Solvent Suppression

Why solvent suppression?

There are two major problems arising from an intense solvent peak:

- The un-deuterated solvent contributes the major intensity of the recorded FID. Therefore the receiver gain must be lowered and becomes very insensitive. Consequently the small signal contributions of the molecule of interest are monitored imperfectly.
  (Dynamic range problem)
- The solvent peak becomes very broad and overlays with peaks arising from the molecule of interest.

Strategies for different methods

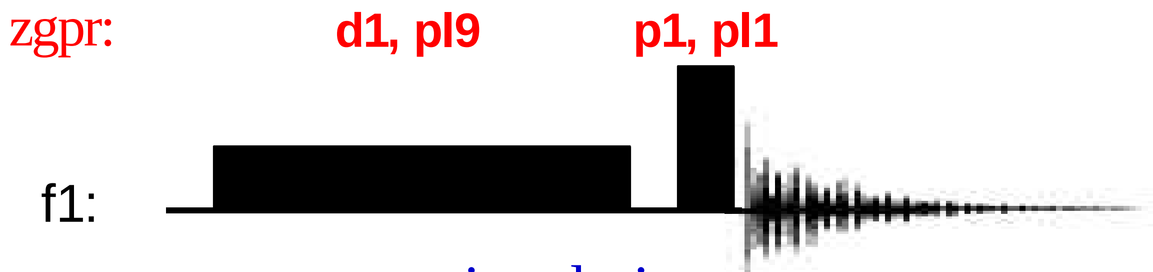
- **Selective dephasing of the solvent resonance**
  - Purge spin-lock pulses
  - WATERGATE, excitation sculpting, WET
- **Realigning solvent magnetization along z-axis**
  - Water flip back (often together with WATERGATE)
  - Jump and Return
  - Manipulation of radiation damping

Radiation damping = Exotisch

- **Other strategies**
  - Presaturation (Chen ill also be presaturated)
  - Coherence selection (e.g. gradient HSQC with EA)

ist auch dephasing aber nicht selective dephasing, gehört also so bisschen zu i

Presaturation



- On- or off-resonance presaturation during recycle or other delays (e.g. during NOE - mixing time d8 in noesy1dpr)
- Problem: saturation transfer to exchanging protons
- zgpr: simple one solvent presaturation:
  power: pl9 (55 - 65dB, calculate in *edprosol*) , duration: d1 (2s)
  offset: on-resonant on solvent peak.
  (Optimize o1 on minimal FID in gs mode)
- noesypr1d: 1D NOESY presaturation for single solvent suppression:
  power: pl9, duration: d1 and d8 (NOESY mixing time)
  offset: on-resonant on solvent peak.
  (Optimize o1 on minimal FID in gs mode)

Gradient coherence selection

Trick: only specific coherences are selected, all others are dephased

Problem: exchanging protons are also dephased

- Pulse programs: large number of 2D pulse programs (e.g. hsqcetgpsi, cosygpmfph etc.)
- Optimization:
  - Use exact gradient ratios based on gyromagnetic ratios (e.g.: 80 : 8 instead of 80 : 8.1 may lead to 30% sensitivity loss)
  - Use lowest possible gradient power to avoid sensitivity losses due to diffusion effects
  - For samples with short T2 relaxation times, use short gradient pulses
  - Avoid static gradients due to large z5 or z6 shim values. They could act as refocussing gradients and compromise the solvent suppression.
    - in hsqcetgpsi, use 80 : 8.1 : -80 : 8.1 or -80 : -8.1 : 80 : -8.1
    - optimize values of z5 and z6 in the gs mode.

- deconvolution of the solvent signal
- removes all signals within the defined range around the solvent frequency

Parameters			
	bc_mod	=	qpol subtracts a 5th order polynomial from the FID
	bc_mod	=	qfil applies a filter according to
	bcfw		range for deconvolution, in ppm
	corroffs		offset from spectrum midpoint, in Hz

kti:

Artifacts:

Static gradient - which could be created by the usage of large values for high-order shims (Z5, Z6) could act as refocussing gradients and thereby compromize the quality of solvent suppression. Some tips to solve this problem, are:

1. i.e. for 'invietgssi', use gradient ratios 80 : 8.1 : -80 : 8.1 instead of 80 : 8.1 : 80 : -8.1

2. completely turn the sign of all gradients, i.e. -80:-8.1:80:-8.1 instead of 80:8.1:-80:8.1

3. A shim perfect for presaturation might not be the best shim for a gradient solvent suppression experiment. Change Z5, Z6 within the GS-mode and observe the changes in the qualtiy of water suppression.

Selective dephasing of solvent signal by rf pulses

Purge pulses (a.k.a spin-lock- or trim pulses)

selectively dephase coherences orthogonal to the RF-field (I_x ,I_z) while preserving coherences locked along the RF-field (I_y)

pulse program	many HSQC-type inverse and triple resonance experiments.	
purge pulse	**p28**	(500µsec - 2ms)
power level for purge pulse	**pl1**	(same as hard proton pulses)

Note: make sure that the probe can stand the rather high power level used for the trim pulse. Otherwise the probe is damaged.

Optimizing conditions:

Change the trim pulse p28 within the GS-mode for minimum solvent signal.

Warning:

When a simple HSQC experiment does not give the expected sensitivity or even no

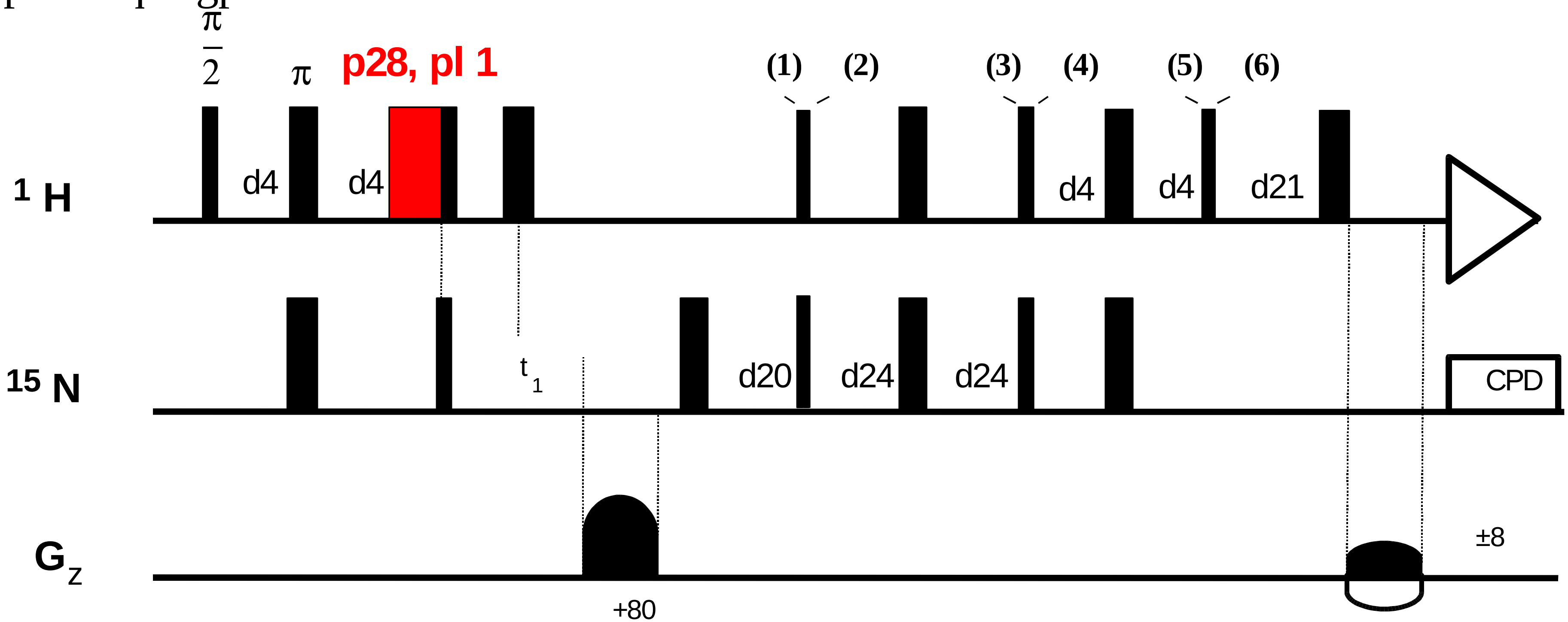
Selective dephasing of solvent signal by rf pulses

Purge pulses (a.k.a spin-lock- or trim pulses)

p28 = 500µs - 2ms @ pl1 !

use p28 only if you have a solvent signal to suppress

Example: hsqcetgpsi



Selective dephasing of solvent signal by gradients

selectively dephase solvent magnetization
dephasing gradients are also called purge or crush gradients

Pulse programs
- many inverse and triple resonance experiments
- Schemes: Watergate, WET, Excitation Sculpting

Optimization
- use lowest possible gradient power strength
- in Watergate use shortest possible gradients to minimize J-coupling artifacts.

Note: dephasing gradients (or dephasing schemes, watergate etc.) can be preceded by flip-back pulses to reduce the gradient strength

WATERGATE

WATER suppression by **G**r**A**dient **T**ailored **E**xcitation

selectively dephase solvent magnetization by Gradients

pulse program	**p3919gp**	(1D-NMR with binomial WATERGATE)
	19 or wg	(nD-experiments using WATERGATE)
watergate pulse (on-resonant)	**p27**	(= hard pulse or ~ 35µsec)
power level for selective pulse	**pl18**	(= value of hard pulse or ~ 35µsec pulse)
delay for binomial suppression	**d19**	(2 * dwell time, 2 * dw, depends on TD and SW)

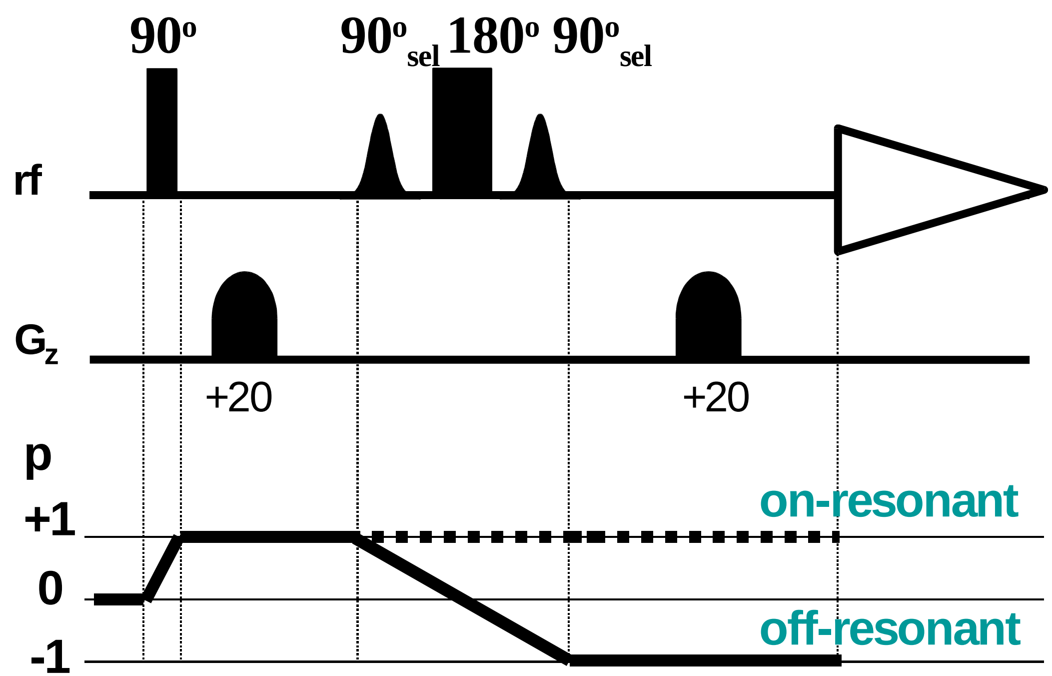
Optimizing conditions:

- Use lowest gradient power level as possible.
- Keep the length of the gradient pulse as short as possible to

WATERGATE

Original WATERGATE Sequence:

- Based on gradient spin echo experiment to refocus chemical shift evolution.
- Coherence orders of water and other signals are changed differently:
    - On resonant coherence unchanged
    - Off resonant coherence inverted
- Gradients discriminate on- and off-resonance coherences by CTP selection.

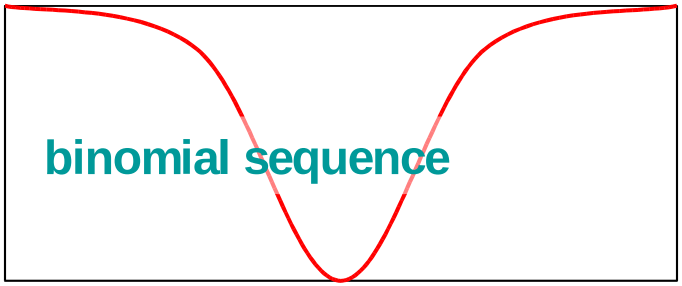


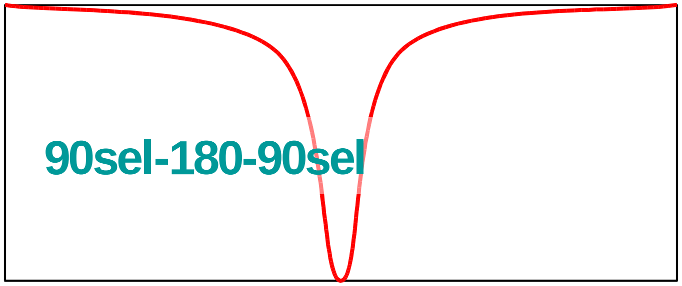
$$E_{tot1} = +20\,(\gamma \cdot 1) = +20$$
$$E_{tot2} = +20\,(\gamma \cdot -1) = -\underline{20}$$
$$0$$

WATERGATE

WATERGATE properties:

- Excitation profile: Notch (band stop-) filter
- in **p3919gp** a binomial pulse sequence is used which is enclosed by the gradients: (no further pulse adjustments)
  - The binomial pulse sequence changes the coherence order of all resonances except that of the on-resonant solvent.
  - The second field gradient dephases the water signal and rephases all other resonances.

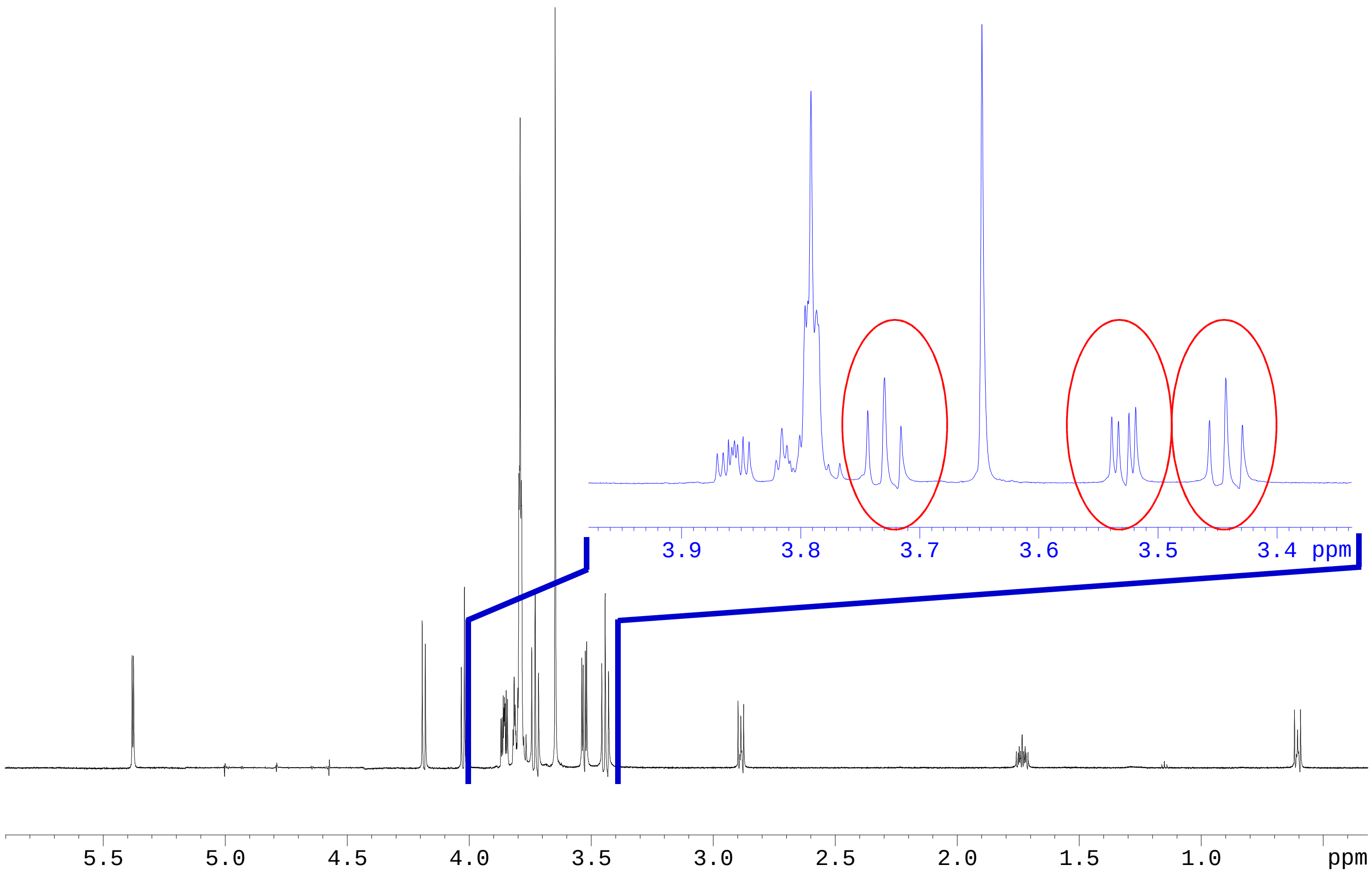




- Gradients and selective pulses: *BEHIND* excitation
  - ⇒ total length of pulse sequence is 4-6ms
  - ⇒ evolution of $^3J(HH)$ scalar couplings leads to phase errors

WATERGATE phase errors

Evolution of ^3J(HH) scalar couplings leads to phase errors



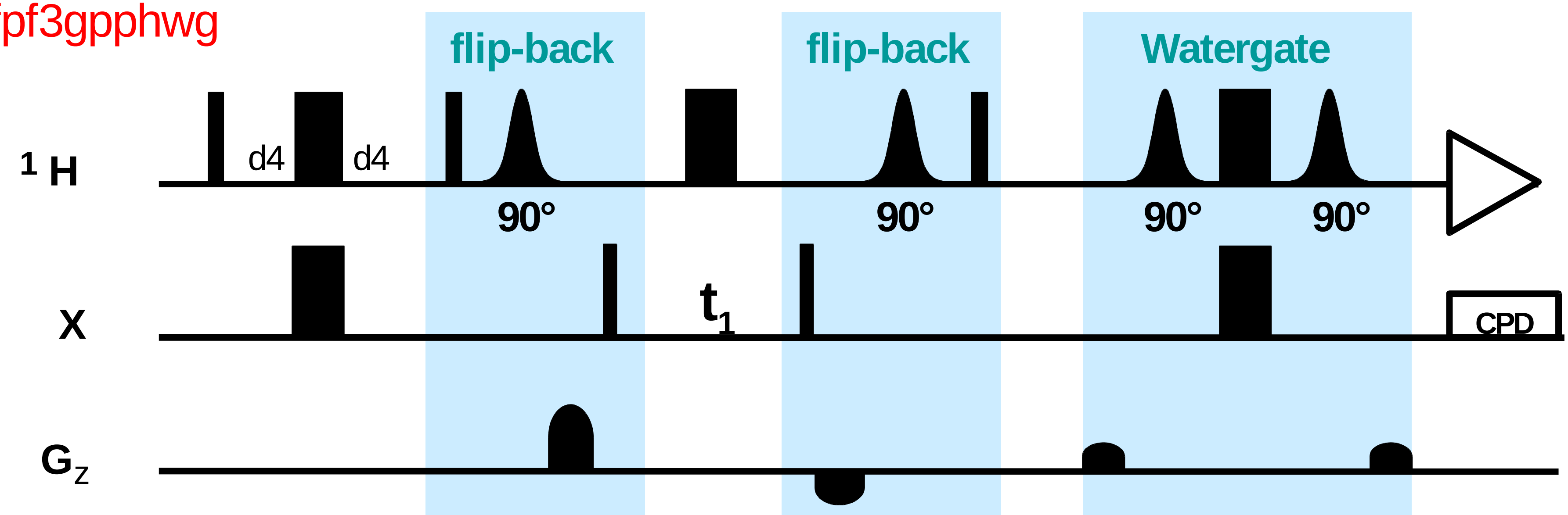
Water-flip-back

Common building block in heteronuclear correlation experiments to improve WATERGATE

- flip-back pulses prior to WATERGATE to align transverse water magnetization along z
- Pulse sequence names: …fp… with the following parameters:

selective on-resonant flip-back pulse:	**p11**	(2 - 3ms the shorter the broader)
shape of the flip-back pulse:	**spnam1**	(sinc or gauss pulse)
power of the flip-back pulse:	**sp1**	(calculate selective 90° pulse in stdisp and optimize in gs-mode)

HSQC with water-flip-back improved WATERGATE:
invifpf3gpphwg



Excitation Sculpting

same principle as WATERGATE:

- selectively dephase the solvent magnetization

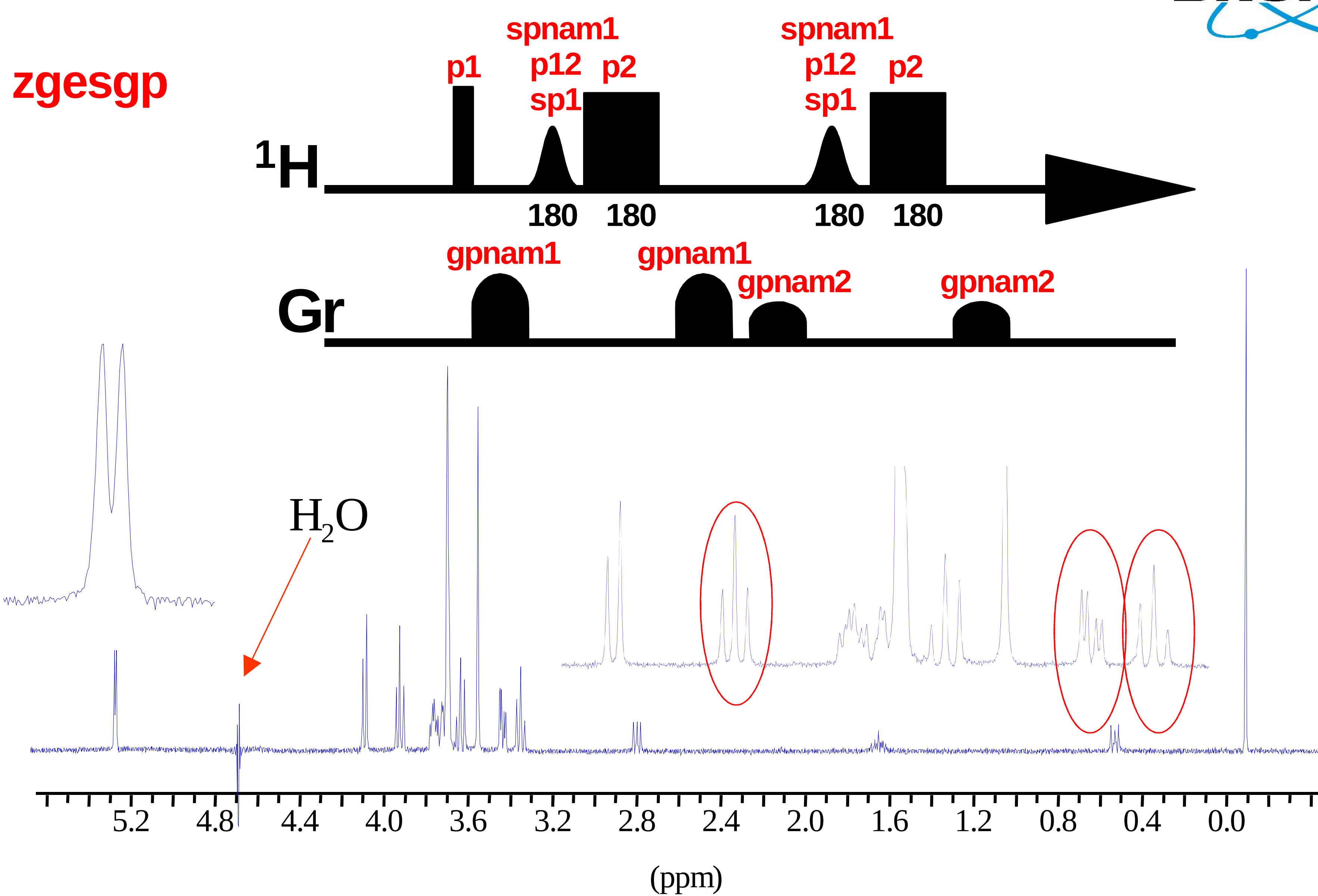
Difference:

- two identical spin echoes flanked by gradients (instead of one spin echo)
- the flanking gradients are of different strength

pulse program	**zgesgp**	(1D-NMR with selective pulses) or
	zggpw5	*binomial W5 pulse train ≡ binomial WATERGATE*)
	es	(nD-experiments)
Parameters for zgesgp and ...es...:		
selective 180° pulse (on-resonant)	**p12**	(1 - 5ms, the shorter the broader)
power level for selective pulse	**sp1**	(calculate with "*pulse*" for p12 length subtract 6dB for 180° pulse)
shape of selective 180° pulse	**spnam1**	(Squa100.1000)

Optimization:

Excitation Sculpting: no phase distortion

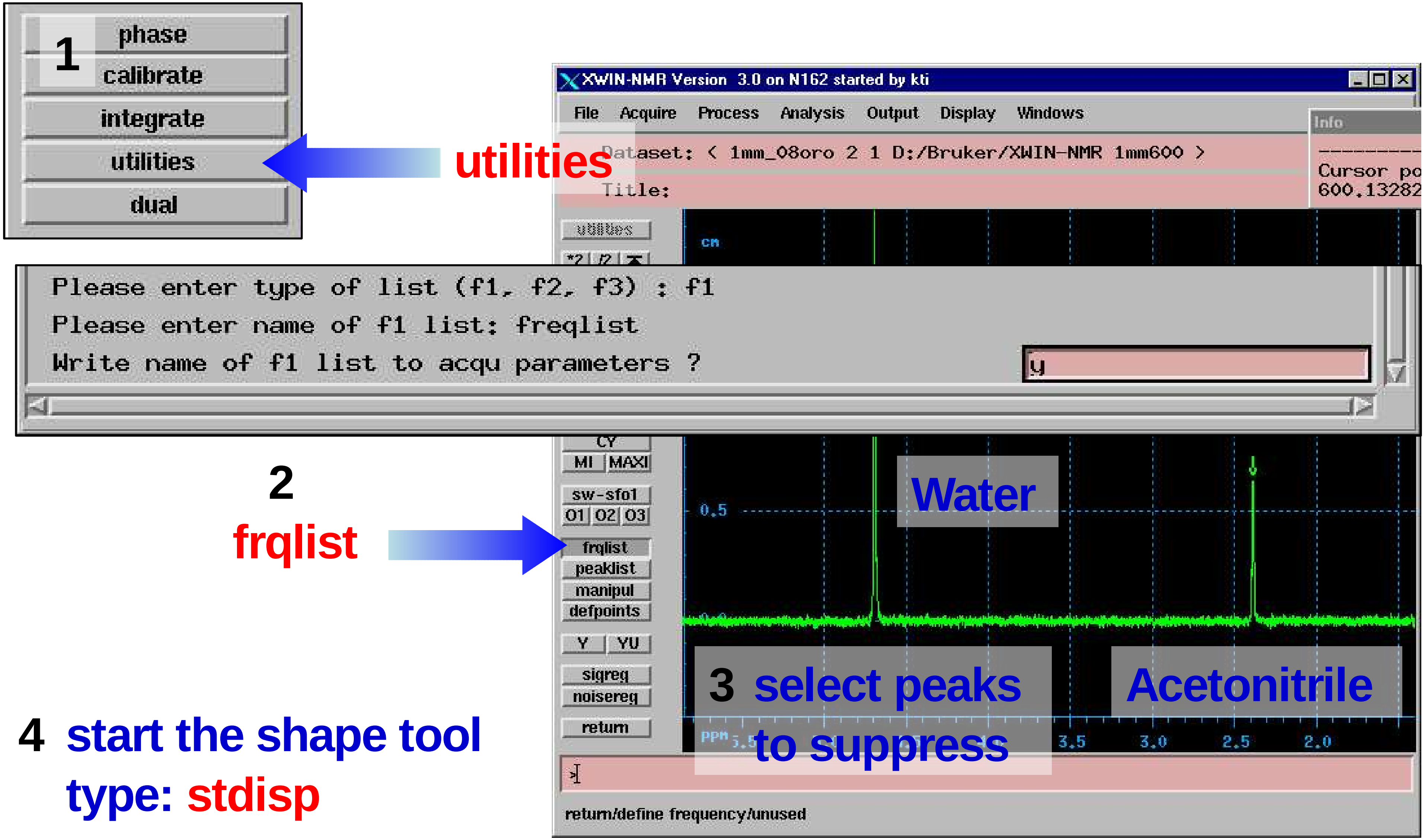


Multiple Solvent Suppression

- zgps: multiple solvent or off resonant presaturation:
  power: sp6 (= pl9 +6dB per additional solvent),
  duration: l6 * p18 (p18 = 10ms, l6 = 200)
  spnam6: square (manipulate with solvent freqlist in *stdisp*)

- zgesgp: multiple solvent suppression using excitation sculpting
  p12 (1 - 5ms)
  spnam1(square, manipulate with solvent freqlist in *stdisp*)
  sp1 (calculate 90° in pulse, subtract 6dB to get 180° and subtract 6dB for each additional signal that has to be suppressed).

Shapes for Multiple Solvent Suppression



Shapes for Multiple Solvent Suppression

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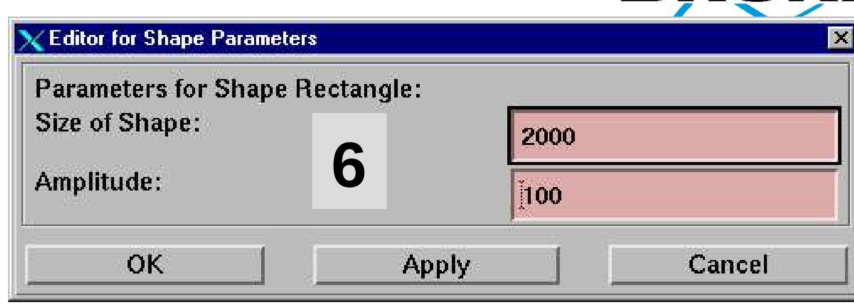
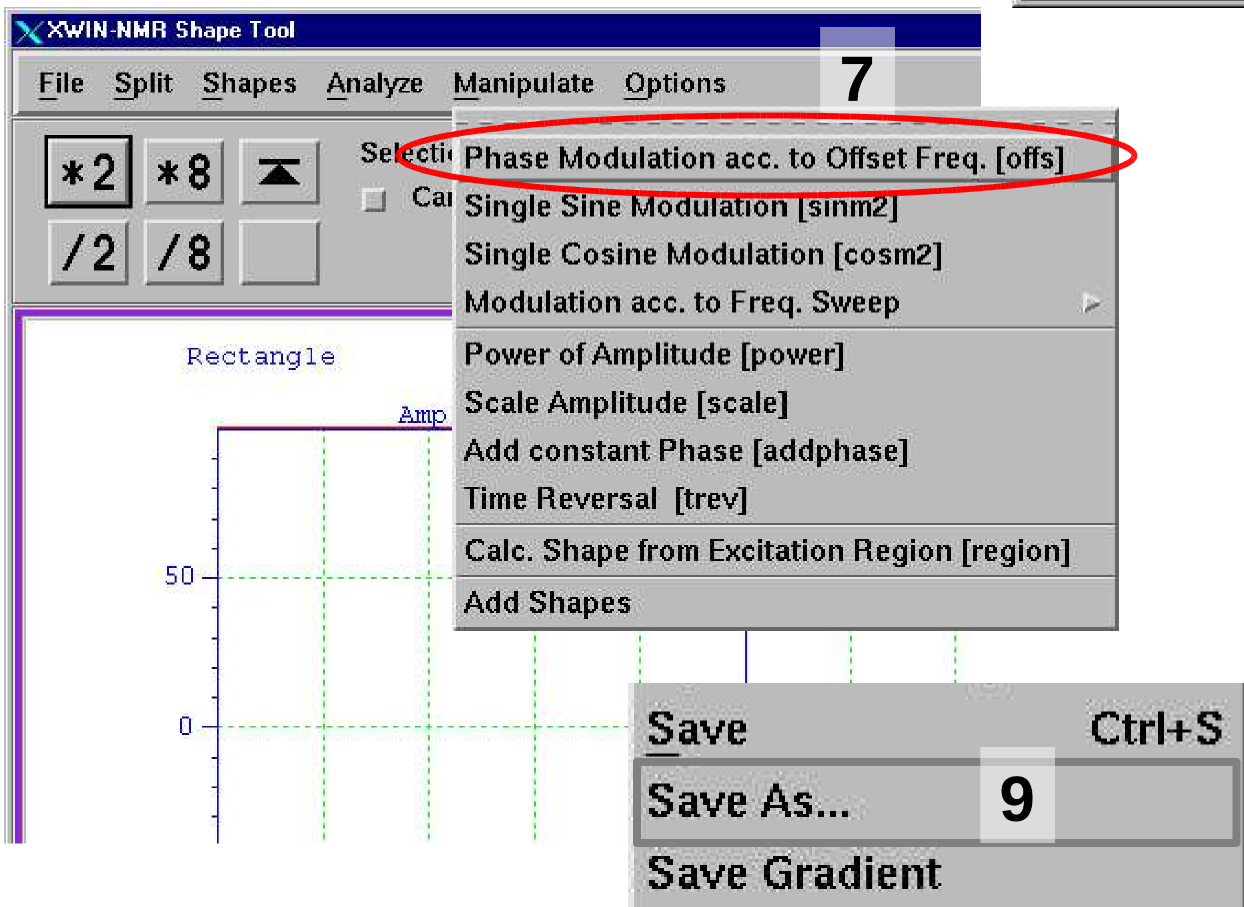
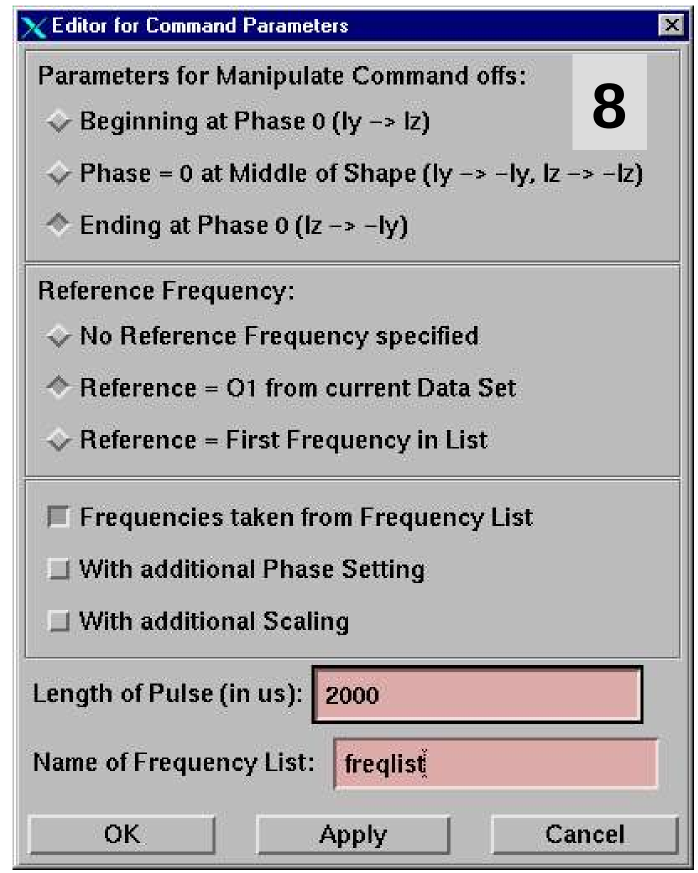
select Shapes → e.g. Rectangle







Multiple Solvent Suppression: WET

Water suppression **E**nhanced through **T**1 effects

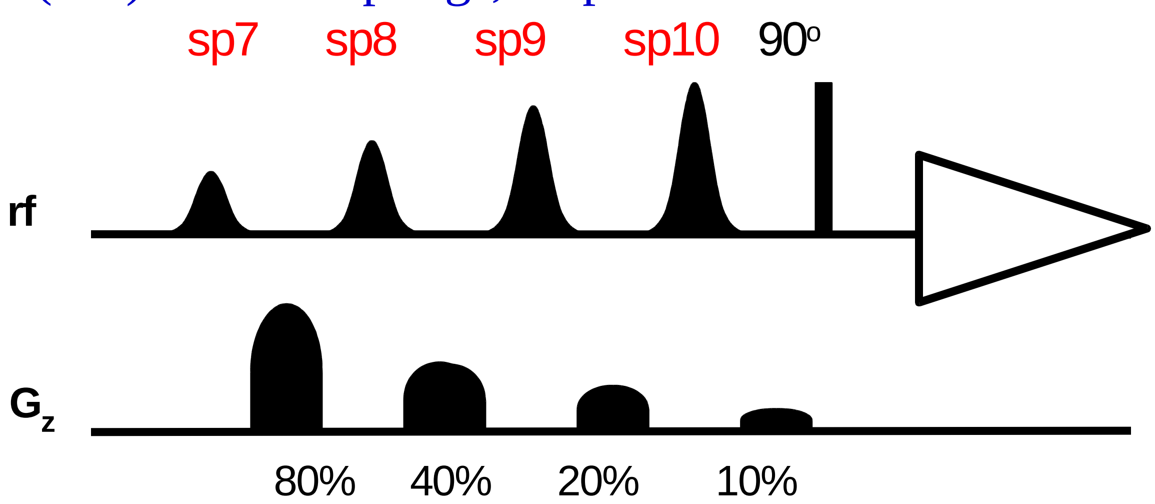
- transferring solvent magnetization to the transverse plane and
- dephasing this solvent magnetization prior to the excitation of the sample magnetization

⇒ 4 *pulse-gradient* units to reduce recovered solvent magnetization (recovery based on T1 relaxation during dephasing gradients).

- Multiple solvent suppression by using off-resonance phase shifted pulses (shifted laminar pulses, SLP)

Gradients and selective pulses: ***BEFORE*** excitation

⇒ no evolution of $^3J(HH)$ scalar couplings, no phase errors.



Multiple Solvent Suppression: WET

WET is commonly used in LC-NMR,
often with 13C decoupling during WET and during acquisition.

pulse program	**lc1wet,**	(1D-NMR with WET, dc = decoupling)
	lc1wetdc or lc1wetdw	
	wt	(nD-experiments using WET)
WET shape pulse length	**p11**	(= 15 - 25 ms)
power level for WET pulses	**sp7**	sp1 + 0.87 dB
	sp8	sp1 - 1.04 dB
	sp9	sp1 + 2.27 dB
	sp10	sp1 - 5.05 dB
shape for WET pulse	**spnam7-10**	gauss or sinc pulse, manipulate with solvent freqlist in stdisp
reference power level for WET	**sp1**	90° gauss or sinc pulse, calculate power

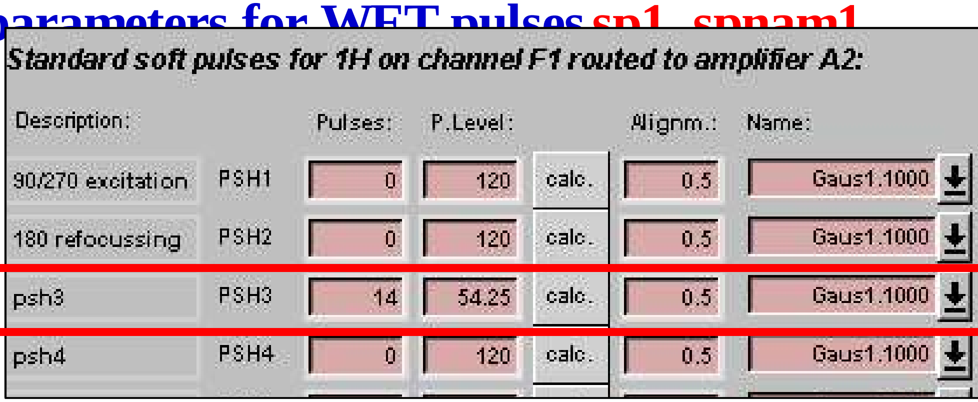
Numbers originate from numeric solutions of Bloch equations with average values for T1 (applies to sp7–sp10)

Multiple Solvent Suppression: WET

WET can be set up automatically, start with **xaua**

Parameter set	**LC1DWTDC**	(1D-NMR with WET using lc1wetdc)
Number of solvents to suppress	**l30**	default value in parameter set: 2
parameters for decoupling	**pcpd2**	decoupling pulse length 80 - 100us
	pl12	power level for GARP decoupling
	cpdprg2	GARP
		if no decoupling is desired: pl12 = 120

parameters for WET pulses sp1, spnam1


Standard soft pulses for 1H on channel F1 routed to amplifier A2:

Description:		Pulses:	P.Level:		Alignm.:	Name:
90/270 excitation	PSH1	0	120	calc.	0.5	Gaus1.1000
180 refocussing	PSH2	0	120	calc.	0.5	Gaus1.1000
psh3	PSH3	14	54.25	calc.	0.5	Gaus1.1000
psh4	PSH4	0	120	calc.	0.5	Gaus1.1000

set parameters in edprosol for PSH3[F1]
in *standard soft pulses*: use ca. 20ms
90° gauss or sinc pulse, calculate power
in stdisp, use analyze → integrate
(older instruments: chose a pulse length
in a way that sp1 < 55dB)

Multiple Solvent Suppression: WET

Gradients and selective pulses: ***BEFORE*** excitation

⇒ no evolution of $^3J(HH)$ scalar couplings

⇒ no phase errors.