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Article

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Radical nitration-debromination of α-bromo-α-fluoroalkenes as a stereoselective route to aromatic α-fluoronitroalkenes – functionalized fluorinated building blocks for organic synthesis

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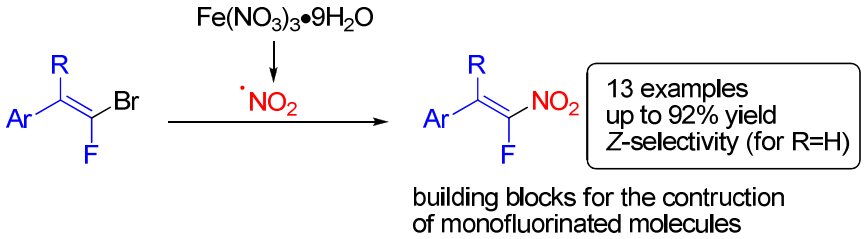
Graphical abstract



Abstract

A new highly efficient method for the synthesis of 2-fluoro-2-nitrostyrenes was described. Radical nitration of readily available 2-bromo-2-fluorostyrenes with $Fe(NO_3)_3 \cdot 9H_2O$ resulted in the formation of the corresponding α-fluoro-nitroalkenes in isolated yields up to 92%. The reaction proceeded as a nitration-debromination sequence to highly stereoselectively give α-fluoro-nitroalkenes as *Z*-isomers only. The broad scope of this method was demonstrated. Prepared monofluorinated alkenes were shown to be versatile building blocks for the synthesis of various fluorinated products.

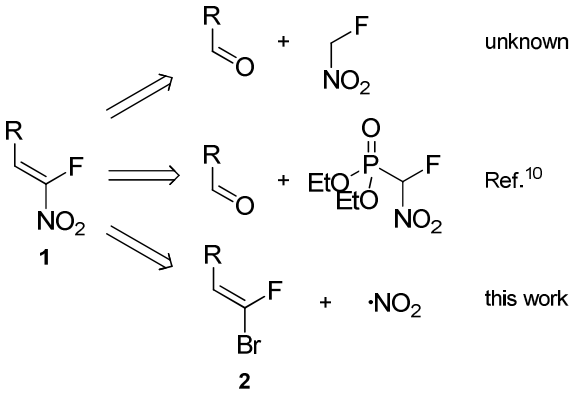
Introduction

Nitroalkenes are well-known versatile building blocks for organic synthesis.[1] These systems contain a highly-polarized alkene activated by a strongly electron-withdrawing nitro group. As a result, a broad spectrum of valuable synthetic transformations has been demonstrated.[2] Thus, nitroalkenes are superb Michael acceptors and a wide variety of nucleophiles can be added to nitroalkenes to generate new C-C or C-heteroatom bonds. A widely used approach to prepare substituted amines is based on a Michael addition and/or subsequent reduction.[1b,f] Stereoselective Michael additions with nitroalkenes provide access to the synthesis of natural compounds, drugs and bioactive molecules. Nitroalkenes can be used as dienophiles and dipolarophiles to participate in various cycloadditions.[3] However, probably the most important application of nitroalkenes is the construction of various heterocycles. For example, pyrroles, pyrazoles, isoxazolines, 1,2-oxazines, and many other derivatives can be prepared using nitroalkenes as key starting materials.[4] It should be noted that this constructive approach allows substituents to be properly installed in desired positions of the heterocyclic core. α-Halosubstituted nitroalkenes are especially interesting activated alkenes. Due to the presence of additional halogen at the double bond, these alkenes can participate in various domino

transformations.[5,6] However, while α-chloro and α-bromo nitroalkenes are well-known compounds, α-fluoro-nitroalkenes **1** remain almost uninvestigated. Considering the importance of fluorine-containing molecules as pharmaceuticals and agrochemicals, the synthesis of novel fluorine-substituted building blocks is a very important task.[7] α-Fluoronitroalkenes **1** could be used as valuable building blocks to prepare a variety of monofluorinated compounds. However, despite the structural simplicity of α-fluoronitroalkenes **1**, their synthesis can not be considered as a trivial task. The classical and most straightforward method to prepare nitroalkenes is the Henry reaction with aliphatic nitroalkanes.[8] However, until now, the Henry reaction between aldehydes and fluoronitromethane (Scheme 1) has not been reported. Apparently, this is due to the low stability of fluoronitromethane in basic media.[9] To our knowledge, only one general method for synthesizing nitroalkenes **1** has been published: the Horner-Wadsworth-Emmons olefination of carbonyl compounds (Scheme 1) with diethyl fluoronitromethyl phosphonate has been recently described by Beier.[10] This new reagent for olefination was prepared by the monofluorination of diethyl nitromethylphosphonate with Selectfluor. Despite its good substrate scope, the method has low diastereoselectivity and thus gives the target nitroalkenes as *E*,*Z*-isomeric mixtures (generally in a 3:1 *Z*:*E*-ratio). Moreover, diethyl nitromethylphosphonate is not commercially available and possesses low stability in the presence of bases.

Therefore, new methods for the synthesis of α-fluoro-nitroalkenes are required, and novel stereoselective protocols for the preparation of these alkenes are especially attractive. Recently, some highly efficient procedures for radical nitration appeared in the literature.[11] We envisioned preparing nitroalkenes **1** from the corresponding 2-bromo-2-fluoroalkenes **2** *via* a radical nitration-debromination sequence (see below discussion of the reaction mechanism). Herein, we report a new general and highly stereoselective synthesis of 2-fluoro-2-nitrostyrenes **1**. Additionally, the broad synthetic scope of these building blocks was demonstrated by preparing a variety of monofluorinated molecules.

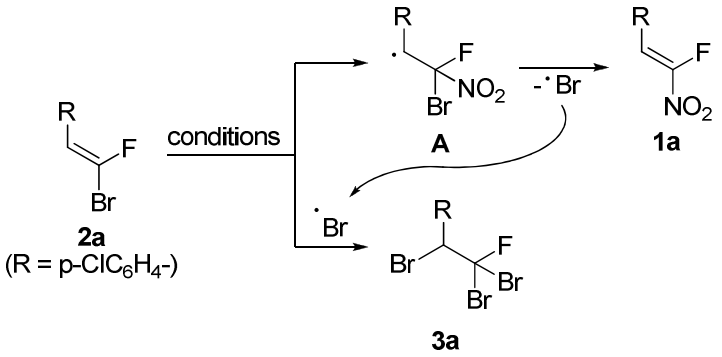
Scheme 1. Approaches to α-fluoronitroalkenes **1**



Results and discussion

Starting alkenes **2** are readily available compounds that can be prepared from the corresponding carbonyl compounds and CBr_3F using either the Corey-Fuchs reaction or copper chloride-mediated catalytic olefination of hydrazones.[12] Styrene **2a** was chosen as the model substrate to search for the optimal reaction conditions for radical nitration. Several types of reaction conditions were used, focusing on the method of generating of NO_2 radicals (Table 1). To our delight, the reaction proceeded as a nitration-debromination sequence. As a rule, the reaction of styrene **2a** with all the studied nitration systems led to the formation of the target nitroalkene **1a**, thus confirming the possibility of our proposed process. Target nitroalkene **1a** can be prepared in moderate yields (up to 43%) using N_2O_4 (Entries 1,2) itself as a source of NO_2 radicals. Generation of NO_2 radicals *via* the oxidation of sodium nitrite with some oxidants resulted in the formation of **1a** in up to 47% yields (Entries 3-10). Thermal decomposition of transition metal nitrates was more efficient for the nitration of **2a**. Various metal nitrates including $Cu(NO_3)_2{\cdot}3H_2O$, $Co(NO_3)_2{\cdot}6H_2O$, $AgNO_3$, $Cr(NO_3)_3{\cdot}9H_2O$, $(NH_4)_2Ce(NO_3)_6$, $Fe(NO_3)_3{\cdot}9H_2O$ gave target nitroalkene **1a** in 28-53% yields (Entries 12-22).

Table 1. Optimization of reaction conditions



Entry	Reagent	Conditions	Yield **1a**, %[a]
1	N_2O_4 (3 equiv.)	MeCN, r.t., 10 h	27
2	N_2O_4 (3 equiv.)	MeCN, 70 °C, 4 h	43
3	$NaNO_2$ (3 equiv.), $FeCl_3$ (1 equiv.)	MeCN, 70 °C, 4 h	47
4	$NaNO_2$ (3 equiv.), $FeCl_3$ (1 equiv.)	MeCN/H_2O (5:1), 70 °C, 6 h	32
5	$NaNO_2$ (3 equiv.), $PhI(OAc)_2$ (1 equiv.)	MeCN, 70 °C, 16 h	41
6	$NaNO_2$ (3 equiv.), $K_2S_2O_8$ (0.5 equiv.)	MeCN, 70 °C, 16 h	14 (60)[b]
7	$NaNO_2$ (3 equiv.), $K_2S_2O_8$ (0.5 equiv.)	DMSO, 80 °C, 4 h	5 (69)[b]
8	$NaNO_2$ (3 equiv.), $(NH_4)_2Ce(NO_3)_6$ (1 equiv.)	MeCN, 70 °C, 6 h	44
9	$NaNO_2$ (3 equiv.), $(NH_4)_2Ce(NO_3)_6$ (1 equiv.)	MeCN/H_2O (5:1), 70 °C, 8 h	18
10	$Bu_4N^+NO_2^-$ (1 equiv.), $FeCl_3$ (1 equiv.)	MeCN, 70 °C, 4 h	27
11	$AgNO_3$ (1 equiv.)	MeCN, r.t., 8 h	n.r.[c]
12	$AgNO_3$ (1 equiv.)	EtOAc, 70 °C, 2 h	27
13	$AgNO_3$ (1 equiv.)	MeCN, 70 °C, 2 h	53
14	$AgNO_3$ (1.1 equiv.), TEMPO (0.2 eq.)	MeCN, 4Å MS, 80 °C, 1.5 h	n.r.
15	$Cu(NO_3)_2{\cdot}3H_2O$ (1 equiv.)	MeCN, 70 °C, 5 h	48
16	$Cu(NO_3)_2{\cdot}3H_2O$ (1 equiv.)	DMSO, 100 °C, 7 h	28

17	$Cu(NO_3)_2 \cdot 3H_2O$ (2 equiv.)	$ClCH_2CH_2Cl$, 80 °C, 8 h	42
18	$Cr(NO_3)_3 \cdot 9H_2O$ (1 equiv.)	MeCN, 70 °C, 8 h	29
19	$(NH_4)_2Ce(NO_3)_6$ (1 equiv.)	MeCN, 70 °C, 5 h	46
20	$Co(NO_3)_2 \cdot 6H_2O$ (1 equiv.)	$ClCH_2CH_2Cl$, 80 °C, 18h	38
21	$Fe(NO_3)_3 \cdot 9H_2O$ (1 equiv.)	MeCN, 70 °C, 7 h	34
22	$Fe(NO_3)_3 \cdot 9H_2O$ (2 equiv.)	$ClCH_2CH_2Cl$, 80 °C, 5 h	41
23	$Cu(NO_3)_2 \cdot 3H_2O$ (2 equiv.), TEMPO (0.2 eq.)	$ClCH_2CH_2Cl$, 4Å MS, 80 °C, 1.5 h	55
24	**$Fe(NO_3)_3 \cdot 9 H_2O$ (2 equiv.), TEMPO (0.2 eq.)**	**$ClCH_2CH_2Cl$,** 4Å MS**, 80 °C, 1.5 h**	**68**
25	$Fe(NO_3)_3 \cdot 9 H_2O$, (2 equiv.) TEMPO (0.2 eq.)	$ClCH_2CH_2Cl$, 80°C, 3 h	50
26	$Fe(NO_3)_3 \cdot 9 H_2O$ (2 equiv.), TEMPO (0.1 eq.)	$ClCH_2CH_2Cl$, 4Å MS, 80 °C, 1.5 h	51
27	$Fe(NO_3)_3 \cdot 9H_2O$ (2 equiv.)	acetone, 70 °C, 10 h	50(20)[b]
28	$Fe(NO_3)_3 \cdot 9H_2O$ (2 equiv.)	1,4-dioxane, 80 °C, 10 h	54
29	$Fe(NO_3)_3 \cdot 9H_2O$ (2 equiv.)	1,4-dioxane[d], 100 °C, 0.5 h	70
30	$Fe(NO_3)_3 \cdot 9H_2O$ (2 equiv.)	1,4-dioxane[e], 100 °C, 0.5 h	81
31	$Fe(NO_3)_3 \cdot 9H_2O$ (8 equiv.)	1,4-dioxane[e], 100 °C, 0.5 h	93
32	**$Fe(NO_3)_3 \cdot 9H_2O$ (3 equiv.)**	**1,4-dioxane[e], 100 °C, 0.5 h**	**87**

[a] Determined by ^{19}F NMR with $PhCF_3$ as internal standard.

[b] Recovery of **2a** is indicated in parentheses

[c] no reaction

[d] 0.3 M solution of **2a**

[e] 0.08 M solution of **2a**

The most promising results were obtained using inexpensive ferric nitrate nonahydrate ($Fe(NO_3)_3 \cdot 9H_2O$). This reagent provided the target product in reasonable yields up to 54%. At this point, attention was paid to the addition of TEMPO (Entries 23-26). Its use in the nitration of

styrenes was recently demonstrated by Maiti[11a] followed by its successful application by his[11b,c] and other research groups.[11d,e] Indeed, improvement of the yield to 68% was achieved using 0.2 equiv. of TEMPO as an additive to the ferric nitrate (Method A, Entry 24). There are two possible explanations for the positive influence of TEMPO on the yield of **1a**. The first reason is that TEMPO inhibited the radical polymerization of either starting styrene **2** or product **1** by trapping any intermediate radicals of type **A**. In the second case, TEMPO may facilitate the release of NO_2 radicals from the metal nitrate through coordination of TEMPO with the metal atom.[13] The decrease in the reaction time when TEMPO is added (Table 1, Entries 22, 24) supports the latter proposal.

Method A was the first one used to investigate the reaction scope. However, in some cases (e.g., **1a-1d**) moderate yields were observed (see below, Table 2). Thus, additional optimization of the reaction conditions was performed. According to the reaction scheme, the elimination of a Br radical is expected (Table 1). Therefore, bromination of the starting alkene in a side reaction is one possible reason for the lower yield of **1a**. Careful analysis of the reaction mixture confirmed this proposal. The formation of the corresponding bromination product **3a** was observed (up to 20%). ^{1}H, ^{19}F NMR and GC-MS data supported the structure of tribromide **3a**, although we did not manage to isolate it in an analytically pure form (a similar product was also isolated in the reaction with *p*-methoxyphenyl substituted substrate **2c**, see Table 2). Keeping in mind the ability of 1,4-dioxane to form a complex with molecular bromine some reevaluation of the procedure was made (Table 1, Entries 28-32). It was found that 1,4-dioxane forms a homogeneous solution with $Fe(NO_3)_3 \cdot 9H_2O$ that is stable for 30 min. However, some degradation and formation of a brown precipitate, likely Fe_2O_3 hydrate was observed at longer time periods. Assuming that suppressing the formation of side-product **3** can be achieved by accelerating the target transformation, the reaction was run with an increased amount of $Fe(NO_3)_3 \cdot 9H_2O$ at higher temperatures. These conditions for the nitration of model alkene **2a** demonstrated very good results. The reaction proceeded in less time (30 min) to give target

alkene **1a** in 87% isolated yield (Method B, Entry 32). An even better yield of **1a** (93%) was reached using a larger excess of $Fe(NO_3)_3$ (8 equiv.) (Entry 31). However, we decided to use 3 equiv. of $Fe(NO_3)_3$ because the improvement was not very significant. We suppose that such conditions favor increased rates of both the NO_2 radical formation and the nitration reaction while lowering or maintaining the rate of the side-reaction, a bromination of **2a** due to a possible deactivation of bromine *via* complexation with 1,4-dioxane.

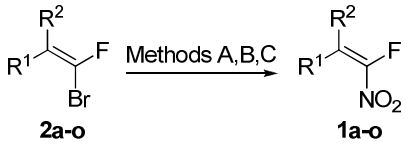
Crucial to our study was the stereochemical result of the reaction. To our delight, in all cases the radical nitration-debromination reaction of **2a** resulted in the formation of a single diastereomer of **1a**. The structure of **1a** was determined unambiguously by ^{1}H, ^{13}C and ^{19}F NMR as well as mass-spectrometry data. Accordingly to NMR data compound **1a** has an H-F coupling constant of 26 Hz, which corresponds to a *trans*-arrangement of hydrogen and fluorine across the C-C double bond.[14] Therefore, only the *Z*-isomer of α-fluoronitrostyrene **1a** is formed in this new nitration-debromination reaction. The proposed protocol is highly stereoselective in contrast to the previously reported method.[10]

Having optimized these reaction conditions, we next studied the scope of the reaction using a diverse set of 2-bromo-2-fluoroalkenes **2** (Table 2). As mentioned above, method A was applied first. In the case of moderate (<75%) yields (see, e.g., **1a-d**, **1m**), method B was also used. Gratifyingly, it was found that the nitration-debromination of alkenes **2** with $Fe(NO_3)_3 \cdot 9H_2O$ opens a general approach to fluoronitroalkenes **1**. Styrenes with varying electronic demand can be converted smoothly to the corresponding α-fluoronitroalkenes in yields of up to 92%.[15] For example, nitro-, cyano-, carbomethoxy-, methoxy-, fluoro-, chloro- and bromo-substituted 2-bromo-2-fluorostyrenes **2** were converted to the target products very efficiently. The naphthalene-derived nitroalkene **1k** was also prepared in high yield (90%) confirming a broad scope for the reaction. High stereocontrol was observed in all cases and the target nitrostyrenes were isolated as single *Z*-isomers.[16] The reaction was also applicable for synthesis of bis-nitroalkenes. Highly stereoselective nitration of bis-nitroalkene **2l** provided the

corresponding product **1l** as a single isomer having a *Z*,*Z*-configuration despite the starting material having a mixture of *E*,*E*-, *E*,*Z*- and *Z*,*Z*-isomers in a 12:6:1 ratio.

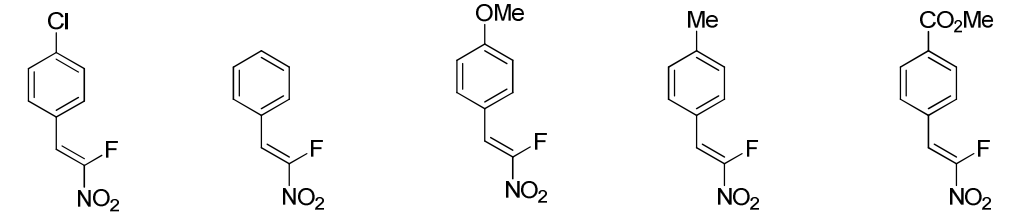
Likewise, the reaction can also be performed with tetra-substituted substrates derived from ketones. Thus, the corresponding α-fluoronitroalkene **1m** was prepared in 75% yield using method B. Method A somehow resulted in a lower yield (50%) and a prolonged reaction time was necessary to complete the nitration. Therefore, this nitration reaction is sensitive to steric hindrance of the C-C double bond of the starting alkene. It should be noted that α-fluoronitroalkene **1m** was isolated as a mixture of *E*/*Z* isomers in a 1:2 ratio in contrast to all the aldehyde-derived alkenes.

Table 2. Synthesis of fluoronitroalkenes **1**



2a-o **1a-o**

Method A: $Fe(NO_3)_3 \bullet 9H_2O$ (2 equiv.), TEMPO (0.2 equiv.), MS 4Å, 1,2-dichloroethane, 80 °C, 1-2 h;
Method B: $Fe(NO_3)_3 \bullet 9H_2O$ (3 equiv.), 1,4-dioxane, 100 °C, 0.5 h;
Method C: $AgNO_3$ (1.3 equiv.), MeCN, 65 °C, 45-60 min



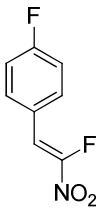
1a
Method A: 68 %
Method B: 86 %
Method C: 46 %

1b
Method A: 71 %
Method B: 78 %

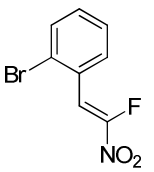
1c
Method A: 64 %
Method B: 79 %[a]

1d
Method A: 70 %
Method B: 74 %

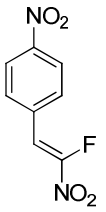
1e
Method A: 92 %
Method B: 74 %



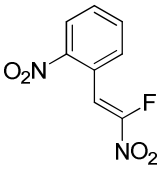
1f
Method A: 83 %



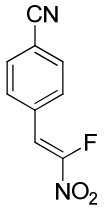
1g
Method A: 82 %



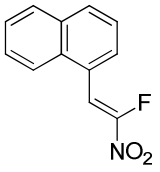
1h
Method A: 85 %



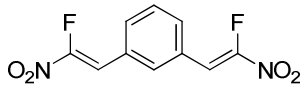
1i
Method A: 86 %



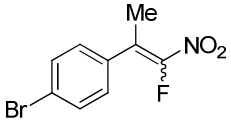
1j
Method A: 86 %



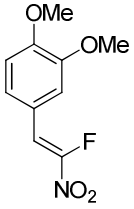
1k
Method A: 90 %



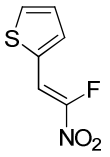
1l
Method A: 77 %



1m (*Z*:*E* = 2:1)
Method A: 50 %[b]
Method B: 75 %



1n
Method C: 53 %

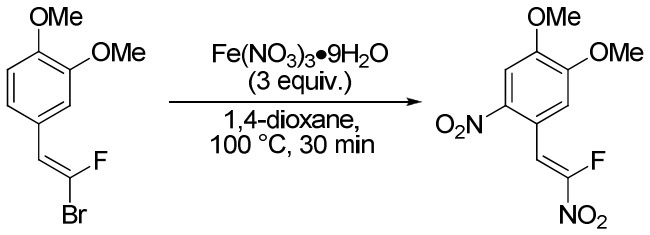


1o
Method C: 37 %

[a] 80 °C, 4 h; [b] $Fe(NO_3)_3 \cdot 9H_2O$ (5 equiv.) and TEMPO (0.4 equiv.) were added in 3 portions. Total reaction time – 5.5 h (see Experimental section)

Some restrictions for this nitration-debromination cascade were observed for highly electron-rich substrates. The nitration of 3,4-dimethoxyphenyl- (**2n**) and 2-thienyl (**2o**) substituted substrates gave complex product mixtures and poor yields of the target fluoronitroalkenes using both methods A and B. These results were predictable since the starting alkenes **2n,o** have highly reactive arene and hetarene rings, which are prone to participate in nitration and bromination reactions. Thus, double-nitration product **1'n** was isolated in the reaction with the 3,4-dimethoxy-substituted substrate **2n** (Scheme 2). However, the use of milder conditions for nitration ($AgNO_3$ in acetonitrile, 65 °C) allowed the selective preparation of nitroalkenes **1n** and **1o** in reasonable yields (Table 2).[17]

Scheme 2. Double nitration of substrate **2n**



2n **1'n** (20%)

Structures of all the obtained nitroalkenes **1a-o** were determined unambiguously by ^{1}H, ^{13}C and ^{19}F NMR as well as mass spectrometry data. As discussed above, the highly selective formation of *Z*-isomers was observed in all cases for trisubstituted alkenes (**1a-l,n,o**). Additionally, X-ray analysis was performed for a single crystal of nitroalkene **1n** (Figure 1)[18] to confirm the *Z*-configuration of these alkenes. An ^{1}H-^{19}F HOESY NMR experiment aided in establishing the configuration of the tetrasubstituted product **1m**.

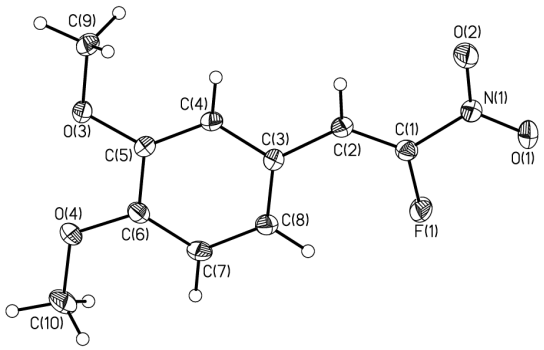
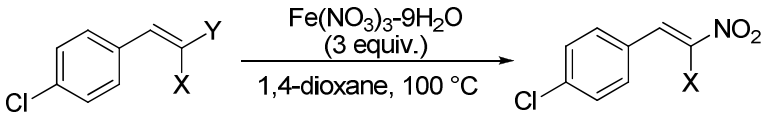


Figure 1. Single-crystal ORTEP drawing for **1n**. Thermal ellipsoids are shown at 50 % probability level.

We also proposed that this nitration-dehalogenation sequence can be used as a new general approach for the preparation of other α-halogenated nitroalkenes. Several mono- and dihalogenated styrenes were subjected to the reaction (Scheme 3). It was found that 2-chloro-2-fluoro- and 2,2-dichlorostyrenes (**4a,b**) failed to give the corresponding nitroalkenes with $Fe(NO_3)_3 \cdot 9H_2O$, while the reaction with monobromo- and 2,2-dibromostyrenes (**4c,d**) afforded the corresponding derivatives **5** in high yields. It should be noted that in these cases, the nitration proceeded with high stereoselectivity to afford **5c**,**d** as single diastereomers. The *trans*-arrangement of aryl and NO_2 groups was confirmed by comparison with literature data as well as by its characteristic *trans*-coupling constant, $^3J_{H,H}$ = 13.7 Hz (for **5d**).[19]

Scheme 3. Nitration of other halogenated styrenes **4**.



4a (X=F, Y=Cl)
4b (X=Cl, Y=Cl)
4c (X=Br, Y=Br)
4d (X=H, Y=Br)

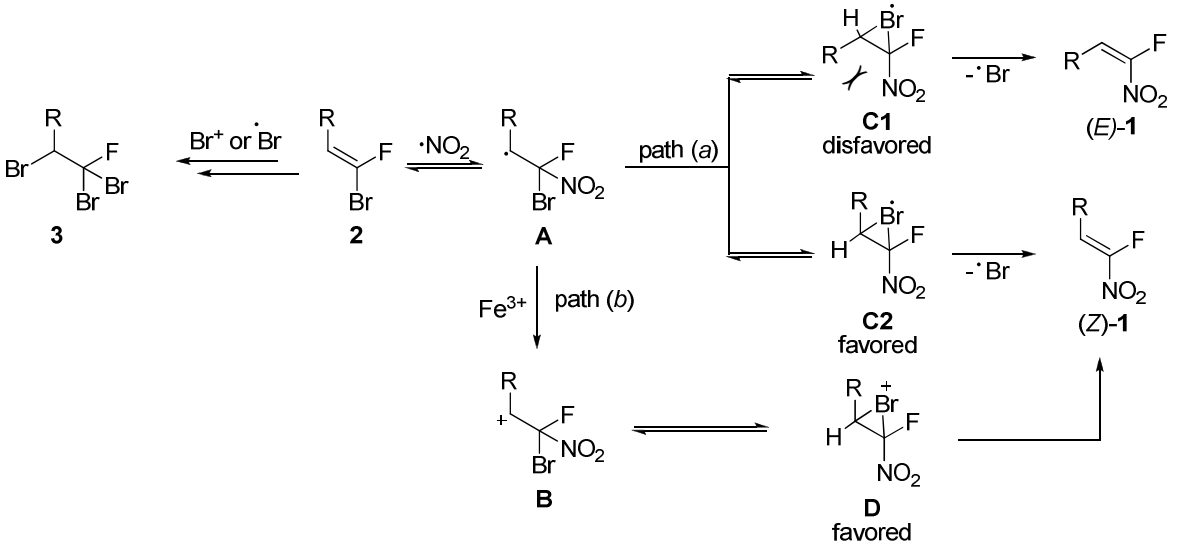
5a: unidentified mixture
5b: no reaction
(*Z*)-**5c:** 63%
(*E*)-**5d:** 80%

A possible mechanism for the nitration-debromination sequence is depicted in Scheme 4. Of course, this reaction is a complicated multistep transformation, but some details of the sequence can be justified. We believe that the first step of the reaction probably includes

generation of an NO_2 radical from the selected precursor. The second step is an attack of an NO_2 radical onto the C=C double bond to form the stabilized benzyl radical **A** which bears a $CBrFNO_2$ group in the adjacent position. Subsequent debromination proceeds either through the elimination of a bromine radical (path (*a*)) or includes the participation of an Fe(III) species to oxidize this radical to the corresponding benzyl cation **B** (path (*b*)) to facilitate the formation of the final fluoronitrostyrenes **1**. Eliminated Br^+ can be reduced with Fe(II) to a bromide anion or can participate in the bromination of a C=C double bond (side-product **3**). Thus, the iron salt is an electron mediator in this reaction, which probably explain the efficacy of using iron nitrate in this reaction over other nitrating agents such as N_2O_4 or $AgNO_3$.[20]

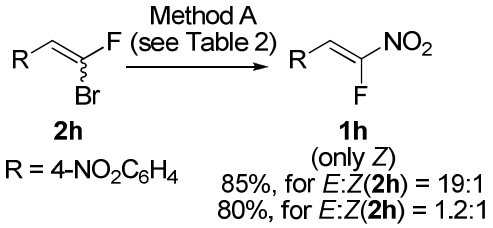
Considering the high stereoselectivity observed during similar radical nitration of unsubstituted styrenes,[11] we also envisioned high stereoselectivity for the nitration-debromination of fluoro-bromostyrenes **2**. The formation of simple nitrostyrenes in a *trans*-configuration is quite predictable: however, to the best our knowledge, *cis*-isomers are much less stable compounds.[21] Stereoselective formation of 1-fluoro-1-nitroalkenes **1** can be explained by the formation of intermediate **A** (Scheme 4). It has been previously reported that β-bromoalkyl radicals exist preferentially in the form of closed 3-membered bromo radicals **C**.[22] Among diastereomeric forms, **C1** should be less favored than its diastereomer **C2** due to the steric repulsion between its large R-group and NO_2 moiety. Thus (*Z*)-isomeric products **1** result from the transformation of the more stable cyclic intermediate **C2** by the elimination of bromine. This proposal is in total agreement with the lower stereoselectivity observed for the nitration of tetra-substituted substrate **2m** to form **1m**, which made a mixture of *Z*/*E* isomers in a 2:1 ratio (see above). Similar considerations are applicable for the elimination of Br^+ from cation **B** and its cyclic form **D** (path (*b*)).

Scheme 4. Rationale for the *Z*-selectivity of the nitration



The ratio of isomers of the starting alkene appears to have no effect on the stereochemical result of the reaction (see Experimental section). To confirm this observation, the reaction was performed with samples of alkene **2h** with different *E*/*Z*-ratios (almost pure (*E)*-isomer and ca. 1:1) (Scheme 5). Indeed, the stereochemical outcome of the reaction was independent on the starting *E*/*Z*-ratio and produced only the (*Z*)-isomer of **1h** in both cases.

Scheme 5. Comparison of the nitration of styrene **2h** with different *E*,*Z*-ratios



To demonstrate the synthetic utility of α-fluoronitroalkenes, we performed some chemical transformations of substrate **1a**. Due to the presence of the electron-withdrawing nitro-group, the obtained nitrostyrenes **1** should be activated electrophiles and dienophiles and can be used for the synthesis of valuable monofluorinated molecules. It should be noted that up to now almost nothing has been known about the reactivity of α-fluoronitroalkenes.[10] Accordingly, our preliminary investigation of the synthetic utility of these very attractive building blocks included reactions with H-, N-, S-, and C-nucleophiles as well as cycloaddition with 2,3-dimethylbuta-

1,3-diene and catalytic hydrogenation were studied (Scheme 6). We were pleased to find that under unoptimized conditions all these reactions proceeded very efficiently to give the corresponding products **6-10** in good isolated yields. Highly valuable monofluorinated products, which are difficult to prepare using alternative methods, can be obtained in one synthetic step from α-fluoronitroalkenes **1**. For example, the Michael addition of hydride ($NaBH_4$),[10] dimethyl malonate, amines (morpholine and isopropylamine) and thiophenol gave the corresponding α-fluorinated nitroalkanes **6-10**, respectively. Two diastereomers can be formed in these reactions, however, the diastereoselectivity of isolated Michael adducts **7-10** was not very high. Most likely, these stereochemical results can be explained by the easy epimerization enabled by the high acidity of the $FCHNO_2$-moiety.[23] In future work we will study these reactions more carefully. Nitroalkenes are a popular type of activated alkenes in asymmetric synthesis. For example, organocatalyzed Michael additions are a highly efficient approach for forming new stereocenters with high enantioselectivity.[1g,24]

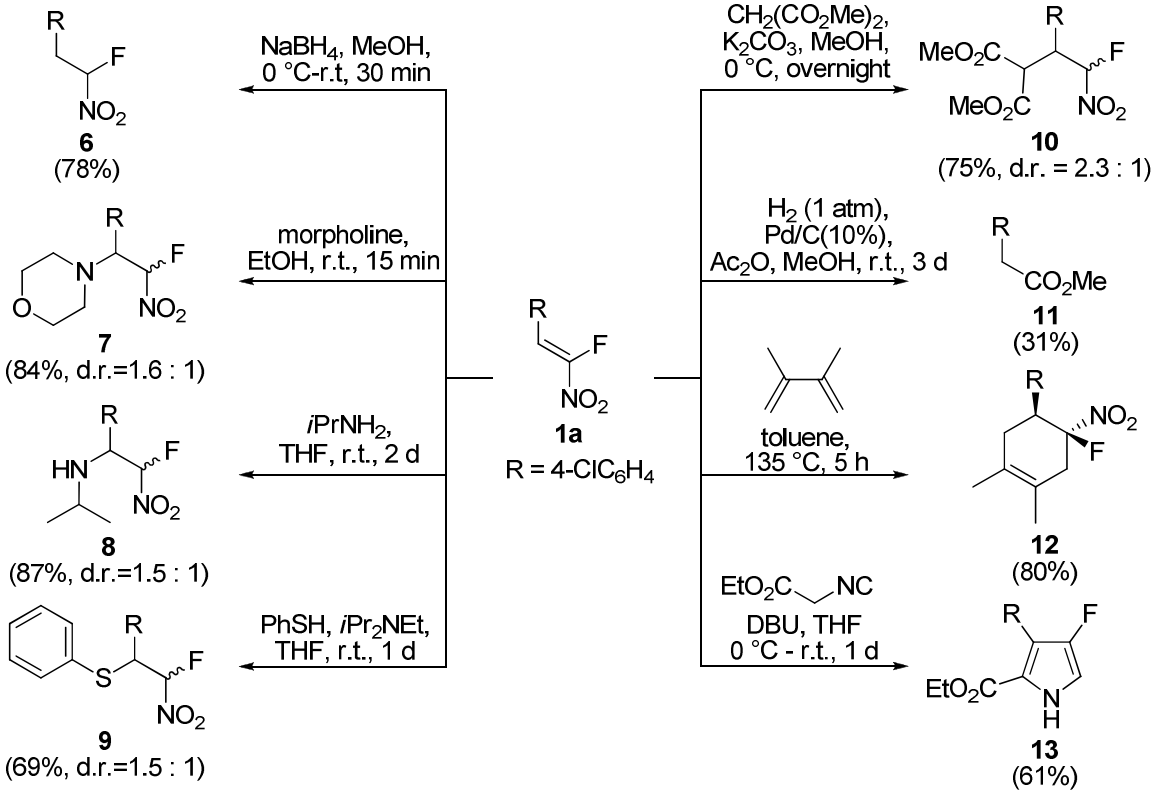
α-Fluoroamines are a very attractive but rather elusive type of organic molecules which exhibit low stability. We attempted to prepare α-fluoroamine by the Pd/C-catalyzed hydrogenation of **1a** in the presence of Ac_2O as a trapping agent. Unfortunately, only ester **11** was isolated as a main reaction product.[25]

Nitroalkene **1a** was found to participate successfully in a Diels-Alder reaction with 2,3-dimethylbuta-1,3-diene, resulting in the corresponding monofluorinated cyclohexene **12** in 80% yield. As expected, Diels-Alder adduct **12** was formed as single diastereomer.

Especially interesting is the prospective use of α-fluoronitroalkenes in the synthesis of monofluorinated heterocycles. In recent decades, the chemistry of fluorinated heterocycles has received substantial attention due to their applications in pharmaceuticals, agrochemicals and the synthesis of biologically active compounds.[7] The domino sequence - Michael addition-heterocyclization-aromatization by elimination of HNO_2 at the last step can open access to a large variety of highly attractive fluorinated heterocycles. Thus, nonfluorinated nitrostyrenes

have found broad applications in the synthesis of different heterocycles.[4] For example, the Barton-Zard reaction is a very useful method for the synthesis of pyrroles.[26] It was demonstrated that a fairly rare type of fluoro-substituted pyrrole,[27] 3-fluorinated pyrrole derivative **13**, can be constructed very efficiently using the reaction of **1a** with ethyl isocyanoacetate in the presence of DBU as a base.

Scheme 6. Selected chemical transformations of nitroalkene **1a**



In conclusion, a new stereoselective method for the synthesis of β-fluoro-β-nitrostyrenes from 2-bromo-2-fluorostyrenes *via* a nitration-debromination sequence was described. Two general protocols for the nitration, both based on the application of $Fe(NO_3)_3$, were proposed. Method A employs a $Fe(NO_3)_3$/TEMPO system that allows milder reaction conditions (80 °C) and Method B ($Fe(NO_3)_3$ in 1,4-dioxane at 100 °C) allows a shorter reaction time. Additionally, the radical nitration of highly electron-rich alkenes can be performed using $AgNO_3$ in acetonitrile (Method C). A rationale for the stereoselectivity of the reaction was proposed. The

high synthetic utility of β-fluoro-β-nitrostyrenes was demonstrated. An investigation of the use of these versatile building blocks to prepare small fluorinated molecules is currently underway.

Experimental section

All reactions were performed in oven-dried (150 °C) glassware. Most of the chemicals were acquired from commercial sources and used as received. Brine refers to a saturated aqueous solution of NaCl. TLC were performed on silica coated on aluminium with UV_{254} indicator. Visualization was accomplished with UV or ninhydrine. Column chromatography was performed on silica (0.04–0.063 mm, 60 Å). NMR spectra were recorded at the following spectrometer frequencies: 400 MHz, 300 MHz or 200 MHz (^{1}H NMR), 100 MHz or 75 MHz (^{13}C NMR), 376 MHz or 282 MHz (^{19}F NMR). Multiplicities are assigned as s (singlet), d (doublet), t (triplet), q (quadruplet), hept (heptet), m (multiplet), br (broad). High resolution mass spectra were acquired at TOF spectrometer using electrospray ionization (ESI).[28] Low resolution mass spectra were acquired using electron impact (EI) ionization (200 °C, ionization energy – 70eV). Intensities relative to most intensive peak are reported in parentheses.

Starting bromoalkenes were synthesized according to described procedures: **2**,[12f,g,28] **4c**,[29] **4d**.[30]

Synthesis of fluoronitroalkenes 1,5.

Method A. 2-bromo-2-fluorobromoalkene **2** was placed into 10 ml vial and dissolved in DCE (3 mL / 1 mmol of **2**). Then $Fe(NO_3)_3{\cdot}9H_2O$ (2 equiv), TEMPO (0.2 equiv) and 4Å MS (0.50 g / mmol alkene **2**) were added. Vial was closed and the reaction mixture was heated at 80°C (oil bath) with stirring for 1-2 h (TLC monitoring). Mixture was cooled to rt and filtered through Celite®. After that celite was washed with EtOAc. Combined filtrate was evaporated and crude product was purified by column chromatography (eluent: PE/EtOAc, 7:1 – 15:1) to give target nitroalkene **1**.

Method B. $Fe(NO_3)_3 \cdot 9H_2O$ (3 equiv) was added to the solution of bromoalkene **2,4** in 1,4-dioxane (12 mL / 1 mmol of **2**) and the reaction mixture was heated at 100 °C (oil bath) with stirring for 0.5 h (TLC monitoring). Mixture was cooled to rt and filtered through Celite®. After that celite was washed with EtOAc or CH_2Cl_2. Combined filtrate was evaporated and crude product was purified by column chromatography (eluent: PE/EtOAc, 7:1 – 15:1 or PE/CH_2Cl_2, 3:1) to give target nitroalkenes **1**,**5**.

Method C. 2-Bromo-2-fluoroalkene **2** was placed into 10 ml vial and dissolved in MeCN (5 mL / 1 mmol of **2**), then $AgNO_3$ (1.3 equiv.) was added. Vial was closed and the reaction mixture was heated at 65 °C (oil bath) with stirring for 45-60 min (TLC monitoring). Mixture was cooled to r.t. and filtered through celite®. After that celite was washed with EtOAc. Filtrate was evaporated and crude product was purified by column chromatography (eluent: PE/EtOAc = 10:1) to give target nitroalkenes **1**.

1-Chloro-4-[(Z)-2-fluoro-2-nitroethenyl]benzene (1a). **A)** Nitroalkene **1a** was obtained from bromofluorostyrene **2a** (0.207 g, 0.88 mmol) (*E*/*Z* = 4:1) according to Method A. Column chromatography (eluent: PE/EtOAc, 10:1) afforded 0.120 g (68 %) of target compound **1a**. **B)** Nitroalkene **1a** was obtained from bromofluorostyrene **2a** (0.470 g, 2 mmol) (*E*/*Z* = 4:1) according to Method B. Column chromatography (eluent: PE/CH_2Cl_2, 3:1) afforded 0.354 g (88 %) of target compound **1a. C)** Nitroalkene **1a** was obtained from bromofluorostyrene **2a** (0.172 g, 0.73 mmol) (*E*/*Z* = 4:1) according to Method C. Column chromatography (eluent: PE/EtOAc, 7:1) afforded 0.067 g (46 %) of target compound **1a.** Slightly yellow solid. R_f 0.27 (PE/CH_2Cl_2, 3:1) (UV). mp = 86-87 °C ($CHCl_3$). NMR matched previously reported data.[10]

[(Z)-2-Fluoro-2-nitroethenyl]benzene (1b). **A)** Nitroalkene **1b** was obtained from bromofluorostyrene **2b** (0.307 g, 1.55 mmol) (*E*/*Z* = 8:1) according to Method A. Column chromatography (eluent: PE/EtOAc, 20:1) afforded 0.180 g (71 %) of target compound **1b**. **B)** Nitroalkene **1b** was obtained from bromofluorostyrene **2b** (0.402 g, 2 mmol) (*E*/*Z* = 8:1) according to Method B. Column chromatography (eluent: PE/CH_2Cl_2, 3:1) afforded 0.261 g

(78 %) of target compound **1b**. Slightly yellow liquid, that solidifies upon storage. R_f 0.28 (PE/CH_2Cl_2, 3:1) (UV). mp = 40-41 °C ($CHCl_3$). NMR matched previously reported data.[10]

1-[(Z)-2-Fluoro-2-nitroethenyl]-4-(methyloxy)benzene (1c). **A)** Nitroalkene **1c** was obtained from corresponding bromofluorostyrene **2c** (0.523 g, 2.26 mmol) (*E*/*Z* = 5:1) according to method A. Column chromatography (eluent: PE/EtOAc, 12:1) with subsequent crystallization PE/EtOAc, 20:1) afforded 0.284 g (64 %) of target compound **1c**. **B)** Nitroalkene **1c** was obtained from bromofluorostyrene **2c** (0.462 g, 2 mmol) (*E*/*Z* = 5:1) according to Method B with following change: reaction was maintained at 80 °C for 4 h. Column chromatography (eluent: PE/CH_2Cl_2, 3:1) afforded 0.312 g (79 %) of target compound **1c**. Yellow solid. R_f = 0.36 (PE/CH_2Cl_2, 1:1) (UV) mp = 100-102 °C ($CHCl_3$). NMR matched previously reported data.[10]

1-[(Z)-2-Fluoro-2-nitroethenyl]-4-methyl-benzene (1d). **A)** Nitroalkene **1d** was obtained from bromofluorostyrene **2d** (0.167 g, 0.77 mmol) (*E*/*Z* = 5:1) according to method A. Column chromatography (eluent: PE/EtOAc, 10:1) afforded 0.098 g (70 %) of target compound **1d**. **B)** Nitroalkene **1d** was obtained from bromofluorostyrene **2d** (0.430 g, 2 mmol) (*E*/*Z* = 5:1) according to Method B. Column chromatography (eluent: PE/CH_2Cl_2, 3:1) afforded 0.354 g (74 %) of target compound **1d**. Slightly yellow solid. R_f 0.59 (PE/EtOAc, 7:1) (UV). mp = 72-74 °C (PE). ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.43 (s, 3H), 7.30 (d, *J* = 8.1 Hz, 2H), 7.40 (d, $^3J_{HF}$ = 26.7 Hz, 1H), 7.56 (d, *J* = 8.1 Hz, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 21.6, 110.1 ($^2J_{CF}$ = 6.4 Hz), 125.1 (d, $^3J_{CF}$ = 6.3 Hz), 130.1, 130.9 (d, $^4J_{CF}$ = 7.7 Hz), 142.4 (d, $^6J_{CF}$ = 2.8 Hz), 152.5 ($^1J_{CF}$ = 293.8 Hz). ^{19}F NMR (282 MHz, $CDCl_3$) δ -112.3 (d, *J* = 26.7 Hz). HRMS (ESI-TOF) *m/z*: [M + Na]$^+$ Calcd. for $C_9H_8FNO_2Na$ 204.0431; Found: 204.0432. MS (EI): *m/z* = 181 (M^+, 76), 123 (100).

Methyl 4-[(Z)-2-fluoro-2-nitroethenyl]benzoate (1e). **A)** Nitroalkene **1e** was obtained from bromofluorostyrene **2e** (0.137 g, 0.53 mmol) (*E*/*Z* = 4:1) according to method A. Column chromatography (eluent: PE/EtOAc, 10:1) afforded 0.110 g of target compound **1e** (92 %) as slightly yellow solid. **B)** Nitroalkene **1e** was obtained from bromofluorostyrene **2e** (0.159 g, 0.61

mmol) (*E*/*Z* = 4:1) according to Method B. Column chromatography (eluent: PE/EtOAc, 5:1) with subsequent crystallization from PE/EtOAc, 10:1 afforded 0.102 g (75 %) of target compound **1e**. R_f 0.48 (PE/EtOAc, 5:1) (UV). mp = 179-180 °C (PE/EtOAc, 10:1). ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.96 (s, 3H), 7.43 (d, $^3J_{HF}$ = 25.9 Hz, 1H), 7.73 (d, *J* = 8.3 Hz, 2H), 8.14 (d, *J* = 8.3 Hz, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 52.5, 108.5 (d, $^2J_{CF}$ = 6.2 Hz), 130.3, 130.6 (d, $^4J_{CF}$ = 8.1 Hz), 132.0 (d, $^3J_{CF}$ = 6.5 Hz), 132.4 (d, $^6J_{CF}$ = 2.6 Hz), 153.0 ($^1J_{CF}$ = 294.6 Hz), 166.0. ^{19}F NMR (282 MHz, $CDCl_3$) δ -109.0 (d, *J* = 25.9 Hz). HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd. for $C_{10}H_8FNO_4Na$ 248.0330; Found: 248.0322. MS (EI): *m/z* = 225 (M^+, 76), 120 (100).

1-Fluoro-4-[(Z)-2-fluoro-2-nitroethenyl]benzene (1f). Nitroalkene **1f** was obtained from bromofluorostyrene **2f** (0.302 g, 1.38 mmol) (*E*/*Z* = 5:1) according to method A. Column chromatography (eluent: PE/EtOAc, 10:1) afforded 0.210 g (83 %) of target compound **1f** as slightly yellow solid. R_f 0.53 (PE/EtOAc, 5:1) (UV). mp = 48-49 °C (PE). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.19 (t, *J* = 8.6 Hz, 2H), 7.40 (d, $^3J_{HF}$ = 26.1 Hz, 1H), 7.64-7.71 (m, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 108.8 (d, $^2J_{CF}$ = 5.4 Hz), 116.8 (d, $^2J_{CF}$ = 22.1 Hz), 124.2, 133.1 (t, $^4J_{CF}$ = 7.9 Hz), 152.5 ($^1J_{CF}$ = 291.5 Hz), 164.3 ($^1J_{CF}$ = 255.7 Hz). ^{19}F NMR (282 MHz, $CDCl_3$): -106.9 - -107.0 (m, 1 F), -113.2 (d, *J* = 26.1 Hz, 1 F). Anal. Calcd. for $C_8H_5F_2NO_2$: C, 51.90; H, 2.72; N, 7.57. Found: C, 51.57; H, 2.51; N, 7.39. MS (EI): *m/z* = 185 (M^+, 62), 127 (100).

1-Bromo-2-[(Z)-2-fluoro-2-nitroethenyl]benzene (1g). Nitroalkene **1g** was obtained from bromofluorostyrene **2g** (0.155 g, 0.56 mmol) (*E*/*Z* = 4:1) according to method A. Column chromatography (eluent: PE/EtOAc, 7:1) afforded 0.112 g (82 %) of target compound **1g** as slightly yellow oil, that solidifies upon storage in a fridge. R_f 0.57 (PE/EtOAc, 7:1) (UV). mp = 37-39 °C (PE). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.33 (td, *J* = 7.8, 1.4 Hz, 1H), 7.50 (t, *J* = 7.5 Hz, 1H), 7.72 (d, *J* = 8.0 Hz, 1H), 7.81 (d, *J* = 7.8 Hz, 1H), 7.87 (d, $^3J_{HF}$ = 25.7 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 108.1 ($^2J_{CF}$ = 4.5 Hz), 126.2 (d, J_{CF} = 2.0 Hz), 128.1, 128.2 (d, overlapped, J_{CF} = 8.7 Hz), 131.0 (d, $^4J_{CF}$ = 12.2 Hz), 132.3 (d, $^6J_{CF}$ = 1.5 Hz), 133.7, 153.0 ($^1J_{CF}$ = 294.9 Hz). ^{19}F NMR (282 MHz, $CDCl_3$) δ -112.1 (d, *J* = 25.7). HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd. for

$C_8H_5{}^{79}BrFNO_2Na$ 267.9380; Found: 267.9383. MS (EI): *m/z* = 247 ($[M+2]^+$, 16), 245 (M^+, 18), 120 (100).

1-[(Z)-2-Fluoro-2-nitroethenyl]-4-nitrobenzene (1h). Nitroalkene **1h** was obtained from corresponding bromofluorostyrene **2h** (0.067 g, 0.27 mmol) (*E*/*Z* = 19:1) according to method A. Column chromatography (eluent: PE/EtOAc, 10:1) afforded 0.049 g (85 %) of target compound **1h** as slightly yellow solid.

The same procedure for bromofluorostyrene **2h** (0.140 g, 0.57 mmol) (*E*/*Z* = 1.2:1) afforded 0.097 g (80%) of target compound **1h**. NMR matched previously reported data.[10]

1-[(Z)-2-Fluoro-2-nitroethenyl]-2-nitrobenzene (1i). Nitroalkene **1i** was obtained from bromofluorostyrene **2i** (0.185 g, 0.75 mmol) (*E*/*Z* = 3:1) according to method A. Column chromatography (eluent: PE/EtOAc, 10:1) afforded 0.137 g (86 %) of target compound **1i** as yellow solid. R_f 0.26 (PE/EtOAc, 10:1) (UV). mp = 66-68 °C (PE/EtOAc, 10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67-7.71 (m, 1H), 7.78-7.82 (m, 2H), 7.94 (d, $^3J_{HF}$ = 23.7 Hz, 1H), 8.21 (d, *J* = 7.9 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 105.3 ($^2J_{CF}$ = 5.7 Hz), 122.9 (d, $^3J_{CF}$ = 5.0 Hz), 125.6, 131.3 (d, $^4J_{CF}$ = 8.4 Hz), 131.5, 134.0, 148.2, 152.9 ($^1J_{CF}$ = 296.7 Hz). ^{19}F NMR (282 MHz, $CDCl_3$) δ -112.1 (d, *J* = 23.7 Hz). HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd. for $C_8H_5FN_2O_4Na$ 235.0126; Found: 235.0135.

4-[(Z)-2-Fluoro-2-nitroethenyl]benzonitrile (1j). Nitroalkene **1j** was obtained from bromofluorostyrene **2j** (0.215 g, 0.95 mmol) (*E*/*Z* = 4:1) according to method A. Column chromatography (eluent: PE/EtOAc, 10:1) afforded 0.155 g (86 %) of target compound **1j** as colorless solid. R_f 0.30 (PE/CH_2Cl_2, 1:1) (UV). mp = 119-120 °C (PE/EtOAc, 10:1). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.41 (d, $^3J_{HF}$ = 25.3 Hz, 1H), 7.75-7.81 (m, 4H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 107.5 (d, $^2J_{CF}$ = 6.1 Hz), 114.7 (d, $^6J_{CF}$ = 3.2 Hz), 117.8, 131.0 (d, $^4J_{CF}$ = 7.9 Hz), 132.2 (d, $^3J_{CF}$ = 6.5 Hz), 132.9, 153.2 ($^1J_{CF}$ = 298.2 Hz). ^{19}F NMR (282 MHz, $CDCl_3$): -107.6 (d, *J* = 25.3 Hz). HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd. for $C_9H_5FN_2O_2Na$ 215.0227; Found: 215.0237. MS (EI): *m/z* = 192 (M^+, 57), 134 (100).

1-[(Z)-2-Fluoro-2-nitroethenyl]naphtalene (1k). Nitroalkene **1k** was obtained from bromofluorostyrene **2k** (0.136 g, 0.54 mmol) (*E*/*Z* = 7:1) according to method A. Column chromatography (eluent: PE/EtOAc, 15:1) afforded 0.106 g (90%) of target compound **1k** as yellow solid. R_f 0.60 (PE/EtOAc, 5:1) (UV). mp = 78-79 °C (PE). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.57-7.63 (m, 2H), 7.65-7.69 (m, 1H), 7.94 (dd, J = 8.1, 1.3 Hz, 1H), 7.97 (d, *J* = 7.8 Hz, 1H), 8.00 (d, *J* = 8.2 Hz, 1H), 8.09 (d, *J* = 8.4 Hz, 1H), 8.20 (d, $^3J_{HF}$ = 24.7 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 106.1 ($^2J_{CF}$ = 6.7 Hz), 122.9, 124.0 (d, $^3J_{CF}$ = 6.1 Hz), 125.5, 126.7, 127.8, 129.2, 129.2 (d, $^4J_{CF}$ = 11.3 Hz), 131.7, 132.0 (d, $^6J_{CF}$ = 1.9 Hz), 133.7, 153.4 ($^1J_{CF}$ = 290.8 Hz). ^{19}F NMR (282 MHz, $CDCl_3$) δ -112.3 (d, *J* = 24.7 Hz). HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd. for $C_{12}H_8FNO_2Na$ 240.0431; Found: 240.0431. MS (EI): *m/z* = 217 (M^+, 39), 170 (100).

1,3-Bis-[(Z)-2-fluoro-2-nitroethenyl]benzene (1l). Nitroalkene **1l** was obtained from bromofluorostyrene **2l** (0.245 g, 0.76 mmol) (*E*,*E*/*E*,*Z*/*Z*,*Z* = 12:6:1) according to method A with following change: 4 equiv $Fe(NO_3)_3{\cdot}9H_2O$ and 0.4 equiv TEMPO were used. Column chromatography (eluent: PE/EtOAc, 10:1) afforded 0.150 g (77 %) of target compound **1l** as slightly yellow solid. R_f 0.43 (PE/EtOAc, 5:1) (UV). mp = 108-109 °C (PE). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.44 (d, 2H, $^3J_{HF}$ = 25.7 Hz, 2H), 7.63 (t, *J* = 7.7 Hz, 1H), 7.80 (d, J = 7.7 Hz, 2H), 7.92 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 108.4 (d, $^2J_{CF}$ = 6.1 Hz), 129.3 (d, $^3J_{CF}$ = 6.4), 130.4, 132.5 (t, $^4J_{CF}$ = 7.6 Hz), 133.0 (dd, $^4J_{CF}$ = 7.9 Hz, $^6J_{CF}$ = 2.2 Hz), 153.0 ($^1J_{CF}$ = 295.3 Hz). ^{19}F NMR (282 MHz, $CDCl_3$) δ -109.6 (d, *J* = 25.7 Hz). Anal. Calcd. for $C_{10}H_6F_2N_2O_4$: C, 46.89; H, 2.36; N, 10.94. Found: C, 46.72; H, 2.26; N, 10.71. MS (EI): *m/z* = 256 (M^+, 71), 151 (100).

1-Bromo-4-[2-fluoro-1-methyl-2-nitroethenyl]benzene (1m). *1-Bromo-4-[2-bromo-2-fluoro-1-methylethenyl] benzene* ***(2m).*** In argon atmosphere the mixture of *p*-bromoacetophenone (0.39 g, 2.0 mmol), PPh_3 (0.79 g, 3.0 mmol, 1.5 equiv.), Zn (0.26 g, 4.0 mmol, 2 equiv.) and CBr_3F (0.49 mL, 5.0 mmol, 2.5 equiv.) in THF (6 mL) was vigorously stirred at 60 °C for 2 hours. After that the mixture was evaporated, crude product was preadsorbed on silica and purified by column chromatography (eluent: PE/CH_2Cl_2, 20:1) to give 0.55 g (95 %) of target compound **2m** as

colorless oil. *E*:*Z* = 1.1 : 1 (^{19}F NMR). Assignment of *E*,*Z*-isomers was made considering $^{4}J_{HF}$ value in H_3C-C=CF scaffold: $^{4}J_{HF}$ = 3-4 Hz for *trans*-arrangement of F and CH_3 groups and $^{4}J_{HF}$ = 4-5 Hz for *cis*-arrangement of F and CH_3 groups.[31] R_f 0.49 (PE/CH_2Cl_2, 20:1) (UV). ^{1}H NMR (300 MHz, $CDCl_3$) (*E*+*Z*) δ 2.08 (d, $^{4}J_{HF}$ = 4.3 Hz, 3H, *Z*-isomer), 2.08 (d, $^{4}J_{HF}$ = 3.5 Hz, 3H, *E*-isomer), 7.16-7.20 (m, 2H), 7.22-7.62 (m, 2H), 7.48-7.53 (m, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) (*E*+*Z*) δ 17.6 (d, $^{4}J_{HF}$ = 4.7 Hz), 20.3, 116.7 (d, $^{2}J_{CF}$ = 8.7 Hz), 118.5 (d, $^{2}J_{CF}$ = 16.9 Hz), 121.6, 121.8, 129.4 ($^{4}J_{CF}$ = 4.2 Hz), 130.0 ($^{4}J_{CF}$ = 3.2 Hz), 131.0 ($^{1}J_{CF}$ = 316.4 Hz), 131.5, 131.6, 132.6 ($^{1}J_{CF}$ = 317.5 Hz), 135.3, 137.8 (d, $^{6}J_{CF}$ = 5.0 Hz). ^{19}F NMR (282 MHz, $CDCl_3$) (*E*+*Z*) δ -73.4 (q, $^{4}J_{HF}$ = 4.3 Hz, *Z*-isomer). -73.5 (qt, $^{4}J_{HF}$ = 3.5 Hz, $^{5}J_{HF}$ = 1.2 Hz, *E*-isomer). MS (EI): *m/z* = 296 ($[M+4]^+$, 23), 294 ($[M+2]^+$, 50), 292 (M^+, 26), 134 (100). **A)** Nitroalkene **1m** was obtained from bromofluoroalkene **2m** (0.157 g, 0.54 mmol) (*E*/*Z* = 1.1:1) according to method A with the following changes: after 3 hour heating $Fe(NO_3)_3{\cdot}9H_2O$ (2 equiv.) and TEMPO (0.2 equiv.) were added. After additional heating at 80 °C for 1.5 h $Fe(NO_3)_3{\cdot}9H_2O$ (1 equiv.) was added. After additional heating for 1 h reaction was worked up as described. Column chromatography (eluent: PE/EtOAc, 15:1) afforded 0.033 g (*Z*-isomer) and 0.037 g (*Z*/*E* = 1:1.5) of target compound **1m** (total yield – 50 %, *Z*/*E* = 2:1) as yellow oils. **B)** Nitroalkene **1m** was obtained from bromofluorostyrene **2m** (0.171 g, 0.58 mmol) (*E*/*Z* = 1.1:1) according to Method B. Column chromatography (eluent: PE/EtOAc, 10:1) afforded 0.113 g (74 %) of target compound **1m.** R_f 0.36 (PE/EtOAc, 15:1) (UV) (*Z*-isomer) and 0.31 (PE/EtOAc, 15:1) (UV) (*E*-isomer). *Z*-isomer: ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.54 (d, $^{4}J_{HF}$ = 3.7 Hz, 3H), 7.28-7.32 (m, 2H, CH_{Ar}), 7.57-7.62 (m, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 19.3, 121.7 (d, $^{2}J_{CF}$ = 11.4 Hz), 124.1, 129.6 ($^{4}J_{CF}$ = 3.4 Hz), 132.0, 134.1, 150.7 (d, $^{1}J_{CF}$ = 277.4 Hz). ^{19}F NMR (282 MHz, $CDCl_3$) δ -108.6 (br s). ^{19}F-^{1}H HOESY interaction: F-CH_{Ar}. *E*-isomer: ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.23 (d, $^{4}J_{HF}$ = 4.6 Hz, 3H, Me), 7.07-7.10 (m, 2H), 7.54-7.57 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.8, 121.3 (d, $^{2}J_{CF}$ = 17.9 Hz), 123.0, 128.4 ($^{4}J_{CF}$ = 1.7 Hz), 132.1, 134.6, 149.7 (d, $^{1}J_{CF}$ = 279.4 Hz). ^{19}F NMR (282 MHz, $CDCl_3$): -109.2 (br s). ^{19}F-^{1}H HOESY interaction: F-Me. HRMS (ESI-TOF) *m/z*: [M

+ Na]$^+$ Calcd. for $C_9H_7{}^{79}BrFNO_2Na$ 281.9536; Found: 281.9534. MS (EI): *m/z* = 261 ([M+2]$^+$, 16), 259 (M$^+$, 16), 133 (100).

4-[(Z)-2-Fluoro-2-nitroethenyl]-1,2-bis(dimethyloxy)benzene (1n). Nitroalkene **1n** was obtained from bromofluorostyrene **2n** (0.290 g, 1.11 mmol) (*E*/*Z* = 5:1) according to Method C. Column chromatography (eluent: PE/EtOAc, 10:1) afforded 0.139 g (53 %) of target compound **1n** as orange crystals. R_f 0.25 (PE/EtOAc, 7:1) (UV). mp = 104-106 °C (15:1 PE/EtOAc). ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.93 (s, 3H), 3.96 (s, 3H), 6.95 (d, *J* = 8.4 Hz, 1H), 7.19 (d, *J* = 2.0 Hz, 1H), 7.27 (dd, *J* = 8.4, 2.0 Hz, 1H), 7.39 (d, $^3J_{HF}$ = 26.7 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 55.9, 56.0, 110.5 (d, $^2J_{CF}$ = 6.2 Hz), 111.5, 112.7 (d, $^4J_{CF}$ = 8.8 Hz), 120.7 (d, $^3J_{CF}$ = 6.2 Hz), 125.8 (d, $^4J_{CF}$ = 7.4 Hz), 149.5, 152.1 (d, $^1J_{CF}$ = 288.4 Hz), 152.2 (d, $^6J_{CF}$ = 3.3 Hz). ^{19}F NMR (282 MHz, $CDCl_3$) δ -114.2 (d, *J* = 26.6 Hz). HRMS (ESI-TOF) *m/z*: [M + Na]$^+$ Calcd. for $C_{10}H_{10}FNO_4Na$ 250.0486; Found: 250.0485. MS (EI): *m/z* = 227 (M$^+$, 100). Single-crystal X-Ray diffraction data for **1n** was deposited at Cambridge Crystallographic Data Centre (CCDC-1527014).

2-[(Z)-2-Fluoro-2-nitroethenyl]thiophene (1o). Nitroalkene **1o** was obtained from bromofluoroalkene **2o** (0.139 g, 0.67 mmol) (*E*/*Z* = 3:1) according to Method C. Column chromatography (eluent: PE/EtOAc, 15:1) afforded 0.043 g (37 %) of target compound **1o** as yellow solid. R_f 0.50 (PE/EtOAc, 5:1) (UV). mp = 70-72 °C (PE/EtOAc, 10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.21 (ddd, *J* = 5.1, 3.8, 1.4 Hz, 1H), 7.54 (d, *J* = 3.7 Hz, 1H), 7.69 (d, *J* = 25.4 Hz, 1H), 7.71 (d, *J* = 5.7 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 105.1 ($^2J_{CF}$ = 9.9 Hz), 128.6, 130.4 (d, $^3J_{CF}$ = 7.1 Hz), 133.2 (d, $^4J_{CF}$ = 8.1 Hz), 134.3, 151.6 (d, $^1J_{CF}$ = 288.1 Hz). ^{19}F NMR (282 MHz, $CDCl_3$) δ -110.7 (d, *J* = 25.4 Hz). HRMS (ESI-TOF) *m/z*: [M + Na]$^+$ Calcd. for $C_6H_4FNO_2SNa$ 195.9839; Found: 195.9844. MS (EI): *m/z* = 173 (M$^+$, 47), 83 (100).

1-[(Z)-2-Fluoro-2-nitroethenyl]-4,5-bis(methyloxy)-2-nitrobenzene (1'n). Nitroalkene **1'n** was obtained from bromofluorostyrene **2n** (0.311 g, 1.19 mmol) (*E*/*Z* = 5:1) subjected to Method B. Column chromatography (eluent: PE/EtOAc, 5:1) with subsequent crystallization (PE/EtOAc,

15:1) afforded 0.054 g (20 %) of target compound **1'n** as yellow solid. R_f = 0.20 (PE/EtOAc, 3:1) (UV). mp = 142-144 °C (15:1 PE/EtOAc). ^{1}H NMR (300 MHz, $CDCl_3$): 4.02 (s, 6 H, OMe), 7.14 (s, 1H, 6-HC_{Ar}), 7.77 (s, 1H, 3-HC_{Ar}), 8.08 (d, $^3J_{HF}$ = 24.4 Hz, 1H, =CH). ^{13}C NMR (75 MHz, $CDCl_3$): 56.6, 106.0 (d, $^2J_{CF}$ = 4.5 Hz), 108.6, 111.9 (d, $^4J_{CF}$ = 9.4 Hz), 116.9 (d, $^3J_{CF}$ = 5.2 Hz), 141.7, 150.7, 152.7 (d, $^1J_{CF}$ = 294.9 Hz), 153.2. ^{19}F NMR (282 MHz, $CDCl_3$): -113.0 (d, J = 24.4 Hz). Characteristic NOESY/HOESY interactions: OMe/3-CH_{Ar}, OMe/6-CH_{Ar}, F/6-HC_{Ar}. HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd. for $C_{10}H_9FN_2O_6Na$ 295.0337; Found: 295.0332. MS (EI): *m/z* = 272 (M^+, 22), 44 (100).

1-[(Z)-2-Bromo-2-nitroethenyl]-4-chlorobenzene (5c). Nitroalkene **5c** was obtained from corresponding dibromostyrene **4c** (0.148 g, 0.5 mmol) according to Method B with the following change: reaction was maintained at 100 °C for 10 h. Column chromatography (eluent: PE/CH_2Cl_2, 3:1) afforded 0.082 g (63 %) of target compound **5c** as slightly yellow solid. R_f 0.31 (PE/CH_2Cl_2 = 3:1) (UV). NMR matched previously reported data.[19b]

1-Chloro-4-[(E)-2-nitroethenyl]benzene (5d). Nitroalkene **5d** was obtained from corresponding bromostyrene **4d** (0.108 g, 0.5 mmol) (*E*/*Z* = 6:1) according to Method B. Column chromatography (eluent: PE/CH_2Cl_2, 3:1) afforded 0.073 g (80 %) of target compound **5d** as slightly yellow solid. R_f = 0.46 (PE/CH_2Cl_2 = 1:1) (UV). NMR matched previously reported data.[11a]

1-Chloro-4-(2-fluoro-2-nitroethyl)benzene (6). To the solution of nitroalkene **1a** (90 mg, 0.45 mmol) in MeOH (4.4 mL) $NaBH_4$ (26 mg, 0.67 mmol, 1.5 equiv.) was added at 0 °C with stirring. Cooling bath was removed, the mixture was stirred for 30 min and diluted with EtOAc (15 mL). Organic layer was washed with H_2O (2 × 15 mL), brine (15 mL), dried over Na_2SO_4 and evaporated. Crude product was subjected to column chromatography (eluent: PE/EtOAc, 7:1) to give 71 mg (78 %) of target compound **6** as colorless oil. R_f = 0.21 (PE/EtOAc, 10:1) (UV). mp = 41-42 °C (pentane). ^{1}H NMR (300 MHz, $CDCl_3$): 3.34-3.57 (m, 2H), 5.95 (ddd, J = 50.4 Hz, 6.2 Hz, 3.9 Hz, 1H), 7.19 (d, J = 8.3 Hz, 2H), 7.35 (d, J = 8.3 Hz, 2H). ^{13}C NMR (75

MHz, $CDCl_3$): 38.8 (d, $^2J_{CF}$ = 19.7 Hz), 110.3 (d, $^1J_{CF}$ = 241.2 Hz), 129.2, 129.3 (d, $^3J_{CF}$ = 1.7 Hz), 130.9, 134.5. ^{19}F NMR (282 MHz, $CDCl_3$): -146.5 - -146.1 (m). Anal. Calcd. for $C_8H_7ClFNO_2$: C, 47.19; H, 3.47; N, 6.88. Found: C, 47.00; H, 3.63; N, 6.69. MS (EI): *m/z* = 205 ($[M+2]^+$, 7), 203 (M^+, 18), 101 (100).

4-[1-(4-Chlorophenyl)-2-fluoro-2-nitroethyl]morpholine (7). To the suspension of nitroalkene **1a** (89 mg, 0.44 mmol) in EtOH (0.88 mL) morpholine (0.042 mL, 0.48 mmol, 1.1 equiv.) was added. The reaction mixture was stirred for 15 min and evaporated. Column chromatography (eluent: PE/EtOAc, 3:1) afforded 107 mg (84 %) of target compound **7** as colorless viscous oil. d.r. = 1.6 : 1 (^{19}F NMR). Relative configuration of stereocenters was not determined. R_f = 0.10 (PE/EtOAc, 5:1) (UV) ^{1}H NMR (300 MHz, $CDCl_3$): 2.36-2.69 (m, 4H, CH_2-N), 3.69 (t, *J* = 4.7 Hz, 4H, CH_2-O), 4.14 (dd, *J* = 21.9 Hz, 5.1 Hz, 1H, CH-N), 6.26 (dd, *J* = 50.5 Hz, 5.1 Hz, 1H, CH-F), 7.23 (d, *J* = 8.5 Hz, 2H, CH_{Ar}), 7.38 (d, *J* = 8.5 Hz, 2H, CH_{Ar}). ^{13}C NMR (75 MHz, $CDCl_3$): 50.9 (CH_2-N), 66.7 (CH_2-O), 69.9 (d, $^2J_{CF}$ = 19.9 Hz, CH-N), 109.8 (d, $^1J_{CF}$ = 245.6 Hz, CH-F), 128.9 (CH_{Ar}), 129.5 (C_{Ar}), 130.7 (d, J_{CF} = 0.8 Hz, CH_{Ar}), 135.3 (C_{Ar}). ^{19}F NMR (272 MHz, $CDCl_3$): -155.2 (dd, *J* = 50.5 Hz, 21.9 Hz). Minor isomer (characteristic signals): ^{1}H NMR (300 MHz, $CDCl_3$): 2.36-2.69 (m, 4H, CH_2-N), 3.64 (t, *J* = 4.7 Hz, 4H, CH_2-O), 4.35 (dd, *J* = 28.5 Hz, 3.0 Hz, 1H, CH-N), 6.03 (dd, *J* = 49.4 Hz, 3.1 Hz, 1H, CH-F), 7.30 (d, *J* = 8.5 Hz, 2H, CH_{Ar}), 7.41 (d, *J* = 8.5 Hz, 2H, CH_{Ar}). ^{13}C NMR (75 MHz, $CDCl_3$): 51.3 (d, $^5J_{CF}$ = 1.4 Hz, CH_2-N), 66.9 (CH_2-O), 69.1 (d, $^2J_{CF}$ = 16.3 Hz, CH-N), 112.3 (d, $^1J_{CF}$ = 246.8 Hz, CH-F), 129.0 (CH_{Ar}), 130.8 (d, J_{CF} = 2.6 Hz, CH_{Ar}), 135.3 (C_{Ar}). ^{19}F NMR (272 MHz, $CDCl_3$): -154.5 (dd, *J* = 49.4 Hz, 28.5 Hz). HRMS (ESI-TOF) *m/z*: $[M + H]^+$ Calcd. for $C_{12}H_{15}{}^{35}ClFN_2O_3$ 289.0750; Found: 289.0747. MS (EI): *m/z* = 290 (M^+, 5), 212 ($[M+2–CHFNO_2]^+$, 33), 210 ($[M–CHFNO_2]^+$, 100).

N-[1-(4-Chlorophenyl)-2-fluoro-2-nitroethyl]propan-2-amine (8). Mixture of nitroalkene **1a** (0.109 g, 0.54 mmol) and isopropyl amine (0.120 g, 2.03 mmol, 3.8 equiv.) in THF (2 mL) was kept at room temperature for 48 h (TLC monitoring). Reaction mixture was evaporated in vacuo

and the residue was purified by column chromatography on silica gel (eluent: PE/CH_2Cl_2, 3:1) to give 0.051 g (d.r. = 1 : 9) and 0.072 g (d.r. = 18 : 1) of target compound **8** as colorless oils. Total yield 87%. Total d.r. = 1.5 : 1 (^{19}F NMR). Relative configuration of stereocenters was not determined. R_f 0.13 (PE/CH_2Cl_2, 1:1) (UV). Major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): 1.04 (d, *J* = 6.3 Hz, 6 H), 1.60 (br s, 1H), 2.70 (hept, J = 6.3 Hz, 1H), 4.43 (dd, *J* = 21.9 Hz, 4.2 Hz, 1H), 5.94 (dd, *J* = 50.5 Hz, 4.2 Hz, 1H), 7.22 (d, *J* = 8.5 Hz, 2H), 7.35 (d, *J* = 8.5 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): 21.7, 23.7, 46.0, 60.7 (d, $^2J_{CF}$ = 19.4 Hz), 111.5 (d, $^1J_{CF}$ = 243.5 Hz), 129.1, 129.3, 133.0, 135.0. ^{19}F NMR (376 MHz, $CDCl_3$): -157.8 (dd, *J* = 50.5 Hz, 21.8 Hz). Minor isomer: ^{1}H NMR (400 MHz, $CDCl_3$): 0.94 (d, *J* = 6.2 Hz, 3H), 1.00 (d, *J* = 6.2 Hz, 3H), 1.68 (br s, 1H), 2.62 (hept, J = 6.2 Hz, 1H), 4.53 (dd, *J* = 25.2 Hz, 2.4 Hz, 1H), 5.78 (dd, *J* = 49.7 Hz, 2.6 Hz, 1H), 7.29 (d, *J* = 8.4 Hz, 2H), 7.40 (d, *J* = 8.4 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): 21.4, 23.8, 45.5, 60.6 (d, $^2J_{CF}$ = 17.6 Hz), 111.8 (d, $^1J_{CF}$ = 243.8 Hz), 128.9, 129.3, 134.2, 134.8. ^{19}F NMR (376 MHz, $CDCl_3$): -161.9 (dd, *J* = 49.7 Hz, 25.1 Hz). HRMS (ESI-TOF) *m/z*: $[M + H]^+$ Calcd. for $C_{11}H_{15}{}^{35}ClFN_2O_2$ 261.0801; Found: 261.0807. MS (EI): *m/z* = 247 ($[M+2–Me]^+$, 6), 245 ($[M–Me]^+$, 18), 184 ($[M+2–CHFNO_2]^+$, 30), 182 ($[M–CHFNO_2]^+$, 84), 156 (100).

1-(4-Chlorophenyl)-2-fluoro-2-nitroethyl phenyl sulfide (9). Mixture of nitroalkene **1a** (0.101 g, 0.5 mmol), thiophenol (0.066 g, 0.6 mmol) and DIPEA (0.069 g, 0.6 mmol) in THF (2 mL) was kept at room temperature for 24 h (TLC monitoring). Reaction mixture was evaporated in vacuo and the residue was purified by column chromatography on silica gel (eluent: PE/CH_2Cl_2, 3:1) to give 0.107 g (69 %) of compound **9** as colorless oil. d.r. = 1.5 : 1 (^{19}F NMR). Relative configuration of stereocenters was not determined. R_f 0.27 (PE/CH_2Cl_2, 1:1) (UV). Major isomer: ^{1}H NMR (400 MHz, $CDCl_3$): 4.87 (dd, *J* = 26.7 Hz, 3.1 Hz, 1H), 5.92 (dd, *J* = 49.6 Hz, 3.2 Hz, 1H), 7.25-7.39 (m, 8 H), 7.51-7.53 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): 54.1 (d, $^2J_{CF}$ = 19.1 Hz), 109.4 (d, $^1J_{CF}$ = 246.1 Hz), 129.1, 129.2, 129.7, 130.2, 130.3 (d, *J* = 1.2 Hz), 130.9, 133.8, 135.4. ^{19}F NMR (376 MHz, $CDCl_3$): -157.8 (dd, *J* = 49.6 Hz, 26.6 Hz). Minor isomer: ^{1}H NMR (400 MHz, $CDCl_3$): 4.80 (dd, *J* = 24.3 Hz, 3.8 Hz, 1H), 6.02 (dd, *J* = 49.6 Hz, 3.8 Hz, 1H),

7.25-7.39 (m, 8 H), 7.51-7.53 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): 55.3 (d, $^2J_{CF}$ = 19.0 Hz), 111.2 (d, $^1J_{CF}$ = 245.0 Hz), 129.0, 129.3, 129.4, 129.7 (d, J = 1.1 Hz), 131.3, 132.9, 133.9, 135.0. ^{19}F NMR (376 MHz, $CDCl_3$): -150.8 (dd, J = 49.6 Hz, 23.9 Hz). Anal. Calcd. for $C_{14}H_{11}ClFNO_2S$: C, 53.94; H, 3.56; N, 4.49. Found: C, 53.89; H, 3.32; N, 4.32. HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd. for $C_{14}H_{11}{}^{35}ClFNO_2SNa$ 334.0075; Found: 334.0062. MS (EI): *m/z* = 313 ($[M+2]^+$, 5), 311 (M^+, 11), 156 (100).

Dimethyl [1-(4-chlorophenyl)-2-fluoro-2-nitroethyl]propanedioate (10). To the solution of K_2CO_3 (39 mg, 0.28 mmol, 0.5 equiv.) in MeOH (1.7 mL) at 0 °C dimethyl malonate (82 mg, 0.62 mmol, 1.1 equiv.) and nitroalkene **1a** (113 mg, 0.56 mmol) were successively added. The reaction mixture was maintained at the same temperature overnight and poured into EtOAc (25 mL) / H_2O (15 mL). Organic layer was washed with brine (15 mL), dried over Na_2SO_4 and evaporated. Column chromatography (eluent: PE/EtOAc, 5:1, 3:1) afforded 141 g (75 %) of target compound **10** as colorless oil, that solidifies upon storage. d.r. = 2.3 : 1. Relative configuration of stereocenters was not determined. R_f 0.28 (PE/EtOAc, 3:1) (UV, ninhydrine).

mp = 111-114 °C (EtOAc). Major isomer: ^{1}H NMR (300 MHz, $CDCl_3$): 3.49 (s, 3H), 3.86 (s, 3H), 4.05 (d, J = 11.9 Hz, 1H), 4.37 (ddd, J = 31.3 Hz, 11.9 Hz, 2.3 Hz, 1H), 6.45 (dd, J = 50.7 Hz, 2.3 Hz, 1H), 7.13-7.18 (m, 2H), 7.27-7.31 (m, 2H). ^{13}C NMR (75 MHz, $CDCl_3$): 46.8 (d, $^2J_{CF}$ = 17.5 Hz), 52.2 (d, $^3J_{CF}$ = 2.9 Hz), 53.0, 53.5, 109.4 (d, $^1J_{CF}$ = 243.3 Hz), 129.1, 130.7 (d, J = 1.7 Hz), 135.4, 166.3, 167.3. ^{19}F NMR (282 MHz, $CDCl_3$): -157.6 (dd, J = 50.7 Hz, 31.3 Hz). Minor isomer (characteristic signals): ^{1}H NMR (300 MHz, $CDCl_3$): 3.54 (s, 3H), 3.83 (s, 3H), 4.22-4.27 (m, 2H), 6.33 (dd, J = 49.3 Hz, 3.3 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): 51.9 (d, $^3J_{CF}$ = 5.3 Hz), 53.1, 53.4, 129.3, 130.1. ^{19}F NMR (282 MHz, $CDCl_3$): -146.9 (br d, J = 49.3 Hz). HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd. for $C_{13}H_{13}{}^{35}ClFNO_6Na$ 356.0308; Found: 356.0314. MS (EI): *m/z* = 335 ($[M+2]^+$, 1.5), 333 (M^+, 3.3), 227 (100).

Methyl (4-chlorophenyl)acetate (11). Nitroalkene **1a** (128 mg, 0.64 mmol) and Ac_2O (0.18 mL, 1.9 mmol, 3 equiv) in MeOH (3.2 mL) was hydrogenated over Pd/C (10%) (15 mg) under 1 atm

of H_2 (balloon) for 3 days with continuous stirring. Reaction mixture was filtered through celite and evaporated. Column chromatography (eluent: PE/EtOAc, 9:1) afforded 37 mg (31 %) of compound **11** as colorless oil. NMR matched previously reported data.[32]

rel 1-Chloro-4-((1S,6S)-6-fluoro-3,4-dimethyl-6-nitrocyclohex-3-en-1-yl)benzene (12). Glass tube with a Young's tap was evacuated and filled with argon. Next, solution of nitroalkene **1a** (0.202 g, 1 mmol) in toluene (0.5 mL) and 2,3-dimethylbuta-1,3-diene (1 mL) were added in argon flow and the tube was tightly sealed. After that the tube was heated at 135 °C for 5 h in oil bath. The excess of the diene and toluene were evaporated at reduced pressure and the residue was purified by column chromatography on silica gel (PE/CH_2Cl_2, 3:1) to give 0.228 g (80 %) of adduct **12** as colorless solid. R_f 0.25 (PE,CH_2Cl_2, 3:1) (UV). mp = 83-84 °C ($CHCl_3$) ^{1}H NMR (400 MHz, $CDCl_3$): 1.71 (s, 3H), 1.72 (s, 3H), 2.35 (dd, *J* = 17.5 Hz, 6.0 Hz, 1H), 2.52-2.65 (m, 2H), 3.18 (dd, *J* = 35.0 Hz, 17.5 Hz, 1H), 3.73 (dd, *J* = 31.3 Hz, 12.2 Hz, 6.1 Hz, 1H), 7.22 (d, *J* = 8.5 Hz, 2H), 7.27 (d, *J* = 8.5 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): 18.2, 18.3, 36.6 (d, *J* = 3.1 Hz), 41.2 (d, *J* = 24.2 Hz), 45.7 (d, *J* = 19.6 Hz), 120.2, 120.3 (d, $^1J_{CF}$ = 242.7 Hz), 125.5, 128.7, 130.0 (d, *J* = 1.8 Hz), 134.0, 134.3. ^{19}F NMR (376 MHz, $CDCl_3$): -136.9 (ddd, *J* = 35.0 Hz, 31.3 Hz, 16.9 Hz). Anal. Calcd. for $C_{14}H_{15}ClFNO_2$: C, 59.26; H, 5.33; N, 4.94. Found: C, 59.40; H, 5.28; N, 4.82. HRMS (ESI-TOF) *m/z*: $[M + Na]^+$ Calcd. for $C_{14}H_{15}{}^{35}ClFNO_2Na$ 306.0668; Found: 306.0672. MS (EI): *m/z* = 238 ($[M+2–HNO_2]^+$, 33), 236 ($[M–HNO_2]^+$, 78), 125 (100).

Ethyl 3-(4-chlorophenyl)-4-fluoro-1H-pyrrole-2-carboxylate (13). To a solution of ethyl isocyanoacetate (0.028 g, 0.25 mmol) in THF (0.5 mL) DBU (0.038 g, 0.25 mmol) was added and mixture thus obtained was cooled to -18 °C at fridge. After that solution of nitroalkene **1a** (0.051 g, 0.25 mmol) in THF (0.5 mL) was added and reaction mixture was left at room temperature for 24 h (TLC monitoring). Volatiles were evaporated in vacuo and the residue was purified by column chromatography on silica gel (eluent: PE/CH_2Cl_2 = 1:1) to give 0.040 g (61 %) of pyrrole **13** as colorless solid. R_f 0.50 (CH_2Cl_2) (UV). mp = 120-122 °C ($CHCl_3$) ^{1}H NMR (400 MHz, $CDCl_3$): 1.24 (t, *J* = 7.1 Hz, 3H), 4.27 (q, *J* = 7.1 Hz, 2H), 6.79 (t, *J* = 3.5 Hz,

1H), 7.37 (d, J = 8.2 Hz, 2H), 7.47 (d, J = 8.2 Hz, 2H), 9.23 (br s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): 14.1, 60.7, 106.5 (d, $^2J_{CF}$ = 27.7 Hz), 115.4, 116.8, 127.9, 128.9, 131.7, 133.3, 149.8 (d, $^1J_{CF}$ = 244.3 Hz), 160.7 (d, $^4J_{CF}$ = 2.6 Hz). ^{19}F NMR (376 MHz, $CDCl_3$): -167.3 (m). HRMS (ESI-TOF) *m/z*: $[M + H]^+$ Calcd. for $C_{13}H_{12}{}^{35}ClFNO_2$ 268.0535; Found: 268.0536. MS (EI): *m/z* = 269 ($[M+2]^+$, 16), 267 (M^+, 50), 221 (100).

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Supporting information

Copies of ^{1}H and ^{13}C NMR spectra of the compounds (.pdf).

Crystal data (.cif).

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the regiochemistry of NO_2 addition as well as the stability of the corresponding nitroalkene to the reaction conditions are questionable.

16. Intensities of ^{19}F NMR signals that can be attributed to *E*-isomers of nitroalkenes **1** were less than 3 % relative to the major peak of (*Z*)-**1**.
17. Brief screening of reaction conditions showed nearly equal yields (48-55% by ^{19}F NMR) of **1o** regardless of concentration (0.05 M, 0.2 M or 0.5 M). Use of 1,2-DCE or toluene as a solvent gave worse yields (<30%) than MeCN.
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