EPFL

Nuclear magnetic resonance gyroscope

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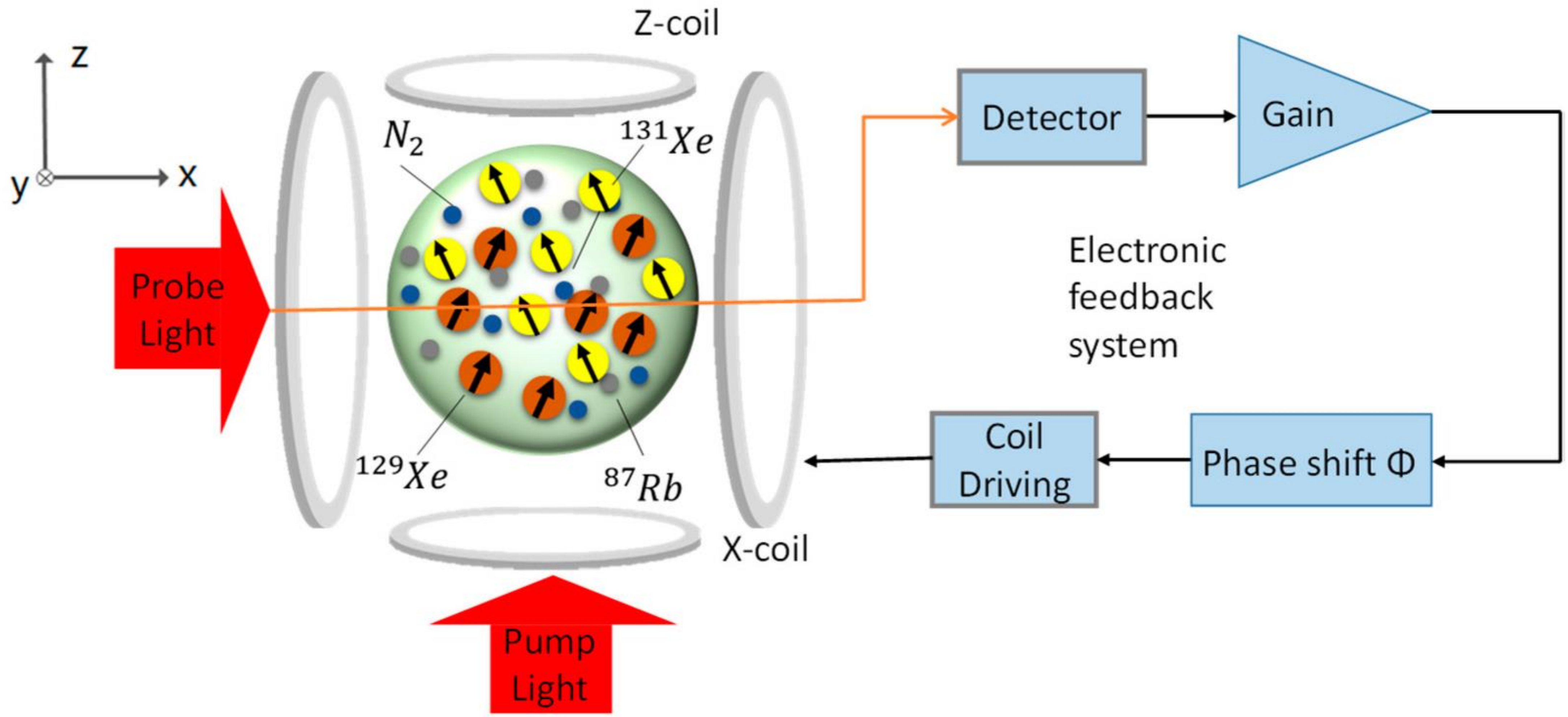


Intro to Nuclear Magnetic Resonance Gyroscope (NMRG) :

- Rival technologies of ring laser gyroscope in the 70s
- No moving part
- Only use the caracteristics of the atomic material and not the ultimate accuracy from precision engineering techniques

Principle of the gyroscope :

Nuclear Spin and Magnetic Moment :

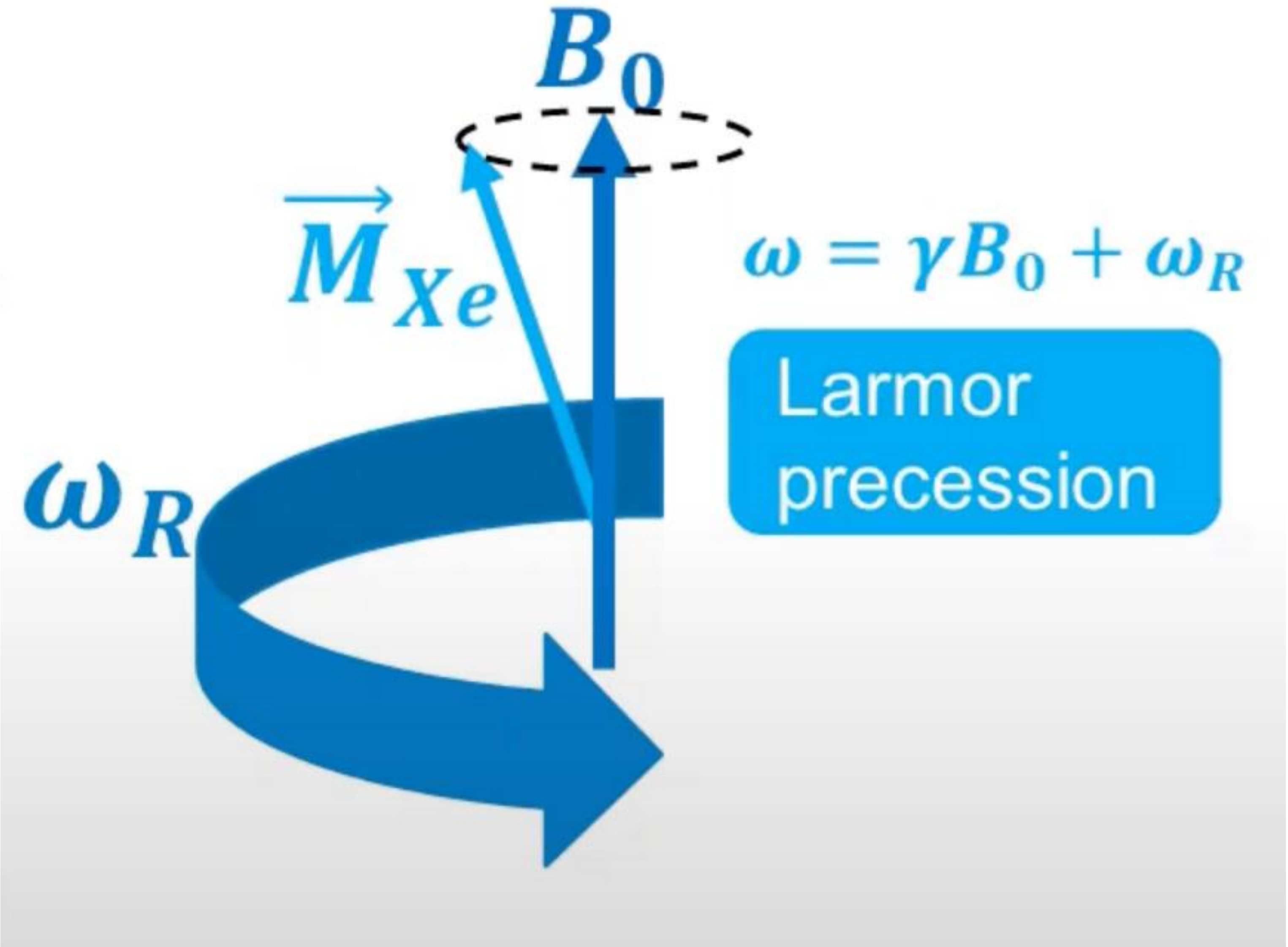
$$\mu = \gamma I$$

Spi
n

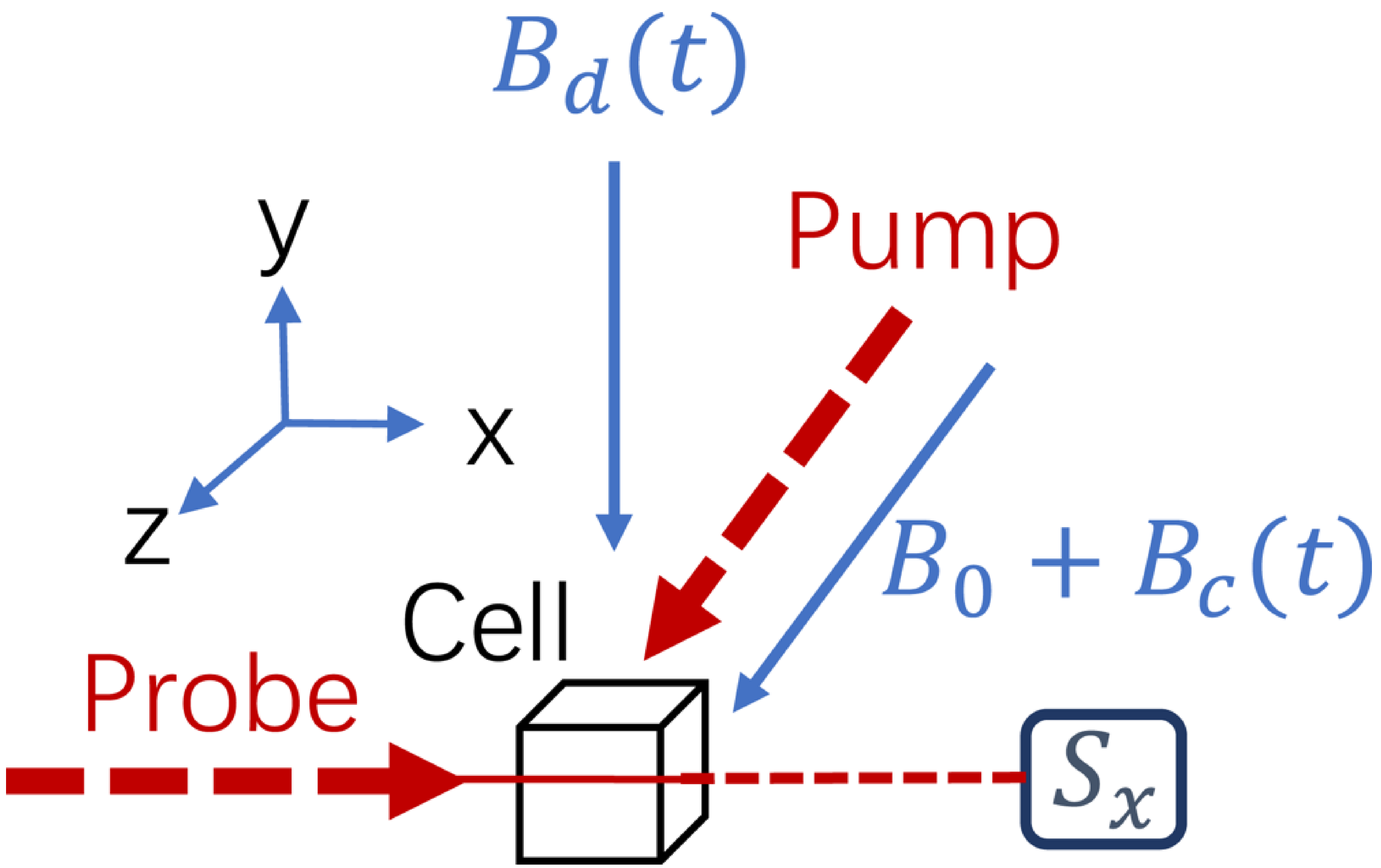
Gyromagnetic
ratio

Larmor frequency :

$$\omega_0 = \gamma B_0$$



Principle of the gyroscope :



- Nuclear spins of noble-gas isotope (e.g. ^{129}Xe or ^{3}He) are polarized by a circularly polarized pump laser
- Apply a transverse magnetic field to start the precession
- Optical detection via the Faraday effect
- Closed-loop operation to adjust Bd and maintain exact resonance with the nuclear precession.

$$\omega_0 = \gamma B_0 + \omega_R$$

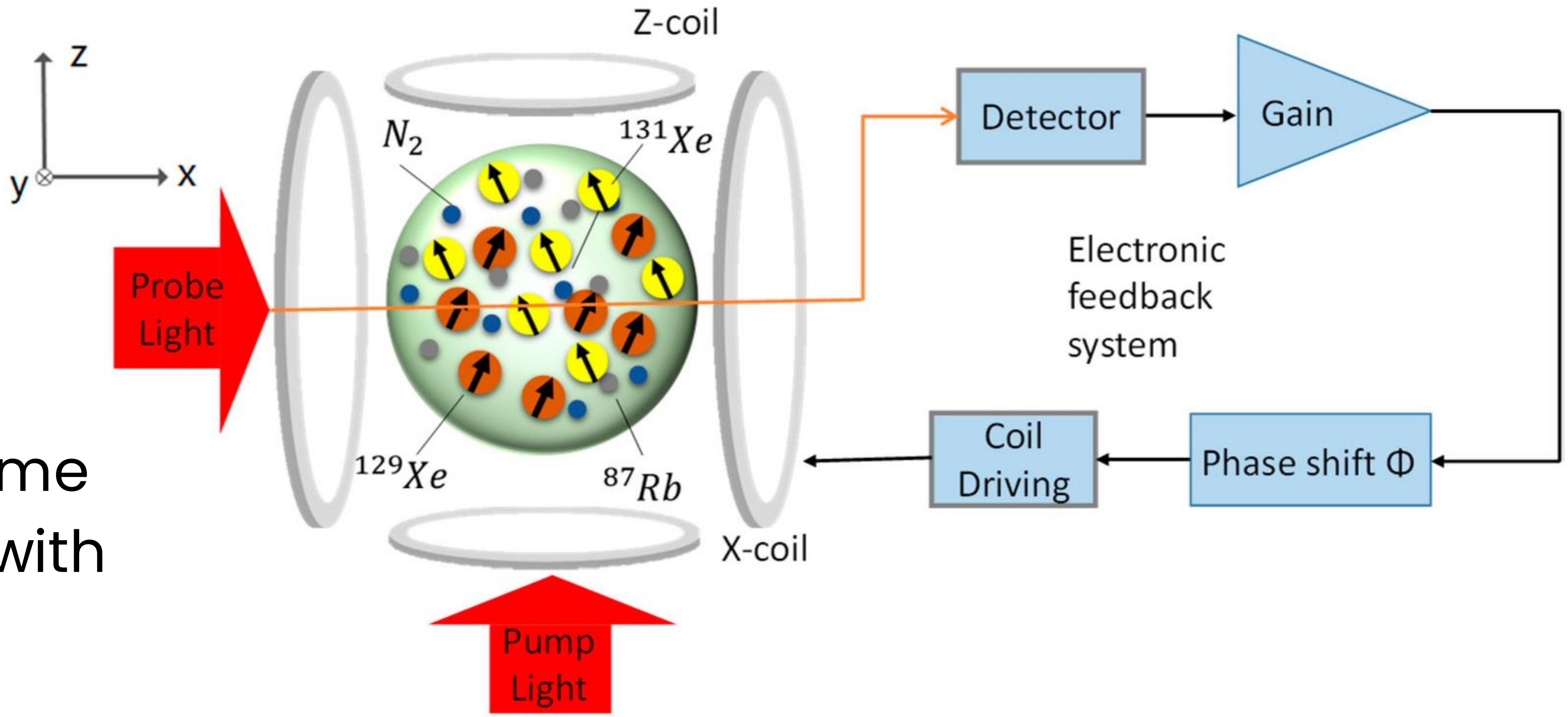
Measurement of the rotation rate :

Problem :

- B_0 as to be stable
- Affected by temperature, cell aging, or light shifts

=> Solution :

Using two nuclear species in the same cell (comagnetometer technique) with their own gyromagnetic ratio



$$\omega_{01} = \gamma_1 B_0 + \omega_R$$
$$\omega_{02} = \gamma_2 B_0 + \omega_R$$

$$\Rightarrow \gamma_1 \omega_{02} - \gamma_2 \omega_{01} = \omega_R (\gamma_1 - \gamma_2)$$

Other variant : Cryogenic NMRG

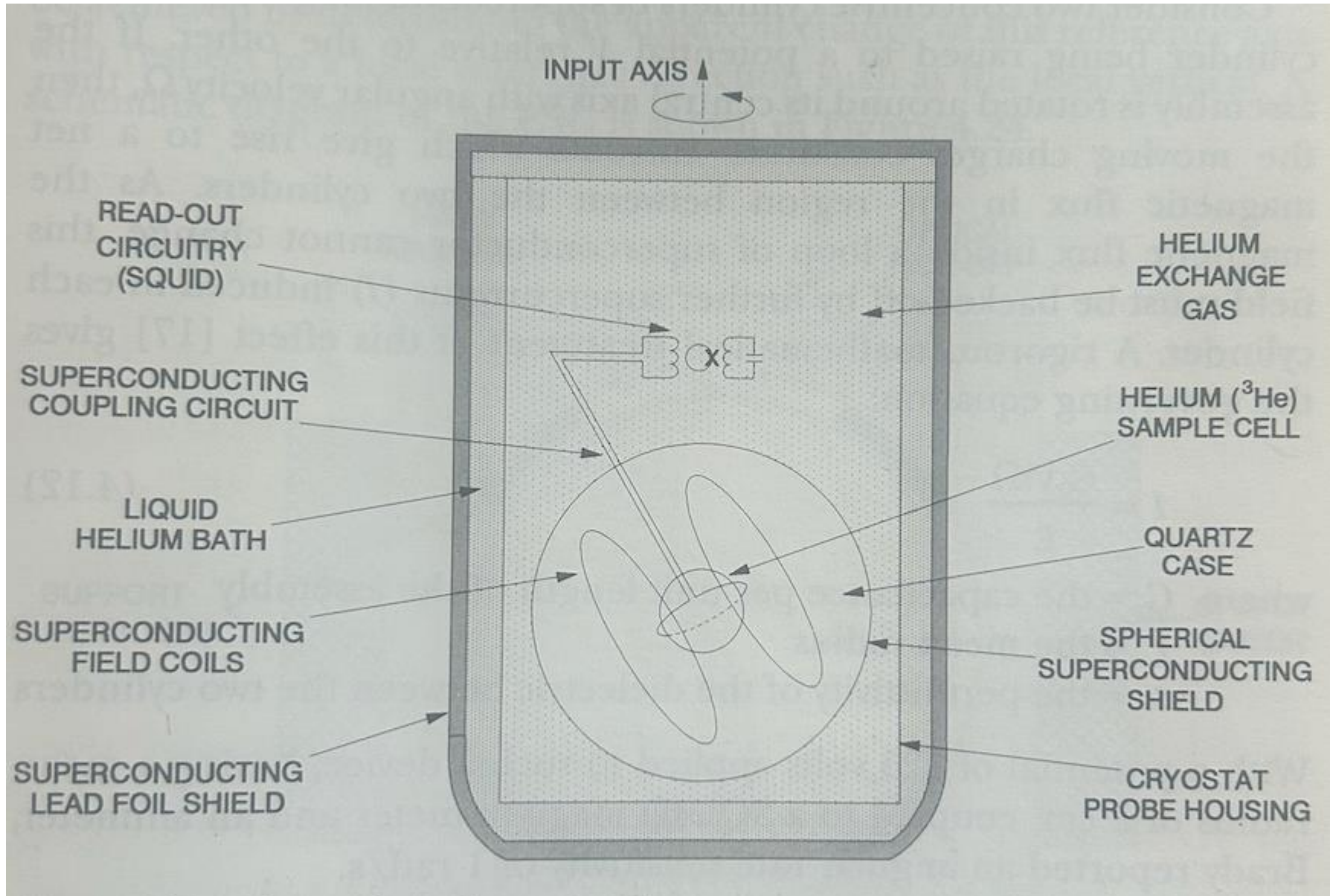


Figure 4.23 *Cryogenic nuclear magnetic resonance gyroscope*

- Spin-polarized gas cell is enclosed within a superconducting cavity, cooled below its critical temperature
- By the Meissner effect, external magnetic flux is expelled
- Theoretical bias drift can be as low as a few arc-seconds per year ($\sim 10^{-7}$ °/h)

Advantages of the NMR Gyroscope

- No moving part ➔ Increase lifespan and reliability
- Totally independent from GPS ➔ Can be used in any environment
- Ultra low drift ➔ 0.001°/hr (can go down to 0.0005°/hr in controlled environment)
- Small Volume ➔ Down to 10 cm^3
- Low Power ➔ Less than 2W
- Bandwidth ➔ Up to 300 Hz

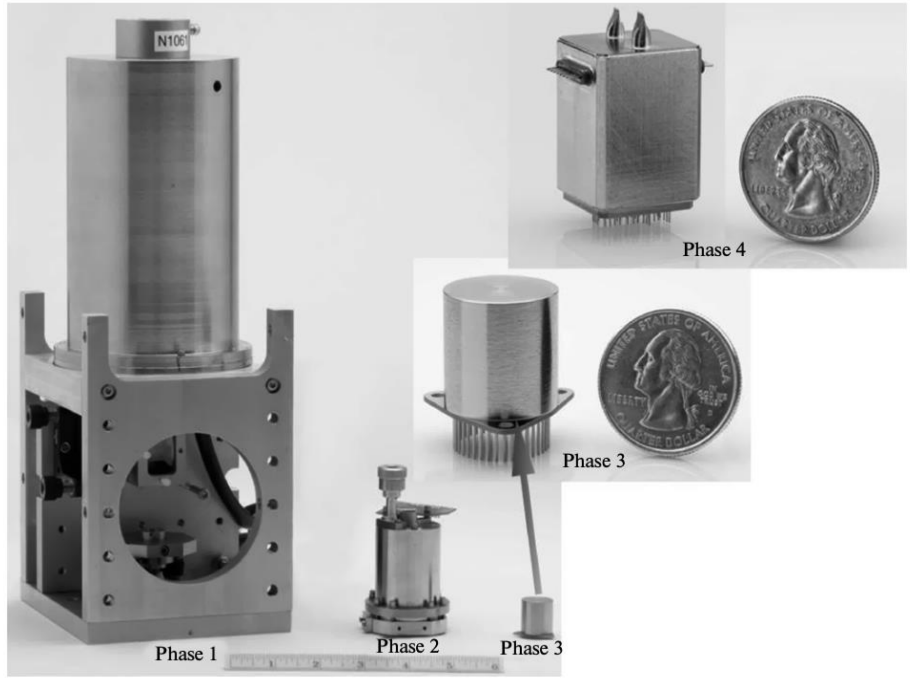


Fig. 7. Size evolution of NMRG physics package; Phase 1, 3000 cc; Phase 2, 55 cc; Phase 3, 6 cc; Phase 4, 10 cc hermetic package.

Limitations of the NMR Gyroscope

- No wide commercial deployment ➔ No large-scale usage possibility
- Is sensitive to magnetic fields ➔ Requires good knowledge of MF for compensation
- Complexity ➔ Requires complex technology such as superconductors
- Mostly Experimental ➔ Only tested by military, mostly in labs (still room for improvement)
- Cost

Applications of the NMR Gyroscope

Documented Applications

- US navy and DARPA (research agency of the DoD) ➔ Development and testing

Potential Applications

- Aerospace
- Submarine
- Space systems

➔ More generally in all GPS-denied area (such as caves, deepwater or space) and where a strategic-grade inertial navigation is needed

Conclusion

+ Advantages

- No moving part, GPS independent, small volume and power consumption

– Limitations

- Cost, mostly experimental, complexity and sensitive to magnetic fields

Applications

- Documented : Military development
- Potential : submarine navigation, aerospace, space systems
- Substitute to ring laser gyroscope