Oxidative Dearomatization. Synthesis of Functionalized Bicyclo[2.2.2]octenones, Sigmatropic shift in Excited State and Radical Induced Cleavage of Cyclopropane ring

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SUPPORTING INFORMATION

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Full experimental detail

The product was characterized by ^{1}H NMR, ^{13}C NMR and mass spectroscopy. The spectral data of reported compounds (**5b**, **8a** and **8b**) match fairly with that reported in literature (references 11b and 13 of main text).

tert-Butyl 4-hydroxy-3-(hydroxymethyl)benzoate (5a)

tert-Butyl-4-hydroxybenzoate **7a** (1.00 g, 5.15 mmol) was added to a solution of NaOH (12%, 5 mL, 12.88 mmol) at 0 ^{o}C with stirring. Formaldehyde (37%, 4 mL) was then added. The reaction mixture stirred at 55 ^{o}C for 16 h. Reaction was quenched with ammonium chloride, diluted with water (15 mL) and extracted with ethyl acetate (3 x 25 mL). The combined organic extract was washed with brine (50 mL) and dried on anhydrous Na_2SO_4. Solvent was removed under reduced pressure, and residue was chromatographed on silica gel. Elution with petroleum ether / ethyl acetate (60:40) gave compound **5a** as a colorless solid (0.43 g, 37%); mp 140 – 142 ^{o}C. [R_f = 0.60 petroleum ether/EtOAc (60:40)]. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.84 (dd, J_1 = 8.4 Hz, J_2 = 1.9 Hz, 1H), 7.67 (d, J = 1.9 Hz, 1H), 6.88 (d, J = 8.4 Hz, 1H), 4.91 (s, 2H), 2.67 (broad s, 1H), 1.57 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$): δ 165.8, 160.4, 131.4, 129.5, 124.1, 123.9, 116.5, 80.9, 64.8, 28.4. HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_{12}H_{16}NaO_4$: 247.0941; found: 247.0945.

Methyl 4-hydroxy-3-(hydroxymethyl)benzoate (5b)

Methyl 4-hydroxybenzoate **7b** (4.00 g, 26.32 mmol) was added to a stirred solution of NaOH (12 %, 20 mL, 60 mmol) at 0 ^{o}C and then formaldehyde solution in water (37%, 16 mL) was added. The reaction mixture was stirred at ~55 ^{o}C for 16 h (tlc). Reaction mixture was quenched with ammonium chloride, diluted with water (50 mL) and extracted with ethyl acetate (3 x 50 mL). The combined extract was washed with brine (100 mL) and dried over anhydrous Na_2SO_4. Solvent was removed under reduced pressure, and residue was chromatographed on silica gel. Elution with petroleum ether /

ethyl acetate (60:40) gave compound **5b** as a colorless solid (1.34 g, 28%); mp 148-150 ^{o}C (lit.[11b] mp 153-154 ^{o}C) [R_f = 0.5 petroleum ether/EtOAc (60:40)]. IR ν_{max}: 3395, 1715, 1657 Cm^{-1}. ^{1}H NMR (500 MHz, CD_3COCD_3): δ 9.20 (bs, 1H), 8.00 (d, J = 2.2 Hz, 1H), 7.78 (dd, J_1 = 8.4 Hz, J_2 = 2.2 Hz, 1H), 6.89 (d, J = 8.4 Hz, 1H), 4.76 (s, 2H), 4.52 (bs, 1H), 3.82 (s, 3H). ^{13}C NMR (125 MHz, CD_3COCD_3): δ 167.2, 160.1, 130.8, 130.1, 128.8, 122.4, 115.8, 61.0, and 51.9. HRMS (ESI): m/z [M + Na]$^{+}$ calcd for $C_9H_{10}NaO_4$: 205.0471; found: 205.0474. The literature reported[11b] only ^{1}H NMR data for this compound, that is in agreement with our data.

Oxidation of 5a: 6-tert-Butyl 8-ethyl 3-oxospiro[bicyclo[2.2.2]oct[5]ene-2,2'-oxirane]-6,8-dicarboxylate (9a) and tert-butyl 3-formyl-4-hydroxybenzoate (8a)

To a stirred solution of the compound **5a** (2.00 g, 8.93 mmol) and ethyl acrylate (7 mL, excess) in acetonitrile (10 mL) was added a solution of $NaIO_4$ (6.00 g, 28.00 mmol) in water (20 mL) drop wise at 0 ^{o}C and the reaction mixture was stirred at ambient temperature for 48 h. Acetonitrile was evaporated under reduced pressure, residue was diluted with water (30 mL) and extracted with ethyl acetate (3 × 50 mL). The organic extract was combined, washed with brine (50 mL) and dried over anhydrous Na_2SO_4. Solvent was removed under reduced pressure and product was chromatographed on silica gel.

Elution with petroleum ether / ethyl acetate (85:15) first gave the minor aldehyde **8a** as a colorless solid (0.183 g, 18%); mp 85 - 87 ^{o}C. [R_f = 0.5 petroleum ether/EtOAc (90:10)]. IR ν_{max}: 3390, 1663 cm^{-1}. ^{1}H NMR (400 MHz, CD_3COCD_3): δ 11.35 (s, 1H), 10.13 (s, 1H), 8.40 (d, J = 2.0 Hz, 1H), 8.14 (dd, J_1 = 8.7 Hz, J_2 = 2.0 Hz, 1H), 7.06 (d, J = 8.7 Hz, 1H), 1.59 (s, 9H). ^{13}C NMR (100 MHz, CD_3COCD_3): δ 197.9, 165.3, 164.8, 138.2, 136.3, 125.0, 121.4, 118.2, 81.7, 28.3. HRMS (ESI): m/z [M + K]$^{+}$ calcd for $C_{12}H_{14}KO_4$: 261.0524; found: 261.0525. The above data is in agreement with those reported in literature.[13]

Continued elution with petroleum ether / ethyl acetate (70:30) gave the desired adduct **9a** as a colorless solid (1.77 g, 62%); mp 104 - 106 ^{o}C. [R_f = 0.5 petroleum ether/EtOAc (70:30)]. IR ν_{max}: 1732, 1712 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.06 (dd, J_1 = 6.4 Hz, J_2 = 1.8 Hz, 1H), 4.15 (q, J = 7.1 Hz, 2H), 3.86 (dd, J_1 = 6.4 Hz, J_2 = 2.2 Hz, 1H), 3.21-3.15 (m, 2H), 3.11 (part of an AB system, J_{AB} = 6.2 Hz, 1H), 2.93 (part of an AB system, J_{AB} = 6.2 Hz, 1H), 2.44 (partly merged ddd, J_1 = 13.3 Hz, J_2 = 10.5 Hz, J_3 = 2.6 Hz, 1H), 2.02 (ddd, J_1 = 13.3 Hz, J_2 = 5.2 Hz, J_3 = 2.9 Hz, 1H), 1.50 (s, 9H), 1.26 (t, J = 7.1 Hz, 3H). ^{13}C NMR (100MHz, $CDCl_3$): δ 203.2, 172.1, 162.5, 140.4, 135.4, 81.9, 61.7, 57.3, 53.2, 51.2, 40.6, 37.8, 28.2, 25.8, 14.2. HRMS (ESI): m/z [M + Na]$^{+}$ calcd for $C_{17}H_{22}NaO_6$: 345.1309; found: 345.1306.

Crystal data of **9a**: Crystal data of compound **9a**: $C_{17}H_{22}O_6$, M = 322.36, triclinic, space group P-1 (# 2), a = 6.636 (4) Å, b = 9.419 (6) Å, c = 13.627 (8) Å, α = 92.616 (10)°, β = 99.969(12)°, γ = 93.654(9)°, V = 835.8 (9) Å^3, D_c = 1.281 g/ cm^3, Z = 2, F(000) = 344.00, Size: 0.45 x 0.20 x 0.09 mm^3, Wavelength = 0.71070 Å, GoF = 0.885, Absorption coefficient = 0.965 cm^{-1}, Total/unique reflections = 8828 / 2929 [R(int) = 0.0950], T = 100 K, 2θ range = 5.0 to 50.0°, Final R [$I > 2s(I)$]: R_1 = 0.0567, wR_2 = 0.1604, R (all data): R_1 = 0.0854, wR_2 = 0.1604. Crystallographic data has been deposited with Cambridge Crystallographic data Centre, CCDC no. 1004667. Copy of the data can be obtained, free of charge, on application to CCDC. E-mail. Deposit@ccdc.cam.ac.UK

Oxidation of 5b: 8-ethyl 6-methyl 3-oxospiro[bicycle[2.2.2]oct[5]ene-2,2'-oxirane]-6,8-dicarboxylate (9b) and Methyl 3-formyl-4-hydroxybenzoate (8b)

To a stirred solution of the compound **5b** (2.00 g, 10.98 mmol) in acetonitrile (10 mL), ethyl acrylate (6 mL, excess) was added a solution of $NaIO_4$ (7.00 g, 32.73 mmol) in water (20 mL) added drop wise in it at 0 ^{o}C and stirred for 48 h. Acetonitrile was evaporated under reduced pressure, diluted with water (50 mL) and extracted with ethyl acetate (3 × 50 mL). The organic extracts were combined and washed with brine (100 mL) and dried over

anhydrous Na_2SO_4, evaporated under reduced pressure, and residue was chromatographed on silica gel.

Elution with petroleum ether / ethyl acetate (85:15) first gave the known aldehyde **8b** as a colorless solid (0.730 g, 37%), mp 79 – 81 ^oC. [R_f = 0.5 petroleum ether/EtOAc (90:10)]. IR ν_{max}: 3391, 2923, 1715, 1647 cm^{-1}. ^1H NMR (400 MHz, CD_3COCD_3): δ 11.40 (bs, 1H), 10.16 (s, 1H), 8.45 (d, J = 2.2 Hz, 1H), 8.18 (dd, J_1 = 8.7 Hz, J_2 = 2.2 Hz, 1H), 7.09 (d, J = 8.7 Hz, 1H), 3.89 (s, 3H). ^{13}C NMR (125 MHz, CD_3COCD_3): δ 197.8, 166.0, 165.6, 138.2, 136.5, 123.2, 121.6, 118.5, 52.4. HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_9H_8NaO_4$: 203.0315; found: 203.0312. The ^1H NMR spectral features are in good agreement with those reported in literature.[13]

Continued elution with petroleum ether / ethyl acetate (70:30) gave compound **9b** as a liquid (1.19 g, 39%) [R_f = 0.5 petroleum ether/EtOAc (70:30)]. ^1H NMR (400 MHz, $CDCl_3$): δ 7.21 (dd, J_1 = 6.4 Hz, J_2 = 1.7 Hz, 1H), 4.16 (q, J = 7.1 Hz, 2H), 3.90 (dd, J_1 = 6.4 Hz, J_2 = 2.3 Hz, 1H), 3.80 (s, 3H), 3.26-3.19 (m, 2H), 3.10 (part of an AB system, J_{AB} = 6.2 Hz, 1H), 2.95 (part of an AB system, J_{AB} = 6.2 Hz, 1H), 2.51-2.44 (m, 1H), 2.07-2.02 (m, 1H), 1.27 (t, J = 7.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 202.8, 171.9, 163.7, 138.4, 136.9, 61.7, 57.2, 53.1, 52.3, 51.2, 40.5, 37.8, 25.8, 14.2. HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_{14}H_{16}NaO_6$: 303.0839; found: 303.0838.

Reduction of 9a with Zinc: 2-tert-Butyl 5-ethyl 7-methyl-8-oxobicyclo[2.2.2]oct-2-ene-2,5-dicarboxylate (10a) and 2-tert-Butyl 5-ethyl 7-(hydroxymethyl)-8-oxobicyclo[2.2.2]oct-2-ene-2,5-dicarboxylate (11a)

To a stirred solution of compound **9a** (0.50 g, 1.55 mmol) in MeOH : H_2O (6 : 1, 35 mL) was added activated Zinc (3.50 g, excess) and NH_4Cl (0.425 g, 8.02 mmol). The reaction mixture was stirred at ambient temperature for 18 h. Reaction mixture was filtered through a small pad of silica gel. Filtrate was concentrated under vacuum and residue was diluted with water

(25 mL) and extracted with ethyl acetate (3 × 50 mL). The organic extract were washed with brine (100 mL) and dried on anhydrous Na_2SO_4, evaporated under reduced pressure, and residue was chromatographed on silica gel.

Elution with petroleum ether / ethyl acetate (75:25) gave the minor compound **10a** as a colorless solid (0.071 g, 15%); mp 84 – 86 ^oC. [R_f = 0.5 petroleum ether/EtOAc (75:25)]. IR ν_{max}: 2982, 1727 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 6.97 (dd, J_1 = 6.3 Hz, J_2 = 1.6 Hz, 1H), 4.11 (q, J = 7.1 Hz, 2H), 3.64 (dd, J_1 = 6.3 Hz, J_2 = 1.9 Hz, 1H), 3.41-3.36 (m, 1H), 2.91 – 2.86 (m, 1H), 2.29 – 2.22 (m, 1H), 2.03 – 1.98 (m, 1H), 1.77 – 1.73 (m, 1H), 1.48 (s, 9H), 1.23 (t, J = 7.1 Hz, 3H), 1.13 (d, J = 7.4 Hz, 3H)(major signals). ^{13}C NMR (100MHz, $CDCl_3$): δ 212.3, 172.5, 163.2, 143.2, 134.8, 81.3, 61.4, 51.9, 41.3, 40.3, 37.3, 28.2, 23.9, 14.5, 14.2. HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_{17}H_{24}NaO_5$: 331.1516; found: 331.1518.

Continued elution with petroleum ether / ethyl acetate (60:40) gave the major compound **11a** as a liquid (0.407 g, 81%) [R_f = 0.5 petroleum ether/EtOAc (60:40)]. IR ν_{max}: 3505, 2980, 1711 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 7.15 & 6.94 (dd, J_1 = 6.5 Hz, J_2 = 1.8 Hz, total 1H), 4.17 – 4.09 (m, 2H), 3.86 – 3.74 (m, 1H), 3.73 – 3.66 (m, 1H) 3.65 – 3.43(m, total 2H), 3.09 – 2.94 (m, 1H), 2.35 – 2.14 (m, 2H), 2.04 (s, 1H), 1.99 – 1.92 & 1.78 – 1.72 (m, total 1H), 1.50 (s, 9H), 1.27 – 1.23 (merged t, 3H). ^{13}C NMR (100MHz, $CDCl_3$): δ 211.7, 209.6, 172.5, 172.4, 164.0, 163.0, 143.1, 141.5, 134.8, 133.2, 81.8, 81.5, 63.5, 62.3, 61.5, 61.5, 60.5, 52.2, 51.8, 49.8, 48.5, 40.5, 39.1, 34.6, 34.0, 29.4, 28.26, 28.20, 25.1, 14.3, 14.2 (signals due to both isomers). HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_{17}H_{24}NaO_6$: 347.1465; found: 347.1459.

Reduction of 9b with Zinc: 5-Ethyl 2-methyl 7-methyl-8-oxobicyclo[2.2.2]oct-2-ene-2,5-dicarboxylate (10b) and 5-Ethyl 2-methyl 7-(hydroxymethyl)-8-oxobicyclo[2.2.2]oct-2-ene-2,5-dicarboxylate (11b)

To a stirred solution of the compound **9b** (1.10 g, 3.78 mmol) in MeOH:H_2O (6:1, 70 mL) was added activated Zinc (7.00 g excess) and NH_4Cl (1.14 g, 21.35 mmol). Reaction mixture was stirred at ambient temperature for 18 h. The reaction mixture was filtered through a small pad of silica gel. Methanol is evaporated and residue diluted with water (50 mL) and extracted with ethyl acetate (3 × 75 mL). The organic extract were washed with brine (150 mL) and dried on anhydrous Na_2SO_4, evaporated under reduced pressure, and residue was chromatographed on silica gel.

Elution with petroleum ether / ethyl acetate (75:25) gave the minor compound **10b** as a liquid (0.06 g, 6%). IR ν_{max}: 2977, 1724, 1625 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 7.10 (dd, J_1 = 6.4 Hz, J_2 = 1.9 Hz, 1H), 4.09 (q, J = 7.0 Hz, 2H), 3.75 (s, 3H), 3.66 (dd, J_1 = 6.4 Hz, J_2 = 2.0 Hz, 1H), 3.43 – 3.40 (m, 1H), 2.92 – 2.88 (m, 1H), 2.30 – 2.23 (m, 1H), 2.03 – 1.96 (m, 1H), 1.77 – 1.71 (m, 1H), 1.22 (t, J = 7.0 Hz, 3H), 1.12 (d, J = 7.3 Hz, 3H). ^{13}C NMR (100MHz, $CDCl_3$): δ 211.9, 172.4, 164.3, 141.4, 136.3, 61.5, 52.1, 52.0, 41.3, 40.3, 37.4, 23.8, 14.4, 14.2. HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_{14}H_{18}NaO_5$: 289.1046; found: 289.1046.

Continued elution with petroleum ether / ethyl acetate (60:40) gave the major compound **11b** as a liquid (0.915 g, 86%). [R_f = 0.5 petroleum ether/EtOAc (60:40)]. IR ν_{max}: 3514, 2955, 1720 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 7.14 (dd, J_1 = 6.4 Hz, J_2 = 1.5 Hz, 1H), 4.12 (q, J = 7.1 Hz, 2H), 3.88 – 3.84 (m, 2H), 3.79 (s, 3H), 3.73 (dd, J_1 = 6.4 Hz, J_2 = 1.3 Hz, 1H), 3.70 – 3.67 (m, 1H), 3.03 – 2.97 (m, 1H), 2.52 (broad s, 1H), 2.37 – 2.34 (m, 1H), 2.20 – 2.17 (m, 1H), 1.78 – 1.73 (m, 1H), 1.24 (t, J = 7.1 Hz, 3H).^{13}C NMR (100MHz, $CDCl_3$): δ 211.0, 172.4, 164.2, 141.3, 136.4, 61.9, 61.5, 52.26, 52.20, 48.6, 40.5, 34.6, 25.0, 14.2. HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_{14}H_{18}NaO_6$: 305.0996; found: 305.0996.

2-tert-Butyl 5-ethyl 8-oxobicyclo[2.2.2]oct-2-ene-2,5-dicarboxylate (2a)

To a solution of keto alcohol **11a** (0.39 g, 1.20 mmol) in acetone (30 mL) was added dropwise freshly prepared Jones reagent with stirring at 0 °C. After the reaction was complete

(TLC, ~1 h), the solvent was removed under vacuum at ambient temperature (30 ^{o}C), and the residue was diluted with H_2O (50 mL) and extracted with ethyl acetate (3 x 50 mL). The combined extracts was washed with brine (100 mL) and dried on anhydrous Na_2SO_4. Removal of solvent under reduced pressure gave a β-keto acid that was directly subjected to decarboxylation as follows.

The β-keto acid thus obtained was taken in THF–H_2O (1:1, 40 mL) and the mixture was refluxed for 20 h. Common salt was added to the reaction mixture and organic layer was separated. The aqueous layer was further extracted with ethyl acetate (3 x 50 mL). The organic layers were combined and dried on anhydrous Na_2SO_4. Solvent was removed under reduced pressure and residue was chromatographed on silica gel. Elution with petroleum ether / ethyl acetate (70:30) gave compound **2a** as a colourless solid (0.18 g, 51% yield), mp 57 – 59 ^{o}C. [R_f = 0.5 petroleum ether/EtOAc (70:30)]. IR ν_{max}: 2979, 1732, 1707 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.00 (dd, J_1 = 6.6 Hz, J_2 = 1.8 Hz, 1H), 4.13 (q, J = 7.1 Hz, 2H), 3.68 (dd, J_1 = 6.6 Hz, J_2 = 2.1 Hz, 1H), 3.63-3.59 (m, 1H), 3.04 – 3.00 (m, 1H), 2.13 – 2.04 (m, 3H), 1.93 – 1.88 (m, 1H), 1.50 (s, 9H), 1.24 (t, J = 7.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 209.3, 172.6, 163.2, 142.1, 134.9, 81.3, 61.4, 52.0, 39.8, 38.8, 31.7, 29.4, 28.2, 14.3. HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_{16}H_{22}NaO_5$: 317.1359; found: 317.1374.

5-Ethyl 2-methyl 8-oxobicyclo[2.2.2]oct-2-ene-2,5-dicarboxylate (2b)

To a solution of keto alcohol **11b** (0.095 g, 0.34 mmol) in acetone (15 mL) was added dropwise freshly prepared Jones reagent with stirring at 0 °C. After the reaction was complete (TLC, ~1 h) the solvent was removed under vacuum at ambient temperature (30 ^{o}C) and the residue was diluted with H_2O (20 mL) and extracted with ethyl acetate (4 x 25 mL). The combined extracts was washed with brine (75 mL) and dried on anhydrous Na_2SO_4, and solvent was removed under reduced pressure, and the resulting β-keto acid was directly subjected to decarboxylation as follows.

The β-keto acid thus obtained was taken in THF–H_2O (1:1, 30 mL) and the mixture was refluxed for 20 h. Salt was added to the reaction mixture and organic layer was separated and the aqueous layer was further extracted with ethyl acetate (3 x 30 mL). The combined organic layers was dried on anhydrous Na_2SO_4, solvent was removed under reduced pressure and product was chromatographed on silica gel. Elution with petroleum ether / ethyl acetate (70:30) gave compound **2b** as a liquid product (0.034 g, 40% yield). [R_f = 0.4 petroleum ether/EtOAc (70:30)]. IR ν_{max}: 1709, 1643 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 7.13 (dd, J_1 = 6.6 Hz, J_2 = 2.0 Hz, 1H), 4.13 (q, J = 7.1 Hz, 2H), 3.78 (s, 3H), 3.72 (dd, J_1 = 6.6 Hz, J_2 = 2.1 Hz, 1H), 3.69 – 3.66 (m, 1H) 3.08 – 3.03 (m, 1H), 2.16 – 2.02 (m, 3H), 1.95 – 1.89 (m, 1H), 1.24 (t, J = 7.1 Hz, 3H). ^{13}C NMR (100MHz, $CDCl_3$): δ 208.8, 172.5, 164.3, 140.3, 136.3, 61.5, 52.1, 52.0, 39.8, 38.8, 31.9, 29.4, 14.2. HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_{13}H_{16}NaO_5$: 275.0890; found: 275.0872.

1-(tert-Butoxycarbonyl)-7-exo-(ethoxycarbonyl)tricyclo[3.3.0.0^{2,8}]octane-3-one (3a)

Ketone **2a** (0.100 g, 0.34 mmol) was dissolved in acetone (100 mL) and degassed by passing nitrogen. It was then irradiated with a mercury vapor lamp (125 W, Bajaj) for 30 min under nitrogen. Solvent was evaporated and residue was chromatographed on silica gel. Elution with petroleum ether / ethyl acetate (70:30) gave compound **3a** as a liquid (0.064 g, 64%). [R_f = 0.5 petroleum ether/EtOAc (70:30)]. IR ν_{max}: 2979, 1731 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 4.18 (q, J = 7.1 Hz, 2H), 3.40 (dd, J_1 = 9.1 Hz, J_2 = 5.9 Hz, 1H), 2.82-2.76 (merged multiplet, 2H), 2.68 (dd, J_1 = 18.2 Hz, J_2 = 9.1 Hz, 1H), 2.59 (d, J = 10.1 Hz, 1H) 2.45 – 2.36 (m, 1H), 1.94 (dd, J_1 = 12.1 Hz, J_2 = 6.4 Hz, 1H), 1.85 (d, J = 18.2 Hz, 1H), 1.46 (s, 9H), 1.27 (t, J = 7.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 211.2, 173.2, 169.9, 81.7, 61.3, 50.6, 47.0, 46.2, 45.1, 43.4, 40.2, 37.7, 28.1, 14.2. HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_{16}H_{22}NaO_5$: 317.1359; found: 317.1351.

7-exo-(Ethoxycarbonyl)-1-(methoxycarbonyl)tricyclo[3.3.0.0^{2,8}]octane-3-one(3b)

A solution of the ketone **2b** (0.100 g, 0.397 mmol) in acetone (100 mL) was irradiated with a mercury vapor lamp (125 W, Bajaj) for 30 min under nitrogen. Solvent was evaporated and residue was chromatographed on silica gel. Elution with petroleum ether / ethyl acetate (70:30) gave compound **3b** as a liquid (0.058 g, 58%). [R_f = 0.5 petroleum ether/EtOAc (70:30)]. IR $_{vmax}$: 2982, 1728 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 4.16 (q, J = 7.1 Hz, 2H), 3.71 (s, 3H), 3.48 (dd, J_1 = 9.5 Hz, J_2 = 6.0 Hz, 1H), 2.91 (d, J = 9.5 Hz, 1H), 2.84 – 2.81 (m, 1H), 2.75 – 2.66 (merged multiplet, 2H), 2.48 – 2.40 (m, 1H), 1.97 (dd, J_1 = 12.2 Hz, J_2 = 6.4 Hz, 1H), 1.90 (d, J = 18.6 Hz, 1H), 1.26 (t, J = 7.1 Hz, 3H). ^{13}C NMR (100MHz, $CDCl_3$): δ 210.6, 173.0, 171.1, 61.4, 52.4, 49.5, 47.0, 46.2, 45.1, 43.4, 40.4, 37.9, 14.3. HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_{13}H_{16}NaO_5$: 275.0890; found: 275.0886.

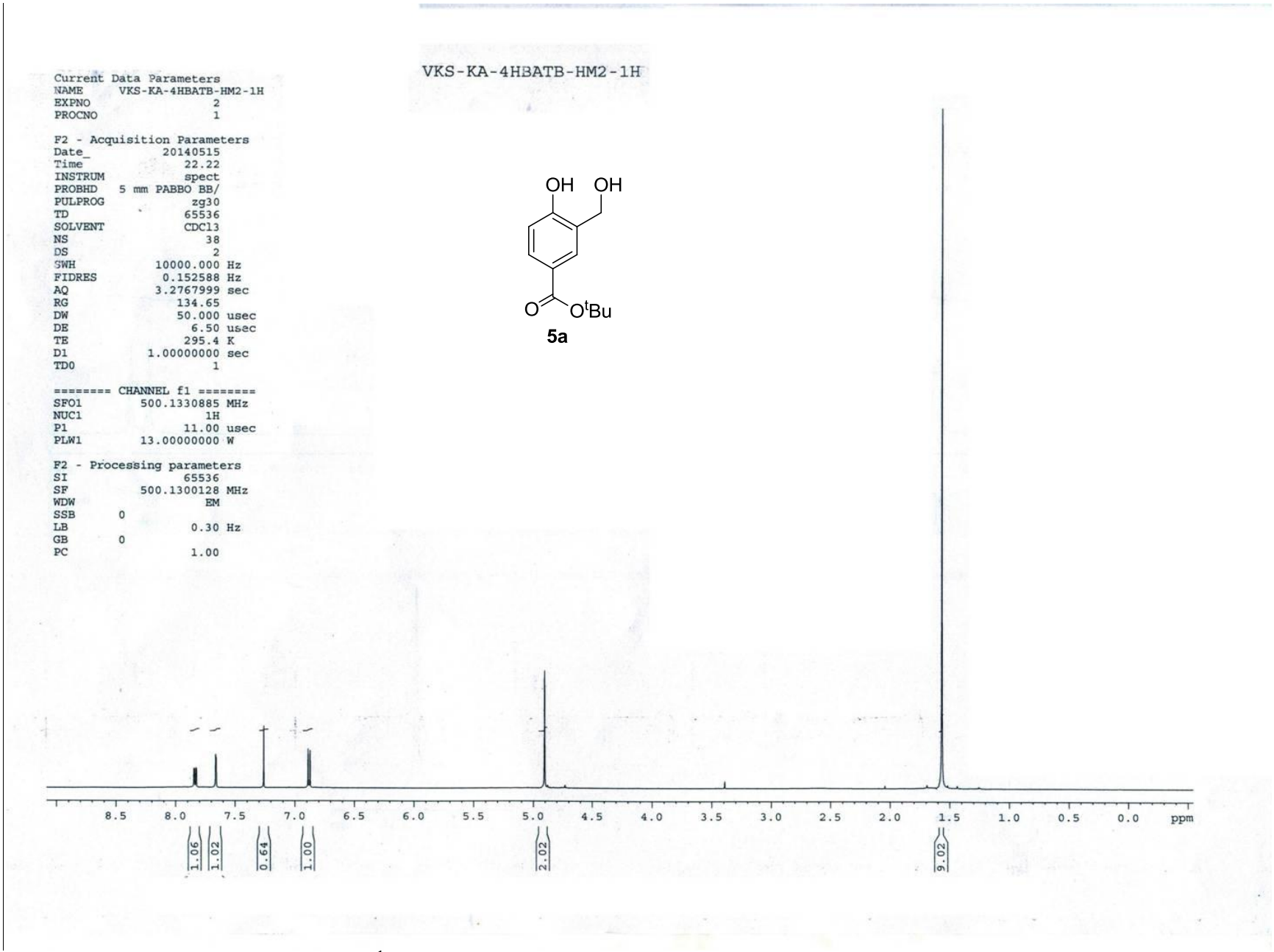
8-tert-Butyl 6-ethyl 3-oxobicyclo[3.2.1]octane-6,8-dicarboxylate (4a)

To a stirred solution of AIBN (0.025 g, 0.153 mmol) in dry benzene (5 mL) was added compound **3a** (0.045 g, 0.1531 mmol) and then Bu_3SnH (0.133 g, 0.459 mmol) was added and the reaction mixture was refluxed for 12 h. Benzene was evaporated and residue was chromatographed on silica gel. Elution with petroleum ether / ethyl acetate (70:30) gave compound **4a** as a liquid (0.042 g, 93%) [R_f = 0.55 petroleum ether/EtOAc (70:30)]. IR ν_{max}: 2979, 1722, 1157 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 4.12 (q, J = 7.1 Hz, 2H), 3.02-2.98 (m, 1H), 2.94-2.86 (m, 2H), 2.82-2.75 (m, 2H), 2.66 (dd, J_1 = 9.5 Hz, J_2 = 5.6 Hz, 1H), 2.38-2.23 (m, 2H), 2.20-2.12 (m, 1H), 1.86(dd, J_1 = 13.9 Hz, J_2 = 9.5 Hz, 1H), 1.48 (s, 9H), 1.25 (t, J =7.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 210.4, 175.3, 171.2, 81.4, 61.1, 49.1, 46.5, 45.9, 45.8, 40.8, 36.8, 33.7, 28.3, 14.3. HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_{16}H_{24}NaO_5$: 319.1516; found: 319.1532.

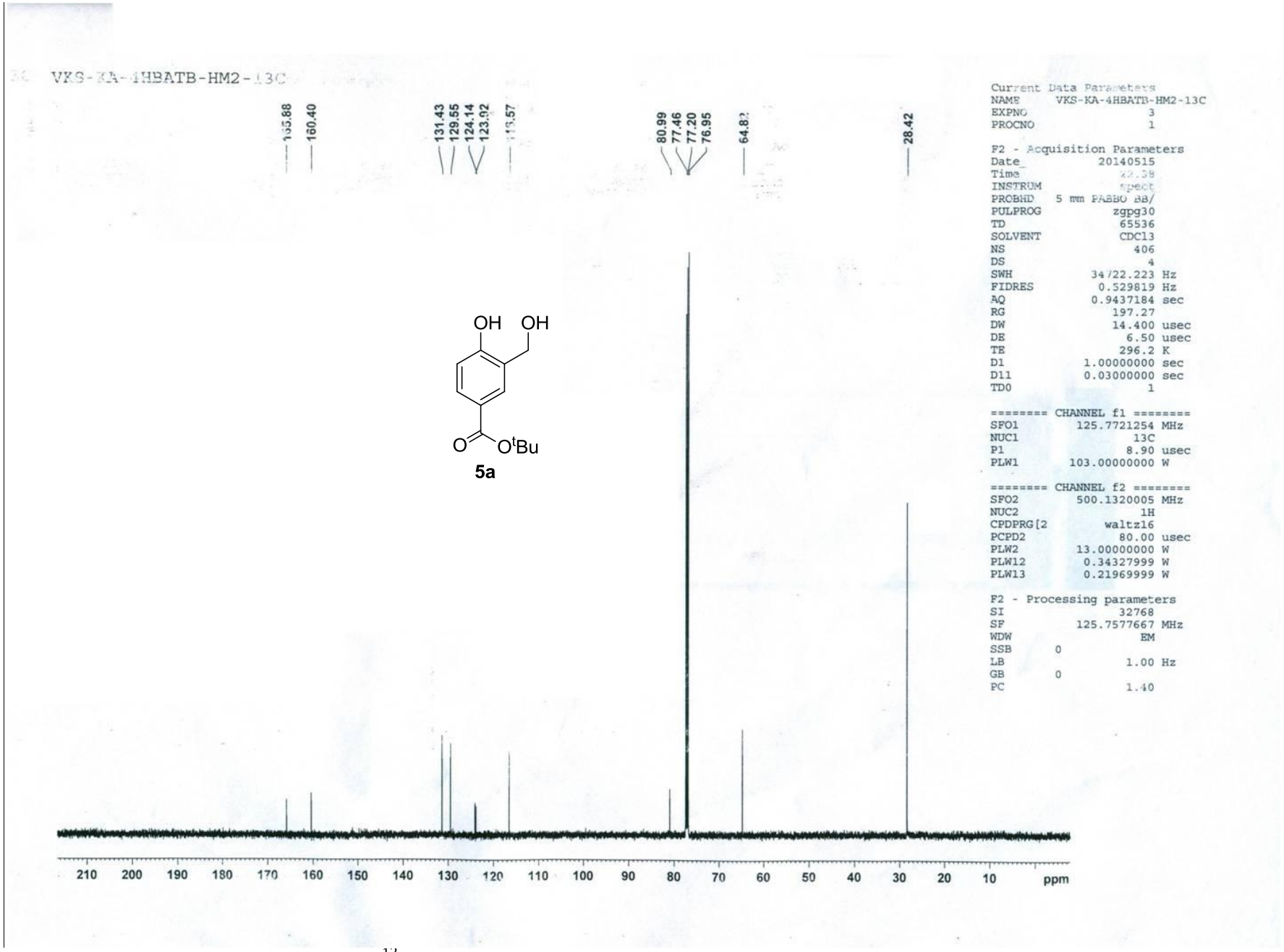
6-Ethyl 8-methyl 3-oxobicyclo[3.2.1]octane-6,8-dicarboxylate (4b)

To a stirred solution of AIBN (0.026 g, 0.1587 mmol) in dry benzene (5 mL) was added compound **3b** (0.040 g, 0.1587 mmol) and then Bu_3SnH (0.138 g, 0.4762 mmol) was added

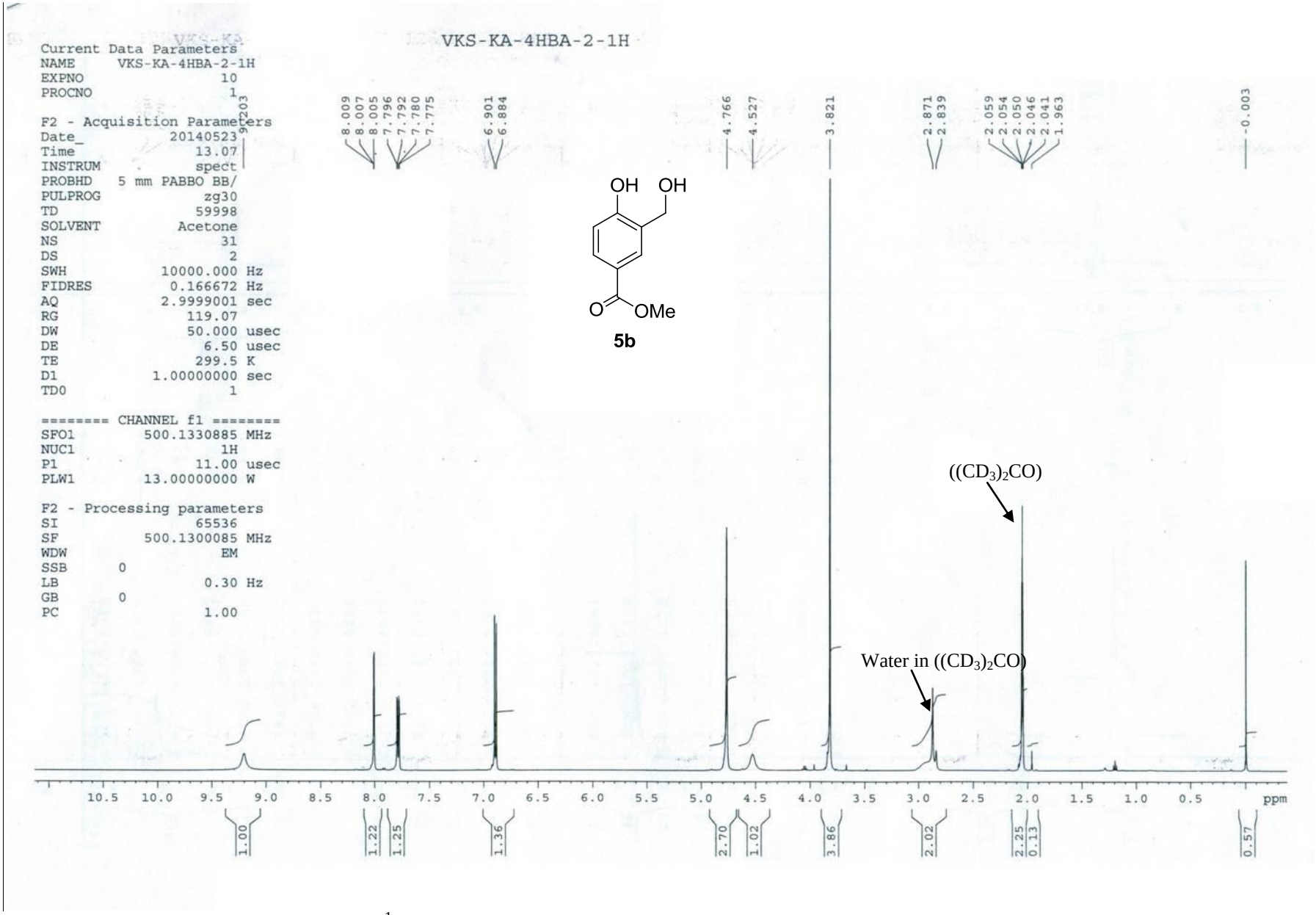
and kept for reflux for 12 h. Benzene was evaporated and residue was chromatographed on silica gel. Elution with petroleum ether / ethyl acetate (70:30) gave compound **4b** as a liquid (0.038 g, 95%) [R_f = 0.55 petroleum ether/EtOAc (70:30)]. IR ν_{max}: 2954, 1730, 1196 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 4.12 (q, J = 7.1 Hz, 2H), 3.74 (s, 3H), 3.08-3.06 (m, 1H), 3.01-2.96 (m, 1H), 2.88-2.81 (m, 2H), 2.76 (dt, J_1 = 16.8 Hz, J_2 = 3.1 Hz, 1H), 2.67 (dd, J_1 = 9.4 Hz, J_2 = 5.6 Hz, 1H), 2.36-2.25 (m, 2H), 2.22-2.14 (m, 1H), 1.89 (dd, J_1 = 9.5 Hz, J_2 = 6.9 Hz, 1H), 1.24 (t, J =7.1Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 210.0, 175.1, 172.4, 61.2, 52.0, 48.2, 46.4, 45.9, 45.8, 40.9, 36.8, 33.7, 14.3. HRMS (ESI): m/z $[M + Na]^+$ calcd for $C_{13}H_{18}NaO_5$: 277.1046; found: 277.1055.



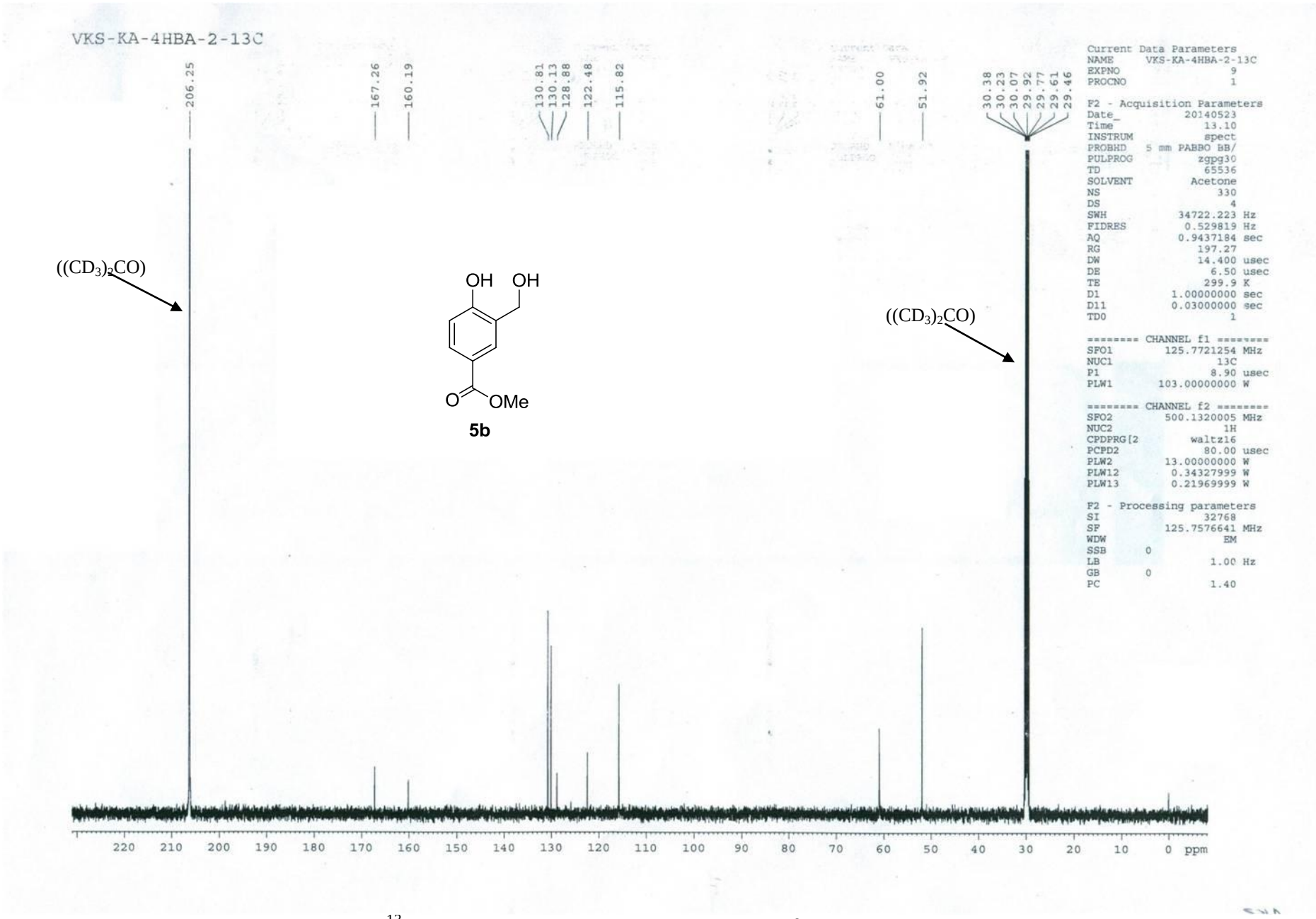
^{1}H NMR (500 MHz, $CDCl_3$) spectrum of compound **5a**



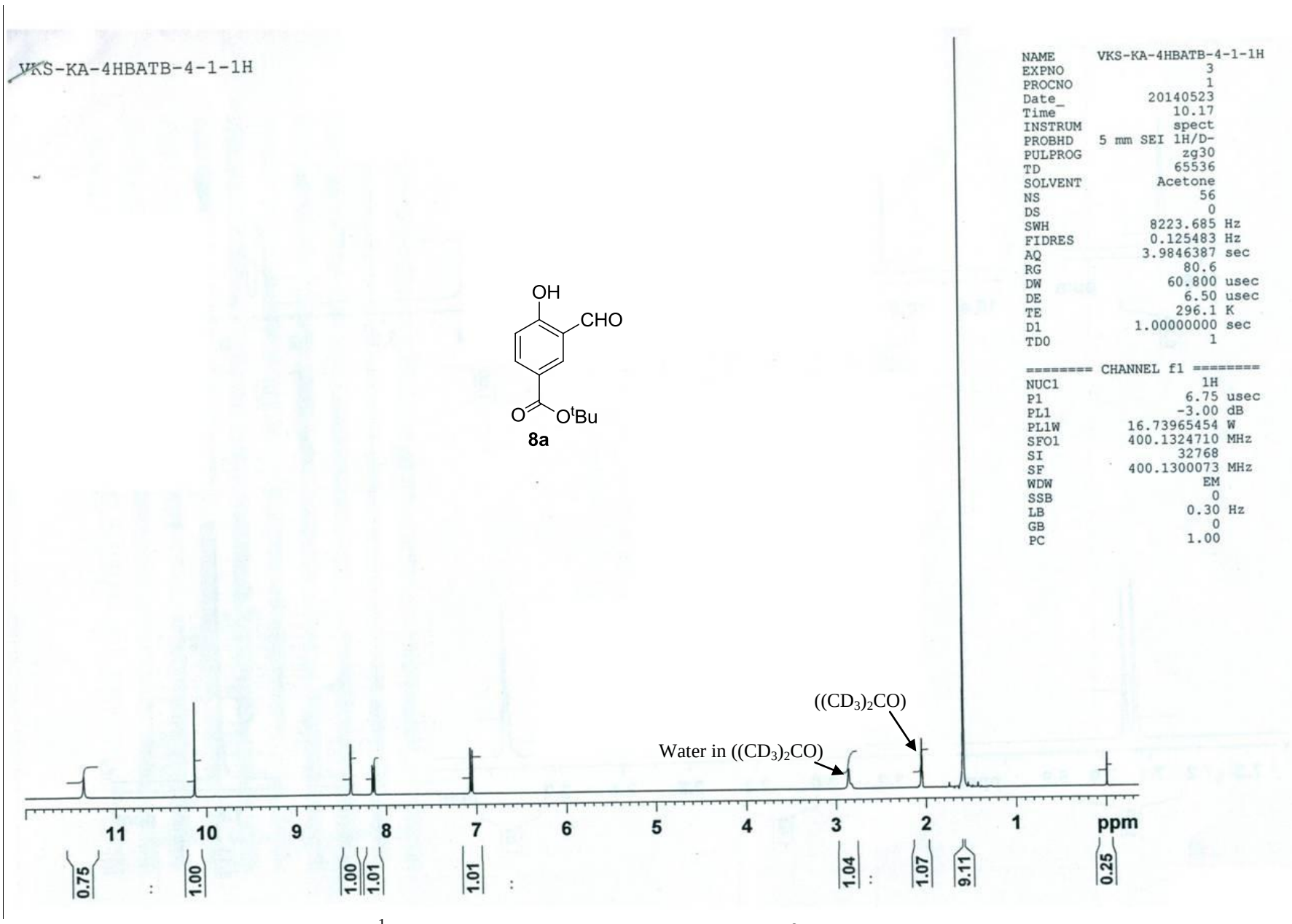
^{13}C NMR (125 MHz, $CDCl_3$) spectrum of compound **5a**



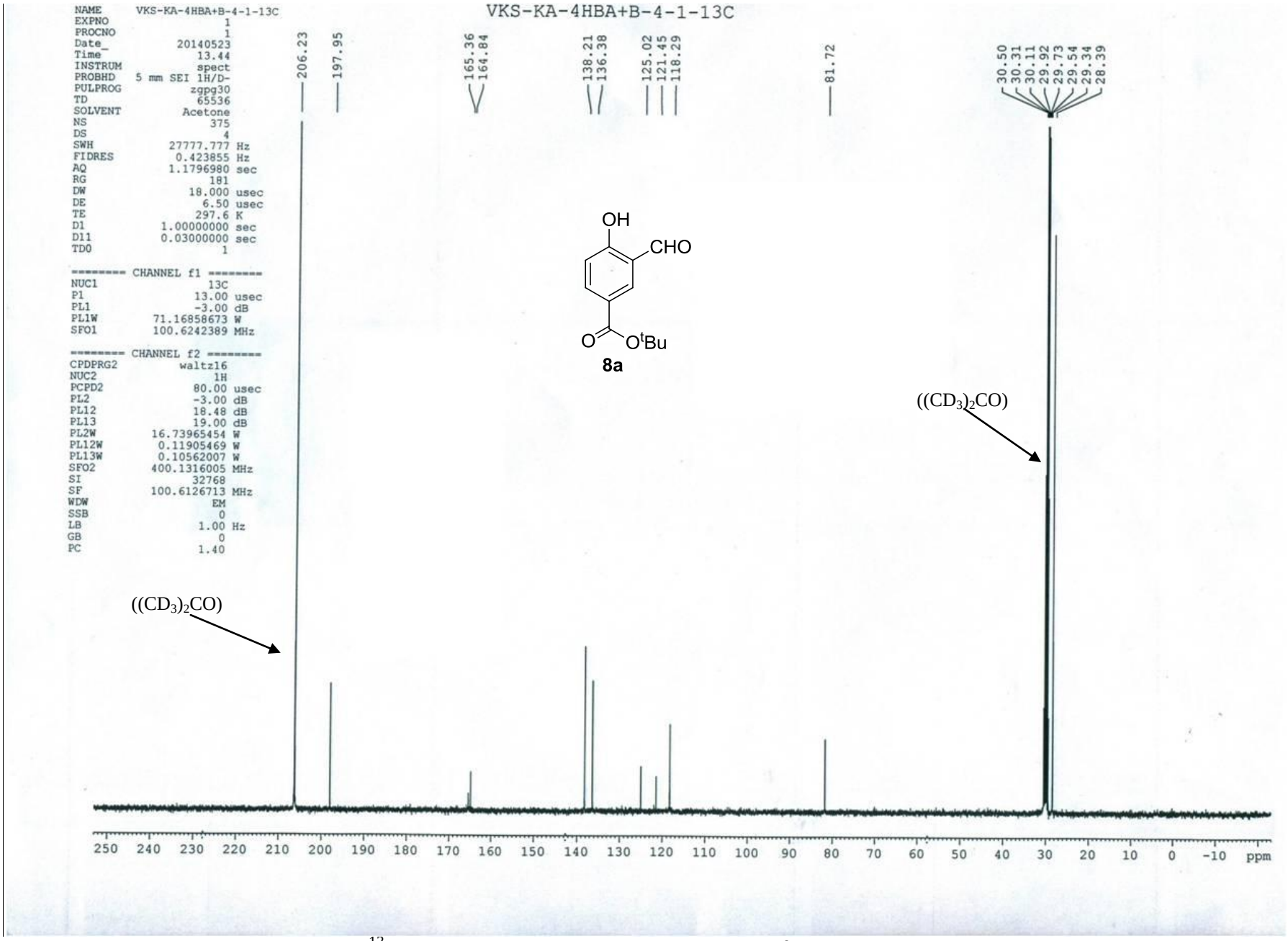
^{1}H NMR (500MHz, $(CD_3)_2CO$) spectrum of compound **5b**



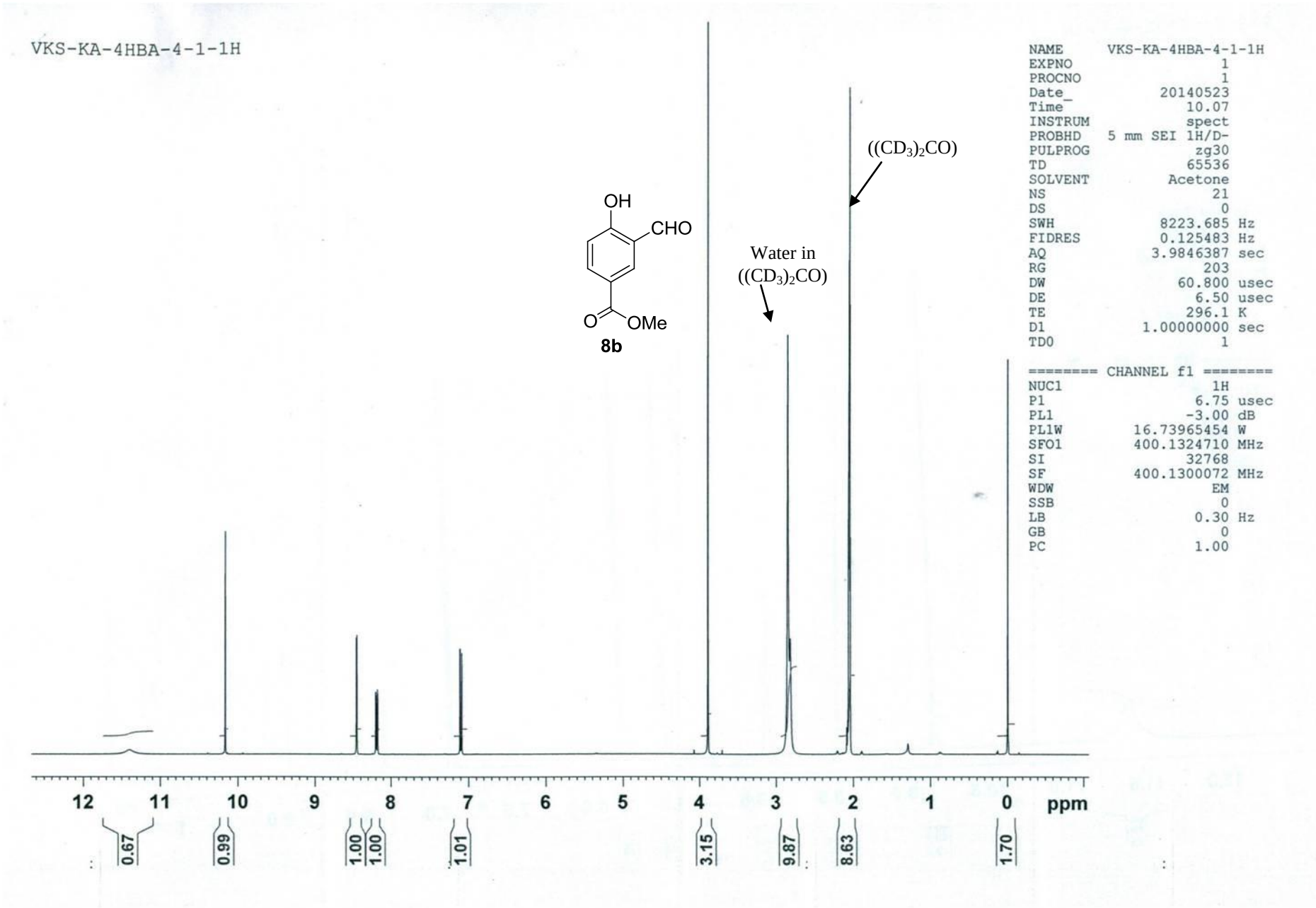
^{13}C NMR (125 MHz, $(CD_3)_2CO$) spectrum of compound **5b**



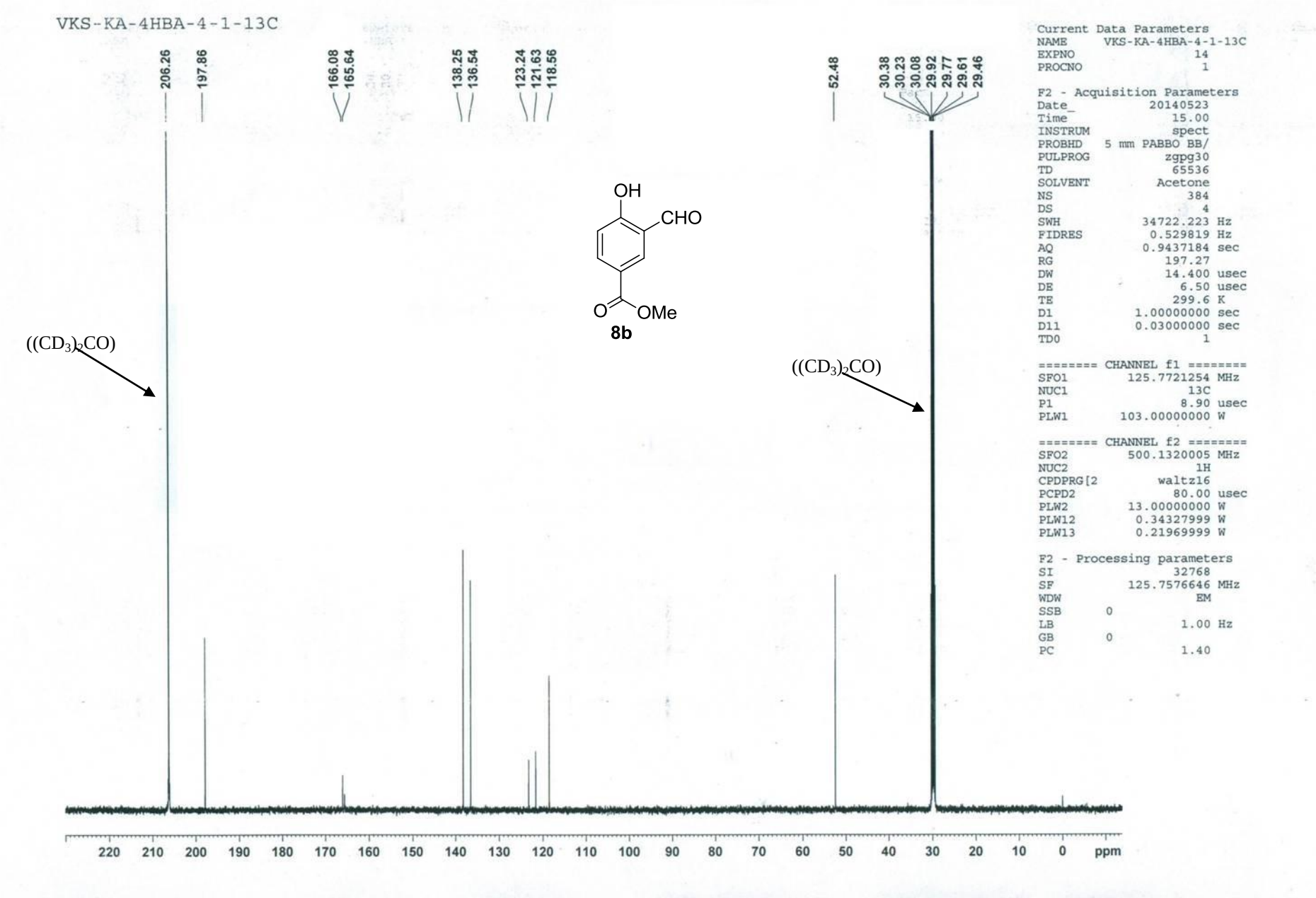
^{1}H NMR (400 MHz, $(CD_3)_2CO$) spectrum of compound **8a**



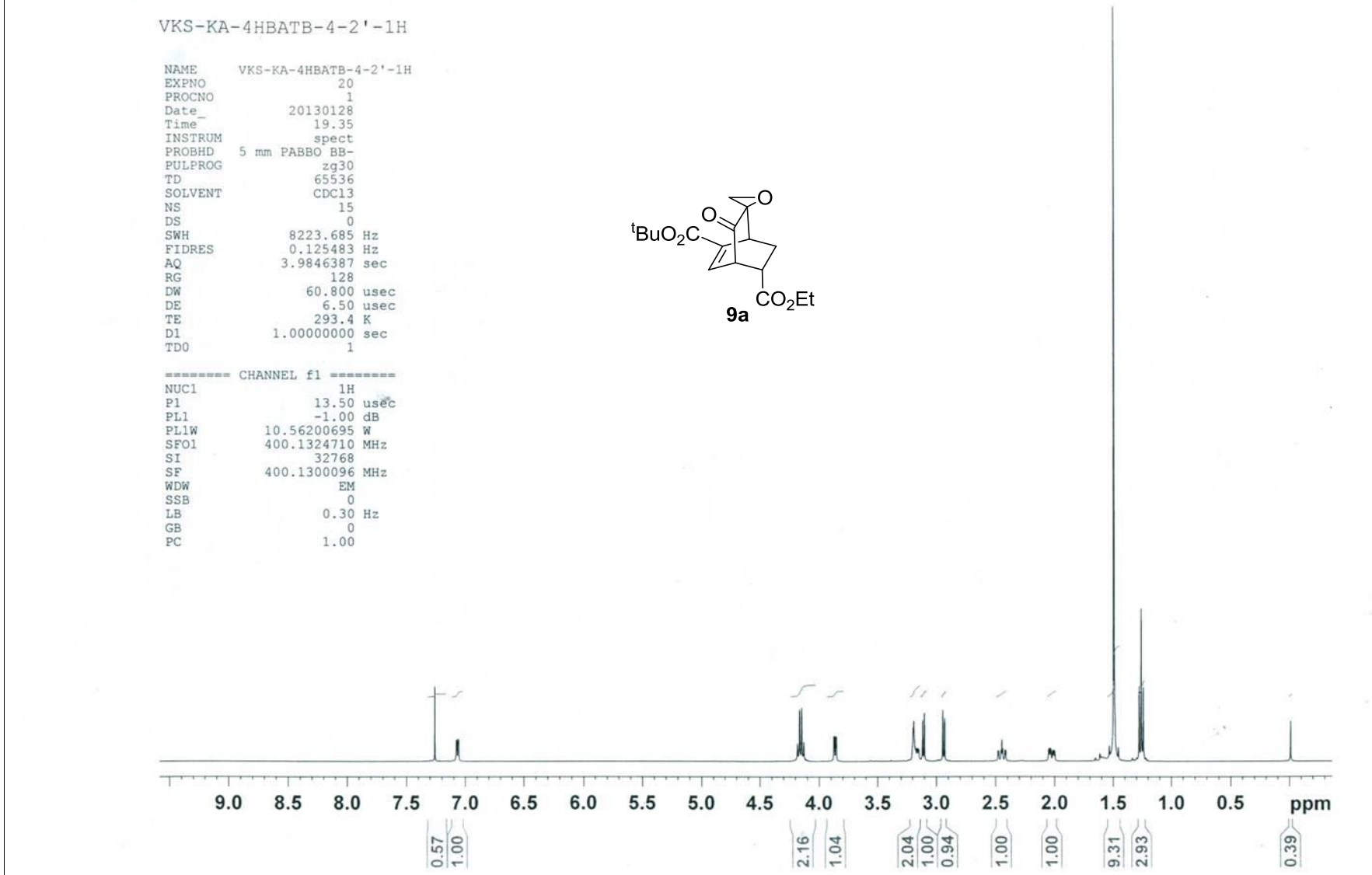
^{13}C NMR (100 MHz, $(CD_3)_2CO$) spectrum of compound **8a**



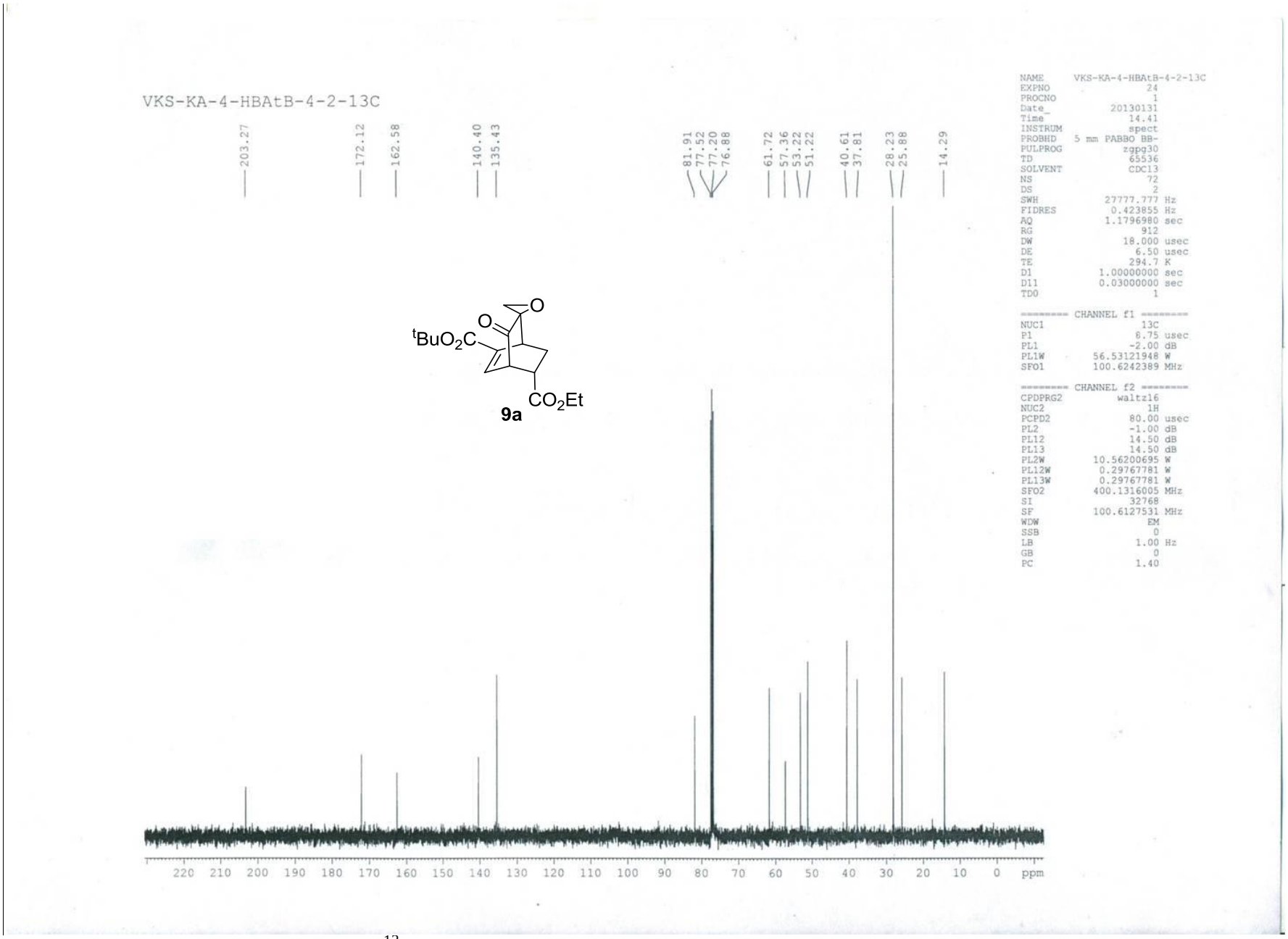
^{1}H NMR (400 MHz, $(CD_3)_2CO$) spectrum of compound **8b**



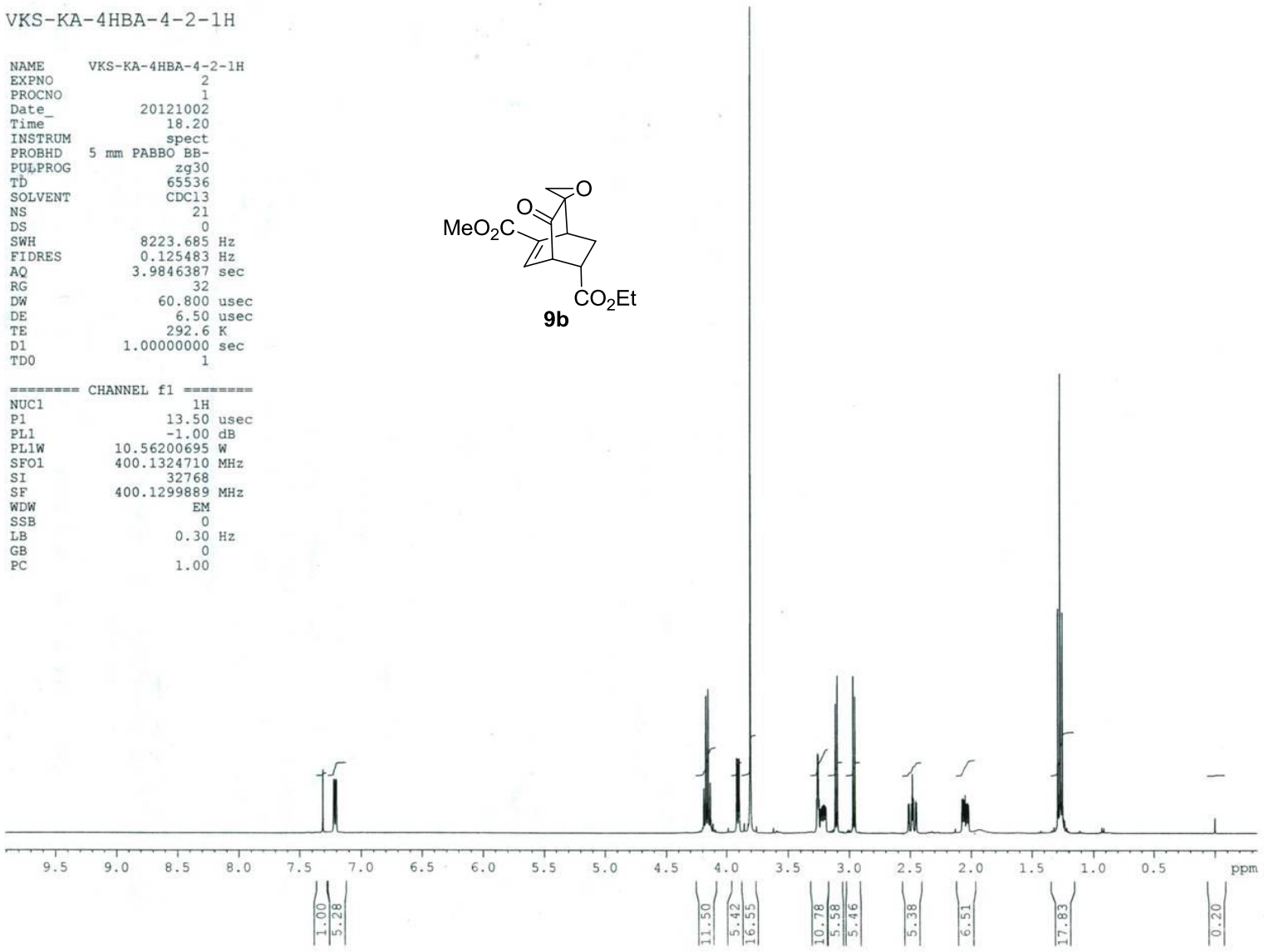
^{13}C NMR (125 MHz, $(CD_3)_2CO$) spectrum of compound **8b**



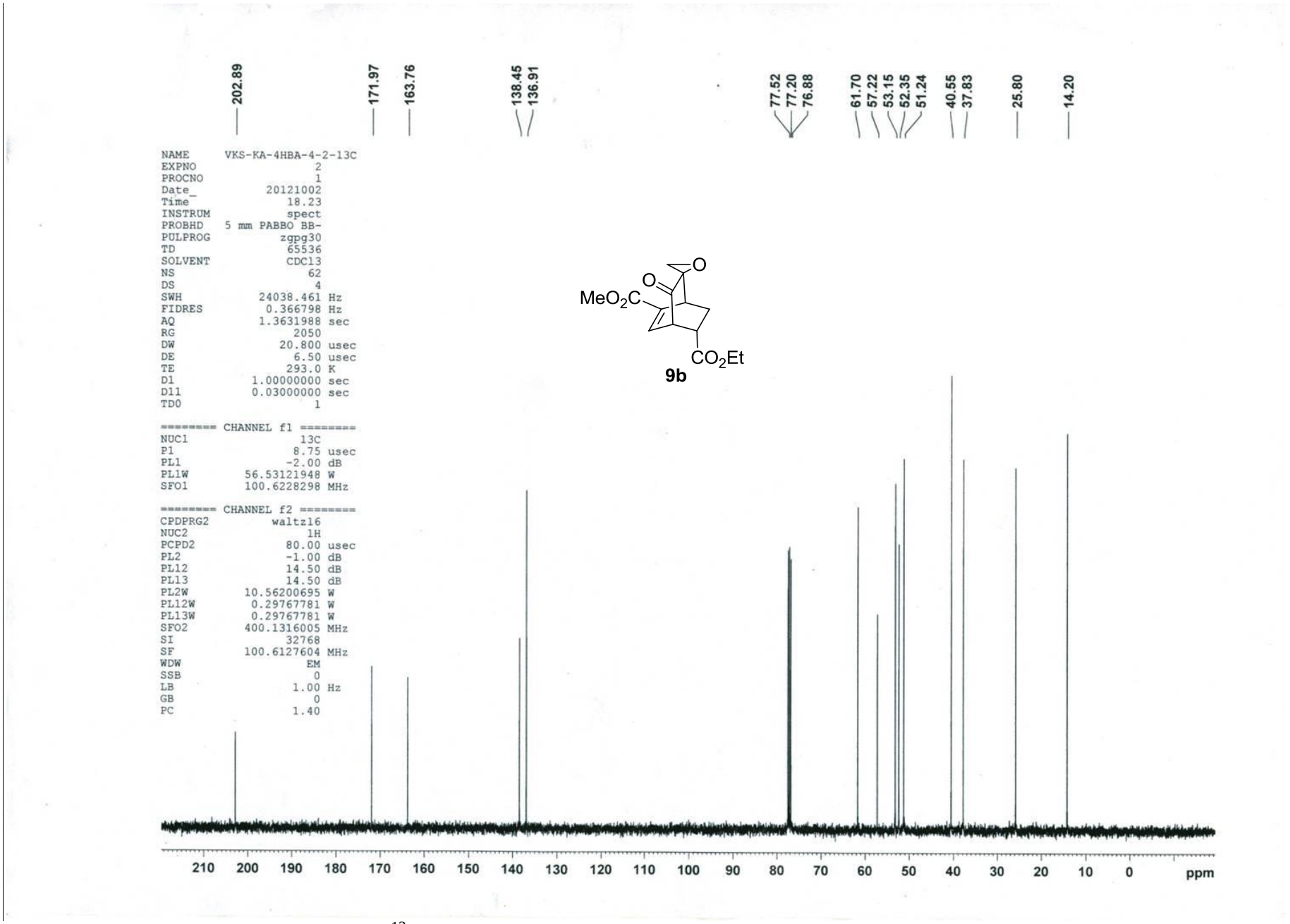
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **9a**



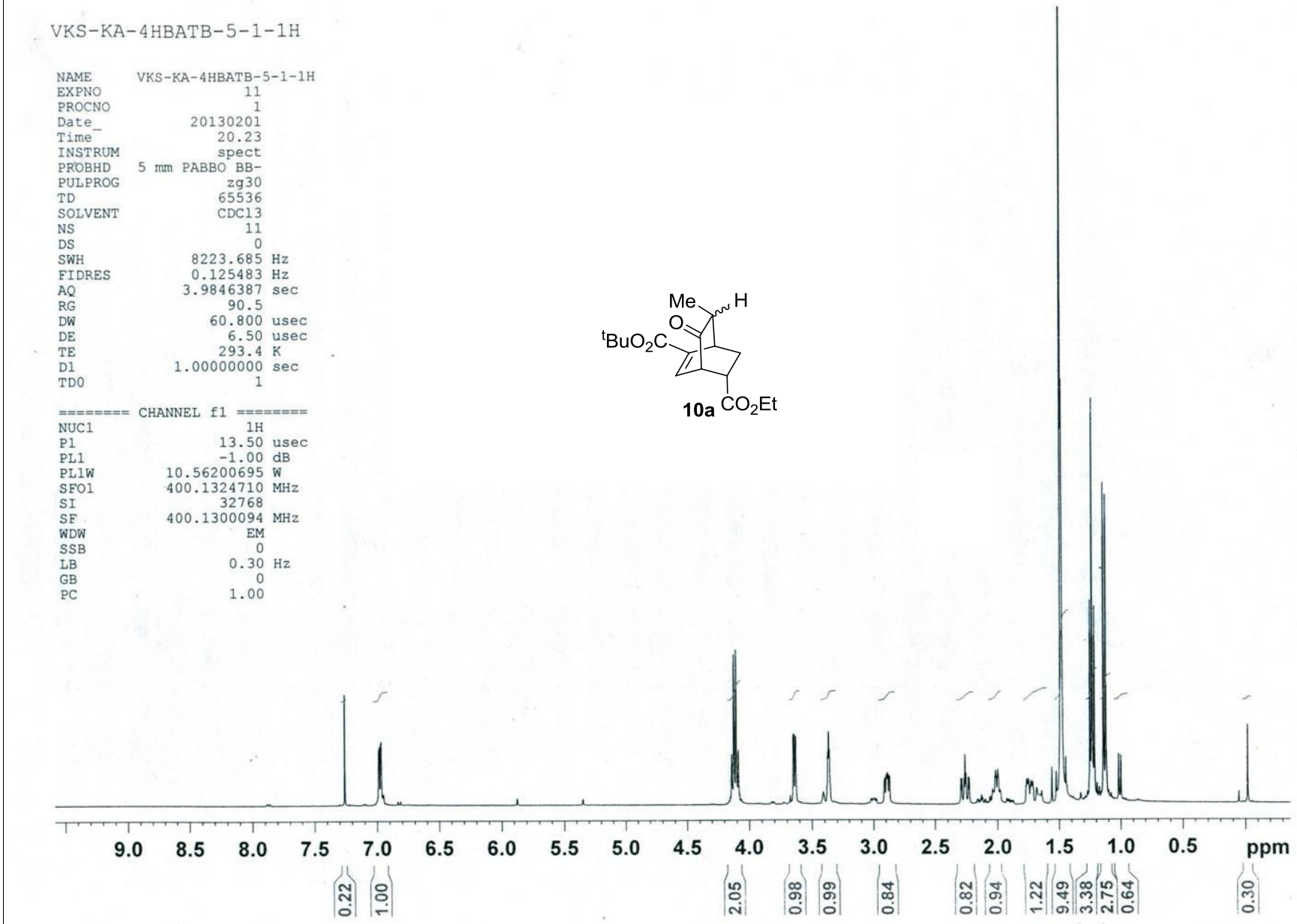
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of compound **9a**



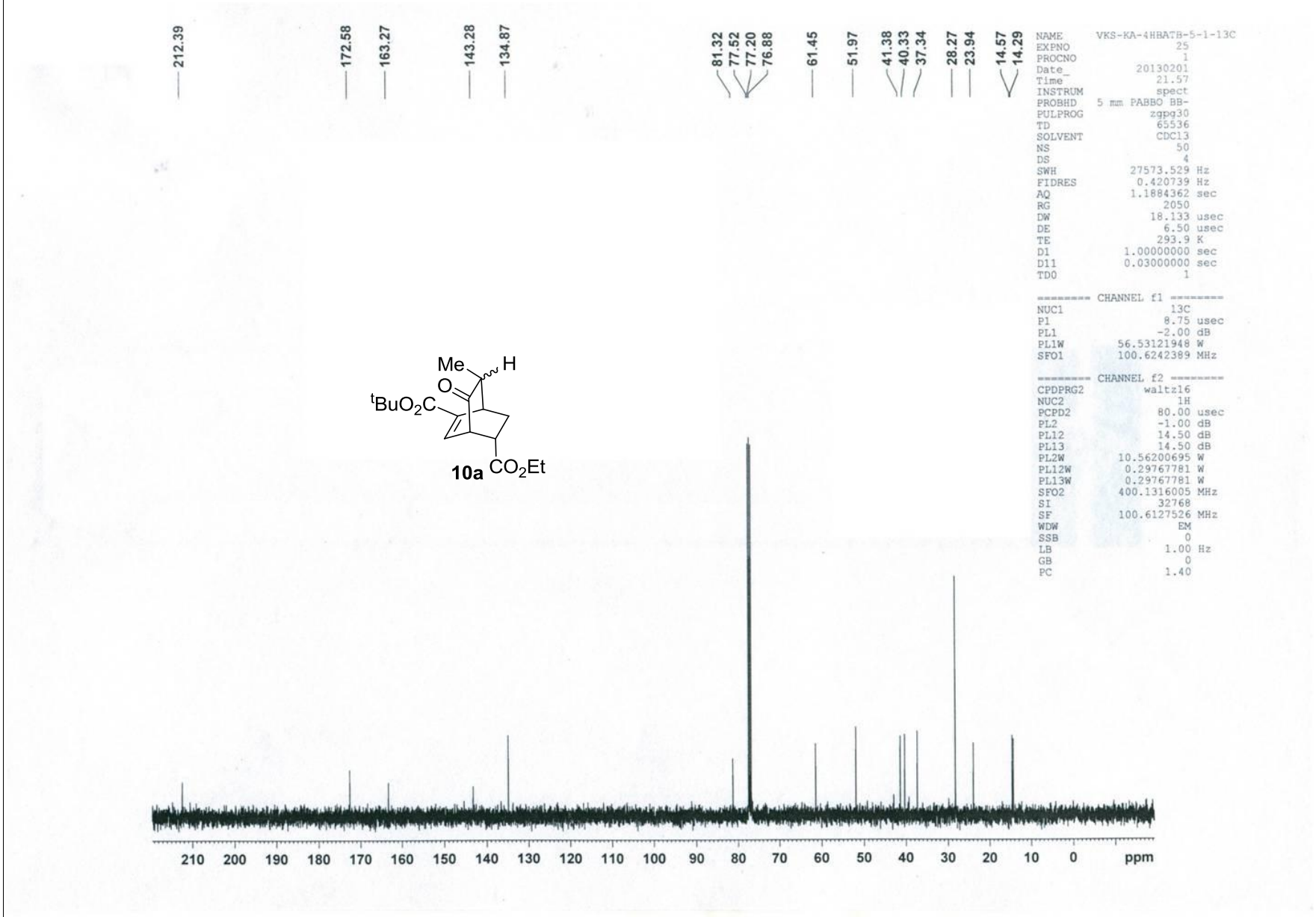
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **9b**



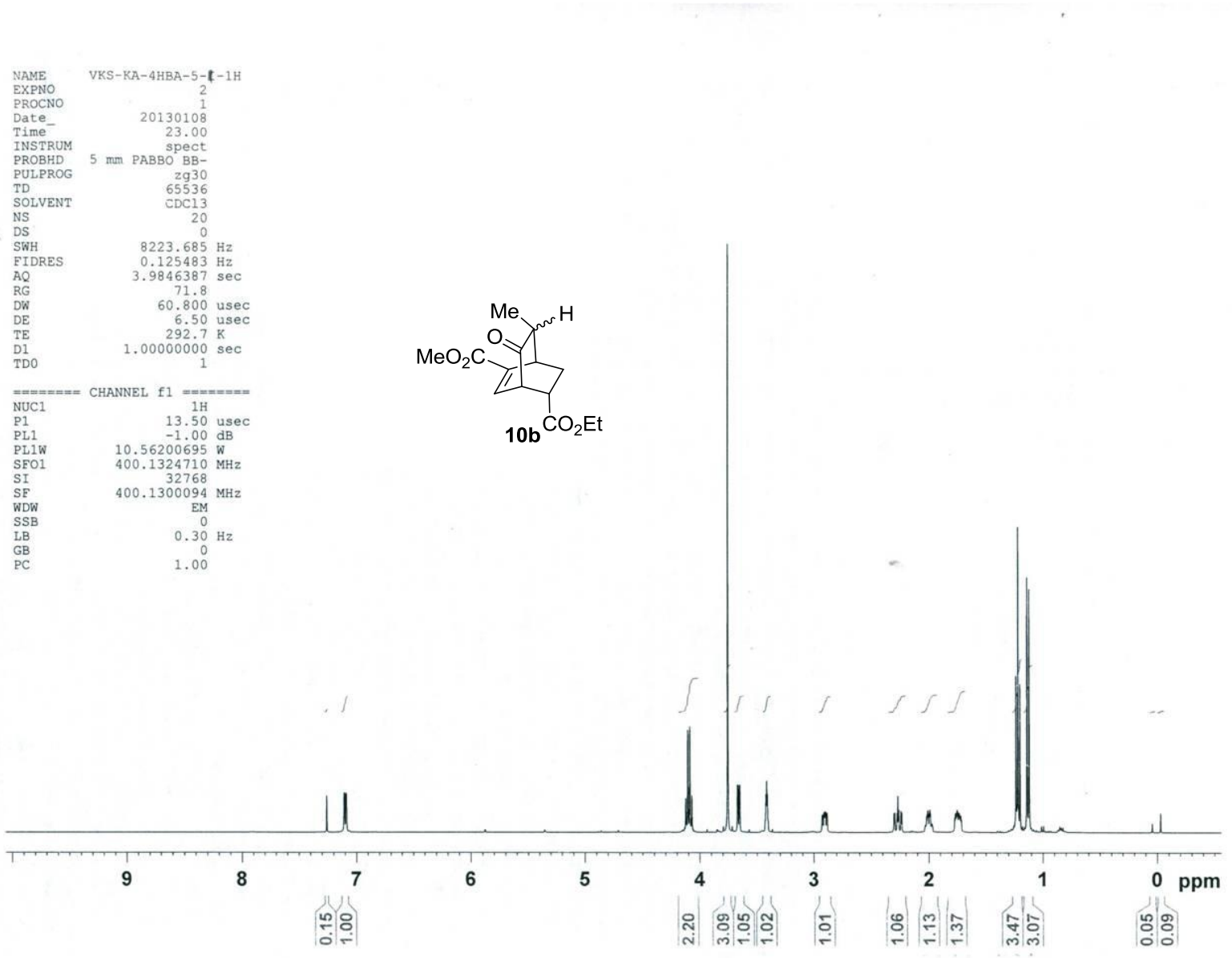
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of compound **9b**



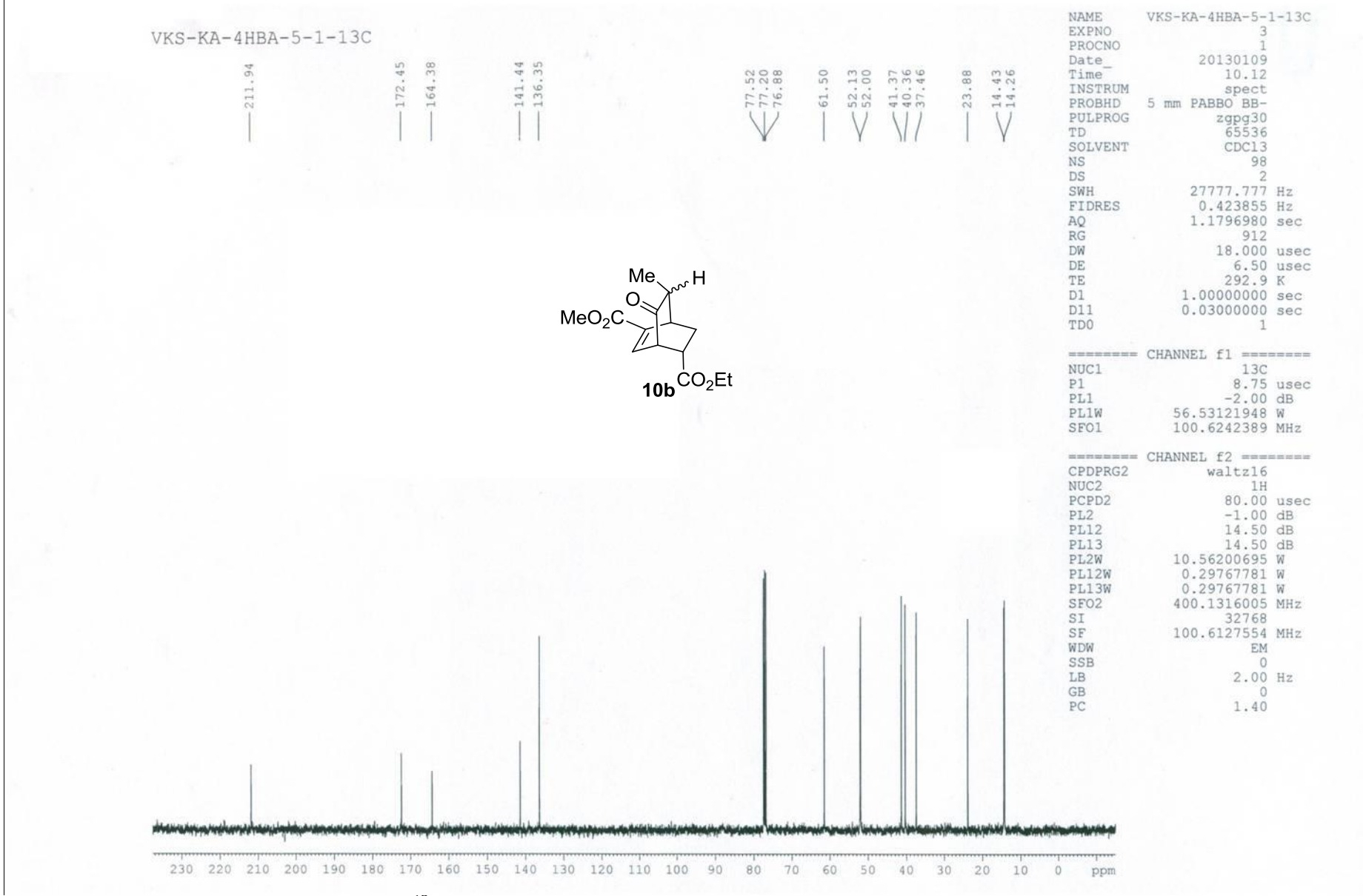
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **10a**



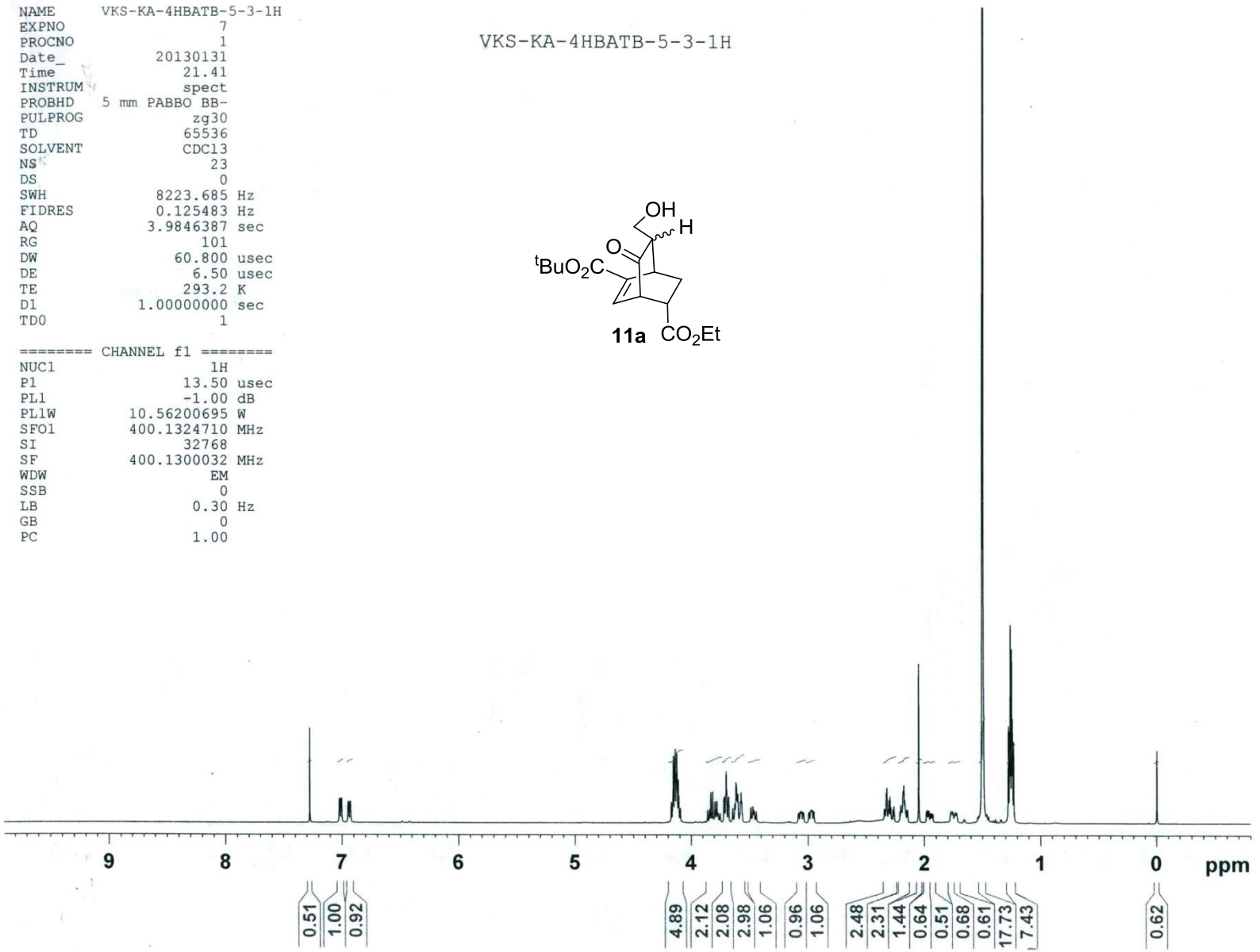
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of compound **10a**



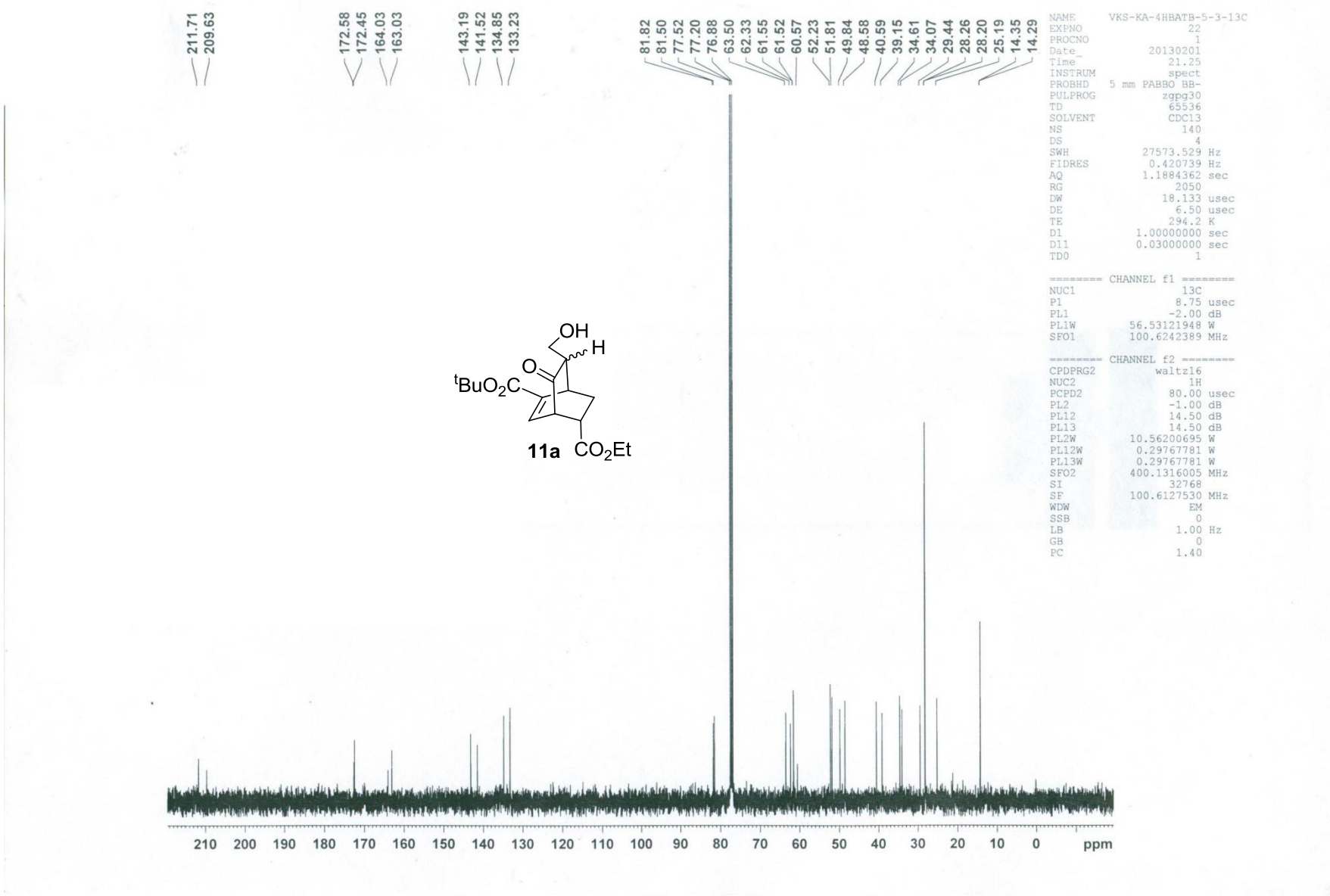
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **10b**



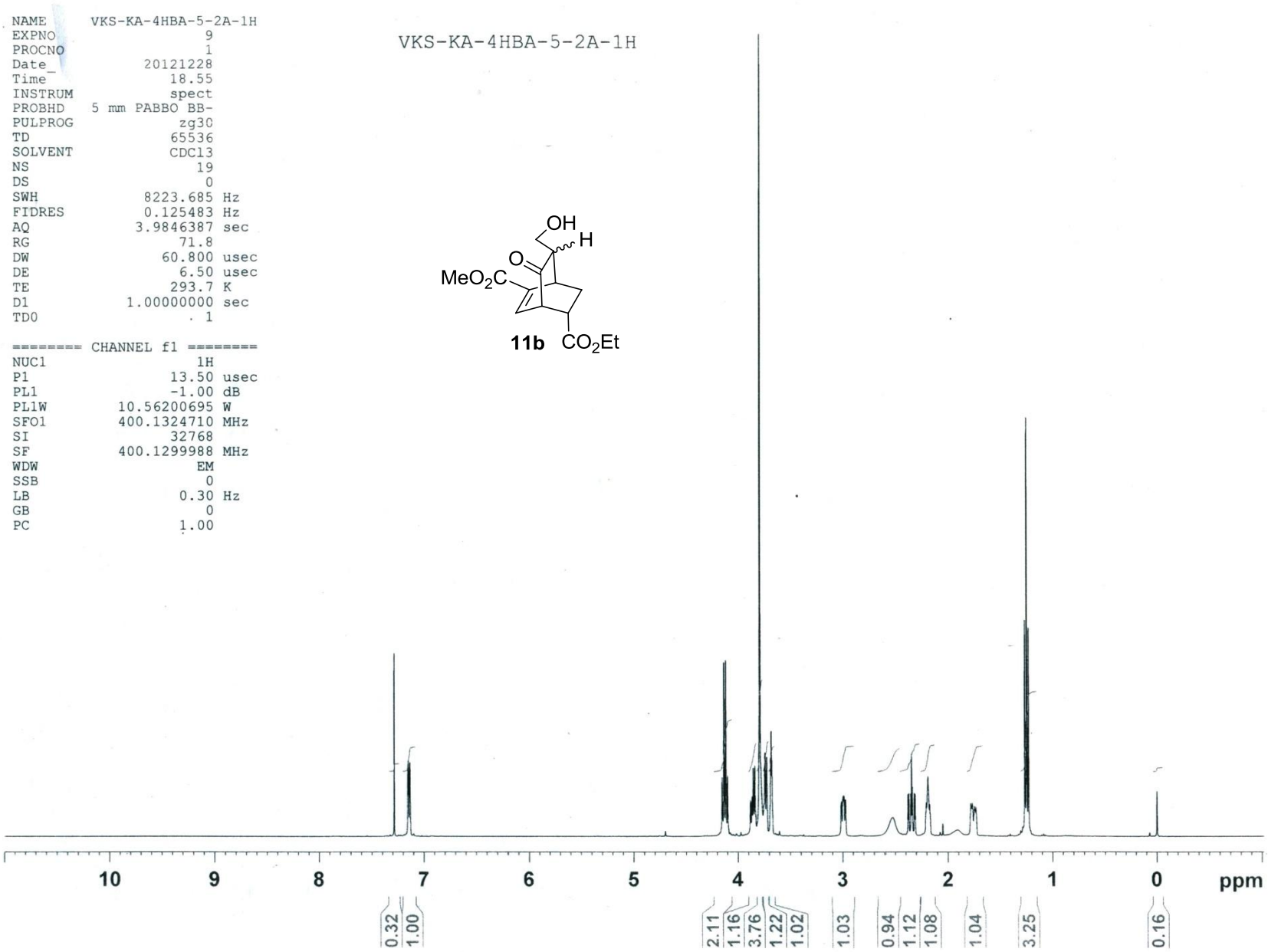
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of compound **10b**



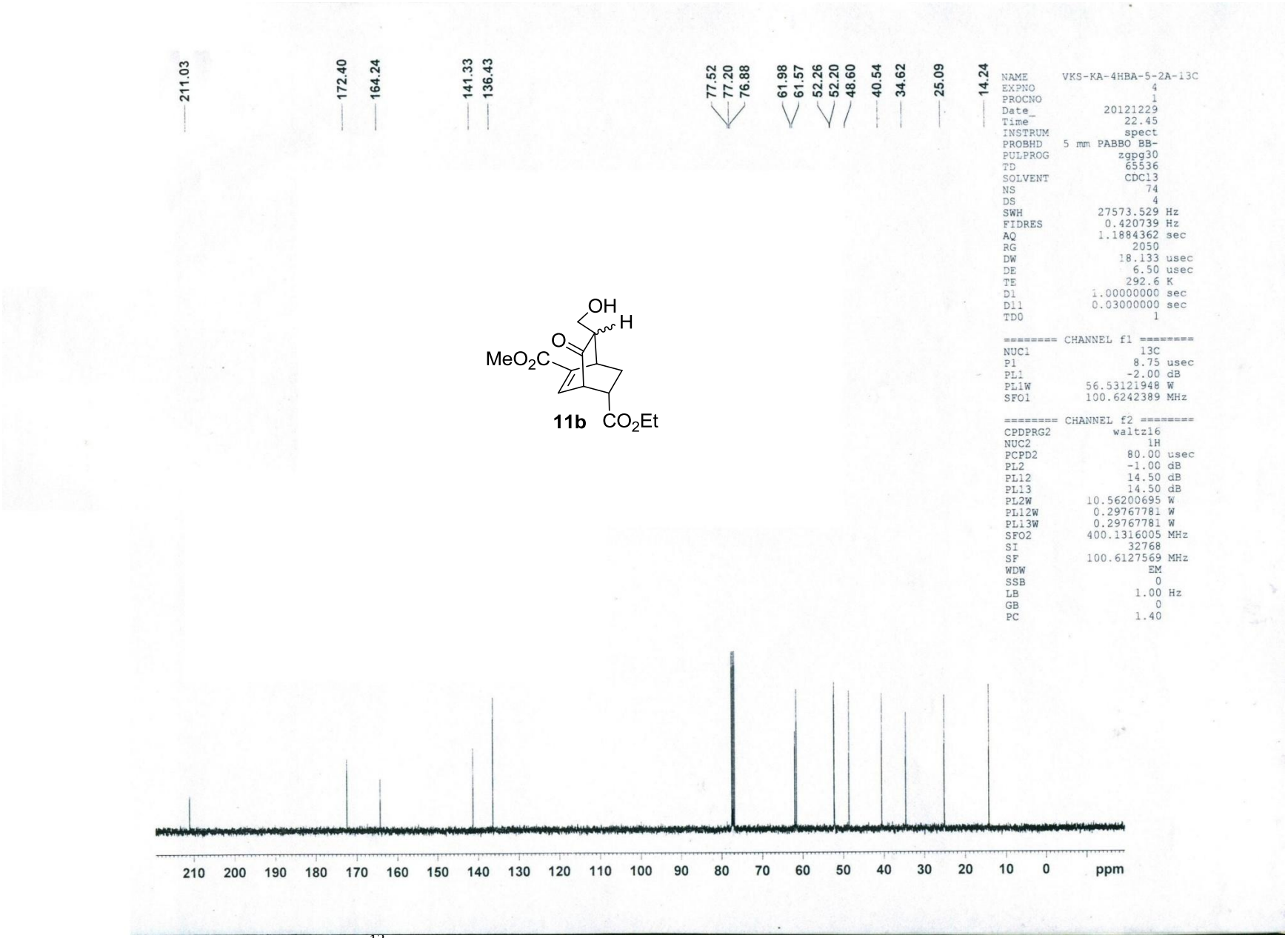
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **11a**



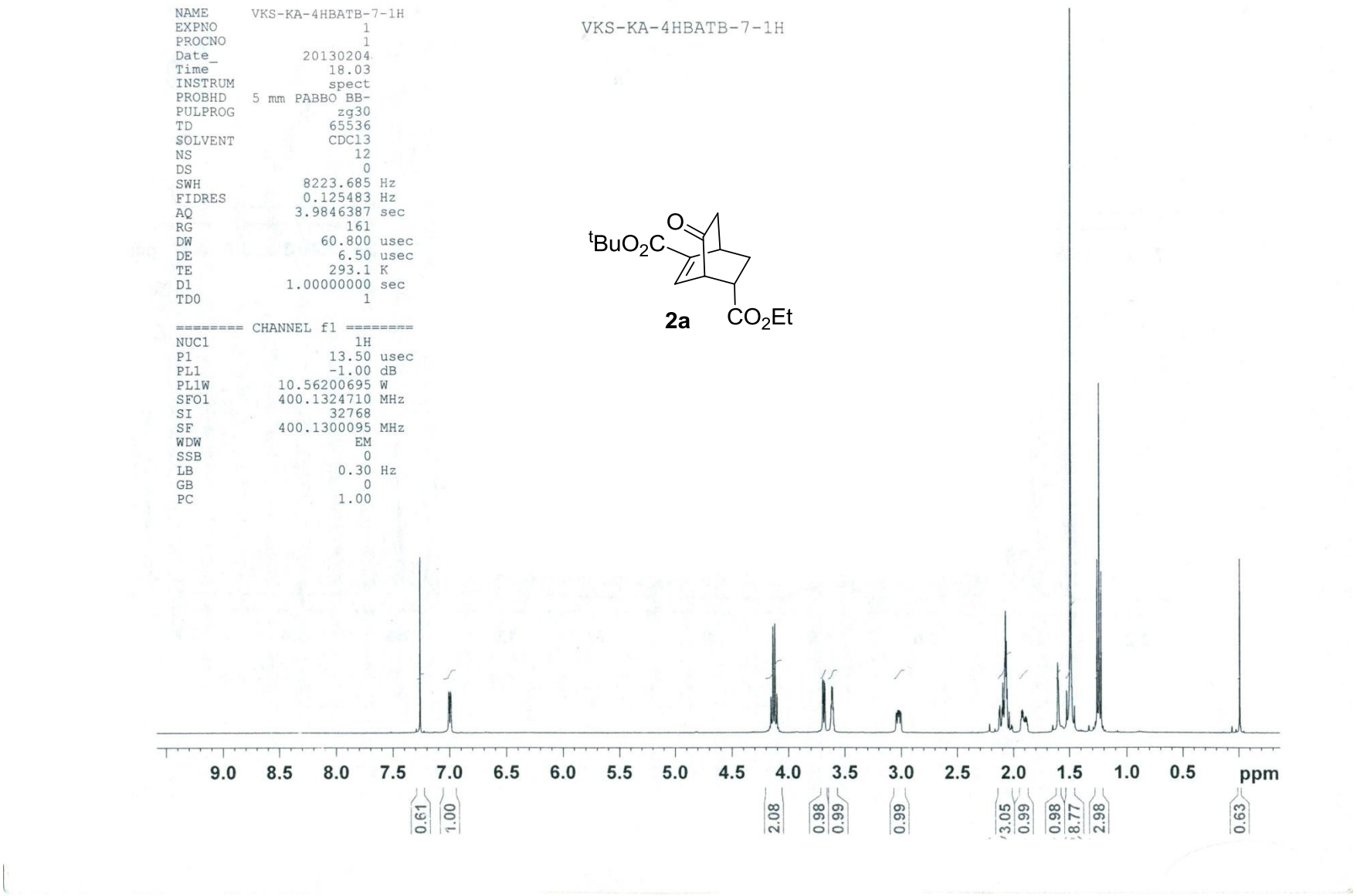
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of compound **11a**



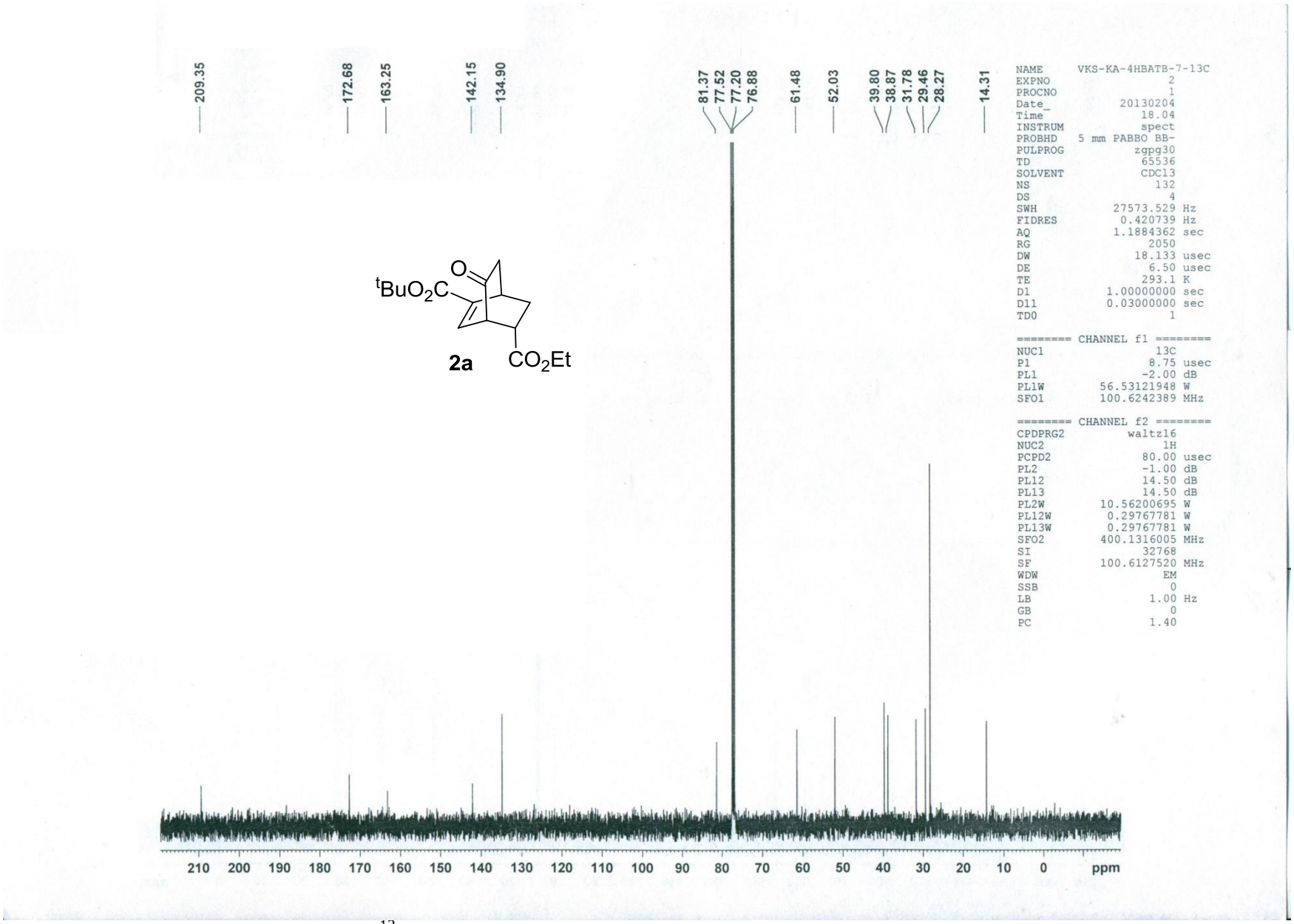
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **11b**



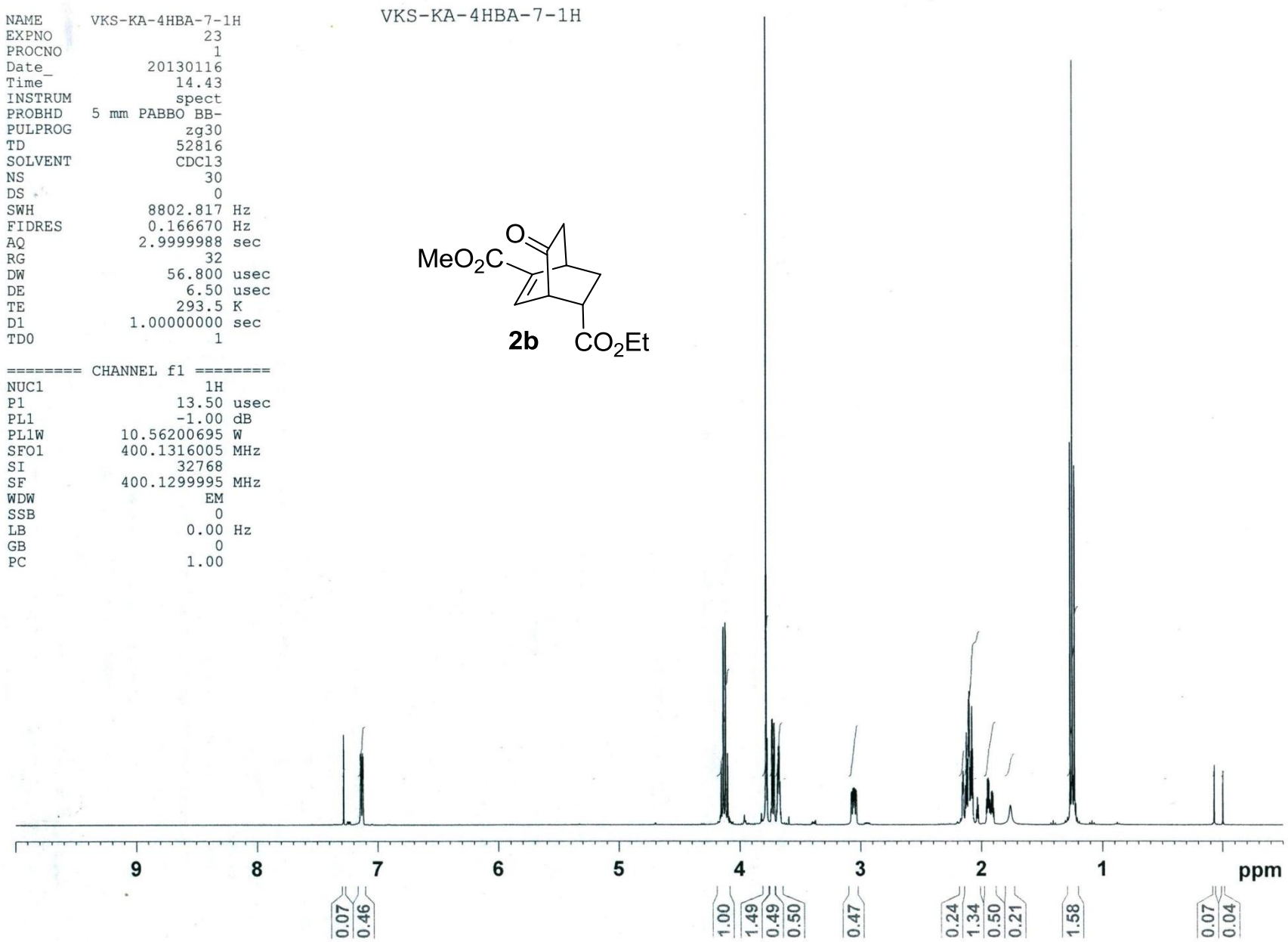
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of compound **11b**



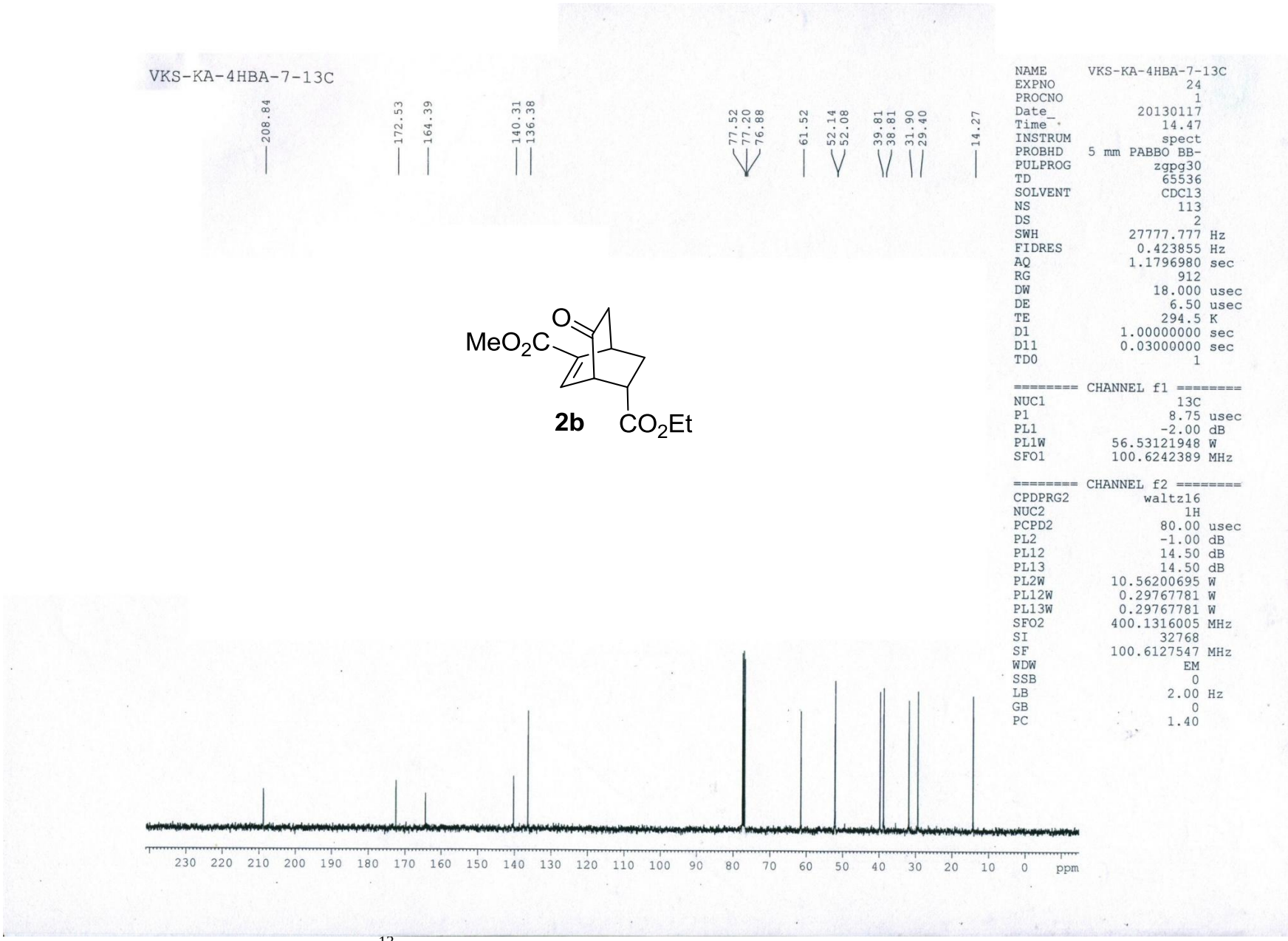
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **2a**



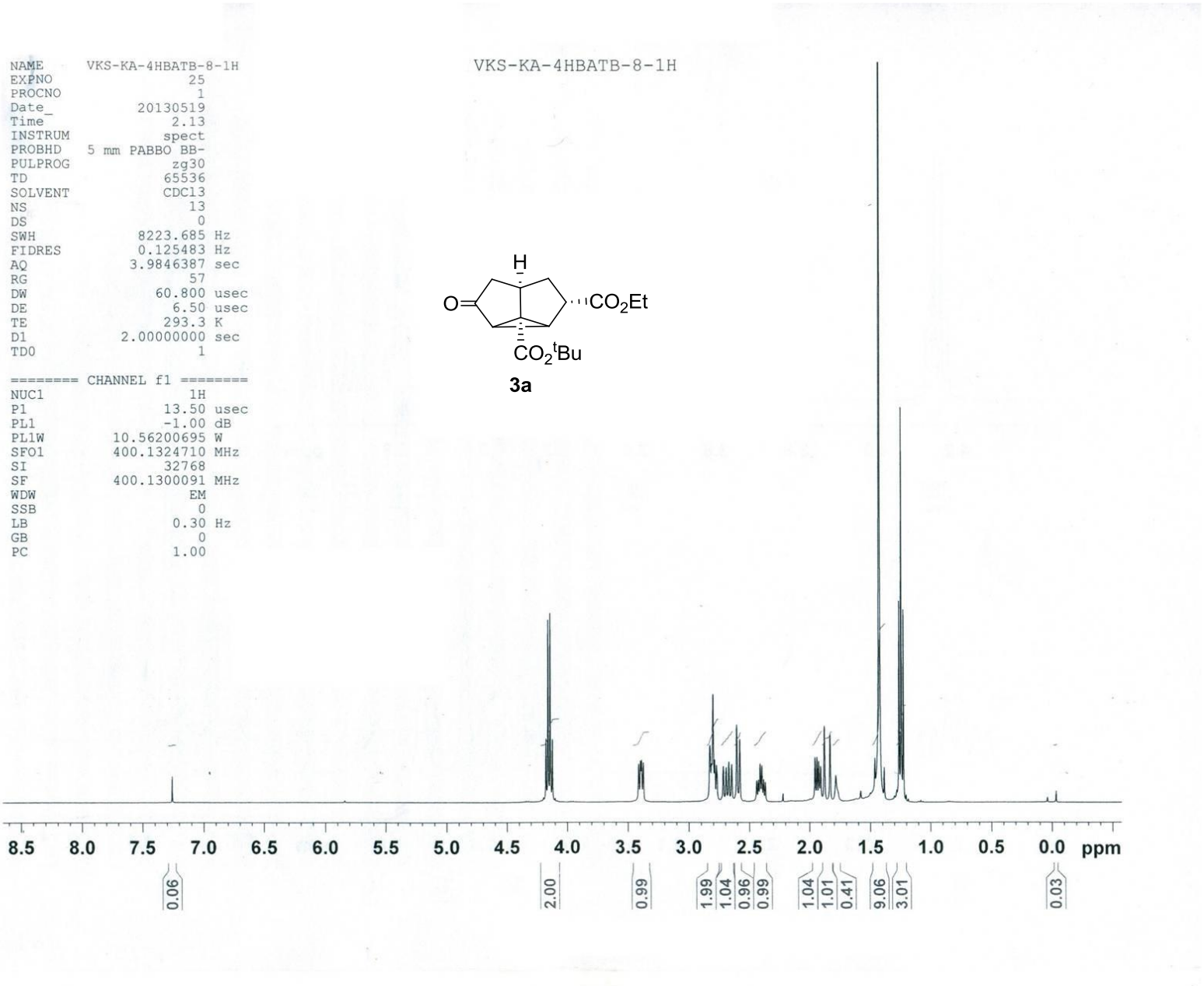
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of compound **2a**



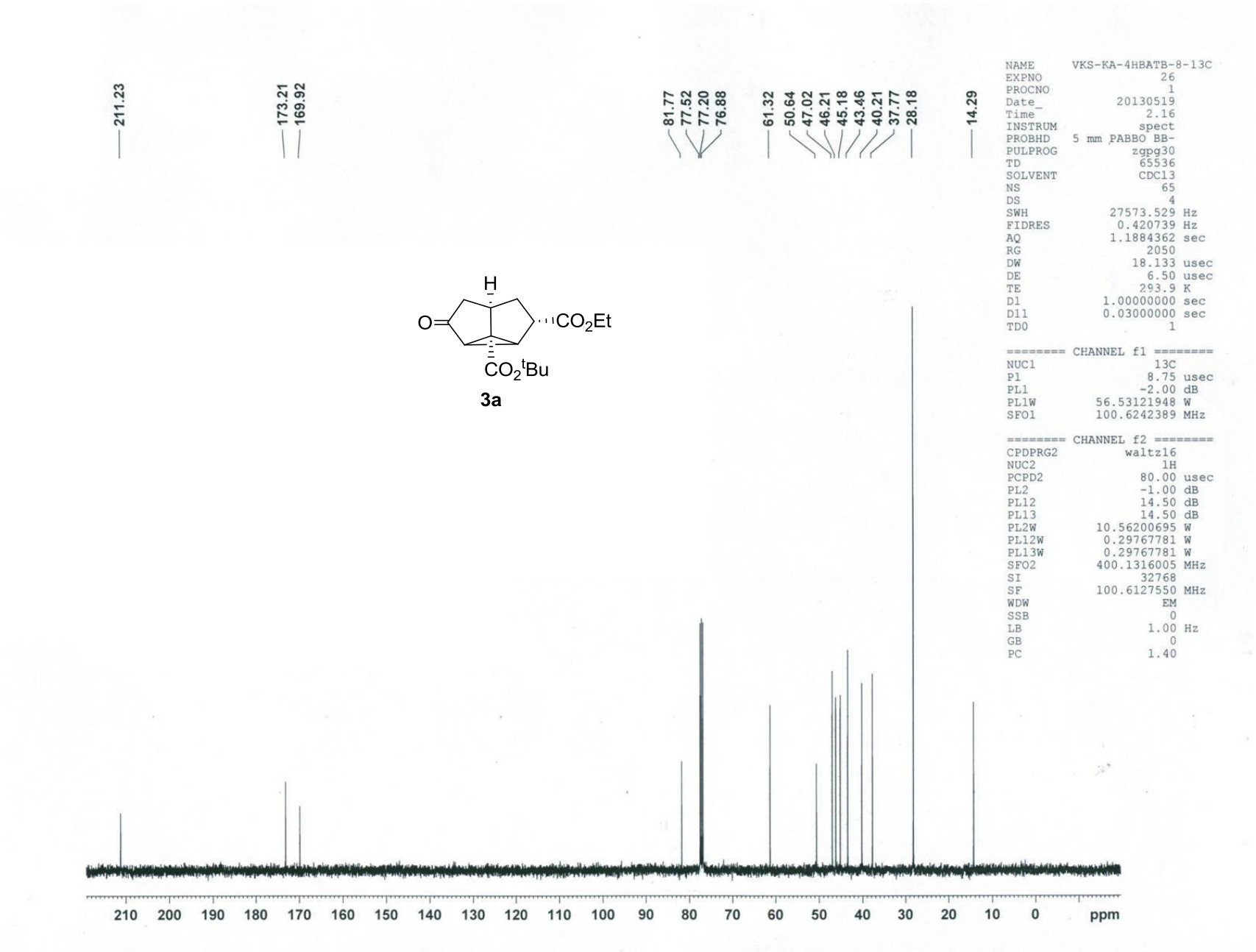
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **2b**



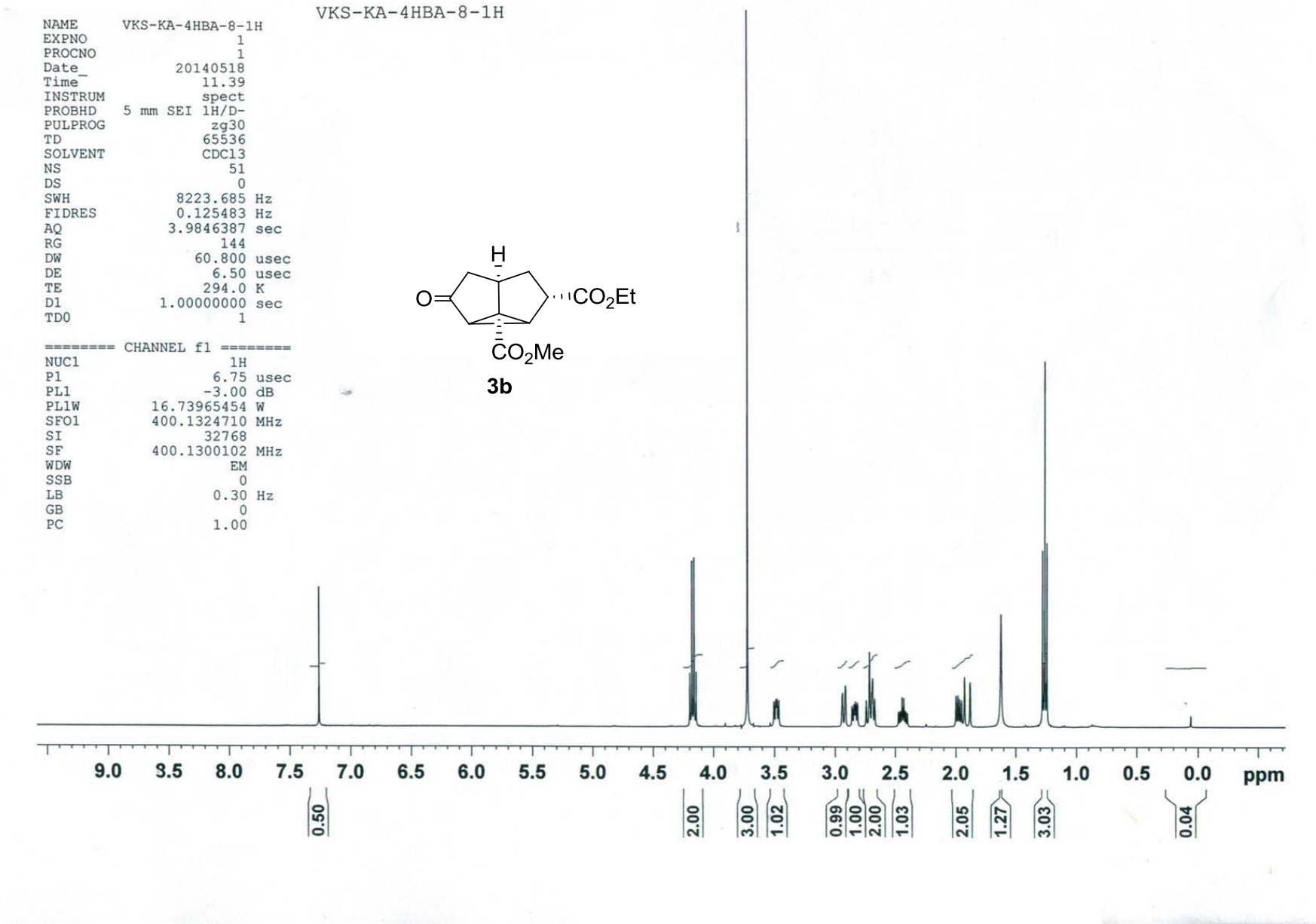
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of compound **2b**



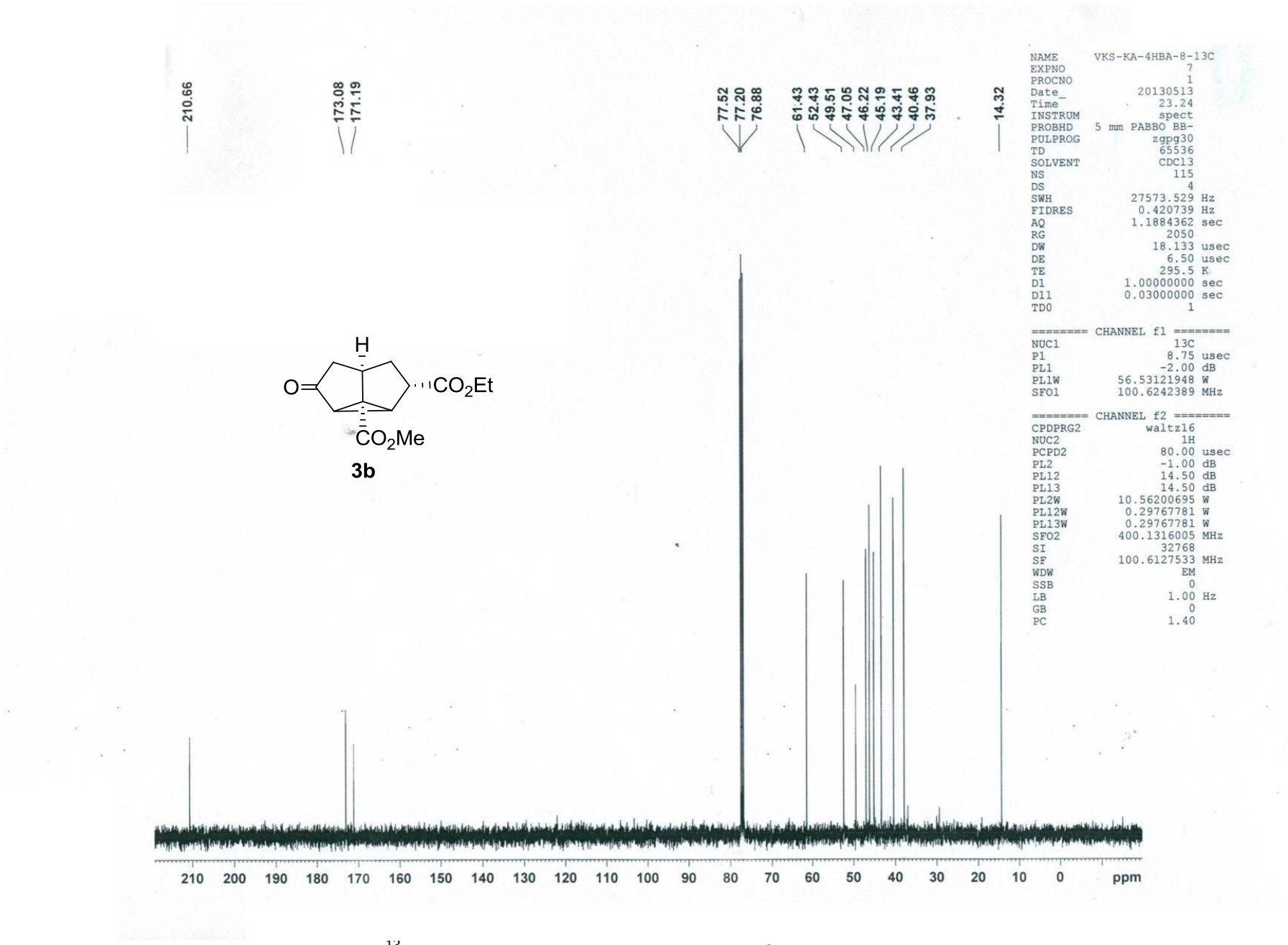
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3a**



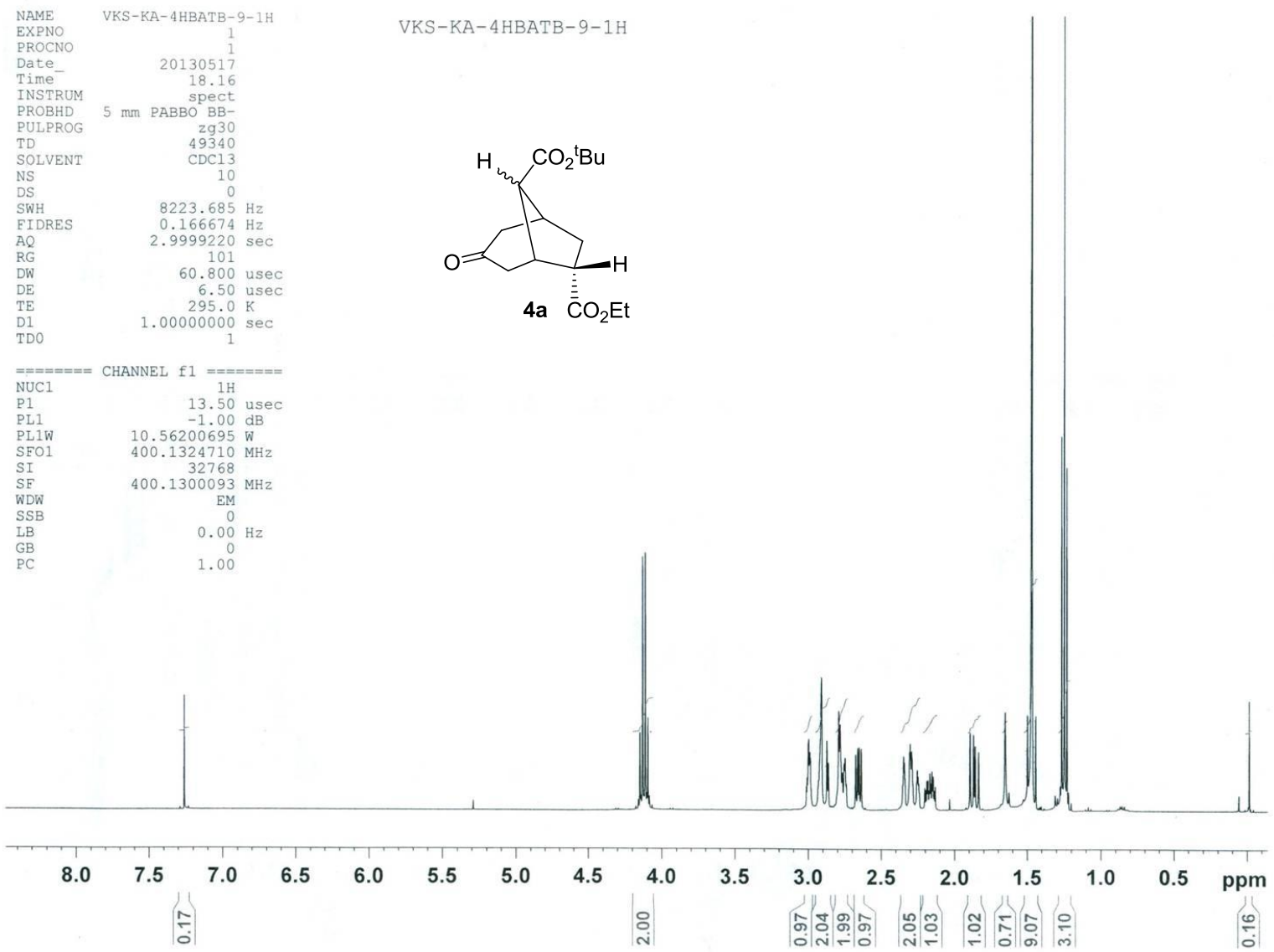
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of compound **3a**



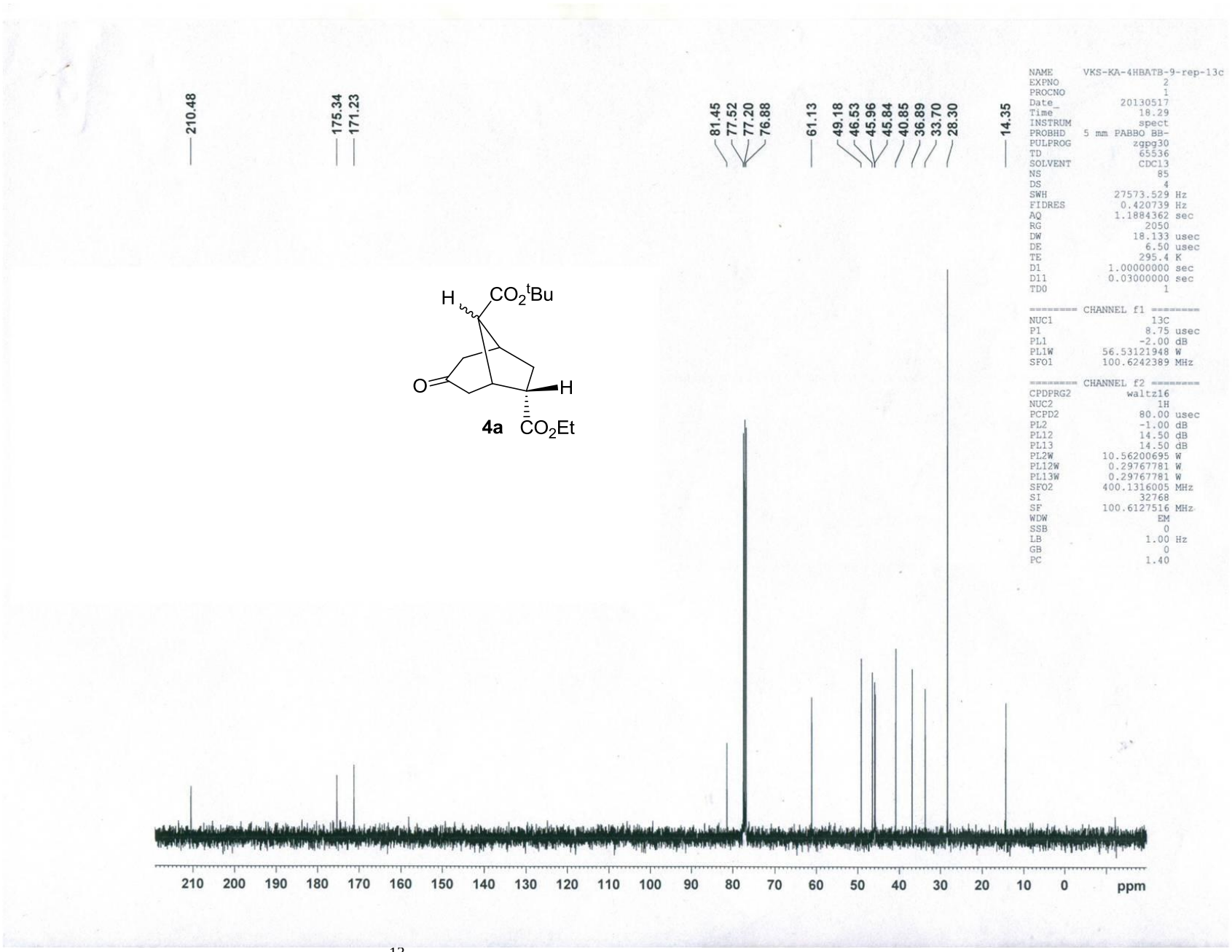
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3b**



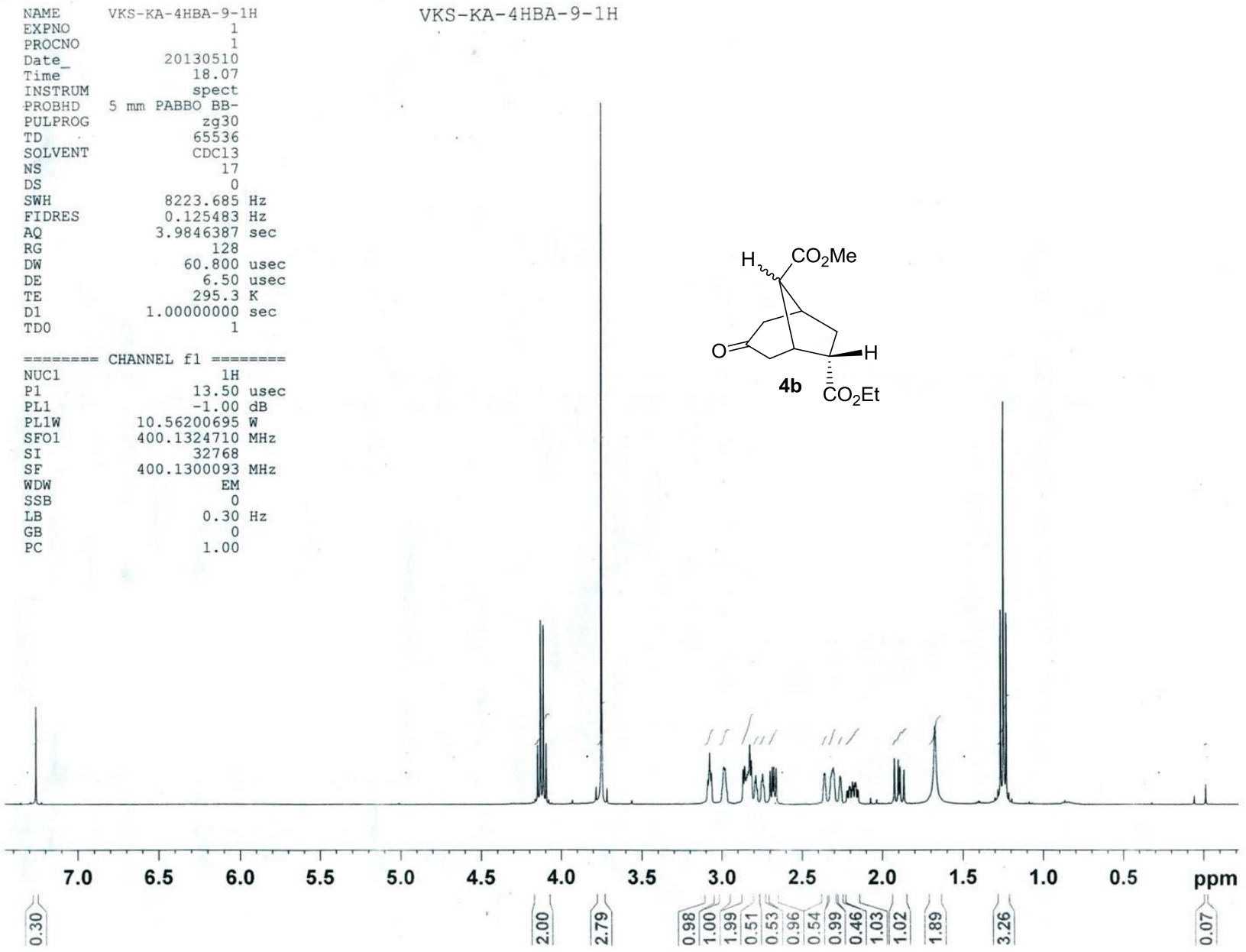
^{13}C NMR (100 MHz, $CDCl_3$) spectrum of compound **3b**



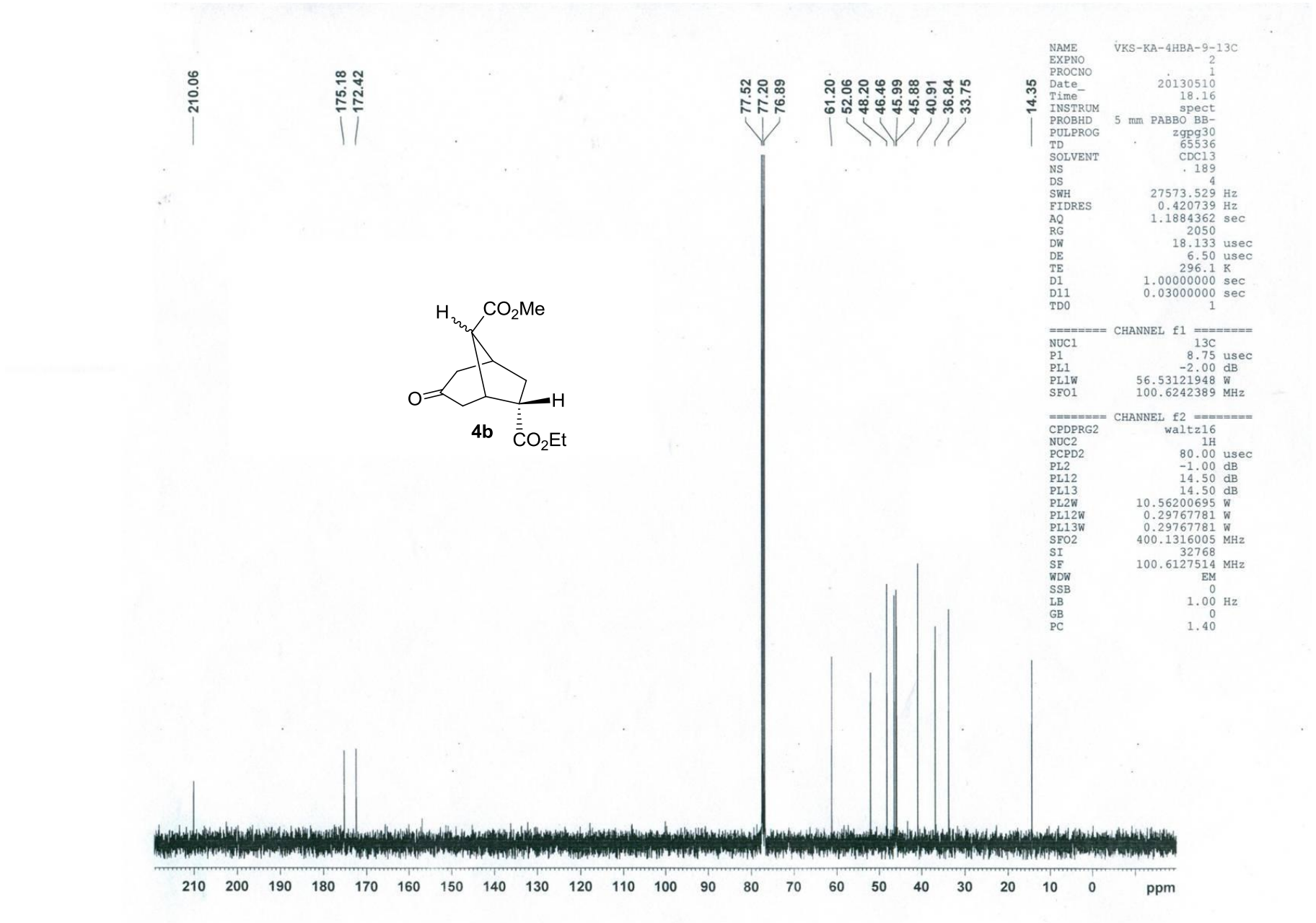
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **4a**



^{13}C NMR (100 MHz, $CDCl_3$) spectrum of compound **4a**



^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **4b**



^{13}C NMR (100 MHz, $CDCl_3$) spectrum of compound **4b**