

9-Borabicyclo[3.3.1]nonane-induced Friedel–Crafts benzylation of arenes with benzyl fluorides

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Supporting Information

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General information

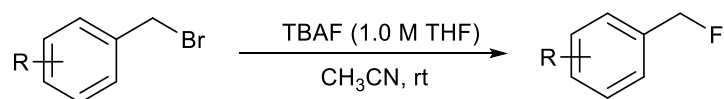
All preparative procedures were performed in an inert atmosphere of dry, deoxygenated ($O_2 < 0.5$ ppm) nitrogen, using glovebox techniques or standard Schlenk techniques unless otherwise specified. Solvents were stored over activated 4Å molecular sieves following drying procedures. Dichloromethane (DCM or CH_2Cl_2) and toluene were purchased from Sigma Aldrich and were dried using a Grubbs-type Innovative Technologies solvent purification system. Mesitylene, benzene, fluorobenzene, 1,2-dichlorobenzene, hexafluorobenzene (C_6F_6), and 1,2-difluorobenzene were obtained from Sigma Aldrich, dried by distillation from CaH_2 or sodium-benzophenone. Deuterated solvents ($CDCl_3$, C_6D_6 , toluene- d_8) were purchased from Cambridge Isotope Laboratories, Inc. and distilled from CaH_2 or sodium-benzophenone prior to use. *p*-Xylene and anisole were obtained from Sigma Aldrich and dried over 4 Å molecular sieves. Spectrograde chloroform used in GC-MS sample preparations was obtained from ACP Chemicals. Tris(pentafluorophenyl)borane was obtained from Boulder Scientific and used without further purification. Piers' borane ($HB(C_6F_5)_2$) was synthesized according to literature procedure.¹ 9-Borabicyclo[3.3.1]nonane dimer (9-BBN dimer), triethylsilane, benzyl bromide, 4-*tert*-butylbenzyl bromide, 3-methylbenzyl bromide, 3-methoxybenzyl bromide, 3-bromobenzyl bromide, 4-fluorobenzyl bromide and diphenylmethane were obtained from Sigma Aldrich and used without further purification. 3-Methylbenzyl bromide and 4-bromomethylbiphenyl were obtained from TCI Chemical. The 1.0 M solution of tetrabutylammonium fluoride in THF used in benzyl fluoride synthesis was obtained from Sigma Aldrich. Acetonitrile and ethyl acetate were obtained from Fisher Chemical. Thin-layer chromatography (TLC) was performed on EMD Silica Gel 60 F254 aluminum plates or EMD basic Aluminium Oxide 60 F254 plastic plates. Silicycle Silia-P Flash Silica Gel was used for all column chromatography. Brockmann I grade basic alumina used for sample preparation for GC-MS was obtained from Sigma Aldrich.

All NMR spectra were collected at 298 K on Agilent VnmrS 400 or Agilent VnmrS 500 spectrometers in 5 mm diameter NMR tubes. 1H chemical shifts are reported relative to proteo-solvent signals ($CDCl_3$, $\delta = 7.26$ ppm). Data are reported as: chemical shift (δ ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, dd = doublet of doublets, td = triplet of doublets, dt = doublet of triplets, ddd = doublet of doublet of doublets), coupling constants (Hz), integration and assignment. $^{13}C\{^1H\}$ chemical shifts are reported relative to proteo-solvent signals ($CDCl_3$, $\delta = 77.00$ ppm). ^{19}F NMR spectra were measured at 376 MHz or 470 MHz, and CFC_3 (-63.2 ppm) was used as an external standard. Hexafluorobenzene (C_6F_6) was used as an internal standard and used to measure the disappearance of C-F resonances of substrates and the

appearance of B-F resonances of fluoroborane by-products. Departmental facilities were used for mass spectrometry (DART: JEOL AccuTOF or ESI: Agilent 6538 Q-TOF).

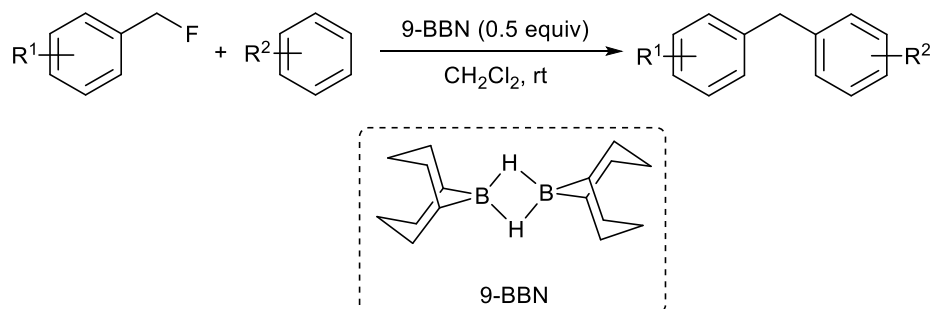
For determination of yield by GC-MS (Table 3), a Mandel GC-MS-QP2010 gas chromatograph-mass spectrometer equipped with a Rxi-5ms fused silica column (30 m length, 0.25 μm thickness, 0.25 mm ID) and helium carrier gas was used. The following 14 min sample program was used: Initial temperature 70 $^{\circ}\text{C}$, hold 2.00 min, increment 25 $^{\circ}\text{C}/\text{min}$ up to 230 $^{\circ}\text{C}$, hold 0 min, increment 35 $^{\circ}\text{C}/\text{min}$ to final temperature 300 $^{\circ}\text{C}$, hold 3.60 min. A solvent cut-off time of 2.50 min was used. The retention time for the standard and product (1) were 6.809 and 8.395 minutes, respectively.

Preparation of benzyl fluorides



The procedures used were based on previously reported methods.^{2,3} To a stirred solution of the benzylic bromide (10 mmol, 1.0 equiv.) in acetonitrile (5 mL) was added a solution 1.0 M of tetrabutylammonium fluoride in THF (20 mL, 2.0 equiv.). The reaction mixture was stirred for 24 h at room temperature. The reaction was subsequently quenched with water and extracted with ethyl acetate. The combined organic extracts were washed with brine, dried with Na_2SO_4 , filtered and concentrated under vacuum. The residue was purified by flash chromatography (hexane or hexanes/ethyl acetate eluent) on silica gel to afford benzyl fluoride product.

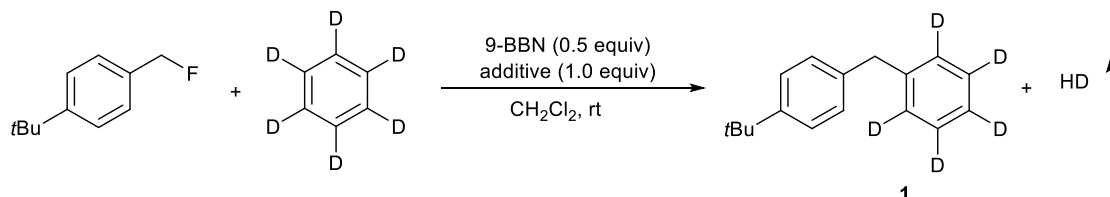
Preparation of diarylmethanes



In an inert atmosphere glovebox, the mixture of benzyl fluorides (0.05 mmol) with the arene nucleophile (0.2 mL or 0.1 mL) and 0.2 mL CH_2Cl_2 was added a solution of 9-BBN dimer (6.2 mg,

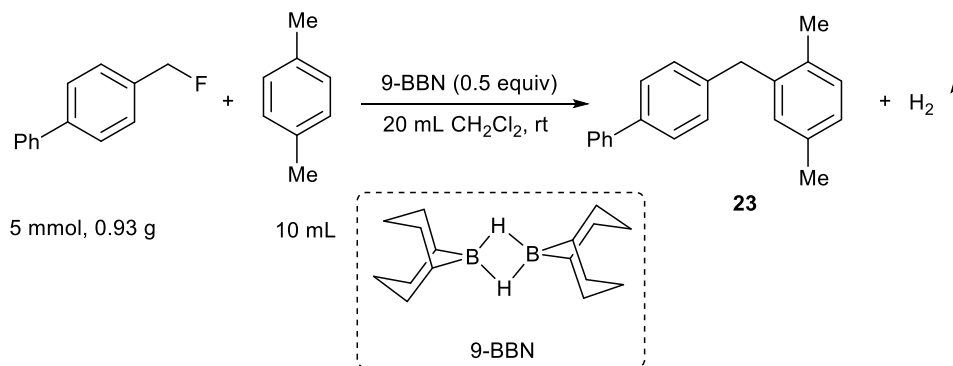
0.025 mmol) in 0.2 mL CH₂Cl₂. The reaction mixture was stirred for the specified time at room temperature and monitored by ¹⁹F NMR spectroscopy. The products were isolated following filtration through a short plug of basic alumina or silica using hexanes as eluent.

Functional group tolerance study for the benzylation



In an inert atmosphere glovebox, a solution of additive (0.05 mmol) in 0.2 mL C₆D₆ was added to 9-BBN dimer (6.2 mg, 0.025 mmol) and transferred to a 5 mm NMR tube loaded with benzyl fluoride (0.05 mmol). An additional 0.4 mL of CH₂Cl₂ was used to transfer the borane/additive mixture to the NMR tube. The reaction was subsequently monitored by multinuclear NMR spectroscopy for 24 hours. After this period, an aliquot of analytically prepared standard stock solution, consisting of diphenylmethane in spectrograde chloroform, was added to the crude reaction mixture. The sample was then filtered through activated basic alumina with distilled pentanes and an aliquot was diluted with spectrograde chloroform for GC analysis.

Typical procedure for Gram-scale version of Friedel–Crafts benzylation

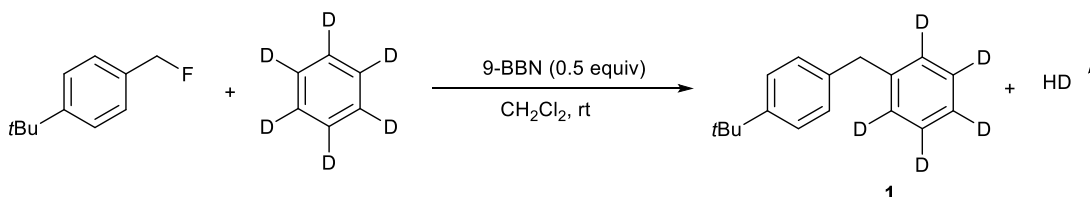


In an inert atmosphere glovebox, a flask (50 mL) was charged with 4-(fluoromethyl)-1,1'-biphenyl (0.93 g, 5.0 mmol). Then, *p*-xylene (10 mL) and 10 mL CH₂Cl₂ (10 mL) was added. Finally, a solution of 9-BBN dimer (0.62 g, 2.5 mmol) in 10 mL CH₂Cl₂ was added to the mixture under stirring. The reaction mixture was stirred at room temperature for **12 h**. The residue was purified

by flash chromatography (eluent: hexane/ethyl acetate = 50/1) on silica gel to afford the product **23** as a white solid (1.05 g, 77% yield).

Optimization of reaction conditions

Table S1 Optimization of reaction conditions^a

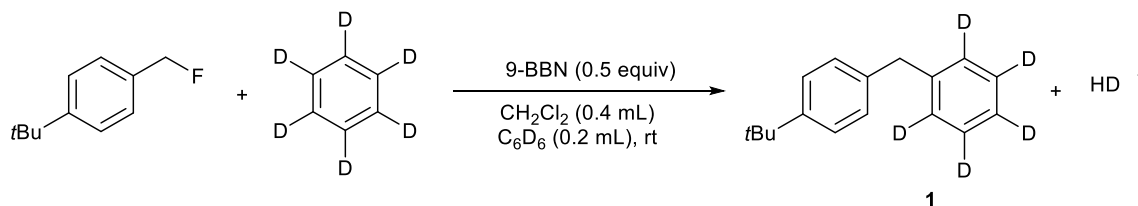


Entry	Volume C_6D_6	Co-solvent	Yield (%) ^b
1	0	0.6 mL DCM	0 ^c
2	9 μ L (1 equiv)	0.6 mL DCM	60 ^c
3	45 μ L (5 equiv)	0.6 mL DCM	78 ^c
4	0.1 mL	0.5 mL DCM	87
5	0.2 mL	0.4 mL DCM	95
6	0.4 mL	0.2 mL DCM	85 ^d
7	0.6 mL	0	45 ^d
8	0.2 mL	0.4 mL $CHCl_3$	72

^a All reactions were performed with 1-(*tert*-butyl)-4-(fluoromethyl)benzene (0.05 mmol), excess C_6D_6 (x mL) and 9-BBN (0.025 mmol, 6.2 mg) in co-solvent at 25 °C for 2 hours. ^b Isolated yield. ^c The polymerization of benzyl fluoride was observed. ^d Benzyl fluoride remained, according to 1H and ^{19}F NMR spectroscopic analysis.

Mechanistic Considerations

Representative reaction NMR spectra



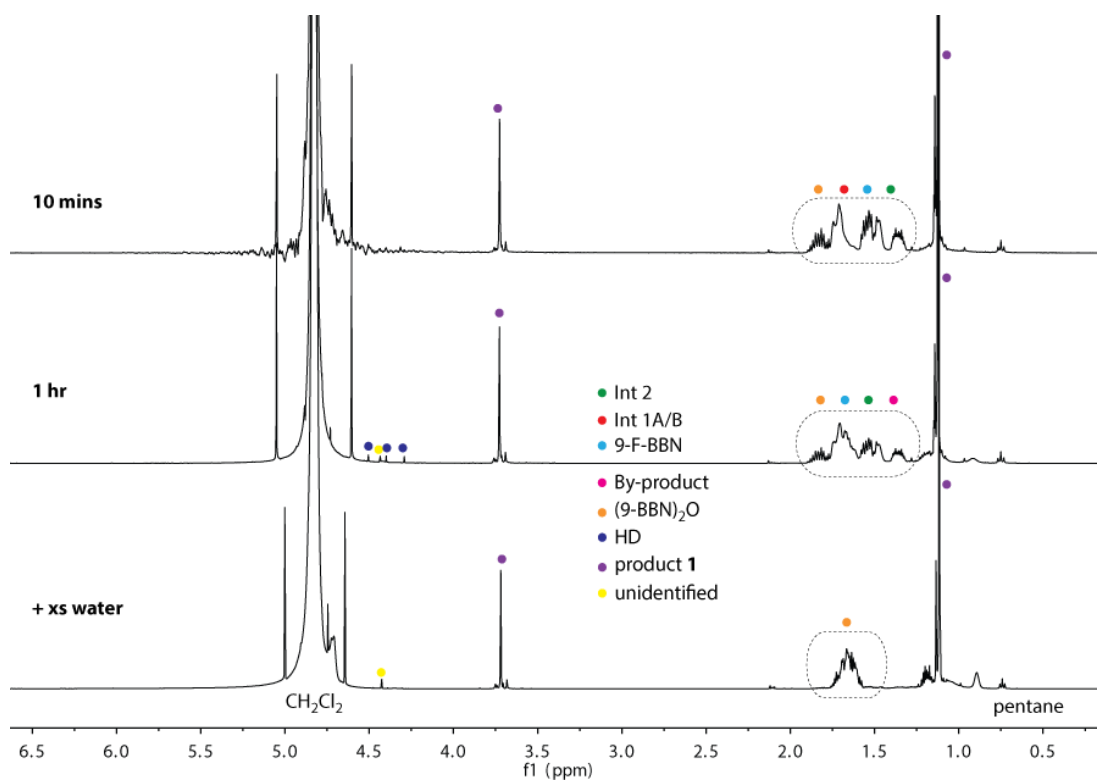


Figure S1. Benzylation of C_6D_6 using 9-BBN dimer (0.5 equiv) in DCM , as monitored by ^1H NMR (500/600 MHz) spectroscopy.

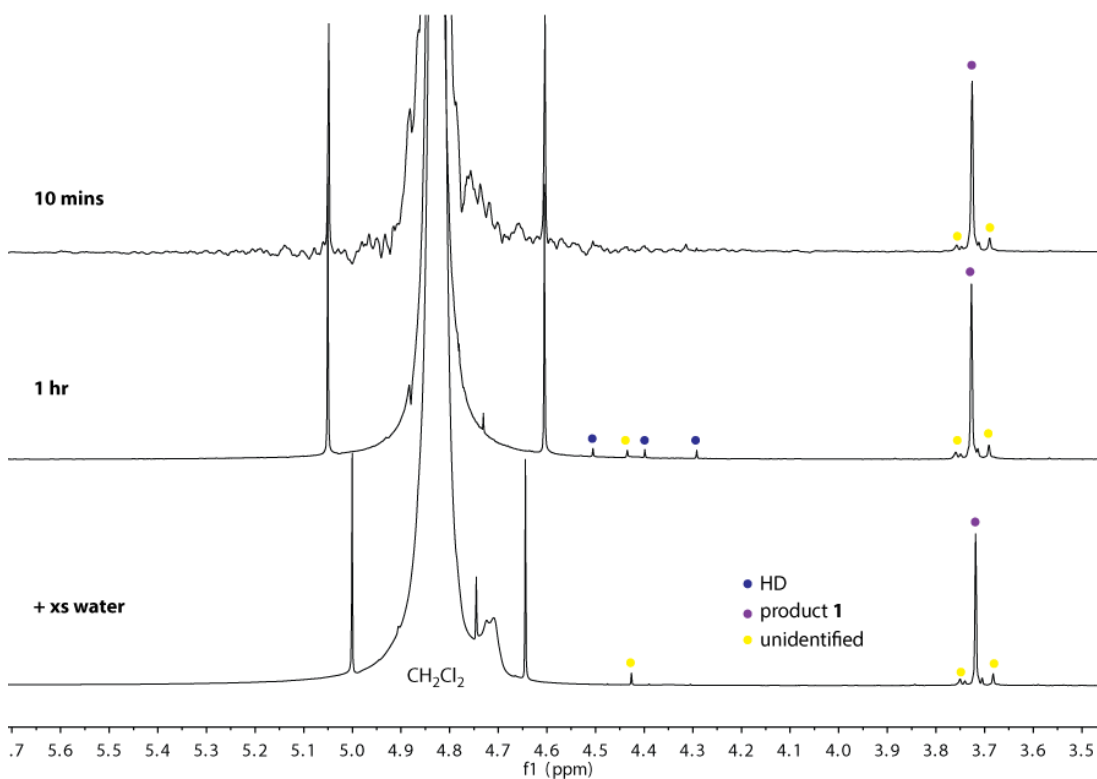


Figure S2. Benzylation of C_6D_6 using 9-BBN dimer (0.5 equiv) in DCM , as monitored by ^1H NMR (400/600 MHz) spectroscopy (expansion indicating HD by-product).

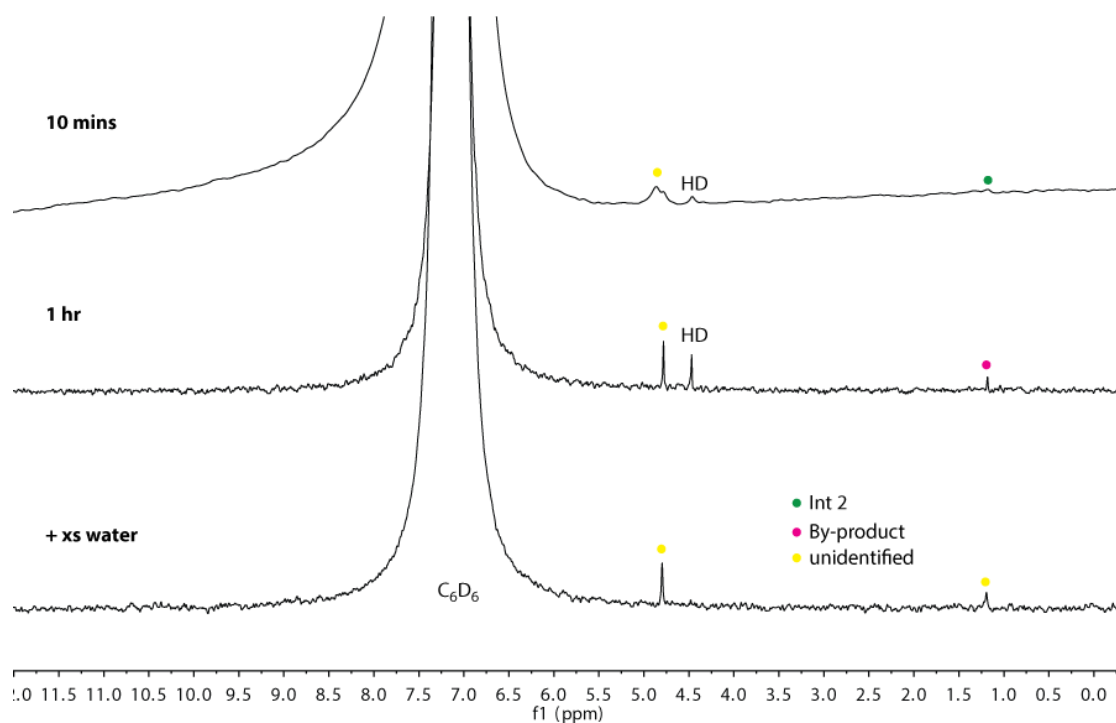


Figure S3. Benzylation of C_6D_6 using 9-BBN dimer (0.5 equiv) in DCM, as monitored by $^2\text{H}\{^1\text{H}\}$ NMR (61/92 MHz) spectroscopy.

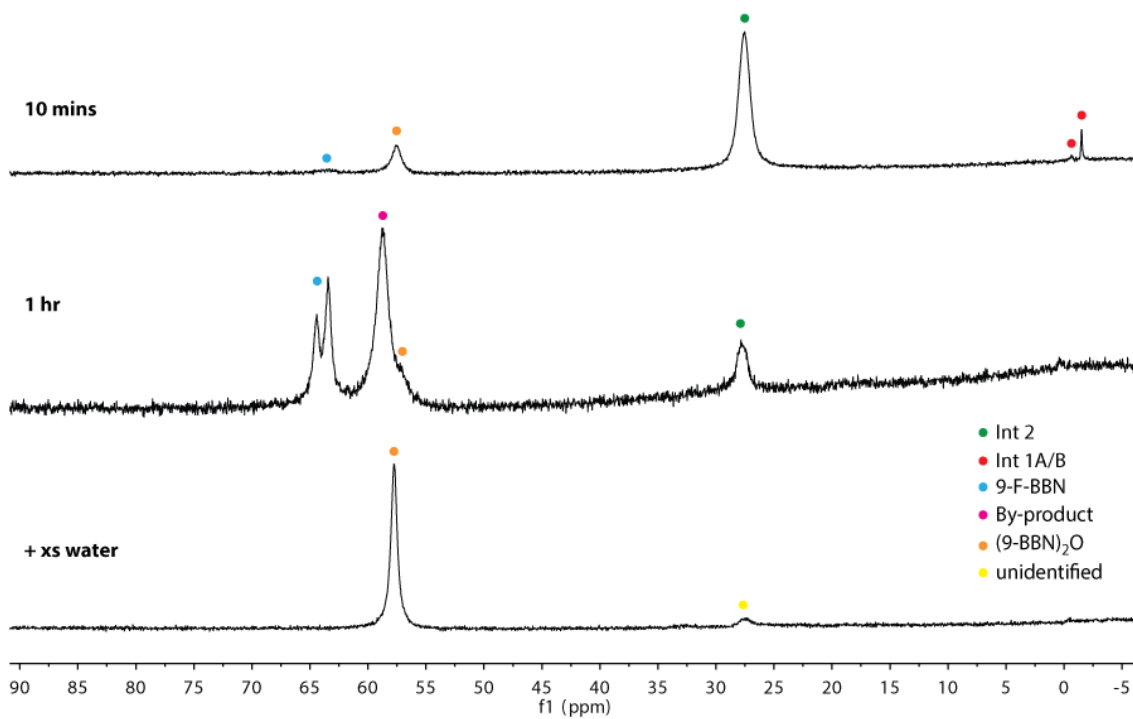


Figure S4. Benzylation of C_6D_6 using 9-BBN dimer (0.5 equiv) in DCM, as monitored by ^{11}B NMR (128 MHz) spectroscopy.

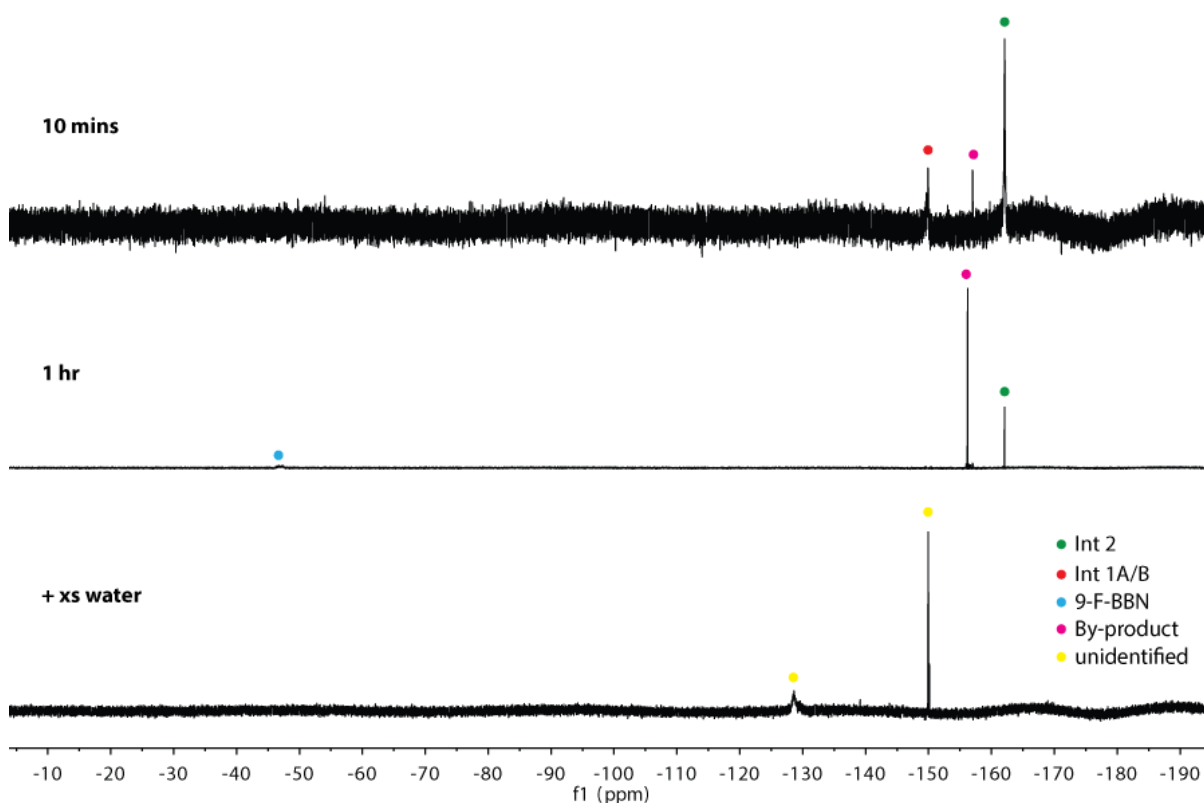


Figure S5. Benzylation of C_6D_6 using 9-BBN dimer (0.5 equiv) in DCM, as monitored by ^{19}F NMR (396 MHz) spectroscopy.

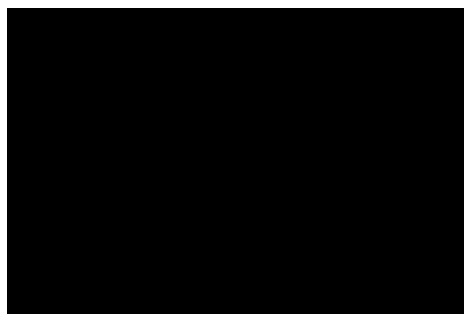
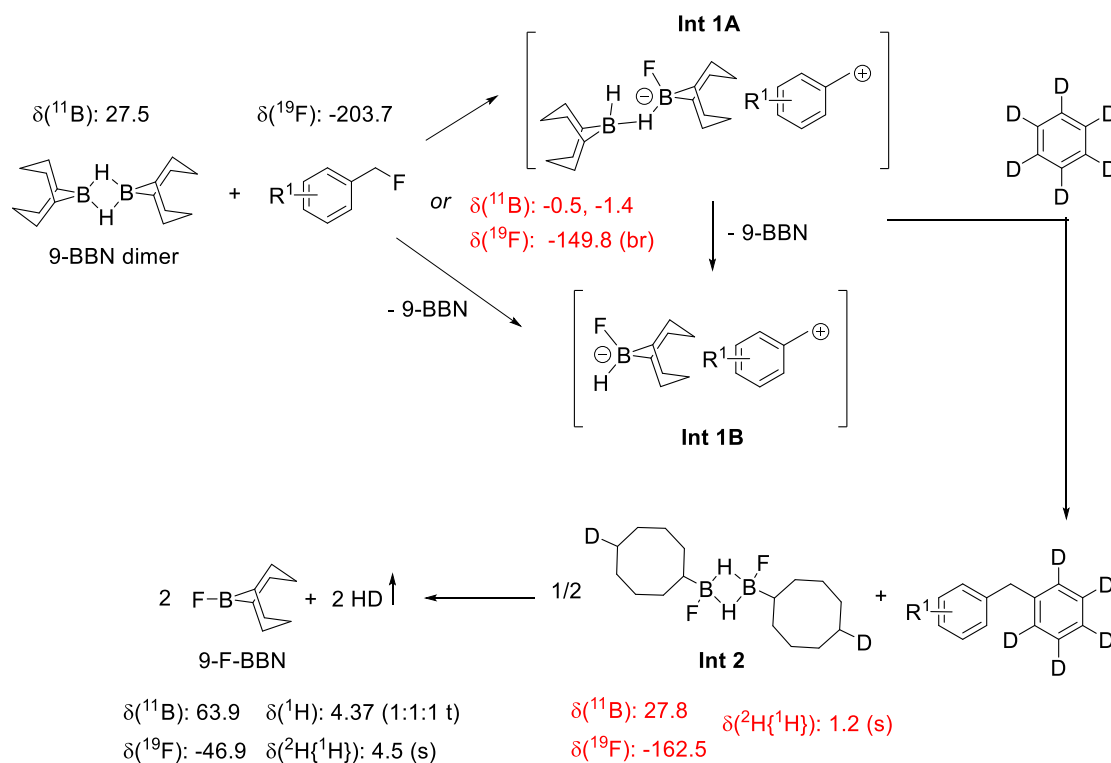


Figure S6. Video of benzylation reactions producing hydrogen gas.

Proposed pathway

Based on the NMR experiments and previous studies,⁴ a possible reaction pathway was proposed (Scheme S1). Multinuclear NMR spectroscopic analysis after a reaction time of 10 minutes demonstrates complete consumption of the benzyl fluoride substrate. The ^{19}F NMR spectrum shows two major ($\delta = -149.8, -162.1$ ppm, broad) and one minor species ($\delta = -157.0$ ppm) of fluoroborate character (Figure S5). The ^{11}B NMR spectrum at this time point indicates a major species in the chemical shift range typical of three coordinated or dimeric boron species ($\delta = 27.8$ ppm) (Figure S4). Minor ^{11}B resonances were assigned to 9-F-BBN ($\delta = 63.9$ ppm) and $(9\text{-BBN})_2\text{O}$ ($\delta = 57.7$ ppm) by comparison with literature values.⁵ This suggests that intermediate fluoroborate species **Int 1A** and **Int 1B** are generated (Scheme S1). Critically, NMR samples at this time point exhibit little perceptible bubbling, despite ^1H NMR spectra indicating complete

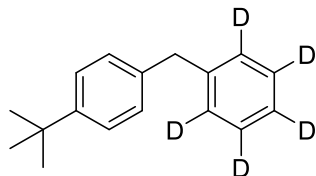
conversion of the benzyl fluoride to the desired product. The major species observed by ^{11}B NMR spectroscopy is thus assigned as the dimer **Int 2**. Over the next hour, bubbling of HD ensues (see video) and the corresponding resonances attributable to HD are detected by ^1H and $^2\text{H}\{^1\text{H}\}$ NMR spectroscopy (Figure S1-3) consistent with the increase in the quantity of 9-F-BBN as **Int 2** decreases (^{11}B NMR: $\delta = 58.6$ ppm). With the addition of excess water, the only boron-containing species observed is $(9\text{-BBN})_2\text{O}$ by ^{11}B NMR spectroscopy.



Scheme S1. Proposed mechanism of benzylation facilitated by 9-BBN dimer. NMR data corresponding to the reaction where R = 4-*tert*-butyl; assignments in black are consistent with literature reports, those in red are proposed. All chemical shifts are quoted in ppm.

Characterization Data

Preparation of 1,2,3,4,5-penta-deuterium-6-(4-*tert*-butylbenzyl)benzene (1)



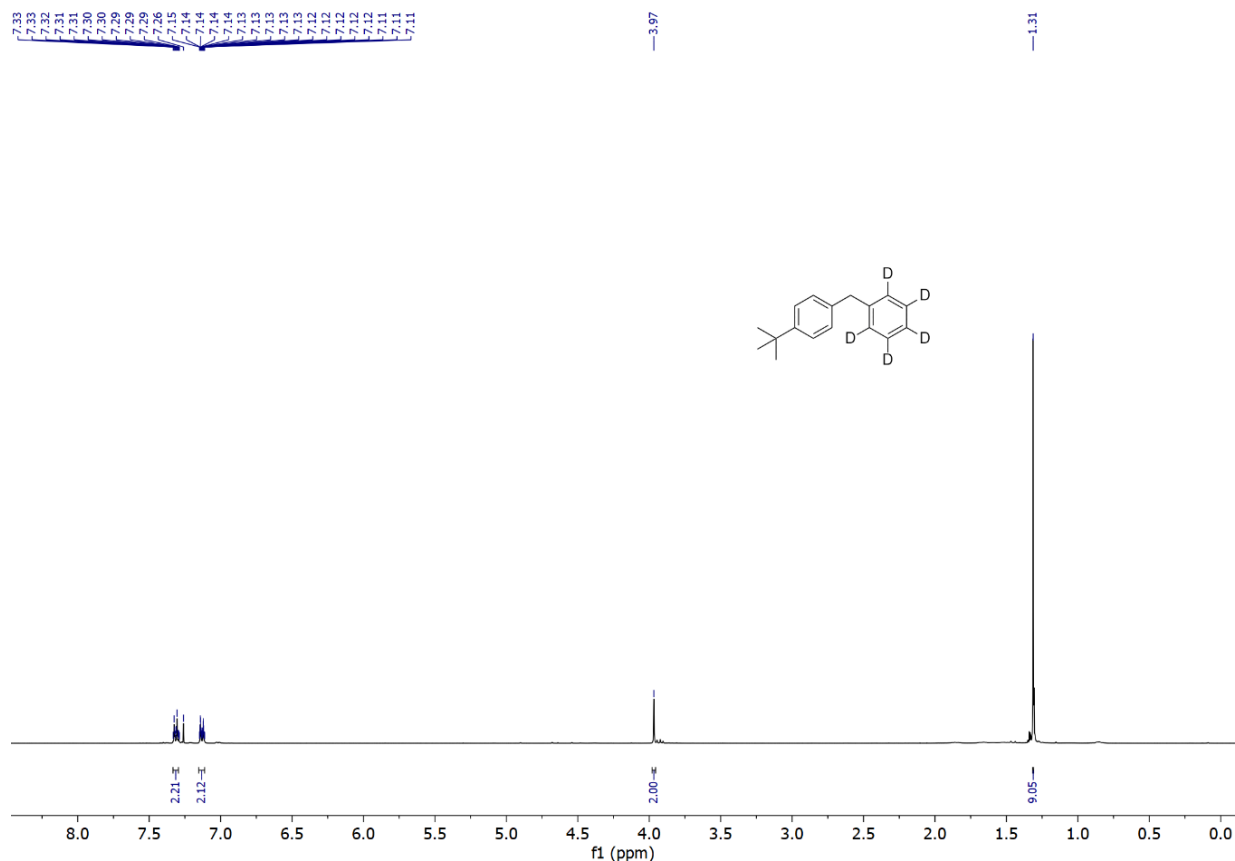
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl)benzene (8.3 mg, 0.05 mmol) in C_6D_6 (0.2 mL) and CH_2Cl_2 (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after 10 minutes at room temperature. The product **1** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (10.9 mg, 95% yield).

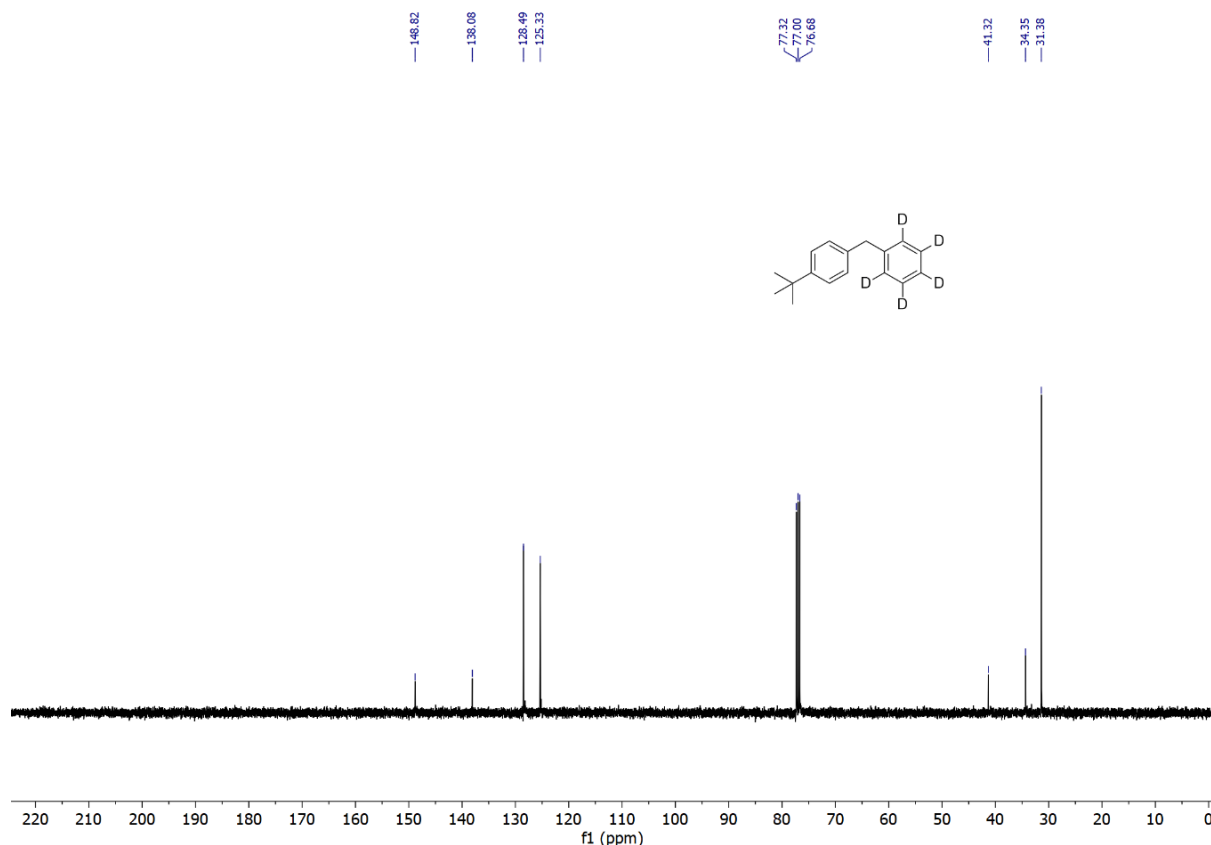
1H NMR (400 MHz, $CDCl_3$), δ : 7.33 – 7.29 (m, 2H), 7.15 – 7.11 (m, 2H), 3.97 (s, 2H), 1.31 (s, 9H).

$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$), δ : 148.82, 138.08, 128.49 (2C), 125.33 (2C), 41.32, 34.35, 31.38 (3C).

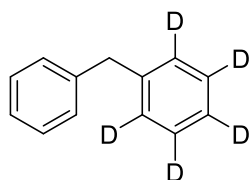
MS (DART Ionization, m/z): 247.2 ($[M+NH_4]^+$).

HRMS (DART Ionization, m/z): Calcd. for $C_{17}H_{19}^2H_5N^+$, ($[M+NH_4]^+$): 247.22226; Found: 247.22177.





Preparation of 1-benzylbenzene-2,3,4,5,6-*d*₅ (**2**)



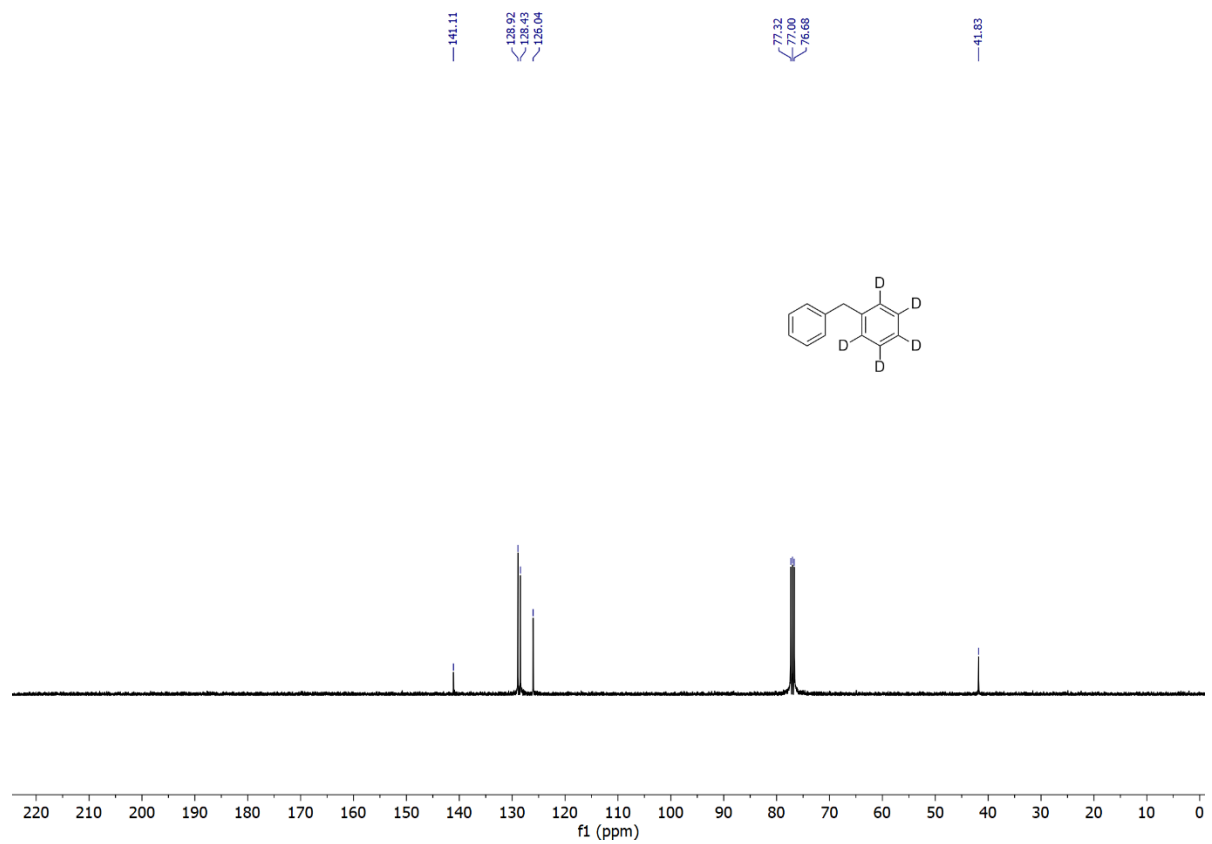
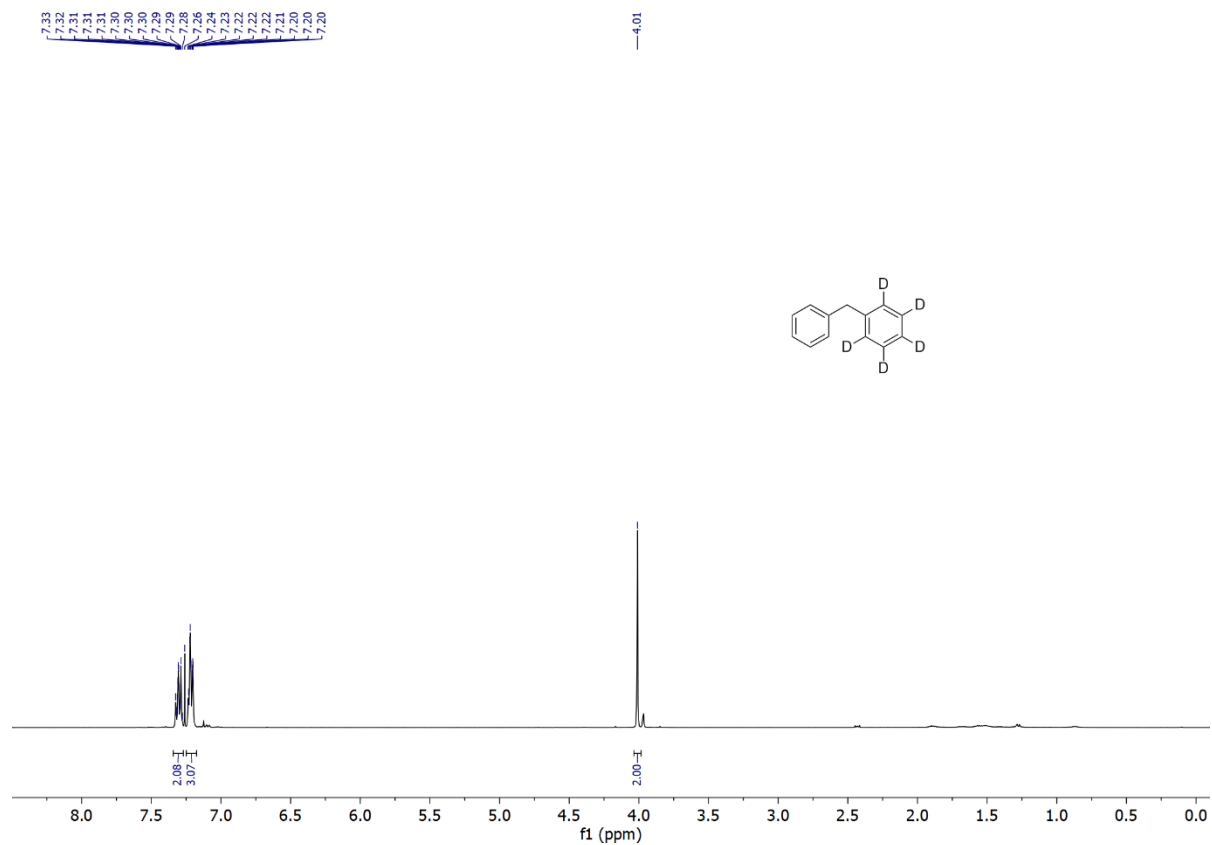
To a solution of 1-(fluoromethyl)benzene (11.0 mg, 0.10 mmol) in C_6D_6 (0.2 mL) and CH_2Cl_2 (0.2 mL) was added a solution of 9-BBN dimer (12.4 mg, 0.025 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after stirring overnight at room temperature. The product **2** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (16.0 mg, 92% yield).

1H NMR (400 MHz, $CDCl_3$), δ : 7.33 – 7.28 (m, 2H), 7.24 – 7.20 (m, 2H), 4.01 (s, 2H).

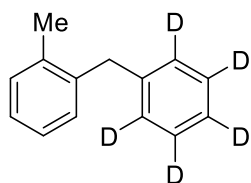
$^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$), δ : 141.11, 128.92, 128.43, 126.04, 41.83.

MS (ESI, m/z): 173.1([$M+H$]⁺).

HRMS (ESI, m/z): Calcd. for $C_{13}^1H_7^2H_5$ ([$M+H$]⁺): 173.1253, Found: 173.1249.



Preparation of 1-(2-methylbenzyl)benzene-2,3,4,5,6-*d*₅ (**3**)



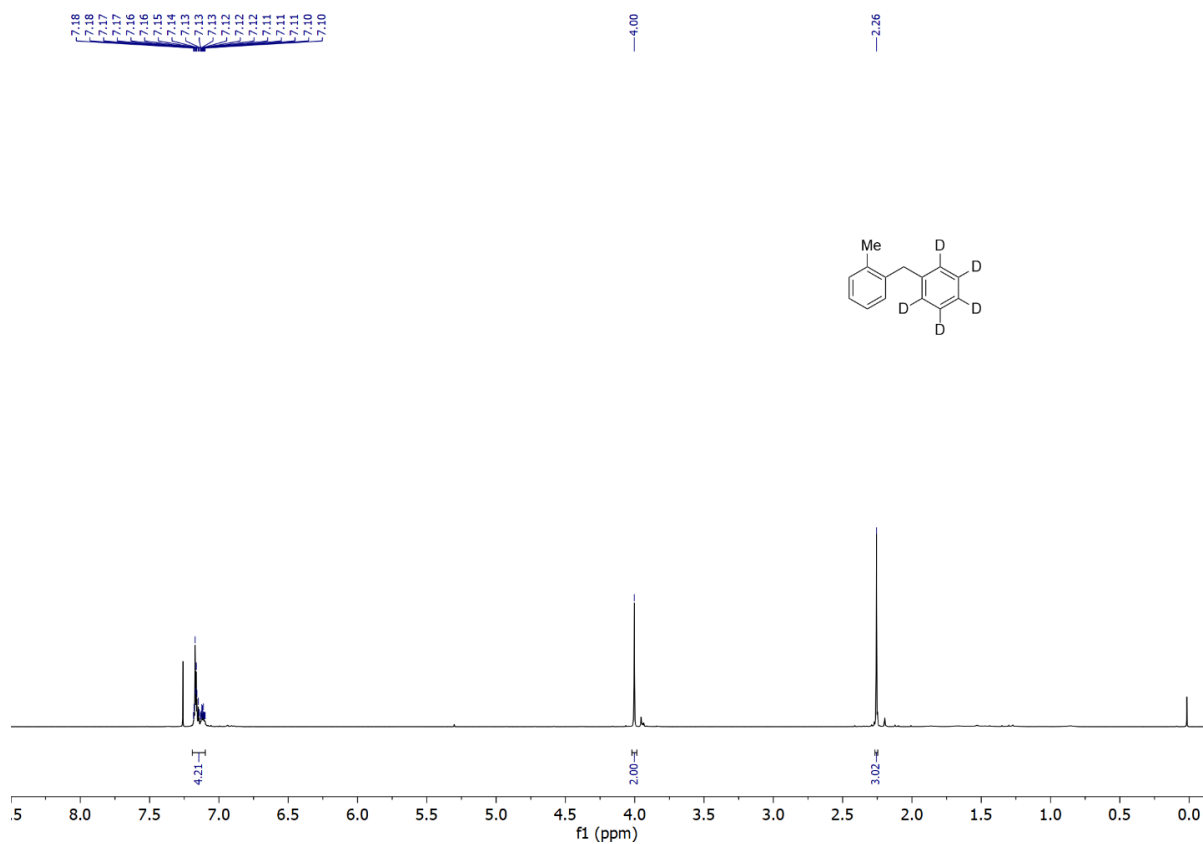
To a solution of 1-(fluoromethyl)-2-methylbenzene (6.2 mg, 0.05 mmol) in C₆D₆ (0.2 mL) and CH₂Cl₂ (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH₂Cl₂ (0.2 mL). The reaction was complete after stirring overnight at room temperature. The product **3** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (8.5 mg, 91% yield).

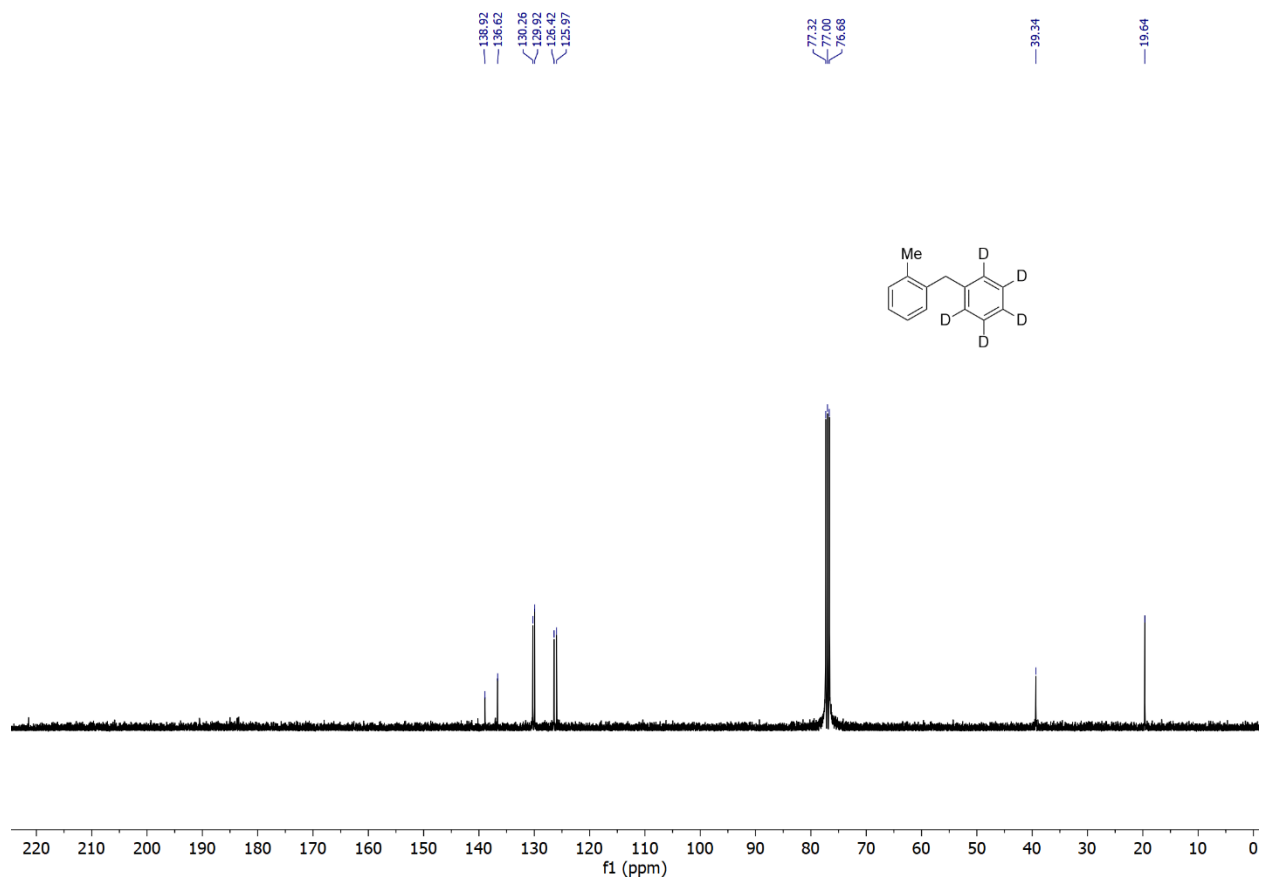
¹H NMR (400 MHz, CDCl₃), δ: 7.18 – 7.10 (m, 4H), 4.00 (s, 2H), 2.26 (s, 3H).

¹³C{¹H} NMR (100 MHz, CDCl₃), δ: 138.92, 136.62, 130.26, 129.92, 126.42, 125.97, 39.34, 19.64.

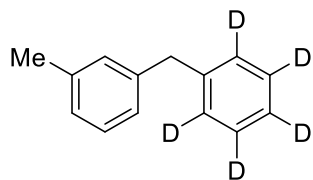
MS (DART Ionization, *m/z*): 205.2 ([M+NH₄]⁺).

HRMS (DART Ionization, *m/z*): Calcd. for C₁₄H₁₃²H₅N⁺, ([M+NH₄]⁺): 205.17531 Found: 205.17598.





Preparation of 1-(3-methylbenzyl)benzene-2,3,4,5,6-d₅ (4)



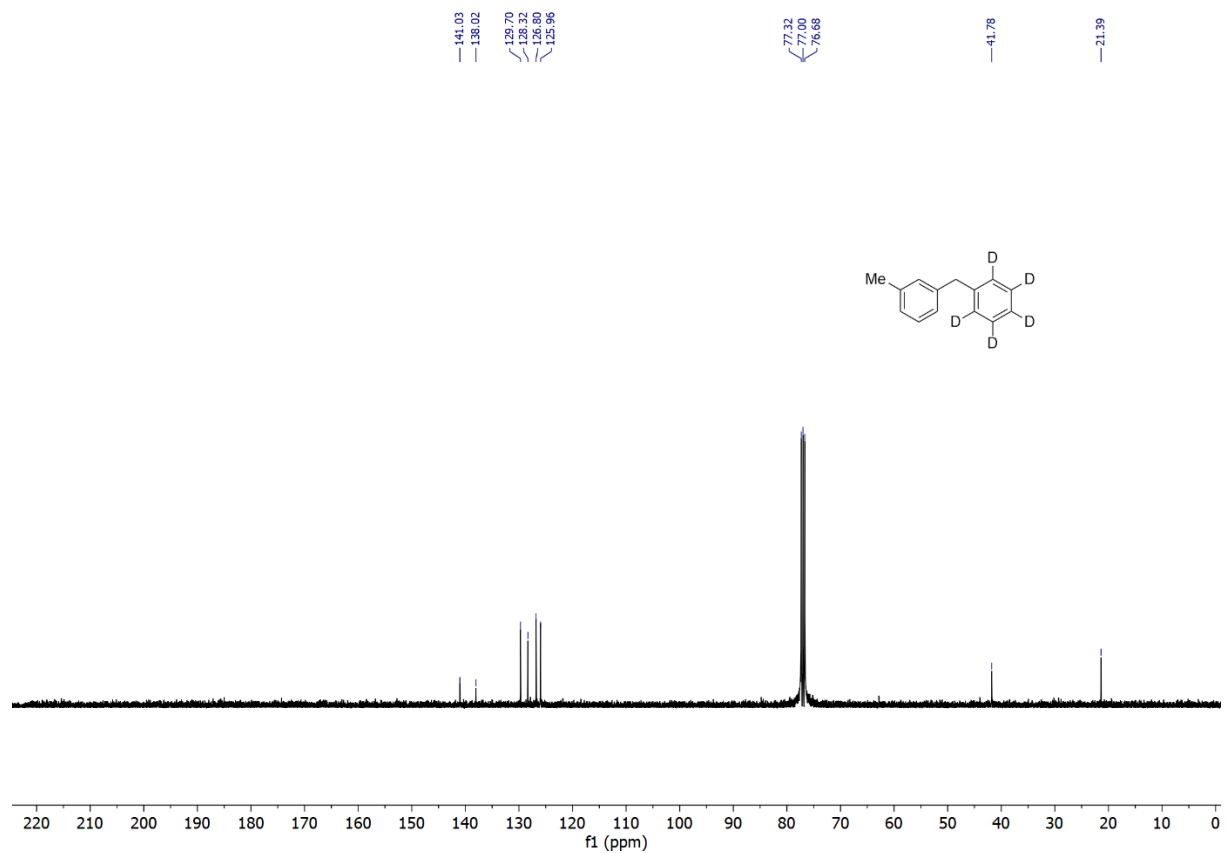
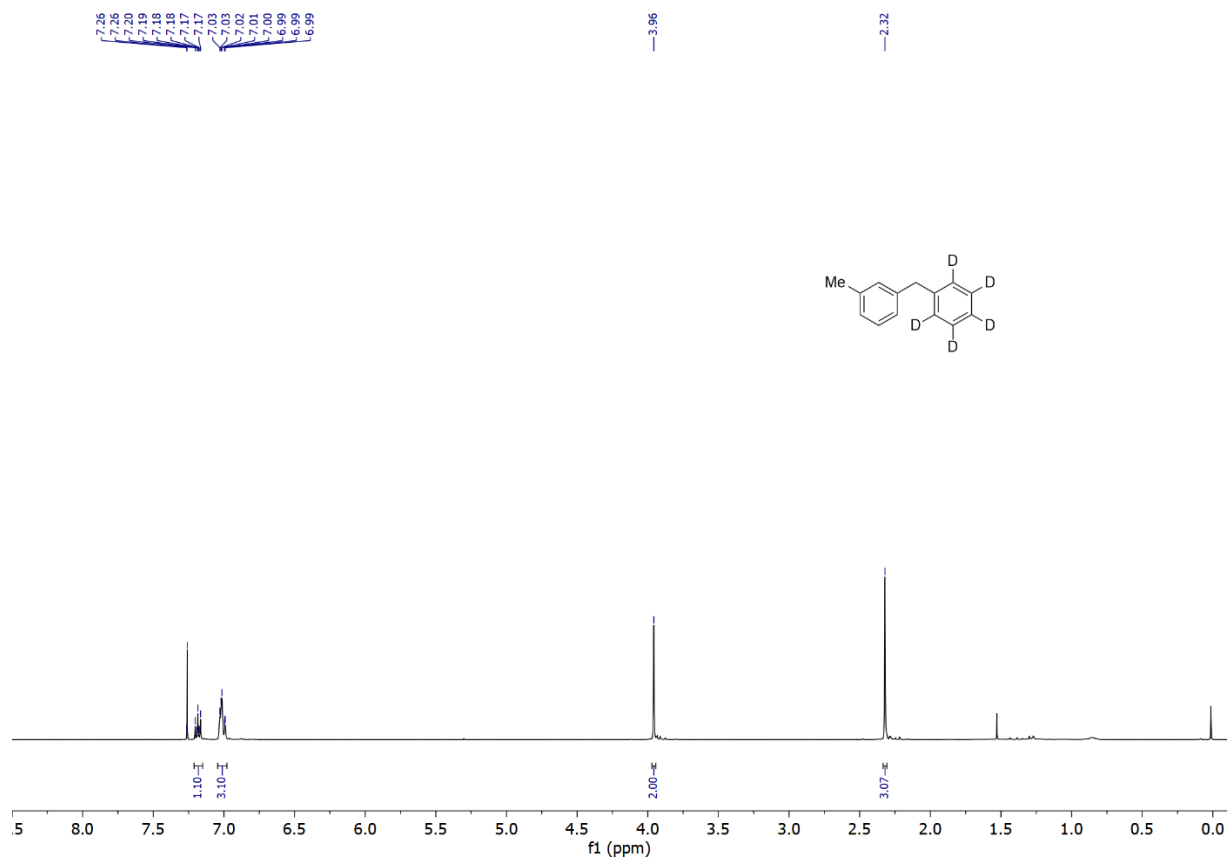
To a solution of 1-(fluoromethyl)-3-methylbenzene (6.2 mg, 0.05 mmol) in C₆D₆ (0.2 mL) and CH₂Cl₂ (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH₂Cl₂ (0.2 mL). The reaction was complete after stirring overnight at room temperature. The product **4** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (8.0 mg, 86% yield).

¹H NMR (400 MHz, CDCl₃), δ: 7.21 – 7.16 (m, 1H), 7.02 – 6.99 (m, 3H), 3.96 (s, 2H), 2.32 (s, 3H).

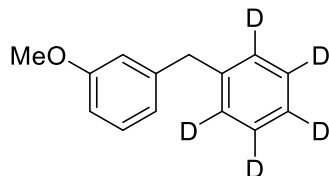
¹³C{¹H} NMR (100 MHz, CDCl₃), δ: 141.03, 138.02, 129.70, 128.32, 126.80, 125.96, 41.78, 21.39.

MS (DART Ionization, *m/z*): 205.2 ([M+NH₄]⁺).

HRMS (DART Ionization, *m/z*): Calcd. for C₁₄H₁₃²D₅N⁺, ([M+NH₄]⁺): 205.17531 Found: 205.17600.



Preparation of 1-(3-methoxybenzyl)benzene-2,3,4,5,6-*d*₅ (**5**)



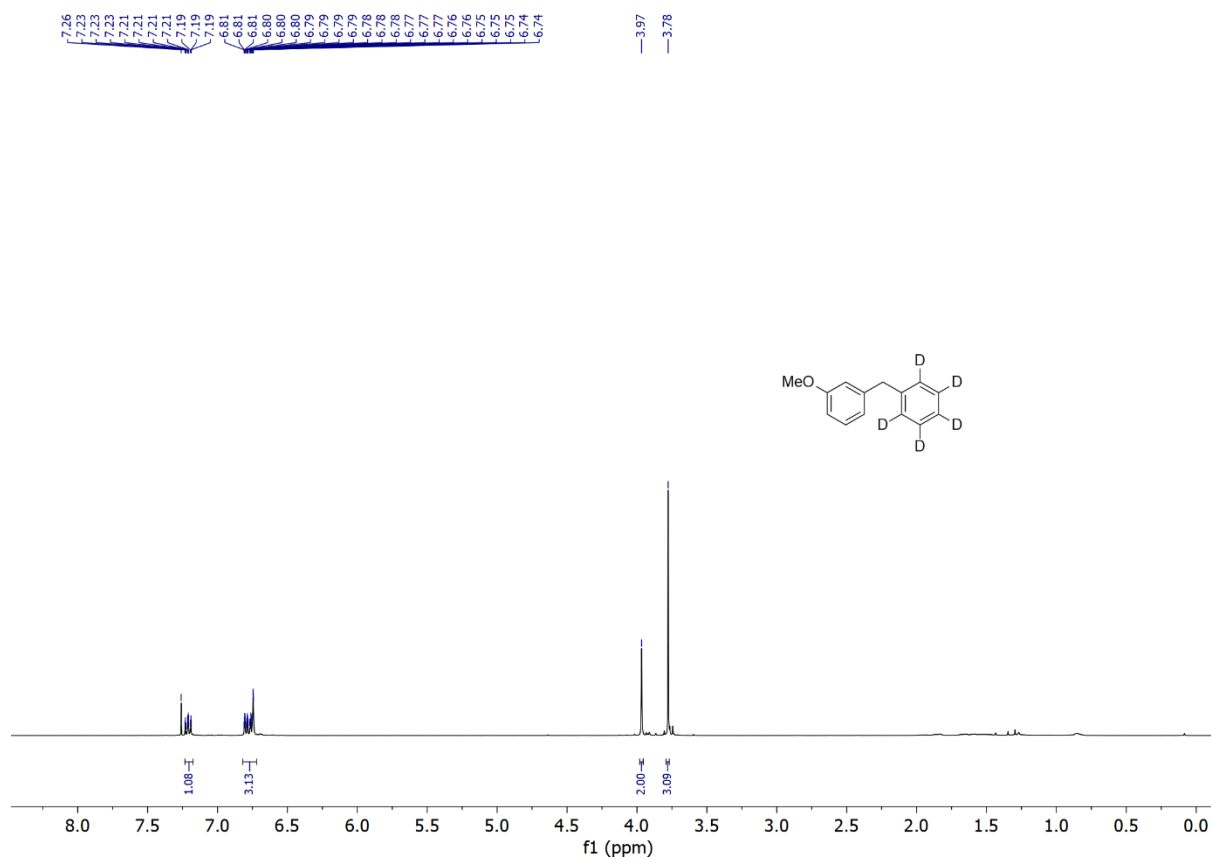
To a solution of 1-(fluoromethyl)-3-methoxybenzene (7.0 mg, 0.05 mmol) in C₆D₆ (0.2 mL) and CH₂Cl₂ (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH₂Cl₂ (0.2 mL). The reaction was complete after stirring overnight at room temperature. The product **5** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (11.5 mg, 90% yield).

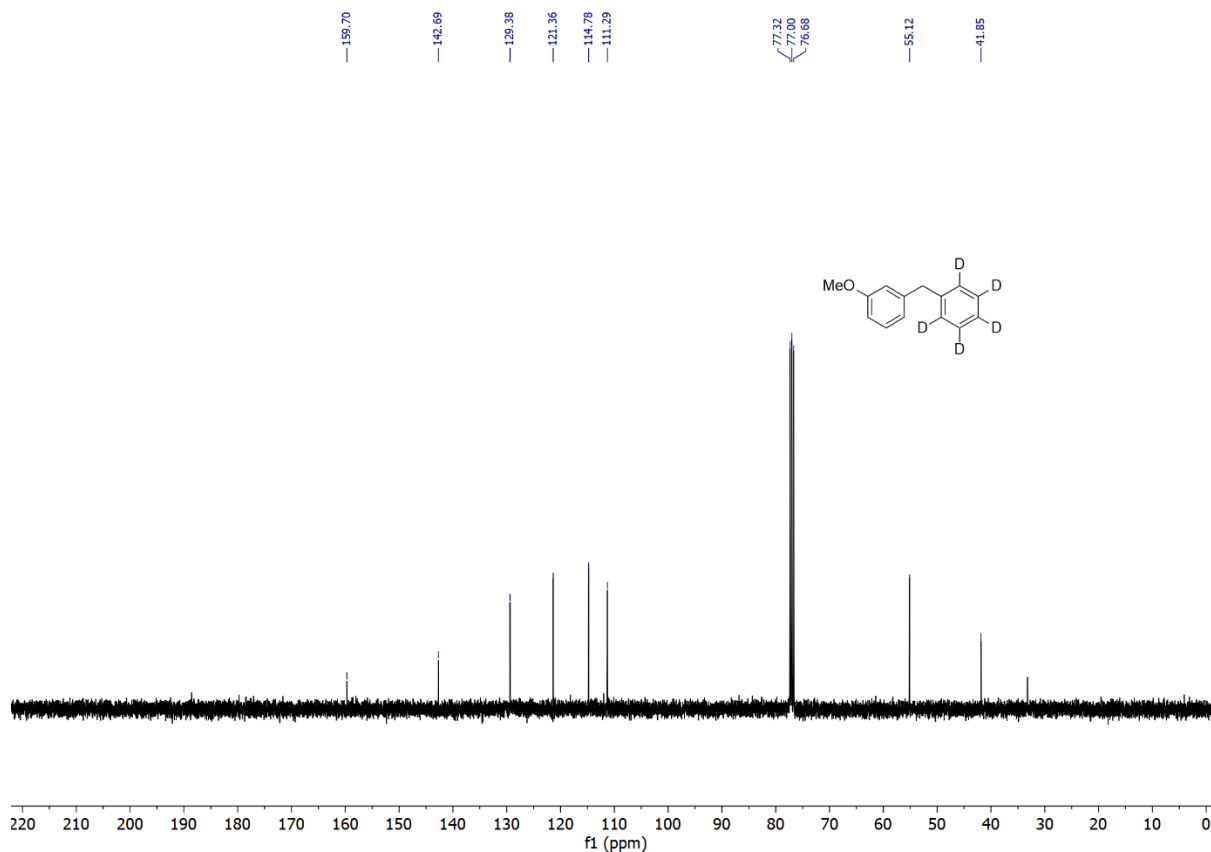
¹H NMR (400 MHz, CDCl₃), δ: 7.26 – 7.19 (m, 1H), 6.81 – 6.74 (m, 3H), 3.97 (s, 2H), 3.78 (s, 3H).

¹³C{¹H} NMR (100 MHz, CDCl₃), δ: 159.70, 142.69, 129.38, 121.36, 114.78, 111.29, 55.12, 41.85.

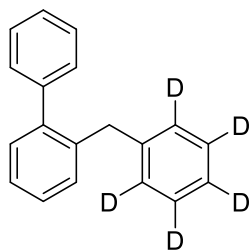
MS (DART Ionization, *m/z*): 204.1 ([M+H]⁺).

HRMS (DART Ionization, *m/z*): Calcd. for C₁₄¹H₁₀²H₅O⁺, ([M+H]⁺): 204.14367; Found: 204.14383.





Preparation of 2-((phenyl- d_5)methyl)-1,1'-biphenyl (6)



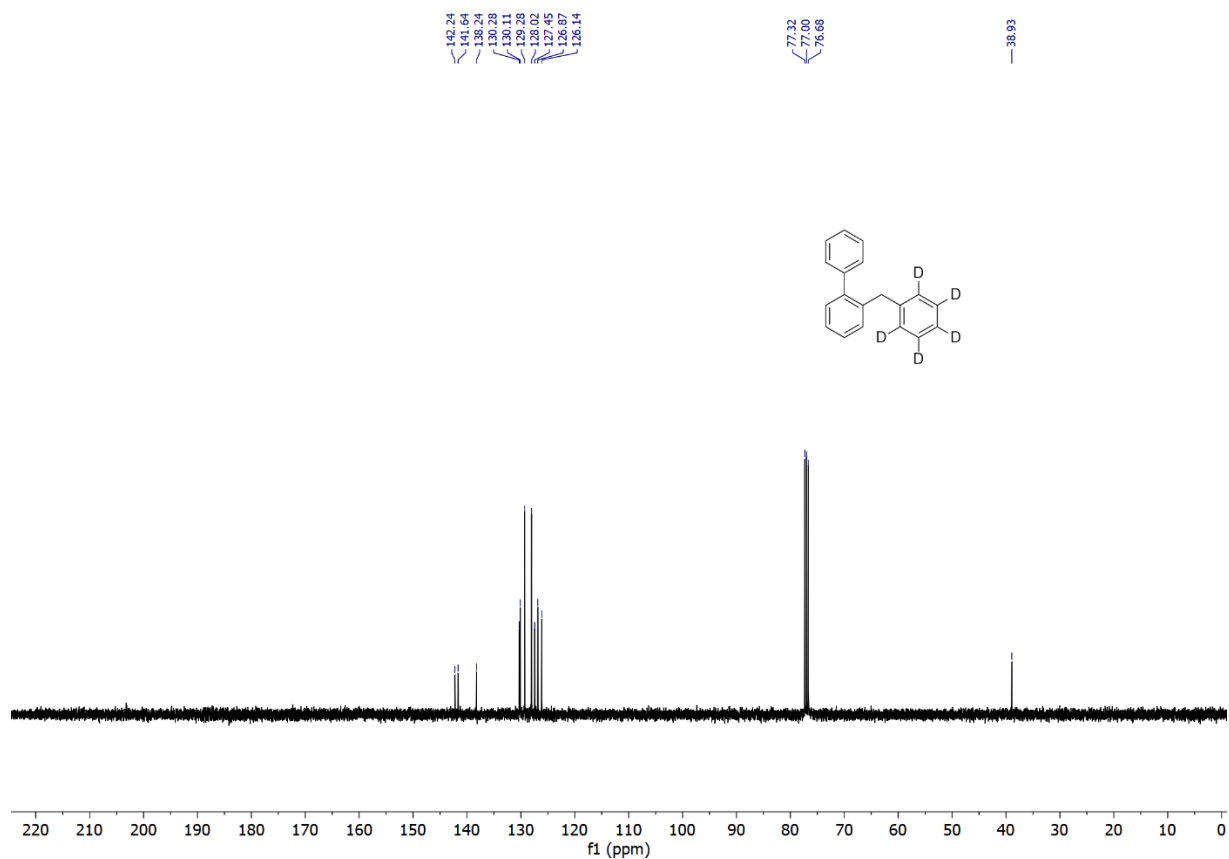
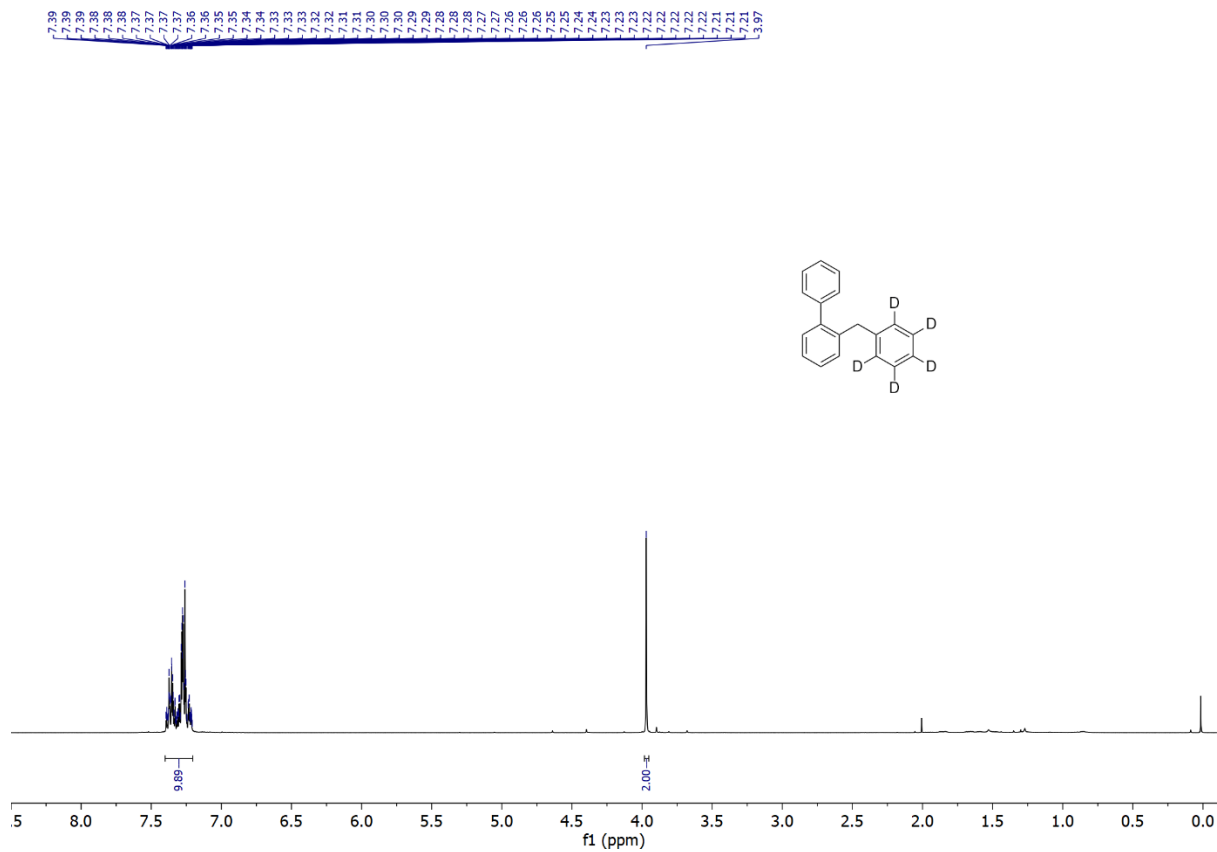
To a solution of 2-(fluoromethyl)-1,1'-biphenyl (9.3 mg, 0.05 mmol) in C_6D_6 (0.2 mL) and CH_2Cl_2 (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after stirring overnight at room temperature. The product **6** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (11.1 mg, 89% yield).

^1H NMR (400 MHz, CDCl_3), δ : 7.40 – 7.20 (m, 9H), 3.97 (s, 3H).

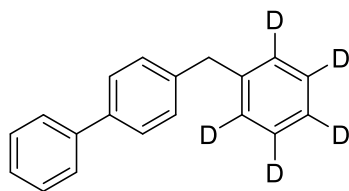
$^{13}\text{C}\{^1\text{H}\}$ NMR (126 MHz, CDCl_3), δ : 142.24, 141.64, 138.24, 130.28, 130.11, 129.28, 128.02, 127.45, 126.87, 126.14, 38.93.

MS (DART Ionization, m/z): 267.2 ($[\text{M}+\text{NH}_4]^+$).

HRMS (DART Ionization, m/z): Calcd. for $\text{C}_{19}\text{H}_{15}^2\text{H}_5\text{N}^+$, ($[\text{M}+\text{NH}_4]^+$): 267.19096; Found: 267.19151.



Preparation of 4-((phenyl-*d*₅)methyl)-1,1'-biphenyl (**7**)



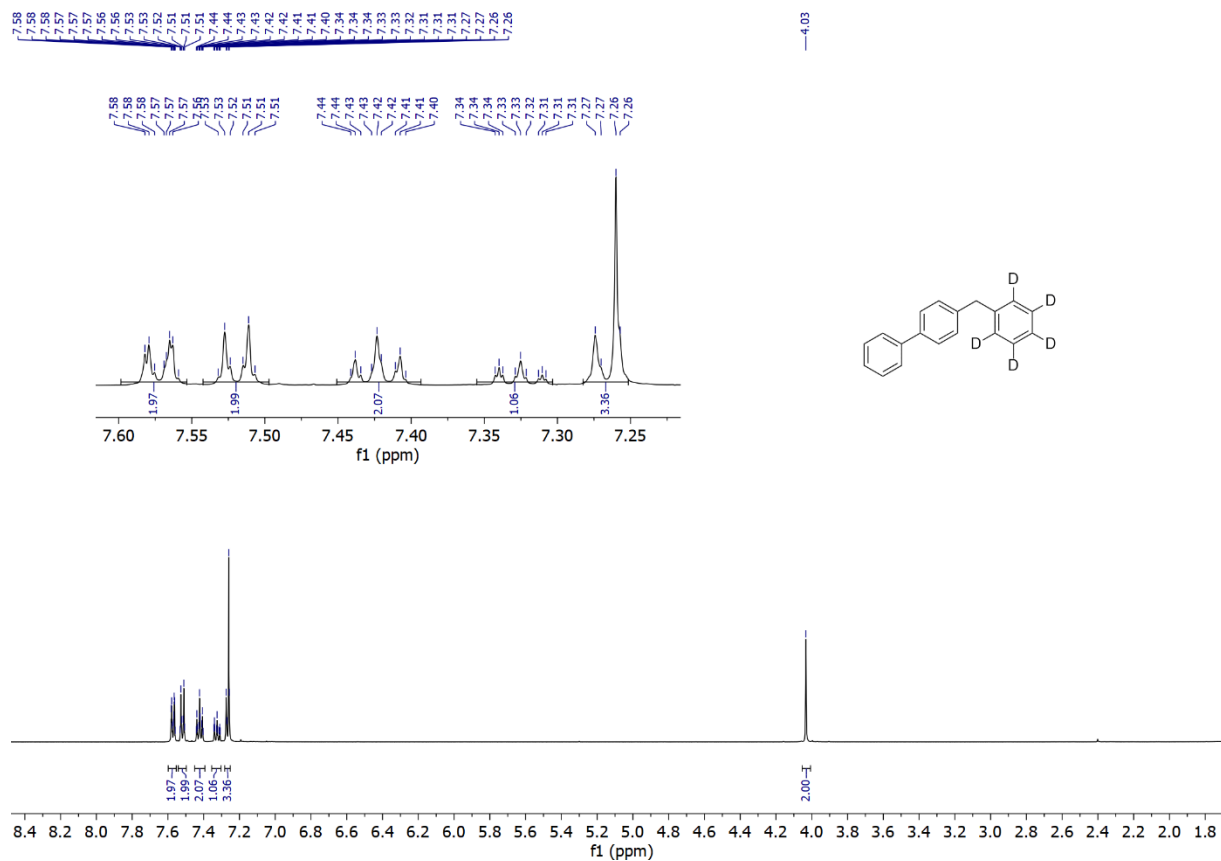
To a solution of 4-(fluoromethyl)-1,1'-biphenyl (18.6 mg, 0.10 mmol) in C₆D₆ (0.2 mL) and CH₂Cl₂ (0.2 mL) was added a solution of 9-BBN dimer (12.4 mg, 0.05 mmol) in CH₂Cl₂ (0.2 mL). The reaction was complete after stirring for 30 minutes at room temperature. The product **7** was isolated as a white solid by column chromatography using hexanes/ethyl acetate (95/5) eluent (22.4 mg, 90% yield).

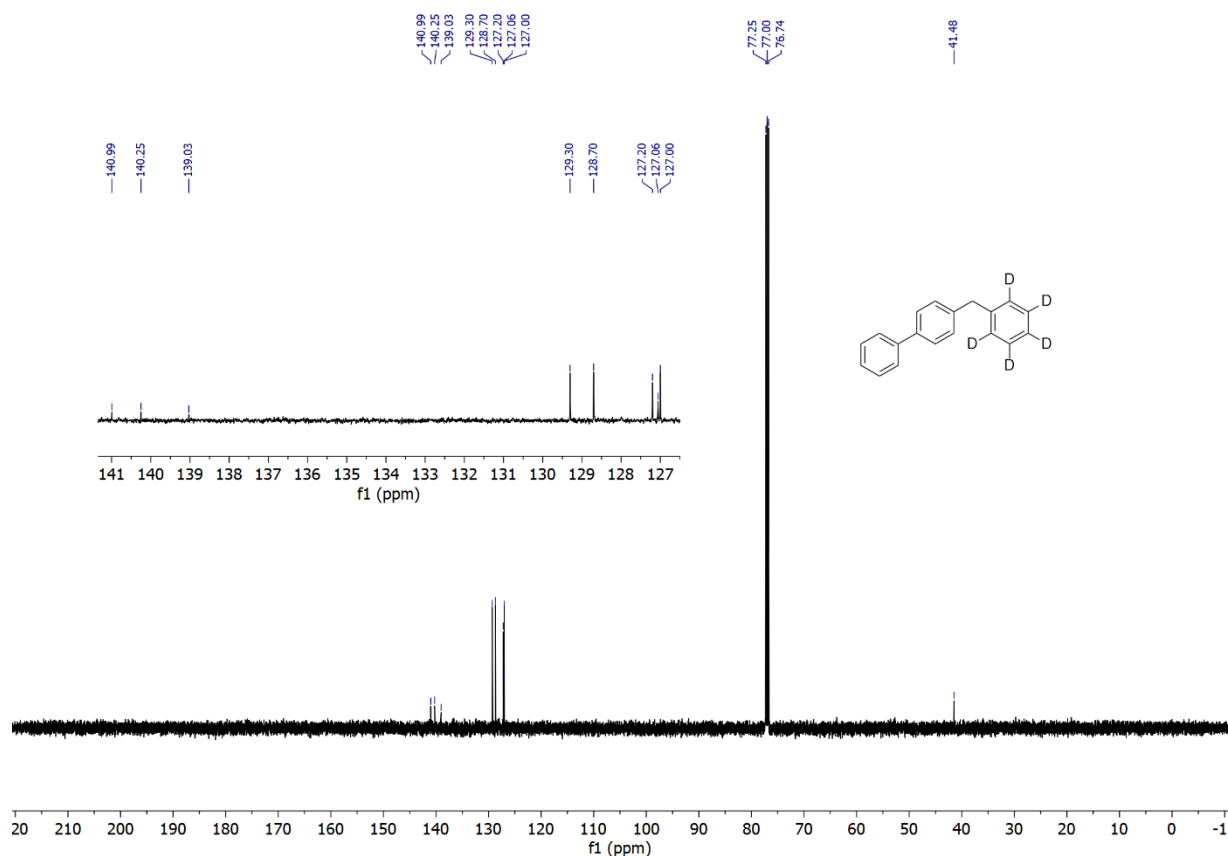
¹H NMR (500 MHz, CDCl₃), δ: 7.58 – 7.56 (m, 2H), 7.53 – 7.51 (m, 2H), 7.44 – 7.40 (m, 2H), 7.34 – 7.31 (m, 1H), 7.27 – 7.25 (d, *J* = 8.3 Hz, 2H), 4.03 (s, 2H).

¹³C{¹H} NMR (126 MHz, CDCl₃), δ: 140.99, 140.25, 139.03, 129.30, 128.70, 127.20, 127.06, 127.00, 41.48.

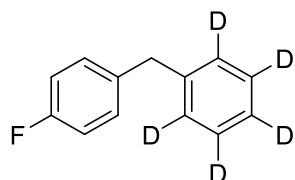
MS (DART Ionization, *m/z*): 267.2 ([M+NH₄]⁺).

HRMS (DART Ionization, *m/z*): Calcd. for C₁₉H₁₅²H₅N⁺, ([M+NH₄]⁺): 267.19096; Found: 267.19126.





Preparation of 1-(4-fluorobenzyl)benzene-2,3,4,5,6-*d*₅ (**8**)



To a solution of 1-fluoro-4-(fluoromethyl)benzene (6.4 mg, 0.05 mmol) in C₆D₆ (0.2 mL) and CH₂Cl₂ (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH₂Cl₂ (0.2 mL). The reaction was complete after 24 hours of stirring at room temperature. The product **8** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (7.6 mg, 80% yield).

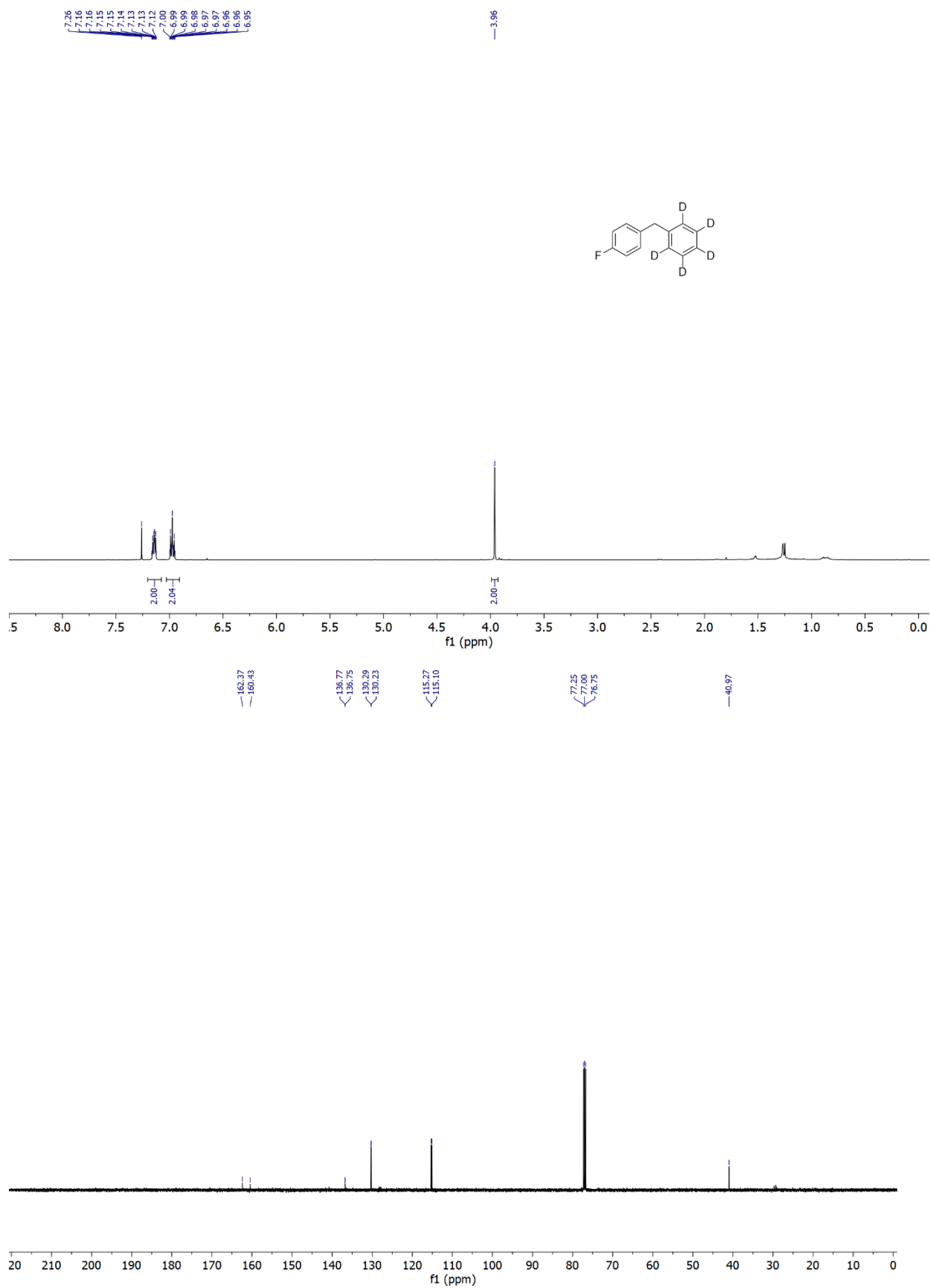
¹H NMR (500 MHz, CDCl₃), δ: 7.17 – 7.11 (m, 2H), 7.00 – 6.95 (m, 2H), 3.96 (s, 2H).

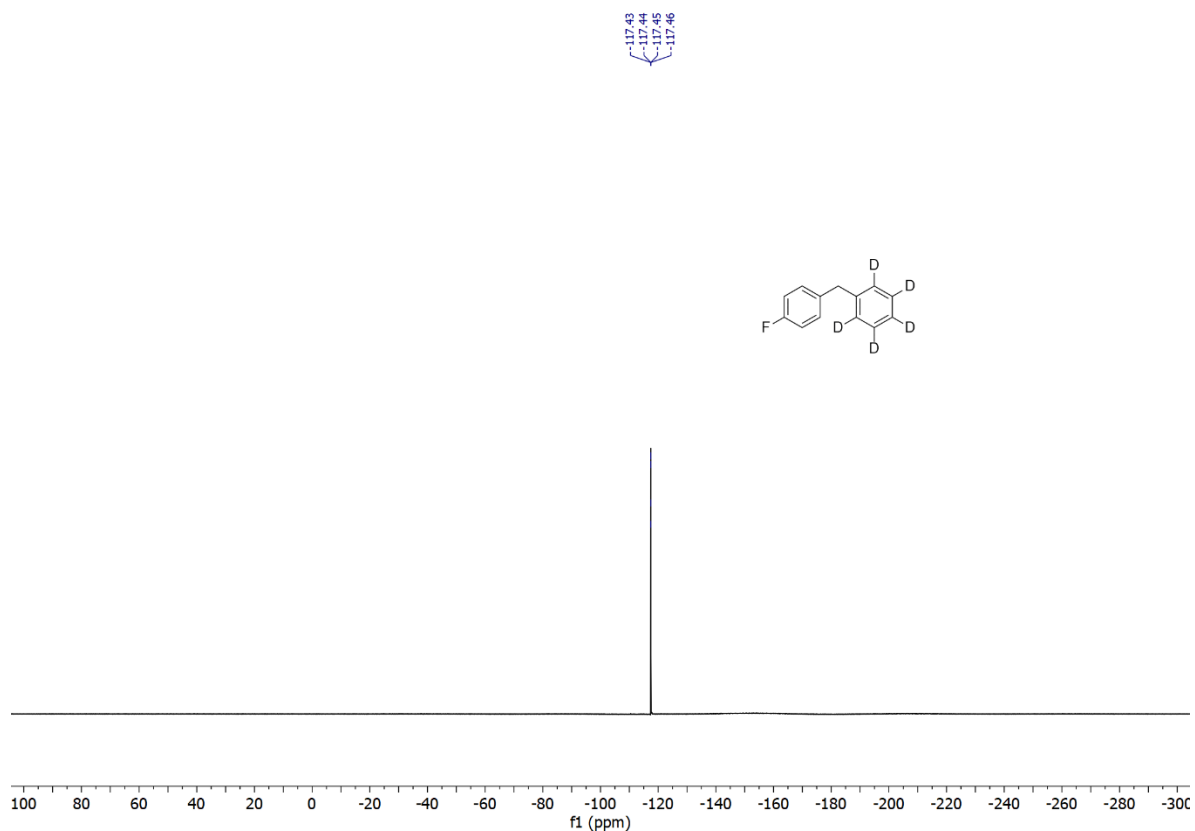
¹³C{¹H} NMR (126 MHz, CDCl₃), δ: 161.40 (d, *J*_{C-F} = 244 Hz), 136.76 (d, *J*_{C-F} = 2.6 Hz), 130.26 (d, *J*_{C-F} = 7.6 Hz), 115.18 (d, *J*_{C-F} = 21.4 Hz), 40.97.

¹⁹F NMR (470 MHz, CDCl₃), δ: -117.44 (t, *J* = 9.4 Hz).

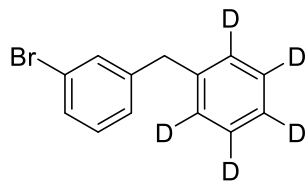
MS (ESI, *m/z*): 191.1([M+H]⁺).

HRMS (ESI, *m/z*): Calcd. for C₁₃¹H₆²H₅F ([M+H]⁺): 191.1159; Found: 191.1162.





Preparation of 1-(3-bromobenzyl)benzene-2,3,4,5,6-*d*₅ (**9**)



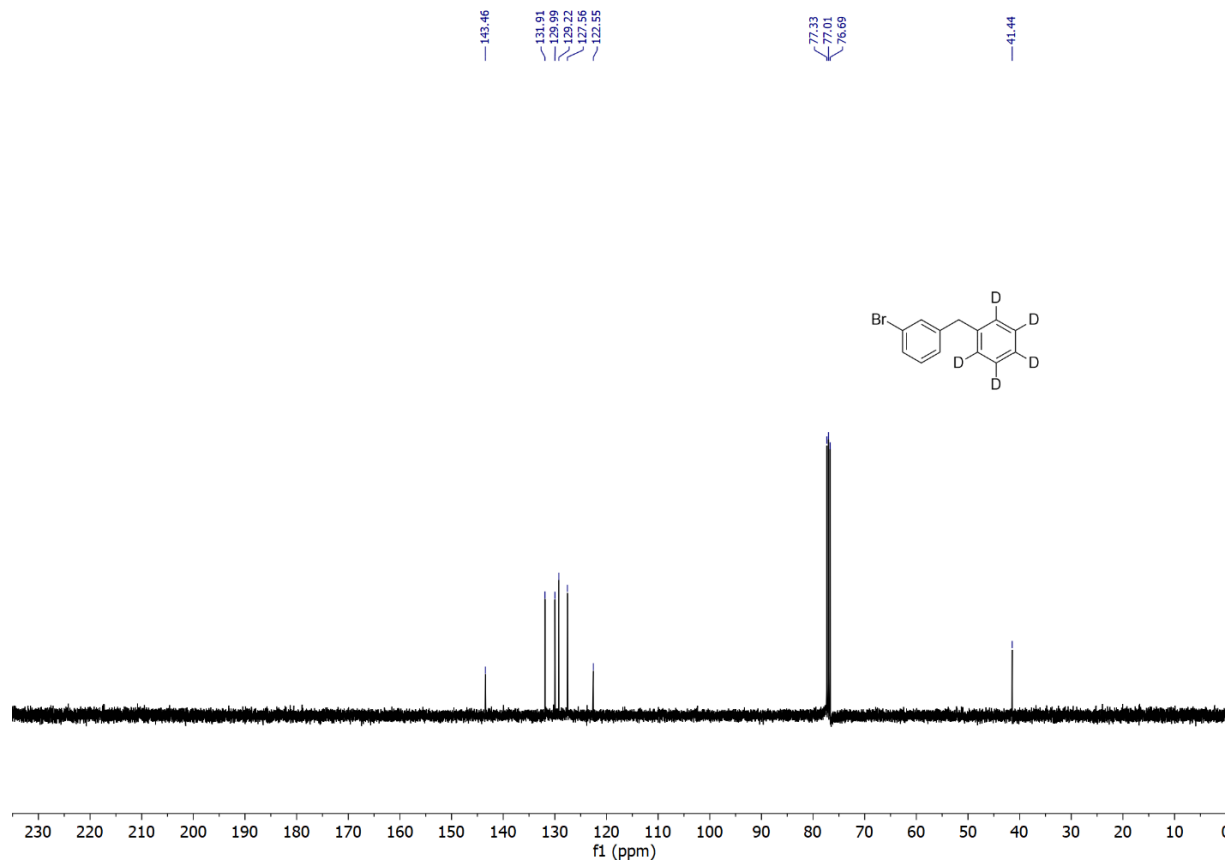
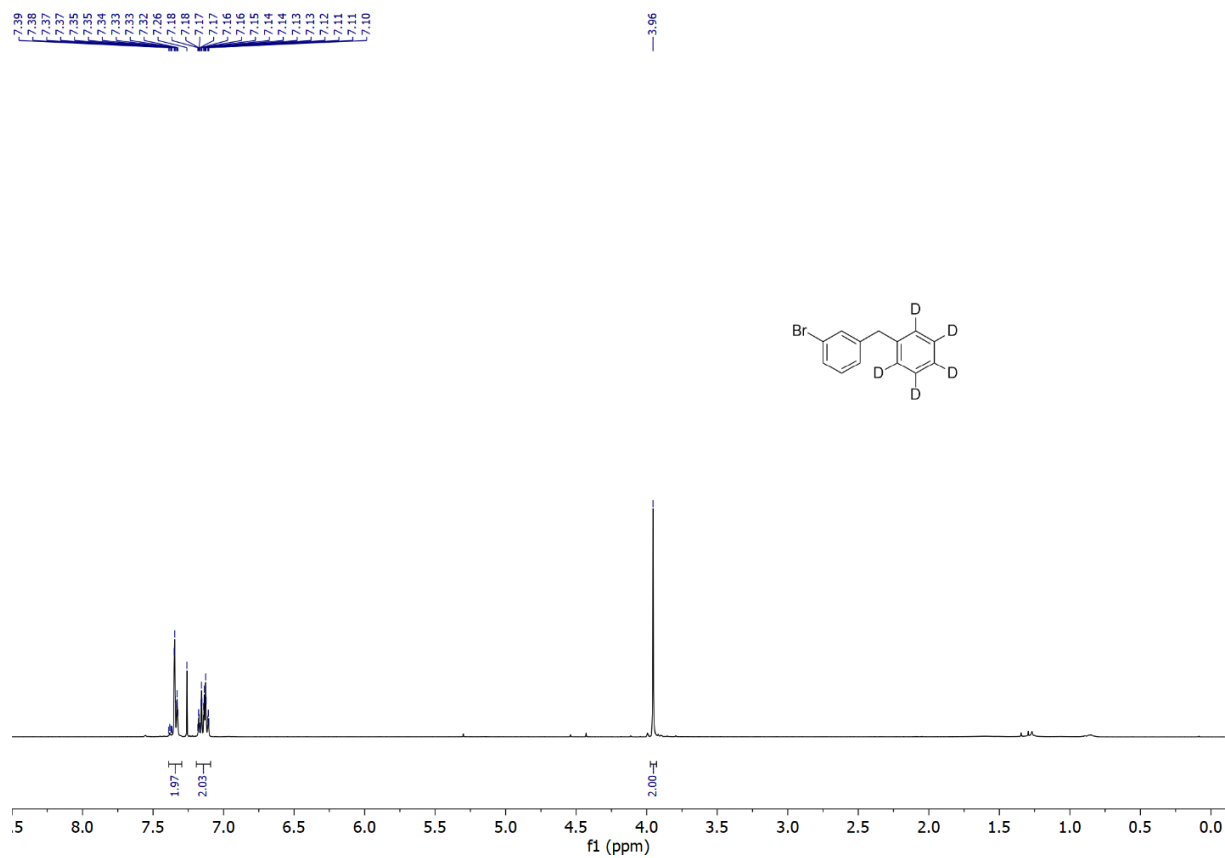
To a solution of 1-fluoro-3-(bromomethyl)benzene (9.5 mg, 0.05 mmol) in C_6D_6 (0.2 mL) and CH_2Cl_2 (0.2 mL) was added a solution of $HB(C_6F_5)_2$ (17.3 mg, 0.05 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after 5 minutes of stirring at room temperature. The product **9** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (12.0 mg, 96% yield).

1H NMR (500 MHz, $CDCl_3$), δ : 7.39 – 7.32 (m, 2H), 7.18 – 7.10 (m, 2H), 3.96 (s, 2H).

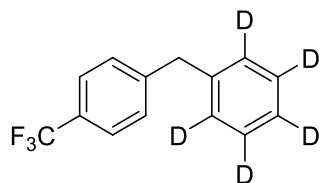
$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$), δ : 143.46, 131.91, 129.99, 129.22, 127.56, 122.55, 41.44.

MS (DART Ionization, m/z): 269.1 ($[M+NH_4]^+$).

HRMS (DART Ionization, m/z): Calcd. for $C_{13}^1H_{10}^2H_5BrN^+$, ($[M+NH_4]^+$): 269.07017; Found: 269.07006.



Preparation of 1-(4-(trifluoromethyl)benzyl)benzene-2,3,4,5,6-*d*₅ (**10**)

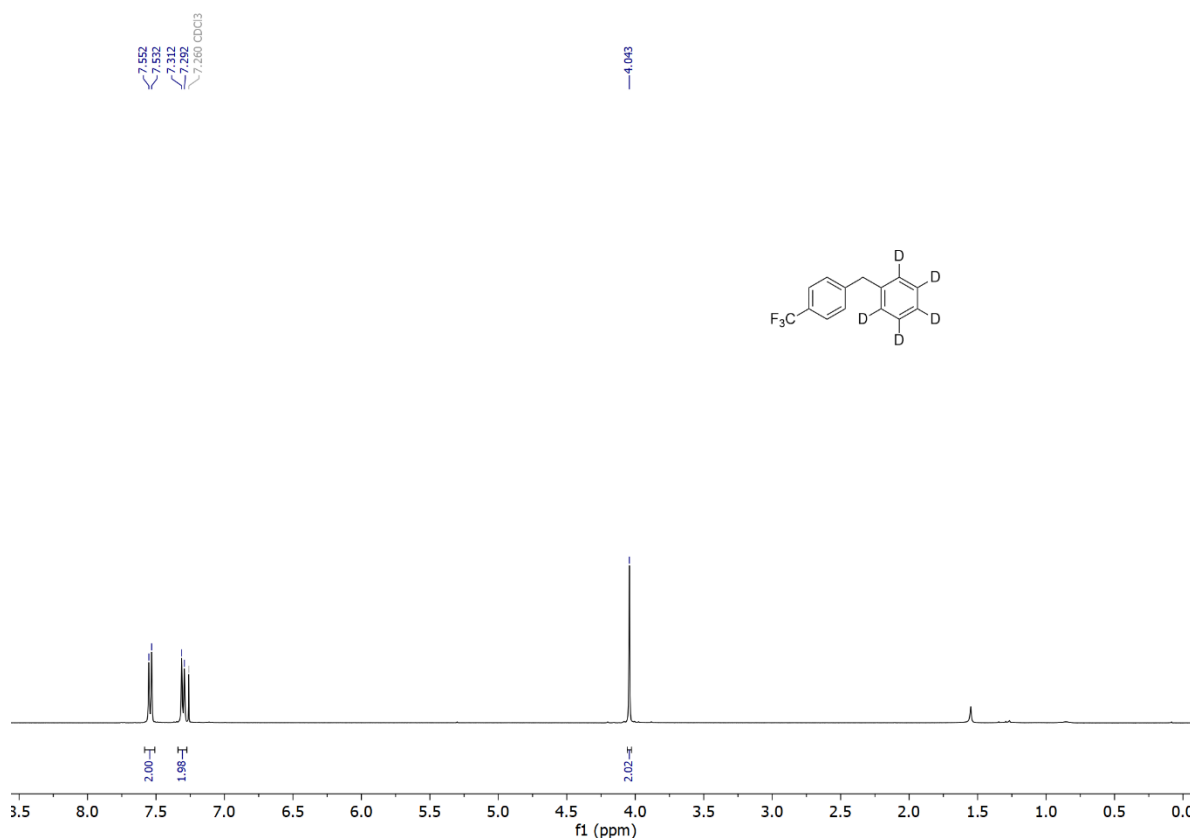


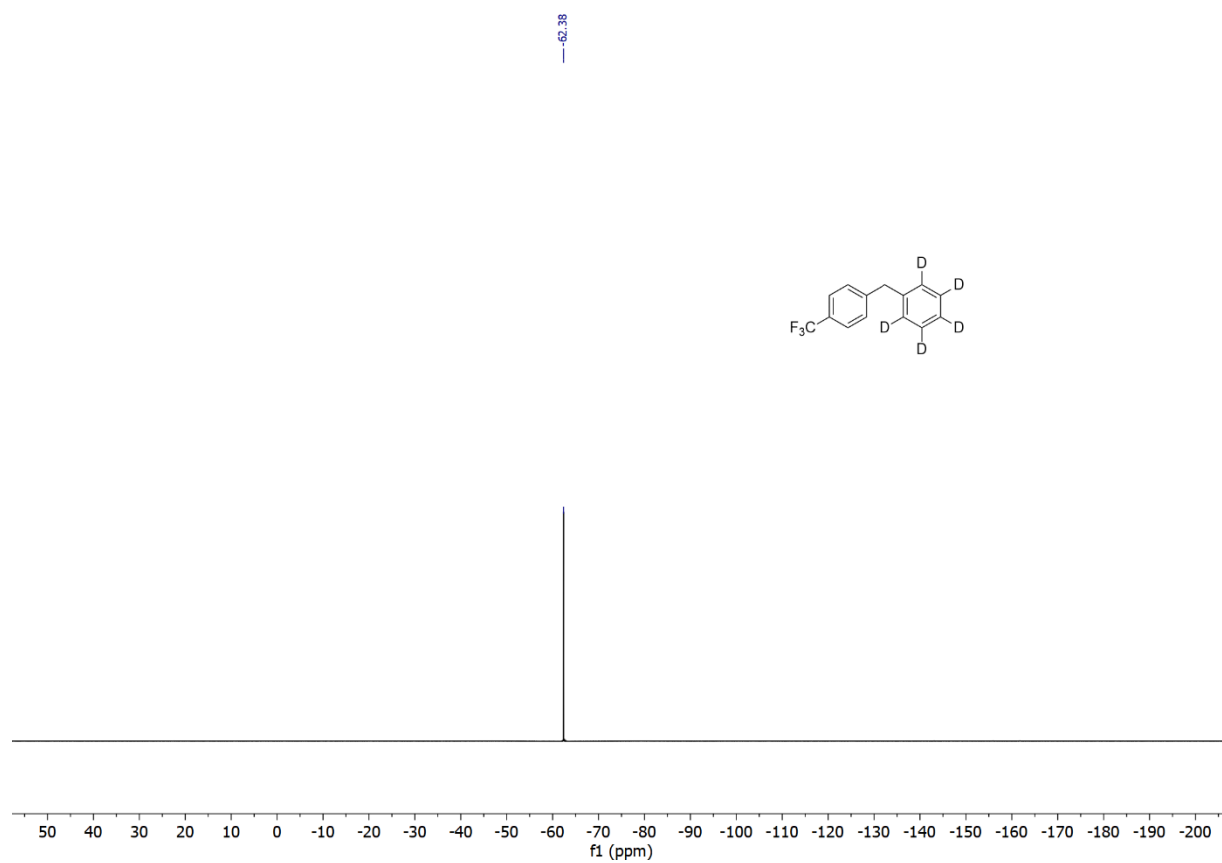
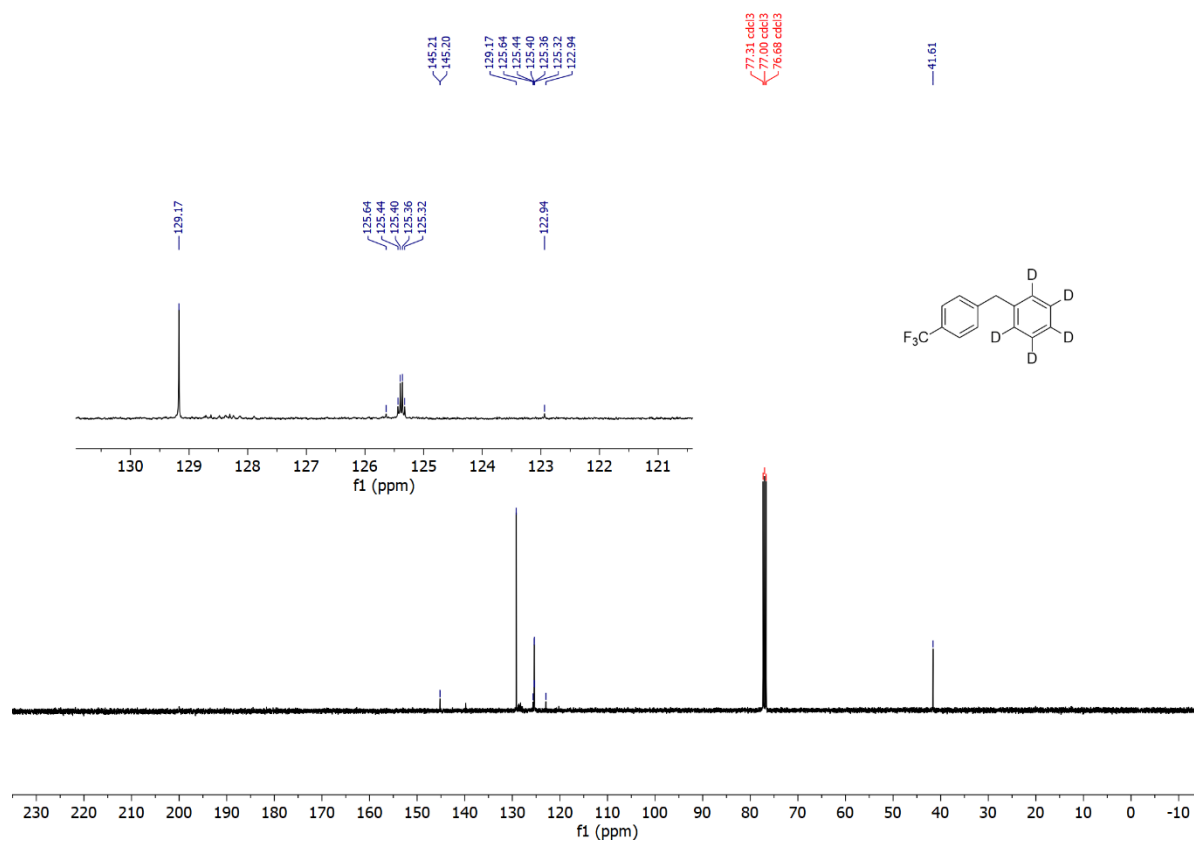
To a solution of 1-fluoro-4-(trifluoromethyl)benzene (8.9 mg, 0.05 mmol) in C₆D₆ (0.2 mL) and CH₂Cl₂ (0.2 mL) was added a solution of HB(C₆F₅)₂ (17.3 mg, 0.05 mmol) in CH₂Cl₂ (0.2 mL). The reaction was complete after 5 minutes of stirring at room temperature. The product **10** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (12.0 mg, 99% yield).

¹H NMR (500 MHz, CDCl₃), δ: 7.54 (d, *J* = 8.0 Hz, 2H), 7.30 (d, *J* = 8.0 Hz, 2H), 4.04 (s, 2H).

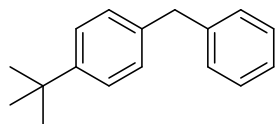
¹³C{¹H} NMR (100 MHz, CDCl₃), δ: 145.20 (d, *J*_{C-F} = 1.0 Hz), 129.17, 125.40 (dd, *J*_{C-F} = 8.0 Hz, 4.0 Hz), 125.38 (d, *J*_{C-F} = 12.0 Hz), 124.29 (d, *J*_{C-F} = 270.0 Hz), 41.61.

¹⁹F NMR (377 MHz, CDCl₃), δ: -62.38.





Preparation of 1-*tert*-butyl-4-(benzyl)benzene (11)



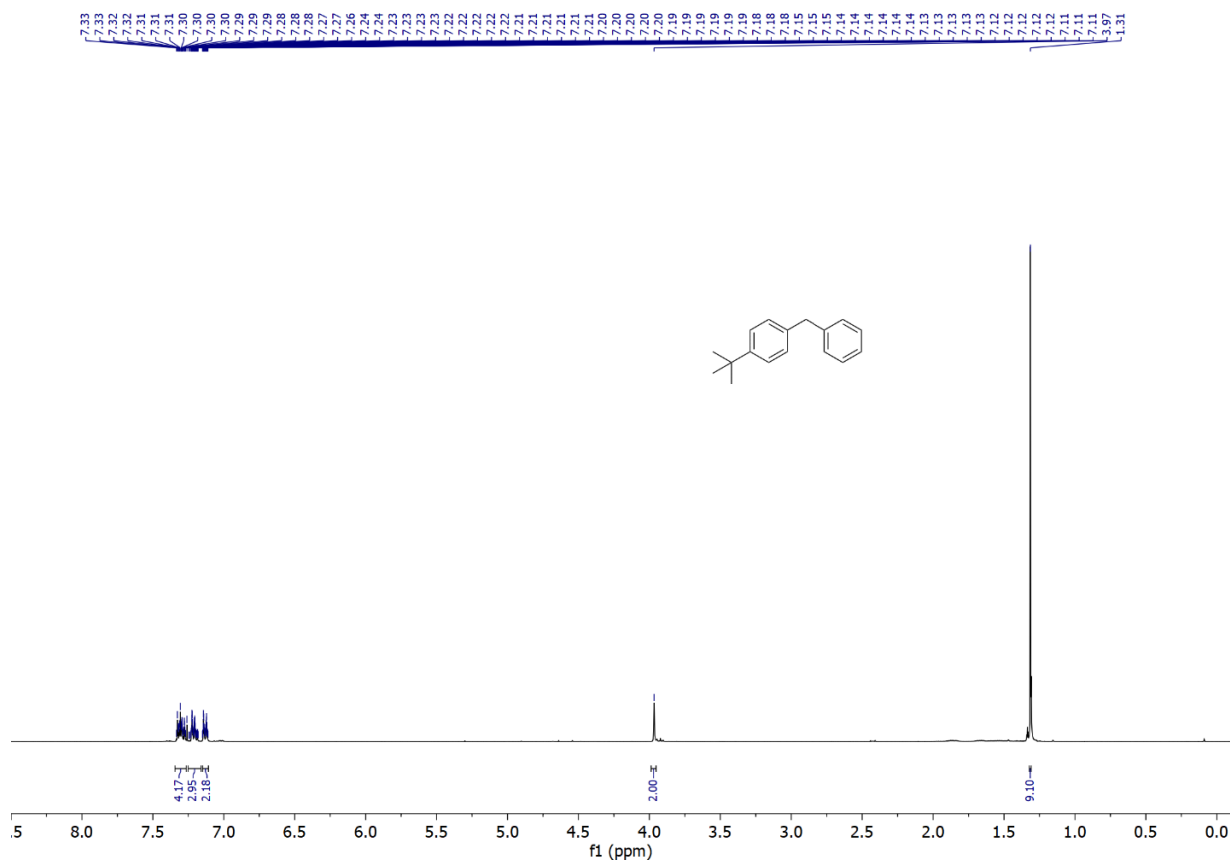
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl)benzene (8.3 mg, 0.05 mmol) in benzene (0.2 mL) and CH_2Cl_2 (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after 10 minutes of stirring at room temperature. The product **11** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (10.5 mg, 92% yield).

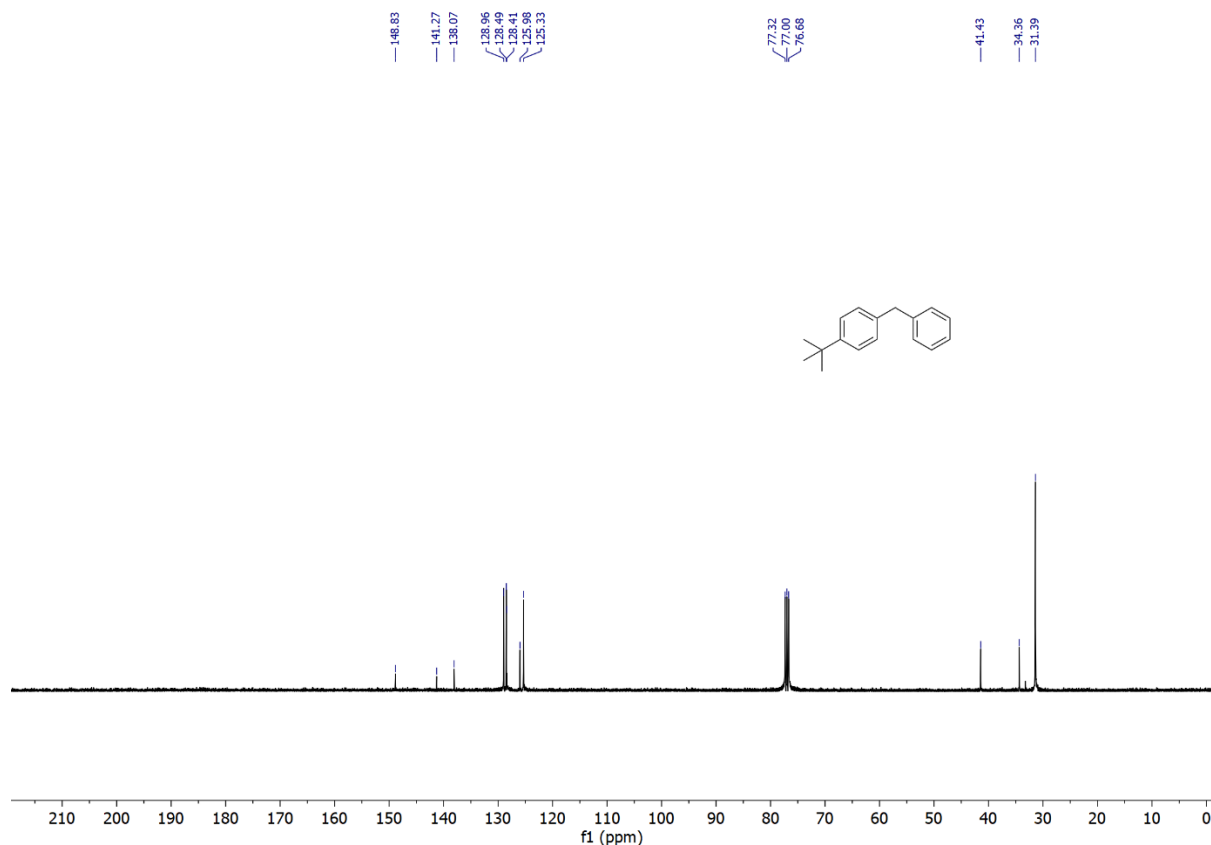
^1H NMR (400 MHz, CDCl_3), δ : 7.33 – 7.26 (m, 4H), 7.25 – 7.18 (m, 2H), 7.15 – 7.11 (m, 2H), 3.97 (s, 2H), 1.31 (s, 9H).

$^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3), δ : 148.83, 141.27, 138.07, 128.96 (2C), 128.49 (2C), 128.41(2C), 125.98, 125.33 (2C), 41.43, 34.36, 31.39 (3C).

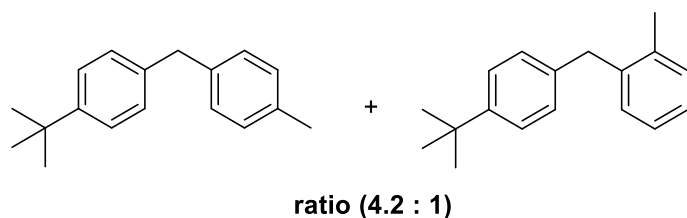
MS (DART Ionization, m/z): 242.2 ($[\text{M}+\text{NH}_4]^+$).

HRMS (DART Ionization, m/z): Calcd. for $\text{C}_{17}\text{H}_{24}\text{N}^+$, ($[\text{M}+\text{NH}_4]^+$): 242.19087; Found: 242.19022.





Preparation of 1-(4-(*tert*-butyl) benzyl)-2-methylbenzene and 1-(*tert*-butyl)-4-(4-methylbenzyl) benzene (**12**):



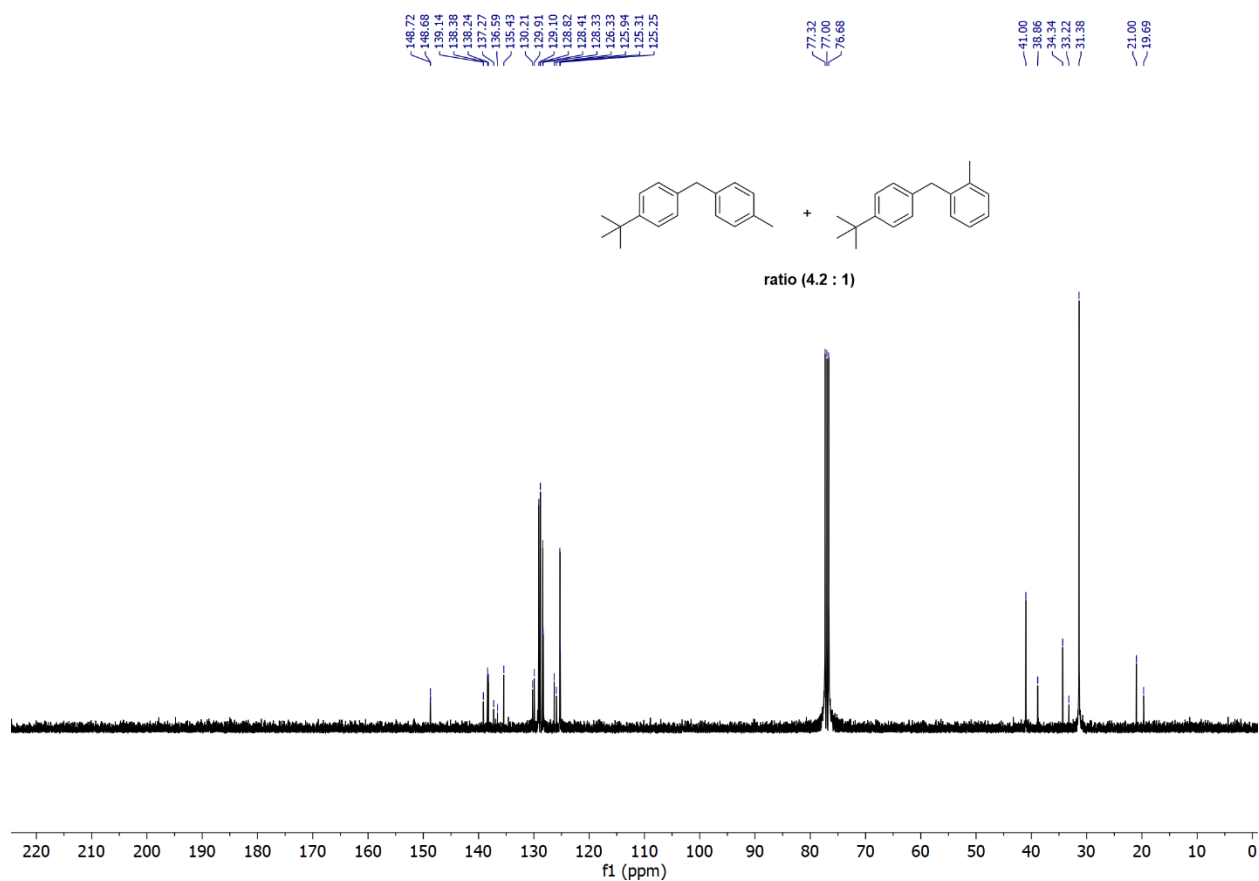
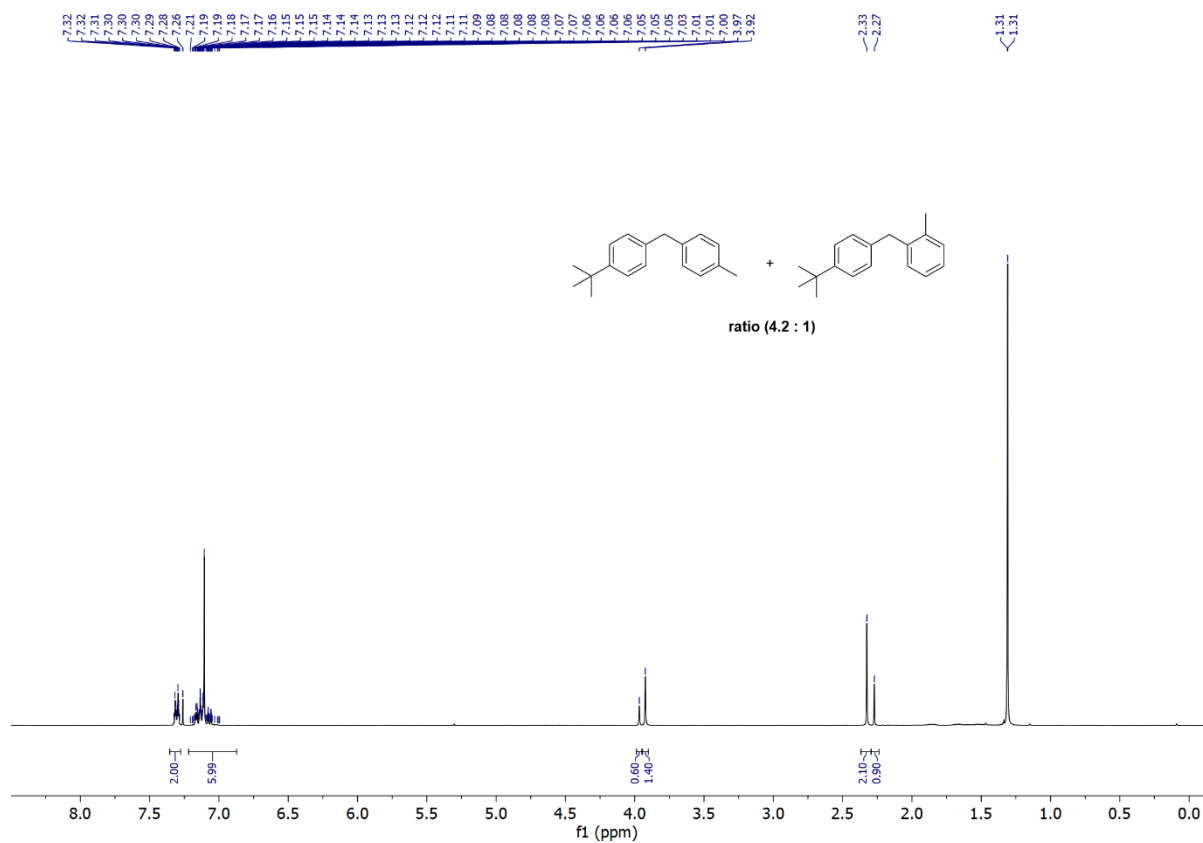
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl)benzene (8.3 mg, 0.05 mmol) in toluene (0.2 mL) and CH₂Cl₂ (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH₂Cl₂ (0.2 mL). The reaction was complete after 10 minutes of stirring at room temperature. The product **12** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (11.4 mg, 96% yield, ratio 4.2:1).

¹H NMR (400 MHz, CDCl₃), δ: 7.32 – 7.28 (m, 2H), 7.18 – 7.00 (m, 6H), 3.97 (s, 0.6H), 3.92 (s, 1.4H), 2.33 (s, 2.1H) 2.27 (s, 0.9H), 1.31 (d, 9H).

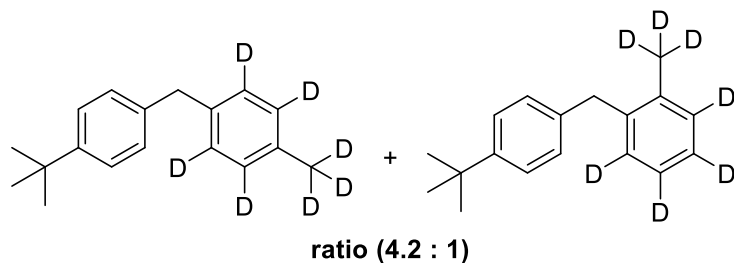
¹³C{¹H} NMR (100 MHz, CDCl₃), δ: 148.72, 148.68, 139.14, 138.38, 138.24, 137.27, 136.59, 135.43, 130.21, 129.91, 129.10, 128.82, 128.41, 128.33, 126.33, 125.94, 125.31, 125.25, 41.00, 38.86, 34.34, 33.22, 31.38, 21.00, 19.69.

MS (DART Ionization, *m/z*): 256.2 ([M+NH₄]⁺).

HRMS (DART Ionization, *m/z*): Calcd. for C₁₈H₂₆N⁺, ([M+NH₄]⁺): 256.20652; Found: 256.20609.



Preparation of 1-(4-(*tert*-butyl) benzyl)-2-methylbenzene and 1-(*tert*-butyl)-4-(4-methylbenzyl) benzene (13**):**



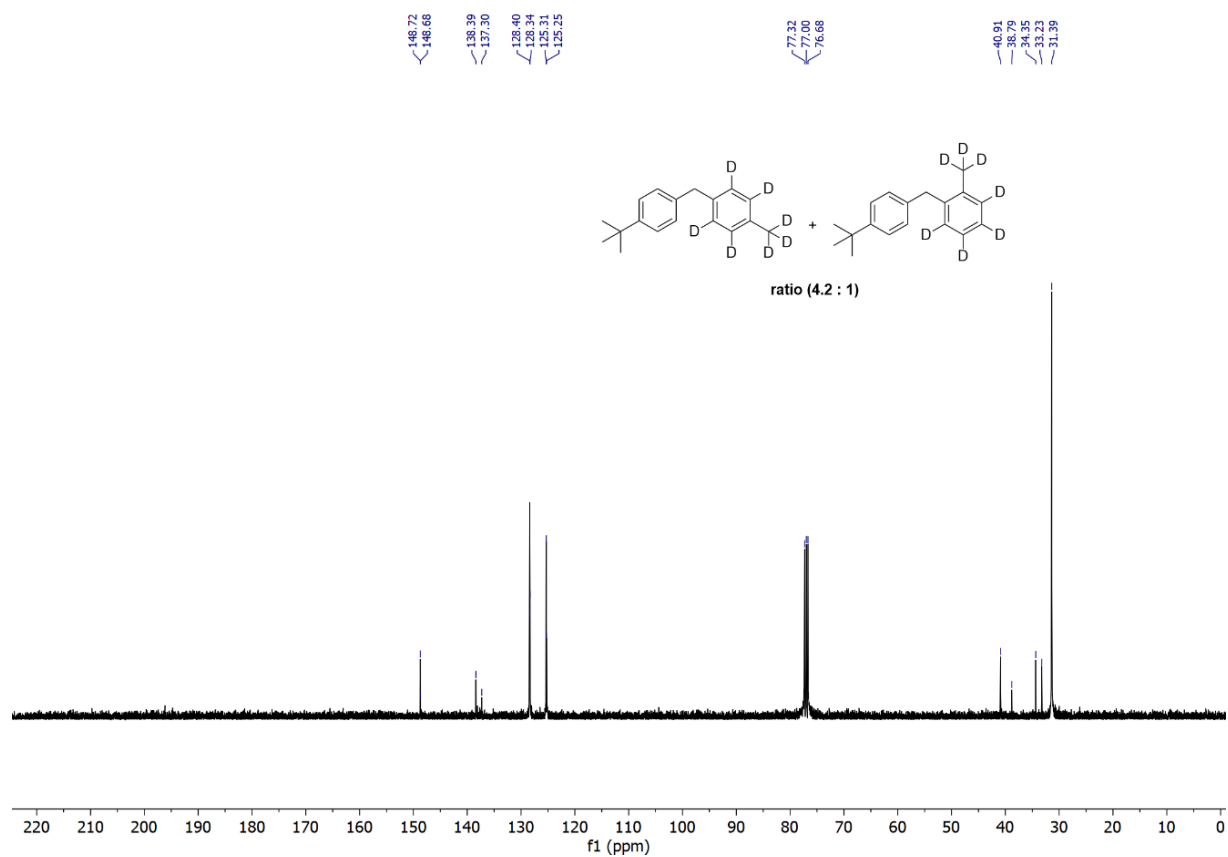
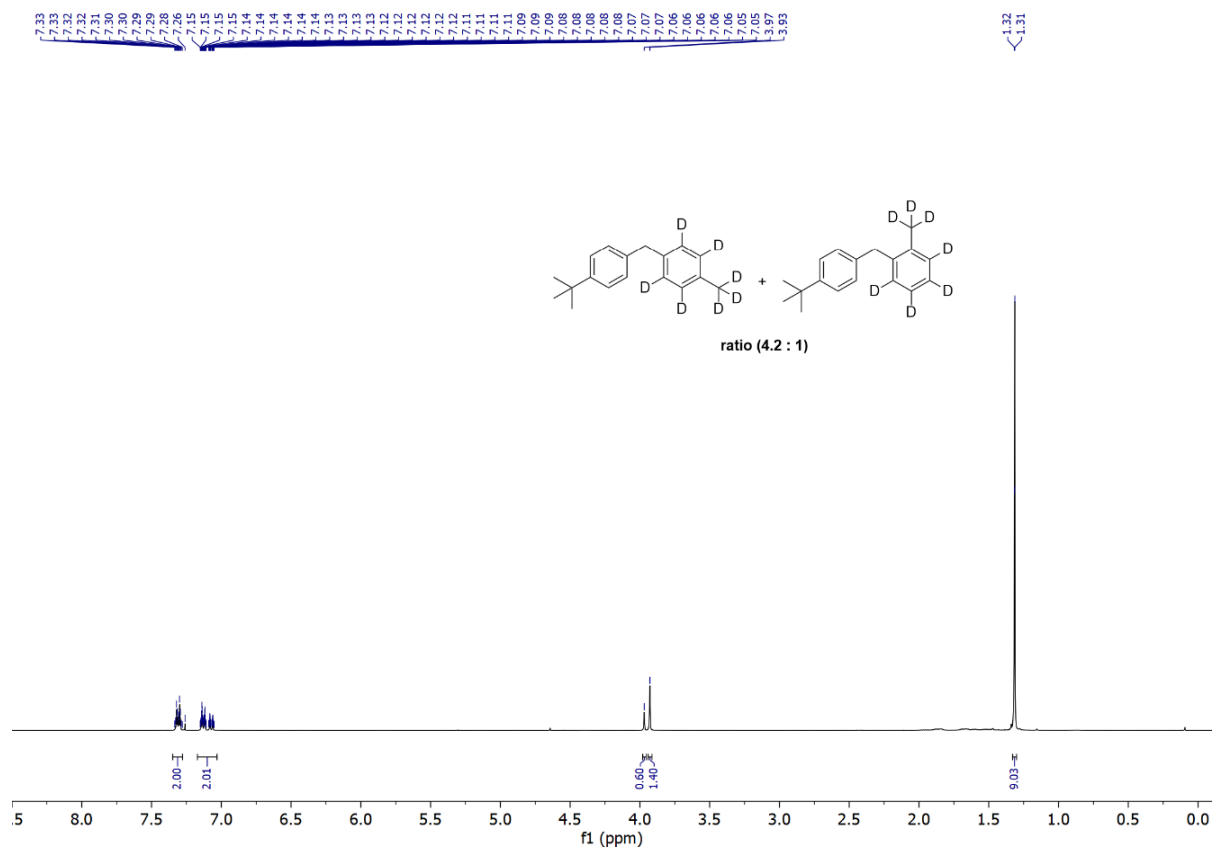
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl) benzene (8.3 mg, 0.05 mmol) in toluene- d_8 (0.2 mL) and CH_2Cl_2 (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after 10 minutes of stirring at room temperature. The product **13** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes (12.0 mg, 98% yield, ratio 4.2:1).

^1H NMR (400 MHz, CDCl_3), δ : 7.33 – 7.28 (m, 2H), 7.15 – 7.05 (m, 6H), 3.97 (s, 0.6H), 3.92 (s, 1.4H), 1.31 (d, 9H).

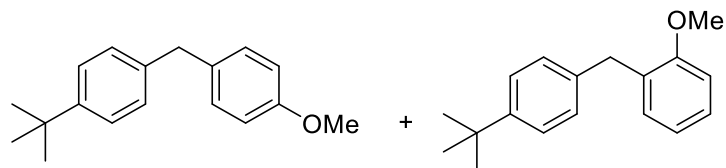
$^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3), δ : 148.72, 148.68, 138.39, 137.30, 128.40, 128.34, 125.31, 125.25, 77.32, 77.00, 76.68, 40.91, 38.79, 34.35, 33.23, 31.39.

MS (DART Ionization, m/z): 263.2 ($[\text{M}+\text{NH}_4]^+$).

HRMS (DART Ionization, m/z): Calcd. for $\text{C}_{18}^1\text{H}_{19}^2\text{H}_7\text{N}^+$, ($[\text{M}+\text{NH}_4]^+$): 242.19087; Found: 263.25060.



Preparation of 1-(4-(*tert*-butyl) benzyl)-2-methoxybenzene and 1-(*tert*-butyl)-4-(4-methoxybenzyl) benzene (**14**):



ratio (1.2 : 1)

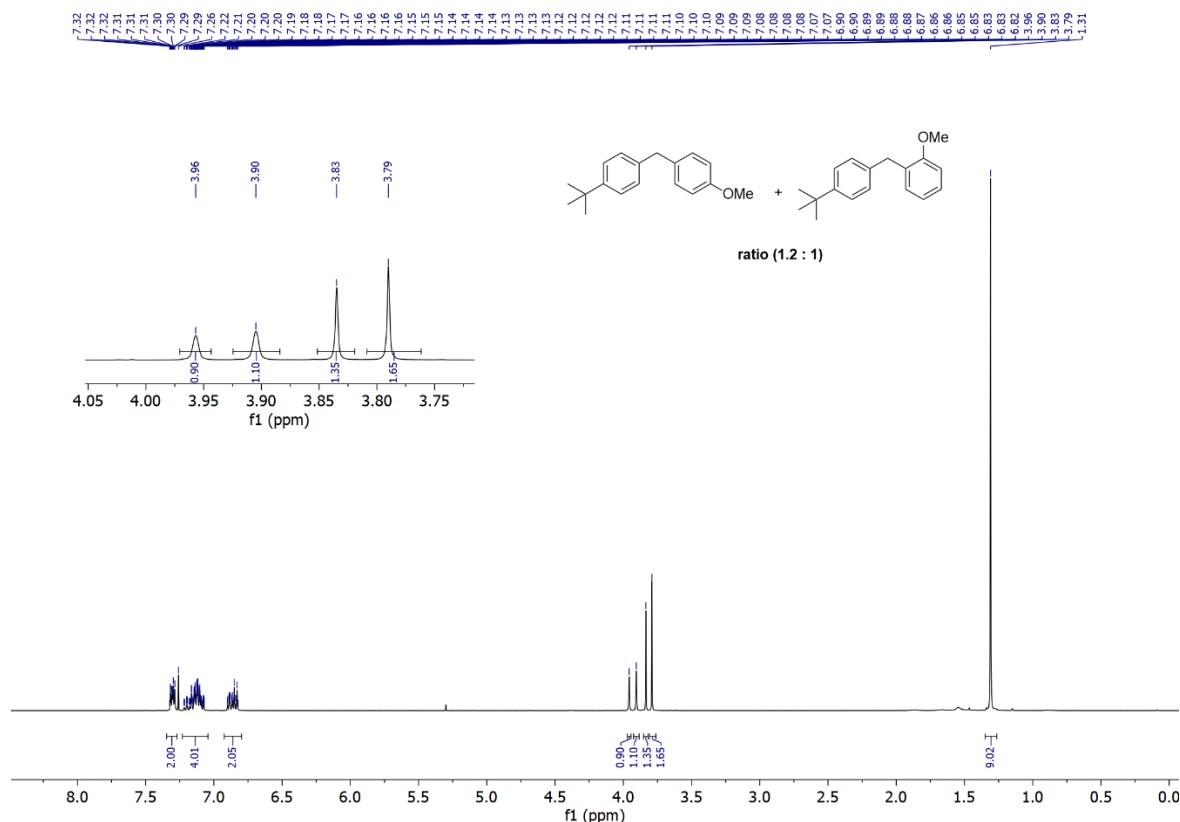
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl)benzene (8.3 mg, 0.05 mmol) in anisole (0.2 mL) and CH_2Cl_2 (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after 10 minutes of stirring at room temperature. The product **14** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (12.4 mg, 98% yield, ratio 1.2:1).

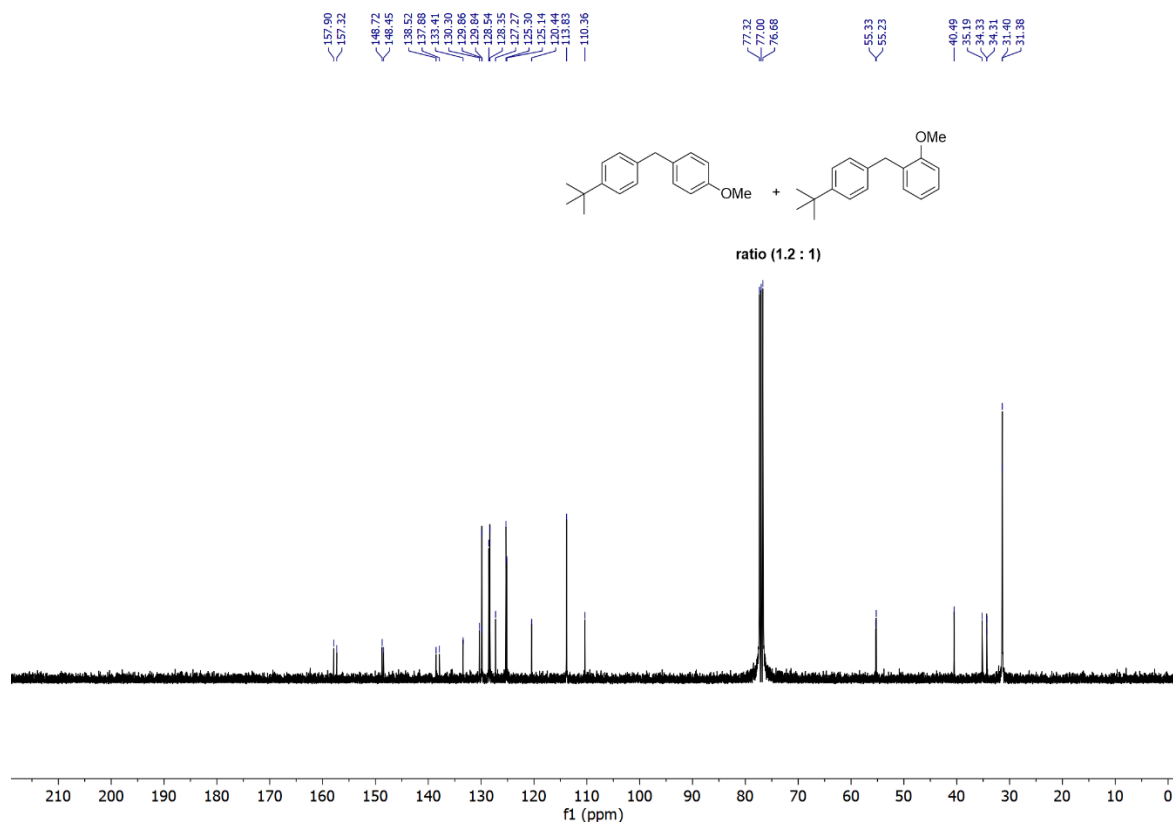
^1H NMR (400 MHz, CDCl_3), δ : 7.32 – 7.29 (m, 2H), 7.22 – 7.02 (m, 4H), 6.90 – 6.82 (m, 2H), 3.96 (s, 0.9H), 3.90 (s, 1.1H), 3.83 (s, 1.35 H) 3.79 (s, 1.65H), 1.31 (s, 9H).

$^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3), δ : 157.90, 157.32, 148.72, 148.45, 138.52, 137.88, 133.41, 130.30, 129.86, 129.84, 128.54, 128.35, 127.27, 125.30, 125.14, 120.44, 113.83, 110.36, 55.33, 55.23, 40.49, 35.19, 34.33, 34.31, 31.40, 31.38.

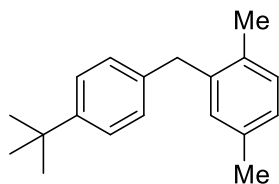
MS (DART Ionization, m/z): 272.2 ($[\text{M}+\text{NH}_4]^+$).

HRMS (DART Ionization, m/z): Calcd. for $\text{C}_{18}\text{H}_{26}\text{NO}^+$, ($[\text{M}+\text{NH}_4]^+$): 272.20144; Found: 272.20217.





Preparation of 2-(4-(*tert*-butyl)benzyl)-1,4-dimethylbenzene (**15**)



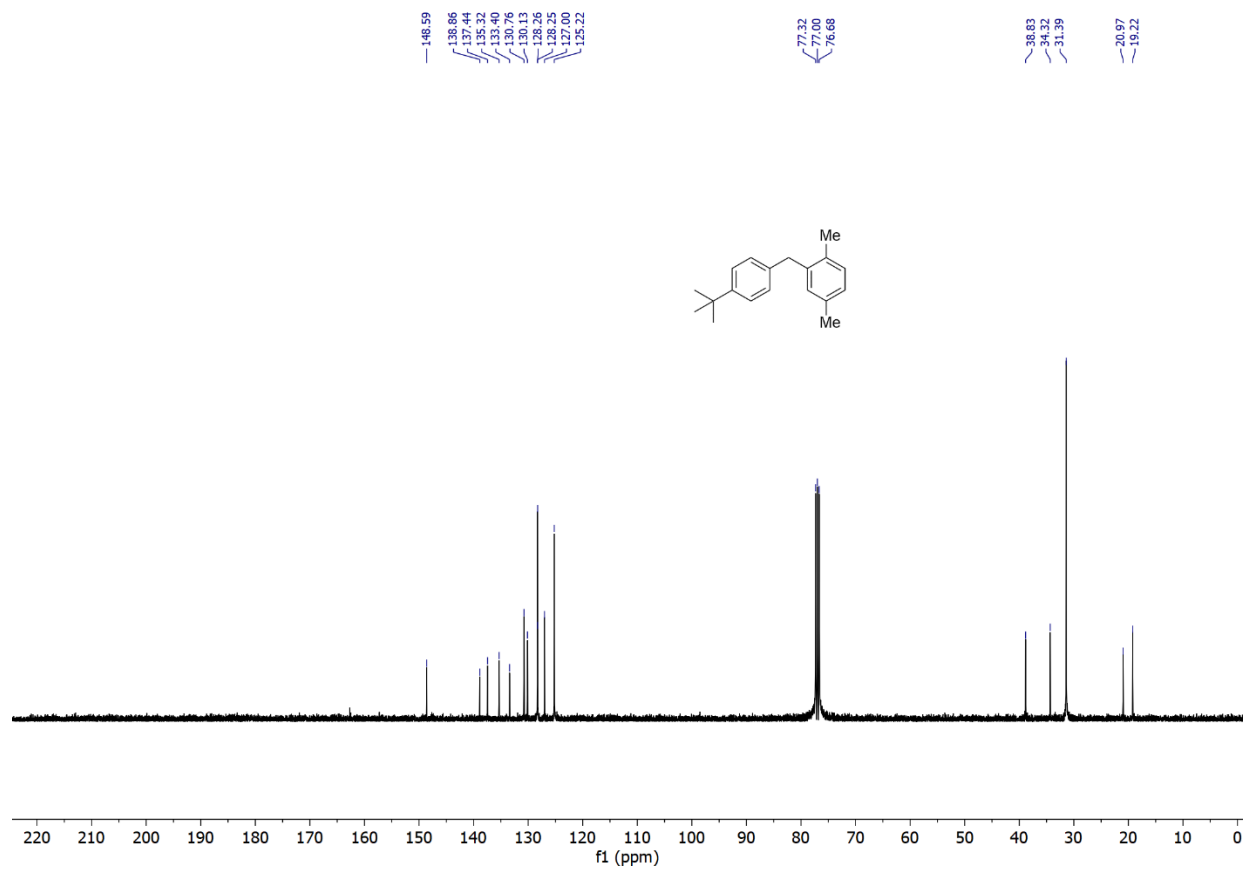
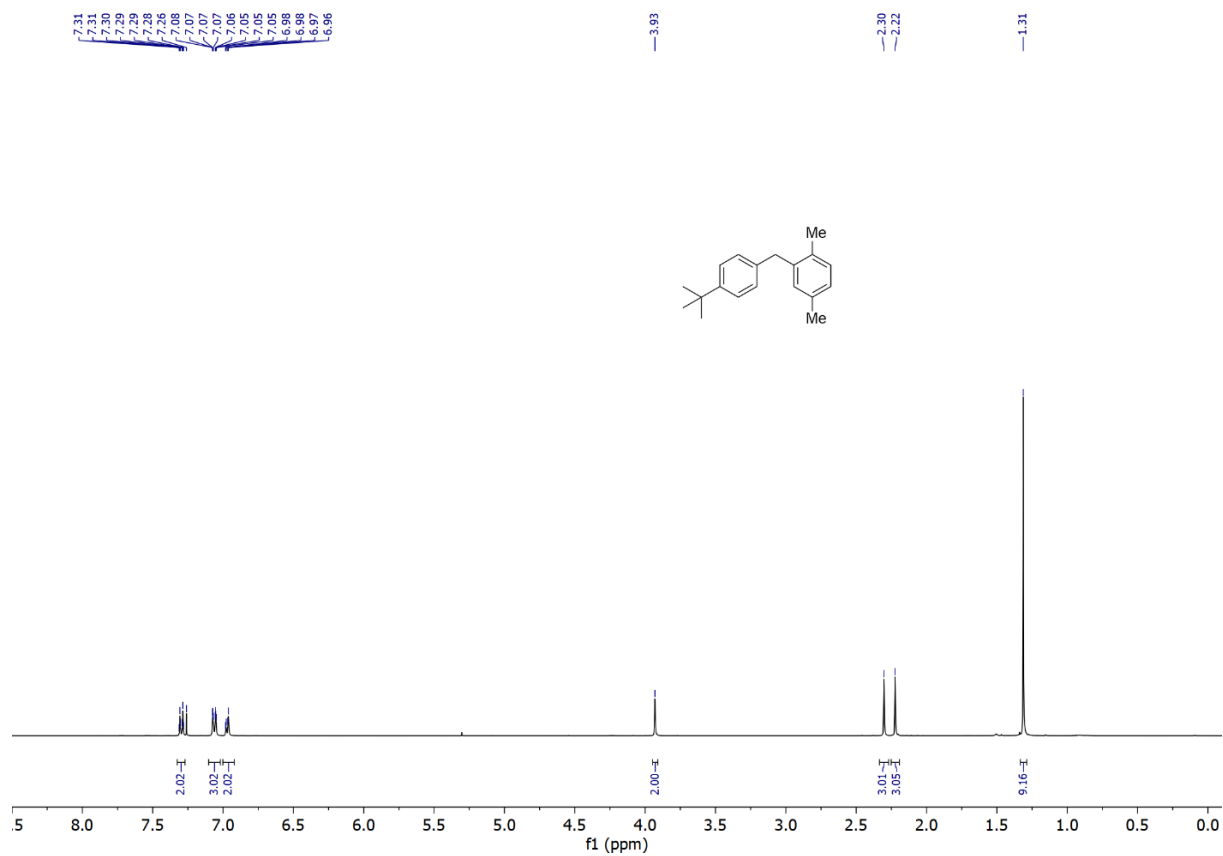
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl)benzene (8.3 mg, 0.05 mmol) in *p*-xylene (0.2 mL) and CH_2Cl_2 (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after 30 minutes of stirring at room temperature. The product **15** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (12.2 mg, 96% yield).

^1H NMR (400 MHz, CDCl_3), δ : 7.31 – 7.28 (m, 2H), 7.09 – 7.05 (m, 3H), 6.99 – 6.92 (m, 2H), 3.93 (s, 2H), 2.30 (s, 3H), 2.22 (s, 3H), 1.31 (s, 9H).

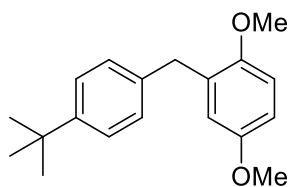
$^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3), δ : 148.59, 138.86, 137.44, 135.32, 133.40, 130.76, 130.13, 128.26, 128.25, 127.00, 125.22, 38.83, 34.32, 31.39, 20.97, 19.22.

MS (DART Ionization, m/z): 270.2 ($[\text{M}+\text{NH}_4]^+$).

HRMS (DART Ionization, m/z): Calcd. for $\text{C}_{19}\text{H}_{28}\text{N}^+$, ($[\text{M}+\text{NH}_4]^+$): 270.22217; Found: 270.22178.



Preparation of 2-(4-(*tert*-butyl)benzyl)-1,4-dimethoxybenzene (**16**)



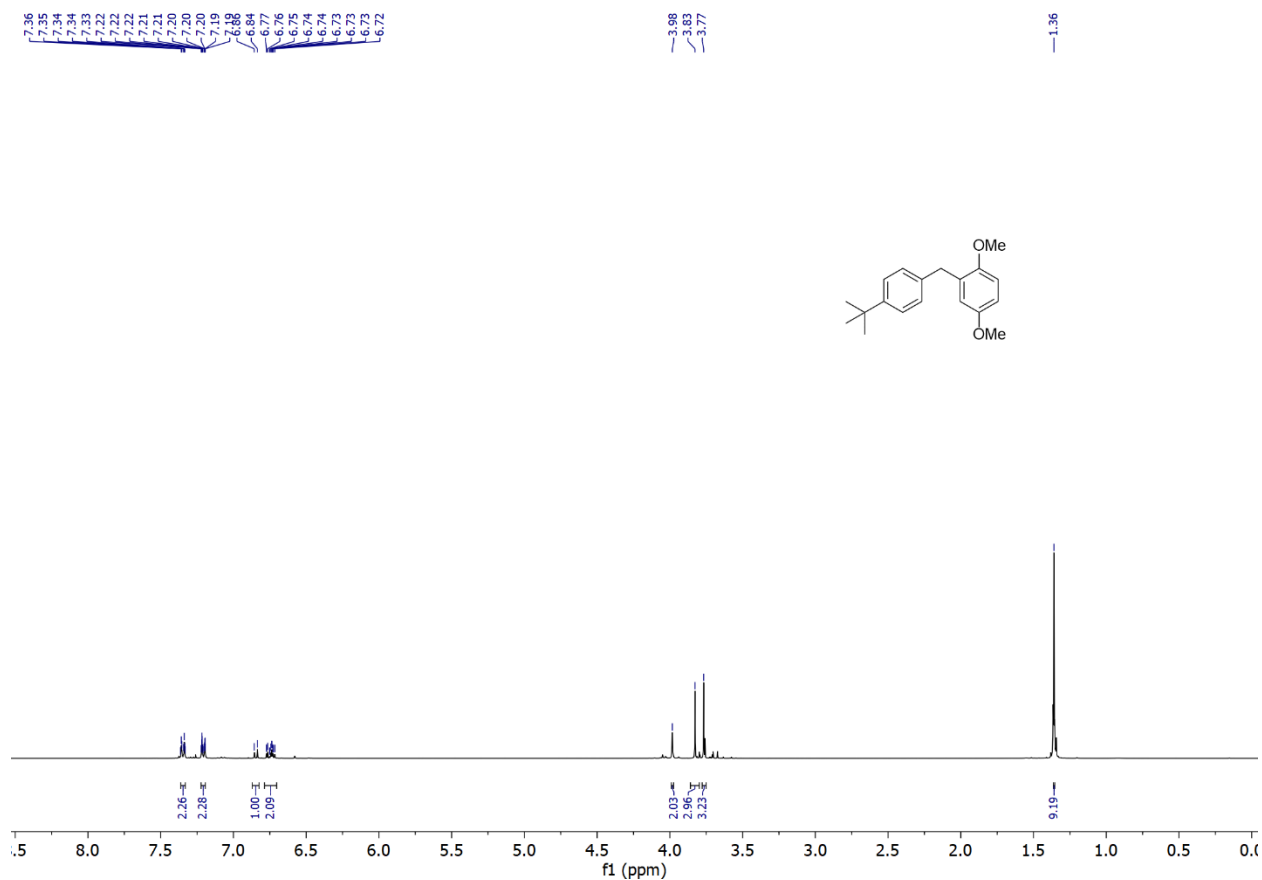
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl)benzene (8.3 mg, 0.05 mmol) in 1,4-dimethoxybenzene (1.1 equiv., 7.6 mg, 0.055 mmol) and CH_2Cl_2 (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after 30 minutes of stirring at room temperature. The product **16** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (12.2 mg, 86% yield).

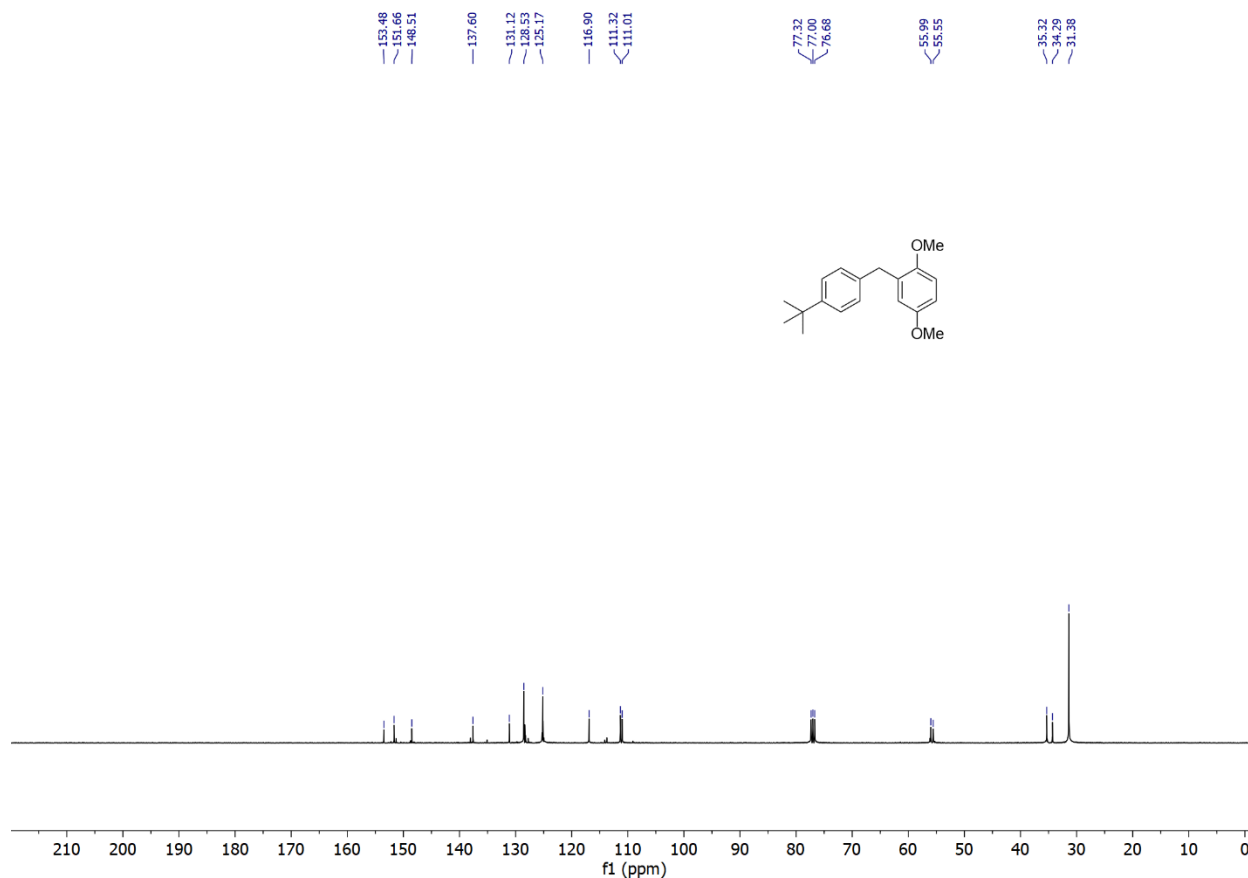
^1H NMR (400 MHz, CDCl_3), δ : 7.36 – 7.33 (m, 2H), 7.22 – 7.19 (m, 2H), 6.85 (d, $J = 8.0$, 1H), 6.77 – 6.72 (m, 2H), 3.98 (s, 2H), 3.83 (s, 3H), 3.77 (s, 3H), 1.36 (s, 9H).

$^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3), δ : 153.48, 151.66, 148.51, 137.60, 131.12, 128.53, 125.17, 116.90, 111.32, 111.01, 55.99, 55.55, 35.32, 34.29, 31.38.

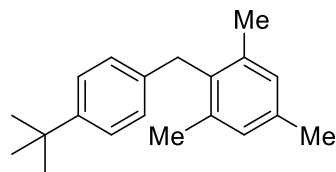
MS (DART Ionization, m/z): 302.2 ($[\text{M}+\text{NH}_4]^+$).

HRMS (DART Ionization, m/z): Calcd. for $\text{C}_{19}\text{H}_{28}\text{NO}_2^+$, ($[\text{M}+\text{NH}_4]^+$): 302.21200; Found: 302.21243.





Preparation of 2-(4-(*tert*-butyl)benzyl)-1,3,5-trimethylbenzene (17)



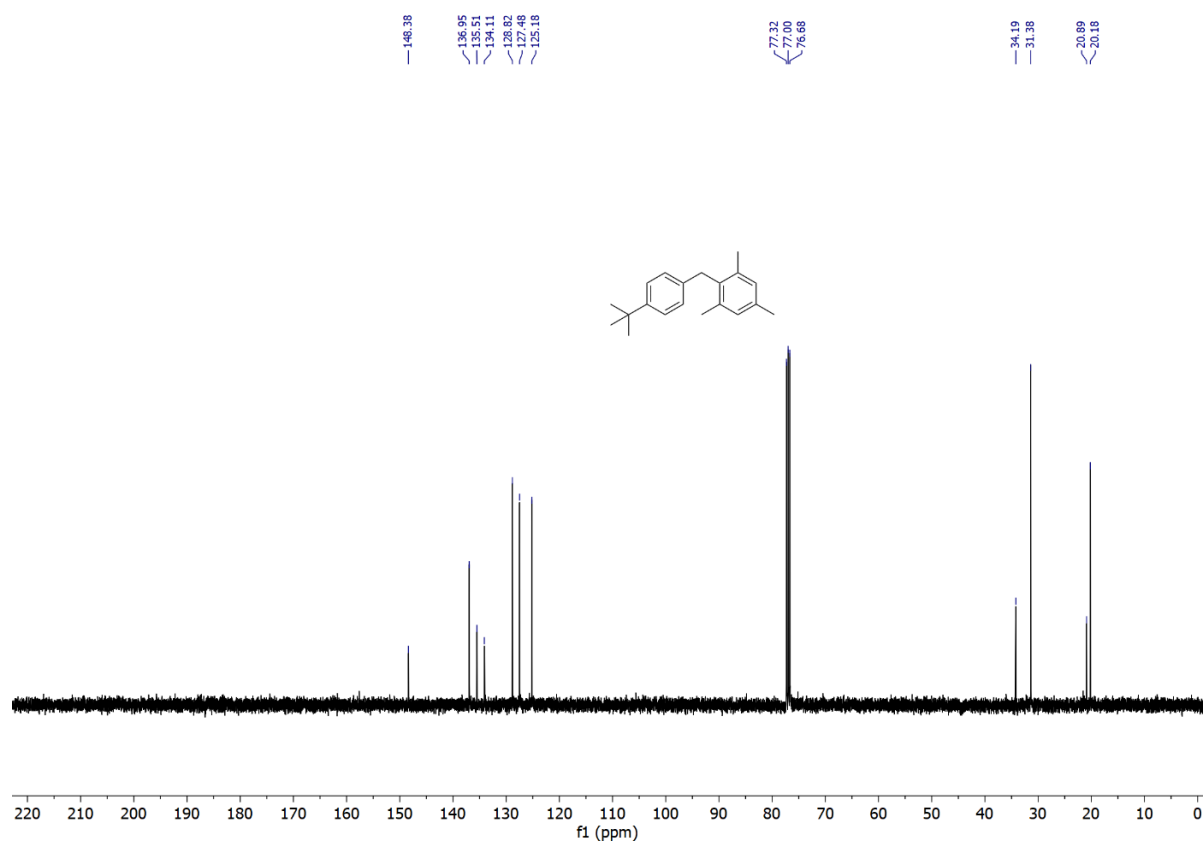
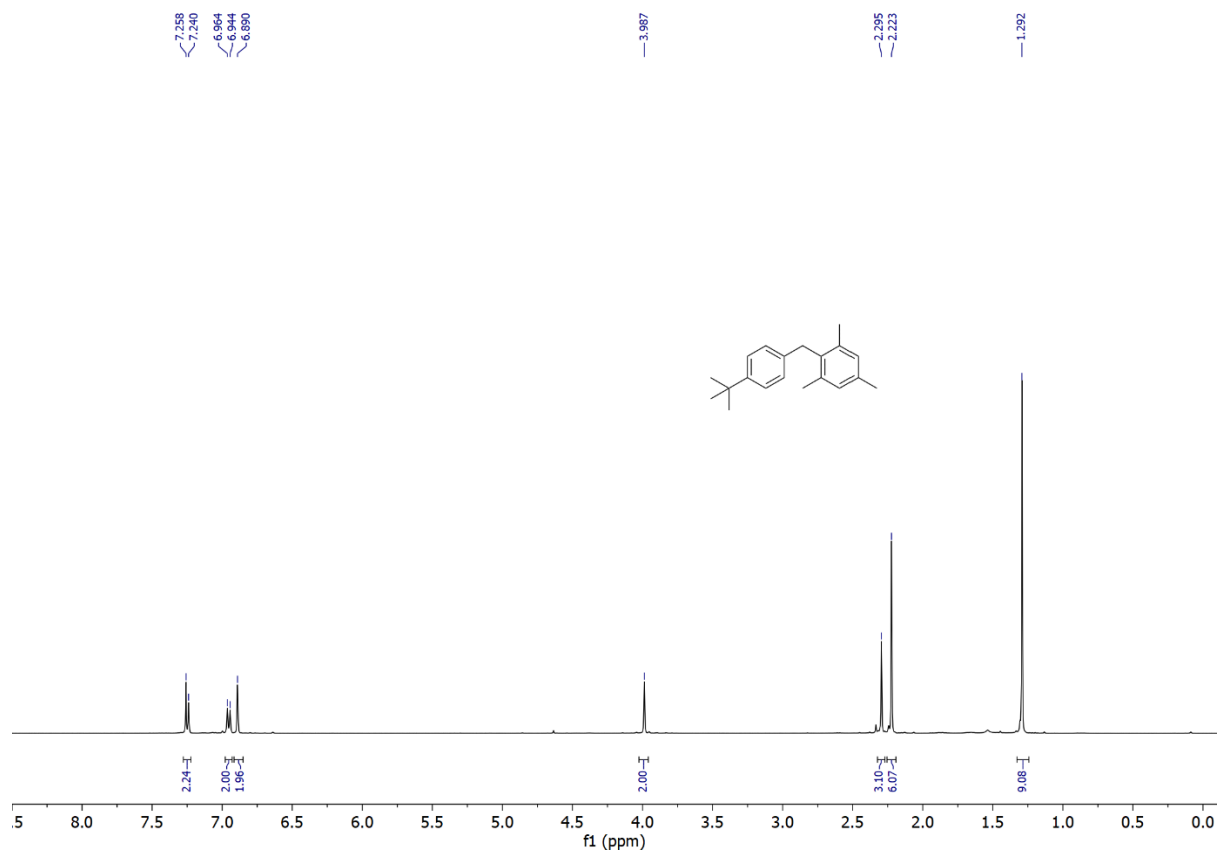
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl)benzene (8.3 mg, 0.05 mmol) in mesitylene (0.2 mL) and CH_2Cl_2 (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after 3 hours of stirring at room temperature. The product **17** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (12.7 mg, 96% yield).

^1H NMR (400 MHz, CDCl_3), δ : 7.25 (d, $J = 7.2$, 2H), 6.95 (d, $J = 8$, 2H), 6.89 (s, 2H), 3.99 (s, 2H), 2.30 (s, 3H), 2.22 (s, 6H), 1.29 (s, 9H).

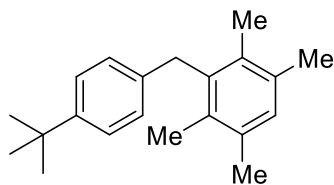
$^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3), δ : 148.38, 136.95, 135.51, 134.11, 128.82, 127.48, 125.18, 77.32, 77.00, 76.68, 34.19, 31.38, 20.89, 20.18.

MS (DART Ionization, m/z): 284.2 ($[\text{M}+\text{NH}_4]^+$).

HRMS (DART Ionization, m/z): Calcd. for $\text{C}_{20}\text{H}_{30}\text{N}^+$, ($[\text{M}+\text{NH}_4]^+$): 284.23782; Found: 284.23872.



Preparation of 3-(4-(tert-butyl)benzyl)-1,2,4,5-tetramethylbenzene (**18**)



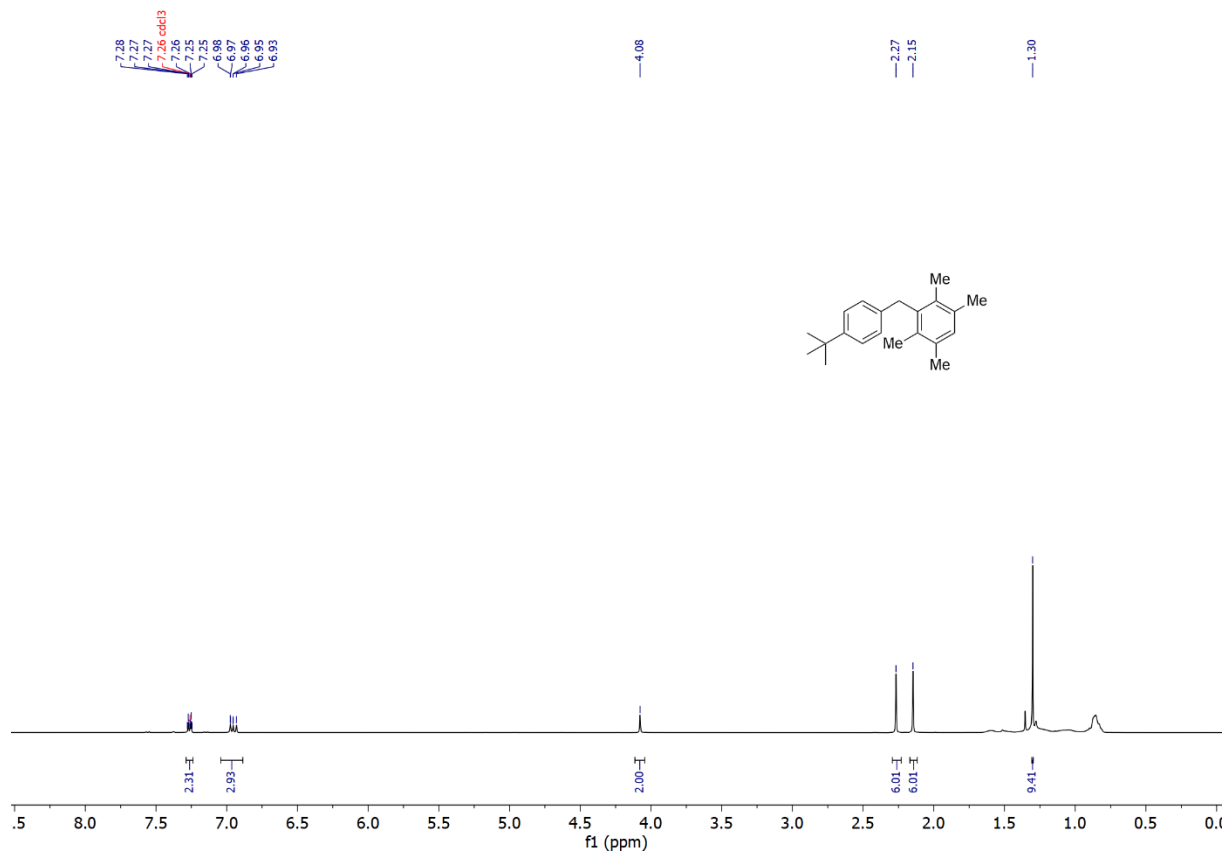
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl)benzene (8.3 mg, 0.05 mmol) in 1,2,4,5-tetramethylbenzene (1.1 equiv., 7.4 mg, 0.055 mmol) and CH_2Cl_2 (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after 3 hours of stirring at room temperature. The residue was purified by flash chromatography (hexane/DCM = 50/1) on silica gel to afford the product **18** as a white solid (11.2 mg, 80% yield).

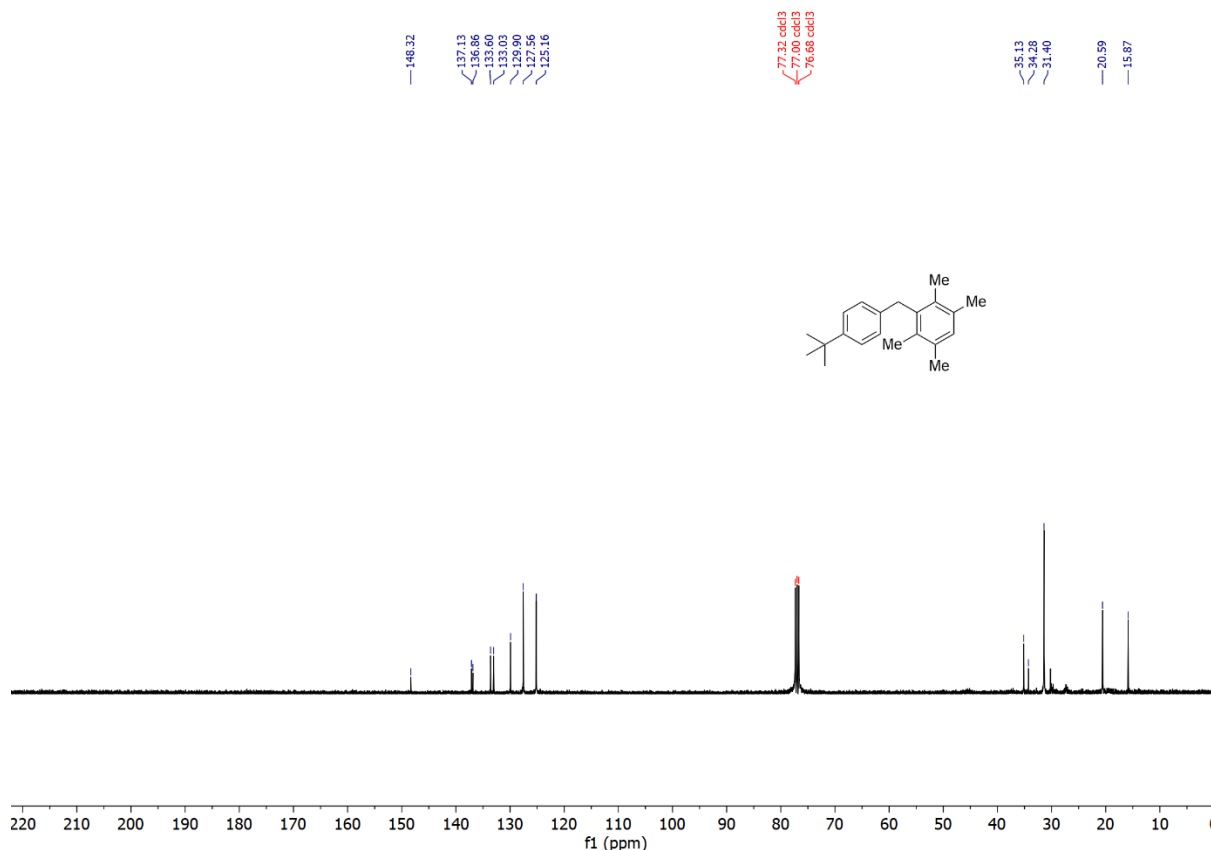
^1H NMR (400 MHz, CDCl_3), δ : 7.25 (d, $J = 7.2$, 2H), 6.95 (d, $J = 8$, 2H), 6.89 (s, 2H), 3.99 (s, 2H), 2.30 (s, 3H), 2.22 (s, 6H), 1.29 (s, 9H).

$^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3), δ : 148.32, 137.13, 136.86, 133.59, 133.03, 129.90, 127.56, 125.16, 35.13, 34.28, 31.40, 20.59, 15.87.

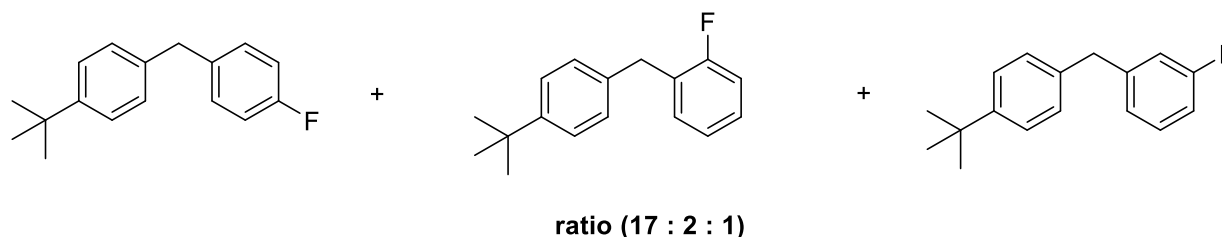
MS (DART Ionization, m/z): 298.3 ($[\text{M}+\text{NH}_4]^+$).

HRMS (DART Ionization, m/z): Calcd. for $\text{C}_{21}\text{H}_{32}\text{N}^+$, ($[\text{M}+\text{NH}_4]^+$): 298.25347; Found: 298.25361.





Preparation of 1-(4-(tert-butyl) benzyl)-2-fluorobenzene, 1-(4-(tert-butyl) benzyl)-4-fluorobenzene and 1-(4-(tert-butyl) benzyl)-3-fluorobenzene (19):



To a solution of 1-(tert-butyl)-4-(fluoromethyl) benzene (8.3 mg, 0.05 mmol) in fluorobenzene (0.2 mL) and CH₂Cl₂ (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH₂Cl₂ (0.2 mL). The reaction was complete after 30 minutes of stirring at room temperature. The product **19** was isolated as a colourless oil following filtration through a short plug of basic alumina using hexanes as eluent (9.7 mg, 80% yield, ratio 17: 2: 1).

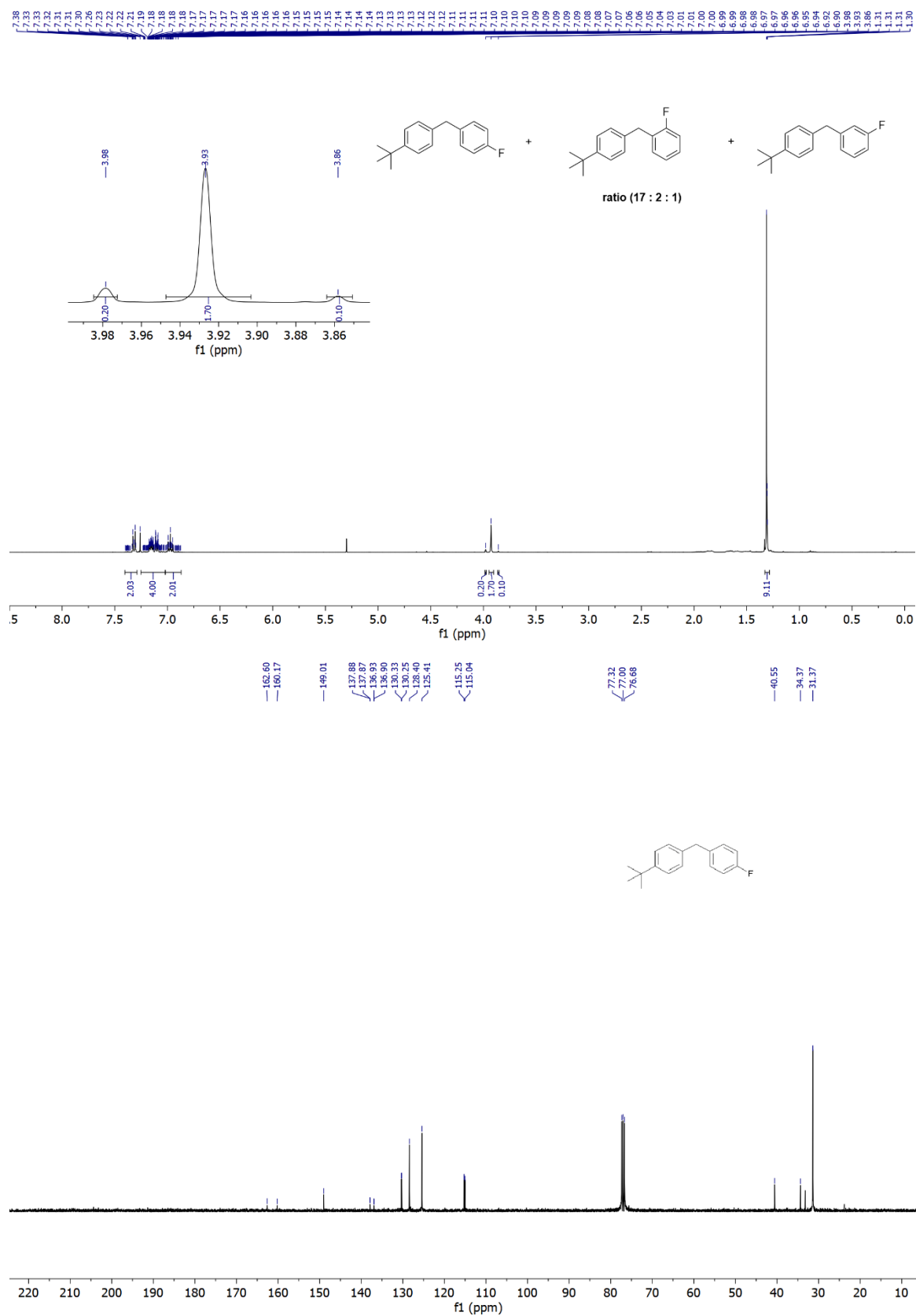
¹H NMR (400 MHz, CDCl₃), δ: 7.40 – 7.30 (m, 2H), 7.23 – 7.03 (m, 4H), 7.01 – 6.88 (m, 2H), 3.98 (s, 0.2H), 3.93 (s, 1.7H, major), 3.86 (s, 0.1H), 1.31 (m, 9H).

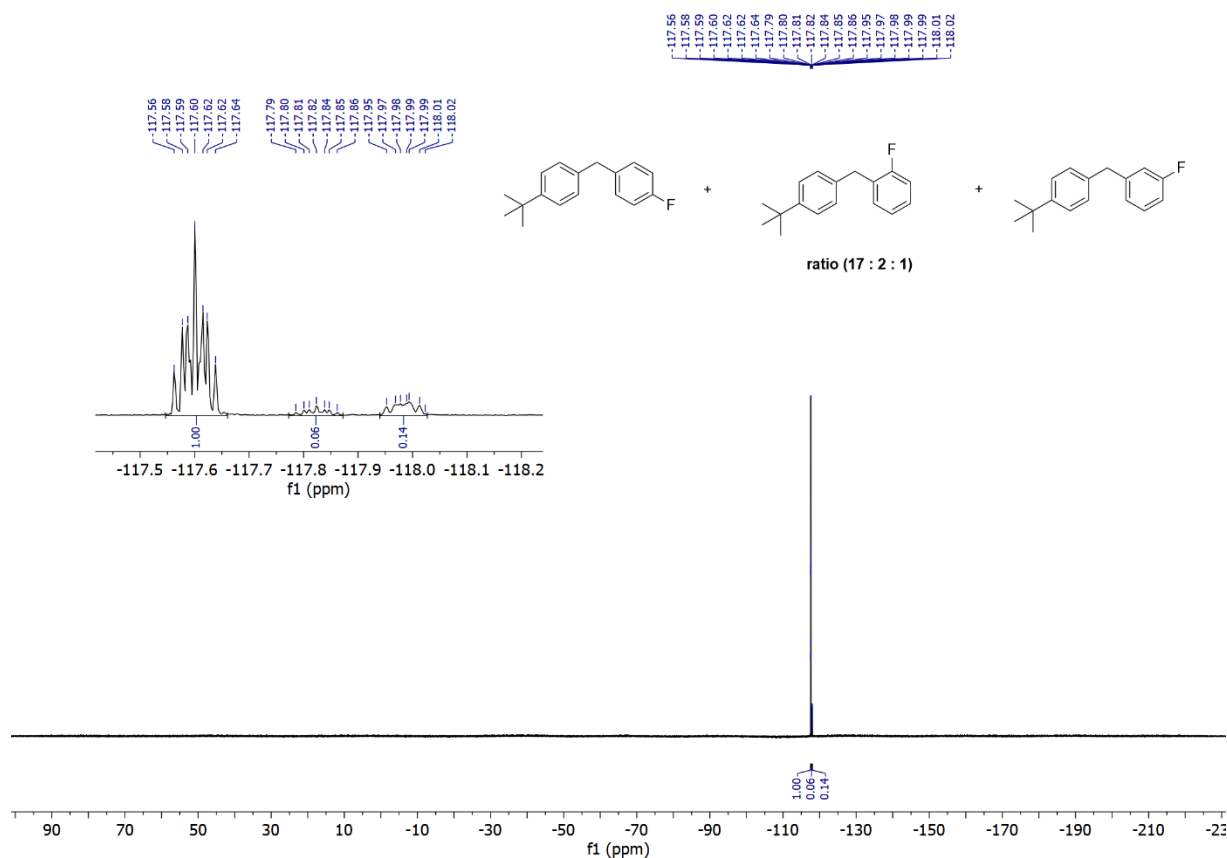
¹³C{¹H} NMR (100 MHz, CDCl₃), δ: 161.39 (d, *J* = 243.0 Hz), 149.01, 137.88, 136.92 (d, *J* = 3.0 Hz), 130.29 (d, *J* = 8.0 Hz), 128.40, 125.41, 115.15 (d, *J* = 21.0 Hz), 40.55, 34.37, 31.37.

¹⁹F NMR (376 MHz, CDCl₃), δ: -117.6 (m, 1F, major), -117.8 (m, 0.06F), -117.8 (m, 0.14F).

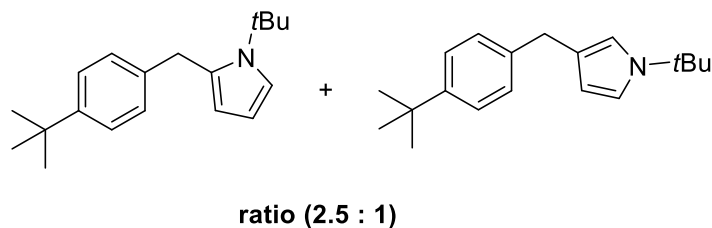
MS (ESI, *m/z*): 242.1([M]⁺).

HRMS (ESI, m/z): Calcd. for $C_{17}H_{19}F$ ($[M]^+$): 242.1471, Found: 242.1477.





Preparation of 2-(4-(*tert*-butyl)benzyl)furan (20):



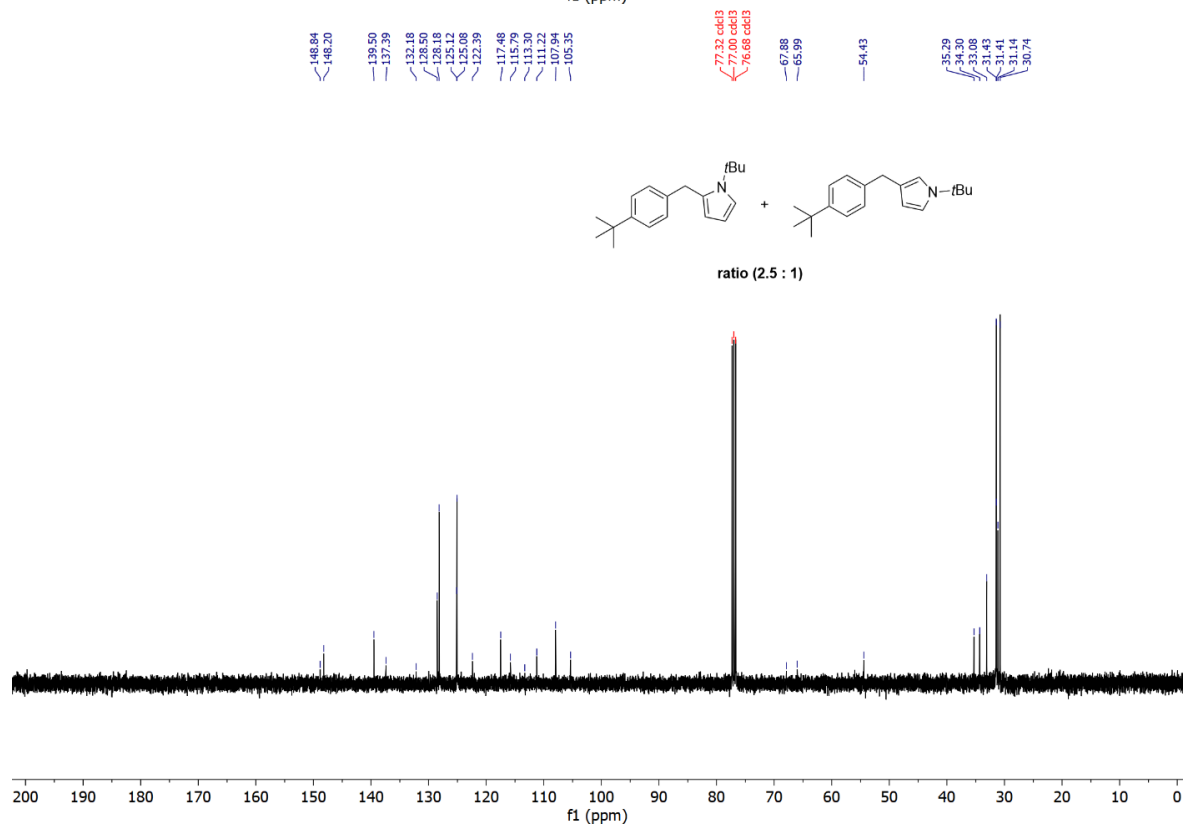
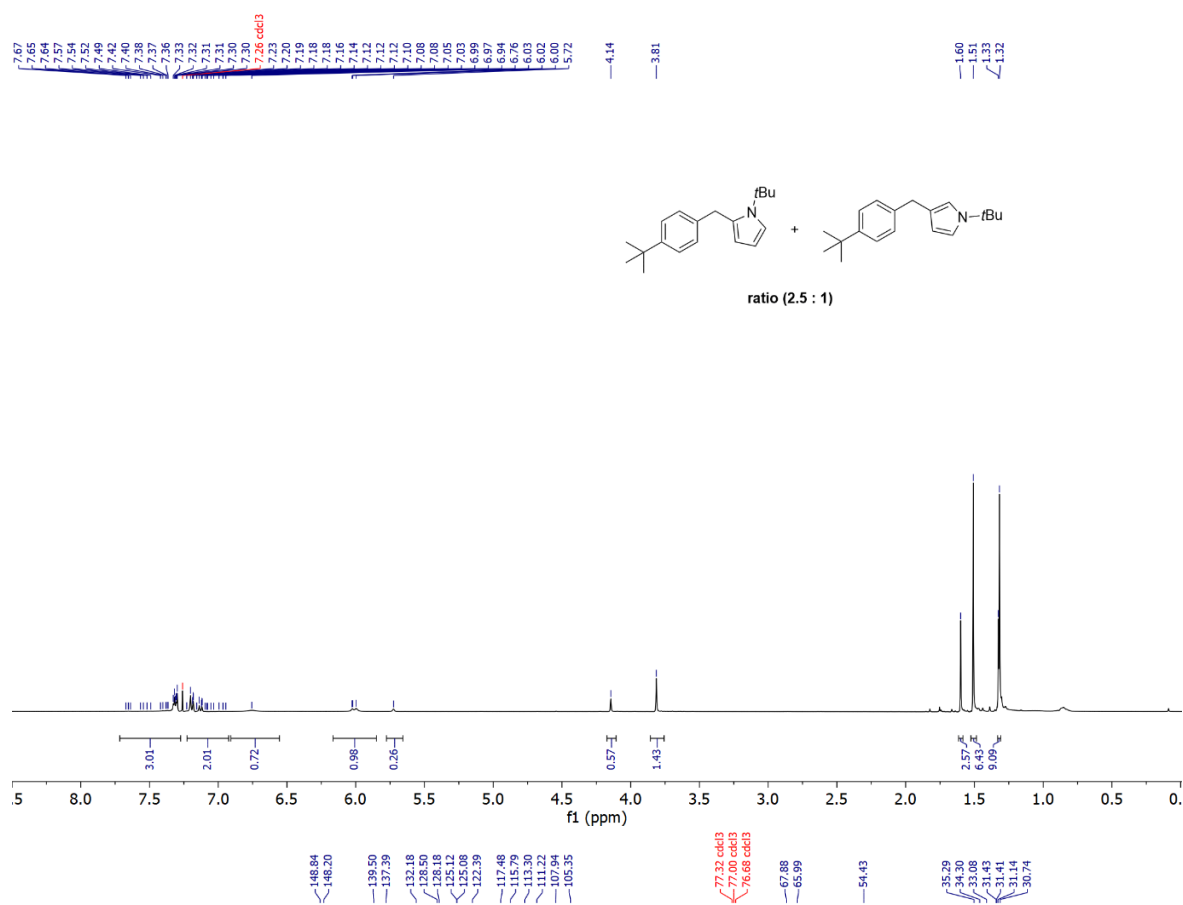
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl)benzene (8.3 mg, 0.05 mmol) in 1-(*tert*-butyl)-1*H*-pyrrole (0.1 mL) and CH_2Cl_2 (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after stirring overnight at room temperature. The product **20** was isolated as a yellow oil following filtration through a short plug of basic alumina using hexanes as eluent (12.9 mg, 96% yield, ratio 2.5:1).

^1H NMR (400 MHz, CDCl_3), δ : 7.67 – 7.30 (m, 3H), 7.23 – 6.94 (m, 2H), 6.76 (s, 0.7H), 6.03 – 6.00 (m, 1H), 5.72 (s, 0.3H), 4.14 (s, 0.6 H), 3.81 (s, 1.4H), 1.60 (s, 2.6H), 1.51 (s, 6.4H), 1.33 – 1.32 (d, 9H).

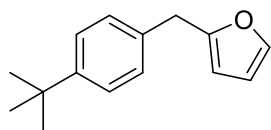
$^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ : 148.84, 148.20, 139.50, 137.39, 132.18, 128.50, 128.18, 125.12, 125.08, 122.39, 117.48, 115.79, 113.30, 111.22, 107.94, 105.35, 67.88, 65.99, 54.43, 35.29, 34.30, 33.08, 31.43, 31.41, 31.14, 30.74.

MS (DART Ionization, m/z): 270.2 ($[\text{M}+\text{H}]^+$).

HRMS (DART Ionization, m/z): Calcd. for $C_{19}H_{28}N^+$, $([M+H]^+)$: 270.22217; Found: 270.22215.



Preparation of 2-(4-(*tert*-butyl)benzyl)furan (21):



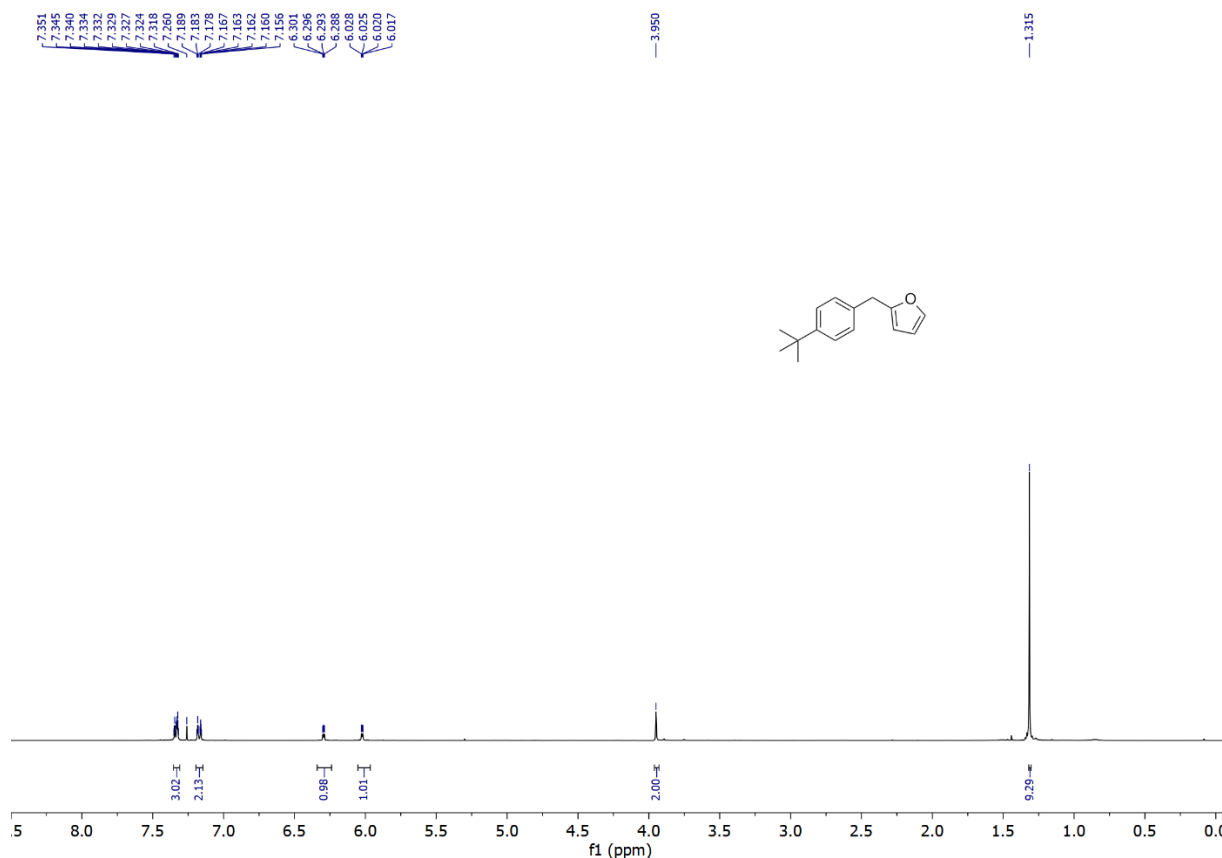
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl)benzene (8.3 mg, 0.05 mmol) in furan (0.1 mL) and CH₂Cl₂ (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH₂Cl₂ (0.2 mL). The reaction was complete after stirring overnight at room temperature. The product **21** was isolated as a yellow oil following filtration through a short plug of basic alumina using hexanes as eluent (10.0 mg, 93% yield).

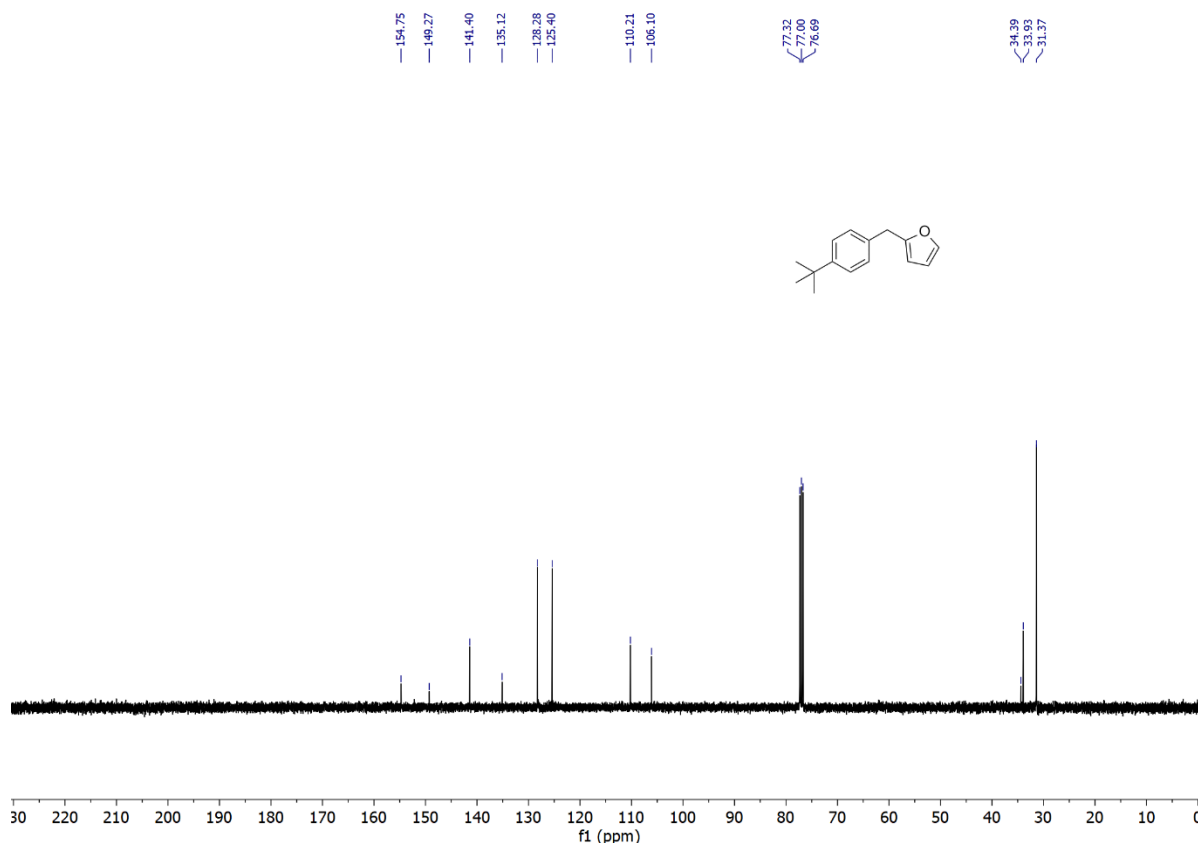
¹H NMR (400 MHz, CDCl₃), δ: 7.35 – 7.32 (m, 3H), 7.19 – 7.16 (m, 2H), 6.30 (dd, *J* = 3.2, 2.0 Hz, 1H), 6.02 (dd, *J* = 3.2, 1.2 Hz, 1H), 3.95 (s, 2H), 1.31 (s, 9H).

¹³C{¹H} NMR (100 MHz, CDCl₃) δ: 154.75, 149.27, 141.40, 135.12, 128.28, 125.40, 110.21, 106.10, 34.39, 33.93, 31.37.

MS (DART Ionization, *m/z*): 215.1 ([M+H]⁺).

HRMS (DART Ionization, *m/z*): Calcd. for C₁₅H₁₉O⁺, ([M+H]⁺): 215.14359; Found: 215.14350.





Preparation of 2-(4-(*tert*-butyl)benzyl)thiophene (**22**):



ratio (2 : 1)

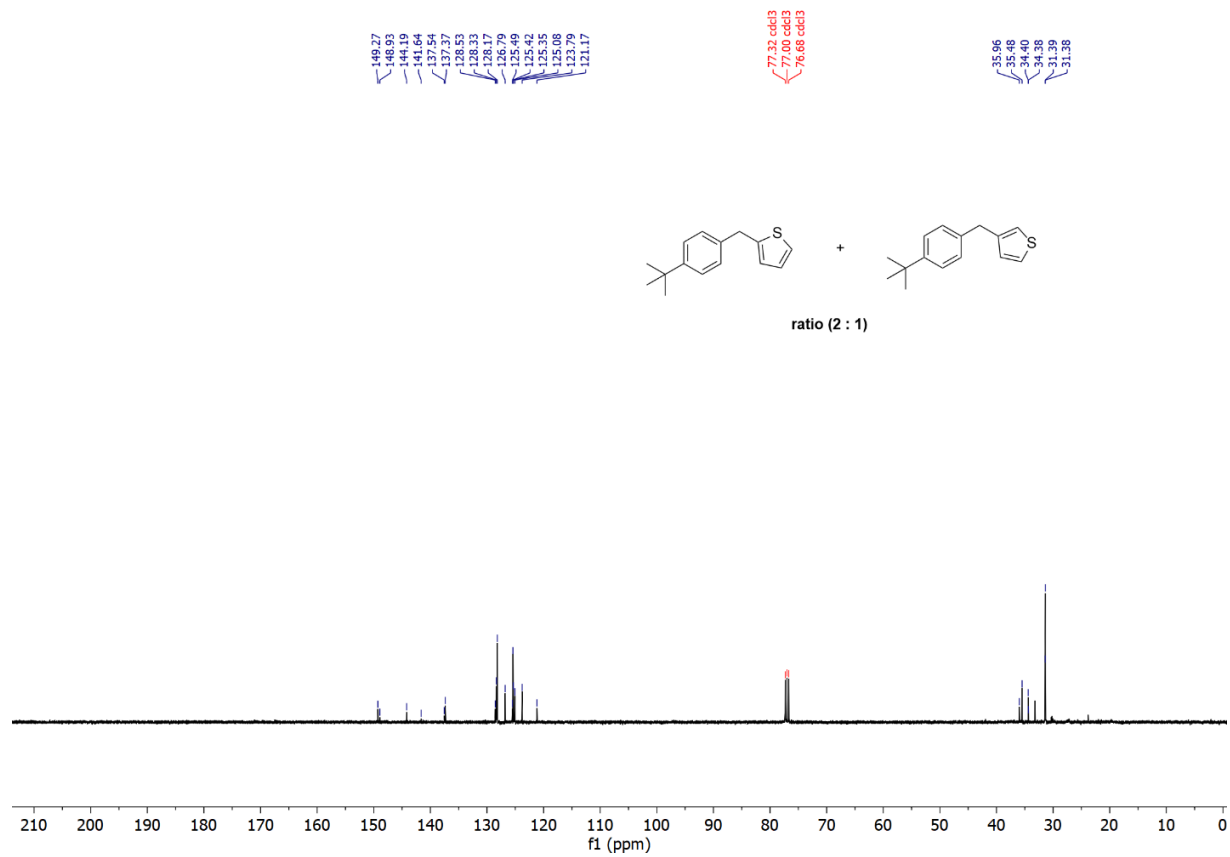
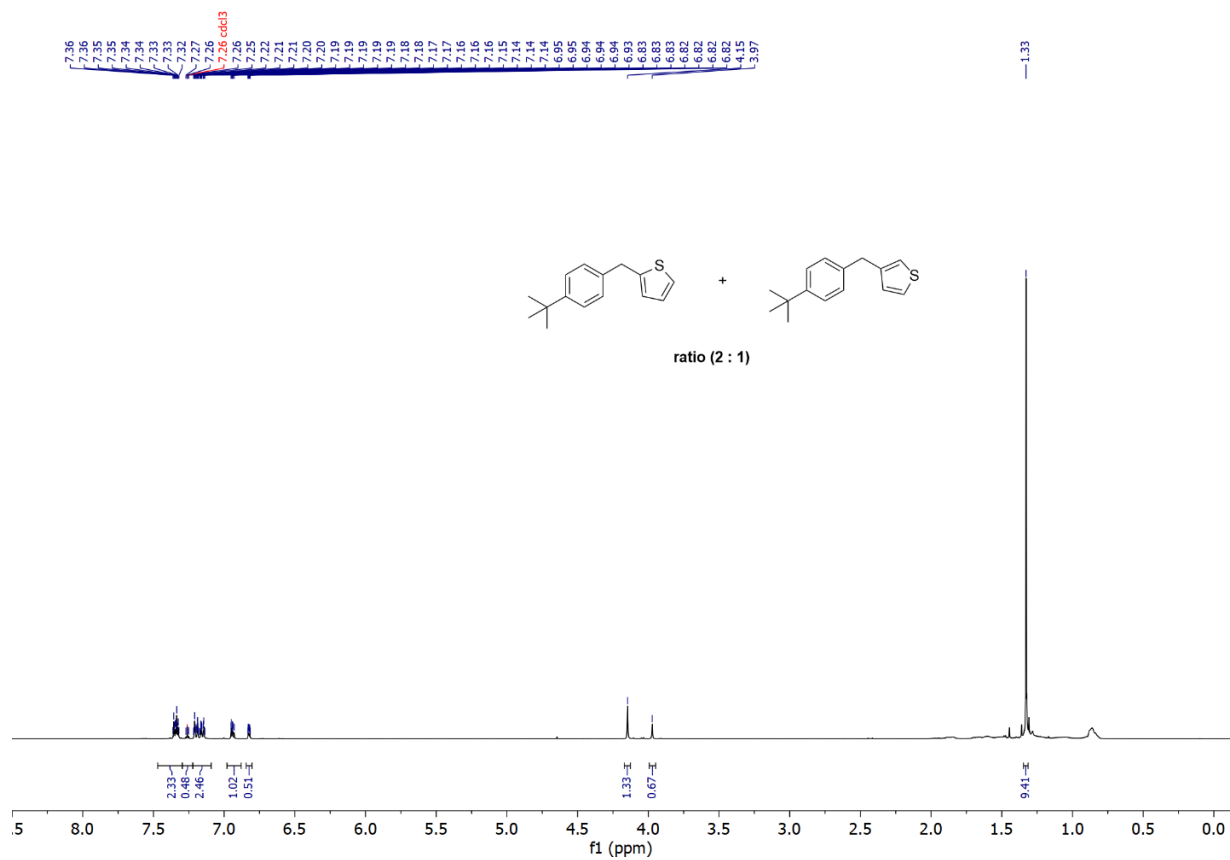
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl)benzene (8.3 mg, 0.05 mmol) in thiophene (0.1 mL) and CH_2Cl_2 (0.2 mL) was added a solution of 9-BBN dimer (6.2 mg, 0.025 mmol) in CH_2Cl_2 (0.2 mL). The reaction was complete after stirring overnight at room temperature. The product **22** was isolated as a light-yellow oil following filtration through a short plug of basic alumina using hexanes as eluent (10.0 mg, 87% yield, ratio 2:1).

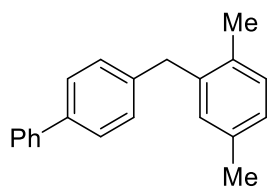
^1H NMR (400 MHz, CDCl_3), δ : 7.36 – 7.32 (m, 2.4H), 7.27 – 7.25 (m, 0.5H), 7.22 – 7.14 (m, 2.5H), 6.95 – 6.93 (m, 1.0H), 6.83 – 6.82 (m, 0.5H), 4.15 (s, 1.3H), 3.97 (s, 0.7H), 1.33 (s, 9H).

$^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ : 149.27, 148.93, 144.19, 141.64, 137.54, 137.37, 128.53, 128.33, 128.17, 126.79, 125.49, 125.42, 125.35, 125.08, 123.79, 121.17, 35.96, 35.48, 34.40, 34.38, 31.39, 31.38.

MS (DART Ionization, m/z): 231.1 ($[\text{M}+\text{H}]^+$).

HRMS (DART Ionization, m/z): Calcd. for $\text{C}_{15}\text{H}_{19}\text{S}^+$, ($[\text{M}+\text{H}]^+$): 231.12075; Found: 231.12107.



Gram-scale synthesis of 4-(2,5-dimethylbenzyl)-1,1'-biphenyl (**23**):

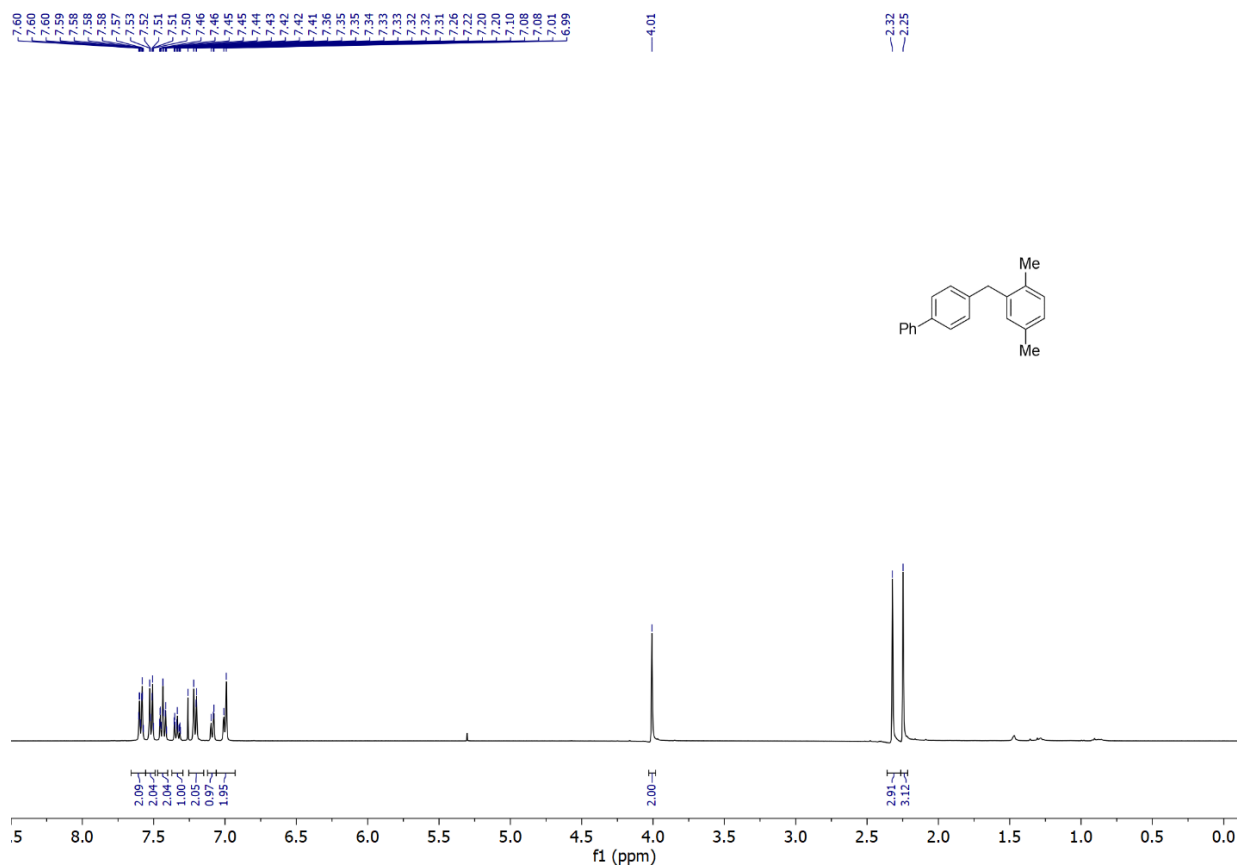
To a solution of 1-(*tert*-butyl)-4-(fluoromethyl) benzene (0.93 g, 5.0 mmol) in *p*-xylene (10 mL) and CH_2Cl_2 (10 mL) was added a solution of 9-BBN dimer (0.62 mg, 2.5 mmol) in CH_2Cl_2 (10 mL). The reaction was complete after 12 h of stirring at room temperature. The residue was purified by flash chromatography (hexane/ethyl acetate = 50/1) on silica gel to afford the product **23** as a white solid (1.05 g, 77% yield).

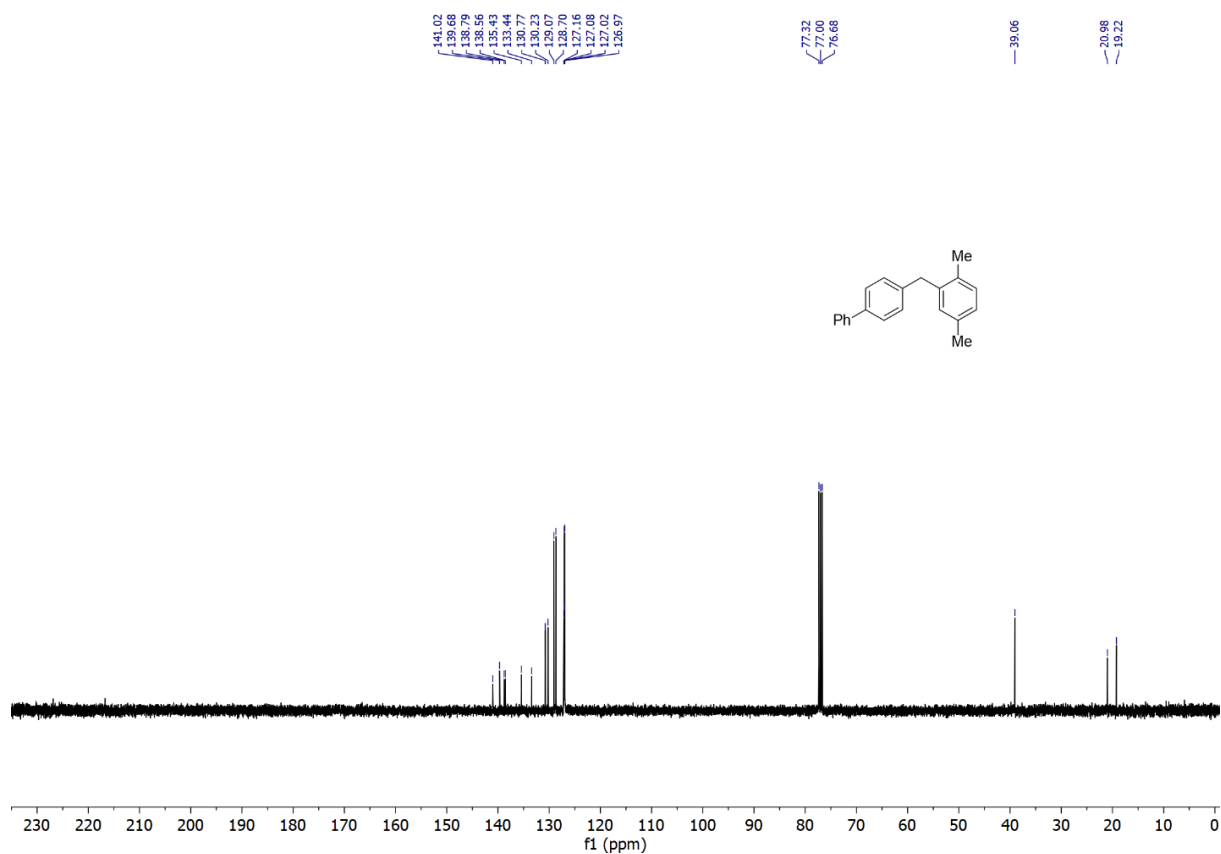
^1H NMR (400 MHz, CDCl_3), δ : 7.62 – 7.56 (m, 2H), 7.55 – 7.49 (m, 2H), 7.46 – 7.40 (m, 2H), 7.36 – 7.31 (m, 1H), 7.22 – 7.20 (m, 2H), 7.10 – 7.08 (m, 1H), 7.01 – 6.93 (m, 2H), 4.01 (s, 2H), 2.32 (s, 3 H), 2.25 (s, 3H).

$^{13}\text{C}\{^1\text{H}\}$ NMR (100 MHz, CDCl_3) δ : 141.02, 139.68, 138.79, 138.56, 135.43, 133.44, 130.77, 130.23, 129.07, 128.70, 127.16, 127.08, 127.02, 126.97, 39.06, 20.98, 19.22.

MS (DART Ionization, m/z): 290.2 ($[\text{M}+\text{NH}_4]^+$).

HRMS (DART Ionization, m/z): Calcd. for $\text{C}_{21}\text{H}_{14}\text{N}^+$, ($[\text{M}+\text{NH}_4]^+$): 290.19087; Found: 290.19055.





References

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- 4 R. Köster, W. Schüßler and R. Borne, *Chem. Ber.*, 1990, **123**, 1945-1952.
- 5 K. L. Bamford, S. S. Chitnis, Z. W. Qu and D. W. Stephan, *Chem. Eur. J.*, 2018, **24**, 16014-16018.