# Supporting Information for

# Mechanistic insights into the base-mediated deuteration of pyridyl phosphonium and ammonium salts

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# 1. MATERIALS AND GENERAL METHODS

### 1.1. General considerations

Unless stated, all starting materials and anhydrous solvents were obtained from commercial sources and used without purification. Reactions were carried out under an inert atmosphere of nitrogen unless stated. Reaction progress was monitored by TLC, with $^{1}$H NMR or LC-MS analyses taken from reaction samples. Column chromatography was performed on silica gel (230-400 mesh) or automated Isolera One Flash Chromatography (Biotage). NMR spectra were recorded with a Bruker AV-400 spectrometer (400 MHz $^{1}$H; 101 MHz $^{13}$C; 162 MHz $^{31}$P; 61 MHz $^{2}$H). $^{1}$H NMR chemical shifts are reported in ppm relative to protio impurities in the deuterated solvents and reported as follow: chemical shift (multiplicity, coupling constants, number of protons). $^{13}$C NMR chemical shifts are reported in ppm using the solvent resonance. $^{31}$P NMR spectra were recorded using $H_3PO_4$ (85%) as an external reference. Coupling constants J are given in Hertz (Hz), while the multiplicity of the signals are indicated as “s”, “d”, “t”, “q”, “pent”, “sept” or “m” for singlet, doublet, triplet, quartet, pentet, septet or multiplet, respectively. Mass spectra were recorded on a Waters QTOF mass spectrometer. Compound names are those generated by ChemDraw Professional 20.0 software (PerkinElmer), following the IUPAC nomenclature.

# 2. EXPERIMENTAL DATA

## 2.1 General Procedures

#### 2.1.1 General Procedure A: synthesis of deuterated compounds using KO*t*Bu in a J Young NMR tube

An oven dried J Young NMR tube was charged with KO*t*Bu and the substrate under a nitrogen atmosphere. DMSO-$d_6$ was then added through a rubber septum and an NMR spectrum was acquired ($t_0$). The tube was sealed and heated to 100 °C, monitoring by NMR, then the mixture was quenched with water and extracted 3 times with $CH_2Cl_2$. The collected organic phases were dried over $Na_2SO_4$, filtered and concentrated *in vacuo*. The crude was purified by automated column chromatography or used without further purification.

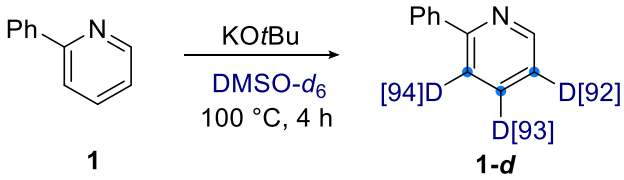
#### 2.1.2 General Procedure B: synthesis of deuterated compounds using *s*BuLi in a J Young NMR tube

An oven dried J Young NMR tube was charged with the substrate under nitrogen atmosphere. DMSO-$d_6$ was then added through a rubber septum, followed by *s*BuLi (1.4 M in hexanes). An NMR spectrum was acquired ($t_0$) then the tube was sealed and heated to 100 °C, monitoring by NMR. After reaction completion, the mixture was quenched with water and extracted 3 times with $CH_2Cl_2$. The collected organic phases were dried over $Na_2SO_4$, filtered and concentrated *in vacuo*. The

crude was purified by automated column chromatography or used without further purification.

## 2.2 Deuteration of 2-phenylpyridine (1)

### 2.2.1 Synthesis of 2-phenylpyridine-3,4,5-$d_3$ (1-*d*) from 2-phenylpyridine (1) using KO*t*Bu

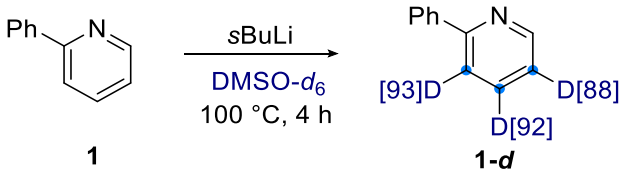



**1** **1-*d***

A sealed J Young NMR tube was charged with 2-phenylpyridine **1** (46 µL, 0.32 mmol, 1.0 equiv.), KO*t*Bu (36 mg, 0.32 mmol, 1.0 equiv.) and DMSO-$d_6$ (0.6 mL, 0.5 M) according to general procedure A and heated at 100 °C for 4h to afford 44 mg of 2-phenylpyridine-3,4,5-$d_3$ **1-*d*** (0.28 mmol, **88% yield**). $^1$H NMR (400 MHz, $CDCl_3$) δ 8.71 (s, 1H), 8.11 – 7.94 (m, 2H), 7.73 (bs, 0.13H), 7.52 – 7.45 (m, 2H), 7.44 – 7.39 (m, 1H), 7.23 (d, *J* = 5.0 Hz, 0.08H). MS: 159.2993 [M+H$^+$], theoretical 158.0923. The data are in agreement with those reported in the literature.[16]

See spectrum

### 2.2.2 Synthesis of 2-phenylpyridine-3,4,5-$d_3$ (1-*d*) from 2-phenylpyridine (1) using *s*BuLi




**1** **1-*d***

A sealed J Young NMR tube was charged with 2-phenylpyridine **1** (46 µL, 0.32 mmol, 1.0 equiv.), DMSO-$d_6$ (0.6 mL, 0.5 M) and *s*BuLi 1.4 M in hexanes (230 µL, 0.32 mmol, 1.0 equiv.) according to general procedure B and heated at 100 °C for 4h to afford 41 mg of 2-phenylpyridine-3,4,5-$d_3$ **(1-*d*)** (0.27 mmol, **86% yield**).

See spectrum

### 2.2.3 Reaction monitoring: deuteration of 2-phenylpyridine (1) in DMSO-$d_6$ using KO*t*Bu

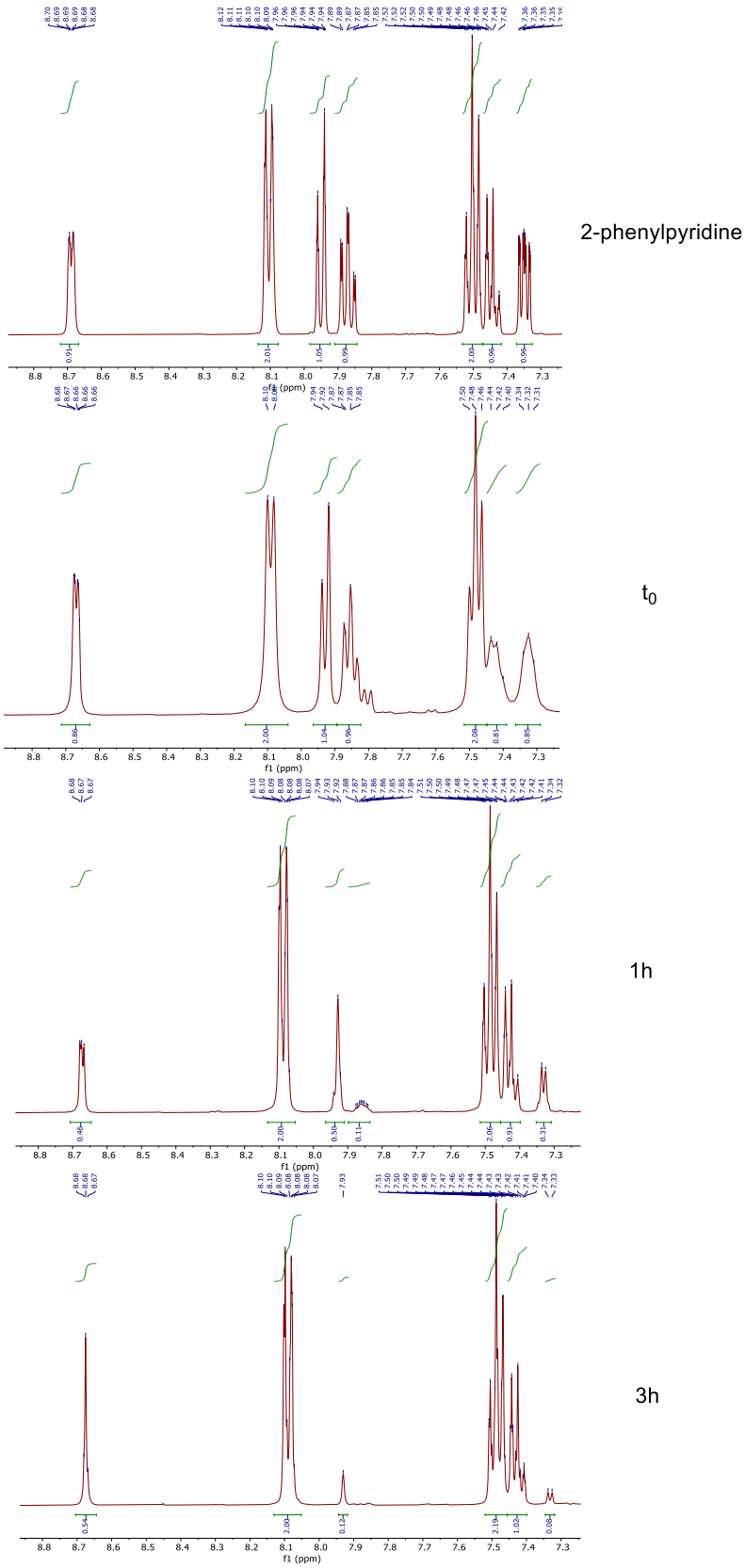
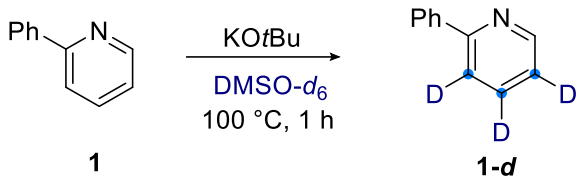



**Fig. S1**: Monitoring of the deuteration of **1** in DMSO-$d_6$ using KO*t*Bu

### 2.2.4 Attempts at ortho-deuteration of 2-phenylpyridine (1)




**1** **1-*d***

During deuteration of **1** in a J Young NMR tube to monitor its progression by *in-situ* $^{1}$H NMR, we observed the expected disappearance of the signals of distal protons, along with a partial loss (up to 50%) of the diagnostic signal at 8.71 ppm of the *ortho*-proton. Yet, no deuteration at this position was observed in **1-*d*** upon an aqueous work-up (see Paragraph **2.2.1**). To attempt an ortho-deuteration, a quenching with $D_2O$ was performed after 1h at 100 °C, followed by **a)** extractions with DCM, **b)** extractions with $CDCl_3$, **c)** direct evaporation of the $D_2O$/DMSO-$d_6$ solvent mixture. The reactions were monitored by NMR showing that the loss of the *ortho* proton (up to now attributed to deuterium incorporation) was maintained after the quenching. In all cases though, after isolation and analysis by $^{1}$H NMR in $CDCl_3$, no deuteration in the ortho position was observed. The figure below shows the reaction monitoring after 1h at 100 °C and the NMR spectra after quenching and workup in conditions **a**, **b** and **c.**

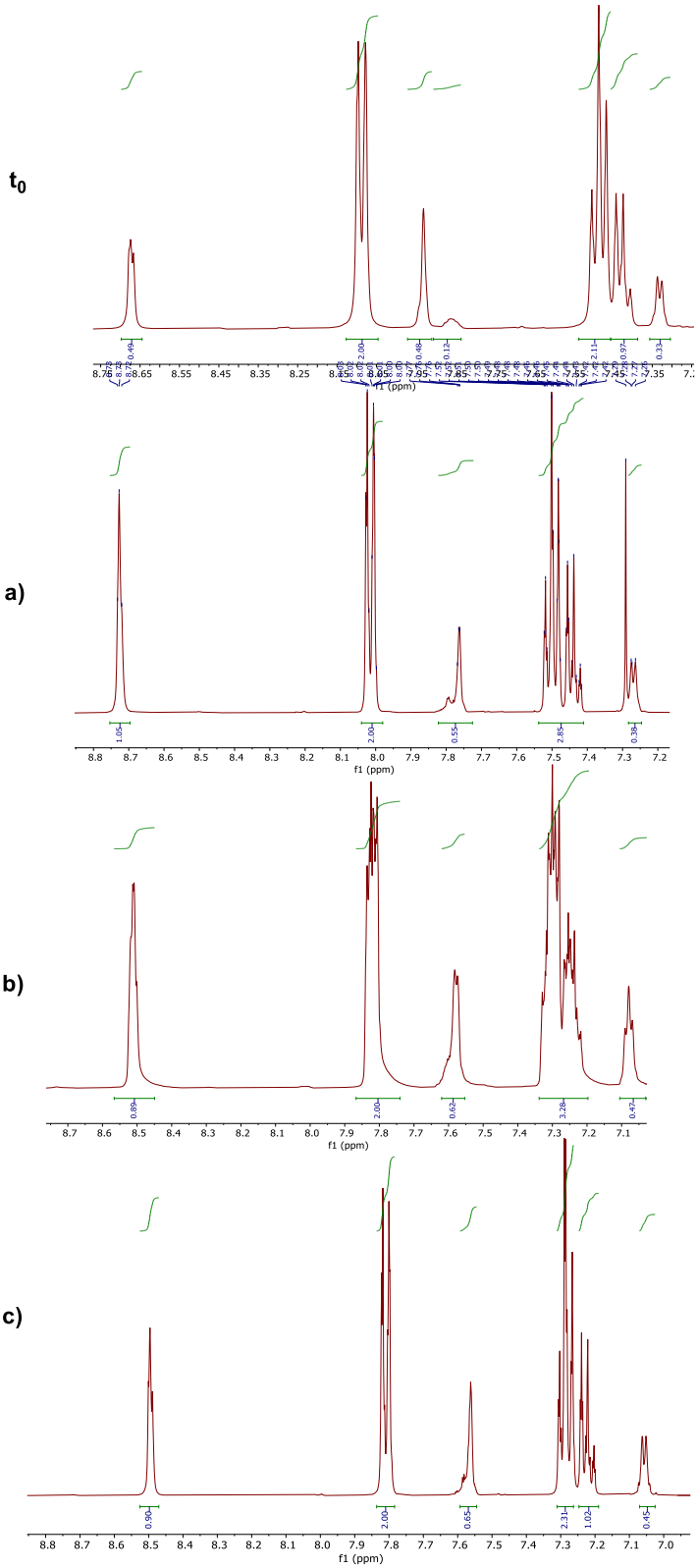



**Fig S2**: NMR spectra of the deuteration of **1** (KO*t*Bu, DMSO-$d_6$, 1h, 100 °C) at $t_0$ and after quenching with $D_2O$ and workup in conditions **a**, **b** and **c**, respectively extractions with DCM, extractions with $CDCl_3$, direct evaporation of the $D_2O$/DMSO-$d_6$ solvent mixture.

### 2.2.5 Relaxation time experiment on deuteration of 1

As reported in the previous paragraphs, during NMR monitoring of the deuteration reaction of compound **1** (see Paragraph **2.2.1**), a partial loss of the signal of the ortho proton was observed but no deuteration was obtained in the isolated product even after treatment with $D_2O$ (Paragraph **2.2.4**). Considering this effect could be ascribable to different relaxation times of the pyridine protons, an experiment was carried out by changing the value of $D_1$ during the NMR analysis and studying the integration of the proton. So, after 1h at 100 °C, the sample was analysed by NMR increasing $D_1$ from 2s to 10s to 20s: the integral of the *ortho*-proton at (8.68 ppm) increased accordingly from 0.55 to 0.72 to 0.82, thus showing no effective deuteration was happening in this position but this effect was only due to the different relaxation time of the *ortho*-proton to the others.

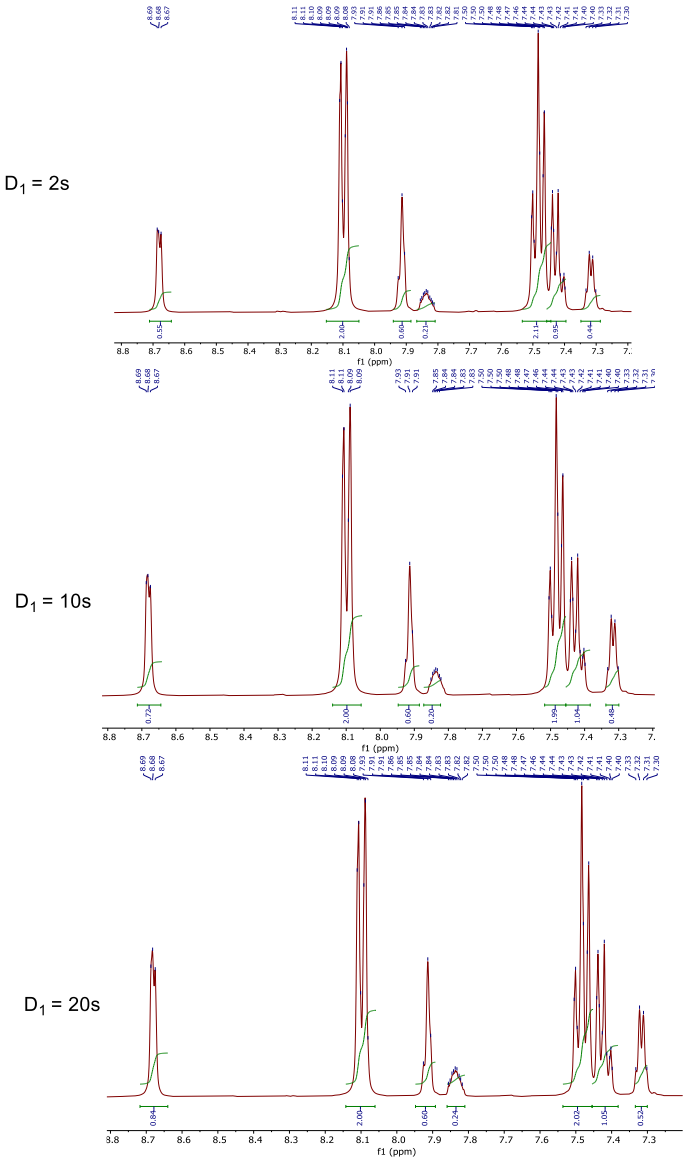
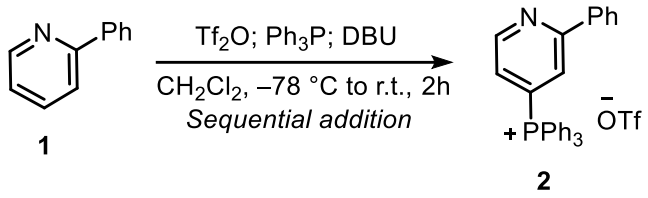



**Fig S3**: Relaxation time experiment on the deuteration of **1** (KO*t*Bu, DMSO-$d_6$, 1h, 100 °C) by increasing the $D_1$ value from 2s to 10s to 20s during NMR acquisition.

## 2.3 Synthesis and deuteration of [2][OTf]

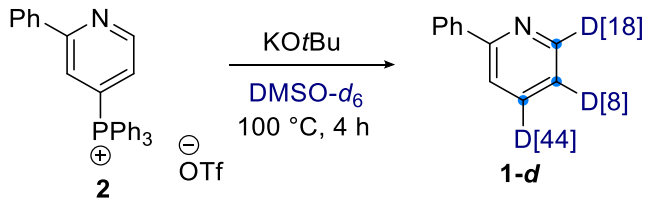
### 2.3.1 Synthesis of triphenyl(2-phenylpyridin-4-yl)phosphonium triflate [2][OTf]




The procedure has been adapted from the literature.[23] A round bottom flask equipped with a stir bar was charged with 2-phenylpyridine **1** (214 µL, 1.50 mmol, 1.0 equiv.) and placed under a nitrogen atmosphere. Then, $CH_2Cl_2$ (7.5 mL, 0.2 M) was added, and the reaction vessel cooled to –78 °C, followed by the dropwise addition of $Tf_2O$ (278 µL, 1.65 mmol, 1.1 equiv.). The reaction mixture was stirred at –78 °C for 30 minutes, followed by the addition of $PPh_3$ (433 mg, 1.65 mmol, 1.1 equiv.), and, after 30 minutes, of DBU (224 µL, 1.50 mmol, 1.0 equiv.). After the last addition, the cooling bath was removed, and the reaction was allowed to warm to room temperature while stirring (approximately 15-30 minutes). The reaction mixture was thus quenched with $H_2O$ (approximately the same volume as $CH_2Cl_2$), the layers separated, and the aqueous phase was washed 3 times with $CH_2Cl_2$. The combined organic layers were dried over anhydrous $Na_2SO_4$, filtered and concentrated under reduced pressure, to approximately 2-10 mL. An excess of chilled $Et_2O$ (0 °C) was added to the concentrated solution as it started to solidify. The resulting suspension was filtered, and the solid was washed with chilled $Et_2O$ (0 °C) and dried *in vacuo* to provide the pure phosphonium salt **[2][OTf]** as a white solid (576 mg, 1.02 mmol, **88% yield**). $^1$H NMR (400 MHz, $CDCl_3$) δ: 9.01 (app t, *J* = 5.1 Hz, 1H), 7.93–7.54 (m, 18H), 7.50 (ddd, *J* = 17.8, 5.1, 1.1 Hz, 1H), 7.42–7.36 (m, 3H) ppm. *Some residual DBU can be observed in the region of the spectra between 1.00 and 4.00 ppm*. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 23.01 ppm. The data are in agreement with those reported in the literature.[23]

See spectra

### 2.3.2 Synthesis of 2-phenylpyridine-4,5,6-*d*$_3$ (1-*d*) from [2][OTf] using KO*t*Bu

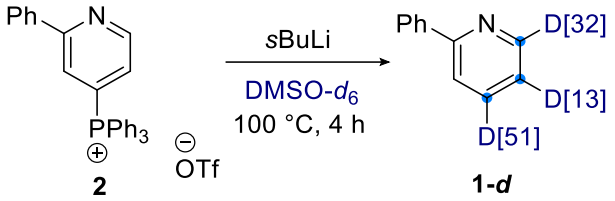



A sealed J Young NMR tube was charged with **[2][OTf]** (113 mg, 0.20 mmol, 1.0 equiv.), KO*t*Bu (22 mg, 0.20 mmol, 1.0 equiv.) and DMSO-$d_6$ (0.4 mL, 0.5 M) according to general procedure A and heated at 100 °C for 4h. The crude was purified by automated column chromatography (eluent

mixture: hex/AcOEt from 100:0 to 0:100) to obtain 19 mg of 2-phenylpyridine-4,5,6-$d_3$ (**1-*d***) (0.12 mmol, **61% yield**). $^1$H NMR (400 MHz, DMSO) δ 8.68 (dt, *J* = 4.8, 0.9 Hz, 0.82H), 8.15 – 8.07 (m, 2H), 8.01 – 7.95 (m, 1H), 7.89 (ddd, *J* = 8.0, 7.4, 1.8 Hz, 0.56H), 7.56 – 7.49 (m, 2H), 7.49 – 7.43 (m, 1H), 7.37 (dtd, *J* = 4.8, 3.8, 1.2 Hz, 0.92H).

See spectrum

### 2.3.3 Synthesis of 2-phenylpyridine-4,5,6-$d_3$ (1-*d*) from [2][OTf] using *s*BuLi




A sealed J Young NMR tube was charged with **[2][OTf]** (113 mg, 0.20 mmol, 1.0 equiv.), DMSO-$d_6$ (0.4 mL, 0.5 M) and *s*BuLi 1.4 M in hexanes (140 µL, 0.20 mmol, 1.0 equiv.) according to general procedure B and heated at 100 °C for 4h. The crude was purified by automated column chromatography (eluent mixture: hex/AcOEt from 100:0 to 0:100) to obtain 16 mg of 2-phenylpyridine-4,5,6-$d_3$ (**1-*d***) (0.10 mmol, **50% yield**).

See spectrum

### 2.3.4 Reaction monitoring: deuteration of [2][OTf] in DMSO-$d_6$ using KO*t*Bu

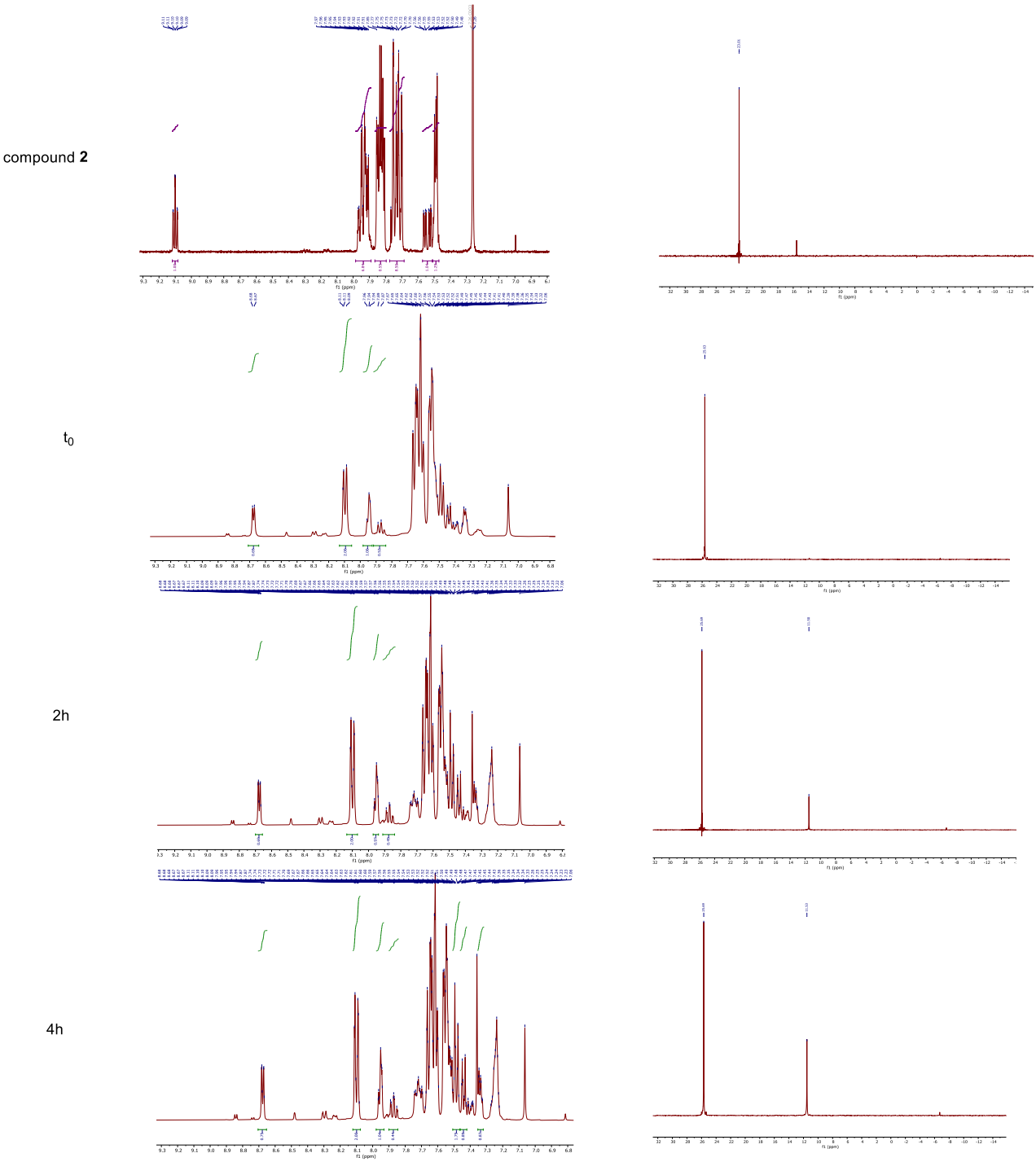
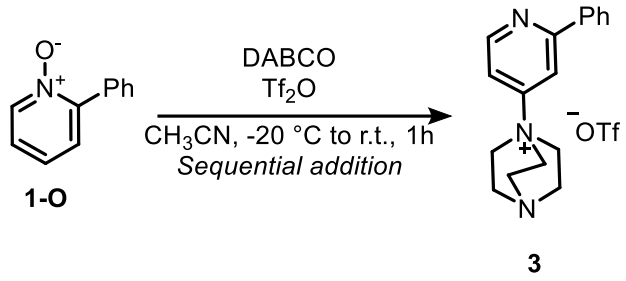



**Fig S4**: Monitoring of the deuteration of **[2][OTf]** in DMSO-$d_6$ using KO*t*Bu by $^{1}$H NMR and $^{31}$P NMR

## 2.4 Synthesis and deuteration of [3][OTf]

### 2.4.1 Synthesis of 1-(2-phenylpyridin-4-yl)-1,4-diazabicyclo[2.2.2]octan-1-ium triflate [3][OTf]

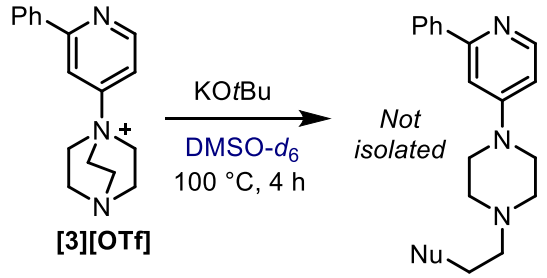



**1-O** **3**

The procedure has been adapted from the literature[27]. A round bottom flask equipped with a stir bar was charged with 2-phenylpyridine 1-oxide **1-O** (100 mg, 0.58 mmol, 1.0 equiv.) and placed under nitrogen atmosphere. Then, $CH_3CN$ (5.8 mL, 0.1 M) was added, and the reaction vessel cooled to –20 °C, followed by the dropwise addition of $Tf_2O$ (110 µL, 0.64 mmol, 1.1 equiv.) over 10 minutes. The reaction mixture was stirred at –20 °C for 30 minutes, followed by the addition of DABCO (131 mg, 1.2 mmol, 2.0 equiv.). The reaction was subjected to three rapid cycles of vacuum/nitrogen backfill, the cooling bath was removed and mixture was stirred for 30 minutes. The mixture was concentrated *in vacuo* and the crude purified by chromatography on silica gel ($CH_2Cl_2$:$CH_3OH$ 3:1) to provide ammonium salt **[3][OTf]** as a white solid (178 mg, 0.43 mmol, **73% yield**). $^1$H NMR (400 MHz, DMSO) δ 8.96 (d, J = 5.8 Hz, 1H), 8.47 (d, J = 2.7 Hz, 1H), 8.27 – 8.15 (m, 2H), 7.88 (dd, J = 5.8, 2.4 Hz, 1H), 7.64 – 7.47 (m, 3H), 3.95 (t, J = 7.5 Hz, 6H), 3.24 (t, J = 7.4 Hz, 6H). *Some residual DABCO can be observed in the region of the spectra between 2.50 and 3.00 ppm.* The data are in agreement with those reported in the literature.[27]

See spectrum

### 2.4.2 Deuteration of [3][OTf] using KO*t*Bu




**[3][OTf]**

A sealed J Young NMR tube was charged with **[3][OTf]** (100 mg, 0.24 mmol, 1.0 equiv.), KO*t*Bu (27 mg, 0.24 mmol, 1.0 equiv.) and DMSO-$d_6$ (0.5 mL, 0.5 M) according to general procedure A and heated at 100 °C for 4 hours. A mixture of products was formed due to degradation and different reactivities of the starting material. The crude was analysed by HPLC-MS and the main product was identified as 2-phenylpyridin-4-ol from mass analysis (see spectra below).

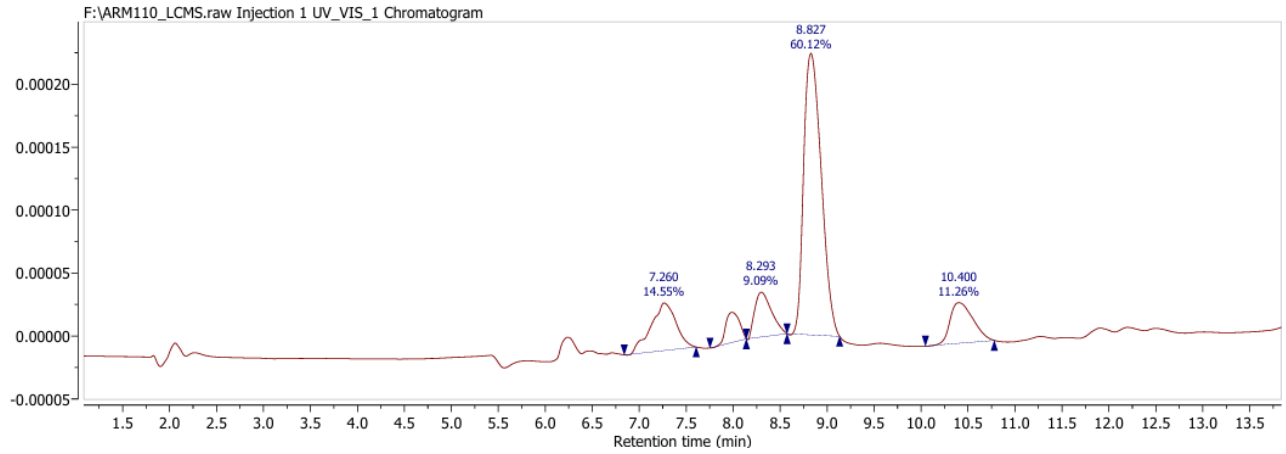



**Fig S5**: HPLC chromatogram of the reaction mixture from the deuteration of **[3][OTf]** with KO*t*Bu

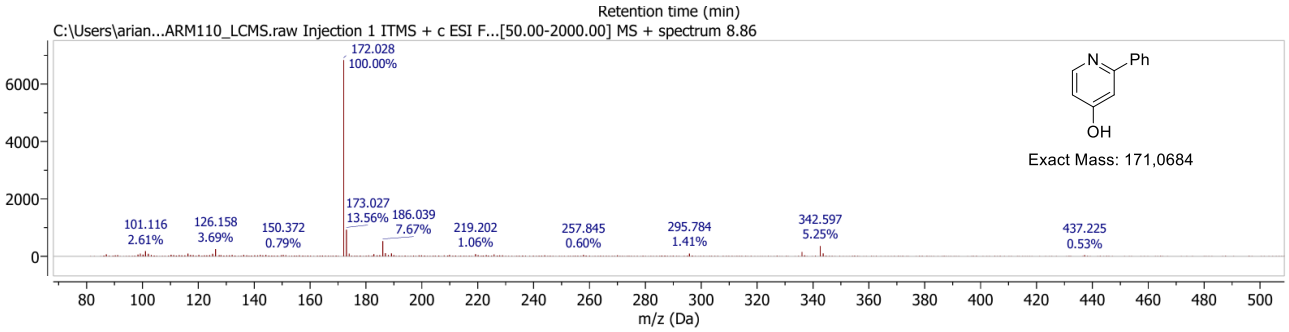
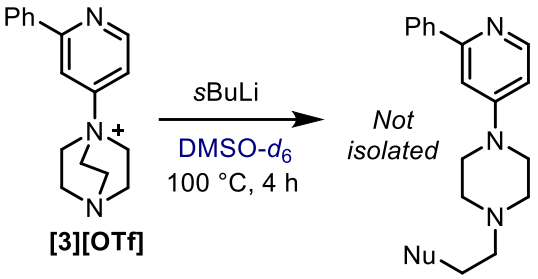



**Fig S6**: Mass spectrum of the peak with retention time 8.82 s of Fig S5

### 2.4.3 Deuteration of [3][OTf] using *s*BuLi




A sealed J Young NMR tube was charged with **[3][OTf]** (50 mg, 0.12 mmol, 1.0 equiv.), DMSO-$d_6$ (0.3 mL, 0.5 M) and *s*BuLi 1.4 M in hexanes (90 µL, 0.12 mmol, 1.0 equiv.) according to general procedure B and heated at 100 °C for 4 hours. A complex mixture was formed, due to incompatibility of the starting material with bases, and was not analysed further.

### 2.4.4 Reaction monitoring: deuteration of [3][OTf] in DMSO-$d_6$ using KO*t*Bu

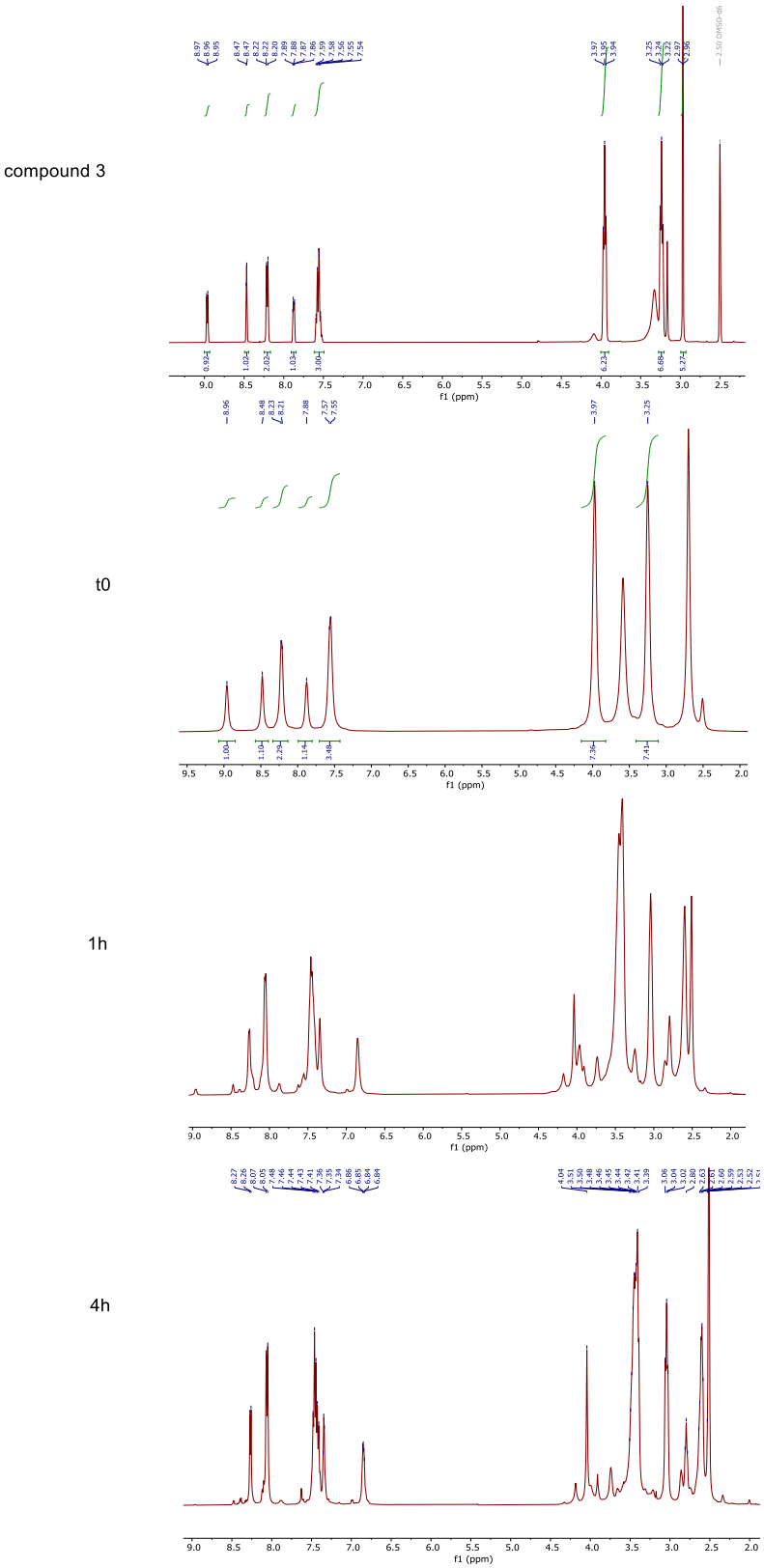
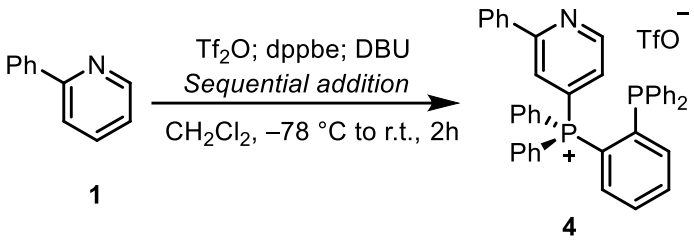



**Fig S7**: Monitoring of the deuteration of **[3][OTf]** in DMSO-$d_6$ using KO*t*Bu

## 2.5 Synthesis and deuteration of [4][OTf]

### 2.5.1 Synthesis of (2-(diphenylphosphaneyl)phenyl)diphenyl(2-phenylpyridin-4-yl)phosphonium trifluoromethanesulfonate [4][OTf]



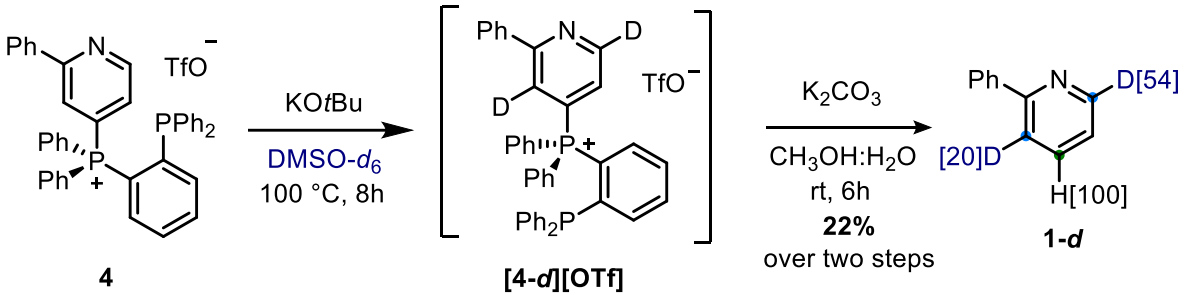

**1** **4**

The procedure has been adapted from the literature.[23] A round bottom flask equipped with a stir bar was charged with 2-phenylpyridine **1** (29 µL, 0.20 mmol, 1.0 equiv.) and placed under nitrogen atmosphere. Then, $CH_2Cl_2$ (1.0 mL, 0.2 M) was added, and the reaction vessel was cooled to –78 °C, followed by the dropwise addition of $Tf_2O$ (34 µL, 0.20 mmol, 1.0 equiv.). The reaction mixture was stirred at –78 °C for 30 minutes, followed by the addition of dppbe (98 mg, 0.22 mmol, 1.1 equiv.), and, after 30 minutes, of DBU (30 µL, 0.20 mmol, 1.0 equiv.). After the last addition, the cooling bath was removed, and the reaction was allowed to warm to room temperature while stirring (approximately 15-30 minutes). The reaction mixture was thus quenched with $H_2O$ (approximately the same volume as $CH_2Cl_2$), the layers separated, and the aqueous phase washed 3 times with $CH_2Cl_2$. The combined organic layers were dried over anhydrous $Na_2SO_4$, filtered and concentrated *in vacuo*. The crude product was purified by automated column chromatography ($CH_2Cl_2$:$CH_3OH$ from 98:2 to 9:1). The obtained product was recrystalized in cold $Et_2O$ and filtered to provide the final phosphonium salt **[4][OTf]** as white solid (125 mg, 0.17 mmol, **84% yield**).

$^1$H NMR (400 MHz, $CDCl_3$) δ 8.81 (t, J = 5.2 Hz, 1H), 7.94 (t, J = 7.1 Hz, 1H), 7.90 – 7.74 (m, 6H), 7.68 (m, 9H), 7.53 (dd, J = 12.2, 4.8 Hz, 2H), 7.48 – 7.42 (m, 3H), 7.29 – 7.23 (m, 2H), 7.16 (td, J = 7.6, 1.8 Hz, 4H), 6.78 (td, J = 8.0, 1.0 Hz, 4H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 158.94 (d, J = 10.3 Hz), 151.29 (d, J = 10.8 Hz), 143.19 (dd, J = 18.8, 11.5 Hz), 139.68 (d, J = 11.7 Hz), 138.36 (dd, J = 13.5, 9.5 Hz), 137.04 (d, J = 1.7 Hz), 136.36 (d, J = 3.0 Hz), 135.69 (d, J = 3.0 Hz), 134.65 (dd, J = 10.2, 2.3 Hz), 133.06 (d, J = 18.9 Hz), 133.06 (d, J = 7.1 Hz), 132.57 (d, J = 13.3 Hz), 131.58 (d, J = 3.8 Hz), 130.76 (d, J = 13.0 Hz), 130.61, 130.11, 129.87, 129.23, 129.02 (d, J = 7.3 Hz), 128.40, 127.34, 125.28 (dd, J = 7.8, 2.5 Hz), 123.31 (dd, J = 8.3, 3.4 Hz), 123.03, 122.68, 122.48, 122.12, 118.32 (d, J = 3.2 Hz), 117.42 (d, J = 3.2 Hz). *Some residual DBU can be observed in the region of the spectra between 1.00 and 4.00 ppm.* $^{31}$P NMR (162 MHz, $CDCl_3$) δ 22.32 (d, J = 30.1 Hz), -14.43 (d, J = 30.3 Hz). $^{19}$F NMR (376 MHz, $CDCl_3$) δ -78.00. MS 600.5518, theoretical 600.2004.

See spectra

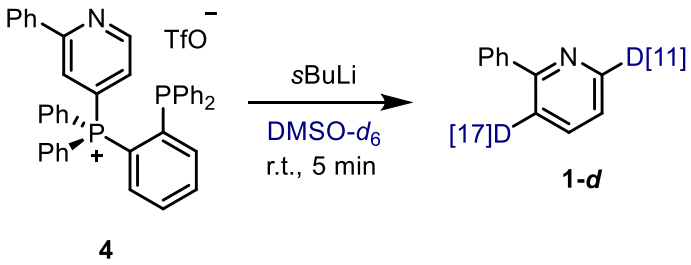
### 2.5.2 Deuteration of [4][OTf] using KO*t*Bu




A sealed J Young NMR tube was charged with **[4][OTf]** (64 mg, 0.085 mmol, 1.0 equiv.), KO*t*Bu (10 mg, 0.085 mmol, 1.0 equiv.) and DMSO-$d_6$ (0.2 mL, 0.5 M) according to general procedure A and heated at 100 °C for 8h. The crude was filtered on a silica plug and used directly in the following protodephosphination. A round-bottom flask was charged with **[4-*d*][OTf]** (14 mg, 0.019 mmol, 1.0 equiv.) and $K_2CO_3$ (4 mg, 0.028 mmol, 1.5 equiv.). The solvent ($CH_3OH$:$H_2O$ 9:1, 400 µL, 0.0.5 M) was added and the reaction was stirred for 6h at room temperature. The mixture was then diluted with water and extracted with $CH_2Cl_2$ (3 x 5 mL). The organic layer was dried over $Na_2SO_4$, filtered and concentrated *in vacuo*. The crude was purified by passage on a short pad of silica to obtain 3 mg of 2-phenylpyridine-3,5,6-$d_3$ (**1-*d***) (0.018 mmol, **22% total yield** over two steps). $^1$H NMR (400 MHz, $CDCl_3$) δ 8.74 (bs, 0.46H), 8.00 (d, *J* = 7.4 Hz, 2H), 7.87 (s, 0.80H), 7.78 (s, 1H), 7.46 (m, 2H), 7.33 (s, 1H), 7.25 (s, 1H).

See spectrum

### 2.5.3 Deuteration of [4][OTf] using *s*BuLi




A sealed J Young NMR tube was charged with **[4][OTf]** (65 mg, 0.087 mmol, 1.0 equiv.), DMSO-$d_6$ (0.2 mL, 0.5 M) and *s*BuLi 1.4 M in hexanes (70 µL, 0.087 mmol, 1.0 equiv.) according to general procedure B. After 5 minutes at room temperature, complete protodephosphination occured and the reaction was stopped. The crude was purified by automated column chromatography (eluent mixture: hex/AcOEt from 100:0 to 0:100) to obtain 7 mg of 2-phenylpyridine-3,6-$d_2$ (**1-*d***) (0.044 mmol, **52% yield**). $^1$H NMR (400 MHz, $CDCl_3$) δ 8.74 – 8.70 (m, 0.89H), 8.09 – 7.98 (m, 2H), 7.81 (dd, *J* = 7.3, 1.8 Hz, 0.83H), 7.79 – 7.73 (m, 1H), 7.57 – 7.47 (m, 2H), 7.47 – 7.43 (m, 1H), 7.32 – 7.27 (m, 1H). See spectrum

### 2.5.4 Reaction monitoring: deuteration of [4][OTf] in DMSO-$d_6$ using KO*t*Bu

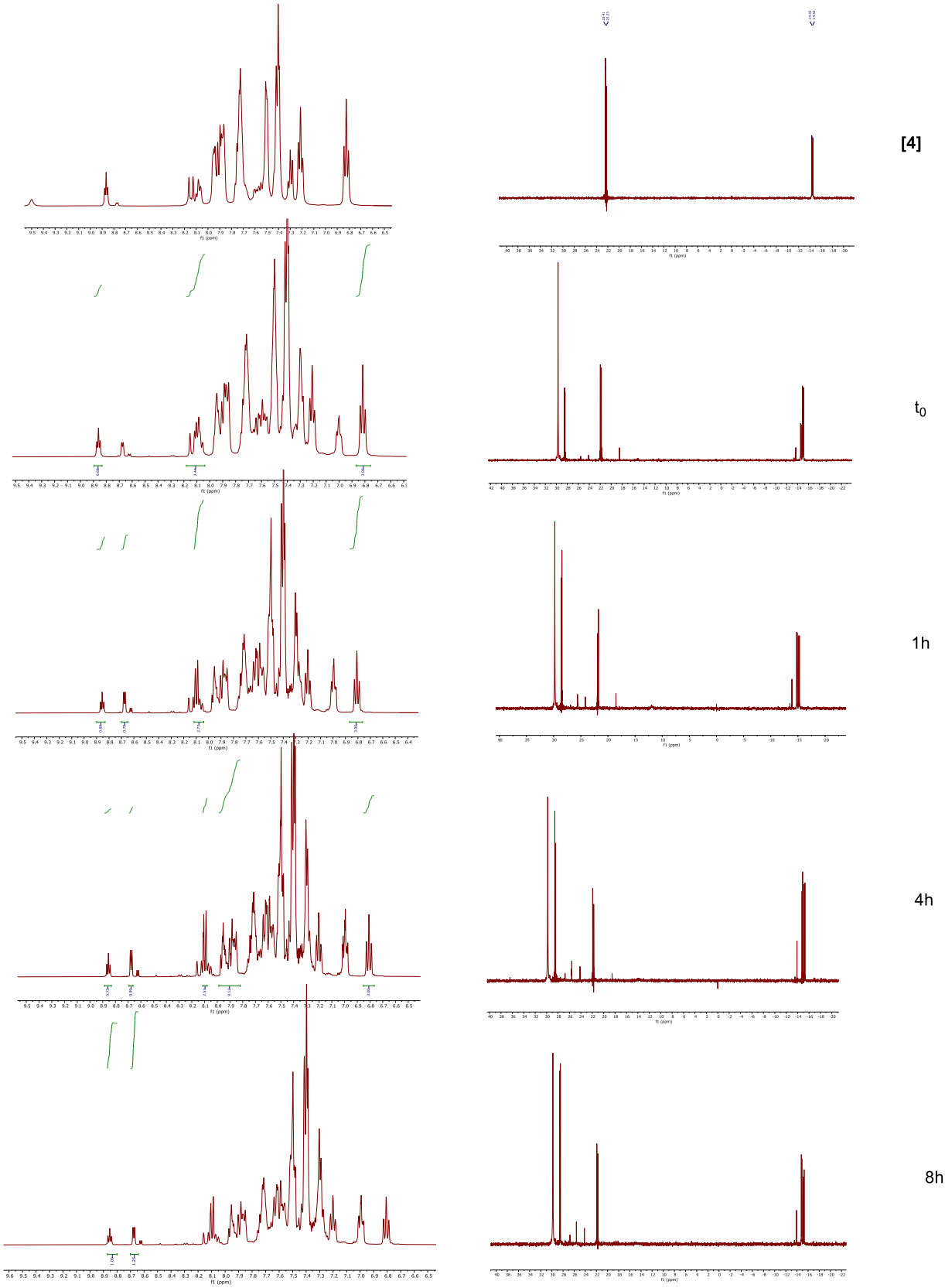
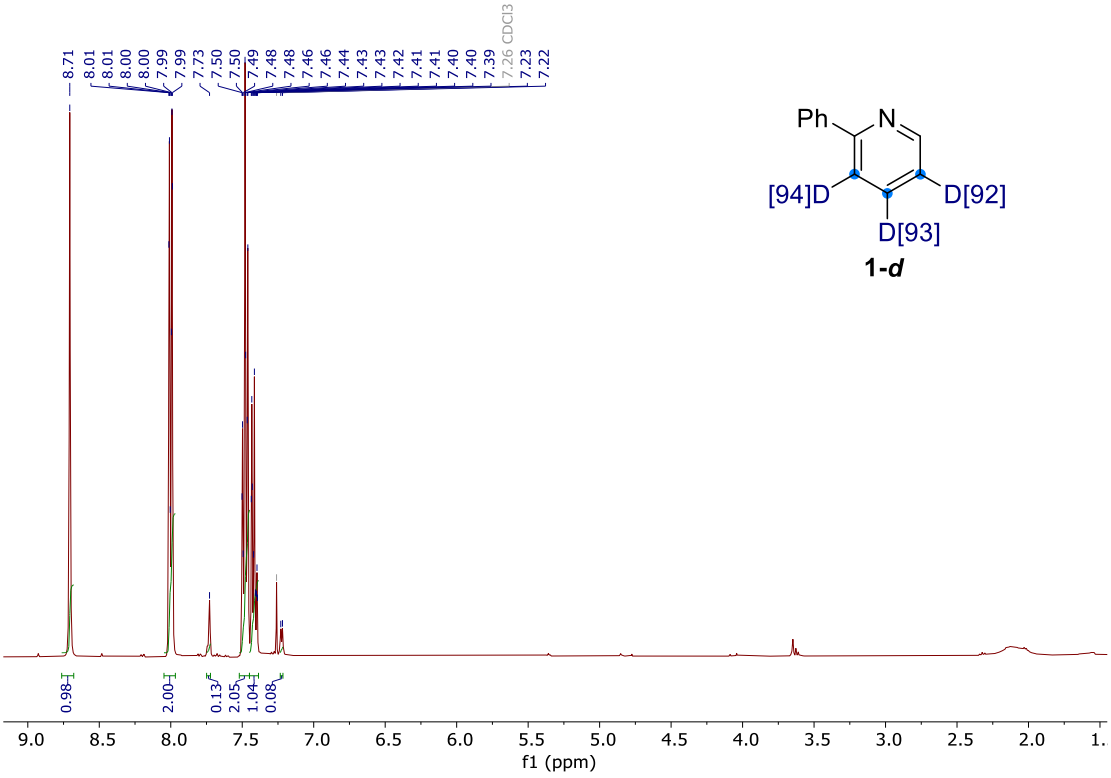



**Fig S8**: Monitoring of the deuteration of **[4][OTf]** in DMSO-$d_6$ using KO*t*Bu

# 3. SPECTROSCOPIC DATA

$^1$H NMR (400 MHz, $CDCl_3$) of 2-phenylpyridine-3,4,5-$d_3$ (1-*d*) (see procedure)

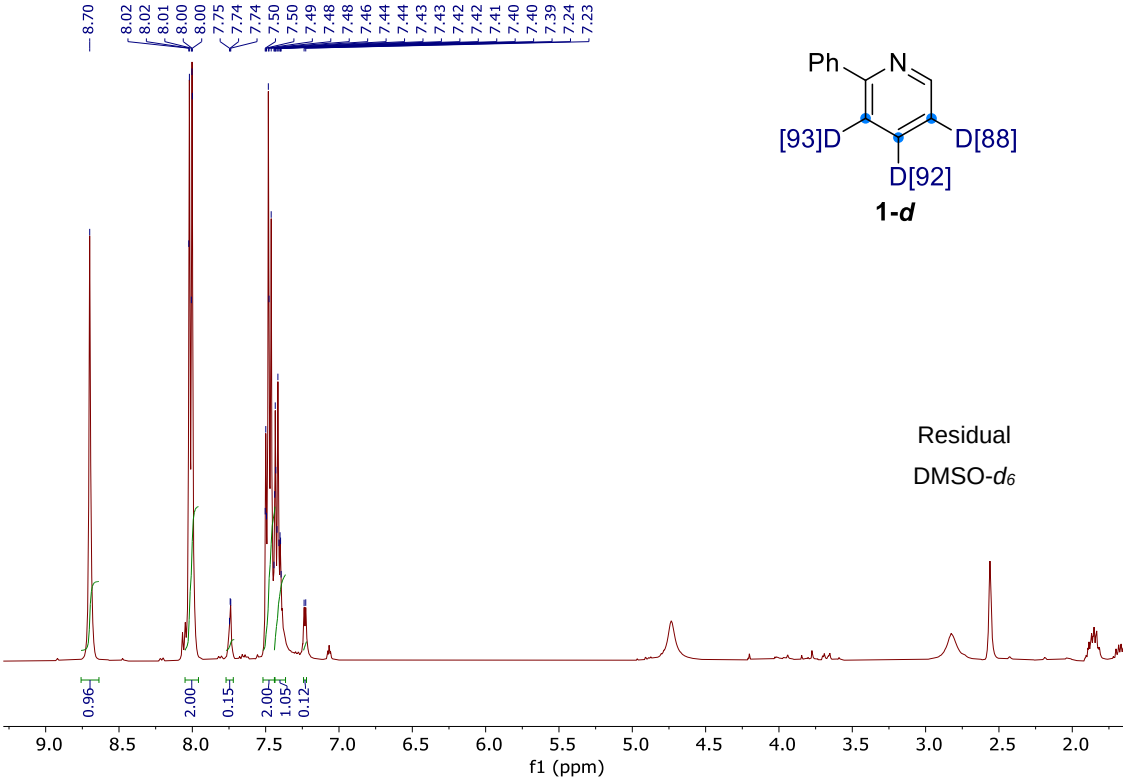






**1-*d***

$^1$H NMR (400 MHz, $CDCl_3$) of 2-phenylpyridine-3,4,5-$d_3$ (**1-*d***) (see procedure)





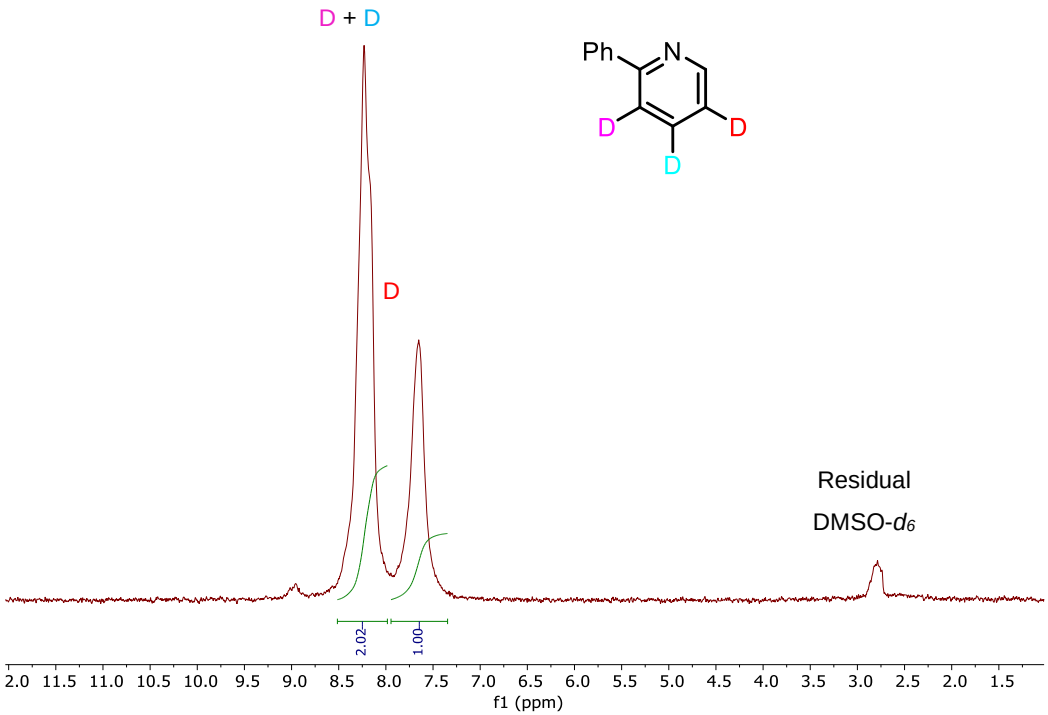


**1-*d***

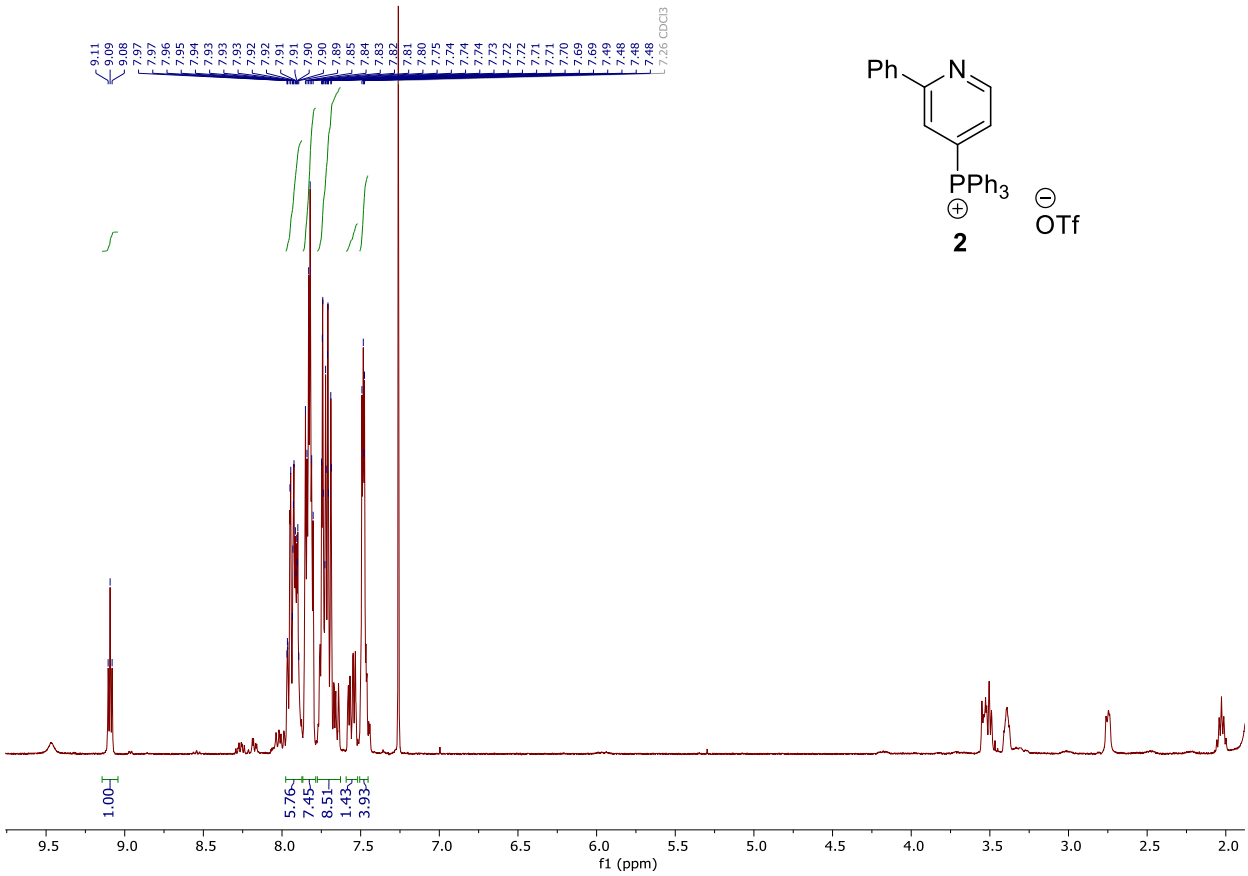
Residual

DMSO-$d_6$

$^{2}$H NMR (61 MHz, DMSO) of 2-phenylpyridine-3,4,5-$d_3$ (**1-*d***) (see procedure)

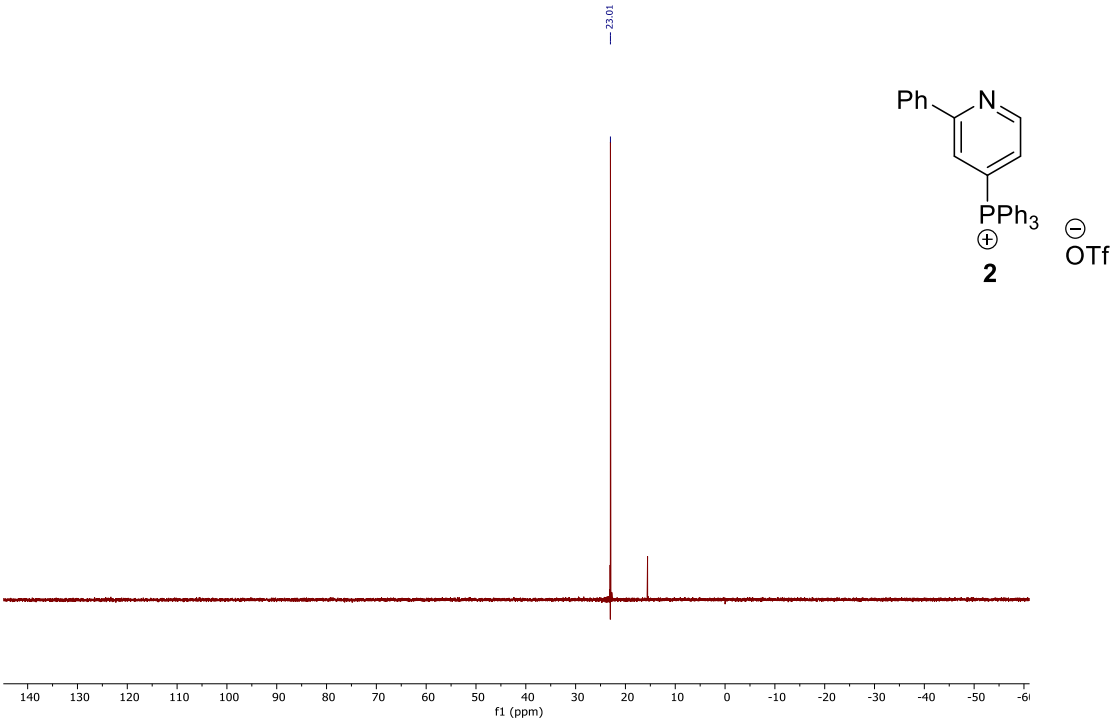



$^{1}$H NMR (400 MHz, $CDCl_3$) of **[2][OTf]** (see procedure)

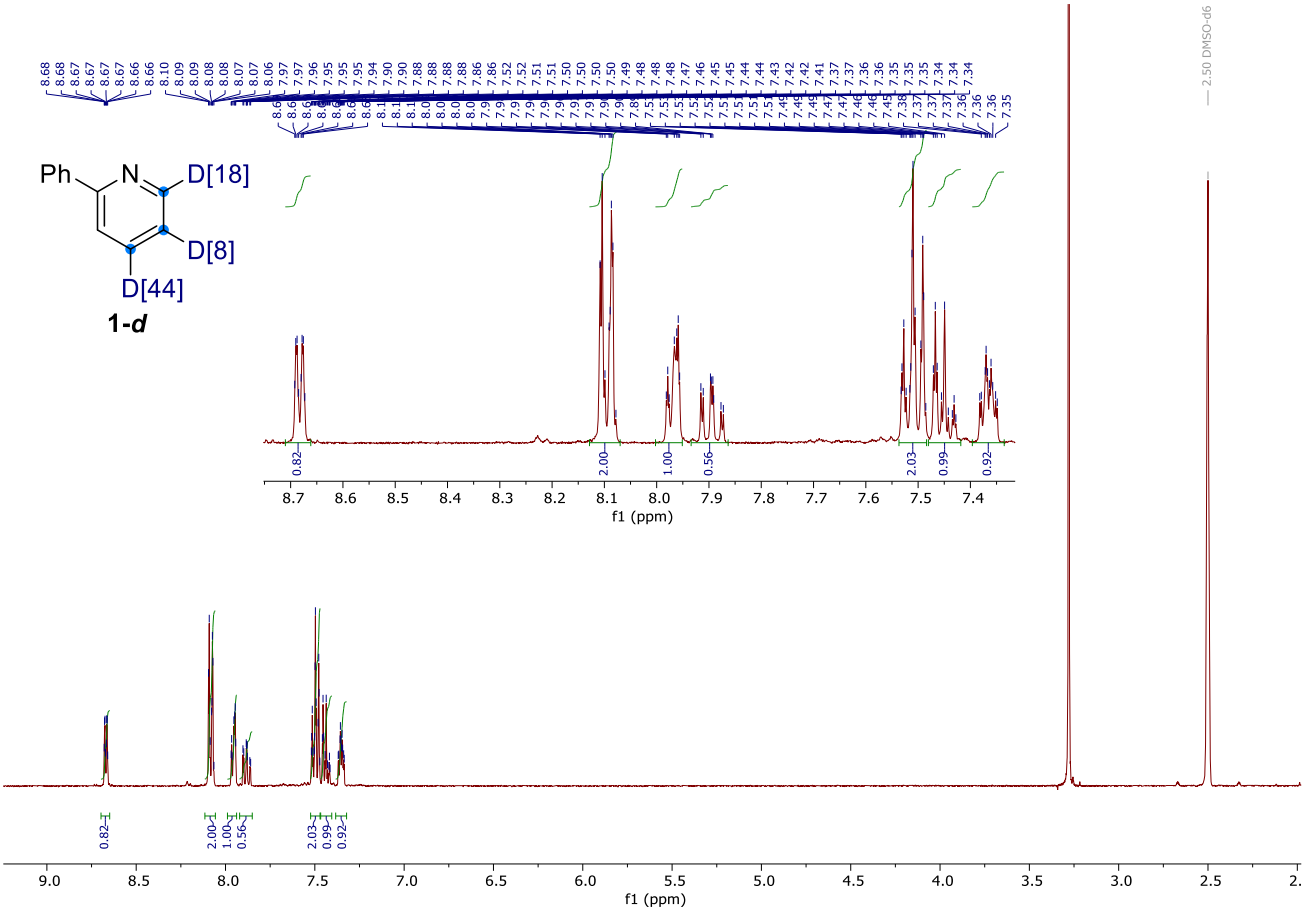



Some residual DBU can be observed in the region of the spectra between 1.00 and 4.00 ppm

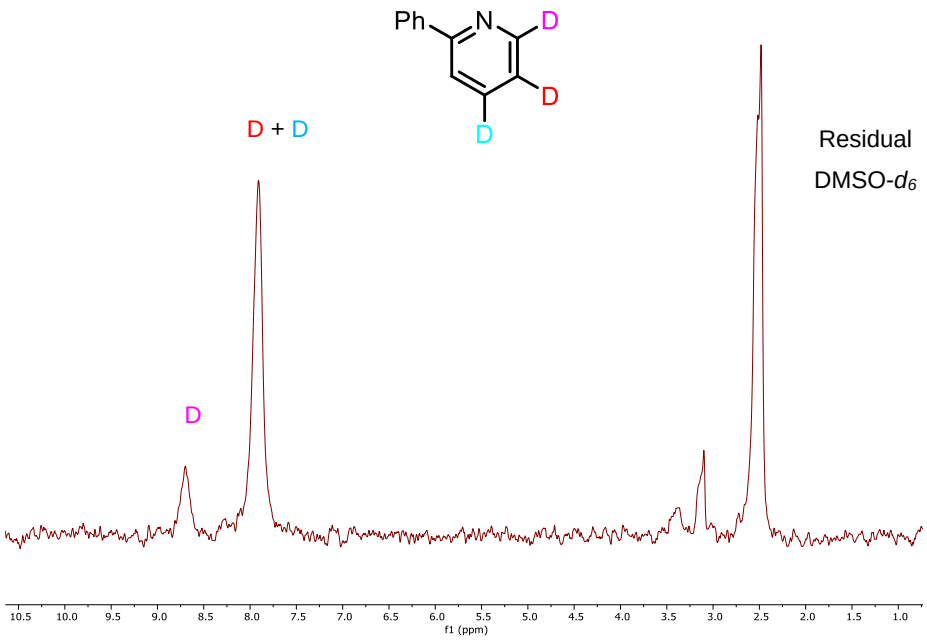
$^{31}$P NMR (162 MHz, $CDCl_3$) of **[2][OTf]** (see procedure)



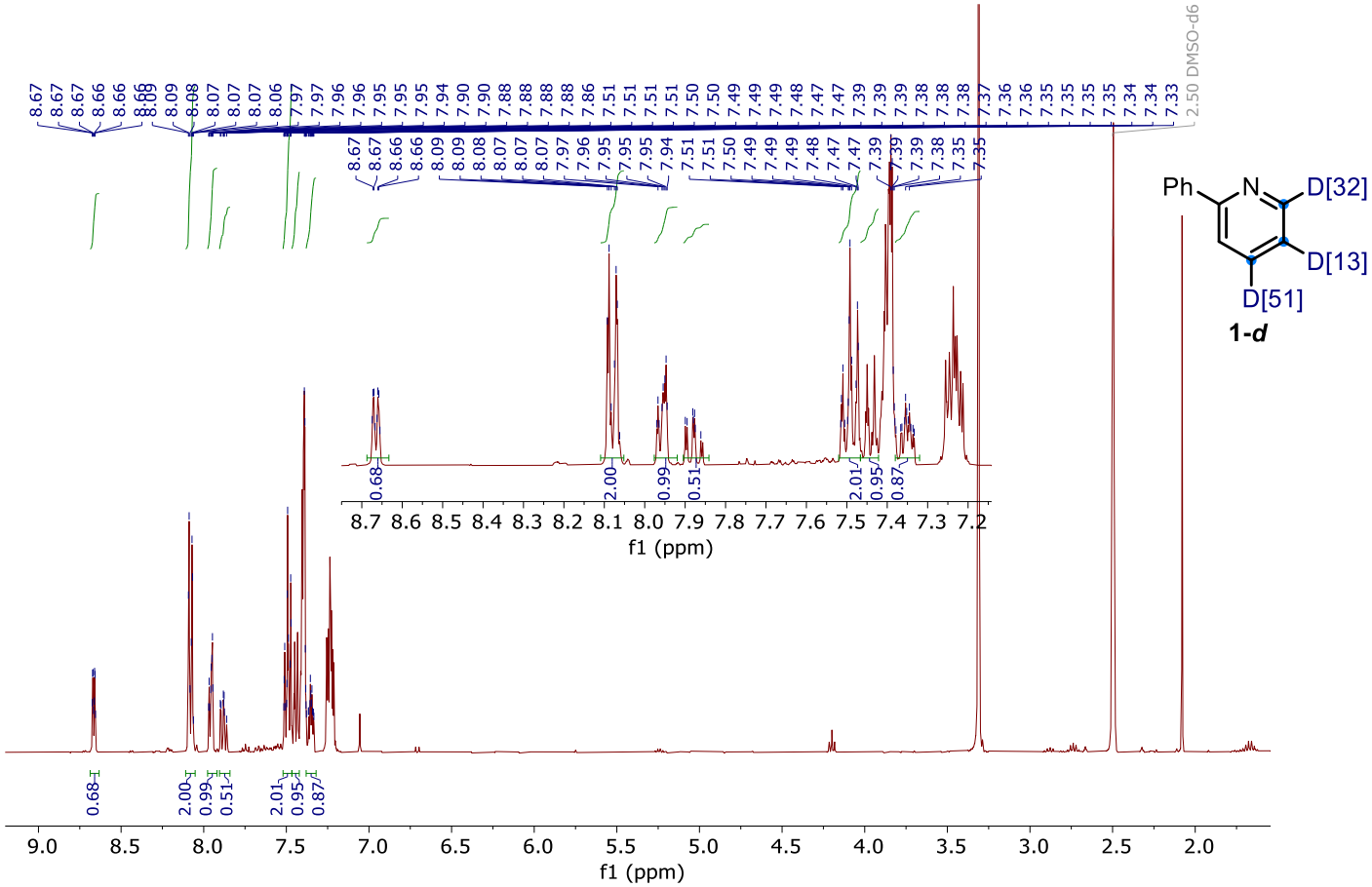

$^{1}$H NMR (400 MHz, DMSO-$d_6$) of 2-phenylpyridine-4,5,6-$d_3$ (**1-*d***) from **[2][OTf]** (see procedure)



$^{2}$H NMR (DMSO)

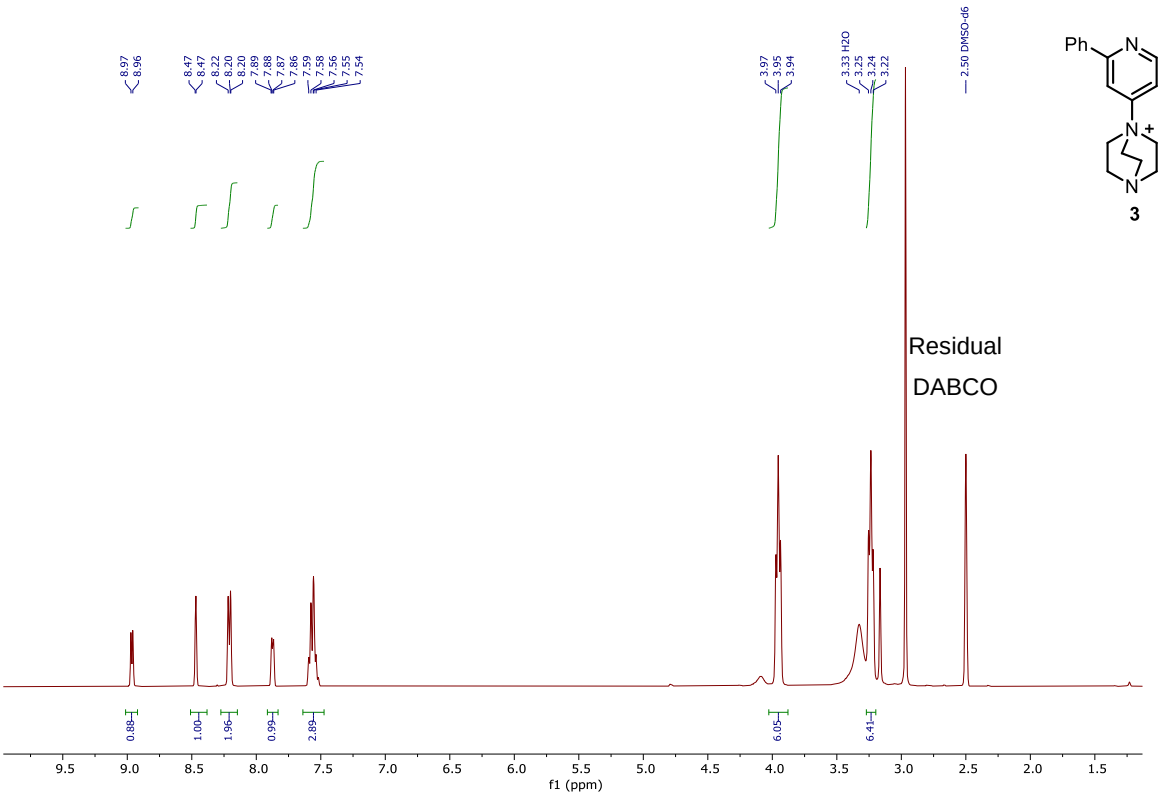



$^{1}$H NMR (400 MHz, DMSO-*d*$_6$) of 2-phenylpyridine-4,5,6-*d*$_3$ (**1-*d***) from **[2][OTf]** (see procedure)

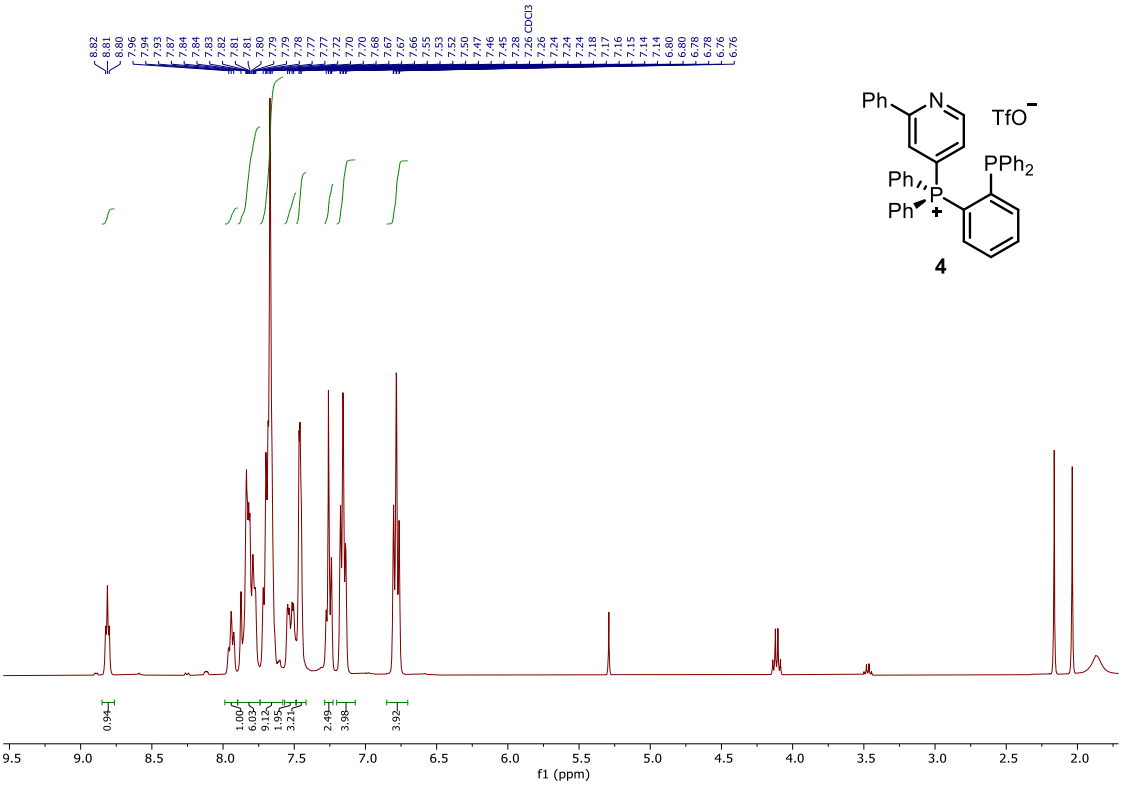



The signals at 7.40 and 7.25 belong to residual $PPh_3$

$^1$H NMR (400 MHz, DMSO-$d_6$) of **[3][OTf]** (see procedure)

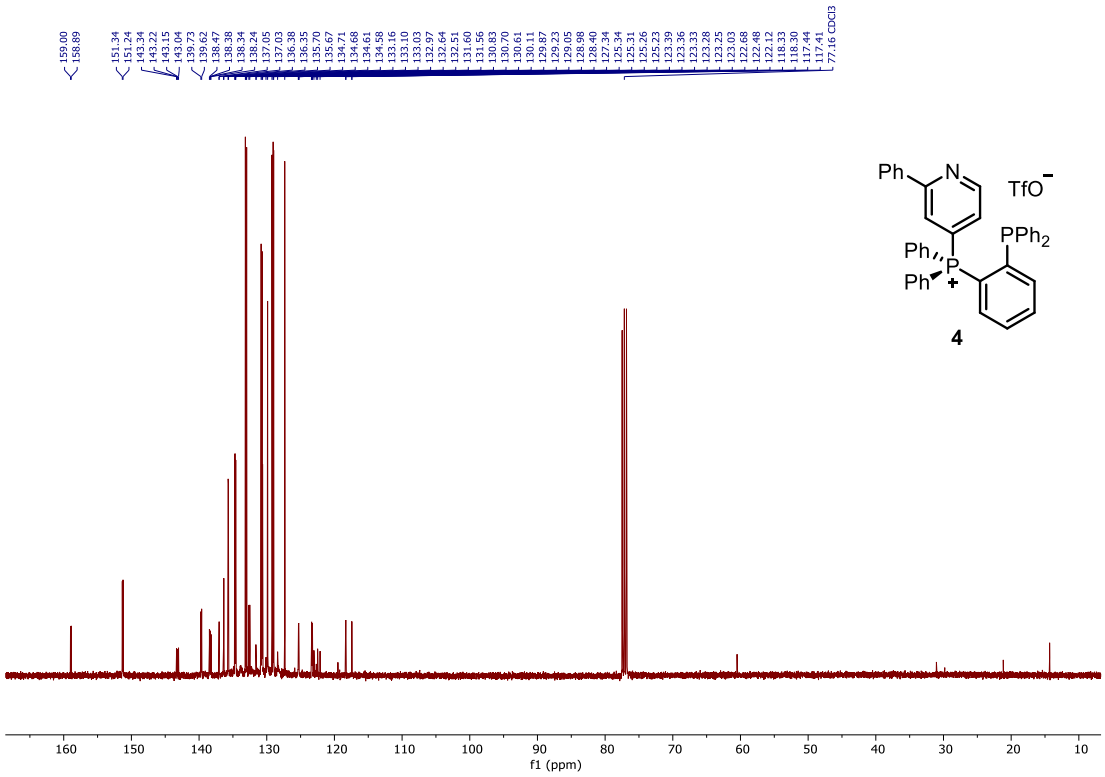



$^1$H NMR (400 MHz, $CDCl_3$) of **[4][OTf]** (see procedure)

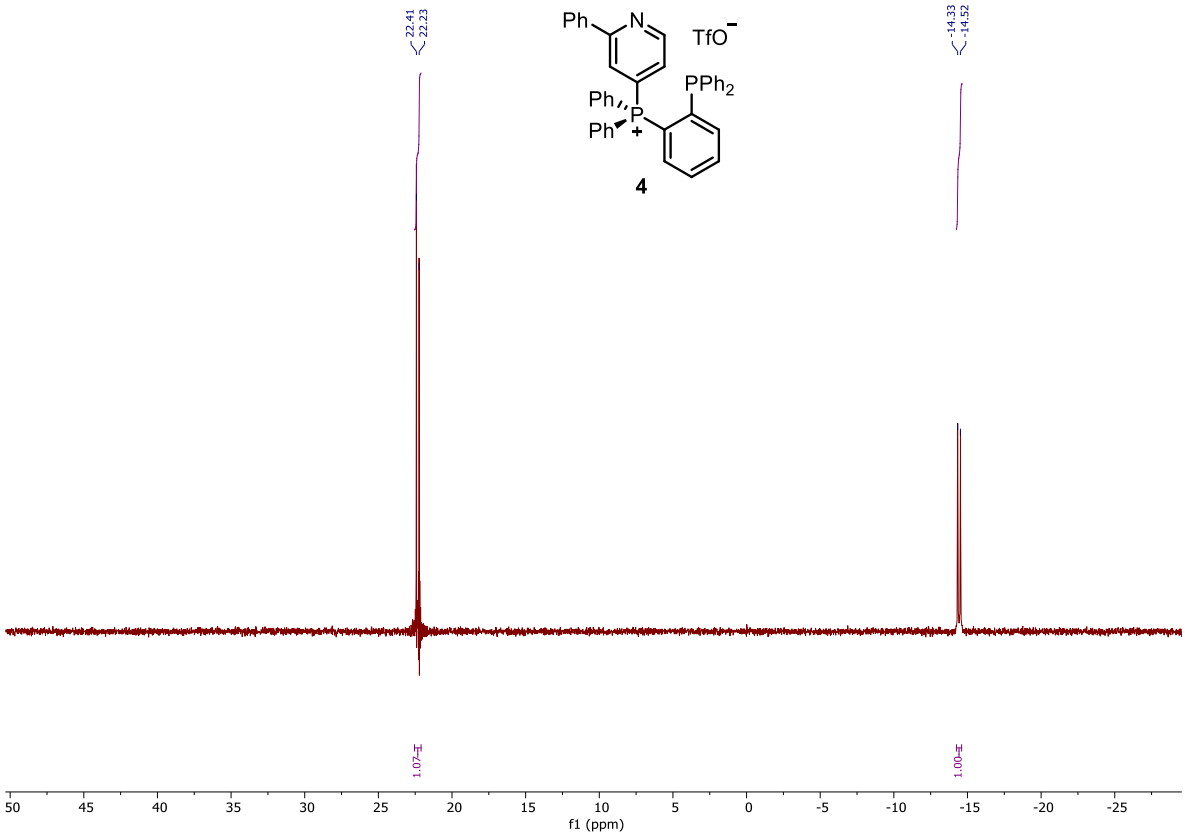



Some residual DBU can be observed in the region of the spectra between 1.00 and 4.00 ppm

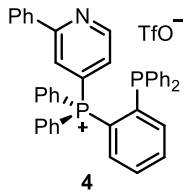
$^{13}$C NMR (101 MHz, $CDCl_3$) of **[4][OTf]** (see procedure)




$^{31}$P NMR (162 MHz, $CDCl_3$) of **[4][OTf]** (see procedure)



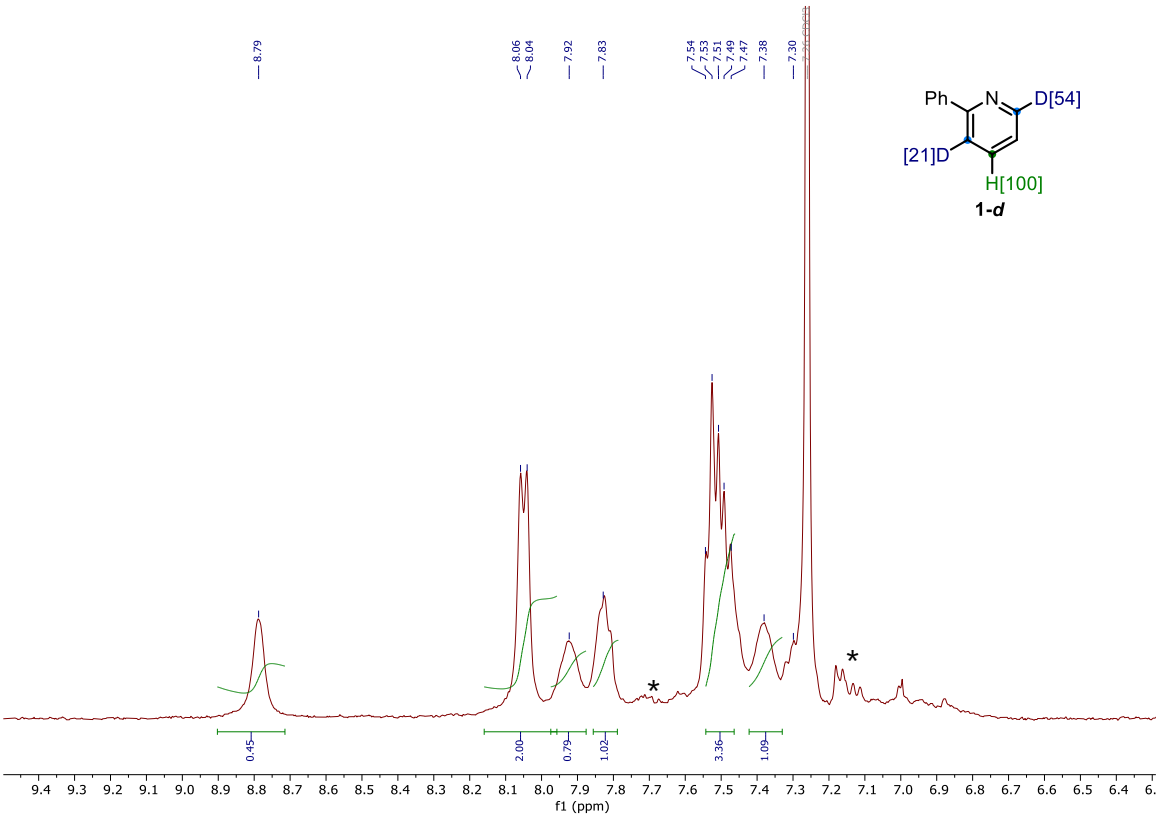
$^{19}$F NMR (376 MHz, $CDCl_3$) of **[4][OTf]** (see procedure)



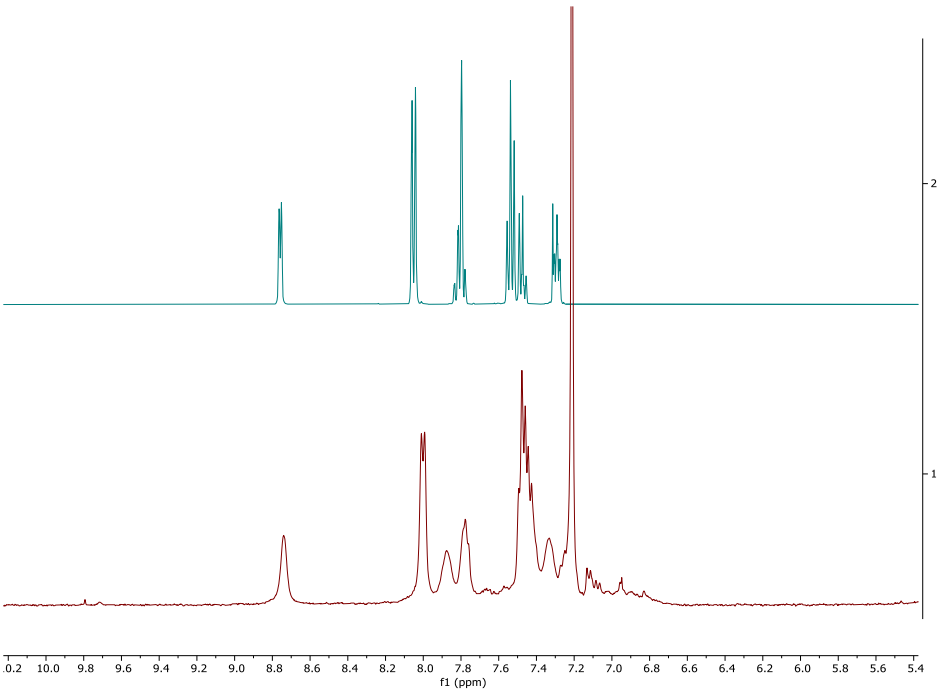

**4**

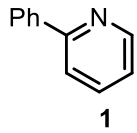



$^{1}$H NMR (400 MHz, $CDCl_3$) of 2-phenylpyridine-3,6-$d_2$ (**1-*d***) from protodephosphination (see procedure).

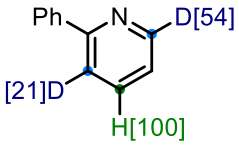



*Some inseparable impurities are present at 7.15 and 7.65 ppm



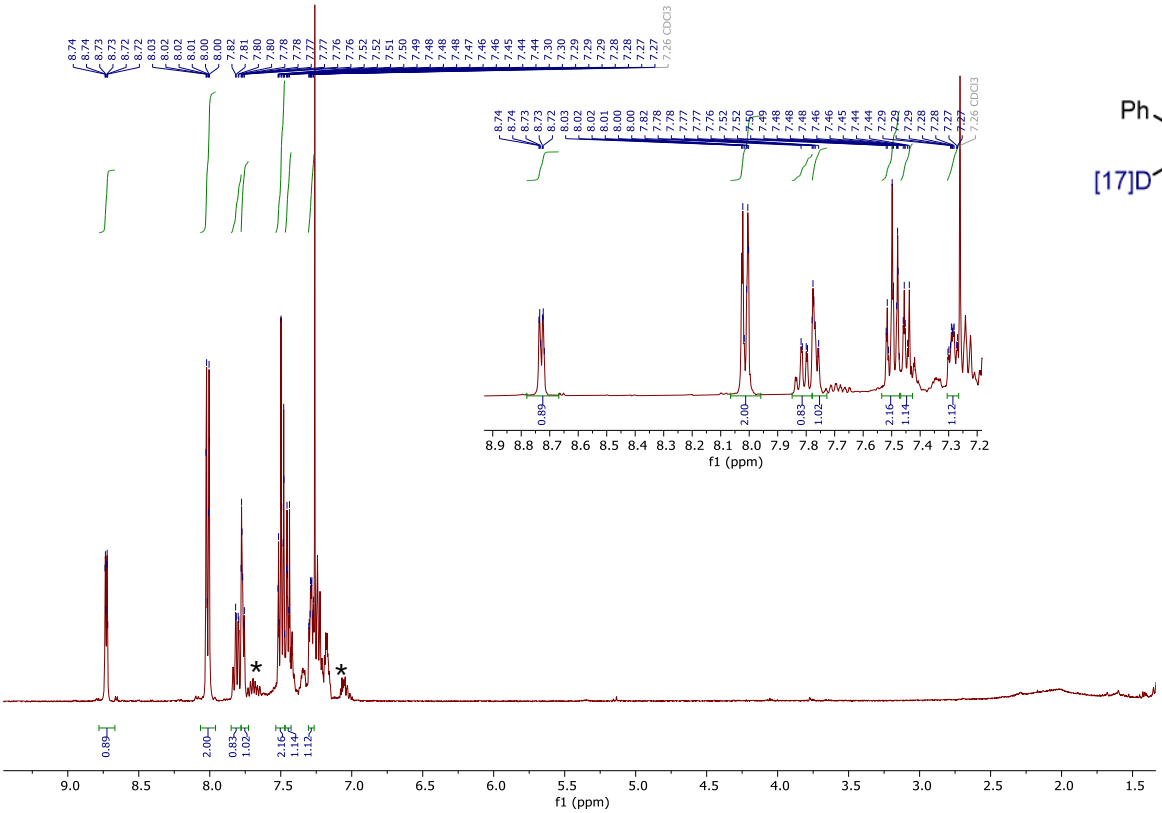



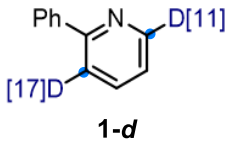

**1**




**1-*d***

$^1$H NMR (400 MHz, $CDCl_3$) of 2-phenylpyridine-3,6-$d_2$ (**1-*d***) from **[4][OTf]** with *s*BuLi (see procedure)




**1-*d***

*Some inseparable impurities are present at 7.15 and 7.65 ppm

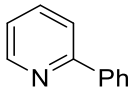
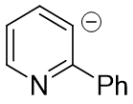
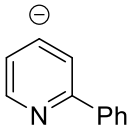
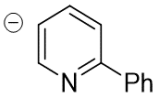
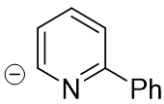
## 4. DFT CALCULATIONS

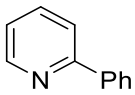
All geometry optimization and frequency analysis of reactants were carried out with Gaussian 16 program rev C.01,[31] using M062X functional[32] with 6-311+G(d,p) basis set. Fully optimization was performed at the same level of theory both in gas phase and in DMSO-$d_6$ according to continuum solvation model based on the quantum mechanical charge density (SMD).[33] Since DMSO-$d_6$ is not by default parametrized within the SMD model implemented in Gaussian, the following parameters were used:

*Eps = 46.7 EpsInf = 2.178576*

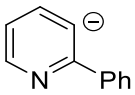
Free Gibbs energies and cartesian coordinates for all the optimized structures are reported below. Energy comparison was made considering the corrected Gibbs free energies at 298.15 K and 1 atm with and without solvation effect.

**Table S1** SMD (DMSO-d6) (M062X / 6-311+G(d,p)), 1 atm, 298.15 °K

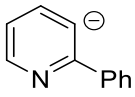
| |  |  |  |  |  |
|---|---|---|---|---|---|
| EE + Thermal Free Energy Correction (hartree) | -479,13456 | -478,6062 | -478,606671 | -478,6056 | -478,599361 |
| EE + Thermal Free Energy Correction (kcal/mol) | -300661,7277 | -300330,1979 | -300330,4721 | -300329,8063 | -300325,885 |



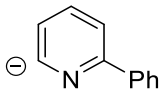
| | | | |
|---|---|---|---|
| C | 2.70371 | -1.17207 | -0.32257 |
| C | 3.50253 | -0.07472 | -0.02188 |
| C | 2.87380 | 1.11879 | 0.31136 |
| C | 1.48695 | 1.16733 | 0.32439 |
| C | 0.76380 | 0.01628 | -0.00457 |
| N | 1.37097 | -1.13718 | -0.31652 |
| H | 3.15676 | -2.12371 | -0.58367 |
| H | 4.58155 | -0.16173 | -0.04507 |
| H | 0.97168 | 2.07771 | 0.60415 |
| C | -0.72425 | 0.01293 | -0.00599 |
| C | -1.42040 | -1.16368 | 0.28974 |
| C | -1.44895 | 1.17197 | -0.30121 |
| C | -2.81047 | -1.17782 | 0.30071 |
| H | -0.86372 | -2.06426 | 0.52043 |
| C | -2.84022 | 1.15484 | -0.29573 |
| H | -0.92881 | 2.08799 | -0.55825 |
| C | -3.52532 | -0.01847 | 0.00787 |
| H | -3.33694 | -2.09462 | 0.54100 |
| H | -3.38868 | 2.05852 | -0.53605 |
| H | -4.60930 | -0.03026 | 0.01389 |
| H | 3.45359 | 1.99839 | 0.56644 |



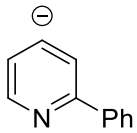
| | | | |
|---|---|---|---|
| C | -0.80189 | 0.09319 | 0.01105 |
| C | -1.47890 | 1.28268 | 0.37586 |
| C | -2.87817 | 1.12733 | 0.34114 |
| C | -3.50776 | -0.06778 | -0.01256 |
| C | -2.70373 | -1.14950 | -0.34698 |
| N | -1.37251 | -1.08137 | -0.33691 |
| H | -3.52215 | 1.96776 | 0.60340 |
| H | -4.58859 | -0.16636 | -0.03140 |
| H | -3.14011 | -2.10245 | -0.63609 |
| C | 0.69886 | 0.05038 | 0.00498 |
| C | 1.38336 | -1.13661 | 0.29641 |
| C | 1.45535 | 1.19080 | -0.28912 |
| C | 2.77429 | -1.18009 | 0.30471 |
| H | 0.81369 | -2.02919 | 0.52733 |
| C | 2.84654 | 1.14731 | -0.29370 |
| H | 0.94270 | 2.11576 | -0.52377 |
| C | 3.51395 | -0.03759 | 0.00779 |
| H | 3.28199 | -2.10767 | 0.54630 |
| H | 3.41100 | 2.04139 | -0.53556 |
| H | 4.59769 | -0.07044 | 0.01073 |



| | | | |
|---|---|---|---|
| C | -0.81173 | 0.03405 | 0.00322 |
| C | -2.93826 | 1.24791 | 0.38858 |
| C | -3.51948 | 0.02087 | -0.00323 |
| C | -2.75918 | -1.09696 | -0.33813 |
| N | -1.42313 | -1.10977 | -0.34362 |
| H | -4.60191 | -0.09540 | -0.05122 |
| H | -3.24160 | -2.03087 | -0.62298 |
| C | 0.67926 | 0.01620 | -0.00529 |
| C | 1.37269 | -1.16133 | 0.29766 |
| C | 1.41630 | 1.16574 | -0.31173 |
| C | 2.76314 | -1.18650 | 0.30513 |
| H | 0.81067 | -2.05689 | 0.53605 |
| C | 2.80794 | 1.13992 | -0.30807 |
| H | 0.90067 | 2.08258 | -0.57477 |
| C | 3.48713 | -0.03505 | 0.00287 |
| H | 3.28332 | -2.10586 | 0.55049 |
| H | 3.36186 | 2.03836 | -0.55661 |
| H | 4.57108 | -0.05441 | 0.00666 |
| C | -1.52824 | 1.17975 | 0.37500 |
| H | -0.93963 | 2.04325 | 0.68179 |

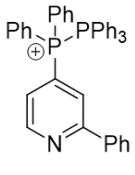
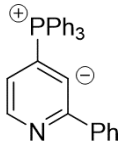
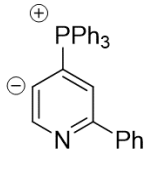
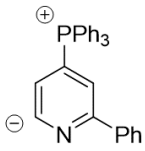
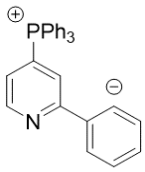
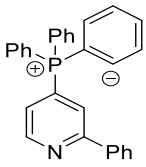


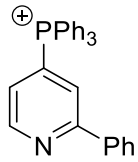
| | | | |
|---|---|---|---|
| C | -0.81044 | -0.01246 | -0.01333 |
| C | -2.77027 | -1.30354 | -0.39391 |
| N | -1.40537 | -1.16748 | -0.36217 |
| C | 0.68163 | 0.00157 | -0.00947 |
| C | 1.39587 | -1.16311 | 0.29378 |
| C | 1.39847 | 1.16611 | -0.30712 |
| C | 2.78661 | -1.16152 | 0.30825 |
| H | 0.84842 | -2.06885 | 0.52607 |
| C | 2.79034 | 1.16721 | -0.29740 |
| H | 0.86727 | 2.07507 | -0.56762 |
| C | 3.49028 | 0.00400 | 0.01213 |
| H | 3.32287 | -2.07147 | 0.55413 |
| H | 3.32821 | 2.07704 | -0.53974 |
| H | 4.57438 | 0.00484 | 0.02053 |
| C | -1.52736 | 1.12927 | 0.34629 |
| H | -1.01921 | 2.03679 | 0.65095 |
| C | -2.91587 | 1.05270 | 0.32492 |
| H | -3.51204 | 1.91836 | 0.60096 |
| C | -3.51448 | -0.14682 | -0.04076 |
| H | -4.60108 | -0.19989 | -0.05023 |



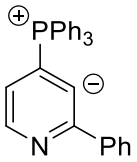
| | | | |
|---|---|---|---|
| C | -0.81226 | 0.01395 | -0.00711 |
| C | -3.65235 | -0.08740 | -0.02068 |
| C | -2.77251 | -1.15172 | -0.30829 |
| N | -1.42773 | -1.13682 | -0.30908 |
| H | -3.17827 | -2.13087 | -0.57128 |
| C | 0.67728 | 0.01158 | -0.00757 |
| C | 1.38024 | -1.16501 | 0.27629 |
| C | 1.40541 | 1.17315 | -0.28929 |
| C | 2.77077 | -1.17791 | 0.28760 |
| H | 0.82512 | -2.06936 | 0.49624 |
| C | 2.79704 | 1.15980 | -0.28031 |
| H | 0.88438 | 2.09139 | -0.53681 |
| C | 3.48591 | -0.01487 | 0.00999 |
| H | 3.29789 | -2.09726 | 0.51767 |
| H | 3.34352 | 2.06800 | -0.50902 |
| H | 4.56994 | -0.02475 | 0.01735 |
| C | -1.54606 | 1.15823 | 0.31085 |
| H | -1.03624 | 2.07689 | 0.58315 |
| C | -2.93928 | 1.08747 | 0.29687 |
| H | -3.47738 | 2.00006 | 0.55613 |

**Table S2** SMD (DMSO-d6) (M062X / 6-311+G(d,p)), 1 atm, 298.15 °K

| |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| EE + Thermal Free Energy Correction (hartree) | -1514,3262 | -1513,8173 | -1513,816224 | -1513,8021 | -1513,798696 | -1513,810852 |
| EE + Thermal Free Energy Correction (kcal/mol) | -950254,8338 | -949935,4914 | -949934,8187 | -949925,9401 | -949923,8197 | -949931,4477 |

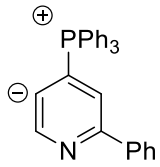


| | | | |
|---|---|---|---|
| C | -0.28471 | 0.85130 | 0.49496 |
| C | -1.37548 | 2.66422 | 1.58143 |
| N | -2.58166 | 2.16713 | 1.31333 |
| C | -2.67162 | 1.01528 | 0.64000 |
| P | 1.23000 | -0.01021 | -0.01890 |
| C | 3.05893 | -2.29083 | 3.49966 |
| C | 3.37378 | -2.65013 | 2.19118 |
| C | 2.80075 | -1.96798 | 1.12568 |
| C | 1.91241 | -0.91771 | 1.38100 |
| C | 1.59344 | -0.55510 | 2.69067 |
| C | 2.17147 | -1.24852 | 3.74861 |
| C | 4.14473 | 3.17044 | -1.54008 |
| C | 2.79217 | 3.25058 | -1.86547 |
| C | 1.90567 | 2.29173 | -1.39360 |
| C | 2.38578 | 1.24680 | -0.59559 |
| C | 3.73922 | 1.16459 | -0.26505 |
| C | 4.61653 | 2.13270 | -0.74273 |
| C | 0.17953 | -2.99209 | -3.32631 |
| C | -0.10156 | -3.29630 | -1.99575 |
| C | 0.23272 | -2.39767 | -0.99147 |
| C | 0.84781 | -1.18645 | -1.33054 |
| C | 1.13356 | -0.87975 | -2.66177 |
| C | 0.79600 | -1.79011 | -3.65805 |
| H | -1.34850 | 3.60029 | 2.12931 |
| H | 3.50510 | -2.82853 | 4.32824 |
| H | 4.06267 | -3.46370 | 1.99849 |
| H | 3.04367 | -2.24937 | 0.10641 |
| H | 0.89931 | 0.25204 | 2.89338 |
| H | 1.92292 | -0.97457 | 4.76685 |
| H | 4.83214 | 3.92388 | -1.90696 |
| H | 2.42593 | 4.06190 | -2.48295 |
| H | 0.85162 | 2.35764 | -1.64280 |
| H | 4.11034 | 0.36273 | 0.36280 |
| H | 5.66737 | 2.07598 | -0.48554 |



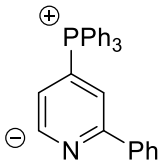
| | | | |
|---|---|---|---|
| C | 0.34800 | -0.67562 | 0.74513 |
| C | 0.24959 | -1.63901 | 1.75366 |
| C | 1.44770 | -2.11564 | 2.26360 |
| N | 2.63466 | -1.69812 | 1.82034 |
| C | 2.67080 | -0.77709 | 0.84017 |
| C | 1.54462 | -0.17333 | 0.22089 |
| P | -1.16185 | 0.00585 | 0.00662 |
| C | -0.87213 | 4.58088 | 0.06155 |
| C | -1.37248 | 3.94428 | -1.06883 |
| C | -1.45758 | 2.55496 | -1.10958 |
| C | -1.03590 | 1.80881 | -0.01000 |
| C | -0.52677 | 2.44639 | 1.12635 |
| C | -0.44967 | 3.83246 | 1.15895 |
| C | -4.83311 | -1.30241 | 2.43169 |
| C | -4.19392 | -2.20031 | 1.57860 |
| C | -3.09598 | -1.78998 | 0.83364 |
| C | -2.63384 | -0.47369 | 0.94732 |
| C | -3.27364 | 0.42621 | 1.80021 |
| C | -4.37506 | 0.00613 | 2.54101 |
| C | -1.85427 | -1.56498 | -4.24772 |
| C | -0.61058 | -1.73812 | -3.64947 |
| C | -0.38155 | -1.26613 | -2.36011 |
| C | -1.40968 | -0.62010 | -1.67331 |
| C | -2.66500 | -0.45334 | -2.26919 |
| C | -2.88115 | -0.92313 | -3.55839 |
| H | -0.69443 | -2.00413 | 2.14221 |
| H | 1.45477 | -2.85323 | 3.06068 |
| H | -0.80505 | 5.66244 | 0.08780 |
| H | -1.69338 | 4.52504 | -1.92546 |
| H | -1.83925 | 2.06785 | -1.99906 |
| H | -0.18850 | 1.86410 | 1.97740 |
| H | -0.05462 | 4.32772 | 2.03798 |
| H | -5.69252 | -1.62431 | 3.00853 |

| | | | |
|---|---|---|---|
| H | -0.07956 | -3.69838 | -4.10653 |
| H | -0.57771 | -4.23491 | -1.73889 |
| H | 0.01896 | -2.63740 | 0.04508 |
| H | 1.62144 | 0.05126 | -2.92592 |
| H | 1.02039 | -1.55868 | -4.69231 |
| C | -4.03491 | 0.49752 | 0.35523 |
| C | -4.27042 | -0.87422 | 0.21937 |
| C | -5.10397 | 1.38922 | 0.22299 |
| C | -5.55220 | -1.34385 | -0.04724 |
| H | -3.45980 | -1.58361 | 0.34504 |
| C | -6.38245 | 0.91766 | -0.05038 |
| H | -4.92415 | 2.45276 | 0.32572 |
| C | -6.61036 | -0.44996 | -0.18599 |
| H | -5.72450 | -2.40993 | -0.14016 |
| H | -7.20183 | 1.61879 | -0.16020 |
| H | -7.60842 | -0.81720 | -0.39593 |
| C | -1.53458 | 0.32607 | 0.19941 |
| H | -1.64122 | -0.58073 | -0.38209 |
| C | -0.18891 | 2.04946 | 1.20064 |
| H | 0.76557 | 2.50165 | 1.44437 |



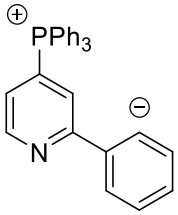

| | | | |
|---|---|---|---|
| C | -0.32252 | -0.76054 | -0.71866 |
| C | -0.14847 | -1.79028 | -1.65596 |
| C | -1.40503 | -2.24981 | -2.11182 |
| N | -2.61715 | -1.81775 | -1.74084 |
| C | -2.70084 | -0.83084 | -0.83762 |
| P | 1.20711 | -0.05994 | -0.04051 |
| C | 3.47667 | 2.44316 | -3.14341 |
| C | 3.81549 | 2.51607 | -1.79372 |
| C | 3.12189 | 1.75521 | -0.86146 |
| C | 2.09054 | 0.91003 | -1.28689 |
| C | 1.74701 | 0.83875 | -2.63708 |
| C | 2.44466 | 1.61008 | -3.56231 |
| C | 3.78165 | -3.49530 | 1.56453 |
| C | 2.40717 | -3.47333 | 1.79530 |
| C | 1.63442 | -2.43561 | 1.29123 |
| C | 2.24516 | -1.41230 | 0.55846 |
| C | 3.61939 | -1.43220 | 0.32513 |
| C | 4.38487 | -2.47976 | 0.83082 |
| C | 0.21318 | 2.83414 | 3.38043 |
| C | -0.01073 | 3.20255 | 2.05495 |
| C | 0.31410 | 2.32800 | 1.02632 |
| C | 0.86181 | 1.07550 | 1.32820 |
| C | 1.08792 | 0.70661 | 2.65426 |
| C | 0.76231 | 1.59185 | 3.67853 |
| H | -1.44589 | -3.05023 | -2.85105 |
| H | 4.01635 | 3.04170 | -3.86837 |
| H | 4.61549 | 3.16898 | -1.46554 |
| H | 3.37981 | 1.82246 | 0.19089 |

| | | | |
|---|---|---|---|
| H | -4.55219 | -3.21911 | 1.49060 |
| H | -2.60252 | -2.49018 | 0.16683 |
| H | -2.92775 | 1.44970 | 1.88649 |
| H | -4.87521 | 0.70620 | 3.19969 |
| H | -2.02726 | -1.93468 | -5.25194 |
| H | 0.18554 | -2.24398 | -4.18272 |
| H | 0.58749 | -1.40031 | -1.89499 |
| H | -3.46969 | 0.03753 | -1.73105 |
| H | -3.85183 | -0.79252 | -4.02181 |
| C | 4.05474 | -0.40260 | 0.40350 |
| C | 5.11210 | -1.31348 | 0.51925 |
| C | 4.32416 | 0.86260 | -0.12970 |
| C | 6.39671 | -0.97253 | 0.10838 |
| H | 4.91877 | -2.29892 | 0.92615 |
| C | 5.61111 | 1.20944 | -0.52996 |
| H | 3.51678 | 1.57908 | -0.22145 |
| C | 6.65306 | 0.29232 | -0.41605 |
| H | 7.19911 | -1.69683 | 0.19606 |
| H | 5.80047 | 2.19933 | -0.93038 |
| H | 7.65473 | 0.56030 | -0.73277 |

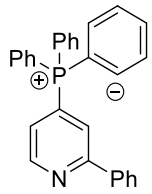



| | | | |
|---|---|---|---|
| C | 0.31062 | -0.84356 | 0.54738 |
| C | 1.38418 | -2.64688 | 1.83273 |
| N | 2.58471 | -2.08950 | 1.48129 |
| C | 2.67594 | -0.99333 | 0.71119 |
| P | -1.20261 | -0.02004 | -0.00630 |
| C | -3.06127 | 2.42564 | 3.39341 |
| C | -3.37233 | 2.72111 | 2.06803 |
| C | -2.79455 | 1.98941 | 1.03828 |
| C | -1.90443 | 0.95414 | 1.34368 |
| C | -1.58966 | 0.65676 | 2.67071 |
| C | -2.17263 | 1.39805 | 3.69344 |
| C | -4.15132 | -3.23264 | -1.40618 |
| C | -2.79522 | -3.34965 | -1.70355 |
| C | -1.90118 | -2.38136 | -1.26523 |
| C | -2.37467 | -1.28920 | -0.53024 |
| C | -3.73215 | -1.17040 | -0.22870 |
| C | -4.61804 | -2.14796 | -0.67056 |
| C | -0.20138 | 2.83796 | -3.44315 |
| C | 0.10278 | 3.18753 | -2.12888 |
| C | -0.21957 | 2.32678 | -1.08784 |
| C | -0.84689 | 1.10769 | -1.37086 |
| C | -1.15345 | 0.75587 | -2.68582 |
| C | -0.82823 | 1.62768 | -3.72049 |
| H | -3.51090 | 3.00151 | 4.19407 |
| H | -4.06186 | 3.52349 | 1.83454 |
| H | -3.03551 | 2.22224 | 0.00637 |
| H | -0.89433 | -0.13911 | 2.91063 |
| H | -1.92678 | 1.17259 | 4.72423 |

| | | | |
|---|---|---|---|
| H | 0.94405 | 0.18962 | -2.96415 |
| H | 2.17642 | 1.55922 | -4.61092 |
| H | 4.38122 | -4.30995 | 1.95417 |
| H | 1.93602 | -4.26740 | 2.36226 |
| H | 0.56276 | -2.42352 | 1.46262 |
| H | 4.09638 | -0.64962 | -0.25304 |
| H | 5.45205 | -2.50074 | 0.64455 |
| H | -0.03787 | 3.52021 | 4.18116 |
| H | -0.43522 | 4.17194 | 1.82211 |
| H | 0.14291 | 2.61876 | -0.00554 |
| H | 1.52097 | -0.25719 | 2.89532 |
| H | 0.94267 | 1.30800 | 4.70855 |
| C | -4.06074 | -0.38061 | -0.43464 |
| C | -4.28741 | 0.92557 | 0.01289 |
| C | -5.14119 | -1.26718 | -0.49824 |
| C | -5.56236 | 1.33227 | 0.39378 |
| H | -3.47017 | 1.63795 | 0.04724 |
| C | -6.41447 | -0.86046 | -0.11506 |
| H | -4.97325 | -2.28075 | -0.84271 |
| C | -6.63021 | 0.44087 | 0.33298 |
| H | -5.72213 | 2.35019 | 0.73103 |
| H | -7.23981 | -1.56202 | -0.16290 |
| H | -7.62320 | 0.75812 | 0.63042 |
| C | -1.55303 | -0.26430 | -0.28483 |
| H | -1.63344 | 0.50869 | 0.47084 |



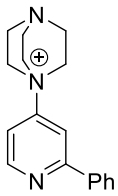
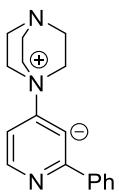
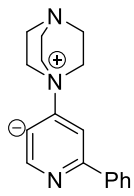
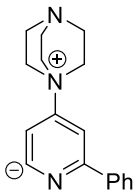
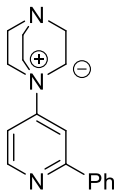

| | | | |
|---|---|---|---|
| C | 0.30732 | -0.86043 | 0.47795 |
| N | 2.61474 | -2.17172 | 1.26279 |
| C | 2.70395 | -1.00592 | 0.60847 |
| P | -1.20873 | 0.00518 | -0.01208 |
| C | -3.02536 | 2.23600 | 3.54598 |
| C | -3.35104 | 2.60945 | 2.24406 |
| C | -2.78394 | 1.94101 | 1.16669 |
| C | -1.89112 | 0.89028 | 1.40294 |
| C | -1.56127 | 0.51382 | 2.70583 |
| C | -2.13323 | 1.19337 | 3.77619 |
| C | -4.12863 | -3.14517 | -1.58804 |
| C | -2.77987 | -3.20627 | -1.93311 |
| C | -1.89336 | -2.25583 | -1.44430 |
| C | -2.36939 | -1.23839 | -0.60928 |
| C | -3.71887 | -1.17507 | -0.25983 |
| C | -4.59649 | -2.13464 | -0.75434 |
| C | -0.18797 | 3.05384 | -3.26759 |
| C | 0.13431 | 3.31532 | -1.93723 |
| C | -0.19270 | 2.39633 | -0.94922 |
| C | -0.84011 | 1.20697 | -1.30437 |
| C | -1.16708 | 0.94309 | -2.63489 |
| C | -0.83783 | 1.87413 | -3.61499 |
| H | -3.46614 | 2.76344 | 4.38401 |
| H | -4.84502 | -3.99328 | -1.74542 |
| H | -2.43175 | -4.19728 | -2.27205 |
| H | -0.84420 | -2.47627 | -1.49066 |
| H | -4.10122 | -0.33256 | 0.35153 |
| H | -5.67171 | -2.06187 | -0.43349 |
| H | 0.04832 | 3.51428 | -4.25250 |
| H | 0.58808 | 4.13196 | -1.91335 |
| H | 0.01319 | 2.60317 | -0.06436 |
| H | -1.64687 | -0.18330 | -2.90797 |
| H | -1.06980 | 1.35945 | -4.74202 |
| C | 4.04408 | -0.49912 | 0.38744 |
| C | 4.29638 | 0.86450 | 0.20273 |
| C | 5.10426 | -1.40318 | 0.26465 |
| C | 5.57826 | 1.31266 | -0.10114 |
| H | 3.49353 | 1.58499 | 0.31747 |
| C | 6.38379 | -0.95542 | -0.04516 |
| H | 4.91380 | -2.46047 | 0.40572 |
| C | 6.62569 | 0.40429 | -0.22878 |
| H | 5.75947 | 2.37360 | -0.23173 |
| H | 7.19357 | -1.66931 | -0.14648 |
| H | 7.62390 | 0.75339 | -0.46740 |
| C | 1.55758 | -0.32867 | 0.20639 |
| H | 1.66649 | 0.52980 | -0.44457 |
| C | 0.22665 | -1.98565 | 1.34085 |
| H | -0.75362 | -2.38792 | 1.58707 |



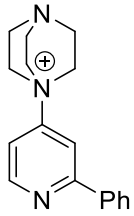

| | | | |
|---|---|---|---|
| C | -0.21297 | -1.00386 | -0.41706 |
| N | -2.53209 | -2.41464 | -1.00074 |
| C | -2.60702 | -1.18072 | -0.48507 |
| P | 1.28189 | -0.04016 | -0.01439 |
| C | 4.90330 | -1.65968 | -2.18938 |
| C | 4.40956 | -0.40974 | -2.56773 |
| C | 3.29998 | 0.09996 | -1.90778 |
| C | 2.72790 | -0.66863 | -0.88222 |
| C | 3.17005 | -1.93062 | -0.43458 |
| C | 4.29519 | -2.38361 | -1.16256 |
| C | 2.01372 | -0.07314 | 4.51062 |
| C | 0.75896 | -0.42261 | 4.02323 |
| C | 0.52035 | -0.43734 | 2.65167 |
| C | 1.54965 | -0.10352 | 1.77235 |
| C | 2.81383 | 0.24271 | 2.25914 |
| C | 3.04045 | 0.26013 | 3.62923 |
| C | 0.31481 | 4.26555 | -1.27804 |
| C | 0.05634 | 3.20312 | -2.14282 |
| C | 0.33725 | 1.90169 | -1.74843 |
| C | 0.88176 | 1.66393 | -0.48079 |
| C | 1.13973 | 2.72621 | 0.38567 |
| C | 0.85425 | 4.02777 | -0.01873 |
| H | 5.77244 | -2.06554 | -2.69978 |
| H | 4.88386 | 0.15757 | -3.36040 |

| | | | |
|---|---|---|---|
| H | -4.04296 | 3.42382 | 2.06602 |
| H | -3.03386 | 2.23403 | 0.15228 |
| H | -0.86182 | -0.29268 | 2.89252 |
| H | -1.87545 | 0.90924 | 4.78935 |
| H | -4.81593 | -3.89215 | -1.96814 |
| H | -2.41660 | -3.99660 | -2.57895 |
| H | -0.84204 | -2.30755 | -1.70835 |
| H | -4.08646 | -0.39406 | 0.39582 |
| H | -5.64425 | -2.09247 | -0.48213 |
| H | 0.06631 | 3.77554 | -4.03521 |
| H | 0.63853 | 4.23555 | -1.66781 |
| H | 0.05459 | 2.60196 | 0.08728 |
| H | -1.67841 | 0.02835 | -2.91123 |
| H | -1.09332 | 1.67538 | -4.64888 |
| C | 4.05767 | -0.44557 | 0.32321 |
| C | 4.21001 | 0.95406 | 0.15889 |
| C | 5.12417 | -1.35849 | 0.24080 |
| C | 5.54484 | 1.34719 | -0.08651 |
| C | 6.41197 | -0.90516 | -0.01481 |
| H | 4.94228 | -2.42085 | 0.36847 |
| C | 6.62388 | 0.46403 | -0.17563 |
| H | 5.77149 | 2.40587 | -0.21845 |
| H | 7.23612 | -1.60664 | -0.08968 |
| H | 7.62590 | 0.83681 | -0.37121 |
| C | 1.54951 | -0.32220 | 0.18909 |
| H | 1.66566 | 0.60216 | -0.35921 |
| C | 0.21759 | -2.07271 | 1.16660 |
| H | -0.73329 | -2.53323 | 1.40830 |
| C | 1.41035 | -2.68076 | 1.52946 |
| H | 1.39334 | -3.62509 | 2.06453 |
| H | 2.90325 | 1.07159 | -2.18472 |
| H | 4.73332 | -3.35068 | -0.91806 |
| H | 2.19541 | -0.06426 | 5.57919 |
| H | -0.03795 | -0.68859 | 4.70746 |
| H | -0.45941 | -0.71721 | 2.28289 |
| H | 3.61523 | 0.49256 | 1.57186 |
| H | 4.01949 | 0.52843 | 4.00811 |
| H | 0.09154 | 5.28003 | -1.58773 |
| H | -0.36564 | 3.38786 | -3.12360 |
| H | 0.13311 | 1.07665 | -2.42389 |
| H | 1.55345 | 2.54805 | 1.37175 |
| H | 1.05074 | 4.85294 | 0.65547 |
| C | -3.96509 | -0.62361 | -0.25228 |
| C | -5.02969 | -1.48190 | 0.04006 |
| C | -5.47701 | 1.26040 | -0.10913 |
| C | -6.30299 | -0.97152 | 0.26431 |
| H | -4.85036 | -2.54884 | 0.09992 |
| C | -6.53052 | 0.40087 | 0.19002 |
| H | -5.64930 | 2.32819 | -0.18027 |
| H | -7.11880 | -1.64560 | 0.49917 |
| H | -7.52458 | 0.79782 | 0.36129 |
| C | -1.46261 | -0.44283 | -0.17015 |
| H | -1.55312 | 0.54357 | 0.26970 |
| C | -0.13510 | -2.27756 | -0.96776 |
| H | 0.81563 | -2.74844 | -1.18118 |
| C | -1.33119 | -2.93848 | -1.23242 |
| H | -1.31399 | -3.93643 | -1.65858 |
| C | -4.20038 | 0.75270 | -0.32725 |
| H | -3.39284 | 1.43113 | -0.58017 |

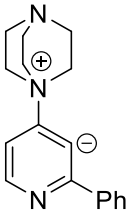
**Table S3** SMD (DMSO-d6) (M062X / 6-311+G(d,p)), 1 atm, 298.15 °K

| | | | | | |
|---|---|---|---|---|---|
| EE + Thermal Free Energy Correction (hartree) | -823,5027 | -822,9966 | -822,995416 | -822,9770 | -822,980556 |
| EE + Thermal Free Energy Correction (kcal/mol) | -516756,1862 | -516438,6122 | -516437,8535 | -516426,2697 | -516428,5287 |

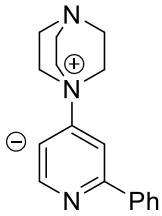


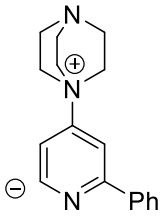
| | | | |
|---|---|---|---|
| C | 0.70654 | 0.85062 | -0.11384 |
| C | -3.06146 | -1.29543 | -0.54318 |
| C | -4.09071 | 0.60316 | 0.53059 |
| C | -4.26445 | -1.98946 | -0.46445 |
| C | -5.28965 | -0.09506 | 0.61416 |
| C | -5.37991 | -1.39333 | 0.11743 |
| C | 3.35996 | -1.78112 | -0.80804 |
| N | 2.00946 | 0.14654 | -0.02357 |
| N | 4.22595 | -1.14488 | 0.18601 |
| C | 2.14391 | -0.88543 | -1.13107 |
| C | 3.53531 | -1.12022 | 1.47622 |
| C | 4.47968 | 0.23317 | -0.23094 |
| C | 3.19204 | 1.08292 | -0.13933 |
| H | -2.20689 | -1.76464 | -1.01825 |
| H | -4.01775 | 1.61180 | 0.91963 |
| H | -4.33091 | -2.99489 | -0.86386 |
| H | -6.15396 | 0.37371 | 1.07052 |
| H | -6.31574 | -1.93661 | 0.18109 |
| H | 3.92430 | -1.95894 | -1.72374 |
| H | 3.02802 | -2.74136 | -0.41132 |
| H | 2.26630 | -0.31586 | -2.05225 |
| H | 1.22266 | -1.45903 | -1.17563 |
| H | 4.11314 | -0.50068 | 2.16298 |
| H | 3.48000 | -2.13121 | 1.88033 |
| H | 5.24277 | 0.67459 | 0.41017 |
| H | 4.85119 | 0.22080 | -1.25619 |
| H | 3.17685 | 1.71603 | 0.74704 |
| H | 3.04949 | 1.68282 | -1.03514 |
| C | 0.63037 | 2.22932 | -0.21844 |
| N | -1.77033 | 2.09607 | -0.21285 |
| C | -1.68579 | 0.76300 | -0.11097 |
| C | -2.96348 | 0.00658 | -0.04313 |



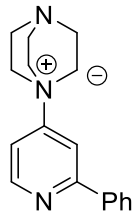
| | | | |
|---|---|---|---|
| C | 0.62867 | 0.69078 | 0.08563 |
| C | -3.17920 | -1.33045 | 0.46272 |
| C | -4.14137 | 0.66146 | -0.47567 |
| C | -4.41925 | -1.95907 | 0.40146 |
| C | -5.37902 | 0.03029 | -0.55011 |
| C | -5.52462 | -1.28313 | -0.10936 |
| C | 4.07398 | -0.19678 | -1.35707 |
| N | 2.00782 | 0.04577 | 0.00389 |
| N | 4.37727 | -0.96680 | -0.14846 |
| C | 2.76609 | 0.60574 | -1.17842 |
| C | 3.36920 | -2.02149 | -0.01328 |
| C | 4.27099 | -0.08054 | 1.01323 |
| C | 2.79974 | 0.32001 | 1.26136 |
| H | -2.32188 | -1.86137 | 0.85861 |
| H | -4.03401 | 1.68338 | -0.81956 |
| H | -4.52239 | -2.97937 | 0.75431 |
| H | -6.23138 | 0.56432 | -0.95568 |
| H | -6.48939 | -1.77472 | -0.16395 |
| H | 4.89349 | 0.49205 | -1.56505 |
| H | 3.98589 | -0.89267 | -2.19267 |
| H | 2.96436 | 1.65383 | -0.96281 |
| H | 2.10662 | 0.53009 | -2.04207 |
| H | 3.49077 | -2.48638 | 0.96664 |
| H | 3.53500 | -2.78205 | -0.77719 |
| H | 4.66047 | -0.58860 | 1.89616 |
| H | 4.88055 | 0.80502 | 0.82597 |
| H | 2.32875 | -0.27151 | 2.04693 |
| H | 2.70652 | 1.37532 | 1.50272 |
| C | 0.62624 | 2.08257 | 0.20750 |
| C | -0.61626 | 2.69029 | 0.27516 |
| N | -1.76161 | 2.00780 | 0.22376 |
| C | -1.68611 | 0.67175 | 0.09871 |

| | | | |
|---|---|---|---|
| C | -0.45884 | 0.10004 | -0.04927 |
| H | -0.43791 | -0.97429 | 0.07201 |
| H | 1.49383 | 2.87563 | -0.25828 |
| C | 2.10443 | -0.56188 | 1.32003 |
| H | 1.35667 | -1.35338 | 1.30529 |
| H | 1.85200 | 0.17380 | 2.08229 |
| C | -0.64267 | 2.79412 | -0.26226 |
| H | -0.74126 | 3.87152 | -0.34497 |
| C | -0.49876 | -0.10056 | 0.01900 |
| C | -3.02045 | -0.00999 | 0.02818 |
| H | 1.51803 | 2.69598 | 0.25035 |
| H | -0.69099 | 3.76858 | 0.37846 |
| C | 1.94283 | -1.44946 | -0.16639 |
| H | 1.52154 | -1.63274 | -1.15329 |
| H | 1.25744 | -1.83499 | 0.58184 |





| | | | |
|---|---|---|---|
| C | 0.67568 | 0.81727 | -0.11855 |
| C | -3.12668 | -1.28536 | -0.52387 |
| C | -4.11946 | 0.64037 | 0.52616 |
| C | -4.34510 | -1.95362 | -0.44841 |
| C | -5.33564 | -0.02915 | 0.60422 |
| C | -5.45321 | -1.32938 | 0.11781 |
| C | 4.32388 | -0.02202 | -0.90984 |
| N | 2.01078 | 0.09252 | -0.02252 |
| N | 4.33881 | -1.00144 | 0.18062 |
| C | 2.88405 | 0.45027 | -1.20239 |
| C | 3.31759 | -2.01255 | -0.09530 |
| C | 3.98709 | -0.31802 | 1.42824 |
| C | 2.70943 | 0.52966 | 1.24566 |
| H | -2.27872 | -1.77700 | -0.98816 |
| H | -4.02759 | 1.65040 | 0.90796 |
| H | -4.42975 | -2.96083 | -0.84058 |
| H | -6.19282 | 0.46349 | 1.04939 |
| H | -6.40182 | -1.85064 | 0.17709 |
| H | 4.95104 | 0.82244 | -0.61922 |
| H | 4.74642 | -0.47291 | -1.80856 |
| H | 2.81629 | 1.52594 | -1.33360 |
| H | 2.44324 | -0.05341 | -2.06360 |
| H | 3.41308 | -2.83068 | 0.61926 |
| H | 3.48778 | -2.40730 | -1.09809 |
| H | 3.83965 | -1.07331 | 2.20185 |
| H | 4.81049 | 0.33010 | 1.73050 |
| H | 1.99895 | 0.39538 | 2.06068 |
| H | 2.92195 | 1.58918 | 1.12183 |
| C | 0.71884 | 2.19940 | -0.24516 |
| C | -0.58015 | 2.73764 | -0.28992 |
| N | -1.74691 | 2.07631 | -0.23147 |
| C | -1.70168 | 0.74685 | -0.10670 |
| C | -2.99820 | 0.01888 | -0.03447 |
| H | -0.70900 | 3.81613 | -0.38596 |
| C | -0.48669 | 0.05980 | -0.03153 |
| H | -0.50016 | -1.01113 | 0.11235 |
| C | 1.89786 | -1.40752 | 0.00937 |
| H | 1.27505 | -1.71134 | -0.82966 |
| H | 1.41161 | -1.67122 | 0.94822 |
| C | 0.69364 | 0.88111 | -0.12503 |
| C | -3.07068 | -1.25614 | -0.56281 |
| C | -4.08330 | 0.62223 | 0.55163 |
| C | -4.27268 | -1.95278 | -0.48009 |
| C | -5.28267 | -0.07618 | 0.63899 |
| C | -5.38204 | -1.36653 | 0.12337 |
| C | 3.34160 | -1.78285 | -0.78138 |
| N | 2.00359 | 0.16602 | -0.02719 |
| N | 4.21801 | -1.13389 | 0.19609 |
| C | 2.13040 | -0.88405 | -1.11353 |
| C | 3.53131 | -1.08044 | 1.48838 |
| C | 4.47298 | 0.23616 | -0.24881 |
| C | 3.18896 | 1.09172 | -0.16345 |
| H | -2.22078 | -1.71867 | -1.05302 |
| H | -4.00430 | 1.62481 | 0.95458 |
| H | -4.34353 | -2.95239 | -0.89386 |
| H | -6.14094 | 0.38657 | 1.11323 |
| H | -6.31768 | -1.91004 | 0.18941 |
| H | 3.90062 | -1.98348 | -1.69583 |
| H | 3.00595 | -2.73334 | -0.36423 |
| H | 2.25334 | -0.33314 | -2.04609 |
| H | 1.20586 | -1.45277 | -1.14728 |
| H | 4.11556 | -0.45088 | 2.16077 |
| H | 3.47438 | -2.08326 | 1.91257 |
| H | 5.24376 | 0.68567 | 0.37763 |
| H | 4.83778 | 0.20200 | -1.27619 |
| H | 3.18251 | 1.73972 | 0.71199 |
| H | 3.04388 | 1.68139 | -1.06534 |
| C | 0.60583 | 2.25617 | -0.23695 |
| C | -0.65290 | 2.92398 | -0.29713 |
| N | -1.76420 | 2.13410 | -0.23811 |
| C | -1.67939 | 0.79818 | -0.12043 |
| C | -2.96063 | 0.03888 | -0.04541 |
| C | -0.46638 | 0.11818 | -0.05241 |
| H | -0.44824 | -0.95541 | 0.07773 |
| H | 1.50032 | 2.86394 | -0.27450 |
| C | 2.10292 | -0.51769 | 1.32468 |
| H | 1.35161 | -1.30591 | 1.33001 |
| H | 1.85621 | 0.23183 | 2.07525 |

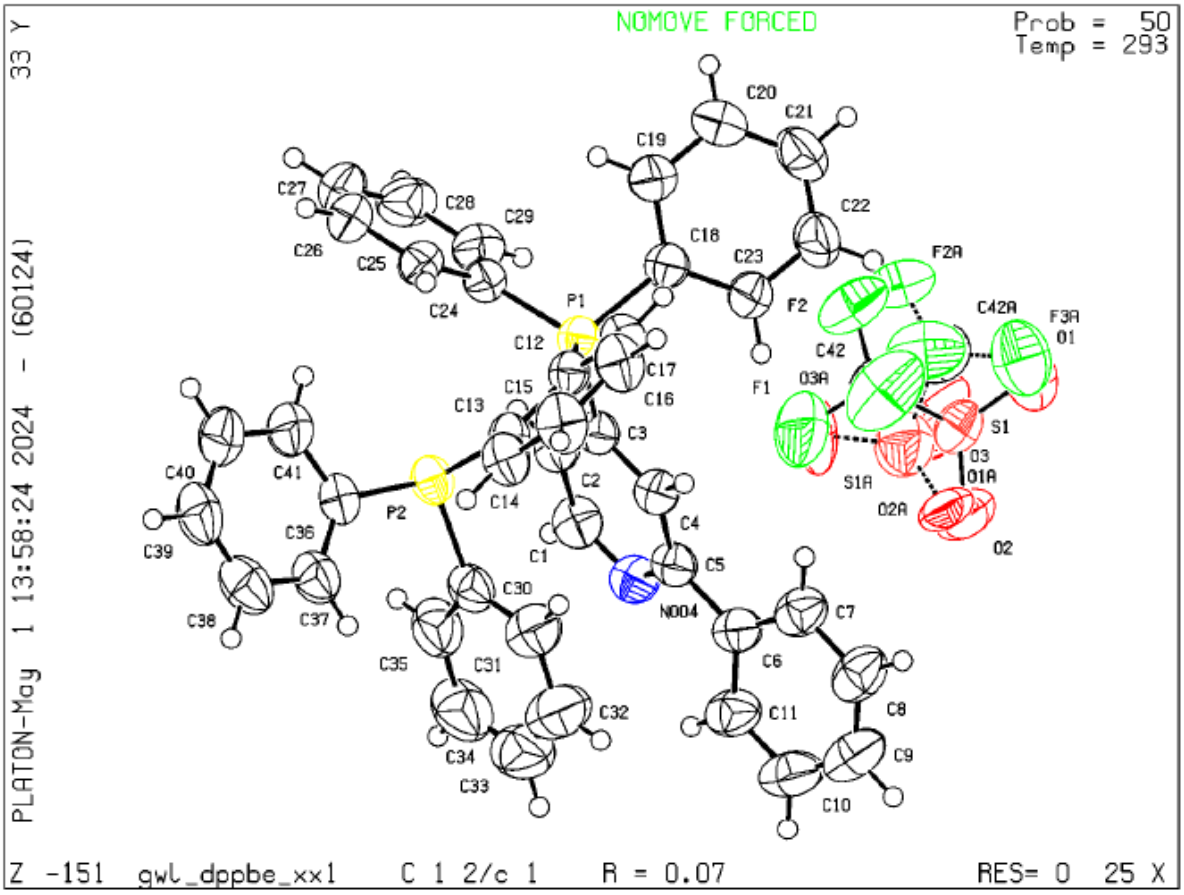



| | | | |
|---|---|---|---|
| C | 0.73288 | 0.86764 | -0.02257 |
| C | -3.01975 | -1.30472 | -0.50986 |
| C | -4.08559 | 0.60554 | 0.50273 |
| C | -4.22190 | -2.00276 | -0.45420 |
| C | -5.28426 | -0.09584 | 0.56312 |
| C | -5.35624 | -1.40230 | 0.08513 |
| C | 4.46018 | 0.30162 | 0.37843 |
| N | 2.04309 | 0.19063 | 0.04824 |
| N | 4.25142 | -1.14119 | 0.09275 |
| C | 3.23351 | 1.17402 | 0.07888 |
| C | 3.60201 | -1.26203 | -1.21385 |
| C | 3.32438 | -1.64052 | 1.11059 |
| C | 2.13835 | -0.66749 | 1.29025 |
| H | -2.15006 | -1.77779 | -0.95251 |
| H | -4.02785 | 1.62080 | 0.87683 |
| H | -4.27285 | -3.01477 | -0.83920 |
| H | -6.16292 | 0.37707 | 0.98682 |
| H | -6.29170 | -1.94811 | 0.13012 |
| H | 4.76467 | 0.34742 | 1.43046 |
| H | 5.30492 | 0.66633 | -0.21456 |
| H | 3.28727 | 1.49474 | -0.97080 |
| H | 3.58193 | -2.31026 | -1.51811 |
| H | 4.19079 | -0.70354 | -1.94290 |
| H | 2.96672 | -2.62636 | 0.80568 |
| H | 3.84438 | -1.74480 | 2.06410 |
| H | 1.20455 | -1.20562 | 1.43236 |
| H | 2.28953 | 0.02910 | 2.11428 |
| C | -0.62707 | 2.79892 | -0.26952 |
| N | -1.75530 | 2.09797 | -0.21564 |
| C | -1.66322 | 0.76828 | -0.07985 |
| C | -2.93955 | 0.00590 | -0.02914 |
| H | -0.73142 | 3.87264 | -0.38997 |
| C | -0.43399 | 0.11448 | 0.02426 |
| H | -0.41164 | -0.95874 | 0.15637 |
| C | 0.64510 | 2.24022 | -0.18506 |
| H | 1.52887 | 2.85729 | -0.22678 |
| C | 2.15805 | -0.72567 | -1.15943 |
| H | 1.90385 | -0.12902 | -2.03460 |
| H | 1.42920 | -1.53001 | -1.04461 |

## 5. CRYSTALLOGRAPHIC DATA FOR 4

Crystallographic data for compound **[4][OTf]** were recorded on a Bruker X8 Prospector diffractometer, at 293 K with Mo Kα radiation (mirror monochromator, λ = 0.71073). The CrysAlisPro[34] software package was used for data collection, cell refinement and data reduction. For all data sets the CrysAlisPro software package was used for empirical absorption corrections, which were applied using spherical harmonics, implemented in SCALE3 ABSPACK scaling algorithm. All further data processing was undertaking within the Olex2 software.[35] The structures were solved using the ShelXT[36] structure solution program using Intrinsic Phasing. All structures were refined with the SHELXL[37] refinement package using Least Squares minimisation against F2. Non-hydrogen atoms were refined anisotropically.

*Special details: The triflate anion (S1 C42 O1-3 F1-3) displayed slight positional disorder. This was modelled over two parts and the two components refined competitively, convering at a ratio of 0.857(3):0.143(3). All distances were restrained to be approximately equal and similarity restraints were applied to the anisotropic displacement parameters of the atoms within the disordered units.*



| | | |
|---|---|---|
| **CCDC code** | 2352491 | |
| **Empirical formula** | C42 H32 F3 N O3 P2 S | |
| **Formula weight** | 749.68 | |
| **Temperature** | 293(2) K | |
| **Wavelength** | 0.71073 Å | |
| **Crystal system** | Monoclinic | |
| **Space group** | C 2/c | |
| **Unit cell dimensions** | a = 25.4662(14) Å | a= 90°. |
| | b = 13.0867(5) Å | b= 114.318(7)°. |
| | c = 24.1761(14) Å | g = 90°. |
| **Volume** | 7342.3(7) $Å^3$ | |
| **Z** | 8 | |
| **Density (calculated)** | 1.358 $Mg/m^3$ | |
| **Absorption coefficient** | 0.232 $mm^{-1}$ | |
| **F(000)** | 3104 | |
| **Crystal size** | 0.450 x 0.220 x 0.080 $mm^3$ | |
| **Theta range for data collection** | 2.819 to 34.862°. | |
| **Index ranges** | -39<=h<=39, -20<=k<=20, -34<=l<=37 | |
| **Reflections collected** | 45399 | |
| **Independent reflections** | 14751 [R(int) = 0.0689] | |
| **Completeness to theta = 34.862°** | 92.2 % | |
| **Refinement method** | Full-matrix least-squares on $F^2$ | |
| **Data / restraints / parameters** | 14751 / 0 / 542 | |
| **Goodness-of-fit on $F^2$** | 1.018 | |
| **Final R indices [I>2sigma(I)]** | R1 = 0.0674, wR2 = 0.2072 | |
| **R indices (all data)** | R1 = 0.2228, wR2 = 0.2940 | |
| **Extinction coefficient** | n/a | |
| **Largest diff. peak and hole** | 1.392 and -0.708 $e.Å^{-3}$ | |

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