UNIVERSITÄT BERN

AEC
ALBERT EINSTEIN CENTER
FOR FUNDAMENTAL PHYSICS

Fundamental Neutron and Precision Physics at AEC

Marc Persoz – PhD student

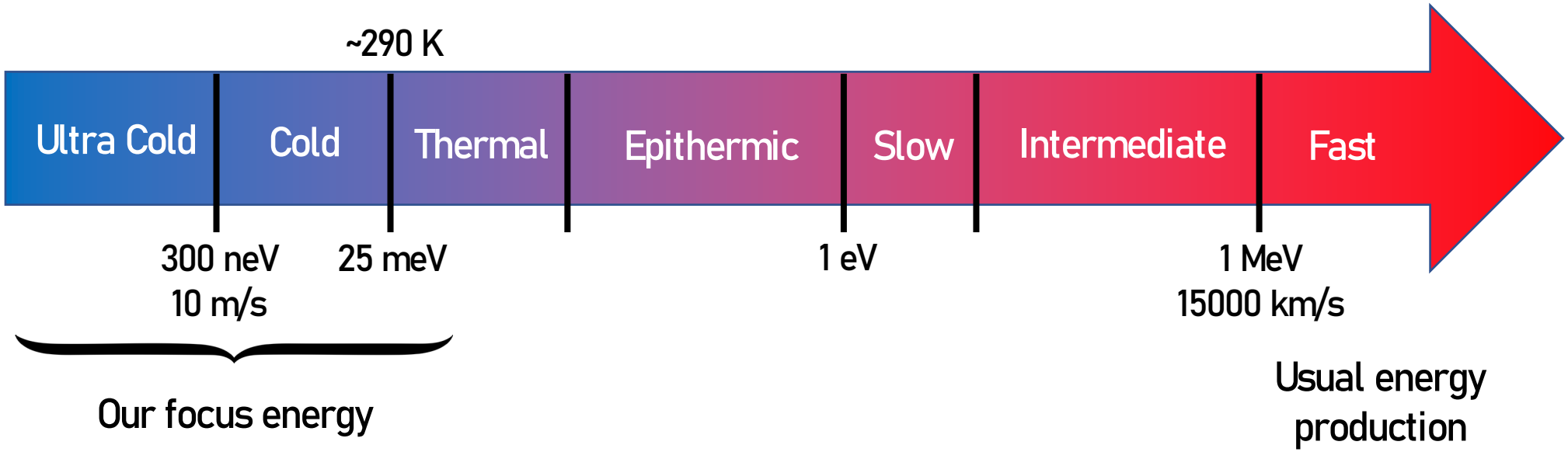
AEC Plenary Meeting
Bern, June 12th 2023

LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

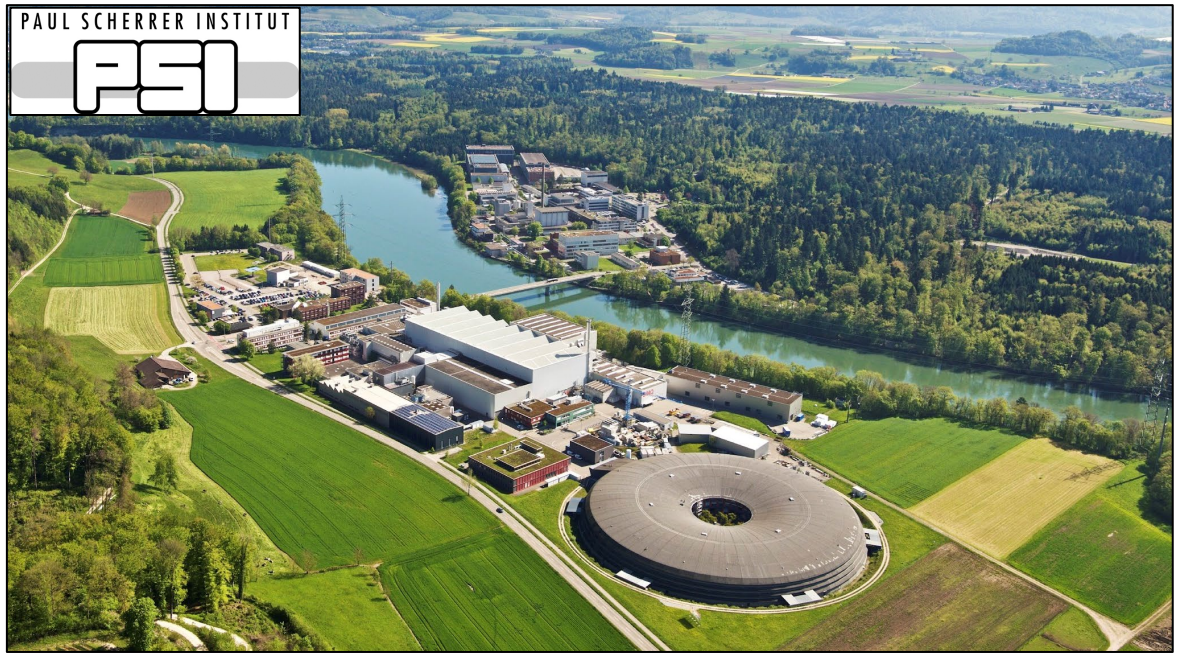
The neutron

A good probe for fundamental physics

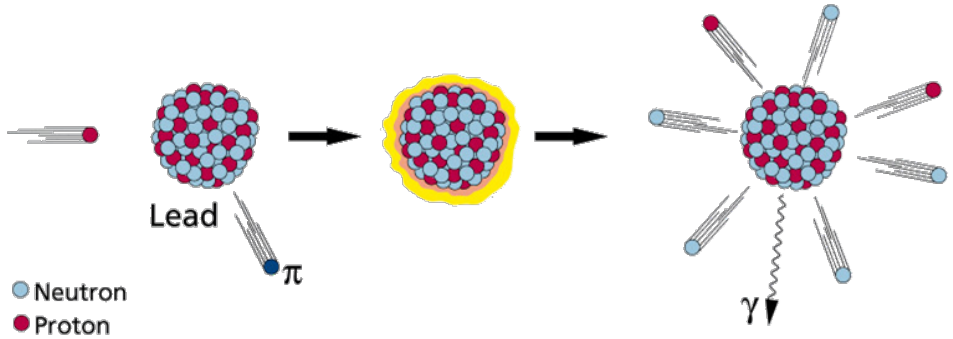
- **Spin :** 1/2
- **Baryon :** (u,d,d)
- **Magnetic moment :** $\mu_n = -9.662 \times 10^{-27}$ J / T
- **Long lifetime :** $\tau_n \sim 880$ s



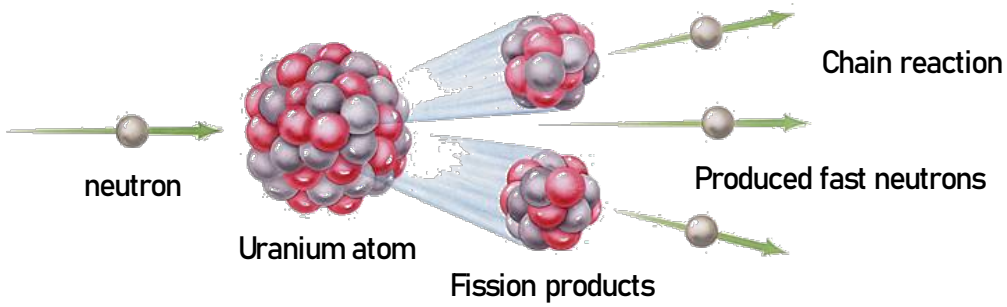
The neutron
Production



Neutron production by spallation



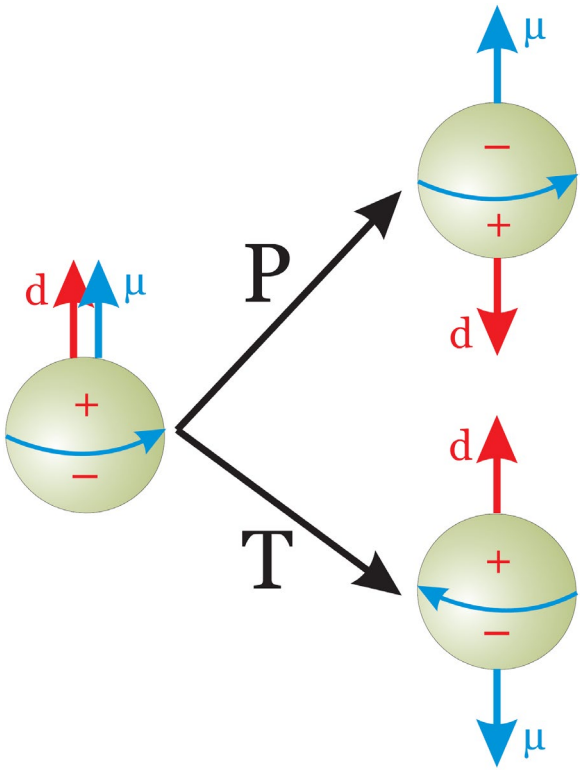
Neutron production by nuclear fission



Search for a neutron electric dipole moment

Electric Dipole Moment

- Neutron EDM violates parity (P) and time reversal symmetry (T)
- CP violation according to CPT-theorem
- Required for matter-antimatter asymmetry (Sakharov)
- Electroweak SM predicitons : $|d_n| \sim 10^{-31}\ e \cdot cm$

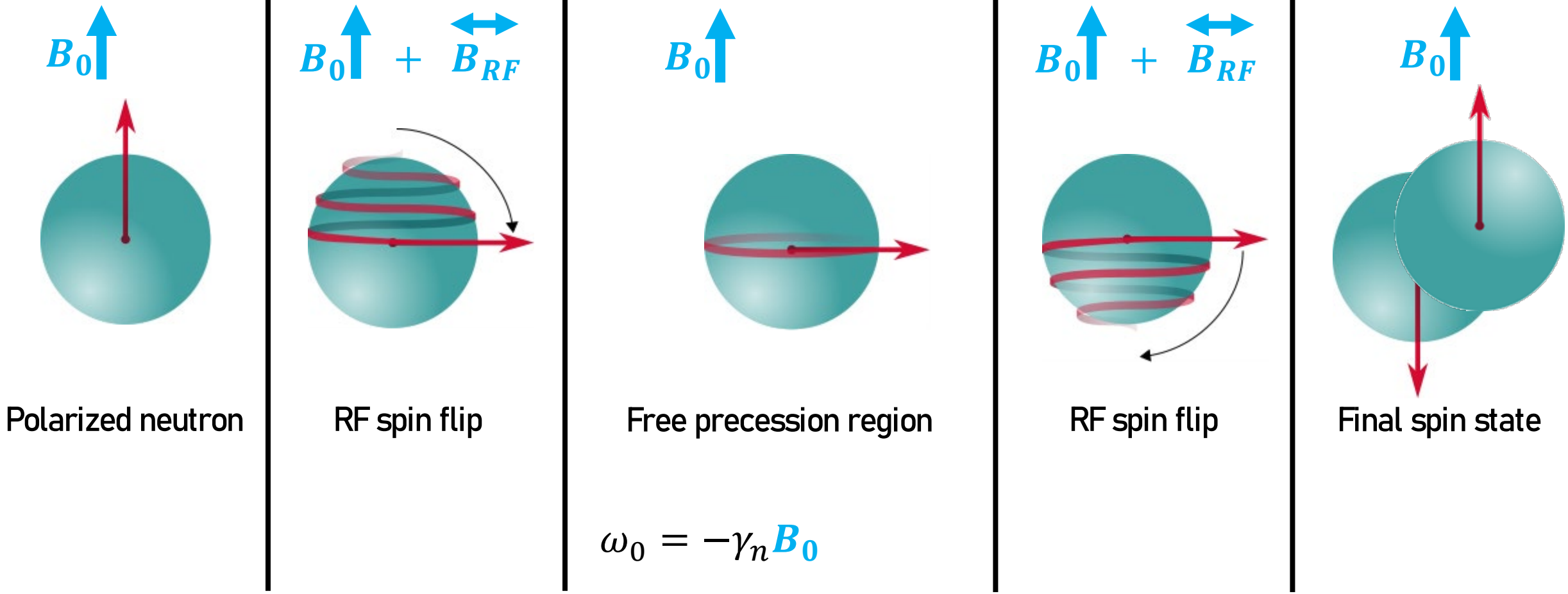


Methodology :

- Measurement of neutron Larmor frequency
- Precession frequency changes with external E-field

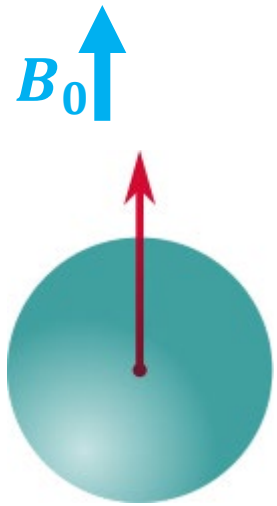
Measuring the EDM

Ramsey technique

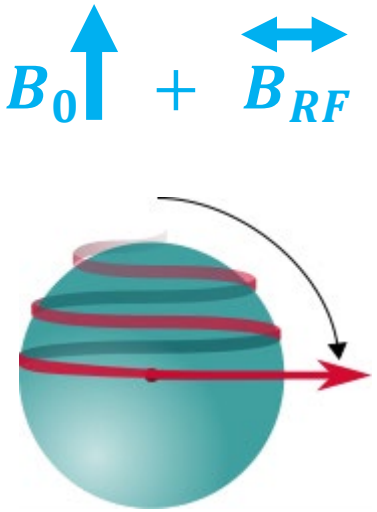


Measuring the EDM

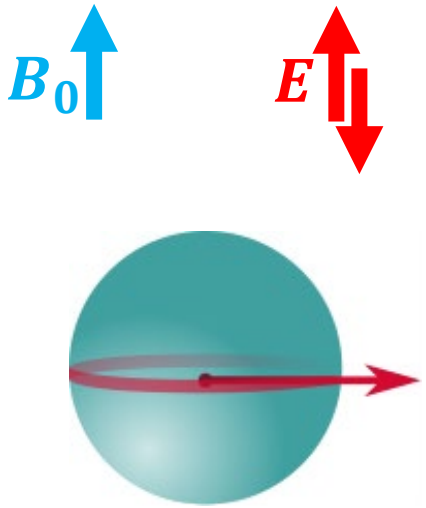
Ramsey technique



Polarized neutron

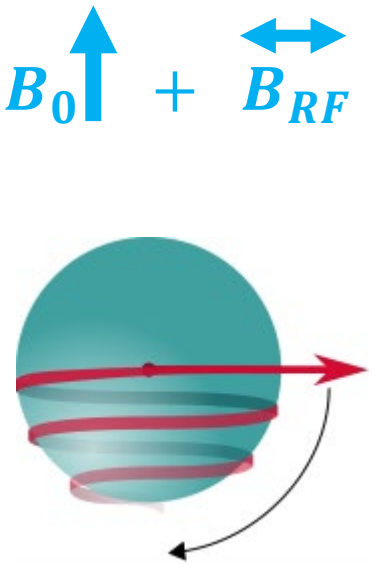


RF spin flip

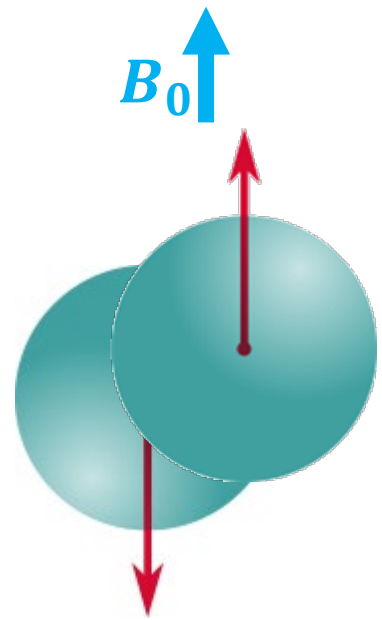


Free precession region

$$\omega_0 = -\gamma_n B_0 \pm \frac{2 d_n E}{\hbar}$$



RF spin flip

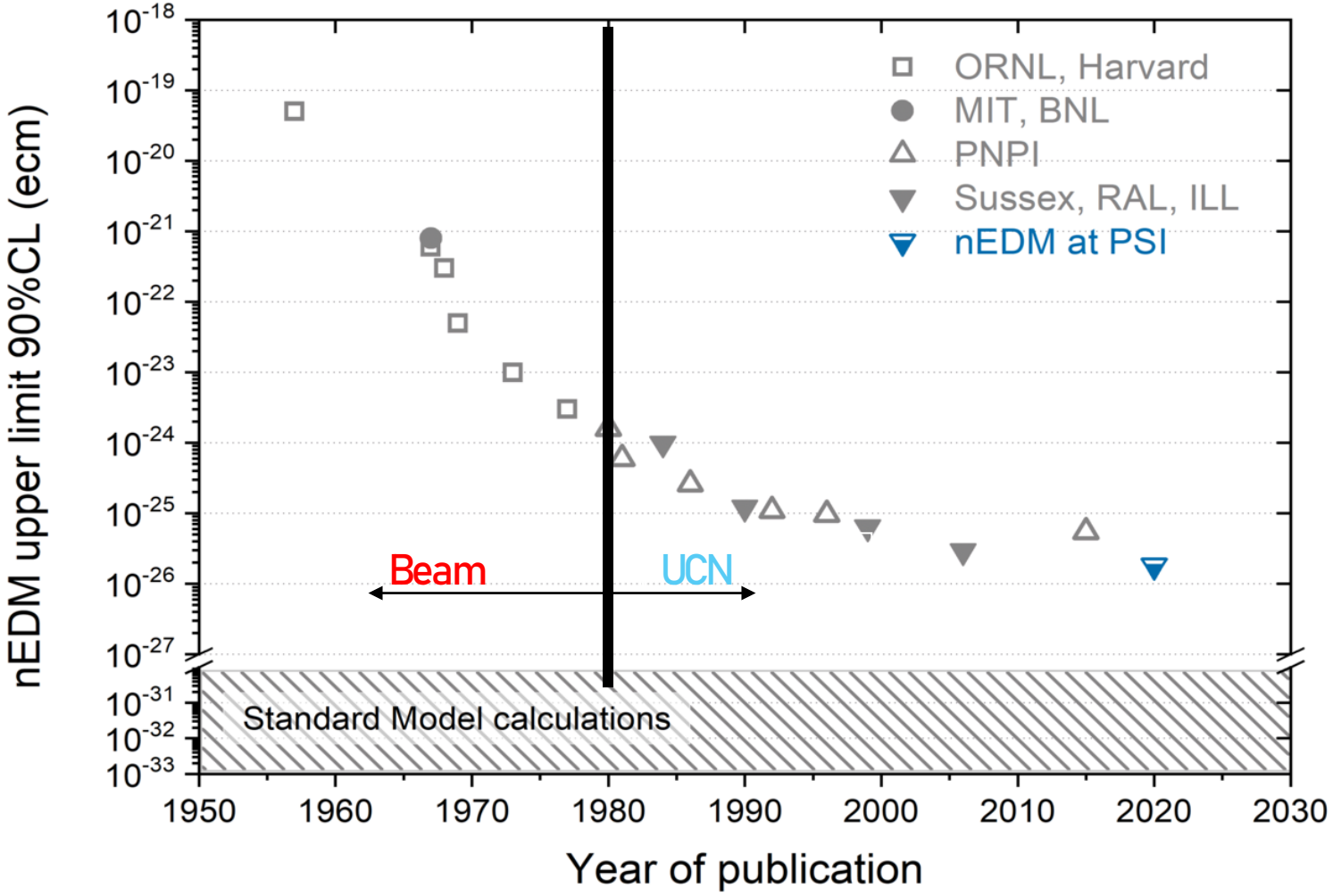


Final spin state

Space or time

Measuring the neutron EDM

State-of-the-art



Two directions :

- Cold neutron beam :

$|d_n| < 3 \times 10^{-24}\ e \cdot \mathrm{cm}$ (90% C.L.)[1]

- Ultracold neutron :

$|d_n| < 1.8 \times 10^{-26}\ e \cdot \mathrm{cm}$ (90% C.L.)[2]

[1] Dress, W. B. et al. Physical Review D 15.9 (1977)

[2] Abel, C. et al. Phys. Rev. Lett. 124, 081803 (2020)

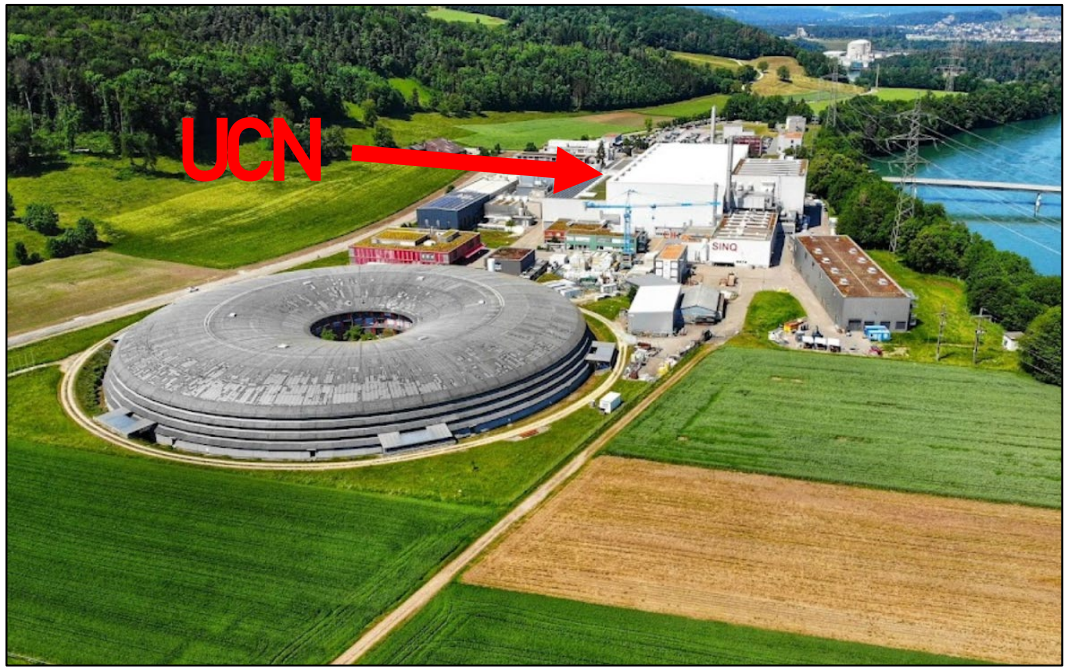
n2EDM

The most sensitive neutron EDM experiment

n2EDM

An international effort for the neutron EDM

- International collaboration with 15 institutions
- Experiment hosted and conducted at PSI
- Successor of the nEDM experiment



Actual limit for neutron EDM :

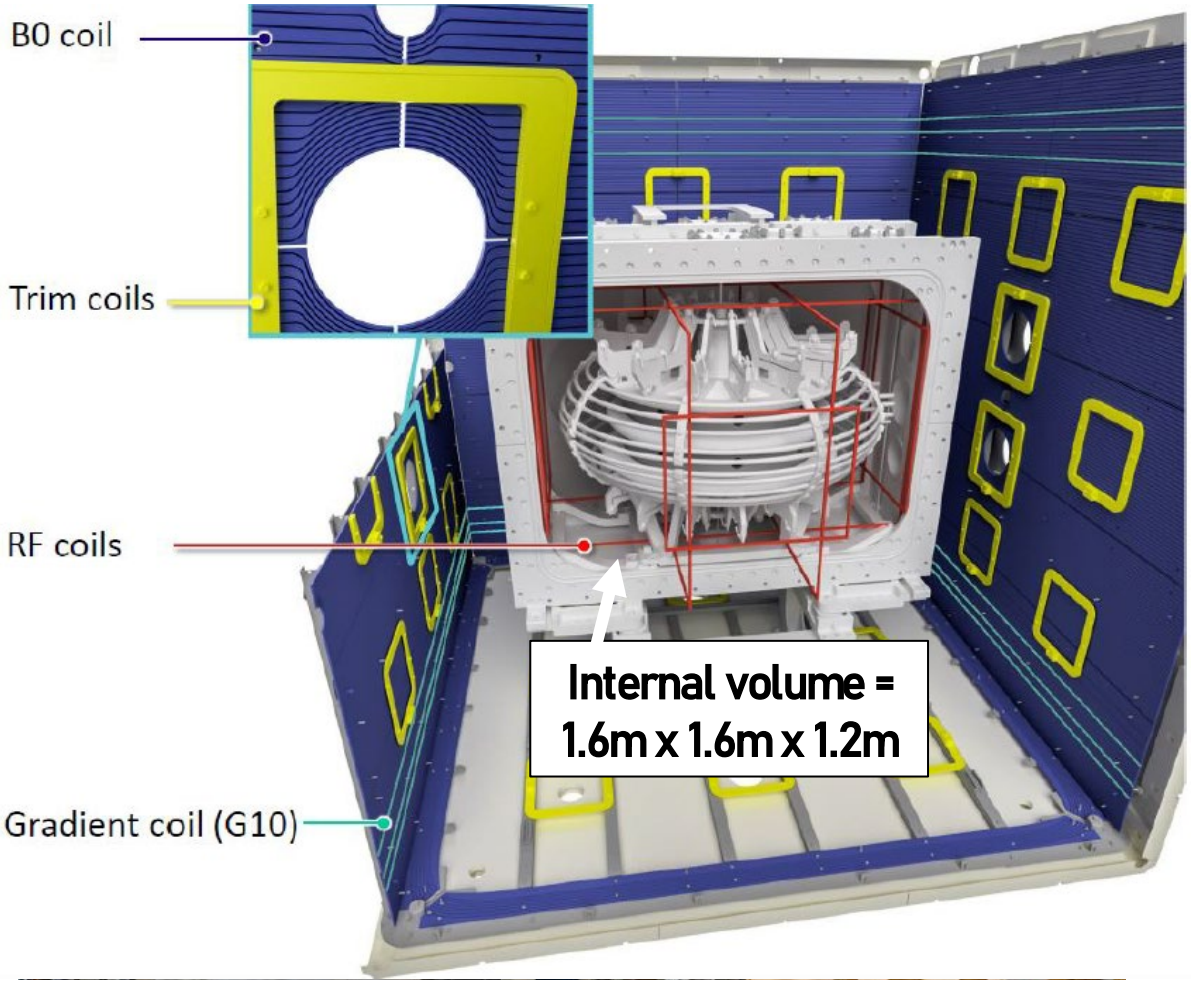
$$d_n = \left(0.0 \pm 1.1_{stat} \pm 0.2_{sys}\right) \times 10^{-26}\ e \cdot \mathrm{cm}$$

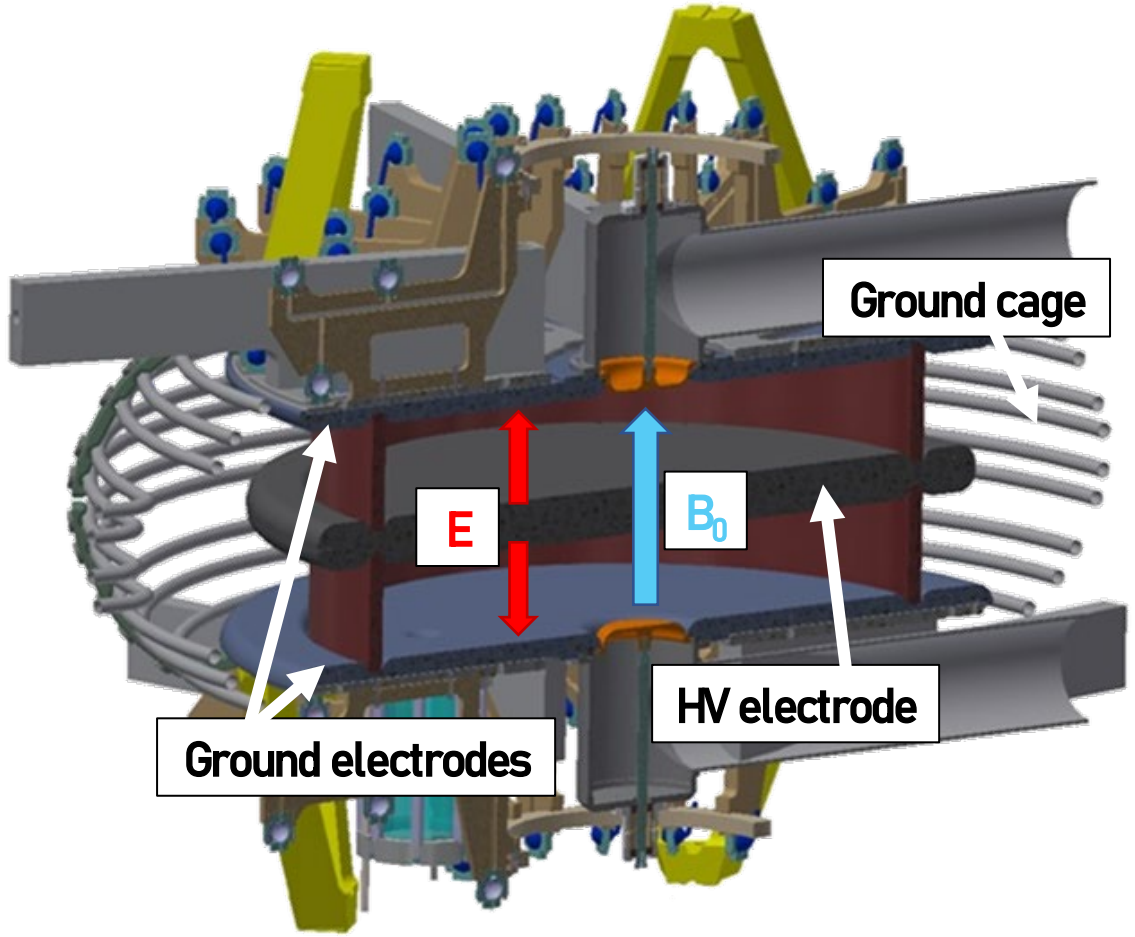
Abel, C et al., Phys. Rev. Lett. 124, 081803 (2020)

University of Bern :

Design, production, characterization and comissioning of HV components

n2EDM
Overview





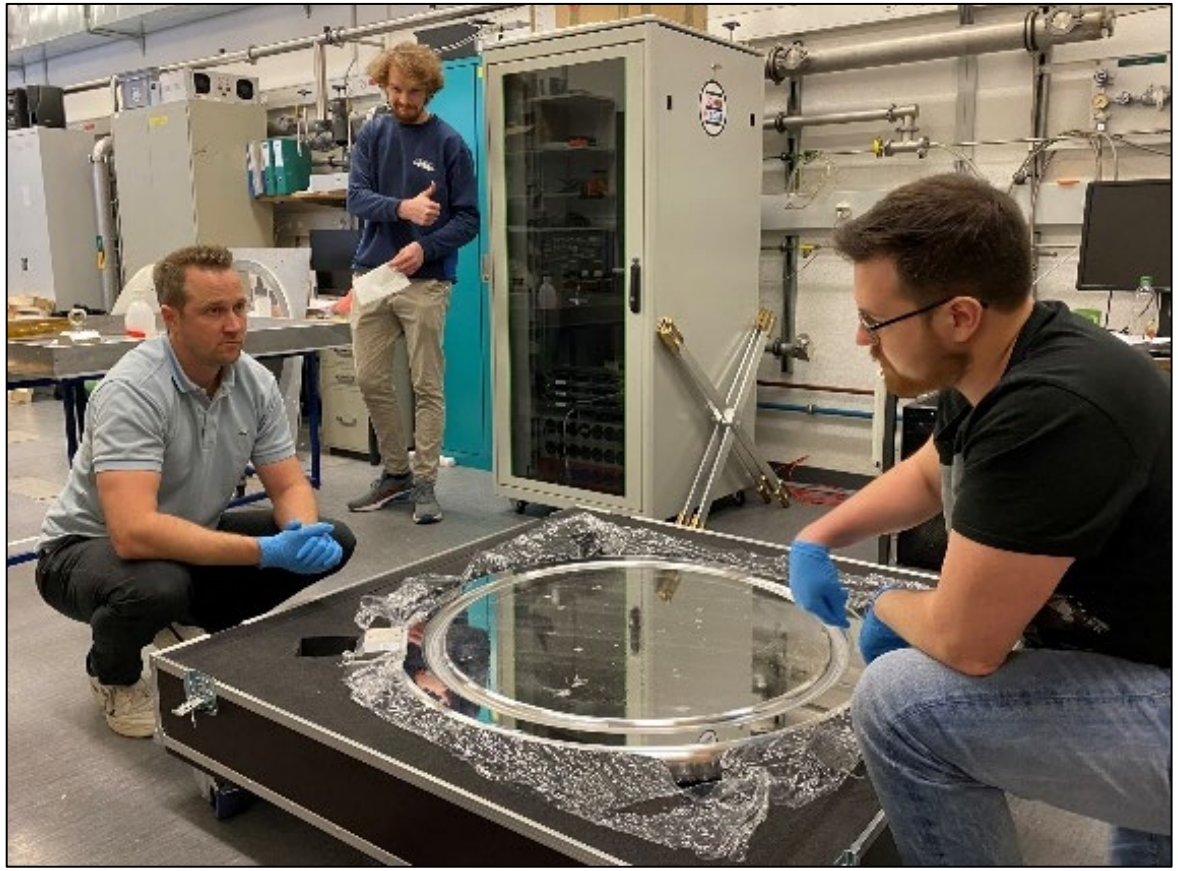
Electrodes production and DLC coating

Electrodes production at KWO, 2022

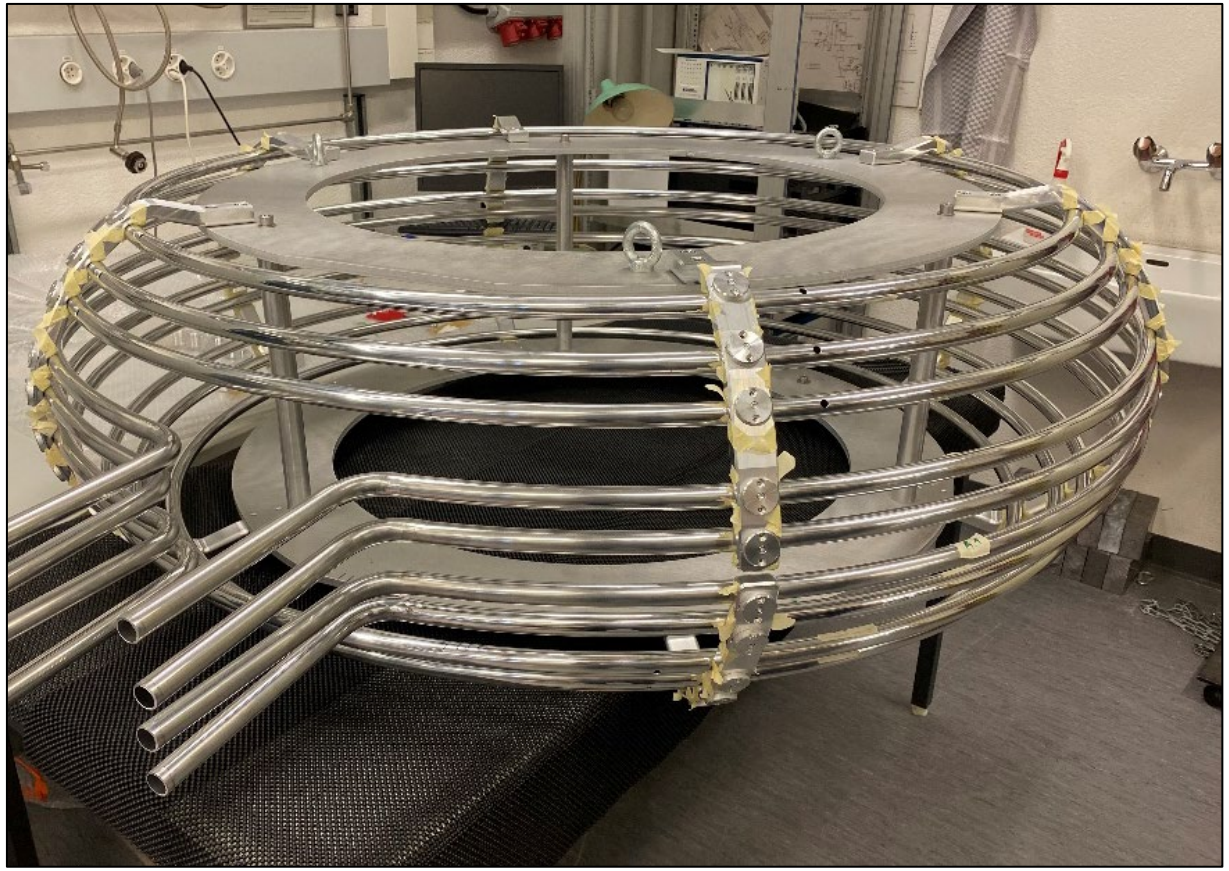
DLC coating, 2022

n2EDM

Preparation in our labs



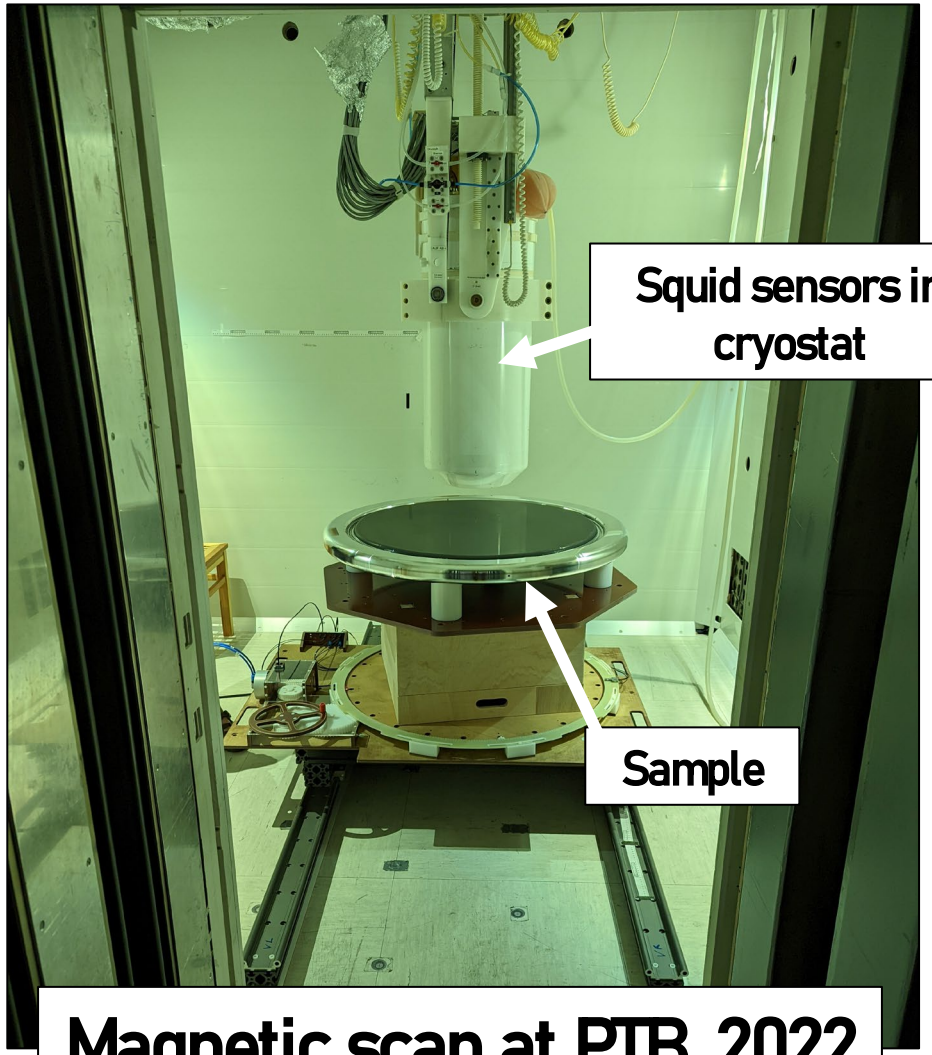
Electrodes cleaning



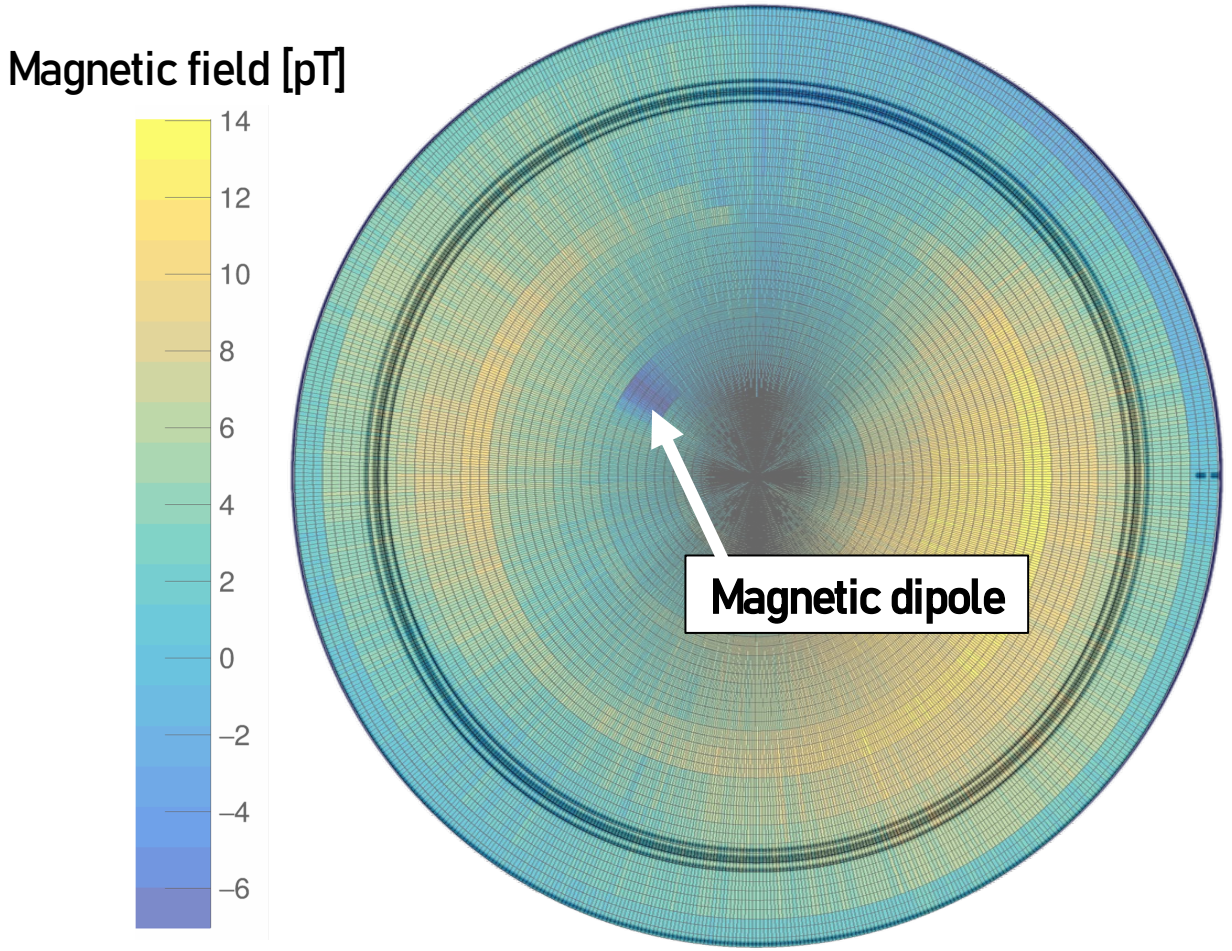
Ground cage

n2EDM

Magnetic scanning at PTB Berlin

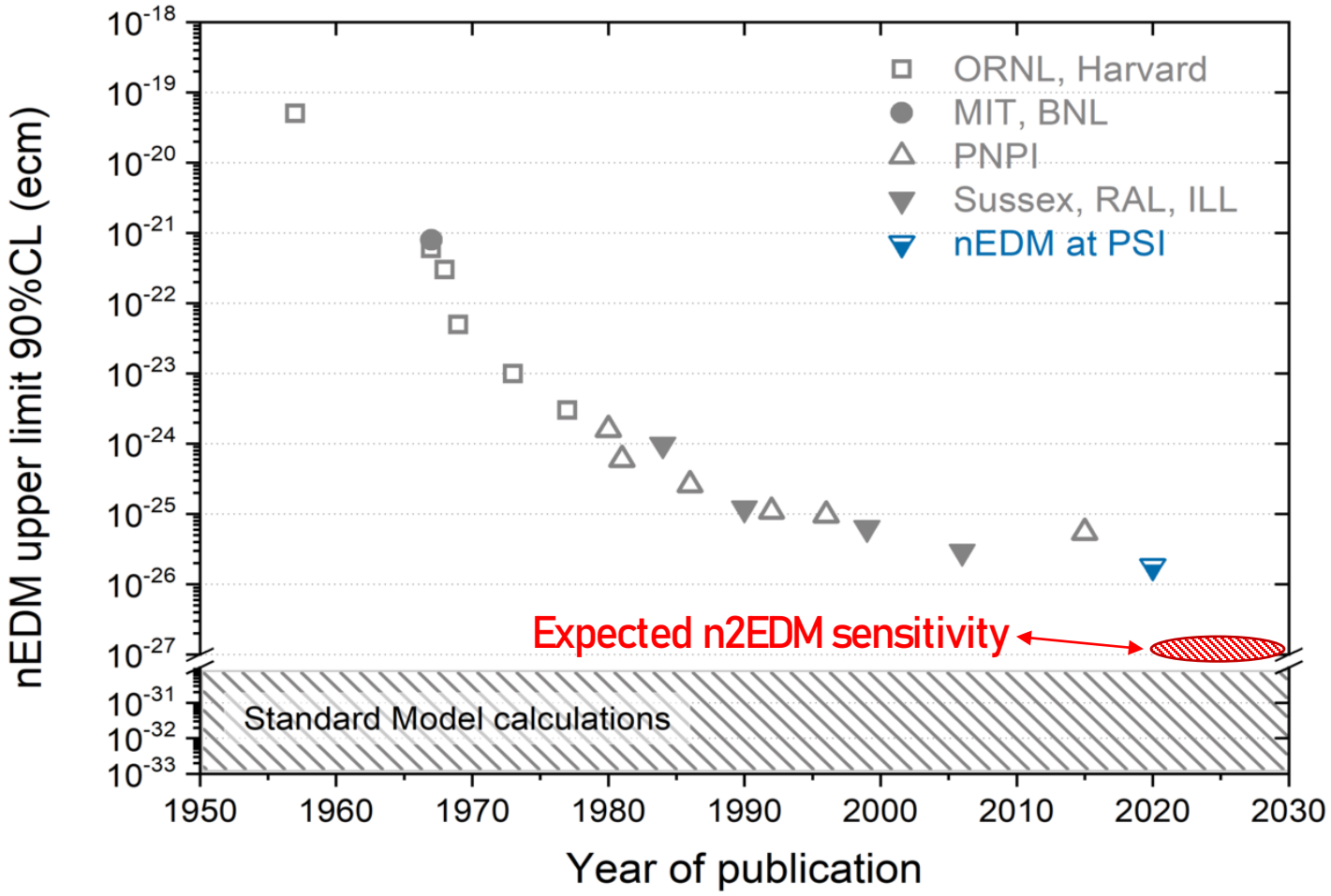


Magnetic scan at PTB, 2022



HV electrode

- Components delivered to PSI
- Assembling phase started
- First UCN planned for 2023



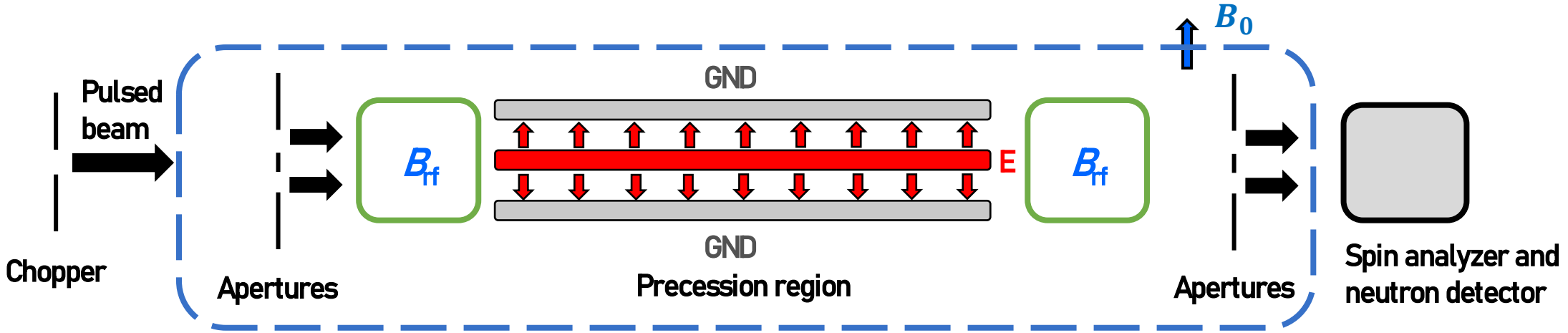
BeamEDM

A complementary search of neutron EDM

BeamEDM

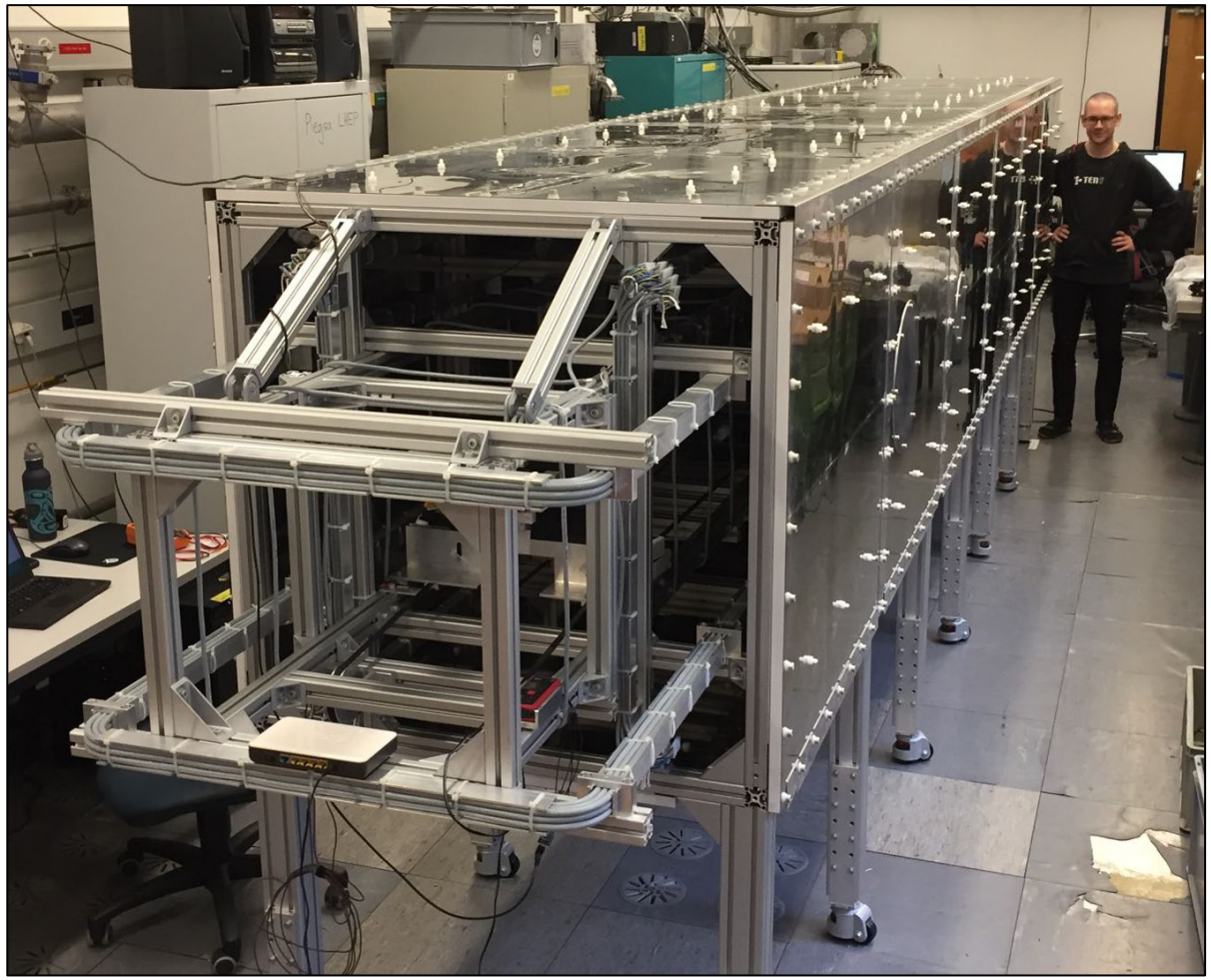
General idea

- Cold neutron beam EDM experiment
- Fully developed at University of Bern
- Proof-of-principle apparatus tested at PSI and ILL
- Intended for future fundamental physics beamline at ESS

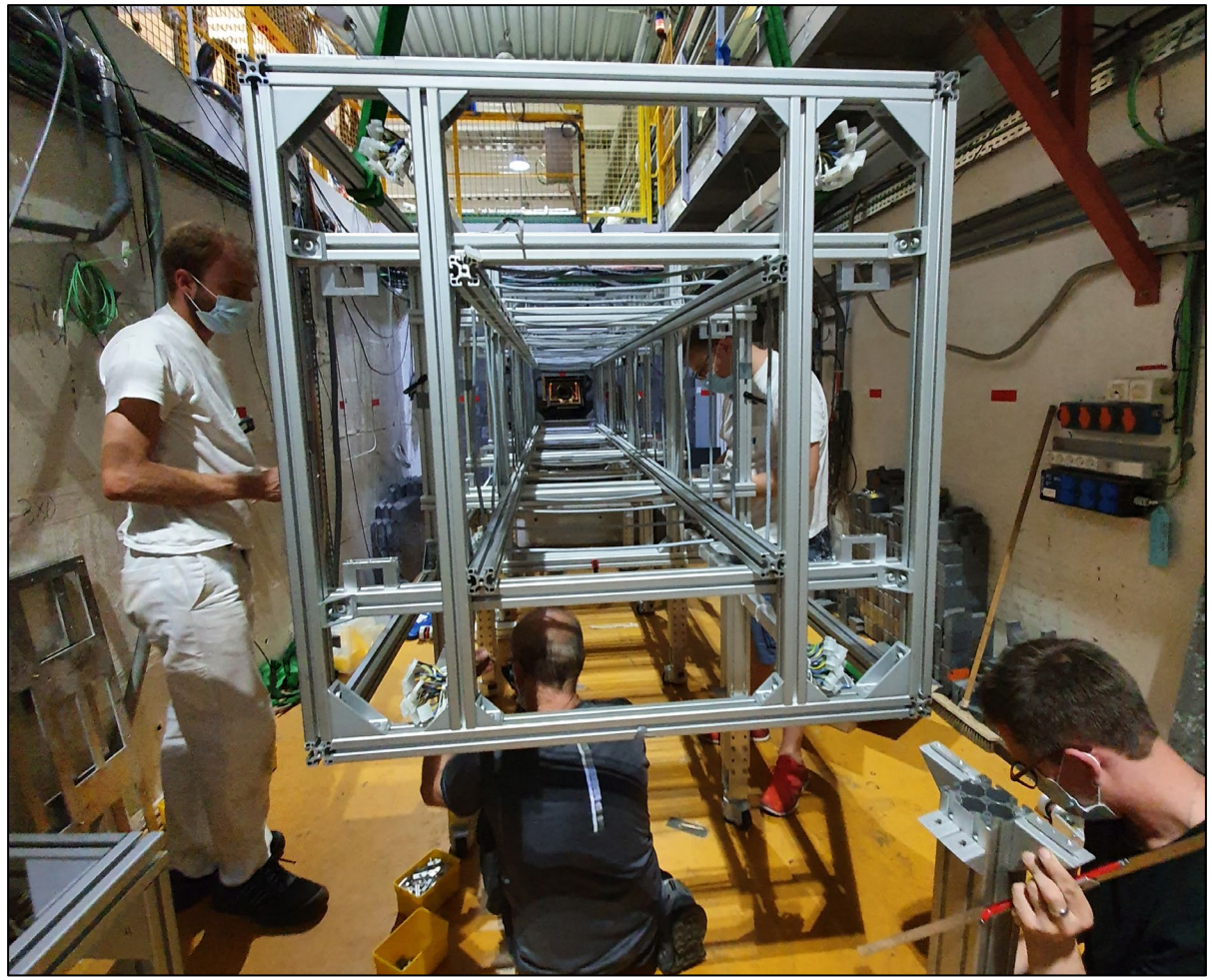


BeamEDM

Development at Uni Bern



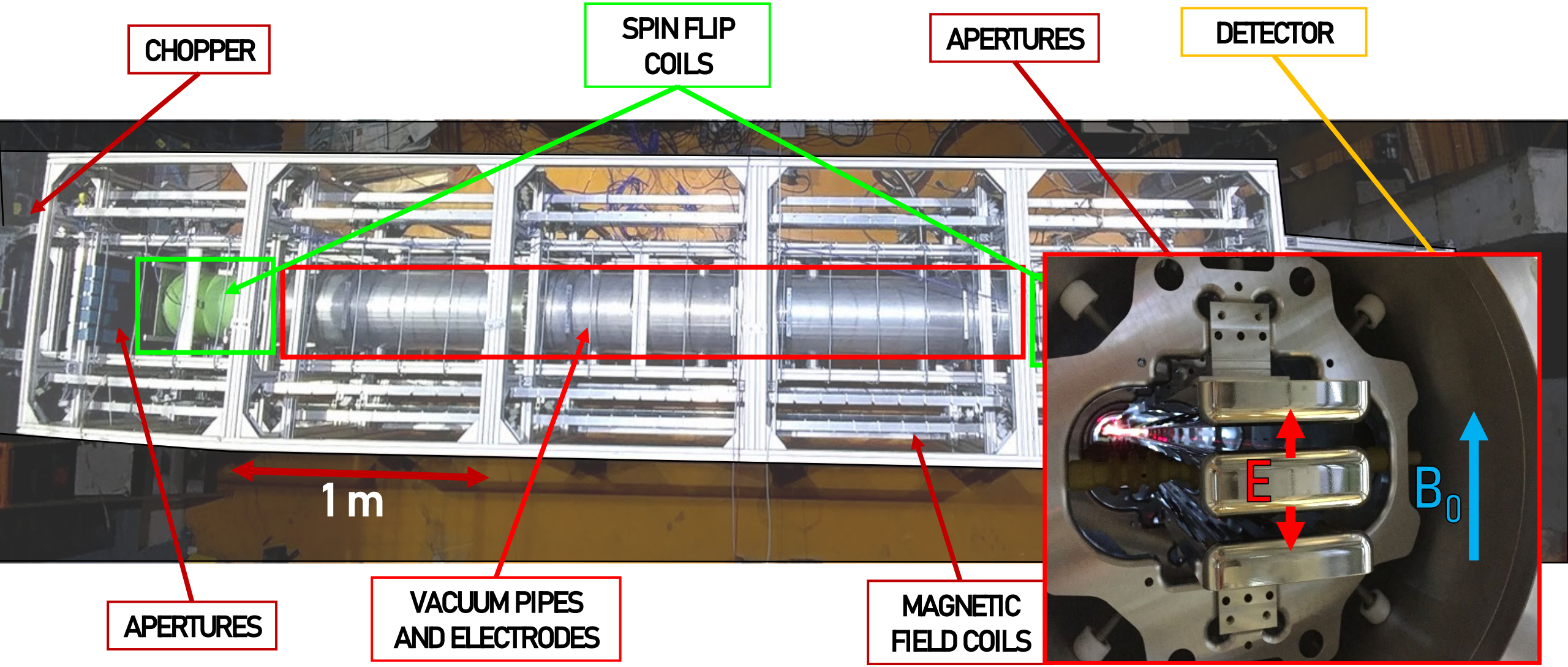
Magnetic scan in our lab



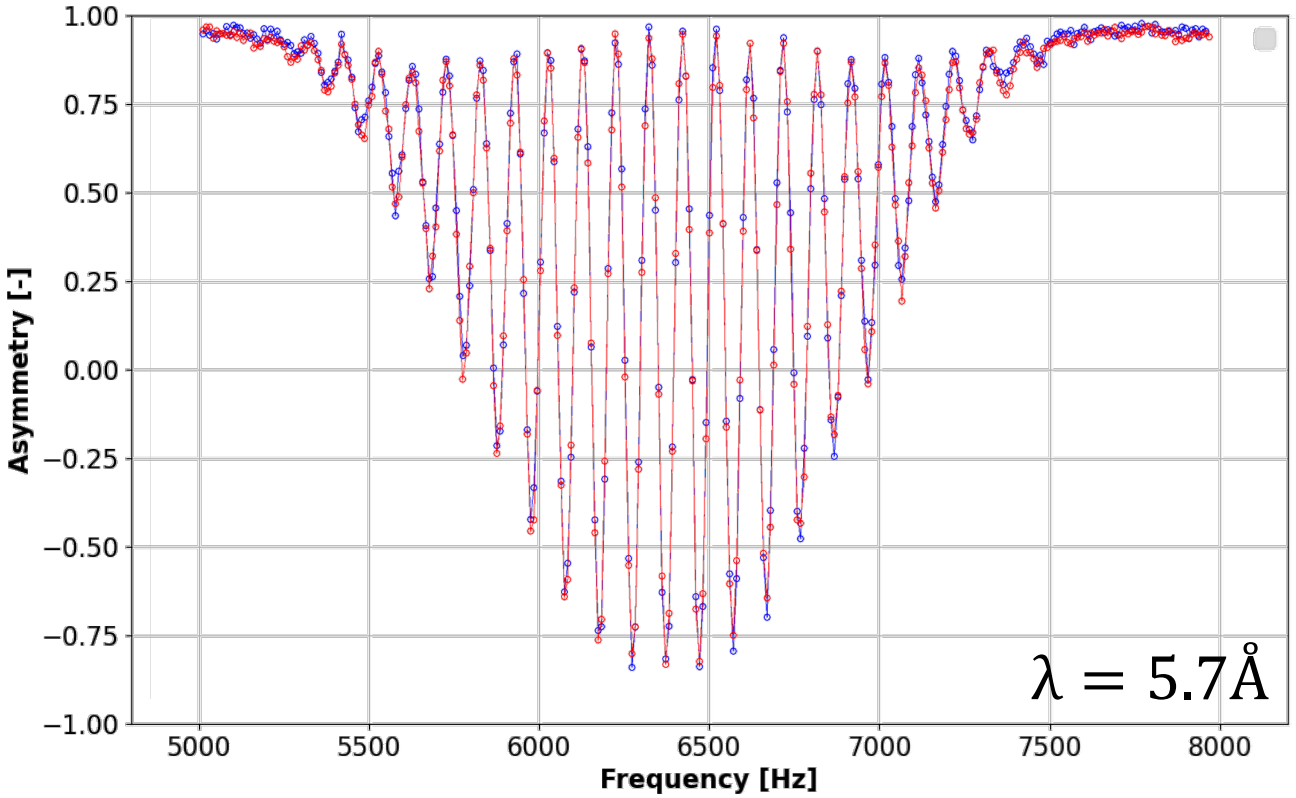
Installation for ILL beamtime, 2020

BeamEDM

Beamtime at ILL – August 2020



Ramsey frequency scan :



- Proof-of-principle apparatus
- Beamtimes at PSI and ILL between 2018 and 2020
- Actual neutron EDM sensitivity :

$$\sigma(d_n) \sim 4 \cdot 10^{-23} e \cdot \mathrm{cm}$$

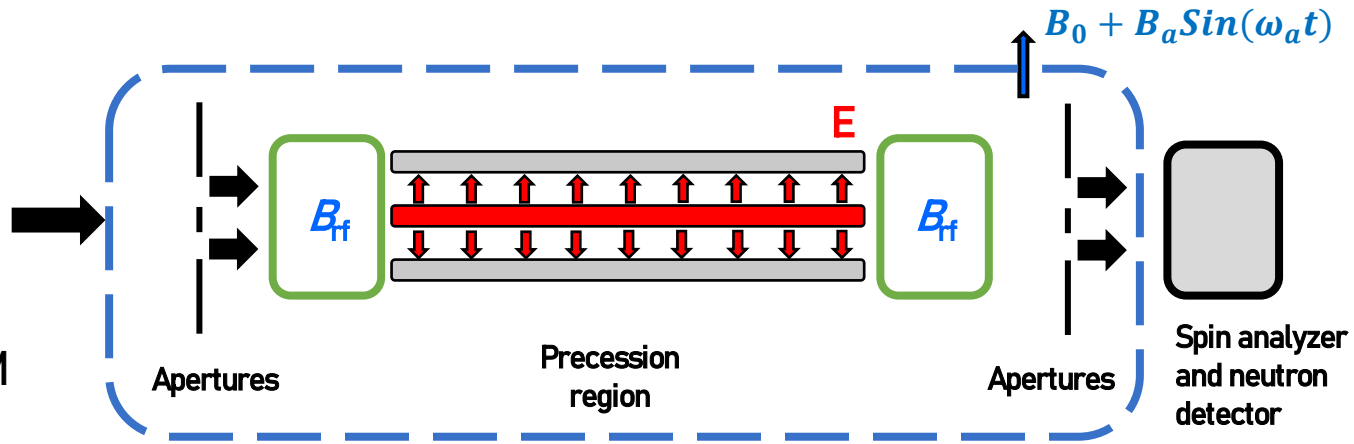
- Future : full-scale experiment at ESS

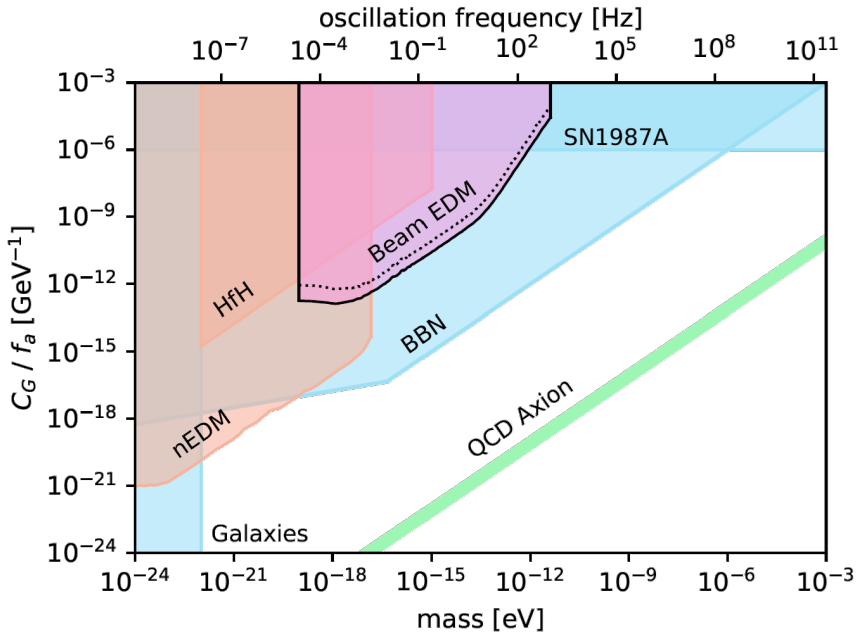
BeamEDM

Search for exotic interactions

Axions or ALPs :

- Proposition for solving strong CP problem
- New ultralight spin-0 particle
- Coupling to gluons inducing oscillating neutron EDM





Results published in PRL in 2022 !

Schulthess et al., Phys. Rev. Lett. 129, 191801 (2022)

Qneutron

Search for the neutron electric charge

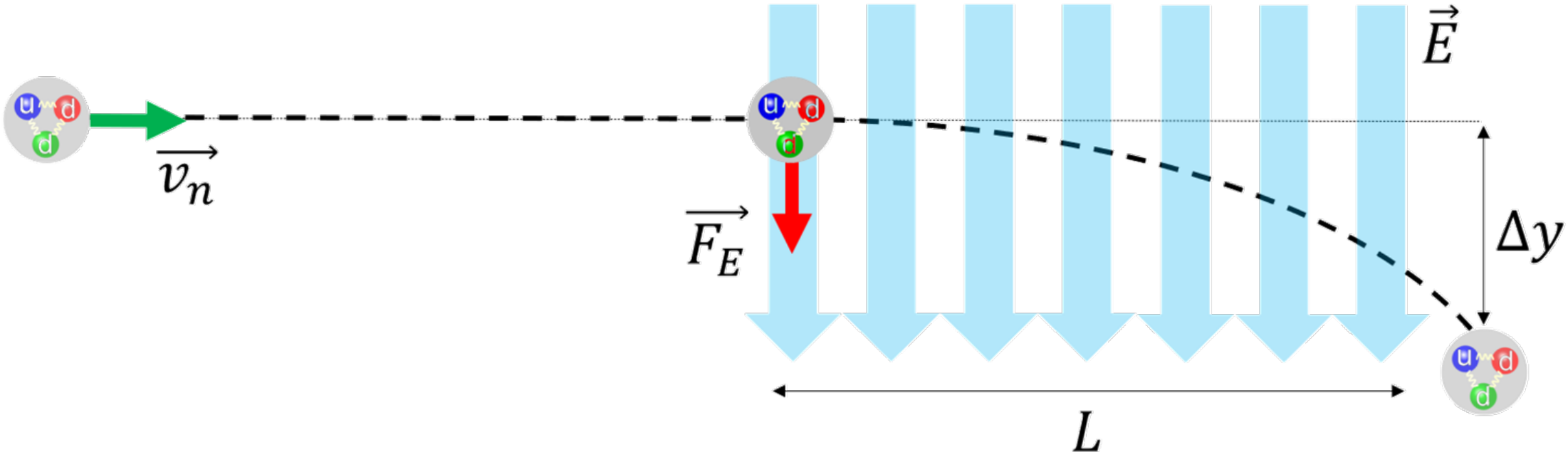
Qneutron

Measurement of a beam deflection

Current charge upper limit :

$$Q < (0.4 \pm 1.1) \times 10^{-21}\ e$$

Baumann et al.,
Phys. Rev. D 37, 3107 (1988)

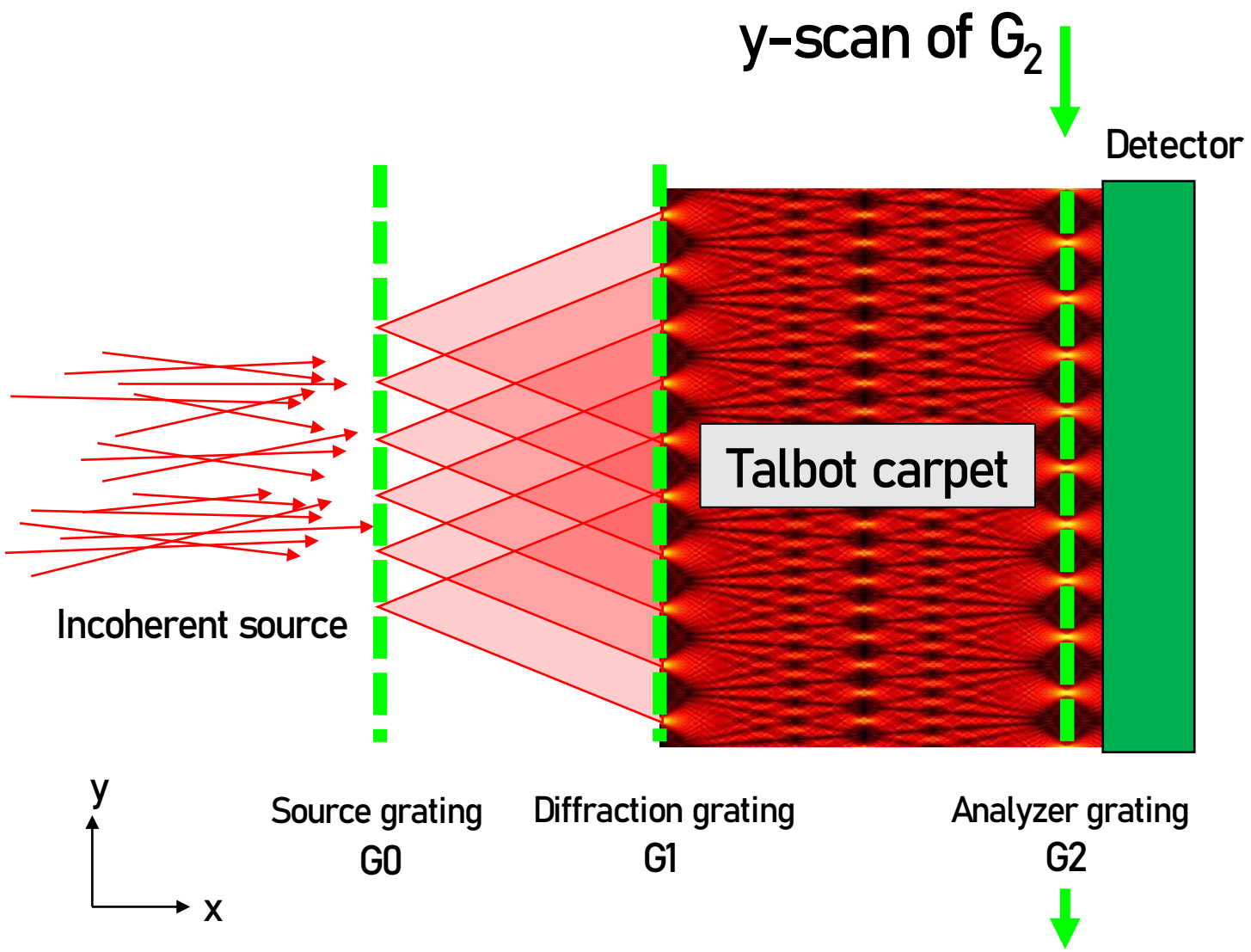


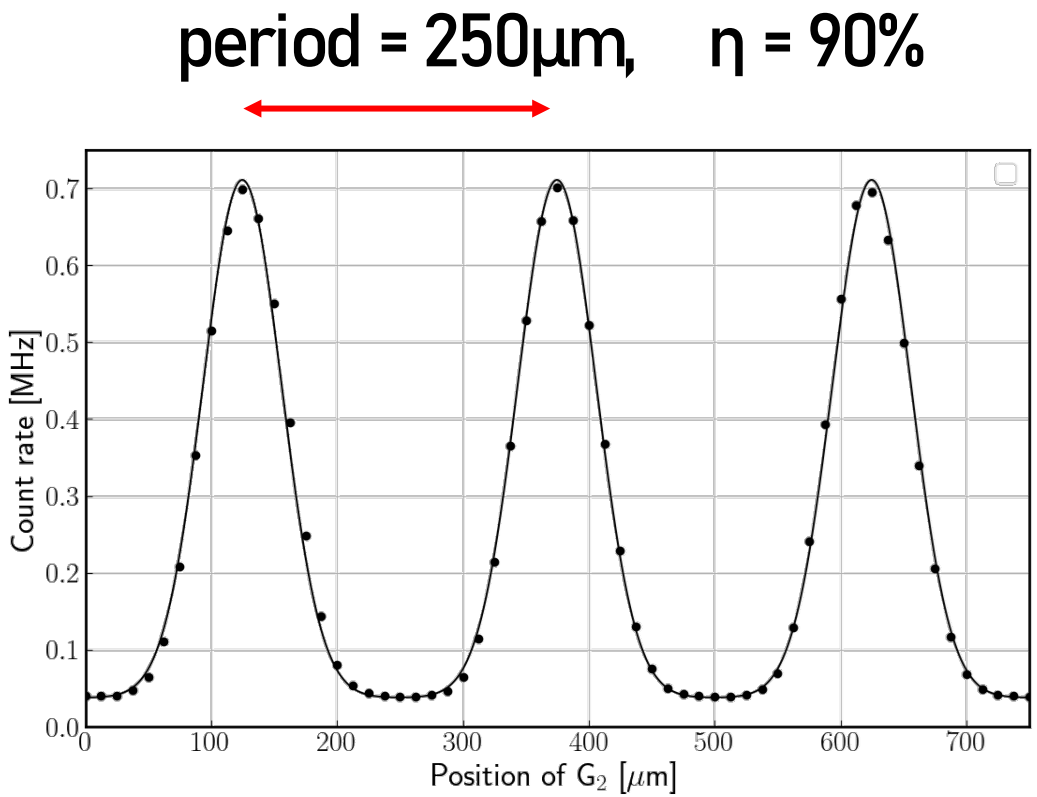
Two orders of magnitude improvement : Δy in picometer scale !

Piegsa, Phys. Rev. C 98, 045503 (2018)

Qneutron

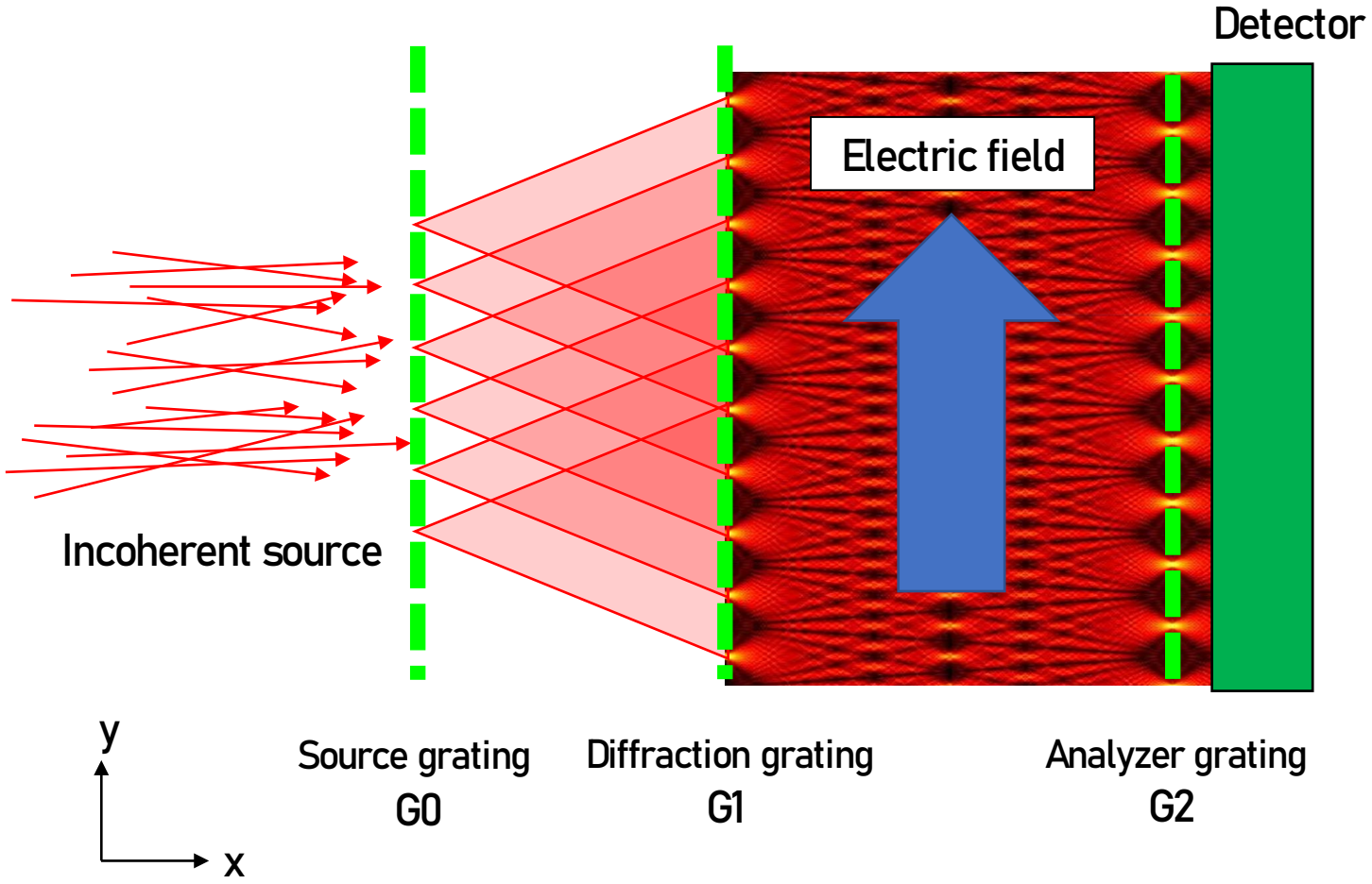
Grating interferometry

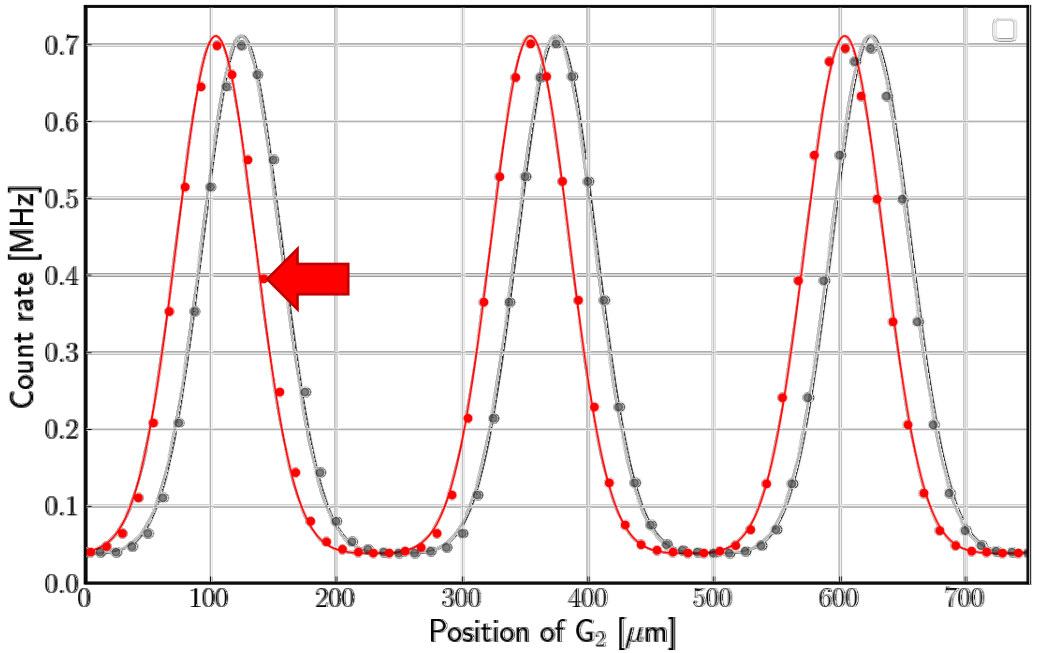




Qneutron

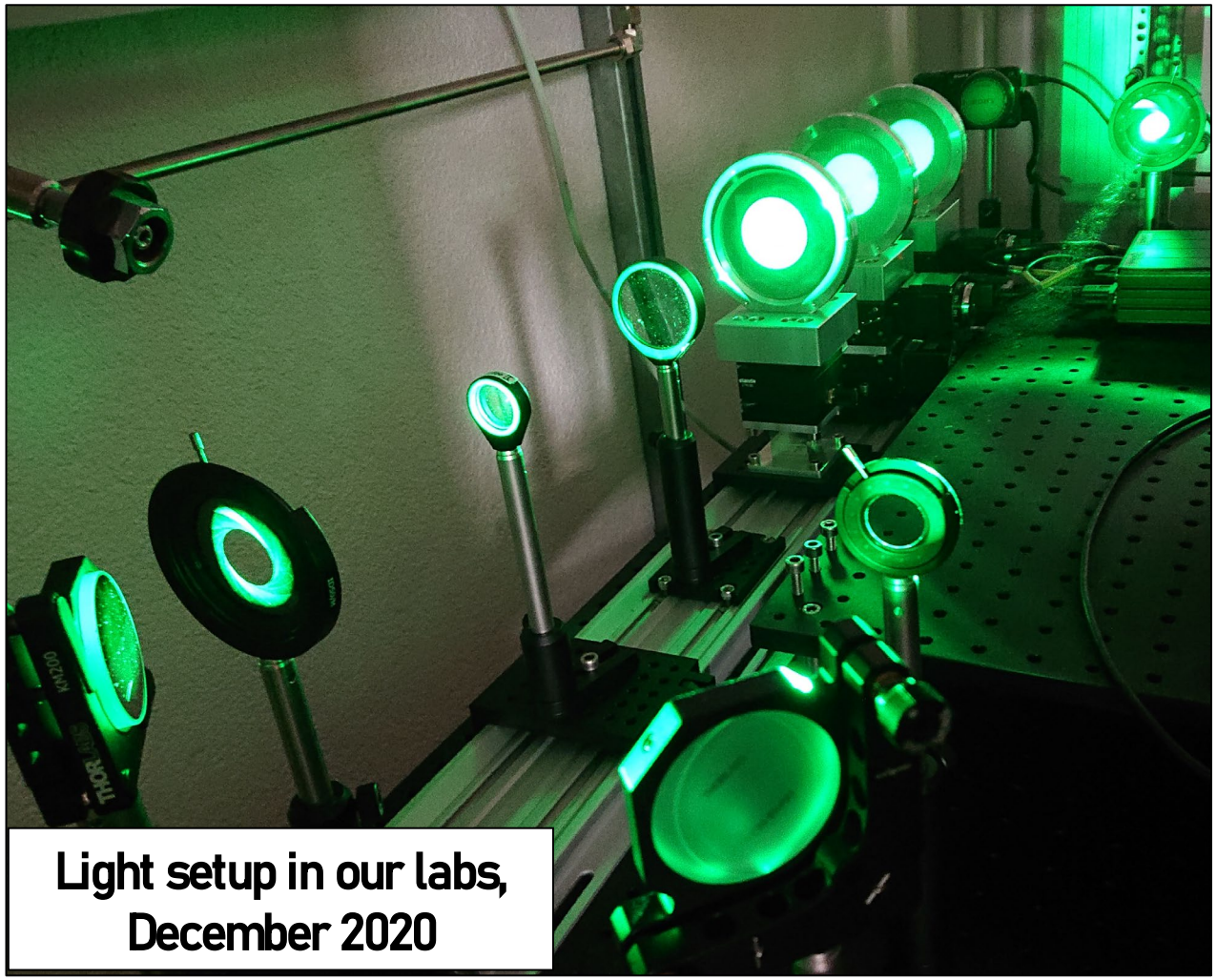
Grating interferometry

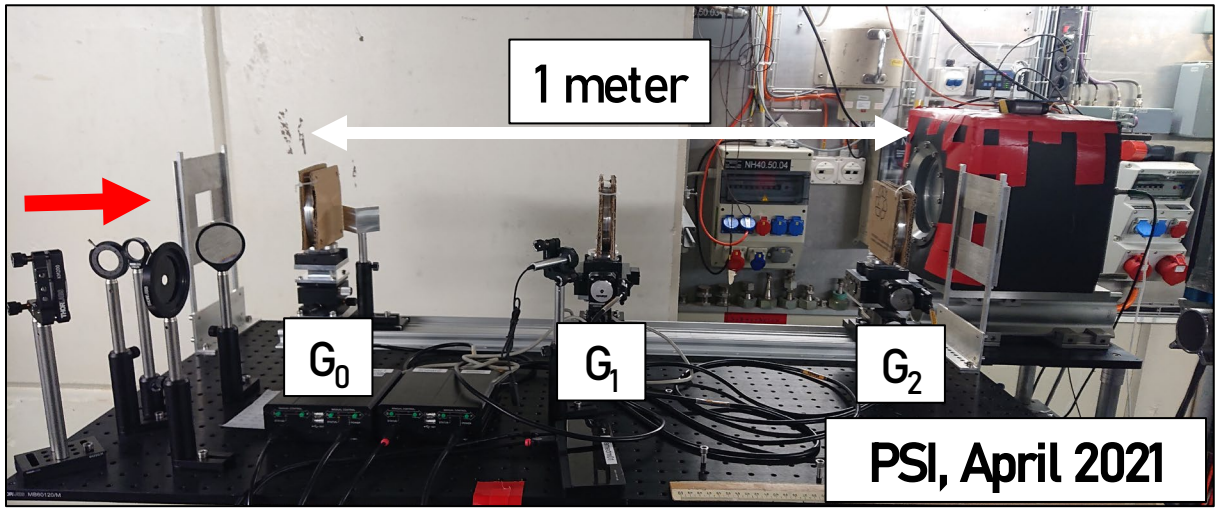


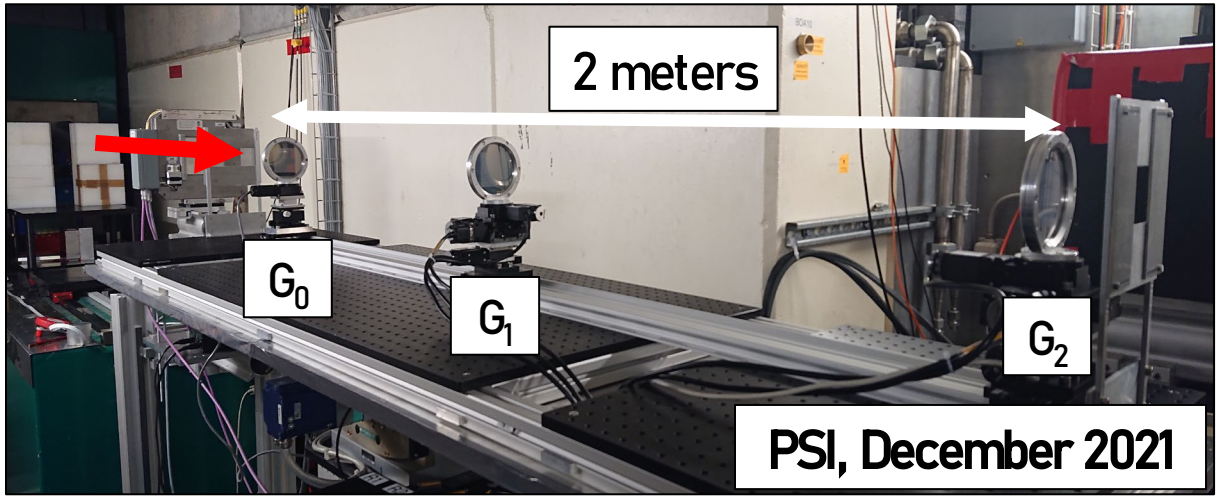


Qneutron

Evolution of the apparatus

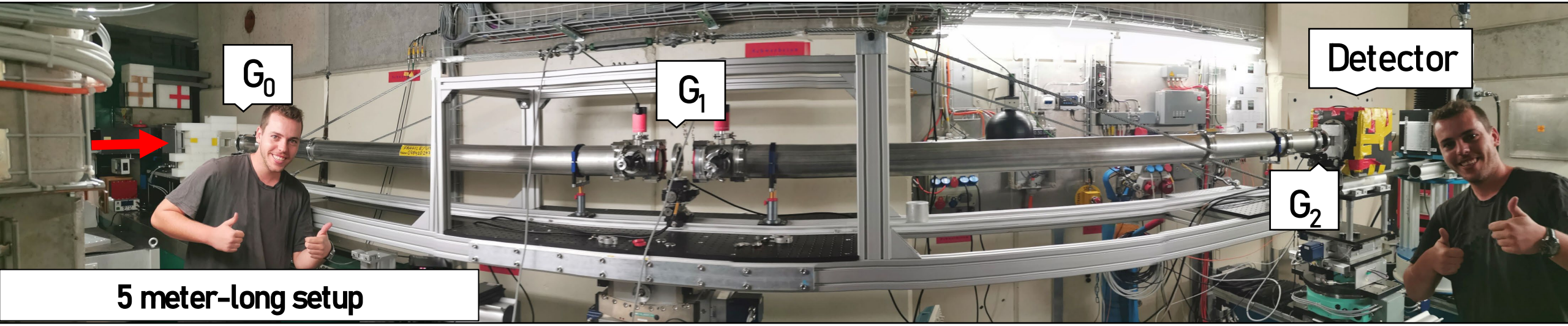




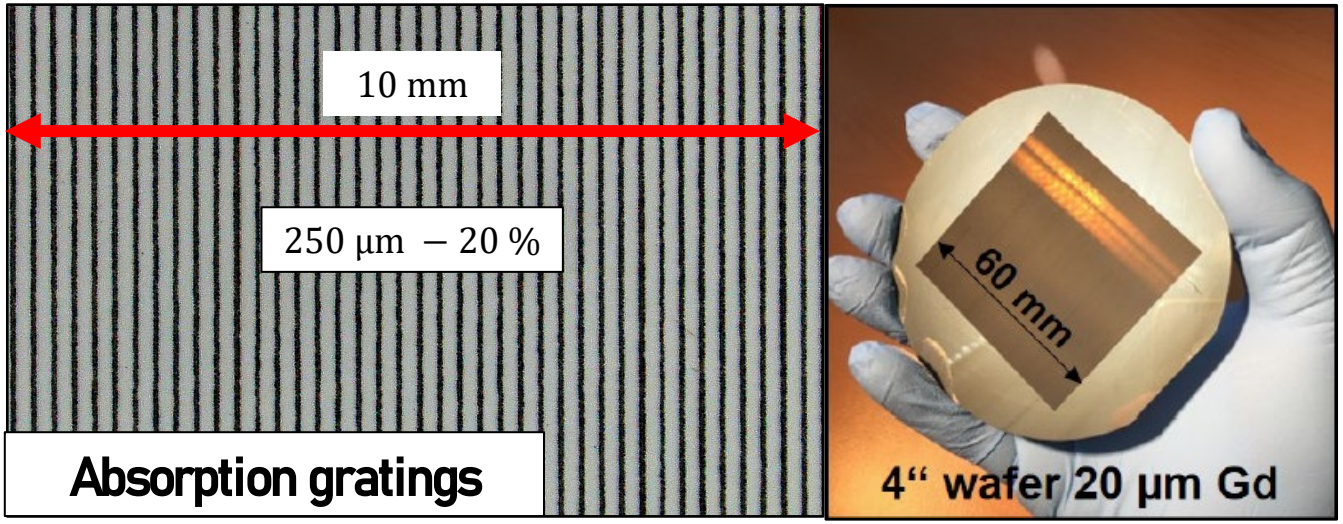


Qneutron

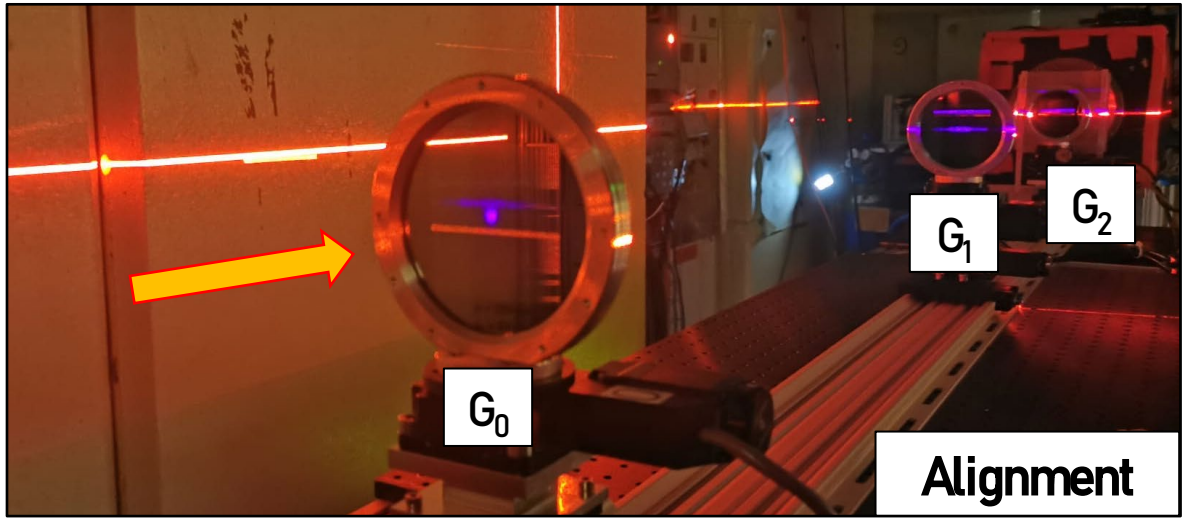
Current apparatus – Beamtime at PSI in August 2022



5 meter-long setup



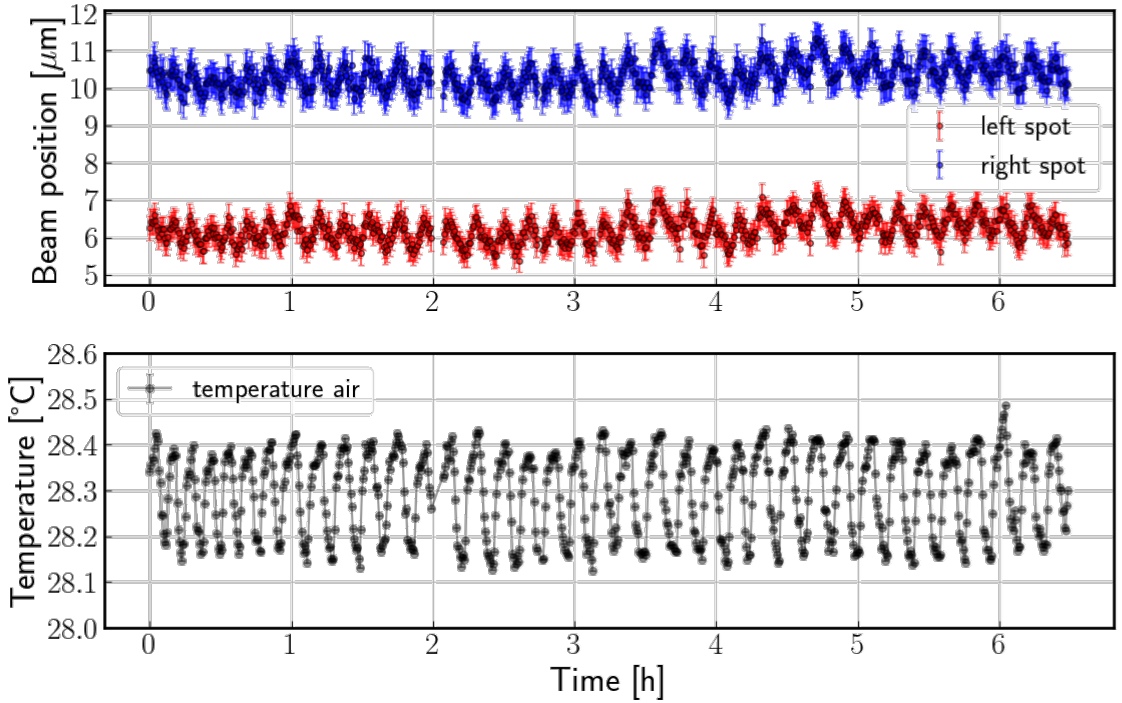
Absorption gratings



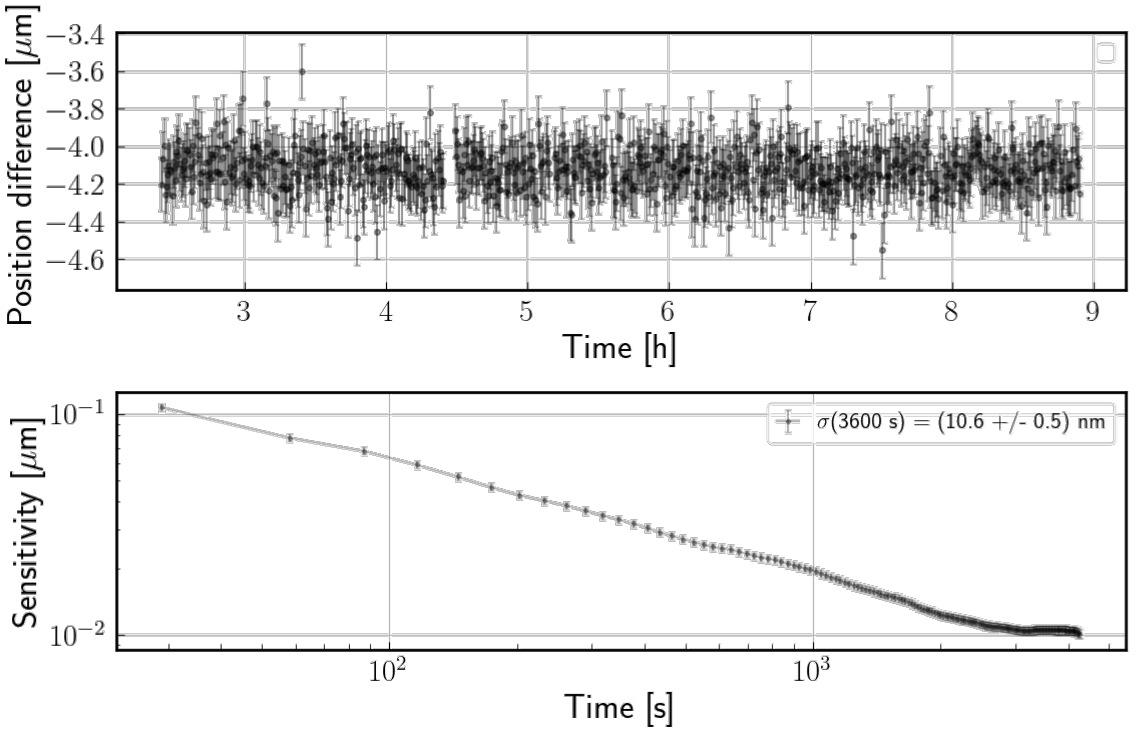
Alignment

Qneutron

Preliminary stability and sensitivity



- Stability with two-beam method
- 6.5 hours measurement time
- Investigate temperature fluctuations effects



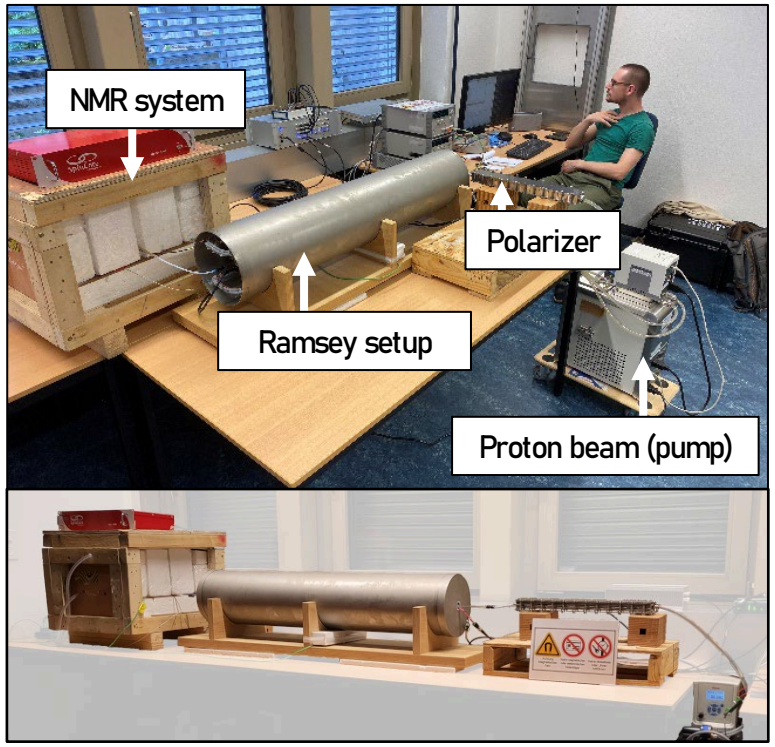
- Consider difference of beamspots
- Allan deviation result for 1 hour :

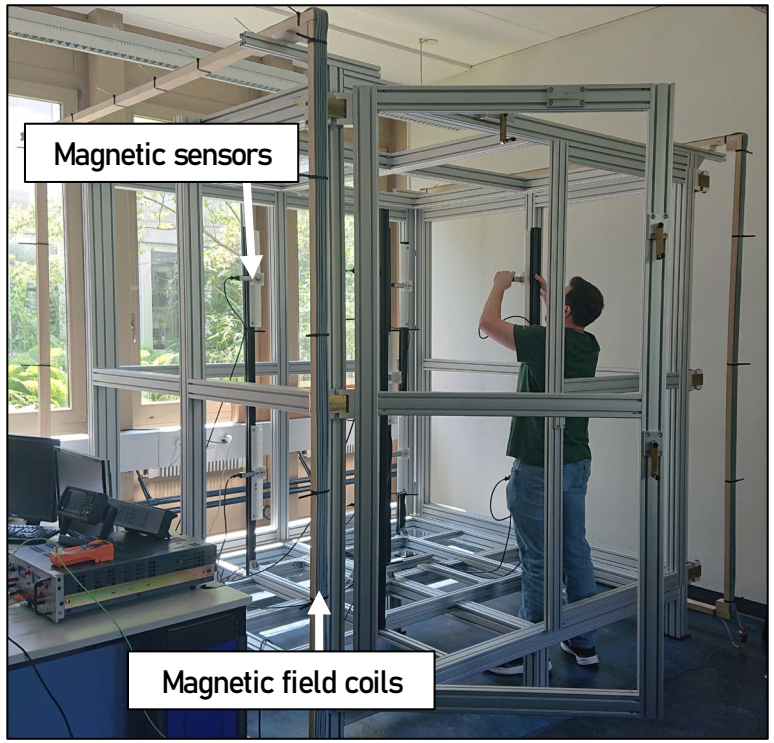
$$\sigma_{ASD}(\tau = 1\text{h}) = (10.6 \pm 0.5)\ \text{nm}$$

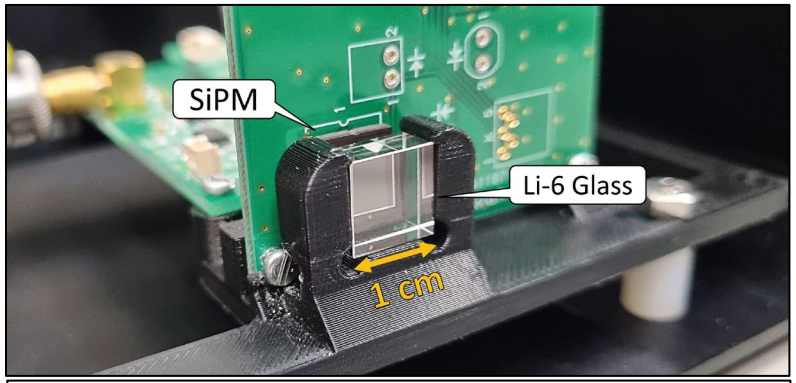
Magnetometry and neutron detection

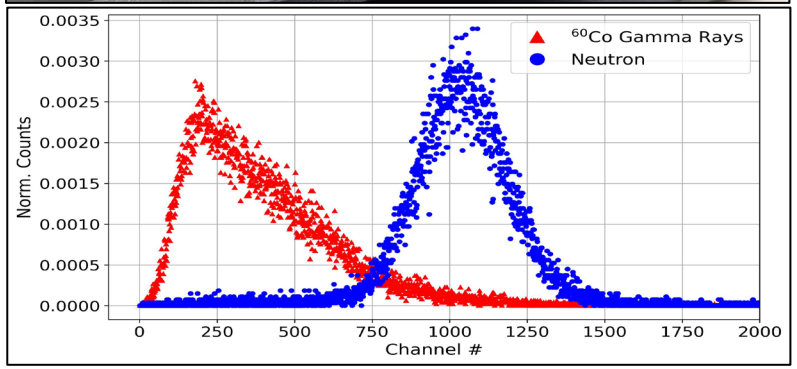
There is more

Magnetometry and neutron detection









Proton NMR

- Ramsey setup for proton
- Physics searches (axions)
- Spin techniques development

Magnetic shielded room

- 2m x 2m x 2m Mu-metal cube
- Medical applications (heart, brain)
- Sensor/sample characterization

New neutron detector

- ^{6}Li glass with Si-photomultiplier
- High rate detection
- High efficiency

Neutron physics at AEC

Conclusion

- Search for new physics beyond standard model (neutron EDM, charge, axions)
- Perform low-energy precision experiments at international research facilities
- Complementary to high-energy physics research

Neutron physics group in Sept. 2022

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SWISS NATIONAL SCIENCE FOUNDATION

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THANK YOU !