Cavitand supported Tetraphosphine: Cyclodextrin offers a useful platform for Suzuki-Miyaura cross-coupling

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General:

Solvents were freshly distilled from Na/benzophenone (THF, toluene), or P₂O₅ (CH₂Cl₂). Xylenes were freshly distilled over sodium, and degassed by freeze-pump-thaw method. Dichloromethane was freshly distilled on P₂O₅ and purged by bubbling argon for 2h. Reactions were carried under Ar. Optical rotations were measured on a Perkin Elmer 241 digital polarimeter with a path length of 1 dm. Fast Atom Bombardment Mass Spectra (FAB-MS) were obtained with a JMS-700 spectrometer. Elemental analyses were performed by the Centre Régional de Mesures Physiques de l’Ouest in Rennes, France. ¹H NMR spectra were recorded with a Bruker DRX 400 for solutions in CDCl₃ at ambient temperature. Assignments were aided by COSY experiments. ¹³C NMR spectra were recorded at 100.6 MHz with a Bruker DRX 400 spectrometer for solutions in CDCl₃ adopting 77.00 ppm for the central line of CDCl₃. Assignments were aided by J-mod technique and HMQC. The numbering of the atoms within a glucose unit is the usual one (see below). Reactions were monitored by thin-layer chromatography (TLC) on a precoated plate of silica gel 60 F₂₅₄ (layer thickness 0.2 mm; E. Merck, Darmstadt, Germany) and detection by charring with sulfuric acid. Flash column chromatography was performed on silica gel 60 (230-400 mesh, E. Merck). Diisobutylaluminium was purchased from Aldrich as a 1.5 M solution in toluene.

Nomenclature for protons and carbons position is precised below:
To a solution of cyclodextrin 2\(^1\) (4.1 g, 1.723 mmol, 1 eq.) in Ac\(_2\)O (50 mL) at \(-35{^\circ}\text{C}\) under argon, was added dropwise a solution of TMSOTf (1.33 mL, 6.89 mmol, 4 eq.) in CH\(_2\)Cl\(_2\) (5 mL). After 2 h stirring, saturated NaHCO\(_3\) (10 mL) at \(-10{^\circ}\text{C}\) was added, then water (10 mL). The aqueous layer was extracted with CH\(_2\)Cl\(_2\) (3×30 mL). The combined organic layers were dried over MgSO\(_4\), filtered and concentrated. Silica gel flash chromatography of the residue (cyclohexane/EtOAc: 2/1) afforded the cyclodextrin 3 (2.87 g, 76 %) as a white foam.

\([\alpha]_{D}^{20} +39.2 \text{ (c 1.0, CHCl}_3)\);

\(R_f 0.25\) (cyclohexane/AcOEt : 2/1);

\(^1\)H NMR (CDCl\(_3\), 400 MHz): \(\delta 7.28-7.19 \text{ (m, 30H, H arom.)}, 5.46 \text{ (d, 1H, }^3J_{1,2} 3.7 \text{ Hz, H-1)}, 5.39 \text{ (d, 1H, }^2J 10.5 \text{ Hz, CHPh)}, 5.24 \text{ (d, 1H, }^2J 10.8 \text{ Hz, CHPh}), 5.00 \text{ (d, 1H, }^2J 11.5 \text{ Hz, CHPh}), 4.95 \text{ (d, 1H, }^2J 10.5 \text{ Hz, CHPh}), 4.94 \text{ (d, 1H, }^2J 11.5 \text{ Hz, CHPh}), 4.88 \text{ (d, 1H, }^2J 10.8 \text{ Hz, CHPh}), 4.85 \text{ (d, 1H, }^3J_{1,2} 3.3 \text{ Hz, H-1)}, 4.72 \text{ (d, 1H, }^2J 12.3 \text{ Hz, CHPh}), 4.70 \text{ (d, 1H, }^3J_{1,2} 3.5 \text{ Hz, H-1)}, 4.63 \text{ (d, 1H, }^2J 12.6 \text{ Hz, CHPh}), 4.56-4.41 \text{ (m, 8H, 4xCHPh, 4xH-6)}, 4.36 \text{ (dd, 1H, }^3J_{2,3} 5.2, ^3J_{5,4} 11.9 \text{ Hz, H-3)}, 4.23 \text{ (dd, 1H, }^3J_{2,3} 8.3, ^3J_{5,4} 9.7 \text{ Hz, H-3)}, 4.17-4.05 \text{ (m, 4H, H-3, 3xH-5)}, 3.81 \text{ (dd, 1H, }^3J_{3,4} 9.9, ^3J_{4,5} 9.8 \text{ Hz, H-4)}, 3.68 \text{ (dd, 1H, }^3J_{3,4} 9.9, ^3J_{4,5} 9.8 \text{ Hz, H-4}), 3.57 \text{ (dd, 1H, }^3J_{1,2} 3.7, ^3J_{2,3} 9.9 \text{ Hz, H-2)}, 3.52-3.48 \text{ (m, 3H, 2xH-2, H-4)}, 2.10 \text{ (s, 3H, COCH}_3\)), 2.08 \text{ (s, 3H, COCH}_3\)), 1.37 \text{ (d, 3H, }^3J_{5,6} 6.2 \text{ Hz, CH}_3\) ;

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^1^C RMN (CDCl₃, 100 MHz): δ 171.03, 170.91 (2× COCH₃), 139.67, 139.62, 139.54, 138.86, 138.64, 138.51 (6× C arom. quat.), 128.79-127.05 (m, 30× C arom. tert.), 99.28, 98.86, 98.73 (3× C-1), 83.58, 82.08, 81.82 (3× C-4), 81.39, 81.20, 80.82 (3× C-3), 80.25, 79.41, 78.73 (3× C-2), 76.63, 76.52, 75.04, 73.75 (2C), 73.30 (6× CH₂Ph), 70.61, 70.08, 67.31 (3× C-5), 64.38, 64.34 (2× C-6), 21.40, 21.28 (2× COCH₃), 19.58 (CH₃);

FAB MS (M+Na)^+: m/z 2212.8;

To a solution of cyclodextrin 3 (1.3 g, 594 µmol, 1 eq.) in MeOH (50 mL) was added sodium (285 mg, 11.88 mmol, 20 eq.) in small fractions. After 3 h stirring, IR120 was added until a pH of 6, the resin was filtrated, and the solvent was evaporated to afford the cyclodextrin 4 (1.197 g, quant.) as a white foam.

\[ [\alpha]_D^{20} +46.5 \ (c \ 1.0, \ CHCl_3) \]

\[ R_f \ 0.40 \ (CH_2Cl_2/MeOH : 95/5) \]

1H NMR (CDCl3, 400 MHz) : δ 7.28-7.16 (m, 30H, H arom.), 5.40 (d, 1H, \(^2\)J 10.1 Hz, CHPh), 5.39 (d, 1H, \(^3\)J\(_{1,2}\) 3.9 Hz, H-1), 5.16 (d, 1H, \(^2\)J 10.8 Hz, CHPh), 4.99 (d, 1H, \(^2\)J 11.5 Hz, CHPh), 4.94-4.91 (m, 3H, H-1, 2×CHPh), 4.85 (d, 1H, \(^2\)J 10.9 Hz, CHPh), 4.84 (d, 1H, \(^3\)J\(_{1,2}\) 3.1 Hz, H-1), 4.75 (d, 1H, \(^2\)J 12.1 Hz, CHPh), 4.66 (d, 1H, \(^2\)J 12.4 Hz, CHPh), 4.55 (d, 1H, \(^2\)J 12.5 Hz, CHPh), 4.52 (d, 1H, \(^2\)J 12.0 Hz, CHPh), 4.52 (d, 1H, \(^2\)J 13.3 Hz, CHPh), 4.45 (d, 1H, \(^2\)J 12.3 Hz, CHPh), 4.19-4.10 (m, 4H, 3×H-3, H-6), 4.05-3.94 (m, 5H, 3×H-5, 2×H-6), 3.81-3.74 (m, 2H, H-4, H-6), 3.64 (dd, 1H, \(^3\)J\(_{3,4}\) 9.3, \(^3\)J\(_{4,5}\) 8.4 Hz, H-4), 3.55 (dd, 1H, \(^3\)J\(_{1,2}\) 3.7, \(^3\)J\(_{2,3}\) 9.9 Hz, H-2), 3.51 (dd, 1H, \(^3\)J\(_{1,2}\) 3.2, \(^3\)J\(_{2,3}\) 9.7 Hz, H-2), 3.50 (dd, 1H, \(^3\)J\(_{1,2}\) 2.8, \(^3\)J\(_{2,3}\) 9.9 Hz, H-2), 3.45 (dd, 1H, \(^3\)J\(_{3,4}\) 8.8, \(^3\)J\(_{4,5}\) 8.1 Hz, H-4), 3.03 (bs, 2H, 2×OH), 1.40 (d, 3H, \(^3\)J\(_{5,6}\) 5.9 Hz, CH₃);

13C RMN (CDCl3, 100 MHz) : δ 139.77, 139.72, 139.64, 138.95, 138.76, 138.68 (6×C arom.quat.), 128.81-127.17 (m, 30×C arom. tert.), 98.64, 98.10, 97.86 (3×C-1), 87.64 (C-2), 81.67 (C-3), 81.46 (C-4), 81.12 (2×C-3), 79.95 (C-2), 79.80 (C-4), 78.88 (C-2), 76.34 (C-4), 76.24, 76.21, 74.98, 73.58,
73.55 (5×CH$_2$Ph), 73.41 (C-5), 73.20 (CH$_3$Ph), 72.18, 68.10 (2×C-5), 63.34, 62.73 (2×C-6), 19.54 (CH$_3$);

FAB MS (M+Na)$^+$: m/z 2044.7;

Anal. Calcd for C$_{120}$H$_{132}$O$_{28}$: C, 71.27; H, 6.58. Found: C, 70.91; H, 6.62.
To a solution of cyclodextrin 4 (1.197 g, 593 µmol, 1 eq.) in CH₂Cl₂ (10 mL) were added Et₃N (660 µL, 4.74 mmol, 8 eq.) and MsCl (370 µL, 4.74 mmol, 8 eq.) at 0°C. The reaction mixture was stirred at r.t. for 1 h under argon, then water (5 mL) was added, the phases were separated and the aqueous layer was extracted with CH₂Cl₂ (3×10 mL). The combined organic layers were dried over MgSO₄, filtered and concentrated. Silica gel flash chromatography of the residue (CH₂Cl₂/MeOH : 95/5) afforded the mesylated cyclodextrin 5 (1.317 g, 95 %) as a white foam.

[α]D²⁰ +38.5 (c 1.0, CHCl₃) ;

Rf 0.80 (CH₂Cl₂/MeOH : 95/5);

¹H NMR (CDCl₃, 400 MHz) : δ 7.28-7.19 (m, 30H, H arom.), 5.24 (d, 1H, 2J 10.9 Hz, CHPH), 5.13 (d, 2H, 2J 11.1 Hz, 2xCHPh), 5.08 (d, 1H, 3J₁₂ 3.5 Hz, H-1), 4.93 (d, 1H, 3J₁₂ 3.5 Hz, H-1), 4.90 (d, 1H, 2J 12.5 Hz, CHPH), 4.87 (d, 1H, 2J 11.0 Hz, CHPH), 4.87 (d, 1H, 2J 11.5 Hz, CHPH), 4.83 (d, 1H, 3J₁₂ 3.6 Hz, H-1), 4.73 (dd, 1H, 3J₅₆ 3.8, 2J 11.2 Hz, H-6), 4.69 (d, 2H, 2J 9.5 Hz, 2xCHPh), 4.57 (d, 1H, 2J 12.4 Hz, CHPH), 4.51 (dd, 1H, 3J₅₆ 4.8, 2J 12.5 Hz, H-6), 4.50 (d, 1H, 2J 12.5 Hz, CHPH), 4.48 (d, 1H, 2J 10.6 Hz, CHPH), 4.45 (d, 1H, 2J 12.3 Hz, CHPH), 4.44 (dd, 1H, 3J₅₆ 5.9, 2J 12.6 Hz, H-6), 4.38 (dd, 1H, 3J₅₆ 5.5, 2J 10.9 Hz, H-6), 4.16-4.08 (m, 5H, 3xH-3, 2xH-5), 3.96 (dq, 1H, 3J₄₅ 9.1, 3J₅₆ 6.2 Hz, H-5), 3.77 (dd, 1H, 3J₃₄ 8.5, 3J₄₅ 9.5 Hz, H-4), 3.62 (dd, 1H, 3J₃₄ 8.4, 3J₄₅ 9.5 Hz, H-4), 3.51-3.45 (m, 3H, 3xH-2), 3.39 (dd, 1H, 3J₃₄ 8.8, 3J₄₅ 8.7 Hz, H-4), 3.02 (s, 3H, S-CH₃), 3.01 (s, 3H, S-CH₃), 1.39 (d, 3H, 3J₅₆ 6.2 Hz, CH₃) ;
$^{13}$C RMN (CDCl$_3$, 100 MHz) : $\delta$ 139.61, 139.56, 139.53, 138.56, 138.50, 138.32 (6×C arom. quat.), 128.76-127.47 (m, 30×C arom. tert.), 100.01, 99.43, 99.26 (3×C-1), 86.29, 81.49, 81.06 (3×C-4), 80.84, 80.76, 80.41 (3×C-3), 79.25, 79.11, 78.99 (3×C-2), 76.39, 75.98, 75.70, 73.62, 73.33 (2C) (6×CH$_2$Ph), 70.62 (C-5), 70.15 (C-6), 70.07 (C-5), 69.84 (C-6), 68.10 (C-5), 37.66 (2×S-CH$_3$), 19.43 (CH$_3$) ;

FAB MS (M+Na)$^+$: m/z 2356.3 ;

Anal. Calcd for C$_{124}$H$_{140}$O$_{36}$S$_4$: C, 63.79 ; H, 6.04. Found: C, 63.72 ; H, 6.13.
P, P', P'', P'''-{6^A, 6^B-dideoxy-6^C, 6^D-dideoxy-6^E, 6^F-Tetra-(diphenylphosphinyl)-2^A^-F, 3^A^-F-Dodeca-O-
Benzyl-α-cyclodextrin} Tetraborane (6)

^"BuLi (410 μL of a 2.5 M solution in hexane, 1.029 mmol, 8 eq.) was added dropwise at -78°C to a
stirred solution of diphenylphosphane (180 μL, 1.029 mmol, 8 eq.) in THF (2 mL). After 30 min., the
mesylated cyclodextrin 5 (300 mg, 129 μmol, 1 eq.) in THF (6 mL) was added dropwise. The solution
was then allowed to reach room temperature. After 3 h, a BH_3-THF solution (1.0 M in THF, 2.58 mL,
2.58 mmol, 20 eq.) was added and the mixture was stirred for 12 h. MeOH (5 mL) was added
dropwise, and the solvents were evaporated. Silica gel flash chromatography of the residue
(cyclohexane/EtOAc: 8/1) afforded the cyclodextrin 6 (218 mg, 61 %) as a white foam.

[α]_D^{20} +87.0 (c 1.0, CHCl_3);

R_f 0.50 (cyclohexane/AcOEt : 2/1);

^1^H NMR (CDCl_3, 400 MHz): δ 7.92 (dd, 2H, 3^J_H,P 8.8, 3^J_H,H 9.0 Hz, 2×H_ortho), 7.61 (dd, 2H, 3^J_H,P 7.2, 3^J_H,H 10.7 Hz, 2×H_ortho), 7.45-6.93 (m, 36H, 4×H_meta, 2×H_para, 30×H arom. Bn), 5.39 (d, 1H, 3^J_1,2 3.3 Hz, H-1), 5.38 (d, 1H, 2^J 12.1 Hz, CHPh), 5.22 (d, 1H, 2^J 10.7 Hz, CHPh), 4.96 (d, 1H, 2^J 11.0 Hz, CHPh), 4.86 (d, 1H, 2^J 10.7 Hz, CHPh), 4.81 (d, 1H, 2^J 11.6 Hz, CHPh), 4.64 (d, 1H, 2^J 11.6 Hz, CHPh), 4.58 (dd, 1H, 3^J_3,4 9.0, 3^J_4,5 9.0 Hz, H-4), 4.54 (d, 1H, 3^J_1,2 2.0 Hz, H-1), 4.53-4.47 (m, 3H, H-3, H-4, H-5, CHPh), 4.44 (d, 1H, 2^J 13.6 Hz, CHPh), 4.38 (d, 1H, 2^J 12.7 Hz, CHPh), 4.31 (s, 2H, CH_2Ph), 4.28 (d, 1H, 2^J 13.6 Hz, CHPh), 4.25-4.20 (m, 2H, H-1, H-5), 4.14 (dd, 1H, 3^J_2,3 8.5, 3^J_3,4 9.8 Hz, H-3), 4.06 (dd, 1H, 3^J_2,3 9.0, 3^J_3,4 9.6 Hz, H-3), 4.02-3.97 (m, 1H, H-5), 3.92 (dd, 1H, 3^J_2,3 8.6, 3^J_3,4 9.4 Hz, H-3), 3.73-3.67 (m, 1H, H-6), 3.50 (dd, 1H, 3^J_1,2 2.8, 3^J_2,3 8.7 Hz, H-2), 3.44 (dd, 1H, 3^J_5,6 6.8, 2^J 14.9 Hz, H-6), 3.35 (dd, 1H, 3^J_1,2 3.3, 3^J_2,3 9.8 Hz, H-2), 3.29 (dd, 1H, 3^J_1,2 3.3, 3^J_2,3 10.1 Hz, H-2),

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3.10-3.00 (m, 1H, H-6), 2.95 (dd, 1H, $^3J_{3,4}$ 8.8, $^3J_{4,5}$ 9.0 Hz, H-4), 2.65-2.57 (m, 1H, H-6), 0.90-1.35 (m, 6H, 2xBH$_3$), 0.59 (d, 3H, $^3J_{5,6}$ 5.9 Hz, CH$_3$) ;

$^{13}$C RMN (CDCl$_3$, 100 MHz) : $\delta$ 140.01, 139.83, 139.77, 138.74, 138.50, 138.47 (6×C arom. quat. Bn), 132.98 (d, $^2J_{C,P}$ 9.5 Hz, 2×C$_{ortho}$), 132.58 (d, $^2J_{C,P}$ 9.5 Hz, 2×C$_{ortho}$), 132.40 (d, $^2J_{C,P}$ 8.6 Hz, 2×C$_{ortho}$), 132.38 (d, $^1J_{C,P}$ 59.1 Hz, 2×C$_{ipso}$), 131.83 (d, $^2J_{C,P}$ 8.6 Hz, 2×C$_{ortho}$), 131.10, 130.81, 130.66, 130.25 (4×C$_{para}$), 129.66 (d, $^1J_{C,P}$ 65.1 Hz, 2×C$_{ipso}$), 128.75-126.38 (m, 8×C$_{meta}$, 30×C arom. tert.), 100.63, 99.01, 98.92 (3×C-1), 88.52, 85.17, 83.51 (3×C-4), 80.19, 80.09, 80.03 (3×C-3), 79.93, 78.13, 77.62 (3×C-2), 76.19, 75.71, 74.32, 73.09, 72.97, 71.62 (6×CH$_2$Ph), 70.75, 69.23, 67.82 (3×C-5), 30.12 (d, $^2J_{C,P}$ 48.3 Hz, C-6), 27.14 (d, $^2J_{C,P}$ 31.0 Hz, C-6), 18.09 (CH$_3$) ;

$^{31}$P RMN (CDCl$_3$, 100 MHz) : $\delta$ 15.17, 13.35;

$^{11}$B NMR (CDCl$_3$, 125 MHz) : $\delta$ -37;

HRMS (ESI): calcd for C$_{168}$H$_{180}$B$_4$KO$_{24}$P$_4$: 2788.1888, Found: 2788.1823 (+ 2.3 ppm) ;

Anal. Calcd for C$_{168}$H$_{180}$O$_{24}$B$_4$P$_4$: C, 73.37 ; H, 6.60. Found: C, 73.01 ; H, 6.59.
$6^A, 6^B$-dideoxy-$6^C, 6^D, 6^E, 6^F$-Tetra-(diphenylphosphinyl)-2$^A$-$F, 3^A$-$F$-Dodeca-O-Benzyl-α-cyclodextrin (α-Cytep)

Tetraphosphine borane 6 (30 mg, 11 µmol) was refluxed in Et$_2$NH (3 mL) during 12 h, then cooled down to r.t., filtrated over a celite pad and Et$_2$NH was evaporated to afford tetraphosphine-CD α-Cytep( 29 mg, quant.) as a white foam.

$^1$H NMR (CDCl$_3$, 400 MHz) : δ 7.41-6.97 (m, 50H, H arom.), 5.72 (d, 1H, $^3$J$_{1,2}$ 3.7 Hz, H-1), 5.38 (d, 1H, $^2$J 10.2 Hz, CHPh), 5.13 (d, 1H, $^2$J 10.7 Hz, CHPh), 4.86 (d, 1H, $^2$J 10.0 Hz, CHPh), 4.85 (d, 1H, $^2$J 12.8 Hz, CHPh), 4.78 (d, 2H, $^2$J 11.9 Hz, CHPh), 4.76 (d, 1H, $^3$J$_{1,2}$ 4.0 Hz, H-1), 4.72 (d, 1H, $^2$J 12.7 Hz, CHPh), 4.69 (d, 1H, $^2$J 10.8 Hz, CHPh), 4.48 (d, 1H, $^2$J 11.8 Hz, CHPh), 4.47-4.41 (m, 2H, 2×H-5), 4.38 (d, 1H, $^2$J 12.5 Hz, CHPh), 4.36 (d, 1H, $^3$J$_{1,2}$ 3.0 Hz, H-1), 4.28 (d, 1H, $^2$J 12.5 Hz, CHPh), 4.24 (d, 1H, $^2$J 12.2 Hz, CHPh), 4.22-4.16 (m, 2H, H-3, H-5), 4.15 (d, 1H, $^2$J 12.1 Hz, CHPh), 4.06 (dd, 1H, $^3$J$_{2,3}$ 9.3, $^3$J$_{3,4}$ 9.1 Hz, H-3), 4.01 (dd, 1H, $^3$J$_{2,3}$ 9.8, $^3$J$_{3,4}$ 8.3 Hz, H-3), 3.90 (ddd, 1H, $^3$J$_{3,4}$ 8.5, $^3$J$_{4,5}$ 8.0, $^3$J$_{5,6}$ 2.6 Hz, H-4), 3.88 (ddd, 1H, $^3$J$_{3,4}$ 8.9, $^3$J$_{4,5}$ 8.5, $^3$J$_{5,6}$ 2.4 Hz, H-4), 3.69 (dd, 1H, $^3$J$_{1,2}$ 3.7, $^3$J$_{2,3}$ 10.1 Hz, H-2), 3.48 (dd, 1H, $^3$J$_{3,4}$ 9.0, $^3$J$_{4,5}$ 9.2 Hz, H-4), 3.41 (dd, 1H, $^3$J$_{1,2}$ 3.0, $^3$J$_{2,3}$ 9.7 Hz, H-2), 3.28 (dd, 1H, $^3$J$_{1,2}$ 3.0, $^3$J$_{2,3}$ 9.9 Hz, H-2), 2.95-2.90 (m, 1H, H-6), 2.82-2.75 (m, 2H, 2×H-6), 2.46 (ddd, 1H, $^3$J$_{5,6}$ 3.2, $^2$J$_{5,6}$ 3.7, $^2$J$_{5,6}$ 15.0 Hz, H-6), 1.45 (d, 3H, $^3$J$_{5,6}$ 6.2 Hz, CH$_3$) ;

$^{13}$C RMN (CDCl$_3$, 100 MHz) : δ 140.58 (d, $^1$J$_{C,P}$ 52.3 Hz, C$_{ipso}$), 140.46 (d, $^1$J$_{C,P}$ 52.3 Hz, C$_{ipso}$), 139.45 (d, $^1$J$_{C,P}$ 55.2 Hz, C$_{ipso}$), 139.39 (C arom. quat. Bn), 139.33 (d, $^1$J$_{C,P}$ 54.9 Hz, C$_{ipso}$), 139.32, 139.27, 138.52 (2C), 138.16 (5×C arom. quat. Bn), 134.77 (C$_{para}$), 134.56 (C$_{para}$), 132.88 (d, $^2$J$_{C,P}$ 19.6 Hz, 2×C$_{ortho}$), 132.85 (d, $^2$J$_{C,P}$ 18.6 Hz, 2×C$_{ortho}$), 132.25 (d, $^2$J$_{C,P}$ 17.9 Hz, 4×C$_{ortho}$), 129.04-126.48 (m, 8×C$_{meta}$, 30×C arom. tert. Bn), 97.87, 97.48, 96.13 (3×C-1), 86.76 (d, $^3$J$_{C,P}$ 10.8 Hz, C-4), 85.53 (d, $^3$J$_{C,P}$ 12.3 Hz, C-4), 81.64, 80.66, 80.43 (3×C-3), 79.92 (2C), 78.93 (3×C-2), 78.20 (C-4), 76.45,
76.39, 73.81, 73.54, 72.38 (5×CH₂Ph), 72.26 (d, $^2J_{CP}$ 12.8 Hz, C-5), 72.13 (CH₂Ph), 70.58 (d, $^2J_{CP}$ 10.9 Hz, C-5), 66.70 (C-5), 33.92 (d, $^1J_{CP}$ 13.0 Hz, C-6), 32.05 (d, $^1J_{CP}$ 15.9 Hz, C-6), 20.40 (CH₃);

$^{31}$P RMN (CDCl₃, 100 MHz) : δ -20.87, -21.17;

HRMS (ESI): calcd for C₁₆₈H₁₆₉O₂₄NaP₄: 1359.04373, Found: 1359.04360 (- 0.2 ppm); calcd for C₁₆₈H₁₇₀O₂₄P₄: 1348.05275, Found: 1348.05334 (+ 0.5 ppm).
General procedure for Suzuki couplings

Preparation of the diluted \([\text{Pd}(\eta^3-C_3H_5)\text{Cl}]_2\) solution for C/S: 10^{-12}

In a flame-dried Schlenk tube reactor equipped with a magnetic stirrer, was introduced \([\text{Pd}(\eta^3-C_3H_5)\text{Cl}]_2\) (3.0 mg, 8.20 µmol), which was purged under argon. The catalyst was dissolved in degassed dichloromethane (20.0 mL). The required amount of the catalyst solution (19.5 mL) was taken off via a syringe. To the remaining catalyst solution (0.5 mL) in the schlenk was again added degassed dichloromethane (19.5 mL) and the intended quantity of the diluted catalyst solution (19.5 mL) was once again taken off via a syringe. This operation was reiterated 4 times. To the last remaining catalyst solution (0.5 mL) in the schlenk was added degassed dichloromethane (1.5 mL) and the intended quantity of the diluted catalyst solution (1.5 mL) was once again taken off via a syringe to reach the expected dilution (0.5×10^{-12} mmol).

Preparation of the diluted Cytep solution for C/S: 10^{-12}

In a flame-dried Schlenk tube reactor equipped with a magnetic stirrer containing the deprotected \(\alpha\)-Cytep (1.0 mg, 0.372 µmol) was introduced degassed dichloromethane (20 mL) (solution A). To a 100 µL of diluted solution A in a schlenk was added dichloromethane (19.9 mL) (solution B). This operation was reiterated 2 times (solution C and D) to obtain the desired concentration (0.430 mL of solution D for 1×10^{-12} mmol).

Coupling reaction

The appropriate solutions of \([\text{Pd}(C_3H_5)\text{Cl}]_2\) and of tetraphosphine \(\alpha\)-Cytep were respectively prepared as previously described in degassed dichloromethane.

To the diluted solution of \([\text{Pd}(C_3H_5)\text{Cl}]_2\) in degassed dichloromethane was added via a purged syringe the diluted solution of tetraphosphine \(\alpha\)-Cytep under argon atmosphere. This solution was stirred at room temperature for 15 min under argon atmosphere. To this catalyst solution were both introduced the aryl halide (1 mmol, 1 eq.), the arylboronic acid (2 mmol, 2 eq.) and potassium carbonate (2 mmol, 2 eq.). After stirring for 5 minutes at room temperature, degassed anhydrous xylene (4 mL) was added under argon and the reaction mixture was then warmed at 120°C. After complete evaporation of dichloromethane under a stream of argon, the reaction mixture was stirred at 120°C under argon. After the indicated time, the reaction was cooled to room temperature and was quenched by water (5 mL). The aqueous layer was extracted three times with dichloromethane. The combined organic layer was dried over magnesium sulfate and filtered on a pad of silica gel. Then, the solvent
was removed in vacuo to give a solid residue. The conversions were determined by integration of the different signals relative to the substrate and the products protons. The NMR yields were determined by using an external standard (butadienesulfone, 0.5 mmol, 0.5 eq.).