Supporting information

Enantioselective vinylogous aldol reaction of acylphosphonates with 3-alkylidene oxindoles

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Experimental Section

General Information

^{1}H and ^{13}C NMR spectra were recorded on a Bruker AV-300 instrument (300/400 MHz and 75/100 MHz, respectively) and internally referenced to Tetramethylsilane signal or residual protonated solvent signals. Data for **^{1}**H NMR are reported as follows: chemical shift (δ, ppm), multiplicity (s- singlet; d- doublet; t- triplet; q- quartet; m- multiplet), integration, coupling constant (Hz). Data for ^{13}C NMR are reported in terms of chemical shift (δ, ppm). Perkin Elmer FT-IR Spectrometer was used to record infrared spectra and is reported in frequency of absorption. MS-TOF mass spectrometer and ESI mass spectrometer were used to record low resolution and high resolution mass spectra. Column chromatographic separations were carried out on silica gel (230–400 mesh). High performance liquid chromatography (HPLC) analysis was performed on an Agilent 1220 Infinity LC instrument equipped with a quaternary pump, using a Chiralpak IA-IH, AS-H Column (250x4.6mm). UV absorption was monitored at 254 nm.

Preparation of the catalysts: Catalyst **I-VII** was prepared according to known literature procedures **(**Figure S1**)**.[1]

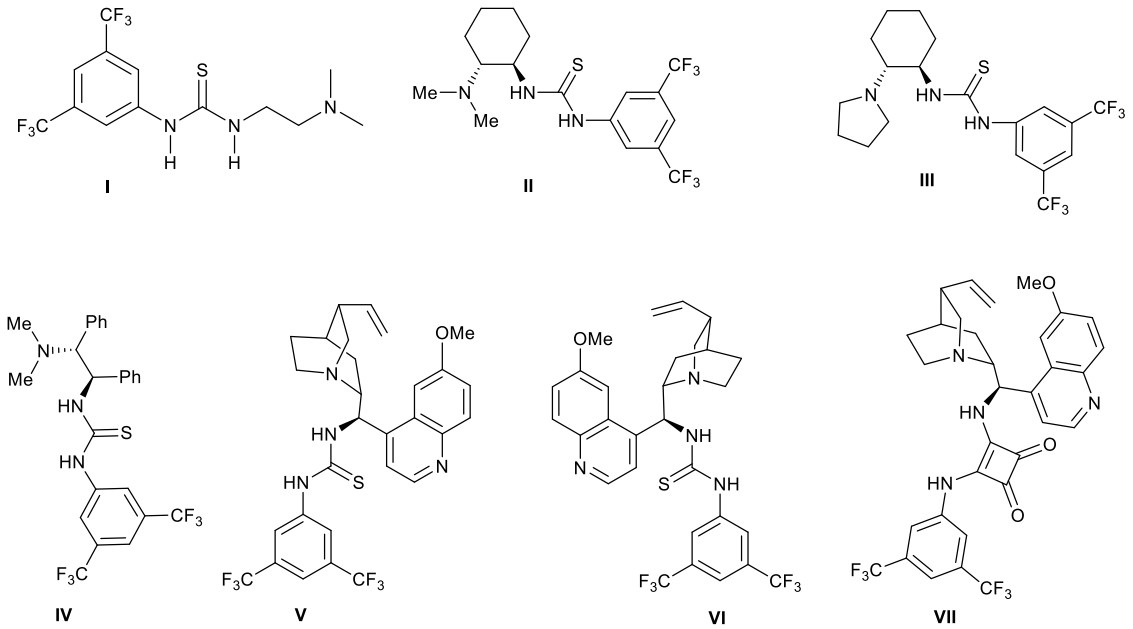
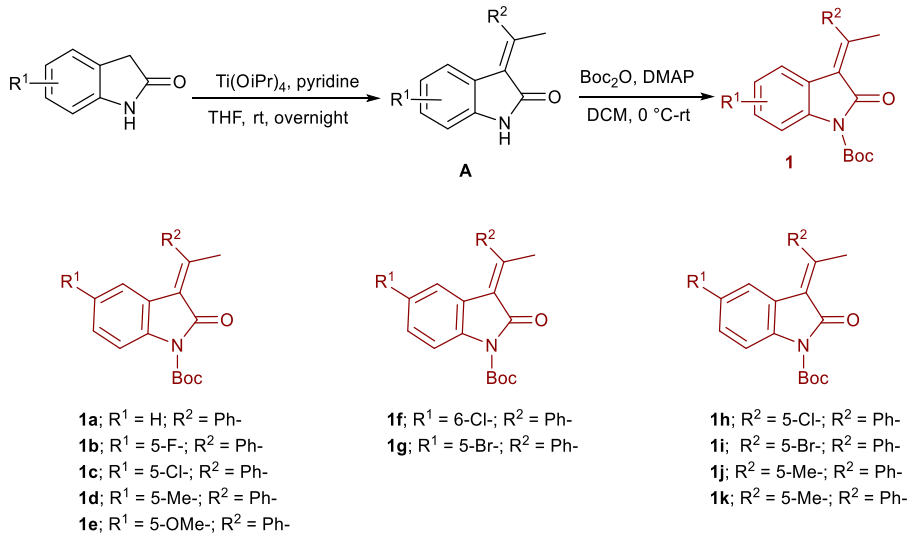


Figure S1 The structure of catalysts used.

Preparation of the substrates:

Synthesis of 3-alkylidene oxindole. 3-alkylidene oxindole were prepared by following the reported literature procedure (Scheme S1**)**.[2]

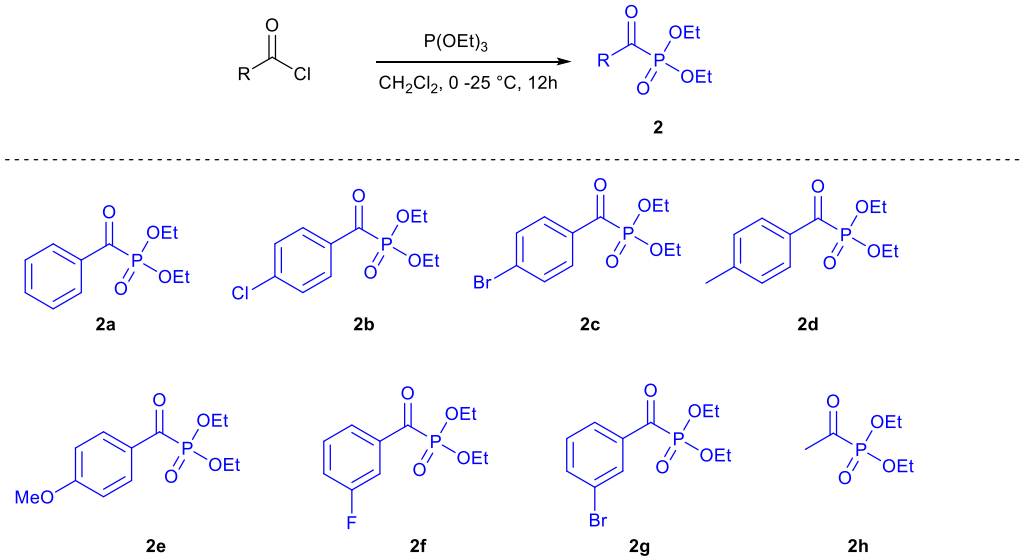


Scheme S1 Synthesis of 3-alkylidene oxindole.

A mixture of 2-oxindole (10 mmol), acetophenone (12 mmol), and pyridine (20 mmol) in dry THF (20 ml) was stirred for 10 min followed by addition of titanium isopropoxide (30 mmol). The resulting mixture was stirred at room temperature for 15h. The reaction mixture was diluted with ethyl acetate and wash with 1N HCl, $NaHCO_3$, and brine. The organic layer was dried over Na_2SO_4, concentrated, and purified by chromatography to provide intermediate **A**. Subsequently, the intermediate **A** in 50 ml of DCM was treated with *Boc*-anhydride (12 mmol), and DMAP (2 mmol) at 0 °C. The solution was then allowed to room temperature, and was stirred for 4h. After quenching with water, the reaction mixture was extracted with ethyl acetate. Organic phase was washed with water and brine, dried ($MgSO_4$), and solvent was evaporated in vacuum. The residue was purified by flash chromatography on silica gel.

Synthesis of α-ketophosphonates: α-ketophosphonates were prepared by following the reported literature procedure (Scheme S2).[3]

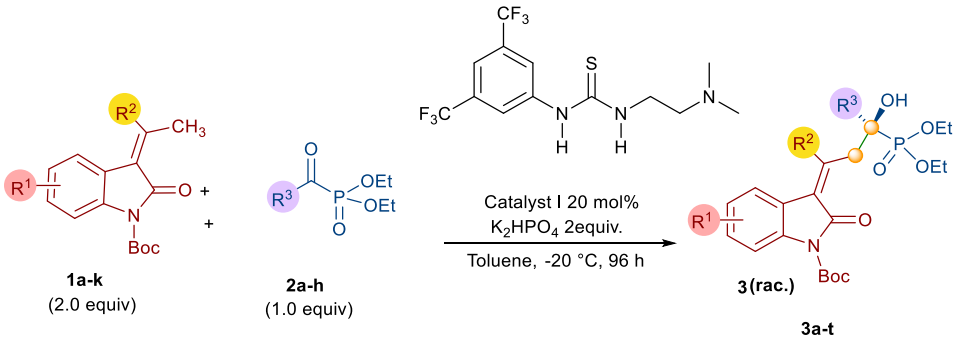
In an oven dried round bottom flask fitted with a magnetic stir-bar, aryl chloride (1.1 equiv) was taken and cooled to 0 °C. Trialkyl phosphite (1.0 equiv) was added dropwise and the resulting reaction mixture was brought to 25 °C and stirred for 12 h. Reaction mixture was concentrated under *vacuo* and crude product was purified by vacuum distillation.



Scheme S2. Synthesis of α-ketophosphonates.

Preparation of racemic aldol adducts

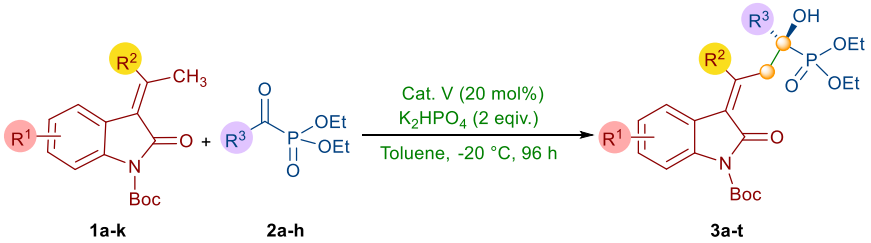
In an oven and vacuum-dried reaction tube, catalyst **I** (0.02 mmol, 0.2 equiv), α ketophosphonate **2** (0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1** (0.2 mmol, 2.0 equiv) were taken in 1 mL of dried toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 hrs. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without workup (Scheme S3).



Scheme S3. Preparation of racemic aldol adducts.

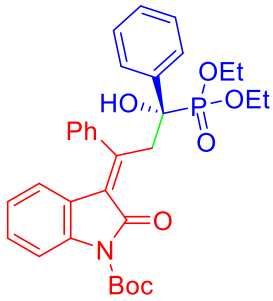
General procedure for asymmetric vinylogous aldol products

In an oven and vacuum-dried reaction tube, catalyst **V** (0.02 mmol, 0.2 equiv), α ketophosphonates **2** (0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1** (0.2 mmol, 2.0 equiv) were taken in 1 mL of dried toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 hrs. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup (Scheme S4).



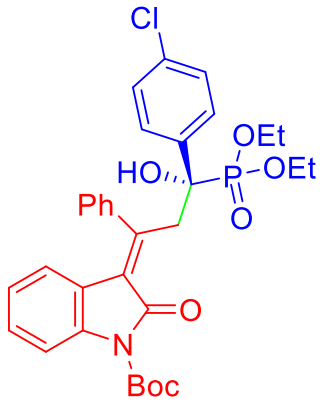
Scheme S4. General procedure for asymmetric vinylogous aldol products.

***tert*-butyl (*S*, *E*)-3-(3-(diethoxyphosphoryl)-3-hydroxy-1,3-diphenylpropylidene)-2-oxoindoline-1-carboxylate (3a):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), *α* ketophosphonate **2a** (24.2 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1a** (67.2 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3a** (47.2 mg, 82% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3a** was determined to be 99% [determined by HPLC, Chiralpak IC, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 8.74 min, t (minor) = 8.13 min]. $[\alpha]^{25}_{D}$ (**3a**) = -166.66° (c 0.13, $CHCl_3$); **^{1}H NMR** (400 MHz, $CDCl_3$) *δ* 7.77 (d, *J* = 7.88 Hz, 1H), 7.41-7.25 (m, 3H), 7.19-7.08 (m, 2H), 7.08 – 6.87 (m, 4H), 6.80-6.68 (m, 1H), 6.63 (t, *J* = 7.27 Hz, 1H), 6.26 (d, *J* = 6.19 Hz, 1H), 6.01 (d, *J* = 7.45 Hz, 1H), 5.51 (s, 1H), 4.90 (dd, *J* = 12.4, 9.3 Hz, 1H), 4.44-4.22 (m, 2H), 3.95 – 3.73 (m, 1H), 3.60-3.37 (m, 2H), 1.66 (s, 9H), 1.46 (t, *J* = 6.86 Hz, 3H), 0.98 (t, *J* = 6.79



Hz, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 168.85, 155.82 (d, J = 16.85 Hz), 149.26, 141.89, 138.41, 137.00, 129.02 , 128.42, 128.26, 128.09, 128.01, 127.50 (d, J = 2.9 Hz), 127.05 (d, J = 3.1 Hz), 126.51 (d, J = 4.6 Hz), 125.52, 123.76, 122.96 (d, J = 2.0 Hz), 114.48, 84.62, 79.41, 64.19 (d, J = 7.32 Hz), 63.32 (d, J = 8.16 Hz), 43.21 (d, J = 9.06 Hz), 28.30 (d, J = 11.11 Hz), 16.62 (d, J = 6.00 Hz), 16.26 (d, J = 5.42 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.69; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{32}H_{36}NNaO_7P$ 600.2127; found 600.2120.

***tert*-butyl (*S*, *E*)-3-(3-(4-chlorophenyl)-3-(diethoxyphosphoryl)-3-hydroxy-1-phenylpropylidene)-2-oxoindoline-1-carboxylate (3b):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9mg, 0.02 mmol, 0.2 equiv), α-ketophosphonate **2b** (27.6 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1a** (67.2 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3b** (41.5 mg, 68% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3b** was determined to be 99% [determined by HPLC, Chiralpak IC, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 8.58 min, t (minor) = 16.22 min]. $[\alpha]^{25}_D$ (**3b**) = -243.10º (c 0.12, $CHCl_3$); **^{1}H NMR** (300 MHz, $CDCl_3$) δ 7.77 (d, J = 8.20 Hz, 1H), 7.49 – 7.28 (m, 3H), 7.25 – 7.08 (m, 2H), 7.03 (d, J = 7.46 Hz, 1H), 6.97 – 6.77 (m, 3H), 6.65 (t, J = 7.70 Hz, 1H), 6.30 (d, J = 7.67 Hz, 1H), 6.09 (d, J = 7.78 Hz, 1H), 5.58 (s, 1H), 4.89 (dd, J = 12.74, 8.72 Hz, 1H), 4.44 – 4.22 (m, 2H), 4.00 – 3.77 (m, 1H), 3.69 – 3.56 (m, 1H), 3.48 (dd, J = 12.67, 2.41 Hz, 1H), 1.66 (s, 9H), 1.46 (t, J = 7.02 Hz, 3H), 1.03 (t, J = 7.03 Hz, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ 168.93, 155.20 (d, J = 16.64 Hz), 149.18, 141.77, 138.45, 136.01, 133.08 (d, J = 3.83 Hz), 129.19, 128.46, 128.24, 128.17, 128.07, 128.05, 127.99, 127.21, 125.63, 123.86, 122.88 (d, J = 6.4 Hz), 114.55, 84.74, 79.41, 64.27 (d, J = 7.33 Hz), 63.50 (d, J = 8.30 Hz), 43.52 (d, J = 8.69 Hz), 28.25, 16.63 (d, J = 5.84 Hz), 16.35 (d, J = 5.38 Hz). ^{31}P NMR (121 MHz, $CDCl_3$) δ 21.17; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{32}H_{35}ClNNaO_7P$ 634.1737; found 634.1732.



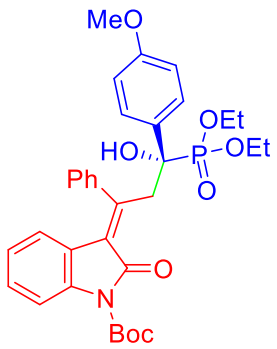
3b

***tert*-butyl (*S*, *E*)-3-(3-(4-bromophenyl)-3-(diethoxyphosphoryl)-3-hydroxy-1-phenylpropylidene)-2-oxoindoline-1-carboxylate (3c):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9mg, 0.02 mmol, 0.2 equiv), *α*-ketophosphonate **2c** (31.9 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1a** (67.2 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3c** (45.8 mg, 70% yield). R*f* = 0.34 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3c** was determined to be 98% [determined by HPLC, Chiralpak IC, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 9.13 min, t (minor) = 18.21 min]. $[\alpha]^{25}_{D}$ (**3c**) = -184.02° (c 0.14, $CHCl_3$); **^{1}H NMR** (300 MHz, $CDCl_3$) *δ* 7.77 (d, *J* = 8.20 Hz, 1H), 7.44 – 7.31 (m, 2H), 7.24 (d, *J* = 7.23 Hz, 2H), 7.17 – 7.11 (m, 1H), 7.09 – 6.99 (m, 3H), 6.85 (t, *J* = 7.55 Hz, 1H), 6.65 (t, *J* = 7.72 Hz, 1H), 6.29 (d, *J* = 7.58 Hz, 1H), 6.10 (d, *J* = 7.89 Hz, 1H), 5.58 (s, 1H), 4.89 (dd, *J* = 12.65, 8.36 Hz, 1H), 4.42 – 4.24 (m, 2H), 3.97 – 3.81 (m, 1H), 3.74 – 3.57 (m, 1H), 3.54 – 3.41 (m, 1H), 1.66 (s, 9H), 1.46 (t, *J* = 7.03 Hz, 3H), 1.04 (t, *J* = 7.03 Hz, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) *δ* 168.93, 155.16 (d, *J* = 16.61 Hz), 149.16, 141.72, 138.43, 136.56, 130.49, 129.19, 128.40, 128.34, 128.32, 127.21, 125.63, 123.86, 122.86 (d, *J* = 7.36 Hz), 121.41, 114.54, 84.74, 79.45, 64.30 (d, *J* = 7.39 Hz), 63.53 (d, *J* = 8.02 Hz), 43.50 (d, *J* = 8.77 Hz), 28.24, 27.55, 16.48 (dd, *J* = 21.4, 5.5 Hz), 16.63 (d, *J* = 5.77 Hz), 16.34 (d, *J* = 5.23 Hz). **^{31}P NMR** (121 MHz, $CDCl_3$) *δ* 21.01.; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{32}H_{35}BrNNaO_7P$ 678.1232; found 678.1234.

***tert*-butyl (*S*, *E*)-3-(3-(diethoxyphosphoryl)-3-hydroxy-1-phenyl-3-(*p*-tolyl)propylidene)-2-oxoindoline-1-carboxylate (3d):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), *α*-ketophosphonate **2d** (25.6mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1a** (67.2 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent:

EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3d** (47.3 mg, 80% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3d** was determined to be 99% [determined by HPLC, Chiralpak ID, hexane: isopropanol = 65:35, 1 mL/min, λ = 254 nm, t (major) = 6.04 min, t (minor) = 7.90 min].. $[\alpha]^{25}_{D}$ (**3d**) = -240.51° (c 0.12, $CHCl_3$); **^{1}H NMR** (400 MHz, $CDCl_3$) *δ* 7.70 (d, *J* = 8.03 Hz, 1H), 7.23 (d, *J* = 6.89 Hz, 1H), 7.15 (d, *J* = 6.58 Hz, 2H), 7.11 – 7.00 (m, 2H), 6.93 (d, *J* = 6.25 Hz, 1H), 6.79 – 6.59 (m, 3H), 6.56 (t, *J* = 7.19 Hz, 1H), 6.18 (d, *J* = 6.50 Hz, 1H), 5.95 (d, *J* = 7.67 Hz, 1H), 5.35 (s, 1H), 4.91 – 4.63 (m, 1H), 4.39 – 4.14 (m, 2H), 3.91 – 3.69 (m, 1H), 3.54 – 3.38 (m, 2H), 2.12 (s, 3H), 1.59 (s, 9H), 1.38 (t, *J* = 6.48 Hz, 3H), 0.94 (t, *J* = 6.58 Hz, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) *δ* 168.80, 156.06 (d, *J* = 17.01 Hz), 149.29, 141.98, 138.41, 136.51, 134.00, 128.97, 128.36, 128.15, 127.81 (d, *J* = 13.79 Hz), 126.98, 126.40 (d, *J* = 4.59 Hz), 125.59, 123.73, 122.98 (d, *J* = 6.67 Hz), 114.47, 84.58, 79.37, 77.78, 64.19 (d, *J* = 7.26 Hz), 63.25 (d, *J* = 8.07 Hz), 43.52 (d, *J* = 9.51 Hz), 28.25, 21.04, 16.62 (d, *J* = 6.00 Hz), 16.32 (d, *J* = 5.34 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) *δ* 21.80; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{33}H_{38}NNaO_7P$ 614.2284; found 614.2283.

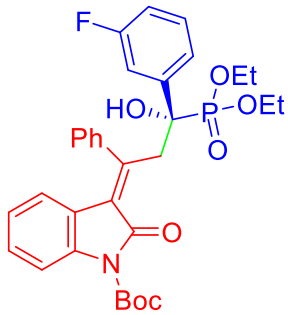
***tert*-butyl (*S*, *E*)-3-(3-(diethoxyphosphoryl)-3-hydroxy-3-(4-methoxyphenyl)-1-phenylpropylidene)-2-oxoindoline-1-carboxylate (3e):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), α ketophosphonate **2e** (27.2 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1a** (67.2 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3e** (45.5 mg, 75% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3e** was determined to be 99% [determined by HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 230 nm, t (major) = 7.14 min, t (minor) = 9.79 min]. $[\alpha]^{D}25$ (**3e**) = +21.23° (c 2.01, $CHCl_3$); **^{1}H NMR** (400 MHz, $CDCl_3$) *δ* 7.98 (d, *J* = 7.18 Hz, 1H), 7.70 (d, *J* = 7.34 Hz, 1H), 7.22-7.14 (m, 2H), 7.10 – 7.04 (m, 1H), 7.01-6.82 (m, 2H), 6.75 (s, 1H), 6.56 (s, 1H), 6.42 (d, *J* = 5.60 Hz, 2H), 6.23 (d, *J* = 5.49 Hz, 1H), 5.96 (d, *J* = 7.04 Hz, 1H), 5.41 (s, 1H), 4.78 (s, 1H), 4.35-4.17 (m, 2H), 3.84-3.76 (m, 2H), 3.63 (s, 3H), 3.49 (d, *J* = 9.91 Hz, 1H), 1.59 (s, 9H), 1.41-1.33 (m, 3H), 1.01-0.88 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) *δ* 170.41, 168.81, 163.90, 158.72, 155.99 (d, *J* = 16.71 Hz), 149.26, 142.05, 138.37, 132.35,



3e

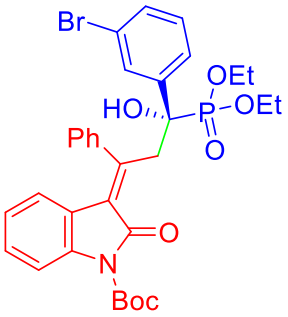
129.01 (d, J = 2.28 Hz), 128.40, 127.97, 127.70 (d, J = 3.94 Hz), 126.97, 125.58, 123.75, 122.94 (d, J = 4.60 Hz), 114.47, 113.79, 112.97, 84.62, 79.35, 64.28 (d, J = 6.71 Hz), 63.34 (d, J = 8.02 Hz), 55.59, 55.34, 43.41, 28.23, 16.61 (d, J = 5.48 Hz), 16.35 (d, J = 5.03 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.86; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{33}H_{38}NNaO_8P$ 630.2233; found 630.2227.

tert-butyl (*S*, *E*)-3-(3-(diethoxyphosphoryl)-3-(3-fluorophenyl)-3-hydroxy-1-phenylpropylidene)-2-oxoindoline-1-carboxylate (3f): In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), α-ketophosphonate **2f** (26.0 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1a** (67.2 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3f** (32.7 mg, 55% yield). R*f* = 0.34 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3f** was determined to be 99% [determined by HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 5.63 min, t (minor) = 8.35 min]. $[\alpha]^{25}_D$ (**3f**) = -123.33° (c 0.21, $CHCl_3$); **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.78 (d, J = 7.25 Hz, 1H), 7.36 (s, 1H), 7.24 – 7.08 (m, 4H), 7.06 (s, 1H), 6.96 – 6.77 (m, 2H), 6.66 (d, J = 7.33 Hz, 2H), 6.38 (s, 1H), 6.08 (d, J = 7.00 Hz, 1H), 5.59 (s, 1H), 5.06 – 4.77 (m, 1H), 4.32 (d, J = 2.81 Hz, 2H), 3.89 (d, J = 6.65 Hz, 1H), 3.63 (d, J = 4.55 Hz, 1H), 3.48 (d, J = 12.5 Hz, 1H), 1.67 (s, 9H), 1.46 (s, 3H), 1.03 (s, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 168.80, 163.62, 161.19, 155.05 (d, J = 16.56 Hz), 149.06, 141.56, 140.03 (d, J = 7.29 Hz), 138.33, 129.05, 128.75 (d, J = 5.09 Hz), 128.25, 127.92, 127.09, 125.55, 123.71, 122.75 (d, J = 5.74 Hz), 122.22, 114.42, 113.84, 113.79, 113.64, 113.60, 113.55, 84.58, 78.98, 64.12 (d, J = 7.41 Hz), 63.37 (d, J = 8.10 Hz), 43.16 (d, J = 8.39 Hz), 28.11, 16.50 (d, J = 5.86 Hz), 16.18 (d, J = 5.39 Hz).^{31}P NMR (121 MHz, $CDCl_3$) δ 21.06; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{32}H_{35}FNNaO_7P$ 618.2033; found 618.2030.



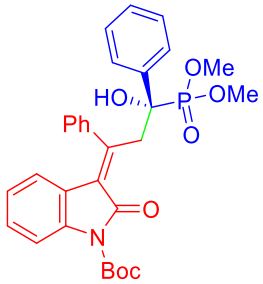
3f

***tert*-butyl (*S*, *E*)-3-(3-(3-bromophenyl)-3-(diethoxyphosphoryl)-3-hydroxy-1-phenylpropylidene)-2-oxoindoline-1-carboxylate (3g):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), α ketophosphonate **2g** (31.9 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1a** (67.2 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20°C for 96 hrs. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3g** (45.8 mg, 70% yield). R*f* = 0.34 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3g** was determined to be 99% [determined by HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 5.64 min, t (minor) = 7.22 min]. $[\alpha]^{25}_{D}$ (**3g**) = -146.42° (c 0.08, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) *δ* 7.78 (d, *J* = 8.16 Hz, 1H), 7.54 (s, 1H), 7.38 (t, *J* = 7.41 Hz, 1H), 7.30 (s, 1H), 7.23 – 7.03 (m, 4H), 6.97 – 6.75 (m, 2H), 6.65 (t, *J* = 7.57 Hz, 1H), 6.39 (d, *J* = 7.75 Hz, 1H), 6.11 (d, *J* = 7.91 Hz, 1H), 5.61 (s, 1H), 4.89 (dd, *J* = 12.73, 8.94 Hz, 1H), 4.44 – 4.27 (m, 2H), 3.99 – 3.85 (m, 1H), 3.75 – 3.60 (m, 1H), 3.46 (dd, *J* = 12.67, 2.11 Hz, 1H), 1.67 (s, 9H), 1.46 (t, *J* = 7.05 Hz, 3H), 1.05 (t, *J* = 7.05 Hz, 3H).; ^{13}C NMR (75 MHz, $CDCl_3$) *δ* 168.98, 155.16 (d, *J* = 16.6 Hz), 149.16, 141.50, 139.69, 138.43, 130.16 (d, *J* = 2.94 Hz), 129.72 (d, *J* = 4.15 Hz), 129.01, 128.60, 128.22 (d, *J* = 29.04 Hz), 127.20, 125.67, 125.23 (d, *J* = 4.4 Hz), 123.84, 122.88, 122.83, 122.00, 114.57, 84.75, 79.29, 64.35 (d, *J* = 7.40 Hz), 63.58 (d, *J* = 8.10 Hz), 43.21 (d, *J* = 8.50 Hz), 28.24, 16.63 (d, *J* = 5.72 Hz), 16.32 (d, *J* = 5.37 Hz); **^{31}P NMR** (121 MHz, $CDCl_3$) *δ* 20.98; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{32}H_{35}BrNNaO_7P$ 678.1232; found 678.1227.



3g

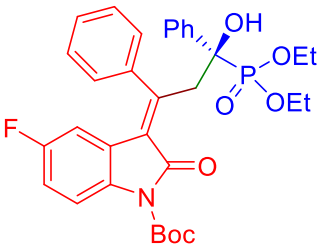
***tert*-butyl (E)-3-(3-(dimethoxyphosphoryl)-3-hydroxy-1,3-diphenylpropylidene)-2-oxoindoline-1-carboxylate (3i):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), α ketophosphonate **2i** (31.9 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1a** (67.2 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20°C for 96 hrs. The reaction mixture was directly processed for the purification by silica gel column chromatography



3i

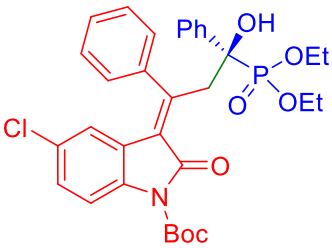
(eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3i** (18.5 mg, 35 % yield). R*f* = 0.3 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3i** was determined to be 99% [determined by HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 5.91 min, t (minor) = 8.73 min]. $[\alpha]^{25}_{D}$ (**3i**) = -154.42° (c 0.08, $CHCl_3$); **^{1}H NMR** (500 MHz, Chloroform-*d*) δ 7.75 (d, *J* = 8.2 Hz, 1H), 7.43 – 7.31 (m, 3H), 7.21 – 7.10 (m, 2H), 7.08 – 6.95 (m, 4H), 6.78 (t, *J* = 7.6 Hz, 1H), 6.66 (td, *J* = 7.7, 1.1 Hz, 1H), 6.27 (d, *J* = 7.7 Hz, 1H), 6.04 (dd, *J* = 8.1, 1.3 Hz, 1H), 5.54 (s, 1H), 4.91 (dd, *J* = 12.8, 9.0 Hz, 1H), 3.97 (d, *J* = 10.1 Hz, 3H), 3.59 (dd, *J* = 12.8, 2.9 Hz, 1H), 3.39 (d, *J* = 10.0 Hz, 3H), 1.70 (s, 9H).; **^{13}C NMR** (126 MHz, Chloroform-*d*) δ 148.93, 141.77, 138.29, 136.87, 128.96, 128.18, 128.05, 128.00, 127.51, 127.49, 127.09, 127.06, 126.39, 126.35, 125.46, 123.71, 122.93, 122.83, 114.39, 84.76, 79.43, 54.81, 53.87, 43.19, 43.11, 28.17.; **^{31}P NMR** (162 MHz, $CDCl_3$) *δ* 21.79; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{30}H_{32}NNaO_7P$ 572.1814; found 572.1817.

tert-butyl (*S*, *E*)-3-(3-(diethoxyphosphoryl)-3-hydroxy-1,3-diphenylpropylidene)-5-fluoro-2-oxoindoline-1-carboxylate (3k): In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), α-ketophosphonate **2a** (24.2 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1b** (70.6 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3k** (41.6 mg, 70% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3k** was determined to be 99% [determined by HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 5.62 min, t (minor) = 6.46 min]. $[\alpha]^{25}_{D}$ (**3k**) = -224.47° (c 0.33, $CHCl_3$); **^{1}H NMR** (300 MHz, $CDCl_3$) *δ* 7.70 (dd, *J* = 9.98, 4.84 Hz, 1H), 7.27 (t, *J* = 7.61 Hz, 3H), 7.08 (t, *J* = 7.49 Hz, 1H), 7.01 – 6.83 (m, 4H), 6.81 – 6.63 (m, 2H), 6.16 (d, *J* = 7.78 Hz, 1H), 5.60 (dd, *J* = 9.73, 2.63 Hz, 1H), 5.35 (s, 1H), 4.83 (dd, *J* = 12.52, 9.20 Hz, 1H), 4.44 – 4.12 (m, 2H), 3.92 – 3.67 (m, 1H), 3.61 – 3.27 (m, 2H), 1.58 (s, 9H), 1.39 (t, *J* = 7.04 Hz, 3H), 0.89 (t, *J* = 7.05 Hz, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) *δ* 168.47, 160.67, 157.81, 157.58, 157.48, 149.19, 141.26, 136.81, 134.44 (d, *J* = 2.08 Hz), 129.19, 128.41, 128.41, 128.24, 127.93, 127.53, 127.90, 126.64, 125.32, 124.28 (d, *J* = 9.44 Hz), 115.66, 115.61, 115.55,



3k

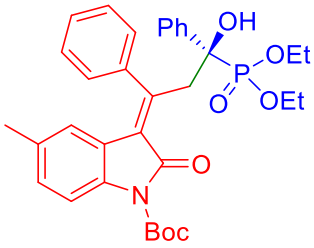
115.30, 110.28, 109.93, 84.74, 79.63, 64.18 (d, J = 7.3 Hz), 63.26 (d, J = 8.14 Hz), 43.30 (d, J = 9.11 Hz), 28.20 (s), 16.57 (d, J = 6.04 Hz), 16.22 (d, J = 5.36 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.54.; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{32}H_{35}FNNaO_7P$ 618.2033; found 618.2030.



3l

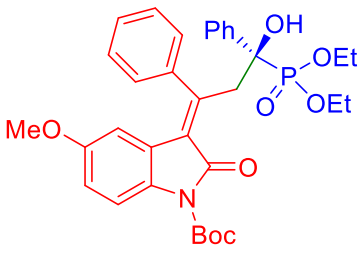
***tert*-butyl (*S*, *E*)-5-chloro-3-(3-(diethoxyphosphoryl)-3-hydroxy-1,3-diphenylpropylidene)-2-oxoindoline-1-carboxylate (3l):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), α-ketophosphonate **2a** (24.2 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1c** (74.0 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3l** (31.8 mg, 52% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3l** was determined to be 86% [determined by HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 12.66 min, t (minor) = 21.21 min]. $[\alpha]^{25}_D$ (**3l**) = -243.80° (c 0.27, $CHCl_3$); **^{1}H NMR** (400 MHz, Chloroform-*d*) δ 8.14 – 8.06 (m, 1H), 7.74 (d, J = 8.7 Hz, 1H), 7.47 (t, J = 7.8 Hz, 1H), 7.36 (d, J = 7.3 Hz, 3H), 7.15-7.18 (m, 1H), 7.09 (dd, J = 8.7, 2.2 Hz, 1H), 7.01 – 6.95 (m, 3H), 6.79 (t, J = 7.7 Hz, 1H), 6.24 (d, J = 7.7 Hz, 1H), 5.91 (s, 1H), 4.89 (dd, J = 12.6, 9.2 Hz, 1H), 4.41 – 4.24 (m, 2H), 3.89 – 3.76 (m, 1H), 3.59 (dd, J = 12.6, 2.7 Hz, 1H), 3.49 (m, 1H), 1.66 (s, 9H), 1.46 (t, J = 7.1 Hz, 3H), 0.98 (t, J = 7.1 Hz, 3H).; **^{13}C NMR** (101 MHz, $CDCl_3$) δ 167.02, 156.75 (d, J = 16.82 Hz), 147.95, 140.13, 135.66, 128.09 (d, J = 3.19 Hz), 127.54, 127.29, 127.07, 126.77, 126.38 (d, J = 2.54 Hz), 126.00 (d, J = 3.01 Hz), 125.34, 125.29, 125.11, 124.18, 123.21, 121.86, 114.47, 83.76, 78.24, 76.64 (s), 63.04 (d, J = 7.3 Hz), 62.12 (d, J = 8.15 Hz), 42.15 (d, J = 9.17 Hz), 27.06, 15.42 (d, J = 6.03 Hz), 15.08 (d, J = 5.38 Hz). **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.52; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{32}H_{35}ClNNaO_7P$ 634.1737; found 634.1730.

***tert*-butyl (*S*, *E*)-3-(3-(diethoxyphosphoryl)-3-hydroxy-1,3-diphenylpropylidene)-5-methyl-2-oxoindoline-1-carboxylate (3m):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), α-ketophosphonate **2a** (24.2 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1d** (70.0 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3m** (46.1 mg, 78% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3m** was determined to be 99% [determined by HPLC, Chiralpak ASH, hexane: isopropanol = 95:05, 0.5ml mL/min, λ = 254 nm, t (major) = 13.62 min, t (minor) = 10.94 min]. $[\alpha]^{25}_{D}$ (**3m**) = -182.27° (c 0.22, $CHCl_3$); **^{1}H NMR** (400 MHz, $CDCl_3$) *δ* 7.64 (d, *J* = 7.81 Hz, 1H), 7.46-7.35 (m, 2H), 7.29-7.22 (m, 1H), 7.14 (s, 1H), 7.06-6.89 (m, 5H), 6.75 (s, 1H), 6.22 (s, 1H), 5.74 (s, 1H), 5.50 (s, 1H), 4.98 – 4.82 (m, 1H), 4.41-4.22 (m, 2H), 3.82 (d, *J* = 6.69 Hz, 1H), 3.55 (d, *J* = 12.63 Hz, 2H), 1.88 (s, 3H), 1.66 (s, 9H), 1.46 (s, 3H), 0.97 (s, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) *δ* 169.05, 155.49, 149.34, 142.04, 137.17, 136.25, 133.07, 129.58, 129.01, 128.35, 127.92, 127.51, 127.31, 127.04, 126.61, 125.51, 123.71, 122.97, 114.27, 84.45, 79.46, 77.87, 64.15 (d, *J* = 7.4 Hz), 63.34, 28.28, 21.14, 16.65 (d, *J* = 5.72), 16.28 (d, *J* = 5.31). **^{31}P NMR** (162 MHz, $CDCl_3$) *δ* 21.75; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{33}H_{38}NNaO_7P$ 614.2284; found 614.2280.



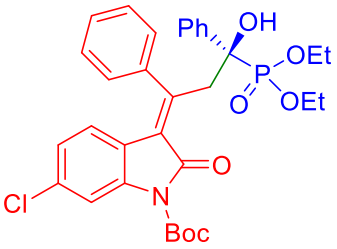
3m

***tert*-butyl (*S*, *E*)-3-(3-(diethoxyphosphoryl)-3-hydroxy-1,3-diphenylpropylidene)-5-methoxy-2-oxoindoline-1-carboxylate (3n):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), α-ketophosphonate **2a** (24.2 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1e** (73.0 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3n** (55.8 mg, 92% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3n** was determined to be 99% [determined by HPLC, Chiralpak ASH, hexane:



3n

isopropanol = 95:05, 0.5 mL/min, λ = 254 nm, t (major) = 16.76 min, t (minor) = 13.46 min. $[\alpha]^{25}_{D}$ (**3n**) = -213.83° (c 0.41, $CHCl_3$); **^{1}H NMR** (400 MHz, Chloroform-*d*) δ 7.68 (d, *J* = 9.0 Hz, 1H), 7.45 – 7.30 (m, 3H), 7.04-7.13 (m, 1H), 7.08 – 6.84 (m, 4H), 6.78 (t, *J* = 7.6 Hz, 1H), 6.67 (dd, *J* = 9.0, 2.7 Hz, 1H), 6.25 (d, *J* = 7.8 Hz, 1H), 5.55 (d, *J* = 2.7 Hz, 1H), 5.51 (s, 1H), 4.90 (dd, *J* = 12.7, 9.1 Hz, 1H), 4.44 – 4.20 (m, 2H), 3.80-3.86 (m, 1H), 3.63 – 3.40 (m, 2H), 3.24 (s, 3H), 1.65 (s, 9H), 1.46 (t, *J* = 7.0 Hz, 3H), 0.97 (t, *J* = 7.0 Hz, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) *δ* 168.87, 155.76 (t, *J* = 8.43 Hz), 149.21, 141.71, 136.98, 132.15, 129.07, 128.27, 127.93, 127.43 (d, *J* = 2.72 Hz), 127.35, 127.04 (d, *J* = 3.15 Hz), 126.49 (d, *J* = 4.59 Hz), 125.50, 123.69, 115.42 (d, *J* = 7.42 Hz), 107.70, 84.33, 79.30, 64.14 (d, *J* = 7.34 Hz), 63.29 (d, *J* = 8.18 Hz), 54.92, 43.09 (d, *J* = 9.05 Hz), 28.18, 16.54 (d, *J* = 5.91 Hz), 16.19 (d, *J* = 5.42 Hz). ^{31}P NMR (162 MHz, $CDCl_3$) *δ* 21.65; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{33}H_{38}NNaO_8P$ 630.2233; found 630.2230.

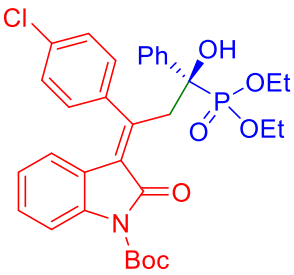


3o

***tert*-butyl (*S*, *E*)-6-chloro-3-(3-(diethoxyphosphoryl)-3-hydroxy-1,3-diphenylpropylidene)-2-oxoindoline-1-carboxylate (3o):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9mg, 0.02 mmol, 0.2 equiv), α-ketophosphonate **2a** (24.2 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1f** (74.0 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3o** (33.6 mg, 55% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3o** was determined to be 98% [determined by HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 5.92 min, t (minor) = 6.94 min]. $[\alpha]^{25}_{D}$ (**3o**) = -299.80° (c 0.50, $CHCl_3$); **^{1}H NMR** (400 MHz, Chloroform-*d*) δ 7.86 (d, *J* = 2.0 Hz, 1H), 7.40 – 7.29 (m, 3H), 7.20 – 7.09 (m, 1H), 7.05 – 6.88 (m, 4H), 6.75 (t, *J* = 7.6 Hz, 1H), 6.62 (dd, *J* = 8.6, 2.1 Hz, 1H), 6.23 (d, *J* = 7.7 Hz, 1H), 5.90 (d, *J* = 8.5 Hz, 1H), 5.32 (s, 1H), 4.88 (dd, *J* = 12.7, 9.1 Hz, 1H), 4.31 (q, *J* = 7.1 Hz, 2H), 3.81 (dt, *J* = 10.1, 7.0 Hz, 1H), 3.61 – 3.40 (m, 2H), 1.66 (s, 9H), 1.46 (t, *J* = 7.0 Hz, 3H), 1.00 – 0.92 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) *δ* 168.24, 156.40 (d, *J* = 16.75 Hz), 148.90, 141.49, 138.98, 136.74, 134.59, 129.00, 128.08, 128.05, 127.94, 127.40, 127.00, 126.34, 126.32, 126.15, 125.33, 123.77, 123.56, 121.30, 114.99, 84.93, 79.25, 77.65, 64.05 (d, *J* = 7.19 Hz), 63.13 (d, *J* = 8.07 Hz), 43.12 (d, *J* = 9.09

Hz), 28.07, 16.46 (d, J = 5.90 Hz), 16.11 (d, J = 5.26 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.56; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{32}H_{35}ClNNaO_7P$ 634.1737; found 634.1730.

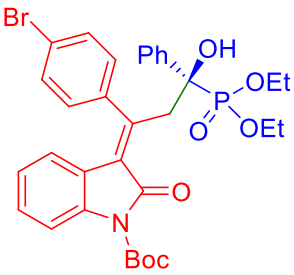
***tert*-butyl (*S*, *E*)-6-bromo-3-(3-(diethoxyphosphoryl)-3-hydroxy-1,3-diphenylpropylidene)-2-oxoindoline-1-carboxylate (3p):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), α-ketophosphonate **2a** (24.2 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1g** (82.0 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3p** (40.6 mg, 62% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3p** was determined to be 98% [determined by HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 7.20 min, t (minor) = 6.24 min]. $[\alpha]^{25}_D$ (**3p**) = -222.36° (c 0.15, $CHCl_3$); **^{1}H NMR** (300 MHz, $CDCl_3$) δ 8.02 (d, J = 1.60 Hz, 1H), 7.35 (d, J = 5.73 Hz, 3H), 7.14 (t, J = 7.44 Hz, 1H), 6.98 (t, J = 9.32 Hz, 4H), 6.85 – 6.67 (m, 2H), 6.22 (d, J = 7.47 Hz, 1H), 5.84 (d, J = 8.47 Hz, 1H), 5.31 (s, 1H), 4.87 (dd, J = 12.51, 9.21 Hz, 1H), 4.46 – 4.24 (m, 2H), 3.93 – 3.74 (m, 1H), 3.62 – 3.39 (m, 2H), 1.66 (s, 9H), 1.46 (t, J = 7.04 Hz, 3H), 0.97 (t, J = 7.04 Hz, 3H); **^{13}C NMR** (75 MHz, $CDCl_3$) δ 168.26, 156.81 (d, J = 16.77 Hz), 149.04, 141.65, 139.19, 136.87, 129.15, 128.25, 128.20, 128.03, 127.54 (d, J = 2.86 Hz), 127.15, 126.86, 126.51, 126.45, 126.37, 125.43, 123.95, 122.81, 121.88, 117.93, 85.11, 79.61, 64.20 (d, J = 7.28 Hz), 63.28 (d, J = 8.16 Hz), 43.31 (d, J = 9.00 Hz), 28.21, 16.60 (d, J = 6.06 Hz), 16.25 (d, J = 5.43 Hz)); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.53; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{32}H_{35}BrNNaO_7P$ 678.1232; found 678.1230.



3q

***tert*-butyl (*S*, *E*)-3-(1-(4-chlorophenyl)-3-(diethoxyphosphoryl)-3-hydroxy-3-phenylpropylidene)-2-oxoindoline-1-carboxylate (3q):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), α-ketophosphonate **2a** (24.2 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1h** (74.0 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly

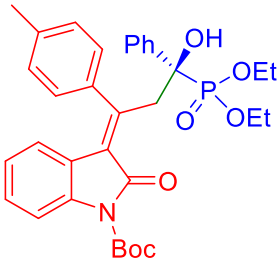
processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3q** (38.5 mg, 63% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3q** was determined to be 99% [determined by HPLC, Chiralpak IC, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 5.87 min, t (minor) = 7.13 min]. $[\alpha]^{25}_{D}$ (**3q**) = -218.40° (c 0.20, $CHCl_3$); **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.79 (d, *J* = 8.05 Hz, 1H), 7.42 – 7.29 (m, 3H), 7.16 (t, *J* = 7.35 Hz, 1H), 7.06 (d, *J* = 5.88 Hz, 1H), 7.00 (d, *J* = 7.23 Hz, 3H), 6.78 – 6.62 (m, 2H), 6.29 – 6.04 (m, 2H), 5.39 (s, 1H), 5.01– 4.78 (m, 1H), 4.45 – 4.21 (m, 2H), 3.83 (dt, *J* = 9.90, 7.00 Hz, 1H), 3.49 (t, *J* = 13.37 Hz, 2H), 1.66 (s, 9H), 1.46 (t, *J* = 6.90 Hz, 3H), 0.97 (t, *J* = 6.82 Hz, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 168.62, 153.95 (d, *J* = 16.82 Hz), 149.15, 140.22, 138.52, 136.99, 134.08, 129.89, 129.30 (d, *J* = 5.86 Hz), 128.31, 127.59 (d, *J* = 2.75 Hz), 127.61, 127.58, 127.35, 127.79, 127.12, 126.50 (d, *J* = 4.62 Hz), 123.86, 122.84, 122.63, 114.64, 84.72, 79.25, 77.85, 64.22 (d, *J* = 7.30 Hz), 63.31 (d, *J* = 8.14 Hz), 43.27 (d, *J* = 9.17 Hz), 28.22, 16.59 (d, *J* = 6.95 Hz), 16.23 (d, *J* = 5.39 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.51; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{32}H_{35Cl}NNaO_7P$ 634.1737; found 634.1725.



3r

***tert*-butyl (*S*, *E*)-3-(1-(4-bromophenyl)-3-(diethoxyphosphoryl)-3-hydroxy-3-phenylpropylidene)-2-oxoindoline-1-carboxylate (3r):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), *α*-ketophosphonate **2a** (24.2 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1i** (82.0 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 hrs. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3r** (42.6 mg, 65% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3r** was determined to be 93% [determined by HPLC, Chiralpak IC, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 5.67 min, t (minor) = 7.023 min]. $[\alpha]^{25}_{D}$ (**3r**) = -56.81° (c 0.04, $CHCl_3$); **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.79 (d, *J* = 7.99 Hz, 1H), 7.46 (d, *J* = 6.39 Hz, 1H), 7.39 – 7.30 (m, 2H), 7.16 (t, *J* = 7.32 Hz, 1H), 7.07 (d, *J* = 5.71 Hz, 1H), 7.04 – 6.95 (m, 2H), 6.94 – 6.80 (m, 2H), 6.69 (t, *J* = 7.31 Hz, 1H), 6.12 (d, *J* = 7.21 Hz, 2H), 5.36 (s, 1H), 4.98 – 4.80 (m, 1H), 4.45 – 4.23 (m, 2H), 3.91 – 3.75 (m, 1H), 3.59 – 3.38 (m, 2H), 1.66 (s, 9H), 1.45 (d, *J* = 6.85

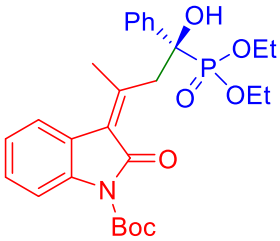
Hz, 3H), 0.96 (d, J = 6.71 Hz, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 168.64, 153.92 (d, J = 16.83 Hz), 149.18, 140.72, 138.57, 137.01, 132.23, 131.29, 130.16, 129.37, 127.66, 127.63, 127.50, 127.32, 127.14, 126.54 (d, J = 4.58 Hz), 123.91, 122.89, 122.64, 122.34, 114.68, 84.76, 79.27, 77.68, 64.24 (d, J = 7.32 Hz), 63.34 (d, J = 8.10 Hz), 43.25 (d, J = 9.31 Hz), 28.25 (s), 16.62 (d, J = 6.00 Hz), 16.26 (d, J = 5.42 Hz);**^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.49; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{32}H_{35}BrNNaO_7P$ 678.1232; found 678.1223.



3s

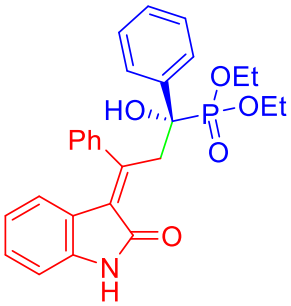
***tert*-butyl (*S*, *E*)-3-(3-(diethoxyphosphoryl)-3-hydroxy-3-phenyl-1-(*p*-tolyl)propylidene)-2-oxoindoline-1-carboxylate (3s):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), α- ketophosphonate **2a** (24.2 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1j** (70.0 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3s** (41.4 mg, 70% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3s** was determined to be 99% [determined by HPLC, Chiralpak Id, hexane: isopropanol = 65:35, 1 mL/min, λ = 254 nm, t (major) = 6.04 min, t (minor) = 7.90 min]. $[\alpha]^{25}_D$ (**3s**) = -227.89° (c 0.15, $CHCl_3$); **^{1}H NMR** (400 MHz, Chloroform-*d*) δ 7.77 (d, J = 8.2 Hz, 1H), 7.32 (t, J = 7.6 Hz, 1H), 7.22 (dd, J = 8.0, 2.5 Hz, 2H), 7.19 – 7.09 (m, 2H), 7.00 (d, J = 7.7 Hz, 1H), 6.74 (dd, J = 7.9, 4.7 Hz, 3H), 6.63 (td, J = 7.8, 1.1 Hz, 1H), 6.24 (d, J = 7.7 Hz, 1H), 6.02 (dd, J = 8.0, 1.3 Hz, 1H), 5.43 (s, 1H), 4.87 (dd, J = 12.7, 8.7 Hz, 1H), 4.41 – 4.21 (m, 2H), 3.85 (dt, J = 10.2, 7.0 Hz, 1H), 3.54 (ddd, J = 9.8, 7.9, 5.0 Hz, 2H), 2.19 (d, J = 2.1 Hz, 3H), 1.66 (s, 9H), 1.45 (t, J = 7.1 Hz, 3H), 1.01 (t, J = 7.1 Hz, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 168.91, 156.39 (d, J = 16.80 Hz), 149.29, 138.91, 138.30, 137.99, 137.07, 129.56, 128.83 (d, J = 6.62 Hz), 128.31, 127.39 (d, J = 2.77 Hz), 126.79, 126.76, 126.65, 126.52, 125.56, 123.71, 123.14, 122.89, 114.43, 84.56, 79.48, 77.89, 64.15 (d, J = 7.32 Hz), 63.30 (d, J = 8.16 Hz), 43.27 (d, J = 8.92 Hz), 28.24, 21.36, 16.61 (d, J = 5.90 Hz), 16.25 (d, J = 5.40 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.76; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{32}H_{38}NNaO_7P$ 614.2284; found 614.2290.

***tert*-butyl (*S*, *Z*)-3-(4-(diethoxyphosphoryl)-4-hydroxy-4-phenylbutan-2-ylidene)-2-oxoindoline-1-carboxylate (3t):** In an oven and vacuum-dried reaction tube, catalyst **V** (11.9 mg, 0.02 mmol, 0.2 equiv), *α*-ketophosphonate **2a** (24.2 mg, 0.1 mmol, 1.0 equiv) and 3-alkylidene oxindole **1k** (67.2 mg, 0.2 mmol, 2.0 equiv) were taken in 1 mL of freshly distilled toluene under positive argon pressure. In the resulting homogenous mixture, K_2HPO_4 (34.6 mg, 0.2 mmol, 2.0 equiv) was added at -20 °C and it was kept at -20 °C for 96 h. The reaction mixture was directly processed for the purification by silica gel column chromatography (eluent: EtOAc/Petroleum ether = 4/6, v/v) without any workup to give light yellow solid **3t** (31.0 mg, 60% yield). R*f* = 0.33 (ethyl acetate/petroleum ether = 4/6); The *ee* of the **3t** was determined to be 99% [determined by HPLC, Chiralpak IC, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 6.60 min, t (minor) = 7.25 min]. $[\alpha]^{25}_{D}$ (**3t**) = -116.03° (c 0.26, $CHCl_3$); **^{1}H NMR** (400 MHz, $CDCl_3$) *δ* 7.80 (d, *J* = 7.09 Hz, 1H), 7.77-6.68 (m, 2H), 7.33-7.25 (m, 3H), 7.25-7.20 (m, 2H), 7.02 (s, 1H), 5.07 (s, 1H), 4.55 (t, *J* = 9.68 Hz, 1H), 4.25 (d, *J* = 6.06 Hz, 2H), 3.88 (s, 1H), 3.64 (d, *J* = 6.99 Hz, 1H), 3.15 (d, *J* = 10.72 Hz, 1H), 1.67 (s, 3H), 1.57 (s, 9H), 1.39-1.31 (m, 3H), 1.05-0.90 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) *δ* 168.51, 154.92 (d, *J* = 15.40 Hz), 149.32, 138.68 (d, *J* = 1.94 Hz), 138.24, 130.16, 128.45, 128.26, 128.24, 127.70 (d, *J* = 2.74 Hz), 126.33 (d, *J* = 4.72 Hz), 124.13 (d, *J* = 16.39 Hz), 123.79, 114.71, 84.54, 78.89, 64.23 (d, *J* = 7.46 Hz), 63.48 (d, *J* = 8.00 Hz), 44.95 (d, *J* = 8.04 Hz), 28.24, 26.59, 16.61 (d, *J* = 5.87 Hz), 16.32 (d, *J* = 5.35 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) *δ* 21.72; **HRMS ESI**: $[M+Na]^+$, Calcd for $C_{27}H_{34}NNaO_7P$ 538.1971; found 538.1970.



3t

diethyl (S,E)-(1-hydroxy-3-(2-oxoindolin-3-ylidene)-1,3-diphenylpropyl)phosphonate (4): In an oven and vacuum-dried reaction tube, **3a** (115.4 mg, 0.2 mmol, 1.0 equiv) was taken in 2 mL of freshly distilled DCM under positive argon pressure at 0 °C. In the resulting solution, TFA (76.5 µl, 5 equiv) was added dropwise for 5 min and the reaction was stirred fat room temperature for 1 hour. Once the reaction was completed, it was quenched with saturated $NaHCO_3$. The organic layer was separated and the aqueous layer was washed with methylene chloride (3 x 3 mL). The combined organic layer was dried over Na_2SO_4, filtered and concentrated. The crude mixture was purified by flash chromatography (silica gel, hexane/ethyl acetate = 20/80) to give the product as a yellow solid. (82.1 mg, 86% yield),



4

diastereomeric ratio (E/Z=19:1), R*f* = 0.2 (ethyl acetate/petroleum ether = 1:1); The *ee* of the **4** was determined to be 99% [determined by HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm, t (major) = 6.94 min, t (minor) = 21.17 min]. **^{1}H NMR** (400 MHz, Chloroform-*d*) δ 8.23 (s, 1H), 7.44 – 7.29 (m, 3H), 7.14 (tt, *J* = 7.5, 1.3 Hz, 1H), 7.06-7.11 (m, 2H), 7.03 – 6.89 (m, 3H), 6.84 – 6.68 (m, 2H), 6.55 (td, *J* = 7.7, 1.1 Hz, 1H), 6.25 (d, *J* = 7.7 Hz, 1H), 6.18 (d, *J* = 7.3 Hz, 1H), 6.01 (d, *J* = 7.9 Hz, 1H), 4.88 (dd, *J* = 12.6, 8.7 Hz, 1H), 4.31 (m, 2H), 3.85 (m, 1H), 3.55 (m, 2H), 1.43 (t, *J* = 7.0 Hz, 3H), 0.98 (t, *J* = 7.0 Hz, 3H); **^{13}C NMR** (101 MHz, Chloroform-*d*) δ 171.68, 141.89, 137.11, 128.72, 128.35, 127.77, 127.32, 126.91, 126.44, 125.47, 123.35, 122.04, 109.77, 79.27, 77.67, 64.02, 63.95, 63.28, 63.20, 42.87, 42.78, 34.13, 22.34, 16.66, 16.60, 16.21, 16.16.

^{1}H NMR spectra of Ketophosphonate 2a and the Cat. V (0.02 mmol in toluene-d$_8$) upon the addition of increasing amounts of α–keto-phosphonate.

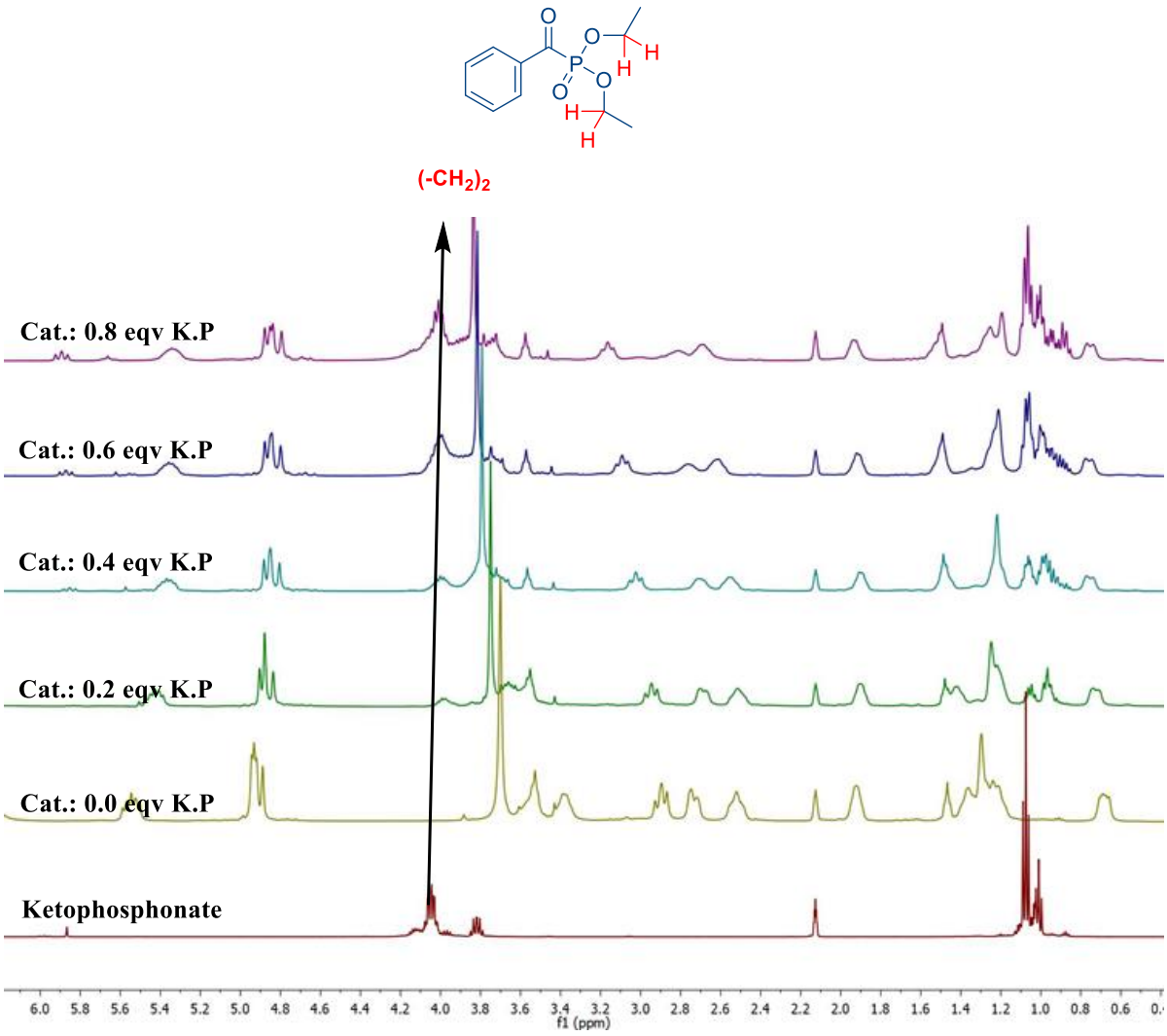


Figure S2. Time-elapsed ^{31}P NMR spectra for the synthesis of aldol product

NMR Spectroscopic Studies: Time-elapsed ^{31}P NMR spectra for the synthesis of aldol product.

To further investigate the mechanism, the formation of **3a** was monitored by ^{31}P NMR spectroscopy as shown in Figure S2. The starting reaction mixture in toluene-d$_8$ showed signal in the ^{31}P NMR spectrum at δ = -1.22 ppm (ketophosphonate), and peak at δ = 6.68 ppm (diethylphosphite). The emergence of peak at δ = 16.17 ppm after the addition

of catalyst possibly corresponds to H-bonded ketophosphonate. As time progressed, the ^{31}P NMR signals of the starting material disappeared gradually and the reaction was almost complete after 96 hours according to the ^{31}P NMR spectra. Additionally, a comparative evaluation ^{31}P NMR of aldol product **3a** and **Cat. V** with ketophosphonate and **Cat. V** clearly shows no significant shift of peaks (Figure S2).

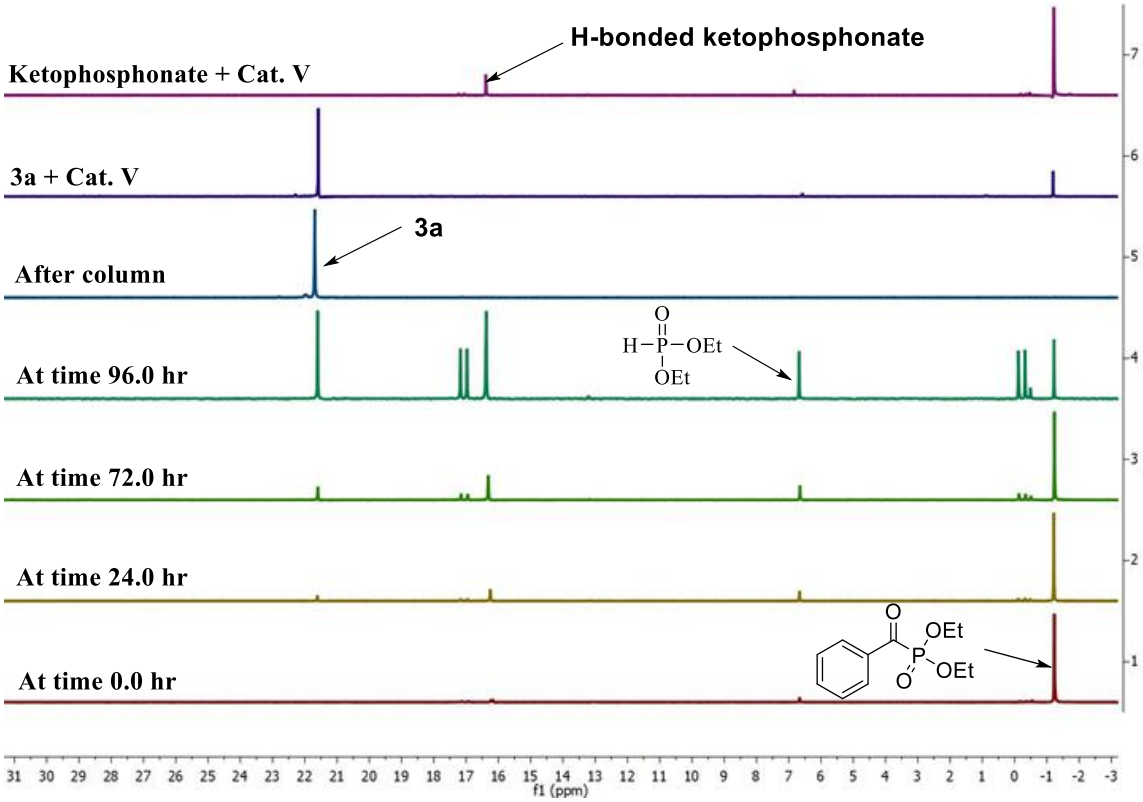
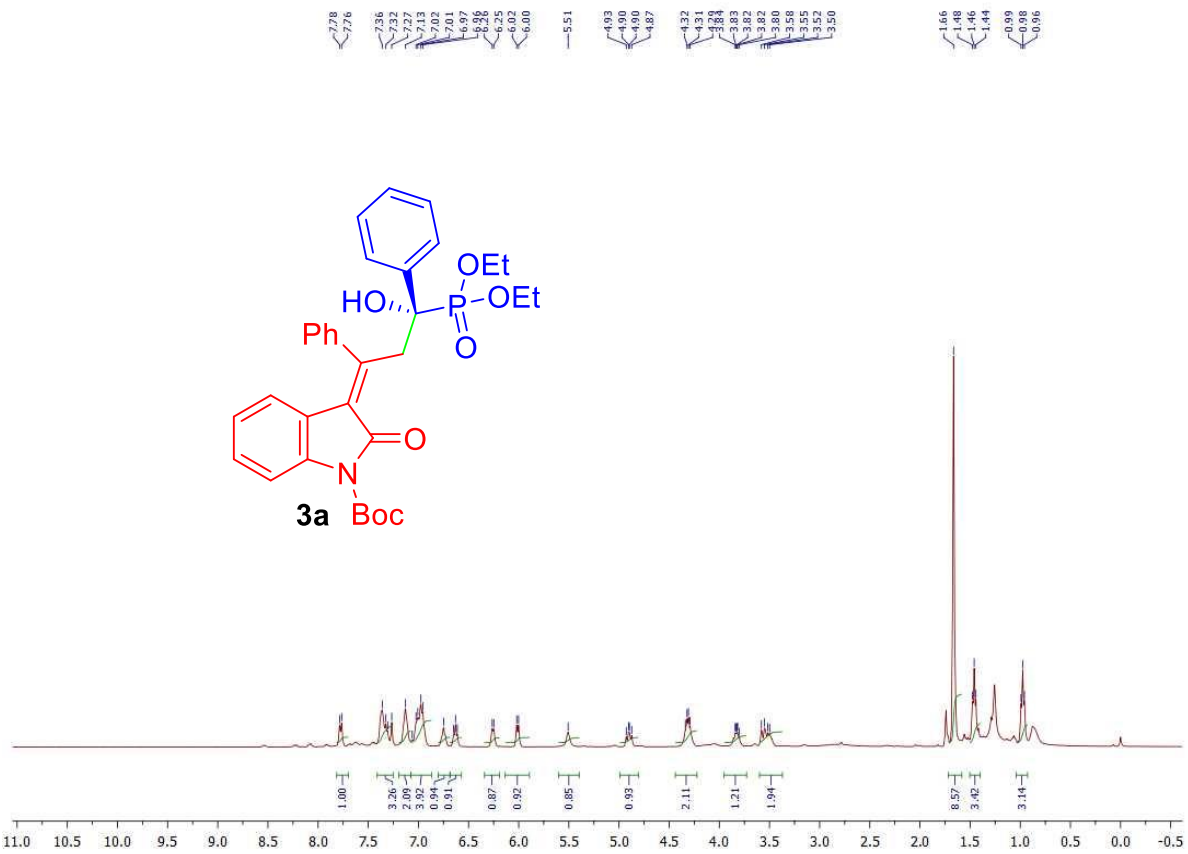
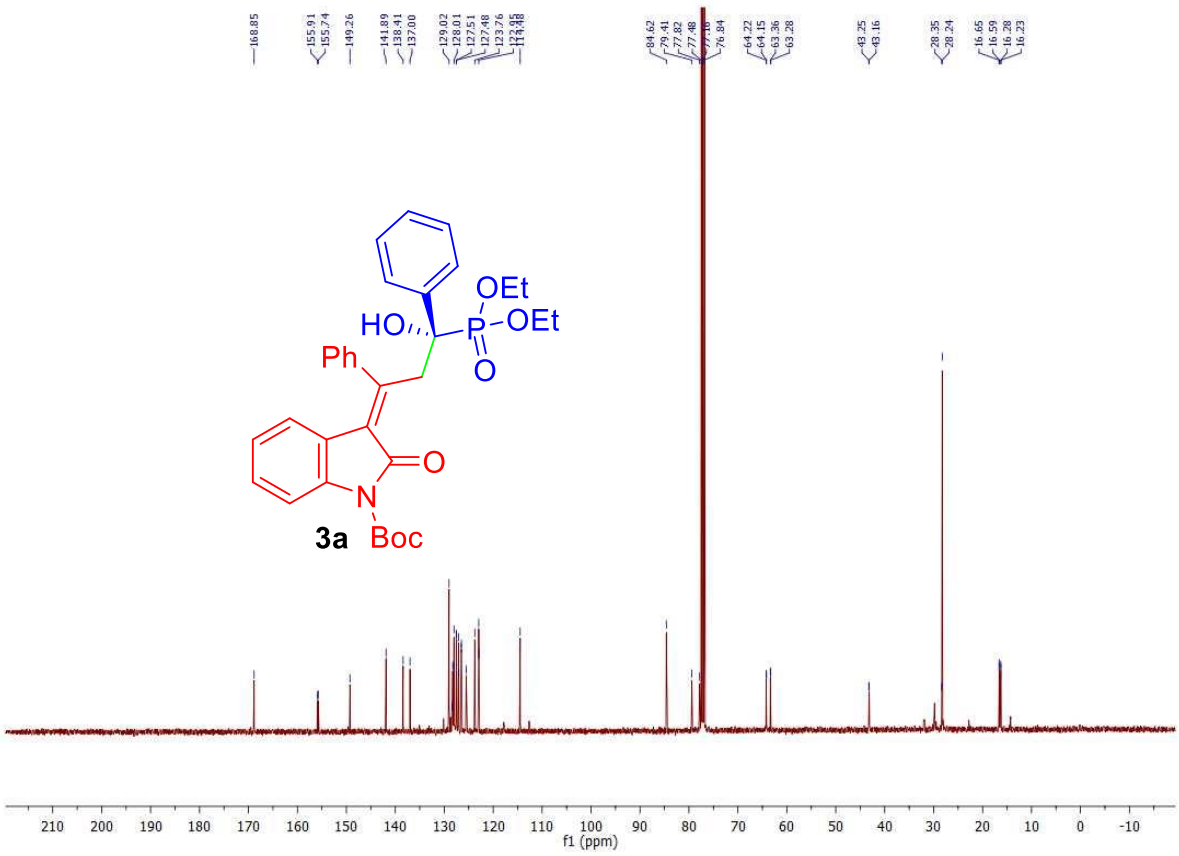
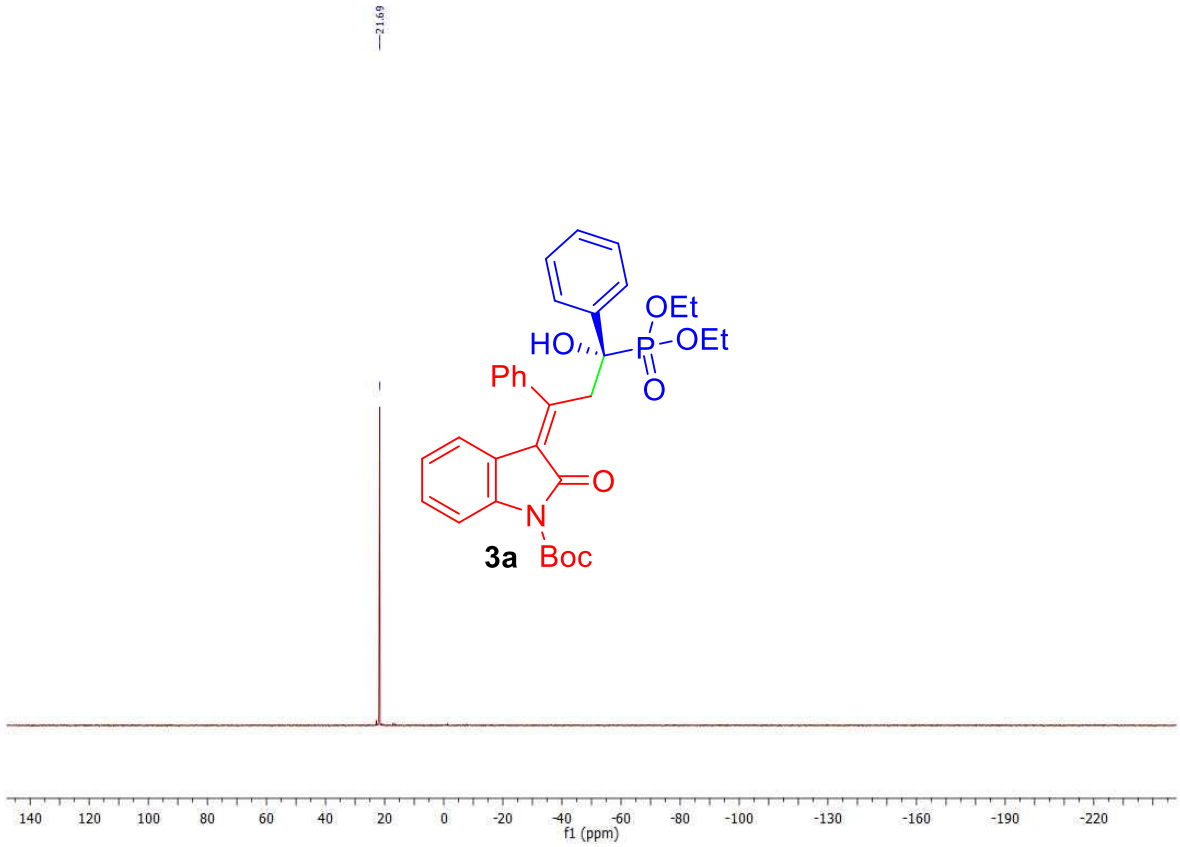
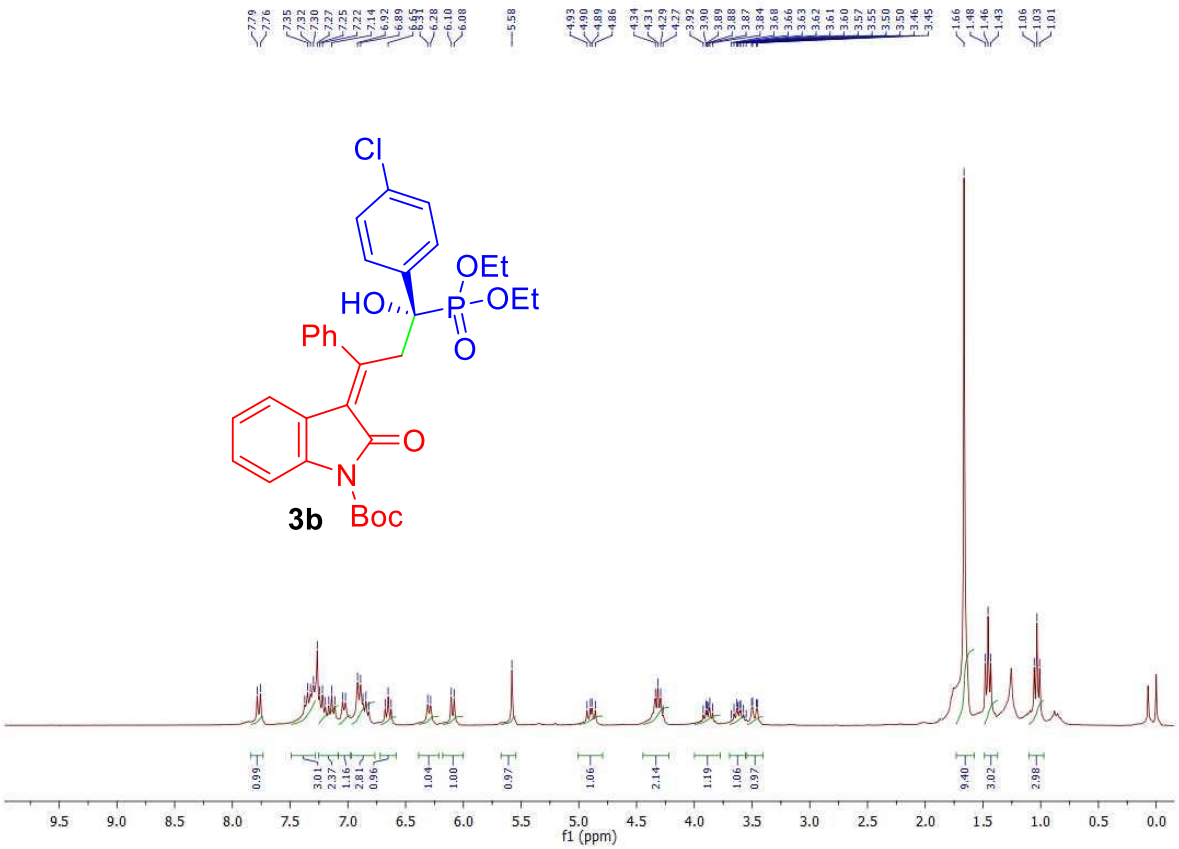


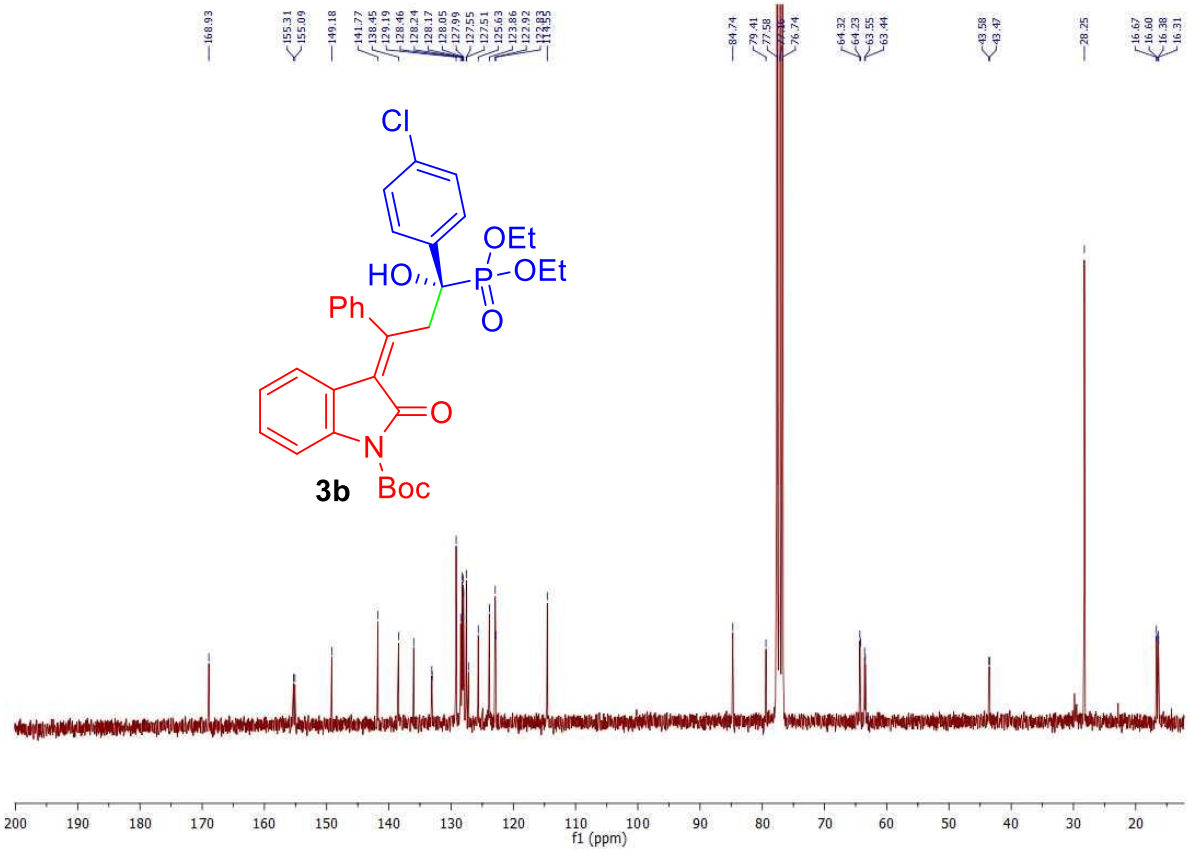
Figure S3. Time-elapsed ^{31}P NMR spectra for the synthesis of aldol product

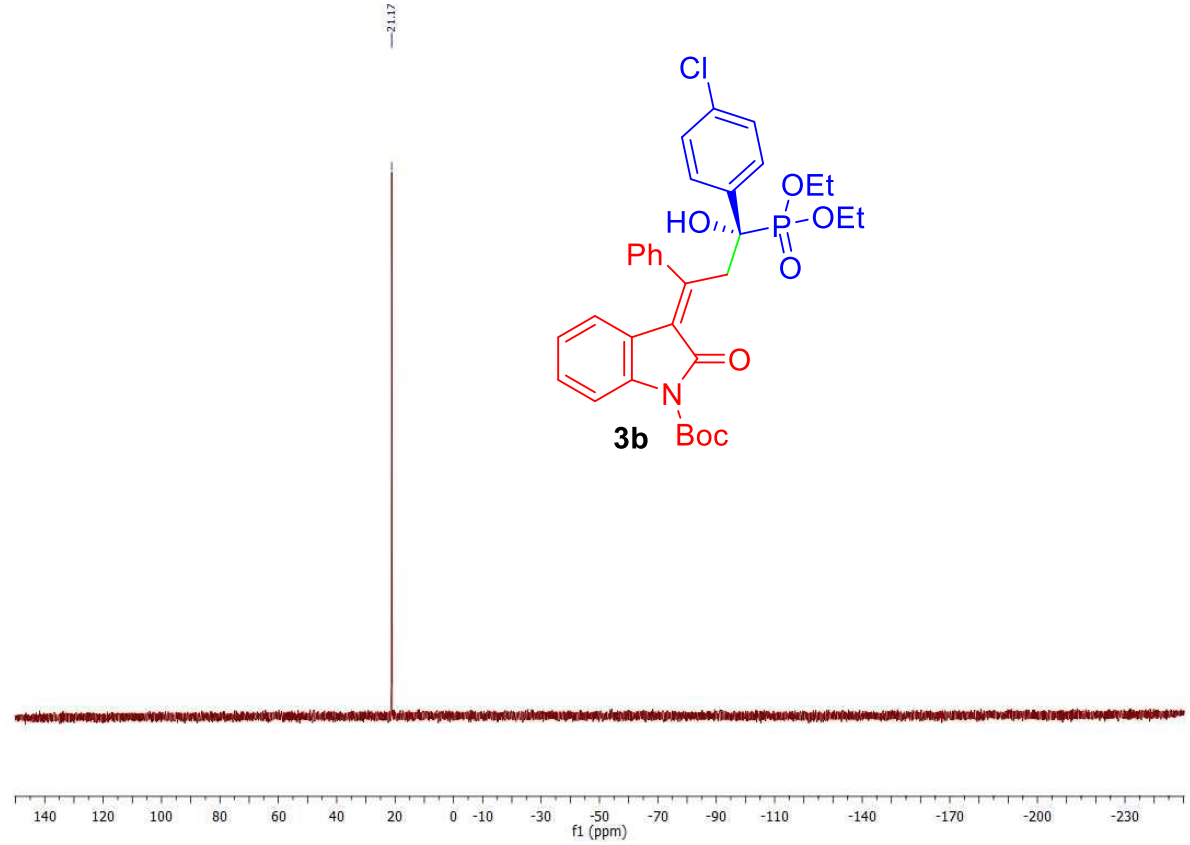

OEt
HO
P
OEt
O
Ph
O
N
Boc
3a

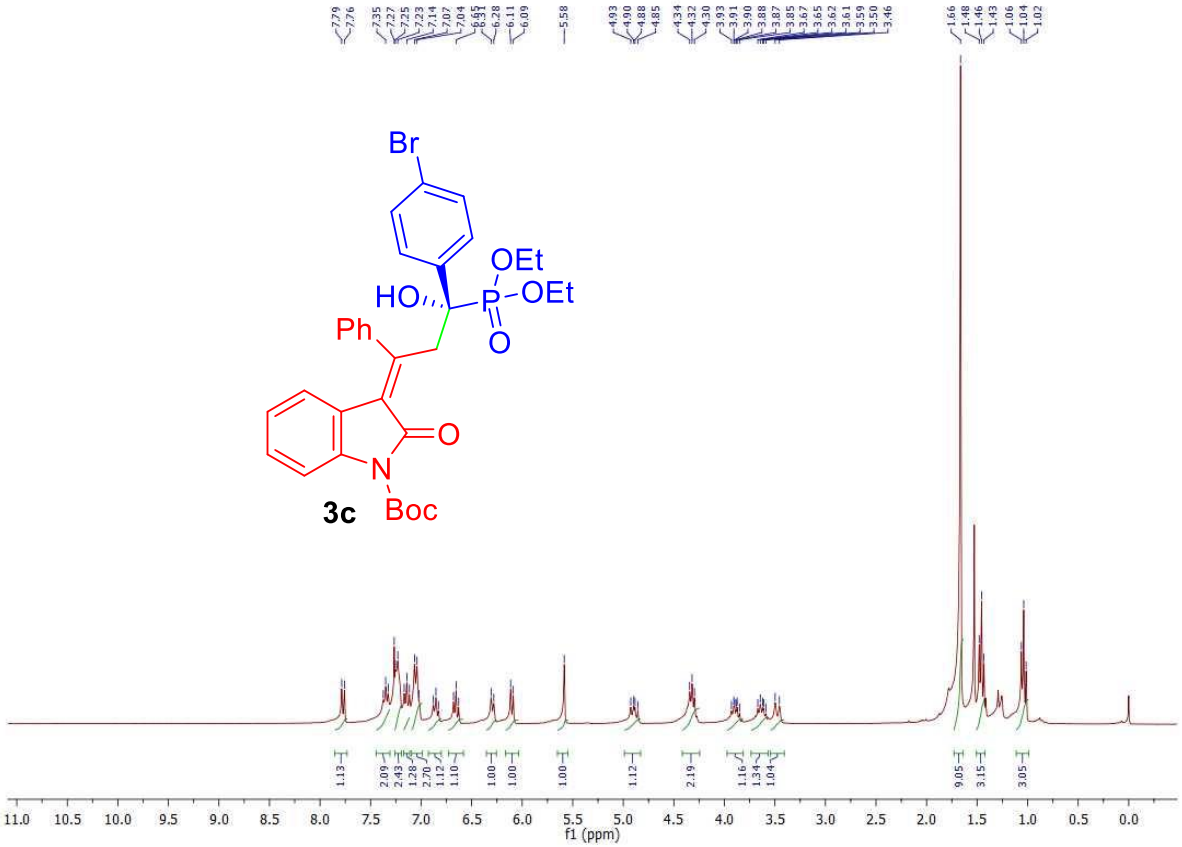

OEt
HO
P
OEt
O
Ph
O
N
Boc
3a
f1 (ppm)

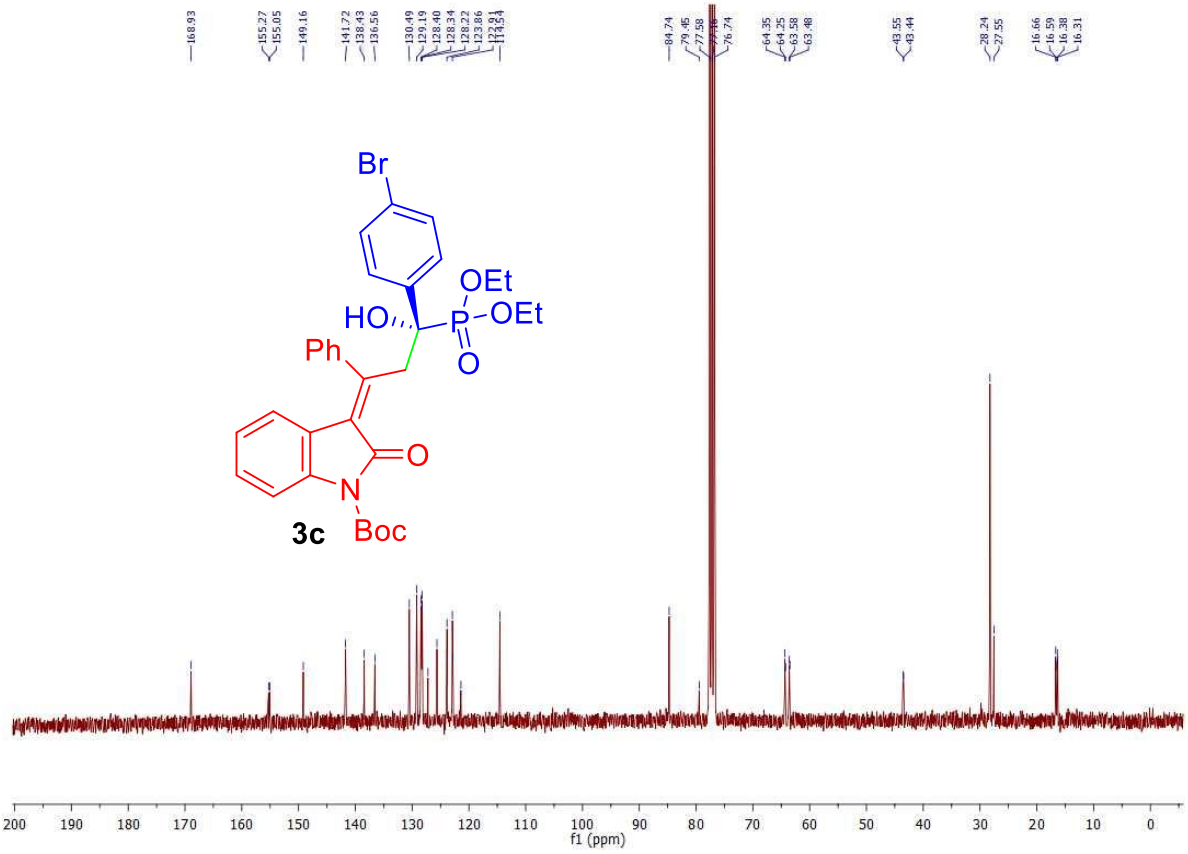

21.69
OEt
HO
P
OEt
O
Ph
O
N
Boc
3a
140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -130 -160 -190 -220
f1 (ppm)

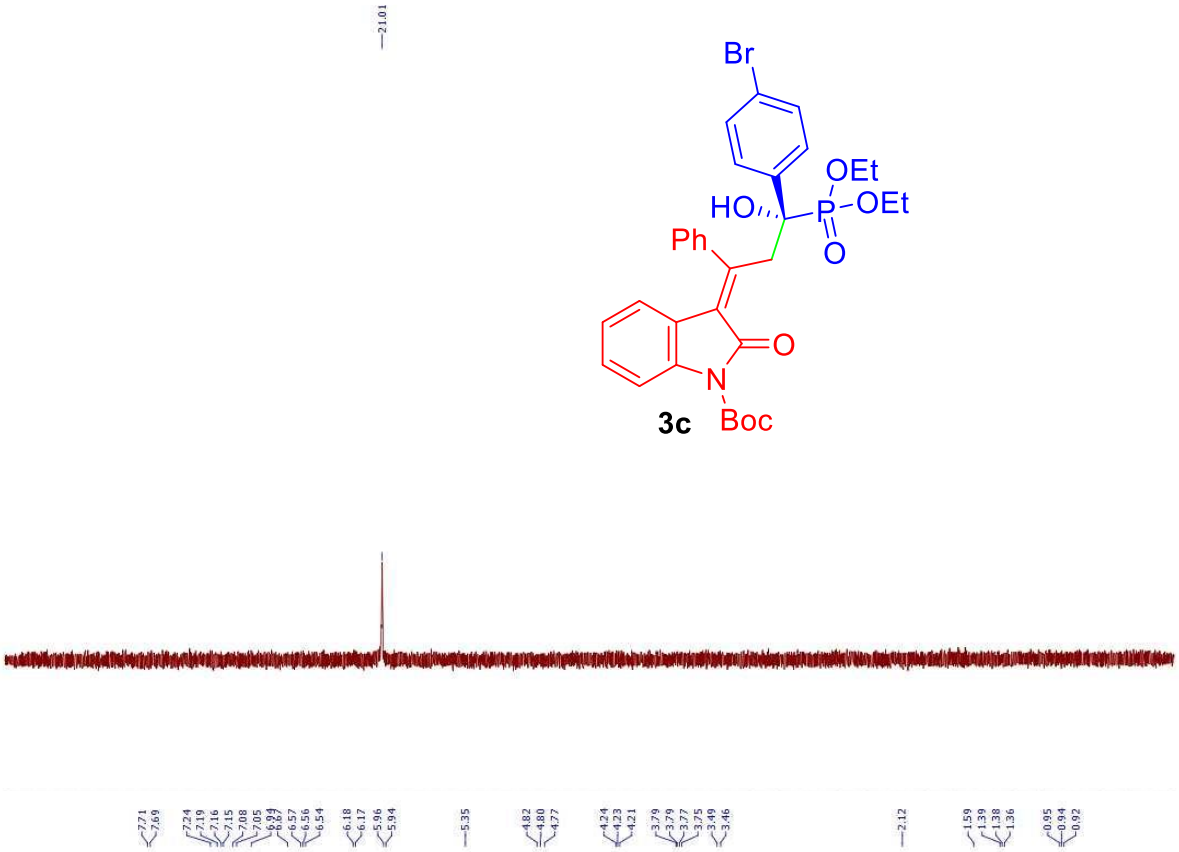

Cl
OEt
HO
P
OEt
O
Ph
O
N
Boc
3b
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

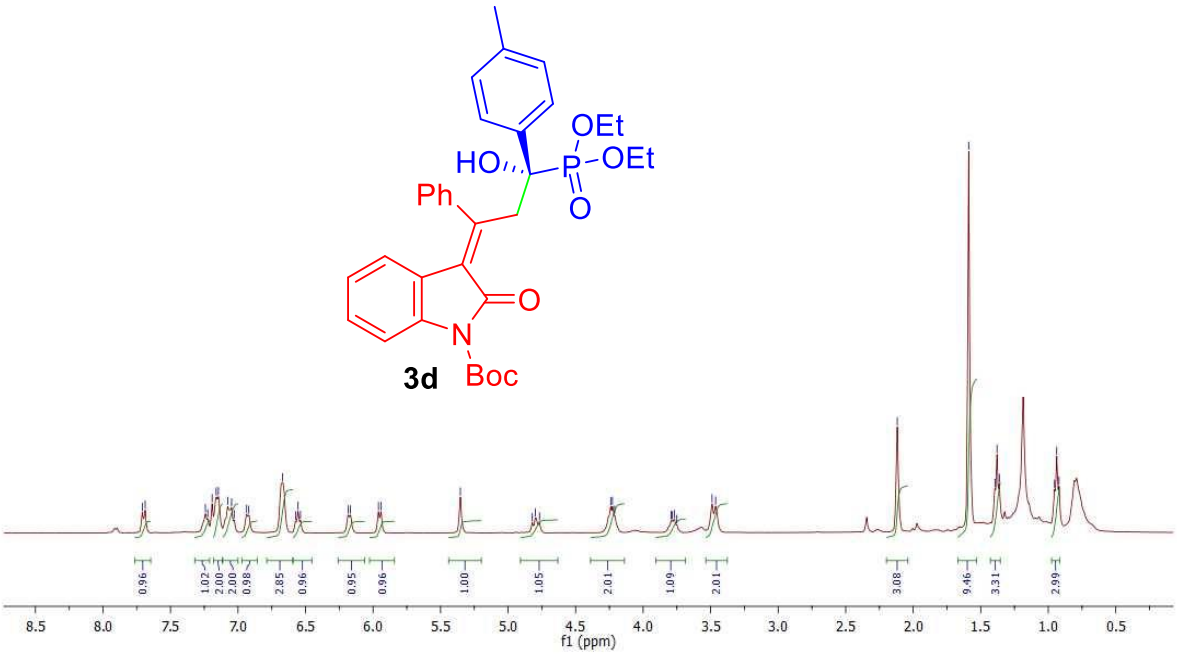

Cl
OEt
HO
P
OEt
O
Ph
O
N
Boc
3b
f1 (ppm)

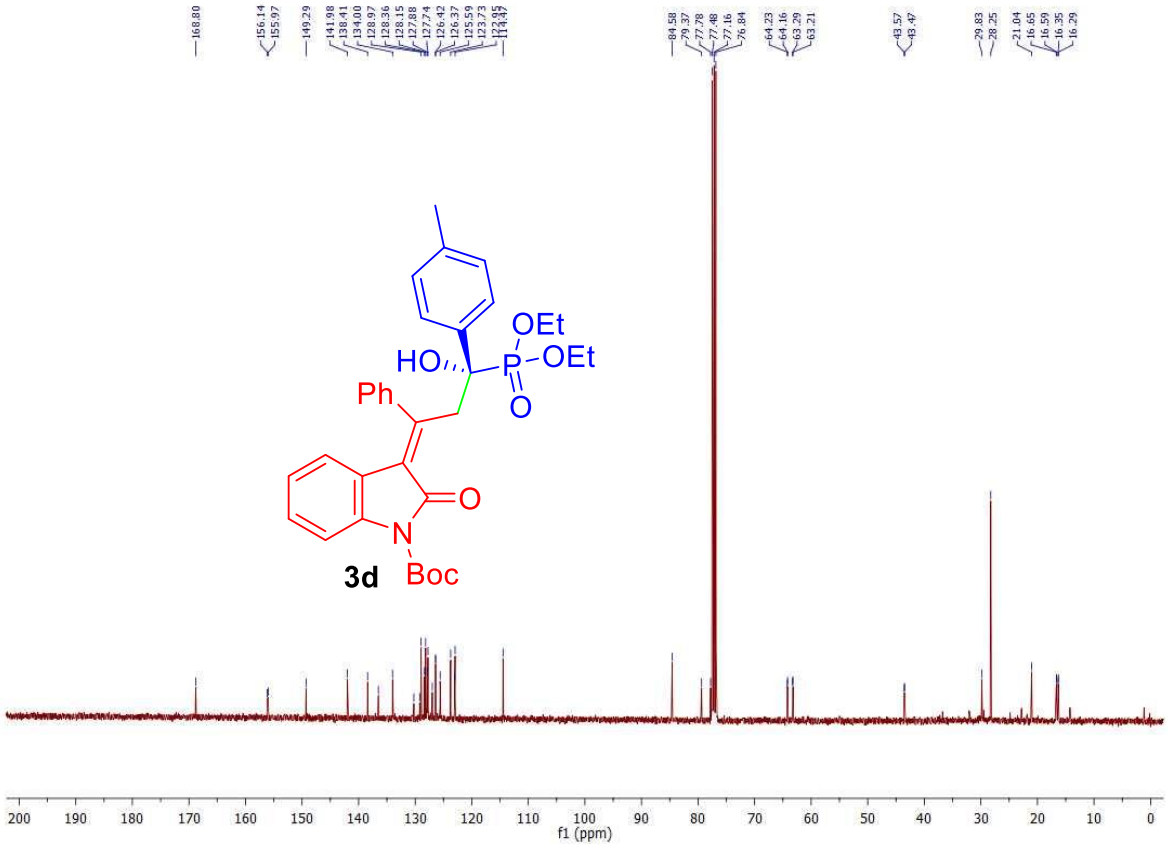

Cl
OEt
HO
P
OEt
O
Ph
O
N
Boc
3b
f1 (ppm)

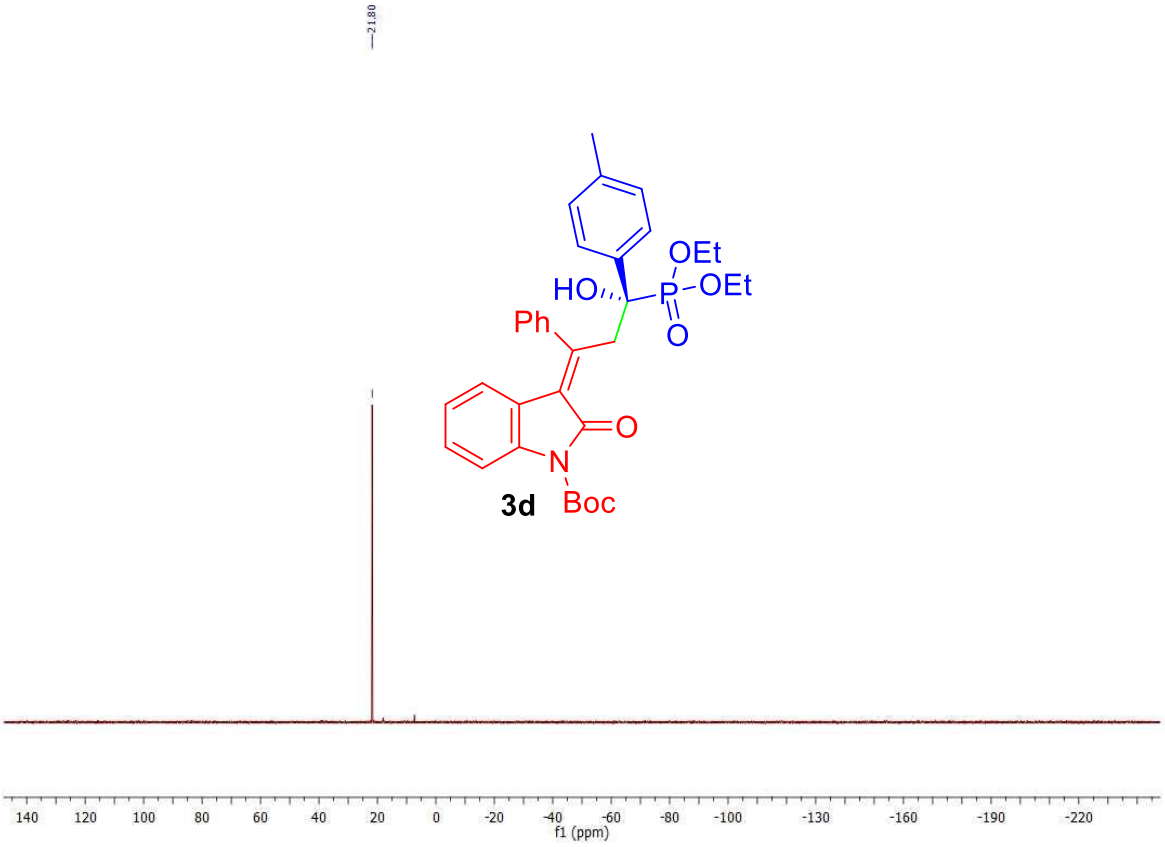

Br
OEt
HO
P
OEt
O
Ph
O
N
Boc
3c
f1 (ppm)

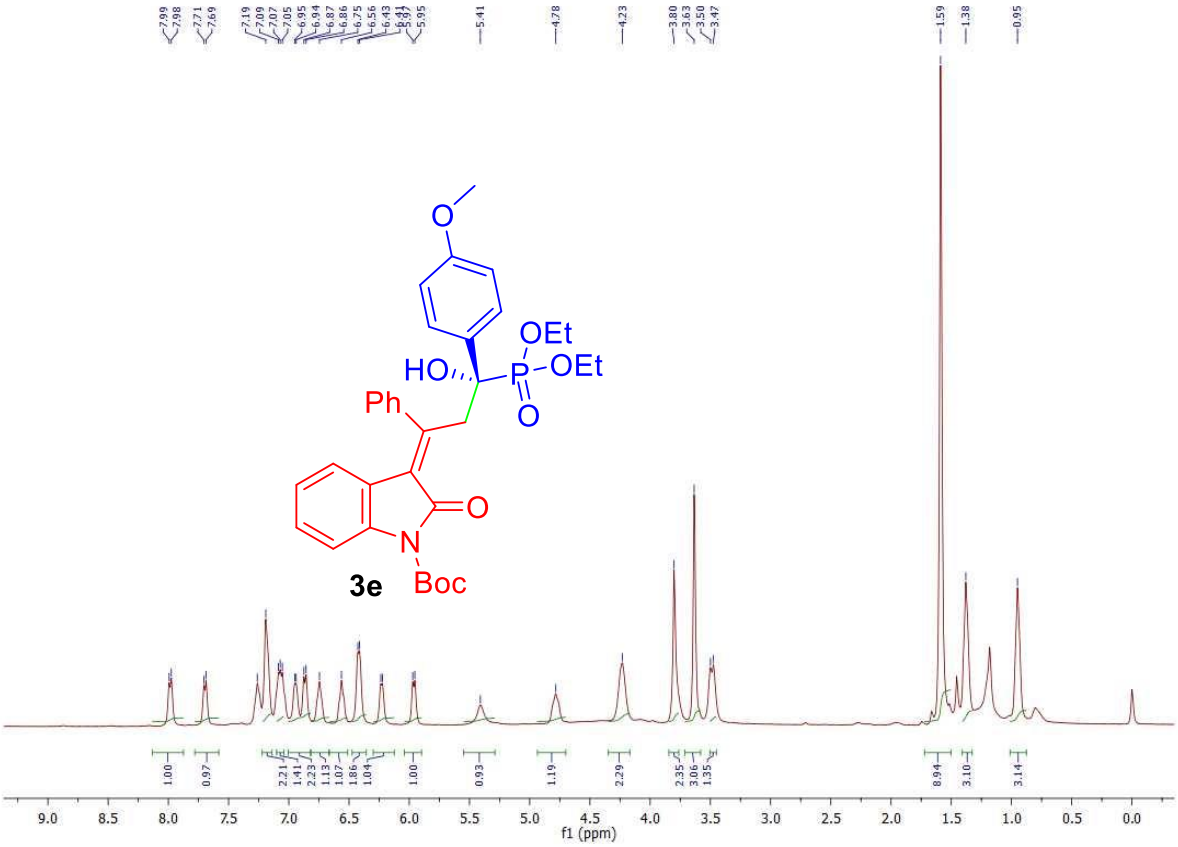

Br
OEt
HO
P
OEt
O
Ph
O
N
Boc
3c
f1 (ppm)

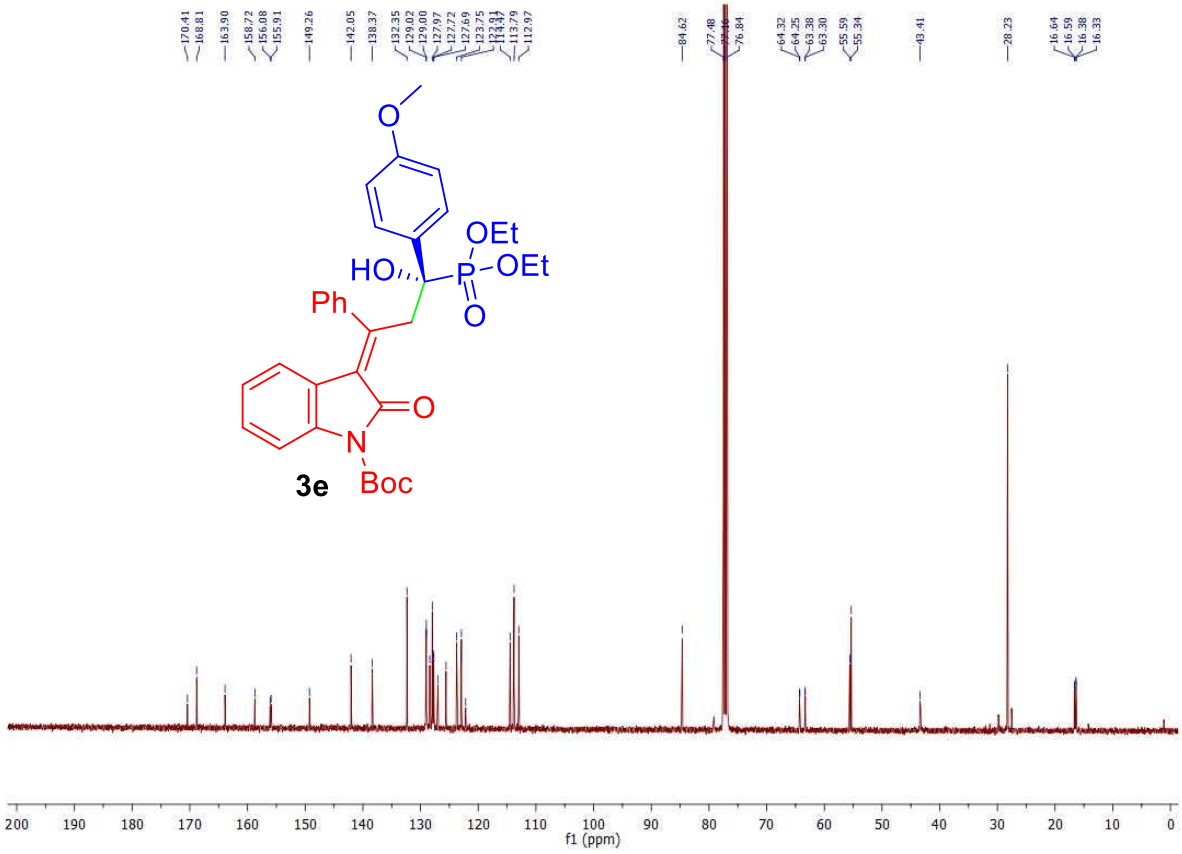

21.01
Br
OEt
HO
P
OEt
O
Ph
O
N
Boc
3c
7.71
7.69
7.24
7.19
7.16
7.15
7.08
7.05
6.87
6.57
6.56
6.54
6.18
6.17
5.96
5.94
5.35
4.82
4.80
4.77
4.24
4.23
4.21
3.79
3.79
3.77
3.75
3.49
3.46
2.12
1.59
1.39
1.38
1.36
0.95
0.94
0.92

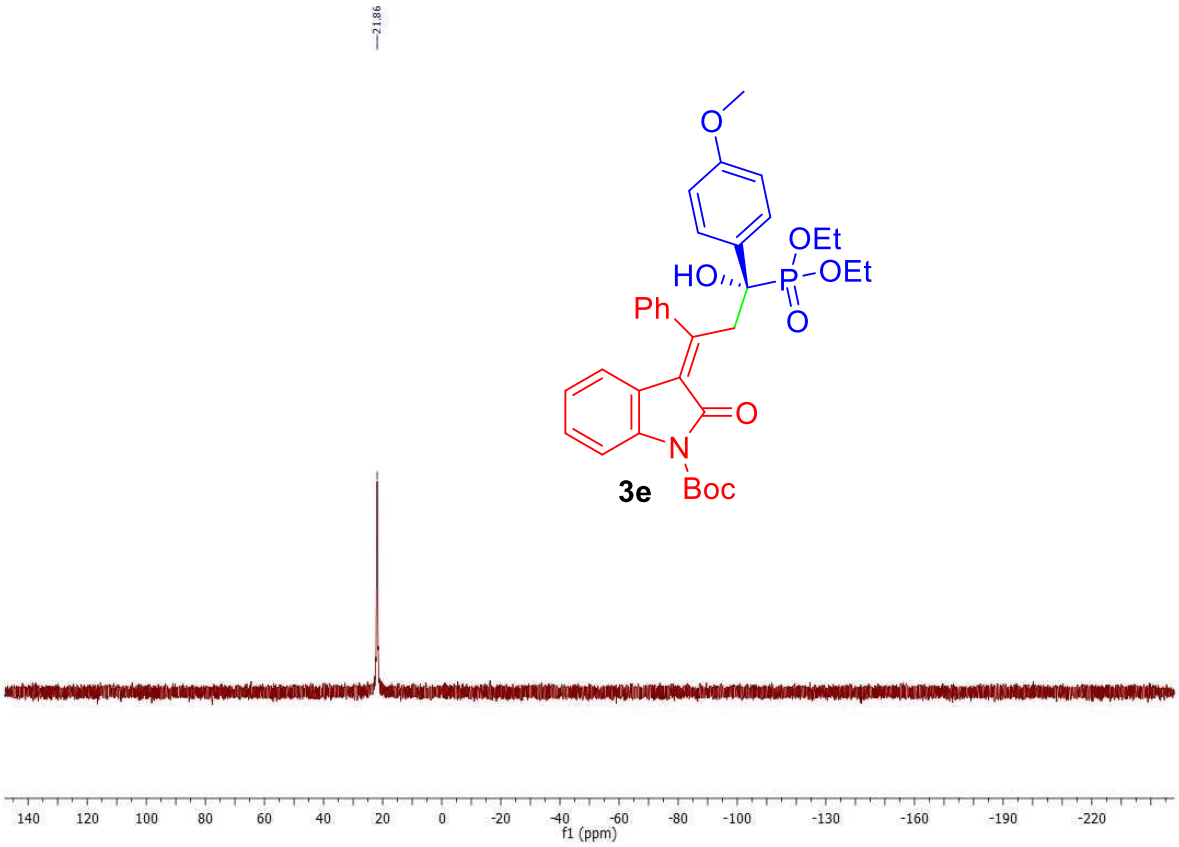

OEt
HO
P
OEt
O
Ph
O
N
Boc
3d
0.96
1.02
2.00
2.00
0.98
2.85
0.96
0.95
0.96
1.00
1.05
2.01
1.09
2.01
3.08
9.46
3.31
2.99
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

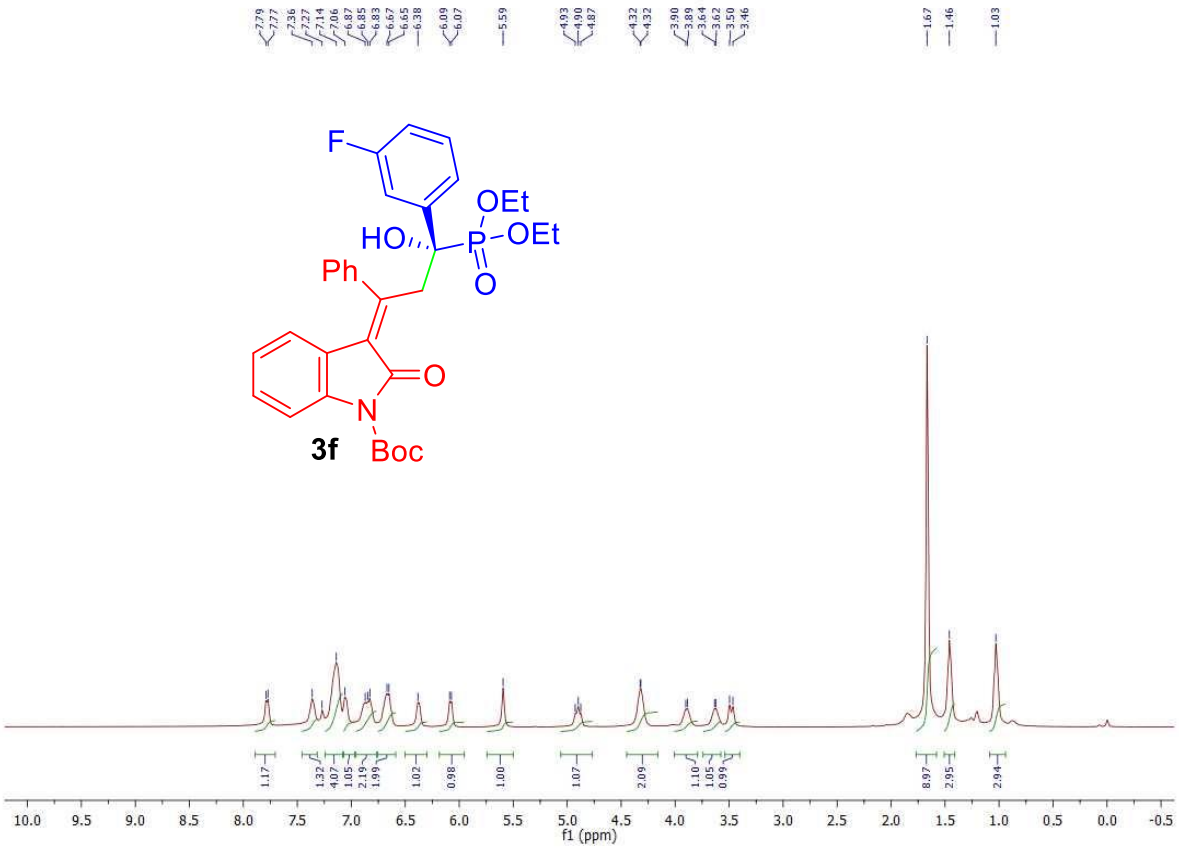

168.80
156.14
155.97
149.29
141.98
138.41
134.00
128.97
128.36
128.15
127.88
127.74
126.42
126.37
125.59
123.73
84.58
79.37
77.78
77.48
77.16
76.84
64.23
64.16
63.29
63.21
43.57
43.47
29.83
28.25
21.04
16.65
16.59
16.35
16.29
OEt
HO
P
OEt
O
Ph
O
N
Boc
3d
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

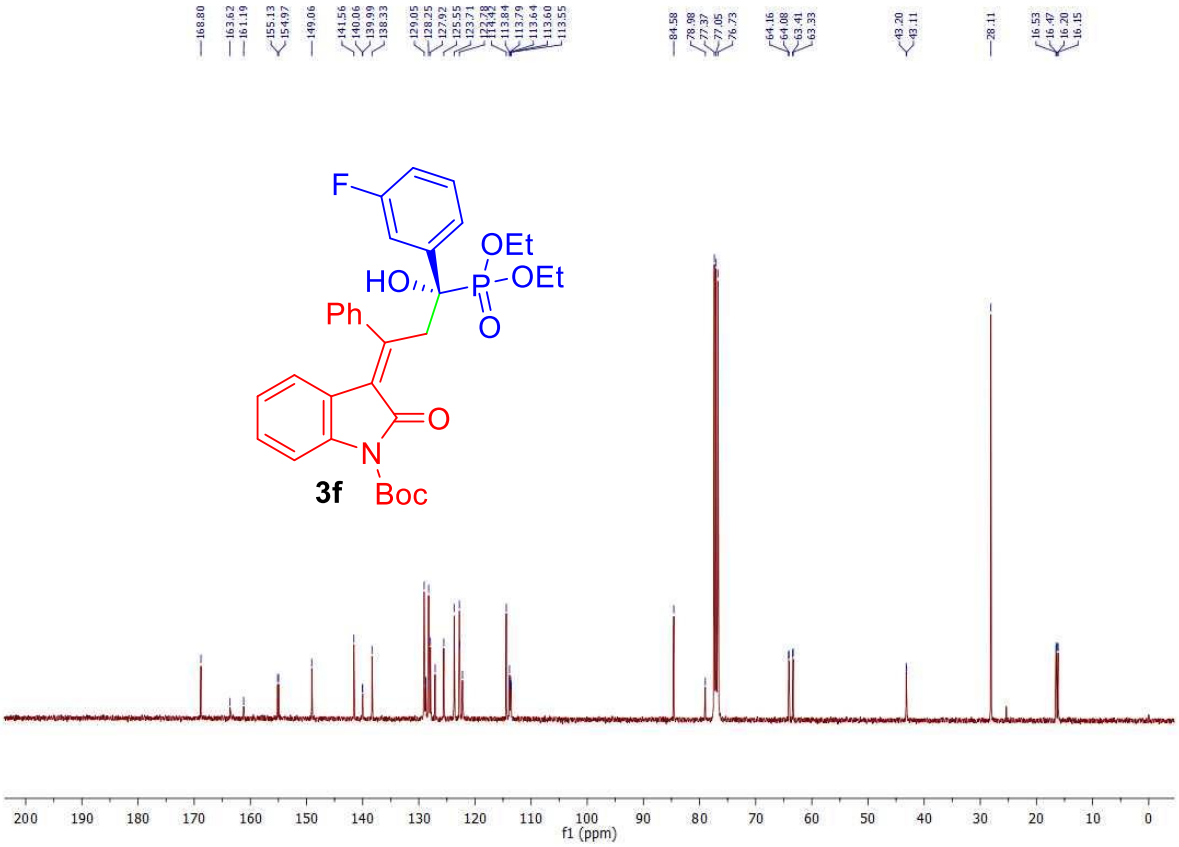

21.80
OEt
HO
P
OEt
O
Ph
O
N
Boc
3d
140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -130 -160 -190 -220
f1 (ppm)

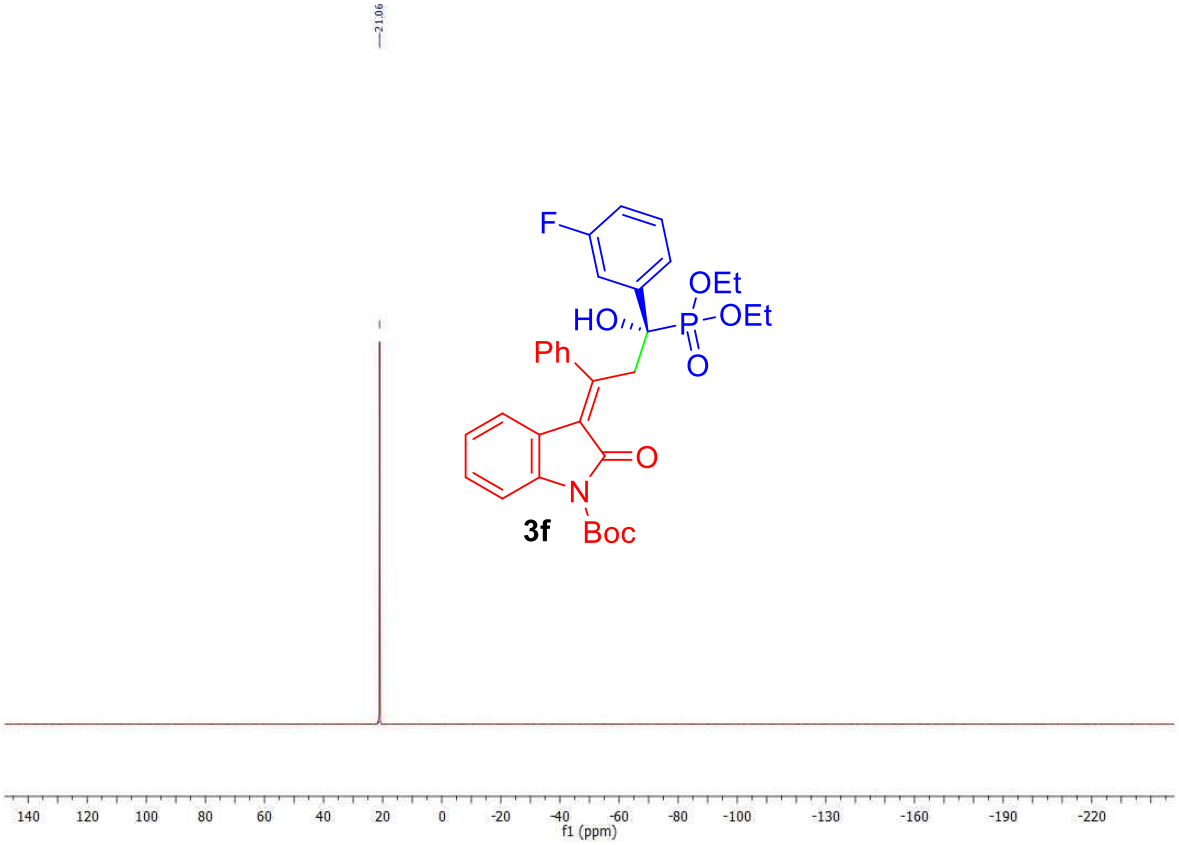

3e
f1 (ppm)

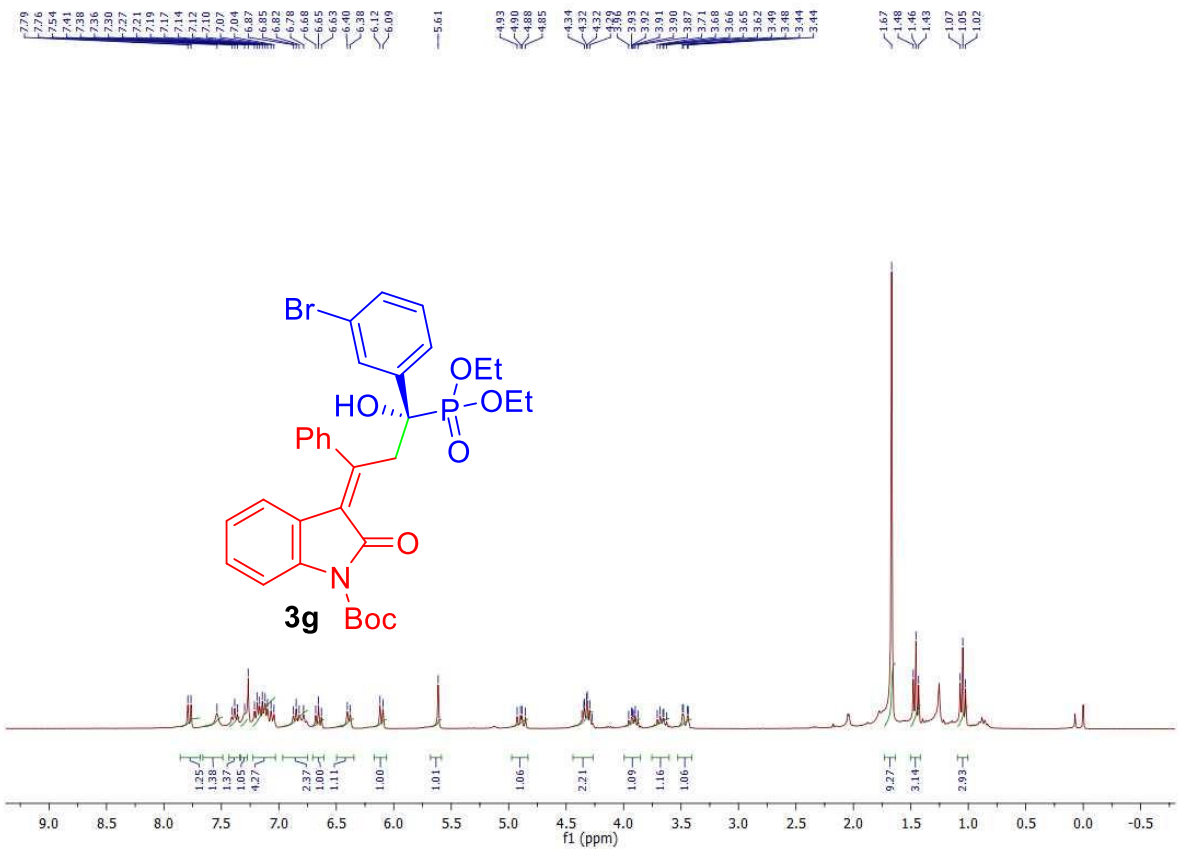

3e
f1 (ppm)

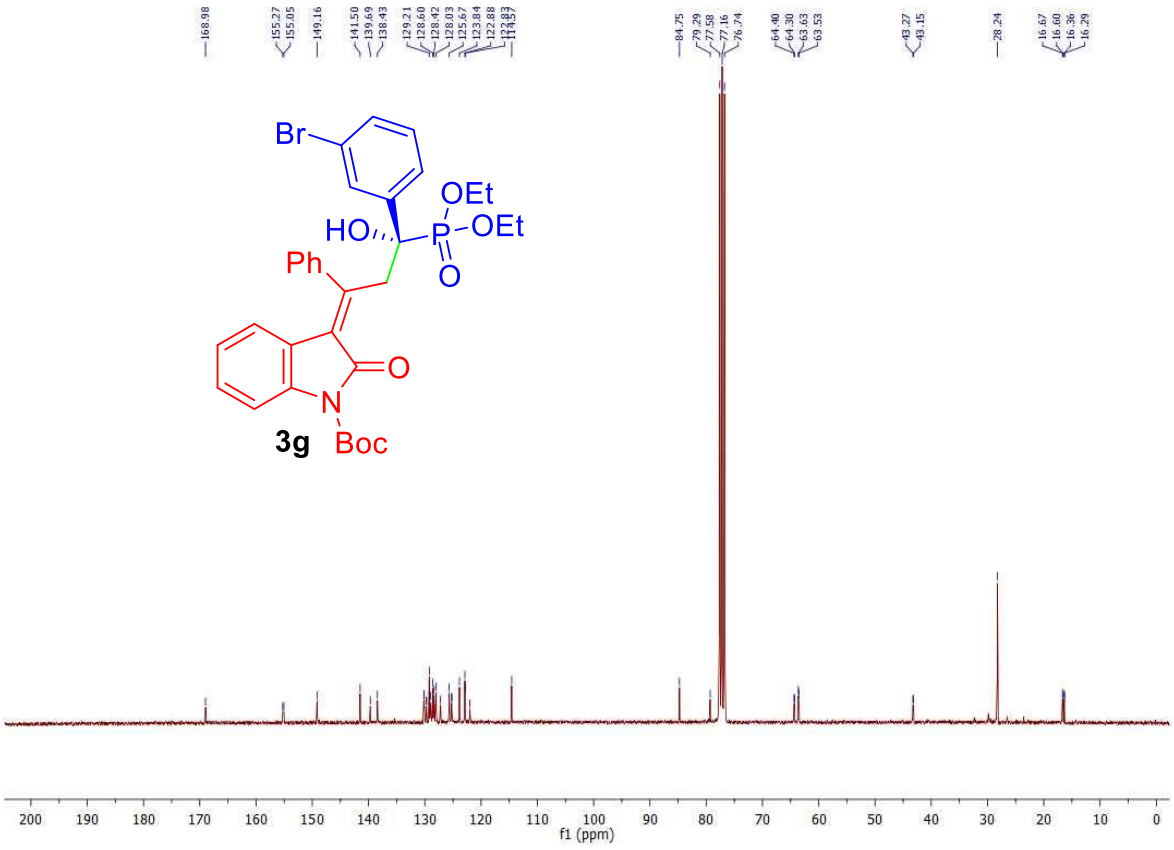

21.86
O
OEt
HO
P
OEt
Ph
O
O
N
Boc
3e
140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -130 -160 -190 -220
f1 (ppm)

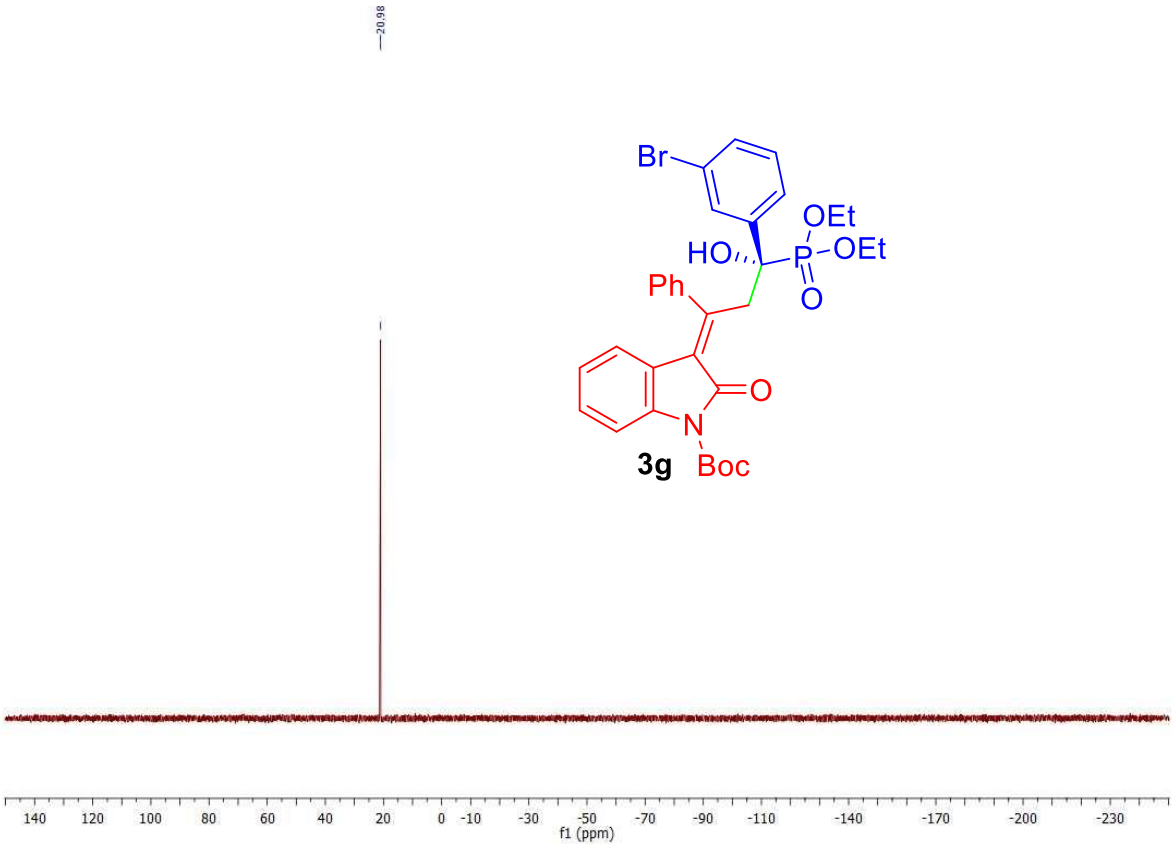

7.79 7.77 7.36 7.27 7.14 7.06 6.87 6.85 6.83 6.67 6.65 6.38 6.09 6.07 5.59 4.93 4.90 4.87 4.32 4.32 3.90 3.89 3.64 3.62 3.50 3.46 1.67 1.46 1.03
F
OEt
HO
P
OEt
Ph
O
O
N
Boc
3f
1.17 1.32 4.07 1.05 2.19 1.99 1.02 0.98 1.00 1.07 2.09 1.10 1.05 0.99 8.97 2.95 2.94
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

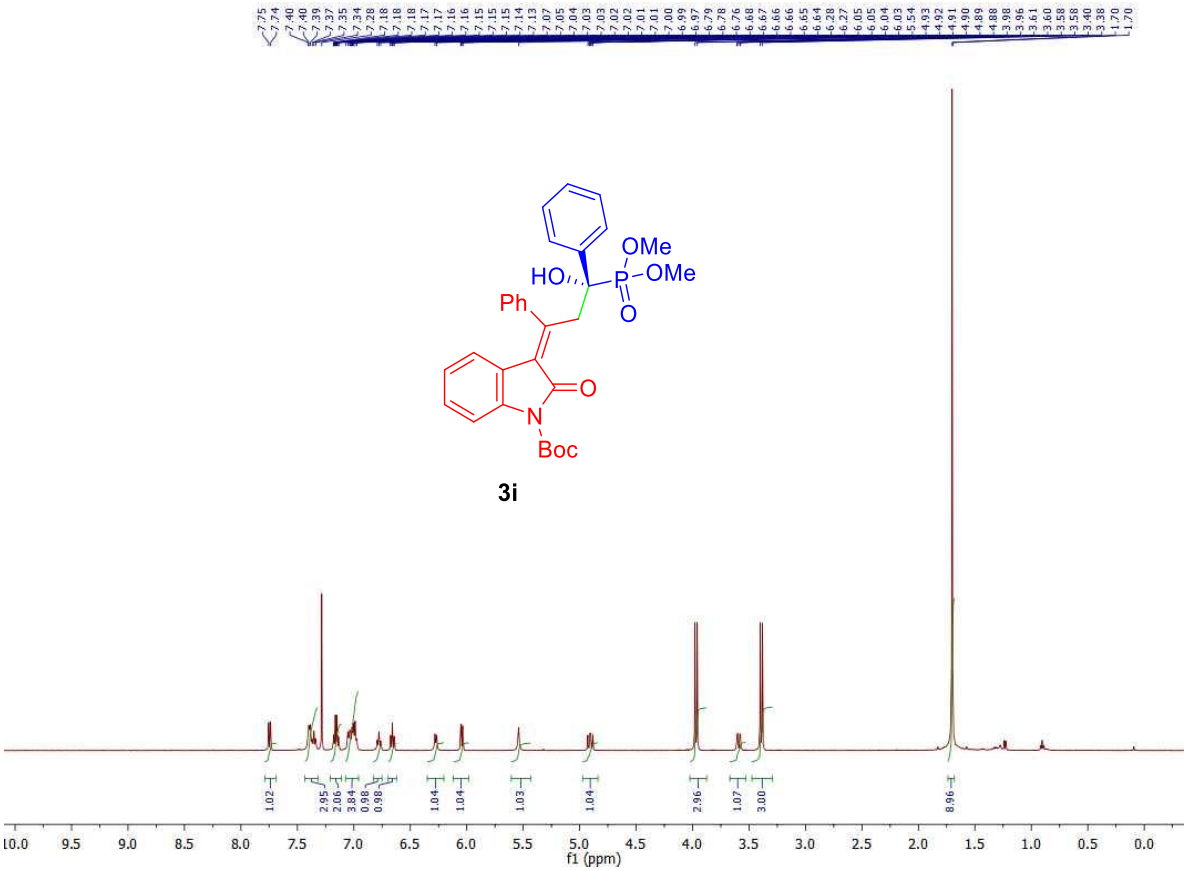

168.80
163.62
161.19
155.13
154.97
149.06
141.56
140.06
139.99
138.33
129.05
128.25
127.92
125.55
123.71
122.78
114.42
113.84
113.79
113.64
113.60
113.55
84.58
78.98
77.37
77.05
76.73
64.16
64.08
63.41
63.33
43.20
43.11
28.11
16.53
16.47
16.20
16.15
F
OEt
HO
P
OEt
O
Ph
O
N
Boc
3f
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

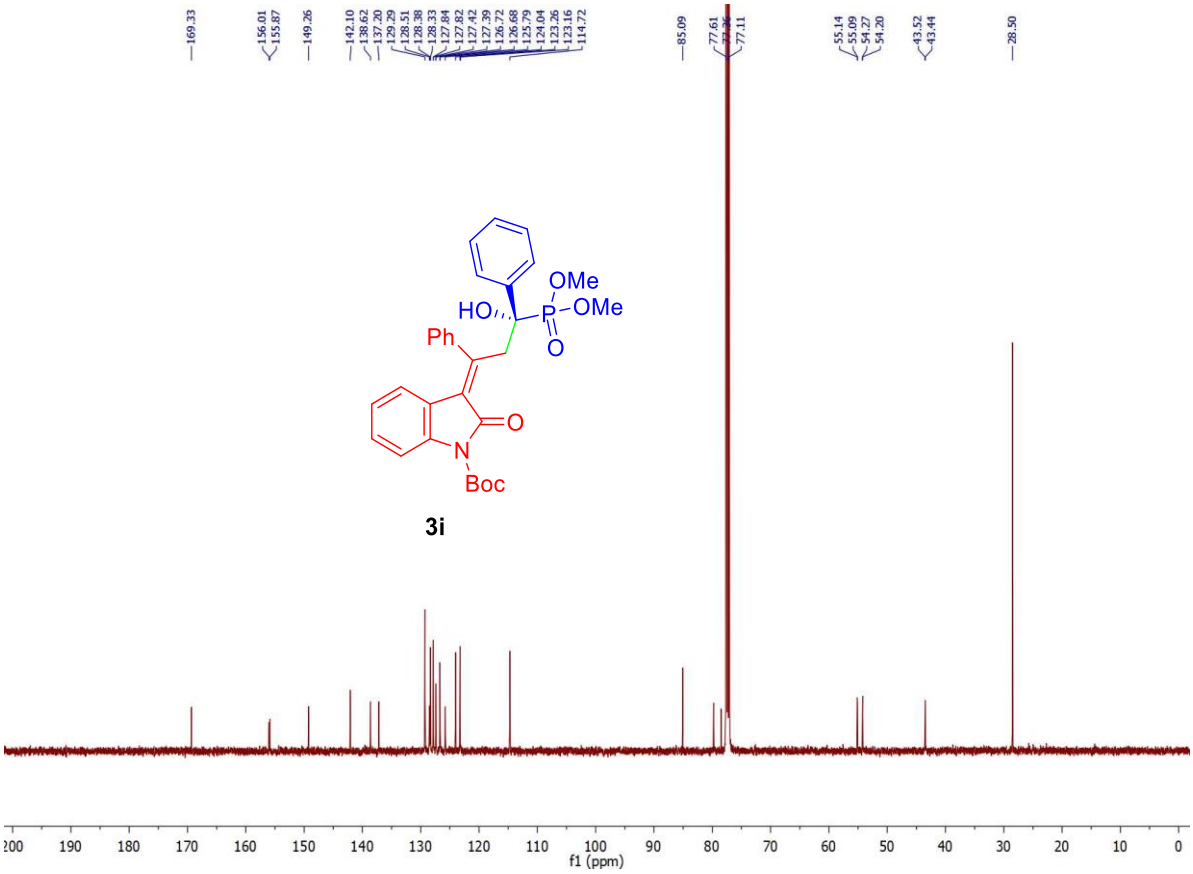

21.06
F
OEt
HO
P
OEt
O
Ph
O
N
Boc
3f
140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -130 -160 -190 -220
f1 (ppm)

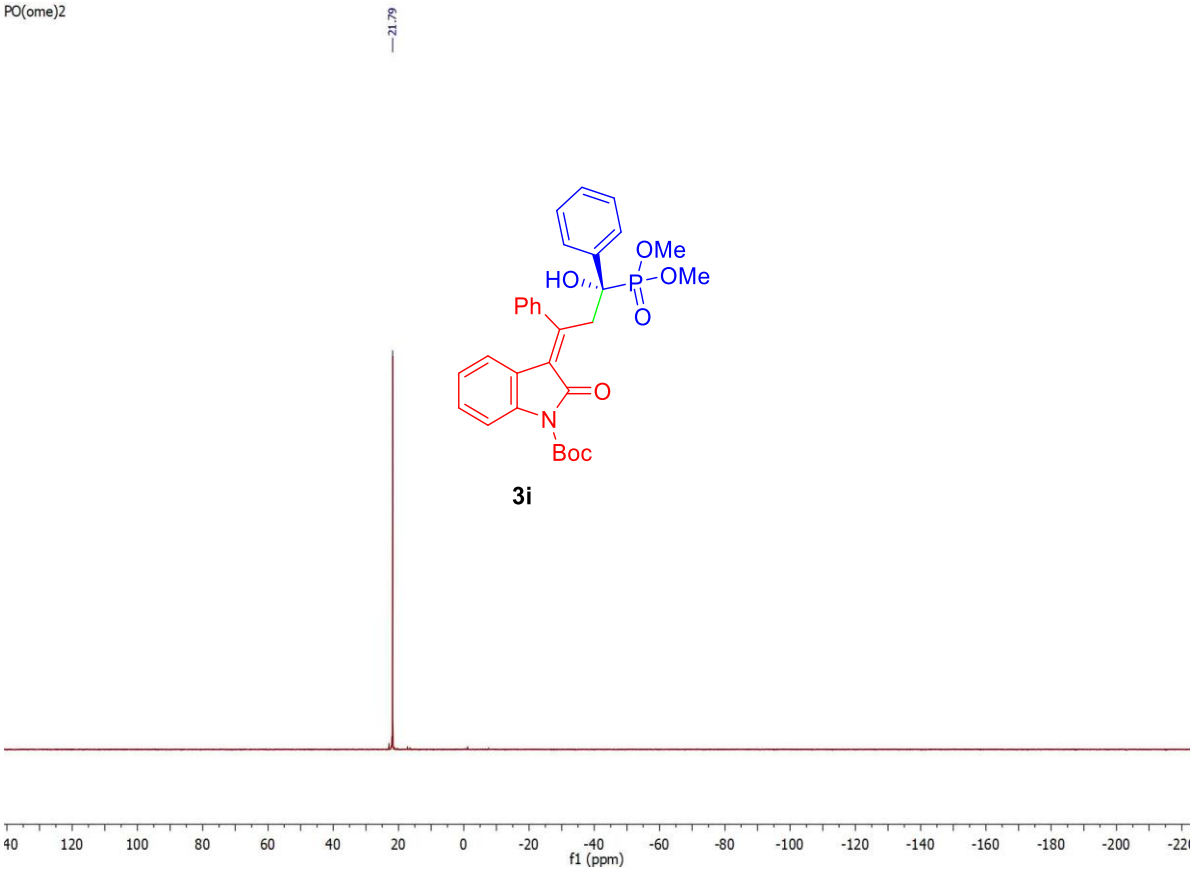

Br
OEt
HO
P
OEt
O
Ph
O
N
Boc
3g
f1 (ppm)

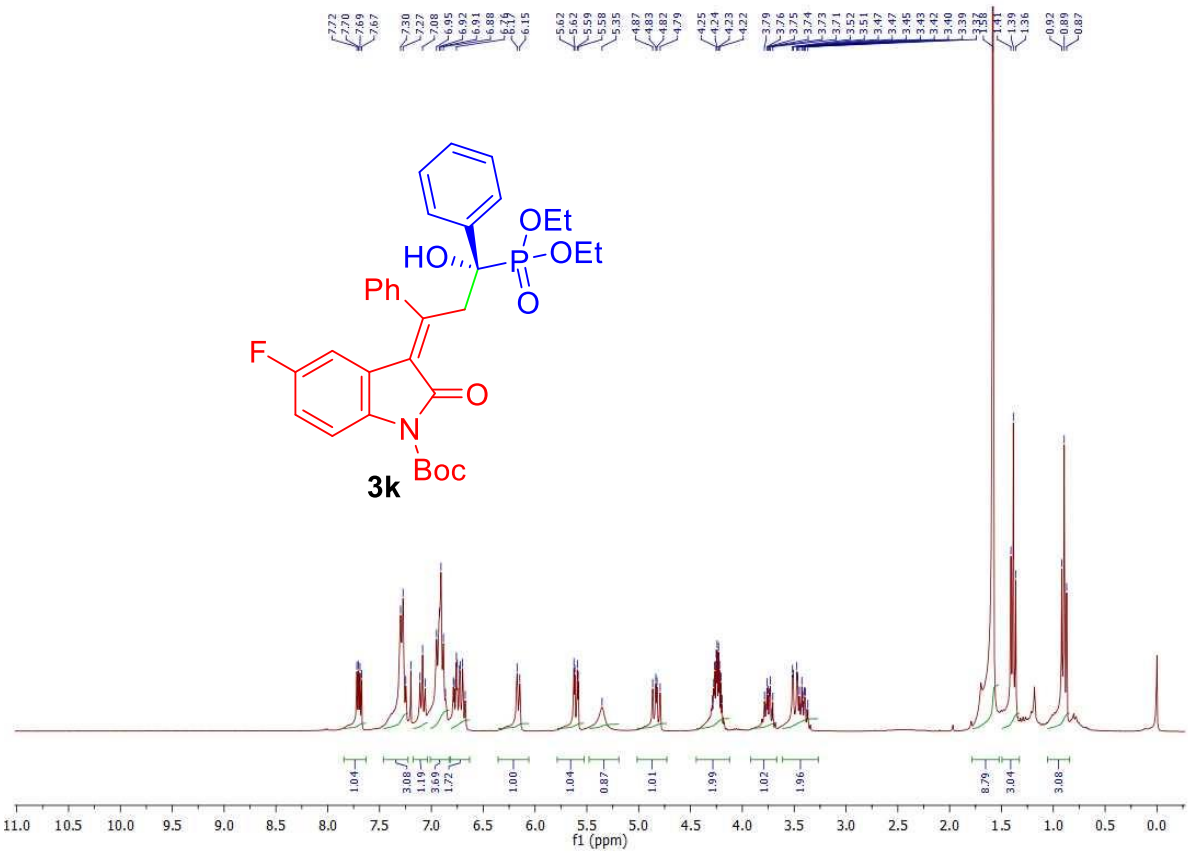

Br
OEt
HO
P
OEt
O
Ph
O
N
Boc
3g
f1 (ppm)

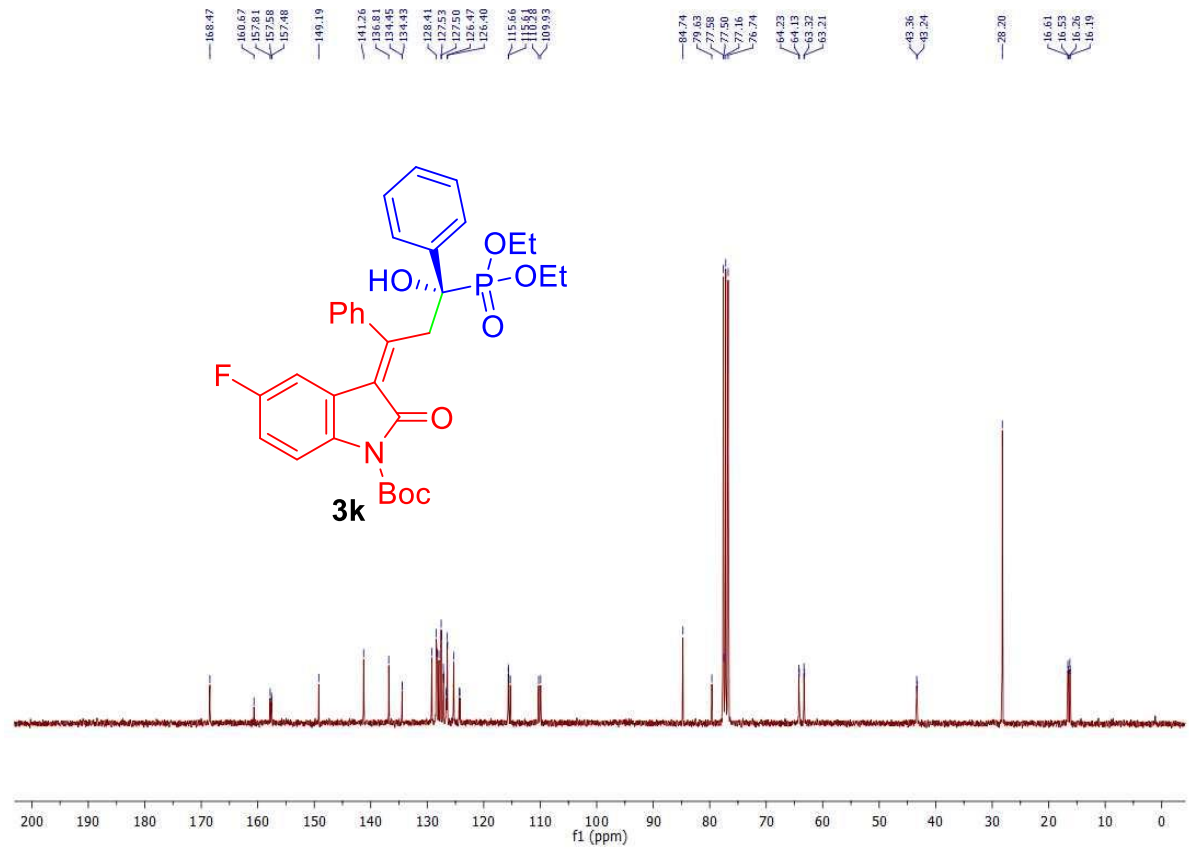

20.98
Br
OEt
HO
P
OEt
O
Ph
O
N
Boc
3g
140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -110 -140 -170 -200 -230
f1 (ppm)

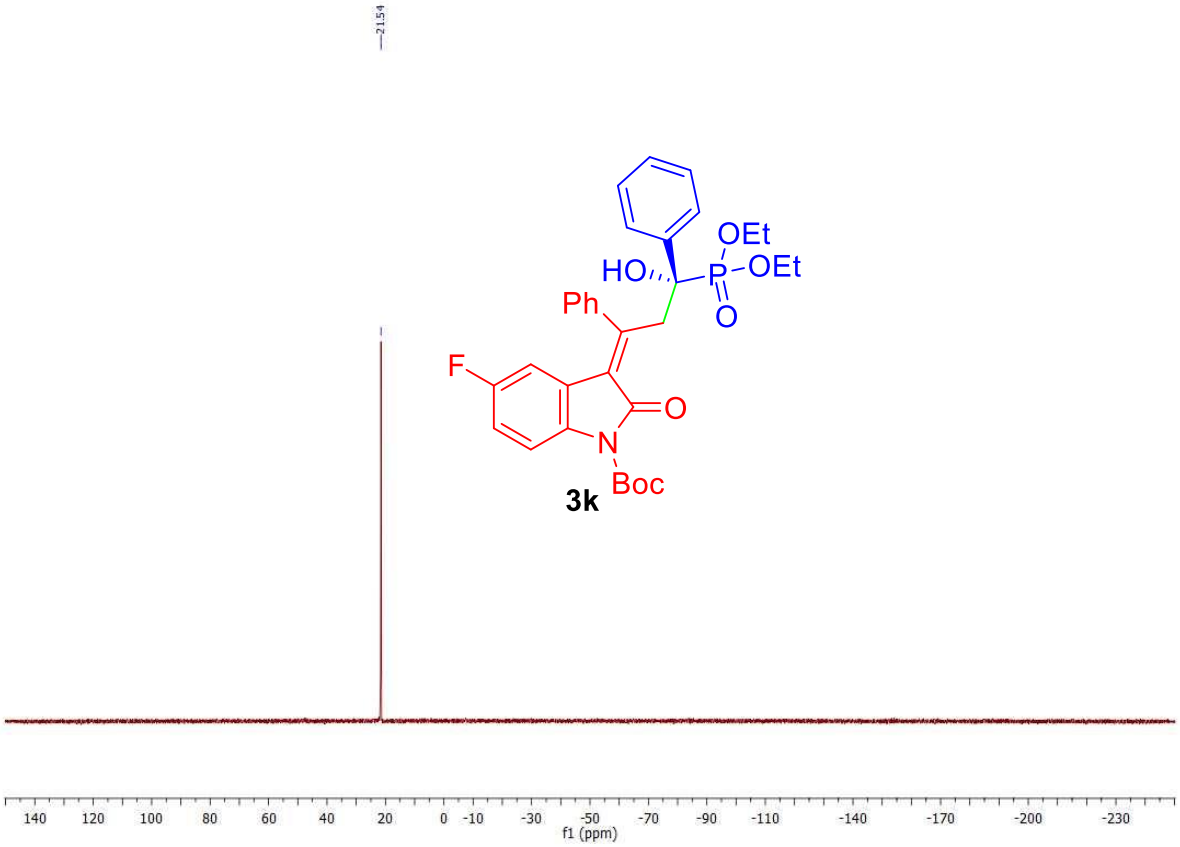

OMe
HO
P
OMe
O
Ph
O
N
Boc
3i
1.02 2.95 2.06 3.84 0.98 0.98 1.04 1.04 1.03 1.04 2.96 1.07 3.00 8.96
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

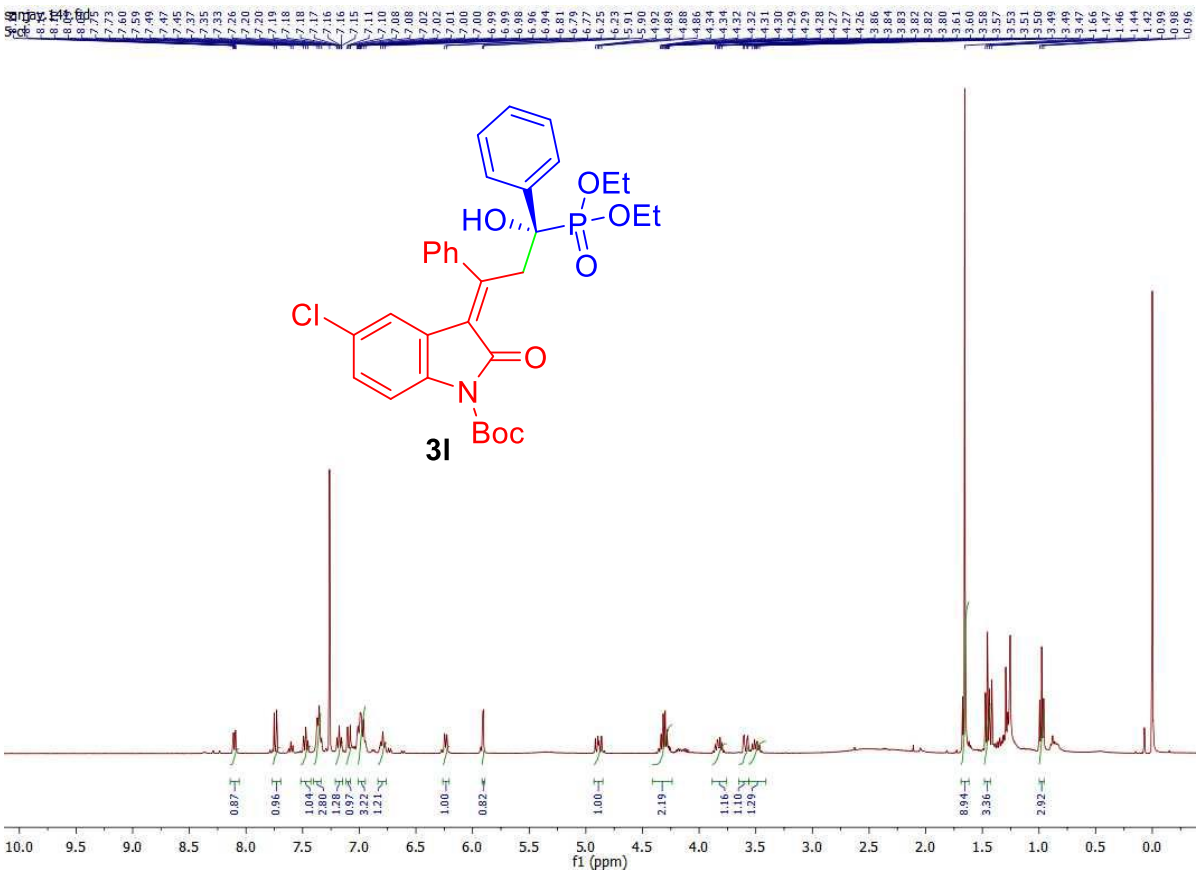

169.33
156.01
155.87
149.26
142.10
138.62
137.20
129.29
128.51
128.38
128.33
127.84
127.82
127.42
127.39
126.72
126.68
125.79
124.04
123.26
123.16
114.72
85.09
77.61
77.11
55.14
55.09
54.27
54.20
43.52
43.44
28.50
OMe
HO
P
OMe
O
Ph
O
N
Boc
3i
f1 (ppm)

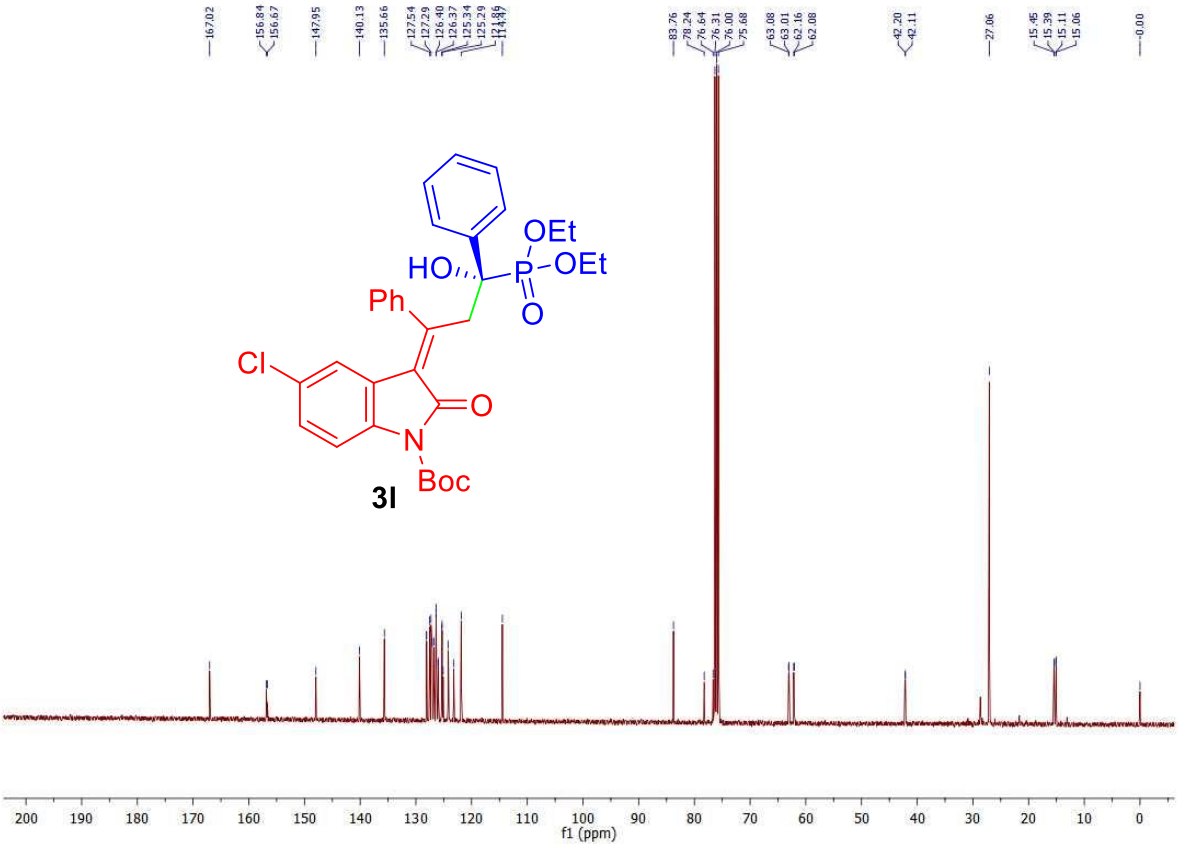

PO(ome)2
21.79
OMe
HO
P
OMe
O
Ph
O
N
Boc
3i
f1 (ppm)

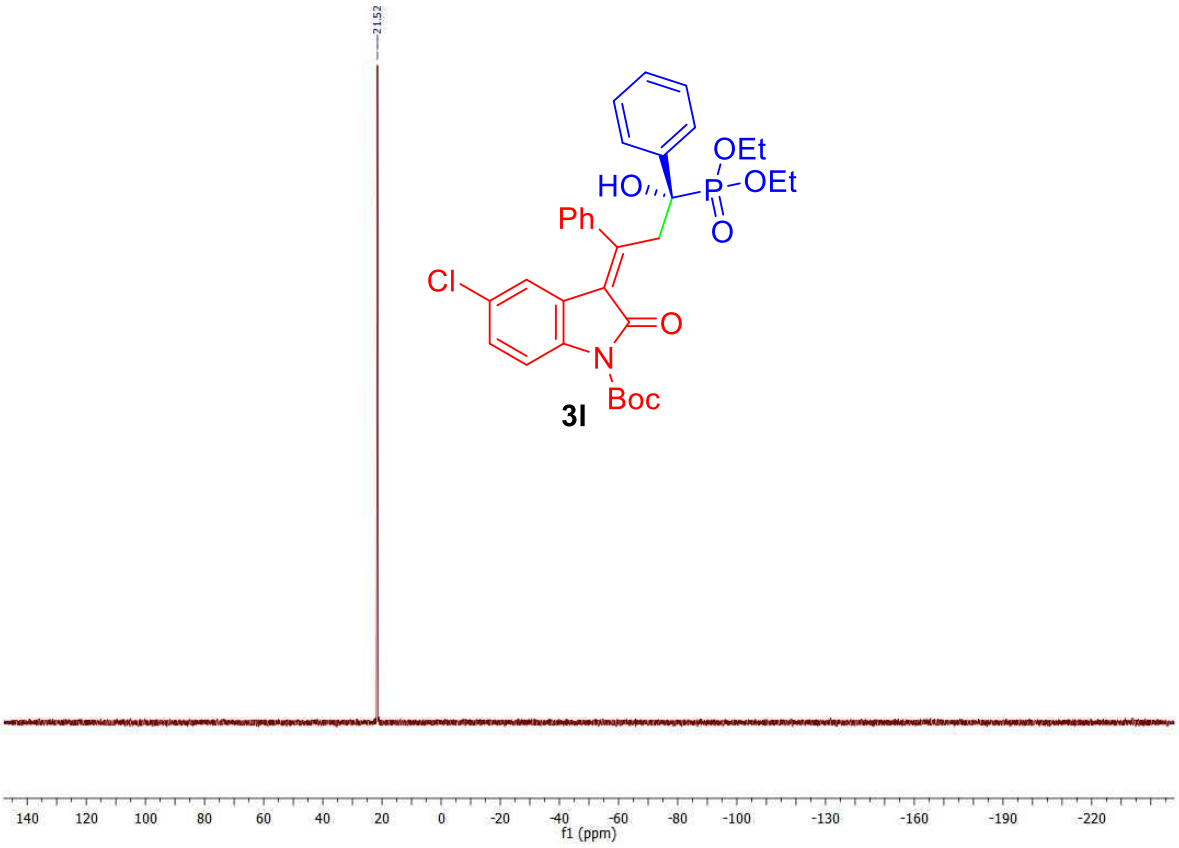

OEt
HO
P
OEt
O
Ph
F
O
N
Boc
3k
f1 (ppm)

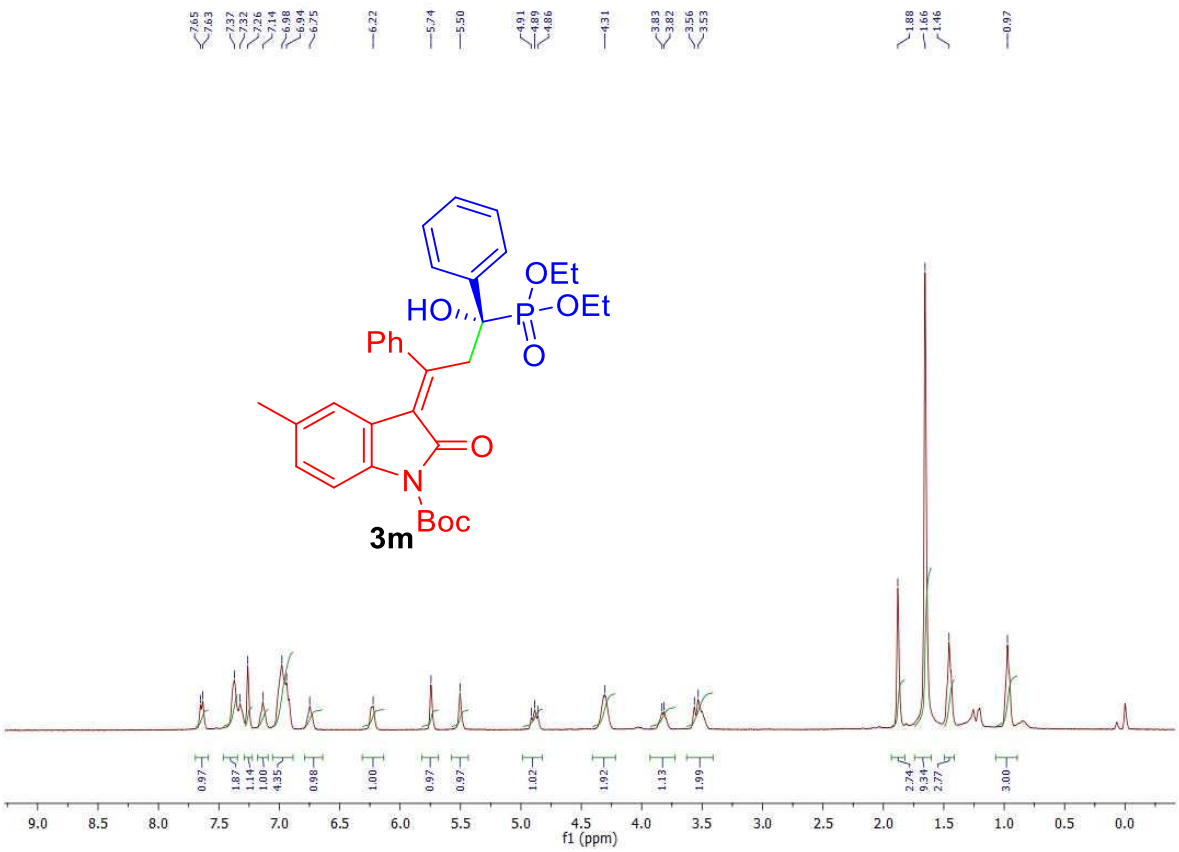

OEt
HO
P
OEt
O
Ph
F
O
N
Boc
3k
f1 (ppm)

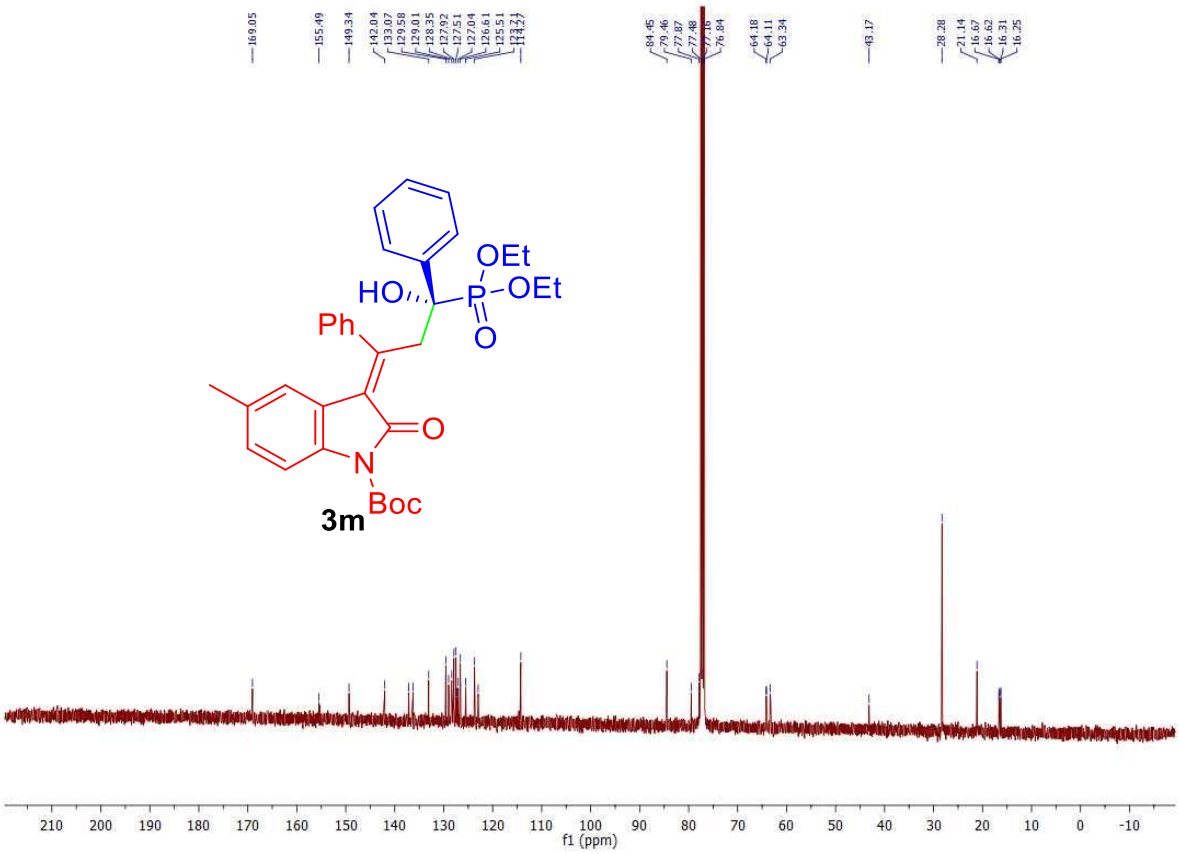

21.54
OEt
HO
P
OEt
O
Ph
F
O
N
Boc
3k
140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -110 -140 -170 -200 -230
f1 (ppm)

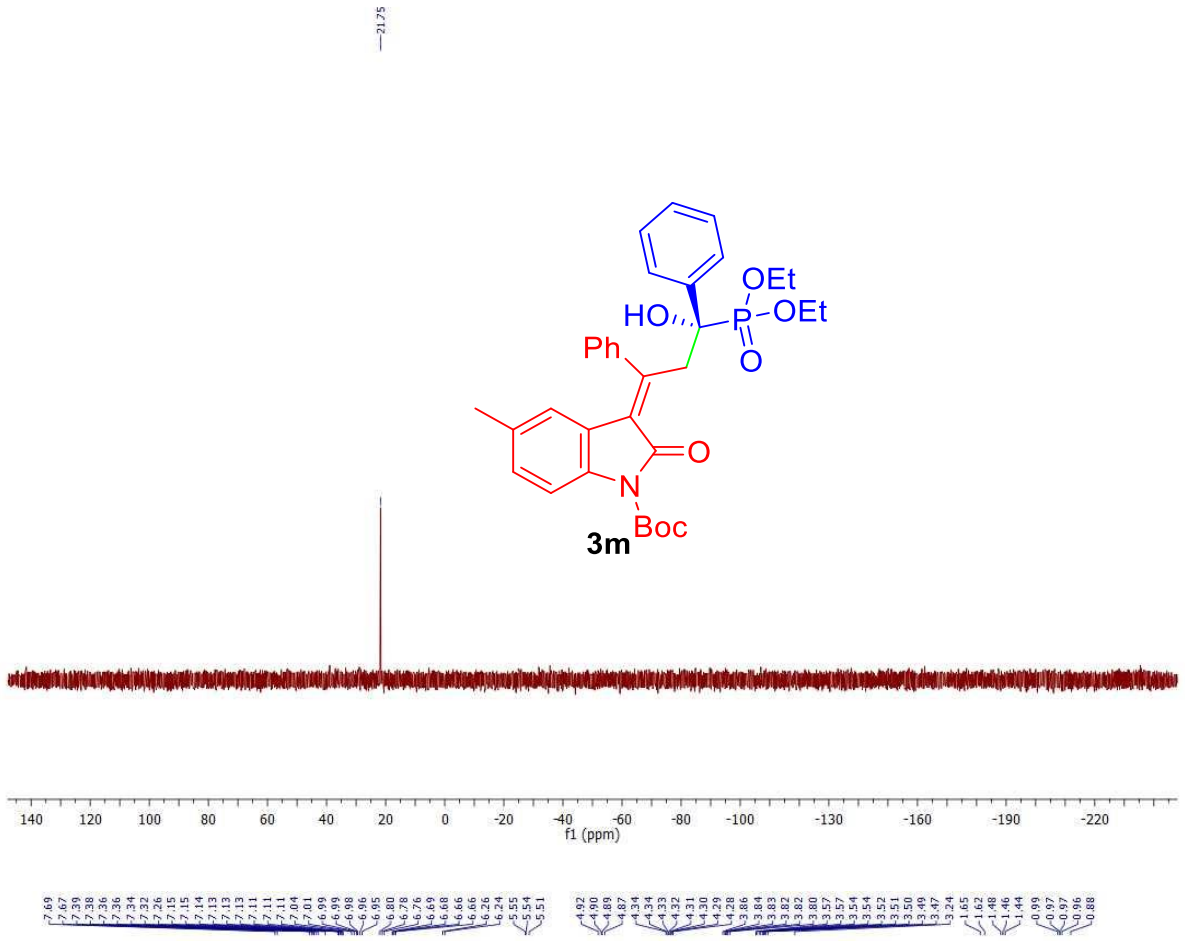

OEt
HO
P
OEt
O
Ph
Cl
O
N
Boc
3l
0.87 0.96 1.04 2.80 1.38 0.97 3.22 1.21 1.00 0.82 1.00 2.19 1.16 1.10 1.29 8.94 3.36 2.92
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

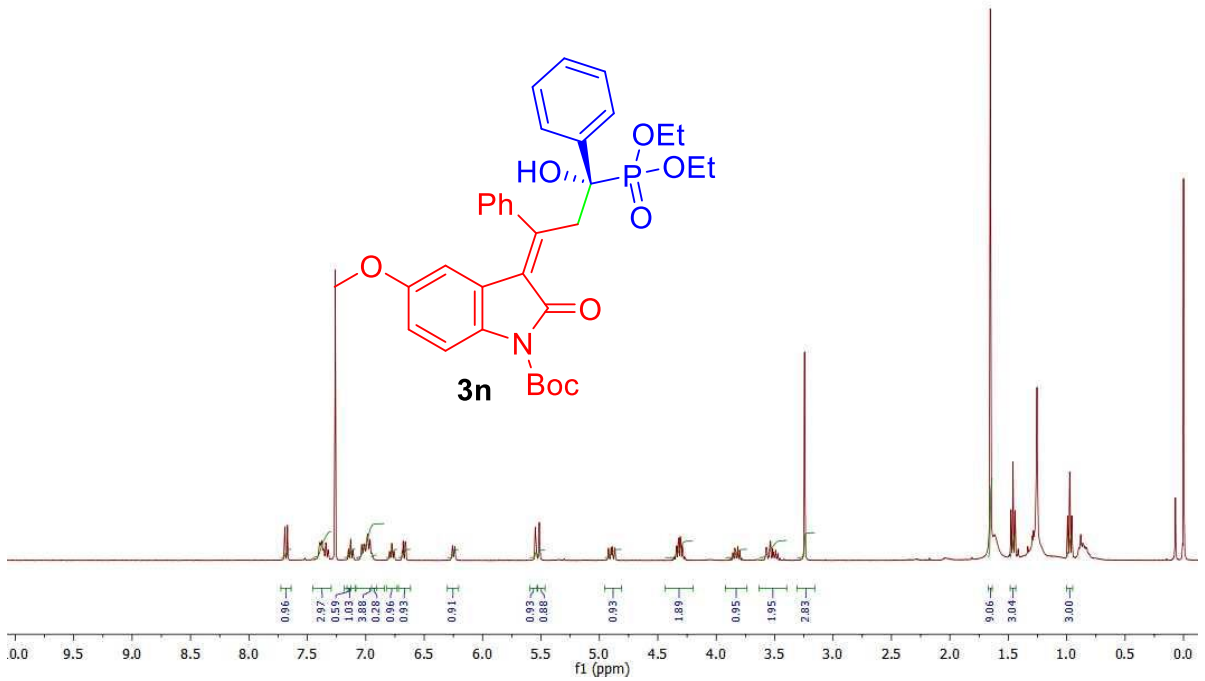

167.02
156.84
156.67
147.95
140.13
135.66
127.54
127.29
126.40
126.37
125.34
125.29
121.86
114.44
83.76
78.24
76.64
76.31
76.00
75.68
63.08
63.01
62.16
62.08
42.20
42.11
27.06
15.45
15.39
15.11
15.06
0.00
OEt
HO
P
OEt
O
Ph
Cl
O
N
Boc
3l
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

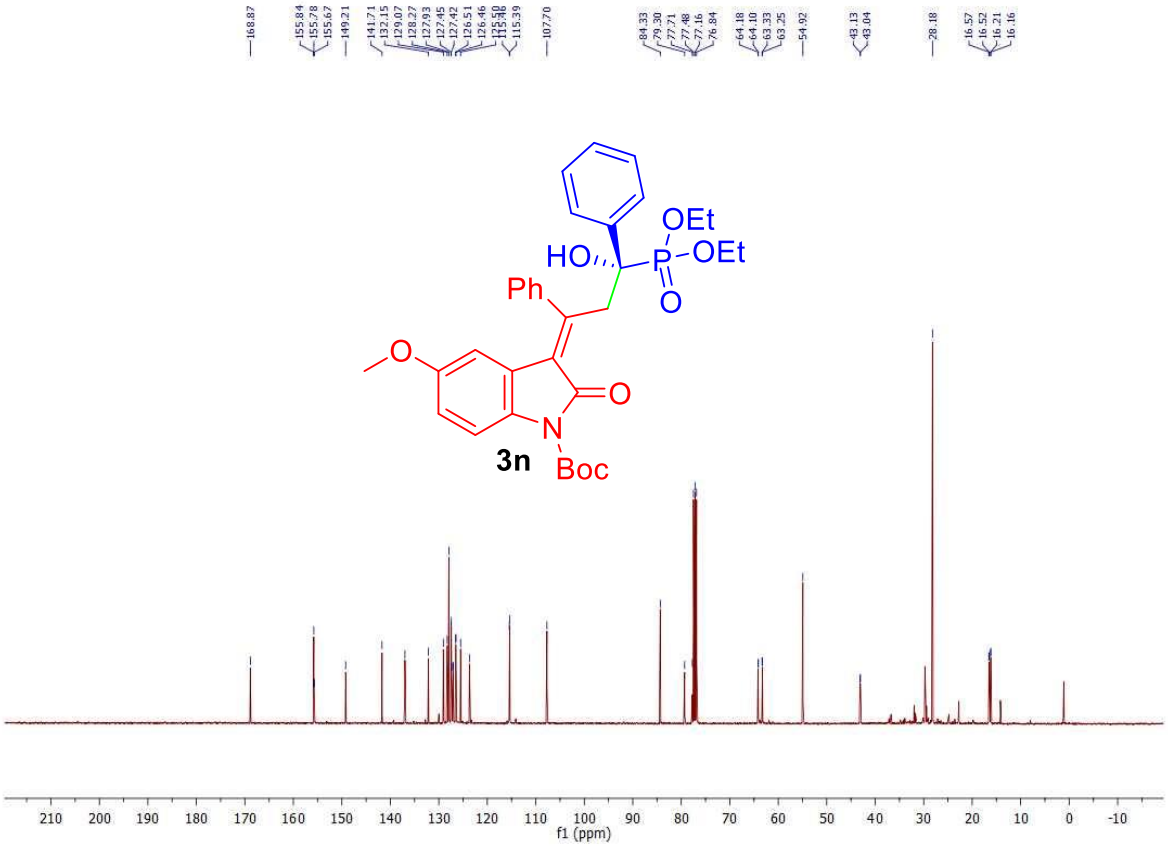

21.52
OEt
HO
P
OEt
O
Ph
Cl
O
N
Boc
3l
140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -130 -160 -190 -220
f1 (ppm)

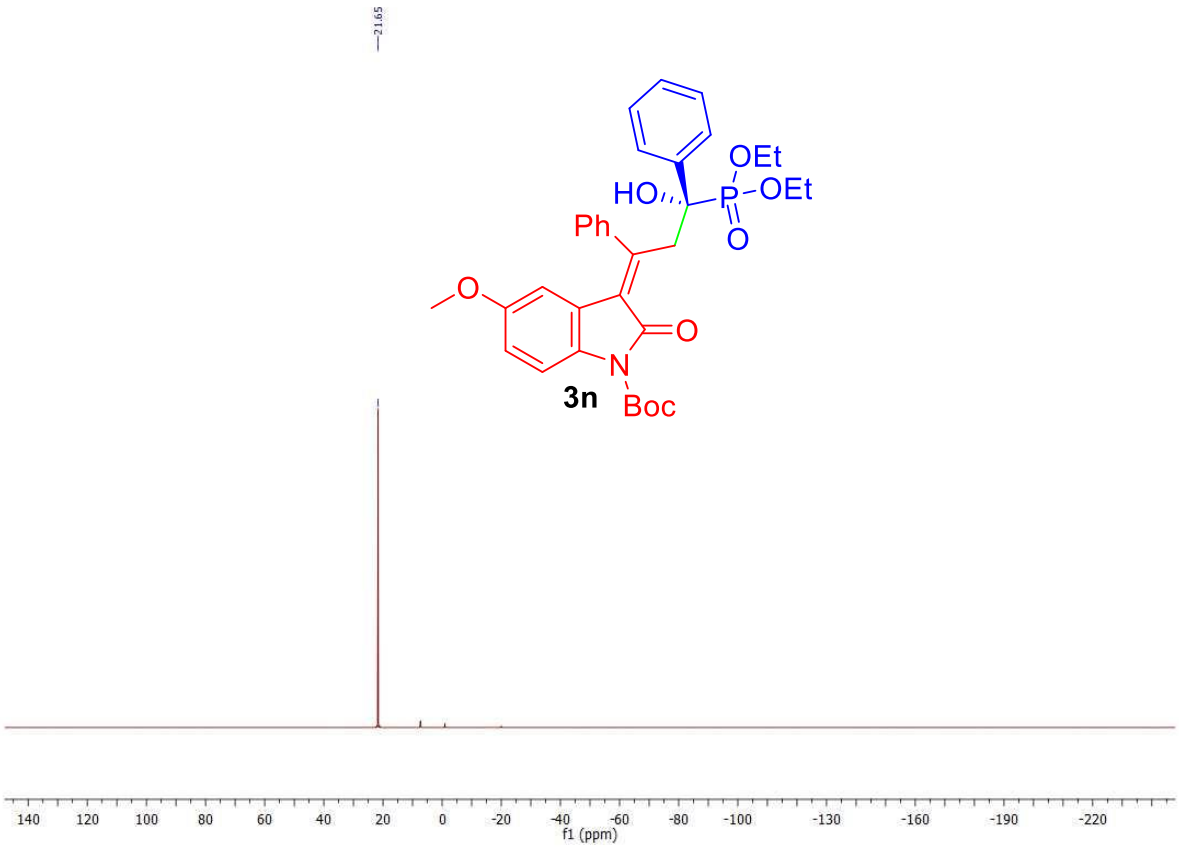

OEt
HO
P
OEt
O
Ph
O
N
Boc
3m
f1 (ppm)

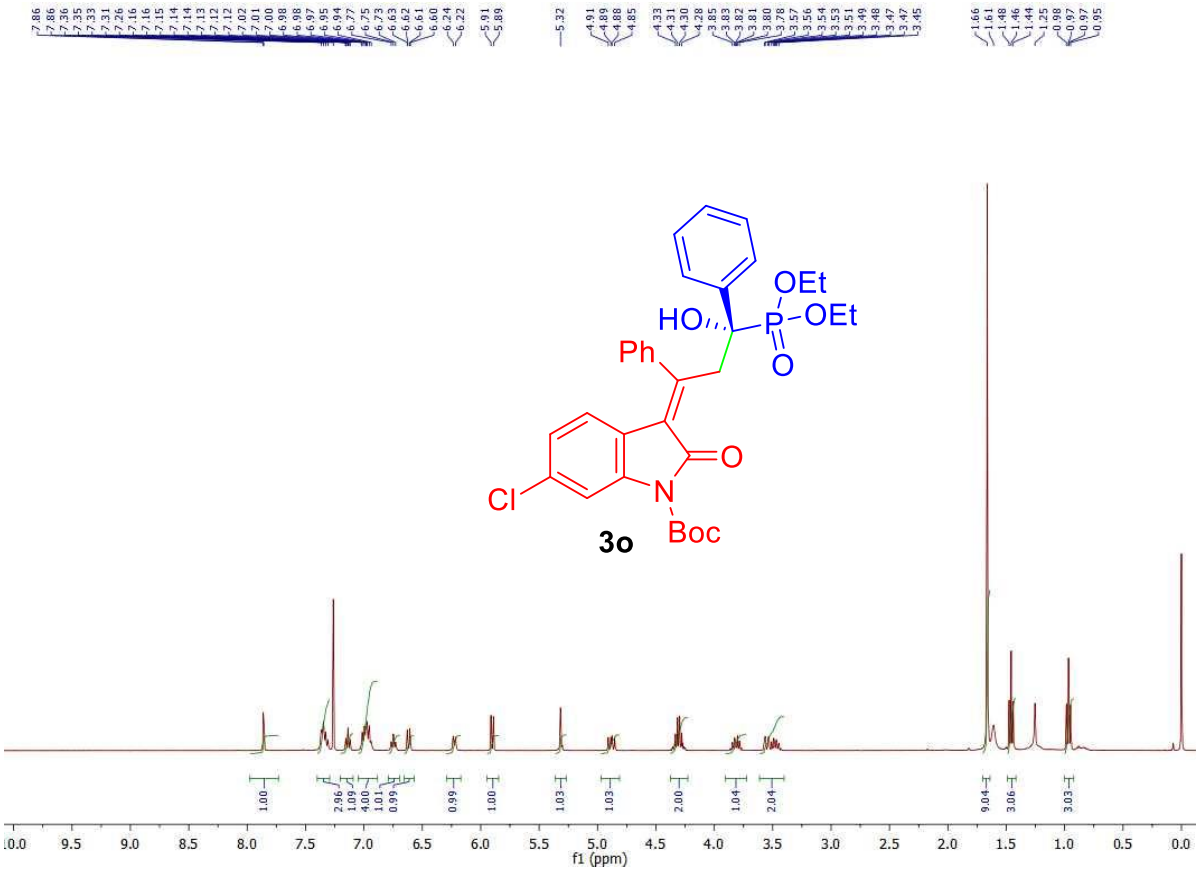

OEt
HO
P
OEt
O
Ph
O
N
Boc
3m
f1 (ppm)

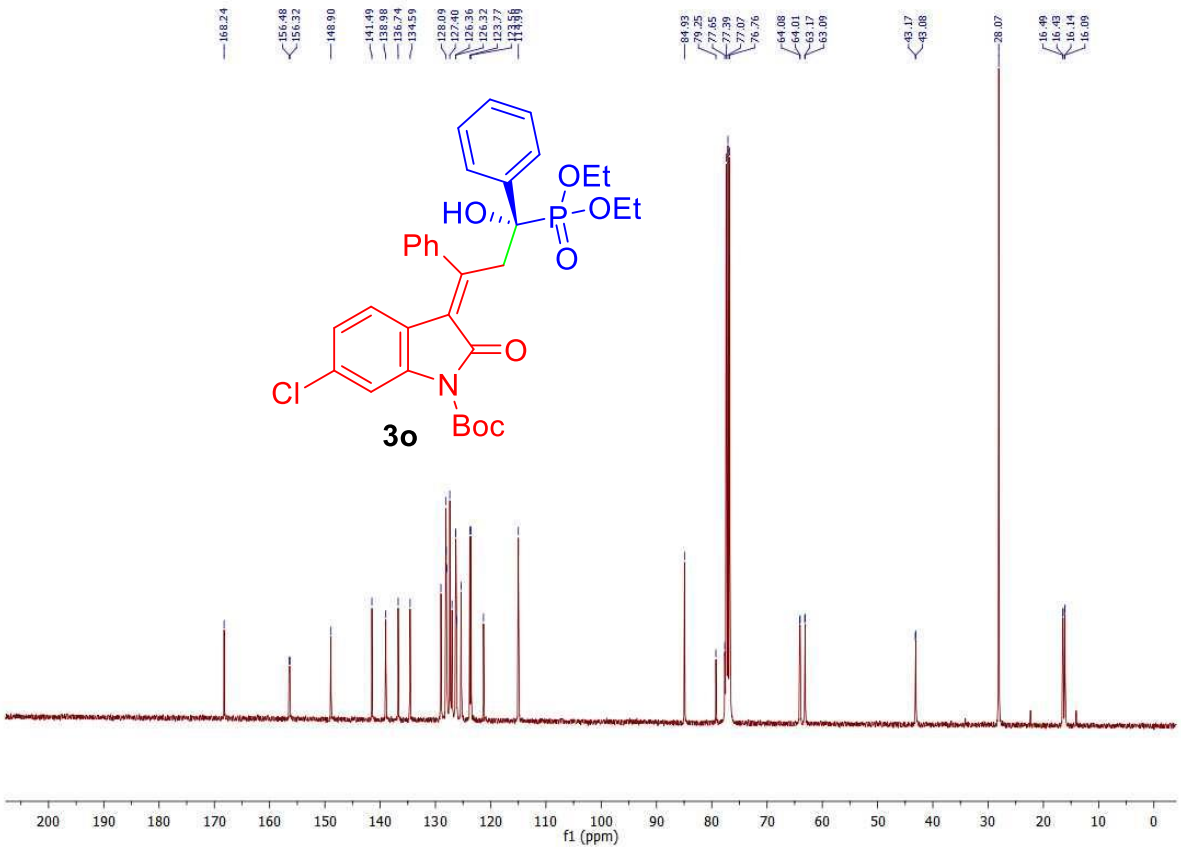

21.75
OEt
HO
P
OEt
O
Ph
O
N
Boc
3m
140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -130 -160 -190 -220
f1 (ppm)

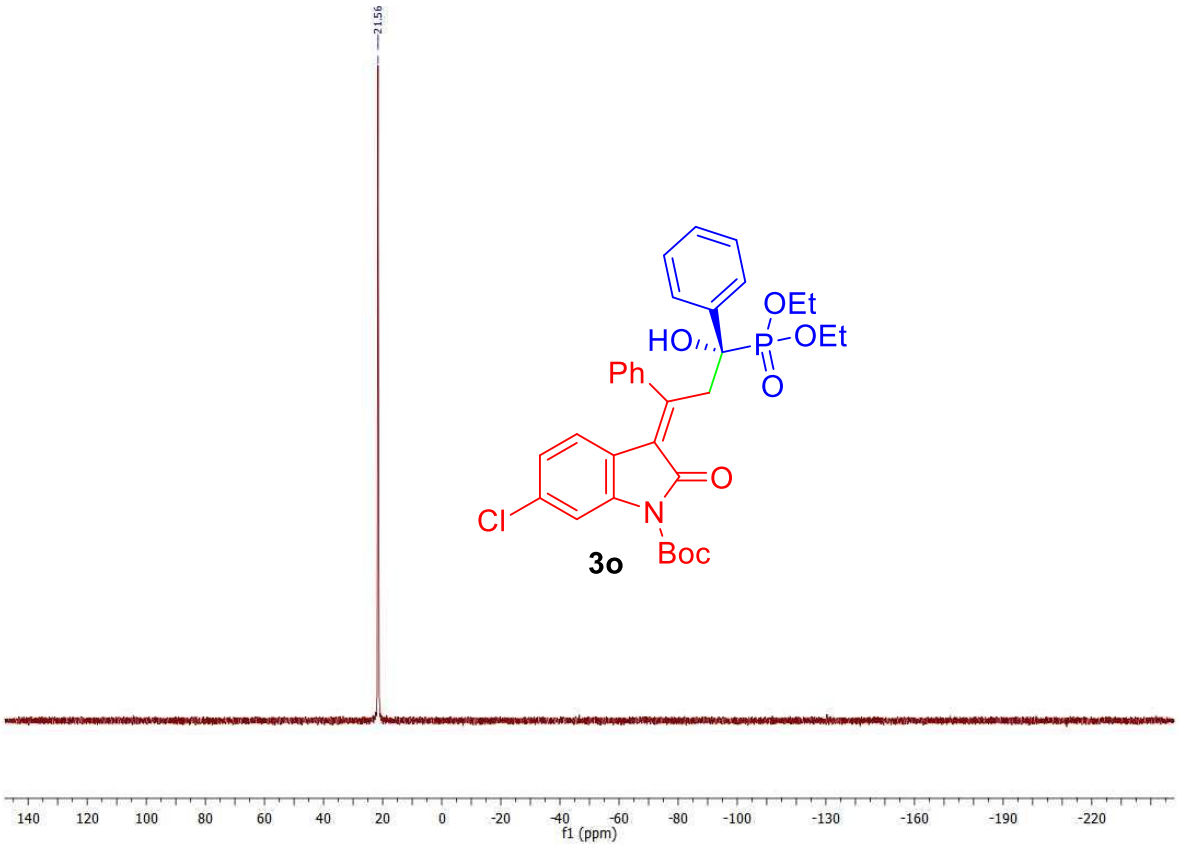

OEt
HO
P
OEt
O
Ph
O
O
N
Boc
3n
0.96 2.97 0.59 1.03 3.88 0.28 0.96 0.93 0.91 0.93 0.88 0.93 1.89 0.95 1.95 2.83 9.06 3.04 3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

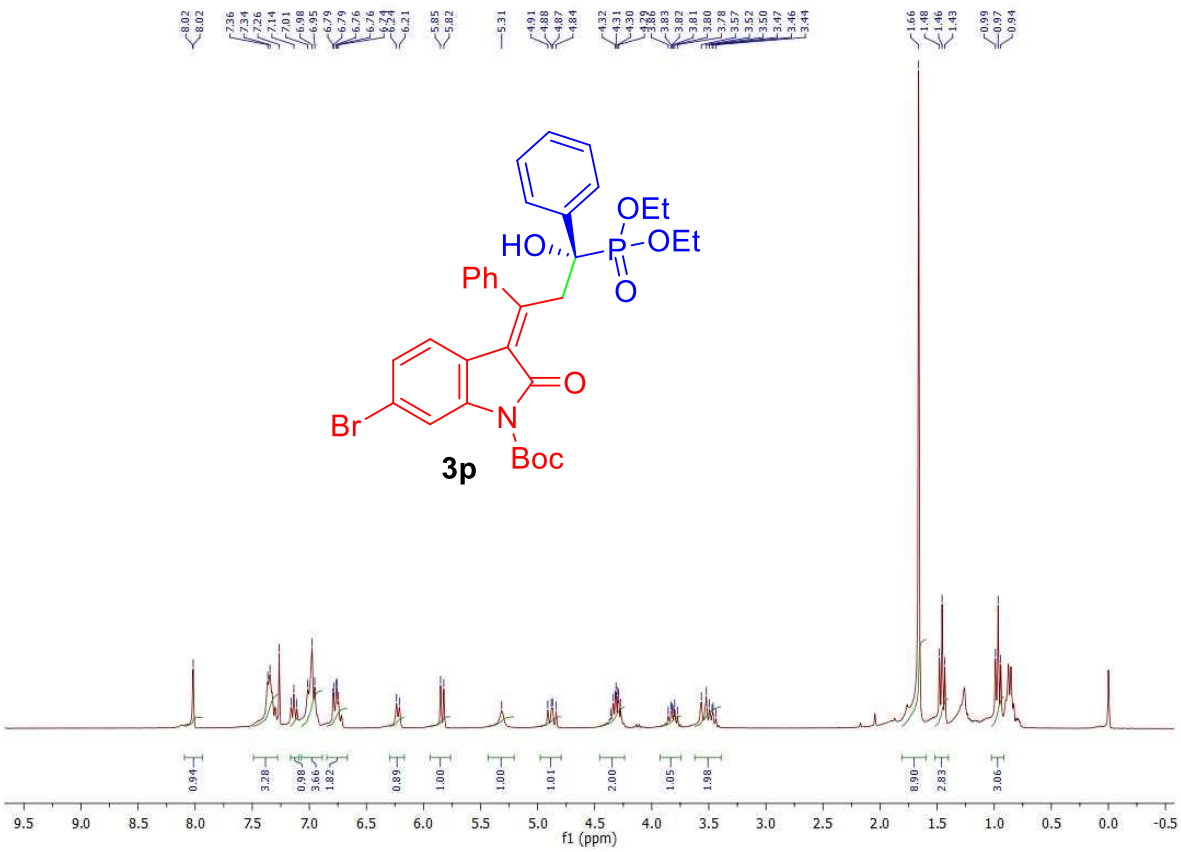

168.87
155.84
155.78
155.67
149.21
141.71
132.15
129.07
128.27
127.93
127.45
127.42
126.51
126.46
115.39
107.70
84.33
79.30
77.71
77.48
77.16
76.84
64.18
64.10
63.33
63.25
54.92
43.13
43.04
28.18
16.57
16.52
16.21
16.16
OEt
HO
P
OEt
O
Ph
O
O
N
Boc
3n
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

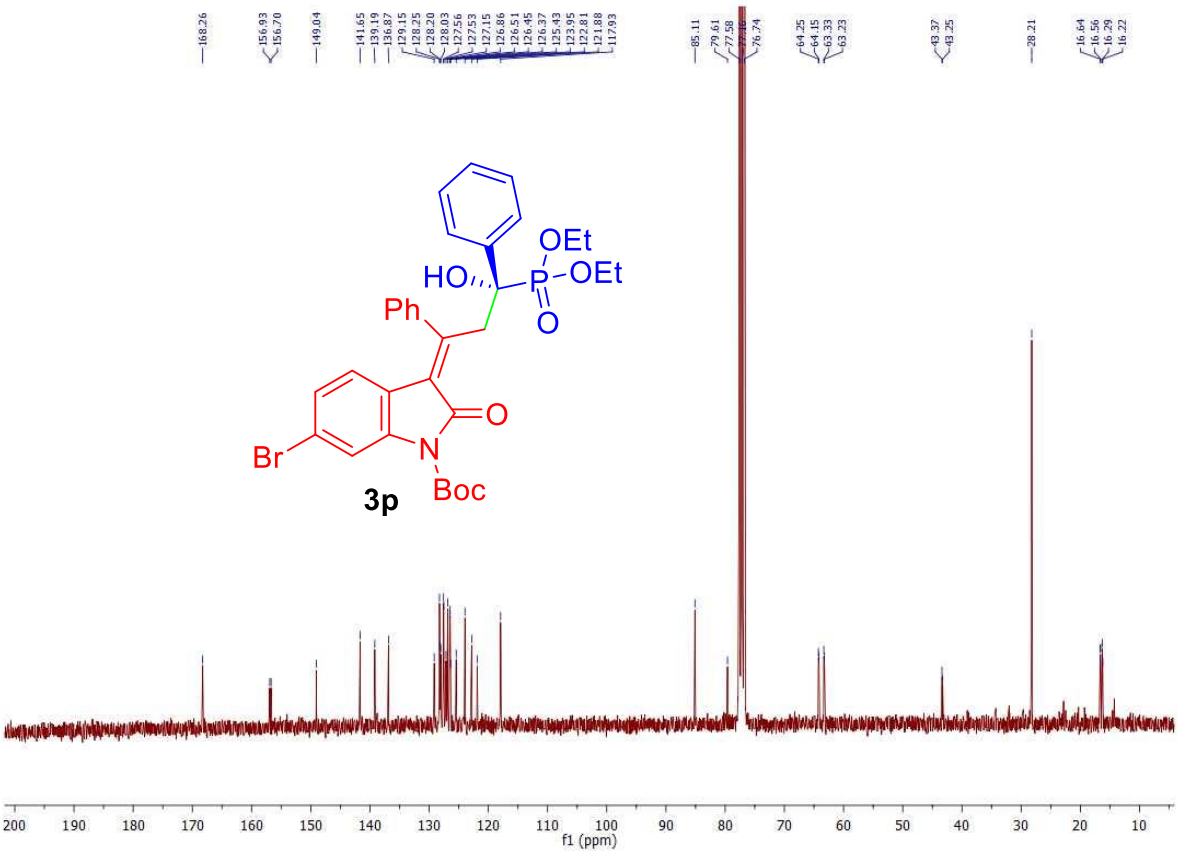

21.65
OEt
HO
P
OEt
O
Ph
O
O
N
Boc
3n
140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -130 -160 -190 -220
f1 (ppm)

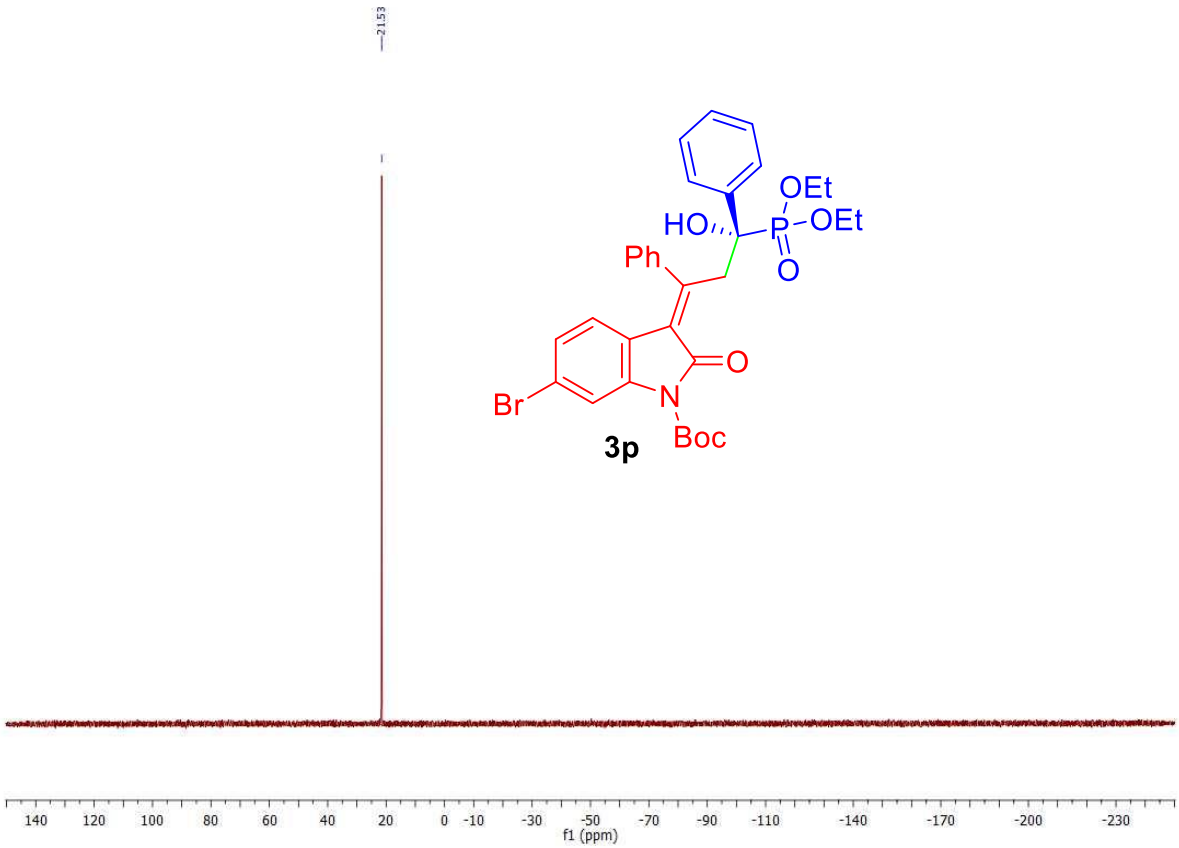

OEt
HO
P
OEt
O
Ph
O
Cl
N
Boc
3o
f1 (ppm)

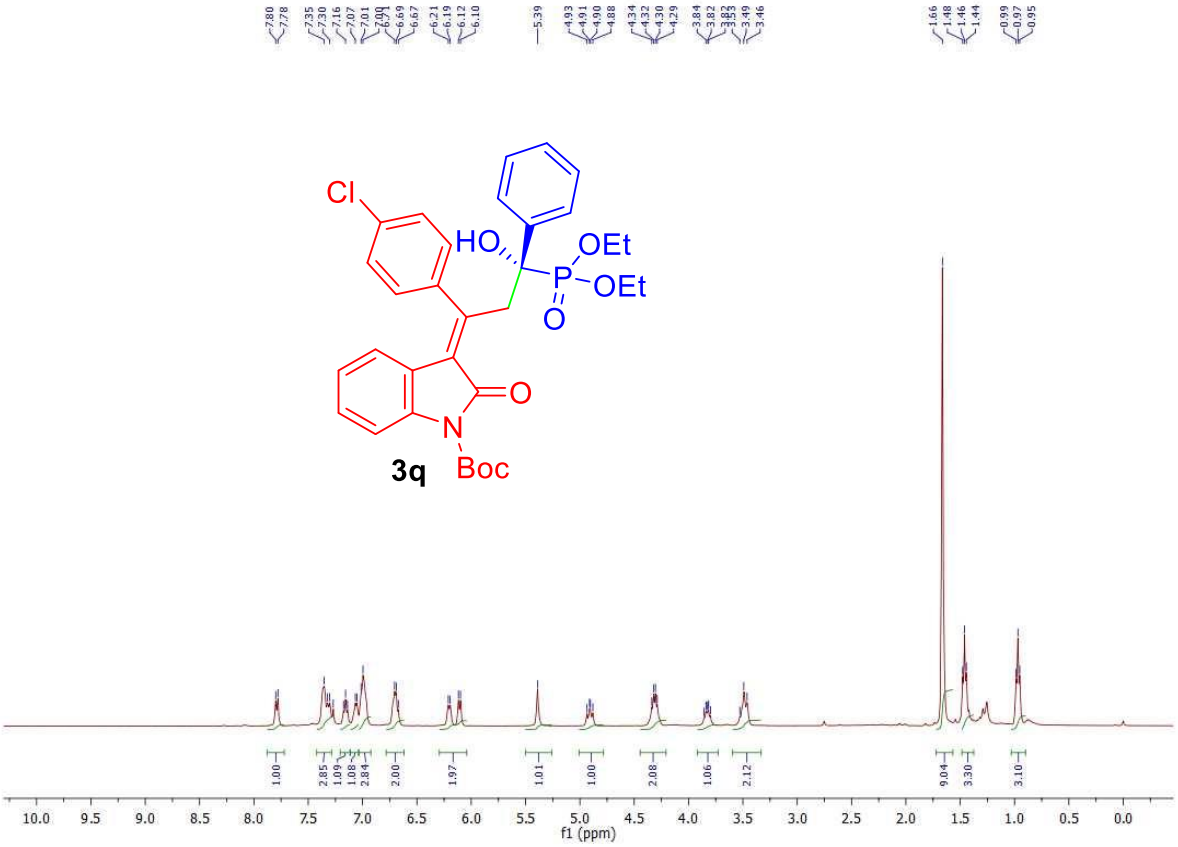

OEt
HO
P
OEt
O
Ph
O
Cl
N
Boc
3o
f1 (ppm)

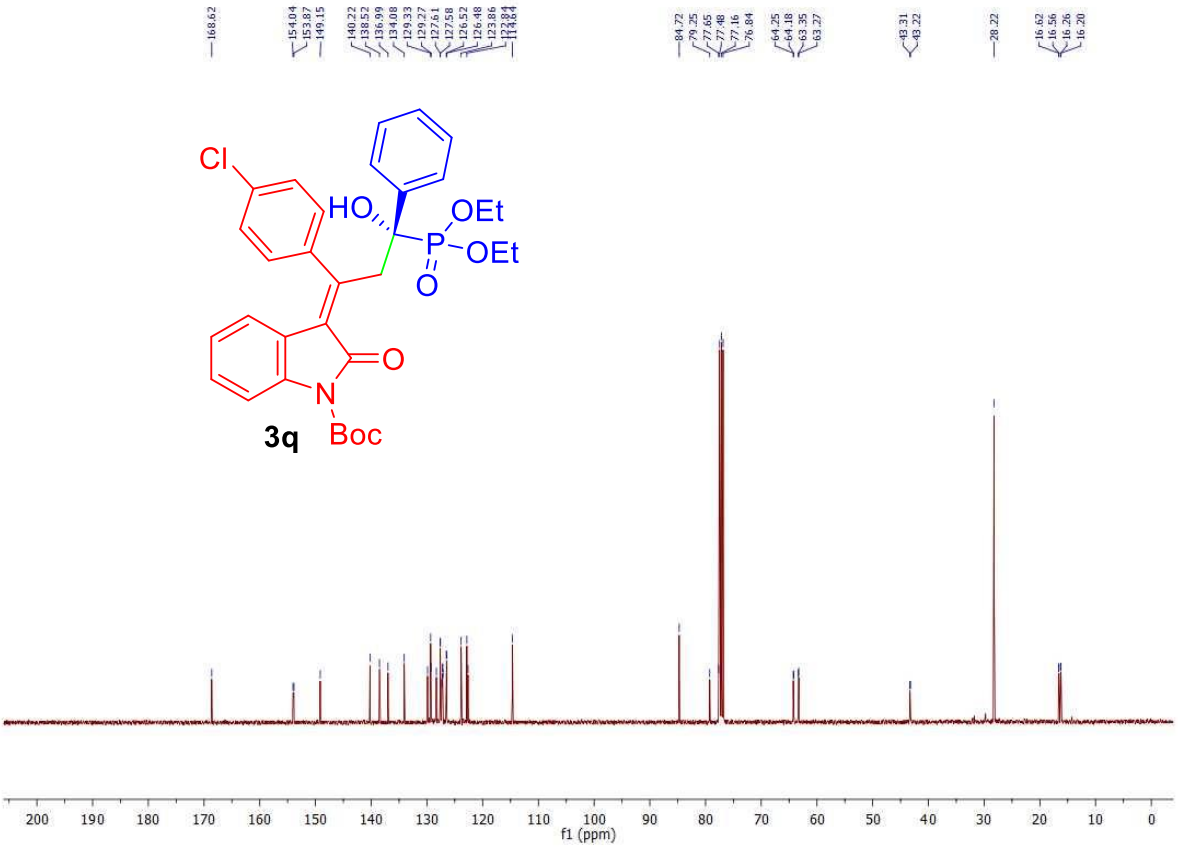

21.56
OEt
HO
P
OEt
O
Ph
O
Cl
N
Boc
3o
140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -130 -160 -190 -220
f1 (ppm)

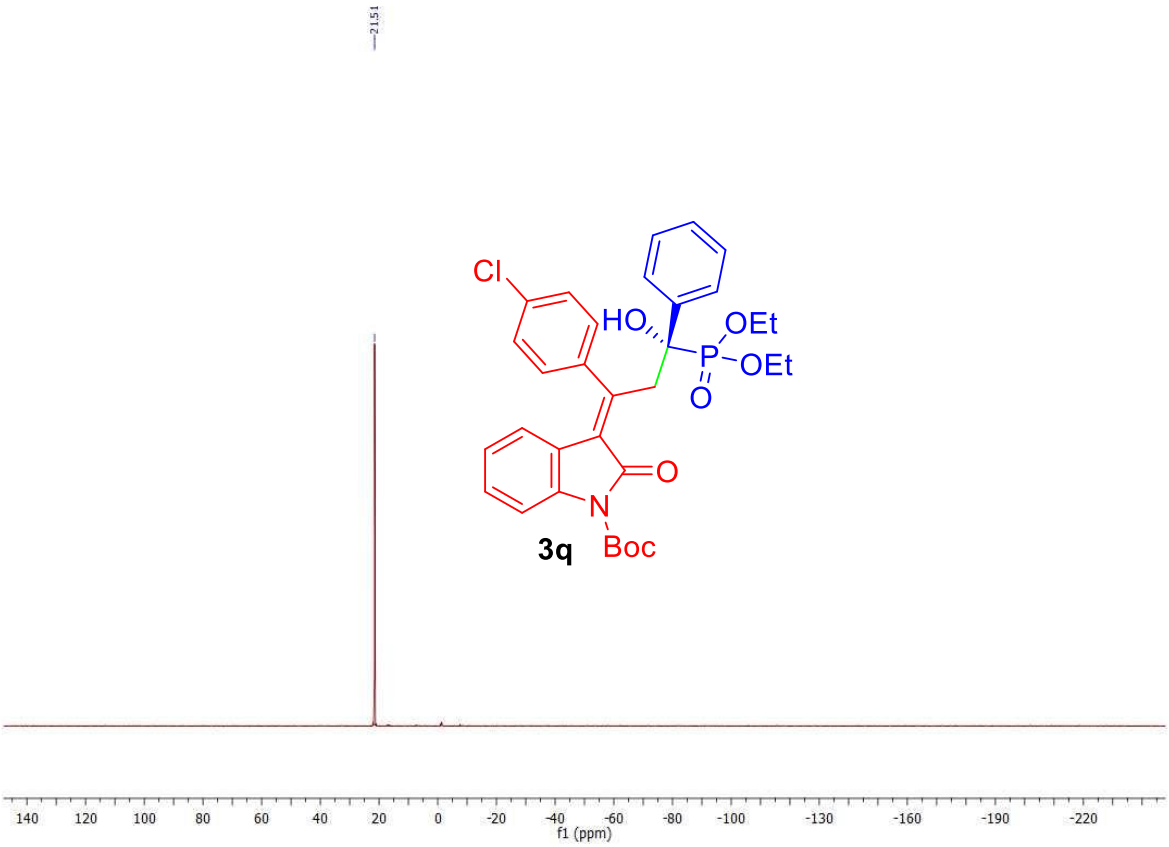

OEt
HO
P
OEt
O
Ph
O
Br
N
Boc
3p
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

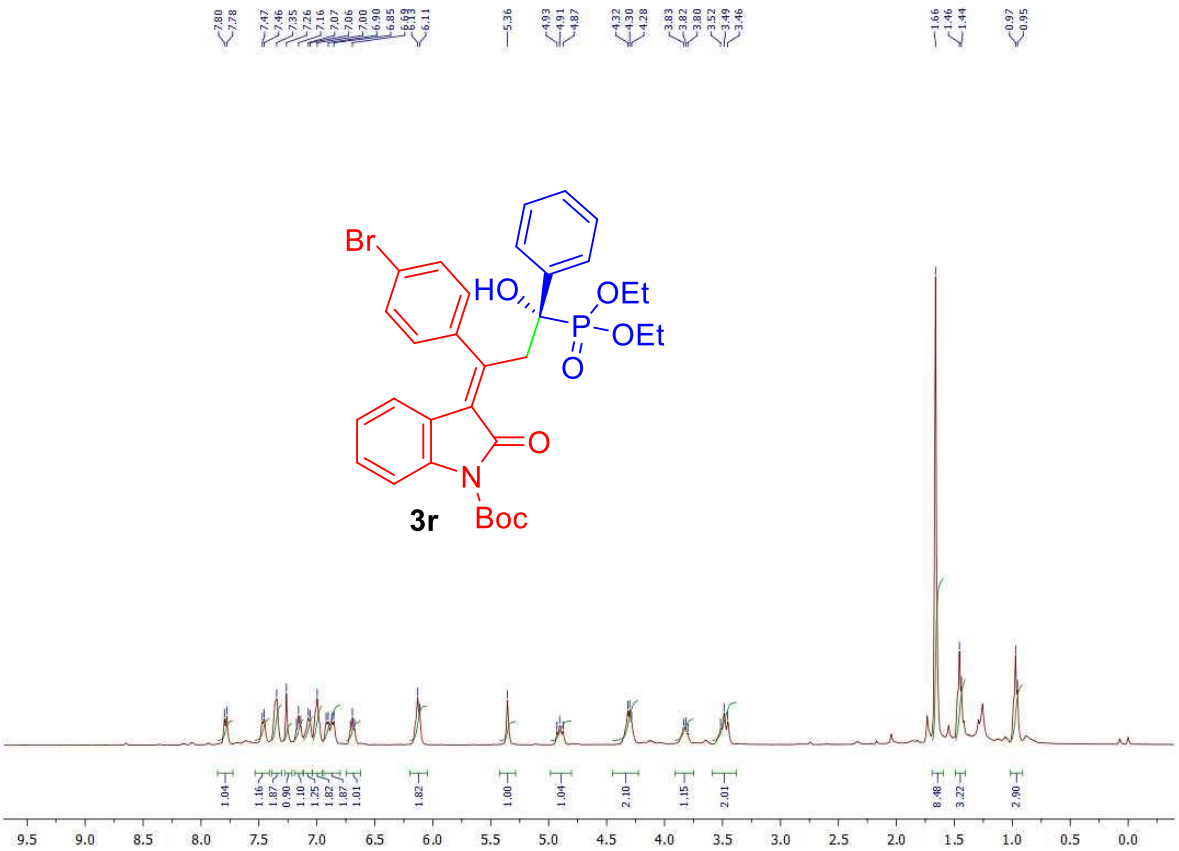

168.26
156.93
156.70
149.04
141.65
139.19
136.27
129.15
128.25
128.20
128.03
127.56
127.53
127.15
126.86
126.51
126.45
126.37
125.43
123.95
122.81
121.88
117.93
85.11
79.61
77.58
76.74
64.25
64.15
63.33
63.23
43.37
43.25
28.21
16.64
16.56
16.29
16.22
OEt
HO
P
OEt
O
Ph
O
Br
N
Boc
3p
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)

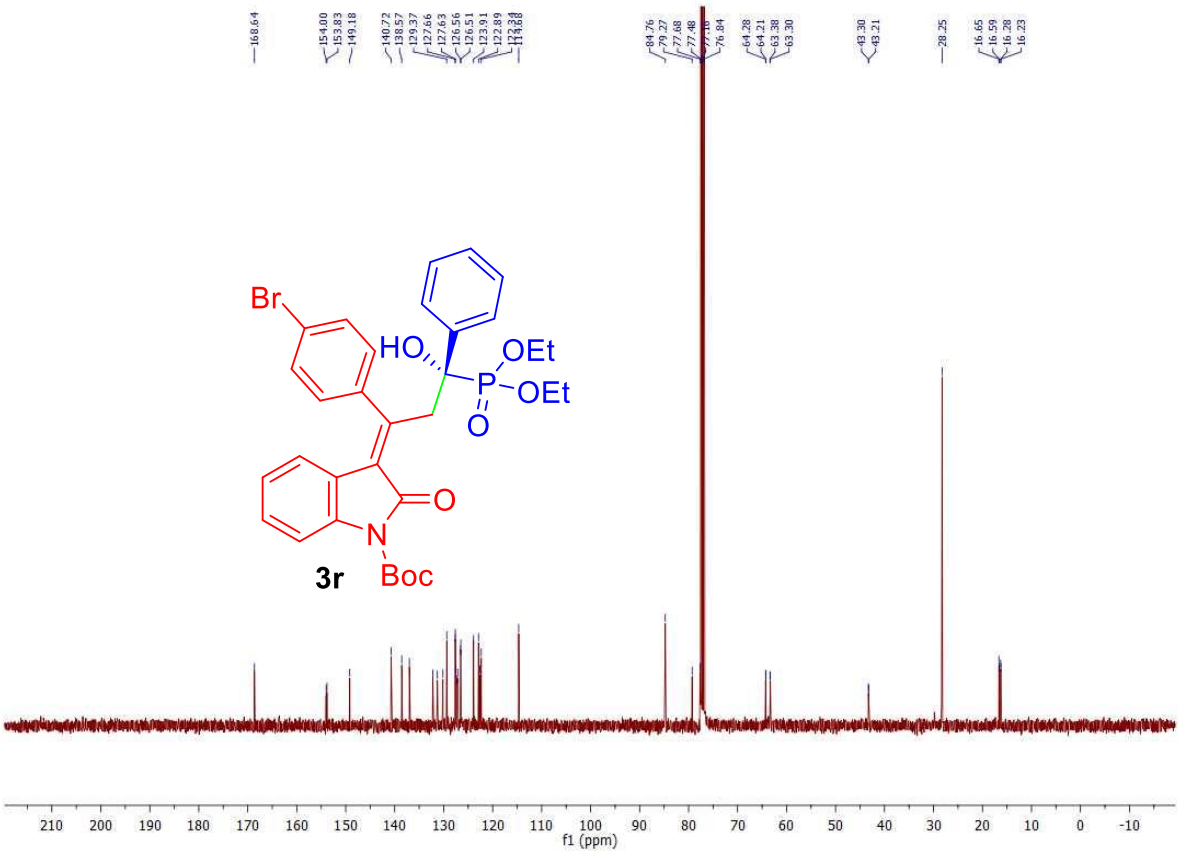

21.53
OEt
HO
P
OEt
O
Ph
O
Br
N
Boc
3p
140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -110 -140 -170 -200 -230
f1 (ppm)

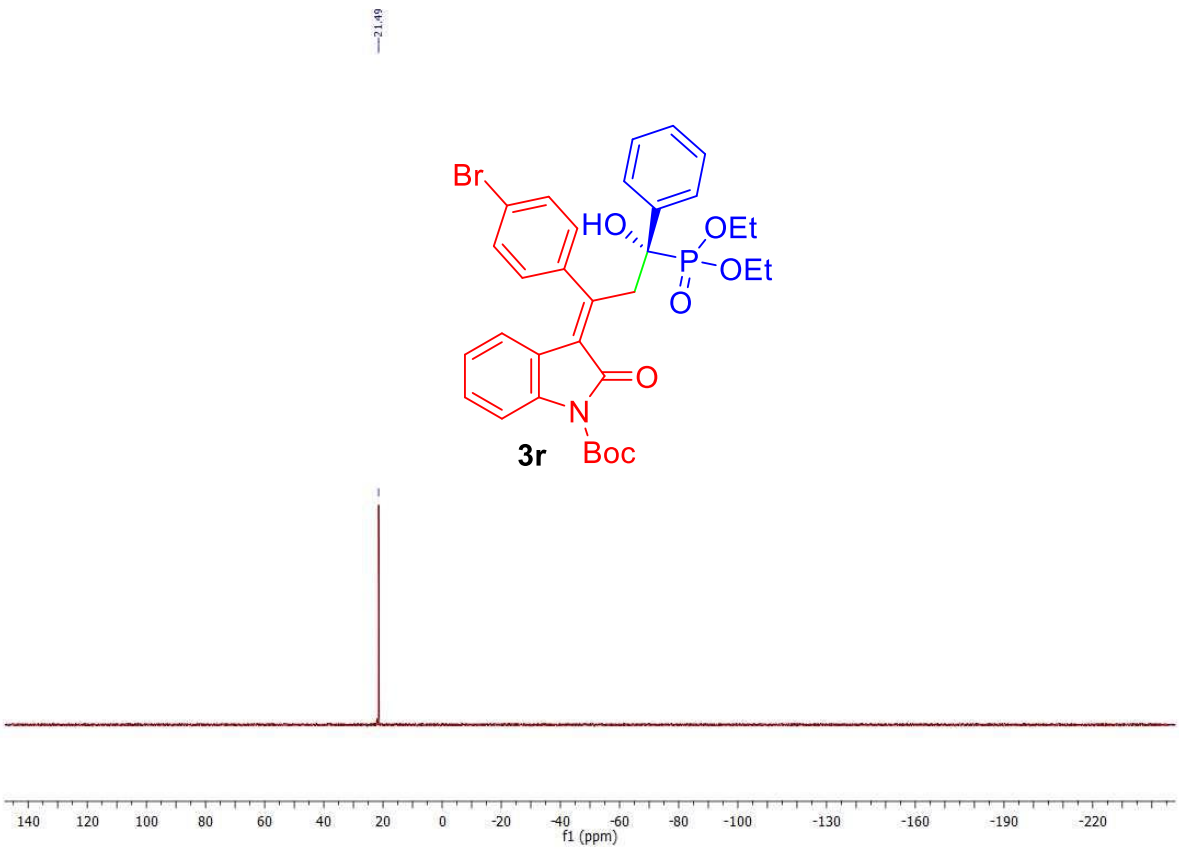

Cl
HO
OEt
P
OEt
O
O
N
Boc
3q
f1 (ppm)

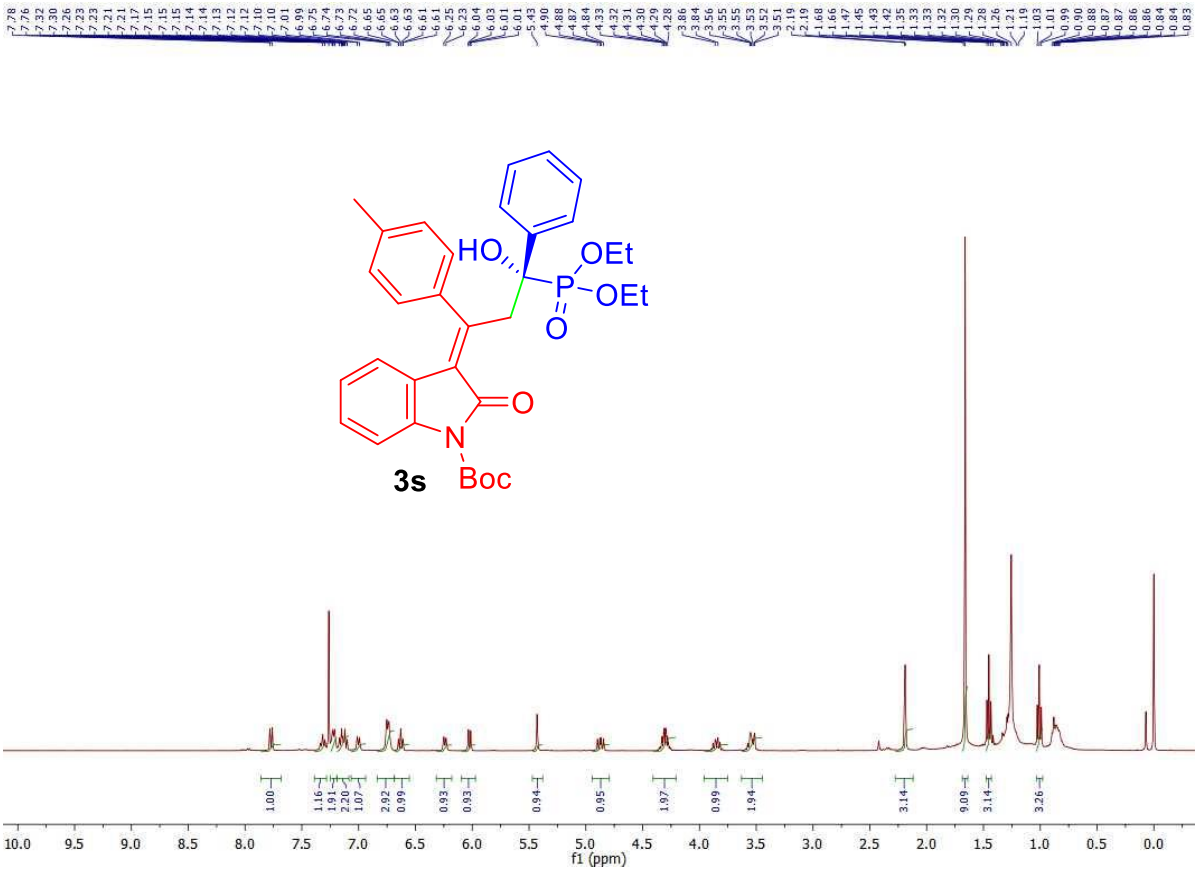

Cl
HO
OEt
P
OEt
O
O
N
Boc
3q
f1 (ppm)

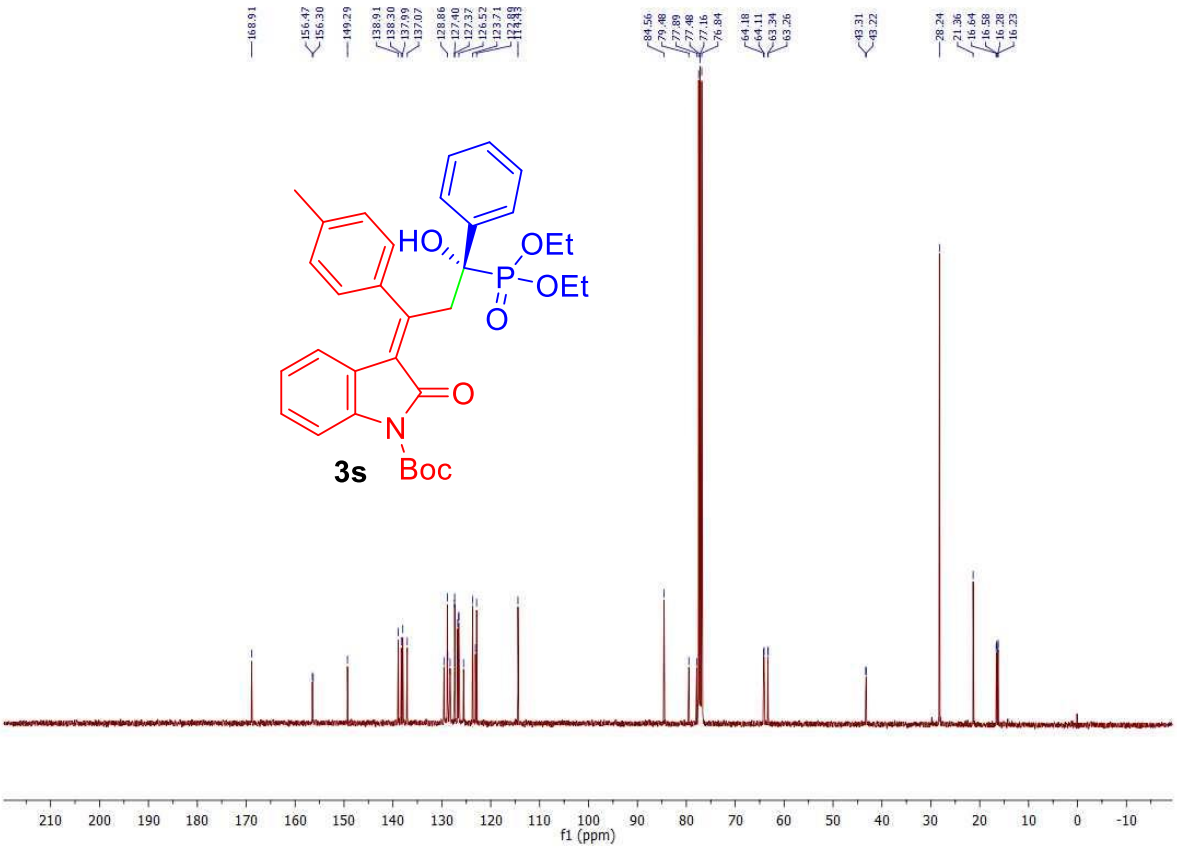

21.51
Cl
HO
OEt
P
OEt
O
O
N
Boc
3q
140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -130 -160 -190 -220
f1 (ppm)

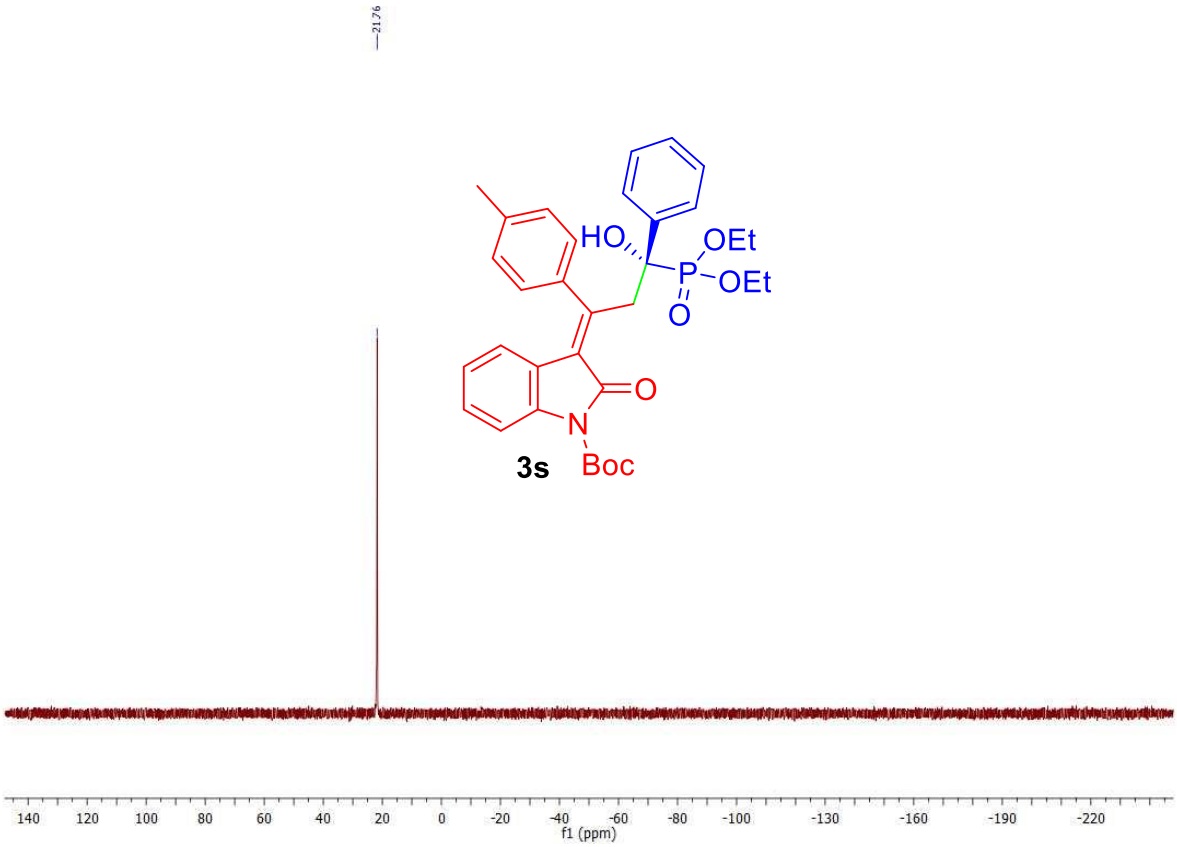

Br
HO
OEt
P
OEt
O
O
N
Boc
3r
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

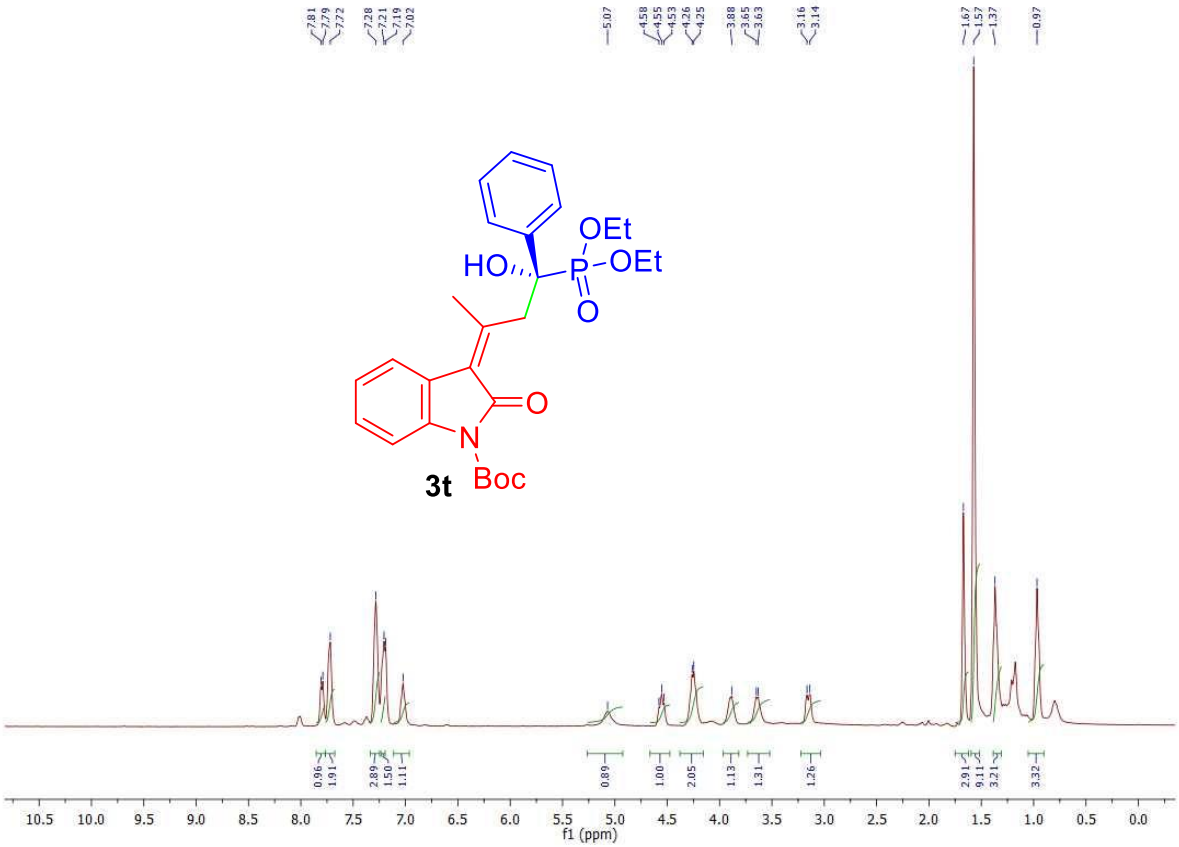

168.64
154.00
153.83
149.18
140.72
138.57
129.37
127.66
127.63
126.56
126.51
123.91
122.89
84.76
79.27
77.68
77.48
76.84
64.28
64.21
63.38
63.30
43.30
43.21
28.25
16.65
16.59
16.28
16.23
Br
HO
OEt
P
OEt
O
O
N
Boc
3r
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

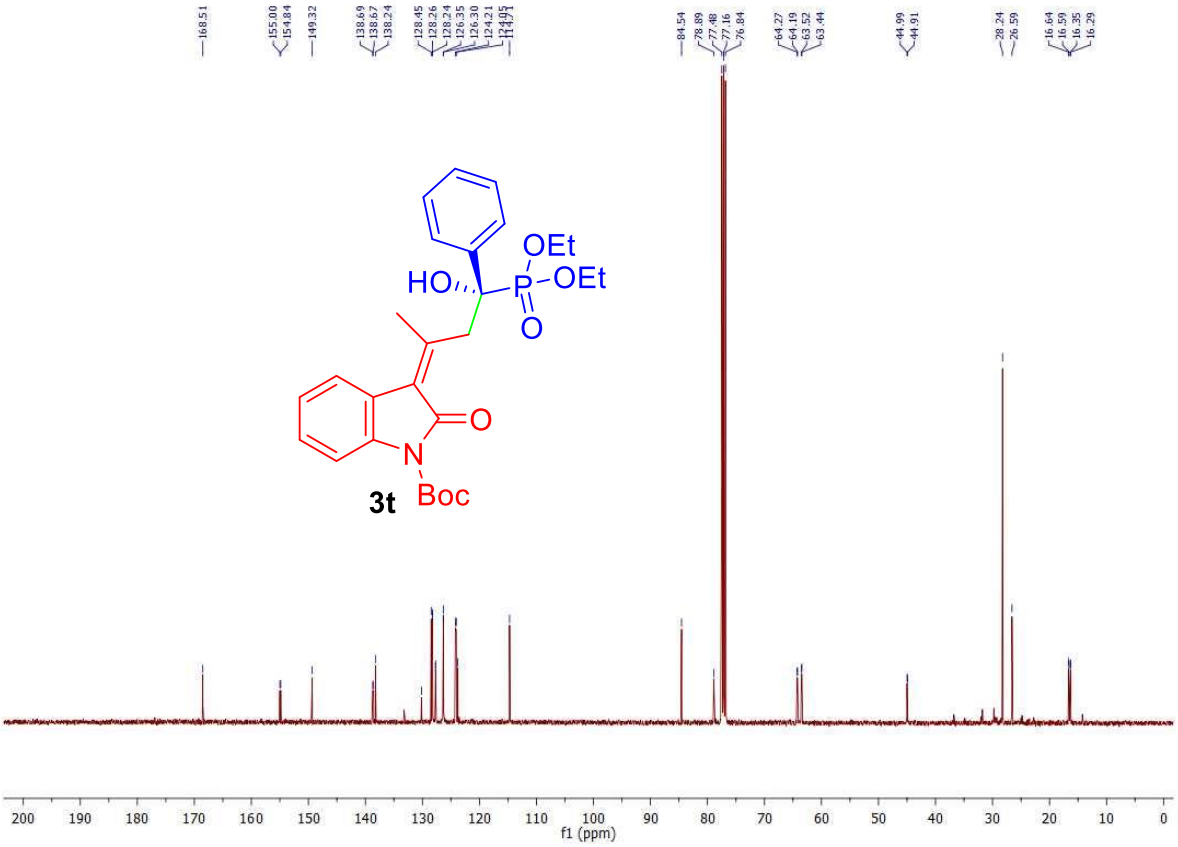

21.49
Br
HO
OEt
P
OEt
O
O
N
Boc
3r
140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -130 -160 -190 -220
f1 (ppm)

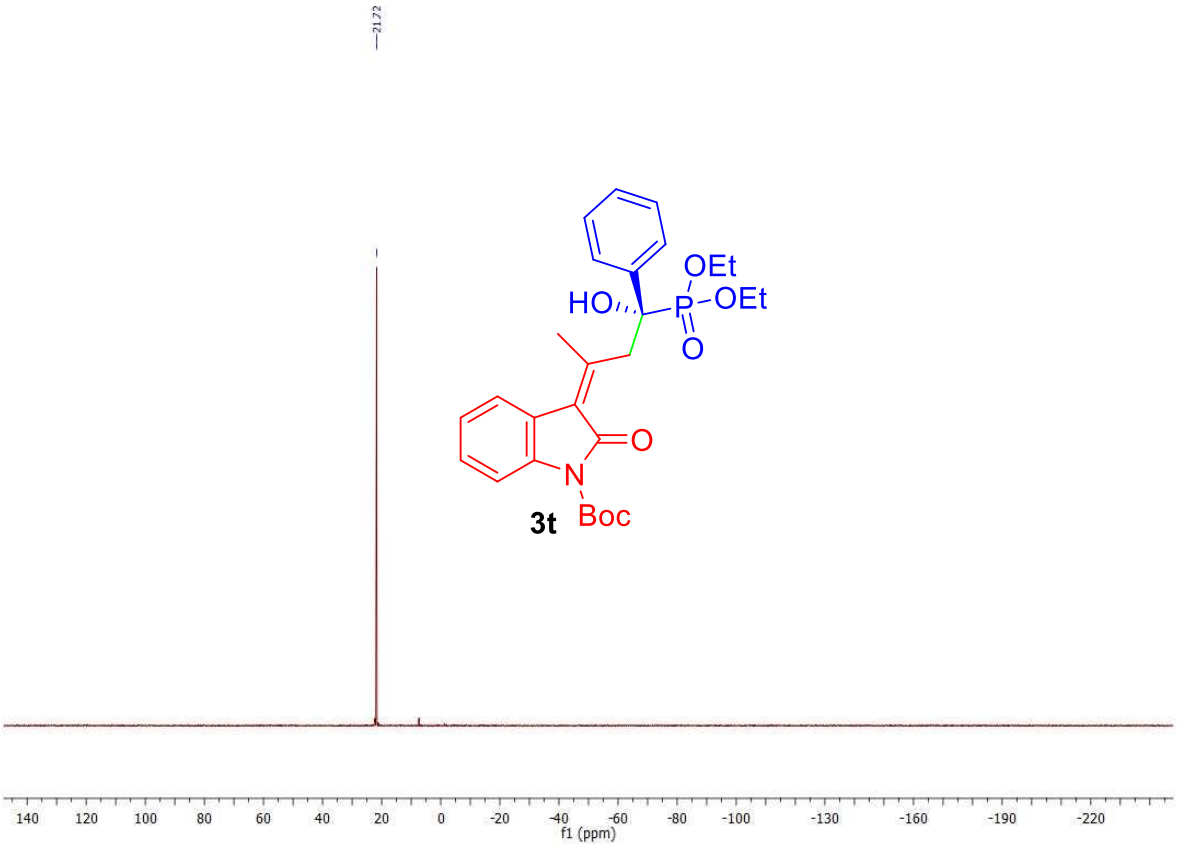

HO
OEt
P
OEt
O
O
N
Boc
3s
f1 (ppm)

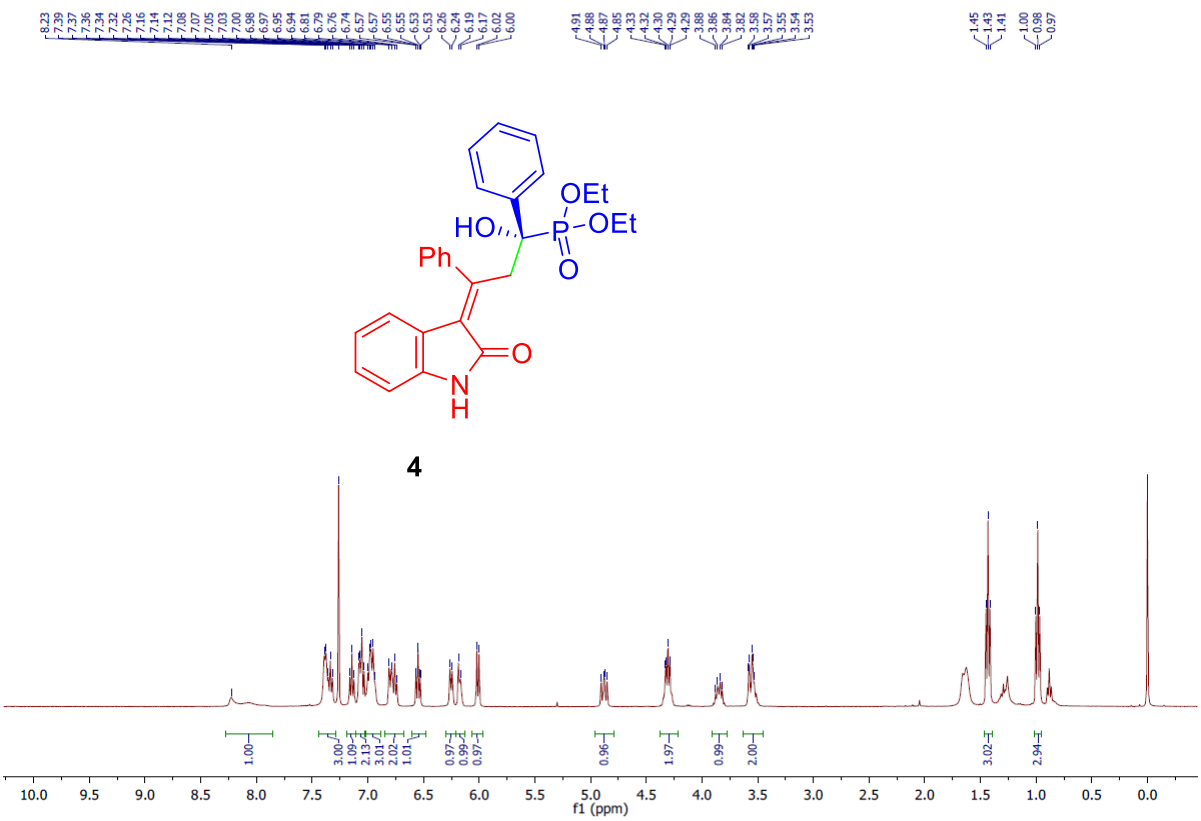

HO
OEt
P
OEt
O
O
N
Boc
3s
f1 (ppm)

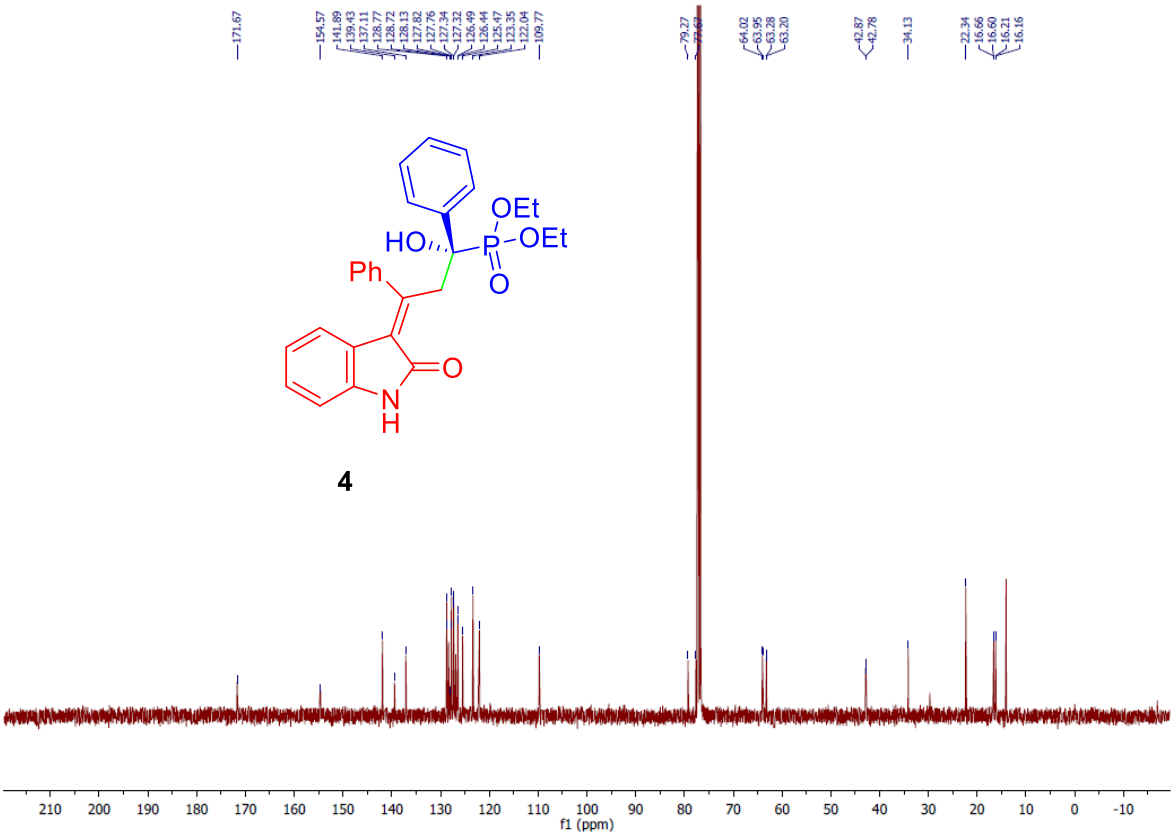

21.76
HO
OEt
P
OEt
O
O
N
Boc
3s
140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -130 -160 -190 -220
f1 (ppm)


7.81
7.79
7.72
7.28
7.21
7.19
7.02
5.07
4.58
4.55
4.53
4.26
4.25
3.88
3.65
3.63
3.16
3.14
1.67
1.57
1.37
0.97
OEt
HO
P
OEt
O
O
N
Boc
3t
0.96
1.91
2.89
1.50
1.11
0.89
1.00
2.05
1.13
1.31
1.26
2.91
9.11
3.21
3.32
10.5 10.0 9.5 9.0 8.5 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
f1 (ppm)

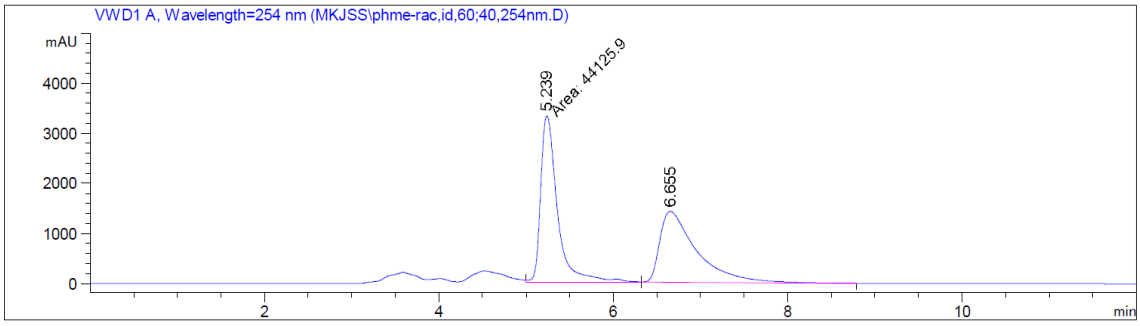

168.51
155.00
154.84
149.32
138.69
138.67
138.24
128.45
128.26
128.24
126.35
126.30
124.21
84.54
78.89
77.48
77.16
76.84
64.27
64.19
63.52
63.44
44.99
44.91
28.24
26.59
16.64
16.59
16.35
16.29
OEt
HO
P
OEt
O
O
N
Boc
3t
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


21.72
OEt
HO
P
OEt
O
O
N
Boc
3t
140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -130 -160 -190 -220
f1 (ppm)

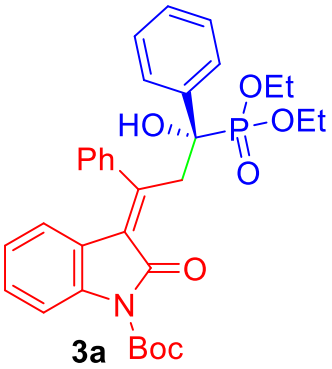

OEt
HO
P
OEt
O
Ph
O
N
H
4
f1 (ppm)


OEt
HO
P
OEt
O
Ph
O
N
H
4
f1 (ppm)

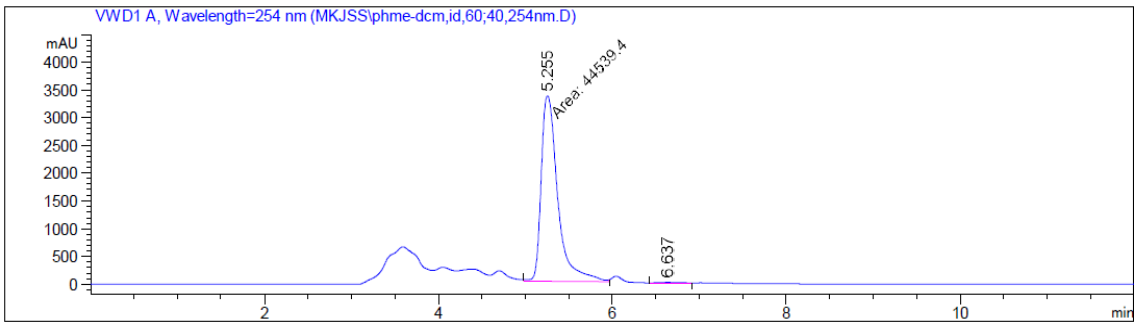
HPLC, Chiralpak Id, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.239 FM    0.2221 4.41259e4  3311.52808  51.7243
   2   6.655 BB    0.4239 4.11839e4  1409.59558  48.2757
```

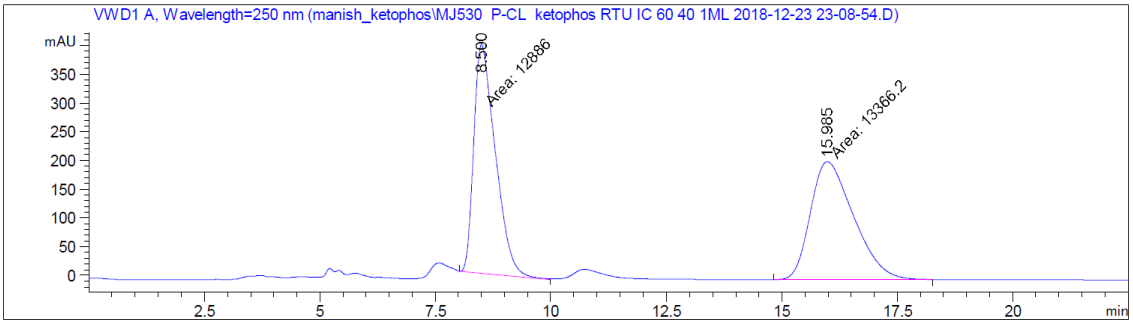


3a

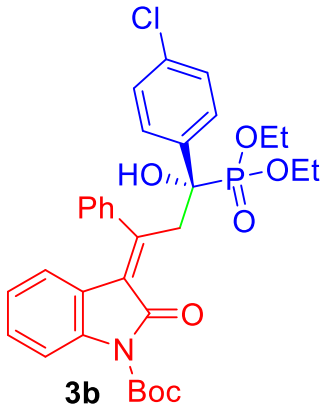


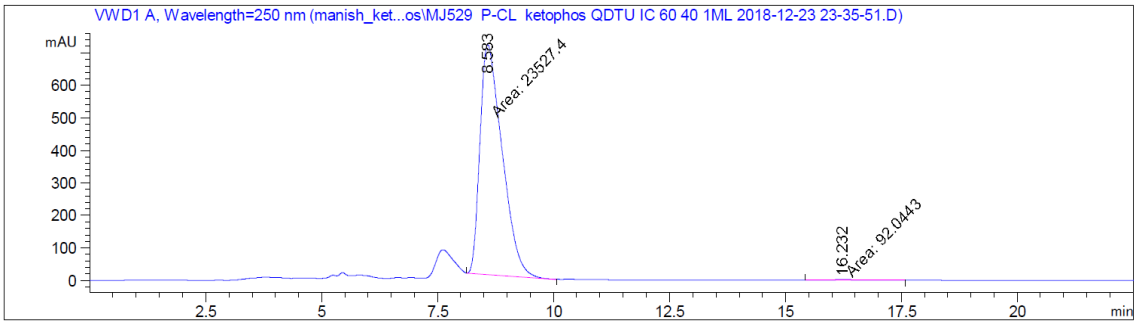

```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.255 MM    0.2222 4.45394e4  3341.03857  99.5103
   2   6.637 BV    0.2426  219.16377   13.06983   0.4897
```

HPLC, Chiralpak IC, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm



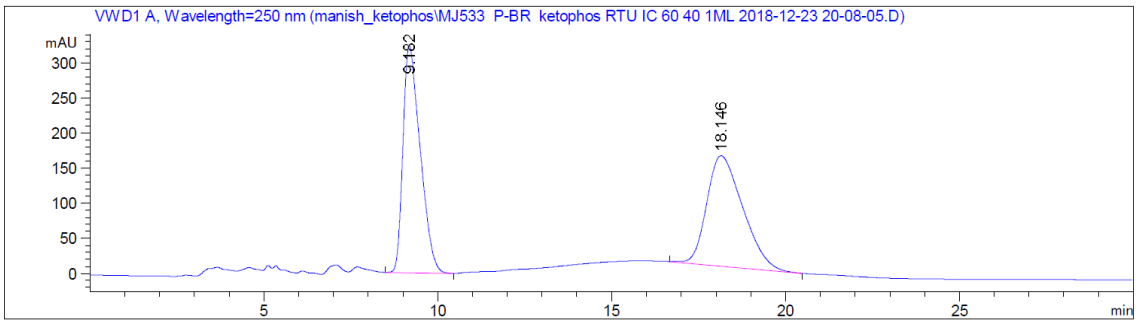

```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   8.500 MM    0.5396 1.28860e4   397.99619  49.0855
   2  15.985 MM    0.1045 1.33662e4   205.41435  50.9145
```



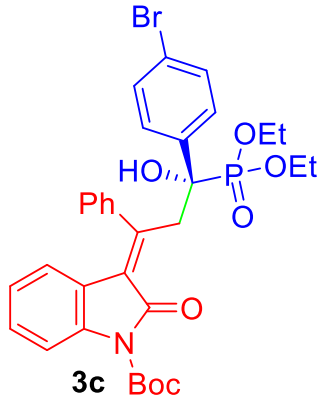



```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   8.583 MM    0.5550 2.35274e4   706.55676  99.6103
   2  16.232 MM    1.0325   92.04428    1.48578   0.3897
```

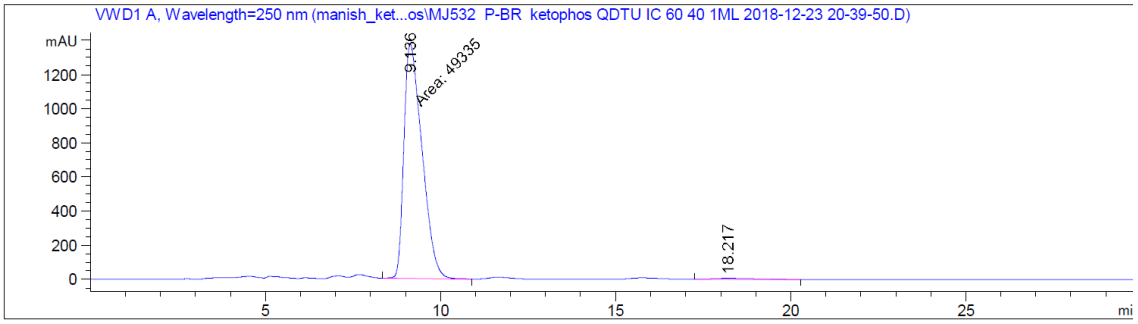
HPLC, Chiralpak IC, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   9.182 BB    0.5069 1.11111e4   323.38364  49.5274
   2  18.146 BB    1.0957 1.13231e4   157.14209  50.4726
```

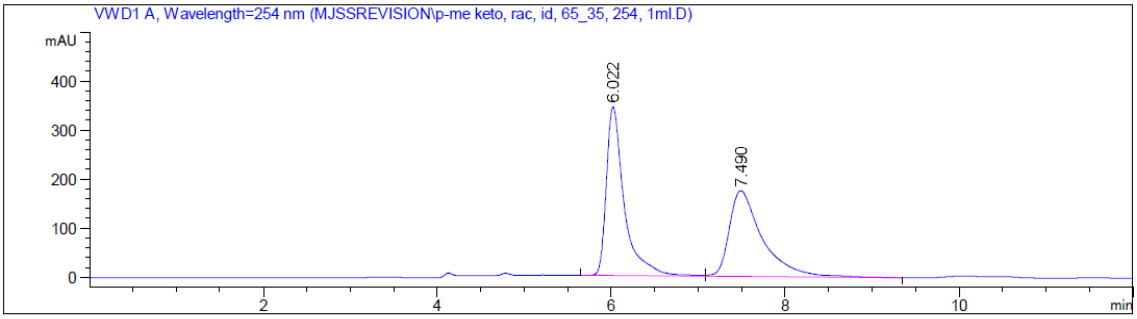


3c

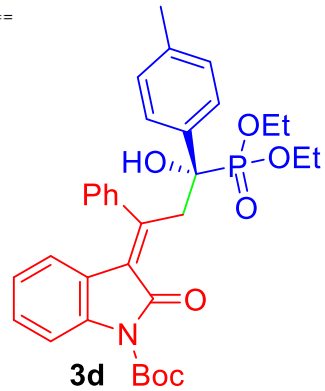



```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   9.136 MM    0.5993 4.93350e4  1372.02771  99.1442
   2  18.217 BB    0.9852  425.86655    6.07995   0.8558
```

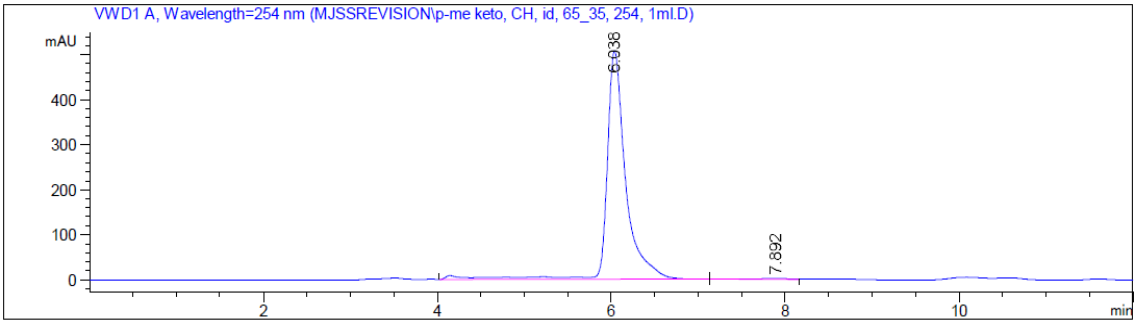
HPLC, Chiralpak ID, hexane: isopropanol = 65:35, 1 mL/min, λ = 254 nm




```
==========================================================================
                          Area Percent Report
==========================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   6.022 BV    0.2110 4916.67041  343.43179  51.6152
   2   7.490 VB    0.3865 4608.94678  174.30978  48.3848
```

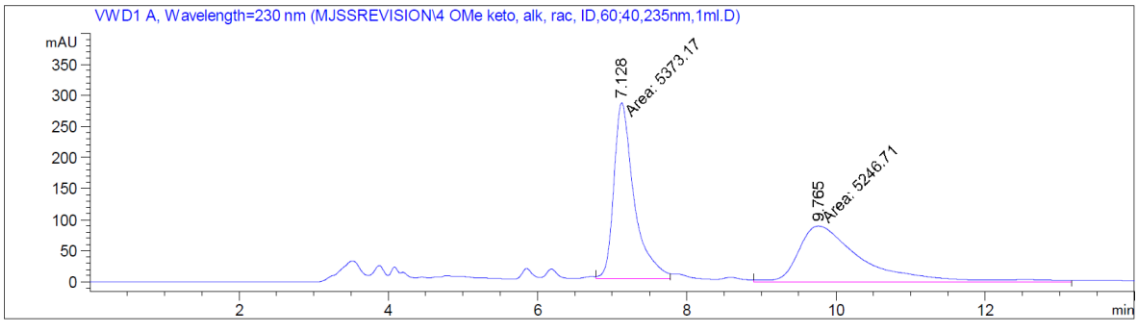


3d

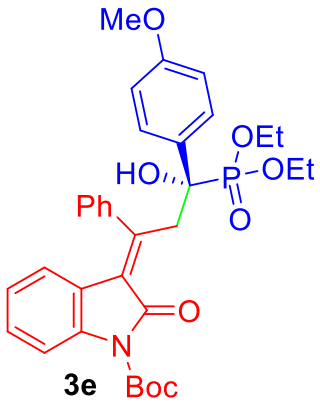



```
==========================================================================
                          Area Percent Report
==========================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   6.038 VB R  0.2106 7734.45703  507.80411  99.1671
   2   7.892 BV    0.4274   64.96202    2.11476   0.8329
```

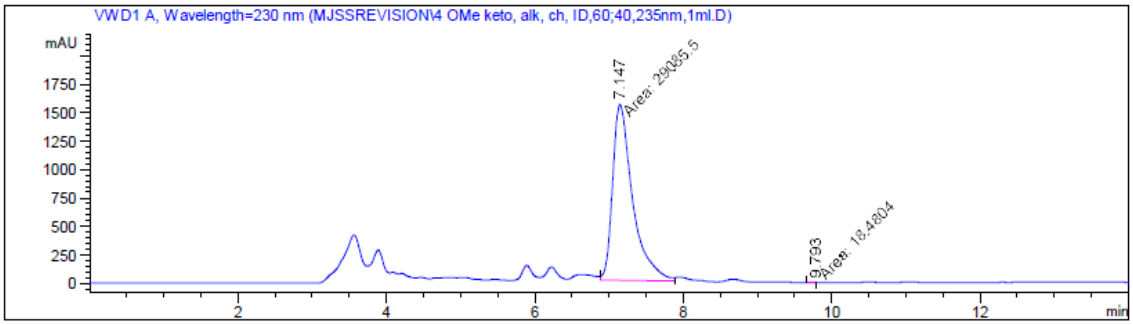
HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 230 nm




```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=230 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   7.128 FM    0.3165 5373.16650  282.93958  50.5954
   2   9.765 MM    0.9772 5246.70508   89.48128  49.4046
```

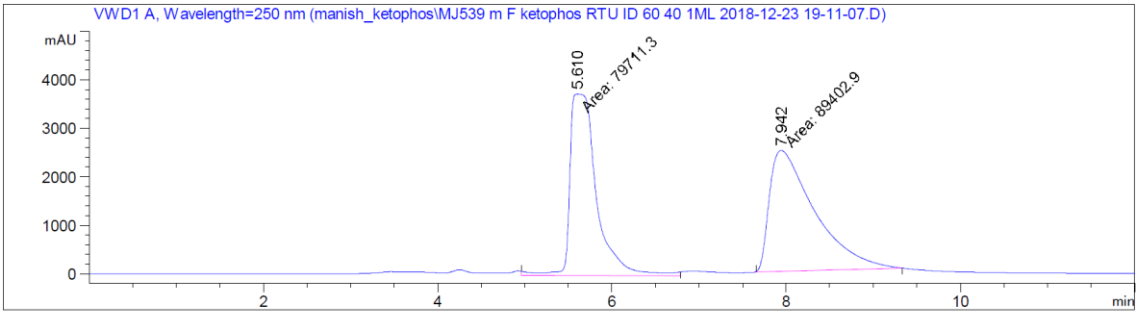


3e

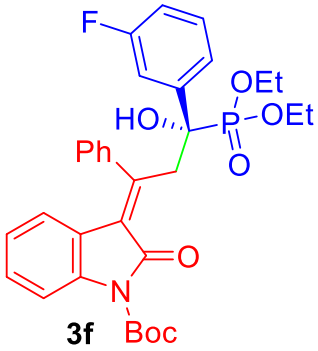



```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=230 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   7.147 MF    0.3132 2.90855e4  1547.99097  99.9365
   2   9.793 MM    0.1161   18.48042    2.65184   0.0635
```

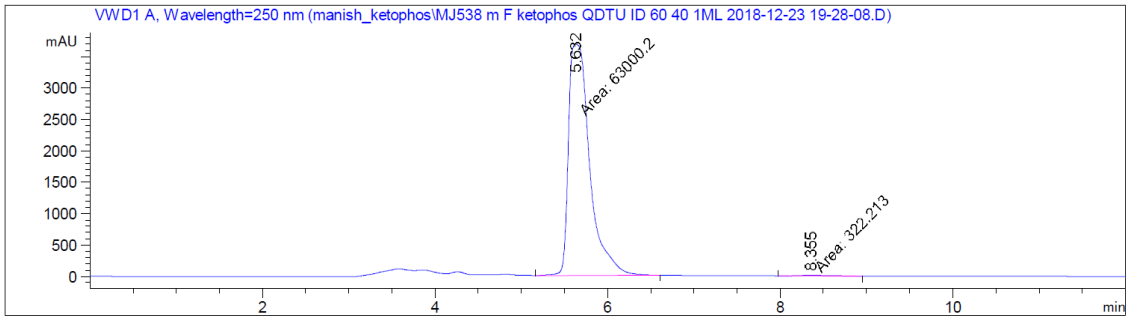
PLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.610 MM    0.3555 7.97113e4  3737.41699  47.1346
   2   7.942 MM    0.5991 8.94029e4  2487.01001  52.8654
```

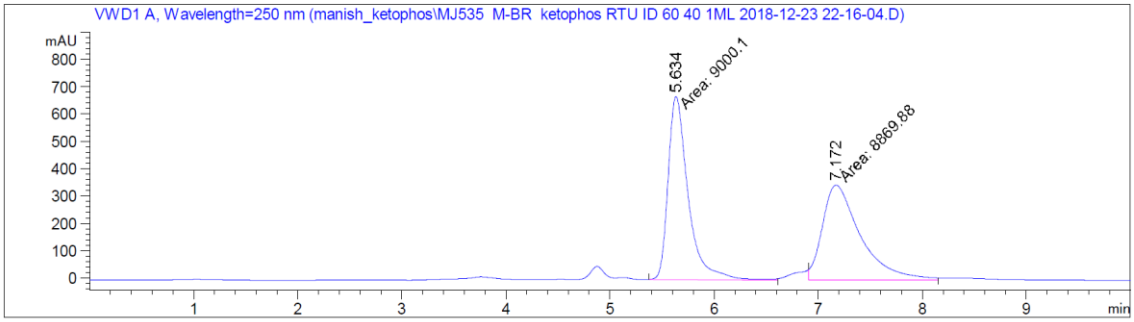


3f

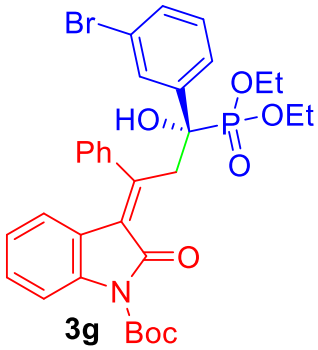



```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.632 MM    0.2852 6.30002e4  3681.93652  99.4912
   2   8.355 MM    0.4045  322.21329   13.27578   0.5088
```

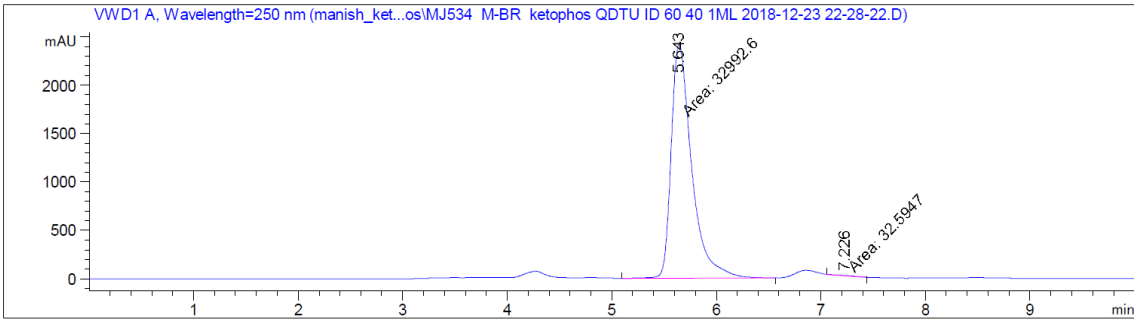
HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.634 MF    0.2238 9000.10352  670.23096  50.3644
   2   7.172 FM    0.4259 8869.87793  347.10147  49.6356
```

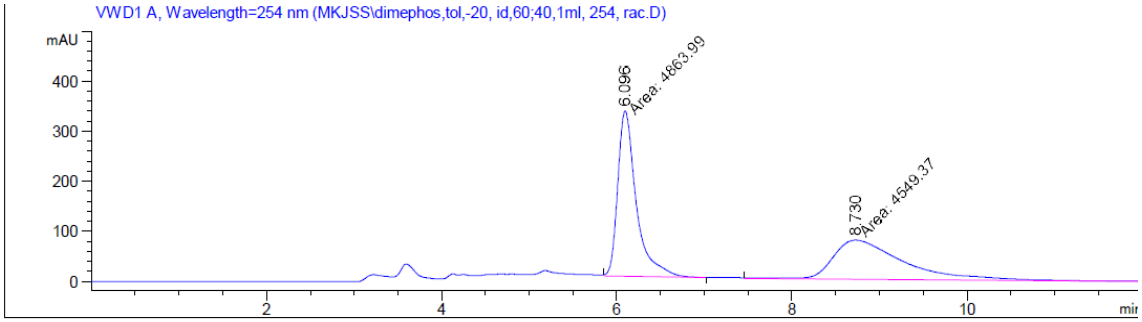


3g

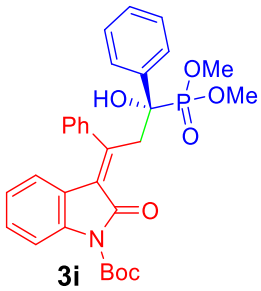



```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.643 MM    0.2273 3.29926e4  2419.12891  99.9013
   2   7.226 MM    0.2198   32.59469    2.63012   0.0987
```

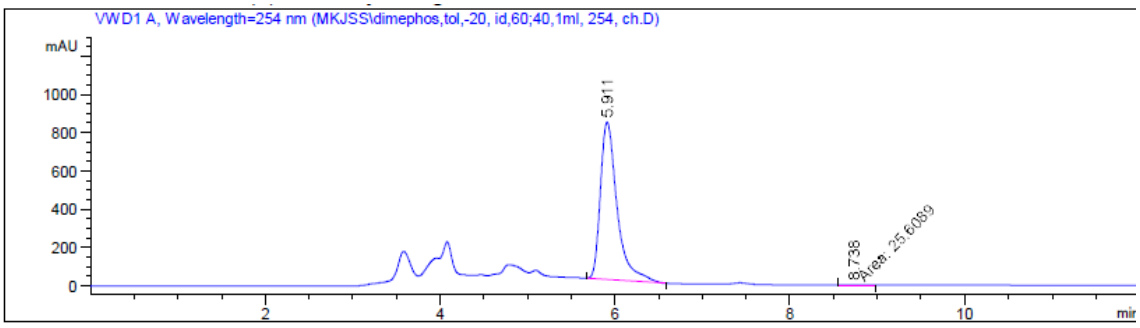
HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   6.096 FM    0.2453 4863.99316  330.42349  51.6712
   2   8.730 MM    0.9640 4549.36523   78.65718  48.3288
```

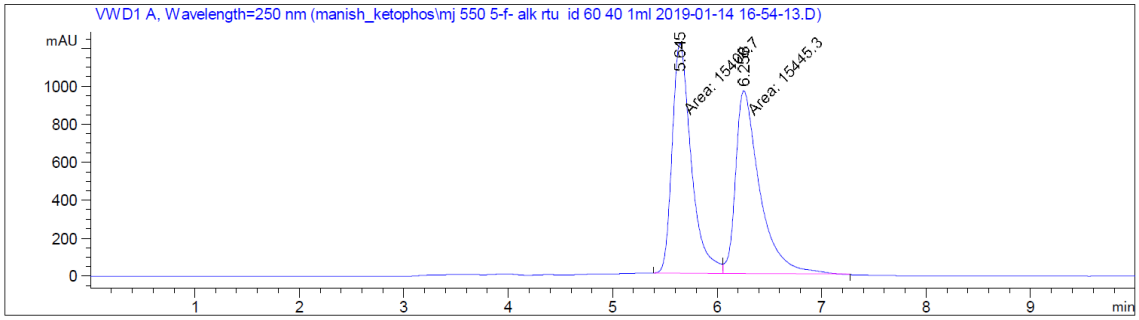


3i

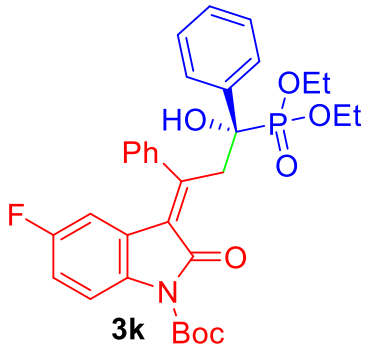



```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.911 BB    0.2014 1.09532e4   822.23517  99.7667
   2   8.738 MM    0.2420   25.60891    1.76374   0.2333
```

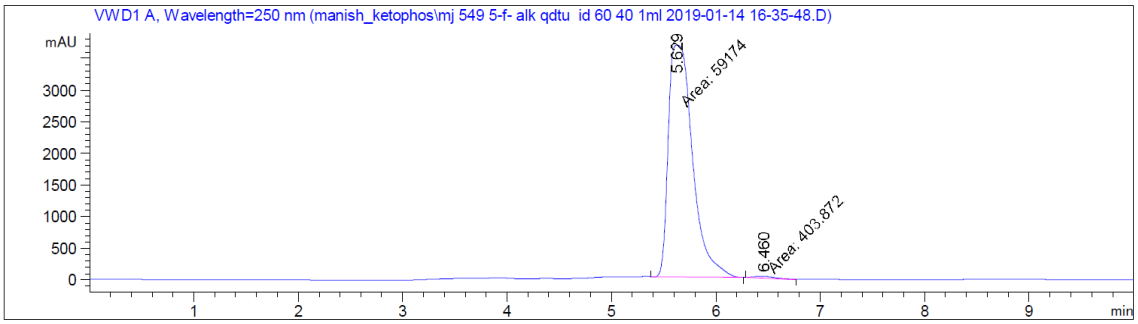
HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==========================================================================
                          Area Percent Report
==========================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.645 MF    0.2123 1.54087e4  1209.73059  49.9407
   2   6.256 FM    0.2673 1.54453e4   963.21143  50.0593
```

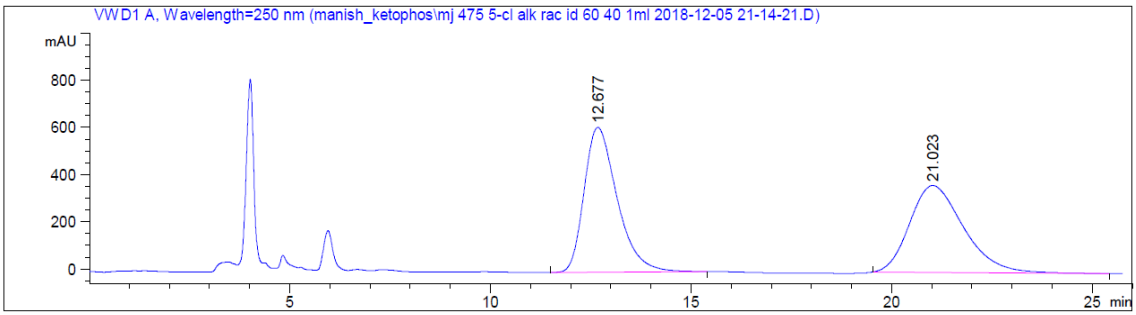


3k

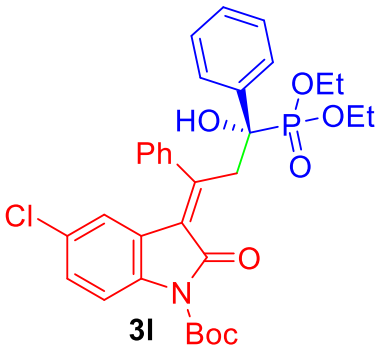



```
==========================================================================
                          Area Percent Report
==========================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.629 MM    0.2690 5.91740e4  3665.86987  99.3221
   2   6.460 MM    0.2196  403.87192   30.64550   0.6779
```

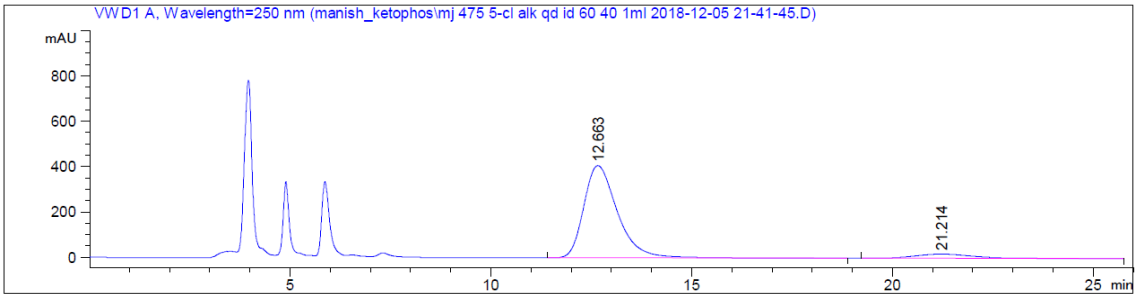
HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1  12.677 BB    0.8752 3.51169e4   613.15472  50.5340
   2  21.023 BBA   1.3520 3.43748e4   367.93561  49.4660
```

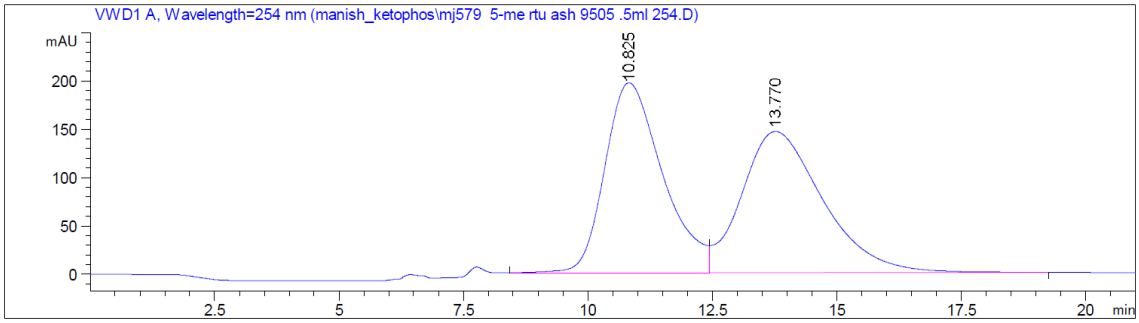


3l

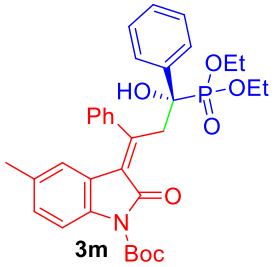



```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1  12.663 BB    0.8904 2.37148e4   406.63763  92.9252
   2  21.214 BBA   1.4280 1805.49512   18.87534   7.0748

Totals :                  2.55203e4   425.51297
```

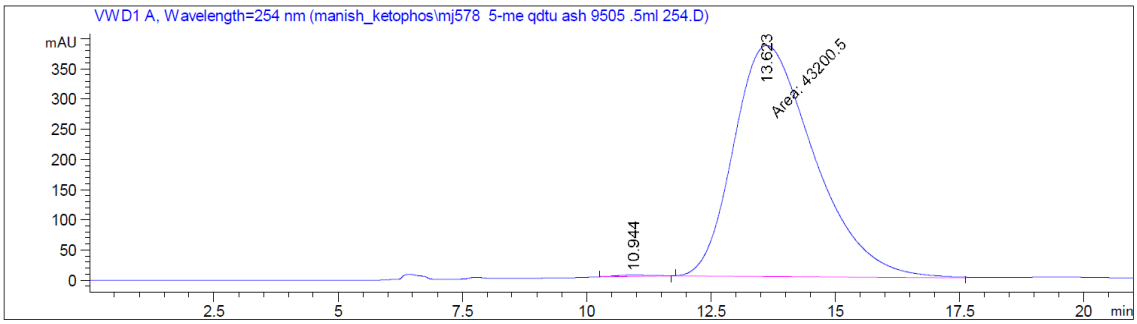
HPLC, Chiralpak ASH, hexane: isopropanol = 95:05, 0.5 mL/min, λ = 254 nm




```
==========================================================================
                          Area Percent Report
==========================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1  10.825 BV    1.2288 1.58901e4   196.42509  48.9779
   2  13.770 VB    1.7165 1.65533e4   146.02483  51.0221
```

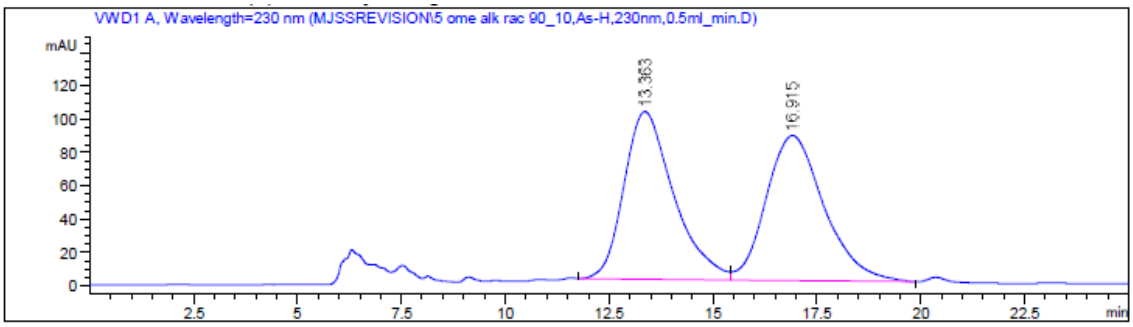


3m

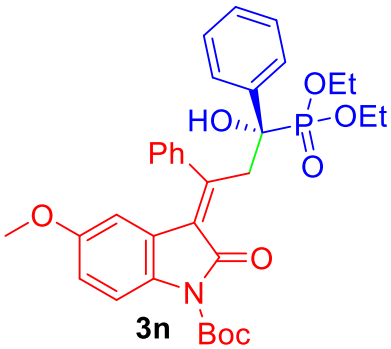



```
==========================================================================
                          Area Percent Report
==========================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1  10.944 BB    0.5947   91.97793    2.13026   0.2125
   2  13.623 MM    1.8789 4.32005e4   383.19907  99.7875
```

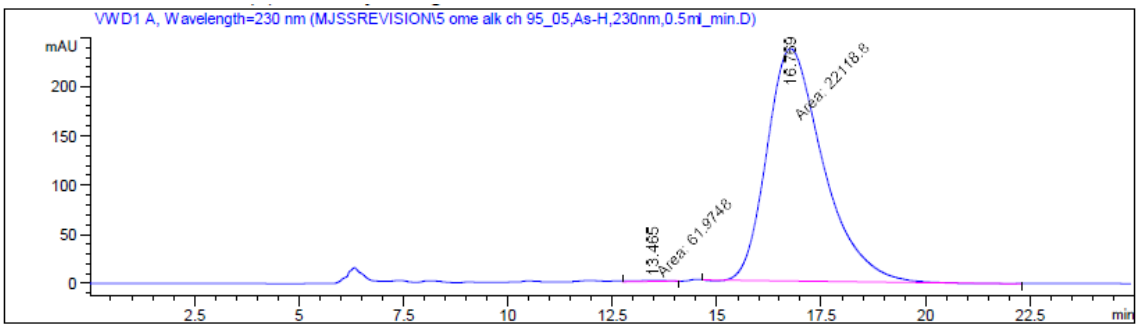
HPLC, Chiralpak ASH, hexane: isopropanol = 95:05, 0.5 mL/min, λ = 254 nm




```
==========================================================================
                          Area Percent Report
==========================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=230 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1  13.363 BV    1.2291 8386.93848  100.65562  49.8408
   2  16.915 VB    1.4820 8440.51563   87.14101  50.1592
```

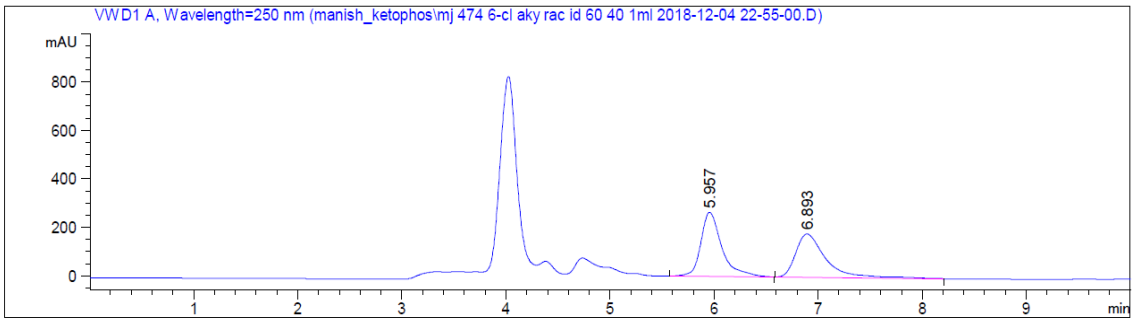


3n

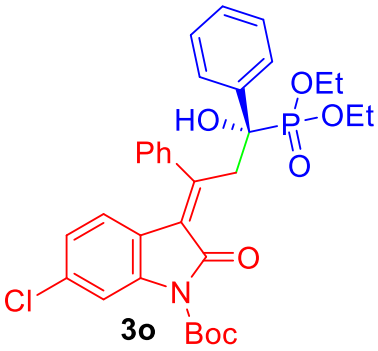



```
==========================================================================
                          Area Percent Report
==========================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=230 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1  13.465 MM    0.8642   61.97480    1.19523   0.2794
   2  16.769 MM    1.5621 2.21188e4   235.99660  99.7206
```

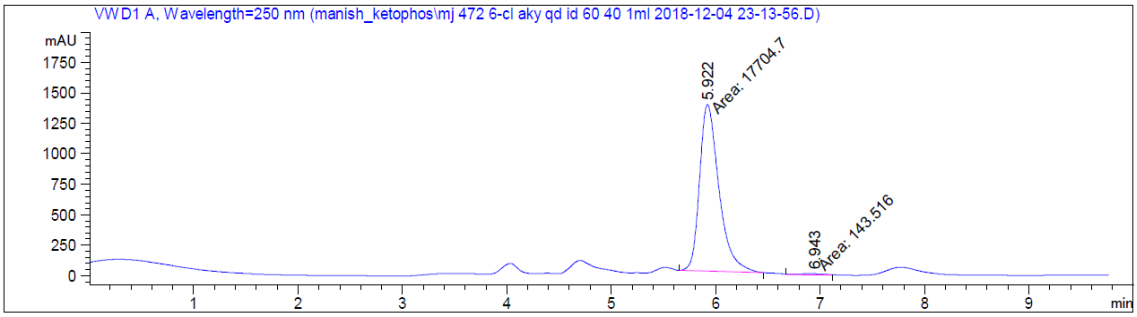
HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.957 BB    0.2101 3720.50781  264.49811  50.9713
   2   6.893 BB    0.2991 3578.70801  178.33482  49.0287
```

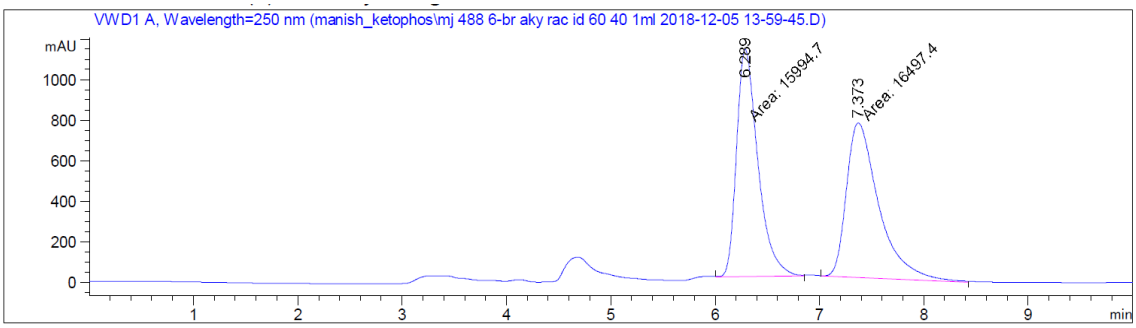


3o

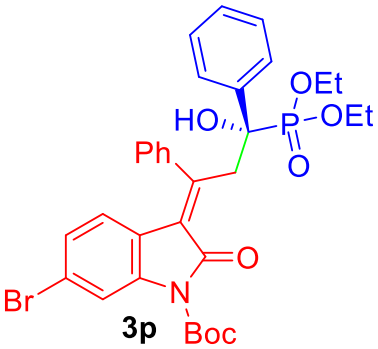



```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.922 MM    0.2158 1.77047e4  1367.38428  99.1959
   2   6.943 MM    0.3120  143.51630    7.66682   0.8041
```

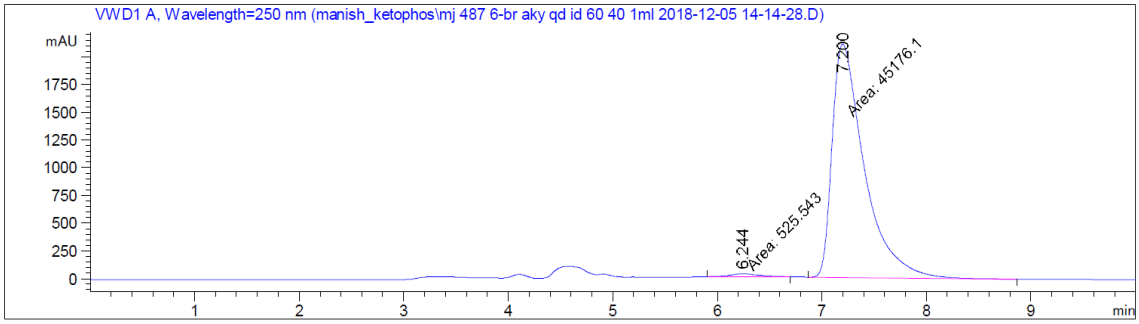
HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   6.289 MM    0.2377 1.59947e4  1121.26318  49.2263
   2   7.373 MM    0.3604 1.64974e4   762.89465  50.7737
```

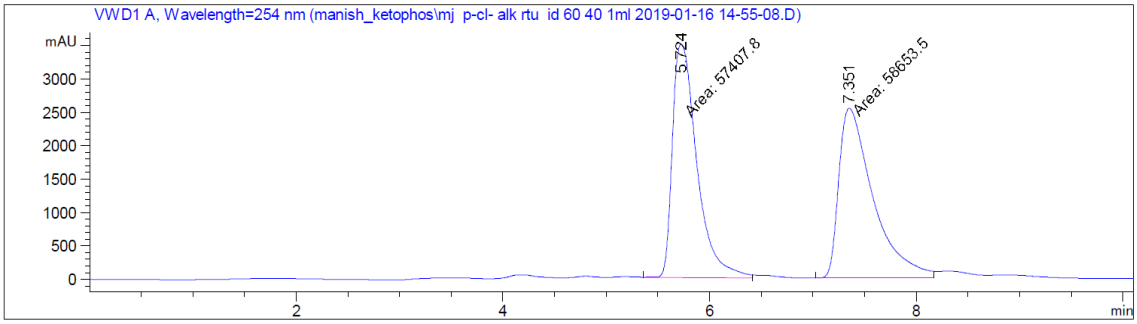


3p

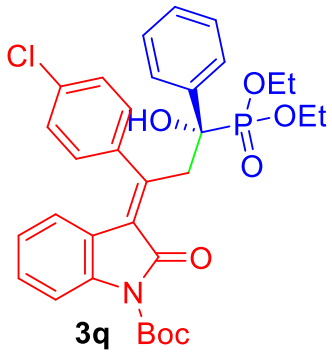



```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=250 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   6.244 MM    0.3256  525.54333   26.90079   1.1499
   2   7.200 MM    0.3574 4.51761e4  2106.44116  98.8501
```

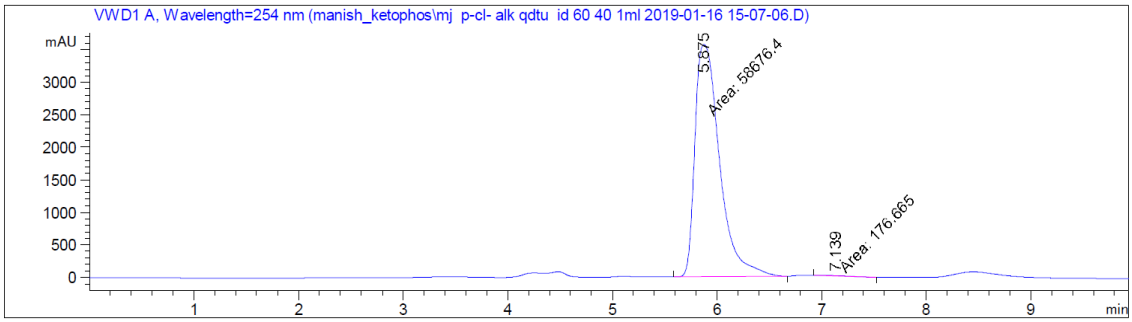
HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==========================================================================
                          Area Percent Report
==========================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.724 MF    0.2746 5.74078e4  3483.69775  49.4633
   2   7.351 MF    0.3851 5.86535e4  2538.58179  50.5367
```

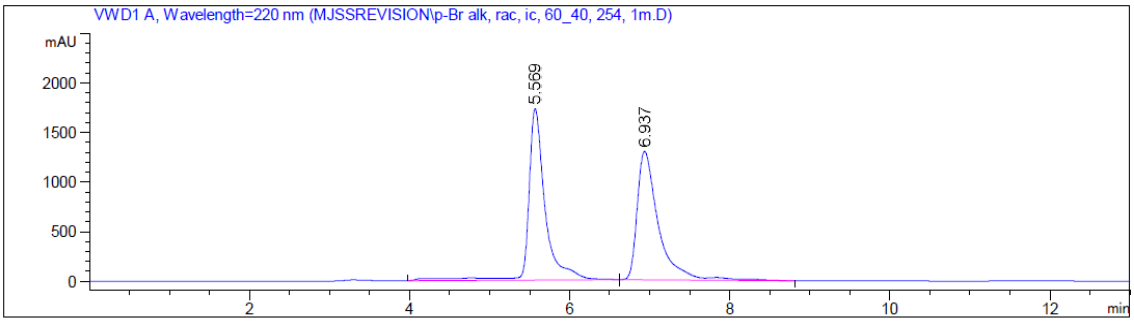


3q

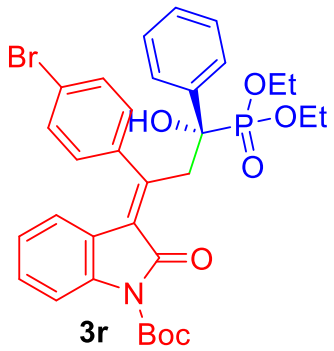



```
==========================================================================
                          Area Percent Report
==========================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.875 MM    0.2738 5.86764e4  3571.20288  99.6998
   2   7.139 MM    0.3264  176.66528    9.02099   0.3002
```

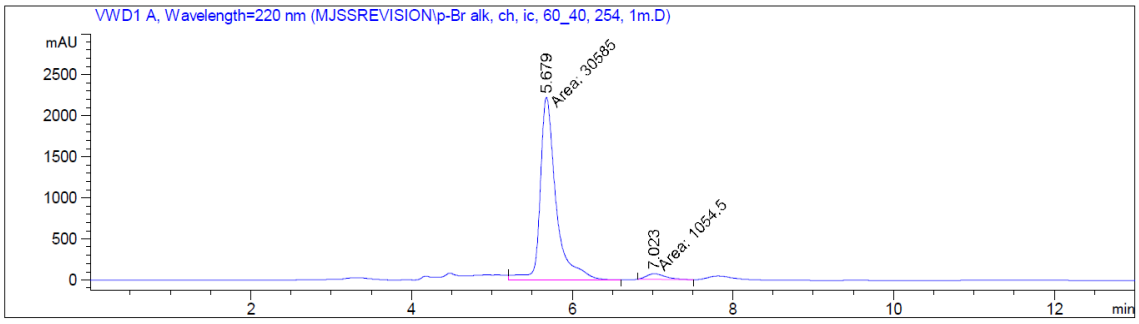
HPLC, Chiralpak IC, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=220 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.569 VB R  0.2084 2.48437e4  1725.12891  51.0500
   2   6.937 BV R  0.2660 2.38217e4  1293.24817  48.9500
```

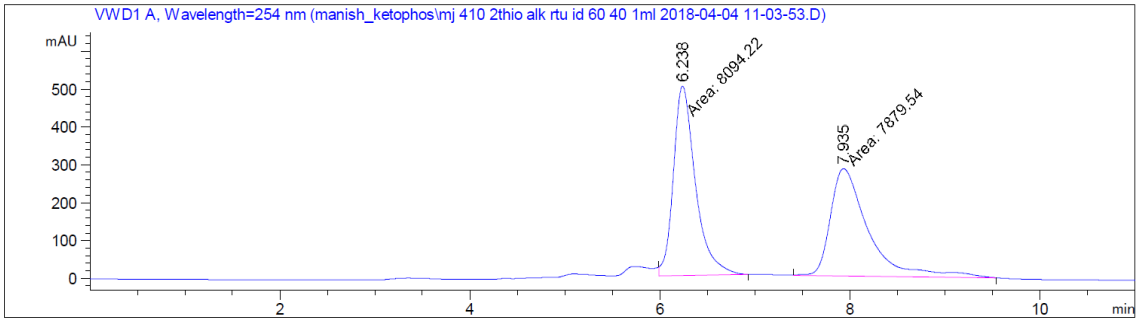


3r

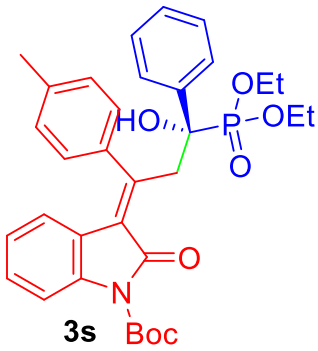



```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=220 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   5.679 FM    0.2292 3.05850e4  2223.82349  96.6671
   2   7.023 MM    0.2627 1054.49841   66.90570   3.3329
```

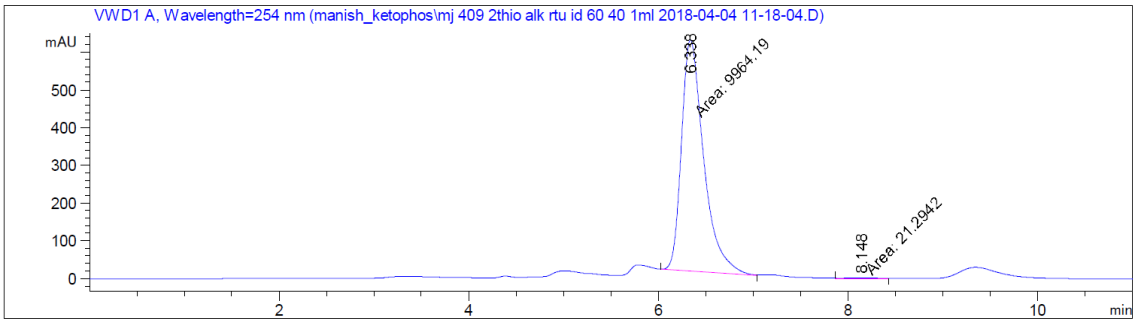
HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   6.238 FM    0.2691 8094.22363  501.23218  50.6720
   2   7.935 MM    0.4630 7879.54297  283.64966  49.3280
```

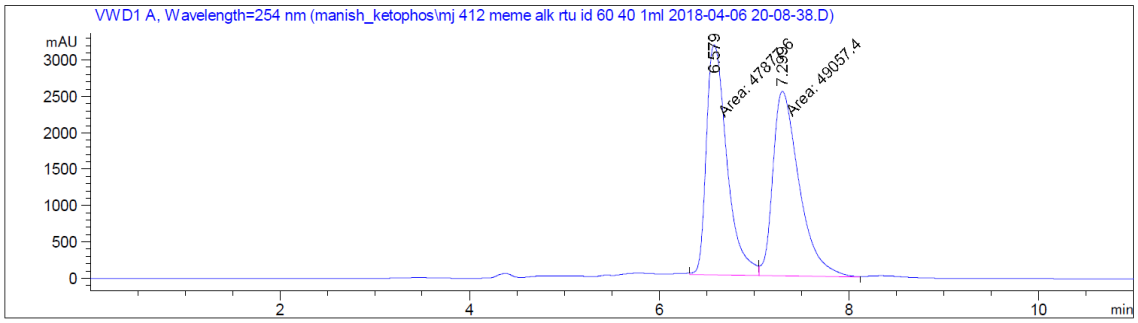


3s

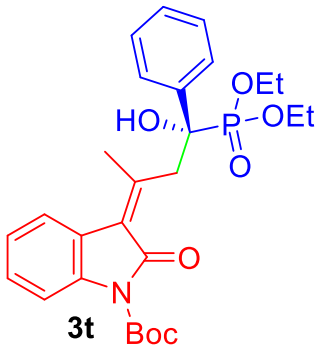



```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   6.338 MM    0.2709 9964.18750  612.93939  99.7867
   2   8.148 MM    0.3081   21.29416    1.15190   0.2133
```

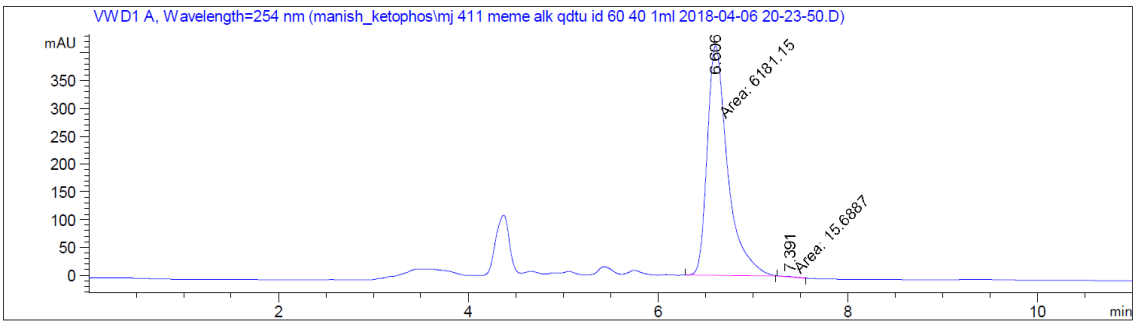
HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   6.579 MF    0.2520 4.78776e4  3166.49658  49.3914
   2   7.299 FM    0.3218 4.90574e4  2541.13110  50.6086
```

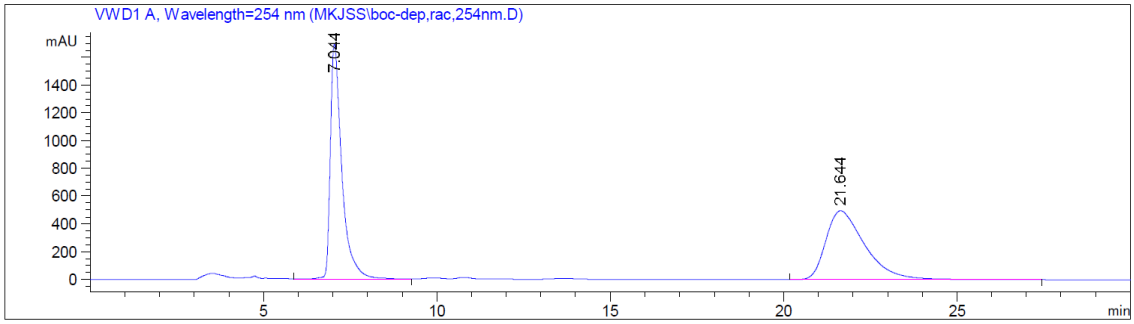


3t

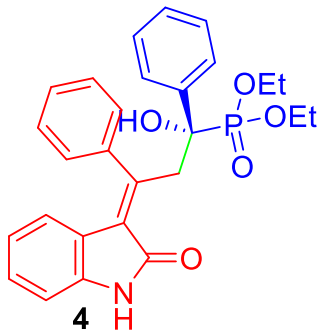


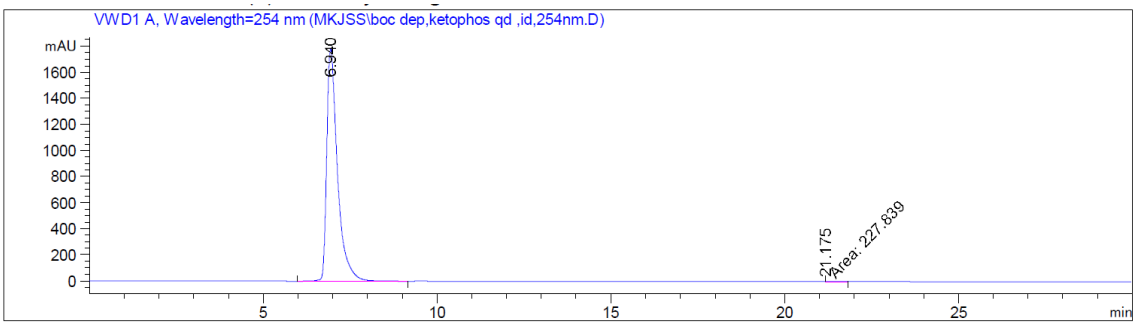

```
==================================================================
                        Area Percent Report
==================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   6.606 MM    0.2497 6181.14551  412.60873  99.7468
   2   7.391 MM    0.2415   15.68868    1.03731   0.2532
```

HPLC, Chiralpak ID, hexane: isopropanol = 60:40, 1 mL/min, λ = 254 nm




```
==========================================================================
                          Area Percent Report
==========================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   7.044 VB R  0.3424 3.90704e4  1692.07239  50.1096
   2  21.644 BB    1.1925 3.88995e4   496.23624  49.8904
```

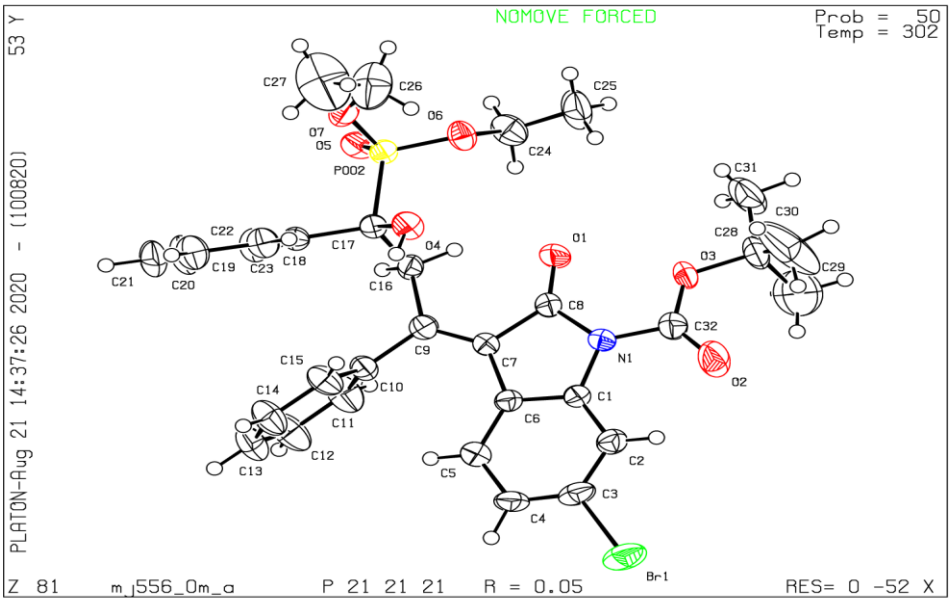





```
==========================================================================
                          Area Percent Report
==========================================================================

Sorted By             :      Signal
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs


Signal 1: VWD1 A, Wavelength=254 nm

Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [mAU*s]     [mAU]       %
----|-------|----|-------|----------|----------|--------|
   1   6.940 BB    0.3219 3.83197e4  1782.12158  99.4089
   2  21.175 MM    0.6286  227.83940    6.04072   0.5911
```

Single crystal XRD data for Compound

Structure Determination of **3p** by X-ray analysis: CCDC Number: **2024642**



Bond precision: C-C = 0.0084 A Wavelength=0.71073

Cell: a=6.5171(3) b=9.8455(6) c=48.456(3)

alpha=90 beta=90 gamma=90

Temperature: 302 K

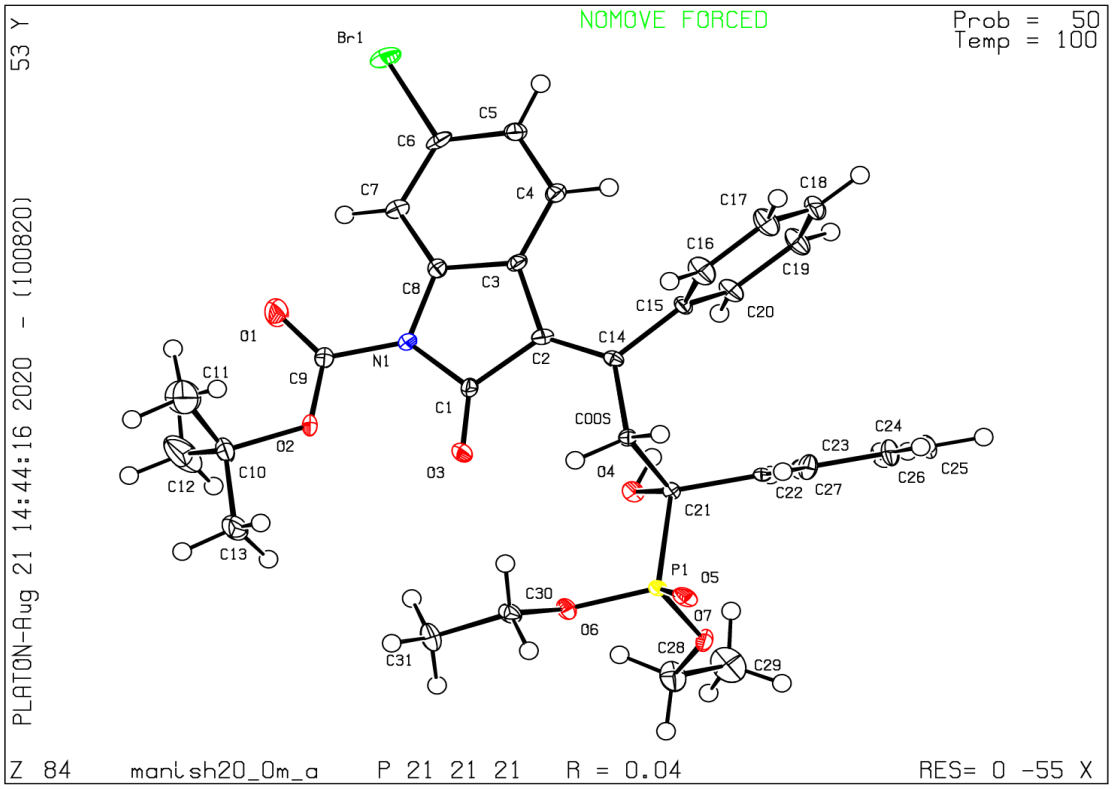
	Calculated	Reported
Volume	3109.1(3)	3109.2(3)
Space group	P 21 21 21	P 21 21 21
Hall group	P 2ac 2ab	P 2ac 2ab
Moiety formula	$C_{32}H_{35}BrNO_7P$	$C_{32}H_{35}BrNO_7P$
Sum formula	$C_{32}H_{35}BrNO_7P$	$C_{32}H_{35}BrNO_7P$
Mr	656.48	656.48
Dx,g cm-3	1.403	1.403
Z	4	4
Mu (mm-1)	1.421	1.421
F000	1360.0	1360.0
F000'	1359.86	
h,k,lmax	8,13,64	8,13,64
Nref	7717[4435]	7717
Tmin,Tmax	0.761,0.843	0.761,0.843
Tmin'	0.672	

Correction method= # Reported T Limits: Tmin=0.761 Tmax=0.843
AbsCorr = MULTI-SCAN

Data completeness= 1.74/1.00 Theta(max)= 28.271

R(reflections)= 0.0489(5197) wR2(reflections)= 0.1455(7675)

S = 0.819 Npar= 385



Structure Determination of **3p'** by X-ray analysis: CCDC Number: **2024647**

Bond precision: C-C = 0.0054 A Wavelength=0.71073

Cell: a=6.4713(9) b=9.6298(12) c=48.285(7)

alpha=90 beta=90 gamma=90

Temperature: 100 K

	Calculated	Reported
Volume	3009.0(7)	3009.0(7)
Space group	P 21 21 21	P 21 21 21
Hall group	P 2ac 2ab	P 2ac 2ab
Moiety formula	C_{32} H_{35} Br N O_7 P	C_{32} H_{35} Br N O_7 P
Sum formula	C_{32} H_{35} Br N O_7 P	C_{32} H_{35} Br N O_7 P
Mr	656.48	656.48

Dx,g cm-3	1.449	1.449
Z	4	4
Mu (mm-1)	1.469	1.469
F000	1360.0	1360.0
F000'	1359.86	
h,k,lmax	8,12,64	8,12,64
Nref	7515[4324]	7515
Tmin,Tmax	0.768,0.863	0.768,0.863
Tmin'	0.693	

Correction method= # Reported T Limits: Tmin=0.768 Tmax=0.863

AbsCorr = MULTI-SCAN

Data completeness= 1.74/1.00 Theta(max)= 28.319

R(reflections)= 0.0393(7156) wR2(reflections)= 0.1214(7515)

S = 0.969 Npar= 385

Reference:

1. a) Y. Takemoto, *Chem. Pharm. Bull.*, 2010, **58**, 593-601; b) C. Cassani, R. Martín-Rapún, E. Arceo, F. Bravo, P. Melchiorre, *Nature Protocols*, 2013, **8**, 325–344; c) J. P. Malerich, K. Hagihara and V. H. Rawal, *J. Am. Chem. Soc.*, 2008, ***130***, 14416–14417; d) Vakulya, B.; Varga, S.; Csámpai, A.; Soós, T. *Org. Lett.*, 2005, ***7***, 1967.
2. Liu, Y.; Yang, Y.; Huang, Y.; Xu, X.-H.; Qing, F.-L. *Synlett*, 2015, ***26***, 67.
3. a) Maeda, H.; Takahashi, K.; Ohmori, H. *Tetrahedron*, 1998, ***54***, 12233. b) E. Breuer, R. Karaman, A. Goldblum and H. Leader, *J. Chem. Soc., Perkin Trans. 2*, 1988, 2029-2034.c) Jang, K. P.; Hutson, G. E.; Johnston, R. C.; McCusker, E. O.; Cheong, P. H. Y.; Scheidt, K. A. *J. Am. Chem. Soc.* 2014, ***136***, 76.