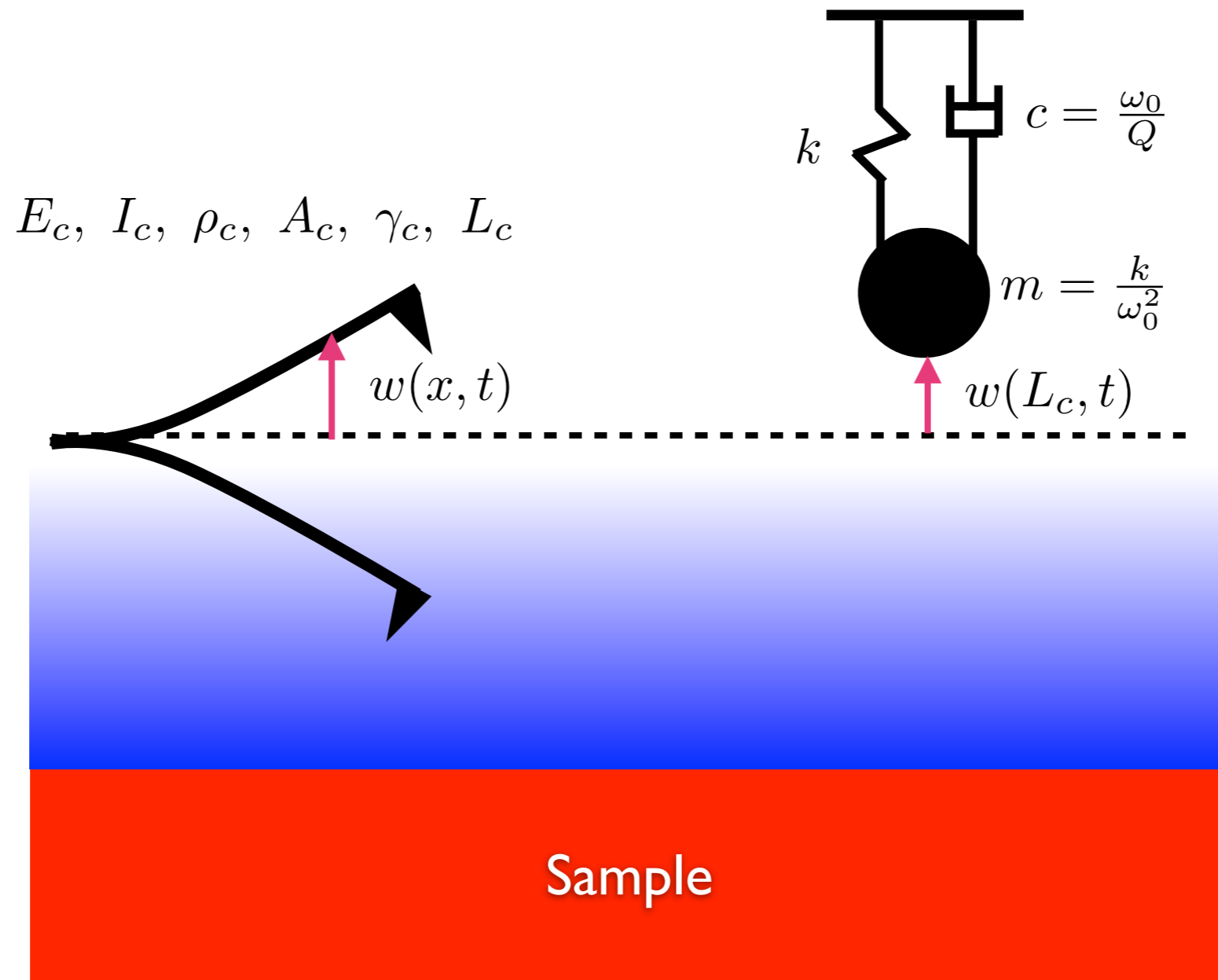


# Dynamic approach curves in AM-AFM

John Melcher  
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# Dynamic AFM in Ambient/UHV



# Tuning curves - inputs

**Application:**  
Frequency Sweep (basic: ambient or UHV only)

**1** Operating conditions and cantilever properties → **2** Tip-sample interaction properties → **3** Simulation ? About this tool Questions?

Choose excitation method: Acoustic excitation

Excitation scheme: Linear Ramp Frequency Sweep

Unconstrained Amplitude (nm): **10**

k1 (N/m): **0.87**

Q1: 33

f1 (kHz): **44**

fd\_start (kHz): **20**

fd\_stop (kHz): **100**

Sweep time (s): **0.3**

Tip mass: **0**

Use setpoint:  no

Set point ratio: **0.9**

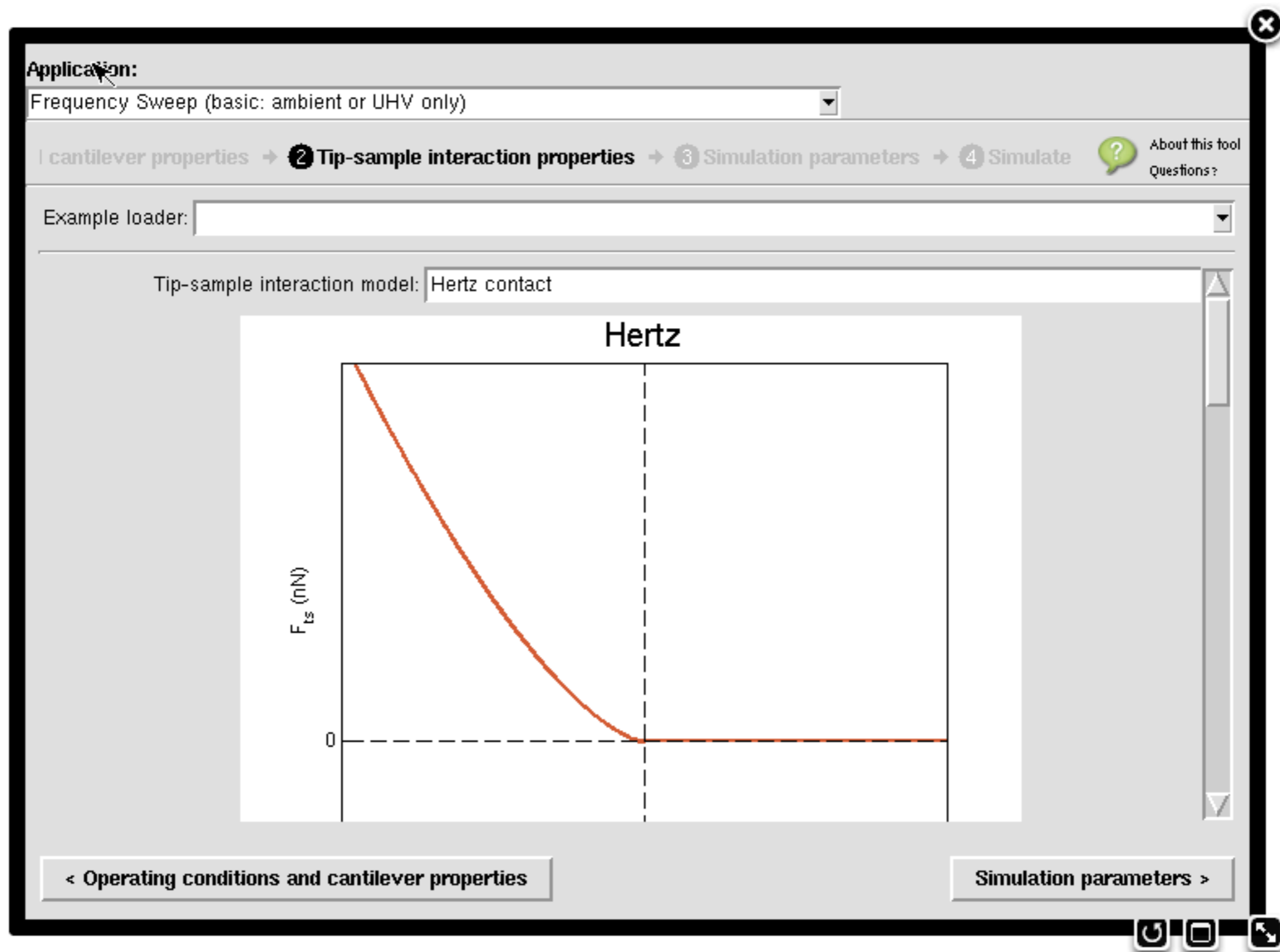
Z separation (nm): **35**

Choose Lock-In Filter Order: 2nd order (40 dB/decade)

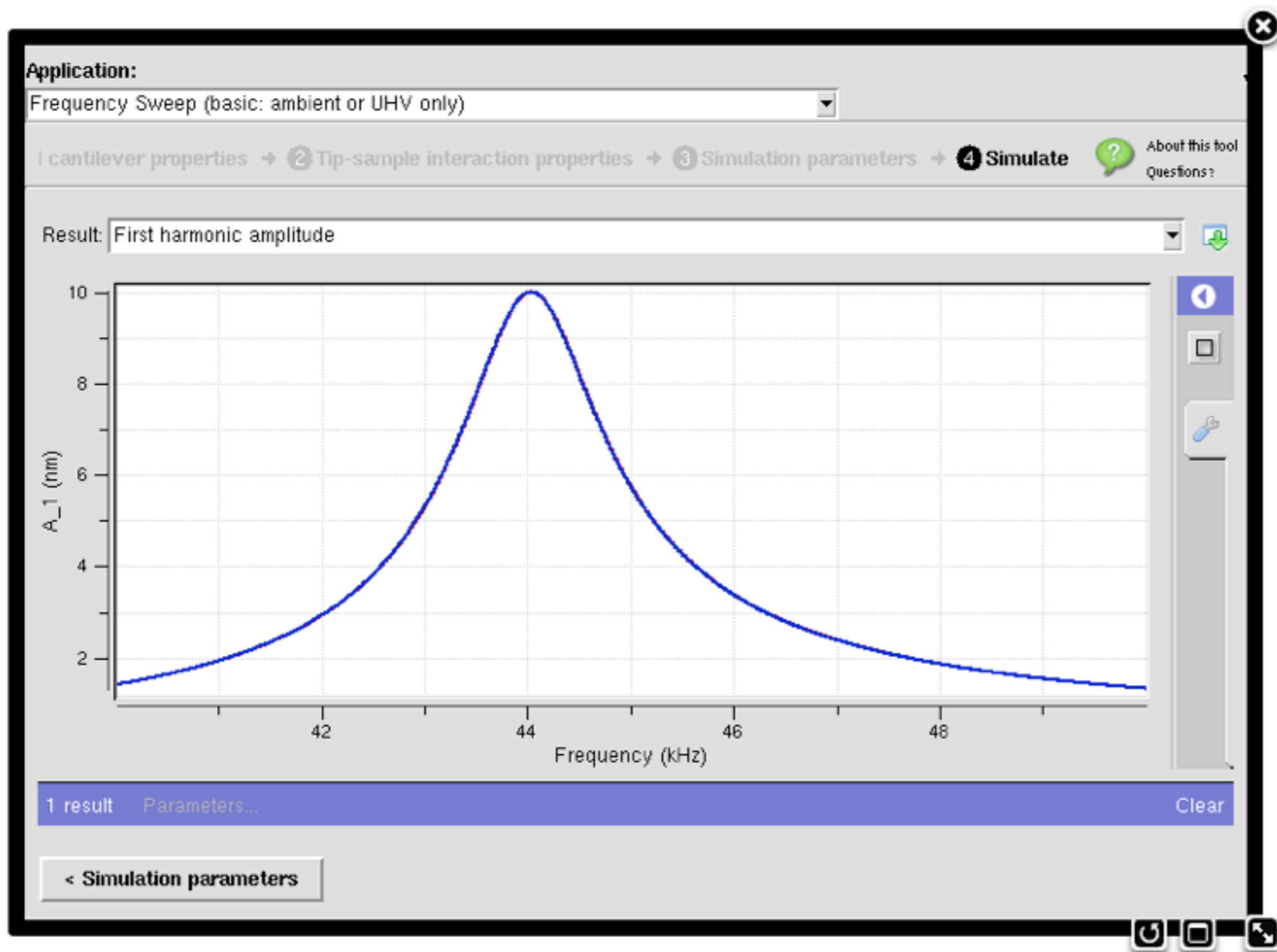
Lock-in time constant: 200 us ( 5 kHz Bandwidth)

[Tip-sample interaction properties >](#)

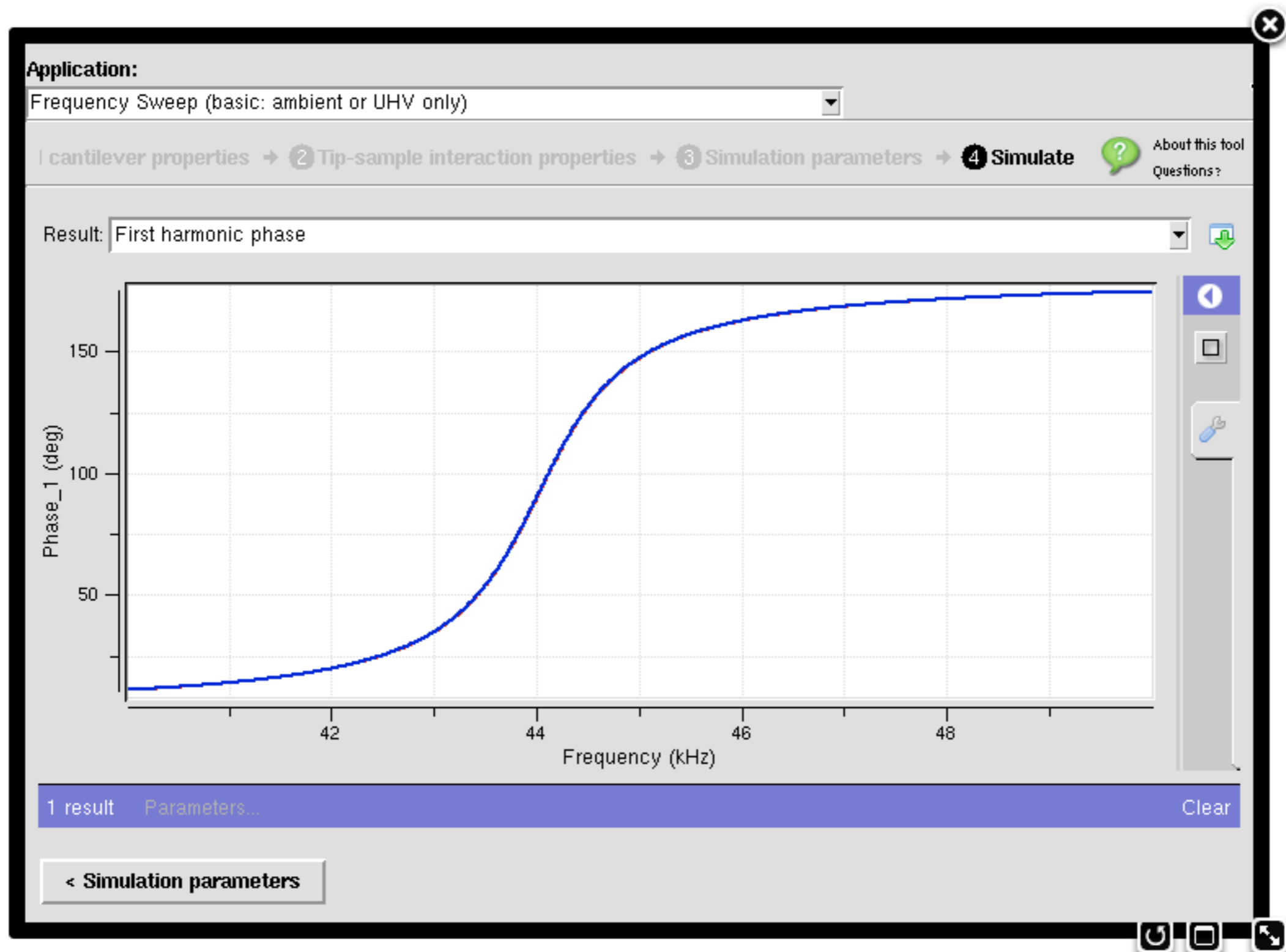
# Tuning curves - inputs



# Tuning curves - outputs

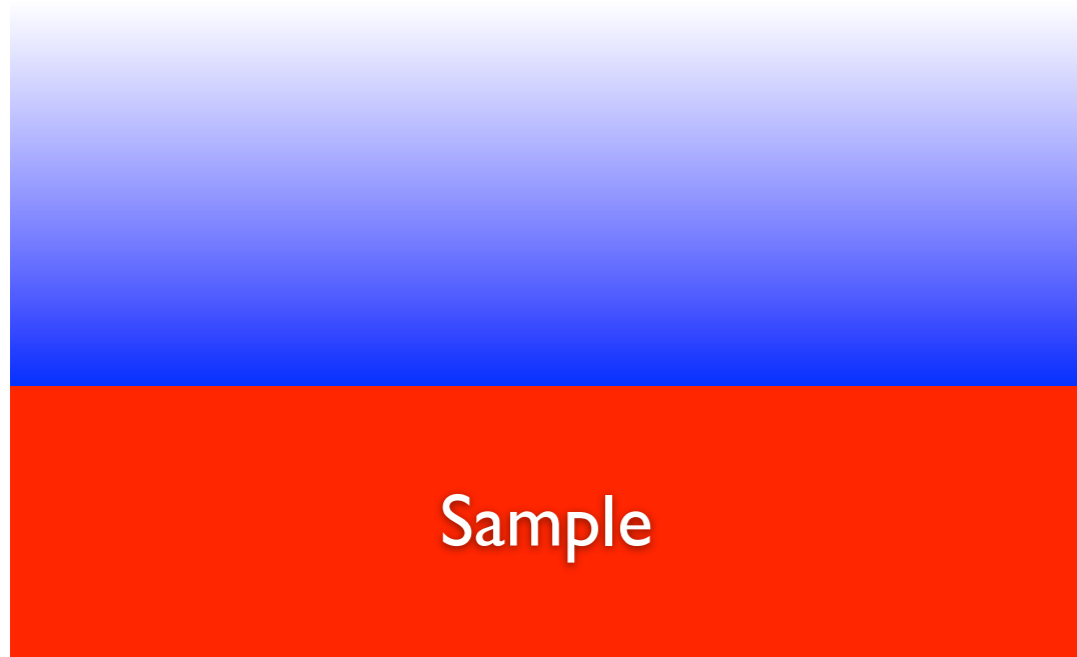


# Tuning curves - outputs

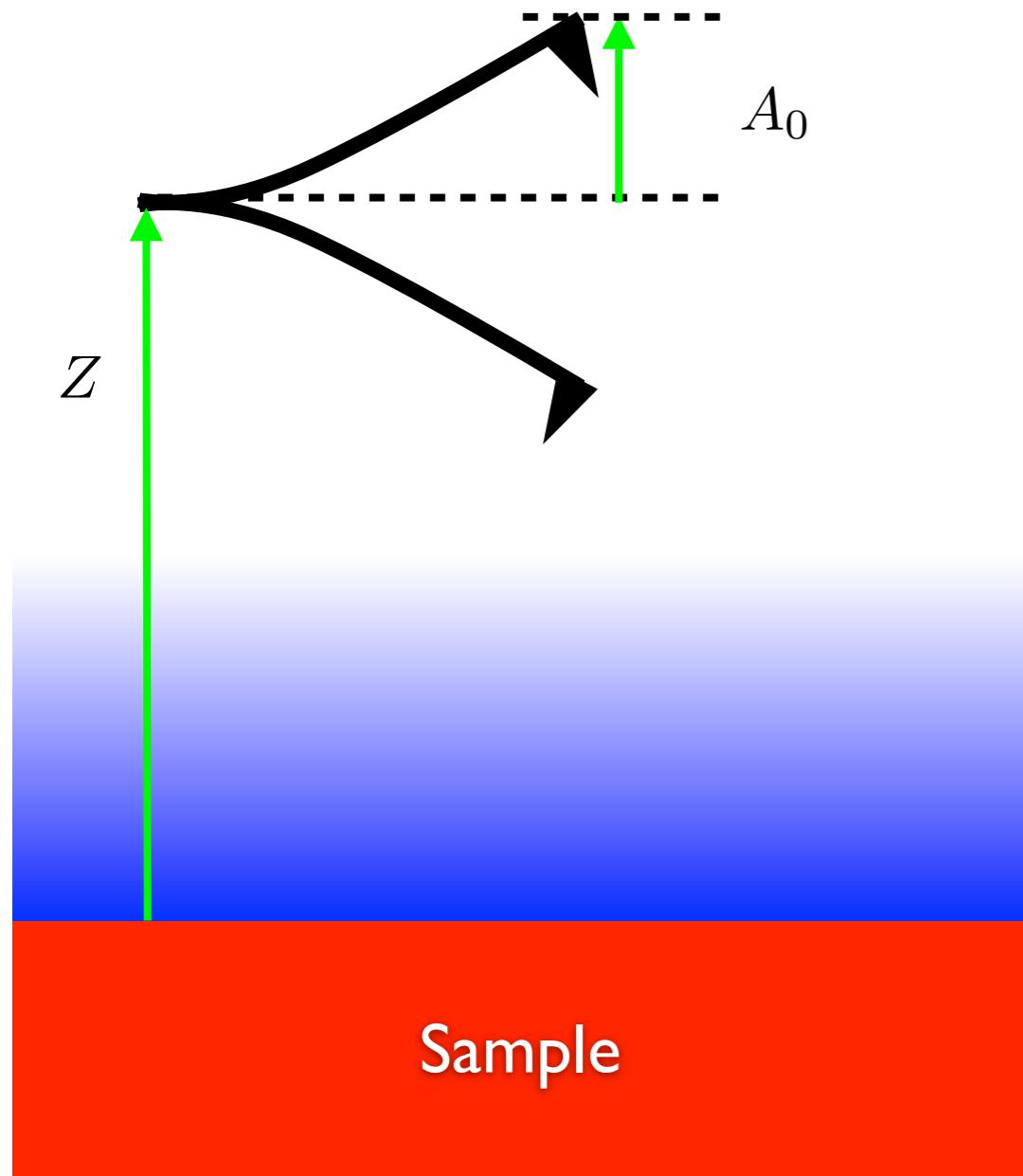


# Dynamic approach curves in AM-AFM

(no feedback regulation)



# Dynamic approach curves in AM-AFM (no feedback regulation)



Experimental observables:

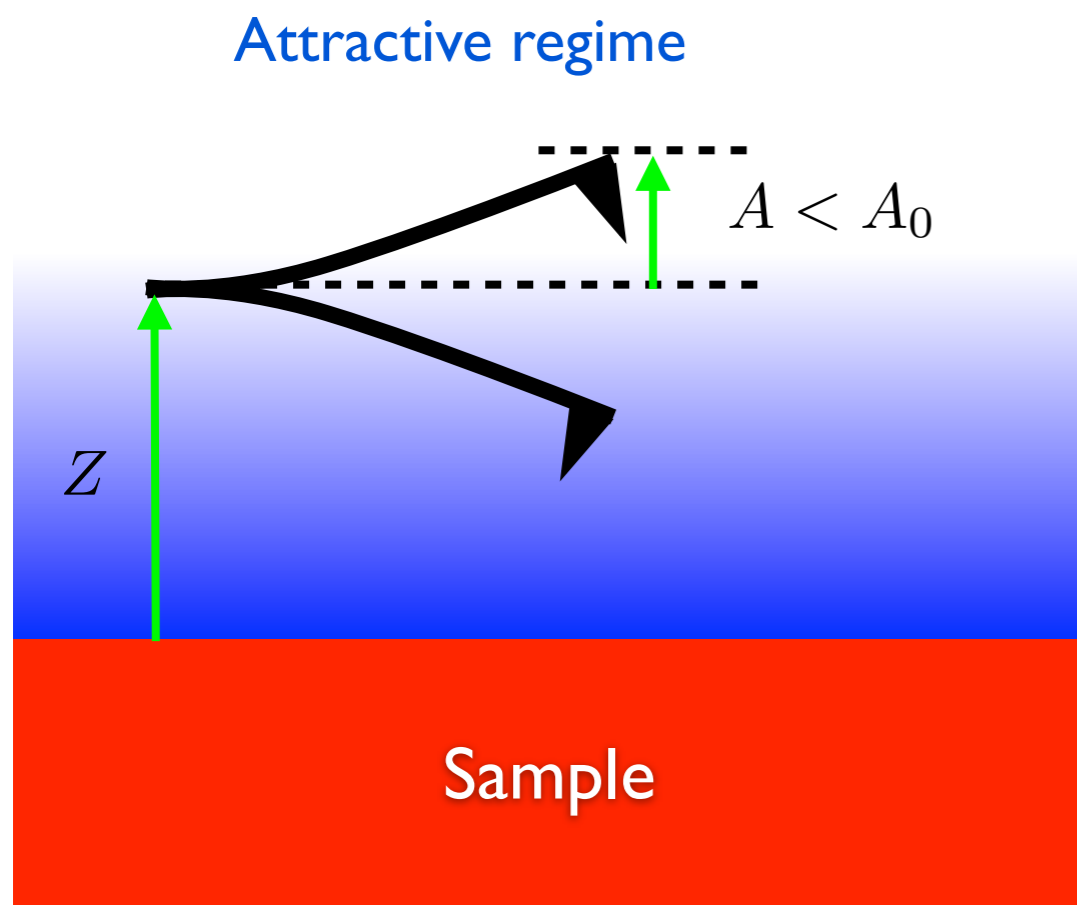
$Z$  : base displacement

$A_0$  : unconstrained amplitude

$\phi_0$  : unconstrained phase



# Dynamic approach curves in AM-AFM (no feedback regulation)



## Experimental observables:

- $Z$  : base displacement
- $A_0$  : unconstrained amplitude
- $\phi_0$  : unconstrained phase
- $A$  : reduced amplitude
- $\phi$  : phase

# Dynamic approach curves in AM-AFM (no feedback regulation)

Experimental observables:

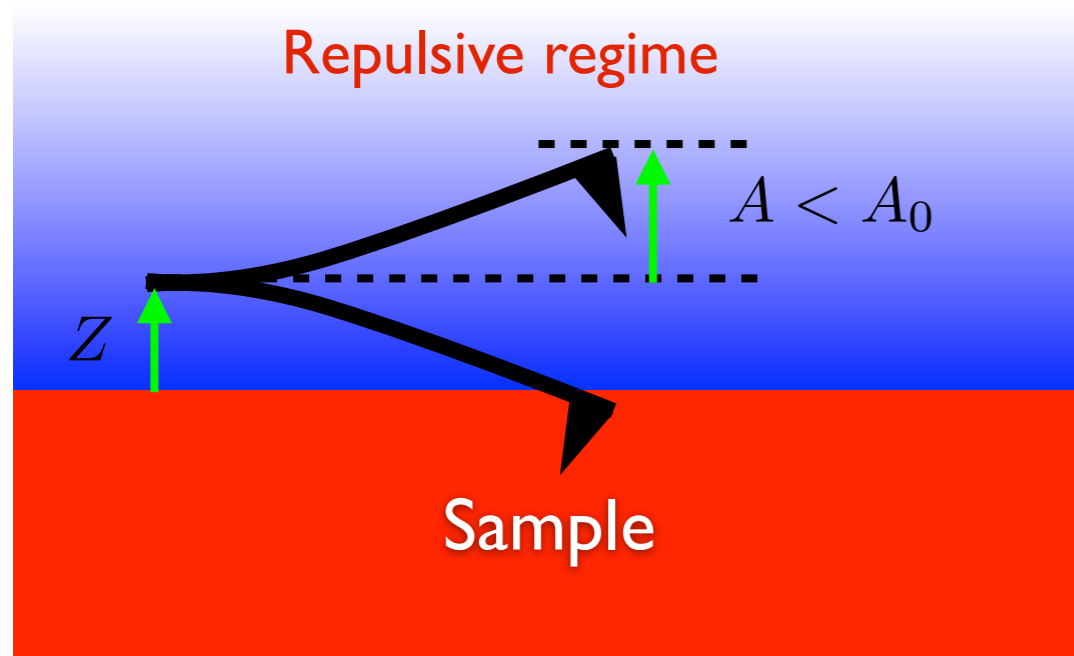
$Z$  : base displacement

$A_0$  : unconstrained amplitude

$\phi_0$  : unconstrained phase

$A$  : reduced amplitude

$\phi$  : phase



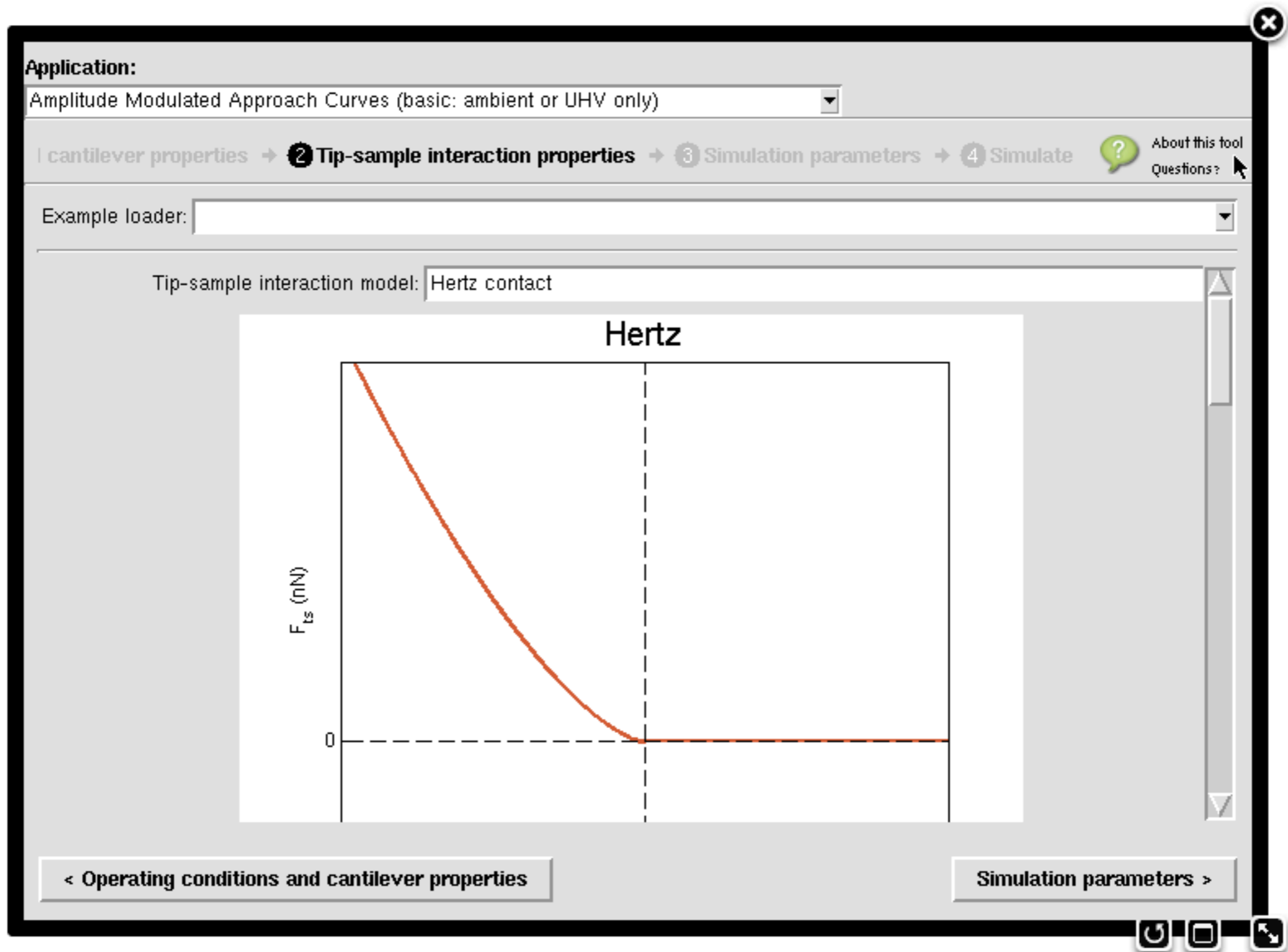
# AM-AFM Approach Curves: Example 1

The screenshot shows a software interface for simulating AM-AFM approach curves. The main window is titled "Application:" and contains a dropdown menu set to "Amplitude Modulated Approach Curves (basic: ambient or UHV only)". Below this, there are three numbered steps: "1 Operating conditions and cantilever properties", "2 Tip-sample interaction properties", and "3 Simulation". A "About this tool Questions?" link is also present. The "Example loader:" dropdown is set to "AMAC Example 1: Attractive and repulsive regimes of oscillation". The simulation parameters are as follows:

Unconstrained Amplitude (nm):	10
k (N/m):	0.87
Q:	33
f (kHz):	44
fd (kHz):	44
Z approach velocity (nm/s):	100
Specify Z range:	<input checked="" type="checkbox"/> yes
Initial Z separation (nm):	15
Final Z separation (nm):	0

At the bottom right, there is a button labeled "Tip-sample interaction properties >". The interface also includes standard window controls (refresh, close, maximize) in the bottom right corner.

# AM-AFM Approach Curves: Example 1



# AM-AFM Approach Curves: Example I

**Application:**  
Amplitude Modulated Approach Curves (basic: ambient or UHV only)

1 cantilever properties → 2 Tip-sample interaction properties → **3 Simulation parameters** → 4 Simulate ? About this tool Questions?

Number of points plotted:

Deflection points per cycle:

Plot a higher harmonic?:  no

Number of higher harmonics:

Choose higher harmonics:

Include time histories:  yes




Number of time histories:

Choose amplitude ratio(s):

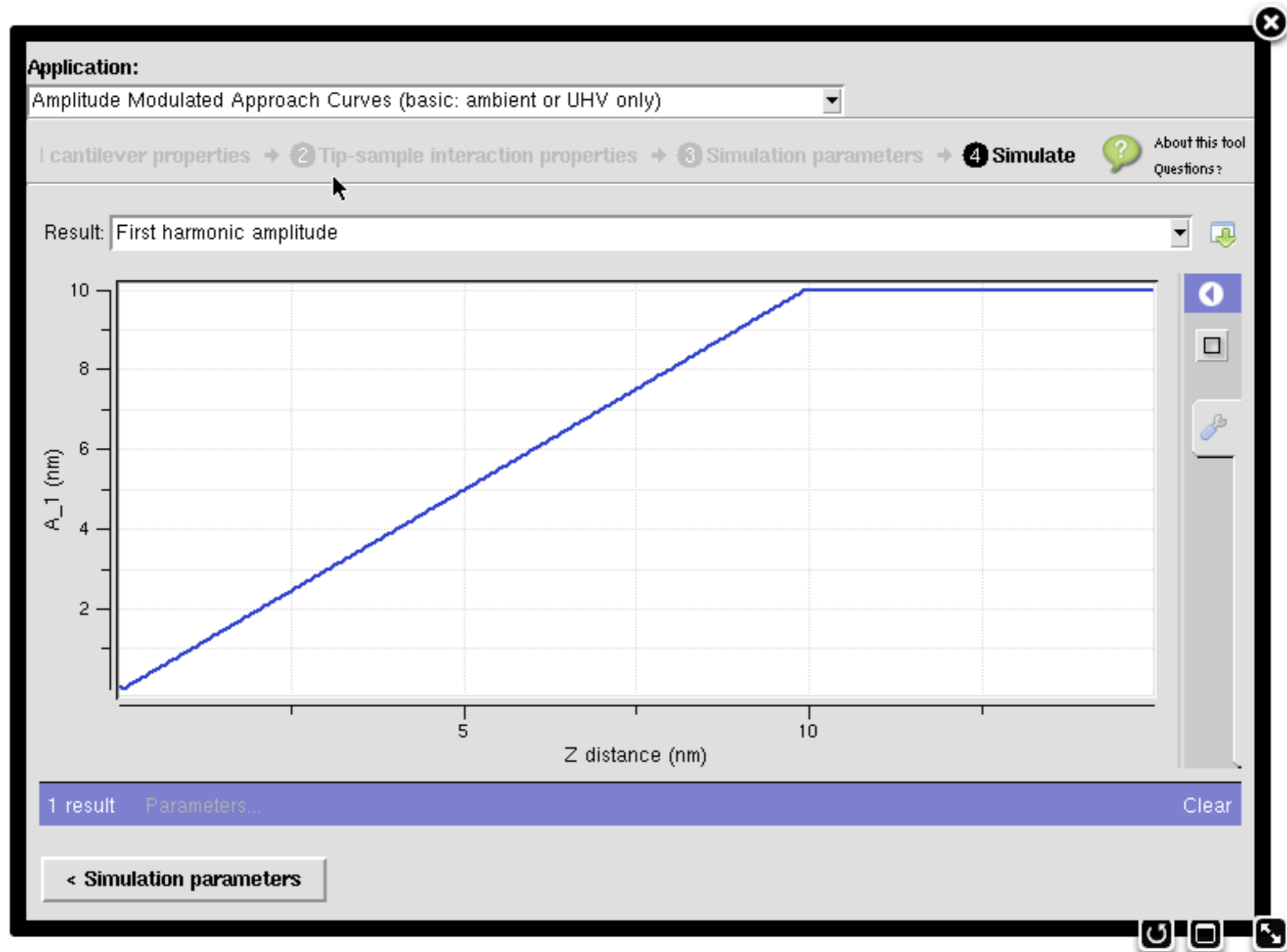
Number of cycles:

Choose X-axis variable:

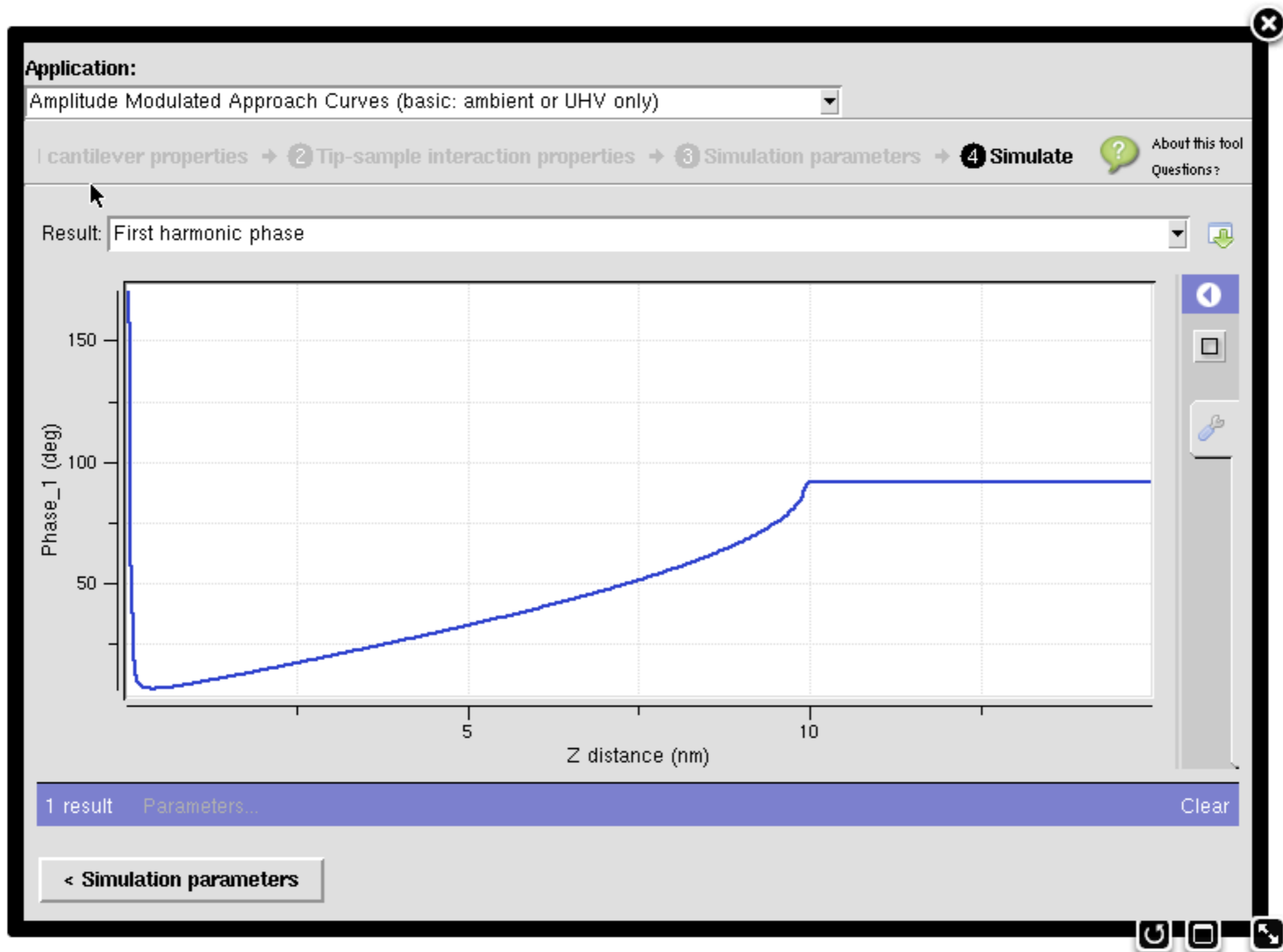
(Note: Scroll up to see simulation tabs)

# AM-AFM Approach Curves: Example 1



# AM-AFM Approach Curves: Example 1



# AM-AFM Approach Curves: Example I

**Question:** At what amplitude ratio are peak forces maximized?



# AM-AFM Approach Curves: Example I

**Question:** At what amplitude ratio are peak forces maximized?

**Application:**  
Amplitude Modulated Approach Curves (basic: ambient or UHV only)

1 cantilever properties → 2 Tip-sample interaction properties → **3 Simulation parameters** → 4 Simulate ? About this tool Questions?

Number of points plotted: 500  
Deflection points per cycle: 500  
Plot a higher harmonic?:  no  
Number of higher harmonics: 2  
Choose higher harmonics: 7,9  
Include time histories:  yes  
Number of time histories: 3  
Choose amplitude ratio(s): 0.9,0.8,0.5  
Number of cycles: 5  
Choose X-axis variable: **Amplitude ratio**

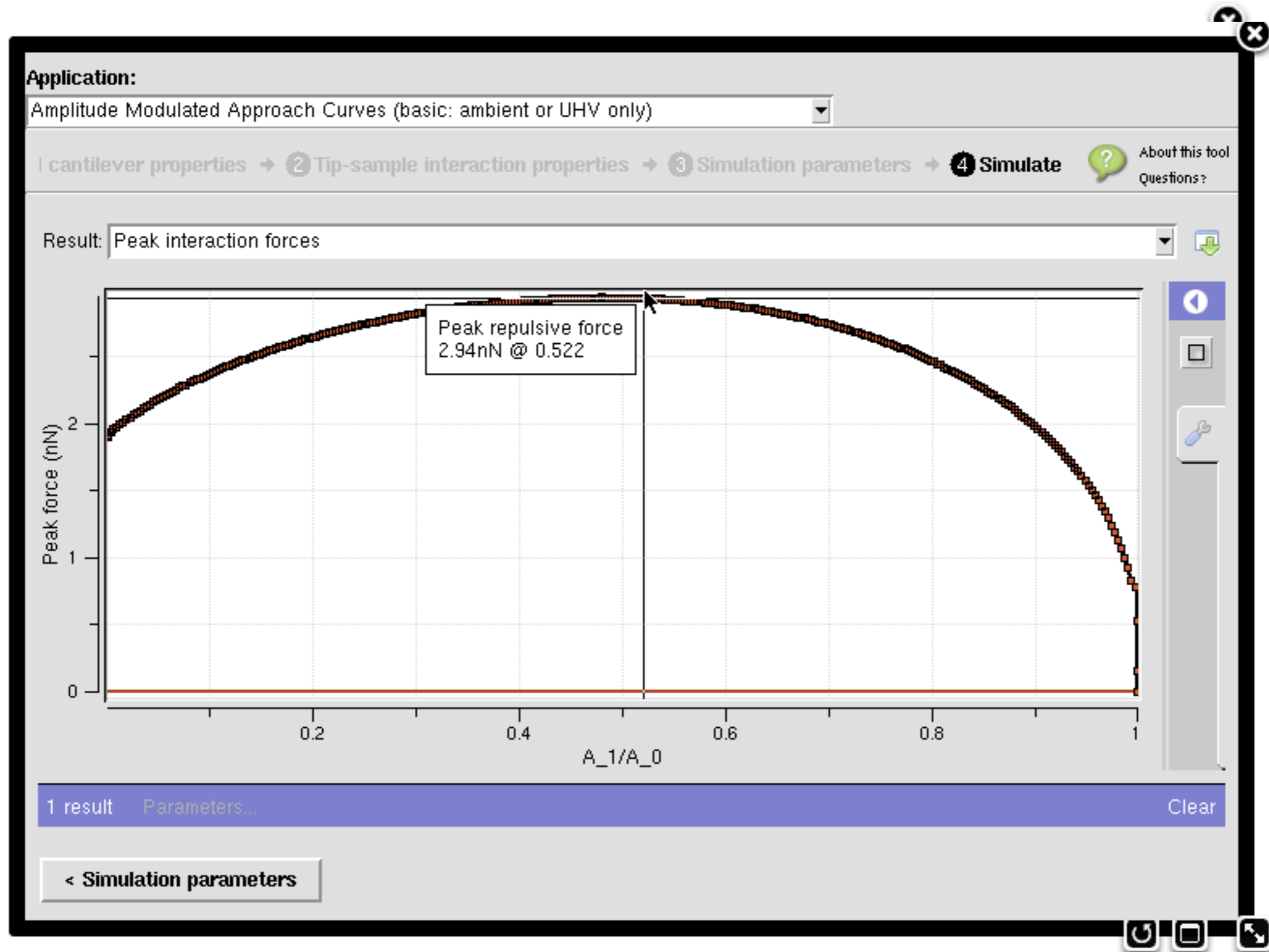
(Note: Scroll up to see simulation tabs)

< Tip-sample interaction properties Simulate >

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# AM-AFM Approach Curves: Example I

**Question:** At what amplitude ratio are peak forces maximized?



# AM-AFM Approach Curves: Example I

The screenshot shows a software interface for simulating AM-AFM approach curves. The application is set to "Amplitude Modulated Approach Curves (basic: ambient or UHV only)". The current step in the workflow is "2 Tip-sample interaction properties", with other steps being "1 cantilever properties", "3 Simulation parameters", and "4 Simulate".

Under the "Non-conservative forces" section, the following parameters are visible:

- Non-conservative solvation forces (viscous):  no
- Scaling (kg/s): 1e-05
- Decay (nm): 1
- Include sample visco-elastic forces?: Kelvin-Voigt viscoelasticity (enter viscosity directly)
- Sample viscosity (Pa-s): 1000
- Loss modulus (GPa): 10
- Kelvin-voigt viscoelasticity damping coefficient (N-s/m): 0
- Include capillary forces?:  no
- Critical gap, D\_0 (nm): 0.6
- Energy dissipated, dE (eV): 5

A warning message is displayed: "WARNING The model used for dynamic elastic modulus (Loss modulus) is an approximation. Make sure you know and understand the limitations of this approximation before using it. Improper use may lead to significant errors depending on the sample. See the manual for more detail."

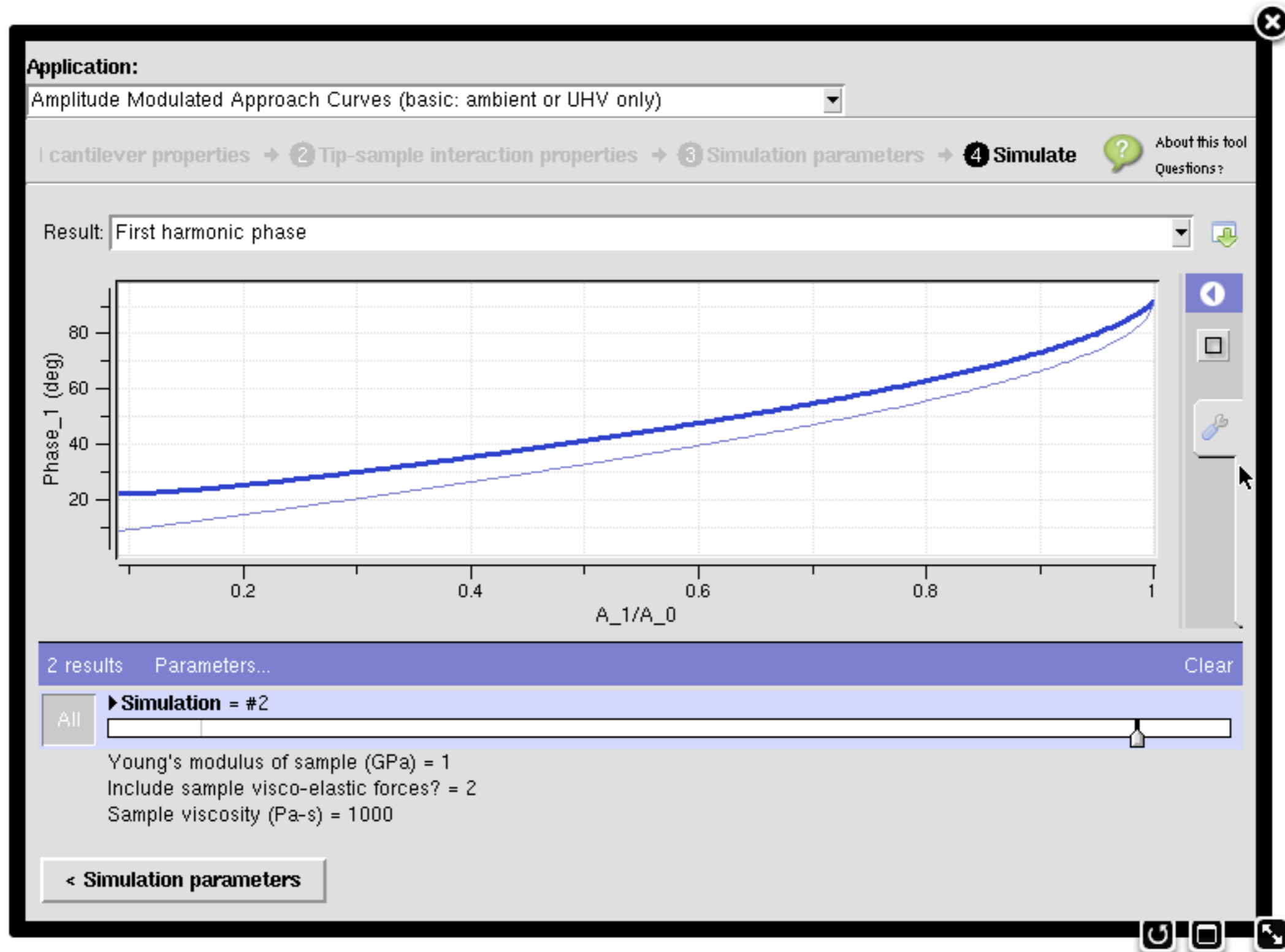
Navigation buttons at the bottom include "< Operating conditions and cantilever properties" and "Simulation parameters >".

# AM-AFM Approach Curves: Example 1

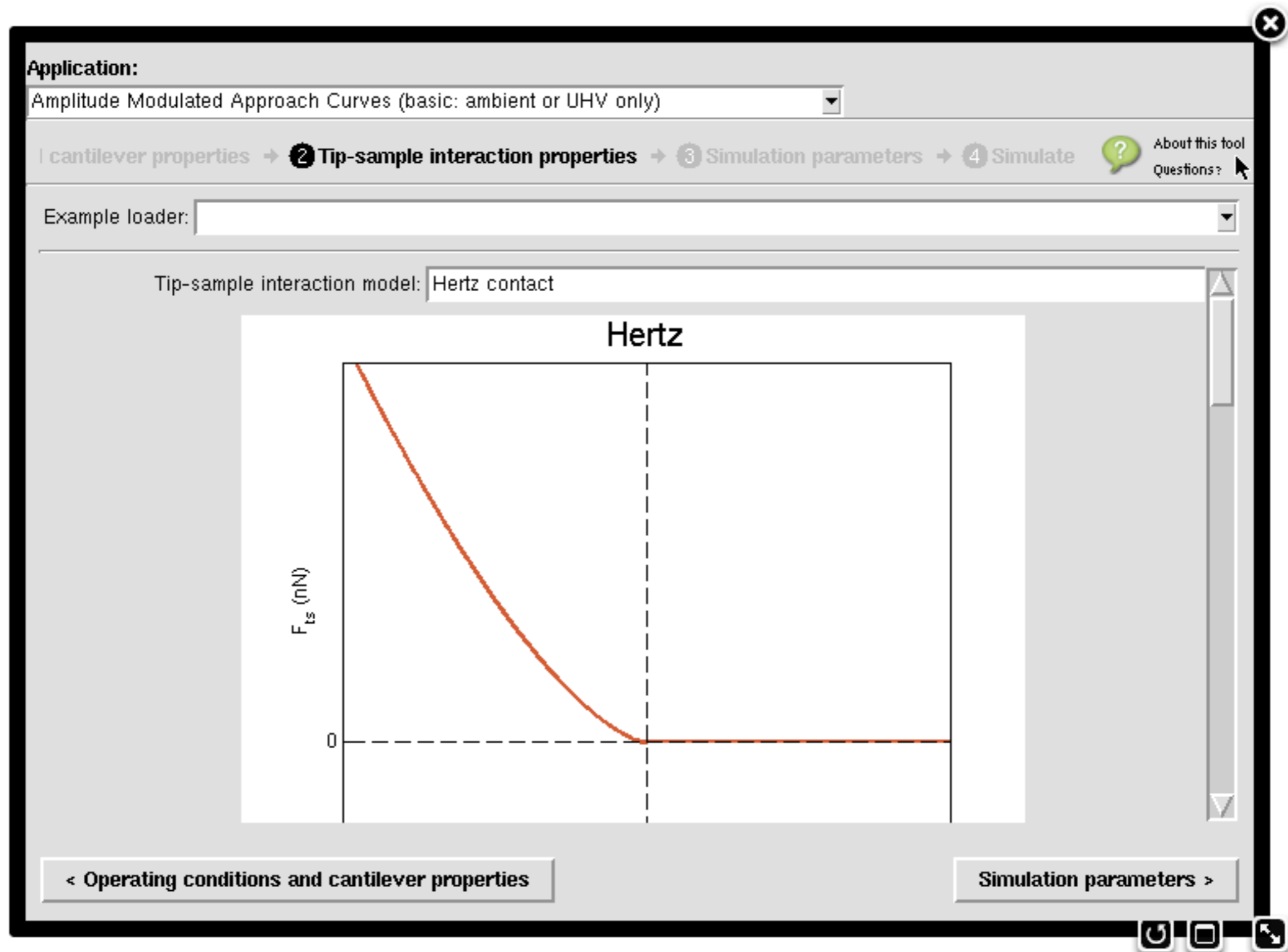
**Question:** What amplitude ratio should we choose in order to enhance phase contrast?

# AM-AFM Approach Curves: Example I

**Question:** What amplitude ratio should we choose in order to enhance phase contrast?



# AM-AFM Approach Curves: Example 2



# AM-AFM Approach Curves: Example 2

**Application:**  
Amplitude Modulated Approach Curves (basic: ambient or UHV only)

1 cantilever properties → 2 Tip-sample interaction properties → **3 Simulation parameters** → 4 Simulate ? About this tool  
Questions?

Number of points plotted: **500**

Deflection points per cycle: **500**

Plot a higher harmonic?:  no

Number of higher harmonics: **2**

Choose higher harmonics: **7,9**

Include time histories:  yes

Number of time histories: **3**




Choose amplitude ratio(s): **0.8,0.3,0.1**

Number of cycles: **6**

Choose X-axis variable: **Amplitude ratio**

(Note: Scroll up to see simulation tabs)

[< Tip-sample interaction properties](#) [Simulate >](#)

# AM-AFM Approach Curves: Example 2

**Application:**  
Amplitude Modulated Approach Curves (basic: ambient or UHV only)

1 **Operating conditions and cantilever properties** → 2 Tip-sample interaction properties → 3 Simulation ? About this tool  
Questions?

Example loader: AMAC Example 1: Attractive and repulsive regimes of oscillation

Unconstrained Amplitude (nm): **10**

k (N/m): **0.87**

Q: 33

f (kHz): 44

fd (kHz): 44

Z approach velocity (nm/s): **100**

Specify Z range:  **yes**

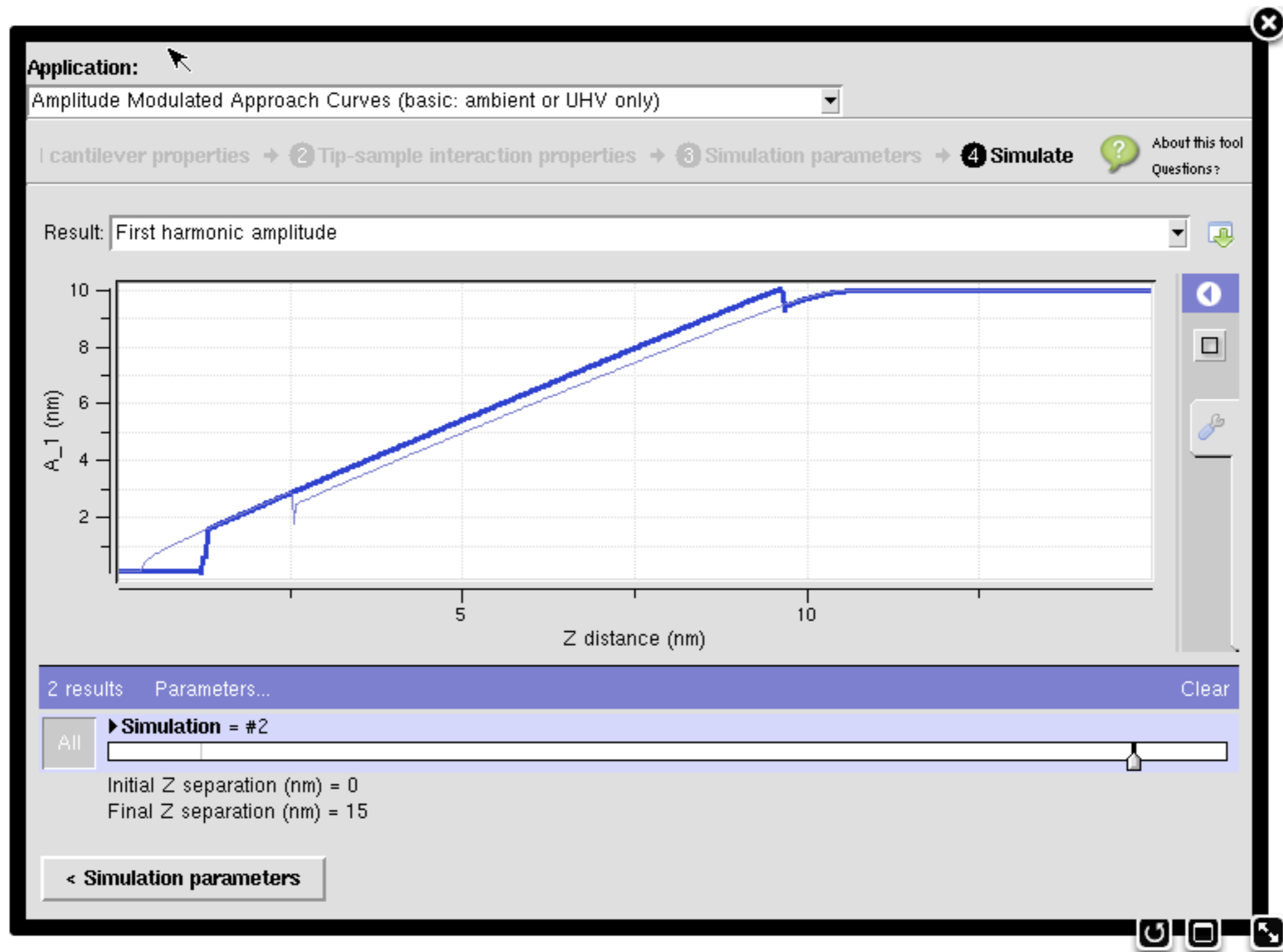
Initial Z separation (nm): **15**

Final Z separation (nm): **0**

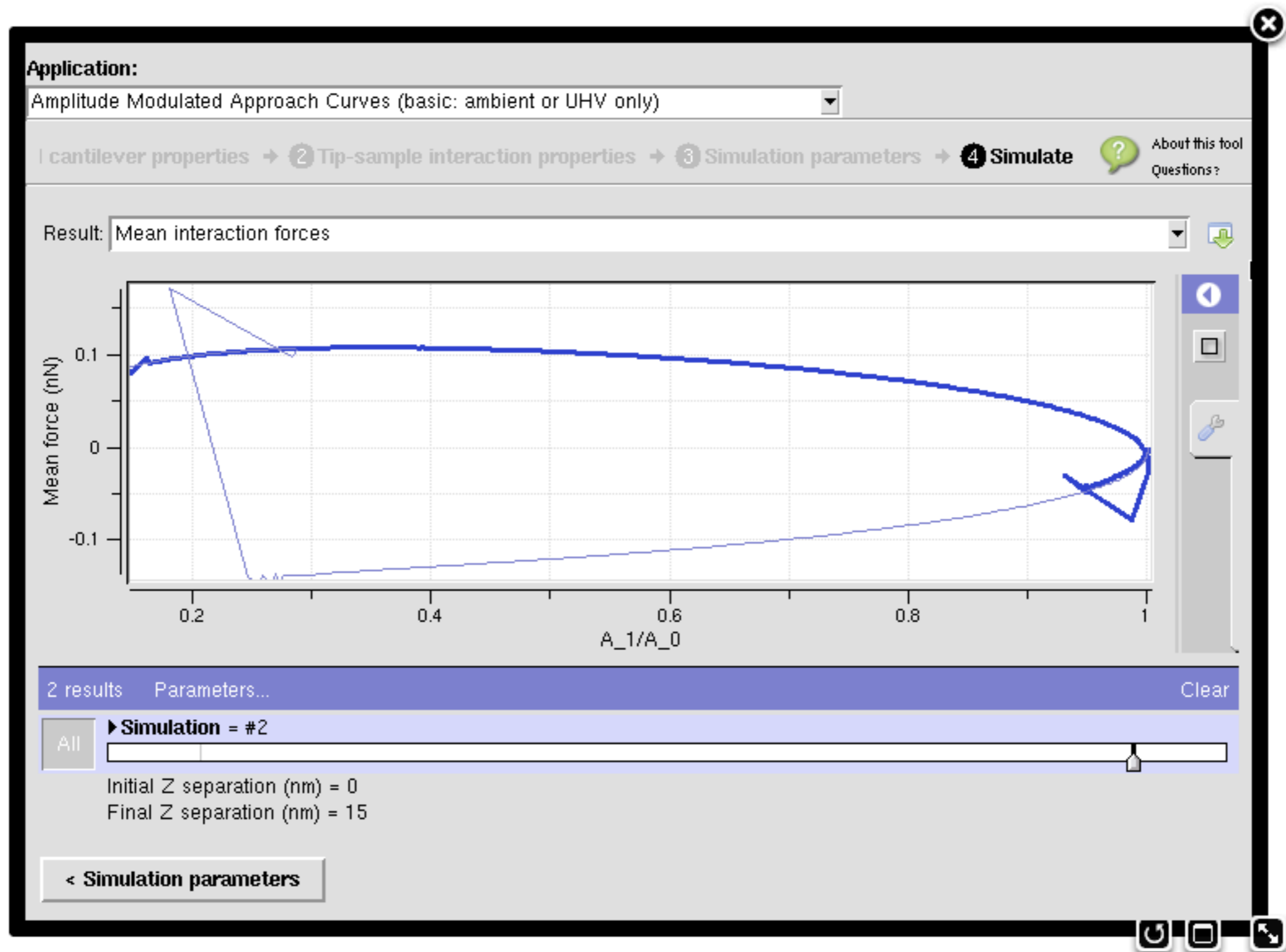
Tip-sample interaction properties >



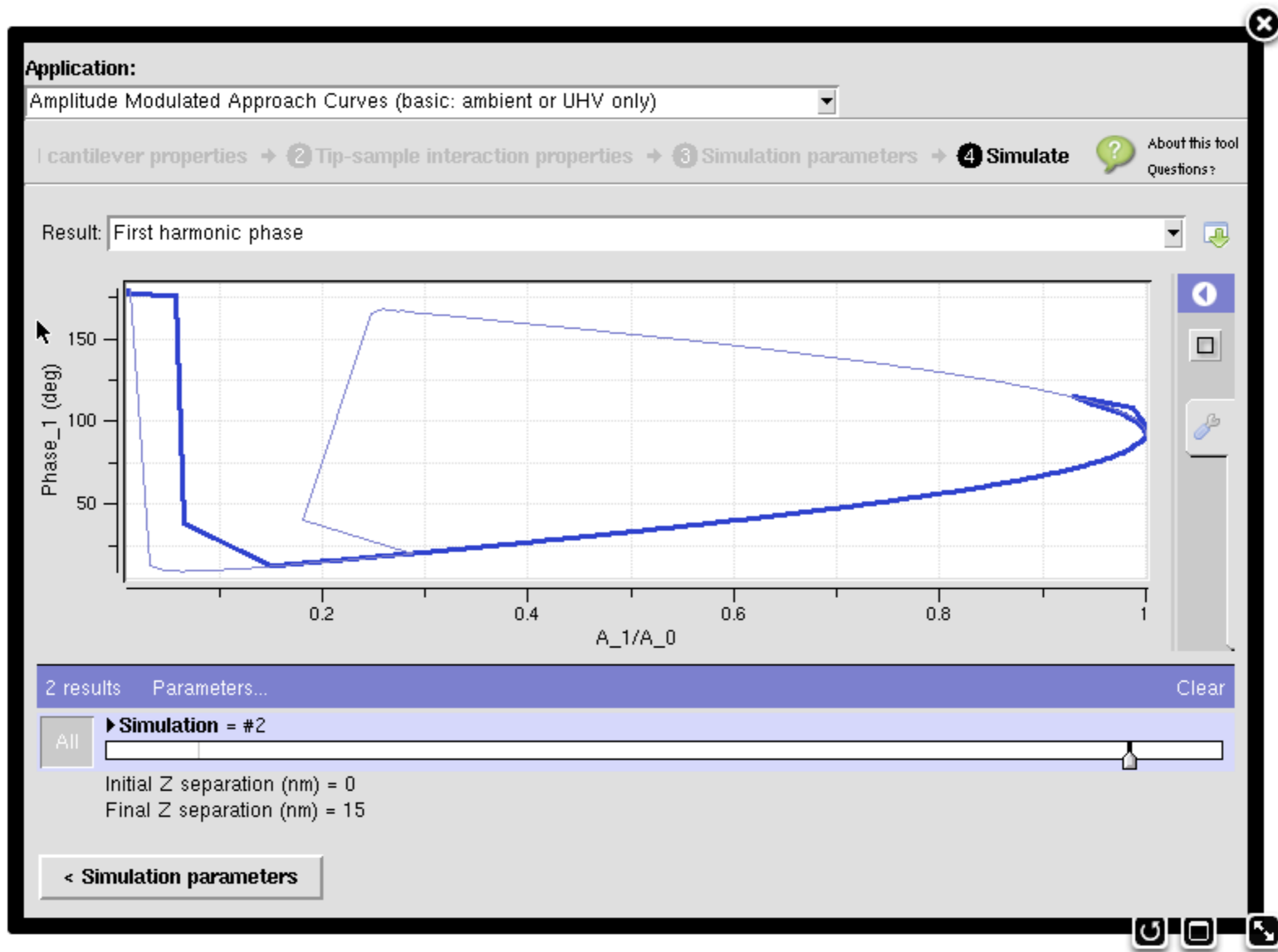
# AM-AFM Approach Curves: Example 2



# AM-AFM Approach Curves: Example 2



# AM-AFM Approach Curves: Example 2



# AM-AFM Approach Curves: Example 2

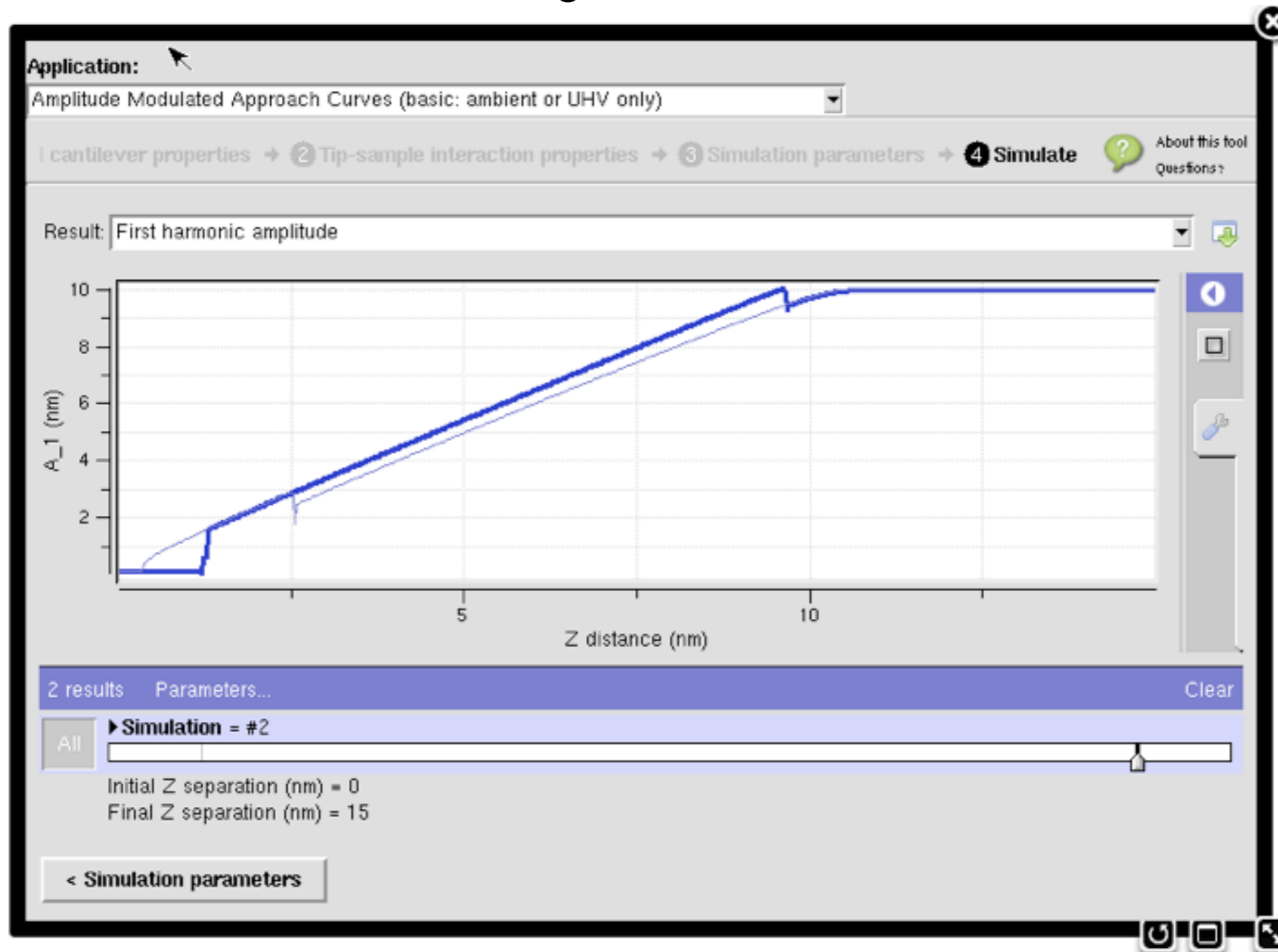
## Questions:

1. What amplitude ratio (set-point) should we choose in order to image in a monostable regime.
2. What kind of artifacts can occur in the topography for an imaging set-point in a bistable regime?
3. What can we do to reduce the bistable regime?

# AM-AFM Approach Curves: Example 2

## Questions:

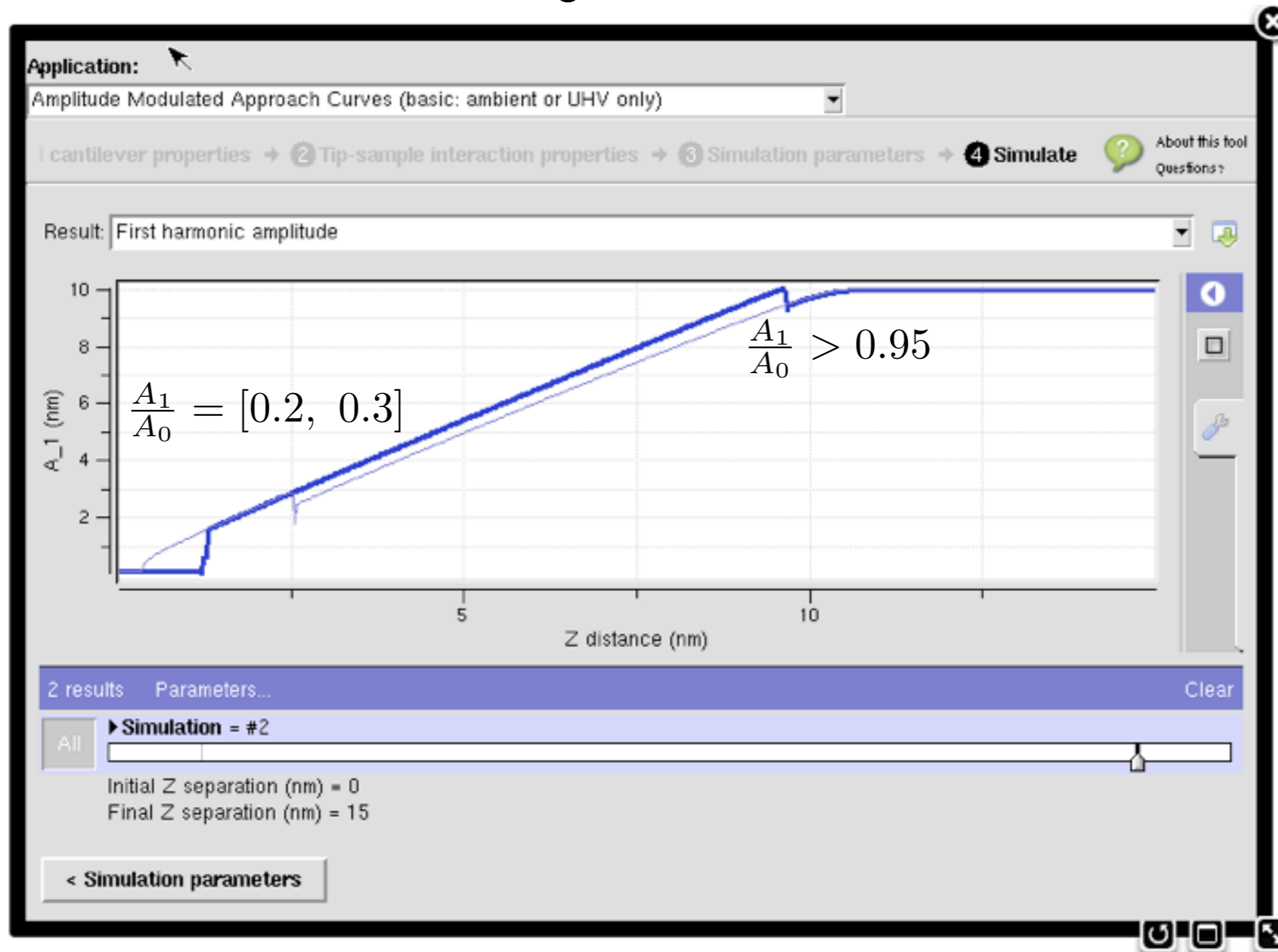
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# AM-AFM Approach Curves: Example 2

## Questions:

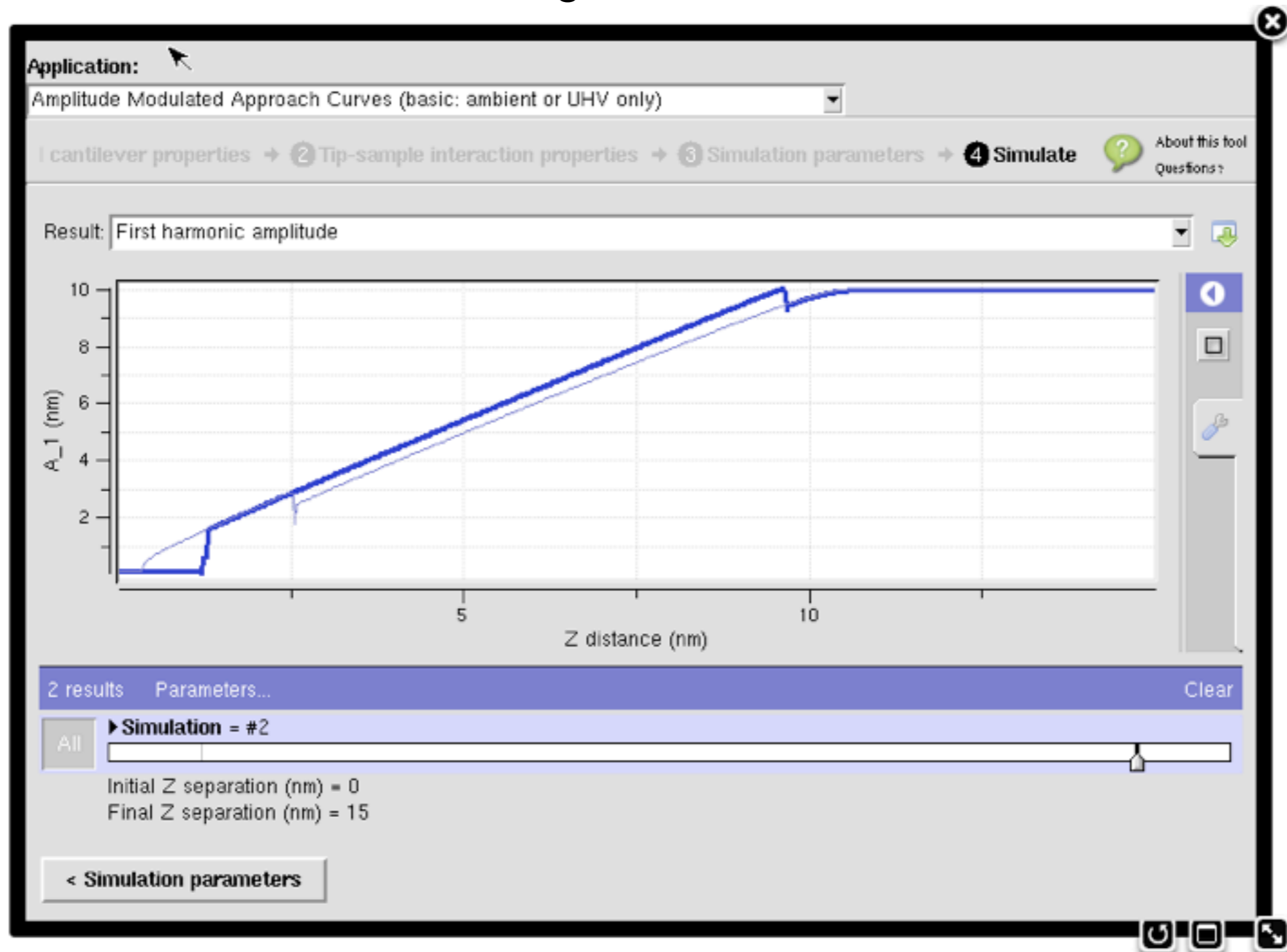
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