Neutron Ramsey Experiments at BOA

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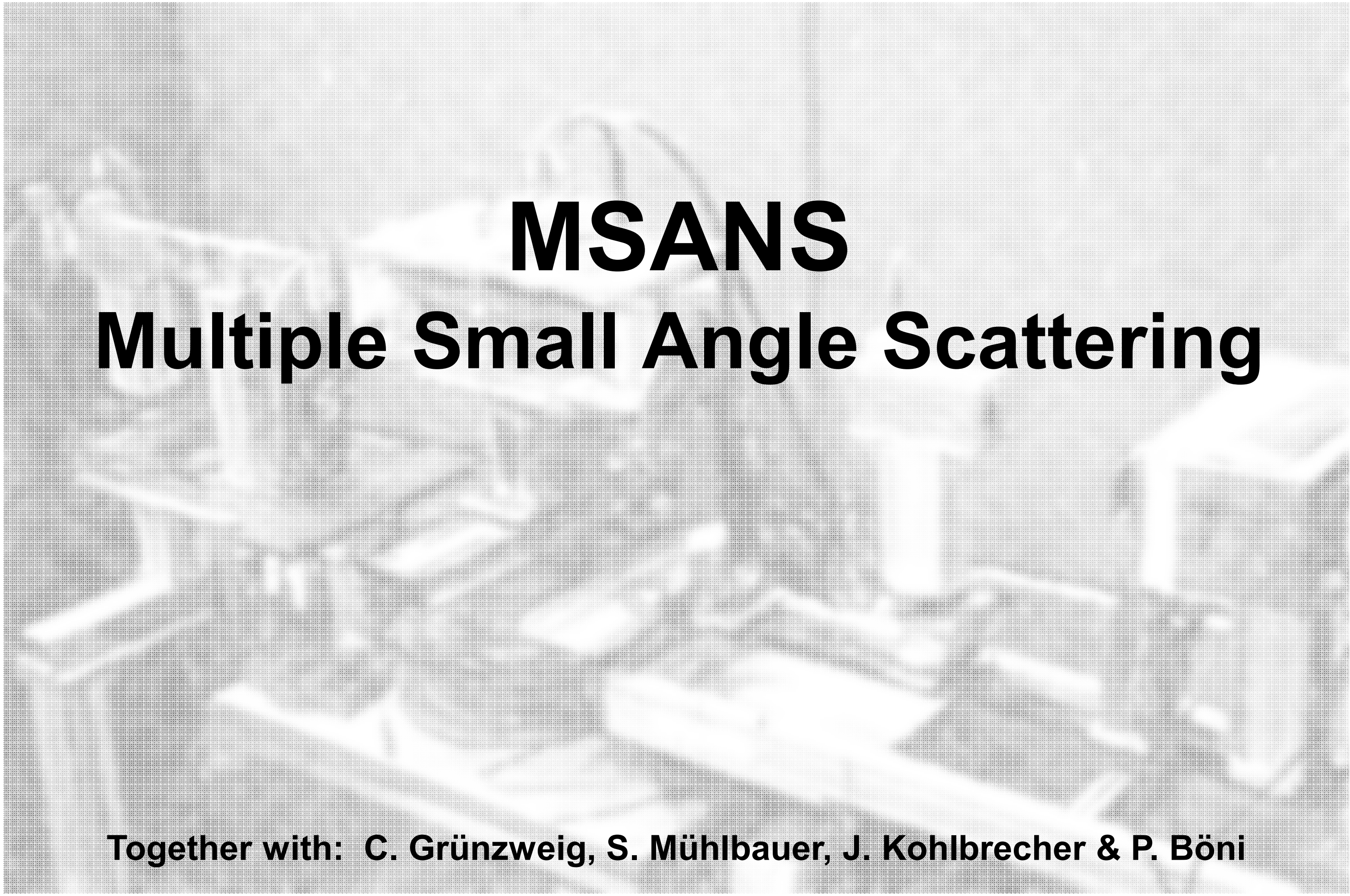
Paul Scherrer Institut – February, 22th 2013
BOA – Meeting

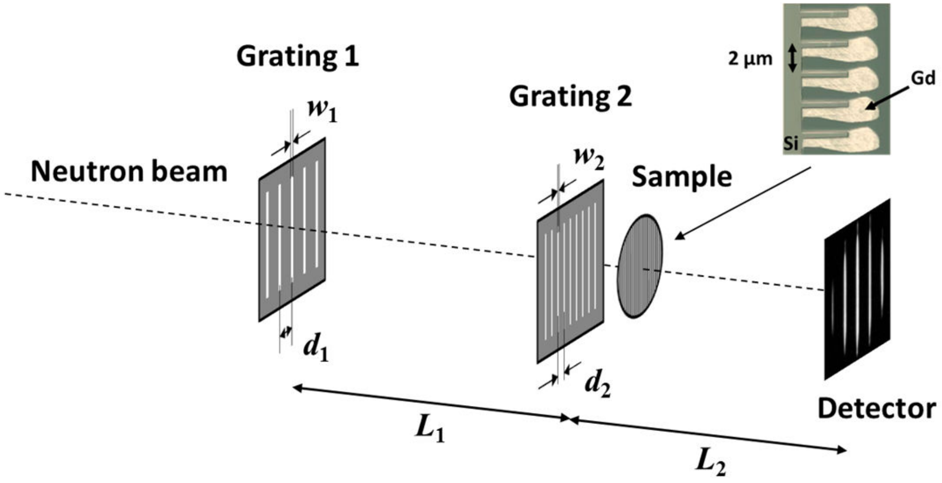
- A brief word on MSANS
- Ramsey’s technique adapted to neutrons
- Search for exotic interactions (at NARZISS)
- Test beam time at BOA (November 2012)
- Beam time request & Conclusion

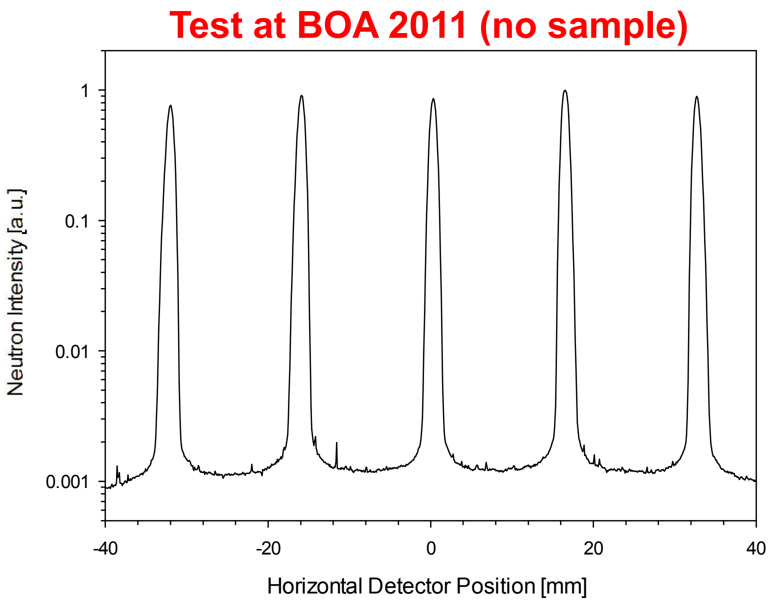


MSANS

Multiple Small Angle Scattering

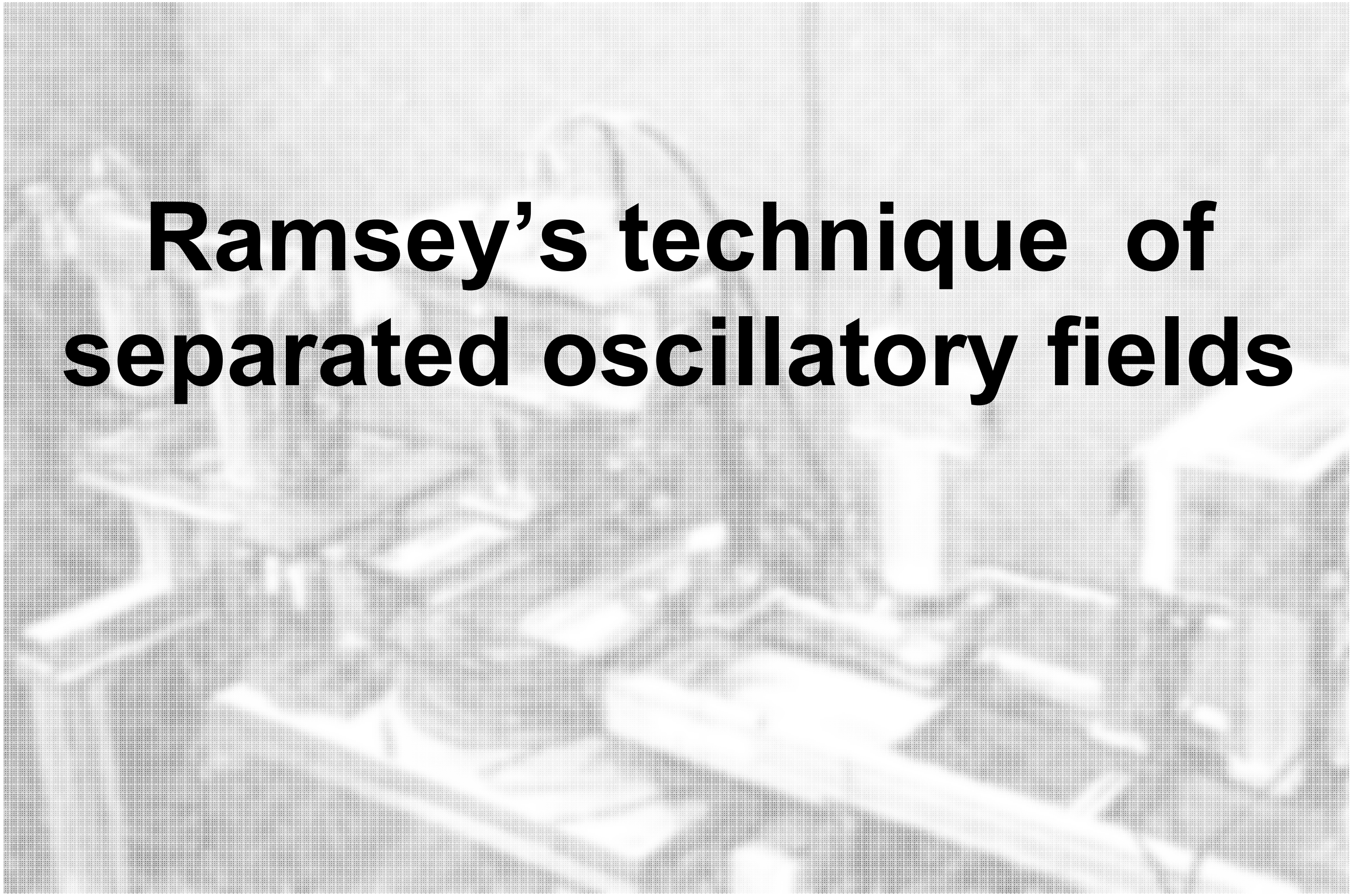
Together with: C. Grünzweig, S. Mühlbauer, J. Kohlbrecher & P. Böni



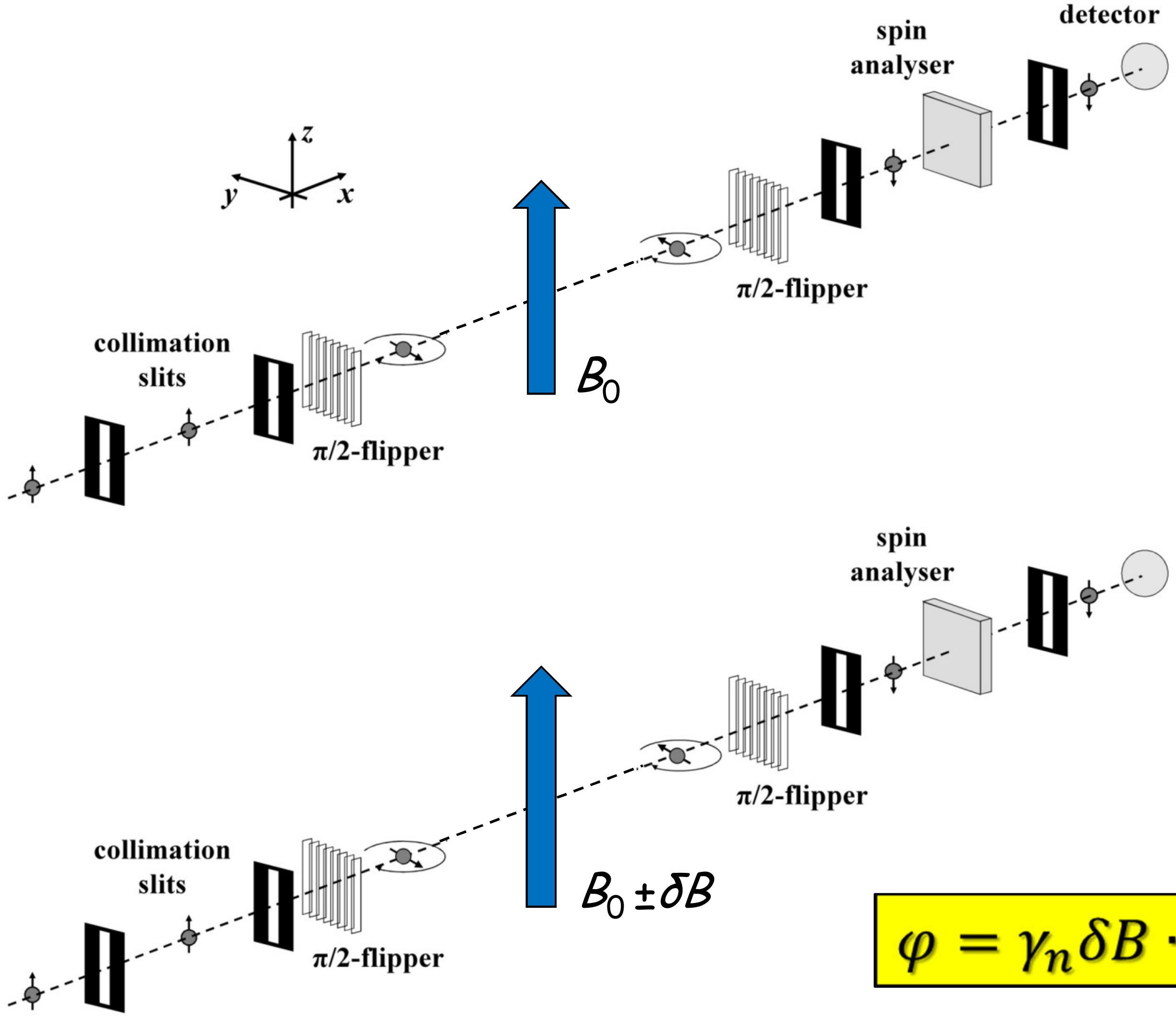


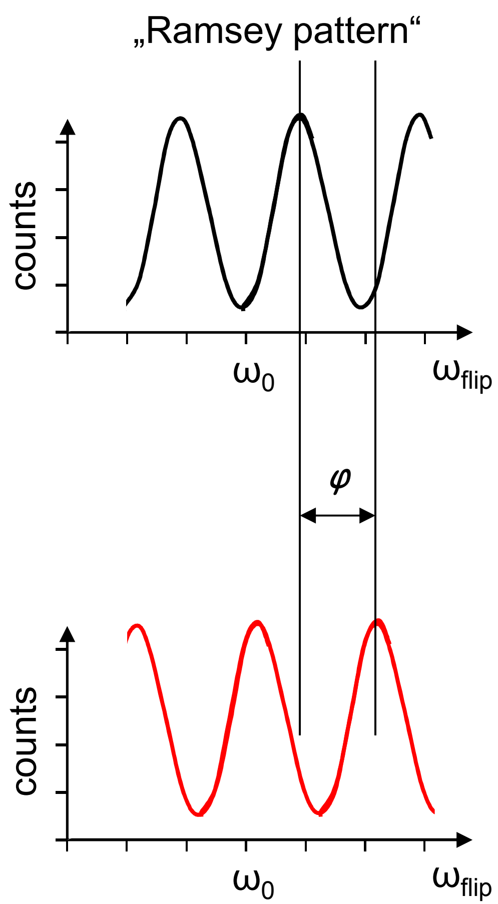
- Idea: extend the q range without loosing in intensity.
- MSANS-S/N at BOA was limited due to fast neutron background to approx. 1-2 x 10^{-3}.
- Accesible q-range down to 2 x 10^{-3} nm^{-1} (at λ=1 nm), compared to 1 x 10^{-2} nm^{-1} (SANS-I).
- Performed succesful test last year at SANS-II: S/N about 2 x 10^{-4} at λ=0.5 nm.
- Would be maybe interested to do additional experiments at BOA, if the fast neutron background can be reduced.

Ramsey's technique of separated oscillatory fields



Ramsey technique (Nobel Prize 1989)

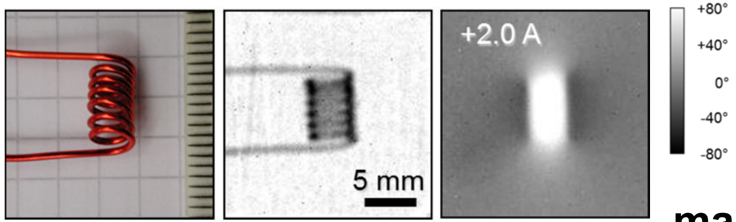




$$\varphi = \gamma_n \delta B \cdot t$$

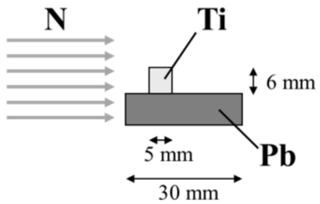
Ramsey, Phys. Rev. **78** (1950) 695

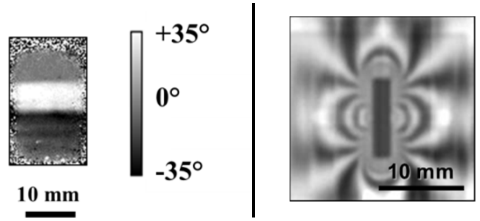
Magnetic and Pseudo-magnetic interaction



Piegsa et al., *NIM A* **605** (2009) 5

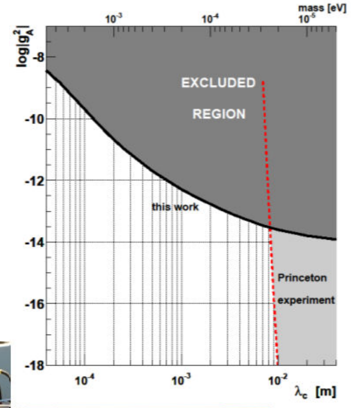
magn. fields



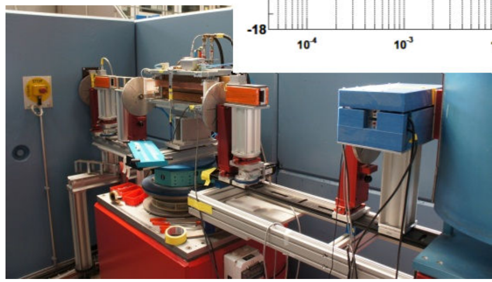


magn. materials

Piegsa et al., *PRL* **102** (2009) 145501
Piegsa et al., *Physica B* **406** (2011) 2409



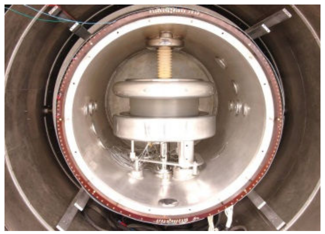
exotic interactions



Piegsa & Pignol, *PRL* **108** (2012) 181801

$$\varphi = \gamma_n \delta B \cdot t$$

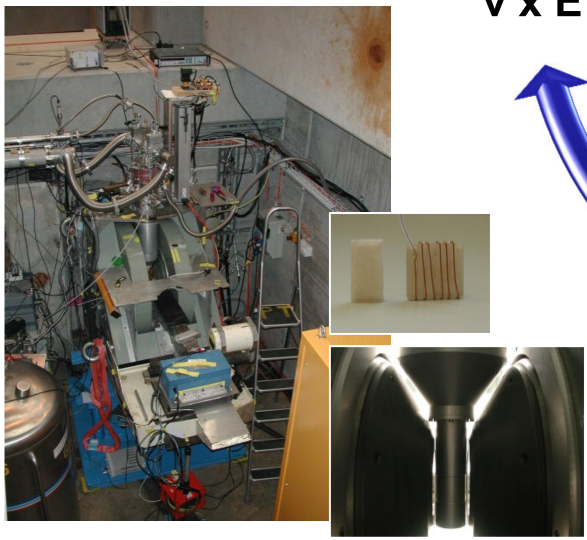
nEDM



incoh. scattering lengths

$$\vec{B}^* = \frac{\vec{v} \times \vec{E}}{c^2}$$

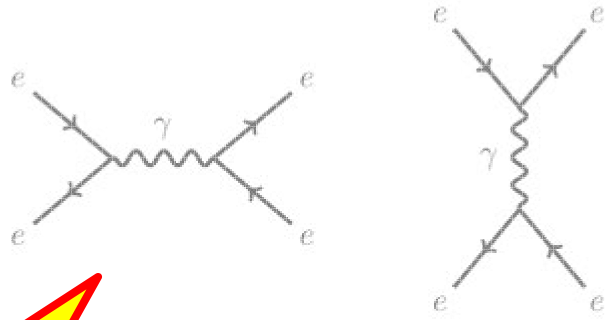
relativistic v x E



van den Brandt et al., *NIM A* **611** (2009) 231

Exotic interactions

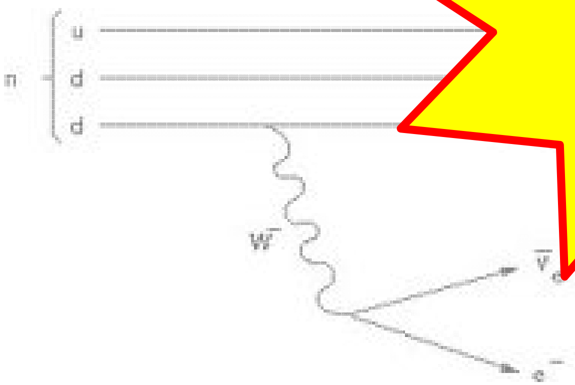
Gravitation



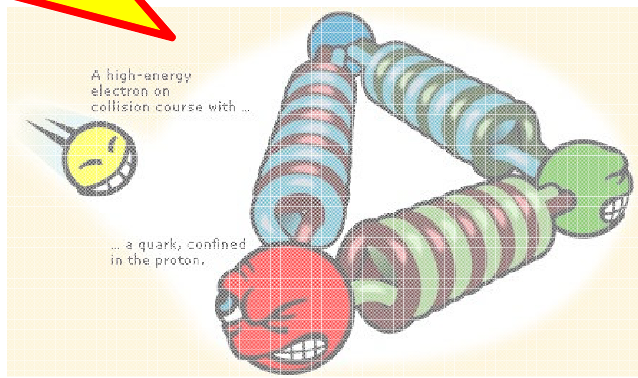
Electromagnetic

Are there additional forces ?

Weak



Strong



new interaction – new exchange boson

Scalar boson: $\mathcal{L} = \bar{\psi}\,(g_S + i g_P \gamma^5)\psi\phi$

Vector boson: $\mathcal{L} = \bar{\psi}\,(g_V \gamma^\mu + g_A \gamma^\mu \gamma^5)\psi\chi_\mu$

e.g. photon: $\mathcal{L} = e\bar{\psi}\gamma^\mu\psi A_\mu$

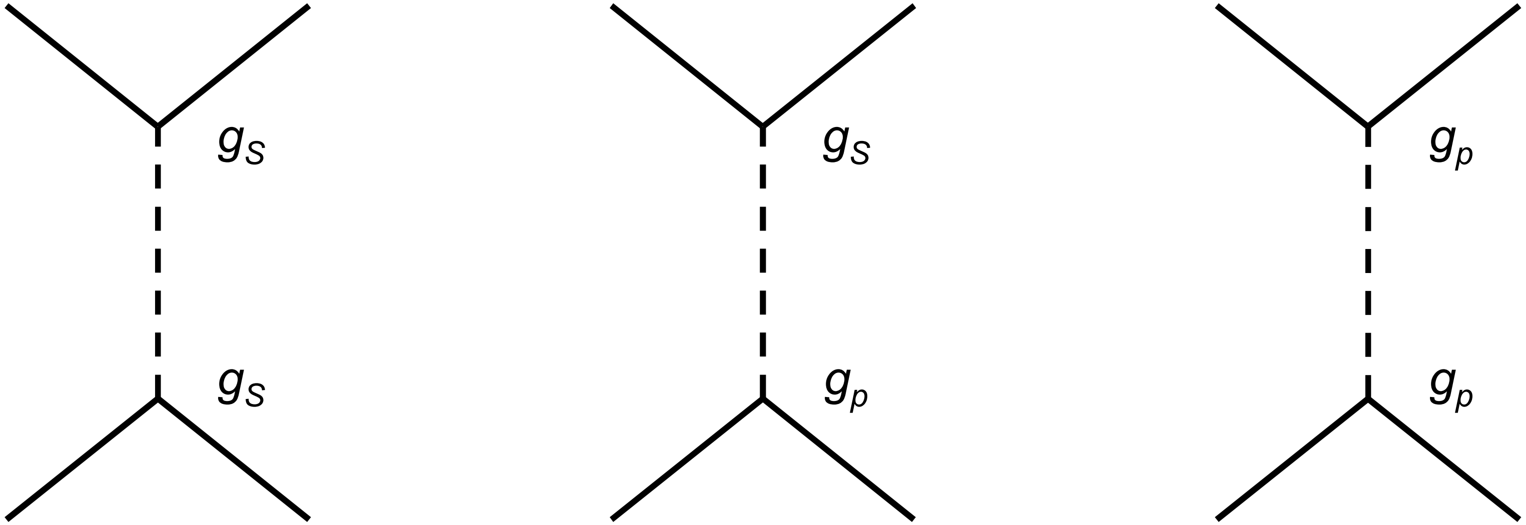
Compton wavelength: $\lambda_c = \frac{\hbar}{Mc}$ e.g. $M = 10^{-4}$ eV/c^2 ⟷ 2 mm

$m_\gamma = 0$, $m_{W,Z} = 80 \ldots 90$ GeV/c^2

⇩

In general a new force is described by a set of dimensionless coupling constants and its interaction range λ_c.

new scalar boson (spin 0)

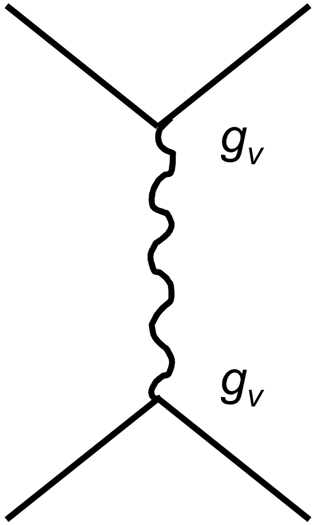


scalar-scalar coupling	scalar-pseudoscalar coupling	pseudoscalar-pseudoscalar coupling
gravity-like ‘5th force’	‘Axion-like’ (dark matter candidate)	

Further reading:

- Fischbach & Talmadge, Nature **356** (1992) 207. (Review Article on 5th force)
- Schlamminger et al., PRL **100** (2008) 041101. (Torsion Balance - Seattle)
- Petukov et al., PRL **105** (2010) 170401. (polarised ^{3}He gas - ILL)
- Serebrov et al., JETP Lett. **91** (2010) 6. (polarised UCN - ILL)
- Vasilakis et al., PRL **103** (2009) 261801 (^{3}He-K/^{3}He - Princeton)

new vector boson (spin 1)



...

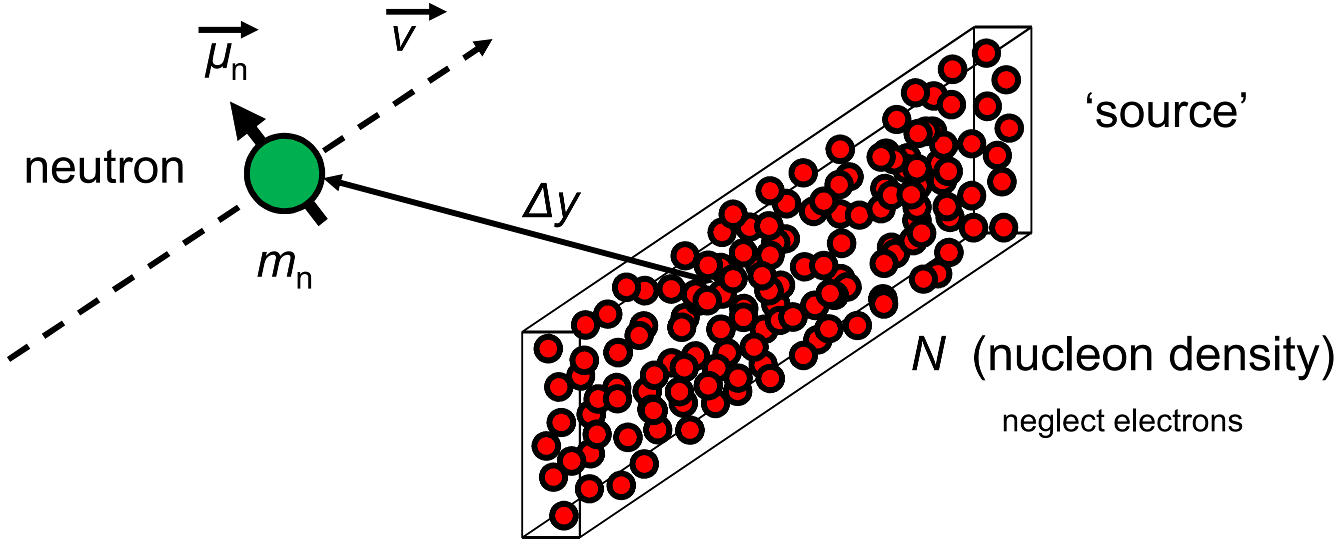
vector-vector coupling

'photon-like'

(in e.m. g_V^2 corresponds to $\alpha \approx 1/137$)

probe the exotic interaction (spin 1)

- **use polarised neutrons as ‘probe’**
- **and a non-magnetic macroscopic bulk matter as ‘source’ (Al, Cu, glass …)**

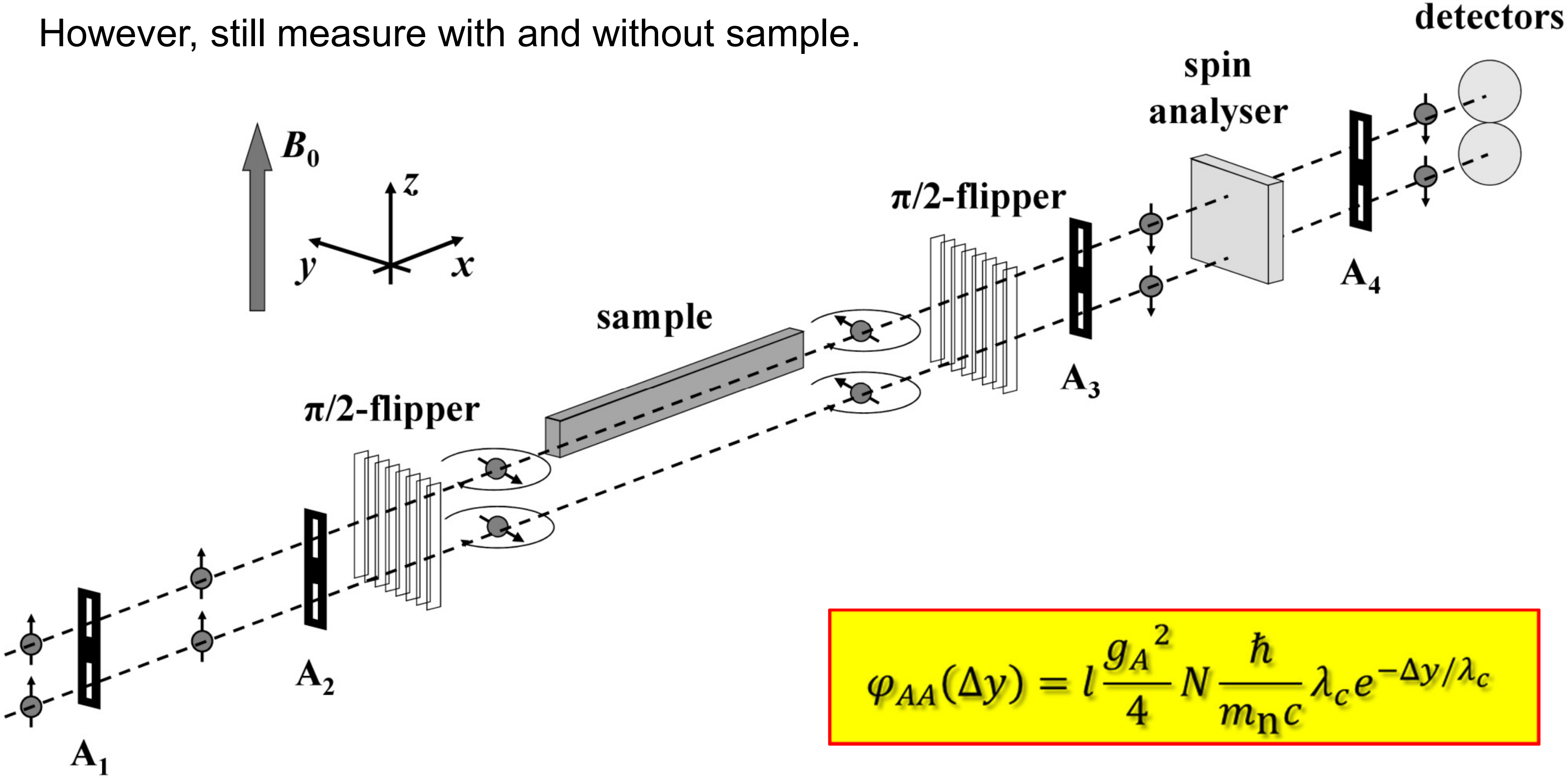


Pseudo-magnetic fields cause pseudo-magnetic precessions of the neutron spins !

Piegsa & Pignol, Jour. Phys. Conf. Ser. **340** (2012) 012043

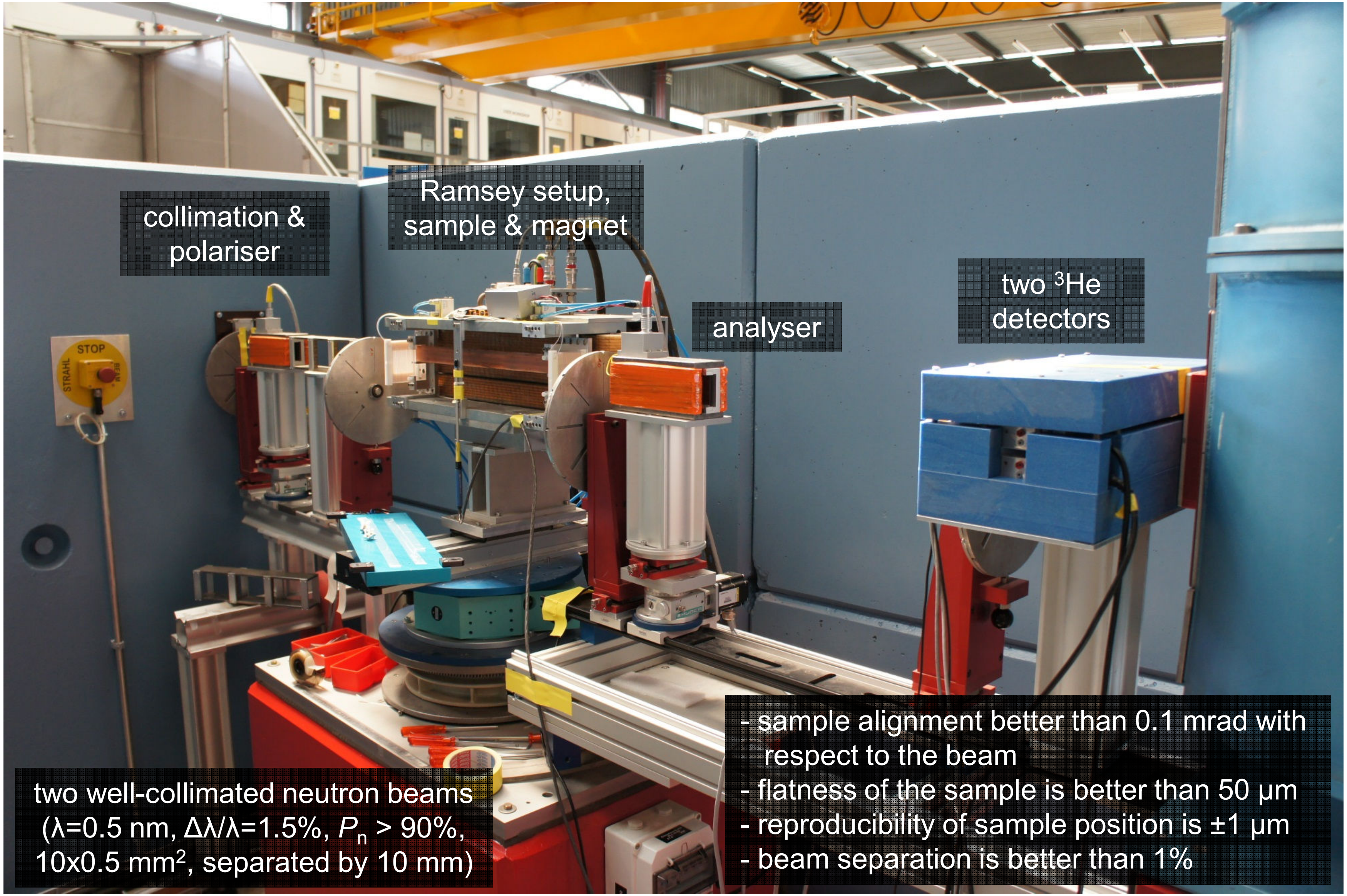
Search for axial-axial coupling:

- Two beam-method helps to compensate for drifts (field, spin flippers, temperature, etc.).
- However, still measure with and without sample.

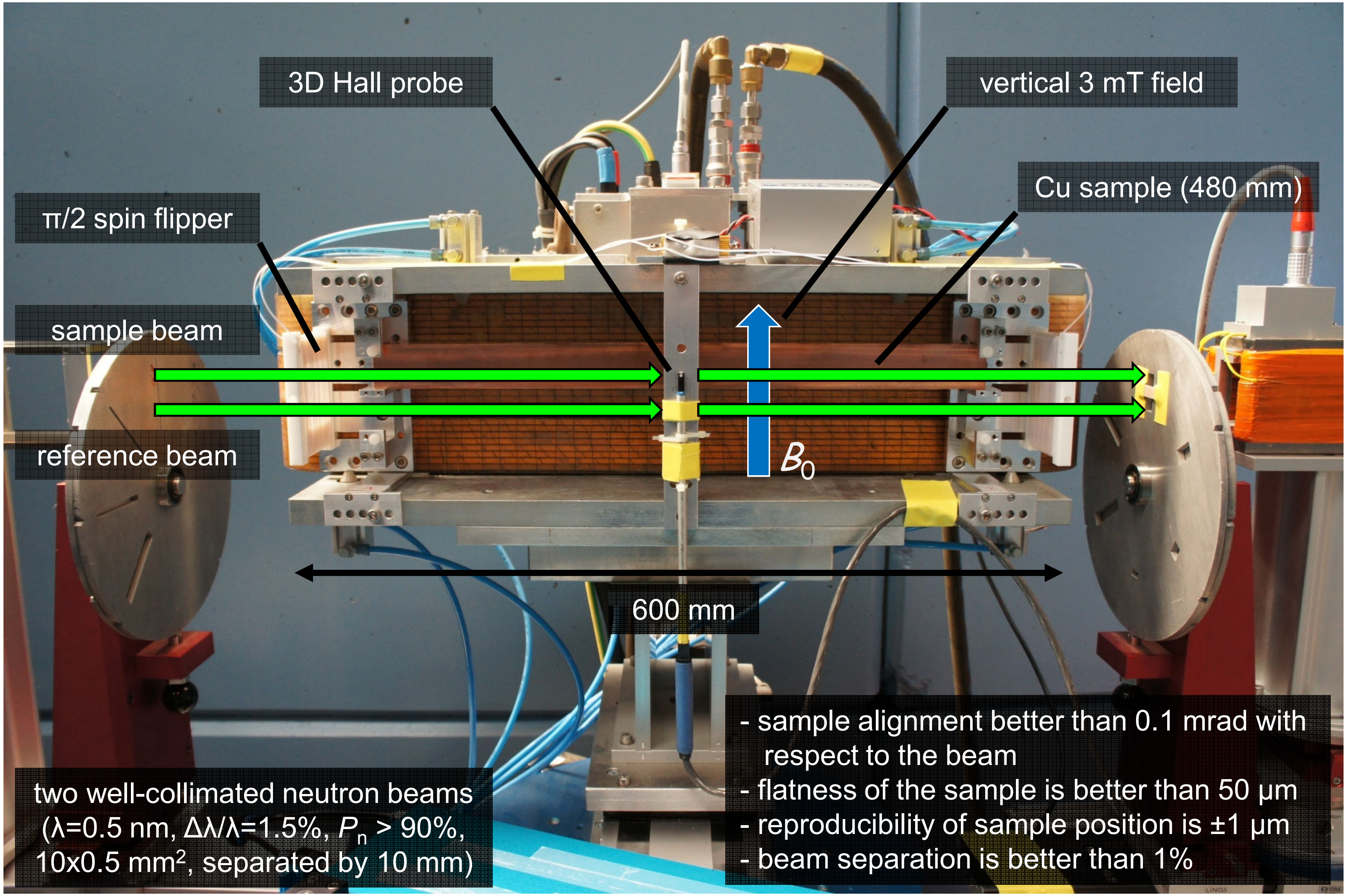


$$\varphi_{AA}(\Delta y) = l\frac{{g_A}^2}{4}N\frac{\hbar}{m_n c}\lambda_c e^{-\Delta y/\lambda_c}$$

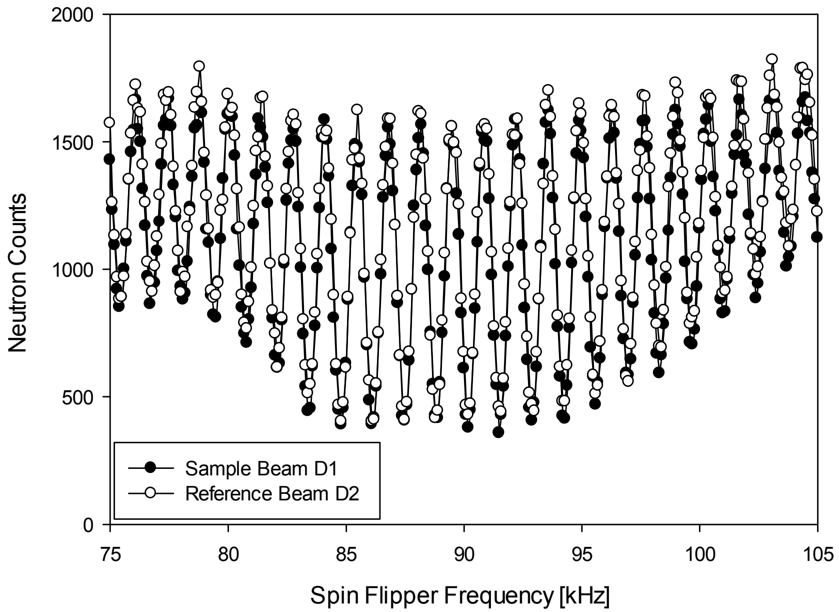
Ramsey setup at Narziss (PSI)



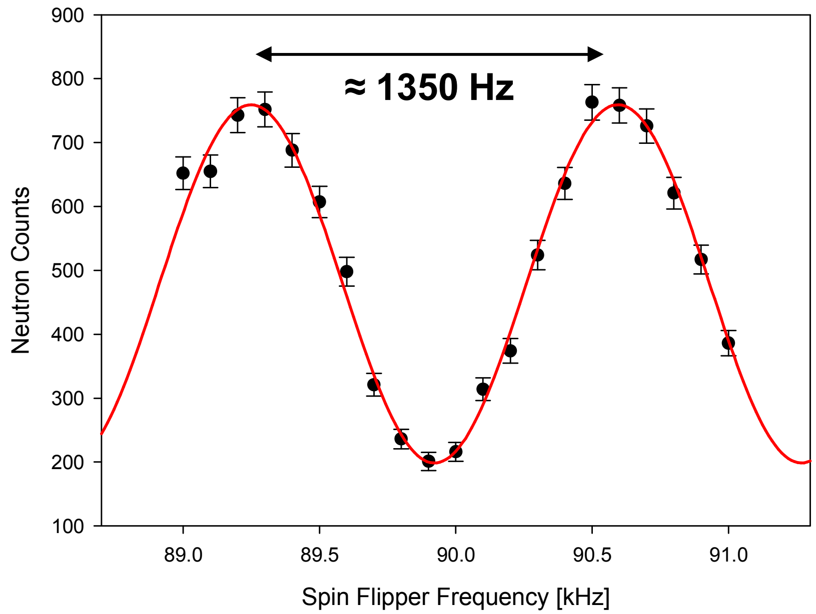
Ramsey setup at Narziss (PSI)



obtained Ramsey patterns

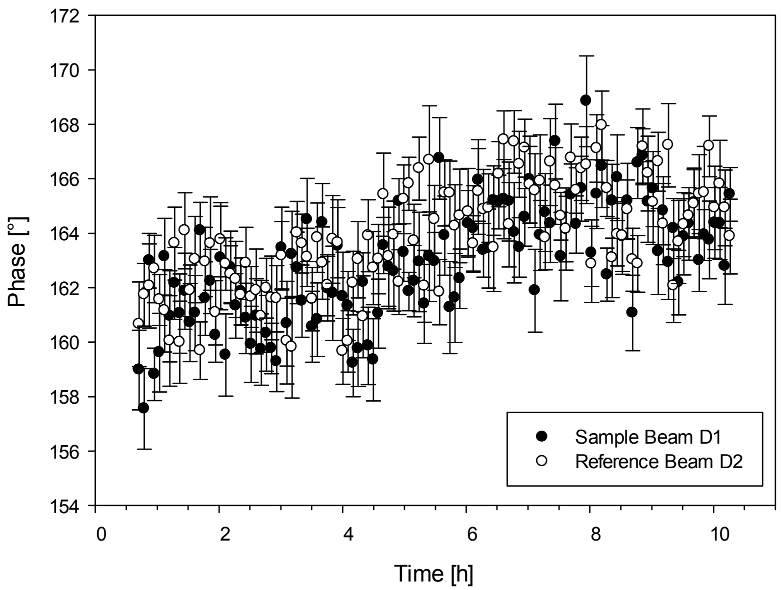


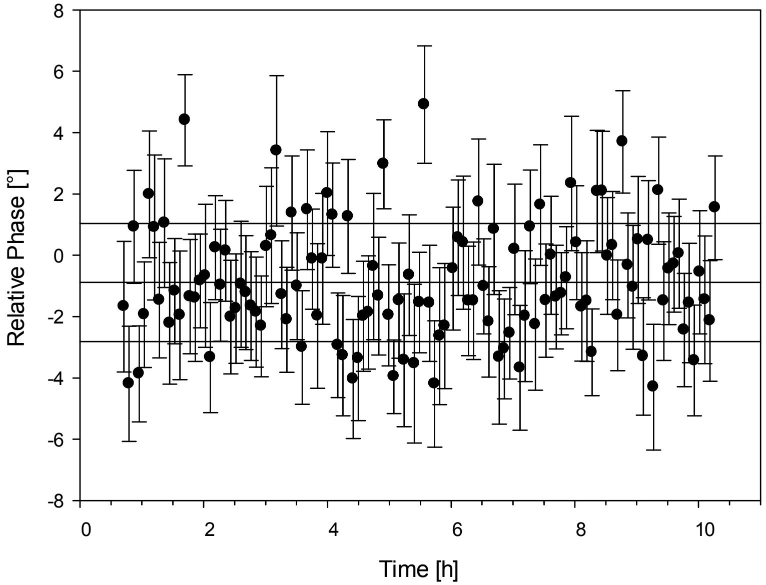
"full" Ramsey signal
(about 2 hours / 90 kHz ≈ 3 mT)



measuring time about 5 min
sinusodial-fit: $\sigma_\varphi \approx 1.4°$

important: phase-stability



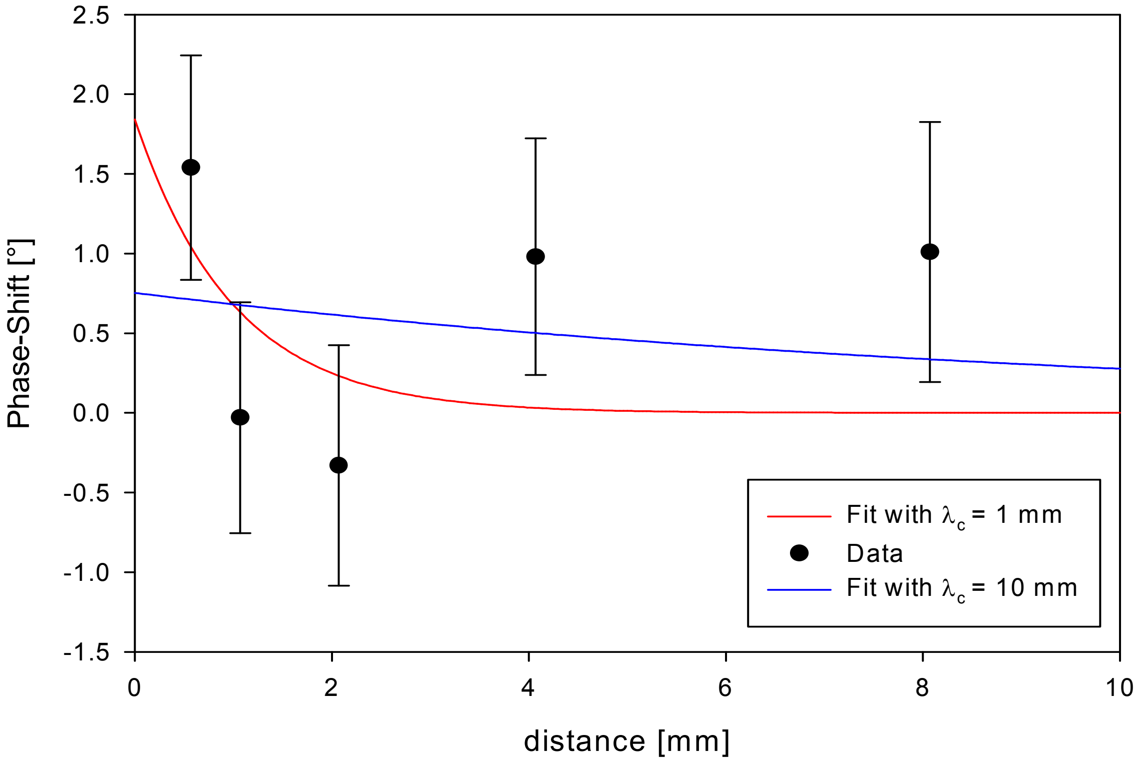


Nicely stable for several hours !!

$\Delta\varphi$ = (-0.9 +- 1.9)°
Average Errorbar ≈ 1.9°

⇨ Error seems purely statistical !

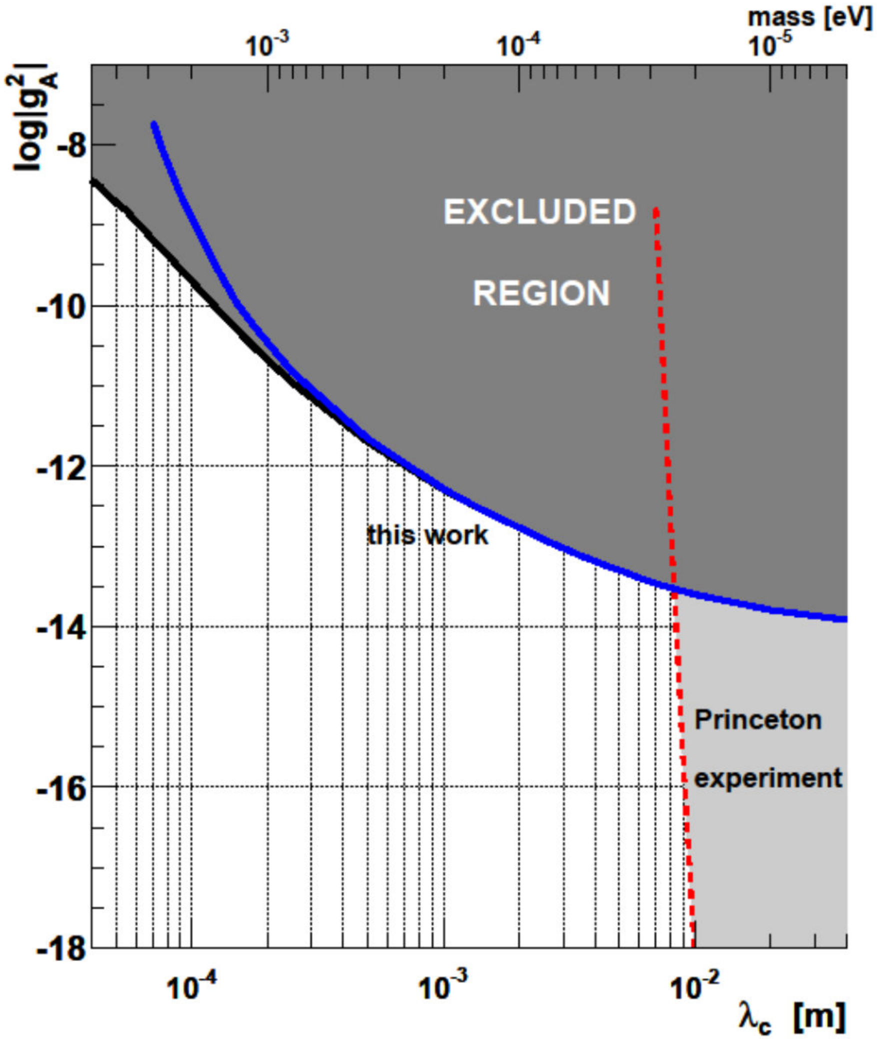
result - copper sample



- (only) about 12 hours of data taking
- fit same data for different fixed λ_c leads to upper limits for g_A^2

$$\varphi_{AA}(\Delta y) = l\frac{g_A{}^2}{4}N\frac{\hbar}{m_n c}\lambda_c e^{-\Delta y/\lambda_c}$$

result - axial-axial coupling



''standard fit''

fit taking beam width into account

$g_A^2 < 6 \times 10^{-13}$ @ λ_c=1 mm (95 C.L.)

compare to

α_{strong}	≈	1
α	≈	1/137
α_{weak}	≈	$10^{-6} \ldots 10^{-8}$
α_{grav}	≈	10^{-38}

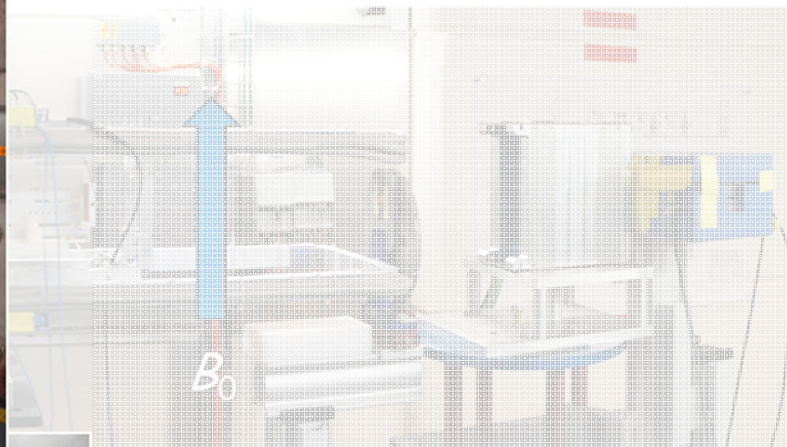
Piegsa & Pignol, PRL **108** (2012) 181801
Princeton: Vasilakis et al., PRL **103** (2009) 261801

Test beam time at BOA

- one week in November 2012
- idea: more intensity – better sensitivity
- completely new setup to measure exotic interactions (g_A^2 & $g_s g_p$) and *vxE*-effect

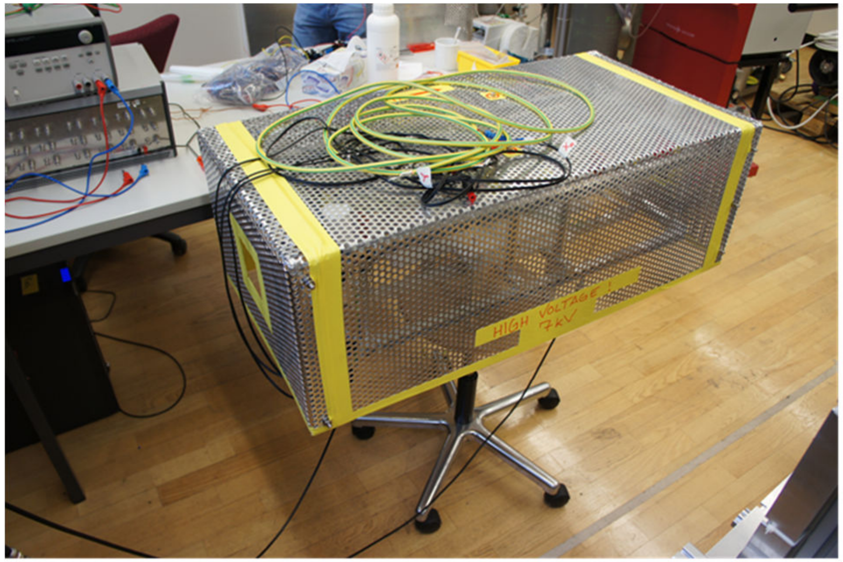
Together with: M. Fertl, K. Kirch, J. Krempel & G. Pignol

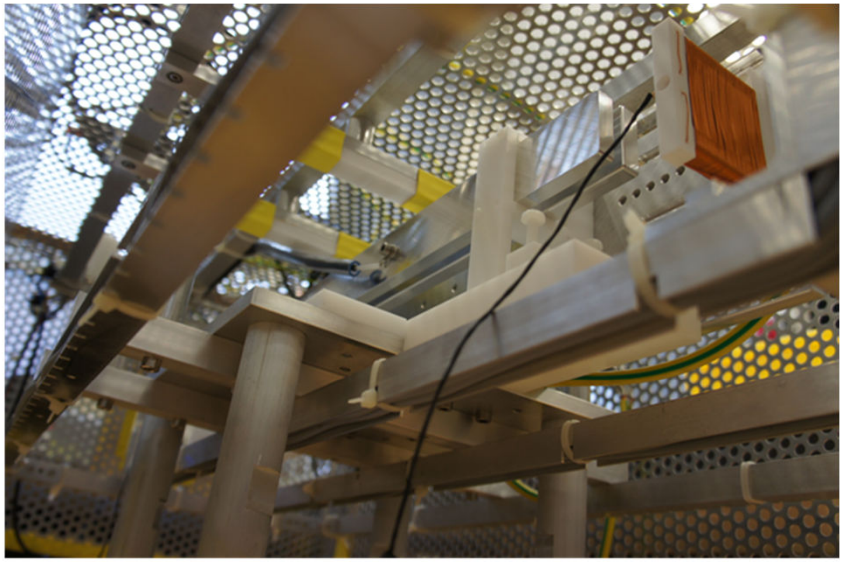
impressions

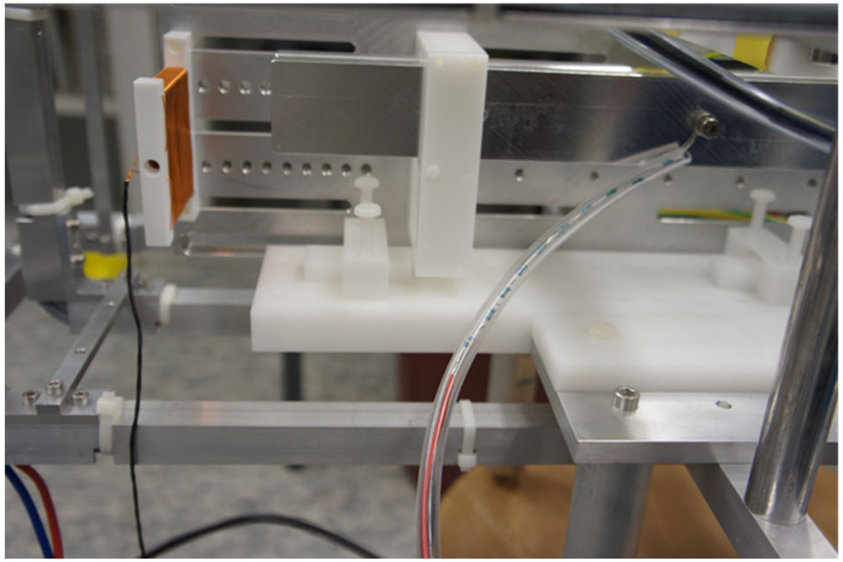


- Magn. field of about 150 µT, actively stabilized to about 1-2 nT
- Very sensitive to magn. environment (e.g. sample table !!)
- Two beam method
- Work with a white beam or with Be-filter
- Trouble with adiabatic spin-flipper
- Trouble with own RF-flippers (problem seems to be fixed)
- g_A^2, $g_s g_p$ and vxE accesible with same setup !

high voltage test in the lab (v x E)







- Electrode distance 5-6 mm
- Voltage up to 7 kV (Power supply limit – no sparks)
- Leakage current < 50 nA
- Produce electric field of more than 1 MV/m in air
- This corresponds to 10 nT, for v = 1000m/s

conclusion & beam time request

- **What do we want to do ?**
  - Search for **exotic Interactions** (at least 10 times better sensitivity than at Narziss)
  - Measure **relativistic *v x E*-effect** (using slow neutrons)

- **How ?**
  - new approx. 2 m long Ramsey apparatus with about 80 cm long samples/electrodes
  - new RF spinflippers (length: 25 cm) and work at 150 μT (stab. by fluxgates to 1-2 nT)

- **Why BOA ?**
  - high intensity polarized beam – more statistics
  - comfortable setup possibilities (sample tables / spin-flipper / polarizers / …)

- **What is important ?**
  - adiabtic spin-flipper and Be-Filter !!
  - magn. field environment – but we stabilize for drifts/changes
  - option to filter high energy neutrons (background)
  - new spin analyser for imaging (??), monochromator improvement (??), stablized temperatures (???)

- **Beam Time Request:** **3 weeks between two shut-downs** to obtain enough statistics
  preferably: **17.6. – 7.7.** or 9.9. – 29.9. (or 7.10. – 27.10.)