

# Simulating muon spins - QUANTUM

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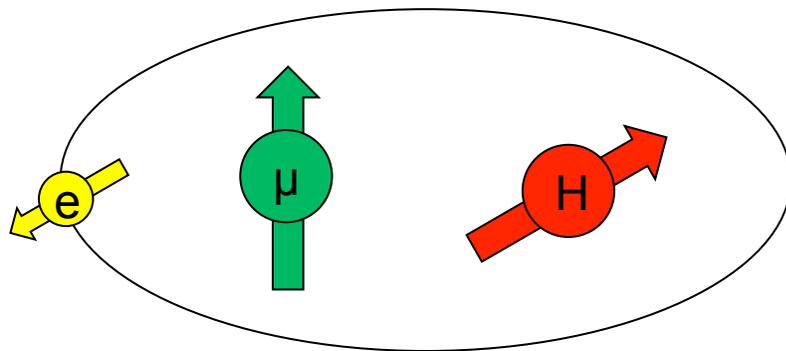


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# The problem

- Muon + nearby nuclei and electrons
- Variety of interactions
  - dipolar, hyperfine, quadrupole
- Static and RF magnetic fields
- Diffusion
- How does the muon's spin evolve?



# Quantum mechanics

- $H\psi = E\psi$

- $P(t) = \langle \psi | S_\mu | \psi \rangle$

- $\psi = a_1 |\uparrow\uparrow\rangle + a_2 |\uparrow\downarrow\rangle + a_3 |\downarrow\uparrow\rangle + a_4 |\downarrow\downarrow\rangle$

- $H = \begin{vmatrix} a & b & c & d \\ b^* & e & f & g \\ c^* & f^* & h & i \\ d^* & g^* & i^* & j \end{vmatrix}$

- $P(t) = p_1 \cos(\omega_1 t + \phi_1) + p_2 \cos(\omega_2 t + \phi_2) + p_3 \cos(\omega_3 t + \phi_3) \dots$



# A job for a computer!

Details of muon/nucleus/electron spins

The screenshot shows the 'Enter Quantum Parameters' dialog box with several sections circled in red:

- Spin Parameters:** A table with columns for position (X, Y, Z), spin (l, MHz/T), easy axis (x, y, z), Electron?, hyperfine splitting (none, A, D, eta), quadrupole (vQ, eta), Spin flip rate, and Random field.
- Calculation type:** Includes 'Plain calc', 'Max time for plot', 'Measurement', and 'Lifetime'.
- Geometry/Averaging:** Includes options for LF, TF, RF, RRF, ZF Powder, and various averaging methods.
- RF parameters:** Includes 'Frequency', 'Intensity (G)', 'Phase (deg)', and 'RRF Harmonic'.
- Sweep:** Includes options for 'Field', 'Field Angle x-z', '2D Vector field x-z', '2D angle theta/phi', '2D field/angle', '2D freq/angle', 'Field', 'Frequency/Hop rate', 'Temperature', 'Quadrupole', 'HFC spin 3', 'Ionisation relative', and 'Ionisation rate / B1'.

Hyperfine coupling

What to calculate

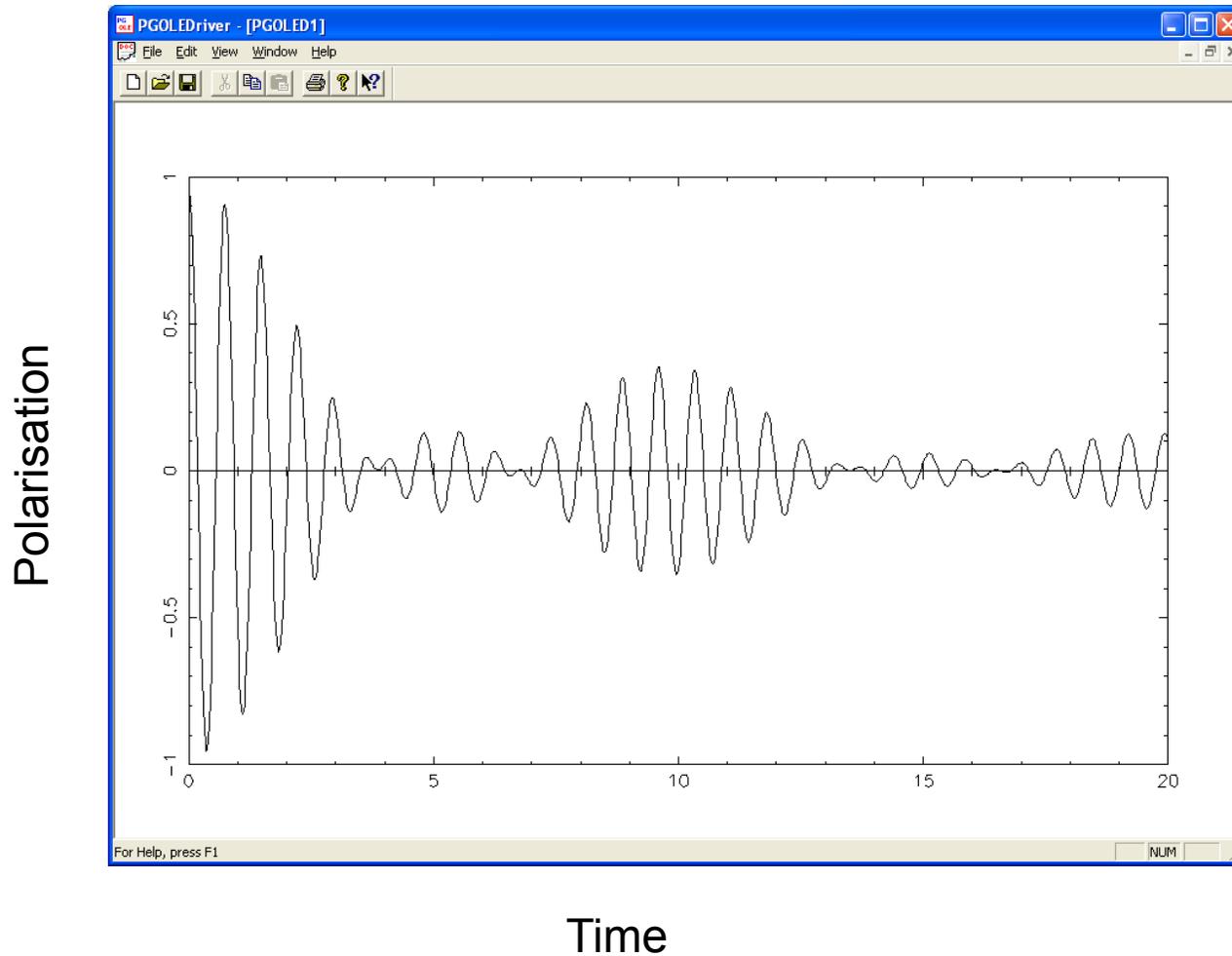
RF settings

LF/TF and powder averaging options

Scan fields or other parameters



# Transverse field spectra

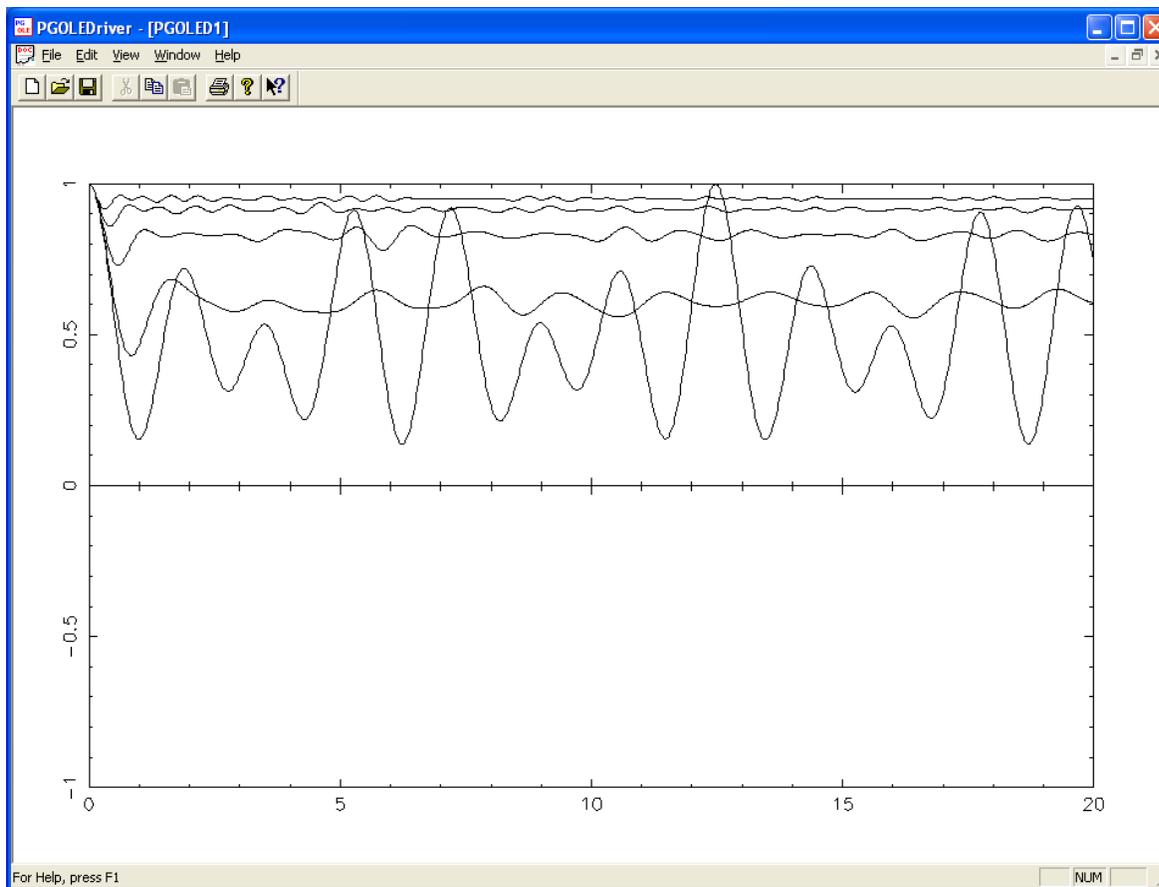


Simulation for CdS including both  $\text{Mu}^+$  and  $\text{Mu}^0$ , with conversion



# Dipolar - $F\mu F$

Polarisation



Longitudinal  
Fields  
0,25,50,75,  
100G

Time

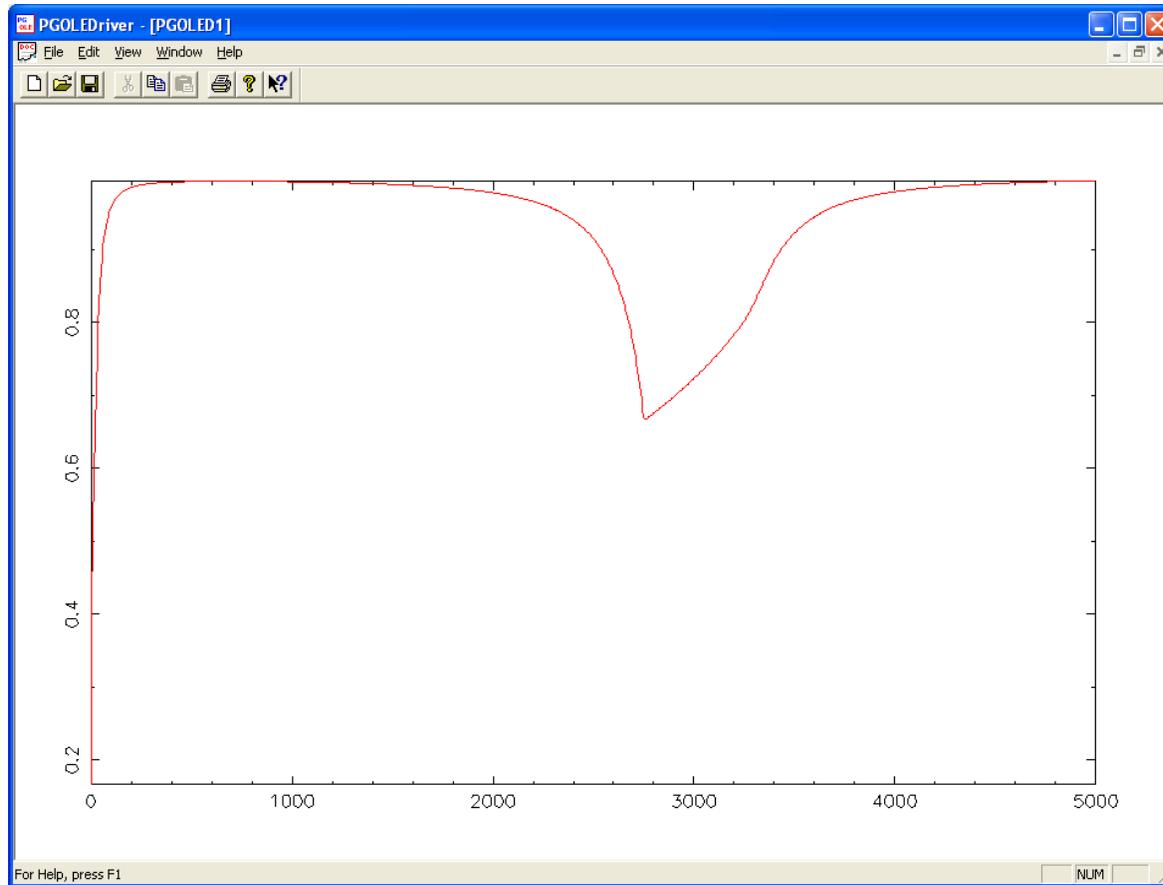


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# Level crossing

Integral asymmetry



Magnetic field



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