Magnetic Field measurements with Cs-magnetometers in nEDM project at PSI

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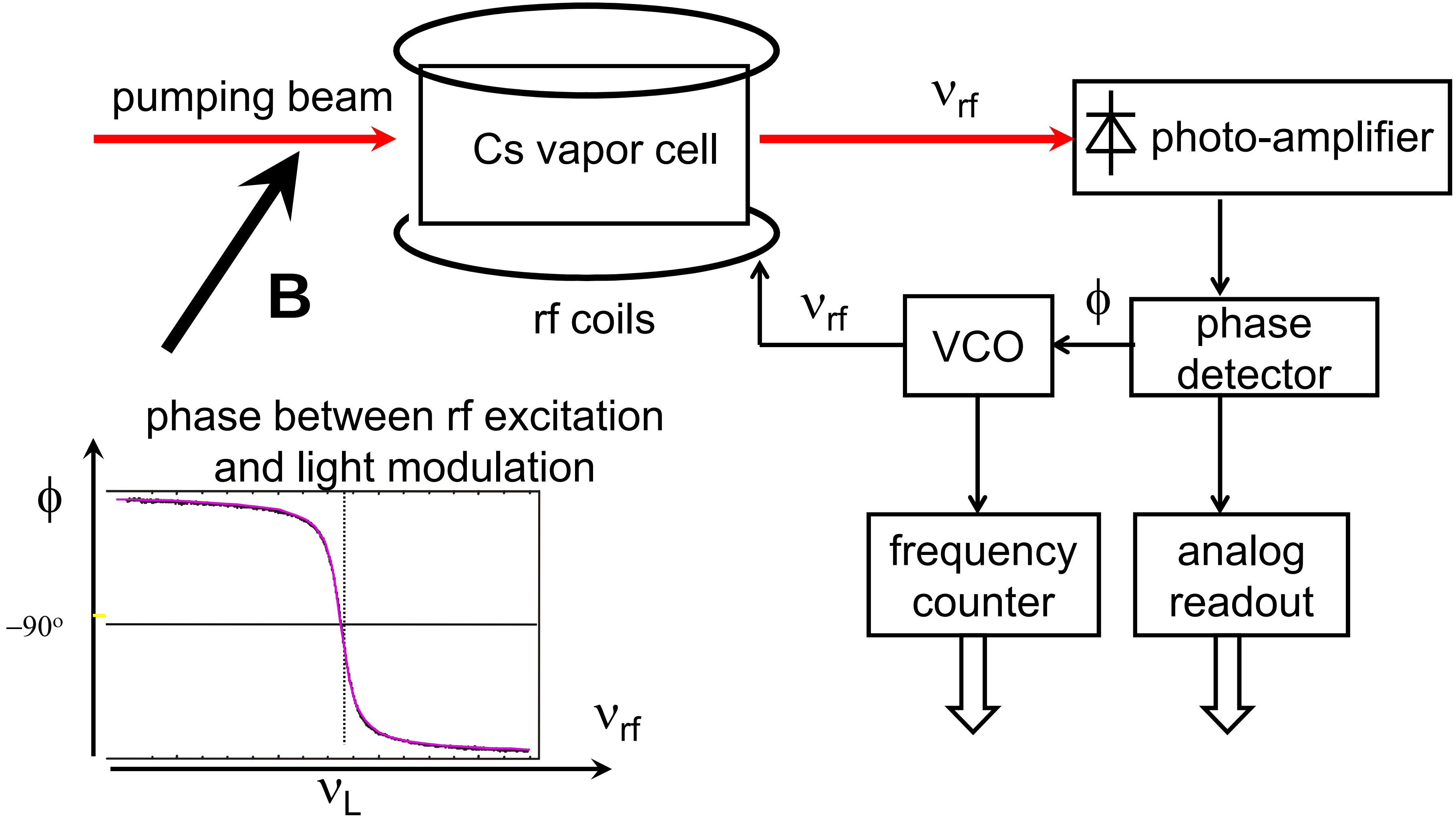
- Magnetic field control in nEDM experiment
- Laser pumped Cs-magnetometer
- Data Acquisition System
- What has been realized
- Future plans
- Conclusion

Magnetic field control in nEDM

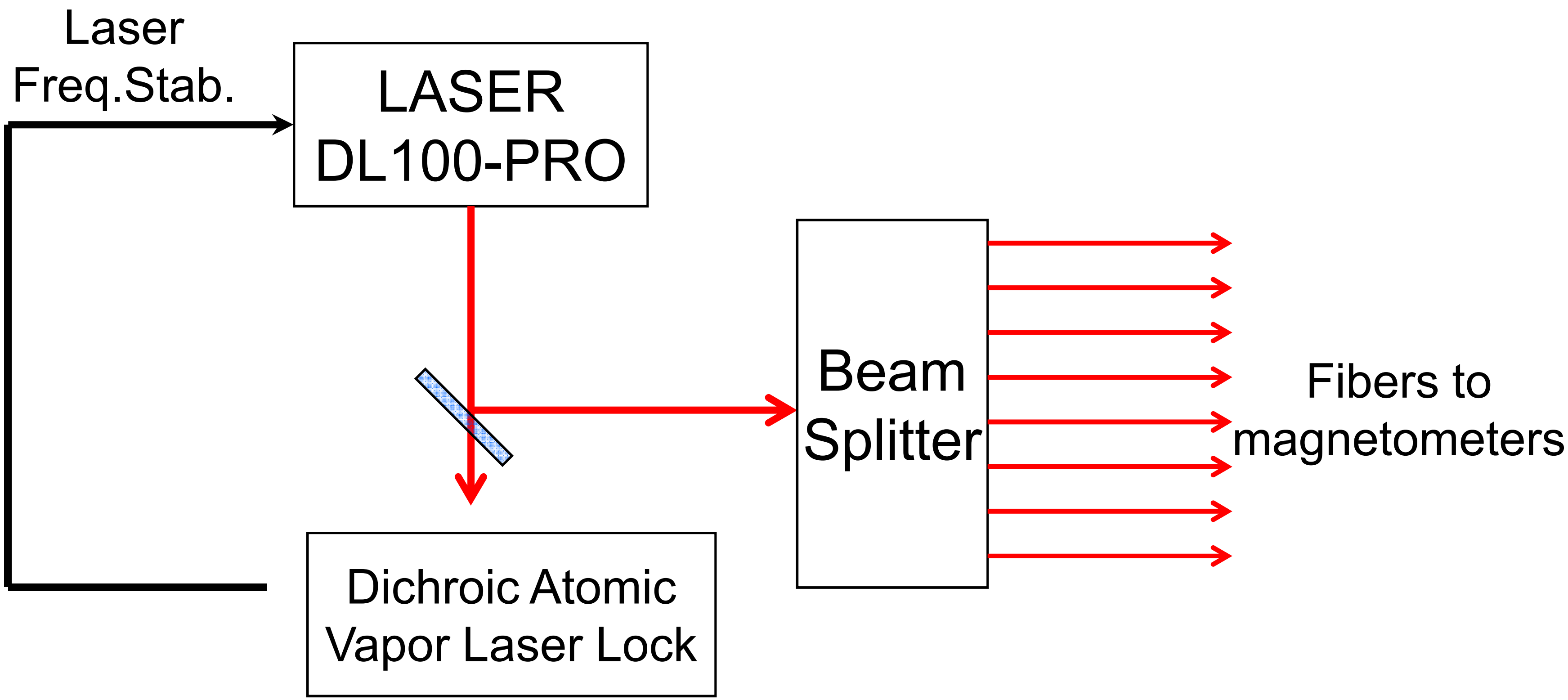
- Magnetic field fluctuations limit the statistical uncertainty of neutron EDM measurement.
- Current EDM limit equivalent to field variations of 1-2pT(100 sec), 100 fT(100 sec) are needed.
- Magnetic field gradients yield systematic error (may mimic true nEDM effect) in double chamber experiments.
- Hg-magnetometer is used as co-magnetometer. It occupies the same space as neutrons and monitors the field.
- With Cs magnetometer it is possible to measure vertical gradients of magnetic field, provide slow field stabilization, and to generate the neutron resonance frequency.
- Future nEDM experiment foresees large ^{3}He magnetometers to measure magnetic flux through neutron chamber (gradient control).

Cesium magnetometer



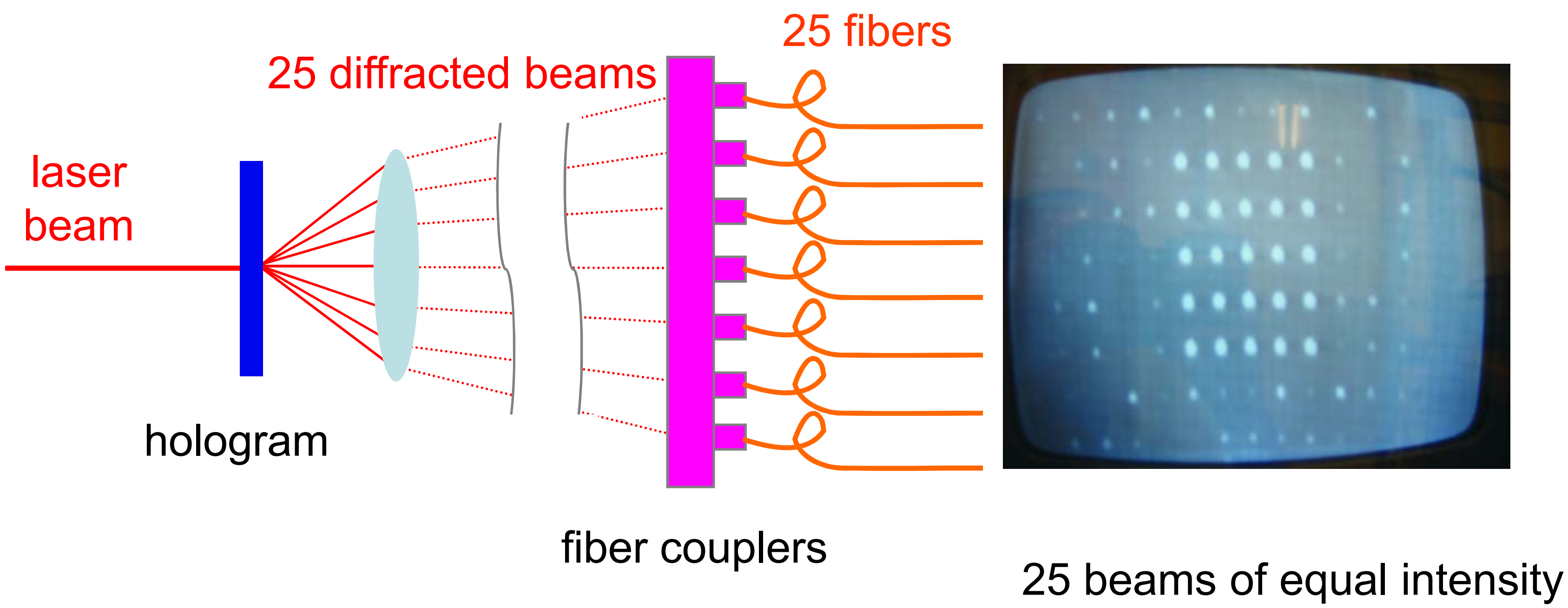
Feedback forces rf frequency ν_{rf} to oscillate at the Larmor frequency ν_L

- External cavity Diode Laser DL100-PRO



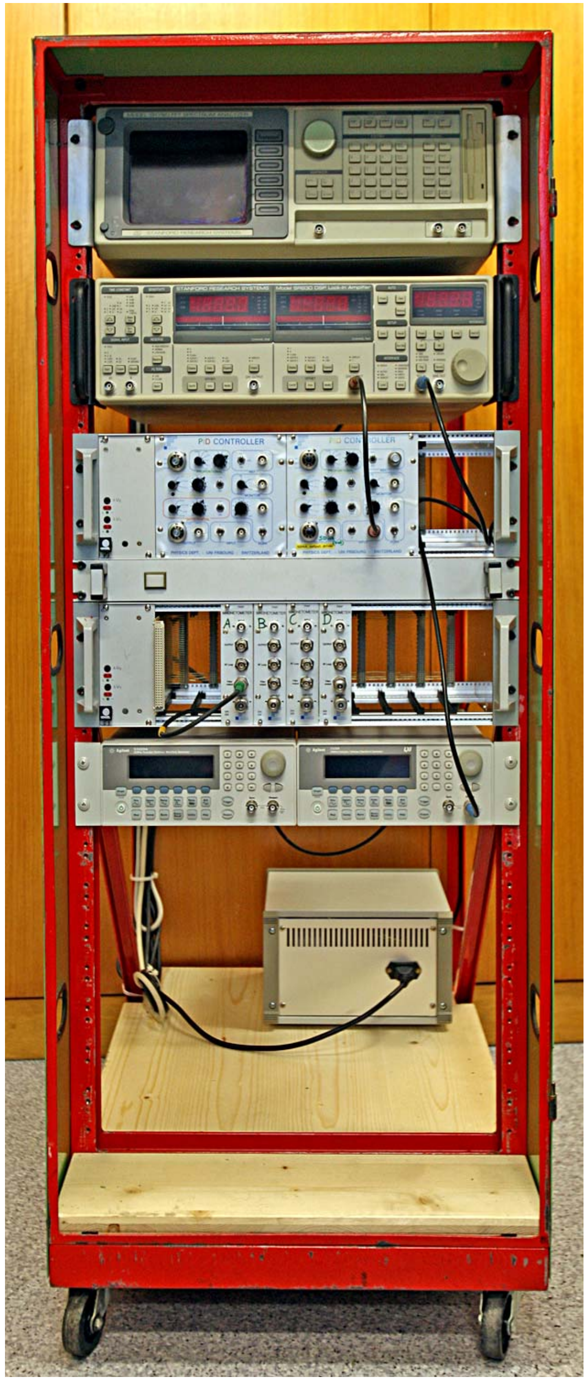
- λ=894 nm (Cs D1 transition); frequency actively stabilized.
- 1 sensor needs less than 10 μW
- 1 laser can operate more than 100 sensors
- Light delivery by optical fibers (vacuum + HV compatible)
- Beam splitting by custom-made hologram

Beam Splitting by Hologram



Laser rack
with analog
feedback
electronics

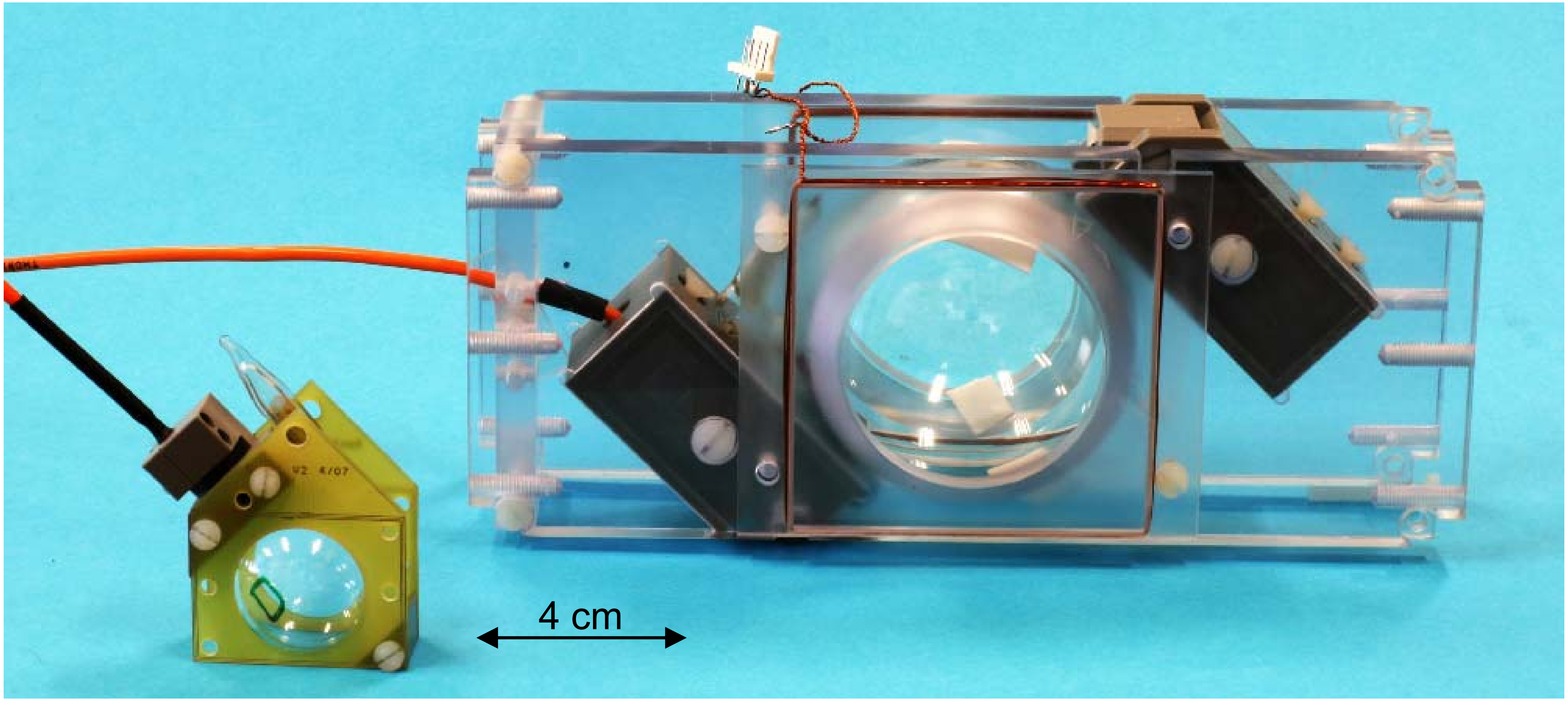
+



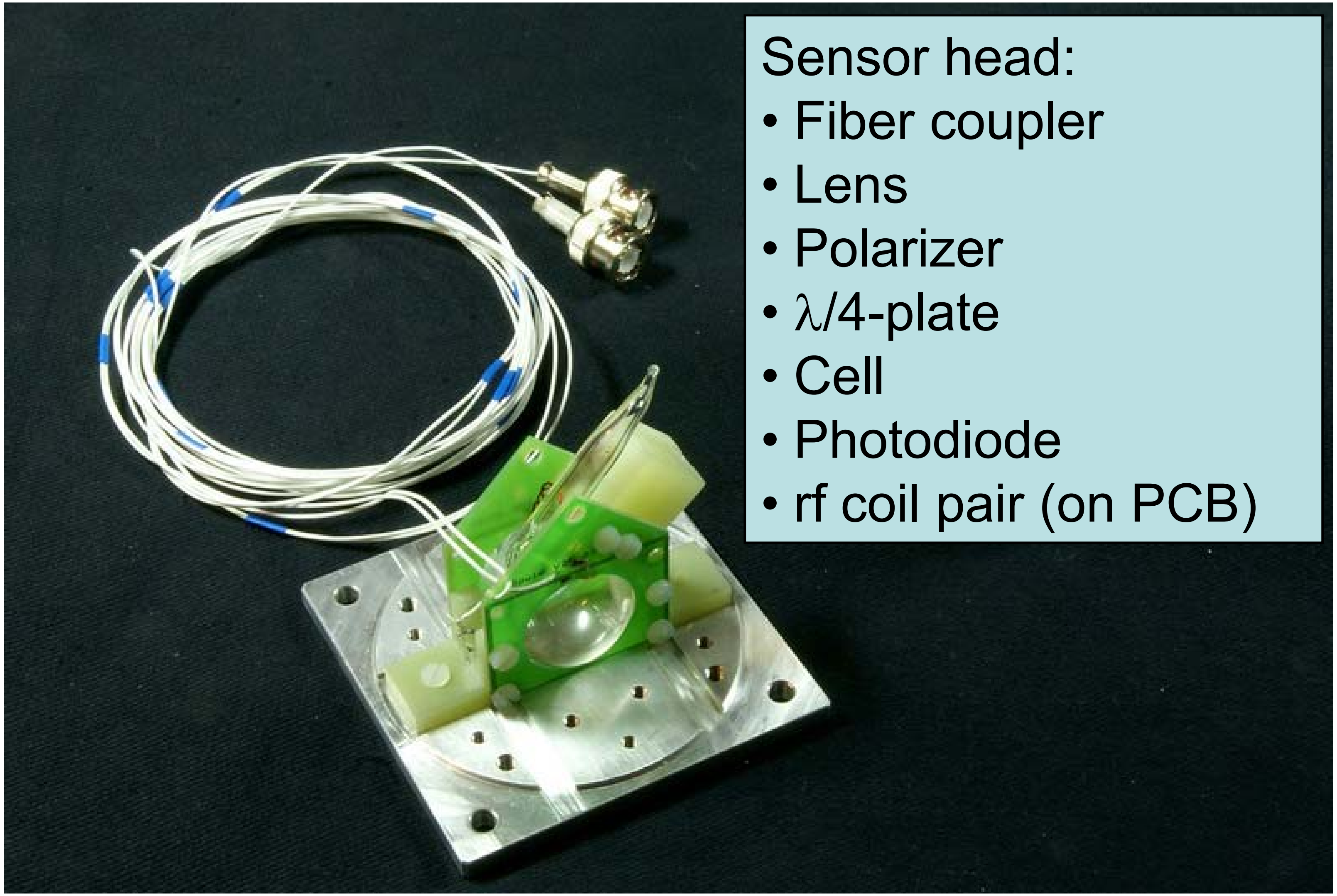
New compact Cs-sensor

- 30mm diameter spherical cell with paraffin coating
- Module has dimensions 90x90x85 mm
- 400/800 micron multimode fibers
- Under optimized conditions:
  - S/N=50000 (1Hz bandwidth)
  - Shot noise limited sensitivity = 15 $fT/Hz^{1/2}$
  - Actual sensitivity = 80 $fT/Hz^{1/2}$
    limited by laser power noise (to be improved with new laser)

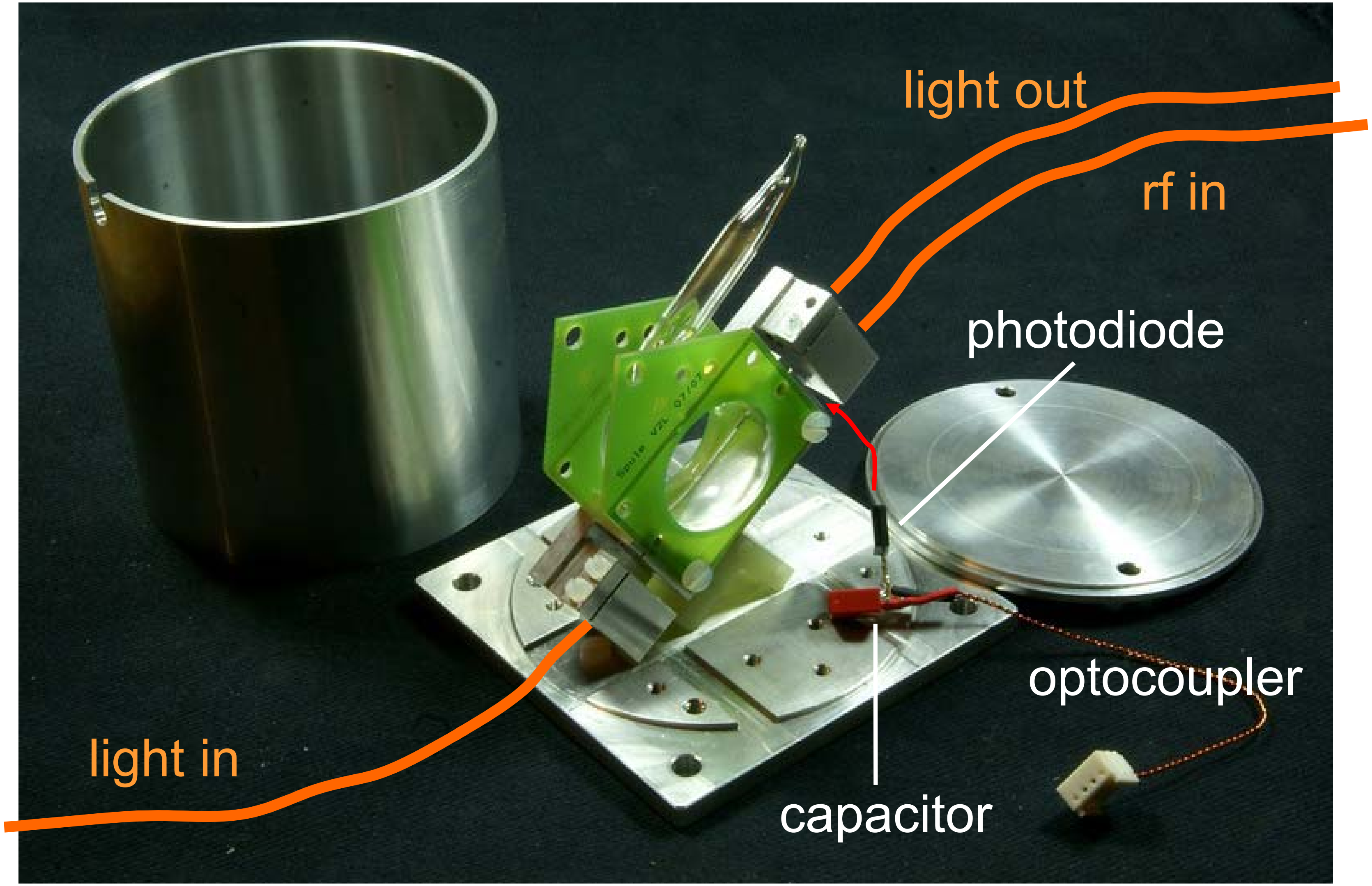
present sensor head



new sensor head


Sensor head:
• Fiber coupler
• Lens
• Polarizer
• λ/4-plate
• Cell
• Photodiode
• rf coil pair (on PCB)

HV-compatible (scalar) module components



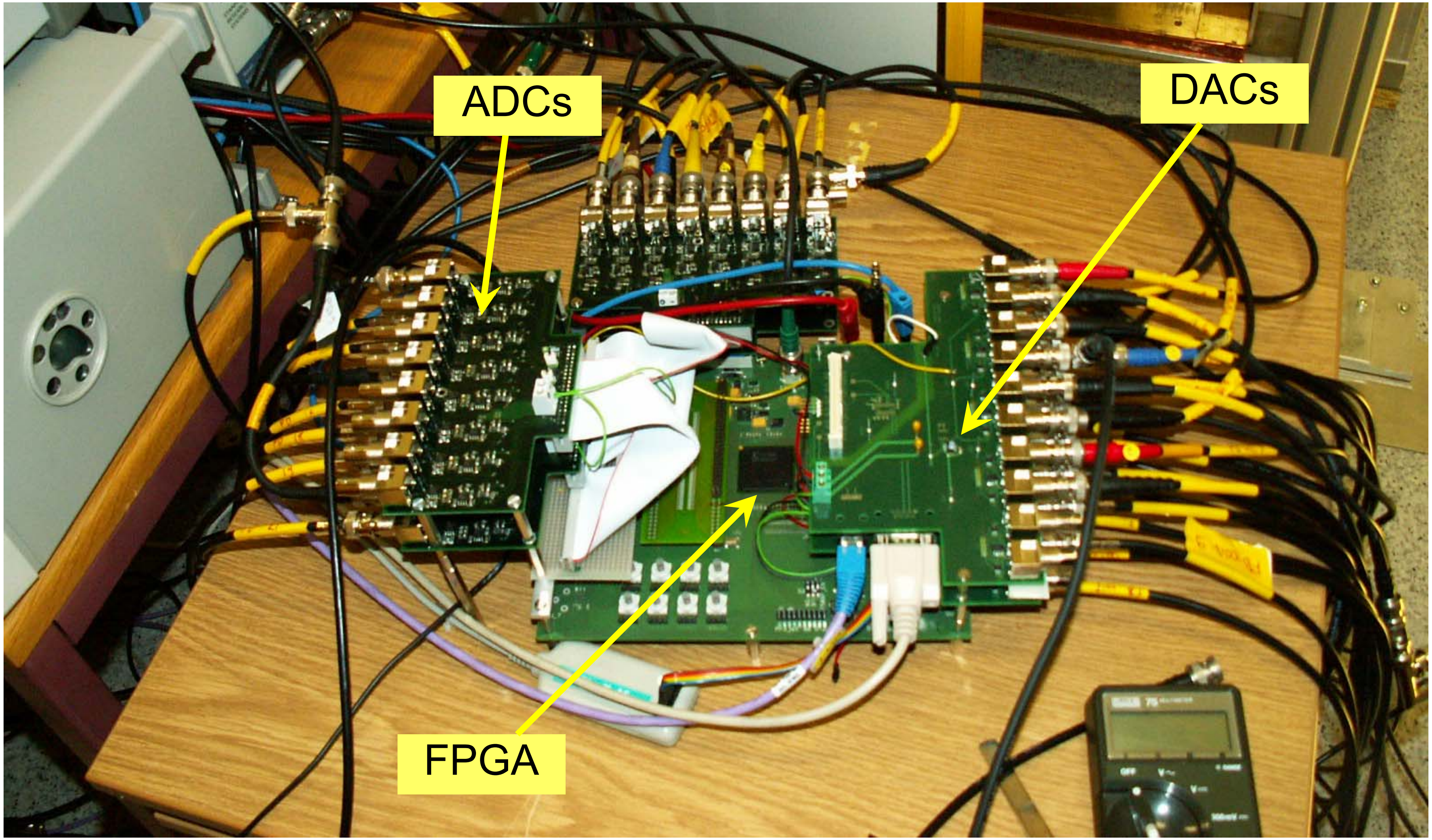
Data Acquisition System

- Present system: based on Commercial Sound Card
  - Magnetometer operated by analog electronics
  - Signal of interest (frequency of Larmor precession) recorded by digitizing sine wave with commercial sound card system

- Future system (under devolopment with PSI):
  - Full digital operation of magnetometers using FPGA electronics
  - Larmor frequency and phase synthesized with 32 bit precision.

- Prototype operating 25 sensor (for cardiac magnetometry) developed and operational in Fribourg

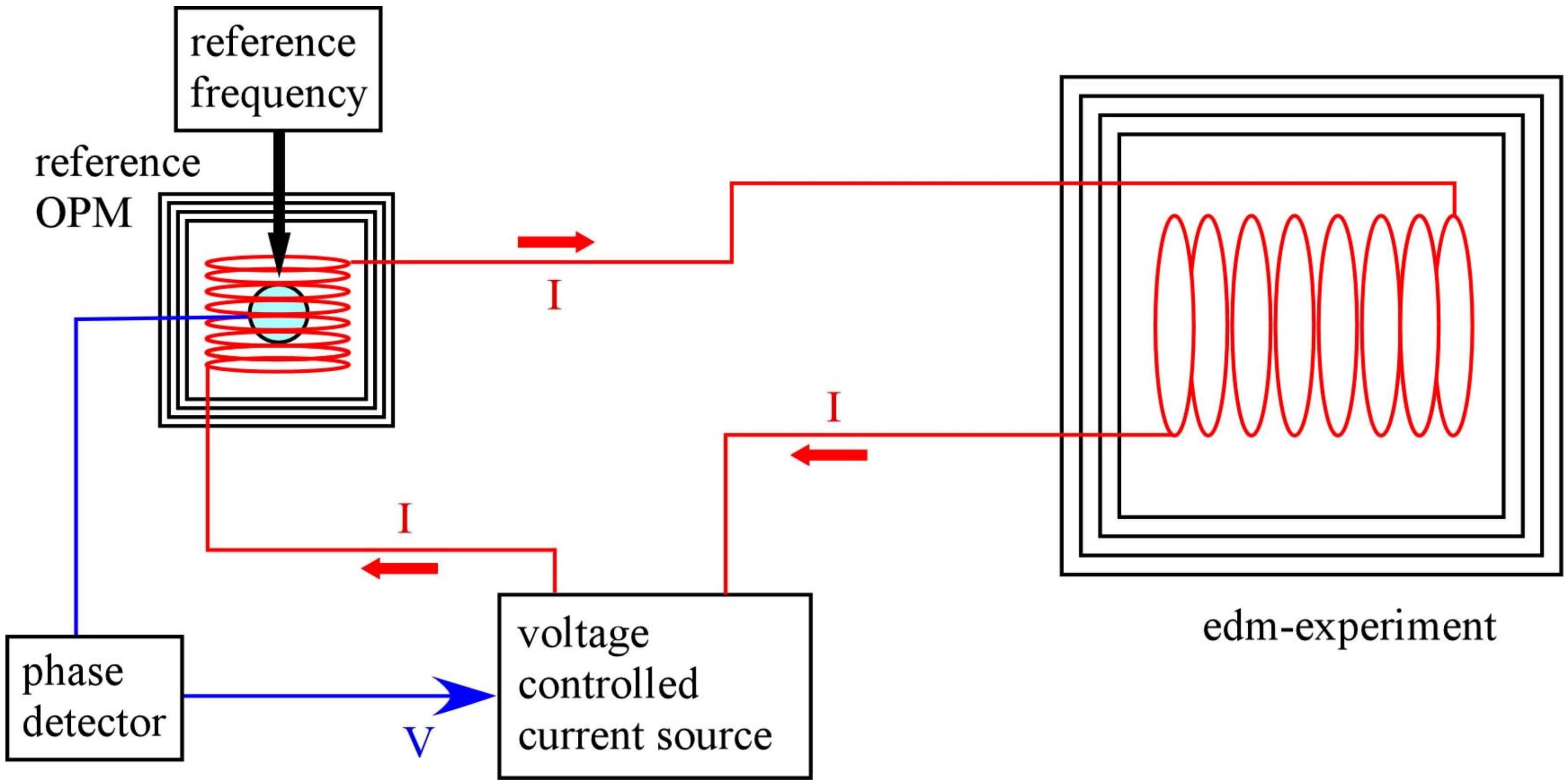
FPGA control of 25 sensor system for biomagnetometry



Current R&D activity

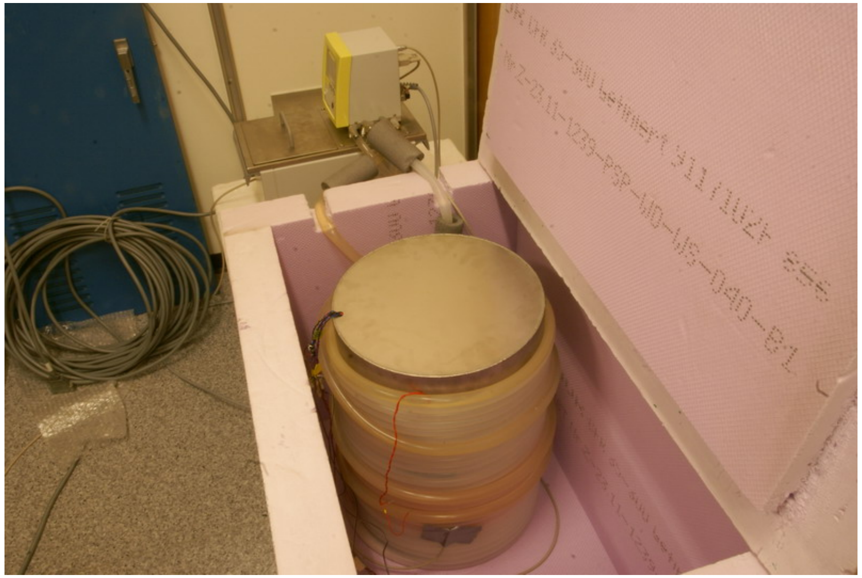
- Stabilized current source
- ^{3}He signal detection with Cs magnetometer
- Field vector components measurements with Cs magnetometer

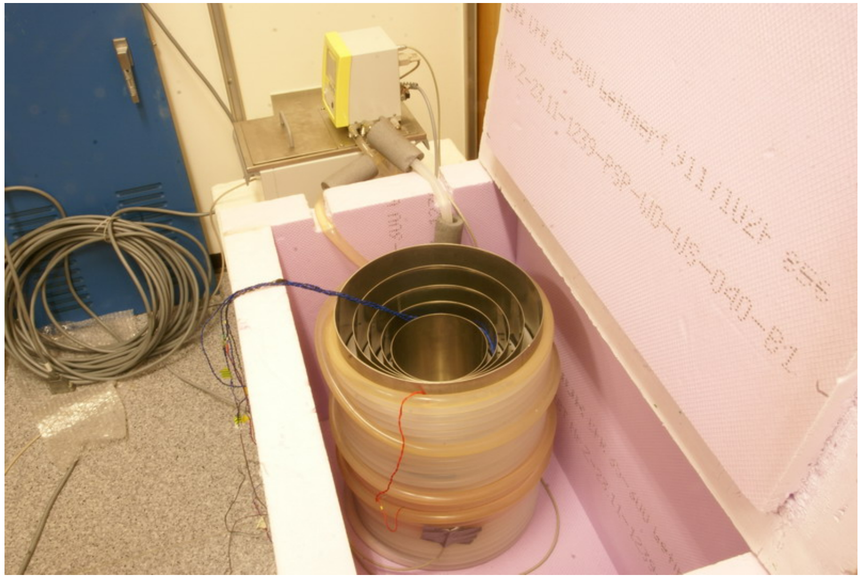
Stabilized Current Source

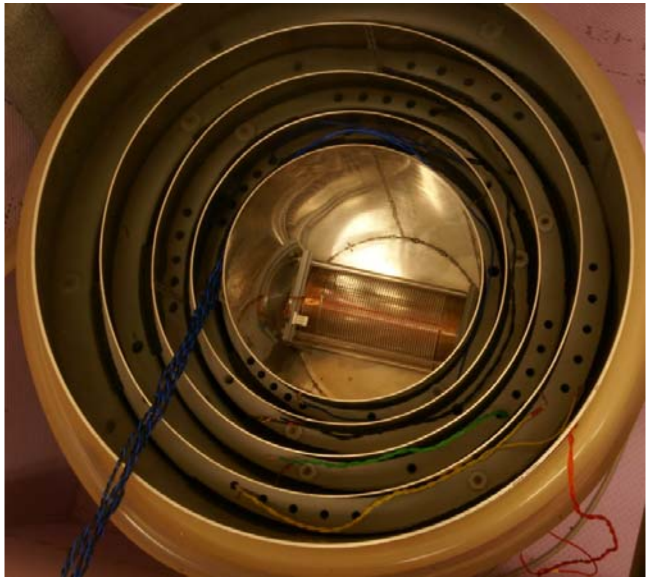


Stabilized current source requirements

Current source stability (Allan dev):	$<10^{-7}$ for 10…10^{5} s
• Current:	~ 10-20 mA
• Stabilized Magnetic Field:	~ 10000 nT
• Magnetometer noise:	< 0.2 pT(1 sec),
• Field stability with temperature d(ΔB/B)/dT:	~ 10^(-6)/K
• Max.temperature variation of inner shield:	~ 0.01 K for t=1-10000 s
• Gradient over the cell volume:	<50 nT over the cell size (30 mm)
• Tolerance to magnetic field fluctuations:	100-500 nT
• Shielding factor:	$\sim 5 \cdot 10^{6}$



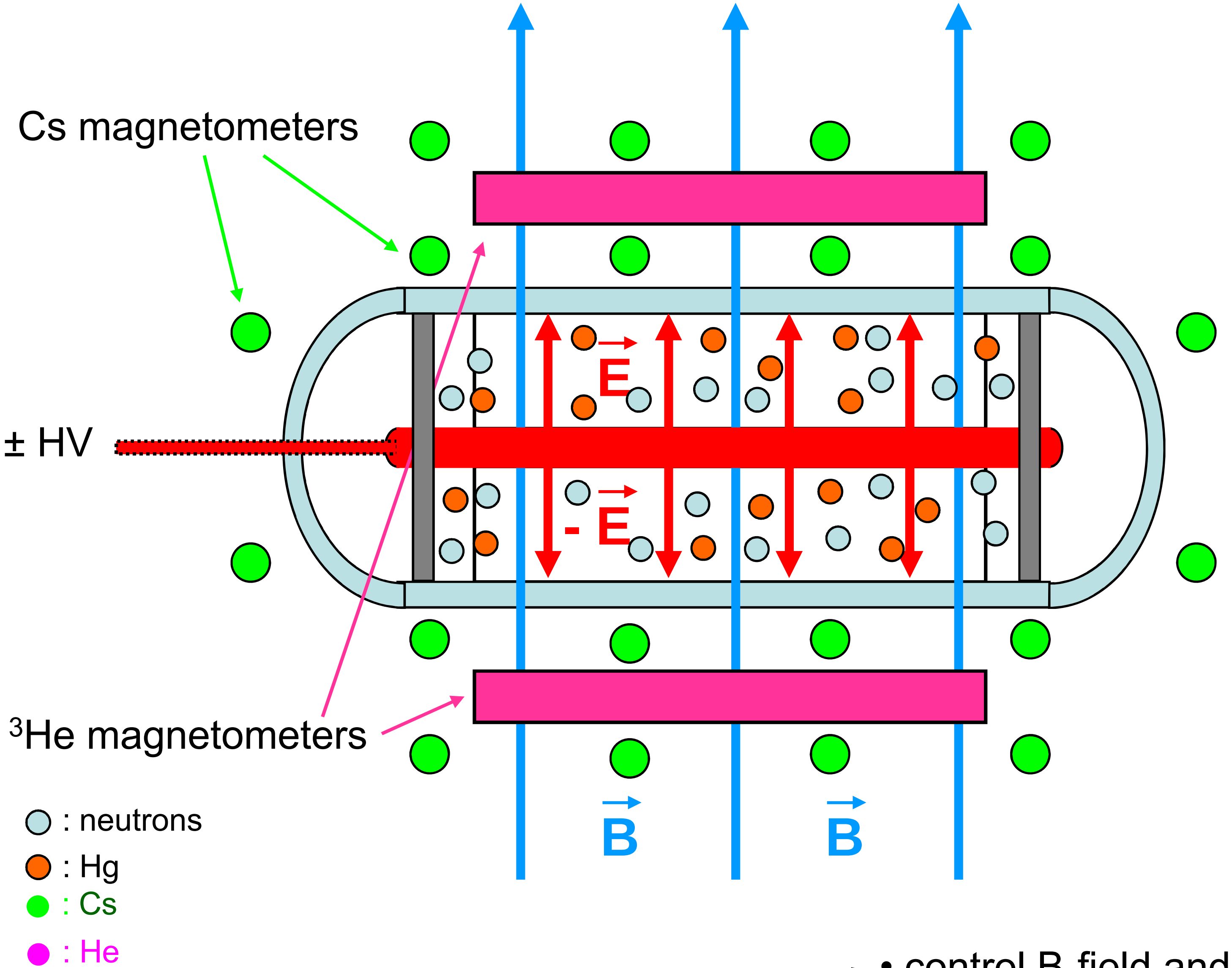




^{3}He-magnetometer read out by Cs-OPM

- The sensitivity of the Cs-magnetometer is sufficient to detect magnetic field (10-20 pT) of ^{3}He nuclei precessing at 10-20 Hz.
- Proof of principle realized at PTB Berlin.
- Compact system under development.

Magnetometry in n2EDM experiment



Cesium magnetometers:
- control B-field and gradients
- read out ^{3}He magnetometers

Vector magnetometry

- Cs magnetometers are scalar magnetometers, i.e., they measure module of magnetic field

$$\left|\vec{B}_0\right| = \sqrt{B_x^2 + B_y^2 + B_z^2} \approx B_z\left(1 + \frac{B_x^2 + B_y^2}{2B_z^2}\right)$$

if $B_z >> B_{x,y}$: $|B_0| \approx B_z$, i.e. they detect mainly B_z-component

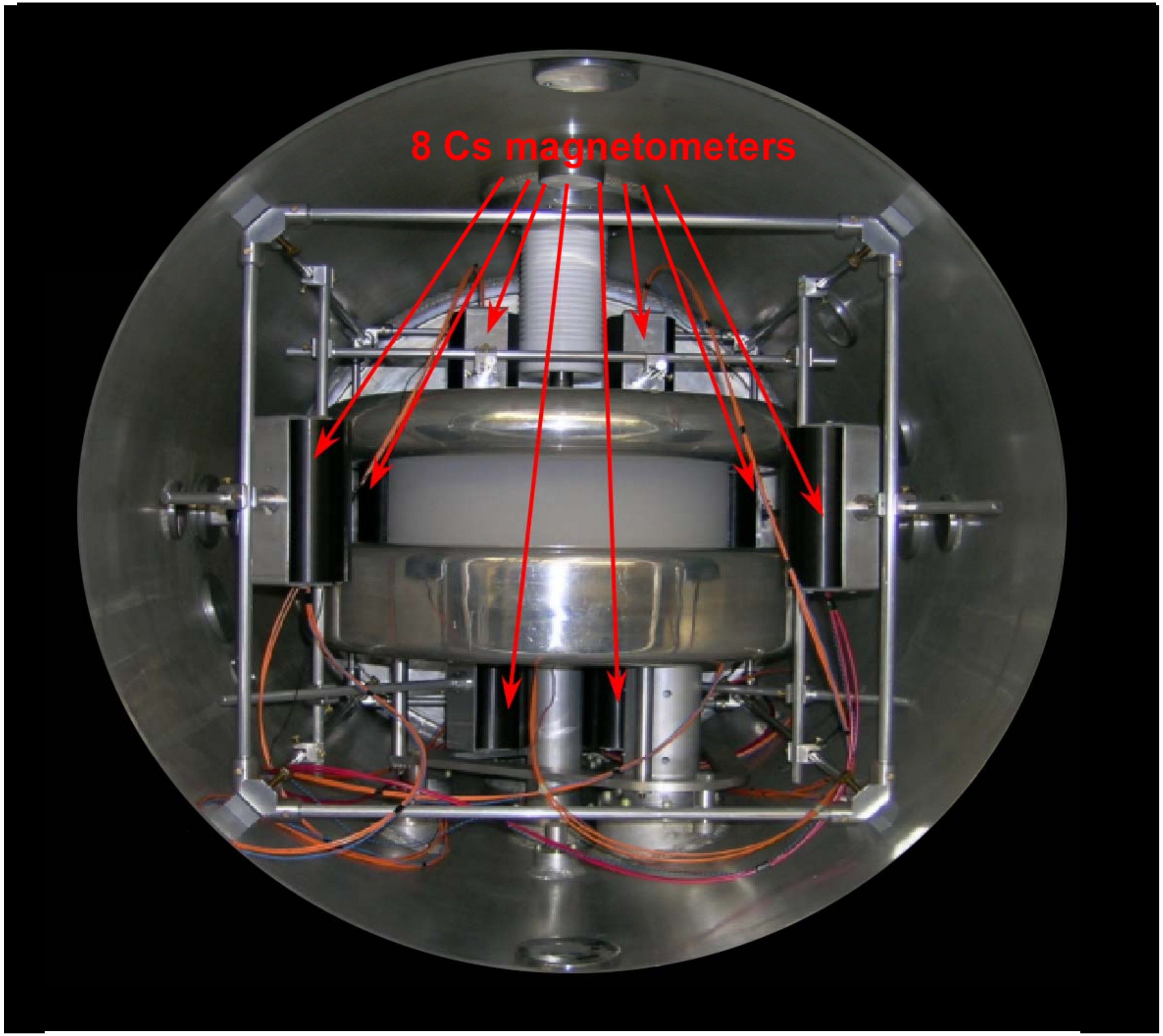
With applied modulation $b_x\cos(\Omega t)$ along x-axis, scalar value of the field appeared to be modulated with amplitude proportional to B_x and b_x:

$$\left|\vec{B}_0\right| = \sqrt{\left(B_x + b_x\cos\Omega t\right)^2 + B_z^2} \approx |B| + \frac{B_x b_x}{|B|}\cos\Omega t + \frac{b_x^2}{4|B|}\cos(2\Omega t)$$

Conclusion

- Thanks

First Cs magnetometry measurements at ILL



Importance of field Stabilization, ILL