Supporting Information

Ruthenium-catalyzed *meta*-selective difluoromethylation of arene phosphines enabled by 1,3-dione

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Contents

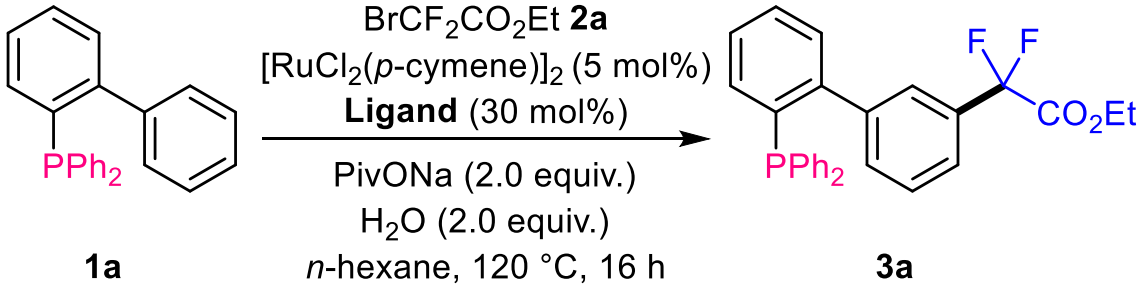
1. General Information

Unless otherwise noted, materials were purchased from Bidepharm, Adamas, Aldrich Inc. and GENERAL-REAGENT and used as received. All reactions were carried out in a flame dried, sealed tube under an atmosphere of argon. Analytical thin layer chromatography (TLC) was performed on silica gel plates with F-254 indicator and compounds were visualized by irradiation with UV light. Prepared column chromatography was performed on silica gel 60N (spherical and neutral, 0.4-0.5 mm thickness). The ^{1}H, ^{13}C, ^{31}P and ^{19}F NMR spectroscopic data were recorded on Bruker Mercury Plus 400 MHz NMR spectrometers. Chemical shifts (δ) for ^{1}H and ^{13}C are referenced to internal solvent resonances and reported relative to $SiMe_4$. Chemical shifts for ^{31}P are reported relative to an external 85% H_3PO_4 standard. ^{1}H NMR coupling constants were reported in Hz, and multiplicity was indicated as follows: s (singlet); d (doublet); t (triplet); q (quartet); m (multiplet); dd (doublet of doublets); td (triplet of doublets). High resolution mass spectra (HRMS) were recorded on the Thermo Scientific Exactive Plus equipped with ESI ionization source.

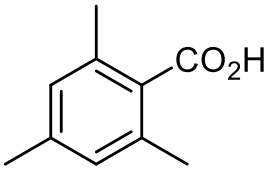
2. Experimental Procedures

2.1 Optimization of Conditions

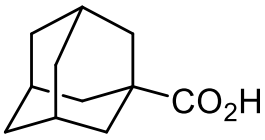
Table S1: Influence of the Ligand



1a **3a**



L1, 19%



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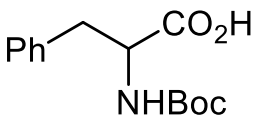
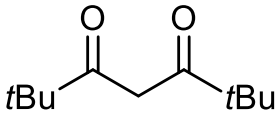
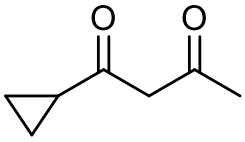


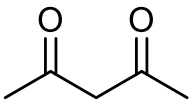
L3, 20%



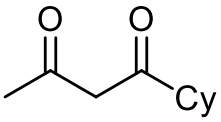
L4, 32%



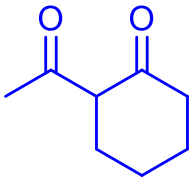
L5, 42%



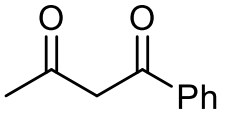
L6, 15%



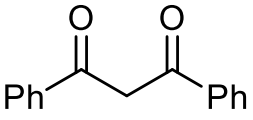
L7, < 10%



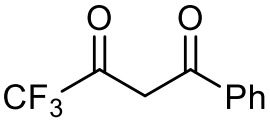
L8, 78%[b]



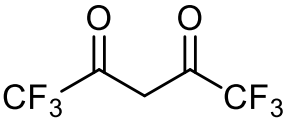
L9, 47%



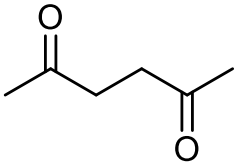
L10, 37%



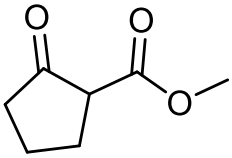
L11, trace



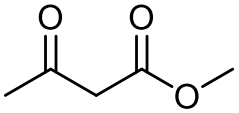
L12, trace



L13, trace

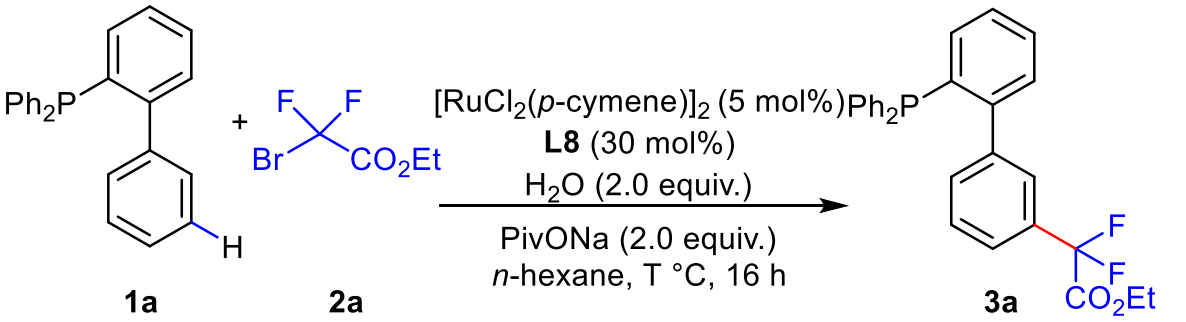


L14, 25%



L15, 15%

Table S2: Influence of the Temperature

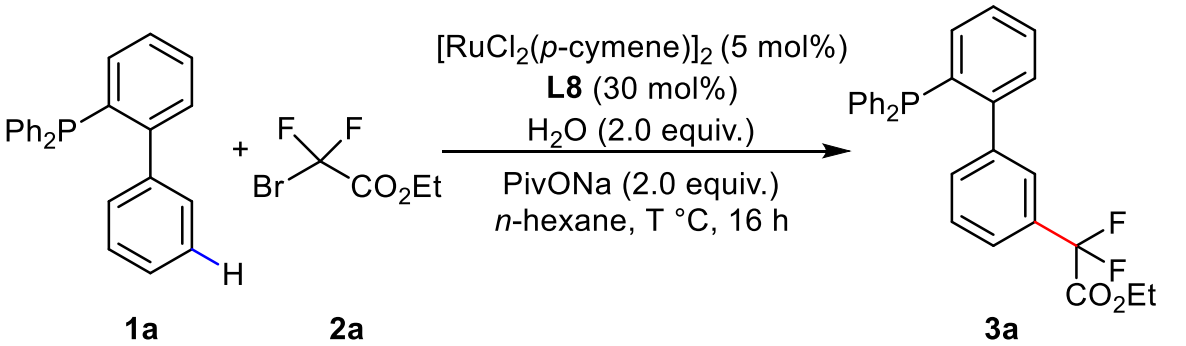


1a **2a** **3a**

Entry	T °C	Yield (%)
1.	80	13
2.	100	35
3.	120	81
4.	140	59

[a]Reaction conditions: **1a** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol %), L8 (30 mol%), PivONa (2.0 equiv) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at T °C under argon, 16 h.Yield was determined by ^1H NMR using CH_2Br_2 as internal standard.

Table S3: Influence of the H_2O



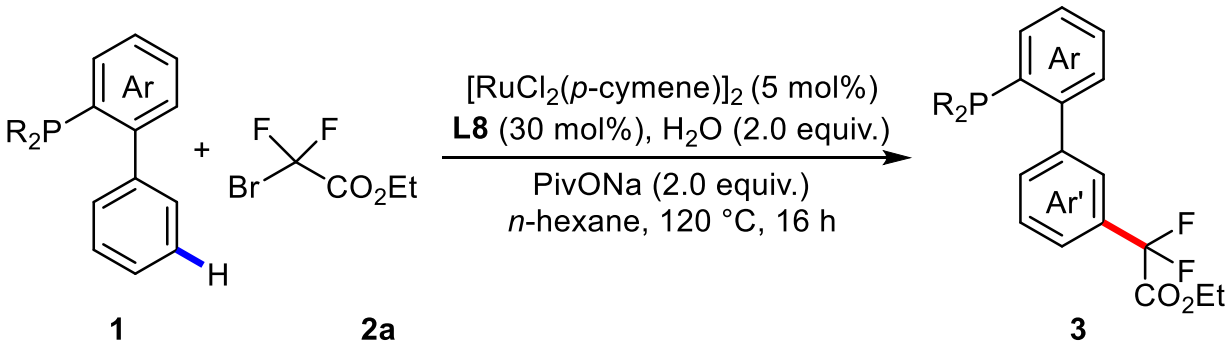
1a **2a** **3a**

Entry	H_2O (2.0 equiv.)	Yield (%)
1.	with	81
2.	without	59

[a]Reaction conditions: **1** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol %), L8 (30 mol%) and PivONa (2.0 equiv) in 1.0 mL of *n*-hexane at 120 °C under argon, 16 h.Yield was determined by ^1H NMR using CH_2Br_2 as internal standard.

2.2 General Procedures for Products

Scheme S1:



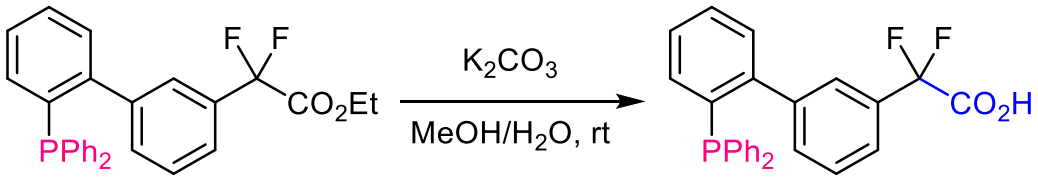
1 **2a** **3**

To a 25 mL Schlenk tube was added **1** (0.1 mmol, 1.0 equiv.), ethyl 2-bromo-2,2-difluoroacetate **2a** (0.5 mmol, 101 mg, 5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (3.1 mg, 5 mol%), **L8** (4.2 mg, 30 mol%), deionized water (3.6 mg, 2.0 equiv.) and PivONa (24.8 mg, 2.0 equiv.). The tube was purged with Ar three times, followed by the addition of *n*-hexane (1 mL). The mixture was stirred at 120 °C in the heating module for 16 h. The solution was then cooled to room temperature and the solvent was removed under vacuum directly. The crude product was purified by column chromatography on silica gel (*n*-hexane/EtOAc: 20/1) affording the *meta*-selective difluoromethylation-substituted products **3**.

2.3 Synthetic Applications

a) post-synthetic modification

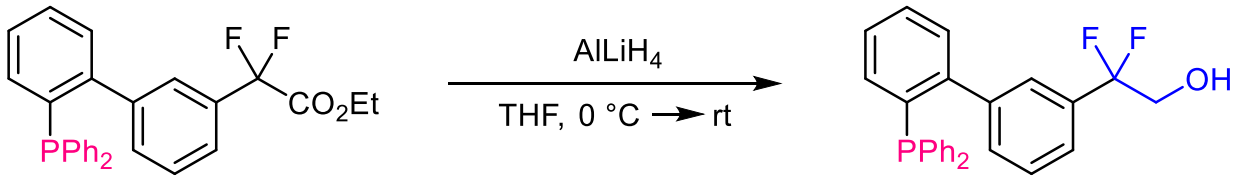
Scheme S2:



3a **4**

To a 50 mL Schlenk tube was added **3a** (230 mg, 0.5 mmol), K_2CO_3 (3.0 mL, 1N). The tube was purged with Ar three times, followed by the addition of MeOH (3 mL). The mixture was stirred at 23 ℃ for 2 h and poured into 5% HCl (3.0 mL), and successively extracted with EtOAc (10 mL * 3). The combined organic phase was washed with brine and dried over anhydrous Na_2SO_4. The crude product was purified by column chromatography on silica gel (DCM/MeOH: 4/1) affording the pure product **4** (white solid, 210 mg, 97%).

Scheme S3:

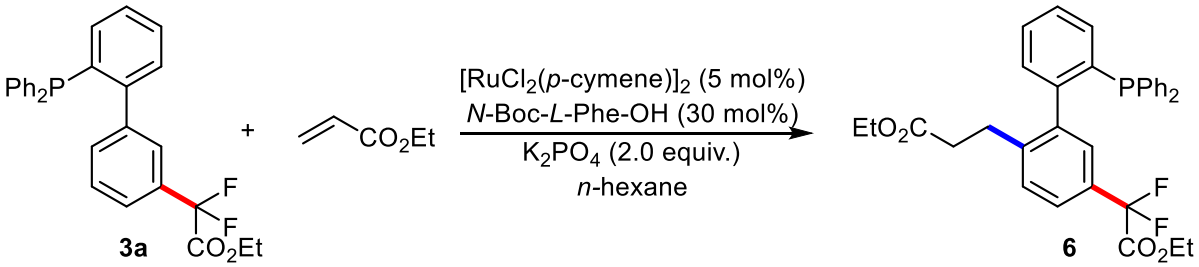


3a **5**

To a 50 mL Round-bottomed flask was added **3a** (92.2 mg, 0.2 mmol), $AlLiH_4$ and dry 1,4-dioxane (15 mL) at 0 ℃. Then the mixture was stirred at room temperature for 1 h. Wash with water after reaction, extracted with EtOAc (10 mL * 3). The combined organic phase was washed with brine and dried over anhydrous Na_2SO_4.The crude product was purified by column chromatography on silica gel (*n*-hexane/EtOAc: 3/1) affording the pure product **5** (colorless oil, 93%)

b) Sythesis of multifunctional biaryphosphine

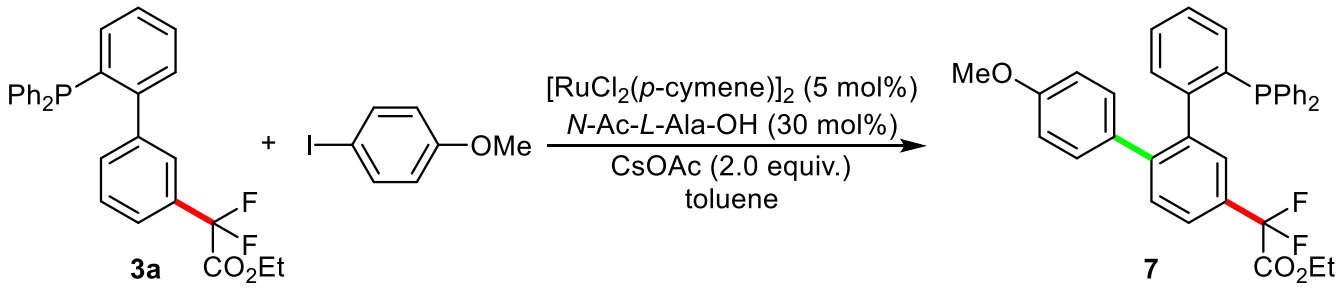
Scheme S4:



3a **6**

To a 25 mL Schlenk tube was added **3a** (0.2 mmol, 1.0 equiv.), ethyl acrylate (60.0 mg, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (6.2 mg, 5 mol%), *N*-Boc-*L*-Phe-OH (15.9 mg, 30 mol%), K_2HPO_4 (69.6 mg, 2.0 equiv). The tube was purged with Ar three times, followed by the addition of *n*-hexane (2 mL). The mixture was stirred at 120 °C in the heating module for 12 h. The solution was then cooled to room temperature and the solvent was removed under vacuum directly. The crude product was purified by column chromatography on silica gel (*n*-hexane/EtOAc: 15/1) affording the pure product **6** (colorless oil, 86.3 mg, 77%).[1]

Scheme S5:



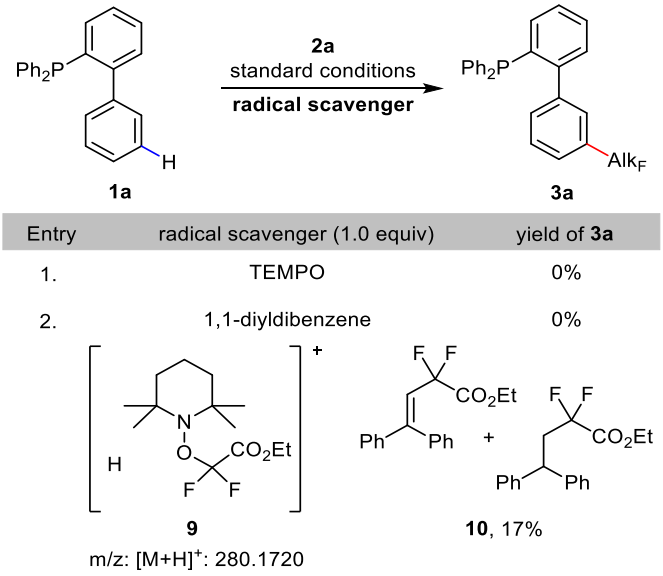
3a **7**

To a 25 mL Schlenk tube was added **3a** (0.2 mmol, 1.0 equiv.), 1-iodo-4-methoxybenzene (70.2 mg, 1.5 equiv), $[RuCl_2(p\text{-cymene})]_2$ (6.2 mg, 5 mol%), *N*-Ac-*L*-Ala-OH (7.9mg, 30 mol%), CsOAc (76.8mg, 0.4 mmol, 2.0 equiv). The tube was purged with Ar three times, followed by the addition of toluene (2 mL). The mixture was stirred at 120 °C in the heating module for 12 h. The solution was then cooled to room temperature and the solvent was removed under vacuum directly. The crude product was purified by column chromatography on silica gel (*n*-hexane/EtOAc: 15/1) affording the pure product **7** (colorless oil, 81.6 mg, 72%).[2]

2.4 Mechanism studies

a) Radical trapping experiment

Scheme S6:



Entry	radical scavenger (1.0 equiv)	yield of **3a**
1.	TEMPO	0%
2.	1,1-diyldibenzene	0%

9

m/z: $[M+H]^+$: 280.1720

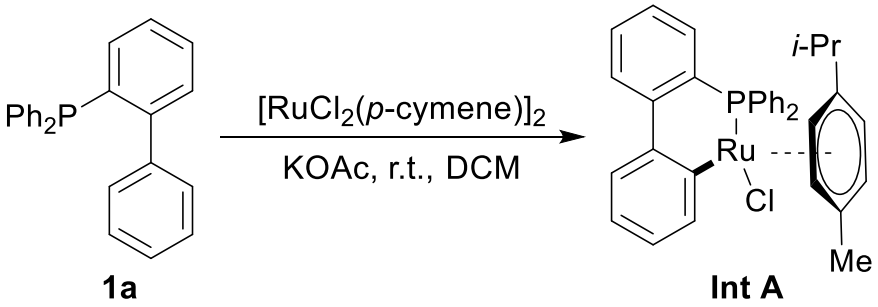
10, 17%

To a 25 mL Schlenk tube was added **1a** (0.1 mmol, 1.0 equiv.), ethyl 2-bromo-2,2-difluoroacetate **2a** (0.5 mmol, 101 mg, 5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (3.1 mg, 5 mol%), L4 (4.2 mg, 30 mol%), deionized water (3.6 mg, 2.0 equiv.), radical scavenger (1.0 equiv.) and PivONa (24.8 mg, 2.0 equiv.). The tube was purged with Ar three times, followed by the addition of *n*-hexane (1 mL). The mixture was stirred at 120 °C in the heating module for 16 h. The solution was then cooled to room temperature and the solvent was removed under vacuum directly. Purified by column chromatography on silica gel (*n*-hexane/EtOAc: 50/1) affording the **1a** (31.4 mg, 93%) and mixture **10**(5.1 mg, 17%). ^1H NMR (400 MHz, $CDCl_3$) δ 7.38-

7.33 (m, 5H), 7.32-7.28 (m, 8H), 7.24-7.17 (m, 8H), 6.27 (t, J = 11.6 Hz, 1H), 4.27 (t, J = 7.2 Hz, 1H), 3.91 (q, J = 7.2 Hz, 2H), 3.83 (t, J = 7.2 Hz, 2H), 2.93 (dd, J = 15.6 Hz, 7.6 Hz, 2H), 1.17 (t, J = 7.2 Hz, 3H), 1.16 (t, J = 7.2 Hz, 3H). ^{19}F NMR (377 MHz, $CDCl_3$) δ -91.0, -103.5. The analytical data are in accordance with those previously published in the literature.[4]

b) Synthesis of **Int A**

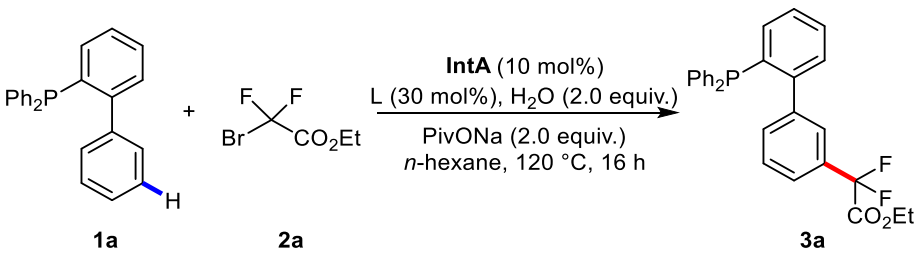
Scheme S7:



To a 50 mL Schlenk flask was added 2-diphenylphosphinobiphenyl **1a** (2 mmol, 676 mg, 1.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (1 mmol, 612 mg, 0.5 equiv.), KOAc (5 mmol, 490 mg, 2.5 equiv.). The tube was purged with Ar three times, followed by the addition of 30 mL DCM. The mixture was stirred at r.t. for 24 h. The solvent was then removed under vacuum directly. The crude product was purified by neutral alumina (Al_2O_3) column chromatography (R_f = 0.5, EA/hexane = 1/2) affording the product **Int A** as red powder (1.07g, 88% yield).[1]

c) **Int A** as the catalyst

Scheme S8:

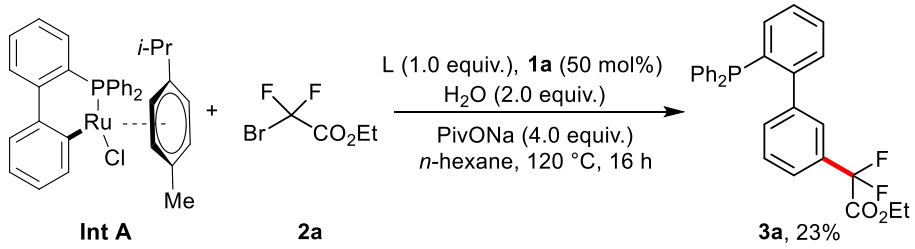


To a 25 mL Schlenk tubes were added 2-diphenylphosphinobiphenyl **1a** (0.1 mmol, 33.8 mg, 1.0 equiv.),

ethyl 2-bromo-2,2-difluoroacetate **2a** (0.5 mmol, 101 mg, 5.0 equiv.), **Int A** (6.2 mg, 10 mol%), L4 (4.2 mg, 30 mol%), deionized water (3.6 mg, 2.0 equiv.) and PivONa (24.8 mg, 2.0 equiv.). The tube was purged with Ar three times, followed by the addition of *n*-hexane (1 mL). The mixture was stirred at 120 °C in the heating module for 16 h. The solution was then cooled to room temperature and the solvent was removed under vacuum directly. The yield of *meta*-selective difluoromethylation-substituted product **3a** was 54% by ^{1}H NMR yield analyzed with CH_2Br_2 as an internal standard.

d) **Int A** as the substrate

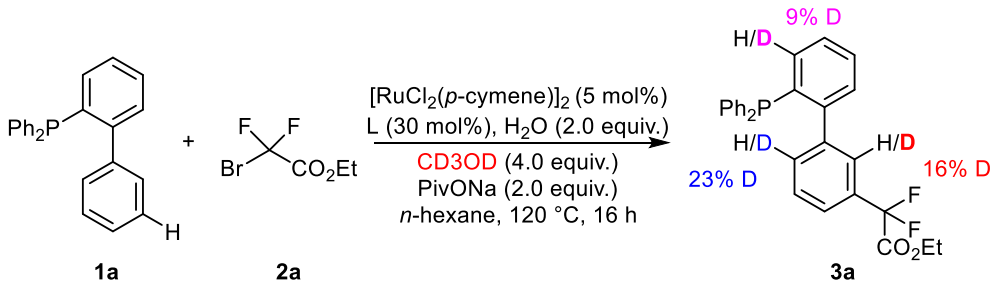
Scheme S9:



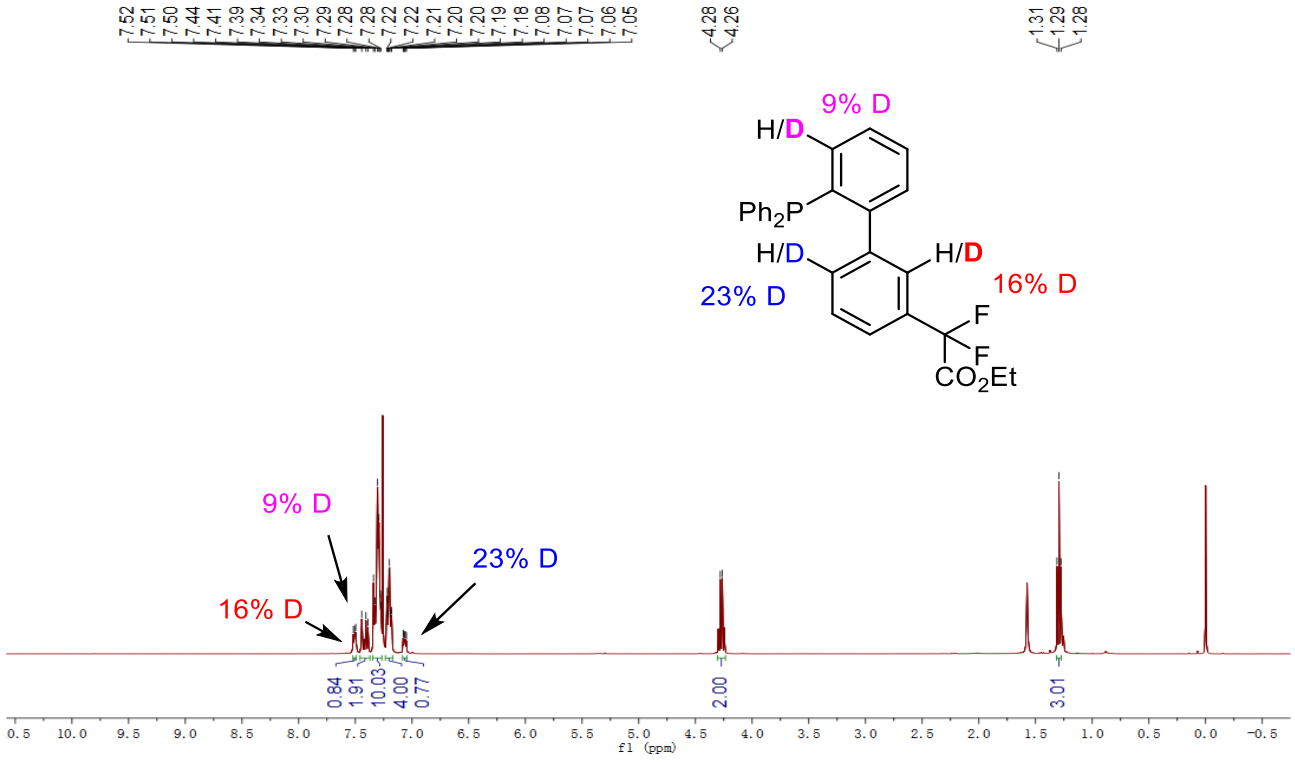
To a 25 mL Schlenk tube was added **Int A** (0.05 mmol, 30.4 mg, 1.0 equiv.), ethyl 2-bromo-2,2-difluoroacetate **2a** (0.5 mmol, 50.5 mg, 5.0 equiv.), 2-diphenyl- phosphinobiphenyl **1a** (0.025 mmol, 8.5 mg, 50 mol%), L4 (7.0 mg, 1.0 equiv.), deionized water (1.8 mg, 2.0 equiv.) and PivONa (24.8 mg, 4.0 equiv.). The tube was purged with Ar three times, followed by the addition of *n*-hexane (1 mL). The mixture was stirred at 120 °C in the heating module for 16 h. The solution was then cooled to room temperature and the solvent was removed under vacuum directly. The yield of *meta*-selective difluoromethylation-substituted product **3a** was 27% by ^{1}H NMR yield analyzed with CH_2Br_2 as an internal standard.

e) H/D exchange

Scheme S10:

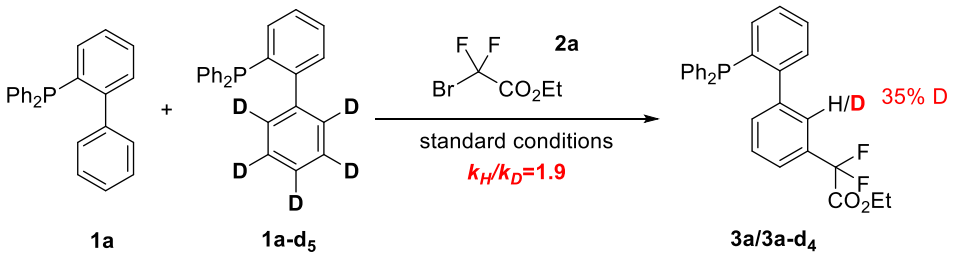


To a 25 mL Schlenk tube was added 1-phenylpropyne **1a** (0.3 mmol, 34.8 mg, 1.5 equiv.), ethyl 2-bromo-2,2-difluoroacetate **2a** (0.5 mmol, 101 mg, 5.0 equiv.), [RuCl2(p-cymene)]2 (3.1 mg, 5 mol%), L4 (4.2 mg, 30 mol%), deionized water (3.6 mg, 2.0 equiv.), CD_3OD (14.4 mg, 10.0 equiv.) and PivONa (24.8 mg, 2.0 equiv.). The tube was purged with Ar three times, followed by the addition of *n*-hexane (1 mL). The mixture was stirred at 120 °C in the heating module for 12 h. The solvent was removed in vacuo and the residue was purified by prepared column chromatography on silica gel (*n*-hexane/EtOAc: 20/1) to afford the mixture products **D-3a** in 78% yield, which was analyzed by ^1H NMR spectroscopy, the isolation of 23% and 16% deuterium at both *ortho*-positions and 9% of the H on the C3- of the biarylphosphine was lost.

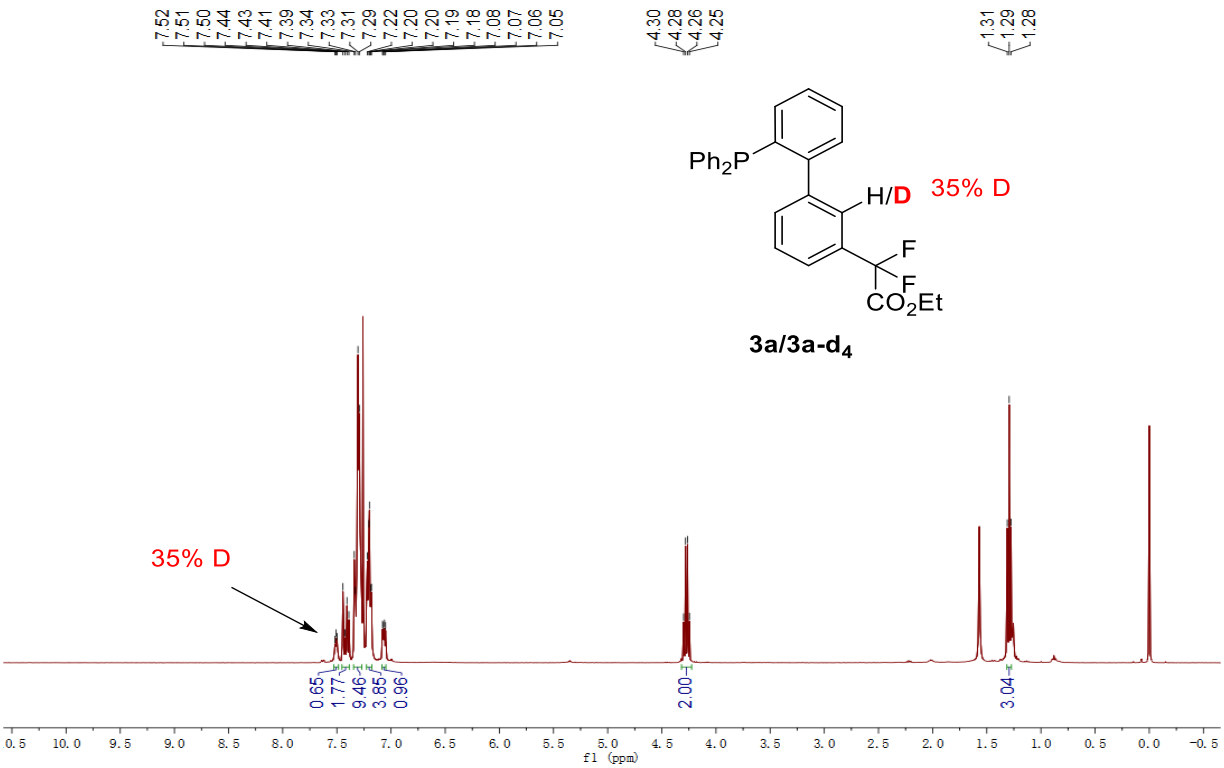


f) Parrallel kinetic isotope effect

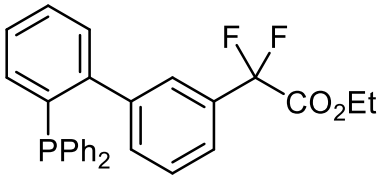
Scheme S11:



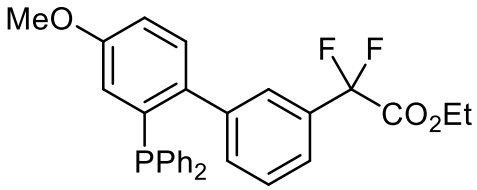
To a 25 mL Schlenk tube was added **1a** (0.1 mmol, 33.8 mg, 0.5 equiv.), **1a-d**$_5$ (0.1 mmol, 34.3 mg, 0.5 equiv.), **2a** (1 mmol, 5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (6.2 mg, 5 mol%), L4 (8.4 mg, 30 mol%), deionized water (7.2 mg, 2.0 equiv.) and PivONa (49.6 mg, 2.0 equiv.). The tube was purged with Ar three times, followed by the addition of *n*-hexane (2 mL).. The mixture was stirred at 120 °C in the heating module for 6 h. The solution was then cooled to room temperature and the solvent was removed under vacuum directly. The solvent was removed in vacuo and the residue was purified by prepared column chromatography on silica gel (*n*-hexane/EtOAc: 20/1) to afford the mixture products **3a**:**3a-d**$_4$, which was analyzed by ^{1}H NMR spectroscopy, based on the integrations related to different hydrogen resonances, the kinetic isotope effect (KIE) was calculated to be k_H/k_D = 1.9.



3. Characterization Data

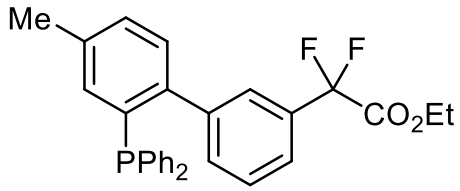


ethyl 2-(2'-(diphenylphosphanyl)-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3a): The general procedure was applied to **1a** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L8 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (35.8 mg, 78%% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52-7.50 (m, 1H), 7.46 (s, 1H), 7.41-7.37 (m, 1H), 7.35-7.32 (m, 2H), 7.30-7.26 (m, 7H), 7.22-7.18 (m, 4H), 7.07 (dd, *J* = 3.6 Hz, 7.2 Hz, 1H), 4.26 (q, *J* = 7.2 Hz, 2H), 1.28 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.2 (t, *J* = 35.4 Hz), 146.8 (d, *J* = 27.3 Hz), 142.2 (d, *J* = 6.1 Hz), 137.1 (d, *J* = 11.1 Hz), 136.3 (d, *J* = 16.2 Hz), 134.1, 134.1, 133.9, 132.4 (d, *J* = 4.0 Hz), 132.3 (t, *J* = 25.3 Hz), 130.2 (d, *J* = 5.1 Hz), 128.9, 128.8, 128.6, 128.5, 128.0 (d, *J* = 5.1 Hz), 126.9 (d, *J* = 4.0 Hz), 126.9 (d, *J* = 16.2 Hz), 124.3 (t, *J* = 6.1 Hz), 113.4 (t, *J* = 253.5 Hz), 63.2, 14.0. ^{31}P NMR (162 MHz, $CDCl_3$) δ -13.0. ^{19}F NMR (377 MHz, $CDCl_3$) δ -103.5. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{28}H_{24}F_2O_2P$ 461.1476; found 461.1472.

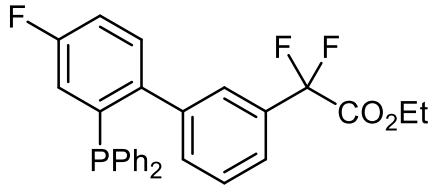


ethyl 2-(2'-(diphenylphosphanyl)-4'-methoxy-[1,1'-biphenyl]-3-yl)-2,2-difluor-oacetate (3b): The general procedure was applied to **1b** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (35.3 mg, 72% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47(d, *J* = 6.8 Hz, 1H), 7.43 (s, 1H), 7.31-7.28 (m, 8H), 7.24-7.23 (m, 2H), 7.22-7.19 (m, 3H), 6.92 (dd, *J* = 2.8 Hz, 8.4 Hz, 1H), 6.59 (t, *J* = 3.2 Hz, 1H), 4.26 (q, *J* = 7.2 Hz, 2H), 3.65 (s, 3H), 1.28 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.3 (t, *J* = 35.4 Hz), 159.0, 142.0 (d, *J* = 6.1 Hz), 139.3 (d, *J* = 26.3 Hz), 137.9 (d, *J* = 17.2 Hz), 136.9 (d, *J* = 11.1 Hz), 134.2, 134.0, 132.7 (d, *J* = 5.1 Hz), 132.2 (t, *J* = 25.3 Hz), 131.4 (d, *J* = 5.1 Hz), 128.9, 128.6, 128.5, 128.0, 127.1 (d, *J* = 4.0 Hz), 127.1 (d, *J* = 15.2 Hz), 124.0 (t, *J* = 6.1 Hz), 119.7, 114.0,

113.4 (t, J = 252.5 Hz), 63.2, 55.2, 14.1. ^{31}P NMR (162 MHz, $CDCl_3$) δ -11.7. ^{19}F NMR (377 MHz, $CDCl_3$) δ -103.5. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{29}H_{26}F_2O_3P$ 491.1582; found 491.1578.

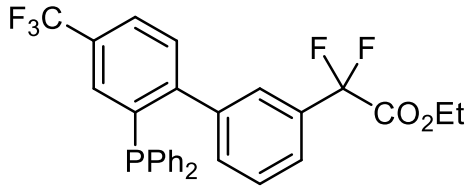


ethyl 2-(2'-(diphenylphosphanyl)-4'-methyl-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3c): The general procedure was applied to **1c** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (34.2 mg, 72% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49-7.47 (m, 1H), 7.43 (s, 1H), 7.32-7.26 (m, 8H), 7.22-7.17 (m, 6H), 6.86 (d, J = 3.6 Hz, 1H), 4.26 (q, J = 7.2 Hz, 2H), 2.26 (s, 3H), 1.28 (t, J = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.3 (t, J = 35.4 Hz), 144.1 (d, J = 28.3 Hz), 142.3 (d, J = 6.1 Hz), 137.6, 137.2 (d, J = 12.1 Hz), 135.9 (d, J = 15.2 Hz), 134.5, 134.2, 134.0, 132.6 (d, J = 4.0 Hz), 132.2 (t, J = 25.3 Hz), 130.2 (d, J = 4.0 Hz), 129.8, 128.7, 128.6, 128.5, 127.9, 127.0 (d, J = 4.0 Hz), 127.0 (d, J = 15.2 Hz), 124.2 (t, J = 6.1 Hz), 113.4 (t, J = 253.5 Hz), 63.2, 21.4, 14.1. ^{31}P NMR (162 MHz, $CDCl_3$) δ -12.8. ^{19}F NMR (377 MHz, $CDCl_3$) δ -103.6. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{29}H_{26}F_2O_2P$ 475.1633; found 475.1630.

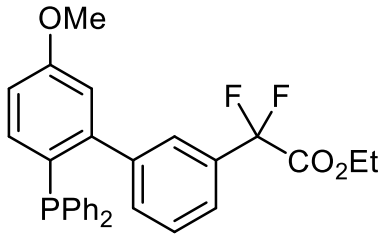


ethyl 2-(2'-(diphenylphosphanyl)-4'-fluoro-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3d): The general procedure was applied to **1d** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (25.8 mg, 54% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 (d, J = 7.2 Hz, 1H), 7.40 (s, 1H), 7.33-7.27 (m, 8H), 7.25-7.16 (m, 5H), 7.08 (td, J = 8.4 Hz, 2.8 Hz, 1H), 6.73 (dt, J = 9.2 Hz, 2.8 Hz, 1H), 4.28 (q, J = 7.2 Hz, 2H), 1.30 (t, J = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.2 (t, J = 35.4 Hz), 162.4 (d, J = 250.5 Hz), 142.7 (dd, J = 3.0 Hz, 26.3 Hz), 141.3 (d, J = 5.1 Hz), 139.9 (d, J = 5.1 Hz, 19.2 Hz), 134.1 (d, J = 20.2 Hz), 132.6 (d, J = 4.0 Hz), 132.4 (t, J = 25.3 Hz), 131.9 (d, J = 5.1 Hz, 8.1

Hz), 129.1, 128.8, 128.7, 128.1, 127.0 (d, J = 4.0 Hz), 124.5 (t, J = 6.1 Hz), 120.3 (d, J = 22.2 Hz), 115.9 (d, J = 21.2 Hz), 113.3 (t, J = 253.5 Hz), 63.2, 14.1. ^{31}P NMR (162 MHz, $CDCl_3$) δ -12.0. ^{19}F NMR (377 MHz, $CDCl_3$) δ -103.6, -113.9. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{28}H_{23}F_3O_2P$ 479.1382; found 479.1379.

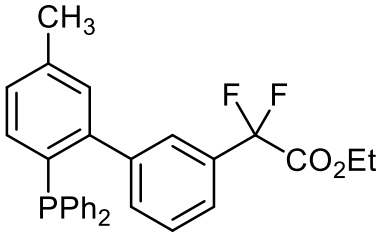


ethyl 2-(2'-(diphenylphosphanyl)-4'-(trifluoromethyl)-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3e): The general procedure was applied to **1e** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (24.8 mg, 47% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66-7.64 (m, 2H), 7.45-7.41 (m, 2H), 7.35-7.29 (m, 8H), 7.24-7.19 (m, 4H), 7.11 (dd, J = 4.0 Hz, 7.6 Hz, 7H), 4.30 (q, J = 8.0 Hz, 2H), 1.29 (t, J = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 163.2 (t, J = 34.3 Hz), 145.7 (d, J = 5.1 Hz), 145.1 (d, J = 27.3 Hz), 136.6 (d, J = 12.2 Hz), 136.5, 134.2, 134.2 (d, J = 20.2 Hz), 132.2 (d, J = 4.0 Hz), 130.1 (d, J = 4.0 Hz), 129.7 (d, J = 4.0 Hz), 129.6 (d, J = 4.0 Hz), 129.5 (d, J = 4.0 Hz), 129.1, 129.0, 128.7, 128.6, 128.6, 127.1 (q, J = 5.1 Hz), 126.4 (d, J = 33.3 Hz), 123.6 (q, J = 273.7 Hz), 112.8 (t, J = 243.4 Hz), 63.4, 13.9. ^{31}P NMR (162 MHz, $CDCl_3$) δ -12.8. ^{19}F NMR (377 MHz, $CDCl_3$) δ -58.2, -98.7. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{29}H_{23}F_5O_2P$ 529.1350; found 529.1348.

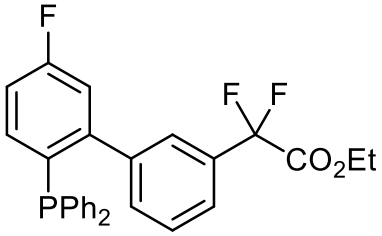


ethyl 2-(2'-(diphenylphosphanyl)-5'-methoxy-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3f): The general procedure was applied to **1f** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (20.6 mg, 42% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55-7.52 (m, 1H), 7.47 (s, 1H), 7.38-7.35 (m, 2H), 7.30-7.29 (m, 6H), 7.22-7.18 (m, 4H), 7.03 (dd, J = 2.0 Hz, 8.0 Hz, 1H), 6.87-6.84 (m,

2H), 4.26 (q, J = 7.2 Hz, 2H), 3.83 (s, 3H), 1.28 (t, J = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.2 (t, J = 35.4 Hz), 160.3, 148.7 (d, J = 30.3 Hz), 142.3 (d, J = 6.1 Hz), 137.9 (d, J = 11.1 Hz), 136.1, 133.8 (d, J = 20.2 Hz), 132.4 (d, J = 5.1 Hz), 132.3 (t, J = 26.3 Hz), 128.6, 128.5, 128.0, 126.8 (d, J = 12.1 Hz), 124.5 (t, J = 6.1 Hz), 115.7 (d, J = 4.0 Hz), 113.9, 113.4 (t, J = 252.5 Hz), 63.2, 55.5, 14.1. ^{31}P NMR (162 MHz, $CDCl_3$) δ -15.3. ^{19}F NMR (377 MHz, $CDCl_3$) δ -103.6. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{29}H_{26}F_2O_3P$ 491.1582; found 491.1579.

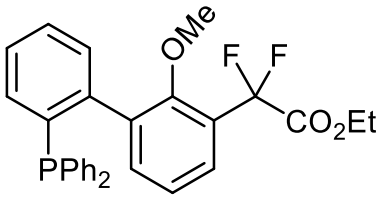


ethyl 2-(2'-(diphenylphosphanyl)-5'-methyl-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3g): The general procedure was applied to **1g** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (26.6 mg, 56% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52-7.50 (m, 1H), 7.45 (s, 1H), 7.34-7.32 (m, 2H), 7.29-7.26 (m, 6H), 7.23-7.18 (m, 4H), 7.14-7.10 (m, 2H), 6.98 (dd, J = 3.6 Hz, 7.6 Hz, 1H), 4.26 (q, J = 7.2 Hz, 2H), 2.38 (s, 3H), 1.28 (t, J = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.3 (t, J = 35.4 Hz), 147.0 (d, J = 28.3 Hz), 142.4 (d, J = 6.1 Hz), 139.1, 137.6, 137.5, 134.4, 134.0, 133.8, 132.6 (d, J = 13.1 Hz), 132.5 (d, J = 5.1 Hz), 132.3 (t, J = 25.3 Hz), 131.1 (d, J = 5.1 Hz), 128.9, 128.6, 128.6, 128.5, 128.0, 126.9 (d, J = 4.0 Hz), 126.9 (d, J = 16.2 Hz), 124.3 (t, J = 6.1 Hz), 113.4 (t, J = 253.5 Hz), 63.2, 21.3, 14.1. ^{31}P NMR (162 MHz, $CDCl_3$) δ -14.1. ^{19}F NMR (377 MHz, $CDCl_3$) δ -103.6. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{29}H_{26}F_2O_2P$ 475.1633; found 475.1630.

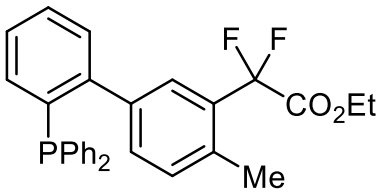


ethyl 2-(2'-(diphenylphosphanyl)-5'-fluoro-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3h): The general procedure was applied to **1h** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound

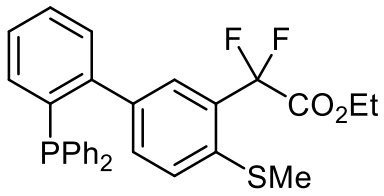
as colorless oil (24.9 mg, 52% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54 (d, *J* = 7.6 Hz, 1H), 7.44 (s, 1H), 7.37-7.33 (m, 2H), 7.32-7.28 (m, 6H), 7.21-7.17 (m, 4H), 7.06-6.98 (m, 3H), 4.27 (q, *J* = 7.2 Hz, 2H), 1.29 (t, *J* = 6.8 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.2 (t, *J* = 35.4 Hz), 163.1 (d, *J* = 251.5 Hz), 149.2 (dd, *J* = 8.1 Hz, 30.3), 141.2 (d, *J* = 6.1 Hz), 137.1 (d, *J* = 11.1 Hz), 136.3 (d, *J* = 8.1 Hz), 134.0, 133.8, 132.5 (t, *J* = 26.3 Hz), 132.3, 132.0 (d, *J* = 3.0 Hz), 131.9 (d, *J* = 3.0 Hz), 128.9, 128.7, 128.6, 128.2, 126.8 (d, *J* = 4.0 Hz), 126.8 (d, *J* = 16.2 Hz), 124.9 (d, *J* = 6.1 Hz), 117.4 (dd, *J* = 5.1 Hz, 21.2 Hz), 115.1 (d, *J* = 20.2 Hz), 113.3 (t, *J* = 253.5 Hz), 63.2, 14.1. ^{31}P NMR (162 MHz, $CDCl_3$) δ -14.6. ^{19}F NMR (377 MHz, $CDCl_3$) δ -103.7, -112.6. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{28}H_{23}F_3O_2P$ 479.1382; found 479.1380.



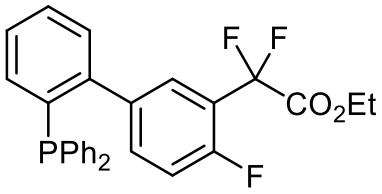
ethyl 2-(2'-(diphenylphosphanyl)-2-methoxy-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3i): The general procedure was applied to **1i** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (17.2 mg, 35% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.64 (dd, *J* = 2.8 Hz, 6.4 Hz, 1H), 7.41-7.38 (m, 1H), 7.34-7.32 (m, 1H), 7.32-7.28 (m, 7H), 7.23-7.17 (m, 5H), 7.04-7.01 (m, 2H), 4.35-4.21 (m, 2H), 3.26 (s, 3H), 1.28 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.0 (t, *J* = 34.3 Hz), 155.0 (t, *J* = 5.1 Hz), 143.6 (d, *J* = 33.3 Hz), 137.9 (d, *J* = 13.1 Hz), 137.6 (d, *J* = 12.1 Hz), 137.1 (d, *J* = 14.1 Hz), 135.4 (d, *J* = 4.0 Hz), 135.2 (d, *J* = 7.1 Hz), 134.9 (d, *J* = 2.0 Hz), 133.7 (t, *J* = 21.2 Hz), 130.7 (d, *J* = 6.1 Hz), 129.1, 128.6, 128.6, 128.5, 128.5 (d, *J* = 6.1 Hz), 128.2, 127.4 (t, *J* = 24.2 Hz), 125.8 (t, *J* = 7.1 Hz), 123.1, 112.5 (d, *J* = 248.5 Hz), 62.9, 60.8, 14.1. ^{31}P NMR (162 MHz, $CDCl_3$) δ -13.9. ^{19}F NMR (377 MHz, $CDCl_3$) δ -101.1 (d, *J* = 1055.6 Hz), -101.1 (d, *J* = 527.8 Hz), . **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{29}H_{26}F_2O_3P$ 491.1582; found 491.1578.



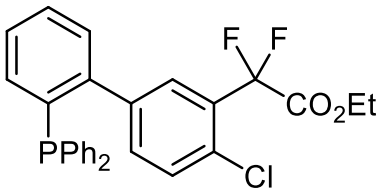
ethyl 2-(2'-(diphenylphosphanyl)-4-methyl-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3j): The general procedure was applied to **1j** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (28.4 mg, 60% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40-7.37 (m, 2H), 7.32-7.27 (m, 8H), 7.25-7.23 (m, 2H), 7.22-7.20 (m, 3H), 7.12 (d, *J* = 7.6 Hz, 1H), 7.09 (dd, *J* = 3.6 Hz, 7.2 Hz, 1H), 4.28 (q, *J* = 7.2 Hz, 2H), 2.40 (s, 3H), 1.28 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.2 (t, *J* = 35.4 Hz), 147.1 (d, *J* = 28.3 Hz), 139.6 (d, *J* = 6.1 Hz), 137.5 (d, *J* = 11.1 Hz), 136.2 (d, *J* = 15.2 Hz), 135.4 (t, *J* = 3.0 Hz), 134.3, 134.1, 133.9, 132.1 (d, *J* = 4.0 Hz), 131.3, 130.5 (t, *J* = 23.2 Hz), 130.3 (d, *J* = 5.1 Hz), 128.9, 128.7, 128.6, 128.5, 127.8, 127.7 (d, *J* = 4.0 Hz), 127.6 (d, *J* = 4.0 Hz), 114.2 (t, *J* = 253.5 Hz), 63.1, 19.6 (t, *J* = 2.0 Hz), 14.1. ^{31}P NMR (162 MHz, $CDCl_3$) δ -13.4. ^{19}F NMR (377 MHz, $CDCl_3$) δ -101.3. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{29}H_{26}F_2O_2P$ 475.1633; found 475.1629.



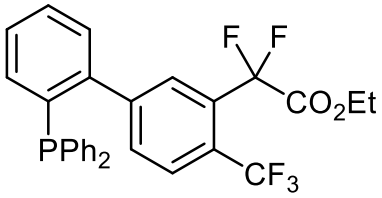
ethyl 2-(2'-(diphenylphosphanyl)-4-(methylthio)-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3k): The general procedure was applied to **1k** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (38.0 mg, 75% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 (s, 1H), 7.42-7.32 (m, 4H), 7.30-7.29 (m, 7H), 7.25-7.21 (m, 4H), 7.09 (dd, *J* = 3.6 Hz, 7.6 Hz, 1H), 4.33 (q, *J* = 7.2 Hz, 2H), 2.41 (s, 3H), 1.32 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 163.9 (t, *J* = 34.3 Hz), 146.4 (d, *J* = 27.3 Hz), 130.9 (d, *J* = 6.1 Hz), 137.1 (d, *J* = 11.1 Hz), 136.4 (d, *J* = 15.2 Hz), 135.5 (t, *J* = 4.0 Hz), 134.2, 134.1, 134.0, 132.4 (t, *J* = 23.2 Hz), 130.2 (d, *J* = 4.0 Hz), 130.1, 128.9, 128.8, 128.6, 128.5, 127.9, 127.9 (d, *J* = 4.0 Hz), 127.8 (d, *J* = 4.0 Hz), 112.9 (t, *J* = 250.5 Hz), 63.1, 18.5, 14.0. ^{31}P NMR (162 MHz, $CDCl_3$) δ -12.9. ^{19}F NMR (377 MHz, $CDCl_3$) δ -99.3. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{29}H_{26}F_2O_2PS$ 507.1354; found 507.1352.



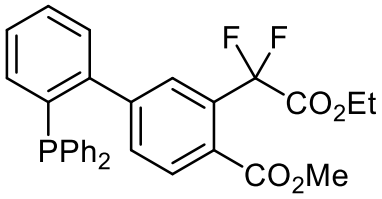
ethyl 2-(2'-(diphenylphosphanyl)-4-fluoro-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3l): The general procedure was applied to **1l** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (34.4 mg, 72% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41-7.37 (m, 2H), 7.34-7.27 (m, 9H), 7.24-7.19 (m, 4H), 7.07-6.98 (m, 2H), 4.34 (q, *J* = 7.2 Hz, 2H), 1.32 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 163.3 (t, *J* = 34.3 Hz), 159.1 (d, *J* = 253.5 Hz), 145.8 (d, *J* = 27.3 Hz), 138.1 (dd, *J* = 3.0 Hz, 5.1 Hz), 136.9 (dd, *J* = 5.1 Hz, 11.1 Hz), 134.3, 134.1, 133.9, 130.2 (d, *J* = 5.1 Hz), 128.9, 128.7, 128.6, 128.1, 120.3 (d, *J* = 12.1 Hz), 120.1 (d, *J* = 13.1 Hz), 119.8 (d, *J* = 13.1 Hz), 115.6 (d, *J* = 21.2 Hz), 115.6 (t, *J* = 251.5 Hz), 63.4, 14.0. ^{31}P NMR (162 MHz, $CDCl_3$) δ -12.6. ^{19}F NMR (377 MHz, $CDCl_3$) δ -101.9, -116.9. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{28}H_{23}F_3O_2P$ 479.1382; found 479.1378.



ethyl 2-(4-chloro-2'-(diphenylphosphanyl)-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3m): The general procedure was applied to **1m** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (35.6 mg, 72% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48 (s, 1H), 7.42-7.38 (m, 1H), 7.34-7.28 (m, 10H), 7.24-7.20 (m, 4H), 7.09-7.06 (m, 1H), 4.34 (q, *J* = 7.2 Hz, 2H), 1.32 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 163.2 (t, *J* = 34.3 Hz), 145.7 (d, *J* = 27.3 Hz), 140.7 (d, *J* = 6.1 Hz), 136.8 (d, *J* = 12.1 Hz), 136.6 (d, *J* = 15.2 Hz), 134.3, 134.1, 133.2 (d, *J* = 4.0 Hz), 130.9 (t, *J* = 4.0 Hz), 130.4 (t, *J* = 24.2 Hz), 130.1 (d, *J* = 4.0 Hz), 129.9, 129.0, 128.9, 128.7, 128.6, 128.2, 112.1 (t, *J* = 251.2 Hz), 63.4, 14.0. ^{31}P NMR (162 MHz, $CDCl_3$) δ -13.0. ^{19}F NMR (377 MHz, $CDCl_3$) δ -102.3. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{28}H_{23}ClF_2O_2P$ 495.1087; found 495.1086.

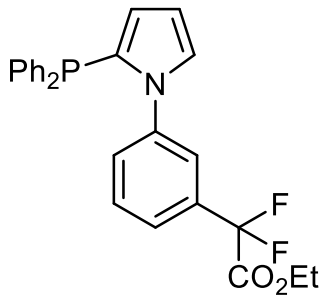


ethyl 2-(2'-(diphenylphosphanyl)-4-(trifluoromethyl)-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3n): The general procedure was applied to **1n** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (28.5 mg, 54% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.65-7.63 (m, 1H), 7.53 (d, *J* = 7.6 Hz, 1H), 7.42 (s, 1H), 7.40 (dd, *J* = 4.0 Hz, 8.0 Hz, 2H), 7.36-7.29 (m, 9H), 7.18 (td, *J* = 7.6 Hz, 1.2 Hz, 4H), 4.28 (q, *J* = 7.2 Hz, 2H), 1.30 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.1 (t, *J* = 35.4 Hz), 149.9 (d, *J* = 26.3 Hz), 141.0 (d, *J* = 5.1 Hz), 138.7 (d, *J* = 19.2 Hz), 135.8 (d, *J* = 11.1 Hz), 134.2, 134.0, 132.6 (d, *J* = 25.3 Hz), 132.1 (d, *J* = 3.0 Hz), 130.6 (d, *J* = 4.0 Hz), 130.3 (d, *J* = 4.0 Hz), 130.2, 130.1 (d, *J* = 22.2 Hz), 129.3, 128.8, 128.8, 128.3, 126.7 (q, *J* = 4.0 Hz), 125.6 (q, *J* = 3.0 Hz), 125.0 (t, *J* = 6.1 Hz), 124.1 (q, *J* = 273.7 Hz), 113.2 (t, *J* = 253.5 Hz), 63.3, 14.1. ^{31}P NMR (162 MHz, $CDCl_3$) δ -12.0. ^{19}F NMR (377 MHz, $CDCl_3$) δ -62.7, -103.6. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{29}H_{23}F_5O_2P$ 529.1350; found 529.1346.

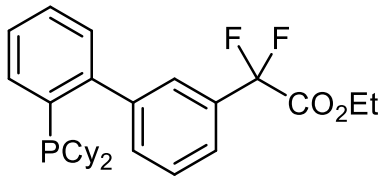


methyl2'-(diphenylphosphanyl)-3-(2-ethoxy-1,1-difluoro-2-oxoethyl)-[1,1'-biphenyl]-4-carboxylate (3o): The general procedure was applied to **1o** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (24.3 mg, 47% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, *J* = 8.0 Hz, 1H), 7.64 (s, 1H), 7.43-7.40 (m, 2H), 7.33-7.28 (m, 8H), 7.24-7.20 (m, 4H), 7.11-7.09 (m, 1H), 4.32 (q, *J* = 7.2 Hz, 2H), 3.86 (s, 3H), 1.31 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.5, 163.4 (t, *J* = 34.3 Hz), 146.2 (d, *J* = 2.0 Hz), 146.0 (d, *J* = 24.2 Hz), 136.8 (d, *J* = 11.1 Hz), 136.4 (d, *J* = 18.2 Hz), 134.2, 134.2, 134.0, 133.0 (t, *J* = 24.2 Hz), 131.8 (d, *J* = 4.0 Hz), 130.6, 130.1 (d, *J* = 5.1 Hz), 129.0, 128.9, 128.7, 128.6, 128.4, 127.3 (t, *J* = 3.0 Hz), 113.0 (t, *J* = 251.5 Hz), 62.8, 52.5, 14.0. ^{31}P NMR (162 MHz,

$CDCl_3$) δ -13.0. ^{19}F NMR (377 MHz, $CDCl_3$) δ -99.0. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{30}H_{26}F_2O_4P$ 519.1531; found 519.1528.

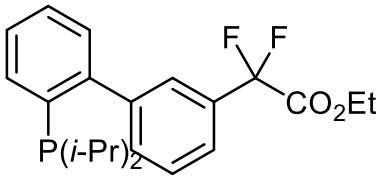


ethyl 2-(3-(2-(diphenylphosphanyl)cyclopenta-2,4-dien-1-yl)phenyl)-2,2-difluoroacetate (3q): The general procedure was applied to **1r** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (27.8 mg, 62% yield). ^1H NMR (400 MHz, $CDCl_3$) δ 7.38-7.30 (m, 7H), 7.29-7.27 (m, 4H), 7.24-7.23 (m, 2H), 7.09 (d, *J* = 7.6 Hz, 2H), 6.62 (d, *J* = 4.0 Hz, 1H), 5.98 (d, *J* = 7.6 Hz, 1H), 7.07 (dd, *J* = 3.6 Hz, 7.2 Hz, 1H), 4.11 (q, *J* = 7.2 Hz, 2H), 1.21 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 163.1 (t, *J* = 34.3 Hz), 137.4 (d, *J* = 3.0 Hz), 136.4, 136.2 (d, *J* = 7.1 Hz), 133.8, 133.6, 129.5 (d, *J* = 2.0 Hz), 129.2, 129.1 (t, *J* = 28.3 Hz), 129.0, 128.6, 128.5, 128.4, 117.3, 112.4 (t, *J* = 5.1 Hz), 110.5 (t, *J* = 247.5 Hz), 63.3, 27.0, 13.9. ^{31}P NMR (162 MHz, $CDCl_3$) δ -30.0. ^{19}F NMR (377 MHz, $CDCl_3$) δ -93.8. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{26}H_{23}F_2NO_2P$ 450.1429; found 450.1427.

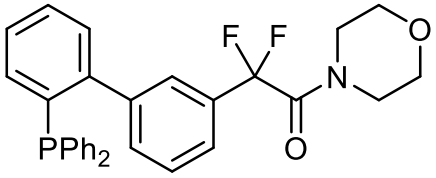


ethyl 2-(2'-(dicyclohexylphosphanyl)-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3r): The general procedure was applied to **1q** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (10.9 mg, 23% yield). ^1H NMR (400 MHz, $CDCl_3$) δ 7.62-7.56 (m, 2H), 7.50 (s, 1H), 7.47-7.42 (m, 2H), 7.40-7.36 (m, 2H), 7.27-7.24 (m, 1H), 4.29 (q, *J* = 7.2 Hz, 2H), 1.85-1.79 (m, 2H), 1.72-1.54 (m, 11H), 1.30 (t, *J* = 7.2 Hz, 3H), 1.25-1.20 (m, 2H), 1.16-1.12 (m, 3H), 1.09-1.04 (m, 2H), 1.03-0.98 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.4 (t, *J* = 35.4 Hz), 149.5 (d, *J* = 28.3 Hz), 143.5, 133.6

(d, J = 4.0 Hz), 133.2, 132.1 (t, J = 25.3 Hz), 130.3 (d, J = 5.1 Hz), 128.6, 127.7, 127.2, 123.9, 113.6 (t, J = 252.5 Hz), 63.2, 34.7 (d, J = 14.1 Hz), 30.5 (d, J = 16.2 Hz), 29.4 (d, J = 9.1 Hz), 27.3 (d, J = 6.1 Hz), 27.2 (d, J = 2.0 Hz), 26.5, 14.1. ^{31}P NMR (162 MHz, $CDCl_3$) δ -13.4. ^{19}F NMR (377 MHz, $CDCl_3$) δ -103.8. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{28}H_{36}F_2O_2P$ 473.2415; found 473.2412.

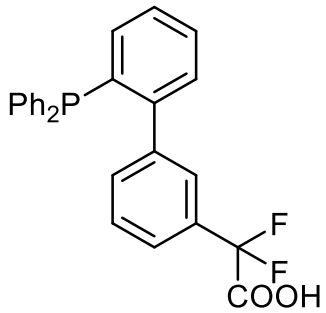


ethyl 2-(2'-(diisopropylphosphanyl)-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetate (3s): The general procedure was applied to **1p** (0.1 mmol), **2a** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), L4 (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (R_f = 0.5, PE/EtOAc = 15/1) to afford the title compound as colorless oil (18.4 mg, 47% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61-7.56 (m, 2H), 7.52 (s, 1H), 7.47-7.45 (m, 2H), 7.40-7.38 (m, 2H), 7.30-7.27 (m, 1H), 4.29 (q, J = 7.2 Hz, 2H), 2.06-2.00 (m, 2H), 1.30 (t, J = 7.2 Hz, 3H), 0.99 (d, J = 7.2 Hz, 3H), 0.95 (d, J = 7.2 Hz, 3H), 0.92 (d, J = 7.2 Hz, 3H), 0.89 (d, J = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.4 (t, J = 35.4 Hz), 149.3 (d, J = 28.3 Hz), 143.4 (d, J = 6.1 Hz), 133.7 (d, J = 5.1 Hz), 132.9 (d, J = 3.0 Hz), 132.1 (t, J = 26.3 Hz), 130.3 (d, J = 5.1 Hz), 128.7, 127.8 (d, J = 4.1 Hz), 127.7, 127.2, 123.9 (t, J = 6.1 Hz), 113.6 (d, J = 252.5 Hz), 63.2, 24.8, 24.6, 20.3, 20.1, 19.6, 19.5, 14.1. ^{31}P NMR (162 MHz, $CDCl_3$) δ -5.0. ^{19}F NMR (377 MHz, $CDCl_3$) δ -103.9. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{22}H_{28}F_2O_2P$ 393.1789; found 393.1783.

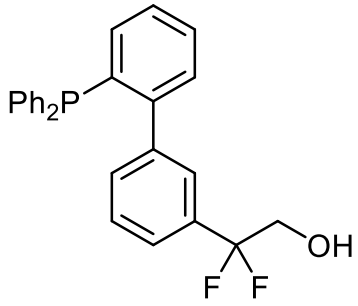


ethyl 2-(2'-(diphenylphosphanyl)-[1,1'-biphenyl]-3-yl)-2,2-difluoro-1-morpholinoethan-1-one (3u): The general procedure was applied to **1a** (0.1 mmol), **2u** (5.0 equiv.), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), Ligand (30 mol%) and H_2O (2.0 equiv.) in 1.0 mL of *n*-hexane at 120 ℃ under argon, 16 h. The crude product was purified by prepared column chromatography (Rf = 0.5, PE/EtOAc = 8/1) to afford the title compound as colorless oil (22.4 mg, 45% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45–7.37 (m, 5H), 7.30–7.28 (m, 8H), 7.18–7.14 (td, J = 7.2, 1.6 Hz, 4H), 7.05-7.03 (dd, J = 7.6, 4.0 Hz, 4H), 3.65 (s, 4H), 3.41(t, 4.4 Hz, 2H) 3.31 (t, J = 4.4 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 162.1 (t, J = 30.2 Hz), 146.8 (d, J =

28.2 Hz), 142.5 (d, *J* = 6.0 Hz), 137.0 (d, *J* = 11.6 Hz), 135.7 (d, *J* = 14.7 Hz), 134.2, 133.9, 133.7, 132.7 (t, *J* = 27.1 Hz),132.4 (d, *J* = 4.5 Hz), 130.1 (d, *J* = 4.7 Hz), 129.0, 128.7, 128.5, 128.5, 128.3, 128.1, 126.4 (d, *J* = 4.2 Hz), 123.9 (t, *J* = 5.5 Hz), 115.1, 66.7 (d, *J* = 28.0 Hz), 46.6, 43.4. ^{31}P NMR (162 MHz, $CDCl_3$) δ -13.6. ^{19}F NMR (377 MHz, $CDCl_3$) δ -94.7. **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{30}H_{27}F_2NO_2P$ 502.1742; found 502.1739.

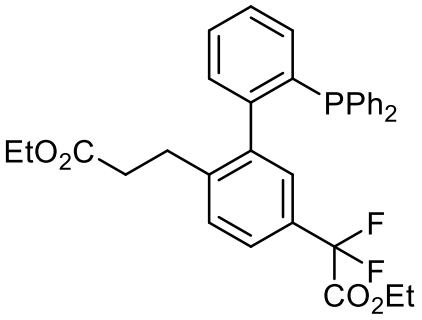


2-(2'-(diphenylphosphanyl)-[1,1'-biphenyl]-3-yl)-2,2-difluoroacetic acid (4): The general procedure was applied to **3a** (0.5 mmol), K_2CO_3 (1M, 2 mL). The tube was purged with Ar three times, followed by the addition of MeOH (2 mL) at 23 ℃ under argon, 2 h. The crude product was purified by prepared column chromatography (R_f = 0.6, DCM/MeOH = 4/1) to afford the title compound as white powder (216 mg, 99% yield). ^{1}H NMR (400 MHz, CD_3OD) δ 7.56-7.53 (m, 2H), 7.42-7.38 (m, 1H), 7.32-7.21 (m, 9H), 7.19-7.11 (m, 5H), 7.03 (dd, *J* = 3.6 Hz, 7.6 Hz, 1H). ^{13}C NMR (101 MHz, CD_3OD) δ 169.5 (t, *J* = 29.3 Hz), 147.4 (d, *J* = 28.3 Hz), 141.7 (d, *J* = 6.1 Hz), 137.3 (d, *J* = 12.1 Hz), 135.9 (d, *J* = 15.2 Hz), 135.6 (d, *J* = 26.3 Hz), 133.7, 133.7, 133.5, 131.2 (d, *J* = 10.1 Hz), 131.1 (d, *J* = 5.1 Hz), 129.9 (d, *J* = 5.1 Hz), 128.6, 128.4, 128.2, 128.1, 127.3, 126.9, 126.4 (d, *J* = 3.0 Hz), 124.0 (t, *J* = 6.1 Hz), 115.1 (t, *J* = 251.5 Hz). ^{31}P NMR (162 MHz, CD_3OD) δ -13.6. ^{19}F NMR (377 MHz, CD_3OD) δ -102.1. **HRMS** (ESI) m/z: $[M-H]^-$ calcd for $C_{26}H_{18}F_2O_2P$ 431.1018; found 431.1015.



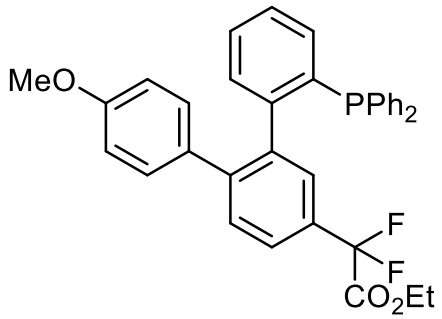
3-(2'-(diphenylphosphanyl)-[1,1'-biphenyl]-3-yl)-2,2-difluoroethan-1-ol (5): To a 50 mL Round bottomed flask was added **3a** (0.2 mmol), $AlLiH_4$ (5.0 equiv.) followed by the addition of dry 1,4-dioxane (2 mL) at 0 ℃, 2 h. Then the mixture was stirred at room temperature for 1 h. The crude product was

purified by prepared column chromatography (R_f = 0.6, *n*-hexane/EtOAc = 3/1) to afford the title compound as colorless oil (79.4 mg, 95% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43-7.36 (m, 4H), 7.33-7.28 (m, 9H), 7.21-7.17 (m, 4H), 7.04 (dd, *J* = 3.6 Hz, 7.6 Hz, 1H), 3.77-3.70 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 147.0 (d, *J* = 27.3 Hz), 142.1 (d, *J* = 5.1 Hz), 137.0 (d, *J* = 11.1 Hz), 136.0 (d, *J* = 14.1 Hz), 134.2, 134.1, 134.0, 133.7 (t, *J* = 25.3 Hz), 131.6 (d, *J* = 4.0 Hz), 130.1 (d, *J* = 5.1 Hz), 129.0, 128.9, 128.6 (d, *J* = 7.1 Hz), 128.2, 128.0, 127.3 (dd, *J* = 6.1 Hz, 11.1 Hz), 124.4 (t, *J* = 6.1 Hz), 120.6 (t, *J* = 245.4 Hz), 66.0 (t, *J* = 32.3 Hz). ^{31}P NMR (162 MHz, $CDCl_3$) δ -12.7. ^{19}F NMR (377 MHz, $CDCl_3$) δ -107.4. **HRMS** (ESI) m/z: $[M-H]^-$ calcd for $C_{26}H_{22}F_2OP$ 419.1371; found 419.1367.



methyl3-(2'-(diphenylphosphanyl)-5-(2-ethoxy-1,1-difluoro-2-oxoethyl)-[1,1'-biphenyl]-2-yl)propanoate (6): The general procedure was applied to **3a** (0.2 mmol), ethyl acrylate (60.0 mg, 3.0 equiv), $[RuCl_2(p\text{-cymene})]_2$ (6.2 mg, 5 mol%), *N*-Boc-*L*-Phe-OH (15.9 mg, 30 mol%), K_2HPO_4 (69.6 mg, 2.0 equiv). The tube was purged with Ar three times, followed by the addition of *n*-hexane (2 mL) at 120 ℃ under argon, 12 h. The crude product was purified by prepared column chromatography (R_f = 0.6, PE/EtOAc = 15/1) to afford the title compound as colorless oil (84.0 mg, 77% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63 (dd, *J* = 1.2 Hz, 8.0 Hz, 1H), 7.49 (dd, *J* = 1.6 Hz, 8.0 Hz, 1H), 7.41-7.37 (m, 1H), 7.32-7.25 (m, 8H), 7.20-7.15 (m, 3H), 7.15-7.09 (m, 3H), 7.02-7.01 (m, 1H), 4.19 (q, *J* = 3.2 Hz, 2H), 4.07 (q, *J* = 7.2 Hz, 2H), 2.77 (t, *J* = 8.0 Hz, 2H), 2.53-2.39 (m, 2H), 1.24 (t, *J* = 7.2 Hz, 3H), 1.20 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 172.8, 164.2 (t, *J* = 35.4 Hz), 145.6 (d, *J* = 30.3 Hz), 141.6, 141.4 (d, *J* = 6.1 Hz), 137.2 (d, *J* = 13.1 Hz), 137.0 (d, *J* = 12.1 Hz), 136.2 (d, *J* = 10.1 Hz), 134.0 (d, *J* = 2.0 Hz), 133.8 (d, *J* = 2.0 Hz), 133.7, 130.0 (d, *J* = 5.1 Hz), 130.0 (t, *J* = 25.3 Hz), 128.9, 128.8 (d, *J* = 10.1 Hz), 128.6, 128.6 (d, *J* = 2.0 Hz), 128.5 (d, *J* = 2.0 Hz), 128.2, 128.0 (d, *J* = 3.0 Hz), 125.0 (t, *J* = 6.1 Hz), 113.2 (d, *J* = 253.5 Hz), 63.0, 60.5, 34.6, 28.5 (d, *J* = 4.0 Hz), 14.3, 14.0. ^{31}P NMR (162 MHz, $CDCl_3$) δ -13.5. ^{19}F NMR (377 MHz, $CDCl_3$) δ -103.4 (d, *J* = 682.4 Hz), -103.4 (d, *J* = 173.4 Hz). **HRMS** (ESI)

m/z: $[M+H]^+$ calcd for $C_{33}H_{32}F_2O_4P$ 561.2001; found 561.1998.



ethyl 2-(2''-(diphenylphosphanyl)-4-methoxy-[1,1':2',1''-terphenyl]-4'-yl)-2,2-difluoroacetate (7): The general procedure was applied to **3a** (0.2 mmol), 1-iodo-4-methoxybenzene (70.2 mg, 1.5 equiv), $[RuCl_2(p\text{-cymene})]_2$ (6.2 mg, 5 mol%), *N*-Ac-*L*-Ala-OH (7.9mg, 30 mol%), CsOAc (76.8mg, 0.4 mmol, 2.0 equiv). The tube was purged with Ar three times, followed by the addition of tolune (2 mL) at 120 ℃ under argon, 12 h. The crude product was purified by prepared column chromatography (R_f = 0.6, PE/EtOAc = 15/1) to afford the title compound as colorless oil (81.6 mg, 72% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63 (dd, *J* = 1.2 Hz, 8.0 Hz, 1H), 7.48 (d, *J* = 8.0 Hz, 1H), 7.32-7.27 (m, 4H), 7.24-7.16 (m, 6H), 7.13-7.07 (m, 4H), 7.03 (dd, *J* = 4.0 Hz, 7.6 Hz, 1H), 6.81-6.76 (m, 2H), 6.67 (d, *J* = 8.4 Hz, 2H), 4.24-4.16 (m, 2H), 3.75 (s, 3H), 1.24 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 164.2 (t, *J* = 30.3 Hz), 158.7, 147.2 (d, *J* = 32.3 Hz), 143.6, 140.7 (d, *J* = 6.1 Hz), 137.8 (d, *J* = 13.1 Hz), 137.1 (d, *J* = 13.1 Hz), 136.5 (d, *J* = 13.1 Hz), 134.7 (d, *J* = 2.0 Hz), 133.7 (d, *J* = 20.2 Hz), 133.1 (d, *J* = 18.2 Hz), 132.9, 131.3, 131.1 (d, *J* = 6.1 Hz), 130.6 (t, *J* = 27.3 Hz), 130.2, 128.8 (d, *J* = 22.2 Hz), 128.5 (d, *J* = 7.1 Hz), 128.2 (d, *J* = 6.1 Hz), 127.9 (d, *J* = 16.2 Hz), 125.0 (t, *J* = 6.1 Hz), 113.4 (t, *J* = 252.5 Hz), 113.3, 63.2, 55.3, 14.0. ^{31}P NMR (162 MHz, $CDCl_3$) δ -14.2. ^{19}F NMR (377 MHz, $CDCl_3$) δ -103.4 (d, *J* = 667.3 Hz), -103.4 (d, *J* = 162.1 Hz). **HRMS** (ESI) m/z: $[M+H]^+$ calcd for $C_{35}H_{30}F_2O_3P$ 567.1895; found 567.1891.

4. References

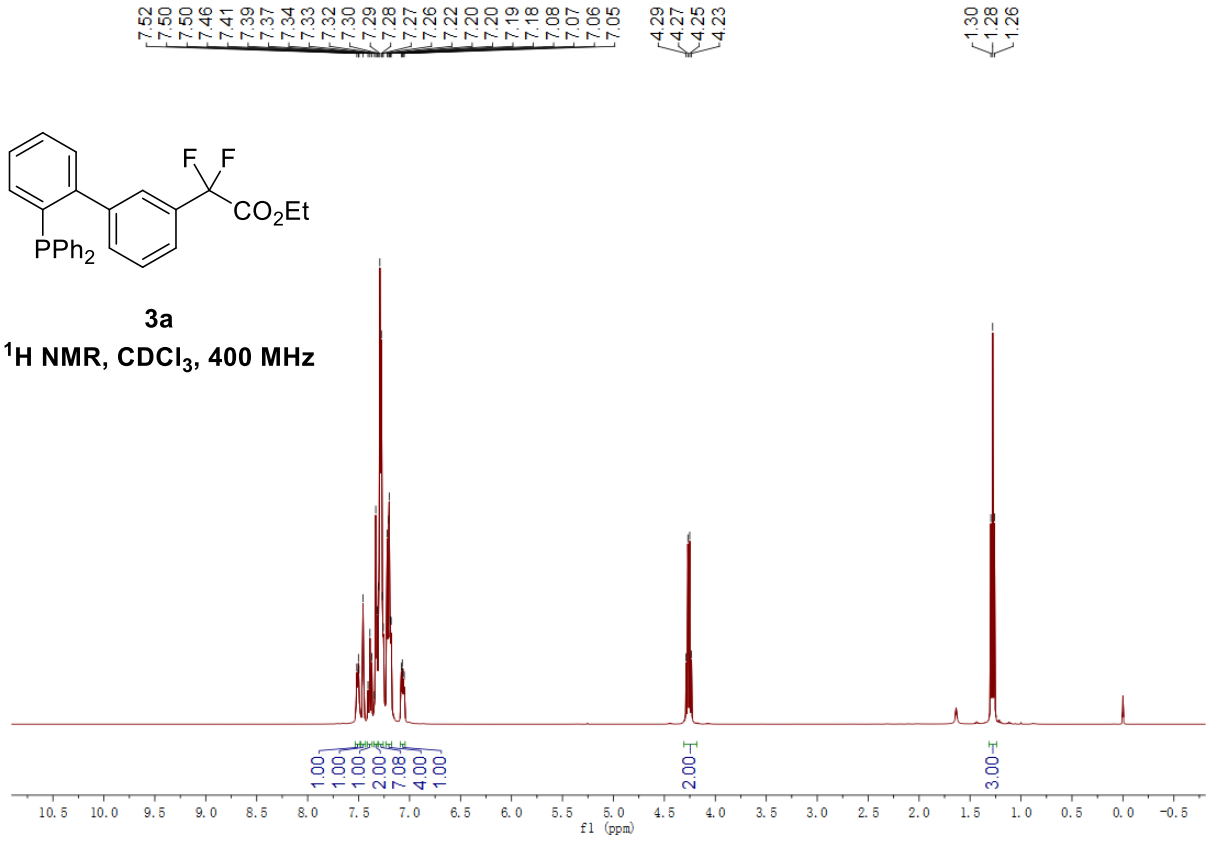
(1) Li J. W., Wang L. N., Li M.; Tang P. T.; Zhang N. J.; Li T.; Liu Y. J. and Zeng M. H. *Organic Letters*, **2020**, 22(*4*), 1331-1335.

(2) Li J. W.; Wang L. N.; Li M.; Tang P. T.; Luo X. P.; Kurmoo M.; Liu Y. J. and Zeng M. H. *Organic letters*, **2019**, *21*(8), 2885-2889.

(3) M. C. Belhomme, T. Poisson, and X. Pannecoucke. *The Journal of Organic Chemistry.* **2014**, *79*, 7205-7211.

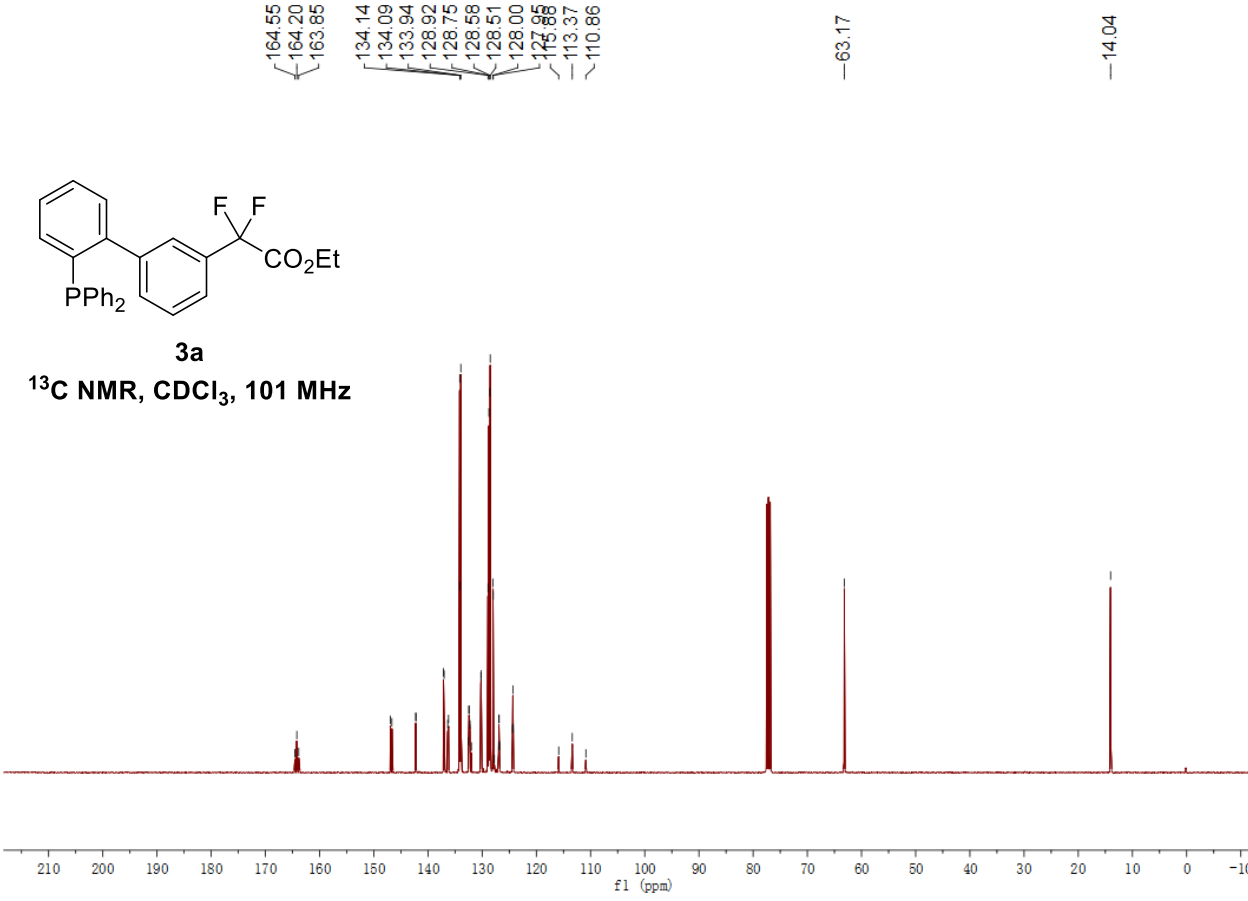
(4) S. Murakami, H. Ishii, T. Fuchigami. *Journal of Fluorine Chemistry.* **2004**, *125*, 609-614.

5. NMR Spectra



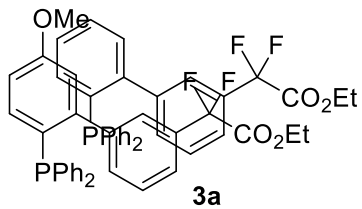
3a

^{1}H NMR, $CDCl_3$, 400 MHz



3a

^{13}C NMR, $CDCl_3$, 101 MHz

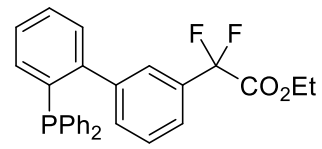


3a

3f

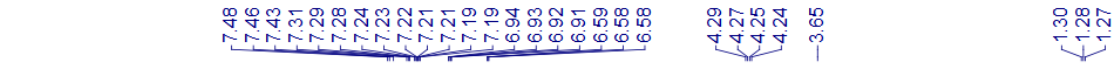
^{31}P NMR, $CDCl_3$, 162 MHz

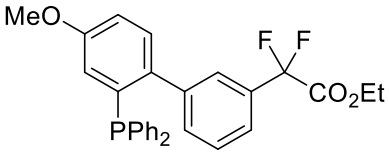
^{1}H NMR, $CDCl_3$, 400 MHz



3a

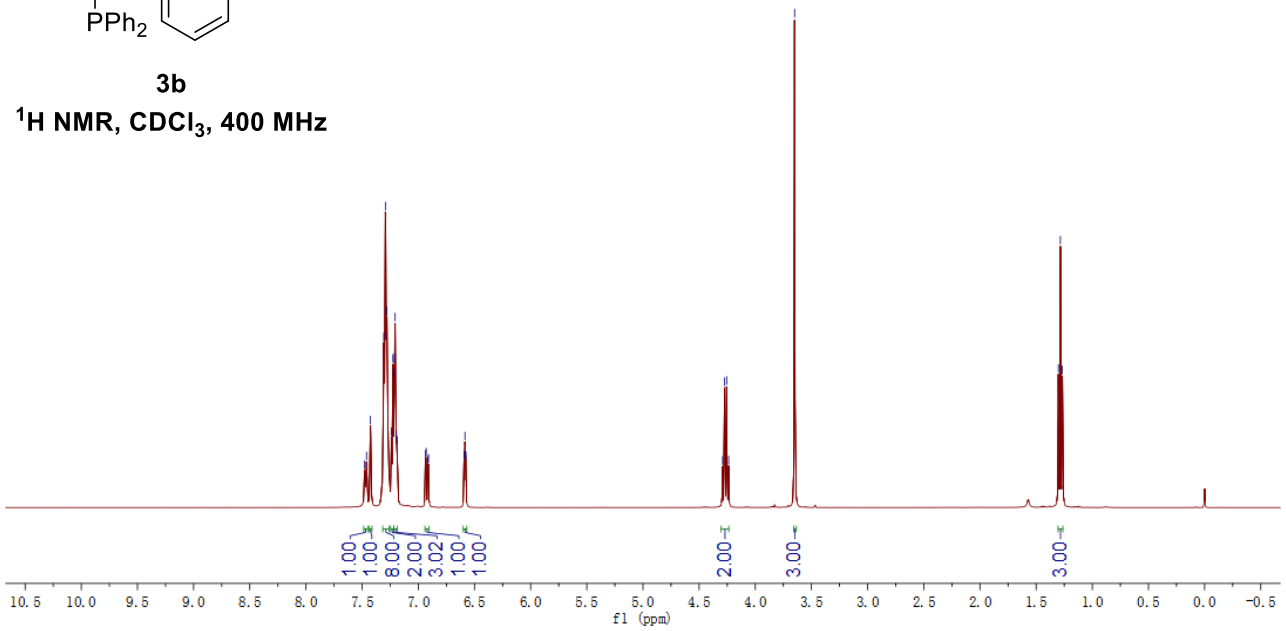
^{19}F NMR, $CDCl_3$, 377 MHz

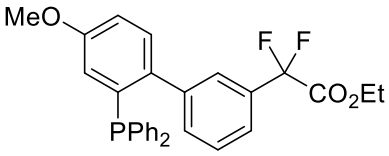




3b

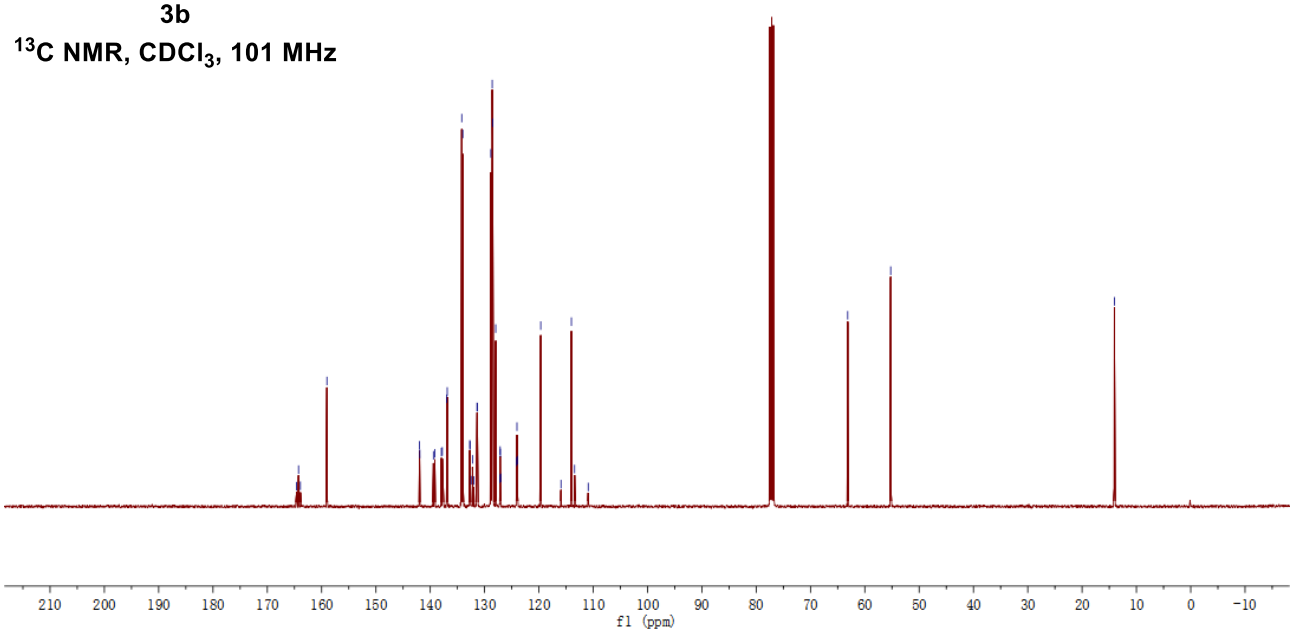
^{1}H NMR, $CDCl_3$, 400 MHz

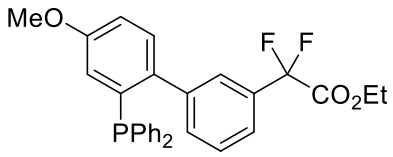




3b

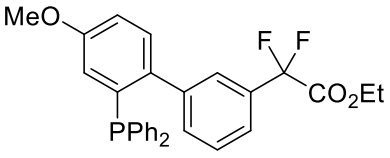
^{13}C NMR, $CDCl_3$, 101 MHz





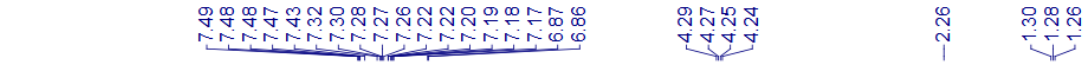
3b

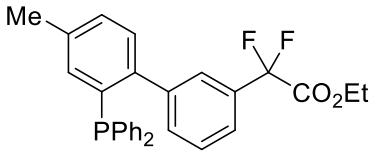
^{31}P NMR, $CDCl_3$, 162 MHz



3b

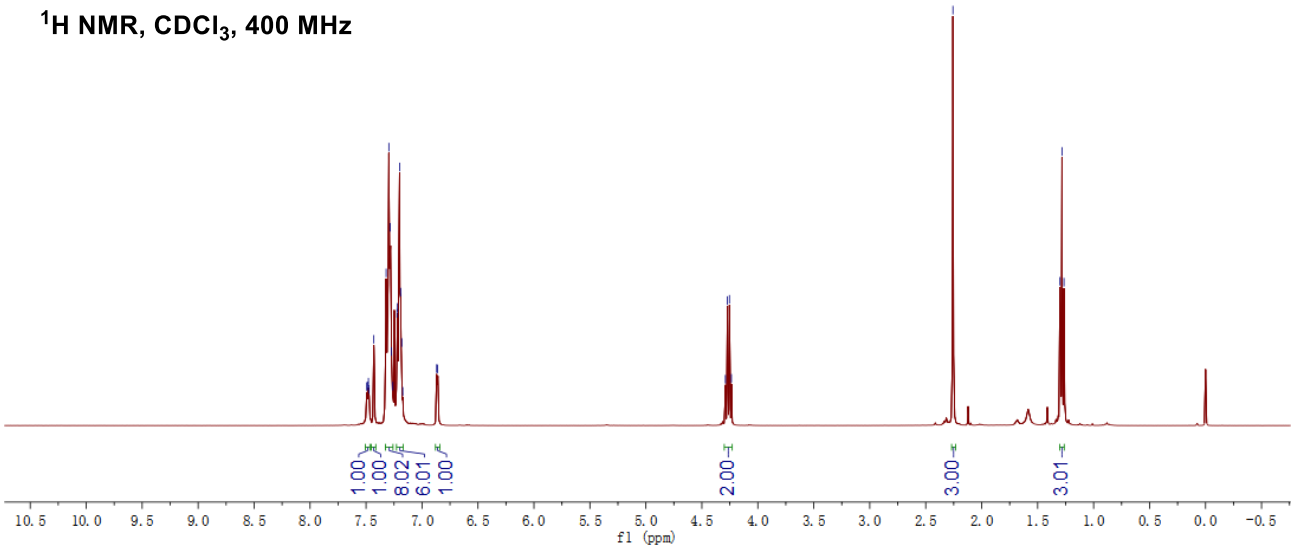
^{19}F NMR, $CDCl_3$, 377 MHz

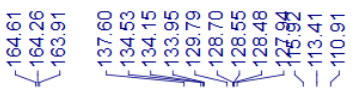


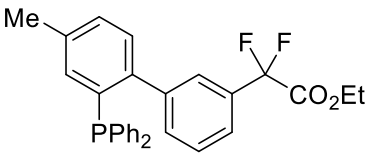


3c

^{1}H NMR, $CDCl_3$, 400 MHz

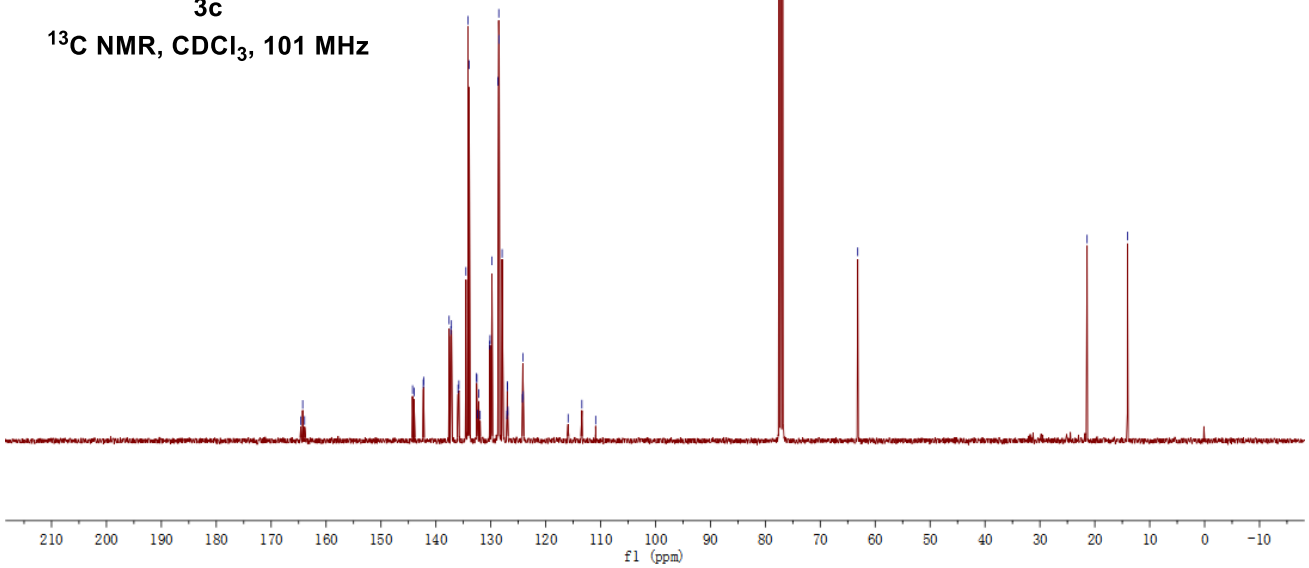


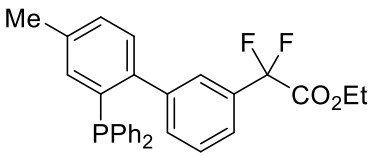




3c

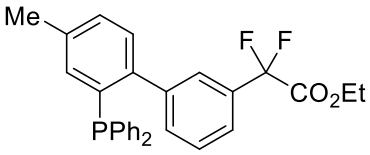
^{13}C NMR, $CDCl_3$, 101 MHz





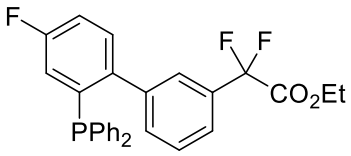
3c

^{31}P NMR, $CDCl_3$, 162 MHz



3c

^{19}F NMR, $CDCl_3$, 377 MHz



3d

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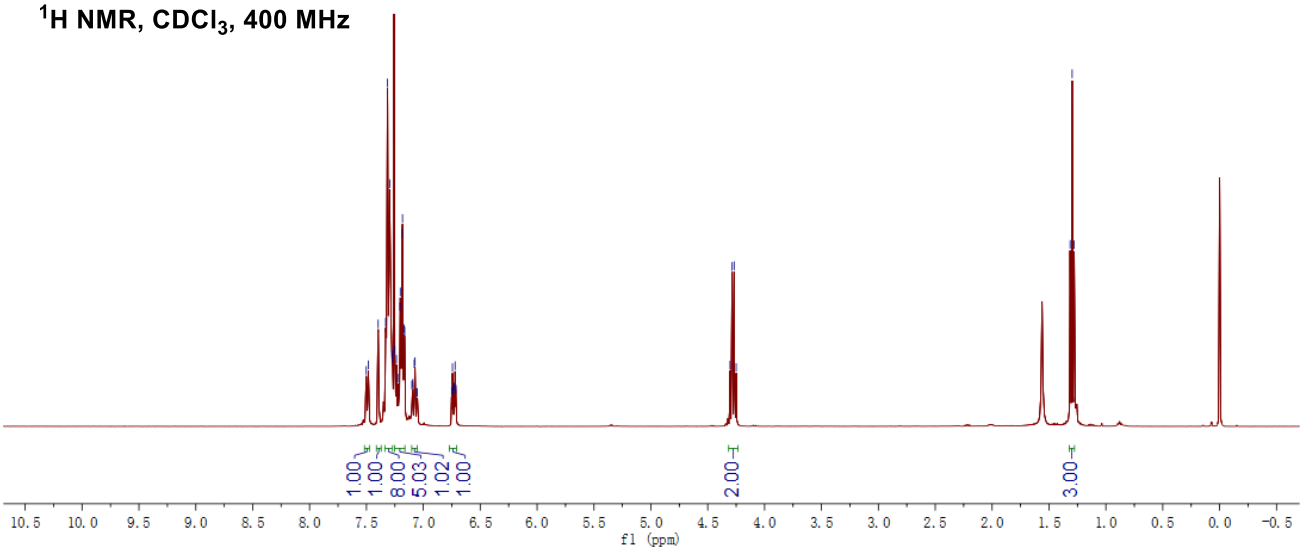
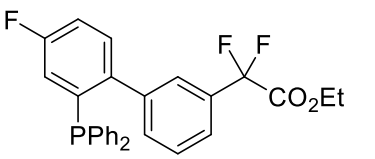
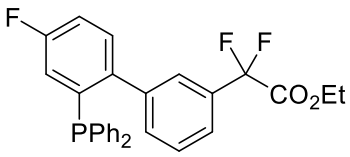




3d

^{13}C NMR, $CDCl_3$, 101 MHz



3d

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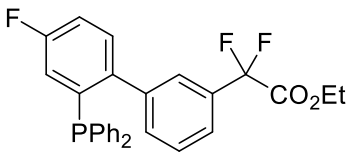
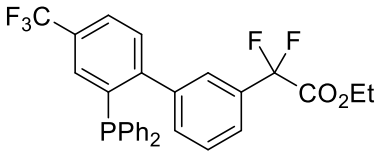


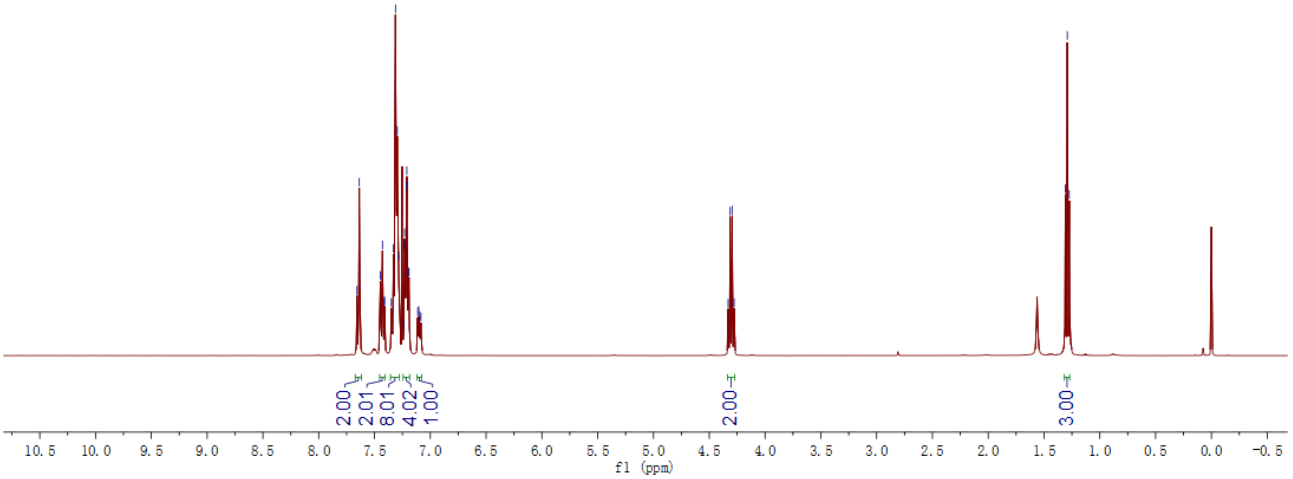
3d

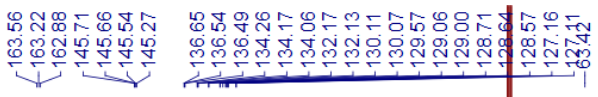
^{19}F NMR, $CDCl_3$, 377 MHz

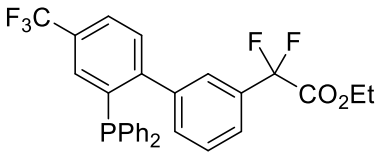


3e

^{1}H NMR, $CDCl_3$, 400 MHz







3e

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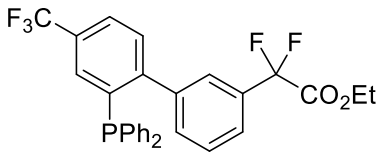
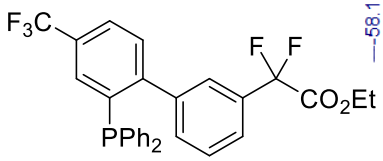


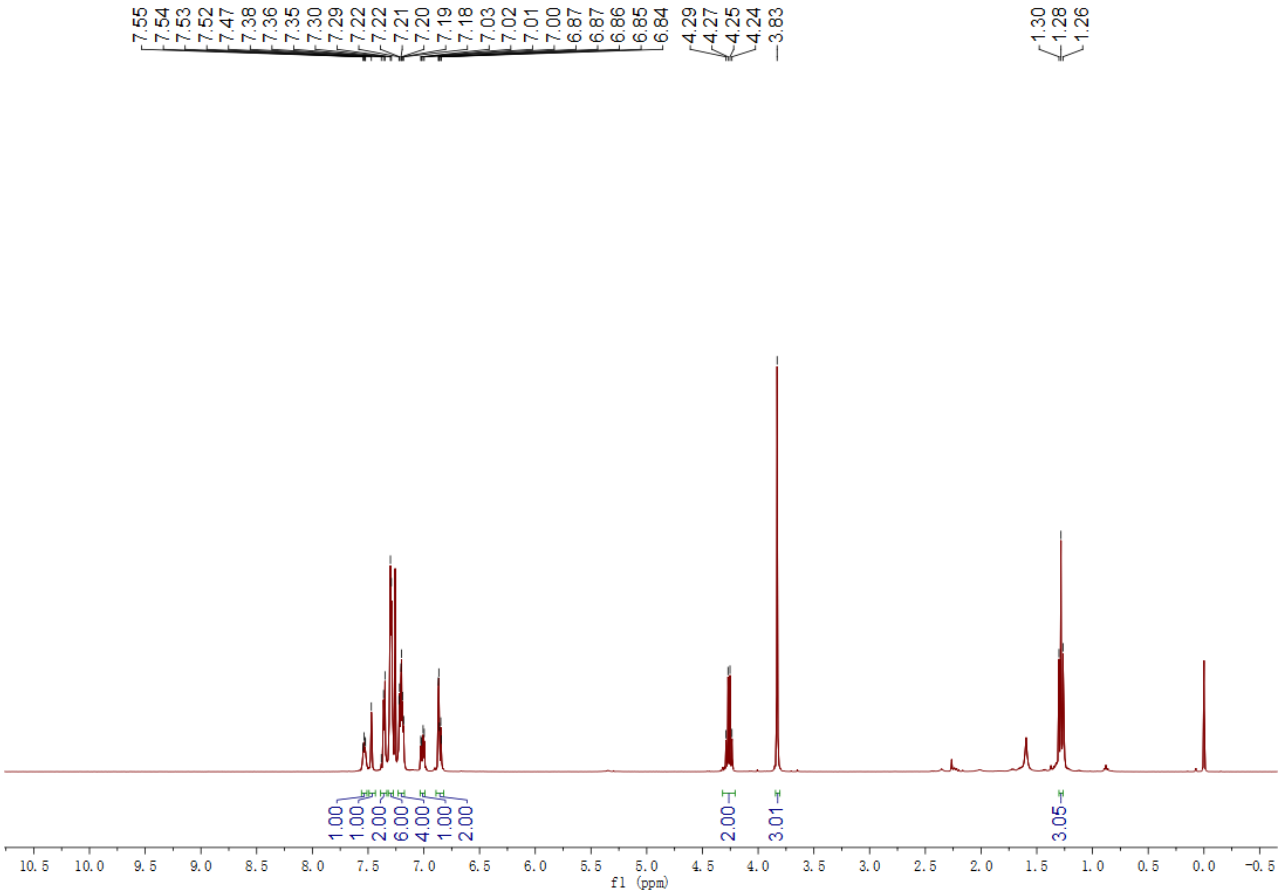
3e

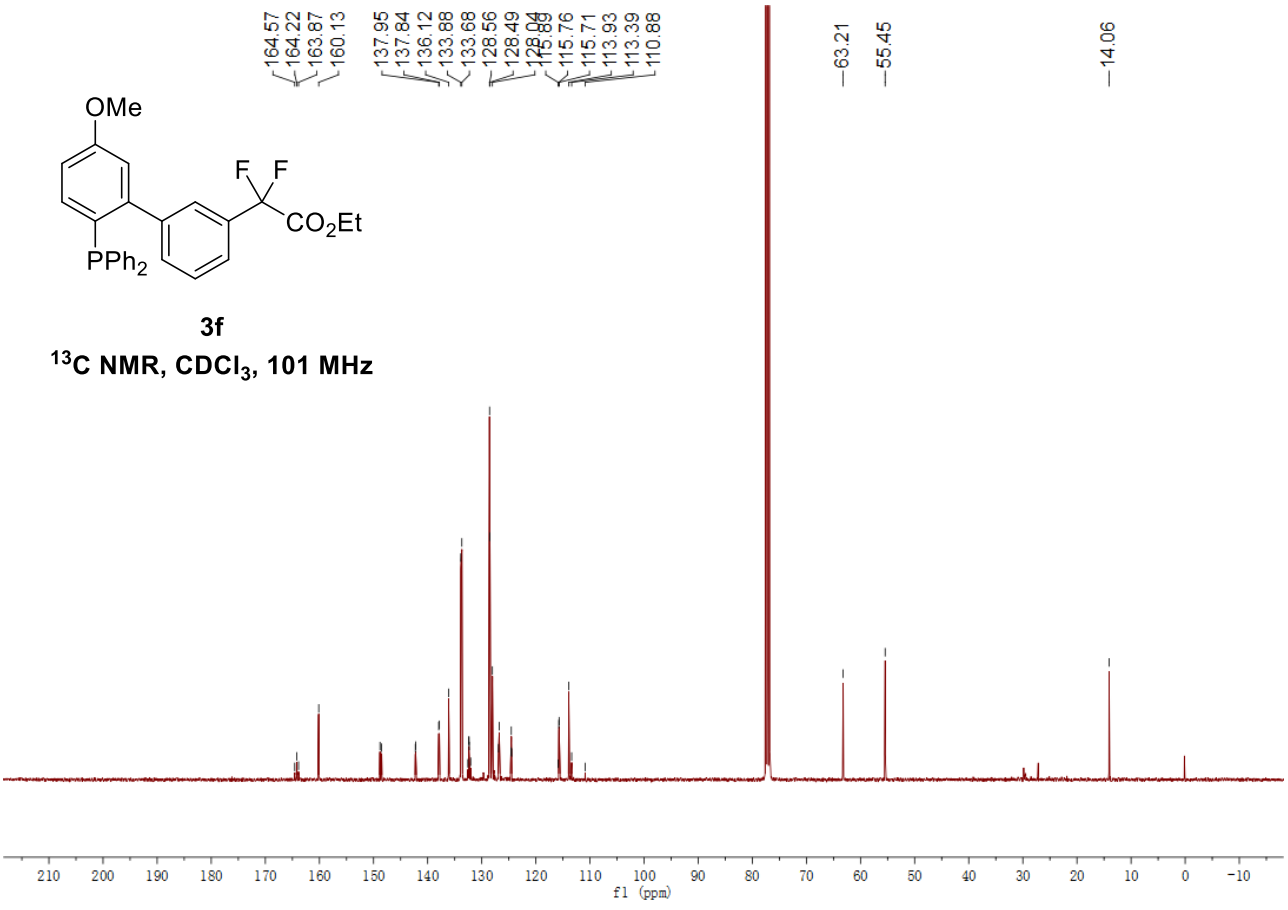
^{31}P NMR, $CDCl_3$, 162 MHz



3e

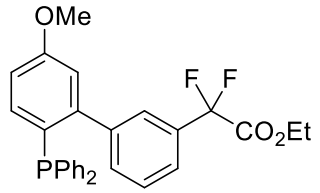
^{19}F NMR, $CDCl_3$, 377 MHz





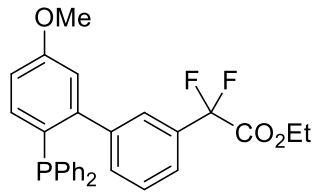
3f

^{13}C NMR, $CDCl_3$, 101 MHz



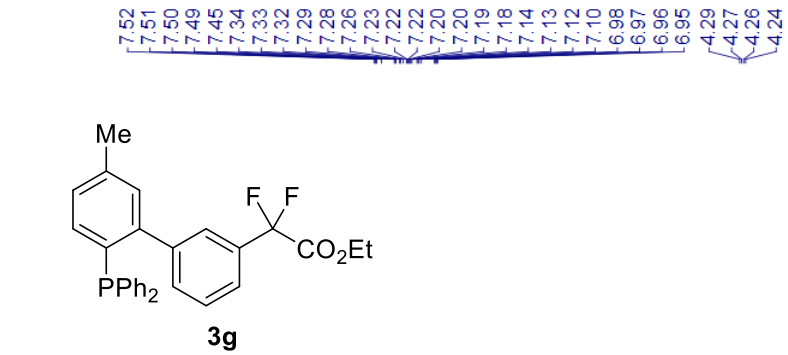
3f

^{31}P NMR, $CDCl_3$, 162 MHz



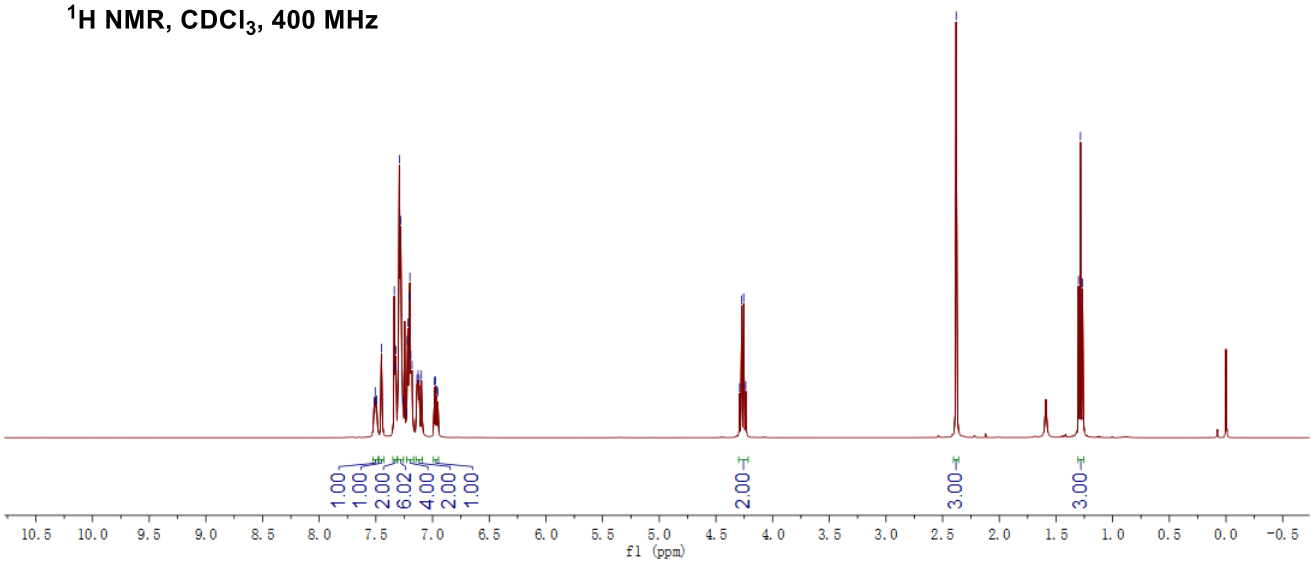
3f

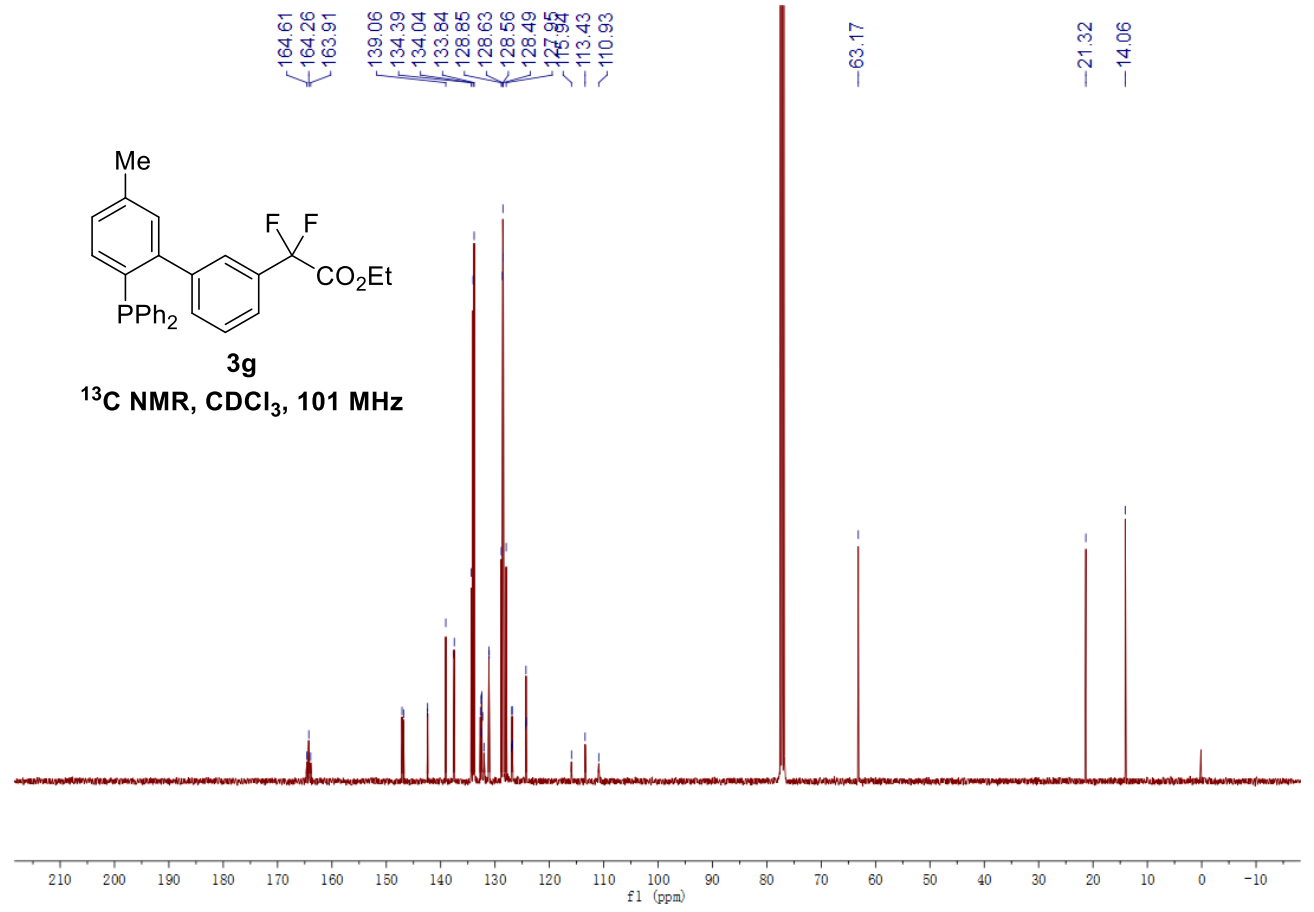
^{19}F NMR, $CDCl_3$, 377 MHz



3g

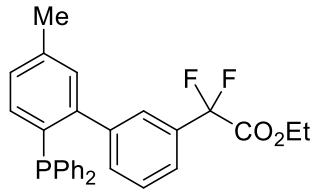
^{1}H NMR, $CDCl_3$, 400 MHz





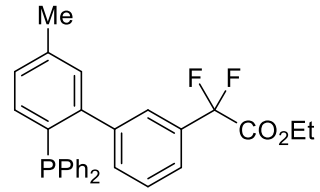
3g

^{13}C NMR, $CDCl_3$, 101 MHz



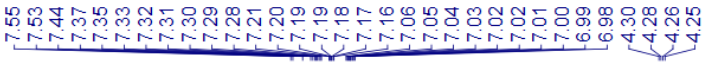
3g

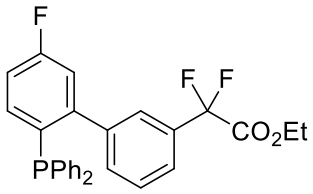
^{31}P NMR, $CDCl_3$, 162 MHz



3g

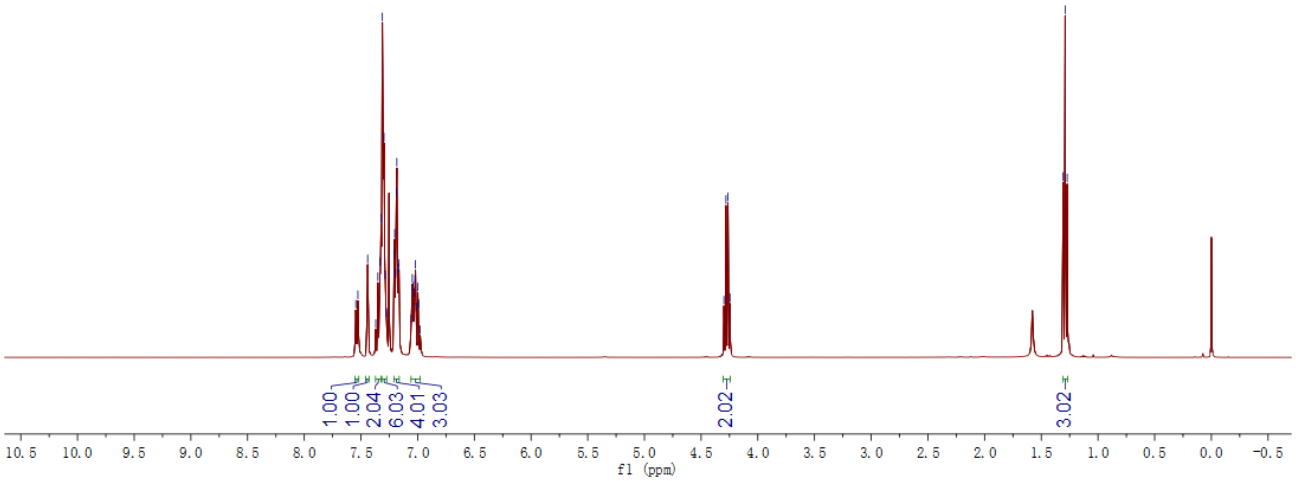
^{19}F NMR, $CDCl_3$, 377 MHz

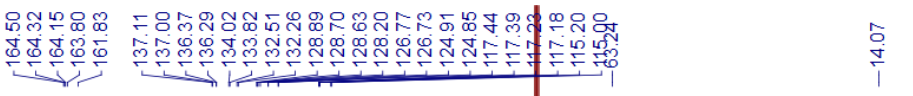


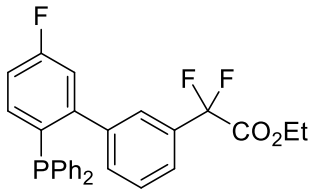


3h

^{1}H NMR, $CDCl_3$, 400 MHz

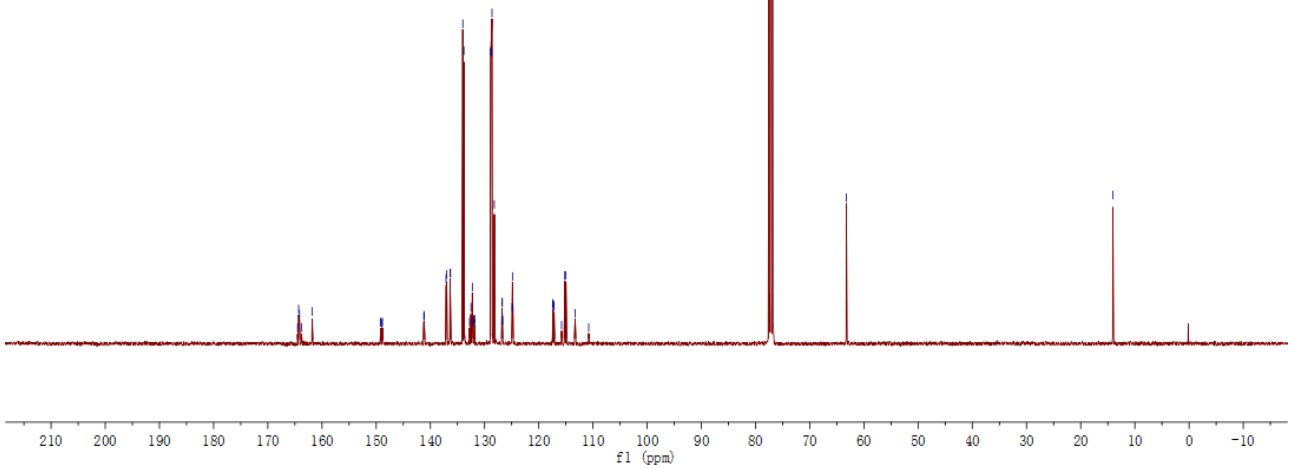


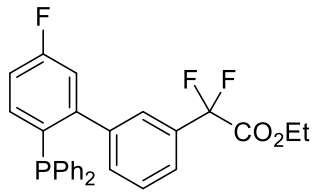




3h

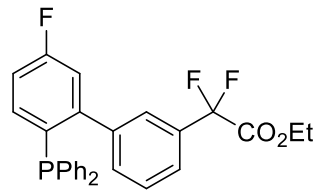
^{13}C NMR, $CDCl_3$, 101 MHz





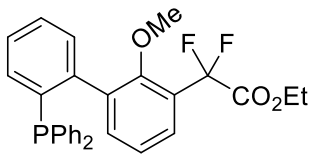
3h

^{31}P NMR, $CDCl_3$, 162 MHz



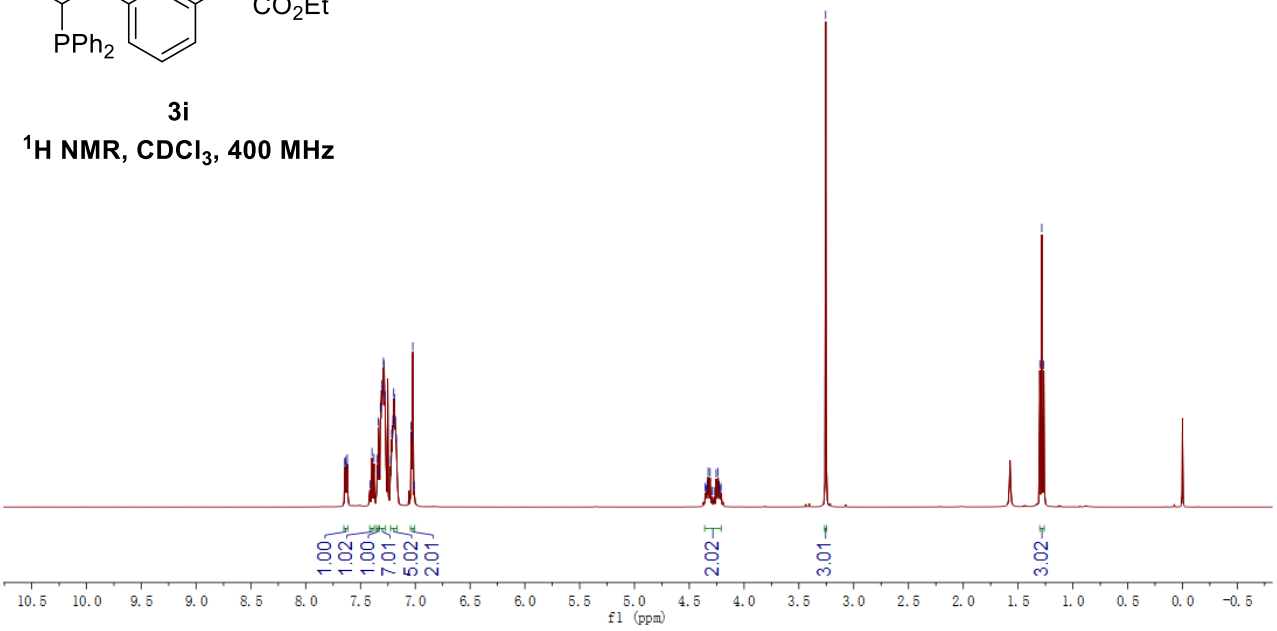
3h

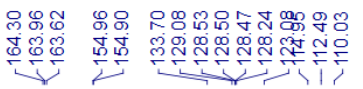
^{19}F NMR, $CDCl_3$, 377 MHz

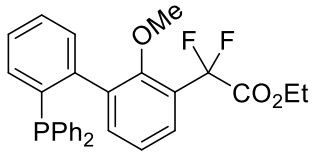


3i

^{1}H NMR, $CDCl_3$, 400 MHz

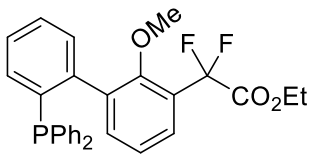






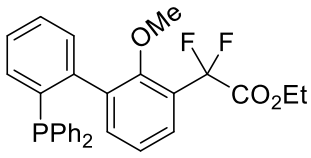
3i

^{13}C NMR, $CDCl_3$, 101 MHz



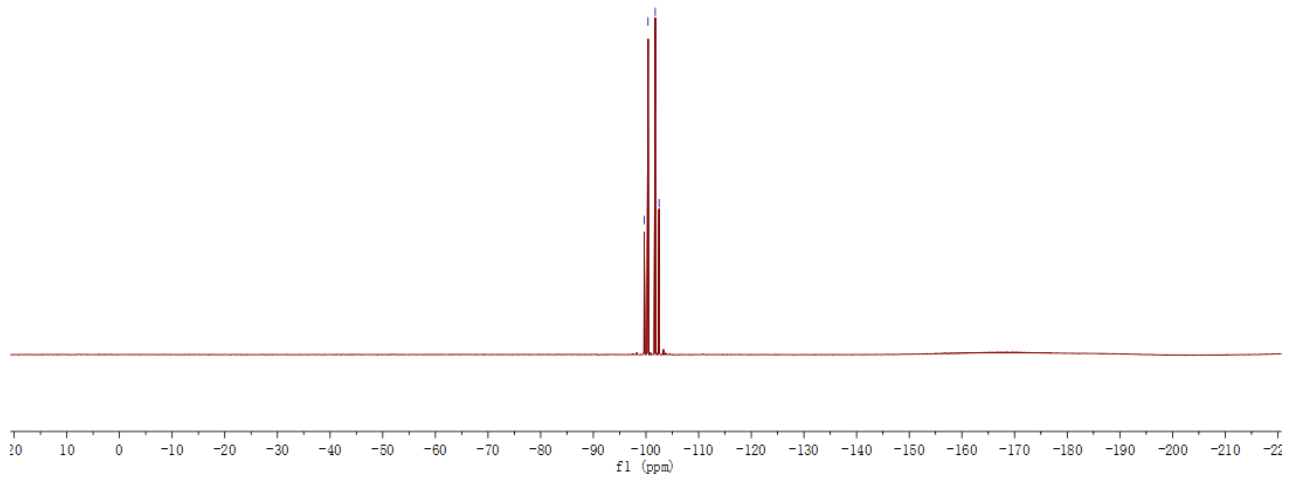
3i

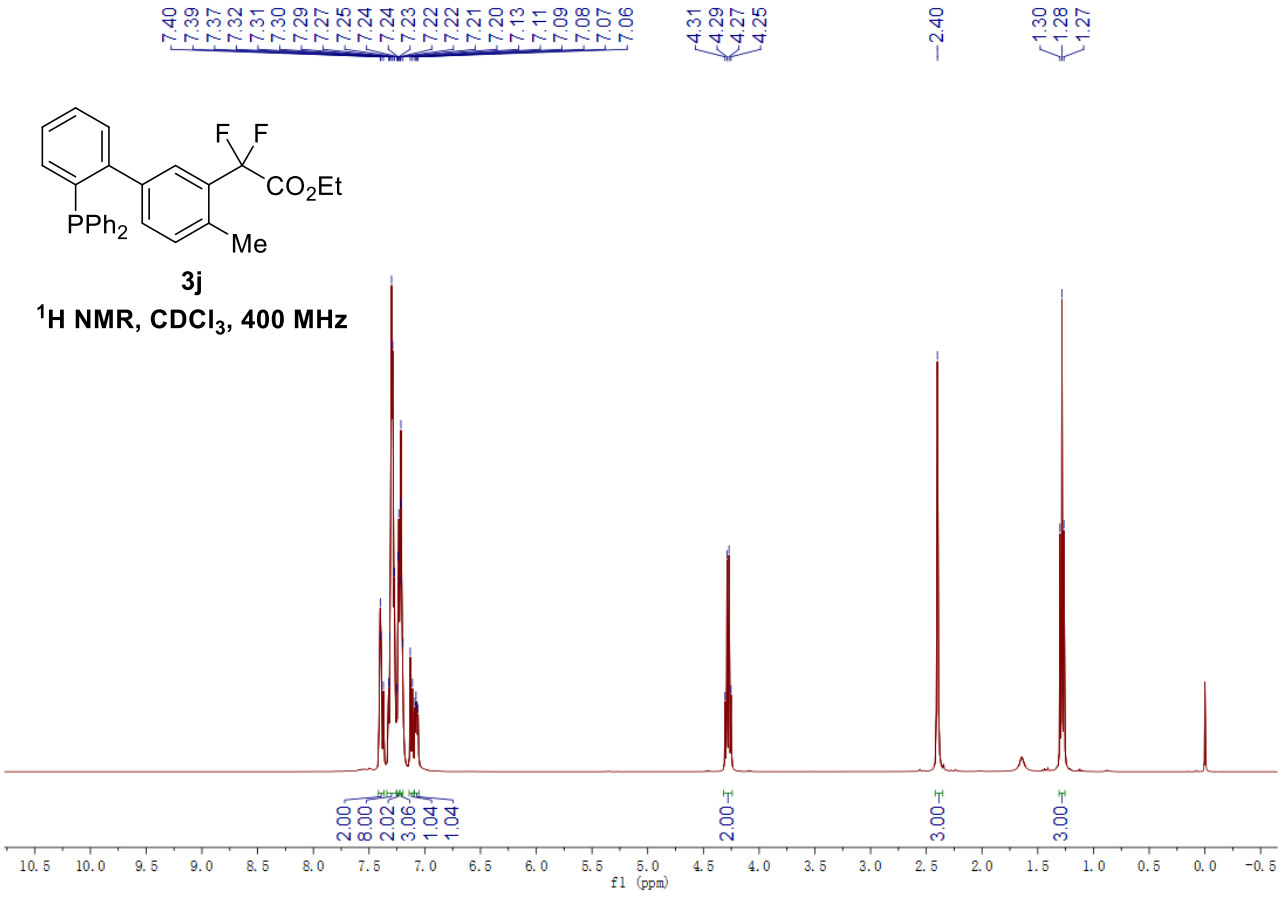
^{31}P NMR, $CDCl_3$, 162 MHz



3i

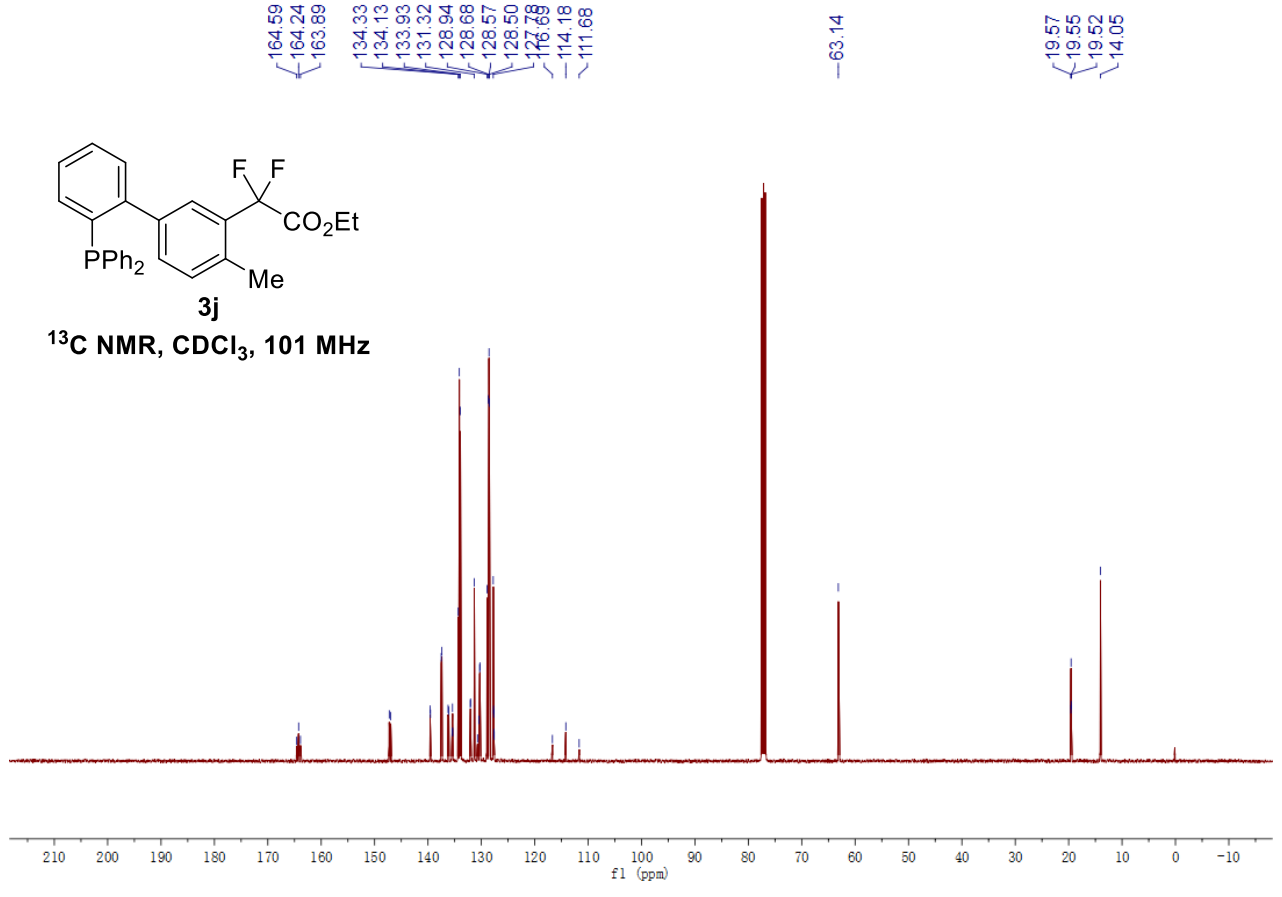
^{19}F NMR, $CDCl_3$, 377 MHz





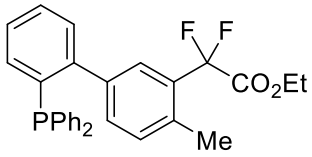
3j

^{1}H NMR, $CDCl_3$, 400 MHz



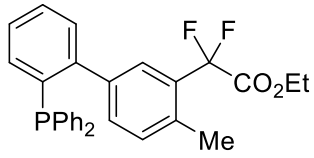
3j

^{13}C NMR, $CDCl_3$, 101 MHz



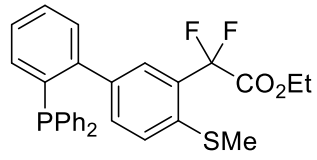
3j

^{31}P NMR, $CDCl_3$, 162 MHz



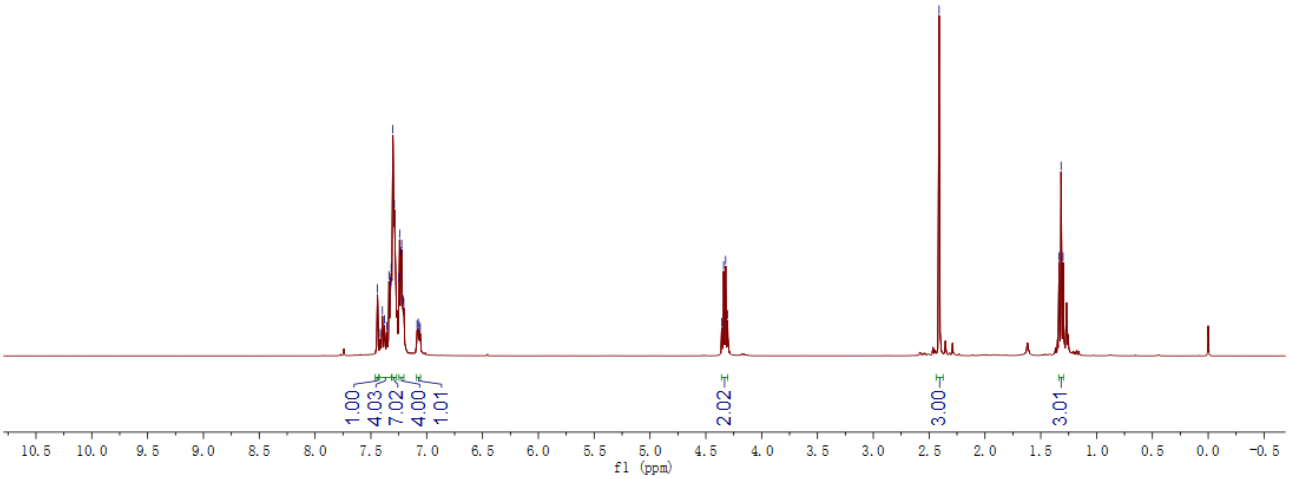
3j

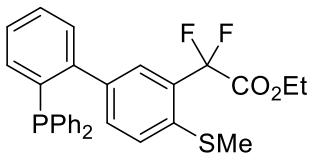
^{19}F NMR, $CDCl_3$, 377 MHz



3k

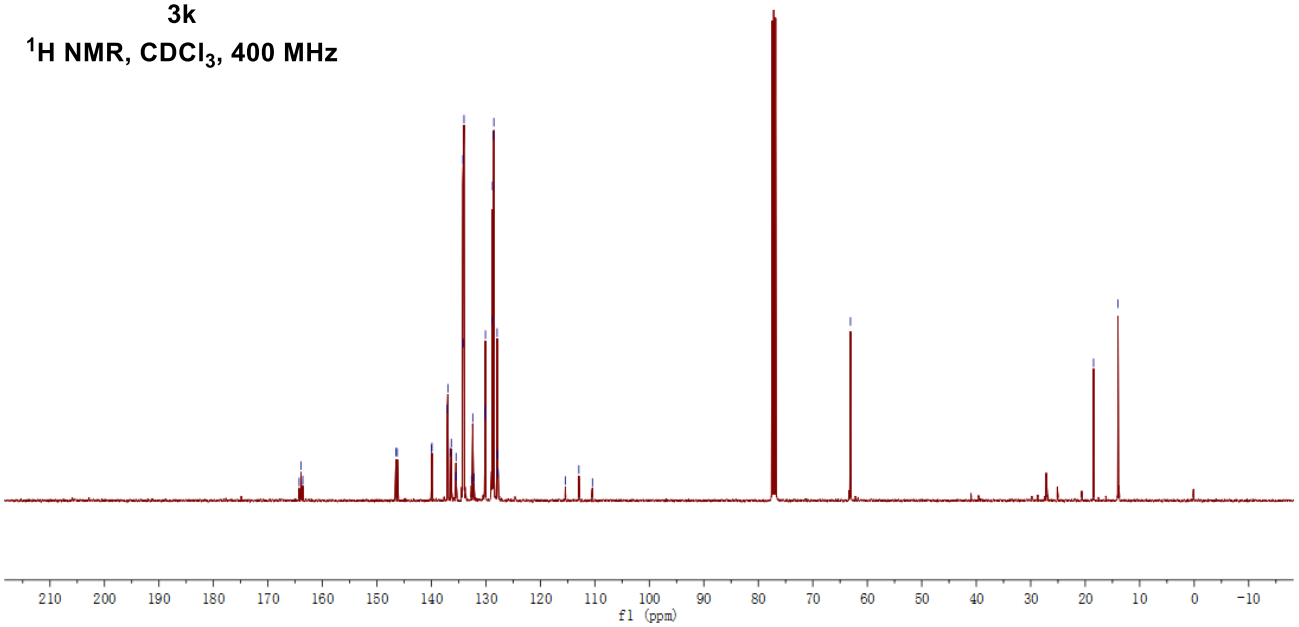
^{13}C NMR, $CDCl_3$, 101 MHz

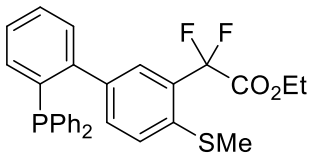




3k

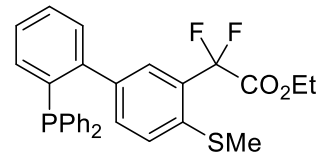
^{1}H NMR, $CDCl_3$, 400 MHz





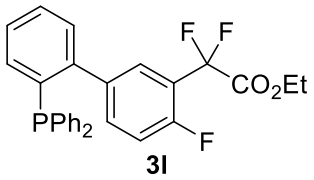
3k

^{31}P NMR, $CDCl_3$, 162 MHz



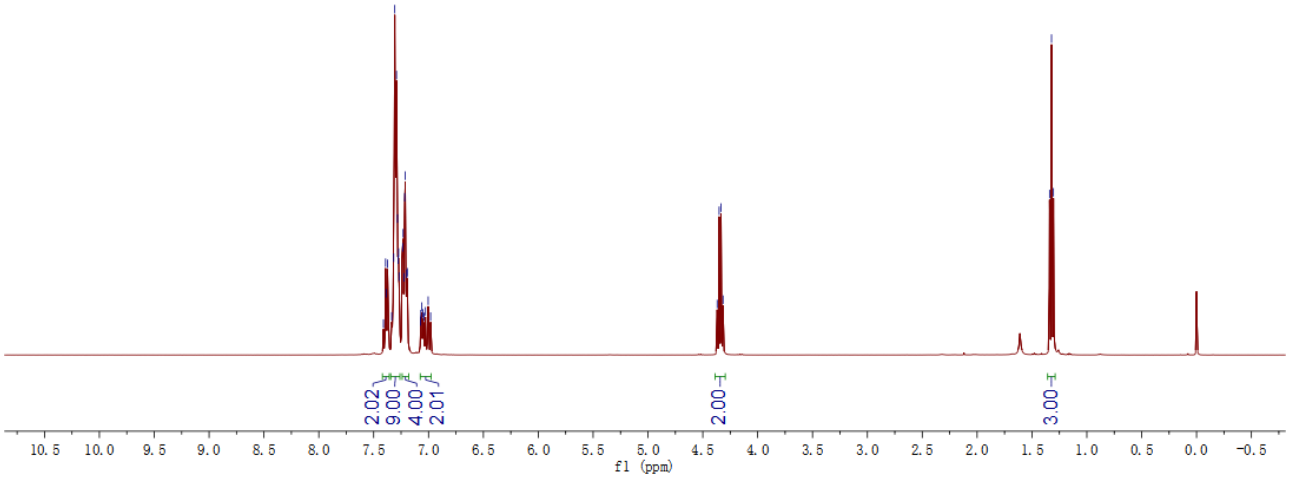
3k

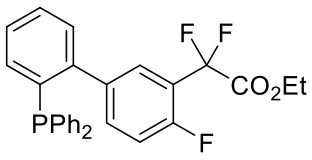
^{19}F NMR, $CDCl_3$, 377 MHz



3l

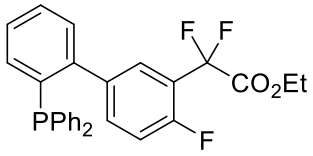
^{1}H NMR, $CDCl_3$, 400 MHz





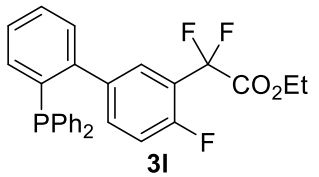
3l

^{13}C NMR, $CDCl_3$, 101 MHz



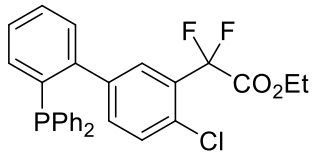
3l

^{31}P NMR, $CDCl_3$, 162 MHz



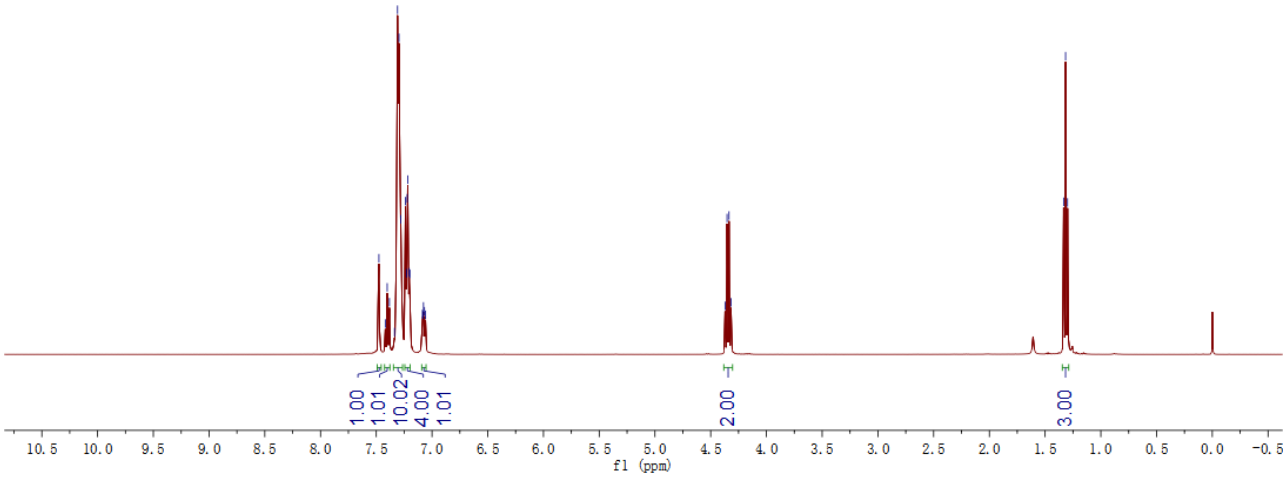
3l

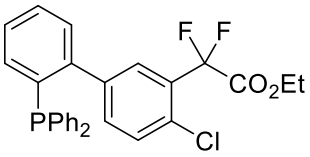
^{19}F NMR, $CDCl_3$, 377 MHz



3m

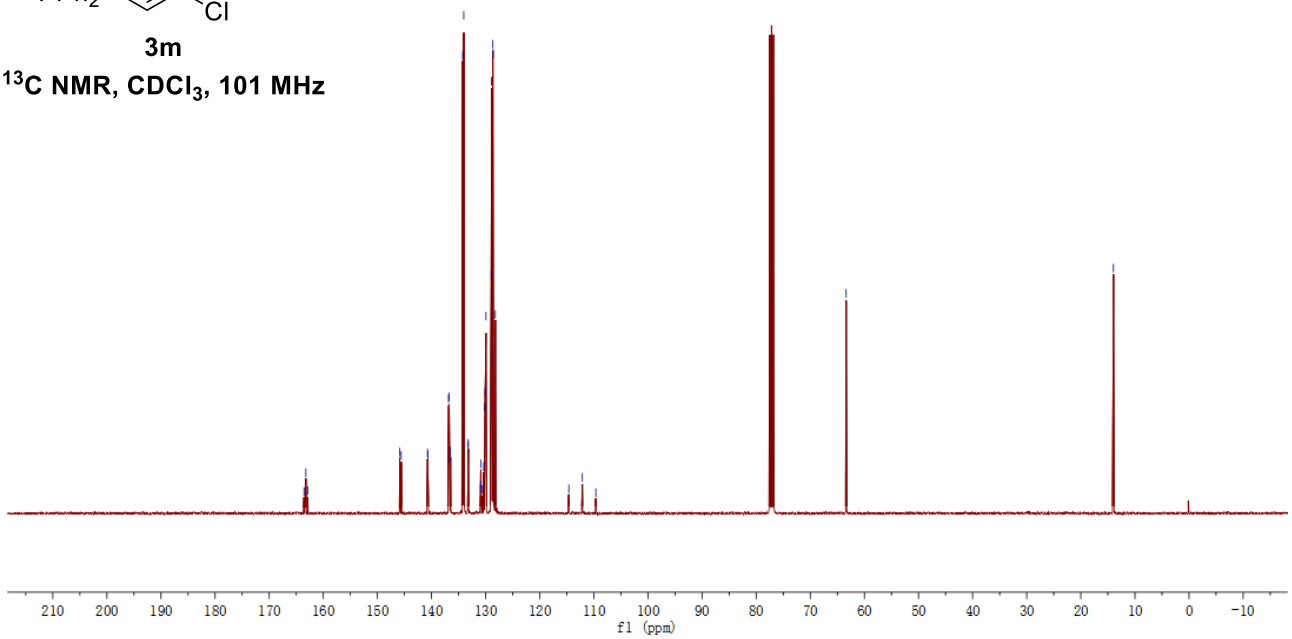
^{1}H NMR, $CDCl_3$, 400 MHz

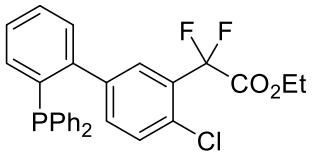




3m

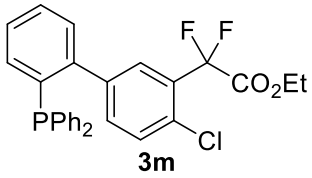
^{13}C NMR, $CDCl_3$, 101 MHz





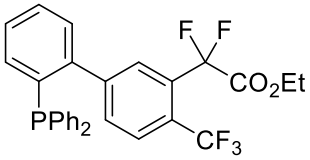
3m

^{31}P NMR, $CDCl_3$, 162 MHz



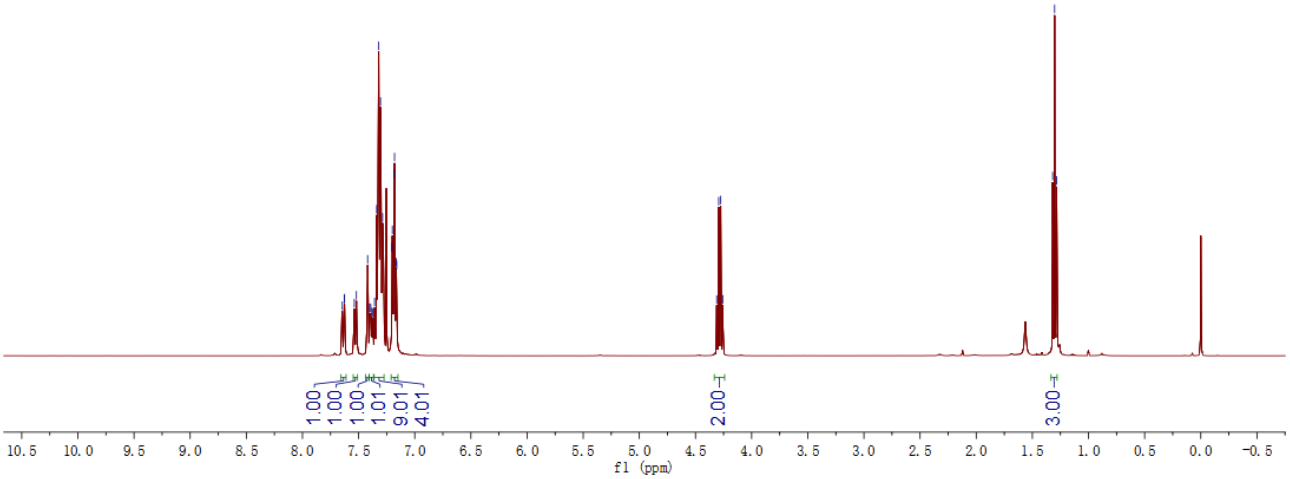
3m

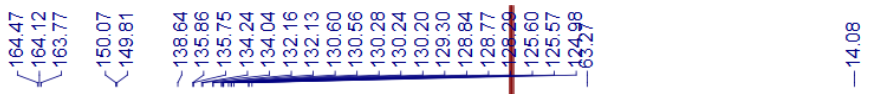
^{19}F NMR, $CDCl_3$, 377 MHz

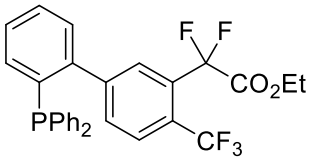


3n

^{1}H NMR, $CDCl_3$, 400 MHz

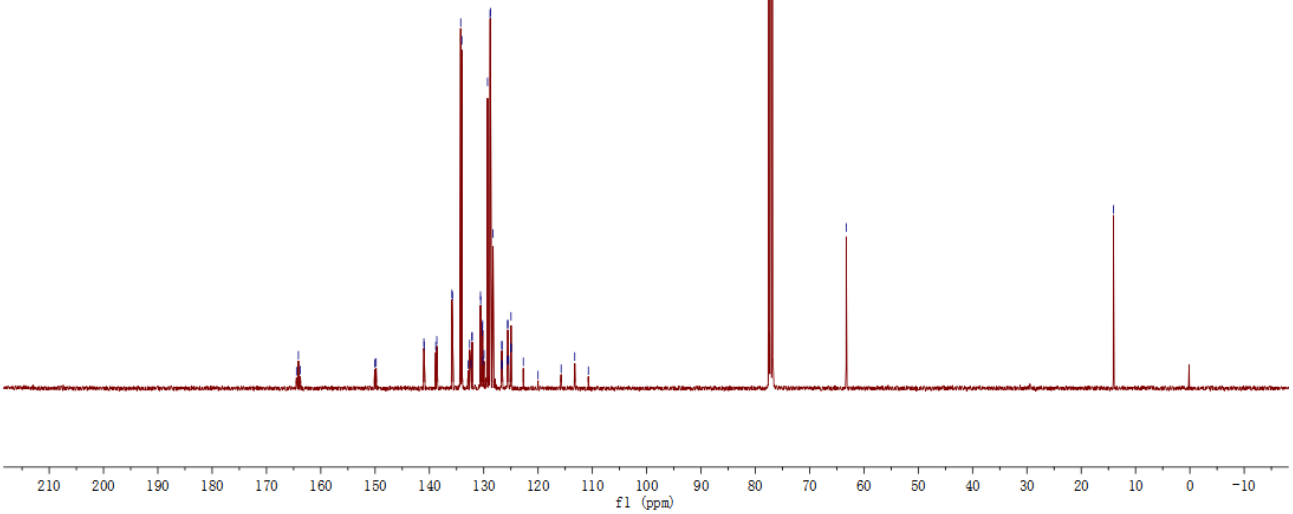


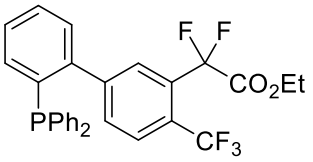




3n

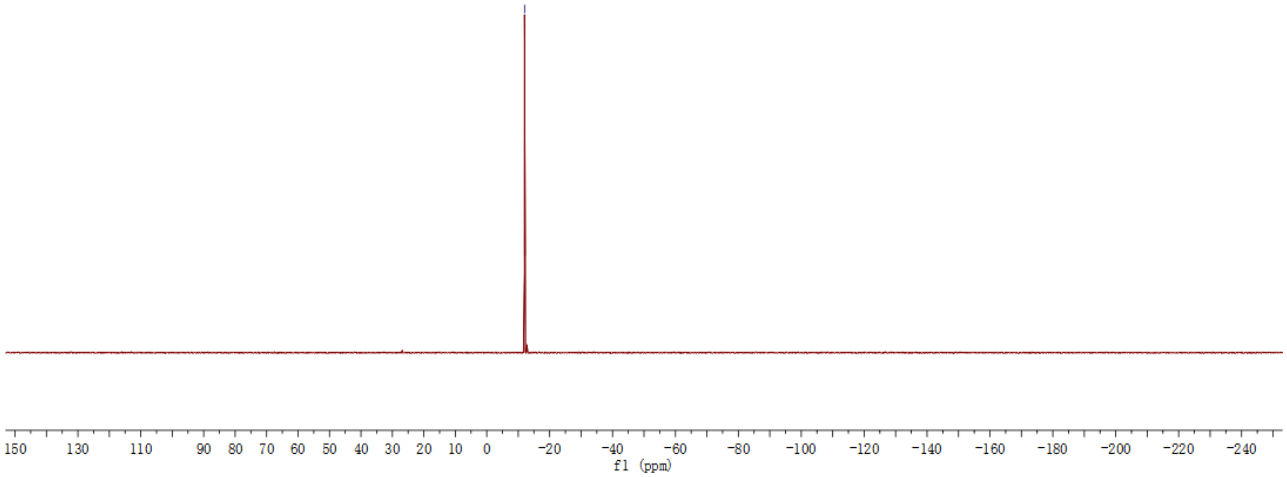
^{13}C NMR, $CDCl_3$, 101 MHz

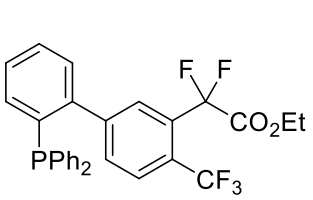




3n

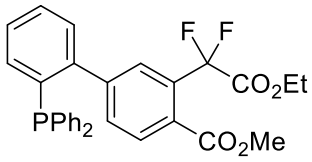
^{31}P NMR, $CDCl_3$, 162 MHz





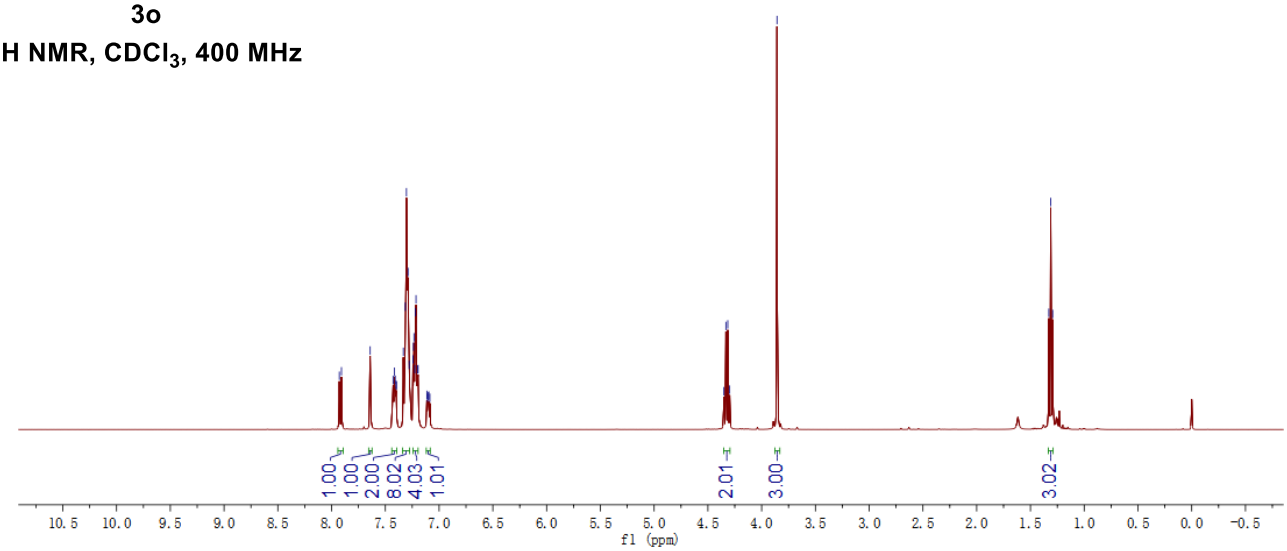
3n

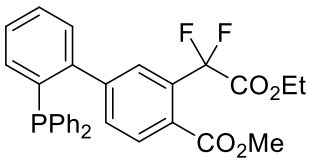
^{19}F NMR, $CDCl_3$, 377 MHz



3o

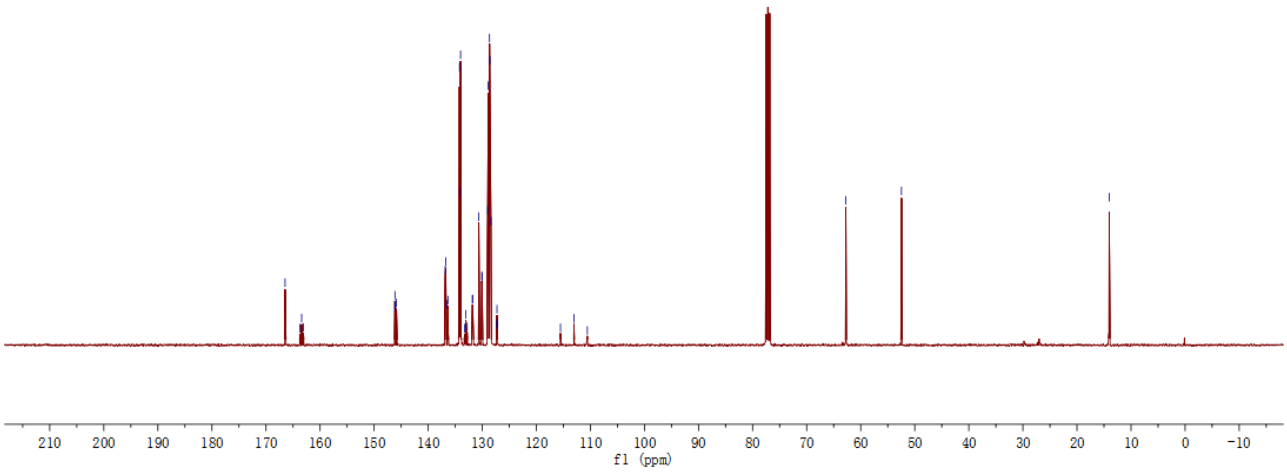
^{1}H NMR, $CDCl_3$, 400 MHz

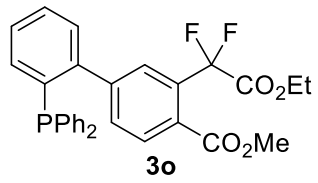




3o

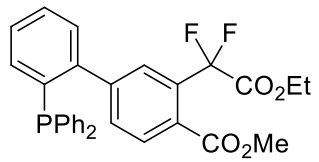
^{13}C NMR, $CDCl_3$, 101 MHz





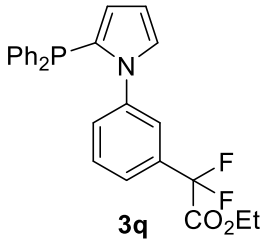
3o

^{31}P NMR, $CDCl_3$, 162 MHz



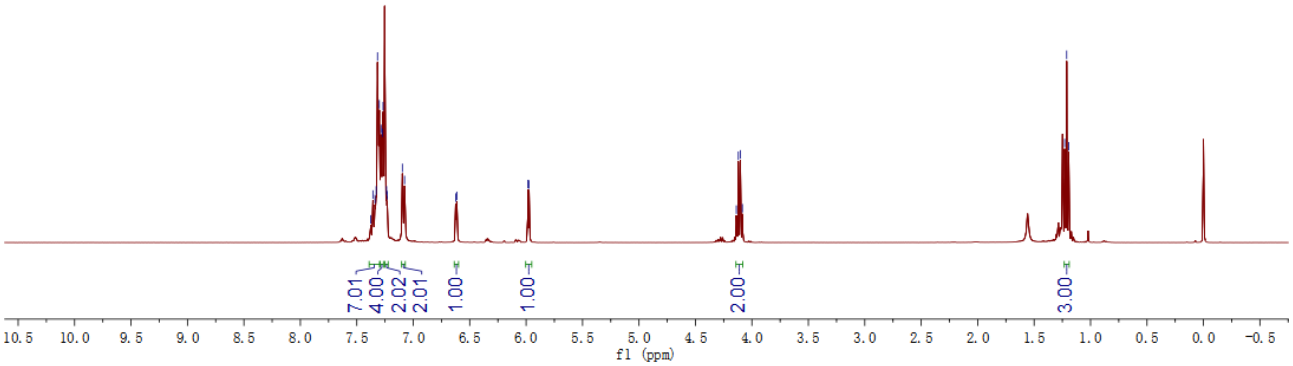
3o

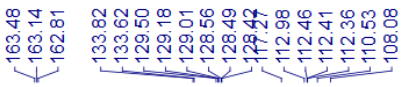
^{19}F NMR, $CDCl_3$, 377 MHz

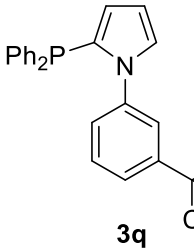


3q

^{1}H NMR, $CDCl_3$, 400 MHz

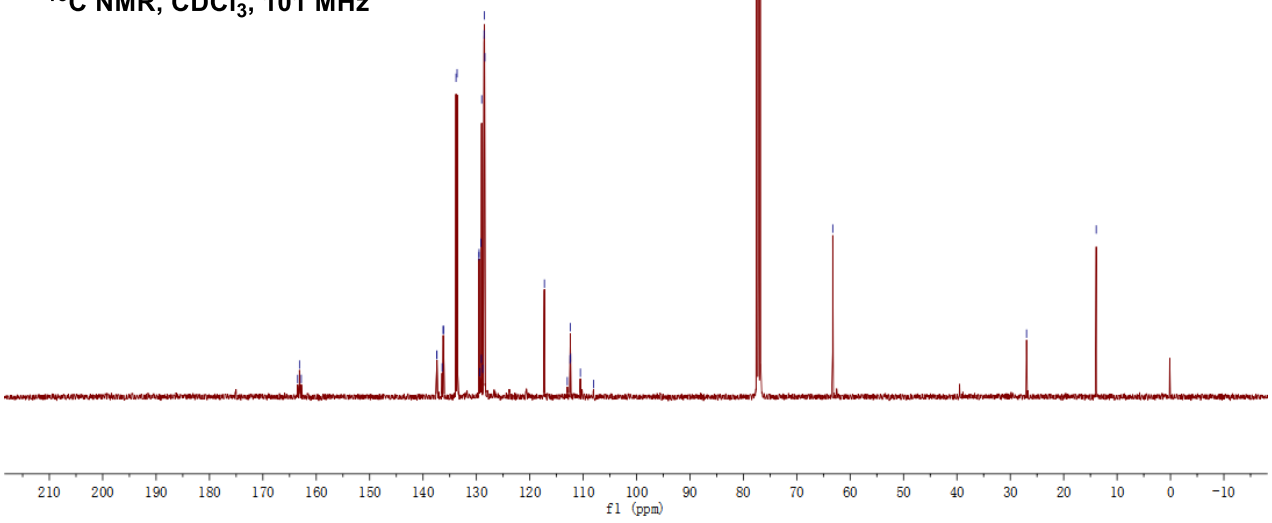


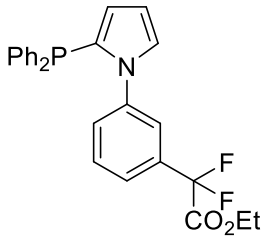




3q

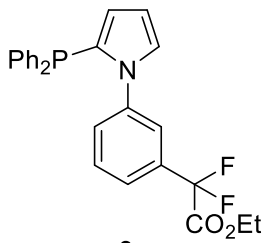
^{13}C NMR, $CDCl_3$, 101 MHz





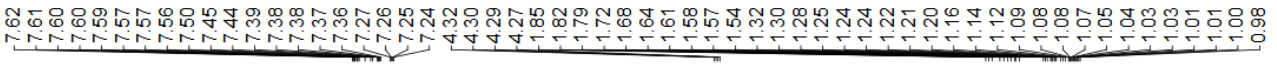
3q

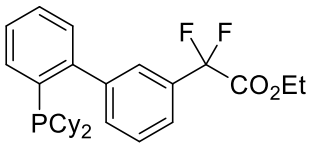
^{31}P NMR, $CDCl_3$, 162 MHz



3q

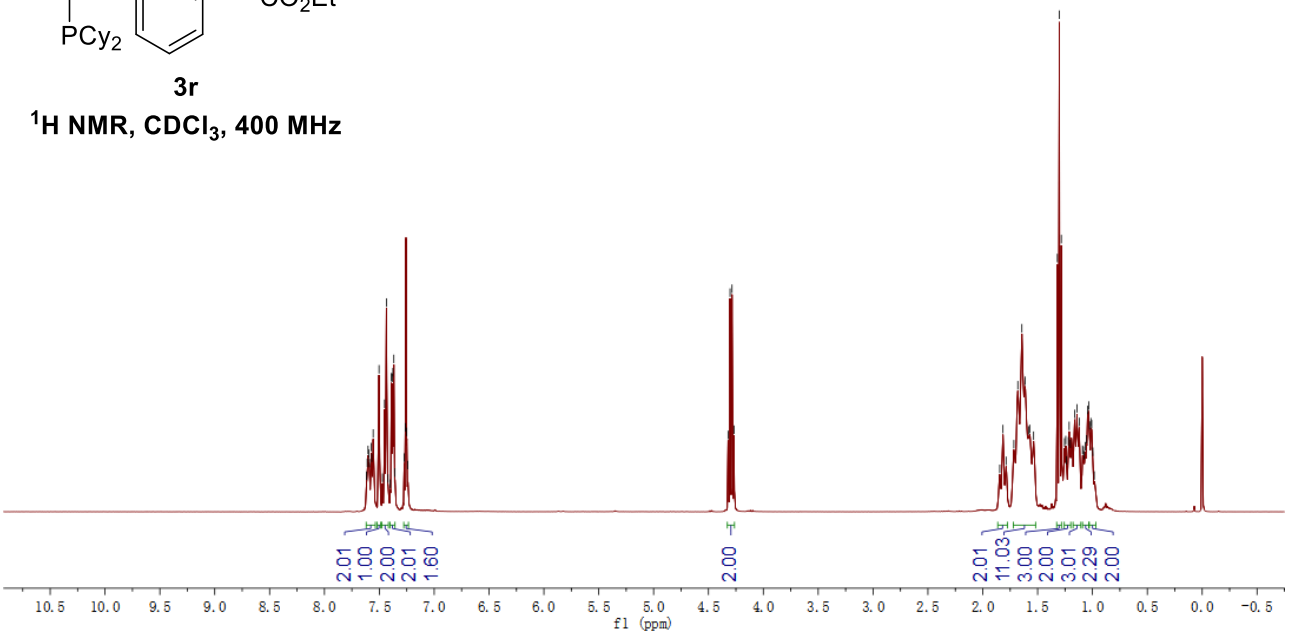
^{19}F NMR, $CDCl_3$, 377 MHz

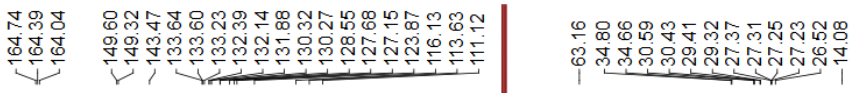


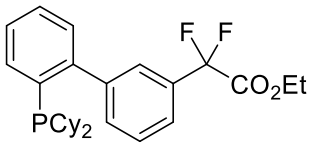


3r

^{1}H NMR, $CDCl_3$, 400 MHz

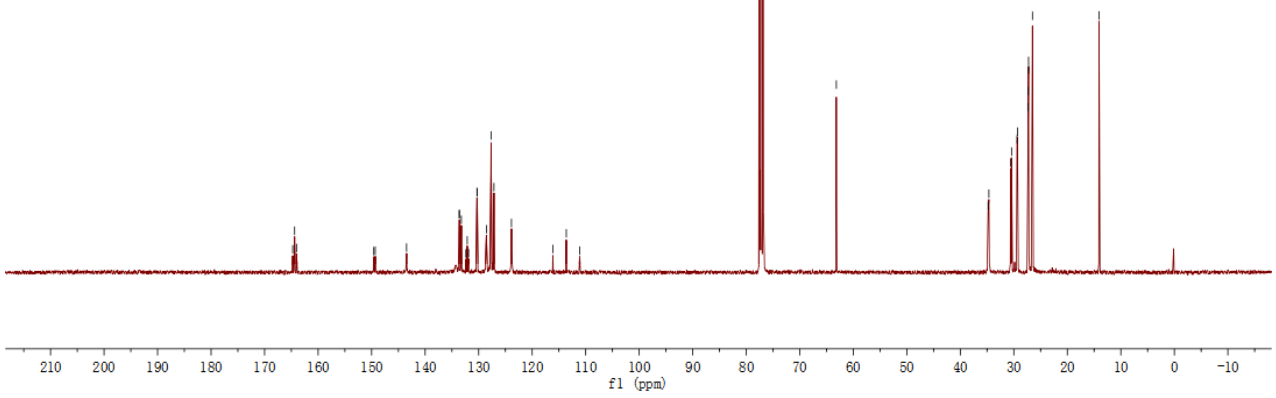


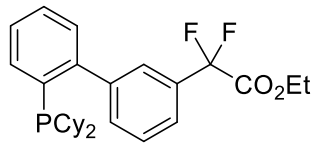




3r

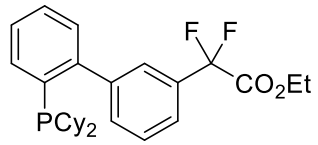
^{13}C NMR, $CDCl_3$, 101 MHz





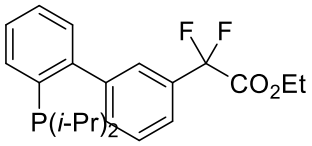
3r

^{31}P NMR, $CDCl_3$, 162 MHz



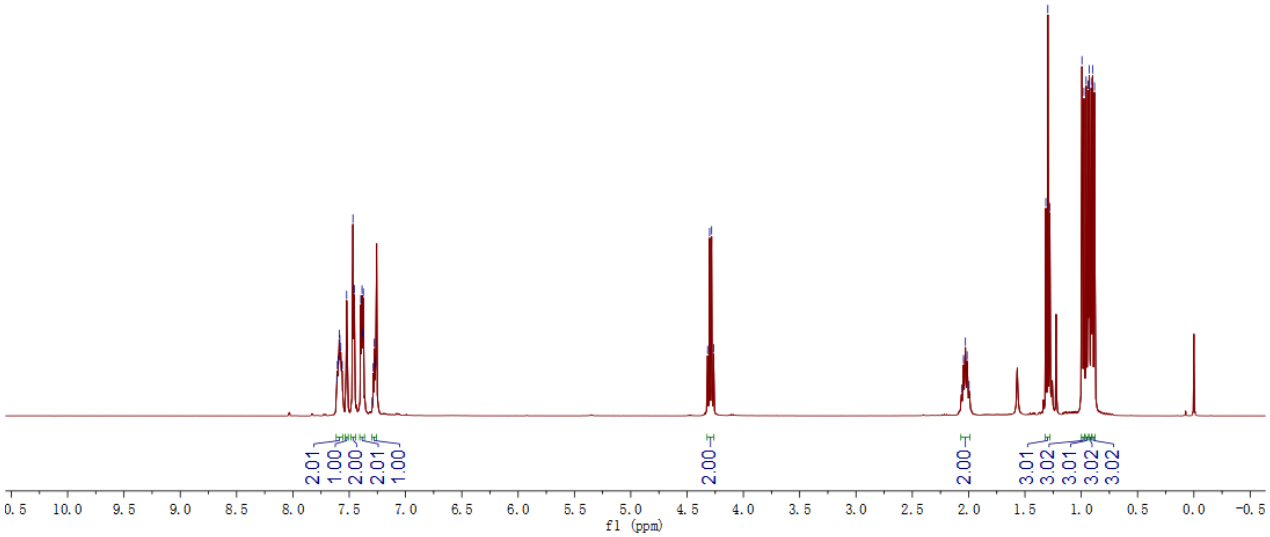
3r

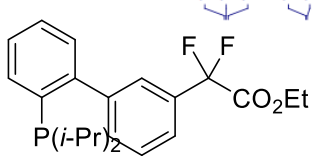
^{19}F NMR, $CDCl_3$, 377 MHz



3s

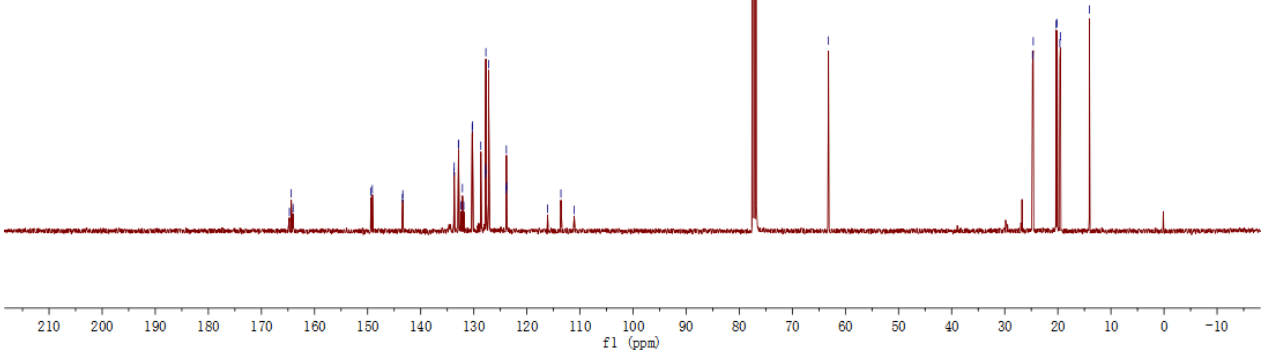
^{1}H NMR, $CDCl_3$, 400 MHz

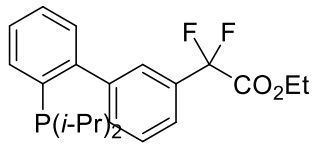




3s

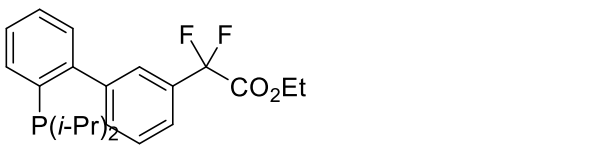
^{13}C NMR, $CDCl_3$, 101 MHz





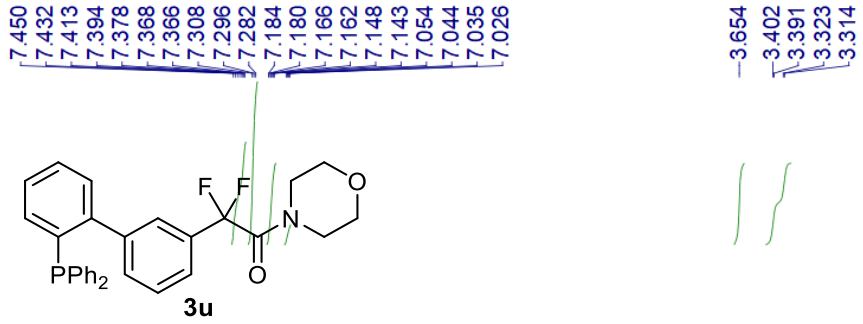
3s

^{31}P NMR, $CDCl_3$, 162 MHz



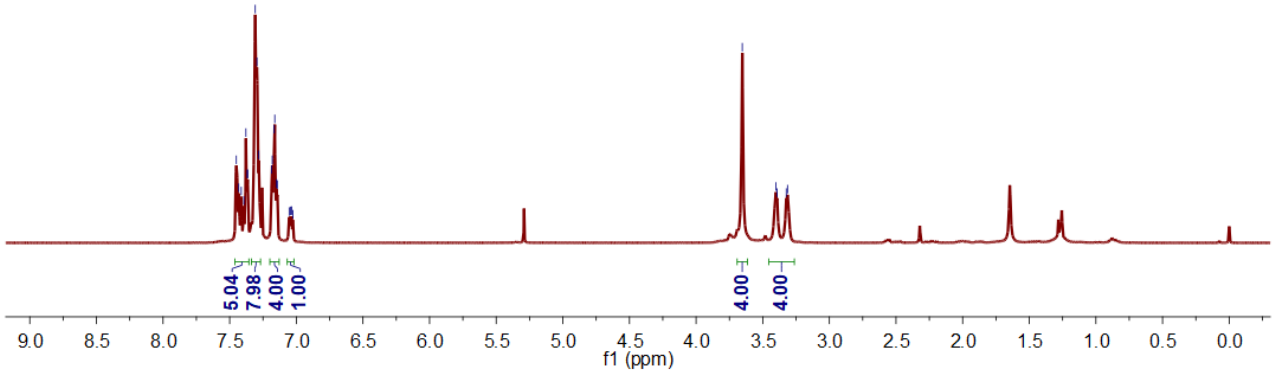
3s

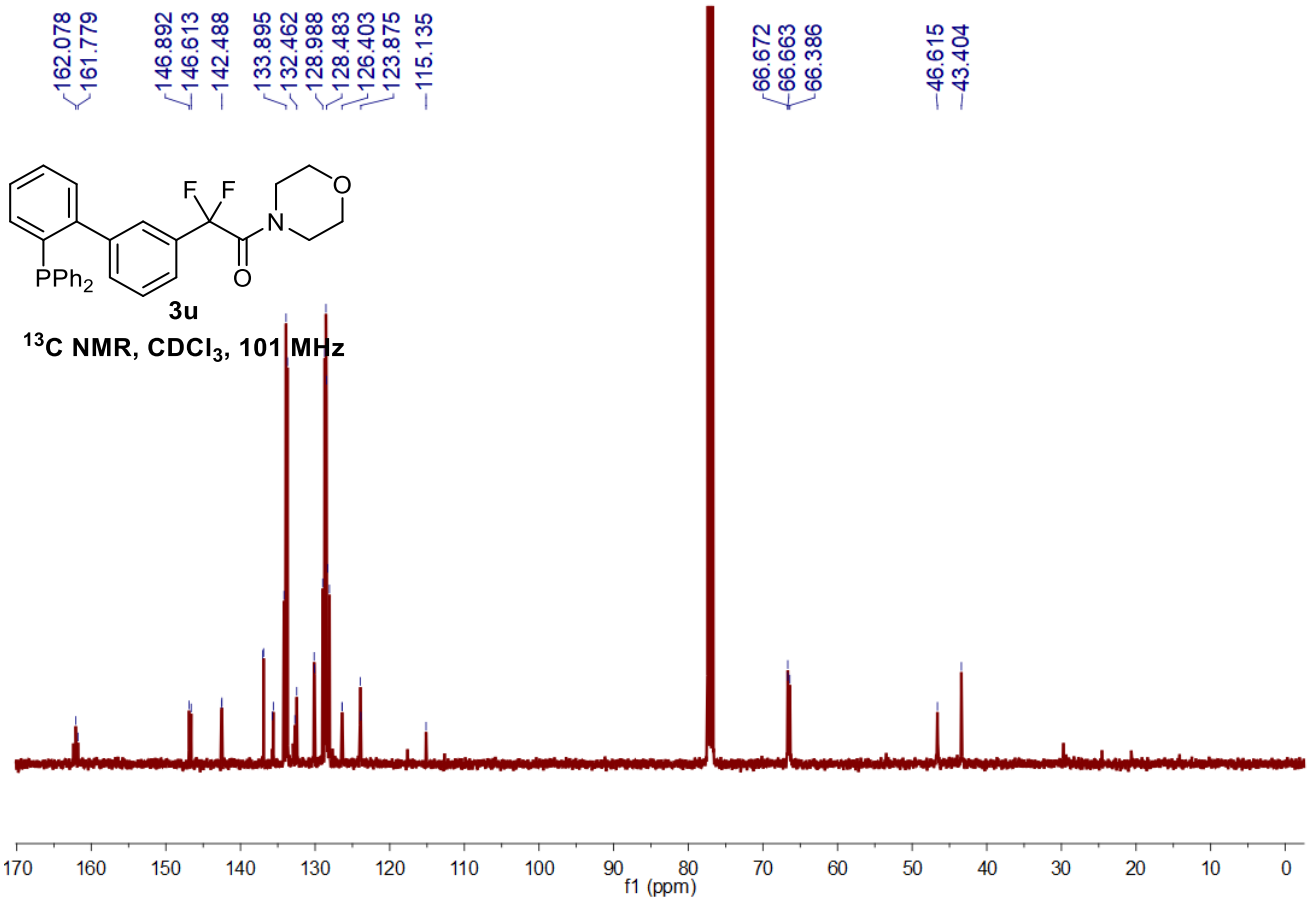
^{19}F NMR, $CDCl_3$, 377 MHz



3u

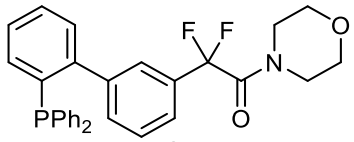
^{1}H NMR, $CDCl_3$, 400 MHz





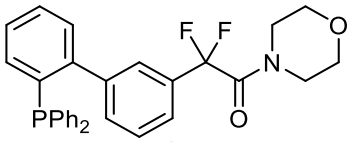
3u

^{13}C NMR, $CDCl_3$, 101 MHz



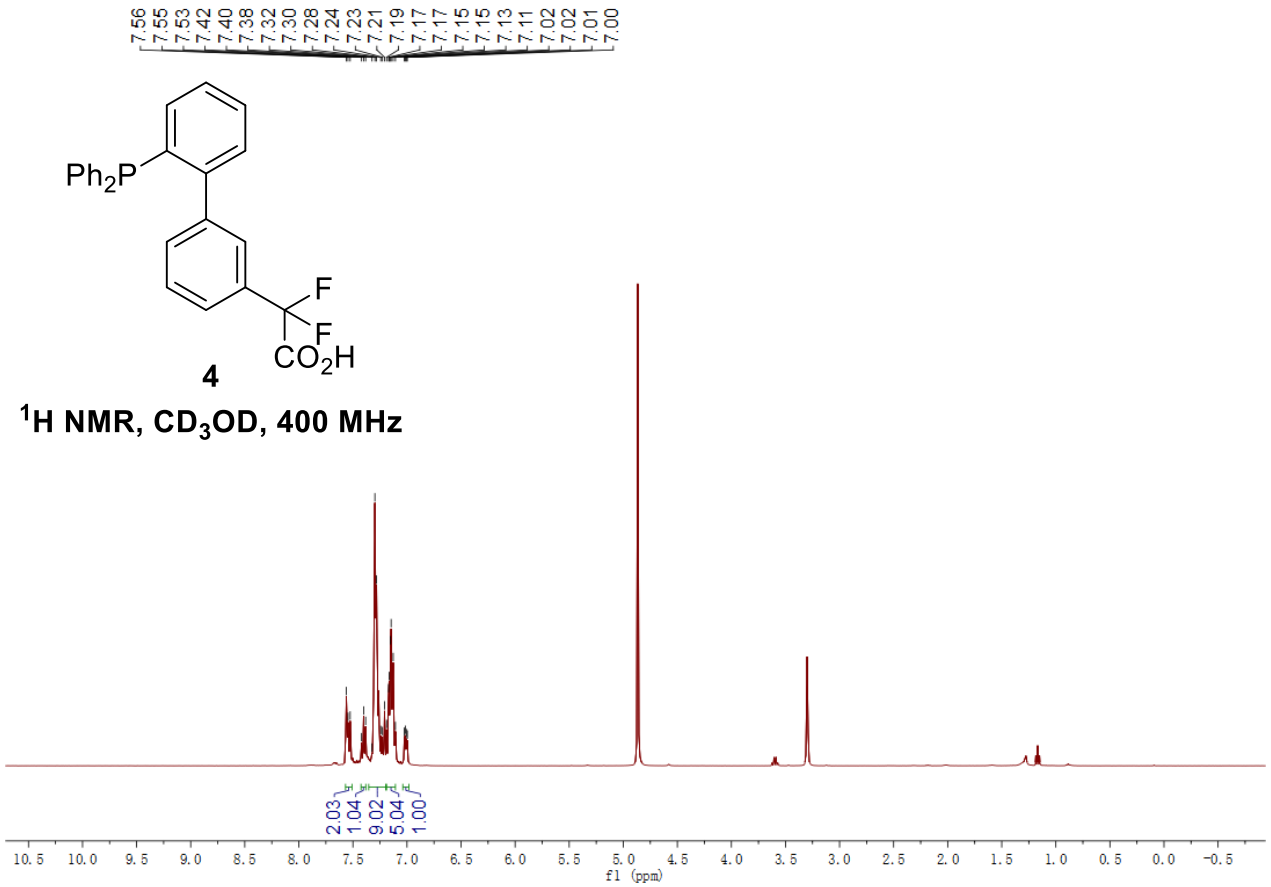
3u

^{31}P NMR, $CDCl_3$, 162 MHz



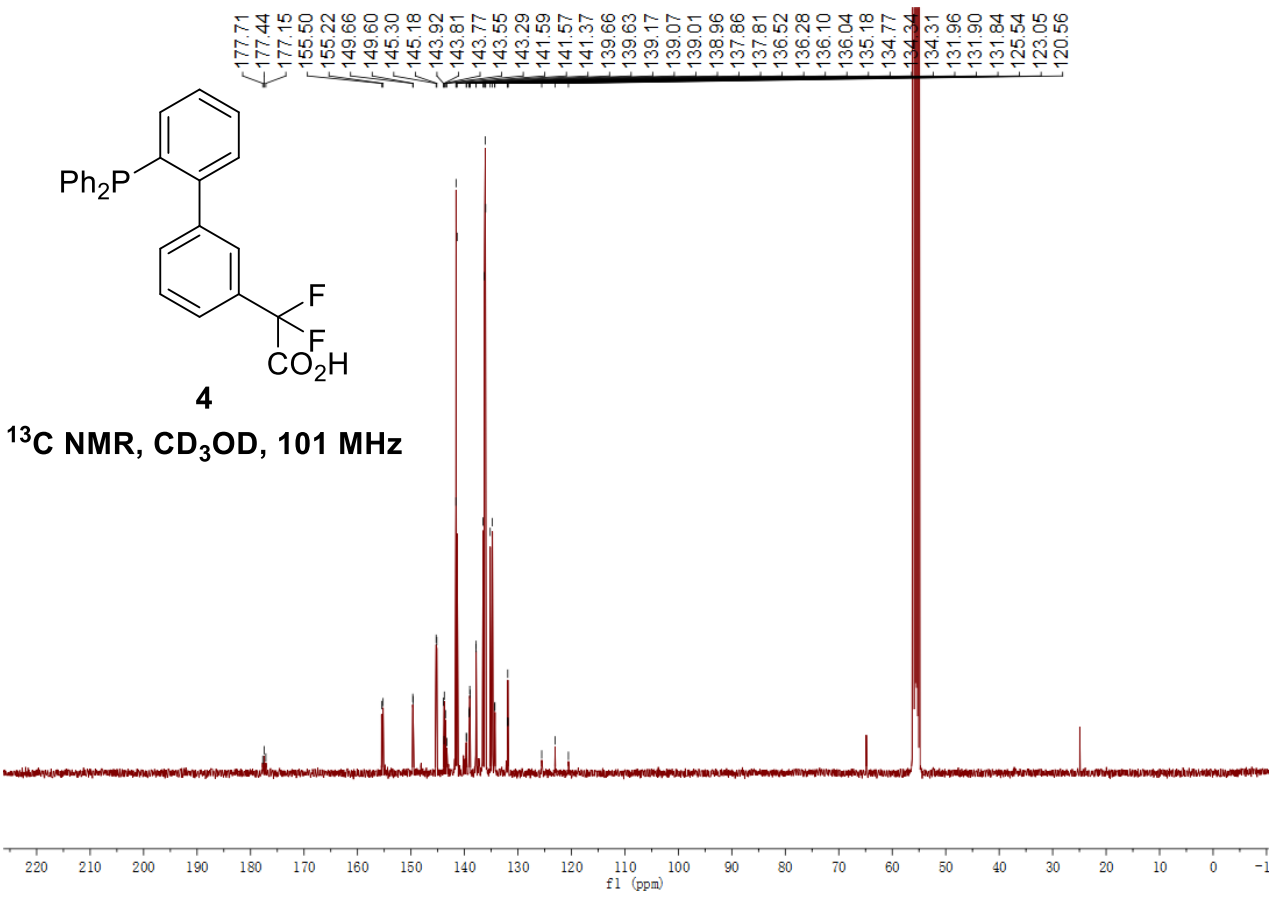
3u

^{19}F NMR, $CDCl_3$, 377 MHz



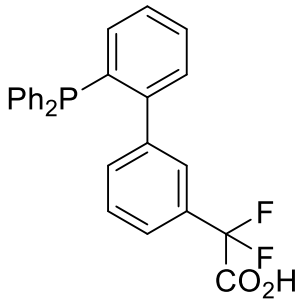
4

^{1}H NMR, CD_3OD, 400 MHz



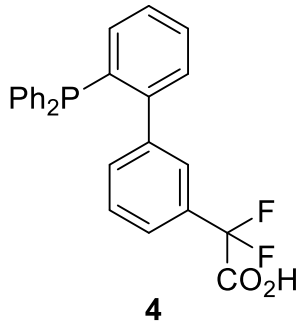
4

^{13}C NMR, CD_3OD, 101 MHz



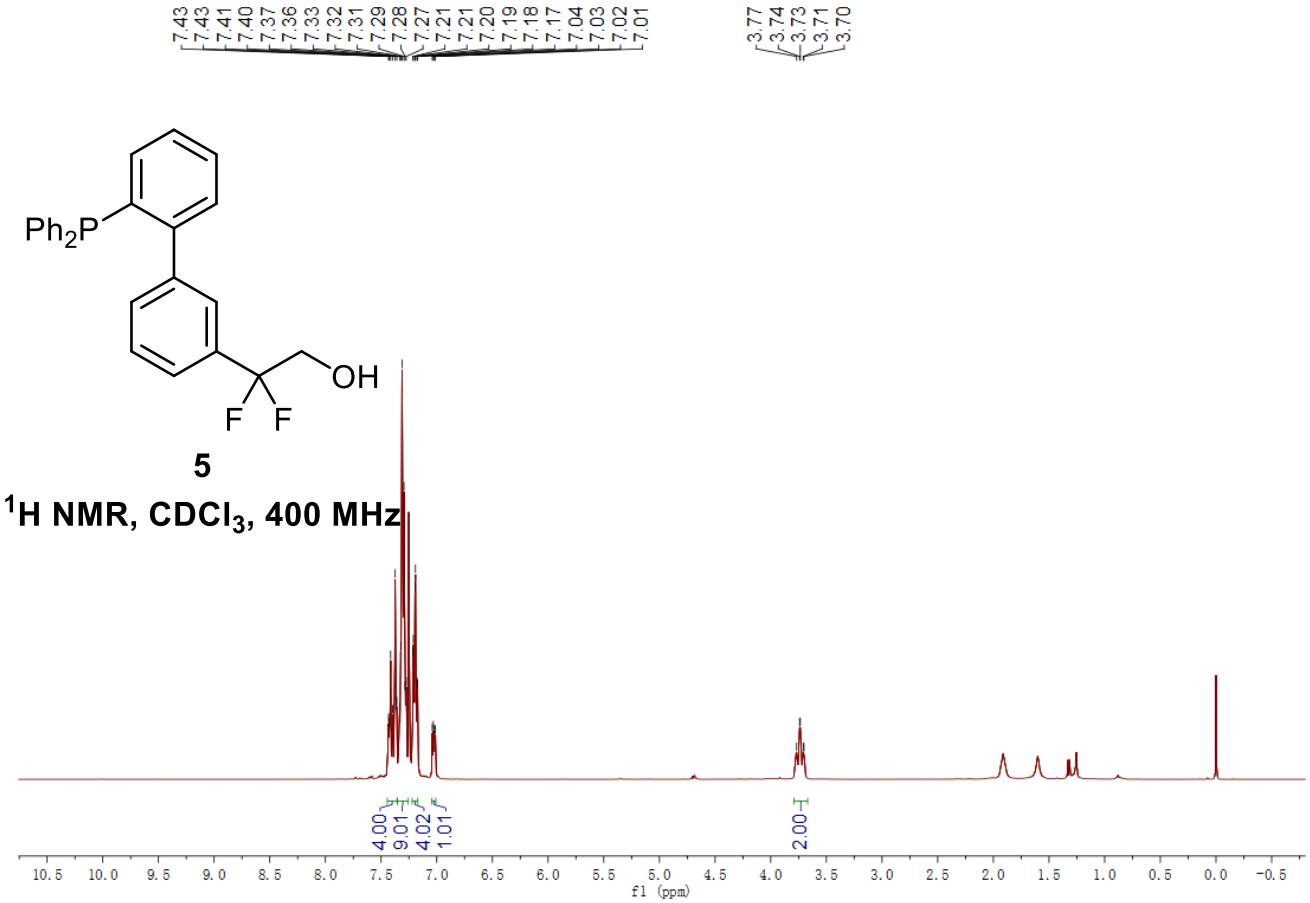
4

^{31}P NMR, CD_3OD, 162 MHz



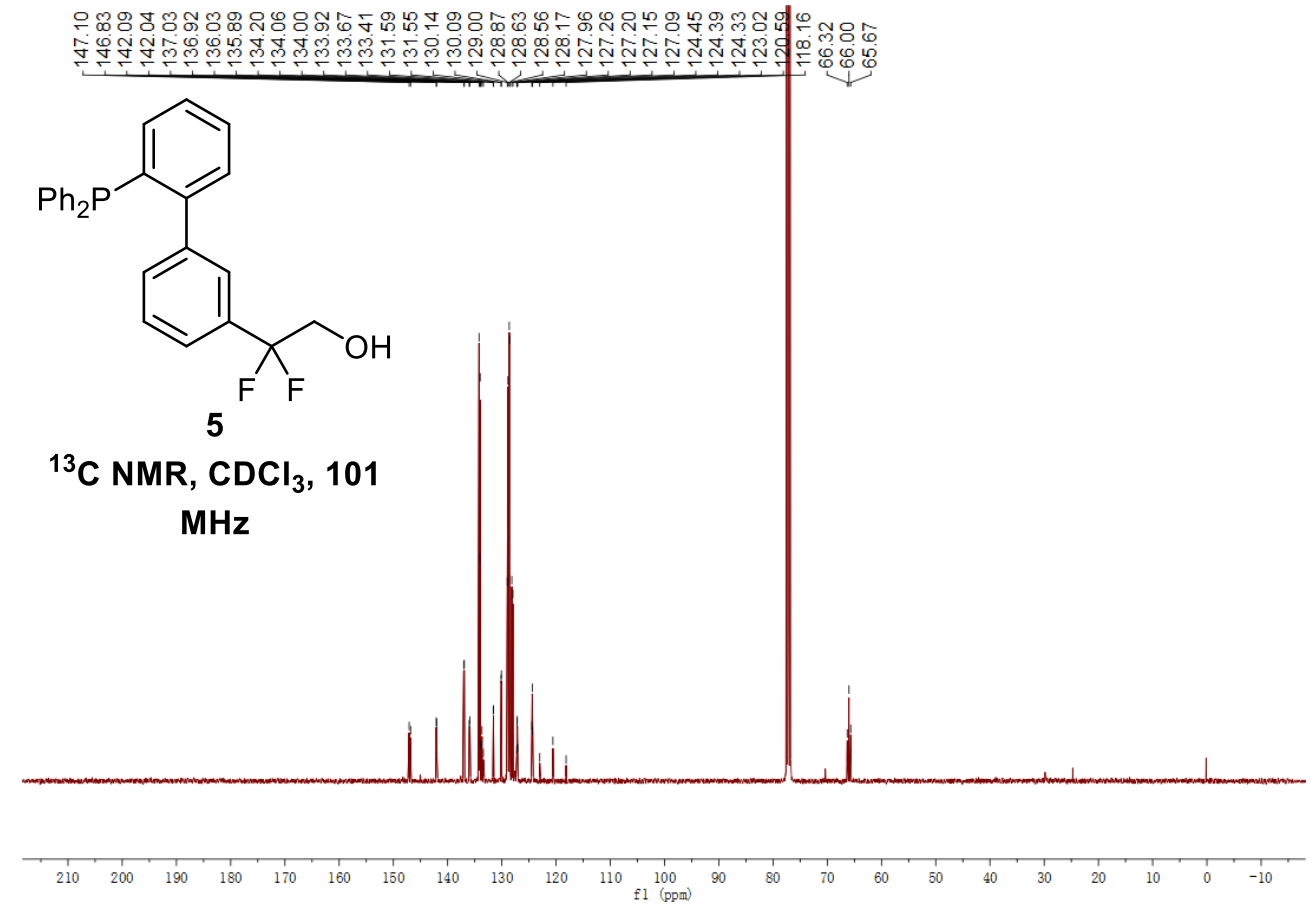
4

^{19}F NMR, CD_3OD, 377 MHz



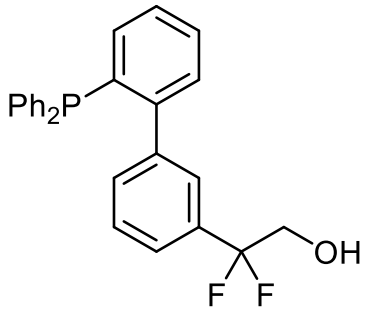
5

^{1}H NMR, $CDCl_3$, 400 MHz



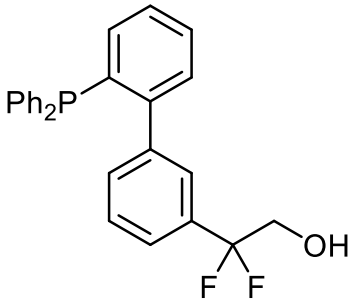
5

^{13}C NMR, $CDCl_3$, 101 MHz



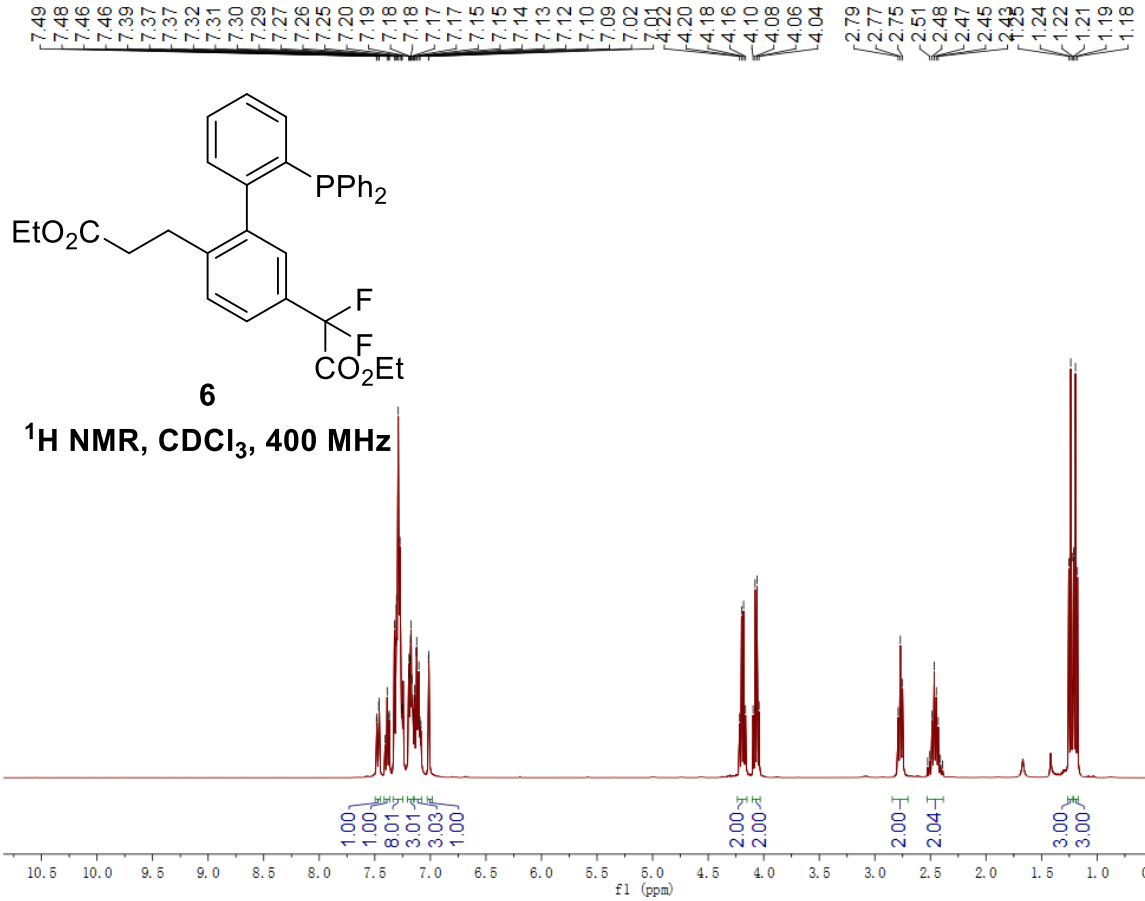
5

^{31}P NMR, $CDCl_3$, 162 MHz



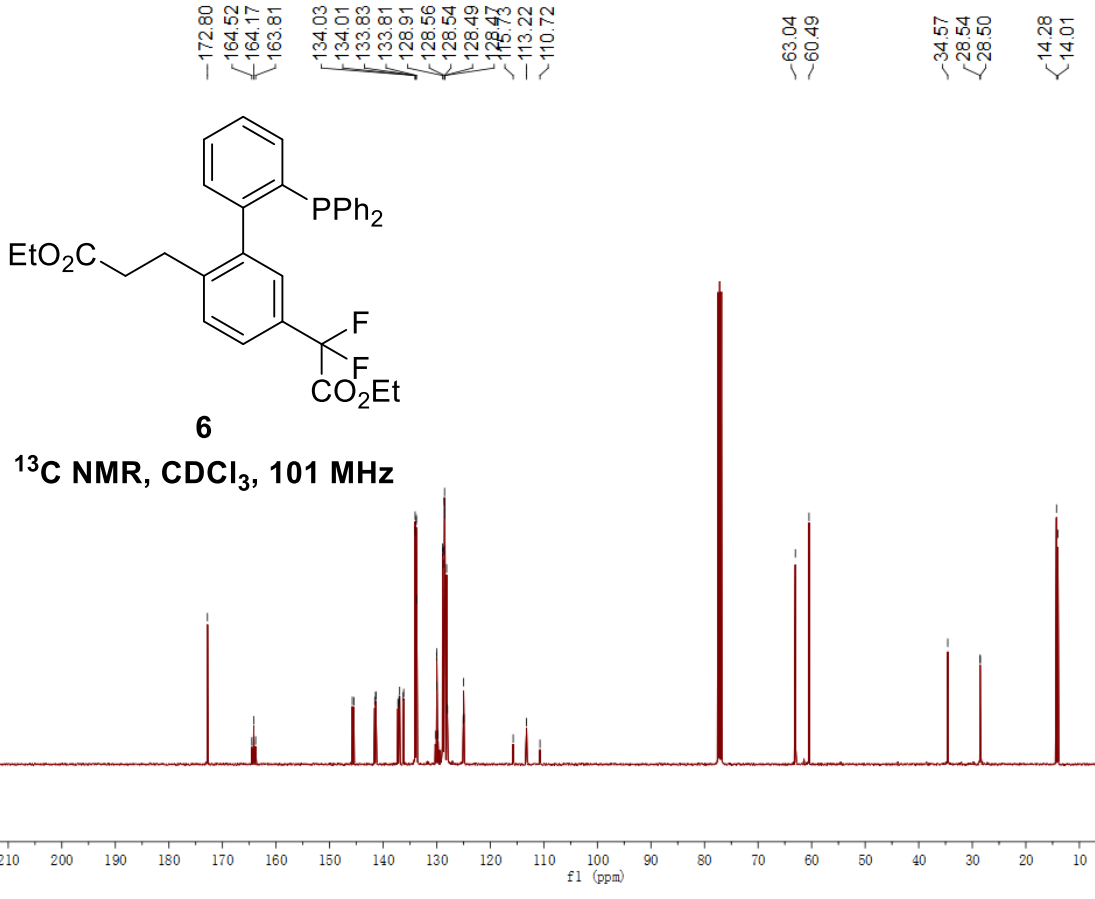
5

^{19}F NMR, $CDCl_3$, 377 MHz



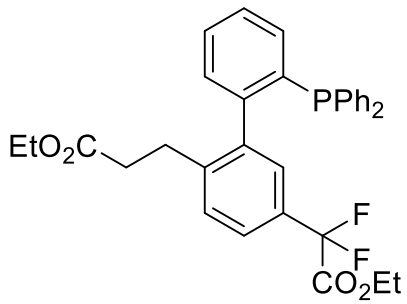
6

^{1}H NMR, $CDCl_3$, 400 MHz



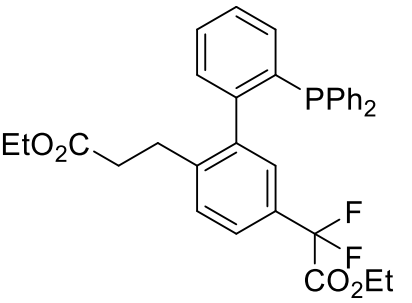
6

^{13}C NMR, $CDCl_3$, 101 MHz



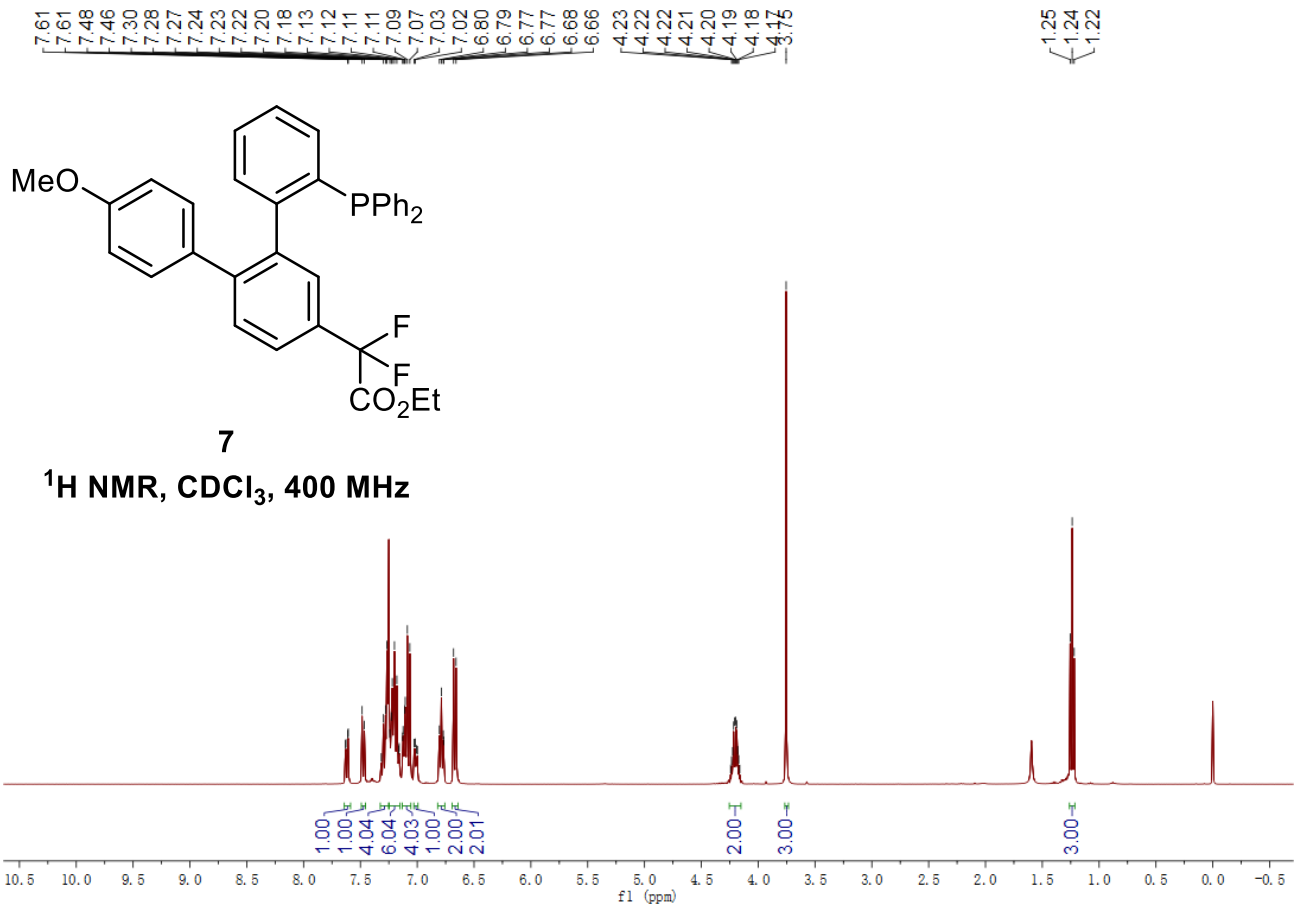
6

^{31}P NMR, $CDCl_3$, 162 MHz



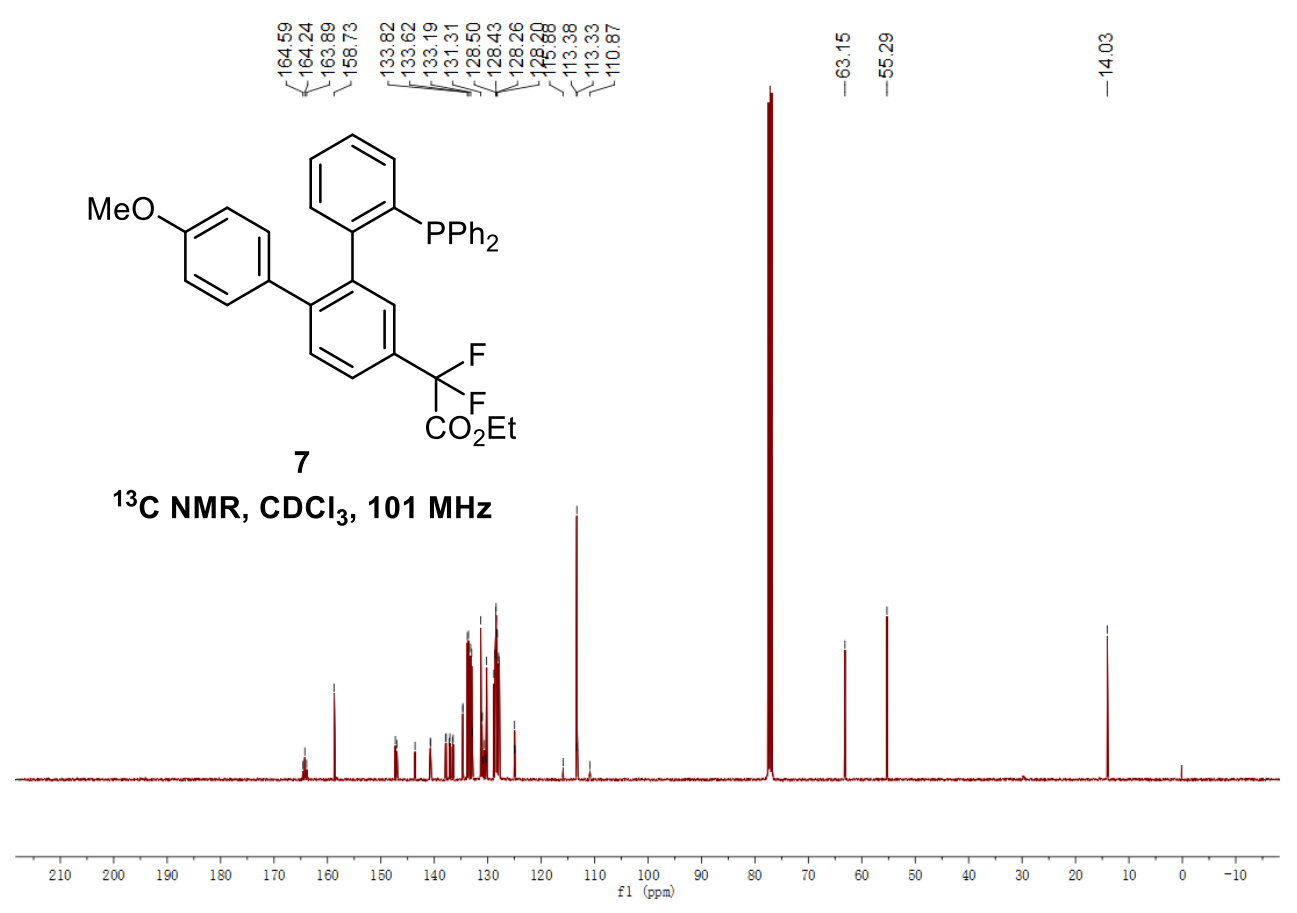
6

^{19}F NMR, $CDCl_3$, 377 MHz



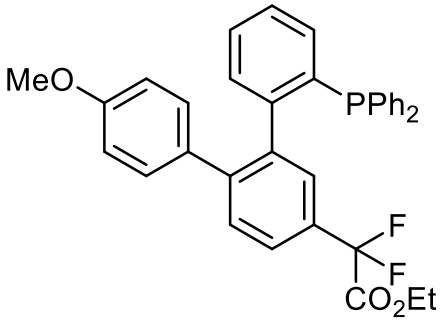
7

^{1}H NMR, $CDCl_3$, 400 MHz



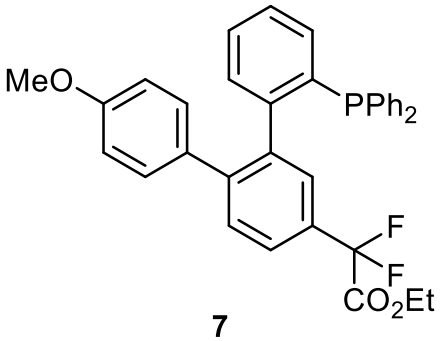
7

^{13}C NMR, $CDCl_3$, 101 MHz



7

^{31}P NMR, $CDCl_3$, 162 MHz



7

^{19}F NMR, $CDCl_3$, 377 MHz