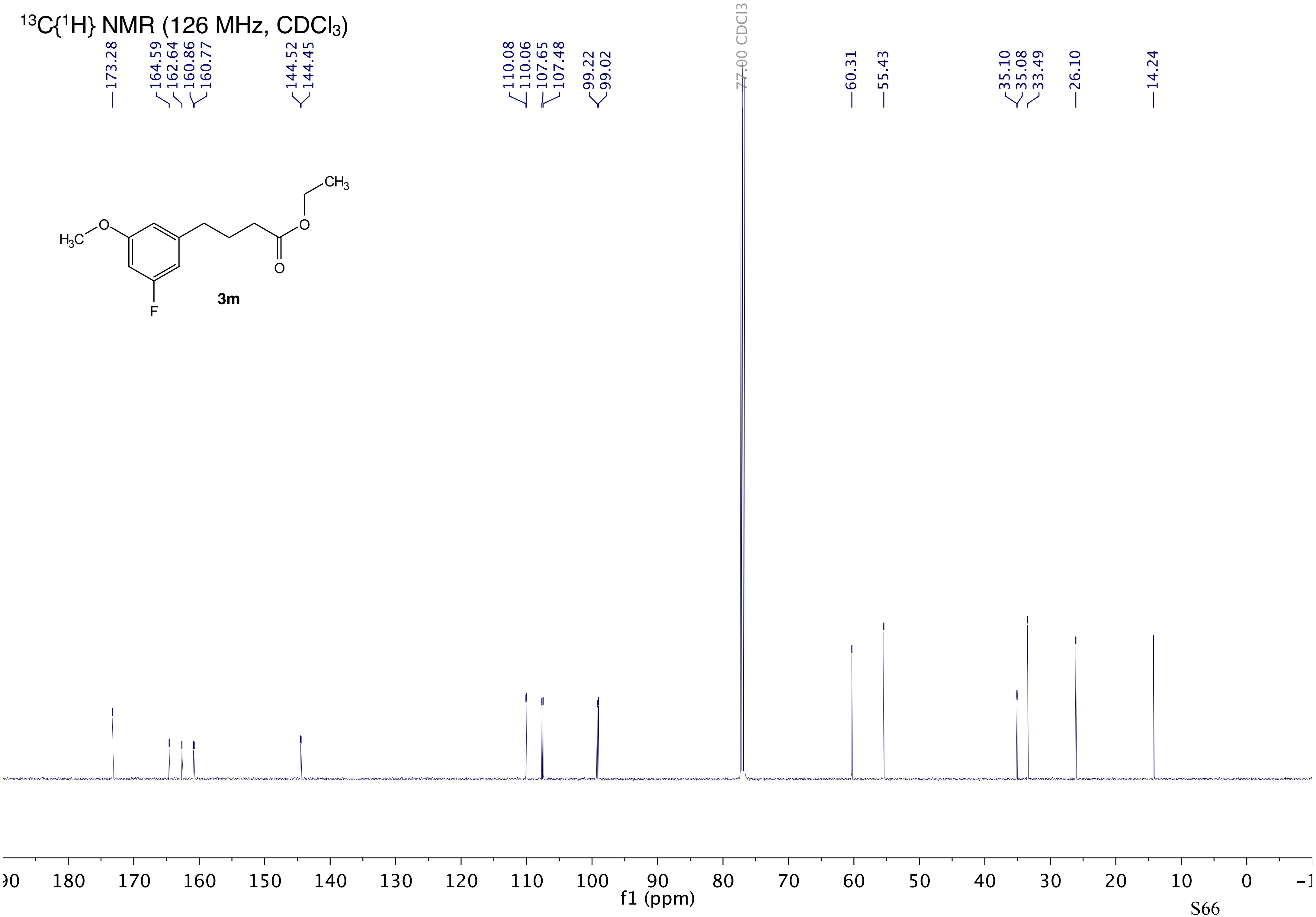
0.5
0.0
−0.5
−1
f1 (ppm)


$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)

^{1}H NMR (500 MHz, $CDCl_3$)

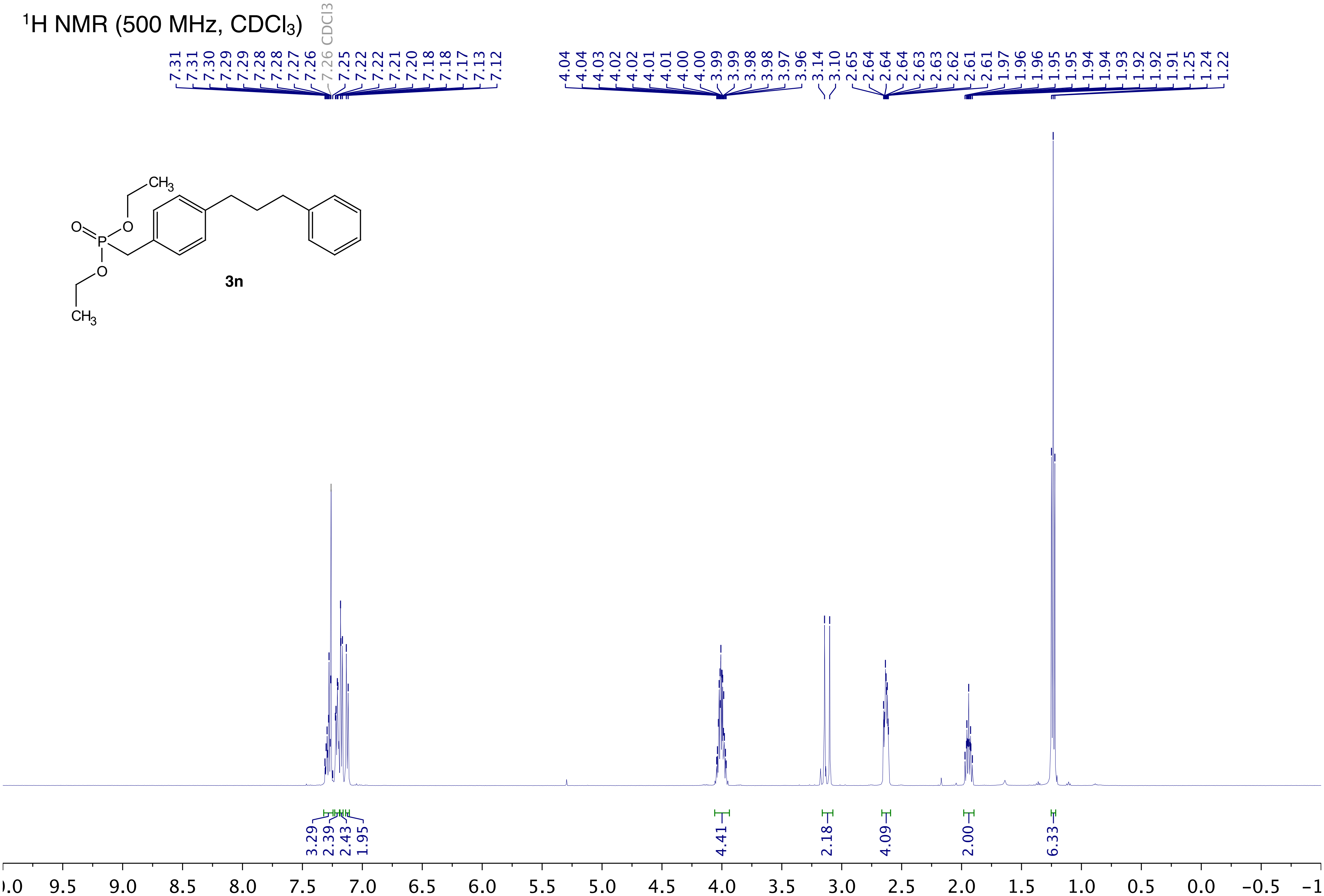


$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)

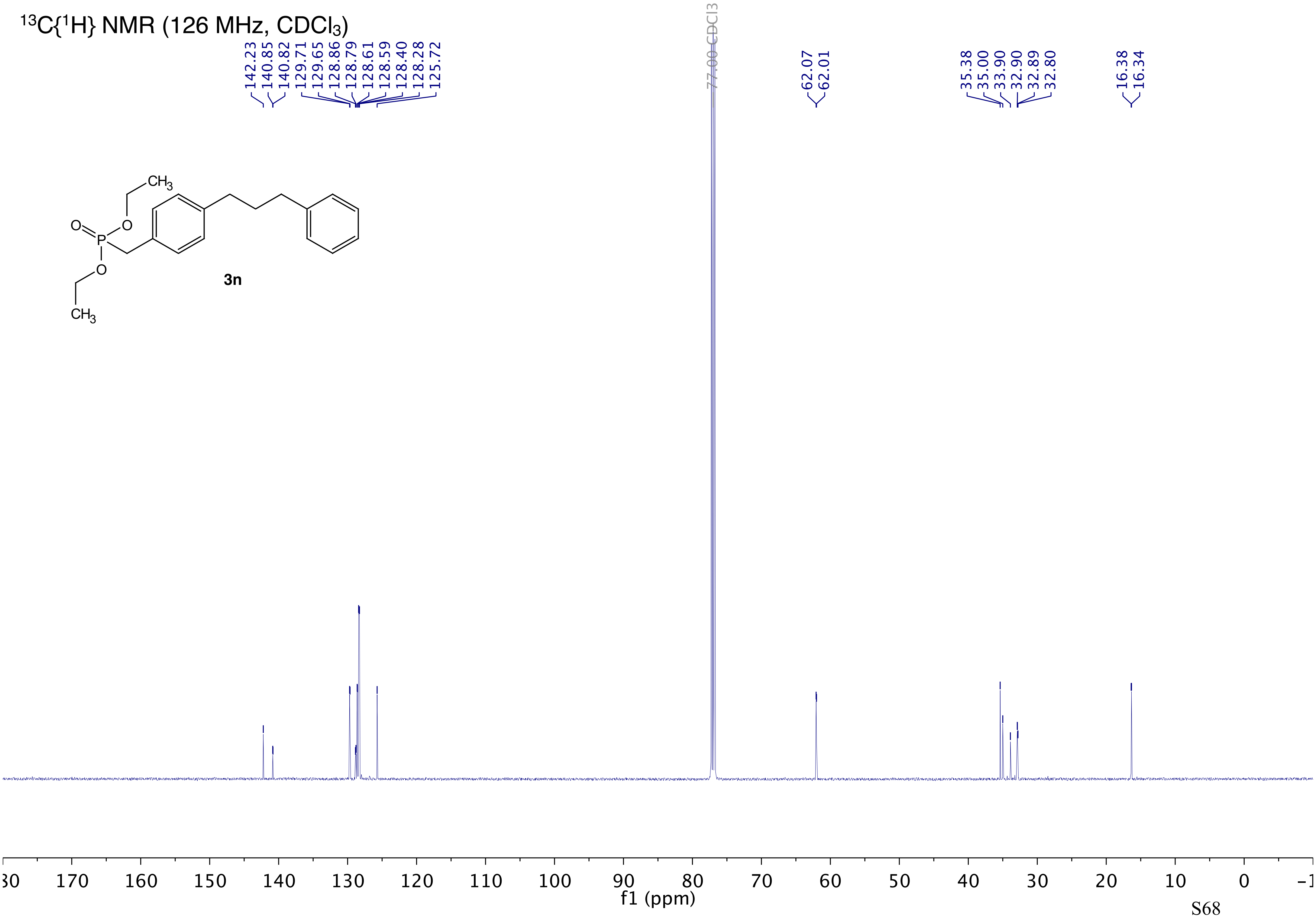


3m

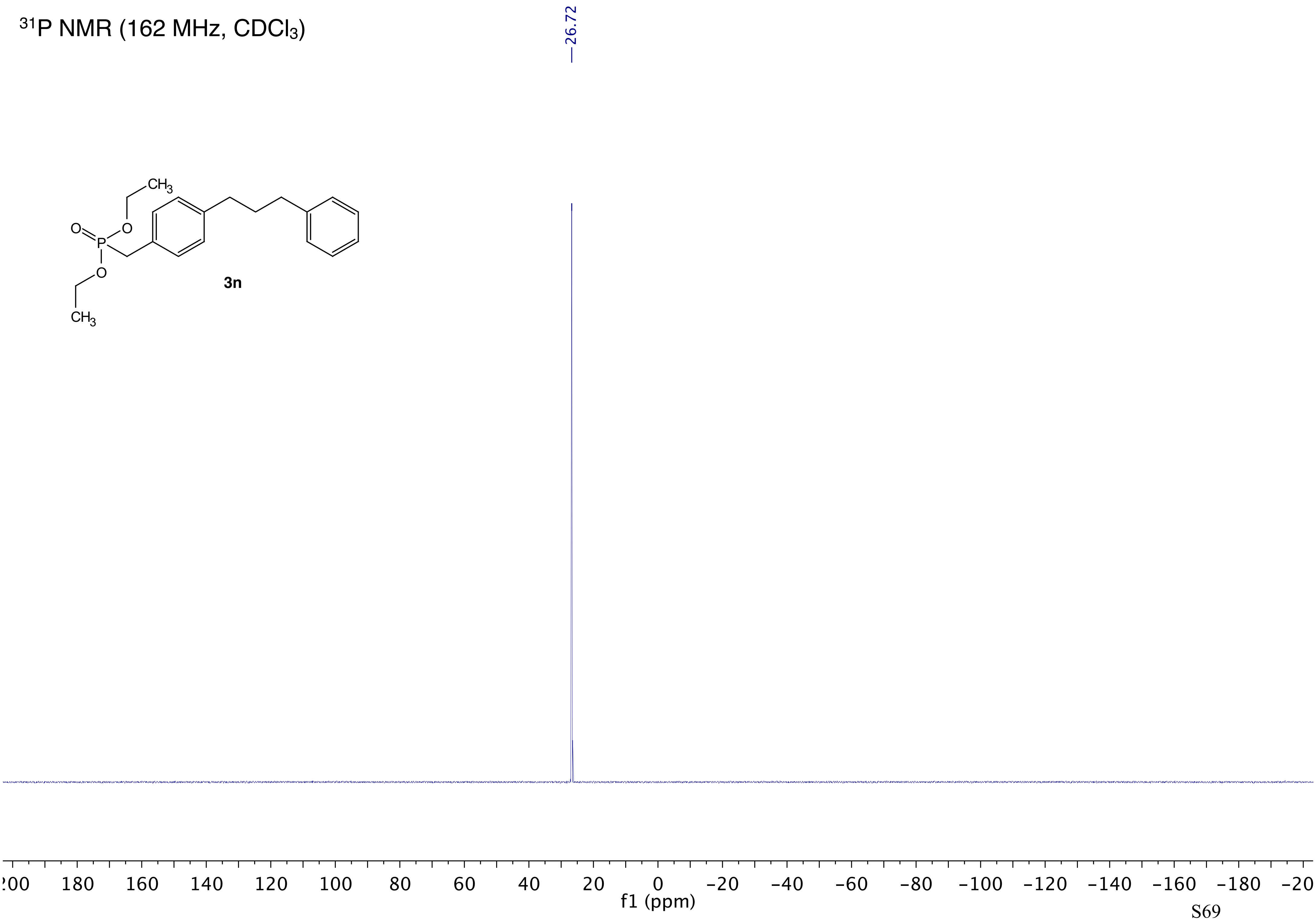
^{1}H NMR (500 MHz, $CDCl_3$)



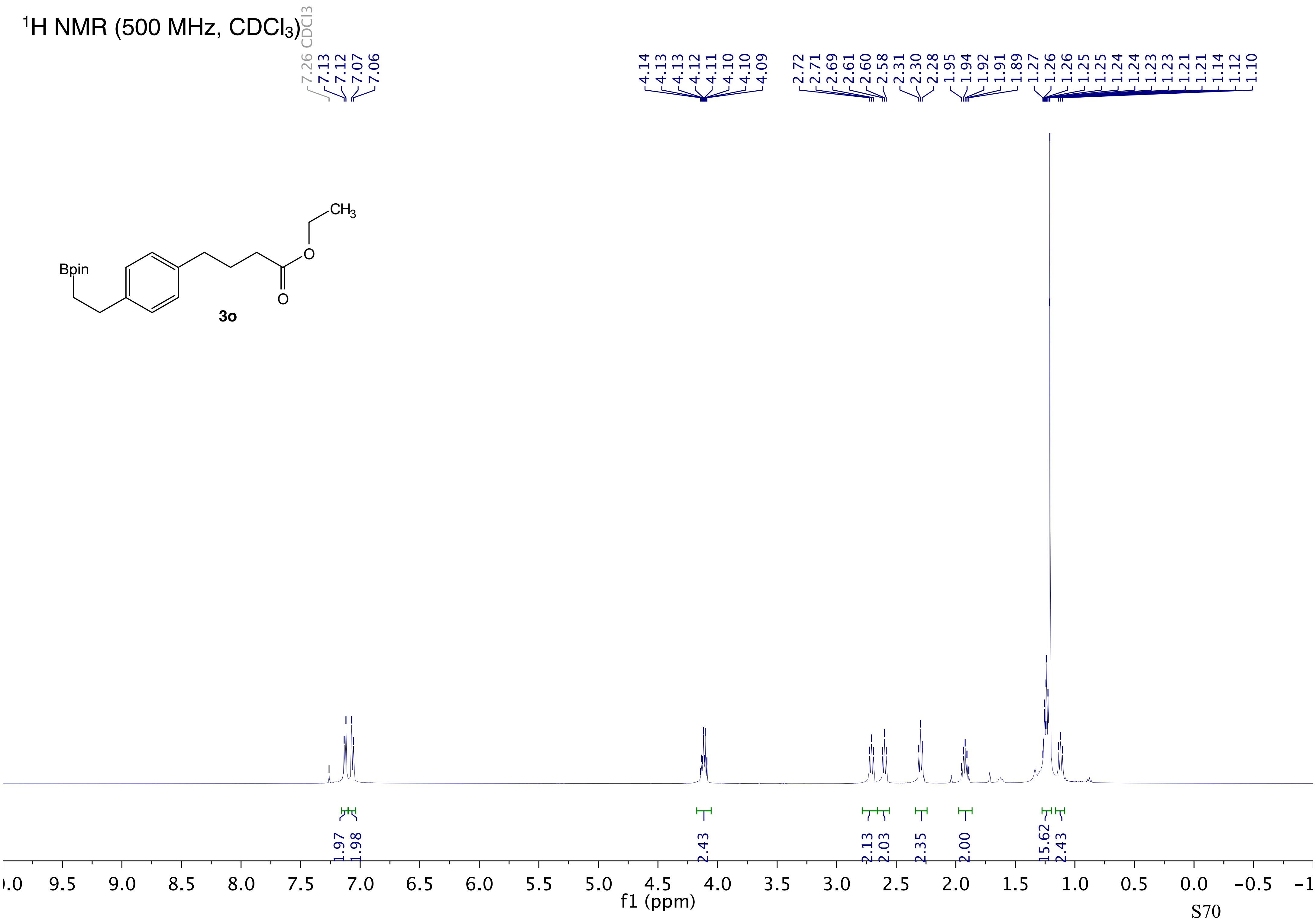
$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$)



^{31}P NMR (162 MHz, CDCl$_3$)



^{1}H NMR (500 MHz, $CDCl_3$)



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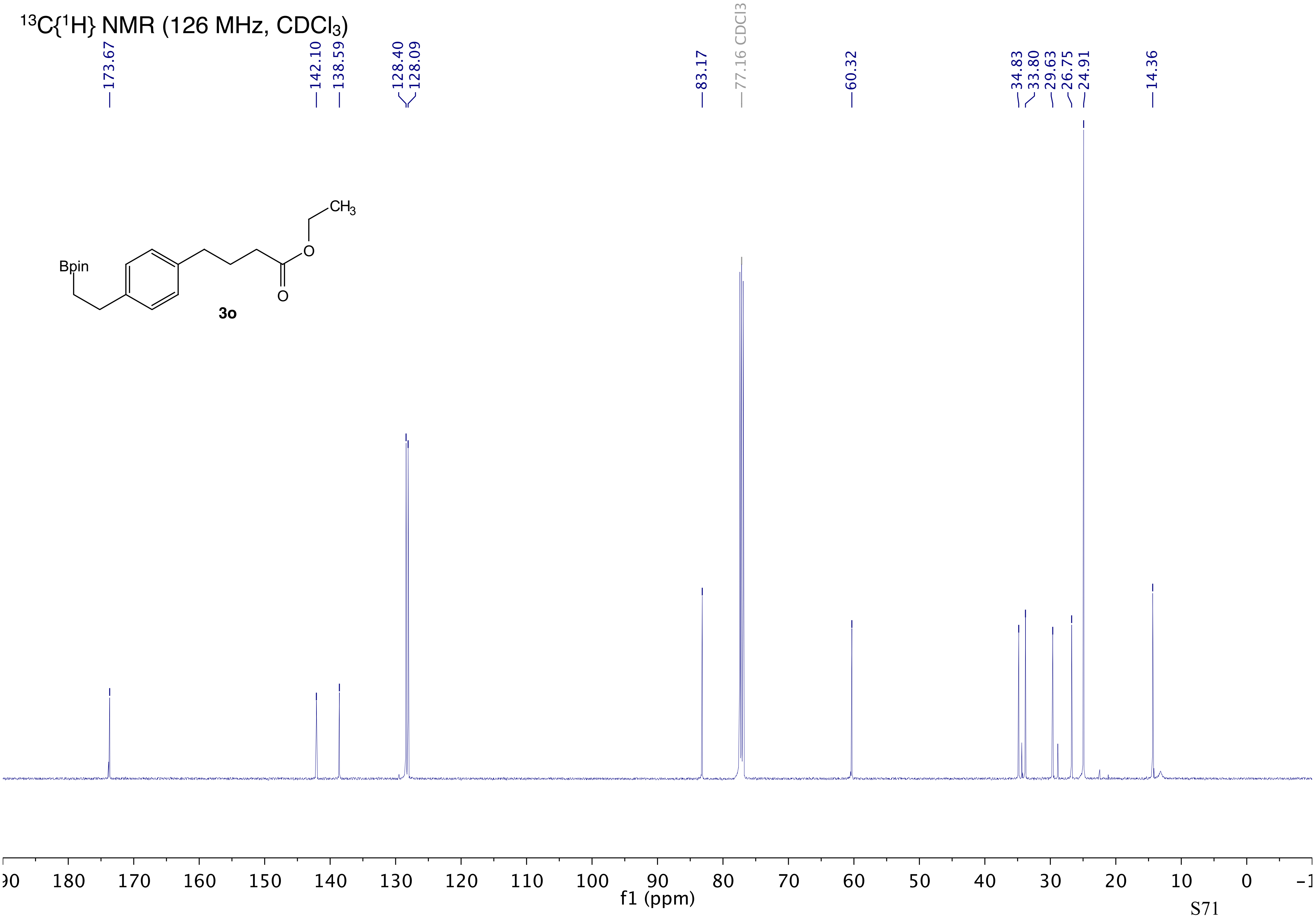
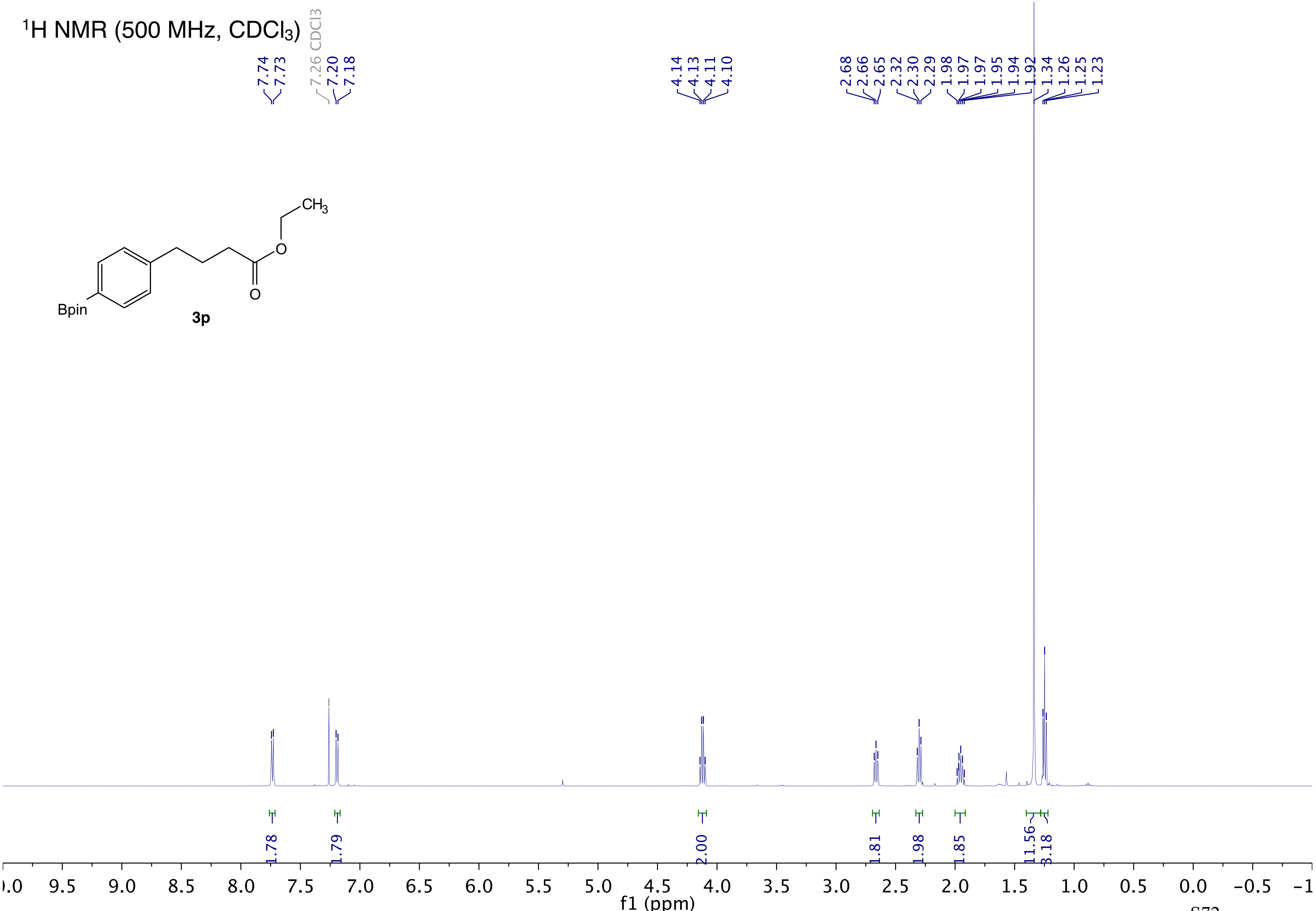


$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)

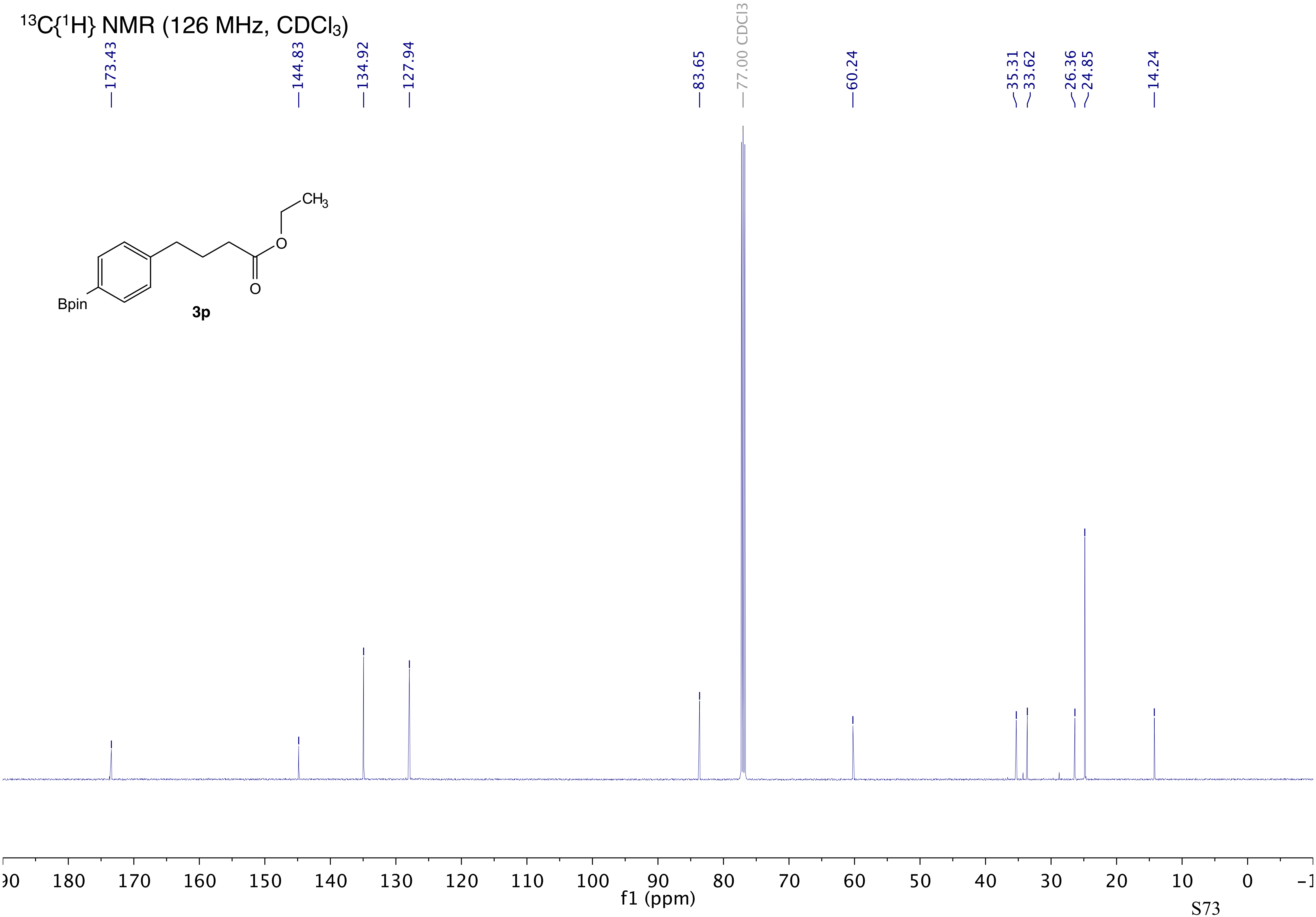
3o



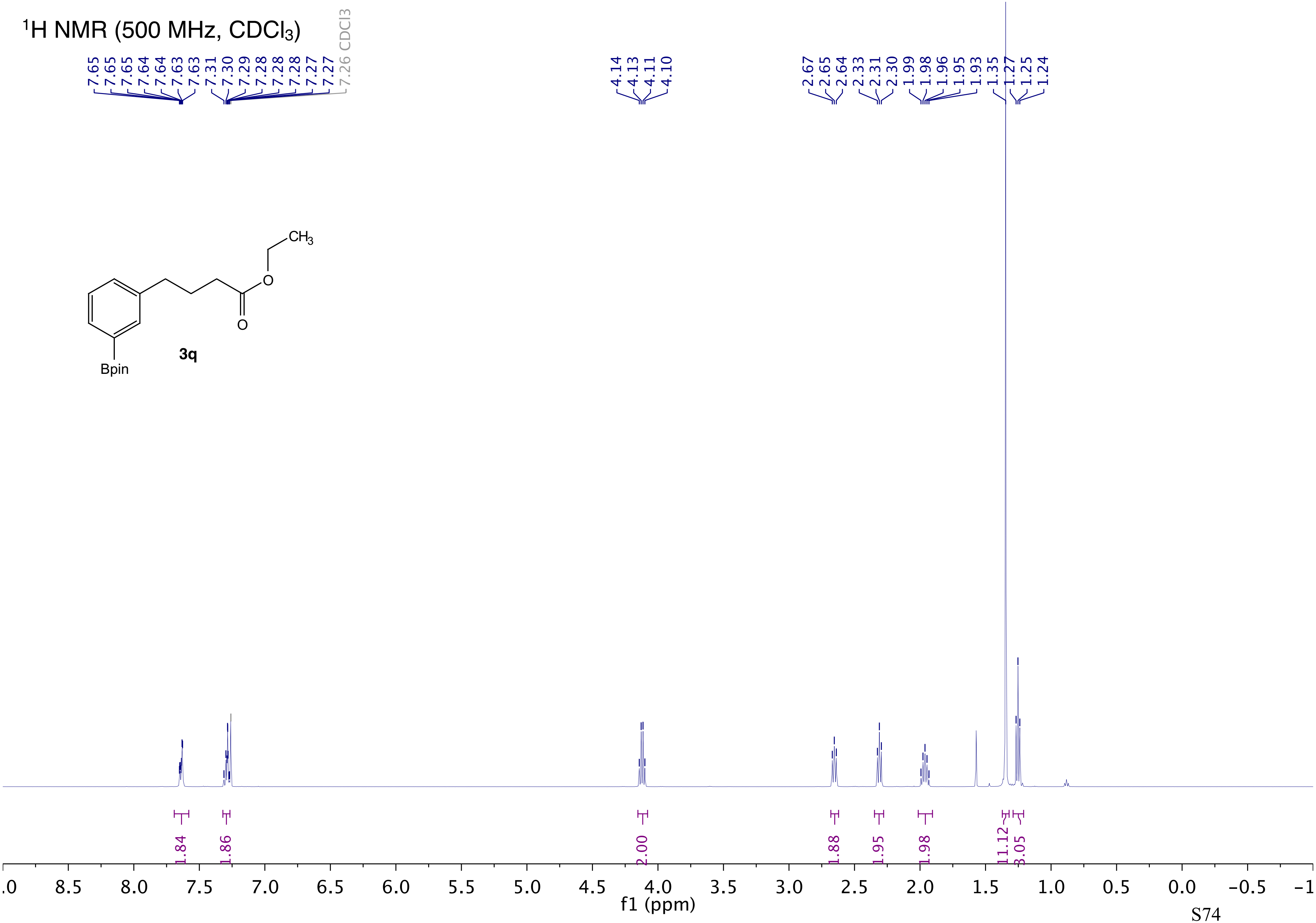
^{1}H NMR (500 MHz, CDCl$_3$)

3p

$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$)

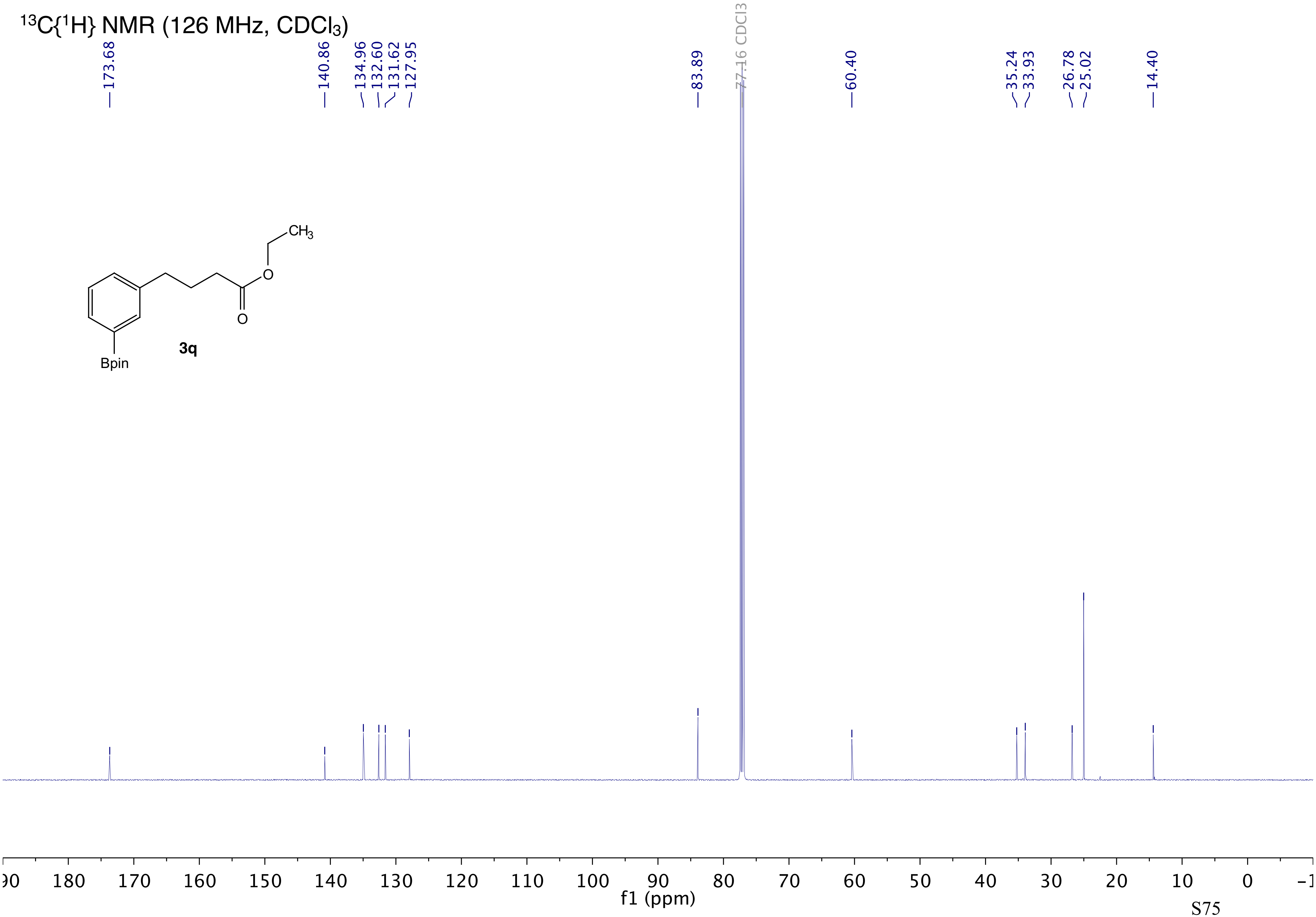


^{1}H NMR (500 MHz, $CDCl_3$)

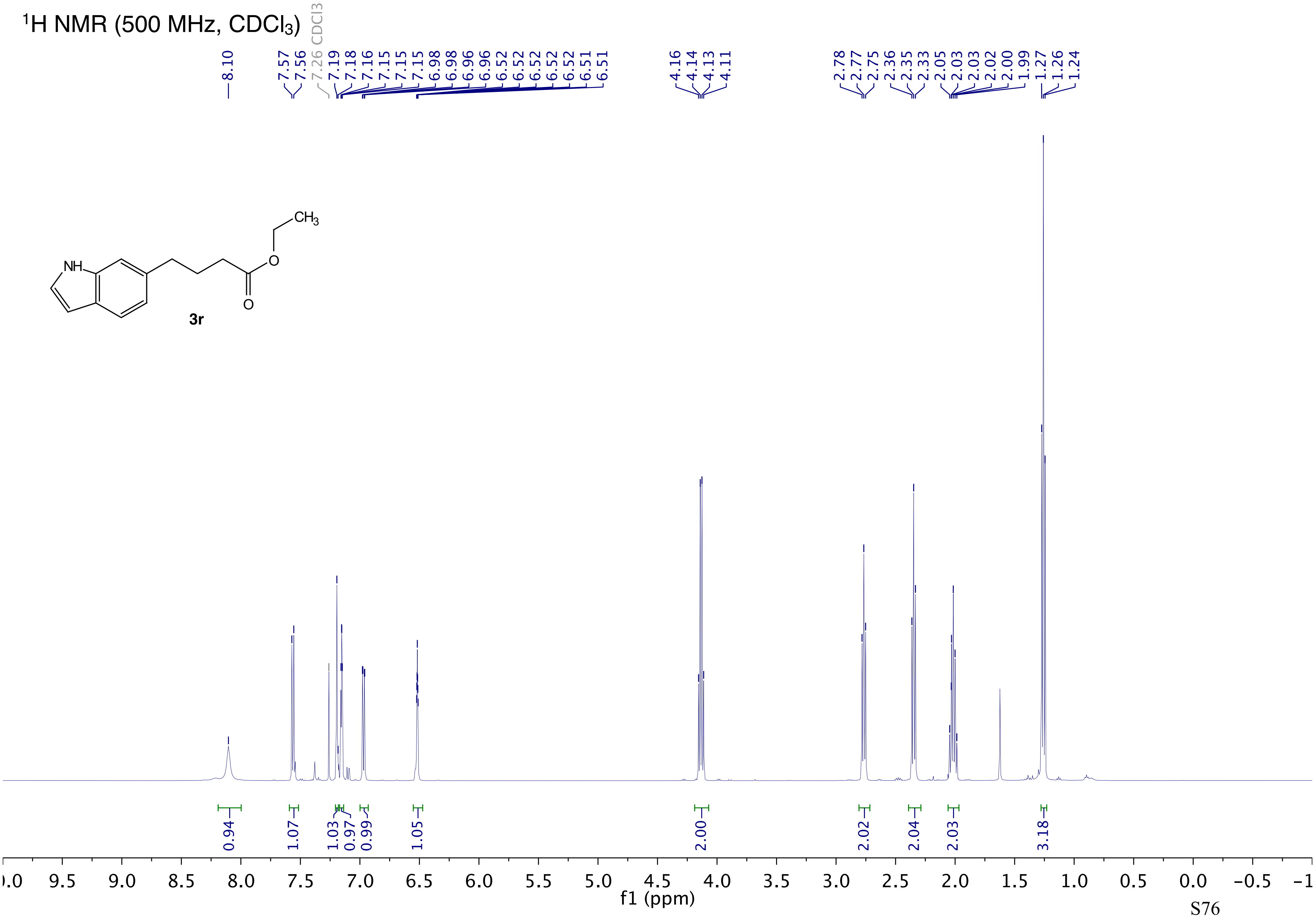


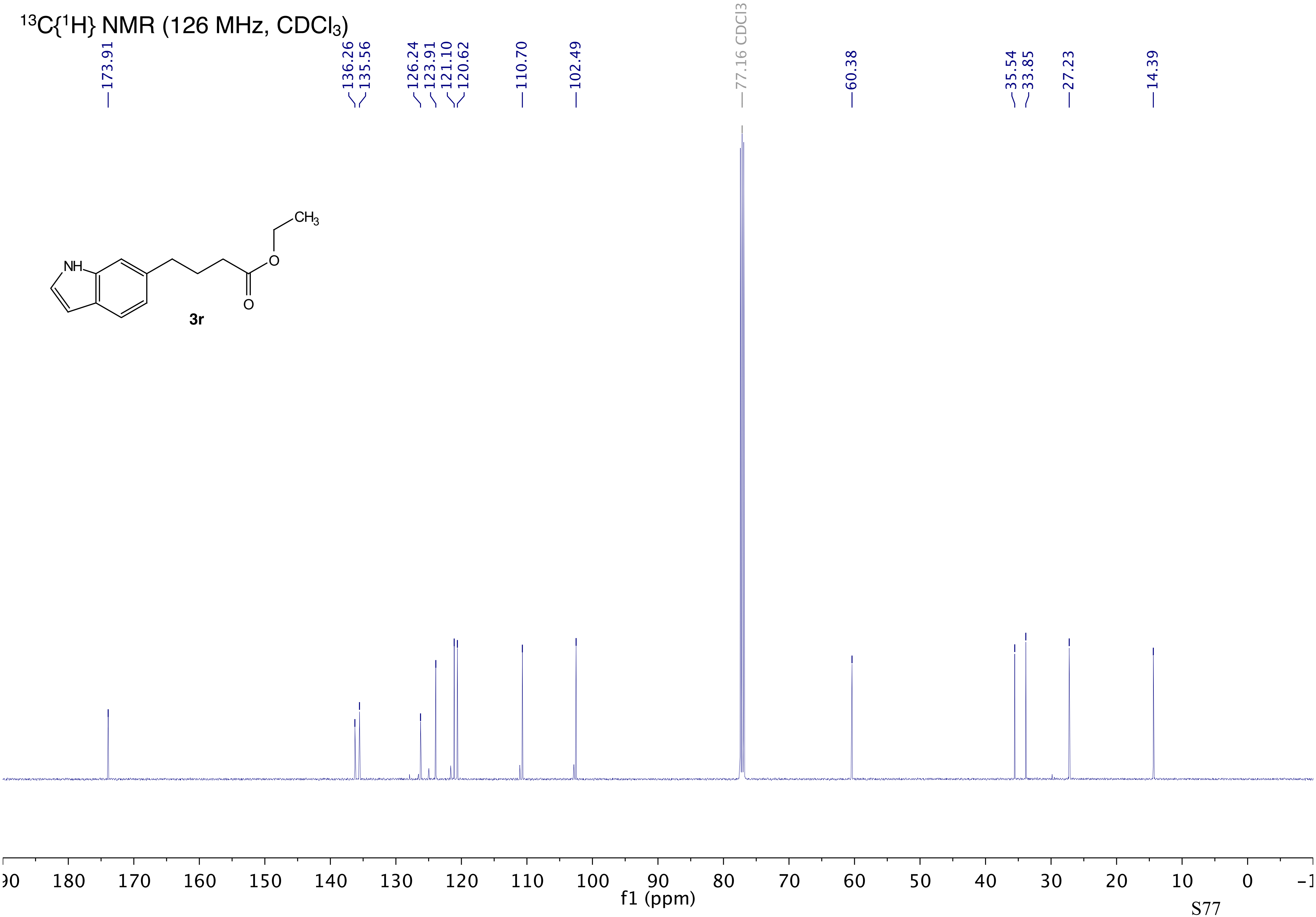
3q

$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$)



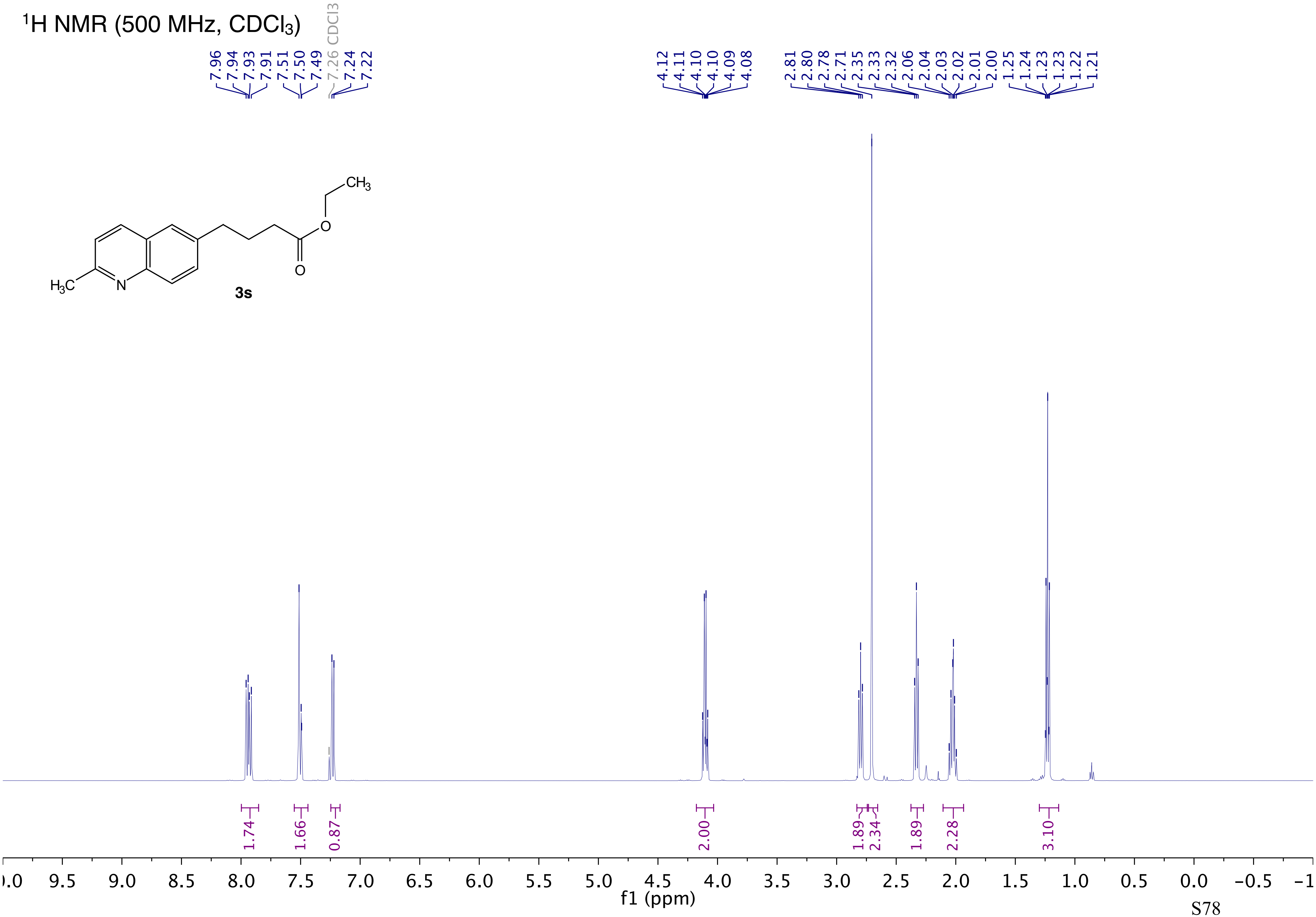
^{1}H NMR (500 MHz, $CDCl_3$)





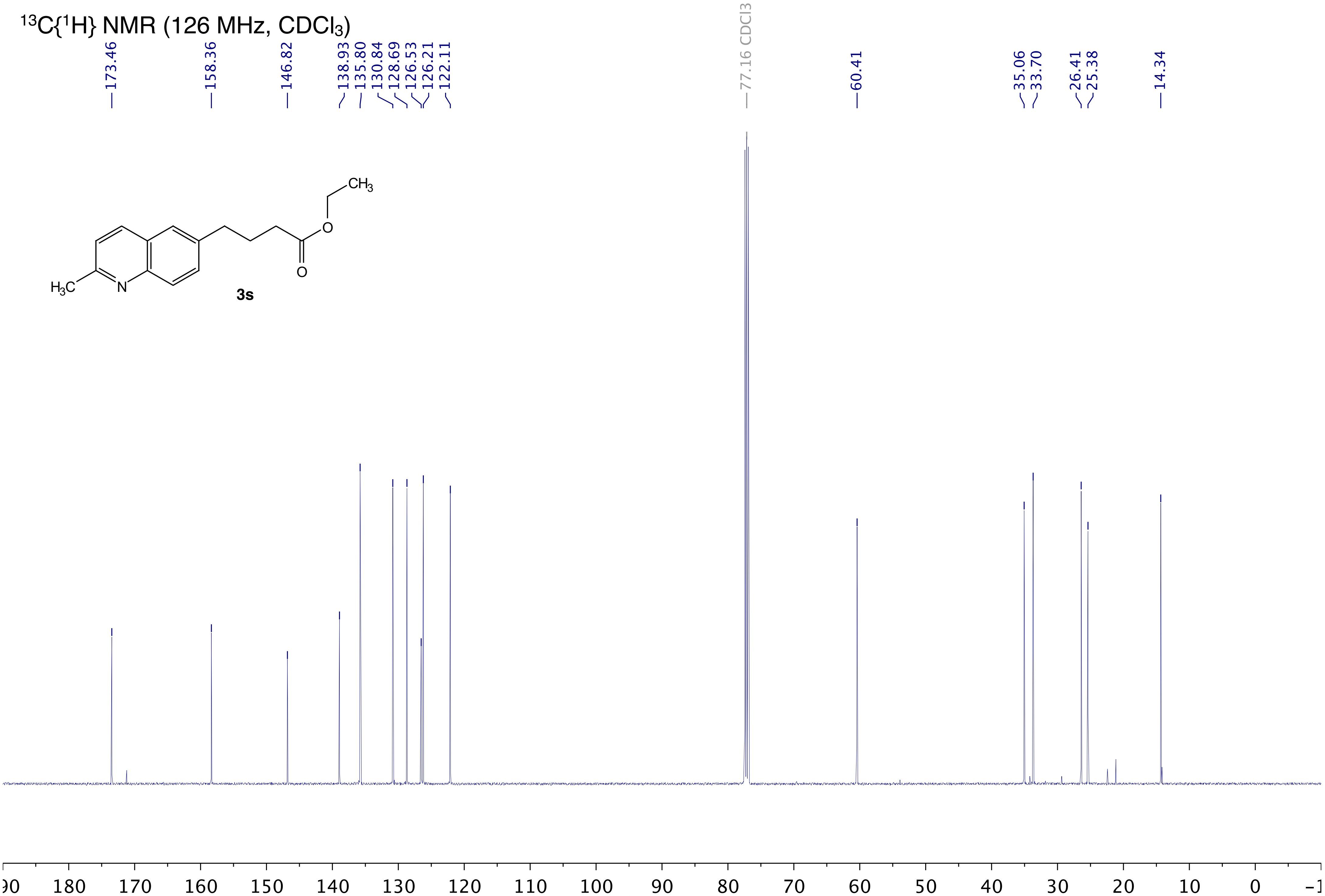
$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$)

^{1}H NMR (500 MHz, CDCl$_3$)

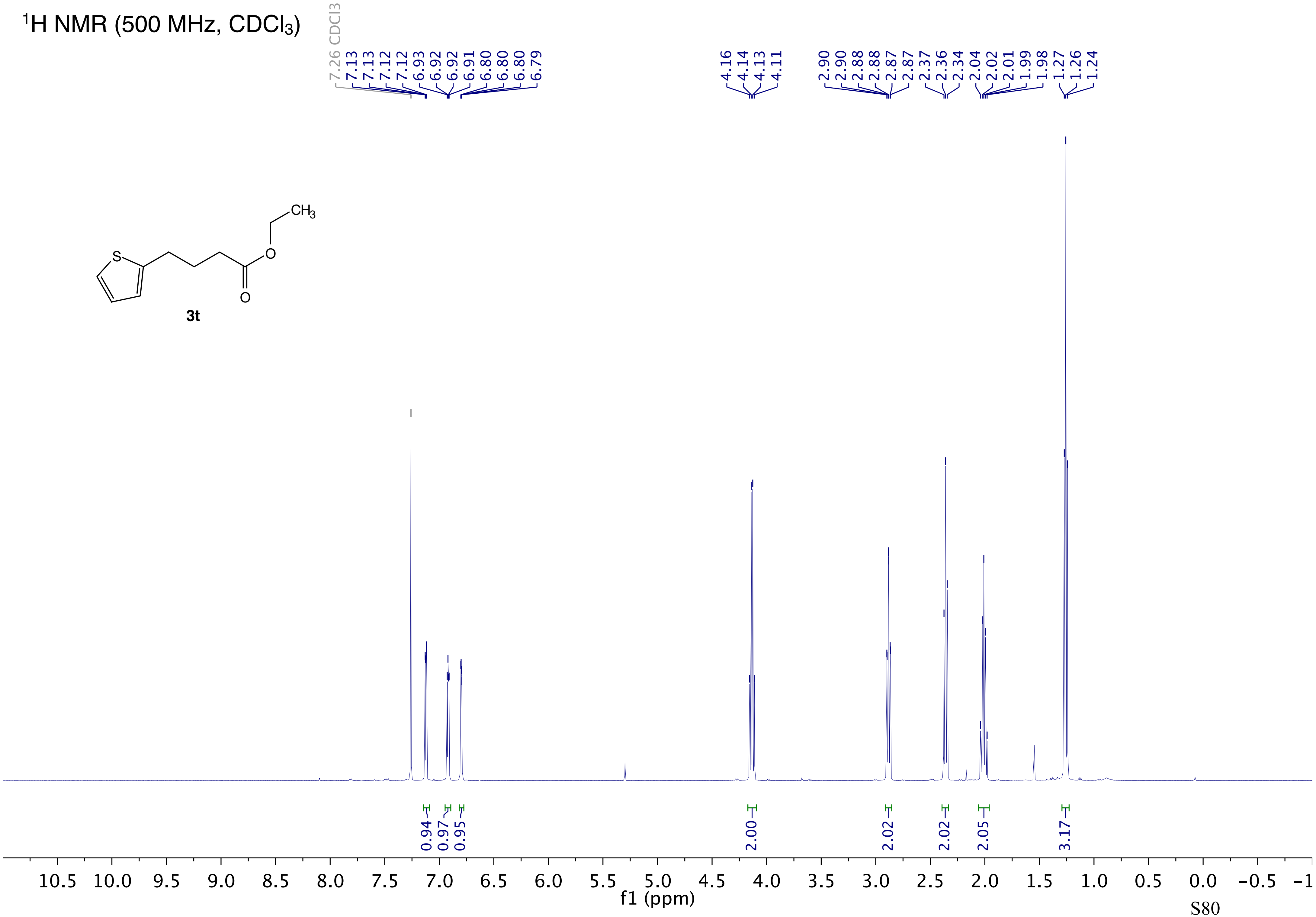


3s

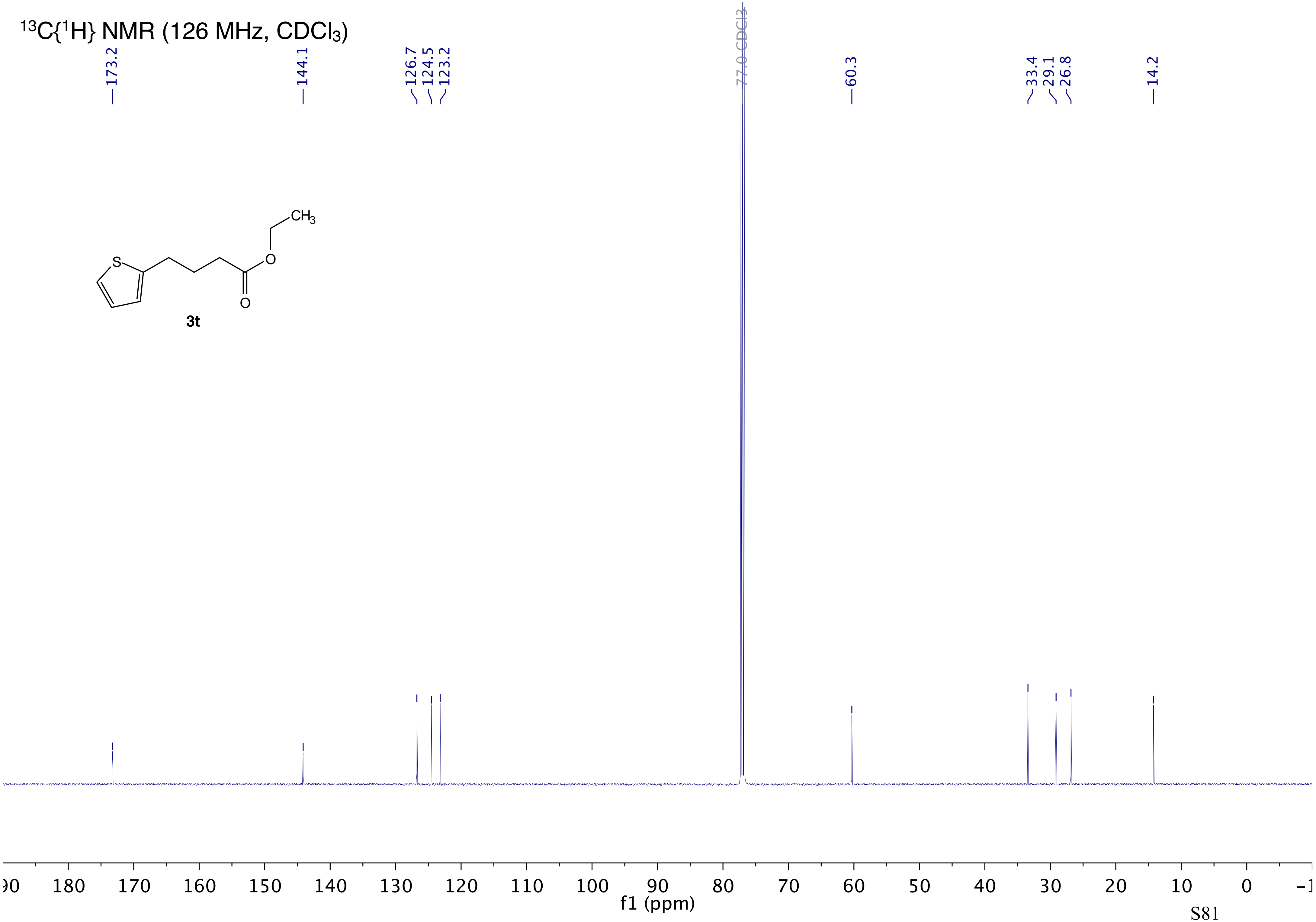
$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$)



^{1}H NMR (500 MHz, $CDCl_3$)

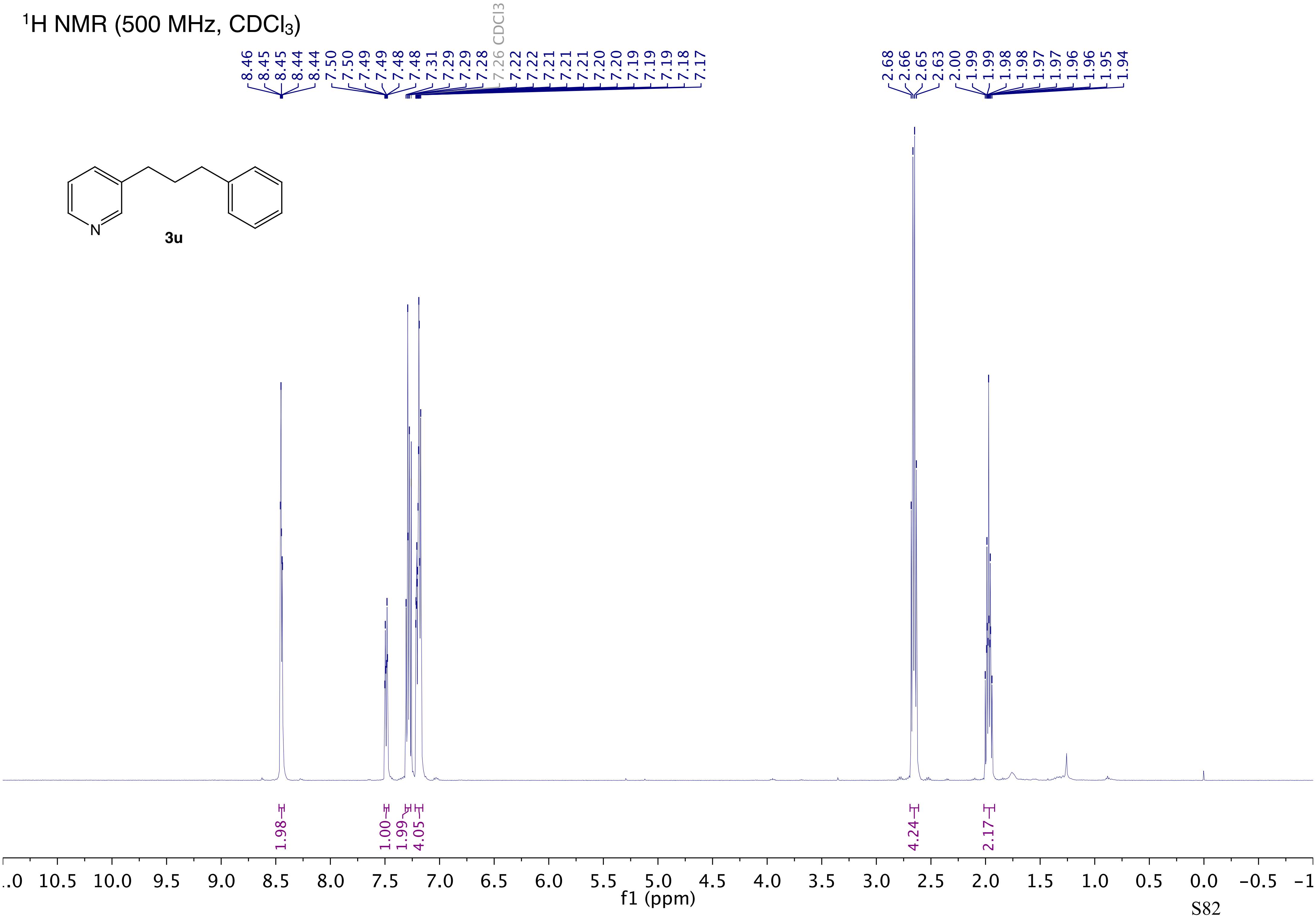


$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)



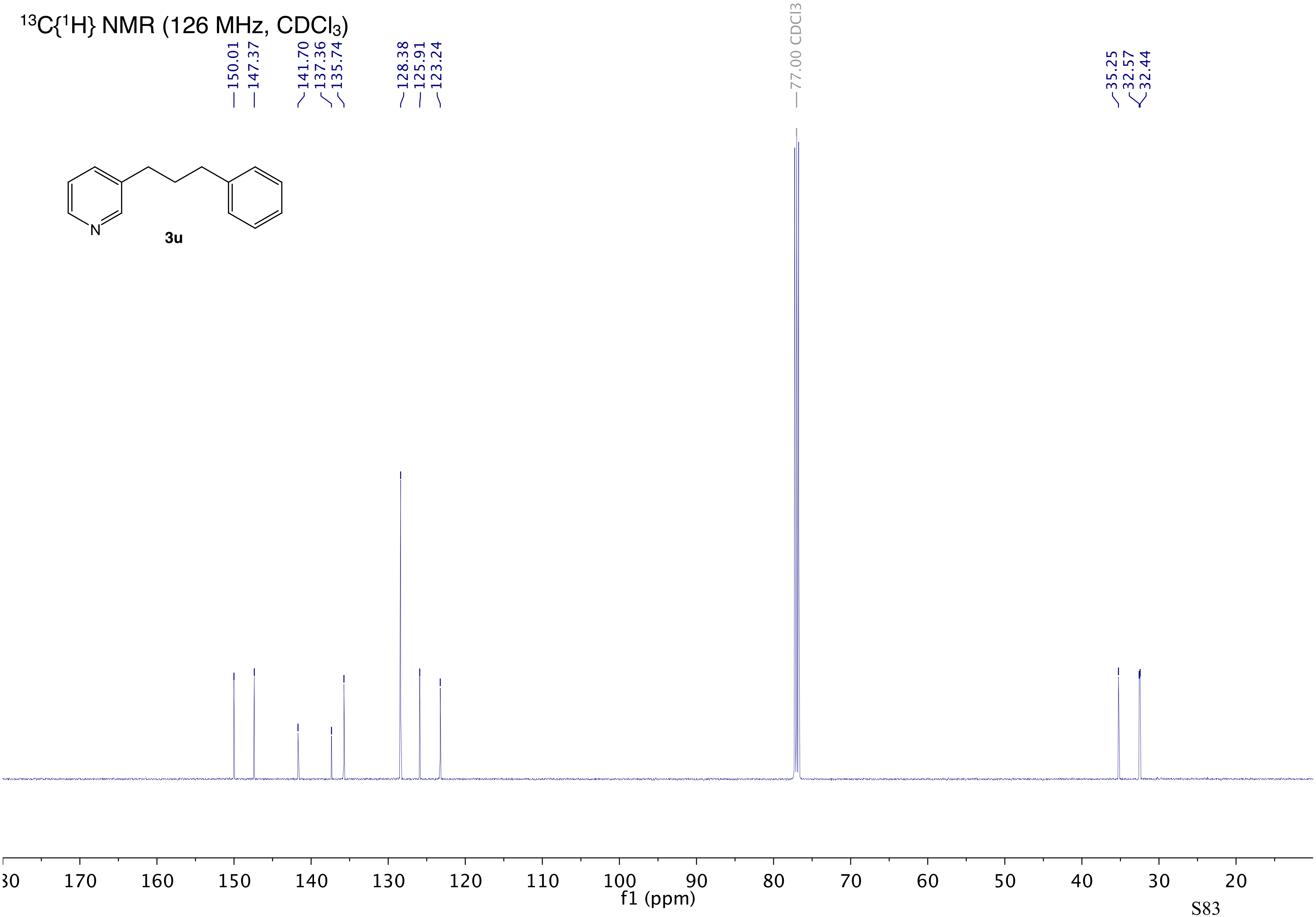
3t

^{1}H NMR (500 MHz, $CDCl_3$)



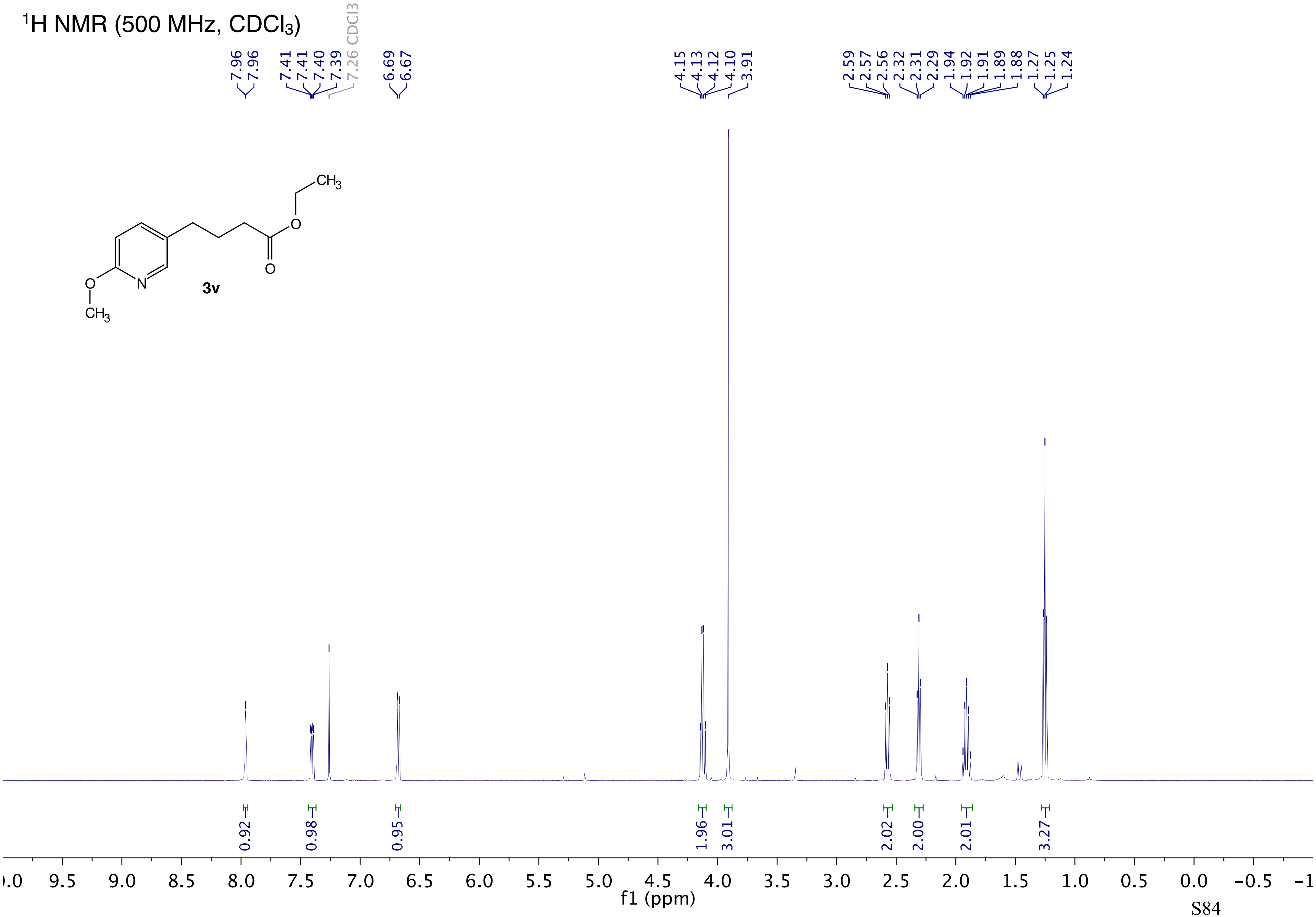
3u

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)

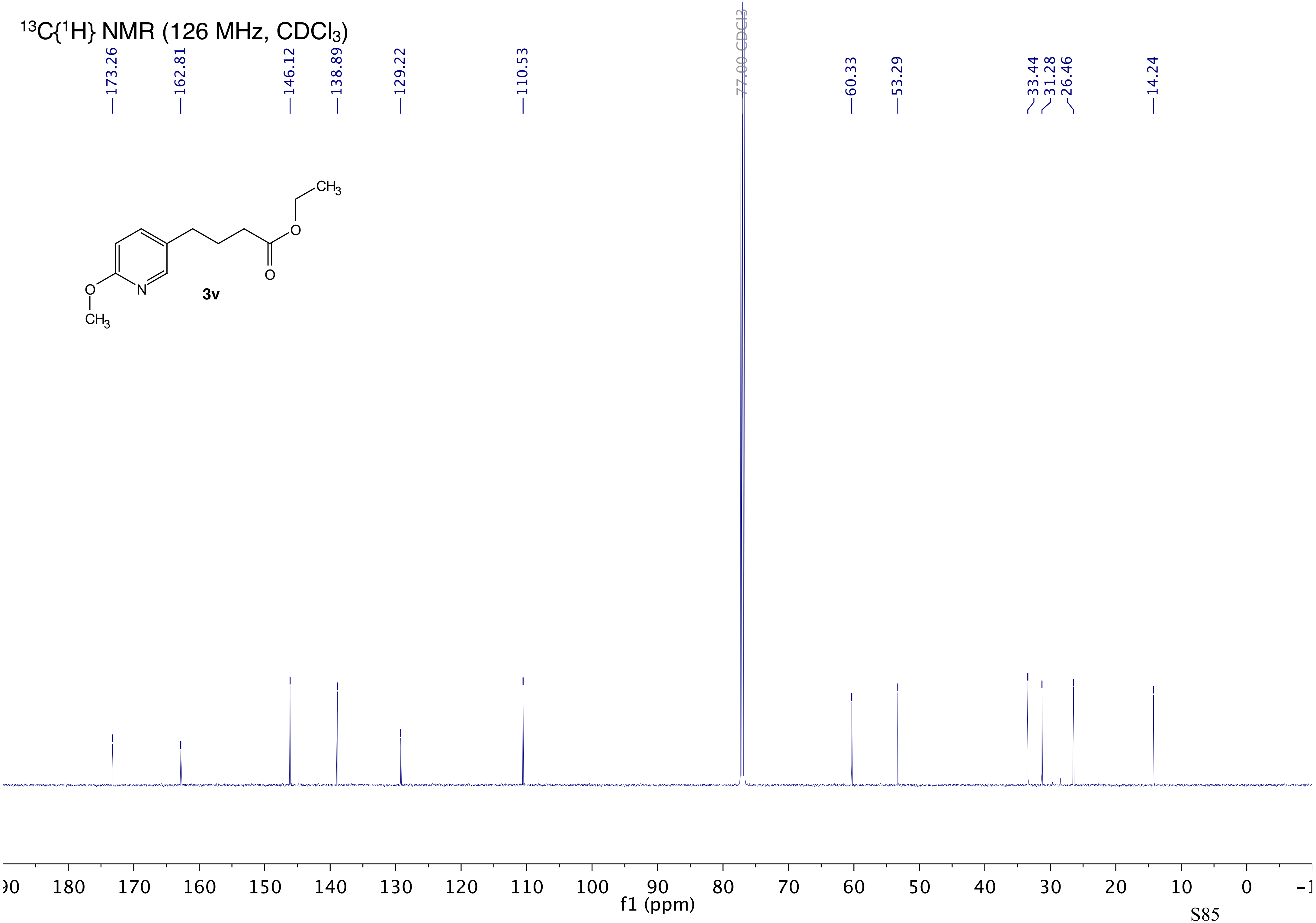


3u

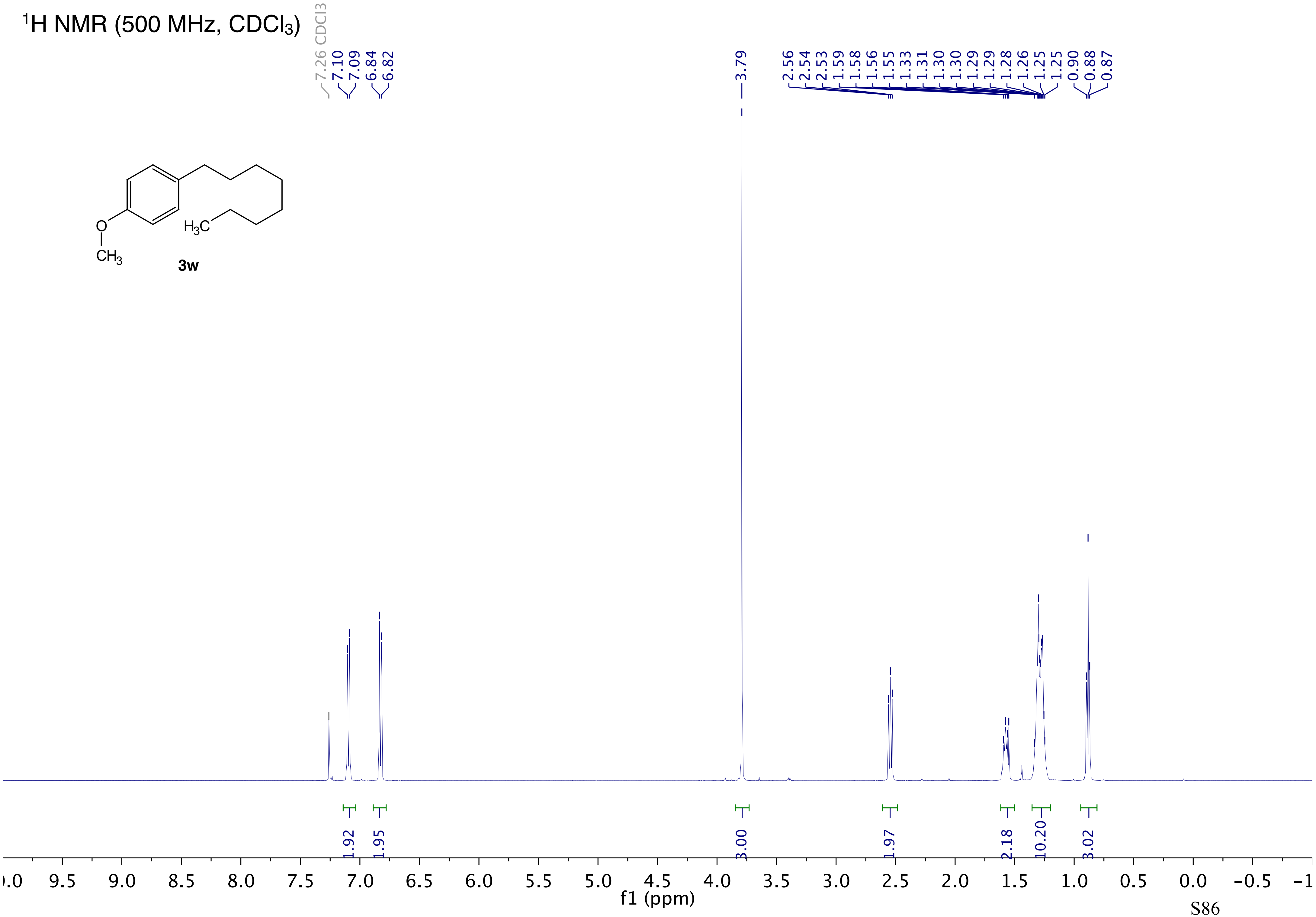
^{1}H NMR (500 MHz, CDCl$_3$)



3v

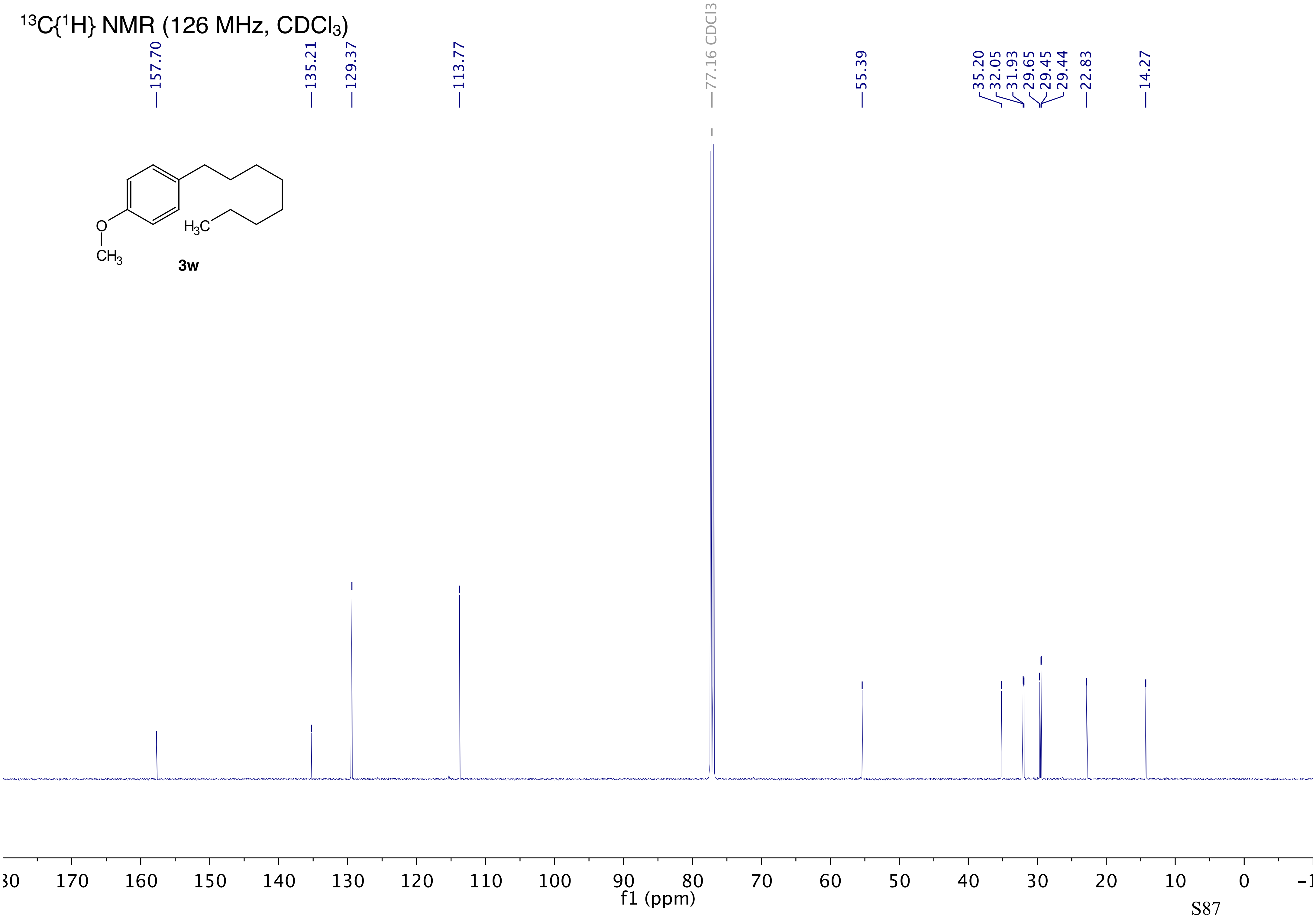

$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$)

^{1}H NMR (500 MHz, $CDCl_3$)



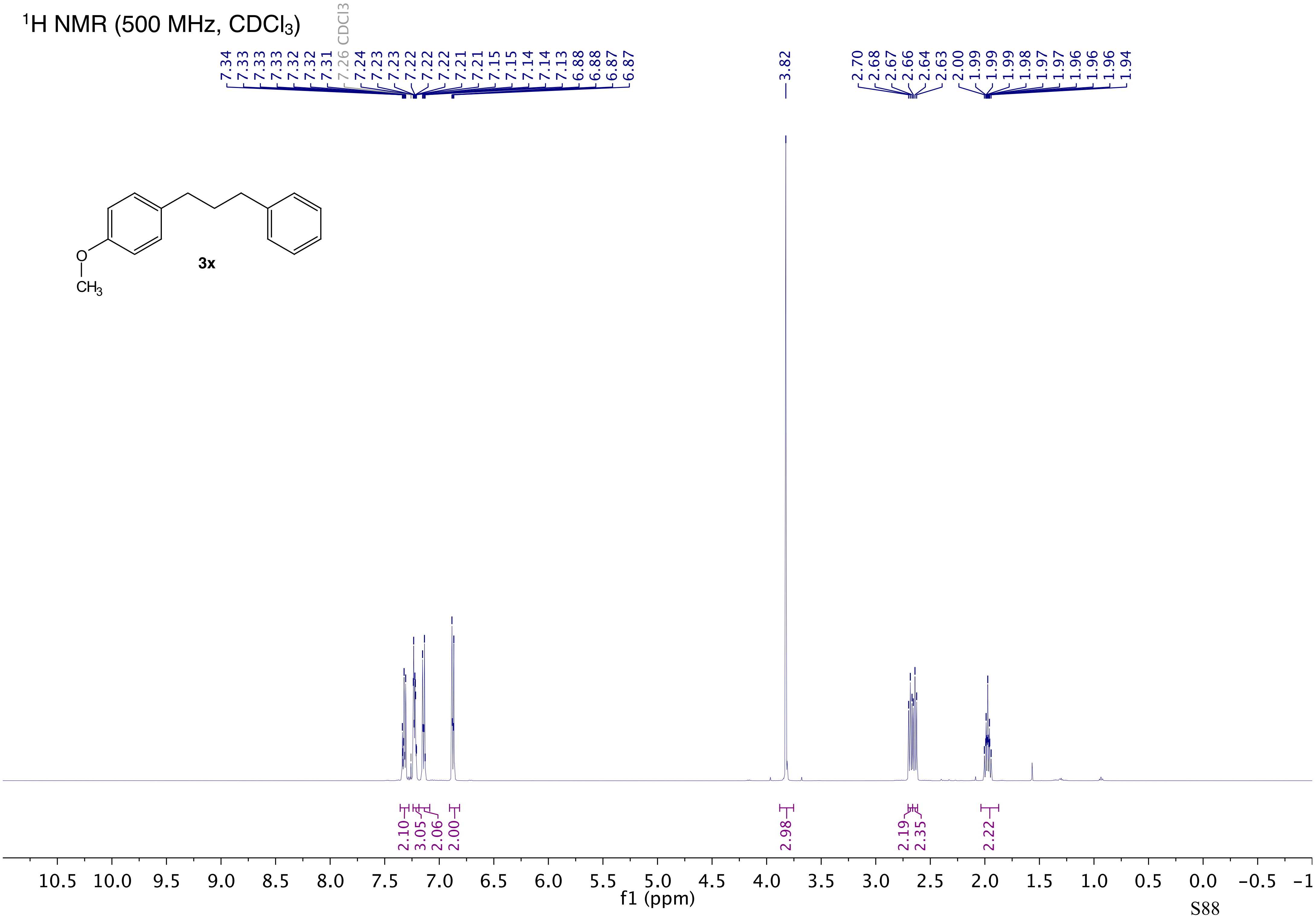
3w

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)

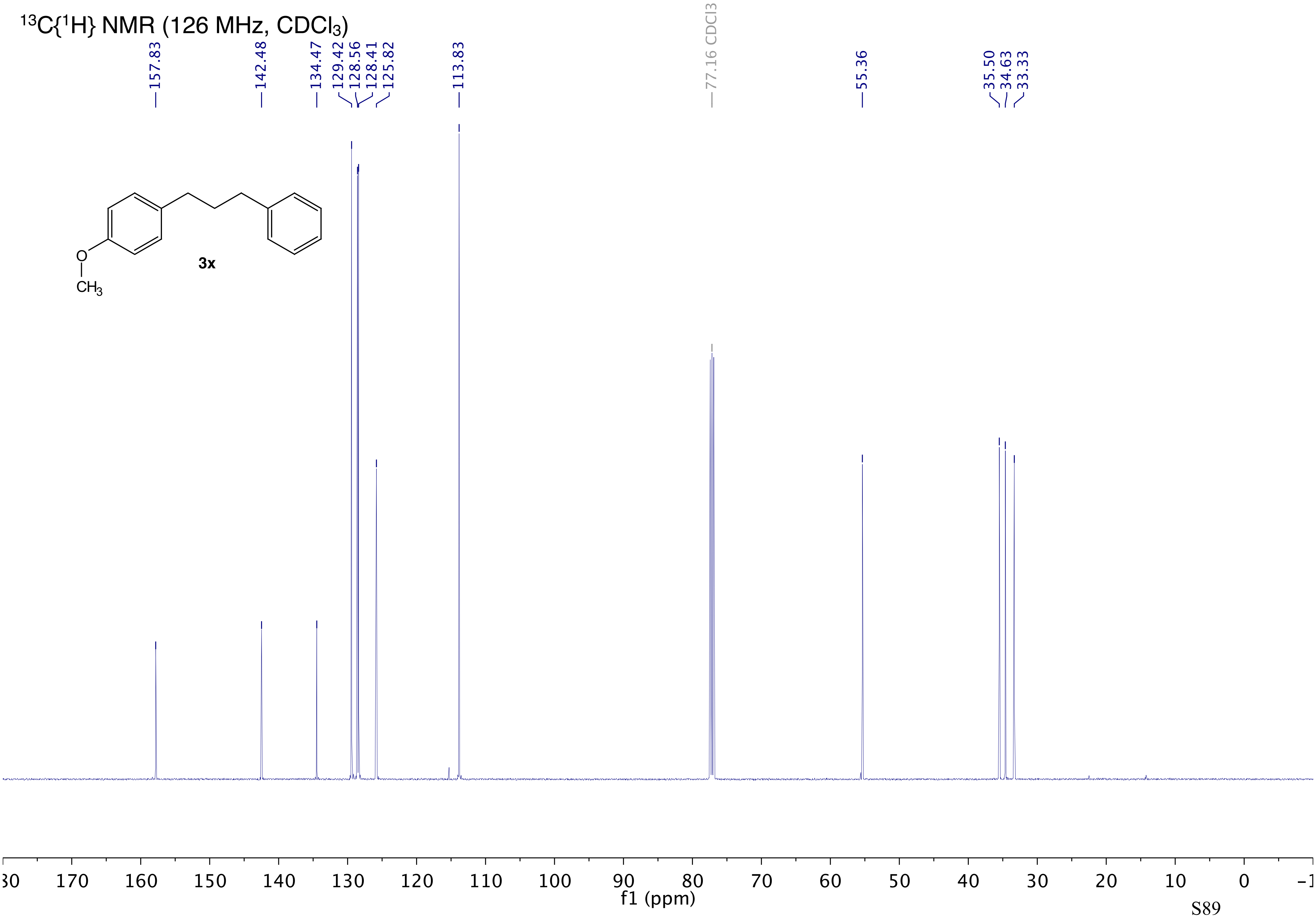


3w

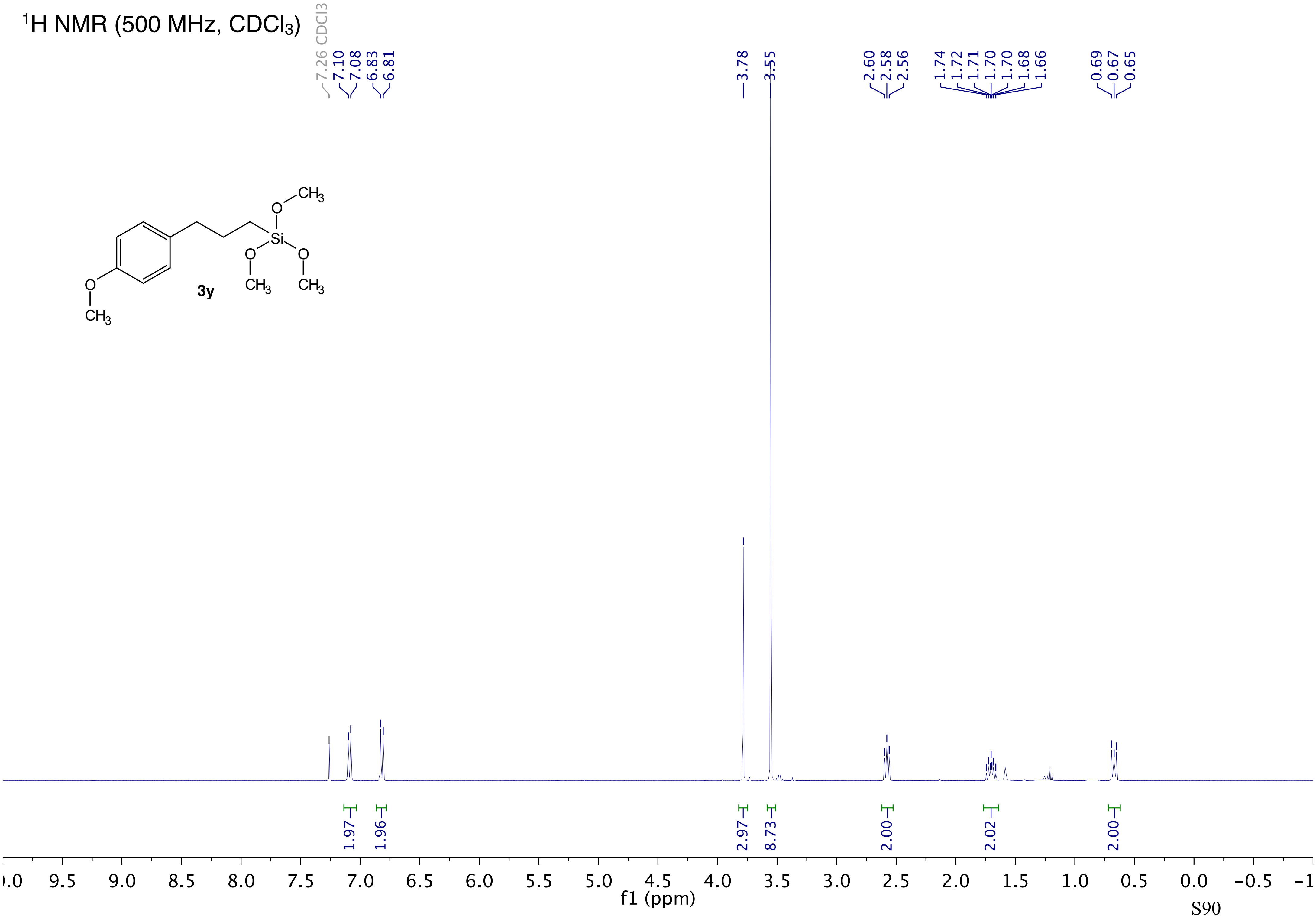
^{1}H NMR (500 MHz, CDCl$_3$)



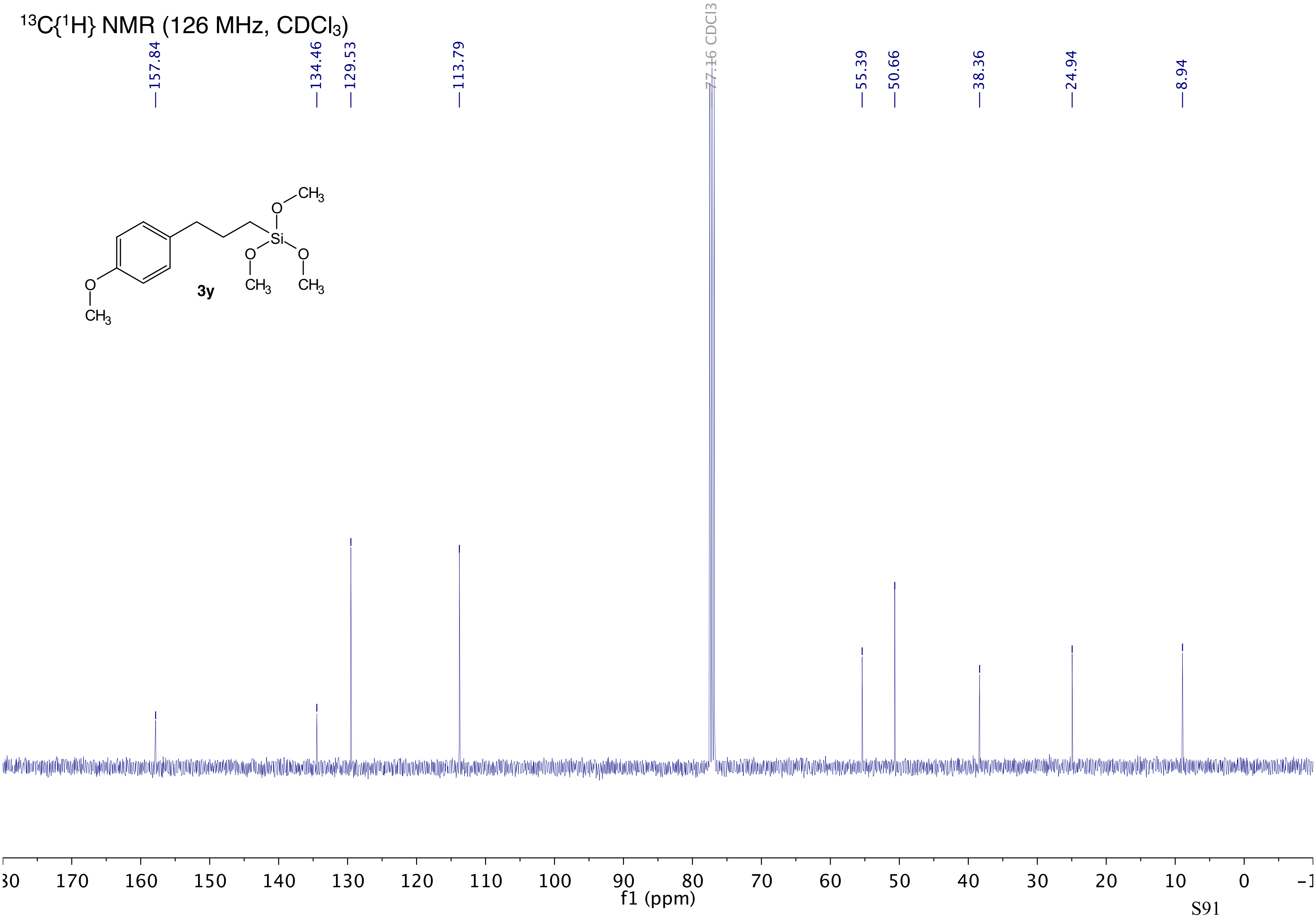
$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$)



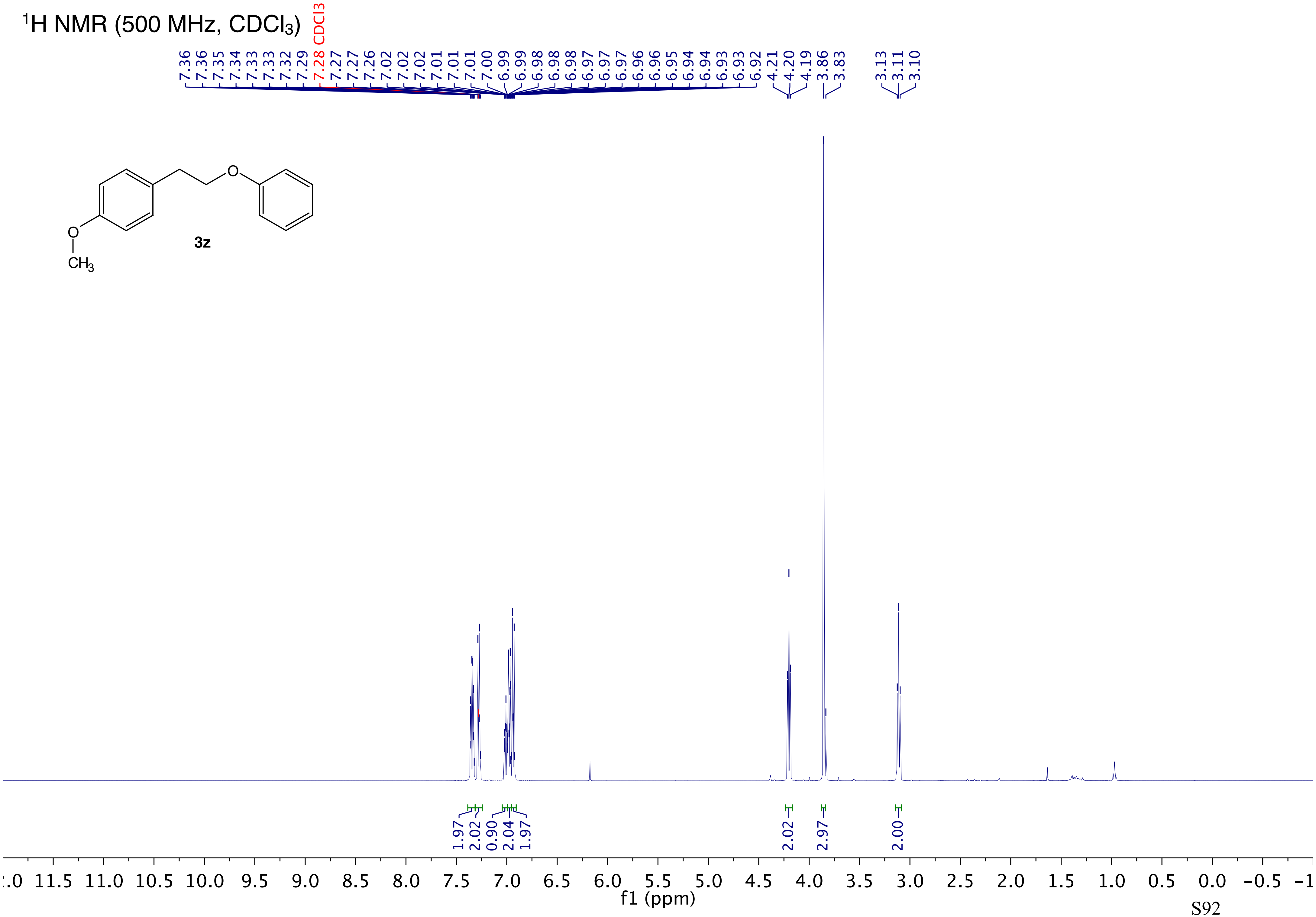
^{1}H NMR (500 MHz, $CDCl_3$)



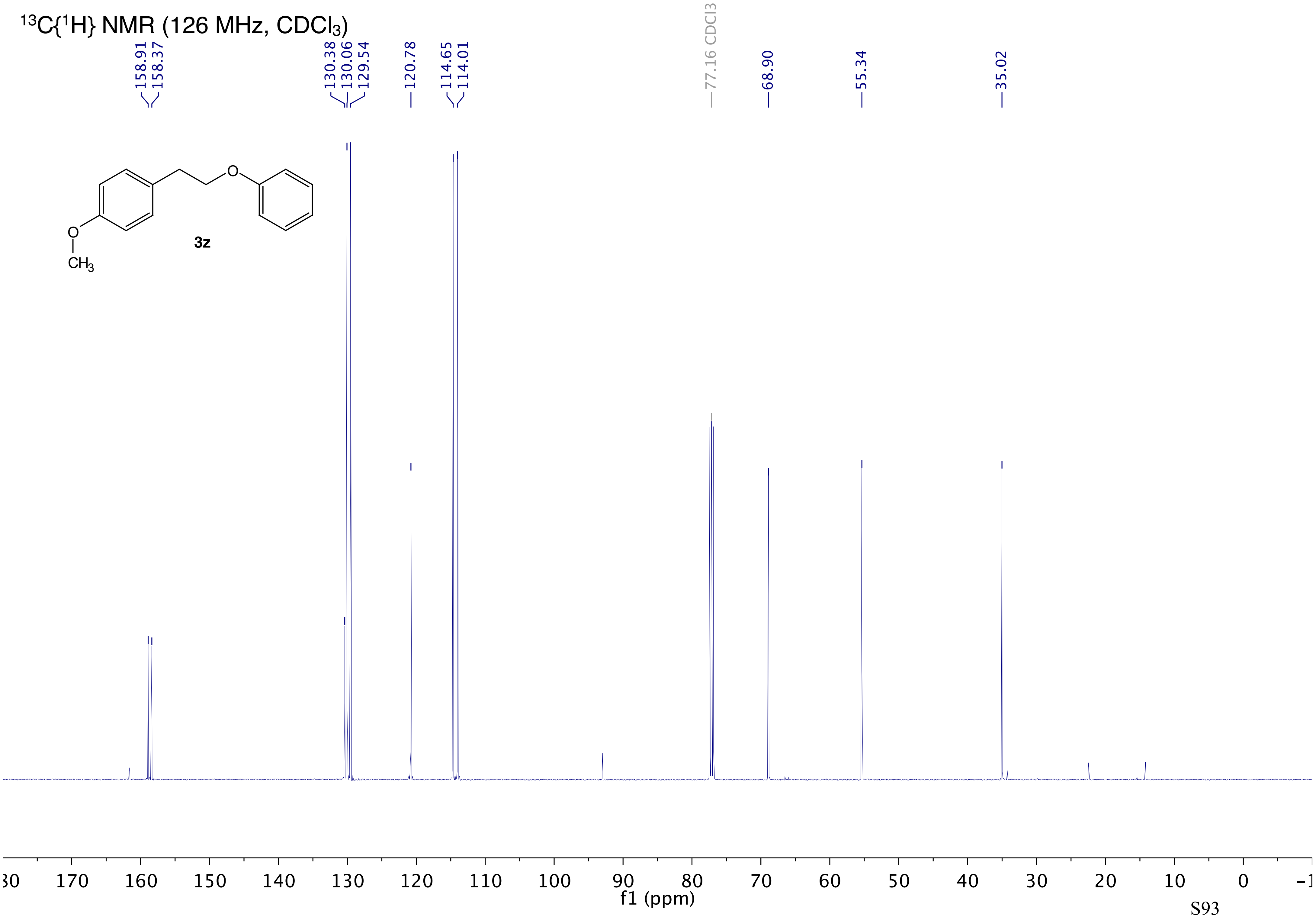
$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)



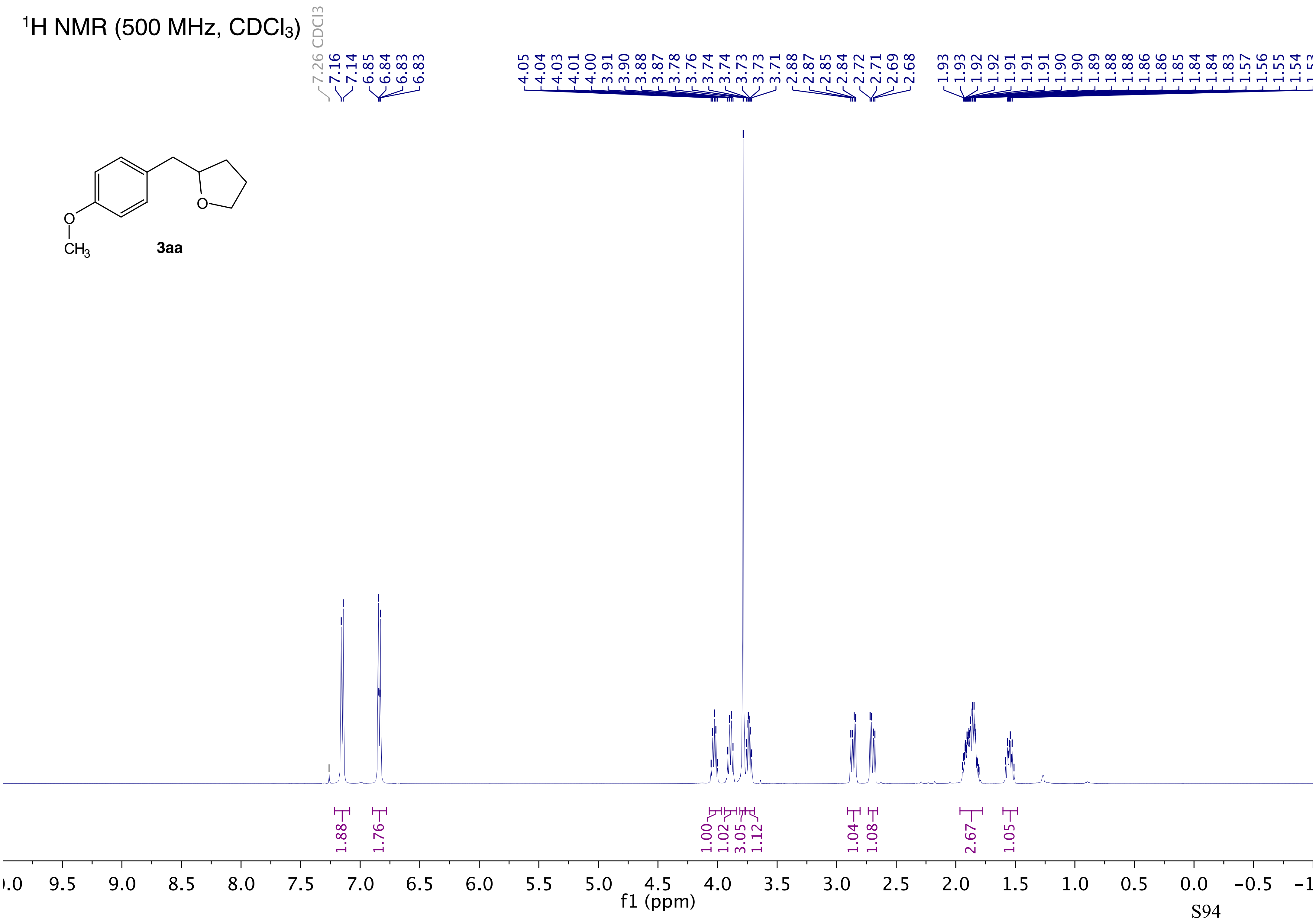
^{1}H NMR (500 MHz, $CDCl_3$)


3z

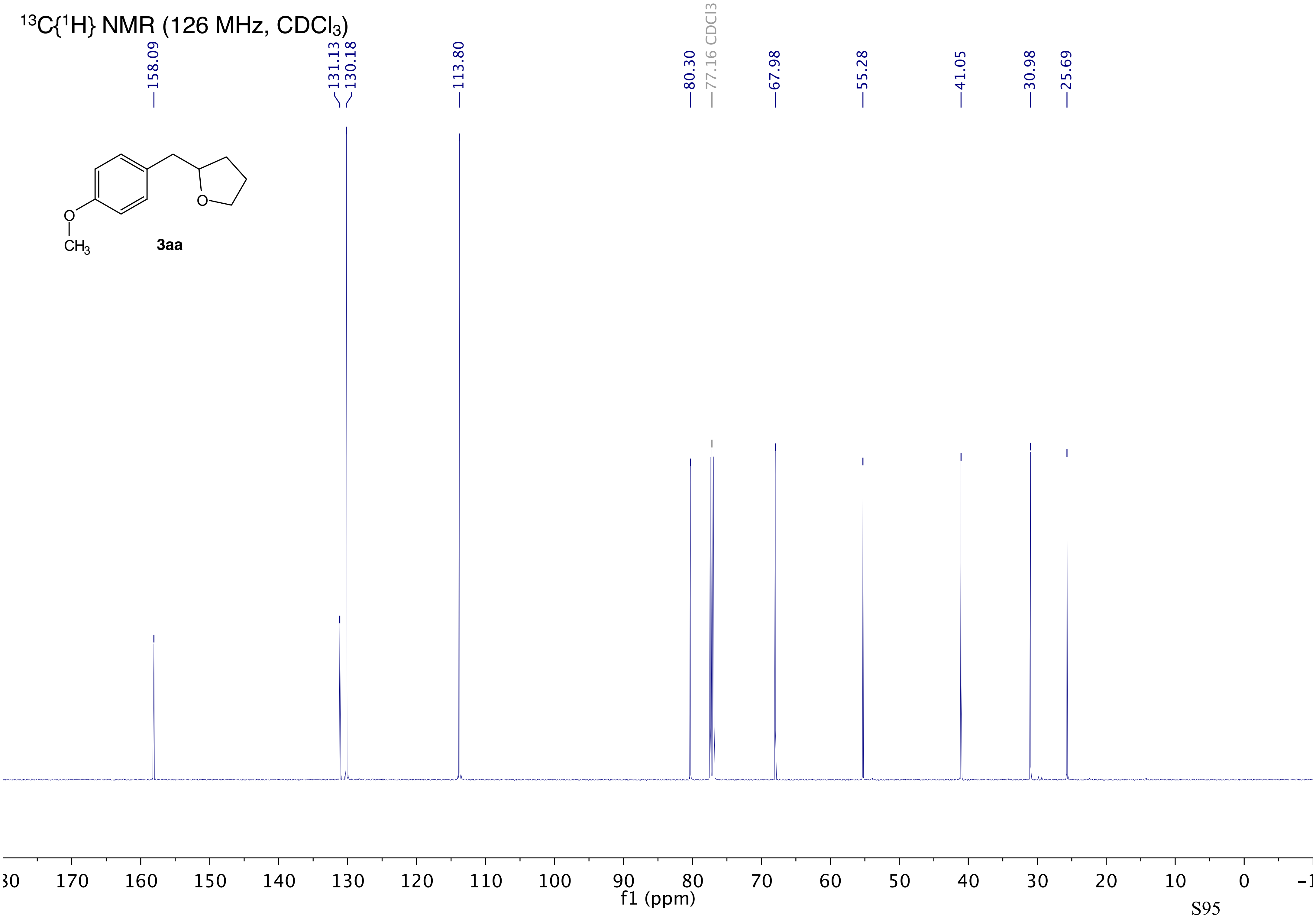
$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$)



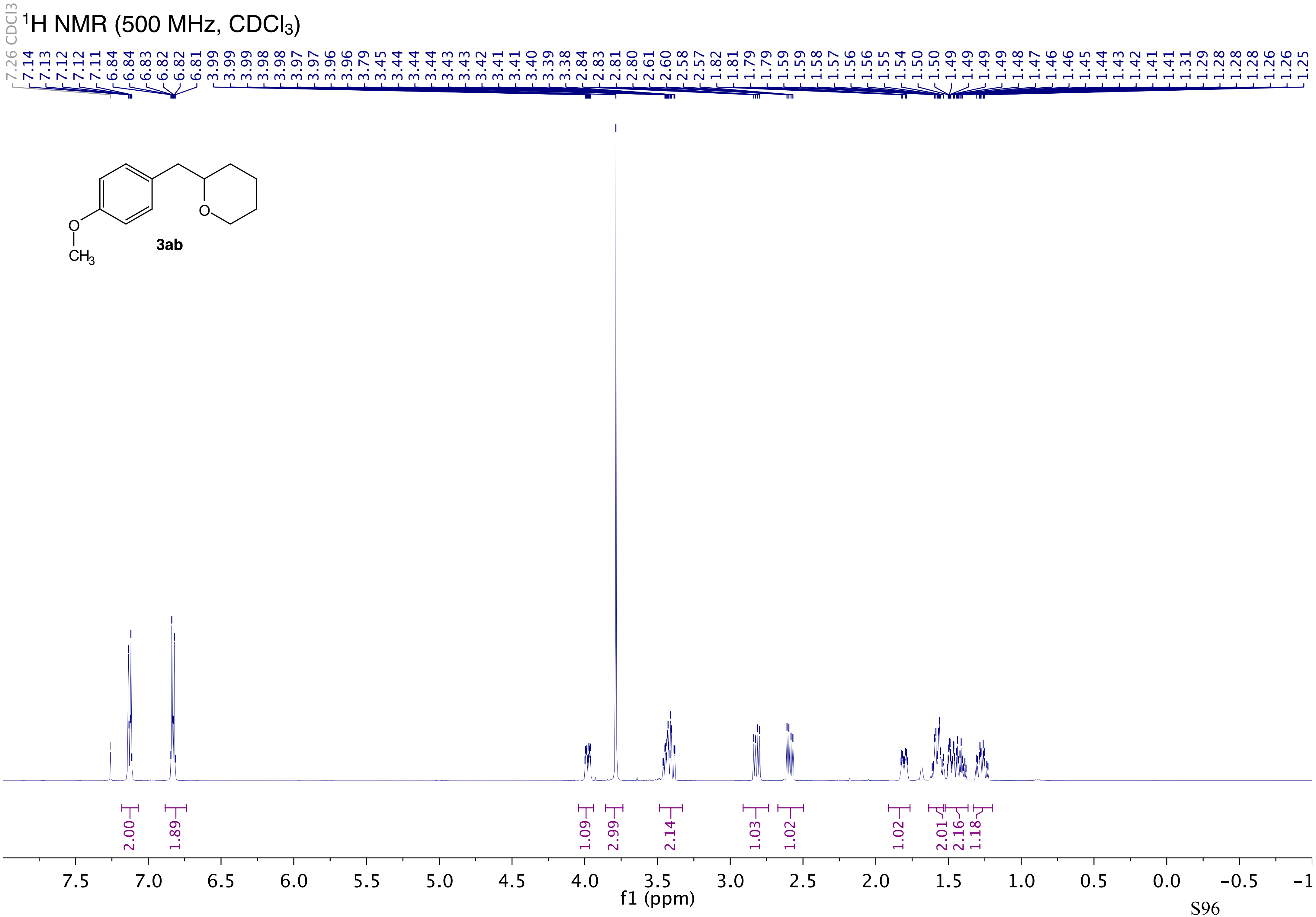
^1H NMR (500 MHz, $CDCl_3$)



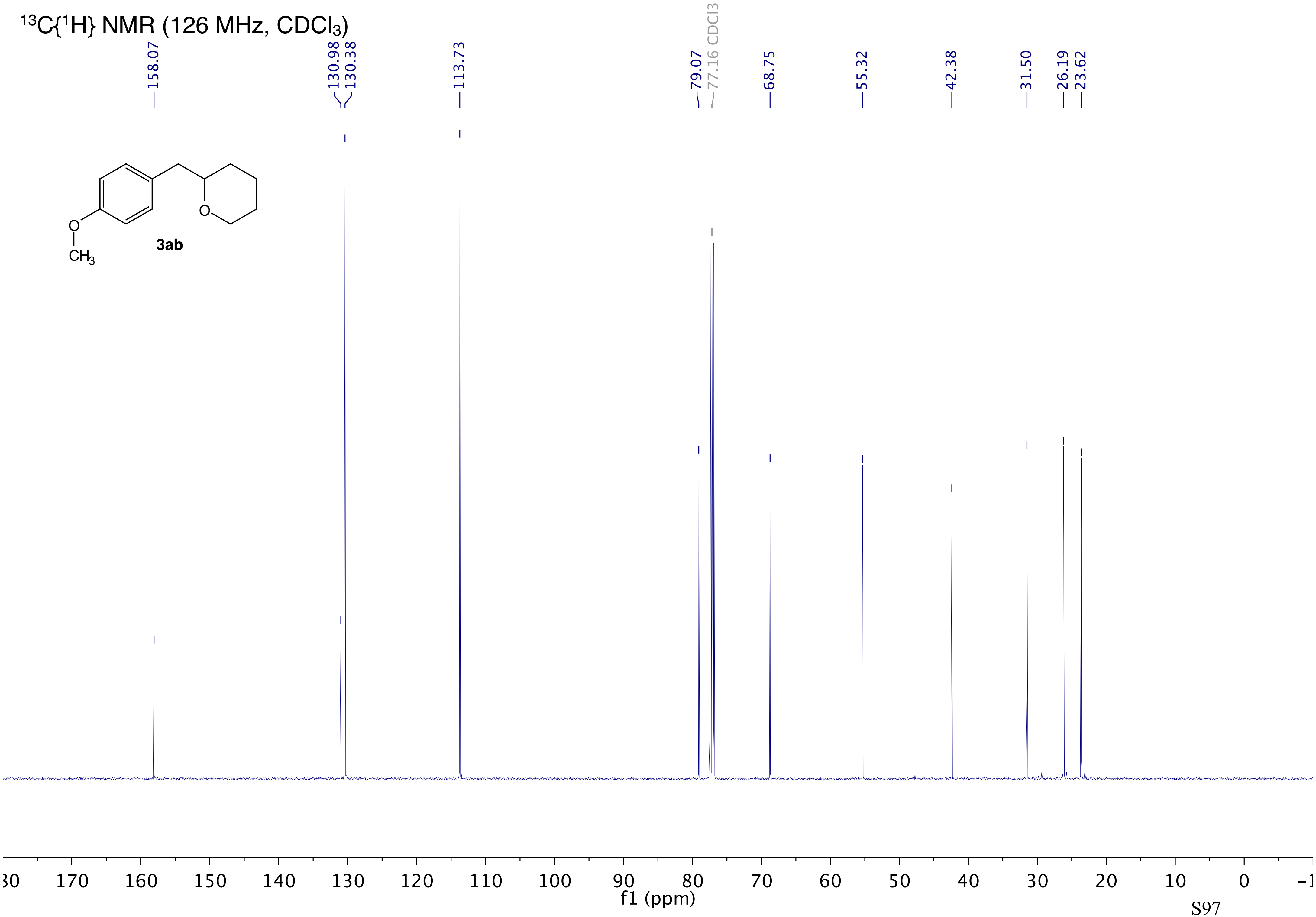
$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)



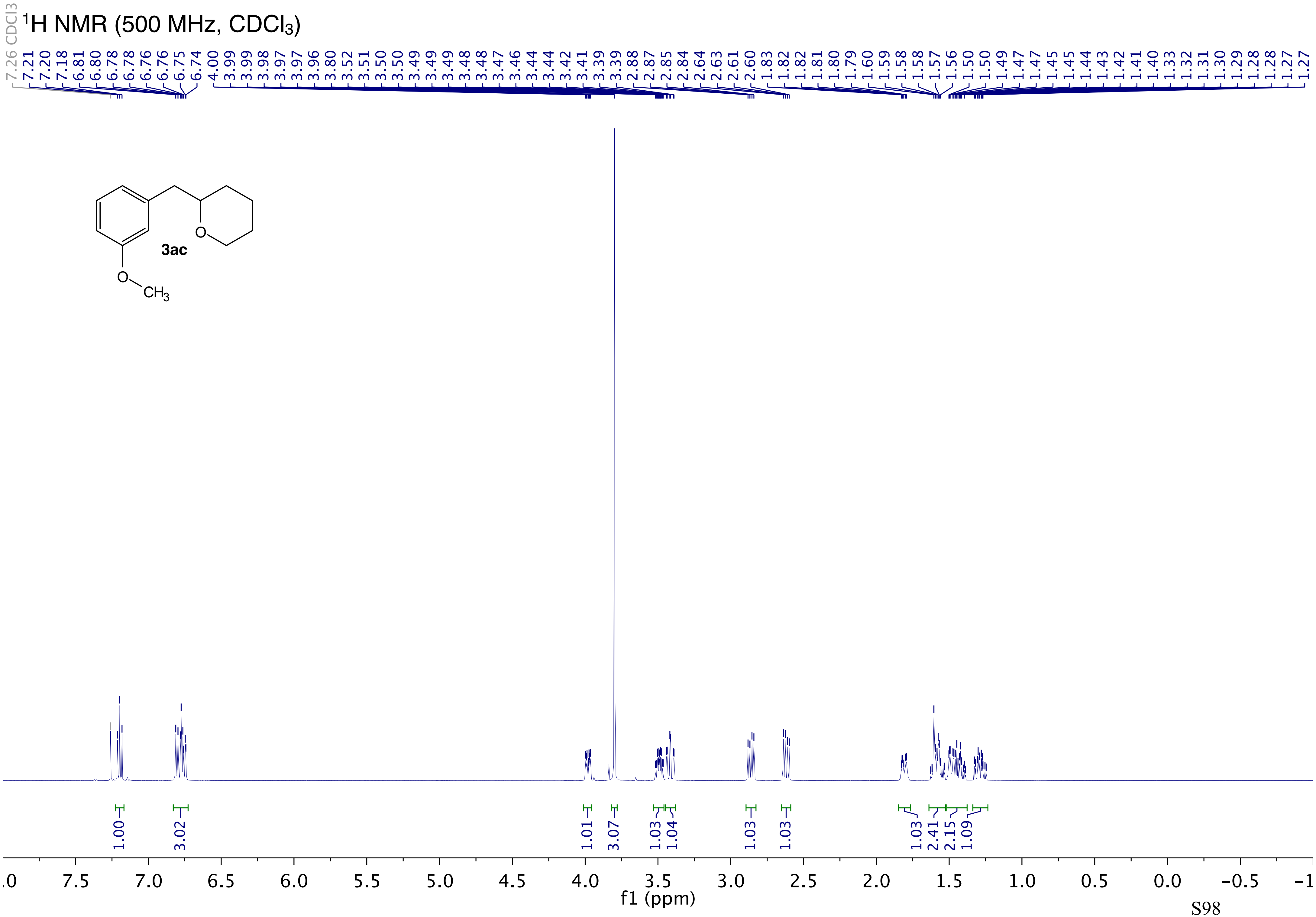
^1H NMR (500 MHz, $CDCl_3$)



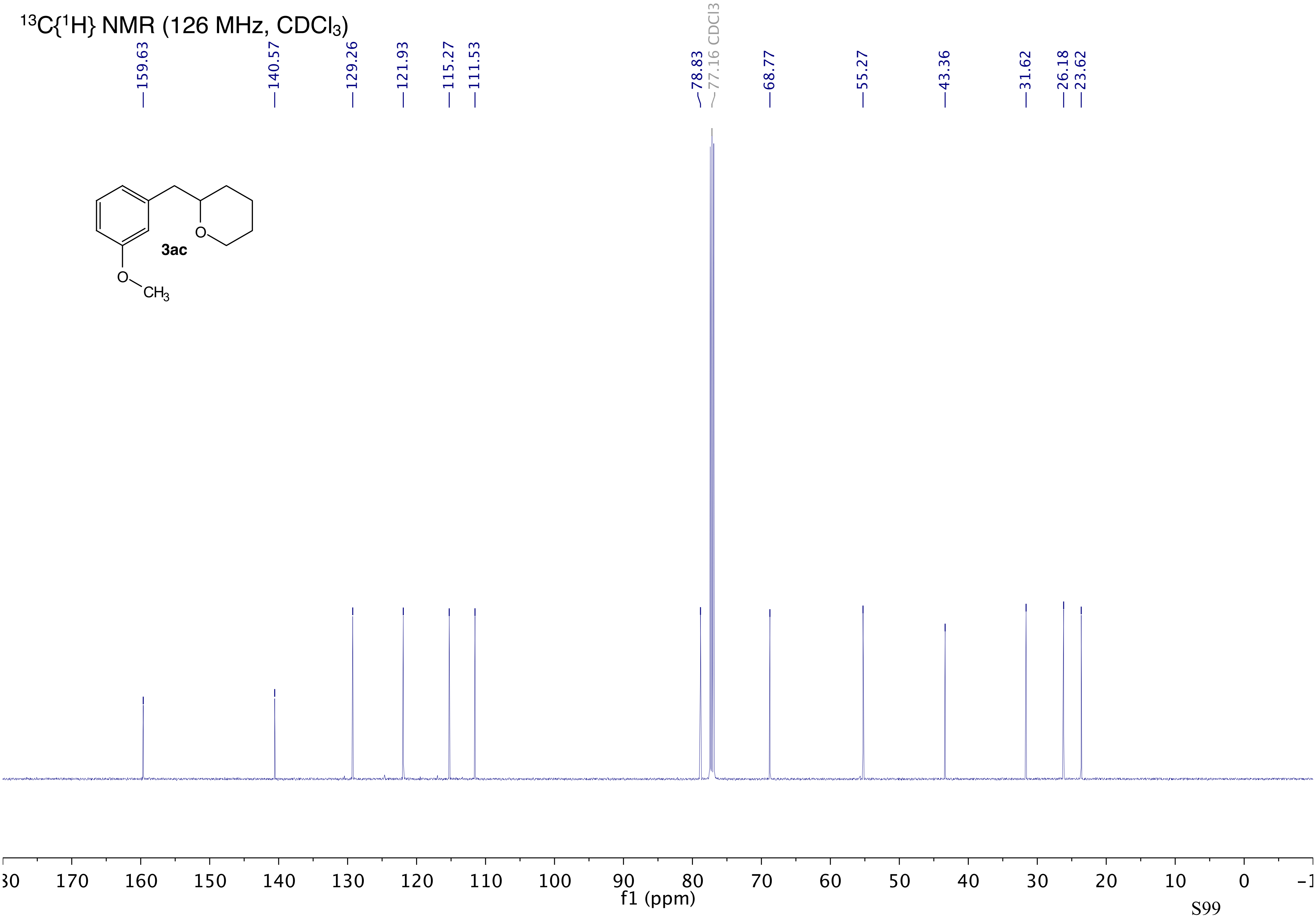
$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$)



^{1}H NMR (500 MHz, $CDCl_3$)

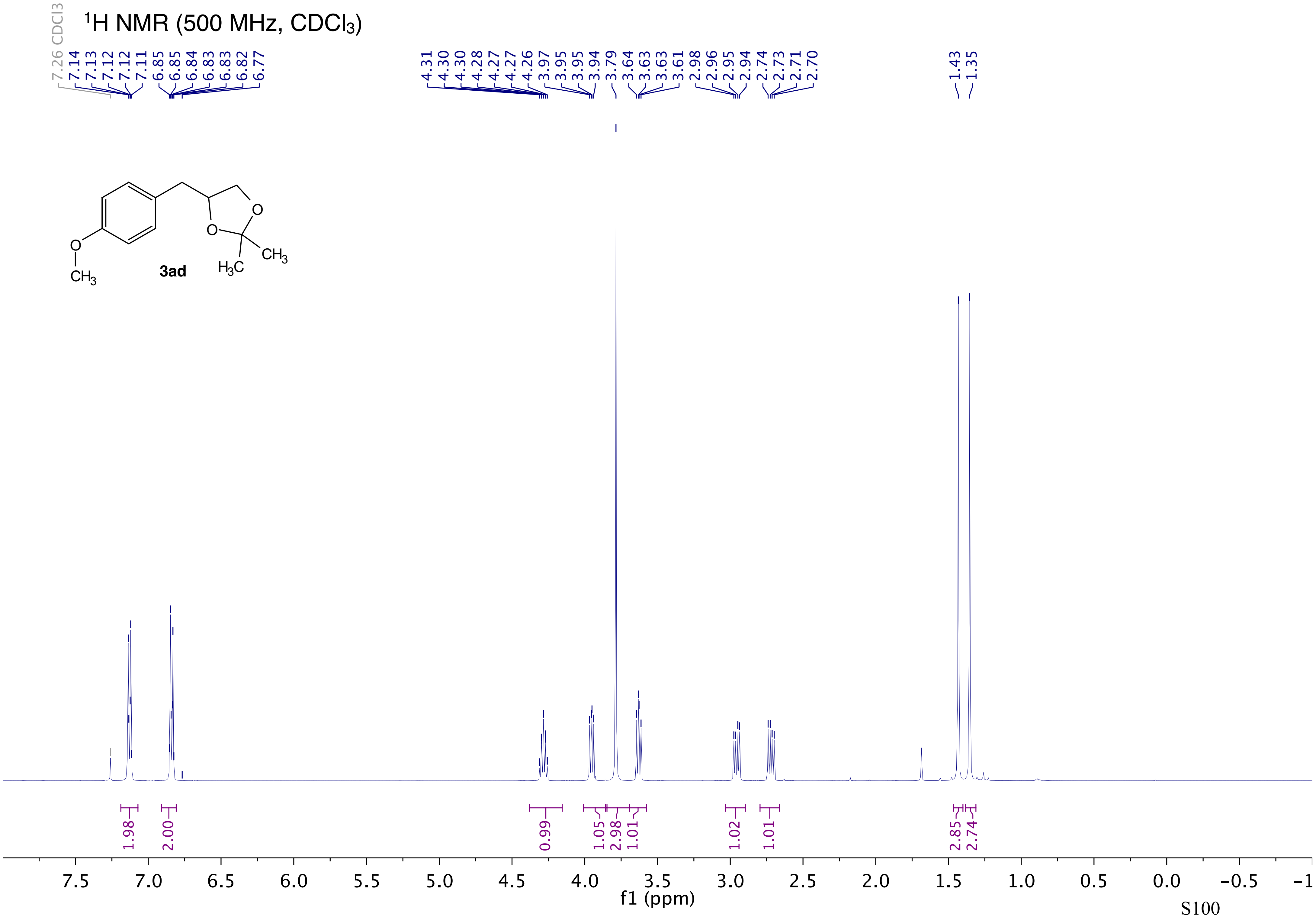


$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)

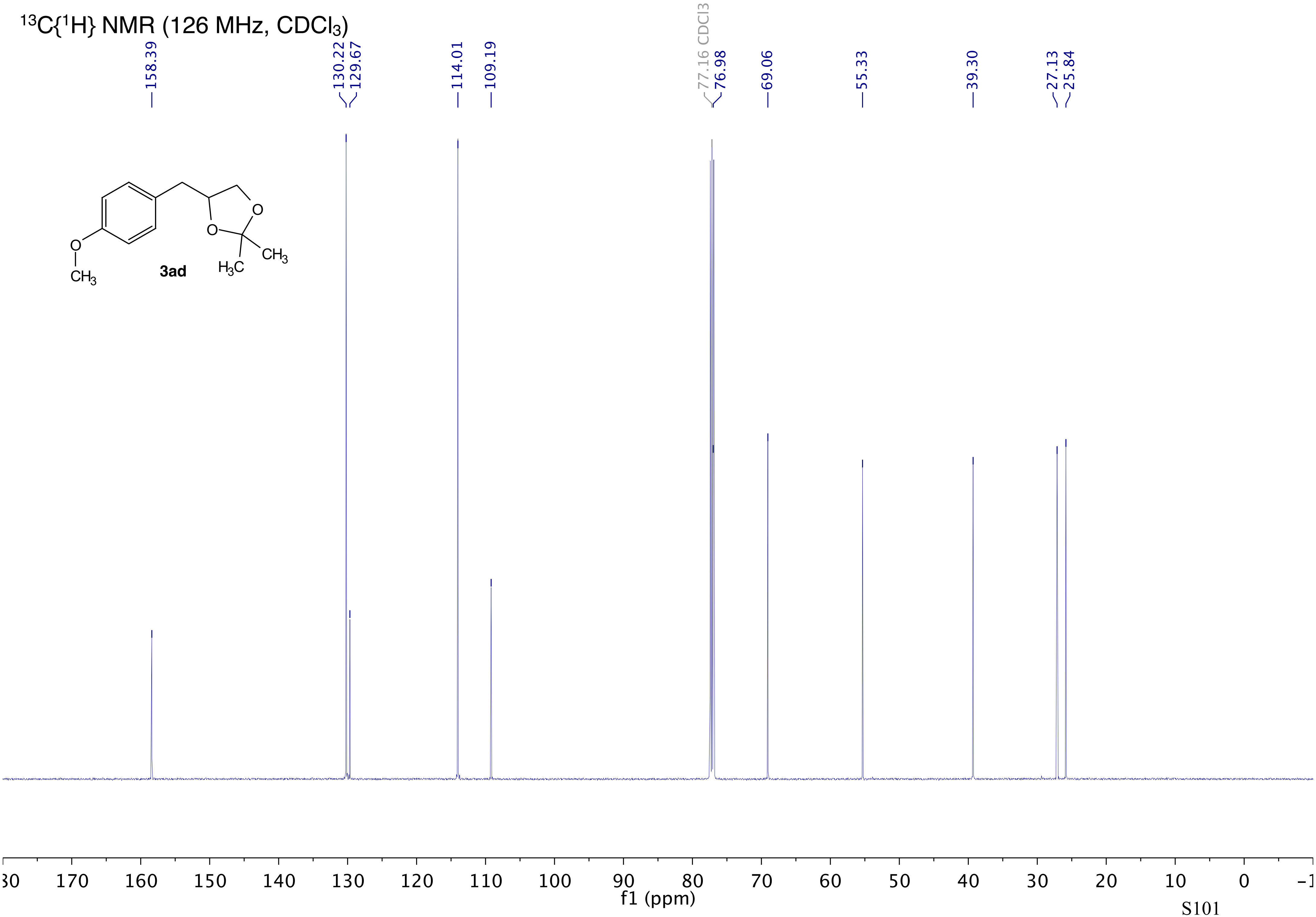


3ac

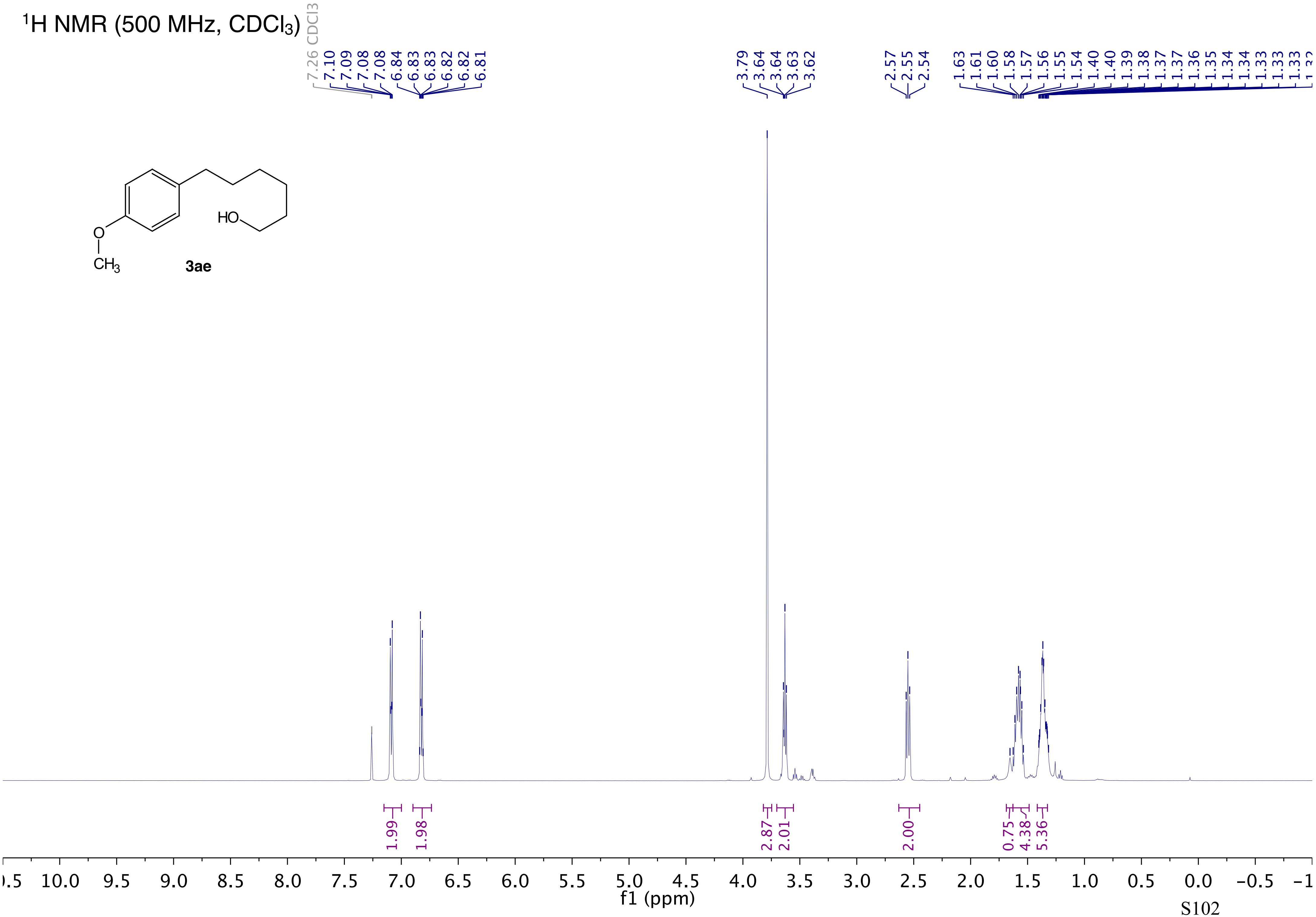
^{1}H NMR (500 MHz, CDCl$_3$)



^{13}C{^{1}H} NMR (126 MHz, CDCl$_3$)

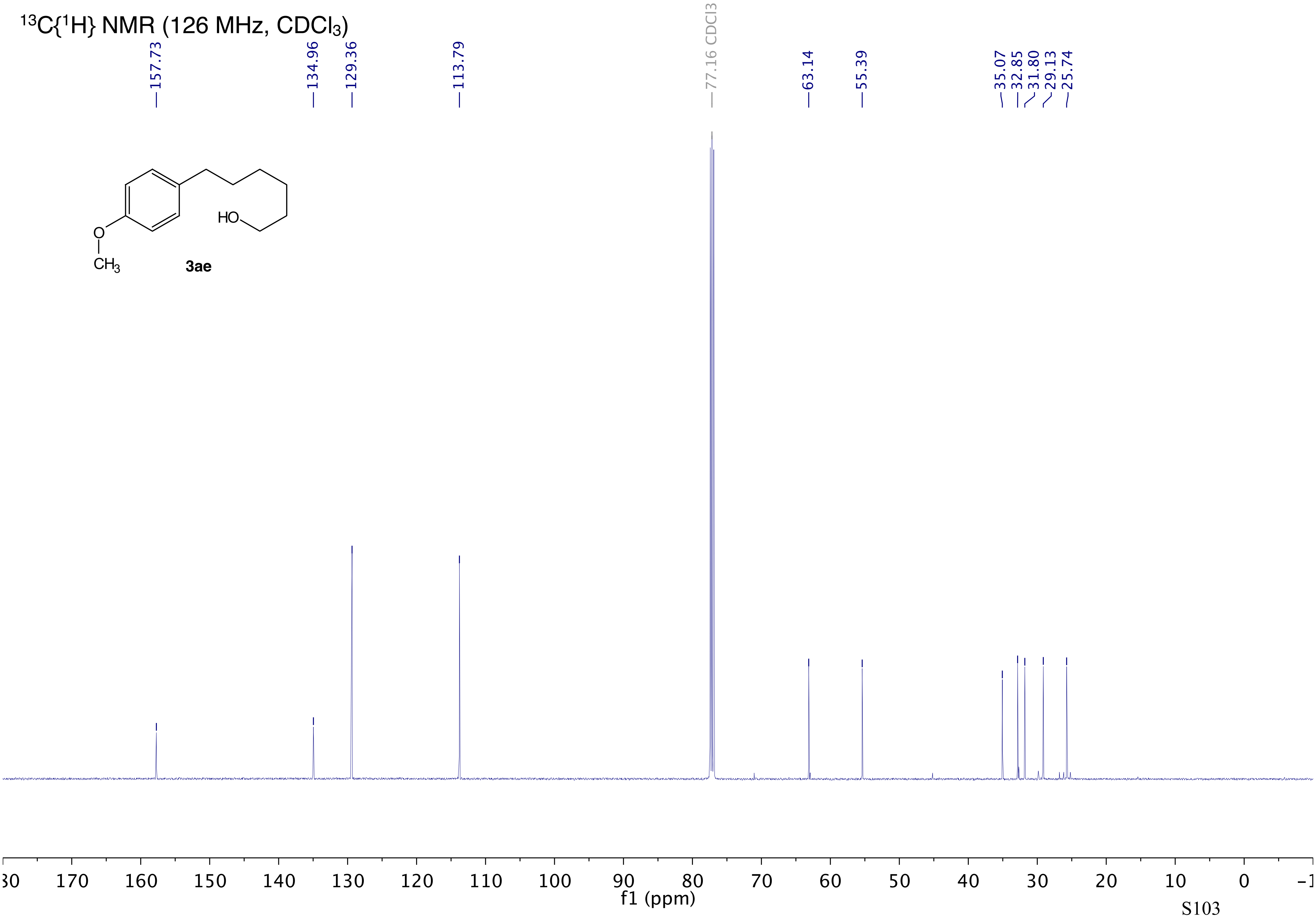


^{1}H NMR (500 MHz, CDCl$_3$)

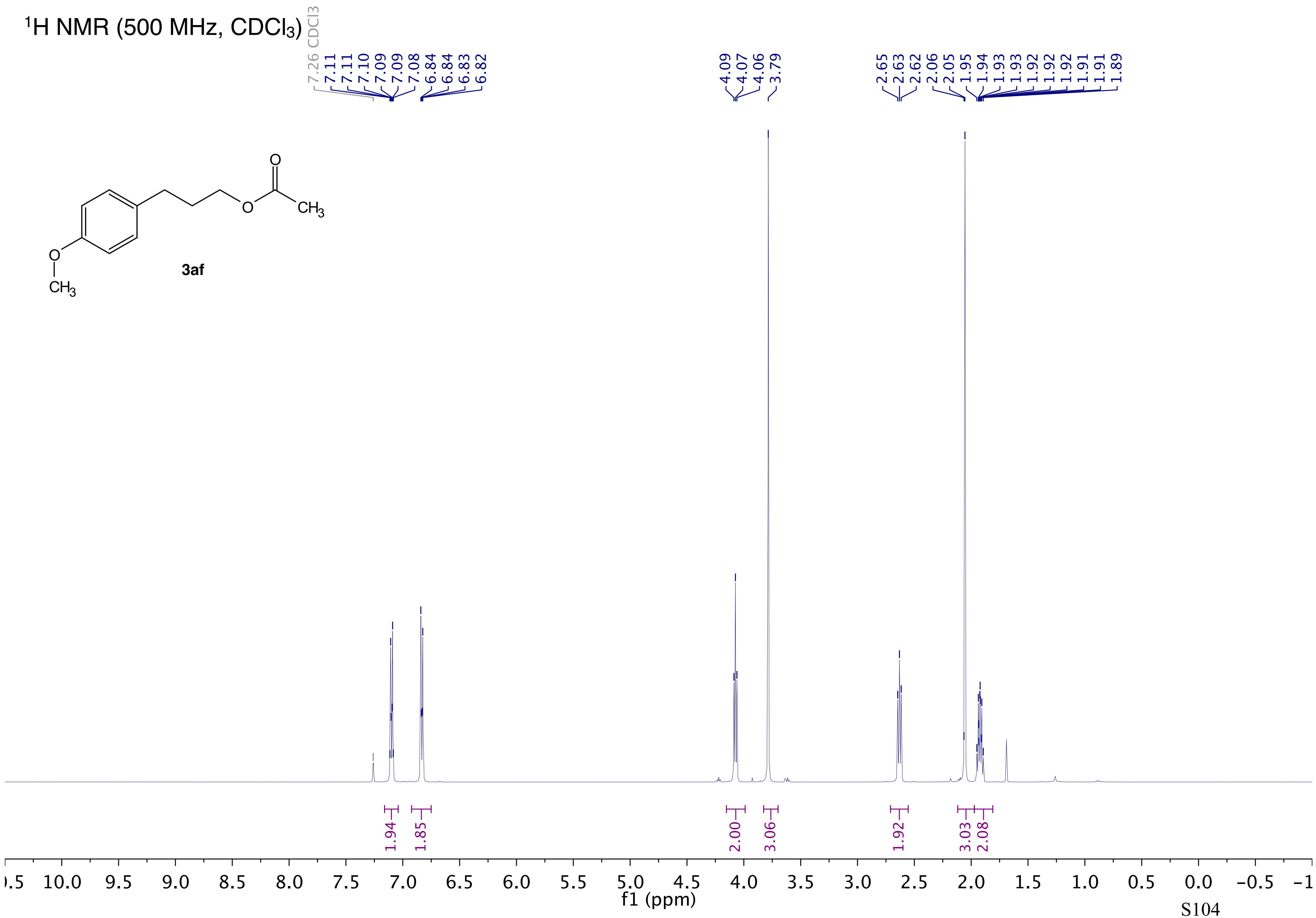


3ae

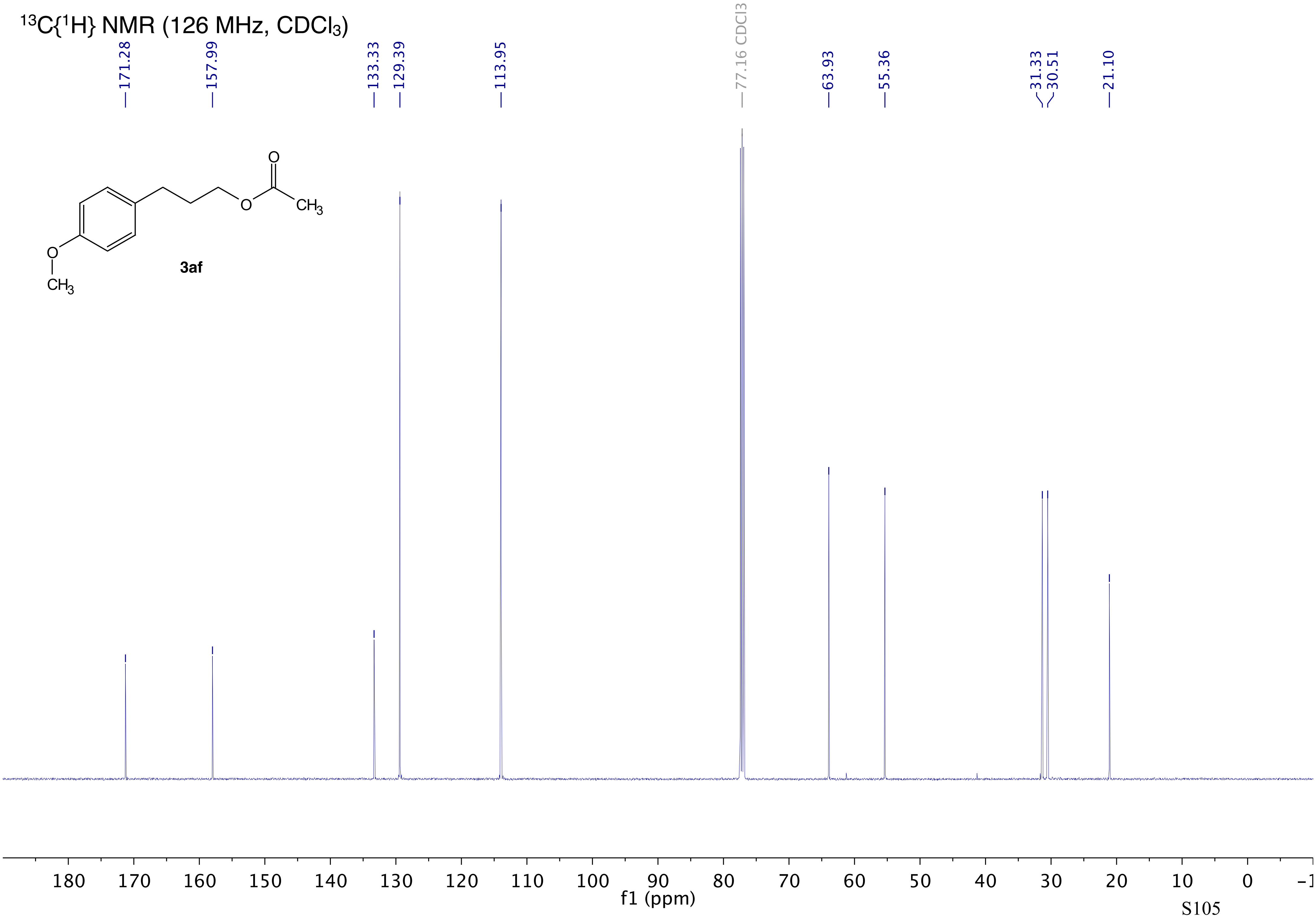
$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$)



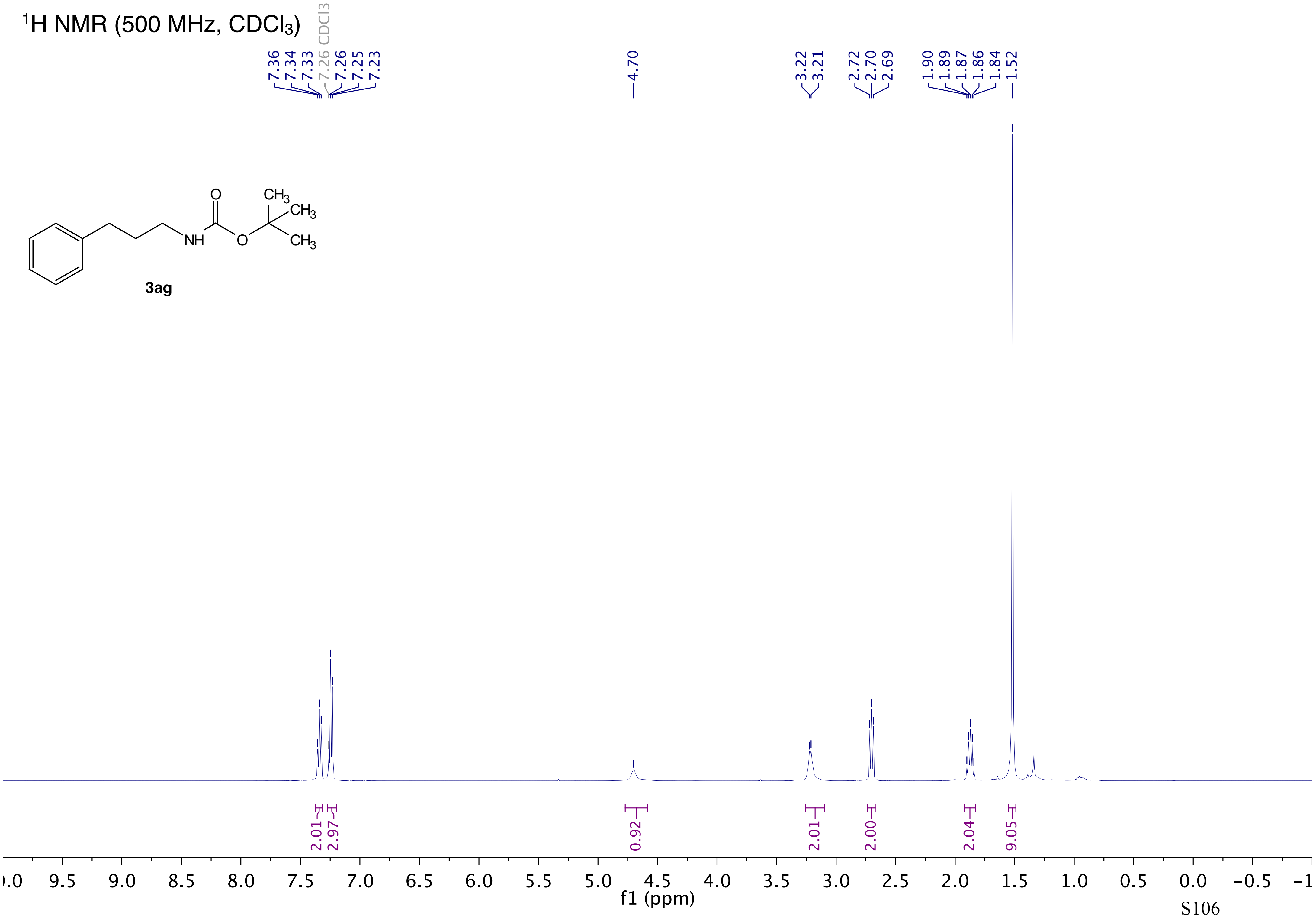
^{1}H NMR (500 MHz, $CDCl_3$)



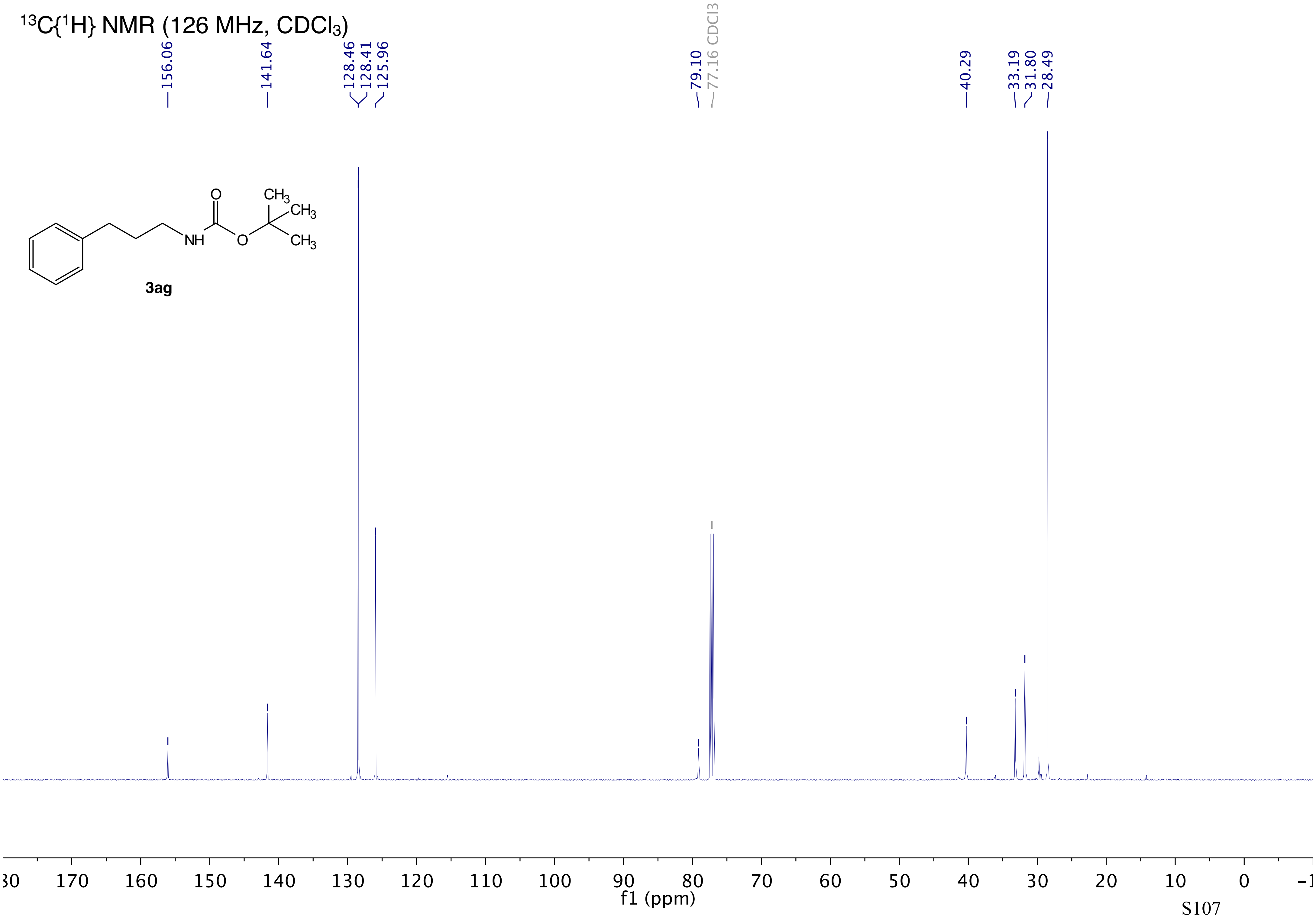
^{13}C{^{1}H} NMR (126 MHz, CDCl$_3$)



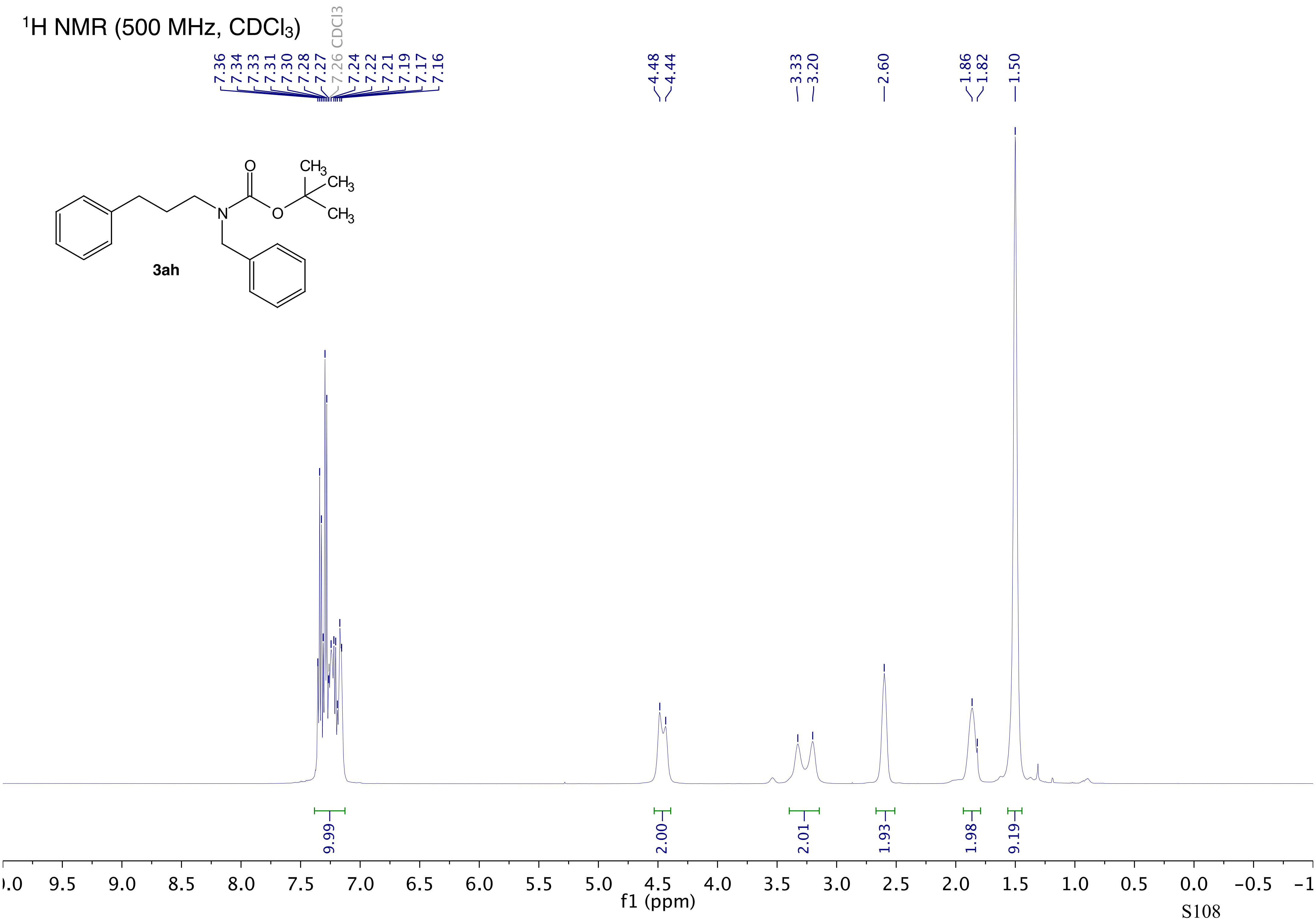
^{1}H NMR (500 MHz, CDCl$_3$)



$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$)

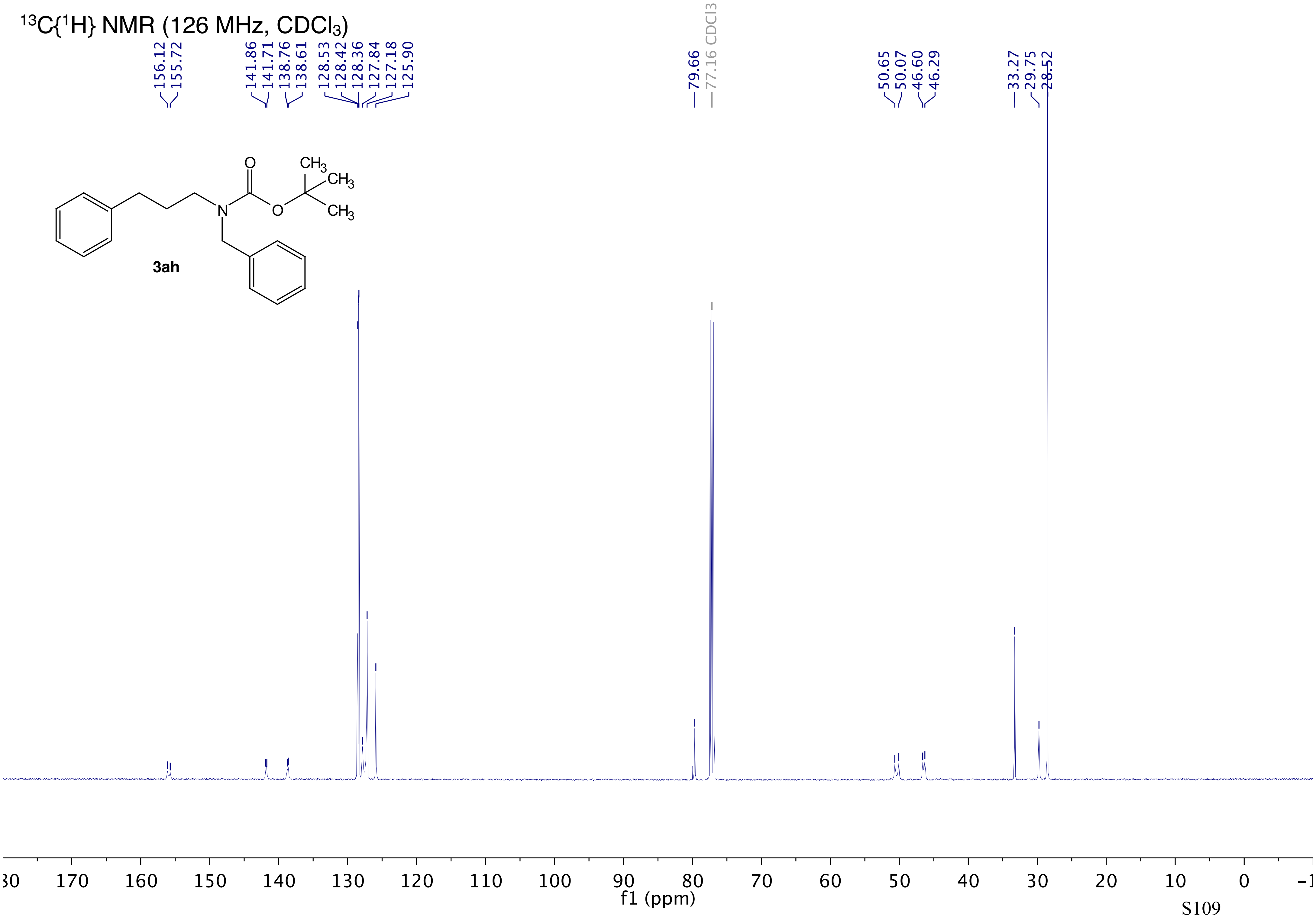


^{1}H NMR (500 MHz, $CDCl_3$)

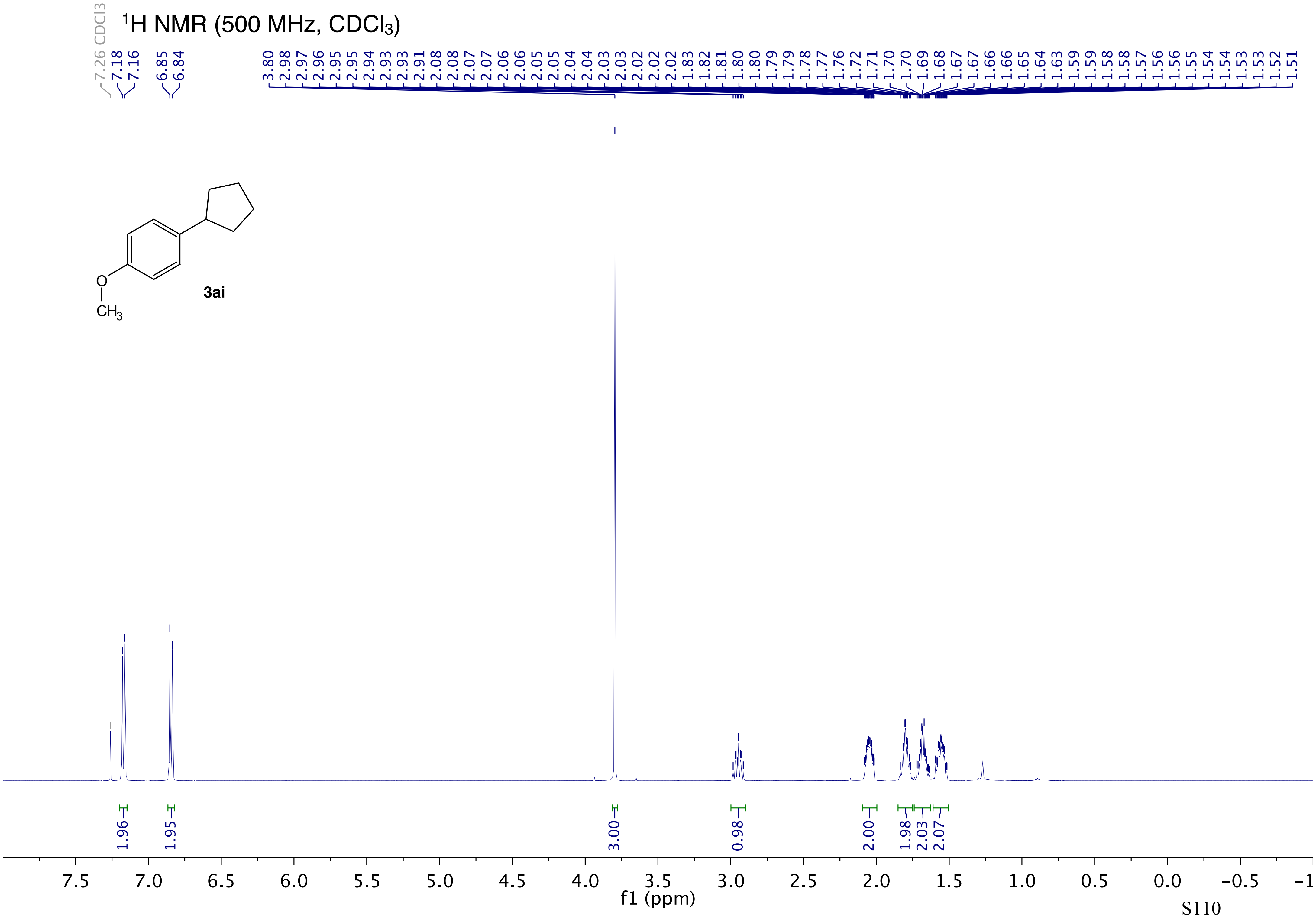


3ah

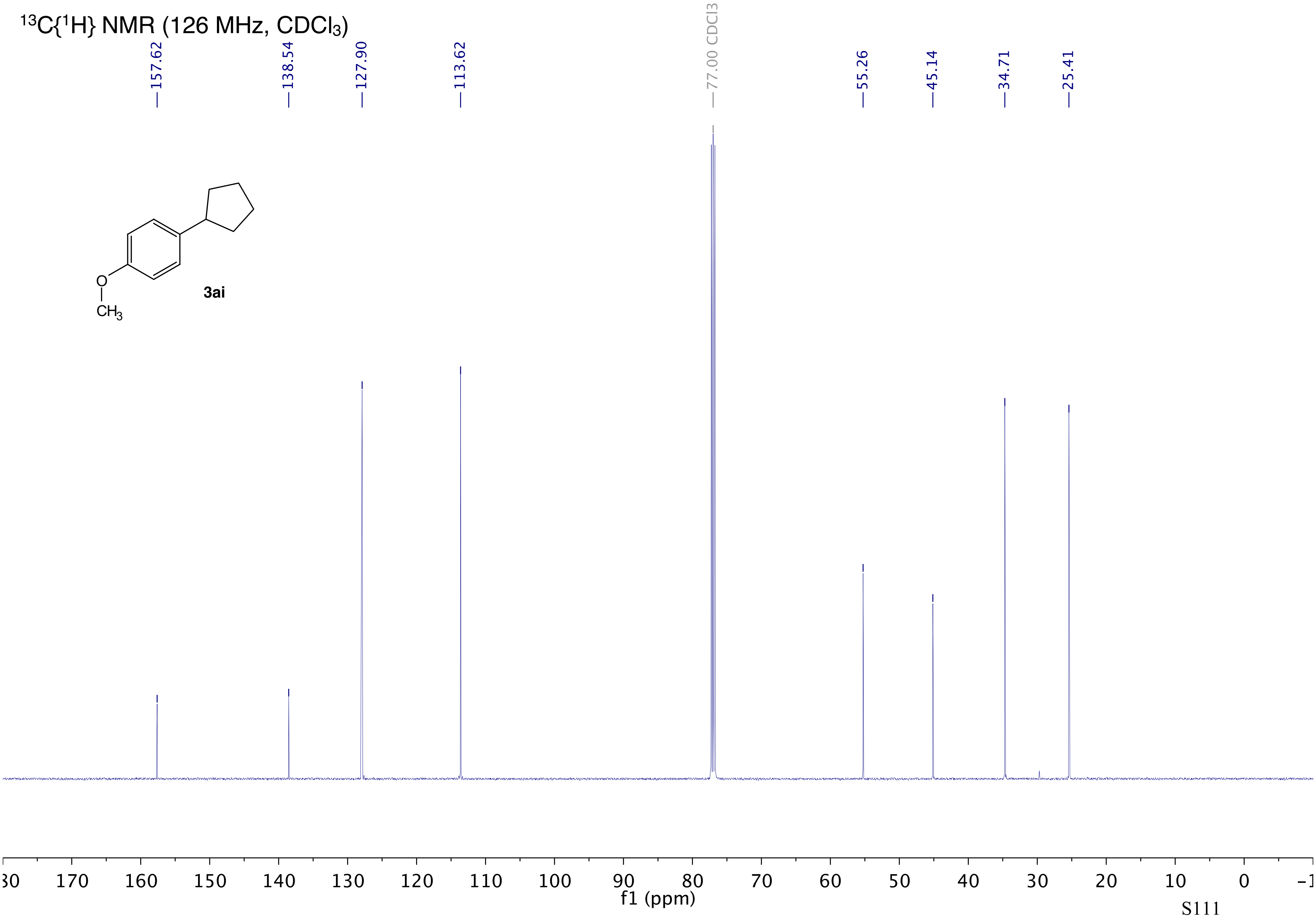
$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)



^{1}H NMR (500 MHz, $CDCl_3$)



$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$)



3ai