Intermolecular Atom Transfer Radical Addition to Olefins Mediated by Oxidative Quenching of Photoredox Catalysts

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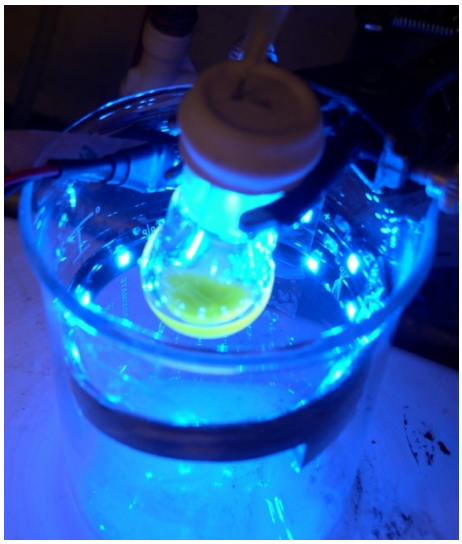
Supporting Information

Table of Contents:

General Information:
Chemicals were either used as received or purified according to *Purification of Common Laboratory Chemicals*. All reactions were performed using common dry, inert atmosphere techniques. Reactions were monitored by TLC and visualized by a dual short wave/long wave UV lamp and stained with an ethanolic solution of potassium permanganate or p-anisaldehyde. Column flash chromatography was performed using 230-400 mesh silica gel. NMR spectra were recorded on Varian Mercury 300, Varian Unity Plus 400, and Varian Mercury 400 spectrometers. Chemical shifts for ^{1}H NMR were reported as δ, parts per million, relative to the signal of residual $CHCl_3$ in $CDCl_3$ at 7.26 ppm. Chemical shifts for ^{13}C NMR were reported as δ, parts per million, relative to the center line signal of the $CDCl_3$ triplet at 77.0 ppm. Proton and carbon assignments were established using spectral data of similar compounds. The abbreviations s, br. s, d, dd, br. d, ddd, t, q, br. q, m, and br. m stand for the resonance multiplicity singlet, broad singlet, doublet, doublet of doublets, broad doublet, doublet of doublet of doublets, triplet, quartet, broad quartet, multiplet and broad multiplet, respectively. IR spectra were recorded on an Avatar 360 FT-IR spectrometer. Mass spectra were recorded at the Mass Spectrometry Facility at the Department of Chemistry of Boston University in Boston, MA on a Waters Q-Tof API-US with ESI high resolution mass spectrometer. Concentration refers to removal of solvent under reduced pressure (house vacuum at ca. 20 mm Hg).

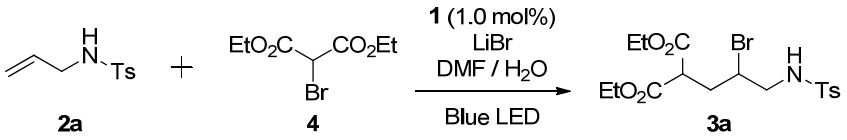
Reaction Apparatus:
Photoredox reactions were carried out under visible light irradiation by a 15 cm blue LED strip (available from http://www.creativelightings.com/, λ_{max} = 435 nm) surrounding the reaction vessel.



General Procedure A: Typical Photoredox Catalyzed Atom Transfer Radical Addition

A 10 mL round bottom flask was equipped with a rubber septum and magnetic stir bar and was charged with olefin (1.0 mmol, 1.0 equiv), atom transfer agent (2.0 mmol, 2.0 equiv), additive (2.0 mmol, 2.0 equiv), DMF (0.20 mL), H_2O (0.80 mL), $Ir(dF(CF_3)ppy)_2(dtbbpy)PF_6$, **1**, (0.010 mmol, 0.010 equiv). The flask was evacuated and backfilled with argon. The heterogeneous mixture was then irradiated by a 1 W blue LED strip under an atmosphere of Ar for 6 – 24h. After the reaction was complete (as judged by TLC analysis), the mixture was poured into a separatory funnel containing 25 mL of EtOAc and 25 mL of H_2O. The layers were separated and the aqueous layer was extracted with EtOAc (2 X 50 mL). The combined organic layers were dried (Na_2SO_4) and concentrated. The residue was purified by chromatography on silica gel, using the solvent system indicated, to afford the desired atom transfer product.

Diethyl 2-(2-bromo-3-(4-methylphenylsulfonamido)propyl)malonate, **3a** (*Table 2, entry 1*):



According to General Procedure A, **2a** (0.19 g, 0.90 mmol), **4** (0.43 g, 1.8 mmol), LiBr (0.16 g, 1.8 mmol), and **1** (10 mg, 9.0 μmol) in DMF (0.20 mL) and H_2O (0.80 mL) afforded **3a** (0.27 g, 67%) as a colorless oil after purification by chromatography on SiO_2 (4:1 to 6:4, hexanes/EtOAc) (48 h reaction time).

R_f (EtOAc/hexane 1:4): 0.16;

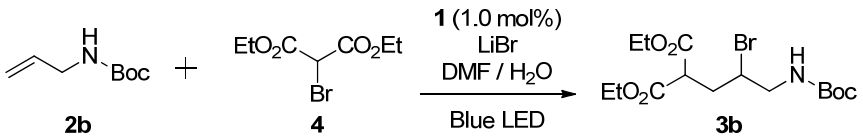
IR (neat): 3282, 2984, 2925, 1730, 1445, 1334, 1304, 1159, 1093, 1026, 815, 665 cm^{-1};

^1H NMR ($CDCl_3$, 400 MHz): δ 7.74 (d, J = 8.0 Hz, 2 H), 7.31 (d, J = 8.0 Hz, 2 H), 4.92 (t, J = 6.3 Hz, 1 H), 4.27 – 4.15 (m, 4 H), 4.10 – 4.04 (m, 1 H), 3.65 (dd, J = 9.4, 4.8 Hz, 1 H), 3.37 – 3.22 (m, 2 H), 2.47 – 2.40 (m, 4 H), 2.30 – 2.23 (m, 1 H), 1.29 – 1.24 (m, 6 H);

^{13}C NMR ($CDCl_3$, 100 MHz): δ 168.6, 168.3, 143.7, 136.7, 129.8, 127.0, 61.8, 61.7, 51.7, 49.9, 49.4, 34.5, 21.5, 13.9, 13.9;

HRMS (ESI) *m/z* calculated for $C_{17}H_{24}BrNNaO_6S^+$ ($[M+Na]^+$) 472.0405, found 472.0403.

Diethyl 2-(2-bromo-3-((tert-butoxycarbonyl)amino)propyl)malonate, **3b** (*Table 2, entry 2*):



2b **4** **3b**

According to General Procedure A, **2b** (0.17 g, 1.1 mmol), **4** (0.52 g, 2.2 mmol), LiBr (0.19 g, 2.2 mmol), and **1** (12 mg, 11 μmol) in DMF (0.20 mL) and H_2O (0.80 mL) afforded **3b** (0.43 g, 99%) as a colorless oil after purification by chromatography on SiO_2 (4:1, hexanes/EtOAc) (24 h reaction time).

R_f (EtOAc/hexane 3:7): 0.48;

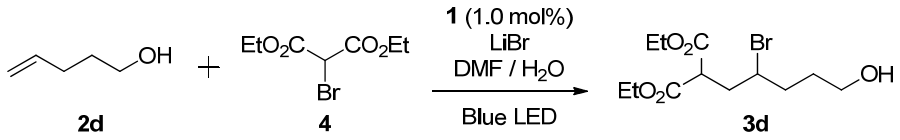
IR (neat): 3388, 2979, 2935, 1728, 1511, 1367, 1249, 1159, 1095, 1028, 860 cm^{-1};

^1H NMR ($CDCl_3$, 400 MHz): δ 4.96 (br. s, 1 H), 4.26 – 4.18 (m, 4 H), 4.14 – 4.10 (m, 1 H), 3.74 (dd, J = 9.6, 4.8 H, 1 H), 3.54 – 3.48 (m, 2 H), 2.51 – 2.44 (m, 1 H), 2.30 – 2.23 (m, 1 H), 1.45 (s, 9 H), 1.30 – 1.25 (m, 6 H);

^{13}C NMR ($CDCl_3$, 125 MHz): δ 168.8, 168.4, 155.6, 79.8, 61.7, 61.7, 53.2, 50.1, 47.1, 34.6, 28.3, 14.0, 14.0;

HRMS (ESI) *m/z* calculated for $C_{15}H_{26}BrNO_6^+$ ($[M+1]^+$) 395.0943, found 395.0941.

Diethyl 2-(2-bromo-5-hydroxypentyl)malonate, **3d** (*Table 2, entry 4*):



2d **4** **3d**

According to General Procedure A, **2d** (0.17 g, 2.0 mmol), **4** (0.95 g, 4.0 mmol), LiBr (0.34 g, 4.0 mmol), and **1** (22mg, 12 µmol) in DMF (0.40 mL) and H_2O (1.6 mL) afforded **3d** (0.62 g, 95%) as a colorless oil after purification by chromatography on SiO_2 (4:1, hexanes/EtOAc) (24 h reaction time).

R_f (EtOAc/hexane 30:70): 0.23;

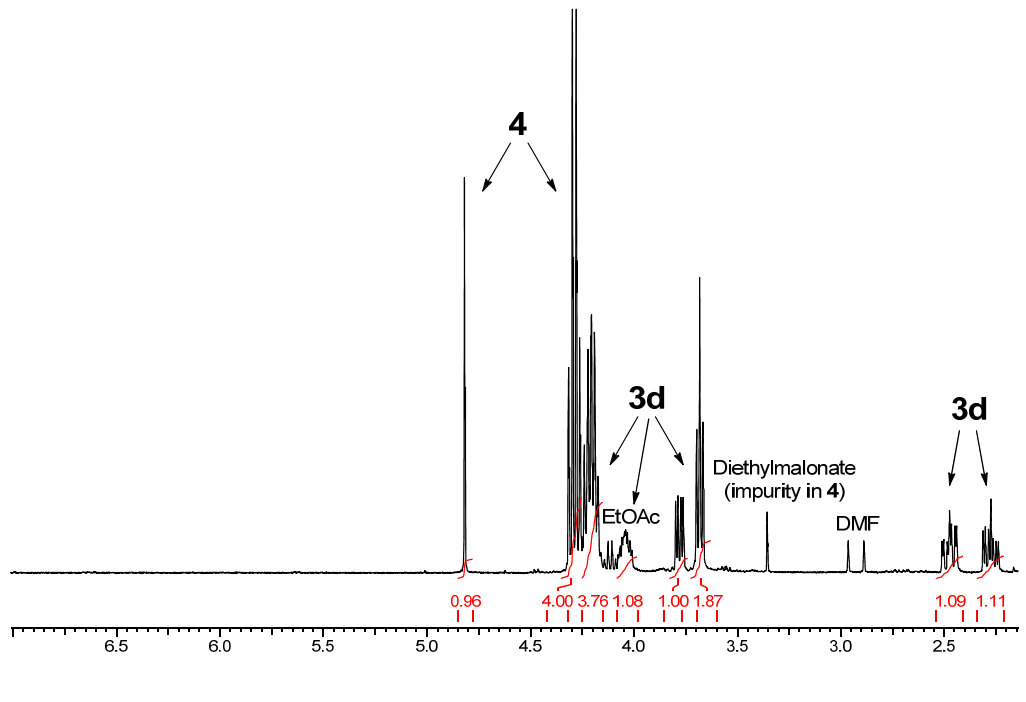
IR (neat): 3442, 2981, 2939, 1729, 1445, 1369, 1264, 1150, 1028 cm^{-1};

^1H NMR ($CDCl_3$, 300 MHz): δ 4.27 – 4.15 (m, 4 H), 4.09 – 4.00 (m, 1 H), 3.78 (dd, J = 10.2, 4.5 Hz, 1 H), 3.69 (t, J = 6.0 Hz, 2 H), 2.48 (ddd, J = 15.0, 10.2, 3.6 Hz, 1 H), 2.27 (ddd, J = 15.0, 10.5, 4.5 Hz, 1 H), 2.03 – 1.67 (m, 4 H), 1.48 (br. s, 1 H), 1.31 – 1.25 (m, 6 H);

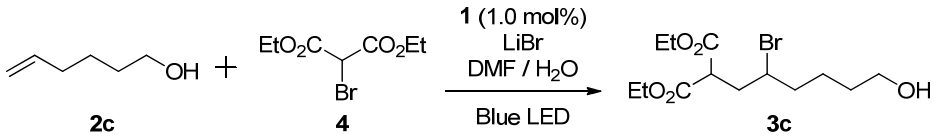
^{13}C NMR ($CDCl_3$, 75 MHz): δ 168.7, 168.6, 61.5, 61.4, 54.4, 50.3, 37.6, 35.5, 30.2, 13.8, 13.8;

HRMS (ESI) *m/z* calculated for $C_{12}H_{22}BrO_5^+$ ($[M+1]^+$) 325.0651, found 325.0679.

Crude ^1H NMR **2d**→**3d**:



Diethyl 2-(2-bromo-6-hydroxyhexyl)malonate, **3c** (*Table 2, entry 3*):



According to General Procedure A, **2c** (0.10 g, 1.0 mmol), **4** (0.48 g, 2.0 mmol), LiBr (0.17 g, 2.0 mmol), and **1** (11 mg, 10 µmol) in DMF (0.20 mL) and H_2O (0.80 mL) afforded **3c** (0.34 g, 99%) as a yellow oil after purification by chromatography on SiO_2 (4:1, hexanes/EtOAc) (24 h reaction time).

R_f (EtOAc/hexane 30:70): 0.23;

IR (neat): 3395, 2982, 2938, 2360, 1728, 1369, 1261, 1151, 1030, 913, 731 cm^{-1};

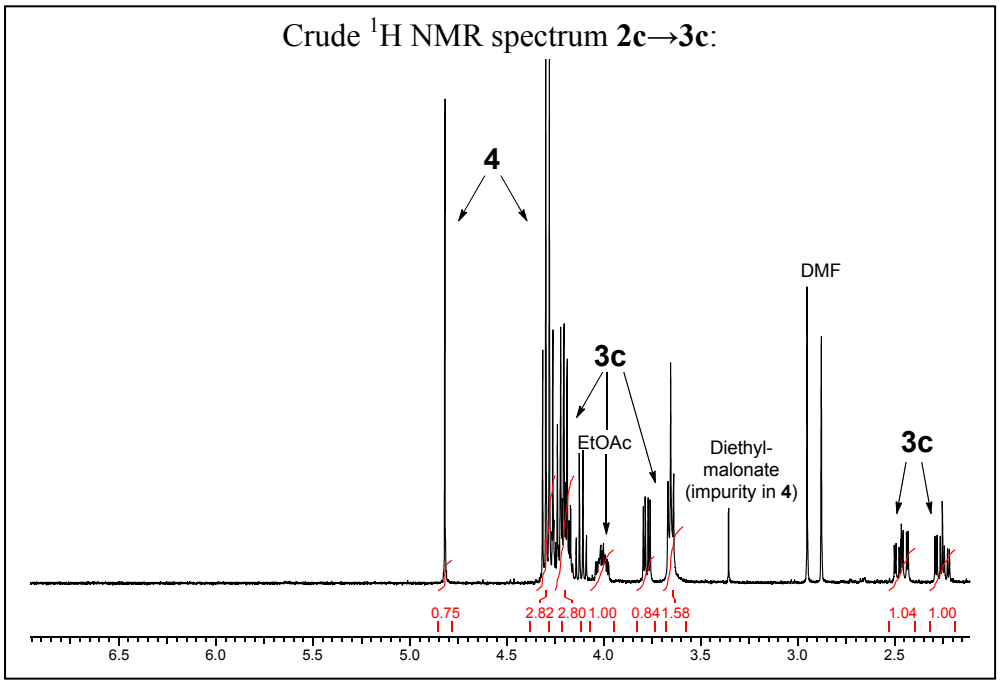
^1H NMR ($CDCl_3$, 500 MHz): δ 4.29 – 4.18 (m, 4 H), 4.05 – 4.00 (m, 1 H), 3.79 (dd, J = 11.6, 4.4 Hz, 1 H), 3.67 (t, J = 6.3 Hz, 2 H), 2.49 (ddd, J = 15.0, 10.5, 3.3 Hz, 1 H), 2.28 (ddd, J = 14.7, 10.5, 4.1 Hz, 1 H) 1.94 – 1.89 (m, 2 H), 1.69 – 1.50 (m, 5 H), 1.32 – 1.28 (m, 6 H);

^{13}C NMR ($CDCl_3$, 125 MHz): δ 168.9, 168.7, 62.4, 61.7, 61.6, 54.6, 50.5, 39.1, 37.8, 31.8, 23.7, 14.0, 14.0;

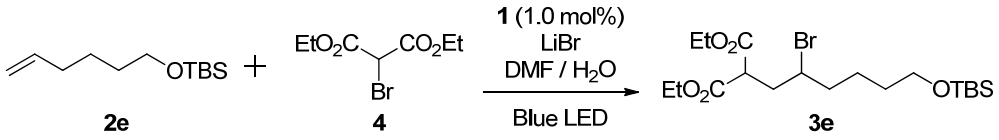
HRMS (ESI) *m/z* calculated for $C_{13}H_{23}BrO_5^+$ ($[M+1]^+$) 339.0807, found 339.0800.

Preparative Scale with Low Catalyst Loading:
According to General Procedure A, **S7** (1.5 g, 15 mmol), **4** (7.1 g, 30 mmol), LiBr (2.6 g, 30 mmol), and **1** (3.3 mg, 3.0 µmol) in DMF (6.1 mL) and H_2O (25 mL) afforded **S8** (4.7 g, 97%) as a yellow oil after purification by chromatography on SiO_2 (4:1, hexanes/EtOAc) (24 h reaction time).

Crude ^1H NMR spectrum **2c**→**3c**:



Diethyl 2-(2-bromo-6-((tert-butyldimethylsilyl)oxy)hexyl)malonate, **3e** (*Table 2, entry 5*):



2e **4** **3e**

According to General Procedure A, **2e** (0.13 g, 0.61 mmol), **4** (0.20 g, 1.2 mmol), LiBr (0.11 g, 1.2 mmol), and **1** (6.8 mg, 6.1 μmol) in DMF (0.20 mL) and H_2O (0.80 mL) afforded **3e** (0.25 g, 90%) as a yellow oil after purification by chromatography on SiO_2 (95:5, hexanes/EtOAc) (24 h reaction time).

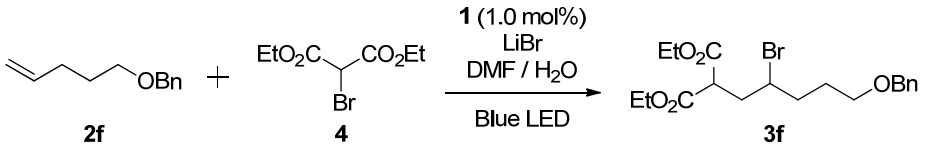
R_f (EtOAc/hexane 5:95): 0.13;

IR (neat): 2931, 2857, 1732, 1471, 1255, 1205, 1096, 835, 775 cm^{-1};

^1H NMR ($CDCl_3$, 400 MHz): δ 4.27 – 4.17 (m, 4 H), 4.03 – 3.97 (m, 1 H), 3.78 (dd, J = 10.4, 4.0 Hz, 1 H), 3.61 (t, J = 5.6 Hz, 2 H), 2.46 (ddd, J = 14.0, 10.5, 3.2 Hz, 1 H), 2.25 (ddd, J = 14.8, 10.5, 4.4 Hz, 1 H), 1.90 – 1.84 (m, 2 H), 1.61 – 1.17 (m, 6 H), 1.30 – 1.25 (m, 6 H), 0.89 (s, 9 H), 0.05 (s, 6 H);

^{13}C NMR ($CDCl_3$, 125 MHz): δ 168.9, 168.7, 62.7, 61.6, 61.5, 54.7, 50.5, 39.1, 37.8, 31.9, 25.9, 23.8, 14.0, 13.9, -5.4.

Diethyl 2-(6-(benzyloxy)-2-bromohexyl)malonate, **3f** (*Table 2, entry 6*):



2f **4** **3f**

According to General Procedure A, **2f** (0.50 g, 2.8 mmol), **4** (1.4 g, 5.7 mmol), LiBr (0.49 g, 5.7 mmol), and **1** (16 mg, 28 μmol) in DMF (0.40 mL) and H_2O (1.6 mL) afforded **3f** (1.1 g, 92%) as a colorless oil after purification by chromatography on SiO_2 (85:15, hexanes/EtOAc) (24 h reaction time).

R_f (EtOAc/hexane 15:85): 0.25;

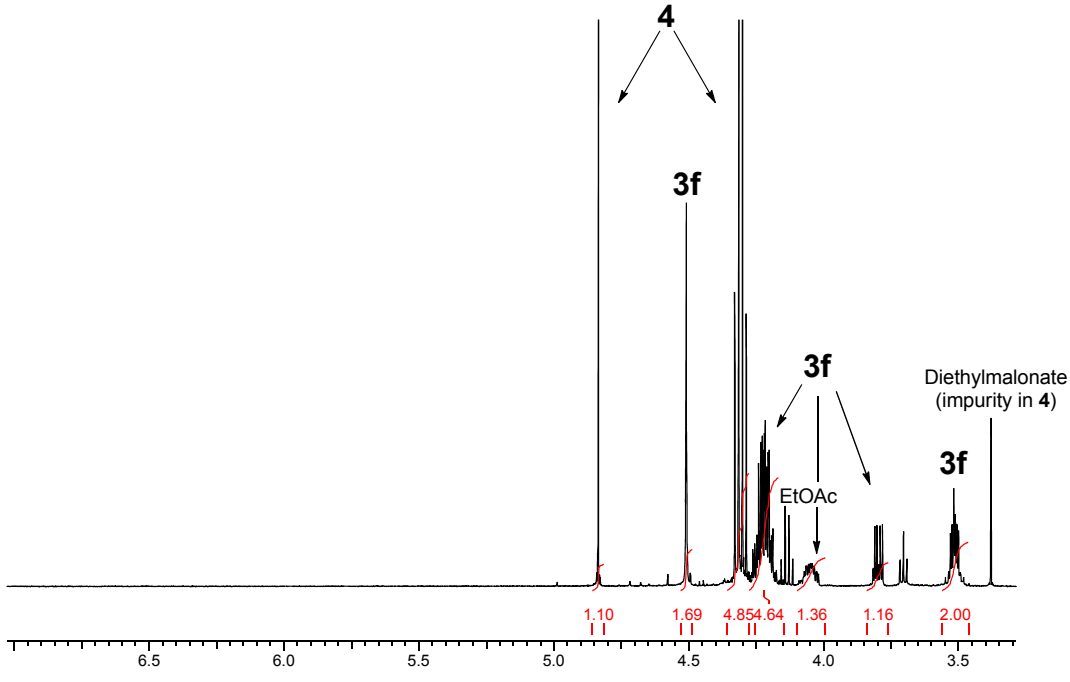
IR (neat): 2981, 2859, 1730, 1453, 1368, 1262, 1150, 1096, 1028, 737 cm^{-1};

^1H NMR ($CDCl_3$, 400 MHz): δ 7.30 – 7.19 (m, 5 H), 4.43 (s, 2 H), 4.19 – 4.10 (m, 4 H), 4.00 – 3.94 (m, 1 H), 3.71 (dd, J = 10.4, 4.4 Hz, 1 H), 3.43 (t, J = 6.0 Hz, 2 H), 2.40 (ddd, J = 14.8, 10.4, 3.2 Hz, 1 H), 2.21 (ddd, J = 14.8, 10.4, 4.0 Hz, 1 H), 1.99 – 1.78 (m, 3 H), 1.74 – 1.64 (m, 1 H) 1.22 – 1.18 (m, 6 H);

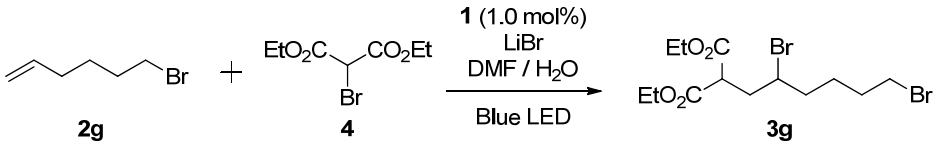
^{13}C NMR ($CDCl_3$, 75 MHz): δ 168.8, 168.6, 138.3, 128.3, 127.5, 127.5, 72.8, 69.2, 61.6, 61.5, 54.7, 50.5, 37.8, 36.1, 27.7, 14.0, 13.9;

HRMS (ESI) *m/z* calculated for $C_{19}H_{27}BrNaO_5^+$ ($[M+Na]^+$) 437.0940, found 437.0938.

Crude ^1H NMR spectrum **2f**→**3f**:



Diethyl 2-(2,6-dibromohexyl)malonate, **3g** (*Table 2, entry 7*):



2g **4** **3g**

According to General Procedure A, **2g** (0.10 g, 0.61 mmol), **4** (0.29 g, 1.2 mmol), LiBr (0.11 g, 1.2 mmol), and **1** (6.9 mg, 6.1 μmol) in DMF (0.20 mL) and H_2O (0.80 mL) afforded **3g** (0.23 g, 94%) as a colorless oil after purification by chromatography on SiO_2 (9:1, hexanes/Et_2O) (24 h reaction time).

R_f (EtOAc/hexane 8:92): 0.29;

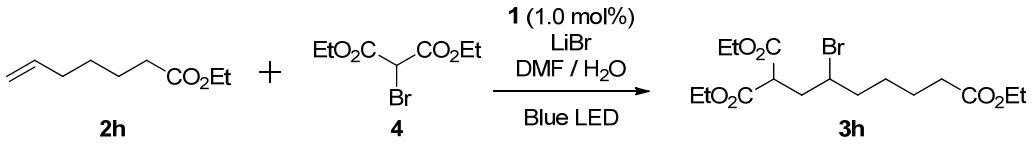
IR (neat): 2981, 2938, 1729, 1445, 1261, 1150, 1096, 1029, 857 cm^{-1};

^1H NMR ($CDCl_3$, 500 MHz): δ 4.27 – 4.19 (m, 4 H), 4.04 – 3.99 (m, 1 H), 3.80 (dd, J = 10.5, 4.5 Hz, 1 H), 3.43 (t, J = 7.0 Hz, 2 H), 2.48 (ddd, J = 15.0, 10.5, 3.0 Hz, 1 H), 2.28 (ddd, J = 14.5, 10.5, 4.0 Hz, 1 H), 1.95 – 1.88 (m, 4 H), 1.78 – 1.73 (m, 1 H), 1.68 – 1.60 (m, 1 H), 1.59 (s, 1 H), 1.33 – 1.29 (m, 6 H);

^{13}C NMR ($CDCl_3$, 100 MHz): δ 168.9, 168.7, 61.7, 61.6, 54.2, 50.5, 38.4, 37.8, 33.2, 31.9, 26.1, 14.0, 14.0;

HRMS (ESI) *m/z* calculated for $C_{13}H_{23}Br_2O_4^+$ ($[M+1]^+$) 400.9963, found 400.9958.

Triethyl 3-bromoheptane-1,1,7-tricarboxylate, **3h** (*Table 2, entry 8*):



2h **4** **3h**

According to General Procedure A, **2g** (0.19 g, 1.2 mmol), **4** (0.58 g, 2.4 mmol), LiBr (0.21 g, 2.4 mmol), and **1** (13 mg, 12 μmol) in DMF (0.20 mL) and H_2O (0.80 mL) afforded **3h** (480 mg, 99%) as a colorless oil after purification by chromatography on SiO_2 (9:1, hexanes/Et_2O) (24 h reaction time).

R_f (EtOAc/hexane 1:4): 0.33;

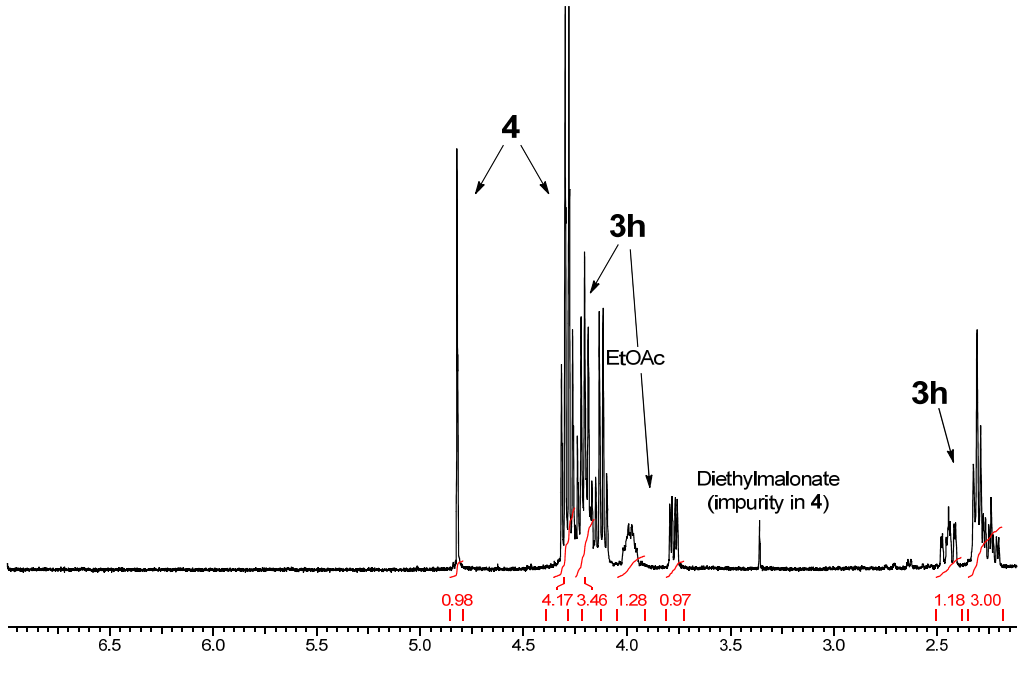
IR (neat): 2981, 2939, 1729, 1446, 1369, 1258, 1178, 1150, 1029 cm^{-1};

^1H NMR ($CDCl_3$, 500 MHz): δ 4.27 – 4.16 (m, 4 H), 4.13 (q, J = 9.0 Hz, 2 H), 4.03 – 3.96 (m, 1 H), 3.77 (dd, J = 13.0, 5.5 Hz, 1 H), 2.45 (ddd, J = 18.5, 13.0, 4.0 Hz, 1 H), 2.31 (t, J = 8.5 Hz, 2 H), 2.25 (ddd, J = 18.5, 13.0, 5.0 Hz, 1 H), 1.89 – 1.84 (m, 2 H), 1.70 – 1.56 (m, 3 H), 1.53 – 1.44 (m, 1 H), 1.30 – 1.24 (m, 9 H);

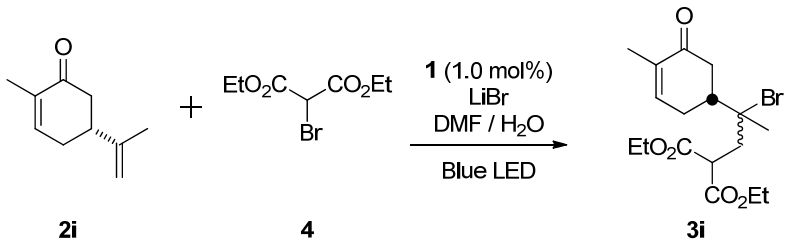
^{13}C NMR ($CDCl_3$, 75 MHz): δ 173.4, 168.9, 168.7, 61.7, 61.6, 60.2, 54.2, 50.2, 39.0, 37.8, 34.0, 26.9, 24.2, 14.2, 14.0, 14.0;

HRMS (ESI) *m/z* calculated for $C_{16}H_{28}BrO_6^+$ ($[M+1]^+$) 395.1069, found 395.1064.

Crude ^1H NMR spectrum **2h**→**3h**:



Diethyl 2-(2-bromo-2-(4-methyl-5-oxocyclohex-3-en-1-yl)propyl)malonate, **3i** (*Table 2, entry 9*):



2i **4** **3i**

According to General Procedure A, **2i** (0.10 g, 0.66 mmol), **4** (0.32 g, 1.3 mmol), LiBr (0.12 g, 1.3 mmol), and **1** (7.5 mg, 6.6 µmol) in DMF (0.20 mL) and H_2O (0.80 mL) afforded **3i** (0.25 g, 95%) as a colorless oil and an inseparable mixture of diastereoisomers after purification by chromatography on SiO_2 (4:1, hexanes/EtOAc) (24 h reaction time).

R_f (EtOAc/hexane 1:4): 0.26;

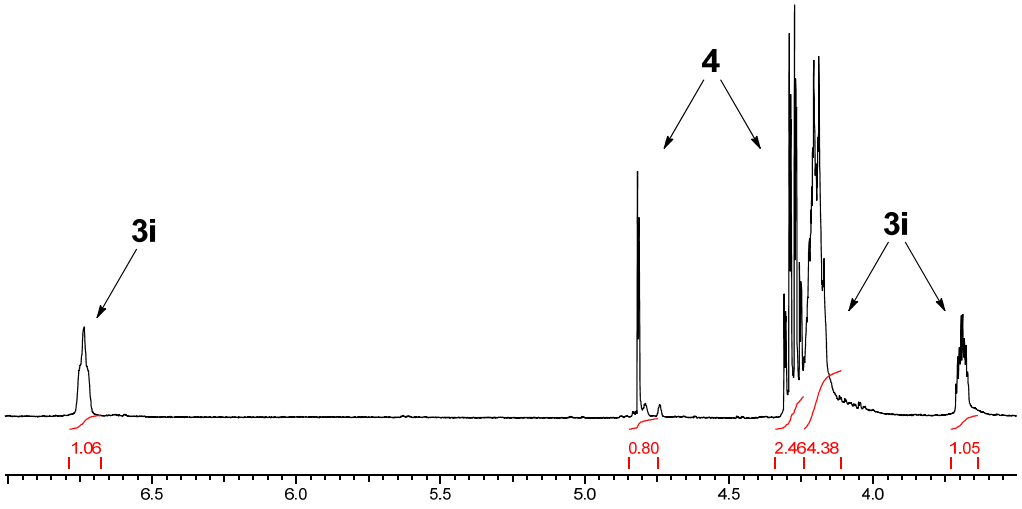
IR (neat): 2981, 2935, 1730, 1673, 1447, 1268, 1254, 1149, 1109, 1026 cm^{-1};

^1H NMR ($CDCl_3$, 500 MHz): δ 6.74 (t, J = 7.0 Hz, 1 H), 4.24 – 4.18 (m, 4 H), 3.71 – 3.68 (m, 1 H), 2.83 – 2.52 (m, 3 H), 2.49 – 2.37 (m, 3 H), 2.25– 2.14 (m, 1 H), 1.78 (s, 3 H), 1.66 (s, 3 H);

^{13}C NMR ($CDCl_3$, 125 MHz): δ 198.6, 198.5, 171.1, 169.4, 169.4, 169.0, 144.0, 143.7, 135.4, 135.3, 72.9, 72.9, 62.0, 61.9, 61.9, 60.4, 49.7, 49.6, 47.1, 46.8, 41.0, 40.9, 40.7, 40.7, 28.9, 28.6, 28.1, 28.1, 21.0, 15.5, 14.2, 13.9;

HRMS (ESI) *m/z* calculated for $C_{17}H_{23}BrNaO_4^+$ ($[M+Na]^+$) 389.0964, found 389.0982.

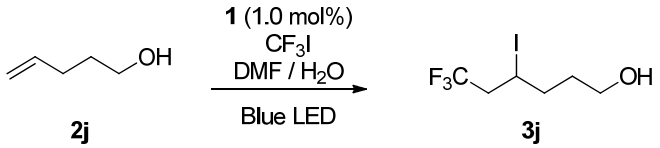
Crude ^1H NMR spectrum **2i**→**3i**:



General Procedure B: Photoredox Atom Transfer Radical Additions of CF_3I

A 15 mL pressure vessel was equipped with a rubber septum and magnetic stir bar and was charged with olefin (1.0 mmol, 1.0 equiv), DMF (0.20 mL), H_2O (0.80 mL), $Ir(dF(CF3)ppy)_2(dtbbpy)PF_6$ (0.01 mmol, 0.01 equiv) and degassed (3 x freeze/pump/thaw). The mixture was then cooled to -78 °C and CF_3I was condensed in. The vessel was then sealed and allowed to warm to room temperature while under irradiation by a 1 W blue LED strip. After 48 h, the mixture was cooled to -78 °C, the vessel was opened and the mixture was allowed to warm to room temperature. The mixture was then poured into a separatory funnel containing 25 mL of EtOAc and 25 mL of H_2O. The layers were separated and the aqueous layer was extracted with EtOAc (2 X 50 mL). The combined organic layers were dried (Na_2SO_4) and concentrated. The residue was purified by chromatography on silica gel, using the solvent system indicated, to afford the desired atom transfer product.

6,6,6-Trifluoro-4-iodohexan-1-ol, **3j** (*Table 2, entry 10*):



2j **3j**

According to General Procedure B **2j** (0.25 g, 2.9 mmol), CF_3I, and **1** (16 mg, 15 μmol) in DMF (1.2 mL) and H_2O (4.8 mL) afforded **3j** (0.74 g, 90%) as a colorless oil after purification by chromatography on SiO_2 (4:1, hexanes/EtOAc) (48 h reaction time).

R_f (EtOAc/hexane 1:4): 0.23;

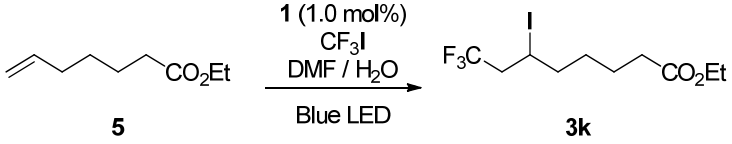
IR (neat): 3346, 2944, 1434, 1367, 1252, 1142, 1109, 1057, 1030 cm^{-1};

^1H NMR ($CDCl_3$, 500 MHz): δ 4.28 – 4.23 (m, 1 H), 3.73 (t, J = 6.5 Hz, 2 H), 3.00 – 2.90 (m, 1 H), 2.87 – 2.77 (m, 1 H), 1.95 – 1.81 (m, 3 H), 1.75 – 1.68 (m, 1 H), 1.38 (br. s, 1 H);

^{13}C NMR ($CDCl_3$, 100 MHz): δ 125.5 (q, $^1J_{C\text{-}F}$ = 277.3 Hz), 61.5, 44.8 (q, $^2J_{C\text{-}F}$ = 28.2 Hz), 36.1, 32.4, 21.3 (q, $^2J_{C\text{-}F}$ = 3.0 Hz);

LRMS (ESI) *m/z* (relative intensity): 337 (100%), 305 (5%), 277 (5%), 261 (37%), 258 (10%), 233 (11%), 130 (6%).

Ethyl 8,8,8-trifluoro-6-iodooctanoate, 3**k** (*Table 2, entry 11*):



5 **3k**

According to General Procedure B, **5** (0.15 g, 0.96 mmol), CF_3I, and **1** (11 mg, 9.6 μmol) in DMF (0.40 mL) and H_2O (1.6 mL) afforded **3k** (0.27 g, 81%) as a yellow oil after purification by chromatography on SiO_2 (19:1, hexanes/EtOAc) (48 h reaction time).

R_f (EtOAc/hexane 5:95): 0.32;

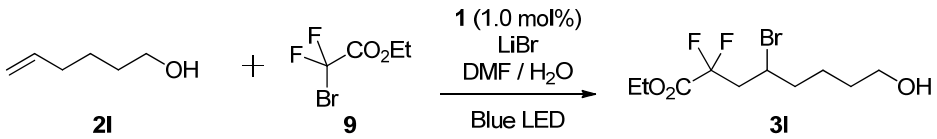
IR (neat): 2981, 2940, 1731, 1433, 1372, 1252, 1144, 1109, 1029 cm^{-1};

^1H NMR ($CDCl_3$, 500 MHz): δ 4.23 – 4.18 (m, 1 H), 4.15 (q, J = 7.0 Hz, 2 H), 2.98 – 2.87 (m, 1 H), 2.85 – 2.71 (m, 1 H), 2.35 (t, J = 7.0 Hz, 2 H), 1.88 – 1.57 (m, 5 H), 1.51 – 1.43 (m, 1 H), 1.29 (t, J = 7.0 Hz, 3 H);

^{13}C NMR ($CDCl_3$, 100 MHz): δ 173.2, 125.5 (q, $^1J_{C\text{-}F}$ = 277.4 Hz), 60.2, 44.8 (q, $^2J_{C\text{-}F}$ = 28.3 Hz), 39.2, 33.9, 28.9, 23.8, 21.0 (q, $^3J_{C\text{-}F}$ = 2.2 Hz), 14.2;

LRMS (ESI) *m/z* (relative intensity): 353 (100%), 344 (57%), 329 (42%), 301 (36%), 243 (29%), 197 (22%), 149 (33%).

Ethyl 4-bromo-2,2-difluoro-8-hydroxyoctanoate, **3l** (*Table 2, entry 12*):



2l **9** **3l**

According to General Procedure A, **2l** (0.15 g, 1.5 mmol), **9** (0.61 g, 3.0 mmol), LiBr (0.26 g, 3.0 mmol), and **1** (17 mg, 15 μmol) in DMF (0.70 mL) and H_2O (2.5 mL) afforded **3l** (0.42 g, 93%) as a colorless oil after purification by chromatography on SiO_2 (70:30, hexanes/EtOAc) (24 h reaction time).

R_f (EtOAc/hexane 30:70): 0.20;

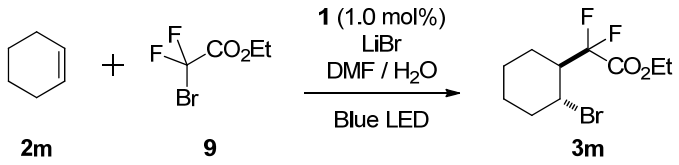
IR (neat): 3369, 2985, 2942, 2874, 1762, 1372, 1339, 1306, 1192, 1071, 851, 775 cm^{-1};

^1H NMR ($CDCl_3$, 500 MHz): δ 4.36 (q, J = 7.5 Hz, 2 H), 4.22 – 4.17 (m, 1 H), 3.69 (t, J = 6.0 Hz, 2 H), 2.90 – 2.79 (m, 1 H), 2.72 – 2.62 (m, 1 H), 1.98 – 1.88 (m, 2 H), 1.72 – 1.54 (m, 4 H), 1.40 (t, J = 7.5 Hz, 3 H);

^{13}C NMR ($CDCl_3$, 125 MHz): δ 163.5 (t, $^2J_{C\text{-}F}$ = 39.3 Hz), 114.7 (dd, $^1J_{C\text{-}F}$ = 251.8, 249.0 Hz) 63.2, 62.5, 46.0 (dd, $^3J_{C\text{-}F}$ = 6.0, 3.75 Hz), 43.5 (t, $^2J_{C\text{-}F}$ = 23.6, 22.6 Hz), 38.8, 31.6, 23.5, 13.8;

LRMS (ESI) *m/z* (relative intensity): 425 (100%), 403 (29%), 329 (22%), 305 (10%), 303 (10%), 287 (34%), 285 (34%), 205 (43%), 177 (13%).

Ethyl 2-(2-bromocyclohexyl)-2,2-difluoroacetate[1], **3m** (*Table 2, entry 13*):



2m **9** **3m**

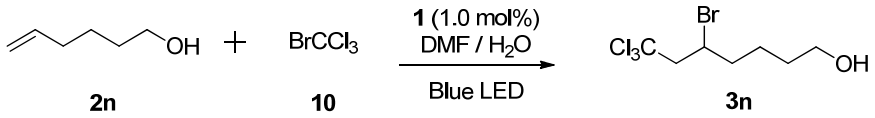
According to General Procedure A, **2m** (0.15 g, 1.8 mmol), **9** (0.74 g, 3.6 mmol), LiBr (0.32 g, 3.6 mmol), and **1** (20 mg, 18 μmol) in DMF (0.40 mL) and H_2O (1.6 mL) afforded **3m** (0.39 g, 75%) as a colorless oil after purification by chromatography on SiO_2 (99:1, petroleum ether/Et_2O) (24 h reaction time).

R_f (Et_2O/Petroleum Ether 2:98): 0.35;

^{1}H NMR ($CDCl_3$, 300 MHz): δ 4.34 (q, J = 7.0 Hz, 2 H), 4.07 (ddd, J = 9.9, 9.9, 3.9 Hz, 1 H), 2.79 – 2.63 (m, 1 H), 2.39 – 2.34 (m, 1 H), 2.16 – 2.11 (m, 1 H), 1.95 – 1.72 (m, 4 H) 1.37 (t, J = 7.0 Hz, 3 H).

[1] Leung, L.; Linclau, B. *J. Fluorine Chem.* **2008**, *129*, 986.

5-Bromo-7,7,7-trichloroheptan-1-ol, **3n** (*Table 2, entry 14*):



2n **10** **3n**

According to General Procedure A, **3n** (0.20 g, 2.0 mmol), **10** (0.79 g, 4.0 mmol), and **1** (22 mg, 20 μmol) in DMF (0.82 mL) and H_2O (3.3 mL) afforded **3n** (0.51 g, 87%) as a colorless oil after purification by chromatography on SiO_2 (70:30, hexanes/EtOAc) (17 h reaction time).

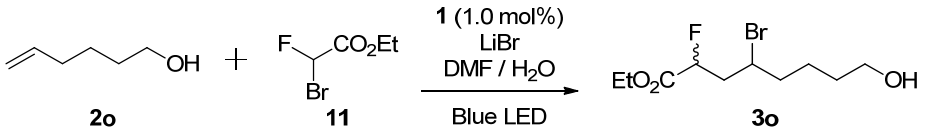
R_f (EtOAc/hexane 30:70): 0.32;

IR (neat): 3344, 2939, 2865, 1457, 1423, 1188, 1053, 785, 699 cm^{-1};

^1H NMR ($CDCl_3$, 500 MHz): δ 4.38 – 4.33 (m, 1 H), 3.70 (t, J = 6.0 Hz, 2 H), 3.48 (dd, J = 15.5, 5.0 Hz, 1 H), 3.25 (dd, J = 15.5, 5.5 Hz, 1 H), 2.14 – 2.07 (m, 1 H), 2.04 – 1.97 (m, 1 H), 1.76 – 1.59 (m, 4 H), 1.36 (br. s, 1 H);

^{13}C NMR ($CDCl_3$, 125 MHz): δ 97.1, 62.5, 62.5, 48.9, 39.2, 31.7, 23.6.

Ethyl 4-bromo-2-fluoro-8-hydroxyoctanoate, **3o** (*Table 2, entry 14*):



2o **11** **3o**

According to General Procedure A, **2o** (0.15 g, 1.5 mmol), **11** (0.55 g, 3.0 mmol), LiBr (0.26 g, 3.0 mmol), and **1** (17 mg, 15 μmol) in DMF (0.70 mL) and H_2O (2.5 mL) afforded **3o** (0.42 g, 99%) as a colorless oil and an inseparable mixture of diastereoisomers after purification by chromatography on SiO_2 (13:7, hexanes/EtOAc) (24 h reaction time).

R_f (EtOAc/hexane 30:70): 0.13;

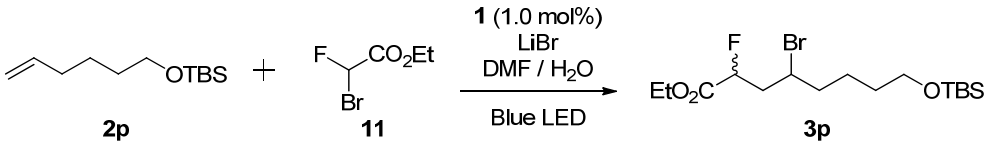
IR (neat): 3368, 2939, 1752, 1457, 1372, 1214, 1100, 1026, 909, 729 cm^{-1};

^1H NMR ($CDCl_3$, 500 MHz): δ 5.30 – 5.07 (m, 1 H), 4.31 – 4.26 (m, 2 H), 4.24 – 4.18 (m, 1 H), 3.69 (t, J = 6.0 Hz, 2 H), 2.56 – 2.44 (m, 1 H), 2.39 – 2.25 (m, 1 H), 1.98 – 1.88 (m, 2 H), 1.73 – 1.52 (m, 4 H), 1.37 – 1.33 (m, 4 H);

^{13}C NMR ($CDCl_3$, 100 MHz): δ 169.2 (d, $^2J_{C\text{-}F}$ = 23.0 Hz), 168.9 (d, $^2J_{C\text{-}F}$ = 23.0 Hz), 87.0 (d, $^1J_{C\text{-}F}$ = 183.7 Hz), 86.7 (d, $^1J_{C\text{-}F}$ = 183.7 Hz), 61.9, 61.6, 51.6, 51.6, 50.6, 50.5, 41.35 (d, $^2J_{C\text{-}F}$ = 20.1 Hz), 41.0 (d, $^2J_{C\text{-}F}$ = 21.6 Hz), 38.7, 37.8, 31.5, 31.5, 23.5, 23.4, 13.8, 13.8;

HRMS (ESI) *m/z* calculated for $C_{10}H_{19}BrFO_3^+$ ($[M+1]^+$) 285.0502, found 285.0497.

Ethyl 4-bromo-8-((tert-butyldimethylsilyl)oxy)-2-fluorooctanoate, **3p** (*Table 2, entry 16*):



2p **11** **3p**

According to General Procedure A, **2p** (0.31 g, 1.4 mmol), **11** (0.53 g, 2.9 mmol), LiBr (0.25 g, 2.9 mmol), and **1** (16 mg, 14 μmol) in DMF (0.80 mL) and H_2O (2.6 mL) afforded **3p** (480 mg, 84%) as a colorless oil and an inseparable mixture of diastereoisomers after purification by chromatography on SiO_2 (93:7, hexanes/EtOAc) (24 h reaction time).

R_f (EtOAc/hexane 5:95): 0.33;

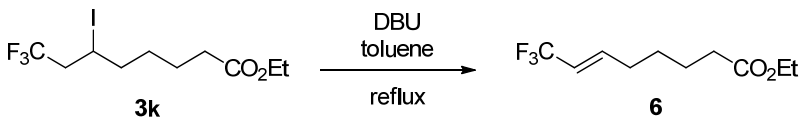
IR (neat): 2953, 2930, 1857, 1763, 1742, 1471, 1254, 1097, 835, 775, 733 cm^{-1};

^1H NMR ($CDCl_3$, 500 MHz): δ 5.30 – 5.07 (m, 1 H), 4.31 – 4.26 (m, 2 H), 4.24 – 4.17 (m, 1 H), 3.64 (t, J = 6.0 Hz, 2 H), 2.53 – 2.44 (m, 1 H), 2.38 – 2.26 (m, 1 H), 1.95 – 1.88 (m, 2 H), 1.68 – 1.49 (m, 4 H), 1.37 – 1.33 (m, 3 H), 0.92 (s, 9 H), 0.08 (s, 6 H);

^{13}C NMR ($CDCl_3$, 100 MHz): δ 169.1 (d, $^2J_{C\text{-}F}$ = 23.1 Hz), 168.8 (d, $^2J_{C\text{-}F}$ = 23.8 Hz), 87.1 (d, $^1J_{C\text{-}F}$ = 183.7 Hz), 86.8 (d, $^1J_{C\text{-}F}$ = 183.7 Hz), 62.5, 61.5, 61.4, 51.6, 51.6, 50.6, 50.5, 41.6 (d, $^2J_{C\text{-}F}$ = 20.9 Hz), 41.2 (d, $^2J_{C\text{-}F}$ = 21.6 Hz), 38.9, 38.0, 31.8, 31.8, 25.8, 23.7, 23.6, 18.1, 13.9, 13.9, -5.5;

HRMS (ESI) *m/z* calculated for $C_{10}H_{33}BrFO_3Si^+$ ($[M+1]^+$) 399.1366, found 399.1367.

Ethyl 8,8,8-trifluorooct-6-enoate, **6**:



3k **6**

A flame dried 10 mL round bottom flask, equipped with a magnetic stir bar and fitted with a reflux condenser, was charged with **3k** (81 mg, 0.23 mmol), dry toluene (2.5 mL) and DBU (0.10 g, 0.46 mmol) and heated to reflux. Upon completion, the mixture was cooled to room temperature and poured into a separatory funnel containing 25 mL of Et_2O and 25 mL of H_2O. The layers were separated and the aqueous layer was extracted with Et_2O (2 x 30 mL). The combined organic layers were dried (Na_2SO_4) and concentrated. The residue was purified by chromatography on silica gel (95:5, hexanes/EtOAc) to afford **6** (48 mg, 94%) as a colorless oil along with a small amount of (*E*) isomer (2 h reaction time).

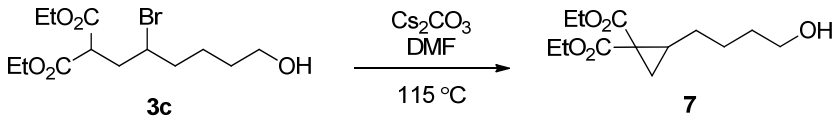
R_f (EtOAc/hexane 5:95): 0.35;

IR (neat): 2934, 2865, 1735, 1274, 1173, 1119, 1088, 974 cm^{-1};

^1H NMR ($CDCl_3$, 400 MHz): δ 6.40 – 6.32 (m, 1 H), 5.66 – 5.57 (m, 1 H), 4.13 (q, J = 7.0 Hz, 2 H), 2.31 (t, J = 8.0 Hz, 2 H), 2.19 – 2.15 (m, 2 H), 1.69 – 1.62 (m, 2 H), 1.52 – 1.44 (m, 2 H), 1.26 (t, J = 7.0 Hz, 3 H);

^{13}C NMR ($CDCl_3$, 75 MHz): δ 173.3, 140.1 (q, $^3J_{C\text{-}F}$ = 6.6 Hz) 123.0 (q, $^1J_{C\text{-}F}$ = 265.7 Hz), 118.7, (q, $^2J_{C\text{-}F}$ = 32.9 Hz), 60.0, 33.6, 30.8, 27.1, 24.1, 13.8.

Diethyl 2-(4-hydroxybutyl)cyclopropane-1,1-dicarboxylate, **7**:



A flame dried 25 mL round bottom flask, equipped with a magnetic stir bar and fitted with a reflux condenser, was charged with **3c** (0.21 g, 0.62 mmol), dry DMF (6.0 mL) and Cs_2CO_3 (0.22 g, 0.68 mmol) and heated to 115 °C. The mixture was poured into a separatory funnel containing 25 mL of Et_2O and 25 mL of H_2O. The layers were separated and the aqueous layer was extracted with Et_2O (2 x 30 mL). The combined organic layers were dried (Na_2SO_4) and concentrated. The residue was purified by chromatography on silica gel (13:7, hexanes/EtOAc) to afford **7** (0.15 g, 94%) as a colorless oil (24 h reaction time).

R_f (EtOAc/hexane 30:70): 0.21;

IR (neat): 3435, 2982, 2937, 2865, 1720, 1446, 1393, 1281, 1204, 1131, 1024, 861 cm^{-1};

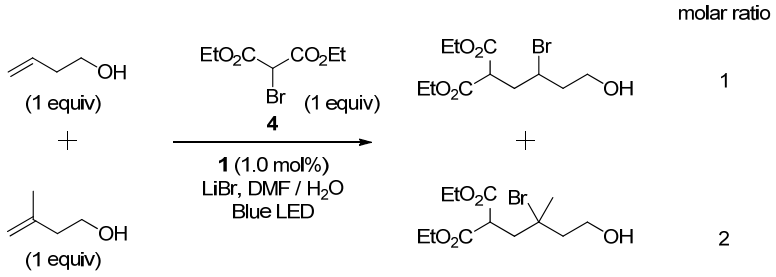
^1H NMR ($CDCl_3$, 500 MHz): δ 4.30 – 4.20 (m, 4 H), 3.64 (t, J = 6.0 Hz, 2 H), 1.94 – 1.88 (m, 1 H), 1.67 – 1.50 (m, 6 H), 1.42 – 1.35 (m, 3 H), 1.33 – 1.26 (m, 7 H);

^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.4, 168.2, 62.3, 61.2, 61.2, 34.0, 32.1, 28.3, 28.0, 24.9, 20.8, 14.0, 13.9;

HRMS (ESI) *m/z* calculated for $C_{13}H_{23}BrO_5^+$ ($[M+1]^+$) 259.1545, found 259.1556.

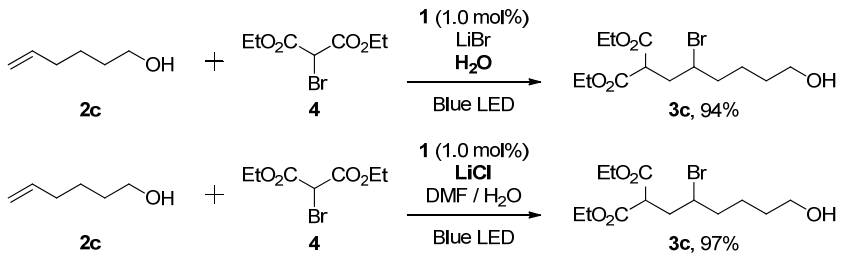
Mechanistic Experiments:

Relative Rates of Substituted Olefins:



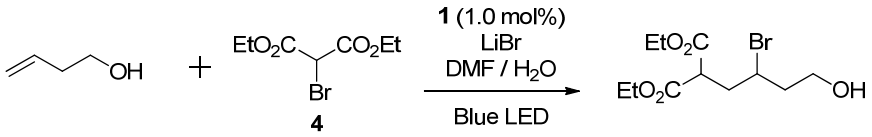
In order to compare the relative reactivity of terminal olefins and their analogous 1,1-disubstituted olefins, 1 equivalent of 3-buten-1-ol and 1 equivalent of 3-methyl-3-buten-1-ol were subjected to the optimized atom transfer conditions with only 1 equivalent of **4**. Upon consumption of **4,** as judged by TLC analysis, it was found that the atom transfer products from 3-methyl-3-buten-1-ol and 3-buten-1-ol were generated in a 2:1 molar ratio (^{1}H NMR analysis), respectively. This observation indicates that the 1,1-disubstituted olefin is more reactive than the terminal olefin due to the more nucleophilic π-bond. However, despite the observed clean conversion of 3-methyl-3-buten-1-ol to the atom transfer product by ^{1}H NMR analysis of the crude reaction mixture, the tertiary bromide is not stable to chromatography, affording a mixture of elimination products. Characterization data of the atom transfer product of 3-buten-1-ol with **4** can be found on the next page.

Selectivity of Carbocation Trapping:



Attempts of using external nucleophiles to trap the carbocation intermediate, including water and chloride, were unsuccessful and only gave the bromohydrin. Furthermore, when LiCl is used as an additive, it is unlikely that a chlorohydrin is initially formed and converted to **3c** via nucleophilic displacement by bromide. Close monitoring of the reaction progress by ^{1}H NMR analysis showed no intermediacy of a chlorohydrin in the reaction.

Diethyl 2-(2-bromo-4-hydroxybutyl)malonate:



A 25 mL round bottom flask was equipped with a rubber septum and magnetic stir bar and was charged with 3-buten-1-ol (72 mg, 1.0 mmol), 3-methyl-3-buten-1-ol (86 mg, 1.0 mmol), **4** (240 mg, 1.0 mmol), LiBr (87 mg, 1.0 mmol), DMF (0.40 mL), H_2O (1.60 mL), and $Ir(dF(CF_3)ppy)_2(dtbbpy)PF_6$, **1**, (11 mg, 0.01 equiv). The flask was evacuated and backfilled with argon. The heterogeneous mixture was then irradiated by a 1 W blue LED strip under an atmosphere of Ar. The mixture was poured into a separatory funnel containing 25 mL of Et_2O and 25 mL of H_2O. The layers were separated and the aqueous layer was extracted with Et_2O (2 x 30 mL). The combined organic layers were dried (Na_2SO_4) and concentrated. The residue was purified by chromatography on silica gel (5:1, hexanes/EtOAc) to afford diethyl 2-(2-bromo-4-hydroxybutyl)malonate (87 mg, 28%) as a colorless oil (12 h reaction time).

R_f (EtOAc/hexane 1:3): 0.21;

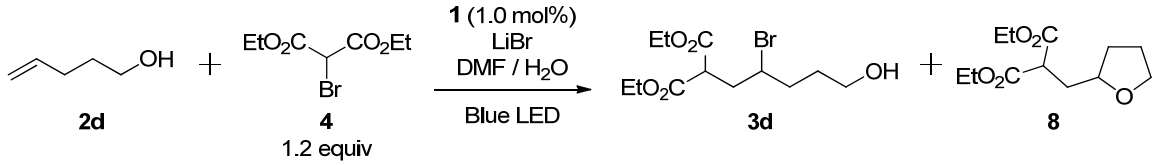
IR (neat): 3433, 2982, 1728, 1445, 1269, 1263, 1150, 1094, 1028, 858 cm^{-1};

^1H NMR ($CDCl_3$, 400 MHz): δ 4.28 – 4.17 (m, 5 H), 3.88 – 3.83 (m, 2 H), 3.80 (dd, J = 10.0, 4.4 Hz, 1 H), 2.52 (ddd, J = 14.8, 10.4, 3.6 Hz, 1 H), 2.31 (ddd, J = 14.8, 10.4, 4.0 Hz, 1 H), 2.17 – 2.02 (m, 2 H), 1.52 (t, J = 6.0 Hz, 1 H), 1.29 (t, J = 6.8 Hz, 3 H), 1.28 (t, J = 6.8 Hz, 3 H);

^{13}C NMR ($CDCl_3$, 100 MHz): δ 168.8, 168.7, 61.6, 61.6, 60.1, 51.0, 50.4, 41.6, 37.8, 13.9, 13.9;

HRMS (ESI) *m/z* calculated for $C_{11}H_{19}BrO_5^+$ ($[M+1]^+$) 311.0494, found 311.0492.

Isolation of THF byproduct, 8:
Diethyl 2-((tetrahydrofuran-2-yl)methyl)malonate, **8**[2] (*eq 1*):



2d **4** 1.2 equiv **3d** **8**

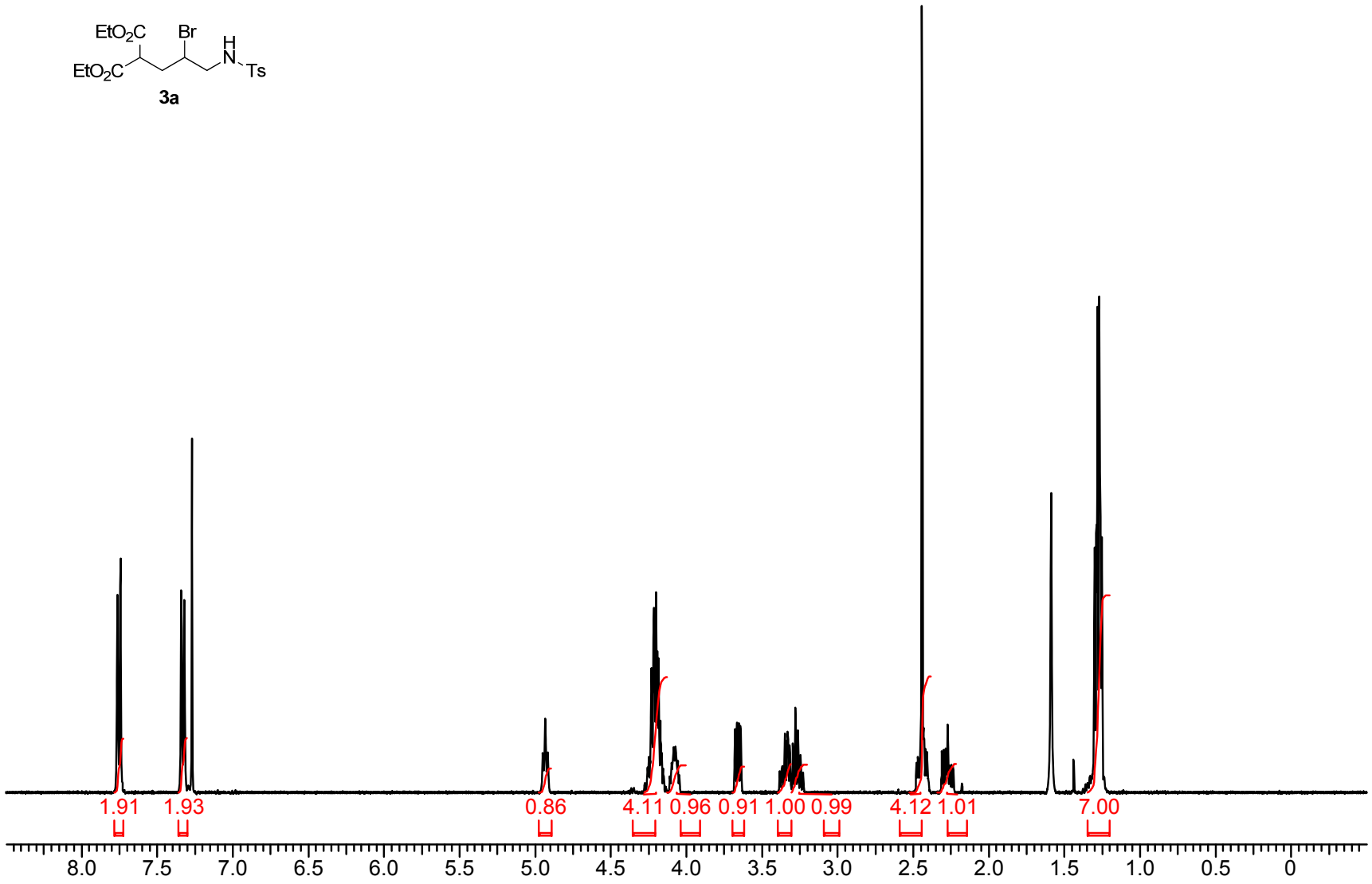
A 10 mL round bottom flask was equipped with a rubber septum and magnetic stir bar and was charged with **2d** (100 mg, 1.2 mmol), **4** (330 mg, 1.4 mmol), LiBr (200 mg, 2.3 mmol), DMF (0.40 mL), H_2O (1.60 mL), and $Ir(dF(CF_3)ppy)_2(dtbbpy)PF_6$, **1**, (13 mg, 1.2 μmol). The flask was evacuated and backfilled with argon. The heterogeneous mixture was then irradiated by a 1 W blue LED strip under an atmosphere of Ar. The mixture was poured into a separatory funnel containing 25 mL of Et_2O and 25 mL of H_2O. The layers were separated and the aqueous layer was extracted with Et_2O (2 x 30 mL). The combined organic layers were dried (Na_2SO_4) and concentrated. The residue was purified by chromatography on silica gel (4:1, hexanes/EtOAc) to afford **3d** (280 mg, 73%) as a colorless oil and **8** (29 mg, 10%) as a colorless oil (12 h reaction time).

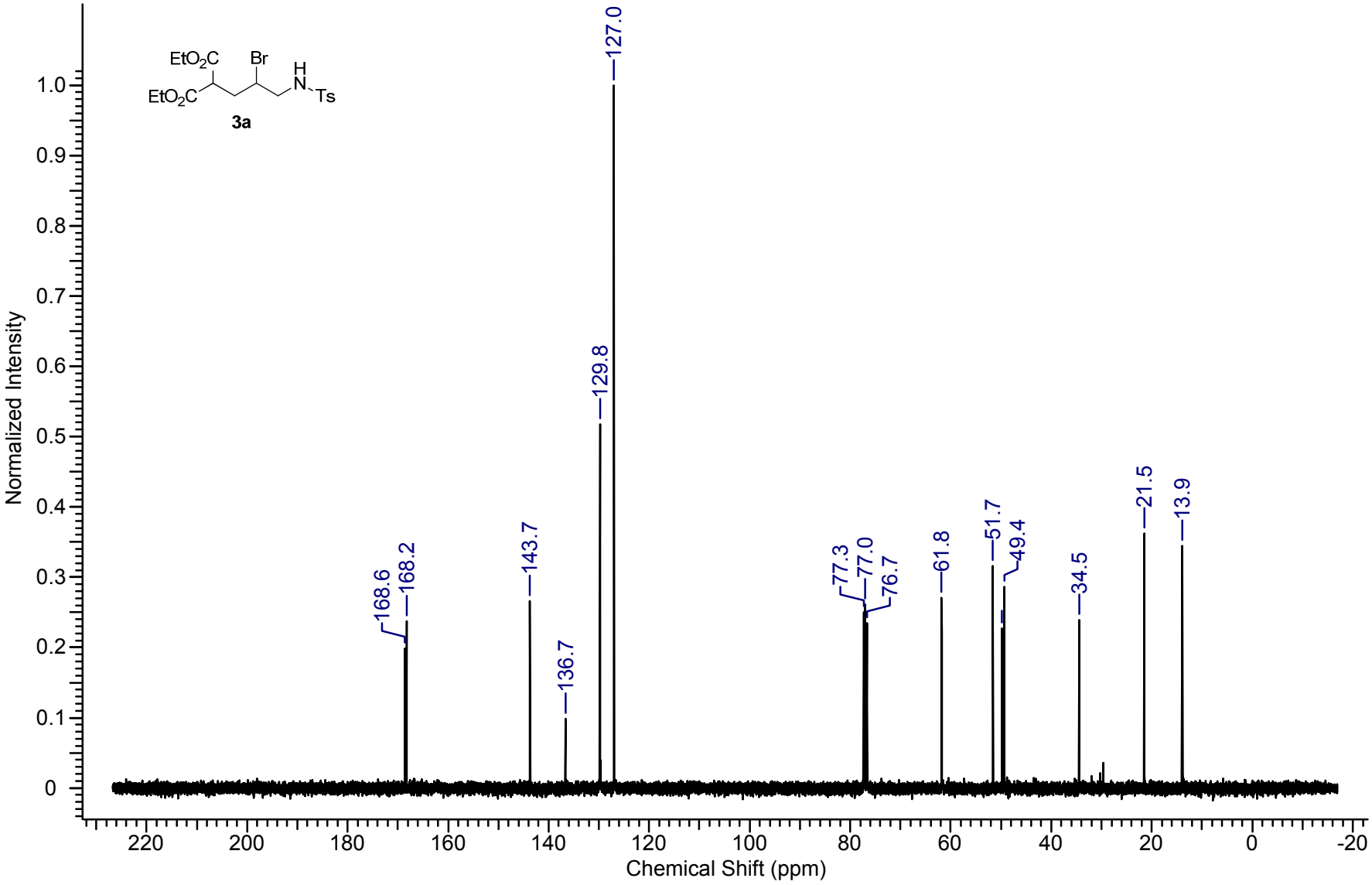
R_f (EtOAc/hexane 30:70): 0.34;

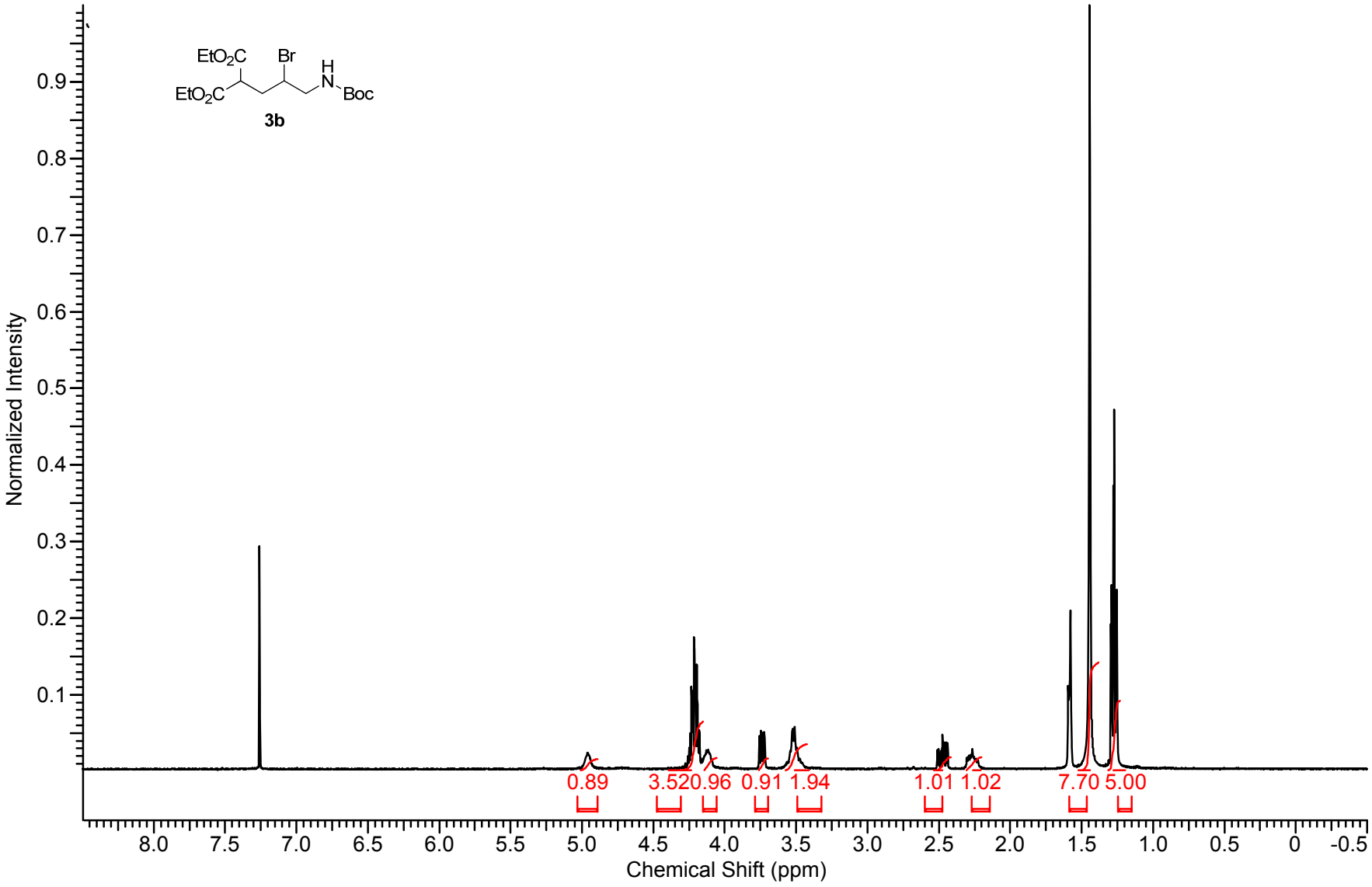
^{1}H NMR ($CDCl_3$, 300 MHz): δ 4.23 - 4.15 (m, 4 H), 3.90 – 3.85 (m, 1 H), 3.80 (t, J = 7.5 Hz, 1 H), 3.74 – 3.66 (m, 1 H), 3.56 (dd, J = 8.7, 6.0 Hz, 1 H), 2.11 (dd, J = 9.3, 4.8 Hz, 1 H), 2.07 – 1.96 (m, 2 H), 1.91 – 1.82 (m, 2 H), 1.56 – 1.45 (m, 1 H), 1.29 – 1.23 (m, 6 H);

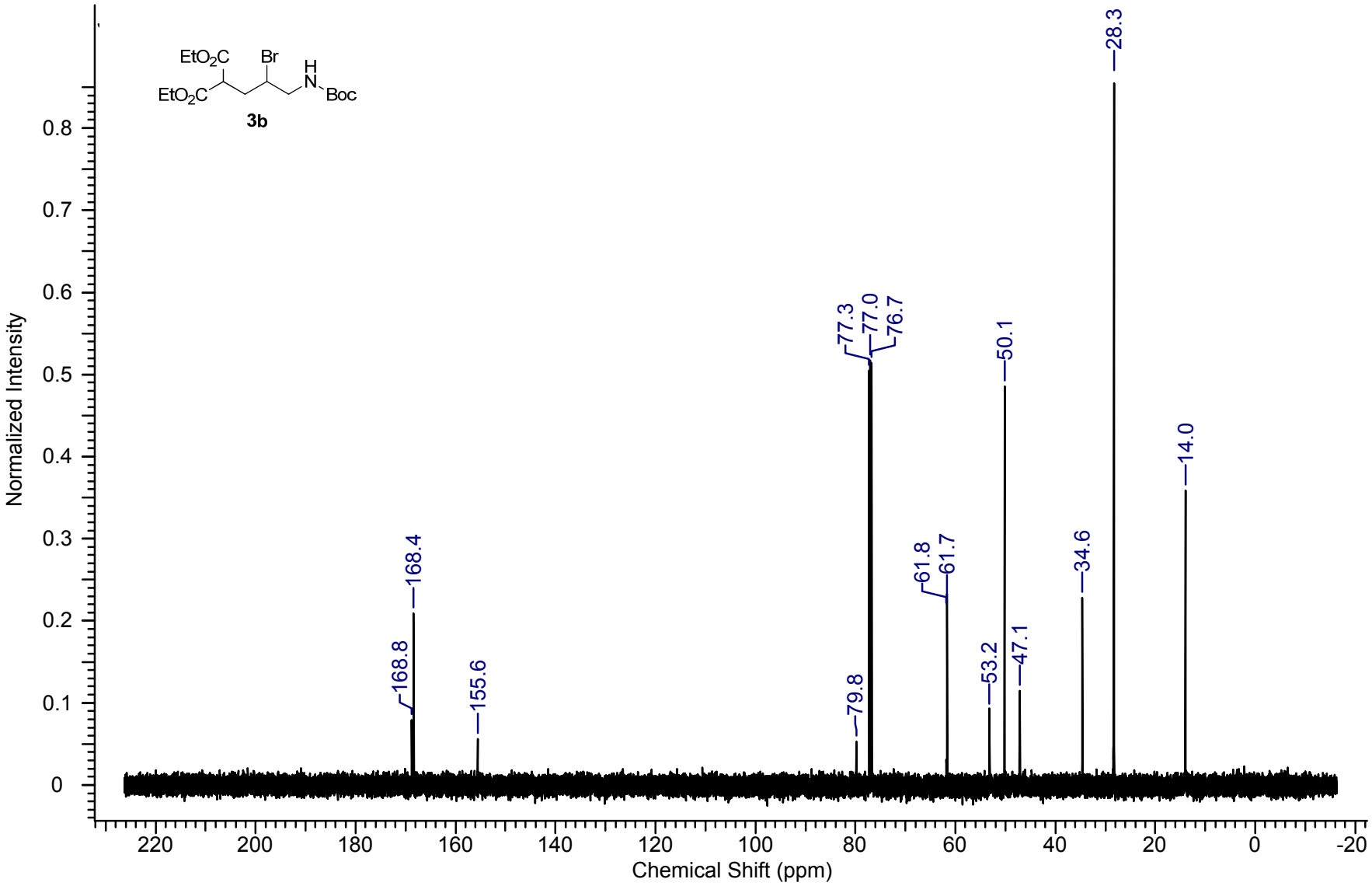
^{13}C NMR ($CDCl_3$, 75 MHz): δ 169.5, 169.3, 76.4, 67.6, 61.2, 49.3, 34.5, 31.3, 25.5, 13.9, 13.9.

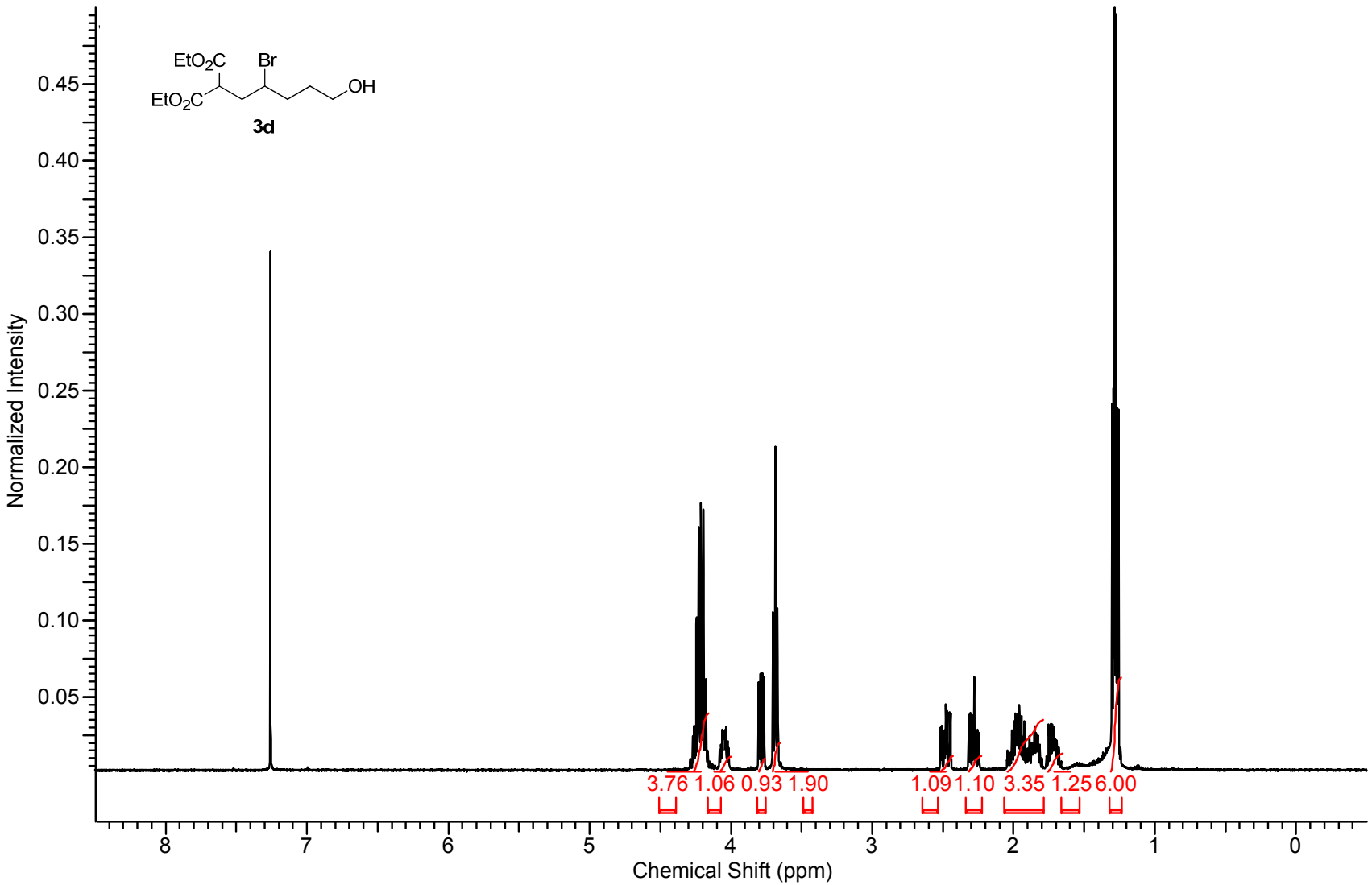
[2] Tetrahydrofuran side product, **8**, was confirmed by ^{1}H and ^{13}C NMR, see: Pastine, S.J.; McQuaid, K.M.; Sames, D. *J. Am. Chem. Soc.* **2005**, *127*, 12180.

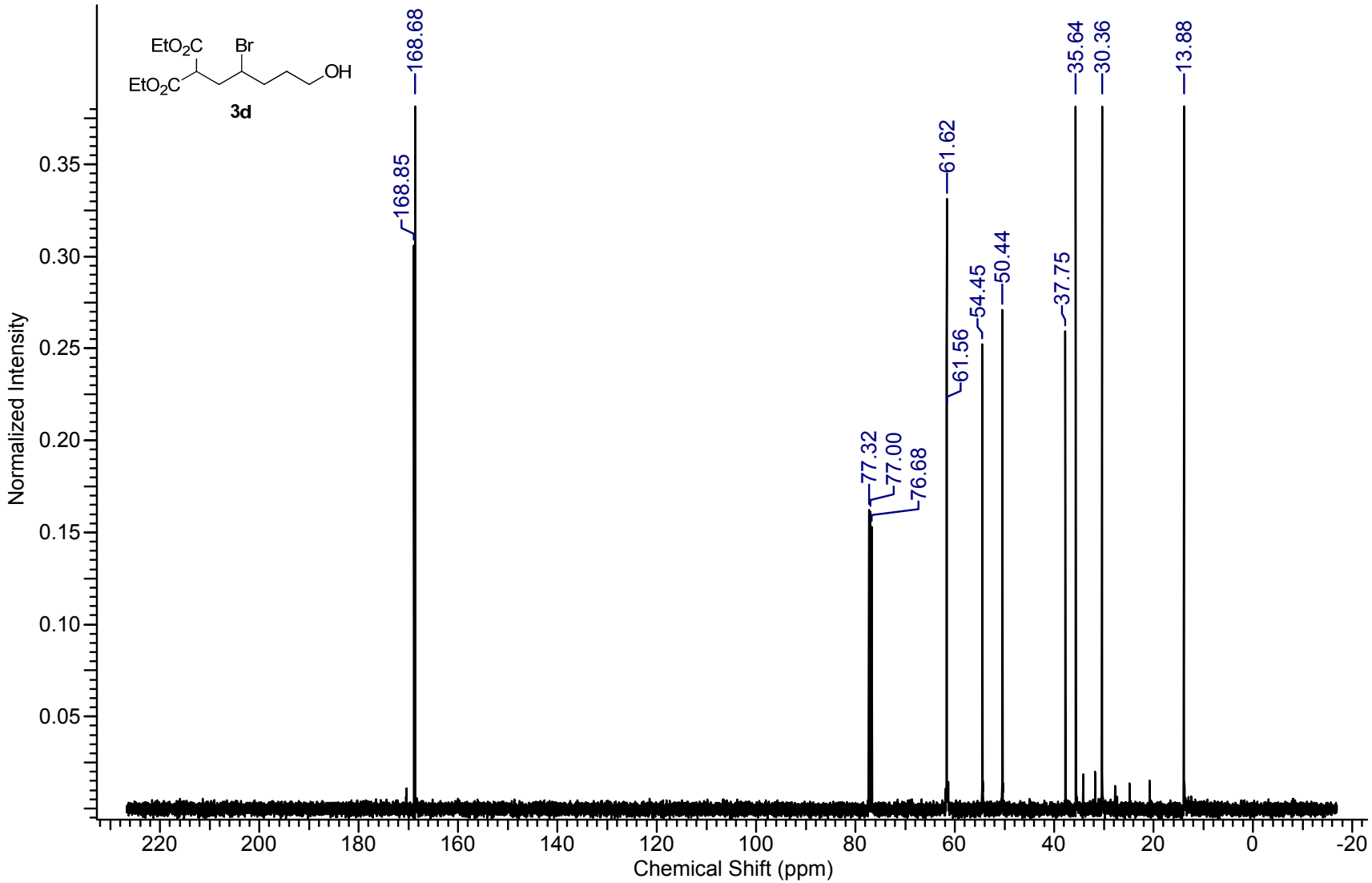

EtO2C
Br
H
N
Ts
EtO2C
3a
1.91
1.93
0.86
4.11
0.96
0.91
1.00
0.99
4.12
1.01
7.00
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0

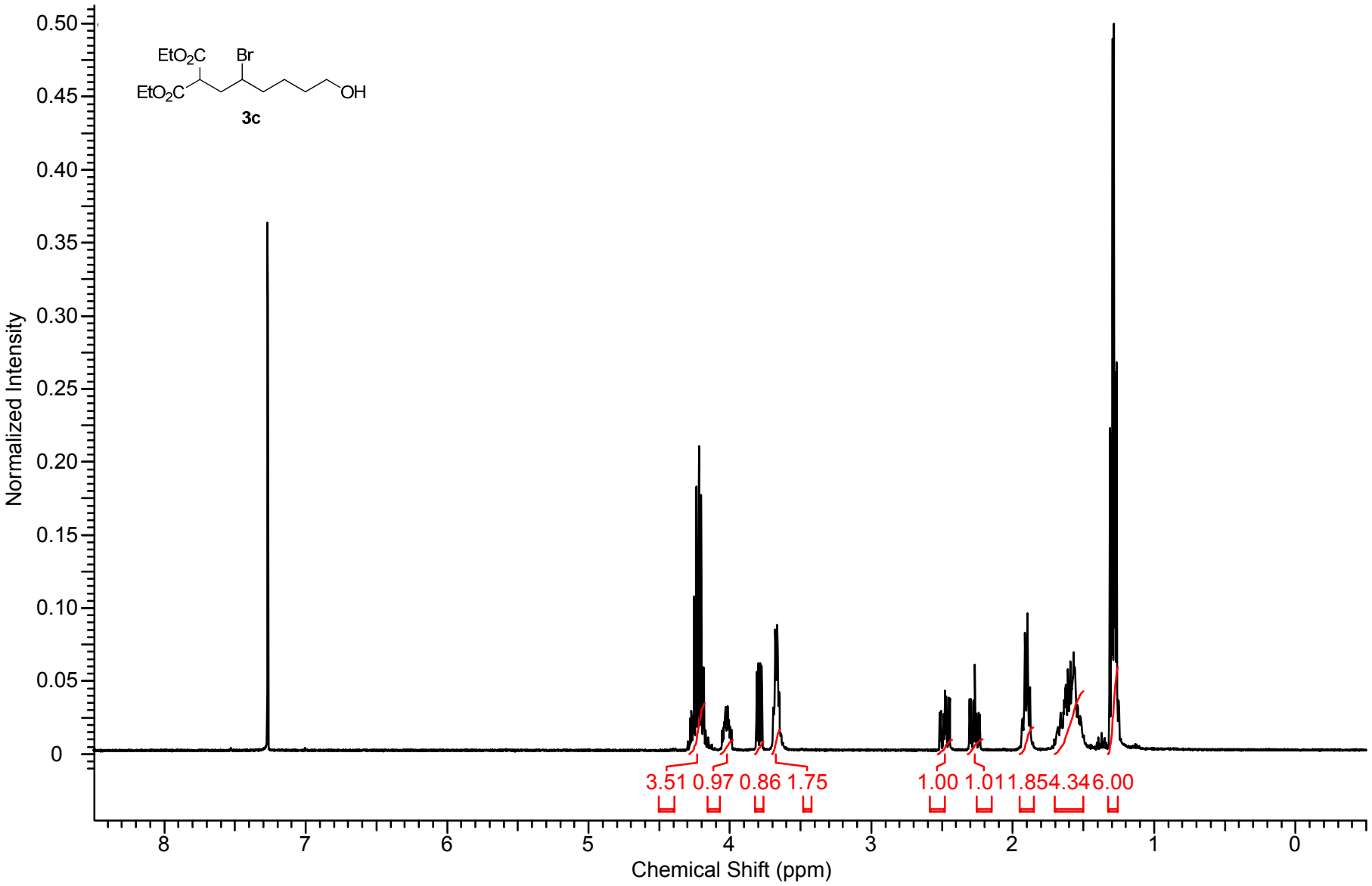

EtO2C
Br
H
N
Ts
EtO2C
3a
Normalized Intensity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
168.6
168.2
143.7
136.7
129.8
127.0
77.3
77.0
76.7
61.8
51.7
49.4
34.5
21.5
13.9
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)

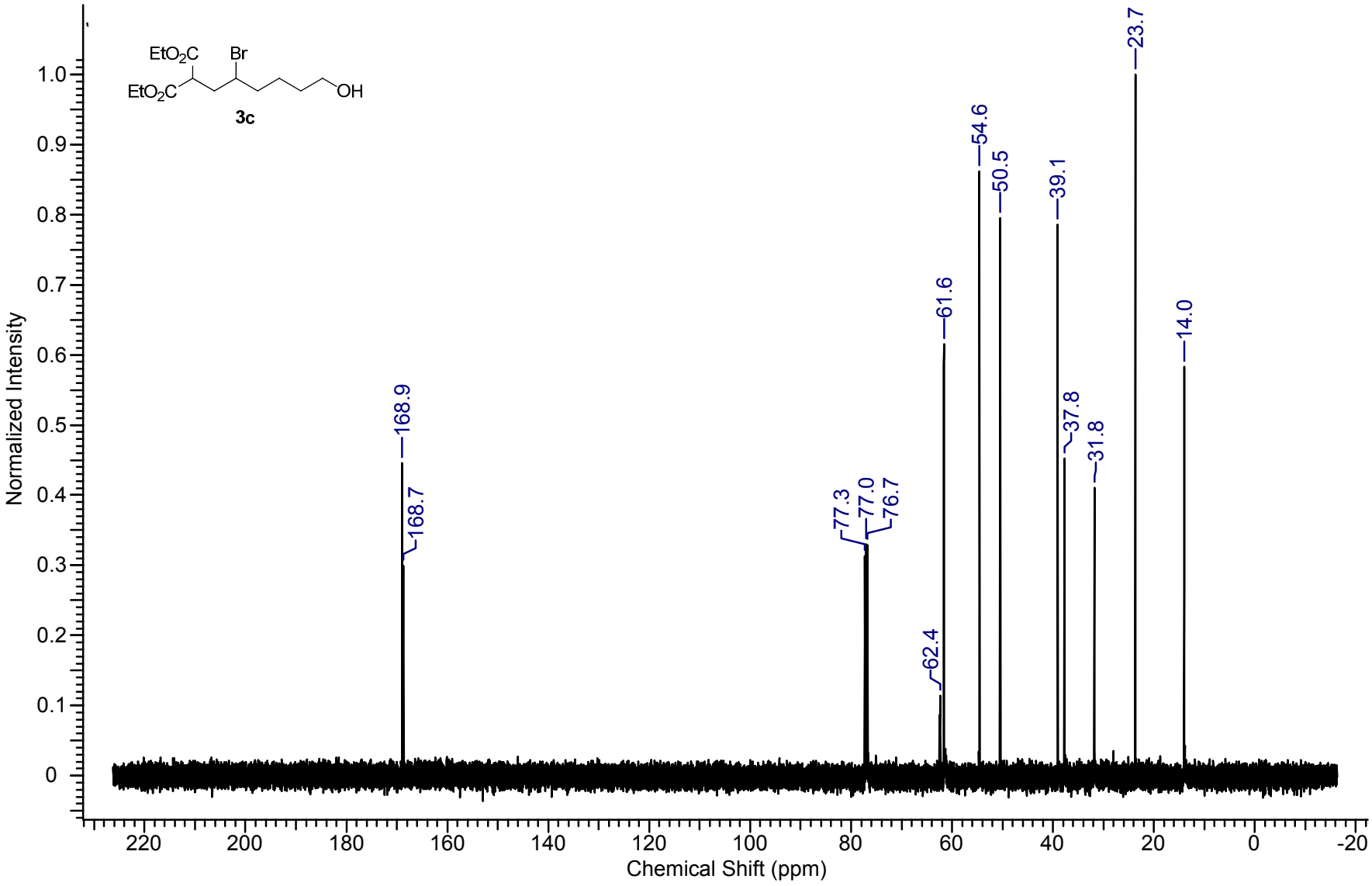

EtO2C
Br
H
N
Boc
EtO2C
3b
Normalized Intensity
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.89
3.52
0.96
0.91
1.94
1.01
1.02
7.70
5.00
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
-0.5
Chemical Shift (ppm)

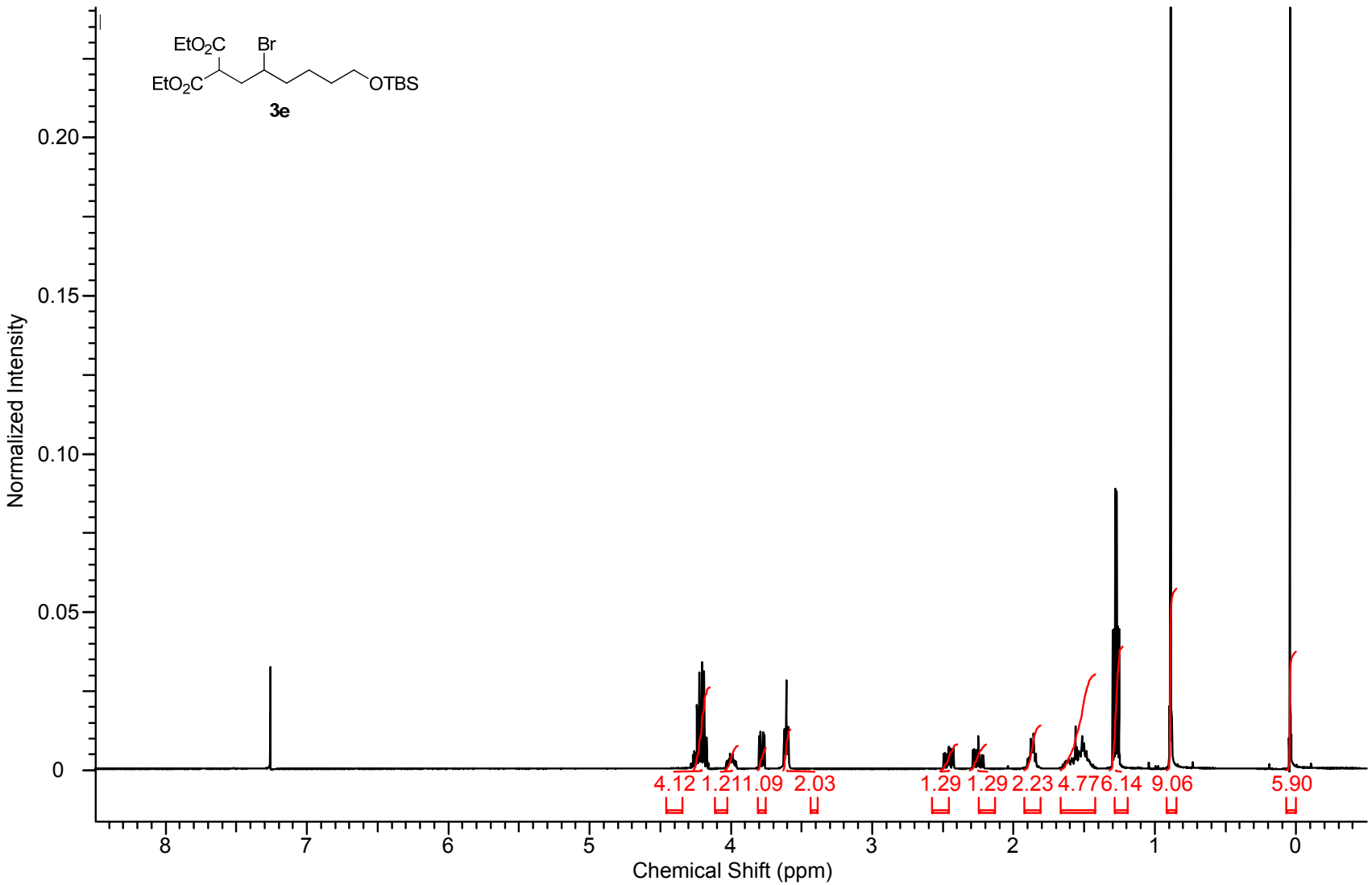

EtO2C
Br
H
N
Boc
EtO2C
3b
Normalized Intensity
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)
168.8
168.4
155.6
79.8
77.3
77.0
76.7
61.8
61.7
53.2
50.1
47.1
34.6
28.3
14.0

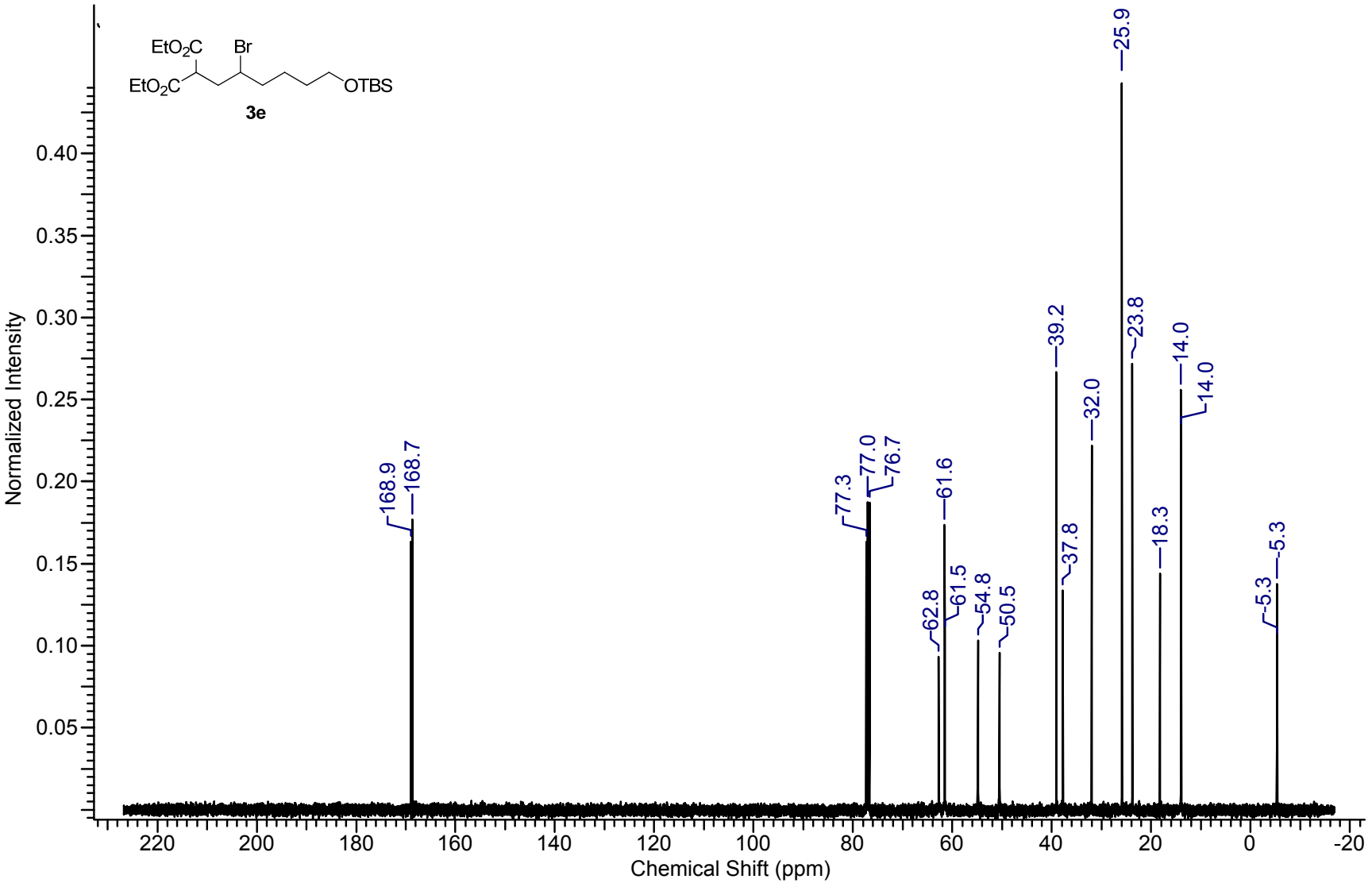

EtO2C
Br
EtO2C
OH
3d
Normalized Intensity
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
3.76
1.06
0.93
1.90
1.09
1.10
3.35
1.25
6.00
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

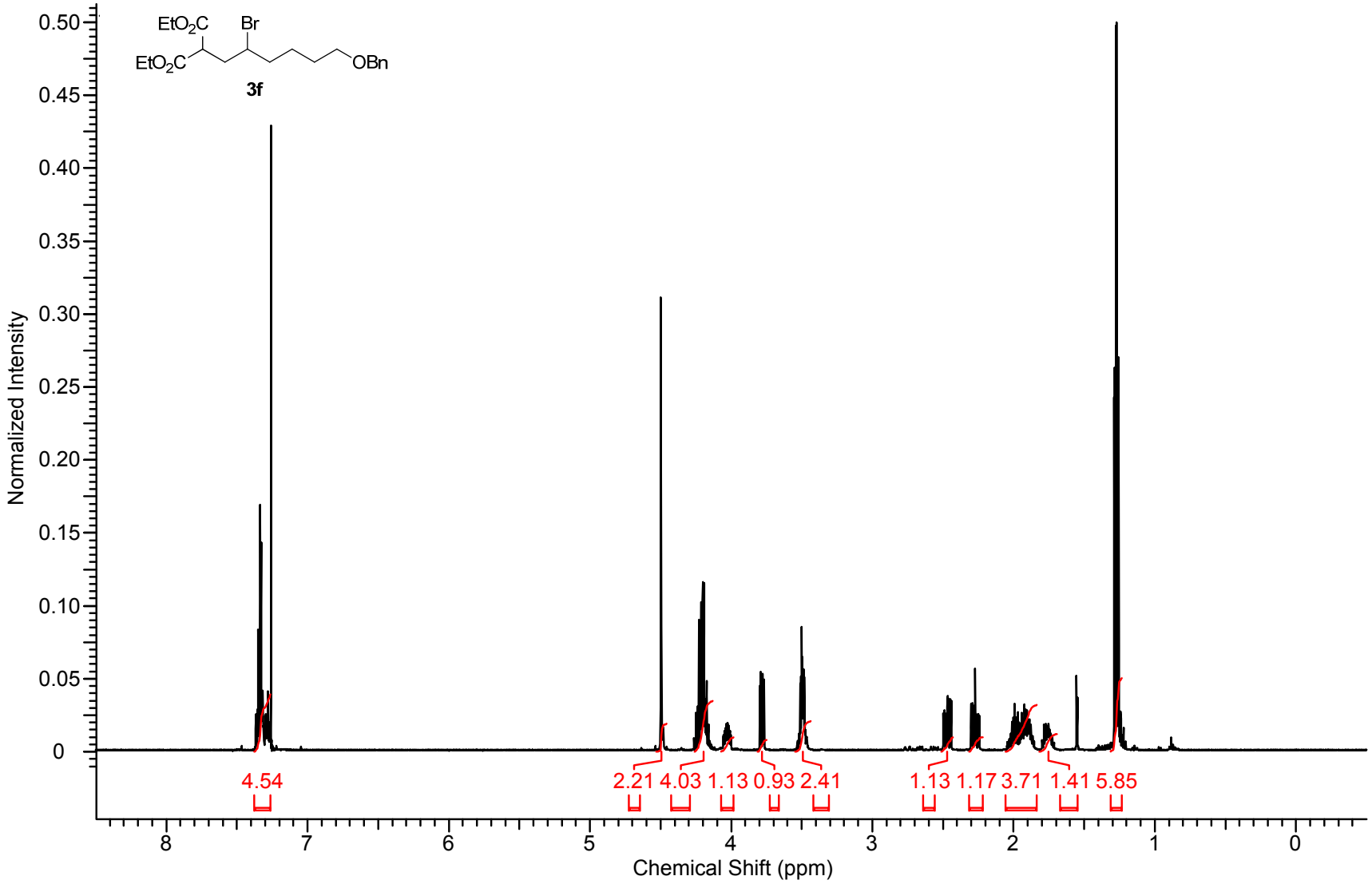

EtO2C
Br
EtO2C
OH
3d
168.68
168.85
61.62
61.56
54.45
50.44
37.75
35.64
30.36
13.88
77.32
77.00
76.68
Normalized Intensity
0.35
0.30
0.25
0.20
0.15
0.10
0.05
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)

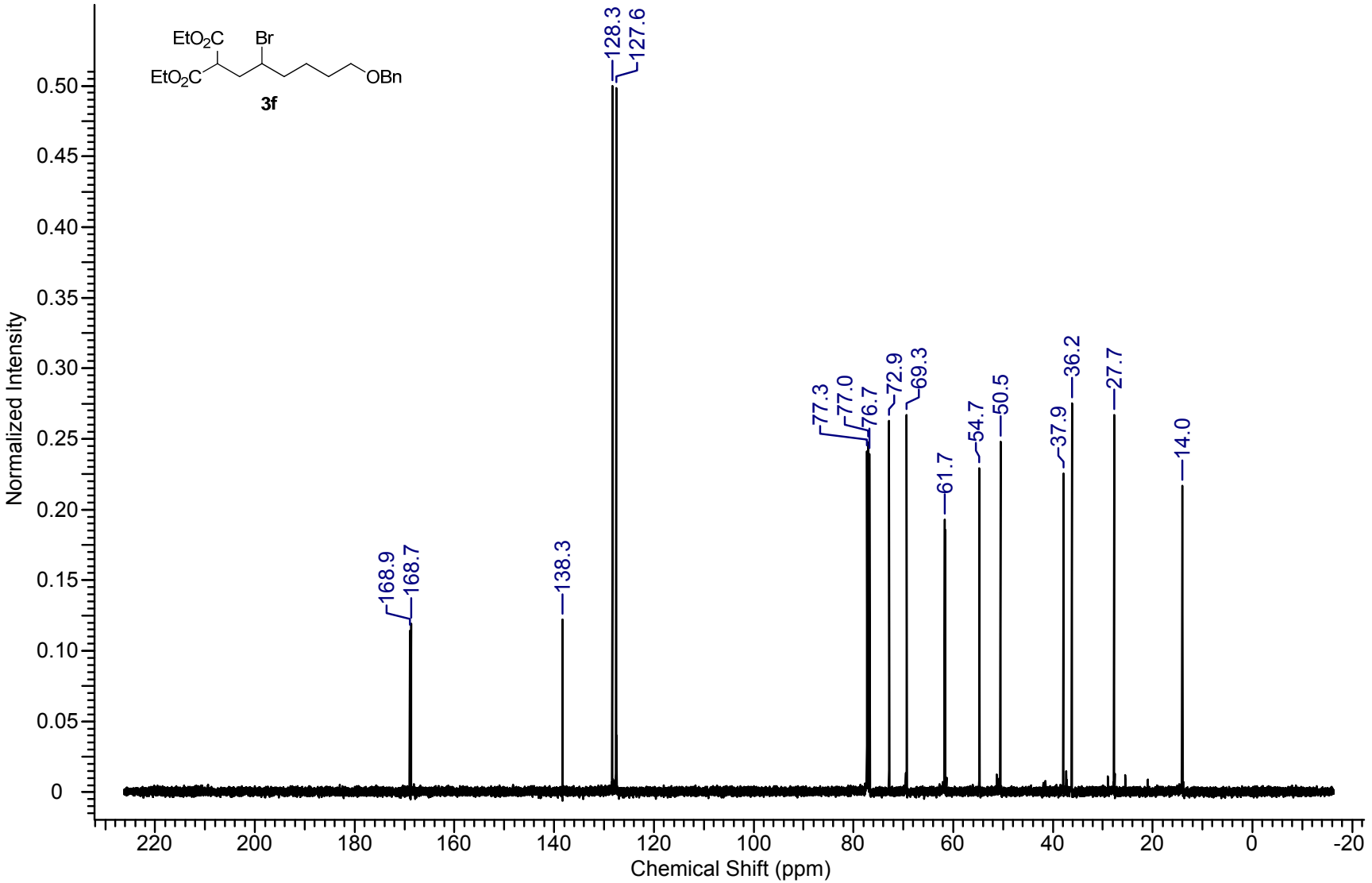

EtO2C
Br
EtO2C
OH
3c
Normalized Intensity
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)
3.51 0.97 0.86 1.75
1.00 1.01 1.85 4.34 6.00

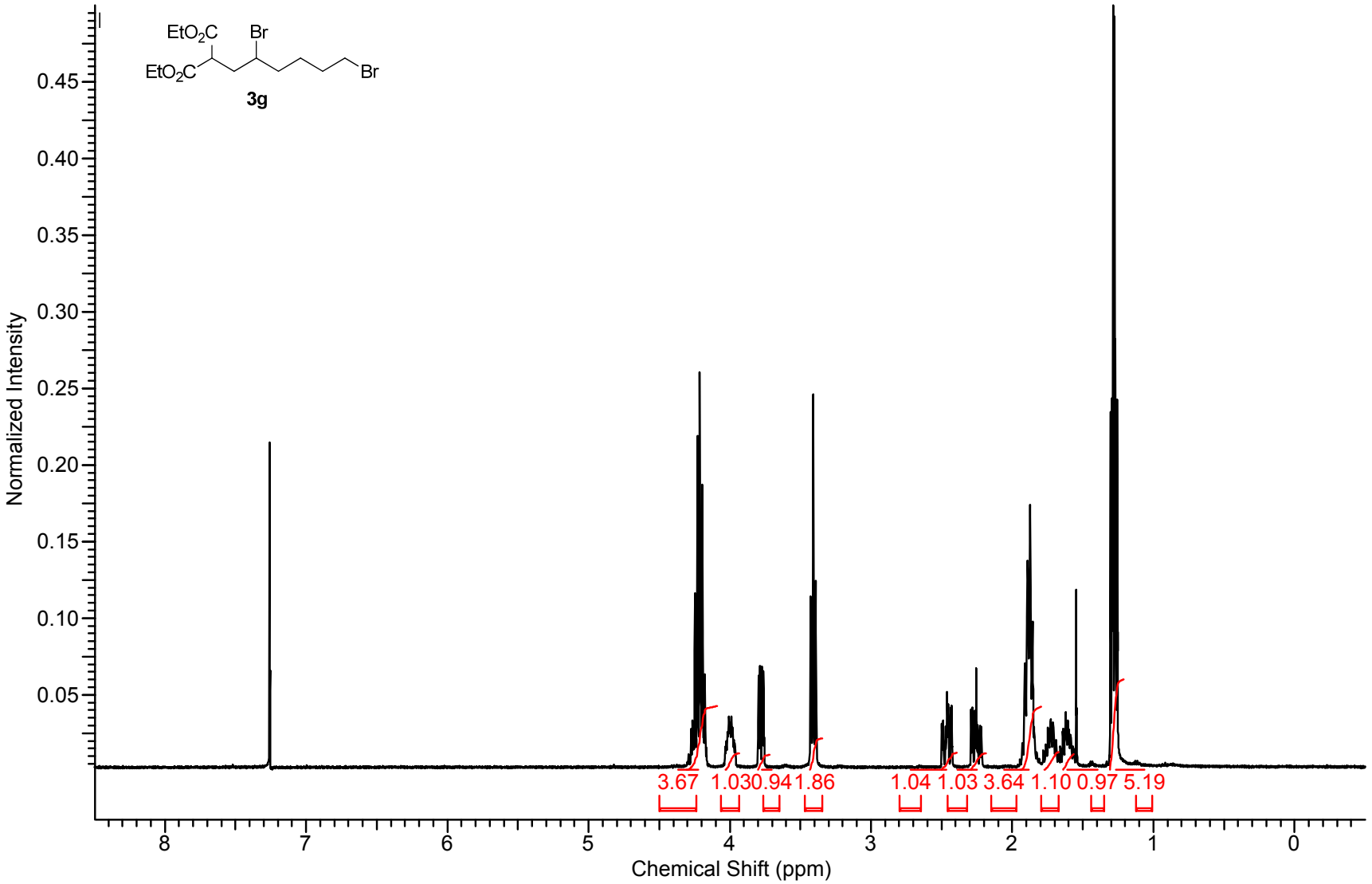

EtO2C
Br
EtO2C
OH
3c
Normalized Intensity
Chemical Shift (ppm)
168.9
168.7
77.3
77.0
76.7
62.4
61.6
54.6
50.5
39.1
37.8
31.8
23.7
14.0

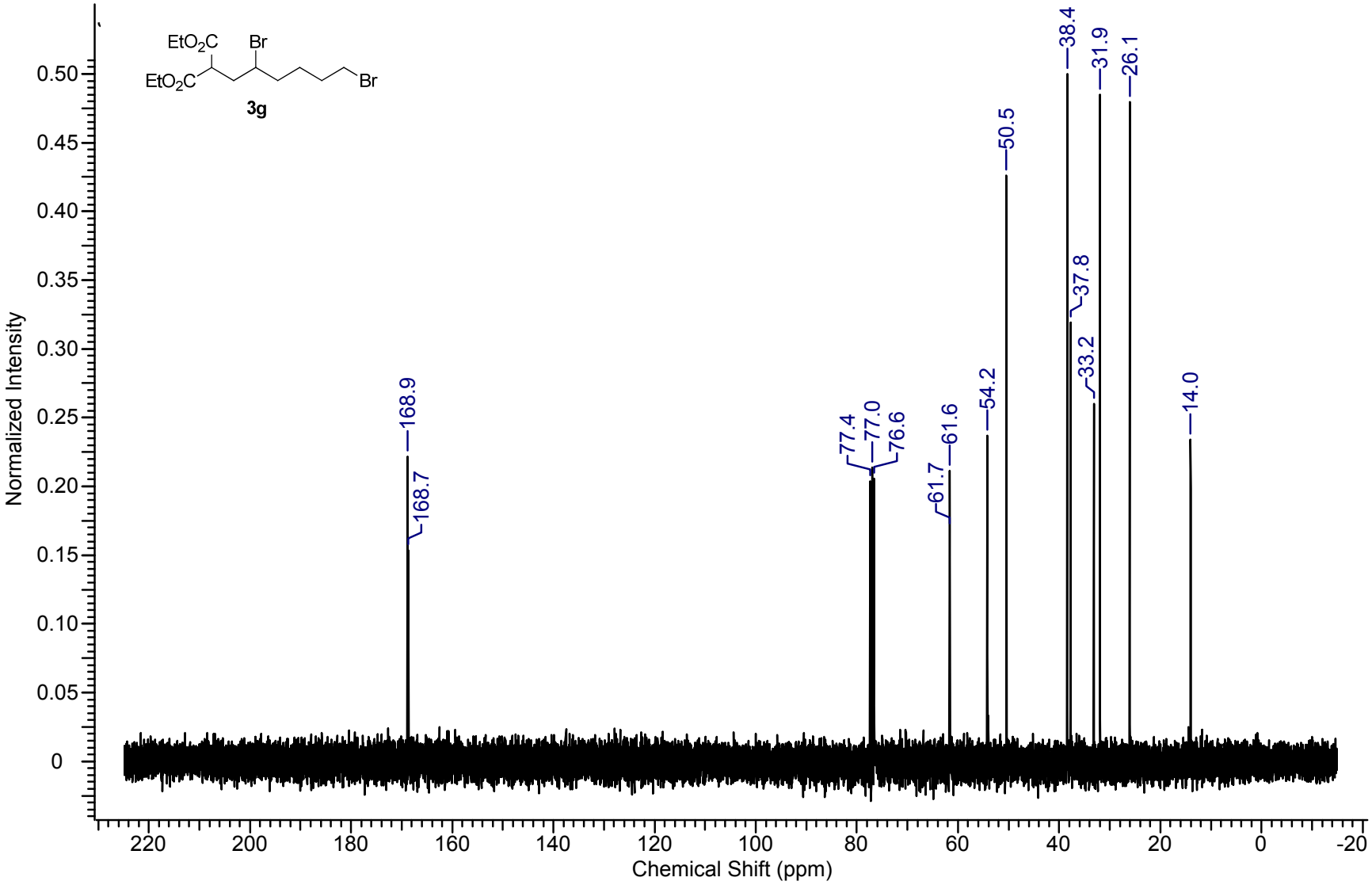

EtO2C
Br
EtO2C
OTBS
3e
Normalized Intensity
0.20
0.15
0.10
0.05
0
4.12
1.21
1.09
2.03
1.29
1.29
2.23
4.77
6.14
9.06
5.90
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

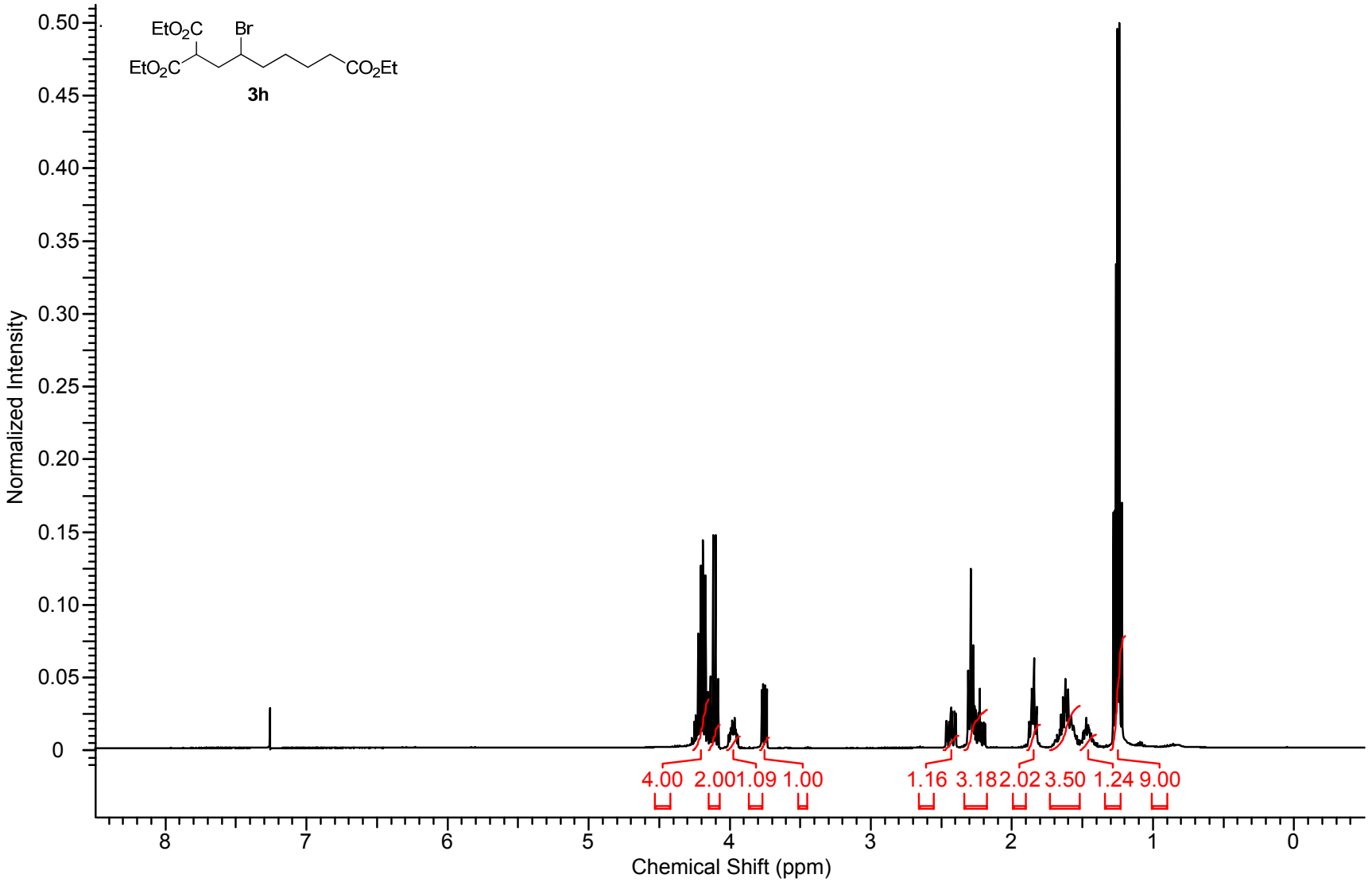

EtO2C
Br
EtO2C
OTBS
3e
Normalized Intensity
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
168.9
168.7
77.3
77.0
76.7
62.8
61.6
61.5
54.8
50.5
39.2
37.8
32.0
25.9
23.8
18.3
14.0
14.0
-5.3
-5.3
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)

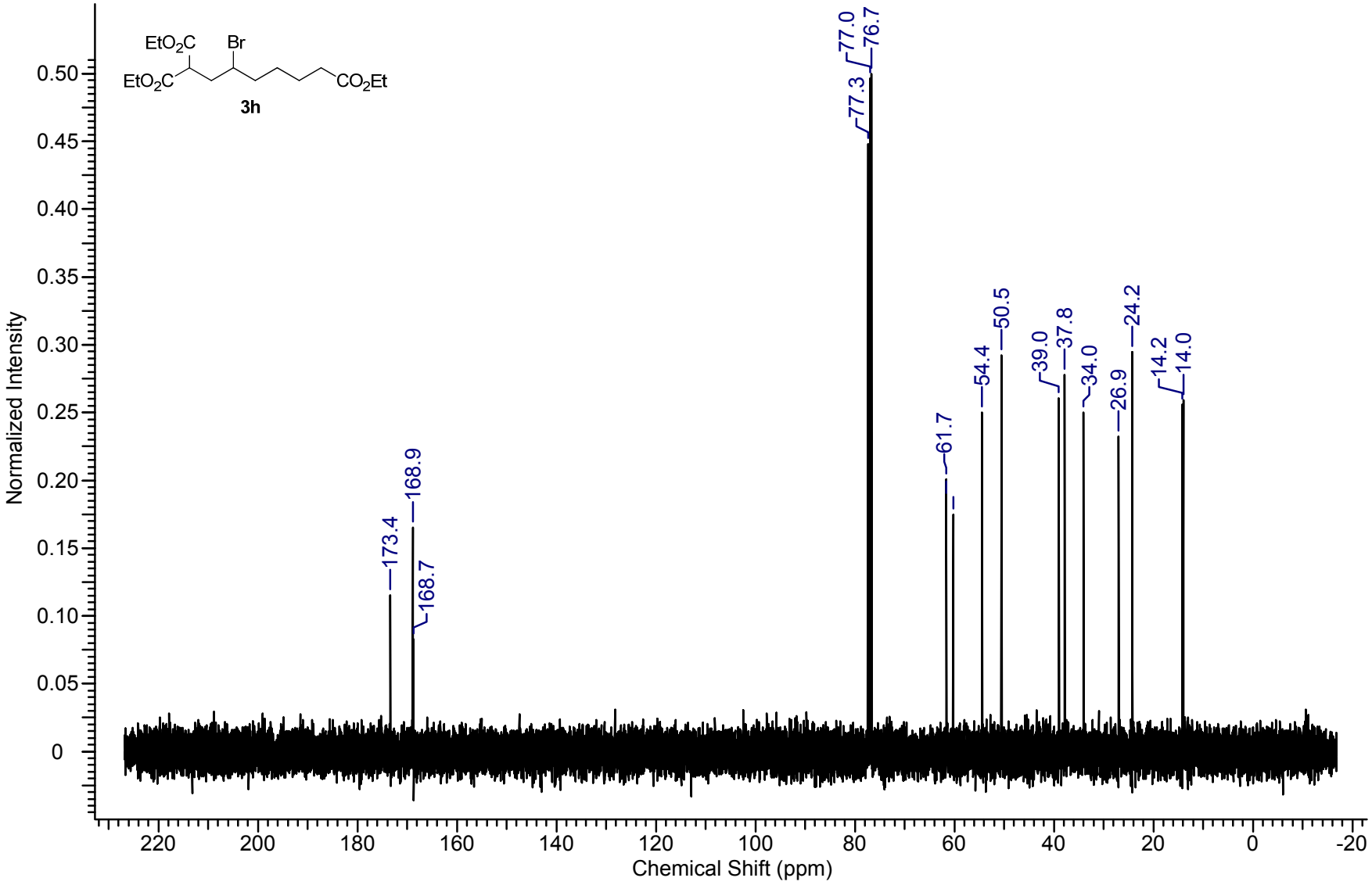

EtO2C
Br
EtO2C
OBn
3f
Normalized Intensity
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
4.54
2.21 4.03 1.13 0.93 2.41
1.13 1.17 3.71 1.41 5.85
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

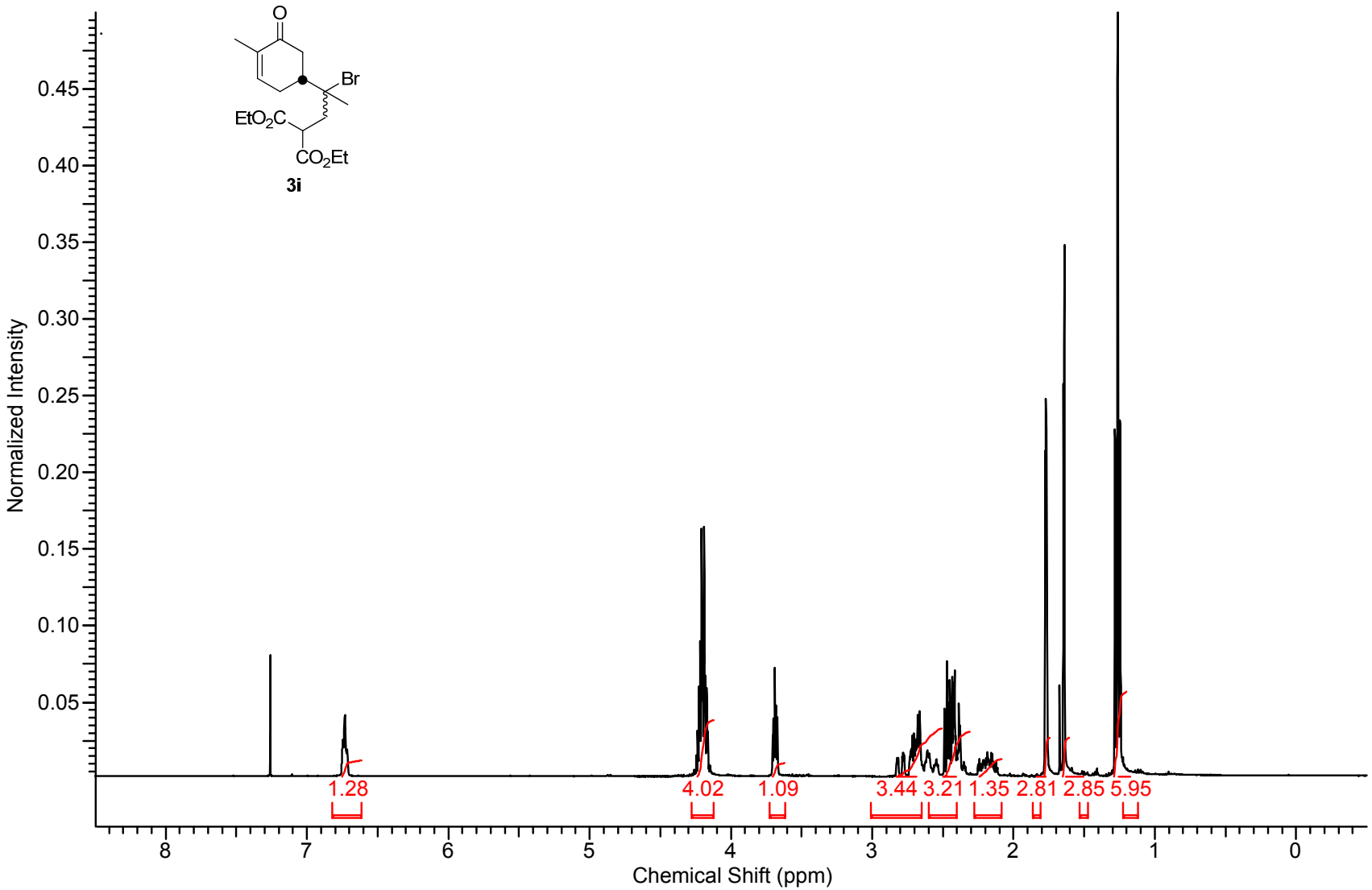

EtO2C
Br
EtO2C
OBn
3f
Normalized Intensity
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)
168.9
168.7
138.3
128.3
127.6
77.3
77.0
76.7
72.9
69.3
61.7
54.7
50.5
37.9
36.2
27.7
14.0

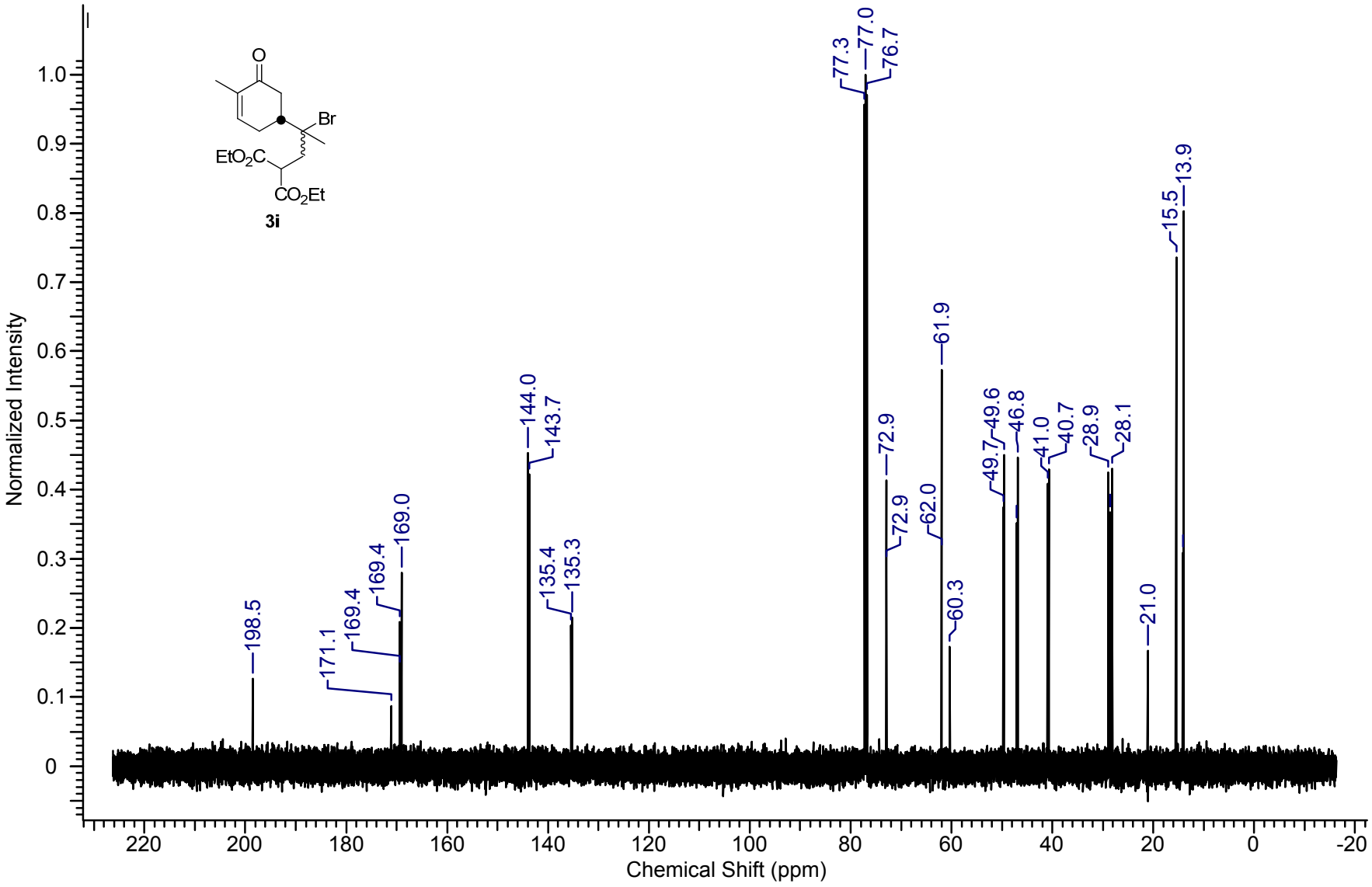

EtO2C
Br
EtO2C
Br
3g
Normalized Intensity
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
3.67
1.03
0.94
1.86
1.04
1.03
3.64
1.10
0.97
5.19
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

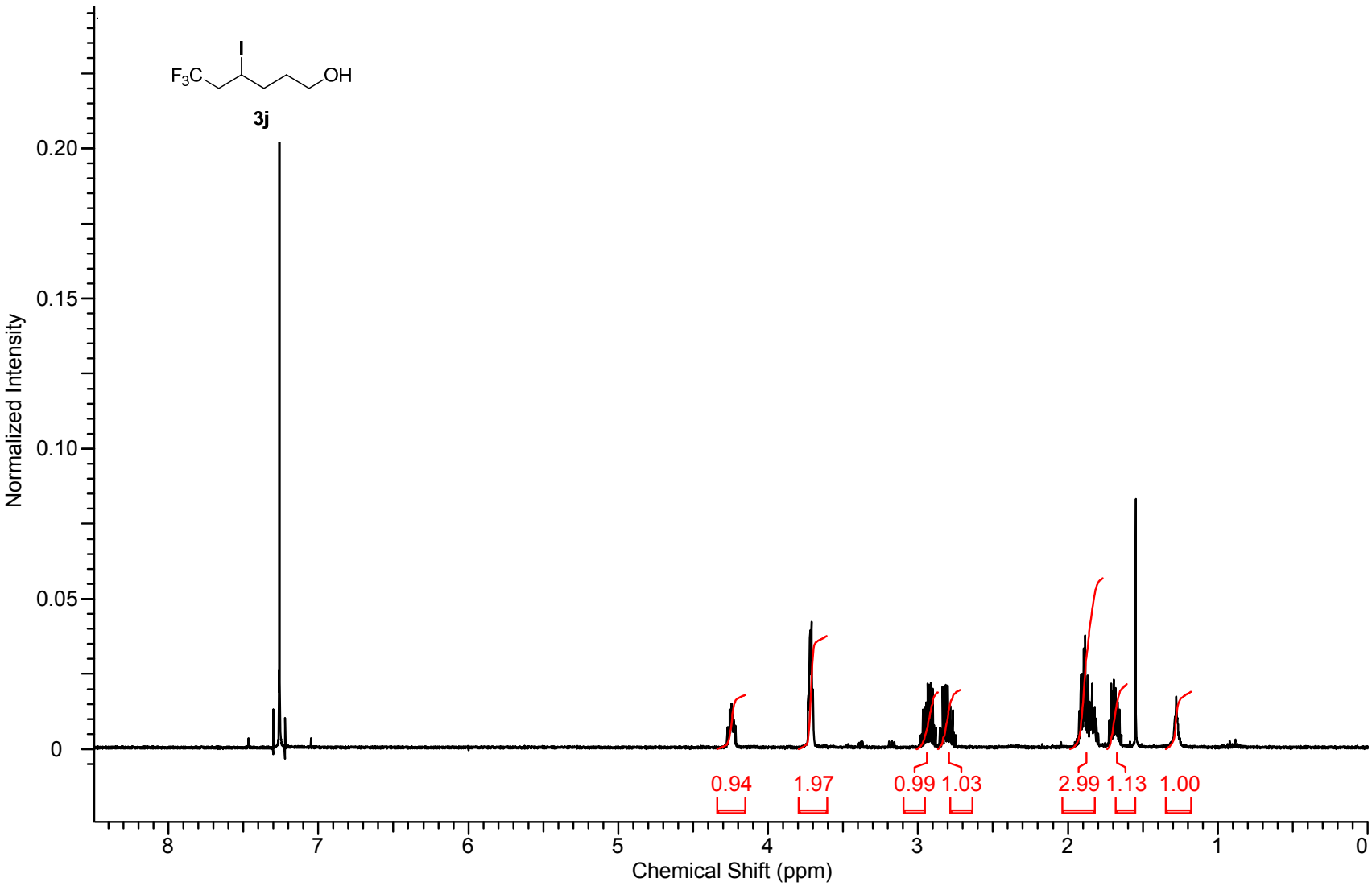

EtO2C
Br
EtO2C
Br
3g
Normalized Intensity
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
168.9
168.7
77.4
77.0
76.6
61.7
61.6
54.2
50.5
38.4
37.8
33.2
31.9
26.1
14.0
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)

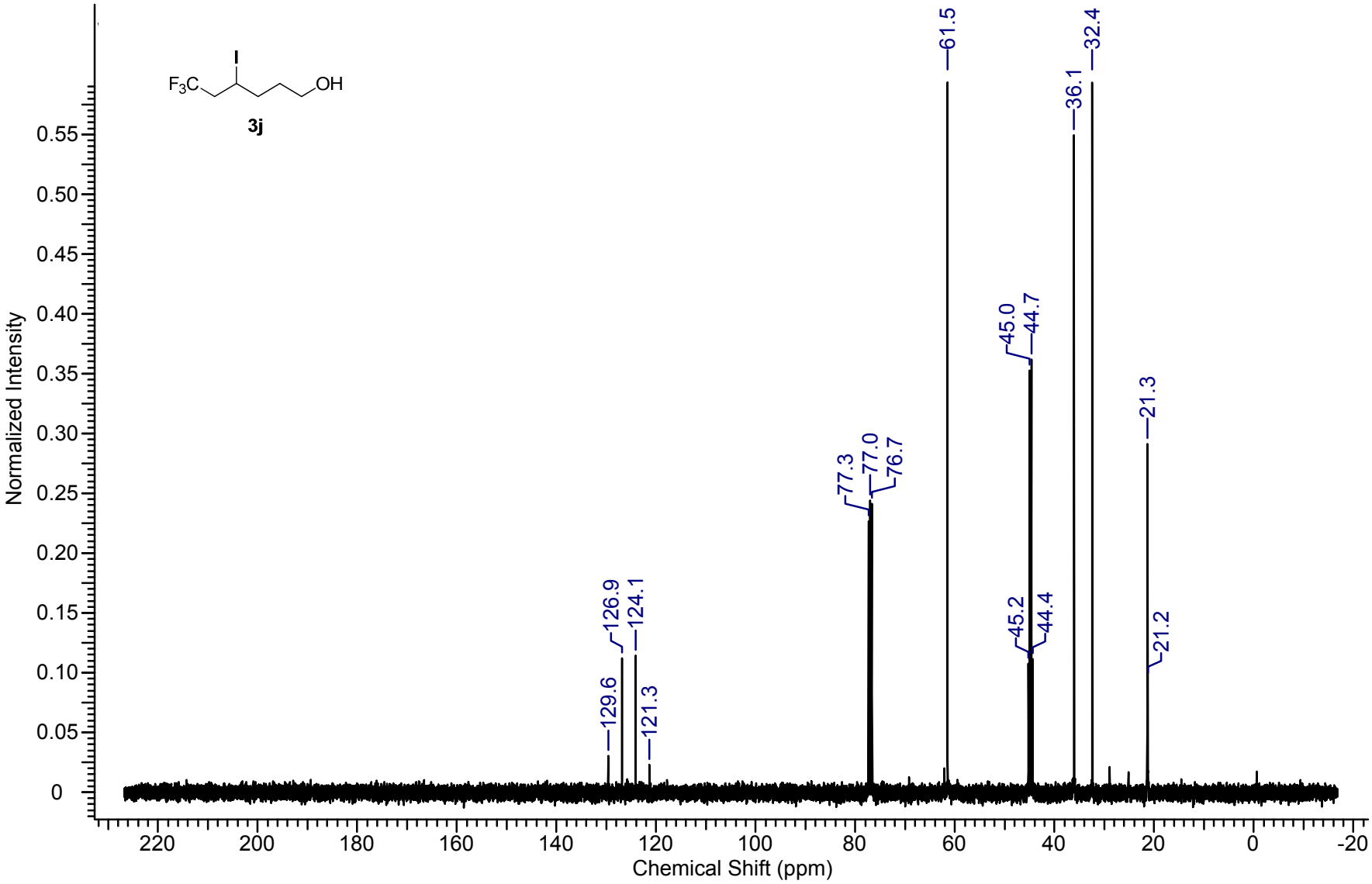

EtO2C
Br
EtO2C
CO2Et
3h
Normalized Intensity
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
4.00
2.00
1.09
1.00
1.16
3.18
2.02
3.50
1.24
9.00
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

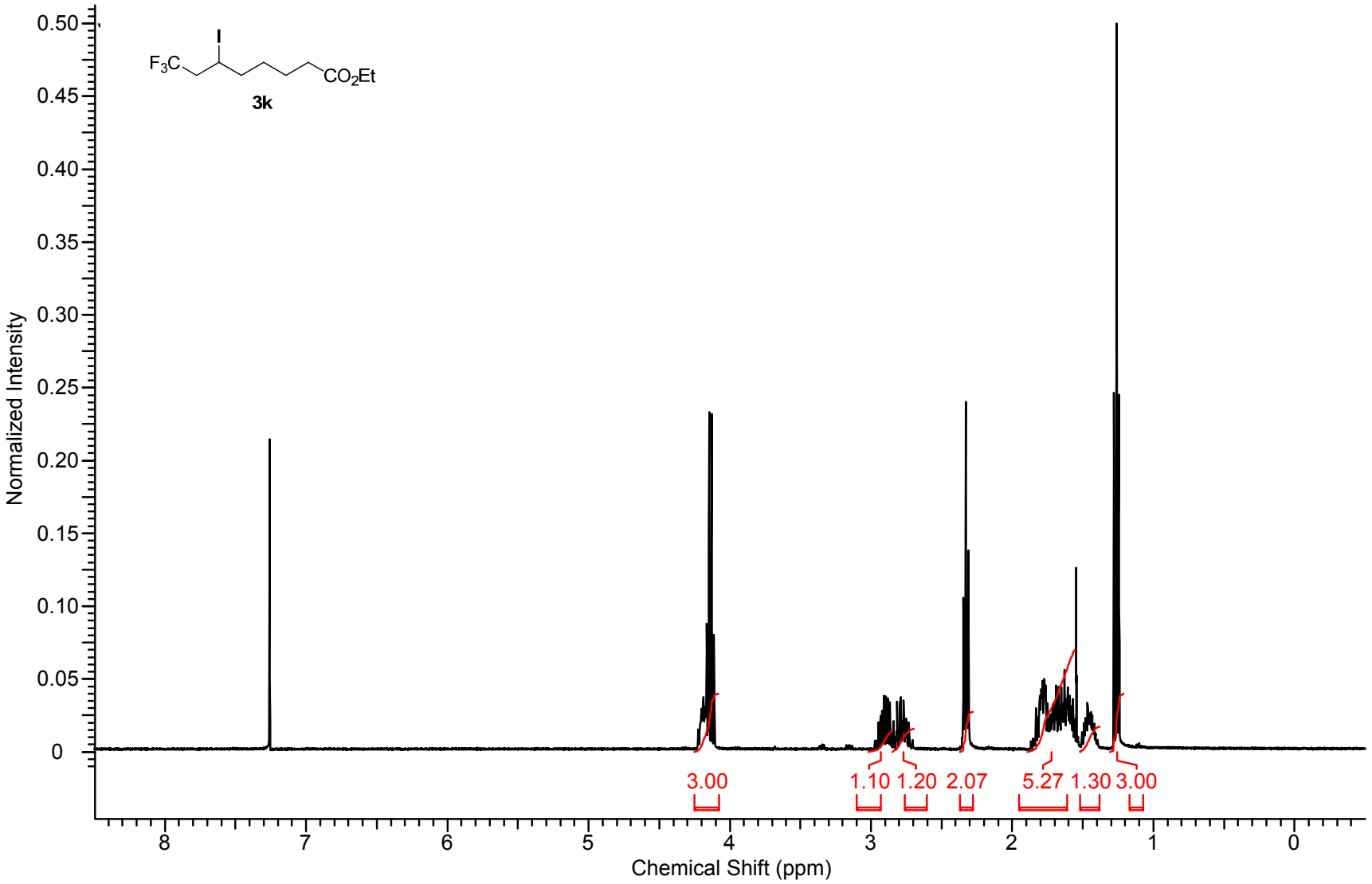

EtO2C
Br
EtO2C
CO2Et
3h
Normalized Intensity
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)
173.4
168.9
168.7
77.0
76.7
77.3
61.7
54.4
50.5
39.0
37.8
34.0
26.9
24.2
14.2
14.0

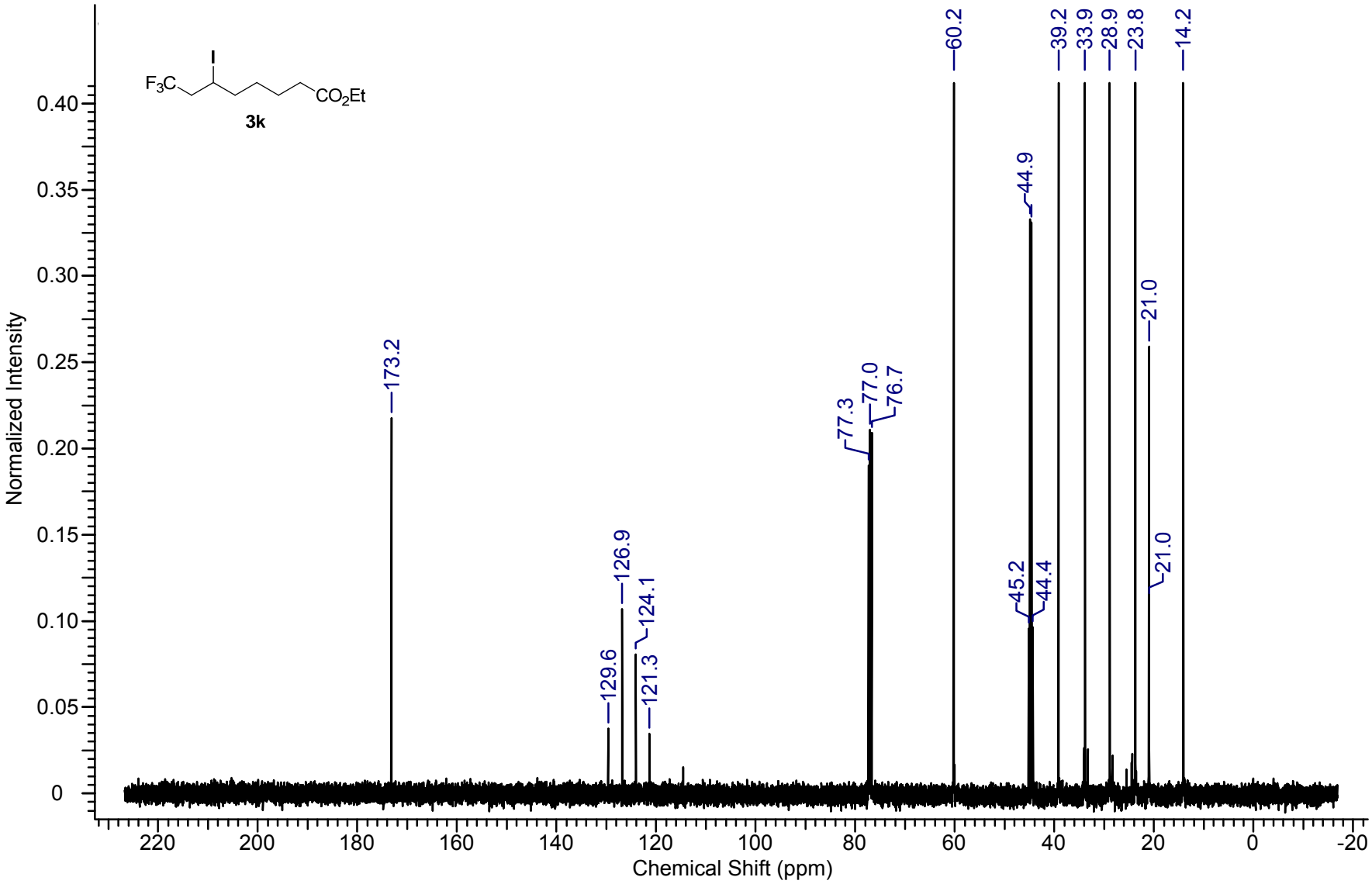

O
Br
EtO2C
CO2Et
3i
Normalized Intensity
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
1.28
4.02
1.09
3.44
3.21
1.35
2.81
2.85
5.95
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

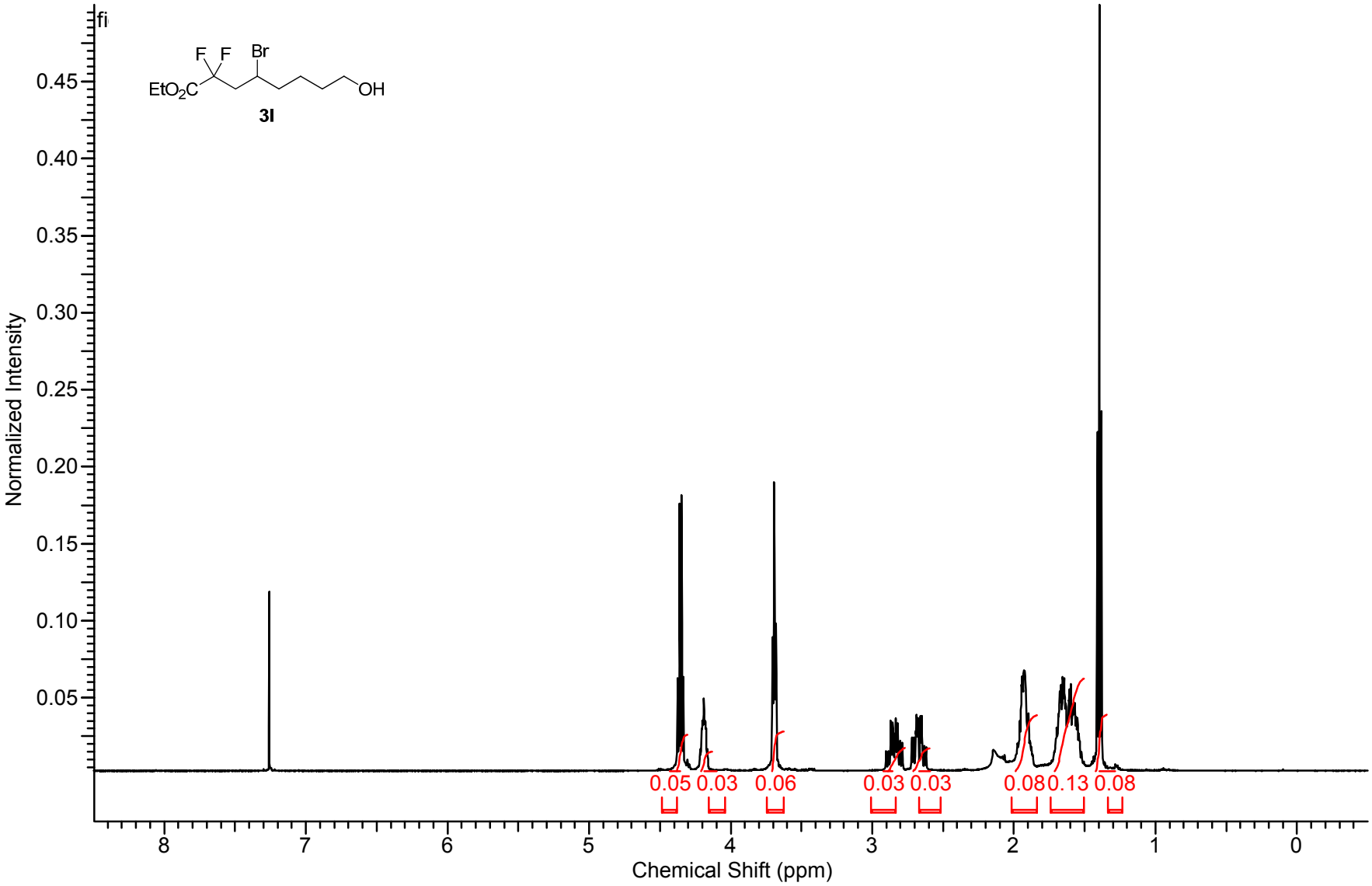

O
Br
EtO2C
CO2Et
3i
198.5
171.1
169.4
169.4
169.0
144.0
143.7
135.4
135.3
77.3
77.0
76.7
72.9
72.9
62.0
61.9
60.3
49.7
49.6
46.8
41.0
40.7
28.9
28.1
21.0
15.5
13.9
Normalized Intensity
Chemical Shift (ppm)

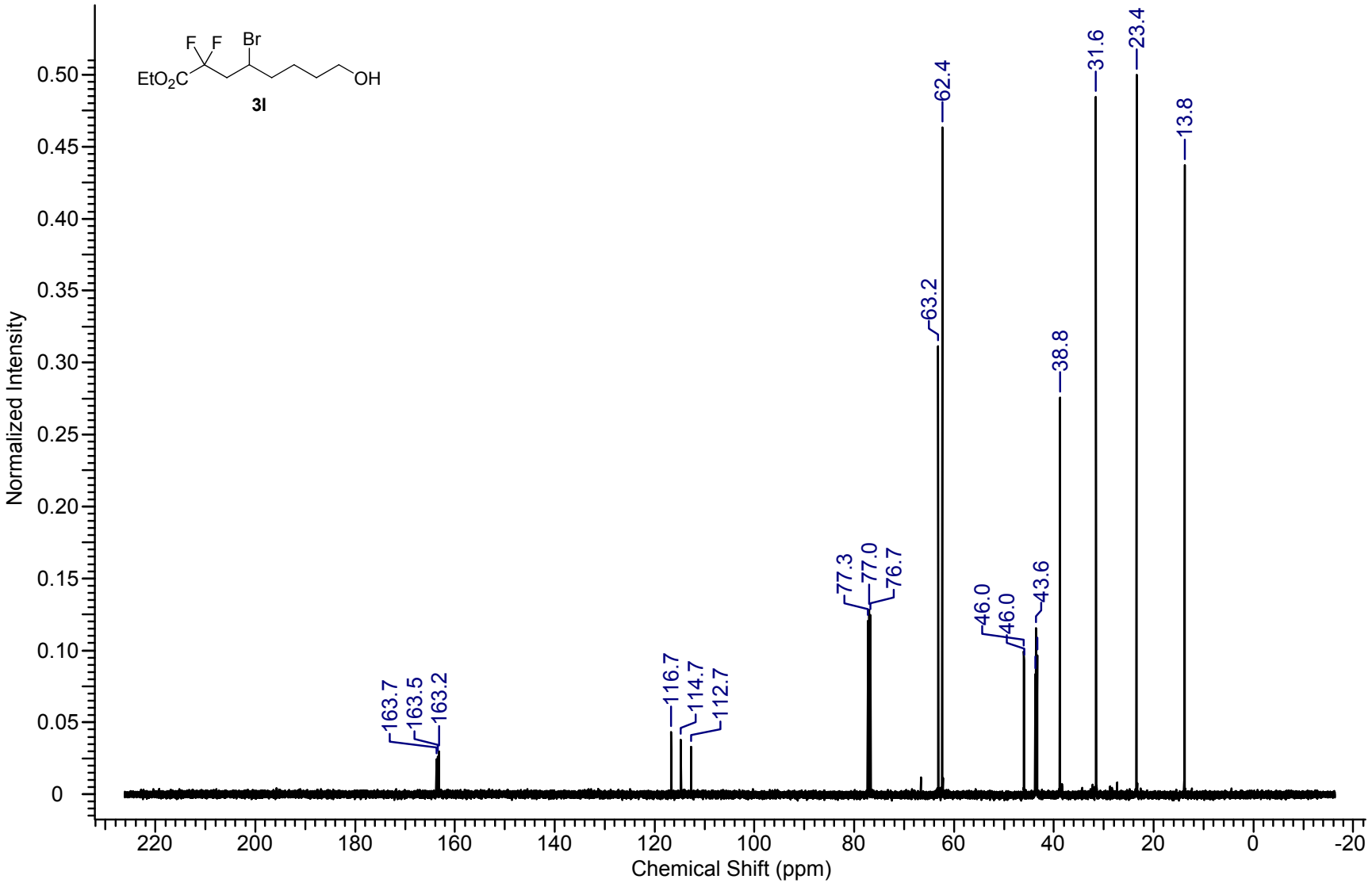

I
F3C
OH
3j
Normalized Intensity
0.20
0.15
0.10
0.05
0
0.94
1.97
0.99
1.03
2.99
1.13
1.00
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

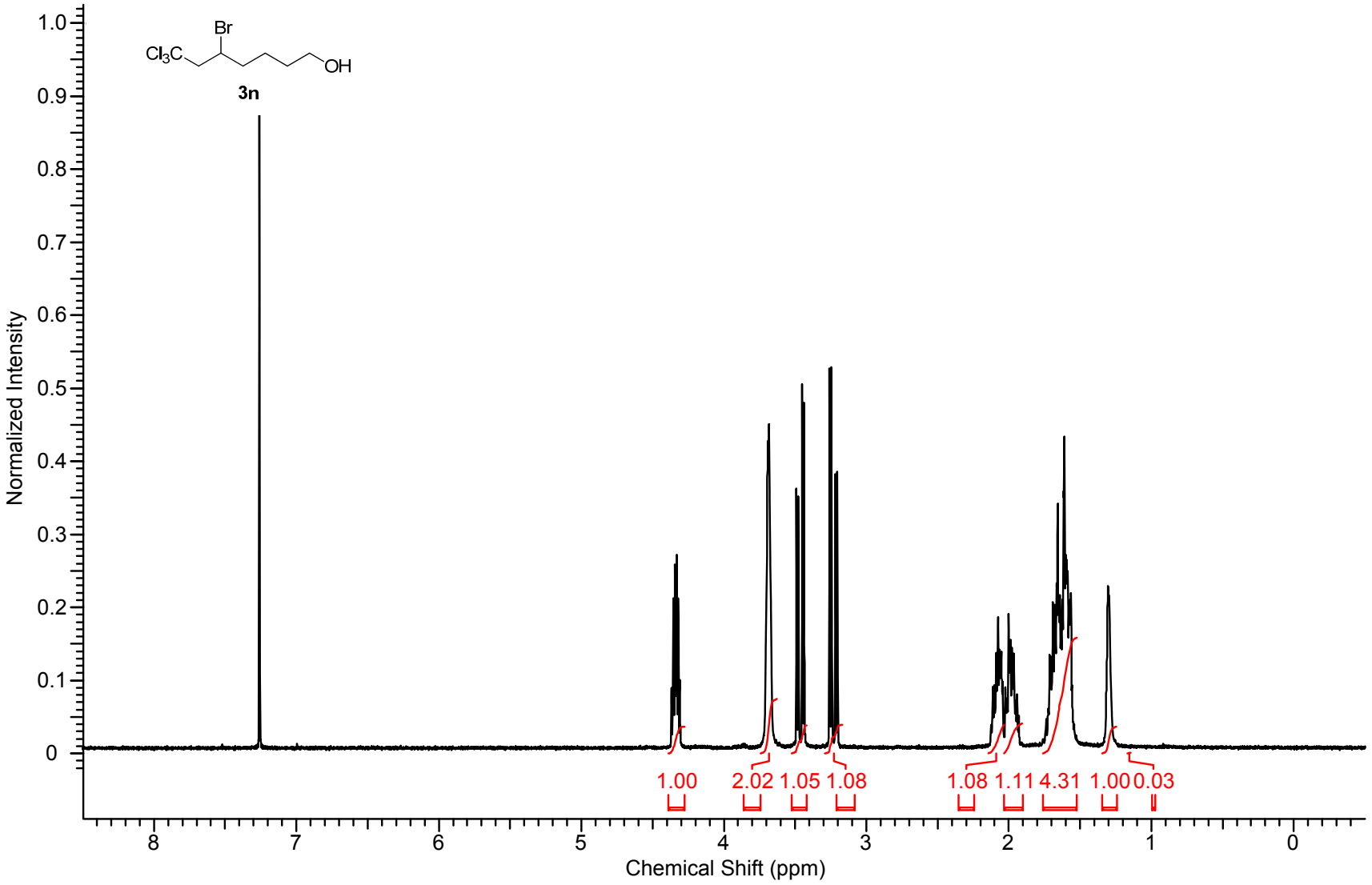

I
F3C
OH
3j
61.5
36.1
32.4
45.0
44.7
21.3
77.3
77.0
76.7
126.9
124.1
129.6
121.3
45.2
44.4
21.2
Normalized Intensity
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)

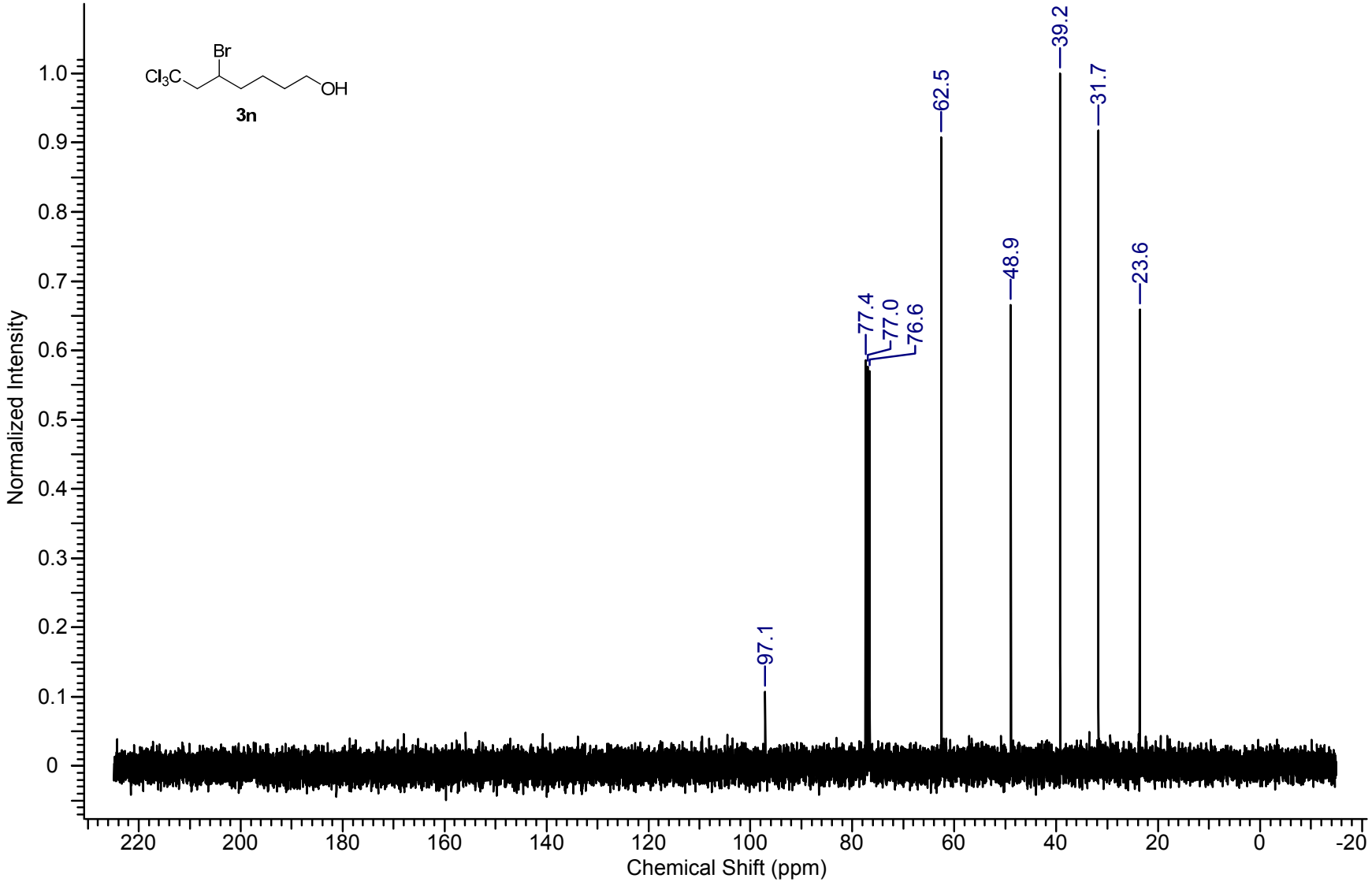

F3C
I
CO2Et
3k
Normalized Intensity
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)
3.00
1.10
1.20
2.07
5.27
1.30
3.00

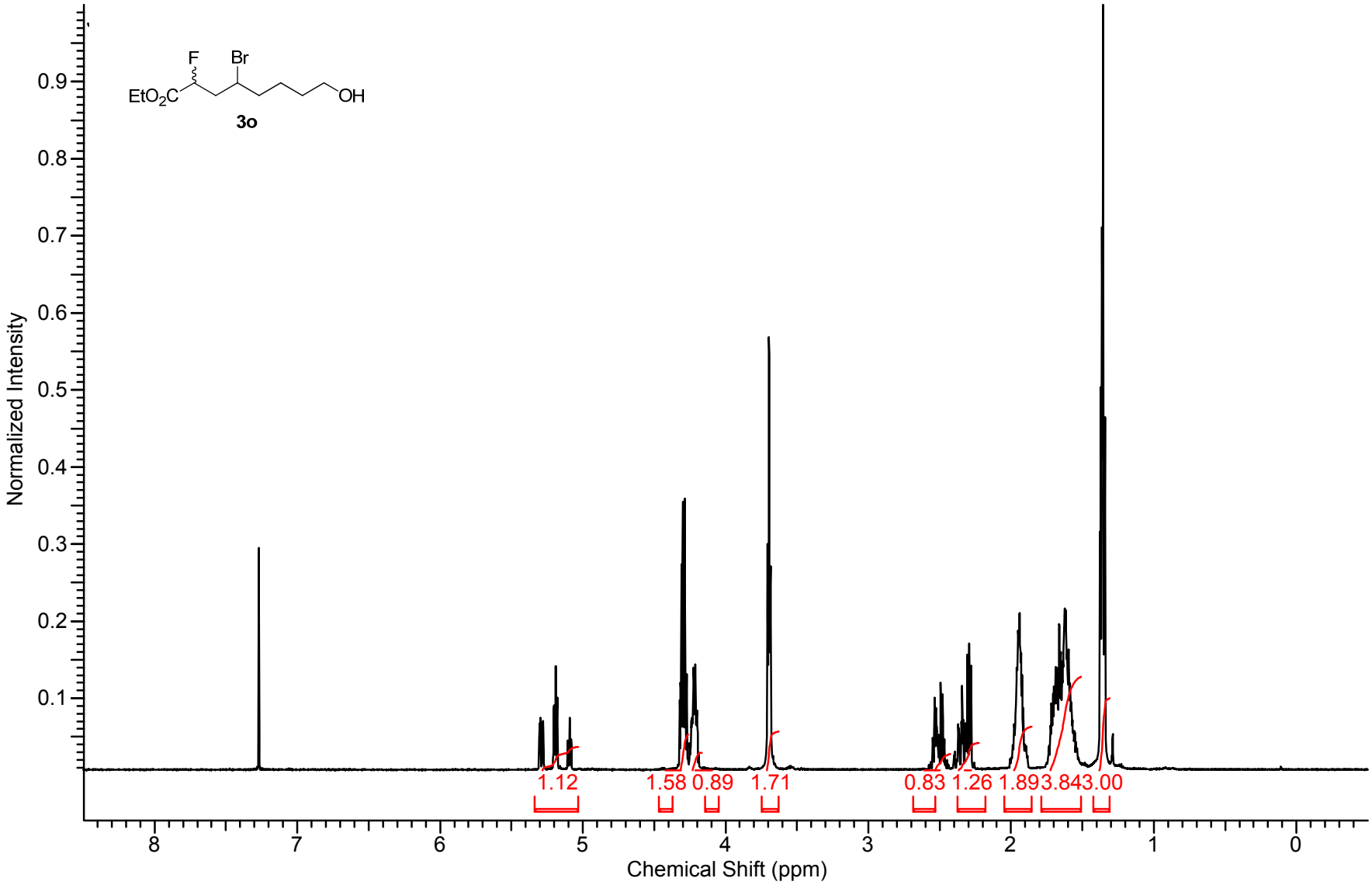

F3C
I
CO2Et
3k
Normalized Intensity
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)
173.2
129.6
126.9
124.1
121.3
77.3
77.0
76.7
60.2
45.2
44.9
44.4
39.2
33.9
28.9
23.8
21.0
21.0
14.2

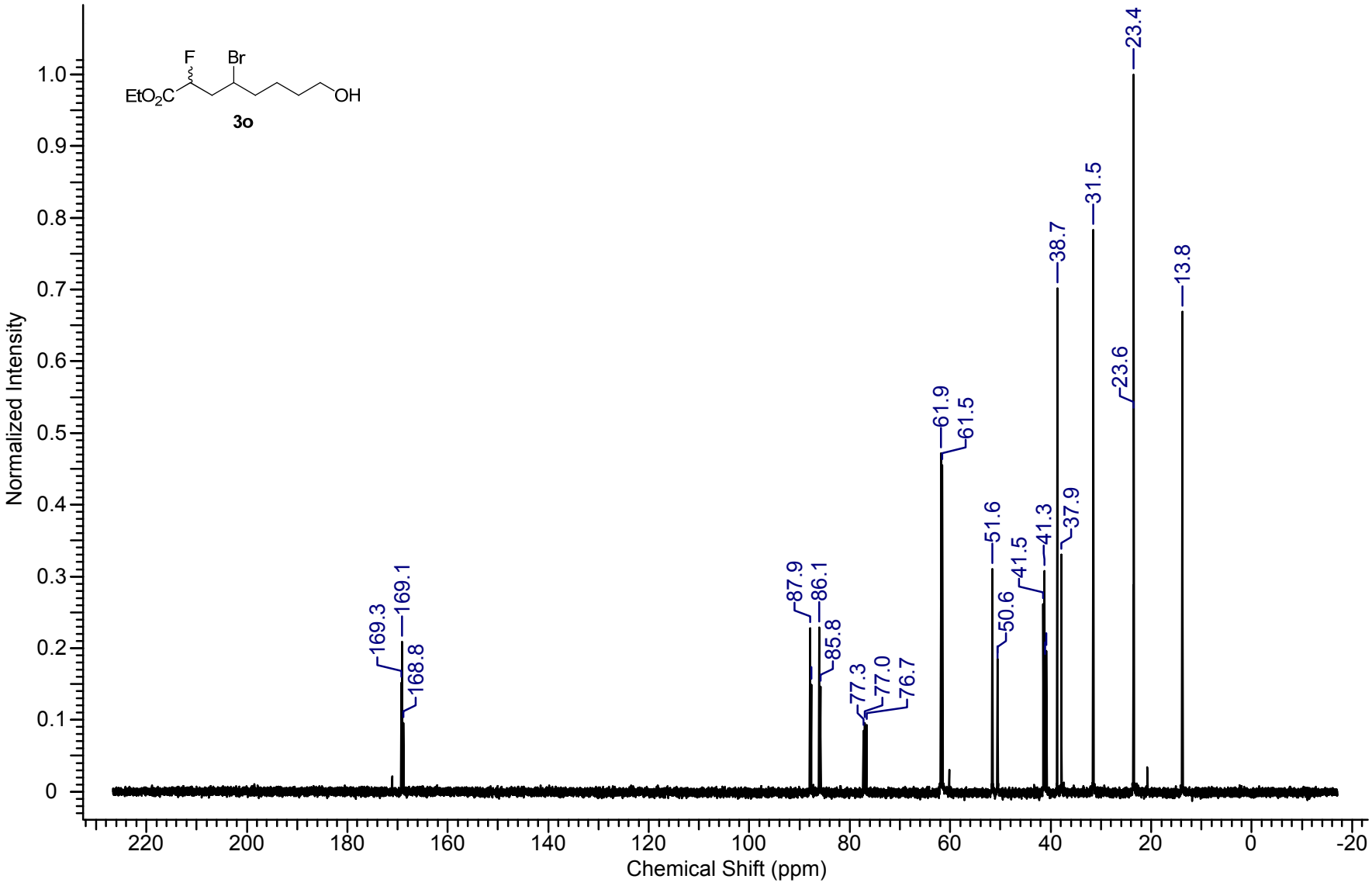

fi
F F Br
EtO2C
OH
3l
Normalized Intensity
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.05 0.03 0.06 0.03 0.03 0.08 0.13 0.08
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

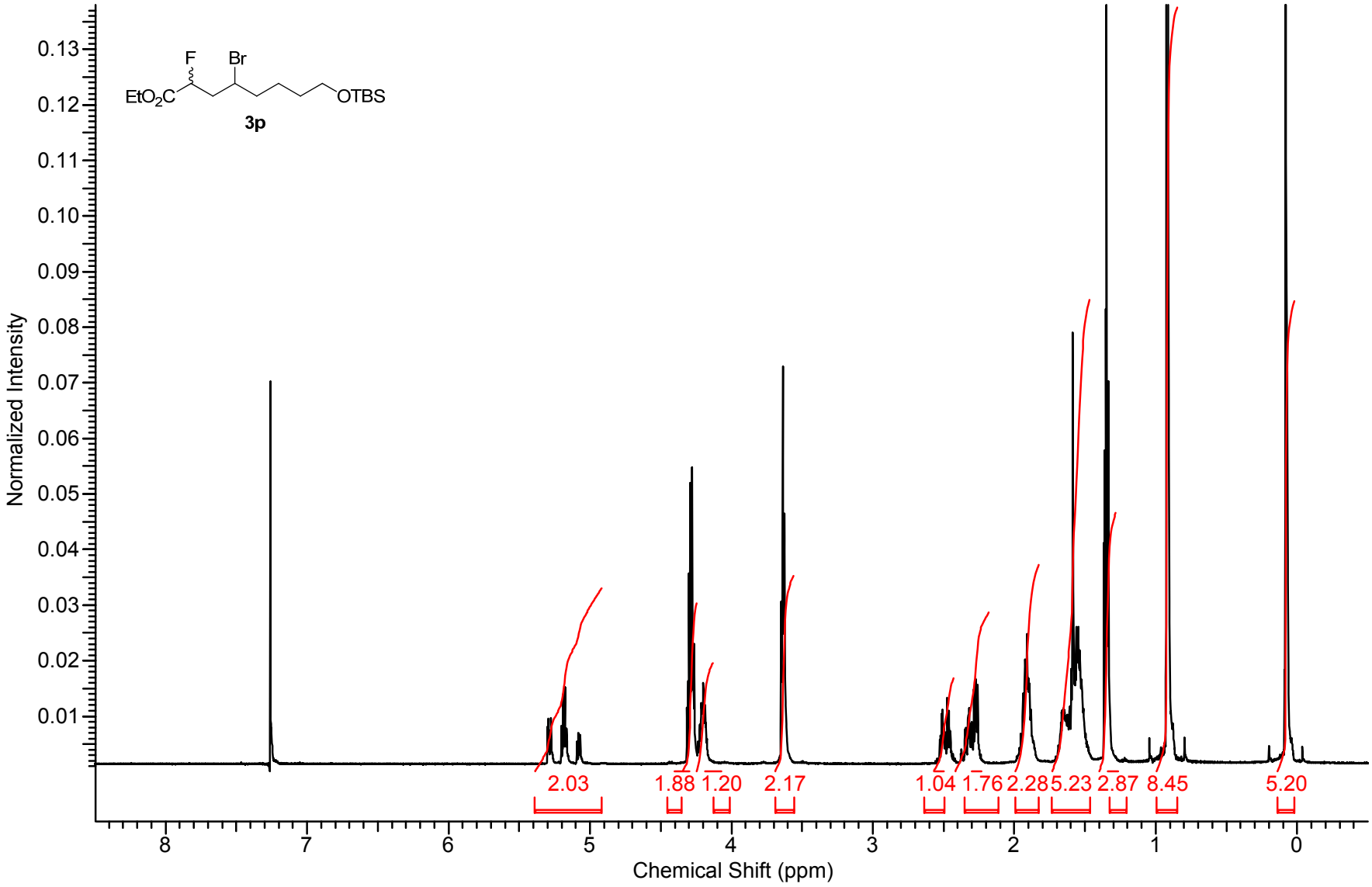

F F Br
EtO2C
OH
3l
Normalized Intensity
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)
163.7
163.5
163.2
116.7
114.7
112.7
77.3
77.0
76.7
62.4
63.2
46.0
46.0
43.6
38.8
31.6
23.4
13.8

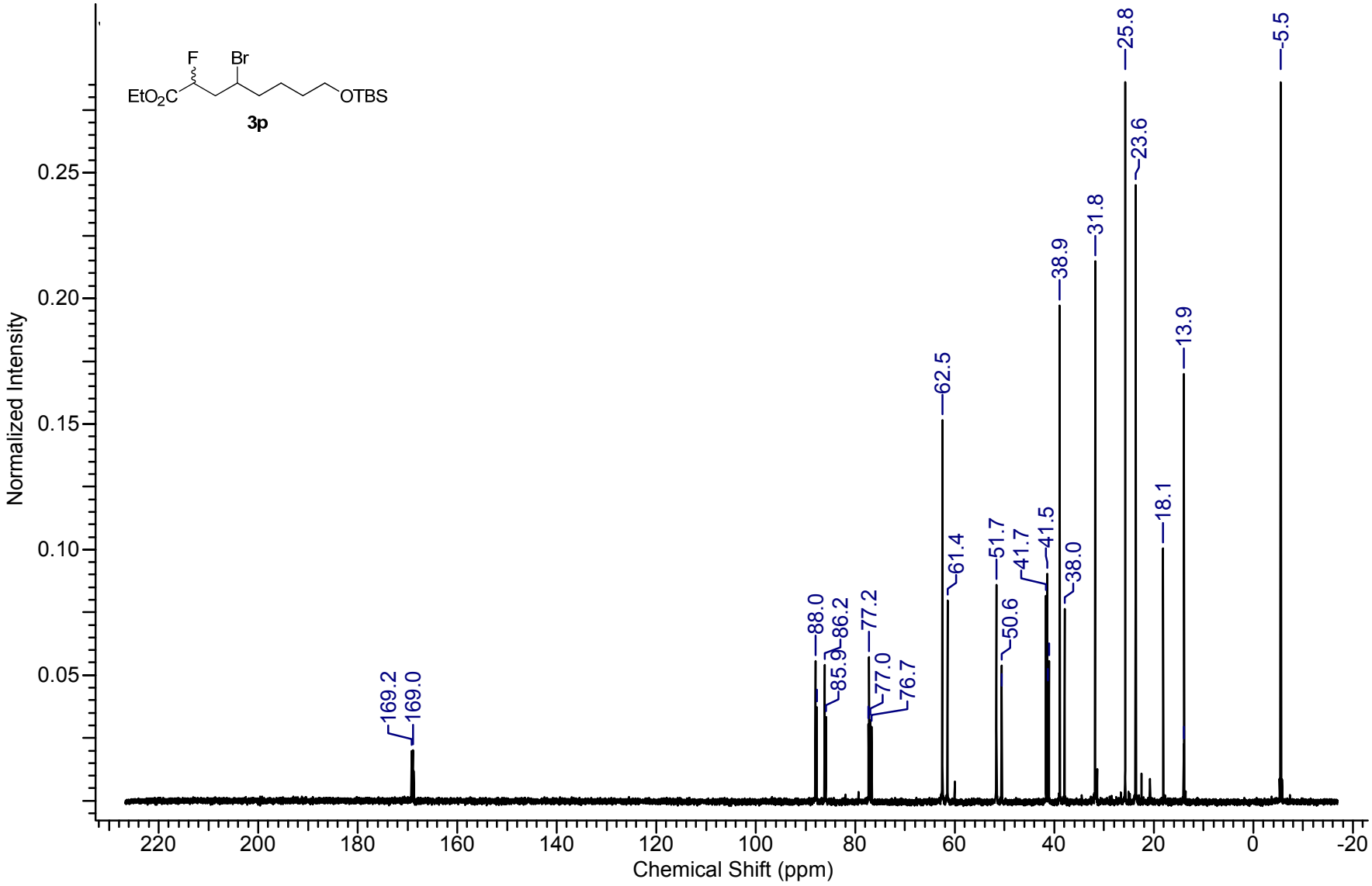

Br
Cl3C
OH
3n
Normalized Intensity
Chemical Shift (ppm)
1.00
2.02
1.05
1.08
1.08
1.11
4.31
1.00
0.03

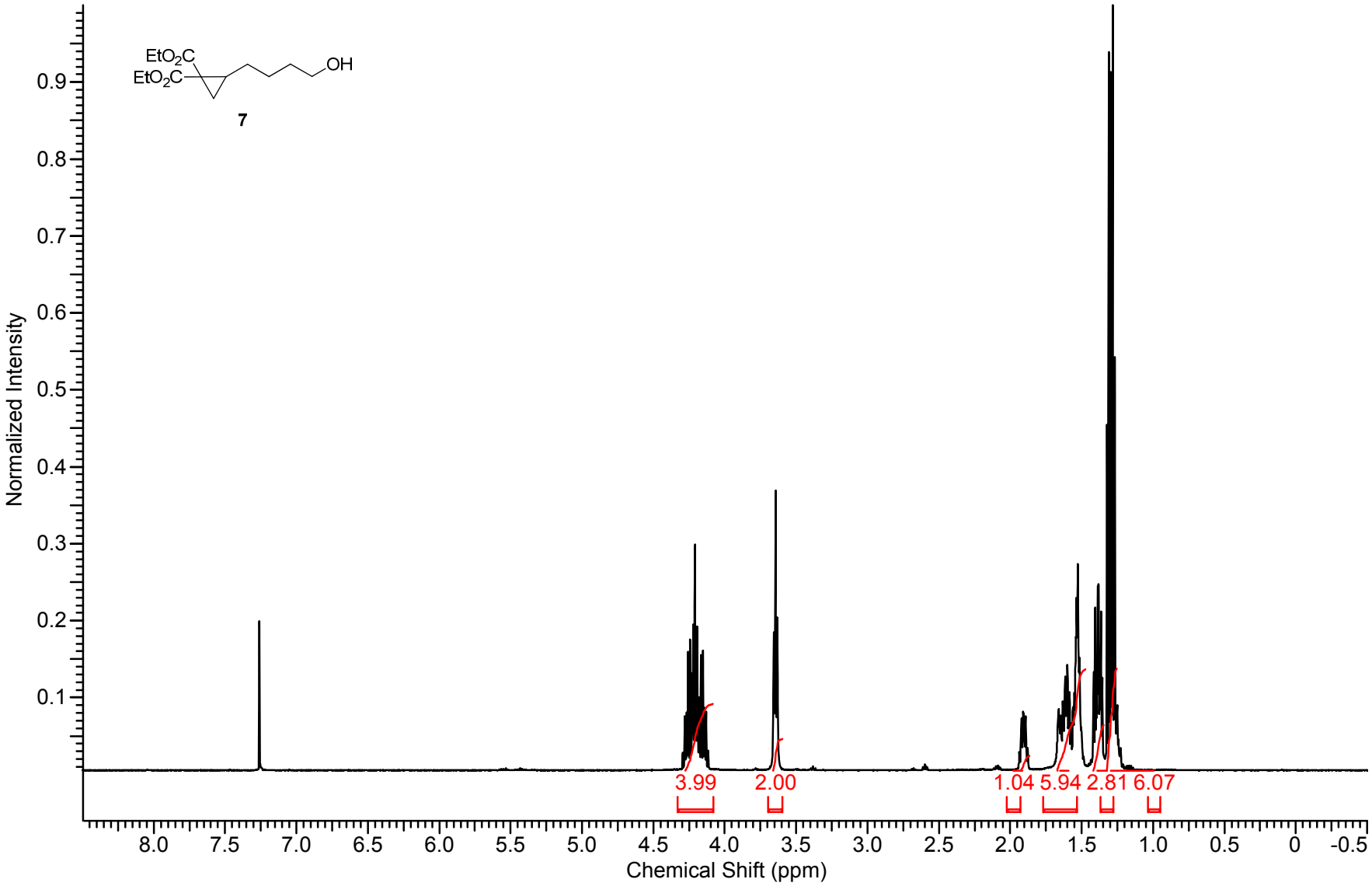

Br
Cl3C
OH
3n
Normalized Intensity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
97.1
77.4
77.0
76.6
62.5
48.9
39.2
31.7
23.6
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)

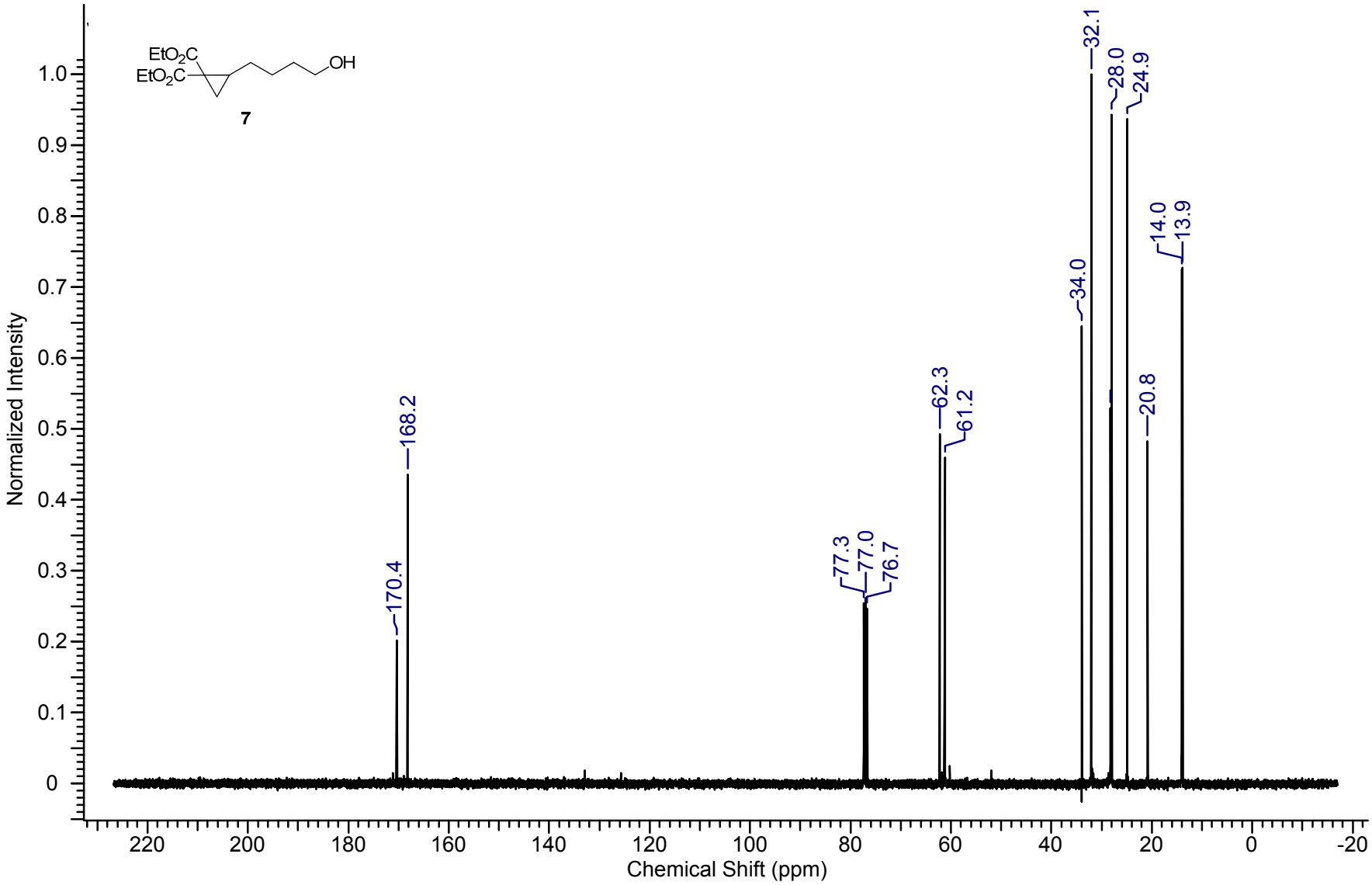

F
Br
EtO2C
OH
3o
Normalized Intensity
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1.12
1.58
0.89
1.71
0.83
1.26
1.89
3.84
3.00
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

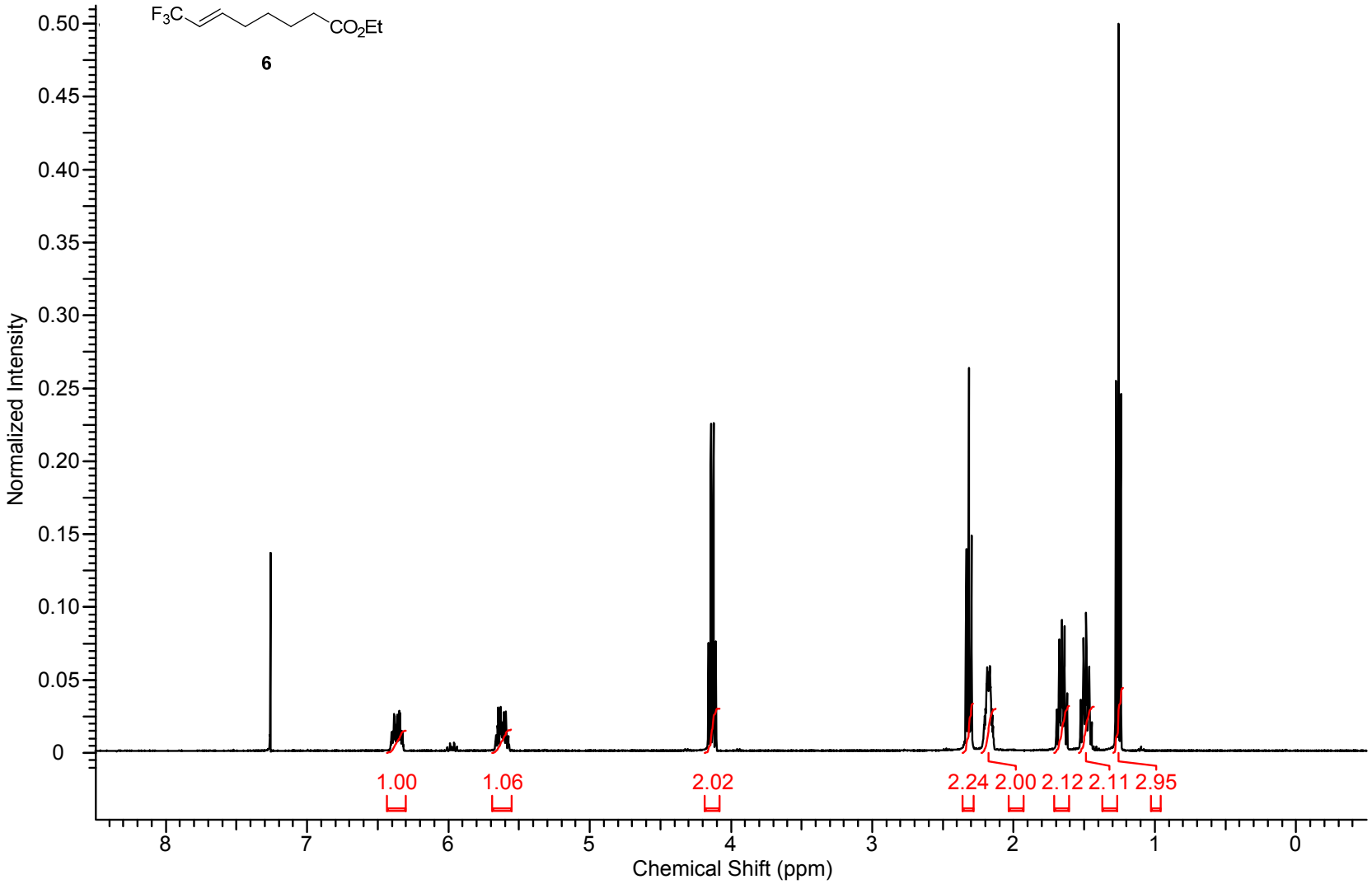

F
Br
EtO2C
OH
3o
Normalized Intensity
Chemical Shift (ppm)
169.3
169.1
168.8
87.9
86.1
85.8
77.3
77.0
76.7
61.9
61.5
51.6
50.6
41.5
41.3
38.7
37.9
31.5
23.6
23.4
13.8

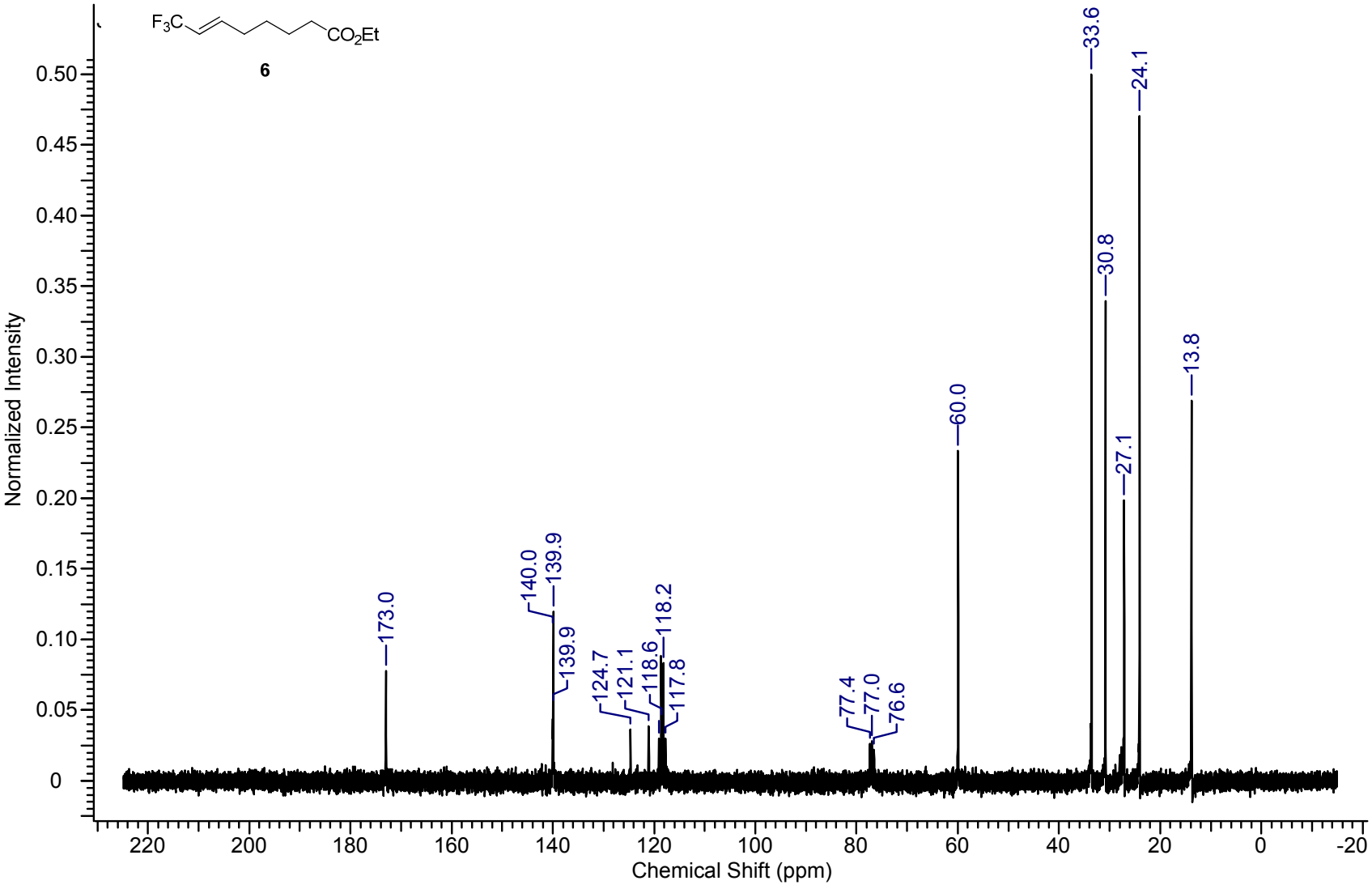

F
Br
EtO2C
OTBS
3p
Normalized Intensity
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
2.03
1.88
1.20
2.17
1.04
1.76
2.28
5.23
2.87
8.45
5.20
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)

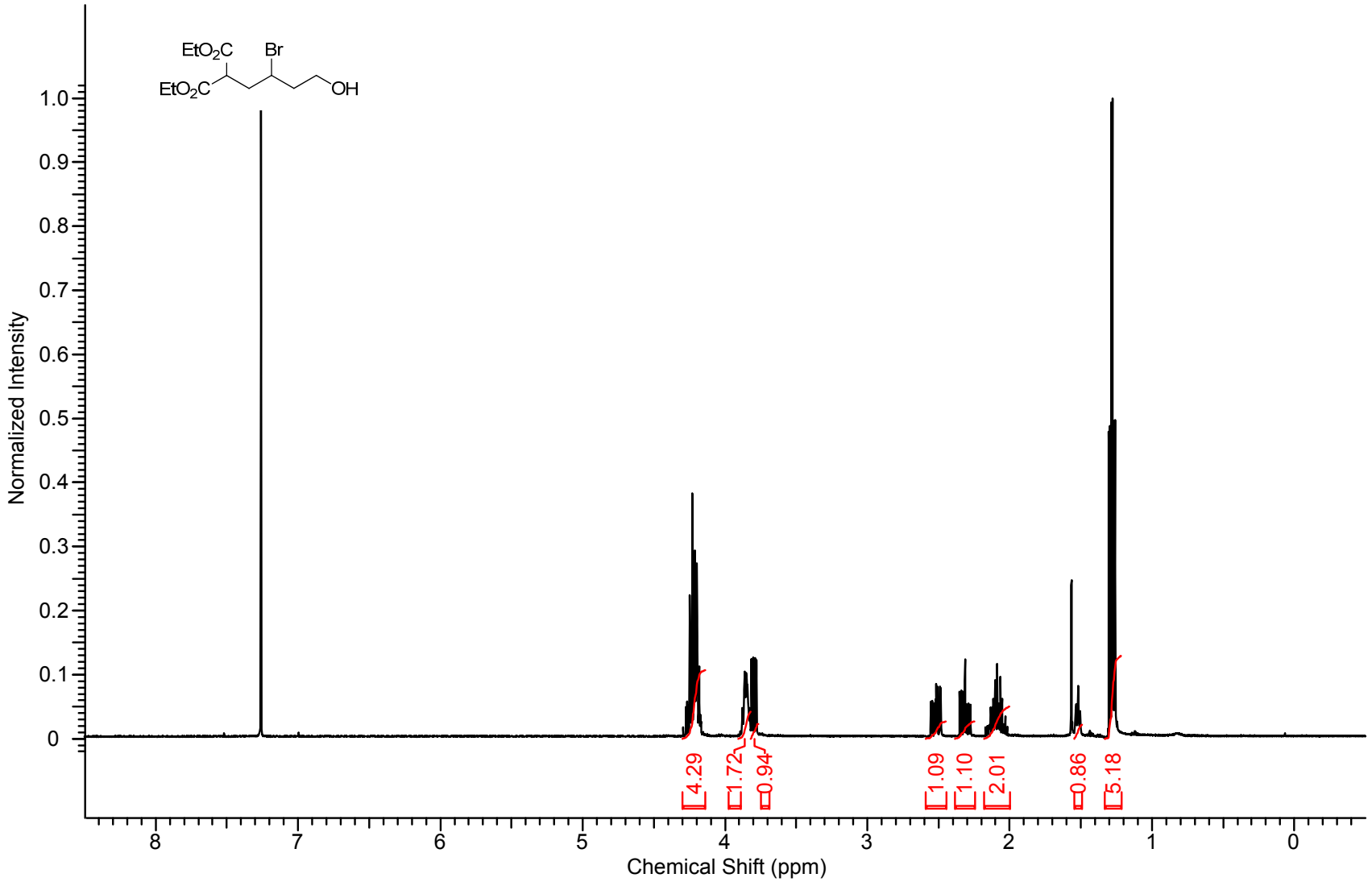

F
Br
EtO2C
OTBS
3p
Normalized Intensity
0.25
0.20
0.15
0.10
0.05
169.2
169.0
88.0
86.2
85.9
77.2
77.0
76.7
62.5
61.4
51.7
50.6
41.7
41.5
38.9
38.0
31.8
25.8
23.6
18.1
13.9
-5.5
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)

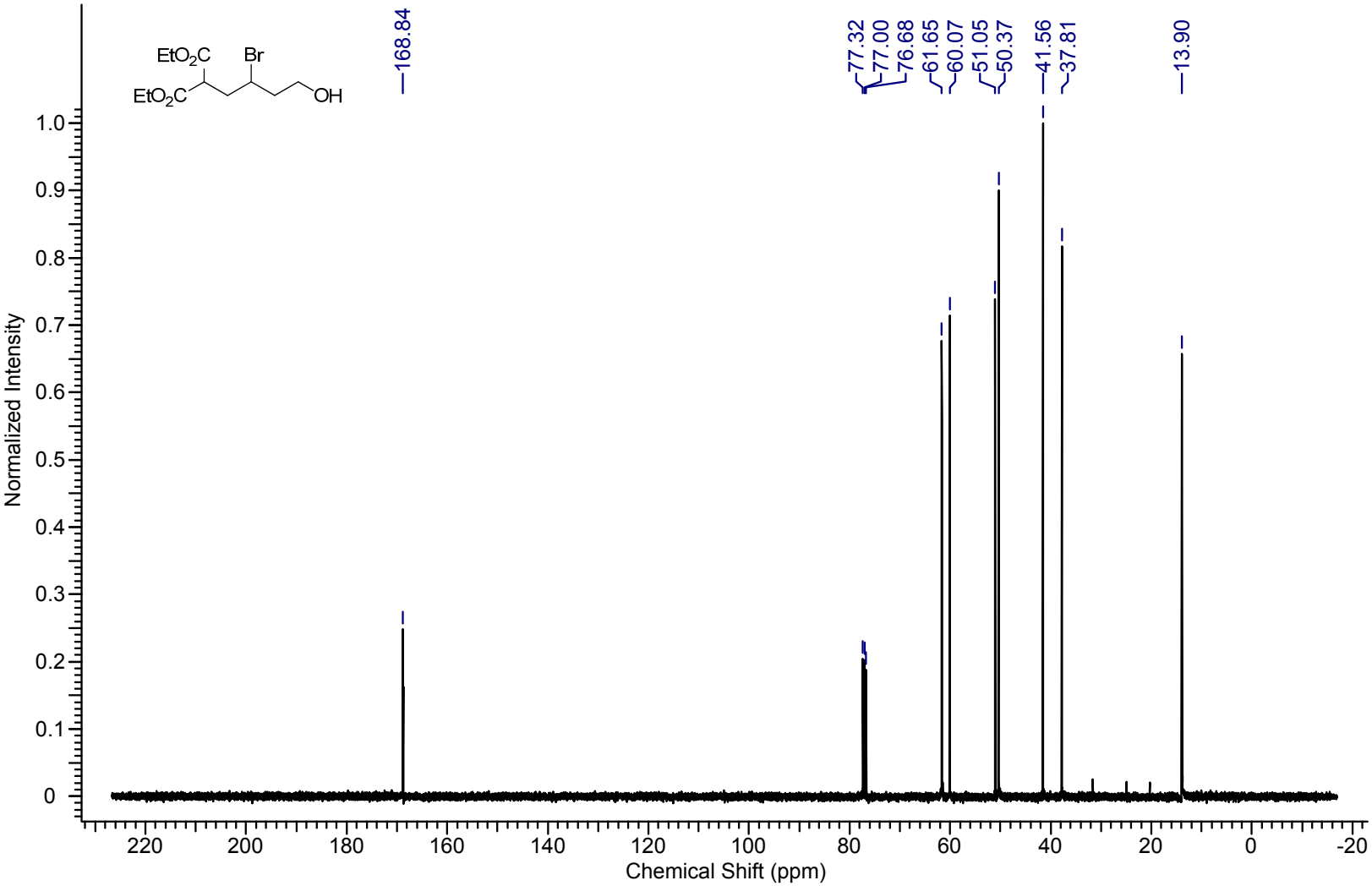

EtO2C
EtO2C
OH
7
Normalized Intensity
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
3.99
2.00
1.04
5.94
2.81
6.07
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
-0.5
Chemical Shift (ppm)


EtO2C
EtO2C
OH
7
Normalized Intensity
Chemical Shift (ppm)
170.4
168.2
77.3
77.0
76.7
62.3
61.2
34.0
32.1
28.0
24.9
20.8
14.0
13.9


F3C
CO2Et
6
Normalized Intensity
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
1.00
1.06
2.02
2.24
2.00
2.12
2.11
2.95
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)


F3C
CO2Et
6
Normalized Intensity
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)
173.0
140.0
139.9
139.9
124.7
121.1
118.6
118.2
117.8
77.4
77.0
76.6
60.0
33.6
30.8
27.1
24.1
13.8


EtO2C
Br
EtO2C
OH
Normalized Intensity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
8
7
6
5
4
3
2
1
0
Chemical Shift (ppm)
4.29
1.72
0.94
1.09
1.10
2.01
0.86
5.18


EtO2C
Br
EtO2C
OH
168.84
77.32
77.00
76.68
61.65
60.07
51.05
50.37
41.56
37.81
13.90
Normalized Intensity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
220
200
180
160
140
120
100
80
60
40
20
0
-20
Chemical Shift (ppm)